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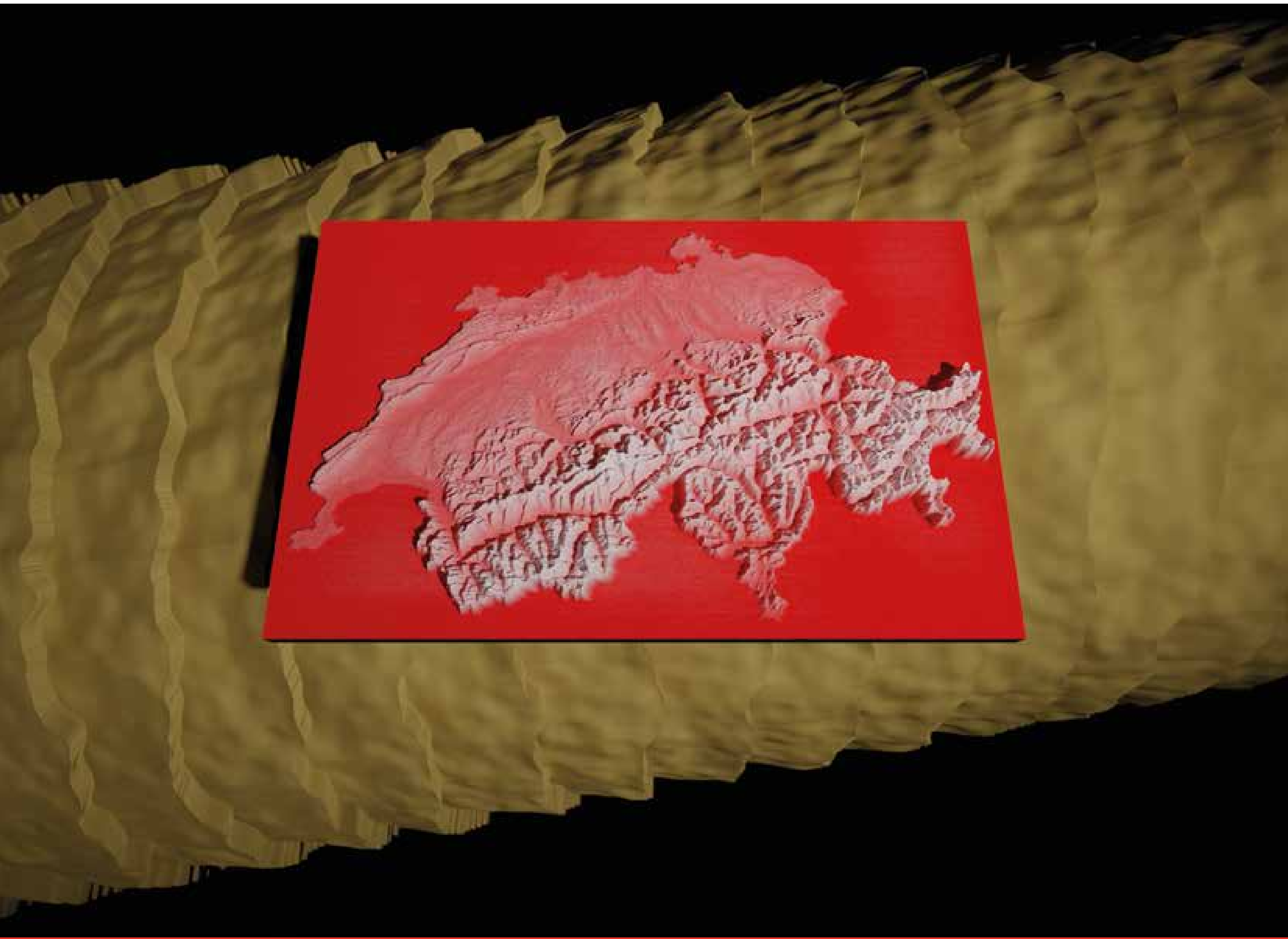
SPS Focus

A special publication of the Swiss Physical Society

Impact of Physics on Swiss Society

Investing in Education and Fundamental Research to foster Innovation



SPS Focus is a publication series of the Swiss Physical Society where a single topic is presented and placed in focus for a broader audience, hence its name. The series is published irregularly and addresses topics that are of broad impact and interest.
Research breakthroughs causing a paradigm shift as for example quantum computing would be among those topics predestined for a ***SPS Focus*** *issue, but also the interplay of physics with other disciplines is of high interest. In particular, it is intended to put the spotlight on interdisciplinary subjects like the interaction with life sciences that to some degree build on physical concepts and apply tools developed in physics to reliably model, measure or even control complicated systems from the micro- to the macro scale.*
Therefore, the presentation style of ***SPS Focus*** *is meant to address not only physicists but scientists in general, and the interested public. To achieve this goal, renowned experts are invited to describe the state of art of a specific topic in an accessible way for the non-expert and put its impact and implications into a wider perspective.*

Title Picture

The front cover shows atomic force microscopy data of probably the smallest topographic map of Switzerland ever created. It was fabricated using scanning thermal probe lithography, a kind of nanoscale chisel to structure a polymer layer on a silicon chip. With its 30 x 20 micrometer size (lateral scale about 1:20'000'000'000) the map would easily fit on a human hair, and the Matterhorn measures less than 400 atoms in height (vertical scale about 1:100'000'000'000, height exaggerated in the image).

This is an excellent example how a fundamental science breakthrough achieved in Switzerland, which was awarded the Nobelprize in Physics in 1986, has opened the door for a new, paradigm changing field, i.e. nanotechnology. Subsequently, ever more advanced tools for measurement and lithography have been developed and commercialized, and today, there is cross-disciplinary impact and applications in many other research areas and industrial sectors (bio-tech, chemistry, material science and even food industry).

Credits: Armin Knoll (IBM Research Europe - Zurich) with data from Swisstopo (height map) and OpenStreetMap (borders), visualization Thilo Stöferle

Imprint

SPS Focus is a special publication of the Swiss Physical Society. The series will appear irregularly and be distributed to all members as well as further interested parties.

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satw it's all about technology

Contents

Executive Summary

The Swiss society and economy is healthy. Trust in the Swiss franc has remained stable over decades. Switzerland fared well through the last global recession in 2008 - 2011. These facts are linked to an impressive diversity of small and medium sized enterprises (SME) - focusing on different niche markets. No recession or technological leap can wipe out all industrial sectors. Switzerland also has a vibrant start-up and entrepreneurial scene that ensures a continuous flow of innovative companies. As such, we can expect economic growth to continue in the decades to come.

Companies typically have a life-cycle. A start-up period with growth is followed by stability before eventually being out-competed or made irrelevant. Very few companies grow into giants like Nestlé, IBM or Toyota. Small or medium size companies are the most common outcome. Having a diverse SME portfolio is of national importance as it provides a stable economy. This structure however impacts innovation. Most companies start with innovative ideas with little capital. Once established, innovation is traded for productivity that typically generates medium size income. As a result, SME are the least innovative and this is our Achilles heel.

It is therefore interesting to analyse how to improve or cultivate innovation for SME's. Recruitment and interaction with academic environments are a promising avenue. Switzerland holds strong traditions for fundamental research. This produces a pool of highly educated people that can innovate within SME's. Research can trigger external innovation demand. Finally, fundamental research is also the starting point for spin-off companies.

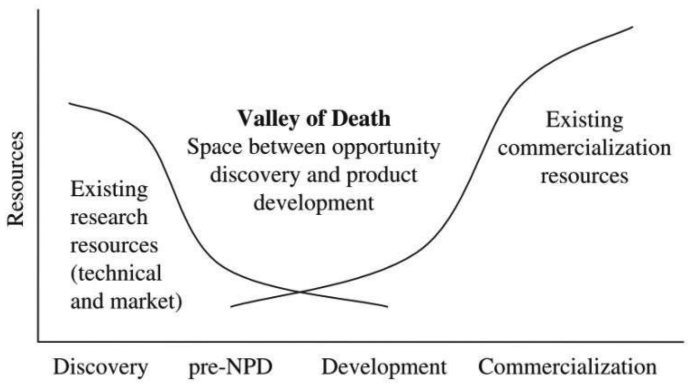
The Swiss Physical Society sought to determine the impact of physics on Swiss society and studied the influence of physics on the Swiss economy, for research, and for society as a whole. With support from the Swiss Academy of Natural Sciences, and engaging IMSD, a company offering consulting services in data science and science communication, a statistical analysis was conducted, revealing key indicators of the value of physics for Switzerland.

Physics' impact on society ranges from deep philosophical considerations to practical tools and applications in daily life. Its impact is paramount. Invention of the computer chip would not have been possible without exquisite understanding of semiconductors. Physics thus underpins the largest industrial revolution of the last century.

Today's successful Swiss economy is built on yesterday's investment. It is the fruit of long-term support for physics in education and research. A longstanding goal is to facilitate the conversion of fundamental research to profitable applications. Academic knowledge transferred to the market is the backbone of spin-off companies. Investors are looking for the spin-off companies that can be scaled-up to small and medium sized enterprises. The lifetime of such enterprises is in modern time very much depending on the ability to adapt and innovate. Even if innovation is the initial spark from which high-tech companies are born, research and development is often underprioritized during and after the scale-up process.

Valley of Death

The figure below is often shown in management seminars and indicates that there are phases of uncertainty between the start-up phase and the establishment of a successful company on the market. Raising new sources of funds and setting up production and sales infrastructures require full concentration on the part of the founding pioneers, often at the expense of their innovative strength. However, as new research results become technically applicable with increasing frequency and complexity, the Valley of Death for SMEs is even deeper than previously assumed when innovation strength wanes. It is therefore all the more important to build up physical competence in SMEs so that they can immediately recognize the benefits of disruptive innovations and apply them in their products in the shortest possible time.



Overcoming the Valley of Death: A Design Innovation Perspective - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/the-valley-of-death-in-Markham-et-al-2010_fig1_325782671

A key message of this ***SPS Focus*** issue is that medium size enterprises can benefit from physics educated employees that can bring innovation and adaptation skills. Investment in innovation is crucial for the global Swiss economy as well as individual enterprises.

In fact, innovation has been and continues to be key for any trading nation or empire. Without innovation, there is nothing to trade. The collapse or fading of trading empires therefore most often stems from lack of innovation. The most innovative nations are those with the best education systems. As such, there is a direct link between education, innovation potential and trading power. Investment in education and research is therefore a strategy to foster innovation and with that the trading potential. With this ***SPS Focus***, we describe how physics contributes to education and research that strengthen our innovation index.

SCNAT Fact Sheet

The message of this ***SPS Focus*** about the role of innovation is also transferable to other areas of fundamental research. In order to reach these circles as well, the Swiss Academy of Natural Sciences SCNAT will prepare a fact sheet of a few pages referring to this report.

1 Introduction

Traditional Innovation Chain

Since the beginning of the industrialisation in the nineteenth century, technical knowledge generation and its use in industry was performed in the same way in modern western societies: research results from the universities which indicated possible industrial relevance were first passed on to so called technical universities, where they were developed to a certain degree of technical pre-maturity. Then larger industries took over in most cases and tested first application cases with prototypes, already in close contact with selected target customers. In the case of a first positive response extensive market tests were launched, mainly in progressive markets as in USA, where customers are traditionally much more open minded to innovations than in Europe and also more easily accept higher initial prices. A successful market access led directly to the foundation of many "small and medium enterprises" (SMEs), which concentrated on more cost-effective product variants and more efficient production methods, in most cases in close cooperation with the new universities of applied sciences. Consequently, technical competence was quickly spread nationwide, created new jobs and definitely opened the consumer mass market. This traditional value adding chain, starting from high lights in physical research to SME engineering competence is even today the well-proved concept of our prosperity, and therefore of great national relevance for the (Swiss) society.

We see that the role of physics has essentially been limited to both pre-processes, i.e. the fundamental research at universities and the development of proof-of-concept modules at technical universities. Physicists in industry were employed only in larger companies, but seldom in SMEs, and if then most in the pre-development phase or in physical testing of products.

Modern Innovation Chain

However, this has dramatically changed in the last decades, since more and more research work in fundamental physics revealed great and technically exploitable potential. On the other hand the physical complexity increased and still worse, products and manufacturing processes must be driven today to their physical limits to remain internationally competitive. We mention as examples larger and larger computing chips with spatial structures in the nanometer range, and the modern chemical diagnostic instruments using lasers of femto- and attosecond pulse widths to understand the dynamics of chemical reactions. It is obvious that a profound understanding of physics is needed today *along* the whole innovation path, i.e. from basic research to product manufacturing. This requests a rethinking of the concepts, however offering dramatic new opportunities for society as a whole.

Chapter Layout

The validity of studies on future developments depends on the seriousness of the presented facts. This ***SPS Focus*** is based on the experience and observations of all SPS board members, on the contacts of our SPS section heads of *Physics in Industry* to start-ups and SMEs, and finally on statistical data of Eurostat. Merging all the input should allow to confirm the message of this ***SPS Focus*** that physics knowledge and education are important for technology driven industries, and here especially medium and small sized companies to stay competitive over time.

We present in ***Chapter 2*** statistical data confirming that the industries with a high penetration factor of physical understanding perform significantly better than their competitors with less physical knowledge. We illustrate this fact in ***Chapter 3*** considering, besides others, those companies sponsoring every year the prestigious SPS Awards for young physicists. In addition we focus on start-ups and SMEs, and illustrate their important role as innovation drivers and link between university research and established industries with high market presence. Then in ***Chapter 4*** we present actual research topics at Swiss universities and research centers. Finally in ***Chapter 5*** we comment on "Physics and Didactics", on equal rights questions and how to present Physics in the society, mainly to motivate young people.

Final Remark

This ***SPS Focus*** is not a scientific study in the strict sense, based on research in the technical literature, but reflects the opinion of experts regarding the role of physics from their daily practice and outlines first-hand how they see the future potential. It is thus similar in structure to, for example, the SATW's *Technology Outlook Report* (see Chapter 3.1), in which experts describe both the status and the potential of various technologies from the perspective of their daily practice. Statistical analyses (Chapter 2), on the other hand, are more neutral, objective and comprehensible, but they lack internal insights.

We think that both, the statistical data (Chapter 2) and the insider knowledge of experts (Chapters 3, 4, 5) make a perfect combination to describe a topic of high social relevance in a credible and comprehensive way.

2 The Impact of Physics on Swiss Economy

2.1 Background

In 2018, the European Physical Society (EPS) commissioned an independent economic analysis from the Centre for Economics and Business Research (CEBR) on the importance of physics to the economies of Europe. The report, using statistics available in the public domain through Eurostat, covered 31 European countries – the EU28 countries, plus Iceland, Norway and Switzerland. Under examination was in 2018 the 6-year period 2011 - 2016, with 2016 being the most recent year for which official data were simultaneously available for all these countries (https://www.eps.org/page/policy_economy).

This caused the SPS in 2018 to start working on a similar position paper concerning the role of Physics and its impact on the economy situation in Switzerland, but also in comparison to its neighboring states. To this purpose we focused on Physics-based industries (PBI) which are defined in the following chapters (2.2) and (6). The work on the 2018 paper, however, stagnated due to internal reasons, but was restarted in 2021. This required an update of the statistical data from IMSD, which proved difficult. At least the data for 2019 could be extracted from Eurostat's data sources, but not yet those for 2020 or even 2021. In the following we present the 2019-PBI data, analyze them with respect to their relevance for the economy of Switzerland, and compare them if possible with the corresponding data of 2015 and 2016.

2.2 Definition of Physics-Based Industries (PBI)

Physics encompasses a vast range of scientific disciplines and is thus omnipresent in most technically oriented industrial sectors. The impact of physics on the economy can be estimated by examining the performance of *Physics-based industries* (PBI). These industries can be defined as heavily reliant on a discipline of physics for their success. The economic data associated with such industries was selected according to the categories of the statistical nomenclature standard NACE [1], as described in Chapter 6. This analysis captures the direct contribution of physics-based industries to the economy, but not that of physicists in the workforce who are frequently also employed in other industries.

A detailed list of NACE categories attributed to physics-based industries is provided in Chapter 6. The selection of physics-based industries is challenged principally by the lack of granularity of statistical data and the difficulty of separating the contributions of different disciplines to the same economic indicator. The set of physics-based industries in this study is comparable to those of other reports [2], which allows a comparison of results from different studies.

Contrary to other studies, the present work only reports on the direct impact of physics-based industries on the Swiss economy. This means that the indirect effects of employment in and income from other industries that supply physics-based industries with goods and services are not considered.

The same holds for the induced effects of household spending associated with economic activity in physics-based industries. The multiplier associated with these indirect and induced effects has been estimated to be between 2.31 and 2.49, implying that for every CHF 1.00 of direct physics-related output, a total of CHF 2.31 – 2.49 of total economy-wide output is realised (Figure 2-1). Additional economic impact due to downstream effects, as represented by the economic activity of industries receiving goods and services from physics-based industries, is not taken into account either. It is therefore expected that the overall impact of physics in the Swiss economy, although difficult to quantify, exceeds the direct impacts reported in this study.

Physics-based industries' GVA Multiplyer (= 2.31)	
Direct Impact CHF 1.00	Expenditure on the physics-based sector triggers the physics industry's supply response. in providing its services, the physics industry generates additional value added. Assume sufficient expenditure to generate CHF 1.00 of GVA. This CHF 1.00 of GVA is the direct GVA impact of the relevant increment in expenditure on physics-based industry.
Indirect Impact CHF 0.65	To increase its supply, the physics-based industry must increase its demands on its suppliers, who increase demands on their suppliers and so on down the supply chain. This generates the indirect impact, an increase in GVA throughot the supply chain of CHF 0.65 for every additional CHF 1.00 of GVA in the physics-based industry.
Induced Impact CHF 0.66	The combined direct and indirect impacts have an impact on household income throughout the economy, through increased employment, profits etc. A proportion of this income will be respent on final good and services, producing a supply response by the producers of these goods / services and further impacts through their supply chains. This produces the induced impact of CHF 0.66 for every additional CHF 1.00 of GVA in the physics-based industry.

Figure 2-1: GVA Multiplier

2.3 Contribution of Physics-based Industries to the Economy of Switzerland

We start considering the statistical data for the year 2019 concerning the Gross Value Added (GVA) and the number of Full time equivalent jobs (FTE) for five major NACE categories PBI, Production, Trade, Construction and Financial Services (Figure 2-2a / 2-2b and Table 2-1).

- As can be seen in Figure 2-2a / 2-2b and Table 2-1, the share of PBI in the Gross Value Added (GVA) of Switzerland was 91.5 billion CHF or 13 % out of a total of 701.6 billion CHF for the year 2019. The number of Full time equivalent jobs (FTE) was 417000 or 9.8 % for PBI out of a total of 4237 thousand jobs. The five selected major

1 Nomenclature statistique des activités économiques dans la Communauté européenne

2 Centre for Economics and Business Research, Re-assessment of the importance of physics to the economies of Europe (2018)

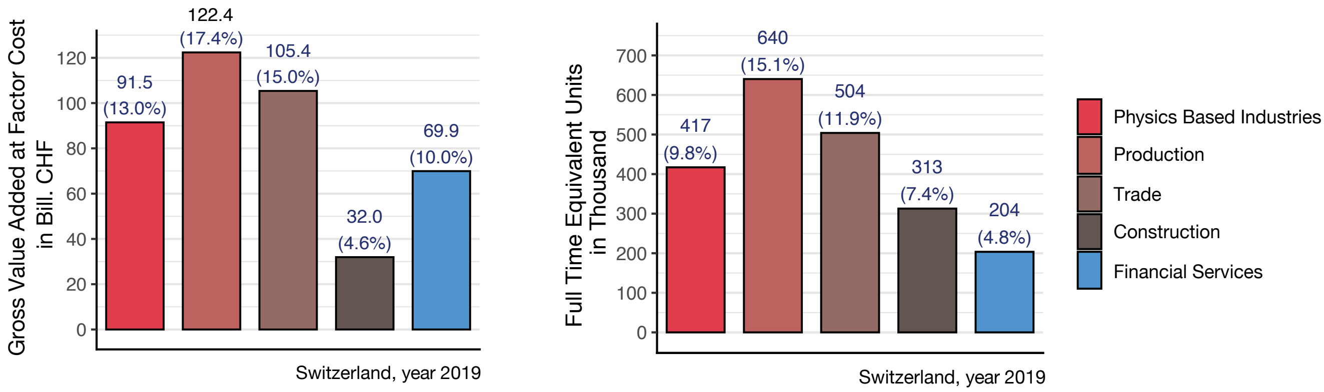


Fig. 2-2a: GVA in Billion CHF and Fig. 2-2b: Number of Full time equivalent jobs (FTE) in thousands for the five NACE categories (PBI, Production, Trade, Construction and Financial Services) for 2019.

NACE categories are economically relevant by contributing with 60.0 % to the total GVA in Switzerland in 2019, and by employing 49 % of all persons with full time equivalent jobs.

- Next we consider the specific GVA defined as the ratio GVA / FTE, which is a measure of the economy efficiency for each NACE category. We find 219.4 kCHF for PBI in 2019, which is larger than the specific GVA in Production and Trade, but significantly less than in Financial Services with 342.6 kCHF. But all five specific factors - besides construction - clearly exceed the average value for Switzerland 165.6 kCHF.
- We further note an improvement of the specific GVA for PBI from 206.7 kCHF in 2015 to 219.4 kCHF in 2019, an increase of 6.3 %, while the average value of Switzerland changes from 161.8 kCHF in 2015 to 165.6 kCHF in 2019, an increase of 2.3 %.
- Thus the NACE-collective PBI is as economically important for Switzerland as Production and Trade.

	1	2	3	4	5	6	7
CH	PBI	Production	Trade	Construction	Financial Services	Sum (1-5)	**Total** (full economy)
2019							
GVA (Billion CHF)	91.5	122.4	105.4	32.0	69.9	421.2	**701.6**
%	13.0	17.4	15.0	4.6	10.0	60.0	**100**
FTE (Thousand)	417	640	504	313	204	2078	**4237**
%	9.8	15.1	11.9	7.4	4.8	49.0	**100**
GVA/FTE (kCHF)	219.4	191.3	209.1	102.2	342.6	202.7	**165.6**
2016							
GVA (Billion CHF)	79.0	106.5	99.0	32.1	59.8	376.4	**670.9**
%	11.8	15.9	14.8	4.8	8.9	56.1	**100**
FTE (Thousand)	395	621	507	307	210	2040	**4133**
%	9.6	15.0	12.4	7.5	5.1	49.4	**100**
GVA/FTE (kCHF)	200.0	171.5	195.3	104.6	284.8	184.5	**162.3**
2015							
GVA (Billion CHF)	83.3	106.2	96.0	31.3	61.7	378.5	**660.3**
%	12.6	16.1	14.5	4.7	9.3	57.3	**100**
FTE (Thousand)	403	631	512	311	216	2073	**4081**
%	9.9	15.5	12.5	7.6	5.3	50.8	**100**
GVA/FTE (kCHF)	206.7	168.3	187.5	100.6	285.6	182.6	**161.8**

Table 2-1: GVA, FTE and GVA/FTE for the five main NACE-categories (PBI, Production, Trade, Construction and Financial Services) for the years 2019, 2016 and 2015.

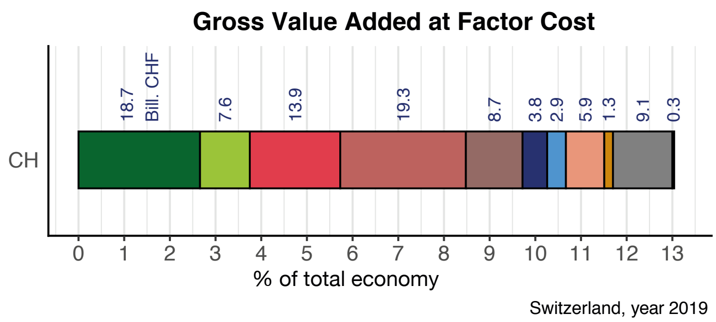
2.4 Composition of the PBI - Data

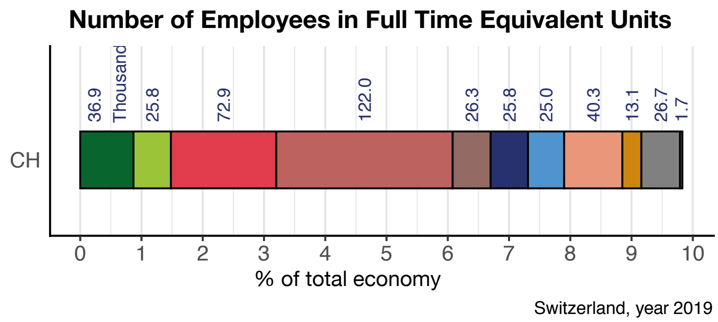
It is necessary to know the composition of Physics-based industries to understand the previous results for Switzerland. The criterion was that the chosen industries are strongly reliant on modern technologies based on a discipline of physics. In Table 6-1 of Chapter 6 we list those 41 NACE categories, which were selected by IMSD and SPS in 2018 to define the collective PBI, including the classes between B09.1, C20.13, …, S95.12. They all were regrouped to eleven new PBI clusters ranging from pharmaceutical industry (Pharma), Medical instruments until General Manufacturing.

	CH in 2019	FTE (thousands)	GVA (Billion CHF)	GVA / FTE (kCHF)	Turnover (Billion CHF)	Turnover / FTE (kCHF)
1	Pharma	36.9	18.7	506.8	74.2	2010.8
2	Medical Instruments	25.8	7.6	294.6	21.7	841.1
3	Metrology	72.9	13.9	190.7	37.0	507.5
4	Technical Service	122.0	19.3	158.2	41.4	339.3
5	Telecommunication	26.3	8.7	330.8	18.1	688.2
6	Electronics	25.8	3.8	147.3	10.4	416.0
7	Electrotechnology	25.0	2.9	116.0	7.6	304.0
8	Machines	40.3	5.9	146.4	15.5	384.6
9	Vehicles	13.1	1.3	99.2	4.8	366.4
10	Electricity Supply	26.7	9.1	340.8	42.9	1606.7
11	General Manufacturing	1.7	0.3	176.5	0.6	352.9
	Total	**416.5**	**91.5**		**274.2**	

Table 2-2: FTE, GVA, Turnover and specific GVA and Turnover for CH in 2019 for the 11 PBI clusters.

In Figure 2-3 a, b, c and in Table 2-2 we see the absolute numbers for GVA, FTE





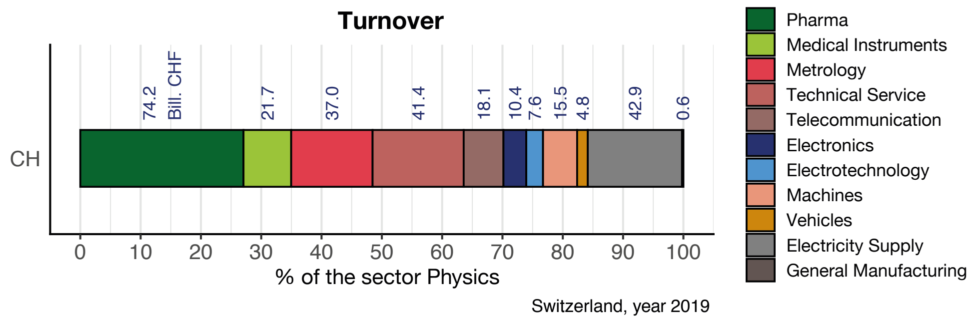


Figure 2-3a: GVA, Figure 2-3b: FTE and Figure 2-3c: Turnover for CH in 2019 for 11 industrial clusters, which define the category PBI.

and Turnover for 2019 for each of the 11 clusters. Additionally we list in Table 2-2 the values for the specific GVA and Turnover for each of them.

- Considering the specific factors GVA & Turnover, we see a rather inhomogenous distribution with Pharma, Electricity Supply, Telecommunication and Medical Instruments as leading industries.

2.5 Comparison of the PBI - Data to Neighboring States

Next we compare the performance data with those of Switzerland's direct neighboring countries Germany (DE), France (FR), Italy (IT) and Austria (AT) in Figures (2-4a, b, c) and in Table 2-3.

	Popula-tion (Million)	FTE (Thousand)	FTE / Capita	GVA (Billion CHF)	GVA / FTE (kCHF)	Turnover (Billion CHF)	Turnover / FTE (kCHF)
	A	B	B/A	C	C/B	D	D/B
CH 2016	8.37	395	0.047	79	200	221	550
CH 2019	8.58	417	0.049	91.5	219	274	658
DE 2016	82.35	3596	0.044	424	110	1689	470
DE 2019	83.1	4109	0.049	505	120	2013	490
FR 2016	66.72	1494	0.022	172	110	608	410
FR 2019	67.2	1189	0.018	204	170	705	590
IT 2016	60.63	944	0.016	133	140	498	530
IT 2019	59.7	1015	0.017	153	150	563	550
AT 2016	8.74	244	0.028	31	120	94	380
AT 2019	8.8	271	0.031	37	140	117	430

Table 2-3: Full time equivalent jobs (FTE), Gross Value Added (GVA) and Turnover data for the years 2019 and 2016 for Switzerland and its direct neighbors. Three specific factors are interesting, the ratio FTE per capita and the amounts GVA per FTE and turnover per FTE.

- (Column B/A in Table 2-3): the ratio of full time equivalent jobs per capita is the same 0.049 for Switzerland and Germany, while France, Italy and Austria perform significantly worse. Both nations CH and DE offer about twice as many high quality jobs per capita as France, Italy and Austria.

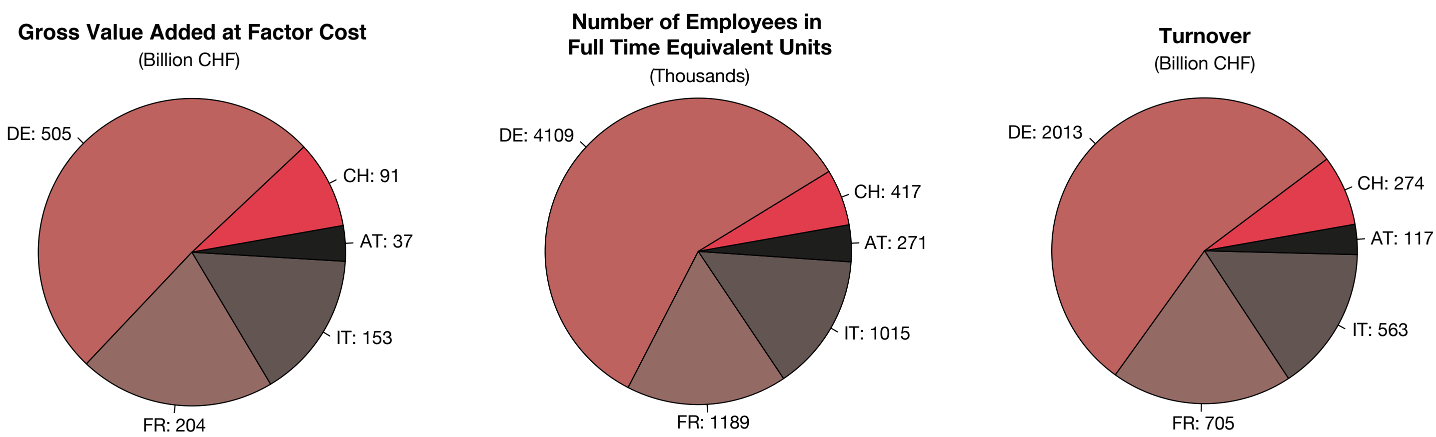


Figure 2-4a: GVA, Figure 2-4b: FTE and Figure 2-4c: Turnover for CH and its neighboring states in 2019

- (Column C/B in Table 2-3): Switzerland leads the ranking concerning the GVA per FTE value with 219.4 kCHF, which is about twice the value of Germany with 120 kCHF.
- (Column D/B in Table 2-3): Considering the third specific factor, the turnover per FTE, Switzerland again performs best with 658.3 kCHF compared e.g. to 430.0 kCHF for Austria.

2.6 Composition of the PBI / GVA - Data of Switzerland and its Neighboring States

Finally to better understand the rather good results for Switzerland we compare its GVA composition with that of the adjacent neighbors. The GVA-values of the 11 subclasses of Table 2-2 are expressed in Figure 2-5 in %, whereby the 91.5 Billion CHF for PBI correspond to 13 % of the total amount of 701.6 Billion CHF in Switzerland. We repeat the same analysis for each of the four neighbored countries.

- While Pharma is the most important part in Switzerland, its ‘pendant’ in Germany is the automotive industry.
- The spectra of France and Italy are rather similar and surprisingly more homogeneously structured than that of Switzerland.
- Comparing Switzerland with Austria shows that Austria is more focussed on Electrotechnology, Electronics, and Electricity supply than Switzerland, while on the other hand Switzerland performs stronger besides Pharma with medical instruments and metrology, i.e. high precision instruments. These results are also to be expected historically.

2.7 Conclusions

The analysis of the statistical data from Eurostat, which describe the economic strength of national industries in terms of GVA, FTE and Turnover numbers, showed a rather positive result for Switzerland, and especially for its physics-based industries PBI.

The facts are:

- Swiss PBI are in the leading position compared to Switzerland’s neighboring countries.
- Swiss PBI contribute as strong as the big Production and Trade divisions to the economy in Switzerland.
- A closer look exhibits that besides the pharmaceutical industry and electricity-supply companies also Medical Instruments, Telecommunication and Metrology Instruments perform strong.
- We will show next in Chapter 3 that we expect many Swiss SMEs as new PBI members in the near future. Their products, instruments and services apply technologies from photonics, quantum engineering, new materials, advanced manufacturing concepts, physical sensor modeling, etc. Thus we expect a growing strength and increasing economical relevance of PBI for the Swiss society.
- Finally, it is surprising why Switzerland, with 219 kCHF, so clearly outperforms Germany, with 120 kCHF, (Table 2-3) for GVA/FTE. One reason could be that the economic integration of the eastern states in Germany has not yet been completed. This is different in Switzerland where technical competence is rather homogenously spread over all cantons by tradition, creating the perfect basis to tackle exciting new challenges.

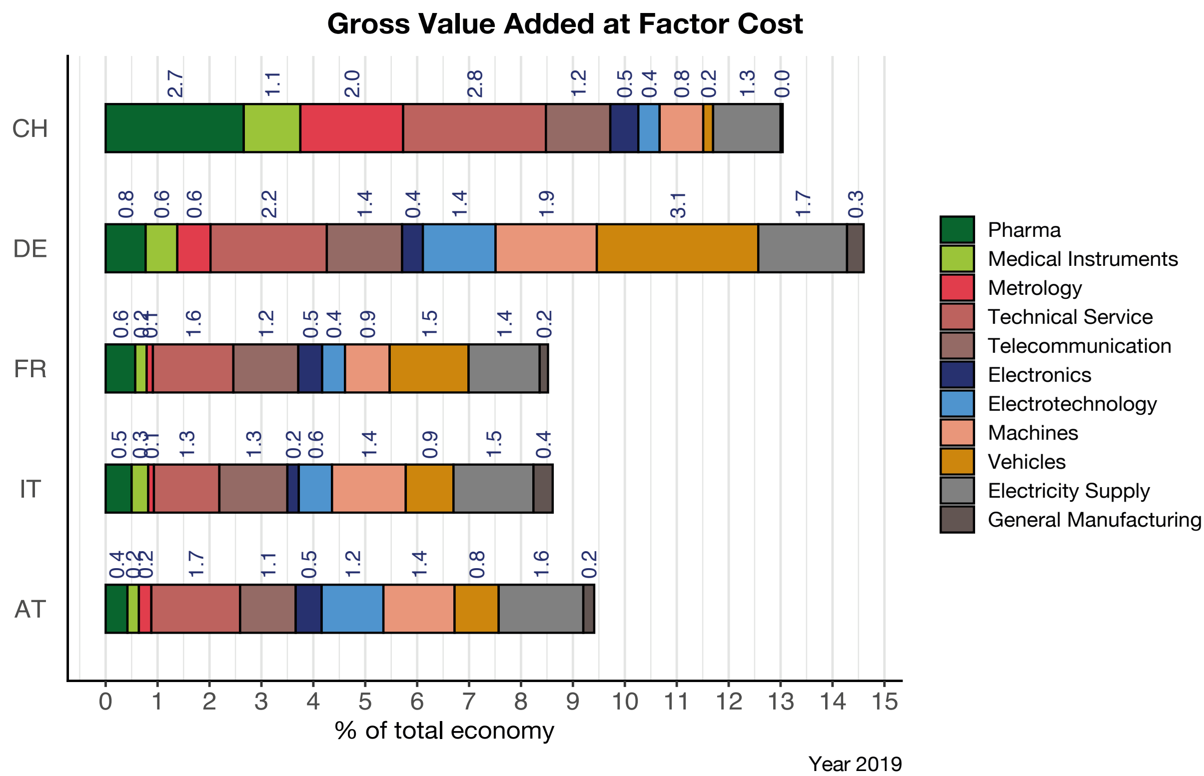


Figure 2-5: The PBI-GVA data for 2019 are expressed in % of the total amount for Switzerland and its four neighbors.

3 Physics – an Important Driver of Innovation

3.1 Innovation Flow in Switzerland

The road from a physics experiment to a tangible product in the marketplace can be long and winding. An established scheme to assess the progress is the "Technology Readiness Level" (TRL) [1], which describes on a scale from 1 ("basic principles observed") to 9 ("actual system proven in operational environment") the maturity of a technology. In-between lies the "valley of death" for innovation, as this maturation process often requires tedious further research and development (R&D), which is time-consuming, expensive, and risky. Boldly building this bridge from a great idea to the final product is vital for a modern economy and creates impact on society.

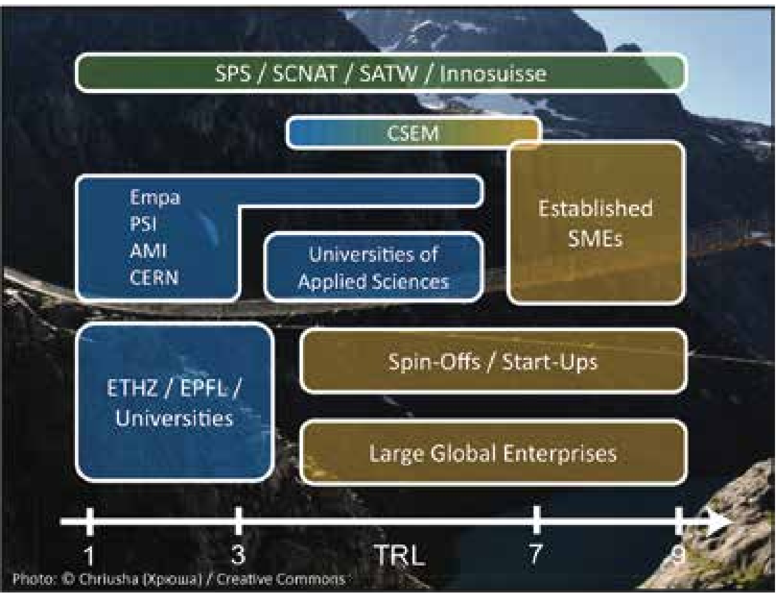


Figure 3-1: Schematic illustration of the innovation landscape of the physics- and technology-related sector in Switzerland, visualizing the manifold of pathways from basic research (TRL 1) to final product (TRL 9).

For the physics and technology sector in Switzerland, Figure 3-1 sketches the interlocked structure between the various stakeholders in this process, with knowledge transferred through spin-off companies and collaborations. Spin-Offs / start-ups as well as small- and medium-sized enterprises (SMEs) are key in transforming scientific results into products. Moreover, institutions like Innosuisse, the Swiss Academy of Natural Sciences (SCNAT), the Swiss Academy of Engineering Sciences (SATW), and last-but-not-least, professional societies like the Swiss Physical Society (SPS) create a network to foster the flow of knowledge and innovation between Swiss research institutions, industry and also more generally society and politics.

In addition to the innovation landscape in Figure 3-1, the flow of know-how through people is essential. Hiring university physics graduates is one of the most effective ways to infuse state-of-the-art knowledge into a company. Therefore, the excellent physics academic education in Switzerland is an important factor for the industry, as evidenced by the fact that more and more global high-tech companies try to hire this talent by establishing R&D labs in Switzerland.

This in turn creates a virtuous feedback loop where high-tech instrumentation and tools made by Swiss SMEs and start-ups further boost the attractiveness and excellence of Switzerland as a research location.

The SPS section "Physics in Industry" organises every year at the annual meeting a session where physicists from selected companies present their motivation, products and applications. The successful idea started in 2011 with an annual Saturday morning symposium "Careers for Physicists" at the ETH Zürich and attracted mostly students and post-graduates. Since then, these events give an excellent impression of how the flow of innovation between academic research and industry comes to life and plays an essential role for Switzerland as a technological powerhouse in Europe.

3.2 Technology Outlook Report of the Swiss Academy of Engineering Sciences

Every two years the Swiss Academy of Engineering Sciences (SATW) publishes its Technology Outlook (TO) Report where most relevant technologies are quantitatively analysed with respect to Swiss research competence and Swiss economic significance. It provides headlights for Swiss industry, to recognize upcoming technological trends, assess paradigm shifts and illuminate developments and "blind spots". In ***TO 2019*** the study described 31 technologies taken from the main categories *Digital World*, *Energy and Environment*, *Manufacturing Processes and Materials*, and *Life Sciences*.

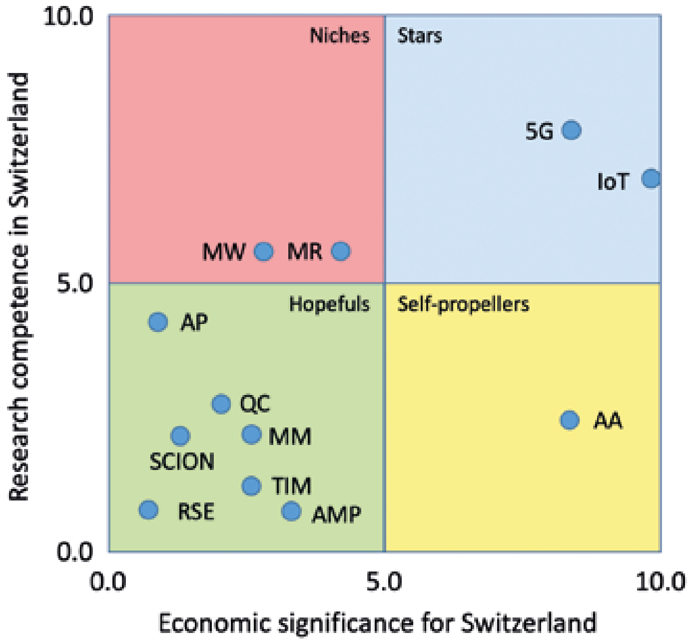


Figure 3-2: Position of the 12 new technologies, added to TO 2021, with respect to Swiss economic significance (abscissa) and Swiss research competence (ordinate).

Abbreviations: (5G) 5G Applications; (IoT) Internet of Things; (AA) Alternate Engine Systems for Vehicles; (AMP) Antimicrobial Polymers; (AP) Artificial Photosynthesis; (MP) Medical Wearables; (MM) Microbiota and Microbiome; (MR) Mobile Robots; (QC) Quantum Computing; (SCION) New Internet Architecture; (RSE) Recycling of Rare Earth Elements; (TIM) Heat-conductive Electrical Isolators

1 https://en.wikipedia.org/wiki/Technology_readiness_level

In *TO 2021* SATW added 12 new technologies leading to a total of 16 in *Digital World*, 10 in *Energy and Environment*, 7 in *Manufacturing Processes and Materials* and 10 in *Life Sciences*. All 43 technologies were placed as points in a 2D matrix with increasing Economic significance for Switzerland indicated on the horizontal axis and Swiss Research competence in each technology measured along the vertical direction. The matrix itself was split into 4 quadrants called: Technological *Hopefuls* or *Talent pool* (green) with 26 entries, *Niches* (red) with 5, *Self-propellers* (yellow) with 4, and *Stars* (blue) with 8 entries (Figure 3-2).

It is not surprising that the green quadrant is typical for technologies still driven by fundamental physics like *Quantum Computing* or *Heat-conductive electrical isolators*, while the more profitable yellow and blue quadrants contain already established technical fields like *Machine Learning*, *Big Data Analytics*, or *Connected Machines*.

On the other side, a more careful look at the analysis of the SATW experts shows that the growing complexity, but also the huge potential of many modern technologies may in the future require much more in-depth understanding of fundamental science for a technology to rapidly develop and enter the Star quadrant, where competence and profitability meet and funding for further R&D work is made available.

This is illustrated in Figure 3-3 for those technologies which most significantly changed their matrix coordinates between 2019 and 2021. Green arrows indicate the positive development of *Machine Learning* (ML) and *Point of Care Diagnostics* (PoC), moving from the red segment to the attractive blue one, but also of *Photonic Manufacturing* (PM), which moved from the green talent pool close to the border between yellow and blue, since competence and business activities were doubled. Also, *Quantum Cryptography* (QCR) moved to the right. On the other hand, the red and yellow arrows indicate the loss of attractiveness of *Smart Grids* (SG), *Augmented Reality* (AR), *Mobility Concepts* (MC) and *Bioplastics* (BP), often linked to less R&D activities in Switzerland, which consequently favoured international competitors.

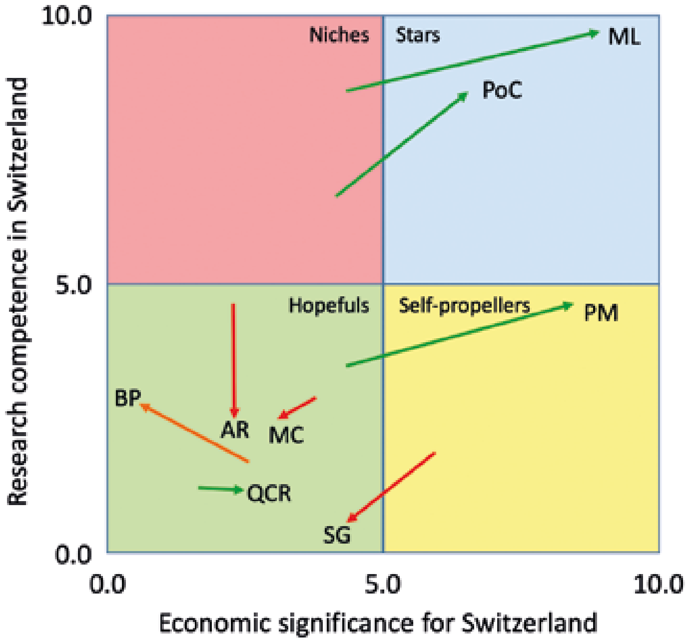


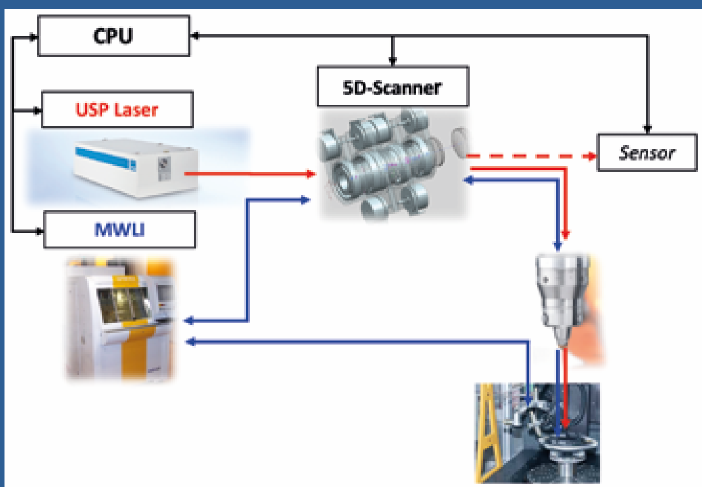
Figure 3-3: The 12 technologies which significantly changed their position between 2019 and 2021.

The main reason for the remarkable success of *Photonic Manufacturing* (PM) is the use of Ultrashort Pulse (USP) Lasers combined with optical in-situ metrology. This all-optical concept offers new micromachining possibilities for subtractive, i.e. material ablation, but also for additive pro-

Box 3-1: Optical Micromachining

The central part is the motor driven Scanner which deflects a laser beam in x,y,z, but also varies its incidence angles on the workpiece in radial and azimutal direction. The Ultrashort Pulse Laser USP (Femtosecond pulses) performs the material ablation. A beamshaper element located at the exit of the USP Laser (not shown in the figure) allows to change in real-time the beamprofile between a focussed spot to drill holes and a special selected pattern for thermal annealing or polishing purposes. The laser beam of the Multi-Wavelength Interferometer MWLI is coaligned with the USP beam and at the same time probes in x,y,z the exposed surface under test with submicrometer accuracy.

The MWLI beam can also be directly guided to the workpiece to determine its shape (plane, sphere, cylinder, freeform surface) at the begin of the machining process, and to measure the workpiece's actual position and tilt angles with respect to a mechanical reference system. Any dislocation or misalignment of the workpiece can lead to a wrong writing/reading pattern of the USP and MWLI laser beam on the workpiece, but can be precompensated by correcting the scanner kinematics. A simple laserdiode (not shown in the figure) monitors the actual scanner deflection pattern by permanently analysing its calculated spot position on a 2D-sensor.



The all optical concept of simultaneous MWLI-pointing and USP-shooting avoids the usual loss of the coordinate system when changing the mechanical tools for e.g. drilling and for 3D-measuring. The beamshaper element allows to change the working tool in realtime, and the permanent control of the workpiece's position and orientation avoids the need for expensive and heavy granite tables, an advantage when larger workpieces must be moved in the step-and-repeat modus.

cesses, used in fast prototype production. It can substitute mechanical drilling, milling, welding and polishing tools by smaller systems with much higher efficiency, flexibility and accuracy (see Box 3-1). The operational parameters such as laser wavelength, pulse duration and repetition frequency depend on heat conductivity, specific heat and material density of the working piece material in a complicated way. This makes a quantitative understanding of the different non-linear thermodynamic behaviour of metals, glass, ceramics, semiconductors and organic materials necessary to avoid inefficient trial and error runs, a knowhow that is missing in many SMEs [2]. Since machining and especially micromachining is a key technology of Switzerland, physics knowhow is essential here, to remain in the pole position [3].

Another important point is to fill the technology matrix of Figure 3-2 with new candidates. Here the competence and network of professional research societies like the SPS can provide valuable guidance. SPS board members proposed in January 2021 four research fields either as direct input for ***TO 2023*** or to be part of a collecting pool for ***TO 2025***:

Research field 1:

Diamond based Photonics for high power laser and X-ray applications

Ultrashort Pulse (USP) Lasers for material processing lead to power peaks of 200 to 500 MW and require resilient coating materials for the optical components. ***Synthetic diamond*** is best suited due to its unique thermal, mechanical and optical properties. To achieve the desired optical functionality e.g. for highly transparent windows or for high reflectivity mirrors, the diamond coated surface is geometrically fine-structured to yield a "zero-order" diffractive element. The required nano-structuring technique called *Laser-induced periodic surface structuring* (LIPSS) uses femtosecond lasers and has already been proven to be a mature technique for advanced manufacturing [4]. The combination of refractive and diffractive coating is also attractive for X-ray optics.

Research field 2:

High field magnets

Studies at CERN deal with the construction of a new ring accelerator FCC (Future Circular Collider) of 100 km circumference in order to reach 100 TeV collision energy (in the center of gravity system). This would require the superconducting Nb-Ti accelerating magnets of the present LHC (Large Hadron Collider) to be upgraded from 8 T to 16 - 20 T. With new material approaches, based on Nb_3Sn, doped with Zr and Ta, experiments confirm being able to reach this range, in a special case even up to 29.2 T at 4.2 K [5]. It is foreseeable that magnets with a smaller size such as the ones used in medical imaging will be the first to benefit from this new technology. The Swiss Accelerator and Technology Initiative CHART [6] [7] is a joint effort of Swiss Universities, PSI and CERN to foster the development of particle accelerator concepts and technologies for a next generation of research infrastructures.

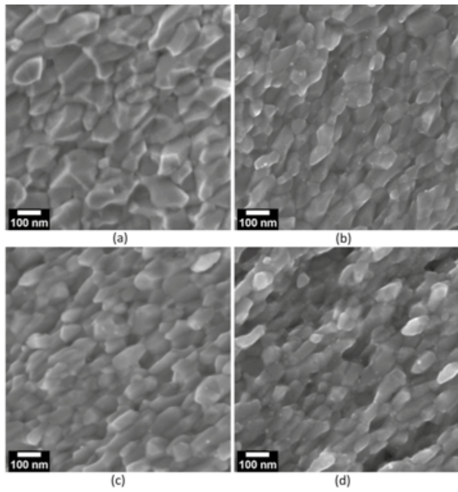


Figure 3-4: SEM images of Nb_3Sn grains at fractured surfaces. For details see [6].

Research field 3:

Ultrafast data transmission by optical comb technology

The optical comb technology provides a sequence of precisely defined time frequencies that can be used for novel clock concepts (optical atomic clocks), for optical telecommunications using glass fibers with data rates of several TB/s, for metrology applications and for spectroscopy.
Recently frequency combs were generated with many silicon nitride microresonators, in which the waveguide and the resonator are integrated on a single substrate. At EPFL, a nanophotonic chip with an integrated frequency comb laser achieved ***a data transmission rate of 1.44 TB/s over 300 km***, ***or 55 TB/s over 75 km*** [8, 9]. If the optical signals of two frequency combs are superimposed, where one is guided through a gas volume, then the beat signal can be used to measure the absorption spectrum of the gas under test faster and more accurately than with conventional methods. This is important for medical and environmental applications. Optical combs can also be used to monitor the strength of turbulences, essential for modern lidar applications.

Research field 4:

Sensitive and reliable sensors for bioprocess monitoring and pharmaceutical research

Basic research on physics regarding the detection of bio-molecular interactions on a chip led to the discovery of mologram and their applications in molecular

2 Comparative theoretical analysis of continous wave laser cutting of metals at 1 and 19 μm wavelength, Michael H. Brügmann, Thomas Feurer, App. Phys. A (2014), DOI 10.1007/s00339-014-8233-6

3 https://www.sps.ch/artikel/physiker-in-der-industrie/a-useful-sw-tool-for-thermal-estimations-in-optics-5, see Application 3: A Heat Conduction Problem in Connection with Laser Ablation

4 J. Bonse *et al.*, "Laser-Induced Periodic Surface Structures (LIPSS) - A Scientific Evergreen," https://www.osapublishing.org/abstract.cfm?uri=cleo_si-2016-sth1q.3

5 https://www.sps.ch/artikel/progresses/advanced-niobium-tin-superconductors-for-the-future-circular-collider-80

6 https://scnat.ch/en/uuid/i/897ee1e9-9e09-556b-9e66-8c17d1a35a2c-Swiss_research_initiative_CHART_works_on_particle_accelerators_of_the_future

7 https://chart.ch

8 J. Pfeifle et al., Coherent terabit communications with microresonator Kerr frequency combs. *Nature Photonics* (2014), DOI: 10.1038/NPHOTON.2014.57

9 P. Marin-Palomo et al., Microresonator-based solitons for massively parallel coherent optical communications, *Nature* (2017), DOI: 10.1038/nature22387

biology and pharmaceutical research [10] [11]. The analytical method "molography" uses molecular diffraction at carefully designed biological nanopatterns on a sensor chip. The nanopatterns have close to zero diffraction efficiency in their bare state, i.e. before analyte binding. If analyte molecules in a sample bind to a mologram on the chip, the bound molecules become diffractive. Thereby the mologram generates a diffraction-limited signal that is used for the read-out of the sensor. The molographic detection principle is robust, sensitive, label-free and insensitive to non-specific binding. Reactive lithography with photo-labile bio-reagents enables the creation of biological naonopattern with molographic properties. Molography enables sensitive and reliable label-free optical biosensors. Such sensors are an invaluable tool for bioprocess monitoring and drug discovery.

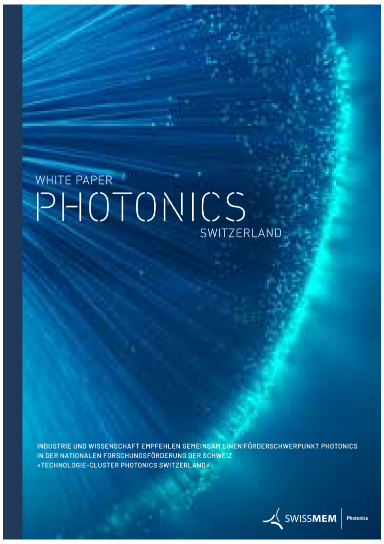
These are four examples where physical principles lie at the heart of a new technology. In a time where such technologies find their way increasingly also into more traditional application fields, physics knowledge is critical not only in the early phases of technology development but throughout the entire development chain including its use in production. To be internationally competitive, physicists and physics knowhow in industry are as important as engineers and engineering skills.

3.3 Selected Technological Fields Relevant for Switzerland

The impact of physics on industry is very diverse and wide-spread, both horizontally over many disciplines and vertically where physics-knowledge can be a pivotal enabler e.g., for certain processes or technologies. The following sections highlight examples where physics has direct impact on Swiss industries.

3.3.1 Photonics

Rapidly developing markets require significantly faster, more powerful, miniaturised, and energy-efficient systems and components that cannot be realized using standard electronic technologies available today. With photonics, completely new technologies and technology combinations are available that enable entry into lucrative growth markets. The main reason is that coherent light sources and sensors can be used, either manufactured on chips using lithographic techniques for highspeed applications or as powerful laser systems for e.g. material processing. Photonics has numerous applications that are important for society and industry, such as image processing and measurement technology, medical instruments and the life sciences, optical components and systems, communication technology, light sources, photovoltaics, production technology, information technology, security and defence technology, and displays. The annual growth rate of photonics is 6 - 8 %. Large initiatives such as "Industry 4.0" and "Data Science" are based on photonics and open up new fields of application.



This caused *Swissmem*, the Swiss Association of Mechanical and Electrical Engineering Industries (MEM industries), in 2018 to publish a 'White Paper Photonics Switzerland', written by representatives from academia and industry. It describes the prospering situation of photonics in Switzerland, the most attractive new photonics fields and provides background information on the relevant technologies [12].

3.3.2 Sensing, Imaging, Measurement & Instrumentation

Switzerland has a long-standing reputation for formidable time-keeping instruments. The high-tech versions of these are no exception to this: atomic clocks, which are essential for satellites and time standards. Moreover, satellite-based referencing has become critical for precise localization in applications from agriculture to logistics. Over the last decades the Swiss passion and excellent skills for fine, high-quality measurement and instrumentation have been extending to many other modern, physics-augmented fields like nuclear magnetic resonance (NMR) spectrometry, cryo-electron microscopy, atomic force microscopy (AFM), and micro-wave / millimeter-wave / terahertz technologies which impact biological, pharmaceutical, and environmental research and related product applications.

In general, sensors have become ubiquitous in our lives. Ever smaller, more power-efficient and innovative sensors for light, pressure, acceleration, and the like are integrated in every smart phone and other devices. Moreover, sensors have become pervasive key components across many industrial sectors, including automotive, health, energy, environmental monitoring and industrial automatization. Exploiting advances in materials and micro- / nanofabrication as well as harnessing even more intricate physical phenomena, like quantum sensing using color centers in diamond, enable improvements of precision, size, and cost.

The extraction of relevant information out of sensor data often requires special measurement concepts and special processing efforts. We mention the well-known tomographic technique to gain information on elements inside a three-dimensional body out of a series of noisy measurements performed at different viewing angles and their subsequent dig-

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10 V. Gatterdam, A. Frutiger, K. P. Stengele, D. Heindl, T. Lübbers, J. Vörös, C. Fattinger, "Focal molography is a new method for the in situ analysis of molecular interactions in biological samples", *Nat. Nanotechnol.* **12**, 1089 (2017).

11 A. Frutiger, C. Fattinger, J. Vörös, "Ultra-Stable Molecular Sensors by Sub-Micron Referencing and Why They Should Be Interrogated by Optical Diffraction - Part I. The Concept of a Spatial Affinity Lock-in Amplifier", *Sensors.* **21** (2), 469 (2021), doi: 10.3390/s21020469.

12 *https://www.swissmem.ch/de/aktuelles/detailansicht/ein-jahrhundert-im-zeichen-der-licht-technologien.html*

ital processing. Here, a related and rather new technology, the so-called cryo-electron microscopy, is used to obtain the three-dimensional structure of proteins with true atomic resolution out of a series of several ten to hundred thousand 2D projection images from different, however unknown viewing perspectives [13].

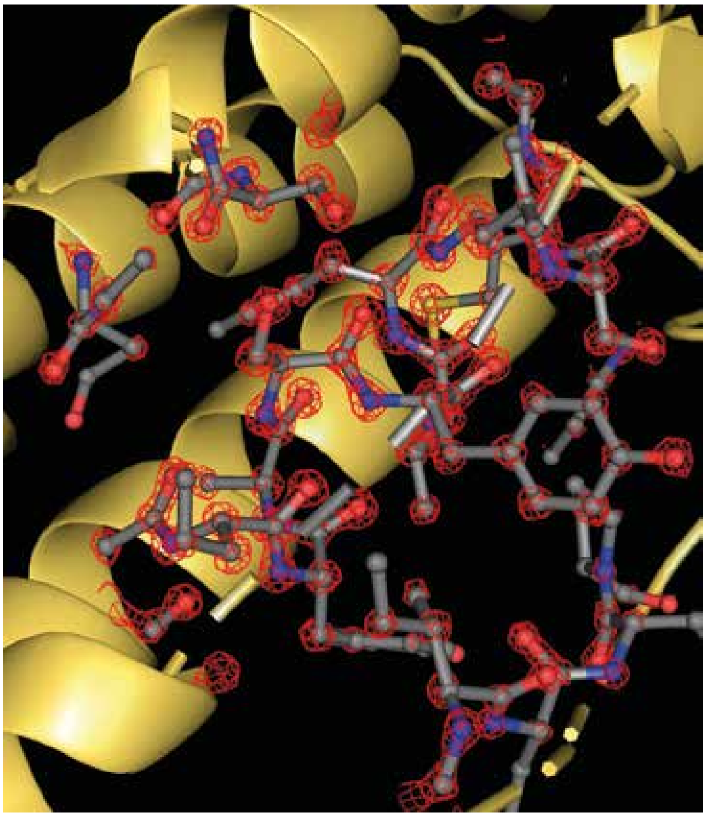


Figure 3-5: Atomic model of apoferritin built into the atomic resolution density map. For details see [13].

Another exciting example of physics-driven image processing is that of earth satellite images which are blurred by atmospheric turbulences or similarly images of astronomical objects observed by earth bound telescopes. These images can be restored to full resolution out of a sequence of single recordings, in this case out of a series of short time exposures. Atmospheric fluctuations then affect each image differently, but in a stationary pattern, and therefore can be processed by phase retrieving algorithms based on physical models of the atmospheric turbulence.

The Nobel prize in physics in 2016 was awarded towards progress in cryo-electron microscopy, and in 2020 for obtaining detailed information about black holes [14]. In both cases digital image restoration guided by physical models were the key to achieve the needed high image resolution.

Finally, we mention the measurement of the concentration profile of greenhouse gases in the troposphere by new weather satellites such as the third generation of Meteosat. Since the linewidth of gas spectra increases with higher atmospheric pressure, the blur width of recorded gas spectra depends on the concentration of the gas molecules along the line of sight. Special deconvolution algorithms allow retrieving the gas concentration profile as function of the height above ground, an important information for weather forecasts and climate models.

13 https://www.sps.ch/artikel/diverse-artikel/cryo-electron-microscopy-reaches-atomic-resolution-for-the-3d-structure-of-proteins

14 https://www.sps.ch/fileadmin/articles-pdf/2021/Mitteilungen_Nobel2020-2.pdf

3.3.3 Medical / Biological Physics

Although not obvious, even particle physics can bring innovations that gladly become mainstream applications: As in numerous flag-ship medical institutes world-wide, proton beams at PSI treat cancer patients. Here protons can deposit controlled amounts of energy limited to accurately defined spatial regions of tissue, with much higher resolution than common radiotherapy, and thereby help to destroy tumours.

In contrast to such large-scale installations, physics also serves the med-tech / biotech sector with the tiniest components through advances in micro- and nanotechnology. Point-of-care diagnostics and ever more sensitive analytics and instrumentation often rely on pushing the boundaries of microfluidics and novel, innovative physical detection methods. Moreover, progress in lasers, optics and imaging finds its way into many health care and biological applications and research, ranging from eye surgery over dental therapy to optical tweezers, opto-genetics and nano-probes to study and control processes in cells.

3.3.4 Communication

Modern communication technologies often combine high frequency electrical components with integrated, miniature optical components. Both rely on the advancements of materials and micro- / nanofabrication methods where physics is playing a key role. A number of SMEs in Switzerland have become important providers of such components, innovating in various ways, such as with novel approaches like optical frequency combs. Moreover, several Swiss startups are eager to establish new platforms with integrated photonics circuits comprising novel, advanced optoelectronic materials for communication applications.

Another dimension is opened up by quantum communication, where quantum mechanics ensures proven, completely secure communications. Switzerland has become a world-wide premier player in this field due to the research from the University of Geneve and products from its offspring idQuantique. There are ambitious plans to bring such secure communication into general applications by developing a worldwide quantum internet and there are even first demonstrations of this using satellite-based quantum communication.

3.3.5 Quantum Computers

In contrast to prevailing digital technology, quantum computers use the basic principles of quantum mechanics (so-called quantum superposition and quantum entanglement) to solve problems. For certain hard problems the computing resources (memory, computing time) required by classical computers grow exponentially with the problem size. An example are complex optimization tasks for simulations in finance, business or chemistry, where the possible configu-

Figure 3-6: Inside a dilution refrigerator for quantum computing research [Picture: IBM Research]

rations to be tested grow so fast with the problem size that conventional computers can only solve small systems. Here, quantum computers are known to provide novel algorithms that can test many or all input configurations simultaneously and thus have an enormous potential compared to classical systems. Its field of application will initially be in data centers as an accelerator for classical high-performance computing.

Nowadays, there are several hardware platforms: Ion traps, superconducting circuits, semiconductor quantum dots and photonic systems. In recent years, research has made huge progress in the control of these quantum systems. The first commercial quantum computers exist from IBM, Rigetti, IonQ, Google, Honeywell and Alpine Quantum Technologies with up to about a hundred quantum bits. Although their performance is still limited by the inherent susceptibility of quantum systems to noise, they can already be used to solve initial problems that are difficult to solve with classical computers. Internationally, a very active ecosystem has formed for this purpose, where initial applications for a wide variety of fields are being tested and component supply chains specific to the respective technology are being established. Switzerland is excellently positioned in quantum research, but apart from a few large companies, only a few SMEs are active in this field and the latter mainly as suppliers of individual high-tech components for the complex quantum computer systems.

Box 3-2: A Look into the Future

In the coming years, hardware development will focus on increasing the number of quantum bits and, in particular, on further suppressing and ideally completely correcting errors that can occur during computations. On the application side, algorithms are being intensively developed for optimization problems in finance, pharmaceuticals, chemicals, transportation, logistics, and other industries. The complexity of the challenges is such that large research collaborations and industrial research centers will probably drive the next development steps of quantum computing. Switzerland must not miss the boat here. In international comparison, there is still some potential for Swiss start-ups and SMEs in the field of quantum software and in sub-areas of quantum hardware. In the next five years, we expect the cloud-based use of quantum computers to develop from research and teaching to the first applications in industry. Not only is it important for larger companies in the financial and pharmaceutical industries to take action now, but smaller companies should also consider whether quantum computers could provide alternative solutions to computationally intensive tasks. In addition, it is worthwhile for manufacturers of high-tech components, especially in the materials, microtechnology, high-frequency and optics sectors, to investigate their use for quantum computer supply chains and, if necessary, to optimize them for this purpose.

3.3.6 Simulation and Modelling

Alongside advances in available computing capability enabled by Moore's Law, simulation and modelling has become the third pillar of science next to experimental and theoretical research. The governing laws of a physical system are cast into a software code which is run on a computer and can then be used for experimentation on the system or to make predictions of a future state of the system given appropriate initial conditions. A prominent example are the Earth system models used for daily weather forecasting and projections of the Earth's future climate. The basis of these complex multi-physics models comprises the domains of fluid dynamics, thermodynamics, electromagnetic radiation, and physical chemistry.

The Nobel Prize in 2021 in physics was awarded to an early pioneer of the physical modelling of the Earth's climate. Nowadays, models are developed in consortia of research institutions by interdisciplinary teams of physicists, mathematicians, computational scientists, biologists and chemists. Information from weather and climate models is omnipresent in both the public and private sector and the demand to deliver more accurate data by better understanding and improving the representation of the underlying physical processes is in high demand.

3.3.7 Cyber-physical Systems

Simulation and modelling of physical systems have also increasing impact in inherently industrial topics: The complete digitalisation of production systems is considered worldwide as fourth major step in the industrial revolution and thus has been termed "Industry 4.0". It connects subsystems with each other, but also with external sources such as the *Internet of Things* (IoT) for optimal information exchange. This creates the attractive possibility of running a digital *twin*, i.e. a virtual production chain parallel to the real production process (Figure 3-7). The output of the virtual module are pseudo-measurement data that are directly comparable with the real measurement results. Special estimation algorithms vary the model parameters so long until a mathematically proven coincidence between real and virtual data is obtained. However, to correctly apply virtual modules, a profound understanding of physics, especially at the system noise level, is indispensable. Signal encoding is an efficient

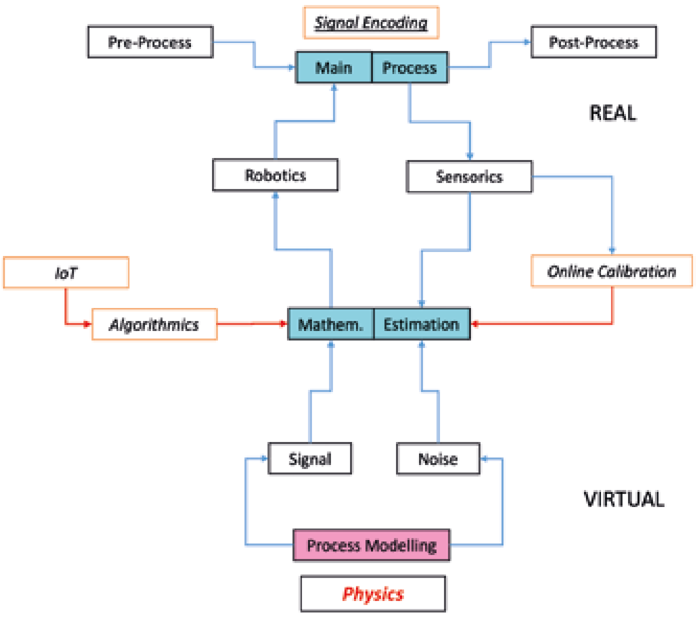


Figure 3-7: Cyber-physical System, based on the equivalence of real and virtual processes.

method to significantly reduce the influence of stochastic process errors, while systematic model errors are eliminated by online calibration [15].

Therefore, the digital twin concept is often understood as a tool to simulate or debug real processes. But it offers much more possibilities aside from just comparing measured and modelled data at the same confidence level. If the model assumptions are physically correct, then the fine-tuning of the model parameters leads to an increase in accuracy (Super-resolution) by e.g. circumventing diffraction limits in optics, or to more process stability by efficient error reduction. While the optimization of the interaction between digital twins is a standard method in many physics experiments, it is a rather new concept for industrial applications [16, 17].

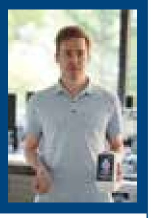
The above examples give a good impression how diversified and broad the impact of physics is on many sectors. This goes far beyond just providing obvious instrumentation for R&D labs, but moreover, physics know-how is pivotal to fabricate, verify and boost the performance of very different kinds of products and bringing competitive advantage across many industries.

3.4 Physics-Related Start-Up Companies

Start-up companies are an important innovation engine that transfers knowledge into products. Despite the COVID pandemic, 2021 has been a record-breaking year with respect to the overall number of companies founded in Switzerland: overall more than 50'000 [18]. But this is just the continuation of a trend that has been going on for a decade. Especially in physics and the technology sector in general, new directions such as quantum technologies are getting traction and are leading a new wave of start-ups. Starting up a new business is generally risky, with 5-year survival rates below 50 % in Switzerland. But technology start-ups generally do significantly better compared to other sectors, and e.g., almost 95 % of all ETHZ start-ups make it past the 5 years mark [19].

Here we present a few short portraits of physics-based start-up companies that in most cases are formed as offspring from academic research, but also spin-outs originating from research labs of larger corporations. This gallery (presented in alphabetical order) is by no means complete but vividly shows the full gamut of newly founded start-ups: Some have just launched their first product, some are seasoned spin-offs that have already become a leader in their market segment. The small selection of featured companies naturally can, of course, only provide a glimpse of the vibrant entrepreneur scene. Yet, these examples make very clear that start-ups are a major force to mature and drive innovation by taking on the challenge to bridge the so-called "valley-of-death" of innovation between academic ideas and real-world products.

1DROP AG



Founded; URL	2017; https://www.1dropdx.com/
Spin-off from	Independent, IBM Research alumni
Employees	21 (~ 25 % physicists)
Investment & funding	10 MCHF
Revenue	0.5 MCHF (2021)
Locations	Neuchâtel (NE), Boston (MA, USA)
Field & application area	Life Sciences / ICT / Photonics
Main partners	EPFL, Harvard University, Massachusetts General Hospital, NASA, pharmaceutical Companies
Main product	Near patient health monitoring of biomarkers from a single drop of sample
Why physicists	Deep R&D in material science, nanofabrication, physical and optical characterization, automation, photonics, simulation and modeling, specialized technical sales
Physicists job roles	CEO, CTO, R&D, technical sales

Basel Precision Instruments GmbH

Founded; URL	2018; https://www.baspi.ch/
Spin-off from	University of Basel
Employees	2 (~ 50 % physicists)
Locations	Basel (BS)
Field & application area	Quantum & low temp physics
Main partners	BASPI and University of Basel
Main product	Ultra-low-noise precision laboratory electronics and cryogenic microwave filters

15 See Editorial in *SPG Mitteilungen* Nr. 57: https://www.sps.ch/fileadmin/doc/Mitteilungen/Mitteilungen.57.pdf

16 Umsetzungsempfehlungen für das Zukunftsprojekt Industrie 4.0, acatech deutsche Akademie der Technikwissenschaften, 2013

17 Framework for Cyber-Physical Systems, Volume 1, Overview, Version 1.0, NIST Special Publication 1500-201, June 2017, https://doi.org/10.6028/NIST.SP.1500-201

18 https://www.ifj.ch/Neugruendungen-in-der-Schweiz-2021

19 https://ethz.ch/en/news-and-events/eth-news/news/2020/10/spin-off-study.html

Why physicists	BASPI's mission is giving researchers a better lens into the quantum world and enabling the 2nd quantum revolution; hence a deep understanding of quantum applications and markets is crucial for BASPI's product development, sales and customer interactions, and business development.
Physicists job roles	CEO, founder, advisor

CARU AG

Founded; URL	2017; https://www.caru-care.com/
Spin-off from	Independent
Employees	10 (~ 20 % physicists)
Investment & funding	7 MCHF
Revenue	> 1 MCHF (2022)
Locations	Zürich (ZH), Zagreb (Croatia)
Field & application area	IOT / AgeTech
Main partners	Fraunhofer Institute
Main product	CARU care, virtual care home for elderly
Why physicists	The AI case management for optimized care services is based on room sensor and interaction data that require involved data analysis.
Physicists job roles	Co-CEO, Head of Product

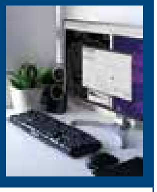
condenZero GmbH

Founded; URL	2018; https://condenzero.com
Spin-off from	University of Zürich
Employees	2 (~ 50 % physicists)
Investment & funding	~ 1 MCHF
Revenue	~ 0.5 MCHF (2021)
Locations	Zürich (ZH)
Field & application area	Microscopy & low temp physics
Main partners	University of Zurich, Forschungszentrum Jülich
Main product	cryogenic sample holder for high resolution transmission electron microscopes for material and life sciences
Why physicists	Fundamental knowledge required in material science and cryogenics
Physicists job roles	CEO, founder, advisor

Daphne Technology SA

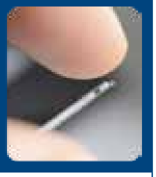
Founded; URL	2018; https://daphnetechnology.com/
Spin-off from	EPFL
Employees	34
Investment & funding	22 MCHF
Locations	St-Sulpice (VD), Sweden, Norway
Field & application area	Plasma physics - Emissions control
Main partners	Aramco, Shell, Trafigura, AET
Main product	Exhaust gas purification systems
Why physicists	Deep R&D in plasma and plasma chemistry, power electronics, material science and energy systems.
Physicists job roles	CEO, R&D

Dotphoton AG



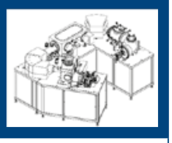
Founded; URL	2018; https://dotphoton.com/
Spin-off from	University of Geneva, GAP-Optique
Employees	13 (~ 25 % physicists)
Locations	Zug (ZG)
Field & application area	ICT / Photonics / Imagery
Main partners	European Space Agency, Bosch, Wyss Center
Main product	Metrologically accurate raw image compression for critical applications and AI
Why physicists	deep knowledge of the entire image acquisition process, optics, sensor as well as algorithms. Accustomed in working in many dimensions (useful for AI). Comfortable with solving both theoretical and practical problems.
Physicists job roles	CTO, Chief Software Architect, Researchers, Junior Scientist

FEMTOprint SA



Founded; URL	2013; https://www.femtoprint.ch/
Spin-off from	EU project (FP7)
Employees	30 (~ 20 % physicists)
Locations	Muzzano (TI), Neuchâtel (NE)
Field & application area	FEMTOprint is a Swiss high-tech Contract Manufacturing and Development Organization (CMDO) specialized in high-precision 3D printing of glass micro-devices using laser-based technologies. Medical, Biotech & Life Sciences, MEMS, Semiconductors, VR/AR, Integrated Photonics, Energy, Micromechanics, Aerospace, Automotive, Industrial machinery, Watchmaking and more.
Main partners	large companies, SME's, startups, research centers worldwide
Main product	Services for the development and the production of lab- and organ-on-a-chip, bioreactors, scaffolds & printheads, through-glass-vias TGV, photonic packaging, free-form optics & microlens array MLA, MEMS & sensing technologies, masters for microimprint and more.
Why physicists	deep R&D in material science, laser-matter interaction, optics and photonics
Physicists job roles	CSO, CTO, R&D, technical sales

Ionplus AG



Founded; URL	2013; https://www.ionplus.ch/
Spin-off from	ETH Zurich
Employees	30 (~ 10 % physicists)
Investment & funding	0.15 MCHF
Revenue	12 MCHF (2021)
Locations	Dietikon (ZH)
Field & application area	Environmental Research, Pharma, Archaeology, Material Science and more

Main partners	large companies, SME's, startups, research centers worldwide
Main product	Compact Accelerator Mass Spectrometer Systems (AMS) and Peripheral Instruments
Why physicists	R&D development of new Mass Spectrometer and all sup aspects of it from Ion Source to Ion Optics, Ion Beam Detection Systems and Software.
Physicists job roles	R&D

Lino Biotech AG

Founded; URL	2020; *https://www.lino-biotech.com/*
Spin-off from	ETH Zurich and F. Hoffmann-La Roche AG
Employees	7 (~ 15 % physicists)
Locations	Zürich (ZH), Düsseldorf (Germany)
Field & application area	Biosensors
Main product	Biosensors for cell and gene therapy manufacturing
Why physicists	Deep R&D in photonics, lithography and nanotechnology
Physicists job roles	VP Operations

Lumiphase AG

Founded; URL	2020; *https://www.lumiphase.com/*
Spin-off from	IBM Research and ETH Zurich
Employees	20 (~ 25 % physicists)
Locations	Kilchberg (ZH)
Field & application area	ICT / Optical communication
Main partners	IBM Research (R&D) and undisclosed partners for production
Main product	Semiconductor communication chips with next-generation photonic integrated circuits for data transmission in transceivers
Why physicists	Physicists are needed to tackle difficult R&D challenges at the interface between materials science, semiconductor processing, photonic/electric design, and optical characterization of communication chips; development of new device concepts and measurement methods; broad technical background and understanding in client interactions.
Physicists job roles	R&D engineers, CEO

Menhir Photonics AG

Founded; URL	2018; *https://menhir-photonics.com/*
Spin-off from	ETH Zurich
Employees	> 10 (~ 70 % physicists)
Investment & funding	Sales
Revenue	> a few MCHF (Cum.)
Locations	Glattbrugg (ZH)
Field & application area	Microwave / Photonics
Main partners	Cycle GmbH, ESA, Particle accelerator facilities, and microwave companies around the world
Main product	Femtosecond lasers (local oscillator) for optical clock distribution and ultra-low noise microwave generation
Why physicists	Development and understanding of laser designs and production processes. Many R&D expertise is required for the laser development and production, the optical characterization but also in the understanding and development of the applications.
Physicists job roles	CEO, CTO, production manager, technical sales, application engineer

MIRO Analytical AG

Founded; URL	2018; *https://miro-analytical.com/*
Spin-off from	Empa
Employees	8 (50 % physicists)
Revenue	>1 MCHF (2021)
Locations	Wallisellen (ZH)
Field & application area	Engineering / Photonics
Main partners	International research institutes / universities, suppliers (optics, machining, electronics)
Main product	Multi-compound gas analyzer for greenhouse gases and air pollutants
Why physicists	Development and production of highly integrated deep-tech product requires knowledge of spectroscopy, optics, electronics and software. Technical sales & marketing require in-depth understanding of customers' scientific applications and our products.
Physicists job roles	CEO, CTO, R&D, production, technical sales & marketing

Polariton Technologies AG

Founded; URL	2019; *https://www.polariton.ch/*
Spin-off from	ETH Zurich
Employees	17
Locations	Rüschlikon (ZH)
Field & application area	plasmonics, nanotechnology, photonics, communications, sensing
Main partners	Ansys, European Commision, ESA BIC, ETH Zurich, ETH Foundation, Gebert Rüf Stiftung, Innovation & Entrepreneurship Lab (ieLab), Innosuisse, Luceda, Venture Kick
Main product	110 GHz C-Band Plasmonic Mach-Zehnder Modulator
Why physicists	Polariton as a team takes pride in teamwork, clear and effective communication, and of course curiosity. As a physicist in Polariton you have a broad range of tasks including R&D chip-development and market viability studies, product testing and more.
Physicists job roles	CEO, CTO, R&D, technical sales, design, nanotechnology, testing

QZabre AG	
Founded; URL	2018; *https://qzabre.com/*
Spin-off from	ETH Zurich
Employees	10 (~ 80 % physicists)
Investment & funding	1 MCHF
Revenue	2 MCHF (2021)
Locations	Oerlikon (ZH)
Field & application area	Quantum sensing for magnetic materials, device characterization and failure analysis
Main partners	ETH Zurich
Main product	Single Nitrogen Vacancy scanning tips and Quantum Scanning Microscopes
Why physicists	Deep R&D in quantum protocols and material science, complex systems combining a wide range of techniques, very specialized fields of applications
Physicists job roles	CEO, CTO, R&D, technical sales

SWISSto12 SA	
Founded; URL	2011; *https://swissto12.com/*
Spin-off from	EPFL
Employees	40 (~ 75 % Masters, 25 % PhDs engineering & physics)
Investment & funding	> 20 MCHF
Revenue	double digit MCHF with fast growth > 50 %
Locations	Renens (VD), California, Israel
Field & application area	Radio Frequency products and systems for aerospace applications
Main partners	Thales, CAES, Airbus Defence & Space, Elbit, IAI and the European Space Agency
Main product	advanced radio-frequency (RF) products and systems for telecommunications, remote sensing and radar applications in the aerospace industry. The company has patented 3D printing technologies for lightweight, compact, highly performing, and competitive RF systems.
Why physicists	An in depth understanding of electromagnetism, mechanical and thermal engineering, materials science, aerospace environments (temperature, shock, vibrations, radiations, etc…), electrical, electronic, telecommunications and signal processing engineering, is necessary to develop and market these products. A physics background gives a perfect top-level overview of this broad range of topics and is a good basis to dig deeper.
Physicists job roles	CEO, CTO, R&D, technical sales

3.5 The Role of Physics in Established Enterprises

Once companies have overcome their "birth pains" and are established and proven as a recognized player in the market, the next chapter for their company story may vary widely: Some might choose to maintain the focus on their legacy and continue to exclusively serve their market niche. Some might look to partner-up and become part of a bigger enterprise that has the resources and portfolio to cover larger parts of a sector. Others will try to boldly take their chances, organically scale up and expand in more and more segments to become a globalized, major force with hundreds of employees and corresponding economic impact. As an illustrative example for the latter path, we discuss in the next section with the CEO of Sensirion what challenges they are/were facing and the role of physics while evolving since 1998 from a start-up founded by two ETHZ physicists to a stock market-listed leader with more than one billion sensors sold.

3.5.1 From Start-Up to Global Player: Sensirion

We interviewed Marc von Waldkirch, since 2016 CEO of Sensirion, with their headquarters located in Stäfa (ZH), about the transition from a start-up to a global leader in sensing and how innovation and economic boundary conditions are important. This is an excerpt of a longer interview published in the *SPG Mitteilungen* Nr. 67.

You entered Sensirion right after your PhD in 2005 at a time when the company was still a start-up company. What were the most important transformations that Sensirion went through, in the time from start-up to SME and what are the next steps in becoming a global enterprise?

I don't think there has been a single big change in these 16 years. On the contrary, Sensirion is constantly changing. But when a company grows, the need for business processes also increases. And that's where you must be careful: Certain processes are simply necessary, but too many or too rigid processes are poison for innovation and agility. That's why you need a good sense of proportion: because the creative minds in the company should be driving innovation, not filling out forms.

What do physicists do in Sensirion? How does an average workday look like?

We have physicists in almost all departments: in research and development as experts or project managers, but also in sales, e.g. in key account management or in leading functions in the operating business. And you will also find numerous physicists in the management team.
Many physicists join Sensirion in product development and then move on to other functions, either within or outside of R&D.

How important is research in Sensirion? Do you think the importance of research will increase / decrease in the future?

When it comes to the word research, we have to make a distinction. As a company, we do not conduct basic research; that is the job of universities. By contrast, applied

Figure 3-8: Research and development laboratory at Sensirion (Stäfa, ZH) [Picture: Sensirion]

research to develop disruptive new technologies plays a central role for us. This is because we have to be aware that disruptively innovative products are not developed overnight but require a long-term orientation that begins at the technology level. Even at this early stage of research, we form R&D and business development pairs to develop the technology in close collaboration with the evaluation of market needs.

As a small start-up typically, patents are expensive to keep and even more expensive to defend. How does Sensirion protect its intellectual property, and at what point in the evolution of the company did this become important? How do you see the importance of patents?

Patents are a crucial element for all innovation-oriented companies. It is important to protect the central elements of one's own technology at an early stage.

Which part of the product development and fabrication is still done in Switzerland? Which parts were maybe shifted to other countries and why?

The majority of product development still takes place in Switzerland. We enjoy the spirit of innovation and the well-trained talent here. At present, we have no intention of actively relocating parts of R&D to other countries. Nevertheless, R&D will become increasingly globalized as part of our active M&A strategy. In operations, we operate production sites in Stäfa, Hungary and in Asia.

More and more research labs from large, global tech corporations are built in the Zürich area. Do you notice effects on the attraction, recruiting or retainment of talents?

Absolutely, Zürich is a vibrant place for technology, especially in the field of software, and moreover all this thanks to ETH Zürich! This is both a blessing and a curse: on the one hand, such an environment is inspiring and attracts many good talents to Zürich. On the other hand, the shortage of talent is getting worse. In this respect, the bilateral agreements with EU are crucial for us and I also hope for a relaxation of the quota rules for third countries. Because the labor market for talent is highly competitive and no one waits for slow authority decisions.

How did Sensirion adapt from chasing and disrupting established players as a start-up to being "chased" itself as an established, mature company?

That's a good question that I've never thought about before... Well, actually we are faced with both situations today... In the humidity markets, we are the undisputed market leader that keeps getting copied. Still, we haven't lost our hunting instinct and continue not to lose any deals. In younger product lines, such as CO_2, we are the newcomer, chasing market share from more established competitors. But at the end of the day, it's the same: you have to identify real customer needs and solve them better than your competitors, regardless of whether you are a predator or prey.

Figure 3-9: Miniaturized differential pressure sensor [Picture: Sensirion]

3.5.2 Comments from Physics-Related Companies

Do traditional, non-high-tech SMEs and established corporations need additional skills besides their engineering knowledge? How important is physical expertise and do we consequently need more physicists in industry and outside of research institutions? These questions must be answered from first-hand experience. Thus, the Swiss Physical Society asked seven physicists heading well known Swiss high-tech companies for their assessment of their business' future. Our experts work in analytics, energy technology, micro-optics, motor engineering, patent processes, X-ray systems and satellite communications [20]. We asked them five questions, leading to the summarized answers below [21].

***Question 1:* How important are concepts from physics in your field of work?**

All seven experts indicated that the physical understanding of all techniques involved in their field was absolutely required to assure their international competence.

20 Ulrich Claessen (Maxon Motors AG), Reinhard Czichy (Synopta GmbH), Bernd-Günther Harmann (Kaminski, Harmann Patentanwälte AG), Reto Holzner (Silent Power AG), René Lenggenhager (Comet Group AG), Markus Rossi (Heptagon-AMS AG), Reinhard Völkel (SUSS MicroOptics SA)

21 see the full article with individual answers to the questions: *https://www.sps.ch/artikel/physiker-in-der-industrie/physics-as-driver-of-innovation-7*

Question 2: **Is the complexity of physical technology approaches generally increasing?**

This was confirmed by six of seven colleagues. The reasons given were the increasing functionality of new products and processes, higher degrees of integration, and the smaller sizes and higher power densities of new technologies. New materials must be adapted to new machining concepts, such as laser processing. The transition from the assembly of components to highly integrated systems increases the complexity of the technology.

Question 3: **To what extent do you differentiate yourself from competitors through physical or technical innovation?**

Two answers were remarkable: The first "Technical innovation is at the heart of business success in a high-wage country", and the second, "We try to realise innovations faster than the competition in our products, and physical innovations play the decisive role".

Question 4: **How important is a profound physical understanding of the technologies used for developing them further and implementing them reliably in industry?**

The answers expressed the fact that shorter "time to market" is only possible if the technological basics are understood and deeply internalised within SMEs. Only then is it possible to use the technologies optimally and push them to their limits.

Question 5: **At what intervals do you expect technological changes in your field in the future, and how important is the discipline of physics to these changes?**

The answers reflected that this depends on the technological field: relevant changes in micro-technologies were expected to take place across shorter periods of 1 to 2 years, while in the case of space technologies, intervals of approximately 10 years were expected between changes. On average, major changes in technologies were expected to occur every three to five years.

It is maybe not surprising that the interviewed experts did not need to be convinced of the power of physics and the necessity to expand physical understanding in the future. However, the diversity of applications, extending from systems at the nanometre scale to geostationary communication satellites, is impressive. In all business cases the interviewed experts agreed that technologies must be driven with a detailed understanding down to their physical limits.

Figure 3-10: Cleanroom nanofabrication facility at the IBM laboratory in Rüschlikon [Picture: IBM Research].

3.5.3 Physics Research in Global Enterprises

In global enterprises the role of physics and physicists is much more diverse and not limited to the core of the technology that is built into the respective products. Many of the largest global technology enterprises like Alphabet, Microsoft, and IBM, but also from other sectors, have local research and development labs in Switzerland, attracted by the high standard of living, the excellent education at Swiss universities and the prime global position of Switzerland in terms of innovation. Switzerland again ranked first on the global innovation index in 2021 [22].

Traditionally, probably the two most physics-centric corporate research labs in Switzerland are the ones of ABB in Baden and the IBM Research Lab in Rüschlikon, ZH. The ABB research center was established in 1967 and focuses on developing industrial solutions in the power, automation, and robotics sector. The IBM Research Lab was founded in 1957 as the first IBM research facility outside the United States. The physics research at the IBM lab led to two Nobel prizes: in 1986 for the invention of the scanning tunnelling microscope by Binnig and Rohrer and in 1987 for the discovery of high-temperature superconductivity by Bednorz and Müller. Further prestigious awards (Kavli Prize, EPS historic site) followed later and recognized the contributions of the labs physics research to technology and society in general. Today the physics research at the IBM lab has a strong focus on semiconductor nanotechnologies, quantum technologies and artificial intelligence related to information technology.

3.6 Cooperation between Industry and Scientific Institutions

R&D happens less and less behind closed doors in isolated company laboratories. Apart from close collaborations with partners along the supply chain, outside partners from academia and other research institutions become increasingly important for infusing fresh know-how and capabilities into the R&D pipeline. This is true not only for tech-driven SMEs but also for large enterprises that want to connect with the newest developments in the world of physics. Here Switzerland's great assets are a variety of major research institutions that provide an excellent infrastructure that is open to industrial collaborations.

Today, basic physical research requires increasingly complex experimental methods and machines, such as the large accelerators at CERN and the Paul Scherrer Institute PSI. These facilities can often also be used advantageously to answer industrial questions. At PSI, for example, ultra-cold neutrons can be generated which, in contrast to X-rays, penetrate metals. This allows, for example, the study of the combustion processes in diesel motors. As another example, high energy particle beams generally exhibit wave-like properties that give them super-microscopic imaging capa-

22 https://www.wipo.int/global_innovation_index/

Box 3-3: Statement from the Industry I

Roche is particularly interested in the structural elucidation of complex molecules. Due to the possibility of determining protein structures at the nearby Paul Scherrer Institute, we have also contributed to the Swiss Synchrotron Light Source. Our collaboration is an example of strong external cooperation, one of the pillars of our innovation model. I am convinced that only academic institutions are suited to devote themselves to basic research. This requires the appropriate freedoms and public funds to be able to work on new findings for decades. The task of the private sector, on the other hand, is to put research into practice… Switzerland is an excellent location for all those who rely on innovation. This also applies to Roche. We are rooted in Switzerland and enjoy being here. The high levels of education and training, excellent universities, and high degree of internationality in university research guarantee a high level of innovative strength. It is very important to me that we manage to maintain this level in Switzerland or, if possible, improve it even further. In my view, this is of existential importance for all of us - science, business, and society.

Severin Schwan, CEO Roche

Box 3-4: Statement from the Industry II

IBM has a long history of creating innovations and shaping the future of computing technologies through fundamental and applied research in physical sciences. In doing that, people, vision and infrastructure are key for success. While our cutting-edge research is focused on advancing information technology, we also believe that cultivating close relationships with academic and industrial partners following our long-standing tradition of scientific collaboration is crucial.

A very successful role model of collaboration is the Binning and Rohrer Nanotechnology Center (BRNC), a state-of-the-art research facility for nanotechnology jointly operated with our partner ETH Zurich. The BRNC provides cutting edge technology and know-how for nanosciences. This close collaboration brings great stimulus and cross-fertilization, fostering the exchange of ideas and the application of research results. In the basic research space, we follow an open, collaborative innovation model. That approach is reflected by the numerous Swiss and European research projects where we aim to explore and lay the foundations for future technologies such as quantum computing and hardware for artificial intelligence. Those technologies hold great potential to become transformative for IT and are therefore crucial from an economic and societal standpoint.

Heike Riel, IBM Fellow and Head Science & Technology, Lead IBM Research Quantum Europe & Africa, IBM Research Europe – Zurich

bilities. They are used in particular by the large-scale pharmaceutical industry for the structural analysis of highly complex molecules, as is explained in the statement of Severin Schwan (Box 3-3). Switzerland, with such close relations between industry and academic institutions, is in an ideal situation to perform highly efficient collaborations.

Collaboration between industry and academia can occur in many ways. One prominent possibility in Switzerland is via Innosuisse programs that support through funding or advice the development of research results into products. But of course, the horizon extends much beyond Switzerland, and international research collaborations are pivotal, just as international business is very important for the Swiss industry. A heavyweight are the European research framework programs where academic, SME and larger industrial partners jointly work towards common goals. The association to these framework programs is a tremendous instrument to anchor Swiss research institutions and technology companies within Europe. The continuous uptake and success of this opportunity is reflected by the more than 4000 Swiss participations in the past Horizon 2020 program [23] where 25 % are from Swiss SME and 12 % from larger enterprises.

Even broader, comprehensive collaboration between industry and academia is possible in public-private partnerships. Not specific to certain individual projects but centered around whole topical areas, they can provide an institutional framework for vivid idea and technology exchange between academia and industry for the mutual benefit of both. In her statement (Box 3-4), Heike Riel explains the idea and importance of such collaboration models, as exemplified by the nanotechnology research center in Rüschlikon that has been jointly established by IBM Research and ETH Zurich and other partners about a decade ago.

In the following, we list some major Swiss research centers which bridge the gap between research at universities and product development at industries. Their competence covers a broad part of the technology spectrum and makes them ideal partners for industrial R&D projects.

CSEM SA (Centre Suisse d'Electronique et de Microtechnique)

CSEM is a private, non-profit research and technology organization and a public–private partnership. Since 35 years it provides its expertise, technologies, processes, and services from precision manufacturing and renewable energies to digitalization technologies to industrial partners.
The organization has a turnover of about 89 million CHF, and employs 525 people that serve 225 industrial clients and holds 210 patent families. The CSEM research centers are located in Neuchâtel, Zürich, Muttenz, Alpnach and Landquart.
https://www.csem.ch/

23 https://www.sbfi.admin.ch/sbfi/en/home/research-and-innovation/international-cooperation-r-and-i/eu-framework-programmes-for-research/f-f-swiss-participation.html

Empa (Eidgenössische Materialprüfungs- und Forschungsanstalt)

Empa conducts cutting-edge materials and technology research, generating interdisciplinary solutions to major challenges faced by industry, and creates the necessary scientific basis to ensure that our society develops in a sustainable manner. As part of the ETH Domain, Empa is committed to excellence in all its activities. The research areas are nanoscale materials & technologies, sustainable built environment, health & performance, resources & pollutants and energy. Empa employs about 1000 people in Dübendorf, St. Gallen and Thun, with a total budget of around 170 million CHF.

https://www.empa.ch/

PSI (Paul Scherrer Institute)

PSI is the largest research institute for natural and engineering sciences in Switzerland, conducting cutting-edge research in three main fields: matter and materials, energy and the environment and human health. PSI operates large scientific research facilities, such as the Swiss Light Source SLS, the free-electron X-ray laser SwissFEL, the SINQ neutron source, the SμS muon source and the Swiss research infrastructure for particle physics CHRISP, which offer out-of-the-ordinary insights into processes taking place in the interior of different substances and materials. These are the only such facilities within Switzerland, and some are the only ones in the world. PSI provides access to their large research facilities via a User Service to researchers from universities, other research centres and industry. Located in Villigen (AG), PSI is part of the ETH Domain and employs 2100 people with an annual budget of approximately CHF 400 million.

https://www.psi.ch/

AMI (Adolphe Merkle Institute)

The Adolphe Merkle Institute is an interdisciplinary center of competence in soft nano- and materials science. AMI strives to be a leader in fundamental and application-oriented interdisciplinary research on soft nanoscience. It educates the next generation of scientists, stimulate innovation, foster industrial competitiveness, and improve the quality of life. The working fields of the main research groups are Polymer Chemistry & Materials, Bionanomaterials, Biophysics and Soft Matter Physics.

https://www.ami.swiss/

3.7 Engagement of Industry for Physics in Switzerland: SPS Awards

Given the impact that fore-front physics research has in many sectors, it is a genuine interest of Swiss industry to maintain strong links to physics in Switzerland. Therefore, several Swiss industries and institutions sponsor every year one of the SPS Awards for excellent scientific work in different fields of physics. Their valuable engagement is a clear signal how relevant physical competence is to their business strategy, and that they may be considered as attractive employer for young physicists.

ABB Corporate Research (Baden-Dättwil)

ABB is a leading technology company that is energetically driving the transformation of society and industry worldwide into a more productive and sustainable future. By combining its portfolio in electrification, robotics, automation and drives with software, ABB defines the boundaries of what is technologically possible and enables new levels of performance. ABB looks back on a successful history of more than 130 years. The company's success is based on the talent of its 105,000 employees in more than 100 countries.
https://new.abb.com/ch/de/

IBM Research Europe - Zurich (Rüschlikon)

The location in Zurich is one of IBM's 12 global research labs. IBM has maintained a research laboratory in Switzerland since 1956. As the first European branch of IBM Research, the mission of the Zurich Lab, in addition to pursuing cutting-edge research for tomorrow's information technology, is to cultivate close relationships with academic and industrial partners, be one of the premier places to work for world-class researchers, to promote women in IT and science, and to help drive Europe's innovation agenda.
https://www.zurich.ibm.com/

Oerlikon Surface Solutions AG (Pfäffikon)

Oerlikon Balzers is a leading global supplier of coatings that significantly improve the performance and service life of precision components and tools for metal and plastics processing. These coatings, developed under the brand names BALINIT and BALIQ, are extremely thin, feature high hardness and significantly reduce friction and wear. The BALIMED thin-film coatings, specially developed for medical applications, are wear-resistant, biocompatible, antimicrobial and chemically inert. With the technology brand BALIFOR, the company has introduced individual solutions for the automotive market, and ePD stands for solutions for the metallization of plastic parts with a chrome look.
https://www.oerlikon.com/balzers/ch/de/ueber-oerlikon-balzers/

METAS (Bern)

The Swiss Federal Institute of Metrology (METAS) is the competence center of the Swiss Confederation for all questions of measurement, for measuring instruments and measuring methods. It is the national metrology institute of Switzerland. As such, it has the mandate to ensure that measurements can be made in Switzerland with the accuracy required for the needs of industry, research and administration. It carries out its mandate together with third parties: In legal metrology with the verification laboratories and the cantons

and their verification masters; in unit dissemination with its designated institutes.
https://www.metas.ch/

COMSOL Multiphysics GmbH (Zürich)

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3.8 Summary

In Switzerland, physics has great direct, indirect and induced impact on the economy as a whole, as presented previously in chapter 2. Here, in this chapter, we discussed and gave vivid examples how this well-oiled innovation engine works and what are the stake holders in Switzerland. Ranging from dynamic start-up companies covering various technology sectors over mature and well established mid-sized companies to large global enterprises, they all rely on “bringing physics to work”. The presented colorful bouquet is by no means complete, as there are many other occasions where genuine physics innovations have either become “standard technologies”, such as in the case of laser-based manufacturing or environmental monitoring or they are more subtle in their use, such as for security features of bank notes.

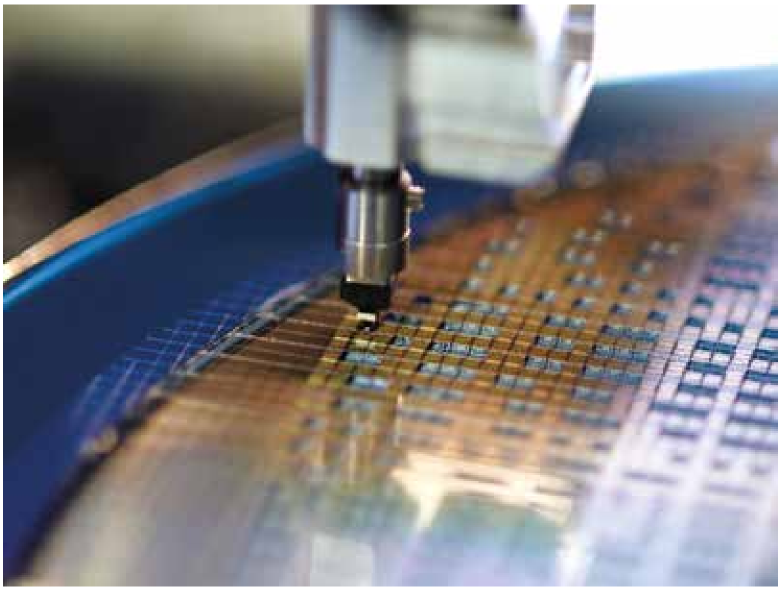


Figure 3-11: Wafer in sensor production [Picture: Sensirion].

One should not be deceived but driving innovation at the forefront of technology remains a perpetual struggle and requires persistent efforts from academia, industry and engagement from organizations like Innosuisse, SATW and SPS to build and maintain these bridges over the life cycle of innovative products. It is crucial to connect physics research with its successful exploitation in the marketplace. Doing so and even increasing the efforts and extending them into novel fields like quantum technology, computational information processing and artificial intelligence are vital for Swiss economy where current turnover of physics-based industries is estimated to exceed 200 billion CHF in revenue and is growing further.

4 Physics in Research

4.1 Introduction

The advancements of many research activities in Physics can create market opportunities. In such cases the main challenges have been moving from lab prototypes to producing sellable products that meet all the requirements for performance, reliability and stability demanded by high-end markets.

As mentioned in the previous chapters many new technologies touch the boundaries of physical understanding, and therefore physical competence is needed along the whole value-added chain, from research to industry.

In this chapter we start with some statistics regarding the funding strategy of the *Swiss National Science Foundation* (SNSF). Since their funding of new research projects often marks the begin of an innovation chain, their data of approved new annual grants are of special importance (4.2).

We will mention in 4.3 the *Swiss Thematic Road Map*, which SCNAT worked out as input for the *State Secretariat for Education, Research and Innovation* SERI with regard to larger projects in the future. Some of those mentioned research areas like *Particle Physics*, *Photon Science* and *Neutron Science* are also part of the SPS section structure, while others are represented only to some extent by SPS sections, but are mainly anchored within their own communities (see the respective sub-chapters in 4.4). This is the case for instance for *Astronomy & Astrophysics*, *Geo- and Environmental Science* and *Bio- and Medical Physics*.

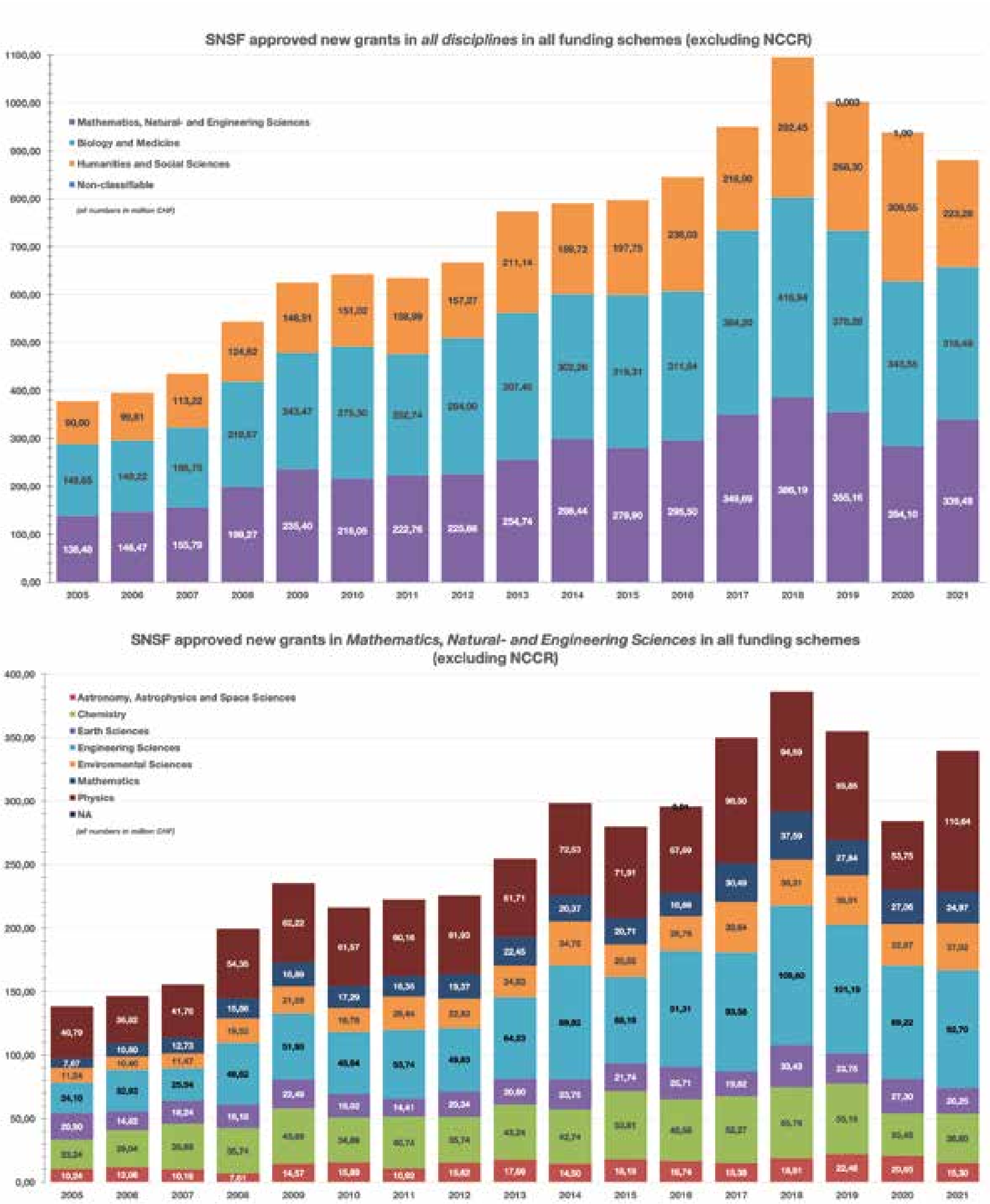


Figure 4-1: Funding schemes of the Swiss National Science Foundation. a: Overall funding, b: MNES disciplines (= purple bars from a)

Further neighboring disciplines with closer contact to physics are, for instance, chemistry, biology and pharmacology, as well as energy research topics.

4.2 SNSF Funding

Figures 4-1a - b show the number of approved new science projects by the SNSF from 2005 to 2021 [1]. While Mathematics, Natural- and Engineering Sciences (MNES) shared about 1/3 of the total funding (Fig. 4-1a), Physics participated with about 1/4 of the approved grants within this MNES subgroup (Fig. 4-1b).

Both figures show a remarkable drop in 2020. As can be seen in Fig. 4-1a the amount for MNES moved from 386.19 Mio CHF (2018) to 284.10 Mio CHF (2020), but came back to 339.49 Mio CHF in 2021. Obviously this also had strong impact on the amounts for new Physics grants, which dropped from 94.59 Mio CHF (2018) to 53.75 Mio CHF (2020), but also recovered significantly to 110.64 Mio CHF in 2021 (see Table 4-2).

1 https://data.snf.ch/key-figures/disciplines

4.2.1 Acceptance of new Projects in Physics between 2018 and 2021

In the following we try to understand the remarkable reduction of approved projects in Physics. To this purpose we consider the five SNSF sub-disciplines Careers, Infrastructure, Programs, Project Funding and Science Communication in more detail. As a first indication we present in Table 4-1 the individual numbers of submitted (brown) and approved (green) new grants for the years 2018 to 2021, and also the ratio approved/submitted, called the yield or success factor, both individually per sub-discipline and year, and summed up for all five sub-discipline together in each year.

Year	Careers	Infra-structure	Programs	Project Funding	Science Communication	Total Physics
2018	70 172 0.41	7 11 0.64	5 23 0.22	75 116 0.64	16 21 0.76	**173** **343** **0.50**
2019	48 122 0.39	17 33 0.51	11 62 0.18	81 149 0.54	32 38 0.84	**189** **404** **0.47**
2020	42 129 0.32	3 16 0.19	5 29 0.17	50 139 0.36	51 58 0.88	**151** **371** **0.41**
2021	43 128 0.33	20 30 0.67	5 21 0.24	65 143 0.45	52 60 0.87	**185** **382** **0.48**
						698 **1500** **0.46**

Table 4-1: Number of SNSF approved (green) and submitted (brown) new grants in Physics (excluding NCCR). Below the bars are the success rates (= the ratio green / brown).

It can be seen that the total yield factor decreased from 0.50 (2018) to 0.47 (2019) down to 0.41 (2020), before recovering to 0.48 in 2021. Was there a quality problem and where? The individual yield factors clearly indicate that there was a common trend towards poorer performance for all sub-disciplines besides Science Communication from 2018 to 2020.

While the pure counting of submitted and accepted projects is a first, however rough indication, the financial contributions listed in Table 4-2 give a deeper insight. Again the numbers in brown are what was asked as funding amount, while the green numbers above them are the amounts approved by SNSF, both in Mio CHF.

Year	Careers	Infra-structure	Programs	Project Funding	Science Communication	Total Physics
2018	34.90 129.33 0.27	2.73 5.16 0.52	6.45 20.15 0.32	50.36 82.72 0.61	0.14 0.54 0.26	**94.58** **237.90** **0.40**
2019	25.18 88.23 0.28	9.87 116.26 0.08	8.04 28.66 0.31	42.61 78.77 0.54	0.15 0.20 0.75	**85.85** **312.12** **0.28**
2020	21.55 97.36 0.22	1.07 7.72 0.13	5.43 28.02 0.17	25.31 68.33 0.37	0.40 0.63 0.63	**53.75** **202.06** **0.27**
2021	21.84 100.66 0.21	26.48 35.73 0.74	7.75 30.24 0.26	54.17 110.58 0.49	0.41 0.63 0.63	**110.65** **277.84** **0.40**

Table 4-2: SNSF approved (green) and submitted (brown) new grants in Physics (excluding NCCR) in Mio CHF. Below the bars are the success rates (= the ratio green / brown).

We see that the new summed up yield factor already dropped from 0.40 in 2018 to 0.28 in 2019, which obviously was not recognised as a warning signal, since the allocated lower amount of 85.85 Mio CHF in 2019 compared to 94.58 in 2018 was perhaps within the normal fluctuations. But then in 2020 all sub-disciplines besides Science Communications performed significantly poor, which is indicated by the individual yield factors.

We note that the total requested contribution amount in 2020 with 202.06 Mio CHF was already about 15% lower than in 2018 with 237.90 Mio CHF, but this could not explain the much stronger reduction of the approved sum by about 43 %, i.e. from 94.58 to 53.75 Mio CHF.

Was there a quality problem of the proposed projects or do we have to review the criteria of the evaluation board ? Or were other accounting methods the reason? So we asked the SNSF experts for some explanations:

- *Decrease in certain funding instruments: The comparison of the approved contributions for physics between the years 2018 and 2020 shows: We see the largest decrease in project funding (-25.05 Mio CHF), followed by certain career development instruments (-7.20 Mio CHF for Eccellenza and its "predecessor" SNSF Professorships; -5.17 Mio CHF for PRIMA). These decreases can be explained as follows:*
  - ◊ *For project funding, the total requested amount for physics has decreased from 82.72 Mio CHF in 2018 to 68.33 Mio CHF in 2020. In addition, success rates in physics decreased between 2018 and 2020, consistent with a general trend in project funding. Nonetheless, the 2020 success rate for physics in project funding was still just above the MNES average (35 %) at 38 % - in 2018, it was more significantly above the MNES average (53 %) at 65 %.*
  - ◊ *For certain career support instruments, demand in physics was lower in 2020 than in 2018: for Eccellenza and SNSF Professorships, there were 53 applications in 2018 (total requested amount: 79.92 Mio CHF), of which 14 were approved; in 2020, there were 27 applications (total requested amount: 45.17 Mio CHF), of which 8 were approved. For PRIMA, in 2018 there were 15 applications (total requested amount: 20.02 Mio CHF), of which 4 were approved; in 2020 there were 10 applications (total requested amount: 13.50 Mio CHF), of which 0 were approved.*

To classify this decrease in approved amounts for physics from 2018 to 2020: we observe a kind of "cycles" in demand (measured by the total amount requested per year) in physics, i.e. demand decreases over a few years, then increases again, and so on. As mentioned above, 2018 was a year of high demand, while 2020 was a year of lower demand. For 2021, we see a clear upward trend again in the first analyses - both in the total demanded and the total approved amount for physics.

In addition, we would like to mention that funding instruments are also included for which there is not a call for proposals every year. Thus, in certain years, no amounts were approved for these instruments. For example, there were *no approved amounts for FLARE [2] in 2018 and 2020, but in 2019 there were around 7.6 Mio CHF.*

Even if in 2021 the SNSF performance data for Physics recovered to those from 2018, in the future such a remarkable reduction should be immediately analysed for its causes. If this could not be explained by normal fluctuations or by administrative reorganizations, then the reasons have to be carefully examined by SPS in close cooperation with SNSF experts and suitable countermeasures have to be discussed and proposed. It would be a disaster if the beginning of a negative trend was not recognised in time.

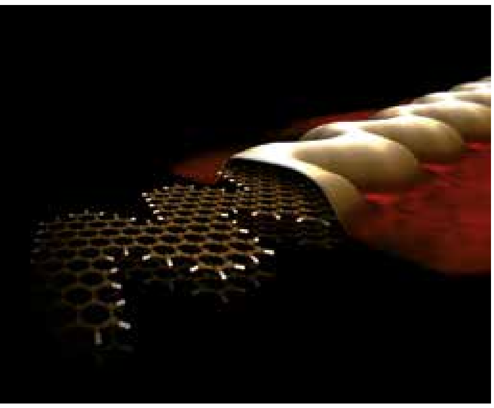
4.3 Swiss Thematic Road Maps

On a mandate of the Confederation, the Swiss Academy of Sciences (SCNAT) elaborated a series of thematic roadmaps for research infrastructures together with the scientific communities by March 31 2021. The Swiss Roadmap for Research Infrastructures is a planning instrument for research infrastructures updated by the State Secretariat for Education, Research and Innovation (SERI) every four years in preparation for the ERI (Education, Research and Innovation) Dispatch. It gives an overview of future needs and likely developments in different areas of research, including *Particle Physics*, *Photon Science* and *Neutron Science*. The roadmaps, coordinated by SCNAT since 2019, will serve as a basis for the 2021–2024 ERI dispatch [3].

4.4 Fields of Actual Physics Research

4.4.1 Condensed Matter

Material science and solid-state physics is in essence about understanding, controlling, and manipulating properties of matter. In the previous century, semiconductors have been exquisitely harnessed to such a degree that manufacturing of computer chips has become possible. The following technological revolution has completely changed and continues to change the way we live, work and communicate. Much of today's modern technology relies on electronic properties of materials and the fundamental understanding is at the heart of condensed matter physics. With two Swiss Nobel prizes in the 1980's (for the discovery of high-temperature superconductivity and the scanning tunneling microscope), Switzerland holds proud traditions in the field of condensed matter physics and material science. To this date, these disciplines are strongly represented at all federal and cantonal research institutions.



2 https://www.snf.ch/de/yZyEJhumi0SmWZ1r/foerderung/infrastrukturen/flare

3 https://scnat.ch/en/for_a_solid_science/networks_and_infrastructures/research_infrastructures

Future applications such as quantum computations are going beyond the physics of elementary silicon and copper. Continued fundamental research in material science and condensed matter is therefore important. Across Switzerland laboratories address curiosity driven research to synthesize new materials, develop novel instrumentation / methodology or investigate material properties.

Materials discovery involves both bulk single crystal growth (solid state chemistry), thin film methodologies and single atom surface science. In the context of research at the borders between academia and industry, the Nobel prize awarded development of blue light emitting diodes (LED) is a prime example of impact. Realization of graphene – a monolayer of graphite – is another example of a material with novel electronic properties that holds enormous potential for application. This discovery, awarded the Nobel prize in 2010, has opened an active field to investigate so-called two-dimensional materials. Combining monolayer materials with different twist angles is currently a promising avenue for design of new electronic properties. This field is closely linked with mesoscopic physics and device design. Device functionalities rely of material properties such as magnetism, ferroelectrics or spintronics.

Quantum matter refers to materials for which properties are governed by the principles of quantum mechanics. Superconductivity is an example of an emerging macroscopic quantum matter state. Typically, such quantum states arise from many body interactions that are being investigated broadly in solid state but also ultracold atomic gasses. These conceptually challenging problems are the center of both equilibrium and non-equilibrium experimental and theoretical developments.

4.4.2 Neutron Science

The ***Swiss neutron science community*** belongs to the most innovative ones worldwide, and is leading both in the development of new instrumentation and the use of neutron scattering to study materials. It profits from a national neutrons source, SINQ, which is based at the Paul Scherrer Institut in Villigen, and from the access to international facilities such as the Institut Laue Langevin (ILL) in Grenoble, France, and the European Spallation Source (ESS) in Lund, Sweden.

Neutron scattering and imaging is of great use to industry, and can support companies with their needs in R&D, quality management, the identification of materials failure or the malfunction of components. Neutrons allow to study materials components non-destructively, *in-situ* and in some cases even *in-operando*. For example, neutron imaging was used to study the distribution of particulate matter within exhaustion filters for the automotive industry (quattro GmbH), or the study of how improper storage of insulin injection needles from Hoffman-La Roche inhibits their functioning. It helped ABB to further refine the manufacture of ceramic components on over-voltage protectors. Neutron imaging is also heavily used in the quality control. For example, the pyrotechnic elements produced by Dassault Aviation used in the Vega and Ariane 5 launchers are all imaged at SINQ before installation.

With the foundation of a Soft Matter group at SINQ in 2020, the first industrial soft-matter customers used small-angle neutron scattering in 2021. It is expected that the use of neutron scattering will rapidly increase, and can contribute towards R&D of a wide range of Swiss companies in the food and health sector - one of the most important industrial sectors in Switzerland. Finally, neutron diffraction is expected to play an important part towards the so-called 4th industrial revolution with the use of additive (or more generally advanced) manufacturing techniques. Because of the non-destructive nature of the measurements, neutron techniques demonstrated to provide the necessary microscopic information that relates additive manufacturing protocols with the desired mechanical physical properties such as a strength. While most of the activities in advanced manufacturing at SINQ are still at the research stage, it is clear that the tailoring of location-specific physical properties through additive manufacturing holds great potential for the Swiss machine industry to keep and extend its worldwide leading position.

SINQ has seen an increasing use by the industry in the last 15 years, and currently sells about 100 days of neutron beam time per year to its industrial customers. An important part of the use of advanced tools such as neutron scattering and imaging is the data analysis, and the preparation of specialized experiments setup for the beam experiments. To offer the best possible service to industrial customers, a public-private partnership was therefore founded in 2019: ANAXAM (Analytics with Neutrons And X-rays for Advanced Manufacturing). The goal of ANAXAM is to market a range of diagnostic tools to small-medium companies, with a strong focus on neutron and X-rays tools, and to provide a comprehensive service that includes the preparation and conduction of the measurements, and their interpretation. It has already gained many companies, many of them small or medium sized, as members of the partnership and was able to further increase the use of large-scale facility use by Swiss industry.

Box 4-1: Some predictions of the future

There was a 108 % increase in researchers using neutron beams between 1999 and 2018 and a further 40 % increase is expected until 2040. The fastest growth will happen in domains like Life Science, Neutron Imaging and Industry R&D. Innovation will be further promoted with spin-off companies like SwissNeutronics, the market leader in the field of neutron guide systems worldwide.

4.4.3 Photon Science

The ***photon science community*** relies on photon sources as central tools in research, for understanding and controlling matter on all levels of complexity. Even if a substantial part of research is done with laboratory-scale instrumentation, Switzerland operates two major large-scale facilities, namely the synchrotron Swiss Light Source (SLS) and the X-ray free-electron laser SwissFEL, both at the PSI location. The Swiss photon science research community organizes itself in the *Swiss Society for Photon Science* (SSPh), which complements the industry network *Swissphotonics*. In a recent roadmap document SSPh made recommendations for future strategic planning, with a view to improving access to relevant state-of-the-art research facilities. Beyond strengthening of university-based activities, these recommendations include further upgrades for SLS (SLS 2.0 upgrade) and SwissFEL (new hard X-ray extension Porthos), and continuous support to the European Synchrotron Radiation Facility (ESRF) in Grenoble and the X-ray Free-Electron-Laser (EU-XFEL) at DESY in Hamburg, with the appropriate funding mechanisms for instrumentation.

Photon science facilities, from single lab to such large-scale infrastructures, not only generate scientific knowledge and breakthroughs but serve also to educate the future generations of scientists and engineers in a key technological field for Swiss industry and to foster interdisciplinary industrial partnership. The Swiss photonics associations and large scale facilities play an important role in conveying the importance of photon science also to the broader public by organizing open days and public events. Switzerland is an important partner in EU research infrastructures and involved in the consortium "League of European Accelerator-Based Photon Sources" (LEAPS).

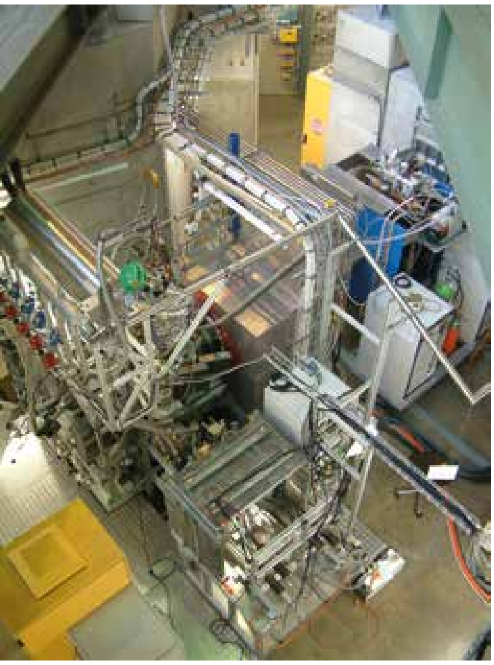
While laser technology in general becomes more and more accessible for an ever growing range of uses, cost and complexity of sources at the frontier of the technically feasible keep increasing. To ensure the international competitiveness of Swiss research, this calls for the establishment of new medium-scale, multi-user facilities. With the FastLAB (Uni Bern) and LACUS (EPFL), first shared laboratories of this kind have recently been established in Switzerland.

Research in photon science includes all kinds of experiments to generate, manipulate and detect photons or use them to investigate or control complex assemblies of matter, hard and soft. It involves physicists, engineers, chemists, biologists, earth scientists as well as researchers in interdisciplinary fields, such as life sciences or environmental sciences, often collaborating within a National Center of Competence in Research (NCCR). The existing Swiss photonics platforms such as QSIT and MUST have helped keeping the Helvetic photon science at the forefront, in addition to international networks and collaborations.

Technology transfer in photon science has a long-standing tradition in Switzerland, with some of the most innovative players in photonics worldwide. Swiss photon science activities on all scales have a long and successful track record of being a fertile breeding ground for a broad range of photonics-related spin-off companies. Professional organisations like *Swissmem* or *Swissphotonics* facilitate strong links between the academic and industrial sectors. Today photonics industries generate a business volume of about 4 billion CHF with economic growth rates of 6 - 8 % and strong impact in image processing, medical technology, communication and information technology, or photovoltaics.

4.4.4 Muon Spectroscopy

The ***muon spectroscopy community*** relies on the use of the most powerful large-scale muon facility, the Swiss Muon Source (SμS) at the High-Intensity-Proton-Accelerator complex (HIPA) at the Paul Scherrer Institute (PSI), Switzerland's largest national laboratory. At SμS, the worldwide highest intensity beams of positive and negative muons are available, enabling a large variety of research ranging from fundamental studies in particle physics, condensed matter physics and materials science, energy research / device technology applications, to depth-resolved, non-destructive elemental analysis of very sensitive samples, e.g., archeological cultural artifacts or meteorites for extra-terrestrial geology. The research activities at SμS are evaluated by the SμS Scientific Advisory Committee, which also provides feedback about the research strategy in muon spectroscopy at PSI. SμS operates and continuously upgrades its comprehensive suite of muon-spin-rotation spectroscopy (μSR) instruments and is developing a new instrument for Muon-Induced-Xray-Emission (MIXE) for elemental analysis. These diverse activities ensure a spectrum of experimental capabilities that is broad and unique with respect to accessible temperatures, magnetic fields, time resolution, measurement geometries, probing depths, minimal sample sizes, and sample composition. With this combination of unique instrumentation and unique methodology, SμS is a world-leading facility for muon spectroscopy. SμS is involved in the development of the High Intensity Muon Beams (HIMB) project at PSI, which has the potential to open new muon research fields in materials and device science by a two orders of magnitude higher beam intensity in connection with novel detector technologies.



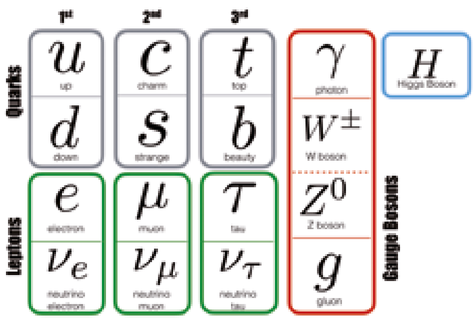
Muons, when implanted in matter, act as very sensitive *local* probes to characterize the electronic and magnetic properties in the vicinity of their stopping sites in the material under investigation. Muon spectroscopy is complementary to neutron and x-ray *scattering* techniques, which, as non-local techniques, measure the response of incoming neutron or x-ray beams to many scatterers, i.e., nuclei or electrons, of the sample. Research in muon spectroscopy comprises the characterization of novel magnetic and superconducting materials, the study of hydrogen-like impurities in semiconductors, high-spin molecules and low-dimensional magnets with potential technological applications, quantum spin systems, polymer dynamics, novel topological materials, diffusion processes in battery materials, and defect studies at the interfaces of solar-cell heterostructures and high-power semiconductor device structures.

The muon experiments at SμS with Swiss users are carried out in close collaborations with research groups from various universities and institutions, i.e., ETH Zürich, Universities of Zürich, Fribourg, and Geneva, the Swiss Federal Laboratories for Materials Science and Technology (EMPA), the Roman Museum Augusta Raurica, and the University of Bern / Natural History Museum. Education and training of the next generation of researchers is a core task at SμS. Funding of the research activities is mainly provided by PSI, the Swiss National Science Foundation (SNSF), and to lesser extent by EU research programs.

4.4.5 Particle Physics

The ***Swiss community active in particle, astroparticle and nuclear physics*** is represented by the *Swiss Institute of Particle Physics* (CHIPP) founded in 2003. CHIPP has developed long time strategies and recommendations to coordinate research and teaching activities in Switzerland, strengthen participation in international projects and promote public awareness of the field. It relies on three main pillars: particle physics at high energy and intensity, astroparticle physics and neutrino physics, pursuing long term scientific goals on large research infrastructures like CERN. In particle physics the constituents of matter and their interactions at the most fundamental level are studied. One great achievement of Quantum Field Theory is the Standard Model (SM) that successfully describes three of the four known interactions – electromagnetic, strong and weak nuclear forces, and gravitation. With the discovery of the Higgs boson, the SM is now a self-consistent theory that can predict many experimental observables to a high level of precision. But several questions remain open such as: what is dark matter and dark energy, is there a substructure of fundamental particles, are there more fundamental forces at the microscopic level, how does gravity behave at the quantum level, etc.? These open questions require to go beyond the successful but limited SM paradigm with new experiments and theories and to connect particle physics to other disciplines like cosmology, astronomy, and astrophysics.

These research fields are international endeavours by their nature, requiring long-term commitments and the availability of sophisticated infrastructures, such as particle accelerators and detectors, telescopes, and satellites. Switzerland is well connected with international organisations such as CERN, the European Southern Observatory (ESO) and the European Space Agency (ESA). It has also with the Paul Scherrer Institute (PSI) a national lab-



oratory with unique particle physics facilities. Of great importance is keeping access to reliable infrastructures and building the next generation of instruments, such as the long baseline neutrino experiments, the High Intensity Muon Beam (HIMB) at PSI, the Cherenkov Telescope Array (CTA), and possibly the proposed Future Circular Collider (FCC) at CERN, etc. Equally important is to maintain high level training capabilities for engineers, postdocs, and students in order to keep and develop the know-how for future sophisticated instrumentation and accelerator technology. Like in other fields funding for research projects is mostly provided by the Swiss National Foundation (SNF) and its FLARE program (Funding LArge international Research) as well as by grants from the European Research Council (ERC). Among its multiple recommendations CHIPP favors a strong Swiss involvement in and support to CERN's flagship, the Large Hadron Collider (LHC), its high luminosity upgrade (HL- LHC) and its future generations of colliders (FCC, electron-positron Higgs factory FCC-ee, hadron collider FCC-hh) as well as in the future exploitation of the HIPA accelerator complex at PSI. Vigorous experimental and theoretical research programs in particle, astroparticle and neutrino physics bring the groups of Swiss Universities (Basel, Bern, Geneva, Zürich, ETHZ, EPFL) and PSI to the forefront of fundamental research and technological innovation. Overall, more than 400 people are actively involved. Special attention is also devoted to attract, educate and train bright students in all areas and particularly in large collaborations.

It is evident that global education, outreach and communication efforts are of highest importance for a dialogue with the public, stakeholders, and politicians to strengthen the integration of science in society. This open dialog is engaged in fact by all Swiss research communities and is also part of the present Open Science, Open Data and Open Innovation mainstream.

4.4.6 Astronomy & Astrophysics

The ***astronomical community*** covers a broad spectrum of natural sciences. Whereas classical astronomy aims to understand the formation and evolution of the Universe as a whole, including galaxies, stars, and planets, modern astronomy calls on fundamental astrophysics and particle physics, computer science, chemistry, geophysics and even biology with the search for extraterrestrial life. Astronomy is of multi-disciplinary nature, diverse in its capabilities involving also large infrastructures, realized through space- and ground-based telescopes and instrumentation, including theoretical and computational developments. Switzerland hosts high-profile research teams in all areas of astronomy and astrophysics, with strong collaboration and leadership at the national and international levels. New projects follow usually recommendations proposed by the Swiss Commission for Space Research (CSR) and the Swiss Commission for Astronomy (SCFA), which acts as board of the College of Helvetic Astronomy Professors (CHAPS). The Swiss Society of Astronomy and Astrophysics (SSAA) gathers the ensemble of scientists active in these fields.

New scientific projects must establish or strengthen the scientific leadership of the Swiss astronomy community and are usually carried out within international organisations like the European Space Agency (ESA) and the European Southern Observatory (ESO). Access to state-of-the-art ground-based instrumentation such as the Very Large Telescope (VLT), the Atacama Large Millimeter / submillimeter Array (ALMA), and eventually the Extreme Large Telescopes (ELT), the Cherenkov Telescope Array (CTA) and the Square Kilometer Array (SKA), will provide Swiss astronomers with experiments covering a broad range of wavelengths. The astronomical community recognizes ESA as the "Swiss Space Agency" and as such the main instrument to implement science projects in space, including the Swiss leadership of the CHEOPS mission. Swiss scientists are heavily involved in many ongoing space missions, as e.g. for studying Mars (ExoMars, InSight), Mercury (Bepi Colombo) or the Sun (Solar Orbiter), and in planned ones like JUICE for studying Jupiter or Euclid for cosmology, just to mention some. Also the recently successfully launched James Webb Space Telescope has an important swiss contribution.

As the continuation of the NCCR PlanetS a Swiss Institute for Planetary Sciences (SIPS) should be established by 2026 to give broader access to space-borne science in general. Switzerland is at the forefront in developing state-of-the-art computer programs for high performance parallel computing and crucial numerical simulations, for which it relies on the Swiss National Supercomputing Center (CSCS) in Lugano. The Swiss research environment is excellent thanks in particular to the FLARE program, a common funding instrument to support the particle physics and astronomy communities and the PRODEX program for space activities. Swiss astronomers are involved in a significant number of large projects covering fields such as exoplanets, galaxy formation and evolution, solar and stellar physics, high energy astrophysics and gravitational waves. In the latter case, Swiss groups will continue to contribute to the LISA mission for detecting gravitational waves in space and to Earth bounded detectors as LIGO/Virgo and the proposed Einstein telescope.

Topics like space geodesy and space weather are also actively investigated. Astronomy has an important societal impact with industrial innovation, and the astronomical community is highly involved in education and outreach.

4.4.7 Earth, Atmosphere und Environmental Physics

Earth, atmosphere and environmental physics can be described in terms of the laws of physics. Examples include a number of environmental issues such as global warming, waste depositories, ozone layer depletion, energy crisis and renewable energy sources, air, soil and water pollution, etc. This section pays tribute to the emphasis placed on monitoring and understanding processes, as well as predicting changes of our physical world. The underlying topics may be regarded as earth- or geo-sciences oriented, being a particular combination of physical, chemical, and biolog-

ical processes linking and determining every components of the Earth system on a wide variety of spatial and temporal scales.

Earth Physics encompasses a number of topics from the geophysics of the globe (plate tectonics, geomagnetism, solid state at high pressures, seismology, geodesy, cosmic rays, extraterrestrial geophysics,…) to engineering geophysics, applied geophysics (analysis of geological resources, of geomaterials, of geological hazards, of geological barriers for waste storage, monitoring of contaminated sites), aiming at a description from first principles.

Atmospheric Physics is concerned with the structure and evolution of the planetary atmospheres and with the wide range of phenomena that occur within them, with a particular focus on the Earth's atmosphere interacting with other components such as the lithosphere, the biosphere, the hydrosphere and the cryosphere.

Environmental Physics involves the many aspects of physics that pervade environmental processes in our everyday lives and in naturally occurring phenomena. This includes energy supply and resources issues, which growing needs and use can impact on environment. It aims at understanding the various links between topics such as, e.g.: sustainability, contribution of renewable sources, efficiency, wastes and pollution, CO_2, climatic impact.

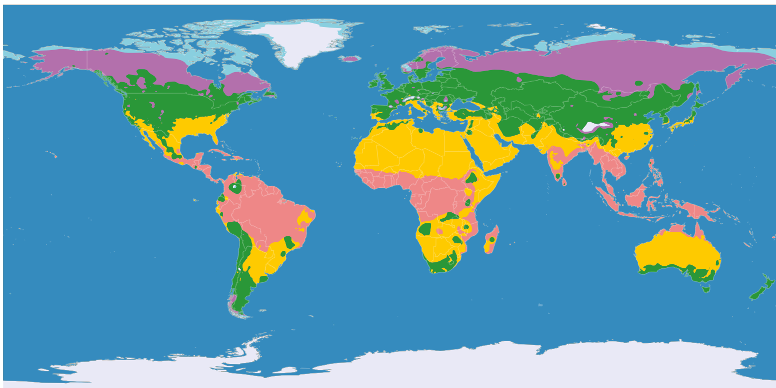
4.4.8 Geoscience

The ***Swiss geoscience community*** is highly involved in multidisciplinary research on societal challenges such as climate change and meteorological extreme events, environmental pollution, mass movements (land and rock slides), earthquakes and seismic hazards, global volcanic hazards, and energy and other natural resources. It provides thus scientific guidelines to politicians, stakeholders, and society on urgent Earth sciences issues. Recently the individual branches in geosciences were merged into an "Integrated Swiss Geosciences" aiming to bundle efforts for large research infrastructural (RI) requirements and optimizing financial and personnel resources. This goal is best achieved with centers of excellence in atmospheric, environmental, surface processes, and deep Earth projects and by merging sectorial activities under the recommended four pillars:

1) The *Integrated Long-Term Observatory* (Geo-OBSERVE) for monitoring climate change and air pollution effects in the Alpine region.
2) The *Mobile Monitoring Infrastructure* (Geo-MOBILE), a versatile infrastructure with distributed sensor arrays.
3) The *Swiss Geo-TIME facility*, a consortium of multi-user facilities for precise determination of timescales and process rates of geoscientific events ranging from near-instantaneous up to the age of the Earth, and
4) The *Geo-DATA platform*, a Swiss national hub for the management, dissemination, and long-term archiving of digital geoscientific datasets.

This latter infrastructure would benefit both national and international research projects while providing means for professional sample and data curation in collaboration with the SwissCollNet / SwissBioColl initiatives.

Geoscience considers Earth functions as an integrated system, in which energy and materials are exchanged and cycled between the different geospheres and the biosphere. It is located at the crossroads between many different topics, and uses tools developed by other science domains to understand our planet. Synergies exist with subsections like geophysics, geochemistry, geobiology, geoengineering, and with new fields such as environmental mineralogy and astrobiology, among others. Through its membership in the European Research Infrastructure Consortium (ERIC), the Swiss geosciences community participates in numerous international networks and programs such as CTRIS, ARES, eLTER, EPOS, GAW, GCW, HFSJG, ICDP, ICP Forests, ICOS, IODP, LWF, SwissOGS). This strengthen the high global visibility and Swiss reputation in these fields. Switzerland is uniquely placed at the crossroads of climate impact on resources such as water, the effects of extreme weather events on natural hazards in mountainous environments, as well as the inherent risks associated with an active mountain range. Since sustainability of the environment has gained larger public awareness, the geosciences are playing a key role for many federal agencies and industrial stakeholders. Its innovative observation and measurement instrumentation are leading to new technologies, commercial products, as well as start-up and spin-off companies. The societal pressure on resources, energy and environment will continue to increase, requiring integrated approaches and a new generation of well-trained Earth scientists. Switzerland is well positioned worldwide with its high-level education in geoscience at its national universities and ETH-domain institutions.



4.4.9 Energy Science

The prediction of global warming and its cause, the relentless burning of fossil fuels (coal, oil, gas) to feed the need for energy in our modern society, is well established scientifically and no longer disputable. Urgent actions are needed to decarbonize the world and thereby a rapid transit to new energy technologies is the task society and world leaders have to take, without further delays and without hesitations.

Box 4-2: Energy consumption versus production

The global primary energy consumption has doubled world-wide within the last 50 years leading to 173340 TWh [1] in 2019 used in transport, heating, industrial production and manufacturing, etc. Over 85 % of it is obtained from burning of fossil fuels, 11 % are covered by renewables (hydropower, solar, wind, geo-thermal, bioenergy, wave and tidal) and the remaining 4 % are based on nuclear power. Electric power generated in the same year was 25900 TWh, produced by renewables (27.3 %), nuclear (10.5 %) and burning of fossil fuels (62.2 %).

Electricity needs will raise further in a decarbonized world, where combustion engines will subsequently be replaced by electric engines, not only in transport but also in industrial production, manufacturing and heating (heat pumps or direct heat production).

New infrastructure to produce, store and distribute electric energy will need to be installed at an unprecedented scale in the coming few and critical decades – world-wide.

Replacing coal plants world-wide fast, while providing fossil-free electricity at the same level – or when anticipating increase of electric energy usage at an ever higher amount, with higher capacities and guaranteed availability considering daily and seasonal variations of production yields needs new concepts in storage and distribution.

Even if much of today's energy research is on the engineering side and also heavily dominated by engineers, physics could still greatly contribute as well. Challenges in a more flexible future energy system that can also be addressed on a more fundamental, physical basis are for instance the following:

Sources:
- new materials and surface coatings for photovoltaics

Distribution:
- Materials: loss-minimized cables for energy conversion & transport
- High-power electronics (converters, rectifiers, …, semiconductor material science)
- Network logistics (load-balancing concepts, smart grids, predictive supply / demand management)

Storage:
- High-capacity short-term storage by e.g. capacitors, batteries
- Long term storage (seasonal)

NET: the Negative Emission Technologies
- They are needed to compensate for residual Greenhouse Gas emissions by e. g. agriculture, but also by CCGT (Combined Cycle Gas Turbines), which are discussed to bridge the time gap until fossil free sources completely take over, and to tackle the CO_2 overshoot in the years after 2050.

There are promising concepts that are workable at smaller scales. Whether full-scale deployment, covering the needs of modern, industrialized society is even possible when fossil free shall be the target (as asking just for CO_2 neutrality will not be good enough) still needs to be shown.

Not all countries in the world have the same possibilities to change their energy production and supply chains and many countries are deciding to continue producing their electricity using nuclear power. Countries like the USA, India, China, France, UK, Finland, etc. will not stop nuclear energy production, in contrary, design and building of new generations of nuclear power plants are taking up pace again. Modern concepts can get rid of the problems current nuclear reactors have and thereby are also offering higher safety and better efficiencies. Further, the production of long-lived isotopes that otherwise remain as nuclear waste is minimized.

When breeding is further considered, no long-term threads occur anymore and transmutation of existing nuclear waste becomes a possibility.

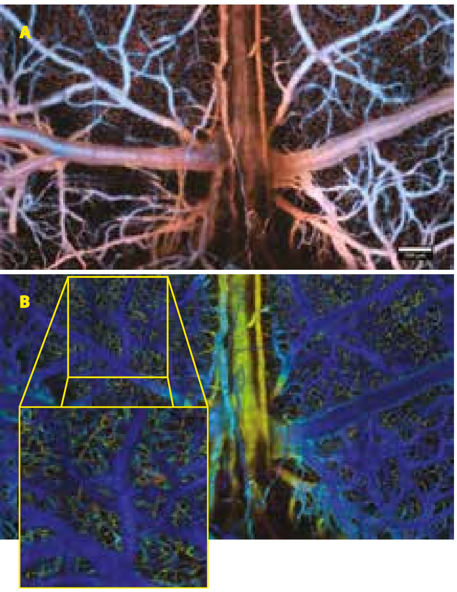
The state of art of nuclear technologies was addressed in ***SPS Focus 1***.

4.4.10 Biophysics, Soft Matter and Medical Physics

Research in soft matter, bio- and medical physics has a very broad range with a major emphasis on interdisciplinary collaboration with either chemists, biologists or engineers. In all of these thematic fields, fundamental understanding and applications go hand in hand, which is also exemplified by the close collaboration of theory and experiment.

In soft matter systems, the use of self-assembly for tailored materials properties has in recent years come to the forefront and has led to great advances in e.g. optimized light harvesting, structural colors or self-healing polymers to name but a few. In all of these applications, a deep understanding of design-synthesis analysis and structure-property relations in soft-matter physics, combined with organic and bioorganic chemistry led to remarkable innovations, notably therapeutic delivery vehicles based on lipid- and capsid-nanoparticles. This breakthrough enables DNA- and RNA-vaccination and enabled society to encounter the Covid-19 pandemic. Life scientists believe that this successful proof-of-concept in soft-matter science will foster the development of medical treatments based on anti-sense oligonucleotides and gene therapies that enable curing of so far untreatable diseases.

In biological physics, while research is often geared towards fundamental understanding of biological systems, physics-augmented methods are crucial for understanding of disease biology, diagnosis of a disease and for clinical



studies. This evolving field depends on "smart molecular sensors" (based on physical principles, such as mology-raphy, spatial lock-in, nano plasmonics, or PET tracers) that enable minimally invasive and time-resolved molecular studies in cell and tissue cultures, in scaffolds for the growth of organoids, and in humans. Machine learning and artificial intelligence in this field is dependent on new molecular observables that are traced with minimal distortion of the biological systems under investigation. Novel microscopic methods, ranging from optical microscopes with either increased speed, resolution or decreased toxicity for the samples in live imaging, to functional magnetic resonance imaging or X-ray imaging with decreased radiation damage e.g. due to the use of phase contrast, are also important for basic and applied research in biological and medical physics.

Finally, medical physics is of great importance in the improvements of diagnostics as well as treatment methods. On the side of diagnostics, the above mentioned sensing and imaging developments are key, while on the side of treatments, irradiation with protons or heavy ions in addition to X-rays can give a much more precise eradication of tumors. Alternatively, combining imaging with irradiation methods and computational modelling of the interaction of radiation with tissues has led to improved treatments with decreased side effects even using X-rays for irradiation.

Thus, a combination of the different research advances seen in biological, medical and soft matter physics will undoubtedly lead to several breakthroughs in materials design, medical diagnostics and treatment.

4.4.11 Plasma Physics

Plasma physics research is the key to fusion energy and to a number of technical applications.

Fusion reactions hold enormous potential for clean and sustainable energy production from geographically equitably distributed resources, but the demonstration of technical and economic viability remains to be carried out. Deuterium-Tritium fusion needs temperatures 10 times larger than in the solar interior, ~ 150 Mio degrees. In magnetic fusion, confinement is provided by magnetic fields, with high temperature plasmas of typically atmospheric pressures and energy confinement time of few seconds, increasing with the size of the device. Out of several magnetic confinement concepts explored during the last 50 years two toroidal device concepts have been successful, the tokamak and the stellarator.

The ITER tokamak, presently under construction in France, represents an essential step toward a practical technical demonstration of fusion energy. ITER is at the threshold of the conditions suitable for baseload power plant operation, consistent with the goal of minimizing physics uncertainty in the next-step device (DEMO), which would be a prototype power plant.

Switzerland participates to this effort with its TCV tokamak, the flexibility of which allows studying essential issues for ITER and DEMO. It also hosts the test facilitiy to qualify the superconductors, in particular those used in ITER. The state of art of ITER is described in ***SPS Focus*** No. 1 [4].

Plasmas find their use also in numerous industrial applications. One key to industrial plasma processing is that high temperature plasma chemistry – at thousands of degrees Centigrade – can be applied to low temperature substrates, such as glass, plastics, and even bio-material. This involves applications like coating, cleaning of surfaces or sterilization. Plasma interaction with bio-material go from the effects on cells to health applications like improved wound healing in atmospheric plasmas. One extremely important and lucrative example of device manufacturing using plasma processing is the field of microelectronics, which has revolutionized our lives over the last 50 years. Plasmas – sustained by wave excitation - are also used in the design of efficient ion sources used for space propulsion, for the production of neutral beams used for the heating of fusion plasmas, or for high-energy particle acceleration like in the AWAKE project at CERN. X-rays lasers on a tabletop are seeing a renaissance using hot and dense plasmas as gain media, pumped electrically or optically [5]. As a last example, active noise control by plasma electroacoustic actuators can be used for frequency domains where passive noise reduction means are not sufficient.

4.5 Final remarks

Not forgetting to mention research and development (R&D) activities in the Universities of Applied Sciences. Many scientists are members of the National Centres of Competence in Research (NCCR) that subsidize top-level research projects on themes of strategic importance for Switzerland. Many of these people are also involved in teaching, training, education and outreach, technology transfer, intellectual property, and societal challenges.

It is a well-accepted opinion that physics is at the origin of great discoveries that have and will continue to impact our life and that it often provides the foundation for other disciplines. Physics and its derived technologies play a central role in many sectors of industries and for the development of a global economy by producing goods, services and creating millions of high-skilled jobs.

4 https://www.sps.ch/artikel/sps-focus/sps-focus-1

5 https://www.sps.ch/artikel/progresses/x-ray-lasers-using-a-plasma-medium-tabletop-beams-got-brighter-than-synchrotrons-87

5 Physics, Education, and Outreach

5.1 Introduction

We live in both a democracy and a "knowledge society", two aspects that are mutually dependent. In autocratic systems, society does not need knowledge; it is enough for knowledge to be accessible to just the "elite". Conversely, a knowledge society cannot – in the long run – be constrained by autocratic decisions.

A democracy, by definition, must be able to make decisions by democratic means, which can only succeed if there is an understanding of the questions to be decided upon. Physics as a fundamental science has a special social role here. It is not a matter of understanding quantum physics and relativity theory in detail, but of having a basic understanding of essential concepts and relations, as well as of the scientific approach of gaining and validating knowledge in general.

This is the only way to empower citizens to recognise fake news in the media, to form a well-founded opinion, and to participate in the discussion about issues of societal importance (such as the energy supply system), and eventually in votes and elections regarding these. Beyond this "political" necessity, physics has a foundational role for understanding other sciences, and for our modern scientific worldview.

From these arguments, the important role of education and communication when dealing with "Physics and Society" becomes apparent, which is treated in the following sections.

5.2 Physics and Education, Physics Education

The life-enhancing potential of science and technology cannot be realized unless the public in general comes to understand science, mathematics, and technology and to acquire scientific habits of mind; without a scientifically literate population, the outlook for a better world is not promising (American Association for the Advancement of Science, [1])

This chapter is about two different but closely related subjects: "Physics and Education" – the specific contribution physics can make to education and general literacy, and "Physics Education" – the question how physics should be taught at school [1].

5.2.1 Physics, education, and literacy

Whether you use your smartphone, have to undergo a magnetic resonance imaging for medical purposes, or marvel at the discovery of extrasolar planets – there is a wealth of physics behind all this, and at the basis of understanding what you are doing, what is happening, and how the world you live in is made up [2]. More generally, in a society so strongly shaped by science and technology, the profound and rapidly enlarging scientific world view(s) have led to today's understanding of "scientific literacy" as essential element of general literacy. In a current definition, it refers to an individual's:

- scientific knowledge to identify questions, acquire new knowledge, explain scientific phenomena and draw evidence-based conclusions about science-related issues;
- understanding of the characteristic features of science as a form of human knowledge and enquiry;
- awareness of how science and technology shape our material, intellectual, and cultural environments;
- willingness to engage in science-related issues and with the ideas of science, as a reflective citizen.

Of course, what is said here for science literacy in general holds also for physics literacy in particular [3] - [4]. In that sense, Table 5-1 summarizes several ways in how physics taught at school can be supportive and even necessary for both the individual and the society. Additionally, the strong and intellectually profound links of physics with culture and general literacy also have led to many stimulating works in the fine arts [5] and literature [6]. The Swiss Physical Society is strongly committed to the public discussion and to the improvement of scientific literacy, as shown by several examples in the following considerations or by the plenary talks "Physics & Education – Perspectives from Particle Physics" (H. P. Beck) and "Physics & Education – Perspectives from Biophysics" (C. Aegerter) held at the Annual Meetings of the SPS in 2021 and 2022, respectively.

Physics literacy as responding to needs of the individual • the need for general culture and orientation (physical/scientific worldview or "Weltbild"); • the contribution of physics, its results and as a way of thinking to personal attitudes and values; • needs for personal development (e.g. choice of a carrier needing physics background).
Physics literacy as responding to necessities of the society • necessity (for a modern society) for people with a knowledge basis and professions in physics; • necessity (in a democracy) for well-informed and responsible citizens to participate in societal problems and decisions involving physics (e.g. climate change or the energy transition).

Table 5-1: How physics literacy is supportive and necessary for both the individual and the society [7].

We now turn to some essential features of physics and its educational potential.

Foundational role: The concepts and laws of physics provide a foundation for scientific literacy. According to a study of the conceptual systems of the various natural sciences, physics accounts for a larger part of the basic concepts common to the natural sciences. According to a study about the conceptual systems of the various natural sciences [8] physics accounts for the largest part of the basic concepts common to all sciences (physics: 59%, chemistry: 30%, biology: 10%, earth sciences: 1%); this shows the foundational role of physis for the scientific approach in general. Moreover, physics is basic knowledge for all engineering and tech-

1 The considerations in this chapter are partially based on several previous papers of the author (e.g. [2]).

2 Of course, a number of the following considerations also holds for the other natural sciences, partly also for mathematics.

nology, and innovation in this area (see e.g. the examples in chapter 3 of this report).

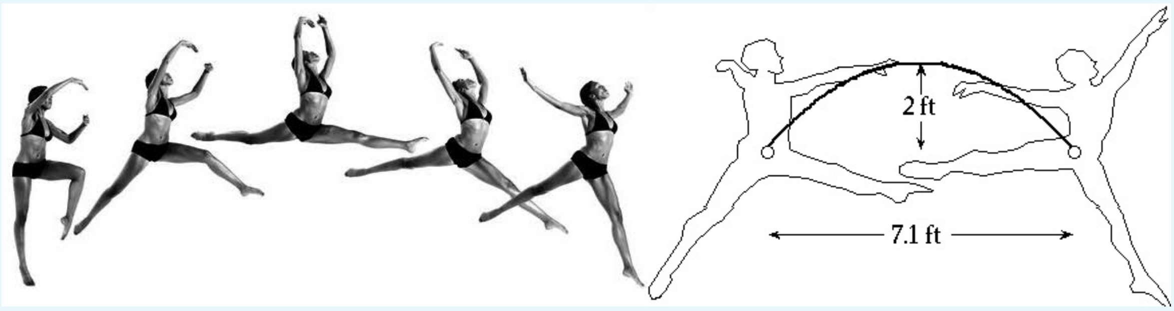
Universality: The universality of the fundamental physical laws of nature [9] belongs to the core of the disciplinary self-understanding, with wide intellectual connections, between the fall of the legendary apple of Newton and the orbit of the moon (see also example in Box 5-1), or the pioneering insight into a common theoretical basis of electric and magnetic fields and of light by Maxwell. An important aspect for the educational value of physics in this context is the far-reaching emancipation that this universality brought with it. It hardly needs to be recalled what fights were necessary for this emancipation, think alone of the case of Galilei. Today, this basic emancipatory idea of the universality of science lives on in the formulation of a kind of human right to an universal access to science - concerning its practice as well as its use - which should not be restricted by any individual, social or political factor, such as ethnic or religious affiliation, gender, political convictions, etc. (Principle of Universality Science, [10]).

Physical worldview ("Weltbild"): The important contributions of physics to epistemology and the worldview of today are well known. For modern physics, relativity, quantum physics, particle physics, astrophysics and nonlinear dynamics take a prominent role in that respect, and Table 5-3 provides some stimulating resources by the Swiss physics community (without any claim of completeness).

Of course, there is a strong interaction of physics and philosophical and historical aspects on that matter [12], [13]. Note that there are also several studies and empirical results about the educational potential of these topics in school. In particular astrophysical topics are among the most interesting ones for young people, girls and boy alike [14].

Examples of the importance of *modern* physics for the "Weltbild" might be more present in the perception of the general public, because they are about more recent developments, and sometimes strongly present in the media (e.g. the discovery of gravitational waves). Yet this importance applies also to *classical* physics. For instance, basic concepts related to the electromagnetic spectrum, already learned in

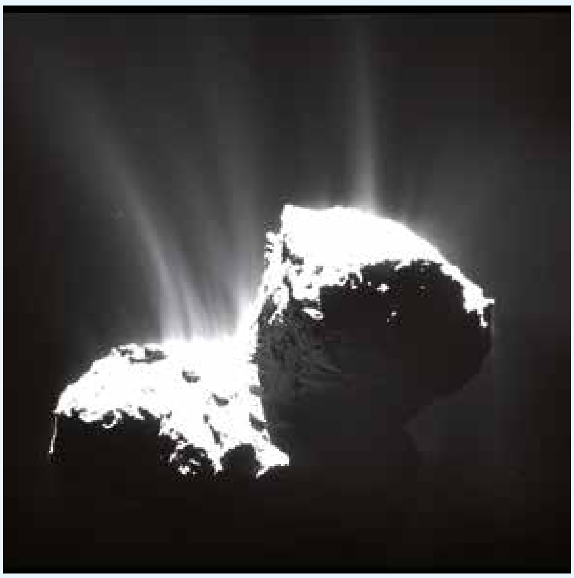
Box 5-1: Universality of Newtonian Mechanics - from the "Grand Jeté" of ballet to the Rosetta space mission

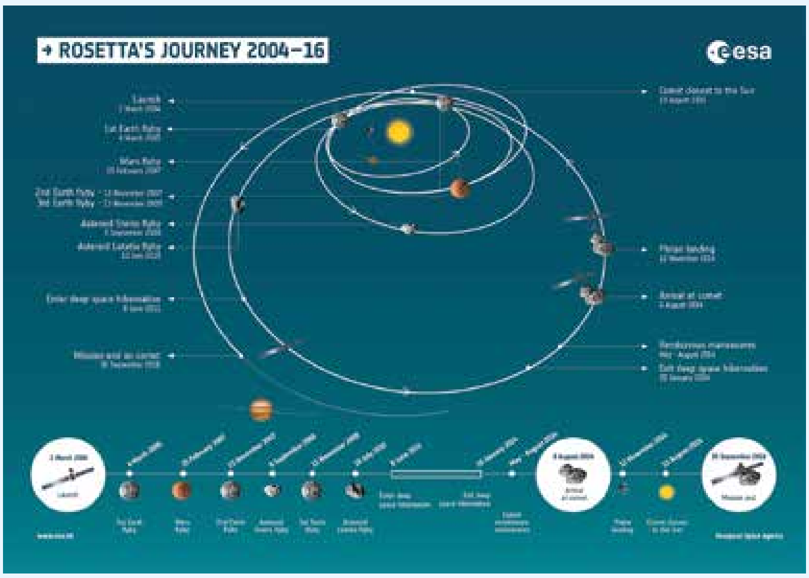


The "Grand Jeté" (image on the right, [11]) is a ballet jump impressively conveying an image of floating and weightlessness. Distance, height and duration (*l*, *h*, t_{cm}) for the body's centre of gravity at a take-off speed v_0 (and an optimal take-off angle of 45°) are given as

$$l = \frac{v_0^2}{g}, \quad h = \frac{v_0^2}{4g}, \quad t_s = \sqrt{2}\,\frac{v_0}{g}$$

With $v_0 \approx 5$ m/s (half the speed of a world-class sprinter, but achieved within a few metres of acceleration distance available on stage), we get $l \approx 2.5$ m, $h \approx 0.6$ m, $t_{cm} \approx 0.7$ s for the maximal values which can be achieved. Such background knowledge is of interest to ballet dancers and coaches, and "Physics and the Art of Dance" [11] provides relevant foundations for improving performance and safety in practice, and develops stimulating relationships between art and science in the field.
Moreover, the very same equations of motion of Newtonian mechanics govern truly far-reaching things, such as the orbit of the Earth around the Sun, the orbit of the solar system around the centre of the Galaxy, or the trajectory of the space probe Rosetta, a pioneer mission with first the successful landing on a comet (see Table 5-3, Altwegg (2015) for more information about that mission).





Rosetta space mission: Comet 67P/Churyumov-Gerasimenko from a distance of 30 km, and part of the trajectory of Rosetta.
http://www.esa.int/ger/ESA_in_your_country/Germany/Kometenmission_Rosetta_Auf_der_Suche_nach_der_Urmaterie_Special

school, are the same ones with which one can experimentally discover exoplanets or determine the cosmological red shift and thus the expansion of the universe at its outermost spatial and temporal limits. Another example is the Rosetta mission, where every metre on this 500 million km journey into the unexplored is governed by Newtonian mechanics (see Box 5-1).

These are striking examples to counter the argument of the so-called "half-life of knowledge" or that allegedly "Everything We Know Has an Expiration Date" [15], and that therefore in teaching and learning knowledge should be largely replaced by "Key Skills", also called "21st century skills" (e.g. communication and collaborative working, etc., [16]). As just shown, knowledge about the electromagnetic spectrum (from the 19th century) and about Newtonian Mechanics (from the 17th century) *is* a 21st century skill at its best.

Finally, the universality of physics (science) is – beyond the various *specific* examples discussed above – a fundamental element of its *general* importance for the modern worldview. In fact, the development of our insight into this universality, between the Earth and the Heavens, between the inanimate and the animate, and between other opposites thought to be ontologically constitutive in antiquity and the Middle Ages, constitutes a chapter of the history of science of its own interest.

Attitudes, Approaches, Modes of Thought: Last but no least, physics as science and as discipline taught at school can provide a stimulating field of experience for attitudes, approaches and modes of thought which are fruitful both for the individual and the society (cf. Table 5-1). A few examples:

First, and in contradiction to current stereotypes regarding physics, *creativity* – as Vladimir Nabokov says “There is no science without fancy, and no art without facts.” Learning and doing physics, from well-made experiments at school to the imagination and problem solving capacities of the working physicists, constantly requires insight and new ideas to go ahead, and scientific and artistic creativity indeed have very interesting points in common, very much in the sense of Nabokov’s quote.

Second, *critical reasoning*, i.e. a critical stance towards claims, evidence and conclusions is an indispensible faculty of responsible citizens and for their active participation in modern society.

Other examples in this context are of course an understanding of the experimental approach, and of the role and power of mathematics for a rational description of natural, social and other phenomena. These and several aspects are discussed in a recent expert analysis on how physics education can support faculties foundational for university studies (“scientific propedeutics”, [18]).

5.2.2 Physics Education

As this is a report on “Physics in Society”, it is not the place for a detailed discussion of physics education, but a few central points on how current society should want that it looks like, and what can it expect from the physics community, appear as useful.

Physics literacy and preparation for studies / carriers in other fields: Above, we have made the case for the importance of physics literacy as part of general literacy of responsible citizens in modern societies. Of course, physics education, i.e. physics as taught at school, then has to be at the height of this potential and obligation. This has to be based on the best available scientific evidence, and on close interaction and collaboration within the community. An example of a 3-dimensional structure of physics education at school in terms of foundational concepts, central practices when “doing” physics, and meaningful contexts (areas of application), which highlight the specific contribution of physics for scientific and general literacy is given in Table 5-2.

Foundational concepts
Matter
Forces and interactions
Energy
Oscillations and waves
Central practices
Asking questions and defining problems
Planning and carrying out experiments, making measurements
Analysing and interpreting data
Using mathematics and computational thinking
Developing and using models, working out explanations
Thinking beyond everyday experience (quantum physics & relativity)
Engaging in arguments from evidence
Evaluating, and communicating results and conclusions
Meaningful Contexts
Physics and people: games, sport, medicine
Physics and technology
Physics and environment, weather, climate
Energy supply system, sustainable energy
Earth and Universe

Table 5-2: Three-dimensional structure of physics education: Foundational concepts, central practices when “doing” physics, and meaningful contexts (areas of application), highlighting the specific contribution of physics for scientific and general literacy (based on [7], [17] also providing detailed examples).

But additionally, and importantly, physics education in school has to ensure also a solid preparation for professional education and university studies (“propedeutics”, [18]) in other fields (other sciences, engineering, medical professions). This is not in contradiction to physics literacy for all pupils, but requires well-though curricular differentiations as in particular the “Specific Option” (“Schwerpunktfach / Option spécifique”) of the Swiss Matura system [3].

Evidence-based Physics / Science Education: Evidence-based practice in general is the approach to base decisions on the best available evidence, in the sense of

3 See in particular the current development of Matura2023, https://matu2023.ch/de/, https://matu2023.ch/fr/

Quanta	Gisin, N. (2014), *Quantum chance: Nonlocality, teleportation and other quantum marvels.* Cham: Springer
Relativity	Beisbart, C., Sauer, T., & Wüthrich, C. (2020), *Thinking About Space and Time: 100 Years of Applying and Interpreting General Relativity.* Cham: Springer
	Gasparini, A. (2018), *Cosmologie & relativité générale: une première approche.* Lausanne: Presses polytechniques et universitaires romandes
Particles	Pohl, M. (2021), *Particles, fields, space-time: From Thomson's electron to Higgs' boson*. Boca Aton: CRC Press
Astronomy, Astrophysics, Cosmology (see also "Relativity" above)	Pepe, F. (2007). Discovery of the first exoplanet in the habitable zone. *SPG Mitteilungen* **21**, 8-11
	Altwegg, K. (2015), Rosetta – a journey back to our origin. *SPG Mitteilungen* **45**, 11-13
	Benz, W. (2020), Michel Mayor and Didier Queloz: 2019 Physics Nobel Prize Laureates. *SPG Mitteilungen* **60**, 9-10
	Thielemann, F. (2021), Origin of the Elements (Part I & II) *SPG Mitteilungen* **63**, 24-31; **64**; 29-39
	Straumann, N. (2021), Roger Penrose, Laureate of the Physics Nobel Prize 2020; Schödel, R. (2021): The Discovery of massive Black Holes at the Centre of the Milky Way». Nobel Prize Articles in *SPG Mitteilungen* **63**, 8-12
	Jetzer, Ph. (2021), Gravitational waves – an update. *SPG Mitteilungen* **64**, 24-28
Philosophy and History of Physics	Beisbart, C. (2019), Philosophy of physics - what is it and why is it worthwhile to study it? *SPG Mitteilungen* **57**, 18-21
	The following series of the *SPG Mitteilungen* also contains many articles of interest in the present context: *https://www.sps.ch/en/articles/history-and-philosophy-of-physics*; *https://www.sps.ch/en/articles/milestones-in-physics*
Physics and Society	Series of the *SPG Mitteilungen*, *https://www.sps.ch/en/articles/physics-and-society*
SPS Symposia adressing topics of current and general interest	***100 Years Nobel Prize for Albert Einstein***, SPS-Symposium, 09.04.2022; *SPG Mitteilungen* **66** (Jan. 2022), 41
	Wilhelm Conrad Röntgen Symposium, SPS-Symposium, 18.09.2022; *SPG Mitteilungen* **65** (Nov. 2021), 59
	125th Anniversary of Georges Lemaître, SPS-Symposium, 21.11.2019; *SPG Mitteilungen* **58** (July 2019), 58
	On the Origin of the Elements, *celebrating 150 years of the Periodic Table*, at the Joint Annual Meeting of SPS and ÖPG, 30.08.2019; *SPG Mitteilungen* **58** (July 2019), 25
	Richard Feynman's centennial celebration, SPS-Symposium, 30.11.2018; *SPG Mitteilungen* **57** (March 2019), 58
	Gravitational Waves (Einstein Lectures), 12. - 14.11.2018; *SPG Mitteilungen* **57** (March 2019), 56

Table 5-3: Physics and the modern scientific worldview – some stimulating resources and events by the Swiss physics community

the best possible – in particular systematic! – use of existing knowledge and research. Evidence-based (science) education (EB(S)E) follows the example of evidence-based medicine, i.e. "[t]he conscientious, explicit and judicious use of current best evidence in making decisions", as D. Sackett, one of its pioneers put it. In the last two decades, EB(S)E has led to a very strong current of research and improvement of science education practice.

For physics education, this can be illustrated by the following analogy: Learning is a dynamical process, driven by relevant forces and interactions, and leading from an initial to a final state; in that sense, a current metaphor is that of a "learning trajectory". As much as physics itself, physics education research tries to understand such trajectories, and design them to attain a given target.

For the background in educational science in general, work by Hattie, based on more than 1850 meta-analyses, comprising more than 300 Mio. individuals [19] is highly influential. In physics and science education, the evidence-based approach has seen a very strong development in the last decades, and the idea has found strong support among many scientists interested in effective teaching and learning of their disciplines, including work finding recognition at very high level [20], among others by the physics Nobel prize winner C. Wieman [21]. An example concerning physics interest, in particular for girls, is given in section 5.3, another example concerning physics outreach initiatives in section 5.4. More examples and sources can be found e.g. in [2], including work targeted for physics teachers and their classroom practices (see also [19]).
Within this rationale, Physics Education Research has the task to contribute to evidence-based decisions, developments, and initiatives, in order to assure the best available basis for physics literacy, and physics teacher education (see next point). As a word of caution, however, it has to be mentioned that there is debate around EBSE, also raising critical points, and that it is certainly not the claim of EBSE to guarantee all by itself a solution to all problems in science education; simplistic recipes are not a goal one is looking for.

Physics teachers, and their education: Teacher education has a pivotal role in an educational system: as studies on university level, it is the last and highest stage of education, and at the same time is the basis and starting point for the educational quality for many generations of school students [22]. This large "teacher leverage" can be quantified by an order-of-magnitude: A full-time teacher typically teaches 100 - 200 students per year, thus 3000 - 6000 students over a 30 year career.

In order to respond to this pivotal role, it is clear that physics teachers have to be well informed about effective approaches to support interest and learning among their pupils on the basis of the best available evidence (see above). Another reason for the pivotal role of teachers, besides the quality of teaching, is found at the (inter)personal level (see Box 5-3). Note that the decisive influence of teachers and other adults for encouragement, advice and as role model found in research is particularly important for a better gender balance in physics (section 5.3), and is also an important perspective in direct contacts with researchers, as provided in science communication initiatives (section 5.4). In line with the decisive role of teachers, the Swiss Physical Society, and with a financial support by SCNAT, has recently initiated first steps for a useful and interesting offer for Swiss physics teachers.

5.3 Gender balance and equal opportunities in physics

The shortage of highly qualified workers in the fields of "hard" and technical sciences and engineering has been a preoccupation in Switzerland for many years. It has been highlighted that the phenomenon also has a significant gender dimension, which has been found to be particularly pronounced in Switzerland. Two decades ago, a national weekly wrote about the "Worldwide low of women in physics" located in Switzerland. The proportion of female students in physics was below 10 % at the beginning of the 1990s, very low also in international comparison. As shown in an analysis by the Swiss federal statistical office, without the capacity of Swiss universities to attract an enhanced share of female PhD students from abroad, the percentage of women at the PhD level in technical sciences would likely be still significantly lower.

Drawing on results from a study on co-education in physics at Swiss high schools, Labudde et al. [24] emphasized the low number of female high school teachers in physics (3 % at the time), and the culturally dominant, stereotypical association between physics, technology, and masculinity prevalent in Swiss society. These cultural patterns negatively influenced both teacher-student and student-student interactions in physics classes. They also had a negative impact on the interest levels, self-confidence, and expectations of girls in physics education [24].

Since the early 90s, figures have improved, but progress is remarkably slow. This is apparent in the still extremely low number of girls in Switzerland who, when entering high school at 14 - 15 years of age, opt for a curriculum with a focus on physics and applied mathematics (Fig. 5-1). The transition from early secondary education to high school thus functions as an early and major filter in the educational and professional trajectory of girls and boys.

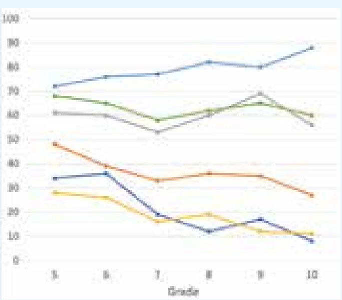
Physics Education research provides evidence how the choice of appropriate contexts (i.e. area of application) can considerably increase girls interest for physics (while not impairing that of boys); such contexts are in particular biomedical contexts (see Box 5-2) and astronomical contexts [14].

However, trying to increase the interest (and hence number) of women from the bottom is not enough to address the gender imbalance in physics and in technical and engineering fields generally. The issue must also be addressed from the other end, by improving career conditions for women and increasing their numbers in leading positions in these fields in order to prevent the "leaky pipeline" phenomenon, i.e. the gradual "disappearance" of women at different stages of STEM careers (Fig. 5-1). This, of course, is also true for universities: Data from 2014/15 show [26] that in Swiss physics departments, the ratio of the number of women to the number of men (gender ratio, $GR = n_w/n_m$) at different stages of education and professional careers starts with a low value of $GR \approx 0.3$ for the phys / math option of the Swiss maturity, stays at this low level from the bachelor to the post-doc stage, and then shows another drop by a factor of 2 - 3 at the transition to permanents posts, in particular professorships (also called "glass ceiling", [27]). The ETH Zürich provides a continuous "Equality Monitoring" and update of these data, including its physics department, which is the largest in Switzerland. Findings are very similar to the previous ones and unfortunately show little improvement over 5 years, confirming results from international surveys [28], [29]. An exception holds for professorships, a success of a dedicated policy of ETHZ; note however, that the improvement takes place on the assistant professor level, while on the full / associate professor level the value is still low.

How are women with a degree in physics welcomed to the Swiss labour market? Based on data from the surveys conducted by the federal statistical office among graduates one year after they obtained their diploma, there is hardly any difference in the employment situations of male and female graduates in physics. According to Markus Diem, a researcher from the University of Basel, some differences do appear in the motivation indicated for employment choices. Men with a diploma in physics seem to have a slightly higher tendency to prioritise revenue over closeness to the field of study, whereas women seem to attribute greater value to the latter. In addition, results from these surveys indicate the average salary of male physicists one year after graduation to be higher than the average salary of female graduates.

Box 5-2: Increasing girls' interest by biomedical contexts

The fact that physics is for girls at the bottom of the popularity scale among all school subjects asks for better educational approaches. Convincing research evidence shows that girls are just as interested in physics as boys, but in the context of their broader interests and long-term career goals, and that the life-science disciplines are among the most important subject areas for girls. The figure in this box illustrates impressively, how this can have a strong positive impact on physics interest of girls. When asking about the same physics topic related to different contexts, it turns out that girls interest for a biomedical context is much larger than that for a technical context; in fact it increases even against the general tendency of decreasing school interest during adolescence (for boys the interest level for both contexts is similar and rather high, i.e. 70 % of the maximal value). Other studies have confirmed this important finding, and it should be taken into account in order to counteract the currently observable lack of interest for physics, especially amongst girls, at least for general level physics courses for pupils who are not going to study science (see [25] for some applications in this area within the SPS). This, however, does not preclude the necessary offer of special advanced courses with a different orientation (modern physics, more math) for those with an in-depth interest for physics.



Percentage of girls with "great" and "very great" interest in selected contexts for the topic of mechanics (here pressure; other topics were motion and force) across time.
Light blue curve: artificial heart as blood pump; orange curve: pumping crude oil from great depths (other contexts not considered here).

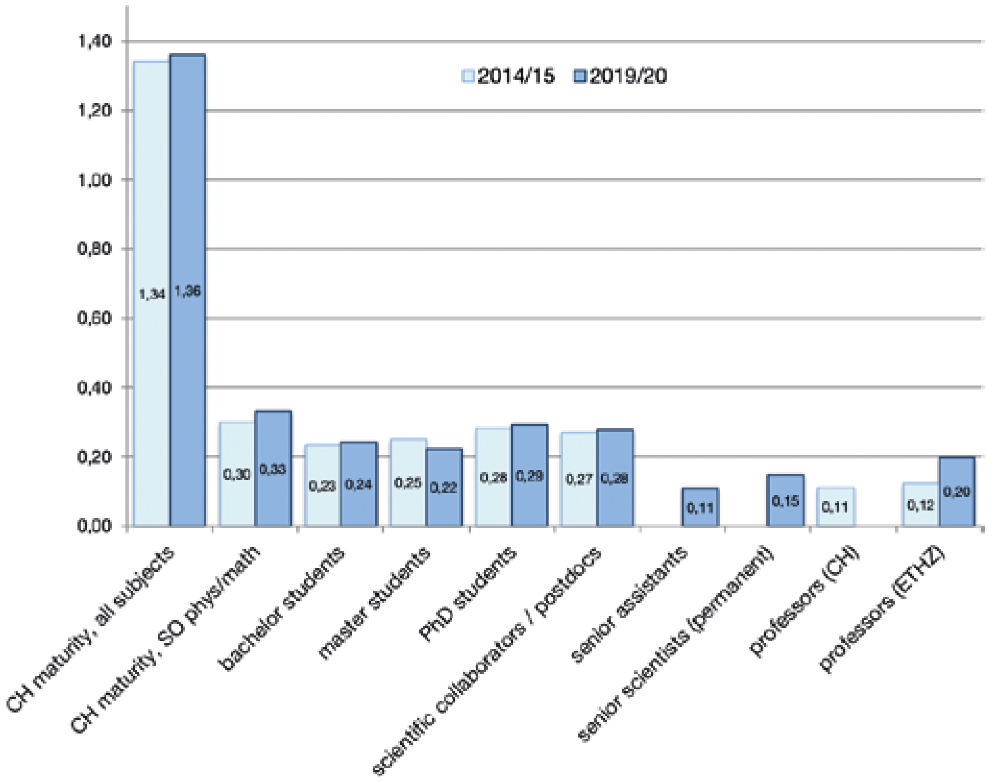


Fig. 5-1: Ratio of number of women to number of men (gender ratio, GR) at different stages of education and professional careers within physics. Values are low and get even lower at two marked steps: a thin and leaky pipeline! (y-axis: GR = n_w/n_m). Values from 2014/15 are for Switzerland (plus professors for ETH Zürich), values from 2019/20 are from ETH (except those for maturity).

Comments:
(i) High school "maturity": young women are a majority!
(ii) High school "maturity": choice of special option (SO) "physics and applications of mathematics": GR drops by a factor of four; young women are a strong minority.
(iii) Study and career stages from bachelor to post-doc: GR stays roughly on the low level (≈ 0.2 – 0.3) of the entrance value of phys/math maturity.
(iv) Values of 2014/15 and 2019/20 are rather similar up to post-doc level.
(v) Values of 2019/20 (ETHZ) differentiate postdocs, senior assistants, and senior scientist: a second drop by a factor of 2 - 3 becomes evident (the values of 2015 do not provide this differentiation).
(vi) Values at the professor level stay low, but note the increase in 2019/2020 which is due to dedicated measures at ETHZ.

Improving career conditions for women implies that institutions must take responsibility in changing the situation and implementing actions: defining targets, actively searching for female candidates and appointing women to leading positions, raising awareness amongst managers and employees about stereotypes and gender bias, and developing an institutional culture and practices adapted to the needs of a diverse work-force – which includes encouraging both women and men to actively combine career and family obligations. Today, most universities in Switzerland have gender action plans that support such measures [4]. Additionally, the Swiss Academy of Arts and Sciences (a+ and daughter academies SCNAT, SATW) and the Swiss National Science Foundation have a series of dedicated actions for a better gender equality in research and funding [5]; an example of the SPS activities in this field, the "Women in Physics Ca-

4 https://www.swissuniversities.ch/en/topics/promotion-of-young-talent/equal-opportunities/

5 a+: https://akademien-schweiz.ch/en/themen/wissenschaftskultur/frauen-in-der-wissenschaft/;
SATW: https://www.satw.ch/fr/promotion-de-la-releve/swiss-tecladies/swiss-tecladies-starke-maedchen-fuer-den-wirtschaftsstandort-schweiz;
SCNAT: https://scnat.ch/fr/uuid/i/d87a53d7-bac7-522f-957c-12f0d9ebc843-Achieving_Gender_Equality_and_Diversity_in_the_Natural_Sciences;
SNF: https://www.snf.ch/en/3FIaA17YxxlbvSCG/page/funding/gender-equality

Box 5-3: Encouragement, advice, role model – the decisive role of teachers and other adults

A large scale study in the UK (UPMAP – Understanding Participation rates in post-16 Mathematics and Physics) clearly showed that learners' relationships with teachers (and other adults) has a decisive impact – through encouragement, advice, or acting as a role model – on their decision to choose the subject physics after their mandatory schooling (see quotes below about the contrast of good and bad physics teachers).

The study arrives at an unambiguous conclusion: in all interviews with physics university students, it turned out "that an adult has been significant in their becoming a physics undergraduate. Not peers, not enrichments, interventions or events, but some adult person or people – usually teachers or family members". This finding is complemented by the quantitative results, where encouragement is found to be the teacher variable with the strongest influence on the choice of physics (correlation r = 0.5), well ahead of all other factors. These results agree with the state of knowledge drawn from many other studies. When it comes to choosing an academic or vocational career in STEM (Science, Technology, Engineering, Mathematics) fields, research, including taking into account female students' own reports, consistently shows that discipline-specific self-concept is a decisive factor, as well as the availability of role models especially for (female] school and university students.

Statement about a good physics teacher, according to a female student (I: Interviewer, S: student).

I: Going back, you said you had a very good teacher at GCSE, what was good about him or her?
S: She was very good at making it interesting, she made the lessons fun and I suppose I got on with her on a personal level so that helped and she was very encouraging.

The same female pupil about a bad science teacher:

S: He was bad because he didn't know my name for maybe nine months and he didn't pay any attention... it got to a point where I wouldn't go to the lessons sometimes and would teach myself from the books.

Statements about the importance of role models

"My math and science teachers were always important role models in my life. My parents wanted me to go into business or something like that."
"I think that one of the reasons why I chose math and science and chose engineering was because I had a teacher that was female. So if there was more females in engineering that could teach, it would make a big difference."

Box 5-4: Why the heck would you study physics?

Dr. Francesca Stocker about her PhD thesis at CERN.
Credit Photo: Geneva Guerin

One could start with the romance of always having been curious about nature and its mechanisms and thus having studied physics at the university. I would love to say that. I've always been curious about everything and nature fascinates me every day, but it wasn't my reason to study physics and discover the fundamental laws of nature. I just stumbled into it and now find myself doing a PhD at CERN, the "place to be" in particle physics. And there is no other place I'd rather be doing my PhD!

When I started my masters at the University of Bern, I decided to direct myself towards particle physics. I entered the Laboratory for High Energy Physics (LHEP) and was offered to build a small prototype detector as a master thesis. That's where I caught fire, that's where IT got me.

My task was to build a small Liquid Argon Time Projection Chamber (LAr TPC) that was testing a new readout under the supervision of a postdoc and a PhD student. This type of detector is used for neutrino physics and the next generation experiments for neutrinos will use this technology.

The small detector we built, is 60 cm long and 10 cm in diameter and it became our baby. We put a lot of time - days and nights - into it and the moment where we turned it on was memorable. Suddenly we were able to record particle tracks and the new readout worked very well.

My masters years and the people I worked with were guiding for me, the environment and individual supervision at the university of Bern was fantastic. Whenever I had a question all doors were open to drop in and get the information and help I needed.

Research is…

- … fascinating. Being able to build a small detector that can "see" particles from the cosmos that we don't see by eye.
- … innovative. Doing new things, testing new technologies can be beneficial for many applications in the daily life.
- … diverse. There are so many research fields I don't know anything about!
- … exciting. No day is like the other.
- … a team effort. Only with a group that helps each other out and learns from each other, new things can be explored and understood.
- … international. I have the privilege to work with people from all over the world, every day I speak at least 3 different languages.

reer Symposium", a satellite event at the annual meeting in 2022, has to be mentioned here.

Representations associating physics, technology, and masculinity not only shape the cultures and practices of professional environments but educational contexts as well. They determine the way that physics is taught at school and the degree to which girls feel that they are expected to excel in physics and will need these competencies for their personal and professional achievement. In accord with this, there are several current initiatives by SCNAT, the SNF and other professional bodies to provide encouragement and “identification anchors” by female role models [6] (see also, Box 5-3, Box 5-4, and Box 3-4 as a prominent example in industrial physics).

Many of these actions promote STEM subjects in general. However, this does not help to effectively address stereotypes about the “hard” and technical sciences in particular, as girls will mainly be drawn to topics such as life sciences and pharmacology. Actions must specifically focus on physics, technology and engineering subjects. They must also strive to present new understandings of these fields that relate them to issues relevant to society and the environment.

In line with these considerations, and the acknowledgement that our understanding of the role that physics and technical and engineering sciences play in our societies must evolve, attention is increasingly focused on schools, curriculum development, and teacher education and training [2]. Yet stereotypes about physics, and technical and engineering sciences and professions are still deeply rooted and very influential. Raising awareness and the introduction of new initiatives if thoroughly implemented, can help to bring about much-needed change. This will require coherent and sustained action at all scales, from universities through societies like the SPS to the federal bodies of research and education (SNF, the national academies, swissuniversities, government departments).

5.4 Physics Communication and Outreach

The specific contribution of physics communication and outreach: These terms include a variety of activities by individual scientists, universities and other research institutes, as well as institutions such as science centres and museums, with the aim to promote public awareness and understanding of physics (science) and making informal contributions to physics (science) education. Modern science communication initiatives most often purport a high degree of interactivity [30].

As an additional aspect, it has to be emphasized that informal or "out-of-school" outreach aims at fostering curiosity and interest of the population towards STEM in general, and physics in particular, with important long-term objectives: First, we want to motivate more students, and in particular female ones (see 5.3), to choose school tracks and studies in the field. Secondly, in order to provide the general public first hand information about research and interaction with researchers, beyond often dubious sources in the internet,

6 SCNAT: Portraits de femmes de science dans les disciplines MAP, *https://map.scnat.ch/fr/activities/women_scientists*;
SNF: youtube channel with female scientist role models, *https://www.snf.ch/en/axAZRXaHYVmk7p66/news/nccrs-100-female-researchers-step-into-the-limelight*;
Swiss Association of Women Engineers: *https://svin.ch/wordpress/fr/activites/ausstellung-ich-bin-ingenieurin/*

where easy availability all too often replaces quality and conscious, open-minded reflection, which is the hallmark of science.

Communication channels: What are the channels of communication used by physicists? What are the science-public intersections? What different formats of science outreach are offered? In the following, a brief overview about outreach offers in Switzerland is given.

First, "traditional" science museums or centres play a major role for science outreach and informal education. In Switzerland, the leading institution of this kind is the *Swiss Science Center Technorama* in Winterthur, following internationally renowned examples like the *Deutsches Museum* in Munich, the *Palais de la Découverte* in Paris or the *Exploratorium* in San Francisco. They offer expositions, hands-on activities, and topical workshops (in particular for school classes) about natural phenomena and technology, and inform about latest developments in science and technology, often in close collaboration with active scientists. Well-known centres run by large science institutions are the CERN public exhibitions in Meyrin and the visitor centre *psiforum* of the Paul Scherrer Institute in Villigen. Additionally, there are many interesting, more specific museums with a reference to physics, like the *Einstein Museum* in Bern, the *Musée d'histoire des sciences* in Geneva, the creativity lab *Smartfeld* in St. Gallen, or *focusTerra* in Zürich (for a broader range of aspects, but without without any claim of representativeness). A useful overview of this kind of science outreach offers in Switzerland is provided by the "ScienceGuide" of the SCNAT [7].

Second, a large and very important contribution to physics communication is provided by "Science Outreach Labs" (SOLs). These are a unique kind of extracurricular science learning opportunities, usually offered by university departments, research institutions, and science centers. SOLs focus on hands-on experimental activities in the STEM field, and recently also increasingly in the humanities and the social sciences. A particularly successful form is a close cooperation between researchers, who provide up-to-date and first-hand science input, and active school teachers, who are key to ensure adaption to the target audience (content difficulty, language level), for support to colleagues interested in the SOL, for teacher professional development courses, and for actively promoting the project through professional networks.

In Switzerland, a broad and high quality spectrum of different foci and formats exists such as *S'CoolLAB* at CERN, *iLAB* at the Paul Scherrer Institute (both integrated in broader outreach activities, see above), the *Scienscope* at the University of Geneva, or the variety of offers by the St. Gallen University of Teacher Education (see Table 5-4 for an overview). A particular kind of SOL is the *Stellarium Gornergrat* (Fig. 5-2), a remote-access observatory for educational purposes run in cooperation by the universities of Bern and Geneva, and other partners: It exploits the high motivational potential of astronomical topics (see above) by integrating them in regular physics (and mathematics) lessons.

Third, the large Science organisations provide powerful communication channels and platforms for science com-

7 https://scienceguide.ch/de/about

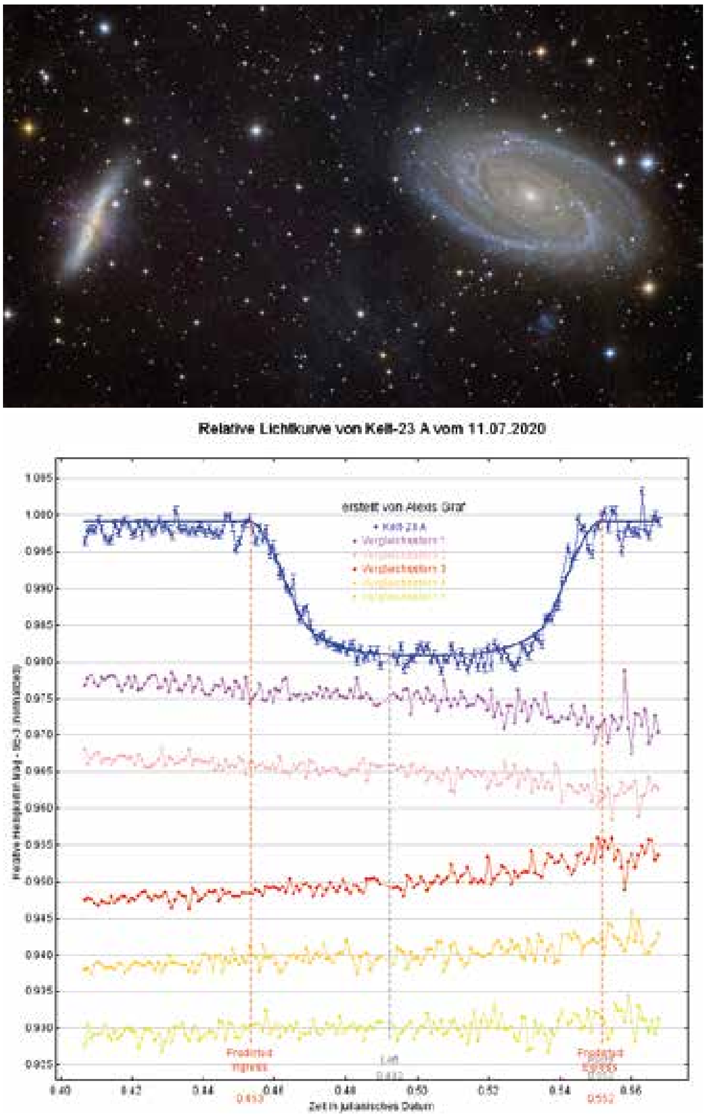


Fig. 5-2: Images and data produced with the Science Outreach Lab "Stellarium Gornergrat". Top: M81 and M82 from the "Galaxy Zoo" module, taken with 60 cm deep sky telescope. Bottom: observation of the exoplanet Kelt-23 with the transit method from a high school thesis made with the Stellarium (x-axis: time as (heliocentric) Julian date; y: relative brightness (arbitrary units); blue: light curve, purple to yellow: comparison to neighbouring reference stars).*

** Matura thesis of Alexis Graf (https://stellarium-gornergrat.ch/matura/ → pdf link in the list)*

munication in general, and for highlighting the interaction of current physical research to other scientific disciplines such as chemistry, biology, pharmacy, and environmental sciences. The SNF has the AGORA funding program [8] to foster dialogue between scientists and society. Examples by the physics community cover a broad and highly stimulating range of approaches, such as *State of the Art – Science and Art in Practice* (Uni Geneva), *Interactions - Swiss particle physicists initiate a dialogue with society* (Uni Bern); *The irresistible attraction of gravity* (Uni Zürich); *Seeing atoms with the naked eye* (ETHZ).

The Swiss Academy of Sciences (SCNAT) and the Swiss Academy of Engineering Sciences (SATW) have a large offer of courses, events, publications and resources for science communication and outreach. By way of example, we

8 https://www.snf.ch/en/JnT2xEAERCgO8qQc/funding/science-communication/agora

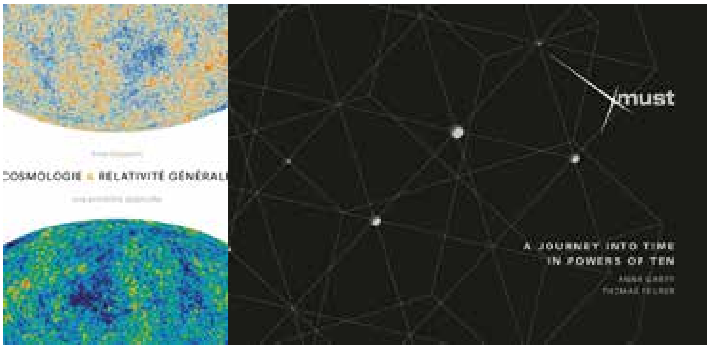


Fig. 5-3: Books produced by NCCR education and communication units. Left: Cosmology and General Relativity (High School public, SwissMAP); right: Time across orders of magnitude (general public, MUST).

have just mentioned the ScienceGuide of SCNAT for outreach offers, and the activities of SATW and SCNAT for improving gender balance and equal opportunities in section 5.3. Moreover, other well-thought and powerful initiatives are provided the SCNAT commission for the promotion of STEM disciplines among young people [9] and by the TecDays organized by SATW since 15 years in order to support technology education at secondary schools [10].

Finally, we mention several other promising types of physics communication activities. Some of the NCCRs as the largest research programs in Switzerland maintain very active outreach and education units [11]; among others, two very nice books have been produced for the general and for a high school public, see Fig. 5-3.

Since 2011, *Be a Scientist*, a collaboration between educational institutions from both sides of the French-Swiss border (University of Geneva, Geneva department of Public Education, French Ministry of Education), introduces every year children aged from 8 to 12 to the scientific research process as they study a mysterious box that one is not allowed to open. The pupils learn about hypotheses, data, and evidence, and how to conduct an experiment, while trying to figure out the hidden content inside the box.

Next, the very popular science fair *Night of Science* attracts many visitors every year. Usually it takes place in parks, places, and pavilions of major cities of science in Switzerland. Local institutions present themselves and their current research and offer scientific lectures and discussions with experts, guided tours, science shows, and hands-on experiments.

Also worth mentioning is *Beamline For Schools* (BL4S), an international physics competition for high school students organized by CERN. Teams of high-school students are invited to propose a scientific experiment to be performed with a particle accelerator facility. The two teams that prepare the best proposals will win a trip to perform their experiments at a fully-equipped beamline. In 2022 the experiments will be performed at one of the beamlines of the CERN Proton Synchrotron accelerator. BL4S offers a great opportunity for students to learn, make new discoveries, and collaborated with experts, all at a world class research institute.

Last but not least, let us mention that Swiss scientists collaborate closely with the Swiss public media to provide high-quality outreach programs for the broad public. For instance, there are two fantastic TV shows targeted to children: *L'oreille des kids* (in French) and *Das Haus der Wissenschaft* (in German) [12].

9 https://mint.scnat.ch/en

10 https://www.satw.ch/de/tecday

11 See e.g. NCCR SwissMAP (The Mathematics of Physics); https://www.nccr-swissmap.ch/school-teachers-children/general-relativity; NCCR MUST (Molecular Ultrafast Science and Technology); http://www.nccr-must.ch/education_training.html

12 https://www.unige.ch/sciences/physique/section-cite/loreille-des-kids/; https://www.srf.ch/sendungen/school/physik-chemie-biologie/das-haus-der-wissenschaft

Box 5-5: Successful TecDays at SATW

A strong concern of our society is how to inspire pupils considering a career in the technical disciplines, but also in the natural sciences? This requires novel and unconventional actions parallel to the normal school day. This is where the SATW-TecDays for secondary schools play an outstanding role. Initiated in 2007 by the physicist and SPS member Karl Knop (1943 - 2018), they are a true success story. No other program to date has such a widespread positive impact and contributes to ensure that more and more young people opt for studies in the natural sciences.

The time schedule of a TecDay is as follows: A one-day program is put together by the school administration and SATW, including a number of teaching modules adapted to the school size and school's didactical orientation. Each pupil can choose three modules, which are performed as lessons of 90 minutes duration for about 20 participants. The speakers are experts from currently 350 companies, universities and research institutes.

So far, SATW has organized 77 TecDays at 57 different secondary schools throughout Switzerland. A total of about 1000 teaching modules have been offered to 60,000 pupils between 2007 and 2021. Surveys showed that 86 % of the pupils rated the TecDays good to excellent, 39 % showed increased interest in technology and science, and 28 % felt encouraged to deal more with scientific and technical topics.

Name	Host institute	Location	Subject areas	Content type	Target population	Website
Physiscope	Université de Genève	Genève (GE)	Astronomy, Electricity, Mechanics, Pressure, Rotations, Colours, State changes, Scientific procedure	Hands-on experiments	Age 6+	scienscope.unige.ch/physiscope/
S'Cool LAB	CERN	Meyrin (GE)	Particle physics, accelerator physics, medical applications	Hands-on experiments	High school, age 14+	scool.web.cern.ch
iLab	Paul Scherrer Institute	Villigen (AG)	Vacuums, Sounds, Materials and structures, Energy & environment, Spectrometry	Hands-on experiments	All school ages	psi.ch/en/ilab
Science Lab UZH	Universität Zürich	Zürich (ZH)	Energy, Cosmis rays, Cosmology, Magnetism, Space/Time/Energy, Particle physics	Hands-on experiments	High school, secundary level I and II	sciencelab.uzh.ch
Stellarium Gornergrat	Universität Bern / Université de Genève	Zermatt (VS)	Astronomy	Telescope observations (remote)	Age 8+	stellarium-gornergrat.ch
MobiLab	Fachhochschule Nordwestschweiz	Mobile around AG/BL/BS/SO	Water, Air, Optics, Materials, Electrictiy, Magnetism, Energy, Sound, Microscopy	Hands-on experiments	Primary school	mobilab-nw.ch
mobiLLab	Pädagogische Hochschule St. Gallen	Mobile around SG/AR/AI/TG	Electromagnetism, X-ray fluorescence, Ion chromatography, Spectroscopy, etc.	Hands-on experiments	High school, secundary level II	mobillab.ch
Technorama	Technorama	Winterthur (ZH)	Light and Colour, Structure of matter, Microwaves, Wave/particle duality, Radioactivity, etc.	Hands-on experiments	Age 6+	technorama.ch
Experio	Roche Pharma AG	Basel (BS)	Robotics, Electronics, Radioactivity, Spectroscopy, Optics	Hands-on experiments	All school ages	roche.ch/standorte/basel-hq/lehre/experio
jetz!		Muttenz (BL)	Electronics, Sensor technology, Programming	Hands-on experiments, technical training	Teenagers, adults, school teachers	jetz.ch
MINT mobil	Kanton Bern	Mobile in canton Bern	Mechanics, Electricity, Matter, Optics, Electromagnetism, Robotics	Hands-on Experiments	Primary school	mint-mobil.ch
International Masterclasses	International Particle Physics Outreach Group	CH	Particle physics	Computer-based "hands-on" particle physics data experiment	High school, age 15+	physicsmasterclasses.org

Table 5-4: Science outreach labs and similar offers related to physics in Switzerland

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6 Attachment: Methodology

Data Collecting

In order to be able to generate the figures for this analysis, the Swiss Physical Society and IMSD worked together to identify those classes of economic activity which can be classified as "physics-based" sectors. The identification of sectors for which it can be assumed that physics is of central importance is difficult and very subjective. The pervasiveness of physics makes it difficult to reach a single conclusive definition. There are no clear boundaries.

It was concluded that the classification used by other studies [IOP2012, EPS2013, IOP2016] is appropriate and can be applied to the Swiss economy with relatively minor adjustments. Another advantage is the possibility of direct comparisons with previous studies. In this regard, it is important to mention that the definition of physics-based sectors refers to the *use of physics* and not to the background of the employees. Thus, it also includes employees who are directly involved in technology or expertise of physics, but do not necessarily have an education in physics, but the physics graduate who works in the construction industry is thus not included.

Data Analysis

All findings and observations that are to be described in the form of statistics require systematic classification. Systematics divide the totality of statistical observations into subgroups that are as homogeneous as possible, taking into account the characteristics of the survey object.

NACE – Statistical Systematics of Industries in the European Community

To segment the Swiss economy, we consulted NACE. NACE is the classification of economic activities in the European Union (EU). Different versions of NACE have been developed since 1970. The acronym NACE derives from the French term *Nomenclature statistique des activités économiques dans la Communauté européenne*.

Statistics compiled on the basis of NACE are comparable across Europe and generally also worldwide. Within the European statistical system, the use of NACE is mandatory. However, national versions may be used by the member states, provided that they follow the given structure [1].

NACE is a four-digit classification and provides the framework for the collection and presentation of a wide range of statistical data broken down by economic activity from the business domain (e.g. production, employment, national accounts) and from other domains within the European Statistical System (ESS).

1 In Switzerland, this is the NOGA (Nomenclature générale des activités économiques). It comprises five levels and distinguishes 794 different economic activities, with each activity corresponding to a six-digit code (called "type"). Up to level 4 ("Classes"), NOGA is compatible with NACE. With level 5 ("NOGA kind"), Swiss peculiarities are taken into account.

A NACE class is relevant for the detailed assignment of units to economic activities and the units falling under each class perform as far as possible the same activities. NACE Rev. 2 is divided into (previous Rev 1.1 in brackets):

21 Sections (previously 17) – Letter code
88 Divisions (previously 62) – two digit number code
272 Groups (previously 224) – three digit number code
615 Classes (previously 514) – four digit number code

A NACE class is thus defined by a four-digit code, and a statistical unit is assigned to the class relevant to it in its activity. The following is an example using a graphical representation of a NACE classification based on a tree.

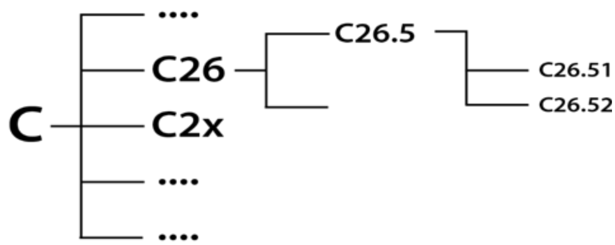

Figure 6-1: NACE Tree to classify econonomic activities. Source: http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Statistical_classification_of_economic_activities_in_the_European_Community (NACE)/de

C	Production
C26	Production of data processing equipment, electronic and optical products
C26.5	Production of instruments and appliances for measurement, control, navigation, etc. instruments and appliances; manufacture of watches and clocks
C26.51	Production of measuring, control, navigation, etc. instruments and devices

Table 6-1 lists the classes included in the definition of the physics-based sectors of this study.

Data Evaluation

The data underlying the analysis in chapter 2 are mainly drawn from the Structural Business Statistics (SBS) publicly available from Eurostat. The SBS database provides information on the structure, behavior and performance of companies in European countries. The statistics are broken down in great detail.

Presented are the estimates of sales, employment and gross value added. Please note that there might be deviations due to rounding in the column totals. The analysis focuses on 2019, the latest year for which data are available.

More specific assumptions used to calculate the individual key figures are not listed here - they are implied in the respective chapters. The number of employees was calculated using full-time equivalents everywhere. It should be explicitly mentioned that missing values are closely examined: if it is clear that over the years the categorization of the subcategories has changed slightly, then missing values

NACE Rev. 2	Category description	Allocation to the sub-areas (as in the graphs)
B09.1	Provision of services for the extraction of crude oil and natural gas	Mining
C20.13	Production of other inorganic basic materials and chemicals	Others
C21.2	Production of pharmaceutical specialties and other pharmaceutical products	Pharma
C25.4	Production of weapons and ammunition	Others
C25.99	Production of other fabricated metal products	Others
C26.1	Production of electronic components and printed circuit boards	Electronics
C26.2	Production of data processing equipment and peripheral devices	Electronics
C26.3	Production of telecommunications equipment and devices	Electronics
C26.4	Production of consumer electronics devices	Electronics
C26.5	Manufacture of instruments and appliances for measurement, control, navigation, etc. Instruments and appliances; manufacture of watches and clocks	Measuring devices
C26.6	Production of irradiation and electrotherapy equipment and electromedical devices	Medical Technology
C26.7	Production of optical and photographic instruments and devices	Measuring devices
C26.8	Production of magnetic and optical data carriers	Others
C27.1	Production of electric motors, generators, transformers, electricity distribution and switching equipment	Electrical engineering
C27.2	Production of batteries and accumulators	Electrical engineering
C27.3	Production of cables and electrical installation material	Electrical engineering
C27.4	Production of electric lamps and luminaires	Electrical engineering
C27.51	Production of electrical household appliances	Electrical engineering
C27.9	Production of other electrical equipment and devices	Electrical engineering
C28.11	Production of internal combustion engines and turbines (excluding engines for aircraft and road vehicles)	Machines
C28.2	Production of other non-industry specific machinery	Machines
C29.1	Production of motor vehicles and motor vehicle engines	Vehicle-, aircraft- & shipbuilding
C29.31	Production of electrical and electronic equipment for motor vehicles	Vehicle-, aircraft- & shipbuilding
C30.11	Shipbuilding (excluding boat and yacht building)	Vehicle-, aircraft- & shipbuilding
C30.2	Rail vehicle construction	Vehicle-, aircraft- & shipbuilding
C30.3	Aircraft and spacecraft construction	Vehicle-, aircraft- & shipbuilding
C30.4	Production of military combat vehicles	Vehicle-, aircraft- & shipbuilding
C30.91	Production of motorcycles	Vehicle-, aircraft- & shipbuilding
C32.5	Production of medical and dental apparatus and materials	Medical Technology
C32.99	Production of other products	Others
C33.1	Repair of metal products, machinery and equipment	Machines
C33.2	Installation of machinery and equipment	Machines
D35.1	Electricity supply	Electricity supply
J61	Telecommunications	Telecommunications
J62.09	Other information technology service activities	Telecommunications
M71.1	Architecture and engineering offices	Technical Service
M71.2	Technical, physical and chemical testing	Technical Service
M72.1	Research and development in natural sciences, engineering, agricultural sciences and medicine	Technical Service
M74.2	Photography and photo labs	Technical Service
M74.9	Other freelance, scientific and technical activities	Technical Service
S95.12	Telecommunication equipment repair	Telecommunications

Table 6-1: NACE categories, which are part of the physics-based industries

can be considered as 0 when summed over all subcategories. However, if a value is missing altogether, interpolation will occur from the other years.

Data Sources

The data used in this report are primarily from publicly available sources. These include:

- Federal Statistical Office (FSO): https://www.bfs.admin.ch/bfs/de/home/statistiken/kataloge-datenbanken.html
- State Secretariat for Economic Affairs (SECO): https://www.seco.admin.ch/seco/de/home/wirtschaftslage---wirtschaftspolitik/Wirtschaftslage.html
- Structural Business Statistics, Eurostat: http://ec.europa.eu/eurostat/web/structural-business-statistics/data/database
- Swiss National Science Foundation: http://p3.snf.ch/Default.aspx?id=grantsbydiscipline
- Schweizerische Nationalbank: https://data.snb.ch/de/topics

7 Glossary

Gross Domestic Product

Gross domestic product (GDP) is the total value of all goods and services produced within the national borders of an economy during one year, after deduction of all intermediate consumption. Thus, only all final goods, i.e. goods at the stage of final use, are included as economic output. In the calculation, goods that are not directly reused but placed in stock are taken into account as changes in inventories.

https://de.wikipedia.org/wiki/Bruttoinlandsprodukt

http://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Gross_domestic_product_(GDP)/de

Gross Value Added at Factor Cost

Gross value added is the total value of goods and services produced in the production process (production value), less the value of intermediate inputs. Value added at factor cost is the value added at market prices minus taxes on production and plus subsidies. Thus, gross value added at factor cost is free of taxes on production (especially excise taxes) or subsidies.

https://de.wikipedia.org/wiki/Bruttowertsch%C3%B6pfung

https://www.destatis.de/DE/ZahlenFakten/Wirtschaftsbereiche/BinnenhandelGastgewerbeTourismus/Glossar_BinnenhandelGastgewerbe/BruttowertschoepfungFaktorkosten.html

Relationship between gross domestic product and gross value added at factor cost:
For conversions, the following correction must be made for conversions:
[gross value added at factor cost of the whole economy] = [gross domestic product] - [taxes on products] + [subsidies]

https://en.wikipedia.org/wiki/Gross_value_added

Structural Business Statistics from Eurostat (SBS)

Structural business statistics cover the business economy with industry, construction and many service activities (sections B to N and division 95 of NACE Rev. 2). The provision of financial and insurance services (section K of NACE Rev. 2) is treated separately within structural business statistics, as this area has special characteristics and the availability of most standard business statistics for it is limited. The term "non-financial business economy" is usually used in business statistics to refer to the economic activities covered by NACE Rev. 2 sections B to J and L to N and division 95, as well as the units engaged in the corresponding activities. However, structural business statistics do not cover agriculture, forestry and fisheries, nor public administration and (largely) non-market services such as education and health care.

http://ec.europa.eu/eurostat/statisticsexplained/index.php/Structural_business_statistics_overview/de

Physics Based Areas / Sectors

Physics-based sectors are defined as those sectors of the Swiss economy in which the use of physics is essential for survival. That is, those that would not exist without the use of physics (in terms of technologies and expertise).

Related Studies:
[IOP2012] The Importance of Physics to the UK Economy, Institute of Physics, 2012
[EPS2013] The importance of physics to the economies of Europe, European Physical Society, 2013
[IOP2016] The role of physics in driving UK economic growth and prosperity, Institute of Physics, 2016