# CHIPP Roadmap for Research and Infrastructure 2029-2032 and beyond by the Swiss Particle Physics Community

Draft V1.3 Pre-release for ETH Board and Swissuniversities

19 January 2024
git commit ID:(None)

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# 1 Foreword

[Main Editor: ]

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December 2023

# 2 Introduction

[Main Editor: ] []

**The Swiss Institute of Particle Physics, CHIPP**

The purpose of CHIPP is to coordinate the involvement of Swiss institutes in particle and astroparticle physics research and teaching. One of its important functions is to recommend priorities within the context of available resources. CHIPP consists of two bodies: the CHIPP Plenary and the CHIPP Board. The CHIPP Plenary consists of physicists with a postgraduate degree (PhD students, postdocs, senior scientists, and professors), who are active in the realm of particle and astroparticle physics, and who work for a Swiss institution; Swiss nationals with a PhD degree and who are employed by CERN are also included. The CHIPP Board is comprised of all professors with activities in experimental or theoretical particle and astroparticle physics, as well as the heads of the experimental and theoretical particle physics groups at the Paul Scherrer Institute (PSI). The CHIPP Board meets at least twice per year, and the CHIPP Plenary at least once. The CHIPP Board elects an Executive Board, consisting of a Chair and one to three Deputy Chairs, for periods of two years.

# 3 Executive summary, findings and recommendations

[Main Editor: Rainer] []

Here we present the major findings and recommendations which summarise the detailed analysis presented in the following chapters. Particle and astroparticle physics are both embedded in an international context, and the Swiss Institute of Particle Physics (CHIPP) endorses the findings of the European Particle Physics Strategy Update [1] by CERN issued in 2020, the findings of the Astroparticle Physics European Consortium (APPEC) Roadmap [2] issued in 2018, and the Nuclear Physics European Collaboration Committee (NuPECC) Long Range Plan 2017 ”Perspectives for Nuclear Physics” [3]. We will provide further guidance on the implementation of the major findings and recommendations of those roadmaps in the Swiss context and provide additional findings and recommendations specific to the CHIPP community.

**Finding 1:** The European particle physics community considers an electron-positron Higgs factory as the highest priority, together with the ambition to operate a proton-proton collider at the high-energy frontier of about or exceeding a centre-of-mass energy of 100 TeV. CHIPP points out that these ambitious goals will be best achieved through the Future Circular Collider (FCC) programme; an electron-positron $Z/W/H/t$ factory (FCC-ee) as a first stage, followed by a hadron collider (FCC-hh) TG: Updated timeline expected in Feb (Canelli, Blondel) around 2045, would secure the future of high-energy particle physics with CERN as a world-leading laboratory well beyond the 2080s. One key ingredient in this ambitious programme is the development of suitable high-field magnets for FCC-hh that define the critical path.

**Recommendation 1a:** CHIPP recommends that Switzerland strongly support CERN as the world-leading laboratory in particle physics. CHIPP's research portfolio is well aligned with CERN's such that CHIPP will continue to benefit greatly from and lend strong support to CERN for the foreseeable future.

**Recommendation 1b:** TG: CHEF decision expected in Fall 2024 (Canelli) CHIPP recommends the development of a national strategy towards the participation in CERN's programme for an FCC, starting with FCC-ee, which encompasses detector development, data analysis and simulation, and importantly theoretical research. CHIPP supports CERN's goal to incorporate sustainability considerations into the design of future colliders.

**Recommendation 1c:** CHIPP recommends that Switzerland maintain involvement in accelerator physics development, especially towards the FCC projects. In particular, CHIPP recommends the continuation of the successful Swiss Accelerator Research and Technology (CHART) programme, it being an excellent example of close collaboration between CERN, a national laboratory, national institutes, and universities.

**Recommendation 1d:** TG: Add CERN DRD connection (Kilminster) CHIPP recommends that Switzerland maintain strong involvement in detector research and development, which is essential for the future of particle physics and which fosters synergies with other scientific fields.

**Finding 2:** TG: Add real-time inference (? Aarestad) In anticipation of the FCC, the Large Hadron Collider (LHC) continues to be the flagship project at the high-energy frontier until the end of its scheduled lifetime in the mid-to-late 2030s. The LHC, with its future high-luminosity running phase (HL-LHC), will provide a plethora of new data which will allow for measurements of the properties of the Higgs boson, provide increased precision measurements of Standard Model (SM) parameters, and enable both further exploration of the flavour sector as well as searches for physics beyond the Standard Model (BSM). The long-term support to operate the LHC detectors and eventually provide performance and longevity upgrades remains crucial during this period. Furthermore, the large volume of collected data will create challenges for computing in the Worldwide LHC Computing Grid (WLCG) paradigm.

**Recommendation 2a:** CHIPP strongly supports the experimental TG: Add FCC (Canelli) HL-LHC programme and recommends that Switzerland continue to secure the operation and upgrades of the ATLAS, CMS, and LHCb detectors, to ensure full exploitation of the investments so far.

**Recommendation 2b:** For the full HL-LHC exploitation to be feasible, further computing infrastructure TG: Add computing R&D (?) (Donega, Lange) is required, possibly in collaboration with other fields facing similar computing challenges with highly performant computing and data handling strategies. CHIPP recommends that Switzerland engage in providing the necessary resources.

**Finding 3:** TG: make case that theory connects LE and HE (Spira) The quest for new physics, through either direct searches or indirect searches via precision measurements of SM particles including the Higgs boson, is complemented by and shared with a diverse set of experimental activities at the low-energy / high-intensity frontier TG: high-intensity is both LE and HE (Golling, Crivelli). These activities are supported by the use of dedicated accelerators, either at the national laboratory (Paul Scherrer Institute, PSI) or elsewhere, or by running in parallel with existing high-energy accelerators. These experimental efforts are avenues towards exploring intriguing BSM scenarios, and are therefore extremely important for CHIPP's multi-prong approach towards searching for BSM physics and putting the Standard Model to the test.

**Recommendation 3a:** CHIPP strongly supports the present and future exploitation of the High-Intensity Accelerator (HIPA) accelerator complex at PSI. CHIPP recommends that a portfolio of dedicated experiments at the low-energy / high-intensity frontier should be pursued and strongly support the envisioned High-Intensity Muon Beam (HIMB) programme at PSI.

**Recommendation 3b:** CHIPP strongly supports the present and future exploitation of the CERN accelerator complex beyond the large LHC experiments, in experiments that search for new physics using novel approaches. It encourages the attempts to establish a high-power beam dump facility at CERN or elsewhere. CHIPP recommends that Switzerland engage in these diverse experiments.

**Finding 4:** Neutrinos continue to provide intriguing puzzles to the Standard Model. The elucidation of their nature (Dirac or Majorana) and properties (violation of charge conjugation parity symmetry, mass hierarchy) continue to be a vibrant sector of particle physics. Progress in neutrino physics depends largely on the next-generation long-baseline programmes as envisioned in the USA (DUNE) and Japan (Hyper-K). Other facilities and experiments such as LEGEND, searching for neutrinoless double-beta decays, are necessary to test the nature of neutrinos.

**Recommendation 4a:** CHIPP recommends that Switzerland strongly support the long-baseline neutrino programmes in both Japan and the USA in order to maximise the scientific reach.

**Recommendation 4b:** Experiments targeting the detection of neutrinoless double-beta decays continue to be vital to explore the nature of neutrinos. CHIPP recommends a continuous and adequate support to such experiments.

**Finding 5:** Dark matter is one of the biggest open questions in particle physics and beyond. Astronomical observations reveal its large abundance in the Universe and underline its pivotal role in cosmic structure formation. The elucidation of the particle nature of dark matter continues to be one of the most important quests in contemporary particle and astroparticle physics. As experimental results begin to stress the paradigm for the Weakly Interacting Massive Particles (WIMPs) interpretation, alternative scenarios for dark matter (axions, an entire dark sector, etc.) come increasingly into focus. Direct dark matter detection experiments (such as DARWIN and DAMIC), searches for dark matter production at accelerators (in particular at the LHC), as well as indirect searches for dark matter via astrophysical observations continue to be the multi-prong approach that needs to be pursued in order to solve this puzzle.

**Recommendation 5:** CHIPP recommends the direct search for dark matter as an effort that needs to be upheld. In addition, complementary approaches targeting dark matter scenarios outside of the WIMP paradigm and indirect detection via multi-messenger astronomical observations are encouraged and should complement the future search portfolio.

**Finding 6:** Astroparticle physics in Switzerland provides a diverse portfolio of experimental efforts, both ground-based and in space. Often, these facilities are of interest to researchers both in particle and astroparticle physics, as well as astrophysics and astronomy. A prime example is the Cherenkov Telescope Array (CTA), a scientific instrument that enables the pursuit of astronomical, as well as astroparticle physics research. The CTA science community in Switzerland is growing at the interface of CHIPP and CHAPS. Future big science endeavours, including research into the detection of gravitational waves, either in their own right or as part of a multi-messenger science programme using future ground-based or space-based facilities, will further excite scientific interest in both research communities and tie them closer together scientifically. To expedite this process, a CHIPP-CHAPS working group was recently established to explore common interest in both communities concerning future gravitational waves research. It is expected that significant investments are needed in this future research domain. While both CHIPP and CHAPS communities have strong scientific focal points that are otherwise very distinct, they share some similarities in their mode of operation, such as being dependent on large-scale instrumentation, which often takes decades to build in the context of large international organisations. CHIPP and CHAPS receive major instrumentation and operations support from the SNSF FLARE funding instrument for ground-based research activities. As project cost and duration tend to rise, an understanding in priorities of research instrumentation across both communities needs to be fostered. Both communities may also face challenges from dealing with large data volumes and hence, could profit from a closer collaboration.

**Recommendation 6:** CHIPP recommends a further strengthening of ties with the CHAPS community, both scientifically and technically. As an instrument of common interest for both communities, Switzerland should secure access to CTA at a level that is appropriate for the size of the Swiss researcher community interested in CTA. Both CHIPP and CHAPS should explore common interests in and develop a common strategy towards future gravitational waves experiments.

**Finding 7:** TG: Make case to strengthen program (); make FCC case (Spira, Blondel) Theoretical physics is of pivotal importance to the development of fundamental physics and is a research area in which Switzerland has an outstanding track record. It is a salient feature of particle physics that its theory provides us with an extremely powerful paradigm, namely the Standard Model. Unravelling the puzzles that the SM cannot answer will require renewed theoretical efforts on phenomenology, precision calculations, and model building. Now that the field seems to be leaving the realm of "guaranteed" discoveries, i.e. theoretically predicted, but very rare phenomena such as the Higgs boson discovery or the detection of gravitational waves, theoretical guidance, even if "only" of heuristic nature, is more important than ever. At the same time, TG: organised efforts towards improved theoretical predictions within the Standard Model are of key relevance for the interpretation of current and planned experiments at particle accelerators. Similarly, theoretical physics plays a key role in the interpretation of astrophysical phenomena, the area from where we presently observe the strongest indications for BSM physics.

**Recommendation 7:** CHIPP recommends that Switzerland continue to strengthen its vigorous programme in theoretical particle and astroparticle physics, and cosmology. Besides its intrinsic goal to understand and adequately formulate the laws of nature, this effort is a necessary ingredient for the interpretation of current and planned experiments at accelerators, as well as astrophysical phenomena. Theoretical research is also of pivotal importance as a guide in planning long-term experimental efforts in particle and astroparticle physics.

**Finding 8:** Swiss particle and astroparticle physicists have been very successful in terms of transferring know-how from their specific research to other fields of science and to industry. In particular, close ties and collaborations exist with many Swiss and international companies, and an important number of start-up companies have been created in recent years.

**Recommendation 8:** CHIPP encourages the academic and research institutions in Switzerland to pursue and further strengthen the support they give to researchers in terms of technology transfer and know-how.

**Finding 9:** Fostering outreach and education becomes ever more important for particle and astroparticle physics. As basic research, whose benefit to society is very tangible but often indirect, CHIPP recommends that efforts be strengthened to communicate the fascination, benefit, and promise of particle physics and astrophysics to the greater public. The field also depends on attracting new talent to join the ranks of our research teams, which is one of the most important assets that we have. The international networks in outreach and education, such as the CERN teachers programme, the International Particle Physics Outreach Group, and the European Particle Physics Communication Network strengthen the outreach efforts and provide support in the form of online platforms, tools, and material.

**Recommendation 9:** CHIPP recommends a continuous pro-active communication and outreach strategy in order to remain engaged and further strengthen the dialogue with the public. Members of CHIPP are well poised to give inspiring outreach talks, lead visitor programmes at their universities, PSI, or CERN, and to convey the fascination of fundamental research to the next generation with events targeting high-school students; CHIPP strongly encourages such activities.

**Finding 10:** Particle physics is a very attractive field for bright young students who wish to get involved at the forefront of fundamental research and technological innovation. Their continuous education and training is of special importance for a sustainable development of the field. Special care should be taken to increase the recognition of individuals working in all areas of experimental work, particularly in large collaborations. Female researchers continue to be underrepresented in all areas of particle and astroparticle physics. CHIPP recognises the value of equality, diversity and inclusion, the importance of role models, and the need for continuous support to improve the gender balance within CHIPP.

**Recommendation 10:** CHIPP strongly encourages all institutes to develop strategies to support further the next generation of scientists, and continues to support early-career researchers by optimising their training in research and other areas and by providing a networking base for the mutual exchange of ideas and support. The CHIPP community remains committed to the principles of equality, diversity, and inclusion in all activities, and recommends the strengthening of efforts in these directions.

# 4 Purpose and scope

[Main Editor: ]

# 5 The present Swiss landscape

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## 5.1 Energy frontier of particle physics

CHIPP Pillar 1 consists of Swiss activities at the high-energy, high-intensity, and precision frontiers of particle physics. Switzerland is in a unique position in terms of large-scale facilities for fundamental particle physics. It is a host country of CERN and it operates the Swiss Research InfraStructure for Particle physics (CHRISP) at the national laboratory, PSI.

Particle physicists of all CHIPP institutions play leading roles in knowledge-frontier experiments run at CERN and at PSI (Appendix 15.1.1). These roles comprise intellectual leadership, hardware R&D, design, construction, implementation, data taking, data analysis, and theory developments, as well as important managerial lead roles. All of these activities significantly enhance the discovery potential of the experiments and considerably extend the boundaries of our current knowledge.

CERN's LHC drives the highest-energy proton-proton collisions in the world; these collisions are recorded by the ATLAS, CMS, and LHCb Experiments, which have used these data to consistently provide new insights and challenge our understanding of Higgs physics, SM parameters, flavour physics, and searches for new phenomena. These large experiments are all pursuing important upgrade activities, in particular, towards the HL-LHC phase. The new FASER Experiment is being installed downstream of ATLAS. Other CERN particle beams also provide unique opportunities, such as for rare event searches with NA64 and delivering antiprotons for precision measurements to the GBAR and BASE Experiments. Other R&D activities concern dedicated dark sector searches with SHiP at a possible future high-power beam dump facility.

CHRISP beams are driven by the HIPA complex at PSI. CHRISP provides the highest intensities of low momentum pions, muons, and ultracold neutrons. The most important Swiss activities concern the n2EDM and Mu3e Experiments and the laser spectroscopy of exotic atoms. They provide some of the most sensitive searches for CP and lepton flavour violation, as well as precision SM measurements and searches for exotic interactions. A new HIMB, with two orders of magnitude increased intensity and allowing for many new experiments, is currently under study.

An outlook of approved projects in which Swiss researchers are engaged is given in Fig. 1.

Swiss researchers are also active in accelerator science and technology developments, which puts Switzerland in an excellent position for the future of particle physics, as detailed in Table 1.

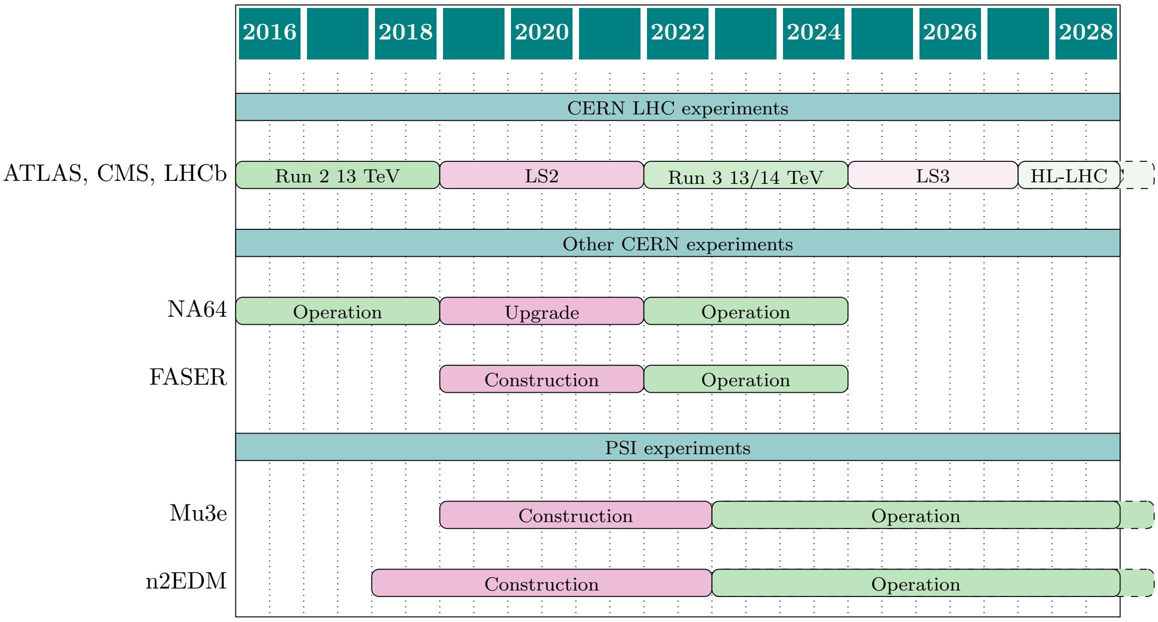

Figure 1: TG: to update The timeline of the various representative ongoing approved projects where Swiss researchers are involved, at CERN and PSI. This timeline demonstrates activities in recent years, starting in 2016, and extending to 2028, one year after the HL-LHC project will have started.

### 5.1.1 High energy: LHC experiments

### 5.1.2 High energy: Other experiments at CERN

### 5.1.3 Experiments with low-energy beams

### 5.1.4 Accelerator physics and technology

Accelerator science and technology developments in Switzerland are at the heart of several large research infrastructures used in particle physics, but also in a number of fields like chemistry, life, and materials sciences. Switzerland maintains a strong tradition of accelerator R&D, both at PSI and at CERN. Going back to the design and construction of high-intensity proton accelerators at PSI in the 1970s, with its world-highest-power proton beam, has resulted in state-of-the-art synchrotron light sources, such as the Swiss Light Source (SLS) and the Swiss Free Electron Laser (SwissFEL). The CHART programme, a collaboration between CERN, Uni Genève, EPFL, ETH Zürich, and PSI, continues to maintain this tradition. The mission of CHART is to support the future-oriented accelerator project of FCC at CERN, together with the development of accelerator concepts beyond currently existing technologies. With extraordinary support by SERI, the ETH Board, and participating institutions, CHART contributes to future accelerator-driven research infrastructures, benefiting science and society.

| Institution | Main involvements |
|---|---|
| Uni Bern | Experiments at CERN: ATLAS and FASER<br>Experiments at PSI: n2EDM<br>Detector R&D: Tracking detectors, data acquisition |
| Uni Genève | Experiments at CERN: ATLAS and FASER<br>Experiments at PSI: Mu3e<br>Detector R&D: Tracking detectors, trigger and data acquisition |
| Uni Zürich | Experiments at CERN: CMS and LHCb<br>Experiments at PSI: Mu3e<br>Detector R&D: Tracking detectors, trigger |
| EPFL | Experiments at CERN: LHCb, SND<br>Detector R&D: Tracking detectors, trigger |
| ETH Zürich | Experiments at CERN: CMS, NA64, GBAR, BASE<br>Experiments at PSI: Mu3e, n2EDM, CREMA, mu-Mass, muX, piHe<br>Detector R&D: Calorimetry, tracking detectors |
| PSI | Experiments at CERN: CMS<br>Experiments at PSI: Mu3e, MEG II, n2EDM, CREMA, mu-Mass, muX, piHe<br>Detector R&D: Tracking detectors |

Table 1: TG: Here only approved projects: add SND and NA62 (Schneider), removed Basel A summary of Swiss involvement in approved accelerator-based particle physics experiments. Research groups in all institutes are also active in detector research and development, which often extend to applications in other scientific fields and industry.

## 5.2 Neutrino physics

Neutrino physics constitutes Pillar 2 of CHIPP, including activities in both theoretical work and experimental measurements. The development of novel detection techniques takes a prominent role in order to cover a large range of neutrino measurements, from very low to extremely high energies, and from the smallest to the highest rates of events. Neutrino physics has become a precision measurement field for which the Swiss institutions have great experience and an outstanding reputation. In the present landscape, multiple Swiss institutes have leading roles in the design and construction of future general-purpose long-baseline experiments in the USA (DUNE) and Japan (Hyper-K): experiments aimed at determining the mass nature of neutrinos and experiments measuring neutrinos as part of their multi-messenger investigations. In parallel, the physics exploitation of running experiments is ongoing (SBN, T2K, GERDA, and IceCube).

## 5.3 Astroparticle physics

Pillar 3 of CHIPP relates to astroparticle physics; Swiss groups are actively working on different aspects of multi-messenger astroparticle physics, which is the most promising direction to follow, in order to understand the highly complex 'cosmic accelerators' observed in the Universe. These groups participate in large international experiments designed for $\gamma$-ray, X-ray, neutrino, and cosmic ray detection. While X-ray experiments must operate from space, $\gamma$-rays can be observed both from space and from the ground, albeit with very different technologies. Such $\gamma$-ray experiments are complementary to ground-based cosmic ray and neutrino observatories. CHIPP groups are also at the forefront of direct dark matter searches, especially with liquid xenon. A summary of the experiments with Swiss involvement can be found in Table 3. A short description of each experiment can be found in Appendices 15.1.3 and 15.1.4.

| Institution | Main involvements |
|---|---|
| Uni Bern | Long-baseline experiment: DUNE<br>Short-baseline experiments: MicroBooNE, SBN |
| Uni Genève | Long-baseline experiment: T2K / Hyper-K<br>Ground-based astroparticle experiment: IceCube |
| Uni Zürich | Neutrinoless double-beta decay experiments: GERDA, LEGEND |
| ETH Zürich | Long-baseline experiment: T2K / Hyper-K |

Table 2: A summary of Swiss involvement in experimental neutrino physics. The experiments are described in Appendix 15.1.2.

| **$X$- and $\gamma$-rays, cosmic rays, and neutrinos** | | | | **Dark Matter** | |
|---|---|---|---|---|---|
| from space | | from the ground | | | |
| AMS-02 | (Uni Genève) | IceCube | (Uni Genève) | XENON1T | (Uni Zürich) |
| DAMPE | (Uni Genève) | LHAASO | (Uni Genève) | XENONnT | (Uni Zürich) |
| HERD | (Uni Genève, EPFL) | CTA | (Uni Genève, Uni Zürich, EPFL, ETH Zürich) | DARWIN | (Uni Zürich) |
| | | | | DAMIC-SNOLAB | (Uni Zürich) |
| EUSO | (Uni Genève) | MAGIC | (Uni Genève, ETH Zürich) | DAMIC-M | (Uni Zürich) |
| POLAR-2 | (Uni Genève) | FACT | (Uni Genève, ETH Zürich) | OSCURA | (Uni Zürich) |
| eXTP | (Uni Genève) | | | | |

Table 3: A summary of astroparticle experiments with Swiss involvement. The institutes presently participating in the experiments are indicated in parentheses. The subjects and goals of each experiment are described in Appendices 15.1.3 and 15.1.4. The timelines are detailed in Fig. 4 of Chapter 11.

| Institution | Main research areas |
|---|---|
| Uni Basel | (II) Neutrino physics, high-energy BSM phenomenology<br>(III) Cosmology, astroparticle physics |
| Uni Bern | (I) Precision low-energy physics, lattice QCD, collider phenomenology<br>(III) Cosmology, astroparticle physics<br>(IV) String theory and formal aspects of QFT |
| Uni Genève | (II) High-energy BSM phenomenology, model-building<br>(III) Cosmology, astroparticle physics, physics of GWs<br>(IV) String theory and formal aspects of QFT |
| Uni Zürich | (I) High-precision perturbative QCD, simulation tools for colliders, precision flavour physics<br>(II) BSM phenomenology at low- and high-energies, model-building<br>(III) Cosmology, physics of Gravitational Waves (GW) |
| EPFL | (II) High-energy BSM phenomenology, model-building<br>(III) Cosmology, astroparticle physics, hidden sectors<br>(IV) Formal aspects of QFT |
| ETH Zürich | (I) Precision perturbative QCD, collider phenomenology<br>(IV) String theory and formal aspects of QFT |
| PSI | (I) Precision low-energy physics, collider phenomenology, simulation tools for colliders<br>(II) BSM phenomenology at low- and high-energies, model building |

Table 4: Overview of the research activities in theoretical particle physics in Switzerland. The Roman numerals refer to the four main research lines discussed in Sect. 5.4

### 5.3.1 X- and $\gamma$-rays, cosmic rays, and neutrinos

### 5.3.2 Dark matter, direct detection

## 5.4 Theoretical physics

Swiss researchers are at the forefront of different aspects of theoretical research, whose ultimate goal is a deeper understanding of the underlying principles governing fundamental interactions. This common objective is pursued along different research lines, which span a wide range of topics from computing precise predictions for processes under experimental investigation to developing new models and new principles.

### I. Precise SM physics

### II. Model-building and BSM phenomenology

### III. Cosmology, astroparticle, and gravitational physics

### IV. Progress in Quantum Fields and String Theory

## 6 Major successes (2017-2020)

[Main Editor: ] []

## 6.1 Energy frontier of particle physics

TG: Expanad LHC successes (Canelli); add FCCee experiment (Sfyrla, Canelli) and theory (Antusch) projects
With the discovery of the Higgs boson in 2012, the SM is now complete. Present activities are concentrated on measuring the parameters of the SM particles with high precision, as well as on searching for BSM physics to answer the many questions that the SM leaves unanswered. The ATLAS and CMS Experiments have recently observed Higgs decay channels that were not previously accessible due to their small production rates, and have provided measurements of other SM properties with unprecedented precision. They have searched for BSM theories and models, often significantly constraining them by setting limits on the masses of associated new particles; in this route, they have also revealed interesting and challenging directions for further searches. TG: Remove flavor anomalies and update flavor section (Schneider) The LHCb Experiment has established itself as the front-runner in heavy flavour physics. Recently, it has discovered CP violation in charm decays, as well as in baryon decays. It improved our knowledge of various rare decays, which has strong implications on BSM physics.

TG: Add SND and NA62 (Schneider), HIKE and SHIP decision expected in March
All three experiments have explored, with Swiss contributions, dark sector particles in regions complementary to the exquisite exclusions by the NA64 Experiment. The newly approved FASER Experiment will complement such searches in a unique way and its construction is successfully proceeding on a fast track. For a future SHiP Experiment, many detailed technical studies have shown an unprecedented DS sensitivity.

TG: Add trigger (Sfyrla), calo (?), timing (Iacobucci, Paolozzi), ML (Golling), processing (Sfyrla)
Swiss groups are responsible for various state-of-the-art tracking detectors used by the LHC experiments, which perform excellently and play a pivotal role in almost all analyses. TG: Add FASER (Sfyrla), LHCb Run 3 upgrade (Schneider), FCCee (Canelli) They are equally engaged in the design and construction of upgraded detectors for the HL-LHC, as well as new detectors for other future experiments.

At PSI, Swiss groups lead experiments with muons and ultracold neutrons. The nEDM Experiment has pushed the limit on the neutron electric dipole moment. The MEG Collaboration has improved the limit on the lepton flavour violating decay of the muon to positron and photon, the best limit on any rare decay to date. Both are also pursuing DS searches and setting new limits. Precision spectroscopy of exotic atoms is undergoing a renaissance, with many activities and landmark results, probing SM parameters and searching for BSM physics. Exciting results come from high-intensity muon beam physics: The MICE Experiment at RAL successfully demonstrated muon ionisation cooling with medium-energy muons, and the muCool Experiment at PSI demonstrated phase space compression for slow muons. In view of the HIMB project at PSI, aiming at two orders of magnitude higher muon intensities, a new configuration of the high-power production target was established.

### 6.1.1 High energy: LHC experiments

### 6.1.2 High energy: Other experiments at CERN

### 6.1.3 Experiments with low-energy beams

### 6.1.4 Accelerator physics and technology

As a consequence of the financial support provided by SERI and the matching funds in the form of person-power and hardware from the participating institutes, the projects of the CHART programme have achieved remarkable results. The activities of CHART have concentrated on three research directions: high-field superconducting magnet developments for FCC, FCC beam dynamic studies, and novel methods of laser acceleration. Exceptional operational conditions have also been achieved at the PSI HIPA facility.

## 6.2 Neutrino physics

Neutrino physics has seen important advances in the last few years, including fundamental science results and discoveries. Neutrino physics also plays an important role in cosmology and astroparticle physics. The measurement of the neutrino oscillation mixing angle ($\Theta_{13}$), the observation of muon-neutrino to tau-neutrino oscillations, and setting the most stringent limit on the germanium double-beta decay lifetime are major achievements in the field, all of which were performed with leading contributions by Swiss researchers.

Swiss groups have also achieved major milestones in detector design and construction (e.g. liquid argon TPCs), operation and physics exploitation of experiments, as well as in theoretical developments.

## 6.3 Astroparticle physics

The Swiss astroparticle physics community has been engaged in numerous experiments, producing remarkable results. The Earth-based cosmic neutrino detector IceCube and the $\gamma$-ray telescope MAGIC, as well as the space-based FERMI-LAT, have discovered strong evidence for neutrinos and $\gamma$-rays from an active galaxy (the blazar TXS 0506+056) in a flaring state. A Swiss team was also involved in the installation of the the first CTA Large Scale Telescope (LST-1). In space, AMS-02, aboard the International Space Station made the most precise measurements of the cosmic flux of 'heavy' nuclei (He, Li, O, Si, Mg); DAMPE made the most precise measurements of the cosmic electron and proton fluxes; and POLAR measured the polarisation of five $\gamma$-ray bursts. Deep underground, the XENON1T Experiment has the world's best sensitivity to dark matter in the mass range from 85 MeV to 6 GeV, and has observed two-neutrino double electron capture events. The ultimate direct dark matter detector, DARWIN, has been invited to send the conceptual design report to the LNGS Scientific Committee. Last but not least, DAMIC has the world's best sensitivity to electronic scattering of dark matter and hidden-photon dark matter at low masses.

### $X$- and $\gamma$-rays, cosmic rays, and neutrinos

### Dark matter, direct detection

## 6.4 Theoretical physics

> Swiss research in theoretical particle physics is of very high quality in all the four main directions outlined in the previous chapter. Swiss scientists are among the world-leading groups in theoretical calculations for collider physics, both at the LHC (high-energy) and the PSI experiments (low-energy). They are at the forefront of developing new theories and models, linking them to the present and future collider searches. They have significantly contributed to recent developments in cosmology, gravitational wave theory, and string theory.

**Precision calculations for collider physics.**

**Precision low-energy physics.**

**The origin of the Fermi scale.**

**The flavour puzzle.**

**Dark sectors and neutrino masses.**

**Cosmology and gravitational waves.**

**Progress in Quantum Fields and String Theory**

# 7 The international context

[Main Editor: ]

> Research in the domains of particle and astroparticle physics is carried out by international collaborations, which can be composed of thousands of members from all over the world. Switzerland, being one of the two host states of CERN and featuring an important number of very strong academic research groups, is a key player in this international environment and has strongly contributed to establishing the main strategic lines for the future evolution of the field, in particular in the context of the recent update of the European Strategy for Particle Physics.

### 7.1 Accelerator research

### 7.2 Experiments at particle accelerators (energy and intensity frontiers)

### 7.3 Long-baseline neutrino physics

### 7.4 Non-accelerator-based particle and astroparticle physics

## 8 Synergies with other scientific fields

[Main Editor: ]

Developments in particle and astroparticle physics naturally provide a solid foundation for synergies with other fields. From instrumentation to large-scale equipment such as accelerators, and from (big) data analysis and computing techniques to theoretical and mathematical tools, particle and astroparticle physics developments find important uses elsewhere. Examples include synergies within the physical sciences, such as in the rapidly emerging field of gravitational waves, as well as in other fields of research, particularly including the medical and bio-medical sectors.

### 8.1 Interdisciplinary research

[Editor: Gino, Ruth]

**Mathematics**

#### 8.1.1 Cosmology and gravitational waves.

**Astronomy**

**Gravitational wave observations**

#### 8.1.2 Detector technologies, data processing, and computing

**Technology**

**Other fields of physics**

**Space technologies**

**Computing and big data**

| Year | Bachelor | Master | PhD | PostDoc |
|---|---|---|---|---|
| 2016 | 1445 | 28 | 167 | 95 |
| 2017 | 1540 | 44 | 172 | 92 |
| 2018 | 1505 | 41 | 180 | 103 |
| 2019 | 1608 | 43 | 166 | 91 |
| 2020 | N/A | 43 | 136 | 95 |

Table 5: The number of Bachelor students in physics programmes at Swiss universities, as well as the number of Master's and PhD students and Postdocs in particle, astroparticle, and nuclear physics.

### 8.2 Medical applications

### 8.3 Accelerator technology and sustainability

## 9 Relationship to industry

[Main Editor: Guenther]

TG: Add computing / ML? The fields of experimental particle and astroparticle physics have a long-standing tradition of (i) very close collaboration with (high-tech) industry and (ii) pushing technological frontiers, ultimately resulting in innovations that are successfully transferred to the private sector and industry. These frontiers are typically related to leading-edge nuclear and particle physics instrumentation, developed for and installed in small- and large-scale detectors, as well as particle accelerator technology. In all of these areas, Switzerland is particularly well placed, thanks to (a) its hosting of a considerable number of national and international high-tech companies, (b) the fertile grounds and resources available for founding spin-off companies, and (c) the substantial support given by the Swiss academic institutions and its national lab (PSI) to those researchers who are interested in the technology transfer of their ideas, developments, and inventions.

## 10 Impact on education and society

[Main Editor: Katharina]

## 11 Vision for the future

[Main Editor: ]

## 11.1 Overall vision

**The future strategy of CHIPP**

**I.** *Long-term prospect at the high-energy frontier*. TG: Double down on FCC; timely is crucial; CERN to remain global world leader (Canelli, Blondel) The FCC programme at CERN represents a unique multi-purpose facility, which can maximise the potential for the discovery of new physics in its possible two stages (ee and hh): it is the facility that would allow for a more in-depth exploration of the high-energy frontier (in the FCC-hh phase) and it is the Higgs-factory with the maximal possible luminosity (in the FCC-ee phase); it would also offer unique opportunities for more specific high-precision searches (again in the FCC-ee phase). Swiss particle physicists are playing a seminal role in the FCC accelerator concept, contributing greatly to the development of high-field magnets and working on key aspects of the FCC-ee accelerator design. At the end of 2018, when providing input to the ESPP update, the Swiss community has clearly indicated the FCC programme as their main long-term priority. This input has been largely endorsed by the official ESPP update released in 2020.

**II.** *Short- and mid-term perspective at accelerator-based facilities*. While anticipating a new large-scale facility, the priority is to exploit the discovery potential of existing facilities in the context of the precision frontier, starting from the HL-LHC project at CERN. At the same time, it is important to also conceive of and develop dedicated smaller-scale experiments with unique discovery potential; this may involve new initiatives in the context of a future beam-dump facility at CERN. At the low-energy side of the high-precision frontier, Switzerland operates a unique word-leading hub in the form of the proton accelerator HIPA at PSI, which provides the highest intensities of low-momentum pions, muons, and ultracold neutrons. The upgrade of this facility via the HIMB that could be implemented at HIPA from 2025 to 2028 is another high-priority project.

**III.** *Neutrino physics*. Long-baseline experiments with high-intensity neutrino beams are essential to answer key questions such as the amount of matter-antimatter asymmetry in the neutrino sector and the neutrino mass hierarchy. This effort should be pursued via participation in the complementary long-baseline facilities under development in the USA and Japan, where the Swiss community is already significantly engaged in both efforts. Underground experiments, in which Swiss groups are leading participants, also play a fundamental role in addressing key complementary physics questions such as the nature of neutrino masses.

**IV.** *Cosmic frontier*. The search for dark matter via direct detection at underground laboratories represents a core CHIPP activity; this effort should be continued with high priority, especially in the experiments where Swiss groups are leading participants. In parallel, it is important to strengthen and diversify efforts in the direction of multi-messenger astronomy; this rapidly expanding field relies upon the use of various complementary experiments at the interface between CHIPP and CHAPS, such as the CTA observatory. A future engagement in gravitational wave experiments is also an interesting possibility.

## 11.2 The Future Circular Collider project

### Overall plan and physics goals

### Accelerator technology for the FCC

## 11.3 Short- and mid-term prospects for experiments at accelerator-based facilities

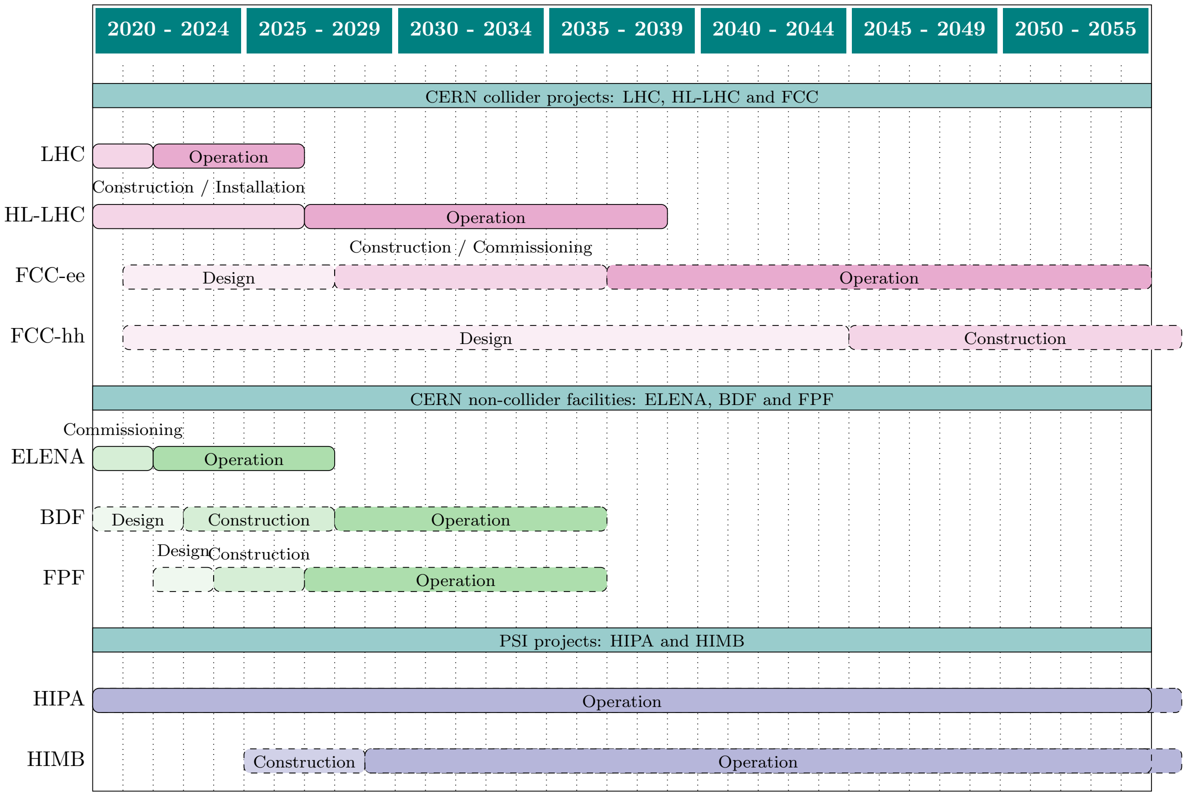

Figure 2: TG: to update The timeline of major approved or prospective accelerator projects and facilities where Switzerland is already or plans to be engaged, at CERN and the PSI. The intensity of a given colour type indicates the project phases: preparation, construction, and operation and exploitation of the machine. Dashed boxes indicate prospective projects that are not yet approved for construction.

### Physics pursuits with ATLAS and CMS at the HL-LHC

### Flavour physics with LHCb at the HL-LHC

### Detectors and computing for the HL-LHC

### Other experiments at CERN

### Low-energy, high-intensity particle physics experiments at PSI

*Accelerator technologies.*

*Experiments.*

A

## 11.4 Neutrino physics

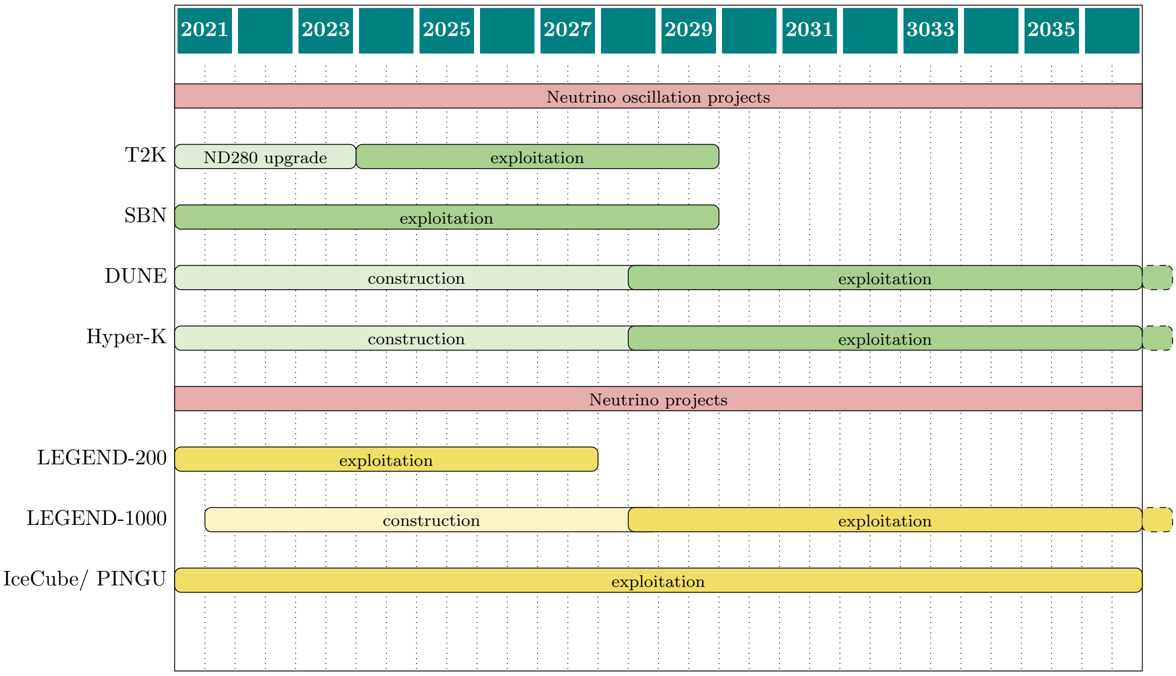

Figure 3: The timeline of major neutrino projects with strong Swiss engagement. The intensity of a given colour indicates the project phase, differentiating between construction (light colour) and exploitation of the machine (dark colour). The timeline of DARWIN is shown in Table 4.

### Long-baseline experiments

**Hyper-K.**

**DUNE.**

**Passive experiments**

**IceCube.**

**LEGEND. DARWIN.**

## 11.5 Astroparticle physics

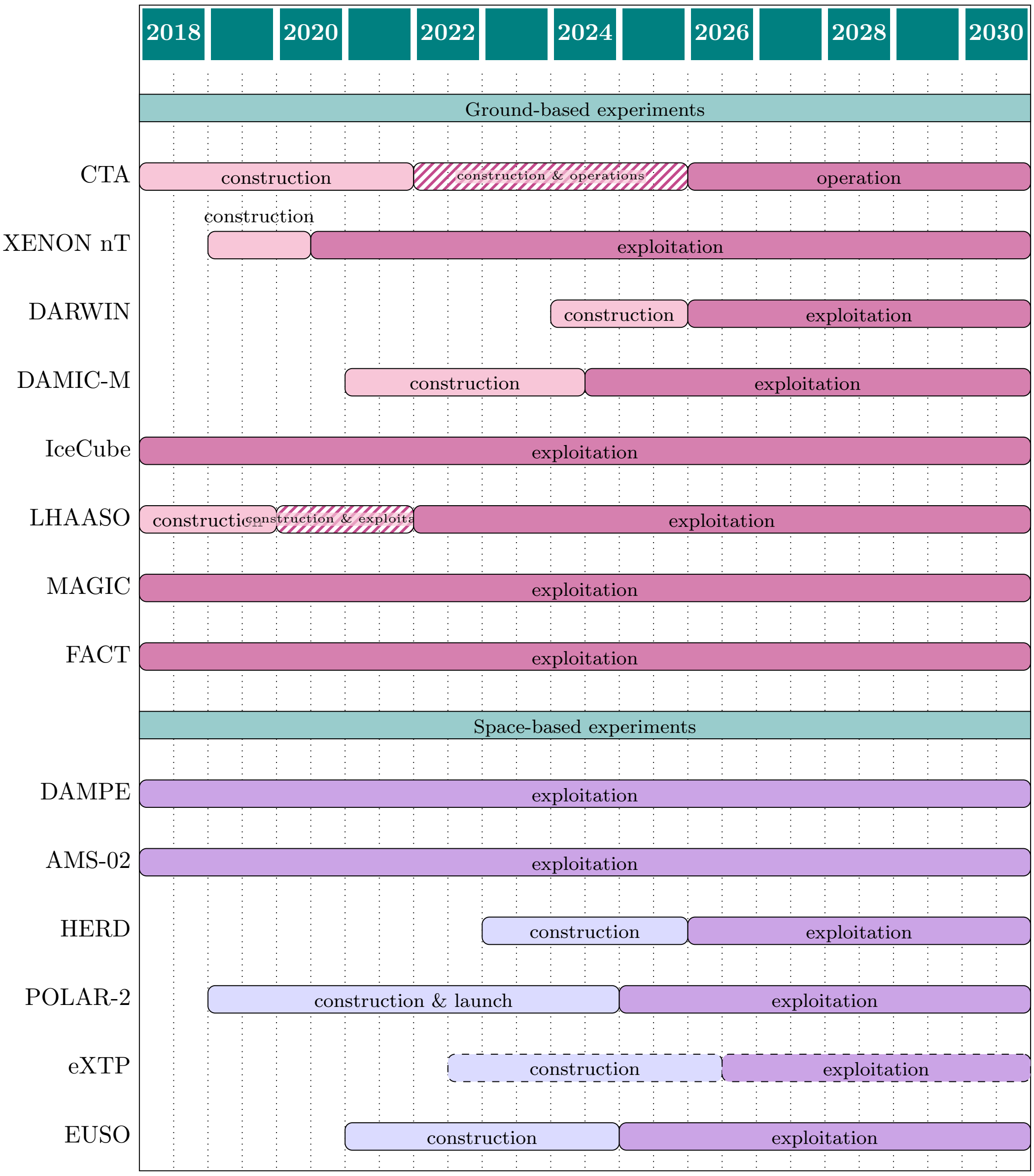

Figure 4: The timeline of major astroparticle physics projects in which Switzerland is engaged. The colour intensity and style indicates the project phases: construction [& launch for the space-based experiments] (light colours), exploitation of the facility (dark colours), and mixed construction and exploitation (line-filled).

**Dark Matter direct detection**

**Multi-messenger astrophysics**

## 12 Development of national infrastructures (2025-2028)

[Main Editor: ]

The computing needs for the High-Luminosity LHC (HL-LHC) era TG: add FCC (operating until the mid-to-late 2030s) are expected to grow by a factor of about 50 with respect to the present. Technology advance alone is expected to accommodate a factor of about five, leaving roughly an order of magnitude increase to be adsorbed in other ways. The particle physics community has started a global effort to expand its computing horizons beyond the classic customised cluster model, and has begun investing in software development to support heterogeneous architectures (mixtures of CPUs, GPUs, FGPAs, and possibly more), which are expected to help in bridging the gap to the HL-LHC computing needs.

CHART, the Swiss Centre for Accelerator Research and Technology, was founded to support the future-oriented accelerator project of the FCC at CERN, as well as the development of advanced accelerator concepts in Switzerland that go beyond existing technologies. Particle accelerators enable a broad range of research activities and applications. The CHART programme is of strategic importance not only for CERN, but also for Switzerland. Research and development efforts in CHART are addressing a number of technological topics, including high-field superconducting magnets, but also conceptual and beam-dynamics aspects for future accelerator facilities.

## 13 Swiss participation in international organisations (2025-2028)

[Main Editor: ]

## 14 Conclusion

[Main Editor: ] []

# 15 Appendix

## 15.1 Experiments

### 15.1.1 Experiments with Swiss contributions at particle accelerators (energy and intensity frontiers)

- **ATLAS:** (A Toroidal LHC ApparatuS) is the largest general-purpose particle detector at the LHC. The ATLAS Detector is 46 metres long, 25 metres in diameter, and weighs about 7'000 tonnes. The ATLAS Collaboration consists of approximately 5'000 members and about 3'000 scientific authors from 183 institutions in 38 countries. (https://atlas.cern/)
- **Beam EDM:** The Beam EDM (Electric Dipole Moment) Experiment will measure the neutron EDM using a pulsed cold neutron beam. The experiment is intended to be conducted at the future European Spallation Source.
  (https://www.lhep.unibe.ch/research/neutron_and_precision)
- **CMS:** (Compact Muon Solenoid) is one of two large general-purpose particle physics detectors at the LHC. The CMS Detector is 21 metres long, 15 metres in diameter, and weighs about 14'000 tonnes. The CMS Collaboration is formed by more than 4'000 people from 206 institutes in 47 countries.
  (https://cms.cern/)
- **CREMA:** (Charge Radius Experiments with Muonic Atoms) is an international collaboration aiming at high-accuracy measurements of the Lamb shift in muonic atoms, to be conducted using laser spectroscopy.
  (https://www.psi.ch/en/muonic-atoms).
- **FASER:** (ForwArd Search ExpeRiment at the LHC) is a small experiment 480 metres downstream of the ATLAS Detector at the CERN LHC. FASER is designed to capture decays of exotic particles produced in the very forward region, which are outside of the ATLAS Detector's acceptance. FASERnu, a FASER sub-detector, is designed to detect collider neutrinos for the first time and to study their properties. The experiment will take data during Run 3 of the LHC.
  (https://faser.web.cern.ch/)
- **GBAR:** (Gravitational Behaviour of Antimatter at Rest) is an experiment that measures the gravitational free-fall acceleration of antimatter. It operates in the Antiproton Decelerator Hall at CERN, using antiprotons slowed down by the ELENA facility. GBAR first combines the antiprotons with two antielectrons, to form antihydrogen ions with a positive charge. Using laser-cooling techniques, these ions are brought to micro-Kelvin temperatures before they are stripped of their additional antielectron, transforming them into antihydrogen atoms. These antihydrogen atoms are then allowed to fall from a height of 20 centimetres, and their annihilation at the end of the fall is recorded. GBAR was approved in May 2012 and received its first beam of antiprotons in 2018.
  (https://gbar.web.cern.ch/public/)

- **LHCb:** (Large Hadron Collider beauty) is a specialised *b*-physics experiment at the LHC, which was primarily designed to measure the parameters of CP violation in decays of bottom (beauty) and charm hadrons. Its evolving physics scope has turned LHCb into a multi-purpose experiment uniquely sensitive to the forward region of LHC collisions, studying not only proton-proton interactions, but also collisions from heavy-ion runs and from a dedicated fixed-target programme. The detector is a forward spectrometer with a length of about 20 metres. It has a polar angular coverage from 10 to 300 milliradians in the horizontal plane and 250 milliradians in the vertical plane. The LHCb Collaboration is composed of approximately 1500 people from 87 institutes, representing 17 countries.
(https://lhcb-public.web.cern.ch/)

- **MEG:** (Mu to E Gamma) was an experiment located at PSI dedicated to measuring the rate at which a muon decays into an electron and a photon; this decay mode is heavily suppressed in the SM by lepton-flavour conservation, but is enhanced in many BSM models. MEG took data from 2008 until 2013, and in doing so established the world's best limit on the decay $\mu \to e\gamma$. In order to increase the sensitivity reach by an order of magnitude, a total upgrade involving substantial changes to the experiment has been performed; this new experiment is known as MEG II.
(https://meg.web.psi.ch/)

- **Mu3e:** the Mu3e Experiment at PSI is designed to search for the lepton-flavour-violating decay of a positive muon converting into two positrons and one electron, which violates lepton-flavour conservation. Since this decay is extremely suppressed in the SM, to the order of $\mathcal{O}(10^{50})$, any measurement of this decay would be a clear sign of new physics. In order to reach its ultimate sensitivity, the Mu3e Experiment will observe more than $10^{16}$ muon decays. This enormous number of muons will be reached by using the world's most intense muon beam, located at PSI, which delivers $10^{9}$ muon-decays/s to the Mu3e detector.
(https://www.psi.ch/en/mu3e)

- **mu-Mass:** (MUoniuM lASer Spectroscopy) is an experiment at PSI which is pushing the frontier of muonium spectroscopy, with the aim of measuring the 1S-2S transition frequency of muonium, an exotic atom consisting of a positive antimuon and an electron. The mu-Mass Experiment plans to measure this transition at an unprecedented precision of 10 kHz, a 1000-fold improvement over previous measurements. This will allow for the best determination of the muon mass at the level of one part per billion.
(https://www.psi.ch/en/ltp/mu-mass)

- **muX:** The muX Experiment measures the charge radii of highly radioactive elements, in addition to measuring atomic parity violation signals in the 2S-1S transition of muonic atoms.
(https://www.psi.ch/en/ltp/mux)

- **NA64:** (North Area 64) is a fixed-target experiment using the 100 GeV electron beam of the CERN SPS fired at a fixed target, where the target is located in the CERN experimental North Area. The primary goal of NA64 is to search for light, dark bosons that are coupled to photons. The experiment started to take data in 2016, and will resume operation with an upgraded detector after the end of LS2 in 2021.
(https://na64.web.cern.ch/)

- **nEDM/n2EDM:** (search for the Neutron Electric Dipole Moment) was designed to measure the electric dipole moment of the neutron with unprecedented precision. It used the ultracold neutron source at PSI, which supplies neutrons at a comparatively slow speed. The collaboration recently published the most sensitive measurement of the neutron EDM to date based on data collected during 2015 and 2016.
(https://www.psi.ch/en/nedm)
- **piHe:** (PIonic HElium) was an experiment at PSI that used laser spectroscopy and exotic atoms: starting from Helium atoms, one electron was replaced by a pion. This combination enabled high-precision measurements of the mass and other properties of the pion.
()
- **SHiP:** (Search for Hidden Particles) is a proposed general-purpose experiment to be installed in a beam dump facility at the CERN SPS. The primary objective of SHiP is to search for hidden particles, as predicted by models of hidden sectors, which are capable of accommodating dark matter, neutrino oscillations, and the origin of the full baryon asymmetry in the Universe. The present detector design incorporates two complementary apparatuses which are capable of searching for hidden particles through both visible decays and scattering signatures involving recoiling electrons or nuclei. Moreover, the facility is ideally suited to study the interactions of tau neutrinos.
(https://ship.web.cern.ch/)

### 15.1.2 Experiments with Swiss contributions in neutrino physics

- **DUNE:** (Deep Underground Neutrino Experiment) is a leading-edge, international experiment for neutrino science and proton decay studies supported by the Long-Baseline Neutrino Facility (LBNF). DUNE will consist of two neutrino detectors positioned in the path of an intense neutrino beam. One detector will be located close to the source of the beam, at the Fermi National Accelerator Laboratory in Illinois, USA. A second detector will be deep underground, and 1300 km away from the source, at the Sanford Underground Research Laboratory in South Dakota. Two prototype far detectors are at CERN; the first started taking data in September 2018 and the second is under construction.
(https://www.dunescience.org/)
- **GERDA:** (GERmanium Detector Array) was an experiment searching for neutrinoless double-beta decay ($0\nu\beta\beta$) in $^{76}$Ge at the underground Laboratori Nazionali del Gran Sasso (LNGS) in Italy. Evidence of such decays would prove that neutrinos and antineutrinos are identical particles. The observation of $0\nu\beta\beta$, a lepton-number-conservation-violating process, is beyond the Standard Model of particle physics. Such an observation could reveal the nature of neutrinos and give hints on both the neutrino absolute mass scale and ordering.
(https://www.mpi-hd.mpg.de/gerda/)
- **Hyper-K:** (HYPER-Kamiokande) is a neutrino observatory being constructed at the site of the Kamioka Observatory, near Kamioka, Japan. It will be the next generation of large-scale water Cherenkov detector, consisting of a tank with a billion litres of ultra-pure water. The first data-taking period is planned for 2027.
(https://www.hyperk.org/)

- **K2K:** (KEK to Kamioka) was a neutrino experiment that ran from 1999 to 2004 in Japan. It was the first experiment that measured neutrino oscillations in a neutrino beam.
  (https://neutrino.kek.jp/)
- **LEGEND:** (Large Enriched Germanium Experiment for Neutrinoless double-beta Decay) is the next-generation experiment searching for neutrinoless double-beta decay ($0\nu\beta\beta$) in $^{76}$Ge. In the first phase of LEGEND, approximately 200 kg of enriched $^{76}$Ge detectors will be operated. LEGEND-200 will be located at LNGS, and will largely reuse the existing GERDA infrastructure, including some of the germanium detectors, the outer water tank, and the inner cryostat. The first data-taking period is planned for mid-2021.
  (http://legend-exp.org/)
- **MicroBooNE:** (Micro BOOster Neutrino Experiment) is a large neutrino experiment based at the Fermilab Booster neutrino beamline. The experiment first started to take data in 2015. It uses a large 170-tonne liquid argon time projection chamber for neutrino detection.
  (https://microboone.fnal.gov/)
- **OPERA:** (Oscillation Project with Emulsion tRacking Apparatus) was a neutrino experiment at LNGS. It used the CERN neutrino beam and was optimised for detecting tau neutrinos from muon neutrino oscillations. The data-taking period ended in 2012.
  (http://operaweb.lngs.infn.it/)
- **T2K:** (Tokai to Kamioka) is a neutrino experiment in Japan studying accelerator neutrino oscillations. T2K was the first experiment which observed the appearance of electron neutrinos in a a beam of muon neutrinos. It uses an intense beam of muon neutrinos produced in the J-PARC facility (Japan Proton Accelerator Research Complex) in Tokai; neutrinos are then detected at the Super-K far detector located 295 km away.
  (https://t2k-experiment.org/)

Other neutrino physics experiments are described in Sect. 15.1.4.

### 15.1.3 Experiments with Swiss contributions in astroparticle physics from space

- **AMS-02:** (Alpha Magnetic Spectrometer) is installed on the international space station (ISS) and is designed to detect particles and antiparticles. It has been taking data for more than nine years and has measured cosmic ray nuclei, electron, positron, and antiproton fluxes in great detail in the GeV to TeV range.
  (https://ams02.space/de)
- **DAMPE:** (DArk Matter Particle Explorer) is a space telescope used for the detection of high-energy $\gamma$-rays, electrons, and cosmic ray ions, as well as for the search for dark matter. It was designed to look for signals of dark matter decays and for direct cosmic ray measurements in the 1 TeV to 100 TeV range. DAMPE was launched by the Chinese Space Agency in 2015.
  (http://dpnc.unige.ch/dampe/)
- **EUSO:** (Extreme Universe Space Observatory) is a 2.5-metre-aperture wide-field-of-view fluorescence telescope, intended for the detection of traces of Ultra-High-Energy Cosmic Rays (UHECR) in the atmosphere. It is

planned for installation in the Russian segment of the ISS around 2024. EUSO's goal is to add an ultra-high-energy channel to the multi-messenger astronomy programme by building the first all-sky high-statistics map of the arrival directions of UHECR.
(http://jem-euso.roma2.infn.it/)

- **eXTP:** (Enhanced X-ray Timing and Polarimetry) is designed to study the state of matter under extreme conditions of density, gravity, and magnetic fields. The primary goals of the experiment are the determination of the equation of state of matter at supranuclear density, the measurement of QED effects in highly magnetised stars, and the study of accretion in the strong-field regime of gravity. The main targets include isolated and binary neutron stars, strong magnetic field systems like magnetars, and stellar-mass and supermassive black holes. The mission carries a unique and unprecedented suite of scientific instruments enabling, for the first time, simultaneous spectral-timing-polarimetry studies of cosmic sources in the energy range from 0.5 to 30 keV and beyond. The mission is expected to be adopted in 2021 and is planned to be launched in 2027.
(https://www.isdc.unige.ch/extp/)
- **HERD:** the (High-Energy cosmic Radiation Detection) facility is a flagship science mission planned to be launched around 2025 and to be installed on board China's Space Station. HERD will extend direct cosmic ray measurements to the PeV regime, allowing for connections to ground-based observations. The main science objectives are the detection of dark matter particles, the study of cosmic ray flux and composition, and high-energy $\gamma$-ray observations.
(http://herd.ihep.ac.cn/)
- **INTEGRAL:** (INTErnational Gamma-Ray Astrophysics Laboratory) was the first space observatory that can simultaneously observe objects in $\gamma$-rays, X-rays, and visible light. It was an ESA Horizon 2000 project, and was launched in 2002. The ground station collecting its data (the Integral Science Data Centre, ISDC) is located in Versoix, near Genève. INTEGRAL is the most sensitive $\gamma$-ray observatory ever launched, and it has led to many discoveries on black holes, active galactic nuclei, $\gamma$-ray bursts, and more.
(https://sci.esa.int/web/integral/)
- **POLAR-2:** (gamma-ray burst POLARimetry on the China space station) is a compact detector for soft $\gamma$-rays with energies below 1 MeV. Its goal is to measure the polarisation of photons from $\gamma$-ray bursts, thereby discriminating between different physics models which have been put forward to explain the mechanism leading to these single most luminous events in the Universe. POLAR-2 is now being constructed in Genève and is planned to be put on the Chinese space station in 2024.
(https://www.astro.unige.ch/polar-2/)

### 15.1.4 Ground-based experiments with Swiss contributions in neutrino and astroparticle physics

- **CTA:** (Cherenkov Telescope Array) is the next-generation array of Imaging Atmospheric Cherenkov Telescopes, which is now entering the implementation phase and expected to be completed in 2025. The CTA Consortium has defined three Key Science Cases on the themes of: understanding the origin and the role of relativistic cosmic particles; probing extreme environments, such as supernova, neutron stars, black holes, and $\gamma$-ray bursts; and

exploring frontiers in physics, such as the nature of dark matter, axions and their interplay with magnetic fields, and quantum gravitational effects in photon propagation. The CTAO (CTA Observatory) will be composed of two arrays with more than 100 telescopes of three different mirror sizes to cover an energy range from about 20 GeV to 300 TeV. One is located in the Northern hemisphere (La Palma), and one in the Southern hemisphere (ESO site of Paranal in Chile), both at about 2000 m above sea level. The three different telescope mirror diameters that will be deployed are 24 metres (LSTs, Large-Size Telescopes), 12 metres (MSTs, Middle-Size Telescopes), and 4 metres (SSTs, Small-Size Telescopes). CTA will be an international open-access observatory governed by the CTAO ERIC, which will become operational in mid-2021.
(https://www.cta-observatory.org/)

- **FACT :** (First g-Apd Cherenkov Telescope) is a small 4-metre Cherenkov telescope pioneering the usage of silicon photomultipliers (also called G-APD: Geiger-mode Avalanche PhotoDiodes) and performing the first unbiased monitoring of variable extragalactic objects at energies above 1 TeV. It is located on the island of La Palma, situated between MAGIC and the first LST of CTA; FACT also supports the commissioning of the first LST.
(https://www.isdc.unige.ch/fact/)

- **IceCube:** is a 1 cubic kilometre instrumented volume of ice, between 1.5 to 2.5 kilometres below the South Pole surface, which was designed to detect high-energy neutrinos. The surface facility detects the electromagnetic component of cosmic ray showers, thus measuring the cosmic ray composition. The in-ice detector consists of 5'600 photomultipliers attached to 86 strings. These photomultipliers detect Cherenkov light produced by charged particles induced through neutrino interactions.
IceCube is undergoing upgrades in two phases. In a first Phase 1, the size of its dense core detector (Precision Icecube Next Generation Upgrade, PINGU) is increased with an additional 7 strings, holding 700 new and enhanced optical modules. This upgrade lowers the energy threshold for neutrino detection down to 1 GeV. The next IceCube upgrade (IceCube Gen-2) will add photosensor-strings to increase the instrumented ice volume by about a factor of 10, extend the surface veto array, and add a radio-detector array exploiting the Askaryan effect to focus on signals induced by high-energy cosmogenic neutrinos.
(https://icecube.wisc.edu/)

- **LHAASO:** (Large High Altitude Air Shower Observatory) is located 4'400 metres above sea level in the mountains of the Sichuan province of China. It is a new-generation Extensive Air Shower (EAS) array for cosmic ray detection in the energy range from $10^{11}$ to $10^{18}$ eV, and for $\gamma$-rays above 1 TeV. The observatory is currently under construction; it is currently 50% in place, and is expected to be completed by the end of 2021. The data-taking activities started in 2019 and the analysis of the data is ongoing. LHAASO is expected to be the most sensitive project to the open questions in Galactic cosmic ray physics, with the unique ability to detect cosmic ray sources and heavy dark matter in the galactic halo. With its large field of view and almost 100% duty cycle, LHAASO has a unique potential to detect the PeVatron(s) in the Galaxy, which also contribute to the cosmic neutrino flux as detected by IceCube .
(http://english.ihep.cas.cn/lhaaso/)

- **MAGIC :** (Major Atmospheric Gamma-Imaging Cherenkov telescopes) is a system of two imaging atmospheric

Cherenkov telescopes, situated at the Roque de los Muchachos Observatory on the island of La Palma, at about 2200 metres above sea level. MAGIC detects particle showers released by $\gamma$-rays through their Cherenkov radiation. The telescopes have two 17 metre-diameter reflectors, now surpassed in size by the first LST of CTA of 24 metres and by the H.E.S.S. II telescope. Together with H.E.S.S. and VERITAS, MAGIC has opened the ground-based $\gamma$-ray field to Big Science, covering a range from the observation of the pulsation of pulsars above 100 GeV to the extension of the $\gamma$-ray burst spectrum up to above 300 GeV.
(https://magic.mpp.mpg.de/)

### 15.1.5 Experiments with Swiss contributions for direct dark matter detection

- **DAMIC and DAMIC-SNOLAB:** (DArk Matter In Ccds) is an experiment, located at SNOLAB in Canada that is based on the idea that DM is a relic from an entire dark or hidden sector; this hidden sector is expected to contain a hidden photon, which then interacts very weakly with the 'visible' sector representing ordinary matter. DAMIC has sensitivity to many orders of magnitude in DM mass for various assumptions on how the hidden photon relates to the dark matter and the formation of dark matter in the early Universe. The subsequent DAMIC-SNOLAB Experiment increased the mass, decreased backgrounds, and concluded in 2019, after having producing several world-leading results extending beyond the standard searches for WIMP dark matter into the domain of hidden-photon DM.
(https://www.snolab.ca/science/experiments/damic)

- **DAMIC-M and OSCURA:** DAMIC-M is an approved and funded international experiment, to be located at the Modane Underground laboratory in France, that is set to begin in 2024. It has a mass ten times larger, a background rate ten times smaller, and an energy threshold ten times lower than DAMIC-SNOLAB. Its ability to detect single ionisation electrons has been made possible through the use of a novel 'skipper' electronics readout. DAMIC-M will probe ten orders of magnitude in DM mass over a range of theoretical scenarios. Studies have also been undertaken for a new experiment to be named OSCURA; this new experiment would be ten times bigger than DAMIC-M and would have an even lower background rate and energy threshold.
(https://damic.uchicago.edu/index.php, https://astro.fnal.gov/science/dark-matter/oscura/)

- **DARWIN:** (DARk matter WImp search with liquid xenoN) is the ultimate DM detector based on liquid xenon, which will explore the full WIMP parameter space (using an exposure of 200 tonne-years) above the so-called 'neutrino floor' where neutrinos will start to dominate the signal. The project is presently in the R&D and design phase, with a CDR planned for 2022 (an invitation was issued by LNGS, after a successful LoI submission and review), and a TDR in 2024. At the earliest, data-taking activities would start in 2026 or 2027. DARWIN will have a similar reach to dedicated future neutrinoless double-beta decay experiments through studies of the decay of $^{136}$Xe, and will enable high-statistics observations of *pp* neutrinos from the Sun. It will also search for solar axions, galactic ALPs and dark photons, a magnetic moment of the neutrino, and measure coherent-elastic neutrino-nucleus scattering from $^{8}$B solar neutrinos and eventually from supernovae.
(https://darwin.physik.uzh.ch/index.html)

- **XENON1T:** The XENON1T Experiment was a 3500kg liquid xenon detector designed to search for dark matter. It acquired data at LNGS from 2016 to 2018, and set the world's best limits on the WIMP-nucleon

elastic scattering cross-section for DM masses above 85 MeV, as well as on the DM-electron scattering cross-section for masses above 30 MeV.
(http://www.xenon1t.org/).

- **XENONnT:** The XENONnT Experiment was installed at LNGS in early 2020, and is currently under commissioning. With a fiducial liquid xenon mass of 4 tonnes and an exposure of 20 tonne-years, the expected sensitivity to spin-independent interactions will reach a cross-section of $1.4 \times 10^{-48}\mathrm{cm}^2$ for a 50 GeV/$c^2$ mass WIMP, which is a factor of 10 improvement compared to XENON1T. XENONnT will also search for the neutrinoless double-beta decay of $^{136}$Xe, and will be able to probe the excess of events observed by XENON1T in the 1.7 keV region within a few months of the start of data-taking activities; it will additionally be able to distinguish between this excess as originating from a tritium component or a solar axion signal.
(http://www.xenonnt.org/).

## 15.2 Links

- **ABB:** https://new.abb.com/ch
- **Advanced Accelerator Technologies AG (AAT):** https://aa-t.ch
- **AMPEGON Power Electronics:** https://ampegon.com
- **AMS-02:** https://ams02.space/de
- **Anaxam:** https://www.anaxam.ch
- **APPEG:** https://appec.org
- **Arktis Radiation Detectors Ltd:** https://www.arktis-detectors.com
- **Arktis detectors:** https://www.arktis-detectors.com/security-radiation-portal-monitors/
- **ASCOM Systec AG:** https://www.ascom.com
- **ATLAS:** https://atlas.cern/
- **ATTRACT:** https://attract-eu.com
- **BAS:** https://www.basf.com/ch/de/who-we-are/BASF-in-Switzerland/group-companies/BASF-Schweiz-AG.html
- **Beam EDM:** https://www.lhep.unibe.ch/research/neutron_and_precision
- **Bolleter Composites AG:** https://bolletercomposites.ch
- **CAEN SpA:** CAEN SpA
- **CERN Open Data Policy:** https://cds.cern.ch/record/2745133/files/CERN-OPEN-2020-013.pdf
- **CERN Open Data Portal:** http://opendata.cern.ch/
- **CERN's Science Gateway project:** https://sciencegateway.cern/

- **CERN summer student programme:** https://home.cern/summer-student-programme
- **CERN Teacher programme:**https://teacher-programmes.web.cern.ch/
- **CHIPP worshops:** https://chipp.ch/en/meetings_documentation/strategic_workshops
- **CMS:** https://cms.cern/
- **Cosylab:** https://swiss-aerospace-cluster.ch/portfolio-item/cosylab/
- **Createch AG** https://www.createch.ch
- **CREMA:** https://www.psi.ch/en/muonic-atoms
- **CTA:** https://www.cta-observatory.org/
- **DAES:** https://daes.pro/en/
- **Daetwyler Industries:** https://www.daetwyler.com/en/
- **DAMIC:** https://www.snolab.ca/science/experiments/damic
- **DAMIC-M:** https://damic.uchicago.edu/
- **DAMPE:** http://dpnc.unige.ch/dampe/
- **DARWIN:** https://darwin.physik.uzh.ch/index.html
- **Dectris** https://www.dectris.com
- **D-Pace:** https://www.d-pace.com
- **DRS4:** https://www.psi.ch/en/drs
- **DUNE:** https://www.dunescience.org/
- **Energiebericht:** https://www.sbfi.admin.ch/sbfi/en/home/services/publications/data-base-publications/report-energy-research.html
- **e-Péron:** https://eperon.omp.eu/
- **EPPCN:** https://espace.cern.ch/EPPCN-site
- **EPS:** www.eps.org
- **Espace Ballon exhibition:** https://www.chateau-doex.ch/de/P395/ballonraum-espace-ballon
- **ESPROS photonics corporation - EPC:** https://www.espros.com
- **Eulitha:** https://www.eulitha.com
- **EUSO:** http://jem-euso.roma2.infn.it/
- **eXTP:** https://www.isdc.unige.ch/extp/

- **FACT:** https://www.isdc.unige.ch/fact/
- **FASER:** https://faser.web.cern.ch/
- **Ferrovac GmbH:** https://www.ferrovac.com
- **FRM-2:** https://www.frm2.tum.de/en/home
- **GBAR:** https://gbar.web.cern.ch/public/
- **GE-General Electric:** https://www.s-ge.com/en/company/general-electric-switzerland-gmbh
- **GERDA:** https://www.mpi-hd.mpg.de/gerda/
- **GratXRay:** https://www.gratxray.com
- **HABA:** https://www.haba.ch/en/
- **Hamamatsu:** https://www.hamamatsu.com/jp/en/index.html
- **HERD:** http://herd.ihep.ac.cn/
- **HEV:** https://hev.web.cern.ch
- **HSSIP:** https://hssip.web.cern.ch/
- **HyperKamiokande:** https://www.hyperk.org/
- **IceCube:** https://icecube.wisc.edu/
- **INTEGRAL:** https://sci.esa.int/web/integral/
- **International Particle Physics Masterclass:** https://physicsmasterclasses.org/
- **iLab:** https://www.psi.ch/ilab/
- **IngCH:** https://ingch.ch
- **InterAx:** https://interaxbiotech.com
- **IPPOG:** http://ippog.org/
- **K2K:** https://neutrino.kek.jp/
- **Kabelwerke Brugg AG:** https://bruggcables.com
- **KM3NeT:** https://www.km3net.org
- **LEGEND:** http://legend-exp.org/
- **LHAASO:** http://english.ihep.cas.cn/lhaaso/
- **LHCb:** https://lhcb-public.web.cern.ch/
- **MAGIC :** https://magic.mpp.mpg.de/

- **MEDELEC SA:** https://resonetics.com/innovations/medelec-swiss-precision-tubing/
- **MEG:** https://meg.web.psi.ch/
- **MicroBooNE:** https://microboone.fnal.gov/
- **Mu3e:** https://www.psi.ch/en/mu3e
- **muCool:** https://edm.ethz.ch/research/muoncooling.html
- **mu-Mass:** https://www.psi.ch/en/ltp/mu-mass
- **muX:** https://www.psi.ch/en/ltp/mux
- **NA64:** https://na64.web.cern.ch/
- **Nacht der Forschung:** https://www.nachtderforschung.unibe.ch/
- **nEDM:** https://www.psi.ch/en/nedm
- **Nestlé:** https://www.nestle.ch
- **Netzwerk Teilchenwelt:** https//www.teilchenwelt.de/
- **Neutrino Platform:** https://home.cern/science/experiments/cern-neutrino-platform
- **Nexans:** https://www.nexans.ch/
- **Novartis:** https://www.novartis.com
- **Nuits de la Science:** http://www.ville-ge.ch/lanuitdelascience/
- **OPERA:** http://operaweb.lngs.infn.it/
- **OSCURA:** https://astro.fnal.gov/science/dark-matter/oscura/
- **Physioscope:** https://dqmp.unige.ch/physics-for-all/physiscope/
- **POLAR-2:** https://www.astro.unige.ch/polar-2/
- **Positrigo AG:** https://www.positrigo.com
- **RADEC GmbH:** https://www.radec.ch
- **Roche:** https://www.roche.com/careers/our-locations/europe/switzerland.htm
- **SATW:** https://www.satw.ch
- **Science Lab:** http://www.sciencelab.uzh.ch
- **Scientifica:** https://www.scientifica.ch
- **SCNAT:** https://naturalsciences.ch
- **SCS-Super Computing Systems:** https://www.scs.ch

- **SE2S GmbH:** http://www.se2s.ch
- **SENSIRION:** https://www.sensirion.com
- **SHiP:** https://ship.web.cern.ch/
- **Sichuan Tianle Photonics Co.:** https://sctlxd.en.china.cn
- **Spalinger Präzisionsmechanik GmbH:** https://www.spalinger.info
- **SURCOTEC:** http://surcotec.ch/en/surcotec-2/
- **SWAN Isotopen AG:** https://www.swanisotopen.ch/en/
- **SwissNeutronics:**https://www.swissneutronics.ch
- **Swiss Physical Society (SPS):** www.sps.ch
- **Swiss Roadmap for Research Infrastructures 2019:** https://www.sbfi.admin.ch/sbfi/en/home/research-and-innovation/research-and-innovation-in-switzerland/swiss-roadmap-for-research-infrastructures.html
- **Swissuniversity:** https://www.swissuniversities.ch
- **T2K:** https://t2k-experiment.org/
- **TecDays:** https://www.satw.ch/en/tecdays/
- **Technology and IT weeks:** https://ingch.ch/en/angebote/technik-und-informatikwochen
- **Thin Film Physics:** http://www.tfpag.ch
- **Transmutex SA:** https://www.transmutex.com
- **UNSOLVeD:** https://www.un-solved.com
- **Varian:** https://www.varian.com/en-ch
- **YouTube channel** 'Das verflixte Higgs'**:** www.youtube.com/user/verflixteshiggs
- **YouTube video** 'How particle-physics works: hope and worries on the $B$-physics anomalies'**:** https://www.youtube.com/watch?v=9dLyTS0Xscw
- **XENON1T:** http://www.xenon1t.org/
- **XENONnT:** http://www.xenonnt.org/

# Acronyms

**ACHIP** Accelerator on a Chip.

**AD** Antiproton Deaccelerator.

**Ad S** Anti-de Sitter space time.

**ADS** Accelerator Driven Subcritical.

**ALP** Axion Like Particle.

**AMS-02** Alpha Magnetic Spectrometer (on the ISS).

**ANITA** Antarctic Impulsive Transient Antenna.

**ANTARES** Astronomy with a Neutrino Telescope and Abyss environmental RESearch.

**APPEC** Astroparticle Physics European Consortium.

**ARIES** Accelerator Research and Innovation for European Science and Society.

**ASIC** Application-Specific Integrated Circuits.

**ATLAS** A Toroidal LHC Apparatus (LHC Experiment).

**BASE** Baryon Antibaryon Symmetry Experiment.

**BBH** Binary Black Hole.

**BDF** Beam Dump Facility.

**BH** Black Hole.

**BNS** Binary Neutron Star.

**BSM** Beyond the Standard Model.

**CCD** Charge-Coupled Device.

**CDR** Critical Design Review.

**CE** Cosmic Explorer.

**CEPC** Circular Electron Positron Collider in China.

**CERN** European Organisation for Nuclear Research.

**CFT** Conformal Field Theory.

**CHAPS** College of Helvetic Astronomy Professors.

**CHART** Swiss Accelerator Research and Technology.

**CHIPP** Swiss Institute of Particle Physics.

**CHRISP** Swiss Research Infrastructure for Particle Physics.

**cLFV** Charged Lepton Flavour Violating reaction.

**CLIC** Compact Linear Collider.

**CMB** Cosmic Microwave Background.

**CMS** Compact Muon Solenoid (LHC Experiment).

**CMSA** Chinese Manned Space Agency.

**CP** Charge-conjugation and Parity symmetry.

**CPT** Charge-conjugation Parity and Time symmetry.

**CPU** Central Processing Unit.

**CREMA** Charge Radius Experiments with Muonic Atoms.

**CSCS** Swiss National Supercomputing Centre.

**CTA** Cherenkov Telescope Array.

**CTAO** CTA Observatory.

**DAMIC** Dark matter in CCDs (experiment at SNOLAB).

**DAMIC-M** Dark matter in CCDs experiment at Modane (experiment at Laboratoire Souterrain de Modane, France).

**DAMPE** Dark Matter Particle Explorer (space telescope).

**DAQ** Data Acquisition.

**DARWIN** Dark Matter Wimp Search with Liquid Xenon (planned experiment at LNGS, Italy).

**DM** Dark Matter.

**DS** Dark Sector.

**DUNE** Deep Underground Neutrino Experiment.

**EAS** Extensive Air Showers.

**EC** European Commission.

**ECFA** European Committee for Future Accelerators.

**EDM** Electron Electric Dipole Moment.

**EFT** Effective Field Theories.

**ELENA** Extra Low Energy Antiproton ring.

**EPFL** École Polytechnique Fédérale de Lausanne.

**EPPCN** European Particle Physics Communication Network.

**EPS-AG** Accelerator Group of the European Physical Society.

**ERC** European Research Council.

**ERIC** European Research Infrastructure Consortium.

**ESA** European Space Agency.

**ESFRI** European Strategy Forum on Research Infrastructures.

**ESO** European Southern Observatory.

**ESPP** European Strategy for Particle Physics.

**ESRF** European Synchrotron Radiation Facility.

**ESS** European Spallation Source.

**ET** Einstein Telescope.

**ETHZ** Eidgenössisch Techniche Hochschule Zürich.

**EUSO** Extreme Universe Space Observatory.

**eV** Electron Volts.

**eXTP** Enhanced X-ray Timing and Polarimetry.

**FACT** First g-Apd Cherenkov Telescope.

**FASER** Forward Search Experiment at the LHC.

**FCC** Future Circular Collider at CERN.

**FCC-ee** Future Circular Collider, colliding electrons and positrons.

**FCC-ep** Future Circular Collider, colliding electrons and protons.

**FCC-hh** Future Circular Collider, colliding hadrons.

**FLARE** Funding Large international Research projects.

**FPF** Forward Physics Facility.

**FPGA** Field-Programmable Gate Array.

**G-APD** Geiger Mode Avalanche Photodiodes.

**GBAR** Gravitational Behaviour of Antimatter at Rest.

**GERDA** Germanium Detector Array (Experiment at LNGS).

**GPU** Graphics Processing Unit.

**GRB** Gamma Ray Burst.

**GW** Gravitational Wave.

**H.E.S.S.** High Energy Stereoscopic System (telescope in Namibia).

**HEP** High-Energy Physics.

**HERD** High-Energy Cosmic Radiation Detection (on board of China's Space Station).

**HEV** High Energy Ventilator.

**HIMB** High-Intensity Muon Beam at PSI.

**HIPA** High-Intensity Accelerator complex at PSI.

**HL** High Luminosity.

**HL-LHC** High-Luminosity LHC.

**HNL** Heavy Neutral Leptons.

**HPC** High-Performance Computer.

**HSF** HEP Software Foundation.

**HSSIP** High-School Students Internship Programme.

**HTS** High-Temperature Superconductors.

**Hyper-K** HYPER-Kamiokande (Neutrino observatory near Kamioka, Japan).

**ICFA** International Committee for Future Accelerators.

**ILC** International Linear Collider.

**ILL** Institut Laue-Langevin in Grenoble.

**INFN** Istituto Nazionale di Fisica Nucleare.

**INTEGRAL** International Gamma-Ray Astrophysics Laboratory.

**IPAC** International Particle Accelerator Conference.

**IPPOG** International Particle Physics Outreach Group.

**IR** Infrared.

**ISFEE** Inertial Sensor Front End Electronics.

**ISS** International Space Station.

**J-PARC** Japan Proton Accelerator Research Complex.

**JUNO** Jiangmen Underground Neutrino Observatory.

**K2K** KEK to Kamioka (neutrino experiment in Japan).
**KEKB** Electron Positron collider (at KEK, Japan).

**LANL** Los Alamos National Laboratory.
**LBNF** Long-Baseline Neutrino Facility.
**LBNL** Lawrence Berkeley National Laboratory.
**LDM** Light Dark Matter.
**LEGEND** Large Enriched Germanium Experiment for Neutrinoless Double-Beta Decay (at LNGS, Italy).
**LHAASO** Large High Altitude Air Shower Observatory (in Sichuan province, China).
**LHC** Large Hadron Collider (at CERN).
**LHCb** Large Hadron Collider beauty (LHC experiment).
**LHEP** Laboratory for High-Energy Physics.
**LIGO** Laser Interferometer Gravitational-Wave Observatory.
**LINAC** Linear Accelerator.
**LISA** Laser Interferometer Space Antenna.
**LNGS** Laboratori Nazionali del Gran Sasso.
**LS2(LS3)** Long Shutdown 2(3) (of the LHC).
**LSS** Cosmological Large-Scale Structure.
**LSST** Vera C. Rubin Observatory Large Synoptic Survey Telescope.
**LST** Large-Size Telescope.
**LXe** Liquid Xenon.

**MAGIC** Major Atmospheric Gamma Imaging Cherenkov Telescopes (La Palma).
**MEG** $\mu \to e\gamma$ (Experiment at PSI).
**MICE** Muon Ionisation Cooling Experiment.
**MicroBooNE** Micro Booster Neutrino Experiment (experiment at Fermilab, USA).
**ML** Machine Learning.
**MST** Medium-Size Telescope.

**mu-Mass** Muonium Laser Spectroscopy (Experiment at PSI).

**Mu3e** $\mu \rightarrow eee$ (Experiment at PSI).

**muX** muX (Experiment at PSI).

**N$^3$LO** Next to next to next to leading order.

**NA64** North Area 64 (experiment at CERN SPS).

**NASA** National Aeronautics and Space Administration.

**ND280** Near Detector of the T2K experiment.

**nEDM/n2EDM** Search for the Neutron Electric Dipole Moment (Experiment at PSI).

**NIST** National Institute of Standards and Technology (USA).

**NLO** Next to leading order.

**NNLO** Next to next to leading order.

**NS** Neutron Star.

**NSF** National Science Foundation.

**NSSC** National Space Science Center.

**NuPECC** Nuclear Physics European Collaboration Committee.

**OPERA** Oscillation Project with Emulsion Tracking Apparatus (neutrino experiment at LNGS, Italy).

**OSCURA** Observatory of Skipper CCDs Unveiling Recoiling Atoms.

**PAN** Penetrating particle ANalyzer.

**PET** Positron Emission Tomography.

**PeV** Peta Electron Volts.

**piHe** Pionic Helium.

**PINGU** Precision IceCube Next Generation Upgrade (dense inner detector of IceCube).

**PMNS** Pontecorvo-Maki-Nakagawa-Sakata.

**POLAR-2** Detector for Gamma Ray Bursts Photon Polarisation Measurements (on the Chinese space station).

**ppm** parts per million.

**PRODEX** Programme de Développement d'Expériences scientifiques.

**PSI** Paul Scherrer Institute.

**QCD** Quantum Chromodynamics.

**QED** Quantum Electrodynamics.

**QFT** Quantum Field Theory.

**R&D** Research & Development.

**RAL** Rutherford Appleton Laboratory (near Oxfordshire, GB).

**RF** Radio Frequency.

**RI** Research Infrastructure.

**RRB** Resource Review Board.

**SATW** Swiss Academy of Engineering Sciences.

**SBN** Short Baseline Near detector.

**SciFi** Scintillating Fibre.

**SCNAT** Swiss Academy of Natural Sciences.

**SENSEI** Sub-Electron-Noise SKIPPER-CCD Experimental Instrument.

**SERI** State Secretariat for Education, Research, and Innovation.

**SESAME** Synchrotron-light for Experimental Science and Applications in the Middle East.

**SHiP** Search for Hidden Particles (proposed experiment).

**SKA** Square Kilometre Array.

**SLS** Swiss Light Source.

**SM** Standard Model.

**SMUS** Swiss Muon Source.

**SND** Scattering and Neutrino Detector.

**SNOLAB** Underground Science Laboratory (near Sudbury, Ontario, Canada).

**SNS** Spallation Neutron Source.

**SNSF** Swiss National Science Foundation.

**SOC** System on Chip.

**SPS** Super Proton Synchrotron.

**SSO** Swiss Space Office.

**SST** Small-Size Telescope.

**STEM** Science, Technology, Engineering, and Mathematics.

**STK** Silicon-Tungsten Tracker.

**SUSY** Supersymmetry.

**SWISSFEL** Swiss Free Electron Laser.

**T2K** Tokai to Kamioka (neutrino experiment in Japan).

**TDR** Technical Design Report.

**TeV** Tera Electron Volts.

**TPC** Time Projection Chamber.

**TRIUMF** Canada's National Laboratory for Particle and Nuclear Physics (formerly an acronym: Tri-University Meson Facility).

**UCN** UltraCold Neutrons.

**UHECR** Ultra-High-Energy Cosmic Rays.

**UV** Ultraviolet.

**VERITAS** Very Energetic Radiation Imaging Telescope Array System.

**WIMP** Weakly Interacting Massive Particle.

**WLCG** Worldwide LHC Computing Grid.

**XFEL** X-ray Free Electron Laser.

# 16 References

[1] *2020 Update of the European Strategy for Particle Physics*. Geneva: CERN Council, 2020.

[2] APPEC, “European astroparticle physics strategy 2017-2026.” APPEC weblink , August 2017.

[3] NuPECC, “Nupecc long range plan 2017 perspectives.” NuPECC weblink , 2017.