National Submission from the Swedish Particle Physics Community to the European Strategy for Particle Physics Update 2018-2020

Abstract

A national submission from the particle physics community (experiment and theory) in Sweden is given. The status and plans of the community are described and are used to inform a set of recommendations to the Strategy Update. In addition to recommendations of direct relevance to ongoing and planned Swedish research, the community's views on proposed major facilities and the general direction of the field are also provided.

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Swedish National Submission to the Strategy Update for European Particle Physics

Overview of document

Elementary particle physics (PP) in Sweden encompasses a range of high-profile activities addressing fundamental open questions in modern physics. This document is a national submission to the update of the European Strategy of Particle Physics (ESPP) and summarises the status and plans of the community and their positions on proposed facilities. The document is primarily concerned with those core research areas which correspond directly to those covered in the ESPP though it also describes, where appropriate, valuable cross-disciplinary activities in nuclear physics and astroparticle physics.

This document is organised as follows. First an executive summary of the document is given in Section 1. This outlines briefly the activities of the community, priorities and its recommendations for the strategy update. The main body of this document then starts with a description of the Swedish PP community (Section 2), followed by an overview of the field and introduces experiments with Swedish participation (Section 3). Section 4 details the activities and goals of the community: LHC experiments, experiments at the intensity frontier, dedicated neutrino experiments, direct dark matter detection, instrumentation and computing, and accelerator development. Section 5 describes the community's position on relevant PP projects of global significance, as well as expressing recommendations for the CERN's and the field's future direction. Here and in the following, the term *community* is used to refer to the Swedish PP community. For further details on the activities described in this document, the reader is invited to consult the individual submissions made to the ESPP update for these activities.

1. Executive Summary

1.1 Particle Physics in Sweden

The Swedish PP community comprises researchers and engineers from Chalmers University of Technology, KTH Royal Institute of Technology, Lund University, Stockholm University and Uppsala University. Experimental research by Swedish institutes largely takes place in big international collaborations such as the ATLAS and ALICE experiments at the CERN Large Hadron Collider (LHC) and the IceCube neutrino observatory. Furthermore, groups are pursuing smaller-scale and planning longer-term PP experiments to take place at CERN and the European Spallation Source (ESS). There are also several research groups developing PP theory, notably in the areas of QCD and Monte Carlo generators, new physics beyond the Standard Model, and neutrino physics. This balance of activities is in keeping with the history of particle physics which has seen progress achieved by a symbiosis of experiments at the high energy and intensity frontiers together with theory development.

1.2 The high energy frontier at the LHC

Experiments at the Large Hadron Collider (LHC) probe the high-energy frontier by analyzing data from proton-proton collisions at 13 TeV centre-of-mass energy. Exploitation and development of experiments at the LHC is the primary research interest of the community, now and in the future. A core activity of the community is the ATLAS experiment. Together with the CMS experiment, ATLAS has discovered the Higgs boson which led to Higgs and Englert receiving the 2013 Nobel Prize for Physics. ATLAS has also established stringent limits on scenarios of new physics. The LHC so far only delivered around 5% of the total data-set expected over its lifetime, which, following a series of upgrades concluding with high-luminosity LHC (HL-LHC) running, will end in ~2035. Swedish groups will continue to develop detector upgrades and use the recorded data for measurements and searches over the lifetime of the ATLAS experiment. Another key activity is the ALICE experiment, which is the only dedicated experiment at the LHC for the study of the quark-gluon plasma (QGP). The LHC is the world-leading facility for studying the QGP now and in the period covered by the strategy update. The LHC and ALICE are currently being upgraded for Run 3 and 4. These upgrades will increase the sensitivity for most measurements by between one and two orders of magnitude. Sweden is playing a leading role in the upgrade of the ALICE TPC for Runs 3 and 4, and contributing to the ATLAS inner detector, tile calorimeter, timing detector and trigger upgrades. The following areas are high priorities of the community's LHC program and should be supported: full exploitation of the LHC and HL-LHC to enable (1) high-precision measurements testing the SM, especially in the Higgs sector; (2) searches for hitherto unobserved particles and processes beyond the SM that can tackle topical open questions such as the nature of dark matter and origin of the matter-antimatter asymmetry; (3) precision measurements probing the quark-gluon plasma.

- **It is critical that the LHC and HL-LHC and their experiments are supported.**

1.3 The intensity frontier

As the LHC has so far found no evidence of new physics, there is renewed emphasis in the international community for a more diverse program of smaller-scale experiments which are complementary to the core LHC activities. Dedicated experiments typically use high-intensity beams to search for ultra-rare processes which offer a unique sensitivity to new physics, often at a higher energy scale and in a different parameter space with respect to what is directly accessible at the high-energy frontier. Swedish groups consider intensity frontier experiments important and are active in the proposed SHIP (heavy neutral lepton search) and LDMX (dark matter search) experiments at SLAC/CERN and the HIBEAM experiment (search for baryon number violation and DM) at the ESS.

- **Activities at the intensity frontier must be supported.**

1.4 Neutrino physics

Neutrinos provide unique opportunities for both new physics searches and multi-messenger astronomy. The IceCube Neutrino Observatory at the South Pole, Antarctica, has discovered cosmic neutrinos and continues to lead the field of neutrino astronomy. IceCube is now planning for a two-stage upgrade of the facility. Together with international partners, the US National Science Foundation has already started funding the first stage, to be deployed in 2022/23. Sweden intends to contribute with hardware for two of the seven planned new strings. A radio based system for the low flux of extremely high energy neutrinos is planned with anticipated Swedish contribution and first stage deployment in 2020/24. The possibility of finding beyond-standard-model physics is pursued by both neutrino telescopes and accelerator-based neutrino experiments. Searches for CP violation at future long-baseline neutrino oscillation experiments hold great promise, with construction starting on DUNE in the U.S. and Hyper-Kamiokande in Japan, and design studies for a future facility ESSnuSB in Sweden. Astroparticle neutrino experiments and accelerator based neutrino experiments, which also detect atmospheric, solar and cosmic neutrinos, both play a complementary role for astrophysics and particle physics. Sweden plans to continue and expand its engagement in these areas on both the experimental and theoretical sides.

- **It is crucial that the strategy for particle physics supports experiments at the overlap of particle and astroparticle physics, in pursuit of common science goals and detector R&D.**
- **Support should be given to long baseline neutrino experiments.**

1.5 Theory

A key activity of the community is the development of phenomenological models. The prime example is the Pythia event generator, one of the major workhorses of the international community and developed by Swedish institutions. Other activities involve dark matter, model building in supersymmetry, Higgs physics, neutrino physics, grand unification and compositeness, Effective Field Theories for both Standard Model and QCD, collider phenomenology, as well as studies on more formal aspects of quantum field theory and string theory.

- **The strategy update must recognise and support the importance of particle physics phenomenology.**

1.6 Instrumentation and computing

Instrumentation and computing are integral tools to experimental particle physics research. To maintain and enhance capabilities to build novel detectors, as well as record, store and process data efficiently and in a cost-effective manner in Sweden, the following recommendations are made:

- **Increased R&D collaboration on instrumentation techniques, organized together with CERN and in collaboration with other disciplines.**

- **Shared instrumentation and computing PhD positions where the student shares time equally between the home institute and CERN.**
- **The creation and support of dedicated inter-experimental software and data acquisition collaborations at the European level, similar to the IRIS-HEP program by the NSF [1].**

1.7 Accelerator development

The development of particle accelerators plays a central role in the development of particle physics, both at the energy and the intensity frontier, with strong return value for other sciences and society. It is essential for Europe's future strategy and competitiveness in particle physics that accelerator physics and development is given adequate support.

- **The development of accelerator technology is essential and must receive strong support in order to create opportunities for next-generation projects as well as for novel high-risk and high-benefit accelerating techniques.**

1.8 The future direction of European Particle Physics and CERN

Following the discovery of the Higgs boson it is now essential that precision measurements are made of this particle and, more generally, the electroweak sector in which it arises. The HL-LHC upgrade will be a Higgs boson factory with over 100 million Higgs bosons expected. It will allow measurements of the Higgs sector at the level of 5% precision for the main channels and 10-20% for rare Higgs channels. In order to go beyond the precision offered by the HL-LHC, a dedicated electron-positron collider with a centre-of-mass energy of at least 500 GeV is needed. Proposals also include hadron-hadron colliders at energies above that of the LHC and high energy lepton-proton machines, which would also provide precision SM measurements as well as search sensitivity substantially beyond what is possible at the LHC. Given the current results from the LHC, a more diverse experimental program is also needed to open discovery windows that complement the range of high-energy colliders. This complementarity of collider and non-collider facilities is relevant for a broad range of questions, such as the nature of dark matter. For the heavy-ion program, an electron-ion collider would allow studies of initial-state gluonic correlations. Design, costing and performance estimations for a range of new facilities are important.

- **The community considers the construction of an e+e- collider with a centre-of-mass energy up to at least 500 GeV as essential.**
- **Design and costing studies for high-energy hadron-hadron and lepton-hadron (including electron-ion) facilities must continue. Such studies are important to the field in driving the development of accelerator and detector technologies.**
- **Whilst maintaining exploitation of the high-energy frontier and the development of major colliders as primary goals of the field, CERN should expand its activities at the intensity frontier, exploiting such possibilities where they arise at CERN.**
- **Full exploitation of the intensity frontier requires a broad set of experiments with unique physics potential taking place at institutions and laboratories outside of CERN.**
- **To address the dark matter (DM) issue, a range of experiments with complementary sensitivity (direct and indirect detection, collider, fixed target and beam dump), able to discover a wide range of DM candidates, should be supported.**

1.9 Further recommendations to the strategy update.

The wording and remit of the ESPP should not inadvertently inhibit PP research. High-profile cross-disciplinary experiments can fall between the cracks of different strategies. Examples include IceCube which measures fundamental neutrino properties and which falls under the remit of both the ESPP and the APPEC[2] strategy, and studies of QGP which follow the ESPP and the NuPECC[3] strategy. Furthermore, PP will also take place at another international European laboratory, the ESS, which will operate a fundamental physics beamline as of its remit. This is technically not covered by the present strategy document which highlights the role of national laboratories.

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[1] http://iris-hep.org

[2] *Astroparticle Physics European Consortium*.

[3] *Nuclear Physics European Collaboration Committee*.

- **The ESPP should emphasise that world-leading particle physics can be performed at experiments which can also be regarded as astroparticle and nuclear physics facilities.**
- **The wording of the ESPP should change to also accommodate the ESS which is an international laboratory.**

2. The Swedish PP Community

Particle physics research groups (experiment and theory) exist at Chalmers University of Technology (CTU), Lund University (LU), KTH Royal Institute of Technology (KTH), Stockholm University (SU), and Uppsala University (UU). In total the experiment (theory) groups comprise 28 (17), 9 (10), and 31 (13) experimental (theoretical) senior faculty staff, postdoctoral researchers, and PhD students, respectively. The groups also benefit from essential engineering and software development support. The community is supported by external sources and faculty funding.

3. Overview of the field and Swedish activities

The field of particle physics finds itself at a crossroads. The discovery of the Higgs boson completes the Standard Model (SM). Outside of the neutrino sector, searches for new physics at colliders so far confirm the correctness of the SM and are somewhat in tension with the paradigm of naturalness, which has driven the development of theories beyond-the-Standard-Model (BSM) in recent decades. However, the SM is known to provide an incomplete picture of nature. It has no candidate particle which explains dark matter, nor can it address the observed matter antimatter asymmetry (baryogenesis). The existence of massive neutrinos may also address the aforementioned problems; precision measurements and the development of phenomenology are required. Furthermore, although the strong sector of the SM is well understood in the perturbative limit, its behaviour in the soft limit and in the quark-gluon plasma requires detailed measurement and phenomenology.

The community is engaged in a range of experiments which tackle the aforementioned topical questions and which are summarised in Table 1. In addition to the activities on experiments, thriving phenomenology groups exist at LU, UU, KTH and CTH and work closely with the experimentalist groups. Another R&D and service activity that pertains to the entire area of PP is distributed computing and data management, known as Grid computing. Grid R&D activities are concentrated in LU and UU, with close cooperation with Swedish National Infrastructure for Computing centres for actual service provisioning.

Activity	Type of experiment	Key physics goals	Institutions	Status
ATLAS	*pp* collisions at the LHC	Precision Higgs physics, beyond standard model Higgs, precision SM, search for new phenomena. Full exploitation of the HL-LHC.	KTH, LU, SU, UU	Running. Approved until ~2035
ALICE	Heavy-ion collisions at the LHC	Quark-gluon plasma	LU	Running. Approved until ~2029.
IceCube	Neutrino observatory	Dark matter, neutrino properties	SU, UU	Running
LDMX	Fixed target (e^- beam)	Dark matter, dark sector	CTU, LU, SU	Proposed and R&D
HIBEAM	Free neutrons	Baryon-number violation, dark matter, baryogenesis	CTU, LU, SU, UU	Proposed and R&D
SHIP	Beam dump	Heavy neutral lepton, dark sector	SU, UU	Proposed and R&D
EssnuSB	Long baseline neutrino facility	Large-scale neutrino superbeam , proton decay	KTH, LU, UU	Proposed and R&D
XENONnT	Rare event underground	Dark matter	SU	Construction
DARWIN	Rare event, underground	Dark matter, neutrino physics	SU	Proposed and R&D
PTOLEMY	Rare event, underground	Dark matter, neutrino physics	SU/UU	Proposed and R&D

Table 1: Overview of experiments in which the community is active. In addition to the listed activities there is also Swedish participation on Hyper-Kamiokande and Dune, which is presently one person on each experiment though this may grow.

4. Research Areas

The major activity during the period of the updated strategy is the return on investment of the ATLAS, ALICE and IceCube upgrades, with the exploitation of the upcoming physics data for these experiments. In the same period an increasing engagement in future experiments is necessary to position the Swedish community for the next big experimental projects.

4.1 The high-energy frontier: ATLAS and ALICE at the Large Hadron Collider

The ATLAS and ALICE experiments at LHC have been the main focus of the particle physics community from the start. Groups from KTH, LU, SU and UU have contributed to the development and construction of ATLAS LAr, TRT, TileCal, SCT and trigger and LU to ALICE TPC. Following commissioning in 2008 and a decade of successful upgrade and operation LHC Run 2 has now ended. As shown in Figure 1, a series of further upgrades are planned, culminating in HL-LHC, after which the LHC will have delivered 3000 fb^{-1} to the LHC experiments, compared with 150 fb^{-1} collected as of today.

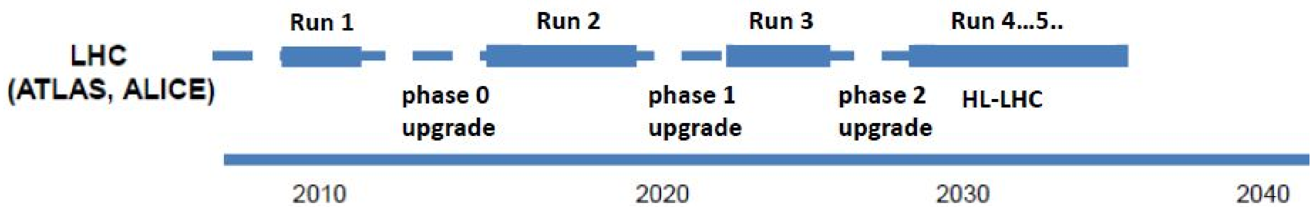

Figure 1: Timeline of the LHC.

At the HL-LHC, we will confront new high-luminosity and pile-up challenges. To achieve the stated goal of 1-2% uncertainty on the luminosity measurement, the degrading effects of increased pile-up needs to be mitigated for all physics objects. The phase-2 ATLAS upgrades are aiming at making this possible with important contributions from the LU and UU groups to the ITk and TDAQ, SU to the TileCal and KTH to the HGTD. Complementary work on the software and analysis side will, however, also be needed. The LHC is thus about to enter the high-precision phase, and one in which rare processes that are difficult to detect can be probed. It is critical that the LHC experiments are strongly supported over their full lifetimes. Sweden is heavily committed to the phase-2 ATLAS upgrades.

4.1.1 Standard Model

The main strategic objectives for SM physics are:

- Precision: both in the measurements and in the theoretical predictions. A core objective is the continued exploration of the Higgs sector.
- To probe extreme corners of the phase space: in inclusive and differential ways, exploring rare production and decay modes. New physics may be hiding in small deviations from high-precision SM predictions.
- To integrate measurements and searches.

The large datasets offered by the HL-LHC will open up the next phase of the high-energy particle physics program, in particular precision Higgs physics and precision TeV-scale physics. The HL-LHC opens up the possibility to measure the Higgs self-coupling, a key parameter of the SM. Precise measurements of SM parameters such as top and *W* masses, as well as soft QCD, jet and differential cross section measurements, will allow to put the SM to stringent tests and improve tools at the boundary between experiment and theory.

On the theory side, we need to improve perturbative calculations by going to higher orders for the precision, but also to improve non-perturbative models to get better accuracy in predictions.

4.1.2 Beyond the Standard Model

With the discovery of the Higgs boson, the SM is complete in terms of particle content. However, a number of questions remain which can be addressed by the LHC, as it enters a precision phase. As a discovery machine and as the highest-energy collider in operation, the LHC is sensitive to a range of hitherto unobserved particles and phenomena at multi-TeV mass scales. While its primary strength is that it provides a model-independent broad-band scan for generic new physics signatures at the TeV scale, it also enables high-sensitivity searches for processes predicted by topical models of new physics. Examples of models under study by the Swedish theory and experiment community are for example extra dimensions, leptoquarks, axion-like particles and partners of the gauge bosons and of the Higgs boson.

As the only apparently fundamental scalar ever observed, the Higgs boson requires precision study and offers a portal to possible new physics. A key task of the LHC experiments is the search for new physics in this sector. This can manifest itself via, eg, anomalous couplings to SM particles and an extended Higgs sector.

Searches for dark matter are also a key activity of the community. The WIMP paradigm is a well-motivated way to explain DM by requiring the existence of a particle (or particles) with a mass around the GeV-TeV scale which is weakly interacting. The LHC is sensitive to WIMP scenarios that are complementary to direct and indirect detection experiments. Supersymmetric models offer good dark matter candidates. Strong production of high-mass (> 10 TeV) coloured particles (eg squarks and gluinos in a SUSY context) can only be probed by high-energy machines, but interesting electroweak production processes can be tested at future lepton colliders. Many SUSY models near the electroweak scale are still viable and provide good DM candidates, but are experimentally challenging to detect.

To fully exploit the increased statistics of HL-LHC for precision searches it is critical that searches and measurements work in tandem, and that theory input is provided for the precise estimation of backgrounds and signal characterisation. It is also necessary to be innovative and go beyond the state-of-the-art in terms of detectors and data acquisition techniques to cope with the much increased data rates and to be able to detect rare, difficult-to-observe new physics phenomena.

4.1.3 Quark-gluon plasma

The original goal of heavy-ion physics was to create and measure the properties of the quark-gluon plasma (QGP). While tremendous progress has been made first at RHIC (from 2000) and then at LHC (from 2010), the microscopic understanding and quantitative description of the observed phenomena are still lacking. At the same time, the discovery of QGP-like effects in small collisional systems has opened up completely new and potentially game-changing directions. The world-leading facility for carrying out these studies is the existing LHC and both accelerator and experiments are now being upgraded for Run 3 and 4. It is imperative that there is a continuous support for QGP and QGP-like studies at LHC. To be able to resolve the many open questions is not only an issue of more statistics, but also of developing new measurements that are more sensitive to the underlying physics and exploring new theoretical directions in models. For this reason, one should leave the door open for dedicated QGP programs at LHC also after Run 4. Specifically for models developed for small systems, several intermediate collision systems such as proton-oxygen, or even proton-deuteron, could provide valuable input. This can also aid the modelling of the cosmic ray showers in the atmosphere.
Regarding future facilities, an electron-ion collider would allow precision studies of initial-state correlations such as the Colour-Glass Condensate.

4.2 Experiments exploring the intensity frontier

Swedish institutions are active on a number of proposed experiments at the intensity frontier, each with a unique physics reach beyond that which can be achieved at colliders.

4.2.1 The SHIP experiment at CERN

The Search for Hidden Particles (SHIP) experiment is an international collaboration with the goal of looking for very weakly coupled particles in the few-GeV mass domain. Particles with such properties, accommodated in various theoretical models beyond the Standard Model, are not well constrained. A beam-dump facility using high-intensity 400 GeV protons would be used as a copious source of such unknown particles in the GeV mass range. In addition to allowing direct detection of heavy neutral leptons, the SHIP experiment can also measure tau-neutrino properties, address the dark matter problem and search for the existence of a dark sector. SHIP would begin data-taking around 2026.

4.2.2 The LDMX experiment at CERN

The Light Dark Matter eXperiment (LDMX) would be a fixed-target experiment to search for very weakly coupled, invisible new particles in the MeV-GeV mass range. Such particles may be part of a dark sector and are highly motivated within the framework of thermal relic dark matter, that necessarily implies a production mechanism at accelerators. LDMX would be a unique, small-scale experiment using the missing-momentum technique. It requires a high-duty-factor electron beam with few (<10) electrons per bunch and an energy of 4-16 GeV, which could become available at CERN/SLAC within the next years, allowing to start taking data in the early 2020s. LDMX will have unparalleled sensitivity reaching far beyond the thermal relic targets, some of which are out of reach for direct detection experiments.

4.2.3 The HIBEAM experiment at the European Spallation Source

The High-Intensity Baryon Extraction and Measurement (HIBEAM) experiment is a Swedish-led international collaboration including physicists from SU, UU, LU, CTU and ESS with the goal to exploit the high cold neutron flux from the ESS to search for baryon-number violation (BNV). Processes in which neutrons can convert to antineutrons and/or mirror neutrons (belonging to a dark sector) are sought. Free neutron searches offer the only clean high-precision means to search for processes in which baryon number is the only hitherto conserved quantity. The experiment addresses open questions such as baryogenesis and dark matter. HIBEAM is the first stage of an experiment to deliver a sensitivity reach ultimately three orders greater than previously achieved. HIBEAM can start ~2024. HIBEAM would be part of the ESS' fundamental physics program, now identified as a high-priority area for the ESS. R&D for stage 1 is underway, the Swedish groups' goal is the construction of the prototype neutron-antineutron annihilation detector. Preparations for the second stage of the experiment are also already being made, with the ESS investing in a specialist high-flux beam port for use in a neutron-antineutron search.

4.3 Experiment exploring the neutrino sector

Neutrinos are increasingly at the forefront of particle and astroparticle physics, providing unique windows for both BSM physics and multi-messenger astronomy. Neutrino experiments at the overlap of particle and astroparticle physics also play an essential role complementary to accelerator-based experiments. Sweden plans to continue and expand its engagement in these areas on both the experimental and theoretical sides.

4.3.1 IceCube and neutrino astroparticle physics

Swedish groups at SU and UU were founding members of the Antarctic neutrino observatories AMANDA and IceCube, which discovered the cosmic neutrino flux. These high-energy astrophysical neutrinos can probe extreme environments where Nature's most powerful accelerators produce ultra-high-energy cosmic rays, or where dark matter particles annihilate. IceCube also provides uniquely high statistics of atmospheric neutrinos accessing regions of oscillation parameter space complementary to long-baseline experiments. The IceCube Collaboration is now undertaking a two-staged upgrade process. NSF has begun funding for the first stage, which will deploy newly-designed optical modules in a dense sub-array during 2022/23. These will allow testing ahead of a large-scale upgrade later in the next decade, precision calibrations of the optical properties of the ice for improved event reconstruction, and a measurement of atmospheric tau neutrino appearance, testing the unitarity of the PMNS mixing matrix. To reach the extremely high energy end of the predicted neutrino flux, at 10^{19} eV, a radio based detection system is needed and a first stage is planned for deployment 2020/24. Sweden would like to contribute to the first stage of the upgrade with hardware for two strings of optical modules and to contribute to part of the radio based system.

4.3.2 Long-baseline neutrino oscillation experiments

Accelerator-based neutrino physics attracts global interest and has both shorter-term and longer-term components. They are equally important. In the shorter-term, DUNE in the US and Hyper-K in Japan announce that they are entering into their construction phases. In each of these two projects there is individual Swedish participation. A design and feasibility study for a second generation neutrino Super Beam project, ESSnuSB, to be located in Sweden, is underway, funded by EU sources. An international consortium comprising 15 European institutes and five Swedish groups, at ESS, KTH, LU, LTU and UU, is collaborating on this study. The 5 MW ESS linear accelerator in Lund would be used to generate a uniquely intense neutrino beam to be directed to a megaton water Cherenkov detector located at the second neutrino oscillation maximum ~500 km away. A Conceptual Design Report will be produced by the ESSnuSB Consortium by

2021. The expressed goal of both Hyper-K and DUNE is to demonstrate experimentally the existence of CP violation in the lepton sector. ESSnuSB's goal, as a second generation facility, is to make precision measurements of the CP violating angle.

4.3.3 PTOLEMY

PTOLEMY (Pontecorvo Tritium Observatory for Light, Early-Universe, Massive-Neutrino Yield) is an experiment designed to detect the cosmic-neutrino background radiation (equivalent to the cosmic microwave background) by neutrino capture and the subsequent catalysed decay of tritium bound to a graphene target. Groups from SU and UU are involved in the experiment, a prototype of which has just been approved to be moved to the Laboratori Nazionali del Gran Sasso (LNGS). In a first phase, while preparing PTOLEMY for neutrino detection, PTOLEMY can be used as target for detection of light dark matter (sub-GeV, complementary to e.g. the LSND experiment), providing directional sensitivity. In that context, PTOLEMY can be seen as a prototype for new class of materials for direct detection of dark matter at the intensity frontier.

4.4 Dark Matter Direct Detection

SU is a member of the XENON collaboration, building and operating time projection chambers (TPCs) based on liquid xenon for direct detection of dark matter in the range of a few GeV to 100 TeV at the Laboratori Nazionali del Gran Sasso. The XENON1T detector has just presented world-leading constraints on dark matter from a one year-tonne exposure. The detector has stopped operating in December 2018 and is now being decommissioned in order to be replaced by XENONnT, a detector with about five times the target mass. XENONnT will start operations early 2019 and reach full sensitivity after a 20 tonne-year exposure, i.e. 2022/2023. The group is also involved in R&D towards the ultimate xenon-TPC, DARWIN, an envisaged 50 tonne TPC, whose design sensitivity will reach the irreducible background of solar and atmospheric neutrinos. DARWIN will push the sensitivity to dark matter by another order of magnitude (as compared to XENONnT). In addition, it will provide excellent opportunities for neutrino physics, e.g. neutrinoless double beta decay.

4.5 Theory development

Theoretical activities in physics beyond the SM span from phenomenology close to experiment to model building and more formal theory, in subjects such as Higgs physics, dark matter, supersymmetry, composite Higgs models, GUTs and flavour physics. An important activity is to develop experimental signatures and techniques to extract information from experimental data. Connections between PP at colliders with cosmology, astroparticle physics and neutrino physics are also very important. It is necessary to have appropriate tools for computation, and the Swedish community has a long tradition of developing a variety of such tools, including MC generators and other software tools, e.g. model calculators and dark matter tools.

The quest for increased experimental precision must be matched with advances in the precision of theoretical calculations. Today the state-of-the art is NLO QCD predictions for arbitrary processes embedded in detailed simulations of full events, with some special observables calculated to NNLO or even N^3LO. Further increased precision requires not only going to even higher orders for selected processes, but also a general scheme for combining EW and QCD corrections with full event simulation, and an improved treatment of resummation and non-perturbative effects in order to understand better the accuracy of the predictions and the effects of pile-up in high-luminosity environments.

For the theoretical modelling of heavy-ion collisions, it is challenging for generators developed for small or large systems to extrapolate to intermediate systems such as proton-lead. Without generators that can explain physics over a wide range of systems and beam energies (e.g. RHIC and LHC), it will be hard to reach broad consensus. At the same time, one could be afraid that current generation proton-proton generators without the QGP-like effects might reduce the discovery potential of LHC and future colliders. On the theory side, Sweden has previously had a strong standing in the phenomenological modelling of heavy-ion collisions with the Fritiof event generator. With the recent inclusion of heavy-ion capabilities in Pythia8, there is now an unique opportunity to achieve a strong, maybe even dominating role also in the future.

The theoretical effort for intensity-frontier and flavour physics experiments in Sweden involves discussing possible signals of new physics. There is also a strong tradition in using modeling and effective field theory techniques in estimating strong interaction and other Standard Model contributions. This includes also relevant calculations for the proposed ESS experiments.

In Sweden, theoretical research in neutrino physics focuses on the potential of future long-baseline neutrino oscillation experiments and signals from astrophysical neutrino sources, both in and beyond the Standard Model, with the interplay of collider signals. The Swedish contribution to neutrino theory also involves construction of models for neutrino mass based on seesaw-like scenarios and extensions to grand unified theories testable by the LHC, including the importance of renormalization group running. The implications of theoretical models need to be thoroughly tested against the current experimental constraints along with the search for new observables of neutrino interactions and additional massive neutrino species using the ongoing and near-future planned measurements. The generic beyond-the-SM constraints from collider and flavor physics measurements make a potentially significant impact on the neutrino sector.

It is considered extremely important by the community that developed software is open source.

4.6 Instrumentation and computing

The Swedish groups are focusing on development of technologies for high-granularity detector systems such as semi-conductor trackers, including high-resolution timing capabilities, particle-flow calorimetry, and TPC for heavy ion physics. A common challenge, and one that Swedish groups are involved in, is handling the high data rates which require advanced processing on- and off-detector (hardware, firmware/software algorithms etc) and low-power high-bandwidth readout and processing technologies. Traditionally, data is analysed “offline” after having recorded the full detector information. This analysis, as well as data reprocessing and simulation, is distributed across a grid of hundreds of data centres worldwide, due to the immense data volumes. Swedish groups are among the leading developers of the distributed computing software, ARC. For HL-LHC, data volumes are expected to exceed capacities of data centres. In the future we therefore consider it desirable to move more towards simultaneous data collection and analysis, as well as to investigate alternatives to storing full simulation events in their entirety, to overcome challenges such as the large storage space required to fully record the vast datasets of HL-LHC and future colliders. Here the interplay between the trigger and data acquisition software that is executed off-detector and the data reduction algorithms and methods run on-detector has an important role. Hence the interaction between sub-detectors and trigger and data acquisition must improve from today. Furthermore, work on new computing technologies and hybrid computing architectures going beyond widely used CPUs should be encouraged for both online and offline computing. This in turn requires new approaches to the distributed computing software and evolution of the current Grid model. We hope to see cooperation across present and future experiments so that trigger-less readout of data is ran wherever possible, in order to support the broadest possible physics program that is as agnostic as possible to new physics phenomena.

The particle physics groups in Sweden share instrumentation laboratories with astro-particle physics groups. Common interests are found in hardware for real-time data processing. In addition semi-conductor devices with extremely low power will also play an important role in future space based astroparticle detectors. Grid computing was in the past used for astroparticle simulations, being another shared facility.

The main technology developments are connected to the construction of major HEP experiments and their upgrades. Software tools for data acquisition, analysis and simulation require continuous development due to the rapid changes in information technologies: Cloud, GPU, Machine Learning can be named among the most prominent disruptive technologies that were introduced after the LHC experiments were designed, having major impacts. Because of the long cycles between construction and/or upgrades there are continuous problems to maintain competence in the groups while having to support outdated technologies. Instrumentation and software support is often not considered meritorious and funding is hard to obtain without a direct connection to (short-term) needs of experiments.

- To maintain future capability in instrumentation we welcome increased R&D collaboration on instrumentation techniques organized through CERN.
- Shared instrumentation and computing PhD positions where the student shares time equally between the home institute and CERN could be a catalyser.

- We encourage the creation of dedicated inter-experimental software, data acquisition and computing collaborations at the European level, similar to the IRIS-HEP program by the NSF (http://iris-hep.org), and support the efforts of the HEP Software Foundation (https://hepsoftwarefoundation.org).

4.7 Accelerator development

The development of particle accelerators is an integral part of the development of particle physics as well as of several other sciences. The design and construction of e.g. MAX IV, ESS and DESIREE accelerators in Sweden, contributions to FAIR and XFEL, and collaboration in several EU network projects have given valuable expertise to the accelerator physics community. This expertise is now being used for the next generation accelerator projects. At present Swedish accelerator physicists participate in three main areas of accelerator development projects for immediate use in particle physics: CLIC, HL-LHC, and the ESS linear accelerator upgrade for ESSnuSB. The progress already made with these projects demonstrates the excellent quality of the Swedish accelerator physics and engineering community and shows its broad range of competence covering both lepton and hadron accelerators as well as normal- and superconducting accelerators.

The Swedish accelerator physics community is educating and training a new generation of accelerator physicists and engineers, and working with Swedish industry to develop state-of-the-art components and production processes that will be critical for future accelerators. Among these we can point to high quality normal conducting magnets, superconducting orbit corrector magnets, cryostats, high voltage pulse modulators, and diagnostics instruments for electron and proton beams. In addition, the FREIA Laboratory at Uppsala University provides a test stand for superconducting magnets, cavities and cryomodules operated for international accelerator projects such as ESS and HL-LHC. All of these projects require dedicated support.

We need to maintain our capability to support ongoing particle physics projects and create opportunities to extend our support for topics highlighted by the European Strategy. Sweden is strongly involved in the CLIC project, and wants to contribute with this technology to develop a new electron linac at CERN as injector to the SPS for delivering beams to experiments like LDMX. We contribute to the HL-LHC project working with industry on technologies that in the future will also be important for the FCC. We are strongly involved in the ESSnuSB project, contributing to the design study of the accumulator ring and the ESS linear accelerator upgrade. We want to contribute to ILC if a positive decision will be taken regarding its construction, and see new possibilities to contribute to MYRRHA and the Fermilab PIP-II accelerator upgrade needed for DUNE. European wide support for these projects is critical to continue and extend the work.

5. Other facilities and recommendations on the general direction of particle physics research and CERN

The community has adopted the following positions on future projects of global significance and the general direction of particle physics research and CERN. The Swedish community may join future proposed experiments.

- The community considers the construction of an e+e- collider with a centre-of-mass energy up to at least 500 GeV as essential.
- Design and costing studies for high-energy hadron-hadron and lepton-hadron (including electron-ion) facilities must continue. Such studies are important to the field in driving the development of accelerator and detector technologies.
- Whilst maintaining exploitation of the high-energy frontier and the development of major colliders as primary goals of the field, CERN should expand its activities at the intensity frontier, exploiting such possibilities where they arise at CERN.
- Full exploitation of the intensity frontier requires a broad set of experiments with unique physics potential taking place at institutions and laboratories outside of CERN.
- The strategy should support the development of novel high-risk and high-benefit accelerating techniques, such as plasma wakefield acceleration.
- To address the dark matter issue, a range of experiments is needed with sensitivity to direct and indirect detection and collider production which cover a variety of DM candidates.