Austria's Strategy on Particle Physics

Input to the European Strategy on Particle Physics

prepared by the Austrian Particle Physics Community

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December 18, 2018

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1 Executive Summary

In the following, Austria's particle physicists outline their current research program on particle physics and define their visions and plans until 2026. The overarching goal is to contribute to the understanding of known particle physics as well as the discovery of physics beyond the standard model and its theoretical understanding. This is achieved through Austria's involvement in major international experimental endeavours, both present and future, as well as in theoretical research in these areas.

In Austria, particle physics research is conducted at the following institutions:

- University of Graz (UG) (Theo)
- University of Innsbruck (UI) (Exp)
- University of Vienna (UV) (Theo)
- Technische Universität Wien (TUV) (Exp/Theo)
- Institute of High Energy Physics of the Austrian Academy of Sciences (HEPHY, Vienna) (Exp/Theo)
- Stefan-Meyer Institute of the Austrian Academy of Sciences (SMI, Vienna) (Exp)

The description below provides a comprehensive overview of the ongoing particle physics activities in Austria and presents the plans for the next decade. The Austrian particle physics community is working on setting up a tightly woven network of cooperation among Austrian institutions in addition to its multitude of international collaborations. This is an ongoing effort, which has manifested itself already in multi-institution third-party funding applications and common scientific events. While it is not our aim to impose uniformity on the research landscape, we want to bring together experts working in the same and adjacent fields in order to strengthen Austria's role in the European particle physics community. This requires common strategic decisions both for experimental involvements and hiring strategies. These should at the same time give each institution room for individuality and specialization but also show up areas and connections common with other institutions in Austria. This will become evident in the detailed discussion of the individual research areas.

Austria's institutions plan to actively participate in several future particle physics experiments. Work on the CMS upgrade for HL-LHC has already started. A contribution to experiments at the next generation of accelerator complexes is envisaged, in particular at the proposed linear collider ILC in Japan. The Austrian science community also emphasises that approaches centered around low-energy precision experiments have an enormous potential and reach out into several domains that are otherwise inaccessible. Furthermore, participation in the PANDA experiment at the FAIR facility is strongly desired. However, the contribution to PANDA planned by SMI is under discussion as there is currently a lack of Austrian support and funding in this respect, in particular for hardware contributions to FAIR experiments.

For the Austrian neutron physics community, the ESFRI Landmark Institute Max von Laue-Paul Langevin (ILL) plays a key role. As the world's flagship center for neutron science, the ILL provides scientists with a very high flux of neutrons feeding some 32 state-of-the-art instruments, which are constantly being developed and upgraded. Participation in experiments at current and future neutron sources at Forschungsreaktor München II (FRM-II) and the European Spallation Source (ESS) is also planned.

Experiment	Location	Institute	Main responsibility	Status
Belle	KEK	HEPHY, SMI	data analysis	completed
Belle II	KEK	HEPHY	SVD, data analysis	running
CMS	CERN	HEPHY	tracker, trigger, HGC, data analysis	running
COSINUS	LNGS	HEPHY, TUV	electronics, simulation, data analysis	approved
CRESST	LNGS	HEPHY, TUV	simulation, data analysis	running
νCleus	TBD	HEPHY, TUV	electronics, simulation, data analysis	approved
ALICE	CERN	SMI	data preparation and analysis, upgrade	running
ANNI	ESS	SMI, TUV	ep/n separator	proposed
ASACUSA	CERN	SMI	positron system, antihydrogen detector, hyperfine spectroscopy apparatus	running
aSPECT	ILL	SMI, TUV	data analysis	completed
E57	JPARC	SMI	detector and cryogenic target system	running
NoMoS	ILL, TU München	SMI	magnet system, detector system	in preparation
PANDA	FAIR	SMI	barrel TOF	in preparation
PERC	TU München	SMI, TUV	magnet, beam stop, magn. spin resonator	construction
PERKEO III	ILL	SMI, TUV	proton retardation, data analysis	running
SIDDHARTA-2	DAΦNE, LNF	SMI	detector and cryogenic target system	running
VIP2	LNGS	SMI	Detector system, data analysis	running
n_Tof	CERN	TUV	detector development	running
qBOUNCE	ILL	TUV	detector development, mechatronic, data analysis	running
S18 beamline	ILL	TUV	Interferometry, USANS, data analysis	running
ATLAS	CERN	UI	data analysis	running
Fermi-LAT	low-Earth orbit	UI	instrument quality monitoring, data analysis	running
CTA	La Palma, Spain & Paranal, Chile	UI	MST cameras, science preparation	construction
HESS	Namibia	UI	camera upgrade CT5, data analysis	running

Table 1: Summary of the current and planned future experimental participation of Austrian particle physicists in international experimental facilities.

Continuing involvement with astronomical observations for astroparticle physics is planned via participation in the Cherenkov Telescope Array.

A summary of all current and future experiments with Austrian participation is given in Table 1.

It is the opinion of the Austrian community that intense accelerator and detector R&D efforts will be an important aspect of the future long-term strategy of particle physics in Europe. As in the past, CERN should play a leading role in this effort. Manpower and funding resources will have to be organized on a worldwide scale under European (co)leadership to realize one or more of the promising concepts for future facilities to be used by the next generation of particle physicists. Independently of the specific implementation of future accelerator research infrastructures, Austrian participation at the forefront of high-energy physics research together with important contributions to technology, detector development, data analysis and theory are strongly supported by the community. This will continue as a long-term scientific activity of Austrian institutes and universities.

In the following the research areas in Austria are listed. They are grouped into four main areas: standard model physics, astroparticle physics, particle physics at the energy frontier and development of experimental and theoretical foundations. The topics are listed alphabetically and their order does not prioritize one field or another. For each topic, the institutions involved are indicated in parentheses.

2 Standard model physics

2.1 Low-energy precision experiments

The success of the standard model is built on the strong interplay between experiments at the high-energy frontier and low-energy precision experiments. In the latter, the contribution from physics beyond the standard model is in general suppressed in a different way than in experiments trying to detect physics beyond the standard model directly. Consequently, the highest energies can also be explored by precision experiments, and Austrian scientists are involved in several such experiments running at low energies and involving neutrons, atoms, anti-matter and neutrinos.

Neutrons: Very slow neutrons are employed as an extremely effective probe for fundamental physics studies and may, among other things, open up possibilities to explore detailed characteristics of the gravitational force that are inaccessible by other means. The information obtained from neutron experiments have wide implications for fundamental physics, touching, for example, on the validity of the standard model and complementing the work performed at high-energy physics laboratories such as CERN.

Austrian scientists are involved in a strong experimental neutron physics program with measurements at sources offering high fluxes, such as ILL in Grenoble (aSPECT, PERKEO III and qBOUNCE experiments, S18 beamline), FRM-II in Munich (future PERC instrument), and n_TOF at CERN (TUV). The latter allows to study topics in nuclear astrophysics and nucleosynthesis. Neutron beta decay is investigated to improve our knowledge on the axial-vector coupling of the weak interaction, to test the unitarity of the quark mixing matrix and to search for physics beyond the standard model, e. g. to measure or find limits on a Fierz term from differential electron distributions in PERKEO III (TUV,SMI).

In the future the sensitivity of neutron beta decay measurements will be further improved with the NoMoS experiment (SMI). A local training facility is the TRIGA research reactor at the Atominstitut in Vienna (TUV). The experimental effort is complemented by work in theoretical nuclear physics necessary to describe neutrons and their interactions (TUV,SMI).

Ultra-cold neutrons: The low-energy experiment qBOUNCE and a cavity-enhanced atom interferometer experiment are currently improving the limits on two specific models for dark energy, namely chameleons and symmetrons, by several orders of magnitude (TUV). By using ultra-cold neutrons these experiments also allow to generically probe for non-Newtonian gravity at short distances with high precision. Future searches for physics beyond the standard model using cold and ultra-cold neutrons are also planned at the ESS. Here, Austria participates in the proposed cold-neutron beam facility for particle physics (ANNI) and in an in-beam source of ultra-cold neutrons (UCN) (SMI,TUV).

Atoms: A cavity-enhanced atom interferometer and a levitated-atom interferometer are currently being built to exploit the fact that atoms have near-perfect test particle properties: they can be selected as pure isotopes, cooled down to far below one nK and have well understood and easily tuneable magnetic and electric properties (TUV). Their small dimensions ($\sim 10^{-10}$ meters) and masses ($\sim 10^{-25}$ kg) make their retroaction on the sensed field negligible. This makes them ideal systems to explore concepts such as the unconstrained parameter space for Yukawa-like and not-Yukawa-like interactions at short distances to search for physics beyond the standard model.

A new type of high-precision optical atomic clock based on a nuclear transition in Thorium-229 is currently being developed (TUV) to probe for variations of fundamental interaction constants and test local Lorentz invariance. This clock promises an improvement of five orders of magnitude in sensitivity to variations of fundamental constants.

Antimatter: Austria is among the key players in the physics of antiprotons and antihydrogen at the CERN AD (SMI), in particular for the ASACUSA experiment, which measures the antihydrogen hyperfine splitting and aims at an initial precision of 1 ppm. The experiment with cold antihydrogen is motivated by the wish to test CPT, a cornerstone of quantum field theory, which states that antihydrogen and hydrogen should have exactly the same spectra. It will also search for differences between matter and antimatter in the reaction to gravity. In the future, after CERN's LS2 shutdown, these projects will continue at the new ELENA facility (SMI). A possible violation of the Pauli principle is being investigated at the VIP2 experiment in the Gran Sasso underground laboratory (SMI).

Neutrinos: In the context of low-energy precision measurements neutrinos will in the future play a relevant part. With the recently observed phenomenon of coherent neutrino-nucleus scattering a new research area in experimental neutrino physics has been opened up. This field will be pursued in a new experiment called νcleus, which is based on the cryogenic technology pioneered by CRESST (see section 3.2). Here, the aims will be development and construction of the experiment (mainly with work on the data acquisition system), simulation and physics analysis (HEPHY,TUV). This will allow Austria to actively participate in an experimental neutrino program to study the neutrino's dipole moment and search for sterile neutrinos or non-standard interactions.

2.2 Hadron physics

Hadron physics at various scales is a central research topic in Austria. Beyond gaining a deeper understanding of nuclear, hadron and QCD physics itself, these studies aim in the long run at an understanding of hadronic effects from first principles in searches for physics beyond the standard model. Most of theoretical hadron physics in Austria focuses on understanding light hadrons below 2 GeV by using ab-initio QCD calculations (UG), chiral perturbation theory (UV), sum rules (UV), and holographic methods (TUV). The primary aims are spectroscopy, hadronic structure and rare (semileptonic) decays. In some cases, low-energy hadron physics also plays an important role in searches for physics beyond the standard model such as for the $g-2$ of the muon (UV). These efforts will continue in the future and are matched with the current and future experimental program in hadron physics.

Experimental strangeness hadron physics is used to reveal the complex dynamics and phenomena of quarks and gluons, e. g. hadron properties in the nuclear medium, symmetry breaking patterns and hadron mass generation, and new forms of hadrons. This covers kaonic atoms and nuclei at DAΦNE and J-PARC and low-mass dileptons at ALICE and in the future also at PANDA at FAIR (SMI). The physics aim for PANDA will be multi-quark mesons including strange mesons already at the initial stage of FAIR. Later the production of charm quarks in proton-antiproton annihilation will be investigated, for which several candidates have already been discovered at low-energy electron-positron colliders as well as at high-energy colliders (SMI). For the future, a unified approach to meson physics for both light and heavy hadrons is an important goal. Its achievement will be facilitated by methods currently being employed in Austria (UG,UV,HEPHY,SMI).

In addition to hadron physics, flavor physics with charm and bottom quarks is also central for understanding QCD and for searching for physics beyond the standard model. Currently, theoretical flavor physics is being conducted by using ab-initio QCD calculations, which are often in line with those for low-energy hadron physics and use similar technologies (HEPHY,UG,UV). In the future this ab-initio approach will be strengthened further (UG). This is complemented experimentally by investigations of quarkonia and other heavy hadrons in BELLE (HEPHY,SMI), BELLE II (HEPHY; SMI participation in BELLE II is under discussion), and CMS (HEPHY), and will in the future also be studied at PANDA (SMI).

2.3 Phenomenology of the standard model

The phenomenology of the standard model is strongly pursued in the context of collider physics as well as in conceptual studies (HEPHY,UG,UV). Collider physics activities include the maintenance of existing Monte-Carlo event generators (in particular Herwig (UV)), as well as the development of a new generation of Monte-Carlo event generators (UV), theoretical work related to the physics of jets (UV), and the properties of the Higgs boson and the top quark (UV,UG) with particular emphasis on the top quark mass (UV). Special efforts are being made for high-precision predictions for collider processes to improve measurements of standard model parameters and to better quantify background processes relevant in searches for physics beyond the standard model. These activities are essential for the interpretation of experimental results. On the conceptual side, developments are being and will be made for the field-theoretical background of Brout-Englert-Higgs physics and its implications for precision measurements (UG). These studies contribute to a better global understanding of the standard model and potentially to an improved description of backgrounds in searches for physics beyond the standard model.

Experimental standard model analyses are currently being pursued and will be continued within the CMS collaboration at the LHC. Investigations focuse both on the Higgs boson and the top quark, and in some cases Austrian physicists are leading the corresponding analysis groups (HEPHY).

2.4 Flavor physics

One focus in flavour physics activities is the decays of B- and D-mesons, which are being studied to gain a deeper understanding of weak interactions. The interplay of strong and weak processes has to be understood to disentangle the underlying electroweak physics, which is closely related to the research topic discussed in section 2.2. The precision determination of the CKM-matrix elements V_{ub} and V_{cb} will be a central focus for future studies at BELLE II (HEPHY). Rare decays of B-mesons are being studied with data from the ATLAS experiment at the LHC (UI). A primary aim for the future is to enhance the synergies of this topic with investigations and in particular also with theoretical studies of hadronic physics and QCD aspects (section 2.2) (UG,UV) and with searches for physics beyond the standard model (section 4) (TUV,UV,HEPHY,UG).

2.5 QCD phase diagram

Currently the physics of many hadrons is being explored experimentally at ALICE (SMI). It is important for the understanding of the early universe and of neutron stars. The focus is on the measurement of thermal radiation by detecting low-mass electron-positron pairs and the spectroscopy of hadrons in central exclusive production in pp collisions. On the detector development side, there is involvement in the R&D and construction of a fast timing detector for the ALICE upgrade for LHC Run 3 and 4 (SMI).

This is complemented by theoretical investigations using various methods ranging from lattice and functional methods to holographic approaches and directed at dealing with the complexities of many-body systems (TUV,UG). The difficulties involved require the continuous development of new concepts and methods (TUV, UG).

The aim is to establish control over the QCD equation of state in the whole phase diagram from both the experimental and the theoretical points of view.

3 Astroparticle physics

3.1 Cosmic-ray and gamma-ray astrophysics

In this context experimental, numerical and theoretical astroparticle physics in the field of cosmic-ray primaries and gamma-ray (and neutrino) secondaries is being performed (UI). The Cherenkov Telescope Array (CTA) is a future gamma-ray observatory planned to significantly improve upon the sensitivity and precision of the current generation of Cherenkov telescopes. Principal interest and responsibility are in the key-science projects AGN jet physics, star formation, galaxy clusters and cosmic-ray astrophysics (UI). The High Energy Stereoscopic System (HESS) will be continuously operated until the performance of the southern site for CTA will outperform the HESS telescope array. The large CT5 telescope in HESS will be upgraded with the prototype camera developed for CTA before 2020 to support an efficient observational and scientific program. Principal activities here relate to studying particle acceleration at TeV energies, diffuse galactic emission, the high-energy cosmic-ray electron spectrum and gamma-ray binary systems as well as active participation in the observations at Namibia (UI). Lastly, the involvement in Fermi-LAT include responsibilities for instrument data quality supervision shifts and research in the field of galactic and extragalactic gamma-ray astronomy (UI). With Fermi-LAT being the forefront observatory for multi-messenger studies (gravitational-wave follow-ups and EM counterparts of neutron-star mergers, or IceCube neutrino coincidences with flaring activities in the gamma-ray sky), synergies are being built up between GeV-scale and TeV-scale observations in time-domain astroparticle physics, e.g. by advanced leptohadronic emission modeling and broadband predictions on diffuse gamma-ray and neutrino emission.

3.2 Searches for dark matter

Currently, search for dark matter is being performed in Austria from both the experimental and the theoretical points of view (TUV,HEPHY,UG). The theoretical work covers the phenomenology of direct detection, collider searches, cosmological constraints and model building. Here a wide range of models is being studied that cover the weakly interacting sectors. In the future also strongly interacting dark matter sectors will be studied.

Dark matter is also the central target for the current experimental activities in terms of direct detection using nuclear scattering processes within the framework of the CRESST collaboration (HEPHY,TUV). The focus is background simulation and composition as well as data analysis. Synergy effects using the cryogenic approach currently pioneered by CRESST will be applied to the future COSINUS experiment to gain further understanding of the annual modulation observed by DAMA/LIBRA (HEPHY,TUV). A complementary strategy will be the experimental search for dark sector particles at Belle II (HEPHY). Possible production at CMS will be theoretically covered (HEPHY). Furthermore, at low energies, neutron beta decay with PERC has a reach into the dark sector (TUV). An R&D effort investigating the possibility to perform searches for dark matter-electron scattering is being studied in the DANAE project. Depending on the outcome of the R&D study, the project will be pursued further, and first above-ground measurements are planned (HEPHY). A large variety of dark-matter candidates can be also probed indirectly by using potential changes measured in experiments with neutrons (qBOUNCE) or in atom interferometers

(TUV). Ultra-precise clocks will allow to probe for still other types of dark-matter and dark-energy candidates (TUV).

4 Particle Physics at the energy frontier: physics beyond the standard model and model building

Currently physics beyond the standard model is being searched for by a multitude of experiments. At the high-energy frontier searches for supersymmetry and other scenarios are being carried out, in particular by using model-independent approaches such as simplified models. They are driven by the involvement in the CMS experiment (HEPHY). These searches for beyond-the-standard-model physics at all scales are accompanied by continuing studies of particular models including supersymmetry (HEPHY,UV) and other models accounting for strongly-interacting QCD-like new sectors and aspects of quantum gravity (HEPHY,UG) as well as string theory (TUV). Of course, current searches for physics beyond the standard model are intricately linked to flavor physics, primarily by measuring deviations with respect to standard-model predictions (see section 2.4). This is especially pursued at the BELLE II experiment (HEPHY). Besides flavor physics, the top quark and the Higgs are currently among the best hopes as portals for discovering physics beyond the standard model. This is followed up on at CMS (HEPHY) and supported by theoretical studies (UV,UG). Both direct searches covering the scale from TeV upwards and indirect searches in the context of flavor physics analyses that extend the reach at the precision frontier (HEPHY) will be continued and intensified in the future. They will be accompanied by the corresponding theoretical studies covering scales from the TeV range to the Planck scale (TUV,HEPHY,UV,UG) and including string theory (UV,TUV). In addition, ways to apply the Austrian expertise in quantum technology and quantum metrology to devising table-top ultra-precision experiments that may probe physics beyond the PeV range will be explored (UI).

5 Development of experimental and theoretical foundations

5.1 Accelerator Development

The development of superconducting materials is highly important for future accelerators such as the FCC and the HE-LHC. These are Nb_3Sn wires for high-field magnets which are being analyzed and characterized in the context of a worldwide Nb_3Sn wire performance improvement program. This is essential for the continuous monitoring and qualification of wire samples produced by industry and for generating proposals for fundamental material- and process-related improvements (TUV). In this context the interdisciplinary cooperation with USTEM (Universitäre Service-Einrichtung für Transmissions-Elektronenmikroskopie) at TUV plays an important role. Also, thallium-based high-temperature superconducting coatings are being developed in a European collaboration for vacuum systems. Here, the characterization of the current transport as well as of the micro-structural and magnetic properties are the primary aims (TUV).

Besides developments for future accelerators, a dedicated accelerator R&D program at the medical accelerator facility MedAustron is ongoing in order to be prepared for the next generation of medical treatment facilities for hadron therapy. This program is a common effort between MedAustron and TUV.

5.2 Instrumentation

Austria's institutes are involved in the development of instrumentation for particle physics. This is to some extent happening for all experimental activities. Especially noteworthy is the current strong involvement in the construction of the silicon strip tracker for the CMS experiment and the Phase-II upgrade of these detectors for HL-LHC. This includes the responsibility and technical specifications for the design of the Si-sensors for both the CMS Tracker and the CMS high-granularity calorimeter (HGC) (HEPHY). These must match both the vendor capabilities and the experiment's needs. Such projects are a basis for current and future cooperation with industry, such as the former collaboration with the Austrian branch of the international semiconductor producer Infineon Technologies (HEPHY). Given this expertise, also central contributions to the Silicon Vertex Detector (SVD) of the Belle II experiment have been made (HEPHY). R&D activities for hadron physics experiments were also performed, including work on fast timing applications using Silicon photomultipliers (SiPMs), work on silicon drift detectors (SDDs) for high precision X-ray spectroscopy, and the construction of a Time Projection Chamber (TPC) with Gas Electron Multiplier readout (SMI). The study of SiPMs has already led to the construction of a hodoscope for CERN-AD and a veto system made of scintillator tiles for experiments at DAΦNE and J-PARC, for which also SDDs will be used (SMI). The expertise gained on fast timing applications with SiPMs will be used for an important future contribution to the planned PANDA experiment and its time-of-flight detector (SMI). In addition, lightweight cryogenic targets for gaseous and liquid hydrogen to be used at these facilities have been developed (SMI). An R&D project foresees using low-noise silicon detectors to detect electron-dark matter scattering (HEPHY). Another R&D project is a "nuclear clock" based on ^{229}Th, which should surpass the accuracy of current atomic clocks (TUV).

Within the context of the CERN RD50 collaboration, the R&D in Si detectors for future HEP experiments is being pursued. The development of a HV-CMOS detector with DAQ hardware and software developments (HEPHY) is of special importance in this context. Moreover, generic developments of characterization techniques and detector concepts will be pursued as well as studies on the radiation hardness and fast timing performance of Si sensors for future experiments. The development of advanced radiation detector systems that will be able to perform high-precision measurements of photons in a (very) broad energy range and will be capable of operating under extreme environmental conditions is also ongoing (SMI). In addition, Micropattern Gas Detectors for Hadron Physics are being developed with the goal to develop an active target TPC, which acts as a target and at the same time performs the tracking of low-energy recoil particles from interactions in the active volume (SMI).

An important spin-off and synergy of detector development has arisen with the startup of the Austrian cancer therapy facility MedAustron in 2016. Here the development of an ion-beam computed tomography system with the aim of clinical use of this system in the long term is currently under way (HEPHY,TUV). From 2019 onwards a proton beam with an energy of up to 800 MeV will be available at MedAustron. This infrastructure will be available as a test beam facility to perform first tests of dedicated detectors for particle physics experiments.

It should be noted that developments of detectors take only a limited time and once they have been installed or developments have been discontinued, resources are freed to move to new projects. The development of Si sensors for the Phase-II upgrade of the LHC experiments (HEPHY) has been discontinued. Moreover, the construction and assembly of the Belle II Silicon Vertex detector has been finished (HEPHY). Similarly, the R&D work on SDDs has been finished and data taking will start 2019 at LNF and J-PARC, where the commissioning phase should come to an end by

2021 (SMI).

Within a hardware consortium, a fully digital high-quantum-efficiency camera for the medium-size telescopes (MST) at the Cherenkov Telescope Array is being developed (UI). The FlashCam camera system is the first to implement a fully digital signal processing chain including a traceable, configurable trigger scheme and flexible signal reconstruction in ground-based Cherenkov astronomy.

5.3 Quantum field theory

Quantum field theories contain numerous aspects that still pose important conceptual and technical challenges. Understanding them is a necessary ingredient for phenomenology, and a wide range of questions from strong-field QED, confinement, representations of quantum field theories, dualities to gravitational theories, emergent and broken symmetries and many other subjects are being studied all over Austria (TUV,UV,UG) to pave the way for future applications. This also includes the further development of technical tools, ranging from lattice gauge theory and functional methods to gauge-gravity duality, event generators and perturbative methods. The latter two include in particular multi-loop calculations and effective field theories (HQET, SCET, Chiral Perturbation Theory) and focus on developing analytic factorization approaches and conceptual advancements concerning event generation and simulations for high-energy particle collisions accounting for a systematic treatment of perturbative and non-perturbative effects, including resummation methods. A particular aim is the development of a new generation of Monte-Carlo event generators. On the other hand, this also touches the very foundations of field theory and gravity and covers conceptual theoretical aspects and open issues not only in quantum field theory but also in quantum gravity and black hole physics up to cosmological aspects such as the cosmological-constant problem and dark energy (TUV,UV). The latter is also being investigated in the context of string theory (TUV).

An interesting possibility in this context could be simulations of quantum field theories in quantum experiments. It is planned to build a quantum field theory lab to investigate the question if it is possible to build (emerging) field theories in flat and curved space time, e. g. in the context of "It from qubit", and, if so, probe their emerging properties and investigate when they break down (UI).

6 Towards the next energy frontier

Research at the energy frontier is one of the clear and promising options to advance our understanding "beyond the standard model". Concrete plans exist for high-precision studies with e^+e^- collisions in the 100 to 500 GeV energy range to probe the unique aspects of the Higgs sector and to achieve indirect sensitivity at the 100 TeV scale. The International Linear Collider (ILC) with an initial energy of 250 GeV, upgradeable to 500 GeV or higher, would be such a tool. Japan is considering to host the project and a decision by the Japanese government is, at the time of this writing, expected in early 2019. If the ILC is built, Austrian participation would be in line with HEPHY's tradition, in view of its past major role at LEP and its present strong involvement in the Belle II experiment at the Japanese 10 GeV e^+e^- facility KEK.

Beyond multi-hundred GeV e^+e^- colliders, Europe should address the next energy frontier. A very large circular collider may be one possibility. Accelerators and detectors are an essential tool for experimental particle physics. However, to reach new energy (and luminosity) ranges in a financially affordable manner, new technologies are required. Therefore, part of the strategy should also involve a new scale of focused accelerator and detector R&D effort. Future projects will require a major change of the “CERN Mode” with significant contributions by non-member states at a commensurate scale. Resources in personnel and funds would have to be organized on a worldwide scale under European leadership to make one of these promising concepts reality for the next generation of particle physicists.

Independently of the specific implementation of future accelerator research infrastructures, Austria’s participation at the forefront of high-energy physics research coupled to important contributions in technology, detector R&D and theory is strongly supported by the community and will continue the long-lasting and successful scientific activity of Austrian institutes and universities. Effects unveiled by low-energy ultra-precision experiments might well be the strongest motivation and provide guideliines for building the next machines.

A Appendix

Besides the core research topics listed above, several additional activities directly connected with particle physics research are going on in Austria and are listed in this appendix.

A.1 HPC (High-performance computing)

Usage of HPC facilities is a central tool in Austria’s particle physics research, including being a Tier 2 center for the CERN grid. These resources are used both in the analysis of experimental data (e. g. ATLAS, CMS and ALICE) as well as theoretical calculations, both in lattice gauge theories and with non-lattice methods. Local resources, the Vienna Scientific Cluster (VSC) and membership in PRACE are being utilized for particle physics purposes.

It is expected that the need for HPC resources in terms of core hours will at the very least not diminish over the next decade, and will probably increase. What will definitely increase is the need for storage capacity. Thus, a continuous effort in maintaining, updating and enlarging the HPC infrastructure in Austria will be necessary. The aim in this respect is to have a two-level structure. Small, omnipurpose clusters and storage capacity at the institutes will provide the resources for code development and small projects. The latter are especially relevant for educational purposes such as bachelor and master projects. At the national level, a central multi-technology computer center is the preferred solution. Such a center should provide not only large omnipurpose clusters but also specialized facilities such as GPU or tensor network clusters. The latter two technologies are of central importance in data mining and machine learning, both of which are expected to become more and more relevant in particle physics over the next decade.

It is our declared intent to coordinate with other computationally demanding branches of science for establishing such a national center. The current initiative of the Austrian Academy of Sciences is one example while another one are the systems of local common infrastructure at individual institutes. A national, science-targeted cluster with diverse technologies is the best solution.

In addition, access to PRACE and the CERN grid will be of importance on this time scale. PRACE is a vital European infrastructure for large-scale theoretical calculations, especially in international collaborations, which substantially exceed the capacity of Austria. Being a Tier-2 center in the CERN grid is vital to support the experimental research of Austrian institutes at CERN. Thus, the particle physics community declares the express intent to continue its membership in both structures.

A.2 Education, Outreach, and Diversity

Austria sustains at this time three structured education programs for students in particle physics. On the physics side the FWF-funded graduate school "Particles and interactions" (DKPI) encompasses all institutes in Vienna. At the University of Graz, the doctoral academy on particle physics has been established as a follow-up to an FWF-funded graduate school. In addition, the successful Austrian-CERN PhD program provides technology-oriented education related to particle physics at the PhD level. Special events such as block lectures within the framework of these structured programs are usually announced Austria-wide, thus allowing also students from other universities with smaller particle-physics groups to join and profit from the larger sites.

We aim at continuing such a structured education program in particle physics at the master and PhD levels in Austria. Of course, the formal organizational structure will need to change when FWF programs expire or priorities of institutes or universities shift. Nonetheless, common education at the larger sites and the possibility for nationwide participation in multiple events per year will remain standard. In particular, the Austrian-CERN technology PhD program is an important element beyond the physics aspects.

The same is true for a comprehensive lecture program for Master's studies in order to guarantee a continuous influx of excellent students from all over the world. In this respect also English-language Master's courses, such as the ones already implemented at the University of Graz, will be essential for the quality of Master-level education in particle physics in Austria.

In addition, particle physics will continue to be part of the training of physics teachers, and there is a wide range of outreach activities on all levels. This includes the continued participation in the CERN masterclasses and other activities at schools. In this respect an important aim has been to increase the amount of under-represented groups in particle physics. Particle physics is a worldwide effort and requires an inclusive environment.

All these measures aim at establishing an inclusive, international and diverse particle physics research landscape in Austria.

A.3 Conference series hosted in Austria

In the particle detector community Vienna is well known as the venue of the "Vienna Conference on Instrumentation", which is organized every three years and regularly attracts some 250 particle physicists from all over the world. The same applies to the EXA conference series. Since 2016 a new annual conference series, ALPS (An Alpine LHC physics summit) is taking place at the University center in Obergurgl, Tyrol. This conference focuses on the latest results presented by the LHC and hot topics in particle physics such as dark matter and is jointly organized by HEPHY and UG. Since 2004 Vienna has been hosting the annual workshop "Vienna Central European Seminar" on current issues in particle physics and quantum field theory, which is jointly organized by UV, TUV and HEPHY. Other regularly organized series in Austria are the Humboldt Kolleg Kitzbühel and the Oberwölz symposia. Furthermore, members of the research groups at all Austrian institutions regularly organize major international workshops and conferences in Austria and internationally.