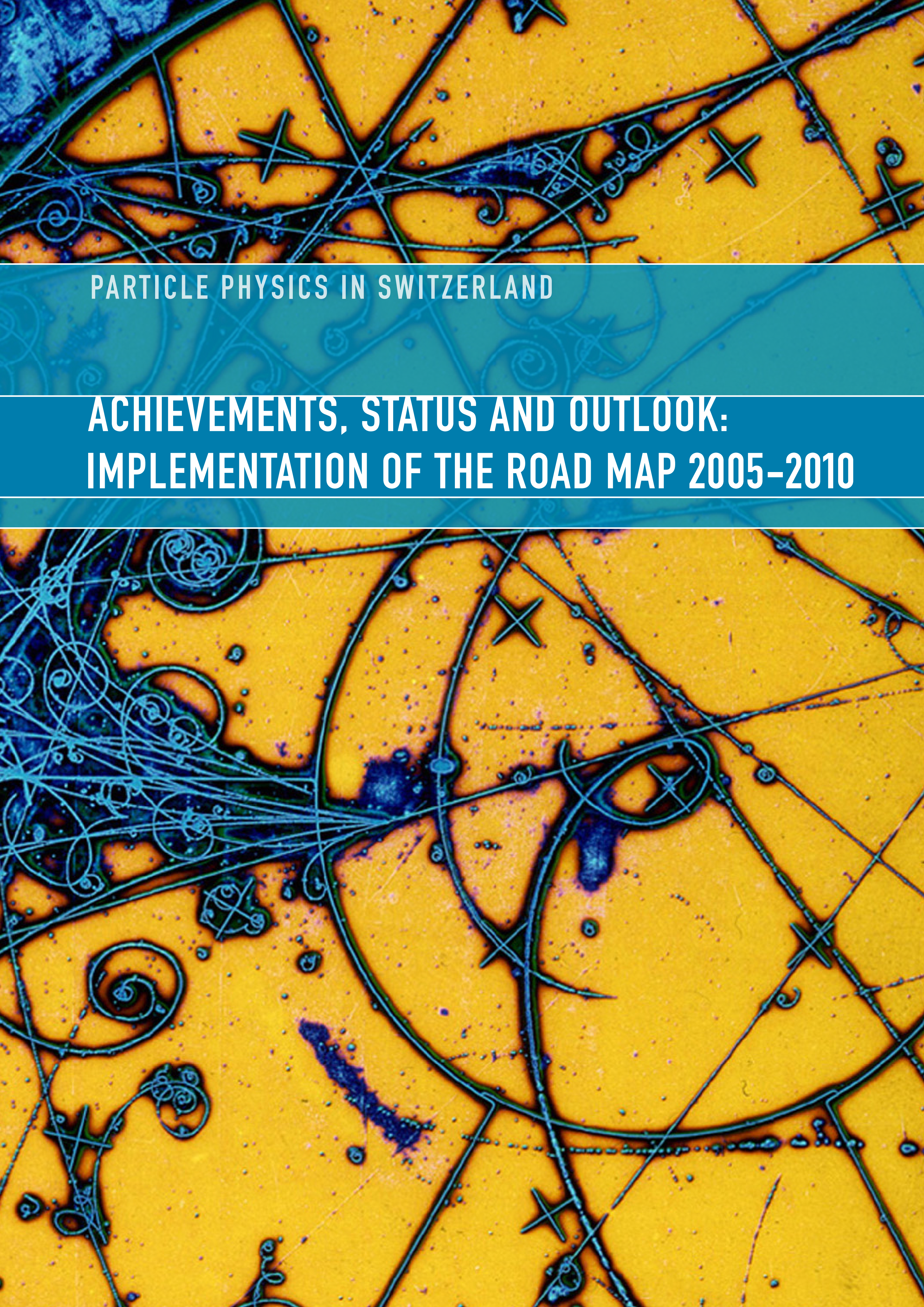
PARTICLE PHYSICS IN SWITZERLAND

ACHIEVEMENTS, STATUS AND OUTLOOK: IMPLEMENTATION OF THE ROAD MAP 2005–2010



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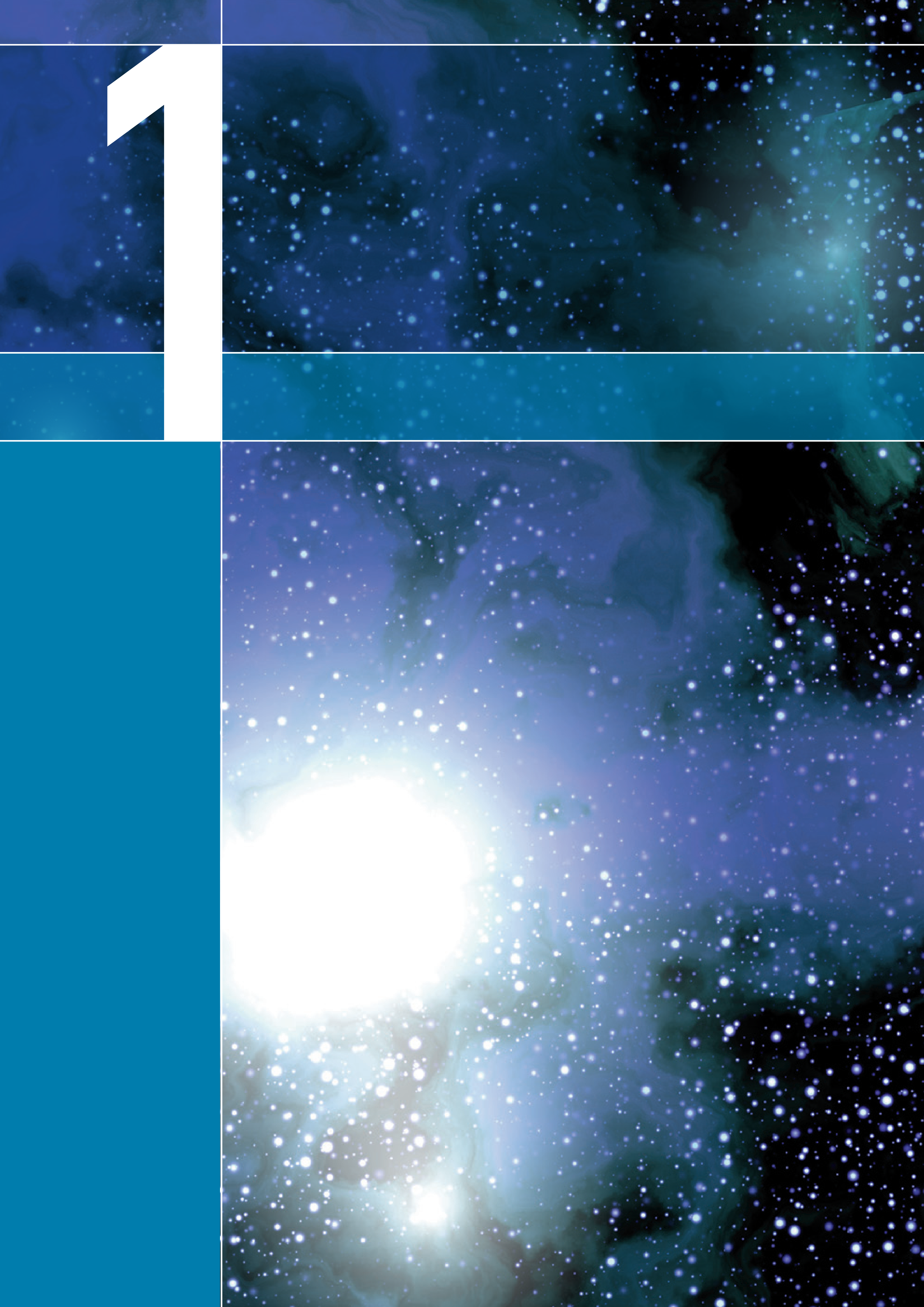

HISTORY OF CHIPP AND ITS ROAD MAP

Particle physics explores the fundamental elements of matter, space and time, and the interactions between them. Experiments at international laboratories (*e.g.* CERN) have established the validity of a theoretical framework for the known electromagnetic, weak and strong interactions between fundamental fermions (quarks and leptons) that form the basis of the so-called Standard Model of particles and interactions. However, many fundamental questions remain unanswered. In close collaboration with theory, some, but certainly not all, will be answered by the running experiments at the high energy and precision frontier, *e.g.* at the Large Hadron Collider and at the Paul Scherrer Institute (PSI), and by the current and coming experiments in neutrino and astroparticle physics. These three main fields of research, supported by solid activities in theoretical physics, particle accelerator and detector Research and Development (R&D), constitute the foundation of the Swiss particle physics research.

In May 2003 the Swiss Particle Physics Forum, replaced in October 2003 by the Swiss Institute for Particle Physics (CHIPP), commissioned a study of the status and outlook of particle physics research and education in Switzerland. In February 2004 the document *Particle Physics in Switzerland: Status and Outlook of Research and Education* was officially endorsed by the CHIPP Board and became the reference Road Map for particle physics in Switzerland. In its Board Meeting of August 2009, CHIPP decided to undertake a critical review of the actual implementation of the Road Map, summarized in the present document. CHIPP encourages Swiss representatives to organizations writing or updating their Road Maps in the relevant domains, such as the CERN Council or the ApPEC Steering Committee, to promote this document.

The original Road Map document considered the development of particle physics in Switzerland for the 10 to 15 years following its publication and makes a series of recommendations. These are meant to provide our vision and input to the Cantonal Universities, Federal Institutes, the Swiss National Foundation and governmental agencies for their future policy planning. The present document does not attempt to revise the main conclusions and recommendations of the Road Map, but it is rather looking at its implementation and progress more than five years after its formulation. In some cases, new facts have brought modifications of the Road Map that are presented here and justified.

With respect to the original Road Map recommendations, one has been left unchanged (no. 1), one has been fulfilled (n. 2), five underwent appreciable modifications (n. 3, 4, 5, 6 and 9), three were adapted to the present situation (n. 7, 8 and 10), and a new one has been introduced (n. 6a).

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CHIPP ORGANIZATION AND DEVELOPMENT

CHIPP has acquired a major role in the coordination of the Swiss activities in particle physics and, notably, in the monitoring of the implementation of the Road Map. Since its birth CHIPP has evolved into a well-organized structure. Four Chairpersons have led the CHIPP Executive Board since 2004 (A. Clark, A. Rubbia, U. Straumann and presently M. Pohl). The successful self-organization of the particle physics community with the CHIPP body and its initiatives has been one of the most significant facts following the editing of the Road Map. In the last years, the activities of CHIPP have materialized in a series of actions towards increased visibility of the community both internally and in international bodies and institutions. CHIPP has organized topical workshops, issued a prize for young researchers, established a school of particle physics, set up a monitoring framework for resources and funding, etc.

CHIPP consists of two bodies: the CHIPP Plenary and the CHIPP Board. The CHIPP Plenary assembles all particle, nuclear, astroparticle and accelerator physicists holding a diploma and working in a Swiss institution, as well as Swiss PhD nationals working at CERN. The CHIPP Plenary meets at least once per year. The CHIPP Board, which meets at least twice per year, includes professors with activities in theoretical and experimental particle, astroparticle, nuclear and accelerator physics, the heads of the experimental and theory groups at PSI, plus additional co-opted members with specific duties. The CHIPP Board elects an Executive Board consisting of a Chair and up to three members for a mandate of 2 years. In 2010 CHIPP has transformed itself into an association according to Swiss law. In 2011 CHIPP will join the Swiss Academy of Natural Sciences, SCNAT.

According to the expectations outlined in the Road Map, particle physics in Switzerland has developed and progressed around CERN (particularly relevant for Switzerland as one of its host countries) and the national laboratory, PSI, in addition to the numerous University[1] laboratories where the excellence of the Swiss particle physics research has produced outstanding results since 2004. CERN is becoming today the world laboratory for particle physics, mainly thanks to the success of the construction and early operation of the LHC. Recent decisions of the CERN Council will lead to a worldwide extension of the membership, while still maintaining its European identity. Discussions on a broadening of the initial mandate towards astroparticle physics have started. CERN has revived its role as the coordinator of European particle physics, as stated in its convention, and created the *European Strategy Session of the Council*, whose recommendations are largely in line with those of the Swiss Road Map and with those worked out by other international bodies such as ASPERA, ApPEC and ECFA.

[1] By the term University we denote in this document the Cantonal Universities and the Swiss Federal Institutes of Technology, in accordance to the current Swiss laws on higher education.

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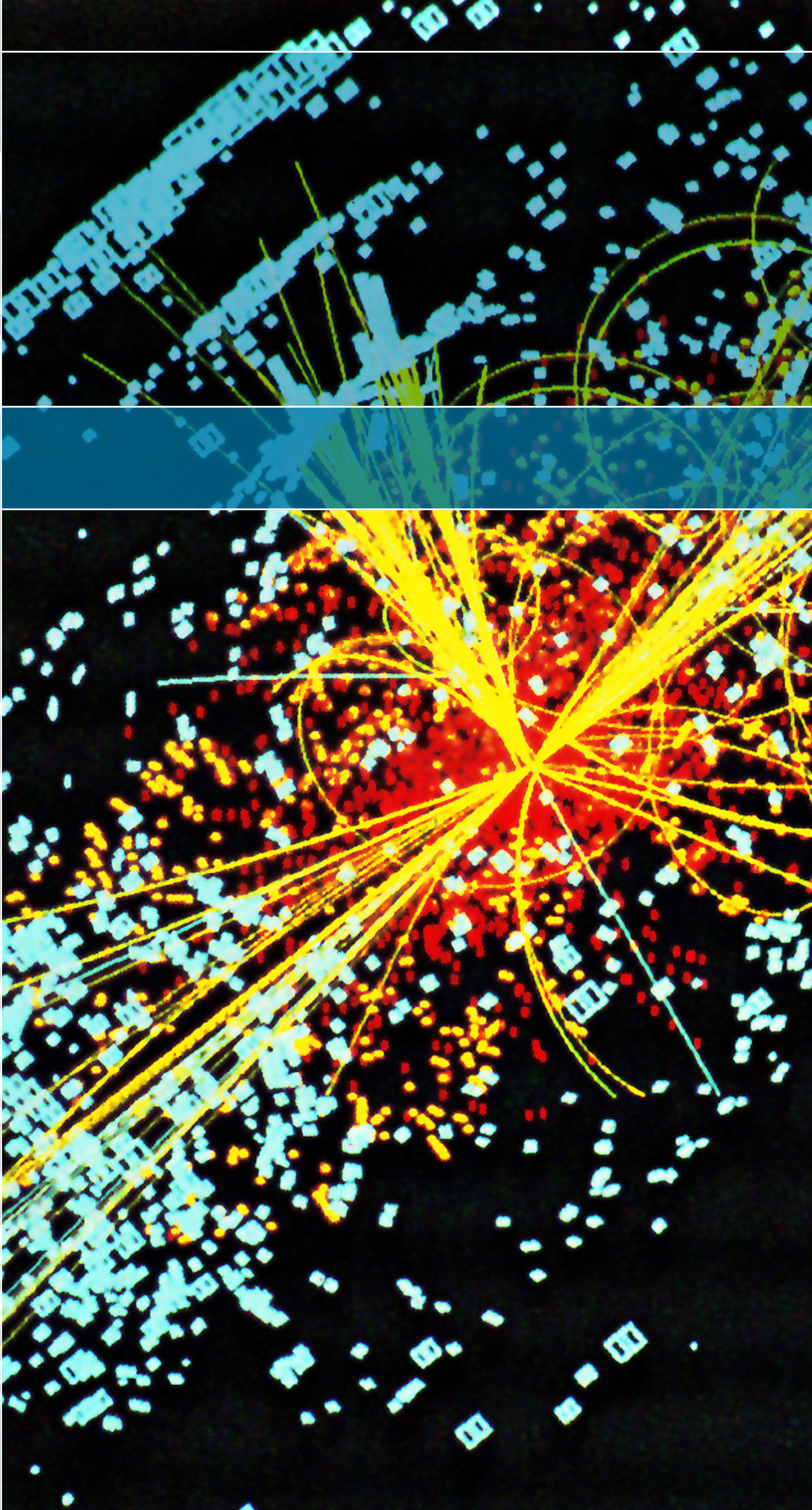

ACHIEVEMENTS, STATUS AND OUTLOOK

As of today, nuclear and particle physics see in Switzerland very active groups at the Cantonal Universities of Basel, Bern, Geneva, and Zürich, at the Federal Institutes of Technology at Lausanne (EPFL) and Zürich (ETHZ), and at the PSI. In addition, the Swiss Centre for Scientific Computing (CSCS) of Manno is an important technical collaborator in the context of the GRID, the remote analysis system developed and adequate for the intense LHC data analyses.

In 2003, the Swiss experimental particle physics community included 135 active researchers plus nearly 100 doctoral students. Today we have 170 researchers and a total of 130 PhD students. Since the publication of the Road Map, of the order of 1000 scientific publications have been co-authored by Swiss particle physicists.

The continuous support from the cantonal and national funding agencies has been essential for the significant progress made by the CHIPP community during the last five years. In addition to the SNF and University grants, the contribution of a dedicated funding instrument from SER (State Secretariat for Education and Research), *i.e.* FORCE, has allowed the construction and operation of the LHC experiments and the support of other CERN projects and R&D activities on site. The success story of the FORCE instrument for advancing particle physics projects has been recently discussed in the document *"FORCE – 10 Years of Funding Research at CERN (1997–2007)"*. For the future, additional funding instruments will be required to also foster research activities outside CERN, notably neutrino and astroparticle physics using other worldwide infrastructures.

From the time the original CHIPP Roadmap was published in 2004, advances in the particle and astroparticle physics landscape have taken place. In spite of these successes, a number of fundamental physics questions are yet to be answered. The most important ones still include those quoted in 2004:

– What are the elementary particles and what is the origin of masses and flavors?
– What are the origins of the fundamental forces and can a unified description of the forces be made?
– Why are neutrino masses so small and what is the nature of neutrino mixing and masses?
– Is the proton stable?
– What is the reason for the matter-antimatter asymmetry in the Universe?
– What is the composition of dark matter in the Milky Way and in the Universe?
– What is the nature of dark energy in the Universe?
– What are the dimensions of space-time and what is the role of gravity?

To contribute to providing answers for the above questions, a strategy was developed and successfully implemented within Switzerland. It is based on a balanced program of three complementary experimental directions (pillars):

• Experiments at the frontier of high-energy interactions between fundamental particles, including indirect searches with high precision experiments at low energy.
• Experiments to explore the observed transitions between different neutrino flavors and ultimately to search for leptonic CP-violation, along with experiments to explore the nature of neutrinos (Majorana versus Dirac particle).
• Fundamental experiments at the interface between observational cosmology, astrophysics, particle and nuclear physics with a strong emphasis on understanding the nature of Dark Matter.

3.1 PARTICLE THEORY

Traversing all of the main pillars, theoretical activities in Switzerland on particle physics have been summarized comprehensively in the Swiss Road Map. One of the major directions beyond the Road Map was the intensive collaboration between theorists and experimentalists in order to cope with the complexity of LHC data and their interpretation. This goal has been approached by the computation of reliable predictions for signal and background processes at the LHC and further by major common efforts of theoretical and experimental groups in developing search strategies for new particles and for the extraction of fundamental parameters from the LHC data. Moreover, the development of new models and their confrontation with observations has been pursued by theory groups in Switzerland as well as studies of the interplay of LHC collider observables with high precision measurements at lower energies and astroparticle physics results. Another very important role of the theory groups in Switzerland is the intensive training of young researchers in particle physics. Particle theory is thus transversal to the three pillars and of fundamental importance to all activities.

As an example of the flourishing theory activities in Switzerland, we note that in the beginning of 2010 CERN has established the LHC Higgs Cross Section Working Group consisting of 10 subgroups for the different Higgs production and decay processes relevant at the LHC. Two experimentalists (ATLAS and CMS) and two theorists coordinate the overall Working Group and each subgroup. The goal is to analyze in detail the theoretical predictions for all Higgs boson production and decay processes at the LHC including all known higher-order corrections and to determine their respective uncertainties. This work has been performed in close collaboration with the parallel work of the PDF4LHC Working Group, which addressed the problem of a global scheme for the uncertainties originating from the parton density functions of the proton and the strong coupling constant.

As a first step the working group analyzed all relevant inclusive cross sections and decay widths, *i.e.* without any experimental cuts. The results of this first step have been summarized in a working group report. Since all leading theorists of Higgs physics worldwide have been brought together with the experimentalists in this working group this first document serves as a reference for the present state-of-the-art predictions for the LHC. Two theorists of the PSI theory group and one theorist from Zürich University are coordinating members of this LHC Higgs Cross Section Working Group. As the next step the working group will address exclusive observables that will enable the experimentalists to introduce cuts within the most-up-to-date framework. The working group is planning to continue its work during the ongoing LHC runs and analyses in an analogous manner as the former LEP working groups.

3.2 EXPERIMENTS AT THE FRONTIER OF HIGH-ENERGY INTERACTIONS BETWEEN FUNDAMENTAL PARTICLES

The LHC went into operation in 2009 with its four large detectors ALICE, ATLAS, CMS and LHCb. Swiss groups are active since many years in ATLAS (Universities of Bern, Geneva), CMS (ETHZ, PSI, University of Zürich) and LHCb (EPFL, University of Zürich), with important contributions to the design, construction and commissioning of the experiments, and with important management and coordination responsibilities. ATLAS and CMS are general-purpose detectors, designed to exploit the full discovery potential of the LHC, while LHCb will take advantage of the high statistics available at the LHC to investigate some of the subtle differences between hadronic matter and antimatter.

The LHC is in continuous operation since first proton-proton collisions were achieved, now running at $\sqrt{s}$ = 7 TeV since March 2010. Peak instantaneous and integrated luminosities evolved almost exponentially with time and a total integrated luminosity of about 40 pb^{-1} per experiment has been delivered by the end of 2010. After a short technical stop, the machine has restarted its operation and it is planned to run for 2011 and 2012, with an expected integrated luminosity of several fb^{-1} per experiment. After a shut-down from 2013 to 2014, the machine should be able to reach the design energy of $\sqrt{s}$ = 14 TeV.

The detector performance observed during 2010 is beyond expectation for all LHC experiments. All detector components operated very satisfactorily and about 90% of the delivered luminosity provides useful data for physics analysis. Swiss particle physicists have made important contributions to three of the four experiments not only to achieve this outstanding operational performance but also shouldering important managerial tasks and providing scientific leadership. Many reactions have been observed and significant samples of W and Z boson, and top quark events have been collected. Data taken were very quickly ready for analysis thanks to the GRID computing infrastructure and readiness of the alignment and calibration procedures prepared by the experiments.

First physics results from the LHC experiments have been presented already at the ICHEP conference in Paris in summer of 2010. Many more are being published based on the 40 pb^{-1} worth of p-p collision data collected by the end of 2010. First limits on new particles and interactions have been obtained, which substantially improve previous results. With these very encouraging early achievements, the path to discoveries is now open, should nature be kind to us. In heavy flavor physics, the B_s oscillation frequency and a branching fraction limit on the very interesting rare decay mode $B_s \rightarrow \mu\mu$ have already been measured with an accuracy comparable to the current best measurements at the Tevatron. Very interesting results have also been obtained from a short heavy ion run at the end of 2010, where the long expected effect of jet quenching has been observed in Pb-Pb collisions.

To increase the impact of Swiss groups on the analysis of LHC data, the Swiss University Conference (SUK) approved the formation of the "Swiss Center of Advanced Studies in Particle Physics in the LHC Era" (Innovation and Cooperation Project C-15). The program supports a total of nine additional post-doctoral fellows from 2008 to 2012. In parallel, a ProDoc entitled "Particle Physics in the LHC Era" supports additional graduate students and a doctoral program in particle physics. Both the C-15 and the ProDoc program are crucial for sustaining CHIPP activities in general. When they end in 2012, a sustainable funding must be established by successive integration into the Universities, through a transitional period from 2013 to 2016 and using a progressive co-funding scheme.

With the expected continuous performance increases of the LHC, the experimental collaborations need to follow in lockstep to upgrade their experiments for best physics exploitation of the LHC data. First upgrade activities for the ATLAS, CMS and LHCb experiments will take place around 2016 to prepare for the phase 1 period of the LHC, where luminosities above the design luminosity of 10^{34} $cm^{-2}s^{-1}$ are expected.

For ATLAS this implies that more radiation hard sensors and electronics must complement the pixel detector. In the near term, it is planned to keep the existing innermost layer in place and insert a new device between a smaller radius beam pipe and the existing inner detector (IBL) with contributions from the

Bern and Geneva groups. This insertion is a first class technological challenge, but will lead to a substantial performance enhancement.

For phase 1, CMS will upgrade its three-layer barrel pixel detector to a four layer design with a state-of-the-art cooling system to reduce the passive material, offset the effects of radiation damage and boost the performance of the system well beyond the original goal. The Swiss consortium, consisting of ETH Zürich, PSI and University of Zürich, will design the new digital readout chip and construct the innermost two layers and assume a leadership role in this international project.

The presently operating LHCb experiment requires the instantaneous luminosity from the LHC to not exceed a value of about 2×10^{32} $cm^{-2}s^{-1}$. This is achieved by displacing the LHC beams to produce only a fraction of the maximum collision rate once the available luminosity exceeds this value. An upgraded LHCb is proposed, which would allow increasing the luminosity by about a factor 10. To overcome the present level 0 hardware trigger limitations, the readout rate will be increased from 1 MHz to 40 MHz allowing for an implementation of a complete software based trigger chain. To cope with the higher track density major changes in the innermost tracking detectors are also necessary. The upgraded experiment as a very precise forward spectrometer at the LHC collider has unique discovery potential that is not only restricted to flavor physics.

After reaching full energy and luminosity of the LHC as planned today, CERN currently intends to extend the machine luminosity around 2020 by an additional factor, to reach of the order of $5\times10^{34}cm^{-2}s^{-1}$. This will require a thorough update of the LHC detectors. For ATLAS, it will be necessary to replace the whole inner detector with finer granularity devices to fight pile-up. Furthermore, the electronics of the liquid argon calorimeter needs to be adapted. CMS will also overhaul their tracking system and prepare an upgrade of the trigger and calorimetry system. R&D is ongoing to study properties of novel scintillating materials that could lead to a possible future upgrade or replacement of the CMS end-cap calorimeters.

Depending on the nature and energy scale of new phenomena discovered at LHC, several types and specifications of a future accelerator project may be envisaged. Superconducting linear colliders or two-beam accelerators of the CLIC type may be appropriate, if an electron-positron collider is the right answer to the physics questions of the next generation. Other options include a possible electron-proton extension of the LHC. More unconventional approaches, such as plasma wake field accelerators or a muon collider, may also qualify as options for the future.

The high energy frontier is complementarily pushed with high precision experiments at low energies. In certain scenarios, energy scales and masses of hypothetical particles are being tested even beyond the reach of direct searches at available or future high energy accelerators. One of the forefront facilities for this kind of research is centered around the high intensity proton accelerator at PSI. A more detailed account is given under “PSI Activities” below.

To answer more detailed questions, additional high-intensity proton beams and high-luminosity flavor factories may be required. Design and construction of future machines is a decadal program. Therefore, R&D activities cannot wait until LHC results will narrow down the choice. Instead, it is necessary to pursue R&D studies for all viable options, with the aim to have sufficient information available when a decision is called for.

Recommendation 1 – Operation and consolidation of LHC experiments

The physics exploitation of the LHC remains the first priority of the particle physics program in

Switzerland. CHIPP calls on the Federal Authorities and the National Science Foundation to cover the maintenance and operation costs of Swiss participation in LHC experiments including GRID in an optimal way. It is recommended that resources be made available to fully exploit the LHC potential by the required consolidation of the detectors in order to cope with the medium term luminosity increase of the machine towards and beyond the design luminosity.

CHIPP recommends that resources be continuously provided, mainly by the SNF, to analyze the data of the LHC experiments. For the years 2013–2016 this should be complemented in a joint endeavor between Universities and the SUK/ETH-Rat through the continuation of the Centre for Advanced Studies in Particle Physics in the LHC Era. After 2016, the Universities should take over the funding of the Centre.

Recommendation 2 – Prior to the LHC

The Road Map recommended: "CHIPP recommends adequate support for the timely completion of ongoing experiments and in particular support for the participation of young physicists in these experiments". This recommendation has been followed.

Recommendation 3 – the step beyond the present LHC

CHIPP recommends that detector upgrades commensurate with the LHC machine upgrades be supported by Swiss cantonal and federal agencies, including the SNF as well as FORCE in its future form, with a level of financing adequate for the Swiss groups to complete successfully the proposed programs.

CHIPP recommends that accelerator and detector R&D for future facilities at CERN, beyond the LHC, be adequately and continuously funded.

3.3 EXPERIMENTS ON NEUTRINO PHYSICS: OSCILLATIONS AND THE NATURE OF NEUTRINOS

The coordinated participation of Swiss researchers in the international long baseline neutrino oscillation experiments OPERA and T2K is an evolution of the initial CHIPP Road Map. In the early phase of the CERN CNGS project the Bern group was member of OPERA and the ETHZ group contributed to the ICARUS experiment, both experiments to be built at the underground Laboratori Nazionali del Gran Sasso (LNGS) along the CNGS beam. Meanwhile, the University of Geneva group spearheaded studies of future neutrino facilities, including the HARP experiment at CERN, which led to participation in the K2K and T2K experiments in Japan. The convergence into two main complementary and parallel streams with OPERA aiming at $\nu_\mu \rightarrow \nu_\tau$ appearance and T2K on the next generation search for $\nu_\mu \rightarrow \nu_e$ appearance has focused Swiss neutrino resources and made most efficient use of investments, hence increasing the impact and visibility of Switzerland in those experiments.

The OPERA experiment has successfully run from 2008 to 2010 collecting several thousand neutrino interactions in the finely segmented 1.25 kton lead/emulsion film target, with good prospects for extended runs in 2011 and 2012. The experiment sees a strong Swiss participation with a leading scientific and management role of researchers from Bern and ETHZ (since 2008 the Neuchatel group has joined the Bern group). In 2010 the collaboration published the observation of a first tau-neutrino candidate event. With the final statistics the experiment will reach a sensitivity adequate for the discovery of the direct appearance of neutrino oscillations.

The next generation T2K experiment, using the newly built very high intensity proton accelerator J-PARC complex in Japan, is the logical continuation of the line of research in neutrino oscillation physics beyond OPERA. A very visible Swiss participation with a leading scientific and management role of researchers from Bern, ETHZ and Geneva was established since 2006. The measurement of the last unknown mixing-angle θ_{13} will be the main goal of the project. The experiment will proceed with a high-sensitivity measurement of ν_μ disappearance and will be the world most sensitive search for ν_e appearance. The experiment started collecting data in 2010. First results have been presented in spring 2011. T2K profits from the ancillary NA61 experiment at CERN, jointly conducted with the collaboration of the three Swiss groups of T2K. The main goal of NA61 is the measurement of hadronic reactions relevant for the understanding of the secondary's production mechanism in the T2K target to precisely predict the neutrino flux at Super-Kamiokande.

The results of OPERA and T2K will contribute in guiding the next steps worldwide. Positive results from these experiments will signify the direct experimental proof of the fully 3×3 nature of the PMNS matrix and the correctness of its formalism to describe lepton flavor violation in nature. In this case, the logical next step will be the proof of the complex nature of the mixing matrix via the measurement of the δ_{CP} phase. This measurement can be achievable by precision-study of the energy dependence of the $\nu_\mu \rightarrow \nu_e$ or $\nu_e \rightarrow \nu_\mu$ appearance probability at a fix baseline. Alternatively, a different oscillatory behavior of neutrinos compared to antineutrinos would indicate CP-violation in the lepton sector, although with the competing effect of neutrino oscillations in matter.

This challenging measurement requires a next-generation underground giant neutrino detector at the 100 to 1000 kton-scale, located at the proper distance of a MW-class conventional neutrino beam source, or of a more powerful neutrino facility of a new type. The feasibility of a new neutrino observatory in Europe is presently being explored in the FP7 LAGUNA design study, including the ETHZ and Bern groups. A rich particle and astro-particle physics program will be aimed at in addition to the accelerator beam measurements, *e.g.* proton decay searches, the study of neutrinos of astrophysical origin, etc. A second phase of LAGUNA has been approved (LAGUNA-LBNO), involving Bern, ETHZ, and Geneva, where by 2013 long baseline neutrino beams from CERN will be studied and detector designs developed with the aim of a future long baseline neutrino oscillation experiment.

More intense neutrino beams, identified as beta-beams or neutrino factories, are likely to be required to study with high sensitivity the neutrino mixing matrix, CP violation and the neutrino mass hierarchy. Swiss groups have been very active in the study of these novel beams since 2000. The most sensitive facility, the neutrino factory, depends critically on the feasibility of a novel accelerator technique, studied by the MICE experiment at RAL, in which Geneva plays a leading management role. An assessment on the technical feasibility and on the costs of such facilities should emerge towards the end of the EUROnu design study around mid-2012.

The GERDA and EXO experiments aim at the detection of the neutrino-less double beta decay in 76-Ge and 136-Xe, respectively, and hence probe the nature of massive neutrinos (Majorana versus Dirac particle), as well as possible lepton number violation. Both experiments feature a visible participation of the Swiss groups of Zürich and Bern (former Neuchatel group). GERDA at LNGS makes use of bare, high-purity germanium (HPGe) crystals enriched in 76-Ge, operated in a cryostat with 100 tons of ultra-pure liquid argon surrounded by a large water Cerenkov shield. The commissioning phase has started in summer 2010. The first science run, using 20 kg of enriched HPGe detectors will commence early 2011. In parallel, the production and testing of an additional 20 kg of HPGe will be pursued. EXO will operate a liquid xenon time projection chamber in a low-background shield at the WIPP underground site in Carlsbad, USA. The commissioning with 200 kg of natural xenon has started, while a science run using 200 kg of enriched 136-Xe will start during 2011. Several methods to tag the resulting 136-Ba^{++} ions are being investigated for a larger scale experiment.

GERDA and EXO will eventually reach a sensitivity of ~130 meV for the effective Majorana neutrino mass. They will explore the nearly degenerate mass pattern of neutrinos within the next years using different isotopes and technologies. The two projects will probe the mass range predicted by neutrino oscillation experiments for the case of an inverted neutrino mass hierarchy.

Options to address the next level of sensitivity, requiring one ton of a double-beta emitter and a background level below one count per year and ton, are being studied. Given the increased complexity of such projects, these will likely be realized in the framework of larger interregional collaboration.

Recommendation 4 – the Present Neutrino Physics Program

Given the leadership of Swiss groups in these projects, CHIPP recommends that the necessary funding be provided by funding agencies for the maintenance, operation and physics exploitation of the OPERA and T2K long baseline neutrino experiments.

Recommendation 5 – the Future Programs

The future of neutrino oscillation physics in Europe, based on the findings of OPERA and T2K, will require the construction of a new large mass underground neutrino observatory and a powerful neutrino beam, at CERN or elsewhere, as studied in the LAGUNA and EUROnu design studies for a long baseline neutrino oscillation experiment. The detector should be, in addition, capable of addressing fundamental physics subjects such as multi-messenger astrophysics and proton decay. CHIPP recommends that Swiss scientists develop a program with a broad international participation towards the realization of the next generation underground observatory and a suitable beam, implemented in synergy between the Swiss institutes.

CHIPP recommends that a strong financial and scientific support be given to the current complementary experiments on neutrino-less double beta decay, GERDA and EXO. CHIPP also recommends a visible Swiss participation in the construction and operation of a future, ton-scale neutrino-less double beta decay experiment.

3.4 EXPERIMENTS AT THE INTERFACE OF PARTICLE PHYSICS WITH ASTROPHYSICS AND COSMOLOGY

One of the most exciting topics in physics today is Dark Matter in the Universe. Although evidence for the gravitational action of cold Dark Matter is well established, its true nature is not yet known. The most promising explanation is Weakly Interacting Massive Particles (WIMPs), since they would naturally lead to the observed abundance and arise in many extensions of the Standard Model. WIMPs could be detected either directly, by their collisions with nuclei in underground detectors, or indirectly, via their self-annihilation products. Discovery of Dark Matter would definitely be a milestone in physics. Since the predicted signal rates for direct detection experiments are much lower than one interaction per kg of target material and day, large detector masses and ultra-low backgrounds are necessary ingredients of any experiment aiming to discover WIMPs.

Results from noble liquid detectors have recently shown that these devices are among the most promising technologies to push the sensitivity of direct WIMP searches far beyond the existing limits into the regime of current theoretical predictions. Liquid argon and xenon, are excellent WIMP targets, thanks to their charge- and light-yield for nuclear recoils.

The XENON100 experiment (Zürich group), using 170 kg of liquid Xe as target, is taking science data at LNGS since January 2010 and has a background two orders of magnitude lower than any other dark matter detector. The XENON1T is currently being planned. It will make use of a total of 2.4 tons of liquid Xe, with the construction phase to start in 2011 and the full physics potential to be reached by 2015. The ArDM experiment (ETHZ and initially Zürich) employs 850 kg of liquid Ar as active target. The experiment is under commissioning at CERN and will be installed at the Canfranc Underground Laboratory in Spain by 2011. The DARWIN project, an R&D and design study for a multi-ton Dark Matter search-facility using liquid Ar and Xe, originated from the joint experience of the XENON and ArDM groups. It has been recently funded by the Astroparticle ERAnet (ASPERA) and has been launched in 2010 under Swiss leadership (Zürich). The goal is to deliver a technical design report on the largest scale facility feasible around 2013 as input for a coordinated proposal for actual construction and operation of such a detector underground.

In addition to direct Dark Matter detection by its interactions, observation of the distribution of Dark Matter around celestial structures and the detection of secondary particles from Dark Matter self-annihilation reveal important information about the nature of the phenomenon. Weak lensing is a tool to probe the matter distribution by using astronomical means in space bound observatories such as the proposed EUCLID mission.

Space bound telescopes from X-ray energies onward and ground based high-energy photon telescopes like MAGIC (with important contributions from ETHZ), may reveal photon signals from Dark Matter agglomerations. In addition, they provide a trace of particle acceleration by astrophysical accelerators, up to the highest energies of order 10^{20} eV. Indirect Dark Matter searches via WIMP annihilation products are complementary to laboratory searches, and Switzerland is involved in the AMS and PEBS experiments (respectively with Geneva and EPFL/ETHZ) to detect galactic antimatter from WIMP annihilation. These experiments provide in addition information about the production, acceleration and transport of cosmic rays.

Future large scale facilities to use the Earth atmosphere for particle detection see an important Swiss participation. In particular, the Cherenkov Telescope Array CTA will detect a large range of high energy photons from the ground, the JEM-EUSO facility on the International Space Station will observe very high energy cosmic rays from above. All Swiss experimental astroparticle groups have joined forces to contribute to the CTA project in a very visible way. An important contribution to JEM-EUSO is in preparation.

Simultaneous observation of high energy sources with data from cosmic rays, photons and neutrinos in as large an energy range as feasible promises new insights of both astrophysical and particle physics phenomena. The major existing projects with Swiss participation, MAGIC, AMS and EUCLID, in addition to scientific goals of their own right, provide a testing ground for the multi-messenger approach. In view of this, it is desirable to establish a multi-messenger data repository in Switzerland. In the mid-term future, major projects such as PEBS, CTA, JEM-EUSO, as well as large underground facilities, will have to include the multi-messenger aspect in their planning and provide wider access to their data.

At the time of the CHIPP Road Map, the phenomenon of Dark Energy, responsible for about 75% of the energy density of the Universe, was not yet firmly established. Since then, corroborating evidence for its existence has been accumulated. Efforts must be made to clarify the nature of this dominating component and to explain its ability to apparently accelerate the expansion of the Universe.

Recommendation 6 – Direct and Indirect Dark Matter Detection

CHIPP recommends that the necessary resources be provided for the construction, maintenance, operation and physics exploitation of the present generation XENON100, XENON1T and ArDM experiments for the direct detection of Dark Matter. The construction and operation of the DARWIN multi-ton Dark Matter search facility should receive an appropriate Swiss contribution.

CHIPP also recommends adequate support for the physics exploitation of AMS and MAGIC. The CTA and JEM-EUSO projects are future facilities of worldwide scale, involving several Swiss astroparticle physics groups and their construction must be funded. On a smaller scale, the construction and operation of the PEBS and POLAR experiments with large contributions of Swiss particle physicists should also receive strong support. A Swiss repository for multi-messenger astroparticle physics data should be established, preferentially at the Center for Astroparticle Physics CAP Genève, which includes the ISDC and profits from its long track record as a scientific data center.

Dark Energy is the dominating component of the Universe and research into its properties and nature must be pursued.

3.5 PSI ACTIVITIES

PSI plays a key role in Switzerland given its nature of national laboratory with an excellent international reputation. At the frontier of high-energy interactions it is involved in the CMS experiment at LHC, contributes to collider phenomenology and supports an active program of precision physics at PSI using the 1.3 MW proton beam 590 MeV cyclotron. This figurehead facility delivers the world's most intense beams of low-energy pions, muons and ultra-cold neutrons. Projects are ongoing or planned for further intensity upgrades in view of a next generation of experiments.

In high-energy physics, the most outstanding recent hardware development is the barrel pixel detector for CMS, built by a PSI lead consortium with ETHZ and University of Zürich. The PSI CMS physics analysis presently concentrates on B-physics and soon also on top and Higgs channels. Preparations for upgrading the CMS pixel detector are ongoing, within the Swiss consortium mentioned above.

The flagship particle physics experiments taking place at PSI are searches for the lepton flavor violating decay $\mu \rightarrow e\gamma$ (MEG) and for the CP-violating electric dipole moment of the neutron (nEDM). Both are unique opportunities to discover physics beyond the Standard Model and complementary to collider experiments. Extensions of these searches are being planned, investigating options for an improved search for the decay $\mu \rightarrow eee$. Other experiments that have received considerable attention are: the measurement of the Lamb-shift in muonic hydrogen, of the positive muon lifetime (FAST and MuLAN), of the negative muon capture on protons (MuCAP) and of the pion branching ratio to electrons versus muons (PEN). Ultracold neutron source as well as muon and muonium beam development is foreseen, both for further improving intensity and beam quality for precision experiments.

Development of technology is an ongoing task at PSI particle physics and often finds wider applications: X-ray detector systems, charged particle and neutron detection systems, APDs and G-APDs to complement PMTs in photon detection. The CDCT (chip design core team) supports electronics developments also in collaboration with external groups. PSI accelerator facilities allow radiation tolerance investigations, mostly for electronics components. A wide range of particle beams can also be used for performance verification and calibration of particle physics detectors.

Recommendation 6a – Role of the PSI National Laboratory
CHIPP recommends strong support for high precision experiments at low energy taking advantage of the unique beam characteristics achieved at the PSI accelerator facilities. CHIPP encourages Swiss University groups to further engage in such challenging experiments, taking into account their scientific as well as their educational value. Consequently, CHIPP recommends an adequate funding for Swiss groups involved in these activities.

CHIPP also recommends that the excellence of detector R&D and construction as well as particle beam test facilities at PSI be maintained and developed further. Close collaboration with University groups as well as CERN exists and should be further intensified.

3.6 ACCELERATOR RESEARCH

The future of particle physics hinges critically on progress in accelerator technology; major developments in particle physics since the 1950s have resulted almost entirely from the parallel development of powerful and increasingly sophisticated accelerator facilities. The time scale for accelerator development is long. As a result, on-going accelerator R&D is impossible to disentangle from the perspective of physics requirements for the future.

The main accelerator R&D at CERN is directed towards:

- full exploitation of the LHC physics potential by insuring fast ramp up to the design parameters and high-luminosity and high-energy (HE-LHC) upgrades;
- a future multi-TeV e^+e^- Compact LInear Collider (CLIC). CERN intends to produce a Technical Design Report (TDR) and to demonstrate the feasibility of the CLIC technology by 2011 using the CTF3 test facility. The scientific case for CLIC, which can also operate as a sub-TeV machine, is strong and will be influenced by results from the LHC;
- exploratory studies in collaboration with other European labs to achieve higher gradients, involving plasma and laser acceleration.

Long-term accelerator R&D is also essential to realize neutrino beams of sufficient intensity to access the possible leptonic CP-violation effects, an essential step towards understanding the matter-antimatter asymmetry in the Universe. The R&D necessary for a neutrino factory has started since several years with the MICE experiments. Now, a full design study, EUROnu, is ongoing to study and compare cost and feasibility of super-beam, beta-beam and neutrino factory with support from the European Union. All possible options for high intensity neutrino beams require a very high-intensity proton source. Such a source would also benefit other aspects of CERN activities, from future luminosity upgrades at the LHC to nuclear physics and even material sciences. Subsequent intensity increases would require the development of many other new techniques to prepare, accelerate and store muons that subsequently decay into neutrinos. That work is starting, with the effective participation of Swiss institutes.

Accelerator activities at PSI have extended outside of particle physics to the construction of the Swiss Light Source (SLS), the use of proton beam for the Neutron Spallation Source (SINQ) and the world's first scanning gantry proton therapy facility. Under construction at PSI is the SwissFEL, a hard X-Ray Free Electron Laser based on a 6 GeV linear electron accelerator. This reservoir of accelerator expertise at PSI is an extremely important resource. Collaboration already exists between the accelerator activities of PSI and CERN but this should be extended and made more visible.

Accelerator physics is a science in its own right and should be promoted in Universities. The decision by EPFL and PSI to create a Chair in Accelerator Science is a very positive step, in view of the need to maintain excellence in accelerator design in Switzerland and at CERN.

Recommendation 7 and 8 – Accelerator R&D

CHIPP recommends that the Swiss delegation actively encourage CERN to fund the necessary accelerator R&D for LHC upgrades towards the full realization of its physics potential. CHIPP further recommends that CERN should adequately fund the R&D towards an e^+e^- linear collider, in particular concentrating on a multi-TeV CLIC scheme.

CHIPP recommends that PSI strives to maintain a leading role at the intensity frontier with its high power proton accelerator and attached secondary beam lines. R&D to further increase beam intensities and secondary beam quality should be pursued and supported.

CHIPP recommends that collaboration on accelerator R&D between CERN and PSI should be fostered and made more visible.

The R&D towards future neutrino facilities should be supported as well, by timely following the results from the present generation of neutrino experiments and the decisions concerning the next experimental steps.

3.7 EDUCATION

As stated in the Road Map document: *The success of particle physics research in Switzerland largely results from the high-qualified and innovative scientific and technical teams within Swiss institutes. To maintain that quality, the best students must be attracted to the field.* This is still very much the focal point of the Swiss strategy, since CHIPP considers that an education in particle physics in all undergraduate physics curricula is mandatory.

The graduate physics education program in Switzerland has made progress in the last few years, due to the initiative of the Universities. In western Switzerland, CUSO has transformed the successful program of the *Troisième cycle de la physique en Suisse romande* into a coherent and well-supported doctoral program for all PhD students from their member institutions. Improving the offer and access conditions of all students in eastern Switzerland should complete a national post-graduate program. As far as specialized education in particle physics is concerned, CHIPP initiated a ProDoc program to improve the offer and access conditions of PhD students all over Switzerland to the local and regional doctoral programs. The *CHIPP Winter School, the Zuoz Summer School and the CERN School of Physics* play an important role in this program.

Recommendation 9 – Post-Graduate Education in Particle Physics

CHIPP recommends that the present doctoral program in particle and accelerator physics – funded through ProDoc and integrated in the Center for Advanced Studies in Particle Physics C15 – should be further developed on the basis of existing resources and at the Swiss level. The basic principle of such a system should be that the thesis adviser and the student freely agree on an individual program, following the *requirements of their institutions. Access to all courses should be granted to all Swiss PhD students free of charge and credits be granted on an equal footing. In particular, CHIPP recommends that the participating Universities take over the funding of the CHIPP ProDoc after its end in 2012, and integrate it into the successor of the C-15 program.*

3.8 OUTREACH ACTIVITIES

Many Swiss groups at their Universities and at PSI pursue outreach activities. A coordinating effort is made by the CHIPP Outreach Group. It brings together people from all Swiss research sites involved in particle physics to discuss individual and common activities, to exchange ideas and contacts. One representative from astroparticle physics (ASPERA) links particle physics outreach activities with the growing community of astroparticle physicists in areas of common interest. In addition, a representative from SER acts as observer and brings in advice.

So far, fact-sheets about the Swiss participation in the LHC experiments, as well as two web sites have been coordinated by the CHIPP outreach group. Further outreach activities are organized individually by CHIPP member institutes: European Physics Master classes in Bern, Geneva and Zürich, public lectures, open days at institutes, etc. A recent additional effort targets high-school teachers and students (master class events, special guided tours at CERN and other Swiss labs, PhysiScope Genève, Kinderuniversität Zürich, psi forum and iLab, etc.). The CHIPP Outreach Group serves as a light coordination body for such events. The future development of these activities is outlined in a separate document, which will soon be submitted to the SNF in the framework of the AGORA program.

Recommendation 10 – Outreach

CHIPP recommends that Cantonal and Federal funding authorities require and allow that a small fraction of each research grant be reserved for outreach purposes. It is further recommended that both authorities ensure that at least one research physicist in each Swiss physics institute has a primary responsibility towards the development of outreach activities. To seed these efforts as far as particle and astroparticle physics are concerned, CHIPP recommends central funding of one full-time equivalent during an initial phase, followed by continuous funding at the level of half a full-time equivalent.

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Text edited by L. Baudis, A. Ereditato and M. Pohl with contributions from the CHIPP Board.

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