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UNIVERSE

An NCCR for Particle and Astroparticle Physics in Switzerland

1. Summary (1 page)

The proposed NCCR comprises research groups all over Switzerland working on accelerator-based and non accelerator-based particle physics and particle theory. It implements transversal structures between the main directions of existing and future research efforts in Switzerland as identified in the Road Map[1] of the Swiss Institute of Particle Physics CHIPP, and its recent Implementation Report[2]:

- Experiments at the frontier of high-energy interactions between fundamental particles, including research with high precision experiments at low energy, as well as particle accelerator research.
- Experiments to explore the fundamental nature of neutrinos, the transitions between different neutrino flavors and ultimately to search for violation of matter-antimatter symmetry with leptons.
- Fundamental experiments at the interface between observational cosmology, astrophysics, particle and nuclear physics with a strong emphasis on understanding the nature of Dark Matter and eventually Dark Energy.
- Cosmology, particle theory and phenomenology relevant to our understanding of the Universe at the largest and smallest distance scale, substantiating the approach that the Universe can be understood on the basis of its microscopic properties.

The aim of the NCCR is to exploit the phenomenal synergies between the above research directions in terms of experimental techniques, analysis methodology and cross-fertilization between theory and experiment. It also aims at ensuring sustainability of the long-term projects in the field and at increasing the competitive edge of Switzerland in the framework of a globalized competition. In this way, the NCCR, its sub-projects and its participants will help establish the successor of the current Standard Model of particle physics. It will also help to identify the next major steps forward beyond its scope, by narrowing down choices on the next generations of accelerator and non-accelerator facilities and experiments for particle physics.

To reach these goals, the NCCR will install transversal structures that coordinate and support cooperation between activities in the main research directions, both inside each direction and between different directions. In particular it will:

- Coordinate and support the Swiss return of investment from LHC experiments, neutrino and astroparticle physics experiments by creating PhD student and post-doctoral fellowships, closely networked and embedded in a Swiss-wide doctoral and post-doctoral research and education program.
- Coordinate and support upgrade projects for the LHC experiments ATLAS, CMS and LHCb, to help the detectors cope with the ultimate LHC performance and maximize the physics output for the Swiss participants and the experimental communities at large.
- Increase the Swiss impact in the planning process for future accelerator facilities, focusing on CERN projects beyond the present LHC.
- Coordinate and support the Swiss contribution to the construction, commissioning and analysis of long base line neutrino oscillation experiments.
- Help with the planning and construction of future large-scale neutrino observatories and the corresponding powerful beams.
- Coordinate and support the efforts to experimentally assess the nature of neutrinos through the currently planned and future large-scale facilities to search for neutrino-less double beta decay.
- Intensify the Swiss participation in experiments seeking to identify the particle content of Dark Matter, using both direct and indirect detection methods.

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[1] Particle Physics in Switzerland, Status and Outlook of Research and Education, CHIPP 2004

[2] Particle Physics in Switzerland, Achievements, Status and Outlook: Implementation of the Road Map 2005-2010, CHIPP 2011

- Implement a cooperative multi-messenger approach to high-energy astrophysics between Swiss groups to identify the nature of astrophysical particle sources and accelerators.

These goals require an ever-increasing exchange of ideas and cooperation between Swiss groups and their international partners. The NCCR will help this evolution by implementing platforms and facilities for joint research and development on future particle detection techniques, data analysis and theoretical methodologies. It will thus contribute to maintain the competitive position of Swiss particle physics in a sustainable way.

2. Scientific Question and its Reference to Society (2 pages)

Our understanding of the universe is both precise and completely unsatisfactory. We have measured with unprecedented precision the content of the cosmos and understand preciously little about the components we have detected. There is 70% "dark energy", 26% "dark matter" and 4% baryons. Dark energy is, however, only a word that describes the cause of the apparent acceleration of the cosmic expansion, while dark matter describes a material that is, to date, observed only through its gravitational pull. We also know that complex structures emerged from the almost uniform early universe, structures made of clusters of galaxies and galaxies. These structures are observed and to some extent their evolution can be described. We also assume that they emerged from the small fluctuations that are measured in the cosmic microwave background. Interestingly, black holes and galaxies seem to have grown in a very similar way as the universe evolved.

The question of the nature of matter is also addressed starting from the properties of matter as observed at accelerators. The LHC—the Large Hadron Collider—is now in operation and giving a string of results changing our views in a fundamental way. Neutrinos are being investigated vigorously now that they have been observed to have a mass. And the structure of the theory that subtends our understanding of matter and gravitation is studied with the goal of not only understanding the properties of the particles we know and the nature of dark matter, but also understanding the four fundamental forms of interaction, and providing a unified understanding of strong and electro-weak interactions on one side and gravitation on the other. All in all, we are witnessing today the birth of a New Standard Model, remedying the shortcomings of the existing one and pointing the way towards future progress in answering some of the most fundamental questions that can be asked about Nature, like those formulated in eth Swiss Road Map:

- What are the elementary particles and what is the origin of their mass?
- What are the origins of the fundamental forces and can a unified description of the forces be made?
- 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?

Particle and astroparticle physics are of strategic importance for Swiss research. As one of the CERN host states, Switzerland has traditionally well supported basic research in this field and the efforts of federal and cantonal authorities have been widely acknowledged. Basic research is recognized as one of the major drivers for innovation beyond the gradual improvement of existing technology. A competitive edge for Swiss researchers in particle physics can be derived from their privileged geographical position close to CERN, *the* major center of competence in this field worldwide. However, exploiting this edge requires an optimization of Swiss research structures aiming at a sustainable coverage of the very long life cycle of particle and astroparticle physics experiments. Fostering this process is the role of the Swiss Institute of Particle Physics CHIPP, a bottom-up association of all particle physicists in Switzerland. In a recent report[3] on particularly cost intensive research, the Swiss Council for Science and Technology SWTR concludes:

> "Mit der Gründung des Swiss Institute for Particle Physics und der Veröffentlichung der Roadmap verfügt die Schweiz über eine klar definierte nationale Forschungsstrategie im Bereich Teilchenphysik. In der Zwischenzeit hat das Swiss Institute for Particle Physics ein Doktoratsprogramm auf nationaler Ebene gegründet. Ferner gewährleistet das Institut eine aktive Vertretung der Wissenschaftsgemeinde im Bereich Teilchenphysik gegenüber den regionalen, nationalen und internationalen Gesprächspartnern."

[3] "Besonders kostenintensive Bereiche" und deren wissenschaftliche Koordination auf nationaler Ebene, Eine Analyse des Schweizerischen Wissenschafts- und Technologierats, SWTR Schrift 4/2009

The outstanding track record of CHIPP member institutions has been recently documented in the implementation report[2] to the CHIPP Road Map. The European Committee for Future Accelerators, on the occasion of a visit to Switzerland in March 2009, has explicitly recognized this track record, concluding in a letter to State Secretary Dell'Ambrigio:

> "The current programme in particle physics appears well focused, yet broad enough to cover the major and most promising directions of the field: Strong and internationally visible contribution to 3 out of 4 LHC experiments, astroparticle physics bridging to the exciting science of the early universe, and precision physics at the PSI, for deep insights into the quantum universe and neutrino physics as an emerging field. Those physics drivers are complemented by highly competent groups in instrumentation and accelerator physics with major spin-offs to industry and other science fields."

The cultural benefit to society coming from this increased knowledge of Nature is obvious. In addition, there are tremendous financial, technological and educational fringe benefits. SWTR concludes:

> "Zudem generieren die in die Teilchenphysik-Forschung investierten Beträge neben dem wissenschaftlichen Fortschritt auch ökonomische Vorteile. Durch den Standortvorteil des CERN in Genf wird geschätzt, dass ungefähr zweimal der Betrag, der von der Schweiz investiert wird, in die Volkswirtschaft des Landes zurückfliesst. Im Rahmen der Zusammenarbeit der Schweiz am internationalen CERN ist eine gegenseitige Stärkung von Lehre, Forschung und Innovation festzustellen, die es den jeweiligen Studierenden ermöglicht, an Spitzenforschung im Rahmen ihrer Ausbildung teilzunehmen."

One of the ways to secure a sustainable leading role of Swiss particle and astroparticle physics in a competitive European and world-wide environment is to ensure an ever improving coordination, ensuring an efficient usage of existing funds and an early identification of promising new directions. The collaborative approach to problems that are too complex or too costly for a single research group to attack is deeply rooted in the tradition of particle physics and no lesson needs to be learned here. However, by implementing and fostering transversal exchange between research directions and projects, further optimization appears feasible. The following important transversal directions can be identified:

- Theoretical activities in cosmology, astrophysics, particle theory and phenomenology are of a particular individual nature and need to stay that way. However, by increasing collaboration and information exchange between theoretical and experimental physicists one can strive to shorten the time lag between major progress in one and awareness in the other field. In addition, better education in fields of common interest may make results more accessible and usable. The NCCR will create structures to facilitate the exchange between theory and experiment.
- Particle detection technology has made remarkable progress in the last decades under the pressure to optimize performance and affordability of large, complex detector systems. In addition, modern particle detection technology has been brought to space experiments. Although particle detectors are not generic in nature and must be carefully adapted to a given problem, general trends can be identified. Examples are: tracking detectors with a high degree of integration, light detection technology, the usage of liquid noble gases for calorimetric and tracking purposes etc. The NCCR will coordinate and support common efforts in the field of instrumentation.
- Data analysis technology is indeed becoming a major bottleneck for future progress, considering that the analysis of LHC data already puts a large fraction of the world computing resources to work. Commonalities in data handling techniques, grid and cloud computing as well as algorithms for the statistical and systematic interpretation of data can be identified. The NCCR will ensure proper exploitation of existing facilities and ensure their integration in the European context. It will support further research in this field.
- Education of our students and information of the general public about particle physics is of obvious common interest. Despite the existing efforts to coordinate the undergraduate and doctoral programs in particle physics in Switzerland, a large diversity in width and depth persists. The NCCR will work towards ensuring a good standard of undergraduate education in particle physics. It will further coordinate and streamline the existing doctoral programs in particle physics. The partners also have a lot to learn from each other and from communication experts, concerning their communication with the general public and in particular with the young generation of potential science students. The NCCR will coordinate a more active information exchange among communicators and work towards a higher level of public awareness in our field.

3. Research Program 2014-2017 (6 pages)

Experimental particle physics in Switzerland progresses along three main research lines, as identified in the Swiss Road Map[1]:

- 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.

With these three pillars of research, Switzerland covers the main experimental directions followed worldwide in search for the ingredients of the successor to today's Standard Model. Such a New Standard Model ought to repair the known shortcomings of the existing one, integrate important missing pieces such as Dark Matter and Dark Energy, and point the way towards future facilities. Supporting these efforts and pushing them forward constantly require equally important efforts in particle theory and accelerator research. The NCCR Universe will follow these lines in its internal organization and research program.

It is obvious that experimental and theoretical subjects of this fundamental nature require a sustainable long duration support. The life cycle of the LHC project and its experiments, to name a prominent example, started with first conceptual studies in (?), leading to the project definition for the accelerator and the experiments in (?). Research and development on the accelerator side took until (?) when a technical design document was published. The experiments published a series of technical design reports from (?) to (?). Finally, in 2009, first beams were produced and in 2010 routine operation was achieved at half the design energy and with luminosities exceeding all expectations. Full energy will be reached in 2014 and the current experimental program is expected to continue until at least 2020. After reaching full energy and luminosity of the LHC, CERN currently intends to extend the machine luminosity around 2020 by an additional factor. This will require a thorough update of the LHC detectors. The construction and operation life cycle of the LHC and its experiments thus covers more than three decades. Similarly, data analysis and interpretation will dominate particle physics in a period of several decades.

Comparable life cycles are observed for non-accelerator experiments, such a particle detectors in space and large underground facilities. The AMS cosmic ray observatory, bringing modern particle detection technology to space, took two decades from concept to deployment. The IceCube projects, with its predecessor Amanda, took a similar time span to complete. Future large-scale underground facilities will no doubt take a similar time to complete and operate.

With their long duration, NCCR are an appropriate instrument to cover the typical life cycles of experimental and theoretical programs. A schematic organization of sub-projects is shown in Figure 1. The sub-projects are detailed in the following sections.

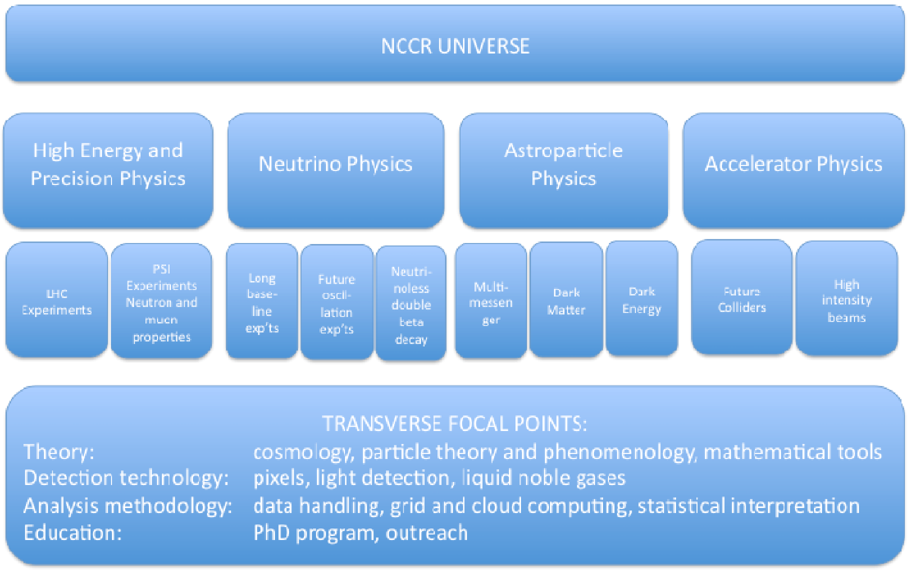

Figure 1: Organizational chart of the NCCR Universe showing its main research directions and action lines.

Important research groups are already active in Switzerland in all of the directions outlined above. Collaboration is typically strong within a given experimental program or collaboration, much looser across those boundaries. The NCCR will initiate common projects beyond the boundaries of existing collaborations within the pillars, and strive to increase collaboration between the pillars. In this way, important synergies can be set free, as far as research and development on particle detection technology is concerned, but also for analysis and interpretation of data. **Give some examples here: pixel detectors, calorimetry, light detection, liquid noble gases.**

Cooperation between theory and experiment is not sufficiently developed in Switzerland. The NCCR Universe will act to improve the situation by forming small joint research teams, regrouping theorists and experimentalists, experienced researchers and PhD students. This will also help smaller research groups in individual universities to reach the necessary critical mass and this increase their visibility and competitive edge. **Give some examples here: heavy flavors, leptons plus missing energy, supersymmetry, astrophysics/cosmology as required for astroparticle physics.**

Be especially specific about transversal activities: What is the NCCR going to do and achieve in the first 4 years?

Demonstrate added value of the NCCR: What can we do in an NCCR that we are unable to do today. Ideas:

- Synergy between pillars
- Increased cooperation between theory and experiment
- Ensured sustainability for long-term projects, replace round table international (?)
- Increase competitive edge wrt other countries
- General idea: cooperative effort to define "New Standard Model"

Must comment on how NCCR fits in with or integrates existing structures: FORCE/FOLIS etc.

Draft perspective for second 4-year period:

- Should definitely cover life cycle of LHC, leading into LC definition
- Neutrino factories, super beams (what is the time line?)
- CTA life cycle also comparable, space projects even longer (c/f ESA Cosmic Vision)

4. Research Plans of Individual Projects (2 pages per project)

4.1 Experiments at the Frontier of High-Energy Interactions between Fundamental Particles

4.1.1 Research question and state of the art

The high-energy frontier in particle physics experiments is represented by the LHC program. At LHC, proton-proton collisions – today at 7 TeV center-of-mass energy, at twice that energy in the future – are used to produce known and unknown particles and states of matter.

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 ?? pb^{-1} per experiment has been delivered by the end of 2011. The LHC will continue to run through 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 2010/11 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.

Update this paragraph! 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 $B_s \to \mu\mu$ 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.

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.

The flagship particle physics experiments taking place at PSI are searches for the lepton flavor violating decay m→eg (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 m→eee. Other experiments that have received considerable attention are: the measurement of the Lambshift 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.

4.1.2 Intended contribution of the project

The NCCR Universe will contribute in a major way to the LHC program in Switzerland. It will increase the return on investment for Swiss groups having contributed to the LHC detectors ATLAS, CMS and LHCb by increasing data analysis personnel in Swiss groups and coordinate their effort better. It will increase the visibility of Swiss groups inside and beyond their respective collaborations by helping them to reach critical mass, by means of cooperation with other experimental groups and with theorists in Switzerland. It will coordinate and finance the upgrade contributions of Swiss groups to the LHC detectors. And it will increase the educational program and public awareness of high-energy particle physics by organizing schools, workshops and public events on the subject.

The NCCR Universe will integrate and enhance the C-15 and ProDoc programs running out in 2012. A total of 12 (?) post-doctoral fellowships will be attributed to the experimental and theoretical physicists working on LHC physics on the basis of their record of scientific excellence and future promise. In addition, a total of 12 PhD fellowships will be made available for first class doctoral students. A selection committee will be set-up to attract the best young scientists worldwide to study and work in Switzerland. This will increase the scientific impact in the physics exploitation and will add visibility and prestige to the existing world-class scientific research and education in Switzerland. It represents a reinforcement of excellence through international competition. The graduate and postgraduate education of these students will be the common responsibility of the participating universities. It will be structured into a doctoral program integrating existing resources as outlined below.

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 Zurich, PSI and University of Zurich, 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.

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. **Add a paragraph about mu -> 3e here!**

4.2 Experiments on Neutrino Physics: Oscillations and the Nature of Neutrinos

4.2.1 Research question and state of the art

Research on neutrinos and their properties focuses on four main scientific questions: What is the mass hierarchy of neutrinos? What are the precise values of the Pontecorvo-Maki-Nkagawa-Sakata mixing matrix elements? Is there a measurable amount of matter-antimatter symmetry violation in the leptonic sector and can its action be described by a phase in the mixing matrix, as seems to be the case in the quark sector? Is the neutrino its own antiparticle (Majorana type particle) or not (Fermi type particle)?

Swiss researchers participate in the international long baseline neutrino oscillation experiments OPERA and T2K in a coordinated fashion. 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 $n_\mu \rightarrow n_\tau$ appearance and T2K on the next generation search for $n_\mu \rightarrow n_\varepsilon$ 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 n_m disappearance and will be the world most sensitive search for n_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 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.

4.2.2 Intended contribution of the project

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 3x3 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 $n_{\mu} \rightarrow n_{e}$ or $n_{e} \rightarrow n_{\mu}$ 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. The NCCR Universe will ensure 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.

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.

Be concrete! What is the NCCR going to do?

4.3 Experiments at the Interface of Particle Physics with Astrophysics and Cosmology

4.3.1 Research question and state of the art

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.

4.3.2 Intended contribution of the project

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.

Corroborating evidence for the existence of Dark Energy, responsible for about 75% of the energy density of the Universe, 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.

Be concrete! What is the NCCR going to do?

4.4 Accelerator Research and Development

4.4.1 Research question and state of the art

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.

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.

4.3.2 Intended contribution of the project

The NCCR Universe will closely collaborate with CERN and PSI in research and development of future accelerators. Depending on the nature and energy scale of new phenomena discovered at LHC, several types and specifications of a future high energy 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.

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.

Long-term accelerator R&D is 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.

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.

Be concrete! What is the NCCR going to do?

5. International Networking (1 page)

Embedding in international scientific co-operation activities of the Swiss Confederation. Refer to Swiss Infrastructure Roadmap here!

6. Knowledge and technology transfer, advancement of young researchers and women, communication (2 pages)

6.1 Knowledge and technology transfer

Must refer to existing measures at partner institute

6.2 Educational support

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. A solid 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.

The present doctoral program in particle and accelerator physics – funded through ProDoc and integrated in the Center for Advanced Studies in Particle Physics C15 – will be further developed on the basis of existing resources and at the Swiss level. The basic principle of such a system will be that the thesis adviser and the student freely agree on an individual program, following the requirements of their institutions. Access to all courses will be granted to all Swiss PhD students free of charge and credits be granted on an equal footing. The HCCR Universe will take over the funding of the CHIPP ProDoc and integrate it with the system of NCCR fellowships.

6.3 Advancement of female researchers

Special fellowship for beginning and advanced female researchers?

6.4 Internal and external communication

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 Zurich, 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.

Be concrete:

- NCCR will finance a part time outreach coordinator?
- A travelling exhibition?

7. Structural Goals of the Home Institution (1 page)

Reinforcement of existing structures:

- NCCR has to be based on existing proven priorities in research and education of the leading house and the partners
    - True for math/astro/physics in Geneva, Einstein Center in Bern
    - ETHZ, EPFL, PSI?
- Increased profile and definition of priorities at partner institutes: chairs, new or refocused institutes, new educational instruments
- Must demonstrate sustainable reinforcement of structures, networks, finances

Leading house:

- Strong competence center:
    - Universities and ETHs all qualify
- Coordination of network of institutions and research groups
- Scientific leadership and direction
- Operative administration of finances and accounting
- Can be split among more than one strong partner:
    - 1 ETH + 1 University?
    - 1 Eastern and 1 Western Switzerland?

Scientific track record and demonstration of leadership:

- Coordinators of NCCR, projects and sub-projects must demonstrate scientific excellence
- High international recognition
- Coordinator must have a professional lifetime covering at least the first 4 years period

8. Organization of the NCCR (1 page)

Organization:

- High degree of autonomy in scientific, organizational and financial matters
- Coordinator must propose organizational structure and management procedures
- Coordinator must have deputy
- Dedicated coordinators for knowledge and technology transfer, education, advancement of women, communication, administration

9. Annexes

a. List of project leaders and titles

b. CV and list of publications of NCCR Director, deputy and project leaders

c. Budget for 1rst phase

Based on input from C-15 follow up, extended to 4 full years, times a factor to account for 3 pillars instead of 1. Investment input from CHIPP tables, minus FORCE/FOLIS. Total should be 3 to 5 MCHF/a.

d. Letter of support from Home Institution

Stating conformity with strategic planning, intended structural measures, self-funding with details about financial support and structural measures.

Home institutions:

- All home institutions must support the project in writing
- Commit to support NCCR during complete duration through personnel and finances
- Commit to realize required organizational measures
- Commit to sustainable structural improvements by NCCR