Strategy for Swiss contributions to large ground-based[1] astro-particle physics research infrastructure

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Finding answers to the fascinating, big questions about the existence and the evolution of our universe, its fundamental constituents and their interaction requires new initiatives for very large research infrastructures, which can only be designed, constructed and operated in powerful, world-wide collaborations.

Individual Swiss physicists contribute with their personal, experimental experience, their theoretical knowledge and their managerial expertise to the design and planning of several medium-size and large projects in this field. Some of them are already operating others are in the construction or planning phase. Apart from the Cern based experiments, these include neutrino-related projects (OPERA, EXO, GERDA, T2K, LAGUNA-LBNO), the direct search for the constituents of dark matter (XENON, ArDM, DARWIN) and the observation of extreme particles from the outer space (charged particles: AMS, PEBS; highest energy gamma rays: MAGIC, FACT, CTA; neutrinos: IceCube).

However, the Swiss research community realizes, that our small country needs to coordinate its efforts in order to be able to continue to play a significant and visible role in the ever increasing collaborations. Given the limited number and size of Swiss particle physics research groups and the modest financial resources, a concentration on only a few projects seems indispensable.

We therefore propose to concentrate our efforts on just one large ground-based future project in each of the three main fields, mentioned above. Given the existing interest and experience of the Swiss physicists, we are convinced that the best choice are the three projects LAGUNA-LBNO (long baseline neutrino oscillation observatory), DARWIN (next generation direct dark matter search detector) and CTA (array of telescopes to observe the highest energy gamma rays from the universe). All three projects are already described in the CHIPP Roadmap for Astroparticle and Particle Physics in Switzerland [1].

This white paper summarizes the three projects, lists the Swiss intellectual and technical contributions and the resources needed in the future. For more details on concrete numbers please refer to the CHIPP Long-Term Financial Tables.

It should be pointed out, that participation in these long-term projects requires a stable financial support over many years, since construction takes long and needs to be planned in detail beforehand. Operation of such infrastructure may last up to 20 years or more and will require funds as well. Both for construction and operation the longterm stability of the support is more important than the absolute size of the funds. In this context the new funding line FLARE which was defined recently by the SNSF seems to represent a promising tool.

[1]Space-borne projects are funded through other channels, and are not considered here.

1 Cherenkov Telescope Array (CTA)

Participating Swiss groups: University of Geneva (DPNC, Prof. T. Montaruli, contact person), University of Geneva (ISDC, Prof. T. Courvoisier), University of Zurich (Prof. U. Straumann), ETHZ (Prof. A. Biland).

The CTA project [2] aims to build the next generation ground-based instruments to measure very high energy gamma-rays originating from the outer space. It will serve as an open observatory to a wide particle and astrophysics community and will provide a deep insight into the non-thermal high-energy universe. CTA will have an important role in solving the long standing problem of discovering the accelerating regions of cosmic rays. It will improve our understanding of diffusive acceleration in supernova remnant shocks and in regions of high star formation rate (starbursts), of pulsars, micro-quasars and magnetars, of black hole jets in active galactic nuclei, or of other catastrophic phenomena such as gamma-ray bursts. CTA will investigate the nature of matter in the universe searching for the sites where dark matter clumps; it will investigate the cosmological distribution of galaxies measuring the extragalactic background light and search for violation of Lorentz Invariance.

CTA employs the Imaging Atmospheric Cherenkov Technique. Photons from the outer space arrive at the earth's atmosphere and produce showers of a large number of electrons and positrons, which in turn radiate Cherenkov light since their speed is mostly larger than the speed of light in the atmosphere. This Cherenkov light spectrum peaks between 300 and 400 nm wavelength and arrives within a spread of a few nanoseconds in a pool of about 70-150 m (depending on altitude) from the primary axis on the ground, where it can be observed by telescopes.

According to the current baseline design, there will be two observatories in the two hemispheres composed of telescopes distributed over surfaces of the order of 1 km^2 that will cover the energy range from $\sim$ 20 GeV to about 300 TeV. There will be a few 24 m (diameter) Large Size Telescopes (LSTs) providing sensitivity in the energy range from 20 GeV to 5 TeV; a few tens of Middle Size Telescopes (MSTs) with 12 m mirrors sensitive to the region 100 GeV - 20 TeV. The observatory in the southern hemisphere, which enjoys a better view of the galactic plane including the galactic centre, will contain in addition about 100 Small Size Telescopes (SSTs) with 4 m mirrors and cameras of 1300 pixels with FoV of $8° - 10°$. SSTs will be sensitive between 1 TeV to 300 TeV.

Swiss contributions: Already since 2008 Swiss groups participate to the R&D for the CTA project. The group of UniZH contributes to the design of an innovative new camera concept, FlashCam [3], which processes a fully digital data stream, while operating the trigger on the same digital data source. It promises significant cost savings, and higher reliability and flexibility in operation. The Swiss groups are responsible for the design and construction of the analog frontend electronics, the camera mechanics, the development and simulation of the trigger algorithms and for testing the prototypes.

Since recently UniGE is leading the project for the construction of Davies Cotton SSTs with 4m-diameter. This will host an innovative camera photodetector plane based of Geiger-Avalanche Photodiodes (G-APDs) coupled to a FlashCam DAQ-trigger system. G-APDs where first employed in a prototype camera built by ETHZ now taking successfully data at La Palma, Canarian Islands. The goal of the Swiss community is to build a minimum of 12 cameras for SSTs with GAPDs or MSTs with conventional photomultipliers. We foresee to continue the R&D phase in 2013-2014 in order to have a technical design ready until 2014. A prototype of the camera should be available for performance tests in 2015.

UniZH has designed and constructed mirror actuators for MSTs and LSTs, which may also be adopted for SSTs as well.

UniGe-ISDC contributed in the fields of telescope array simulations, telescope array control and data management definition. In addition ISDC scientists had an important science impact, discovering, among others, the highest energy electrons known in the Universe and one of the few known galactic source of hadronic acceleration. Building on the current achievements, UniGE-ISDC plans to provide CTA with (1) the telescope array data acquisition software (incl part of the trigger), from the telescope cameras to the raw data files, (2) the software development, support and calibration activities required by the CTA observatory users to get data and perform high-level analysis from the reconstructed events to the astronomical science products, and (3) a lively scientific environment to support and extract CTA results and combine them with the outcome of a spectrum of other astronomical multi-wavelength observing facilities.

Collaboration and costs: Originally a European collaboration, the CTA project, thanks to its very attractive scientific prospects, grew quickly to a worldwide consortium and presently consists of over 1000 members working in 28 countries: Argentina, Armenia, Austria, Brazil, Bulgaria, Croatia, Chile, Czech Republic, Finland, France, Germany, Greece, India, Ireland, Italy, Japan, Mexico, Namibia, Netherlands, Norway, Poland, Slovenia, South Africa, Spain, Sweden, Switzerland, the UK, and the USA.

CTA is included in the 2008 roadmap of the European Strategy Forum on Research Infrastructures (ESFRI). It is one of the Magnificent Seven of the European strategy for astroparticle physics published by ASPERA and is a recommended project for the next decade by the US National Academy of Sciences Decadal Survey.

The total investment cost is expected to be about 200M€. The annual operation will be about 8% of this amount. Based on the relative size of the Swiss community compared to the full CTA, our contribution is expected to be of order 2%, corresponding to about 5 MCHF investment during 2016 to 2019, and 450 kCHF for annual operation.

2 Dark matter WIMP search with noble liquids (DARWIN)

Participating Swiss groups: University of Zurich (Prof. L. Baudis, contact person; Prof. B. Kilminster), University of Bern (Prof. M. Schumann).

DARWIN is an initiative to build a next-generation, multi-ton dark matter detector in Europe [4,5]. Its primary goal is to probe the spin-independent WIMP-nucleon cross section down to $10^{-48}\,\mathrm{cm}^2$ for $50\,\mathrm{GeV/c}^2$ WIMPs and to measure WIMP-induced nuclear recoil spectra with high-statistics, should they be discovered by an existing or near-future experiment such as XENON1T [6]. Such a measurement would allow to constrain the mass and the scattering cross section of the dark matter particle [7]. The other two main physics goals of DARWIN are the first real-time detection of solar pp-neutrinos with high statistics and the search for the neutrinoless double beta decay of ^{136}Xe, which has a natural abundance of 8.9% in xenon. Thus DARWIN has a large discovery potential in the areas of astroparticle and low-energy neutrino physics.

The baseline design foresees a 20 t liquid xenon detector in a large water Cherenkov shield. The second part of DARWIN, a 20 t liquid argon (LAr) detector, is endorsed by the European Roadmap only in the case in which dark matter liquid argon detectors will show that they are technically feasible and competitive with xenon projects. The liquid xenon part of DARWIN will employ a large, unsegmented target mass of about 20 t of liquid xenon, capable of fiducialization. The cryostat containing the noble liquid is immersed in a large water Cherenkov shield to suppress the background originating from cosmic muons and muon induced neutrons to negligible levels. It will be located either at LNGS, or at the approved extension of the Modane Laboratory in France. The goal is to achieve an energy threshold of 2 keV, which translates into a ∼7 keV threshold for observing nuclear recoils as expected from WIMP interactions. In its baseline design, DARWIN will operate a dual-phase noble liquid time projection chamber (TPC). A similar design is successfully used in the current XENON100 detector [8] and is proposed for XENON1T [6]: the primary light signal is detected predominantly by a photosensor array immersed in the liquid, while the charge signal is either detected directly, or via proportional scintillation by a photosensor array placed in the vapor phase above the liquid target. The time difference between the two signals provides the z-position of an event, while the localized charge or proportional light signal yield the xy-position. The 3-D position resolution allows to define a central detector region with an ultra-low background ("fiducial volume") and to identify multiple-scatters which are unlikely to come from WIMPs, solar neutrinos, or from double beta decays.

Swiss contributions: The UniZH group is a founding and leading member of the DARWIN consortium, with the Swiss PI being the DARWIN project coordinator.

The Swiss groups are leading the following activities: inner detector structure and TPC, data acquisition and trigger schemes, Monte Carlo simulations of the gamma and neutron backgrounds from detector components and internal background sources (such as radon, ^{85}Kr, and cosmogenically produced radio-nuclides), tests of light read-out schemes (such as photomultiplier tubes and large avalanche photodiodes) in LXe, measurements of the radioactivities of potential detector components with the UniZH Gator facility [9] at LNGS, as well as charge and light yield measurements of nuclear and electronic recoils at low-energies with small, dedicated detectors.

Collaboration and costs: Presently the consortium is composed of 25 groups from Europe, Israel and the USA, with a total of 97 members: University of Zürich, Bern University, ETH Zürich, Mainz University, University of Münster, Karlsruhe Institute of Technology (KIT), MPI für Kernphysik (Heidelberg), TU Dresden, Imperial College London, INFN (Bologna, Torino, LNGS, Milano, Padova, Pavia, Perugia, Napoli), Nikhef (Amsterdam), Subatech (Nantes), Weizmann Institute of Science (Rehovot), Arizona State University (ASU), Columbia University, Princeton University, Purdue University and University of California, Los Angeles

DARWIN is endorsed by the European Roadmap for Astroparticle Physics and has received initial funding through the first ASPERA common call. It unites for the first time in a coherent manner the ample expertise in Europe on liquid noble gas detectors, on low-background techniques, on cryogenic infrastructures, on underground infrastructures and shields, as well as on the physics related to direct dark matter and neutrino detection.

The total construction costs of DARWIN are expected to be about 60 MCHF for the xenon detector part, to which the Swiss groups aim to keep their leading contribution. A 5% Swiss contribution would amount to 3 MCHF, distributed over about 3-4 years. Based on our experience with XENON, the annual operation and maintenance costs is expected to be about 4% of the investment costs, a 5% Swiss contribution would mean 120'000 CHF per year. While the actual construction of the facility would start around 2017, funding will be required, apart from R&D costs, to start purchasing the xenon gas and the photosensors well in advance, starting in 2015 and continuing in 2016.

3 LAGUNA-LBNO

Participating Swiss groups: University of Geneva (Prof. A. Blondel), University of Bern (Prof. A. Ereditato), ETHZ (Prof. A. Rubbia, contact person).

A wealth of new results over the last years is clarifying the landscape in Particle Physics at the various frontiers and confirm the Standard Model (SM). The discovery of the SM Higgs boson and other results on rare decays have by now crowned the already very successful SM. In this rapidly emerging picture, neutrino masses and mixing represent the first established evidence of physics Beyond the Standard Model (BSM). Being the only elementary fermions whose basic properties are still largely unknown, neutrinos must naturally be one of the main priorities in the quest to complete our knowledge of the SM.

The "Large Apparatus for Grand Unification and Neutrino Astrophysics - Long Baseline Neutrino Oscillations" [10–12] physics goals comprise next-generation accelerator-driven long-baseline neutrino oscillation studies, primarily aimed at the determination of the neutrino mass hierarchy and the discovery of leptonic CP-violation. It will also significantly improve the sensitivity of searches for proton decays, thereby testing theories beyond the SM which predict the unification of the elementary forces (Grand Unified Theories). Lastly, it will act as a neutrino observatory to study atmospheric neutrinos and several astrophysical neutrino sources. For instance, it will precisely measure neutrinos emitted by exploding stars and likely resolve the long-standing problem of the violent processes leading to supernovae and the production of heavy elements in the Universe.

According to the current baseline, the experiment will be composed of a Liquid Argon Time Projection Chamber with an active mass of 20 kilotons, complemented by a magnetised iron muon detector. An optimal location would be deep underground at -1400 m depth level of the Pyhäsalmi mine (Finland) at a distance of 2300 km from CERN. The long-baseline neutrino oscillation experiment will be based on a new conventional neutrino beam to be built at the CERN North Area.

LAGUNA-LBNO will start physics data-taking in 2023 at the earliest and physics exploitation will last more than a decade.

Swiss contributions: Swiss groups have acquired an internationally recognised expertise in the field of neutrino physics and neutrino detector technologies. They are involved in all key technological developments of the LAGUNA-LBNO project. Bern and ETHZ tightly collaborate on the developments of the liquid argon technology. The Geneva group leads the design of the near neutrino detector.

The ETHZ group has proposed and coordinated the LAGUNA and LAGUNA-LBNO studies. The ETHZ group has strong commitments and responsibilities in the organisation and management of the project. A. Rubbia acts as the contact person for the project.

The Swiss contributions to the detector construction will be finalised in the LAGUNA-LBNO Technical Design Report (TDR expected by 2015 — see below).

Collaboration and costs: Since 2008, the FP7 LAGUNA and LAGUNA-LBNO design studies funded by the European Commission, have addressed the feasibility of a next-generation deep-underground neutrino observatory in Europe. The project presently involves 40 beneficiaries from 13 countries and is coordinated by ETHZ.

LAGUNA-LBNO is one of the Magnificent Seven of the European strategy for astroparticle physics published by ASPERA.

CERN, recognising the scientific importance of the project and its relevance for the future programmes of the laboratory, joined LAGUNA-LBNO in 2011. CERN is presently developing an engineering design of the CERN to Pyhäsalmi neutrino beam and is assisting the LAGUNA undertakings by providing appropriate space infrastructure and the necessary technical support.

In June 2012, an Expression of Interest (CERN-SPSC-2012-021, CERN-SPS-EOI-007) signed by 50 institutions and 250 authors, has been submitted to the CERN SPS Committee (SPSC). At its session of January 2013, the SPSC endorsed the physics case of the EoI, supporting the double-phase LAr TPC option as a promising technique to instrument very large LAr neutrino detectors. The SPSC therefore encouraged the LBNO consortium to proceed with the R&D necessary to validate the technology on a large scale. A decision by the CERN Research Board is expected in spring 2013.

In the currently proposed time plan[2], CERN could launch civil engineering works for the neutrino facility in the North Area in 2013 and occupancy of the EHN1 building extension would be granted to the LBNO consortium in Summer 2014. In order to match this timescale and to perform the construction of the LAGUNA LAr prototype in 2014 and 2015, a FLARE request (20FL20_147464, under evaluation) has been submitted in November 2012 to support the pre-engineering studies and the design and assembly of some pre-series of the various detector components to be performed in 2013. Requests for funds for construction would be submitted for 2014 and beyond.

Although several good options exist for the location of the underground large-scale LAGUNA detector, no final decision on this has been taken yet. A reliable cost estimate and a concrete timeline for the construction is presently being established and will be submitted to the SPSC and ApPEC committees for their scrutiny within the fall of 2013. Thus, it seems premature

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to give already now a precise estimate of the expected Swiss contribution. The construction of the final instrument will likely start beyond 2017. Swiss contributions can be defined once the cost of LAGUNA have been reviewed by the external committees.

Conclusions

We have proposed to concentrate our efforts on just one large future project in each of the three main fields of ground-based astro-particle physics. We are convinced that the best choices are the three projects CTA (array of telescopes to observe the highest energy gamma rays from the universe), DARWIN (next generation direct dark matter search detector) and LAGUNA- LBNO (long baseline neutrino oscillation observatory). All three projects have been described earlier in the CHIPP Roadmap for Astro-particle and Particle Physics in Switzerland.

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