LAGUNA-LBNO: Large Apparatus studying Grand Unification and Neutrino Astrophysics and Long Baseline Neutrino Oscillations

T. Patzak\(^1\) on behalf of the LAGUNA-LBNO collaboration

\(^1\) AstroParticule et Cosmologie (APC), CNRS, Université Paris Diderot-Paris 7, CEA, Obs. de Paris
E-mail: patzak@apc.univ-paris7.fr

Abstract. LAGUNA (Large Apparatus studying Grand Unification and Neutrino Astrophysics) and LAGUNA-LBNO (Large Apparatus studying Grand Unification and Neutrino Astrophysics and Long Baseline Neutrino Oscillations) are European FP7 Design Studies. Within these studies Pan-European research infrastructures in deep underground cavities able to host a very large multipurpose next-generation neutrino observatory are investigated. These future megaton scale detectors are dedicated to nucleon decay, neutrinos from supernovae, solar and atmospheric neutrinos, as well as neutrinos from a future Super-Beam or $\beta$-Beam to measure the mixing angle $\theta_{13}$, the CP violating phase $\delta$ and the mass hierarchy.

1. Introduction

Neutrinos are messengers from astrophysical objects as well as from the early universe and can give us information on processes, which cannot be studied otherwise. Underground experiments, like SuperKamiokande (SK) [1], have made important discoveries. Next-generation very large volume underground experiments will answer fundamental questions on particle and astroparticle physics. The construction of a large scale detector devoted to particle and astroparticle physics in Europe is one of the priorities of the ASPERA [2] roadmap (2008). These detectors will search for a possible finite lifetime for the proton with a sensitivity one order of magnitude better than the current limit. With a neutrino beam they will measure with unprecedented sensitivity the last unknown mixing angle ($\theta_{13}$) of neutrinos and unveil through neutrino oscillations the existence of CP violation in the leptonic sector, which in turn could provide an explanation of the matter-antimatter asymmetry in the Universe. Moreover they will study astrophysical objects, in particular the Sun and Supernovae [3]. The FP7 Design Studies LAGUNA (2008 - 2011) [4] [5] and LAGUNA-LBNO (2011 - 2014) [6] support studies of European research infrastructures in deep underground cavities able to host a very large multipurpose next-generation neutrino observatory - GLACIER (Liquid Argon) [7], LENA (Liquid Scintillator) [8], MEMPHYS (Water Cherenkov) [9] [10].
2. LAGUNA (2008 - 2011)
The FP7 Design Study LAGUNA (2008 - 2011) was a Pan-European effort of 21 beneficiaries, composed of academic institutions from Denmark, Finland, France, Germany, Poland, Spain, Switzerland and the United Kingdom, as well as industrial partners specialized in civil and mechanical engineering and rock mechanics. The goal of the study was to assess the feasibility of this research infrastructure in Europe and the related costs.

The LAGUNA consortium has evaluated possible extensions of the existing deep underground laboratories in Europe: Boulby (UK), Canfranc (Spain) and Modane (France) and considered the creation of new laboratories in the following regions: Caso Umbria Region (Italy), Pyhäsalmi (Finland), Sierozsowice (Poland) and Slanic (Romania). In Europe there are three different proposed detectors: GLACIER (Liquid Argon), LENA (Liquid Scintillator) and MEMPHYS (Water Cherenkov). For all three detectors there are, in the LAGUNA context, specific studies concerning the construction feasibility, the required depth, the muon and reactor neutrino flux etc. In figure 1 the seven sites are shown, as well as an example of the construction studies developed by the different beneficiaries. The main conclusion of the LAGUNA study is that from a rock mechanical point of view all the proposed excavations are possible. Detailed cost estimations for the site construction and estimations for the detector constructions have been delivered. It turned out that the cavern construction itself is not the most important cost driver in such a future project. In order to make a realistic overall cost estimation, the detector construction costs and the costs related to the operation of the infrastructure for at least 30 years or more have to be studied in more detail. Furthermore the physics potential of each combination of site and detector has to be investigated in detail and in a common way. This led the collaboration to propose the second phase study - LAGUNA-LBNO which was accepted within the European FP7 framework.

3. LAGUNA-LBNO (2011 - 2014)
The LAGUNA collaboration decided to go ahead with a new study, LAGUNA-LBNO (2011 - 2014) to investigate two sites in detail: The shortest baseline from CERN, Fréjus at 130 km with no matter effect and therefore providing a clean measurement of CP violation and the longest baseline at Pyhäsalmi (2300 km) with matter effects and therefore able to determine the mass hierarchy. A third site, Umbria in Italy at 730 km from CERN, is investigated with lower priority. Umbria is a green field location in the existing CERN-CNGS beam.
LAGUNA-LBNO is a collaboration of about 300 physicists and engineers from 13 countries.
including 39 research institutions and industrial partners. Two non-European countries, Japan and Russia, are partners of the project. LAGUNA-LBNO will provide a realistic scheme for the tank construction and the costing of the detector itself. The costs involved with liquid procurement and long term running of the new underground laboratory (> 30 years) will be evaluated. New beam options based on the existing CERN accelerator complex are investigated and the physics potential of each detector option at the two locations will be studied.

At the Pyhäjärvi site, two options are studied: The LENA detector at a depth of 4000 m.w.e. and Glacier at a depth of 2500 m.w.e.. For the Fréjus site the MEMPHYS project in combination with a β-Beam (βB) from CERN is under investigation. In parallel a hybrid option of one or two MEMPHYS tanks together with the LENA experiment will be investigated [11].

4. The 3 detectors: GLACIER, LENA and MEMPHYS

The GLACIER (Giant Liquid Argon Charge Imaging ExpeRiment) detector is based on a new liquid argon detector concept, scalable to a single unit of mass 100 kton: it relies on a cryogenic storage tank developed by the petrochemical industry (LNG technology) and on a novel method of operation called the LAr LEM-TPC. LAr LEM-TPCs operate in double phase with charge extraction and amplification in the vapor phase. Thanks to the very good imaging capabilities of the GLACIER detector in combination with a neutrino beam from CERN the experiment has outstanding physics potential. The high resolution of the detector allows the precise measurement of the first and second oscillation maximum and therefore the precise determination of θ13, the CP violating phase δ and the mass hierarchy.

LENA (Low Energy Neutrino Astronomy) is a proposed large (~ 50 ktons) liquid scintillator (LSc) neutrino detector for particle-astrophysics, located in a deep underground laboratory. Because of its low energy threshold, LENA would be sensitive to neutrinos from very different sources: the measurement of the diffuse Supernova neutrino background; the precise determination of thermo-nuclear fusion processes and the matter-effects in solar matter by measuring solar neutrinos with high statistics; a measurement of geo-neutrinos probing Earth’s models; in case of an actual galactic type II Supernova an accurate measurement of the time development and flavor content of the emitted neutrino burst. Moreover, LENA can search for proton decay, especially $p \rightarrow K^+\bar{\nu}$, thus probing grand unified theories. In addition, LENA will be used as a detector for low energy atmospheric neutrinos and may perform an indirect search for Dark Matter. The MEMPHYS (MEgaton MAss PHYSics) project is discussed here with particular interest for deployment in an extended Modane Laboratory (LSM: Laboratoire Souterrain de Modane France), the distance from CERN being optimal for a low energy neutrino beam [12]. Due to the short distance to CERN this experiment has an excellent reach for leptonic CP violation search. The experiment is based on one of the most understood techniques for neutrino detection: Cherenkov light emission in water by the final state particles resulting from neutrino interactions. At beam energies below 1 GeV the water Cherenkov technique is well adapted to the physics scope of LAGUNA. Therefore the possibility of building a water Cherenkov detector with a fiducial mass of about 20 times larger than SuperKamiokande is currently investigated by different groups around the world, and for different underground sites. Each tank of MEMPHYS is about 10 times SuperKamiokande and therefore only a mild extrapolation from an existing detector is necessary. Figure 2 shows the dimensions and base line requirements for the photodetectors and the front end electronics.

5. Conclusions

In this paper we gave an overview over the results of the recently finished FP7 Design Study LAGUNA and the scientific and technical aspects studied within the current FP7 Design Study LAGUNA-LBNO.
Memphys: 2 x 330 kt
220'000 8" or 10" PMT’s
QE > 25%
DR 1 to 300 p.e.
Time resolution 1 ns
Low after pulsing
Pressure 10 bars
Lifetime > 30 y

LENA: 50 kt
55'000 8" PMT’s
QE > 25%
DR 0.2 MeV to 10 GeV
Time resolution < ns
Low after pulsing
Pressure 15 bars
Lifetime > 30 y

Glacier: 100 kt
1’000 8" WLS-coated cryo PMT’s
27’000 cryogenic PMT’s
 QE > 25%
Time resolution 0 ns
2 x 10^6 FADC channels
Lifetime > 30 y cryogenic

Figure 2. The three detector options for LAGUNA-LBNO and their requirements for the photo detectors and front end electronics. Left: MEMPHYS detector. Middle: Lena Detector. Right: Glacier detector.

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7. References
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