FUTURE PERSPECTIVES IN NEUTRINO PHYSICS: THE LAGUNA-LBNO CASE

M. BUIZZA AVANZINI on behalf of the LAGUNA-LBNO Consortium
Laboratoire APC, 10, rue A.Domon et L.Duquet, 75205 Paris, France

LAGUNA-LBNO is a Design Study funded by the European Commission to develop the design of a deep underground neutrino observatory; its physics program involves the study of neutrino oscillations at long baselines, the investigation of the Grand Unification of elementary forces and the detection of neutrinos from known and unknown astrophysical sources. Building on the successful format and on the findings of the previous LAGUNA Design Study, LAGUNA-LBNO is more focused and is specifically considering Long Baseline Neutrino Oscillations (LBNO) with neutrino beams from CERN. Two sites, Fréjus (in France at 130 km) and Pyhäsalmi (in Finland at 2300 km), are being considered. Three different detector technologies are being studied: Water Cherenkov, Liquid Scintillator and Liquid Argon. Recently the LAGUNA-LBNO consortium has submitted an Expression of Interest for a very long baseline neutrino experiment, selecting as a first priority the option of a Liquid Argon detector at Pyhäsalmi.

1 Introduction

Since many decades, Neutrinos represent an exciting subject of research, as their peculiarity is to be at the same time a particle to be studied and a probe to explore different sources. The project for the future is to combine the AstroParticle and Neutrino Physics programs within a single experiment. This requires the development of new infrastructures and a new concept of Detector: next years will be the era of Large Multipurpose Detectors. Projects are already under study in USA [1], Japan [2] and Europe [3]. In particular, 45 European Institutions, connecting scientists with industrial partners, are involved in the Design Study LAGUNA-LBNO, aiming at the feasibility study of a new large European underground infrastructure for the observation of proton decay, accelerator beam neutrinos and low-energy neutrinos from astrohysics sources. More precisely, the observatory will search for a possible finite proton lifetime with a sensitivity one order of magnitude better than the current limit. In addition, with a neutrino beam, it will determine with unequaled sensitivity the still unknown Neutrino Mass Hierarchy (MH), fundamental ingredient for Physics beyond the Standard Model, and unveil through neutrino oscillations the existence of CP Violation (CPV) in the leptonic sector, which in turn could provide an explanation of the matter-antimatter asymmetry in the Universe. Finally, it will

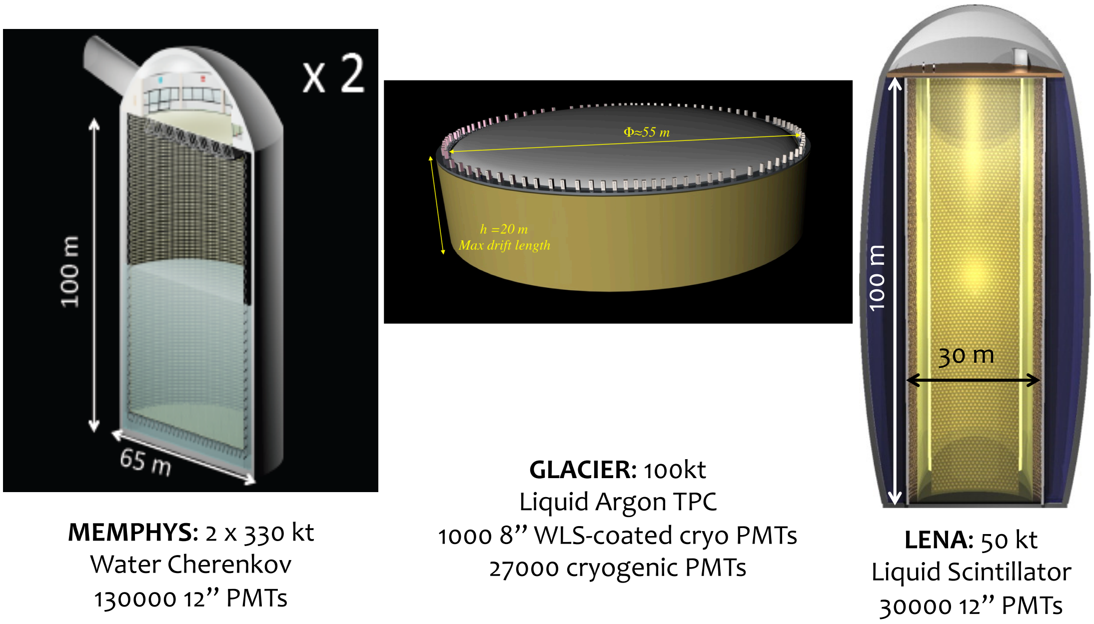

Figure 1: Main features of the three detectors considered by the LAGUNA collaboration.

study astrophysical objects, especially the Sun and Supernovae.

2 LAGUNA and LAGUNA-LBNO

In a first phase, the FP7 Design Study LAGUNA [4] (2008-2011) supported a Pan-European effort of 21 beneficiaries, composed of academic institutions from Denmark, Finland, France, Germany, Poland, Spain, Switzerland, United Kingdom and of industrial partners specialized in civil and mechanical engineering and rock mechanics, to assess the feasibility of such a research infrastructure in Europe. The LAGUNA consortium evaluated possible extensions of the existing deep underground laboratories in Europe: Boulby (UK), Canfranc (Spain) and Modane (France) and considers the creation of new laboratories in the following regions: Caso Umbria Region (Italy), Pyhäsalmi (Finland), Sierozsowice (Poland) and Slanic (Romania). Since the next generation deep underground neutrino detector should be coupled to advanced neutrino beams, the investigation offered a wide range of possible baselines, from 130 km to 2300 km, if a beam from CERN is envisaged.

At the same time, three different detector technologies have been considered: a Liquid Argon (LAr) detector (GLACIER) [5], a Liquid Scintillator (LSc) detector (LENA) [6] and a Water Cherenkov (WC) detector (MEMPHYS) [7]. A summary of the detector requirements is shown in Figure 1. For all three detectors, specific studies concerning the construction feasibility, the required depth, the muons and reactor neutrinos flux have been performed for each site, offering a large number of possible detector-site combinations, that is a large number of possible scenarios. The seven possible locations are shown in Figure 2, as well as an example of the cavity construction and infrastructure studies.

The selection of the optimal configuration involves several aspects (physics performances, technical feasibility, safety and legal aspects, socio-economic and environmental impact, costs,...) and this implies a particular attention of LAGUNA to interdisciplinary matter, since both physicists and engineers as well as geo-technical experts are directly involved. The conclusions of the LAGUNA design study are that it appears technically feasible to excavate the desired underground caverns and infrastructures in each of the pre-selected sites.

The LAGUNA collaboration decided to go ahead with a new study, LAGUNA-LBNO [8] (2011-2014) to further evaluate the findings of LAGUNA and, in particular, to assess the underground

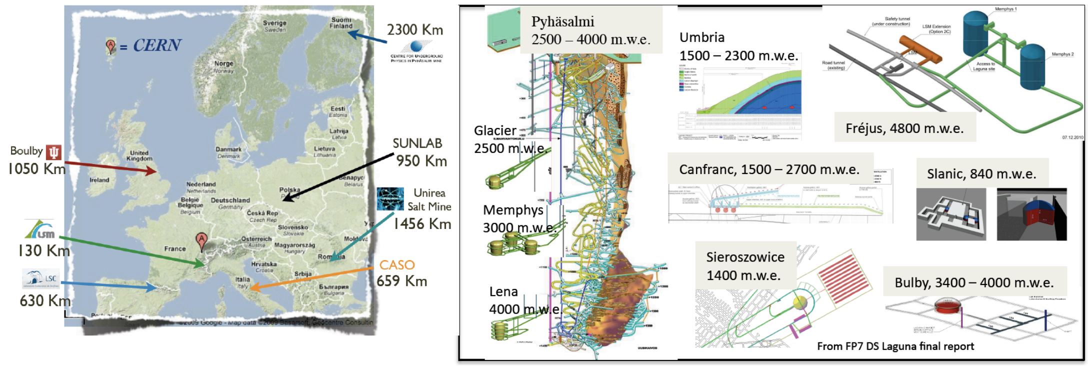

Figure 2: *Left*: Map of the seven possible underground sites in Europe. *Right*: Typical example of layouts studied in LAGUNA DS for each site.

construction of large detectors, their commissioning, and the long-term operation of the facility. LAGUNA-LBNO is in addition specifically considering long baseline beams from CERN. The collaboration counts 300 physicists and engineers from 13 countries including 40 research institutions and industrial partners.

The study of long baseline neutrino oscillations is one of the main scientific goals, and LAGUNA-LBNO is developping an incremental path towards neutrino MH determination and CPV discovery. The far sites provide two complementary baselines from CERN and the following scenarios are being considered:

- the MEMPHYS detector at the shortest baseline from CERN (Fréjus at 130 km) with no matter effect and therefore providing a clean measurement of CP violation phase (δ_{CP});
- the GLACIER detector at the longest baseline (Pyhäsalmi at 2300 km) with matter effects and therefore able to determine also the Neutrinos Mass Hierarchy.

Both these far locations offer excellent opportunities to include the LENA detector, to enhance the physics program at the lowest energy range, in particular for solar, geo-neutrinos detection and short baseline oscillometry studies with artificial low energy neutrino sources.

However, the longest baseline is the most attractive solution, since it allows a more complete physics program, involving the two challenging measurements of the MH and δ_{CP}.

3 The Expression of Interest

In summer 2012, 230 members of the LAGUNA-LBNO collaboration submitted to the European Strategy Roadmap an Expression of Interest (EOI) for a very long baseline neutrino oscillation experiment [9] with a new conventional neutrino beamline facility from CERN, focusing an option that would be specific to Europe. The recommended technology for the far detector is the double phase LAr Large Electron Multiplier Time Projection Chamber (LAr LEM-TPC), known to provide excellent tracking and calorimetry performance. The collaboration proposes an "incremental approach" involving two phases:

1. For a first phase, a 20 kt LAr detector and beam power of 700 kW are recommended; this configuration will offer a new insight and an increase in sensitivity reach for many physics channels. The LAr detector will be coupled to a magnetized iron calorimeter (MIND) with muon momentum and charge determination, that will collect an independent neutrino sample and will serve as a tail catcher for CERN beam events occurring in the LAr target.

2. Then, in a second phase an increase of the detector mass up to 70 kt and a possible increase of the beam power up to 2 MW is envisaged.

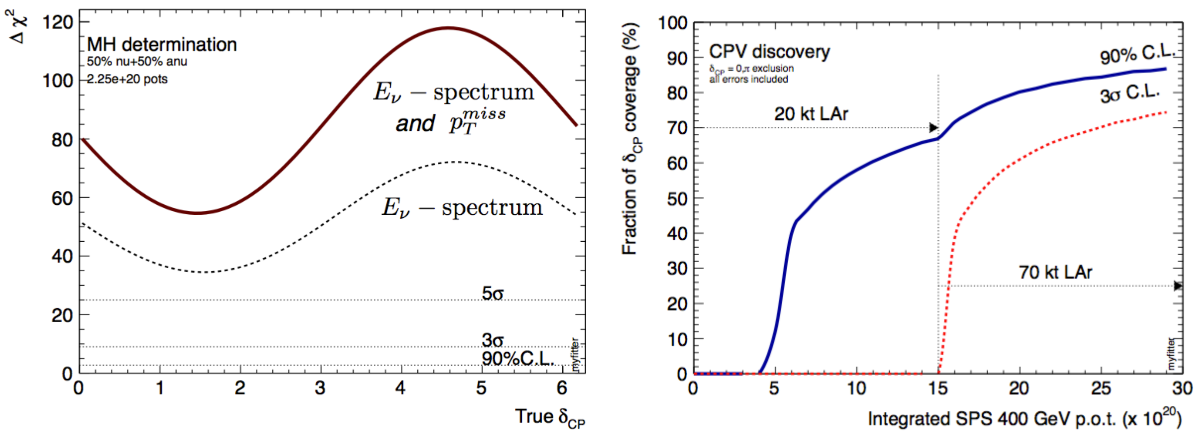

Figure 3: *Left*: $\Delta\chi^2$ of the mass hierarchy discriminant as a function of true δ_{CP}. The MH determination can be reached both by a simple analysis based on the reconstructed ν_e ($\overline{\nu}_e$) energy spectrum (dashed line) and by considering also the distribution of the missed transverse momentum (solid line) [9]. *Right*: sensitivity to CPV dependence as a function of p.o.t. either assuming an increase of the far detector mass up to 70 kt or increasing significantly the beam power to the 2 MW level (blue line) [9].

In addition, the precision requirements for the LBNO experiment demand the construction of near detector, ensuring the overall normalization of the experiment in terms of event rates. The envisaged technology will reproduce the far detector one (LAr TPC coupled with a MIND detector).

The long baseline physics objectives comprise the precise investigation of all flavor oscillations ($\nu_\mu \to \nu_e$, $\nu_\mu \to \nu_\mu$, $\nu_\mu \to \nu_\tau$) with neutrinos and antineutrinos, exploiting the energy spectrum information of the oscillation probability (L/E method) in appearance and disappearance modes, to provide unambiguous sensitivity to oscillation parameters, and a stringent test of the 3-generation mixing. With an exposure of 2.25×10^{20} p.o.t. from the SPS at 400 GeV, a conclusive determination ($> 5\sigma$ C.L.) of the neutrino MH is possible, independently from the value of δ_{CP} and θ_{23} (see left panel of Figure 3). This unprecedented result can be obtained in just 2 years of exposure. Presently, the LBNO proposed one is the most efficient configuration to solve the neutrino MH problem. Although limited by statistics in the initial configuration, the L/E method also yields a clean measurement of the CP-violating phase. With 1.25×10^{21} p.o.t. the existence CPV can be demonstrated at the 90%C.L. for about 60% of the δ_{CP} parameter space. This CPV-sensitivity is achievable in about 12 years at the upgraded SPS. It can improve further with the increased exposure resulting from longer running periods and/or an increase in beam power and far detector mass, as envisaged for the LBNO phase 2 (see right panel of Figure 3).

4 Conclusions

The design of next generation experiments with appropriate baselines and powerful conventional beams for the measurement of the MH and the δ_{CP} represents one of the most important steps for the future of Particle Physics. In particular, in Europe the LAGUNA-LBNO Design Study, a more focused continuation of the LAGUNA project, is ongoing, aiming at proposing a realistic plan for a medium- and long-term European long baseline program, with large discovery potentials at each phase. The first goal is to determine the neutrino mass hierarchy (with the 2300 km baseline). Then, incrementally exploring the phase space, leading to CPV discovery. In parallel, ultimate searches for proton decay and interesting neutrino astrophysics measurements will be possible. An Expression of Interest to the European Strategy Roadmap has been submitted in summer 2012, presenting unprecedented Physics Potentials for a LAr TPC detector coupled with a conventional high-power neutrino beam from CERN.

References

1. http://lbne.fnal.gov.
2. K. Abe et al., arXiv:1109.3262.
3. http://laguna.ethz.ch:8080/Plone.
4. D. Autiero et al., Journal of Cosmology and Astroparticle Physics 11 (2007) 011 arXiv:0705.0116v2 [hep-ph].
5. A. Rubbia et al., Journal of Physics: Conference Series 171 (2009).
6. L. Oberauer et al., Nuclear Physics Proceedings Supplements 138 (2005) 108; M. Wurm, et al., Acta Physica Polonica B 41 (2010).
7. A. de Bellefon et al., arXiv:hep-ex/0607026.; J.L. Borne et al., Nuclear Instruments and Methods in Physics Research Section A 639 (2011) 287.
8. LAGUNA-LBNO FP7 Design Study, Grant agreement no: 284518.
9. CERN-SPSC-2012-021; SPSC-EOI-007.