PROCEEDINGS OF SCIENCE

ESSνSB Neutrino Oscillation Project

Eric Baussan*
IPHC, Université de Strasbourg, CNRS/IN2P3, F-67037 Strasbourg, France
E-mail: eric.baussan@iphc.cnrs.fr

on behalf of the ESSνSB Collaboration

The recent measurements of the last mixing angle performed by the reactor experiments in the neutrino sector enable the search for CP violation in the leptonic sector. The next generation of experiments will require new intense neutrino beams and large detector infrastructures. In this context, a new facility is proposed using the European Spallation Source (ESS), currently under construction in Lund (Sweden), to produce the world's most intense neutrino beam with a megaton Water Cherenkov detector installed 1000 m down in a mine at a distance of about 500 km. This detector will also extent the physics program to proton-decay, atmospheric neutrinos and astrophysics searches.

Frontiers of Fundamental Physics 14
15-18 July 2014
Aix Marseille University (AMU) Saint-Charles Campus, Marseille, France

*Speaker.

PoS(FFP14)105

1. Toward the precision era in the neutrino physics

The last decades have seen lots of progresses in neutrino physics. The landscape has been recently completed with the measurement of the last mixing angle θ_{13} by the reactor experiments. In the three oscillation framework, the flavor states are linked to the mass states thanks to the PMNS[1] mixing matrix which can be expressed in a standard parametrization form with the mixing angles θ_{ij}:

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}.e^{-i\delta_{CP}} \\ 0 & 1 & 0 \\ -s_{13}.e^{i\delta_{CP}} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

with $c_{ij} = cos(\theta_{ij})$, $s_{ij} = sin(\theta_{ij})$ and δ_{CP} the CP phase. The future experiments will measure precisely the mixing parameters and search the CP violation in the leptonic sector. Before knowing the value of θ_{13}, the future facilities were tuned to look at the first maximum of the oscillation probability $\nu_\mu \rightarrow \nu_e$ which can be expanded in a sum of three terms respectively referenced as atmospheric, solar and an interference term containing the CP phase:

$$P_{\overset{(-)}{\nu}_\mu \rightarrow \overset{(-)}{\nu}_e} = s_{23}^2.sin^2 2\theta_{13}.sin^2\left(\frac{\Delta_{13}L}{2}\right) + c_{23}^2.sin^2 2\theta_{12}.sin^2\left(\frac{\Delta_{21}L}{2}\right) + \widetilde{J}.cos\left(\pm\delta - \frac{\Delta_{13}L}{2}\right).sin\left(\frac{\Delta_{21}L}{2}\right).sin\left(\frac{\Delta_{31}L}{2}\right)$$

The upper/lower sign refers to neutrinos/antineutrinos, E_ν being the neutrino energy, L the source-detector distance, $\Delta_{ij} = \frac{\Delta m_{ij}^2}{2E_\nu}$ and $\widetilde{J} = c_{13}.sin2\theta_{12}.sin2\theta_{23}.sin2\theta_{13}$ the Jarlskog invariant. Considering the measured value of θ_{13}, the atmospheric term becomes prominant compared to the interference term at the first maximum. An interesting possibility to increase the sensitivity to CP discovery and be less sensitive to systematic errors will be to considere a longer baseline looking at the second oscillation maximum in which the interference term is enhanced[1].

A large international research program is investigating the best facilities to address these questions. In this context, the ESSνSB collaboration[2] proposes to take benefit from the European Spallation Source currently under construction at Lund in Sweden to produce a very intense neutrino superbeam.

2. A very intense neutrino super beam with a high CP violation discovery potential

The future facilities for precision measurements will require the elaboration of a proton driver at Mega Watt (MW) scale. The European Spallation Source[3] will be able to deliver a 5 MW beam power for neutron experiments in a near future. A modification of the linac is proposed by the ESSνSB collaboration in which the initial power will be increased to reach 10 MW. The proton driver will be shared simultaneously for neutron (5MW) and neutrino (5MW) applications with no reduction in the spallation neutron prodution. Specific beam profile on the proton pulses is required for neutrino users and imply to adapt the linac parameters.

[1]Pontecorvo-Maki-Nakagawa-Sakata

PoS(FFP14)105

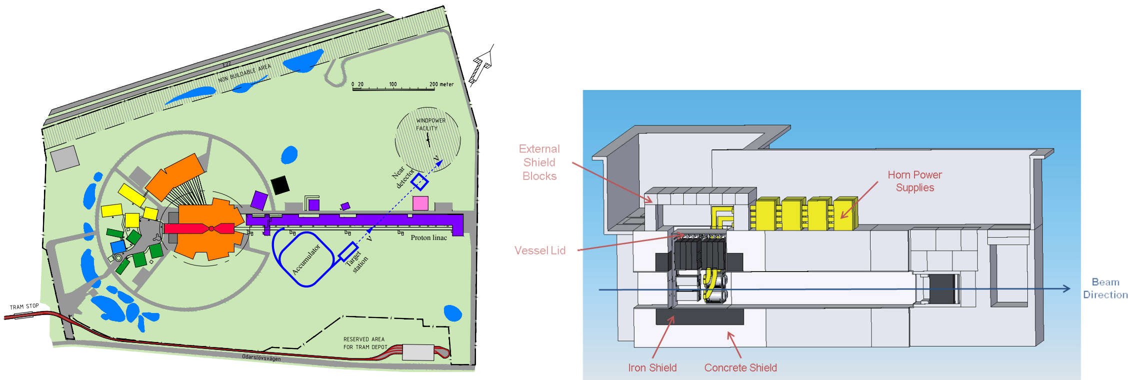

Figure 1: ESS neutrino beam layout and target station concept.

An accumulator system[4], placed at the end of the linac as illustrated in Fig 1. is essential to reduce the initial proton pulse length from 2.86 ms to a few μs in order to minimize the duration of the current pulses in the beam focusing system. Due to charge space effect at the entrance of the accumulator an H^- source has to be implemented in complement with the H^+ one for neutron mode.

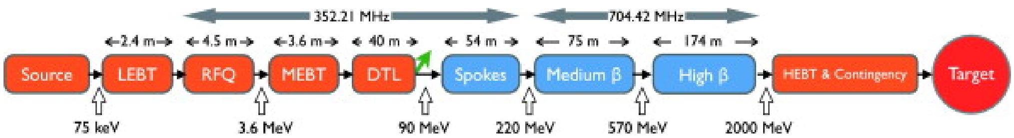

Figure 2: ESS linac implementation.

At the end of the accumulator, the 5 MW proton beam is distributed via four beam-lines onto the four targets of the hadronic collector. The beam is splitted by kicker magnets, bended by dipoles and finally is focused onto the four targets by a system of quadrupoles. Each target is embedded in a magnetic horn which focus the secondary particles escaping the target into the decay tunnel. A large part of the energy carried out by the proton beam will be released in the surrounding environment of the hadronic collector. A target station concept inspired from EUROnu Design Study[5] with an appropriate shielding has to be implemented in order to be in agreement with the regulation and safety rules.

3. An hadronic collector design for a proton driver at MW scale

Compared to the existing neutrino beams, the hadronic collector will be designed to work with 5 MW proton beam power from the ESS linac with a 56 Hz repetition rate. Many constraints appears du to the high particle rate limiting the lifetime of the whole system. The design proposed by the ESSνSB collaboration is inspired from previous studies[5] and should be able to work under these extreme working conditions. Each proposed element has been studied to take into account the present technological limitations and to provide good reliability during the running time of the experiment:

- The target technology is based on a packed bed titanium spheres cooled with pressurized helium gas for an efficient cooling.
- For the four horn system shown in Fig 3, a peak current of 350 kA is pulsed at 14 Hz repetition frequency. About 52 kW are dissipated from resistive heating in the horn structure. In case of one horn is damaged, the beam power will be shared by the three other horns. Each horn will be able to work under a 1.6 MW beam power.

Figure 3: Horn view and four horn system.

- Horn structure: the aluminium skin is made of Al 6061 T6 alloy; good trade-off between mechanical strength, resistance to corrosion and electrical conductivity. The horn skin has to be as thin as possible for the best physics performance and to limit the energy deposition from secondary particles. The horn wall has also to be thick enough to sustain dynamic stress from the pulsed currents.
- Mechanical studies: a finite element model allows the calculation of the horn stress and deformation due to the magnetic pressure and thermal dilatation minimum stress ($<$ 30 MPa), maximal lifetime when the horn has a uniform temperature (around 60^{o}C) maintained by water cooling.
- Heat transfer and cooling: the current is transmitted to each horn by a 33 m transmition line based on eight aluminum striplines spaced by 1 cm. The dimensions of striplines allow them to have small resistivity and inductance.

4. Physics Performance

The combined experiments of the super beam with a megaton scale water Cherenkov detector detector offers a very good discovery potential of CP violation[6]. The MEgaton Mass PHYSics (MEMPHYS) detector is a proposed 0.5 Mton scale underground Water Cherenkov experiment to be performed deep under-ground[7]. It consists of two modules of 103 m height and 65 m diameter: each module has 120000 10" PMTs and ~30% optical coverage.
Several simulations based on GLoBES [8] have been performed considering three proton beam energy 2.0, 2.5 and 3.0 GeV corresponding to possible linac upgrades and with several distances as illustrated in Fig 4. The Leptonic CP violation could be discovered at 5σ confidence level

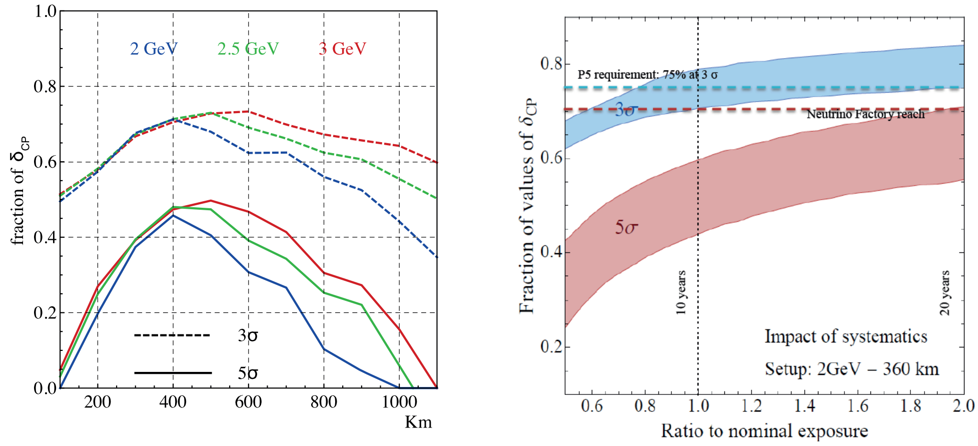

Figure 4: Fraction of the full δ_{CP} range as function of the baseline (left) and CP discovery potential in terms of standard deviation at 2.0 GeV proton beam energy (right) .

within at least 50% of phase range for a baseline between 300-550 km. In addition, the neutrino mass hierarchy can also be discovered when data from the atmospheric neutrinos are combined as a benefit of a very large $\sin^2(2\theta_{13})$. MEMPHYS is also dedicated to physics related to nucleon decay, neutrinos from supernovae, solar and atmospheric neutrinos. It is foreseen to be placed at the Garpenberg Mine at 540 km from the ESS facility.

5. Conclusion

The ESSνSB neutrino oscillation project appears to be a competitive facility able to discover a CP violation in the leptonic sector in a relatively near future and it also offers a rich non accelerator physics program.

References

[1] P. Coloma and E. Fernandez-Martinez, JHEP **1204** (2012) 089 [arXiv:1110.4583].

[2] E. Baussan *et al.* [ESSnuSB Collaboration], Phys. Lett. B **885**, 127 (2014) [arXiv:1309.7022].

[3] European Spallation Source ESS AB, http://www.esss.se

[4] E. Wildner, J. Jonnerby, J. P. Koutchouk, M. Martini, H. Schönauer, E. Bouquerel, M. Dracos and N. Vassilopoulos *et al.*, Proceedings of IPAC2014, Dresden, Germany

[5] T. R. Edgecock, O. Caretta, T. Davenne, C. Densham, M. Fitton, D. Kelliher, P. Loveridge and S. Machida *et al.*, Phys. Rev. ST Accel. Beams **16** (2013) 021002 [arXiv:1305.4067].

[6] P. Coloma, P. Huber, J. Kopp and W. Winter, Phys. Rev. D **87** (2013) 3, 033004 [arXiv:1209.5973].

[7] L. Agostino *et al.* [MEMPHYS Collaboration], JCAP **1301** (2013) 024 [arXiv:1206.6665].

[8] P. Huber, J. Kopp, M. Lindner and W. Winter, PoS NUFACT **08** (2008) 145.