PROCEEDINGS OF SCIENCE

The ESSνSB High Intensity SuperBeam

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The measurement of the matter/antimatter asymmetry in the leptonic sector is one of the highest priority of the particle physics community in the next decades. The ESSνSB collaboration proposes to design a long baseline experiment based on the European Spallation Source at Lund in Sweden. This experiment will be able to measure the δ_{CP} parameter with an unprecedent sensitivity thanks to a very intense neutrino superbeams and to the observation of the ν_μ to ν_e oscillation at the second oscillation maximum. To reach this goal, the European Spallation Source facility will be upgraded to provide an additional 5 MW proton beam by doubling the linac pulse frequency from 14 Hz to 28 Hz. The pulse time width will be reduced thanks to an accumulator ring from 2.86 ms to 1.3 µs and shared in four parts by a beam switchyard before entering into the target station. The produced neutrino superbeam will be sent to a large 538 kt fiducial mass far detector based on water Cherenkov technology. A global overview of the project with its physics potentials will be reviewed and additional possibilities offered by this high intensity facility for complementary R&D activities will also be discussed.

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1. The ESSνSB Superbeam

Since the measurement of the last mixing angle θ_{13} by the reactor experiments, numerous questions remain still opened in neutrino physics, in particular the mass ordering and the matter/antimatter asymmetry in the leptonic sector. A new generation of neutrino superbeam is investigating these major questions such the Deep Underground Neutrino Experiment (DUNE) [1] whose the building of the facility is in progress in US and the HyperKamiokande experiment in Japan [2]. ESSνSB is a cost effective experiment based on the European Spallation Source (ESS) currently under construction at Lund in Sweden to produce a very intense neutrino superbeam based on a 5 MW proton linac. The experiment allows to measure the δ_{CP} parameter with good precision due to its specific baseline looking at the second maximum of the ν_μ to ν_e oscillation [3].

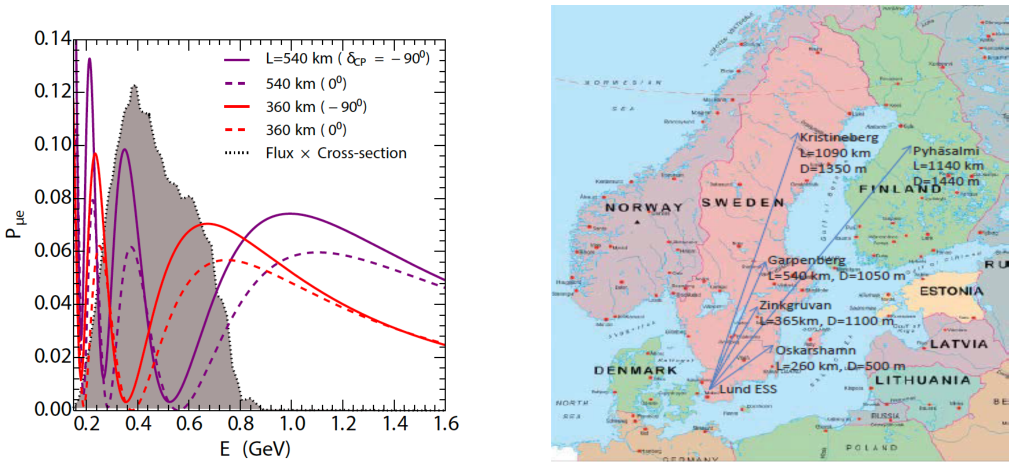

Figure 1: Neutrino fluxes (left) ESSνSB possible baselines (right)

Two baselines were under consideration in which a Mt scale far detector based on water Cherenkov technique were located in the Garpenberg mine at 540 km or, as an alternative choice, in the Zinkgruvan mine at 360 km from the source. These mines are almost aligned as shown in Figure 1 (right) and many optimisations were done to find the best baseline.

2. Physics performances

Additional facilities are necessary to produce a high intensity neutrino superbeam at ESS and their localisation is shown on Figure 2. After the upgrade of the proton linac from 5 MW to 10 MW, the additional part of the protons are injected by a tranfert line (blue) into the accumulator ring (red) to shorten the initial pulse width from 2.86 ms to 1.3 µs corresponding to the working conditions of the focussing elements. The resulting proton pulses are separated in four parts by a beam switchyard (purple) before entering into the target station facility (green) which contains four magnetic horns equipped each with a titanium granular target. The primary protons are converted by the target into secondary particles which decay in neutrinos inside the decay tunnel of the target station facility.

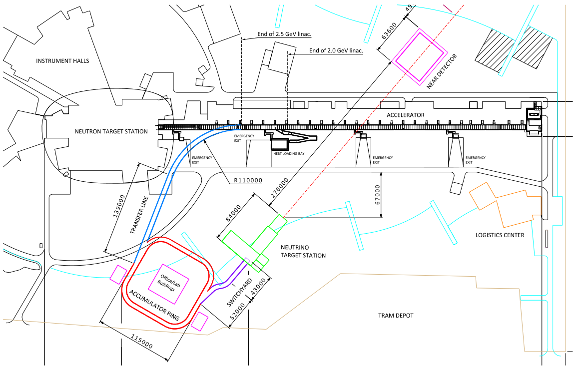

Figure 2: ESSνSB facility at ESS site.

The first optimisation of the baseline has been performed on the shape of the horn by using a deep-learning technics based on a genetic algorithm. This technique is an evolutionary algorithm, in which a set of different geometric configurations of the system to be optimised is allowed to evolve towards the best Figure of Merit (FoM) which is the fraction of δ_{CP} in this case.

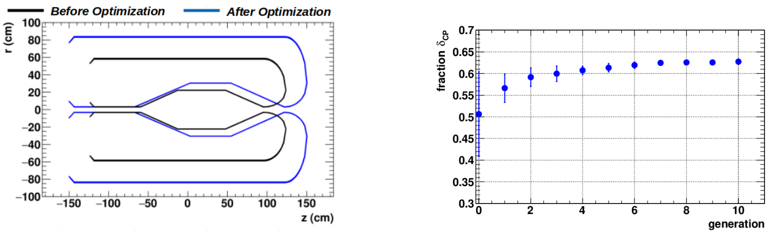

Figure 3: Horn shape optimisation (left) Genetic algorithm convergence (right)

After convergence of the FoM, the final dimensions of the horn has been increased as shown in Figure 3. The size of the target station facility has been also modified in consequence and the decay tunnel has been prolongated from 25 m to 50 m. The resulting neutrino fluxes are shown in Figure 4 with their composition given in Table 1.

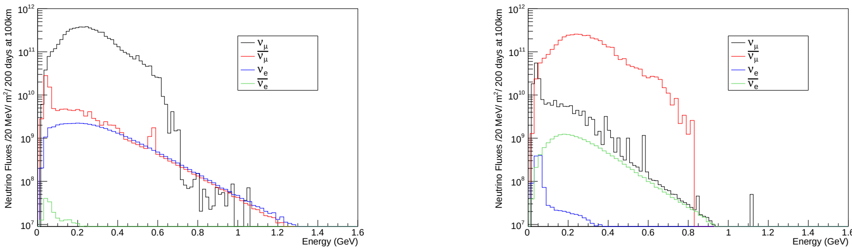

Figure 4: Neutrino fluxes obtained after the modifications of the size of the target station and of the decay tunnel extension.

Table 1: Neutrino flux composition at 100 km.

	ν Mode		$\overline{\nu}$ Mode	
Flavor	$N_\nu(10^{10}/m^2)$	%	$N_\nu(10^{10}/m^2)$	%
ν_μ	674	97.6	20	4.7
$\overline{\nu}_\mu$	11.8	1.7	396	94.8
ν_e	4..76	0.67	0.13	0.03
$\overline{\nu}_e$	0.03	0.03	1.85	0.43

As a sizeable part of the optimisation, new migration matrices has been implemented using the T2K-like reconstruction algorithm which have significantly improvement the reconstruction efficiency [4].

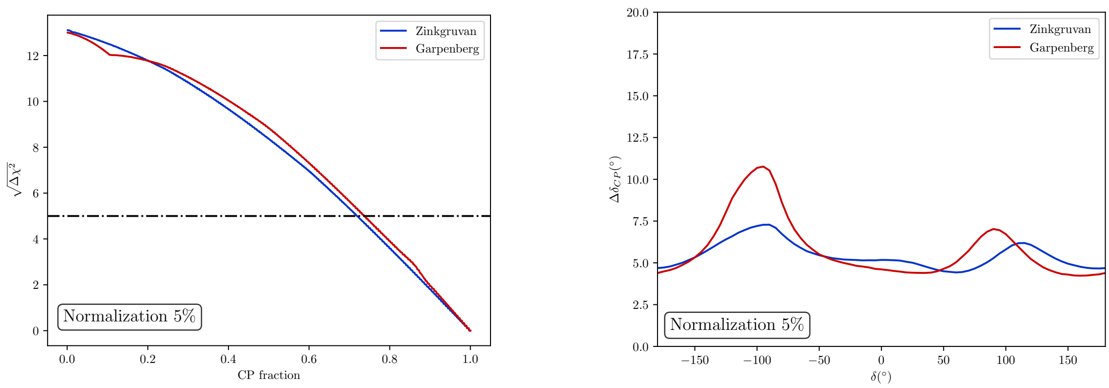

Figure 5: δ_{CP} coverage (left) δ_{CP} precision measurements (right)

After 10 years of data taking, the experiment will cover 72% of the δ_{CP} phase space and will be able to measure it with a precision of less than 8° for all value of the phase space as shown on Figure 5. For the precision measurement, the Zinkgruvan mine is the better choice.

3. Next phase of the project : ESSνSB+

With the publication of the conceptual design report [5], the ESSνSB collaboration has demonstrated the feasibility of a very high intensity neutrino superbeam based on an upgrade of the European Spallation Source Facility. This project has opened a complementary research program to the neutron one and paved the way for future possible interests which could be beyond neutrino physics [6].

ESSνSB+ is a new project, approved for four years by European Union, which will participate to this effort and proposes to reinforce and develop additional features to this proposal in order to improve and widen the scientific and technological scope. This new facility, whose plan is shown on Figure 6, could be considered as an intermediate step before going to the neutrino superbeam with the development of a second target station (yellow) which will work at 1.25 MW proton beam

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power and other complementary elements such a muon race track storage ring (red) and a Low Energy Monitored Neutrino Beam.

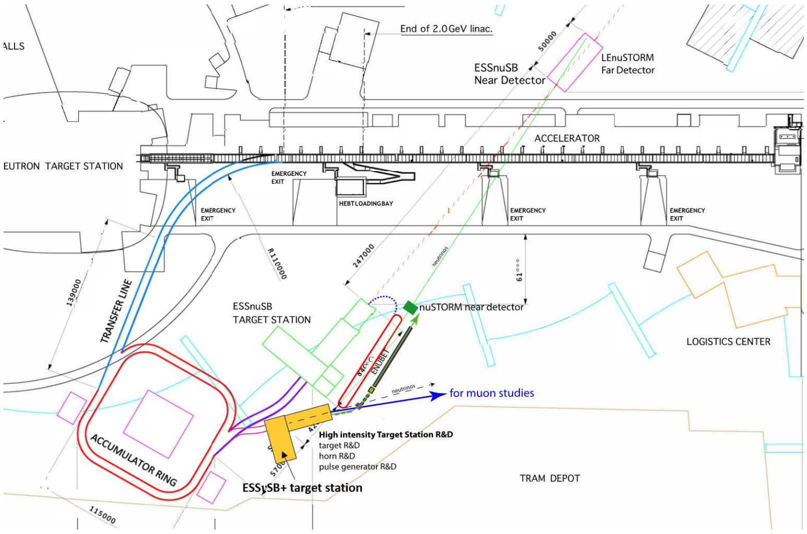

Figure 6: ESSνSB+ implementation on ESS site.

The main objectives of the project are summarized below:

1. Design of a racetrack storage ring for low energy muons produced with a beam from the ESS linac.

2. Design a transfer system from the initial collection and extraction of pions behind the target station, up to the injection point.

3. Design a transfer line from the ESSνSB ring-to-switchyard transfer line to the low energy nuSTORM target (cross section measurement, sterile neutrino searches).

4. Design an injection scheme for the racetrack storage ring.

5. Design a monitored neutrino beam (low energy ENUBET for cross section measurement).

6. Optimise the performance of the ESSνSB accelerator complex.

The design of all these elements represents real challenges and some technical difficulties are common to the other superbeam experiments in particular for the intermediate target station which will work at 1.25 MW and which has the same order of magnitude of proton beam power for the next generation of superbeam experiment. The role of this target station is to feed, at the early stage, the low energy monitored neutrino beam at low power and, at the second stage, the racetrack storage ring at full power. Due to the large spread of the pion distribution $\sigma \sim 0.38$ m (under a gaussian approximation), at 10 m from the horn based on the ESSνSB shape, the elaboration of the collection and extraction system at the end of the target station is really challenging.

4. Conclusion

The ESSνSB project has recently published its Conceptual Design Report [5] and proposes a concept of a high intensity neutrino superbeam in Europe which will cover more than 72% of δ_{CP} range and will be able to measure this parameter with 8° precision after 10 years of data taking at 5 MW proton beam power. A new European project called ESSνSB+ has been approved to perform complementary researches on the production of a neutrino superbeam based on muons decay and will offer a broad range of fundamental physics complementary to neutrino physics (proton lifetime, astroparticules,. . .).

5. Acknowledgements

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