Updates on the ESSνSB Target Station potentialities for CP violation discovery.

Julie Thomas, Eric Baussan, Loris D'Alessi, Marcos Dracos
IPHC, Université de Strasbourg, CNRS/IN2P3, 67037 Strasbourg, France.
On behalf of the ESSνSB project

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CP Violation in leptonic sector

The asymmetry between matter and anti-matter observed in the Universe could be explained by the CP violation in leptonic sector. This would imply that the probability for neutrino to change flavour, called oscillation, $P(\nu_i \rightarrow \nu_j)$ is different from the same probability for anti-neutrino $P(\bar{\nu}_i \rightarrow \bar{\nu}_j)$. Thanks to the relatively large value of θ_{13} in the PMNS matrix, neutrino beam experiments can be developped and are trying to measure these probabilities.

The ESSνSB project [1]

The ESS Neutrino Super Beam project proposes to use the linac of ESS[2] in Lund (Sweden) to produce a high-intensity and low-energy neutrino beam.

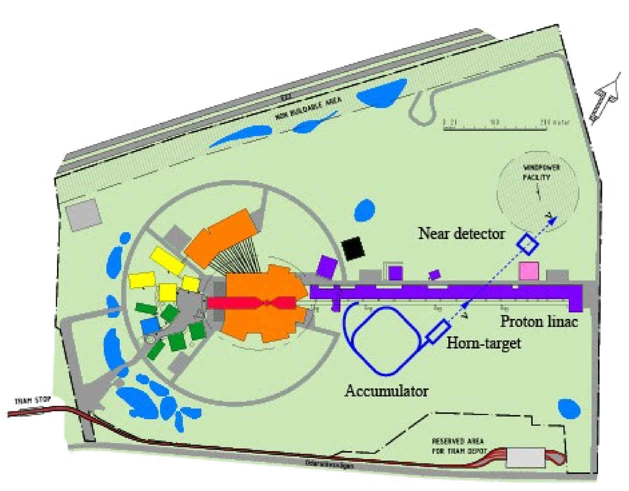

Fig. 1 : ESSνSB site in Lund

The ESS Linac will provide 2.5 GeV protons with an intensity of 5 MW. The 2.86 ms pulses proton beam will be sent to an accumulator ring to reduce its length to less than 1.5 µs with a frequency of 14 Hz, reaching 8.9×10^{14} ppp. Then, through a switchyard, it will be split in four beams to reach the target station, where the neutrino super beam will be produced. The neutrino flux will finally be measured 540 km away from the target station in the mine of Garpenberg in Sweden with a 500 kt, Memphis like[3], Water Cerenkov detector, allowing the measurement of these low-energy neutrinos.

This combination of high intensity and low energy will allow to access the second maximum in the neutrino oscillation probability, improving sensitivity for CP violation measurement compared with the first oscillation maximum.

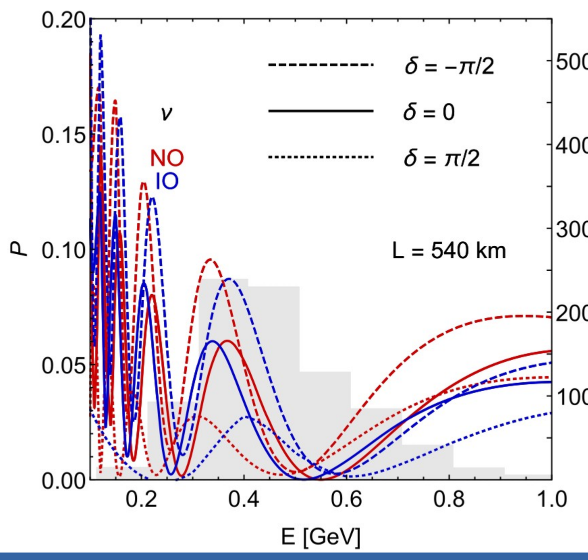

Fig. 2 : Oscillation probability as function of neutrino energy for different values of δ_{CP}[4]

The Target Station

The target station is made of three major elements : the hadron collector, the decay tunnel and the beam dump.

- Our hadron collector complex is made of four magnetic horn-target systems, type van der Meer, supplied by a 350 kA pulsed current. These horns can operate in two focusing modes in order to produce the neutrino or antineutrino beam.

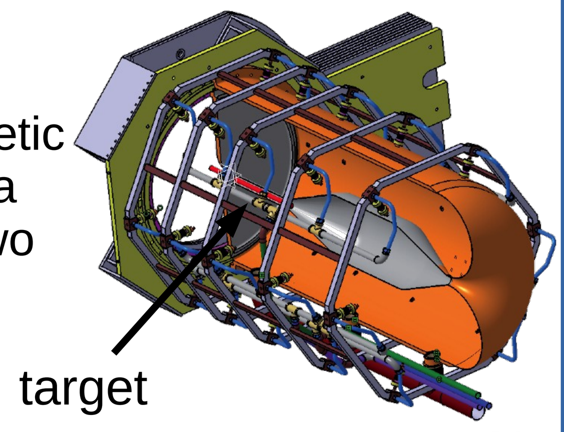

Fig. 3 : A magnetic horn[5][6]

- The packed-bed targets are made of 3 mm diameter titanium spheres, with a length of 78 cm and 1.5 cm radius. Each target receives a 1.25 MW proton beam, allowing to produced hadrons and especially pions.
- The magnetic field directs the produced pions to the 25 m long decay tunnel where they will decay and produce the neutrino super beam.
- Finally, the remaining hadrons will be stopped at the end of the decay tunnel by a one-block graphite beam dump (4*4*3.2 m³) in order to limit the radioactivation of the cave.

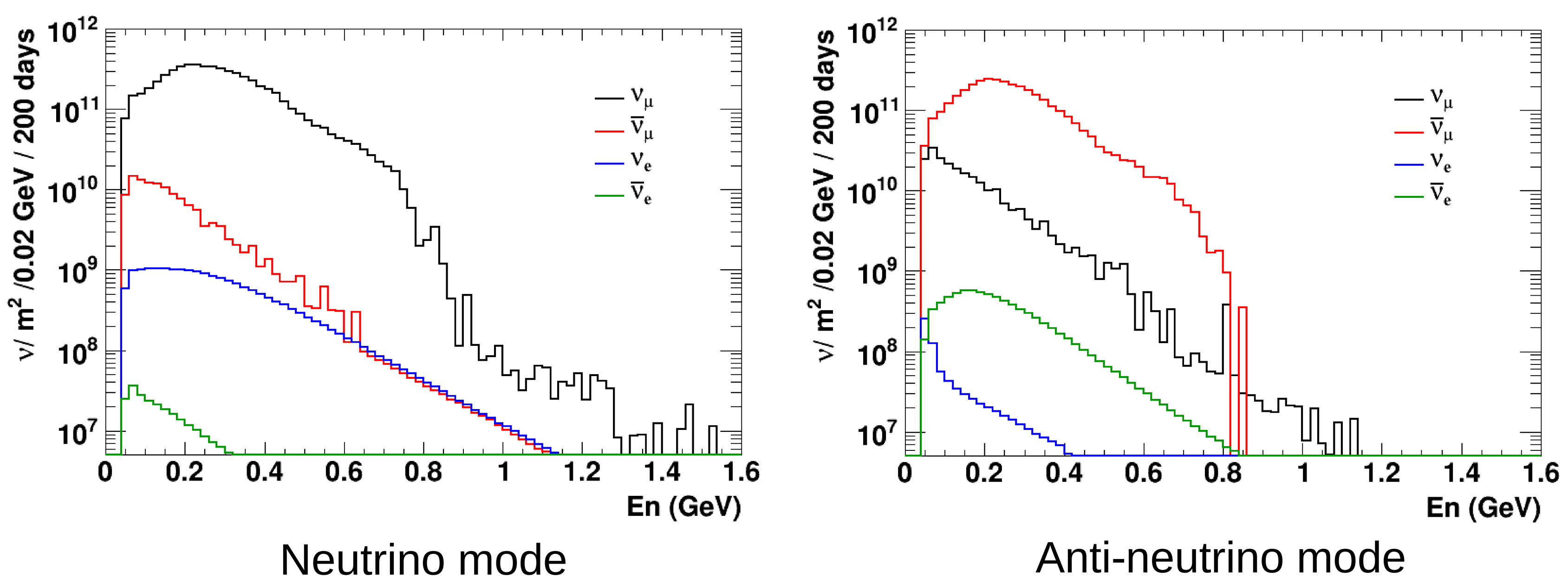

Fig. 4 : Neutrino fluxes as function of energy for a year of running time for positive and negative focusing respectively.[7]

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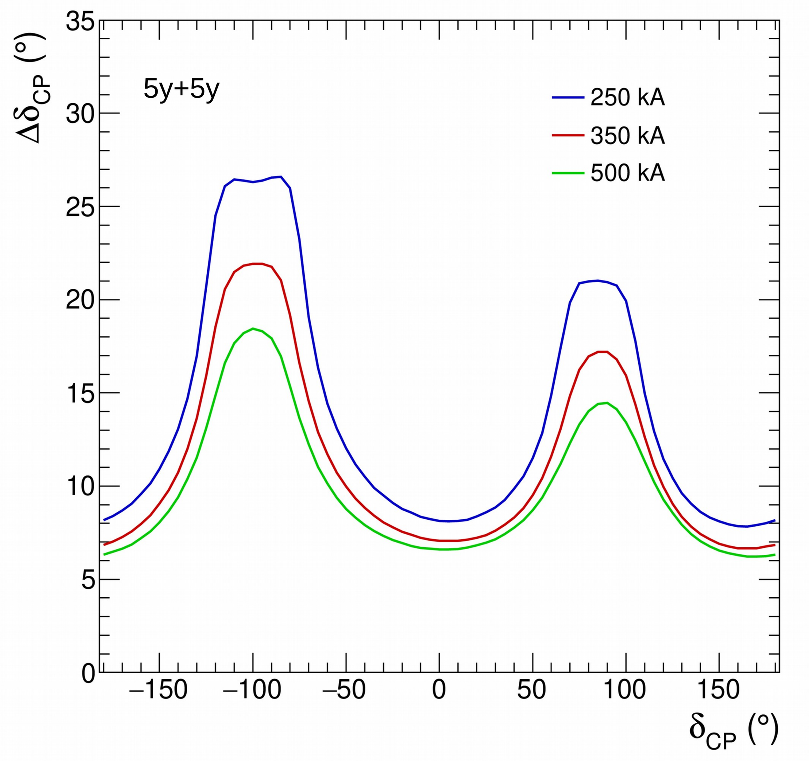
A parameter study for physics optimization

Different studies have been done at the level of the target station facility and the magnetic horns in order to improve the sensitivity of ESSνSB for the measurement of δ_{CP}. For this study, neutrino fluxes were generated with Geant4[8][9][10] and used in GLoBES[11][12] software to produce the sensitivity plots.
We can first see the influence of the current delivered to the horn on the performances.



An increase of the current would give a better precision on the measurement of δ_{CP} however 350 kA is a good compromise from the technical point of view.

Fig. 5 : Precision at 540 km on the measurement of δ_{CP} according to true values of δ_{CP} for different values of the current.

We also studied the influence of different baselines. There are two predominant choices : the mine of Garpenberg at 540 km and the mine of Zinkgruvan at 360 km.

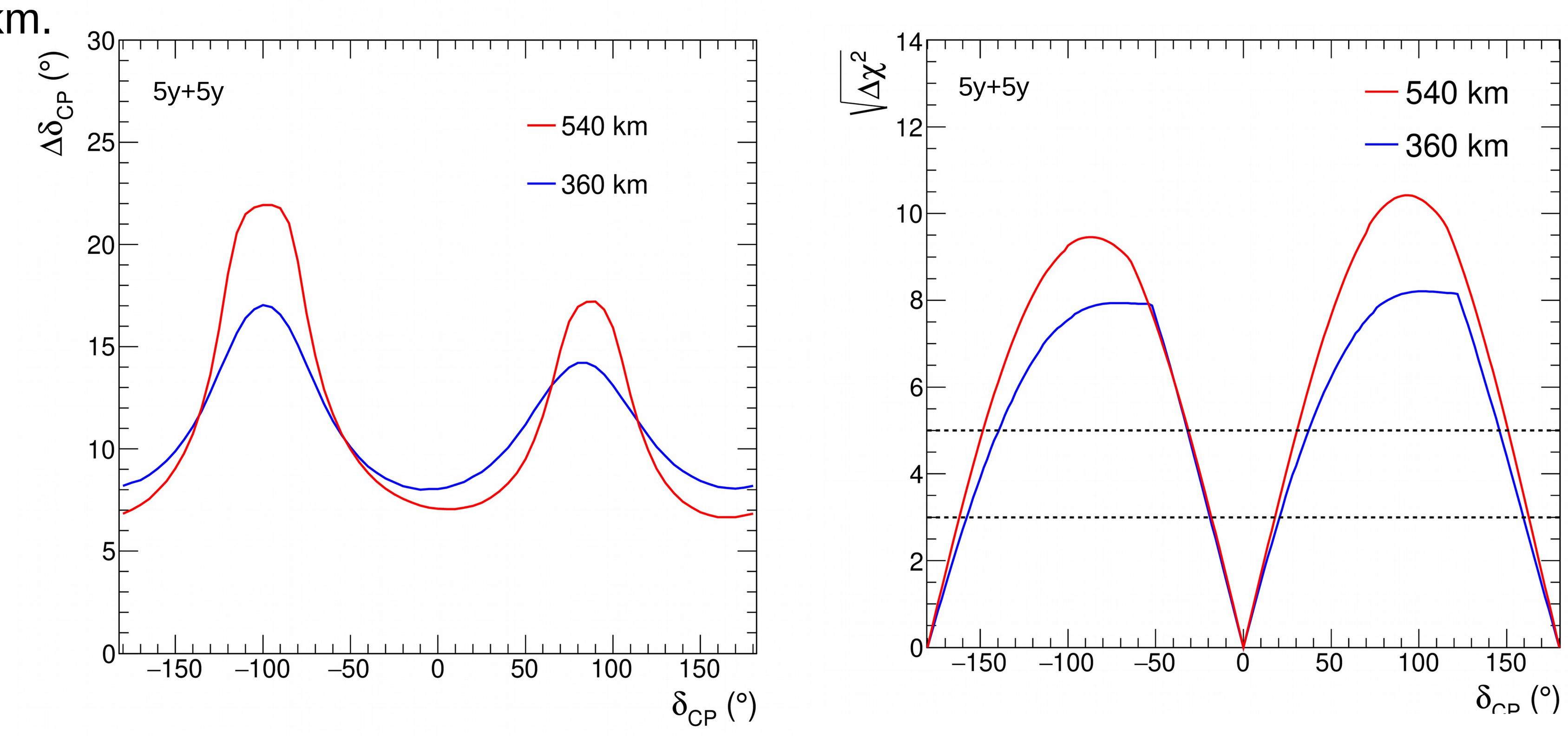


Fig. 6 : Sensitivity for the measurement of δ_{CP} (left) and CP discovery potential (right) according to true values of δ_{CP} for different baselines.

The CP discovery potential reaches a fraction of δ_{CP} covered at 5σ of more than 60 % for the two baselines. With also a better precision for the measurement of the value of δ_{CP} around -90°, the baseline at 360 km is a very interesting candidate .
A parametric study on the horn dimensions and the decay tunnel has also been made :

- Both total length and radius of the horn are modified (Scale Factor),
- Only the total length of the horn is modified (L_{TOT} Horn),
- Only the total radius of the horn is modified (R_{TOT} Horn).

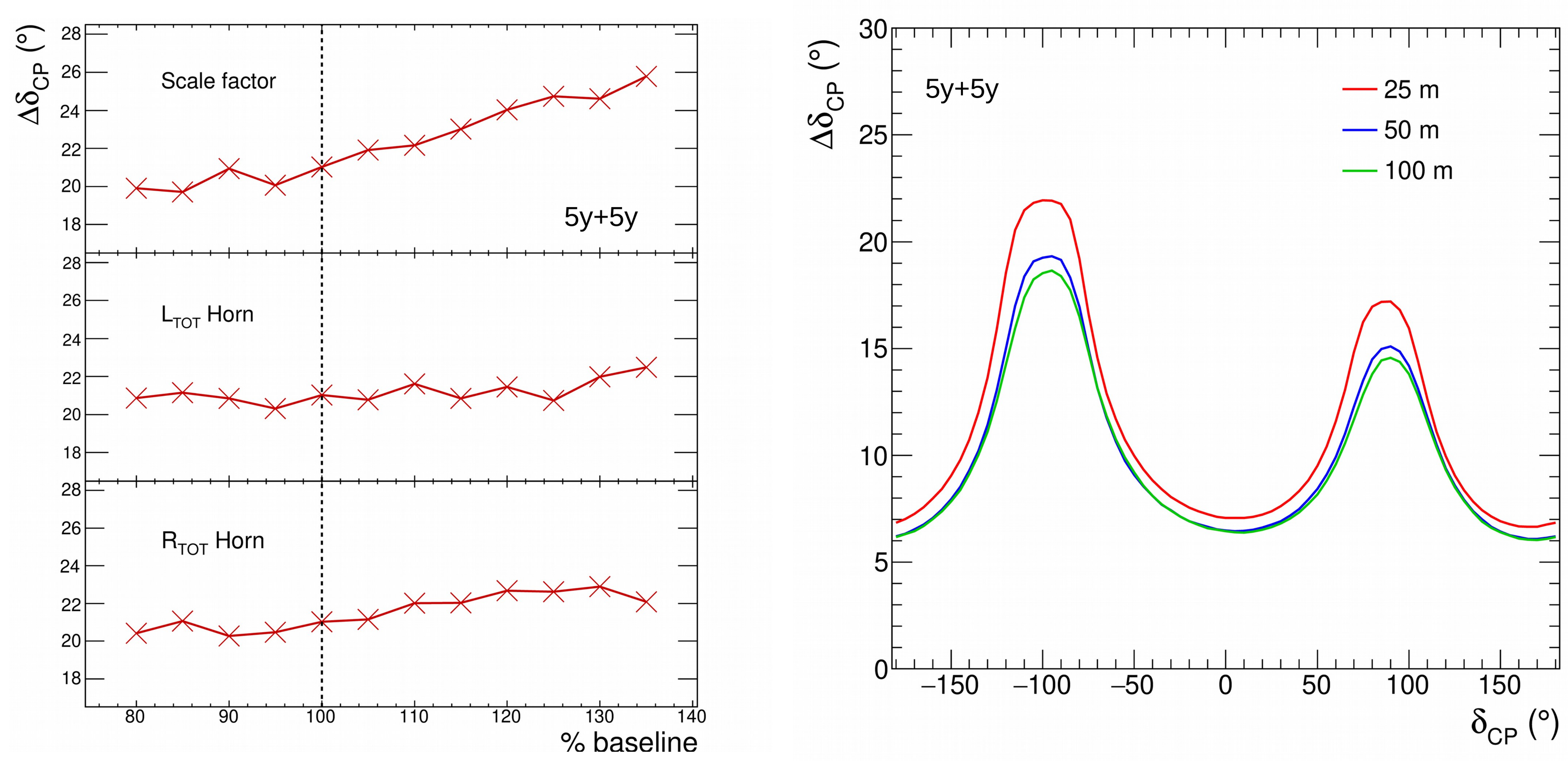


Fig. 7 : Evolution at 540 km of the precision on the measurement for δ_{CP}= -90° according to the dimensions of the horn (left) and for different lengths of the decay tunnel (right).

We can see that reducing the dimensions of the horn to 95 % of the current baseline can give an improvement in the measurement of δ_{CP}.
Fig. 7 also shows that increasing the length of the decay tunnel will allow more pions to decay and will improve the sensitivity, even if more muons will decay.

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