# EURO$\nu$ Super Beam Studies

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**Abstract.** Neutrino Super Beams use conventional techniques to significantly increase the neutrino beam intensity compared to the present neutrino facilities. An essential part of these facilities is an intense proton driver producing a beam power higher than a MW. The protons hit a target able to accept the high proton beam intensity. The produced charged particles are focused by a system of magnetic horns towards the experiment detectors. The main challenge of these projects is to deal with the high beam intensity for many years. New high power neutrino facilities could be build at CERN profiting from an eventual construction of a high power proton driver. The European FP7 Design Study EURO$\nu$, among other neutrino beams, studies this Super Beam possibility. This paper will give the latest developments in this direction.

**Keywords:** neutrino, super-beam, horn, target, SPL
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## INTRODUCTION

The European FP7 Design Study EURO$\nu$ (`http://euronu.org`) studies three different ways of producing intense neutrino beams, the CERN SPL [1] Super Beam, the Beta Beam and the Neutrino Factory. The CERN SPL Super Beam uses conventional muon neutrino beam produced by the decay of mesons (pions and kaons). These mesons are produced by colliding a MW proton beam with a target. The mesons are focused towards the detector direction by a hadron collector. The hadron collector used very often in these applications is a magnetic horn pulsed with a very high electrical current. In the case of the CERN SPL Super Beam (SB) the operation conditions will be much more severe than in previous applications. The proton driver power intended to be used by this application is 4 MW with a repetition rate of 50 Hz, two parameters considerably higher than the present applications.

An initial design of a horn prototype system (horn+reflector) [2, 3] foreseen for a neutrino factory (NF) has been made at CERN for a 2.2 GeV proton beam. An optimisation and a redesign has been made in a SB context [4, 5], driven by the physics case of a long–baseline experiment (130 km) between CERN and Fréjus (MEMPHYS detector location [6]). From these studies, it came out that the optimal proton energy is between 3.5 and 4.5 GeV. The circulating electrical current is then required to be 300 kA in the horn and 600 kA in the reflector enveloping the horn. Both studies concluded that the proton target has to be installed inside the horn to maximize the hadron collection. For the power dissipation of the system, this condition (coming from the relatively low proton energy and the consequently low forward hadron boost) imposes a very severe constraint.

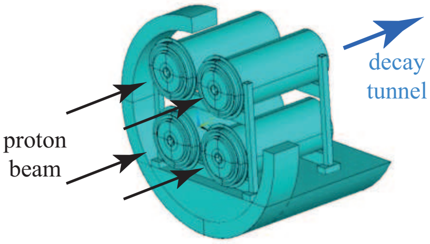

**FIGURE 1.** The 4 target/horn system.

## ISSUES DUE TO HIGH POWER

Solid targets cannot afford such high power of the proton beam. The utilization of permanently recirculating liquid targets such as mercury, envisaged by the Neutrino Factory, is not convenient for the SB application. A mercury jet is not easy to be sent through the hole of the horn and recuperate it back (in absence of magnetic field it is not possible to maintain the integrity of the mercury jet). Moreover, mercury is not compatible with aluminum, the material used for horn construction.

In order to come back to solid targets, a multi–system target/horn is proposed ([8]) to share the proton beam power. Recent studies show that the maximum beam energy using solid targets could not exceed 2 MW. The adopted configuration uses 4 systems as depicted by Fig. 1. This takes advantage of the small horn transversal size, keeping the diameter of the hadron decay tunnel reasonable ($\sim$4 m) inducing a reduced decay volume. The length of the the decay tunnel is estimated to be ($\sim$ 30 m) leaving enough time to hadrons to decay. In this case, the proton beam power for each target/horn system is reduced to 1 MW. This scheme presents other advantages such as less exposure to radiation and easier power dissipation. The main disadvantage comes from the beam sharing. To send the proton beam in the 4 systems, 4 proton lines will need to be pulsed simultaneously (with $1/4th$ of the total proton power) or one after the other (with the totality of the proton power). These 4 beam lines will add a non negligible extra cost to the proton beam facility.

The 4 target/horn system doesn't reduce the operation load of the horn pulsing system which always has to be operated with the same high current and repetition rate. This can be improved by using 4 pulsing systems, one per horn, but of course, with an extra cost. In this configuration, the 4 target/horn systems can be pulsed one after the other with the total power per pulse but with a frequency reduced by a factor of 4, that would increase the lifetime of the pulsing system.

## COLLECTING SYSTEM OPTIMISATION

The horn shape strongly depends on the hadron energy and thus on the primary proton beam energy. Since the CERN design, the physics requirements have changed according to recent physics results and the actual required proton energy is of the order of 4 GeV instead of 2.2 GeV. Mainly for this reason and to profit from new technological developments, a new horn design has been undertaken. An optimized horn design maximizing the neutrino beam intensity could help to reduce the challenging proton beam intensity or to reduce the experiment's duration by a few years.

Instead of a conical horn, a new design based on a "MiniBooNE" horn shape ([7]) has been studied (Fig. 2). A significant technical simplification has also been performed by removing the reflector of the initial design [4, 5] on top of the horn (the integration of the two objects would be extremely difficult from all points of view: vibrations, cooling, strip lines, etc.). Moreover, this reflector was supposed to be pulsed by a very high current of the order of 600 kA. The replacement of the Hg target by a low $Z$ one considerably reduced the amount of produced neutrons by at least a factor of 10, inducing much less radiation damages.

After optimizing the shape of the internal part of a "MiniBooNE" like horn and increasing reasonably its external diameter to compensate the absence of the reflector, very promising results have been obtained. The replacement of the Hg 30 cm long target by a much longer low $Z$ solid one (beryllium) to keep two radiation lengths, led to the utilization of a longer horn than for previous studies. Fig. 3 presents the physics performance of the new horn in terms of $\theta_{13}$ for 4 different configurations [9]. The 2 "MiniBooNE" like configurations behave better than the conical ones, while there is almost no difference with and without reflector for the first configuration. Moreover, in the "MiniBooNE" configuration without reflector, the current circulation in the horn remains at the level of 300 kA, compared to the 300 kA to 600 kA of the previous configurations.

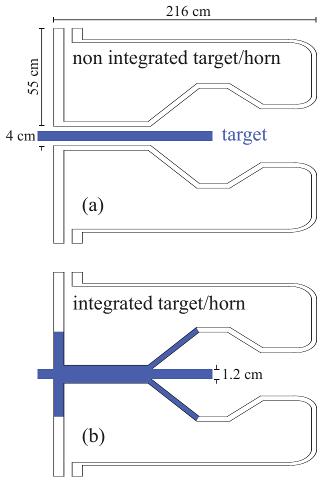

**FIGURE 2.** MiniBooNE like target/horn system for (a) the baseline configuration and (b) the fully integrated option.

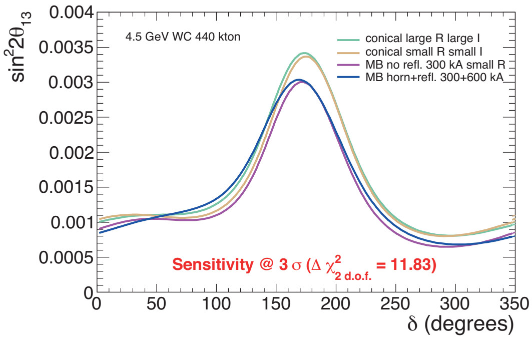

**FIGURE 3.** $3\sigma$ C.L. sensitivity curves on $\sin^2(2\theta_{13})$ as a function of $\delta_{CP}$ for two conical and two MiniBooNE like horns.

## COOLING CONSIDERATIONS

Due to the very severe operating conditions, the whole system's integration including the target, the horn, the pulser and the cooling system, has to be carefully studied [10].

To dissipate the high power deposited in the horn (~8 kW + 30 kW by joule effect) and mainly the target (~63 kW), a very efficient cooling system has to be applied. Fig. 2 (a) presents the baseline configuration (non integrated) where the horn and the target are two different objects without contact. The space between the two will be used to flow high pressure gas helium for the target cooling (like in T2K [11]).

Studies are underway, but in case the needed gas flow is too high, other solutions have to be found. To take advantage of the water sprayers foreseen to be placed inside the horn for its cooling to also cool the target, the optional configuration of Fig. 2 (b) is proposed (integrated). In this configuration, the inner part of the horn and the target are only one object made of beryllium. The rest of the horn could be made by aluminum welded on the beryllium part taking care to place the welding points at non–critical positions. The target could be cooled down by the same water as than circulating in the horn. In case this flow is not enough, a double layer of the horn can be envisaged (as was the case of the CERN prototype), circulating water between the two layers in direct contact with the target.

The advantages and disadvantages of both configurations are the following: In the non integrated configuration, the target could be replaced independently of the horn and the cooling could be done by He gas. But, the target, about 80 cm long, needs to be guided and supported inside the horn which could not be an easy task due to the high operating temperature and expansion of the target. In the integrated option, the target replacement alone is impossible (in case of failure the whole target/horn has to be replaced). The target shocks and vibration will be shared by the horn too, probably reducing the horn lifetime. The cooling of the target could be done using the water flowing inside the horn which probably would be more efficient than the He cooling. The big advantage of the integrated option is the reduced inner radius of the horn allowing the magnetic field (the current circulates in the target/horn skin) to be very close to the target (1.2 cm diameter) inducing better focusing/defocusing of the hadrons and better physics performance. The other big advantage of this option comes from the fact that the target doesn't need a guiding/alignment system.

## TARGET STATION

The whole region around the target including the decay tunnel will be considered as one volume without separations and filled with helium as in the case of T2K.

Studies are underway to estimate the necessary shielding and beam dump to stop all radiations. The cooling of all walls is also under study profiting from the studies done for the T2K project where it has been foreseen to go up to 4 MW proton beam, similar to power in the CERN Super Beam case.

Remote systems are also under study to replace faulty parts of the system. The 4–target/horn system would be installed on rails with a spare one nearby separated by concrete blocks. In case the system has to be replaced, the one to be repaired is pushed on the side (garage position) and the spare system takes the position of the first one. The strip lines and cooling pipes have to be easily connected and disconnected remotely. After cooling down, the replaced system could be repaired in a safe position.

It is foreseen to replace the whole system only after having more than one target/horn system failing. In case one system has to be stopped, the total proton power will be shared by the remaining 3 systems. This is why each system is designed to acceptat least a proton beam power of 1.4 MW.

The air around the target station has to be recycled as does the cooling water of all systems. All safety issues are now under study. Another important point under study is the lifetime of the whole system taking into account all vibrations, shocks, fatigue and radiation damages.

## ACKNOWLEDGEMENTS

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