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THE ESSνSB TARGET STATION

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on behalf of the ESSνSB project

Abstract

The ESSνSB project, financed by the EU H2020 programme as a 4-year design study (2018-2021), proposes to use the protons produced by the linac (2 GeV, 5 MW) of the European Spallation Source (ESS), currently in construction at Lund (Sweden) to deliver a neutrino super beam [1]. It follows the investigations made by the FP7 Design Study EUROν, which compared different options for future neutrino facilities. The primary proton beam line completing the linear accelerator will consist of one or several accumulator rings and a proton beam switchyard. The secondary beam line producing neutrinos will consist of a four-horn/target station, a decay tunnel and a beam dump. A challenging component of this project is the enormous target heat load generated by the 5 MW proton beam. In order to reduce this heat load there are going to be four targets, which will be hit in sequence by the compressed proton pulses, thereby reducing the beam power on each target to 1.25 MW. The hadron collection will be performed by four hadron collectors (magnetic horns), one for each target. Each of these target/hadron-collector assemblies will receive an average beam power of 1.25 MW, which is twice as high as in other neutrino projects at present. The status of the design of the target station for the ESSνSB project is discussed here.

ESSνSB PROJECT

The ESSνSB (standing for European Spallation Source Neutrino Super Beam) project proposes to use the high power LINAC of the ESS facility based at Lund in Sweden as a proton driver to produce an intense neutrino beam. A Water Cherenkov type detector, MEMPHYS [2, 3], will be located in a deep mine near the second neutrino oscillation maximum (540 km).

ESS will deliver by 2023 a first proton beam for neutron production at the nominal power of 5 MW and energy 2.0 GeV distributed in 14 pulses of 62.5 mA current with 2.86 ms time width per second. To allow the LINAC to generate a neutrino beam in parallel with the spallation neutrons, some modifications of the accelerator are necessary. A preliminary study of these modifications that are required to allow simultaneous acceleration of H^+ (for neutron production) and H^- (for neutrinos) ions at an average power of 5 + 5 MW has been made.

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An accumulator ring compressing the pulses to about 1.3 µs time width is mandatory to reach the power dissipation requirements for the target station. A first estimation gives a ring having a circumference of about 376 m, compact enough to be located in the already allocated ESS area. Each pulse from the ESS LINAC will contain 2.2×10^{14} protons, which for an un-normalized beam emittance of 70-120 π mm mrad in the ring by multi-turn injection would lead to the space-charge tune shift of about 0.05 [4]. The H^- ions will be fully stripped during the injection into the accumulator using either stripping foils or a laser-stripping device.

THE TARGET STATION LAYOUT

The Target Station includes the proton target itself, the hadron collector, the decay tunnel and the beam dump (Fig.1).

Target and Hadron Collector

The design of this element consists of four titanium targets, each surrounded by one magnetic horn made of aluminium (Fig.2).

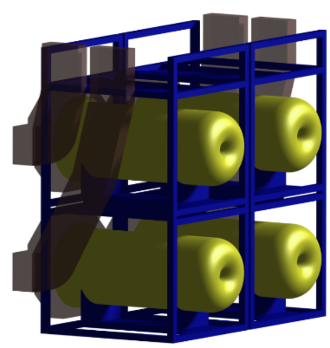

Figure 2: Horn layout (the targets are inside the horns).

The interaction of the protons with the target material will lead to the production of short-lived mesons, mainly pions, producing neutrinos by their decay. This represents a considerable challenge for the hadron collector and its power supply. A first design demonstrated on paper that the construction is feasible [1]. Studies are made to adapt this system to the new ESSνSB conditions.

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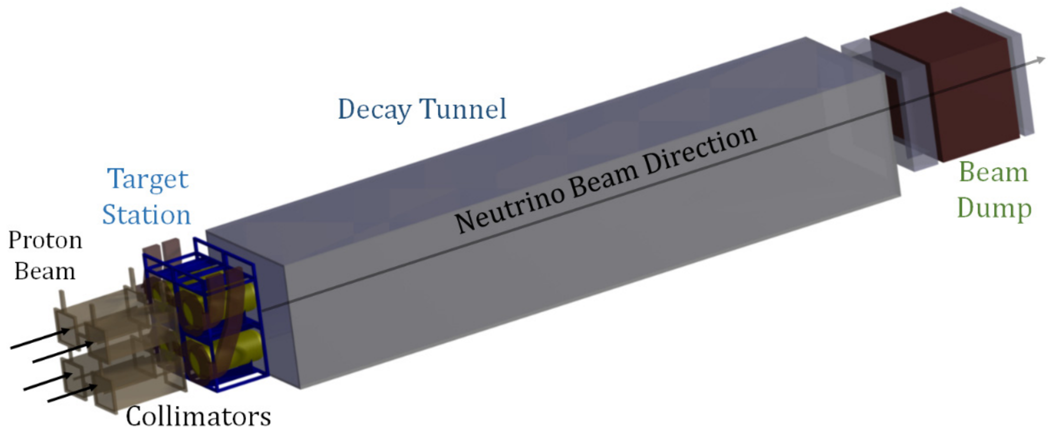

Figure 1: Schematic view of the target/horn station, the tunnel and the beam dump.

Due to the high current of 350 kA passed in pulses through the skin of the horn in order to produce the necessary toroidal magnetic field for bending the hadrons into the forward direction, the pulses must be as short as possible for the system to be cooled down and recharged before the next pulse. This limits the duration of the beam pulses to a few µs, which is significantly shorter than the 2.86 ms duration of the ESS LINAC pulses.

Decay Tunnel

The decay tunnel area is surrounded by an iron vessel filled with helium gas and by an additional concrete layer to prevent soil activation. This tunnel is designed long enough to allow the mesons to decay, but not as long as to allow for a significant amount of the muons to decay. The actual estimated length of this tunnel is 25 m.

Beam Dump

The beam dump is foreseen to have dimensions 4 x 4 x 3.2 m3. The core consists of a main graphite block and several shields to dump the remaining hadron particles, and finally to reduce the energy deposition outside the experimental layout.

ENERGY DEPOSITION

In the geometry of FLUKA, the entire experimental area is considered, including the main components of the target station, that is the 4 titanium targets, each of them assumed as a continuous medium with 66% reduced density, the 4 magnetic horns, the decay tunnel and the beam dump. The main part of the 1.25 MW incoming beam power received by each target is absorbed upstream, and in the inner conductor around the target region, where the particle fluency is maximal (Table 1).

Recent estimations showed that the overall power absorbed by the system is estimated to be 4.22 MW. This value represents 84.5 % of the 5 MW incoming beam power. The 15.5 % remaining is identified as “missing energy” in FLUKA [5, 6]. It refers to the energy which cannot be made available to detection, but which has been correctly considered in the process. In practice, this is the energy lost in nuclear binding, and it can be "large" for heavy nuclei targets. The power deposited in each target and each horn is estimated to be 168 kW and 50 kW, respectively (Fig. 3).

From the simulations, a total power of 1566 kW is deposited in the tunnel including 424 kW and 467 kW in the iron vessel and in the surrounding concrete respectively.

In the entrance of the decay tunnel, an upstream iron-shield is foreseen to protect the areas above it. This will allow positioning the strip-lines and the horns’ power supply above the beginning of the tunnel. This iron shield will absorb 640 kW of the overall incoming power (Fig.4).

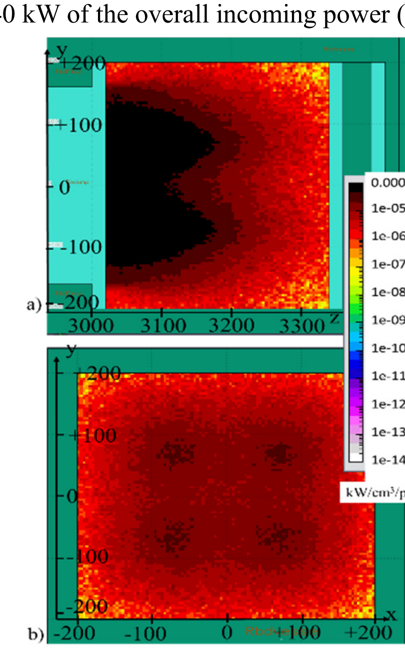

Figure 4: Longitudinal (a) and transversal (b) distributions of the power densities in the dump.

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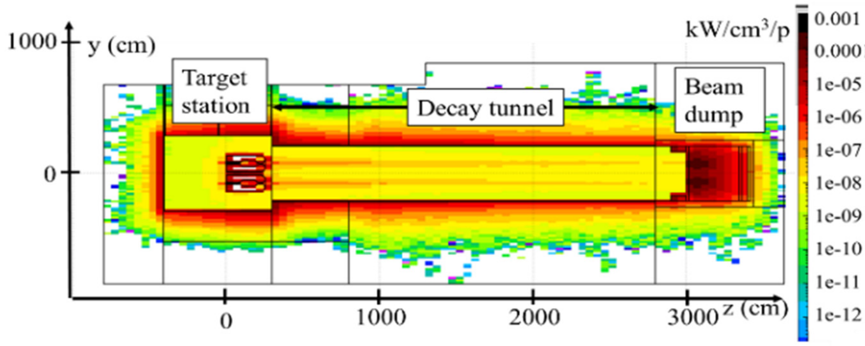

Figure 3: Power density deposited in the whole system.

Table 1: Summary of the Power Absorbed

Location	Power absorbed (kW)
Target station (targets, horns)	1497 (672, 200)
Decay tunnel (Iron shield)	1566 (640)
Beam dump (Graphite block)	1157 (950)
Whole system	4220

Detailed studies are also under way aimed at assessing the feasibility of the proposed target station design. These include the determination of the dynamic stress levels in the horn skin due to a sequence of current- and thermal pulses, as well as the calculation of the stress levels in the spheres that make up the pebble-bed target. These stress levels will be used to assess the operation lifetime of both the horn and the target. Potential disadvantages of the pebble-bed target are being studied, including the impacts between the spheres that can take place when the spheres do not touch. The efficiency of the horn and the target cooling system is also being investigated, as well as several material issues including: irradiation damage, cyclic thermal load or surface erosion.

SIMULATIONS OF THE NEUTRINO PRODUCTION

Since the detection in the far detector will be done by taking into account the $\nu_\mu \rightarrow \nu_e$ oscillation, the optimization study of the target station design will be aimed at the optimization of the production of muon neutrinos and the reduction of the contribution of the electron neutrino component to the total neutrino beam.

Fig. 5 shows the neutrino flux at 100 km distance from the experimental area, obtained by considering as primary protons of 2.5 GeV kinetic energy and Gaussian beam profile with 4 mm diameter at 1σ. In this simulation, the magnetic field in the horn produced by considering a current intensity of 350 kA, is included, which focuses the positive pions and defocus the negative ones.

Although the contribution of the electron neutrino component to the total neutrino beam is expected to be of the order of 0.5% with respect to the main contribution from the muon neutrinos, the former represents the main source of background for the measurement of the neutrino CP violation parameters δ_{CP}.

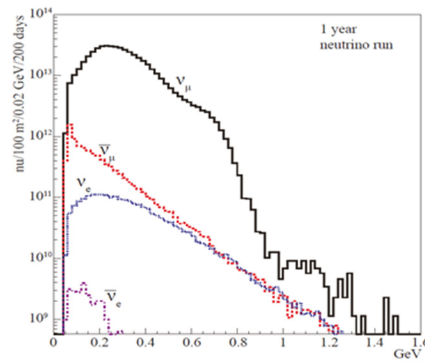

Figure 5: Neutrino flux at an arbitrary distance of 100 km from the experimental area for positive horn current polarity [7].

Furthermore, the electron neutrinos could be used to measure electron-neutrino cross-sections in the near detector at the relevant energies of the project. A detailed study on the muon production is necessary, therefore, to monitor the production of electron neutrinos. The study of muon production in the target station is also important for future projects of Neutrino Factory or as feeding of a muon collider.

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