PROCEEDINGS OF SCIENCE

Status of the ESSνSB Target Station

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The goal of the ESSνSB project is to discover and measure neutrino CP violation with unprecedented sensitivity. The associated ESSνSB H2020 Design Study is aimed at investigating and proposing a conceptual design of a new neutrino superbeam in Europe. The Target Station is a key element of this project, since it will produce a high intensity neutrino superbeam from a 5 MW proton beam delivered by the European Spallation Source at Lund. Work Package 4 of this project focuses on the optimization of the physics performance of the elements producing the beam, such as the targets and the magnetic horns, as well as on the technical aspects related to the Target Station design. The 5 MW proton beam will be split laterally into four 1.25 MW beams, each with 1.3 µs proton pulses and 14 Hz repetition rate, which will hit four separate targets inserted inside four horns. The production of the neutrino beam under such conditions requires the development of technologies capable of working at a MW power scale, both for the target and for the other components of the target station facility.

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1. Target station facility

In all long baseline neutrino oscillation experiments, the target station is an essential element, which converts the protons coming from a LINAC into a neutrino superbeam. The ESSνSB project proposes to upgrade the LINAC of the European Spallation Source from 5 MW to 10 MW, in which 5 MW will be dedicated to the neutrino users. With such a high intensity beam we are at the limit of the present technology used in the running experiments. For these reasons, a specific design of the target station capable of working at a multi-MW level has been proposed based on a four horn system. Each target embedded in a magnetic horn will receive a 1.3 µs proton pulse with 2.5 GeV energy at a frequency of 14 Hz.

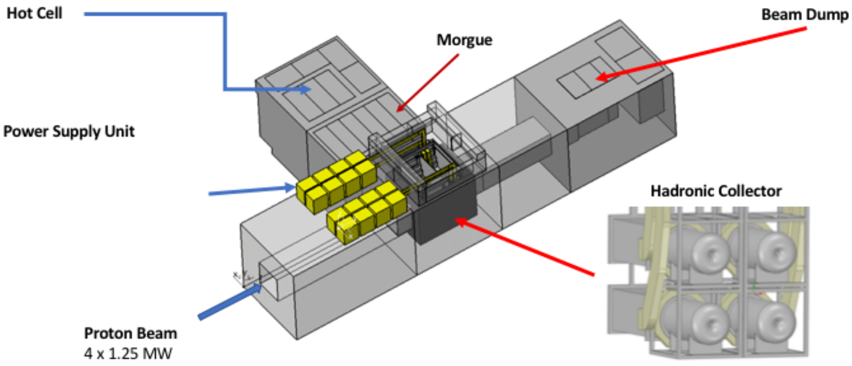

Figure 1: Overview of the target station facility.

The design of the target station is shown in Figure 1. It is composed of several major parts:

- The hadronic collector consists of four targets and four horns. The secondary particles produced by the interaction of the proton beam with the target will be focused in the decay tunnel to allow them to decay into neutrinos.
- The power supply unit consists of 16 modules. The magnetic field in the horn will be produced by a 350 kA current pulse passing through the horn skin. Each of the eight modules connected in parallel will deliver 44 kA.
- The hot cell will be used for manipulating and repairing the irradiated components, e.g., the hadronic collector.
- The morgue will be used to store radioactive waste.
- The beam dump is located at the end of the decay tunnel and it will stop the unused particles.

In this document, the present concept of target integration and the beam dump design will be outlined.

2. Target-horn integration concept

The concept of the target to be used in the ESSνSB project is a packed bed (granular) design. The main advantages of the target made up of small spherical granules contained within a metallic container are: the efficient removal of heat, thanks to the possibility of passing the cooling medium (gaseous helium) directly through the target, and lower thermal stress levels inside the target compared to a monolithic design. Figure 2a shows a simplified model of the target, together with the direction of the incoming beam.

The target length is 780 mm, with a diameter of 30 mm. The diameter of each sphere contained inside the target is equal to 3 mm. All results consider the case of titanium spheres, for the packing ratio of 0.66. Figure 2b shows a map of the average power density deposited by the proton beam in each of the targets, estimated using FLUKA [1]. The corresponding average power is equal to 138.53 kW, which is almost three times higher than in the EUROnu project [2].

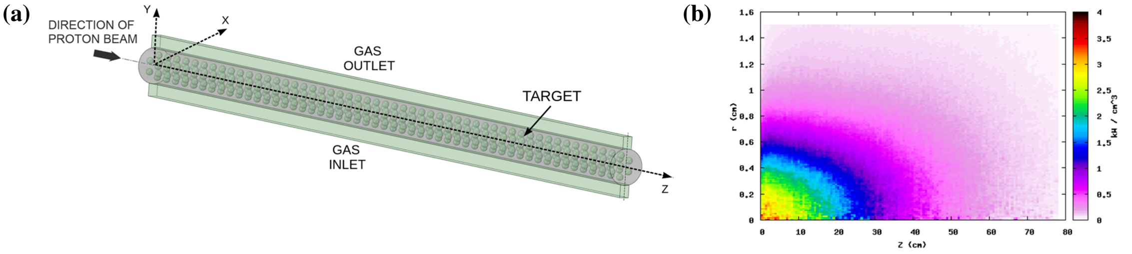

Figure 2: a) Simplified model of the granular target, b) power density inside the target.

Figure 3a shows the cross-section of the proposed integration of a target inside a horn. The design consists of: the granular target spheres placed inside a titanium container (in red), the outer shell (also in red), two plates which connect the target container with the outer shell and the horn inner conductor (in violet). Between the outer shell and the horn inner conductor there is a layer of gaseous helium (in blue), which serves the purpose of thermal insulation. Figure 3b shows the inlet and the outlet channels for gaseous helium. Helium can enter and leave the target through a number of openings in the target container. The proposed design allows for an efficient flow of cooling gas through the regions with the highest power deposition (close to the target axis).

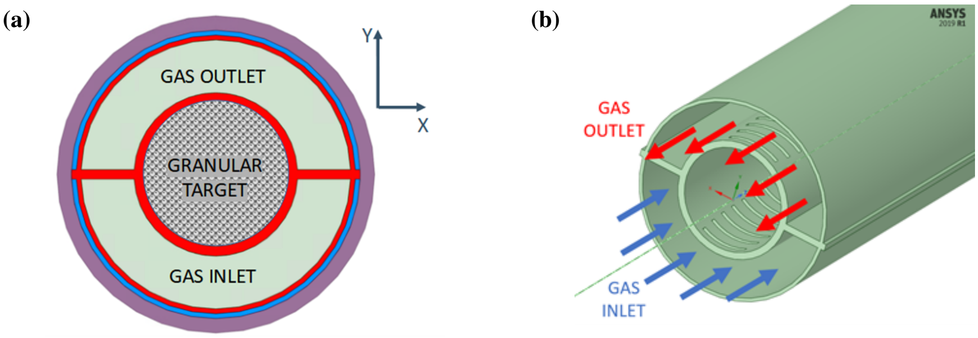

Figure 3: a) Cross-section of the target-horn integration layout, b) the target-horn integration concept with gas inlet and outlet channels for helium flow.

Figure 4 gives the temperature and velocity of helium obtained using computational fluid dynamics simulations (ANSYS Fluent [3]), with a mass flow rate of helium equal to 0.2 kg/s. Cooling for this design is feasible, since even accounting for the fact that the temperature at the centre of the spheres is about 200 – 300 K higher than that of the surrounding medium, the

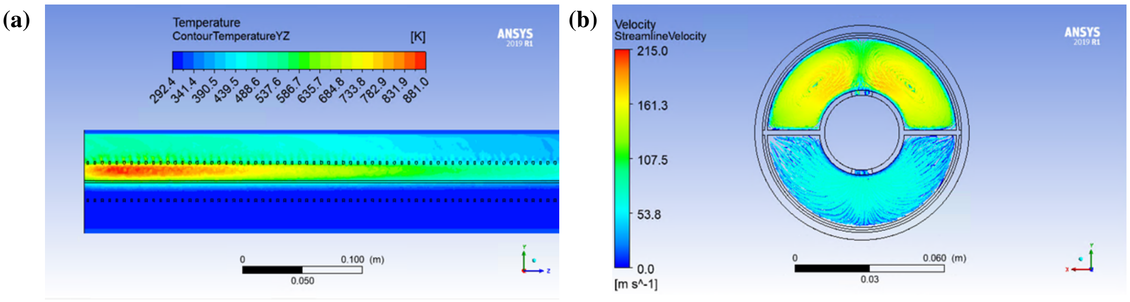

Figure 4: Results of helium flow inside the target-horn integrated system under the steady-state operation condition: a) temperature of helium, b) velocity of helium.

maximum local temperature of the granules is still much below the melting point of titanium (1900 K). Regarding the local gas outlet velocity, it is about 200 m/s (0.2 Mach for helium), which means it is still within a safe margin.

It has been verified that bending resulting from the temperature gradient across the integrated target should be feasible.

3. Beam dump

The ESSνSB has proposed a new design of the beam dump structure that is constructed from four independent core blocks (segments). Each block faces one of the four horns. The four segments are separated by- and placed on- a cross-like support structure. Each segment is in turn made up of two zigzag blocks with 1 cm clearance between them, to allow for thermal expansion of the individual blocks. Using the power deposition map generated by a FLUKA simulation as a heat load in the beam dump in COMSOL 3D thermo-structural simulations, several cooling schemes were investigated. The satisfactory cooling structure was validated by minimising the maximum temperature, structural displacement and von Mises stress in the entire volume of the beam dump structure, for a steady-state solution. A total energy deposition in the beam damp core of about 840 kW/4-horns was found. The support plates and the outer heat sink plates are assumed to be made of a Copper-Chromium-Zirconium alloy [4], similar to that used for the new proton synchrotron booster [5] and the ESS dump core. Figure 5*a* shows the geometrical structure of the beam dump, the segmented blocks and the beam dump cooling system.

Figure 5*b* shows the temperature distribution on the surface of the beam dump. The distribution shows that the highest temperature (522 K) is found at the interface between the two blocks of each segment, which then decreases through the core bulk. The maximum increase in the temperature of the cooling water at the exit of the channels relative to the entrance is 10 K. The simulations also show that the maximum von Mises stress is the highest on the surface of the middle heat sink channels, and its maximum value is about 207 MPa. This high value is due to the thermal expansion of the graphite blocks, which exert extra pressure on the heat sink plates. However, it is still below the yield strength of the Cu alloy which is 310 MPa (@20 °C). The deformation in the core structure was also studied and was found to be small, with a maximum displacement of 1.46 mm.

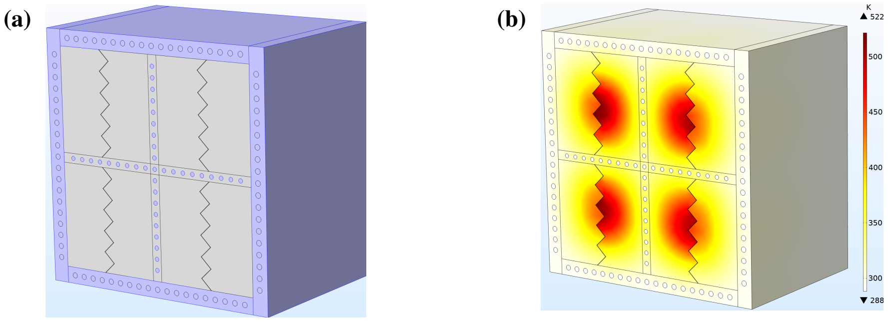

Figure 5: a) Design structure of the beam dump, b) temperature on the face of the beam dump.

4. Conclusions

An efficient method of the cooling of the packed-bed target has been proposed. The calculated temperatures of the cooling gas and the spheres making up the target seem to be acceptable. ESSνSB target integration is more challenging than for most other experiments, mainly due to the high power deposited in the target integrated inside a very limited space within a magnetic horn.

The proposed scheme for the Power Supply Unit will allow for the required 350 kA electrical pulses to be applied to each horn at a frequency of 14 Hz, taking into account the challenging fast commutation between the four horns imposed by the proton beam time structure of the LINAC.

A new concept of the beam dump has been proposed as part of the target station facility design, capable of withstanding 850 kW power deposition.

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