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THE MULTI-MEGA-WATT TARGET STATION FOR THE EUROPEAN SPALLATION SOURCE NEUTRINO SUPER BEAM*

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Abstract

One of the next challenges in fundamental physics is to understand the origin of matter/antimatter asymmetry in the Universe. In particular, intense neutrinos have an important role to elucidate this mystery and better understand the expansion of the Universe. The ESSνSB collaboration proposes to use the proton linac of the European Spallation Source currently under construction in Lund (Sweden) to produce a very intense neutrino super beam, in parallel with the spallation neutron production. A very challenging part of the proposed facility is the Target Station which will have to afford 5 MW proton beam power. In this article, the hadronic collector and the facility to produce the next generation of neutrino superbeam will be presented.

A NEW NEUTRINO SUPERBEAM IN EUROPE

New generations of neutrino experiments will be focused on the determination of the neutrino mass ordering and the discovery of matter/antimatter in the leptonic sector. Several superbeam experiments have been proposed to answer these questions, in particular the DUNE experiment in USA [1], and T2HK in Japan [2]. All these accelerator based experiments will use a intense neutrino beam produced by a proton driver working at MW scale in combinaison with a Megaton Scale detector located several hundred of km downstream of the source.

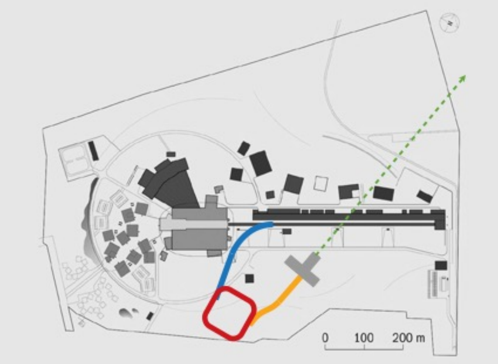

Figure 1: The ESSνSB facility at ESS site (Lund, Sweden).

The ESSνSB collaboration [3] proposes to use the European Spallation Source [4] in construction at Lund (Sweden) to build a very intense neutrino beam with a Water Cherenkov detector located 540 km in the Garpenberg mine. This baseline offers an improve sensitivity by looking a the second oscillation maximum compared to the first one [5]. This project requires an increase of the linac power from 5 MW to 10 MW and the implementation of a second target station fully dedicated to the neutrino production whose the layout is shown on Fig. 1.

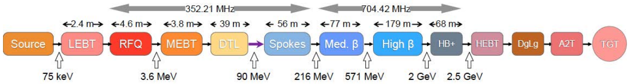

Figure 2: The European Spallation Source LINAC.

The 5 MW proton beam power dedicated to the neutrino production will travel through a transfer line (blue) to an accumulator (red) which will shorten the initial time width of the proton pulses coming from the LINAC (Fig. 2) from 2.86 ms to 1.3 µs due to the working conditions of the hadronic collector.

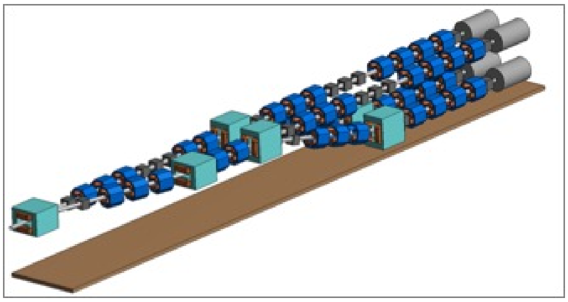

Figure 3: Beam switchyard splitting the initial beam into four 1.25 MW proton beams.

After the accumulator, the compressed proton beam reaches another transfer line (yellow) to the switchyard (Fig. 3) which will split the beam in four parts with a reduced beam power at 1.25 MW before entering into the target station (gray). The neutrino superbeam produced by the latter will travel through a Near Detector which will precisely characterize the neutrino beam and to the Far Detector at Garpenberg mine located 540 km away from the source. This high intensity neutrino superbeam will allow to discover the matter/antimatter asymmetry in the leptonic sector by

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the comparison between neutrinos and antineutrinos fluxes in the far detector.

THE ESSνSB TARGET STATION

The neutrino beam is produced by the decay in flight of secondary particles (essentially pions) produced by the impact of the proton beam onto a target and focused by magnetic horns in a decay tunnel. The neutrino/antineutrino mode can be selected through the current polarity (positive/negative) producing the magnetic field in the horns through the following decay reactions:

$$\pi^+ \rightarrow \mu^+ + \nu_\mu \quad \text{(Positive mode)}$$
$$\pi^- \rightarrow \mu^- + \overline{\nu_\mu} \quad \text{(Negative mode)}$$

The key element of the Target Station Facility is the hadronic collector which focuses the secondary particles into the decay tunnel. In order to mitigate the 5 MW beam power, the beam is shared thanks to the switchyard over four targets. Each of them is embedded in a magnetic horn and constitutes one of the four elements of the hadronic collector shown on Fig. 4.

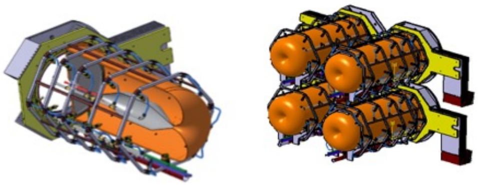

Figure 4: Single horn (left) Hadronic collector (right).

The target technology is based on granular target concept able to afford 1.25 MW proton beam power with 2.5 GeV proton kinetic energy. The geometry consists of a packed bed target 78 cm long with 3 cm diameter filled with 3 mm diameter spheres made of titanium.

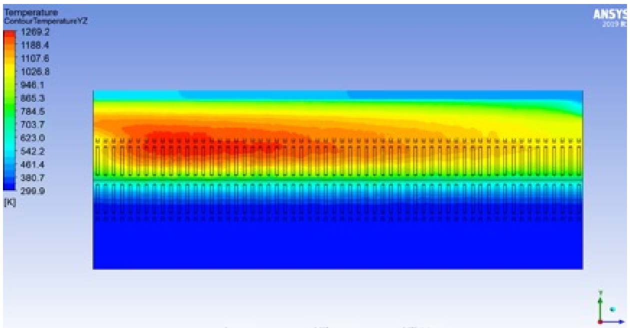

Figure 5: Transverse cooling simulation of the target by helium flow.

The canister is drilled with apertures on each side to provide an efficient transverse cooling with an helium flow working at 10 bars to extract the 138 kW of deposited power (Fig. 5). The horn is submitted to hard working condition due to the radiations coming from the target and the 350 kA current pulse producing the magnetic field.

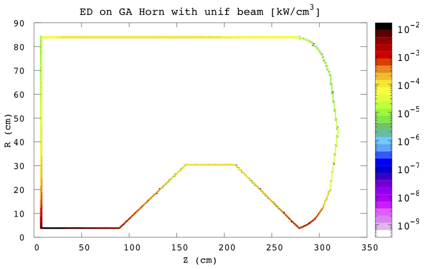

Figure 6: Power deposition in the horn.

The power deposited by secondary particles is shown in Fig. 6. It can be seen that the highest power will be deposited inside the upstream inner part of the horn, which lies in the direct proximity of the target. The time averaged power deposited in this section is equal to 7.5 kW, while for the complete horn it is equal to 35.8 kW. Taking also into account the Joule effect contribution, the cooling temperature provided by water jets by simulation reaches to 80°C.

The Power Supply Unit (PSU)

The four horns are working in cascade according to the pulse frequency shown in Fig. 7.

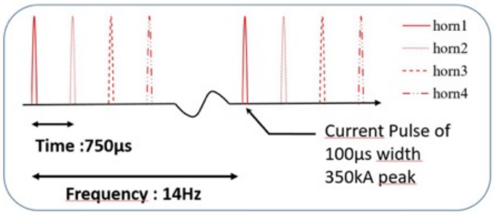

Figure 7: Current pulse structure to the four horns.

Each horn is pulsed by a half-sinusoid current waveform of 100 µs width and 350 kA peak current, with a very high RMS current of 9.3 kA. The magnetic horn has a very low inductance of 0.9 µH and a low resistance value of 0.235 mΩ. The proposed electrical solution must reduce the thermal dissipation in the horns to its minimum. The electrical consumption is minimized by studying a solution that allows to recover the maximum amount of energy shown in Fig. 8.

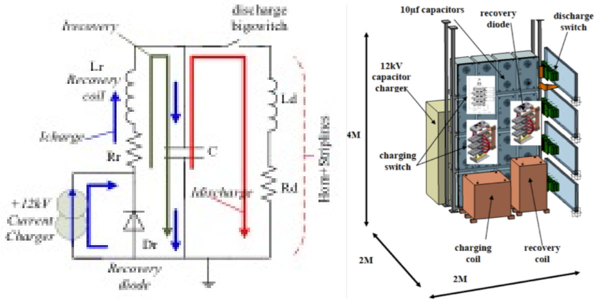

Figure 8: Electrical principle (left) One PSU Module (right).

The power supply modules are located above the switchyard tunnel as shown on Fig. 9 and are connected to the horns thanks to the striplines.

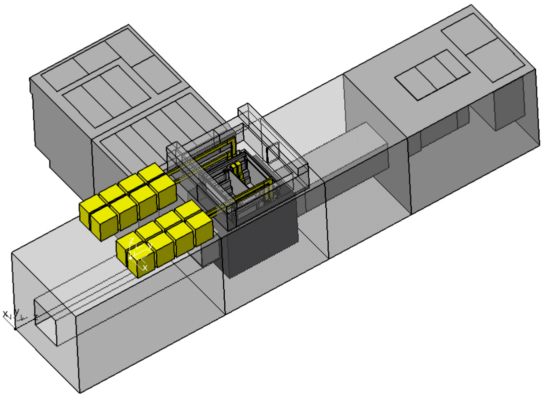

Figure 9: Target station facility layout.

The PSU components are dimensioned to accept very high electrical constraints during their operation for a long lifetime of 3.6 billion of cycles (300 days in a year, during 10 years).

Physics Performance

The definition of the horn shape has been done by maximizing the sensitivity of the experiments to the CP sensitivity whose fluxes,shown in Fig. 10 and in Table 1, are referred as baseline [6].

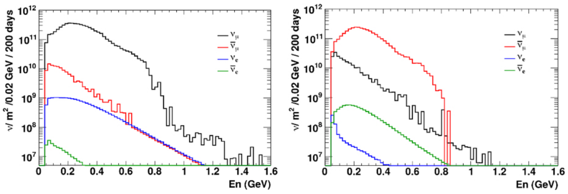

Figure 10: Neutrino fluxes at 100 km distance from the target station for the positive (left) and negative (right) mode.

Table 1: Neutrino Flux Composition at 100 km Distance from the Target Station for the Baseline.

	Positive mode		**Negative mode**	
	$10^{10}/m^2$	%	$10^{10}/m^2$	%
ν_μ	583	98%	23.9	6.55%
$\overline{\nu_\mu}$	12.8	2.1%	340	93.2%
ν_e	1.93	0.2%	0.08	0.02%
$\overline{\nu_e}$	0.03	0.01%	0.78	0.21%

New deep learning methods based on Genetic Algorithm (GA) has been considered to improve the sensitivity of the experiment [7]. This new method has been applied to optimize the size and the inner conductor of the hadronic collector with the geometrical parameter (length and width) of the decay tunnel. The first results depicted on Fig. 11 shows a significant gain in time exposure on the δ_{CP} for the same coverage fraction.

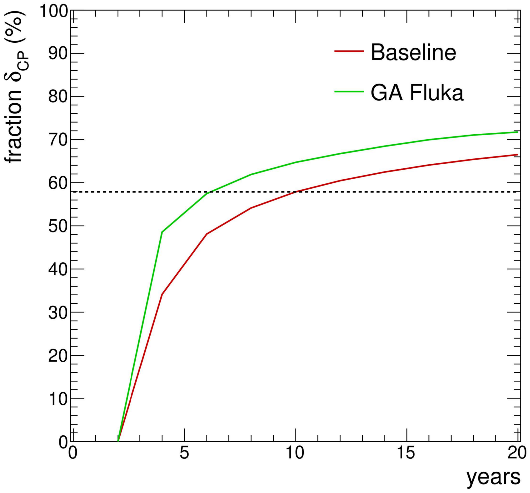

Figure 11: Comparison between the Target Station baseline and the optimized baseline based on genetic algorithm (GA) on time exposure to reach 5σ.

CONCLUSION

The ESSνSB project takes the opportunity to have a neutrino superbeam in Europe. In addition, due to an important production of muons at the beam dump level, this project offers an unique opportunity to develop a muon facility for Research and Development which are necessary for the development of a future neutrino factory or a muon collider.

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