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DESIGN STATUS OF THE ESSνSB SWITCHYARD

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Abstract

The feasibility of the distribution of 5 MW proton beam power pulsed at 70 Hz onto a 4-target station for the production of neutrino super beams is discussed. To deflect and focus the beam having a magnetic rigidity of 11.0 Tm onto the targets, different configurations of beam switchyard are proposed and compared. The number of dipoles and quadrupoles composing this system is defined for each scenario. The length, the aperture, the magnetic fields and the field gradients of these optical elements are determined. The code TraceWin is used to simulate and optimize the envelopes of the beam along the beam lines. The transverse emittances at the exit of the system are shown.

INTRODUCTION

The next generation of neutrino beams are based on multi MW scale proton drivers. The proposal for the ESSνSB (European Spallation Source Neutrino Super Beam) project has been submitted to H2020 Design Study and is led by the Neutrino Group of the IPHC (Institut Pluridisciplinaire Hubert Curien) of Strasbourg and the University of Uppsala. It foresees the use of the ESS linac currently being constructed at Lund, to accelerate H^- ions (2.5 GeV, 5 MW, 70 Hz) and produce neutrino super beams [1]. It succeeds the studies made by the FP7 Design Study EUROν [2], regarding future neutrino facilities. The primary proton beam-line completing the linac will consist of an accumulator ring and a switchyard to distribute the protons onto the different targets composing the horn system (4 targets of 15 mm radius). The BSY (beam switchyard) is one of the key systems of the project. Its efficiency and reliability directly impact the production of yields of secondary particles.

Table 1: Beam Parameters for EUROν and ESSνSB [1]

Parameter	EUROν	ESSνSB
Particle	H^-	H^-
Proton kinetic energy (GeV)	4.5	2.5
Pulse intensity (mA)	40	62.5
Avg beam power (MW)	4	5
Beam rigidity (Tm)	17.85	11.02
Macro-pulse length (linac) (ms)	2.86	0.715
Pulse length (accu.) (μs)	1.5	1.5
Pulse repetition rate (Hz)	50	70

Preliminary studies were done on such system within EUROν [3]. Although the horn requires similar conditions as for EUROν, the parameters of the primary beam being different from those used for this previous project (Table 1) implies considering an upgrade or even new solutions for the distribution of the protons onto the horn system.

SPLITTING AND DISTRIBUTING THE PROTONS

Different Configurations Investigated

Besides the configuration studied for EUROν (labelled “config1” in this paper), other scenarios to deflect the beam onto the horn system have been recently under considerations. Among several layouts, two new configurations, in addition to config1, could be seriously retained for further detailed studies. These new solutions will be labelled “config2” and “config2a” respectively. The selection criteria relied on the number of magnetic elements necessary, on the type of operation (i.e. simple or bi-polar devices) and on the prospective of beam dump requirements.

Deflecting Elements

Although kicker technology was raised for config1 in the framework of the EUROν Design Study, the rise and fall times of few ms and the repetition rates of 17.5 Hz (35 Hz according to the configuration) needed by each device would actually allow the use of simple classical dipoles (O- and H-types), to deflect the protons onto the 4 target axes [4]. This would have the advantage of making easier the design of both the magnets and the power supplies, thus reducing their cost.

BEAM FOCUSSING SYSTEM

Beam Parameter Definition

The normalised rms transverse emittances of the beam extracted from the ESS linac are foreseen to be 0.33 μm [5]. The charge exchange injection with high power beam requires a modest number of foil hits during the phase space painting, resulting in a larger emittance than the injected beam. Therefore transverse emittances at the exit of the accumulator will be much larger than the one at the end of the ESS linac. Current studies suggest the emittances of the beam coming from the accumulator to be of several tenths of μm [6]. In the following, the normalised transverse emittances of the proton beam are assumed to be 225 μm (99.7%) and the rms momentum dispersion 0.1%. The required beam size at the target station is 4 mm rms.

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Beam Optics

Configuration 1 is an upgrade of the system designed for EUROν. The beam is deflected diagonally onto the target axes (T1, T2, T3 and T4) using two bipolar magnetic dipoles. A total of 12 quadrupoles are necessary to focus the protons onto the target station (Fig. 1). The maximum B-field needed by the 2 m long dipoles is calculated to be 0.65 T (25.7 kA turns per pole).

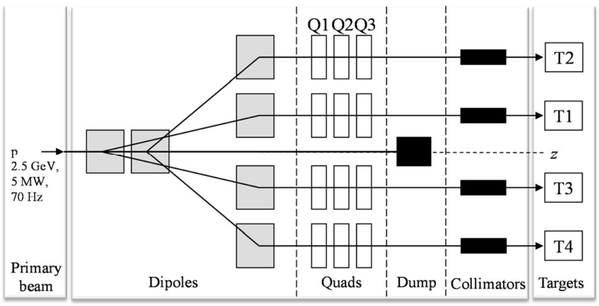

Figure 1: Principle of config1.

The quadrupoles are 1 m long (200 mm aperture). Their field gradients are presented in Table 2. The total length of the BSY is estimated to be 43.4 m.

Table 2: Field Gradients and Intensities (config1)

Quadrupole	**Q1**	**Q2**	**Q3**
Field gradient, T/m	1.9	-2.4	1.1
Intensity, NI per pole, kA	30.8	39.0	17.8

The beam envelopes and the emittances were investigated using the code TraceWin [7]. The maximum size of the beam envelope is estimated to be 160 mm (y axis in the 2nd quadrupole) which represents 80% of the total aperture of the quadrupoles (Fig. 2).

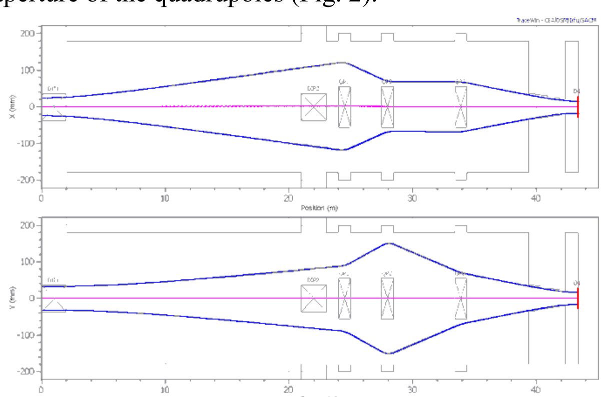

Figure 2: Beam envelopes (4σ) – T1 axis (config1).

The plots of the beam output phase-space confirm that the proton beam meets the requirements once at the target with Xmax and Ymax equals to 14.92 mm and to 14.93 mm respectively (Fig. 3).

A beam dump, made of graphite-cast iron and water cooled, is foreseen after the pair of bipolar devices to be able to stop a beam power of 71.4 kW (one pulse of protons).

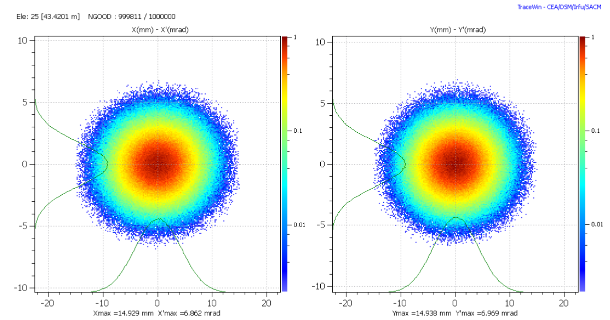

Figure 3: Beam output phase-space distributions in (x, x') and (y, y'); T1-T3 beam lines of config1.

Configuration 2 exclusively uses classical dipoles deflecting the beam at one single angle. The aim here is to make easier the deflection process in avoiding having a second device with a large aperture to let the beam deflected by the previous device to pass through it. In this configuration no beam dump is necessary, nevertheless, investigations showed the necessity of having 2 triplets of quadrupoles in addition to the 4 triplets located at the end of each beam line of the system (Fig. 4) to meet the beam requirements at the target station.

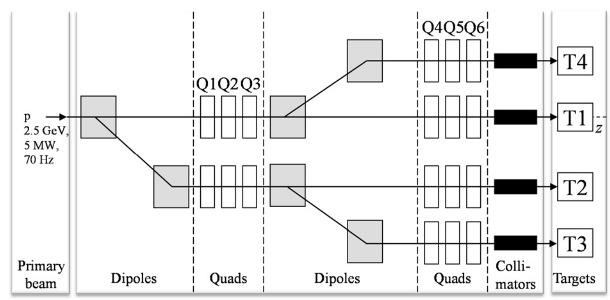

Figure 4: Principle of config2.

This BSY is estimated to be 72.2 m long. The maximum B-field needed by the deflecting magnets is 0.73 T (29 kA turns per pole). The distance between one deflecting dipole and its respective compensating dipole is the same for each case (15 m). All the dipoles are similar, this could ease their manufacturing.

Table 3: Field Gradients and Intensities (config2)

Quadrupole	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**
Grad., T/m	1.7	-3.0	1.7	2.6	-3.6	2.0
Intensity, NI / pole, kA	27.2	48.3	28.5	41.8	59.9	33.7

A total of 18 quadrupoles are necessary in this configuration and their field gradients are in Table 3.
Figure 5 shows the envelopes of the beam along the system of config2. The beam size meets the requirements at the target station, Xmax (Ymax) equals to 14.96 mm (14.72 mm) (Fig. 6).

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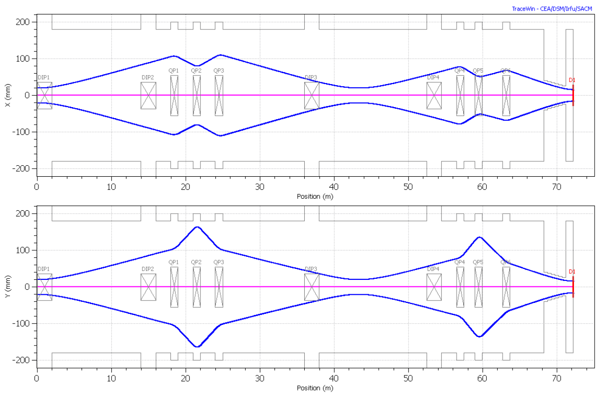

Figure 5: Beam envelopes (4σ) – T3 axis (config2).

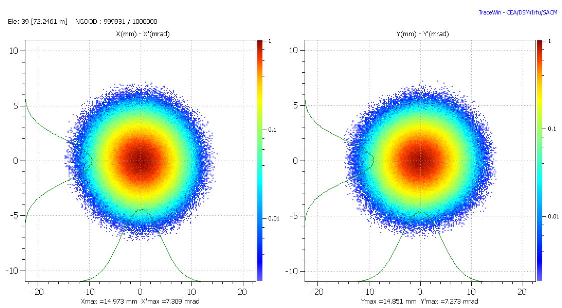

Figure 6: Beam output phase-space distributions in (x, x') and (y, y'); T3 beam line of config2.

Configuration 2a is an alternative to config2. Indeed, in this solution the beam is deflected to the other target axes from one single beam line (i.e. T1 axis) (Fig. 7). The first dipole deflects the beam diagonally from T1 to T3 axis. A distance of 19 m between the first dipole and the compensating dipole would require a magnetic field of 0.81 T thus an intensity of 32.3 kA turns per pole.

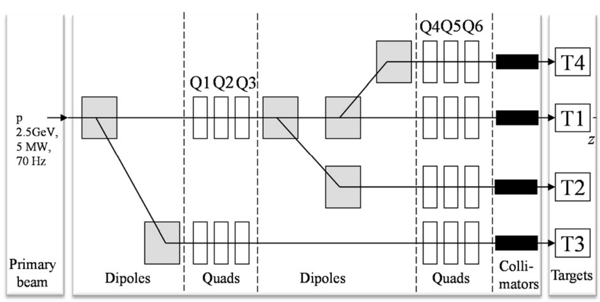

Figure 7: Principle of config2a.

This configuration of BSY suggests a total length of 79.2 m. The values of the field gradients for the quadrupoles are 90% similar from those used in config2.

ONGOING INVESTIGATIONS

Thorough investigations are currently being performed to allow a complete comparison between the different solutions mentioned above and to determine the most suitable one. These investigations concern the impact of any eventual fluctuations of one of the physical parameters involved in the transport of the proton beam along the BSY. These parameters are, *inter alia*, the magnetic fields of the optical elements, the size and the position of the beam and the energy. The design of the dipoles and quadrupoles composing the beam lines are also being investigated. The feasibility of the power supply units of these elements has to be evaluated and confirmed.

Additional beam instruments such as monitors, diagnostics and steerers are foreseen all along the beam lines.

SUMMARY

Three configurations have been described for a switchyard capable of distributing and focusing a 5 MW proton beam power pulsed at 70 Hz onto a 4-target station for the production of super beams of neutrinos. Figure 8 shows the drawings of 2 of them.

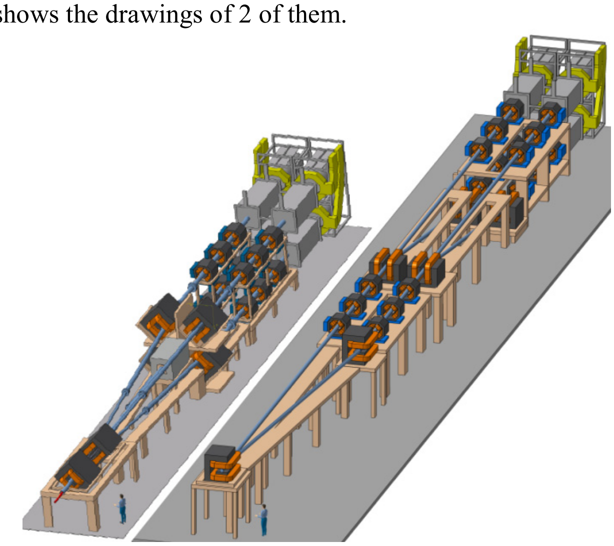

Figure 8: 3D drawings of config1 (left) and 2 (right).

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