PROCEEDINGS OF SCIENCE

ESSνSB:Update on secondary beam studies

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The ESS neutrino super beam (ESSνSB) has a great potential to discover the CP-violation in the leptonic sector. The beam consists of a four-horns/targets system in order to produce and focus the charged mesons that decay in flight inside a 25 m long tunnel and produce the neutrino beam. The horns power supply unit is described along with its possible synchronization with the accumulator-rings system that will deliver the proton beams to the four targets. The accumulator system is necessary to shorten the primary proton beam pulses lengths and as sequence to shorten the horns current pulses lengths which is crucial for the horn survival. In addition, details of the muon flux at the end of the decay tunnel are given. This high intensity muon beam, which is produced also from the decaying mesons could be introduced to the nuSTORM racetrack in order to measure the neutrino cross sections of interest for the ESSνSB.

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1. Introduction

ESSνSB is a long baseline neutrino super beam in Sweden proposed mainly for the discovery of the CP-violation in the leptonic sector and the neutrino mass hierarchy [1]. It will use the European Spallation Source (ESS) linac [2] that will be modified in order to accelerate up to 2 GeV protons for both the spallation source and the neutrino beam with 10 MW of power at 28 Hz, and the future Water Cherenkov MEMPHYS detector [3].

The main elements of the secondary neutrino beam are the target station with the four-horns and targets system to produce and focus the charged mesons, the 25 m long decay tunnel to produce the neutrinos from the meson decay and the beam dump to absorb the un-decayed mesons. All the apparatus will be heavily shielded with iron and concrete due the high radiation produced.

Each horn is accepting 350 kA pulses at 14 Hz in order to focus the mesons. Each proton spill to the target lasts a few milliseconds and as result the current pulse will cause the horn to melt using the known methods of horn-cooling. Therefore it is needed to include one or more accumulators [5] between the ESS linac and the secondary beam in order to compress the proton beam from few milliseconds to microseconds. A beam switching yard has also been studied [6] in order to split the initial proton beam into four-beams after the linac and guide the protons towards the accumulators or the horns depending on the scenarios studied in the next sessions.

In this paper are presented different scenarios of the function of the power supply of the four-horns system with respect to the function of the accumulators. In addition, the high intensity muon beam produced from the mesons-decays with the neutrinos is studied. These muons could be introduced to nuSTORM experiment [7] in order to measure the neutrino cross sections of interest for the ESSνSB.

The detailed description of the ESSνSB super beam layout, the neutrino fluxes at the detector site and the physics results are presented in [1] and in the previous Neutrino Factory workshops proceedings [4].

2. Power supply description for the four-horns system

The power supply unit of ESSνSB, which provides the necessary current pulses to the four-horns system, is a modular direct capacitor discharge and energy recovery device [8]. In the main design, a one-half sinusoid current waveform with a 350 kA maximum current and pulse length of 100 μs at 56 Hz is generated and distributed into the four-horns. That 350 kA maximum value that lasts 1.5 μs is of our interest in order to focus the particles. In order to provide the current, a bench of capacitors is charged at 56 Hz to a +12 kV reference voltage and then discharged through a large switch to each horn via a set of strip-lines at the same rate. A current recovery stage allows to invert rapidly the negative voltage of the capacitor after the discharging stage in order to recuperate large part of the injected energy and thus to limit the power consumption. The energy recovery efficiency of that system is very high at 97%. For feasibility reasons, a modular architecture has been adopted with 8 modules connected in parallel to deliver 44 kA peak currents into the four-horn system [8].

2.1 ESSνSB operation with four accumulator rings, only neutrinos at ESS

This scenario is described schematically in figure 1. The 2.8 ms proton pulse at 14 Hz is

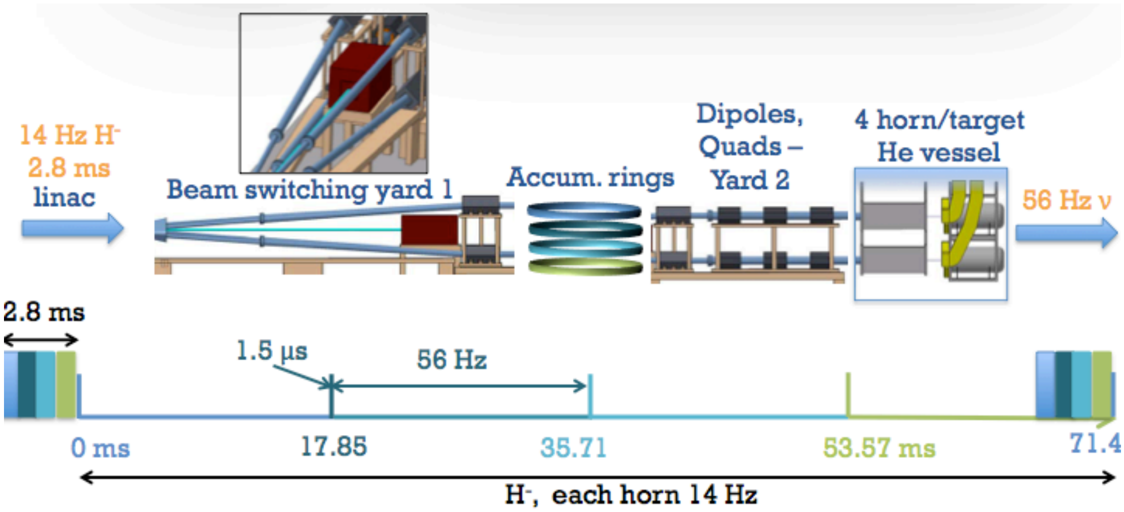

Figure 1: ESSνSB 4-rings, ν at 56 Hz.

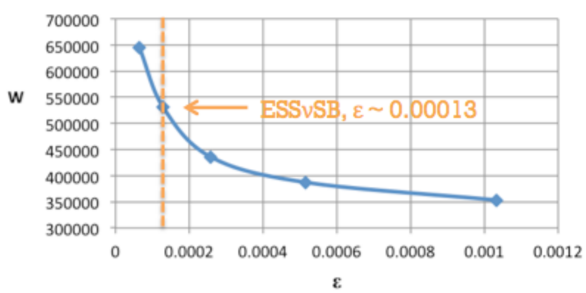

Figure 2: Power supply consuption, proton beam 1.5 μs, 4-Horns, W rms at 56 Hz.

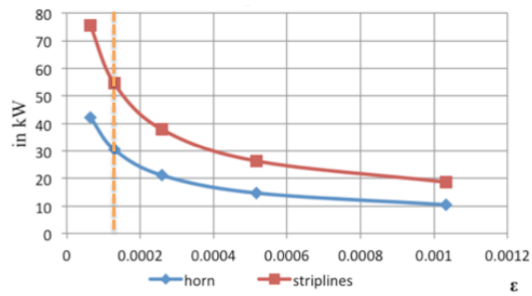

Figure 3: Horn power dissipation, proton beam 1.5 μs, 350 kA peak, at 14 Hz.

split into four individual 0.7 ms proton beams and guided into four accumulator-rings in where the proton pulses are reduced to 1.5 microseconds. Then the proton pulses are guided into the four-horns system in such a way that the neutrino beam is produced at 56 Hz while each horn works at 14 Hz. The power supply provides to each horn the maximum current for 1.5 μs at 56 Hz. Its consumption is 560 kW while it costs 4 MEuro [8]. Its power consumption and the power dissipation of the current on the horn as function of the parameter epsilon ε[1] are shown in figures 2 and 3 respectively, where epsilon reflects the variation of the current pulse at the maximum 350 kA and is correlated to the energy storage and power consuption of the power supply. As result, the smaller the ε the higher the power consumption and the costlier or less feasible the power supply.

2.2 ESSνSB operation with four accumulator-rings, neutrinos and neutrons

In this case the neutrino beam is produced 4 times every 0.7 ms with a 68.7 ms time gap that is dedicated to the spallation source, with a cycle of 14 Hz. The power supply has to be modified with two ways. One is to double the capacitor chargers increasing the total cost by a factor of 1.5 or

[1] $\varepsilon = 1 - cos(\tau_{H^-}/2 \times \pi/\tau_0)$, where $\tau_{H^-} = 1.5\ \mu s$ is the duration of the current pulse at the peak when the protons are hitting the target and $\tau_0 = 100\ \mu s$ is the width of the one-half solenoid pulse.

to increase their frequency at 112 Hz increasing the power consumption and total cost by a factor of 1.5 and 1.1 respectively.

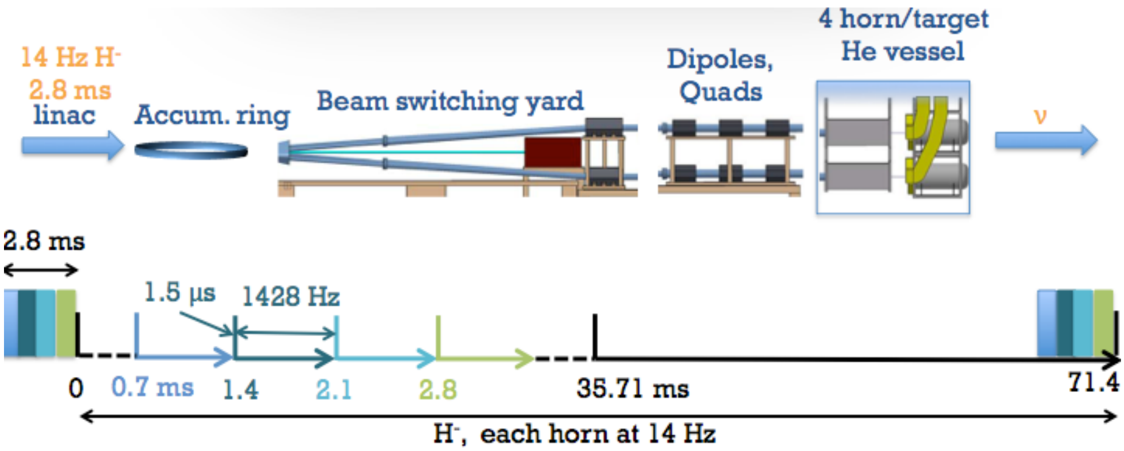

Figure 4: ESSνSB 1-ring, neutrinos every 0.7 ms + 68.6 ms gap for the spallation source.

2.3 ESSνSB operation with one accumulator ring

This scenario is described schematically in figure 4. The 2.7 ms proton pulse at 14 Hz is guided to one accumulator ring. where every 0.7 ms the proton beam is compressed to one 1.5 μs pulse. Then, each one of the four proton pulses is guided by the switching yard to the four horns system. The neutrino beam is produced as in the section before and it is needed to quadruple the capacitor chargers increasing the total cost by 2.5 compared to the first case.

2.4 Other configurations

Other configurations have been studied [9] such as reconfiguring the horns in series or without any accumulator along the beam-line but abandoned due to enormous power supply consumption and power dissipation on the horns, and operational and safety issues.

3. Muon fluxes at the end of the decay tunnel

The muon fluxes and their spatial distribution were studied in case the nuSTORM project is adopted at ESS site. At ESSνSB a delivery of 2.7×10^{23} protons on target (p.o.t) is expected per year. Out of those protons, 3.7×10^{20} and 3.5×10^{20} pions, at the corner and the center of the beam-axis respectively, are expected to survive at the end of the decay tunnel. Also 4.1×10^{20} and 4.2×10^{20} muons, at the corner and the center of the beam-axis respectively, are expected to go through the decay tunnel. Their spatial distribution and momentum are shown in figures 6 and 5 respectively. These muons could be used to create a lower energy beam at the nuSTORM-racetrack for measuring the low neutrino energy cross sections (below 1 GeV), which are important for the ESSνSB project.

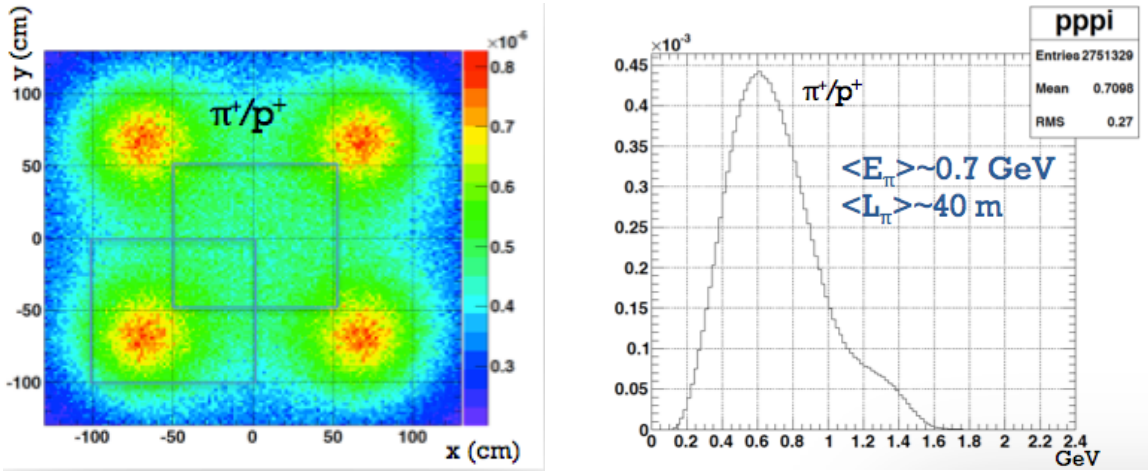

Figure 5: The transversal xy spatial distribution with respect to the beam z-axis and momentum of muons at the end of the decay tunnel.

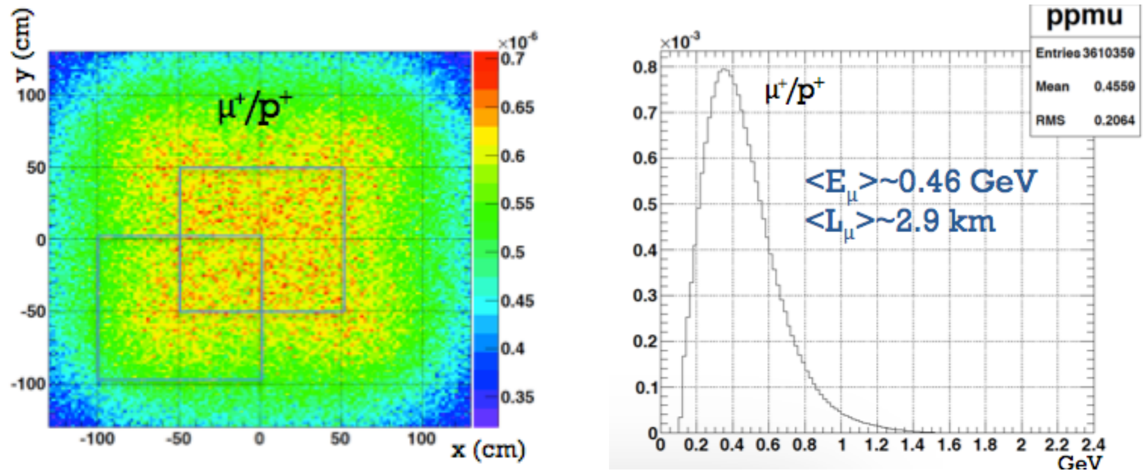

Figure 6: The transversal xy spatial distribution with respect to the beam z-axis and momentum of muons at the end of the decay tunnel.

4. Conclusions

In this paper different feasible scenarios of the ESSνSB power supply and accumulator configuration are presented in order to create the neutrino beam. In addition the muon fluxes were calculated at the end of the decay tunnel in case the nuSTORM project is adopted at ESS but without any further analysis.

Acknowledgments

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