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The European Spallation Source neutrino Super Beam plus Project

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The European Spallation Source neutrino Super Beam (ESSnuSB) is a design study for a long-baseline neutrino experiment to measure the CP violation in the leptonic sector at the second neutrino oscillation maximum using a neutrino beam driven by the uniquely powerful ESS linear accelerator. The reduced impact of systematic errors on sensitivity at the second maximum allows for a very precise measurement of the CP violating parameter. The ESSnuSB CDR showed that after 10 years of data taking, more than 70% of the possible CP-violating phase, δCP, range will be covered with 5σ C.L. to reject the no-CP-violation hypothesis. The expected value of δCP precision is smaller than 8° for all δCP values, making it the most precise proposed experiment in the field by a large margin. The recently started extension project, the ESSnuSB+, aims in designing two new facilities, a Low Energy nuSTORM (LEnuSTORM) and a Low Energy Monitored Neutrino Beam (LEMNB) to use them to precisely measure the neutrino-nucleus cross-section (the dominant term of the systematic uncertainty) in the energy range of 0.2 – 0.6 GeV.

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1. Introduction

Neutrino experiments have provided vital information in the searches for the CP-violation in the leptonic sector [1]. With intense "super" neutrino beam experiments, the measurement of the third neutrino mixing angle, θ_{13}, made it possible to determine Dirac leptonic CP violating phase, δ_{CP}. Several experiments, including T2K [2] and NOvA [3], have begun to offer the first clues about the CP-violating phase. As compared to observations at the first oscillation maximum, the second oscillation maximum exhibits increased sensitivity to CP violation and violating parameter, δ_{CP} [4]. To accumulate a significant statistical sample at the 2nd maximum, a very intense neutrino beam is required. To achieve this, the ESSnuSB project foresees to use uniquely powerful 5 MW, 2 GeV, ESS proton linear accelerator that is currently in construction near Lund in Sweden. As the next generation of long-baseline neutrino experiments, several Super Beam detectors have been suggested, most notably the DUNE experiment in the USA [5] and the T2HK in Japan [6]. However, the far detector will be positioned at the first oscillation maximum in these experiments, not the second and this where the ESSnuSB stands out.

2. European Spallation Source neutrino Super Beam Experiment

The ESSnuSB [7] is a future accelerator-based neutrino oscillation experiment designed to measure the CP violation in the leptonic sector, by observing neutrino oscillations primarily at the second oscillation maximum. By using the high power proton beam of the European Spallation Source (ESS) linear accelerator (linac) in Lund, Sweden[8], the ESSnuSB seeks to create the most intense neutrino beam in the world in order to precisely search for and measure the CP-violation in the leptonic sector, at 5σ significance level in more than 70% percent of the leptonic Dirac CP violating phase range. If shape statistics are under control, the measurement precision of δ could be significantly less than 8°. Several technical advancements involving the proton beam energy, charge stripping, and beam accumulation schemes are required in order to achieve the physics objectives of ESSnuSB. To complement the physics potential of the ESSnuSB and also to study the neutrino cross-sections at lower energies (0.2-0.6 GeV) an additional synergic facility the ESSnuSB+ is developed.

3. ESSnuSB+

The ESSnuSB+ proposes to build an R&D target station which will contain one target/horn system, and operating at 1.25 MW beam power. Furthermore, as in the nuSTORM project [9], the pions generated in the secondary hadron beam will be extracted and directed towards a low energy muon storage ring (LEnuSTORM). Figure 1(a) shows a conceptual drawing of the ESSnuSB+ target station facility, with the concept of the pion extraction, deflection and focusing system.

In order to design the pion extraction, deflection, and focusing system , the R&D target station will comprise magnetic systems that rely on the use of conventional dipoles to bend the beam in horizontal and/or vertical planes. Sets of components for magnetic focusing, such as quadrupoles positioned either ahead of or behind the extraction system, will guarantee that the transverse envelope of the extracted pion beam is kept to a minimum as it propagates through the beam line. To obtain

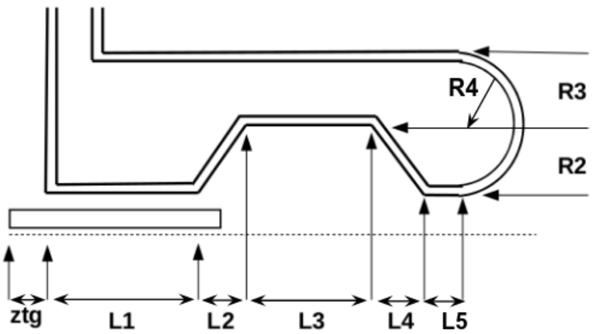

Figure 1: Horn parameter set.

a dense flux of pion beam one must optimise the horn geometry to design the dipole which would then deflect the beam. The detailed horn geometry with the relevant parameter set is shown in Figure 1.

4. Genetic Algorithm (GA)

The GA is a meta-heuristic approach that falls under the broad category of evolutionary algorithms in computational mathematics and informatics, and it is driven by the process of evolution [10]. GA is a way to solve the problem of optimizing towards better options by using the population of the candidate, which can be people, animals, or in our case the horn parameters. Each potential solution possesses a set of traits (the phenotype or genes) that are alterable. The group of individuals contribute to a population which undergoes evolution (an iterative process) producing new individuals at ever generation. The most fit individuals of a generation are selected and propagated (through crossovers or mutation) to the next generations. Therefore, every new generation has better solution than the old generation. The algorithm usually terminates when the maximum number of generations is reached or until the certain criteria is satisfied. The same principle is used in optimizing the horn parameters.

5. Optimization of Horn geometry using GA

The simulation of the horn geometry is done in FLUKA [11]. The corresponding pion flux (which is the figure of merit) is generated from FLUKA and is sent to the GA which is developed with the help of DEAP library toolkit in Python. The GA then derives the correlation between the horn parameters and pion flux and makes several generations of population and returns the optimized set of horn parameters. At a given generation, after which no significant improvements in the optimization procedure are observed, the configuration with the maximum of pion production is considered as the optimal configuration. The pion distribution obtained and the spatial distribution is shown in Figure(2). The detection efficiency is calculated from the ratio of the flux in a selected region to the ratio of whole flux and is 40% for the region of 10m from the horn geometry. The width σ_x and σ_y are 17cm & 13cm respectively and this is crucial to decide the distance between the dipole. The above are results from a 5 generation study. A detailed study will be carried out to see at which generations the parameters become optimal and stay optimal.

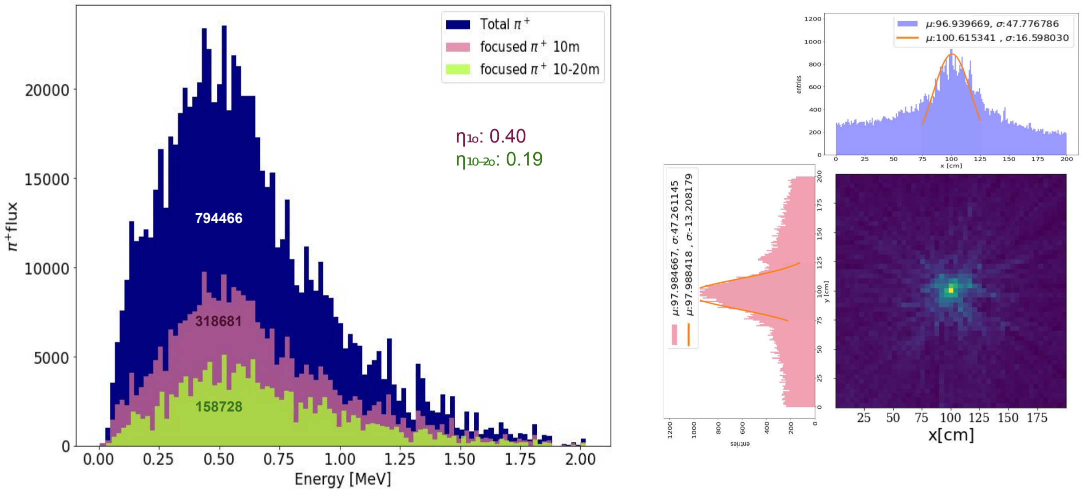

Figure 2: (Left panel) Pion distribution over different volumes; (Right panel) spatial distribution at a distance of 10m from horn.

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