Physics Potential of the SPL Super Beam

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Abstract. Performances of a neutrino beam generated by the CERN SPL proton driver are computed considering a 440 kton water Čerenkov detector at 130 km from the target. θ_{13} sensitivity down to 1.2° and a δ sensitivity comparable to a Neutrino Factory, for $\theta_{13} \geq 3°$, are within the reach of such a project.

1. Introduction

The planned Super Proton Linac (SPL) is a 2.2 GeV proton beam of 4 MW power [1] working with a repetition rate of 75 Hz delivering $1.5 \cdot 10^{14}$ protons per pulse (10^{23} protons on target (pot) in a 10^7 s conventional year). It could be the first stage of a CERN based Neutrino Factory or of a Beta Beam.

Studies of the capabilities of a neutrino beam generated by SPL have been already published in [2], [3], in this paper the fluxes and the overall physical performances will be reviewed in the light of the new design of the beam optics, specially optimized for the SuperBeam needs [4]. They are computed for a gigantic water Čerenkov detector, as the proposed UNO detector [5] (440 kton fiducial) located in the Modane laboratory under the Frejus tunnel at a baseline of 130 km from CERN.

The SPL SuperBeam capabilities would constitute a natural follow-up of the JHF phase I experiment [6], with excellent sensitivity on θ_{13} (section 3) and good sensitivity on the CP phase δ (section 4). Furthermore the SPL SuperBeam could be used to complement the results of a Neutrino Factory experiment, helping in resolving the ambiguities, as discussed in [7]; or could be combined with a Beta Beam, as discussed in [8].

Signal efficiency and backgrounds have already been discussed in [2], they are computed by using the NUANCE neutrino event generator [9] and reconstructing the events with standard SuperKamiokande algorithms, with the addition of improved π° rejection algorithms. They can be summarized as signal efficiency $\epsilon \simeq 70\%$ and π° and μ/e background rejection, normalized to the non oscillated ν_μ charged current interactions, $f_B^{\pi^\circ} = 4.2 \cdot 10^{-4}$, $f_B^{\mu/e} = 3 \cdot 10^{-3}$.

2. Fluxes

Details of the new beam optics can be found in [4]. The use of an horn and a reflector increases by $\sim 40\%$ the overall ν_μ flux with respect to the former single horn optics, slightly increases the ν_e contamination, while the $\overline{\nu}_\mu$ and $\overline{\nu}_e$ contaminations are reduced by $\sim 30\%$.

The length of the decay tunnel has been re-optimized having in mind CP searches more than θ_{13} . Table 1 reports details of the beam properties as function of the length of the decay tunnel, including the sensitivity on θ_{13} for a 2200 kton/year exposure. In spite of the fact that the θ_{13} sensitivity is maximum for the lowest length (20 m), a 60 m decay length is preferred because of the lower $\overline{\nu}_\mu$ contamination, that results in a better CP sensitivity. The neutrino spectra for the π^+ and π^- focussed beams are displayed in Fig. 1.

Table 1. Neutrino fluxes and contamination for different values of the decay tunnel length. The last line refers of the single horn optics of ref. [2].

	$\pi^+ focus$			$\pi^- focus$			$\pi^+ focus$
Length (m)	ν_μ $(\nu/m^2/yr)$ (@50 km)	ν_e (%)	$\overline{\nu}_\mu$ (%)	$\overline{\nu}_\mu$ $(\nu/m^2/yr)$ (@50 km)	$\overline{\nu}_e$ (%)	ν_μ (%)	θ_{13} (90%CL) (2200 kton/yr)
20	$2.43 \cdot 10^{+12}$	0.38	1.71	$1.73 \cdot 10^{+12}$	0.41	3.9	1.20
60	$3.23 \cdot 10^{+12}$	0.67	1.50	$2.25 \cdot 10^{+12}$	0.70	3.3	1.25
100	$3.35 \cdot 10^{+12}$	0.76	1.62	$2.33 \cdot 10^{+12}$	0.79	3.3	1.30
20 (old)	$1.71 \cdot 10^{+12}$	0.36	2.4	$1.12 \cdot 10^{+12}$	0.38	5.6	1.47

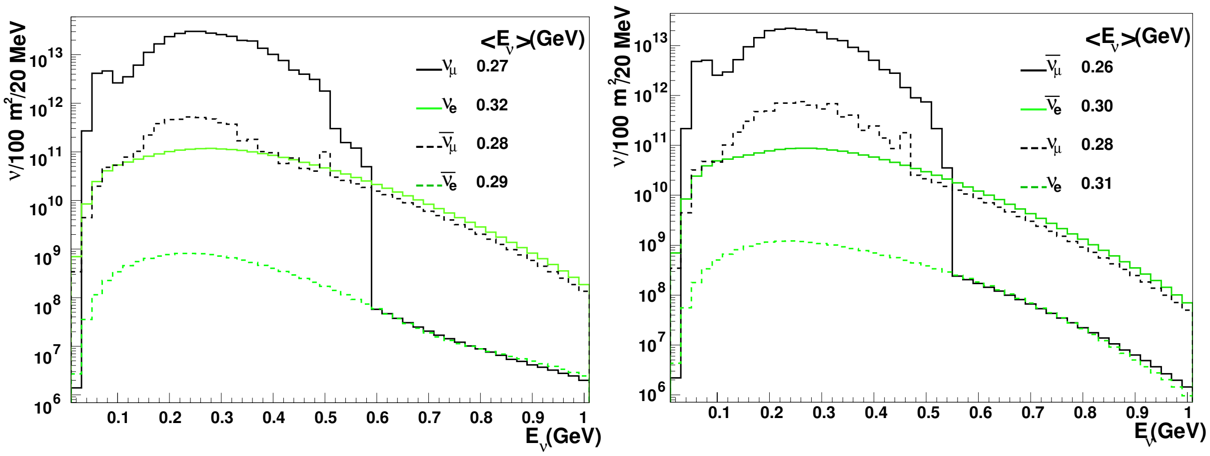


Figure 1. Neutrino spectra for the π^+ (left) and the π^- (right) focussed beam for a decay tunnel length of 60 m.

3. Sensitivity on θ_{13}

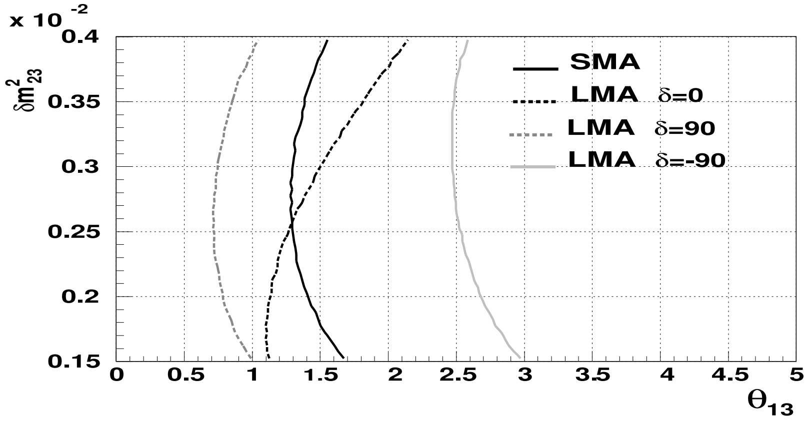
The θ_{13} sensitivity is computed assuming $\delta = 0$, solar SMA solution, $\delta m^2_{23} = 2.5 \cdot 10^{-3}$ eV^2, $\theta_{23} = 45°$ and 5 years of data taking. These are the standard benchmark assumptions used by similar projects [6], [10].

Fig. 2 shows the θ_{13} sensitivity (90% CL) in case of no signal and summarizes the event rate computed for $\theta_{13} = 2°$. The experiment would have sensitivity down to $\theta_{13} = 1.2°$ ($\sin^2 2\theta_{13} = 1.75 \cdot 10^{-3}$)

4. CP sensitivity

CP sensitivity is computed assuming a 2 year run with the π^+ focussed beam and 8 years with the π^- focussed beam. This sharing is motivated by the unfavorable cross section ratio $\overline{\nu}_e / \nu_e \sim 1/6$ at 300 MeV.

A 10% error on the solar δm^2 and $\sin^2 2\theta$, as expected from the KamLAND experiment [11] and a 2% error on the atmospheric δm^2 and $\sin^2 2\theta$, as expected from the JHF neutrino experiment [6] are taken into account. Correlations between θ_{13} and



ν_μ^{CC} (no osc.)	76782
Beam ν_e	294
NC	32
μ/e	43
Signal	104

Figure 2. Left: θ_{13} sensitivity (90%CL) computed for a 2200 kton exposure, under the solar SMA solution or under LMA and different δ values. Right: Number of events for the same exposure, SMA solution, in case of $\theta_{13} = 2°$.

δ are fully accounted for, while the sign δm^2_{13} and the $\theta_{23}/(\pi/2 - \theta_{23})$ ambiguities are not considered. A systematic error of 2% is accounted for the signal efficiency and background normalization, as discussed in [2].

Solutions for different values of δ and θ_{13}, Fig.3-left, show very small correlations between the two parameters.

Since the sensitivity to CP violation heavily depends on the true value of δm^2_{12} and θ_{13}, we prefer to express the CP sensitivity for a fixed value of δ in the δm^2_{12}, θ_{13} parameter space. The CP sensitivity to separate $\delta = 90°$ from $\delta = 0°$ at the 99%CL as a function of δm^2_{12} and θ_{13}, following the convention of [12], is plotted in Fig. 3-right.

It is fair to say that SPL SuperBeam CP sensitivity approaches the Neutrino Factory sensitivity in the parameter space that will be explored by the JHF experiment: $\theta_{13} \geq 2.3°$.

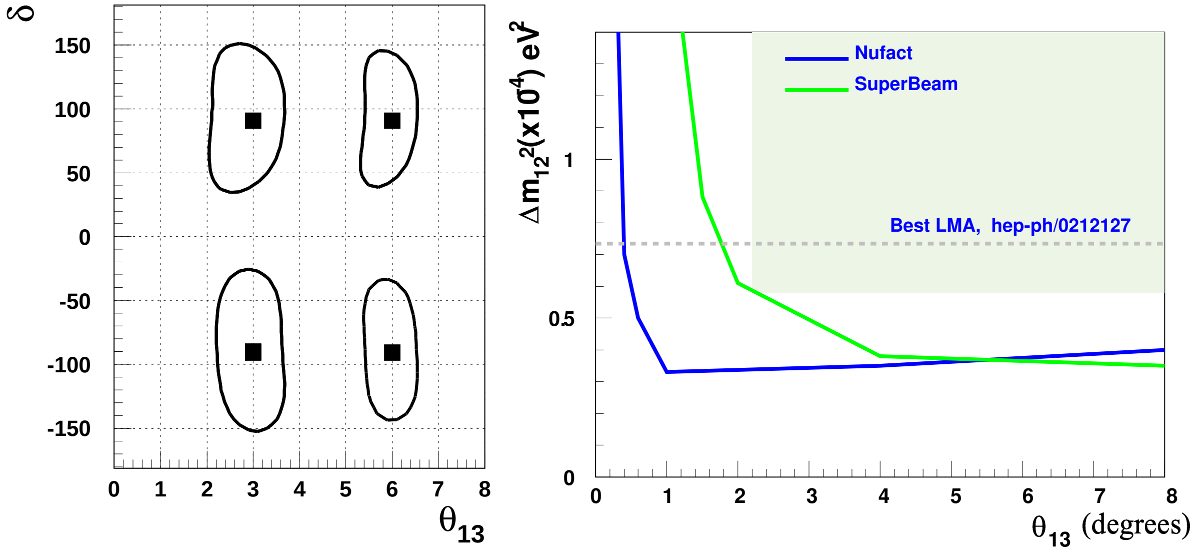


Figure 3. Left: $\theta_{13} - \delta$ fits (99% CL) computed for $\delta m_{12}^2 = 10^{-4}$ eV^2, $\sin^2 2\theta_{12} = 0.8$. The squares indicate the starting points. Right: CP sensitivity of the SPL-SuperBeam, see text, compared with a 50 GeV Neutrino Factory producing $2 \cdot 10^{20} \mu$ decays/straight section/year, and two 40 kton detectors at 3000 and 7000 km [12]; the shaded region corresponds to the allowed LMA solution and the θ_{13} sensitivity of JHF.

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