

A neutrino program based on the machine upgrades of the LHC

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Abstract. In this paper, we discuss the possibilities offered to neutrino physics by the upgrades of the CERN accelerator complex. Emphasis is on the physics reach of a medium γ (350-580) β -beam that fully exploits the improvements in the CERN accelerator complex for the luminosity/energy upgrade of the LHC. We show that, this design not only profits of the ongoing efforts for the upgrades of the LHC, but also leverage out the existing infrastructures of the LNGS underground laboratory. Furthermore, given the involved high neutrino energies, above 1 GeV, a non-magnetized iron detector could efficiently exploit the neutrino beam. We show that the performance of this complex for what concerns the discovery of the CP violation in the leptonic sector, in case θ_{13} is discovered by Phase I experiments, is comparable with the current baseline design based on a gigantic water Cherenkov at Frejus. Furthermore, this complex has also some sensitivity to the neutrino mass hierarchy.

1. Introduction

Among the oscillation parameters, a relevant role is played by the mixing angle θ_{13} . Indeed, a vanishing or too small value for θ_{13} , would make impossible the observation of the CP violation in the leptonic sector and fix the neutrino mass hierarchy (sign of Δm_{23}^2 exploiting matter effects). If θ_{13} is large enough ($> 3^\circ$) to allow for its discovery by the forthcoming experiments [1], new facilities and new experiments [2] would be needed in order to precisely measure the PMNS matrix.

Several projects have been proposed for the Phase II (see [3, 4] and references therein). In this paper we investigate a possible window of opportunity for the neutrino oscillation physics compatible with the upgrade of the LHC (after 2015) that fully exploits European infrastructures and that has an adequate sensitivity to the 1-3 sector of the PMNS matrix. We consider a medium γ (350-580) β -beam that fully exploits the improvements in the CERN accelerator complex for the luminosity/energy upgrade of the LHC and shoots (anti-)neutrinos towards a non-magnetized detector at the Gran Sasso. For details on the accelerator complex and on the envisaged detector we refer to [5].

2. Physics reach of the medium γ scenario

The expected neutrino flux at a β -beam as a function of the γ is still under evaluation. Therefore, we evaluated the physics reach as a function of the flux normalized to the one assumed in the baseline design (F_0). Finally, we note that in this work only the intrinsic degeneracy is taken

into account. The expected number of events as a function of δ and θ_{13} has been obtained in the framework of a three family scenario.

2.1. Extraction of the neutrino oscillation parameters in presence of signal

Since the neutrino flux from a β -beam is not yet well defined, we studied, for $\delta = 90^\circ$, the minimum θ_{13} that can be distinguished from zero at 99% C.L. as a function of the flux (1 corresponds to F_0). Notice that, if the flux is at least half of F_0 , it is possible to discover a non vanishing θ_{13} even in the case of no signal observed in the T2K experiment. Assuming a flux equal to F_0 , values of θ_{13} down to 1° can be distinguished from zero. On the other hand, for $\theta_{13} = 3^\circ$, the minimum δ that can be distinguished from zero, at 99% C.L., as a function of the neutrino flux. The value $\theta_{13} = 3^\circ$ has been chosen being the minimum value for which T2K may discover a non-zero θ_{13} . Also in this case, unless the flux is smaller than $F_0/10$, it would be possible for the whole θ_{13} range covered by the T2K discovery potential discover CP violation in the leptonic sector. The minimum δ_{CP} that can be discovered at 99% C.L., as a function of θ_{13} , is shown in figure 1. As for comparison, the discovery potential of the baseline scenario is also reported. We can argue that, down to fluxes half of F_0 and for $\theta_{13} > 3^\circ$ (the discovery region of T2K), the discovery potential of the baseline and of the medium γ scenarios are comparable.

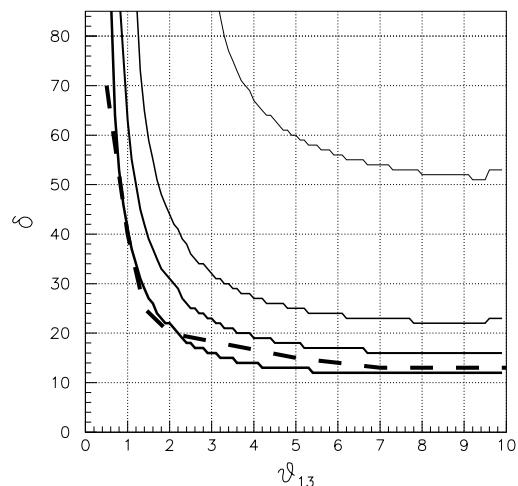


Figure 1. δ_{CP} discovery potential at 99% C.L. as a function of θ_{13} . The different solid lines corresponds at different fluxes. From left to right: $2 \times F_0$, F_0 , $F_0/2$ and $F_0/10$. The dashed line shows the discovery potential for the baseline scenario as computed in [6].

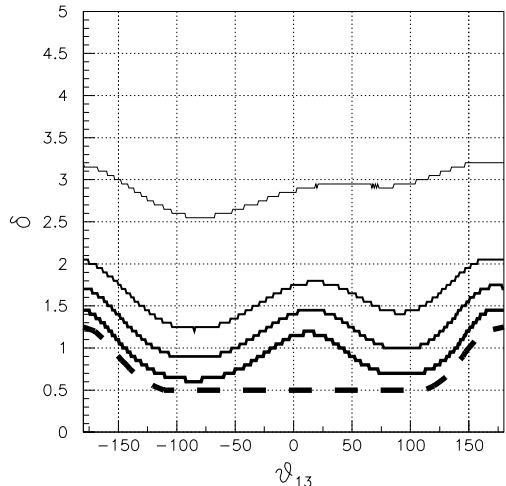


Figure 2. θ_{13} discovery potential at 90% C.L. as a function of δ . The different solid lines corresponds at different fluxes. From down to top: $2 \times F_0$, F_0 , $F_0/2$ and $F_0/10$. The dashed line shows the discovery potential for the baseline scenario as computed in [6].

2.2. Exclusion plots in absence of signal

In figure 2 we draw the 90% C.L. contour defining the sensitivity limit on θ_{13} in case of absence of a signal, with δ_{CP} as a fixed free parameter. The sensitivity has been computed applying a χ^2 analysis including the expected background and a 2% systematic error. The sensitivity is rather good, as can be argued from figure 2, but it is systematically worse than the one of the baseline scenario.

3. Conclusion

The next generation of accelerator based neutrino oscillation experiments has the challenging purpose to discover the missing oscillation parameter θ_{13} . The relevant role played by this parameter in the neutrino oscillation physics and the wide experimental program developed to discover it are related to its strong correlation with the CP violation in the leptonic sector. Indeed, a vanishing or too small value for θ_{13} would make impossible the observation of the CP violation parameter δ and of to fix the neutrino mass hierarchy.

In this paper we discussed in particular a neutrino program based on the machine upgrades of the LHC. Indeed, it turns out that the Super-SPS option for the luminosity/energy upgrade of the LHC has the ideal features for the construction of a β -beam facility with a γ in the range $350 - 580$ whose physics case would be enormously strengthened in the case of θ_{13} discovery in Phase I experiments. Given that the luminosity/energy upgrade of the LHC is foreseen after 2015, and that Phase I experiments are expected to complete their program around that date, we see a window of opportunity for a Phase II neutrino program in Europe compatible with the LHC (and its upgrade) running. This would allow, contrarily to other proposed neutrino physics program, the full exploitation of European accelerator facilities during the LHC era. Other advantages are that the proposed experimental program does not imply the construction of a Megaton detector, but of a very dense detector (iron slabs interleaved with e.g. glass RPC segmented into $2 \times 2 \text{ cm}^2$ cells) with a few tens of kiloton mass. This would fit into the underground facilities existing at the Gran Sasso, whose distance from CERN, given the neutrino energy of this facility, happens to be at the peak of oscillation probability!

The proposed detector will be able not only to identify ν_μ and $\bar{\nu}_\mu$ charged/current interactions, but also to measure the energy of the incident neutrino. This opens, given the long baseline, the possibility to measure the neutrino mass hierarchy. In case Phase I experiments will discover a non vanishing $\theta_{13} (> 3^\circ)$, the proposed set-up will be able to discover CP violation for δ values down to 30° . These performances are comparable with the one obtained by the baseline β -beam that foresee the construction of an accelerator complex with no overlap with the LHC program and the excavation of a very large cavern able to host a megaton water Cherenkov detector. Note, however, that the sensitivities at small values of θ_{13} of the medium γ facilities result to be worse than the ones for the baseline β -beam scenario, mainly due to the large difference of mass (40 vs 1000 kton) of the corresponding detectors.

Finally, we want to point out that at the present, although very promising, a detailed study of a β -beam complex is still missing. There is an EURISOL design study group that is scrutinizing the baseline option, but the medium γ scenario is beyond its scope. Nevertheless, the latter option surely deserves careful consideration.

References

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