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Comparison of the CERN–MEMPHYS and T2HK neutrino oscillation experiments*

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In this talk I compare the physics potential of possible future neutrino oscillation experiments from CERN to a Mt scale water Čerenkov detector at Fréjus (MEMPHYS) and of the T2HK proposal in Japan, where for the CERN experiments an SPL Superbeam and a $\gamma = 100$ Beta Beam are considered.

1. INTRODUCTION

Neutrino oscillation physics is now entering the era of precision experiments [1]. The main aim of the upcoming generation of experiments will be to establish a non-zero value of the mixing angle θ_{13} or to push further the bound. On a time scale of 5 to 10 years decisions on a subsequent generation of high precision neutrino oscillation facilities will have to be taken, and currently active investigations on comparing various options are performed [2]. Along these lines, in this talk I consider three particular setups which are comparable in size and time scale, namely two CERN based neutrino oscillation experiments consisting of a Beta Beam (β B) [3] with $\gamma = 100$ and a Superbeam (SPL) [4], as well as the phase II of the T2K experiment in Japan (T2HK) [5]. All three configurations use a Mt scale water Čerenkov detector [6]: MEMPHYS [7] at Fréjus or the Hyper-Kamiokande [8] detector in Japan. The main characteristics of the setups are displayed in Tab. 1. The results presented here are based on the work [9], where details on the calculations, references, and more physics results and discussions can be found.

2. SENSITIVITY TO θ_{13} and CPV

As performance indicators for the considered experiments we use the potential to establish a non-zero value of θ_{13} and the sensitivity to CP

| | β B | SPL | T2HK |
|-------------------------------|--------------------------|--------|--------|
| Det. mass | 440 kt | 440 kt | 440 kt |
| Baseline | 130 km | 130 km | 295 km |
| $\langle E_\nu \rangle$ [MeV] | 400 | 300 | 760 |
| Time ($\nu/\bar{\nu}$) | 5/5 yr | 2/8 yr | 2/8 yr |
| Beam | $5.8(2.2) \cdot 10^{18}$ | 4 MW | 4 MW |
| Systematics | 2–5% | 2–5% | 2–5% |

Table 1

Summary of default parameters used for the simulation of the β B, SPL, and T2HK experiments. For the β B the beam intensity is given in ${}^6\text{He}({}^{18}\text{Ne})$ decays/yr.

violation (CPV). The θ_{13} sensitivity is shown in Fig. 1 (left) as a function of the value of the CP phase δ_{CP} : above the curves $\theta_{13} = 0$ can be excluded at more than 3σ CL (i.e., with $\Delta\chi^2 \geq 9$), whereas Fig. 1 (right) shows the region in the $\theta_{13} - \delta_{\text{CP}}$ plane where CPV can be established at 3σ .

One finds from these plots that SPL and T2HK perform rather similar. In fact, the experimental setups of these two configurations are similar (Superbeam technology, multi-MW beam power, detector, L/E_ν), the main differences being the shorter baseline of SPL which implies lower neutrino energies (compare Tab. 1), as well as the use of an on-axis (off-axis) configuration for SPL (T2HK). The lower energies for SPL imply that the cross section is completely dominated by quasi-elastic (QE) scattering which allows a good reconstruction of the neutrino energy, whereas at

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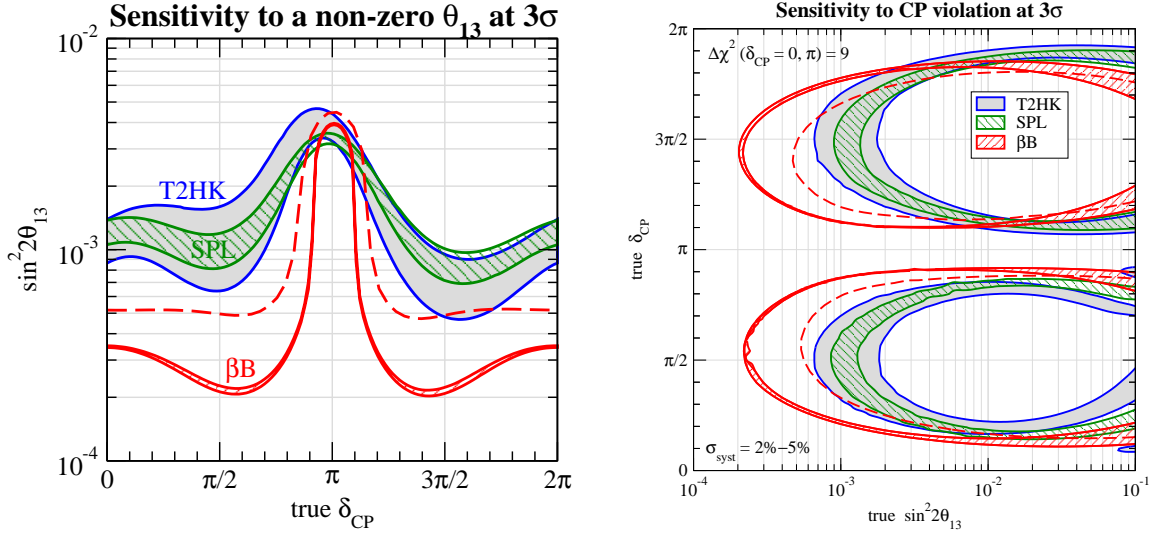


Figure 1. Left: 3σ sensitivity to $\sin^2 2\theta_{13}$ for βB , SPL, and T2HK as a function of δ_{CP} . Right: CPV discovery potential for βB , SPL, and T2HK: for parameter values inside the ellipse-shaped curves CP conserving values of δ_{CP} can be excluded at 3σ ($\Delta\chi^2 > 9$). The width of the bands corresponds to values for the systematical errors between 2% and 5%. The dashed curves show the sensitivity of the βB when the number of ion decays/yr are reduced by a factor of two with respect to the values given in Tab. 1.

T2HK energies non-QE events contribute significantly. On the other hand in the low energy regime Fermi motion becomes important which limits energy reconstruction. In our analysis we have taken these issues into account by a migration matrix between true and reconstructed neutrino energies based on detailed event simulations [9].

Within our standard setup the βB performs clearly better than the Superbeams. For the βB a crucial parameter is the total number of ion decays. The conservative numbers from the EURISOL βB studies [10], which are two times smaller than our standard values, lead to the sensitivities shown as dashed curves in Fig. 1.

The widths of the curves in the figures shows the effect of varying the (uncorrelated) systematical uncertainties on signal and backgrounds between 2% and 5%. One can see that the βB is practically unaffected, whereas the Superbeam performances, and in particular the one of T2HK, depend to some extent on the systematics. The relevant systematic in this respect is the uncertainty on the background. In the βB

the most important background comes from pions produced mainly in NC $\nu_e/\bar{\nu}_e$ interactions which are misidentified as muons. This background is efficiently reduced by requiring to see the Michel electron from the muon decay. After applying all the cuts roughly 300 background events remain. The reason why an uncertainty on this number has so little impact for the βB is that the background has a very different shape than the signal. As visible in Fig. 2 it is peaked at low energies and therefore spectral information makes the βB very insensitive to the systematical uncertainty.

In contrast, for the Superbeams the background comes mainly from the intrinsic $\nu_e/\bar{\nu}_e$ component of the beam and has a spectral shape rather similar to the signal, as illustrated in Fig. 2 for the SPL. Therefore spectral information is not as efficient to distinguish the background from the signal, as in the case of the βB .

3. COMMENTS ON DEGENERACIES

In analyses of long-baseline experiments parameter degeneracies play an important role.

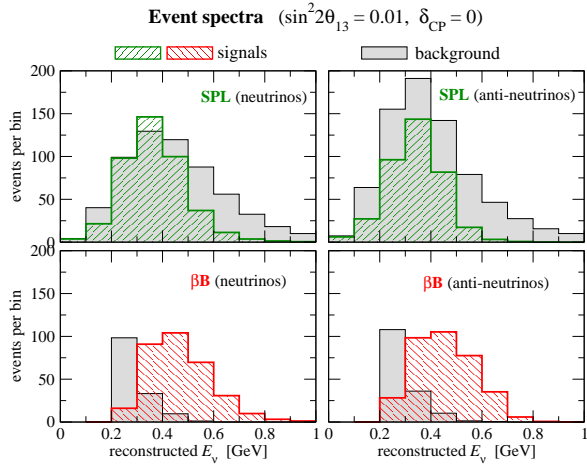


Figure 2. Signal and background energy spectra for SPL (top) and βB (bottom).

There are three types of degeneracies [11], traditionally referred to as intrinsic-, octant-, and $\text{sign}(\Delta m_{31}^2)$ -degeneracy. For the experiments discussed here the intrinsic degeneracy is resolved by spectral information but the degeneracies related to the octant of θ_{23} and the neutrino mass hierarchy are present and lead to ambiguities in the determination of θ_{13} and δ_{CP} . However, thanks to the fact that the matter effect is rather small (due to the relatively short baselines) the degeneracies have very little impact on the sensitivity to CPV. In other words, if the true parameter values are CP violating also the parameter values of the degenerate solutions will be CP violating.

Moreover, as shown in Ref. [12] atmospheric neutrino data in Mt scale water Čerenkov detectors as considered here can be used to resolve degeneracies (see also Ref. [9]). By combining long-baseline and atmospheric data the mass hierarchy can be identified at 2σ CL provided $\sin^2 2\theta_{13} \gtrsim 0.02 - 0.03$, although none of the considered experiments has sensitivity to the hierarchy from long-baseline data alone. Furthermore, atmospheric data provides sensitivity to the octant of θ_{23} , and if combined with the ν_μ disappearance channel available in the Superbeam experiments there is sensitivity to the octant for $|\sin^2 \theta_{23} - 0.5| \gtrsim 0.05$.

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