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Probing neutrino parameters with a Two-Baseline Beta-beam set-up

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We discuss the prospects of exploring the neutrino mass parameters with a CERN based Beta-beam experiment using two different detectors at two different baselines. The proposed set-up consists of a 50 kton iron calorimeter (ICAL) at a baseline of around 7150 km which is roughly the magic baseline, e.g., ICAL@INO, and a 50 kton Totally Active Scintillator Detector at a distance of 730 km, e.g., at Gran Sasso. We take ^{8}B and ^{8}Li source ions with a boost factor γ of 650 for the magic baseline while for the closer detector we consider ^{18}Ne and ^{6}He ions with a range of Lorentz boosts. We find that the locations of the two detectors complement each other leading to an exceptional high sensitivity. With $\gamma = 650$ for ^{8}B/^{8}Li and $\gamma = 575$ for ^{18}Ne/^{6}He and total luminosity corresponding to $5 \times (1.1 \times 10^{19})$ and $5 \times (2.9 \times 10^{19})$ useful ion decays in neutrino and antineutrino modes respectively, we find that the two-detector set-up can probe maximal CP violation and establish the neutrino mass ordering if $\sin^2 2\theta_{13}$ is 1.8×10^{-5} and 4.6×10^{-5}, respectively, or more. The sensitivity reach for $\sin^2 2\theta_{13}$ itself is 5.3×10^{-5}. CP violation can be discovered for 64% of the possible δ_{CP} values for $\sin^2 2\theta_{13} \geq 8 \times 10^{-5}$.

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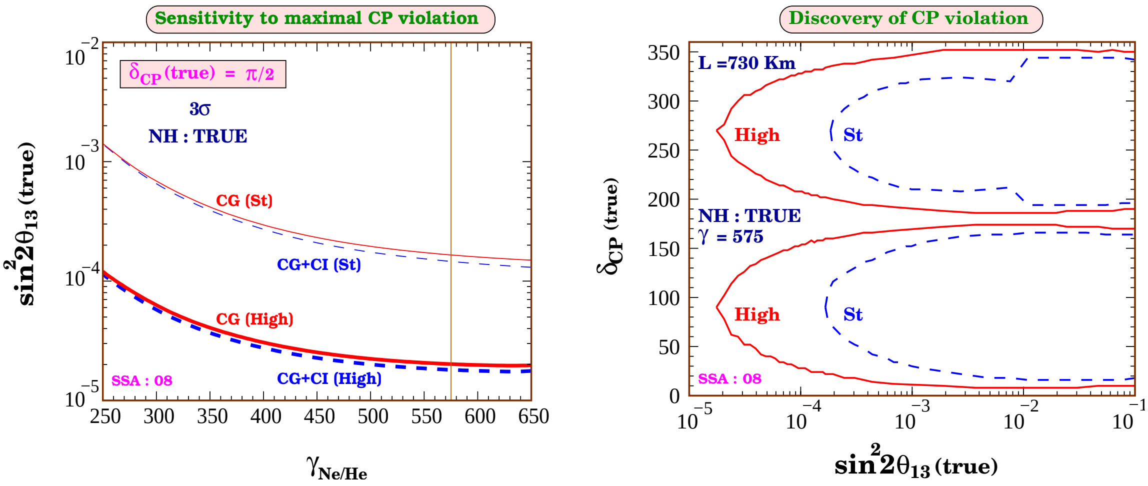

Figure 1: Left panel shows the 3σ $\sin^2 2\theta_{13}$(true) reach for sensitivity to "maximal CP violation". The red solid curves (marked as 'CG') are for the CERN-TASD@LNGS alone while the blue dashed lines (marked as 'CG+CI') are for the combined data from CERN-TASD@LNGS and CERN-ICAL@INO. The results are shown as a function of the Lorentz boost for ^{18}Ne and ^{6}He (taken same for both ions), for δ_{CP}(true) $= 90°$. Thick lines (marked "High") are for $5\times(1.1\times10^{19})$ useful ^{18}Ne and ^{8}B decays and $5\times(2.9\times10^{19})$ useful ^{6}He and ^{8}Li decays, while thin lines (marked "St") are for $5\times(1.1\times10^{18})$ and $5\times(2.9\times10^{18})$ useful ion decays respectively. In the right panel, the area enclosed by the curves represents the 3σ range of δ_{CP}(true) as a function of $\sin^2 2\theta_{13}$(true) for which the data can be used to rule out the CP-conserving scenario using the CERN-Gran Sasso reference TASD set-up with ^{18}Ne and ^{6}He as source ions.

We consider a two-baseline Beta-beam [1] set-up, one with $L = 7152$ km, the CERN-INO baseline [2], and another with $L = 730$ km which is the CERN-Gran Sasso (LNGS) distance. For the CERN-INO case ^{8}B and ^{8}Li are the preferred source ions and we take $\gamma = 650$. For the CERN-LNGS set-up, on the other hand, we choose the ^{18}Ne and ^{6}He ions and allow their γ to vary between 250-650. Since the ^{8}B and ^{8}Li ions would produce multi-GeV neutrino beams for $\gamma = 650$, we use a 50 kton iron calorimeter (ICAL) for the longer baseline at INO [3]. For the intermediate baseline option, since we are interested in the lower energy ^{18}Ne and ^{6}He ions, we assume a 50 kton Totally Active Scintillator Detector (TASD) in order to harness the low energy events required for better CP sensitivity. We present results for $5\times(1.1\times10^{19})$ and $5\times(2.9\times10^{19})$ useful ion decays in neutrino and antineutrino modes respectively for both baseline set-ups. We also show the projected sensitivity with one order less statistics.

The 3σ sensitivity to "maximal CP violation" is presented in Fig. 1. The two-baseline combined results for $sgn(\Delta m^2_{31})$ and $\sin^2 2\theta_{13}$ sensitivity reach have been depicted in Fig. 2.

In conclusion, we present Table 1 containing all the essential results.

References

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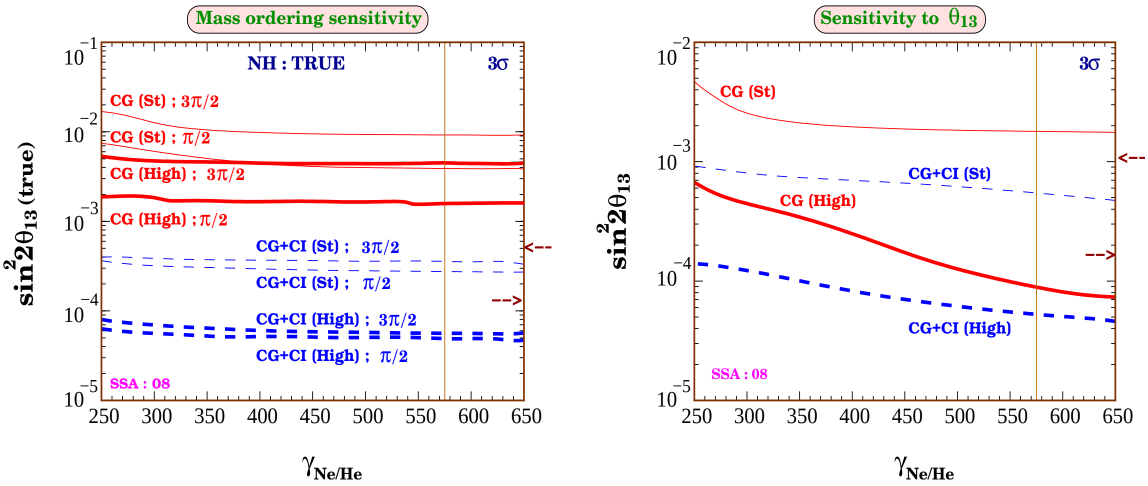

Figure 2: The left and right panels depict the $sgn(\Delta m^2_{31})$ sensitivity reach and the $\sin^2 2\theta_{13}$ sensitivity reach, respectively, at 3σ as a function of the boost factor for ^{18}Ne and ^{6}He. In both panels, the red solid lines are for CERN-TASD@LNGS alone while the blue dashed lines are for the combined data from CERN-ICAL@INO and CERN-TASD@LNGS. Results for $\delta_{CP}(\text{true}) = \pi/2$ and $3\pi/2$ are shown. Thick lines are for $5 \times (1.1 \times 10^{19})$ useful ^{18}Ne and ^{8}B decays and $5 \times (2.9 \times 10^{19})$ useful ^{6}He and ^{8}Li decays, while thin lines are for $5 \times (1.1 \times 10^{18})$ and $5 \times (2.9 \times 10^{18})$ useful ion decays respectively. The sensitivity reaches for the CERN-ICAL@INO set-up alone are indicated for both luminosities (for $\delta_{CP}(\text{true}) = 0$ in the left panel) by arrows on the right side of the panels. The location of $\gamma = 575$ is shown.

Set-up	$\sin^2 2\theta_{13}$ Discovery (3σ)	Mass Ordering (3σ)	Maximal CP violation (3σ)
CERN-INO ^{8}B+^{8}Li, $\gamma = 650$	9.5×10^{-5}	9.4×10^{-5}	Not possible
CERN-LNGS ^{18}Ne+^{6}He, $\gamma = 575$	2.07×10^{-5}	1.58×10^{-3}	1.97×10^{-5}
CERN-LNGS ^{18}Ne+^{6}He, $\gamma = 575$ + CERN-INO ^{8}B+^{8}Li, $\gamma = 650$	1.88×10^{-5}	4.64×10^{-5}	1.78×10^{-5}
Optimized Neutrino Factory	1.5×10^{-5}	1.5×10^{-5}	1.5×10^{-5}

Table 1: Results are shown for a five-year run with the luminosity 1.1×10^{19} (2.9×10^{19}) useful ion decays per year in the ν ($\overline{\nu}$) mode. The numbers correspond to $\delta_{CP}(\text{true}) = 90°$. For comparison, the expectations from an optimized two-baseline Neutrino Factory set-up with upgraded magnetized iron detectors are also listed [4, 5].

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