Sensitivity to 1–2 oscillation parameters with GeV neutrinos and their effects on δ_{CP} measurement

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Introduction

- Two current unknowns in neutrino oscillation physics - Neutrino mass ordering (MO) and the value of leptonic δ_{CP}.
- Dedicated accelerator long–baseline experiments to probe δ_{CP} → T2K, NOνA, DUNE etc.
- What about atmospheric neutrinos? → Sub–GeV atmospheric neutrino events to determine δ_{CP} irrespective of neutrino mass hierarchy. PRD 100, 115027 (2019).
- "What will be the influence of solar (1–2) parameters on δ_{CP} determination?

Hierarchy independence at sub-GeV energies

$$\overset{(-)}{P}{}^{vac}_{\alpha\beta} = \delta_{\alpha\beta} - 4\sum_{i>j} Re\left[U_{\alpha i}U^*_{\beta i}U^*_{\alpha j}U_{\beta j}\right]\sin^2\left(\frac{1.27\Delta m^2_{ij}L}{E}\right)$$

$$\pm 2\sum_{i>j} Im\left[U_{\alpha i}U^*_{\beta i}U^*_{\alpha j}U_{\beta j}\right]\sin\left(\frac{2.53\Delta m^2_{ij}L}{E}\right),$$

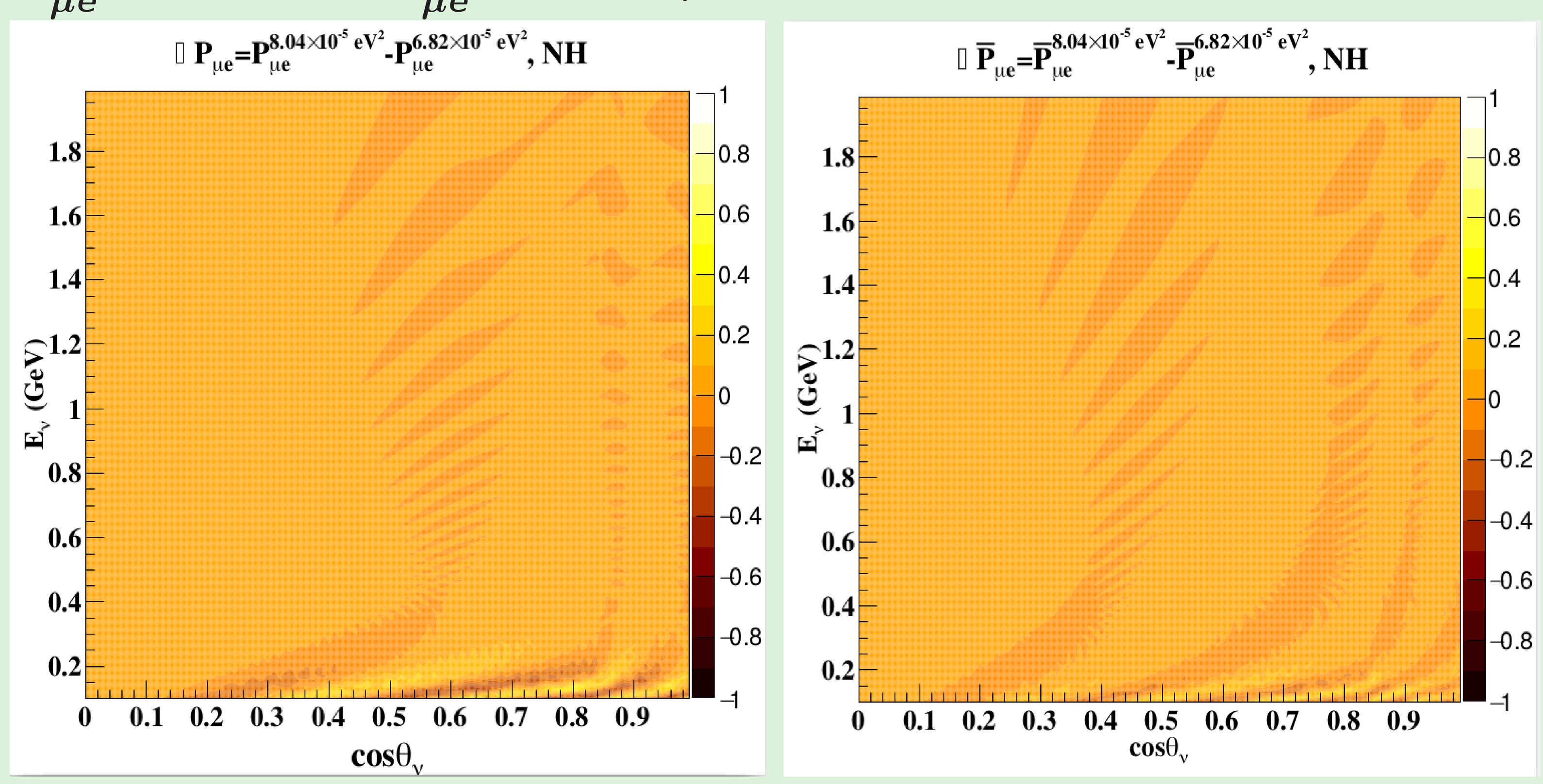
where $\alpha,\beta = e,\mu,\tau$; $i,j = 1,2,3$ and $\mp$ for $\overset{(-)}{\nu}$. $U_{\alpha i}$ are functions of θ_{ij}, Δm^2_{ij} = mass squared difference and δ_{CP}. L (in km) = distance travelled by a neutrino of energy E (in GeV).

When L/E is large compared to Δm^2_{ij}, the corresponding oscillatory terms average out when E is small $\sim$ a few 100 MeV.

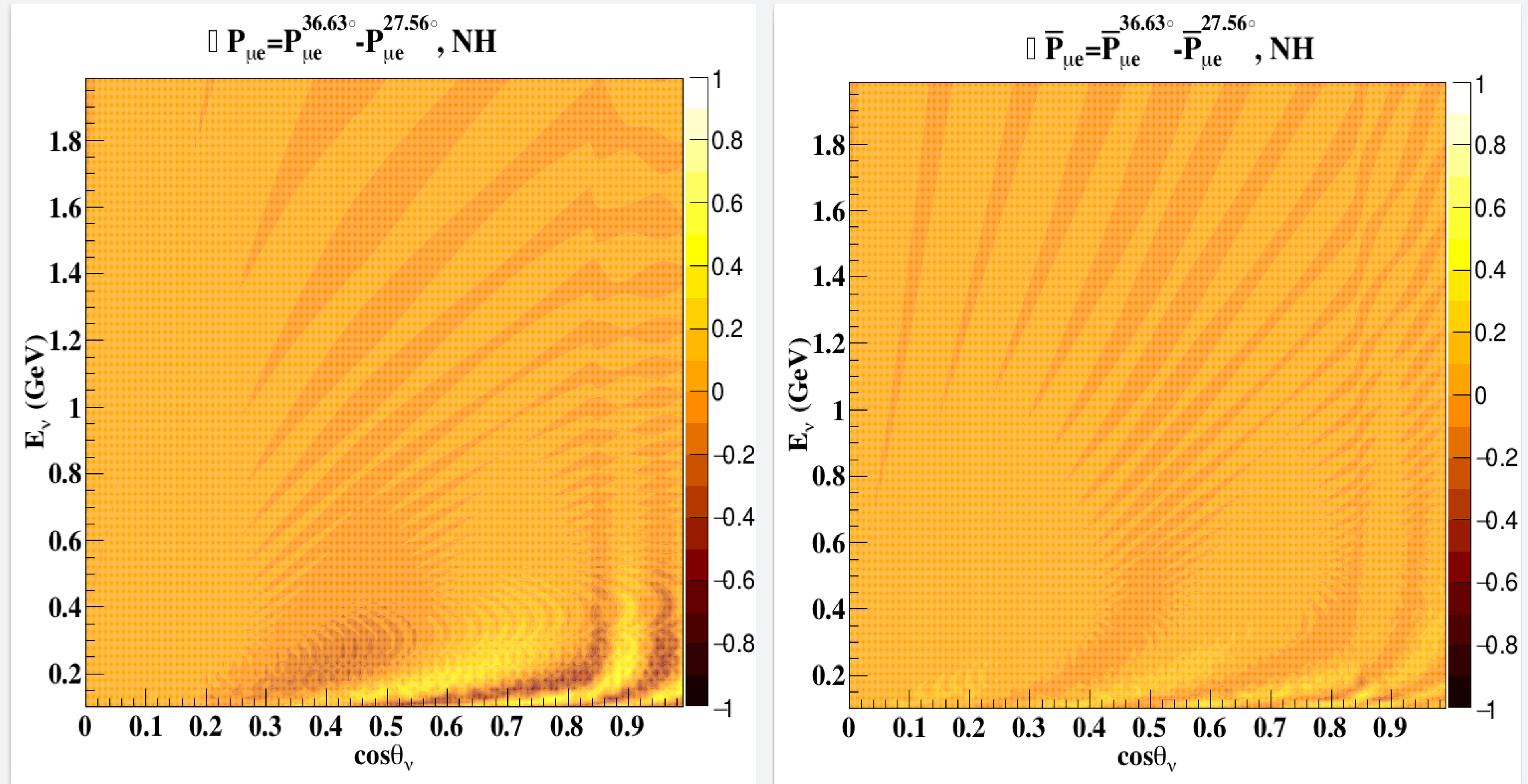
- "Atmospheric terms": Rapid oscillations and averaging out $1.27\Delta m^2_{3j}\frac{L}{E} \approx \pi\frac{(L/100\ \mathrm{km})}{(E/0.1\ \mathrm{GeV})}$ - Independent of $\Delta m^2_{32(1)}$ → Independent of the unknown hierarchy.
- "Solar Δm^2" remain: $1.27\Delta m^2_{21}\frac{L}{E} \approx \pi\frac{(L/3000\ \mathrm{km})}{(E/0.1\ \mathrm{GeV})}$ - but its magnitude and sign are well known.
- Values of $\theta_{13}, \Delta m^2_{21}$ change in matter, but the nature of the dependencies described remain.

Sensitivity to 1–2 parameters

$P^{8.04\times10^{-5}eV^2}_{\mu e} - P^{6.82\times10^{-5}eV^2}_{\mu e}$, NH



$P^{36.63circ}_{\mu e} - P^{27.56circ}_{\mu e}$, NH



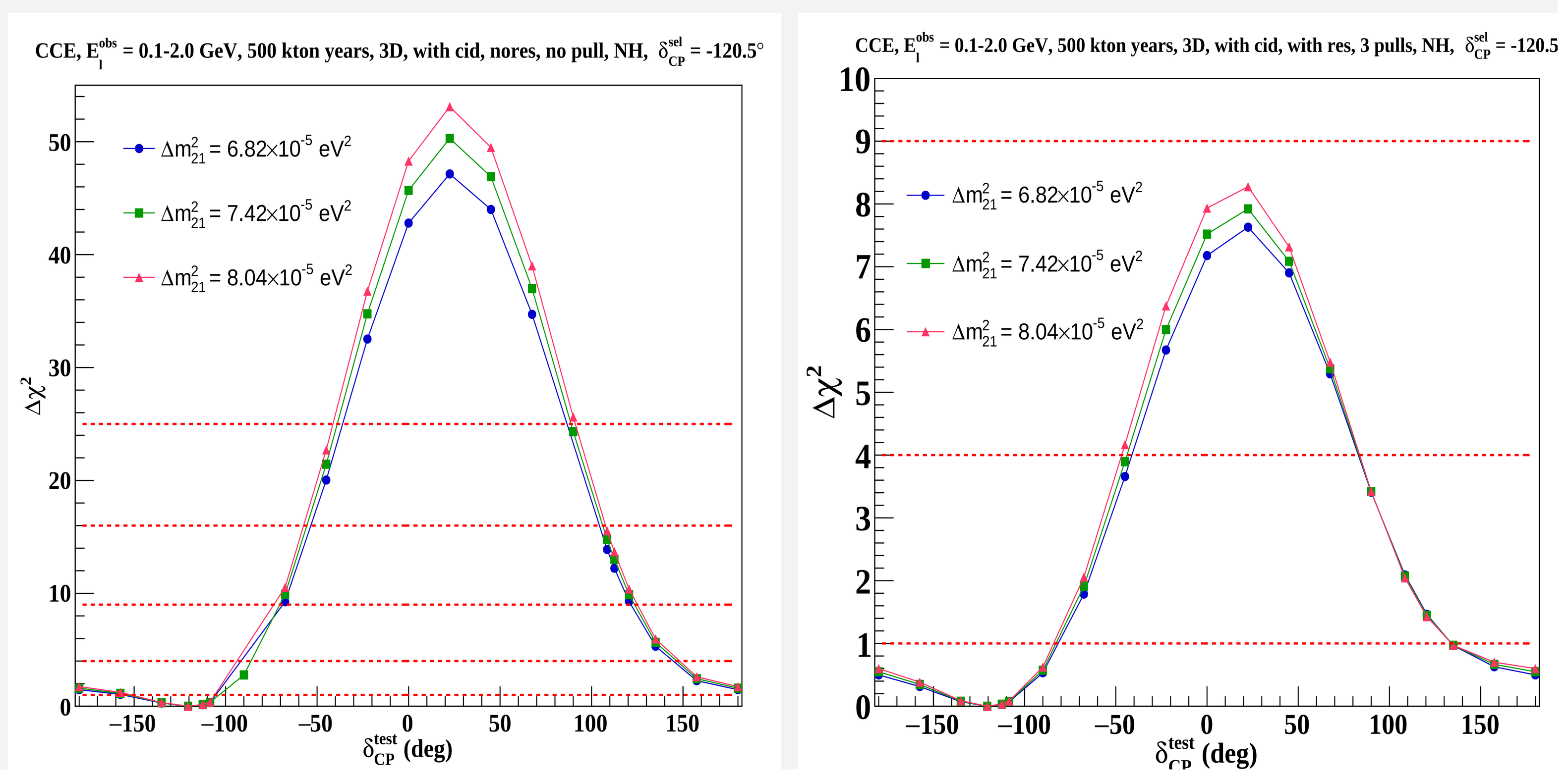
Number of charged current ν_e events

$$\mathcal{N}^e = t\times n_d \times \int d\sigma_{\nu_e}\times\left[P^m_{ee}\frac{d^2\Phi_e}{dE_\nu\, d\cos\theta_\nu} + P^m_{\mu e}\frac{d^2\Phi_\mu}{dE_\nu\, d\cos\theta_\nu}\right]$$

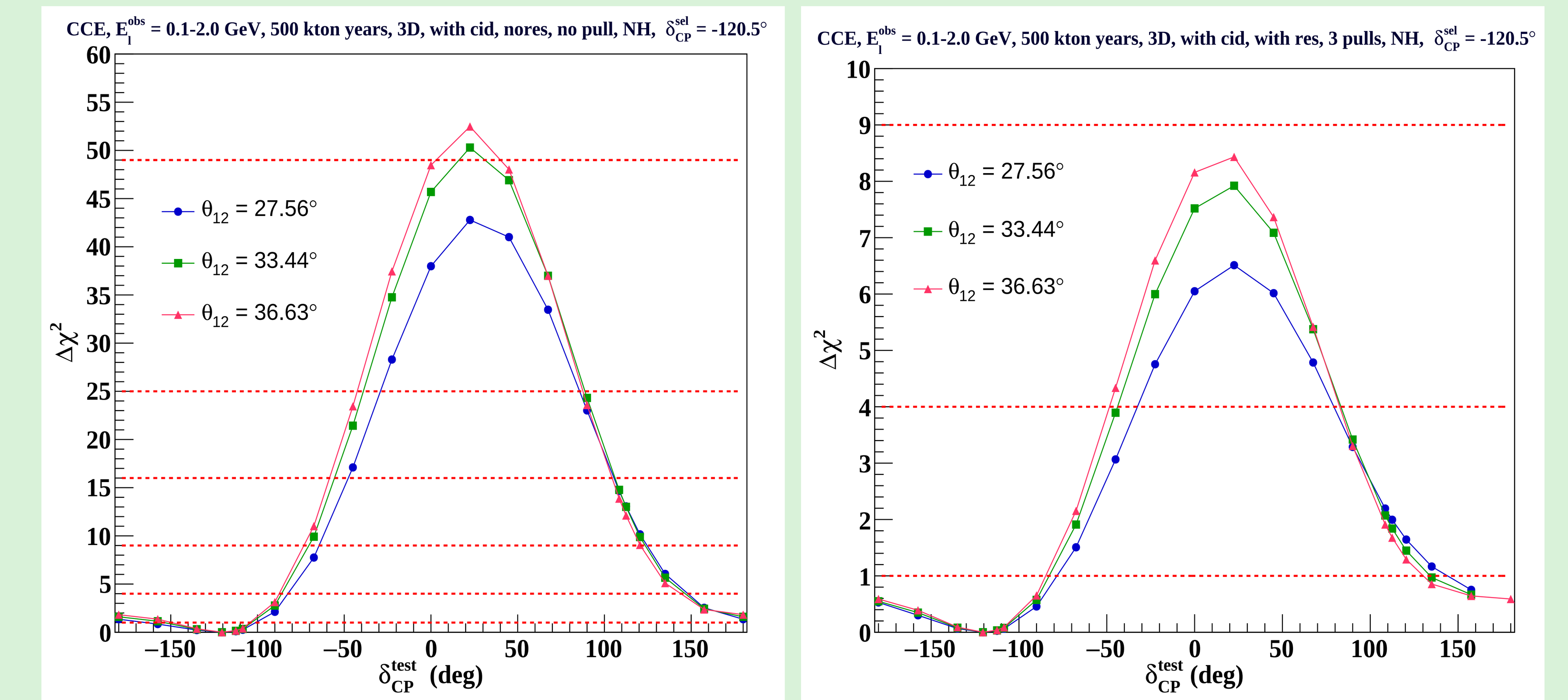
$P^m_{\alpha\beta}$ are the oscillation probabilities in Earth matter
t = exposure time (10 years here); n_d = number of targets i[n] the isoscalar detector (50 kton here)
$d\sigma_{\nu_e}$ = differential neutrino interaction cross section (differenti[al] in E_e and/or $\cos\theta_e$ respectively)
$d\Phi_{\nu_\mu}$ ($d\Phi_{\nu_e}$) = ν_μ (ν_e) fluxes.
Similarly for $\overline{\nu}_e$.

Central values of oscillation parameters	Specs of analysis
$\theta_{13} = 8.585°$ $\theta_{23} = 49.25°$ $\Delta m^2_{eff} = 2.4523\times10^{-3}\ \mathrm{eV}^2$ $\theta_{12} = 27.56,\ 33.44,\ 36.63°$ $\Delta m^2_{21} = 6.82,\ 7.42,\ 8.04)\times10^{-5}\ \mathrm{eV}^2$ $\delta_{CP} = -120.5°$	No fluctuation in theory Binning in $(E^{obs}_l, \cos\theta^{obs}_l, E'^{obs}_h)$ E^{obs}_l = [0.1, 2.0] GeV Perfect and smeared E_l resolutions $E_{res} = 2.5\%\sqrt{E}$ for $e^\pm$ ν_e and $\bar{\nu}_e$ separable Poisson χ2No pulls and 3 pulls (5% each on "tilt", flux normalizati[on] cross section; Poisson χ^2

Results: $\Delta m^2_{21} - \delta_{CP}$

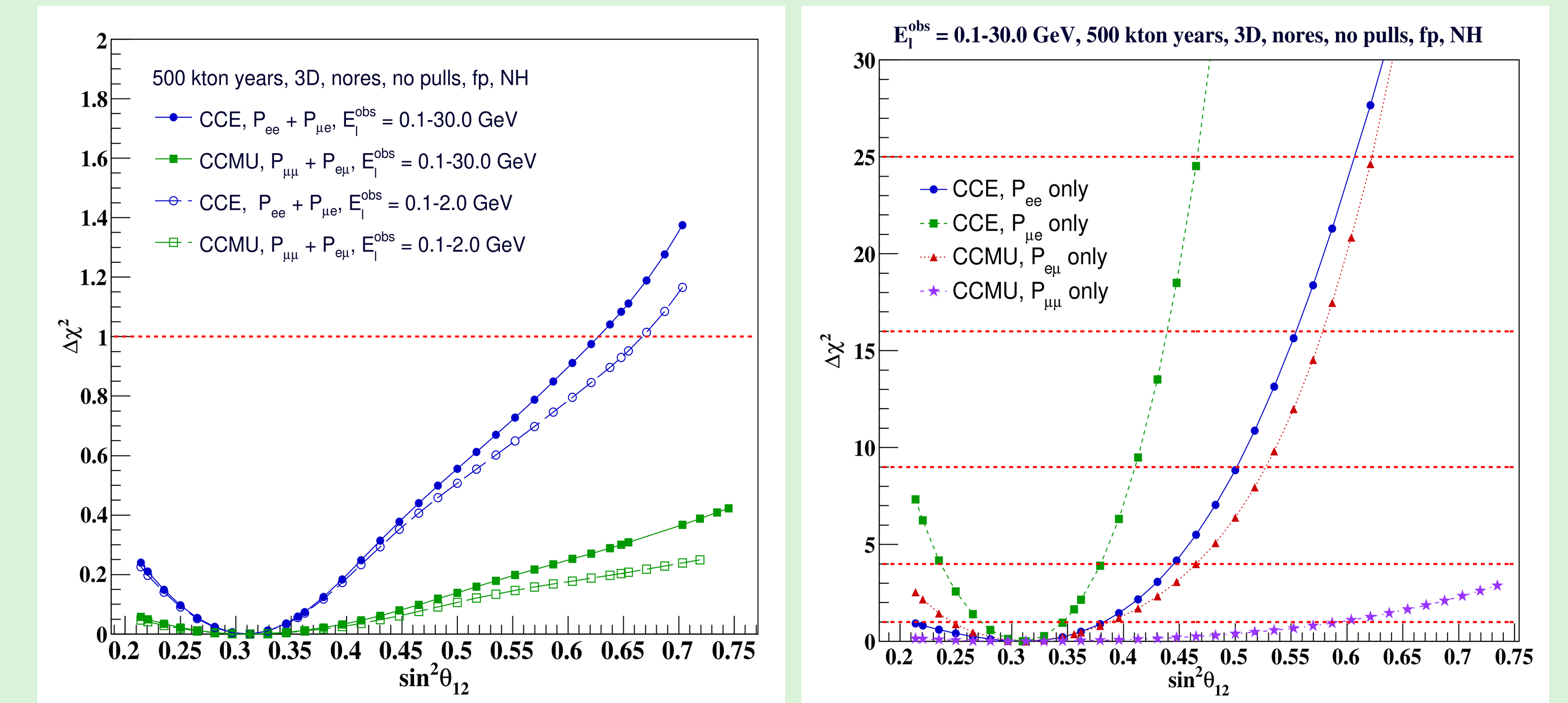


Results: $\theta_{12} - \delta_{CP}$



- Sensitivity to δ_{CP} decreases with decrease in θ_{12} and Δm^2_{21}.
- Effect of Δm^2_{21} on δ_{CP} sensitivity is not very significant, θ_{12} has a bit more effect than that, even with fixed parameters.
- In presence of marginalization the effect may be negligible.

θ_{12} sensitivity



- No significant sensitivity to θ_{12} from atmospheric $\nu_e + \bar{\nu}_e$ or $\nu_\mu + \bar{\nu}_\mu$ events.
- Contribution to ν_e (ν_μ) CC events from P^m_{ee} ($P^m_{\mu\mu}$) + $P_{\mu\,e}$ ($P_{e\mu}$).
- Individual channels except $\nu_\mu \to \nu_\mu$ have better sensitivity to θ_{12}. (Similarly for $\bar{\nu}$.)
- Possible types of experiments with GeV ν and $\bar{\nu}$ beams: β beams pure (ν_e or $\bar{\nu}_e$ beams), accelerator long base line (LBL) experiments ($\nu_\mu \to \nu_e$, $\bar{\nu}_\mu \to \bar{\nu}_e$).
- LBL with which E_ν, L_ν? ∼[0.1, 0.4] GeV and ∼ 4000–12000 km.

References

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