Atmospheric ν as a Probe of CPT Violation

(based on hep-ph/0312027)

Poonam Mehta

Department of Physics and Astrophysics, University of Delhi, India
work done with **A. Datta, R. Gandhi and S. Uma Sankar**

Abstract . . .

We show that atmospheric neutrinos can provide a sensitive and robust probe of CPT violation (CPTV). We study the variations of the ratio of total muon to antimuon survival rates with L/E and L and demonstrate that the charge discrimination capability of such a detector when coupled with the broad L and E range which characterizes the atmospheric neutrino spectrum provides a method of both detecting the presence of such violations and putting bounds on them.

CP, T & CPT in ν oscillations . . .

- ν oscillations are sensitive to violation of discrete symmetries :

$$\begin{tikzcd}
P(\nu_\alpha \longrightarrow \nu_\beta) \arrow[r, leftrightarrow, dashed, "CP"] \arrow[d, leftrightarrow, dashed, "T"'] \arrow[dr, leftrightarrow, dashed, "CPT"'] & P(\bar{\nu}_\alpha \longrightarrow \bar{\nu}_\beta) \arrow[d, leftrightarrow, dashed, "T"] \\
P(\nu_\beta \longrightarrow \nu_\alpha) \arrow[r, leftrightarrow, dashed, "CP"'] & P(\bar{\nu}_\beta \longrightarrow \bar{\nu}_\alpha)
\end{tikzcd}$$

CPTV in neutrino interactions . . .

- DISPERSION RELATION for ultrarelativistic neutrinos,

$$A = \frac{m^2}{2p} + b$$

Coleman & Glashow, PRD 59, 116008 (1999); Pakvasa, hep-ph/0110175

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$$\mathcal{L}_{eff} = \bar{\nu}^{\alpha}_{L} b^{\mu}_{\alpha\beta} \gamma_{\mu} \nu^{\beta}_{L}$$

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- $m^2 \equiv mm^{\dagger}$

Survival Probability . . .

➢ For simple 2f case :

$$P_{\alpha\alpha}(L) = 1 - \sin^2 2\theta \, \sin^2\left[\left(\frac{\delta m^2}{4E} \overset{\nu/\bar{\nu}}{\pm} \frac{\delta b}{2} \pm \frac{\delta c \; E}{2}\right) L\right]$$

➢ Probability Difference : $\Delta P^{CPT}_{\alpha\alpha} = P_{\alpha\alpha} - P_{\bar{\alpha}\bar{\alpha}}$

$$\Delta P^{CPT}_{\alpha\alpha} = - \sin^2 2\theta \, \sin\left(\frac{\delta m^2 L}{2E}\right) \, \sin(\delta b \; L + \delta c \; E \; L)$$

- Observable CPTV in 2f case ⇨

consequence of interference of the CPT-EVEN AND CPT-ODD terms

- Compare $\nu_\mu \to \nu_\mu$ vs $\bar{\nu}_\mu \to \bar{\nu}_\mu$

CPT ODD oscillation argument ➜ L

CPT EVEN oscillation argument ➜ L/E

- Look at Ratio of muon to anti-muon events :

$N(\nu_\mu \to \nu_\mu)/N(\bar{\nu}_\mu \to \bar{\nu}_\mu)$ vs L, L/E

- Look at Ratio of Up by Down events :

$\mathrm{Up/Down}$ vs L/E

Event rate . . .

- The number of muon events :

$$N = N_n \times M_d \int \sigma^{CC}_{\nu_\mu - N} \, P(\nu_\mu \rightarrow \nu_\mu) \, \frac{dN_\nu}{dE_\nu} \, dE_\nu$$

- $N_n = 6.023 \times 10^{32}$
- $M_d \longrightarrow$ detector mass (in kT)
- For E $>$ 1.8 GeV ➢ $\sigma^{CC}_{\nu_\mu - N} \longrightarrow$ DIS X-section
- For E $<$ 1.8 GeV ➢ $\sigma^{CC}_{\nu_\mu - N} \longrightarrow$ QE X-section
- Bartol Atmospheric flux is used.
- Muon detection threshold, E_{th} = 1-3 GeV .

- Resolution in L/E ➪

$$R(\delta m^2, L/E) = \exp(-0.25 \, \delta m^2 L/E)$$

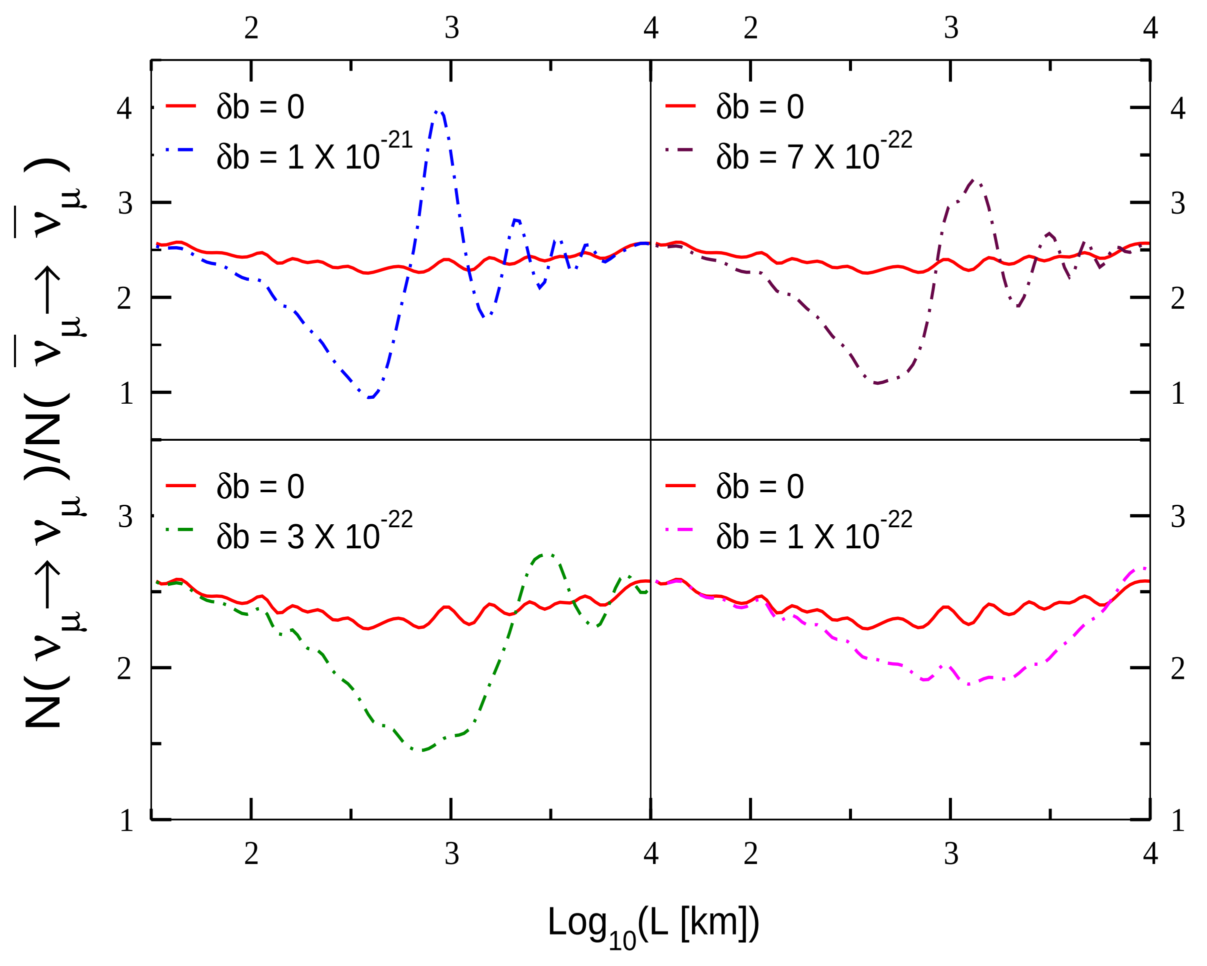
MONOLITH proposal,
http://castore.mi.infn.it/∼monolith

- Survival Probability gets modified ➪

$$P_{\alpha\alpha}(L) = 1 - \frac{1}{2} \sin^2 2\theta \left[1 - R \cos 2\hat{\phi} L \right]$$

where, $\hat{\phi} = \left(\frac{\delta m^2}{4E} \pm \frac{\delta b}{2} \pm \frac{\delta c \, E}{2} \right)$

Results for δb . . .



- 2f Parameters :

Δm^2_{31} = 2.0×10^{-3}eV^2

$\sin^2\theta_{23}$ = 1.0

Fogli et. al., hep-ph/0308055

- Nodes :

$$\sin(\delta b L) = 0$$

$$L(km) = n\pi/\delta b(GeV)$$

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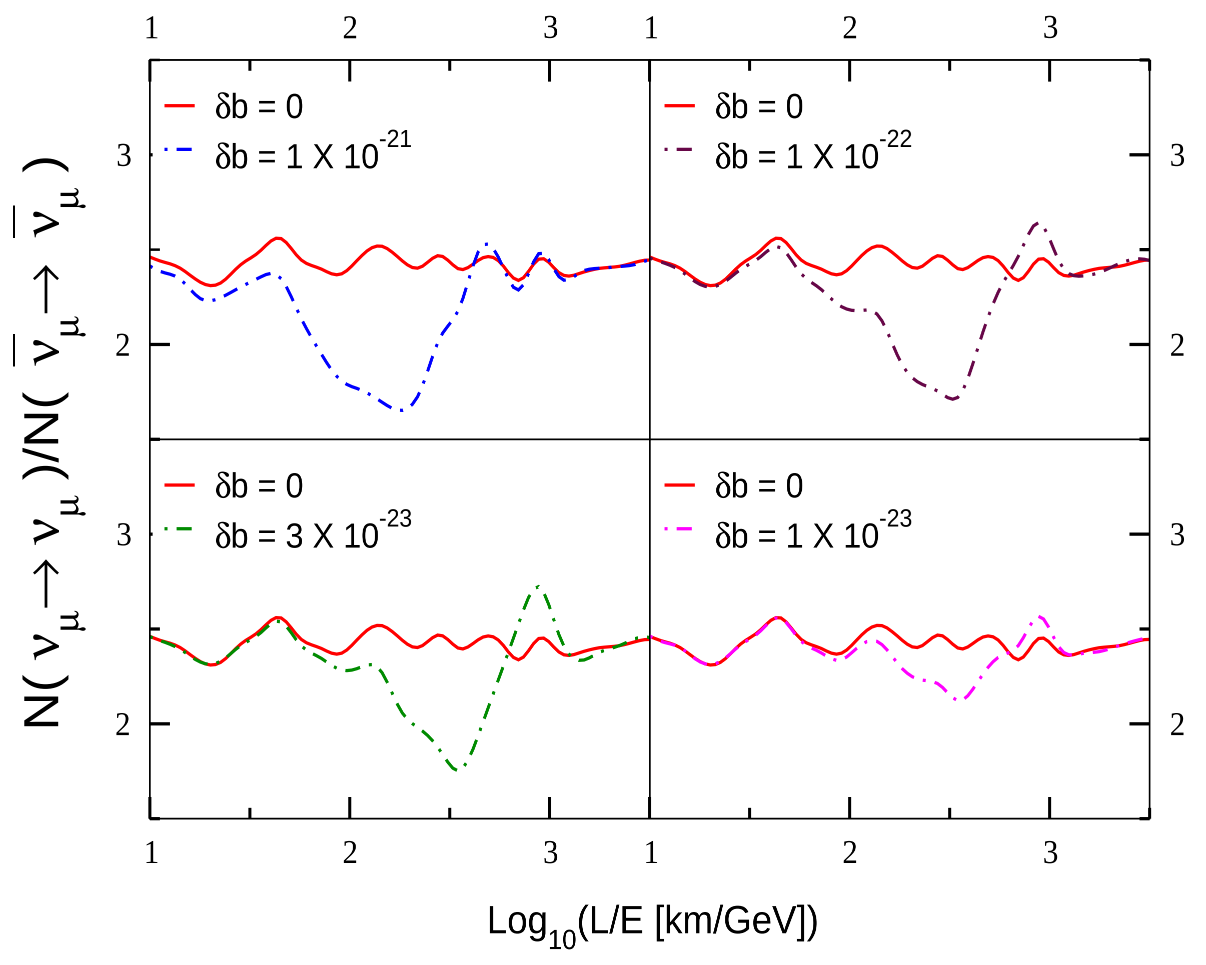

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Common Node

Comparing bounds on CPTV . . .

- NF bounds on δb ➪

$\delta b > 3 \times 10^{-23}$ GeV

V. Barger *et. al.*, PRL 85, 5055 (2000)

- Our bounds on δb ➪

➜ The L/E dependance of ratio of muon to anti-muon events shows sensitivity to the presence of CPTV for

$\delta b > 3 \times 10^{-23}$ GeV

➜ The L dependance of the ratio of muon to anti-muon events is sensitive to detecting both the presence and magnitude of CPTV for

$\delta b > 3 \times 10^{-22}$ GeV

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vs L, L/E for $\delta b > 3 \times 10^{-23} GeV$.

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- **Up/Down** rates provide additional handles on these violations.