Some constraints on new physics by atmospheric neutrinos

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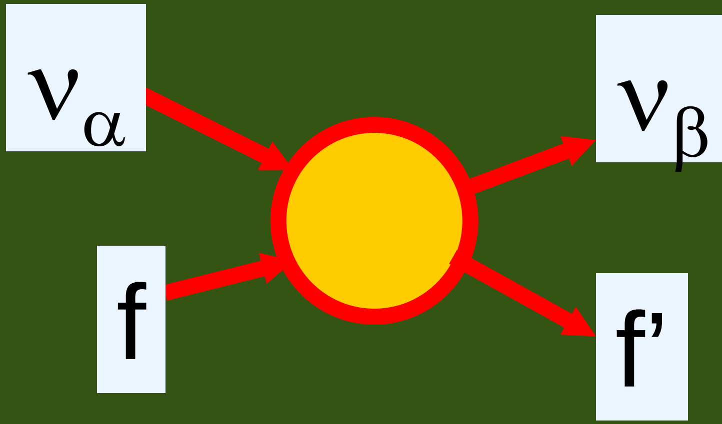
1. Motivation for research on New Physics

Just like at B factories, high precision measurements of ν oscillation in future experiments can be used also to probe physics beyond SM by looking at deviation from SM+massive ν. → Research on New Physics is important.

Here I consider phenomenologically New Physics which is described by 4-fermi exotic interactions:

$$\mathcal{L}_{eff} = G_{NP}^{\alpha\beta}\,\bar{\nu}_\alpha\gamma^\mu\nu_\beta\,\bar{f}\gamma_\mu f'$$

I discuss analytically possible current bounds on NP by the HE atmospheric neutrino data which is complementary to other current experimental data.



neutral current non-standard interaction

● NP in propagation (NP matter effect)

$$i\frac{d}{dt}\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \left[U\,\mathrm{diag}\,(E_1, E_2, E_3)\,U^{-1} + A\begin{pmatrix}1+\epsilon_{ee} & \epsilon_{e\mu} & \epsilon_{e\tau}\\ \epsilon_{\mu e} & \epsilon_{\mu\mu} & \epsilon_{\mu\tau}\\ \epsilon_{\tau e} & \epsilon_{\tau\mu} & \epsilon_{\tau\tau}\end{pmatrix}\right]\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix}$$

NP

$A \equiv \sqrt{2}G_F N_e$ $\quad N_e \equiv$ electron density

● Constraints on $\varepsilon_{\alpha\beta}$

Davidson et al., JHEP 0303:011,2003; Berezhiani, Rossi, PLB535 ('02) 207; Barranco et al., PRD73 ('06) 113001; Barranco et al., arXiv:0711.0698

Biggio et al., JHEP 0908, 090 (2009) w/o 1-loop arguments

related to each other by ν_{atm}

improved by ν_{atm}

$$\begin{pmatrix}|\epsilon_{ee}| \lesssim 4\times 10^0 & |\epsilon_{e\mu}| \lesssim 3\times 10^{-1} & |\epsilon_{e\tau}| \lesssim 3\times 10^0\\ & |\epsilon_{\mu\mu}| \lesssim 7\times 10^{-2} & |\epsilon_{\mu\tau}| \lesssim 3\times 10^{-1}\\ & & |\epsilon_{\tau\tau}| \lesssim 2\times 10^{1}\end{pmatrix}$$

2. High energy behavior of ν_{atm} data

- **Standard case with N_ν=2**

$$1 - P(\nu_\mu \to \nu_\mu) \sim \sin^2 2\theta_{\rm atm} \sin^2 \left(\frac{\Delta m^2_{\rm atm} L}{4E} \right) \propto \frac{1}{E^2}$$

- **Standard case with N_ν=3**

$$1 - P(\nu_\mu \to \nu_\mu) \ \sim \ \left(\frac{\Delta m^2_{31}}{2AE} \right)^2 \left[\sin^2 2\theta_{23} \left(\frac{c^2_{13} AL}{2} \right)^2 + s^2_{23} \sin^2 2\theta_{13} \sin^2 \left(\frac{AL}{2} \right) \right]$$

- **Deviation of 1-P($\nu_\mu \to \nu_\mu$) due to NP contradicts with data**

$$1 - P(\nu_\mu \to \nu_\mu) \ \simeq \ c_0 + \frac{c_1}{E} + \frac{c_{20} L^2 + c_{21} \sin^2(c_{22} L)}{E^2}$$

→ **High ν_{atm} data gives constraints on NP:**

$|c_0| \ll 1, \ |c_1| \ll 1$

O(1)

$$1 - P(\nu_\mu \to \nu_\mu) \simeq c_0 + \frac{c_1}{E} + \frac{c_{20}L^2 + c_{21}\sin^2(c_{22}L)}{E^2}$$

$$c_0 \simeq 4\tilde{X}_1^{\mu\mu}\tilde{X}_2^{\mu\mu}\sin^2\left(\frac{\Delta\tilde{E}_{21}L}{2}\right) + 4\tilde{X}_3^{\mu\mu}\sin^2\left(\frac{(1+\epsilon_{ee}+\epsilon_{\tau\tau})AL}{2}\right)$$

$$4\tilde{X}_1^{\mu\mu}\tilde{X}_2^{\mu\mu} \simeq 1 - \frac{1+\epsilon_{ee}+\epsilon_{\tau\tau}}{(1+\epsilon_{ee})|\epsilon_{\mu\tau}|^2 + \epsilon_{\tau\tau}|\epsilon_{e\mu}|^2 - 2\mathrm{Re}(\epsilon_{e\mu}\epsilon_{\mu\tau}(\epsilon_{e\tau})^*)}\left(\frac{|\epsilon_{e\mu}|^2+|\epsilon_{\mu\mu}|^2+|\epsilon_{\mu\tau}|^2}{1+\epsilon_{ee}+\epsilon_{\tau\tau}} - \epsilon_{\mu\mu}\right)^2$$

$$4\tilde{X}_3^{\mu\mu} \simeq 4\frac{|\epsilon_{e\mu}|^2+|\epsilon_{\mu\mu}|^2+|\epsilon_{\mu\tau}|^2}{(1+\epsilon_{ee}+\epsilon_{\tau\tau})^2} - 4\frac{(1+\epsilon_{ee})|\epsilon_{\mu\tau}|^2 + \epsilon_{\tau\tau}|\epsilon_{e\mu}|^2 - 2\mathrm{Re}(\epsilon_{e\mu}\epsilon_{\mu\tau}(\epsilon_{e\tau})^*)}{(1+\epsilon_{ee}+\epsilon_{\tau\tau})^3}$$

$$\Delta\tilde{E}_{21} \simeq 2A\left[\frac{(1+\epsilon_{ee})|\epsilon_{\mu\tau}|^2 + \epsilon_{\tau\tau}|\epsilon_{e\mu}|^2 - 2\mathrm{Re}(\epsilon_{e\mu}\epsilon_{\mu\tau}(\epsilon_{e\tau})^*)}{1+\epsilon_{ee}+\epsilon_{\tau\tau}}\right]$$

→ $|\varepsilon_{e\mu}| \ll 1$, $|\varepsilon_{\mu\mu}| \ll 1$, $|\varepsilon_{\mu\tau}| \ll 1$

$|\varepsilon_{\mu\tau}| \ll 1$: Already shown by Fornengo et al. PRD65, 013010, '02

$|\varepsilon_{\mu\mu}| \ll 1$: Already shown by Davidson et al. JHEP 0303:011, '03

$|\varepsilon_{e\mu}| \ll 1$: New observation

O(1/E)

$$1 - P(\nu_\mu \to \nu_\mu) \simeq c_0 + \frac{c_1}{E} + \frac{c_{20}L^2 + c_{21}\sin^2(c_{22}L)}{E^2}$$

$$\frac{c_1}{E} \simeq -2s_{23}^2(\epsilon_{ee}+\epsilon_{\tau\tau})(1+\epsilon_{ee}+\epsilon_{\tau\tau})A\zeta\frac{\Delta m_{31}^2}{E}\sin^2\left[\frac{A\zeta}{2(1+\epsilon_{ee}+\epsilon_{\tau\tau})}\right]$$

$$\zeta \equiv \epsilon_{\tau\tau} - |\epsilon_{e\tau}|^2/(1+\epsilon_{ee})$$

$\rightarrow \quad |\, \varepsilon_{\tau\tau} - |\varepsilon_{e\tau}|^2/(1+\varepsilon_{ee}) \,| << 1$

Already shown by Friedland-Lunardini, PRD72:053009,'05

To summarize

$$A\begin{pmatrix} 1+\epsilon_{ee} & \epsilon_{e\mu} & \epsilon_{e\tau} \\ \epsilon_{\mu e} & \epsilon_{\mu\mu} & \epsilon_{\mu\tau} \\ \epsilon_{\tau e} & \epsilon_{\tau\mu} & \epsilon_{\tau\tau} \end{pmatrix} \Rightarrow A\begin{pmatrix} 1+\epsilon_{ee} & 0 & \epsilon_{e\tau} \\ 0 & 0 & 0 \\ \epsilon_{e\tau}^* & 0 & |\epsilon_{e\tau}|^2/(1+\epsilon_{ee}) \end{pmatrix}$$

3.Conclusions

- From the analytical form of the oscillation probability for high energy ν_{atm} it is expected that

  $|\varepsilon_{e\mu}| \ll 1$, $|\varepsilon_{\mu\mu}| \ll 1$, $|\varepsilon_{\mu\tau}| \ll 1$,

  $|\varepsilon_{\tau\tau} - |\varepsilon_{e\tau}|^2/(1+\varepsilon_{ee})| \ll 1$.

  Although the 1st one has to be checked by explicit numerical calculations, it presumably gives a bound stronger than the present ones.

- Deviation of $1-P(\nu_\mu \to \nu_\mu)$ from the standard case in high energy ν_{atm} data may give strong constraints on New Physics.

- **It would be great if we can determine the coefficients c_{2j} (j=0,1,2) in high energy ν_{atm} data:**

$$1 - P(\nu_\mu \to \nu_\mu) \simeq \frac{c_{20} L^2 + c_{21} \sin^2(c_{22} L)}{E^2}$$

It is possible at SK, IceCube, HK?

cf. Standard case with N_ν=3

$$1 - P(\nu_\mu \to \nu_\mu) \sim \left(\frac{\Delta m^2_{31}}{2AE}\right)^2 \left[\sin^2 2\theta_{23} \left(\frac{c^2_{13} AL}{2}\right)^2 + s^2_{23} \sin^2 2\theta_{13} \sin^2\left(\frac{AL}{2}\right)\right]$$