# Signatures of sterile $\nu$ mixing in high energy cosmic $\nu$ flux

Osamu Yasuda
Tokyo Metropolitan University

Work in collaboration with
Andrea Donini
IFT, Madrid (UAM/CSIC)

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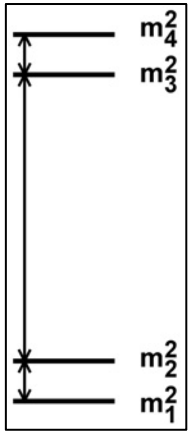
# 1. Four flavor $\nu$ oscillation

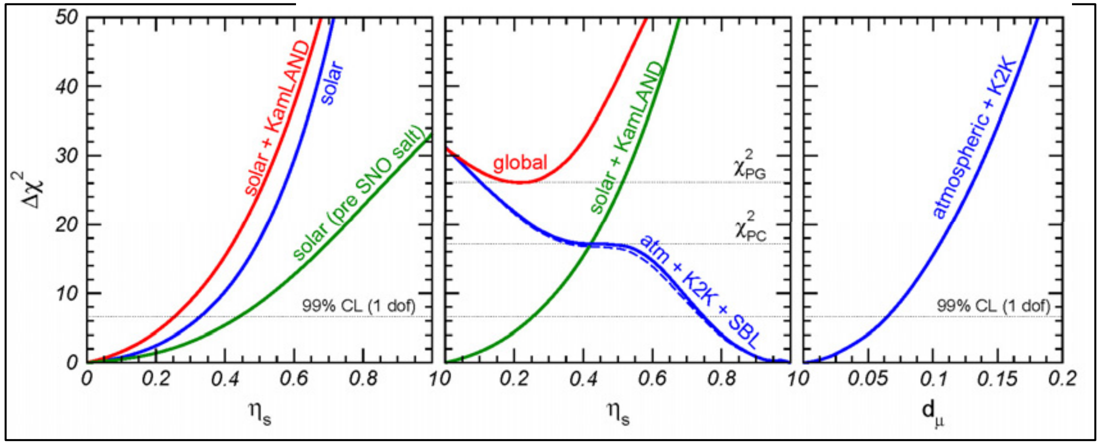
## 1.1 Schemes with LSND

### (1) (2+2)-scheme

**excluded (~4.9 $\sigma$ ) because it contradicts with $\nu_{atm}$ or $\nu_{solar}$**



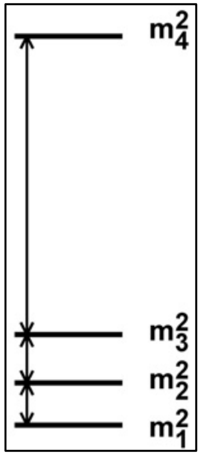

**Maltoni et al, hep-ph/0405172**

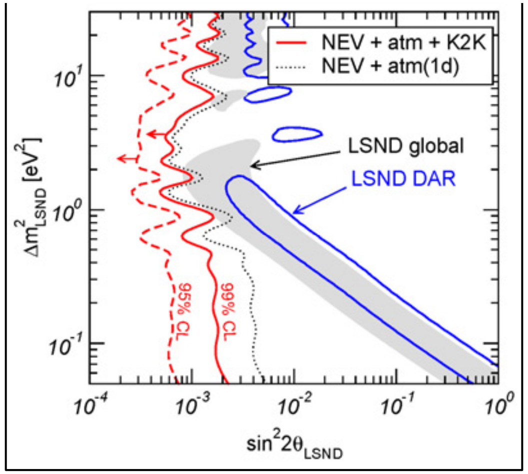



### (2) (3+1)-scheme

**Maltoni et al, hep-ph/0405172**

**Strongly disfavored (~3.2 $\sigma$ L) because of the tension between LSND and Bugey+CDHSW (+other negative results)**



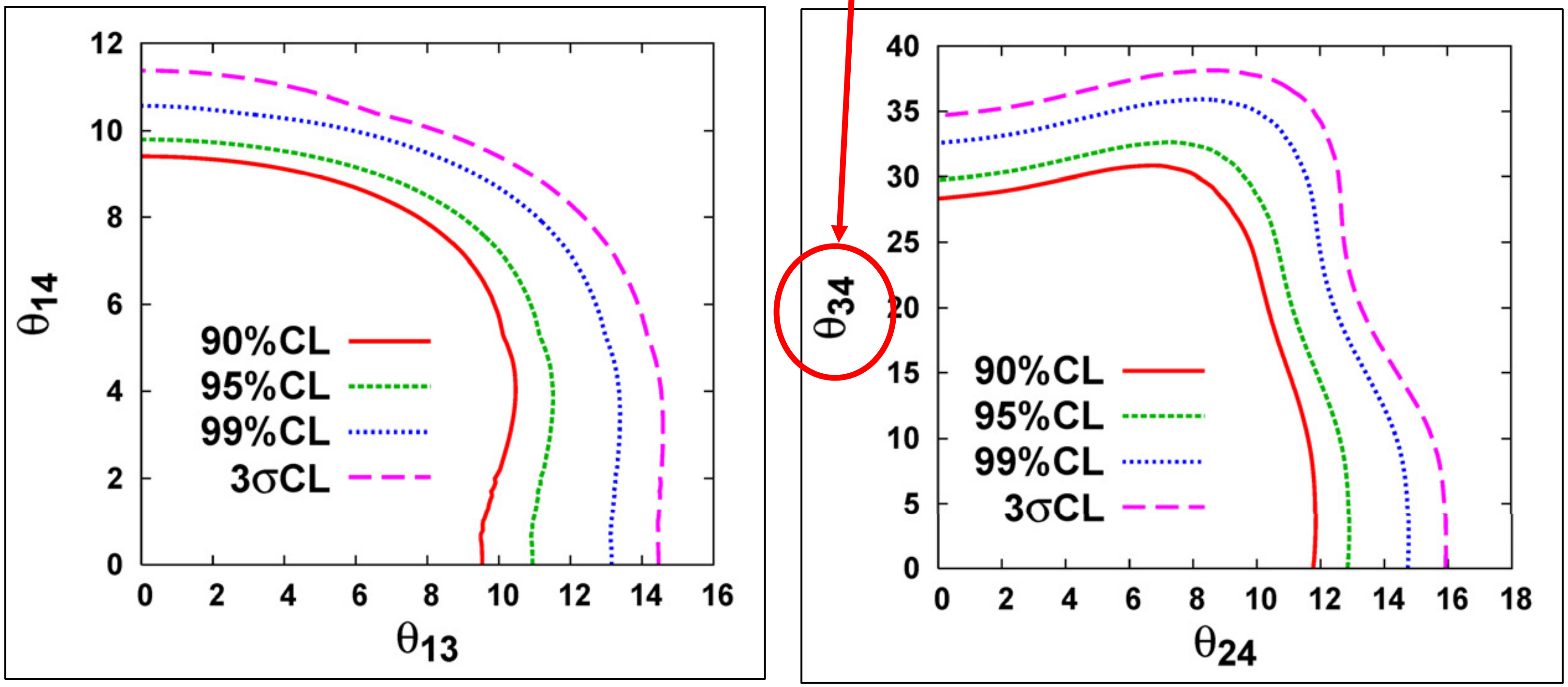
# 1.2 (3+1)-scheme without LSND

**Donini-Maltoni-Meloni-Migliozzi-Terranova**
**arXiv:0704.0388v2**

$$U = R_{34}(\theta_{34})\ R_{24}(\theta_{24})\ R_{23}(\theta_{23},\ \delta_3)\ R_{14}(\theta_{14})\ R_{13}(\theta_{13},\ \delta_2)\ R_{12}(\theta_{12},\ \delta_1)$$

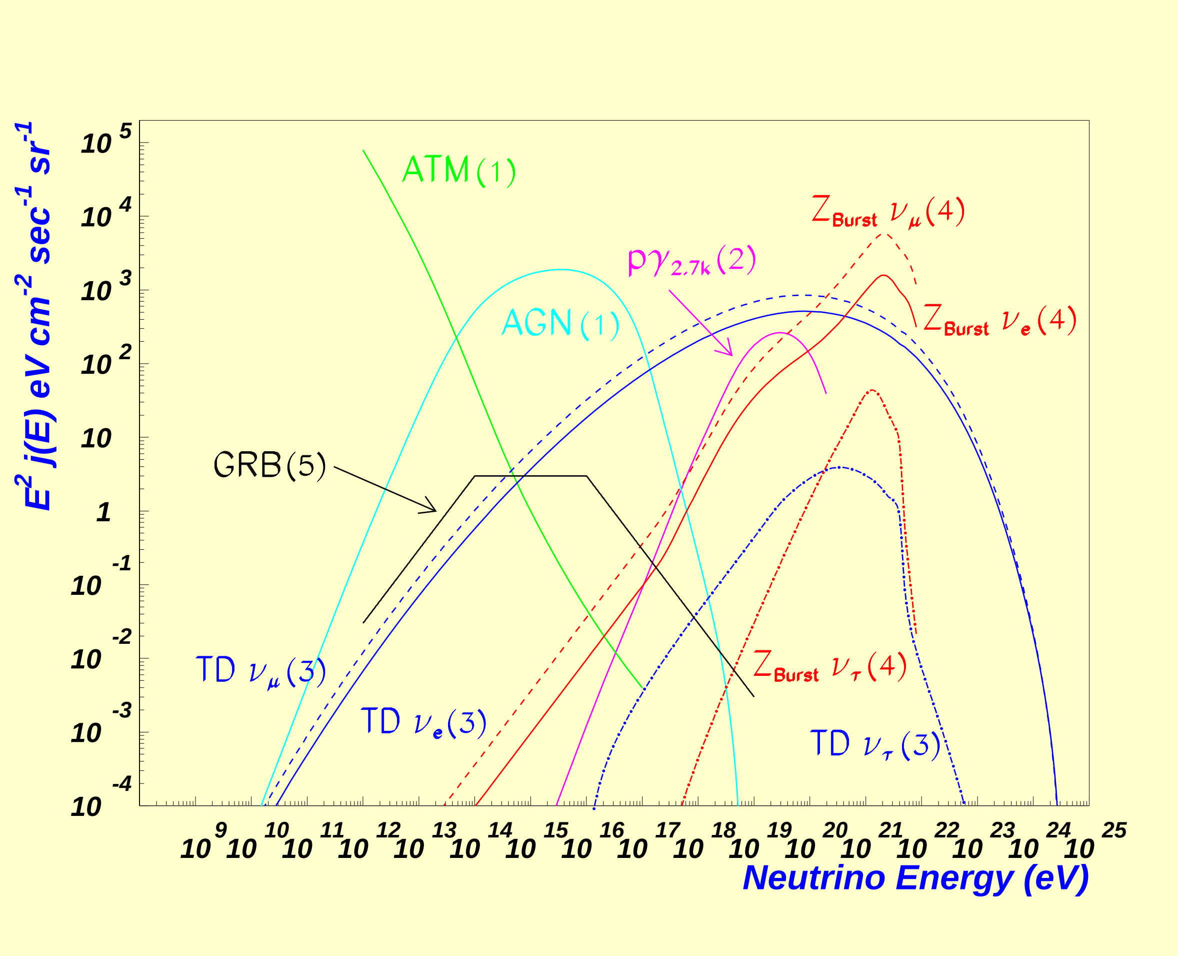
**Constraints by all the negative results give the allowed region**

$\theta_{34}$ **: could be relatively large**



# 2. Effects of ν oscillation on high energy cosmic ν

## 2.1 Flux of high energy cosmic ν




- Active Galactic Nuclei (AGN) & Gamma Ray Burst (GRB) are speculated to produce high energy ν
- E>1TeV: small BG from $\nu_{atm}$

# 2.2 Flavor ratio of ν flux for $N_\nu$ =3

Learned, Pakvasa '95

## In standard $N_\nu$=3, when L→∞

- **Oscillation for L→∞ :**

$$P(\nu_\alpha \to \nu_\beta) \cong \sum_j |U_{\alpha j}|^2 |U_{\beta j}|^2$$

**CHOOZ+ $\nu_{atm}$ : $|\theta_{13}| \ll 1$**

**$\nu_{atm}$ : $|\pi/4 - \theta_{23}| \ll 1$**

- **Initial flux:**

**Just like in $\nu_{atm}$ , the source of ν is π decay**

$$F^0(\nu_e):F^0(\nu_\mu):F^0(\nu_\tau) \cong 1:2:0$$

- **Observed flux:**

$$F(\nu_e):F(\nu_\mu):F(\nu_\tau) \cong 1:1:1$$

# 2.3 Triangle representation of flux

**Athar-Jezabek-OY '00**

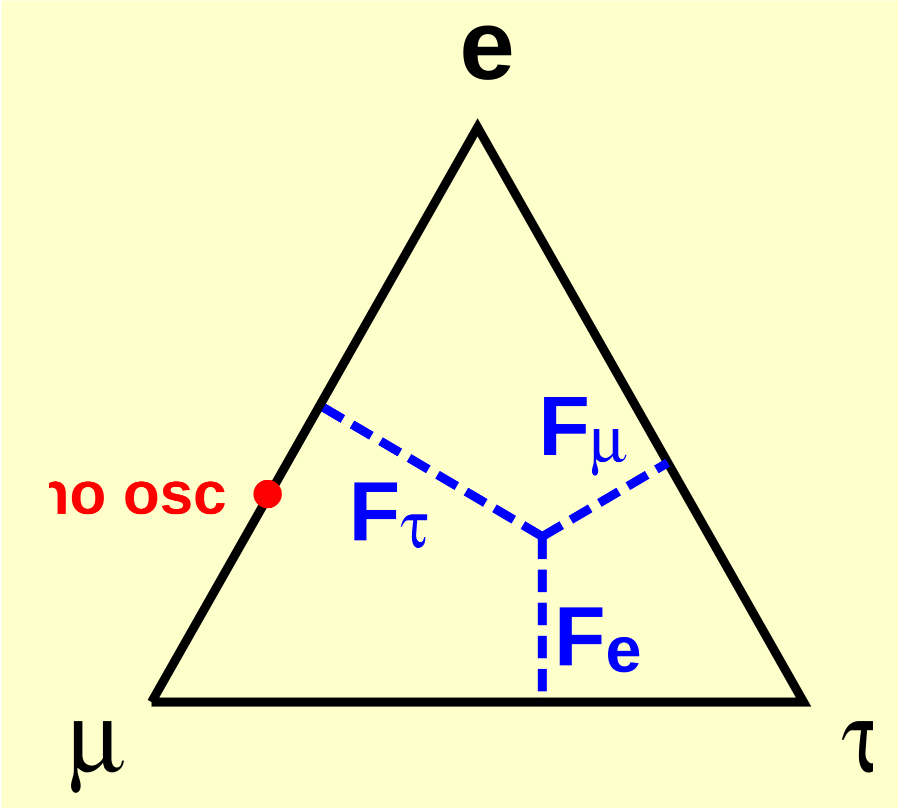
**Precise normalization is not known**

→ **The ratio of different flavors is important quantity to observe**

● **The case for sterile ν**

**The normalized ratio of active flavors is useful:**

$$\widetilde{F}(\nu_\alpha) \equiv \frac{F(\nu_\alpha)}{F(\nu_e) + F(\nu_\mu) + F(\nu_\tau)}$$

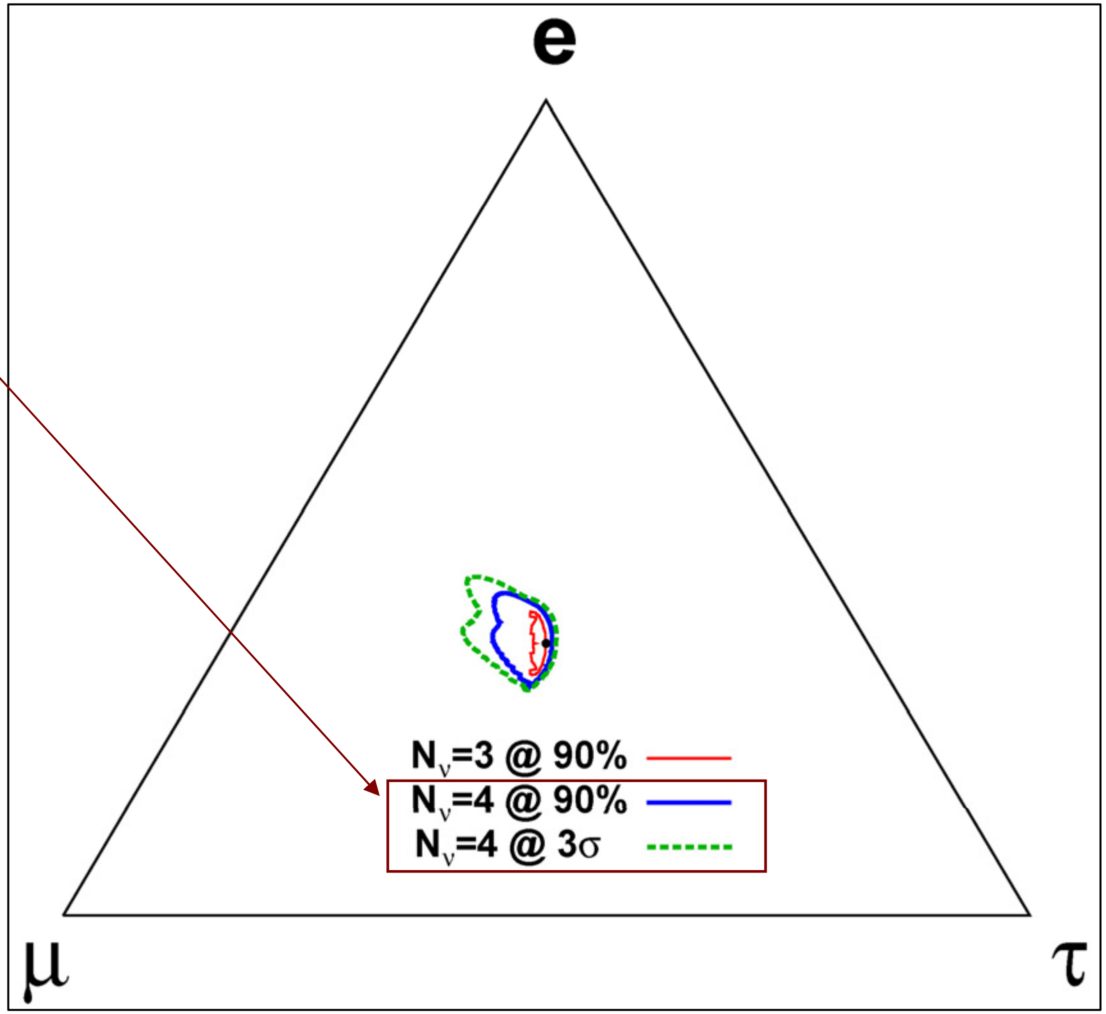


# 2.4 Flavor ratio of ν flux for (3+1)- scheme

Donini-OY '07

**(3+1)-scheme w/o LSND gives the prediction which could be distinguished from $N_\nu$=3 case**

**In principle, (3+1)-scheme could be distinguished from the three flavor case**



# 2.5 Theoretical uncertainties of original ν flux

**Lipari-Lusignoli-Meloni Phys.Rev.D75:123005,2007**

**For illustrations, they discussed ν flux from GRB using Waxman-Bahcall**

- **Proton energy spectrum**

$$N_p(E_p) \propto E_p^{-\alpha}$$

- **Photon number density**

$$n_\gamma(\epsilon) \propto \begin{cases} (\epsilon/\epsilon_b)^{-\beta_1} & \text{for } \epsilon \le \epsilon_b, \\ (\epsilon/\epsilon_b)^{-\beta_2} & \text{for } \epsilon_b < \epsilon < \epsilon_{max} \\ 0 & \text{for } \epsilon \ge \epsilon_{max}, \end{cases}$$

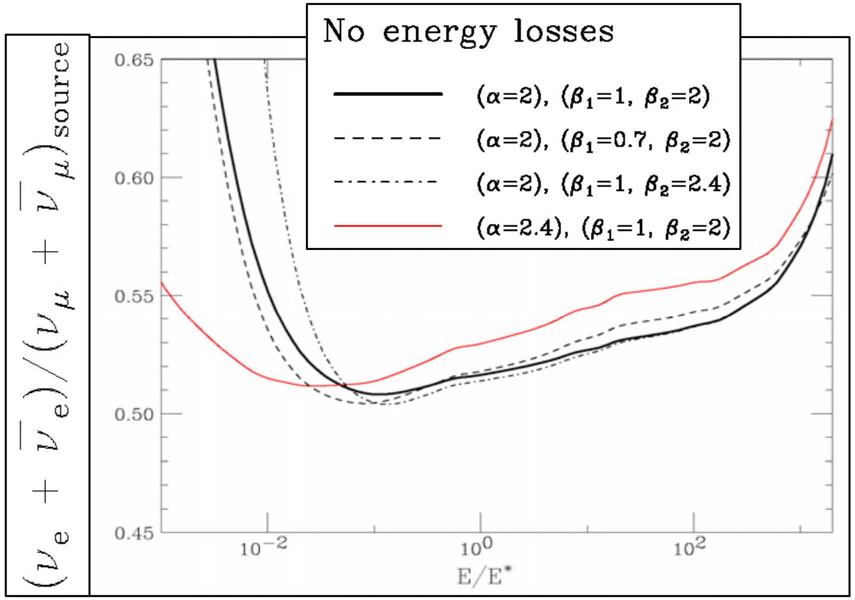
- **Muon energy loss due to synchrotron radiation**

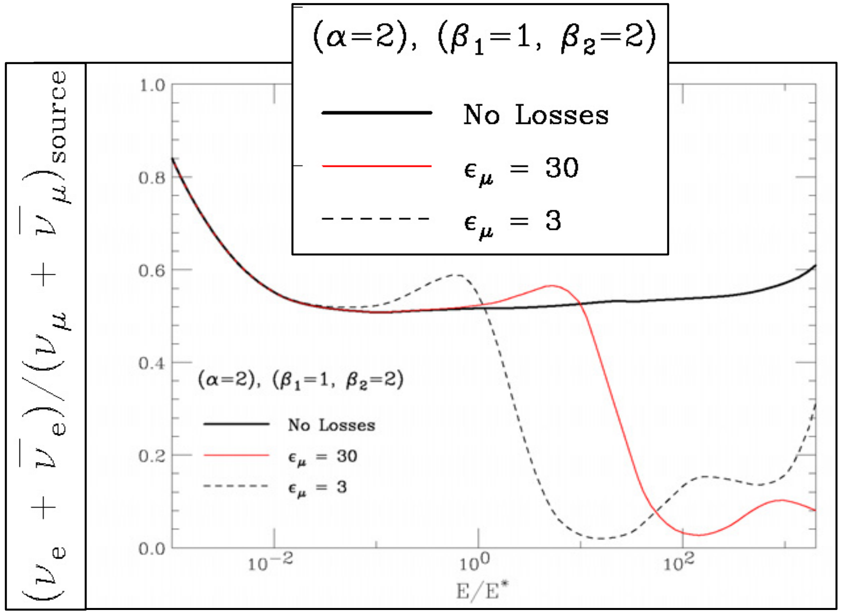
$$\epsilon_\mu = \frac{E^\mu_{syn}}{E^*} = 8.4 \times 10^4 \left(\frac{\text{Gauss}}{B}\right)\left(\frac{\epsilon_b}{\text{KeV}}\right)$$

$$E^* \simeq 6.9 \times 10^{13} (\epsilon_b/\text{KeV})^{-1} \text{eV}$$

**: Proton threshold energy for inelastic interactions with γ**

- **e:μ=1:2 not necessarily correct**
- **Energy dependence expected**

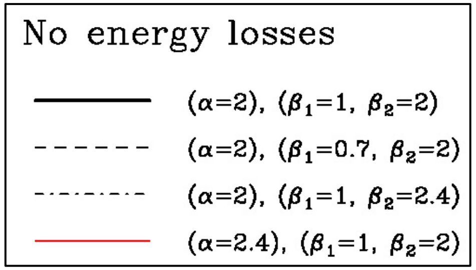


# 2.6 e/μ ratio vs μ/τ ratio & energy spectrum for (3+1)- scheme

**Donini-OY '07**

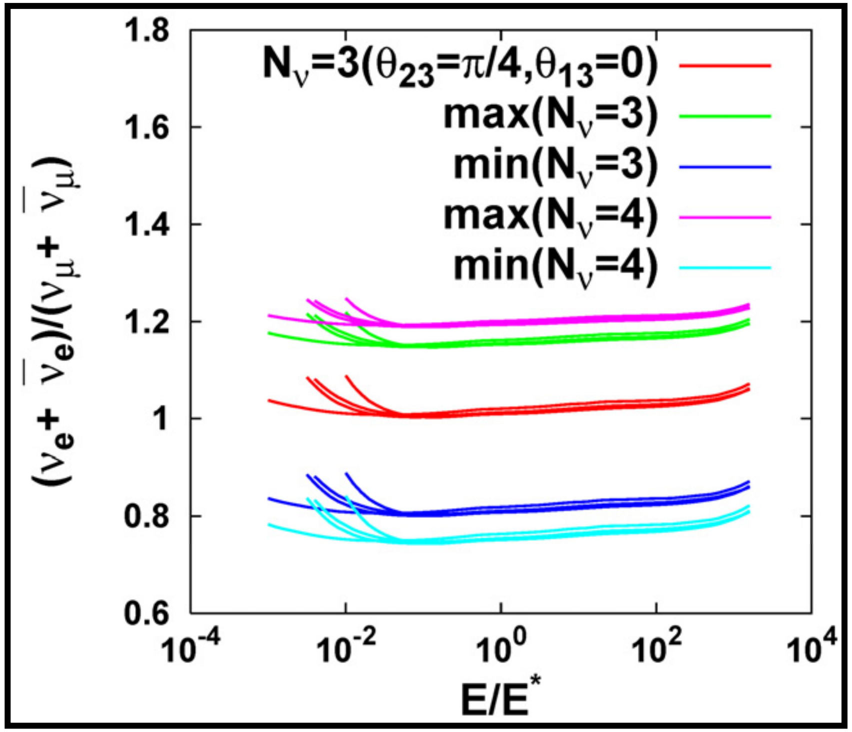
**4 curves (energy dependence of p, γ) corresponding to uncertainties by Lipari et al.**

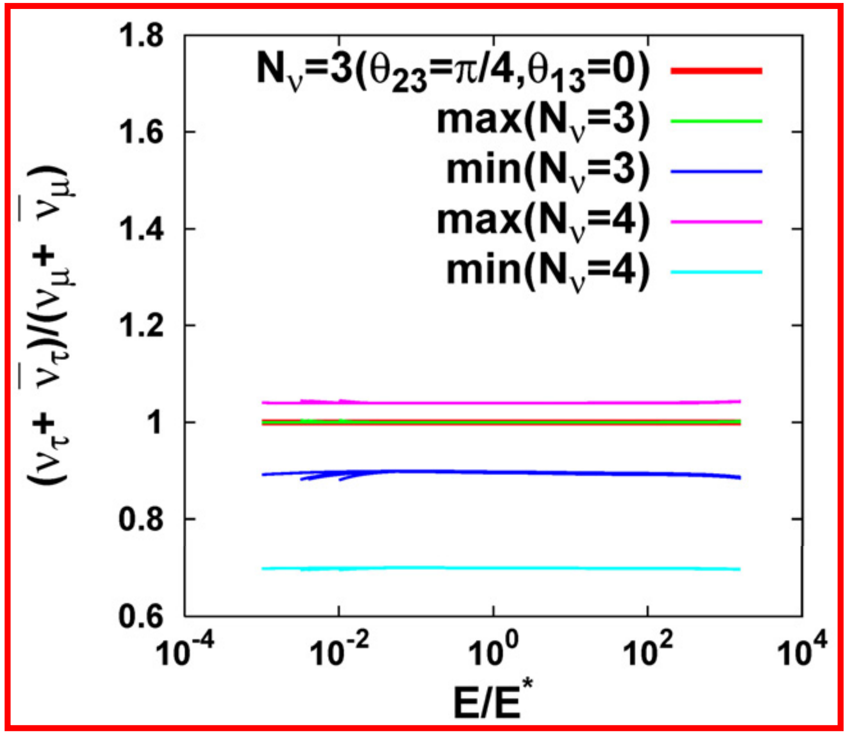



**μ/τ ratio is less energy dependent**

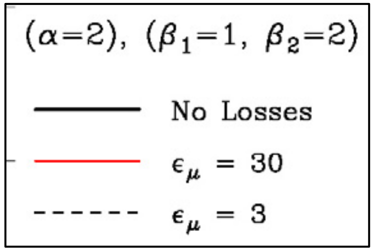
**(to 1st order in small parameters)**

$$R^{(4-fam)}_{\tau\mu} = c^2_{34} = c^2_{34} R^{(3-fam)}_{\tau\mu}$$

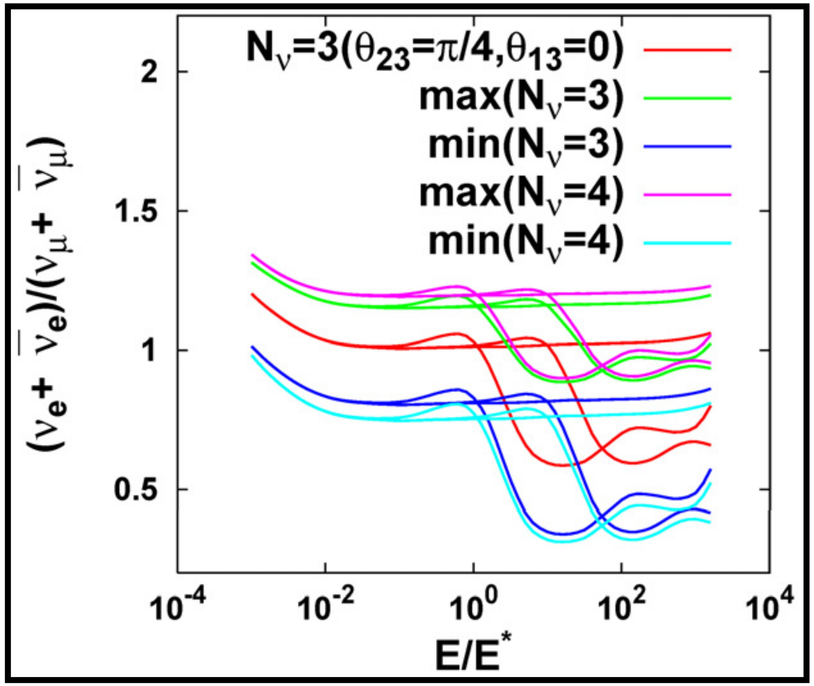


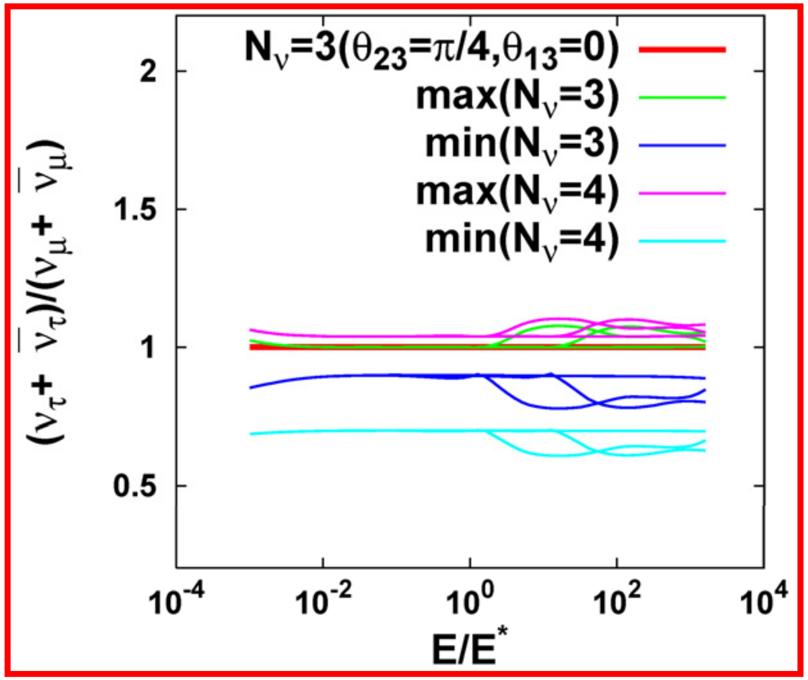



**3 curves (muon enery loss) corresponding to uncertainties by Lipari et al.**




**Donini-OY '07**




- **Energy dependence gives us hint on the uncertainties**
- **$\mu/\tau$ ratio is less energy dependent**

$$R_{\tau\mu}^{(4-fam)} = c_{34}^2 = c_{34}^2 R_{\tau\mu}^{(3-fam)}$$

**(to 1st order in small parameters)**

## 2.7 Statistics of expected events

For a typical galactic source, ten years of running at a $km^3$ water equivalent detector:

e, $\mu$ events ~ O(100)

P. Lipari, astro-ph/0605535

$\tau$ events ~ O(30)

⇨ $\mu/\tau$ ratio ($N_\nu$=3) = 0.30 ∓ 0.03(theo) ∓ 0.06(stat)

$\mu/\tau$ ratio ($N_\nu$=4) ~ 0.2

Statistics is not sufficient at all!

A possible way out:

- to integrate over all the galactic and extragalactic sources, or
- to sum over many GRB's events of similar intensities

# 3.Conclusions

- The (3+1)-scheme without LSND constraint predicts flavor ratio of HE cosmic $\nu$ which could be in principle distinguished from standard case.
- The $\mu/\tau$ ratio suffers relatively less from theoretical uncertainties, and plays an important role to look for signatures of sterile $\nu$.
- Information from energy spectrum could be also important to check theoretical uncertainties.
- Statistics from one source is not sufficient to get signatures of sterile $\nu$, but if we sum over data from many sources then we may be able to say something about sterile $\nu$.