Tau detection and new physics

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12 October 2009 4th IDS meeting@Mumbai
(through video or phone)

Many apologies for
my physical absence
at this meeting!

1. Introduction
2. New Physics in propagation (matter effect)
3. New Physics at source and detector
4. Violation of unitarity
5. Light sterile neutrinos
6. Summary

References:

- Donini, talk at 3rd IDS Plenary Meeting@CERN, March 2009
- "ν_τ detection and the IDS-NF baseline", Donini-Kopp, IDS-NF note

1. Introduction

Motivation for research on New Physics and τ detection

- Just like at B factories, high precision measurements of ν oscillation in future experiments will allow us to probe physics beyond SM by looking at deviation from SM+massive ν.
- If θ_{13} turns out to be large, search for new physics and test of unitarity will be even more important subjects at ν factory. (cf. $\sin^2\theta_{13}=0.02\pm0.01@1\sigma$, Fogli et al, arXiv:0905.3549 [hep-ph])

- τ detection is potentially advantage of ν factory:
  - Detection of large number of τ's is possible at ν factory
  - No ν_τ contamination at a neutrino factory (cf. super-beam, [Van de Vyver-Zucchelli, NIM A385:91,1997])
- τ channels in 3 family model are not so useful:
  - (golden) @4000km+7500km is better than (silver)+(golden) @4000km to solve intrinsic degeneracy [ISS report]
  - (disappearance) is better than (discovery) to measure atmospheric parameters [Donini, 0th IDS mtg@CERN]

$\nu_e \to \nu_\mu$ golden channel

$\nu_\mu \to \nu_\mu$ disappearance channel

$\nu_e \to \nu_\tau$ silver channel

$\nu_\mu \to \nu_\tau$ discovery channel

● If 3 flavor unitarity is guaranteed, then roughly speaking, we could guess (discovery) from (golden) + (disappearance) at ν factory from 3 flavor unitarity:

$$P(\nu_\mu \to \nu_e) + P(\nu_\mu \to \nu_\mu) + P(\nu_\mu \to \nu_\tau) = 1$$

disappearance channel

discovery channel

$\nu_e \to \nu_\mu$

golden channel

Probability of the time reversal process could be obtained if we can guess the CP phase.

● Intuitively, therefore, τ detection is supposed to be important to test New Physics which violates unitarity.

→ Quantitative estimate is necessary to draw conclusions.

New physics which can be probed at a neutrino factory includes:

- Non standard interactions in propagation
- Non standard interactions at production / detection
- Violation of unitarity due to heavy particles
- Schemes with light sterile neutrinos

$$\sum_{\beta=e,\mu,\tau} P(\nu_\alpha \to \nu_\beta) = 1$$

Scenarios	3 flavor unitarity
NSI in propagation	✓
NSI at production / detection	×
Violation of unitarity due to heavy particles	×
Light sterile neutrinos	×

τ detectors

- **Emulsion Cloud Chamber (ECC)**

  Prototype: the OPERA detector at the CNGS

  active target: lead

  spectrometers to measure the charge

  only $\tau \to \mu$ decay is used: detection efficiency～O(5%)

→Proposal of Magnetized Emulsion Cloud Chamber (MECC)

active target: iron

$\tau \to \mu$ decay + $\tau \to e$ decay + $\tau \to$hadron decay are used:

detection efficiency～O(25%)

- **Liquid Argon TPC (LAr-TPC)**

  Prototype: the ICARUS T600 at the CNGS

2. New Physics in propagation (matter effect)

● Oscillation probability w/ NP in propagation

$$\mathcal{M} \equiv U\,\mathrm{diag}(E_j)\,U^{-1} + \mathcal{A} = \tilde{U}\,\mathrm{diag}(\tilde{E}_j)\,\tilde{U}^{-1}$$

$$\mathcal{A} \equiv A \begin{pmatrix} 1+\epsilon_{ee} & \epsilon_{e\mu} & \epsilon_{e\tau} \\ \epsilon_{e\mu}^* & \epsilon_{\mu\mu} & \epsilon_{\mu\tau} \\ \epsilon_{e\tau}^* & \epsilon_{\mu\tau}^* & \epsilon_{\tau\tau} \end{pmatrix}$$

$$A \equiv \sqrt{2} G_F N_e$$

$$N_e \equiv \text{electron density}$$

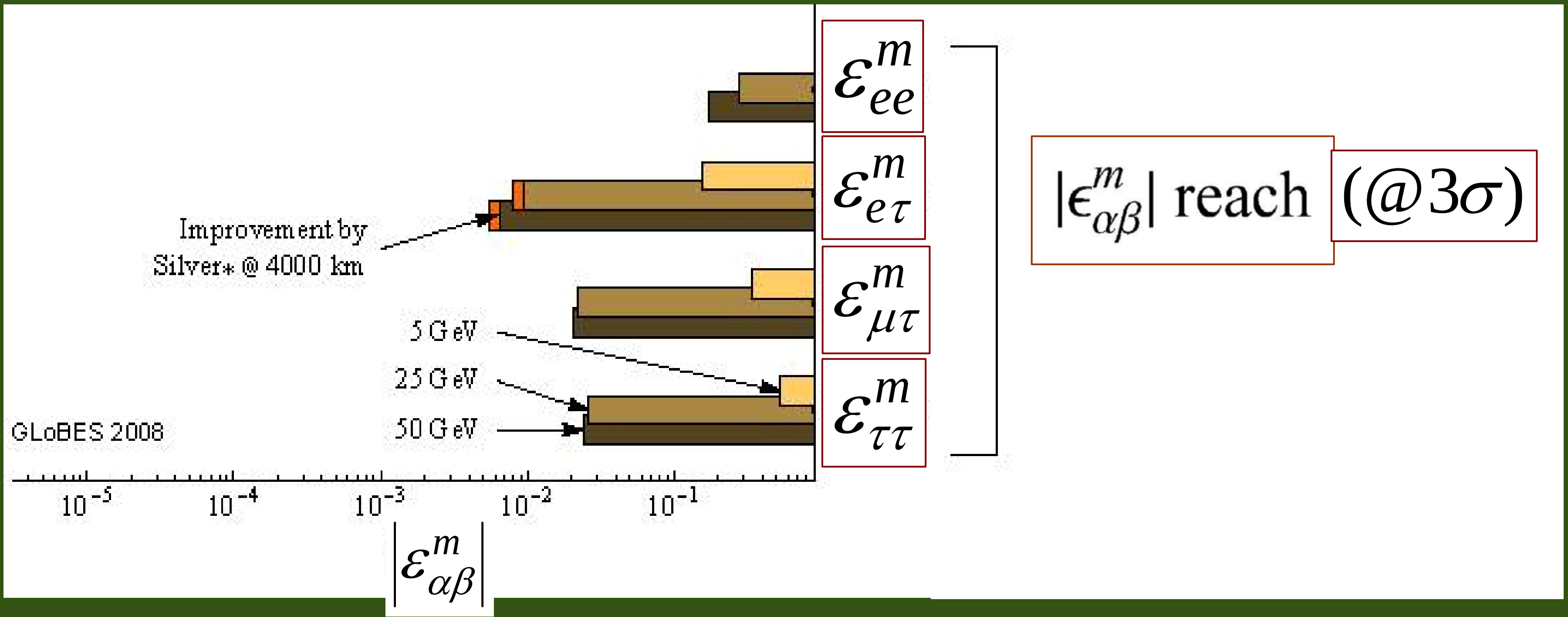
$$P(\nu_\alpha \to \beta) = \left| \left[\tilde{U} \exp\left\{ -i\mathrm{diag}(\tilde{E}_j) L \right\} \tilde{U}^{-1} \right]_{\beta\alpha} \right|^2$$

- **Mass matrix $\mathcal{M}$ is hermitian**
- **There are only 3 flavors**

Oscillation probability satisfies 3 flavor unitarity

Sensitivity at ν factory

Kopp-Ota-Winter,
Phys.Rev.D78:053007,2008



- **Improvement by silver channel is modest**
- **Impact of discovery channel has not been investigated but improvement is expected to be modest, too, because of 3 flavor unitarity**

Sensitivity at ν factory w/ near τ detector

Tang-Winter, Phys.Rev.D80:053001,2009

- Near τ detector does not improve, either

	Without ν_τ ND5	With ν_τ ND5
$\lvert\epsilon^m_{e\tau}\rvert$	0.004	0.004
$\lvert\epsilon^m_{\mu\tau}\rvert$	0.02	0.02

ND5: mass 2 kton, L=1 km

3. New Physics at source and detector

Grossman, Phys. Lett. B359, 141 (1995)

● NP at source

$$\mu^+ \rightarrow e^+ + \overline{\nu}_\mu + \nu_\mu^s$$

$$\nu_e^s = \nu_e + \epsilon_{e\mu}^s \nu_\mu$$

Effective eigenstate

$$\begin{pmatrix} \nu_e^s \\ \nu_\mu^s \end{pmatrix} = \begin{pmatrix} 1 & \epsilon_{e\mu}^s \\ -\epsilon_{e\mu}^s & 1 \end{pmatrix} \begin{pmatrix} \nu_e \\ \nu_\mu \end{pmatrix}$$

● NP at detector

$$\nu_\mu^d + n \rightarrow \mu^- + p$$

$$\nu_\mu^d = \nu_\mu - \epsilon_{e\mu}^d \nu_e$$

Effective eigenstate

$$\begin{pmatrix} \nu_e^d \\ \nu_\mu^d \end{pmatrix} = \begin{pmatrix} 1 & \epsilon_{e\mu}^d \\ -\epsilon_{e\mu}^d & 1 \end{pmatrix} \begin{pmatrix} \nu_e \\ \nu_\mu \end{pmatrix}$$

Oscillation probability w/ NP @ source/detector

$$\mathcal{M} \equiv U\,\mathrm{diag}(E_j)\,U^{-1} + \mathcal{A}_0 = \tilde{U}_0\,\mathrm{diag}(\tilde{E}_j^0)\,\tilde{U}_0^{-1}$$

$$\mathcal{A}_0 \equiv A \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

$$P(\nu_\alpha \to \beta) = \left| \left[U^d \tilde{U}_0 \exp\left\{ -i\mathrm{diag}(\tilde{E}_j^0) L \right\} \tilde{U}_0^{-1} (U^s)^{-1} \right]_{\beta\alpha} \right|^2$$

- There are only 3 flavors
- But matrix $U^d \mathcal{M} (U^s)^{-1}$ is not hermitian

↓

Oscillation probability does not satisfy 3 flavor unitarity

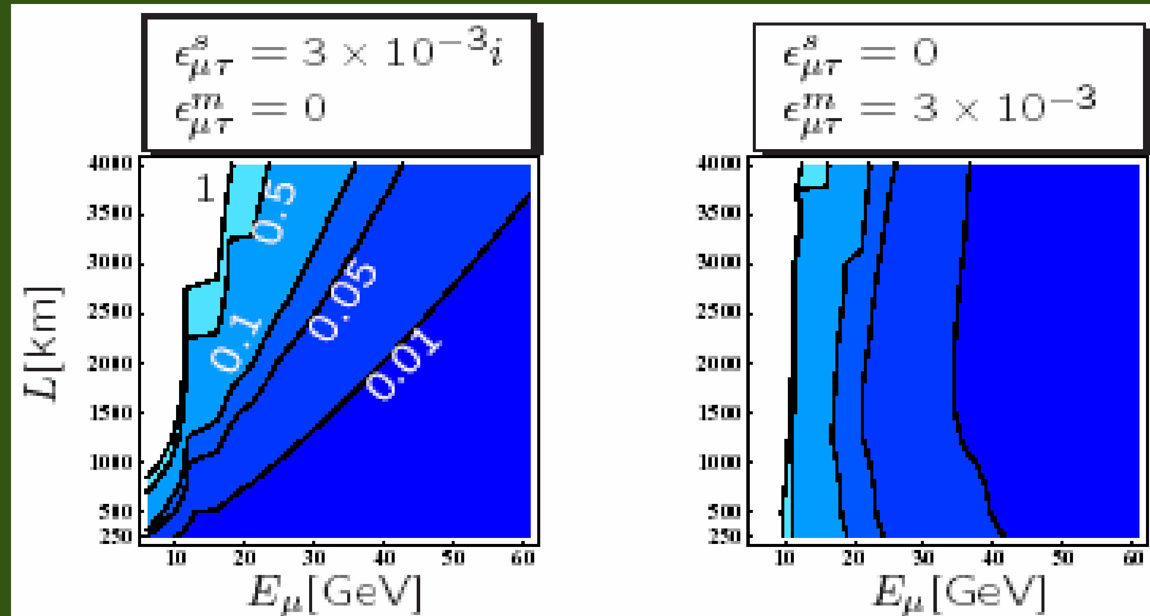
Sensitivity to $\varepsilon_{\mu\tau}$ at ν factory

Ota-Sato-Yamashita, PRD65:093015,2002

$\nu_\mu \to \nu_\tau$

$\left|\varepsilon_{\mu\tau}^{s,m}\right| = 3\times10^{-3}$

Required data size in unit of 10^{21} μ ×100kt



■ The expected sensitivity is $\epsilon \gtrsim \mathcal{O}(10^{-4})$.

	$\epsilon^{s,m}_{e\mu}\ (\epsilon^{s}_{\mu e})$	$\epsilon^{s,m}_{e\tau}$	$\epsilon^{s,m}_{\mu\tau}$
$\nu_e \to \nu_\mu$	△	△	×
$\nu_\mu \to \nu_\mu$	×	×	○
$\nu_e \to \nu_\tau$	×	○	△
$\nu_\mu \to \nu_\tau$	×	△	○
$\nu_\mu \to \nu_e$	△	×	×
$\nu_e \to \nu_e$	×	×	×

Sato: ISS 2nd plenary @ KEK

Sensitivity to $\varepsilon_{e\tau}$, $\varepsilon_{\mu\tau}$ at ν factory

Tang-Winter,
Phys.Rev.D80:053001,2009

- **Near τ detector improves sensitivity**

	Without ν_τ ND5	With ν_τ ND5
$\lvert\epsilon^s_{e\tau}\rvert$	0.004	0.0007
$\lvert\epsilon^s_{\mu\tau}\rvert$	0.4	0.0006

ND5: mass 2 kton, L=1 km

4. Violation of unitarity w/o light ν_s
(Minimal Unitarity Violation)

Antusch, Biggio, Fernandez-Martinez, Gavela, Lopez-Pavon, JHEP0610,084, '06

In generic see-saw models, after integrating out ν_R, the kinetic term gets modified, and unitarity is expected to be violated.

$$L = \frac{1}{2}\left(i\bar{\nu}_\alpha \partial K_{\alpha\beta}\nu_\beta - \bar{\nu}^c{}_\alpha M_{\alpha\beta}\nu_\beta\right) - \frac{g}{\sqrt{2}}\left(W^+_\mu \bar{l}_\alpha \gamma^\mu P_L \nu_\alpha + h.c.\right) + \ldots$$

rescaling ν

$$L = \frac{1}{2}\left(i\bar{\nu}_i \partial \nu_i - \bar{\nu}^c{}_i m_{ii}\nu_i\right) - \frac{g}{\sqrt{2}}\left(W^+_\mu \bar{l}_\alpha \gamma^\mu P_L N_{\alpha i}\nu_i\right) + \ldots$$

***N*: non-unitary**

Oscillation probability w/ Minimal Unitarity Violation

$$P(\nu_\alpha \to \beta) = \left| \left[H\tilde{U} \exp\left\{ -i\mathrm{diag}(\tilde{E}_j)L \right\} \tilde{U}^{-1} H \right]_{\beta\alpha} \right|^2$$

$$U \,\mathrm{diag}(E_j)\, U^{-1} + H \mathcal{A}_0 H = \tilde{U}\, \mathrm{diag}(\tilde{E}_j)\, \tilde{U}^{-1}$$

$N \equiv HU$

$\eta = H$-1: deviation from unitarity

- There are only 3 flavors
- But matrix $H\tilde{U}$ is not unitary

↓

Oscillation probability does not satisfy 3 flavor unitarity

Sensitivity to MUV parameters at ν factory (1)

- **4kt OPERA-like near detector @100 m**

Antusch et al, JHEP0610,084, '06

$\nu_\mu \to \nu_\tau$

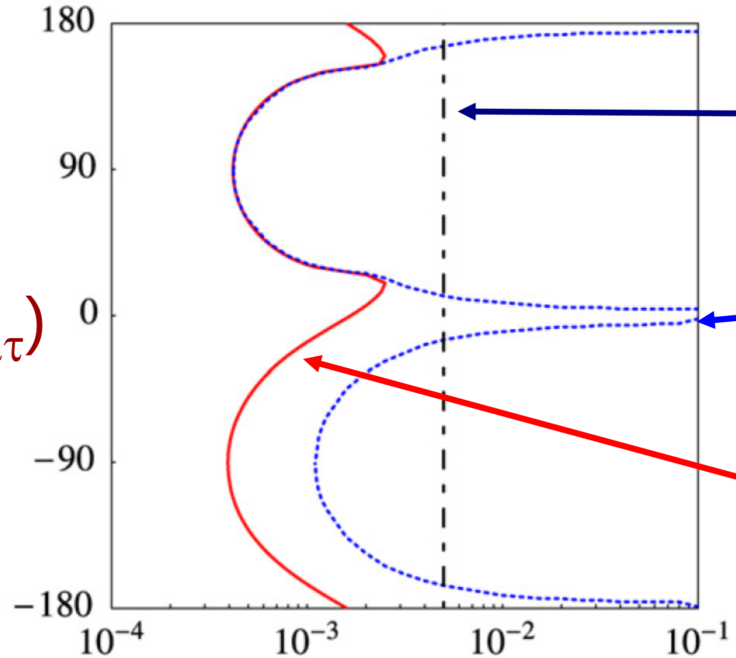
$|\eta_{\mu\tau}|<1.3\mathrm{x}10^{-3}$ (present: $6.5\mathrm{x}10^{-3}$)

$H \equiv 1+\eta$

- **5kt OPERA-like far detector @130 km**

Fernandez-Martinez et al, PLB649:427,'07

$\nu_\mu \to \nu_\tau$



$\arg(\eta_{\mu\tau})$

$|\eta_{\mu\tau}|$

Present bound from $\tau \to \mu\gamma$

Sensitivity to $\arg(\eta_{\mu\tau})$

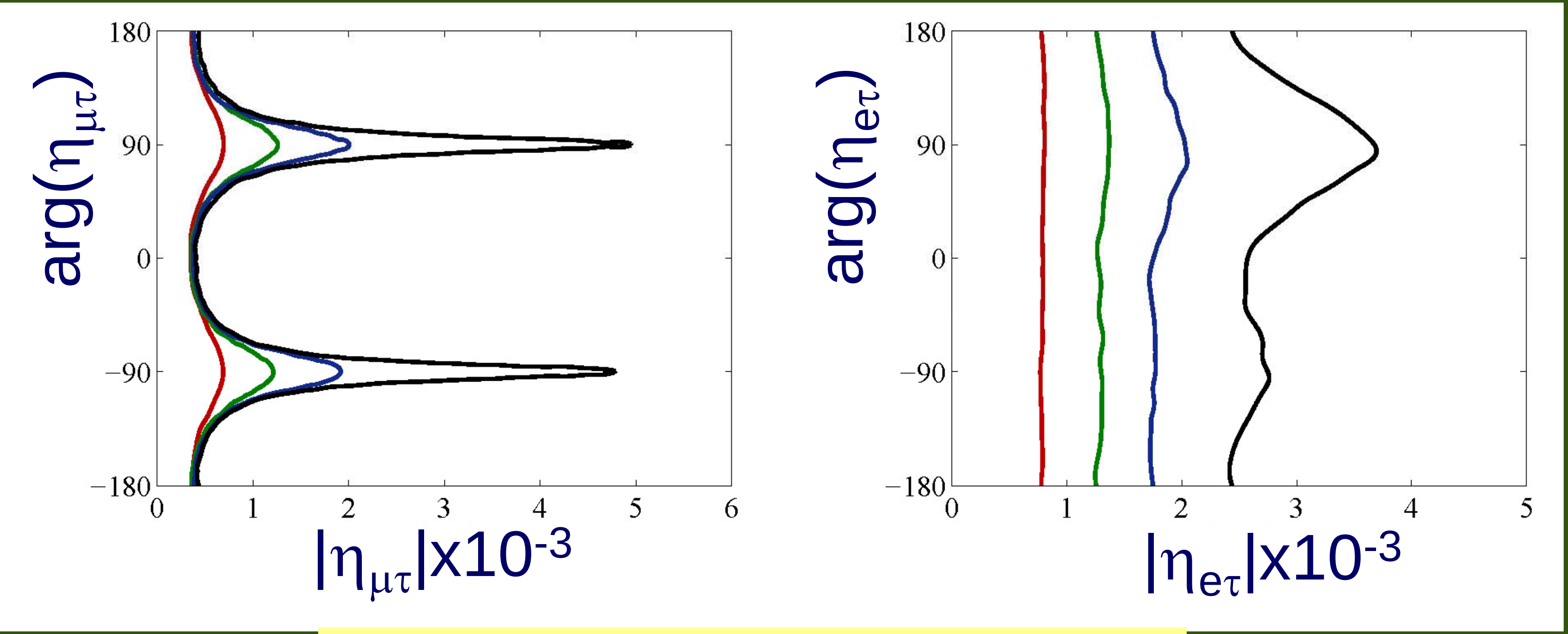
Sensitivity to $|\eta_{\mu\tau}|$

For non-trivial $\arg(\eta_{\mu\tau})$, one order of magnitude improvement for $|\eta_{\mu\tau}|$

Sensitivity to MUV parameters at ν factory (2)

τ detectors at L=1km & 7500km

Antusch, Blennow, Fernandez-Martinez, Lopez-Pavon, Phys.Rev.D80:033002,2009

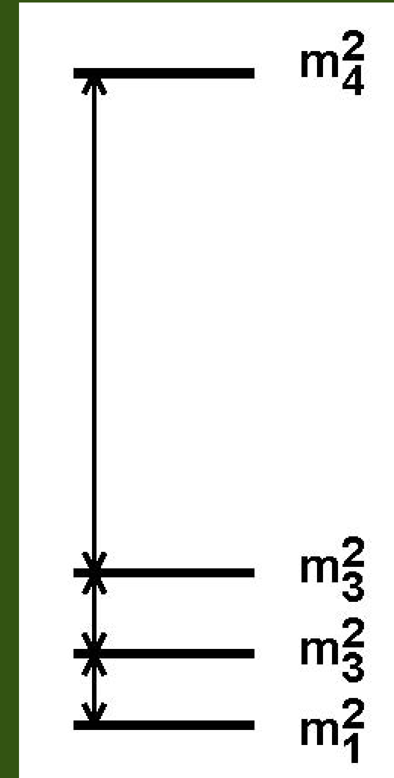


Near detector mass = 10kt, 1kt, 100t, 0

1kt for near detector mass seems to be enough

5. Light sterile neutrinos

(3+1)-scheme w/o LSND: still a possible scenario, provided that the mixing angles satisfy all the constraints of the negative results



$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \\ \nu_s \end{pmatrix} = U \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \\ \nu_4 \end{pmatrix}$$

$$U = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} \\ U_{\mu1} & U_{\mu2} & U_{\mu3} & U_{\mu4} \\ U_{\tau1} & U_{\tau2} & U_{\tau3} & U_{\tau4} \\ U_{s1} & U_{s2} & U_{s3} & U_{s4} \end{pmatrix}$$

Obviously oscillation probability does not satisfy 3 flavor unitarity

Sensitivity to θ_{24}, θ_{34} at ν factory

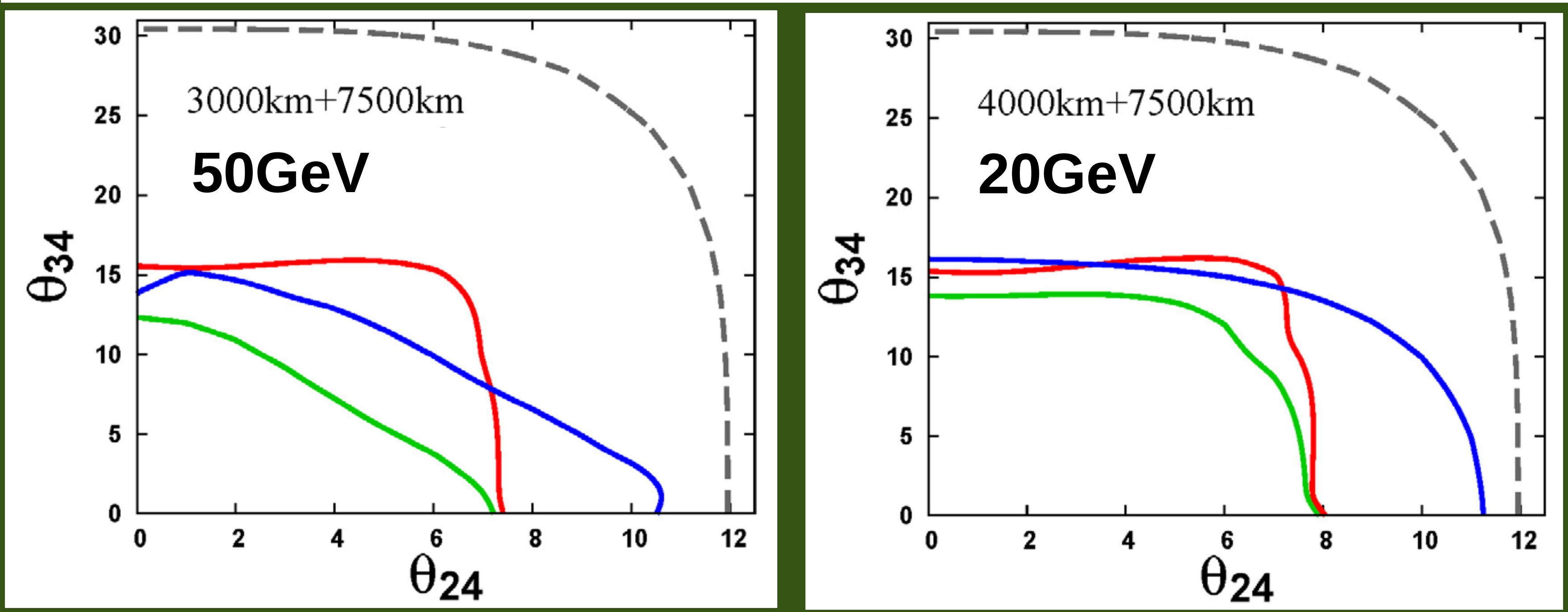
Donini et al, JHEP 0908:041,2009

$$U = R_{34}(\theta_{34},\,0)\;R_{24}(\theta_{24},\,0)\;R_{23}(\theta_{23},\,\delta_3)\;R_{14}(\theta_{14},\,0)\;R_{13}(\theta_{13},\,\delta_2)\;R_{12}(\theta_{12},\,\delta_1)$$

θ_{34} : ratio of $\nu_\mu \leftrightarrow \nu_\tau$ and $\nu_\mu \leftrightarrow \nu_s$ in ν_{atm}

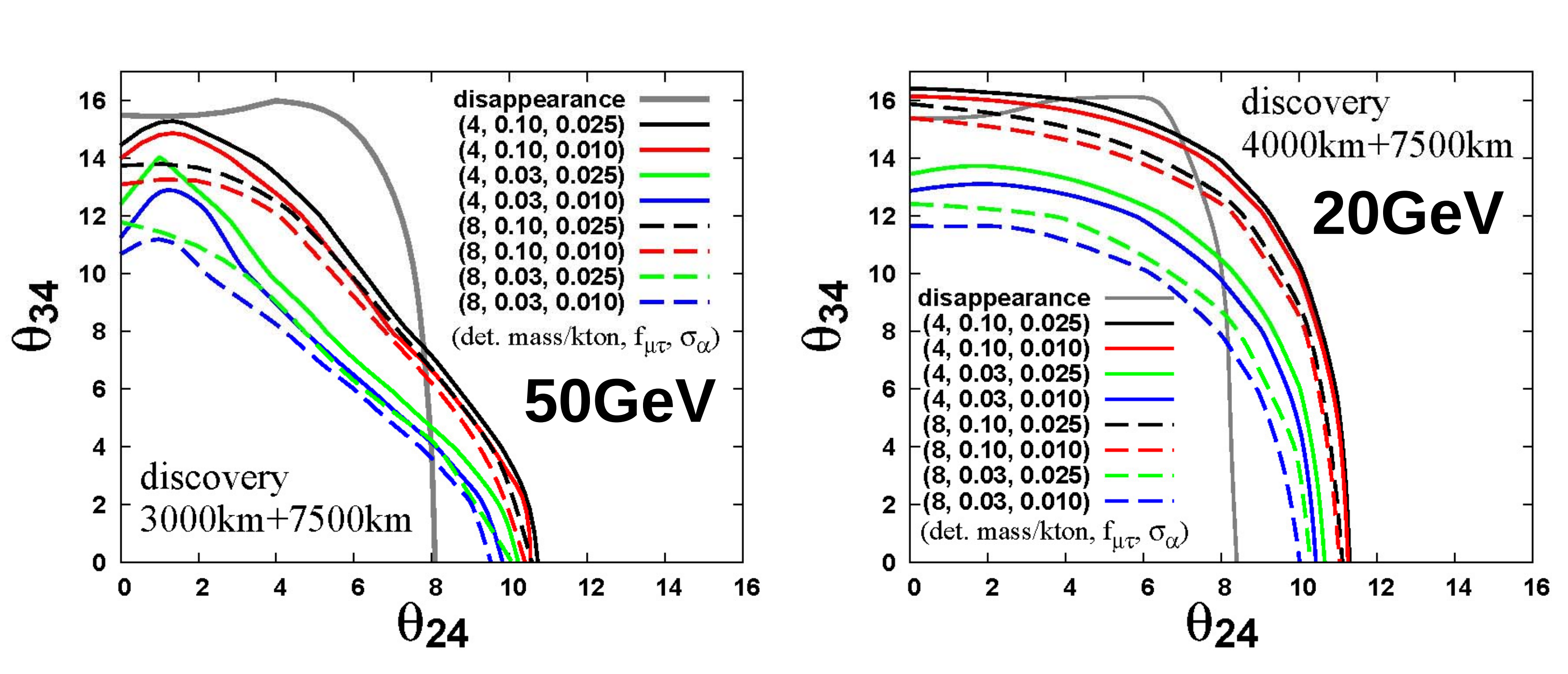
θ_{24} : ratio of $\sin^2(\frac{\Delta m^2_{\rm atm} L}{4E})$ and $\sin^2(\frac{\Delta m^2_{\rm SBL} L}{4E})$ in ν_{atm}

--- current — disappearance — discovery — combined



Dependence of sensitivity on systematic errors

Donini et al, JHEP 0908:041,2009



$f_{\mu\tau}$: uncorrelated bin-to-bin systematic error (error in detection efficiency in each bin etc.)

σ_α : correlated systematic error (error in detector volume etc.)

In previous page, $f_{\mu\tau}$=10%, σ_α=2.5% (black solid lines above) was assumed

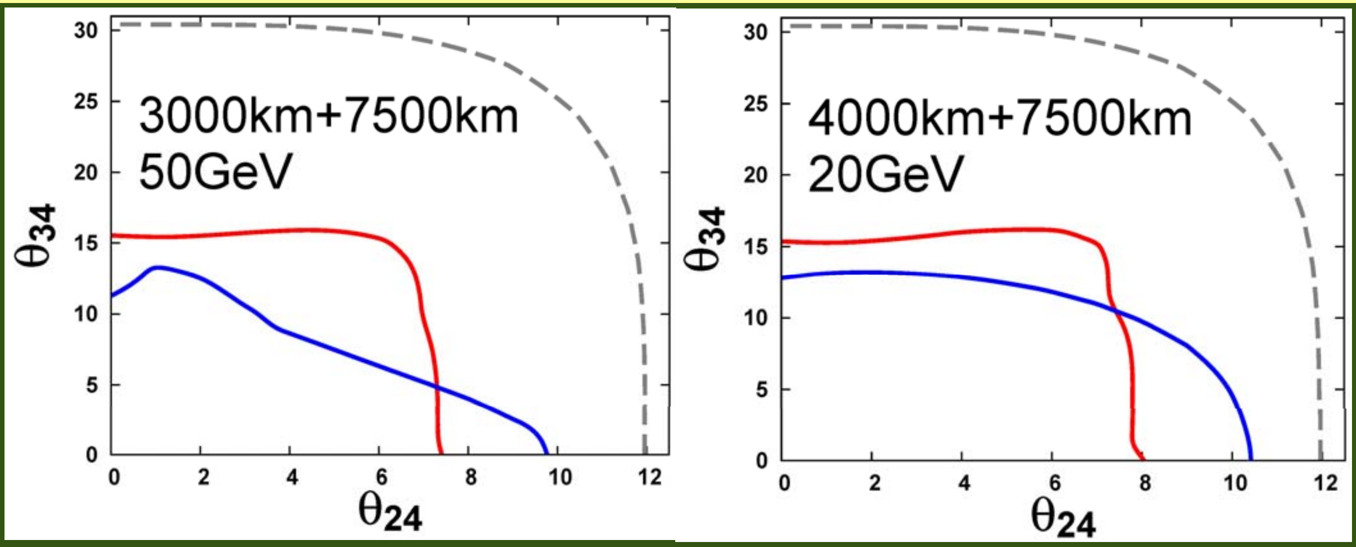
By placing a near τ detector, systematic errors could be reduced

cf. Reduction of systematic errors in the 2 detector complex at reactor experiments

Minakata et al., Phys.Rev.D68:033017,2003

CHOOZ–like	absolute normalization	relative normalization (expected)	relative/absolute
flux	2.1%	0.0%	0
number of protons	0.8%	0.3%	0.38
detection efficiency	1.5%	0.7%	0.47
total	2.7% →	0.8%	
for bins	8.1% →	2.4%	

If we can attain $f_{\mu\tau}$=3%, σ_α=1% w/ ND, then discovery channel could perform better than disappearance:

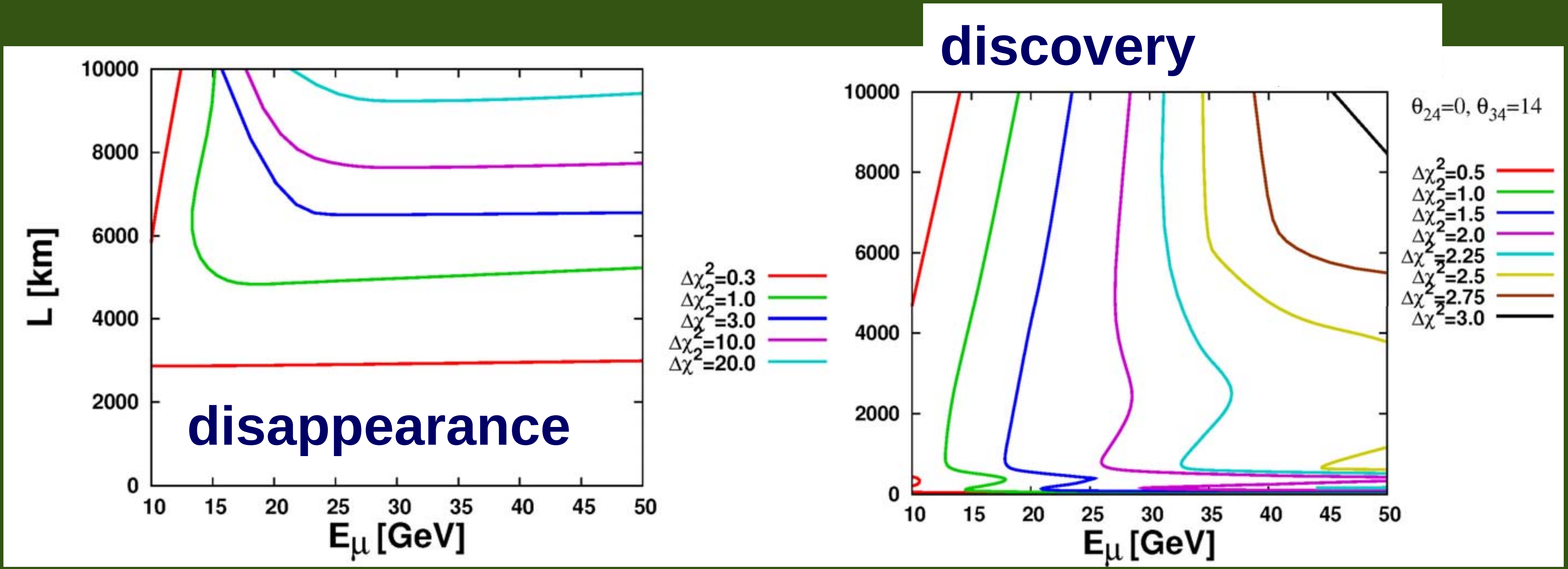


$f_{\mu\tau}$=3%, σ_α=1%

--- current
— disappearance
— discovery

Which τ detector is less important, @3000km or @7500km ?

Contour plot of significance for signal with $\theta_{24}=0$, $\theta_{34}=14$

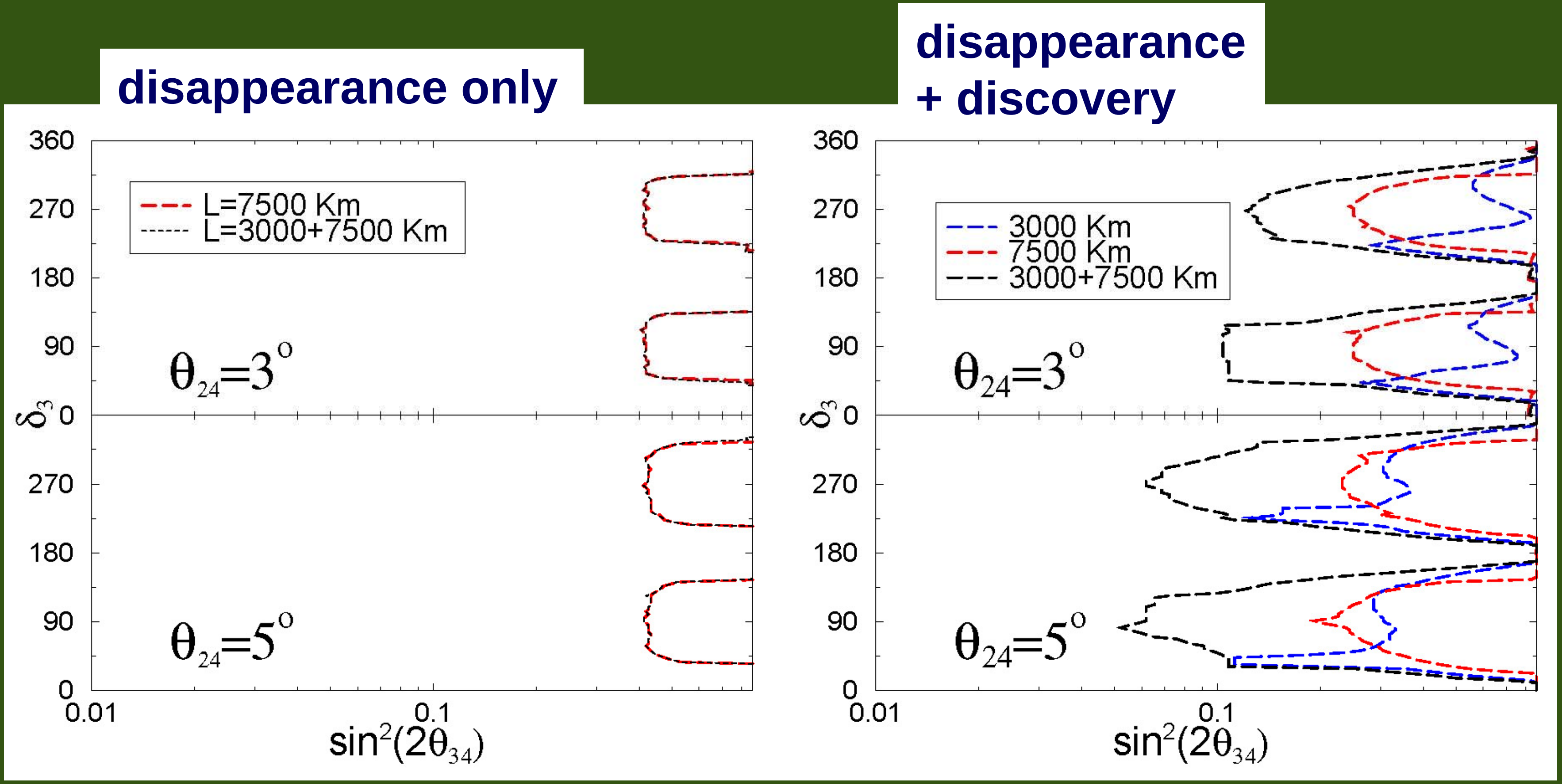


For 50GeV (20GeV), L=3000km (L=4000km) performs (slightly) poor. This is also the case w/ disappearance.

One @7500km seems better in most cases

Sensitivity to the new CP phase

Donini et al, JHEP 0908:041,2009



Discovery channel is crucial to measure the new CP phase

6. Summary

- ν factory can search for new physics beyond the standard model with ν mass, such as
  - Non standard interactions in propagation
  - Non standard interactions at production / detection
  - Violation of unitarity due to heavy particles
  - Schemes with light sterile neutrinos

  (the last 3 scenarios violate 3 flavor unitarity)

- In absence of 3 flavor unitarity, τ detectors in principle give us important information on New Physics, but in practice it depends on the statistical/systematic errors.

- In some cases disappearance channel performs better than discovery one, but again it depends on the systematic errors.

- **To measure the new CP phase due to New Physics, discovery channel is crucial.**

- **Near τ detectors are useful not only to improve sensitivity to New Physics by themselves, but also to reduce the systematic errors of the far τ detectors.**

- **Far τ detectors @7500km seem to be more useful than those @3000km or 4000km.**

- **Study on the systematic errors of τ detectors is very important.**

- **Study on parameter degeneracy in the presence of New Physics has to be done:**
  - **Unitarity violation** [Goswami-Ota, Phys.Rev.D78:033012,2008]
  - **NP in propagation** [Gago et al, arXiv:0904.3360 [hep-ph]]

- **We have physics case for τ channels, but the technological requirements to take full advantage of them are not yet met at this moment.**

→ No τ detector is needed in the baseline scenario, but we have to keep going on R&D to take advantage of better understanding of τ detectors after OPERA and to come up with a possible proposal for τ detectors in a few years from now.

Backup slides

Oscillation probability w/ Minimal Unitarity Violation

Antusch et al, Phys.Rev.D80, 033002, 2009

$$\hat{P}_{\mu\mu} = P^{\rm SM}_{\mu\mu} + 4\varepsilon_{\mu\mu} + 4\varepsilon^2_{\mu\mu} + 4\left\{-\varepsilon_{\mu\mu} + 2\,{\rm Re}(\varepsilon_{\mu\tau})\delta\theta_{23} - 2\delta\theta_{23}(\varepsilon_{\mu\mu} - \varepsilon_{\tau\tau})\frac{A}{E_3}\right\}\sin^2\left(\frac{E_3 L}{2}\right) - [2\,{\rm Re}(\varepsilon_{\mu\tau}) - \delta\theta_{23}(\varepsilon_{\mu\mu} - \varepsilon_{\tau\tau})]AL\sin(E_3 L) + \mathcal{O}(\varepsilon^2_{\alpha\beta}),$$

$$\hat{P}_{\mu\tau} = P^{\rm SM}_{\mu\tau} + 4|\varepsilon_{\mu\tau}|^2 + \left[2\,{\rm Re}(\varepsilon_{\mu\mu} + \varepsilon_{\tau\tau}) + 8\delta\theta_{23}(\varepsilon_{\mu\mu} - \varepsilon_{\tau\tau})\frac{A}{E_3}\right]\sin^2\left(\frac{E_3 L}{2}\right) + [-2\,{\rm Im}(\varepsilon_{\mu\tau}) - \delta\theta_{23}(\varepsilon_{\mu\mu} - \varepsilon_{\tau\tau})AL] \times \sin(E_3 L) - \sqrt{2}\,{\rm Im}\left\{\varepsilon_{e\tau}\left[\frac{E_2}{A}\sin(2\theta_{12}) + \frac{2E_3 s_{13} e^{i\delta}}{A - E_3}\right]\right\}\sin\left(\frac{AL}{2}\right)\sin\left(\frac{E_3 L}{2}\right)\sin\left(\frac{E_3 - A}{2}L\right) + \sqrt{2}\,{\rm Re}\left\{\varepsilon_{e\tau}\left[\frac{E_2}{A}\sin(2\theta_{12})\sin\left(\frac{AL}{2}\right)\cos\left(\frac{E_3 - A}{2}L\right) - \frac{2E_3 s_{13} e^{i\delta}}{A - E_3}\cos\left(\frac{AL}{2}\right)\sin\left(\frac{E_3 - A}{2}L\right)\right]\right\}\sin\left(\frac{E_3 L}{2}\right) + \mathcal{O}(\varepsilon^2_{\alpha\beta}),$$

$$\hat{P}_{e\mu} = P^{\rm SM}_{e\mu} + |\varepsilon_{e\tau}|^2\sin^2\left(\frac{E_3 L}{2}\right) + {\rm Im}\left\{\varepsilon_{e\tau}\left[\frac{1}{2}\frac{E_2}{A}\sin(2\theta_{12}) + \frac{E_3 s_{13} e^{i\delta}}{A - E_3}\right]\right\}\sin\left(\frac{AL}{2}\right)\sin\left(\frac{E_3 L}{2}\right)\sin\left(\frac{E_3 - A}{2}L\right) + {\rm Re}\left\{\varepsilon_{e\tau}\left[\frac{1}{\sqrt{2}}\frac{E_2}{A}\sin(2\theta_{12})\sin\left(\frac{AL}{2}\right)\cos\left(\frac{E_3 - A}{2}L\right) - \frac{2\sqrt{2}E_3 s_{13} e^{i\delta}}{A - E_3}\cos\left(\frac{AL}{2}\right)\sin\left(\frac{E_3 - A}{2}L\right)\right]\right\}\sin\left(\frac{E_3 L}{2}\right) + \mathcal{O}(\varepsilon^3),$$

$$\hat{P}_{e\tau} = P^{\rm SM}_{e\tau} + 4|\varepsilon_{e\tau}|^2 - 2\left[|\varepsilon_{e\tau}|^2 - \frac{\sqrt{2}E_3 s_{13}}{A - E_3}{\rm Re}(\varepsilon_{e\tau}e^{i\delta})\right]\sin^2\left(\frac{E_3 - A}{2}L\right) - 2\left[|\varepsilon_{e\tau}|^2 - \frac{1}{\sqrt{2}}\frac{E_2}{A}\sin(2\theta_{12}){\rm Re}(\varepsilon_{e\tau})\right] \times \sin^2\left(\frac{AL}{2}\right) - {\rm Im}\left\{\varepsilon^*_{e\tau}\left[\frac{1}{\sqrt{2}}\frac{E_2}{A}\sin(2\theta_{12})\sin(AL) - \frac{\sqrt{2}E_3 s_{13} e^{-i\delta}}{A - E_3}\sin(\{E_3 - A\}L)\right]\right\} - 2\sqrt{2}\,{\rm Re}\left\{\varepsilon_{e\tau}\left[\frac{1}{2}\frac{E_2}{A}\sin(2\theta_{12}) - \frac{E_3 s_{13} e^{i\delta}}{A - E_3}\right]\right\}\sin\left(\frac{AL}{2}\right)\cos\left(\frac{E_3 L}{2}\right)\sin\left(\frac{E_3 - A}{2}L\right) + {\rm Im}\left\{\varepsilon_{e\tau}\left[\sqrt{2}\frac{E_2}{A}\sin(2\theta_{12})\sin\left(\frac{AL}{2}\right)\cos\left(\frac{E_3 - A}{2}L\right) + \frac{2\sqrt{2}E_3 s_{13} e^{i\delta}}{A - E_3}\cos\left(\frac{AL}{2}\right)\sin\left(\frac{E_3 - A}{2}L\right)\right]\right\}\cos\left(\frac{E_3 L}{2}\right) + \mathcal{O}(\varepsilon^3).$$

Oscillation probability in (3+1)-scheme

Donini, Fuki, Lopez-Pavon, Meloni, Yasuda, JHEP 0908:041,2009

$$P_{\mu\mu} = 1 - 2\,\theta_{24}^2 - \left[1 - 4(\delta\theta_{23})^2 - 2\theta_{24}^2 + \theta_{34}^2 \frac{A_n}{\Delta_{31}}\left(4\delta\theta_{23} - \theta_{34}^2 \frac{A_n}{\Delta_{31}}\right)\right] \sin^2\frac{\Delta_{31} L}{2}$$
$$- (A_n L)\left\{2\theta_{24}\,\theta_{34}\cos\delta_3 - \frac{\theta_{34}^2}{2}\left(4\delta\theta_{23} - \theta_{34}^2 \frac{A_n}{2\Delta_{31}}\right)\right\}\sin\Delta_{31} L + O(\epsilon^5)\ , \qquad (16)$$

$$P_{\mu\tau} = \left\{1 - 4(\delta\theta_{23})^2 - \theta_{24}^2 - \theta_{34}^2\left[1 - \frac{\theta_{34}^2}{3} - \frac{A_n}{\Delta_{31}}\left(4\delta\theta_{23} - \theta_{34}^2\frac{A_n}{\Delta_{31}}\right)\right]\right\}\sin^2\frac{\Delta_{31} L}{2}$$
$$+ \left\{\theta_{24}\,\theta_{34}\sin\delta_3 + (A_n L)\left[2\theta_{24}\,\theta_{34}\cos\delta_3 - \frac{\theta_{34}^2}{2}\left(4\delta\theta_{23} - \theta_{34}^2\frac{A_n}{2\Delta_{31}}\right)\right]\right\}\sin\Delta_{31} L$$
$$+ O(\epsilon^5)\ , \qquad (17)$$

Numbers of events in (3+1)-scheme

Donini, Fuki, Lopez-Pavon, Meloni, Yasuda, JHEP 0908:041,2009

$(\theta_{13};\theta_{14};\theta_{24};\theta_{34})$	$N_{\tau^-}^{3000}$ ($\nu_\mu \to \nu_\tau$)	$N_{\tau^+}^{3000}$ ($\bar{\nu}_e \to \bar{\nu}_\tau$)	$N_{\tau^-}^{7500}$ ($\nu_\mu \to \nu_\tau$)	$N_{\tau^+}^{7500}$ ($\bar{\nu}_e \to \bar{\nu}_\tau$)
$(5°;5°;5°;20°)$	559	10	544	2
$(5°;5°;10°;20°)$	474	11	529	2
$(5°;5°;10°;30°)$	384	18	454	3
$(5°;5°;10°;30°)$	384	18	454	3
$(10°;5°;5°;20°)$	522	22	512	2
$(10°;5°;10°;20°)$	443	22	498	2
$(10°;5°;5°;30°)$	397	30	413	4
$(10°;5°;10°;30°)$	361	30	428	4
3 families, $\theta_{13}=5°$	797	3	666	0
3 families, $\theta_{13}=10°$	755	12	632	1

Number of events
2 x10^{20} flux
1 year
1 Kton MECC
perfect efficiency

Dependence of sensitivity on systematic errors in (3+1)-scheme

Donini, Fuki, Lopez-Pavon, Meloni, Yasuda, JHEP 0908:041,2009