Summary of Phenomenology Subgroup

Tokyo Metropolitan University

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International scoping study of a future
Neutrino Factory and super-beam facility
Plenary Meetings
21 August 2006 @UCI

Talks on phenomenology @ ISS meetings

- 1st Physics Workshop @ Imperial College

P. Huber: Phenomenological studies of new physics
M. Zralek: Nonunitary neutrino mixing
A. Romanino: New physics in neutrino oscillations in matter
Y. Grossman: Nonstandard interactions and neutrino oscillations

- 2nd Plenary Meeting @ KEK

Z.Z. Xing: Unitarity of lepton sectors
M. Sorel: Status of (3+2)-scheme
J. Sato: New Physics at Long baseline experiments

- 2nd Physics Workshop @ Boston University

A. Friedland: Probe of new physics with solar/atmospheric neutrinos
D. Marfatia: Mass varying neutrino oscillations

- 3rd Plenary Meeting @ RAL

S. Geer: Neutral currents and tests of three-neutrino unitarity in long-baseline experiments
J. Lopez: Unitarity of the lepton sector
O. Yasuda: Model independent analysis of new physics interactions and implications for long baseline experiments

Phenomenology Subgroup mainly focused on deviation from SM+massive ν. The main two issues are:

1. Effects of new physics

1-1. Origin of New Physics

1-2. New Physics at source and detector

1-3. New Physics in propagation (matter effect)

2. Tests of 3 flavor unitarity

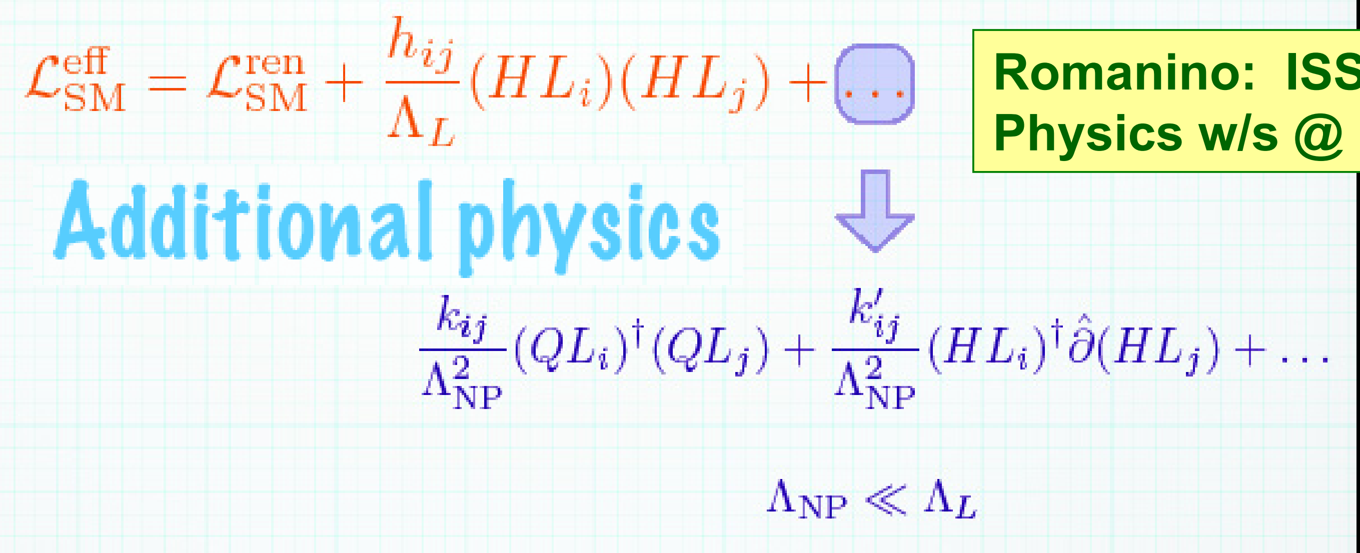
2-1. Discussions in the context of light ν_s (w/ or w/o LSND)

2-2. Discussions on 3 flavor unitarity w/o light ν_s

1. Effects of New Physics

1-1.Origin of New Physics

Theoretically we have to explain the origin of New Physics:



$$\mathcal{L}^{\rm eff}_{\rm SM} = \mathcal{L}^{\rm ren}_{\rm SM} + \frac{h_{ij}}{\Lambda_L}(HL_i)(HL_j) + \boxed{\dots}$$

Additional physics

⇩

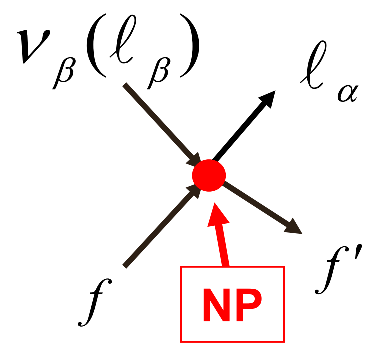
$$\frac{k_{ij}}{\Lambda^2_{\rm NP}}(QL_i)^\dagger(QL_j) + \frac{k'_{ij}}{\Lambda^2_{\rm NP}}(HL_i)^\dagger\hat{\partial}(HL_j) + \dots$$

$$\Lambda_{\rm NP} \ll \Lambda_L$$

Romanino: ISS 1st Physics w/s @ IC

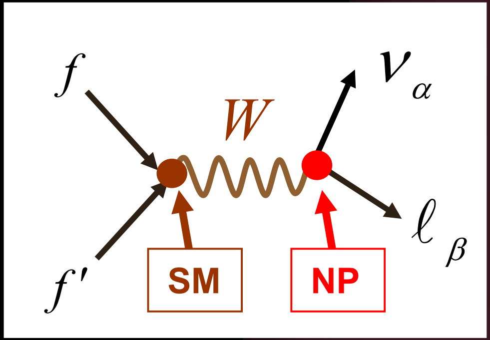
But in **phenomenological** analysis, we take into account only the constraints from the experiments, and we do not assume a particular form of the interaction at higher energy scale.

If either of the particles with flavor α and β in the NP interaction is charged lepton, then



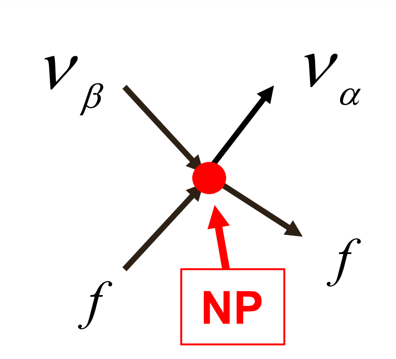
Current bounds on $\varepsilon_{\alpha\beta}$ are typically of order 10^{-3}

- New Physics at source and detector



- Discussions on 3 flavor unitarity w/o light ν_s (Zralek: ISS 1st Physics w/s @ IC, Lopez: ISS 3rd plenary @ RAL)

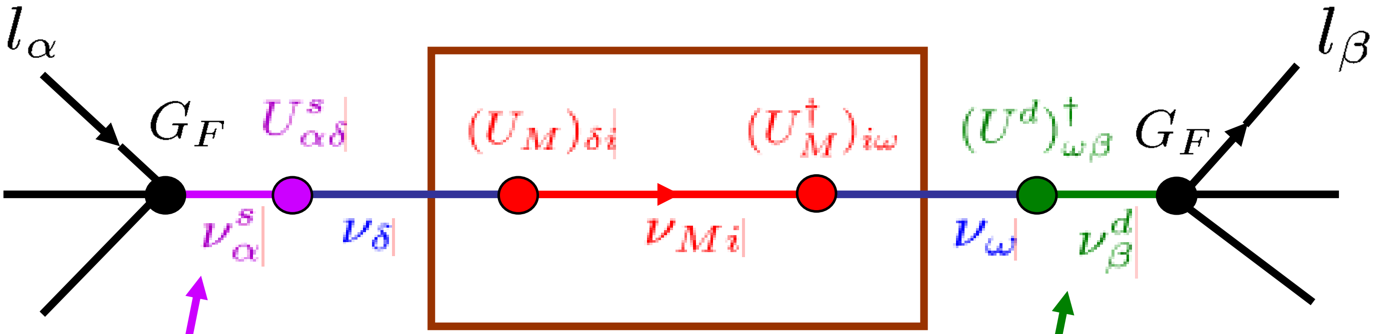
If the particles with flavor α and β in the NP interaction are both neutrinos, then



Current bounds on $\varepsilon_{\alpha\beta}$ are typically of order 10^{-2}

- New Physics in propagation (matter effect)

ν oscillation in the presence of New Physics



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

At source

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

At detector

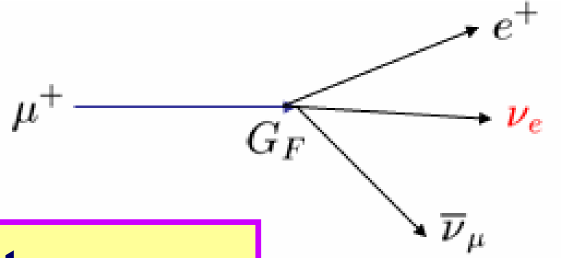
$$\mathcal{L}_{eff} \quad = \quad G_{NP}^{\alpha\beta}\,\bar{\nu}_\alpha\gamma^\mu\nu_\beta\,\bar{f}\gamma_\mu f'$$

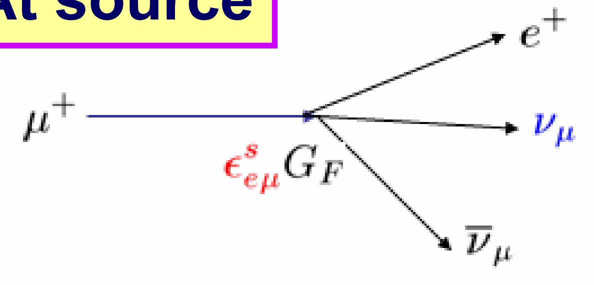
in propagation

Effects of New Physics at source and detector

$$\mathcal{L}_{NP} = G_N^{\alpha\beta}\bar{\nu}_\alpha\gamma^\mu\ell_\beta\bar{f}\gamma_\mu f'$$

At source



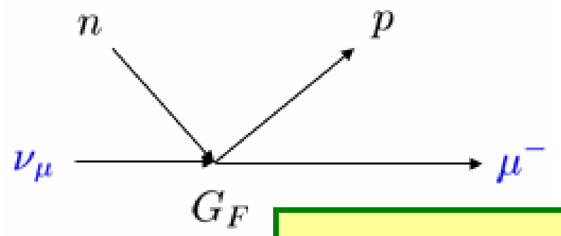


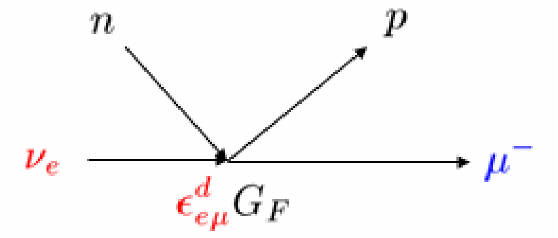
$$\mu^+ \to e^+ + \overline{\nu}_\mu + \nu^s_\mu$$

$$\nu^s_e = \nu_e + \epsilon^s_{e\mu}\nu_\mu$$

$$\begin{pmatrix} \nu^s_e \\ \nu^s_\mu \end{pmatrix} = \begin{pmatrix} 1 & \epsilon^s_{e\mu} \\ -\epsilon^s_{e\mu} & 1 \end{pmatrix} \begin{pmatrix} \nu_e \\ \nu_\mu \end{pmatrix}$$

At detector





$$\nu^d_\mu + n \to \mu^- + p$$

$$\nu^d_\mu = \nu_\mu - \epsilon^d_{e\mu}\nu_e$$

$$\begin{pmatrix} \nu^d_e \\ \nu^d_\mu \end{pmatrix} = \begin{pmatrix} 1 & \epsilon^d_{e\mu} \\ -\epsilon^d_{e\mu} & 1 \end{pmatrix} \begin{pmatrix} \nu_e \\ \nu_\mu \end{pmatrix}$$

Effects of New Physics in propagation (matter effect)

$$\boxed{\mathcal{L}_{\rm eff}^{\rm NSI} = -2\sqrt{2}G_F\,\epsilon^{fP}_{\alpha\beta}\left(\overline{\nu}_\alpha\gamma_\rho P_L\nu_\beta\right)\left(\overline{f}\gamma^\rho P f\right)}$$

$f = e, u, d$

$P = P_L, P_R$

Standard case

$$U\begin{pmatrix} E_1 & 0 & 0 \\ 0 & E_2 & 0 \\ 0 & 0 & E_3 \end{pmatrix}U^{-1} + \begin{pmatrix} A & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

$$\Downarrow$$

with NP

$$U\begin{pmatrix} E_1 & 0 & 0 \\ 0 & E_2 & 0 \\ 0 & 0 & E_3 \end{pmatrix}U^{-1} + \begin{pmatrix} A+\varepsilon_{ee} & \varepsilon_{e\mu} & \varepsilon_{e\tau} \\ \varepsilon^*_{e\mu} & \varepsilon_{\mu\mu} & \varepsilon_{\tau\mu} \\ \varepsilon^*_{e\tau} & \varepsilon^*_{\tau\mu} & \varepsilon_{\tau\tau} \end{pmatrix}$$

Oscillation Probability in the presence of New Physics

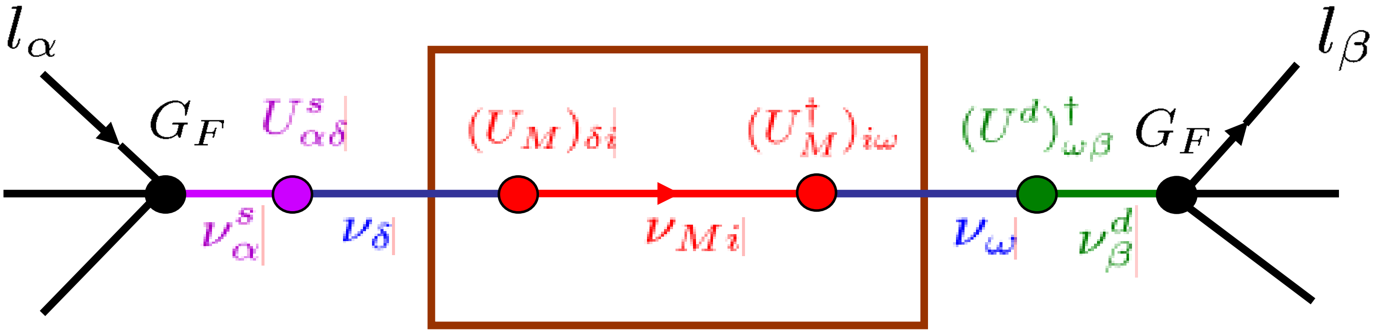
$$\boxed{P(\nu_\alpha \to \nu_\beta) = \left| \left[\boxed{U^d} \boxed{\tilde{U} \exp\left\{-i\, \mathrm{diag}(\tilde{E}_j) L\right\} \tilde{U}^{-1}} \boxed{(U^s)^{-1}} \right]_{\beta\alpha} \right|^2}$$

with $\boxed{U_{MNS}\, \mathrm{diag}(E_j)\, U_{MNS}^{-1} + \mathcal{A}}$

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

$$\begin{pmatrix} \nu_e^s \\ \nu_\mu^s \\ \nu_\tau^s \end{pmatrix} = \boxed{U^s} U_{MNS} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

$$\begin{pmatrix} \nu_e^d \\ \nu_\mu \\ \nu_\tau^d \end{pmatrix} = \boxed{U^d} U_{MNS} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$



In general:

NP effects at production and at detection becomes important when L is smaller

$$P\left(\nu_\alpha \to \nu_\beta\right) \to \left| \left[U^d \left(U^s\right)^{-1} \right]_{\beta\,\alpha} \right|^2$$

i.e., no BG from ν osc.
in the limit of L → 0

➡ Experiments with a shorter baseline are advantageous

NP effects in propagation becomes important when L is larger

because $AL\,\varepsilon_{\alpha\beta} \sim \varepsilon_{\alpha\beta}$ (L/2000km)

➡ Experiments with a longer baseline are advantageous

Works which discussed NP in ν oscillation include:

Grossman, Phys. Lett. B359, 141 (1995);
Gonzalez-Garcia, Grossman, Gusso, Nir, Phys. Rev. D64, 096006 (2001);
Gago, Guzzo, Nunokawa, Teves, Zukanovich Funchal, Phys. Rev. D64, 073003 ('01);
Ota, Sato, Yamashita, Phys. Rev. D65, 093015 (2002);
Huber, Schwetz, Valle, Phys. Rev. Lett. 88, 101804 (2002);
Campanelli, Romanino, Phys. Rev. D66, 113001 (2002);
Huber, Schwetz, Valle, Phys. Rev. D66, 013006 (2002);
Ota, Sato, Phys. Lett. B545, 367 (2002);
Ota, Sato, Phys. Rev. D71, 096004 (2005);
Blennow, Ohlsson, Winter, hep-ph/0508175;
Honda, Okamura, Takeuchi, hep-ph/0603268;
Kitazawa, Sugiyama, OY, hep-ph/0606013;
Friedland, Lunardini, hep-ph/0606101;
Ota et al, "Discovery Reach for Non-Standard Interactions in a Neutrino Factory", (to be presented @ NuFACT06).

Models which predict relatively large NP effect include:

Grossman (Randall-Sundrum model), ISS 1st Physics Workshop @Imperial Coll.: http://www.hep.ph.ic.ac.uk/~longkr/UKNF/Scoping-study/ISS-www-site/WG1-PhysPhen/Workshops/2005-11/Programme/Talks/iss-london-yuvalg.pdf

1-2. New Physics at source and detector

Current bounds on $\varepsilon_{\alpha\beta}$ are typically of order 10^{-3}:

$$|\varepsilon^s_{e\mu}| < 3\times10^{-3} \qquad |\varepsilon^s_{e\tau}| < 3\times10^{-3}$$

$$|\varepsilon^d_{\mu e}| < 2\times10^{-6} \qquad |\varepsilon^d_{\mu\tau}| < 10^{-2}$$

Grossman, Phys. Lett. B359, 141 (1995);Gonzalez-Garcia, Grossman, Gusso, Nir, Phys. Rev. D64, 096006 (2001)

→ Future LBL may be able to probe $\varepsilon_{\alpha\beta}$ to order 10^{-4}

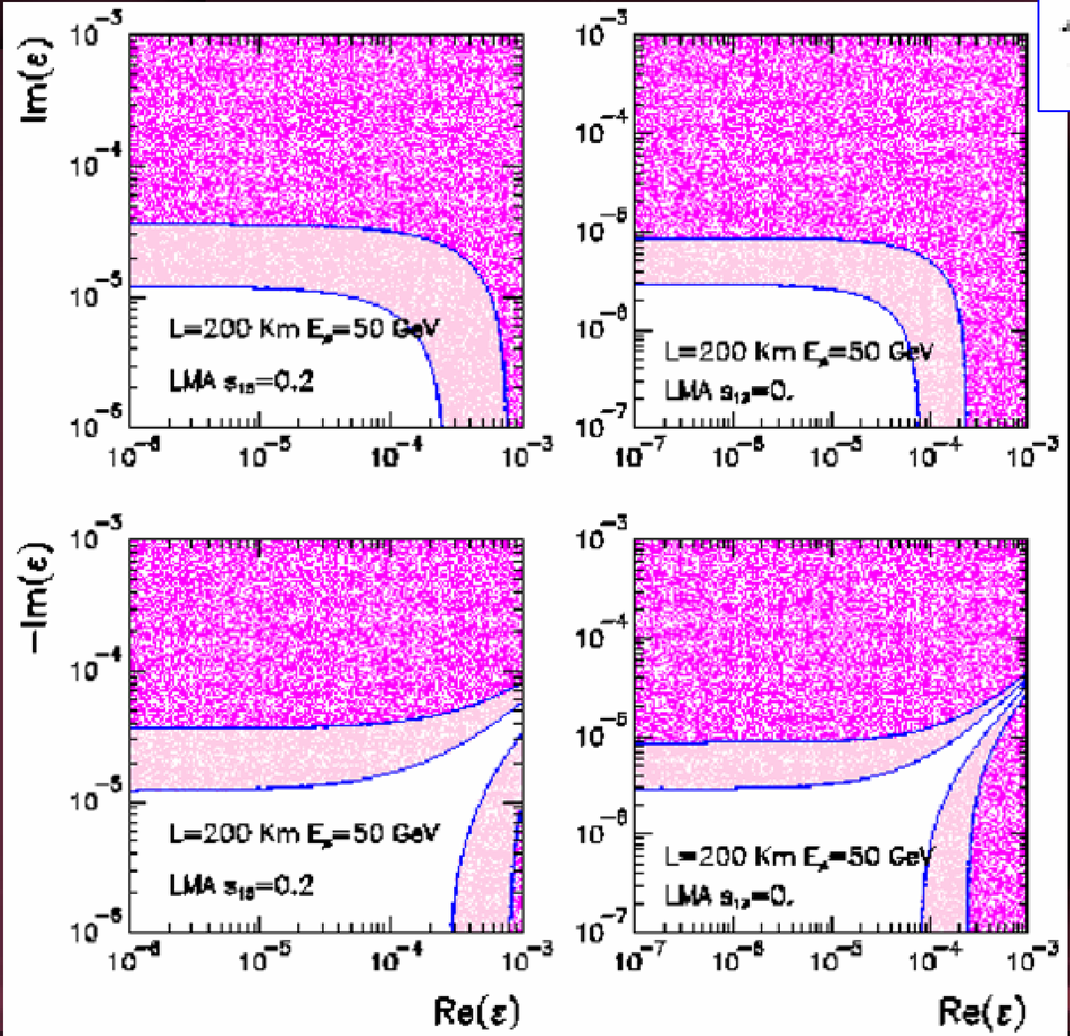
Grossman: ISS 1st Physics w/s @ IC

Nonstandard interactions and neutrino oscillations

Sato: ISS 2nd plenary @ KEK

New Physics at Long baseline experiments

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



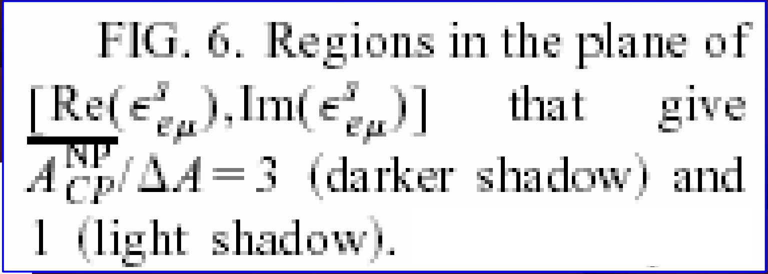


FIG. 6. Regions in the plane of $[\mathrm{Re}(\epsilon^s_{e\mu}), \mathrm{Im}(\epsilon^s_{e\mu})]$ that give $A^{NP}_{CP}/\Delta A = 3$ (darker shadow) and 1 (light shadow).

$$A_{CP} \equiv \frac{P_{e\mu} - P_{\bar{e}\bar{\mu}}}{P_{e\mu} + P_{\bar{e}\bar{\mu}}}$$

Statistics only; naïve arguments

Gonzalez-Garcia, Grossman, Gusso, Nir, Phys. Rev. D64, 096006 (2001)

$\nu_e \to \nu_\mu$

$\left|\varepsilon^{s}_{e\mu}\right| = 3\times10^{-3}$

$\left|\varepsilon^{s}_{e\tau}\right| = 3\times10^{-3}$

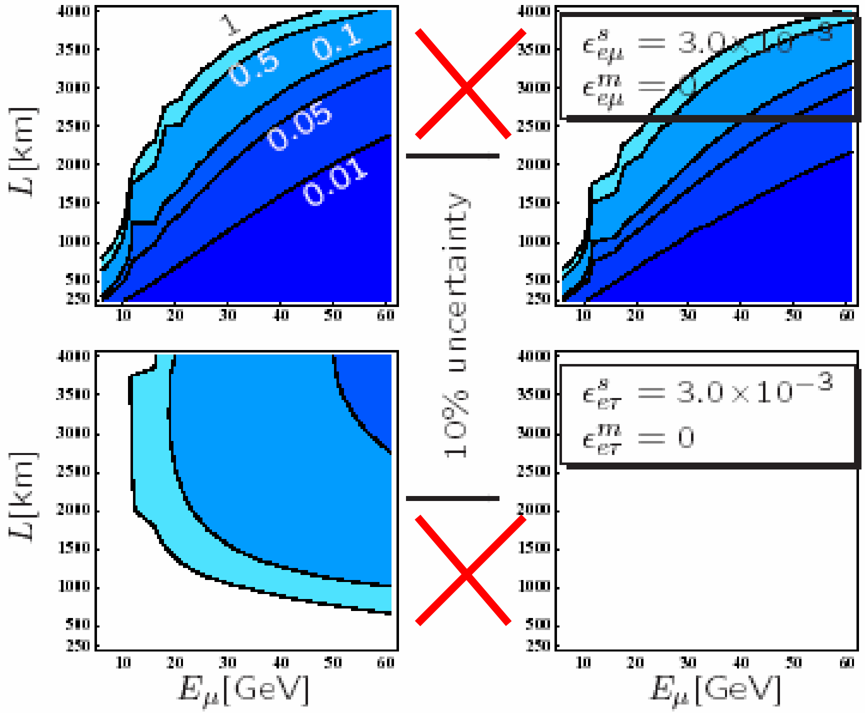
Statistics + some correlations of errors

J. Sato: NuFACT02, WG4 @ IC

$\nu_e \to \nu_\mu$ channel, $\left|\epsilon^{s,m}_{\alpha\beta}\right| = 3\times10^{-3}$, $(V-A)(V-A)$ type

◇ The effects induced by $\epsilon^{s,m}_{e\mu}$ and $\epsilon^{s,m}_{e\tau}$ are large enough to be observed.

◇ However, the $\epsilon^{s,m}_{e\tau}$ effects have the same energy dependence as the main contribution of the standard oscillation. The errors of the oscillation parameters absorb the $\epsilon^{s,m}_{e\tau}$ effects.

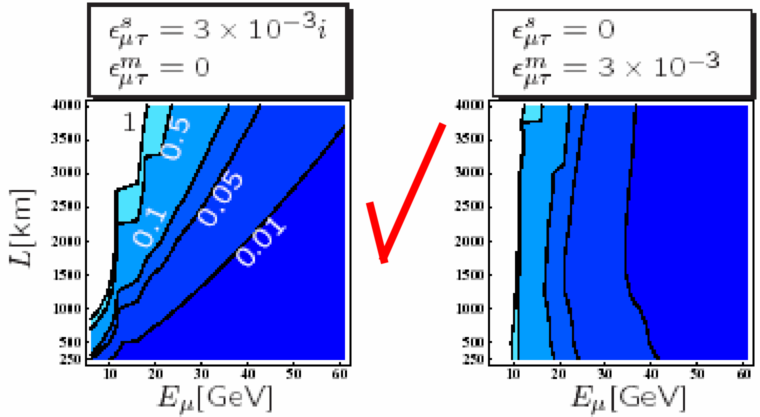


$\nu_\mu \to \nu_\tau$

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

$\nu_\mu \to \nu_\tau$ channel, $\left|\epsilon^{s,m}_{\alpha\beta}\right| = 3\times10^{-3}$, $(V-A)(V-A)$ type

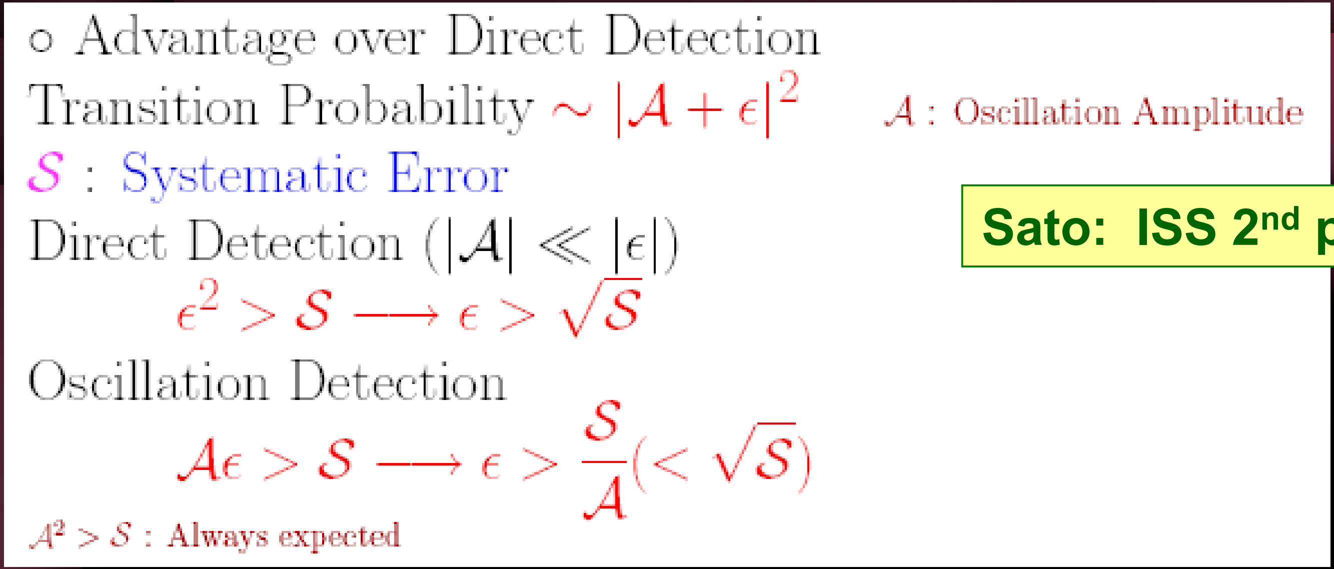
◇ The statistical error gives the appearance channel an advantage over disappearance channel.



◇ The technologies for ν_τ detection are under R&D.

▼

★ The CERN is now putting two experiments that aim at $\nu_\mu \to \nu_\tau$ into practice. **ICARUS** and **OPERA**



○ Advantage over Direct Detection

Transition Probability $\sim |\mathcal{A}+\epsilon|^2$ $\mathcal{A}$: Oscillation Amplitude

$\mathcal{S}$: Systematic Error

Direct Detection $(|\mathcal{A}| \ll |\epsilon|)$

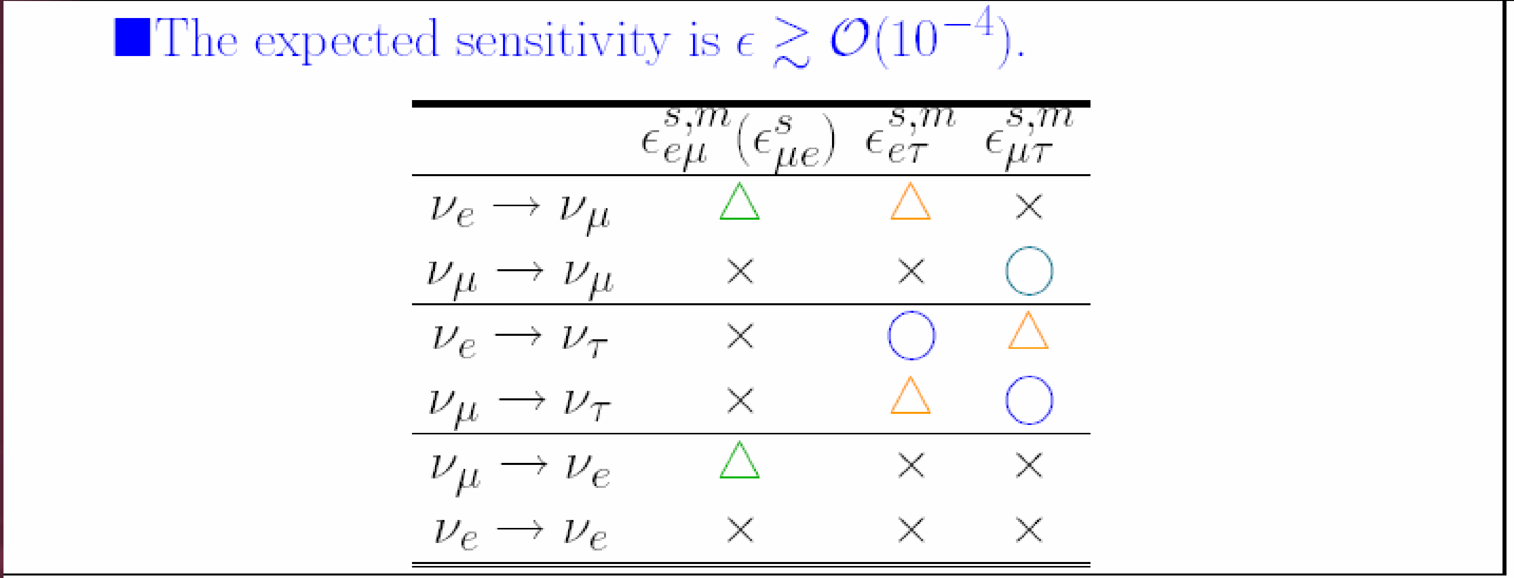
$$\epsilon^2 > \mathcal{S} \longrightarrow \epsilon > \sqrt{\mathcal{S}}$$

Oscillation Detection

$$\mathcal{A}\epsilon > \mathcal{S} \longrightarrow \epsilon > \frac{\mathcal{S}}{\mathcal{A}} (< \sqrt{\mathcal{S}})$$

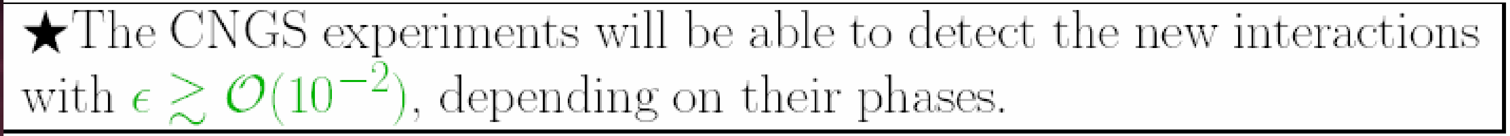
$\mathcal{A}^2 > \mathcal{S}$: Always expected

Sato: ISS 2nd plenary @ KEK



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

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



★The CNGS experiments will be able to detect the new interactions with $\epsilon \gtrsim \mathcal{O}(10^{-2})$, depending on their phases.

Heavy neutrino

The effect of a new interaction is the same as the effect of violation of three generation unitarity

- With NP only in the production

$$\langle \nu_\mu^d | \nu_e^s \rangle = \epsilon^s$$

- With heavy neutrino

$$\langle \nu_\mu^d | \nu_e^s \rangle = U_{eh} U_{\mu h}^*$$

Grossman: ISS 1st Physics w/s @ IC

1-3. New Physics in propagation (matter effect)

Most of $\varepsilon_{\alpha\beta}$ are smaller than O(10^{-2}) except ε_{ee} $\varepsilon_{e\tau}$ $\varepsilon_{\tau\tau}$ ~O(1)

Friedland: ISS 2nd Physics w/s @ BU

Probe of new physics with solar/atmospheric neutrinos

OY: ISS 3rd plenary @ RAL

Model independent analysis of new physics interactions and implications for long baseline experiments

Huber: ISS 1st Physics w/s @ IC

Phenomenological studies of new physics

→ Ongoing LBL may see the effect of ε_{ee} $\varepsilon_{e\tau}$ $\varepsilon_{\tau\tau}$ ~O(1)

→ Future LBL may be able to probe $\varepsilon_{\alpha\beta}$ to order 10^{-3}

→ Degeneracy between θ_{13} and $\varepsilon_{\alpha\beta}$ have to be considered

Constraints from various ν experiments (CHARM, LEP, LSND, NuTeV)

Davidson, Pena-Garay, Rius, Santamaria, JHEP 0303:011,2003

$$\epsilon_{\alpha\beta} \sim \epsilon^{e}_{\alpha\beta} + 3\epsilon^{u}_{\alpha\beta} + 3\epsilon^{d}_{\alpha\beta}$$

$$\begin{pmatrix} -3 \lesssim \epsilon_{ee} \lesssim 2 & |\epsilon_{e\mu}| \lesssim 0.5 & |\epsilon_{e\tau}| \lesssim 1.5 \\ |\epsilon_{e\mu}| \lesssim 0.5 & |\epsilon_{\mu\mu}| \lesssim 0.05 & |\epsilon_{\mu\tau}| \lesssim 0.15 \\ |\epsilon_{e\tau}| \lesssim 1.5 & |\epsilon_{\mu\tau}| \lesssim 0.15 & |\epsilon_{\tau\tau}| \lesssim 6 \end{pmatrix}$$

ε_{ee}, $\varepsilon_{e\tau}$, $\varepsilon_{\tau\tau}$ ~O(1) are consistent with accelerator experiments data

Constraints from atmospheric neutrinos

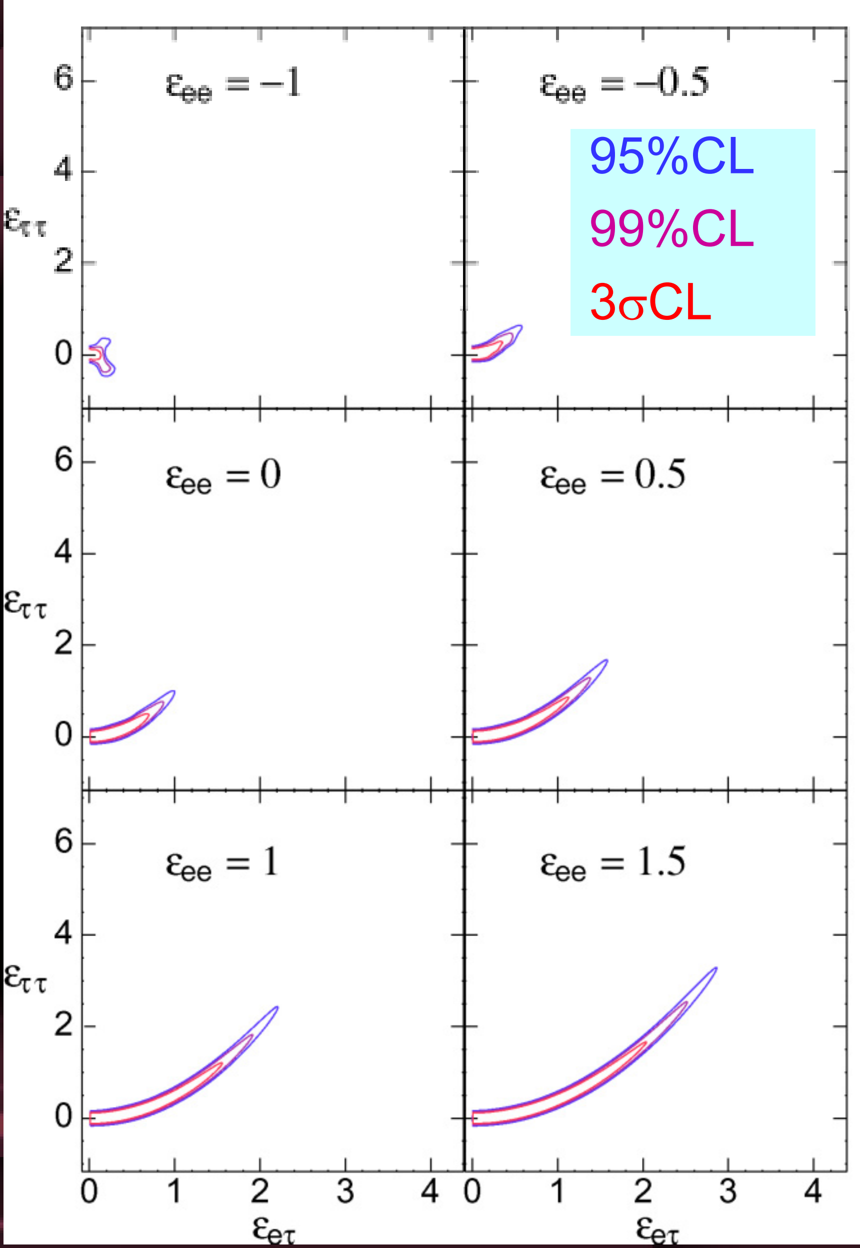
$$\epsilon_{\tau\tau} \sim \frac{|\epsilon_{e\tau}|^2}{1+\epsilon_{ee}}$$

$$0 \le |\epsilon_{e\tau}| \lesssim 1+\epsilon_{ee}$$

$$-1 \lesssim \epsilon_{ee} \lesssim 1.5$$

ε_{ee}, $\varepsilon_{e\tau}$, $\varepsilon_{\tau\tau}$ ~O(1) are consistent with atmospheric neutrino data

Friedland, Lunardini, Phys.Rev.D72:053009,2005



Effect of NSI on the oscillation fit

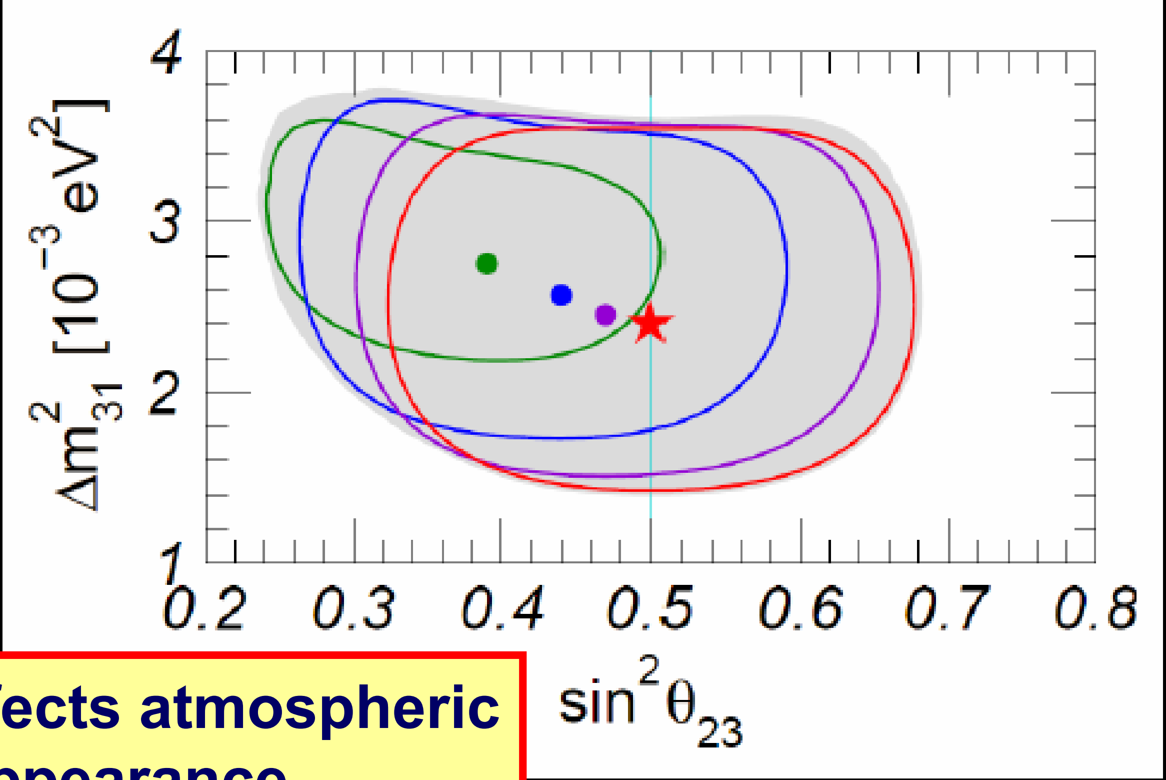
- The best-fit region shifts to smaller θ and larger Δm²: $\cos 2\theta \simeq s_\beta^2/(1+c_\beta^2)$; $\Delta m^2 \simeq \Delta m_m^2(1+\cos^{-2}\beta)/2$

$\epsilon_{e\tau} = 0, \epsilon_{\tau\tau} = 0;$

$\epsilon_{e\tau} = 0.30, \epsilon_{\tau\tau} = 0.106;$

$\epsilon_{e\tau} = 0.60, \epsilon_{\tau\tau} = 0.424;$

$\epsilon_{e\tau} = 0.90, \epsilon_{\tau\tau} = 0.953.$



Effect of $\varepsilon_{\alpha\beta}$~O(1) affects atmospheric parameters → disappearance channel in MINOS may distinguish

NSI can even lead to a new solution: LMA-0…

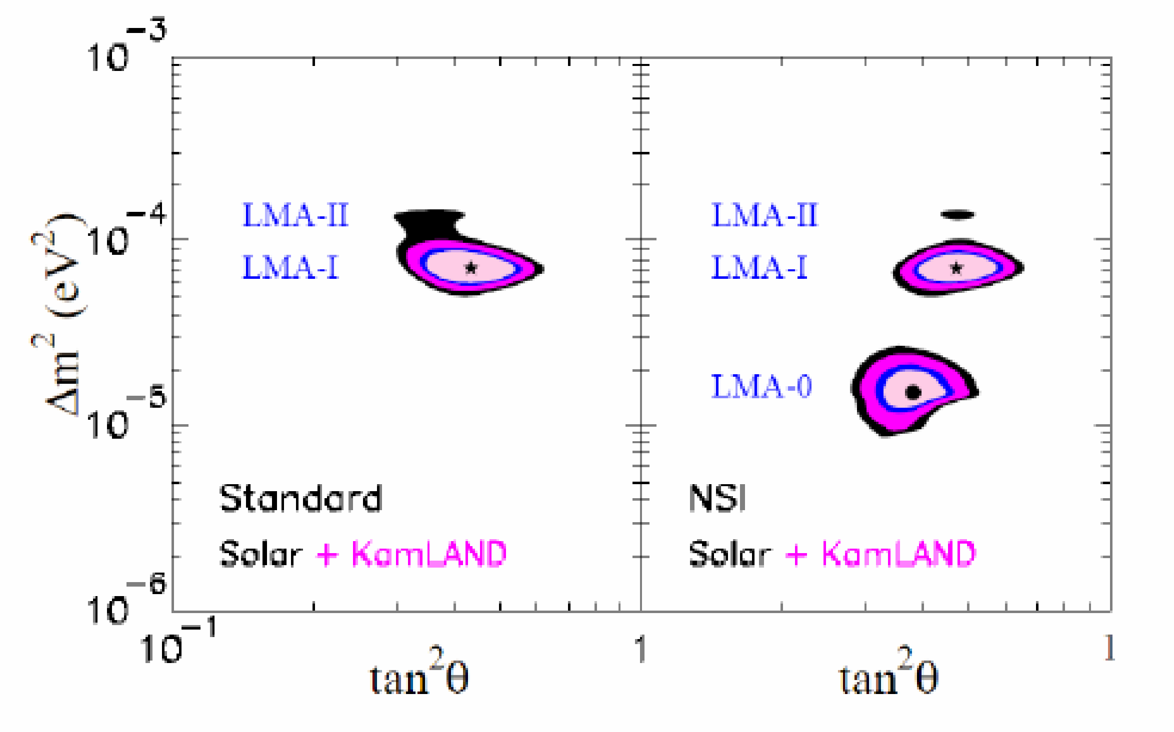
Friedland: ISS 2nd Physics w/s @ BU

- Choose a point that cancels the d/n effect:

$\varepsilon_{ee}^{d} = \varepsilon_{ee}^{u} = -0.025$,

$\varepsilon_{e\tau}^{d} = \varepsilon_{e\tau}^{u} = 0.11$,

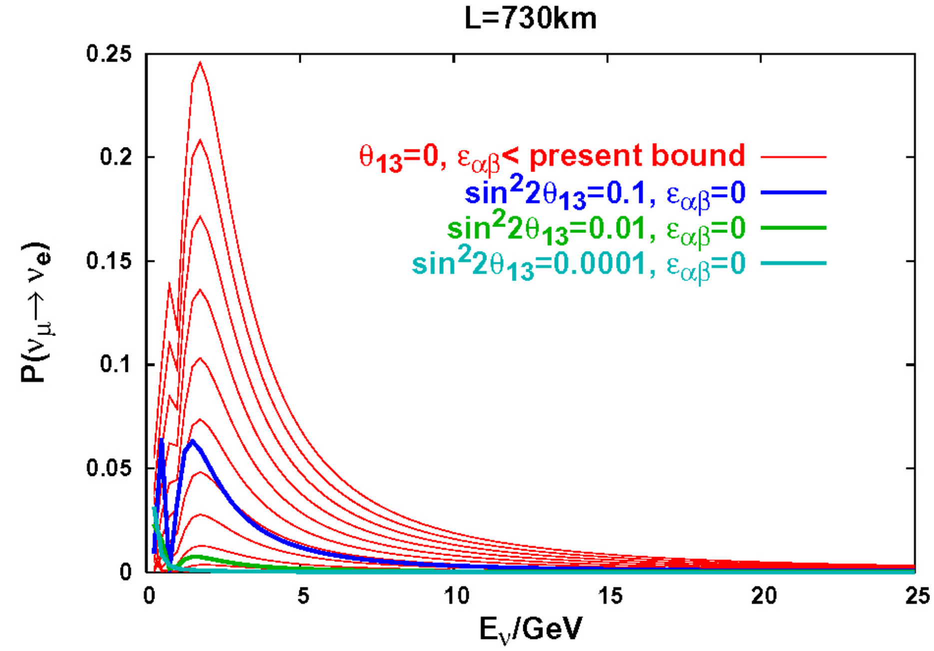
$\varepsilon_{\tau\tau}^{d} = \varepsilon_{\tau\tau}^{u} = 0.08$.



Existence of $\varepsilon_{\alpha\beta}$ leads to a new solar solution

MINOS (ν_e appearance)

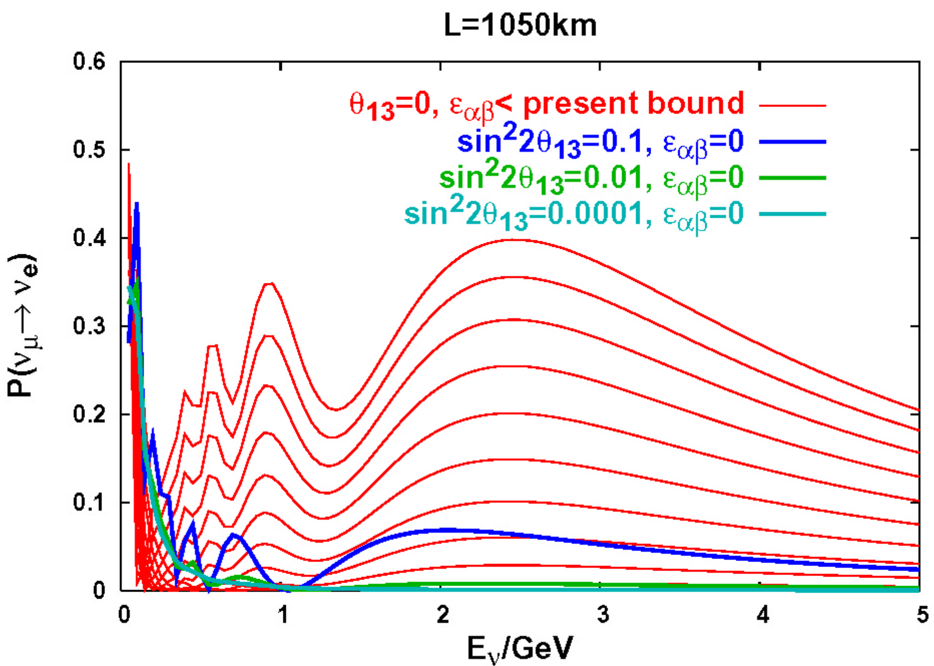
$\nu_\mu \to \nu_e$



OY: ISS 3rd plenary @ RAL

T2KK (ν_e appearance)

$\nu_\mu \to \nu_e$

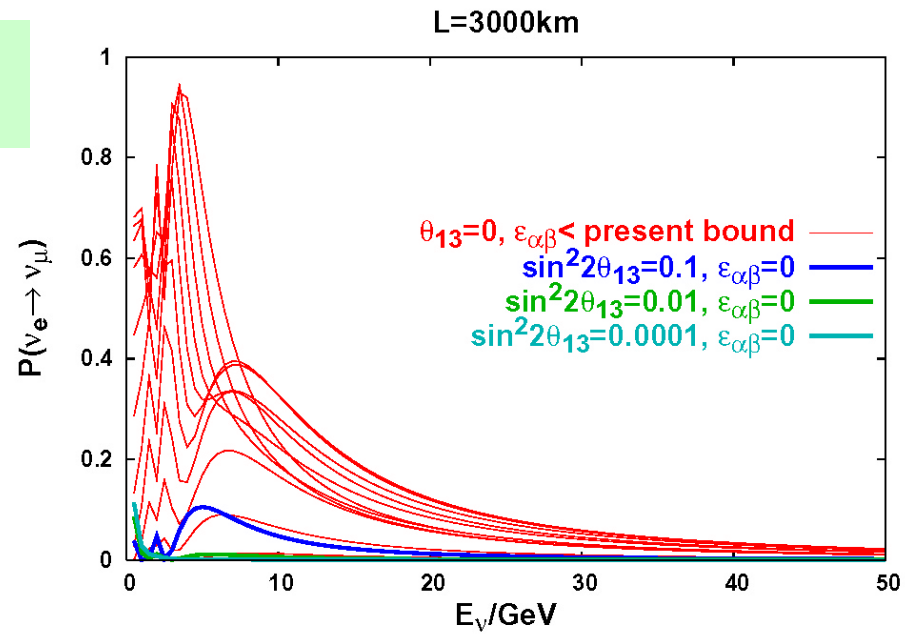


Existence of $\varepsilon_{\alpha\beta}\sim O(1)$ predicts signals in appearance channel of MINOS and future LBL

ν **factory** (golden channel)

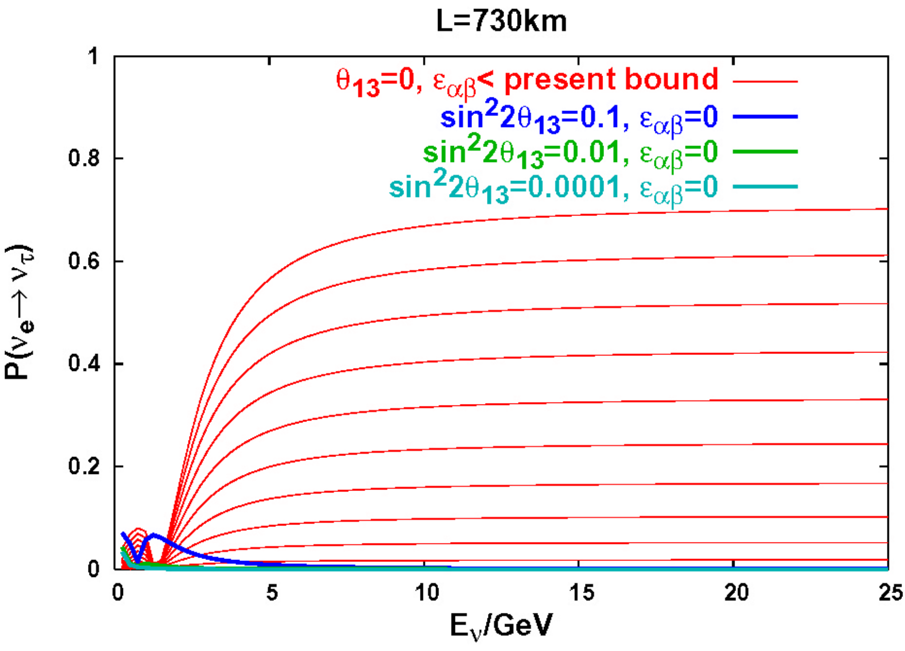
$\nu_e \to \nu_\mu$

OY: ISS 3rd plenary @ RAL



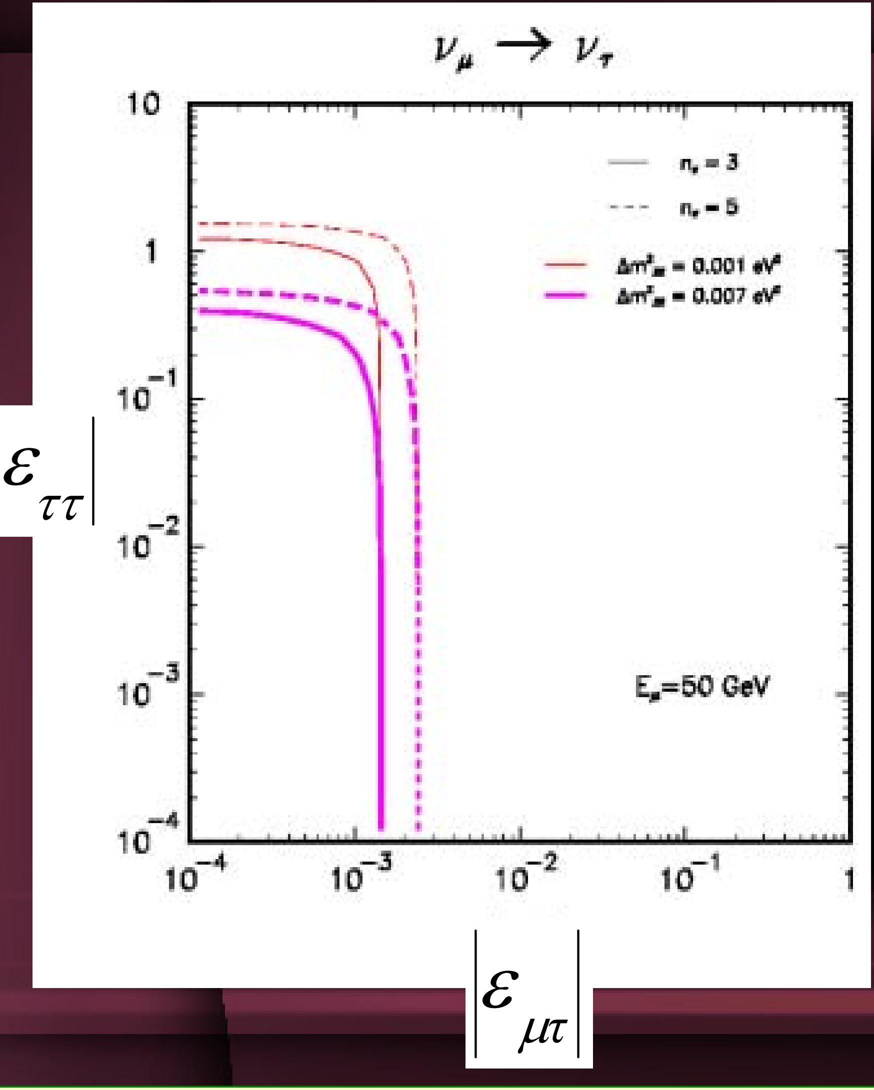
ν **factory** (silver channel)

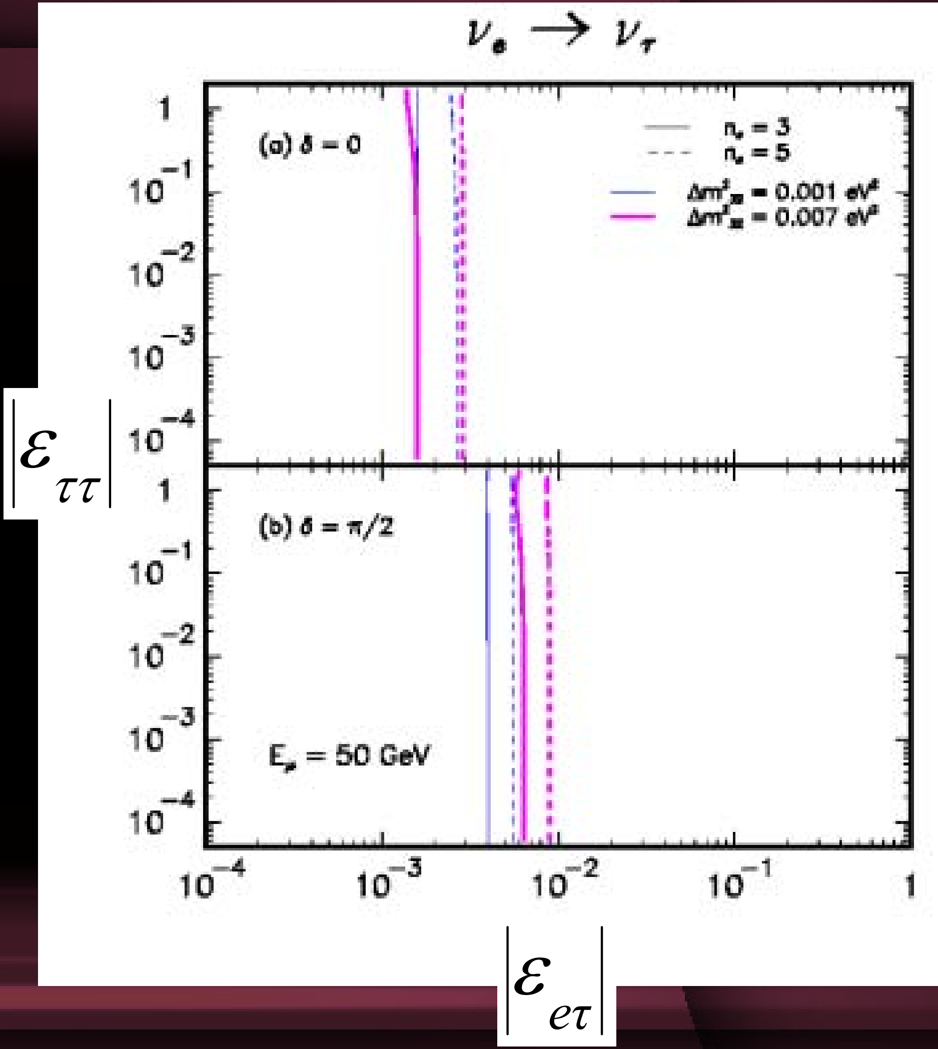
$\nu_e \to \nu_\tau$



Sensitivity at ν factory

Statistics only



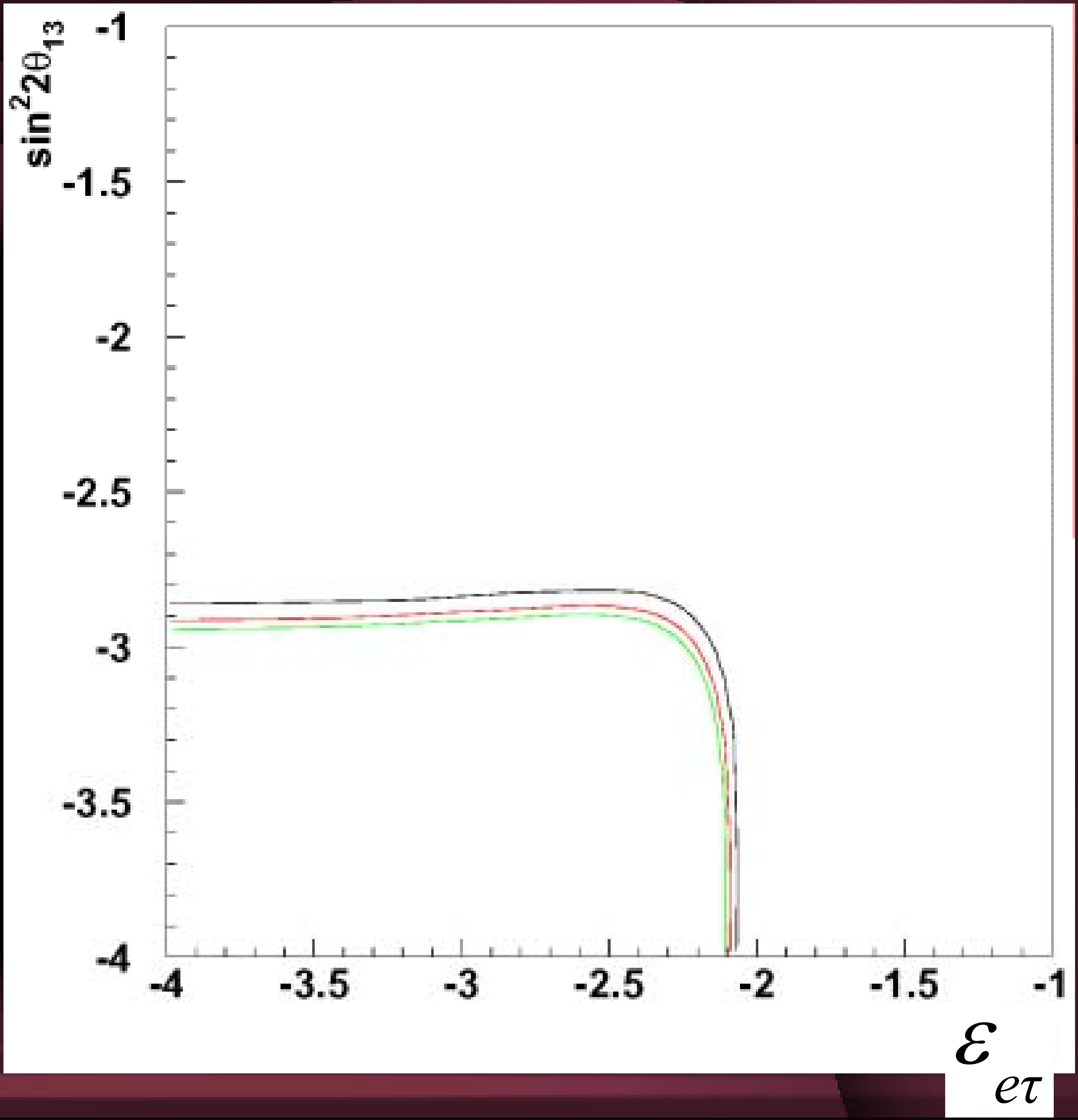


Gago-Guzzo-Nunokawa-Teves-Zukanovich Funchal, Phys.Rev.D64:073003,2001

Sensitivity at ν factory

$\nu_e \rightarrow \nu_\tau$

Statistics only



Campanelli-Romanino, Phys.Rev.D66:113001,2002

Davidson, Pena-Garay, Rius, Santamaria, JHEP 0303:011,2003

$$\epsilon_{\alpha\beta} \sim \epsilon^{e}_{\alpha\beta} + 3\epsilon^{u}_{\alpha\beta} + 3\epsilon^{d}_{\alpha\beta}$$

Sensitivity at near detectors of ν factory

$$\left|\varepsilon^{f}_{ee}\right| < O(10^{-3})$$

$$\left|\varepsilon^{f}_{\mu\mu}\right| < O(10^{-3})$$

$$f = e, u, d$$

$$\left|\varepsilon^{f}_{\mu\tau}\right| < O(10^{-2})$$

$$\left|\varepsilon^{f}_{e\tau}\right| < O(10^{-2})$$

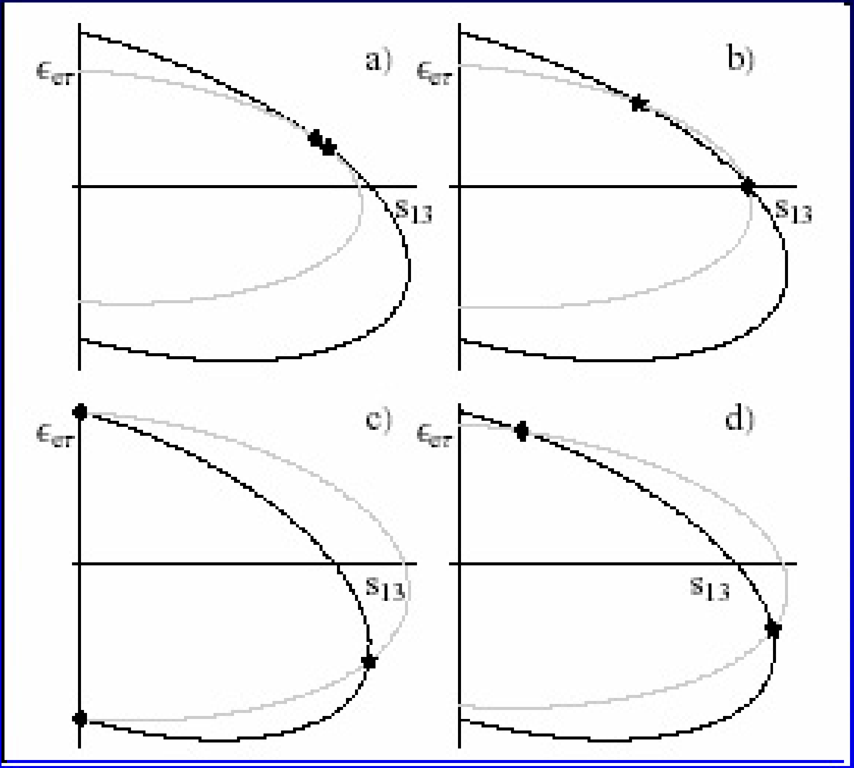
Sensitivity of KamLAND and SNO/SK

$$\left|\varepsilon^{f}_{\tau\tau}\right| < 0.3$$

Huber: ISS 1st Physics w/s @ IC

Flavour violation

The problem usually is that the new physics and θ_{13} can be both small and thus are very difficult to separate

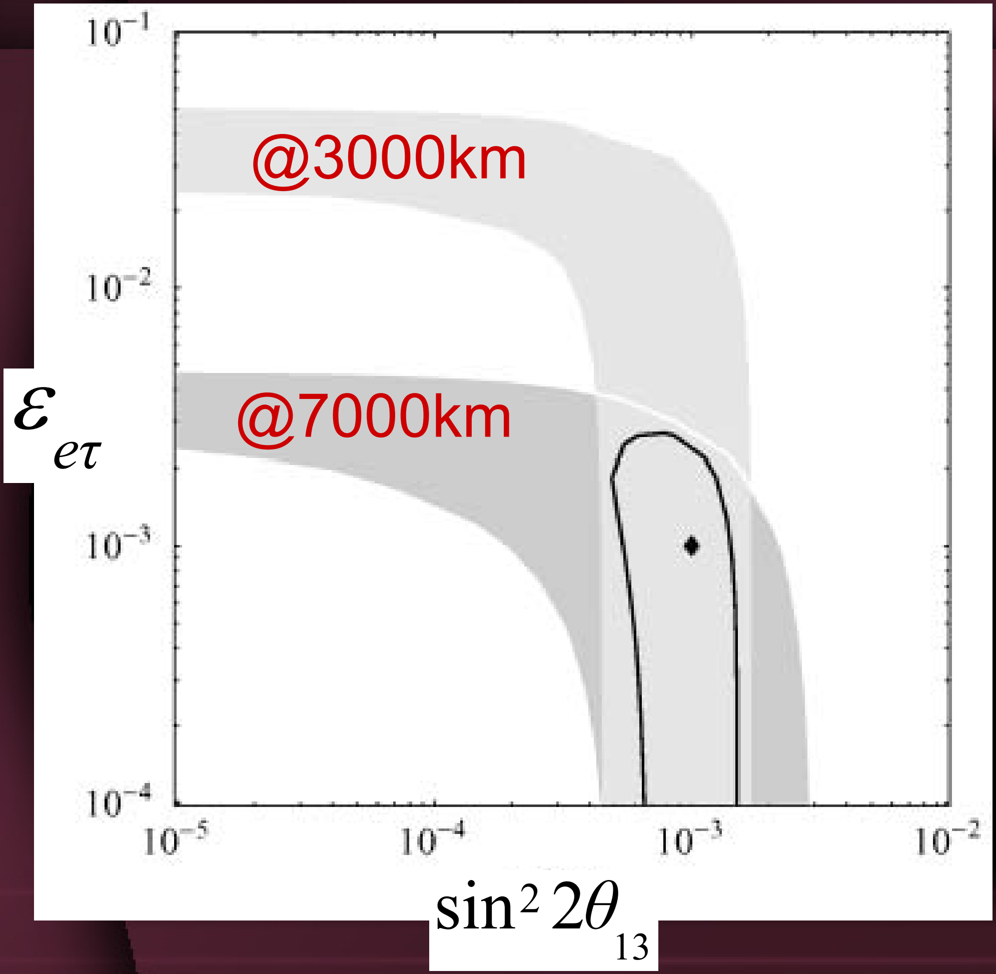


degeneracy between θ_{13} and $\varepsilon_{e\tau}$

In all the analyses θ_{13} is assumed to be known → Simultaneous determination of θ_{13} and $\varepsilon_{\alpha\beta}$ has to be considered in future

figure from Huber, Schwetz, Valle 2001

$\nu_e \rightarrow \nu_\mu$



Degeneracy between θ_{13} and $\varepsilon_{e\tau}$ may be removed by combining two baselines

Huber, Schwetz, Valle, Phys. Rev. Lett. 88, 101804 (2002)

2. Tests of 3 flavor unitarity

2-1. Discussions in the context of light ν_s (w/ or w/o LSND)

Sorel: ISS 2nd plenary @ KEK

(3+2)- sterile ν scheme: now in tension

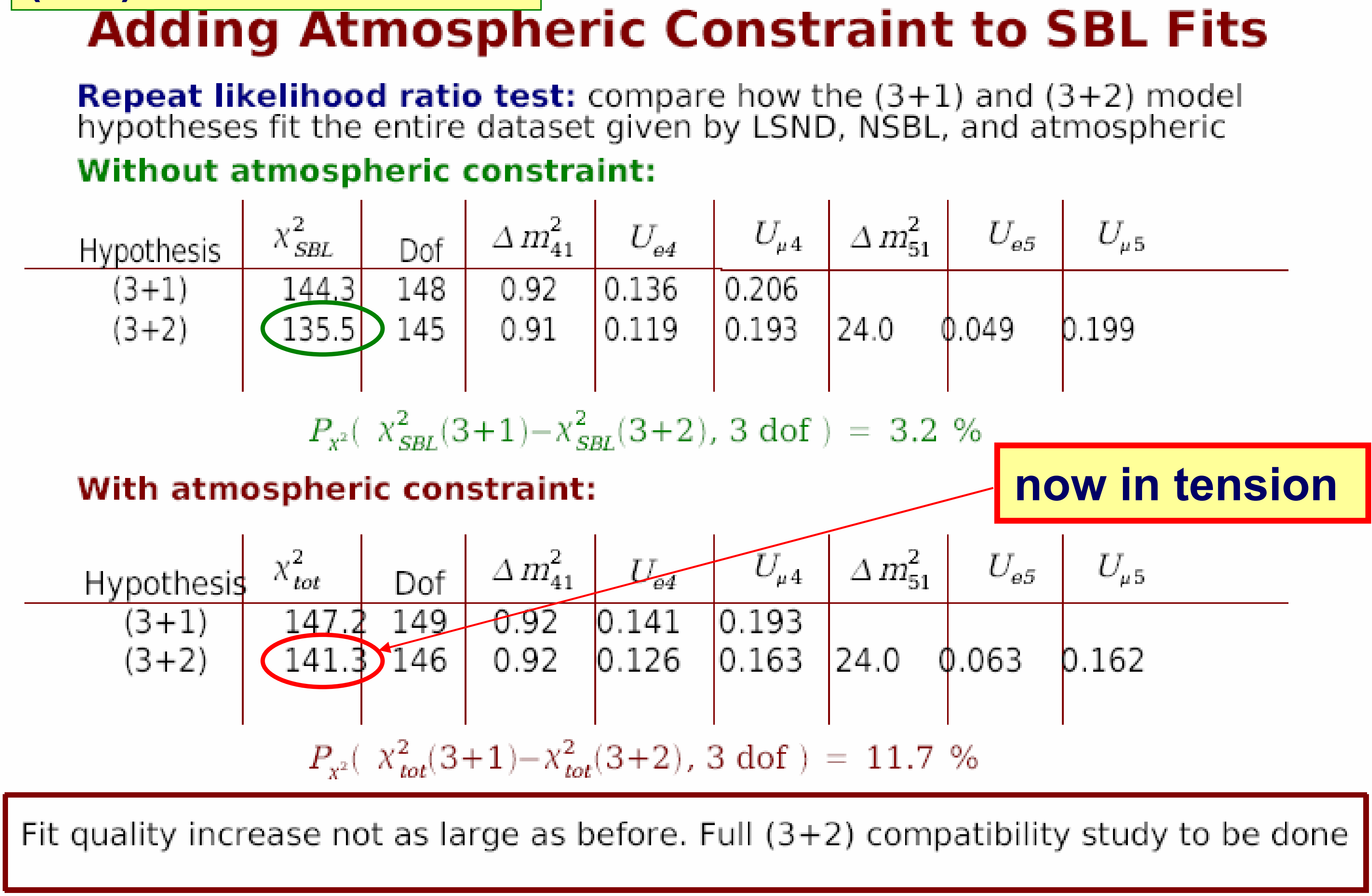
Marfatia: ISS 2nd Physics w/s @ BU

Mass varying neutrino + one light ν_s : even if MiniBooNE sees none, could be consistent with LSND

Geer: ISS 3rd plenary @ RAL

Neutral currents & tests of unitarity: to 10-15% level accuracy

(3+2)- sterile ν scheme



Adding Atmospheric Constraint to SBL Fits

Repeat likelihood ratio test: compare how the (3+1) and (3+2) model hypotheses fit the entire dataset given by LSND, NSBL, and atmospheric

Without atmospheric constraint:

Hypothesis	χ^2_{SBL}	Dof	Δm^2_{41}	U_{e4}	$U_{\mu 4}$	Δm^2_{51}	U_{e5}	$U_{\mu 5}$
(3+1)	144.3	148	0.92	0.136	0.206			
(3+2)	135.5	145	0.91	0.119	0.193	24.0	0.049	0.199

$$P_{\chi^2}(\ \chi^2_{SBL}(3+1)-\chi^2_{SBL}(3+2),\ 3\ \text{dof}\ )\ =\ 3.2\ \%$$

With atmospheric constraint:

Hypothesis	χ^2_{tot}	Dof	Δm^2_{41}	U_{e4}	$U_{\mu 4}$	Δm^2_{51}	U_{e5}	$U_{\mu 5}$
(3+1)	147.2	149	0.92	0.141	0.193			
(3+2)	141.3	146	0.92	0.126	0.163	24.0	0.063	0.162

$$P_{\chi^2}(\ \chi^2_{tot}(3+1)-\chi^2_{tot}(3+2),\ 3\ \text{dof}\ )\ =\ 11.7\ \%$$

now in tension

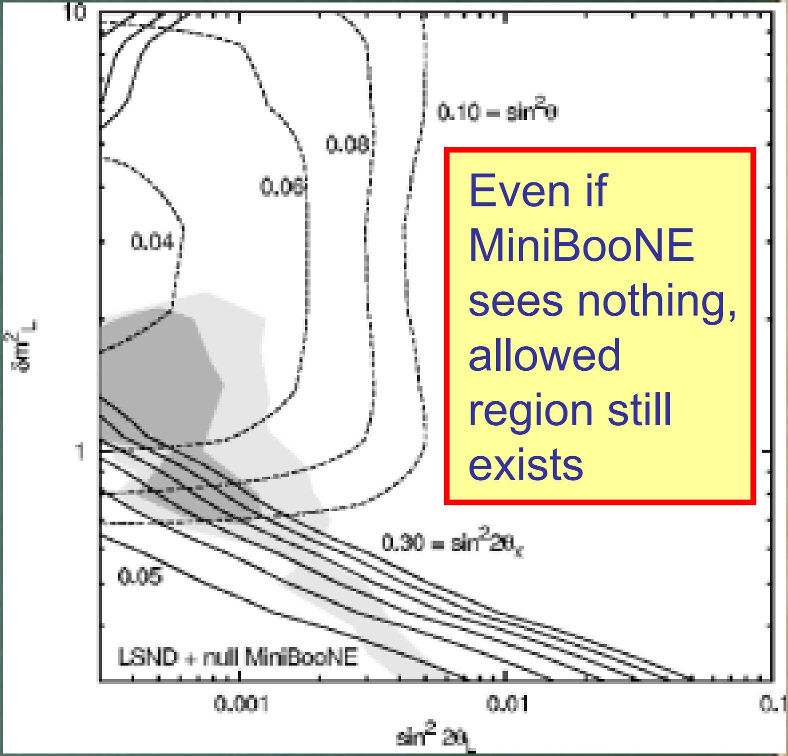
Fit quality increase not as large as before. Full (3+2) compatibility study to be done

Sorel: ISS 2nd plenary @ KEK

Signatures

- 3+1 MaVaN model explains all oscillation data including LSND and a null-MiniBooNE result
- Need $0.1 < \sin^2 2\theta_x < 0.3$

\- Underground reactor experiments (Angra, Braidwood,
Daya Bay, KASKA) should see a signal
The above-ground Double-CHOOZ should not see a signal



Even if MiniBooNE sees nothing, allowed region still exists

\- Long-baseline experiments (MINOS, ICARUS) should see $\nu_\mu \to \nu_e$ oscillations

Mass varying neutrino scenario + one ν_s

Marfatia: ISS 2nd Physics w/s @ BU

FINAL COMMENTS

$P_{xe}+P_{x\mu}+P_{x\tau}=1$?

tests of ν_s to 10-15% level accuracy

It may be possible for NC measurements to be sensitive to oscillations to sterile neutrinos if the oscillation probability exceeds a few percent, but this requires:

1. Event samples of at least a few thousand events.
2. Systematic uncertainties on the expected number of NC interactions (from flux and cross-section uncertainties) of at most a few %.
3. Good event identification, with only modest contaminations of the NC signal from CC interactions.

Challenging but worthwhile

Geer: ISS 3rd plenary @ RAL

2-2. Discussions on 3 flavor unitarity w/o light ν_s

Constraints from weak decays turned out to be more stringent than ν oscillation:

Zralek: ISS 1st Physics w/s @ IC

Nonunitary neutrino mixing

Lopez: ISS 3rd plenary @ RAL

Unitarity of the lepton sector

→ Deviation from unitarity < O(1%)

6. CONCLUSIONS

Zralek: ISS 1st Physics w/s @ IC

1. Some models are able to predict visible mixing between light and heavy neutrinos, but the departure from the SM predictions, resulting from the charged lepton processes, are small,

2. Present limits postpone any observation of non – unitary mixing in the neutrino oscillation to the ν factory experiments,

3. The main signature is the observation of CP violation together with no mixing between first and third families $(\theta_{13} \longrightarrow 0)$,

4. Other effect, like the sum of probabilities not adding to 1 or modified resonance effects will be difficult to discriminate,

5. Ten best place to look for lack of unitarity is the μ and τ processes not involving e because there present limits are less stringent.

The L=0 effect

$$P(\nu_\alpha \to \nu_\beta, L=0) = \left| \sum_i N_{\alpha i} N^*_{\beta i} \right|^2$$

$= \delta_{\alpha\beta}$?

PRESENT

KARMEN

$\bar{\nu}_\mu \to \bar{\nu}_e$

$$\left| \sum_i N_{\mu i} N^*_{ei} \right| < 0.05$$

NOMAD

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

$$\left| \sum_i N_{ei} N^*_{\tau i} \right| < 0.09$$

$$\left| \sum_i N_{\mu i} N^*_{\tau i} \right| < 0.013$$

FROM DECAYS

$\mu \to e\gamma$

$$\left| \sum_i N_{\mu i} N^*_{ei} \right| < 7.2 \cdot 10^{-5}$$

$\tau \to e\gamma$ $\tau \to \mu\gamma$

$$\left| \sum_i N_{ei} N^*_{\tau i} \right| < 0.016$$

$$\left| \sum_i N_{\mu i} N^*_{\tau i} \right| < 0.013$$

FUTURE@NF

40kt Iron cal

$\nu_e \to \nu_\mu$

$$\left| \sum_i N_{\mu i} N^*_{ei} \right| < 2.3 \cdot 10^{-4}$$

4kt OPERA (100 m)

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

$$\left| \sum_i N_{ei} N^*_{\tau i} \right| < 2.9 \cdot 10^{-3}$$

$$\left| \sum_i N_{\mu i} N^*_{\tau i} \right| < 2.6 \cdot 10^{-3}$$

Lopez: ISS 3rd plenary @ RAL

Works which discussed/predicted non-unitarity in ν oscillation include:

Langacker, London, Phys. Rev. D 38 (1988) 907;
Bilenky, Giunti, Phys. Lett. B300 (1993) 137;
Nardi, Roulet, Tommasini, Phys. Lett. B327 (1994) 319;
Bergmann, Kagan, Nucl. Phys. B538 (1999) 368;
Czakon, Gluza, Zralek, Acta Phys. Polon. B32 (2001) 3735;
Bekman, Gluza, Holeczek, Syska Zralek, Phys. Rev. D66 (2002) 093004;
De Gouvea, Giudice, Strumia, Tobe, Nucl. Phys. B623 (2002) 395;
Broncano, Gavela, Jenkins, Phys. Lett. B552 (2003) 177;
Loinaz, Okamura, Takeuchi, Wijewardhana, Phys. Rev. D67, 073012 (2003);
Loinaz, Okamura, Rayyan, Takeuchi, Wijewardhana,
  Phys. Rev. D68, 073001 (2003); Phys. Rev. D70, 113004 (2004);
Fukuyama, Kikuchi, Matsuda, hep-ph/0510054;
Antusch, Biggio, Fernandez-Martinez, Gavela, Lopez-Pavon, hep-ph/0607020.

3. Summary

Phenomenology Subgroup mainly studied on deviation from **SM+massive ν**. The main two issues are:

- ● new physics

Current bounds on $\varepsilon_{\alpha\beta}$ are typically of order 10^{-3} for production and detection, and of order 10^{-2} for propagation → ν factory may be able to improve roughly by one order of magnitude

- ● tests of 3 flavor unitarity

→ Deviation from unitarity < O(1%); Further studies necessary

Due to time constraint, only qualitative aspects on deviation from SM+massive ν have been discussed.

↓

There are a lot of problems to be worked out:

- Quantitative discussions on measuring θ_{13} and effects of new physics and/or non-unitarity (correlations of errors, degeneracies, dependence on the beam energy and the baseline, etc.)
- Distinction between the new physics effects (e.g., 4-fermi interactions vs. non-unitarity from modification in the kinetic term)
- Predictions of various models on deviation from SM+massive ν

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