-----------------(Phenomenology session of WG2)-----------------

Wednesday (3 July, 2002)

10:~~00~~ 22 - 10:~~30~~ 52	S. Choubey	Global analysis of solar neutrinos
10:~~30~~ ~~48~~ - 11:~~00~~ ~~18~~	K. Kimura	EXACT FORMULA OF PROBABILITY AND CP VIOLATION FOR NEUTRINO OSCILLATIONS IN MATTER
11:~~30~~ 45 - 12:~~00~~ 15	H. Minakata	METHOD FOR DETERMINATION OF |U(E3)| IN NEUTRINO OSCILLATION APPEARANCE EXPERIMENTS
12:~~00~~ 15 - 12:~~30~~ 45	K. Whisnant	BREAKING EIGHT FOLD DEGENERACIES IN NEUTRINO CP VIOLATION, MIXING, AND MASS HIERARCHY
12:~~30~~ 45 - 13:~~00~~ 15	O. Mena	Resolving degeneracies between CP-delta and theta_{13}
~~13:55~~ 14:10 - ~~14:30~~ 14:45	P. Huber	CP, T & CPT violation at future LBL experiments
14:30-15:00	Y.Y.Y. Wong	T-violation tests for relativity principles
15:00-15:30	M. Campanelli	Effects of new physics in Oscillations in matter
~~15:30~~ 16:00 - 16:~~00~~ 30	D. Meloni	The nu_e -> nu_tau channel as a tool to improve the leptonic CP violation measurement
16:30-17:00	T. Ota	Matter profile effect in neutrino factory
17:00-17:30	W. Winter	The effects of matter density uncertainties on neutrino oscillations in the Earth

-----------------(Theory session of WG2)-----------------

17:30-18:00	T. Morozumi	LEPTOGENESIS AND LOW ENERGY CP VIOLATION
18:00-18:30	A. Ibarra	Leptogenesis and low energy phases

not covered in this summary

----------------(Theory session of WG2)----------------------------

Tuesday (2 July, 2002)

16:30-17:00	Q. Shafi	Neutrino mass in extra dimensions
17:00-17:30	T. Blazek	GUT models
17:30-18:15	J.W.F. Valle	std & Non-standard interpretations

not covered in this summay

----------------(Joint theory session with WG4)----------------------------

Thursday (4 July, 2002)

14:15 45 14:~~00~~-14:~~30~~	Y. Shimizu	Theories of lepton flavor violation
14:30-15:00	N. Shimoyama	Neutrino Bimaximal Texture in MSSM with Right-handed Neutrino and Lepton Flavor Violation
15:00-15:30	M. Koike	Calculation of mu-e conversion
~~15:30~~-16:~~00~~ 16:00 30	J. Sato	OSCILLATION ENHANCED SEARCH FOR NEW INTERACTION WITH NEUTRINOS
Break		
16:30-17:10	K. Babu	LEPTON NUMBER VIOLATING MUON DECAY AND THE LSND NEUTRINO ANOMALY

WG2 Summary (Phenomenology)

O. YASUDA
(安田 修)

anomalies in ν physics

$\nu_\odot$ $\Delta m_\odot^2 \sim O(10^{-5}\mathrm{eV}^2)$ $\sin^2 2\theta_\odot \sim 0.8$ LMA

ν_{atm} $\Delta m_{atm}^2 \sim O(10^{-3}\mathrm{eV}^2)$ $\sin^2 2\theta_{atm} \sim 1.0$

LSND $\Delta m_{LSND}^2 \sim O(1\mathrm{eV}^2)$ $\sin^2 2\theta_{LSND} \sim O(10^{-3}-10^{-2})$

(not disscussed here)

$(\beta\beta)_{0\nu}$ $0.11\mathrm{eV} \lesssim m_\nu \lesssim 0.58\mathrm{eV}$

↳ Phenomenologists can always assume Majorana mass term and can shift m_ν, so no problem arises.

framework		$\nu_\odot$	ν_{atm}	LSND	comments
$N_\nu=3$		✓(ν-osc)	✓(ν-osc)	×	Perfect except for LSND.
$N_\nu=4$	(2+2)	Δ(tension between $\nu_\odot$ & ν_{atm})		✓(ν-osc)	Both schemes have tension, so this doesn't work well.
	(3+1)	✓(ν-osc)	✓(ν-osc)	Δ(tension w/ Bugey, CDHSW, KARMEN2)	
Babu-Pakvasa		✓(ν-osc)	✓(ν-osc)	✓(LFV)	Phenomenologically perfect.
~~CPT~~ w/ $N_\nu=3$		✓(ν-osc)	✓(ν-osc)	✓(ν-osc)	Lorentz inv. is broken. (to be killed by KamLAND)

$N_\nu=3$ — main subject @ WG2

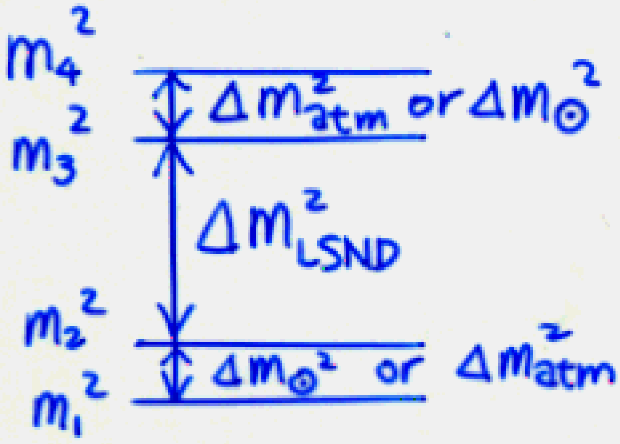
$N_\nu=4$ — not discussed

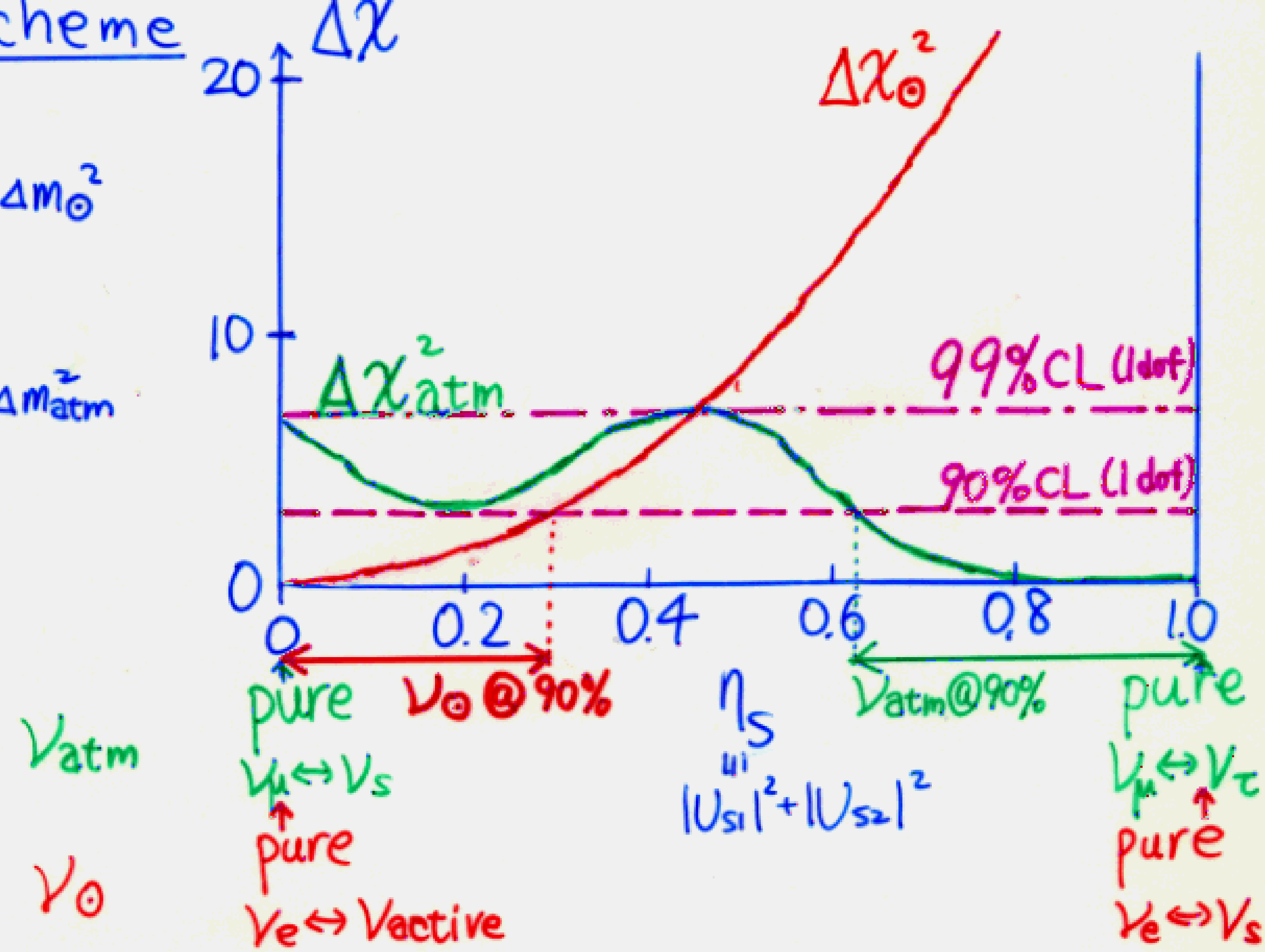
Babu-Pakvasa — discussed @ joint WG2+WG4

- 4ν scenarios have tension w/ data

J. W. F. Valle

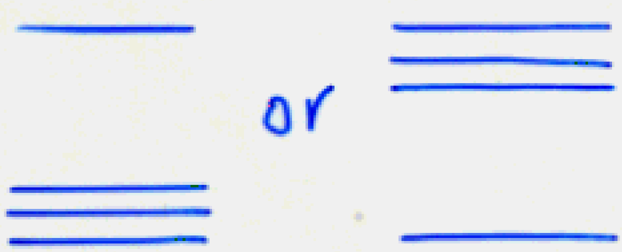
(2+2) - scheme

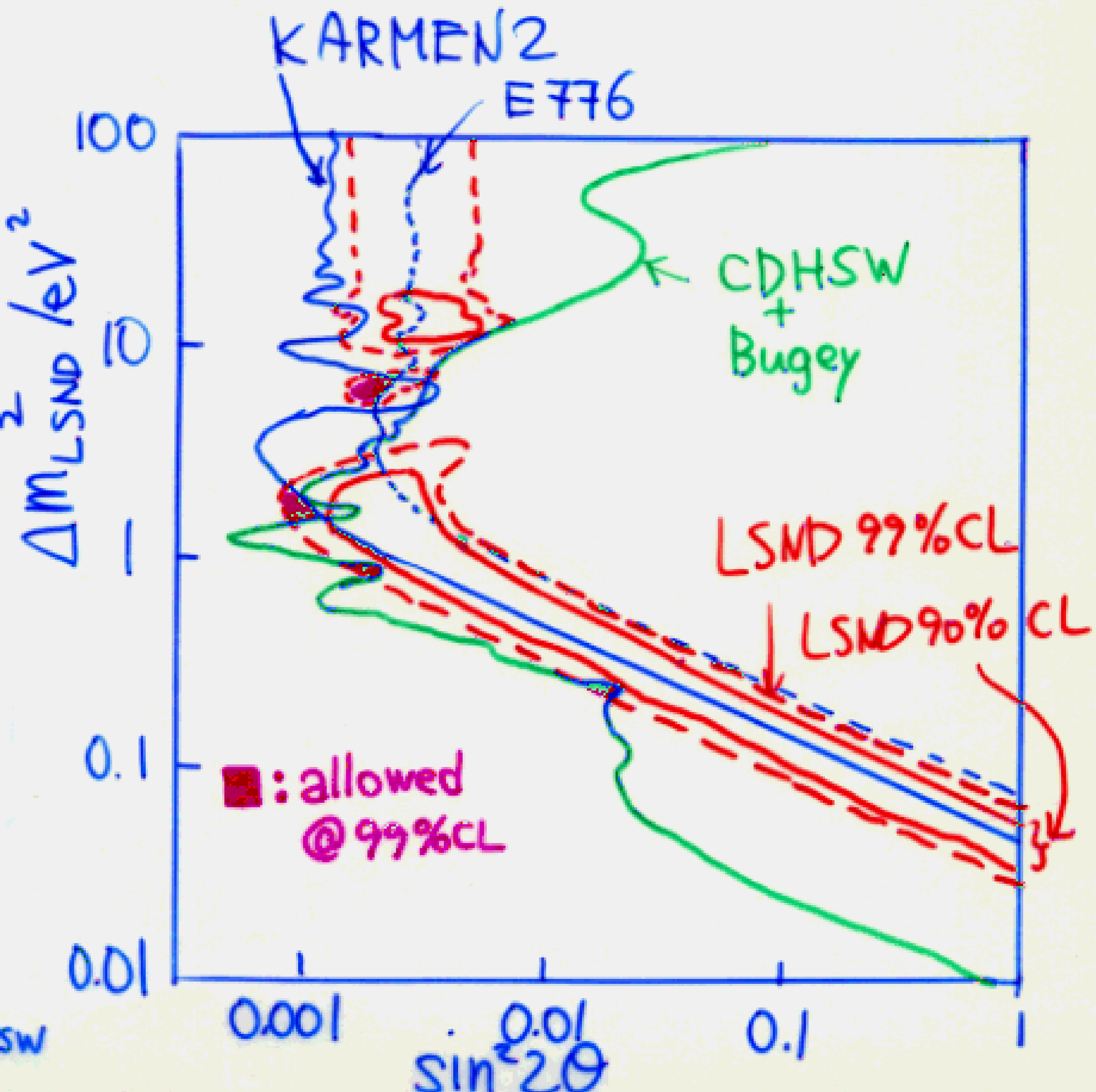




no overlap of 90% CL allowed regions of ν_{atm} & $\nu_\odot$

(3+1) - scheme





Bugey ($\bar{\nu}_e \to \bar{\nu}_e$) :
$4|U_{e4}|^2 \le \sin^2 2\theta_{Bugey}$

CDHSW ($\nu_\mu \to \nu_\mu$) :
$4|U_{\mu 4}|^2 \le \sin^2 2\theta_{CDHSW}$

↳ LSND in (3+1) - scheme

$$\sin^2 2\theta_{LSND} = 4|U_{e4}|^2 |U_{\mu 4}|^2 \le \frac{1}{4} \sin^2 2\theta_{Bugey} \sin^2 2\theta_{CDHSW}$$

- Lepton # violation in μ-decay

K. S. Babu

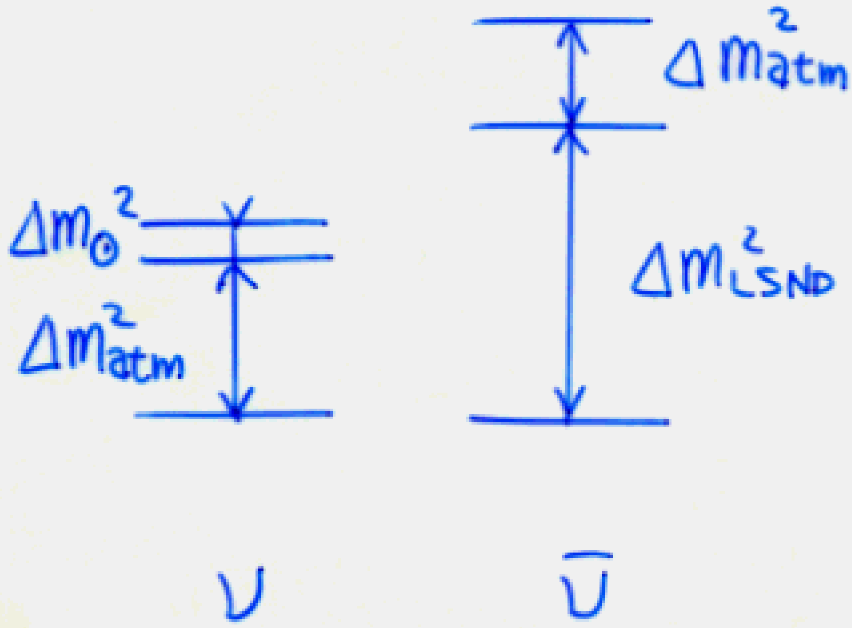
$$\mu^+ \to e^+ + \bar{\nu}_e + \bar{\nu}_i \qquad (i = e, \mu, \tau)$$

$\Delta L = 2$ process explains LSND

NB Mini-Boone will see nothing.
(π-decay)

- CPT violation

Murayama-Yanagida '01



If Δm^2_{ij} is different for ν & $\bar{\nu}$
then $N_\nu = 3$ is enough to explain
LSND. : no $\bar{\nu}_e \leftrightarrow \bar{\nu}_e$ for $\Delta m^2_{ij} = \Delta m^2_\odot$

$\Rightarrow$ If Kamland sees deficit in $\bar{\nu}_e \leftrightarrow \bar{\nu}_e$
for $\Delta m^2 = \Delta m^2_\odot$ (LMA) then this scenario
will be excluded.

Subjects discussed @ WG2 (phenomenology)

$\boxed{N_\nu = 3}$

$\underbrace{(\Delta m^2_{21}, \theta_{12})}_{\nu_\odot}$, $\underbrace{(\Delta m^2_{32}, \theta_{23})}_{\nu_{atm}}$, $\boxed{\theta_{13},\ \mathrm{sign}(\Delta m^2_{32}),\ \delta}$

$\nu_\odot$
S. Choubey
J.W.F. Valle

ν_{atm}

to be measured by future long baseline experiments
main motivation

- exact formula for $P(\nu_\alpha \to \nu_\beta)$ in matter with constant density
  K. Kimura

- degeneracy in parameter space
  - (δ, θ_{13})
  - $\pm \Delta m^2_{32}$
  - $(\theta_{23}, \frac{\pi}{2} - \theta_{23})$

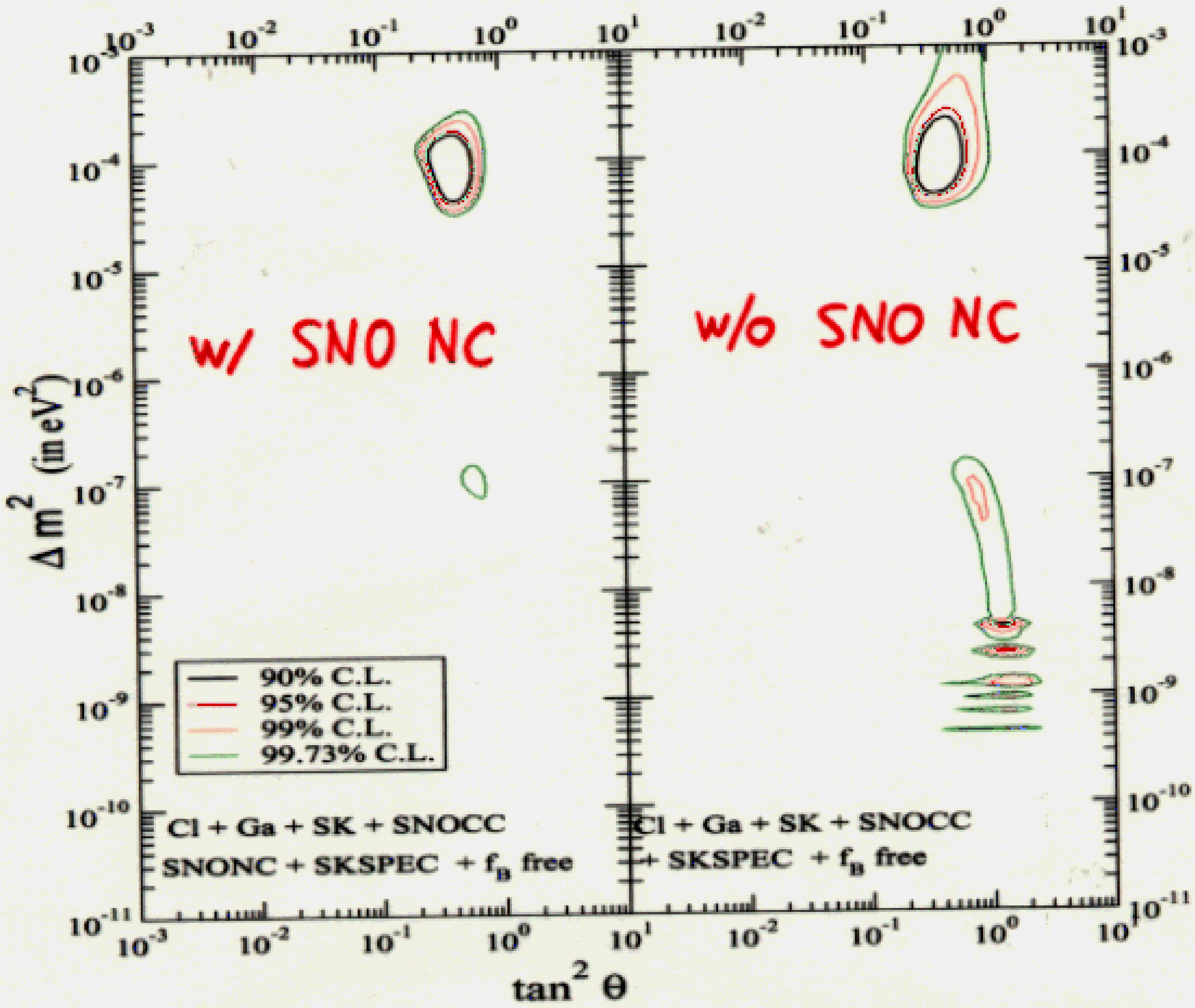
  H. Minakata
  K. Whisnant
  O. Mena
  D. Meloni

- determination of $N_e(x)$ from LBL exp.
  T. Ota
  W. Winter

- exotic scenarios
  P. Huber — ~~CPT~~ as well as ~~CP~~, ~~T~~
  Y. Y. Y. Wong — violation of equivalence principle
  M. Campanelli, J. Sato — new exotic interactions

Impact of SNO NC on Parameter Space

S. Choubey (सन्ध्या चौबे)



- LOW appears only at 3σ
- Values of Δm^2 above 3×10^{-4} disfavored
- VO-QVO and Just-So not allowed at 3σ
- Maximal Mixing is disfavored at 3σ
- SMA further disfavored
- Dark Side solutions are gone $\Rightarrow \Delta m^2 > 0$

K. Kimura (木村恵一) Exact formula of $P(\nu_\alpha \to \nu_\beta)$ in matter w/ const. density

$$P(\nu_\alpha \to \nu_\beta)_{\text{in matter}} = \delta_{\alpha\beta} - 4\sum_{j<k} \mathrm{Re}(\tilde{X}_j^{\alpha\beta} \tilde{X}_k^{\alpha\beta *}) \sin^2\left(\frac{\Delta\tilde{E}_{jk} L}{2}\right) + 2\sum_{j<k} \mathrm{Im}(\tilde{X}_j^{\alpha\beta} \tilde{X}_k^{\alpha\beta *}) \sin(\Delta\tilde{E}_{jk} L)$$

$$\begin{pmatrix} \tilde{X}_1^{\alpha\beta} \\ \tilde{X}_2^{\alpha\beta} \\ \tilde{X}_3^{\alpha\beta} \end{pmatrix} = \begin{pmatrix} \frac{1}{\Delta\tilde{E}_{21}\Delta\tilde{E}_{32}} (\tilde{E}_2\tilde{E}_3 & -(\tilde{E}_2+\tilde{E}_3) & 1) \\ \frac{1}{\Delta\tilde{E}_{21}\Delta\tilde{E}_{32}} (-\tilde{E}_1\tilde{E}_3 & \tilde{E}_1+\tilde{E}_3 & -1) \\ \frac{1}{\Delta\tilde{E}_{32}\Delta\tilde{E}_{31}} (\tilde{E}_1\tilde{E}_2 & -(\tilde{E}_1+\tilde{E}_2) & 1) \end{pmatrix} \begin{pmatrix} \delta^{\alpha\beta} \\ \sum_j E_j X_j^{\alpha\beta} \\ \sum_j E_j^2 X_j^{\alpha\beta} + \delta^{\alpha e} A \sum_j E_j X_j^{e\beta} + \delta^{\beta e} A \sum_j E_j X_j^{\alpha e} \end{pmatrix}$$

where
$$\begin{cases} U \mathrm{diag}(E_1, E_2, E_3) U^{-1} + \mathrm{diag}(A, 0, 0) = \tilde{U} \mathrm{diag}(\tilde{E}_1, \tilde{E}_2, \tilde{E}_3) \tilde{U}^{-1} \\ \alpha, \beta = e, \mu, \tau \quad , \quad E_j \equiv \sqrt{\vec{p}^2 + m_j^2} \\ X_j^{\alpha\beta} \equiv U_{\alpha j} U_{\beta j}^* \quad \text{(in vacuum)} \\ \tilde{X}_j^{\alpha\beta} \equiv \tilde{U}_{\alpha j} \tilde{U}_{\beta j}^* \quad \text{(in matter)} \end{cases}$$

K. Kimura showed for $N_\nu = 3$

① $\tilde{X}_j^{\alpha\beta}$ can be explicitly expressed in terms of $X_j^{\alpha\beta}$, $\tilde{E}_j$ and E_j (linear in $X_j^{\alpha\beta}$).

② $P(\nu_\mu \to \nu_e) = A\cos\delta + B\sin\delta + C$
where A, B, C are functions of E_j & θ_{ij}.

His results are more useful than previous works (e.g. Zaglauer - Schwarzer '88) because

i) the expression does not use particular parametrization for $U_{\alpha j}$.

ii) it is relatively easy to see under what condition enhancement occurs.

H. Minakata (南方久和)

Method for determination of $|U_{e3}|$

$$\Delta_{13} \equiv \frac{\Delta m^2_{13} L}{2E}$$

$$Q \equiv \frac{1}{4} \sin 2\theta_{12} \sin 2\theta_{23} \sin\frac{\Delta_{13}}{2} \cdot \frac{\Delta m^2_{12} L}{2E}$$

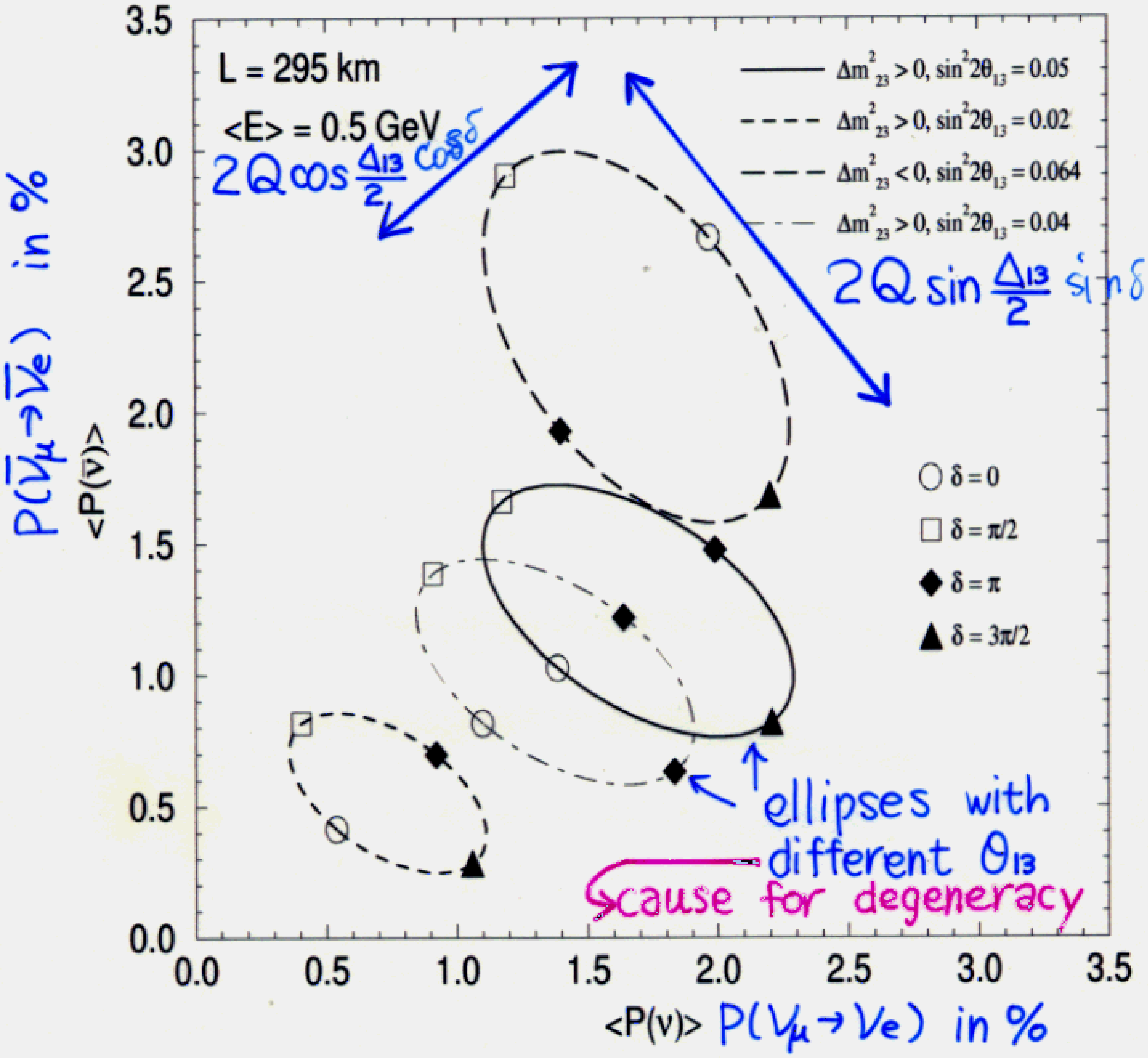


FIG. 1. CP trajectory diagrams showing the contours of $\langle P(\nu)\rangle \equiv \langle P(\nu_\mu \to \nu_e)\rangle$ and $\langle P(\bar{\nu})\rangle \equiv \langle P(\bar{\nu}_\mu \to \bar{\nu}_e)\rangle$ as a function of δ. The Gaussian energy distribution of neutrino beam with $\langle E\rangle = 0.5$ GeV with width $\sigma = 0.1$ GeV is assumed and the baseline length is taken as $L = 295$ km. The mixing parameters are fixed to be $\Delta m^2_{23} = \pm 3 \times 10^{-3}$ eV^2, $\sin^2 2\theta_{23} = 1.0$, $\Delta m^2_{12} = 6.2 \times 10^{-5}$ eV^2, $\tan^2\theta_{12} = 0.35$. We take the matter density as $\rho = 2.8$ g/cm^3 and the electron fraction as $Y_e = 0.5$.

H. Minakata

Tune (E, L) such that $\frac{\Delta m_{13}^2 L}{2E} = \pi$.

Then the ellipsis becomes thin and the degeneracy in (δ, θ_{13}) is reduced.

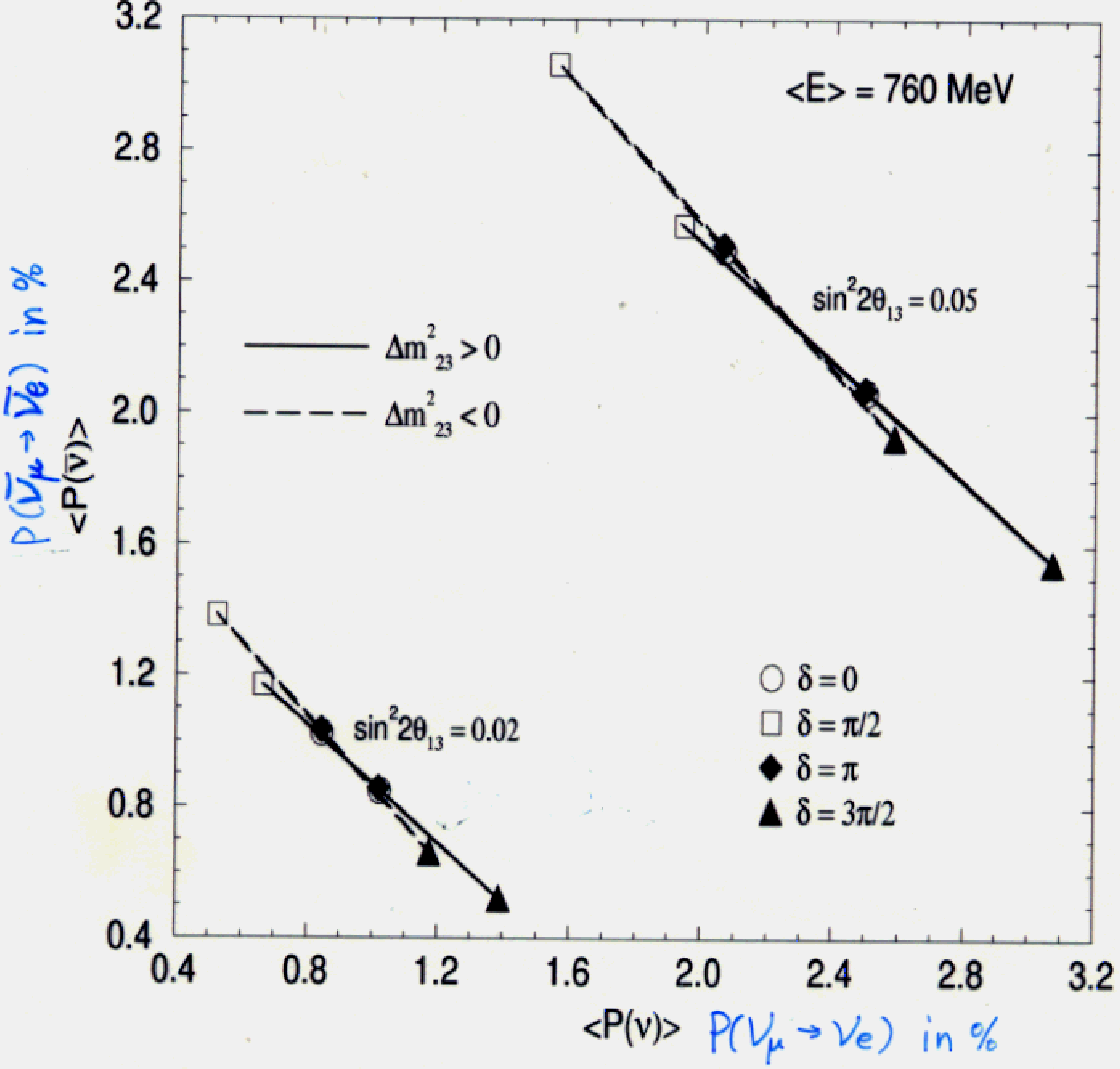


FIG. 3. The thinnest CP trajectories for a tuned peak energy for $\sin^2 2\theta_{13} = 0.05$ and 0.02. The beam profile, the mixing parameters and the matter density are taken as in Fig. 1.

K. Whisnant

Breaking 2^3-fold degeneracy

(δ, θ_{13}) ambiguity

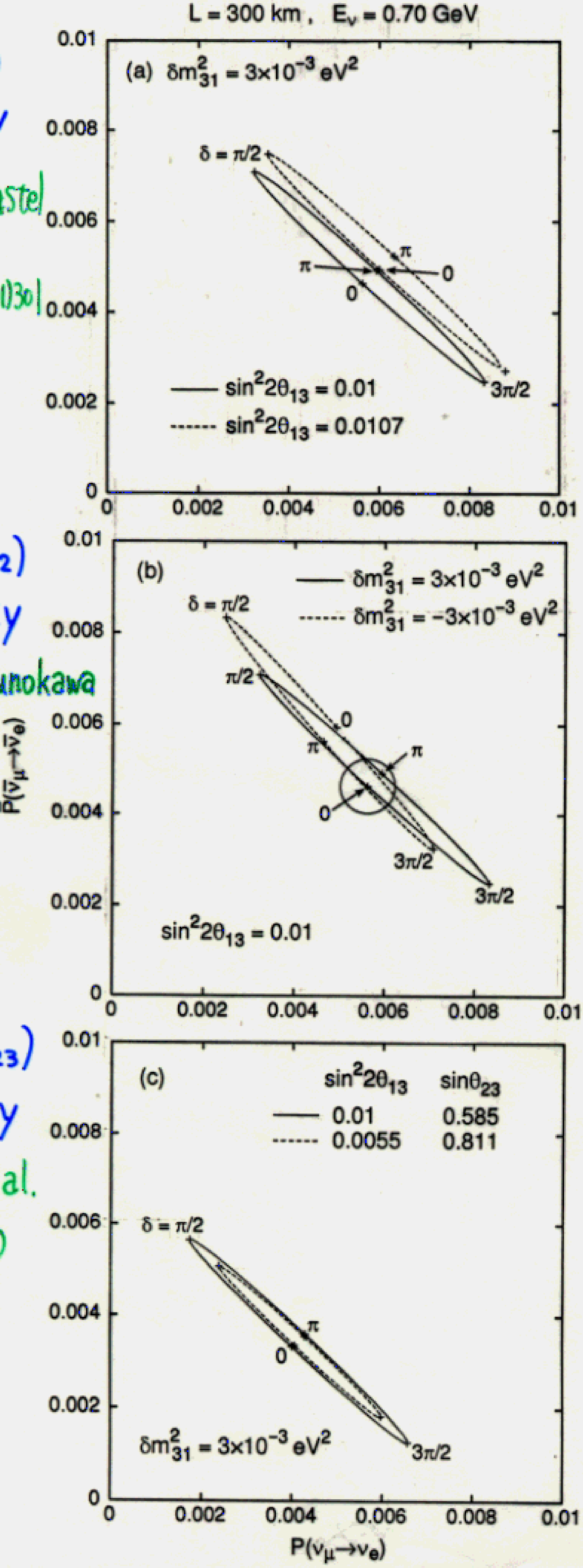
Burguet-Castel et. al. NPB608('01)301

sign(Δm^2_{32}) ambiguity

Minakata-Nunokawa JHEP 0110 ('01)001

$(\theta_{23}, \frac{\pi}{2}-\theta_{23})$ ambiguity

Barger et. al. PRD65('02) 073023



Measurements at two baselines lift these ambiguities

→ Measurement of $\nu_e \to \nu_\tau$ at a ν factory lifts this degeneracy

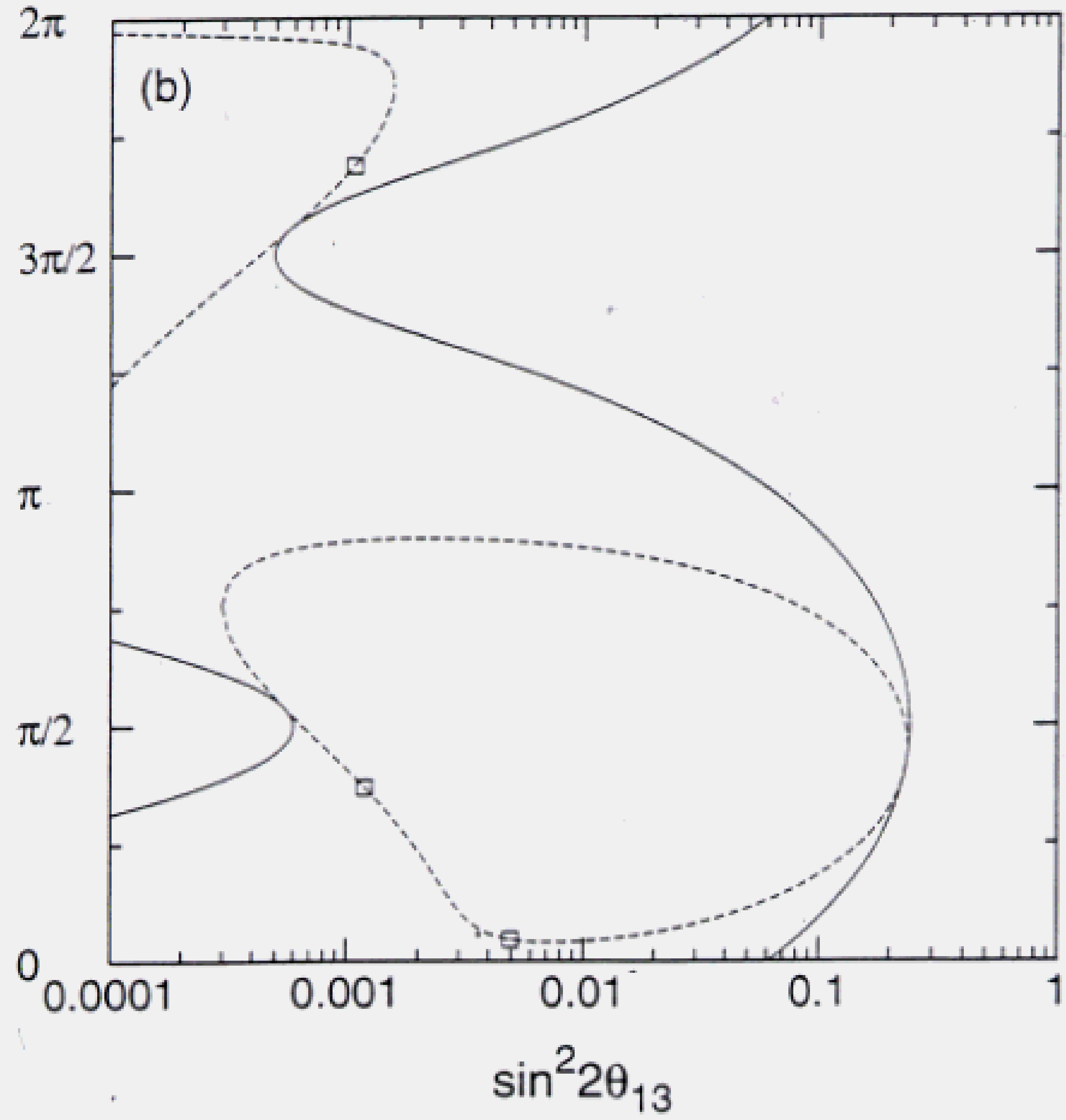
cf. in vacuum

$$P(\nu_e \to \nu_\mu) = s_{23}^2 \sin^2 2\theta_{13}\, \Delta$$
$$P(\nu_e \to \nu_\tau) = c_{23}^2 \sin^2 2\theta_{13}\, \Delta$$
$$\Delta \simeq \sin^2(\Delta m^2_{32} L/4E)$$

K. Whisnant

Adding a 4th measurement reduces regions with degeneracies to isolated points in (δ, θ_{13}) space

L = 300 km

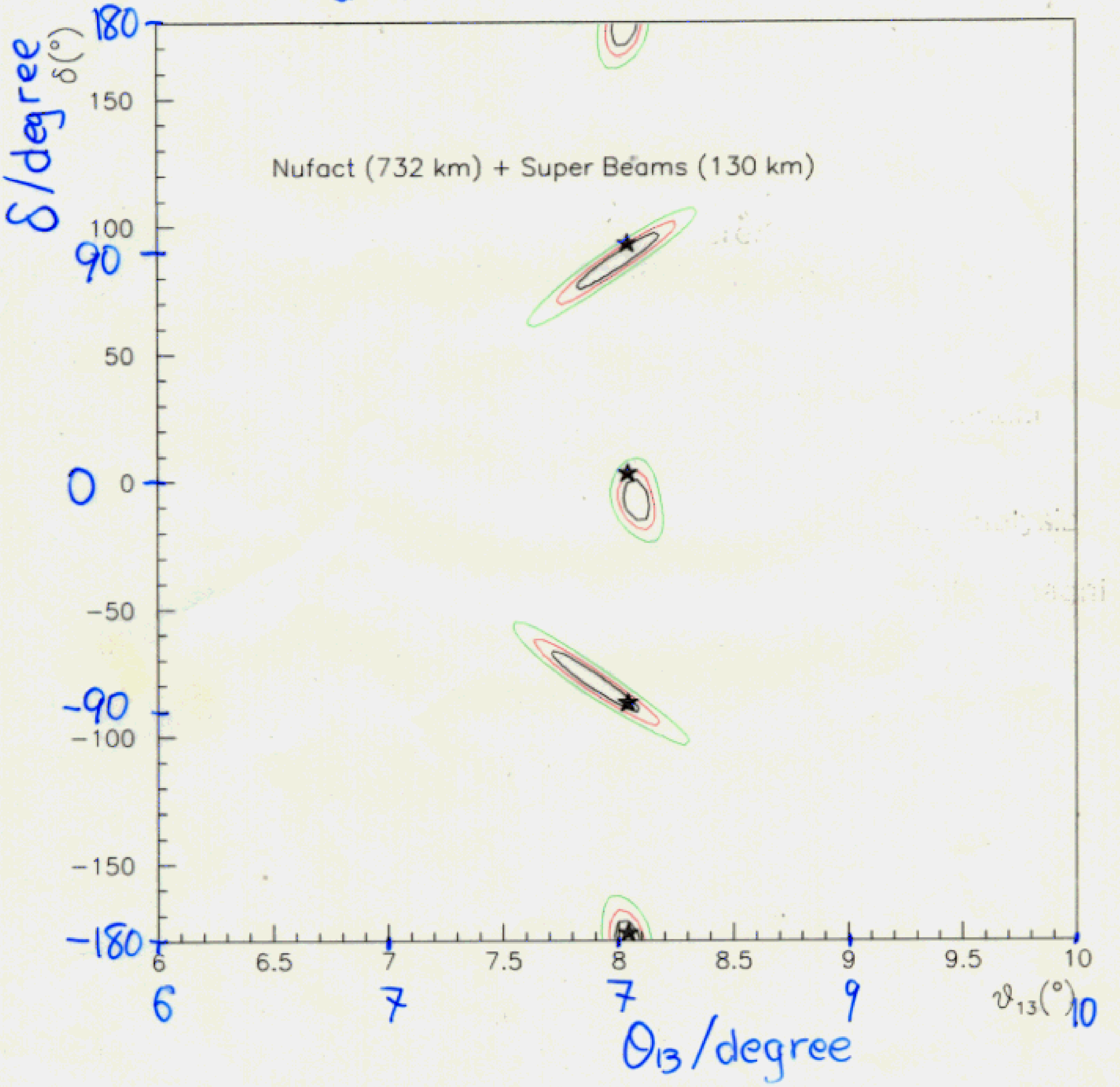


Measurements	Region with degeneraces
$\nu, \bar{\nu}$ @ $\Delta = \frac{\pi}{2}$	between solid lines
add ν@ $\Delta = \frac{\pi}{3}$	along dashed curves
add $\bar{\nu}$@ $\Delta = \frac{\pi}{3}$	boxes only

Degeneracies do not have to be removed completely; they are not a problem if they occur at $\sin^2 2\theta_{13}$ below the reach of the experiment

O. Mena

ν fact (732 km) + super beam (130km)
different E, L



D. Meloni $\nu_e \to \nu_\tau$ channel : silver

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

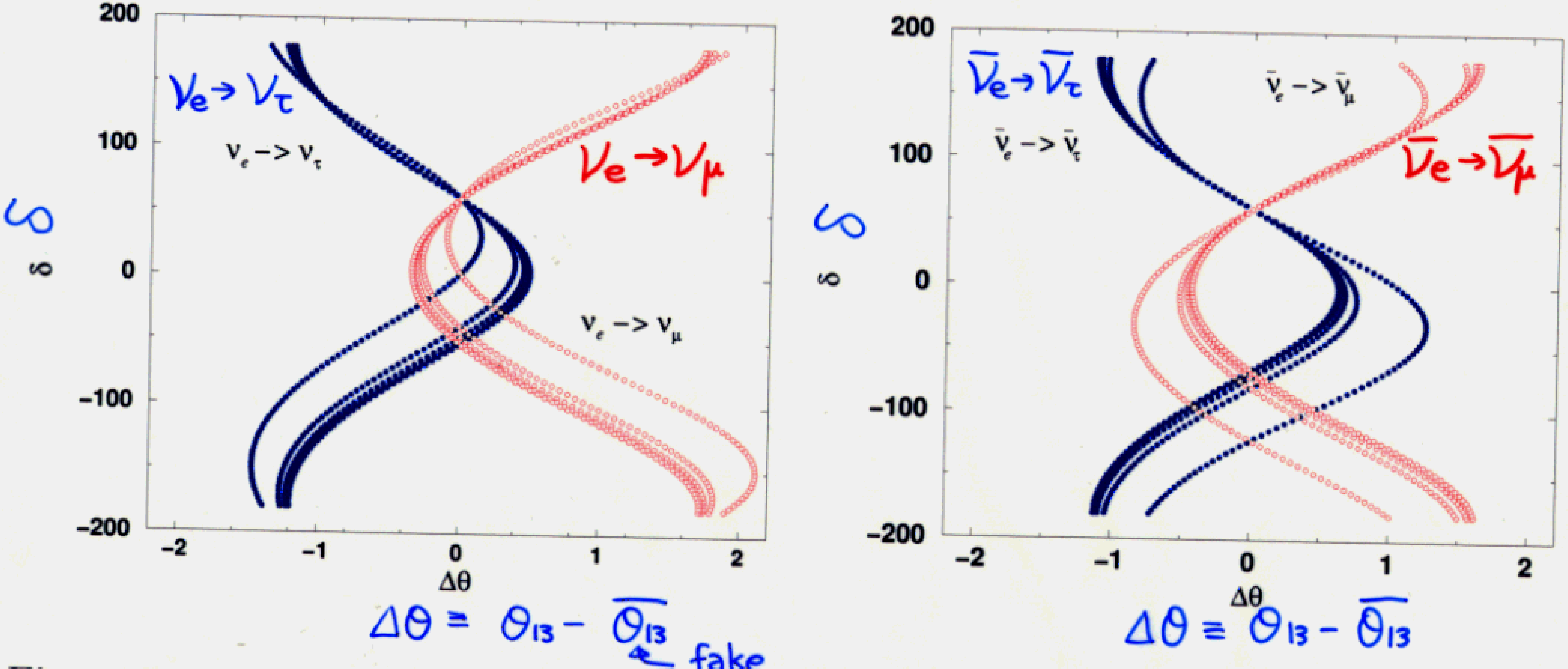


Figure 7: *Equiprobability curves in the $(\Delta\theta, \delta)$ plane, for $\bar{\theta}_{13} = 5°, \bar{\delta} = 60°$, $E_\nu \in [5, 50$ GeV and $L = 732$ Km for the $\nu_e \to \nu_\mu$ and $\nu_e \to \nu_\tau$ oscillation (neutrinos on the left antineutrinos on the right).*

D. Meloni

both $\overset{(-)}{\nu}_e \to \overset{(-)}{\nu}_\mu$ & $\overset{(-)}{\nu}_e \to \overset{(-)}{\nu}_\tau$ w/ L = 732 km, 3000 km

$\overset{(-)}{\nu}_e \to \overset{(-)}{\nu}_\mu$ only w/ L = $\begin{cases} 732\ \text{km} \\ 3000\ \text{km} \end{cases}$

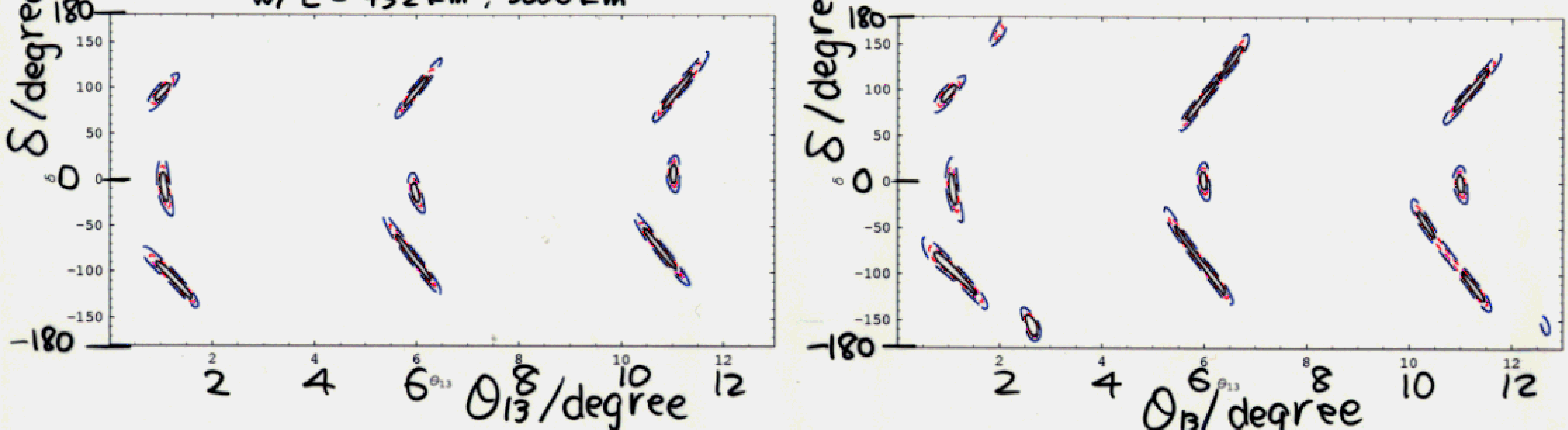


Figure 12: *68.5, 90 and 99 % C.L. contours resulting from a χ^2 fit of θ_{13} and δ, for $\bar{\theta}_{13} = 1°, 6°$ and $11°$, and $\bar{\delta} = -90°, 0°$ and $90°$, for the combination of an iron detector at $L = 3000$ Km and an emulsion detector at $L = 732$ Km: (left) both "silver" and "golden" muon events are taken into account (same figure as in Fig. 11, lower right); (right) only "golden" muon events are taken into account. Five years of data taking for both polarities in the distant detector and only five years in the μ^+ polarity in the near detector have been considered.*

With the silver channel, the errors are significantly reduced.

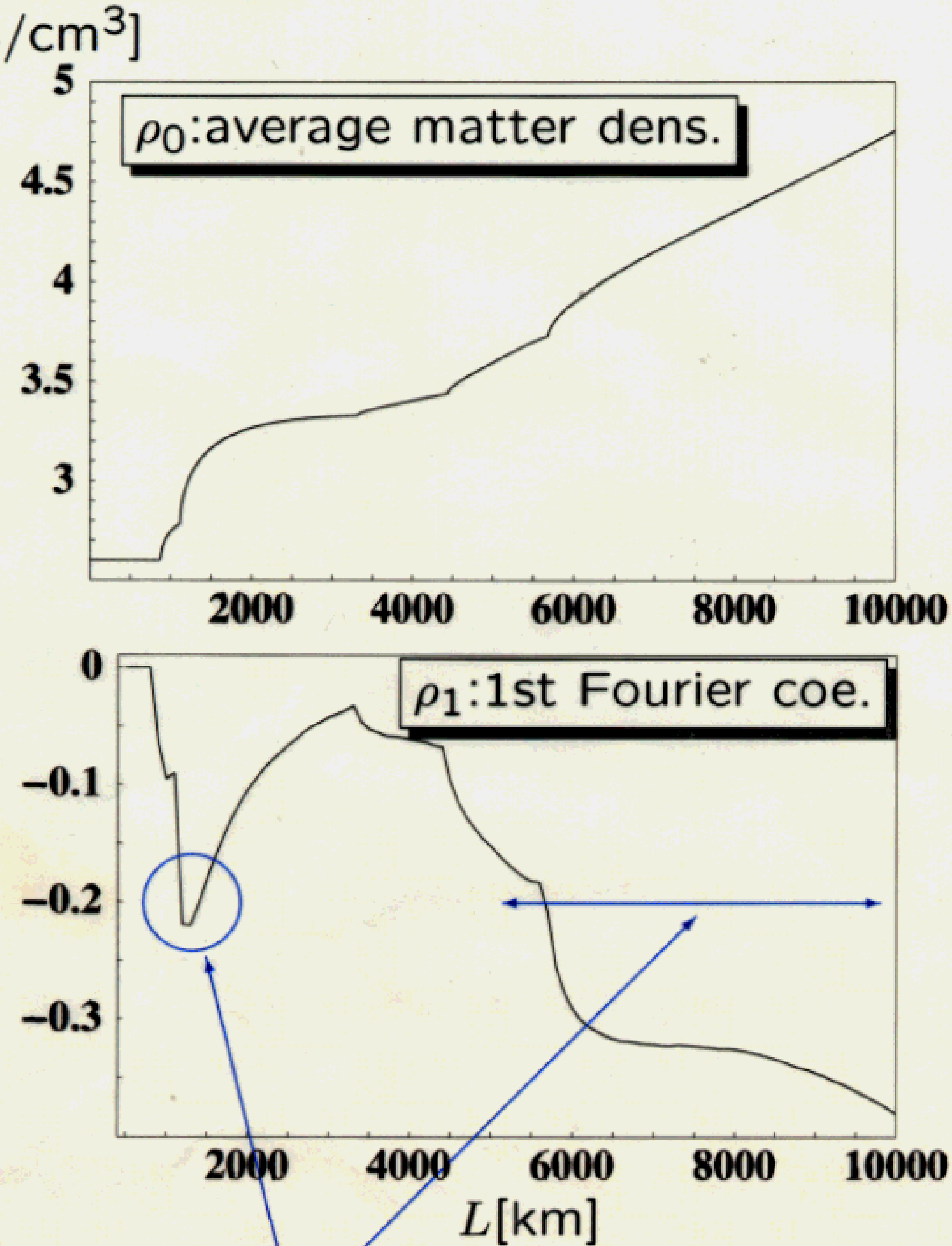
T. Ota
(太田俊彦)

Matter profile effect

$A(x) \equiv \sqrt{2} G_F N_e(x) = \sum_{n=-\infty}^{\infty} a_n e^{-ip_n x}$: only a_0, a_1 are important

■How large is the matter profile effect?

Based on PREM



In these regions, the matter profile effect is large in terms of the comparison with the average density.

T. Ota

■Conclusion:

In $L \lesssim 10,000$km,

★ The profile including up to a_1 can reproduce the event number using PREM.

★ There is a strong correlation between a_0 and a_1.

■ To ignore the matter profile effect. $\overset{\bigstar}{=}$ $a_1 \to 0$.
$\overset{\bigstar}{=}$ To shift a_0 from *the average* based on PREM.

▼

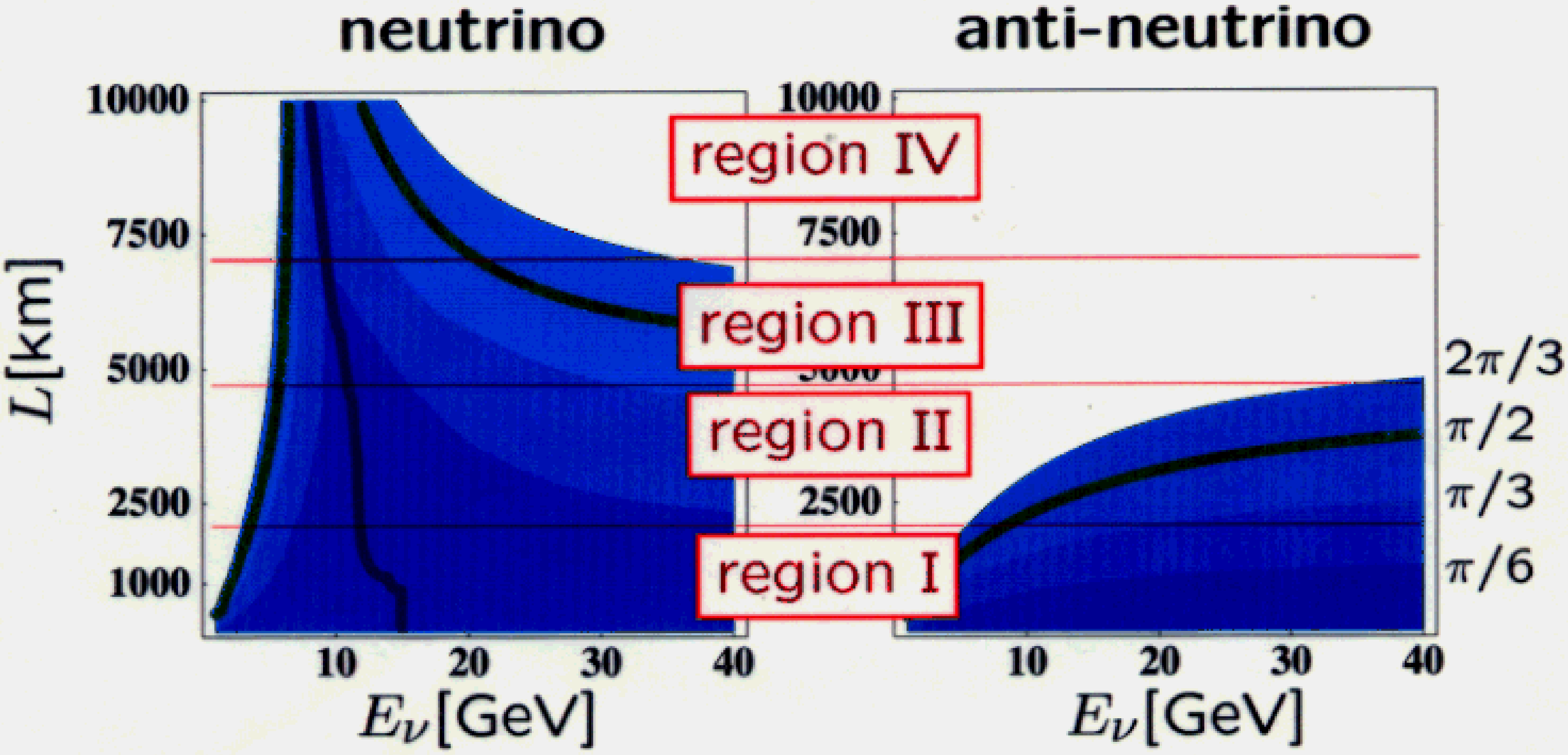
1. Even if we use the average density based on PREM, a disregard of the matter profile effect brings unexpected extra uncertainty ($\sim 5\%$) to a_0 in $5,000\text{km} \lesssim L \lesssim 10,000$km.

2. From the viewpoint that the analyses should be independent of the Earth model, the matter profile should be fitted in experiments. We recommend to introduce a_1 as a fitting parameter.

2'. We can deal with the change of the matter profile keeping average density value.

■The region where the correlation exists

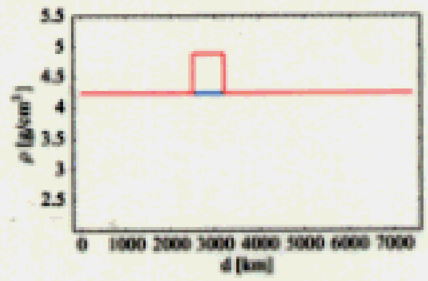
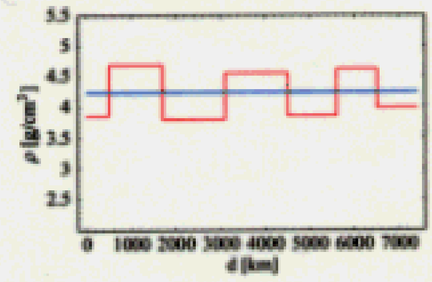
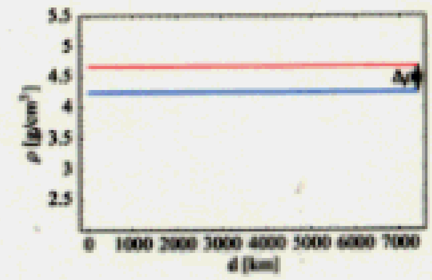
Contour plots of $\frac{\lambda_+ - \lambda_-}{4E_\nu}L$



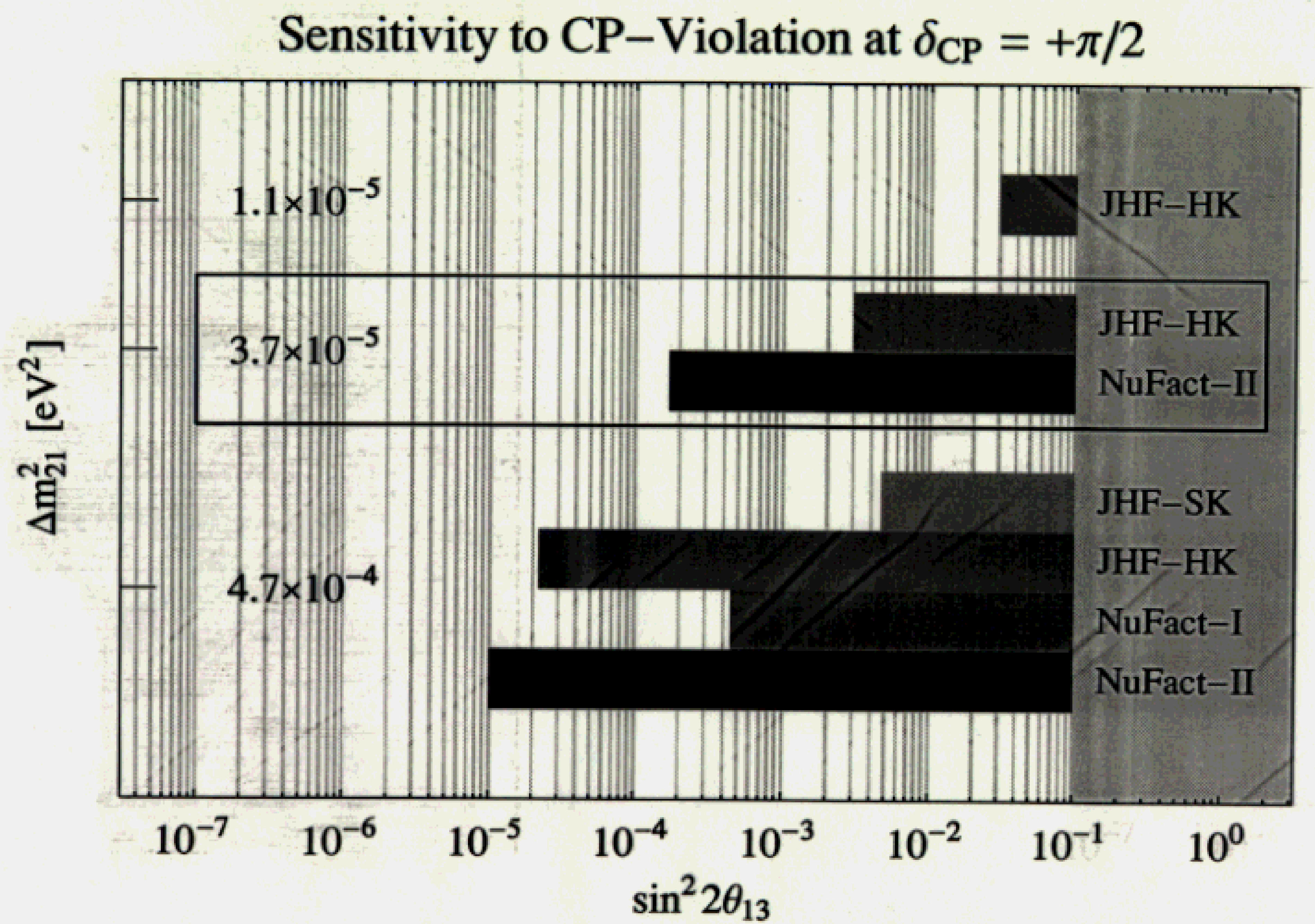
	neutrino	anti-neutrino	correlation
region I	0	0	○
region II	0	$\pi/2$	○
region III	0, $\pi/2$	—	○
region IV	0, $\pi/2$ ...	—	—

*In these regions, anti-neutrino events are not significant in statistical sense.

Summary: Comparison of models

Type	1. Single perturbation 	2. Random fluctuations 	3. Measured mean 
Averaging	No	Yes	No
Dep. on	$\lambda \cdot \Delta\rho$	$\lambda \otimes \Delta\rho$ (Interference effects remaining)	$\Delta\rho$
Evaluation	Analytical	Numerical	Numerical
Level	Osc. probs.	Osc. probs.	Full analysis
Impact	Small for lakes, mines, etc.	For $\lambda \ll L$: small For $\lambda > L$: 3. good approximation	Similar magnitude as other error sources
Problem	Only limited applications	High computational effort	Conservative choice

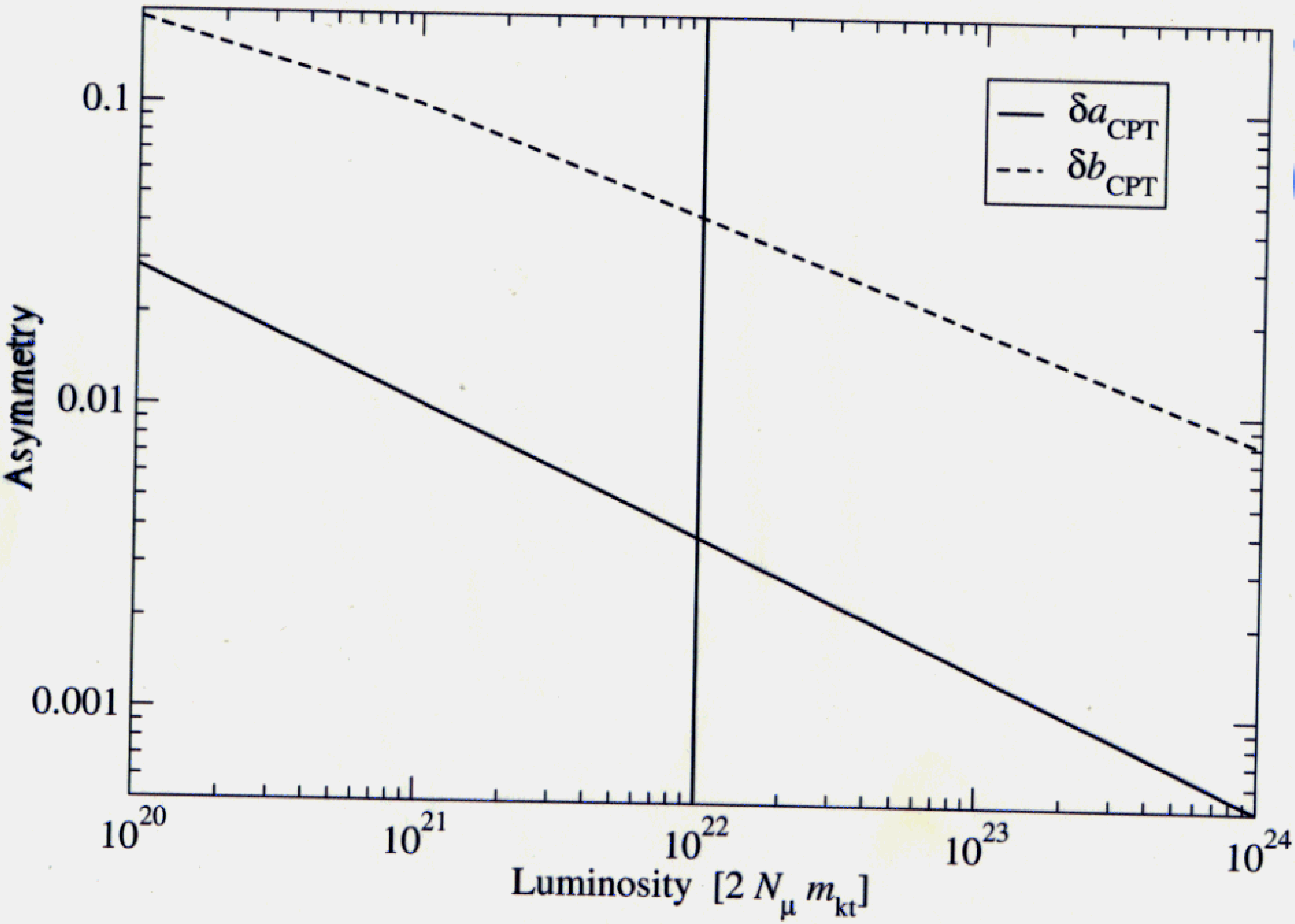
21 P. Huber



dependence on Δm^2_{21} is strong

Figure 21: *The sensitivity to CP violation for $\delta_{CP} = +\pi/2$ at the 90% confidence level, plotted as function of $\sin^2 2\theta_{13}$. The plot shows the ranges of the sensitivity to CP violation for several values of Δm^2_{21}, where the top row corresponds to the lower bound, the bottom row to the upper bound, and the middle row to the best-fit value of the LMA region. If no bar is drawn for an experiment, it does not have any CP violation sensitivity. For the parameters, the choose the LMA values.*

22 P. Huber



$a_{CPT} \equiv \frac{|m_3 - \bar{m}_3|}{(m_3)_{average}}$

$b_{CPT} \equiv \frac{|\theta_{23} - \bar{\theta}_{23}|}{(\theta_{23})_{average}}$

difference for ν & $\bar{\nu}$

Y. Y. Y. Wong
(黃婉瑩)

$$H = U\,\mathrm{diag}(E_j)\,U^{-1} + \mathrm{diag}(A,0,0) + 2E|\phi|\,U_G\,\mathrm{diag}(\gamma_j)\,U_G^{-1}$$

$\gamma_j \neq 1$: different grav. coupl.

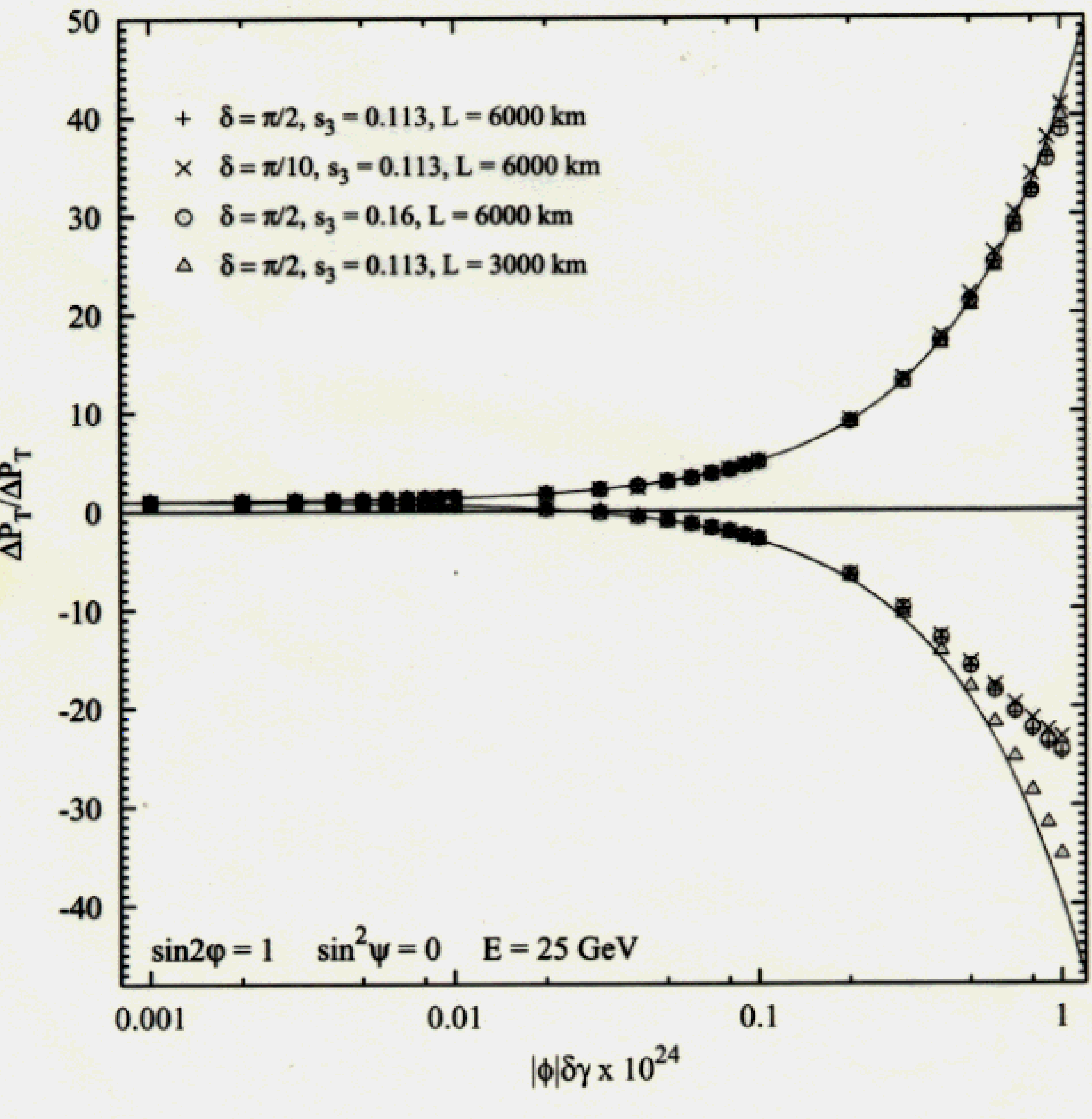
$N_\nu = 3$ w/ violation of equivalence principle

Assume $|\Delta\gamma_{32}| \gg |\Delta\gamma_{21}|$ other phases → 0

$$\frac{\Delta\tilde{P}_T}{\Delta P_T} = 1 - \frac{4E^2}{\Delta m^2_{21}} \cdot \frac{\sin 2\theta_{atm}}{\sin 2\theta_\odot} \cdot |\phi|\,\Delta\gamma\,\sin 2\varphi$$

T violation

$|\phi|$: gravitational potential



- New exotic interactions

J. Sato (佐藤 文)
M. Campanelli

$$\mathcal{L}_{new} = \lambda (\bar{e} \gamma^{\kappa} \mu)(\bar{\nu}_{\mu} \gamma_{\kappa} \nu_{\beta}) \quad \beta \neq e$$

gives the same signal w/ ν osc.

$$U \,\mathrm{diag}(E_1, E_2, E_3) U^{-1} + \mathrm{diag}(A, 0, 0)$$

$$+ V \begin{pmatrix} \epsilon_{ee} & \epsilon_{e\mu} & \epsilon_{e\tau} \\ \epsilon_{\mu e} & \epsilon_{\mu\mu} & \epsilon_{\mu\tau} \\ \epsilon_{\tau e} & \epsilon_{\tau\mu} & \epsilon_{\tau\tau} \end{pmatrix}$$

However the energy dependence
is different from ν osc.

◇ For $(\boldsymbol{V-A})(\boldsymbol{V-A})$ interaction type

■In $\boldsymbol{\nu_\alpha \longrightarrow \nu_\beta}$, the effects induced by $\boldsymbol{\epsilon^{s,m}_{\alpha\beta}}$. The others are too small or easy to be absorbed into the error of the oscillation parameters.

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

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

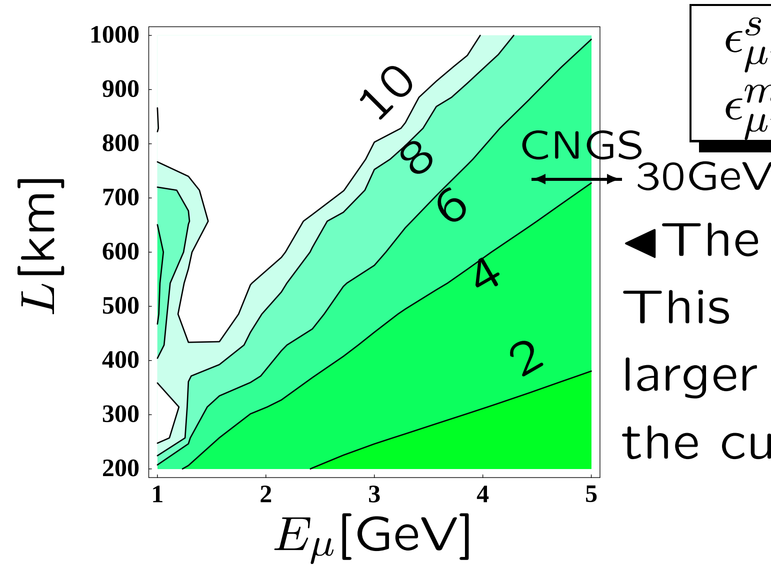
◇ In many models $\boldsymbol{\epsilon_{\mu\tau}}$ is large.

$\longrightarrow \boldsymbol{\tau}$ appearance is important !

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

Using the conventional beam: $\nu_\mu \to \nu_\tau$ channel

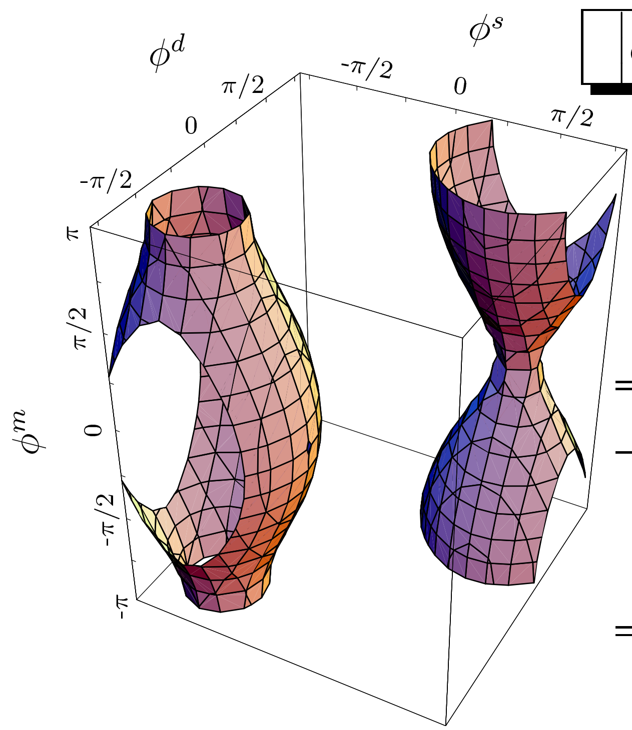
$$\boxed{\begin{aligned}\epsilon^s_{\mu\tau} &= 3\times 10^{-3} i\\ \epsilon^m_{\mu\tau} &= 0\end{aligned}}$$



◀The unit is 10^5 neutrinos. This is the $\mathcal{O}(10^2)$ times larger exposure than that of the current experiments.

ICARUS and OPERA:

◇ Low statistics make a study of the energy spectra infeasible. We compare the total event number made by the new interaction with the error.



$$\boxed{\epsilon^s_{\mu\tau} = \epsilon^m_{\mu\tau} = \epsilon^d_{\mu\tau} = 0.01}$$

◀The contour denotes that the effect made by new interactions is as large as the 1σ error.

	N_τ^{SM}	σ^2_{sys}	σ_{tot}
ICARUS-A	40.4	11	7.4
ICARUS-B	23.5	1.5	5.2
OPERA	16.3	0.75	4.3

M. Campanelli

Use the energy spectrum of the wrong sign μ on's from $\tau \to \mu$ decays.

$$U\,\mathrm{diag}(E_j)\,U^{-1} + \mathrm{diag}(A,0,0) + V\begin{pmatrix} \epsilon_{ee} & \epsilon_{e\mu} & \epsilon_{e\tau} \\ \epsilon_{\mu e} & \epsilon_{\mu\mu} & \epsilon_{\mu\tau} \\ \epsilon_{\tau e} & \epsilon_{\tau\mu} & \epsilon_{\tau\tau} \end{pmatrix}$$