Physics Prospects of Future Neutrino Oscillation Experiments

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based on works with Mayumi Aoki (Helsinki)

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Ken-ichi Senda (Ibaraki)

and colleagues from KEK, Kyoto

1. Introduction to Neutrino Masses and Mixings

2. Present & Future of Long Baseline Neutrino Oscillation Experiments

		L/E		
K2K	KEK → SK	250km/1GeV	2000~2005	
MINOS	Fermilab → Soudan	730km/a few GeV	2005~	
OPERA, ICARUS	CERN → Gran Sasso	730km/~10GeV	2006~	
J-PARC → SK		300km/1GeV	2009~	
J-PARC → Korea		~1100km/1GeV	?	★
J-PARC → Hyper-Kamiokande (1Mton)		300km/1GeV	??	★
new beam line → BAND @ Beijing (100kton)		2100km/4~5GeV	???	★
νFactory @ J-PARC → BAND @ Beijing		2100km/1~10GeV	????	★

3. Conclusions

3 neutrino model (with Majorana masses) has

3	masses	m_1	m_2	m_3
3	angles	θ_{12}	θ_{13}	θ_{23}
3	phases	δ_{MNS}	φ_2	φ_3

Neutrino oscillation expt's probe

2	mass^2 differences	$\delta m^2_{12} = m^2_2 - m^2_1$, $\delta m^2_{13} = m^2_3 - m^2_1$
3	angles	θ_{12}, θ_{13}, θ_{23}
1	phase	δ_{MNS}

Present constraints

• $\delta m^2_{12} = \delta m^2_{SOL}$	$(6-8)\times 10^{-5}\,eV^2$
• $\lvert\delta m^2_{13}\rvert = \delta m^2_{ATM}$	$(2-3)\times 10^{-3}\,eV^2$
• $4\lvert U_{\mu 3}\rvert^2(1-\lvert U_{\mu 3}\rvert^2) = \sin^2 2\theta_{ATM}$	$0.9-1$
• $4\lvert U_{e2}\rvert^2(1-\lvert U_{e2}\rvert^2) = \sin^2 2\theta_{SOL}$	$0.7-0.9$
• $4\lvert U_{e3}\rvert^2(1-\lvert U_{e3}\rvert^2) = \sin^2 2\theta_{RCT}$	<0.1
• δ_{MNS}	no constraint

Targets of future neutrino oscillation experiments

• measure	$\sin^2\theta_{RCT}$	
• measure	δ_{MNS}	
• determine	the sign of δm^2_{13}	$(m^2_3 \gtrless m^2_1)$
• determine	the sign of $\sin^2\theta_{ATM} - \frac{1}{2}$	$(\sin^2\theta_{ATM} \gtrless 0.5)$
• more pracise measurements	$\lvert U_{\mu 3}\rvert^2$	

Present and future LBL neutrino oscillation experiments

KEK $\xrightarrow{\sim 250\,km}$ SK — K2K — 2000 ? 2005 — δm^2_{ATM}, $\sin^2 2\theta_{ATM}$

Fermilab $\xrightarrow{\sim 730\,km}$ Soudan — MINOS — 2005~ — $\Delta(\delta m^2_{ATM}) \sim 10\%$, $\Delta(\sin^2 2\theta_{ATM}) \sim 10\%$

CERN $\xrightarrow{\sim 730\,km}$ Gran Sasso — OPERA, ICARUS — 2006~ — $\nu_\mu \to \nu_\tau$ appearance

J-PARC $\xrightarrow{\sim 300\,km}$ SK (22kt) — T2K — 2009~ — $\Delta(\delta m^2_{ATM}) \sim 1\times10^{-4}\,eV^2$, $\Delta(\sin^2 2\theta_{ATM}) \sim 1\%$

50GeV PS
0.75MW

$\sim 1100\,km$ ④ Korea — ? — $\nu_\mu \to \nu_e$ appearance if $\sin^2 2\theta_{RCT} > 0.02$ (3σ)

$\sim 300\,km$ ② HyperKamiokande (1000kt) — $\nu_\mu \to \nu_e$ vs $\bar{\nu}_\mu \to \bar{\nu}_e$ ⇒ $\not{CP}(\delta_{MNS})$ if $\sin^2 2\theta_{RCT} > 0.01$

$\sim 2100\,km$ ① BAND@Beijing (100kt, Water Čerenkov Calorimeter) — $\nu_\mu \to \nu_e$ ⇒ sign of δm^2_{13} if $\sin^2 2\theta_{RCT} > 0.04$ (3σ)

ν Factory@J-PARC (4MW, $10^{21}\,\mu^+$) $\xrightarrow[③]{\sim 2100\,km}$ BAND@Beijing — sign of δm^2_{13} if $\sin^2 2\theta_{RCT} > 0.004$; sign of $\sin^2\theta_{ATM} - \frac{1}{2}$ for $\sin^2 2\theta_{ATM} = 0.96$ if $\sin^2 2\theta_{RCT} > 0.02$; $\not{CP}(\delta_{MNS})$ if $\sin^2 2\theta_{RCT} > 0.01$

① M. Aoki et al., hep-ph/0112338 ; PRD69:093004 (2003)

② M. Aoki, KH, N. Okamura, hep-ph/0208227 ; PLB554:121-132 (2003)

③ M. Aoki, KH, N. Okamura, hep-ph/0211324

④ KH, K. Senda, N. Okamura

K 2 K

2000 ~ 2005

$$\frac{L}{E} \approx \frac{250\,km}{1\,GeV} \approx 250\ (km/GeV)$$

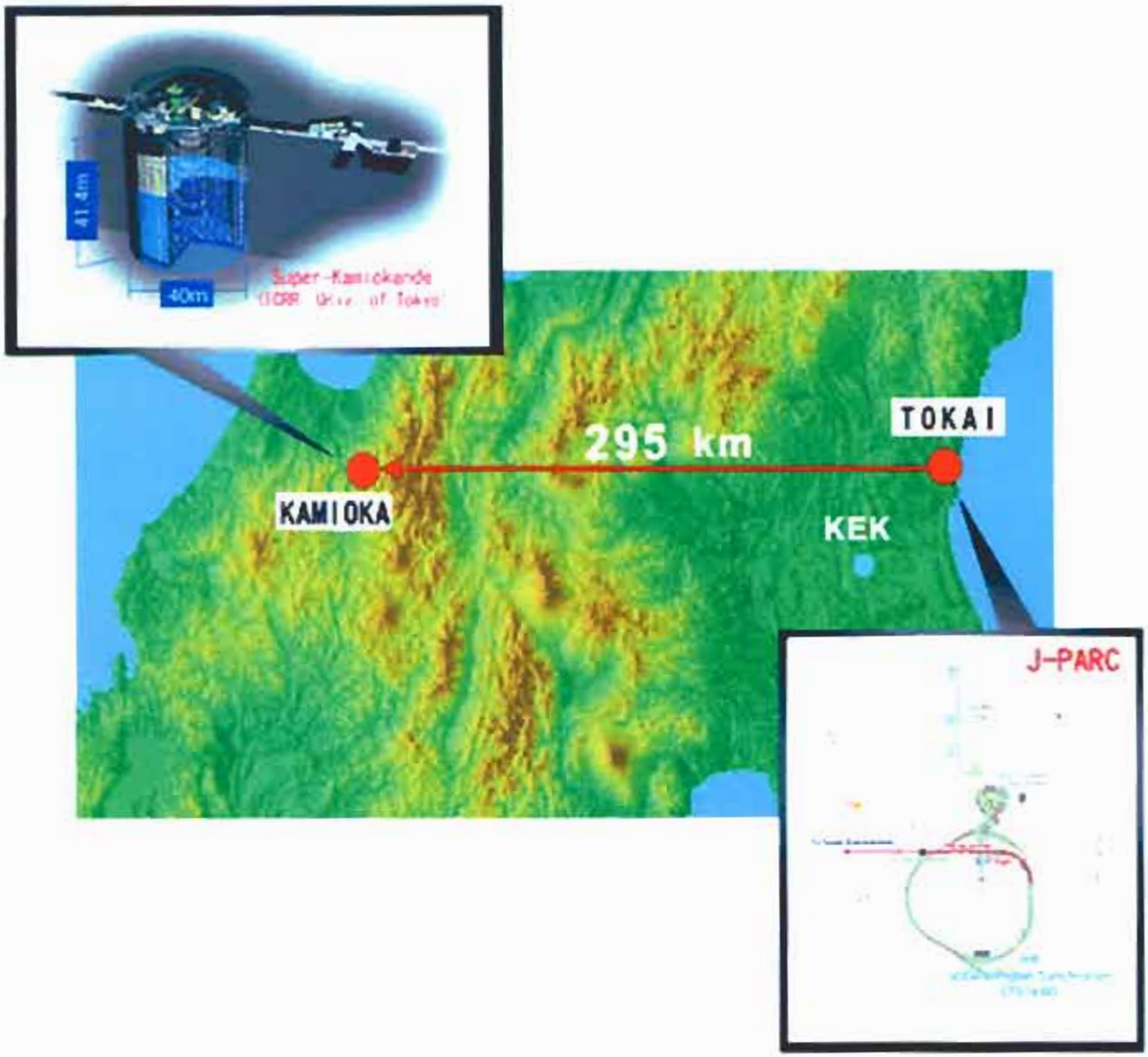
10^{20} POT in 5 years

$$\Rightarrow P(\nu_\mu \to \nu_\mu) = 1 - \sin^2 2\theta_{ATM} \sin^2\left(\frac{\delta m^2_{ATM}}{4E} L\right)$$

$0.6 \times \frac{\pi}{2}$ ... $\delta m^2 = 3 \times 10^{-3}\,eV^2$

$0.5 \times \frac{\pi}{2}$ ... $\delta m^2 = 2.5 \times 10^{-3}\,eV^2$

$0.4 \times \frac{\pi}{2}$ ... $\delta m^2 = 2 \times 10^{-3}\,eV^2$



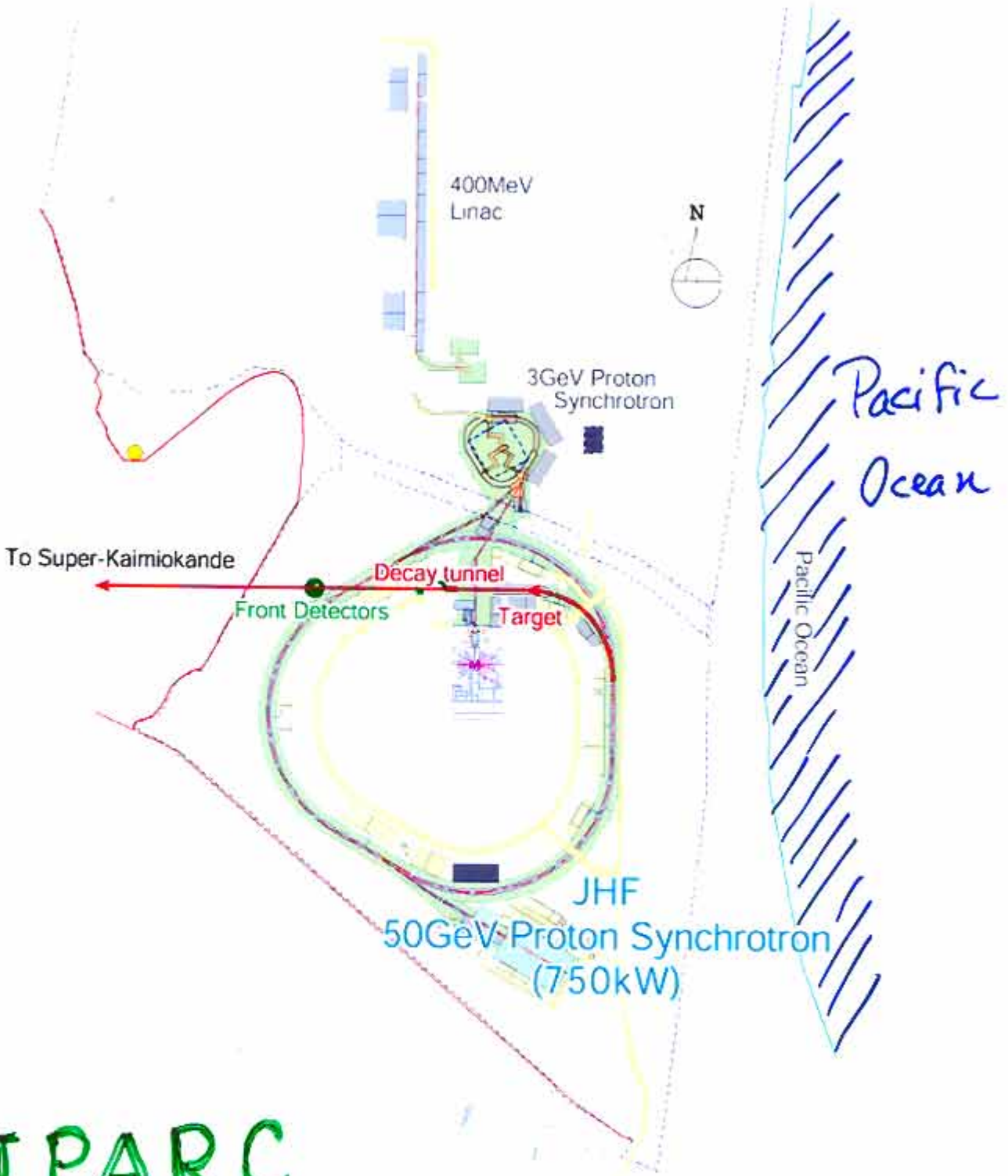
JPARC-to-SK 2009~

$\frac{L}{E} \approx \frac{300\,km}{1\,GeV} \approx 300\,(km/GeV)$

10^{21} POT in 1 year — 50 times K2K !

- Precise measurement of δm^2_{ATM}, $\sin^2 2\theta_{ATM}$
- Discovery of $\nu_\mu \to \nu_e$ oscillation $\sin^2 2\theta_{RCT} \gtrsim 0.02\ (3\sigma)$

cf. http://neutrino.kek.jp/jhfnu/



JPARC

Japan Proton Accelerator Research Complex

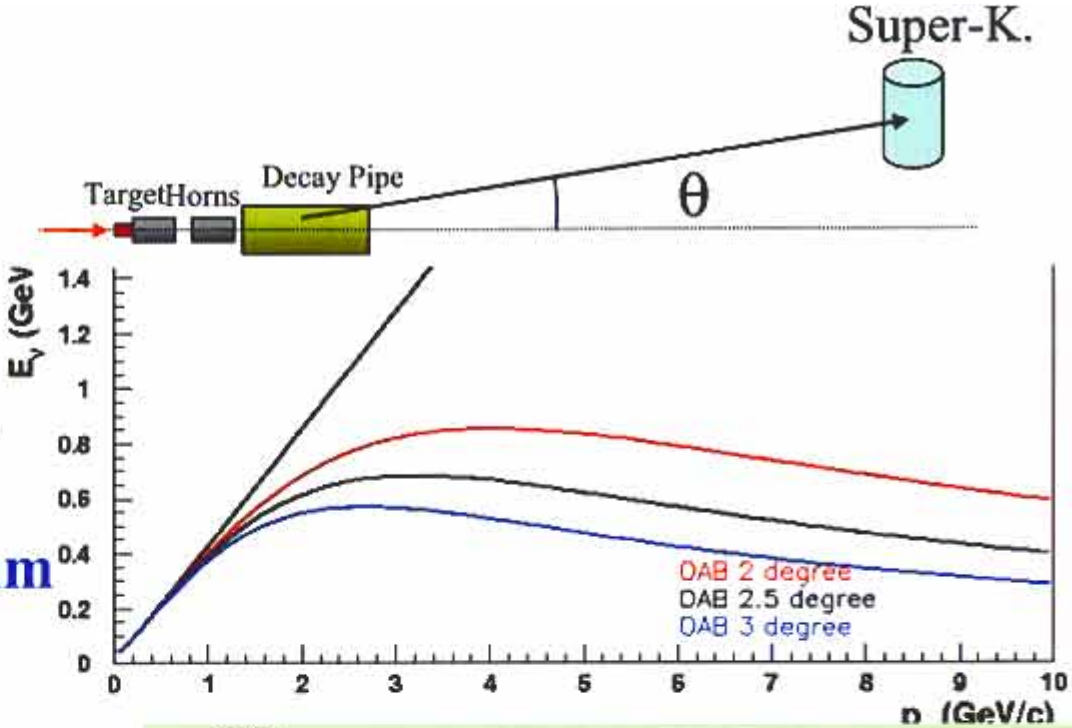
close

Off Axis Beam

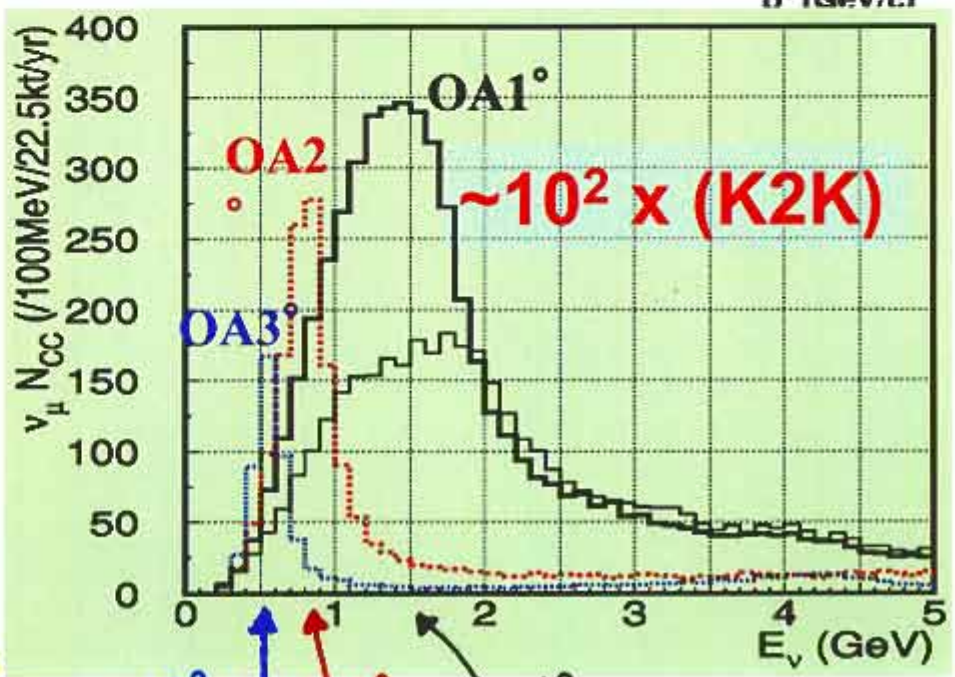
(ref.: BNL-E889 Proposal)

- **Quasi Monochromatic Beam**
- **x 2~3 intense than NBB**

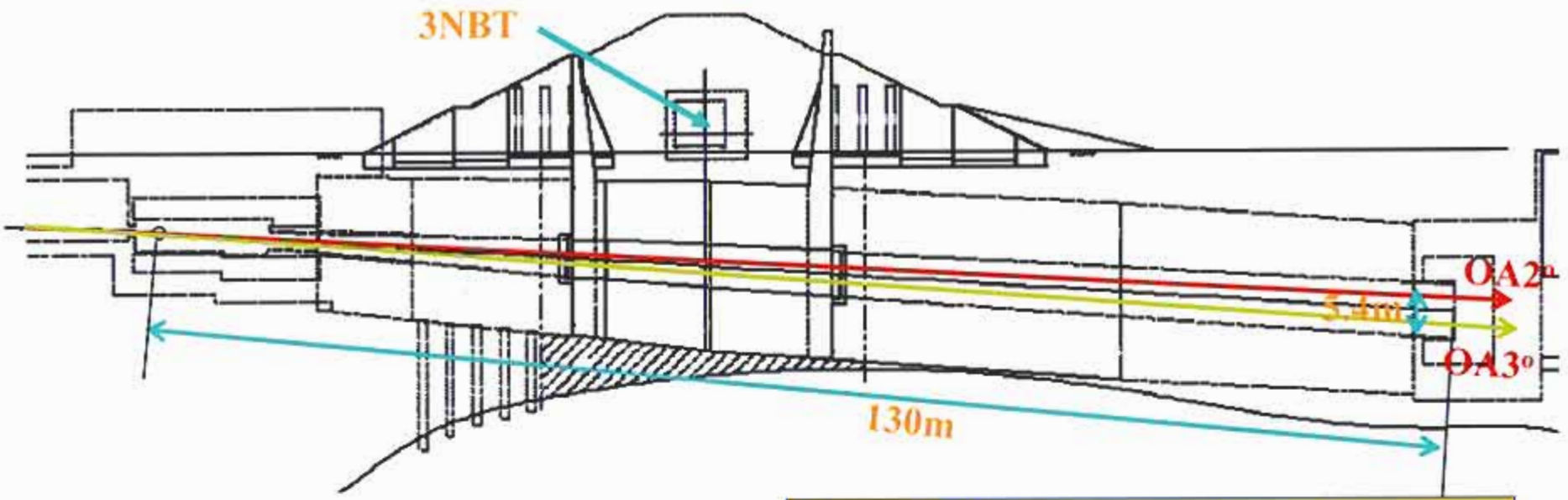
Tuned at oscillation maximum



Statistics at SK
(OAB 2 deg,1 yr,22.5 kt)
~ 4500 ν_μ tot
~ 3000 ν_μ CC
ν_e ~0.2% at ν_μ peak



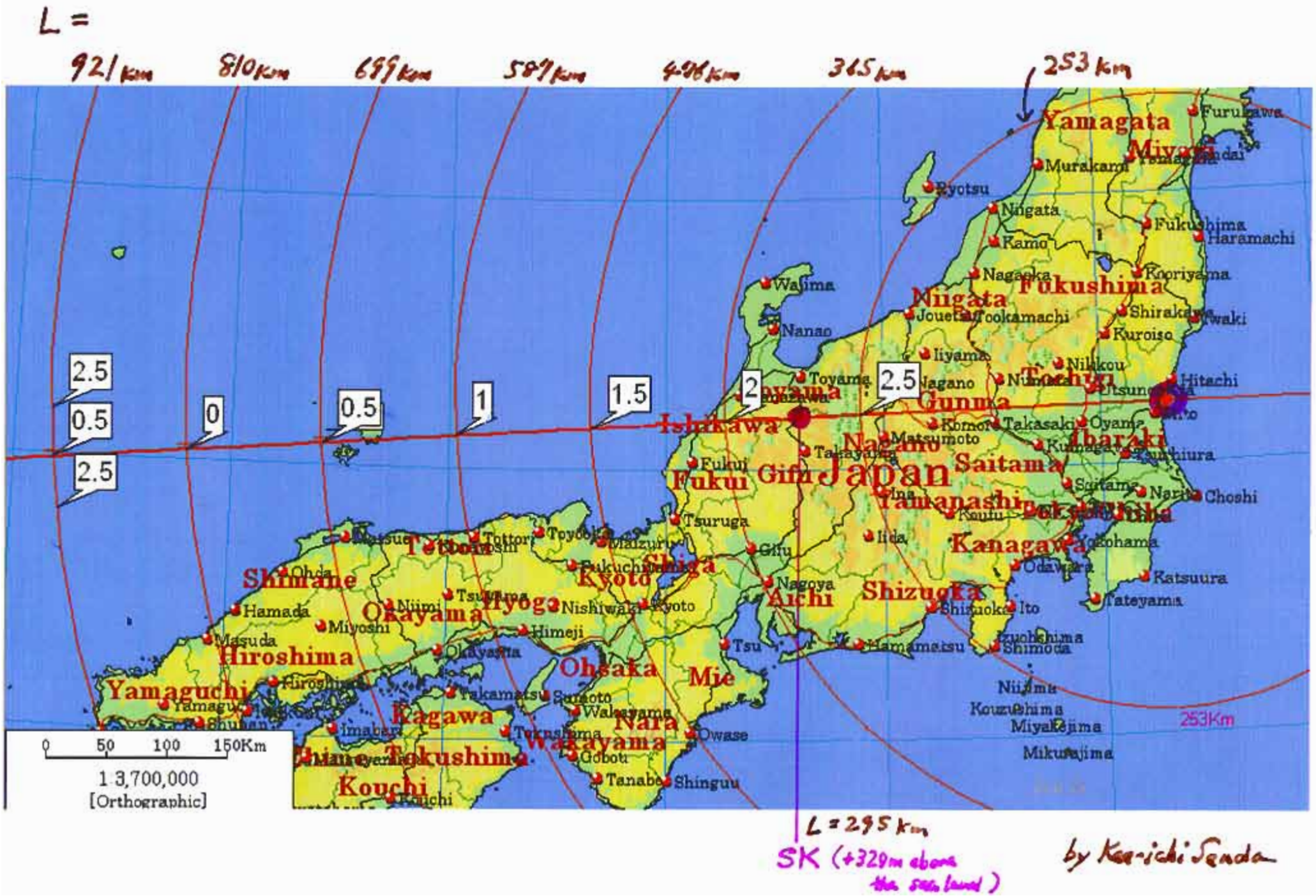
Decay volume

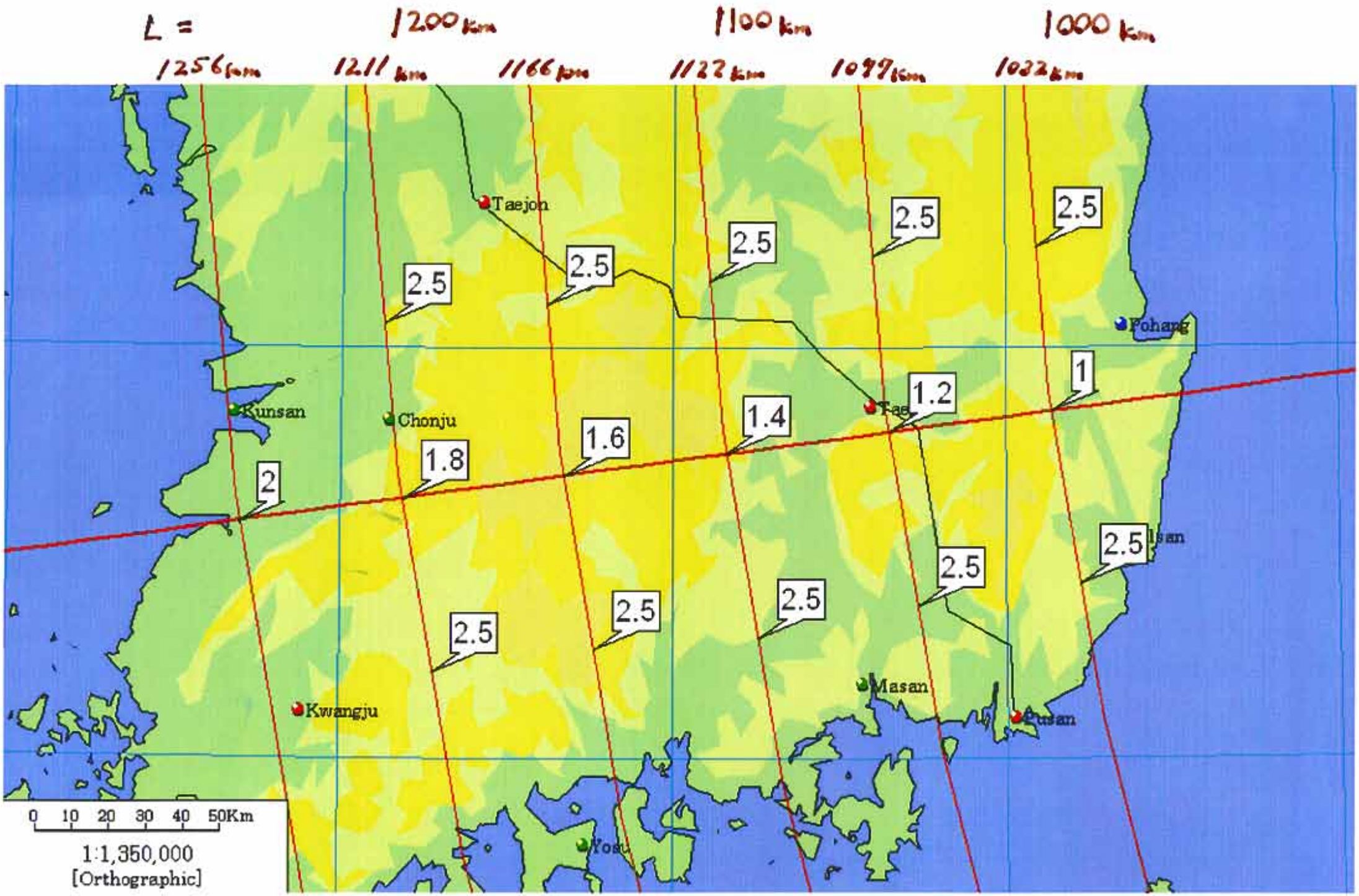


- Cover OAB 2~3deg.
  - Peak Eν ~ 500-800MeV
- Helium filled to reduce absorption.
- Water-cooled He vessel inside concrete shield
- Start construction of crossing part: May 2004

He vessel wall equipped w/ water piping

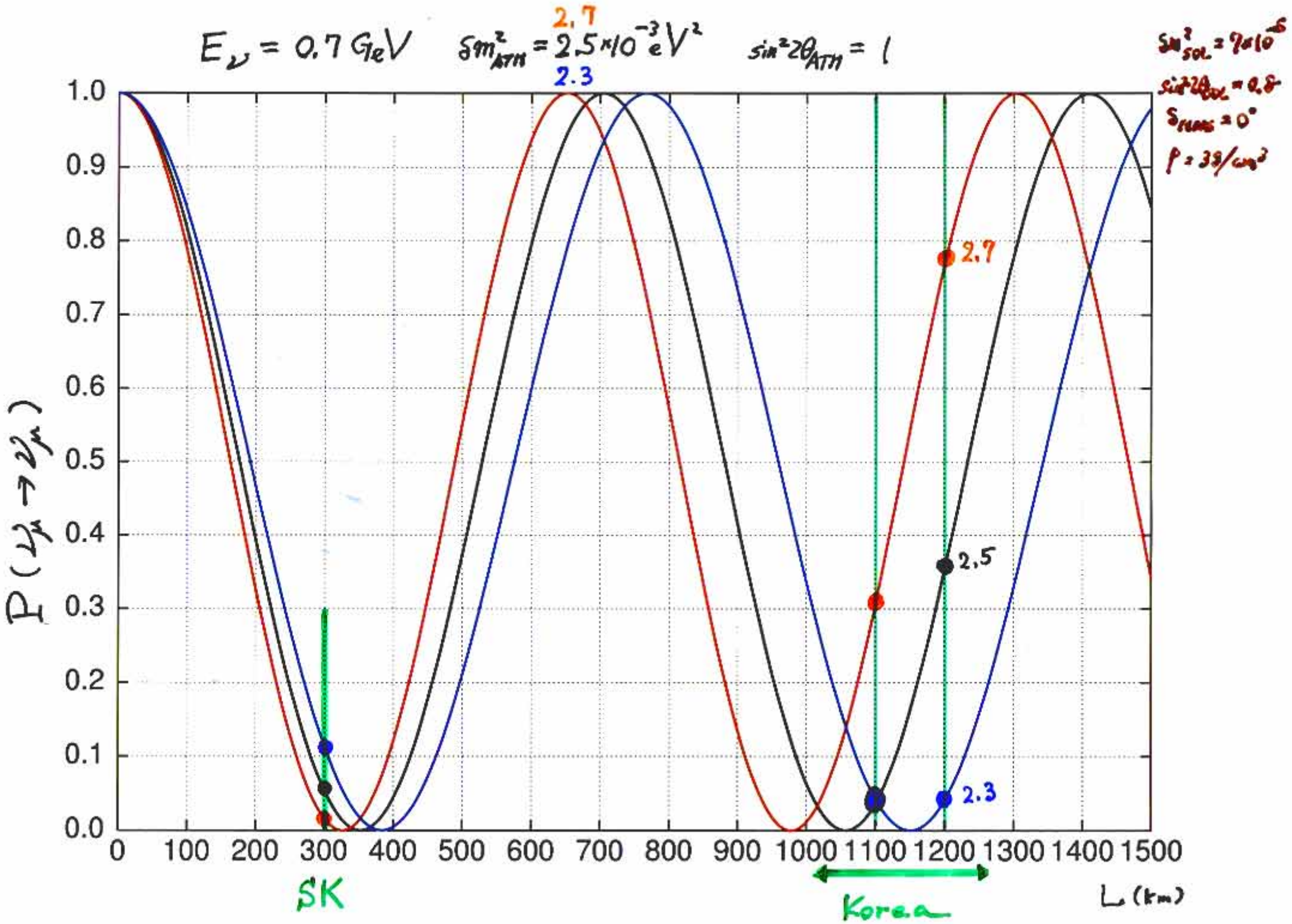
Fate of OA 2.5° beam from J-PARC

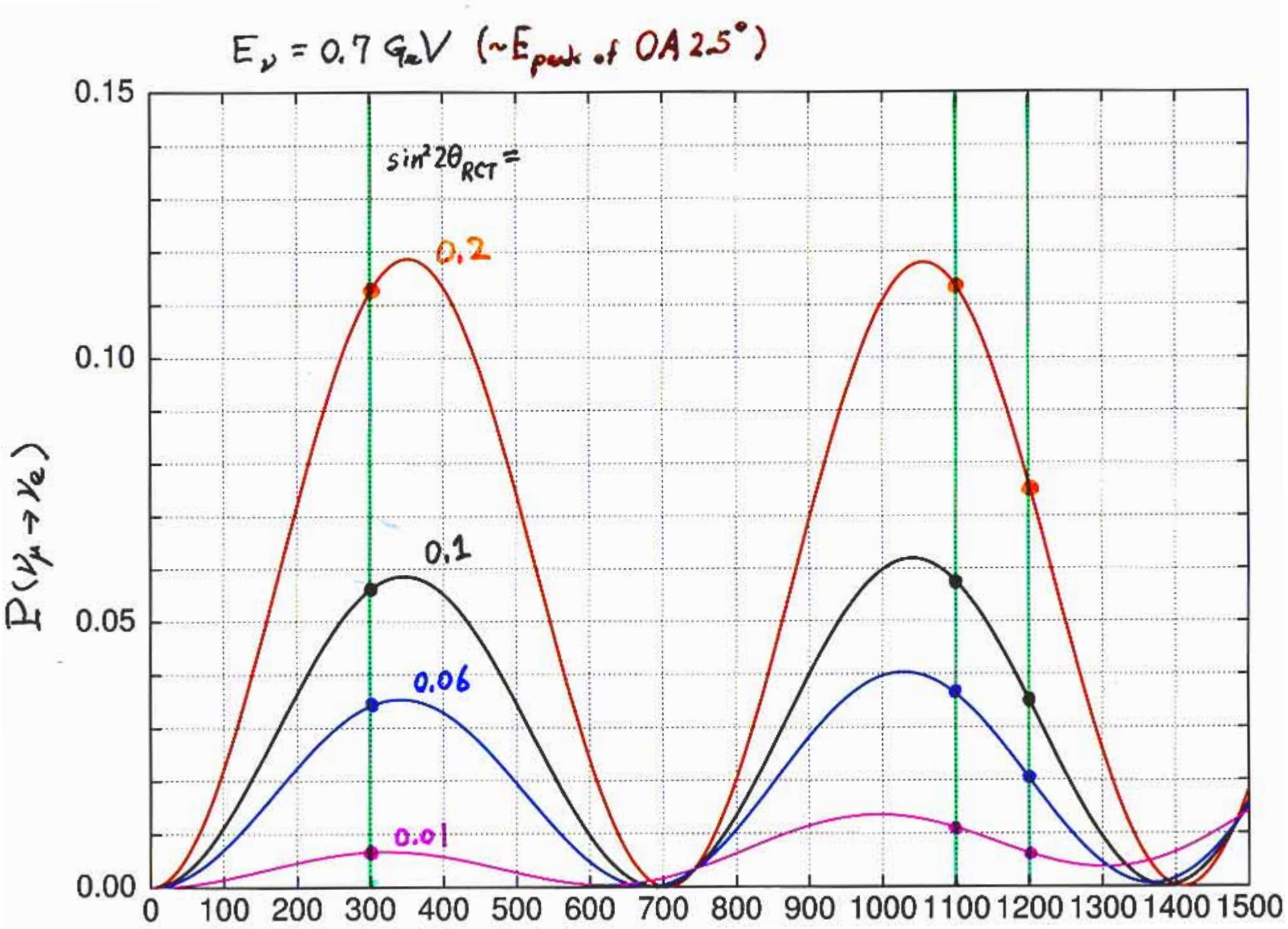




KOREA

by Kenichi Sanda


$E_\nu = 0.7\ GeV$
$\delta m^2_{ATM} = 2.5 \times 10^{-3}\ eV^2$
2.7
2.3
$\sin^2 2\theta_{ATM} = 1$
$\sin^2_{SOL} = 7 \times 10^{-5}$
$\sin^2 2\theta_{SOL} = 0.8$
$\delta_{CP} = 0°$
$\rho = 3\ g/cm^3$
$P(\nu_\mu \to \nu_\mu)$
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
2.7
2.5
2.3
SK
Korea
L (km)


E_ν = 0.7 GeV (~E_{peak} of OA 2.5°)
$\sin^2 2\theta_{RCT}$ =
0.2
0.1
0.06
0.01
$P(\nu_\mu \to \nu_e)$
0.15
0.10
0.05
0.00
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500

Measuring δ_{MNS} by LBL experiments

J-PARC → Hyper-Kamiokande

M. Aoki, K.H., N. Okamura
hep-ph/0208223
PLB554, 121 (2003)

* Update : NBB → OAB

J-PARC ν	10^{21} POT/year	~50 × K2K
HK	1000 kt water Čerenkov	~50 × SK

case study

ν_μ	OAB 2°	1 year	
$\bar{\nu}_\mu$	OAB 2°	4 years	
ν_μ	OAB 8°	1 year	← necessary to resolve $\delta = 0°$ from 180°

BG from { secondary beam contributions
π^0/e mis-identification (neutral current)

ΔFlux ~2% α_f = 33%

We find

$\delta_{MNS}^{true} = 90°, 290°$

⇓

$\Delta\delta_{MNS} = \pm 30°$

CP can be established at 4σ
if $|\delta_1, |\delta - 180°| > 30°$
$\sin^2 2\theta_{RCT} > 0.02$

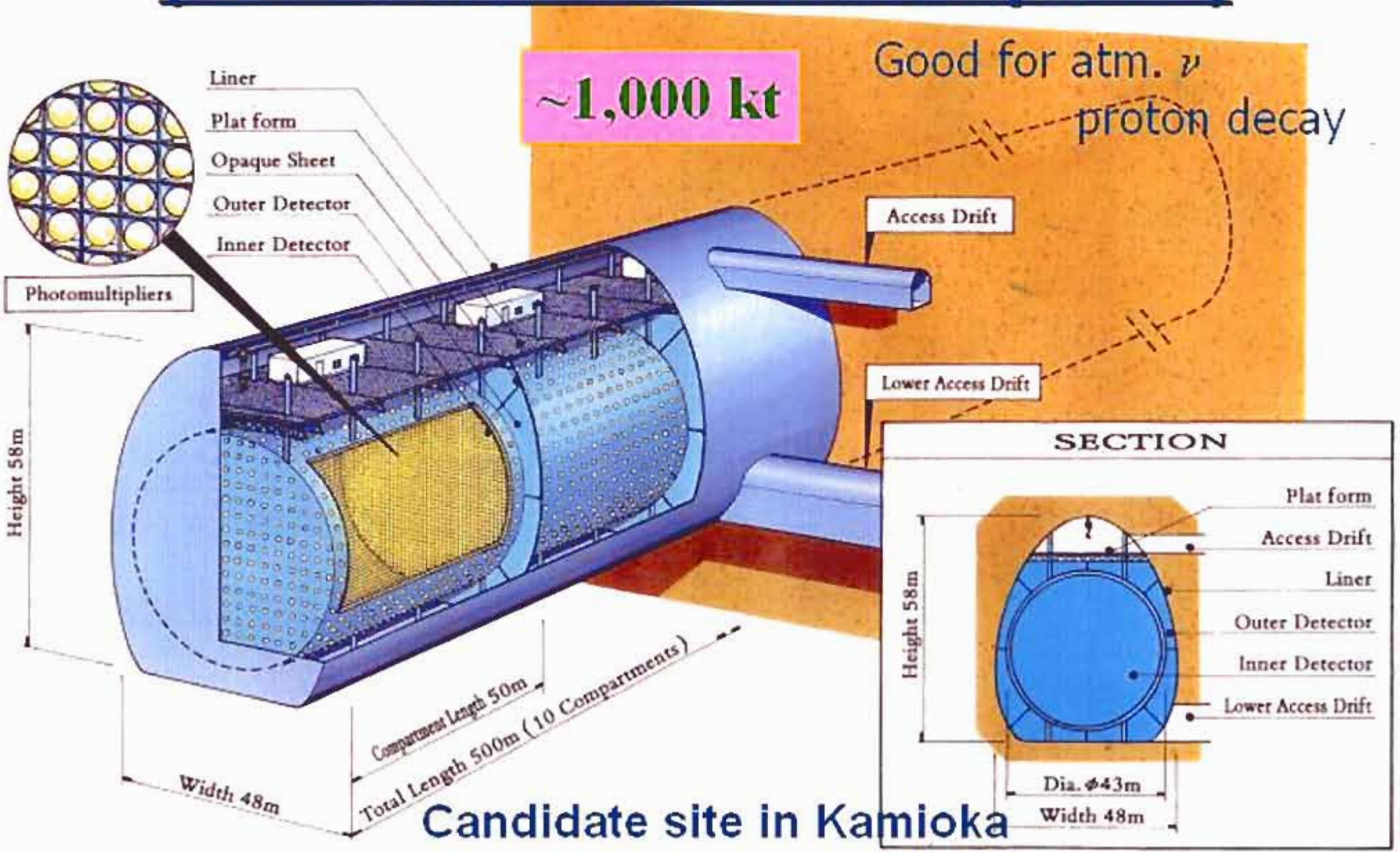
$\delta_{MNS}^{true} = 0°, 180°$

⇓

$\Delta\delta_{MNS} = \pm 9°$

0° vs 180° degeneracy
OAB2 + OAB3 ⇒ 2σ ($\sin^2 2\theta_{RCT}$ ~0.06)
1σ (" ~0.01)

Hyper-Kamiokande
(a far detector in the 2nd phase)

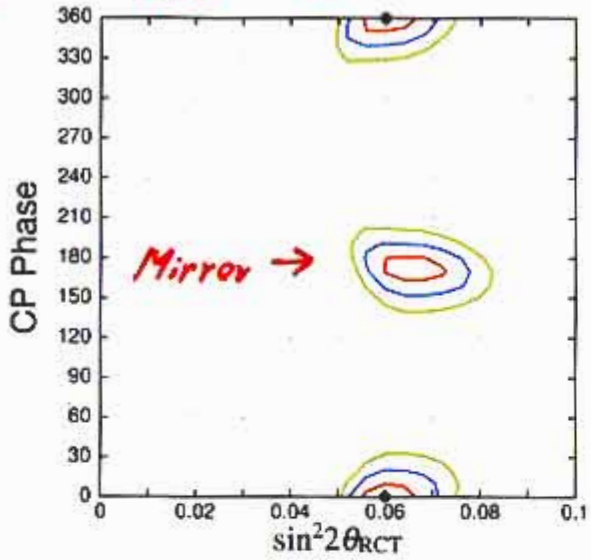


Candidate site in Kamioka

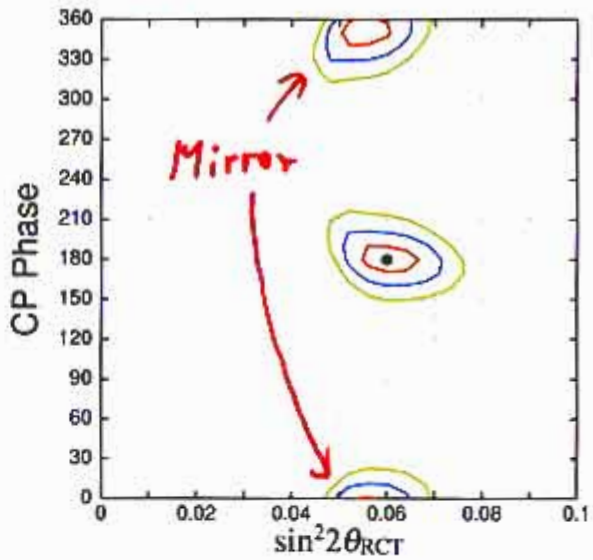
Ambiguity between

$\delta = 0° \leftrightarrow 180°$

$\delta_{MNS}^{true} = 0°$



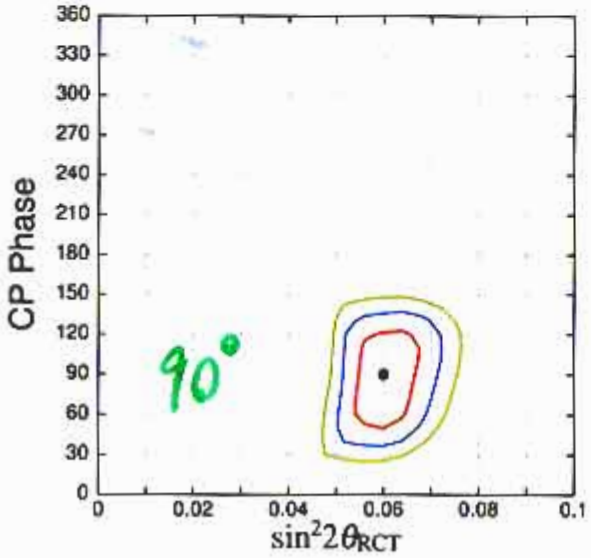
180°

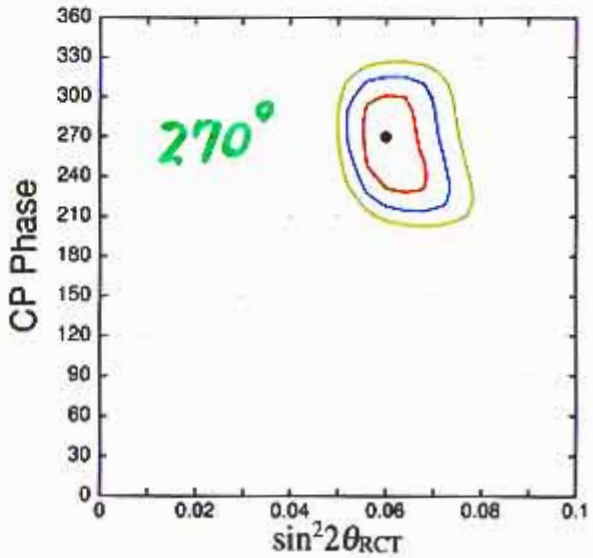


ν_μ (OA 2°) 1 year

+

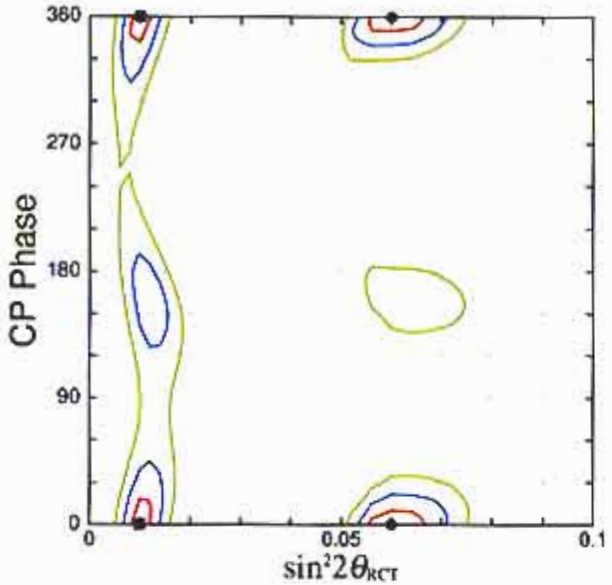
$\bar{\nu}_\mu$ (OA 2°) 4 years



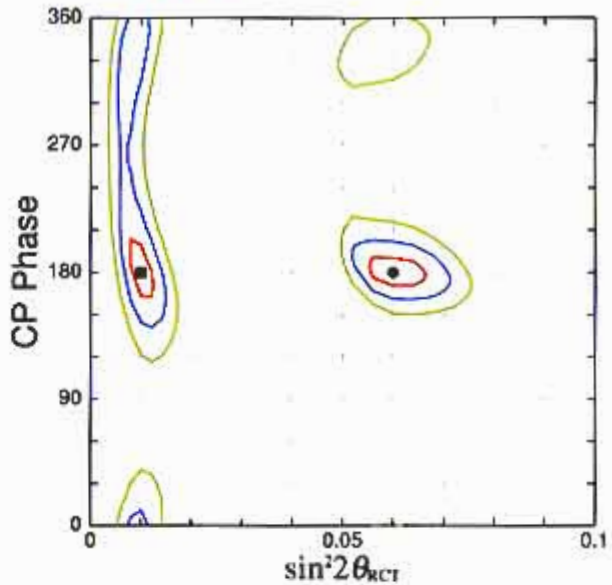


$\sin^2 2\theta_{RCT}^{true} = 0.06$

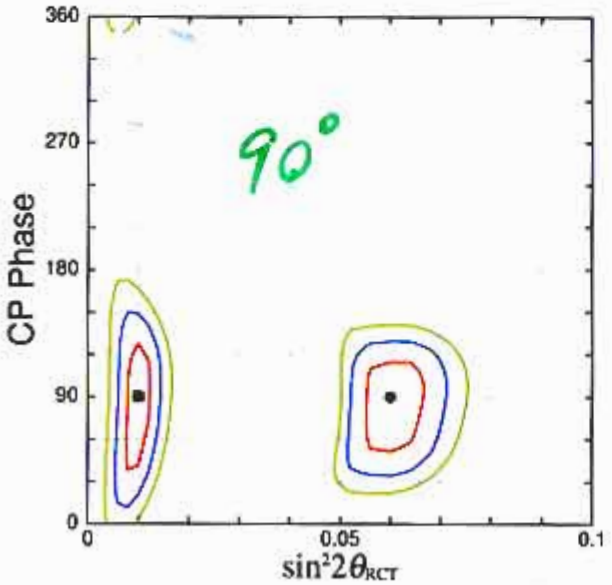
$\delta_{MNS}^{true} = 0°$



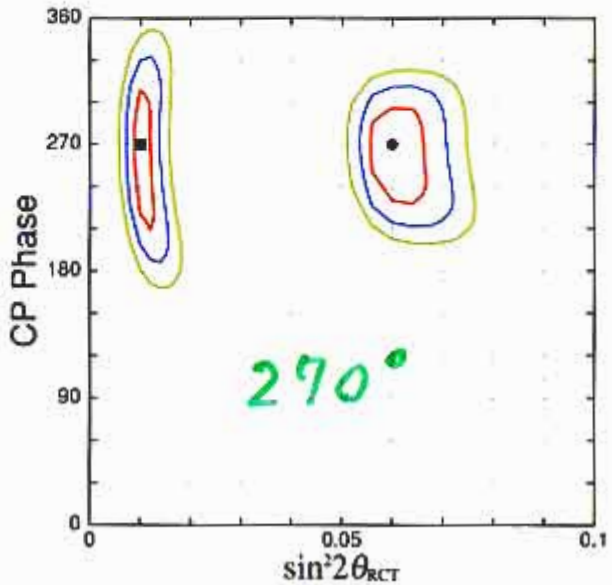
180°



90°

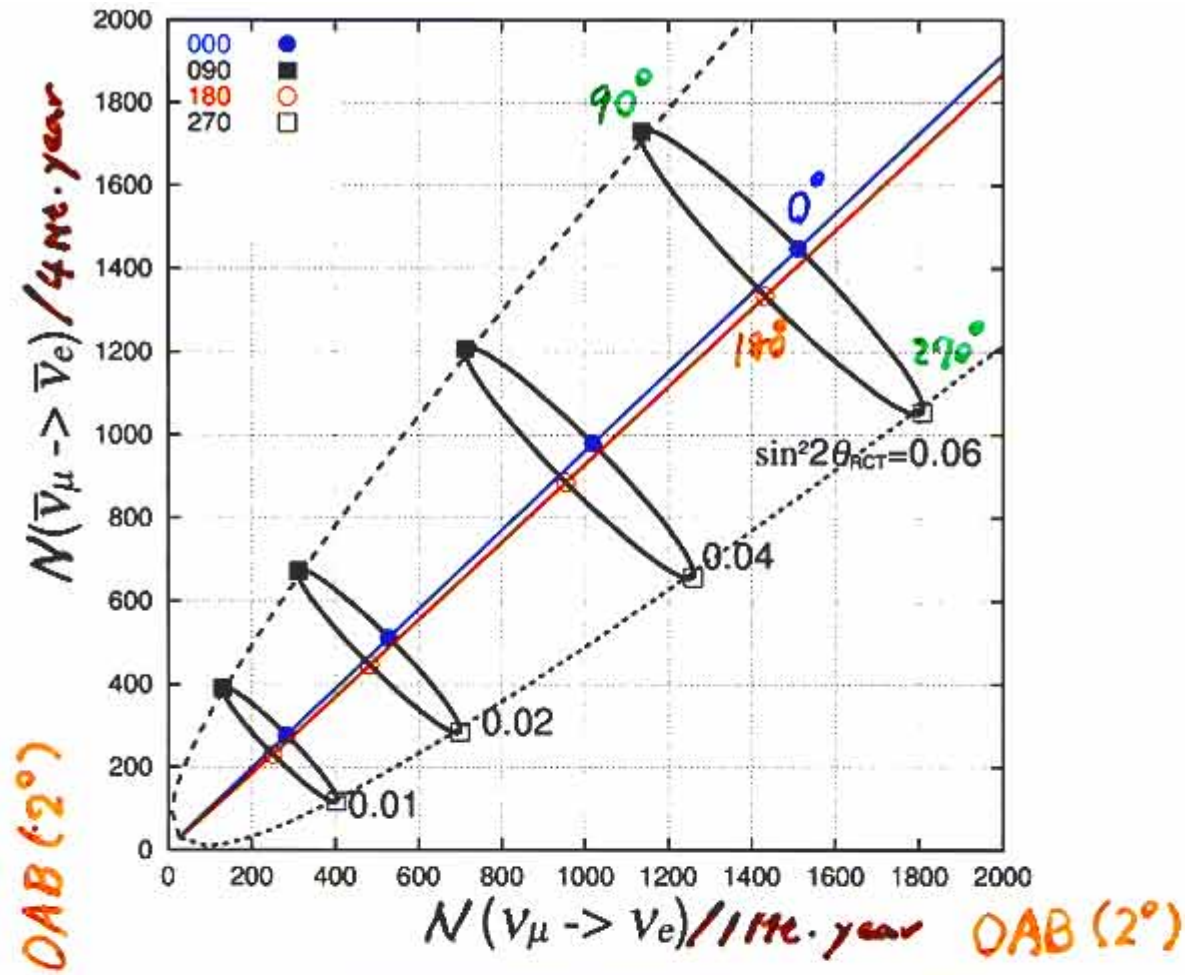


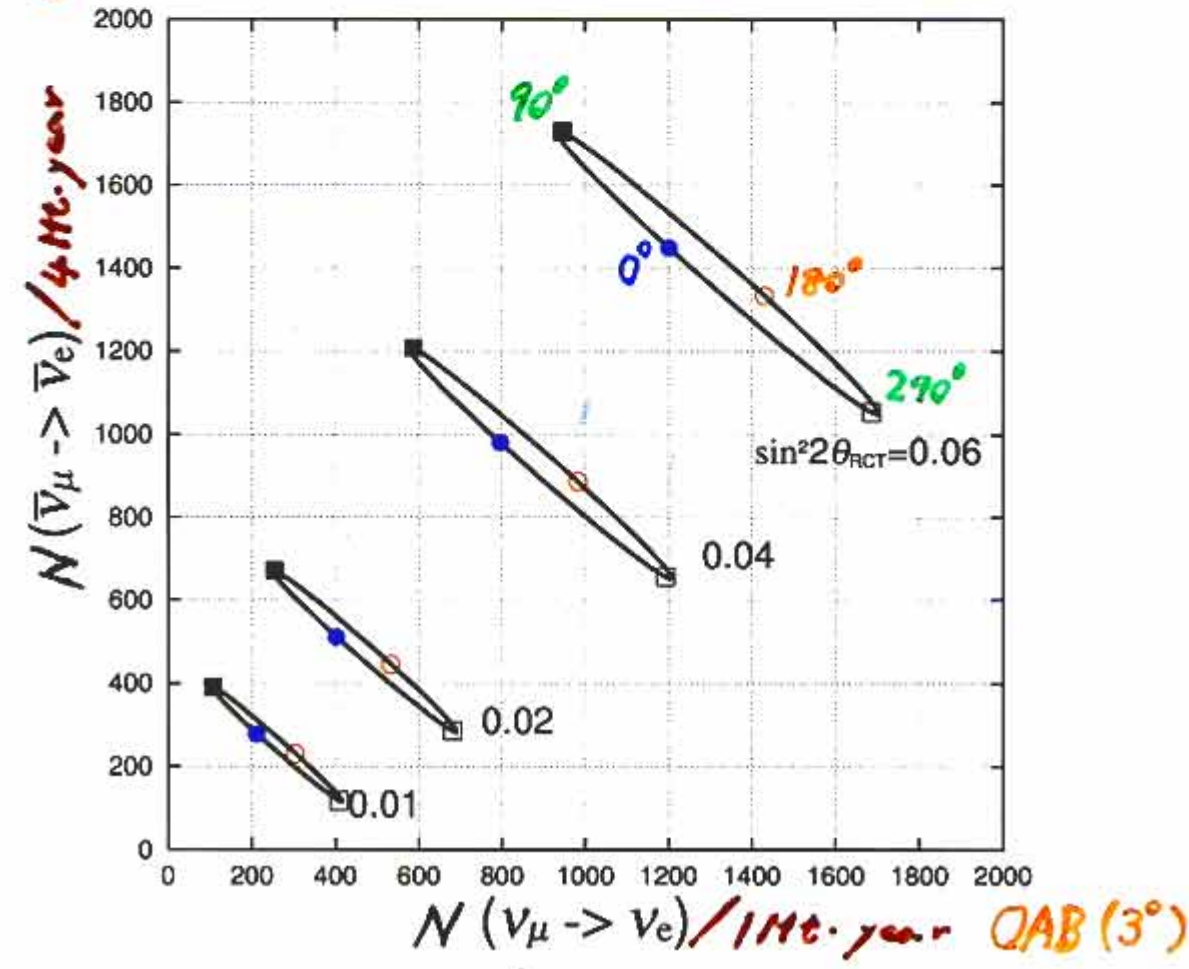
270°



ν_μ (OA 2°)
1 year
+
$\bar{\nu}_\mu$ (OA 2°)
4 years
+
ν_μ (OA 3°)
1 year

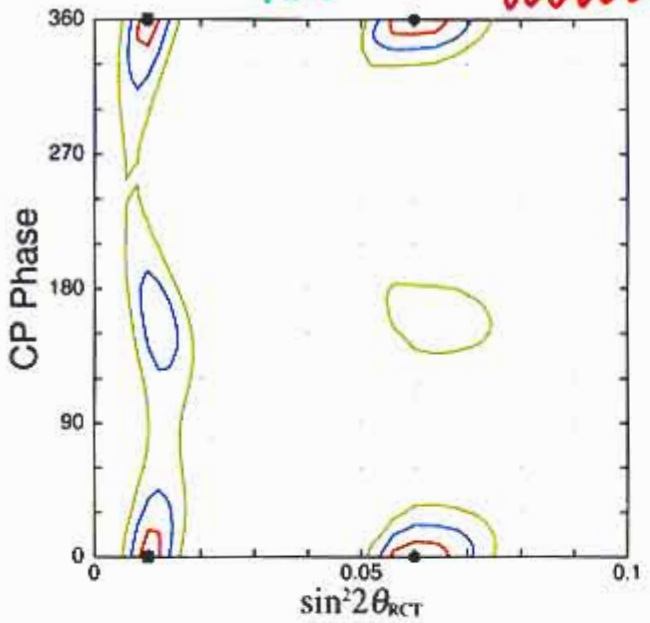
$\sin^2 2\theta_{RCT}^{true} = 0.01, 0.06$

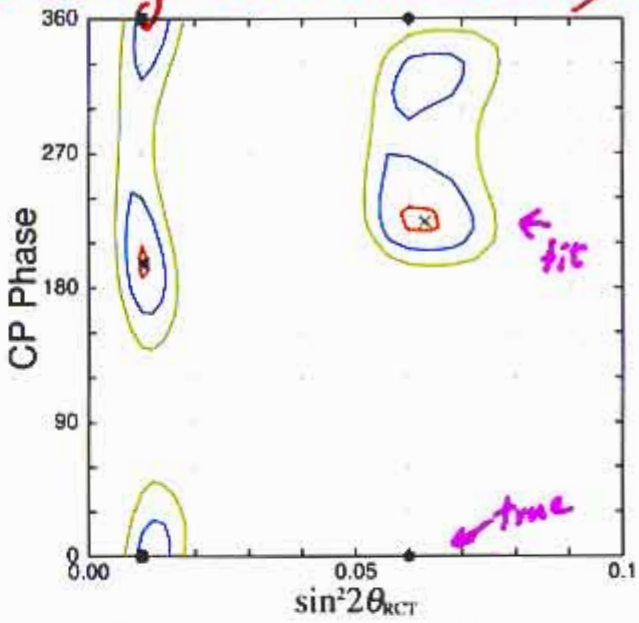

000
090
180
270
90°
0°
180°
270°
sin²2θRCT=0.06
0.04
0.02
0.01
N(ν̄μ -> ν̄e)/4Mt·year
N (νμ -> νe)/1Mt·year
OAB (2°)


90°
0°
180°
270°
sin²2θRCT=0.06
0.04
0.02
0.01
N(ν̄μ -> ν̄e)/4Mt·year
N (νμ -> νe)/1Mt·year
OAB (3°)

HOWEVER

$\delta_{MNS}^{true} = 0°$ $\delta m^{2\,true}_{13} > 0$

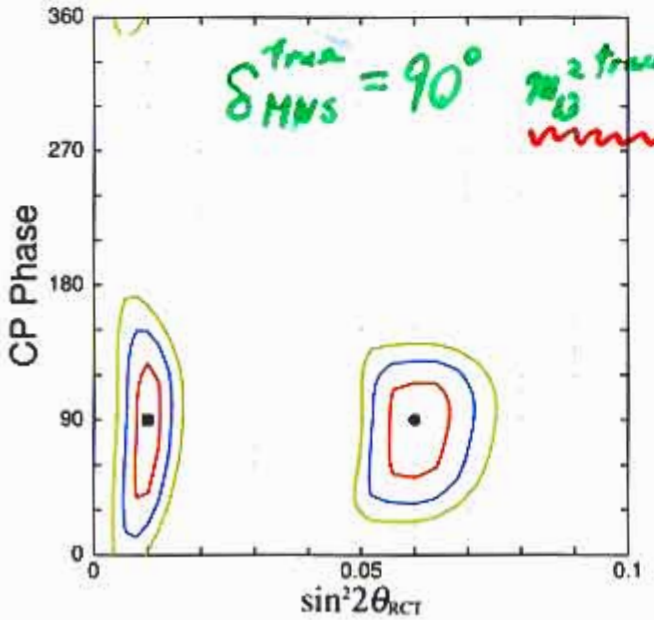


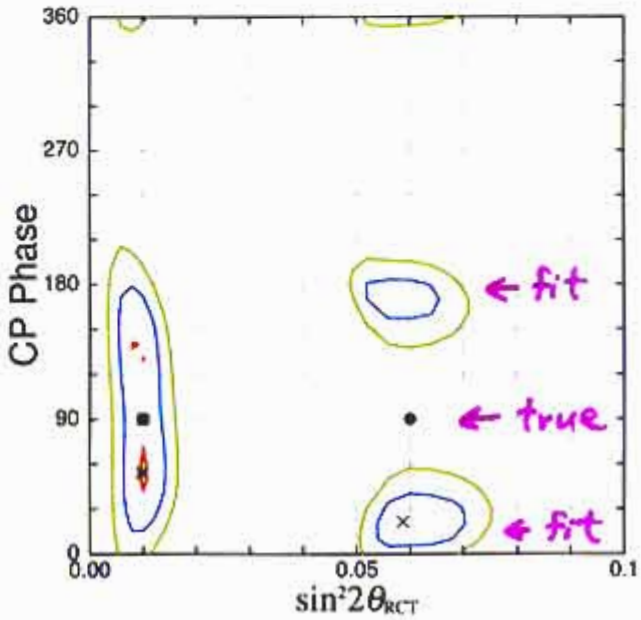


If the same data is analized by assuming the inverted hierarchy : $\delta m^2_{13} < 0$

~~CP~~ ?

$\delta_{MNS}^{true} = 90°$ $\delta m^{2\,true}_{13} > 0$





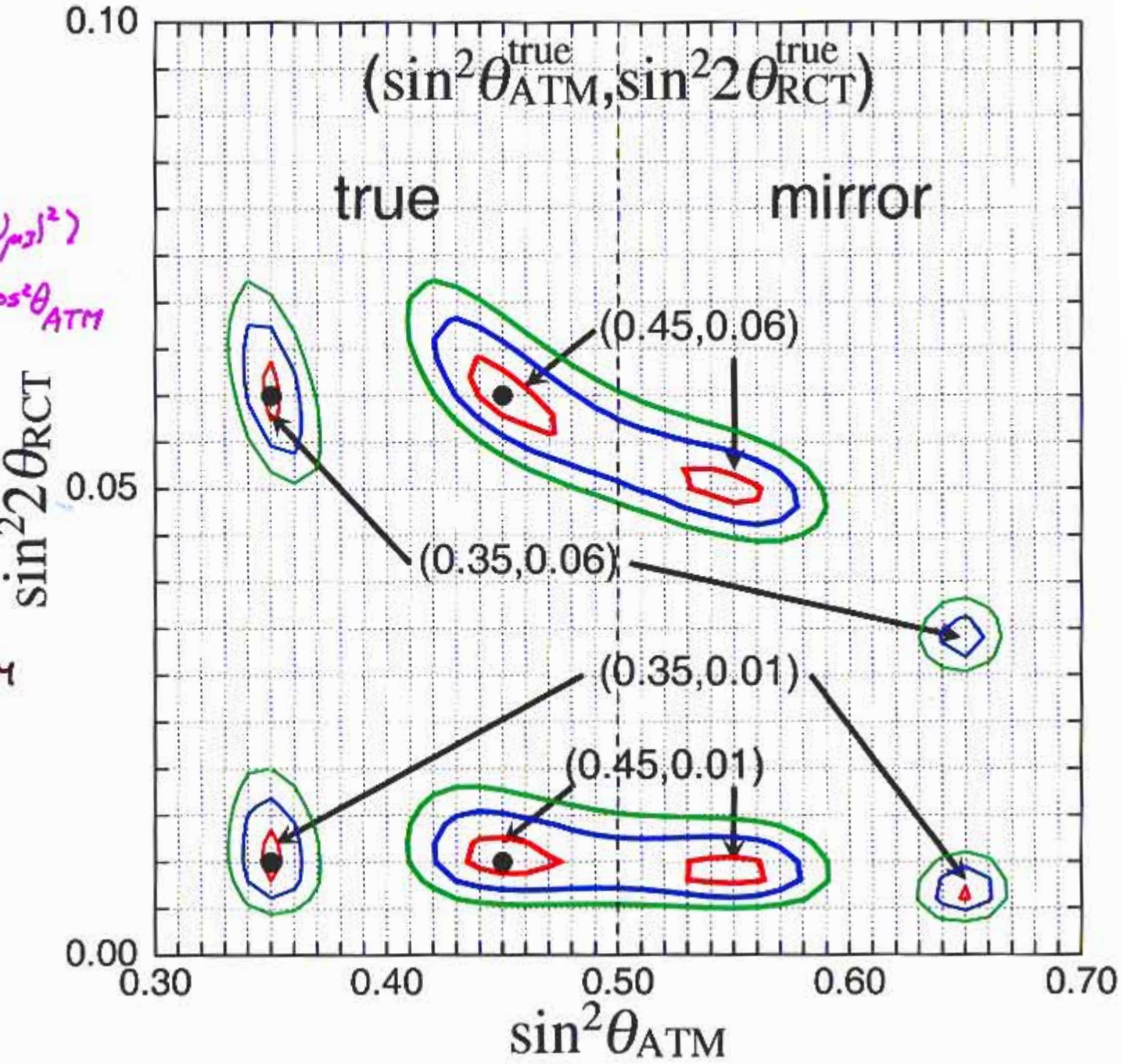
No ~~CP~~ ?

$\sin^2 2\theta_{RCT}^{true} = 0.01, 0.06$

More ambiguity ③ $\sin^2\theta_{ATM} \lesssim 0.5$

$\sin^2 2\theta_{ATM} = 4|V_{\mu 3}|^2(1-|V_{\mu 3}|^2)$
$= 4\sin^2\theta_{ATM}\cos^2\theta_{ATM}$

$\sin^2\theta_{ATM}$	$\sin^2 2\theta_{ATM}$
0.35	0.91
0.40	0.96
0.45	0.99



In order to resolve the mass hierarchy ambiguity

$$m_1^2 \lessgtr m_3^2$$

normal $(\delta m^2_{13} > 0)$

inverted $(\delta m^2_{13} < 0)$

wee need to make use of the earth matter effect

⇓

higher E_ν

⇓

longer L

BAND @ Beijing has been proposed: Y.F. Wang, hep-ex/0010001

Y.F. Wang et al. PRD65: 073021 (2002)

100 kt

Water Čerenkov Calorimeter

$$L = 2{,}100 \text{ km}$$

We examined the possibility of using High-Energy-Narrow Band-Beam (new beam line)

from J-PARC $\quad \langle E_\nu \rangle \sim 3 - 5$ GeV

We find

$$P(\nu_\mu \to \nu_e)_{\delta m^2_{13}<0} \ll P(\nu_\mu \to \nu_e)_{\delta m^2_{13}>0}$$

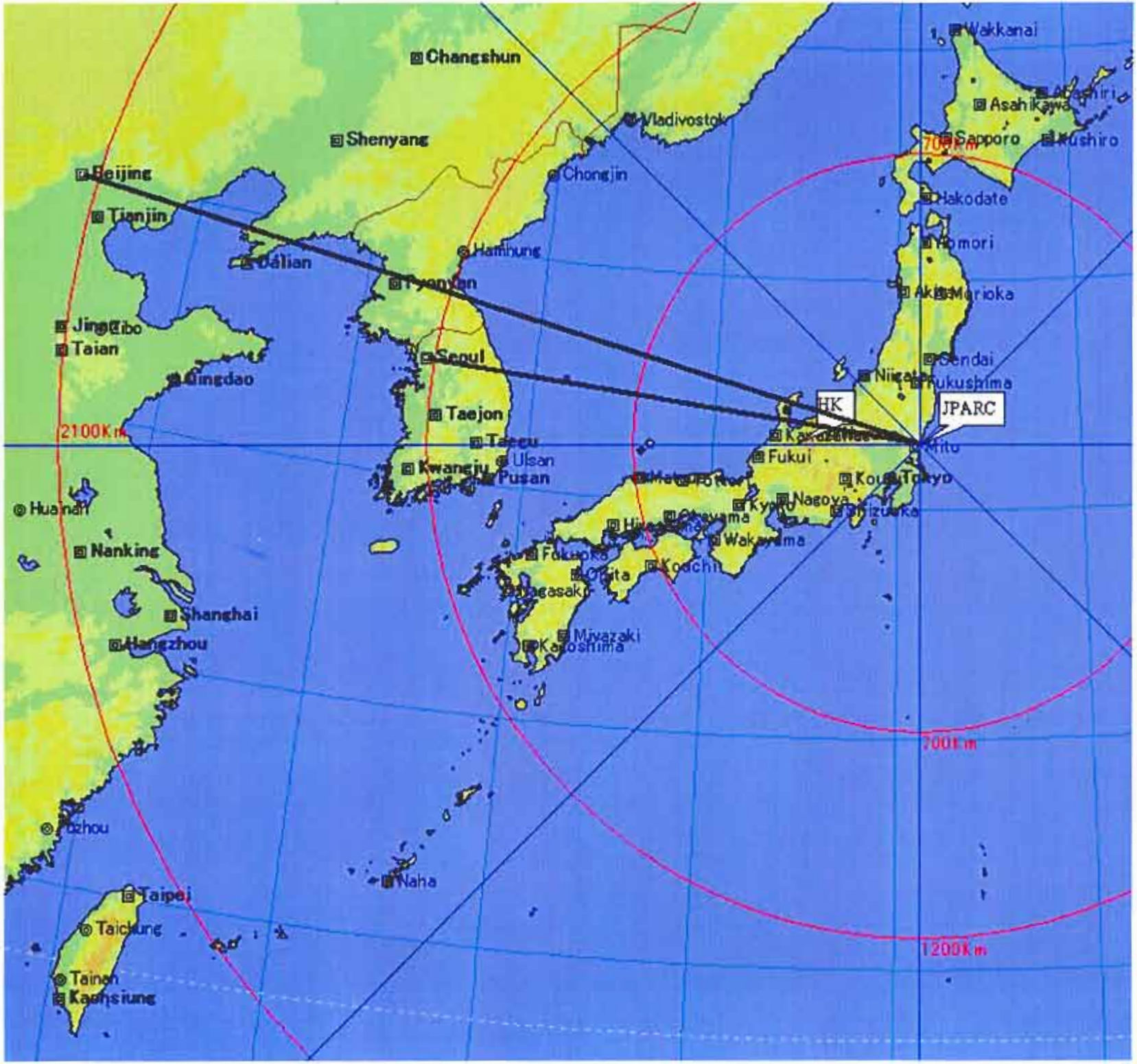
If $\nu_\mu \to \nu_e$ is observed Both at SK and at BAND,

then $\delta m^2_{13} > 0$ can be established.

$m_3^2 \gtrless m_1^2$ resolved if $\sin^2 2\theta_{RCT} > 0.04$ (3σ)

M. Aoki-KH-Hayato-Kobayashi-Nishikawa-Okamura,

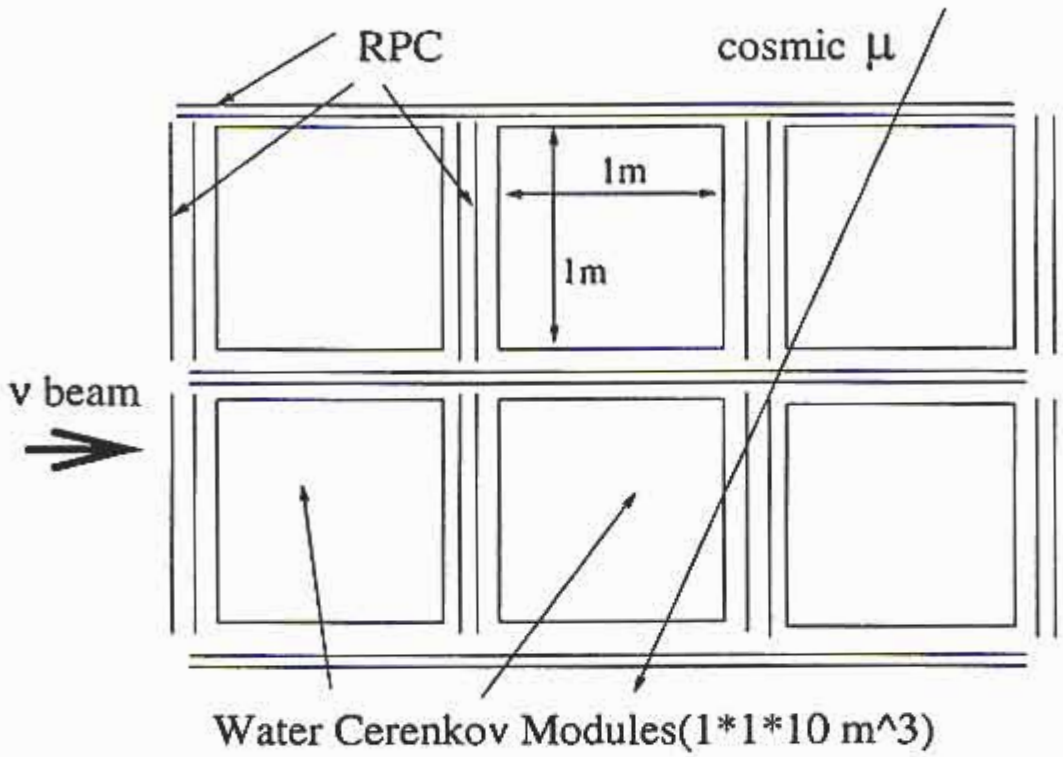
PRD69: 093004 (2003)

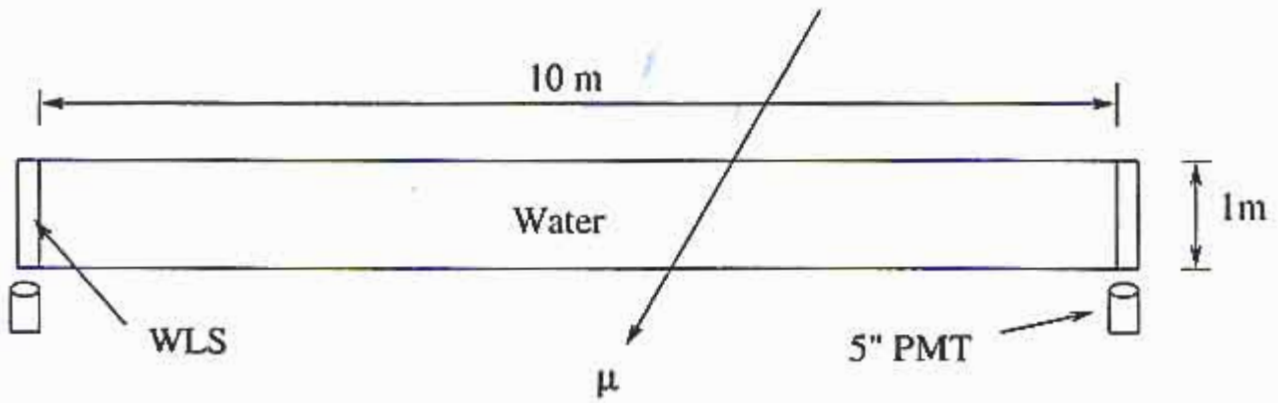

Changchun
Shenyang
Beijing
Tianjin
Dalian
Hamhung
Pyongyan
Jinan
Zibo
Taian
Qingdao
Seoul
Taejon
Taegu
Kwangju
Ulsan
Pusan
Huainan
Nanking
Shanghai
Hangzhou
Taipei
Taichung
Tainan
Kaohsiung
Naha
Miyazaki
Fukui
Nagoya
Wakayama
Vladivostok
Chongjin
Wakkanai
Asahikawa
Sapporo
Hakodate
Aomori
Morioka
Sendai
Fukushima
Niigata
Tokyo
Mito
HK
JPARC
700Km
2100Km
700Km
1200Km

Beijing Astrophysics & Neutrino Detector

Y. F. Wang, hep-ex/0010081

Y. F. Wang, K. Whisnant, B. L. Young, PRD65:073021(2002)





(1m × 1m × 10m) unit

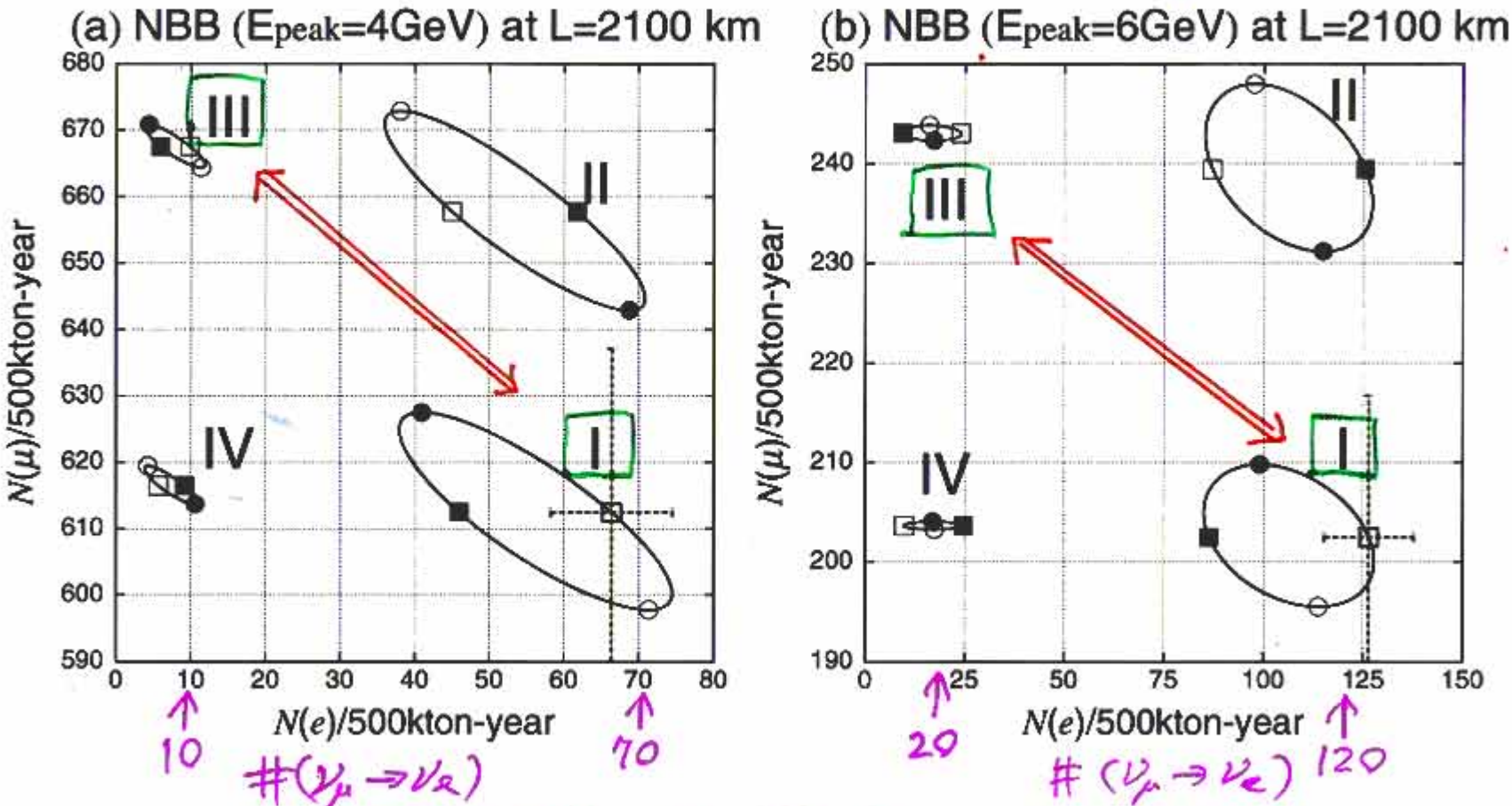
2100km

Inputs : $\delta m^2_{ATM} = 3.5 \times 10^{-3}\,eV^2$ $\sin^2 2\theta_{ATM} = 1$

$\delta m^2_{SOL} = 1 \times 10^{-4}\,eV^2$ $\sin^2 2\theta_{SOL} = 0.8$

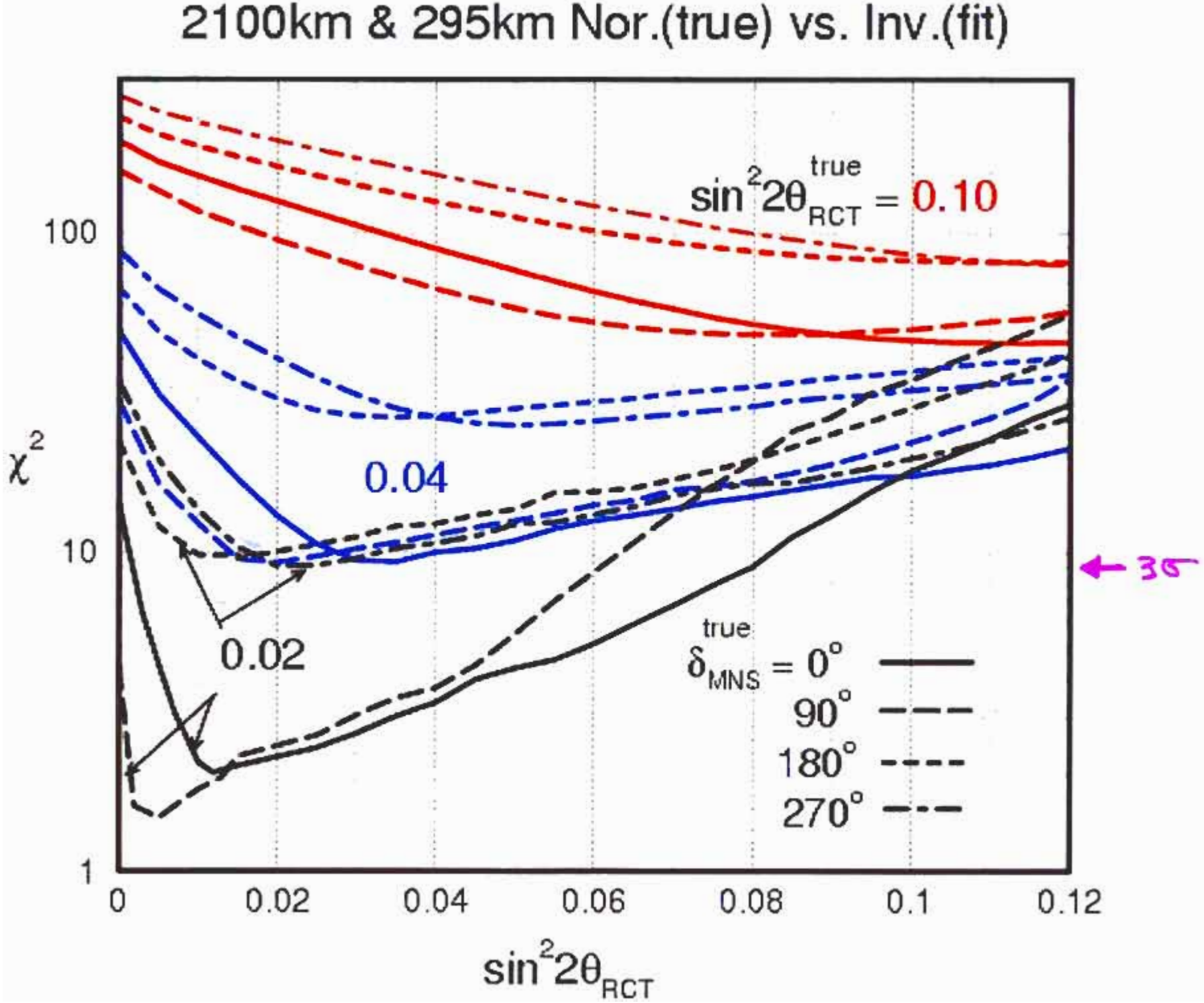
$\delta_{MNS} = 0° - 90° - 180° - 270° - 360°$ $\sin^2 2\theta_{CHOOZ} = 0.1$

$\rho = 3\,g/cm^3$



JPARC-to-Beijing

M. Aoki et al, PRD67 : 093004 (2003)


2100km & 295km Nor.(true) vs. Inv.(fit)
$\sin^2 2\theta_{RCT}^{true} = 0.10$
0.04
0.02
χ^2
100
10
1
0
0.02
0.04
0.06
0.08
0.1
0.12
$\sin^2 2\theta_{RCT}$
δ_{MNS}^{true} = 0°
90°
180°
270°
← 3σ

Remaining problems :

- mass hierarchy : what if $\sin^2 2\theta_{RCT} < 0.04$?
- $\delta_{MNS} = 0^\circ$ vs 180° : we may want 3σ resolution
- $\sin^2\theta_{ATM} \gtrless \frac{1}{2}$: how powerful will new Reactor experiments be ?

Our proposal : M.Aoki, KH, N.Okamura, hep-ph/0311324

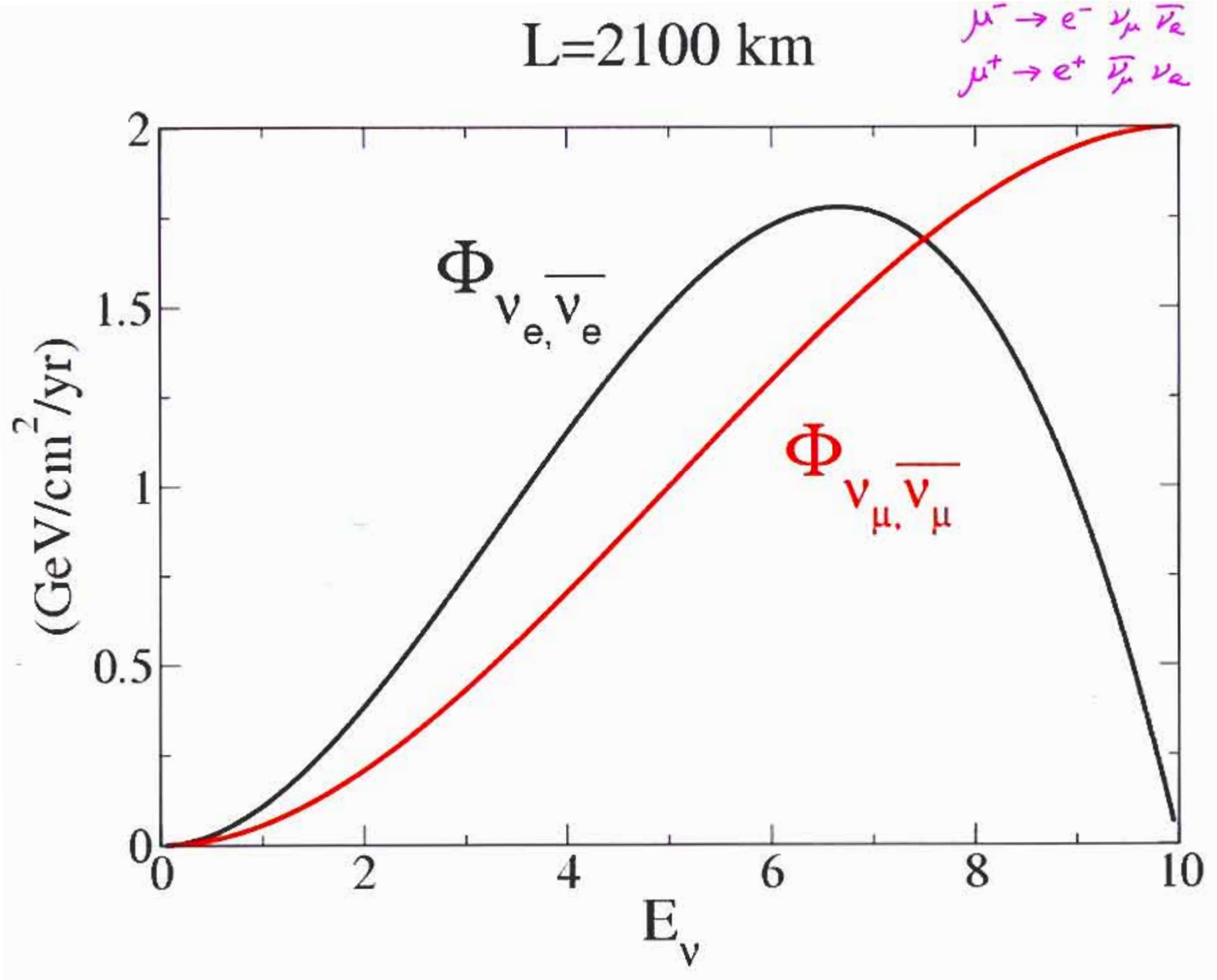
νFactor @ J-PARC $\xrightarrow{2100\ \text{km}}$ BAND @ Beijing

4 MW PS (5×)
PRISM → μ-storage ring
10^{21} μ^+ & μ^- @ 10 GeV

look WC Calorimeter
e/μ separation
no charge identification
event energy ~10%
$\tau \to e/\mu$ backgrounds

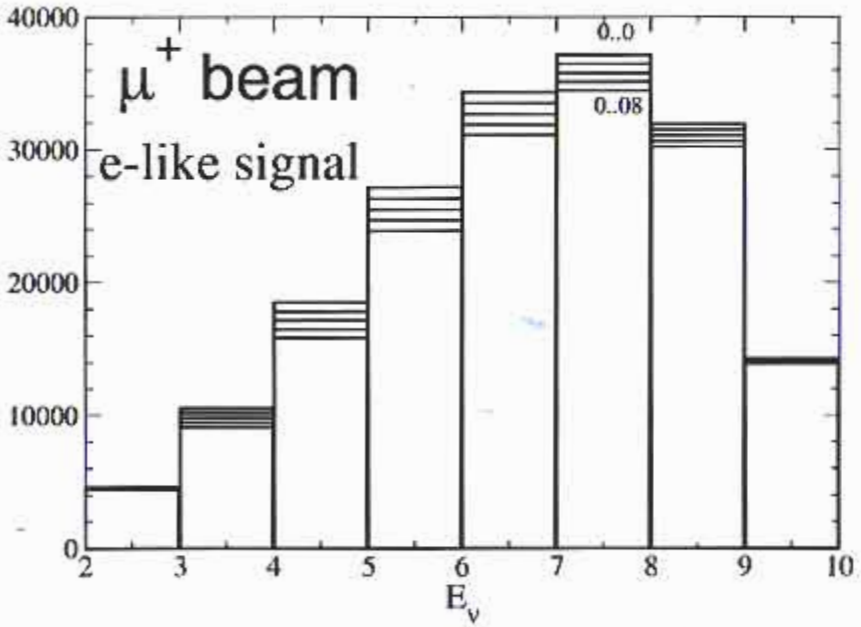
$\Downarrow$

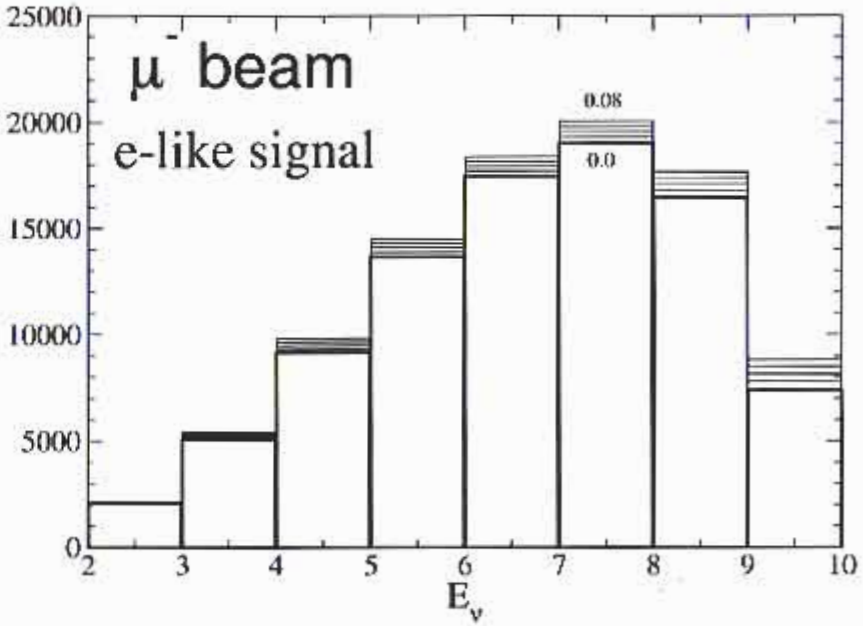
- $m_3 \gtrless m_1$ resolved if $\sin^2 2\theta_{RCT} > 0.004$
- $\delta_{MNS} = 0^\circ \leftrightarrow 180^\circ$ resolved if $\sin^2 2\theta_{RCT} > 0.02$
- $\sin^2\theta_{ATM} \gtrless \frac{1}{2}$ resolved if $\sin^2 2\theta_{RCT} > 0.02$ for $\sin^2 2\theta_{ATM} < 0.96$


L=2100 km
$\mu^- \to e^- \nu_\mu \bar{\nu}_e$
$\mu^+ \to e^+ \bar{\nu}_\mu \nu_e$
$\Phi_{\nu_e, \bar{\nu}_e}$
$\Phi_{\nu_\mu, \bar{\nu}_\mu}$
(GeV/cm^2/yr)
E_ν
0
0.5
1
1.5
2
0
2
4
6
8
10

ν Factory -to- Beijing

$\sin^2 2\theta_{RCT} = 0, 0.02, 0.04, 0.06, 0.08$





$\mu^+ \to e^+ \nu_e \bar{\nu}_\mu$ — suppressed by the matter effect

- $\bar{\nu}_e \to e^+$
- $\nu_e \to e^-$ } e-like
  - $\bar{\nu}_\tau \to \tau^+ \to e^+$
  - $\nu_\tau \to \tau^- \to e^-$

$\mu^- \to e^- \bar{\nu}_e \nu_\mu$ — enhanced by the matter effect

- $\nu_e \to e^-$
- $\bar{\nu}_e \to e^+$ } e-like
  - $\nu_\tau \to \tau^- \to e^-$
  - $\bar{\nu}_\tau \to \tau^+ \to e^+$

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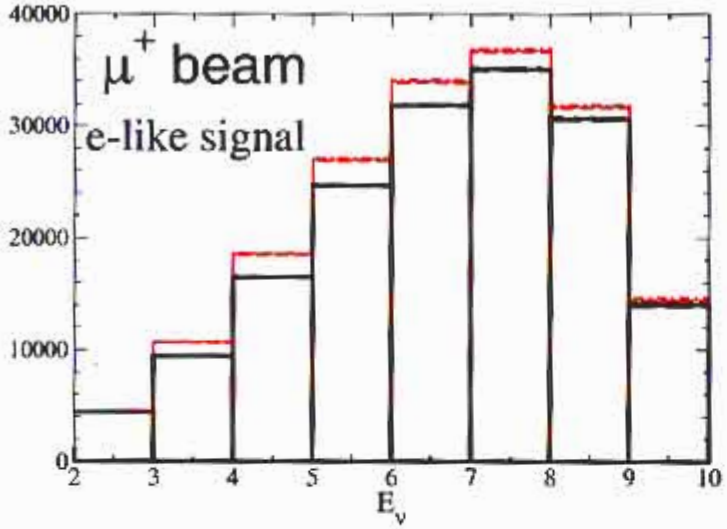
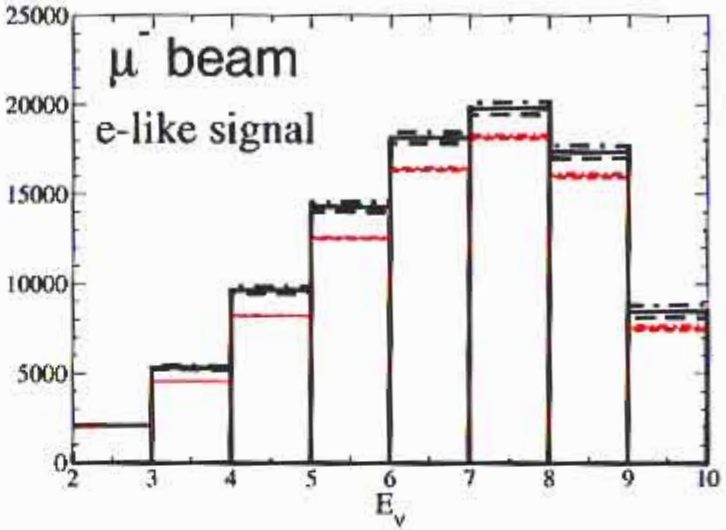
$m_1 < m_3$ normal

$m_1 > m_3$ inverted

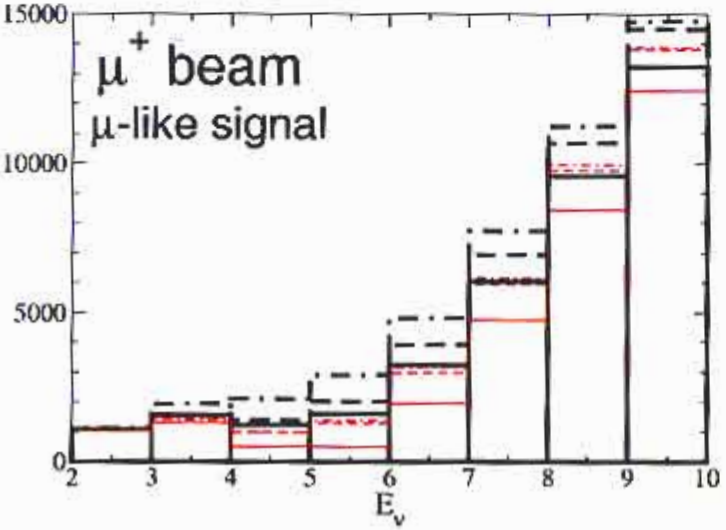


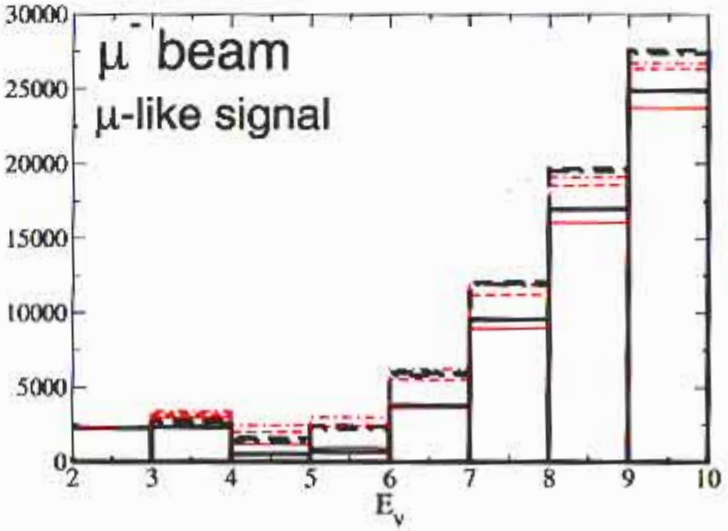


e-like signals are sensitive to $m_1 \gtrless m_3$

$\sin^2\theta_{ATM}$

$= \begin{cases} 0.35 & - - - \\ 0.5 & ——— \\ 0.65 & -\cdot-\cdot- \end{cases}$





μ-like signals are sensitive to $\sin^2\theta_{ATM} \gtrless \frac{1}{2}$

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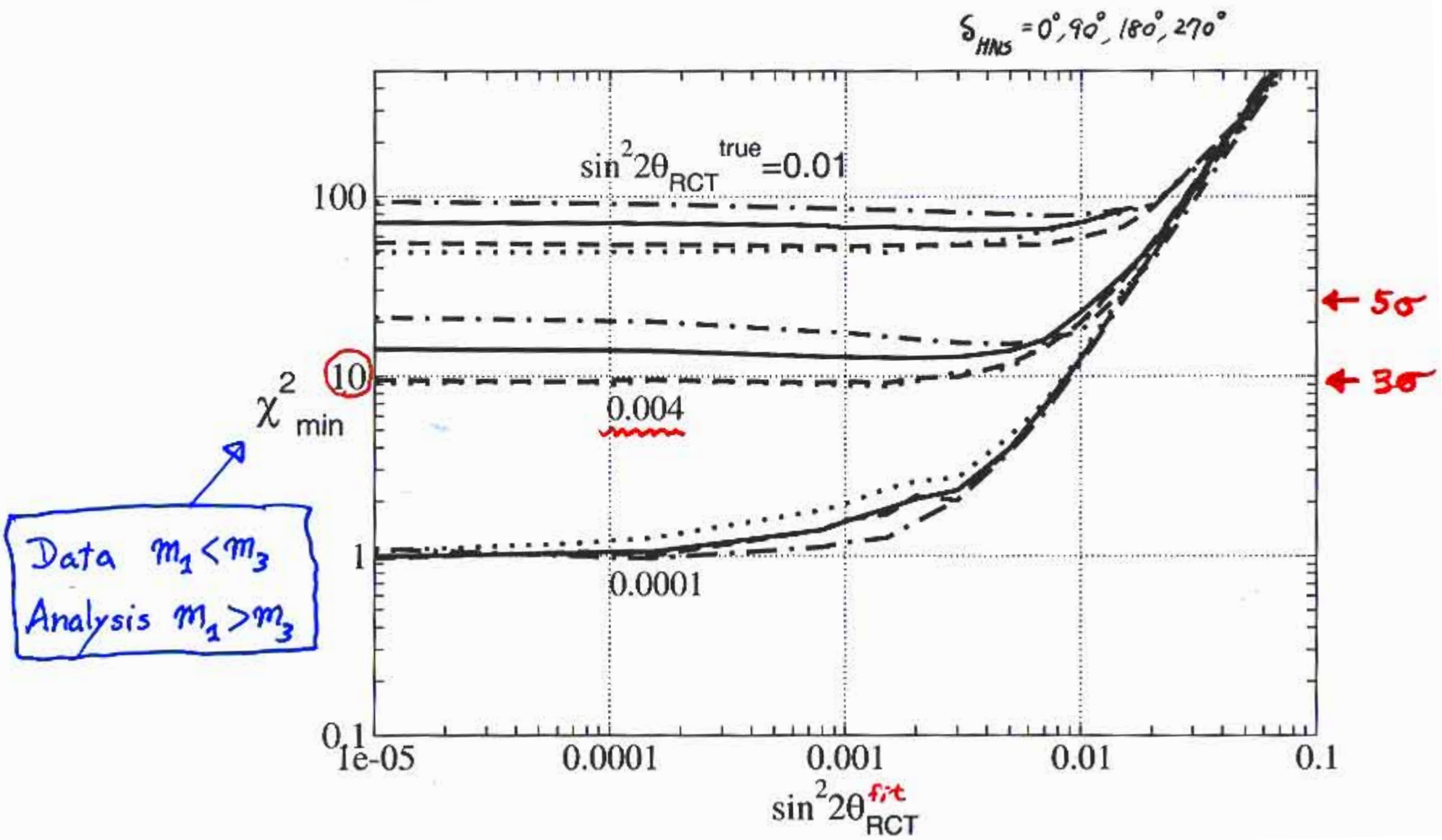

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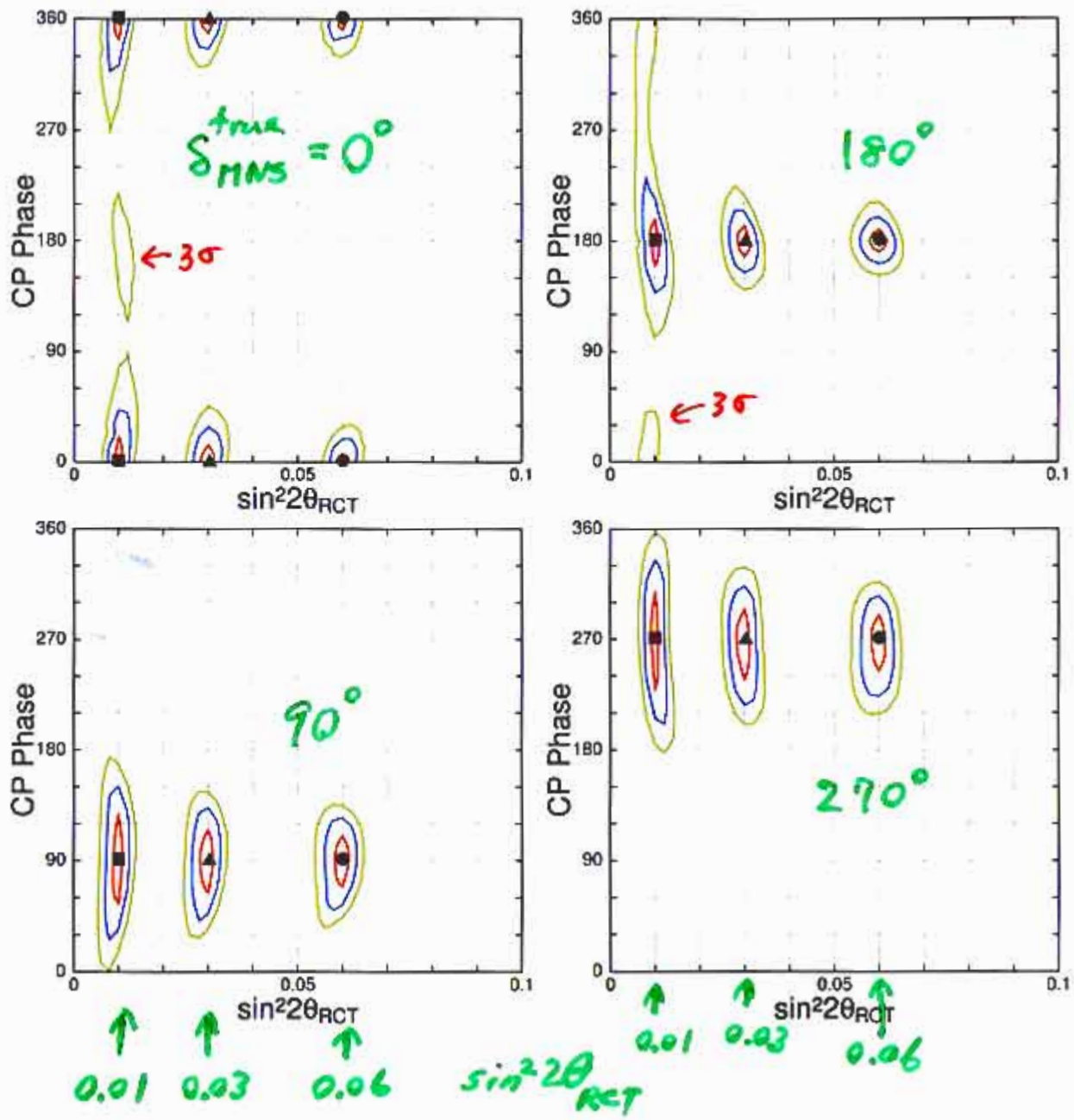
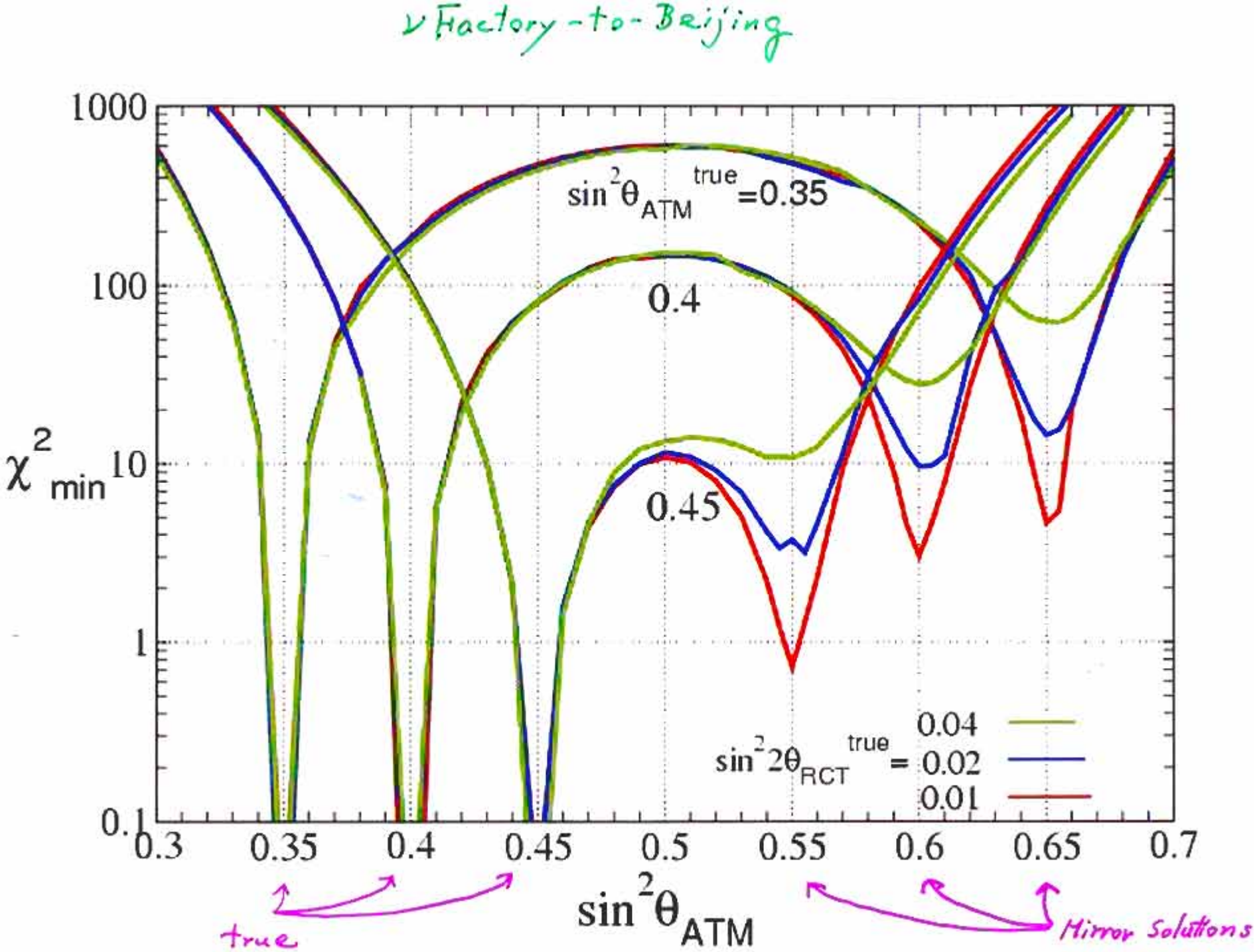



ν Factory - to - Beijing
1000
100
10
1
0.1
χ^2_{min}
$\sin^2\theta_{ATM}^{true}$=0.35
0.4
0.45
$\sin^2 2\theta_{RCT}^{true}$ = 0.04
0.02
0.01
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0.65
0.7
$\sin^2\theta_{ATM}$
true
Mirror Solutions

In the vacuum :

$(1-\sin^2\theta_{RCT})^2 > \sin^2 2\theta_{SOL} \sim 0.8$

$$P(\nu_e \to \nu_e) = 1 - 4\underbrace{|U_{e3}|^2}_{\sin^2\theta_{RCT}}(1-|U_{e3}|^2)\sin^2\left(\frac{\delta m^2_{13}}{4E}L\right) + \cdots$$

$$\sin^2\theta_{RCT} = \frac{1-\sqrt{1-\sin^2 2\theta_{RCT}}}{2}$$

$$P(\nu_\mu \to \nu_\mu) = 1 - 4\underbrace{U^2_{\mu 3}}_{\sin^2\theta_{ATM}}(1-U^2_{\mu 3})\sin^2\left(\frac{\delta m^2_{13}}{4E}L\right) + \cdots$$

$$\sin^2\theta_{ATM} = \frac{1\pm\sqrt{1-\sin^2 2\theta_{ATM}}}{2}$$

$$P(\nu_\mu \to \nu_e) = -4\underbrace{U^2_{\mu 3}}_{\sin^2\theta_{ATM}}\underbrace{|U_{e3}|^2}_{\sin^2\theta_{RCT}}\sin^2\left(\frac{\delta m^2_{13}}{4E}L\right) + \cdots$$

Observation of $P(\nu_\mu \to \nu_e)$ tells $\sin^2\theta_{RCT} \neq 0$

but the two-fold ambiguity in $\sin^2\theta_{ATM}$ leads to

two-fold ambiguity in $\sin^2\theta_{RCT}$ leads to

two-fold ambiguity in δ_{MNS}

Unique determination of $\sin^2\theta_{RCT}$ requires $P(\nu_e \to \nu_e)$, $P(\bar{\nu}_e \to \bar{\nu}_e)$:

ν-Factory @ BAND

Reactor experiment @ Kashiwazaki

$$\frac{L}{E} \approx \frac{1\,\text{km}}{0.005\,\text{GeV}} \approx 200\ (\text{km/GeV})$$

$\frac{\delta m^2}{4E}L = \frac{\pi}{2}$

	$\frac{L}{E}$ (km/GeV)	L = 1 km	L = 300 km	L = 730 km	L = 2100 km
$\delta m^2 = 3\times10^{-3}\,eV^2$	400	2.5 MeV	0.75 GeV	1.8 GeV	5 GeV
$2.5\times10^{-3}\,eV^2$	500	2 MeV	0.6 GeV	1.5 GeV	4 GeV
$2\times10^{-3}\,eV^2$	600	1.7 MeV	0.5 GeV	1.2 GeV	3.5 GeV

Conclusions:

- Among the 9 parameters of the 3-neutrino model
  (3 masses 3 angles 3 phases)

  only 6 parameters (2 mass² differences $m_2^2-m_1^2$ $m_3^2-m_1^2$; 3 angles $\sin^2\theta_{SOL}$, $\sin^2\theta_{ATM}$, $\sin^2\theta_{RCT}$; 1 phase δ_{MNS})

  can be measured by ν-oscillation experiments.

  $0\nu\beta\beta$ decay → 1 constraint
  cosmology → hot dark matter, leptogenesis
  flavor physics → quark-lepton relations, ...

- Among the 6 observables (2 are known uniquely $m_2^2-m_1^2=\delta m^2_{SOL}$, $\sin^2\theta_{SOL}$; 2 are known 2-fold (up to) $m_3^2-m_1^2=\pm\delta m^2_{ATM}$, $\sin^2\theta_{ATM}=\frac{1\pm\sqrt{1-\sin^2 2\theta_{ATM}}}{2}$; 1 is constrained $\sin^2\theta_{RCT}\lesssim 0.05$; 1 is unknown $\delta_{MNS}=0^\circ\sim 360^\circ$)

- K2K 2000~2005 confirmation of $P(\nu_\mu\to\nu_\mu)\neq 1$
  MINOS 2005~ precise measurement of δm^2_{ATM}, $\sin^2 2\theta_{ATM}$
  OPERA, ICARUS 2006~ confirmation of $P(\nu_\mu\to\nu_e)\neq 0$

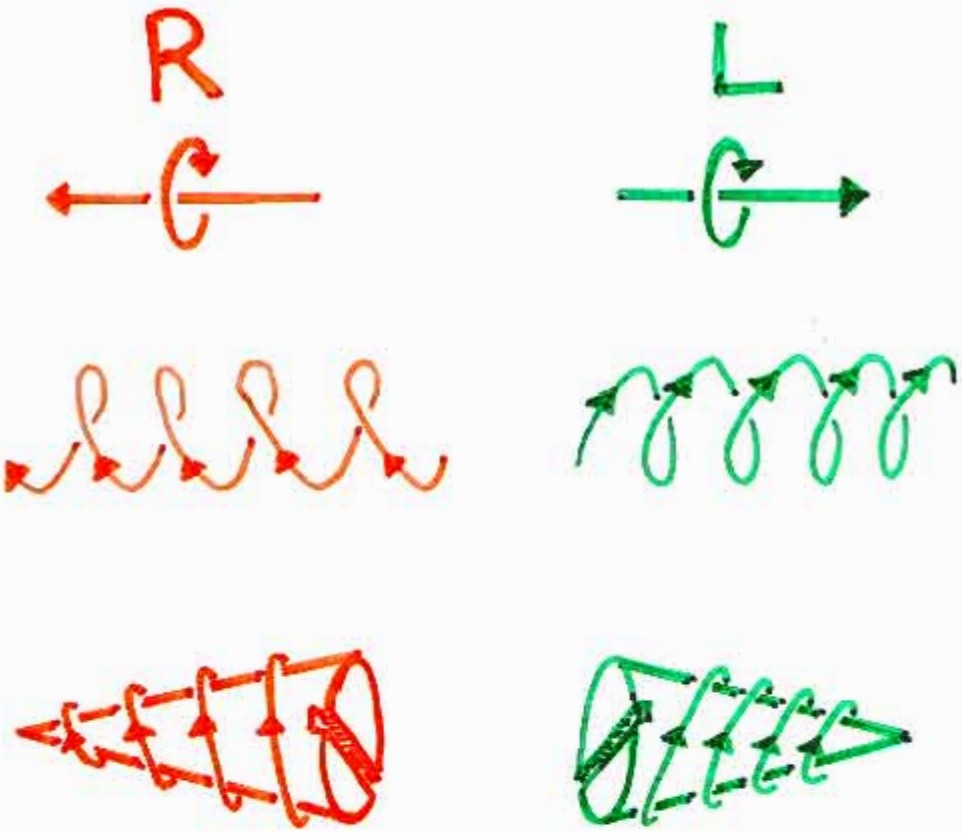
- J-PARC → SK (→ Korea ?) 2009~ precise measurement of δm^2_{ATM}, $\sin^2 2\theta_{ATM}$
  detection of $P(\nu_\mu\to\nu_e)\neq 0 \Rightarrow \sin^2\theta_{RCT}\neq 0$ (2-fold)

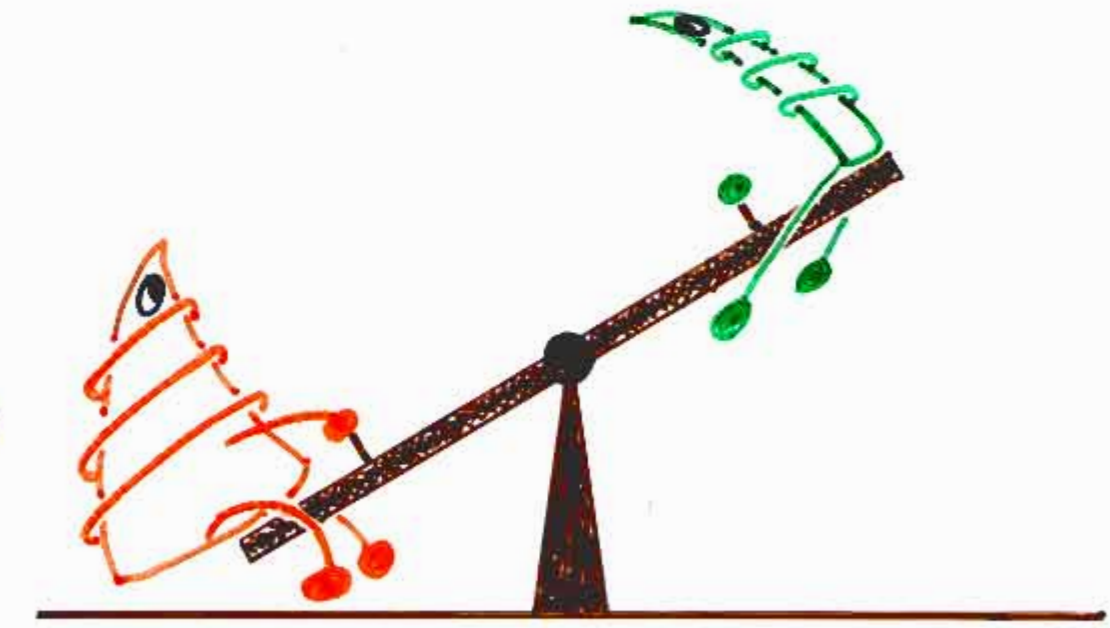
- Reactor exp. @ Kashiwazaki $P(\bar\nu_e\to\bar\nu_e)\neq 1 \Rightarrow \sin^2\theta_{RCT}\neq 0$ uniquely

- J-PARC → Hyper-Kamiokande $P(\nu_\mu\to\nu_e)\neq P(\bar\nu_\mu\to\bar\nu_e) \Rightarrow \delta_{MNS}$, $\sin^2\theta_{RCT}$ (4-fold ambiguity)

- J-PARC → BAND @ Beijing $P(\nu_\mu\to\nu_e)\neq 0 \Rightarrow m_3^2-m_1^2 \gtrless 0$ if $\sin^2 2\theta_{RCT}\gtrsim 0.04$

- ν Factory @ J-PARC → BAND $P(\nu_e\to\nu_e)\neq 0$ etc. $\Rightarrow m_3^2-m_1^2 \gtrless 0$ if $\sin^2 2\theta_{RCT}\gtrsim 0.004$
  $\sin^2\theta_{ATM} \gtrless \frac{1}{2}$ if $\sin^2 2\theta_{RCT}\gtrsim 0.02$ for $\sin^2 2\theta_{ATM}=0.96$.





1979

2004.2.23-25 @ KEK

See Saw 25 yeas