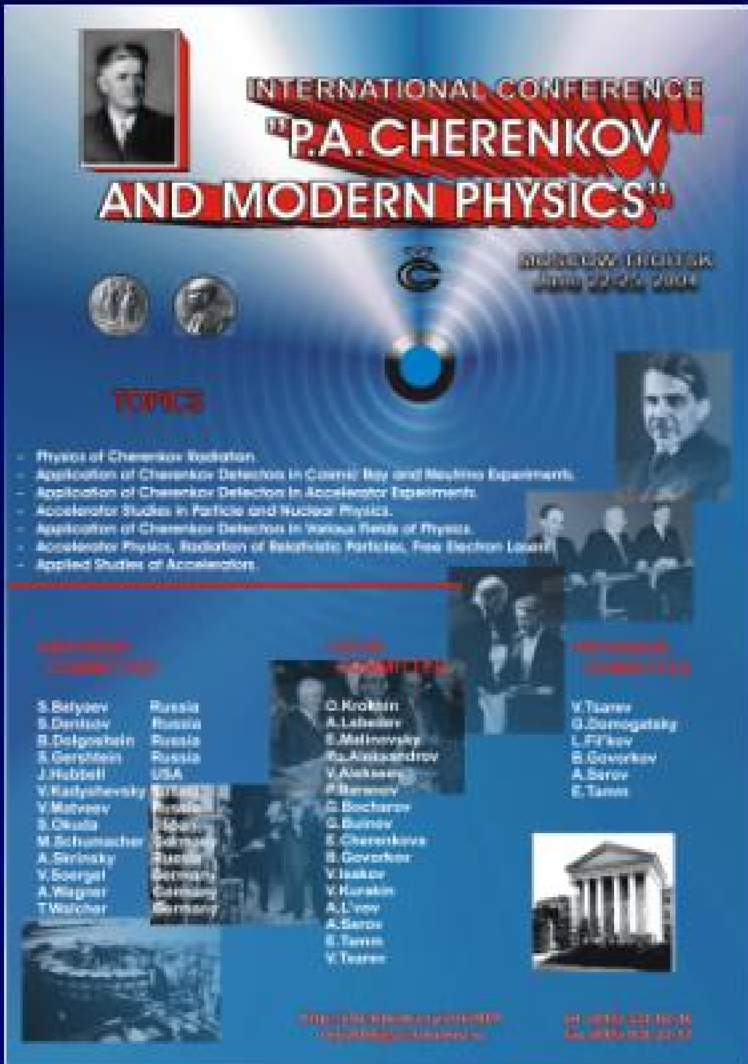


Super-Kamiokande Results and Prospects

Kenzo NAKAMURA

KEK

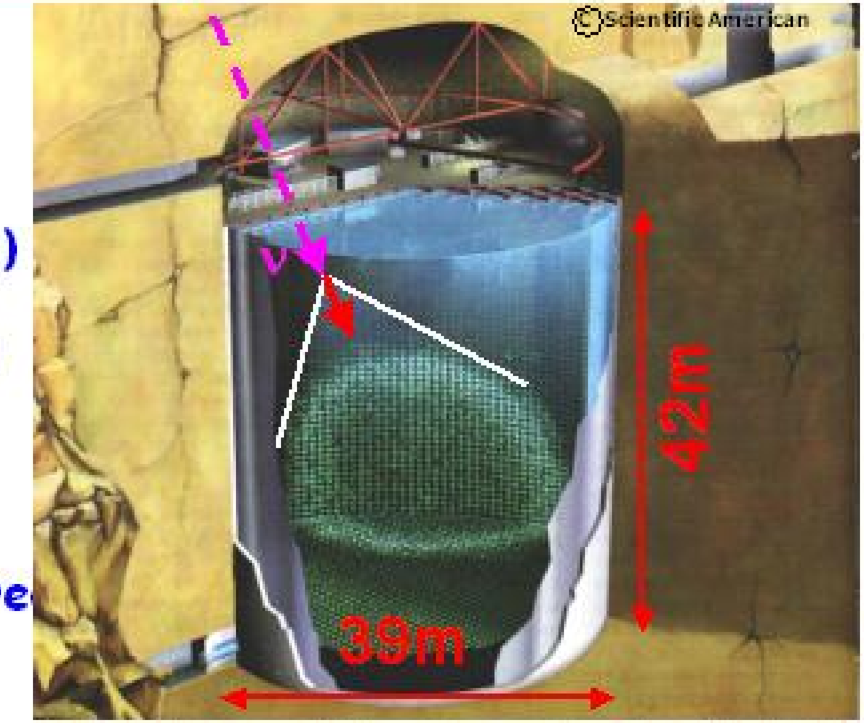
June 24, 2004

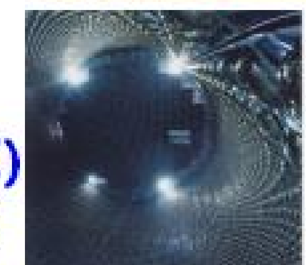
1. Introduction
2. Solar Neutrino Results
3. Atmospheric Neutrino Results
4. K2K Results
5. Proton Decay Results
6. Future Prospects
7. Summary

1. Introduction

Super-Kamiokande

- Giant water Cherenkov detector
  - Total mass: 50,000 tons
  - Fiducial mass: 22,500 tons
  - Location: 1,000 m underground
  - Inner detector: 11,146 PMTs (50-cmϕ)
    (5,182: SK-II)
  - Outer detector: 1,885 PMTs (20-cmϕ)
- Construction started in December 1991
- Observation started on April 1, 1996
  (as scheduled)
- Atmospheric neutrino oscillation discovered in 1998
- Solar neutrino oscillation discovered in 2001 (together with SNO CC meas.)
- Accident on November 12, 2001
- Partially rebuilt in October 2002 (SK-II)
- Full rebuilding to start in summer, 2005

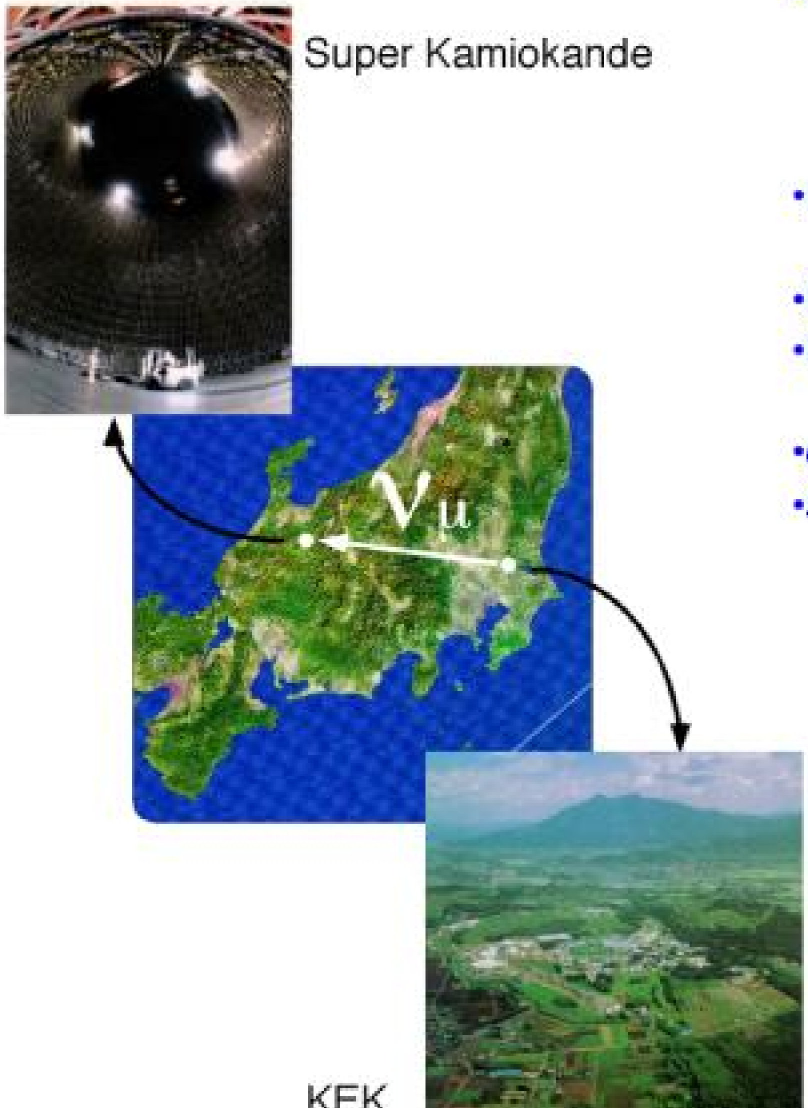




1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007

SK-I accident SK-II full reconstruction SK-III

K2K (KEK-to-Kamioka)



- Accelerator : 12 GeV proton synchrotron
  - Beam intensity : 6×10^{12} protons / pulse
  - Repetition : 1 pulse / 2.2 sec
  - Pulse width : 1.1 μs (9 bunches)
- Horn-focused wide-band beam
  - Average neutrino energy : 1.3 GeV
- Near detector : 300 m from the target
- Far detector (Super-Kamiokande) :
  250 km from the target
- Goal : 10^{20} protons on target
- Started : April, 1999

3 Flavor Neutrino Oscillation

Neutrino Mixing $|\nu_l\rangle = \Sigma U_{li} |\nu_i\rangle$

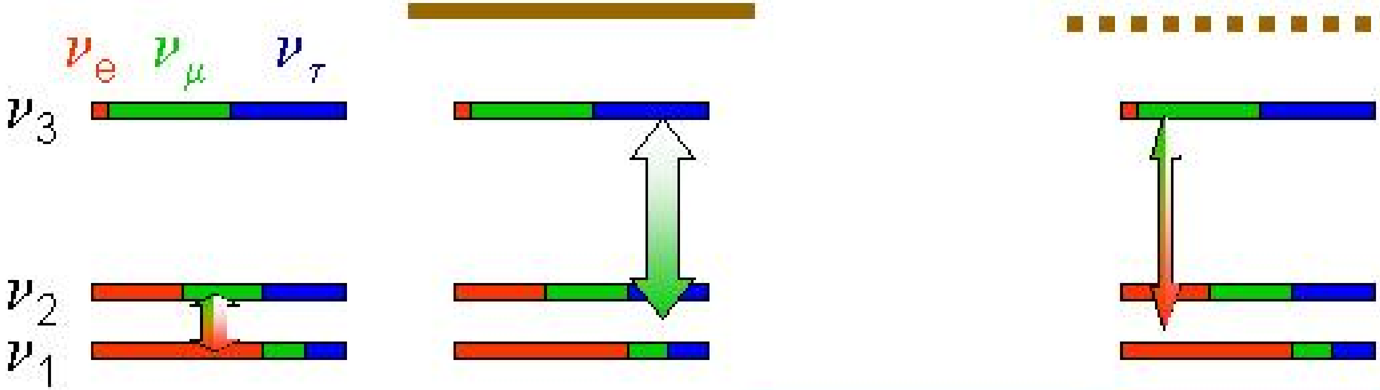
Weak eigenstates — Mass eigenstates

CP violating phase

small

$$U = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} = \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & e^{-i\delta} \end{pmatrix} \cdot \begin{pmatrix} c_{13} & 0 & s_{13} \\ 0 & 1 & 0 \\ -s_{13} & 0 & c_{13} \end{pmatrix}$$

Normal mass hierarchy assumed:

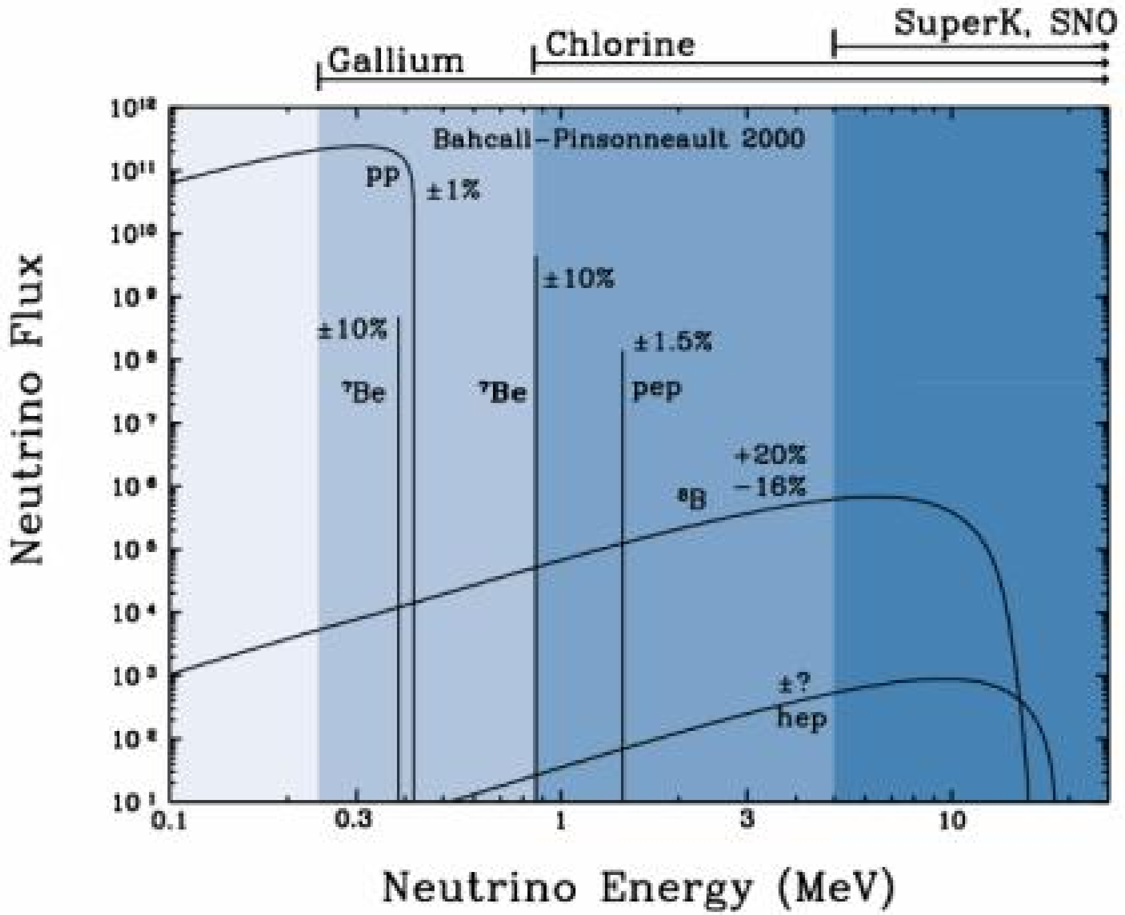


Solar, KamLAND	Atmospheric Long baseline	(future) Super-beam Neutrino factory	(future) LBL Reactor

2. Solar Neutrino Results

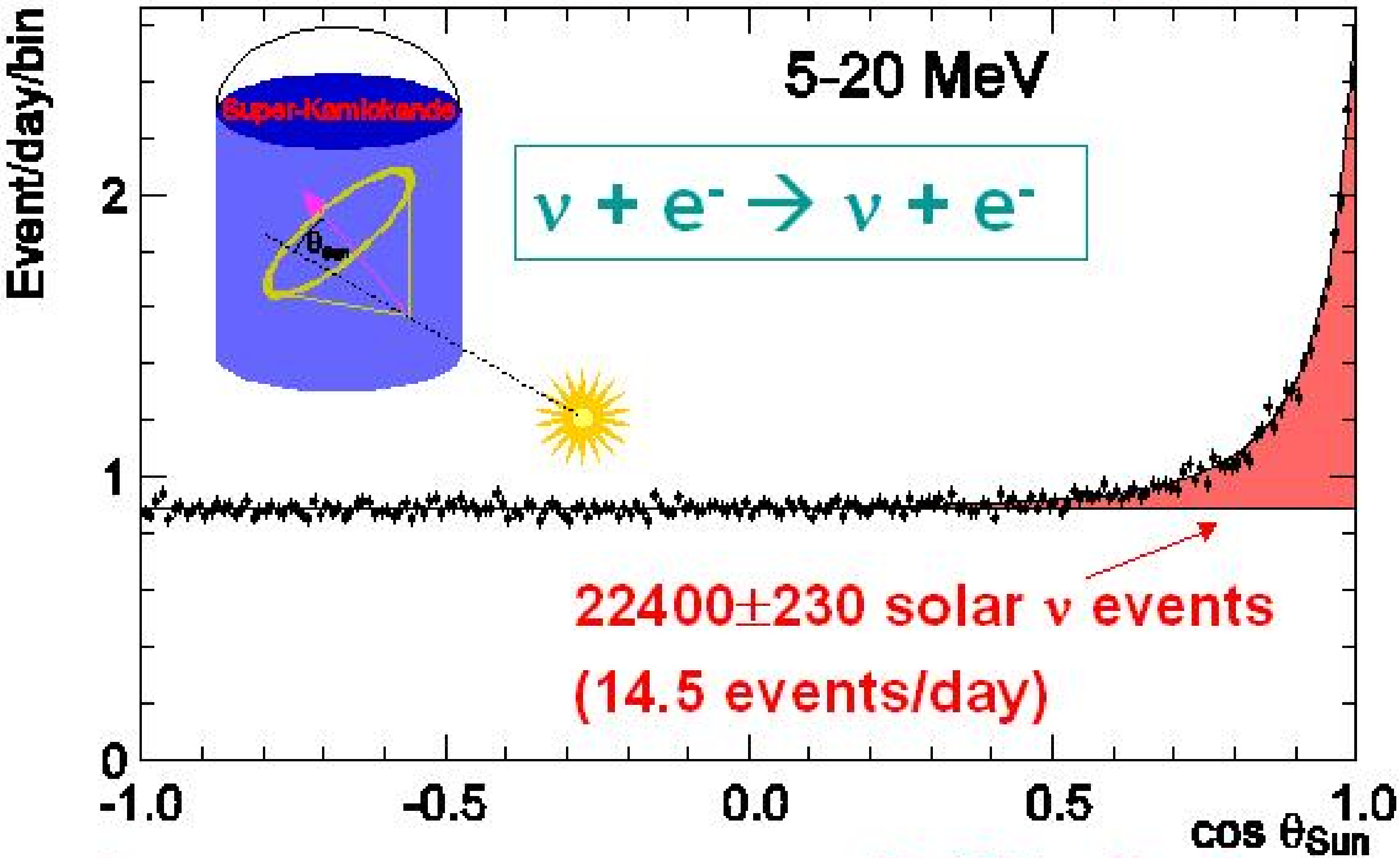
Solar Neutrino Observation in Super-K

- ^8B neutrino measurement by $\nu + e^- \rightarrow \nu + e^-$
- Sensitive to ν_e, ν_μ, ν_τ
  $\sigma(\nu_{\mu(\tau)}+e^-) = \sim 0.15 \times \sigma(\nu_e+e^-)$
- High statistics
  ~15ev./day with E_e > 5MeV
- Real time measurement. Studies of time variations.
- Studies of energy spectrum.
- Precise energy calibration by LINAC and ^{16}N.



Super-Kamiokande-I solar neutrino data

May 31, 1996 – July 13, 2001 (1496 days)

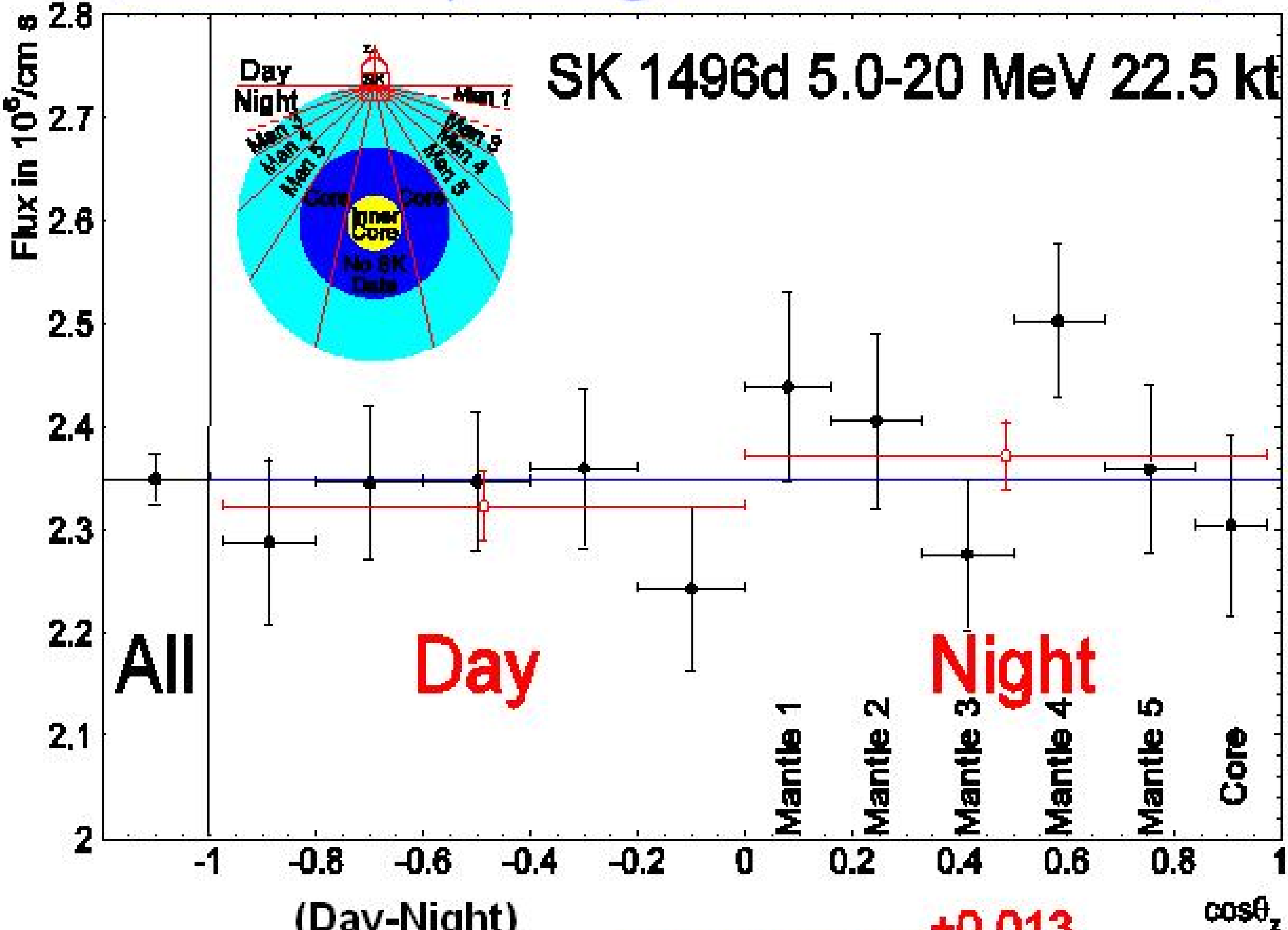


^8B flux : $2.35 \pm 0.02 \pm 0.08$ [x 10^6 /cm^2/sec]

$$\frac{\text{Data}}{\text{SSM(BP2004)}} = 0.406 \pm 0.004 ^{+0.014}_{-0.013}$$

(Data/SSM(BP2000) = 0.465 ± 0.005 +0.016/-0.015)

SK-I Day/Night Difference



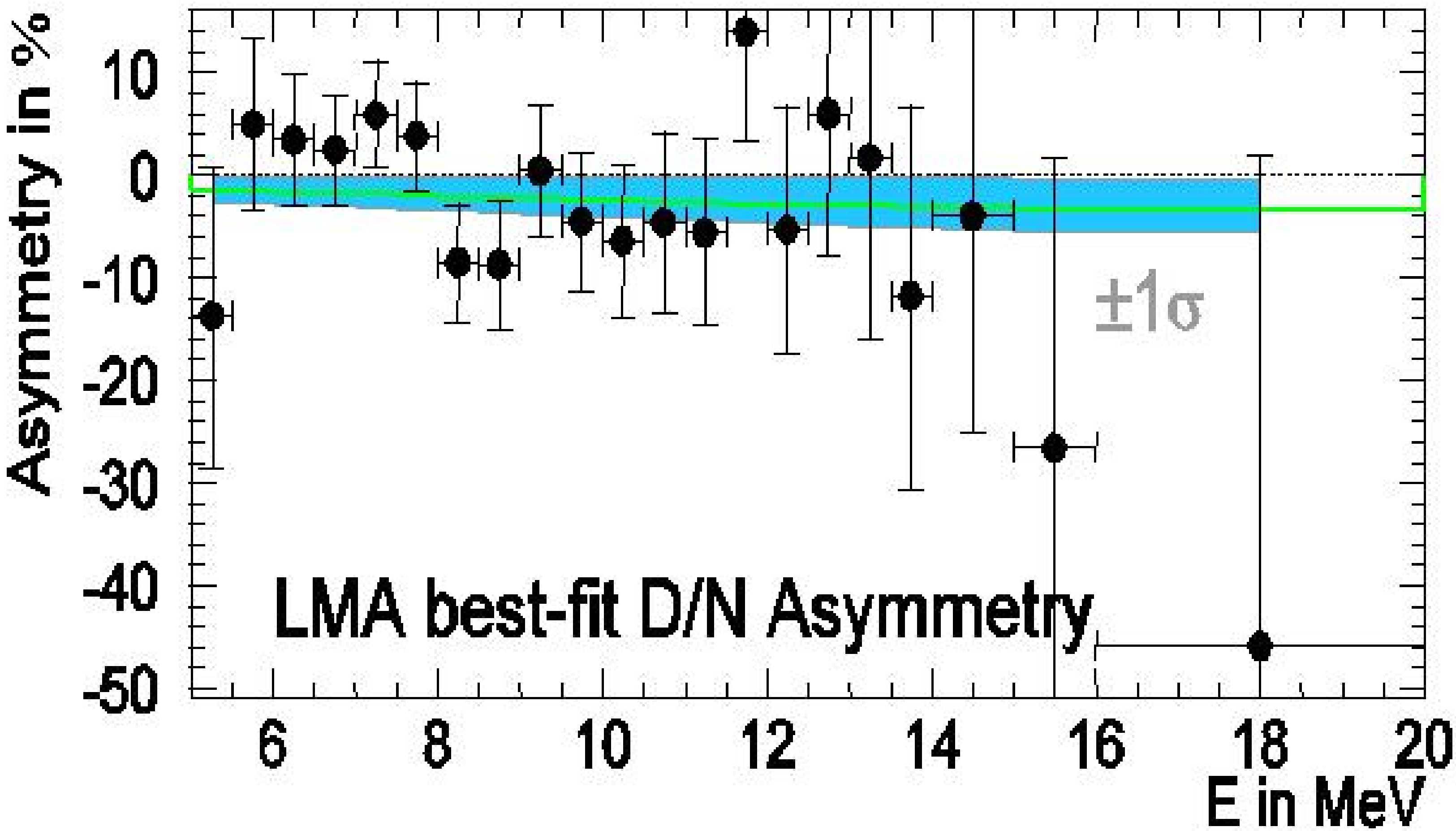
$$A_{DN} = \frac{(\text{Day-Night})}{(\text{Day+Night})/2} = -0.021 \pm 0.020^{+0.013}_{-0.012}$$

Day/Night Asymmetry

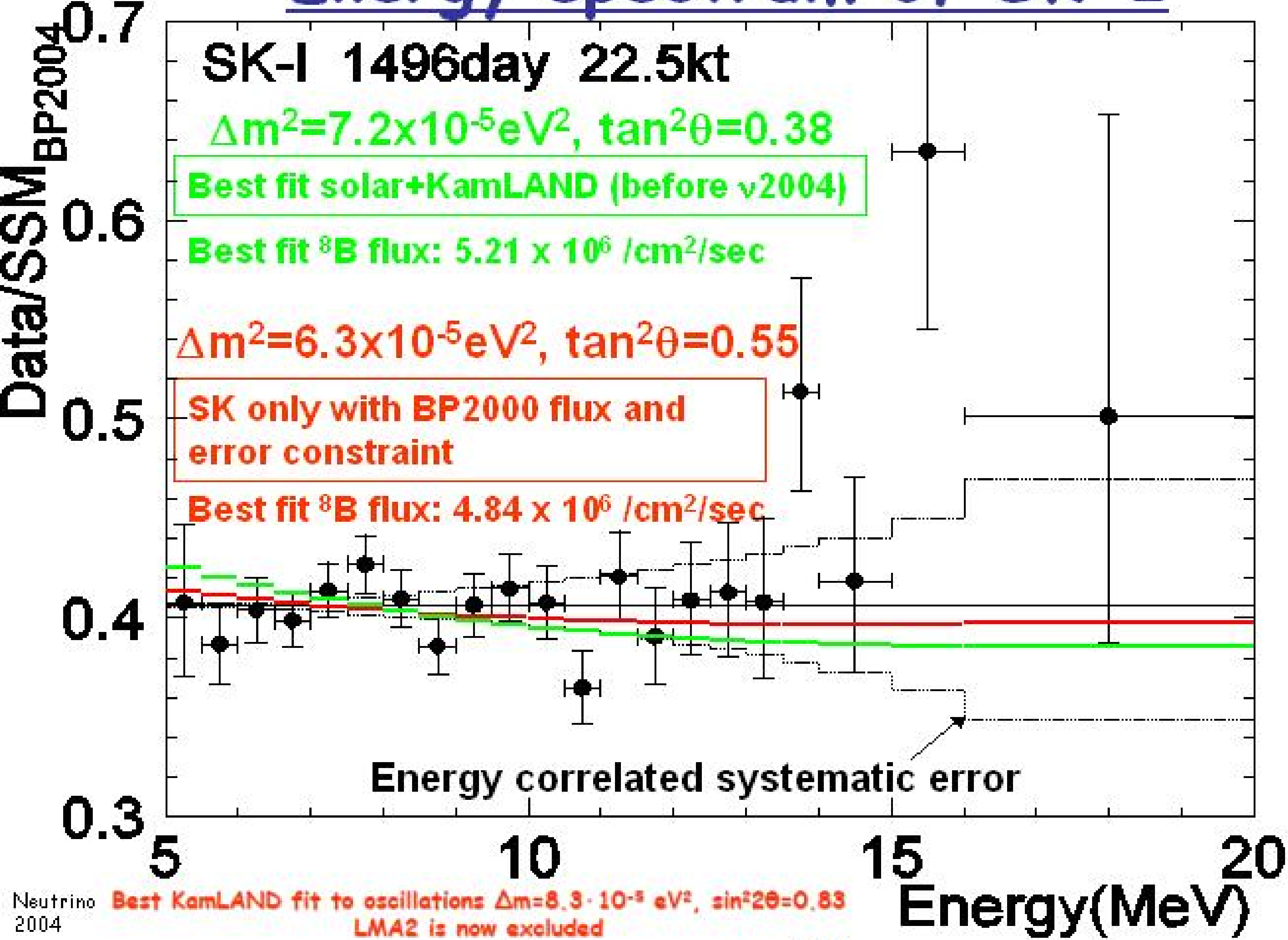
(Assuming BP2000 flux and error)

$\Delta m^2 = 6.3 \times 10^{-5} eV^2$
$\tan^2\theta = 0.55$

$A_{DN} = -1.8 \pm 1.6 ^{+1.3}_{-1.2} \%$



Energy spectrum of SK-I

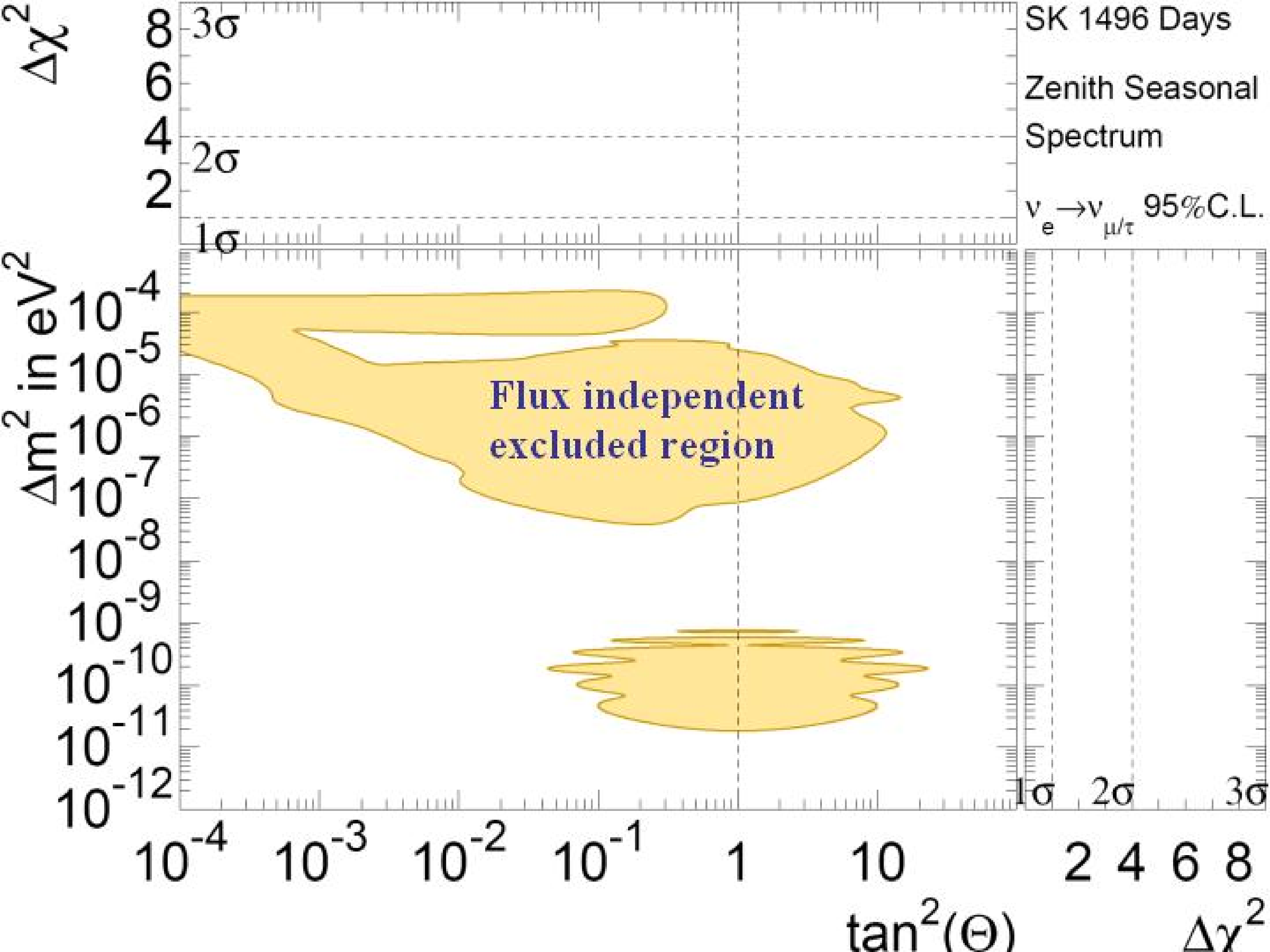


Neutrino 2004

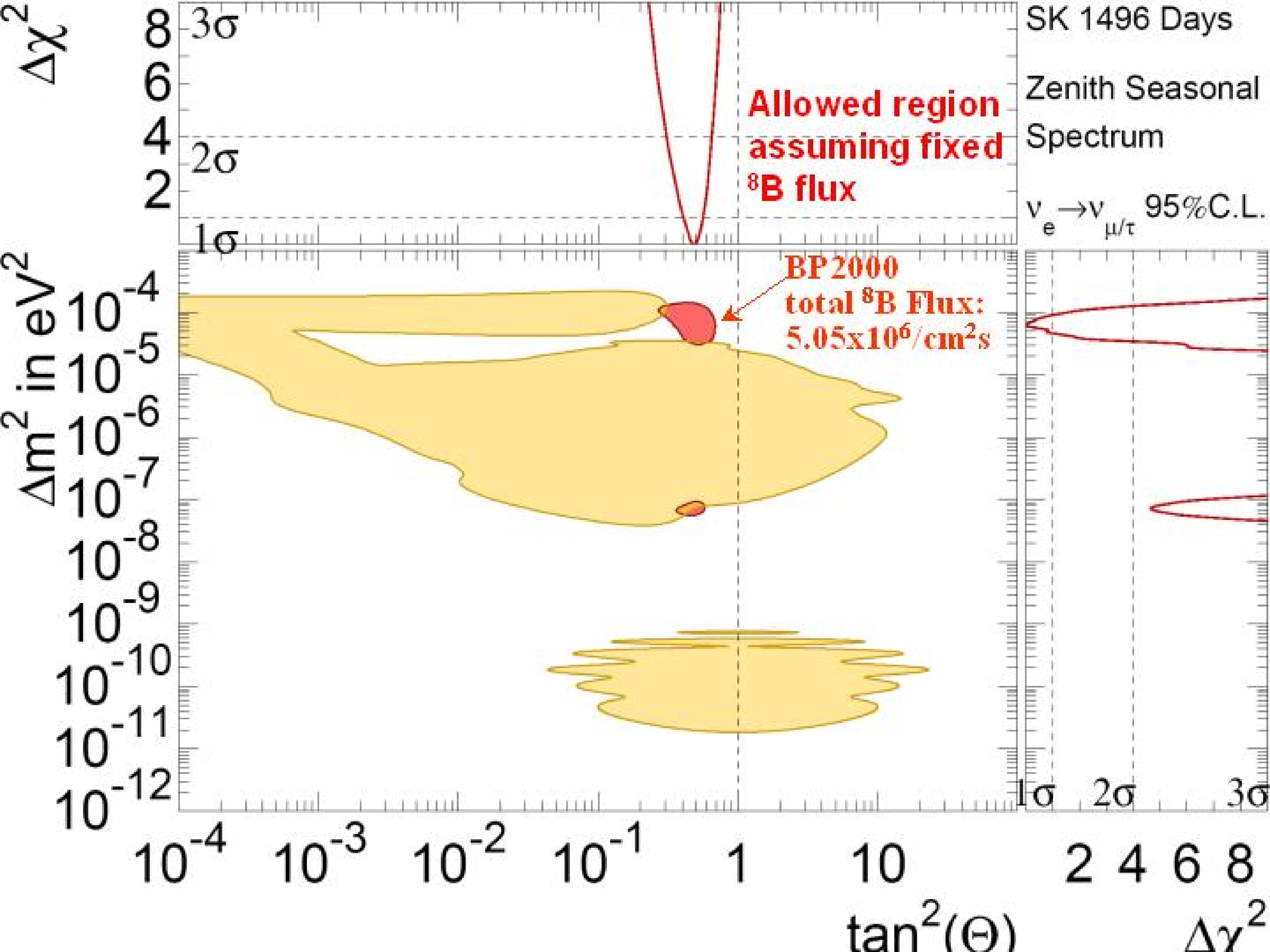
Best KamLAND fit to oscillations $\Delta m = 8.3 \cdot 10^{-5}$ eV², $\sin^2 2\theta = 0.83$

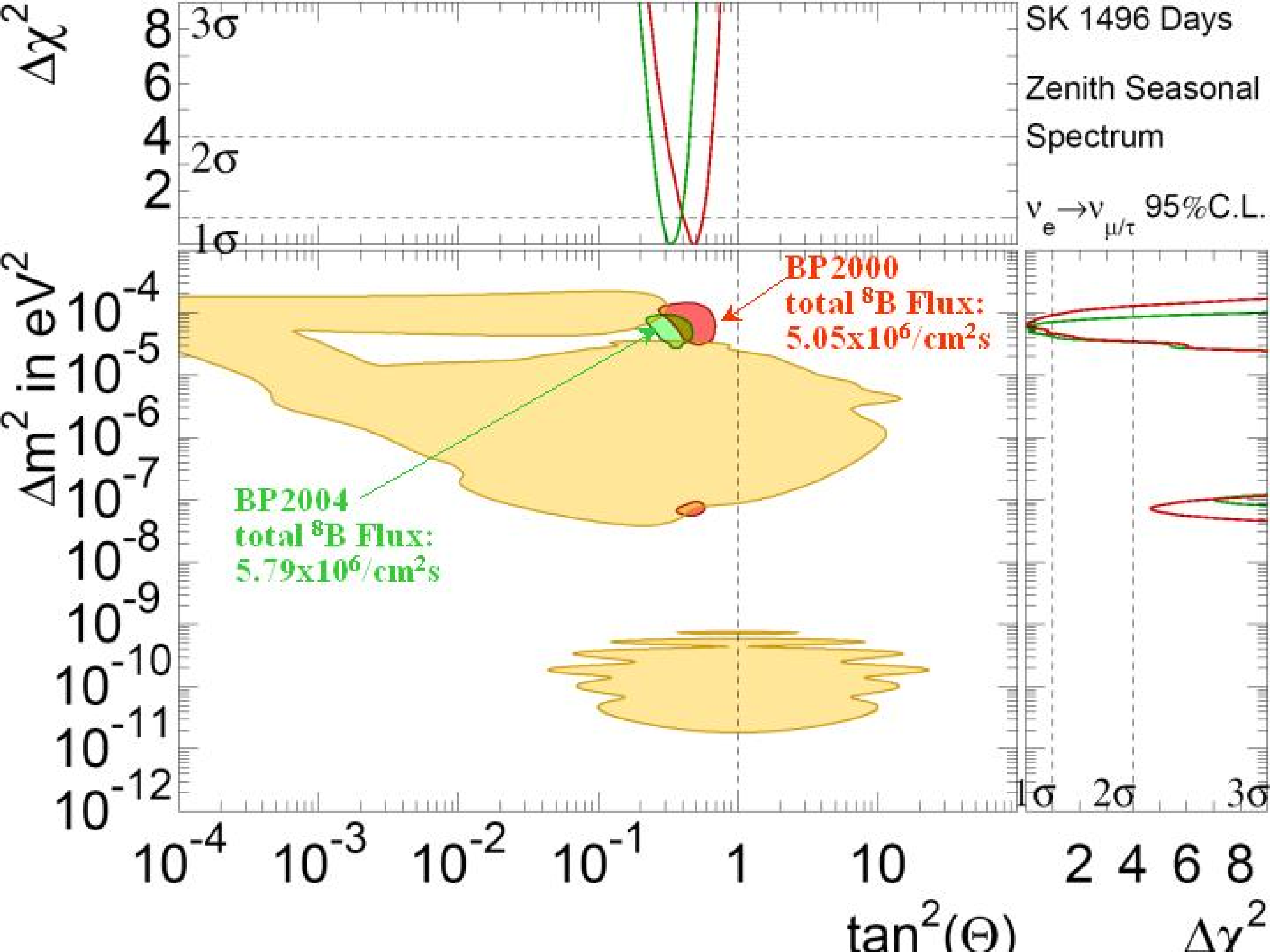
LMA2 is now excluded

Together with solar ν $\Delta m^2_{12} = 8.2^{+0.6}_{-0.5} \times 10^{-5} eV^2; \tan^2\theta_{12} = 0.40^{+0.09}_{-0.07}$

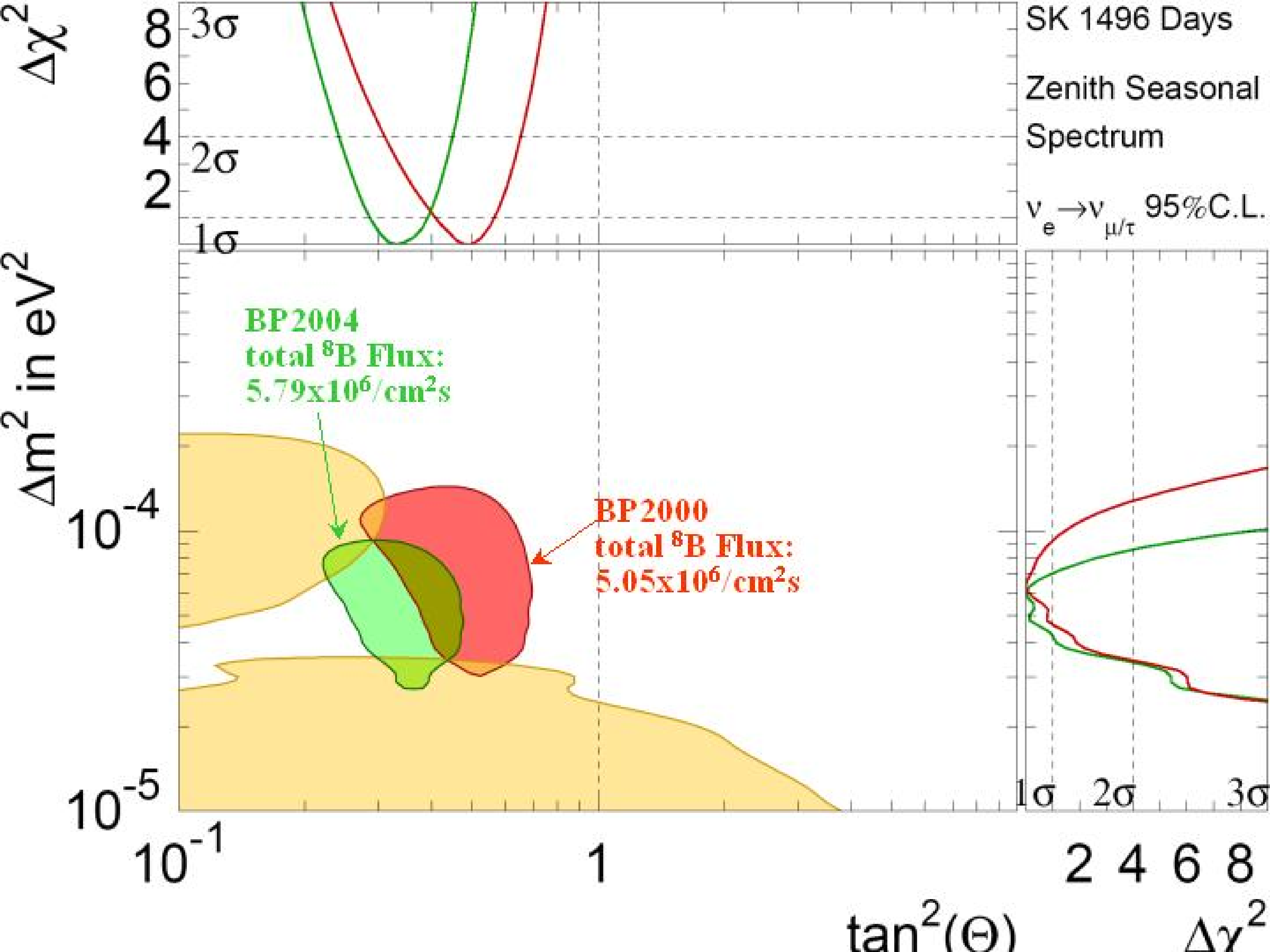


SK 1496 Days
Zenith Seasonal
Spectrum
$\nu_e \rightarrow \nu_{\mu/\tau}$ 95%C.L.
Flux independent
excluded region
$\Delta\chi^2$
Δm^2 in eV^2
$\tan^2(\Theta)$
1σ
2σ
3σ


SK 1496 Days
Zenith Seasonal
Spectrum
$\nu_e \rightarrow \nu_{\mu/\tau}$ 95%C.L.
Allowed region
assuming fixed
^{8}B flux
BP2000
total ^{8}B Flux:
$5.05\times10^6/cm^2s$
$\Delta\chi^2$
3σ
2σ
1σ
Δm^2 in eV^2
$\tan^2(\Theta)$
10^{-4} 10^{-3} 10^{-2} 10^{-1} 1 10
10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9} 10^{-10} 10^{-11} 10^{-12}
2 4 6 8

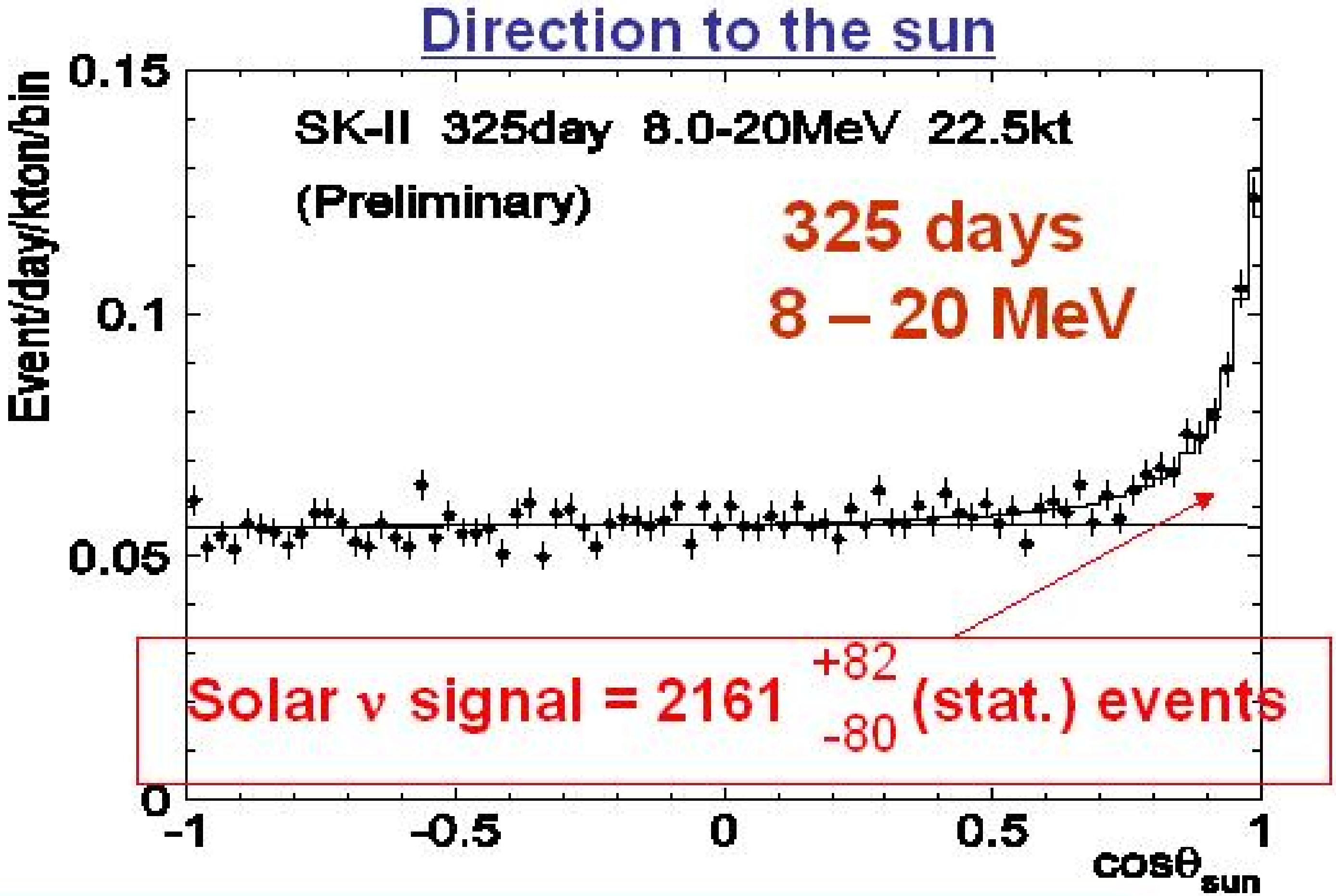


SK 1496 Days
Zenith Seasonal
Spectrum
$\nu_e \rightarrow \nu_{\mu/\tau}$ 95%C.L.
$\Delta\chi^2$
3σ
2σ
1σ
Δm^2 in eV^2
BP2000
total ^{8}B Flux:
5.05x10^6/cm^{2}s
BP2004
total ^{8}B Flux:
5.79x10^6/cm^{2}s
$\tan^2(\Theta)$


SK 1496 Days
Zenith Seasonal
Spectrum
$\nu_e \rightarrow \nu_{\mu/\tau}$ 95%C.L.
$\Delta\chi^2$
8
6
4
2
3σ
2σ
1σ
Δm^2 in eV^2
10^{-4}
10^{-5}
BP2004
total ^8B Flux:
$5.79 \times 10^6/cm^2s$
BP2000
total ^8B Flux:
$5.05 \times 10^6/cm^2s$
10^{-1}
1
$\tan^2(\Theta)$
1σ 2σ 3σ
2 4 6 8
$\Delta\chi^2$

SK-II preliminary results

Dec.24,2002 – March 25, 2004

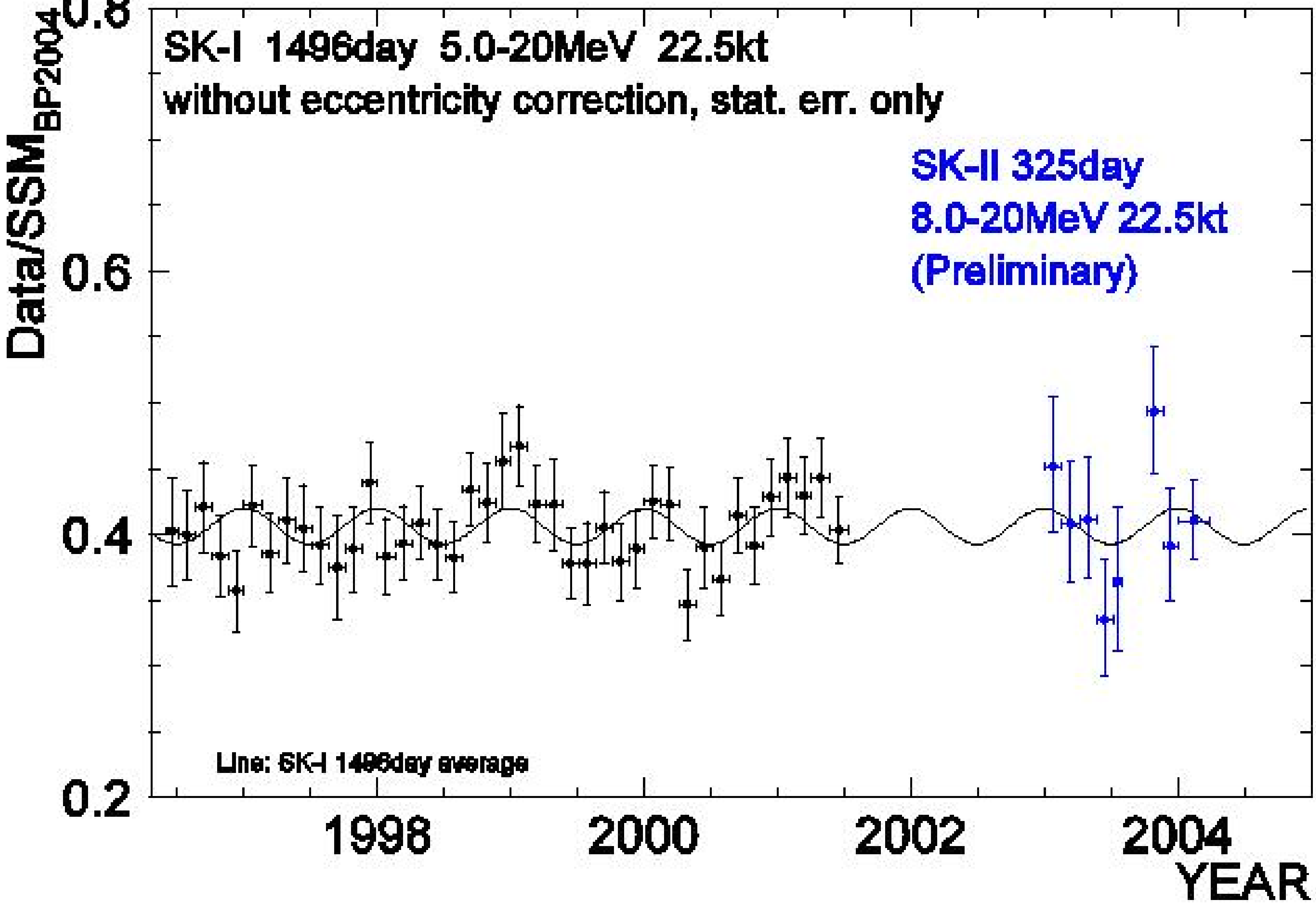


Flux= 2.38 ± 0.09 (stat.) $(\times 10^6/cm^2/s)$

(Systematic error under study)

(cf. SK-I result: 2.35 ± 0.02(stat.) ± 0.08(sys.))

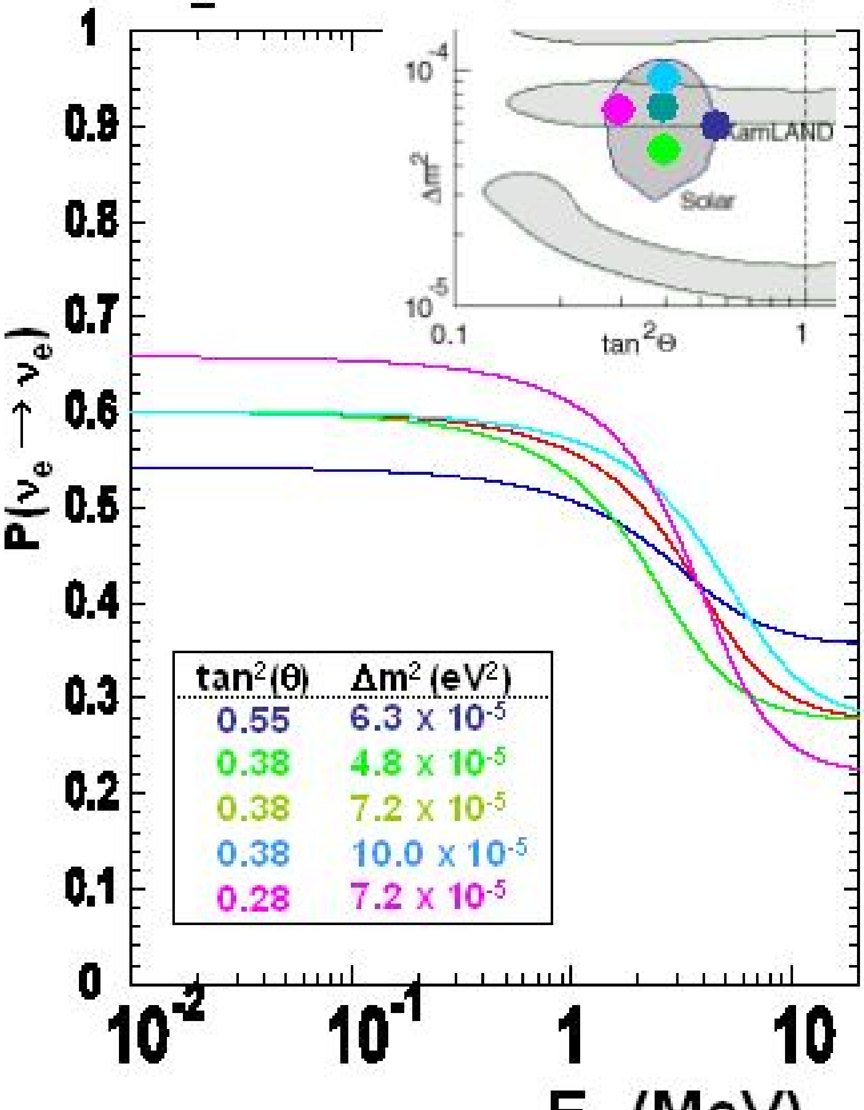
Time variation



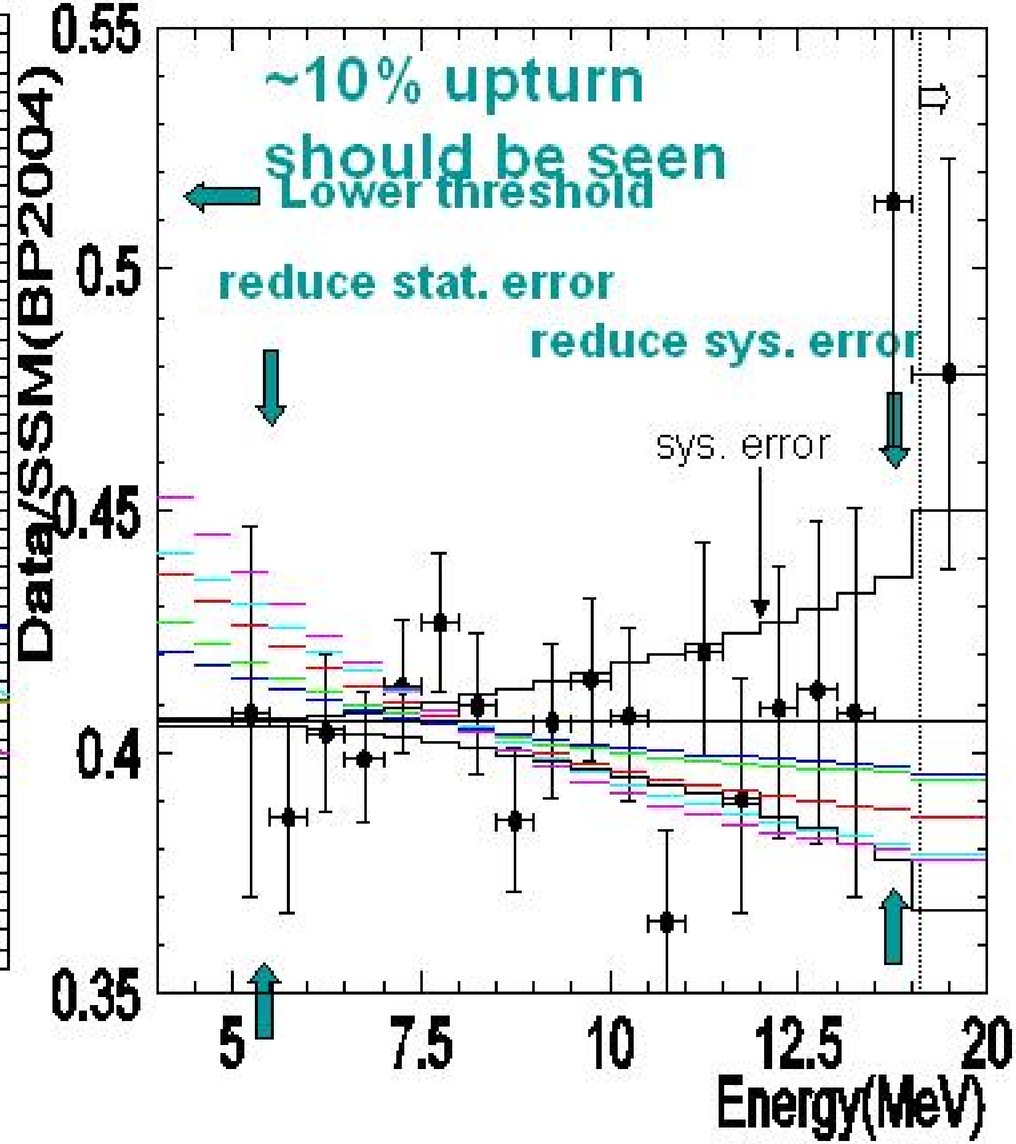
Future prospects towards SK-III

Possibility of detecting spectrum distortion

ν_e survival probability



Recoil electron spectrum



SK Solar Neutrino Observation Summary

- High statistics solar neutrino data has been obtained.
  - ^{8}B flux : 2.35 ± 0.02 ± 0.08 [x 106 /cm2/sec]
  - Day/night asymmetry: A_{DN}= -1.8 ± 1.6 +1.3/-1.2 %.
  - Energy spectrum: SK prefers smaller Δm^2 and larger $\tan^2\theta$ compared with global best fit parameters.
- Assuming ^{8}B total flux of the SSM predictions, LMA solution is preferred.
- Preliminary results from SK-II are consistent with SK-I.
- Hope to see definite energy spectrum distortion in SK-III, if the MSW prediction is correct.

3. Atmospheric Neutrino Results

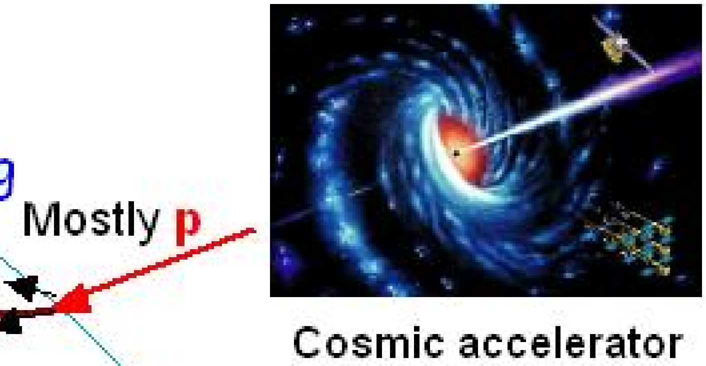
Similarity and Differences of Atmospheric ν and Accelerator ν Experiments

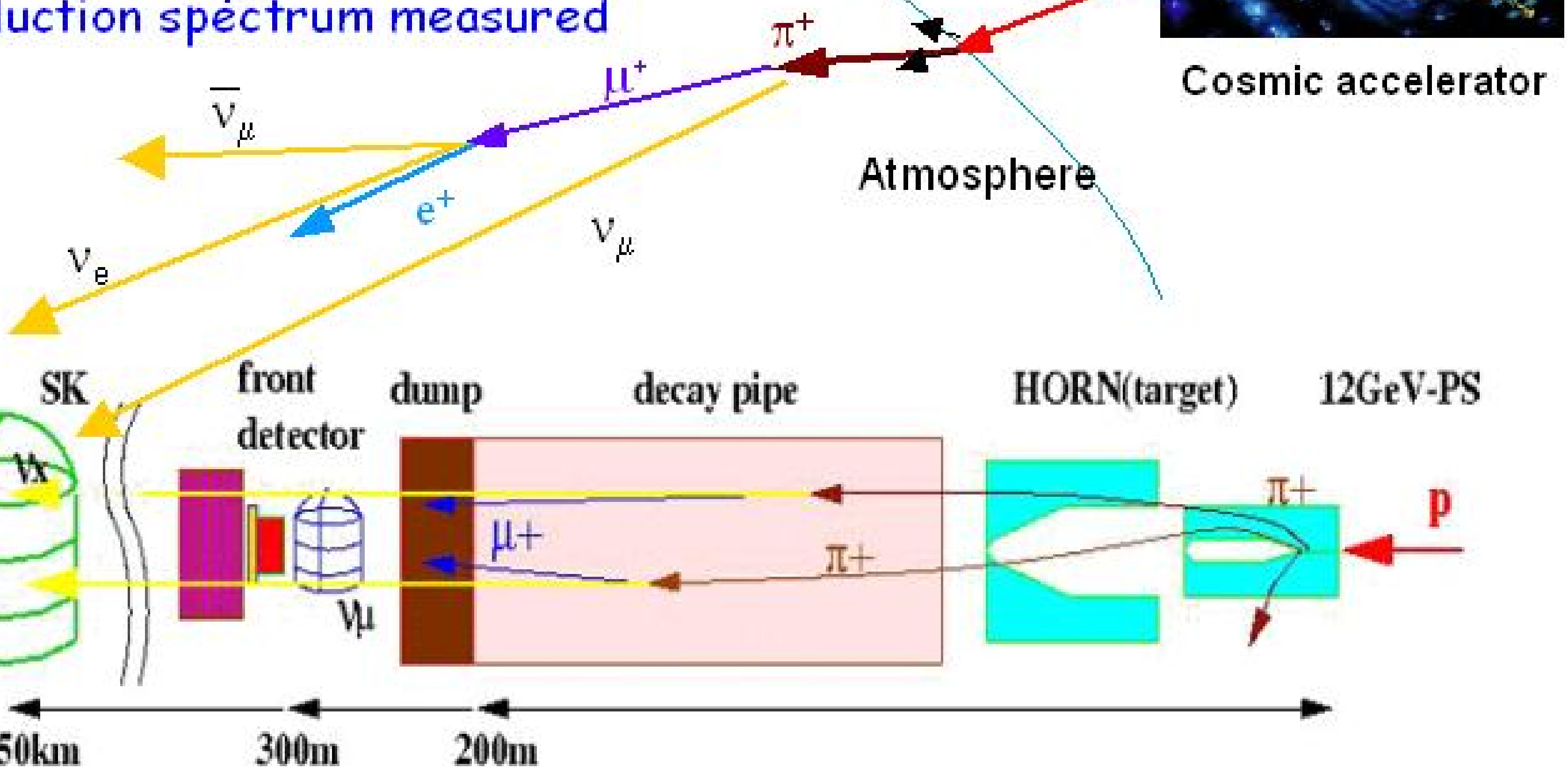
Atmospheric neutrinos

- Wide range of L and E

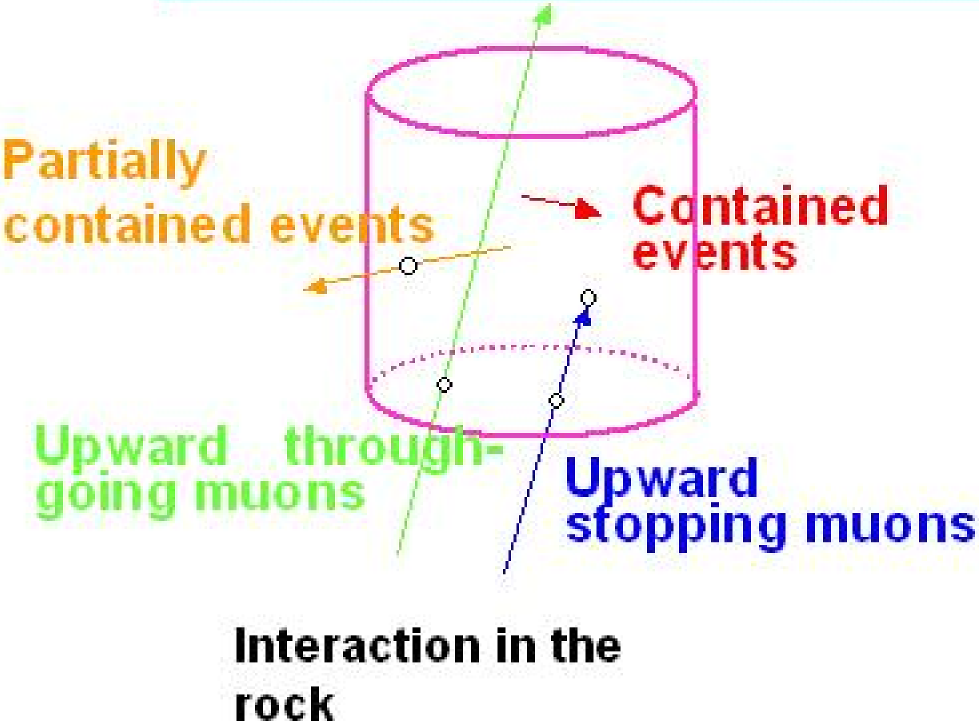
Accelerator neutrinos

- Fixed L, fixed direction, well-defined timing
- Almost pure ν_μ beam
- Production spectrum measured

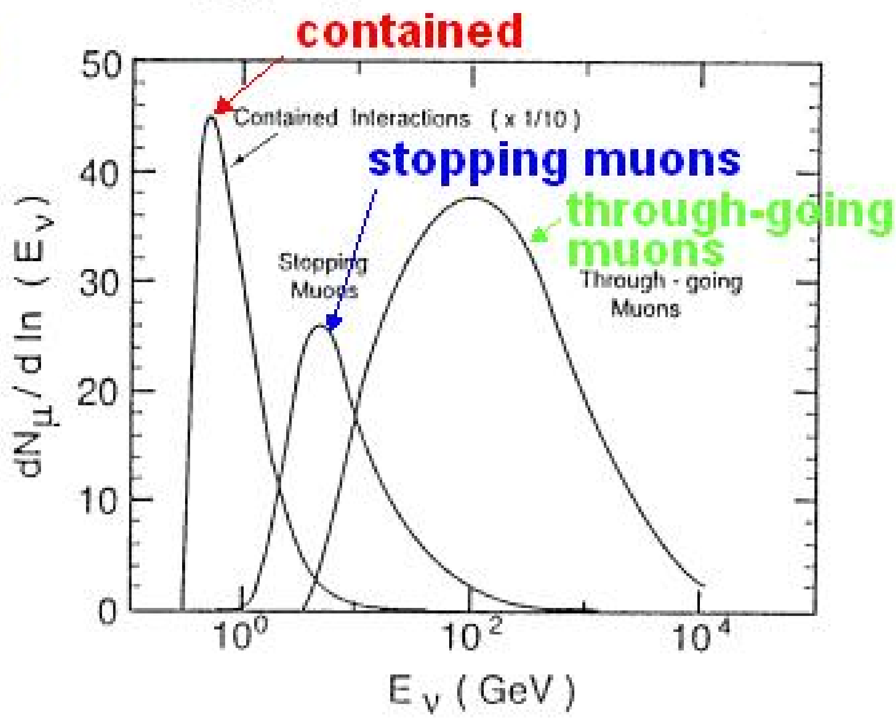




Atmospheric Neutrinos



Initial atmospheric neutrino energy spectrum



Sub-GeV contained events
$E_{vis} < 1.33$ GeV,
$P_e > 100$ MeV, $P_\mu > 200$ MeV/c

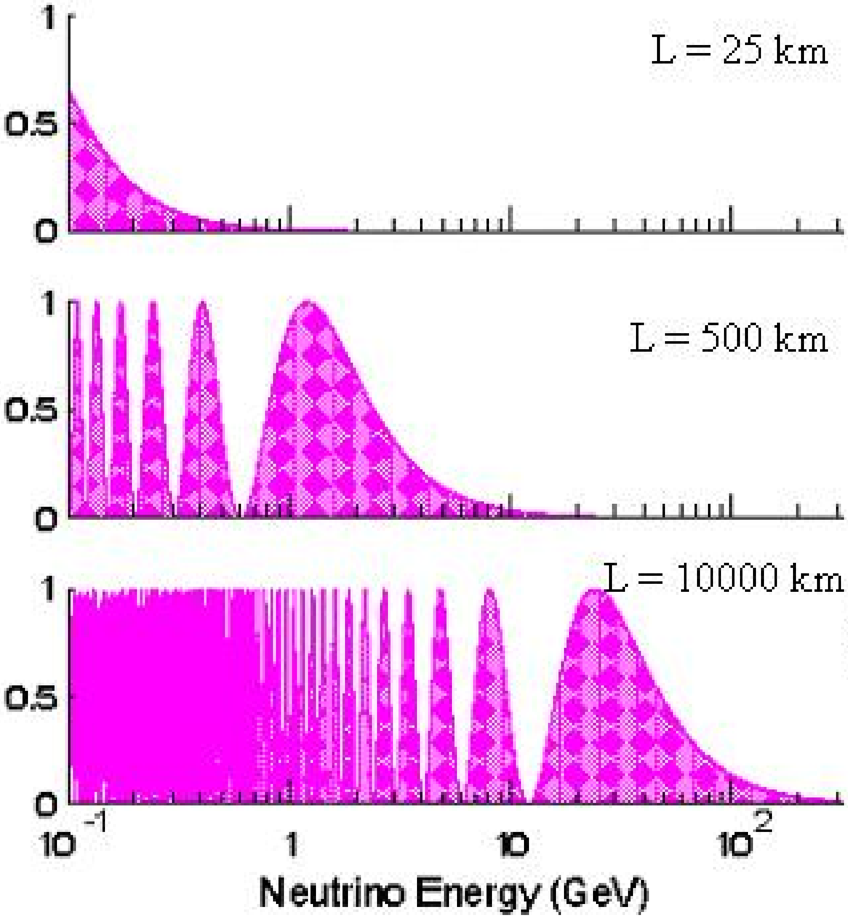
Multi-GeV contained events

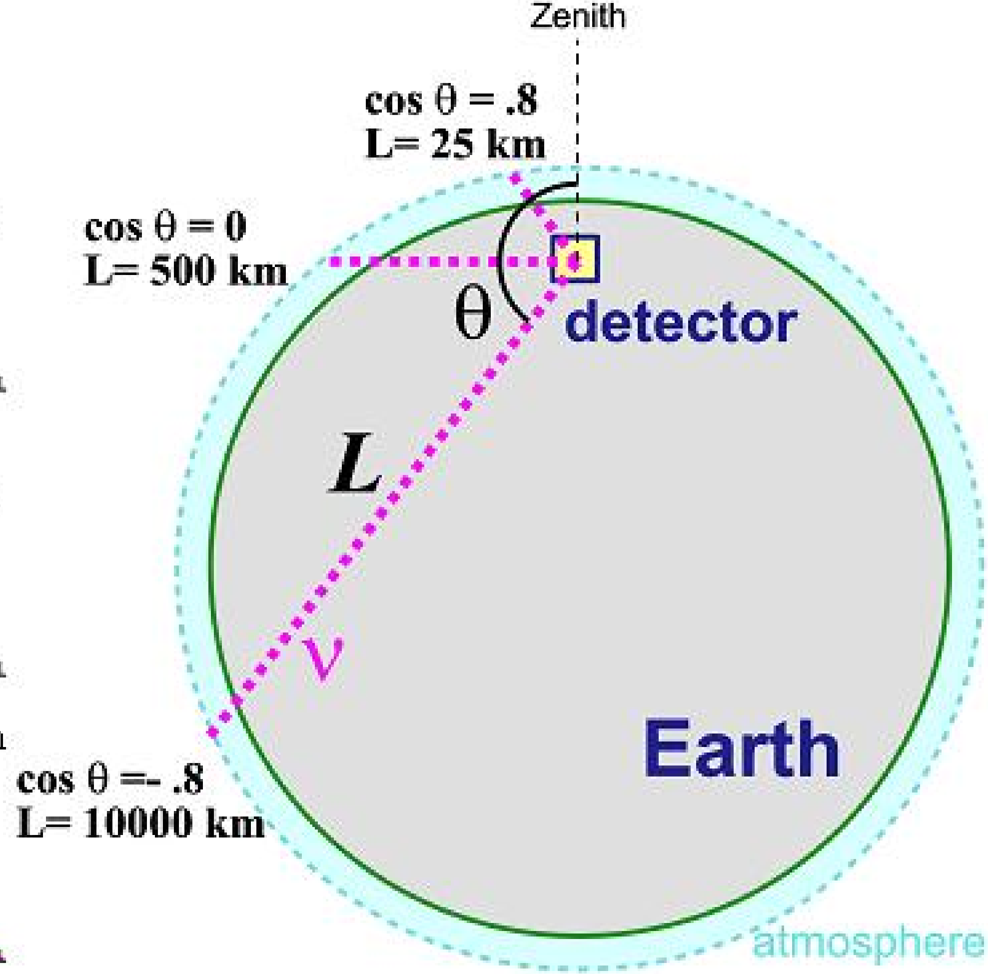
$E_{vis} > 1.33$ GeV

Atmospheric Neutrino Oscillation

$$P_{\nu\nu'} = \sin^2 2\theta \ \sin^2 \frac{1.27\, \Delta m^2 L}{E}$$

$\sin^2 2\theta = 1$ $\Delta m^2 = .003\ \mathrm{eV}^2$



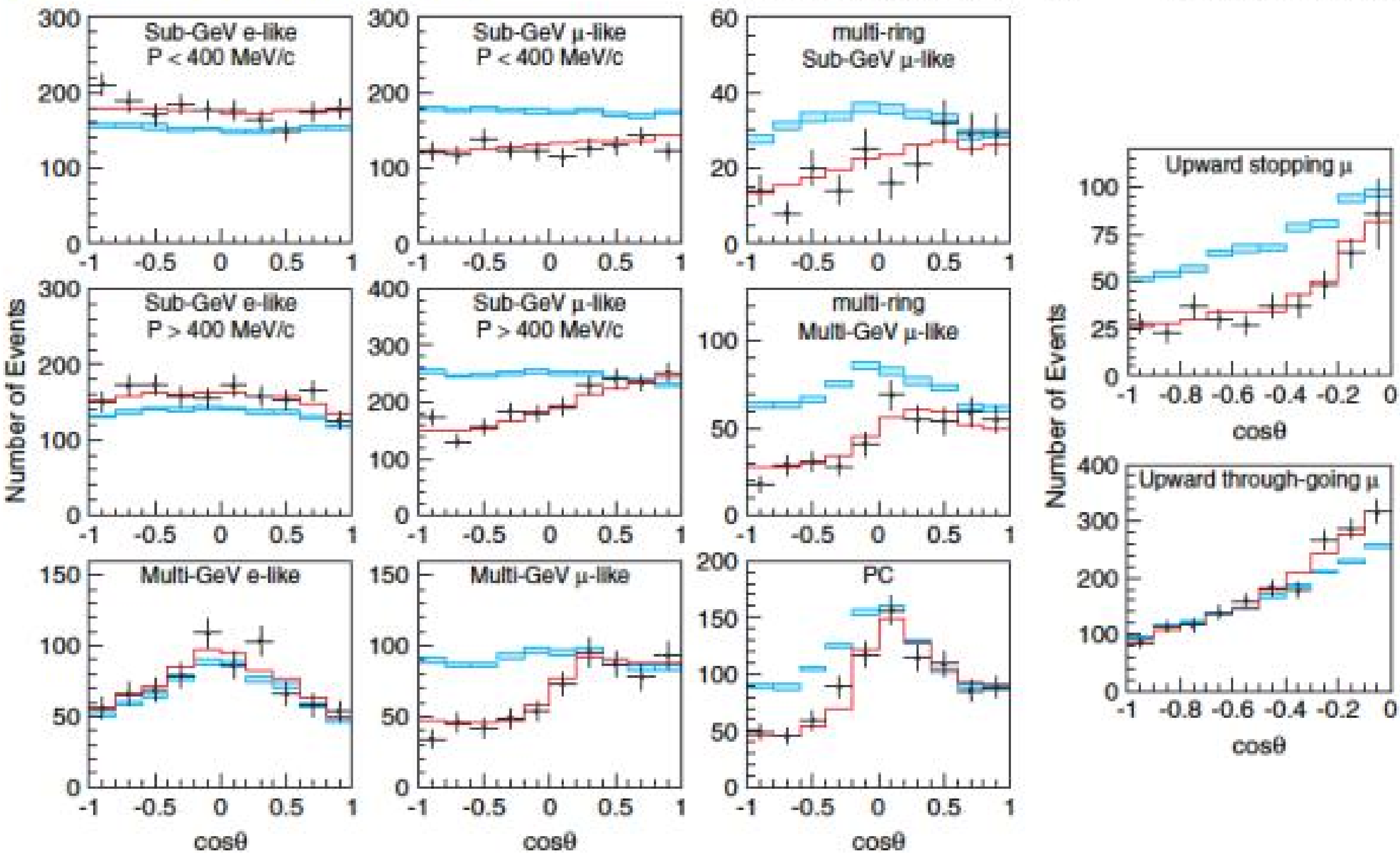


SK-I Zenith Angle Distributions

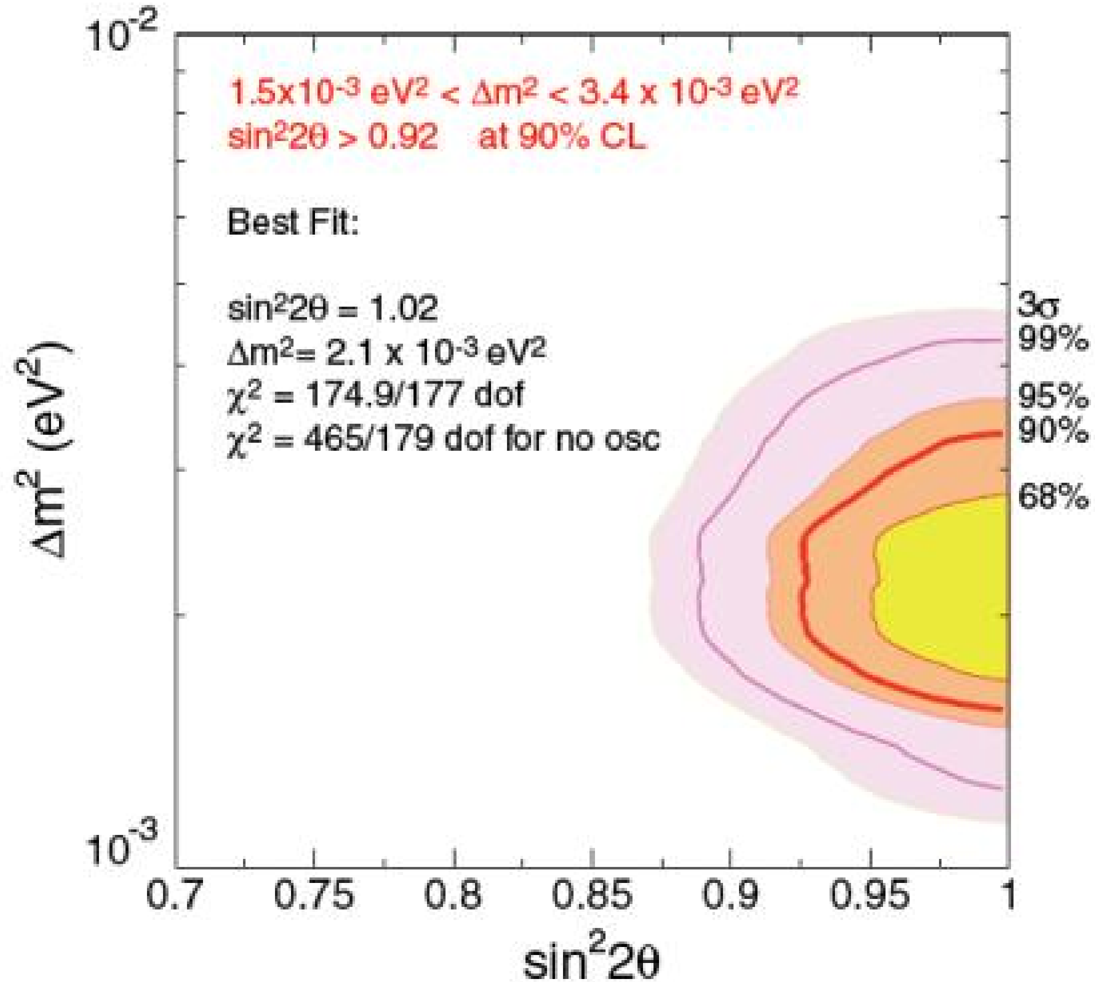
Assume $\nu_\mu \Leftrightarrow \nu_\tau$
2-flavor oscillation

— Best fit (Δm^2=2.1 x10^{-3}eV^2,$\sin^2 2\theta$=1.02
χ^2_{min}=174.9/177 d.o.f)

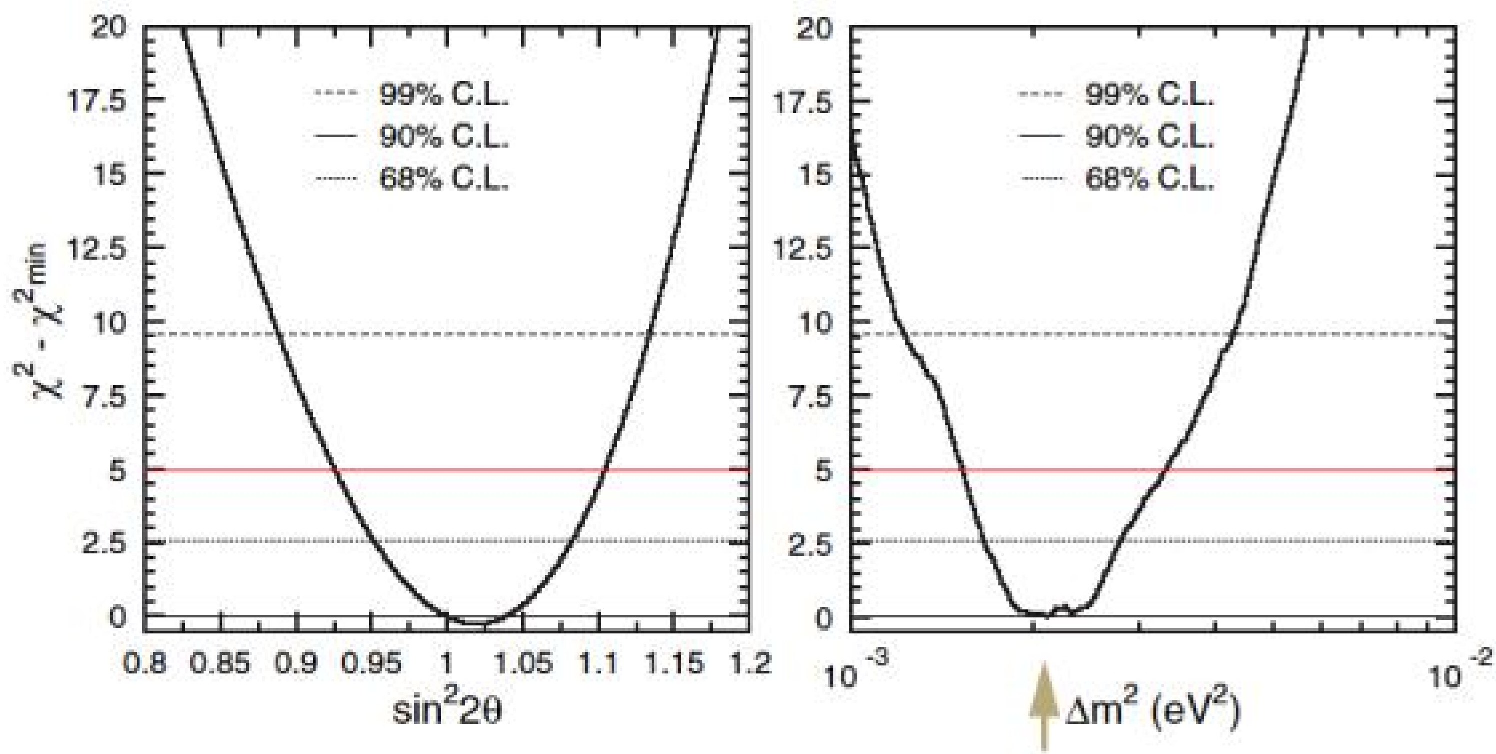
No oscillation χ^2 =465/179 d.o.f



Best Fit and Contours for SK-I



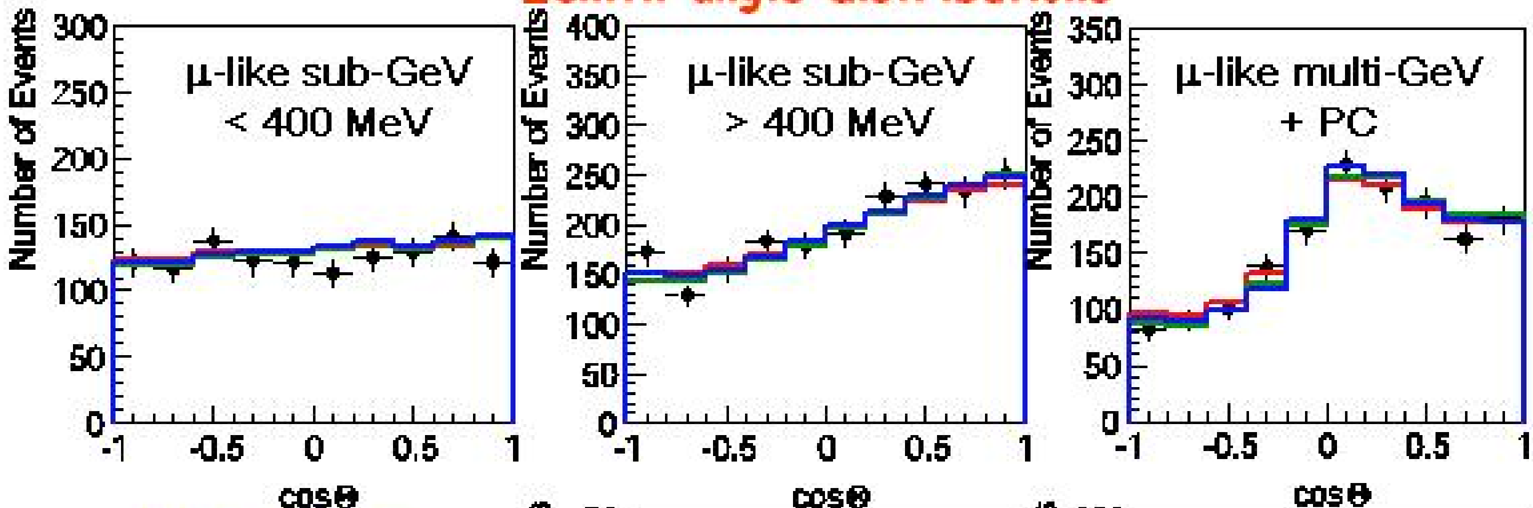
Chi-Squared Shape

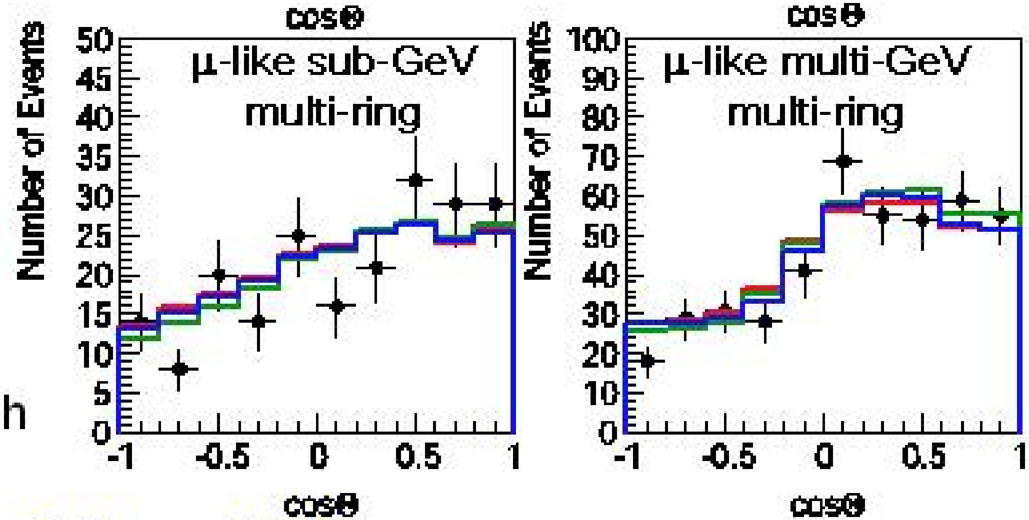


$\Delta\chi^2$ shape is rather flat and uneven between 2.0-2.5 x 10^{-3} eV^2

L/E Analysis: Motivation

Zenith angle distributions





Other models can explain zenith angle dependent muon deficit.

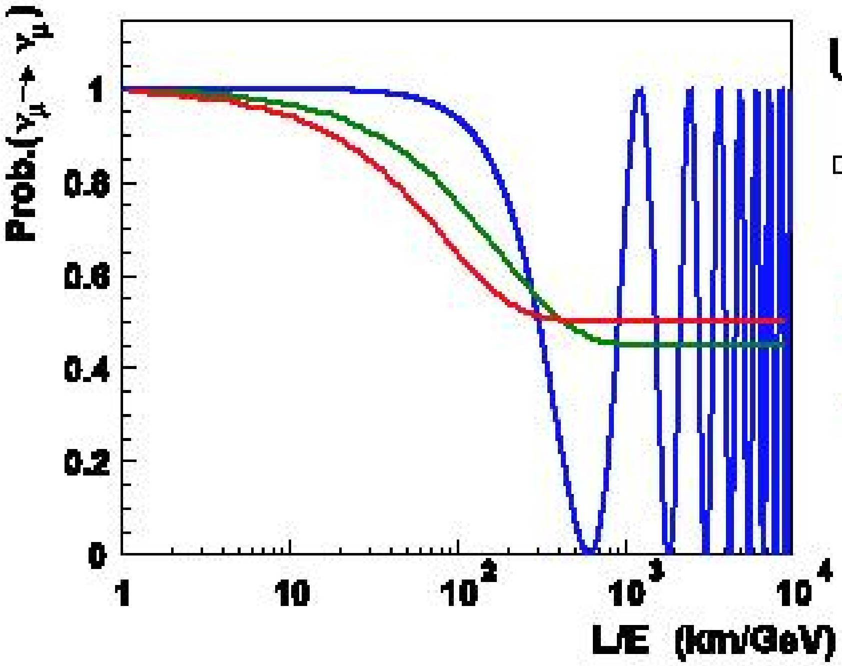
⇨ **How can we distinguish oscillation from other hypotheses ?**

L/E Analysis: Method

Neutrino oscillation : $P_{\mu\mu} = 1 - \sin^2 2\theta \sin^2(1.27 \frac{\Delta m^2 L}{E})$

Neutrino decay : $P_{\mu\mu} = (\cos^2\theta + \sin^2\theta \times \exp(-\frac{m}{2\tau}\frac{L}{E}))^2$

Neutrino decoherence : $P_{\mu\mu} = 1 - \frac{1}{2}\sin^2 2\theta \times (1 - \exp(-\gamma_0 \frac{L}{E}))$



Use events with high resolution in L/E

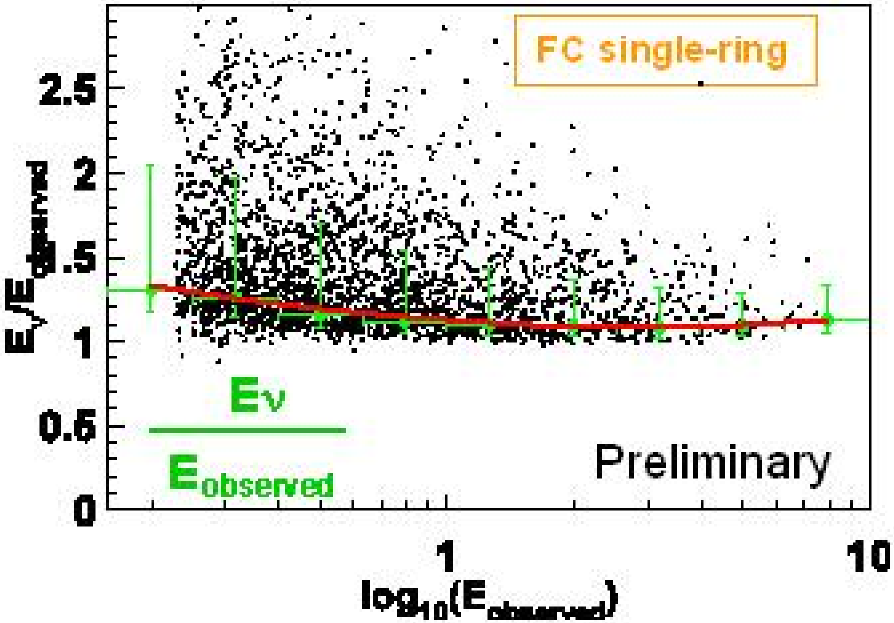
⇨ **The first dip can be observed**

→ Direct evidence for oscillations

→ Strong constraint to oscillation parameters, especially Δm^2 value

Reconstruction of E and L

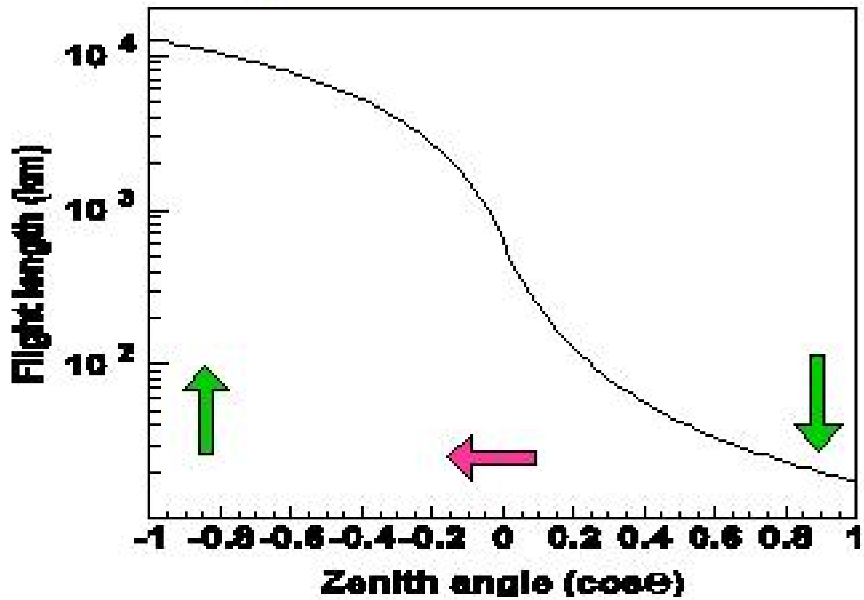
Neutrino energy



$E_{observed} \rightarrow E_\nu$

Neutrino energy is reconstructed from observed energy using relations based on MC simulation

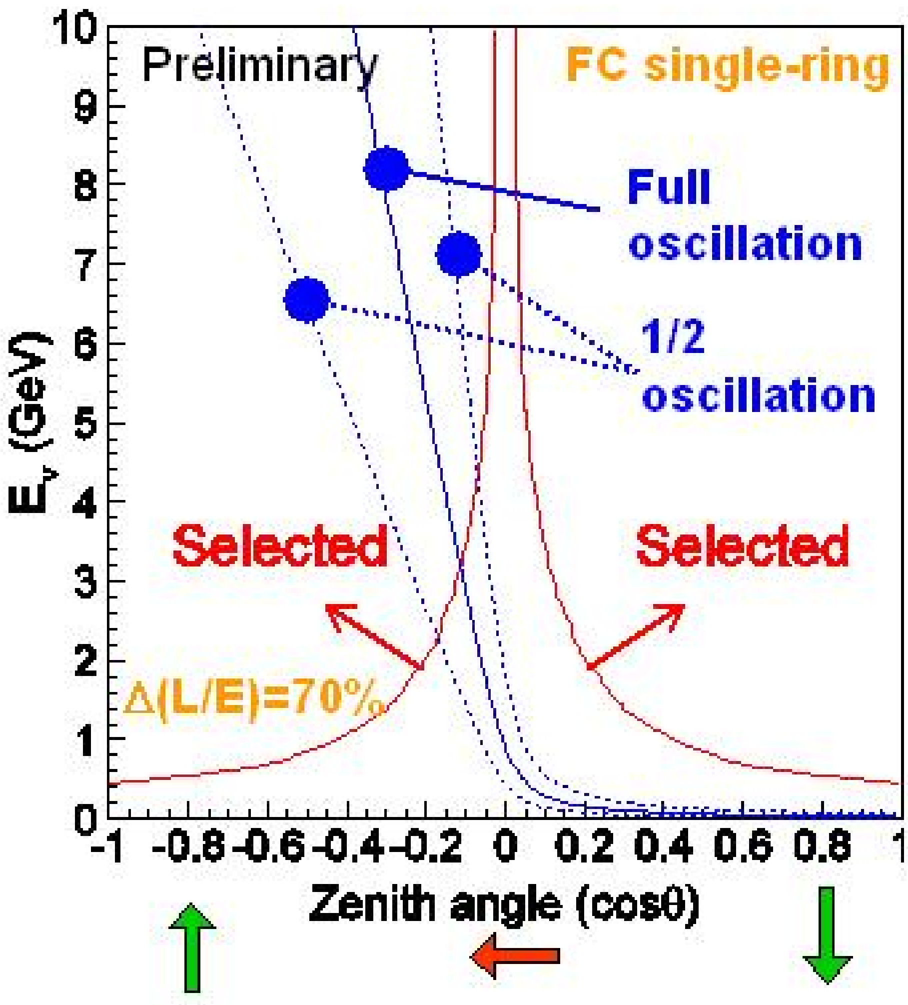
Neutrino direction



Zenith angle
→ Flight length

Neutrino flight length is estimated from zenith angle of particle direction

L/E resolution cut



Select events with high resolution in L/E

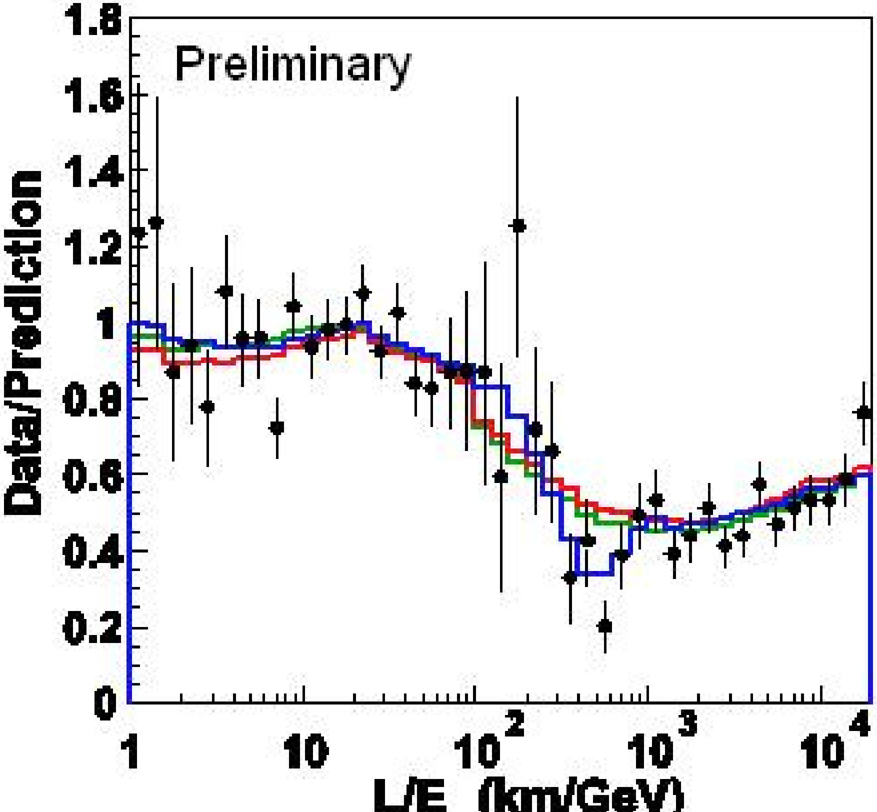
Bad L/E resolution for

horizontally going events
→ due to large dL/dcosθ

low energy events
→ due to large scattering angle

Tests for neutrino decay & decoherence

—	**Oscillation**	χ^2_{min}=37.8/40 d.o.f
—	**Decay**	χ^2_{min}=49.2/40 d.o.f → $\Delta\chi^2$ =11.4
—	**Decoherence**	χ^2_{min}=52.4/40 d.o.f → $\Delta\chi^2$ =14.6



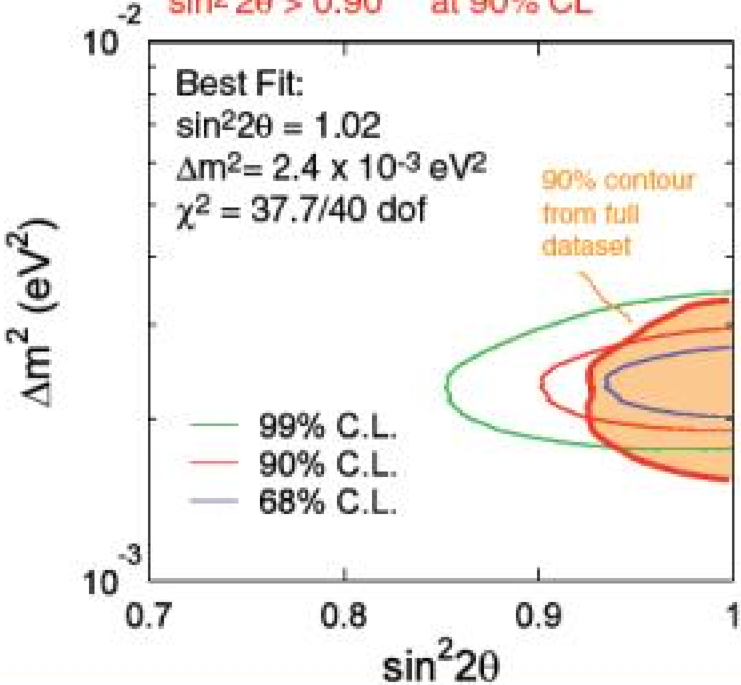
3.4 σ to ν decay

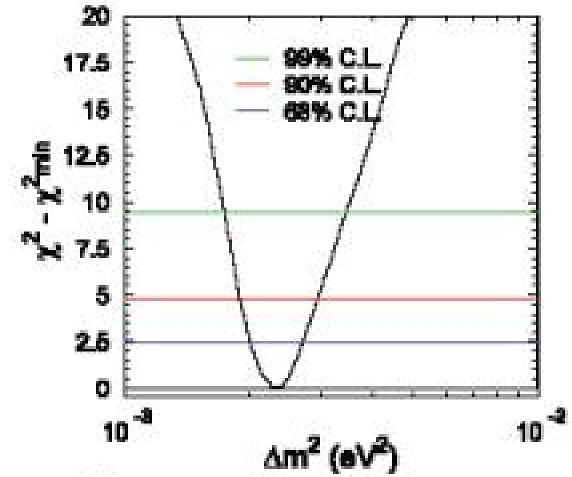
3.8 σ to ν decoherence

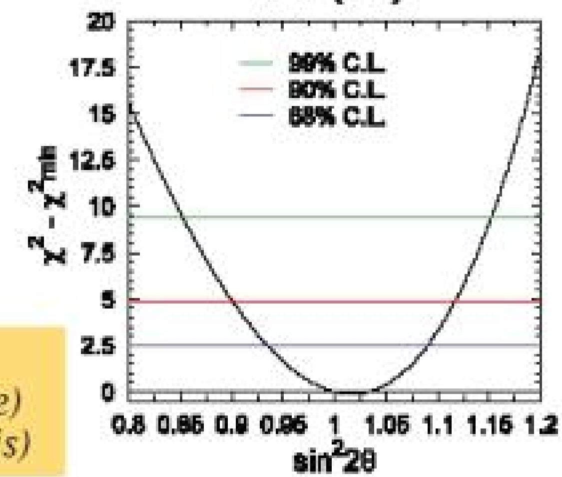
First dip observed in data cannot be explained by alternative hypotheses

L/E Analysis Oscillation Fit

1.9x10-3 eV2 < Δm2 < 3.0 x 10-3 eV2
sin2 2θ > 0.90 at 90% CL







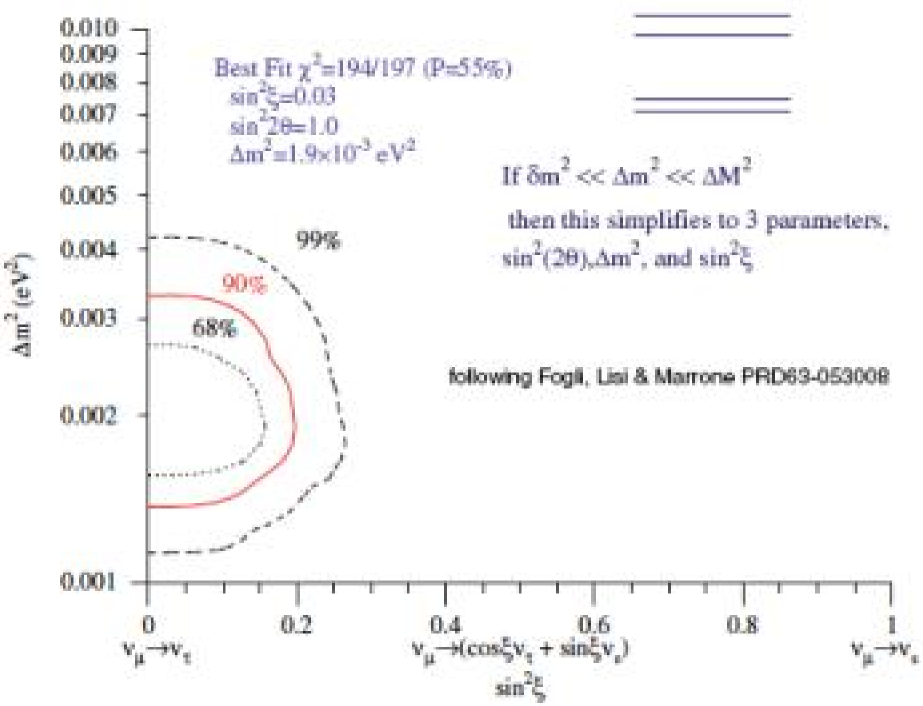
Strong constraint on minimum value of Δm2
with data sub-sample (not independent of course)
no use of upward muons (cf. full dataset analysis)

Exotic scenarios

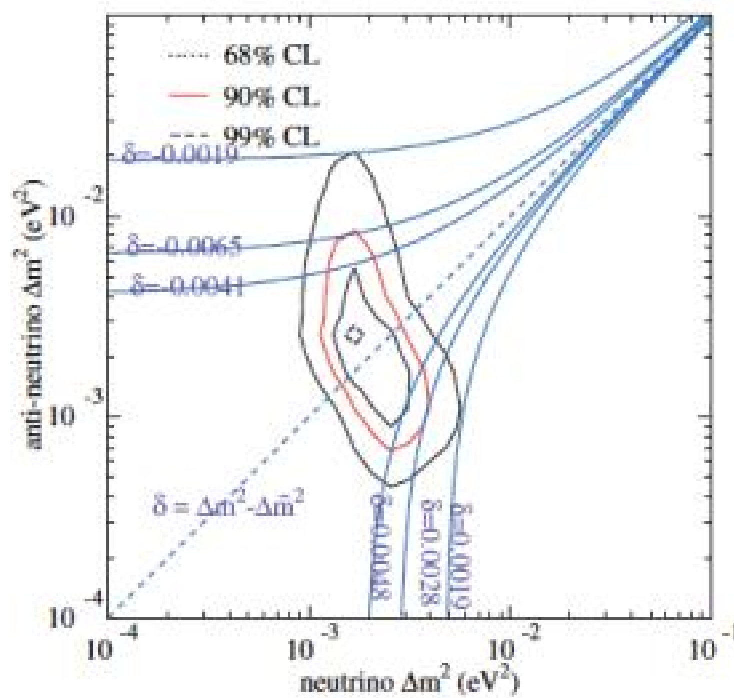
sterile neutrino admixture

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

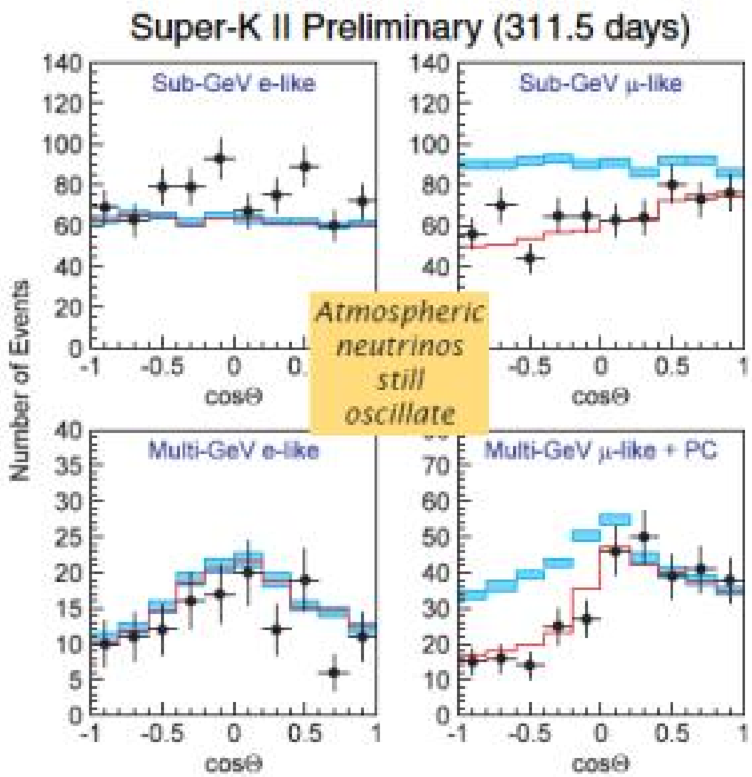
δm^2 - Solar Neutrinos ($< 10^{-4}$ eV^2)
Δm^2 - Atmosperic Neutrinos ($\approx 10^{-3}$-10^{-2} eV^2)
ΔM^2 - LSND (≈ 1 eV^2)



CPT violation



SK-II Preliminary Results

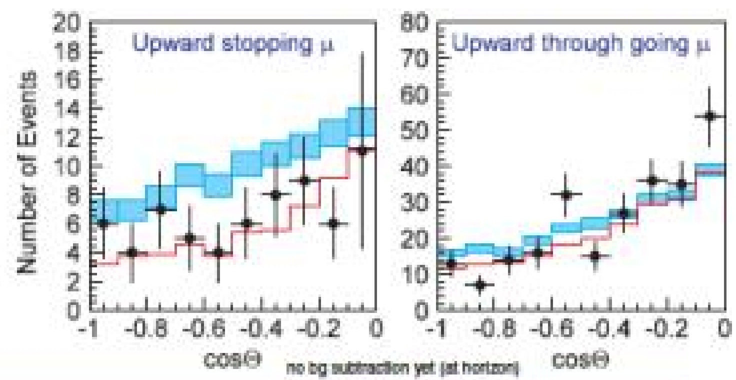


FC data reduction:
8.22 ± 0.16 ev/day (cf. 8.17 SK-I)

PC data reduction:
0.51 ± 0.04 ev/day (cf. 0.61 SK-I)

$R_{sub\text{-}GeV} = 0.61 \pm 0.03 \pm 0.05$

$R_{multi\text{-}GeV} = 0.89 \pm 0.10 \pm 0.16$



SK-II data is consistent with SK-I results. e/μ ID, energy scale look very good.
Current studies emphasize ring counting, PC reduction, OD simulation.

Atmospheric Neutrino Summary

- Consistent picture of $\nu_\mu \rightarrow \nu_\tau$ oscillation has been obtained.
- Oscillation pattern in L/E analysis has been demonstrated.
- SK-II data are consistent with the SK-I results.

4. K2K Results

K2K Collaboration

JAPAN: High Energy Accelerator Research Organization (KEK) / Institute for Cosmic Ray Research (ICRR), Univ. of Tokyo / Kobe University / Kyoto University / Niigata University / Okayama University / Tokyo University of Science / Tohoku University

KOREA: Chonnam National University / Dongshin University / Korea University / Seoul National University

U.S.A.: Boston University / University of California, Irvine / University of Hawaii, Manoa / Massachusetts Institute of Technology / State University of New York at Stony Brook / University of Washington at Seattle

POLAND: Warsaw University / Soltan Institute

Since 2002

JAPAN: Hiroshima University / Osaka University

CANADA: TRIUMF / University of British Columbia

Italy: Rome France: Saclay Spain: Barcelona / Valencia Switzerland: Geneva

RUSSIA: INR-Moscow

Since 2004

U.S.A.: Duke University

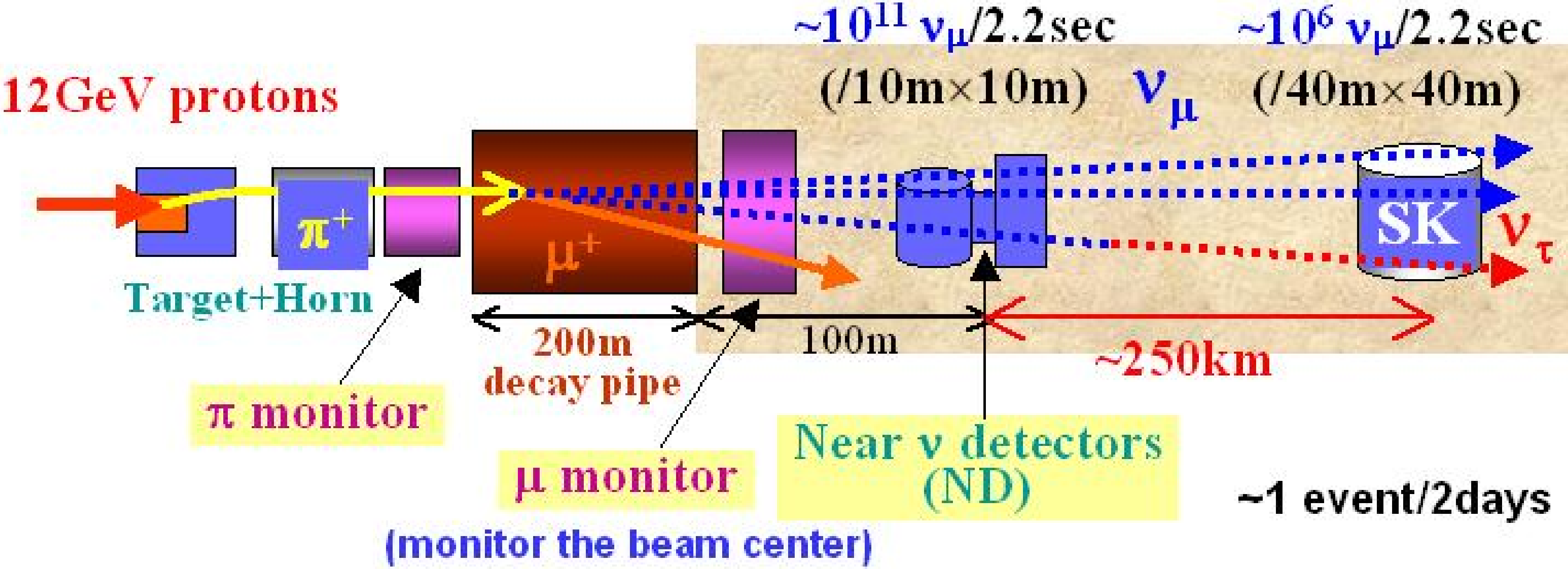
Goals for K2K

- Confirm Super-Kamiokande's results on atmospheric neutrino oscillation with n_m disappearance by
  - Counting observed/expected numbers of events
  - Comparison of the near and far spectra
    - Observation of oscillation pattern as a function of energy
- Measurements of neutrino cross sections in the GeV region
  - Particularly interesting is the NC π^0 production

History of K2K

- 1995 Proposed to study neutrino oscillation for atmospheric neutrinos anomaly.
- 1999 Started taking data.
- 2000 Detected the less number of neutrinos than the expectation at a distance of 250 km. Disfavored nulloscillation at the 2σ level.
- 2002 Observed indications of neutrino oscillation. The probability of null oscillation is less than 1%.
- 2004 Confirmed neutrino oscillation with both a deficit of ν_μ and the distortion of the E_ν spectrum.

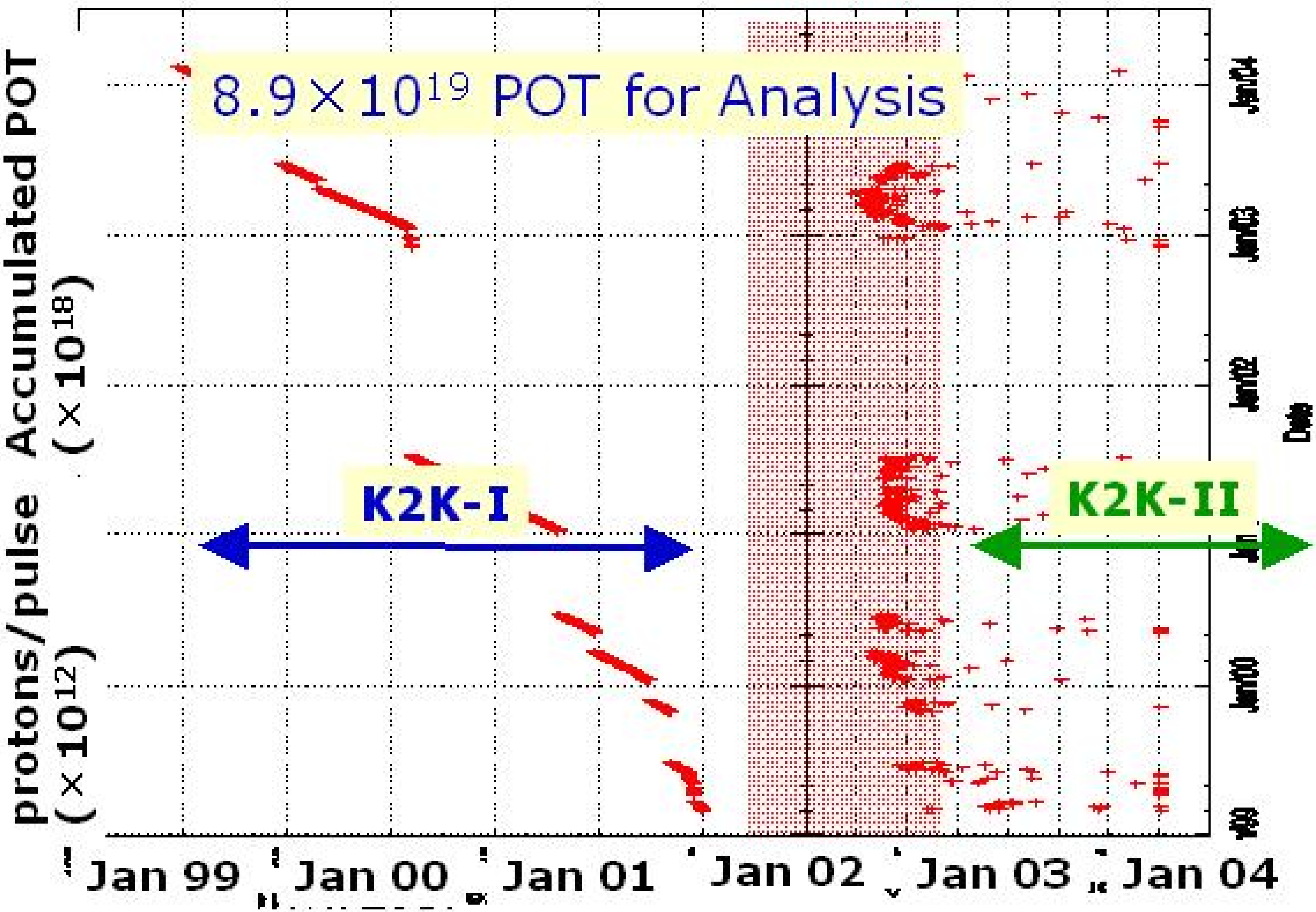
K2K experiment



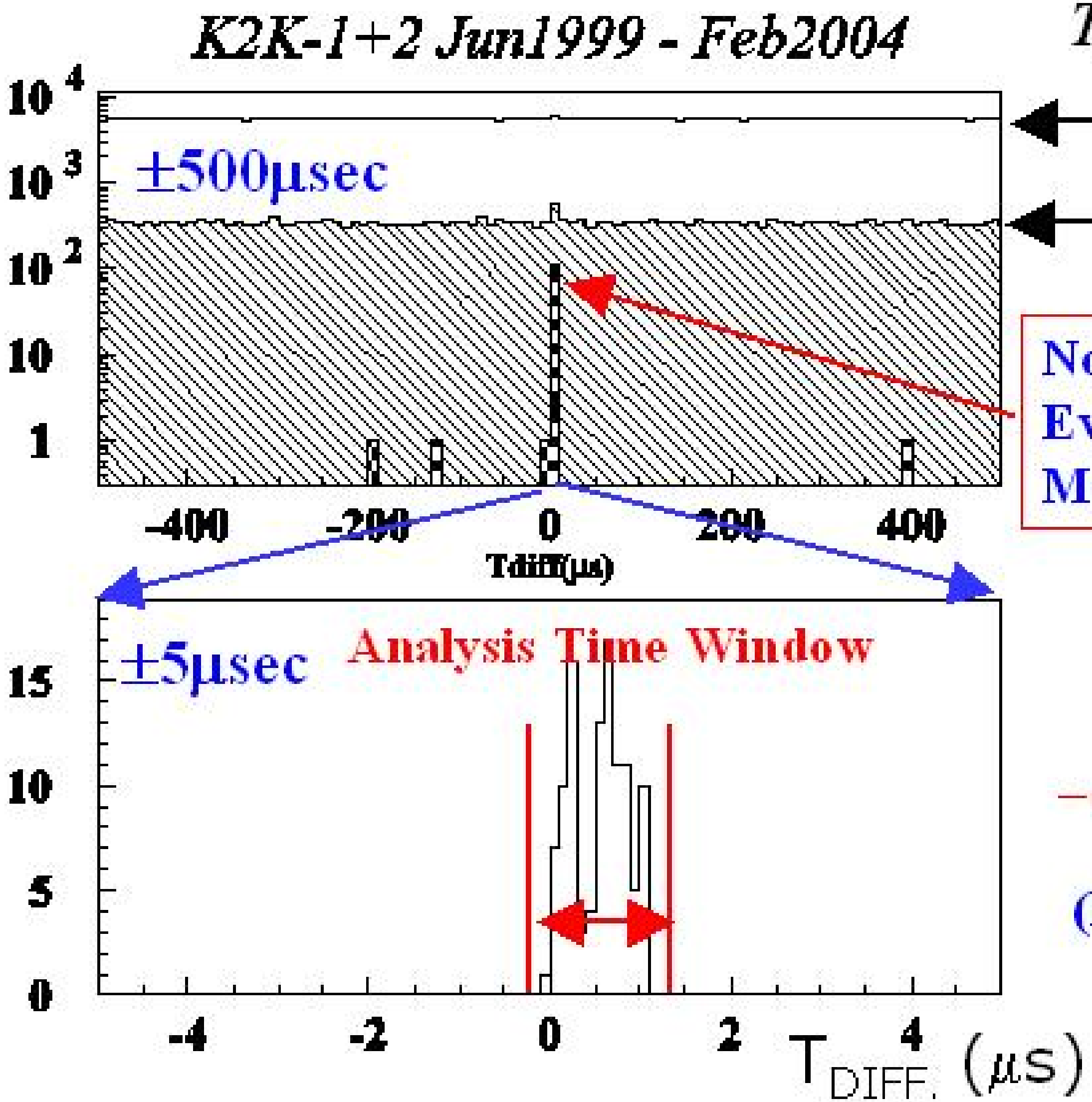
Signal of ν oscillation at K2K

- Reduction of ν_μ events
- Distortion of ν_μ energy spectrum

Accumulated POT (Protons On Target)



SK Events



Decay electron cut.

≥20MeV Deposited Energy

No Activity in Outer Detector
Event Vertex in Fiducial Volume
More than 30MeV Deposited Energy

108 events

$-0.2 < T_{SK} - T_{spill} - TOF < 1.3 \mu sec$

(BG: 1.6 events within ±500μs
2.4×10^{-3} events in 1.5μs)

K2K-SK events

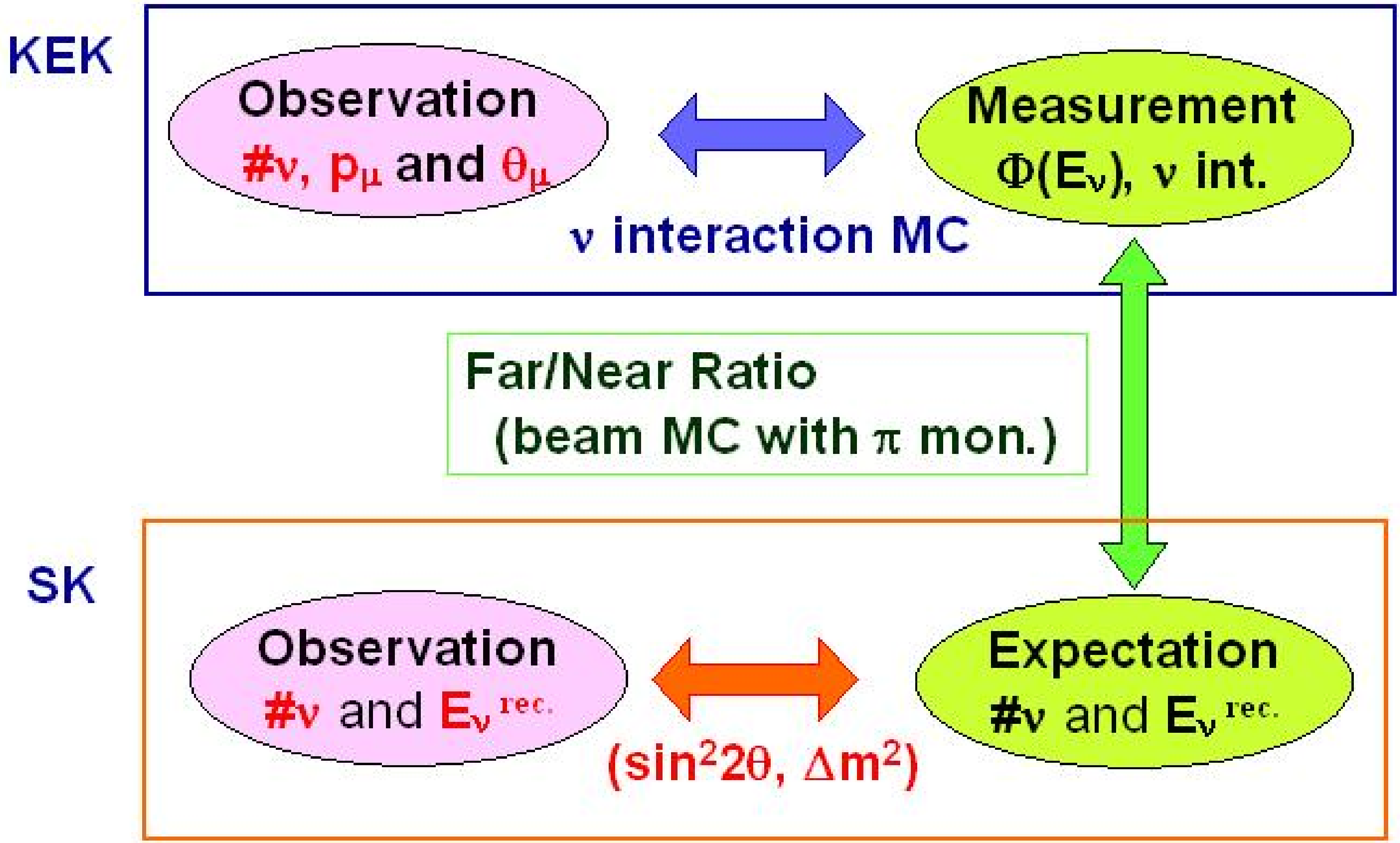
preliminary

K2K-aIII (K2K-I, K2K-II)	DATA (K2K-I, K2K-II)	MC (K2K-I, K2K-II)
FC 22.5kt	**108** (56, 52)	**150.9** (79.1*, 71.8)
1ring	**66** (32, 34)	**93.7** (48.6, 45.1)
μ-like	**57** **(56)** for E_ν^{rec} (30, 27)	**84.8** (44.3, 40.5)
e-like	**9** (2, 7)	**8.8** (4.3, 4.5)
Multi Ring	**42** (24, 18)	**57.2** (30.5, 26.7)

Ref; K2K-I(47.9×10^{18}POT), K2K-II(41.2×10^{18}POT)

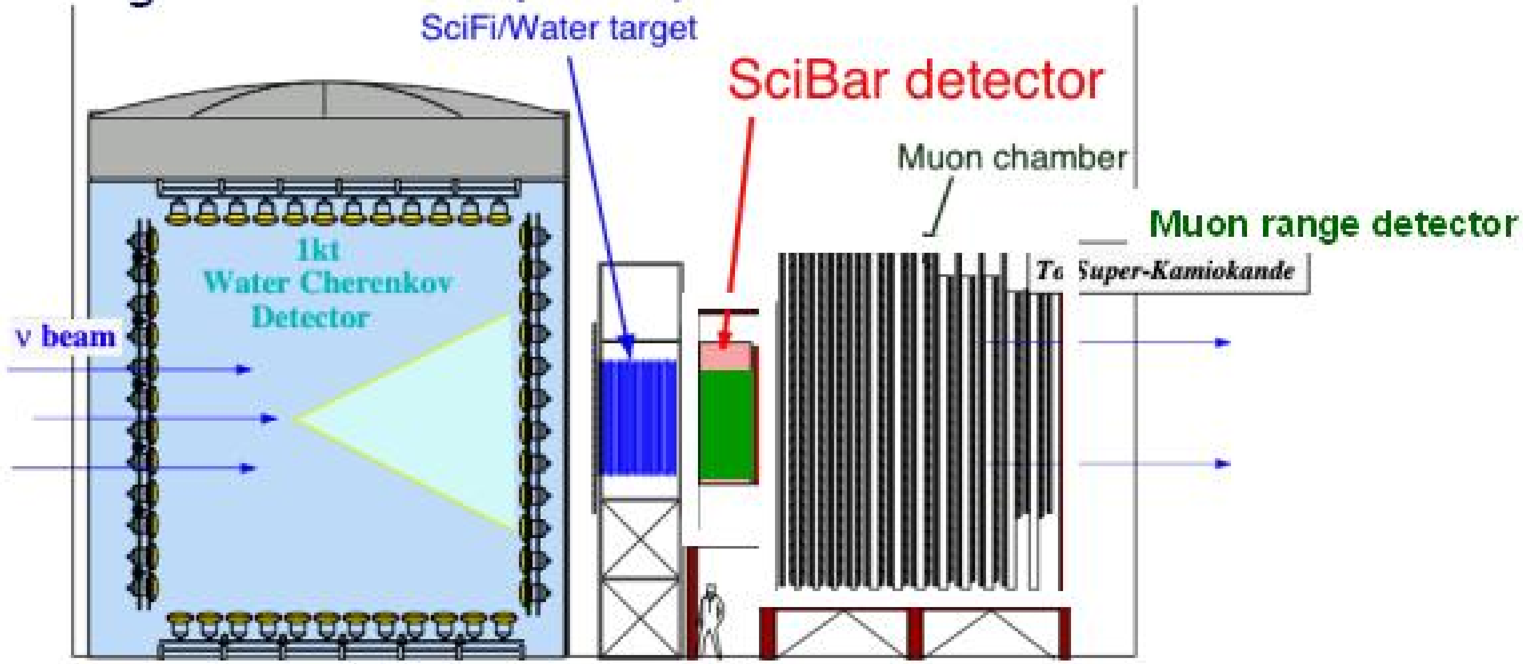
*: The number is changed from the previous one.

Analysis Overview



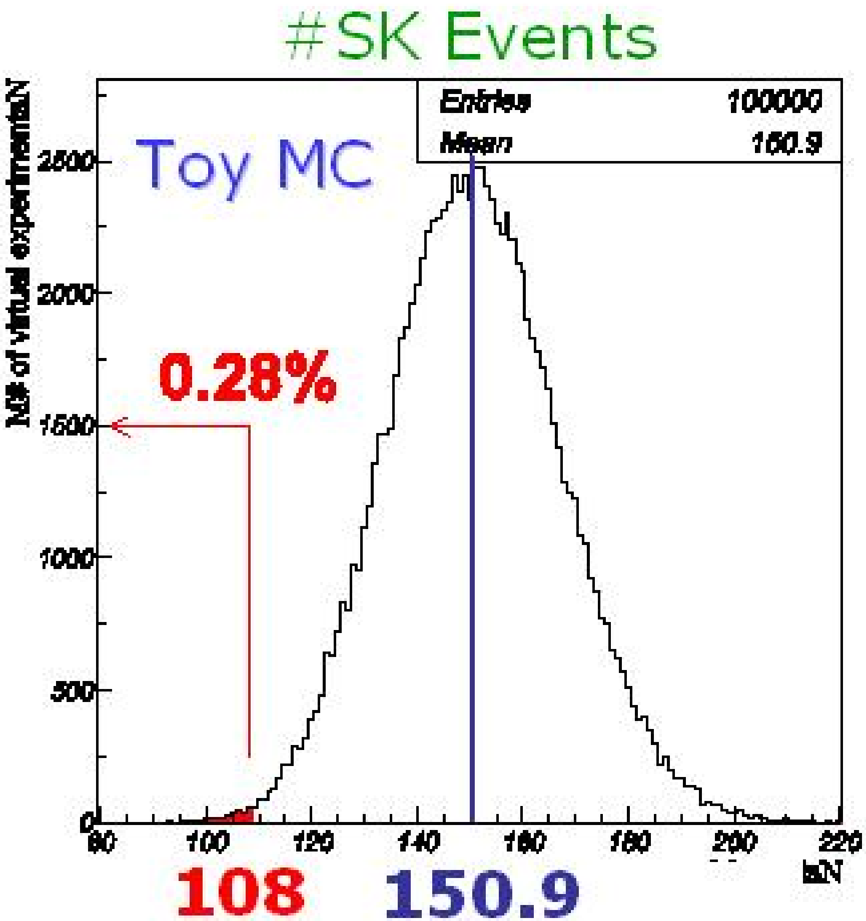
Near detector measurements

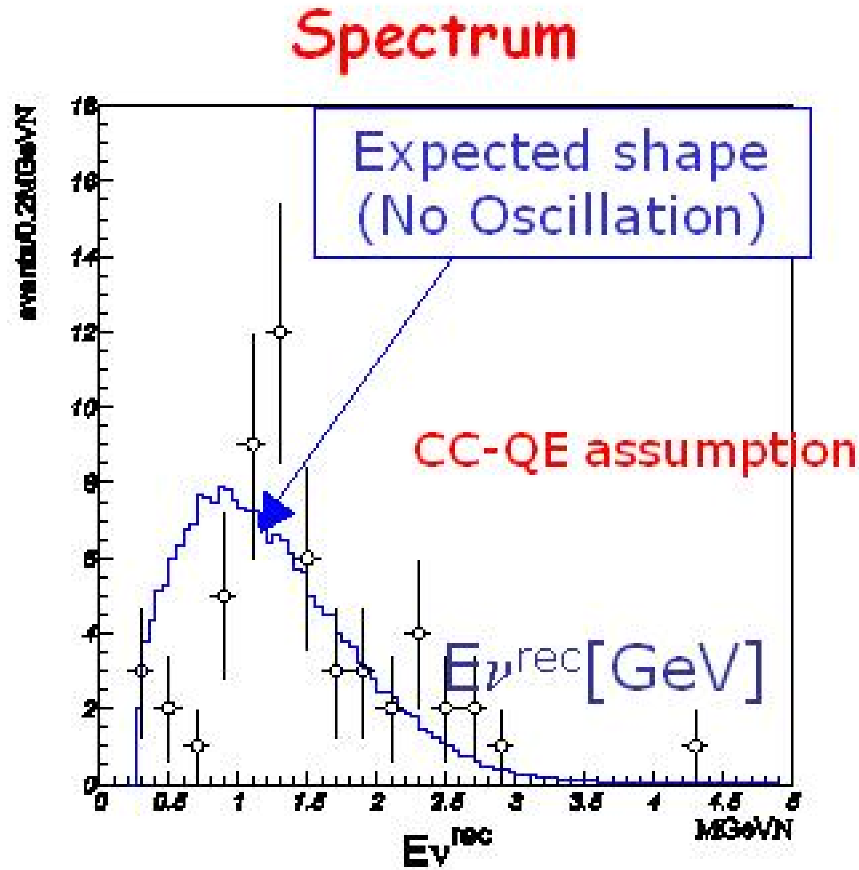
- 1KT Water Cherenkov Detector (1KT)
- Scintillating-fiber/Water sandwich Detector (SciFi)
- Lead Glass calorimeter (LG) before 2002
- Scintillator Bar Detector (SciBar) after 2003
- Muon Range Detector (MRD)



Results

$N_{SK}^{exp} = 150.9^{+11.6}_{-10.0}$ ⟺ $N_{SK}^{obs} = 108$



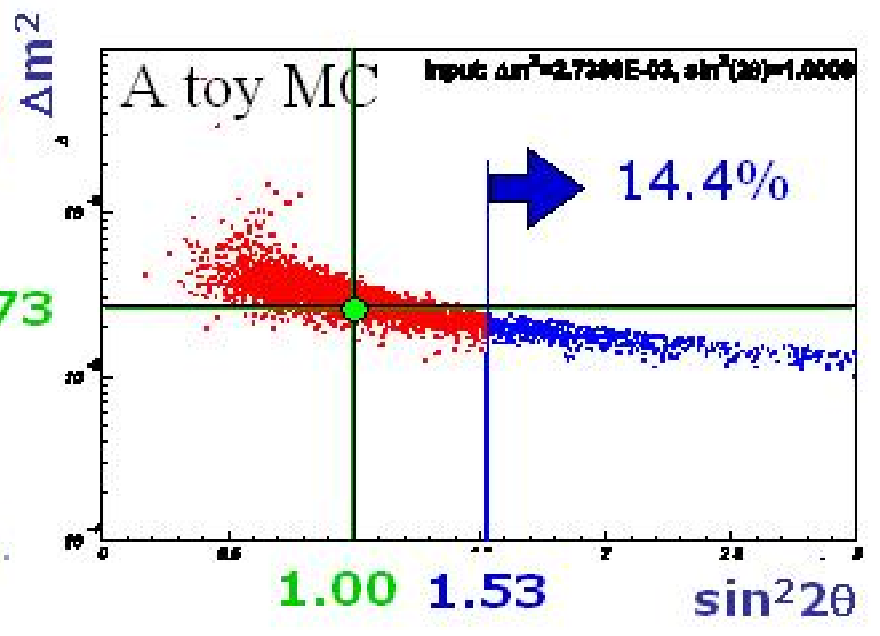


K2K Oscillation Analysis Results

preliminary

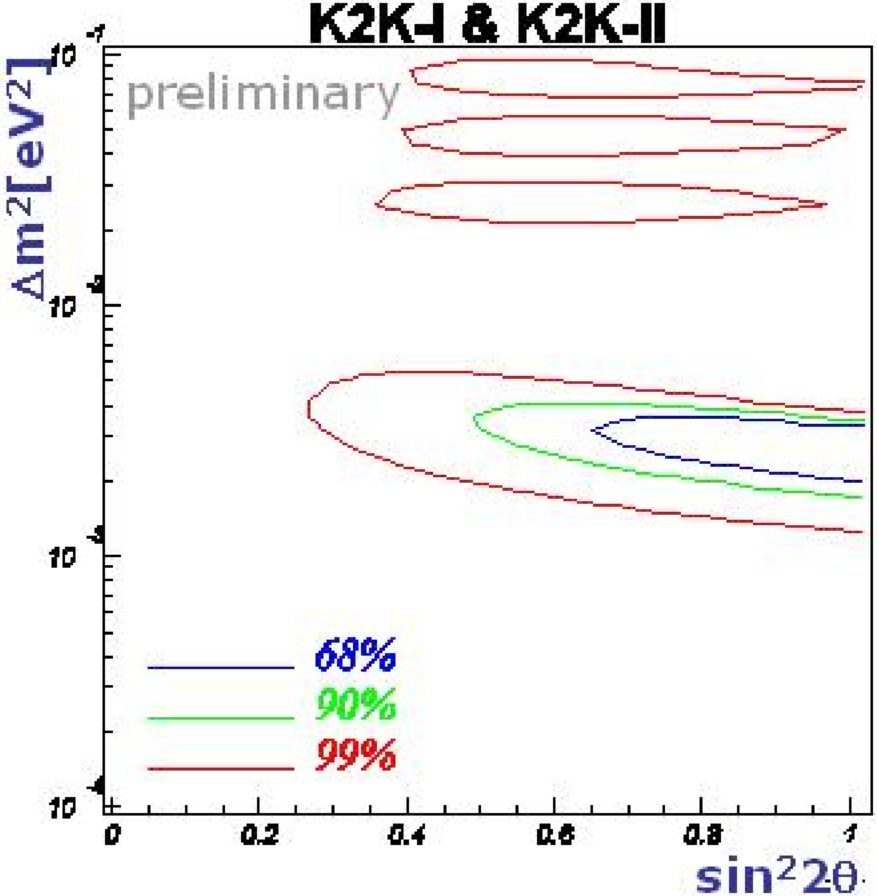
- Best fit values.
  - $\sin^2 2\theta = 1.53$
  - $\Delta m^2\,[eV^2] = 2.12\times10^{-3}$
- Best fit values in the physical region.
  - $\sin^2 2\theta = 1.00$
  - $\Delta m^2\,[eV^2] = 2.73\times10$

$\Delta \log L = 0.64$



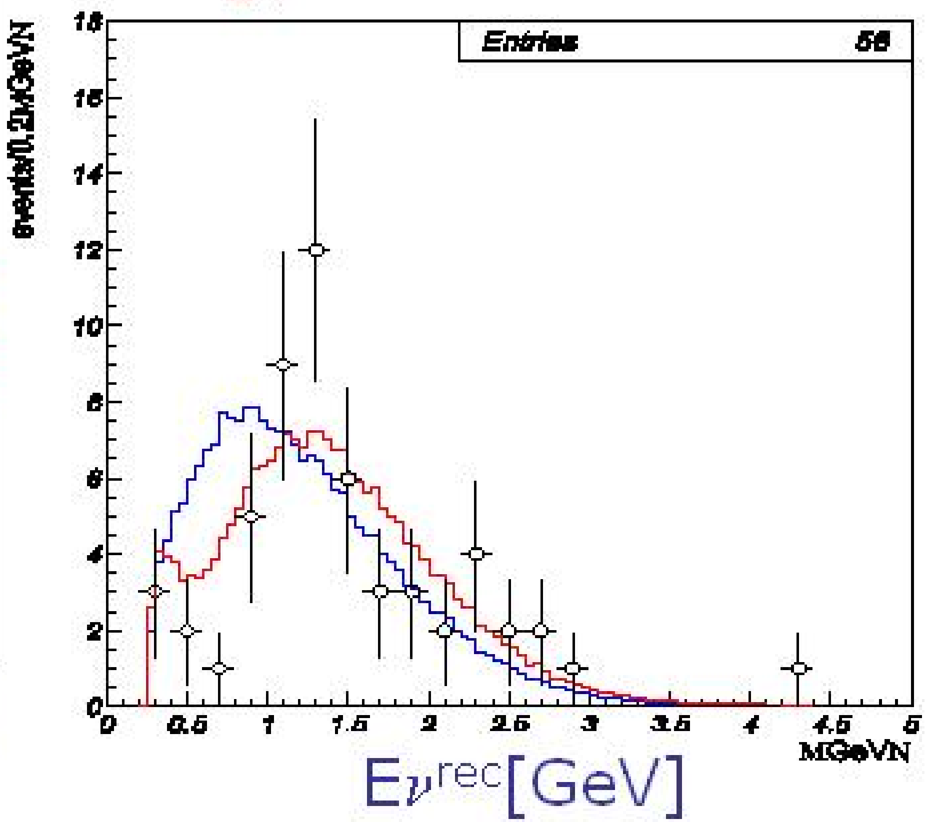
$\sin^2 2\theta = 1.53$ can be occurred by statistical fluctuation with 14.4%.

Contours and Best Fit Spectrum

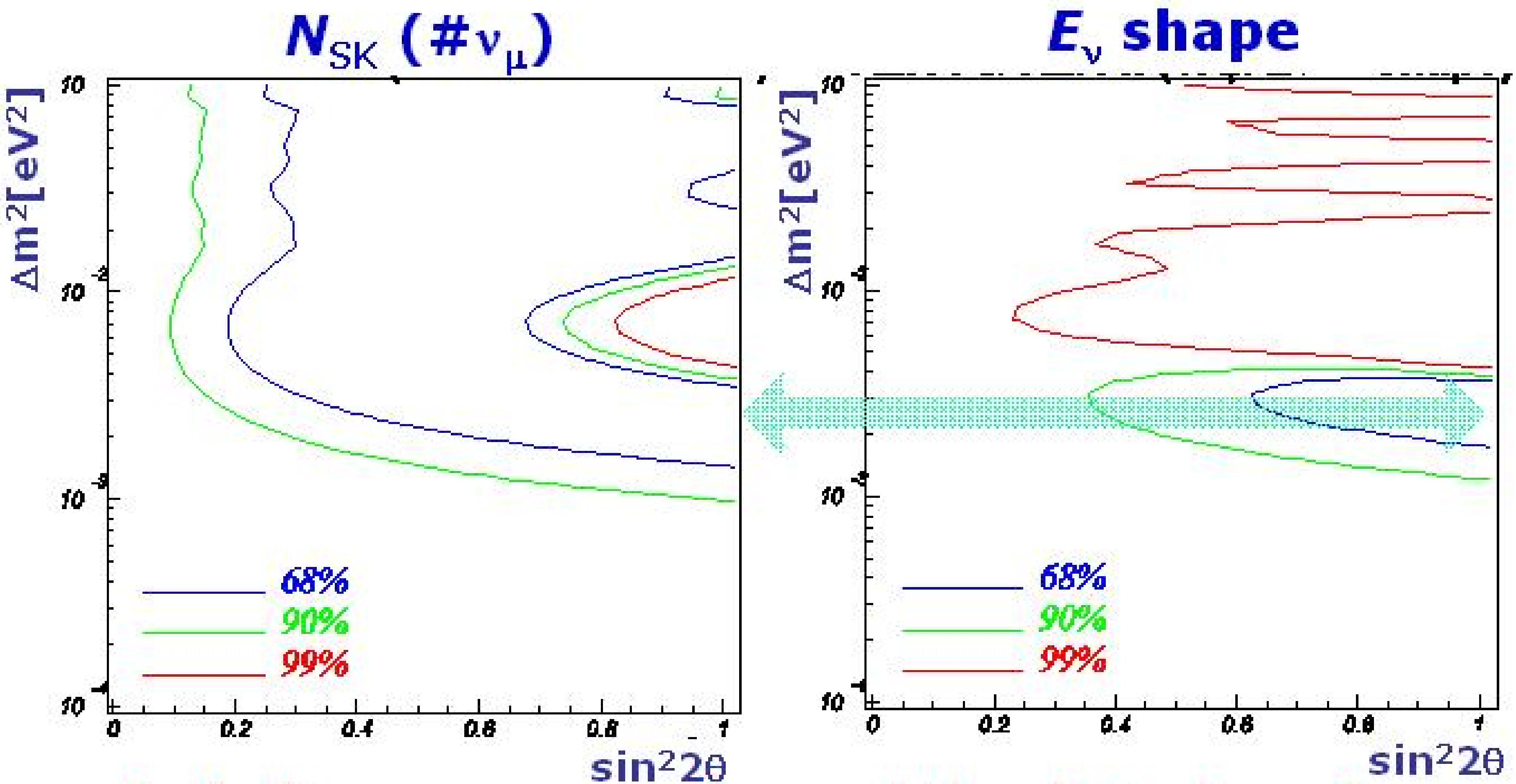


Based on $\Delta \ln L$

- $N_{SK}^{obs}=108$
- N_{SK}^{exp} (best fit)$=104.8$



ν_μ disappearance versus E_ν shape distortion



Both disappearance of ν_μ and the distortion of E_ν spectrum have the consistent result.

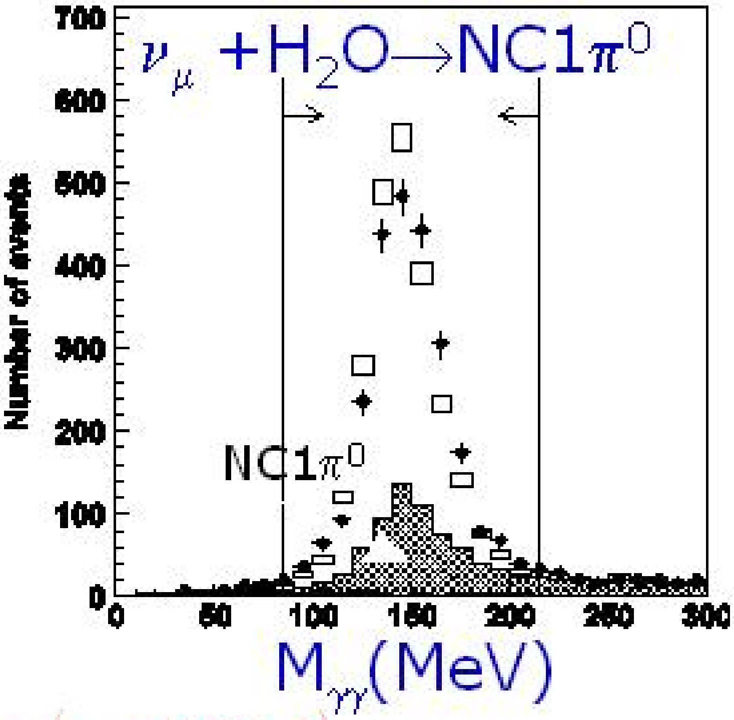
Null oscillation probability

preliminary

	K2K-I	K2K-II	K2K-all
ν_μ disappearance	2.0%	3.7%	0.33%(2.9σ)
E_ν spectrum distortion	19.5%	5.4%	1.1% (2.5σ)
Combined	1.3% (2.5σ)	0.56% (2.8σ)	0.011% (3.9σ)

K2K <u>confirmed</u> atmospheric ***neutrino oscillation*** *discovered by Super-K.*

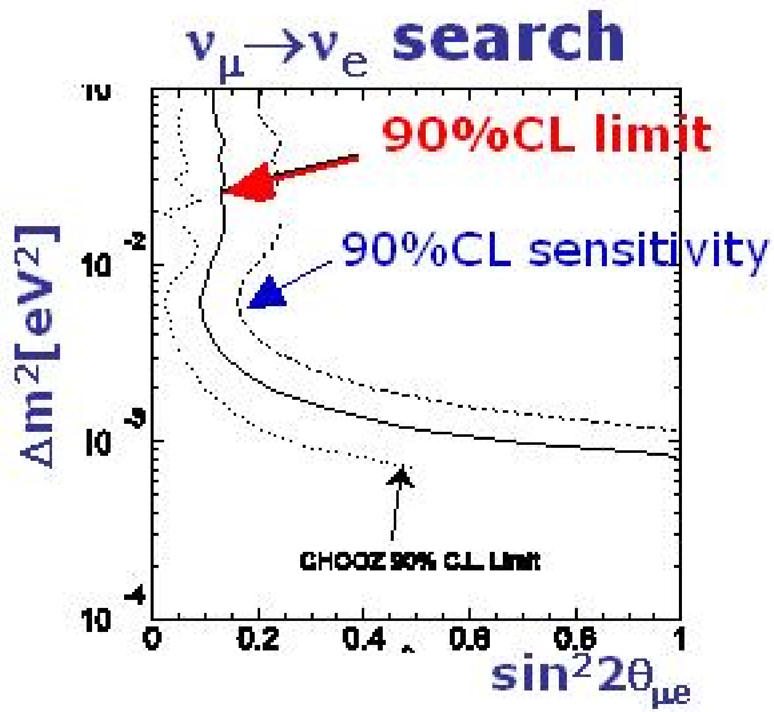
Other K2K Results



$$\frac{\sigma(\nu_\mu \to NC1\pi^0)}{\sigma(\nu_\mu \to CCall)} = 0.065 \pm 0.001 \pm 0.007$$

=0.064 (prediction)

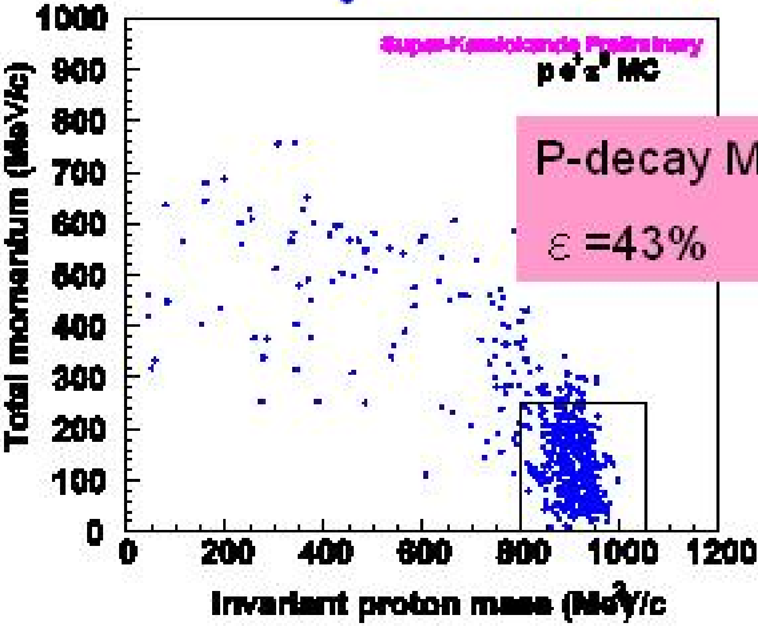
preliminary



PRL, to be published

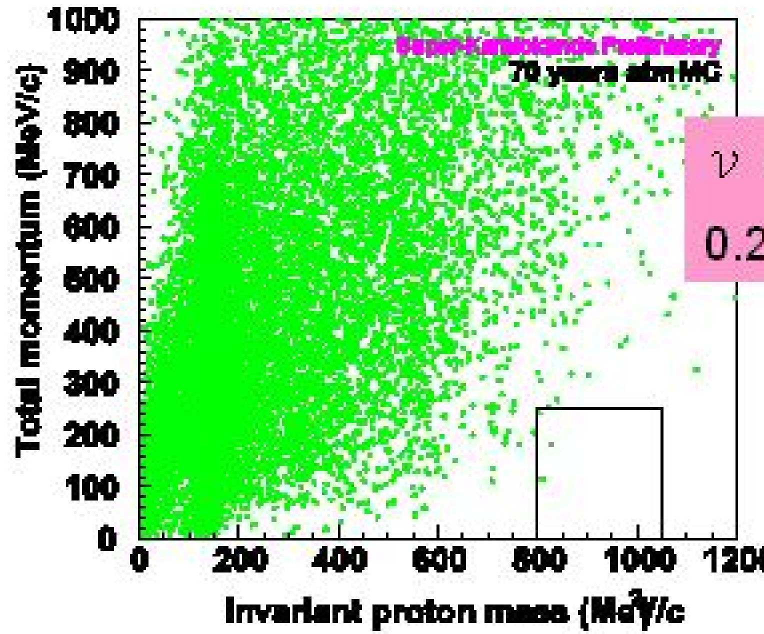
5. Proton Decay Results

$p \rightarrow e^{+}\pi^{0}$: Present Status



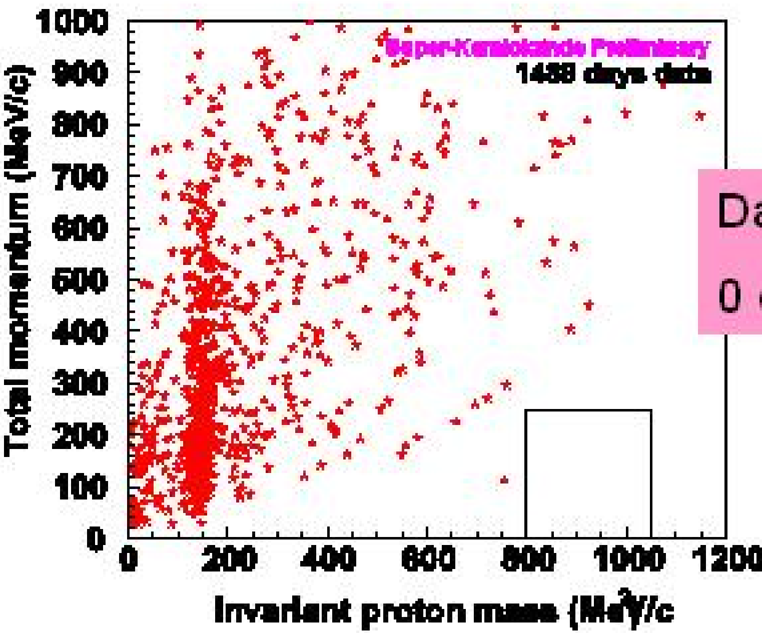
P-decay MC

ε =43%



ν MC

0.2BG/1489d



Data

0 candidate

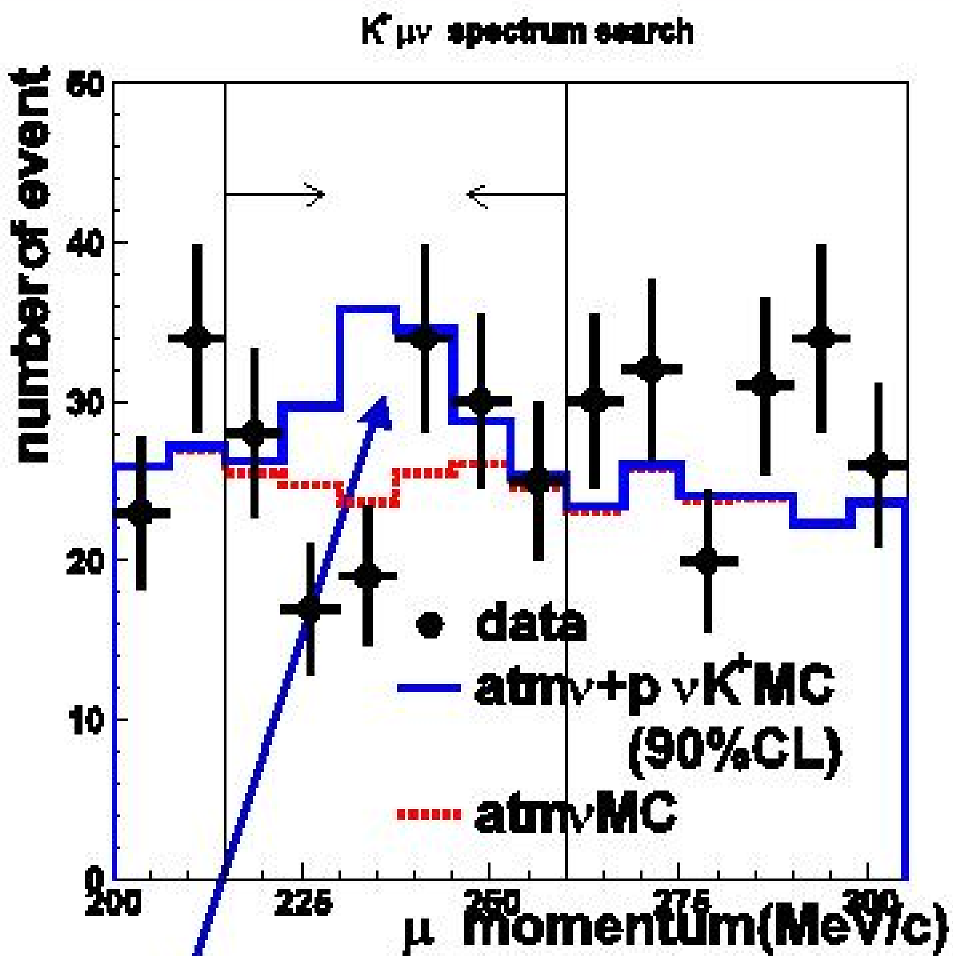
τ /B > 5.7 × 10^{33}yr

(Super-K, 90%C.L)

$p \rightarrow \nu K^+$: Present Status (1)

(1) $P \rightarrow \nu K^+$, $K^+ \rightarrow \mu^+ \nu$

236 MeV/c



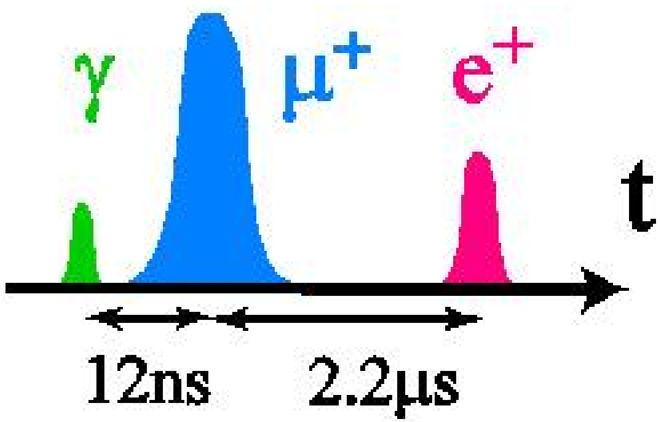
No significant excess near 236MeV/c.

$p \rightarrow \nu K^+$: Present Status (2)

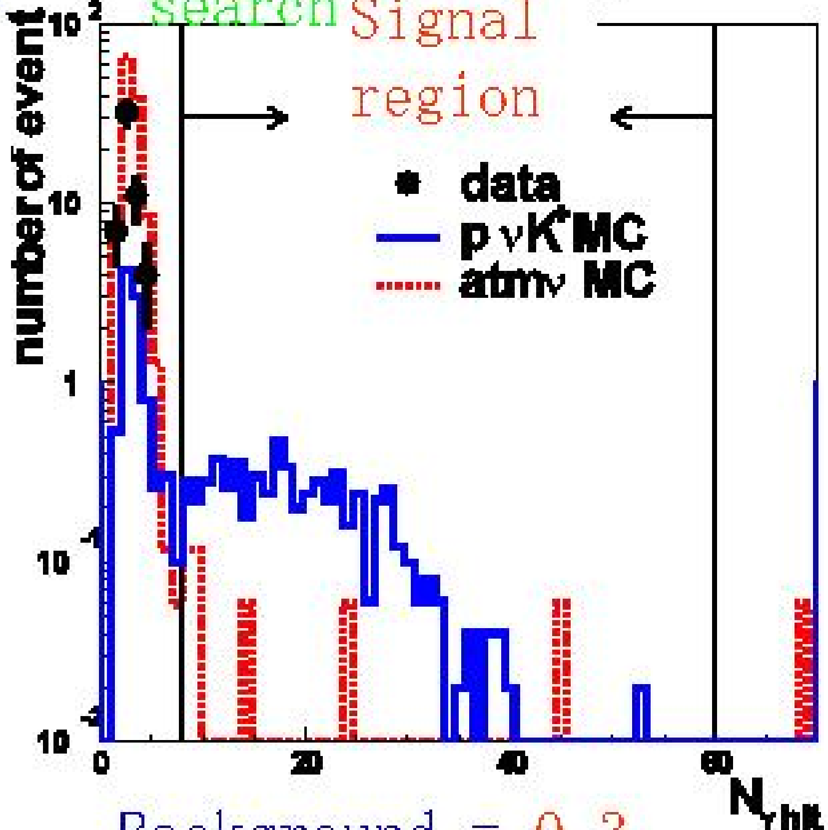
(2) $^{16}O \rightarrow \nu K^{+} {}^{15}N \gamma$, $K^+ \rightarrow \mu^+ \nu$

$\hookrightarrow e^+ \nu \nu$

6 – 10 MeV 236MeV/c



Nhit distribution for the prompt gamma search



Background = 0.3

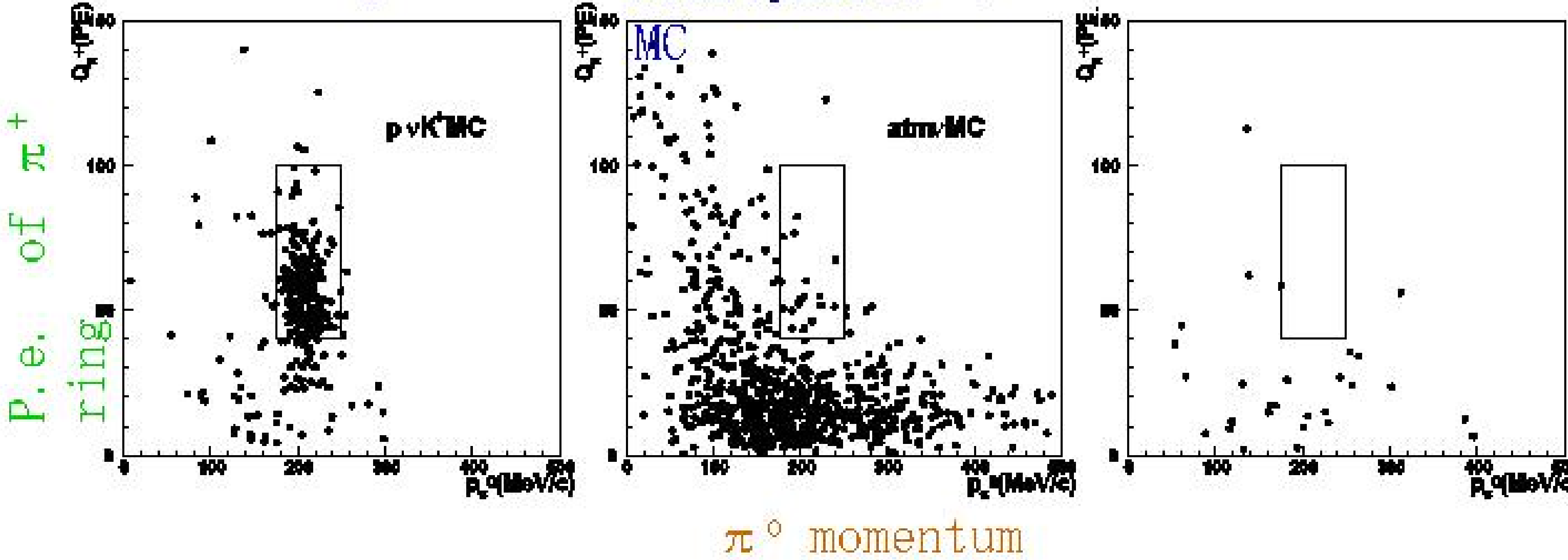
ε = 8.7%

Candidate = 0

$p \rightarrow \nu K^+$: Present Status (3)

(3) $P \rightarrow \nu K^+$, $K^+ \rightarrow \pi^+ \pi^0$ ◀······ Back to back 205MeV/c each

P-decay MC | Atmospheric ν | Data



ε = 6.5 %

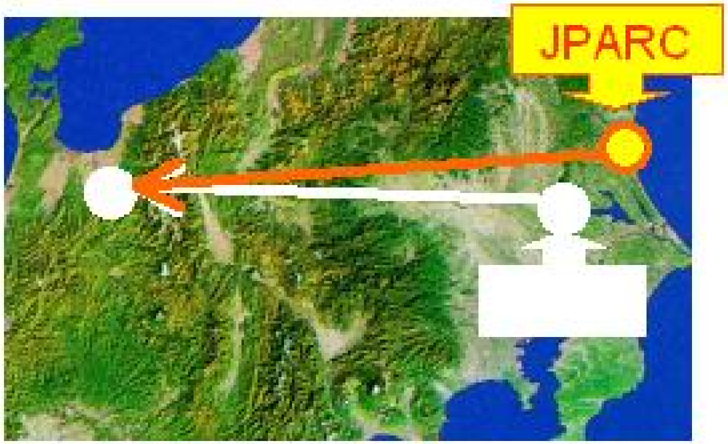
BG=0.9 ev/92ktonyr

Data=0 ev.

(1),(2) and (3) ⟹ τ /B 2.0×10^{33}yr (90%CL, Super-K)

6. Future Prospects

J-PARC neutrino project

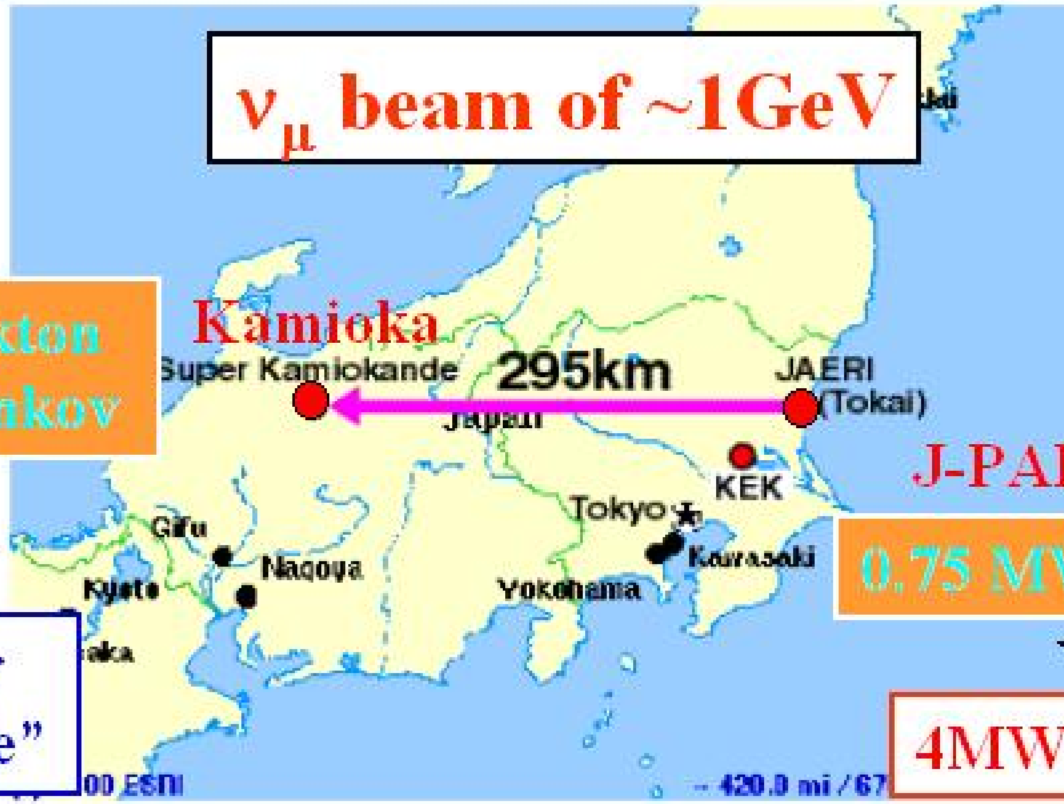


	J-PARC	NuMI (FNAL)	K2K
E(GeV)	**50**	120	12
Int.(10^{12}ppp)	**330**	40	6
Rate(Hz)	**0.275**	0.53	0.45
Power(MW)	**0.75**	0.41	0.0052

Overview of the T2K Experiment

ν_μ beam of ~1GeV

Super-K: 50 kton
Water Cherenkov



J-PARC

0.75 MW 50 GeV PS

~Mt "Hyper Kamiokande"

4MW 50 GeV PS

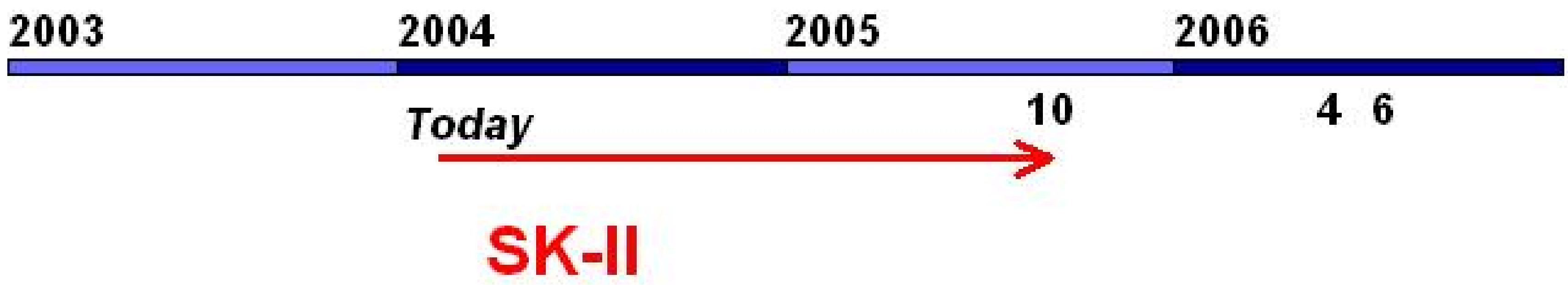
1st Phase

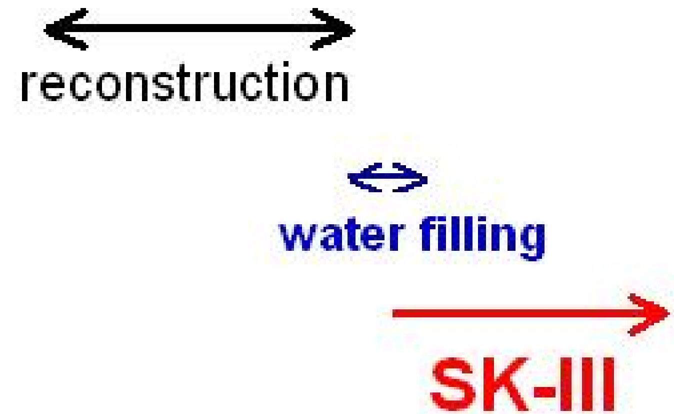
- $\nu_\mu \rightarrow \nu_x$ disappearance
- $\nu_\mu \rightarrow \nu_e$ appearance
- NC measurement

2nd Phase

- CPV
- proton decay

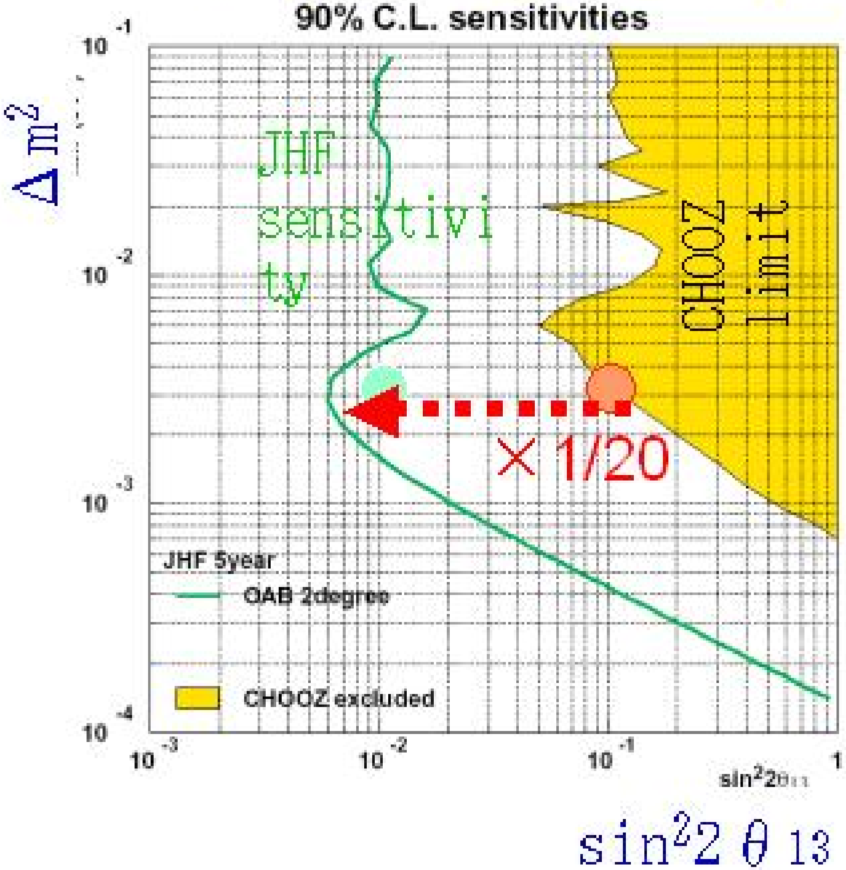
Super-K Full Reconstruction Schedule



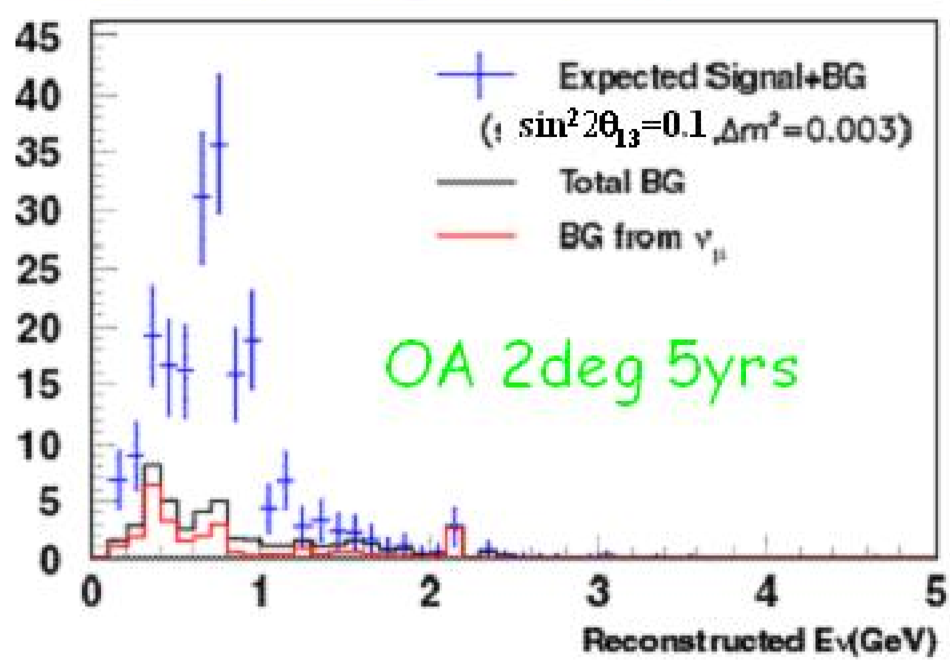


- **Reconstruction for T2K Phase-I:**
  After the K2K experiments complete data-taking.
  Nov,2005 to March, 2006
- **Water filling: April and May in 2006**
- **Start taking data from June 2006**

T2K Phase I: Measurement of $\sin^2 2\theta_{13}$

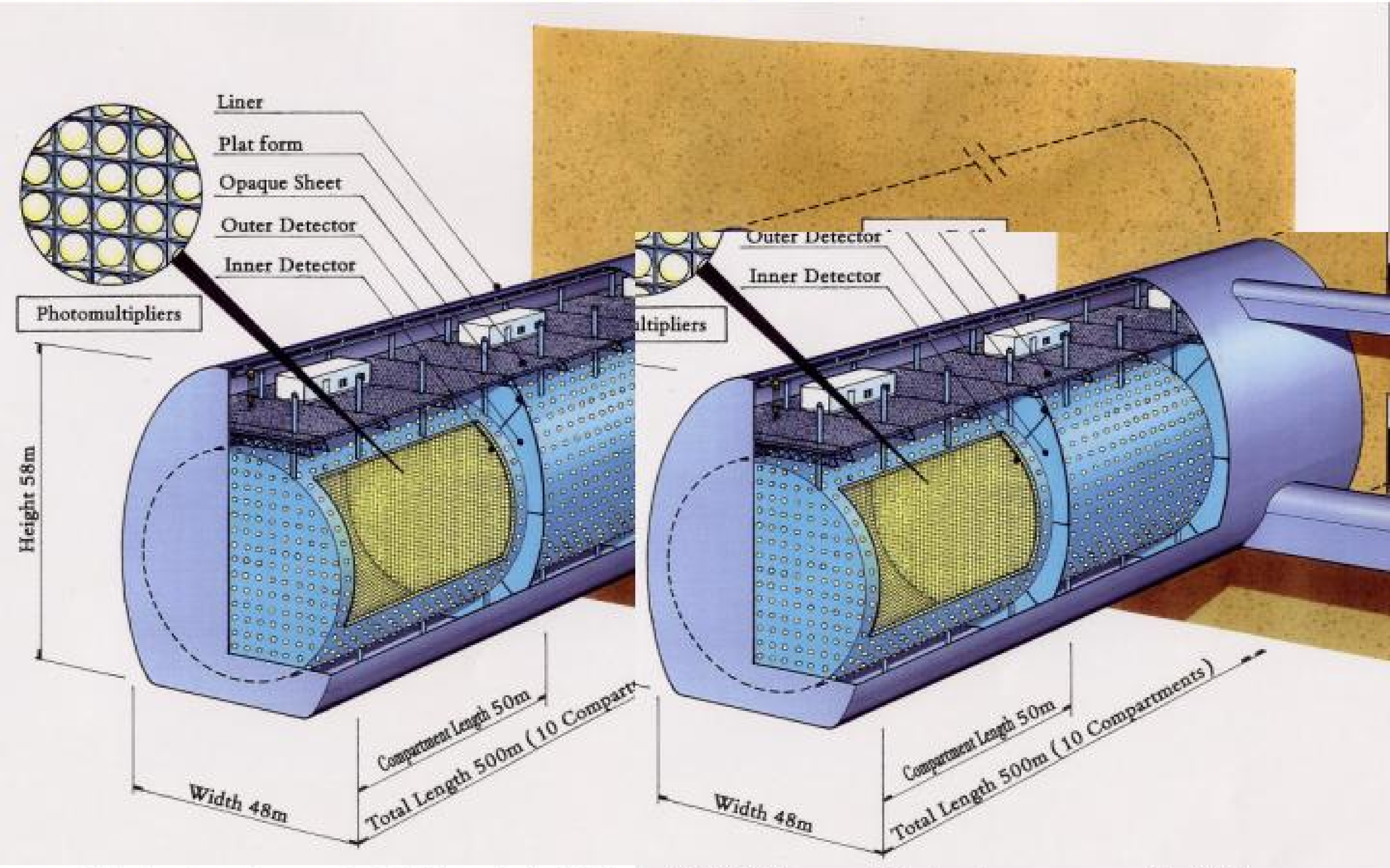


Expected signal for



$\sin^2 2\theta_{13}$	ν_μ(CC+NC)	Beam ν_e	Osc'd ν_e	Signal+BG
0.1	11.1	11.1	123.2	145.5
0.01	11.1	11.1	12.3	34.5

Twin Detector Hyper-Kamiokande



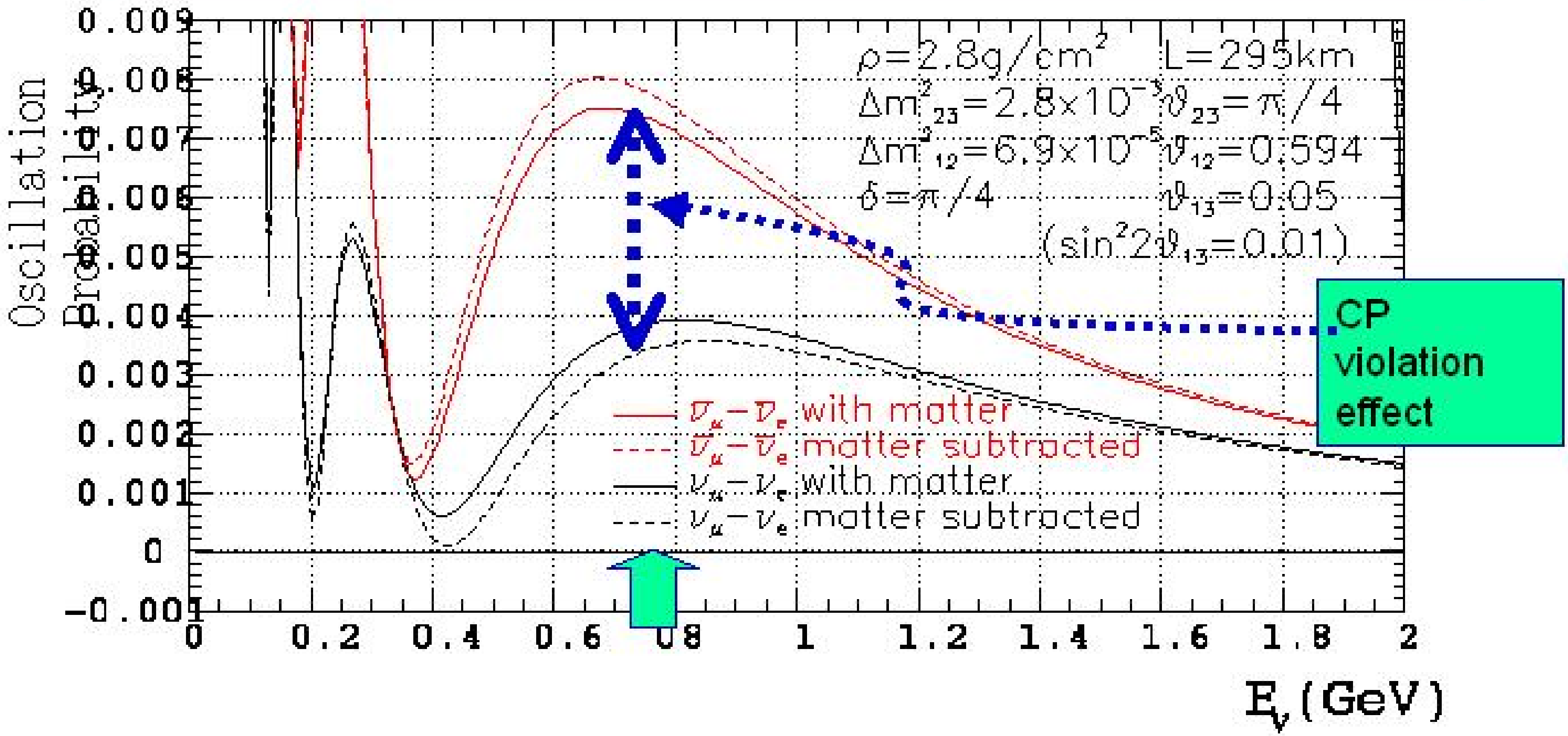
2 detectors × 48m × 50m × 250m, Total mass = 1 Mton

3 Generations of Kamioka Nucleon Decay Experiments

	Kamiokande	Super-Kamiokande	Hyper-Kamiokande
Mass	3,000 t (+1,500 t)	50,000 t	1,000,000 t
Photosensitive Coverage	20 %	40 % (SK-I, III) ~20 % (SK-II)	?
Observation Started	1983	1996	?
Cost (Oku-Yen)*	5	100	500?**

* 1 Oku-Yen ≈ 1M$
** Target cost; No realistic estimate yet

Oscillation Probabilities



$$A_{CP} \equiv \frac{P-\overline{P}}{P+\overline{P}} \approx \frac{\Delta m_{12}^2 L}{E} \cdot \frac{\sin 2\theta_{12}}{\sin \theta_{13}} \cdot \sin \delta$$

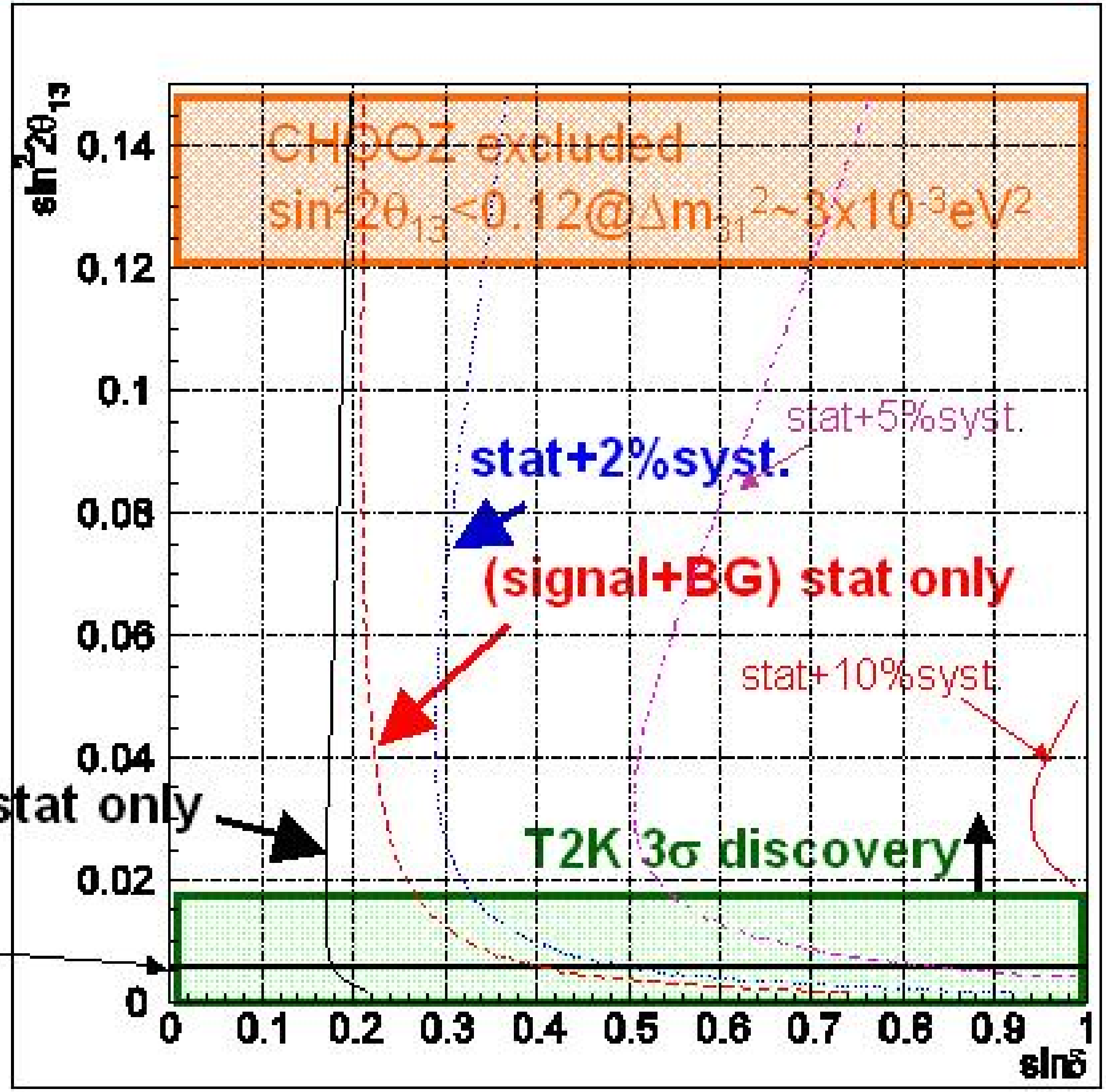
At low energies, the event rate decreases but the CP asymmetry increases.

T2K: CP Violation Sensitivity

4MW, 540kt
2yr for ν_μ
6~7yr for $\bar{\nu}_\mu$

$\Delta m_{21}^2 = 6.9\times10^{-5}eV^2$
$\Delta m_{32}^2 = 2.8\times10^{-3}eV^2$
$\theta_{12} = 0.594$
$\theta_{23} = \pi/4$

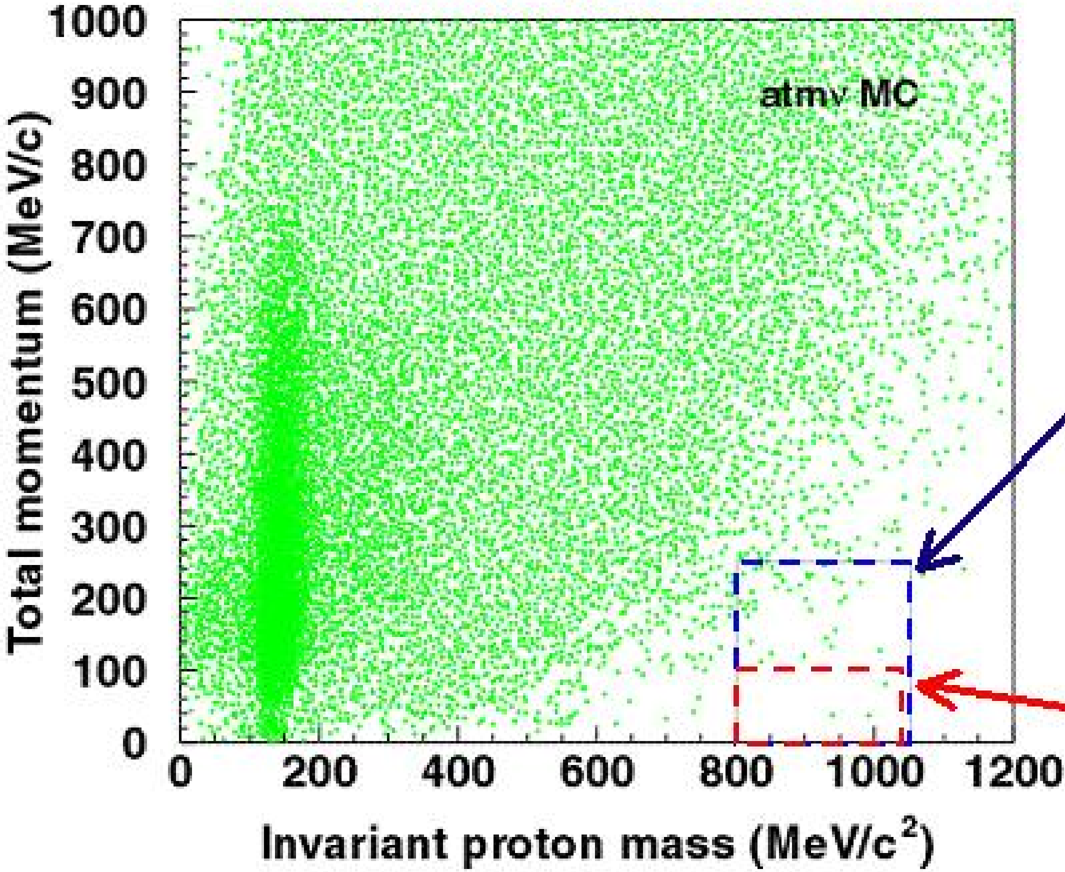
$$A_{CP} \approx \frac{\Delta m^2_{12}}{4E_\nu}\cdot\frac{\sin 2\theta_{12}}{\sin\theta_{13}}\cdot\sin\delta$$



3σ CP sensitivity : |δ|>20° for $\sin^2 2\theta_{13} > 0.01$ with 2% syst.

$p \rightarrow e^+\pi^0$ in Hyper-K

20 Mton · yr atm ν BG MC



"SK cut"

~2.3 events/Mton · yr

ε = 43 %

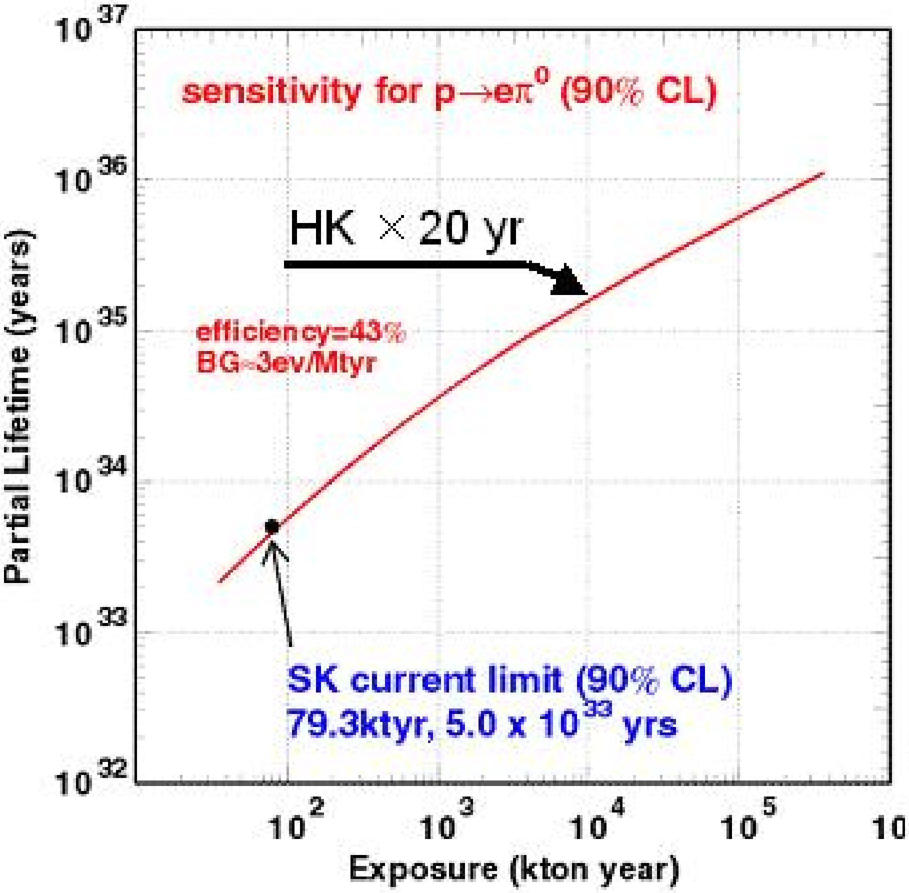
"tight cut"

~0.15 events/Mton · yr

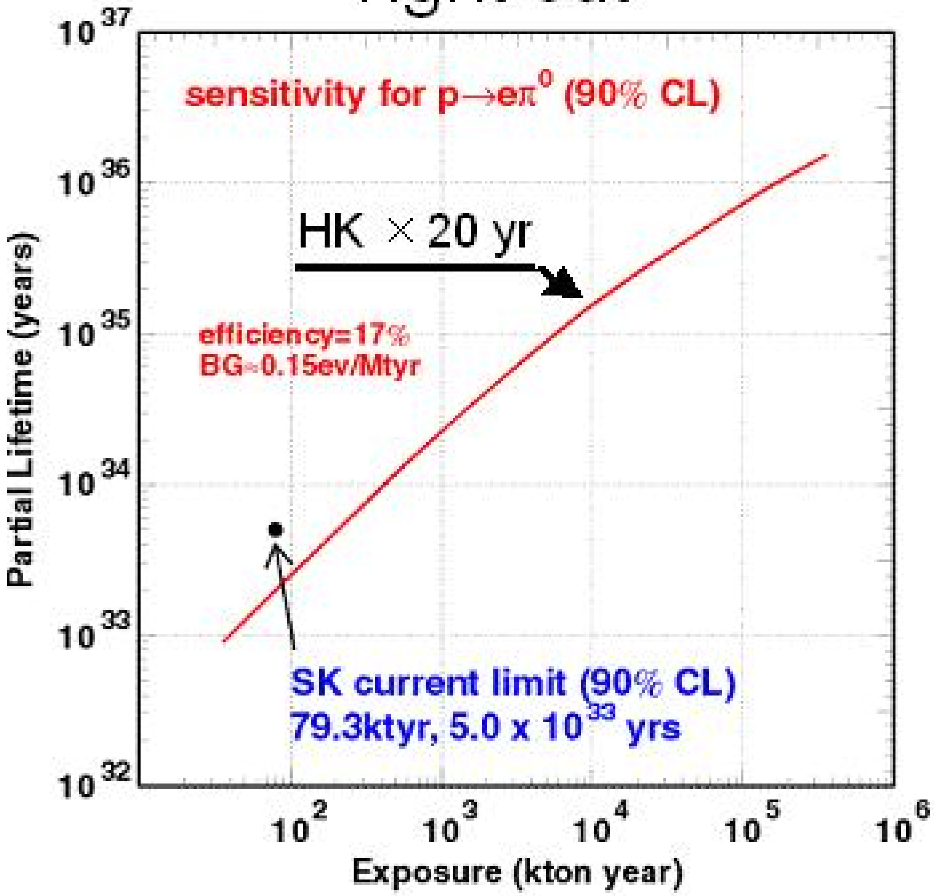
ε = 17 %

$p \rightarrow e^+\pi^0$ in Hyper-K : Sensitivity

SK cut



Tight cut

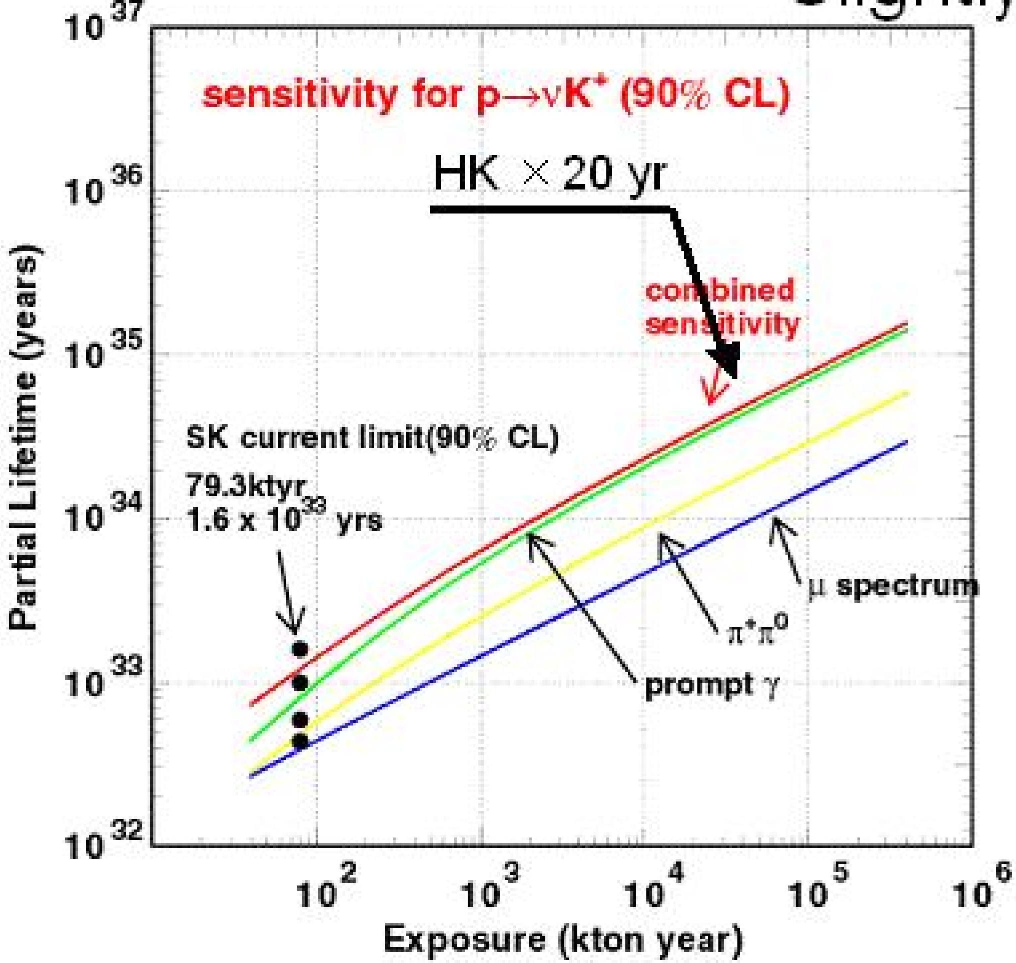


$\tau / B > 2 \times 10^{35}$ yr (Hyper-K 20yrs, 90%CL)

(×40 of the present limit)

$p \rightarrow \nu K^+$ in Hyper-K : Sensitivity

Slightly old cut

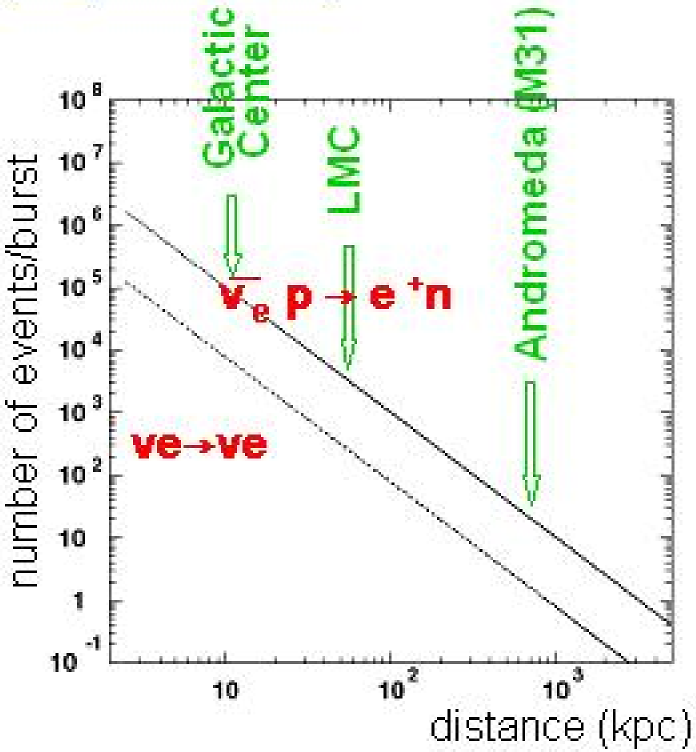


$\tau/B > 3 \times 10^{34}$ yr (Hyper-K 20yrs, 90%CL)

(×15 of the present limit)

Supernova Neutrino Observation with a 1 Mton (Fiducial Volume) Water Cherenkov

Supernova

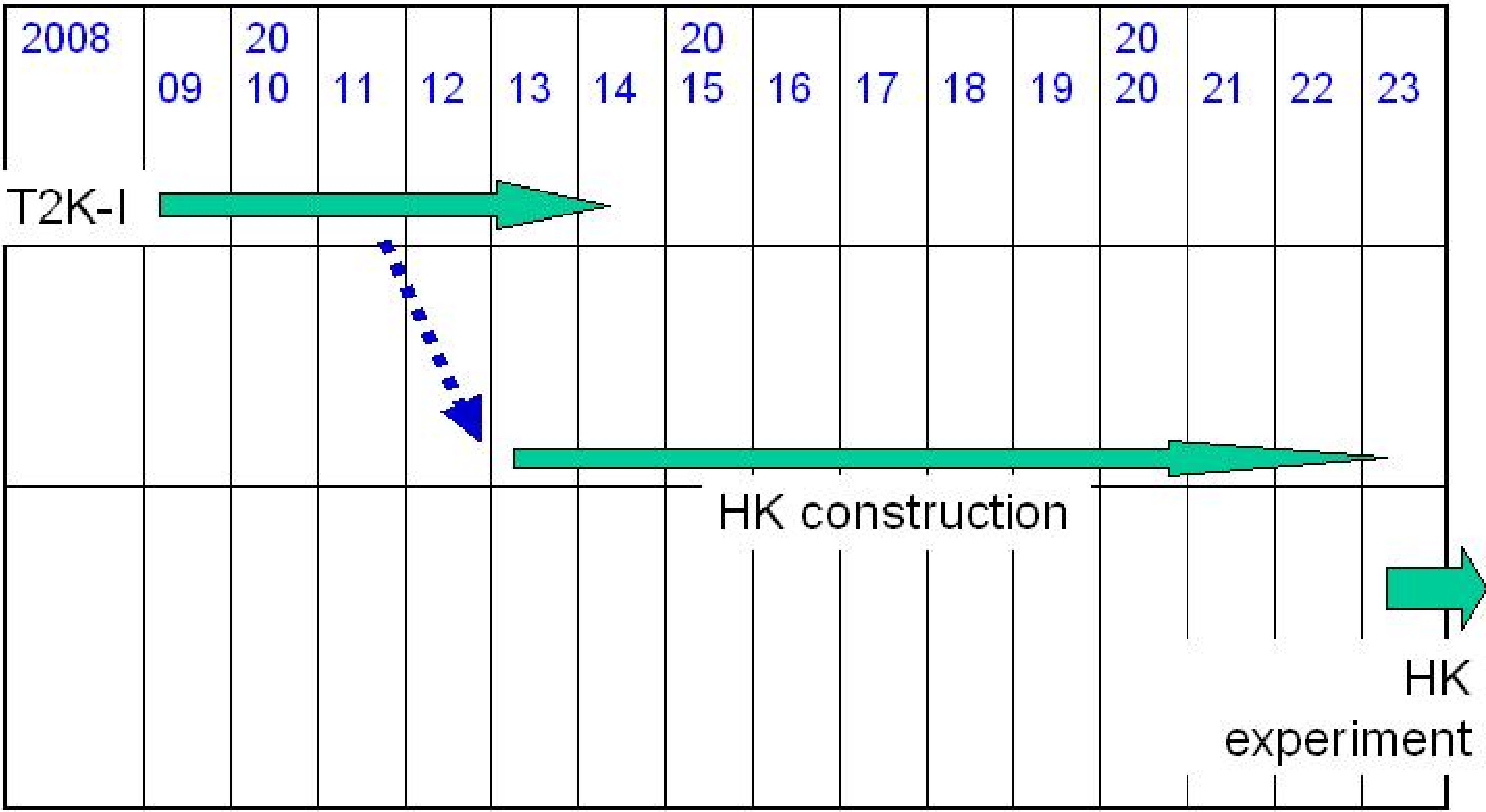


~100,000 $\bar{\nu}_e\, p \rightarrow e^+ n$ events
~8,000 νe→νe events
(for Galactic Center SN)

~20 events at Andromeda

Precise observation of explosion process and neutrino mass test <~1eV

Wished Construction Plan



Hypaer-Kamiokande Summary

- In the future long baseline neutrino oscillation experiments, measurements of θ_{13} and CPV are the most important targets. If θ_{13} turns out to be not too small, CPV measurements may be within the reach of super/beta beam experiments. For relatively short distance and low energy beam, a 1-Mton class giant water Cherenkov detector gives an opportunity to conduct a clean experiment.
- A giant water Cherenkov detector also gives an opportunity to search for nucleon decay. Moreover, once a type-2 supernova explosion occurs in our galaxy, explosion mechanisms as well as neutrino properties can be studied in detail
- Time scale of Hyper-Kamiokande project is rather remote, and its funding most probably depends on the outcome of T2K Phase-I. However, currently it is the only project with a clear road map envisioned.

7. Summary

Summary

- Super-Kamiokande's high-statistics solar neutrino observation favors the MSW LMA solution.
- Super-Kamiokande discovered atmospheric neutrino oscillation. The recent L/E analysis has demonstrated the first observation of the oscillation pattern.
- K2K confirmed the atmospheric neutrino oscillation with the artificial neutrino beam. Oscillation pattern has been observed.
- No proton decay signal observed so far.
- Future 1-Mton water Charenkov detecor, Hyper-Kamiokande, provides unique opportunities for neutrino physics and proton decay search.