Different Reactions in SNO

Charged-Current (CC) ν_e only

$\nu_e + d \rightarrow e^- + p + p$

Elastic Scattering (ES) ν_x, but enhanced for ν_e since $\sigma(\nu_e) \approx 7\ \sigma(\nu_{\mu\tau})$

$\nu_x + e^- \rightarrow \nu_x + e^-$

Neutral-Current (NC) all ν_x

$\nu_x + d \rightarrow \nu_x + n + p$

SNO Run Sequence

I. Pure D_2O	CC, ES some NC n+d “ t+ γ ... (E_γ= 6.25 MeV, ε_n~24%)
II. D_2O+NaCl (added salt)	CC, ES enhanced NC n+^{35}Cl “ ^{36}Cl+ ∑γ ($E_{\sum\gamma}$= 8.6 MeV, ε_n~45% above threshold)
III. D_2O+NCDs (^{3}He proportional counters)	Concurrent CC, NC, ES n+^{3}He “ p+t “ event by event separation (ε_n~37%)

First Solar Neutrino Results from SNO

Solar Angle Distribution

$T_{eff} \geq 6.75$ MeV and $R_{fit} \leq 550$ cm

Energy Spectrum

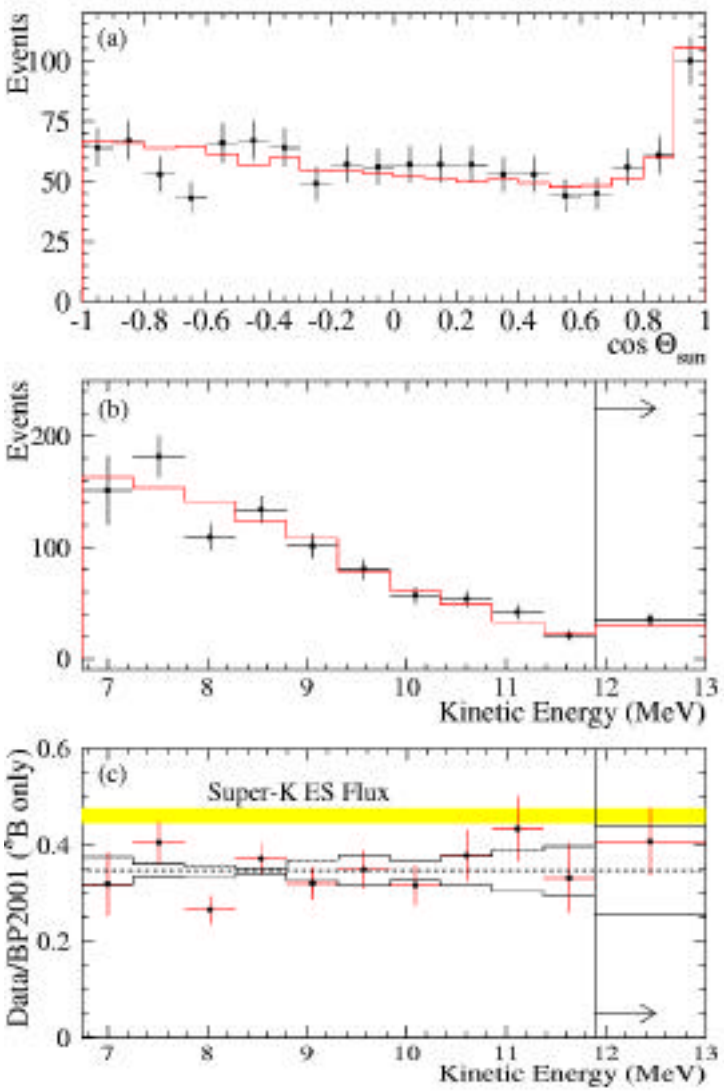
$T_{eff} \geq 6.75$ MeV and $R_{fit} \leq 550$ cm

derived from fit without constraint on ^{8}B shape

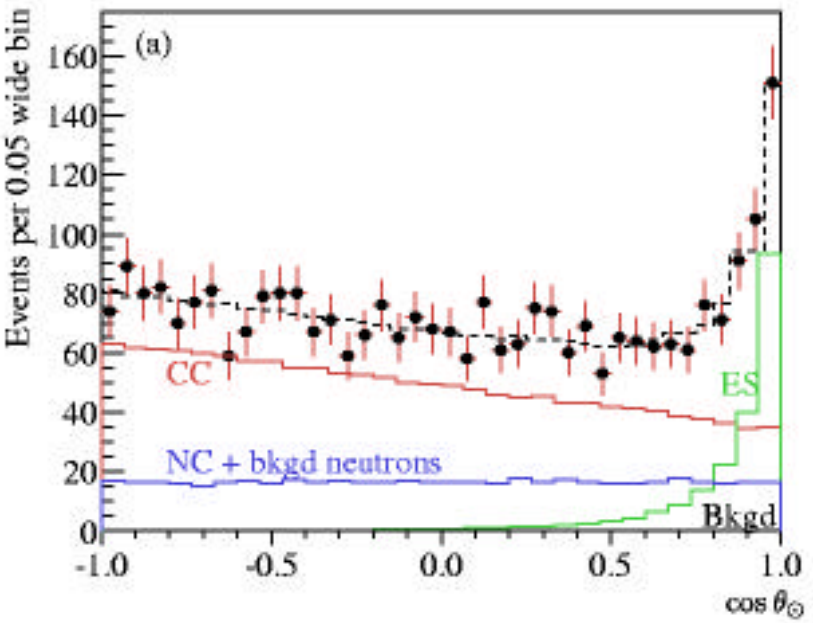
CC Spectrum Normalized to Predicted ^{8}B Spectrum

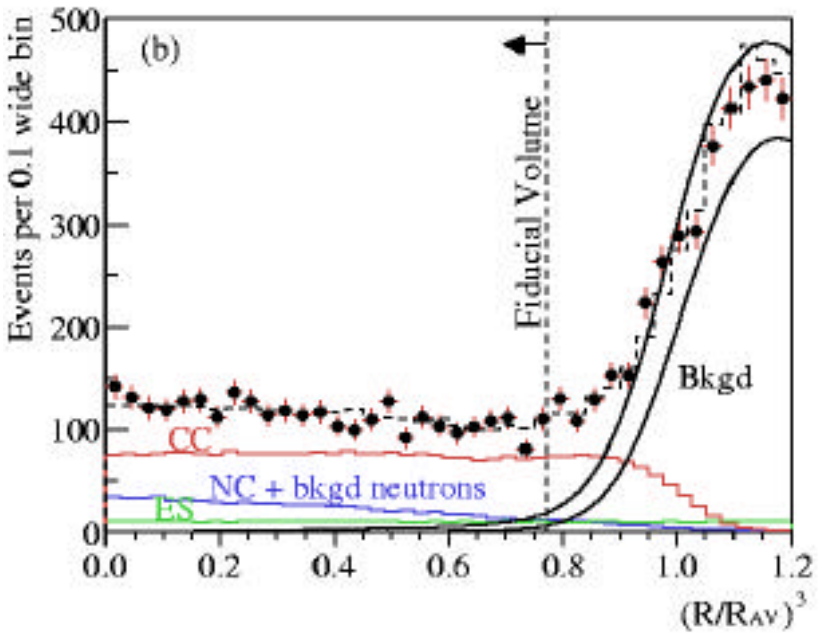
$T_{eff} \geq 6.75$ MeV and $R_{fit} \leq 550$ cm

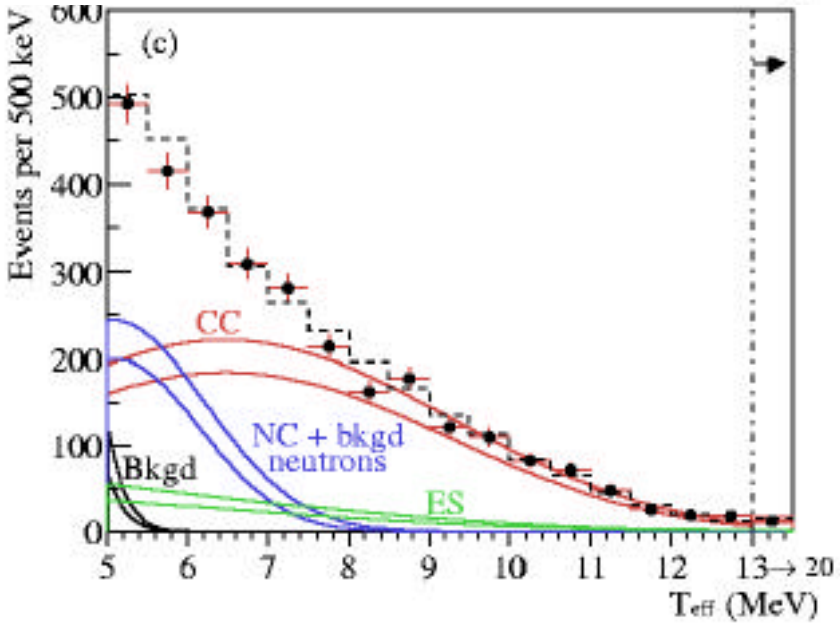
With correlated systematic errors



New Solar Neutrino Results from SNO







Fluxes from fit:

$$\phi_{\mathrm{CC}}^{\mathrm{SNO}} = 1.76^{+0.06}_{-0.05}(\mathrm{stat.})^{+0.09}_{-0.09}\ (\mathrm{syst.})$$

$$\phi_{\mathrm{ES}}^{\mathrm{SNO}} = 2.39^{+0.24}_{-0.23}(\mathrm{stat.})^{+0.12}_{-0.12}\ (\mathrm{syst.})$$

$$\phi_{\mathrm{NC}}^{\mathrm{SNO}} = 5.09^{+0.44}_{-0.43}(\mathrm{stat.})^{+0.46}_{-0.43}\ (\mathrm{syst.}).$$

$$10^6\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$$

Flavour Composition of ^{8}B Flux

φ^{SNO}_{CC} = 1.76 ± 0.06 ± 0.09

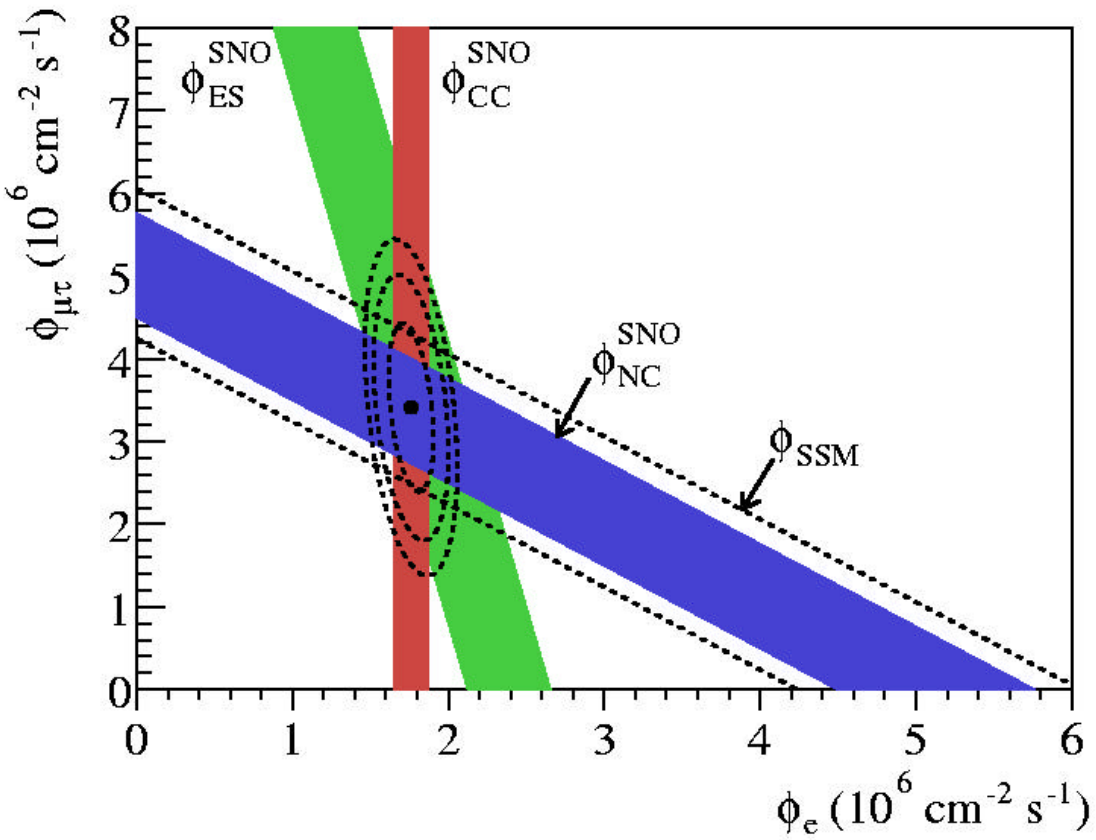
φ^{SNO}_{ES} = 2.39 ± 0.24 ± 0.12

φ^{SK}_{ES} = 2.32 ± 0.09

φ^{SNO}_{NC} = 5.09 ± 0.44 ± 0.45

φ_e = 1.76 ± 0.05 ± 0.09

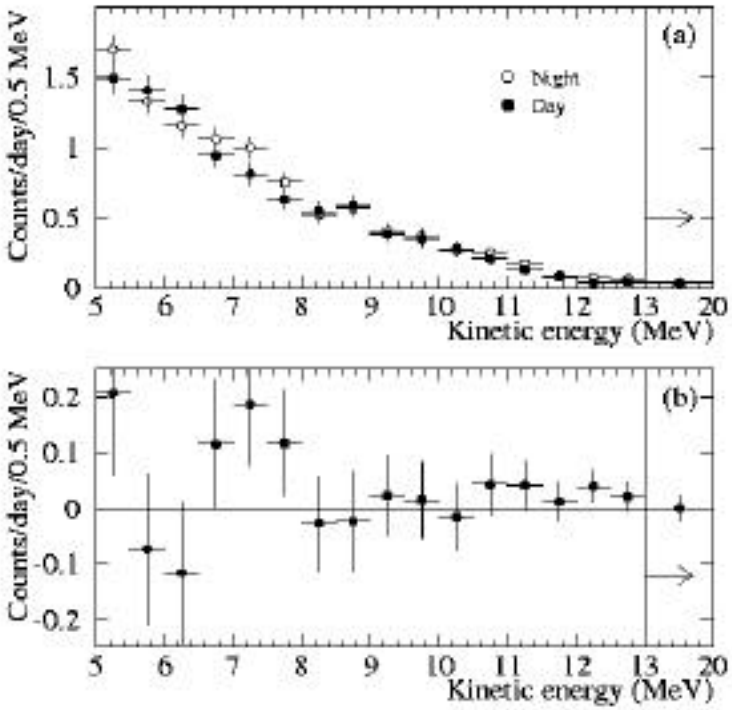
$\varphi_{\mu,\tau}$ = 3.41 ± 0.45 ± 0.46



Evidence for appearance of $\nu_e \rightarrow \nu_{\mu\tau}$ at significance of 5.6σ

(All previous evidence for disappearance $\nu_e \rightarrow$?)

SNO Day-Night Effect

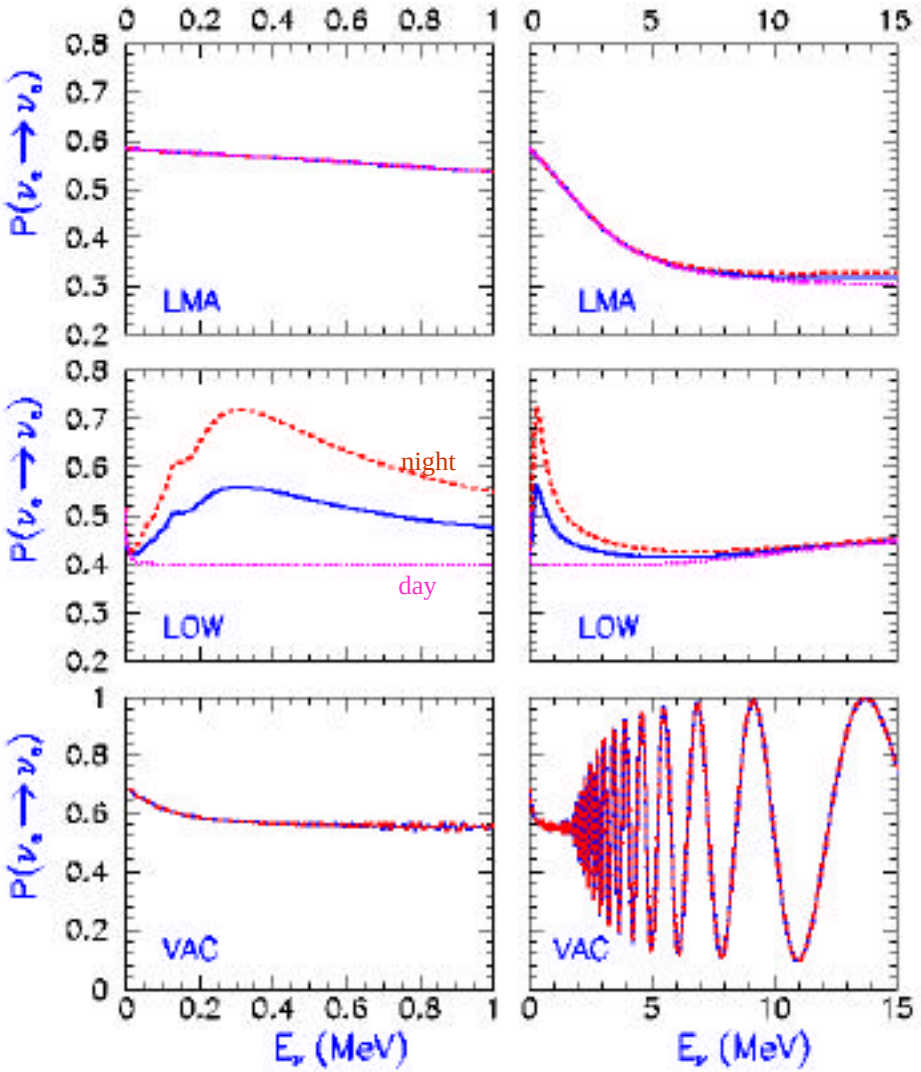


Signal	Day-Night Asymmetry (%)
CC	$+ 14.0 \pm 6.3 \pm 1.4$
ES	$- 17.4 \pm 19.5 \pm 2.3$
NC	$- 20.4 \pm 16.9 \pm 2.4$

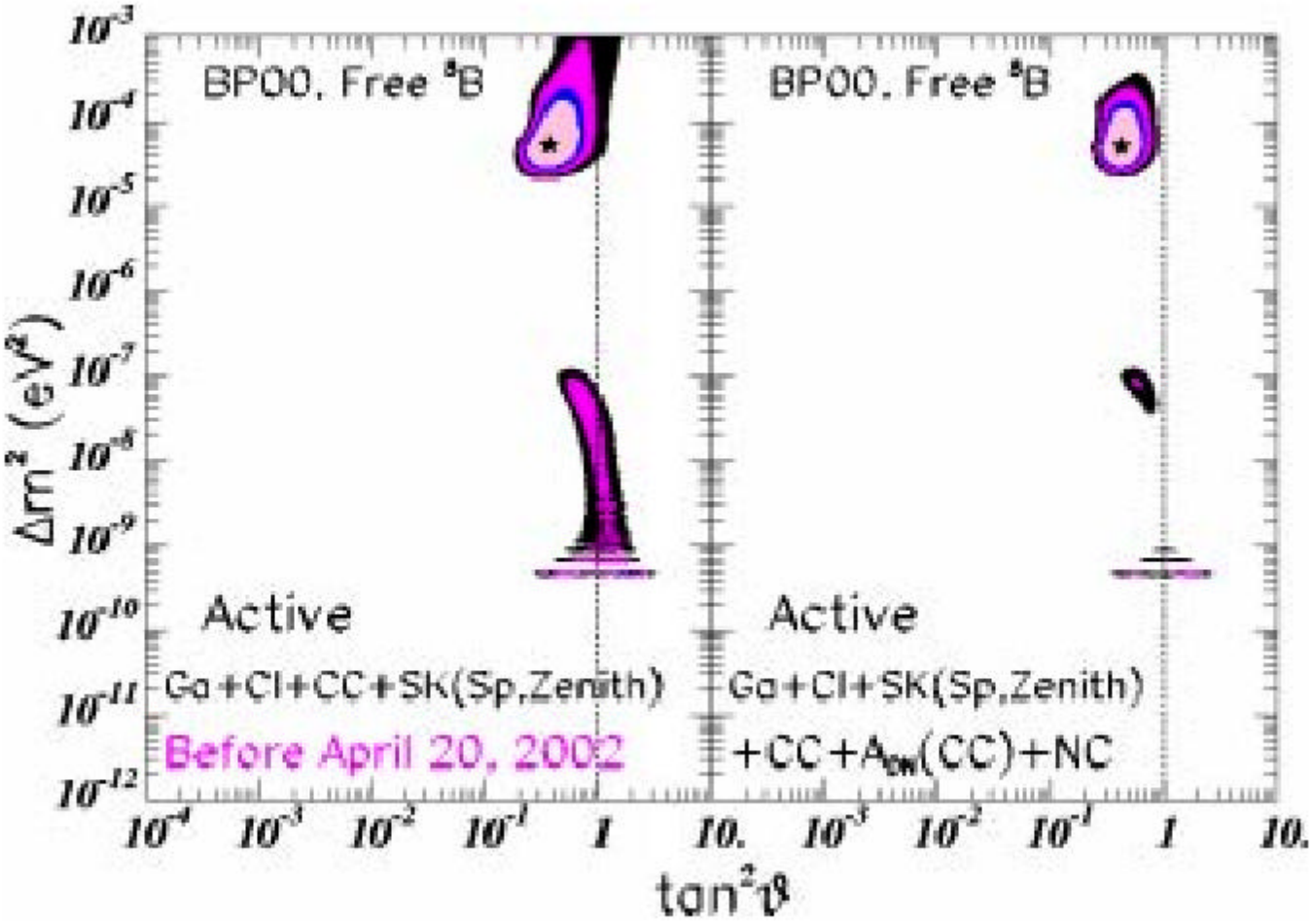
Supports MSW LMA oscillation solution

Allowed Oscillation Solutions

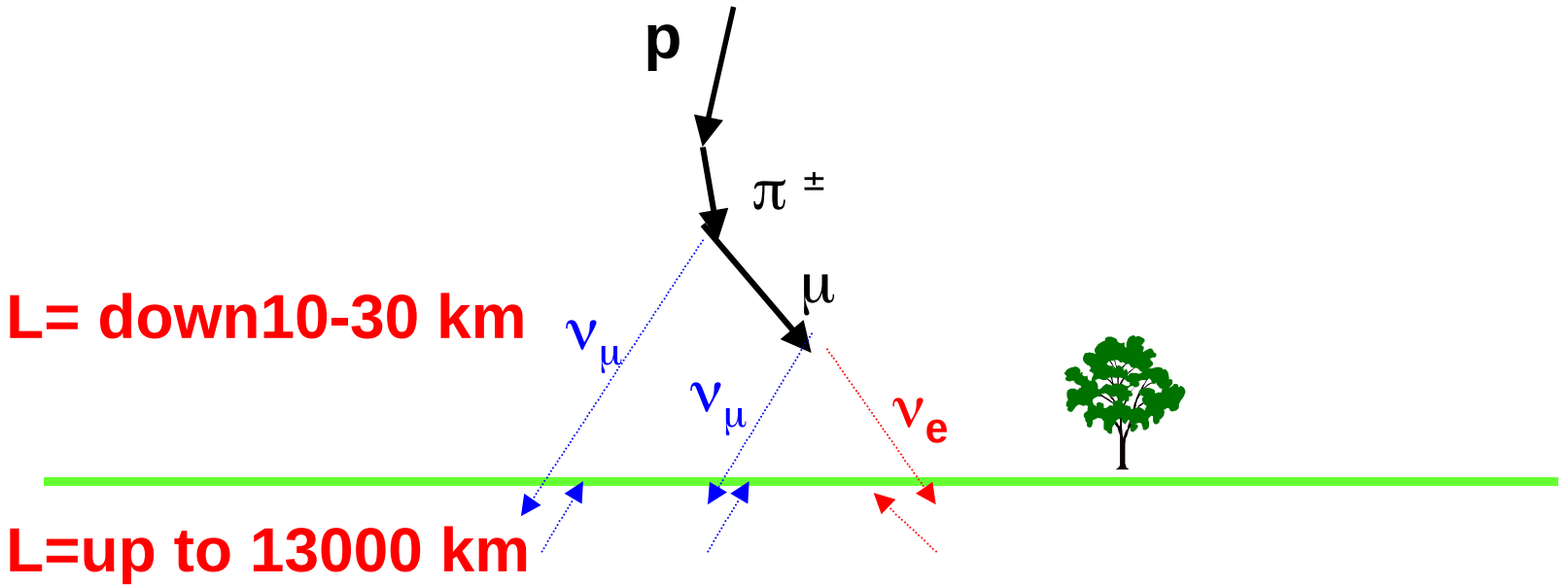
Solution	Δm^2	$\tan^2(\theta)$	$f_{B,\mathrm{best}}$	χ^2_{min}	g.o.f.
LMA	5.0×10^{-5}	4.2×10^{-1}	1.07	45.5	49%
LOW	7.9×10^{-8}	6.1×10^{-1}	0.91	54.3	19%
VAC	4.6×10^{-10}	1.8×10^{0}	0.77	52.0	25%
SMA	5.0×10^{-6}	1.5×10^{-3}	0.89	62.7	5.1%
Just So^2	5.8×10^{-12}	1.0×10^{0}	0.46	86.3	$\sim$ 0%
Sterile VAC	4.6×10^{-10}	2.3×10^{0}	0.81	81.6	$\sim$ 0%
Sterile Just So^2	5.8×10^{-12}	1.0×10^{0}	0.46	87.1	$\sim$ 0%
Sterile SMA	3.7×10^{-6}	4.7×10^{-4}	0.55	89.3	$\sim$ 0%



Effect of SNO Data on Allowed Oscillations



Atmospheric neutrinos



Ratio : $\frac{\nu_\mu + \bar{\nu}_\mu}{\nu_e + \bar{\nu}_e}$ = ~ **2** at low energy, higher at high energies (less μ decay)

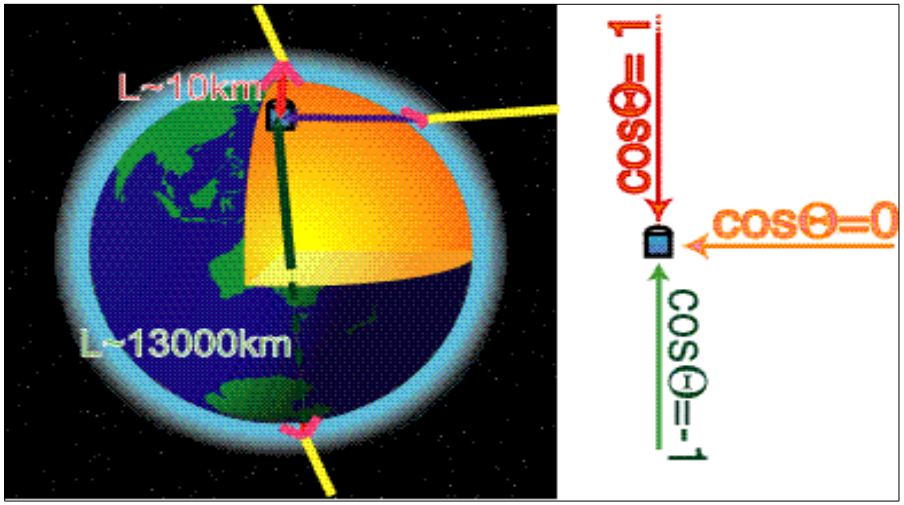
error in absolute flux ~20%, but ν_μ / ν_e ratio~5%

Neutrino oscillations :

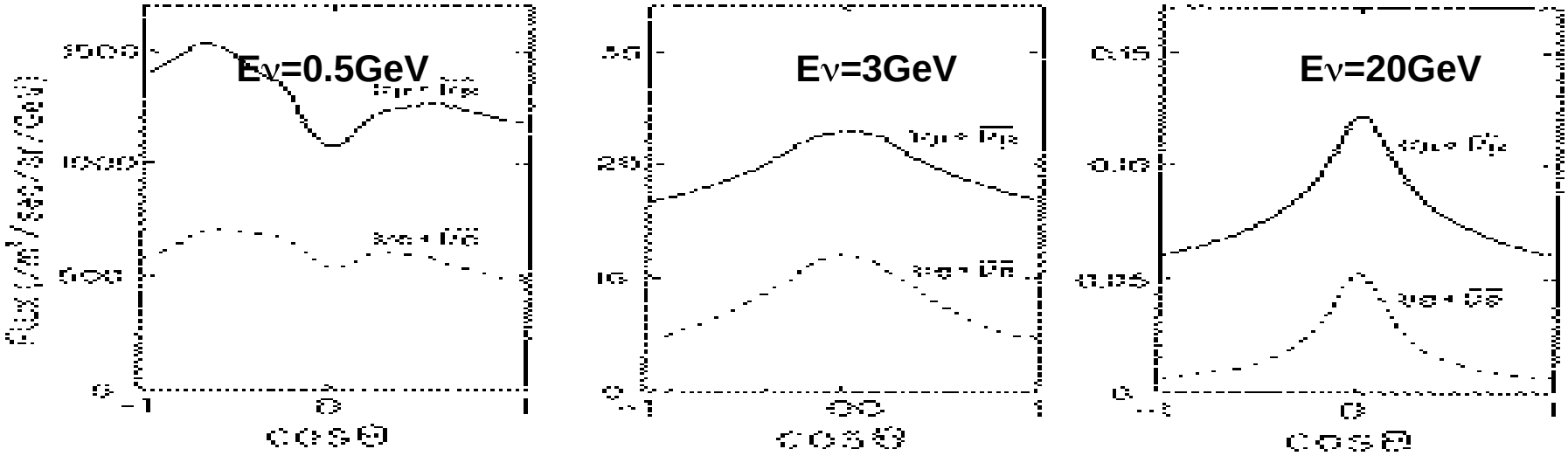
$$R = \left(\frac{\nu_\mu + \bar{\nu}_\mu}{\nu_e + \bar{\nu}_e} \right)_{\text{data}} \Big/ \left(\frac{\nu_\mu + \bar{\nu}_\mu}{\nu_e + \bar{\nu}_e} \right)_{\text{MC}} \neq 1$$

- measured ~ 0.6 by IMB and Kamiokande

Zenith angle distribution(1D)



Vary oscillation length L
by varying zenith angle Θ

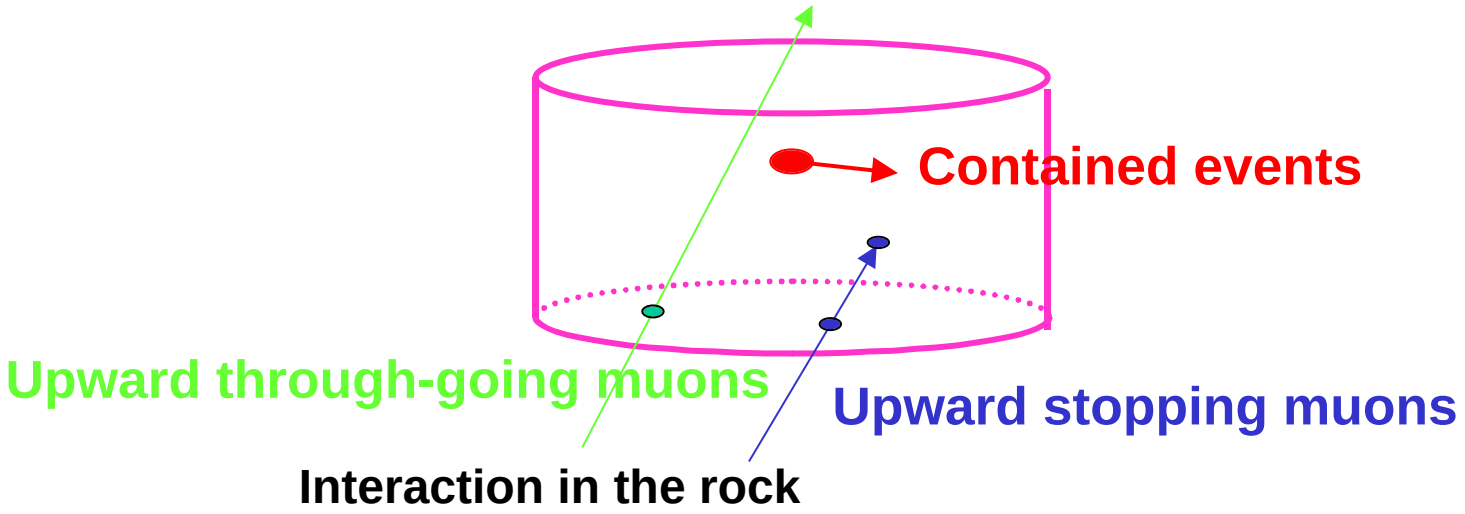


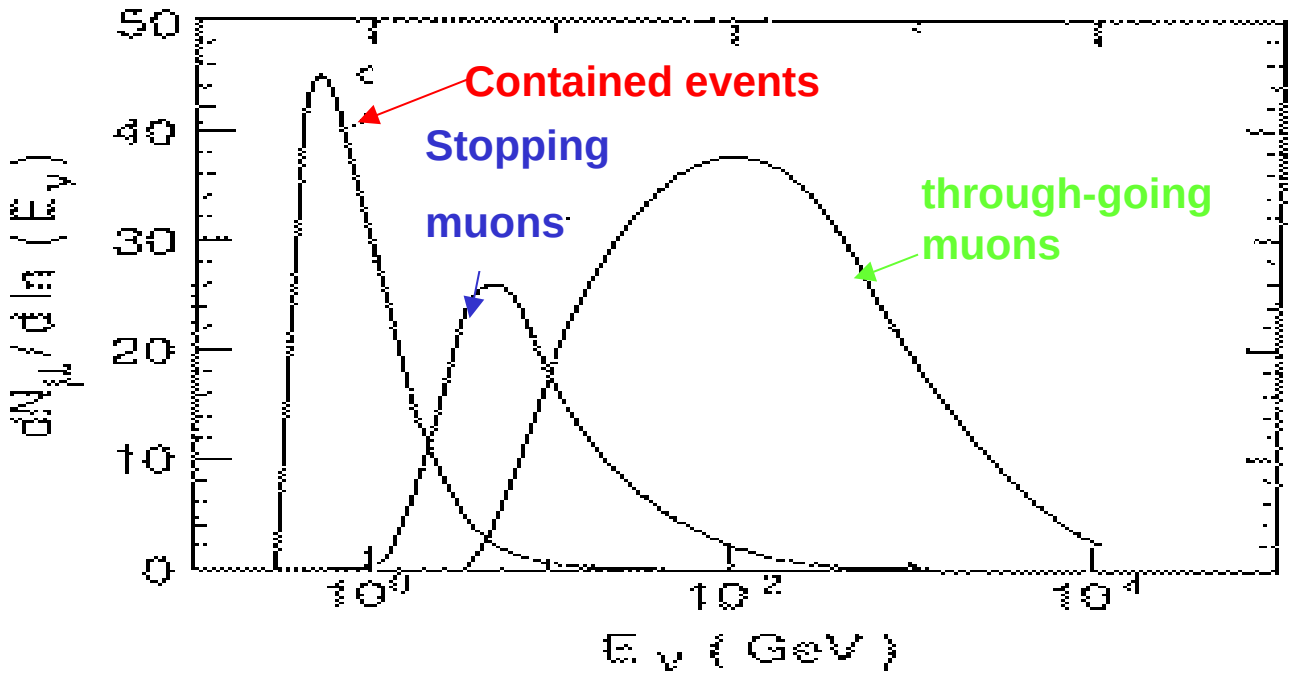
For E_ν > a few GeV,

Upward / downward = 1 (within a few %)

Up/Down asymmetry for neutrino oscillations

Event Types in Super-Kamiokande





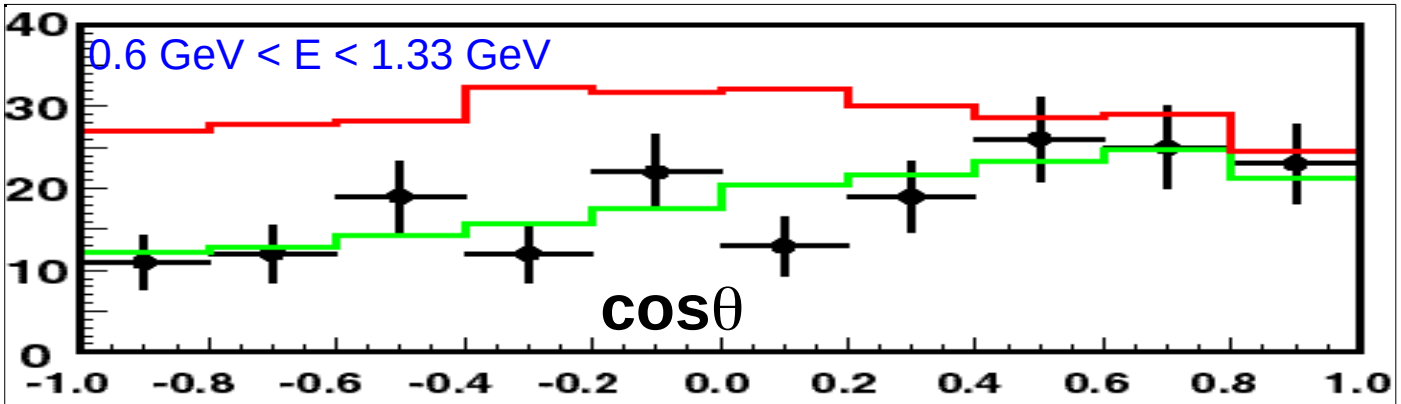
SK Multi-ring event analysis

Zenith angle distributions

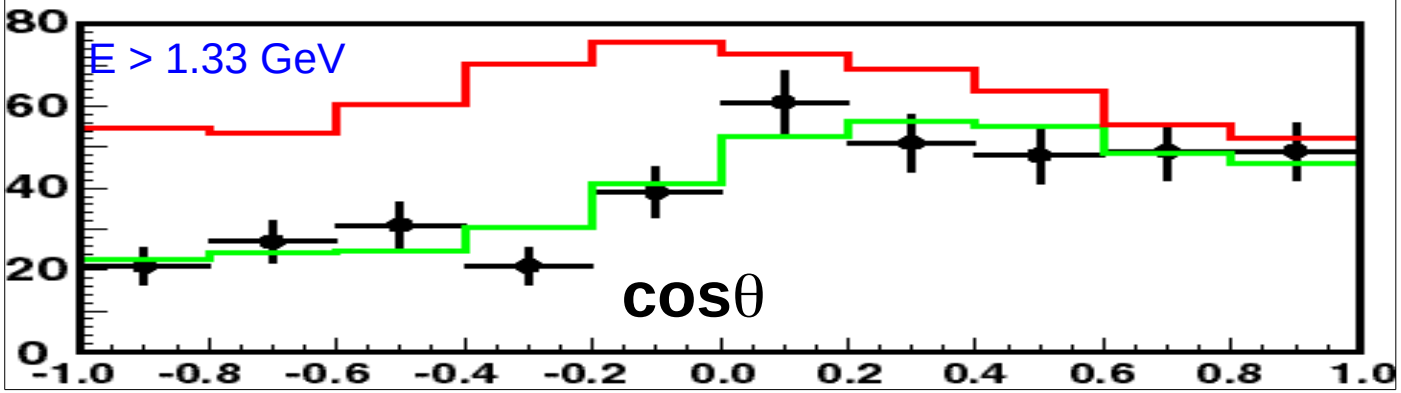
No oscillation

Best fit ($\Delta m^2 = 2.0 \times 10^{-3} eV^2$, $\sin^2 2\theta = 1.00$)

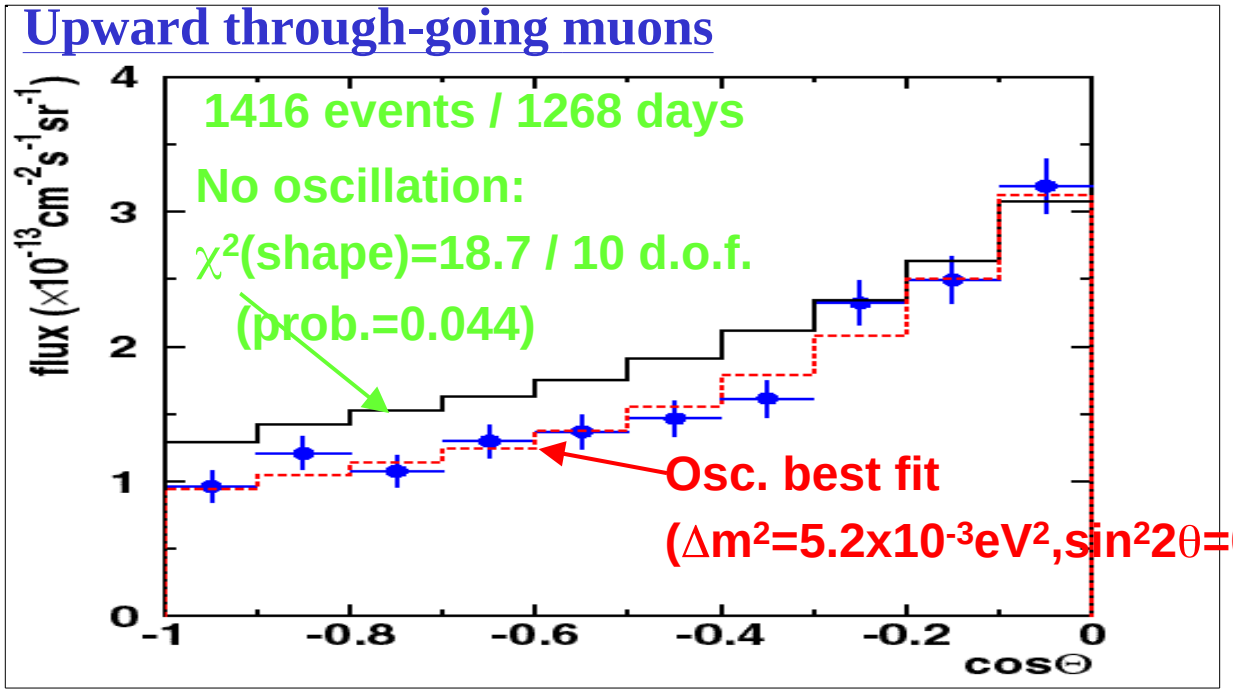
Sub-GeV multi-ring μ-like sample

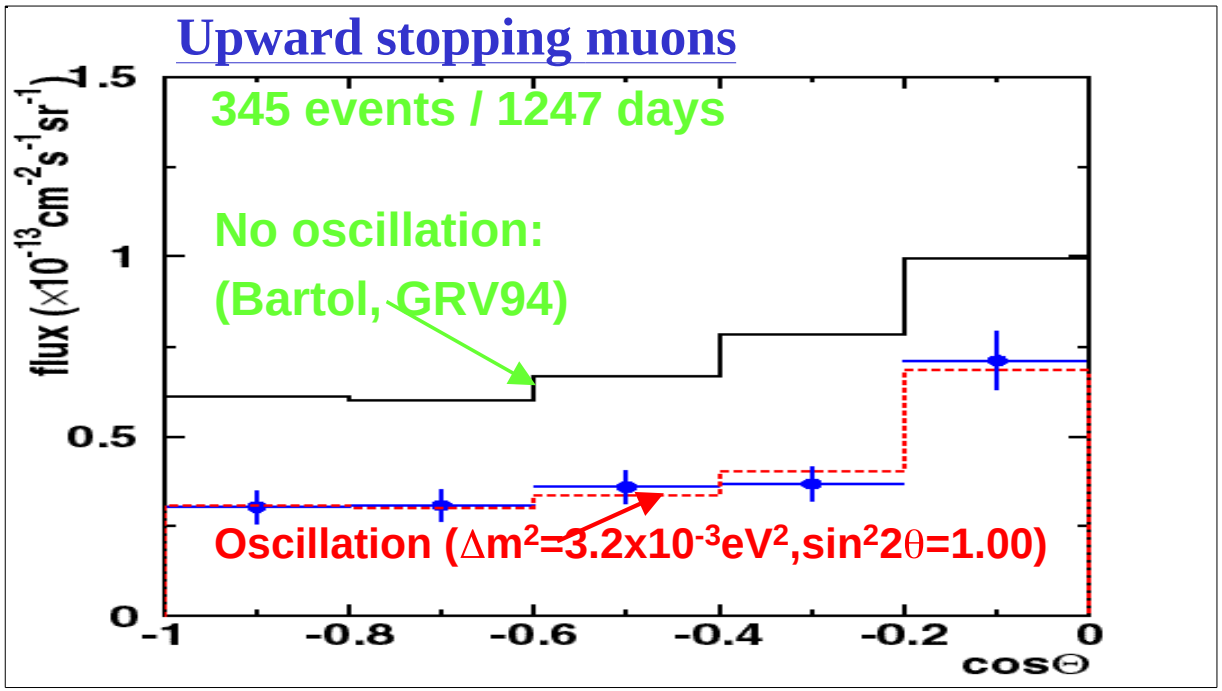


Multi-GeV multi-ring μ-like sample



SK Data

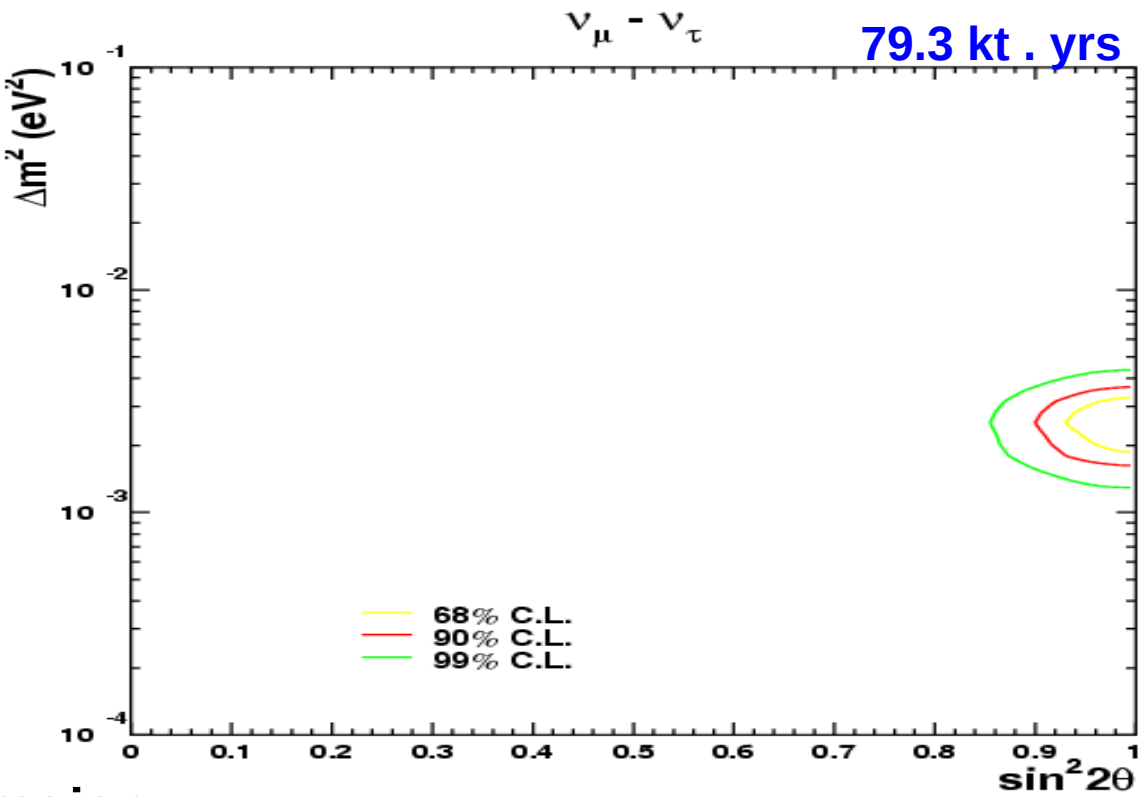




R = 0.65 ± 0.04 ± 0.09

<< 1 clear oscillations

Super-K Allowed Region (Global fit all event types)



Within physical region;

χ^2 minimum = 157.5/170 dof

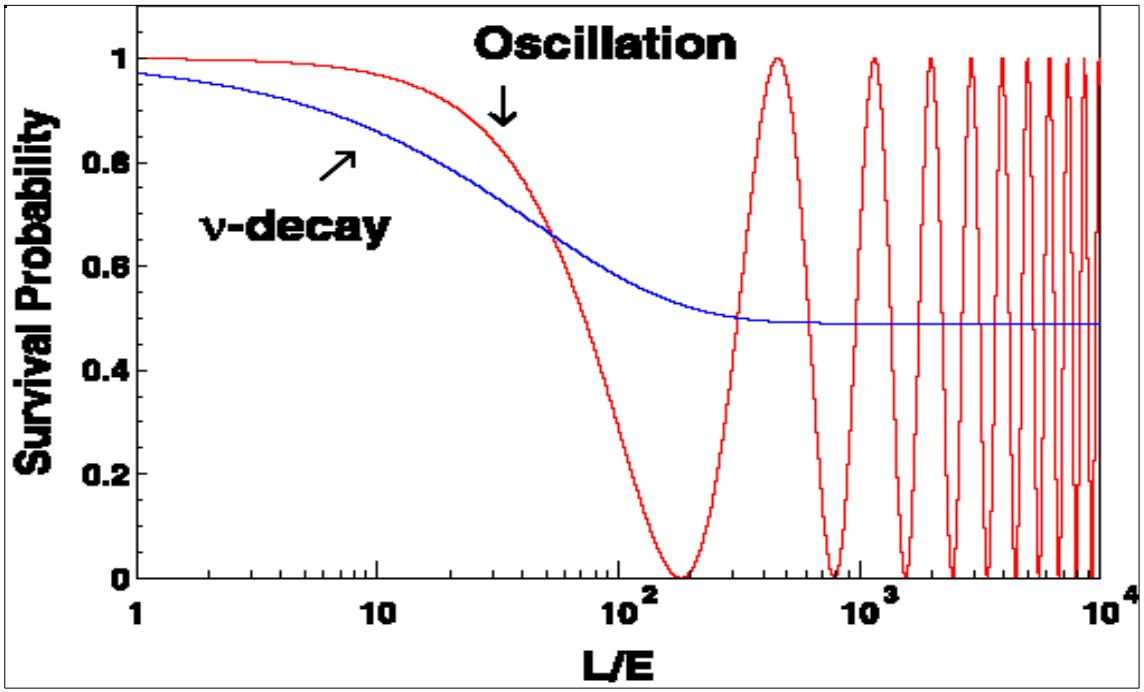
at $\sin^2 2\theta = 1.0$, $\Delta m^2 = 2.5 \times 10^{-3}$ eV^2

With unphysical region;

χ^2 minimumu = 157.4/170 dof

at $\sin^2 2\theta = 1.01$, $\Delta m^2 = 2.5 \times 10^{-3}$ eV^2

No Oscillations but Neutrino Decay?



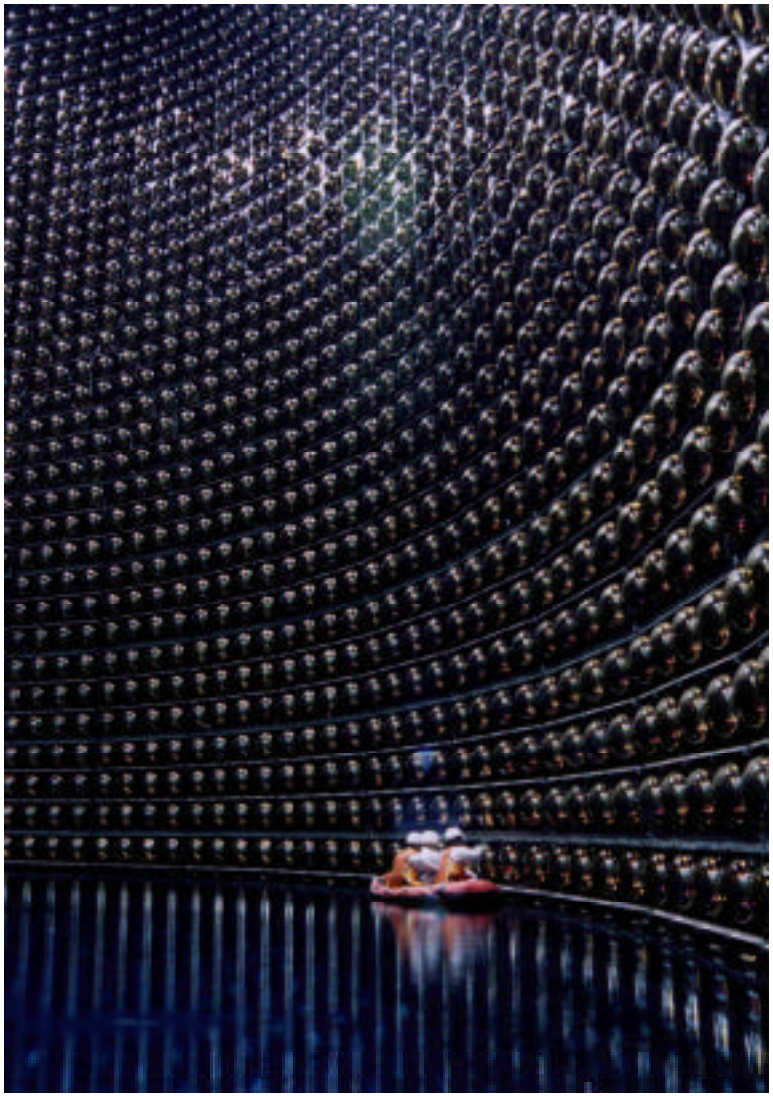
Fit with neutrino decay χ^2 = 221/153 dof

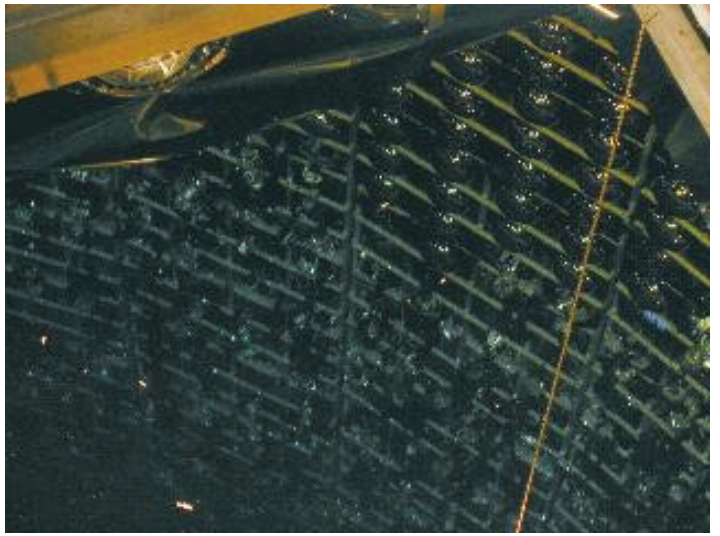
oscillations = 147/153 clearly favoured

(Also sterile neutrinos disfavoured by π^0 data)

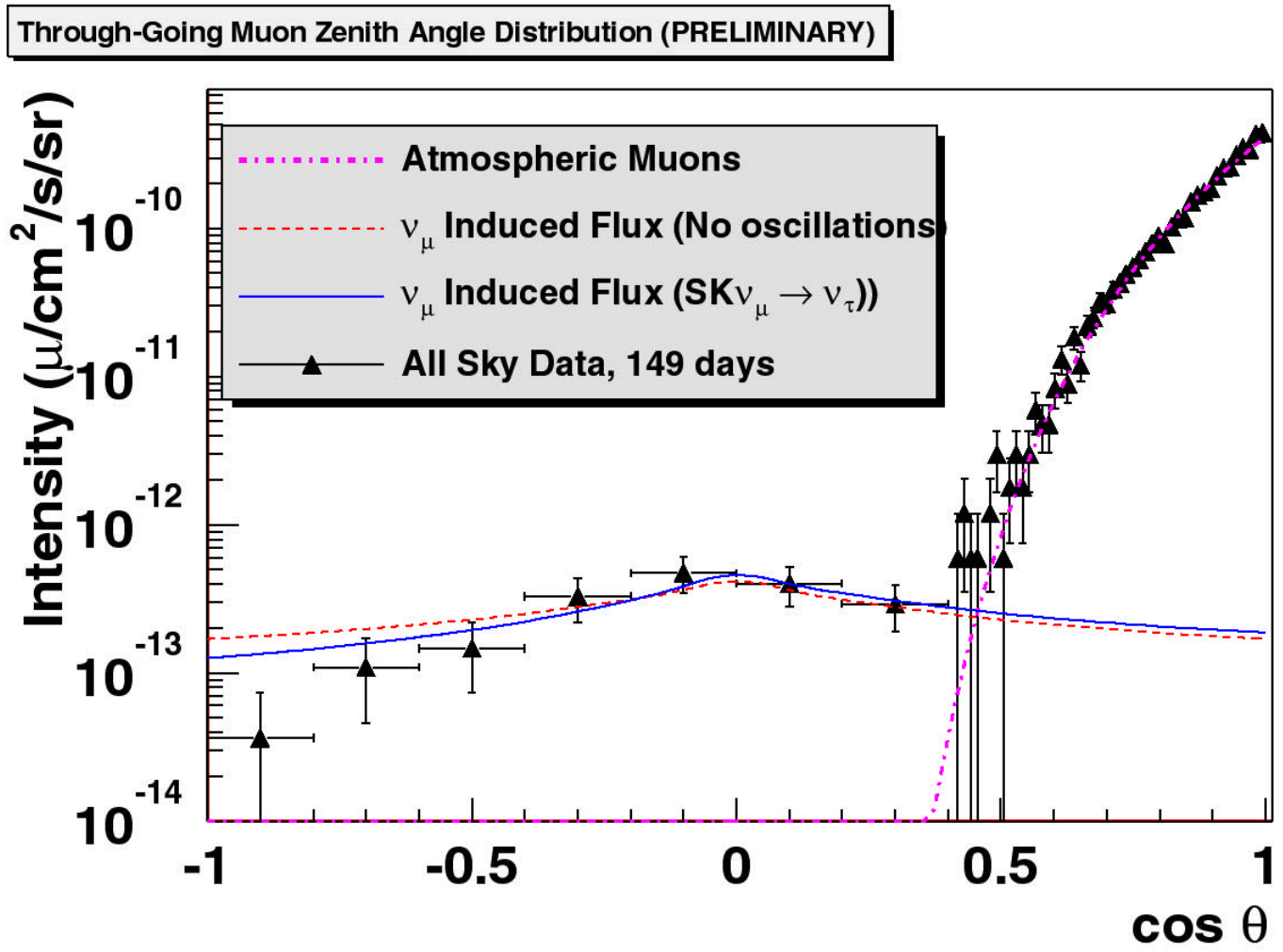
Super-Kamiokande Damaged 2001

80% of photomultipliers broken, will be repaired by Nov 2002



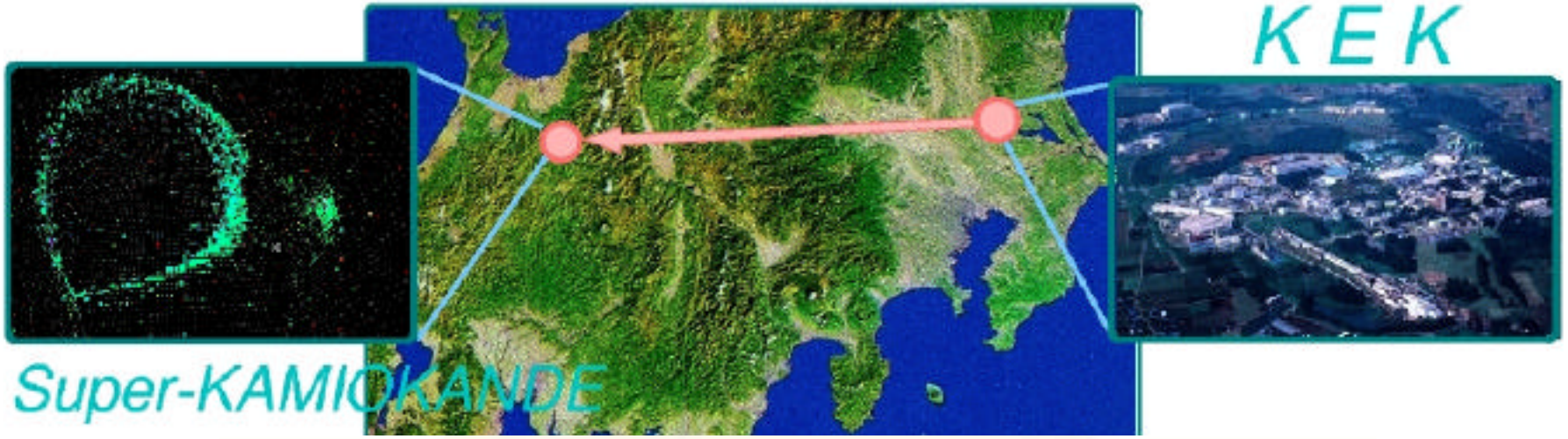


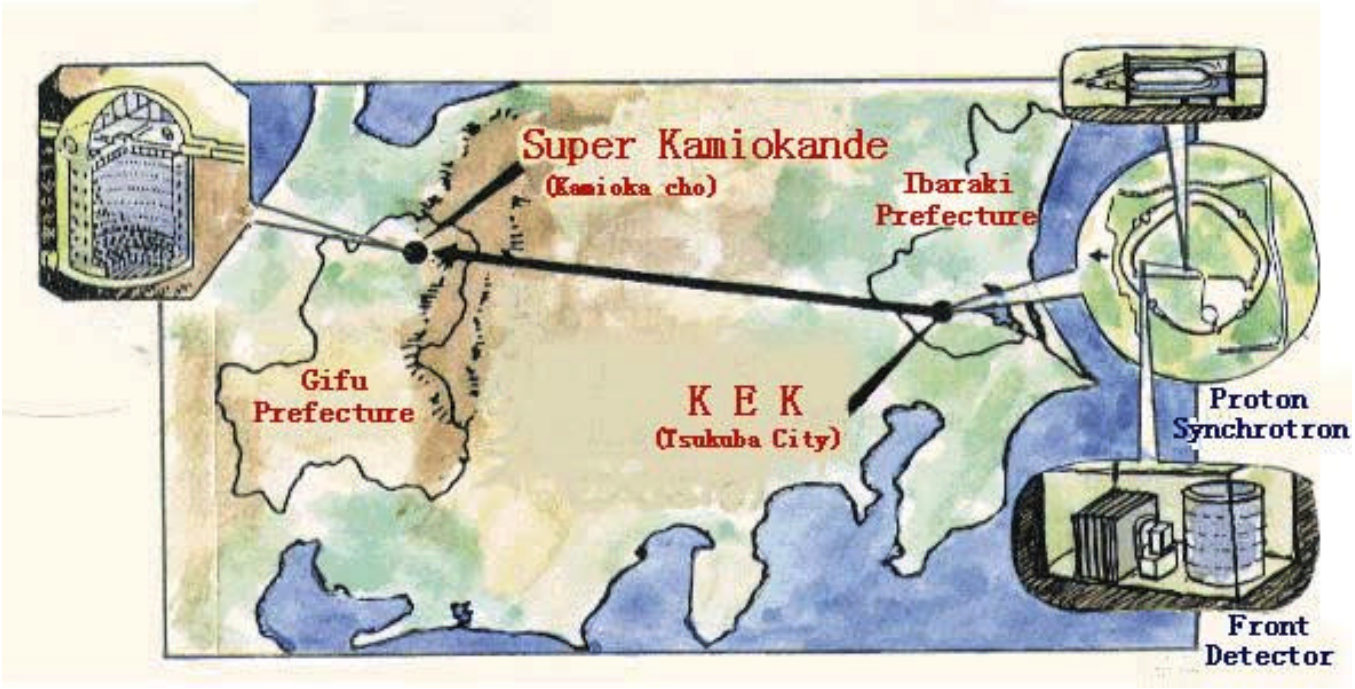
SNO Atmospheric Neutrino Analysis



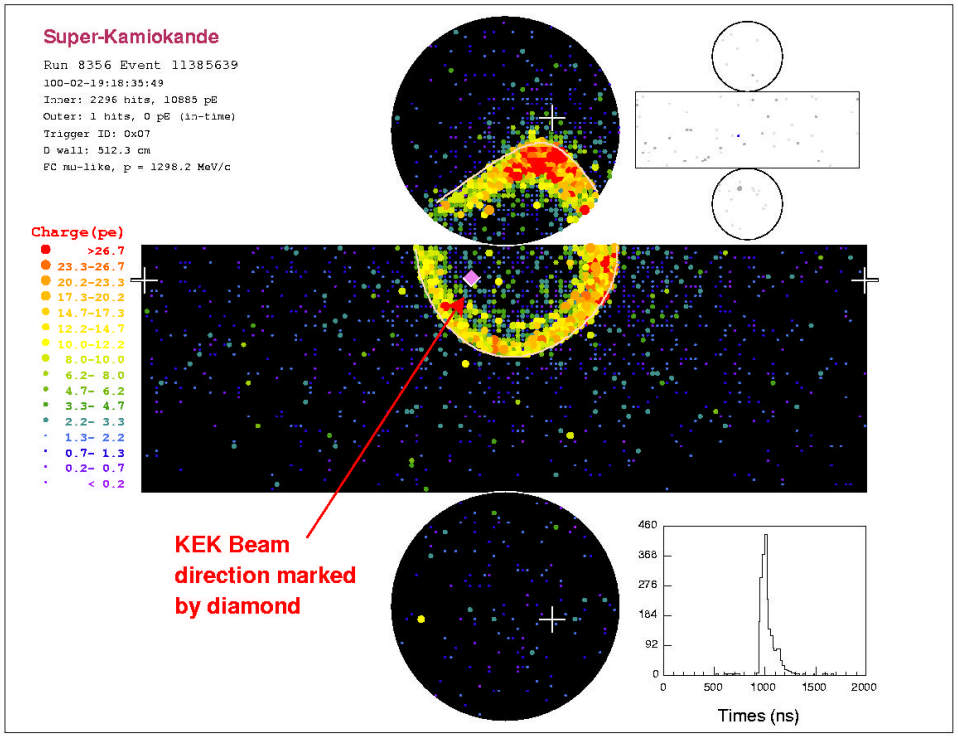
So far only preliminary, no conclusion …..

K2K


KEK
Super-KAMIOKANDE


Super Kamiokande
(Kamioka cho)
Ibaraki
Prefecture
Gifu
Prefecture
K E K
(Tsukuba City)
Proton
Synchrotron
Front
Detector

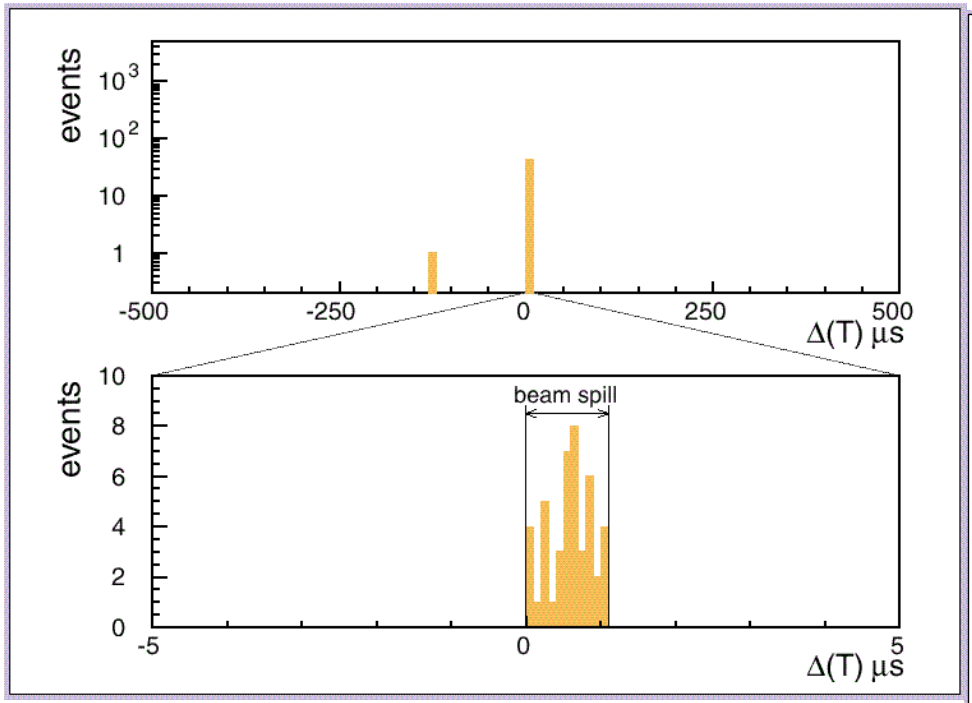
K2K Event

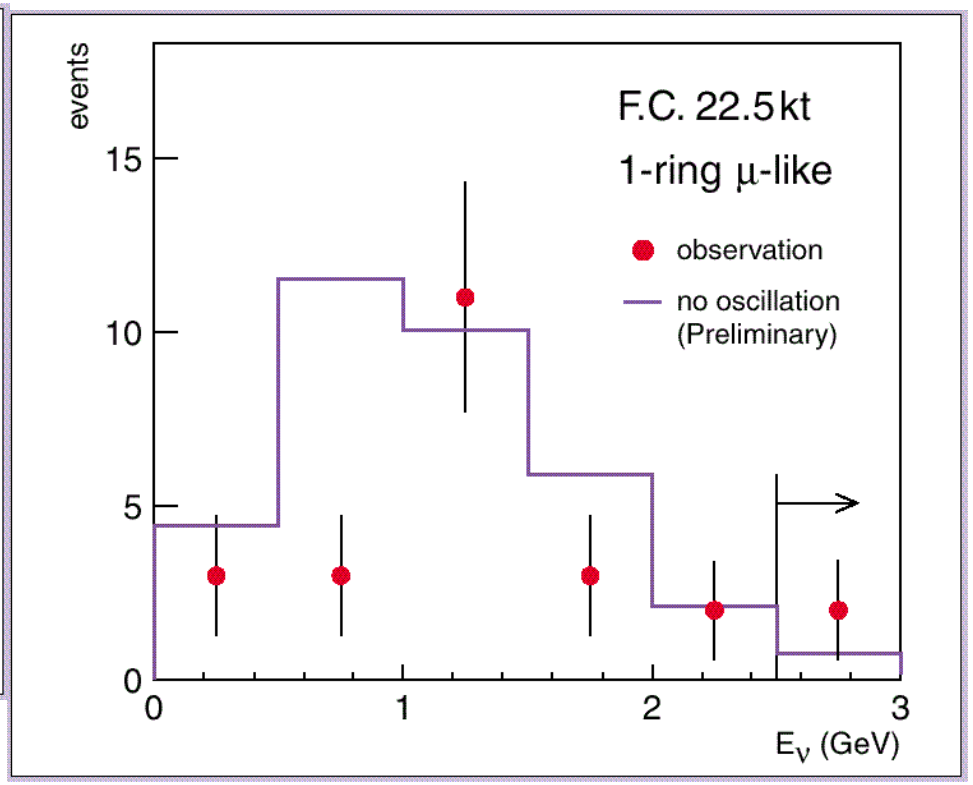


K2K event selection at SK

- No pre-activity in 30μsec
- p.e. in 300ns window > 200
- OD Nhit in largetst cluster<10
- Deposite Energy > 30MeV
- Fiducial cut (distance from wall>2m)

K2K Data


events
10^3
10^2
10
1
-500
-250
0
250
500
Δ(T) μs
events
10
8
6
4
2
0
beam spill
-5
0
5
Δ(T) μs

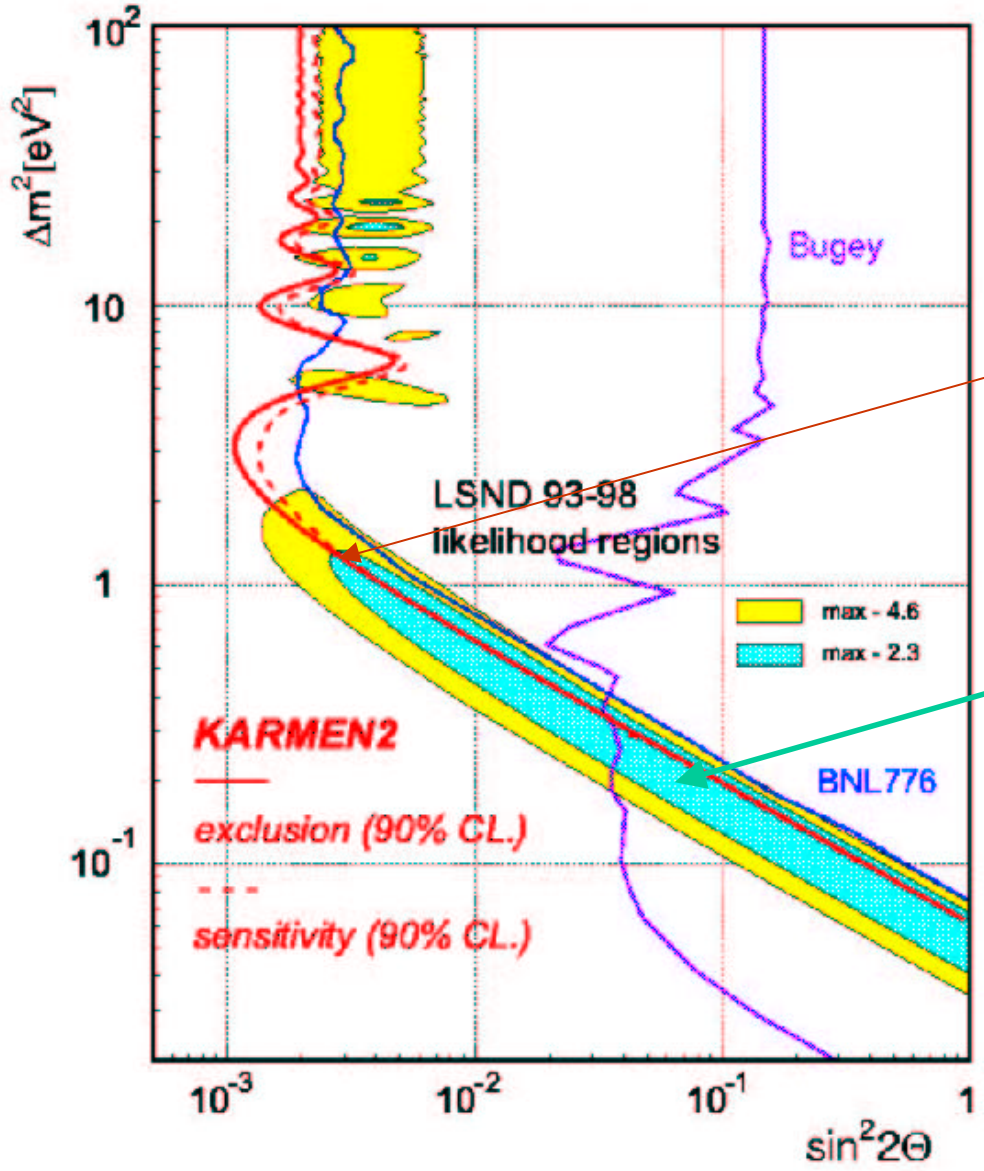

events
15
10
5
0
F.C. 22.5kt
1-ring μ-like
observation
no oscillation
(Preliminary)
0
1
2
3
E_ν (GeV)

K2K Observed vs Expected

	Obs.	No Ocsi.
FC 22.5kt	28	$37.8\ ^{+3.5}_{-3.8}$
1-ring	15	22.7 ± 3.2
μ-like	14	20.8 ± 3.2
e-like	1	1.9 ± 0.4
multi ring	13	15.1 ± 2.5

K2K consistent with Super-Kamiokande

Reactor and Accelerator Experiments



Excluded region from Karmen

Allowed region from LSND