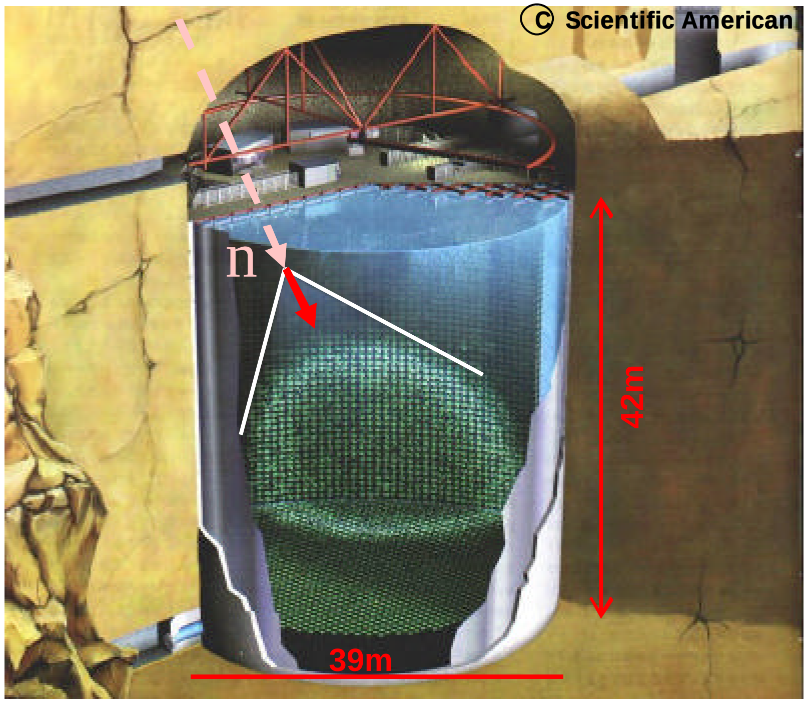
Atmospheric n in Super- Kamiokande-I and Accelerator n in K2K-I

For the Super-Kamiokande and K2K collaboration

Univ. of Tokyo, Kamioka Observatory
Masato Shiozawa

History of Super- Kamiokande and K2K

- 1996.4 Start data taking (SK- I)



Water Cherenkov detector

- 1000 m underground
- 50,000 ton
  (22,500 ton fid.)
- 11,146 20 inch PMTs
- 1,885 anti-counter PMTs

SK- I
~5years

- 1999.3 K2K start

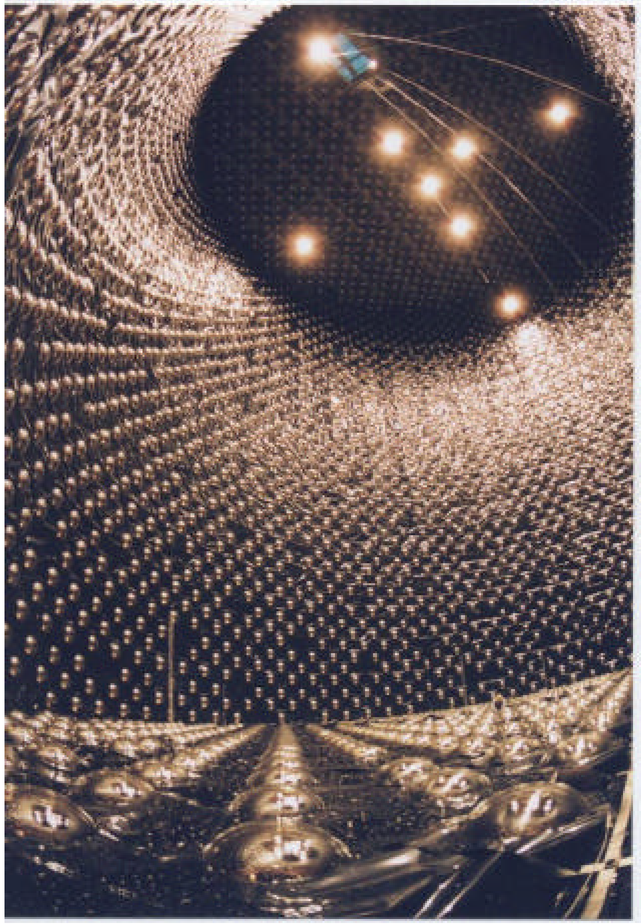
- 2001.7 Stop data taking for detector upgrade
- 2001.11 Accident (6777 inner PMTs, 1100 outer PMTs were destroyed)
  partial reconstruction of the detector

SK- II
K2K-II

- 2002.10 resume data taking (SK- II)
- 2002.12 resume K2K beam (K2K-II)

SK is back !

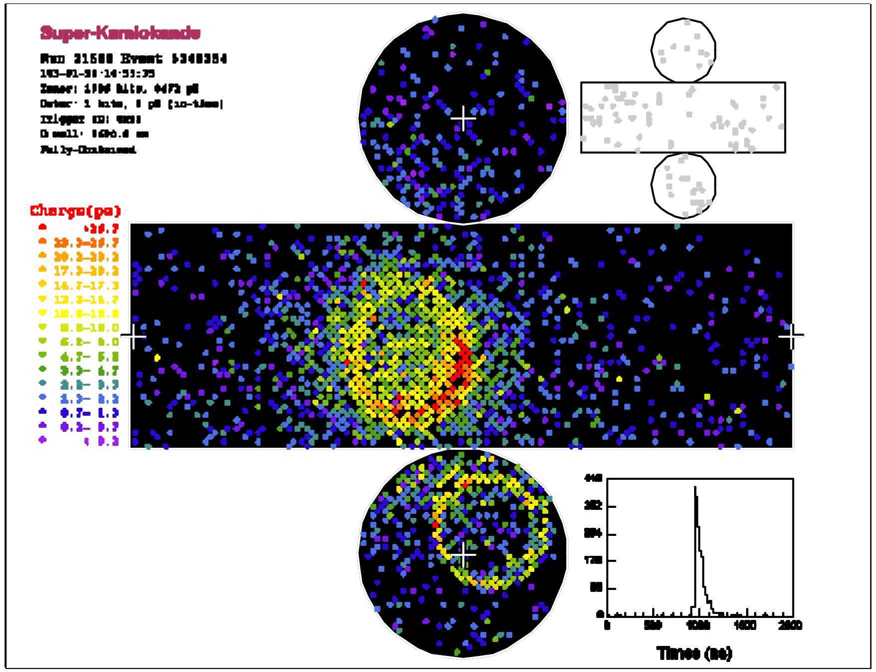
Full water on 10-Dec.-2002



Sep.-2002, before water filling

Acrylic + FRP vessel

Jan.-2003, fully contained event



This talk

Neutrino oscillation study using full SK- I atmn data

- $\nu_\mu \leftrightarrow \nu_\tau$ two flavor oscillation analyses
- $\nu_e \leftrightarrow \nu_\mu \leftrightarrow \nu_\tau$ three flavor oscillation analyses
- Limit on $\nu_\mu \leftrightarrow \nu_s$ admixture

Neutrino oscillation study using full K2K- I data

- new detector and future prospects
- $\nu_\mu \leftrightarrow \nu_\tau$ two flavor oscillation analyses using total event rate and spectrum shape

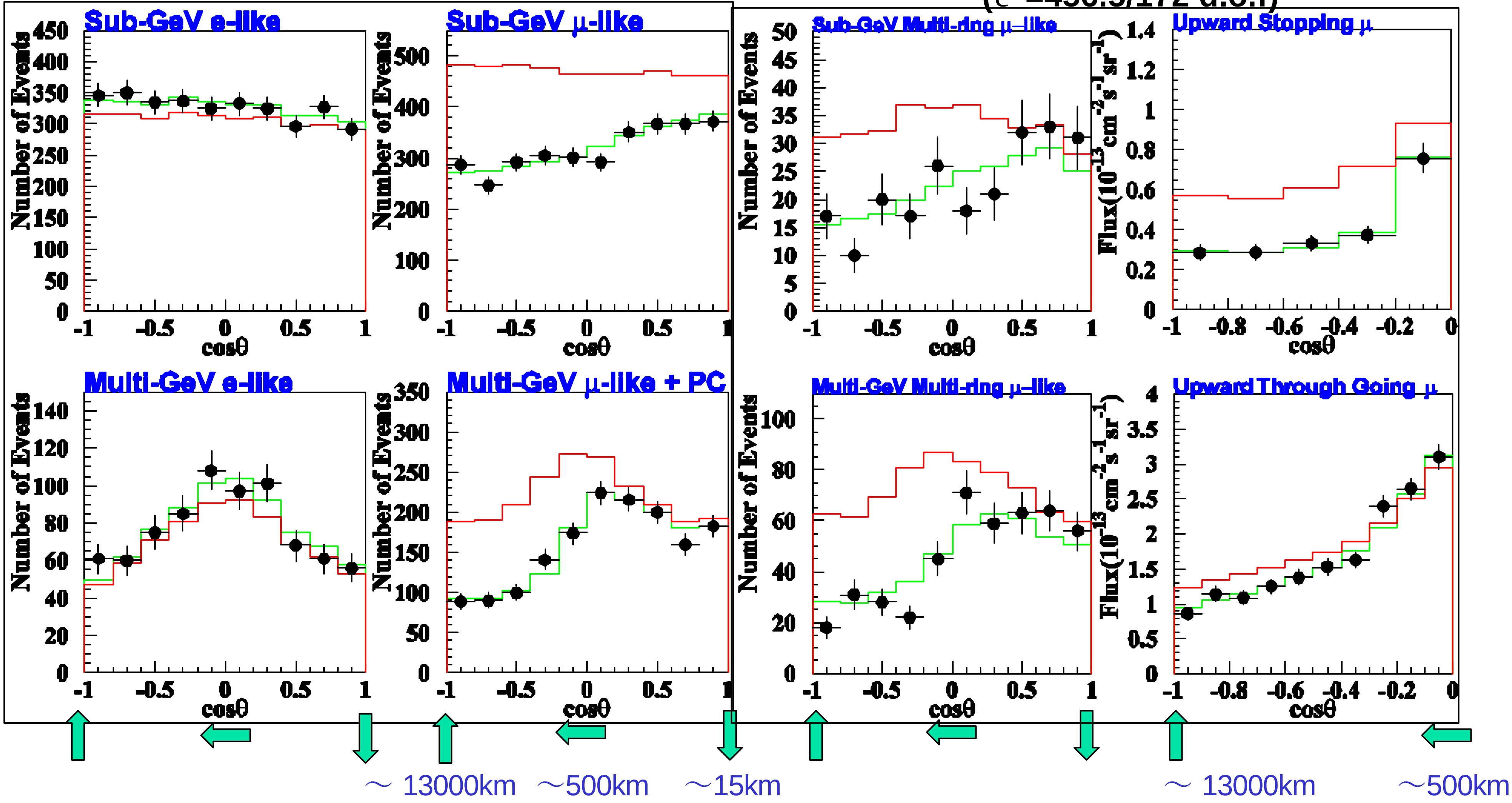
Zenith angle distributions (FC+PC+up-m)

$n_m \leftrightarrow n_t$

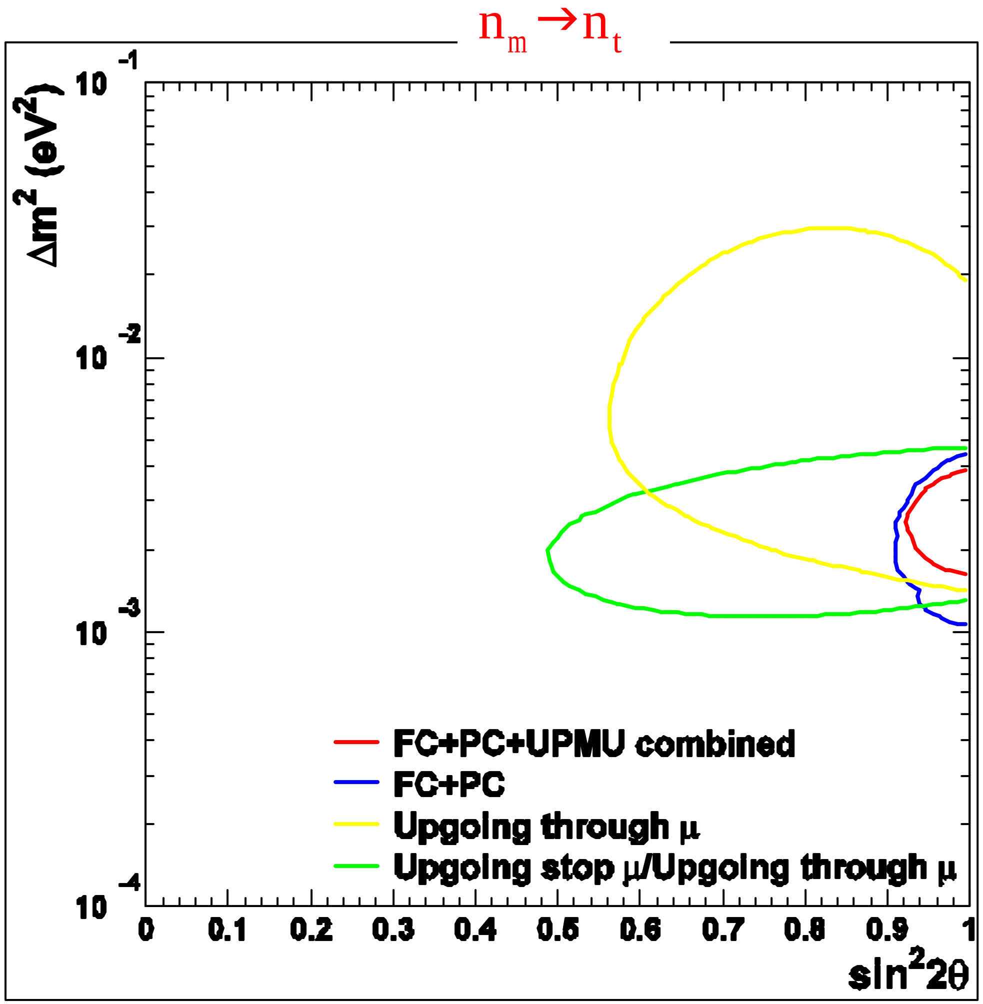
2-flavor oscillations

Best fit (Dm^2=2.5x10^{-3}eV^2, sin^{2}2q=1.0
c$^2_{min}$=163.2/170 d.o.f)

Null oscillation
(c^2=456.5/172 d.o.f)



Combined allowed regions



$n_m \leftrightarrow n_t$ oscillations

Best fit(Dm²=2.5x10⁻³,sin²2q=1.0

c^2_{min}=163.2/170 d.o.f)

No oscillation

(c^2 =456.5/172 d.o.f)

$Dm^2 = (1.5\sim4.0)x10^{-3}eV^2$

$sin^2 2q > 0.92$ @ 90%CL

t detection in atmospheric n

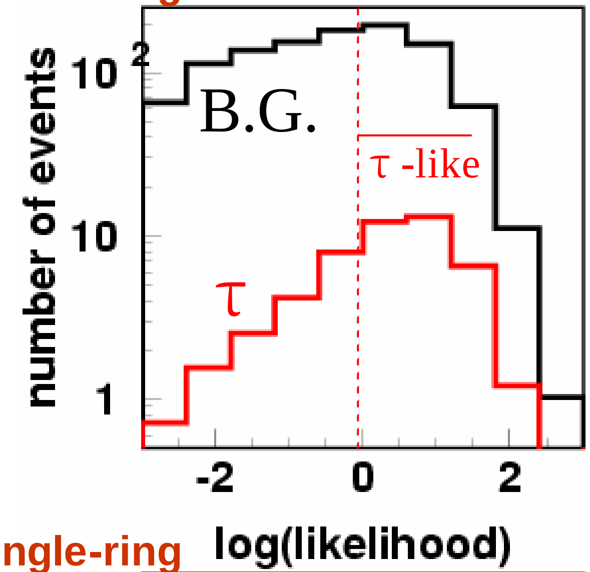
Selection Criteria
- multi-GeV, multi-ring
- most energetic ring is e-like
- log(likelihood) > 0 (single-ring)
  > 1 (multi-ring)

t likelihood is defined using;
- total energy
- number of rings
- number of decay electrons
- max(Ei)/ Σ Ei
- distance between n interaction point and decay-e point
- max(P_m)
- Pt/Evis$^{3/4}$
- PID likelihood of most energetic ring

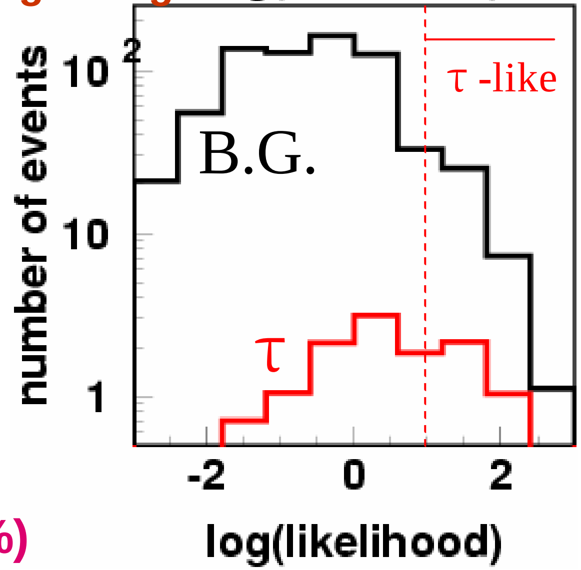
t-like selection; efft=44%, S/N=8%

observed t-like events; 506
MC expectation; CC n_t 37 events,
BG 461 events (CCn_e 43.1%, CCn_m 24.5%, NC 32.4%)

Multi-ring

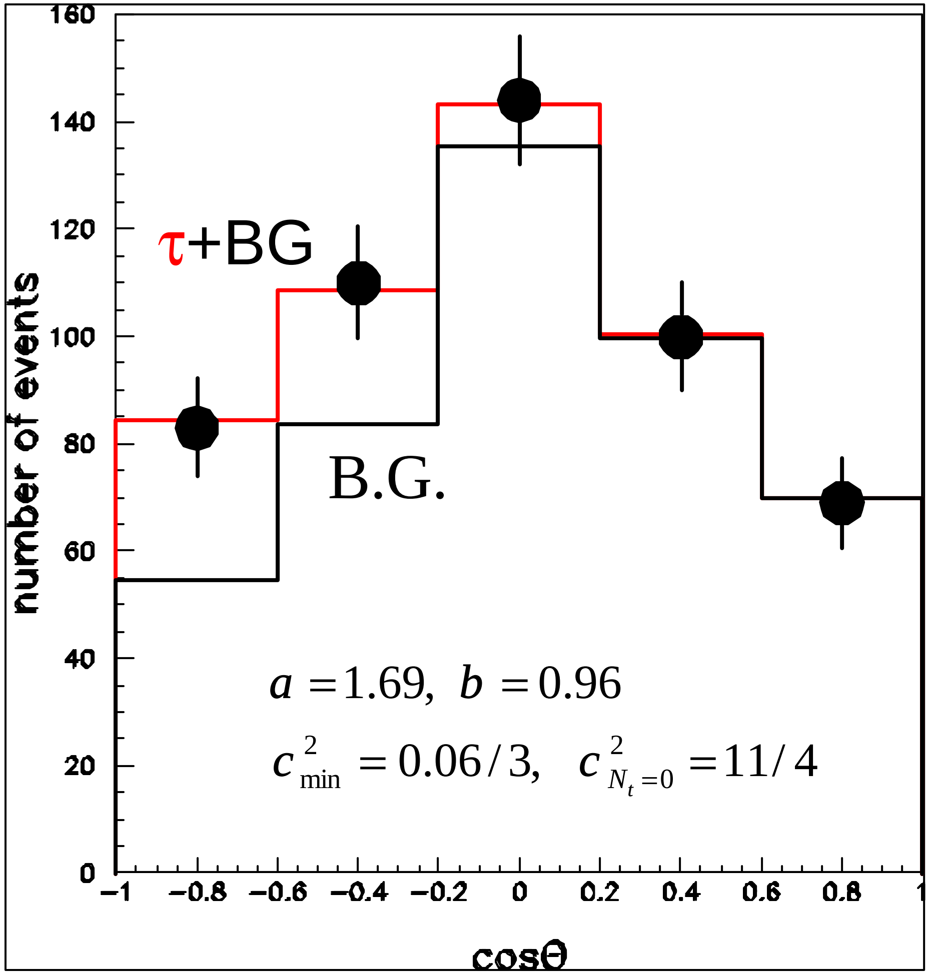


Single-ring



zenith angle dist. of t-like events

$$c^2 = \sum_{\cos\Theta}^{5} \left(\frac{N_{data} - \left(aN_{MC}^{t} + bN_{MC}^{BG}\right)}{s} \right)^2$$

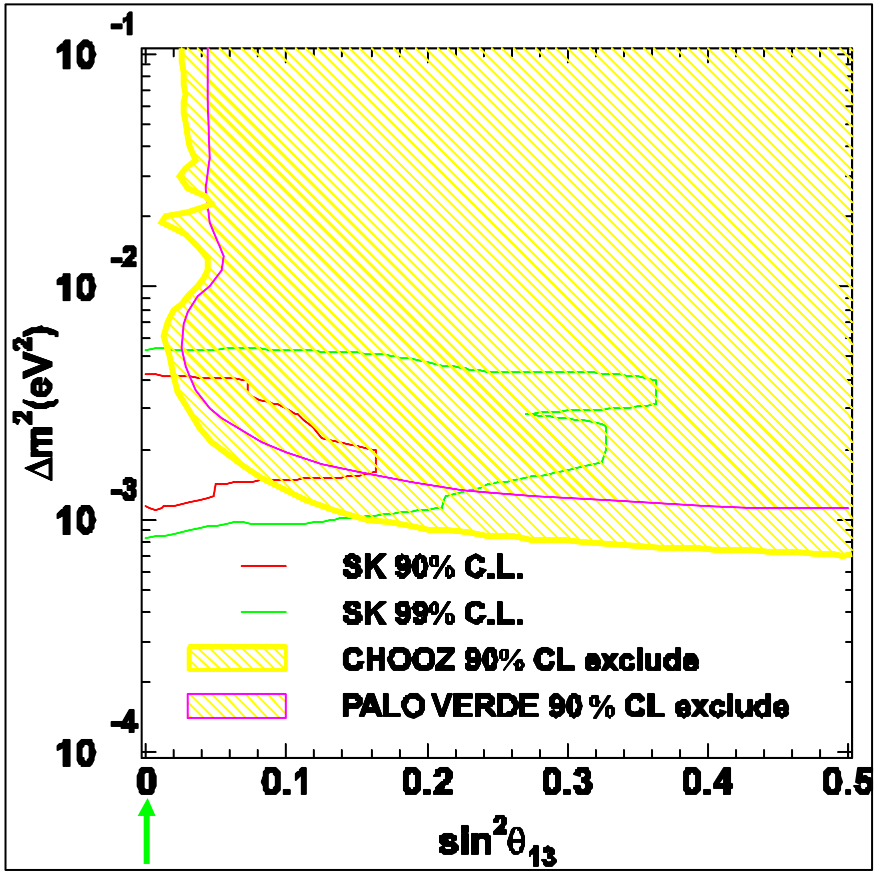


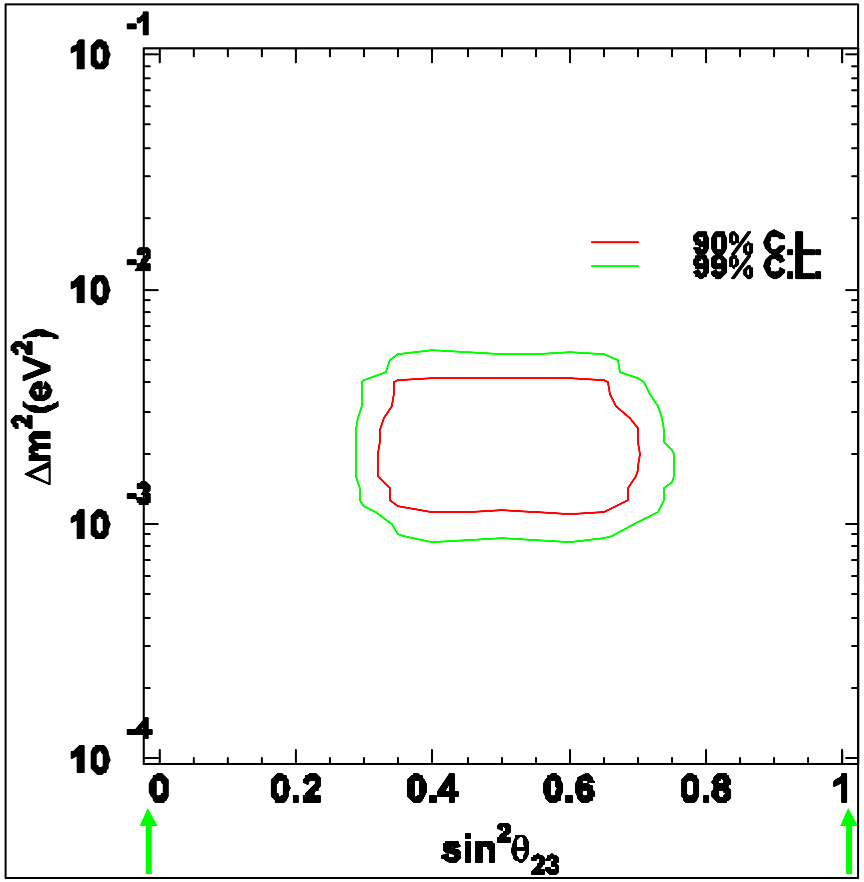
- $N^{FC}_{\tau} = \alpha N^{\tau}_{MC}$/(eff.=0.44)
  =145+-44(stat.)
  +11/-16(sys.)
  N_{exp}=86

- consistent with $\nu_\mu \leftrightarrow \nu_\tau$

- other two analysis give similar results:
  *analysis-2(neural network)
  N^{FC}_{τ}=99+-39(stat.)
  +-13(Δm^2)
  +0/-16(3-flavor)
  *analysis-3(energy flow)
  N^{FC}_{τ}=135+47-44(stat.+sys.)

Allowed region for active 3-flavor oscillations





Pure $n_m \leftrightarrow n_t$

getting close to CHOOZ's limit on q_{13}

Pure $n_e \leftrightarrow n_t$

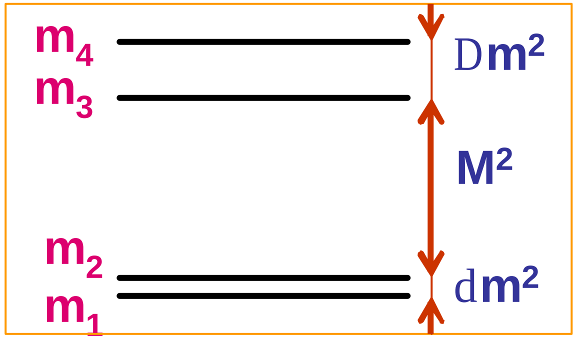
Pure $n_e \leftrightarrow n_m$

consistent with CHOOZ's excluded region

Limit on sterile n

analyses following to Fogli, Lisi, Marrone (PRD63,053008)

assuming 3 active n + 1 sterile n having
dm^2 (solar) << Dm^2(atm) << M^2(LSND)



simplifies to 3 parameters;
Dm^2(atm), sin^{2}2q , sin^{2}x

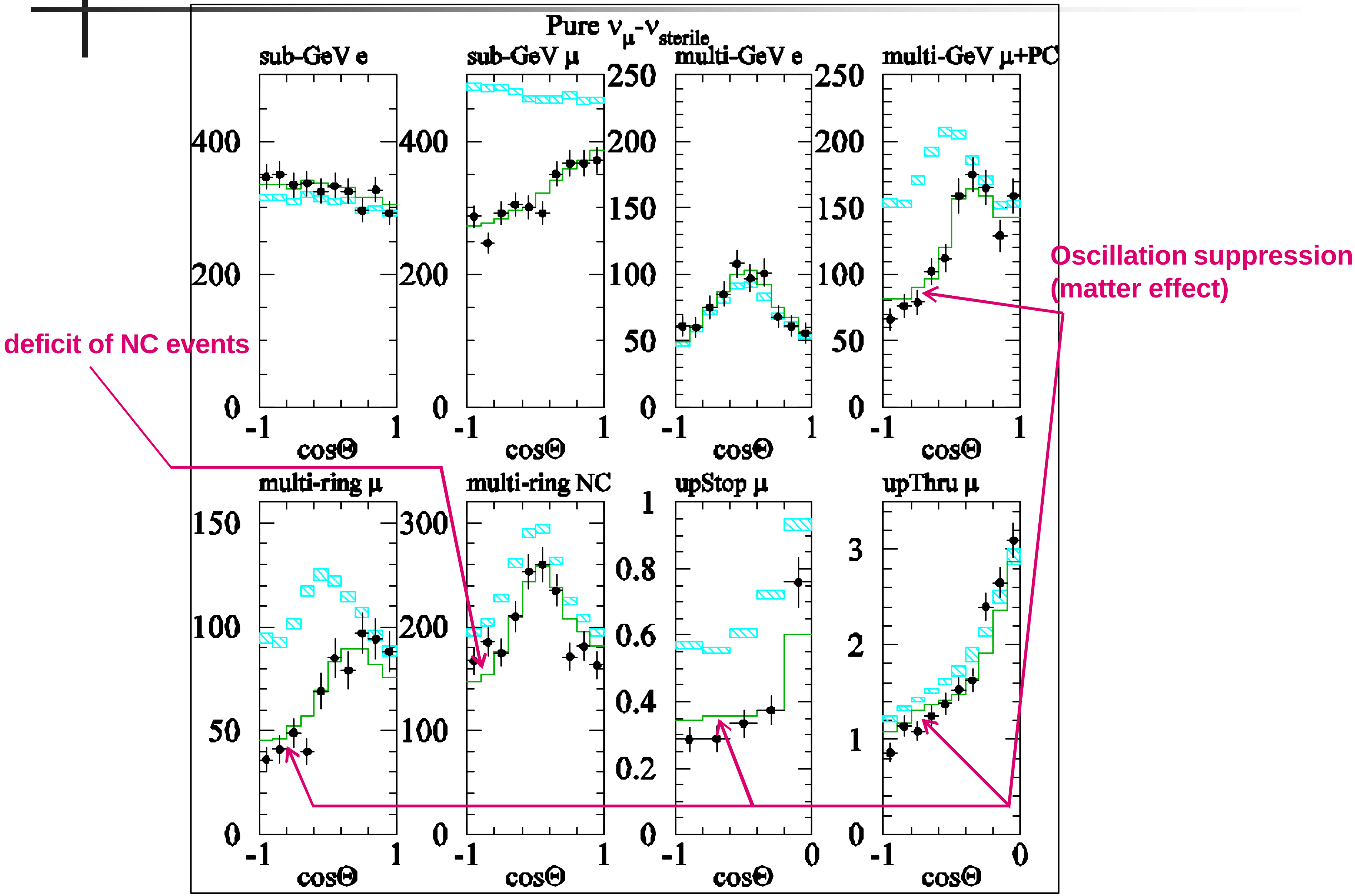
$n_m \rightarrow$ cosxn_t + sinxn_s

sin^{2}x=0; pure $n_m \rightarrow n_t$
sin^{2}x=1; pure $n_m \rightarrow n_s$

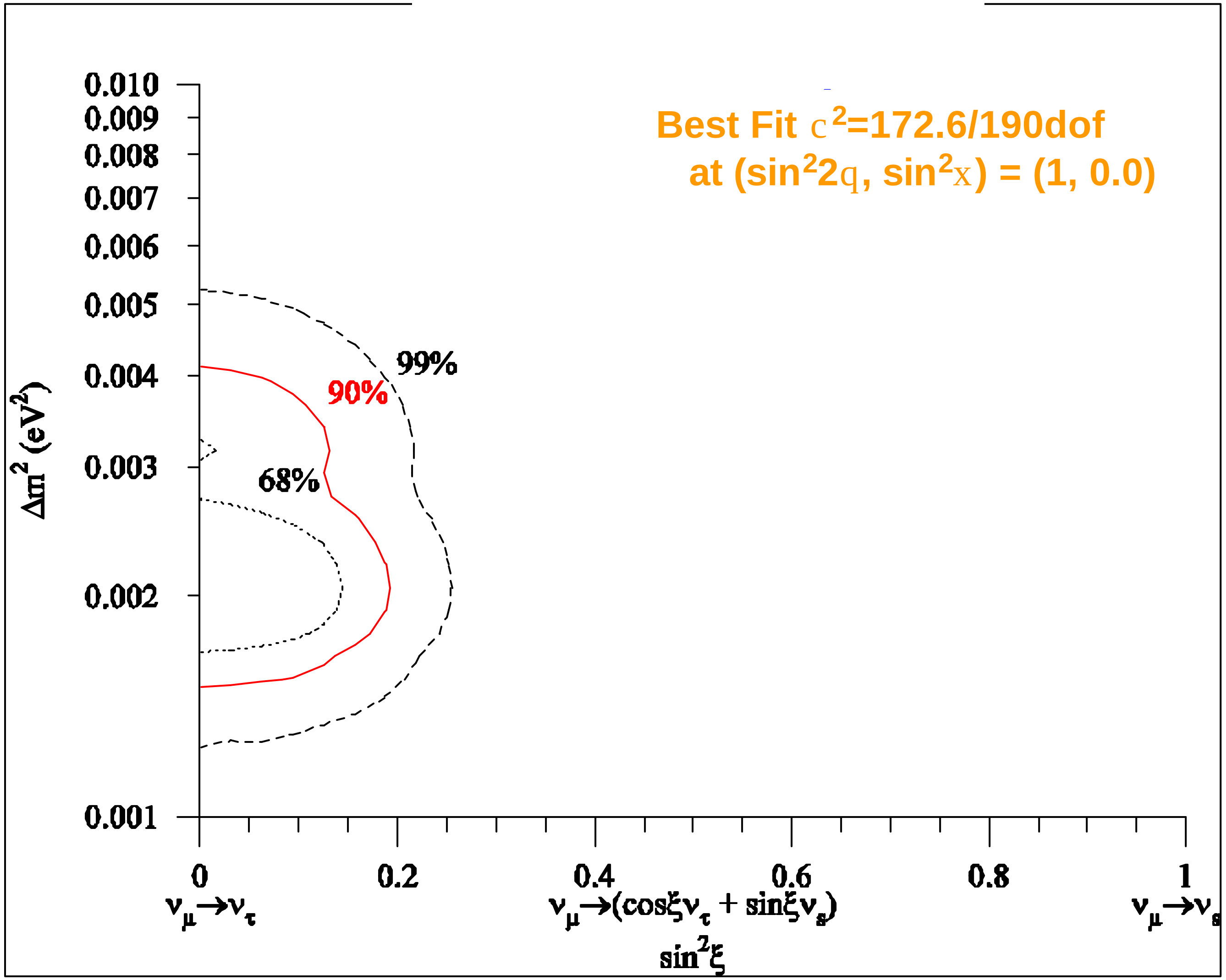
nonzero sin^{2}x

- oscillation suppression happens at multi-GeV region due to matter effect
- deficit of NC events in upward bins is expected

shape of pure $n_m \leftrightarrow n_s$



limit on $\nu_\mu \leftrightarrow \nu_s$ add mixture

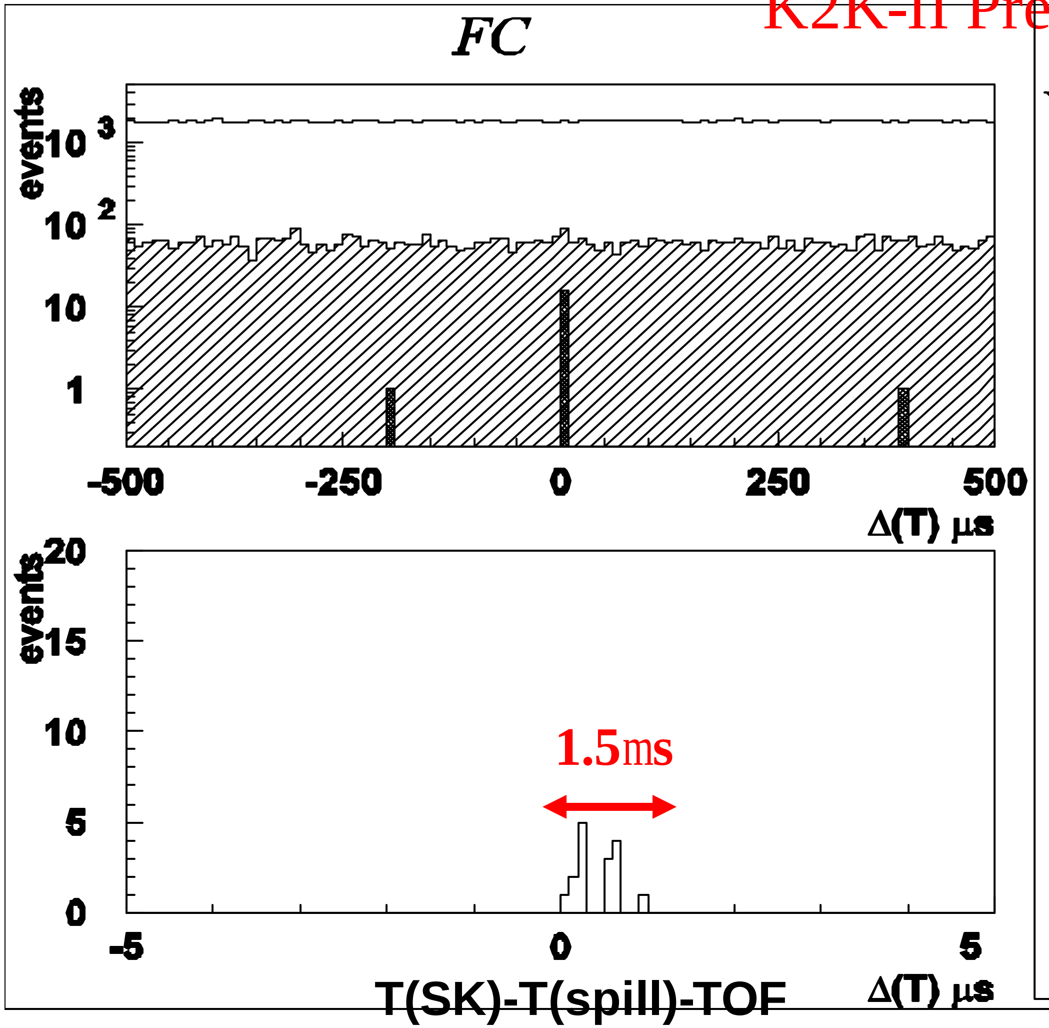


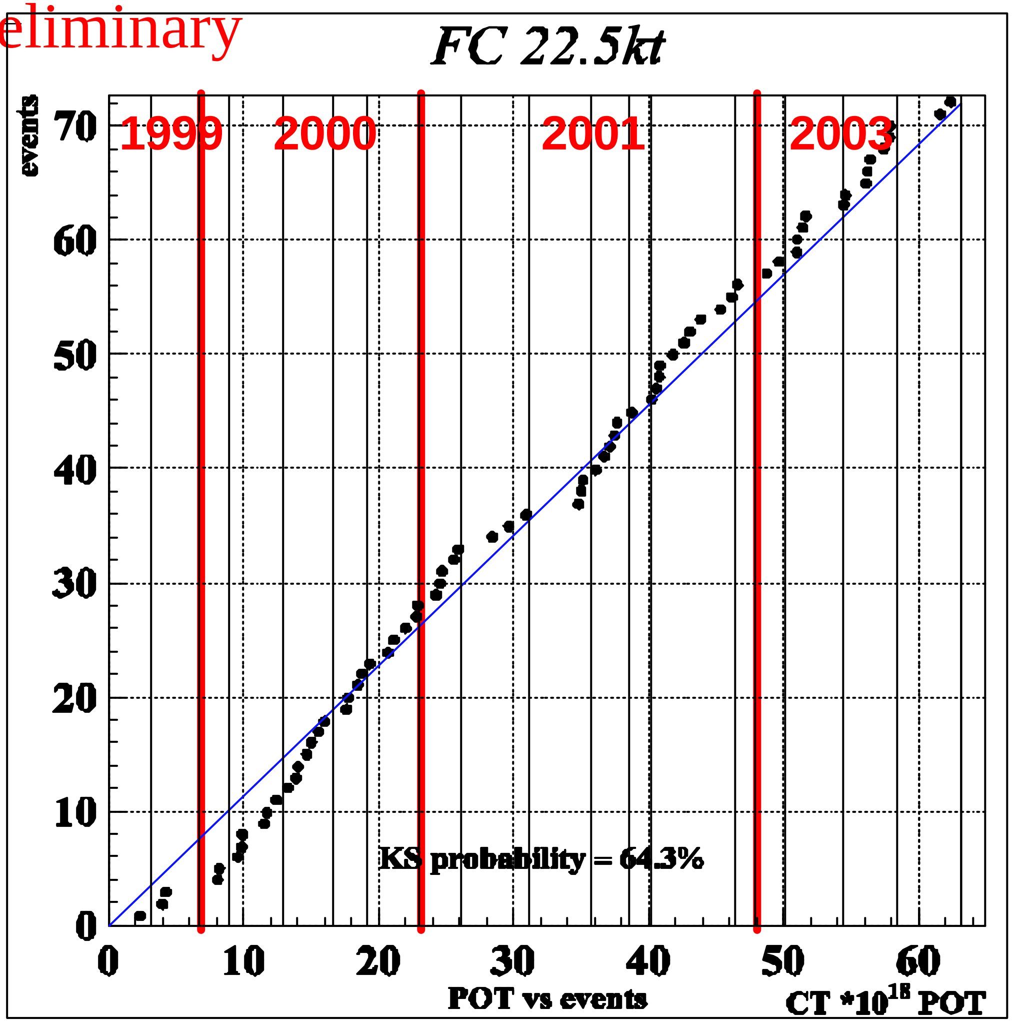
Summary of atmospheric n observations

- **Atmospheric neutrinos are measured using various techniques in SK- I and analyzed in detail**
  - $n_m \leftrightarrow n_t$ 2 **flavor oscillations**
    - **all data are well fitted and agree with each other**
    - $Dm^2 = 1.5\sim4\times10^{-3}$ eV^2, $\sin^2 2q > 0.92$ @ 90%CL
    - **observed** t**–like events also support** $n_m \leftrightarrow n_t$
  - $n_e \leftrightarrow n_m \leftrightarrow n_t$ 3 **flavor oscillations**
    - **limit on** q_{13} **consistent with CHOOZ**
  - **sterile neutrino admixture**
    - n_s **is disfavored as a prominent oscillation partner of** n_m
    - $\sin^2 x < 0.19$ @ 90%CL

Updated SK events in K2K-II

K2K-II Preliminary

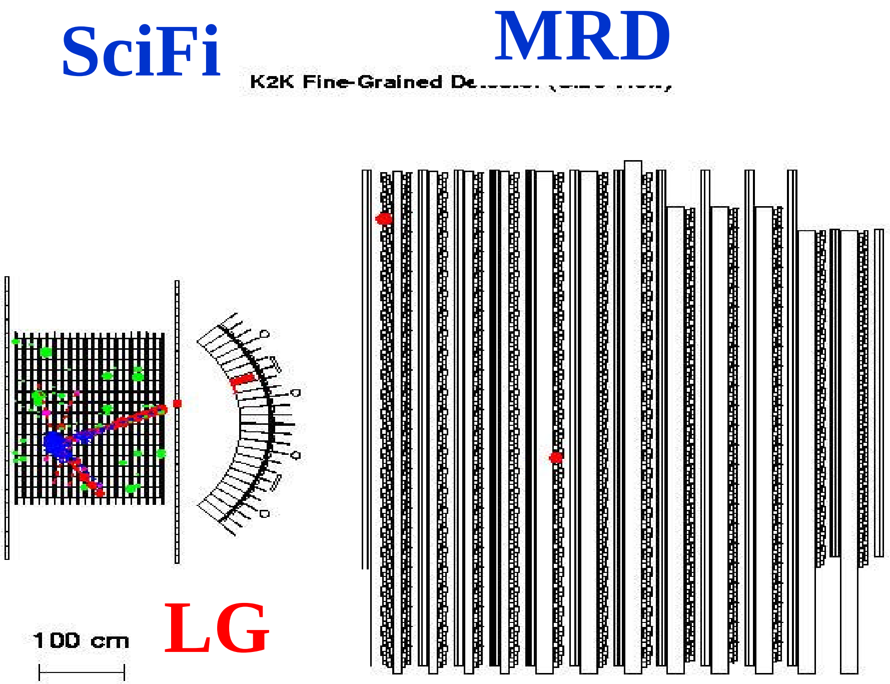


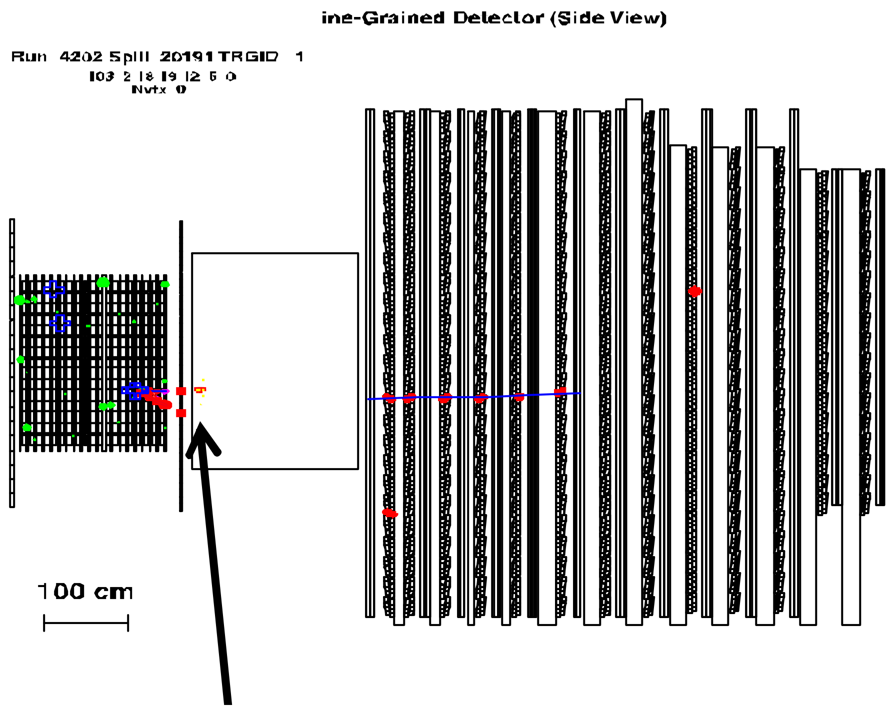


K2K-II experiment successfully observed SK events

Fine-Grained Detector

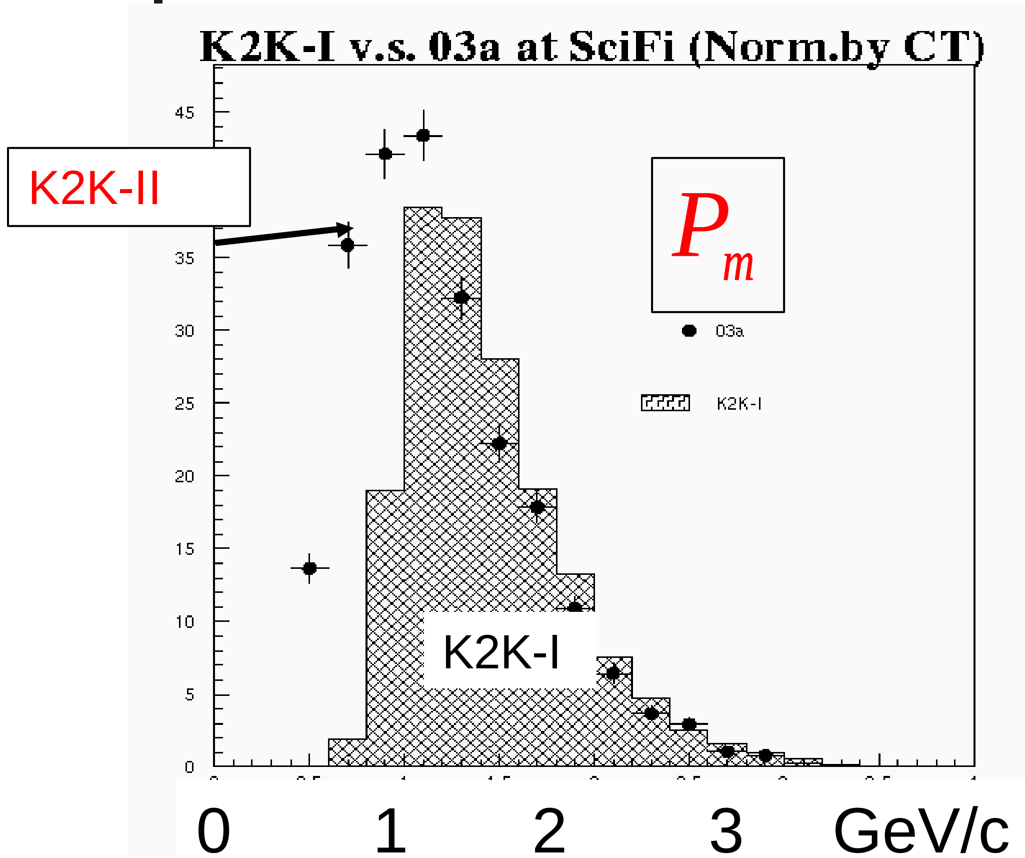
K2K-I → K2K-II

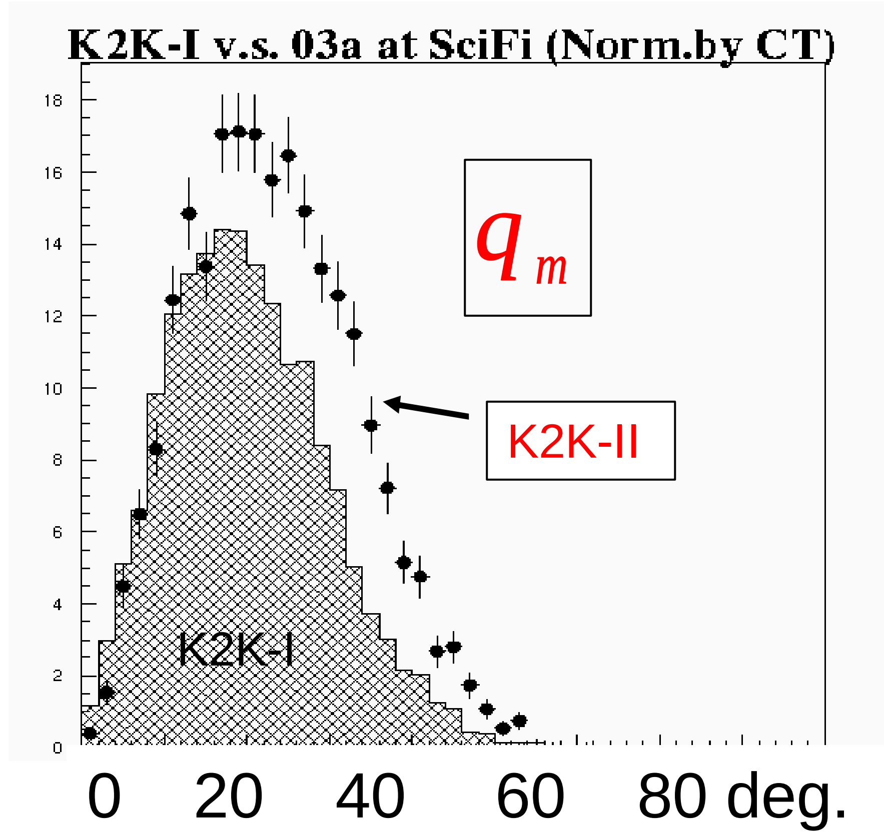




Scibar 4layers exists.
Full installation this summer.

Improved Acceptance





- Increased acceptance at low energy
  - Important for the oscillation analysis
- Increased acceptance at large angle

Newly installed SciBar neutrino detector

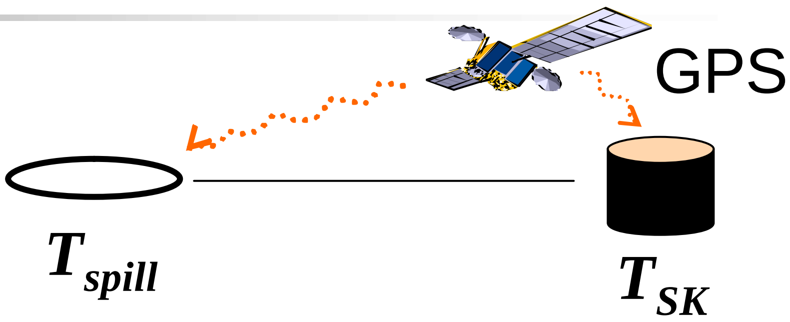
A partial SciBar detector was installed in January 2003.
The full installation will be conducted from July to September in 2003.

full active fine-grained detector
→precise measurements of ν int.

- **QE measurement by proton tagging and pion rejection**
  → precise spectrum measurement
  → constraint on far/near ratio
- **precise measurement of each int. modes (CC single-pion production, multi-pion, coherent pion, NC elastic, pi0, nue CC…)**

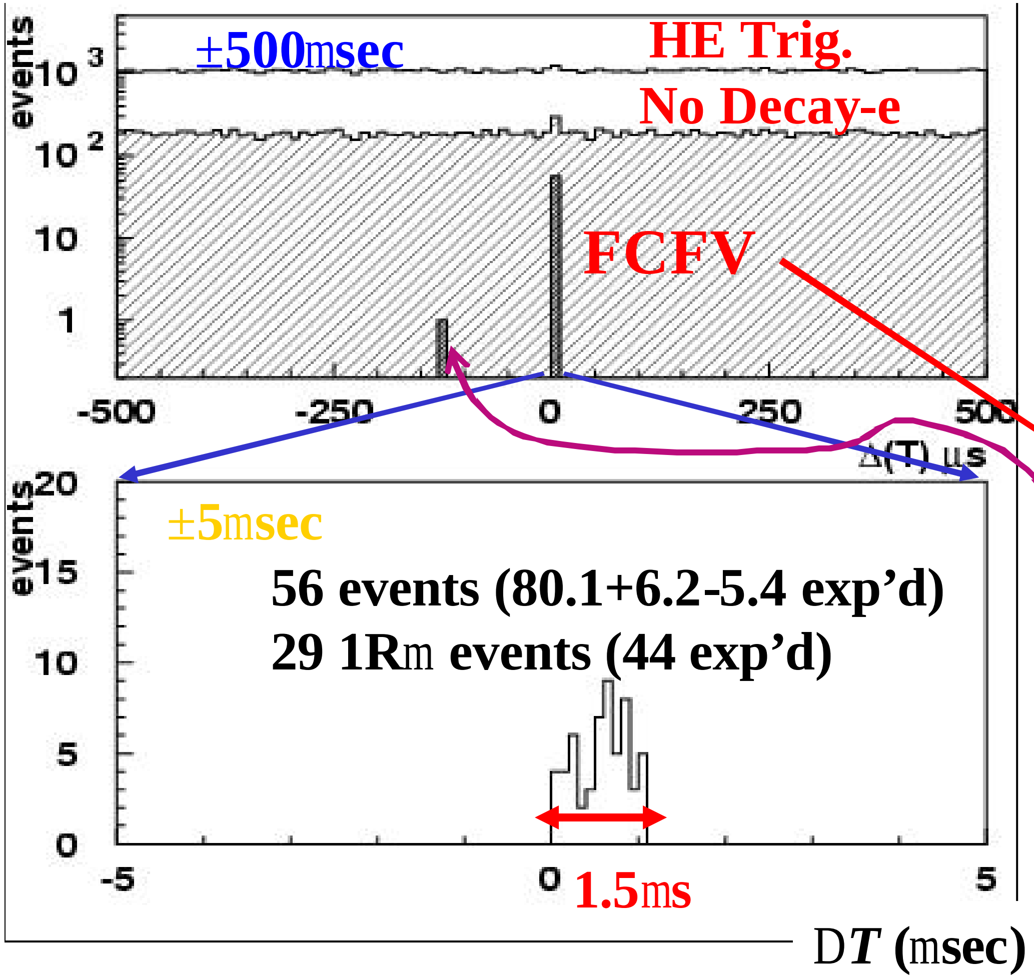
Observed SK Event in K2K-I

$$-0.2 \le \Delta T \equiv T_{SK} - T_{Spill} - \mathrm{TOF} \le 1.3 m\,\mathrm{sec}$$



T_{Spill}: Abs. time of spill start
T_{SK}: Abs. time of SK event
TOF: 0.83ms (KEK to Kamioka)

June99 – July01
4.8 x 10^{19} proton on target



FC: fully contained
(No activity in Outer Detector)
FV: 22.5kt Fiducial Volume

Expected Atm. n BG
$<10^{-3}$ within 1.5ms.

Null Oscillation Probability

Null Oscillation Probability

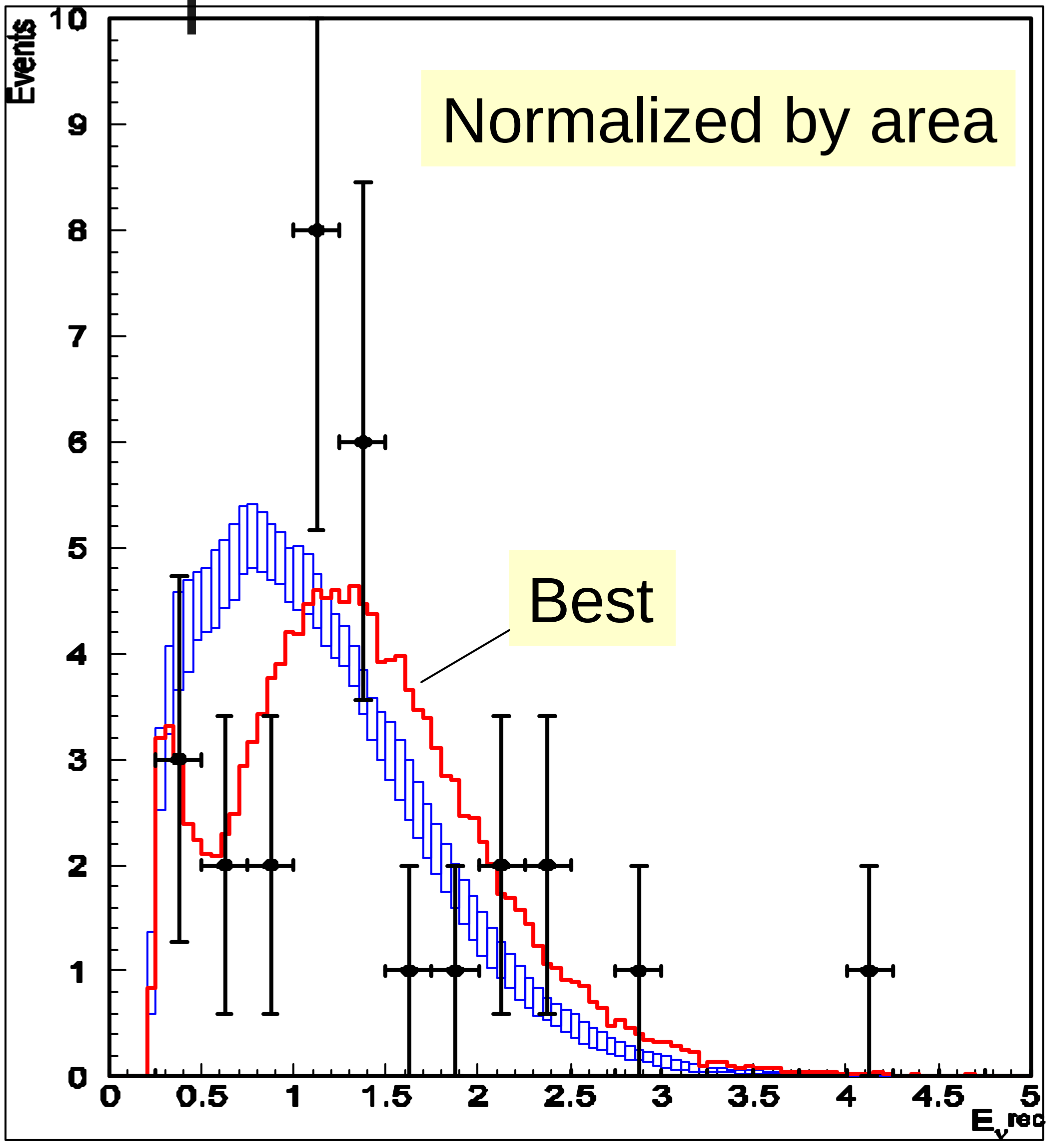
	analysis-1	analysis-2
N_{SK} only	1.3%	0.7%
Shape only	15.7%	14.3%
N_{SK}+Shape	0.7%	0.4%

Best fit (sin^{2}2q , Dm^2)

Shape only	(1.0, 3.0×10^{-3}eV^2)	(1.0, 3.2×10^{-3}eV^2)
(Allowing unphys.)	(1.09, 3.0×10^{-3}eV^2)	(1.05, 3.2×10^{-3}eV^2)
N_{SK} +Shape	(1.0, 2.8×10^{-3}eV^2)	(1.0, 2.7×10^{-3}eV^2)
(Allowing unphys.)	(1.03, 2.8×10^{-3}eV^2)	(1.05, 2.7×10^{-3}eV^2)

Both Shape and N_{SK} +Shape indicate consistent parameter region

Best fit 1Rm spectrum & Nsk



Best fit point (sin^{2}2q, Dm^2)
= (1.0, 2.8x10^{-3}eV^2)

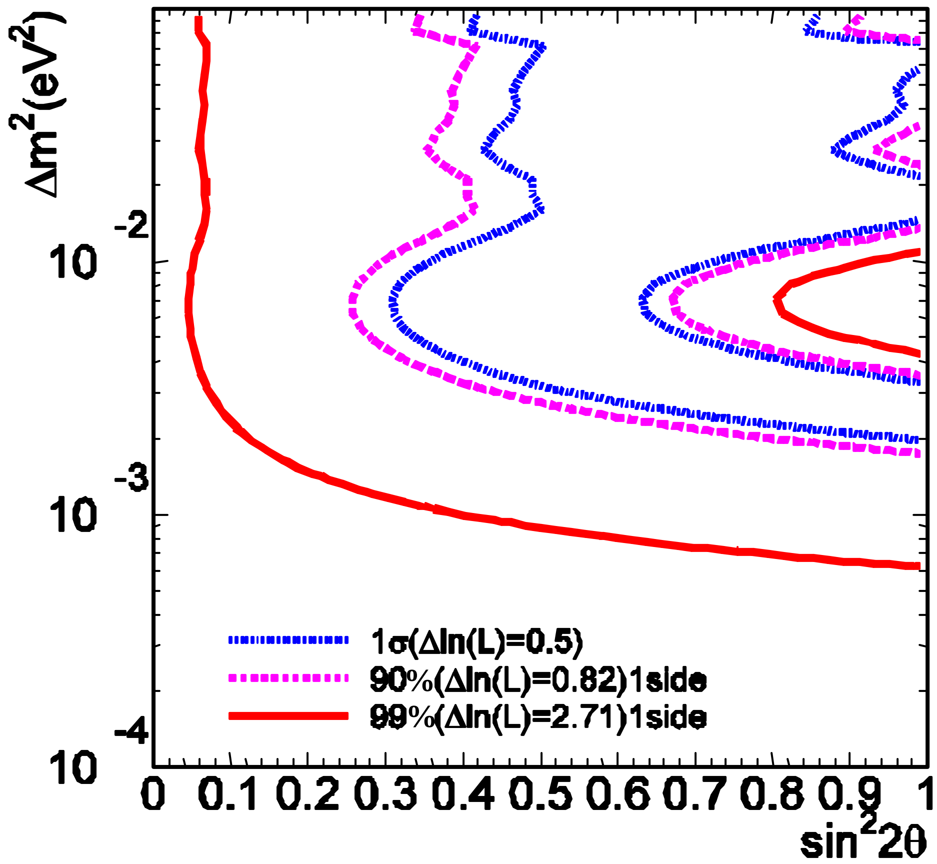
KS test prob.(shape): 79%

N_{SK}=54 (Obs.=56)

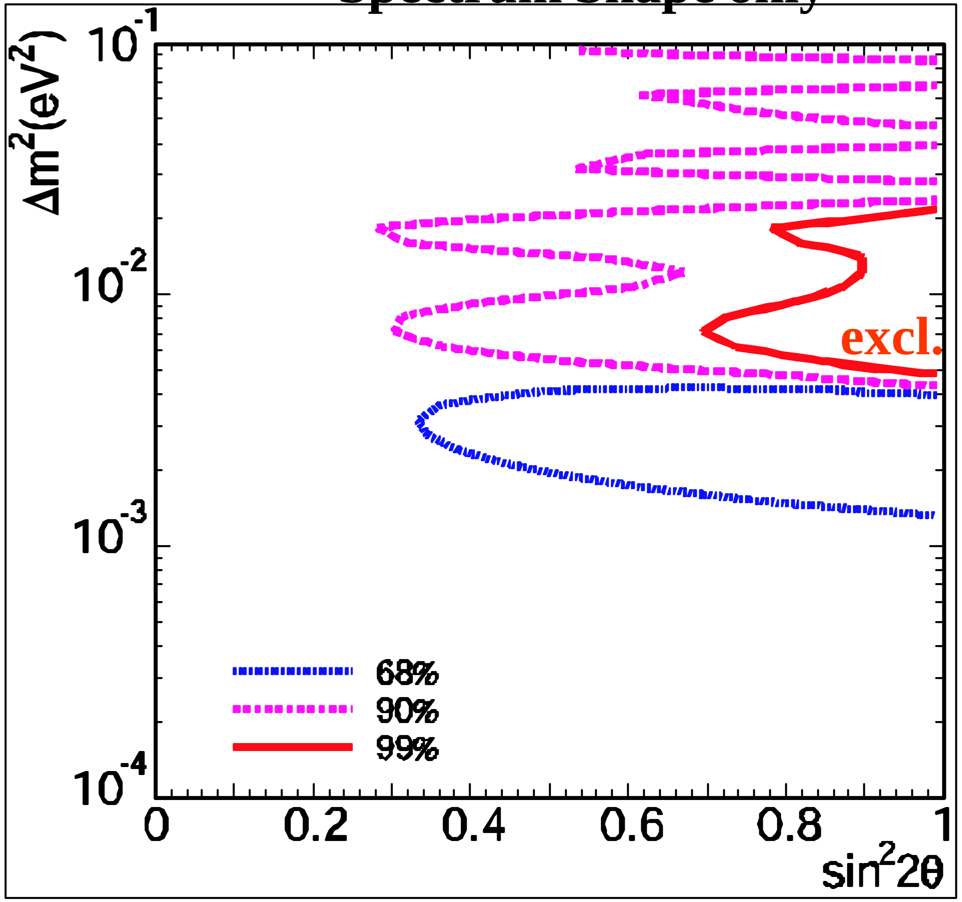
Very good agreement
Shape & N_{SK}

Allowed regions

Total no. of Events only

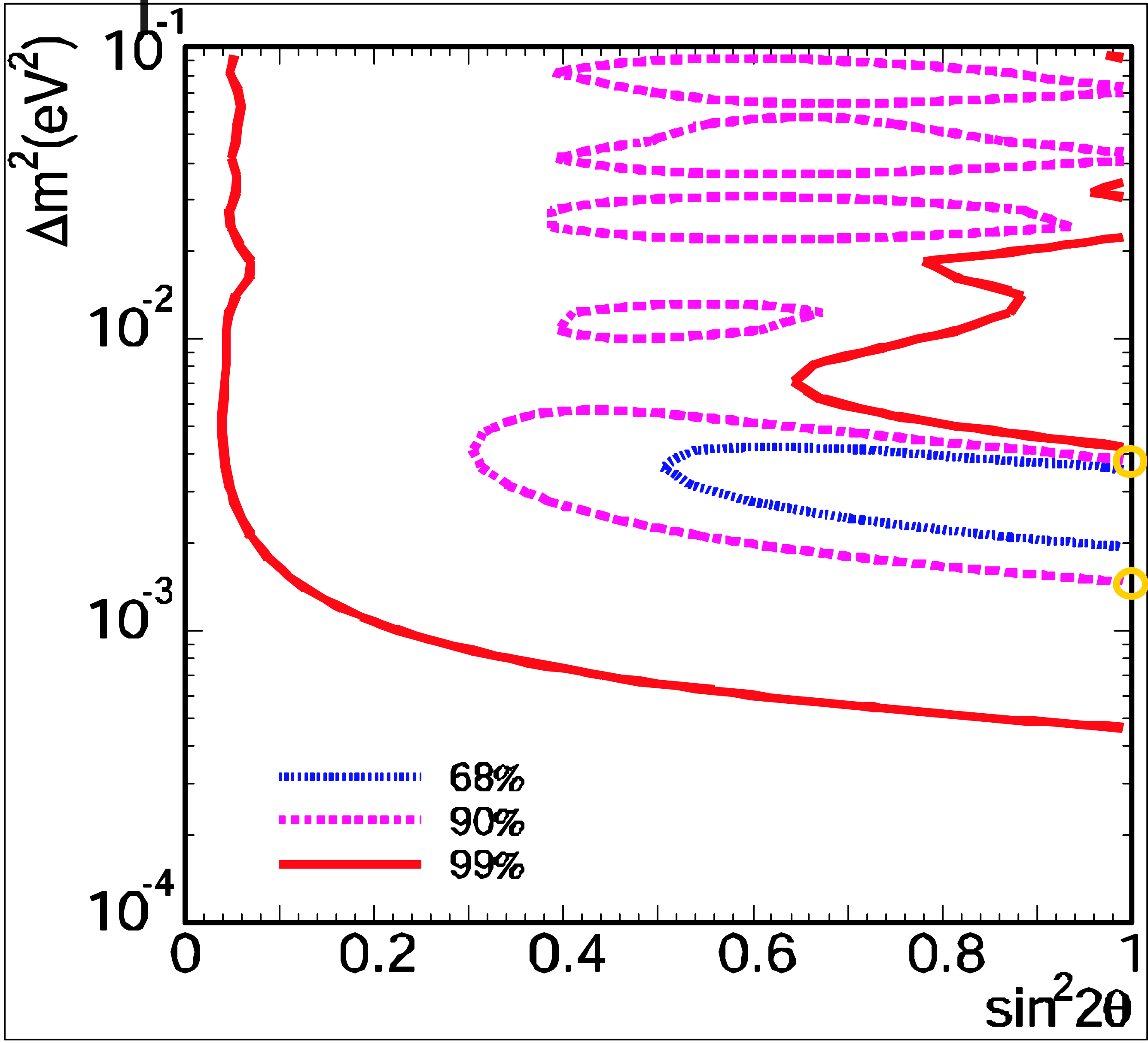


Spectrum Shape only



Both indicate consistent Dm² region

Allowed region (Shape+Norm)



Dm^2=
1.5~3.9x10^{-3}eV^2
@ sin^{2}2q=1
@90%CL

Summary of K2K

- K2K-II successfully resumed and new detector will improve knowledge of neutrino flux and interactions

- K2K Oscillation analysis on June99 ~July01 data

1. Null oscillation probability is less than 1%
2. Both SK rate reduction and E_{nu}^{rec} shape indicate consistent oscillation parameters region
3. $\Delta m^2 = 1.5 \sim 3.9 \times 10^{-3} eV^2$ for $\sin^2 2\theta = 1$ @ 90%CL
4. $\sin^2 2\theta$, Δm^2 are consistent with atmospheric neutrino results

- K2K will double the statistics (10^{20} pot) in two years