K2K: Status

Kenzo NAKAMURA
KEK
For the K2K Collaboration

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Sudbury, Canada

K2K (KEK-to-Kamioka)

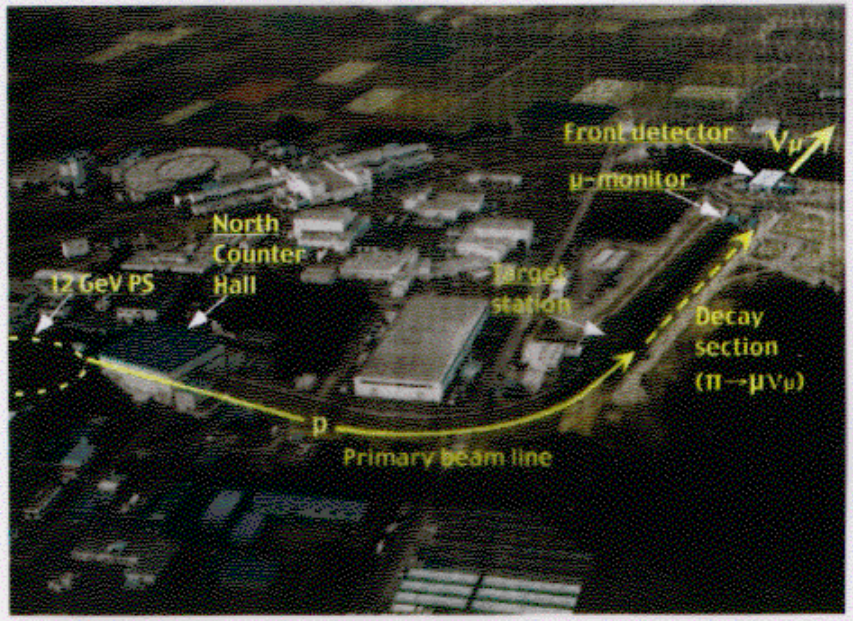
Super Kamiokande

Water Cherenkov detector

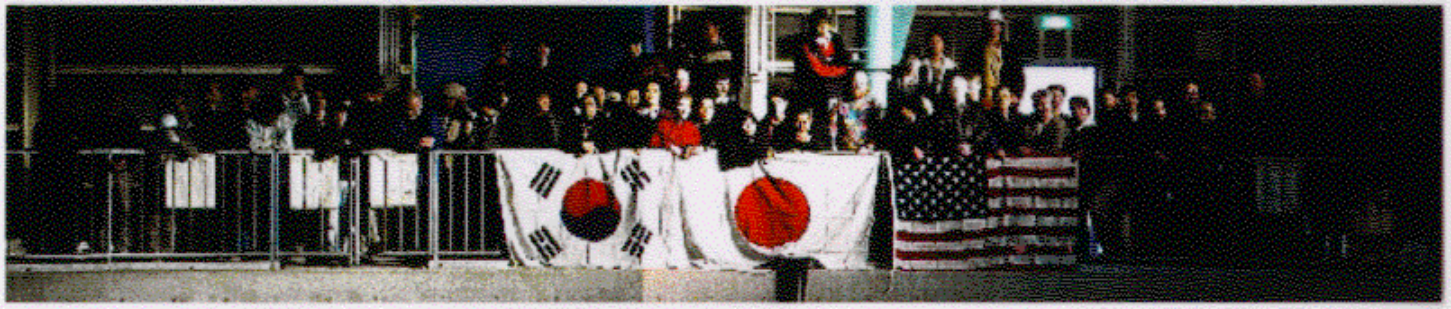
Total mass:	50 kton
Inner mass:	32 kton
Fiducial mass:	22.5 kton

KEK

- 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: 1.4 GeV → ν_μ–ν_τ disappearence
- Near detector: 300 m from the target
- Far detector (Super-Kamiokande): 250 km from the target
- Goal: 10^{20} protons on target



K2K Collaboration

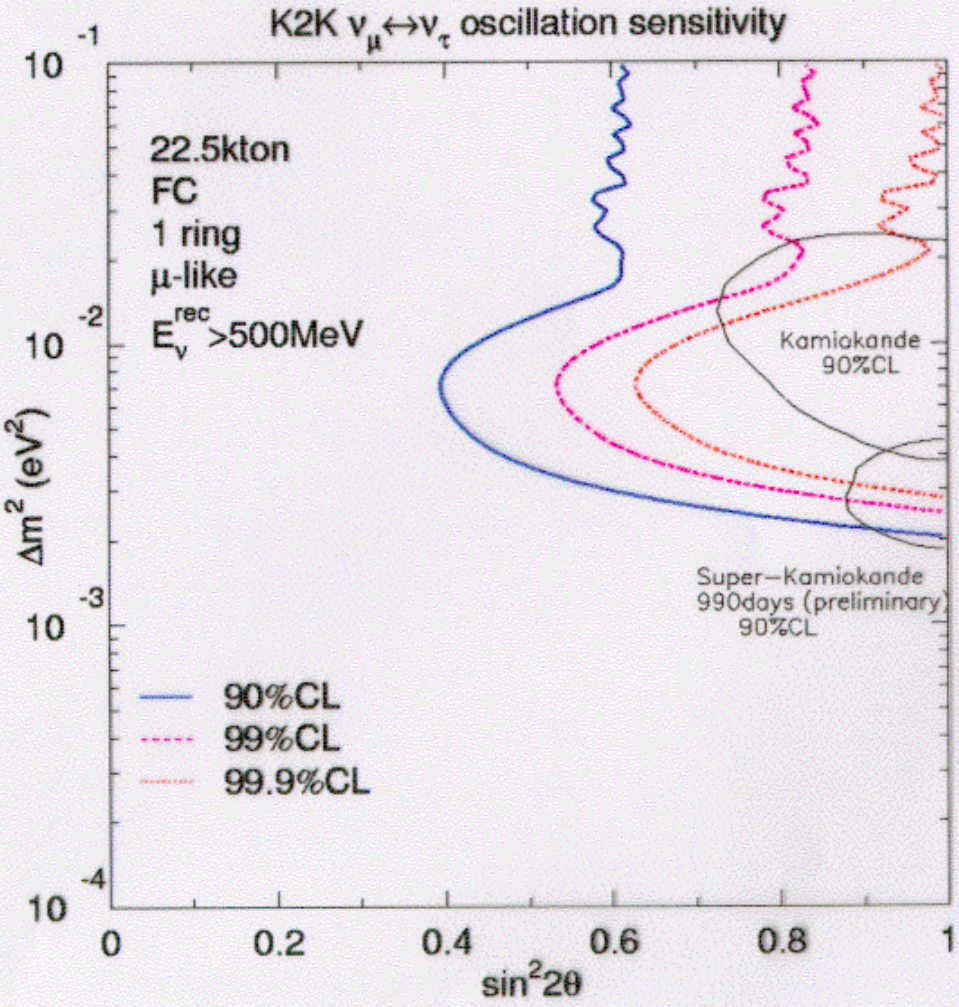


Chonnum National Univ.
Donshin Univ.
Seoul National Univ.

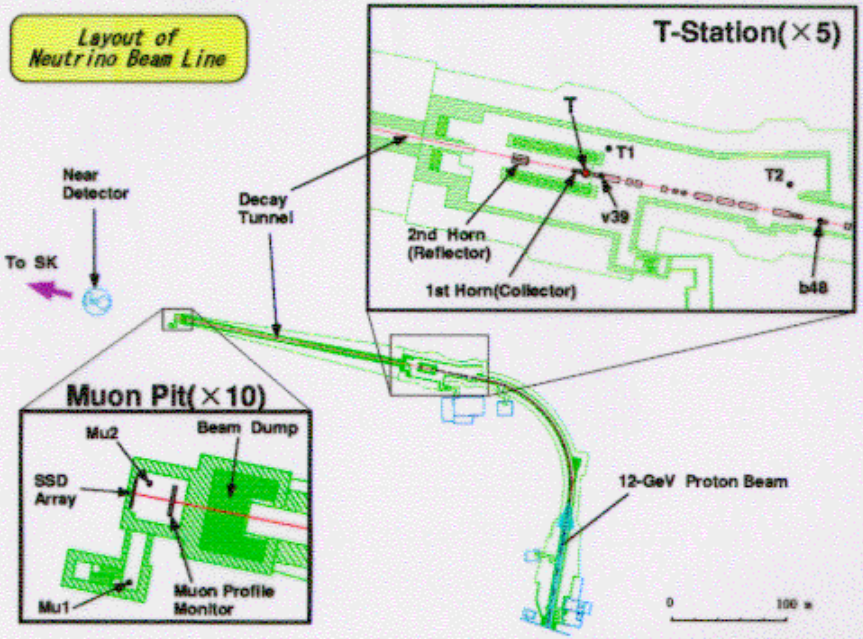
ICRR, Univ. of Tokyo
KEK
Kobe Univ.
Kyoto Univ.
Niigata Univ.
Okayama Univ.
Osaka Univ.
Science Univ. of Tokyo
Tohoku Univ.

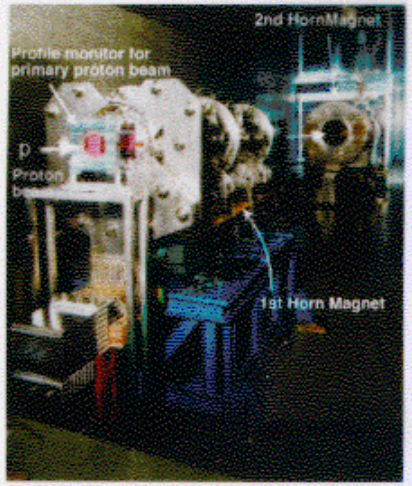
Boston Univ.
Univ. of California at Irvine
Univ. of Hawaii at Manoa
SUNY at Stony Brook
Univ. of Washington at Seattle

Warsaw Univ.


K2K $\nu_\mu \leftrightarrow \nu_\tau$ oscillation sensitivity
22.5kton
FC
1 ring
μ-like
E_ν^{rec}>500MeV
Kamiokande
90%CL
Super−Kamiokande
990days (preliminary)
90%CL
90%CL
99%CL
99.9%CL
Δm^2 (eV^2)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
0.2
0.4
0.6
0.8
1
$\sin^2 2\theta$

Beamline and pion monitor

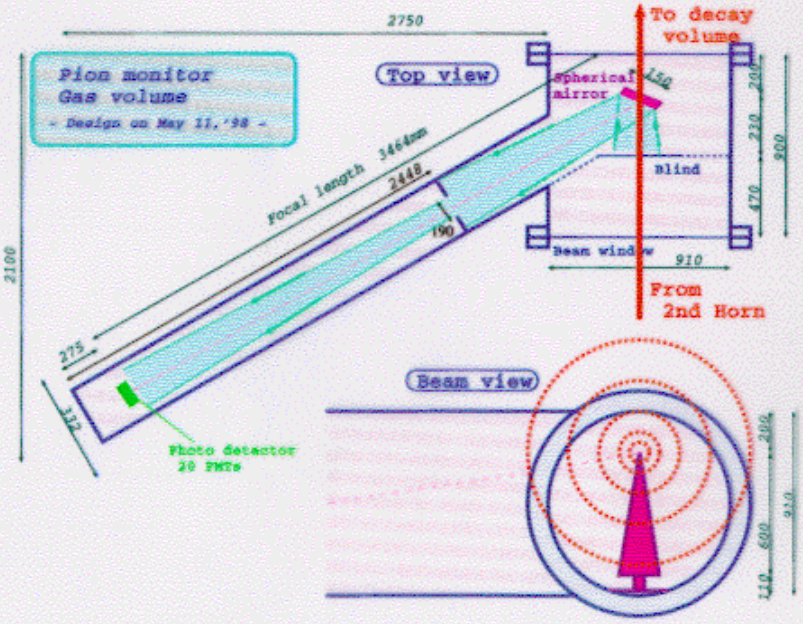




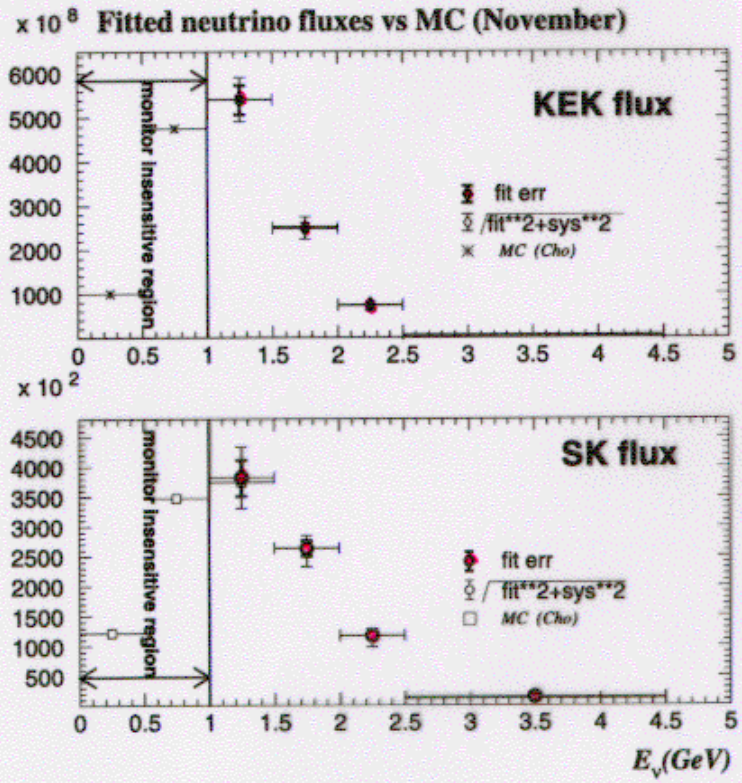
- Production target: Al 66 cm × 3 cmϕ
- Horn current: 250 kA

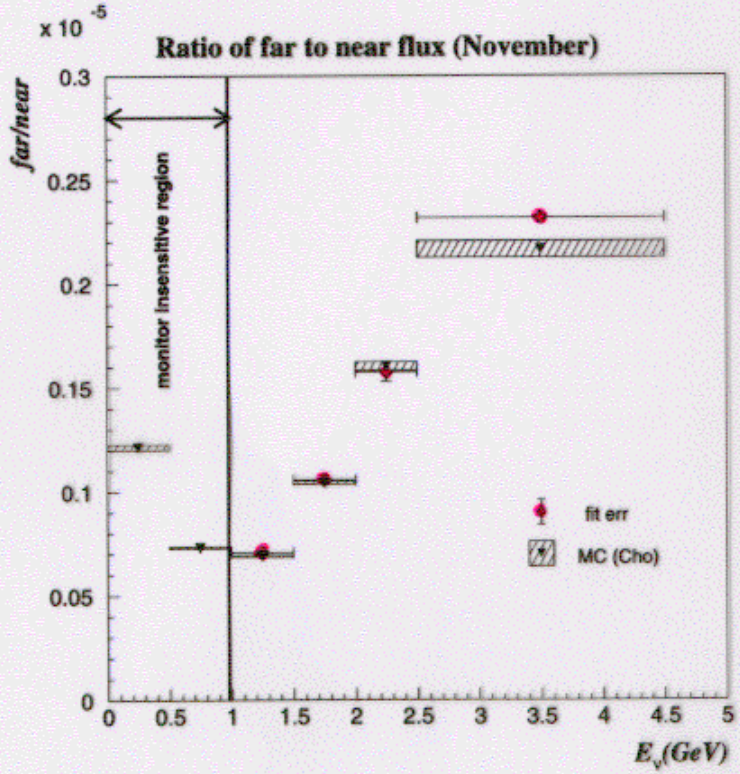
Pion monitor is a gas-Cherenkov counter which measures the pion p_π-θ_π distribution just after the magnetic horn.

- Predict near/far flux ratio above 1 GeV
- Normally retracted from the beamline
- Special low-intensity runs for measurementt



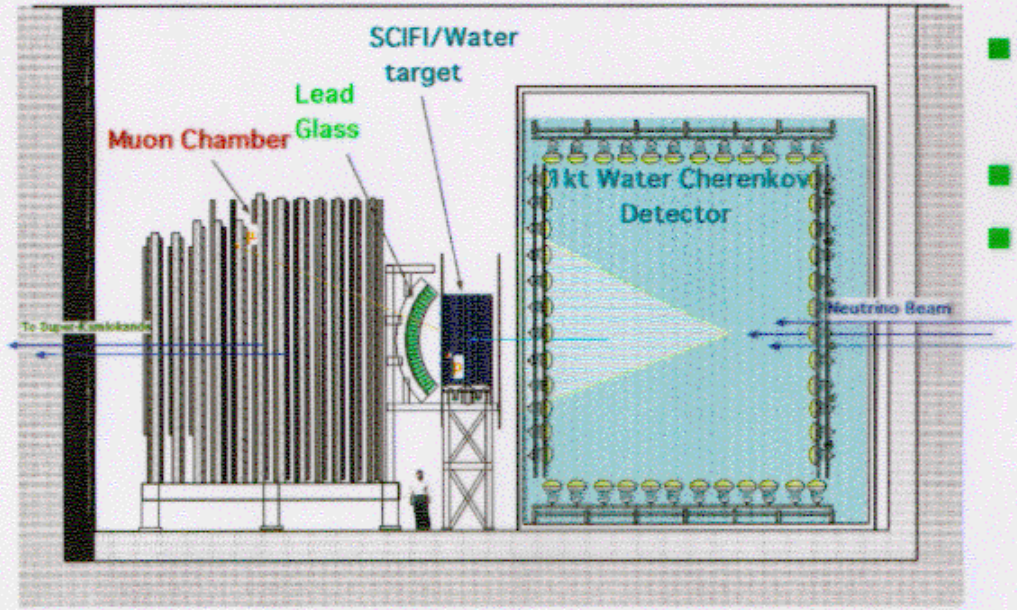
Pion monitor results vs. beam MC





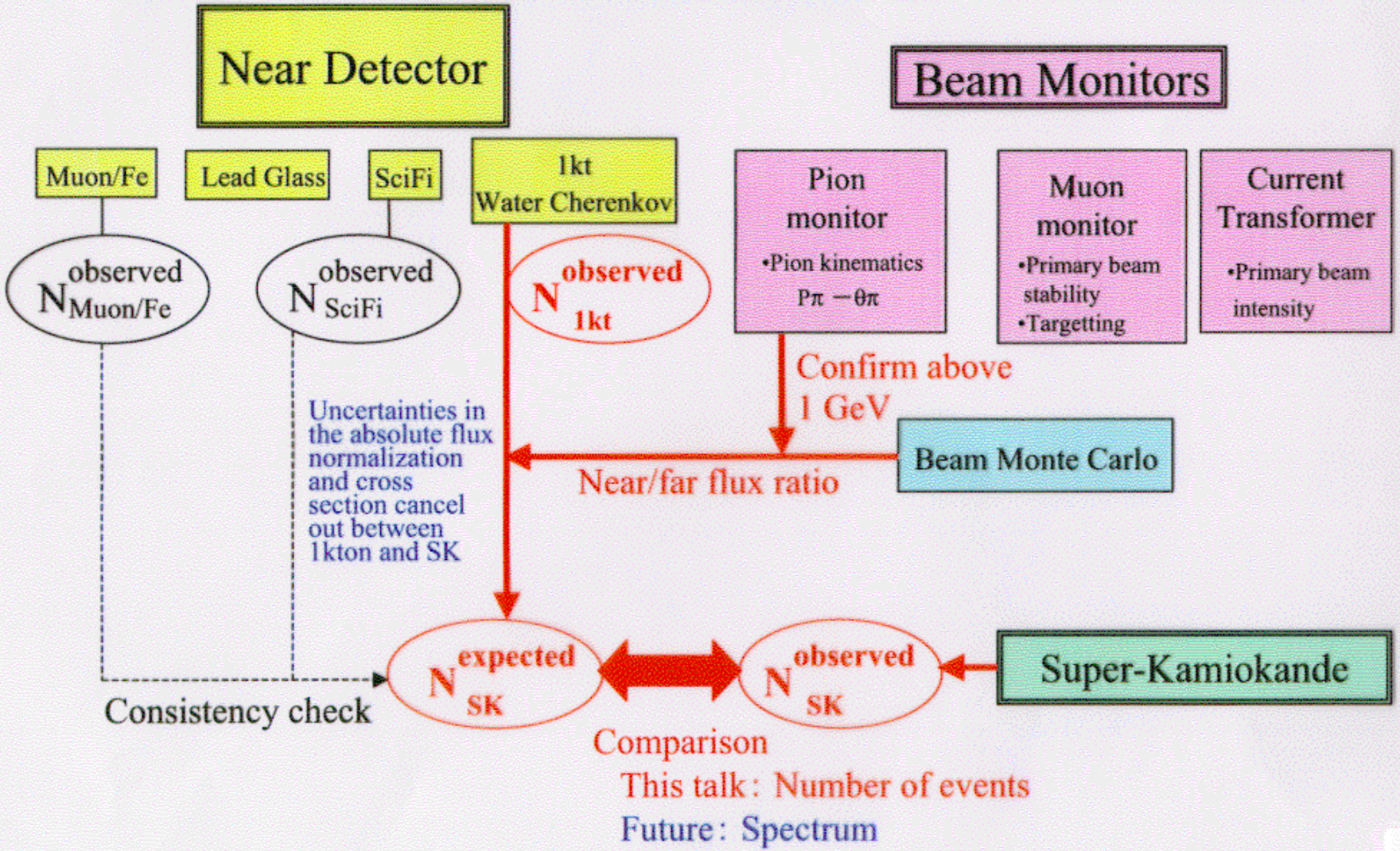
K2K near detector

- Measure ν_μ flux, spectrum, profile
- Measure ν_e contamination
- Study ν interactions at ~ 1 GeV

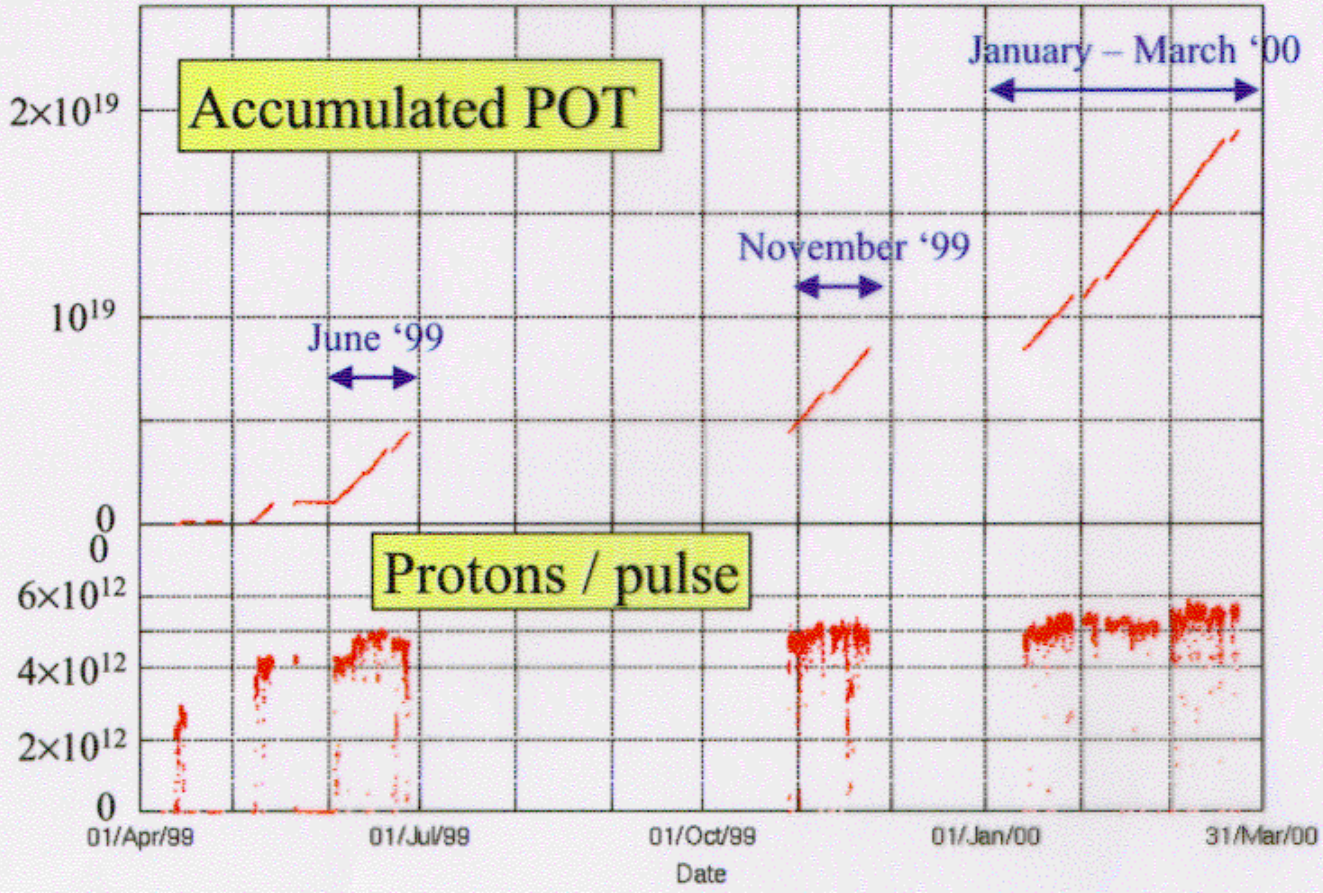


- 1 kton water Cherenkov detector
  - Same structure and systematics as SuperK
  - Common water target
- Scintillating-Fiber tracker
  - Active area: 2.4 m × 2.4 m × 20 (x,y) layer
- Water target
  - 19 layers of 60-mm thick water
- Lead-glass counter
- Muon/Fe
  - 12 layers of iron plates (total mass ~ 1,000 tons interleaved with muon drift chambers

K2K Experiment: Schematic



Protons delivered to the target

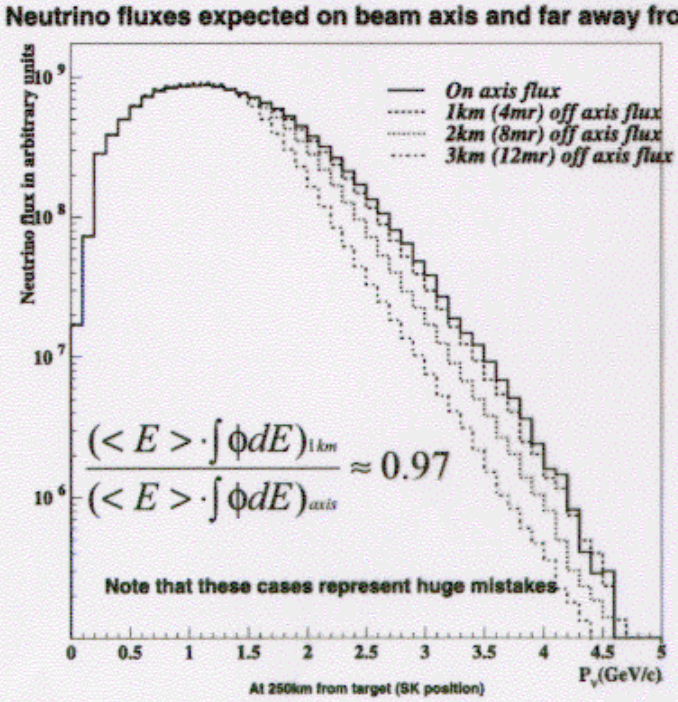


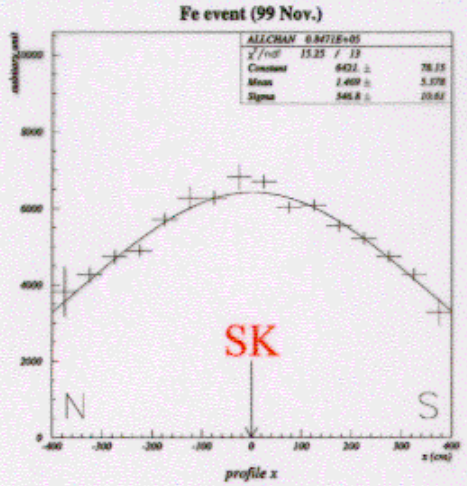
Beam Aiming

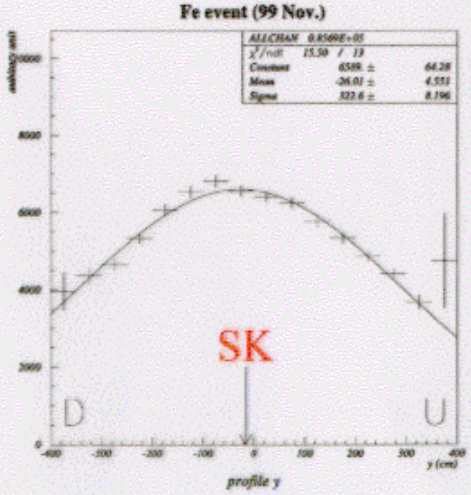
Survey accuracy: ~ 0.01 mr

Civil construction accuracy: ~ 0.1 mr

Beam aiming accuracy: < 1 mr

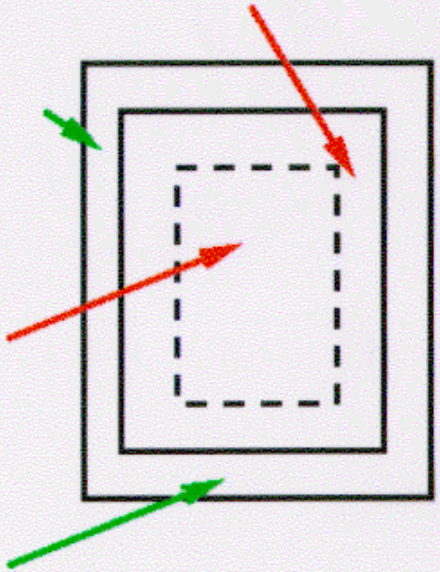




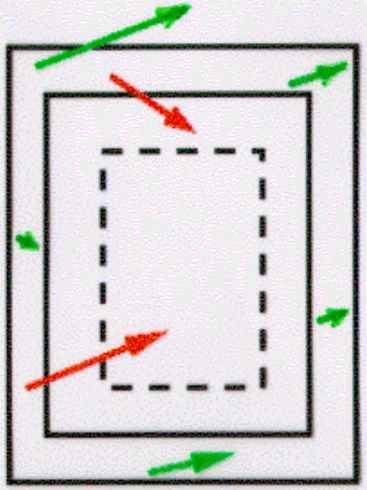


Profile of the neutrino flux
at 300 m measured by Muon/Fe

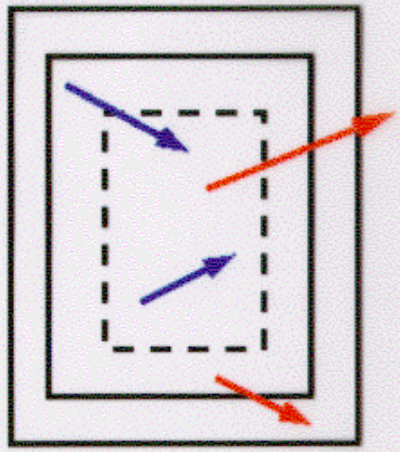
SK event category



Vertex in rock



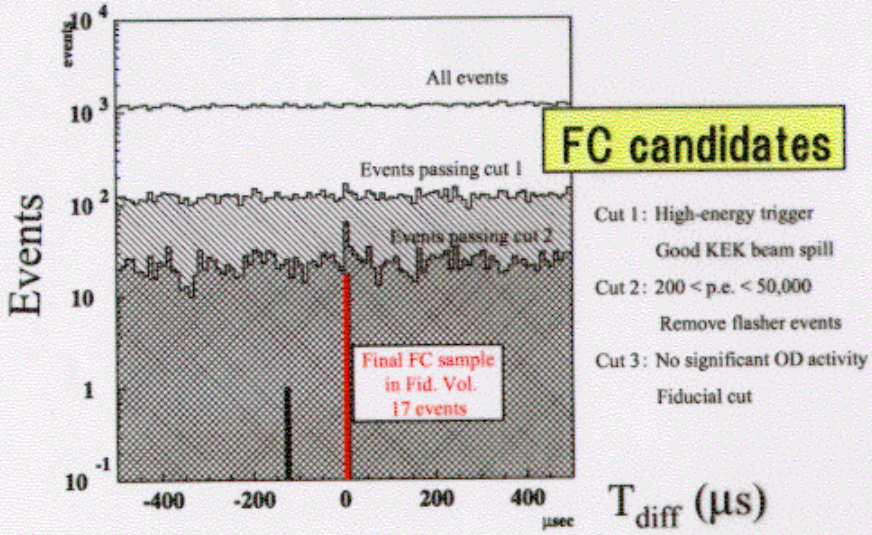
Vertex in OD



Vertex in ID

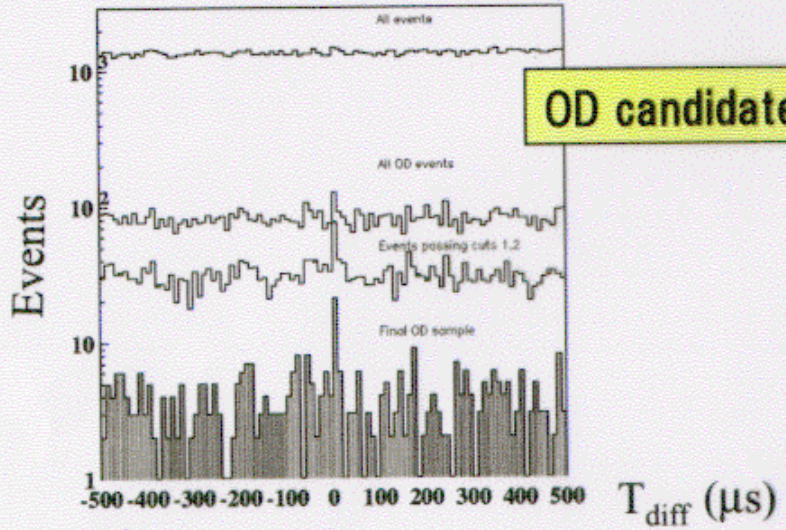
- FC (Fully Contained; Light in ID only)
  - Vertex inside the 22.5 kton fiducial volume
  - Vertex outside the fiducial volume
- OD contained (Light in OD only)
- Crossing (Light in both ID and OD)

Time difference distributions



FC candidates

Cut 1 : High-energy trigger
Good KEK beam spill
Cut 2 : 200 < p.e. < 50,000
Remove flasher events
Cut 3 : No significant OD activity
Fiducial cut

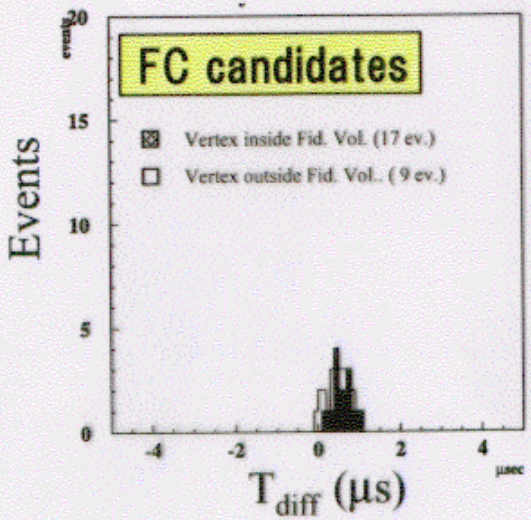


OD candidates

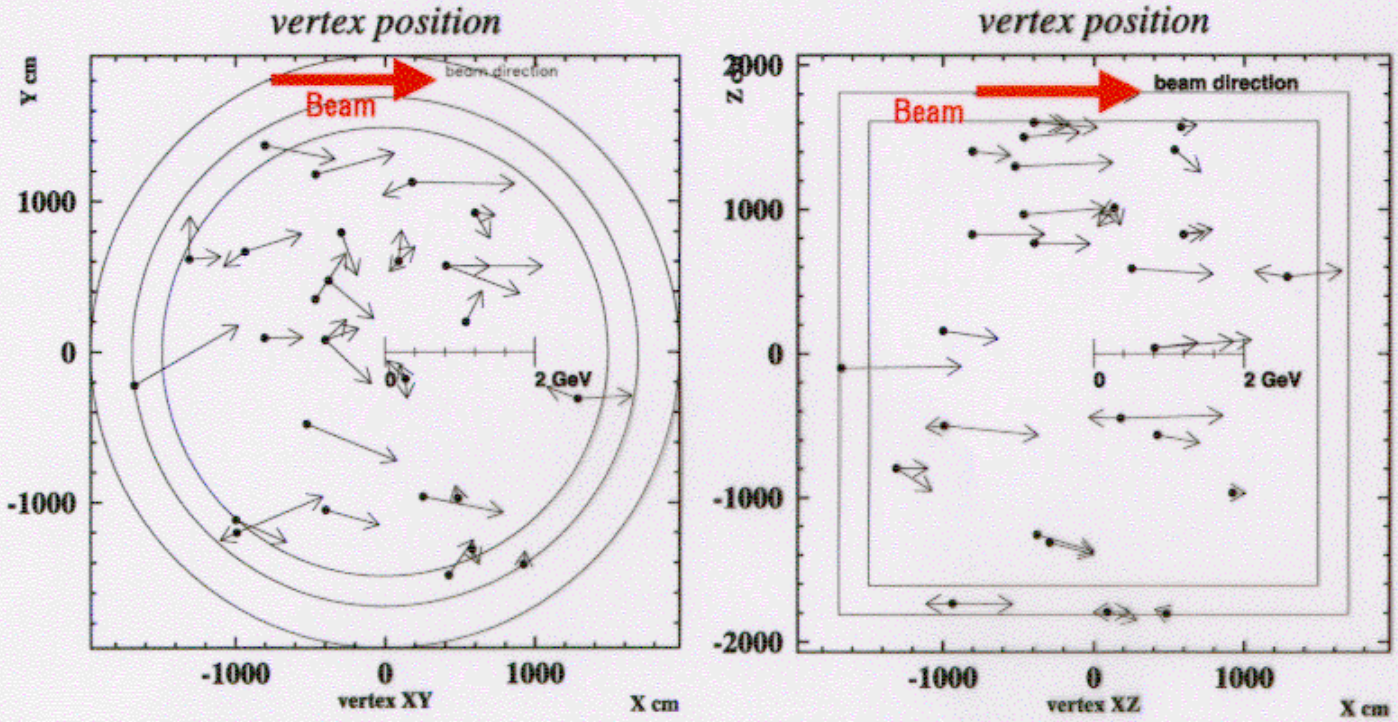
SK Events

$$-0.2 \leq T_{\mathrm{Diff}} \equiv T_{SK} - T_{Spill} - \mathrm{TOF} \leq 1.3\ \mu\mathrm{sec}$$

T_{Spill}, T_{SK}: Abs. time of spill start, SK event measured with GPS
TOF: Time of flight of neutrino from KEK to Kamioka
GPS: Global Positioning System

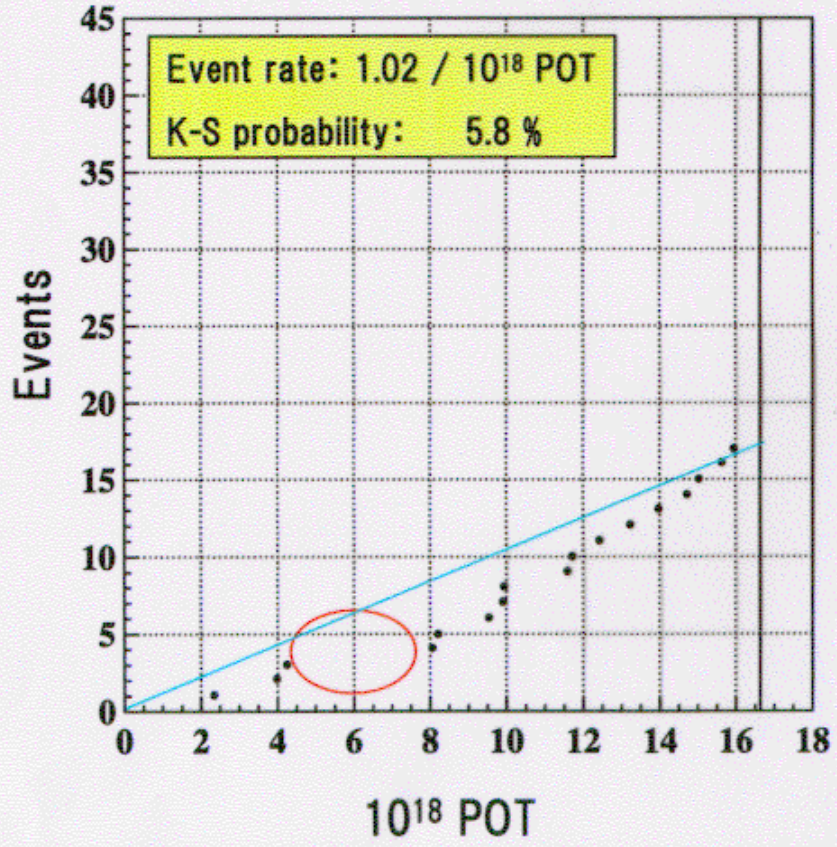


Vertex distribution of FC events

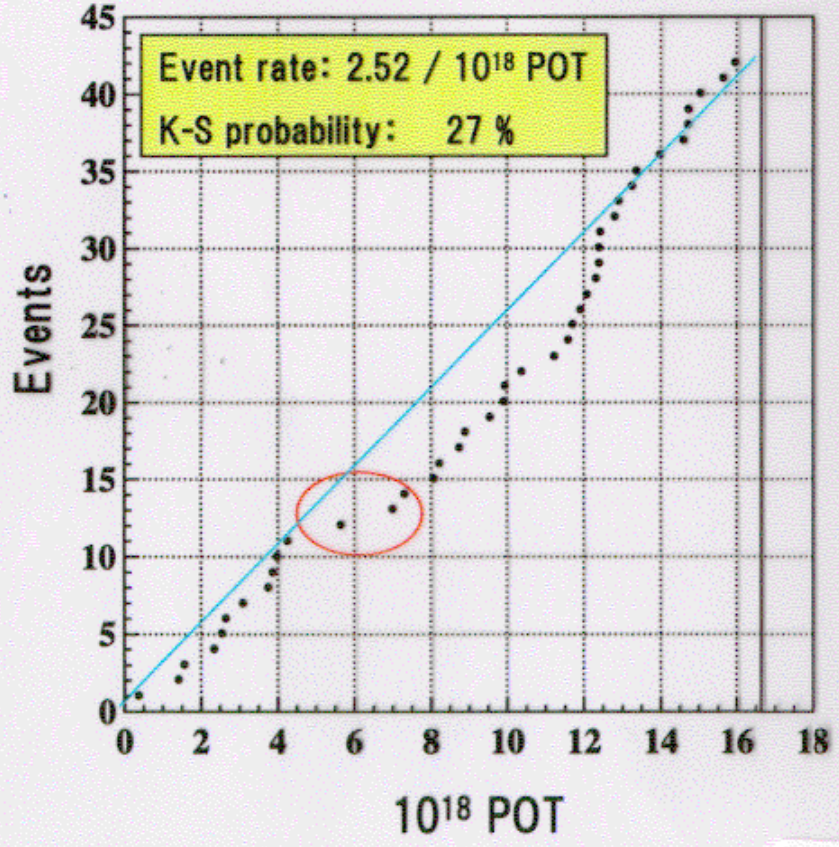


Events vs no. of protons on target

FC events in 22.5 kton fiducial volume



All events (FC + OD)



Calculation of expected number of SK events

$$N_{SK}^{expected}(\text{null osc.}) = N_{KEK}^{observed} \cdot R$$

R: Calculated Event Ratio
(Far-to-Near Ratio)

$$R = \frac{\int F_{SK}(E_\nu)\ \sigma(E_\nu)\ dE_\nu}{\int F_{KEK}(E_\nu)\,\sigma(E_\nu)\,dE_\nu} \bullet \frac{N_{SK}^{target}}{N_{KEK}^{target}}$$

- ν_μ flux (ratio) from beam Monte Carlo
  - Confirmed by the pion monitor above 1 GeV
- 1 kton and SK
  - Water target ⇒ common cross section
  - Cross section uncertainty cancels out

SK events summary

Period: June 1999 – March 2000

SK live POT: 16.64×10^{18}

- **Fully Contained** 26
  - Vertex in 22.5 kton fiducial volume 17
    - 1-ring 10
      - μ-like 9
      - e-like 1
    - Multi-ring 7
  - Vertex outside of fiducial volume 9
- **Crossing** 10
  - Exiting 4
  - Entering 6
- **OD contained** 8

Background		
	FC:	negligible
	Crossing:	0.17 ev.
	ODC:	0.37 ev.

Expected number of SK events

(FC in the fiducial volume; for the case of null oscillation)

	1 kton	Muon/Fe	SciFi
Total mass (ton)/ Fiducial mass (ton)	496 (inner) /50.3	1000/312	8.42/4.94
Acceptance*Efficiency (as of Jan-Mar' 00)	0.714	0.33	0.27
Live POT	13.5×10^{18}	15.0×10^{18}	12.4×10^{18}
Number of Events	47486	157723	1997
Live POT(SK)	1.66×10^{19}		
$N^{\text{expected}}_{\text{SK}}$	$29.2^{+3.5}_{-3.3}$	29.8 ± 4.6	$28.9^{+3.7}_{-4.1}$

Systematic errors

(For expected number of FC events in Fid. Vol., deduced from 1 kton)

- 1 kton – SK correlated error on the detection efficiency : 1 kton pe.>1000, SK pe.>200

	1 kton	SK	residual
• σ_{NC} (±30%)	-4.1% +4.8%	-3.3% +3.9%	+0.8% -0.9%
• Spectrum uncertainty	-2.4% +3.4%	-1.1% +1.6%	+1.3% -1.7%

- 1 kton
  - Fiducial volume ±6%
  - Multi-event ambiguity ±3%
- SK (Fiducial volume, MC statistics) ±3%
- CT normalization ±1%
- Near/far ratio +5.8% -7.4%

- $N_{SK}^{expected}$ ~±10% (~±15% in '99 runs)

SK observed vs. expected

		Expected			
			$\Delta m^2(\times 10^{-3} eV^2)$		$\sin^2 2\theta = 1$
	Obs.	Null Osc.	3	5	7
FC 22.5kt	17	$29.2^{+3.5}_{-3.3}$	$19.3^{+2.5}_{-2.4}$	$12.9^{+1.6}_{-1.6}$	$10.8^{+1.4}_{-1.3}$
1-ring	10	17.6±2.5	10.4±1.7	6.8±1.1	6.2±1.0
μ-like	9	15.8±2.6	9.0±1.5	5.4±0.9	4.9±0.8
e-like	1	1.7±0.3	1.5±0.3	1.4±0.3	1.3±0.3
multi ring	7	11.6±2.0	8.8±1.6	6.1±1.1	4.6±0.8
FC Out of FV	9	12.4±2.5	8.1±1.7	5.5±1.1	4.8±1.0
OD contained	8	21.8±8.3	14.5	9.5	7.7
Crossing	10	10.4±3.8	7.9	5.2	3.6

Conclusions

- June 1999 – March 2000 Summary:
  SK live POT = 16.64×10^{18}
  Fully contained events with vertices inside the SK 22.5 kton FV
  $N_{SK}^{observed} = 17$
  $N_{SK}^{expected}$(null oscillation) = $29.2^{+3.5}_{-3.3}$
- The observed result disfavors null oscillation at the 2σ level.
- Future:
  - More statistics
    ➔To be updated at ICHEP2000: May – June '00 data will be included.
  - Spectrum comparison
  - Study of neutrino interactions at ~ 1 GeV