K2K and T2K

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For the 2006 External Review Panel

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University of Barcelona, Boston University, Chonnam National University, Dongshin University, University of Geneva, Hiroshima University, ICRR, Inst. for Nuclear Research Moscow, KEK, Kobe University, Korea University, Kyoto University, Massachusetts Institute of Technology, Niigata University, Okayama University, University of Rome "La Sapienza", Saclay (DSM-DAPNIA), Seoul National University, SUNY at Stony Brook, Tokyo University of Science, Tohoku University, University of California Irvine, University of Hawaii, University of Tokyo, University of Washington, University of Valencia, Warsaw University

35 institutes, 219 collaborators for latest K2K paper hep-ex/0606032

Publications (only refereed journal)

1) Measurement of Neutrino Oscillation by the K2K Experiment.
By K2K Collaboration
accepted for publication in Phys.Rev.D. [hep-ex/0606032]
2) Measurement of the quasi-elastic axial vector mass in neutrino-oxygen interactions.
By K2K Collaboration
Phys.Rev.D74:052002,2006. [hep-ex/0603034]
3) An Improved search for nu(mu) ---> nu(e) oscillation in a long-baseline accelerator experiment.
By K2K Collaboration
Phys.Rev.Lett.96:181801,2006. [hep-ex/0603004]
4) Search for coherent charged pion production in neutrino-carbon interactions.
By K2K Collaboration
Phys.Rev.Lett.95:252301,2005. [hep-ex/0506008]
5) Evidence for muon neutrino oscillation in an accelerator-based experiment.
By K2K Collaboration
Phys.Rev.Lett.94:081802,2005. [hep-ex/0411038]
6) Measurement of single pi0 production in neutral current neutrino interactions with water by a 1.3-GeV wide band muon neutrino beam.
By K2K Collaboration
Phys.Lett.B619:255-262,2005. [hep-ex/0408134]
7) The K2K SciBar detector.
By K. Nitta, et al.,
Nucl.Instrum.Meth.A535:147-151,2004. [hep-ex/0406023]
8) Search for electron neutrino appearance in a 250 km long baseline experiment.
By K2K Collaboration
Phys.Rev.Lett.93:051801,2004. [hep-ex/0402017]
9) Indications of neutrino oscillation in a 250 km long baseline experiment.
By K2K Collaboration
Phys.Rev.Lett.90:041801,2003. [hep-ex/0212007]
10) Near muon range detector for the K2K experiment: Construction and performance.
By K2K MRD GROUP
Nucl.Instrum.Meth.A482:244-253,2002, Erratum-ibid.A488:673,2002. [hep-ex/0107041]
11) Detection of accelerator produced neutrinos at a distance of 250-km.
By K2K Collaboration
Phys.Lett.B511:178-184,2001. [hep-ex/0103001]
12) Design, construction, and operation of SciFi tracking detector for K2K experiment.
By K2K Collaboration
Nucl.Instrum.Meth.A453:165-176,2000. [hep-ex/0004024]

- oscillation 6
- ν interactions 3
- detector 3

K2K experiment overview

- long baseline neutrino oscillation experiment using muon neutrino beam produced by 12GeV PS at KEK

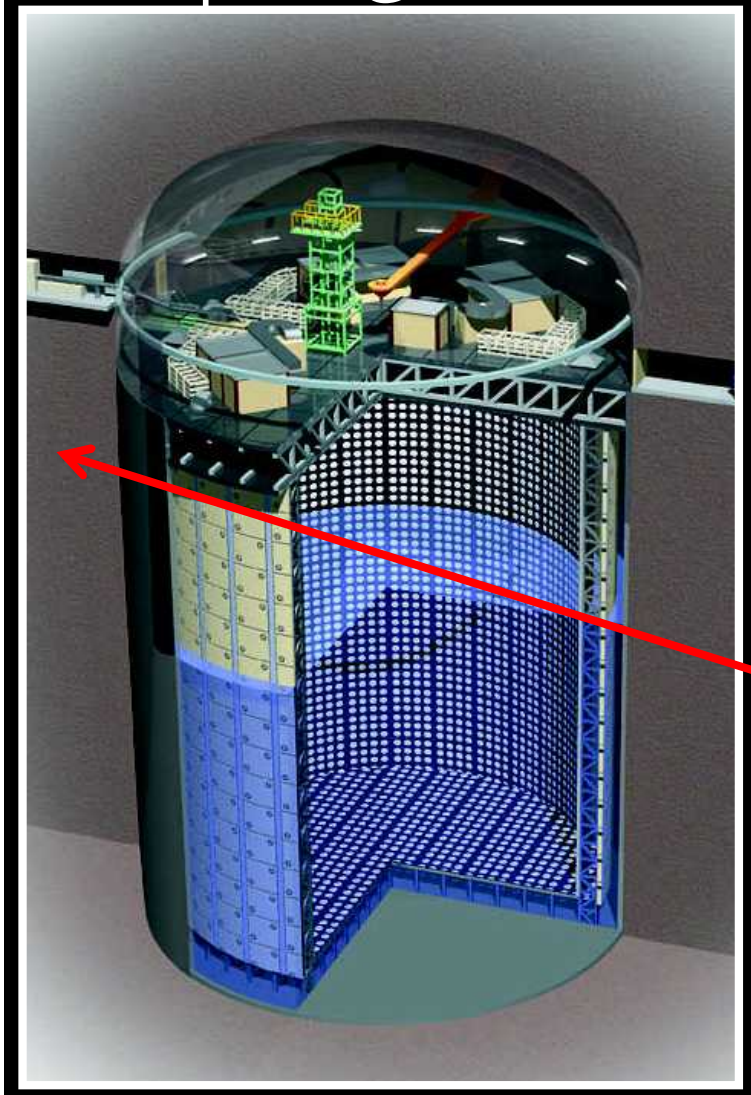
- Neutrino data have been accumulated successfully during Jan. 1999 to Nov. 2004 (completed).

- $\nu\mu$ disappearance phenomena was confirmed by accelerator-based neutrino beam at the first time; $\nu\mu$ oscillation parameters (Δm^2 and $\sin^2 2\theta$) consistent with the atmospheric neutrino oscillation parameters.

- No νe appearance signal was observed, $\sin^2 2\theta_{e\mu} < 0.13$ @ $\Delta m^2 = 2.8 \times 10^{-3} eV^2$

K2K experiment overview (cont.)

Super-K@250km

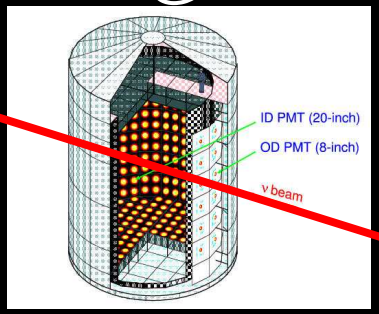


- ICRR hosts two detectors.
  - Super-K (the far detector) at 250km.
  - 1KT (1,000ton Water Cherenkov) at 300m.

- took the responsibility for construction, calibration, data reduction, analyses

ν

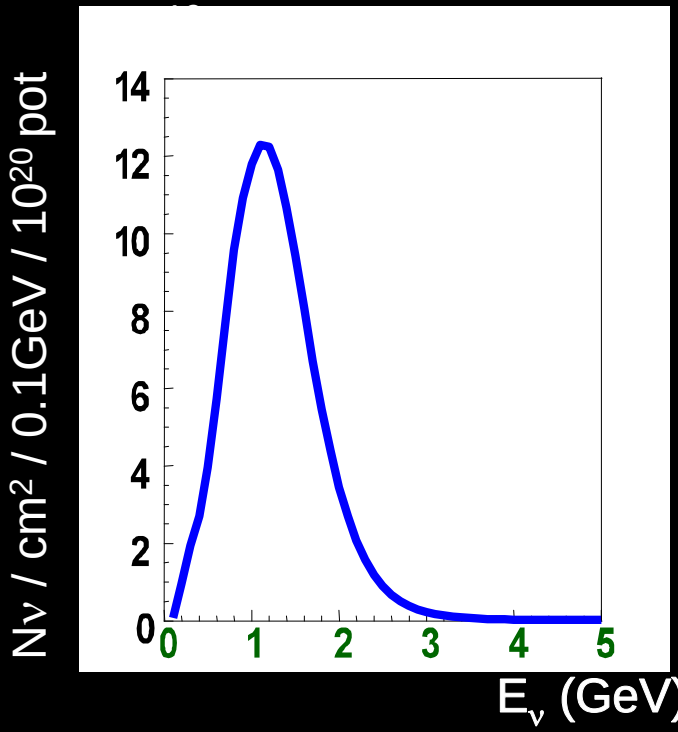
1KT@300m



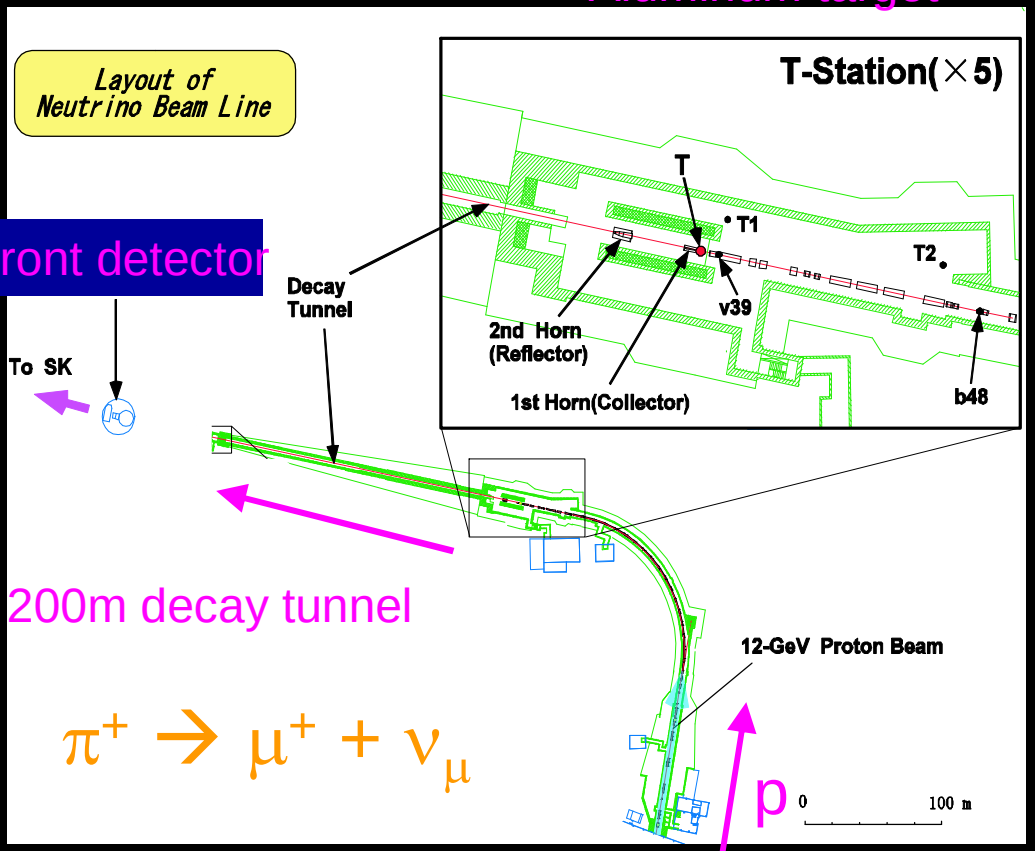
K2K neutrino beam (in KEK)

- almost pure ν_μ beam (~98%)
- Eν ~ 1.3 GeV

ν_μ energy spectrum
@ front detector site

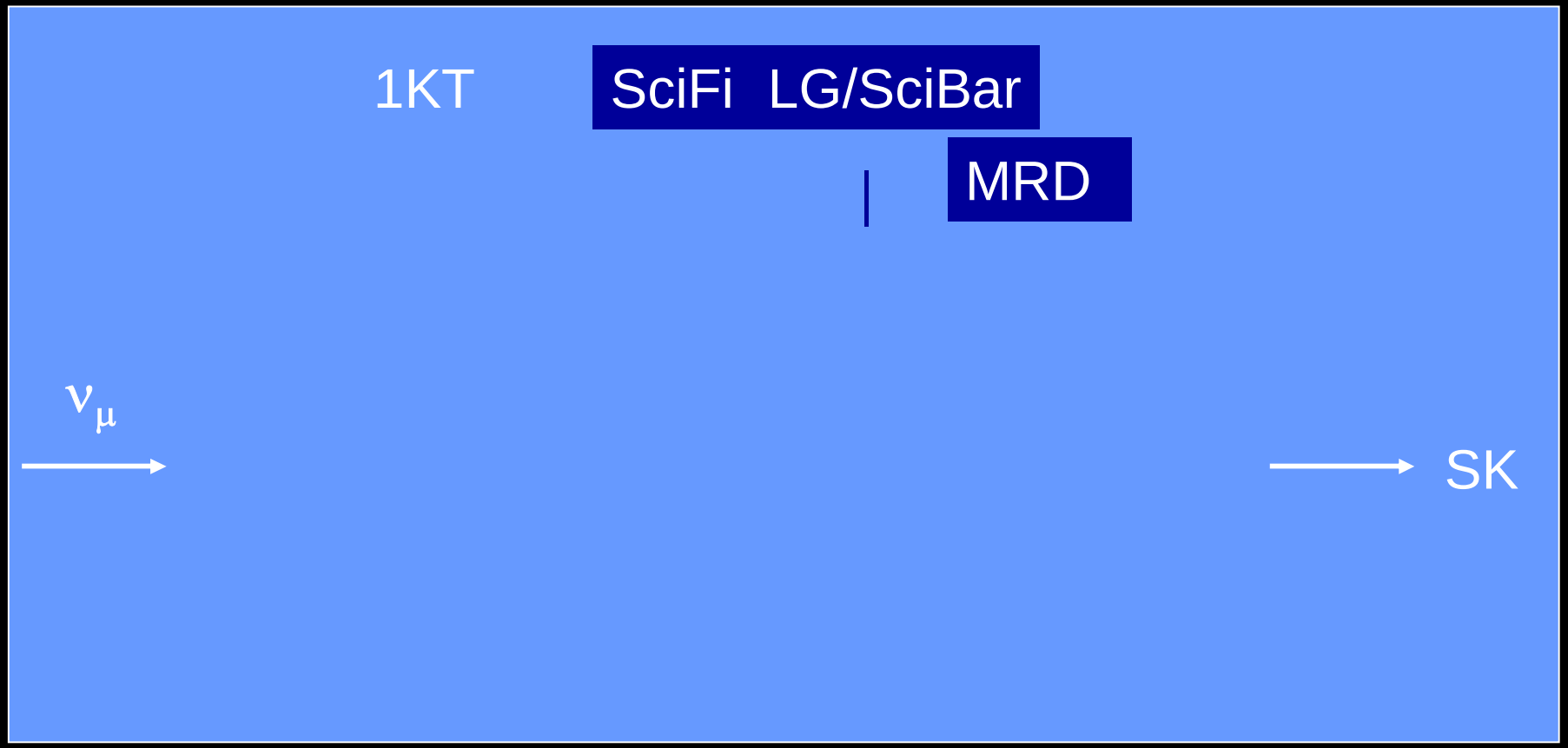


Aluminum target



12GeV PS

Near Detectors at 300m



- 1KT: water cherenkov detector
- SciFi: scintillating fiber and water target
- LG: Lead glass calorimeter (removed in 2002)
- SciBar: full-active scintillator detector (installed in 2003)
- MRD: muon ranger, iron absorbers and drift tubes

ND neutrino measurement

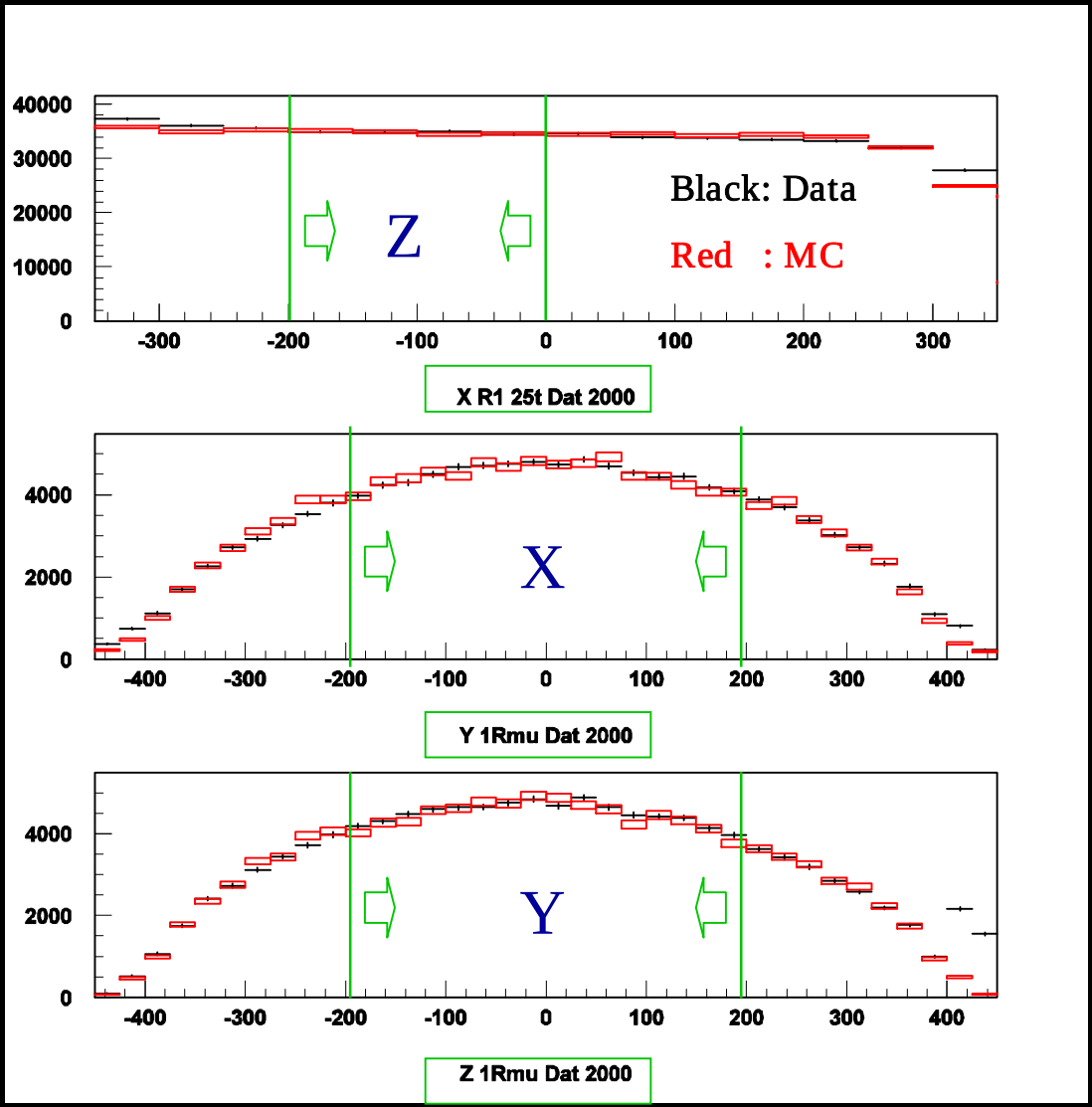
- **Absolute flux measurement**
  - 1KT water Cherenkov data

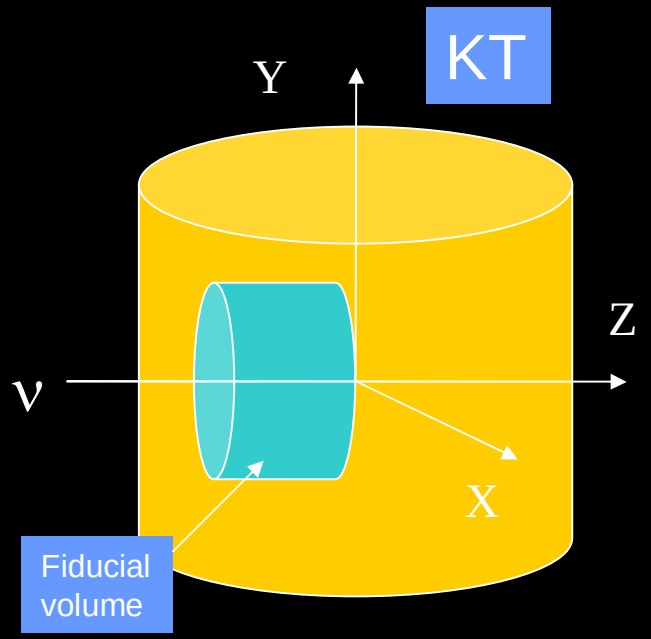
$$N_{SK}^{exp} = N_{KT}^{int} \bullet \frac{\int \Phi_{SK}(E_\nu)\sigma(E_\nu)\varepsilon_{SK}\,dE_\nu}{\int \Phi_{KT}(E_\nu)\sigma(E_\nu)\varepsilon_{KT}\,dE_\nu} \bullet \frac{M_{SK}}{M_{KT}} \bullet \frac{POT_{SK}}{POT_{KT}} \bullet C_{\nu e}$$

- **Spectrum measurement**
  - 1KT
    - Fully contained 1 ring μ-like sample
  - SciFi
    - 1track, 2track QE and 2track nonQE sample
  - SciBar
    - 1track, 2track QE and 2-track nonQE sample

KT data
(and other near detectors)

Observed ν events in KT



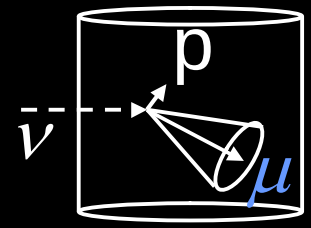


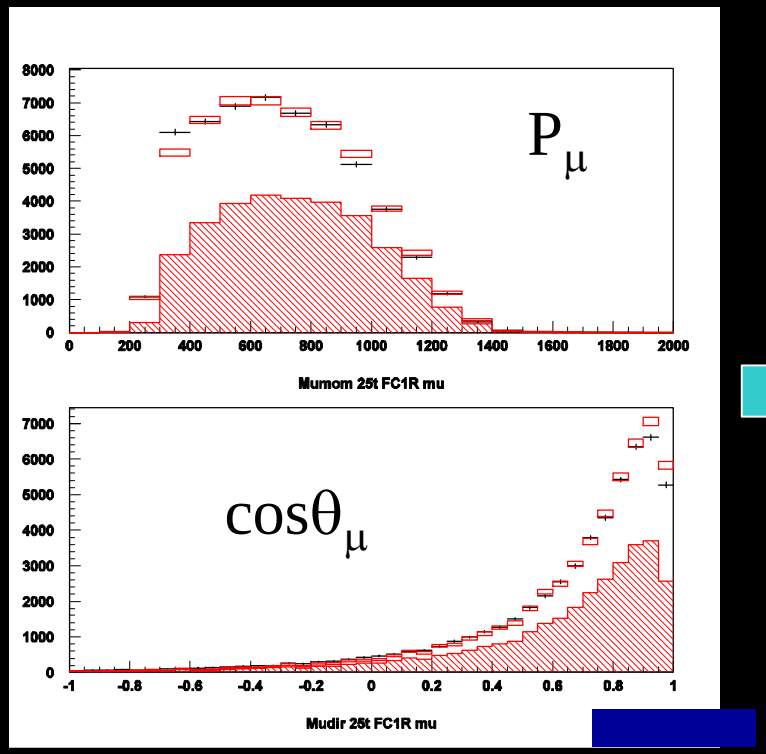
Very good agreement btw data and MC.

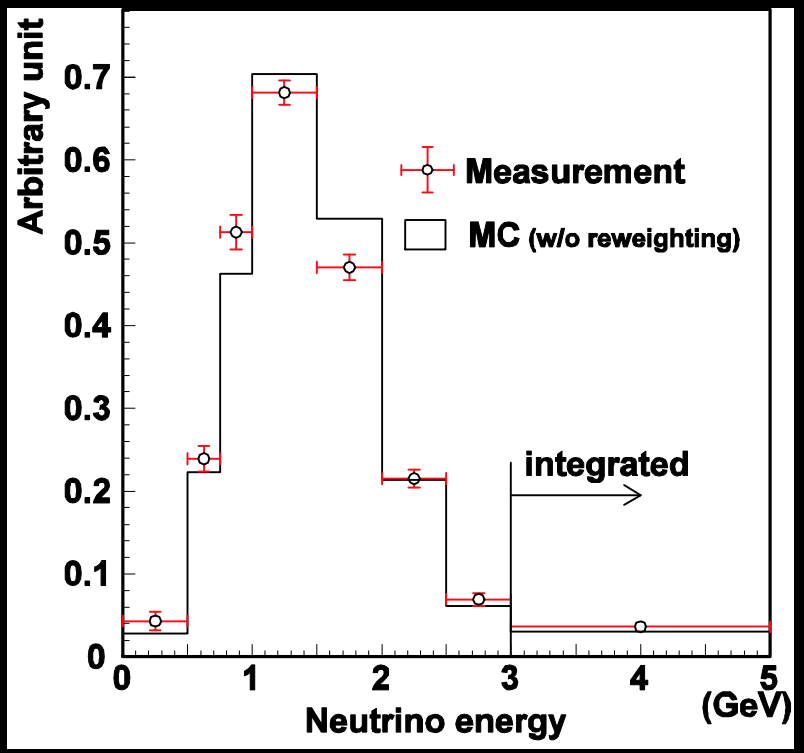
$$N_{KT}^{int} \rightarrow N_{SK} = 158.1^{+9.2}_{-8.6} \text{ events expected}$$

Spectrum fit at near detector

Fully Contained single-ring μ
(CCQE:60%)



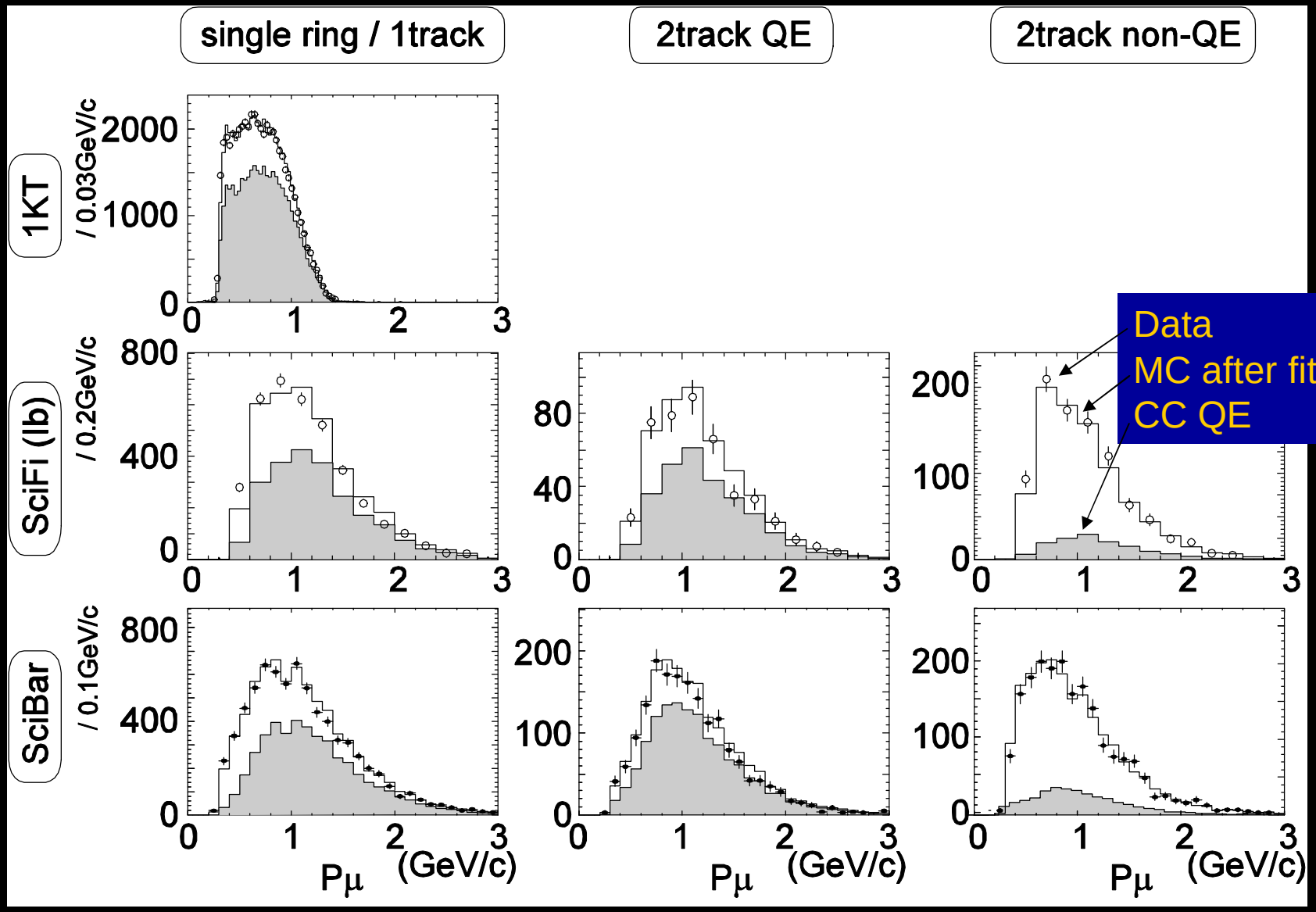




(**p**μ, θμ) for 1ring μ-like sample (1KT), 1track, 2track QE and 2track nonQE sample (SciFi, SciBar)

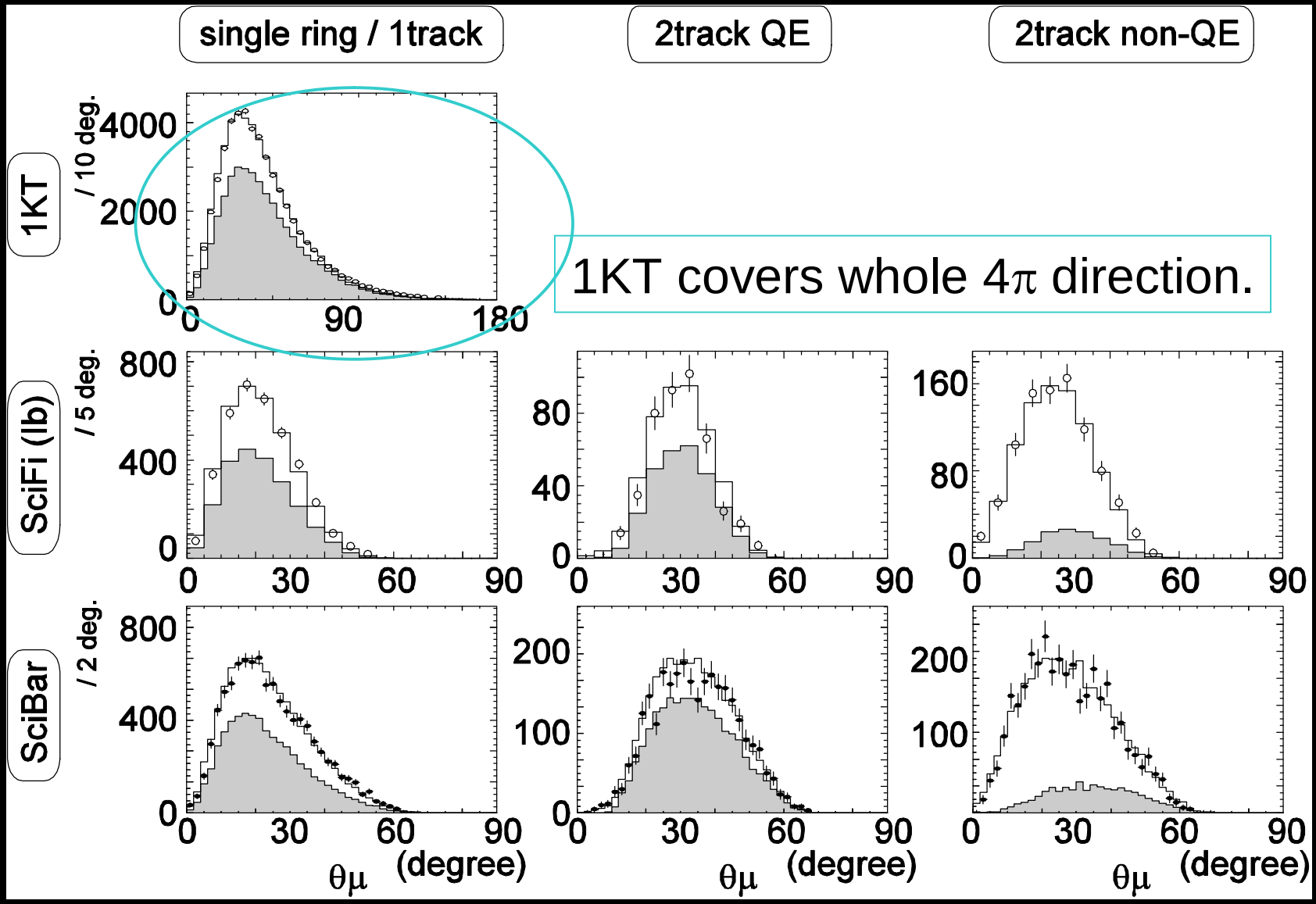
→ Φ(Eν), nonQE/QE ratio are obtained

Pμ distributions in each detector



Best fit MC reproduces all data well.

μ directions at near detectors

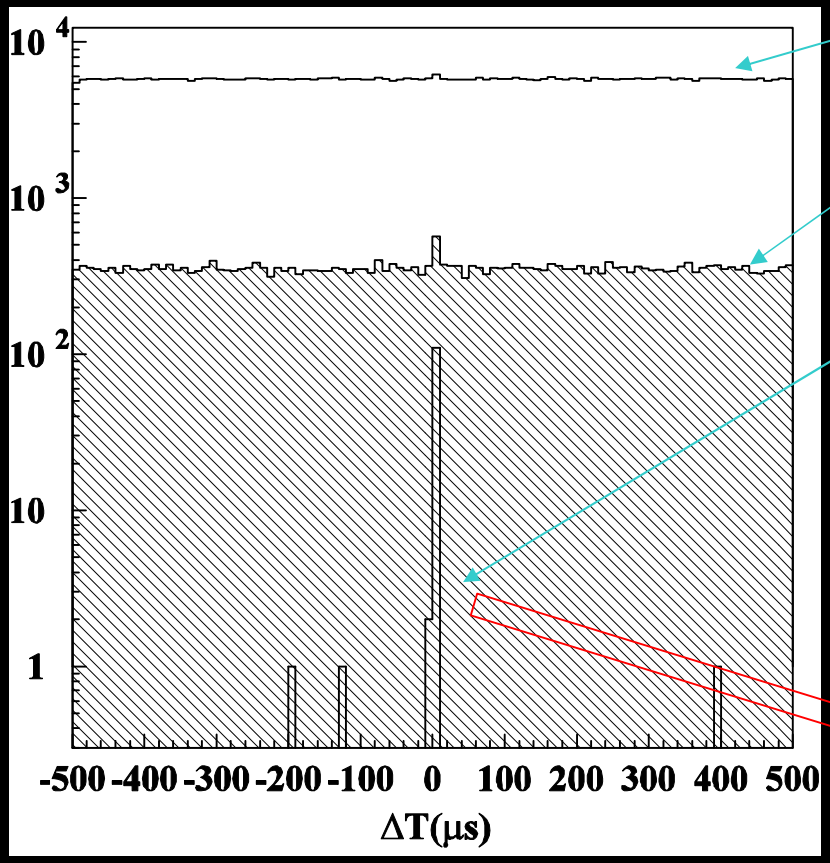


Good agreement in angular distributions as well.

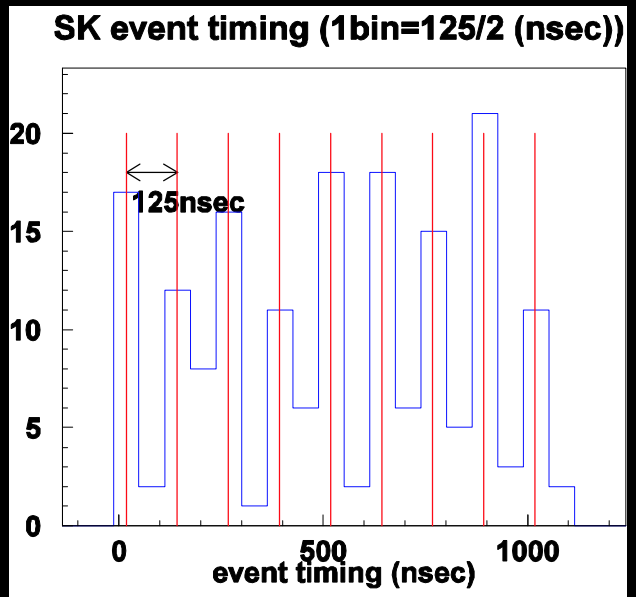
Super-K data
(and neutrino oscillation study)

Event selection @ SK

TOF (0.83m sec) cut using GPS



Selection criteria	# of events
|ΔT|<500μsec, no pre-activity (Decay-e cut)	578k
Total q within 300n sec >200(K2K-I), 94(K2K-II) (~20MeV)	53k
No OD activity (FC), Evis>30MeV, Fiducial volume(Dwall>2m)	115
|ΔT|=-0.2 ~ +1.3μsec	112



112 on-timing fully contained events in fiducial volume are observed.

SK event summary

	SK events
FC	112
1ring	67
1ring μ	58
1ring e	9
multi ring	45

Number

Spectrum

92.2×10^{18}POT

112 FC events are observed
158.1 +9.2 / - 8.6 events are expected (no osc.).

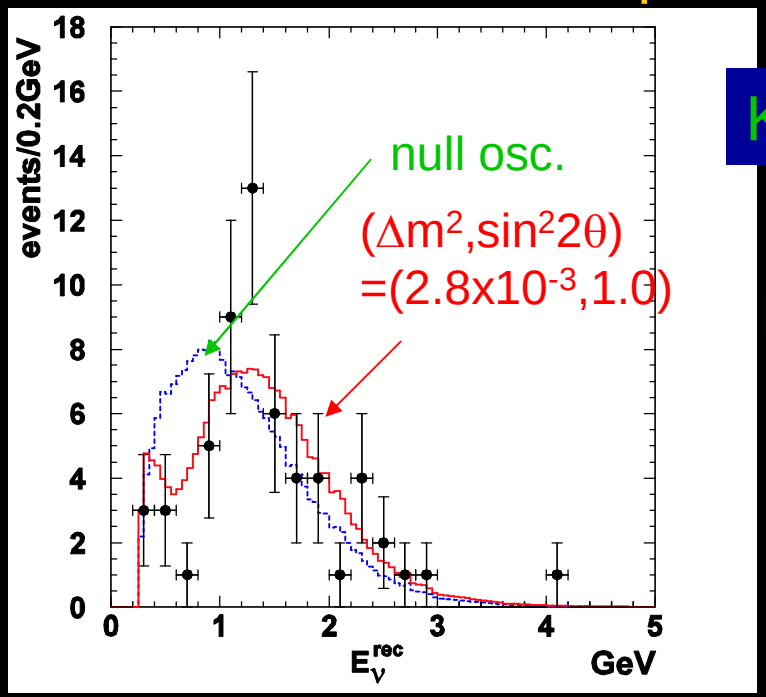
ν_μ disappearance analysis

Number of FC events

Obs. 112

Expected. $158.1^{+9.2}_{-8.6}$ (null osc.)

Reconstructed Eν spectrum



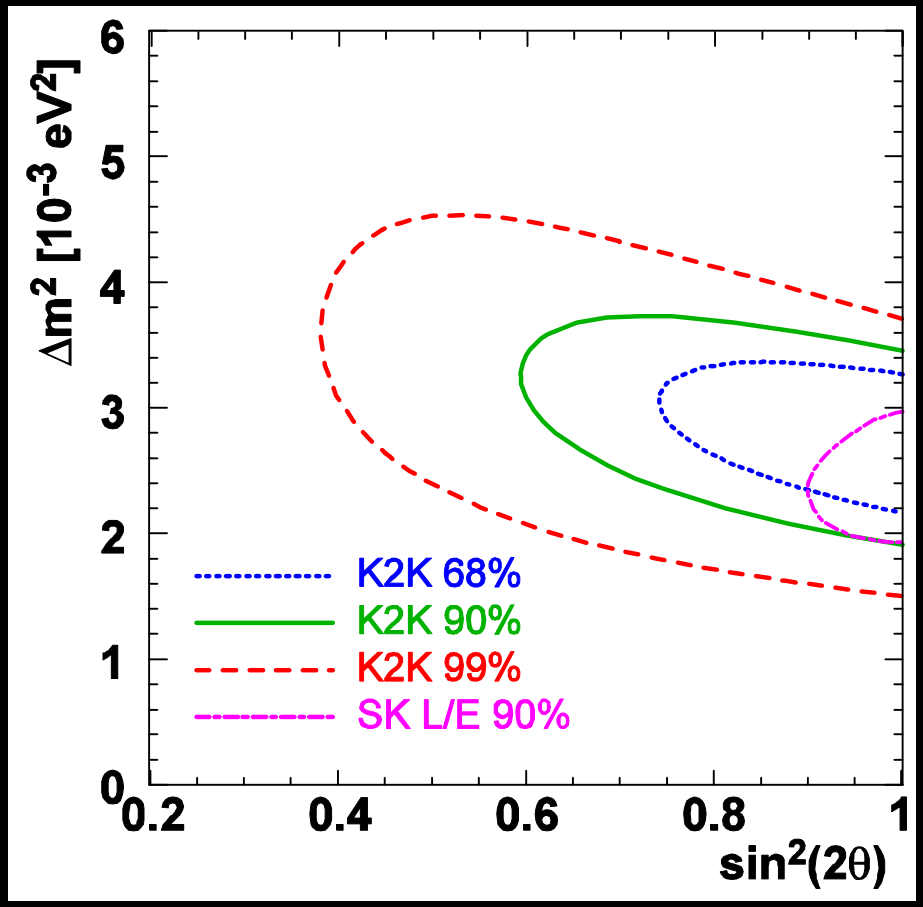
KS test probability for spectrum shape

Data-best fit $(2.8\times10^{-3},1.0)$	37%
Data-null osc.	0.07%

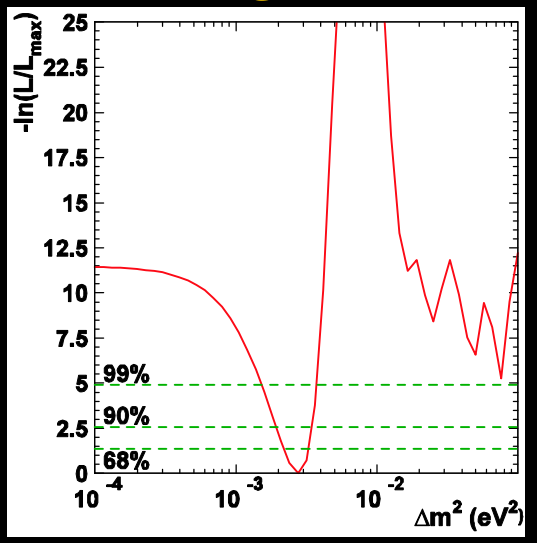
Null oscillation probability

	K2K	
Norm.	0.06%	(3.4σ)
Shape	0.42%	(2.9σ)
Shape+Norm.	0.0015%	(4.3σ)

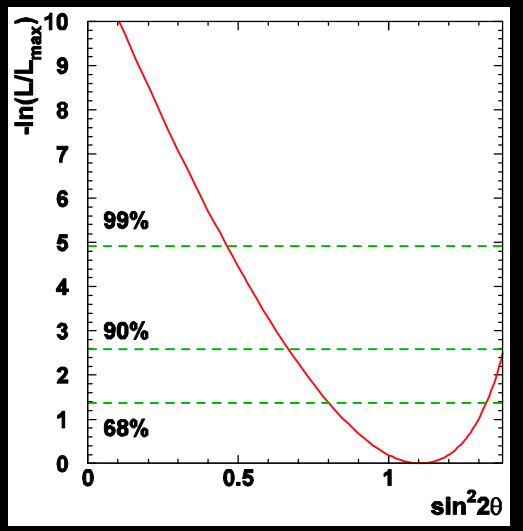
ν_μ disappearance allowed region



Δlikelihood @ $\sin^2 2\theta$=1.0



Δlikelihood @ Δm^2=2.8x10^{-3}



Best fit : (Δm^2,$\sin^2 2\theta$)

(2.55x10^{-3}, 1.19) (all region)

(2.75x10^{-3}, 1.0) (physical)

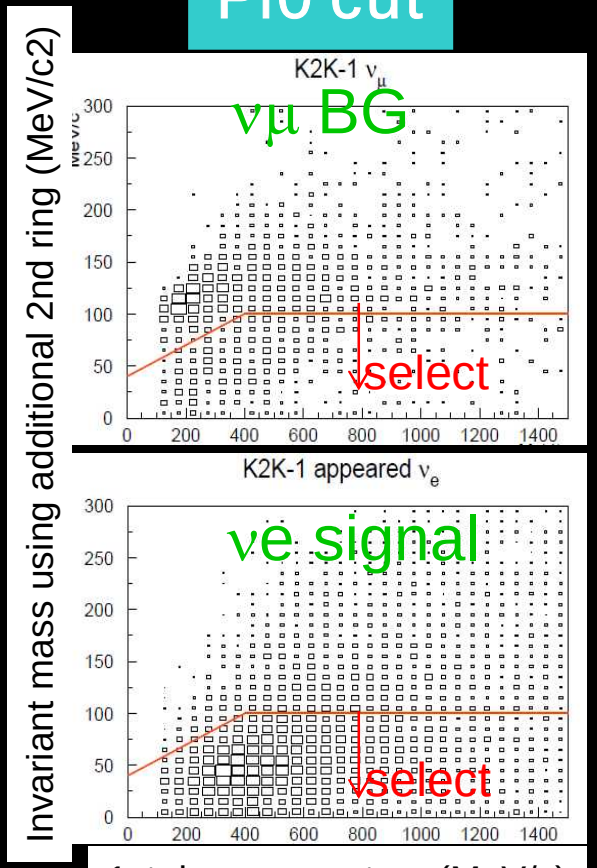
K2K confirmed neutrino oscillations discovered by atm ν.

Event selection for ν_e appearance search

—K2K-1—	νμ MC	beam νe	Data
FCFV	81.1	0.81	55
Single ring	50.92	0.47	33
Tight e-like cut	2.66	0.40	3
Evis > 100 MeV	2.47	0.40	2
No decay-e	1.90	0.35	1
Pi0 cut	0.58	0.17	0

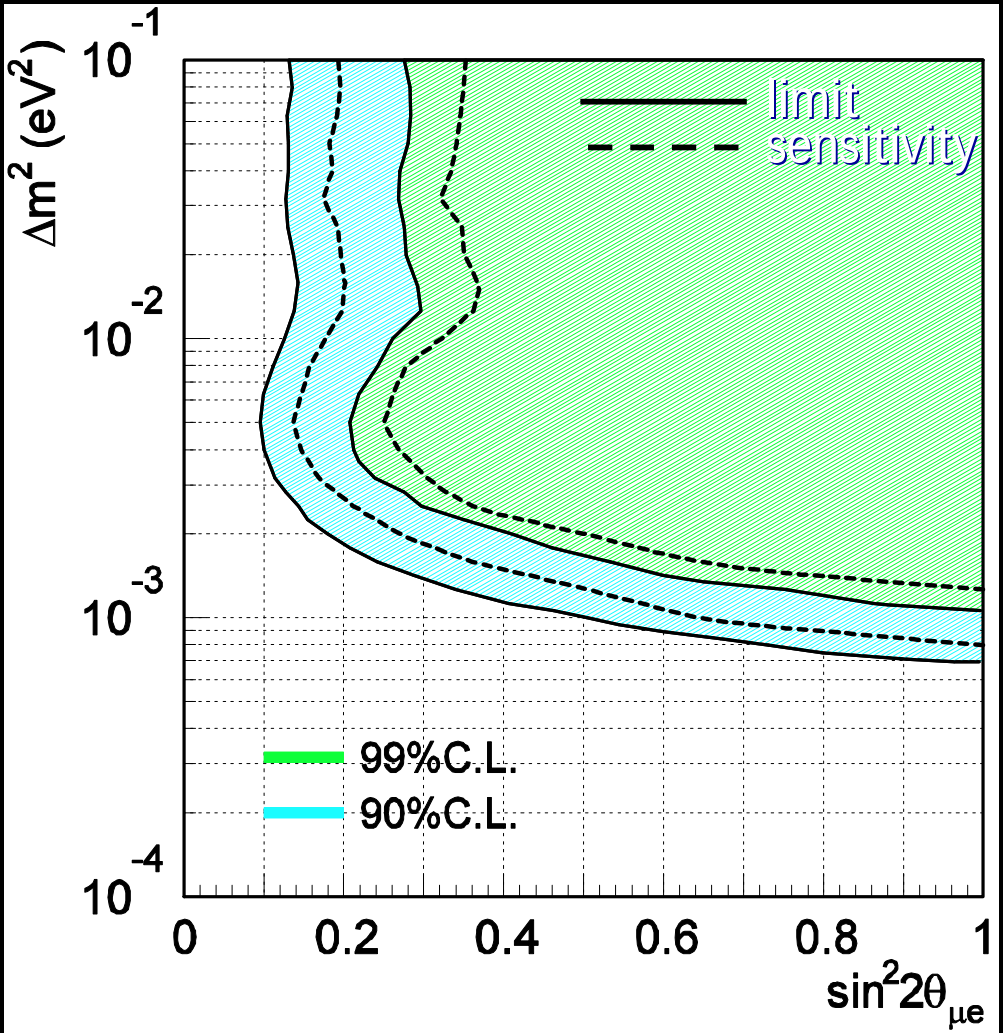
—K2K-2—	νμ MC	beam νe	Data
FCFV	77.4	0.86	57
Single ring	49.41	0.52	34
Tight e-like cut	3.21	0.44	5
Evis > 100 MeV	2.93	0.44	5
No decay-e	2.17	0.39	4
Pi0 cut	0.74	0.21	1

Pi0 cut



In total,
#expected BG = 1.70
#observed = 1

Exclude region for ν_e appearance search



upper limit (90% CL)

$\sin^2 2\theta_{\mu e} < 0.13$ @2.8×10^{-3} eV^2

K2K

$\sin^2\theta_{13} < \sim 0.06$ @2.8×10^{-3}eV^2

(assuming $\sin^2 2\theta_{23} = 1.0$)

Consistent result

CHOOZ(reactor)

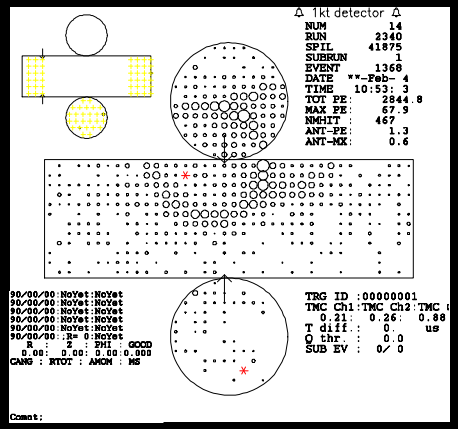
$\sin^2\theta_{13} < \sim 0.03$ @2.8×10^{-3}eV^2

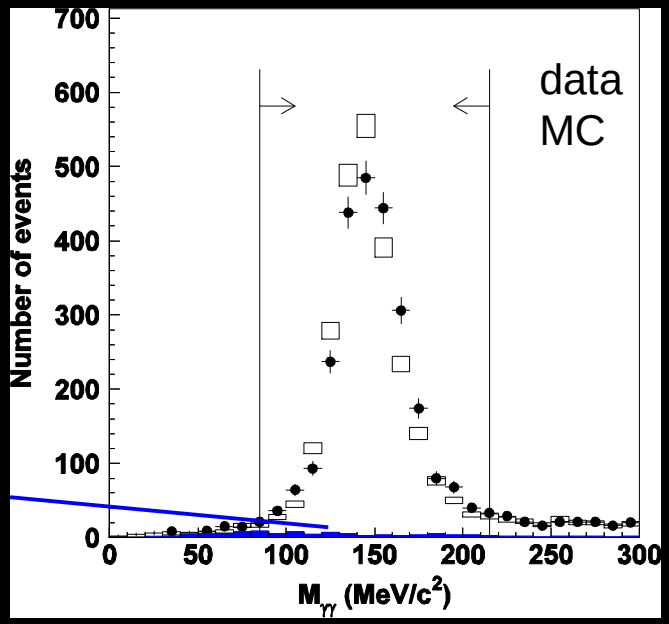
Cross section measurements in KT

Measurement of single π^0 production in neutral current neutrino interactions

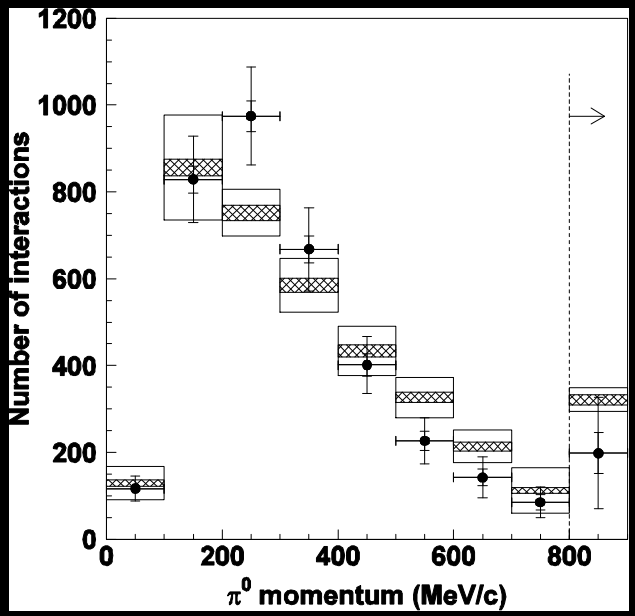
π^0 events

- single-event spill
- Fully-Contained
- number of rings = 2
- both e-like PID
- Mγγ : 85 ~ 215 MeV/c^2





non-π^0 BG



Large NC fraction of 87%

Results

Phys.Lett.B619:255-262,2005.

stat. sys.

$$\sigma(\mathrm{NC1}\pi^0) / \sigma(\nu_\mu \mathrm{CC}) = 0.064 \pm 0.001 \pm 0.007$$

at the K2K beam energy, $\langle E\nu \rangle \sim 1.3$ GeV

cf. $\sigma(\mathrm{NC1}\pi^0) / \sigma(\nu_\mu \mathrm{CC}) = 0.065$ from NEUT

cf. $\sigma(\nu_\mu \mathrm{CC}) \sim 1.1 \times 10^{-38}$ cm^2 / nucleon from NEUT

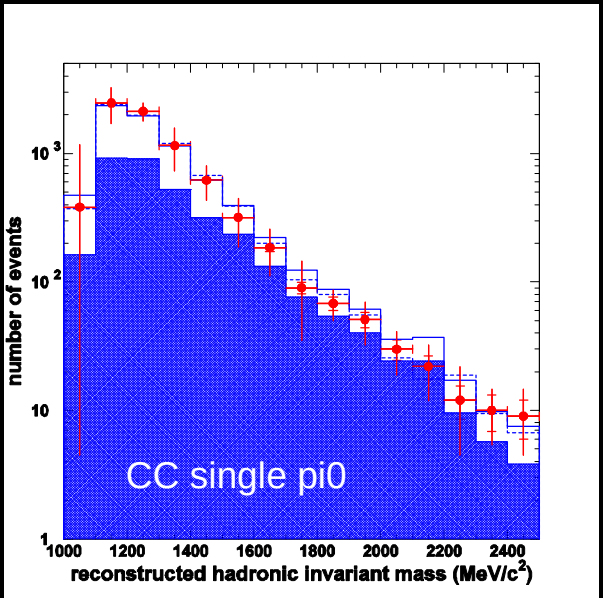
(K2K beam spectrum averaged)

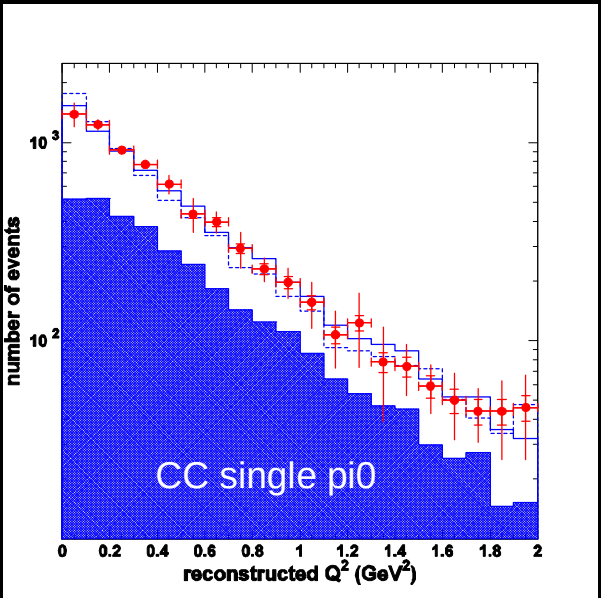
$\langle E\nu \rangle \sim 1.3$ GeV

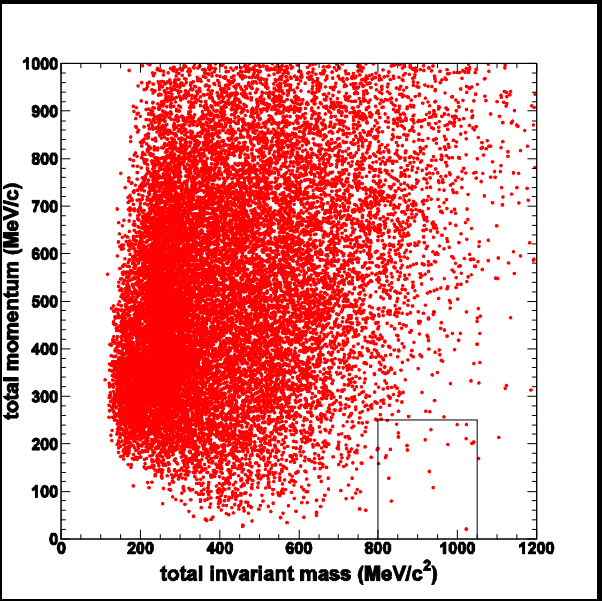
Study of atmospheric neutrino background for proton decay search

- K2K neutrino energy well matches proton decay $p \rightarrow e^+\pi^0$ BG
- KT data statistics ~ 10Megatonyears (Super-K ~400years)

2- or 3-ring $\mu\pi^0$ events in KT







$$\text{Atmospheric } \nu \text{ BG for } p \rightarrow e^+\pi^0 = 0.15^{+0.05}_{-0.03}(\text{stat.}) \pm 0.05(\text{syst.})\ (\text{Mtonyrs})^{-1}$$

(Draft in preparation)

Summary of K2K

- first detection of accelerator produced neutrinos at 250km distance.

- $\nu\mu$ disappearance phenomena was confirmed by controlled neutrino beam, at known distance.

- gives data for neutrino interaction studies.

- There are still unknown mixing angle θ_{13}. Precise determination of ($\sin^2 2\theta_{23}$, Δm^2) may help us to understand unknown underlying physics.

Next generation long baseline experiment, T2K

Future experiment, T2K

T2K experiment overview

• commissioning of the JPARC neutrino beam-line is expected to be in 2009.

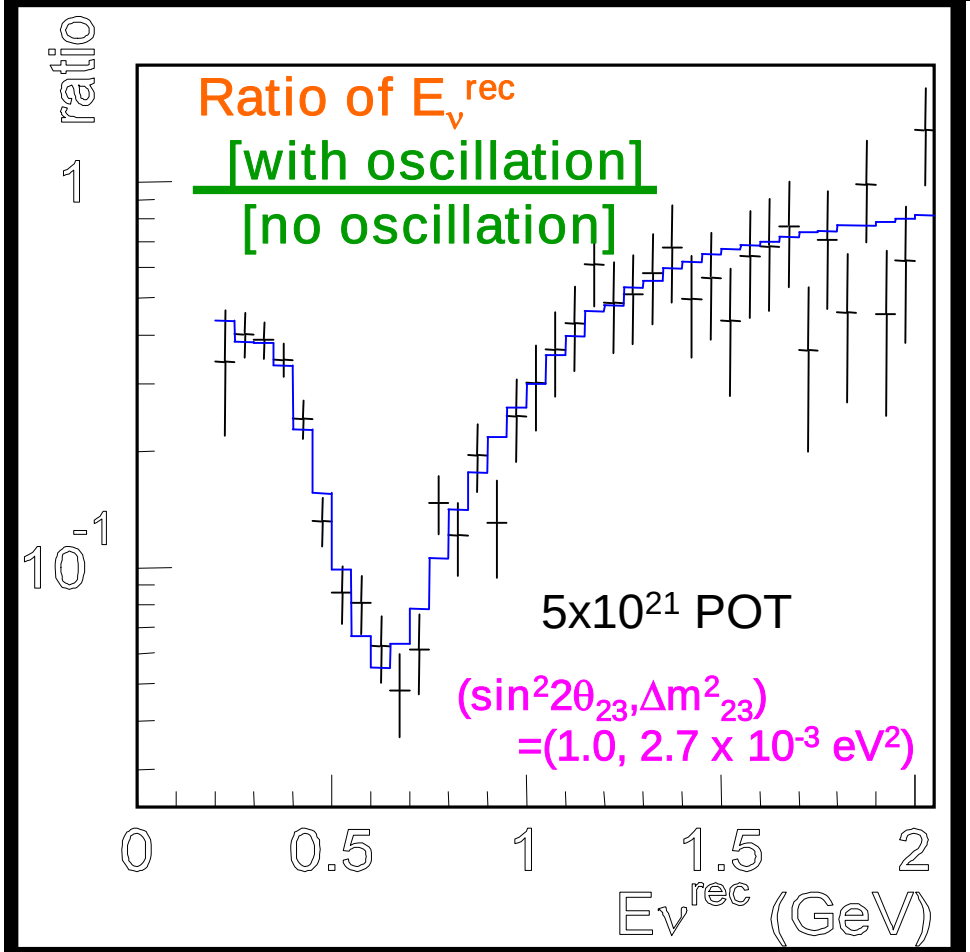
• ~50 times intense neutrino beam compared with K2K.
• physics sensitivities are maximized by using quasi-monochromatic neutrino beam (beam pointing to off-axis angle)

• aim to precisely measure $\nu\mu$ oscillation parameters (Δm^2 and $\sin^2 2\theta$) with the accuracy of ~1% level.

• aim to discover nonzero θ_{13} down to $\sin^2 2\theta_{13}$=~0.01 by νe appearance signal.

ν oscillation study: ν_μ disappearance and ν_e appearance

Single-ring μ



Single-ring electron (w/ π^0 cut)

of events
in 0.35~0.85 [GeV]

Signal … 103

Beam ν_e BG … 13

BG from ν_μ … 10

$5x10^{21}$ POT

$(\sin^2 2\theta_{13}, \delta, \Delta m^2_{23})$
$=(0.1., 0, 2.5 \times 10^{-3}\ eV^2)$

Super-K should be well prepared for T2K beam

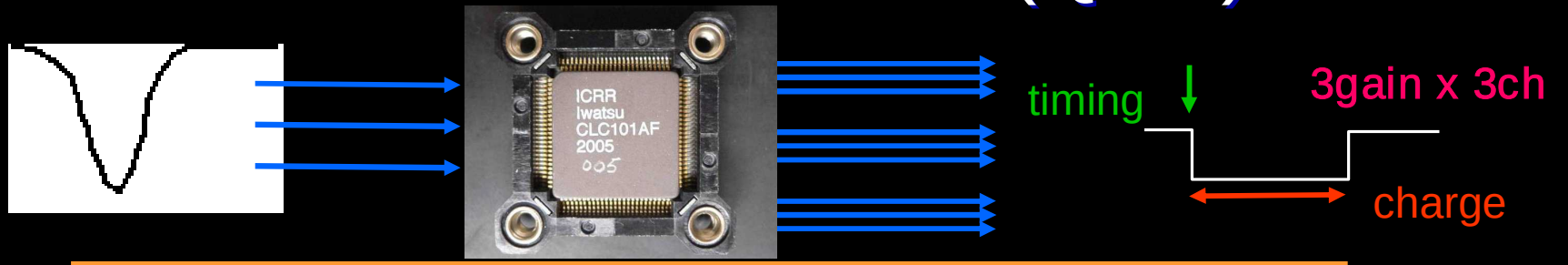
- ICRR hosts the far detector, Super-K at 300km.

- All front-end electronics will be replaced by newly developed ones in 2008.
  - The ASIC front-end chip development is ongoing
  - ν observation with good stability and accuracy

- Further detector calibration
  - study ring-ID capability for π^0 BG rejection in electron appearance
  - improve absolute energy scale uncertainty < 1%
  - light scattering and absorption in water, reflection on detector wall, TQ response of PMTs are also indispensable.

- software upgrade
  - improvements of reconstruction algorithms
  - Cherenkov ring finding, vertex fitter, energy determination…

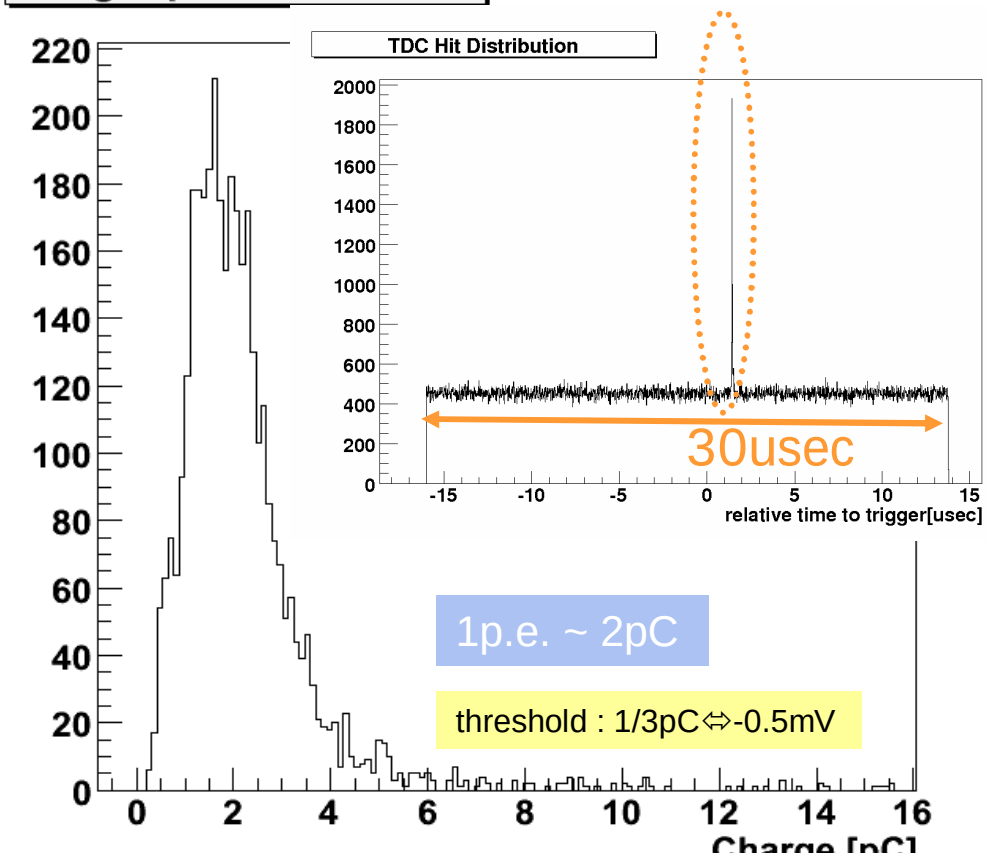
New front-end ASIC (QTC)



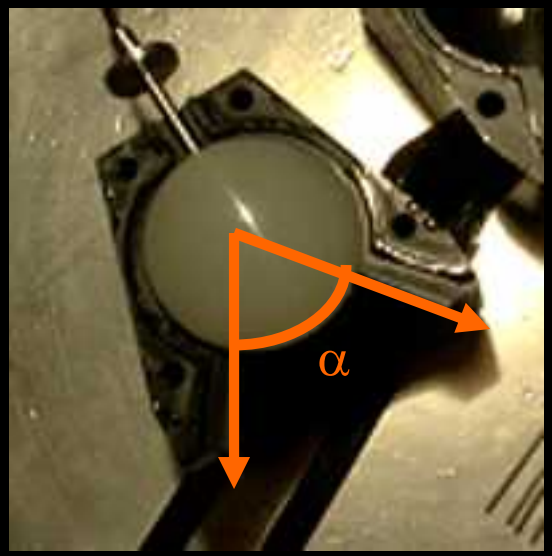
Implement all delicate analog processes in one chip
→ aim to achieve noise free, accurate response of electronics

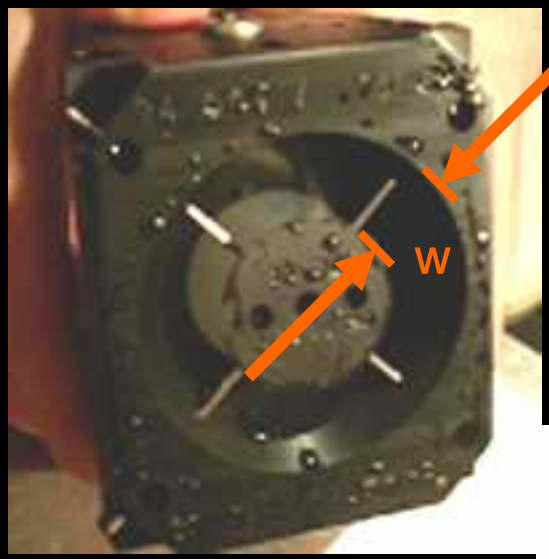
- 3 channel input
- High-speed
  - 500nsec per one cycle
- Build-in discriminator
- Wider dynamic range
  - ~ 1250 p.e. by 3 gain
  (c.f. ~250p.e. w/current FE)
- Charge resolution
  - 0.1pC ~ 0.05p.e.
- Timing resolution
  - < 0.1nsec (RMS)
- Lower Noise
  - No noise hit @ - 0.5mV(~1/6 p.e.)
- power dissipation
  - < 200 mW/ch
- Process
  - 0.35μm CMOS

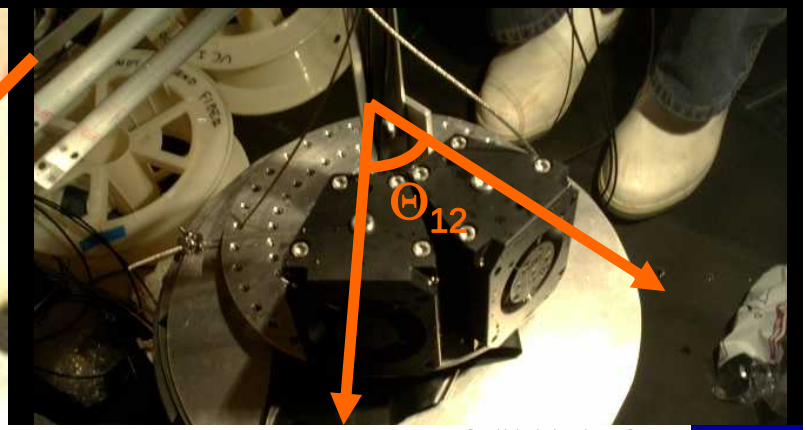
single-pe distribution



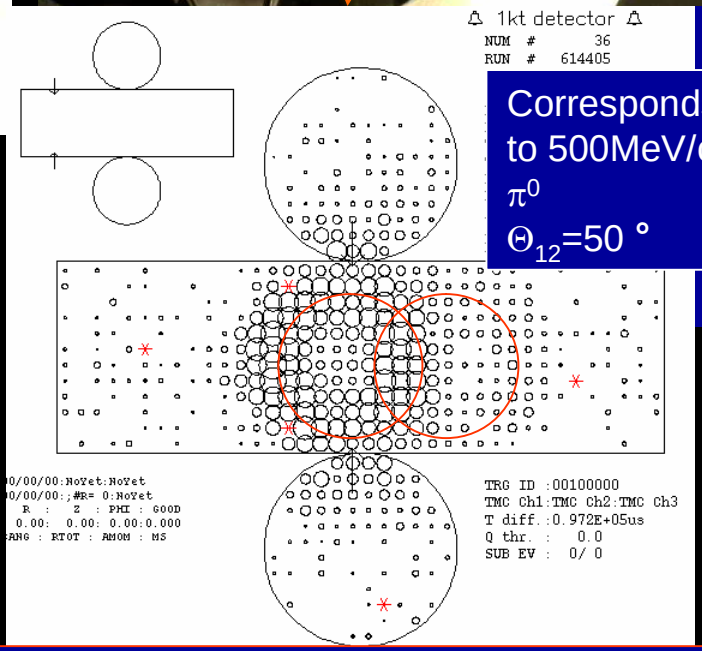
Cone light Generator (Prototype)







- Laser ball enclosed in delrin vessel.
- Adjustable:
  - cone angle (α), width (w) & opening angle (Θ_{12})
- To study π^0 ring finding efficiency



Corresponds to 500MeV/c π^0 Θ_{12}=50 °

Data taking successful at 1KT

Summary of T2K

- ICRR will take the responsibility for the far detector (operation, calibration, data analyses)
- aim to measure $\nu\mu$ oscillation parameter with ~1% accuracy.
- aim to discover unknown θ_{13} down to $\sin^2 2\theta_{13}$~0.01.

Thank you very much.