E362 (K2K)

12 GeV PS review

June 7、2004

1. Physics goal
2. Experimental principle
3. Status
4. Run plan for fiscal 2004
5. Activities before T2K

Koichiro Nishikawa
for K2K collaboration

Japan

KEK, ICRR, Kobe U, Kyoto U, Niigata U, Okayama U,

Tokyo U of Science, Tohoku U

Korea

Chonnam National U, Dongshin U, Korea U, Seoul National U

U.S.A.

Boston U, U of California (Irvine), U of Hawaii (Manoa), M. I.T.
S UNY at Stony Brook, U of Washington

Poland

Warsaw U, Solton Institute for Nnuclear Study

New members since 2002

Hiroshima U., Osaka U.

Canada

TRIUMF, U. of British Columbia

Europe

U. of Barcelona, U. of Geneva, U. of Rome, Saclay, U. of Valencia,

Institute of Nuclear Study-Moscow

Brief history of K2K

- **1995**
  - **Proposed to study neutrino oscillation for atmospheric neutrino anomaly.**
- **1999**
  - **Started taking data.**
- **2000**
  - **Detected the less number of neutrinos than the expectation at a distance of 250 km. Disfavored null oscillation at the 2σ level.**
- **2002**
  - **Observed indications of neutrino oscillation. The probability of null oscillation is less than 1%.**
- **2003**
  - **installed new detector (SciBar)**
- **2004**
  - **Confirmed neutrino oscillation with both number of events and spectrum distortion**
  - **Detail will be presented at KEK seminar (June 9) and will be presented**

Principle of K2K

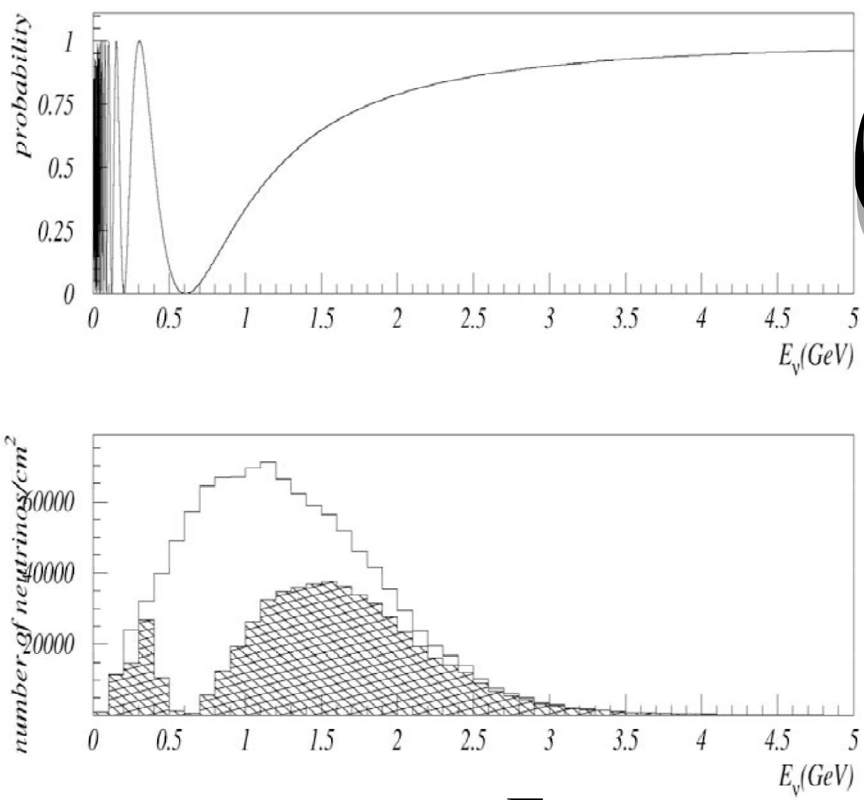
Fixed distance, direction
(E_ν~1.3 GeV, L=250km)
(99% ν_μ, $\sigma_\tau << \sigma_\mu$)

$$\textbf{prob.} = \sin^2 2\theta \cdot \sin^2\left(\frac{1.27\Delta m^2\ L}{E_\nu}\right)$$

Observations

- **Reduction of events**
- **Spectrum distortion**

Neutrino Oscillation (Δm^2=0.003eV^2)

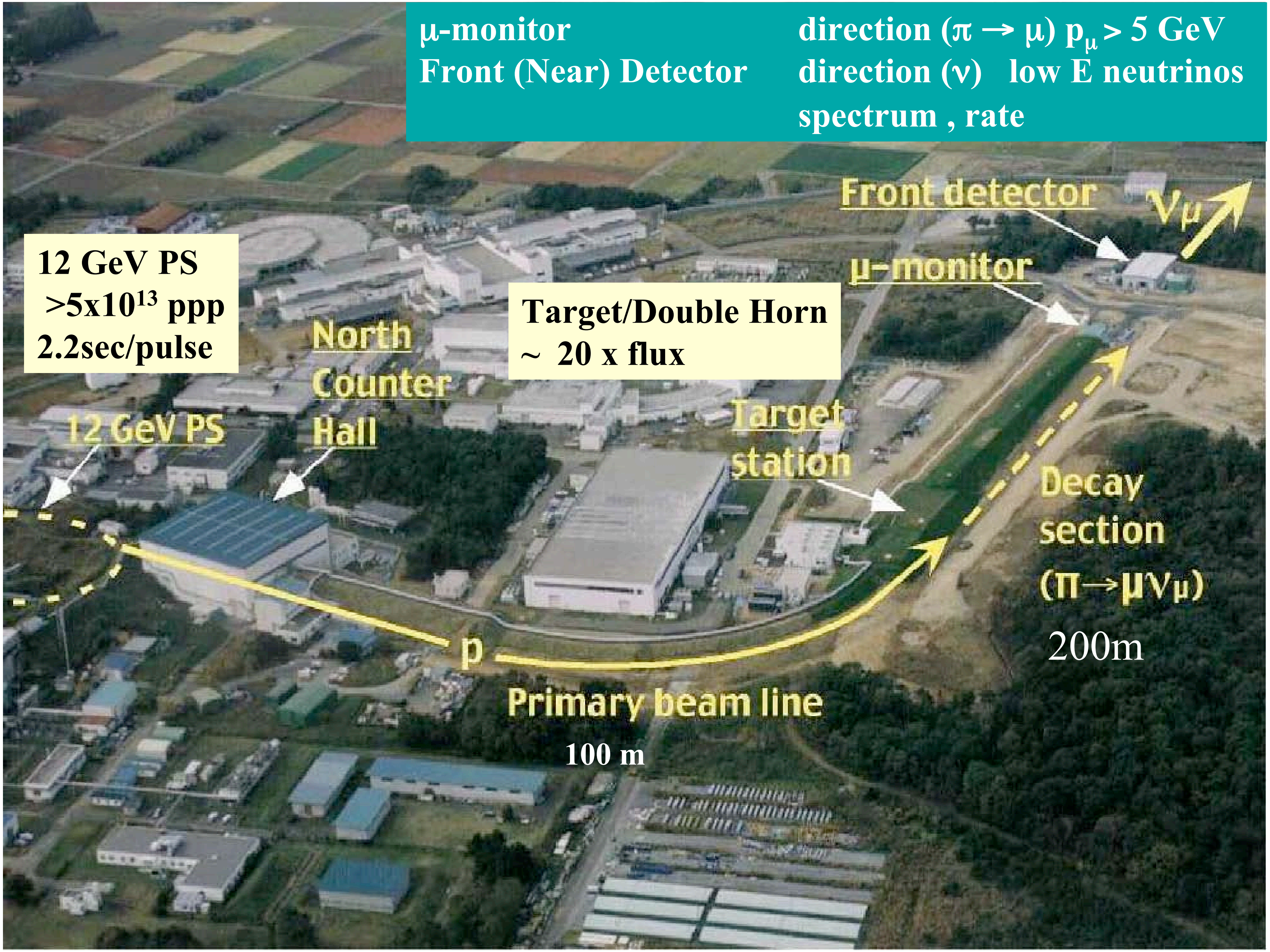


E_ν

Goal

- **Does ν_μ decrease ?**
- **Does it depend on E_ν ?**
- **What is Δm^2 ?**
- **(Is it consistent to $\sin^2(1/E\nu)$?)**

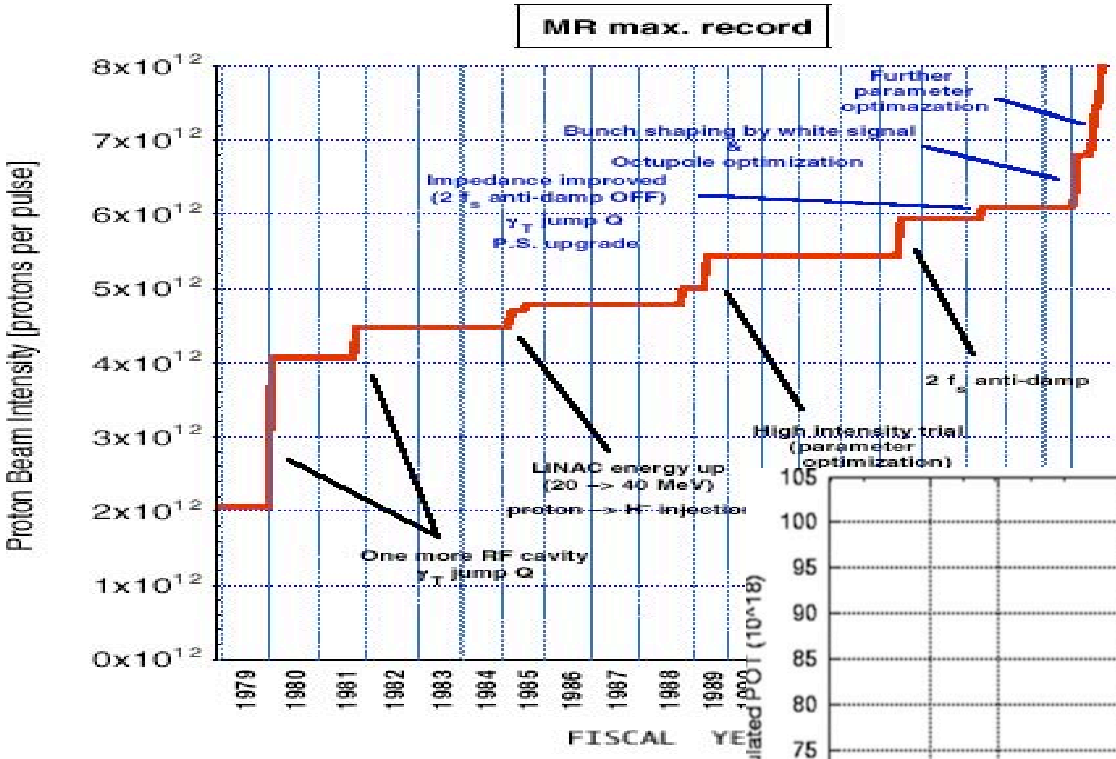
Setup and
Neutrino beam monitoring

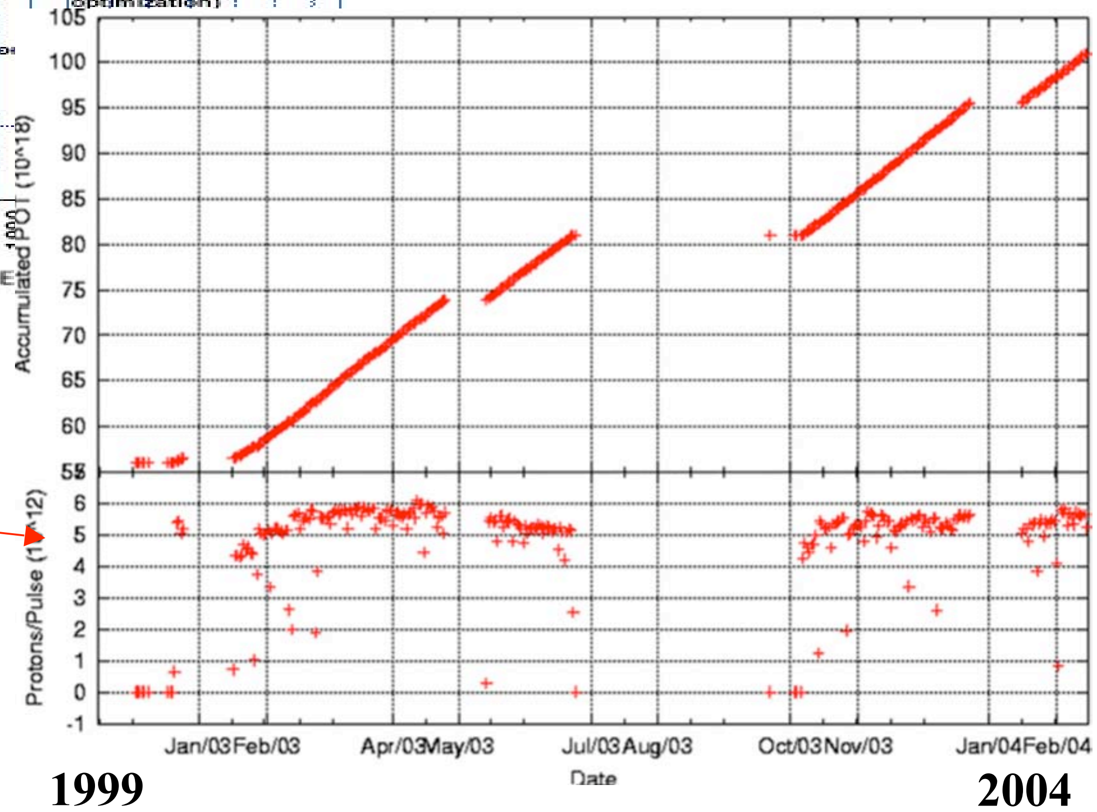


μ-monitor
direction (π → μ) pμ > 5 GeV
Front (Near) Detector
direction (ν) low E neutrinos
spectrum , rate
12 GeV PS
>5x10^13 ppp
2.2sec/pulse
Target/Double Horn
~ 20 x flux
Front detector
νμ
μ-monitor
North
Counter
Hall
12 GeV PS
Target
station
Decay
section
(π→μνμ)
200m
p
Primary beam line
100 m

1 Accelerator

Total Delivered POT
Jun 1999 - Feb. 15, 2004
101.12x10^{18}POT

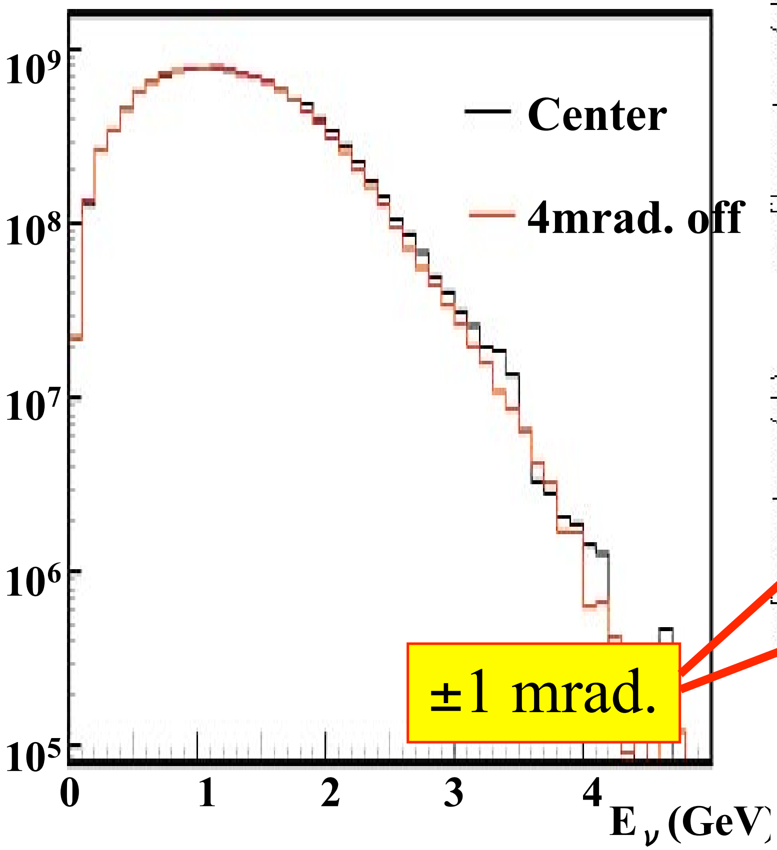


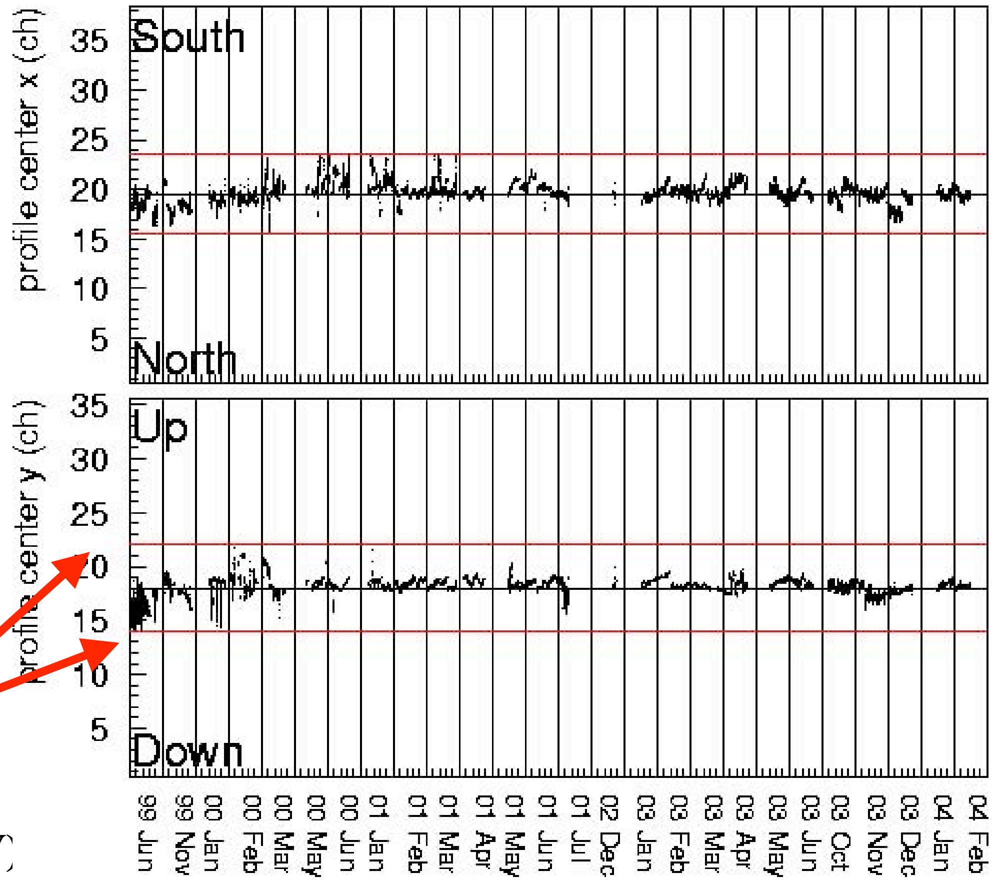


POT/spill
= ~ 5.4x10^{12}
Protons

K2K thanks to the PS division for great accomplishments

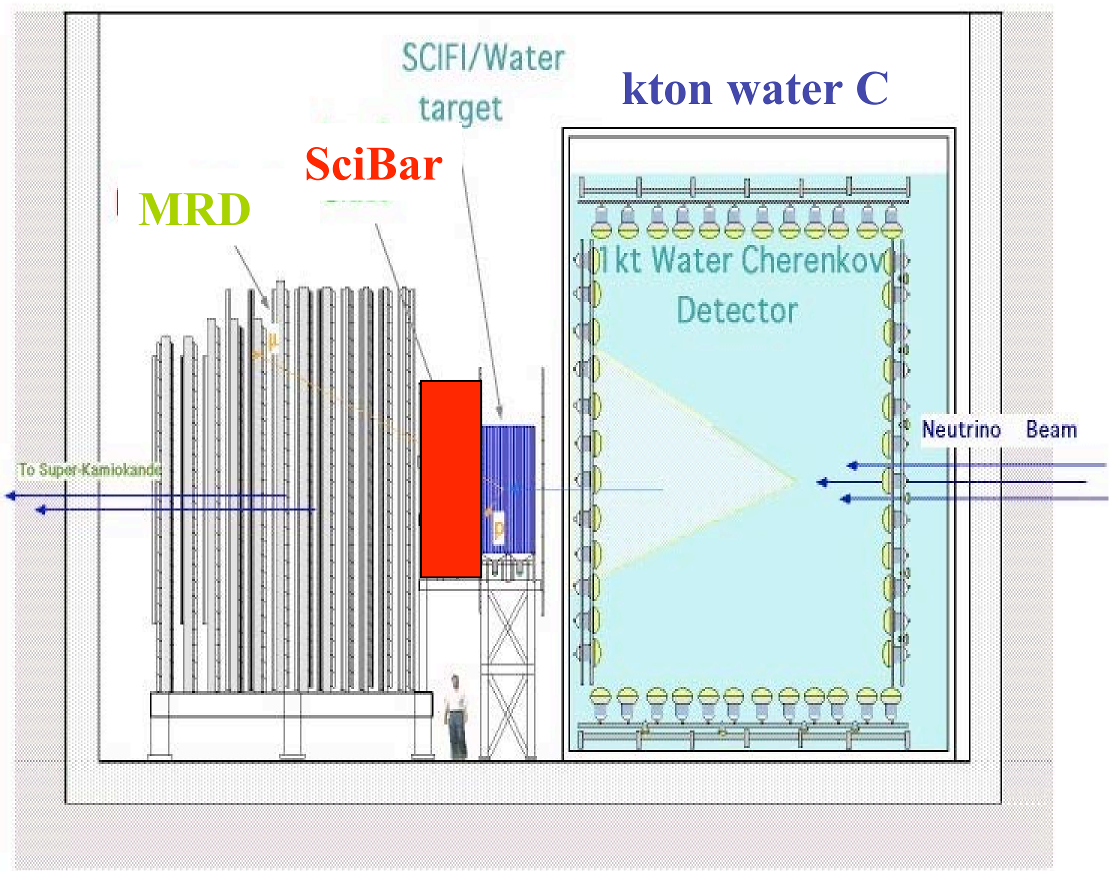
Requirement from MC and muon monitor results (segmented ionization ch. + Si pads)





Neutrino (pion) direction has been controlled within 1 mrad

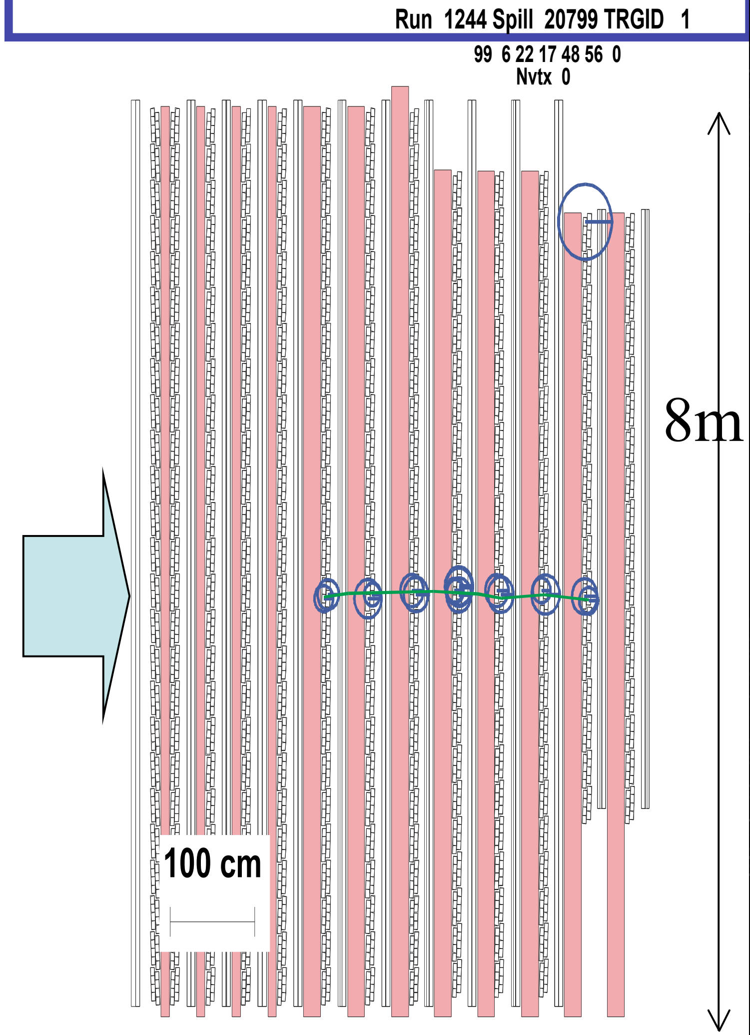
Near Detectors at KEK

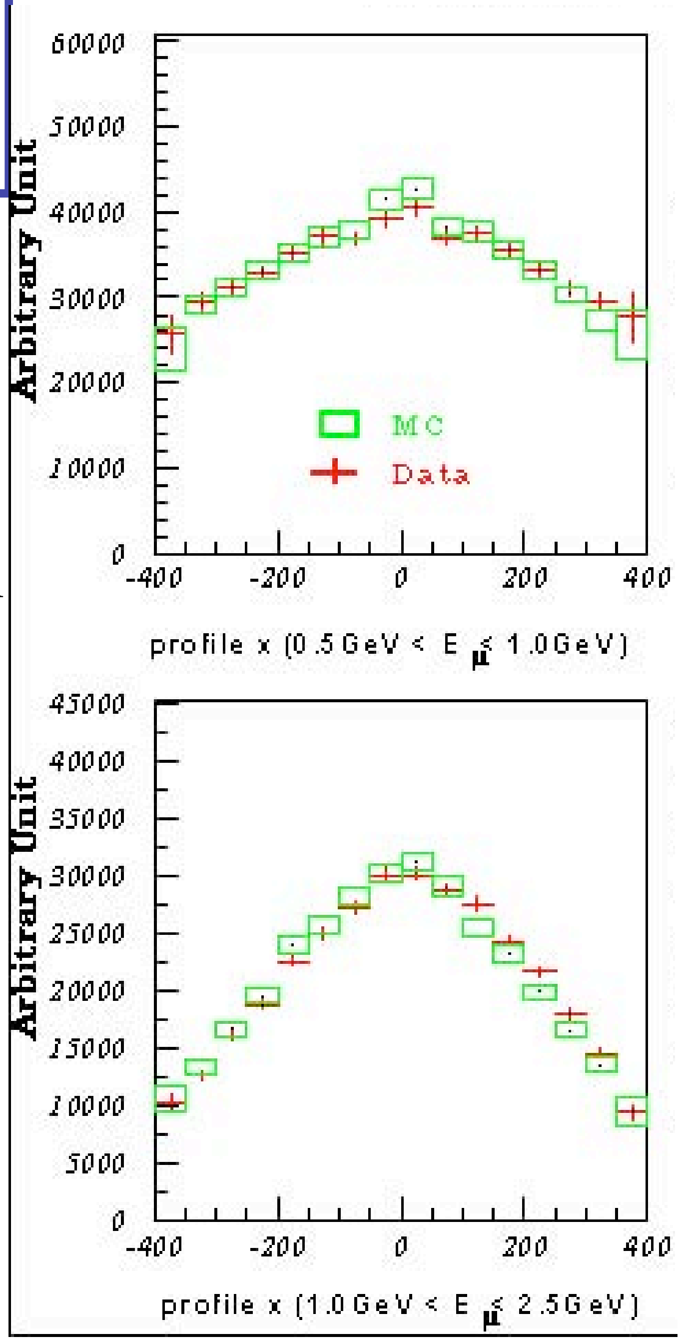


At 300 m from target

1. neutrino beam profile
   - massive MRD
2. νe contamination
3. rate in KT
   - same response as SK for each interaction
4. spectrum
   - selection of CCQE
5. CCQE nonQE NC
   - PID (p _ π,μ)
   - Low energy particles
6. neutron backgrounds
   - good timing

MRD (419 ton fid.) Fe & drift tubes





- Profile width
  beam stability during spill
- <u>Center of beam</u>
  within 1 mrad
  <u>Rate</u>
  weekly basis
- Stability of
  E_{μ}, θ_{μ}
  monthly basis

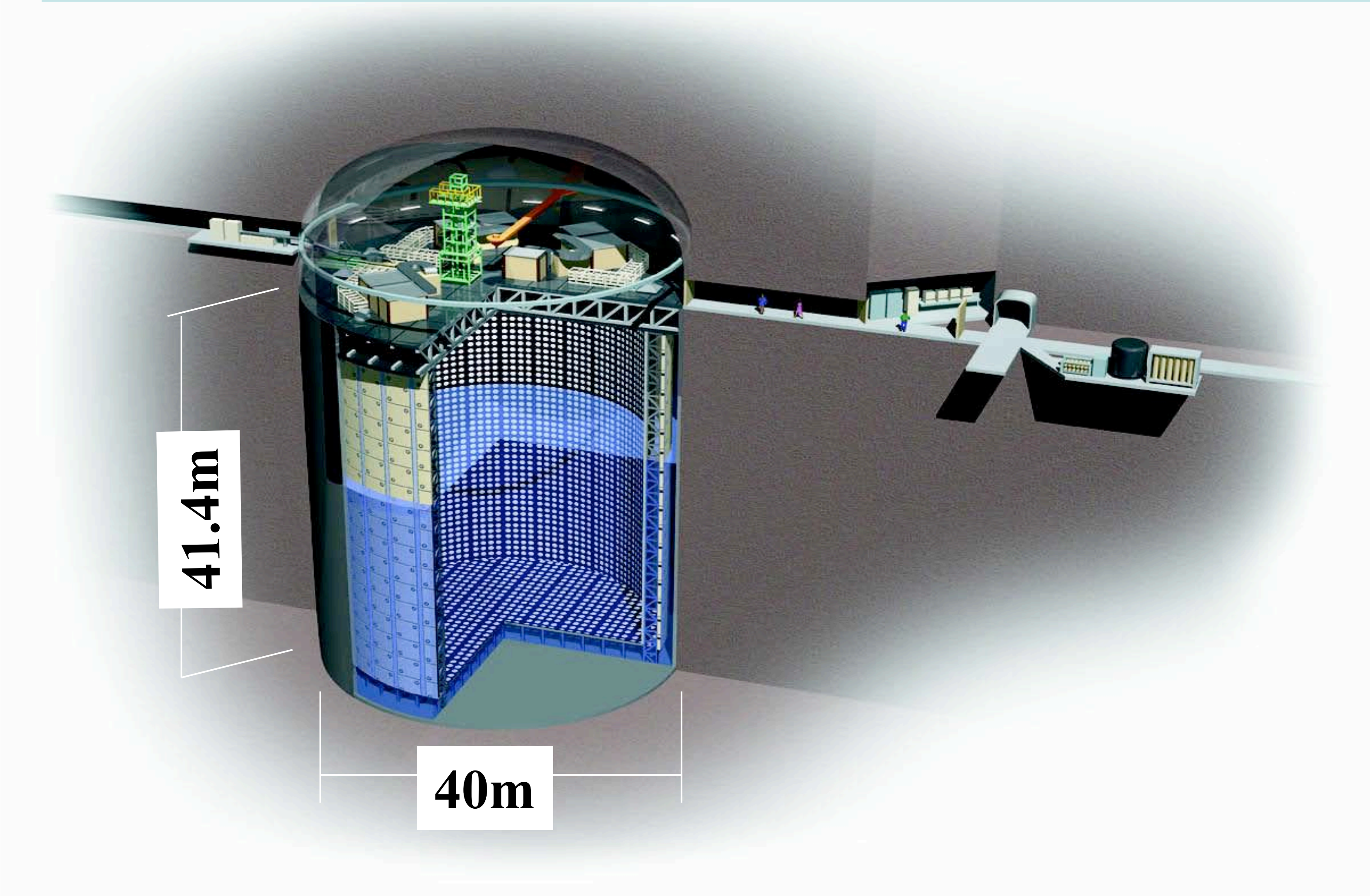
Number of events

（April 1996 commissioned）

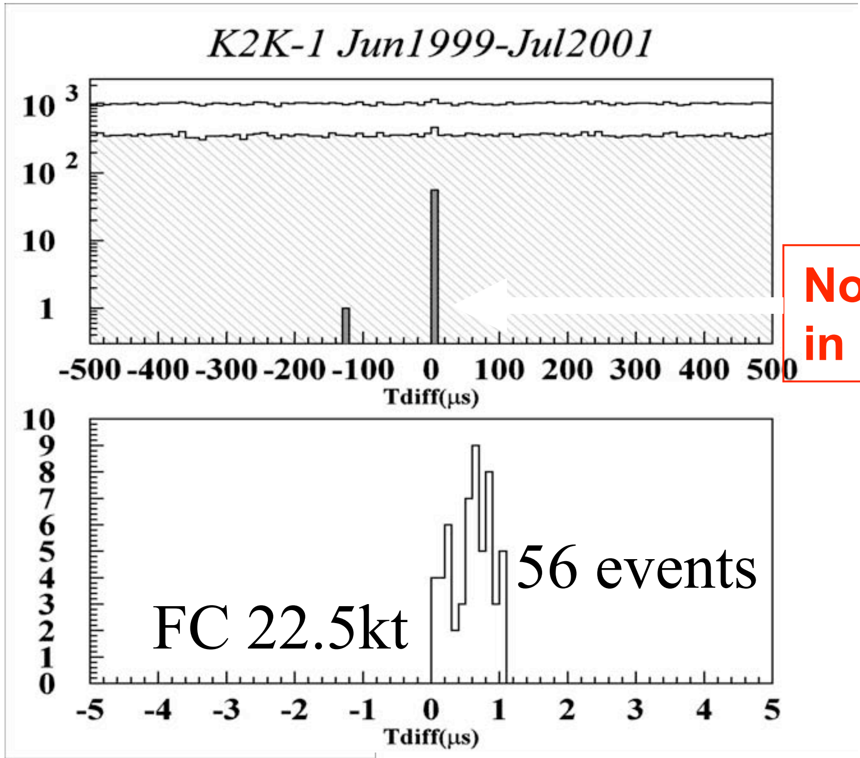
Super-Kamiokande

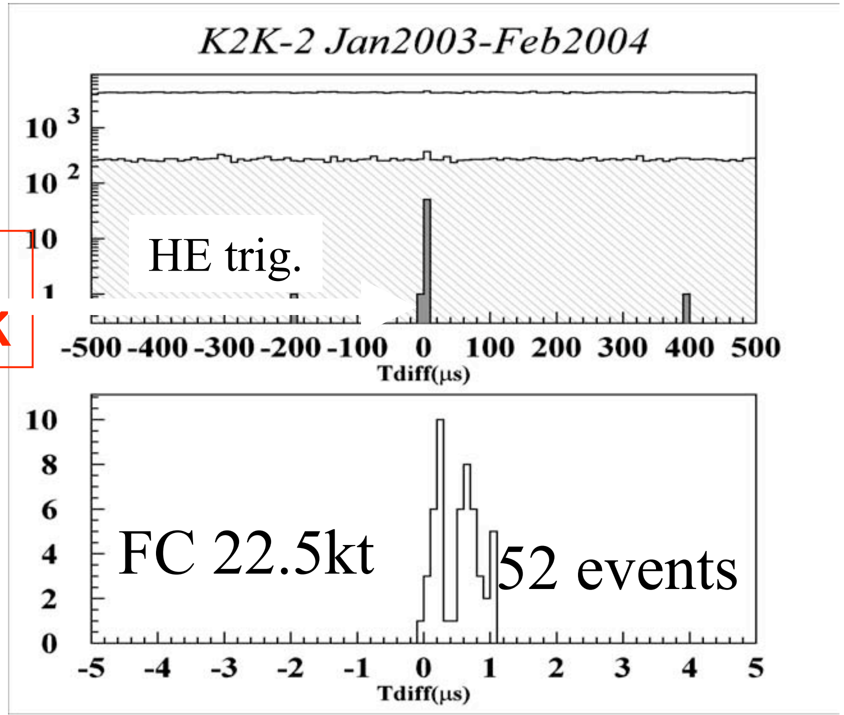
50,000 ton water Cherenkov detector (22.5 kton fiducial volume)

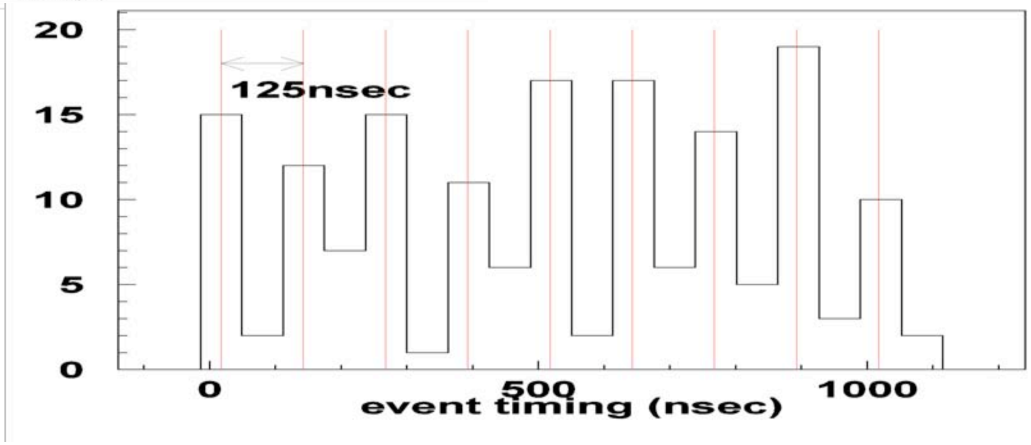
Optically separated INNER and OUTER detector



Selection of SK events : $T_{SK}^{GPS} - T_{acc}^{GPS}$ -TOF

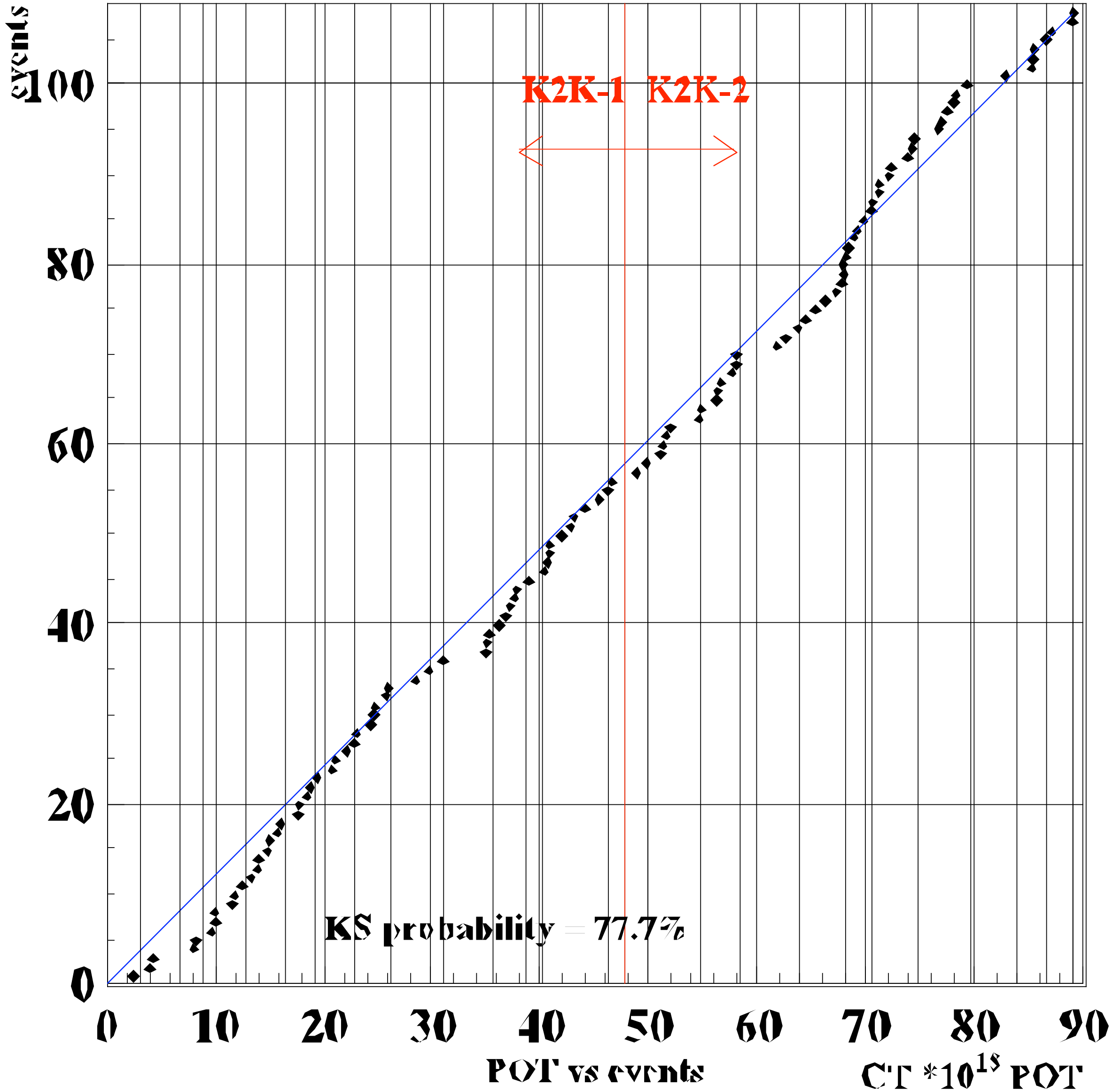






Number of Events vs POT

FC 22.5kt

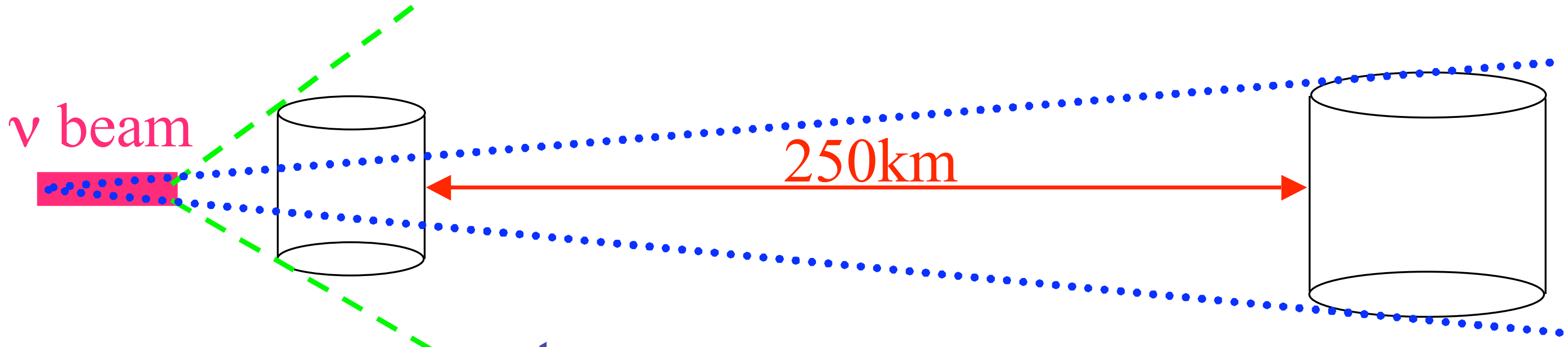


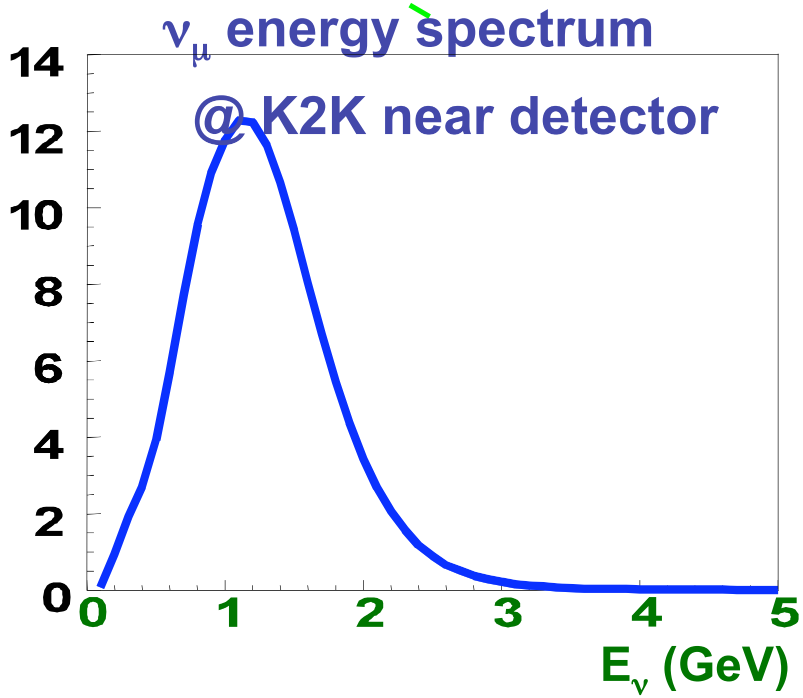
K2K-SK events

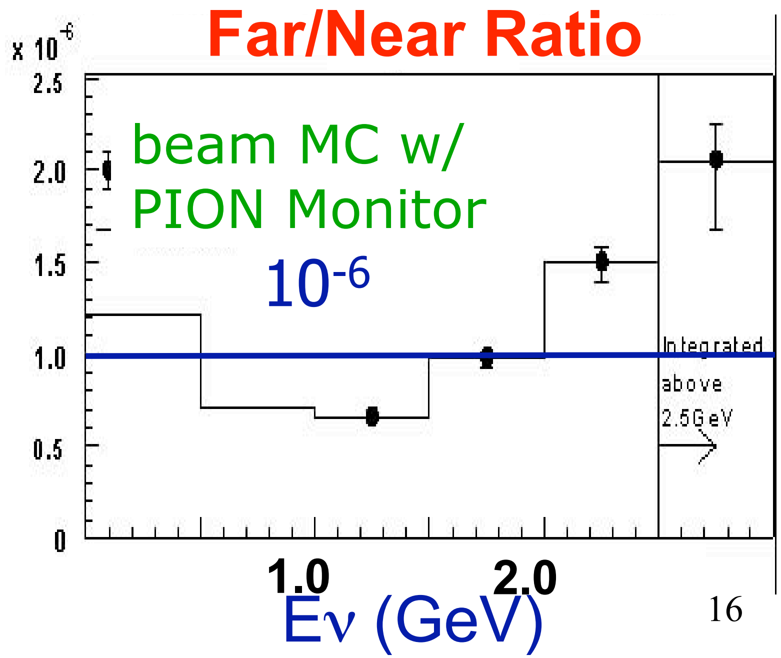
K2K-all (K2K-I, K2K-II)	DATA (K2K-I, K2K-II)	MC (K2K-I, K2K-II)
FC 22.5kt	108 **(56, 52)**	150.9 **(79.1, 71.8)**
1ring for E_ν^{rec}	66 **(32, 34)**	93.7 **(48.6, 45.1)**
μ-like	57 **(30, 27)**	84.8 **(44.3, 40.5)**
e-like	9 **(2, 7)**	8.8 **(4.3, 4.5)**
Multi Ring	42 **(24, 18)**	57.2 **(30.5, 26.7)**

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

Neutrino spectrum and the far/near ratio







1KT Flux measurement

- The same detector technology as Super-K.
  (same response for each interaction)
- Sensitive to low energy neutrinos.

$$N_{SK}^{exp} = N_{KT}^{obs} \bullet \boxed{\frac{\int \Phi_{SK}(E_\nu)\sigma(E_\nu)dE_\nu}{\int \Phi_{KT}(E_\nu)\sigma(E_\nu)dE_\nu}} \bullet \frac{M_{SK}}{M_{KT}} \bullet \frac{\varepsilon_{SK}}{\varepsilon_{KT}}$$

≡Far/Near Ratio (by MC)~1×10^{-6}

M: Fiducial mass M_{SK}=22,500ton, M_{KT}=25ton
ε: efficiency $\varepsilon_{SK\text{-}I(II)}$=77.0(78.2)%, ε_{KT}=74.5%

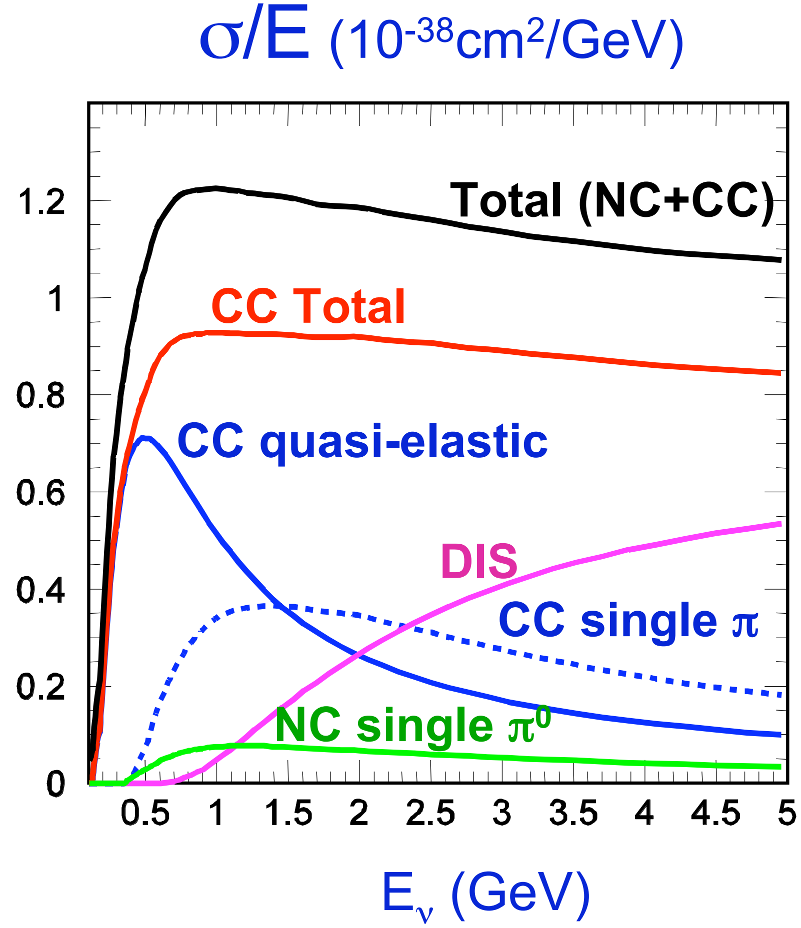
$N_{SK}^{expect} = 150.9\ ^{+10.3}_{-\ 9.1}$ ⟺ $N_{SK}^{obs} = 108$

Spectrum measurement

NEUT: K2K Neutrino interaction MC

- CC quasi elastic (CCQE)
  - **Llewellyn Smith's with M_A=1.1GeV**
- CC (resonance) single π(CC-1π)
  - **Rein and Sehgal's with M_A=1.1GeV**
- DIS
  - **GRV94 + JETSET with Bodek and Yang correction.**
- CC coherent π
  - **Rein&Sehgal with the cross section rescale by J. Marteau**
- NC

with Nuclear Effect

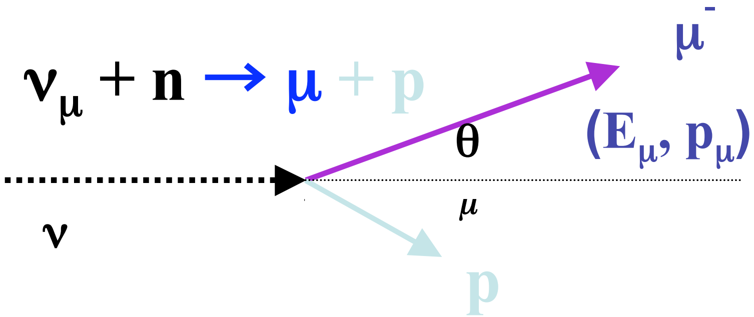


E_ν reconstruction

$$P = \sin^2 2\theta \cdot \sin\left(\frac{1.27\Delta m^2 \cdot L}{E_\nu}\right)$$

p,n no signal in W-C
E_{had} measurement!

$\nu_\mu + n \rightarrow \mu + p$

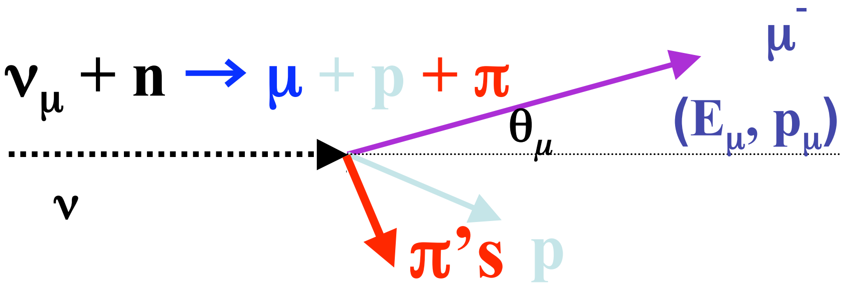


✧ CC QE (1Rμ in W-Cherenkov)

✧ can reconstruct Eν ←(θ_μ,p_μ)

$$E_\nu^{rec} = \frac{m_N E_\mu - m_\mu^2/2}{m_N - E_\mu + p_\mu \cos\theta_\mu}$$

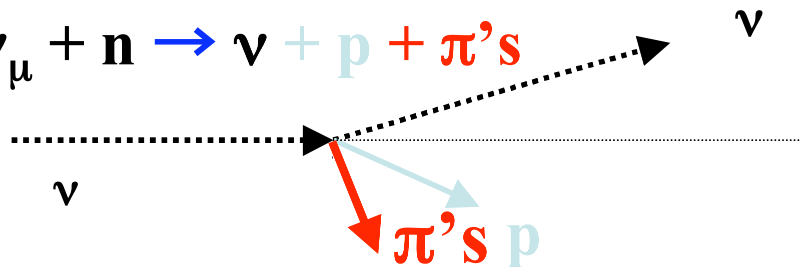
$\nu_\mu + n \rightarrow \mu + p + \pi$



✧ CC nQE

✧ Bkg. for E_ν measurement

$\nu_\mu + n \rightarrow \nu + p + \pi$'s



✧ NC

Oscillation analysis

1. Obtain Eν flux and spectrum shape just after production $\phi_{KEK}(E_\nu)$

$$\text{Events} = \sum_{i=QE,nonQE,NC} \sigma_i \times F(E_\nu) \times \varepsilon_i(E_\nu)$$

Int. Model

σ(CCQE), σ(1π), NC ratios known to ~30% 1KT to predict N_{SK}

2. Extrapolate from near to far without oscillation $\phi_{SK}(E_\nu)$
3. $\phi_{SK}(E_\nu) \otimes$ **Oscillation** $(\sin^2 2\theta, \Delta m^2) \otimes$ **Int. Model**

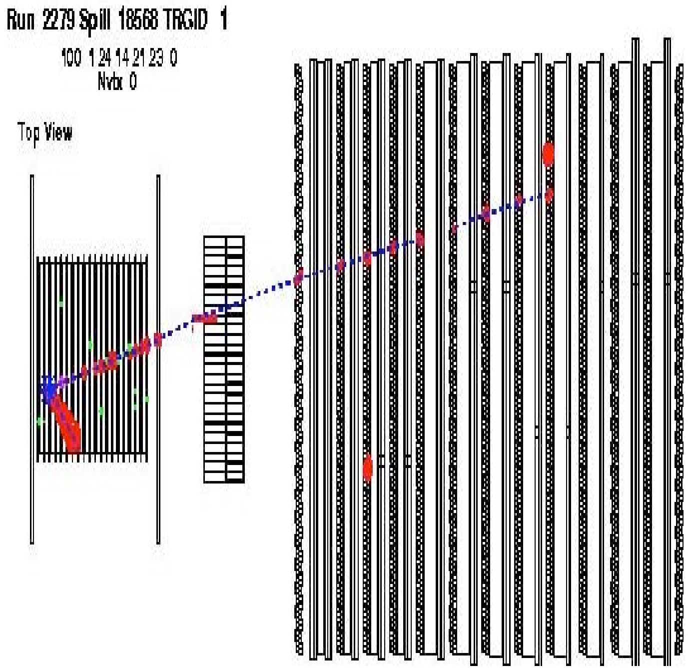
Prediction
N_{SK}(exp't) : Expected no. of SK events
$S_{SK}(E_{rec})$:1Rμ Erecdistribution(shape)

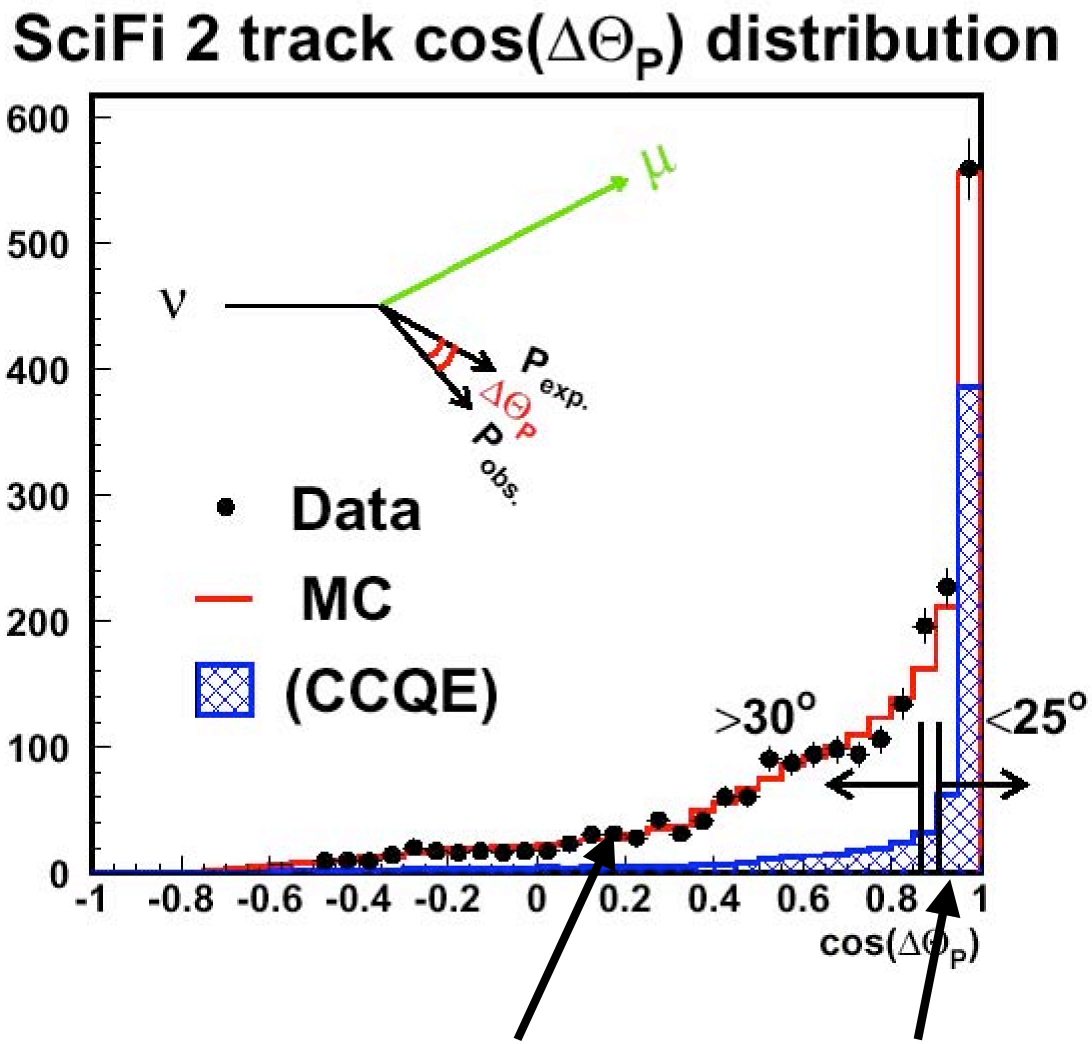
⟷

SK observation
N_{SK}(obs)
1Rμ E_{rec} distribution

Maximum Likelihood Fit in $(\sin^2 2\theta, \Delta m^2)$

QE and nQE seperation in SciFi



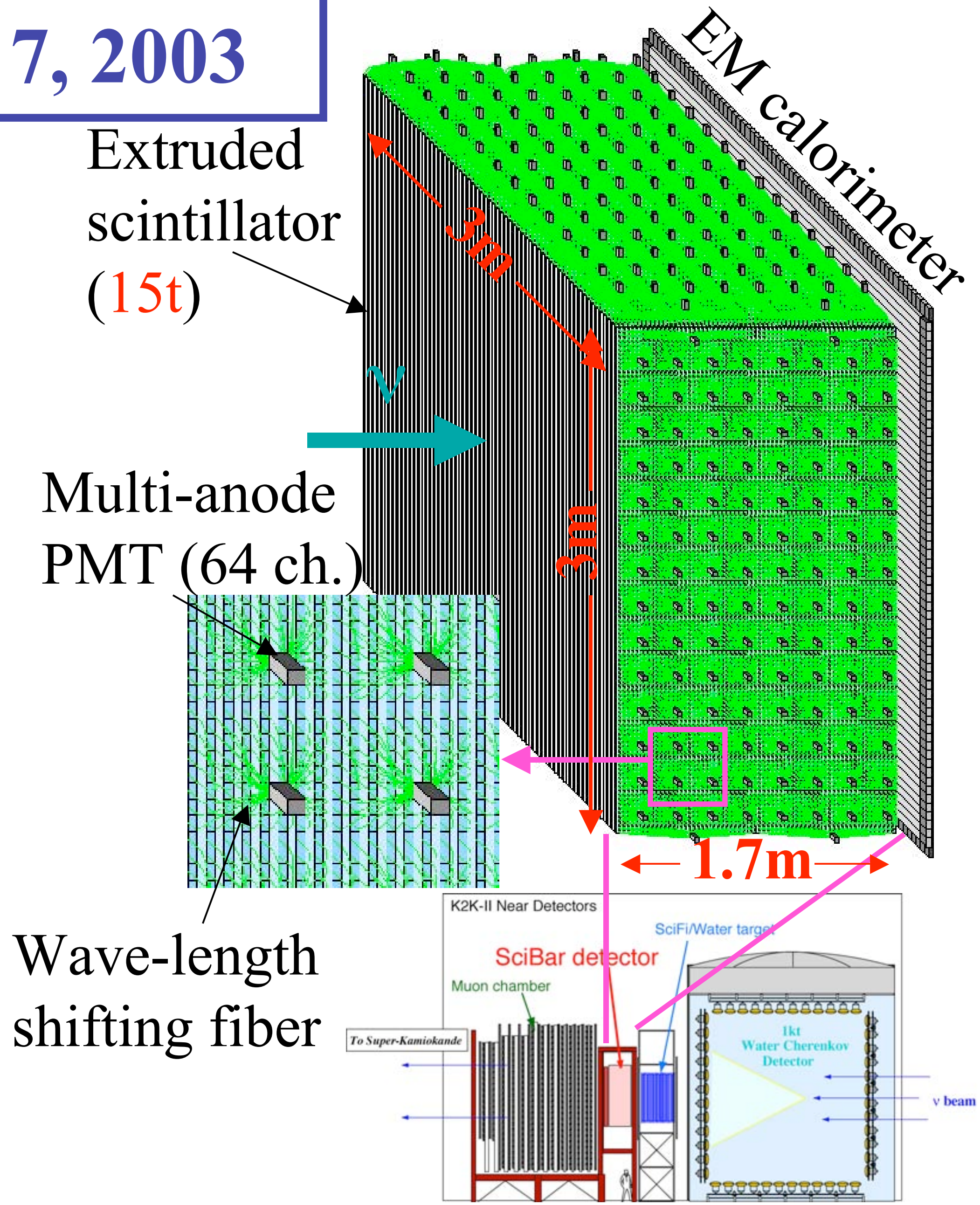


nQElike

QElike

SciBar Detector
start taking data Oct. 7, 2003

π0, Ee measurement



- **Extruded scintillator with WLS fiber readout**
- **No dead material**
- **2.5 x 1.3 x 300 cm^3 cell**
- **~15000 channels**
- **Light yield**

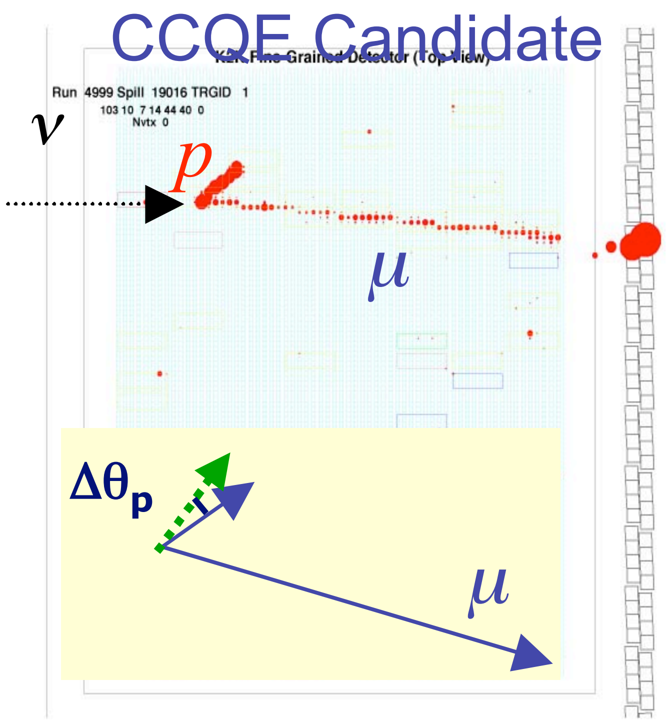
  7~20p.e./MIP/cm (2 MeV)
- **Detect 10 cm track**
- **Proton ID by using dE/dx**

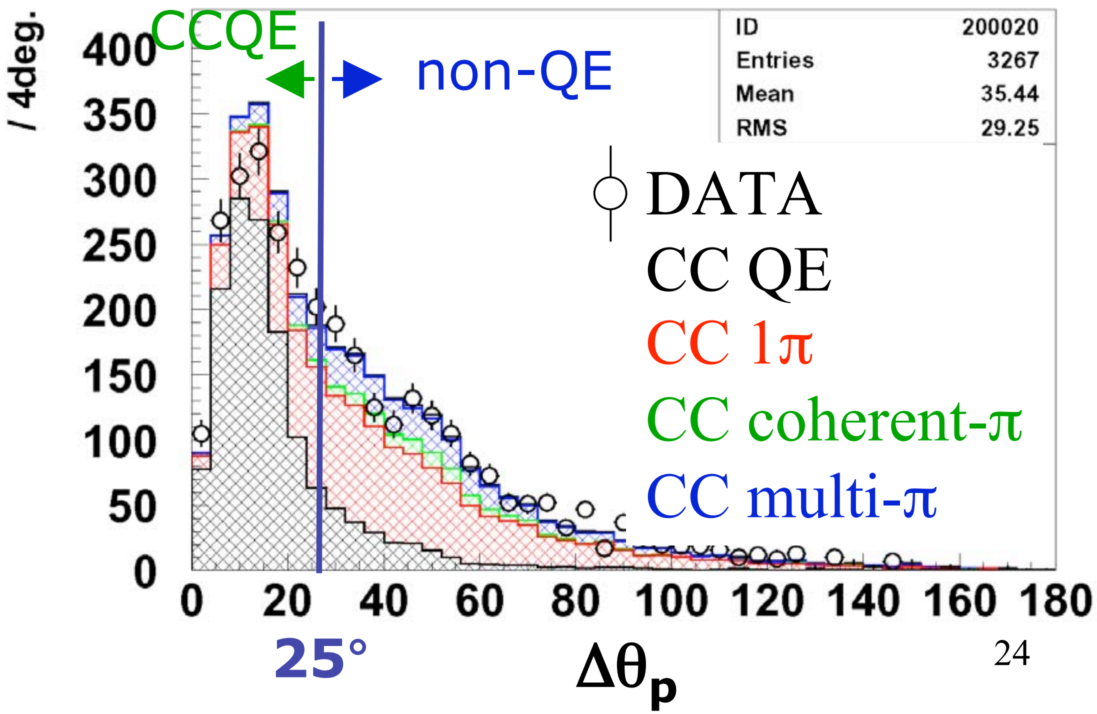
➔High CC-QE efficiency

➔Low non-QE backgrounds

SciBar neutrino interaction study.

- **Full Active Fine-Grained detector.**
  - **Sensitive to a low momentum track.**
  - **Identify CCQE events and other interactions (non-QE) separately.**





Used data for $\phi_{near}(E\nu)$

KT

Fully Contained Fiducial Volume (FCFV) events

- No. of events (Evis>100MeV)

(1)Single μ–like events

SciFi

(2) 1-track μ events

(3) 2-track QE-like events

(4) 2-track nonQE-like events

SciBar

(5) 1-track m events

(6) 2-track QE-like events

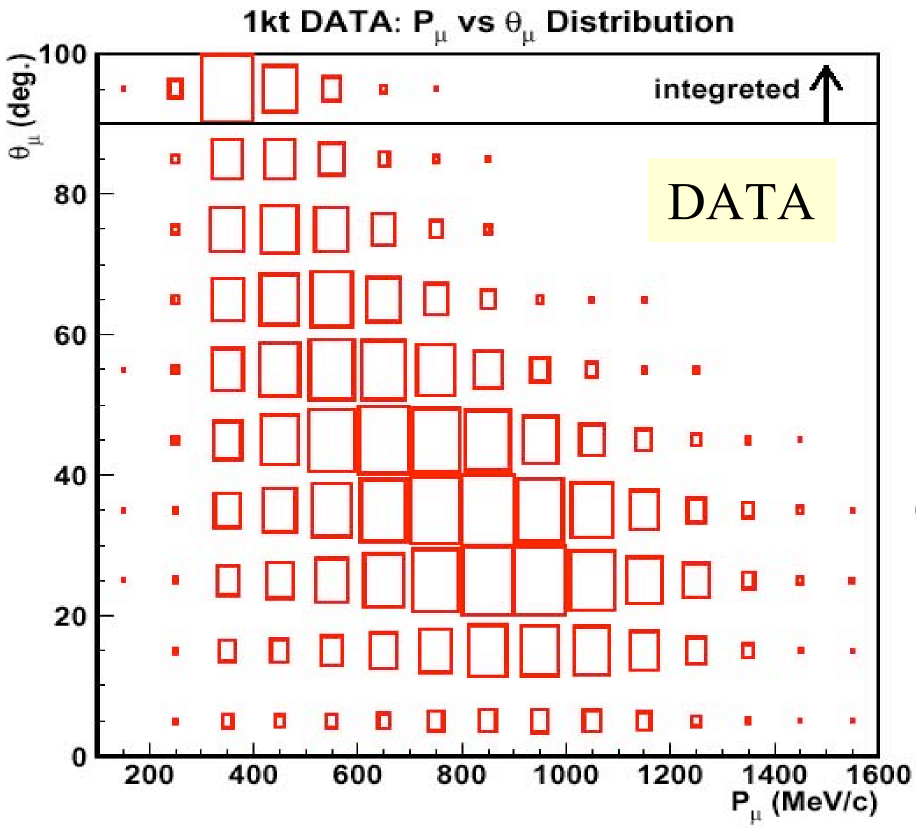
(7) 2-track nonQE-like events

norm. (N_{SK}) from KT & 7 sets of (p_μ, θ_μ) distributions

- ν flux $\phi_{near}(E\nu)$ (8 bins)
- ν interaction model (nQE/QE ratio as parameter)

Actual Procedure

$(p_\mu, \theta_\mu) \rightarrow \phi(E\nu)$, nQE/QE

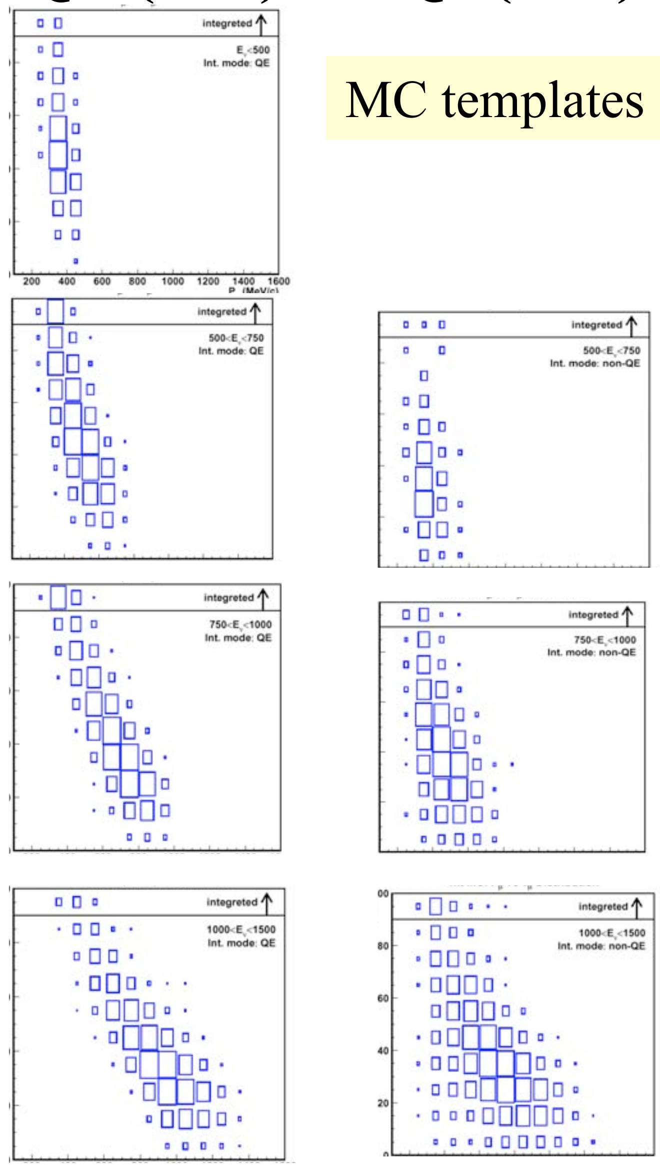


eight 2-dimensional hist's

χ^2 =638.1 for 609 d.o.f.

Eν	QE (MC)	nQE(MC)
0-0.5 GeV		
0.5-0.75GeV		
0.75-1.0GeV		
1.0-1.5GeV		

MC templates

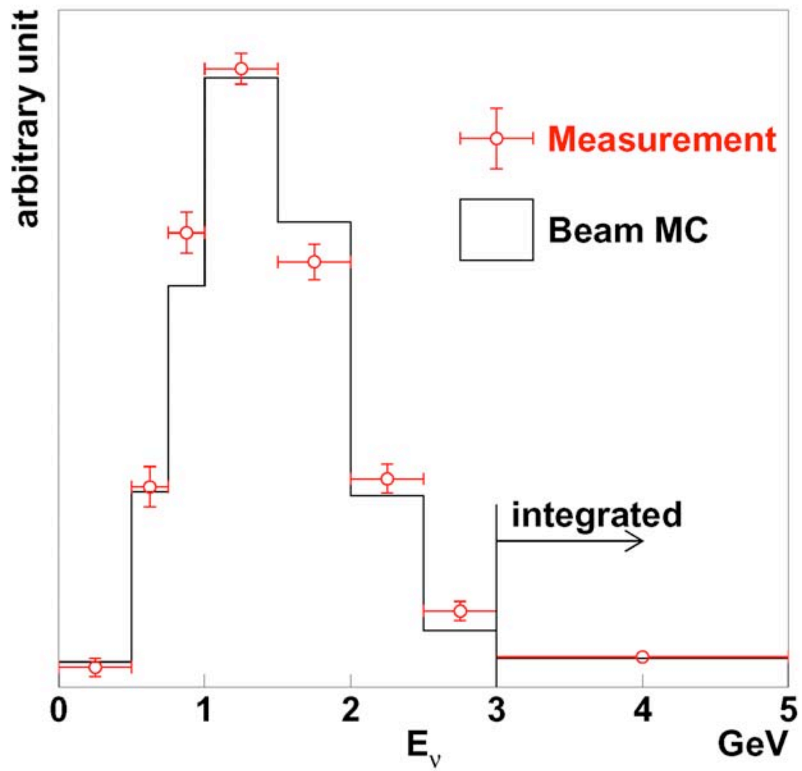


Flux measurements

preliminary

χ^2=638.1 for 609 *d.o.f*

- Φ1 (Eν < 500) = 0.78 ± 0.36
- Φ2 (500≤ Eν < 750) = 1.01 ± 0.09
- Φ3 (750≤ Eν <1000) = 1.12 ± 0.07
- Φ4 (1500≤ Eν <2000) = 0.90 ± 0.04
- Φ5 (2000≤ Eν <2500) = 1.07 ± 0.06
- Φ5 (2500≤ Eν <3000) = 1.33 ± 0.17
- Φ6 (3000≤ Eν   ) = 1.04 ± 0.18
- nQE/QE   = 1.02 ± 0.10

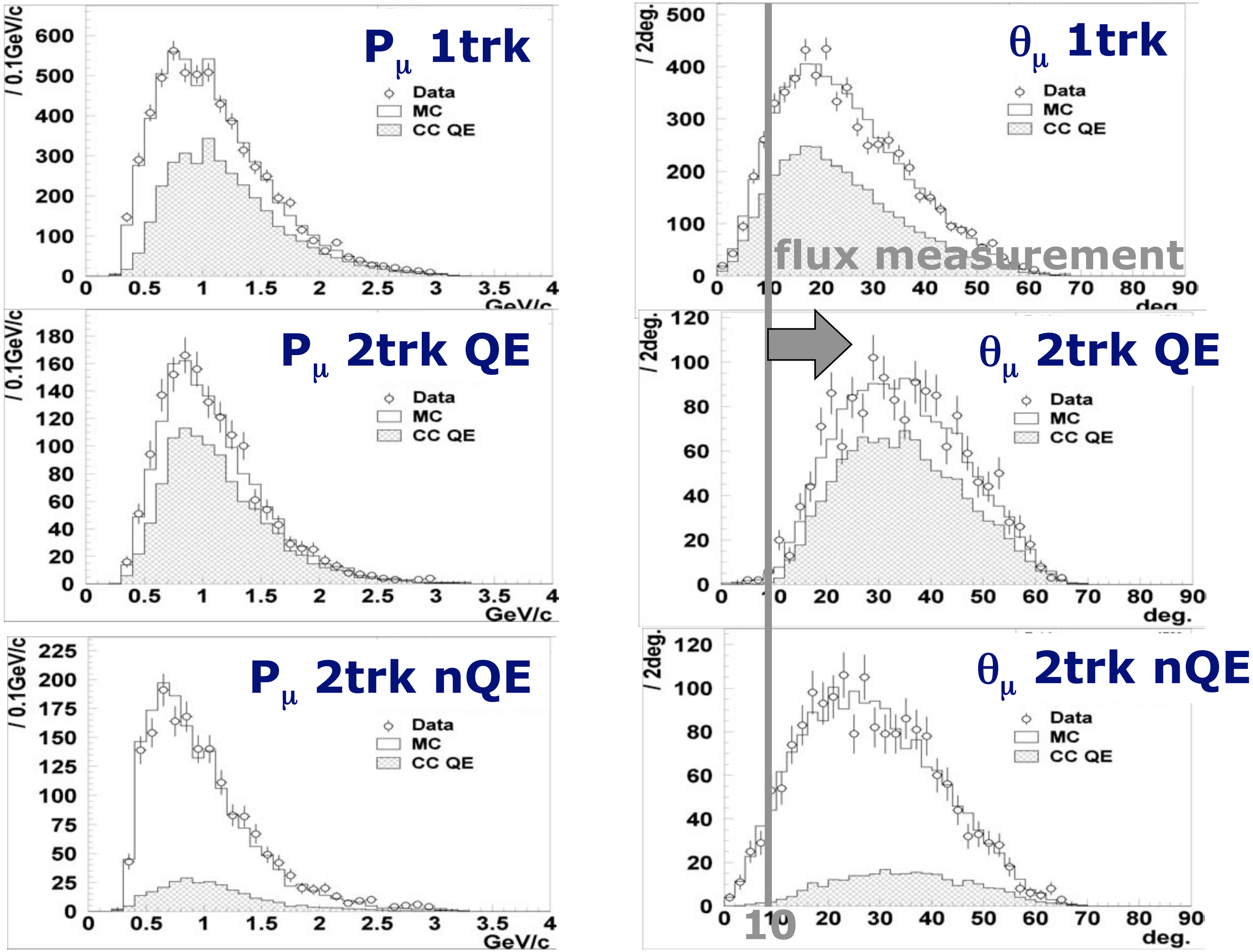


The nQE/QE error is assigned based on the variation by the fit condition.

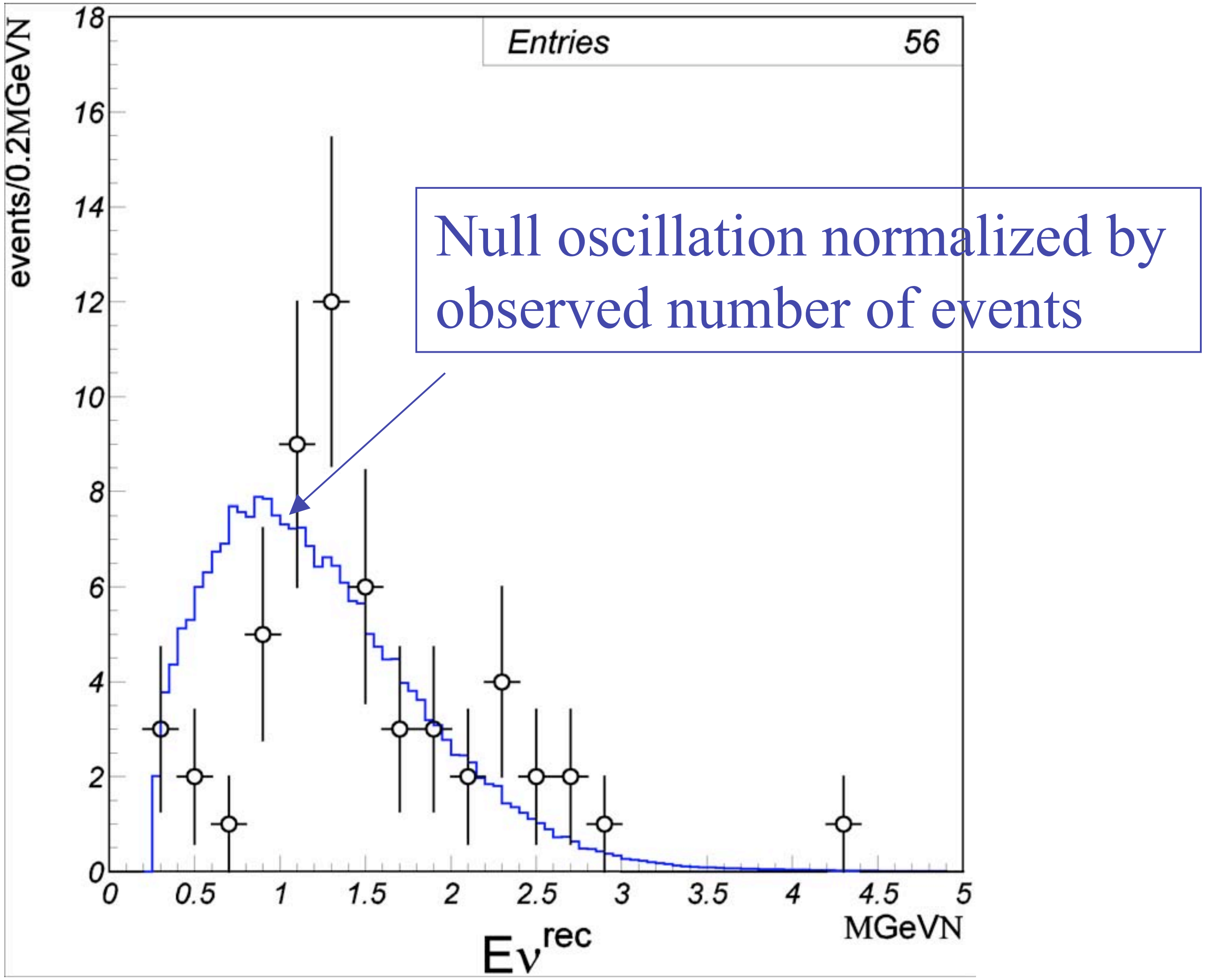
∀ θ>10° cut: nQE/QE=0.95 ±0.04

- **standard(CC-1π low q^2 corr.): nQE/QE=1.02 ±0.03**
- **No coherent: π=nQE/QE=1.06 ±0.03**

SciBar (with measured flux) (also for KT,SciFi)

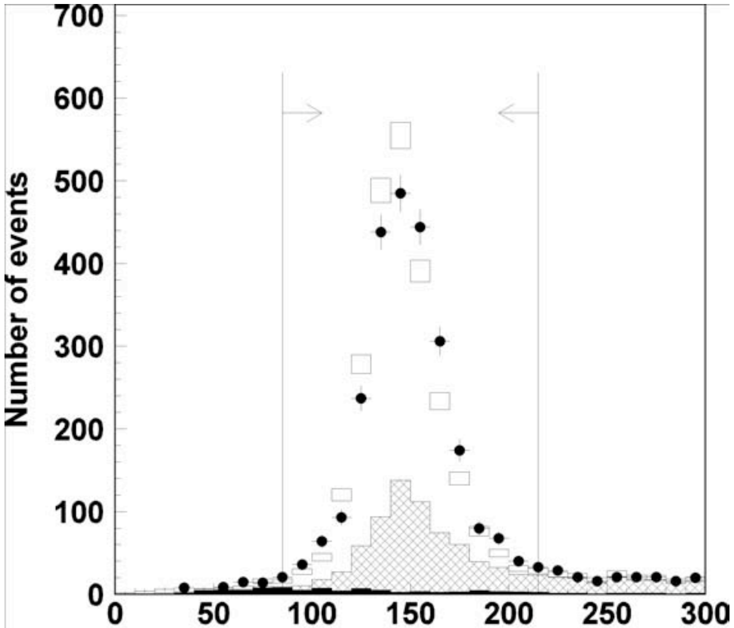


Observed spectrum shape and null oscillation prediction



Other Physics in K2K (based on K2K-I data)

$\nu_\mu + H_2O \rightarrow NC1\pi^0$



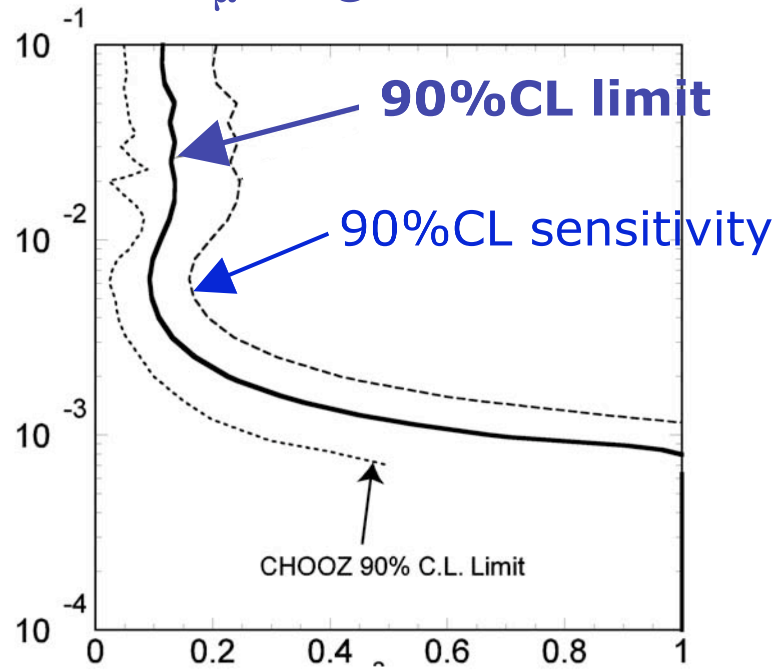
$M_{\gamma\gamma}$(MeV)

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

=0.064 (MC prediction)

preliminary

$\nu_\mu \rightarrow \nu_e$ search



$\sin^2 2\theta_{\mu e}$

PRL accepted

Near future

1. Systematic errors
   - Far Near ratio +5.6 -7.3%
     - π production measurements should be available soon
   - N_{SK} from 1kton detector 5% (fiducial)

Run plan for 2004

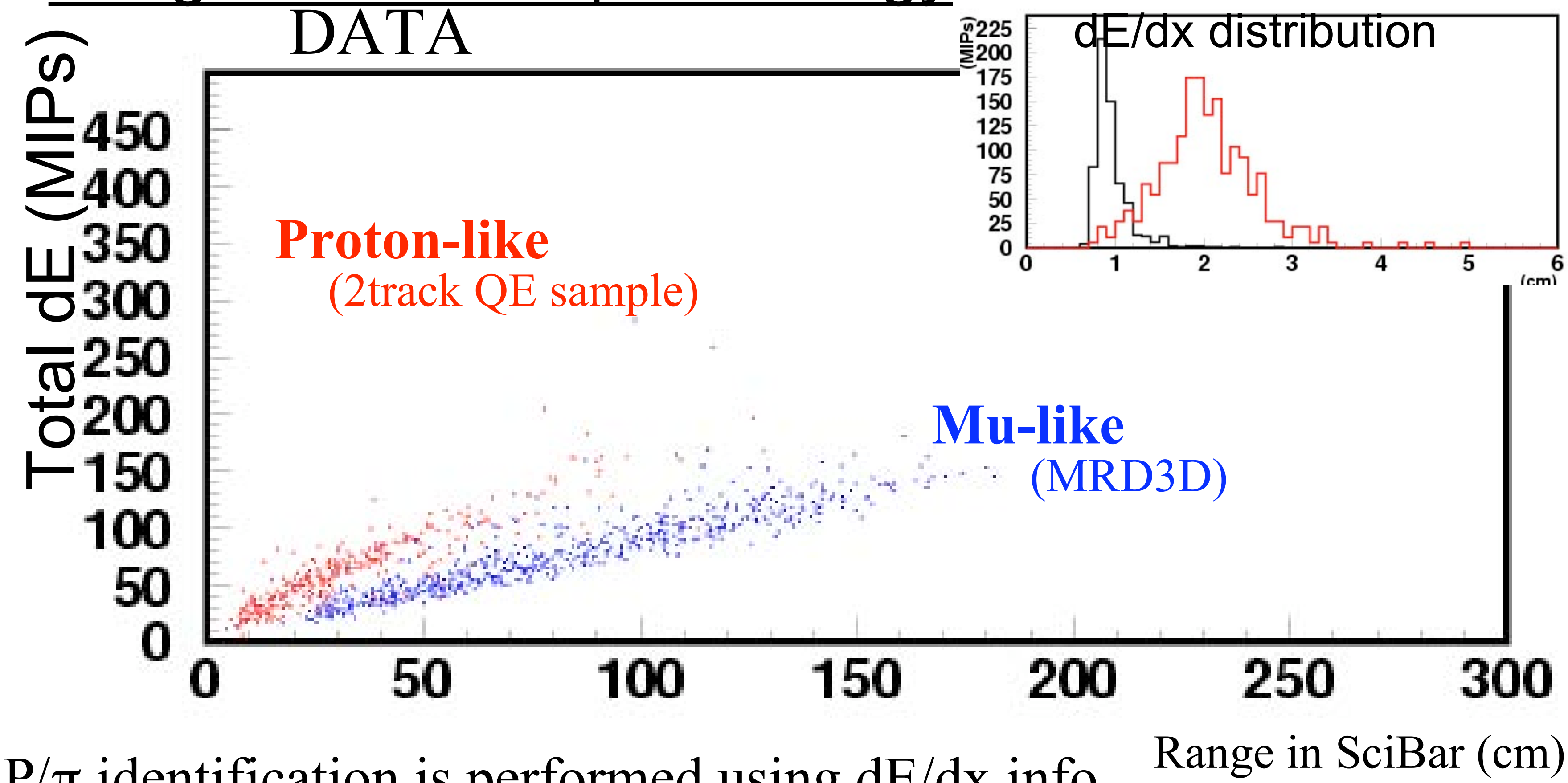
- More data in SciBar (Proton ID, low-E track)

  ~20,000 total events (1,500 CCQE <1 GeV) ~4 months

  Determine neutrino interaction model
  - Can use 2 ring events in SK(in addtion to 1Rμ like events) almost double the statistics
  - SciBar can determine normalization with small fid. error、and spectrum
- Low energy neutrino interaction studies
  - determine background in low E^{rec}
  - ....
- Anti neutrino (engineering run)

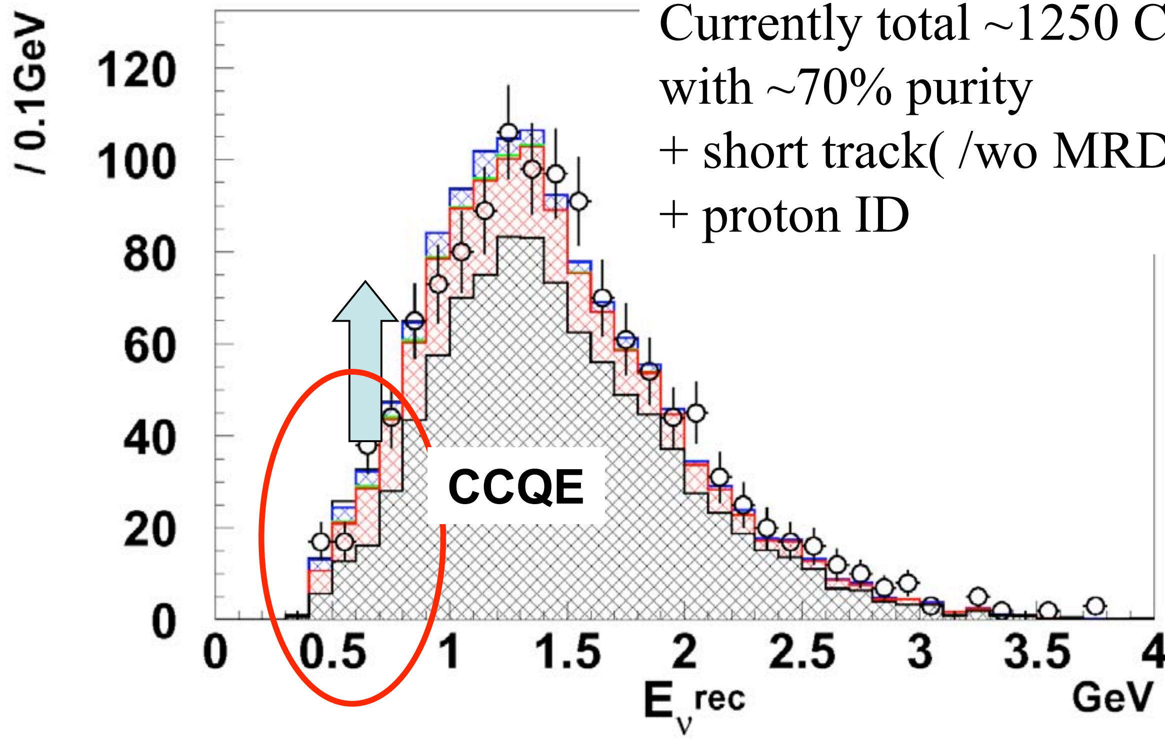
Status of proton ID in SciBar

Range vs Total deposit energy

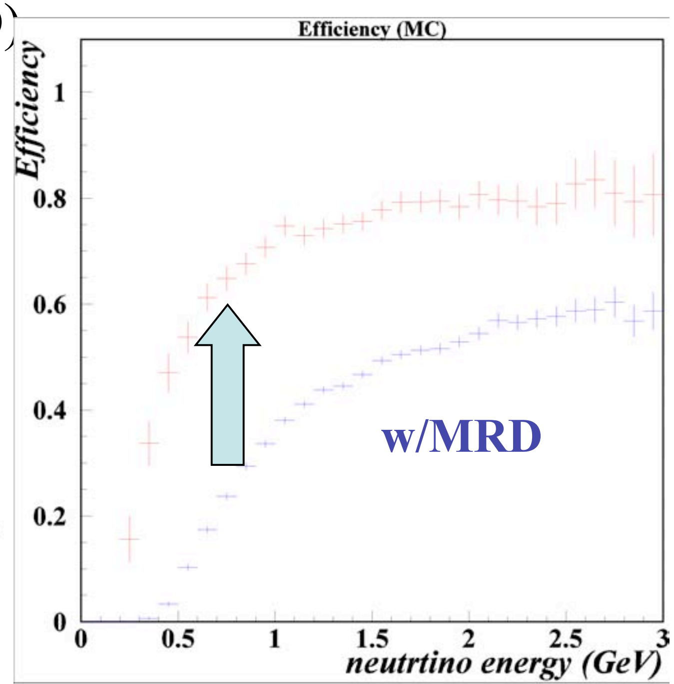


P/π identification is performed using dE/dx info.

Spectrum measurement at low energy w/ exclusive reconstruction



Currently total ~1250 CC-QE candidates
with ~70% purity
+ short track(/wo MRD)
+ proton ID

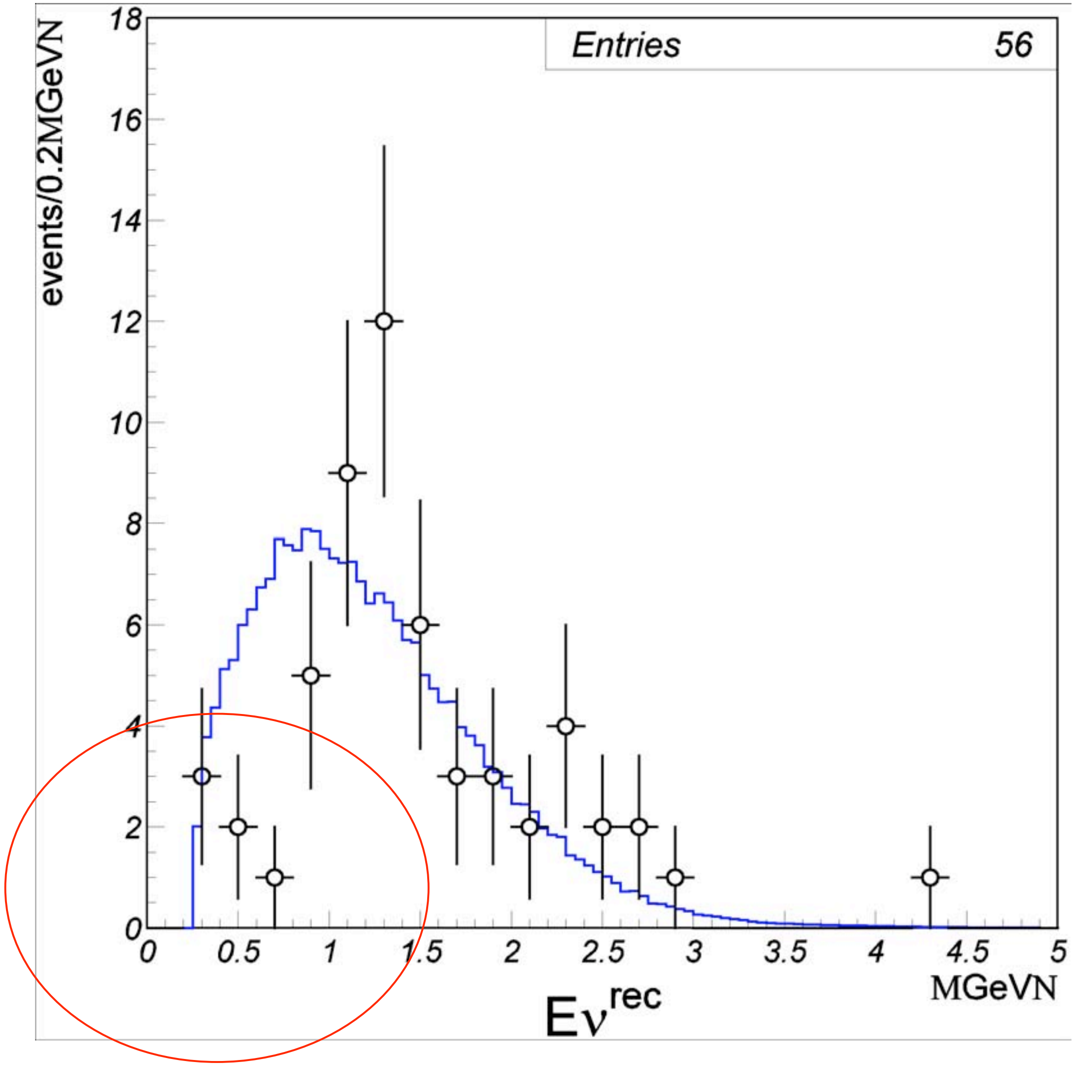


*Efficiency for low-energy events will be improved (x 2)

<u>x2 more data</u> **~200 events <1GeV→ ~1000 events**

More data in SciBar

Level of nonQE background to low E_ν^{rec} ?



A hint of K2K forward μ deficit.

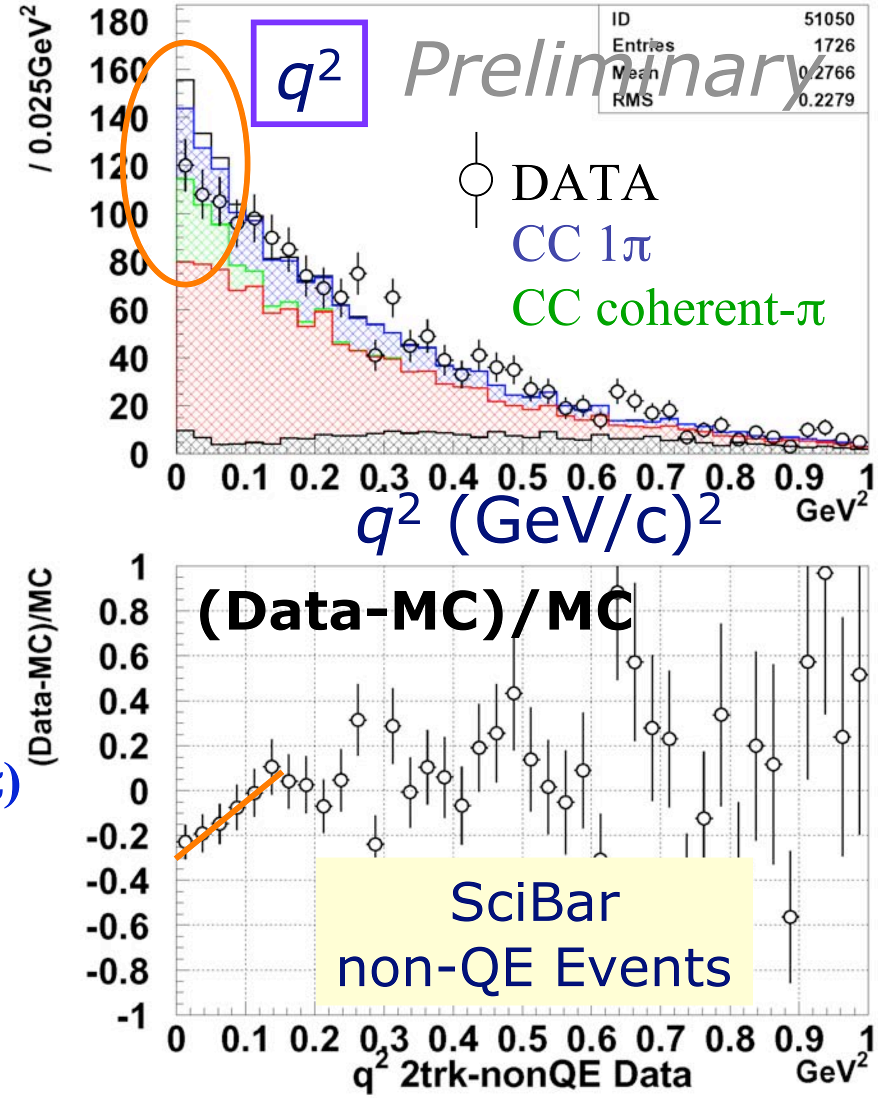
preliminary

K2K observed forward μ deficit.

- **A source is non-QE events.**
- **For CC-1π,**
  - Suppression of ~q^2/0.1[GeV^2] at q^2<0.1[GeV^2] may exist.
- **For CC-coherent π,**
  - The coherent π may not exist.

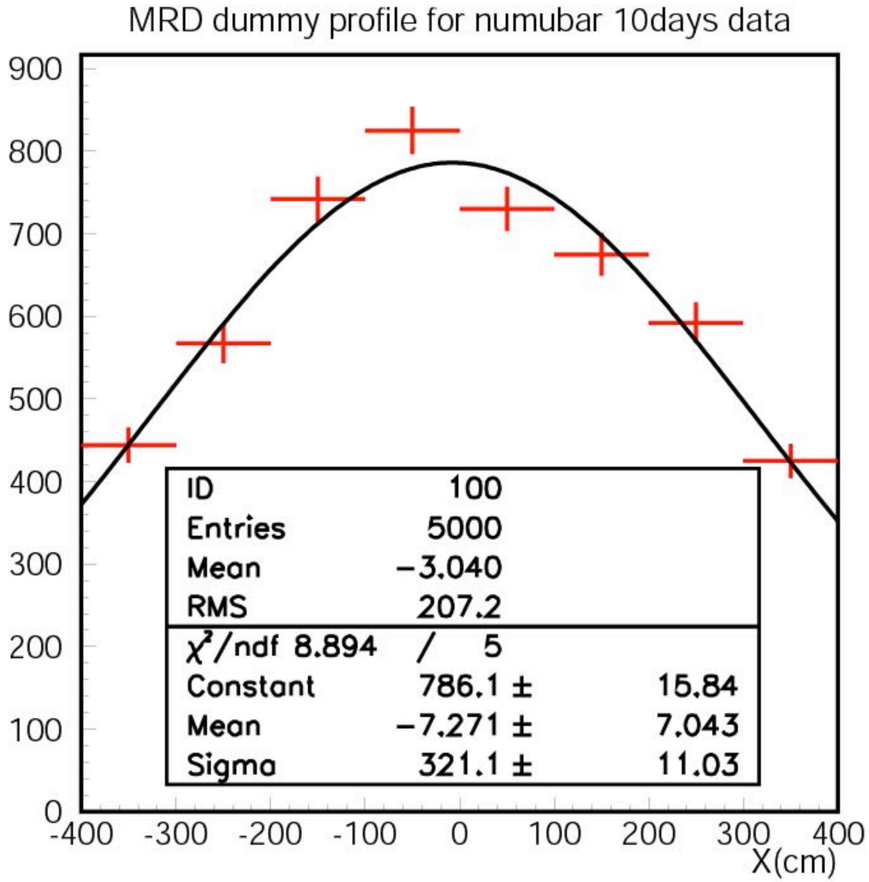
We do not identify which process causes the effect. The MC CC-1π (coherent π) model is corrected phenomelogically.

Oscillation analysis is insensitive to the choice.



Anti-neutrinos

- <u>On paper</u>, just flipping the polarity of horn.
  Need actual testing
- Geomagnetic effect to the beam
- Scibar
  - ~400 int / 10days / 10ton
- MRD
  - ~15,000 int/ 10days/ 419 ton
  - Error in
  - Beam center: 7cm
  - width : 10cm



Activities before T2K

Fiscal yr	2004	2005	2006	2007	2008
K2K data taking					
Full paper on oscillation incl. νe					
Analysis of neutrino interactions					
SK full rebuild					
SK analysis tool					
T2K construction and commissioning					
?					

Summary

- K2K Oscillation analysis on June 99 ~Feb 04 data

1. Long baseline experimental method is working well
2. We observed ν_μ deficiency and spectrum distortion over 250 km flight length
3. $\sin^2 2\theta$, Δm^2 are consistent with atmospheric neutrino results

For detail please attend the KEK seminar day after tomorrow

- In 2004, at least 6 months run can improve the quality of K2K
- More data in SciBar (at least four more months) can further improve statistical significance of K2K results
- More measurement of low energy neutrino interactions can be done