

Indication of Neutrino Oscillation in a 250km Long Baseline Experiment

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for K2K collaboration

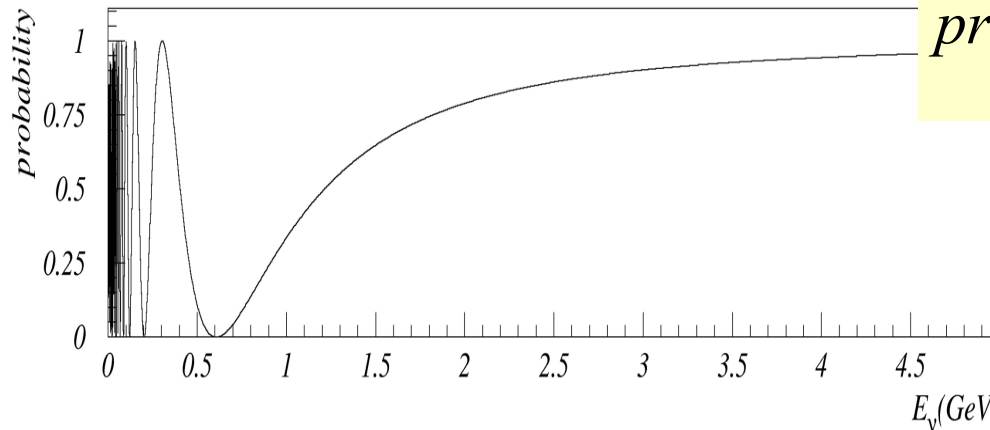
IPNS, KEK

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2. Latest results ([hep-ex/0212007](#), PRL**90**(2003)041801)
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Principle of Long Baseline Neutrino Oscillation Experiment

Neutrino Oscillation ($\Delta m^2 = 0.003 \text{eV}^2$)

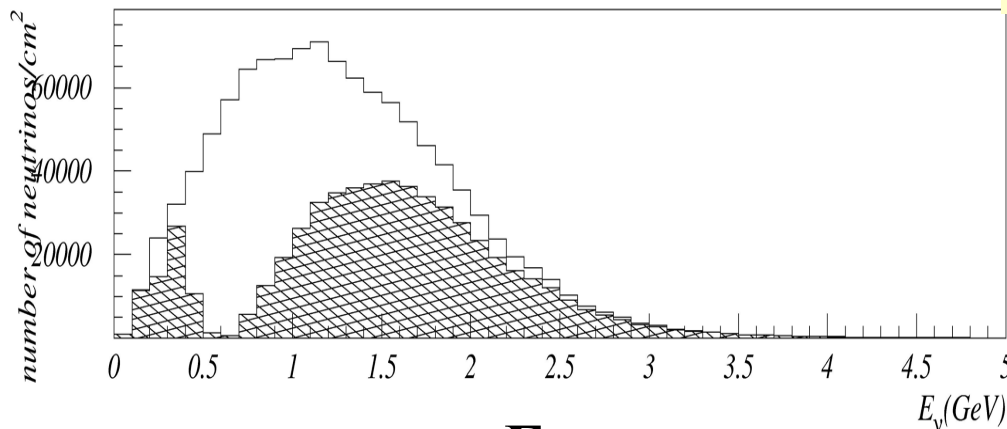


$$prob. = \sin^2 2\theta \cdot \sin^2 \left(\frac{1.27 \Delta m^2 L}{E_\nu} \right)$$

Fixed distance, direction
($E_\nu \sim \text{GeV}$, $L \sim \text{O}(100)\text{km}$)

(99% ν_μ , $\sigma_\tau \ll \sigma_\mu$)

Meas. @ production



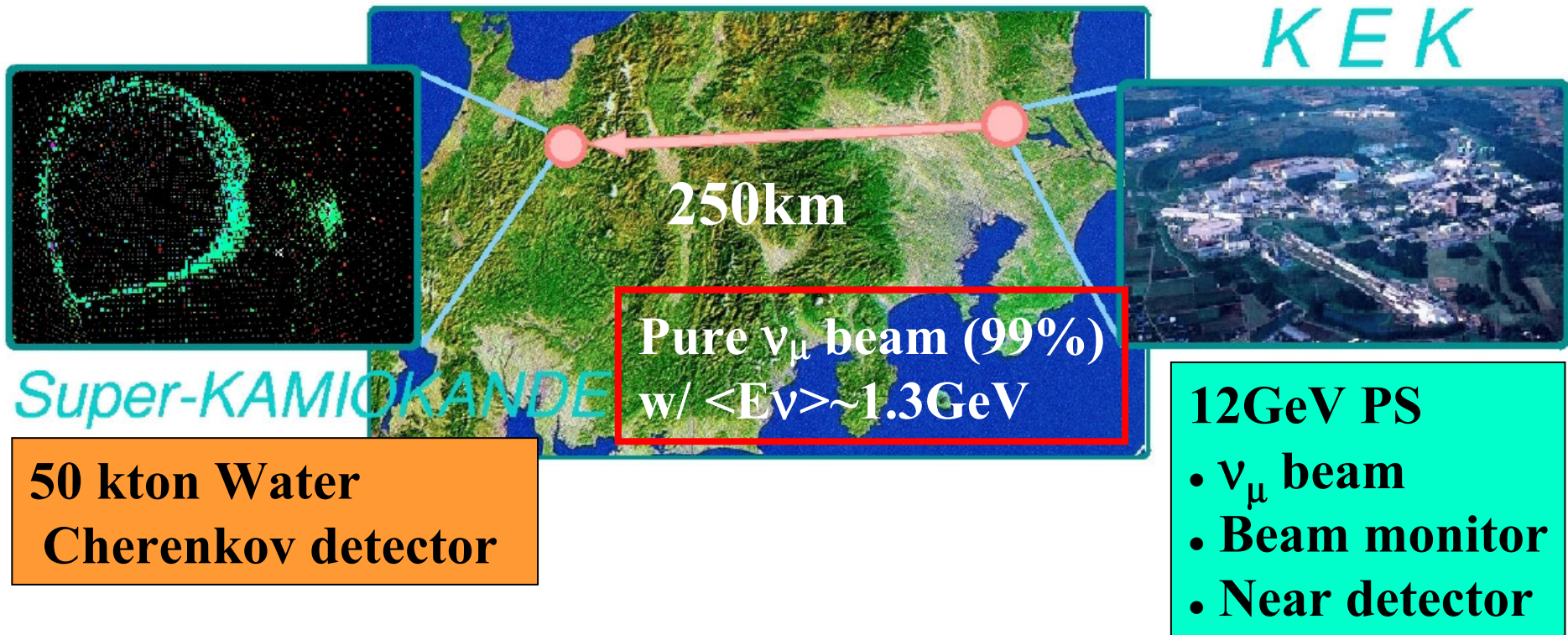
E_ν

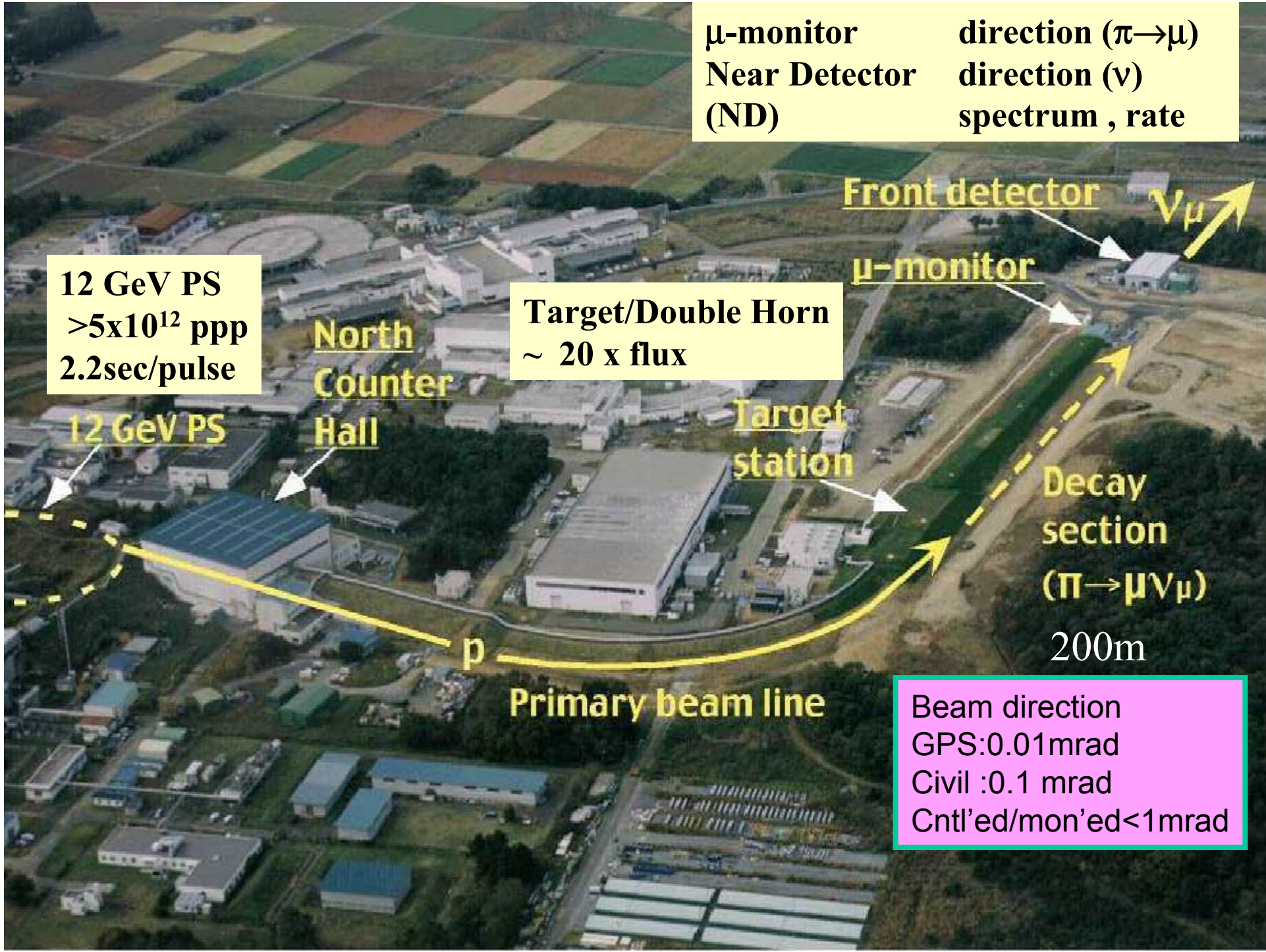
Signature

- Reduction of events
- Spectrum distortion
- Appearance of ν_e, ν_τ

K2K experiment

First long baseline (250km) neutrino experiment.
(Still only one)
Search for ν_μ disappearance and ν_e appearance





μ-monitor **direction ($\pi \rightarrow \mu$)**
Near Detector **direction (ν)**
(ND) **spectrum , rate**

12 GeV PS
 $>5 \times 10^{12}$ ppp
2.2sec/pulse

Target/Double Horn
 $\sim 20 \times$ flux

Beam direction
GPS:0.01mrad
Civil :0.1 mrad
Cntl'ed/mon'ed<1mrad

12 GeV PS

North Counter Hall

Target station

Decay section ($\pi \rightarrow \mu \nu \mu$)

200m

Primary beam line

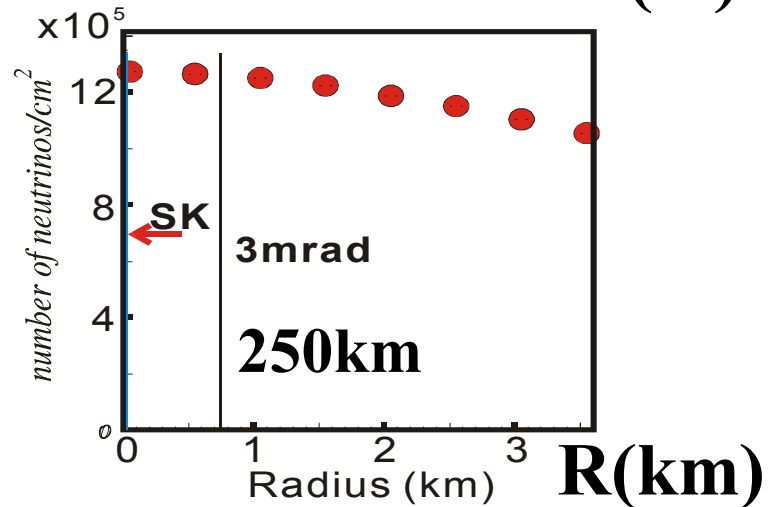
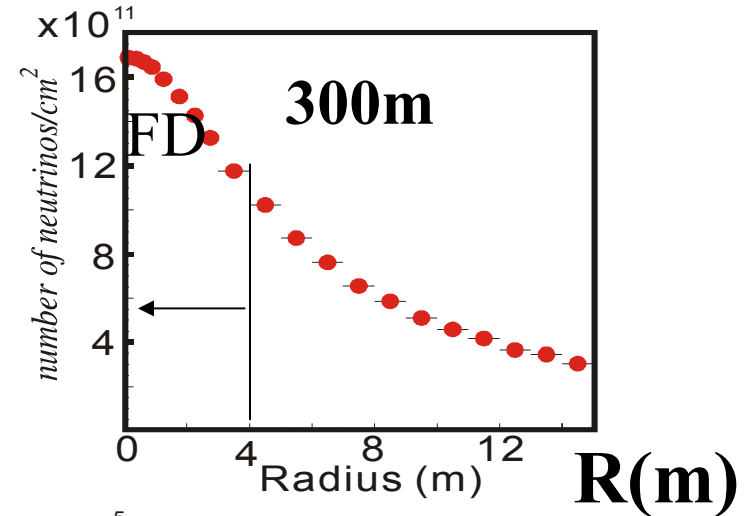
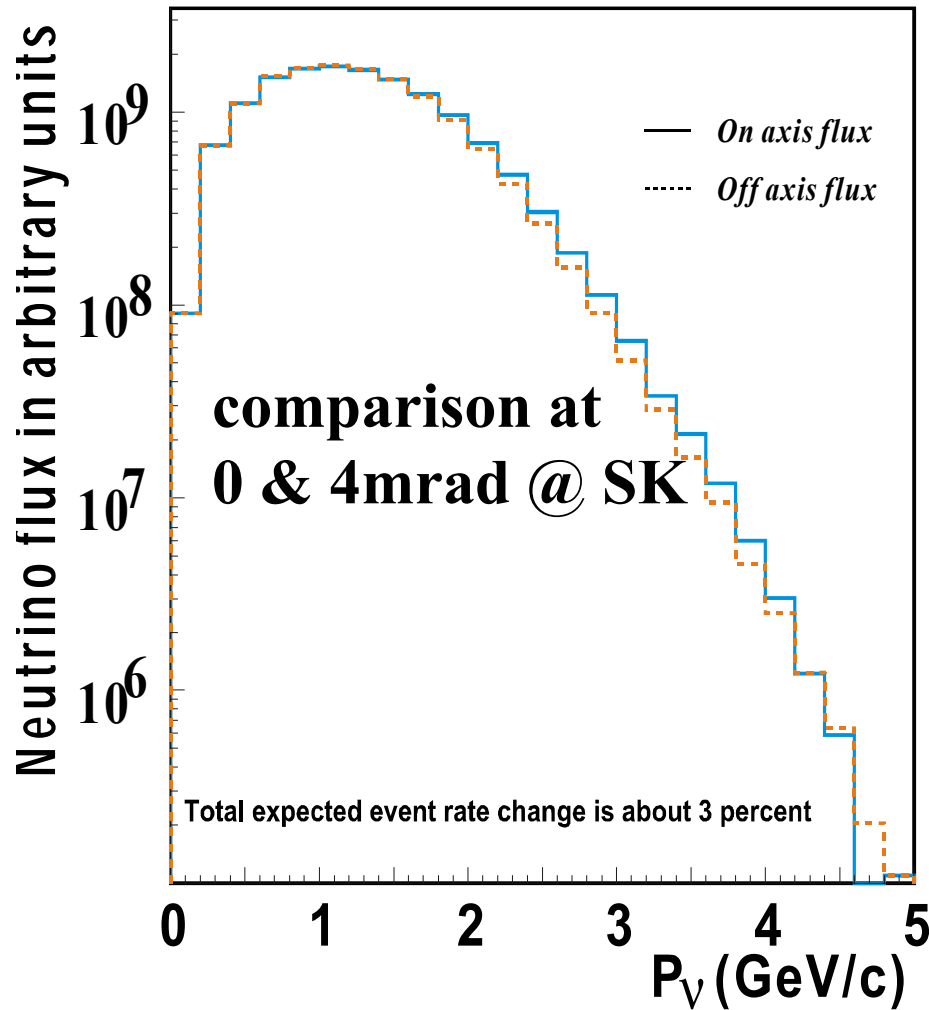
Front detector

μ-monitor

$\nu \mu$

p

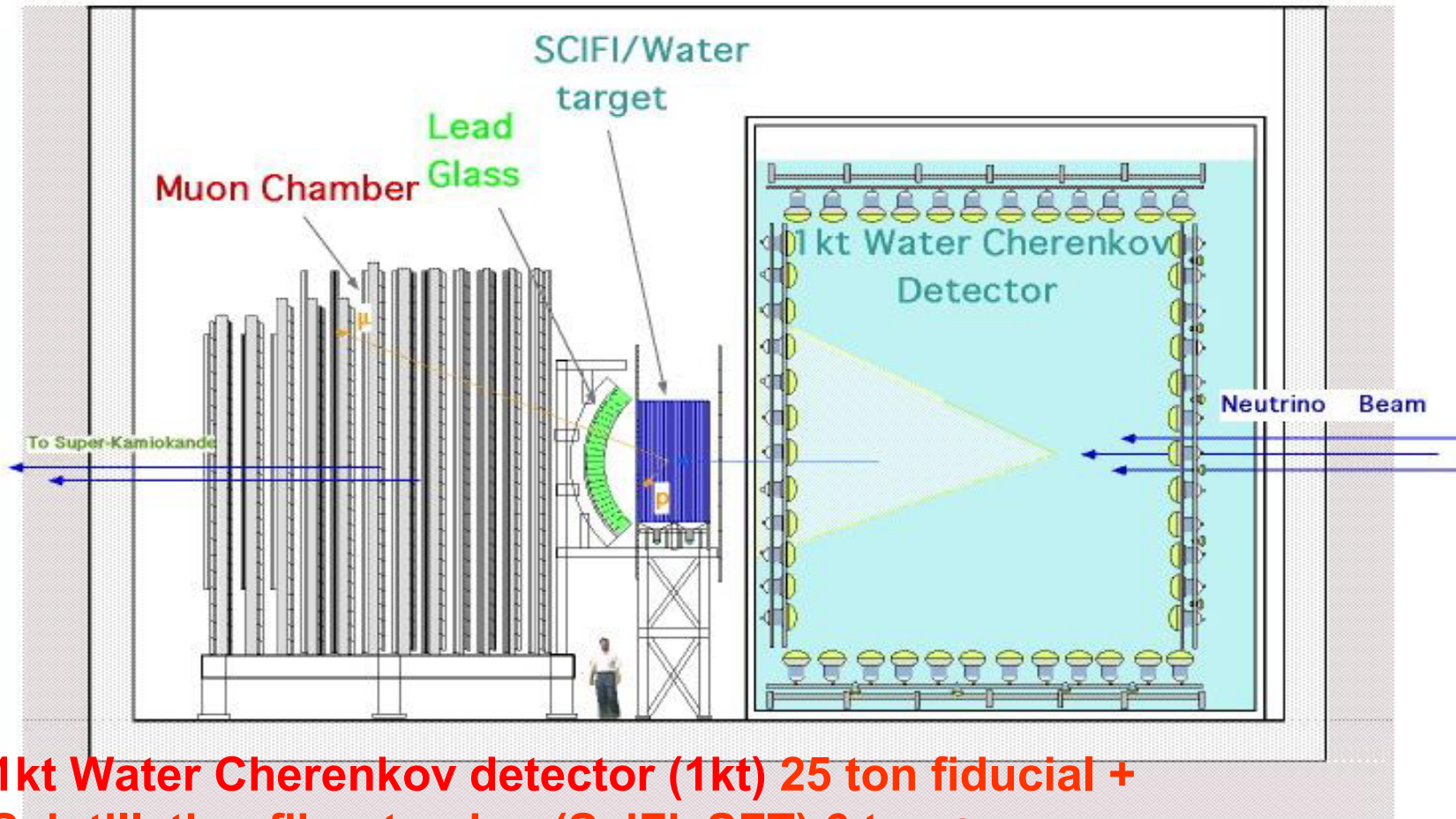
Expected (MC) Neutrino Spectra and Radial Distributions at 300m/250km



1km(4mr) off axis @ SK no change in rate and spectrum

Near Detectors (ND)

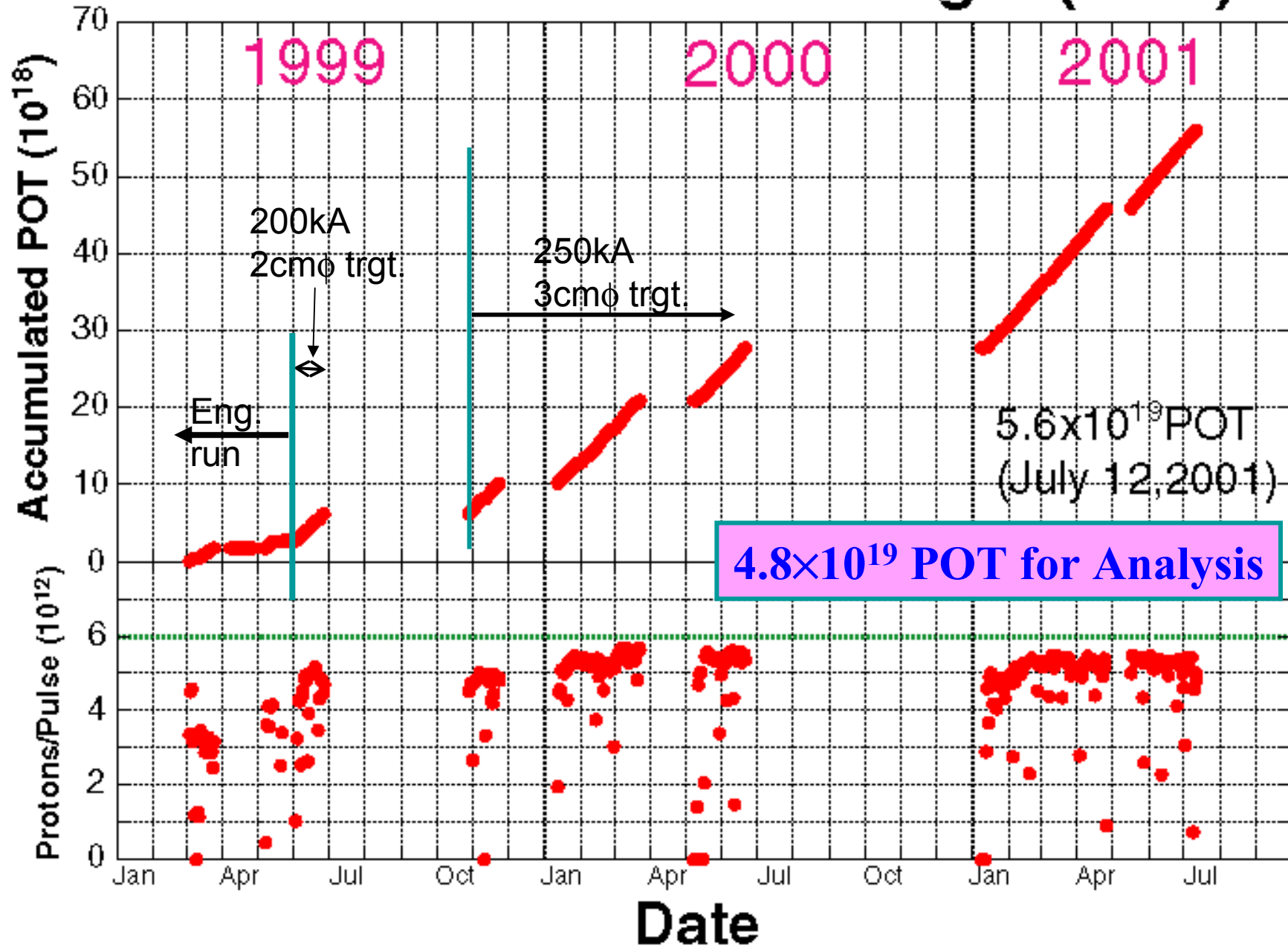
300m downstream
from the target



**1kt Water Cherenkov detector (1kt) 25 ton fiducial +
Scintillation fiber tracker (SciFi, SFT) 6 ton +
Muon range detector(MRD) 329 ton fiducial
+Lead glass detector (LG)**

Beam monitoring (intensity, direction) + Spectrum measurement

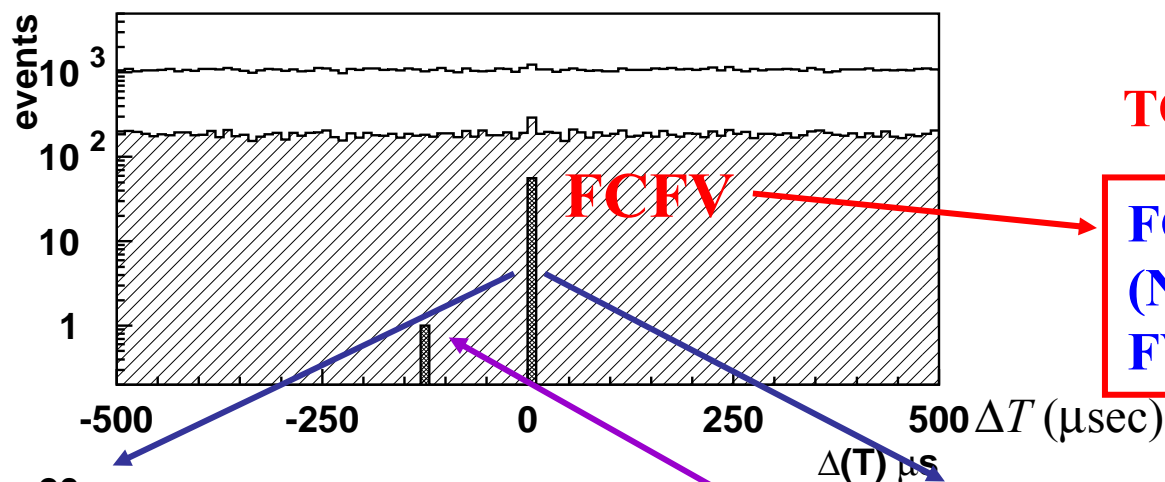
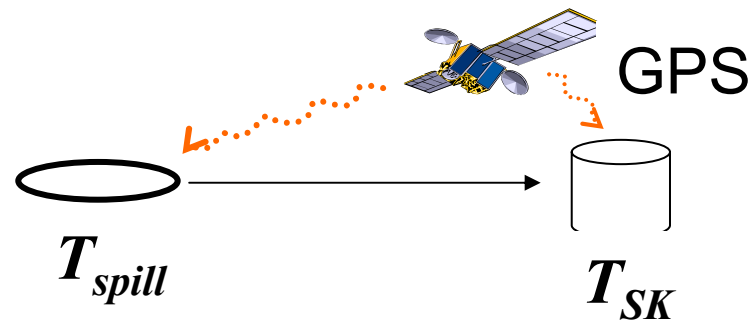
Delivered Protons on Target (POT)



Observation at Super-K

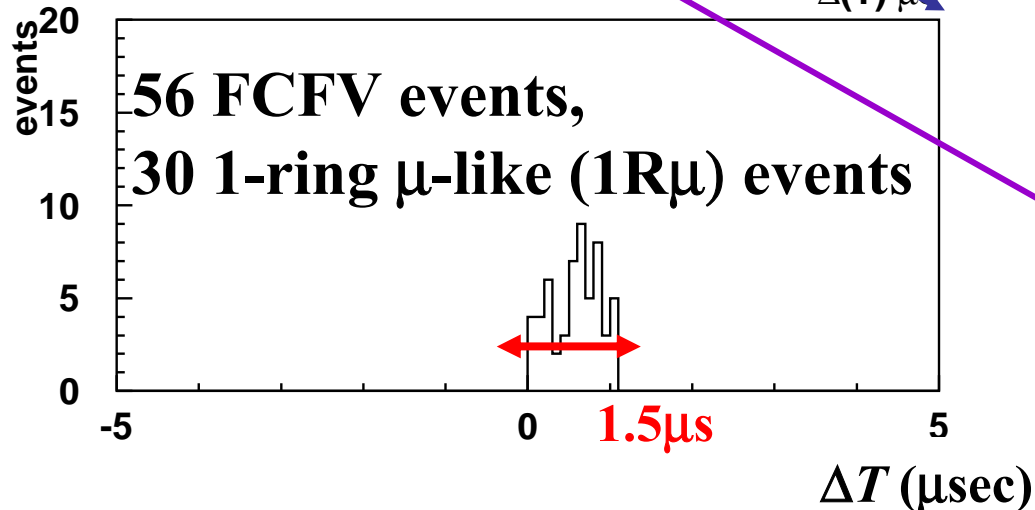
$$-0.2 \leq \Delta T \equiv T_{SK} - T_{Spill} - \text{TOF} \leq 1.3 \mu\text{sec}$$

NC Decay-e HE Trig.



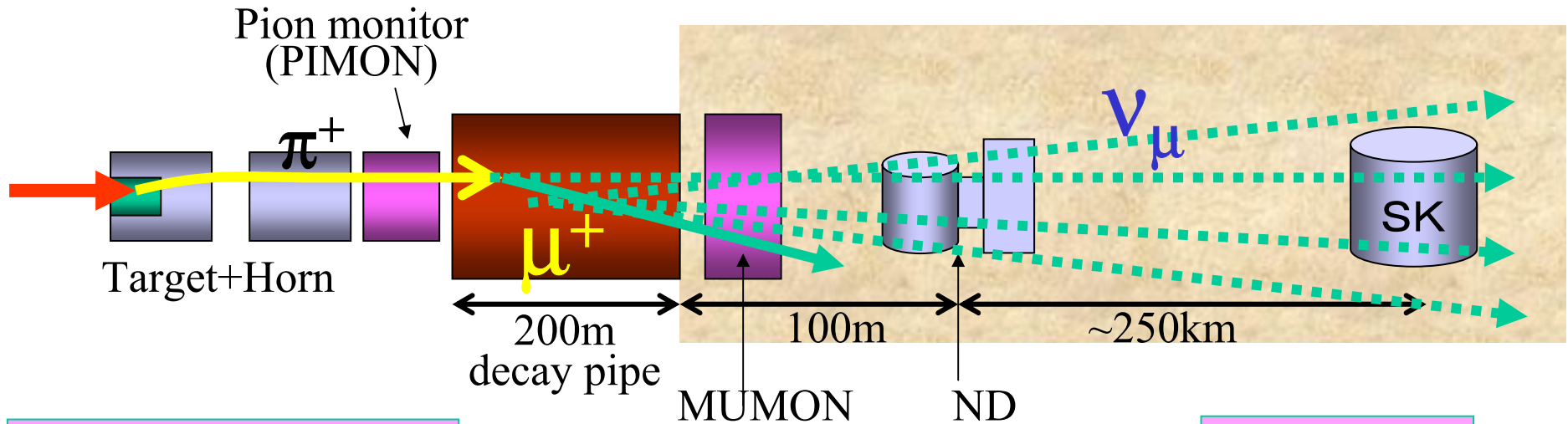
**FC: fully contained
(No activity in Outer Detector)
FV: 22.5kt Fiducial Volume**

~30MeV threshold



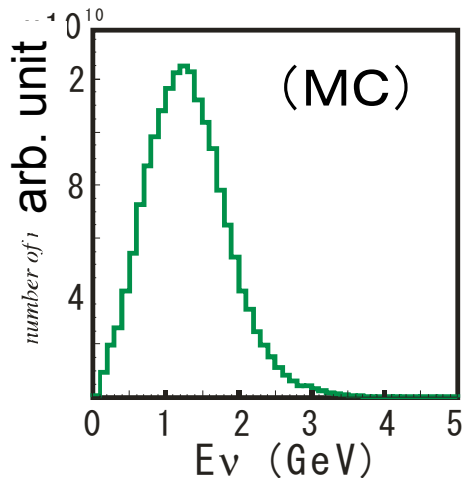
**Expected Atm. ν BG
10^{-3} within 1.5 $\mu\text{s}</math>.$**

Strategy of K2K



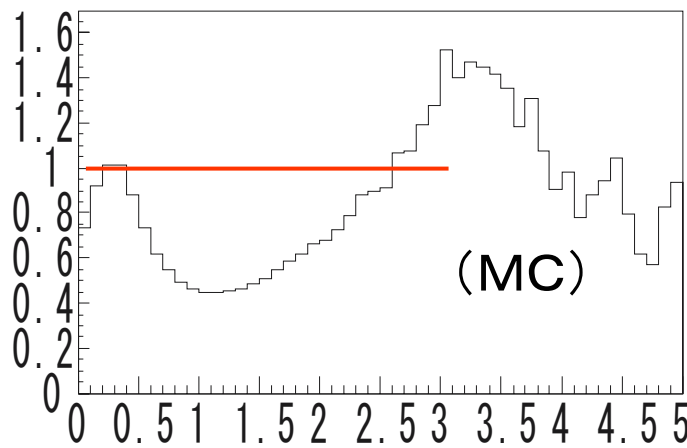
ν_μ @ production

- Abs. norm: 1KT
- spectrum: 1KT&FGD



measure w/ ND

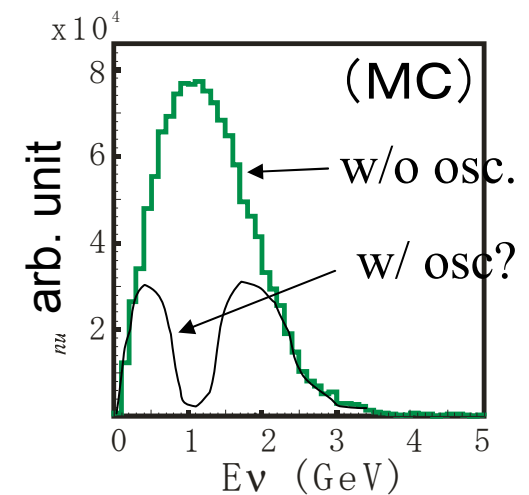
Extrapolate by
multiplying ratio($\neq 1$)



measured by PIMON

Predict

- # of events
- ν_μ spectrum



Neutrino Interaction @ ~1 GeV

&

E_ν reconstruction

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

μ^- (E_μ, p_μ)

θ_μ

p

ν

- ✧ CC QE
- ✧ ~100% efficiency for N_{SK}
- ✧ can reconstruct $E_\nu \leftarrow (\theta_\mu, p_\mu)$

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

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

μ^- (E_μ, p_μ)

θ_μ

π 's

p

ν

- ✧ CC nQE
- ✧ ~100% efficiency for N_{SK}
- ✧ Bkg. for E_ν measurement

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

ν

π 's

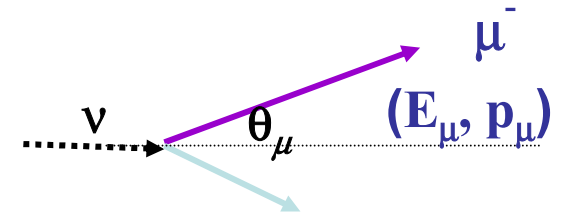
p

- ✧ NC
- ✧ ~40% efficiency for N_{SK}

Spectrum Measurements @ ND

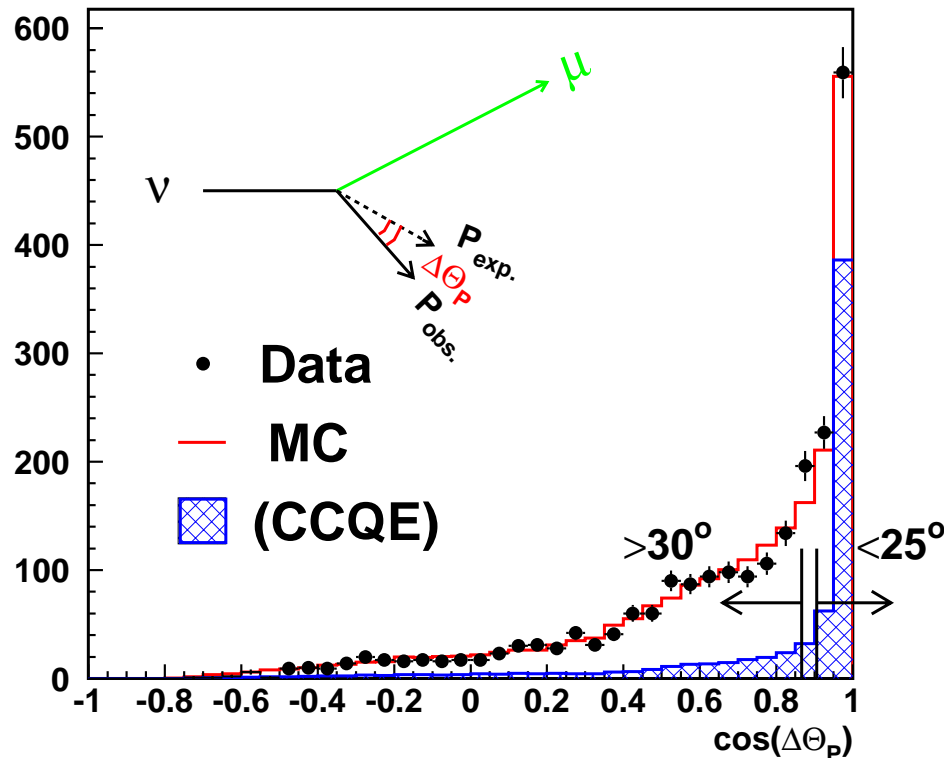
(p_μ, θ_μ) 2-d dist of four event categories

- 1KT FCFV(25t) 1R μ 22,476ev
- Scifi 1tr. μ 5,963ev
- Scifi 2tr. QE-enh($\Delta\theta_p < 25^\circ$) 764ev
- Scifi 2tr. nQE-enh($\Delta\theta_p > 30^\circ$) 1,288ev



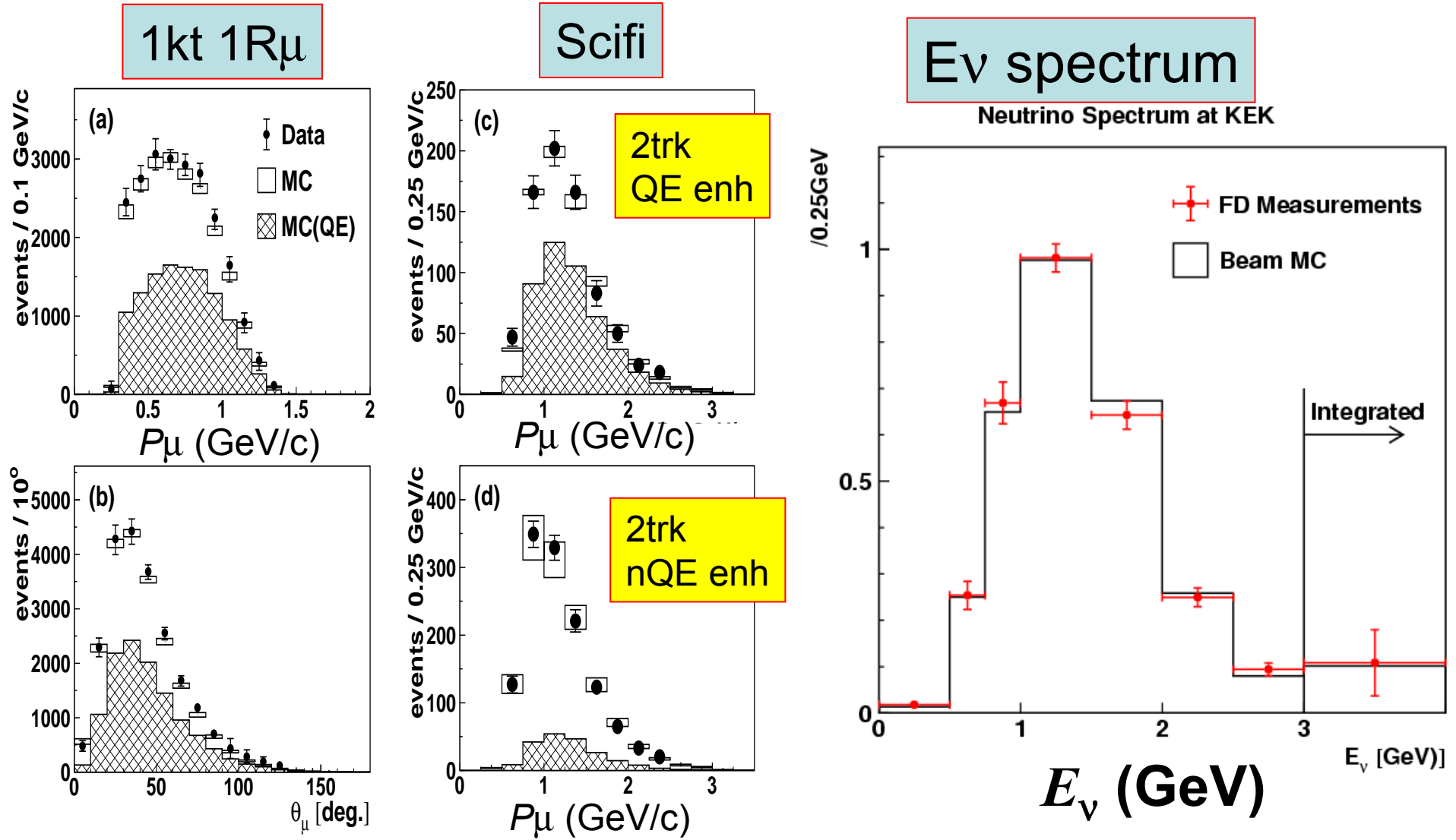
SciFi 2 track $\cos(\Delta\theta_p)$ distribution

Simultaneously fitted



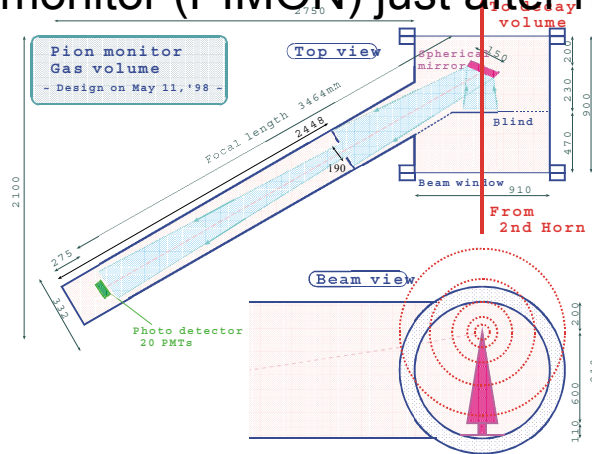
Angular diff. btw 2nd trk & Predicted proton track assuming QE

Results of Fitting : Spectrum@KEK

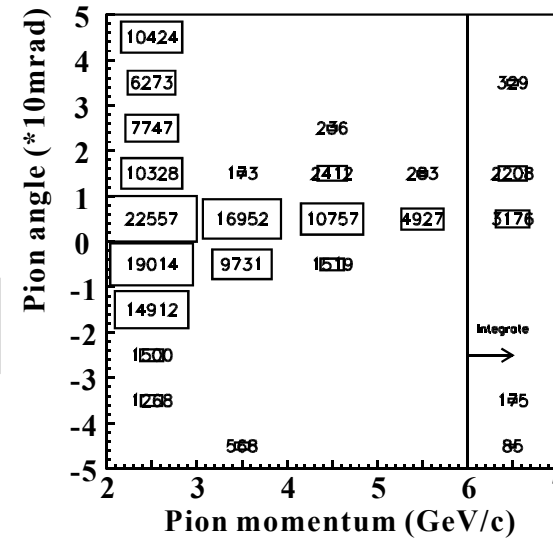
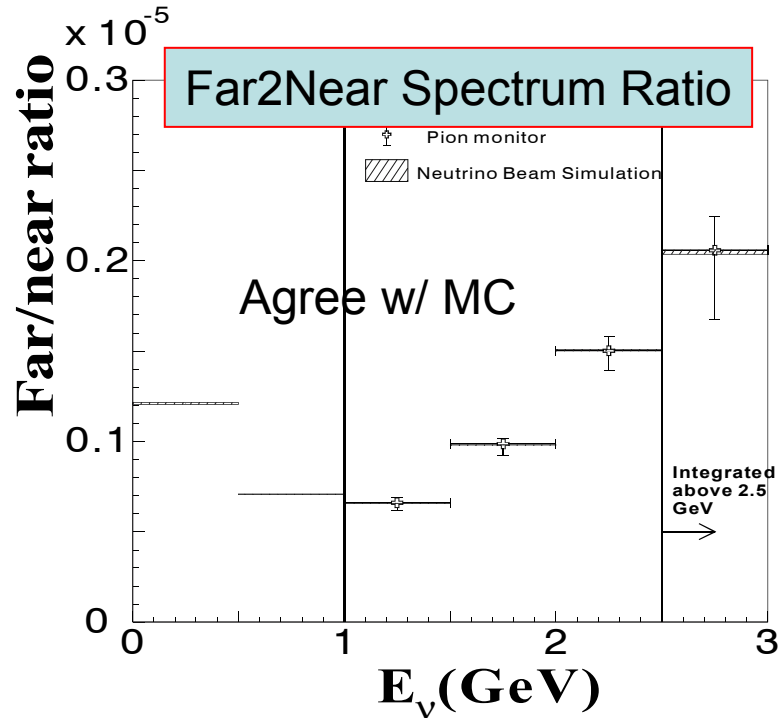
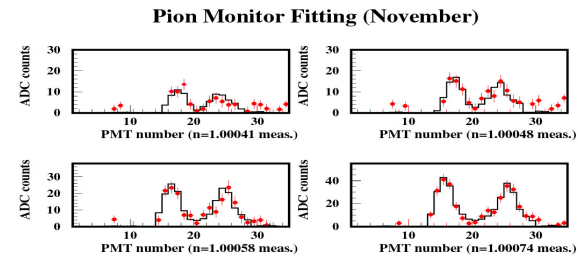


Near2far extrapolation

Pion monitor (PIMON) just after horn



Cherenkov light distributions



$p_\pi - \theta_\pi$ distribution

Expected # of events @ SK w/o oscillation

$$N_{\text{exp}} = N_{\text{KT}}^{\text{obs}} \cdot \frac{N_{\text{SK}}^{\text{MC}}}{N_{\text{KT}}^{\text{MC}}}$$

ND spec.
N/F ratio enter

80.1 $\begin{matrix} +6.2 \\ -5.4 \end{matrix}$

Spectrum/cross section errors mostly cancel since
 same interaction target (water)
 Eff. of both KT/SK is high and similar

Summary of syst. errors

Jun99	Total	+1.0%
		-0.9%
Nov99~	Spectrum	+0.6%
		-0.6%
	nQE/QE	+0.5%
		-1.1%
Far/Near	+4.9%	
	-5.0%	
Norm		5.0%
Total		+7.7%
		-6.7%

Results of oscillation analysis

Null osc. probability

	Analysis	
(%)	(1)	(2)
Norm only	1.3	0.7
Shape only	16	14
N+S	0.7	0.4

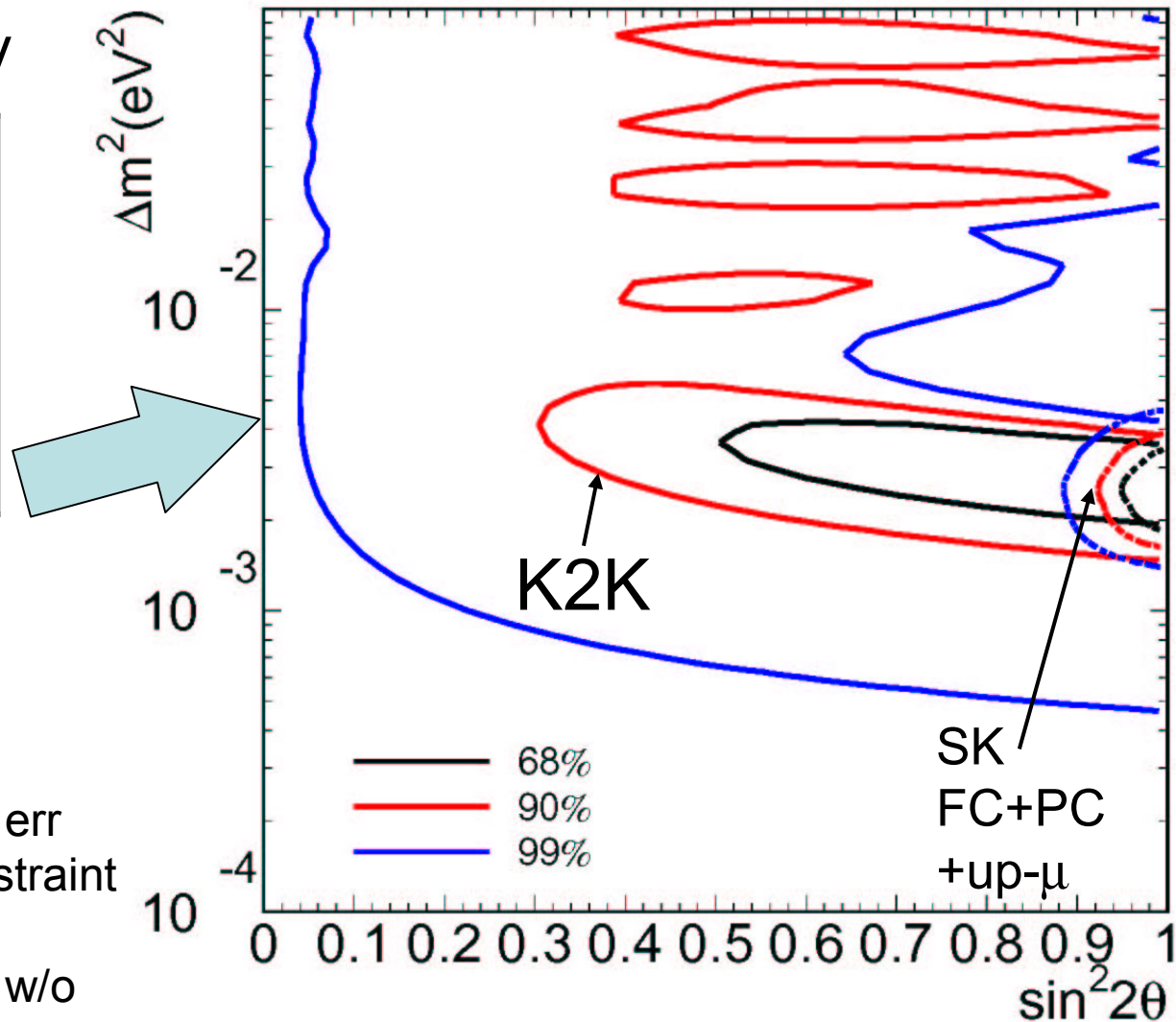
< 1%

Two analysis

different treatment of syst. err

(1) As fitting params w/ constraint term

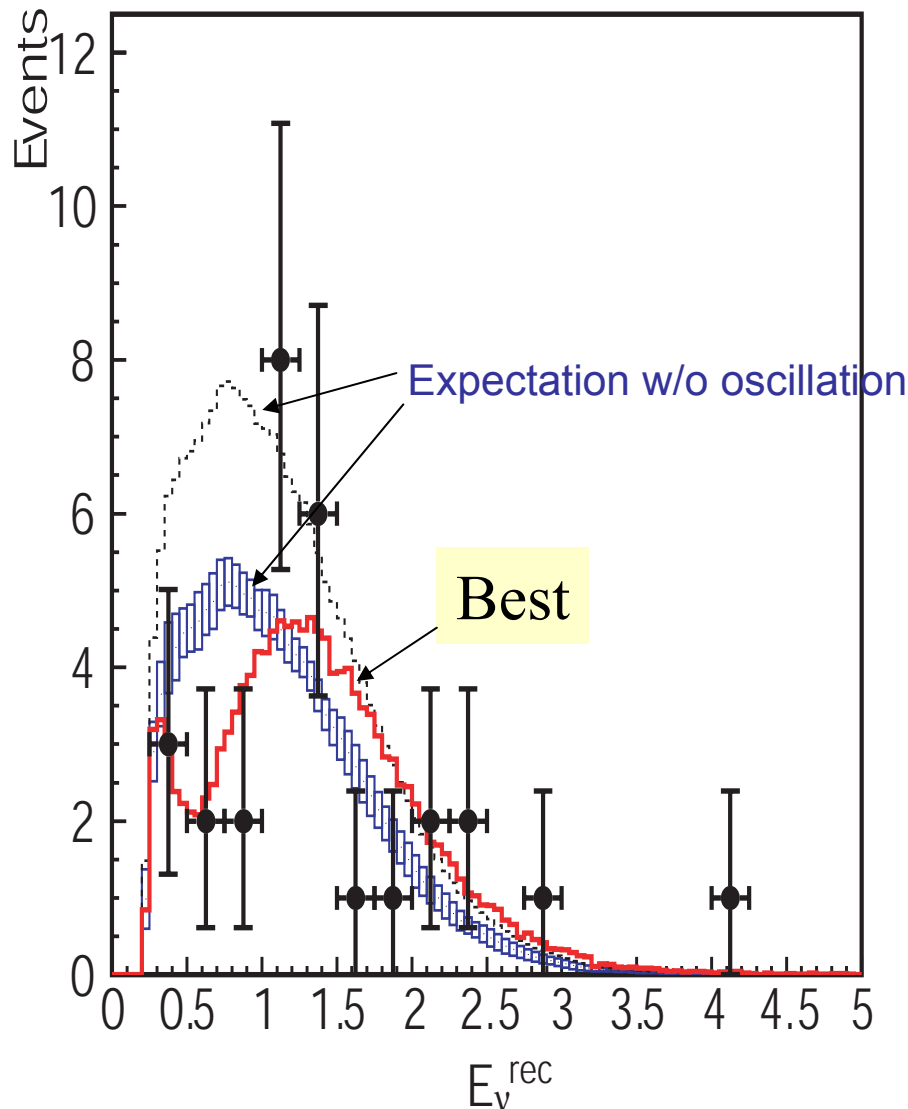
(2) wgt:'et ave. of likelihood w/o constraint term



consistent with SK atmospheric ν results

Best fit 1ring μ -like spectrum & N_{SK}

reconstructed E_ν



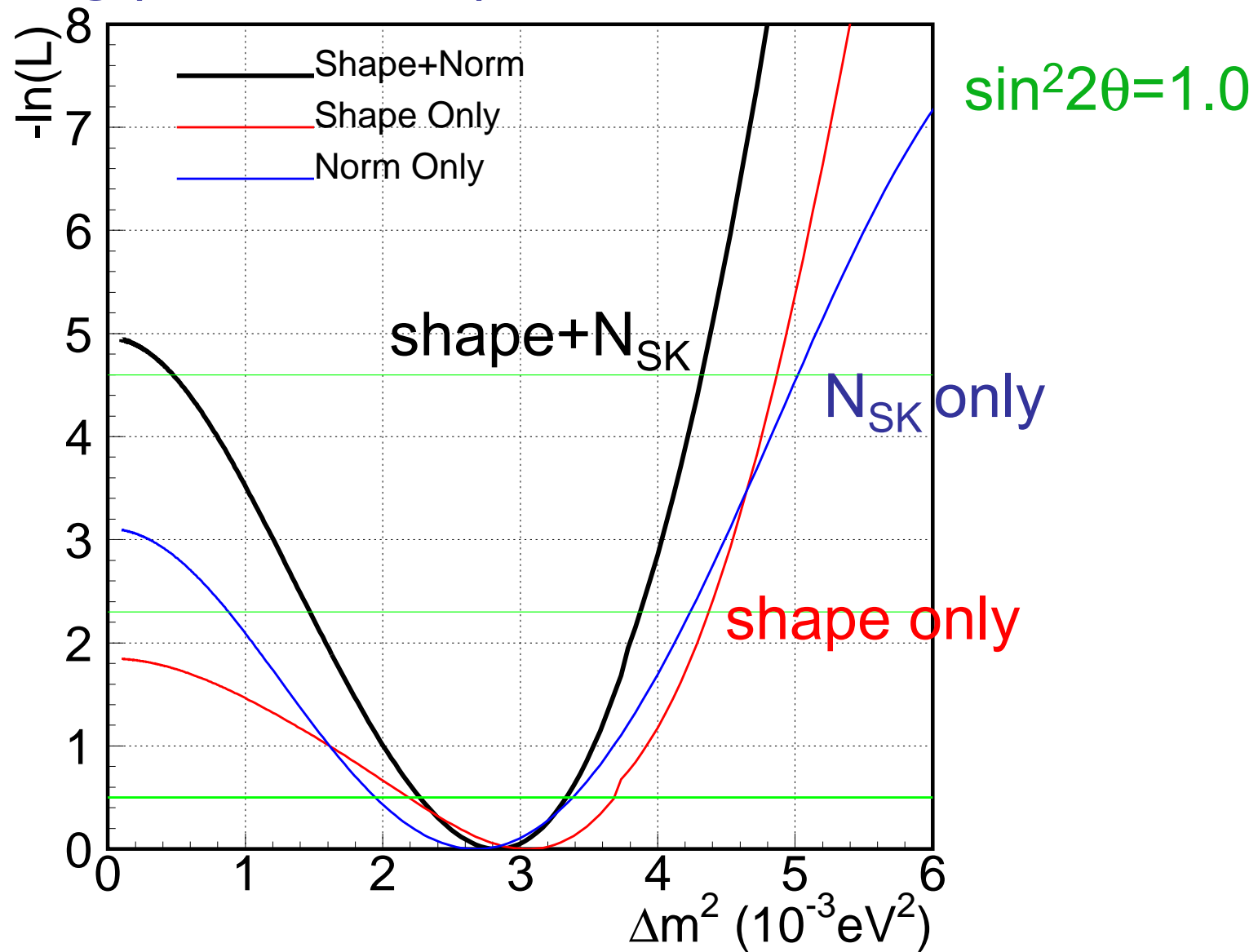
Best fit point
($\sin^2 2\theta$, Δm^2)
= (1.0, $2.8 \times 10^{-3} \text{eV}^2$)

KS test (shape): 79%

for N_{SK}
56ev obs. / 54ev exp.

Both Shape & N_{SK}
agree with best fit
expectation

$-\Delta\log(\text{likelihood})$ distribution

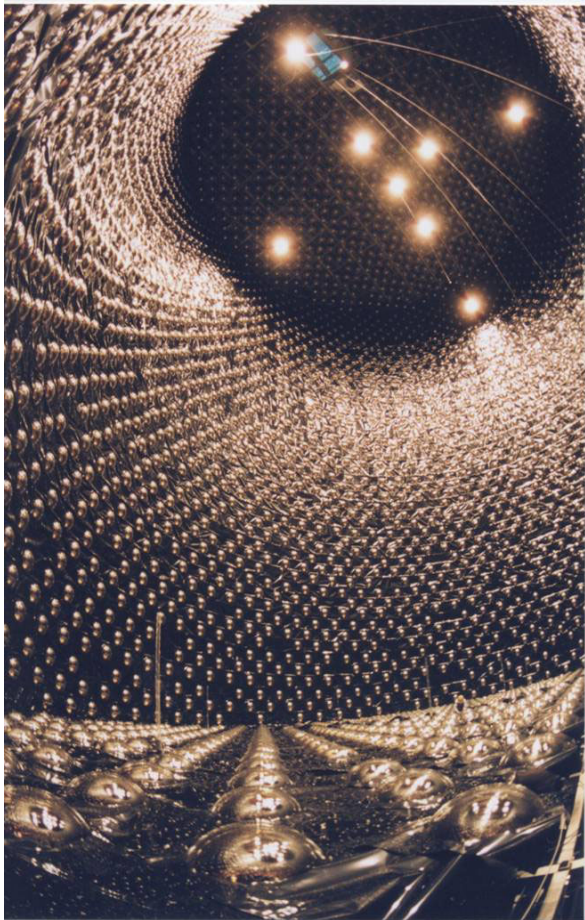


Shape & N_{SK} indicate consistent Δm^2 region

SK is back !

Nov.12,2001 accident
Reconstruction work in 2002

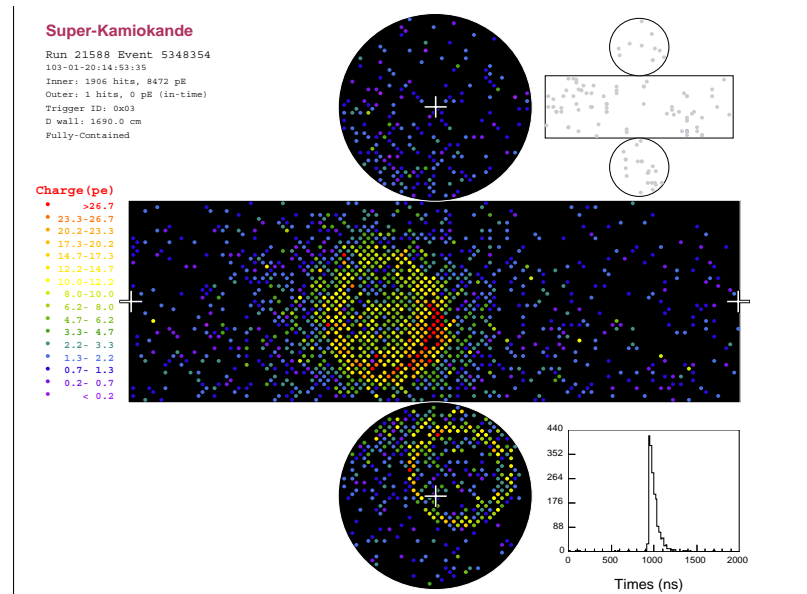
Full water on 10-Dec.-2002



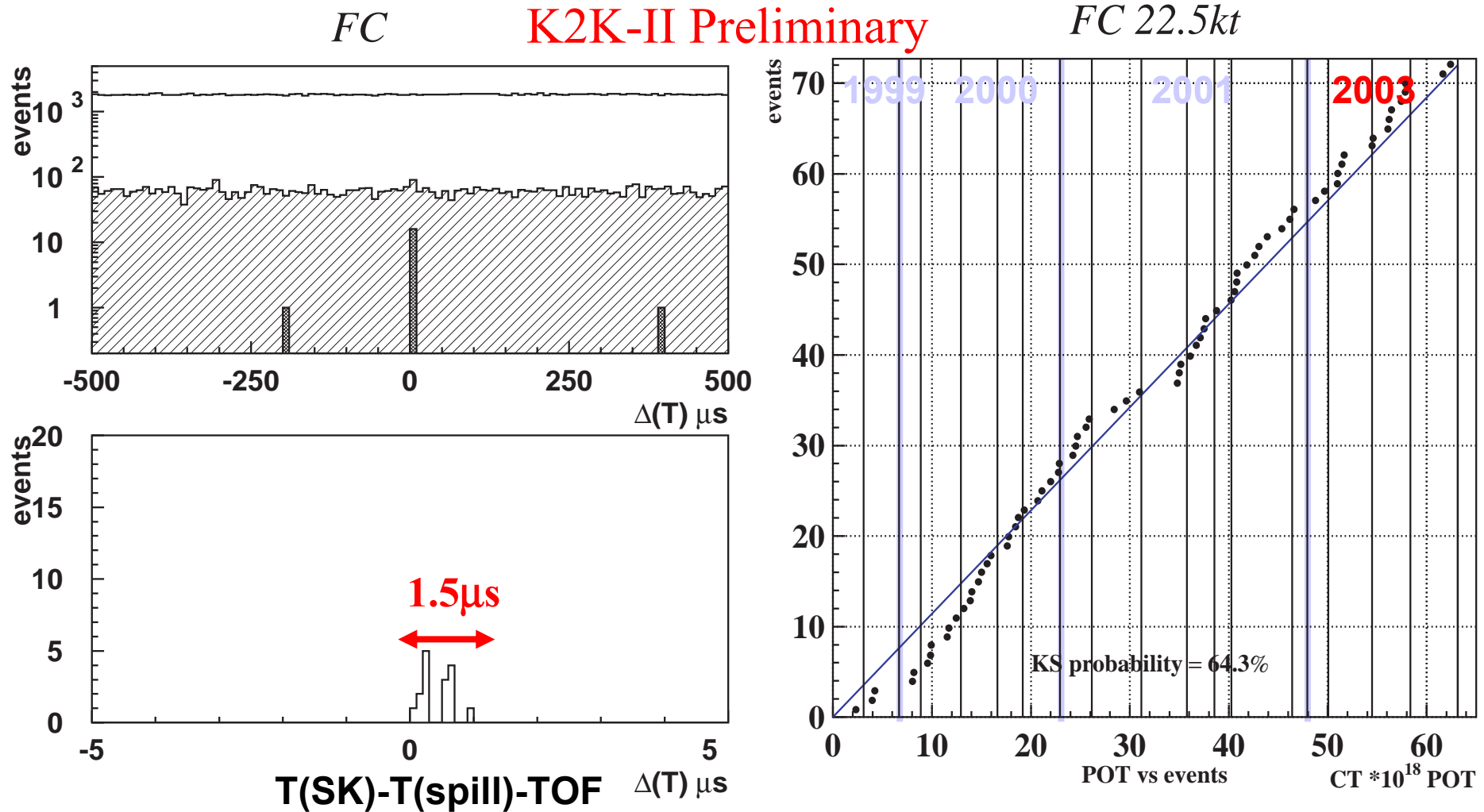
Acrylic + FRP
vessel

Sep.-2002, before water filling

Jan.-2003, fully contained event



Updated SK events in K2K-II



K2K-II experiment successfully observed SK events

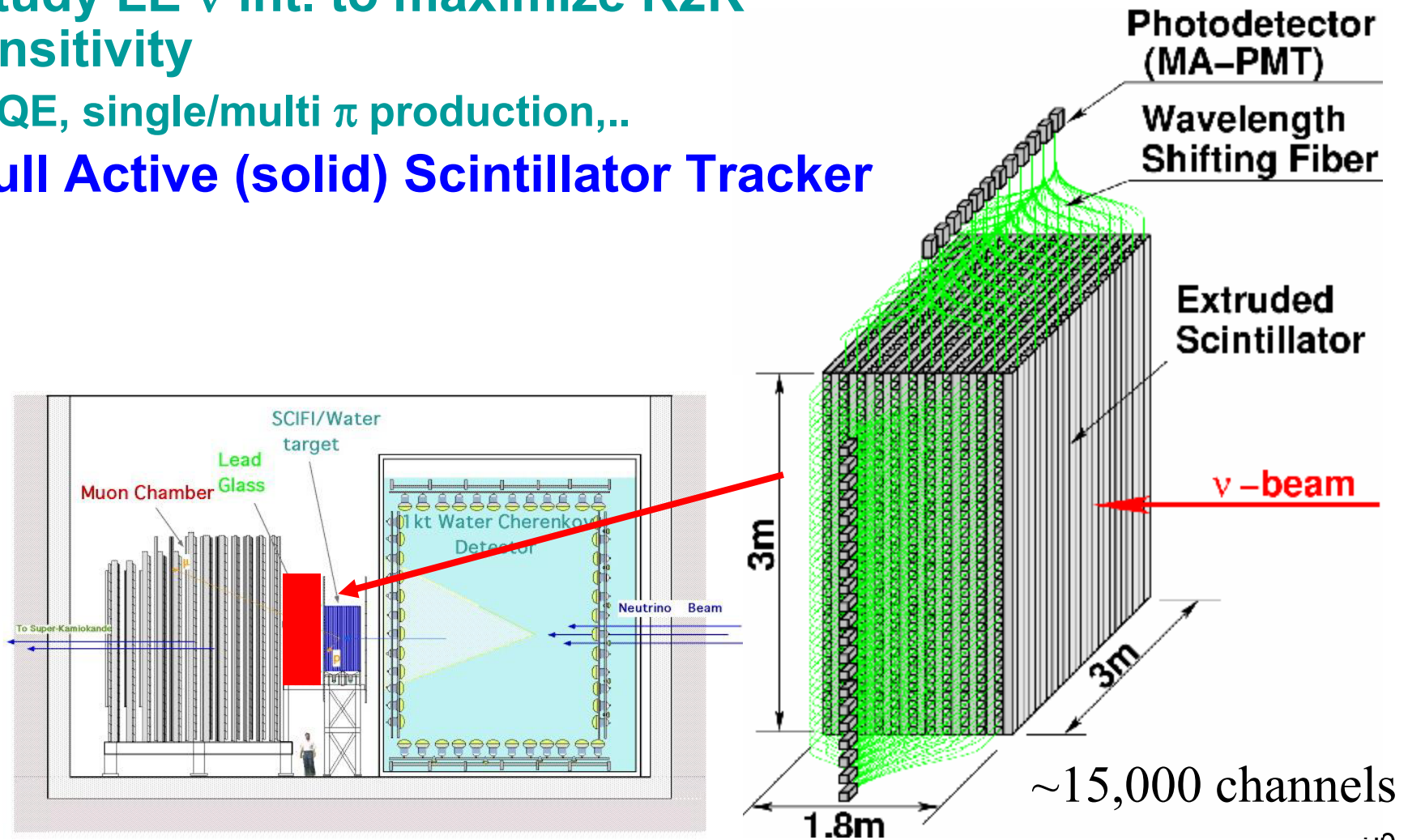
K2K Upgrade (SciBar detector)

• $L=250\text{km}$, $\Delta m^2 = 3 \times 10^{-3}$ $E_\nu \sim 0.6\text{GeV}$

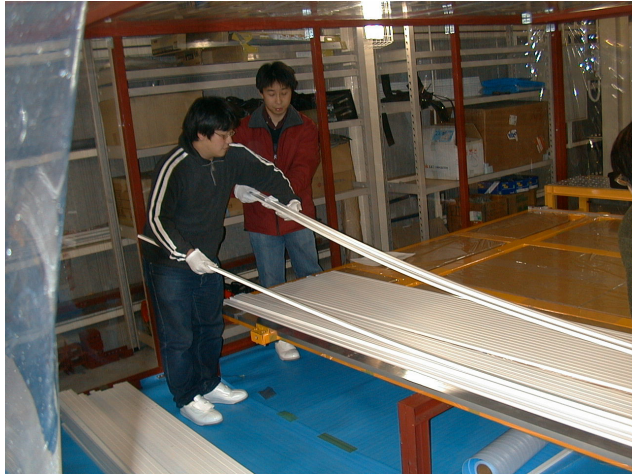
• Study LE ν int. to maximize K2K sensitivity

–QE, single/multi π production,...

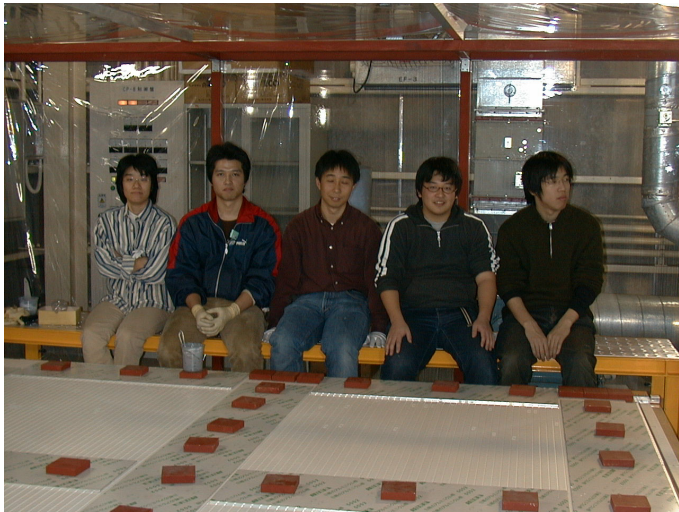
• Full Active (solid) Scintillator Tracker



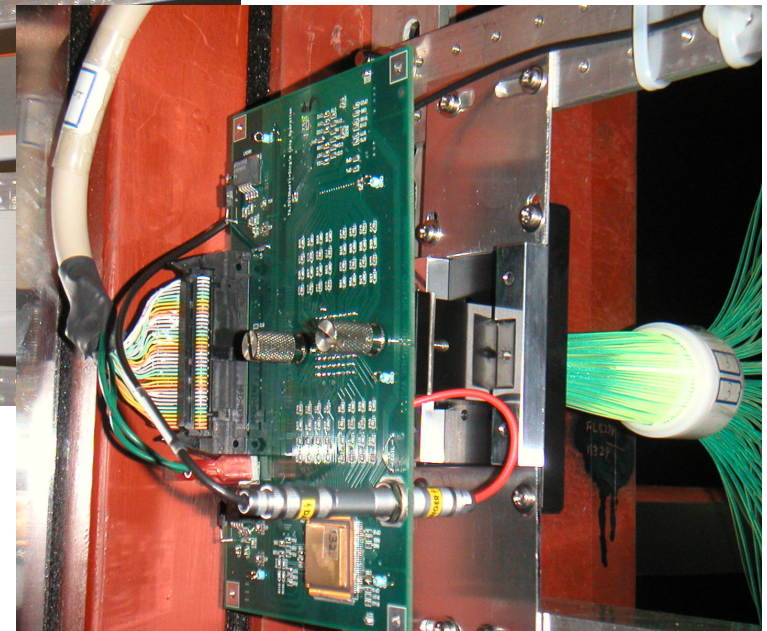
Construction of SciBar



Layer module construction



First 4 layer
modules
Installed!! In
Jan.2003



Installation of remaining part in
summer 2003

Fine-grained detector

K2K-I



K2K-II

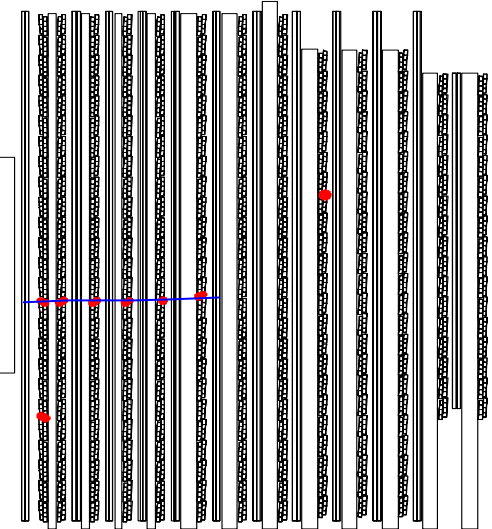
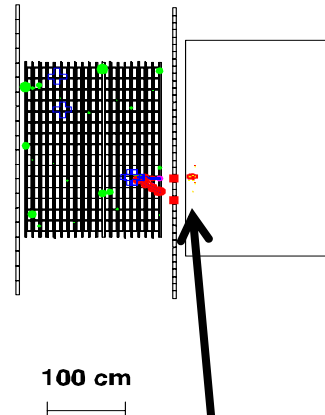
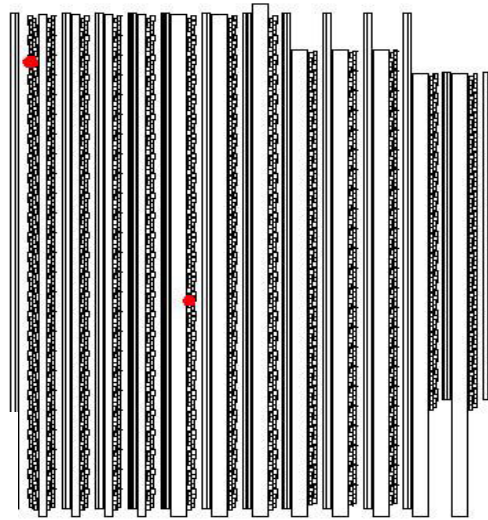
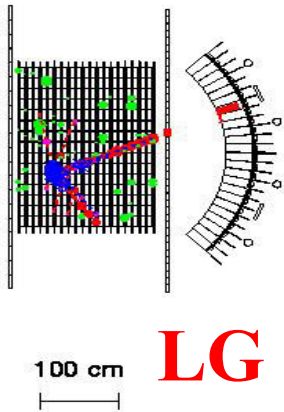
SciFi

MRD

K2K Fine-Grained Detector

Fine-Grained Detector (Side View)

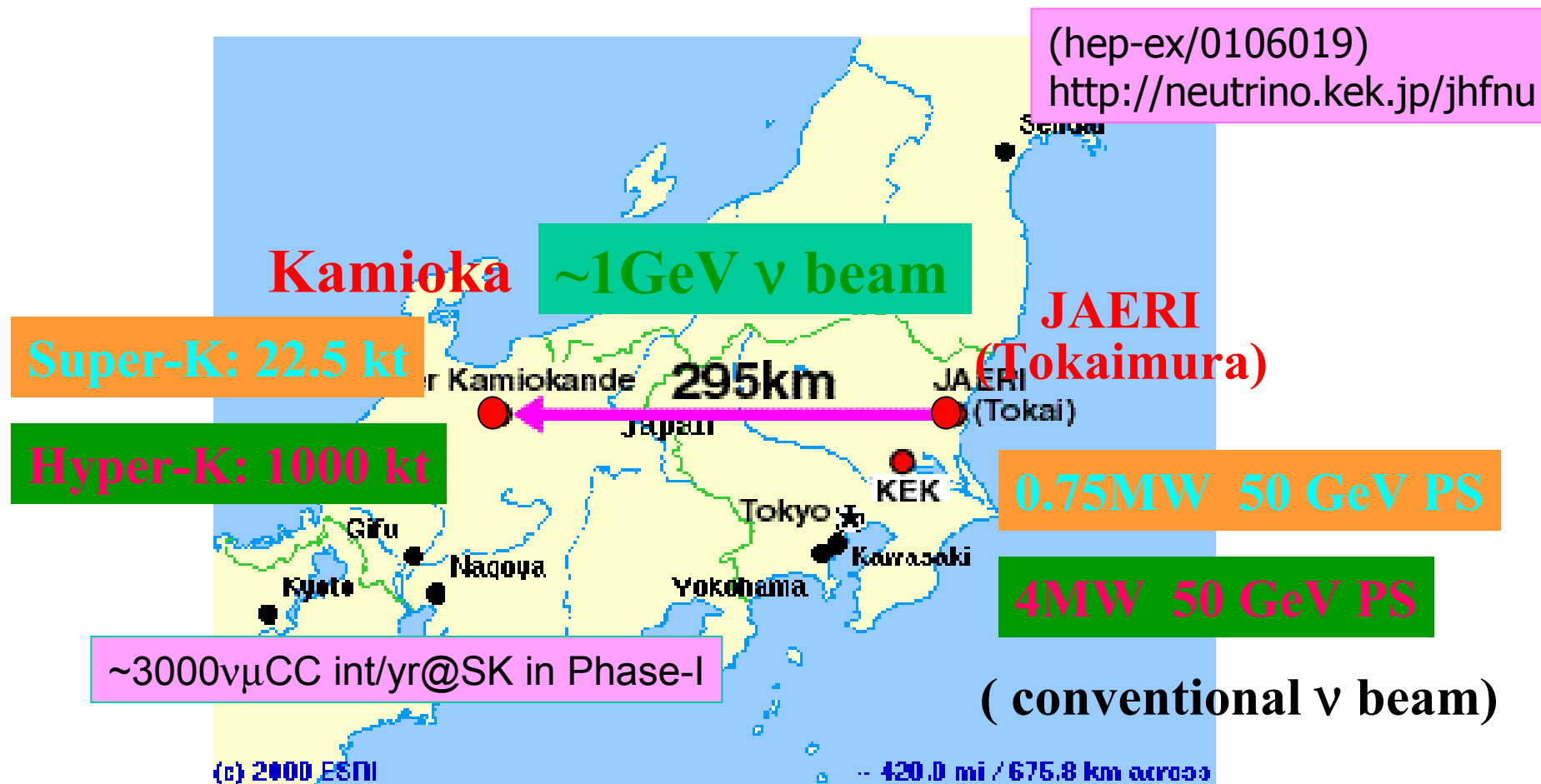
Run 4202 Spill 20191 TRGID 1
103 2 18 19 12 5 0
Nvtx 0



Scibar 4layers exists.
Full installation this
summer.

Next generation LBL experiments in Japan

J-PARC-Kamioka project



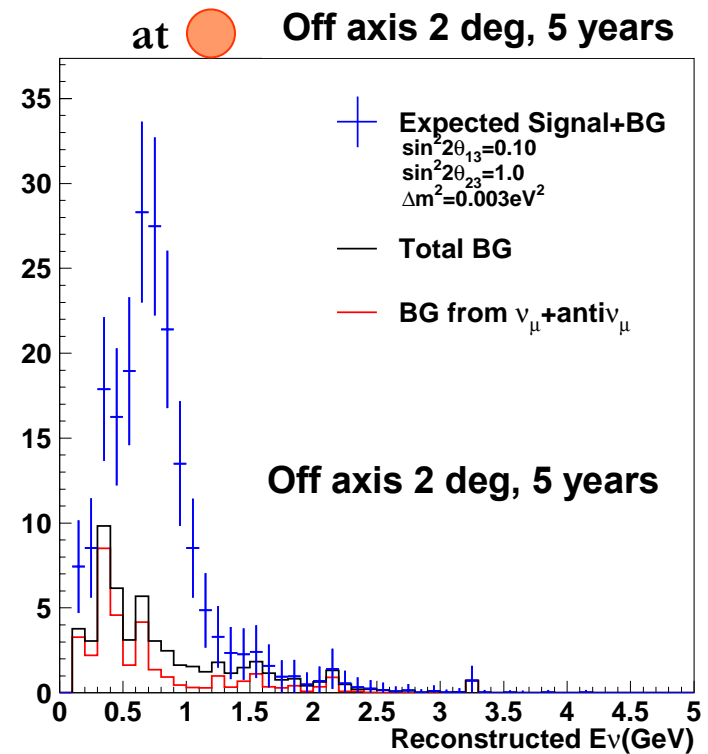
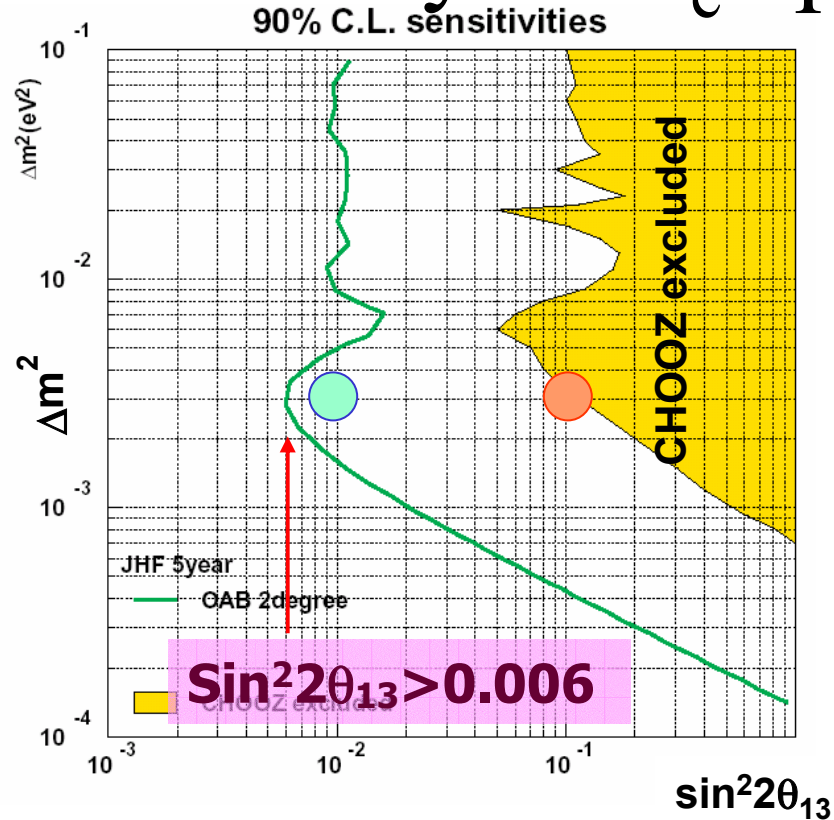
Phase-I (0.75MW + Super-Kamiokande) 2007(8)~

Phase-II (4MW+Hyper-K) ~ Phase-I $\times 200$ 201x?~





Sensitivity on ν_e appearance at J-PARC



sin ² 2θ ₁₃	Background in Super-K (as of Oct 25, 2001)					Signal	Signal + BG
	ν_μ	ν_e	$\bar{\nu}_\mu$	$\bar{\nu}_e$	total		
● 0.1	12.0	10.7	1.7	0.5	24.9	114.6	139.5
● 0.01	12.0	10.7	1.7	0.5	24.9	11.5	36.4

Summary

- K2K observed indication of ν oscillation ($\nu_{\mu} \rightarrow \nu_{\tau}$)
 - decrease in total number of events
 - $80.1^{+6.2}_{-5.4}$ exp'd \rightarrow 56 observed.
 - distortion of spectrum
 - null oscillation probability $< 1\%$
 - allowed region: $1.5 \sim 3.9 \times 10^{-3} \text{eV}^2$ @ $\sin^2 2\theta = 1$ (90%CL)
 - consistent w/ atmospheric neutrino observation
- **K2K-II started on Dec.21, 2002**
- Part of SciBar detector is installed. Full detector installation this summer
- plan to accumulate at least 10^{20} POT
- Next generation experiment w/ high statistics/sensitivity is planned.