Feb.11,2003
NOON03
@Kanazawa

Results in K2K and future

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for K2K collaboration

IPNS, KEK

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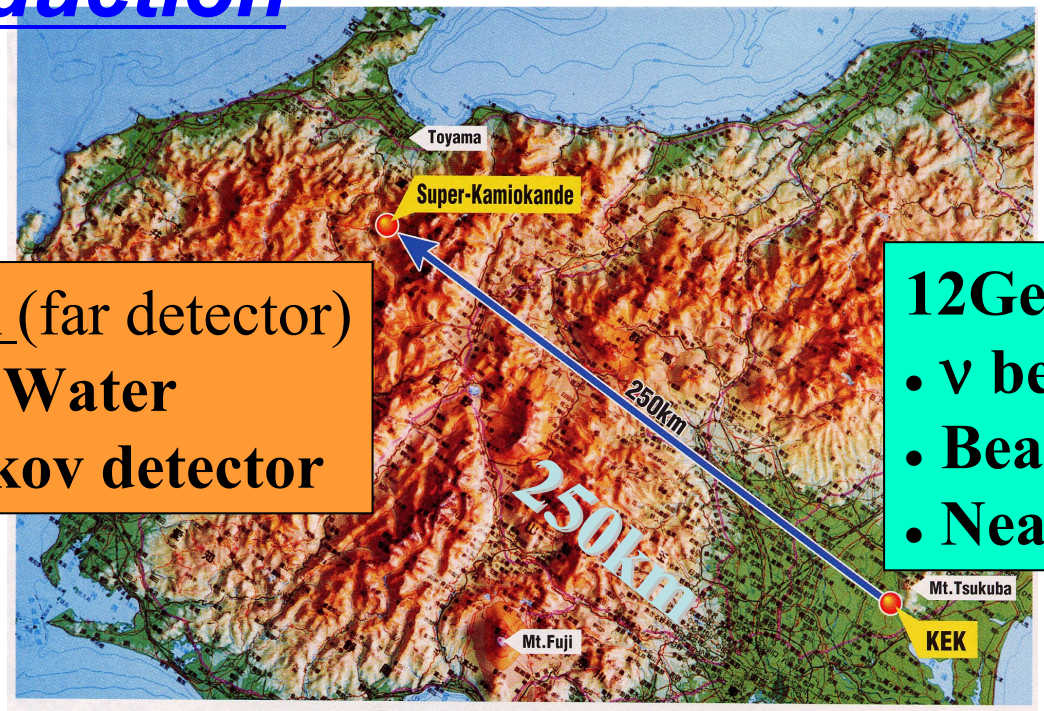
1. Introduction



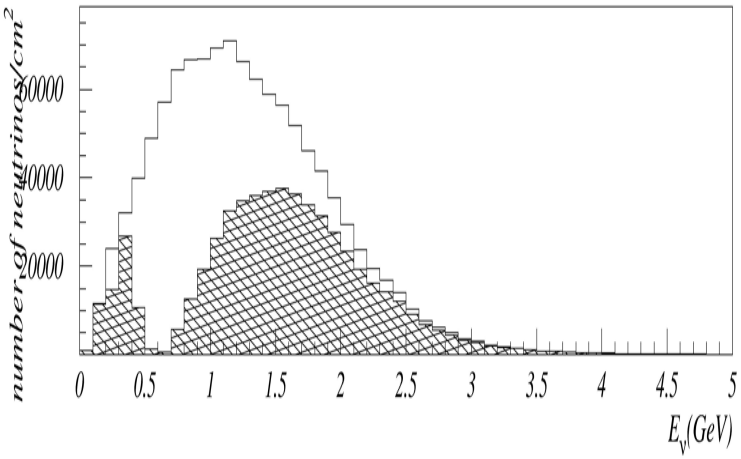
Super-K (far detector)
50 kton Water Cherenkov detector

12GeV PS@KEK
- **ν beam**
- **Beam monitor**
- **Near detector**

Eν~1.3GeV

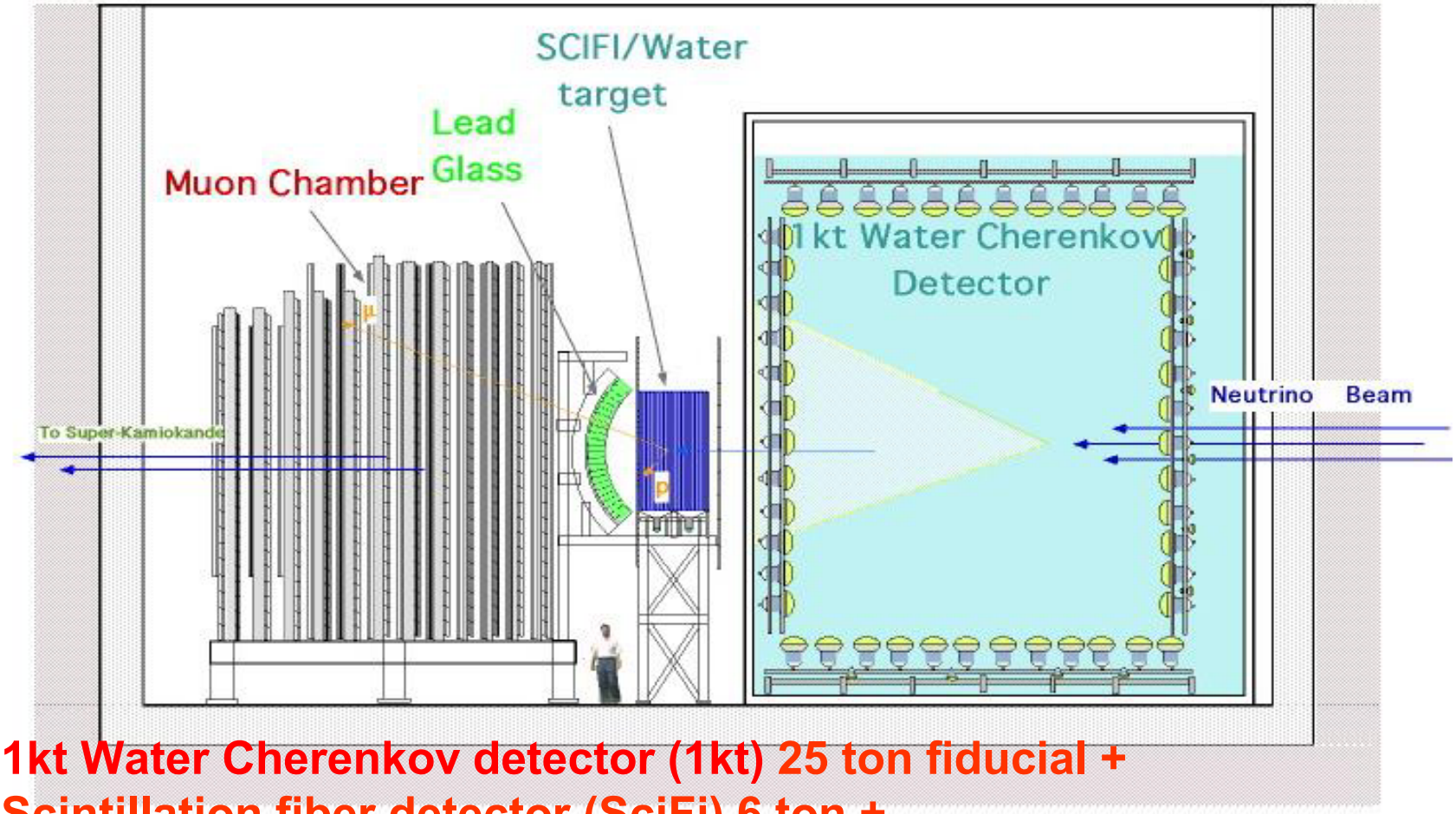
- First accelerator based long baseline experiment
- Sinsitive @ atm ν Δm^2 region

Signature of νμ disappearance
- Reduction of # of events
- Spectrum shape distortion



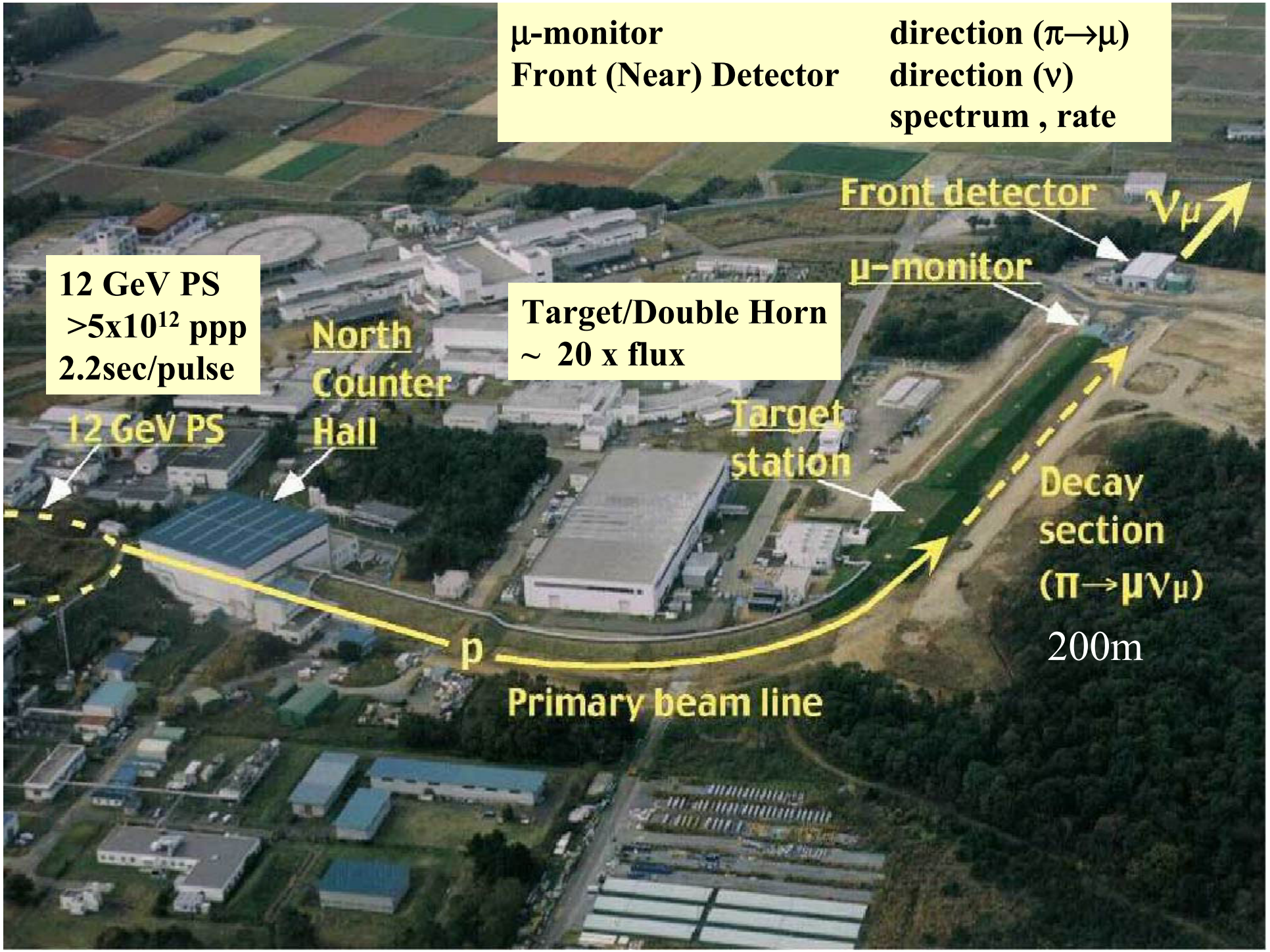
Near Detectors (ND)

300m downstream from the target



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

Beam monitoring (intensity, direction) + Spectrum measurement


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

Analysis strategy in K2K

- Measure norm. & spectrum by near detector
  - 1kt detector for norm. (small syst.)
  - 1kt/FGD for spectrum (new!)

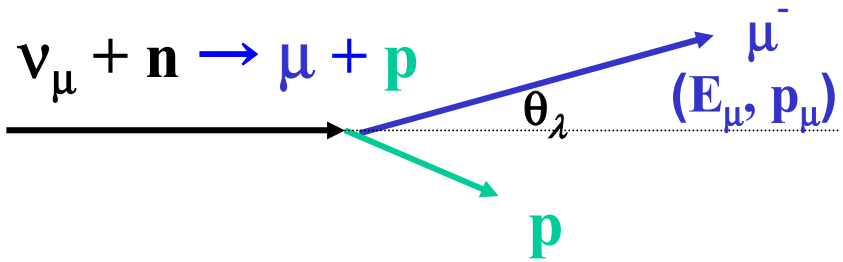
ν int.

- Extrapolate them to SK
  - Correct near-far spectrum difference
    - In-situ meas. of pion dist. (PIMON) → far near ratio for >1GeV
    - MC tuned with previous data for <1GeV
- Compare exp'ed # of events/spectrum w/ observation
  - maximum likelihood method
    - # of events
    - Spectrum shpae

ν int.

Neutrino Energy E_ν Reconstruction

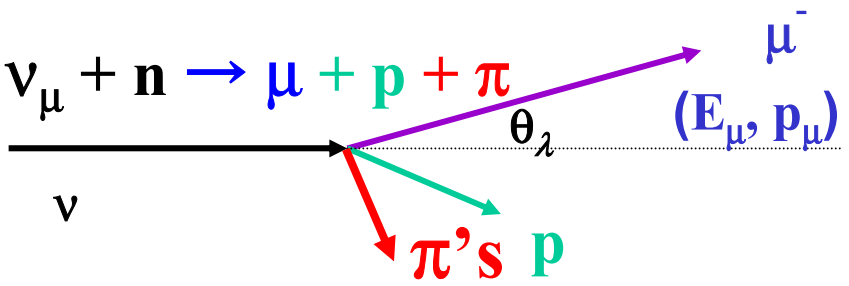
CC quasi elastic (QE)

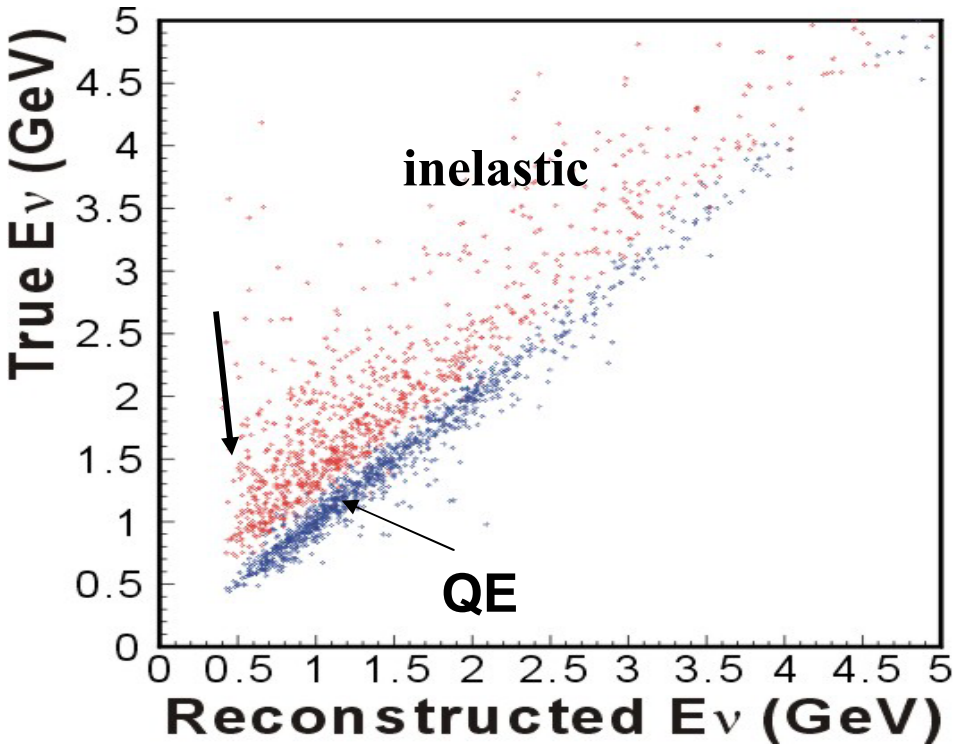


$$E_\nu = \frac{m_N E_\mu - m_\mu^2/2}{m_N - E_\mu + p_\mu \cos\theta_\mu}$$

$$\text{Rate}(E\nu,\text{Near}) \rightarrow \underline{\phi(E\nu,\text{Near})} \uparrow \sigma(\text{QE}),\ \sigma(\text{nonQE})$$

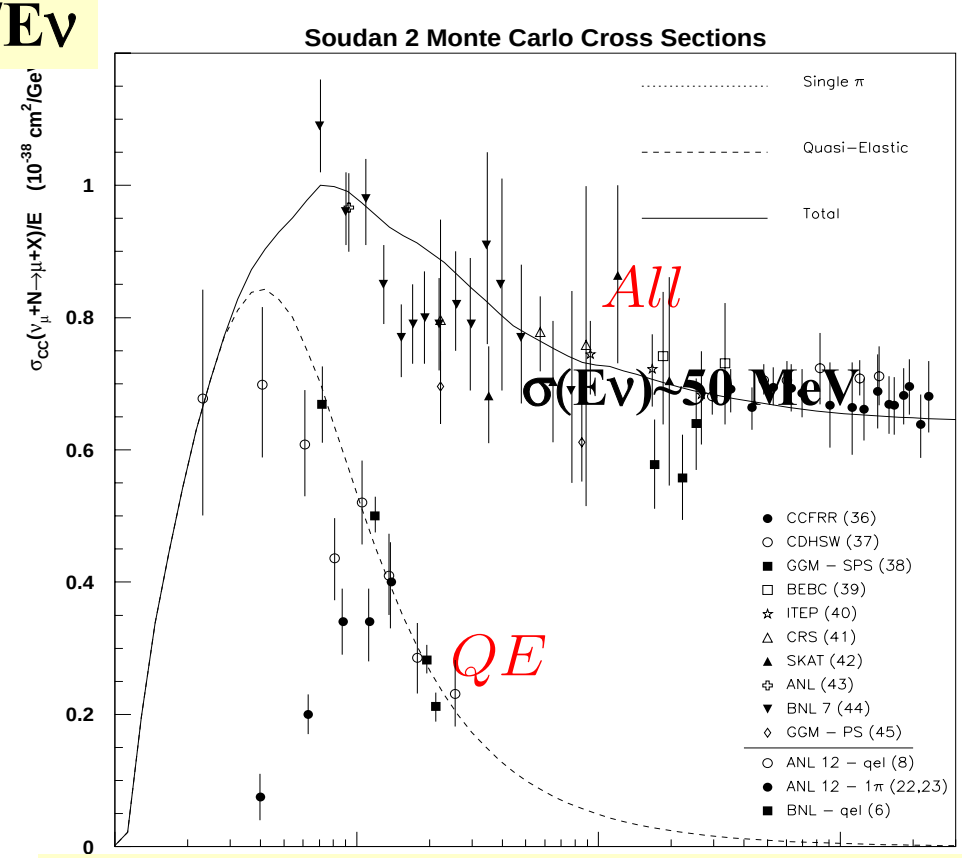
CC inelastic





CC Quasi Elastic(QE) and Other Processes(nQE)

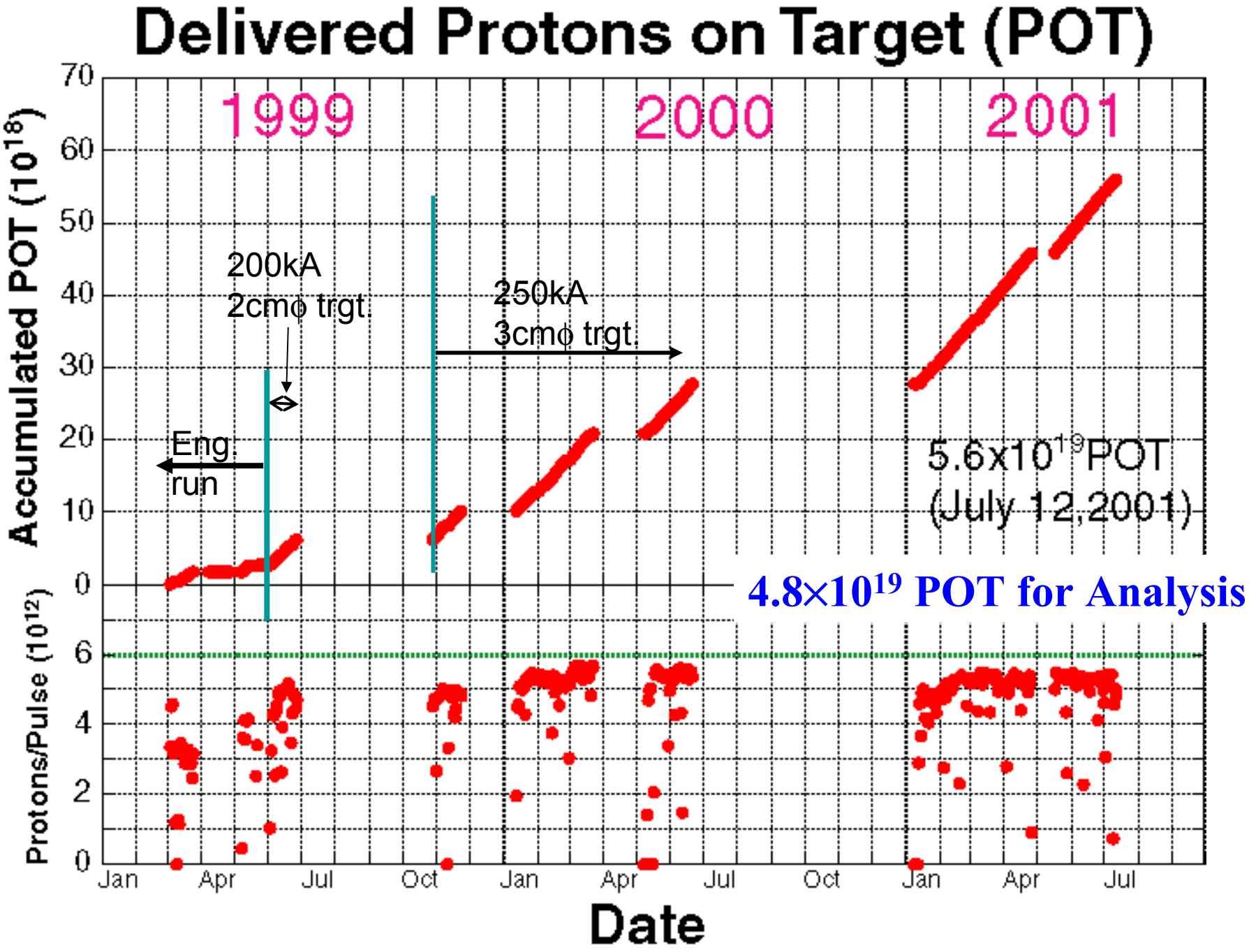
σ/Eν



Used Parameters
MA(QE)=1.11GeV
MA(1π)=1.21 GeV
Coherent π : Marteau et.al.
Multi-π: use hep-ex/0203009

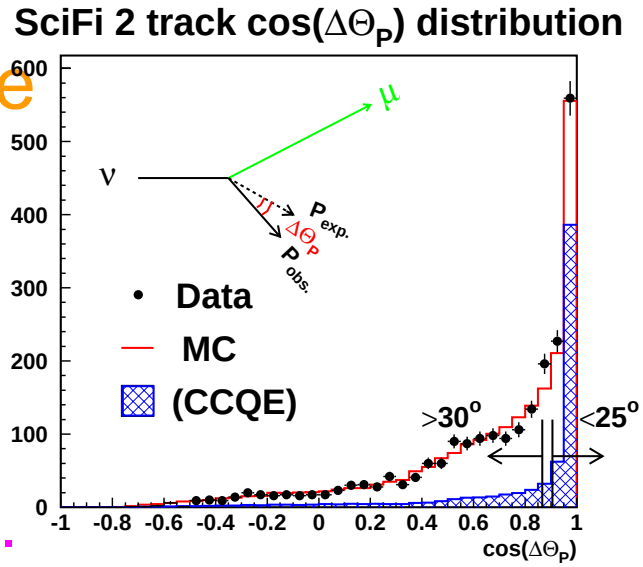
Checked
MA(QE)=1.01-1.11
MA(1p)=1.01-1.51
GRV94-Mod.GRV94

Very small effect on oscilllation anlysis


Delivered Protons on Target (POT)
1999
2000
2001
200kA
2cmϕ trgt.
250kA
3cmϕ trgt.
Eng.
run
5.6x10^19 POT
(July 12,2001)
4.8×10^19 POT for Analysis
Accumulated POT (10^18)
Protons/Pulse (10^12)
Jan
Apr
Jul
Oct
Jan
Apr
Jul
Oct
Jan
Apr
Jul
Date

Spectrum Measurements @ ND

- 1KT : P_μ<1.5GeV/c, 4π acceptance
  - 1-ring μ-like(1Rμ) fully contained in Fid.25ton(FC) : 22,476ev.
- SciFi : P_μ>1GeV/c, θ_μ<60deg.
  - 1-track μ-like : 5963ev.
  - 2-track QE-like ($\Delta\theta_p$<25deg.) : 764ev.
  - 2-track nonQE-like ($\Delta\theta_p$>30deg.) : 1288ev.
- PIMON
  - π (p,θ) distribution ⇒ Neutrino Spectrum (>1GeV)



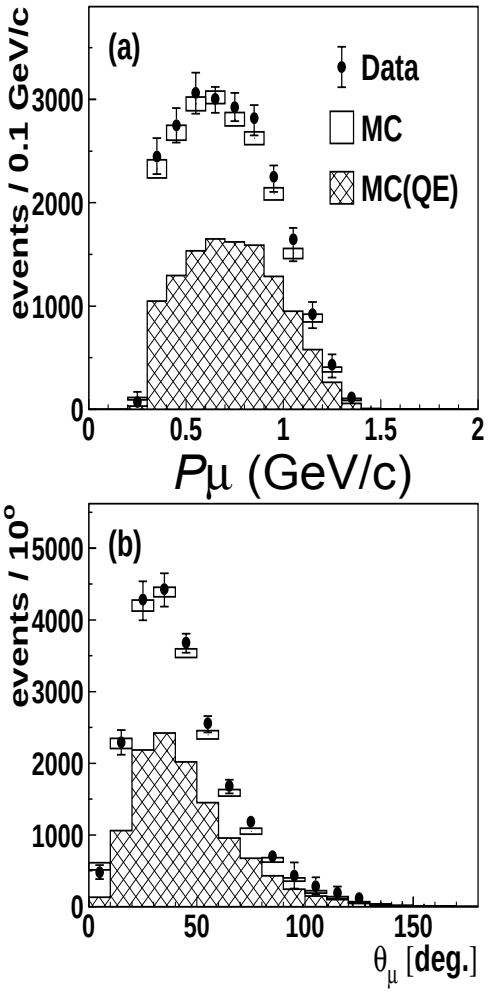
Fitting Parameters

E_ν : 8 bins, nonQE/QE ratio : 1

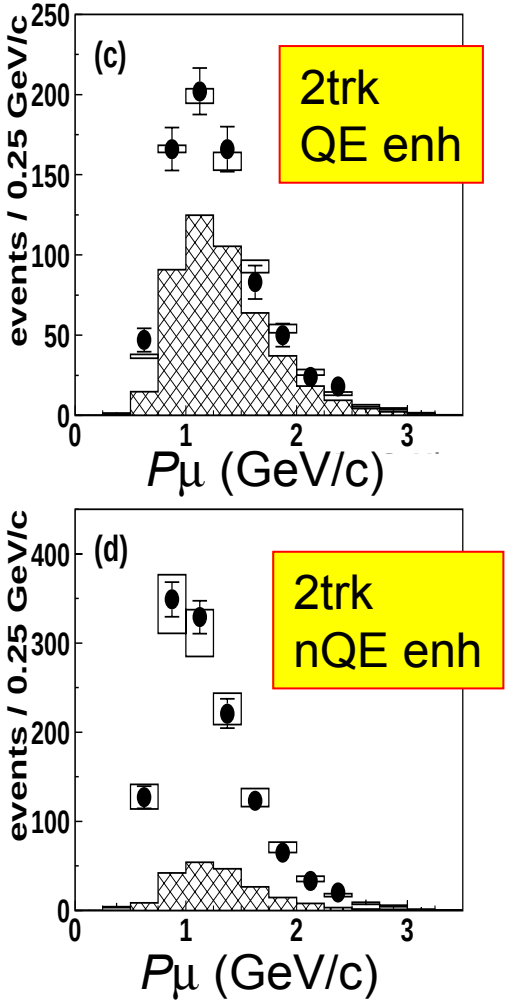
(+ normalization, detector systematic parameters)

Results of Fitting : Spectrum@KEK

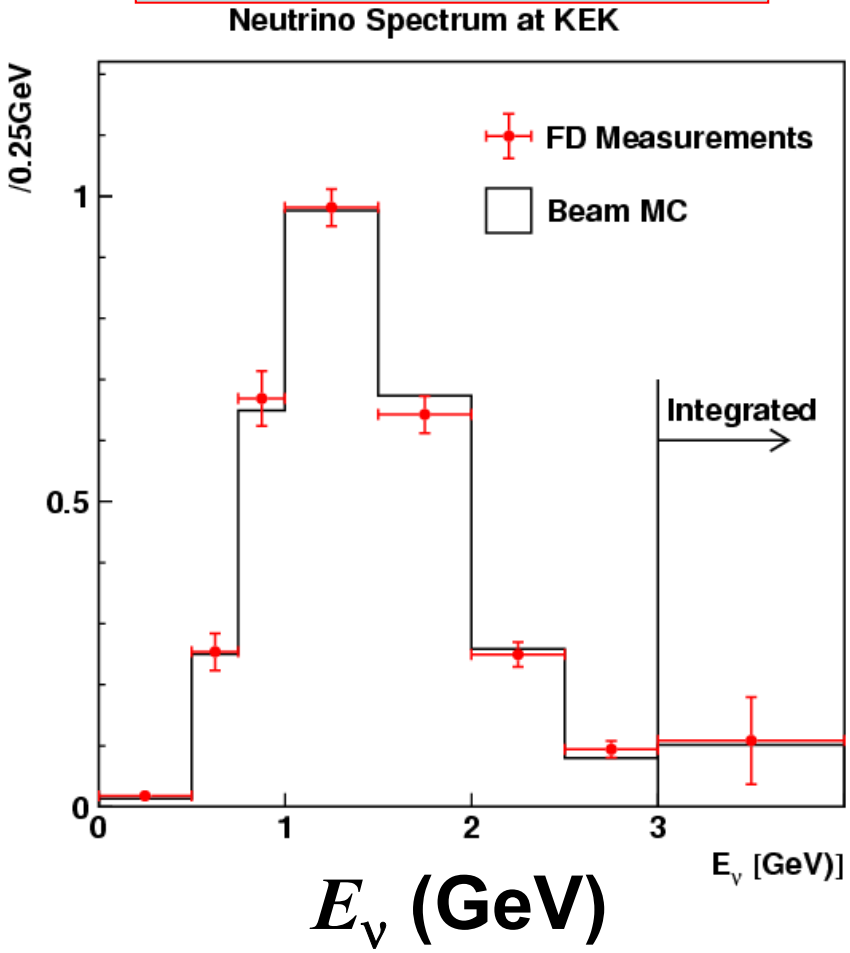
1kt 1Rμ



Scifi

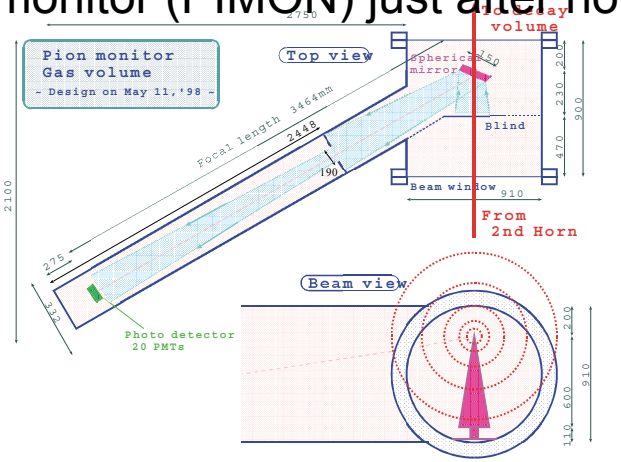


True Eν spectrum

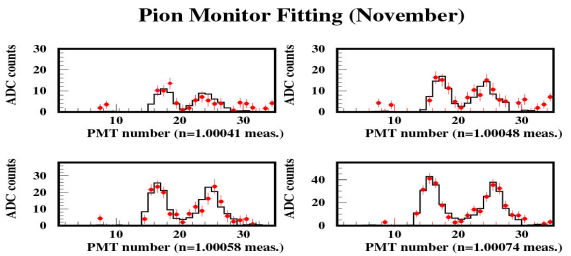


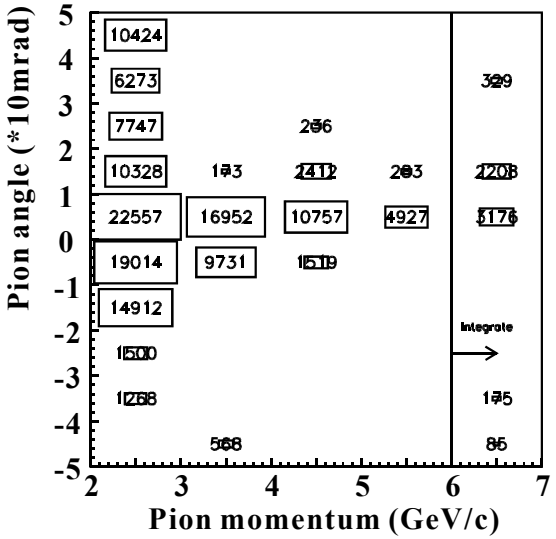
Near2far extrapolation

Pion monitor (PIMON) just after horn

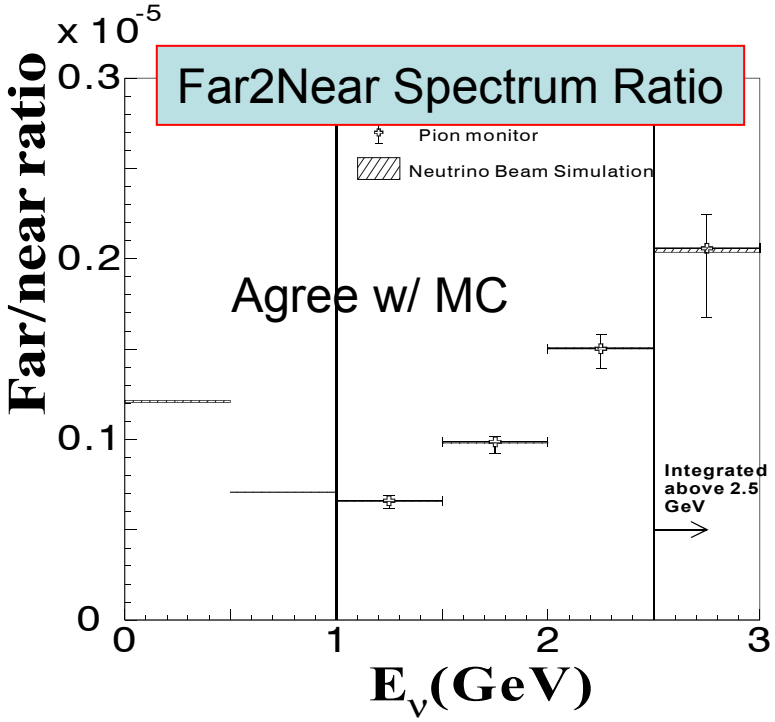


Cherenkov light distributions





p_π-θ_π distribution



Oscillation analysis (likelihood)

$$L_{tot} = L_{norm}(f) \cdot L_{shape}(f) \cdot L_{syst}(f)$$

Normalization term

$$L_{norm} = Poisson(N_{obs}, N_{\exp}(f))$$

Shape term for FCFV 1Rμ

$$L_{shape} \equiv \prod_{i=1}^{29} P((f_{Esk} \cdot E_i), \Delta m^2, \sin^2 2\theta, f)$$

Systematic error constraint term

$$L_{syst} \equiv \exp\left(-\Delta f^{T}_{\Phi,nQE} \cdot M^{-1}_{FD} \cdot \Delta f_{\Phi,nQE} / 2\right) \bullet\bullet\bullet\bullet\bullet$$
$$\times \exp\left(-f^2_{n6}/2\sigma^2_{n6}\right)\exp\left(-f^2_{n11}/2\sigma^2_{n11}\right)exp\left(-\Delta f^2_{Esk}/2\sigma^2_{Esk}\right)$$

Parameters w/ syst. error

$$f = (f_{\Phi}, f_{nQE}, f_{\mathrm{F/N}}, f_{\varepsilon sk}, f_{Esk}, f_{n6}, f_{n11})$$

f_{ϕ} : Flux (8 energy bins)
f_{nQE} : QE/nQE ratio
$f_{F/N}$: Far/Near ratio
$f_{\varepsilon SK}$: SK reconstruction (Fid, PID, Nring)
f_{ESK} : SK energy scale
f_{n6} : Norm. for June 99
f_{n11} : Norm. Nov 99 ~ Jul 01

Data set for oscillation analysis

- Total number of events
  - Fully contained (FC) in fid. Vol., Evis>30MeV
  - Jun.99~July 01
  - 56 events observed
- E_ν^{rec} spec. shape
  - FC 1Rμ events
  - Nov.99~July 01
  - 29 events observed

Expected # of events @ SK w/o oscillation

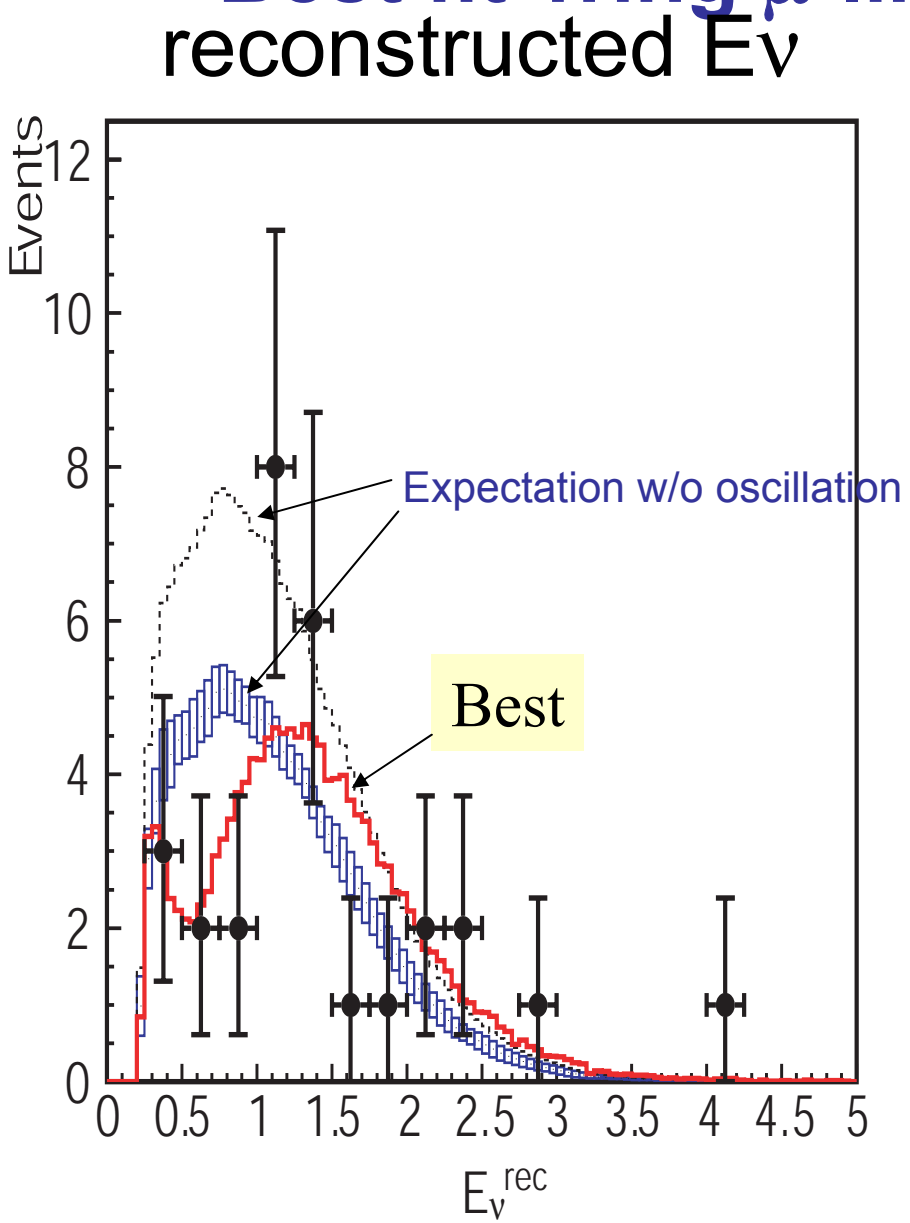
$$N_{\exp} = N_{KT}^{obs} \cdot \frac{N_{SK}^{MC}}{N_{KT}^{MC}} = N_{KT}^{obs} \cdot \frac{\sum_{i,j} f_{\Phi i} f_{F/Ni} \cdot \Phi_{SK}^{MC}(E_i) \cdot (f_j \sigma_{ij}) \cdot \varepsilon_{ij}^{SK}}{\sum_{i,j} f_{\Phi i} \cdot \Phi_{KT}^{MC}(E_i) \cdot (f_j \sigma_{ij}) \cdot \varepsilon_{ij}^{KT}}$$

$$80.1^{+6.2}_{-5.4}$$

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%**

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



Best fit point
($\sin^2 2\theta$, Δm^2)
= (1.0, 2.8x10^{-3}eV^2)

KS test (shape):79%

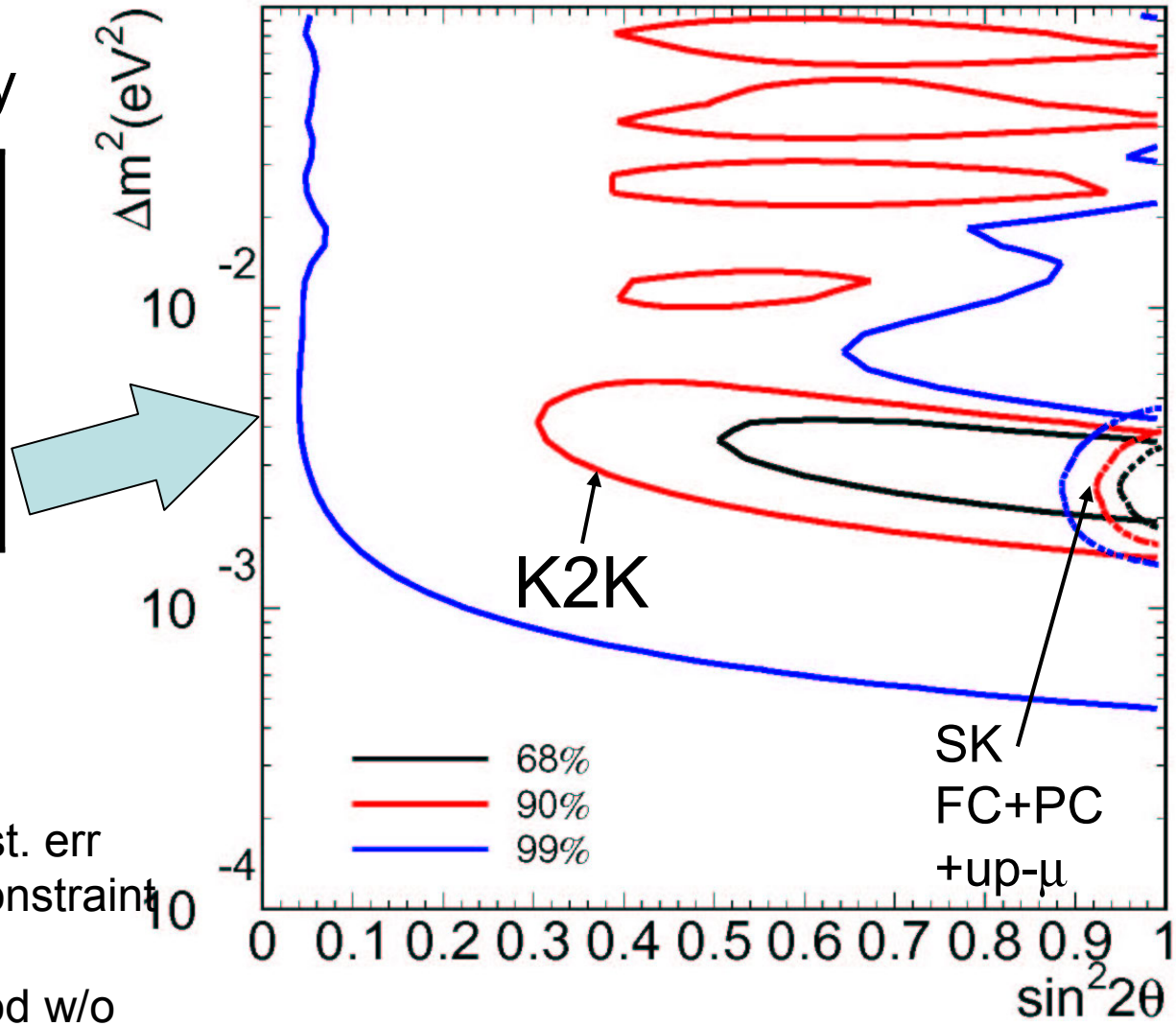
for N_{SK}
56ev obs. / 54ev exp.

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

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**

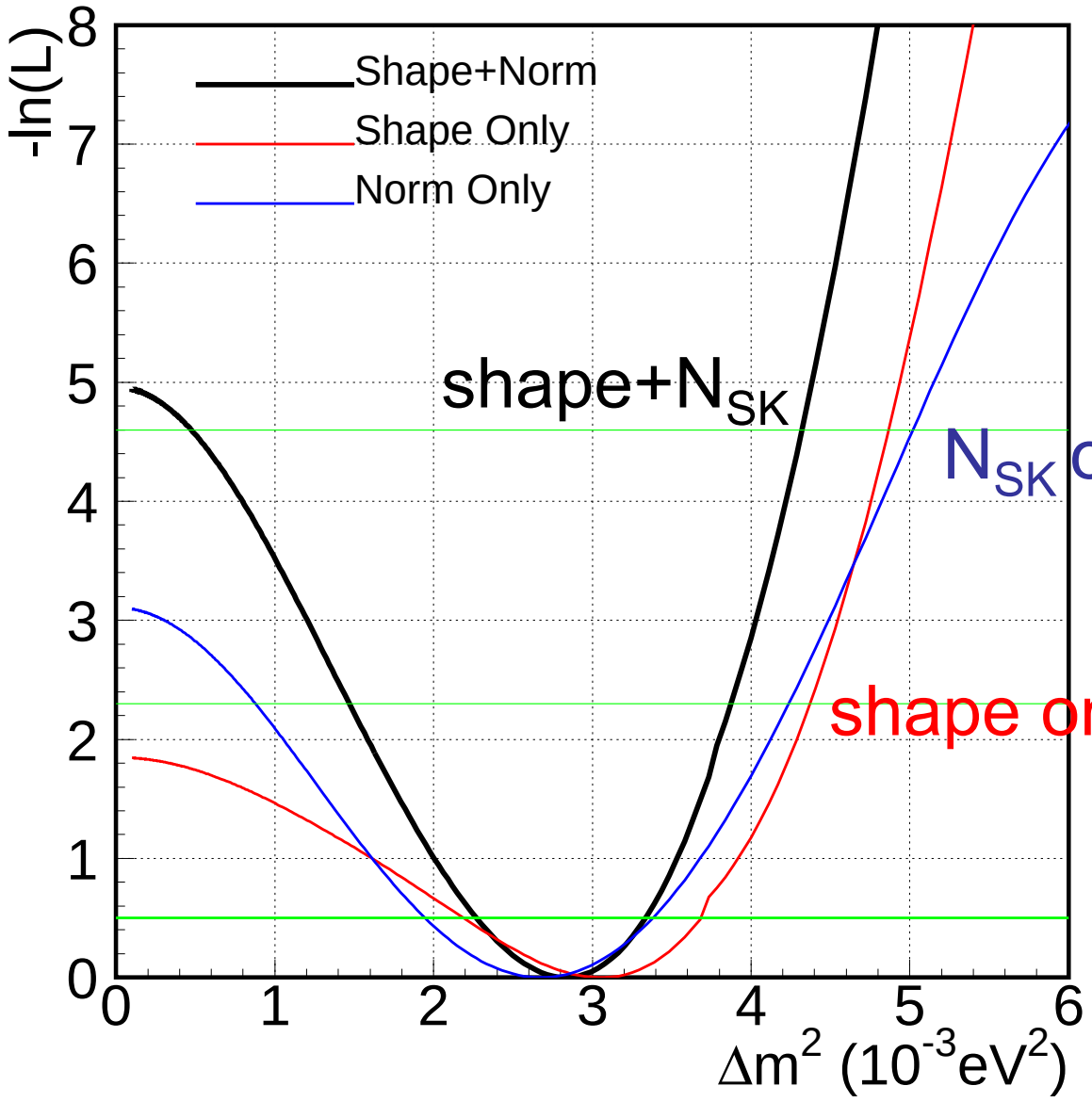


<1%

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

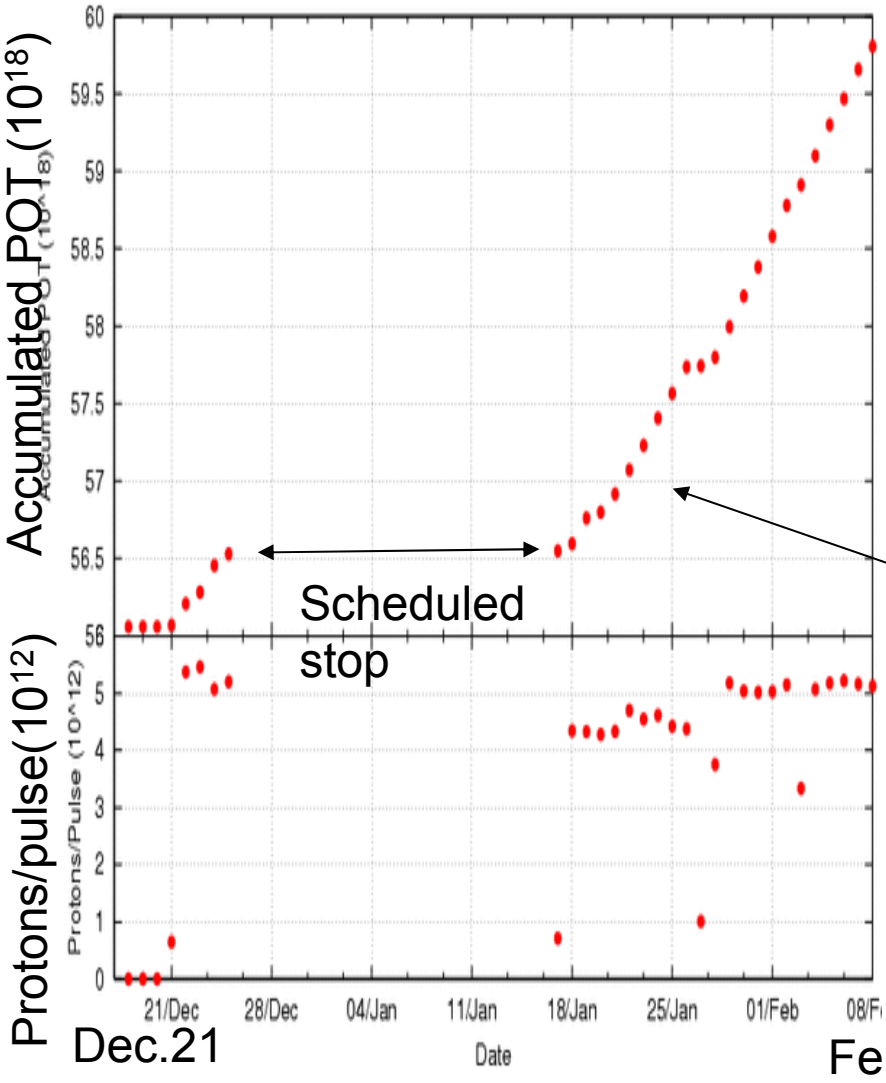
-Δlog(likelihood) distribution



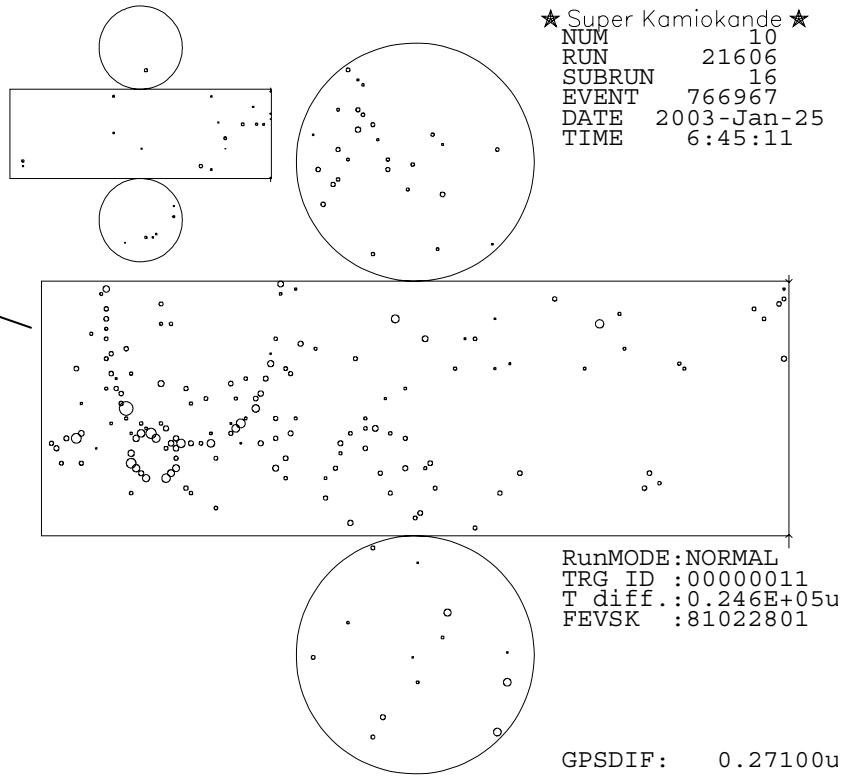
$\sin^2 2\theta = 1.0$

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

K2K resumed



1st K2K-II event candidate!



Acc., beam line (incl. target/horn), ND, SK working well!!

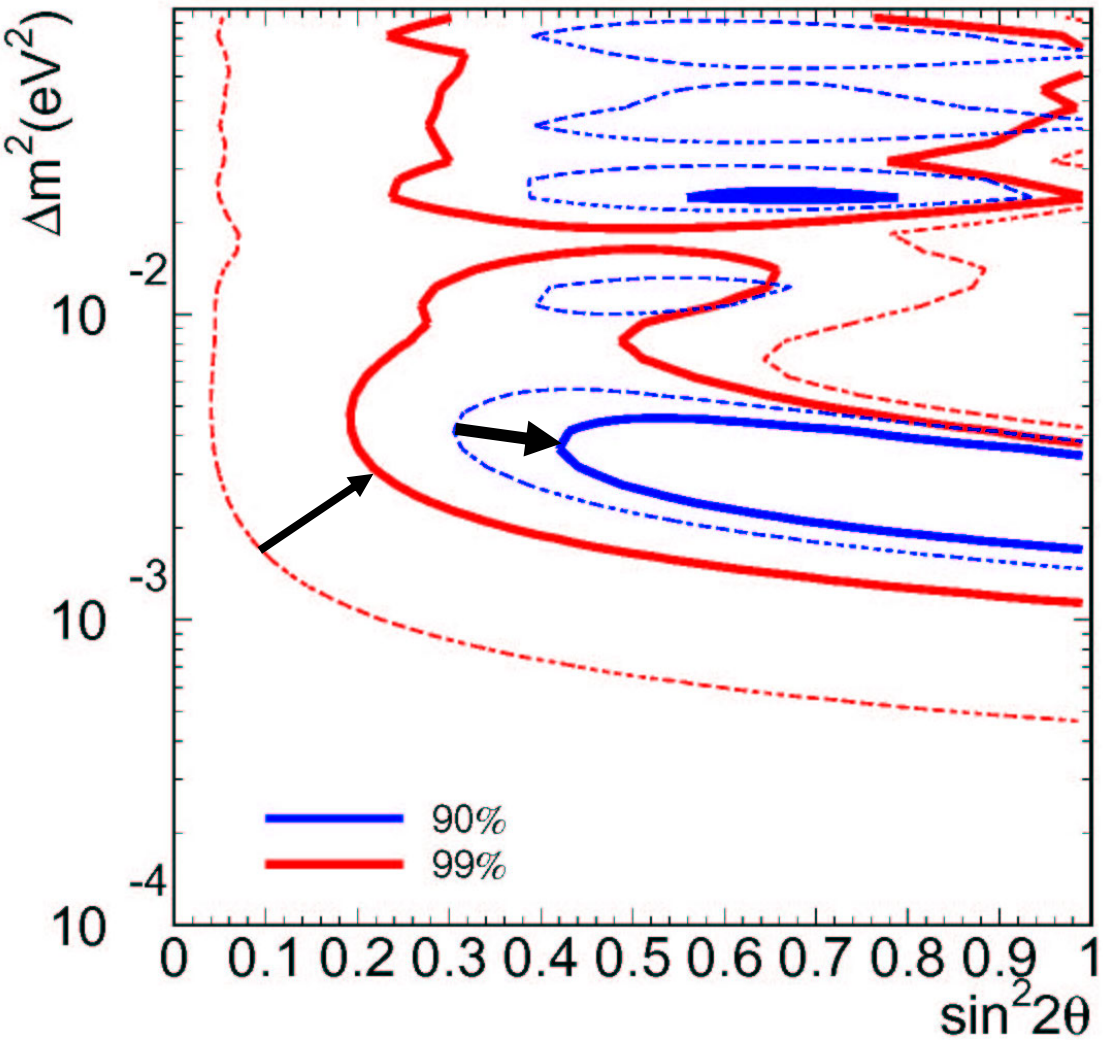
Expected sensitivity @ 10^{20}POT

Same analysis
Same syst. errors
as present

Exp'ed null prob.

shape	**: 2.9%**	**(16%)**
norm	**: 0.76%**	**(1.3%)**
s+n	**: 0.08%**	**(0.7%)**
		Now

Null prob. greatly reduced
(>3 "σ")



Future

ν_μ disappearance

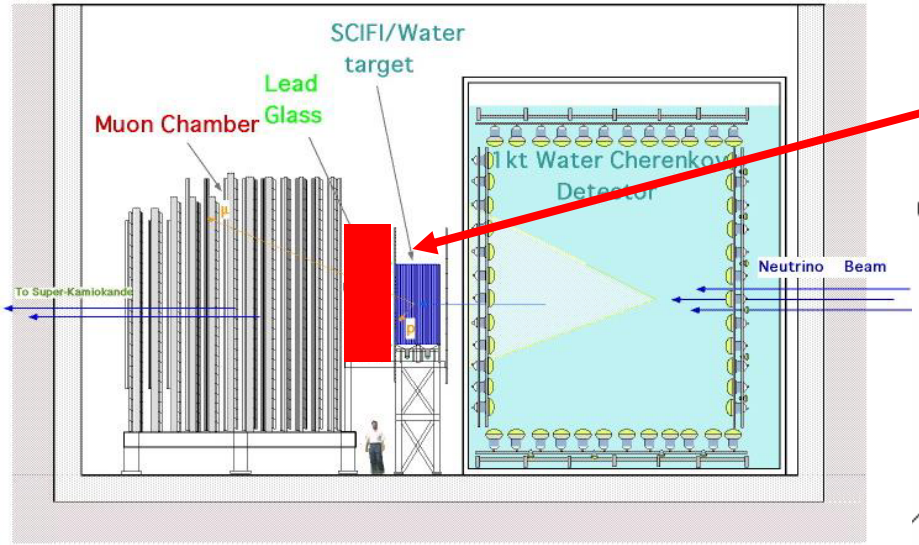
- Increase statistics
  - Take data more!! 10^{20}POT in total at least
- Decrease syst. error
  - HARP (hadr. prod. exp. @ CERN) data analysis → far/near ratio
  - Vertex reconstruction → norm. error.
- Improve analysis
  - Add other quantities sensitive to ν osc.
    - 1R/mR, mR "spectrum", (PC, (in coming)...)

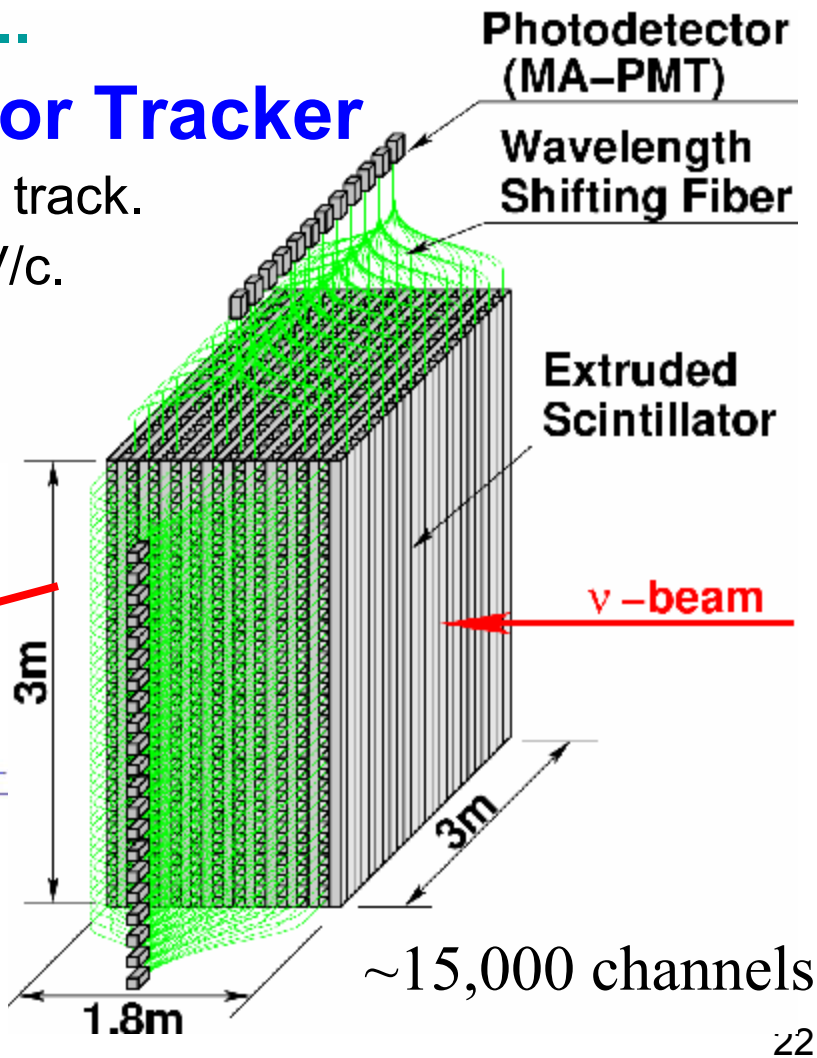
  → Study on neutrino interactions
    - 1kt, Scifi, New SciBar detector

ν_e appearance

4. K2K Upgrade (SciBar detector)

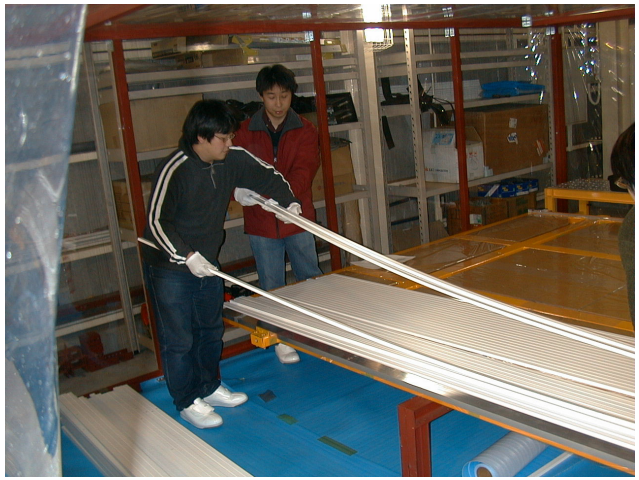
- L=250km, $\Delta m^2 = 3 \times 10^{-3}$ Eν ~ 0.6GeV
- **Study LE ν int. to maximize K2K sensitivity**
  - **–QE, single/multi π production,..**
- **Full Active (solid) Scintillator Tracker**
  - High efficiency for a short (<4cm) track.
  - Detect a proton down to 350 MeV/c.
  - PID (p/π) and the momentum
  - measurement by dE/dx.



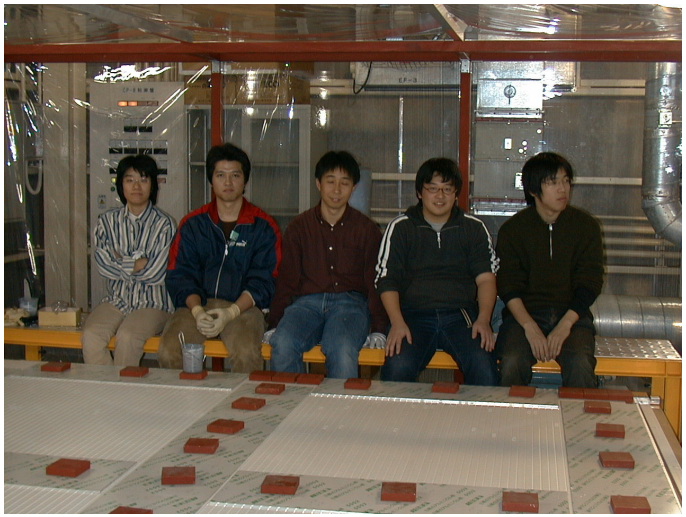


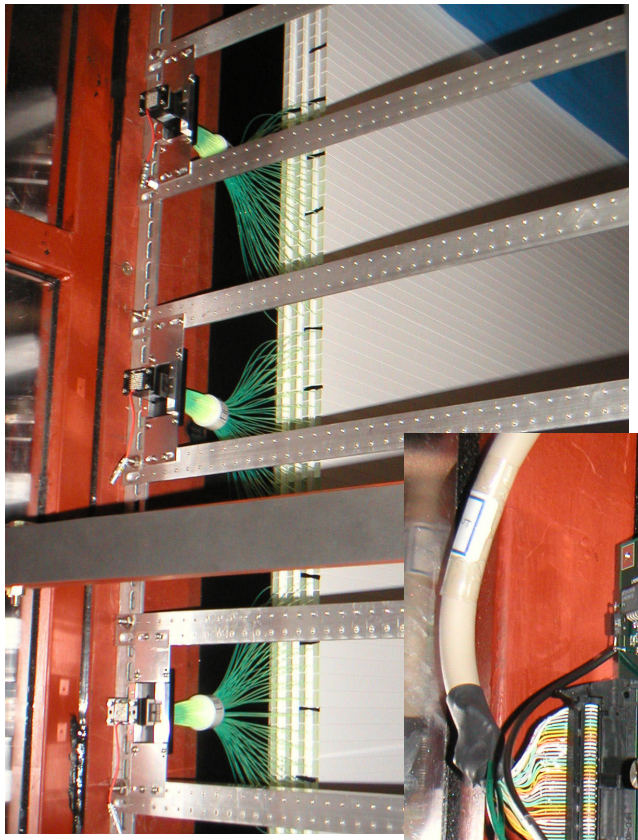
~15,000 channels

Construction of SciBar

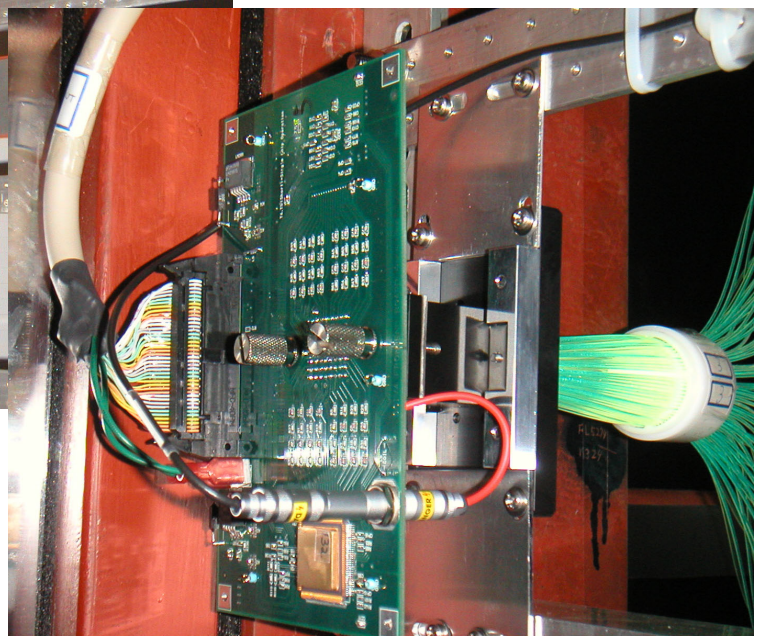


Layer module construction





First 4 layer modules Installed!! In Jan.2003



Installation of remaining part in summer 2003

Summary

- K2K observed indication of ν oscillation($\nu_\mu \rightarrow \nu_x$)
  - decrease in total number of events
    - $80.1\ ^{+6.2}_{-5.4}$ exp'ed → 56 observed.
  - distortion of spectrum
  - null oscillation probability < 1%
  - allowed region:$1.5\sim3.9\times10^{-3}eV^2$ @ $\sin^2 2\theta=1$(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