RECENT RESULTS IN K2K EXPERIMENT

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10th ICEPP Symposium @Hakuba

16-FEB-2004

K2K collaboration

- JAPAN: High Energy Accelerator Research Organization (KEK)
  Institute for Cosmic Ray Research (ICRR), University of Tokyo
  Kobe University / Kyoto University
  Niigata University / Okayama University
  Tokyo University of Science / Tohoku University
- KOREA: Chonnam National University
  Dongshin University / Korea University
  Seoul National University
- U.S.A.: Boston University / University of California, Irvine
  University of Hawaii, Manoa
  Massachusetts Institute of Technology
  State University of New York at Stony Brook
  University of Washington at Seattle
- POLAND: Warsaw University / Solton Institute

Since 2002

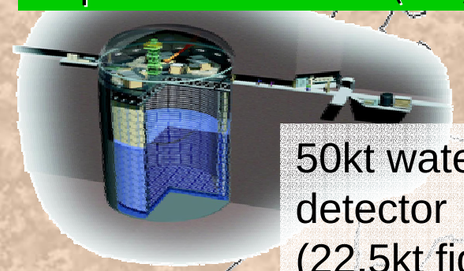
- JAPAN: Hiroshima University, Osaka University
- CANADA: TRIUMF / University of British Columbia
- EUROPE: Rome / Saclay / Barcelona / Valencia / Geneva
- RUSSIA: INR-Moscow

Outline

- K2K & neutrino oscillation
- Recent status & results
  - $\nu_\mu \rightarrow \nu_x$ oscillation analysis
  - ν_e appearance
  - New near detector “SciBar”
- Prospects
- Summary

K2K LBL ν oscillation exp.

Super-Kamiokande (SK)



50kt water cherenkov detector
(22.5kt fid. vol.)

ν_μ

LG (K2K-I)
SciBar (K2K-II)
SciFi
MRD
ν_μ
1kt

Near Detectors

$\langle E_\nu \rangle$ = 1.3GeV
L=250km (fixed)
98% ν_μ

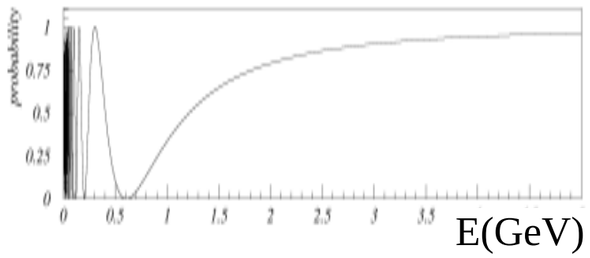
12GeV-PS@KEK
ν beamline
Beam monitor

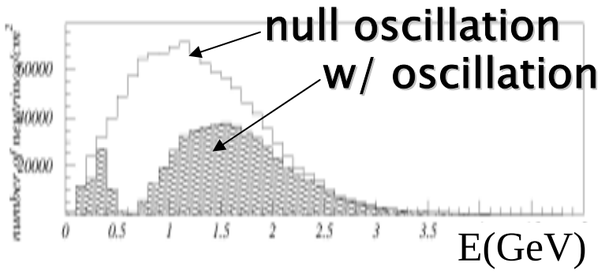
Neutrino Oscillation in K2K

oscillation prob.:

$$P(\nu_\mu \to \nu_\mu) = 1 - \sin^2 2\theta \sin\left(1.27\Delta m^2[\mathrm{eV}^2]\frac{L[\mathrm{km}]}{E[\mathrm{GeV}]}\right)$$

$L = 250km, \Delta m^2 = 3\times10^{-3} eV^2$





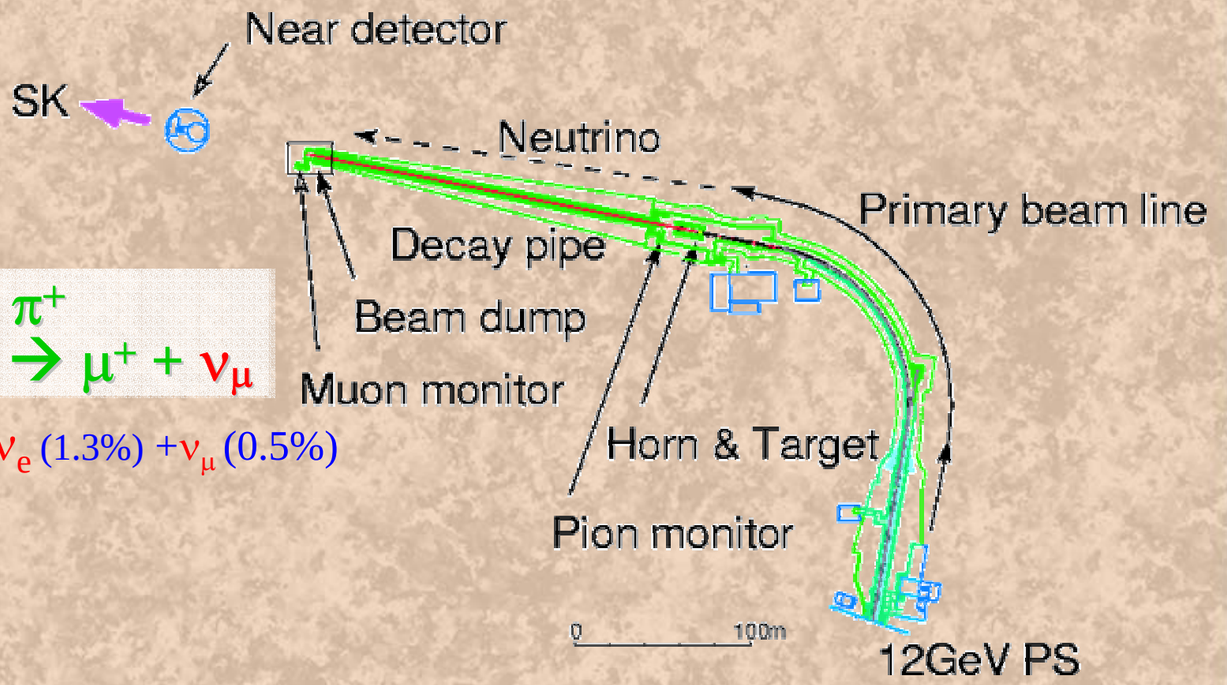
Aiming results:

- -Reduction of ν events
- -Distortion of ν_μ spectrum
- -ν_e appearance

➔ osci. parameters ($\sin^2 2\theta$, Δm^2)

- -Near to far extrapolation
- -Rate & spectrum shape @SK

Neutrino Beamline



p+Al → π^+
→ $\mu^+ + \nu_\mu$

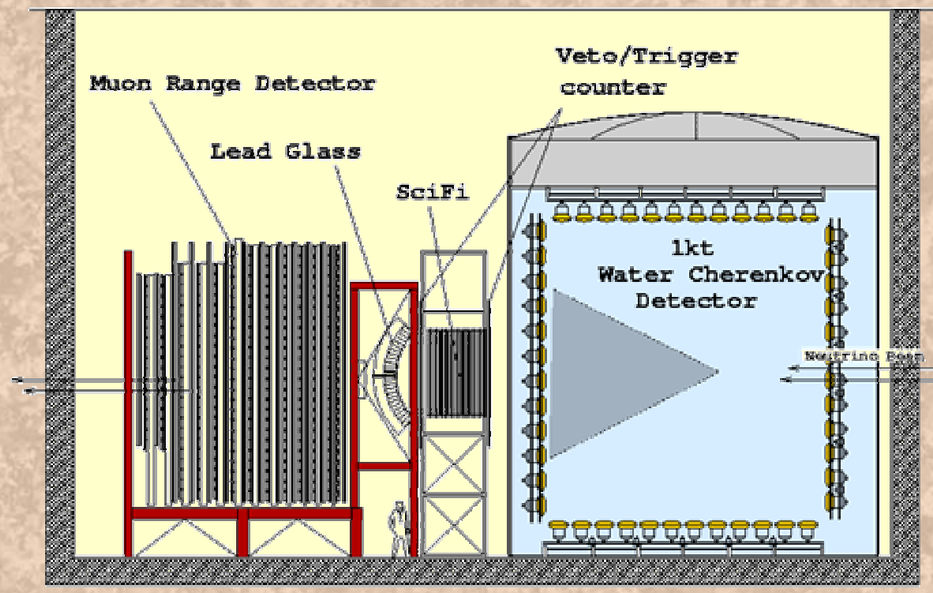
$e^+ + \nu_e$ (1.3%) + ν_μ (0.5%)

- Fast extraction every 2.2sec
- Beam spill 1.1us

<u>double horm</u>: high eff. of π collection
<u>Pion monitor</u>: near/far flux ratio
<u>Muon monitor</u>: beam intensity & direction

Near Detectors (ND)

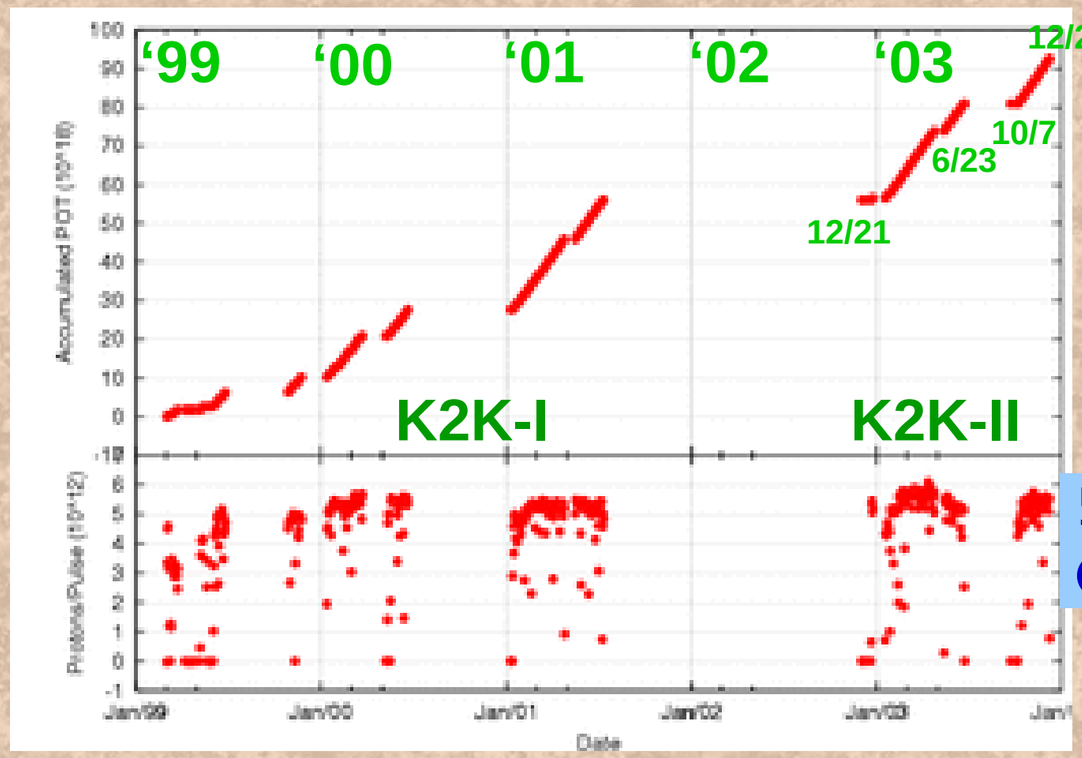
	fiducial	
1kt Water Cherenkov detector (KT)	25 ton	same type as SK
Scintillation Fiber tracker (SciFi)	6 ton	detect protons → QE/nQE
Muon Range Detector (MRD)	~700 ton (Fe)	ν beam monitor
Lead Glass calorimeter (LG)		detect electrons from SciFi



K2K-I
Mar,1999 – Jul,2001
SKI (11146PMTs)
|
SK accident
|
K2K-II
Dec,2002 –
SKII (~5200PMTs)
LG removed
SciBar (Oct,2003 –)

Delivered protons on target

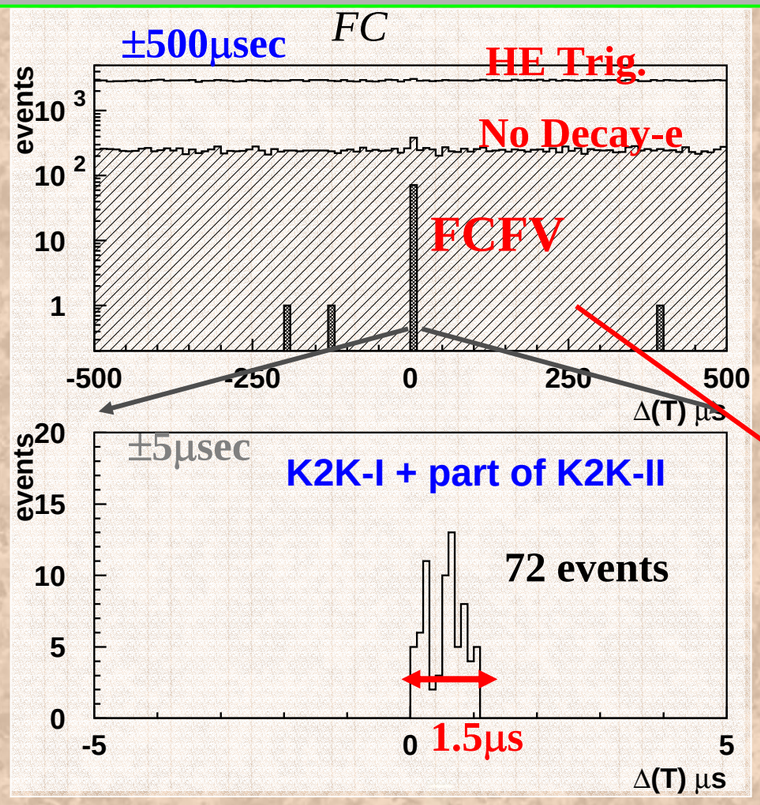
9.5×10^{19} POT
(8.4×10^{19} for analysis)

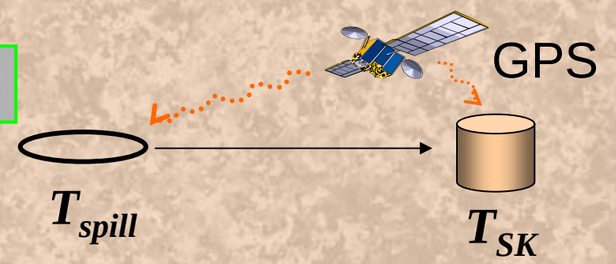


$5 \sim 6 \times 10^{12}$
(*protons per pulse*)

K2K event selection in SK

$$-0.2 \le \Delta T \equiv T_{SK} - T_{Spill} - \mathrm{TOF} \le 1.3\,\mu\mathrm{sec}$$





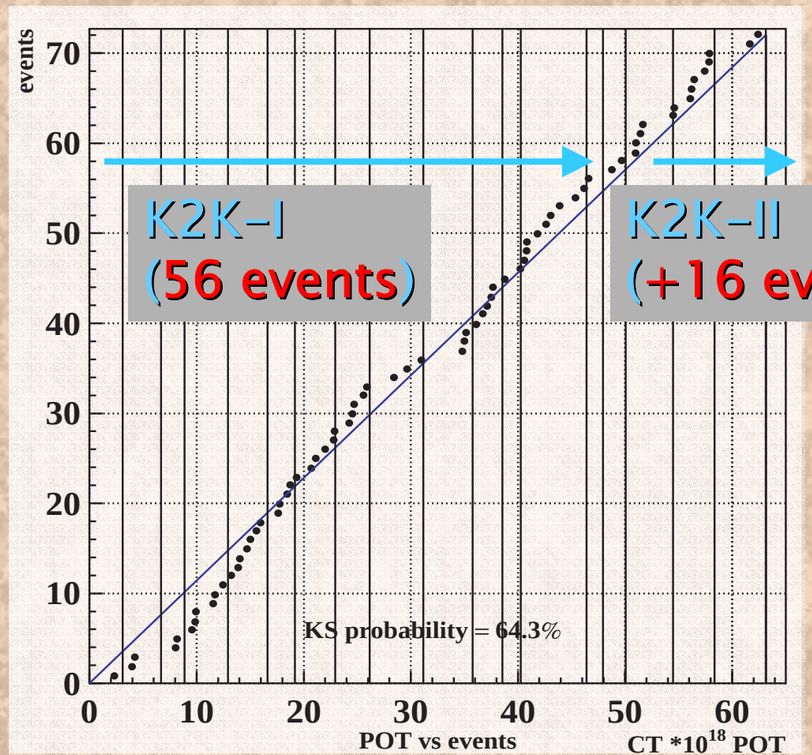
T_{Spill}: Abs. time of spill start
T_{SK}: Abs. time of SK event
TOF: 0.83ms (KEK to Kamioka)

Jun.'99 – Apr.'03
6.4 x 10^{19} proton on target

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

Expected atm. ν BG
~2x10^{-3} within 1.5μs.

K2K events in SK



Jun.1999~Apr.2003

K2K-I
(56 events)

K2K-II
(+16 events)

$\nu_\mu \rightarrow \nu_X$ oscillation analysis (K2K-I)

Analysis flow

Near site

- Num. of events & Observed (ρ_μ,θ_μ) distributions

↓

- Neutrino Flux
- Fit ν_μ spectrum & interaction model
  - $f_{near}(E\nu)$ (8 bins)
  - nQE/QE ratio
  - Error matrix (to include correlation)

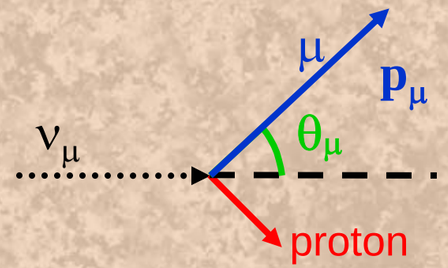
Near to Far extrapolation: $R_{FN}(E\nu)$

Prediction @far site

- N_{SK} : Number of FCFV events
- $S_{SK}(E_\nu^{rec})$: E_ν^{rec} distribution (shape) of 1Rμ

Use Maximum Likelihood Fit in ($\sin^2 2\theta$, Δm^2)

Reconstruction of E_ν



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

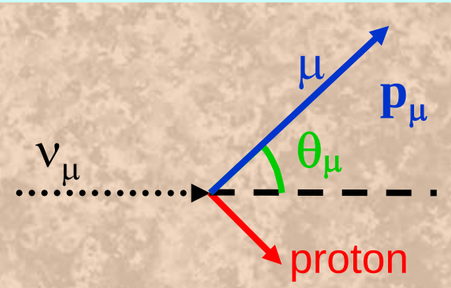
E rec. @SK:

- Use single-ring μ-like FCFV ($1R_\mu$) events
- Assume QE int. and reconstruct Eν

(~50% of K2K 1Rμ events are CCQE)

ν interaction (~1GeV)

Charged current quasi-elastic scat, (CCQE)



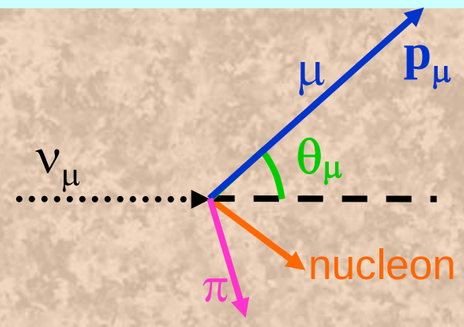
p_μ : muon momentum

θ_μ : muon angle

※ E_ν can be reconstructed from P_μ and θ_μ.

1kt : single ring μ-like FCFV
SciFi: QE-like 2track
single track (proton invisible)

pion productions (nonQE)



1kt : single/multi ring FCFV
SciFi: nonQE-like 2track

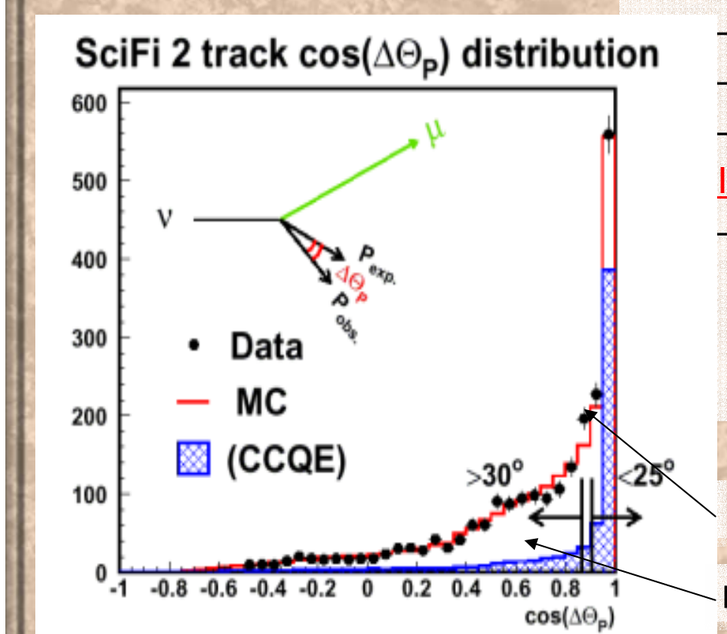
Spectrum measurement @ND

- 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.
- IMON
  - π (p,θ) distribution

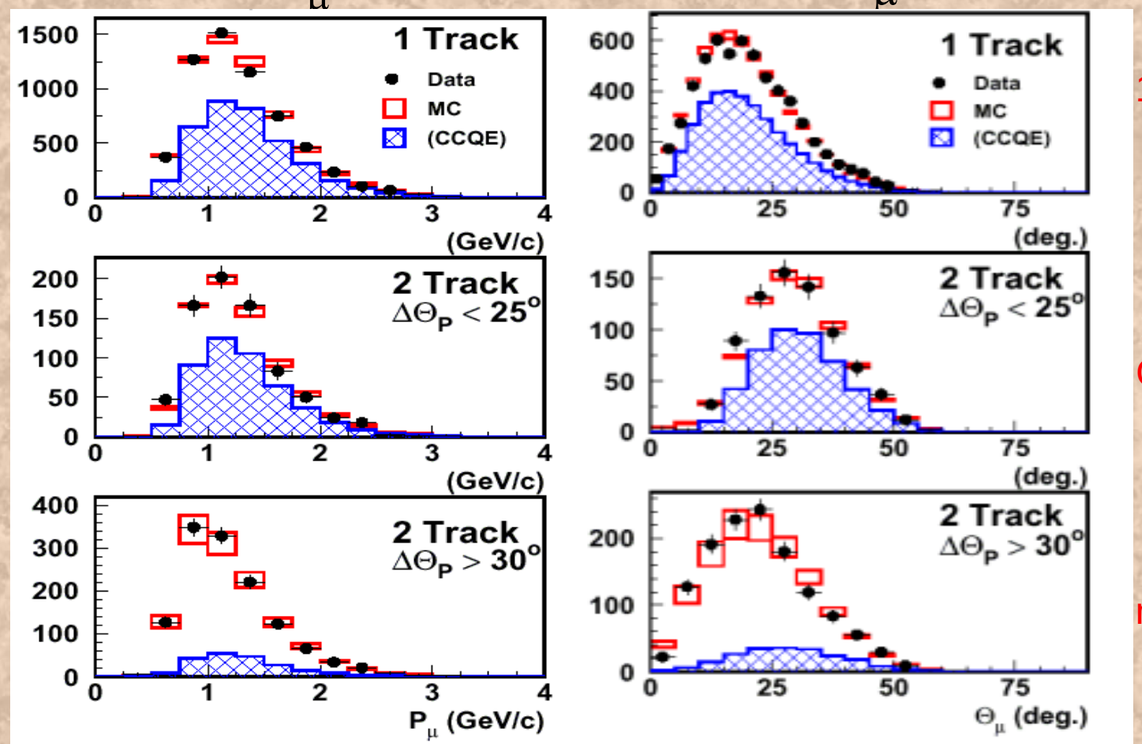
⇒ Neutrino Spectrum (>1GeV)

Fitting Parameters

E_ν : 8 bins, nonQE/QE ratio



SciFi p_μ/θ_μ



1-track
μ

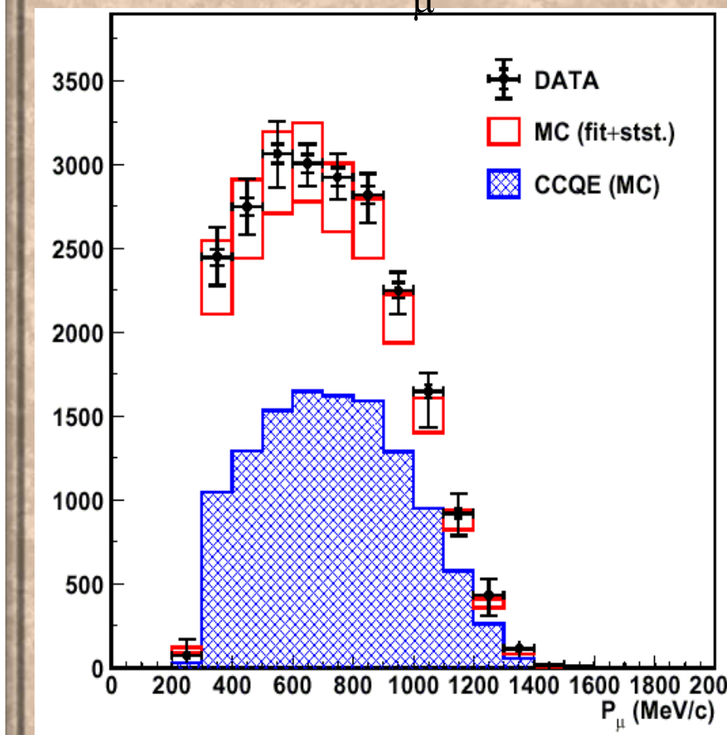
2-track
QE-like

2-track
nQE-like

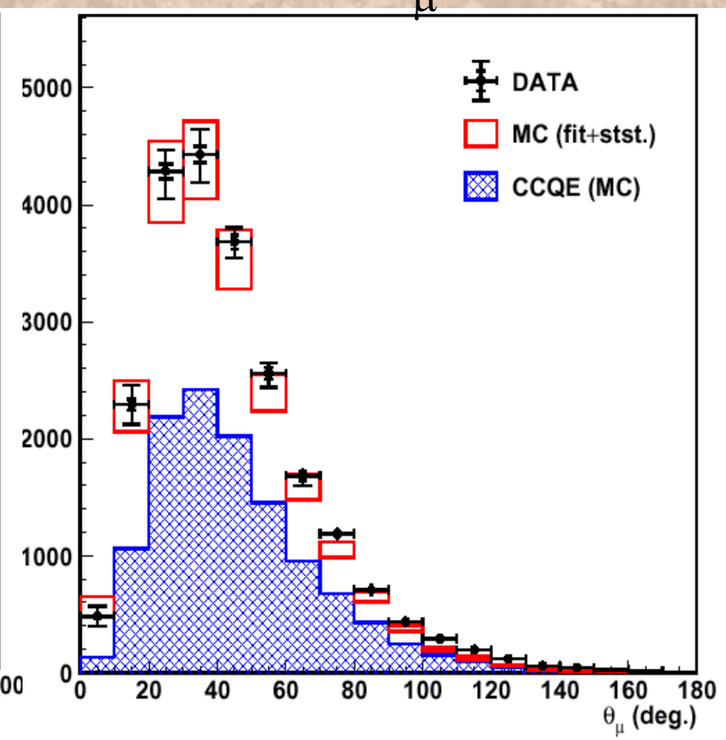
1kt p_μ/θ_μ

p_μ and θ_μ distributions of 1kt 1ring μ-like FCFV events

P_μ



θ_μ



Allowed region ($\nu_\mu \rightarrow \nu_X$)

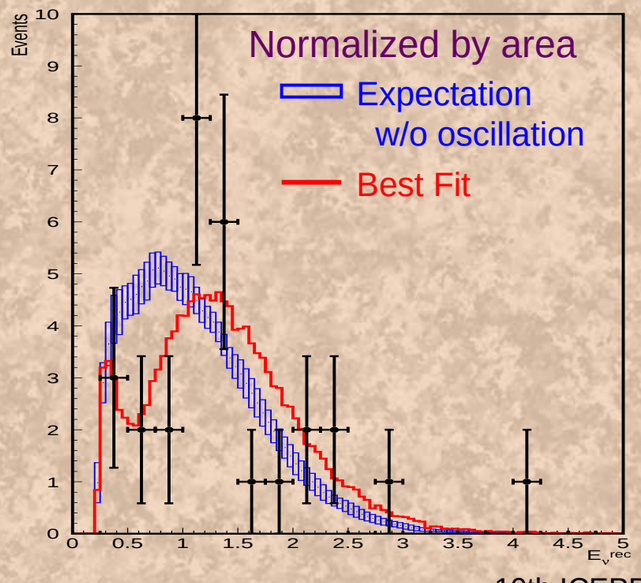
Use both Number of events + Spectrum shape

(June '99 – July '01) **(Nov. '99 – July '01)**

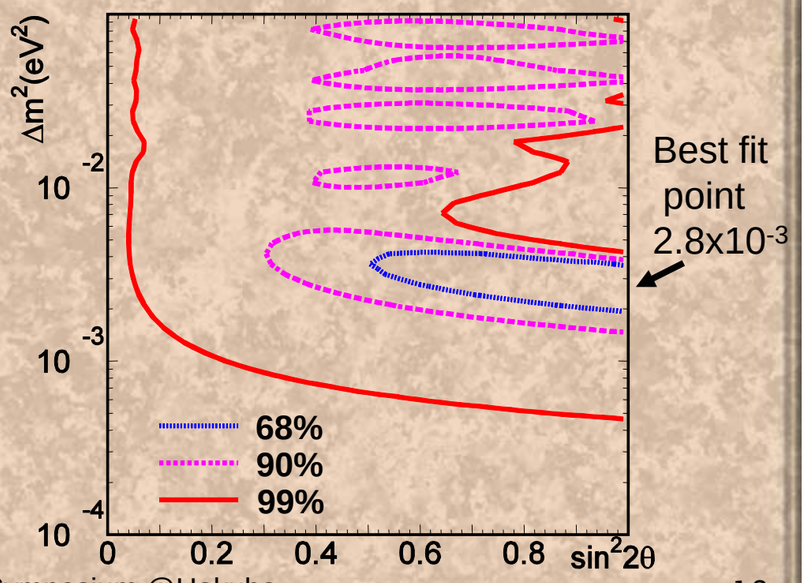
$56_{obs} \leftrightarrow 80.1^{+6.2}_{-5.4\ exp}$

- Null oscillation probability: less than 1%.
- $\Delta m^2 = 1.5 \sim 3.9 \times 10^{-3}\ eV^2$, $\sin^2 2\theta = 1$ (90%CL)

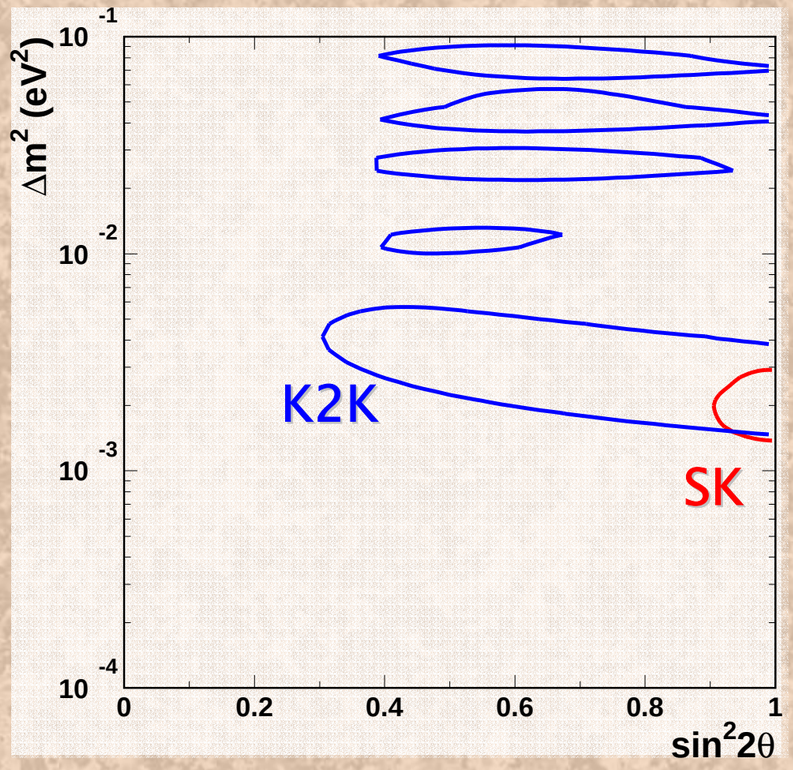
reconstructed Eν



Allowed region



Comparison w/ SK result



90% C.L.

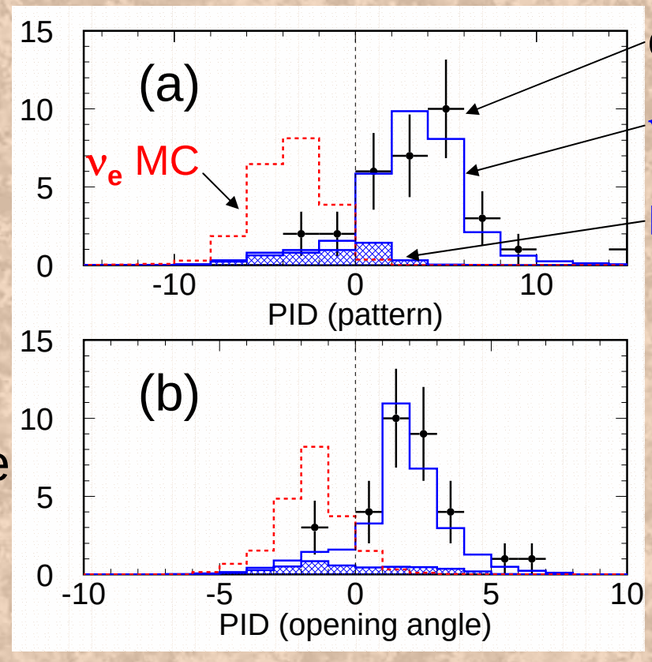
Search for ν_e appearance (K2K-I)

Search for ν_e appearance

Fully contained – Single ring – e-like
(ring pattern and opening angle)
Visible energy>100MeV – w/o decay electrons

Ring pattern

Opening angle



To be submitted for publication

Data reduction summary

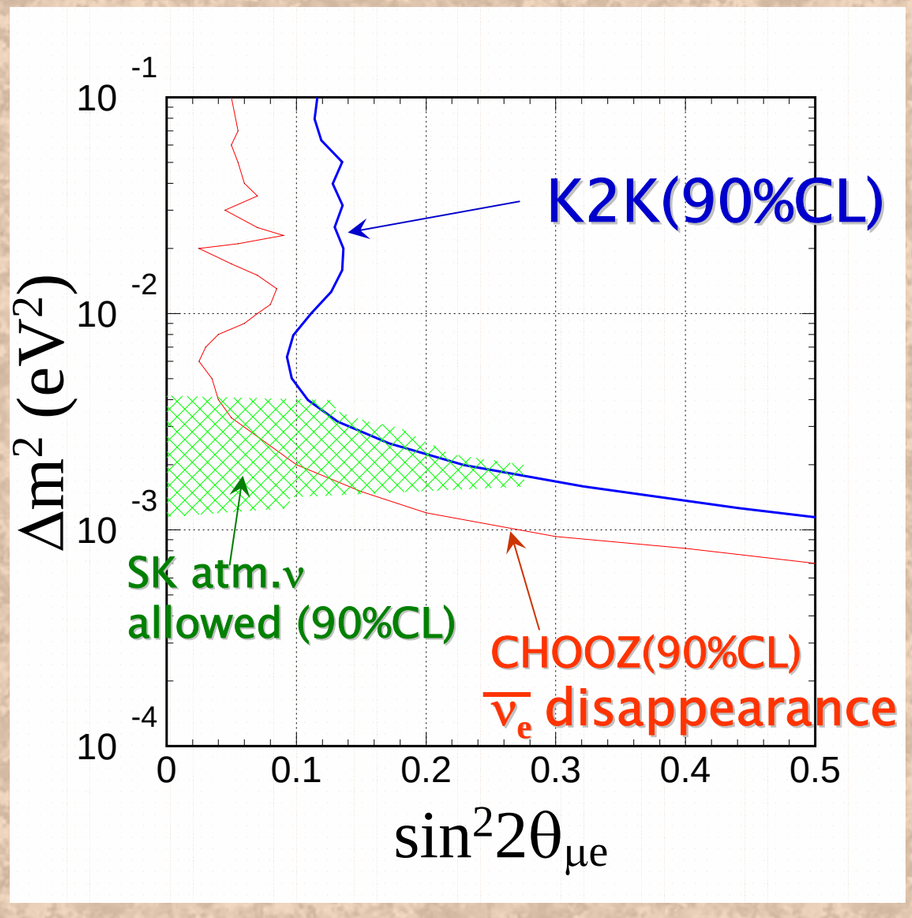
DATA SET: June'99 – July'01 (4.8×10^{19}POT)

electron candidate: 1 event (obs.)
2.4 events (exp.)

	DATA	ν_μ MC	beam ν_e MC	signal ν_e MC (CC) $\sin^2 2\theta_{\mu e}=1$, $\Delta m^2=2.8\times10^{-3}$eV^2
FCFV	56	80	0.82	28
Single ring	32	50	0.48	20
PID (e-like)	1	2.9	0.42	18
Evis>100MeV	1	2.6	0.41	18
w/o decay-e	1	2.0	0.35	16

NC:87% CC1π:7% CCmπ:4% CCQE:2%

Excluded region ($\nu_\mu \rightarrow \nu_e$)

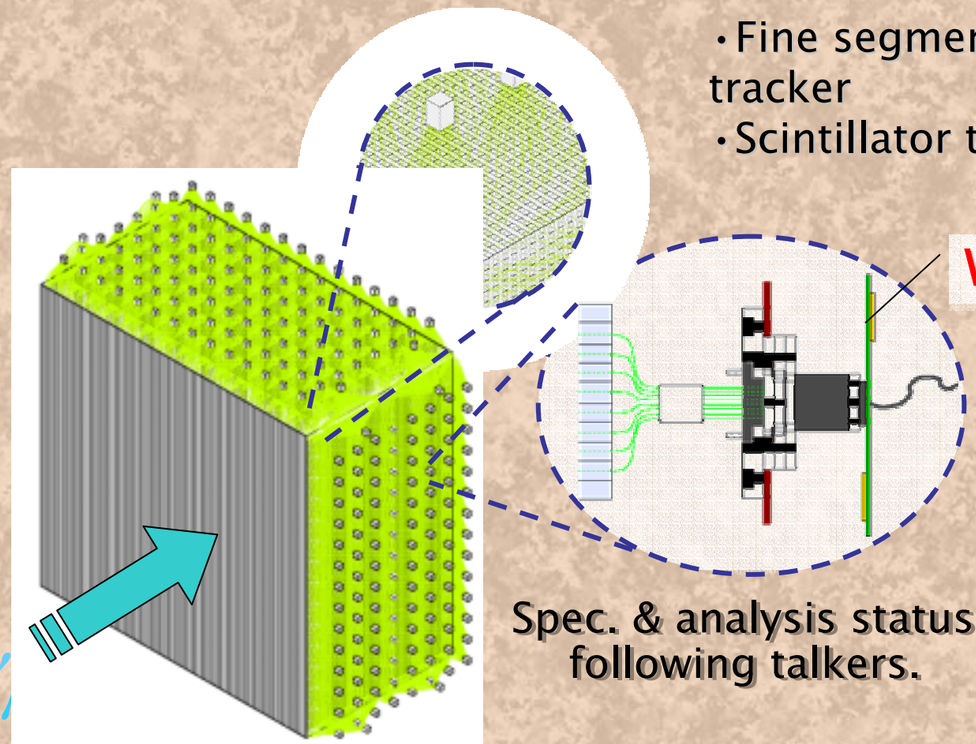


Near Detector Upgrade

SciBar detector

Upgrade near detector to explore low E region
(after removal of LG)

2003.10.03~



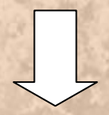
- Fine segmented scintillator tracker
- Scintillator target & fully active

Working well !!

Spec. & analysis status will be presented by following talkers.

Prospects

- K2K-II is running stably
  - —ν flux in low energy region by SciBar
  - —SciFI ν flux measurement using PID
  - —Improvement of Near/Far extrapolation (Harp)
  - —K2K events in SK-II



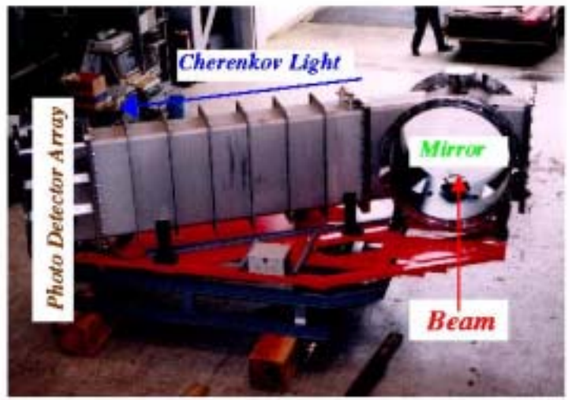
New results of oscillation analysis come soon !

Summary

- K2K-I data has been analyzed so far:
  - $\nu_\mu \rightarrow \nu_x$ oscillation analysis
    - ✓Null oscillation prob: less than 1%
    - ✓$\Delta m^2 = 1.5 \sim 3.9 \times 10^{-3}$ eV^2 @$\sin^2 2\theta = 1$(90%CL) (consistent w/ atm. ν)
  - ν_e appearance search
    - ✓1 ν_e candidate (consistent with BG)
- K2K-II running stably
  - New near detector SciBar
  - Low energy neutrino flux @ND
  - K2K events in SK-II
  - New results of oscillation analysis will come soon

supplements

Pion monitor



Ring Image Gas Cherenkov Detector
(Index of Refraction is Changeable)

Measure Momentum / Angle Dist.
of π's Just after Horn/Target

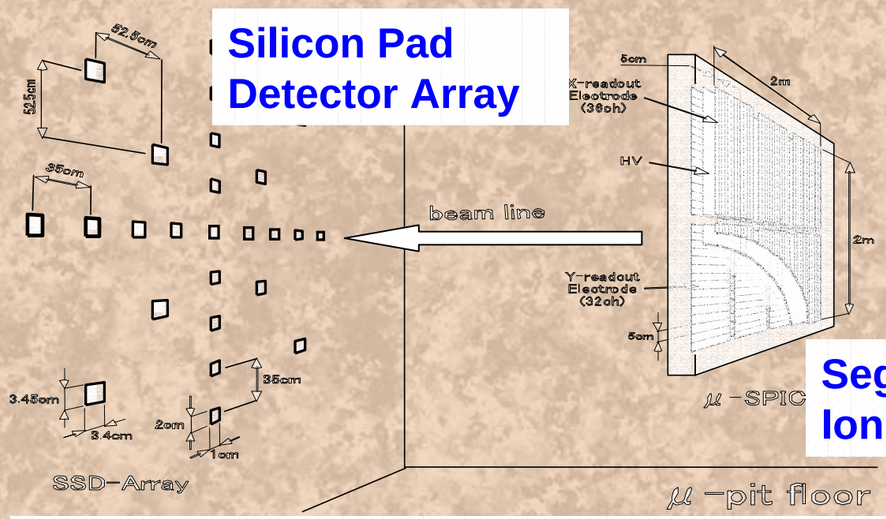
+Well known π Decay Kinematics
+Well Defined Decay Volume Geometry

⇒Predict
ν_μ Energy Spectrum at Near Site
Far Site

ν_μ Flux Ratio (Far/Near)
as a Function of Neutrino Energy

To Avoid Severe Proton Beam Background,
ν_μ Energy Information above 1GeV is Available
(β of 12GeV Proton ~ β of 2GeV π)

Muon monitor



Silicon Pad Detector Array

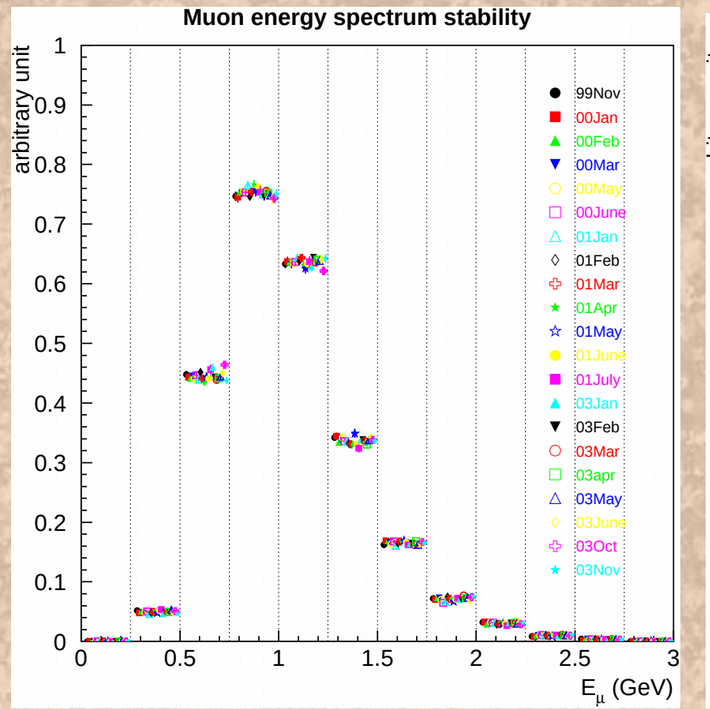
Segmented Ionization Chamber

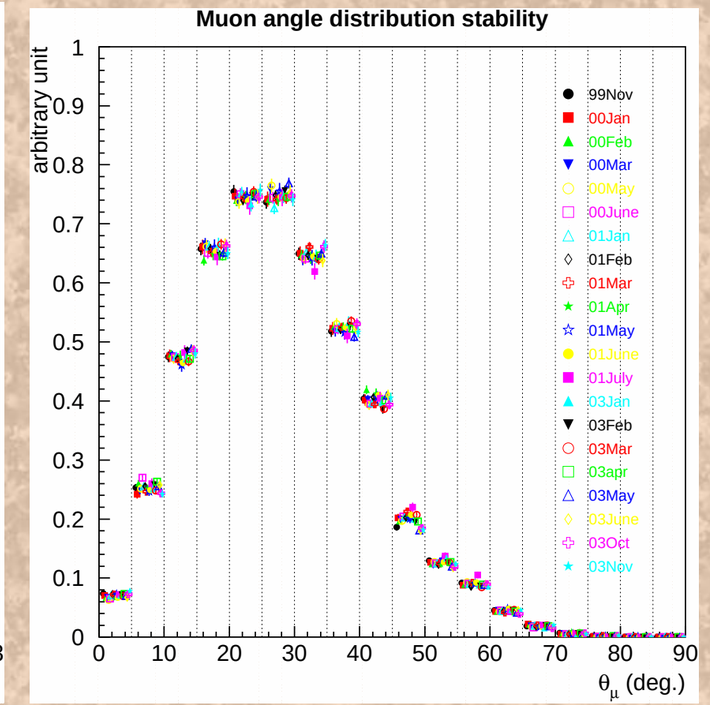
Behind beam dump
→sensitive to initially high energy μ (>5.5GeV)
Provide **fast (spill-by-spill)** monitoring of
- **Intensity** → targeting/horn stability
- **Profile** → beam direction

Stability of ν spectrum @ND

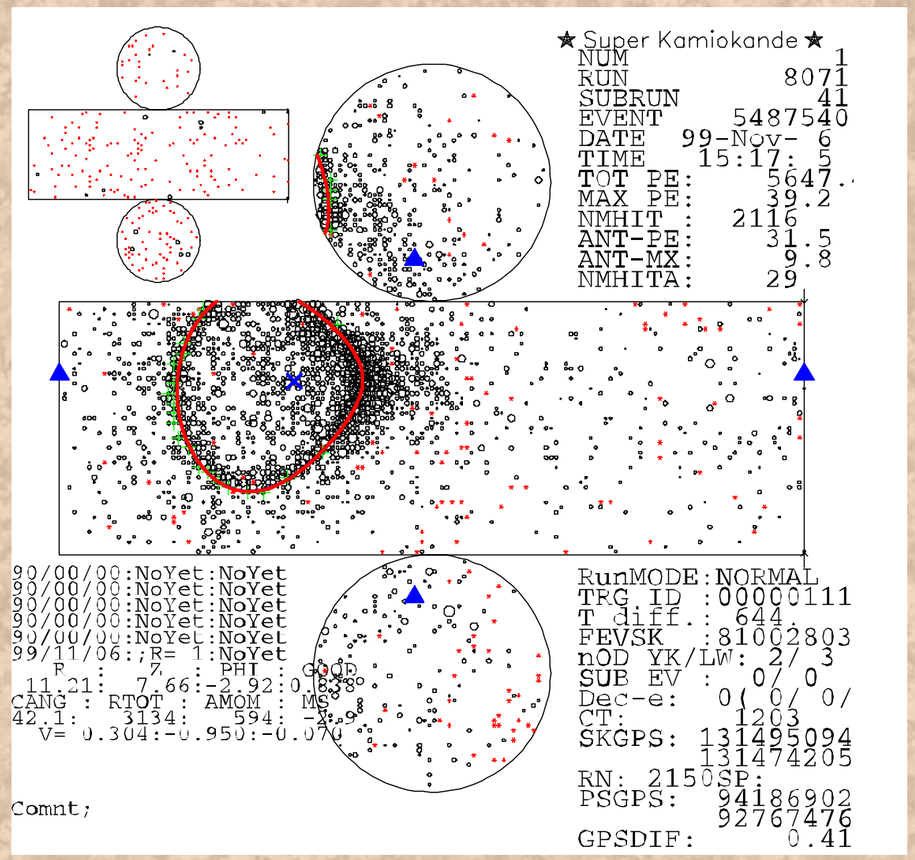
Neutrino spectrum measurement by the *Pion monitor*

Energy and angle of muons produced in the CC interactions by *MRD*





ν_e candidate event



Method of ν flux fitting (ND)

Prepare MC templates

neutrino spectrum $\phi(E_\nu)$

and ν interaction model

(**QE/non-QE ratio**).

E_ν **QE(MC)** **non-QE(MC)**

0

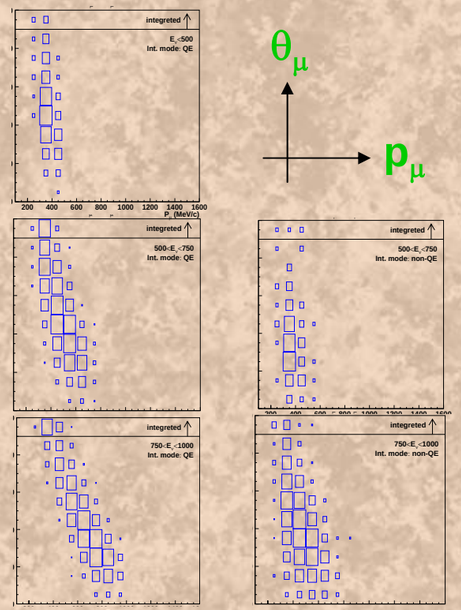
~0.5 GeV

0.5

~0.75GeV

0.75

~1.0GeV

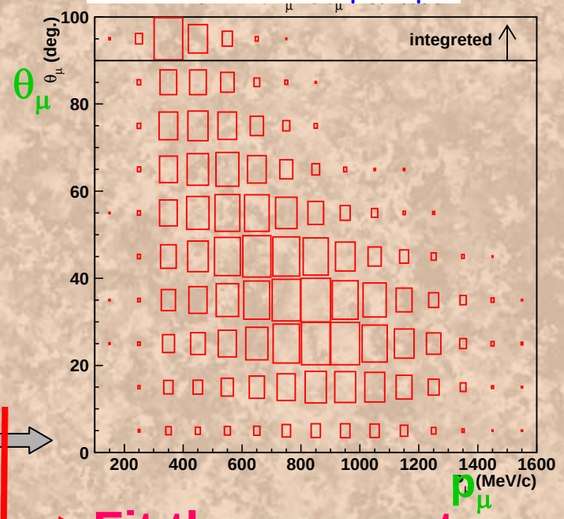


8bins 7bins

θ_μ

p_μ

Measured (p_μ, θ_μ)



Fit the parameters.

$\phi(E\nu)$, QE/non-QE ratio …

χ^2=227 for 197 d.o.f.

(90 from 1kt, 137 from FGD)

for fitted (p_μ, θ_μ) dist. of 1KT and FGD (124 data points)

Contribution of sys. errors on spectrum

Syst. err on spectrum(null)