New Results from K2K

March 2002, La Thuile
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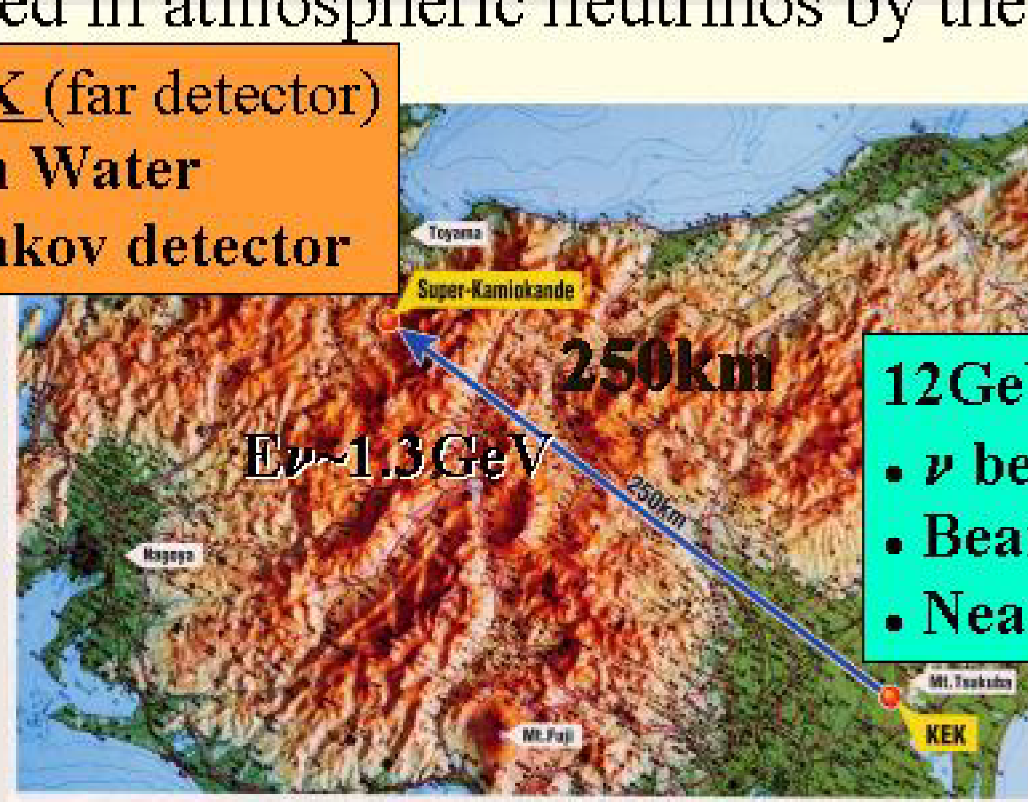
for the K2K Collaboration

Contents

1. Introduction

- **K2K** is the first long baseline (***250*km**) neutrino experiment to investigate the neutrino oscillation observed in atmospheric neutrinos by the Super-K

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



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

Motivation

Atmospheric ν anomaly by Kamiokande

Evidence for oscillation of atm. ν by SK

$\Delta m^2 = 2.5 \times 10^{-3}$ eV^2

$\sin^2 2\theta > 0.88$

almost $\nu_\mu \rightarrow \nu_\tau$

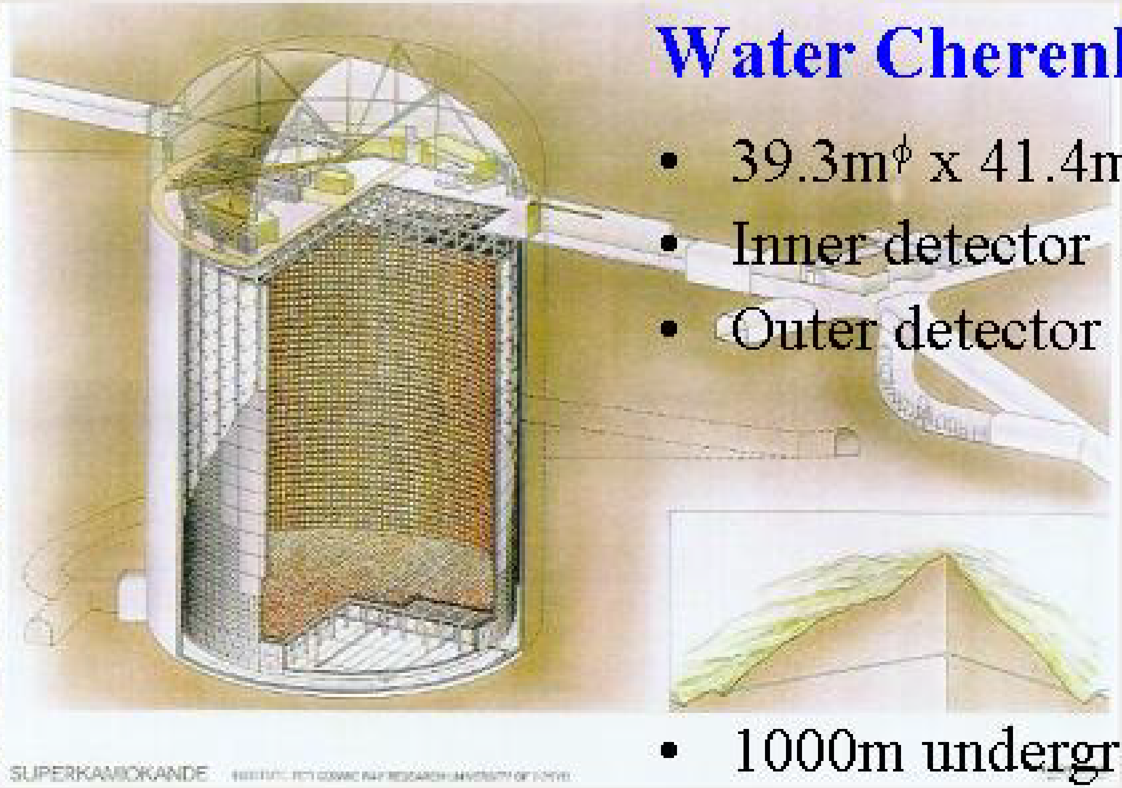
Neutrino Oscillation (in 2flavor approximation)

$$P(\nu_\mu \rightarrow \nu_\mu) = 1 - \sin^2 2\theta \sin^2(1.27 \Delta m^2 L/E)$$

K2K aims to **establish the neutrino oscillation** in

- **ν_μ disappearance and ν_e appearance**
- **well defined flight length (=250 km)**
- **well understood flux of pure (98%) ν_μ beam with <Eν>~1.3GeV**

Super-Kamiokande (SK) as Far Detector



Water Cherenkov detector

- 39.3m$^{\phi}$ x 41.4m --- 50kton water
- Inner detector 11146 PMTs(20'')
- Outer detector 1885 PMTs(8'')
- 1000m underground
- Atmospheric ν B.G. ~8events/day reduced by 10^{-6} by timing window (GPS)

The Accident on Nov.12

Many PMTs were broken within a few seconds

60% of the inner PMTs,
half of the outer PMTs
were broken.
Small water leak found.

Most possible cause is
one PMT broken and
chain reaction occurred
by a shock wave.

http://www-sk.icrr.u-tokyo.ac.jp/doc/news/appeal.html

By Prof. Totsuka

We will rebuild the detector. There is no question. The strategy may be the following two steps, which will be proposed and discussed among my colleagues.

1. Quick restart of the K2K experiment.

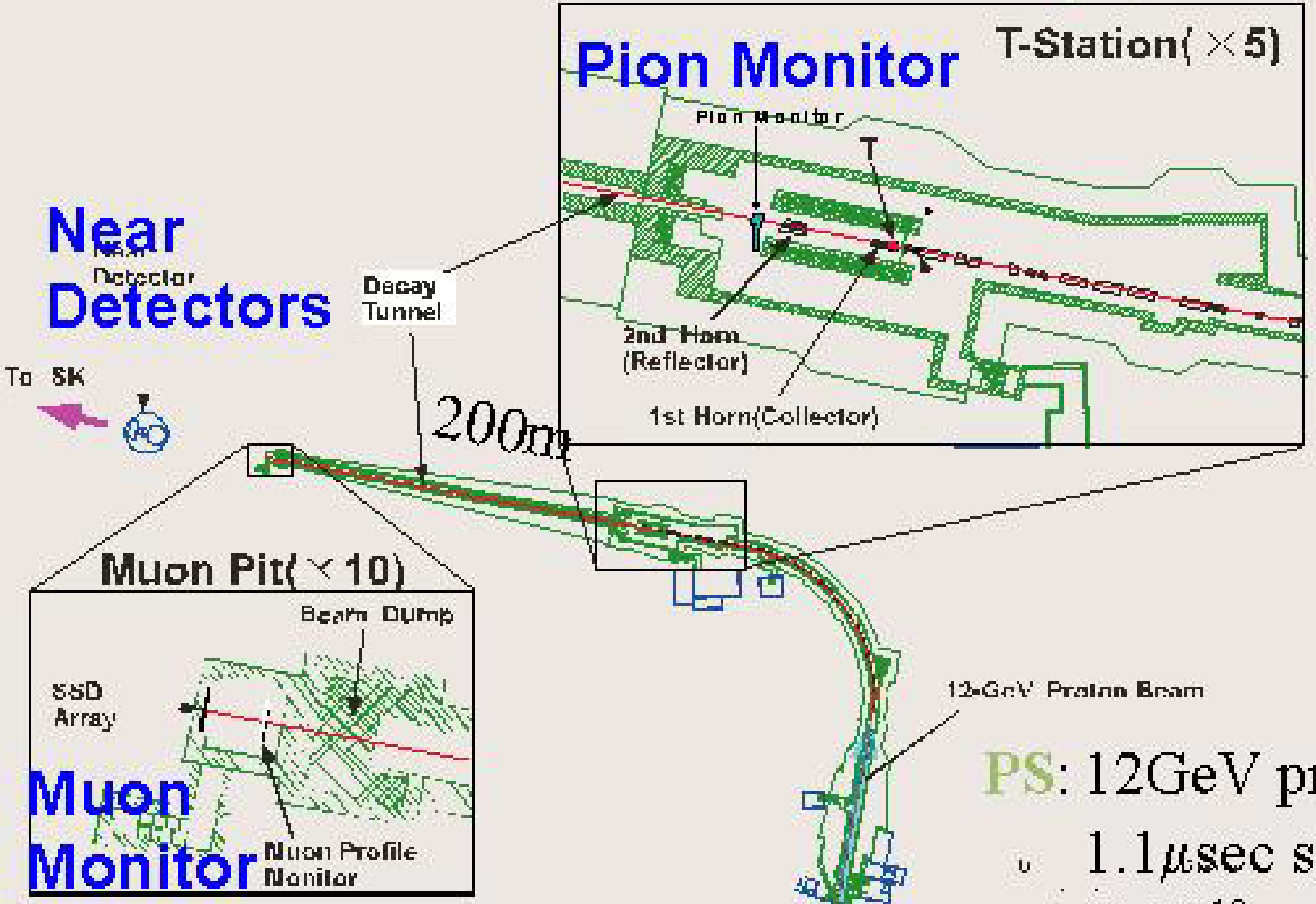
(1) We will clear the safety measures which may be suggested by the committees, (2) reduce the number density of the photomultiplier tubes by about a half, (3) use the existing resources, (4) **resume the K2K experiment** as soon as possible; the goal may be **within one year**.

To achieve our objective is formidable but we are determined to do so. We certainly need your encouragement, advice and help. I should appreciate it very much if you could support our effort as you have kindly done so before.

Neutrino Beam Production

$p + \mathrm{Al} \rightarrow \pi^+ \rightarrow \mu^+ + \nu_\mu$

$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$ (1%)

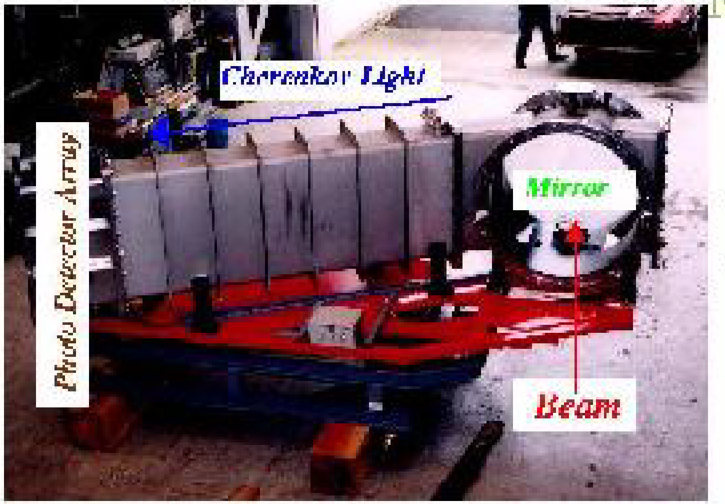


PS: 12GeV proton

1.1μsec spill/2.2sec

6x10^{12}protons/spill

Pion Monitor



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

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

.Predict

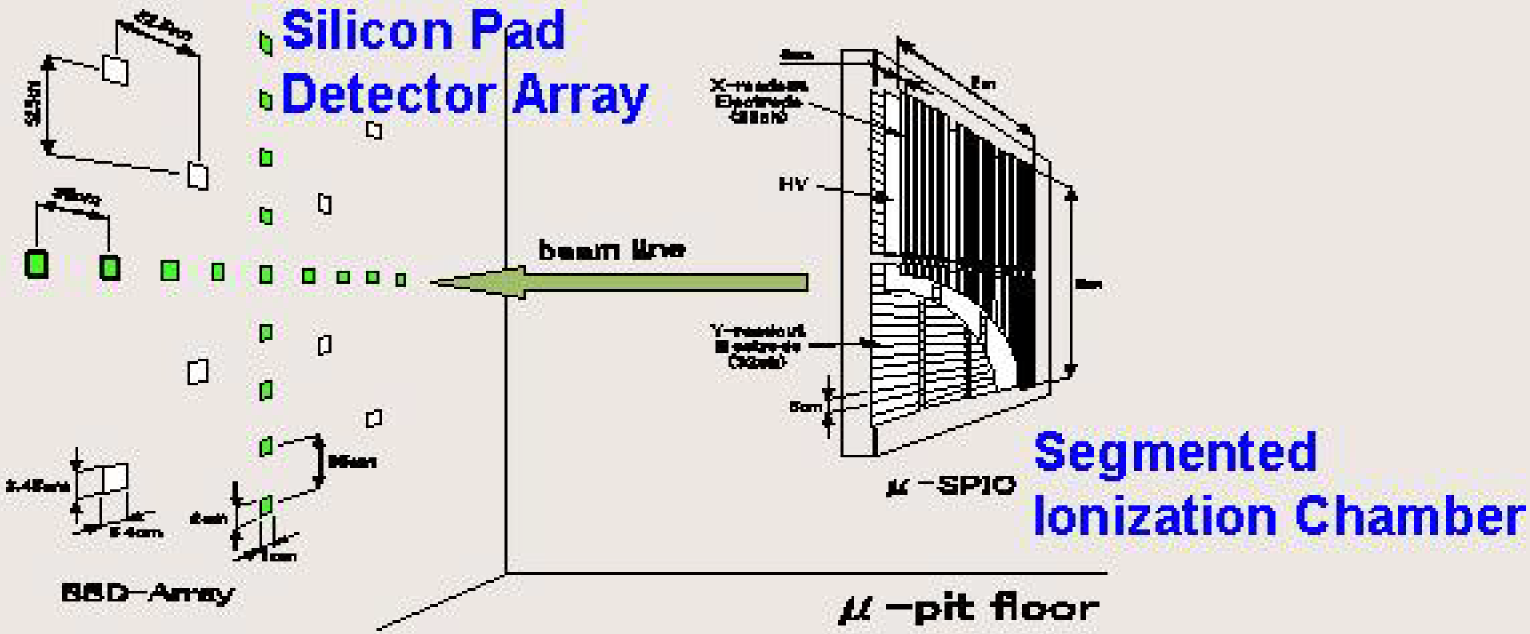
ν_μ Energy Spectrum at Near Site
Far Site.

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

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

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

Muon Monitor



Behind beam dump

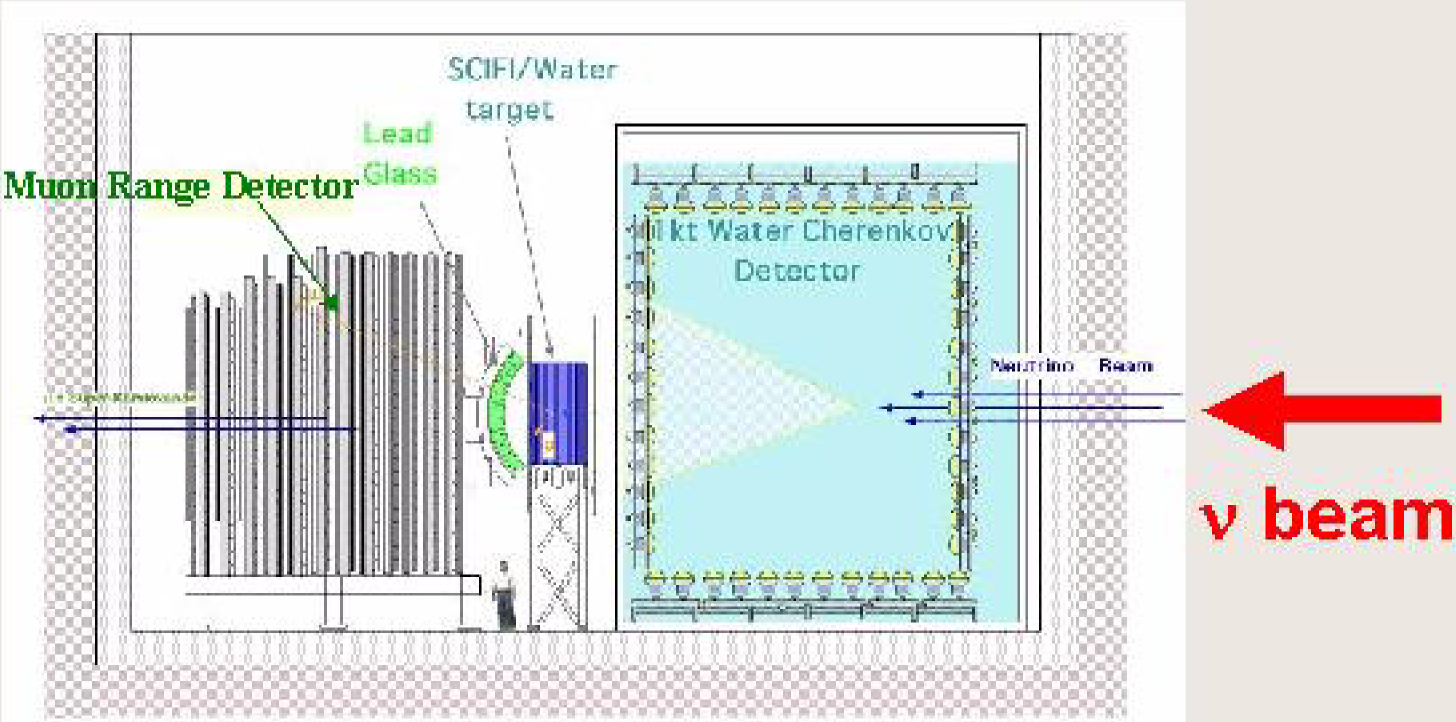
→sensitive to initially high energy μ (>5.5GeV)

Provide **fast (spill-by-spill)** monitoring of

Intensity → targeting/horn stability

Profile → beam direction

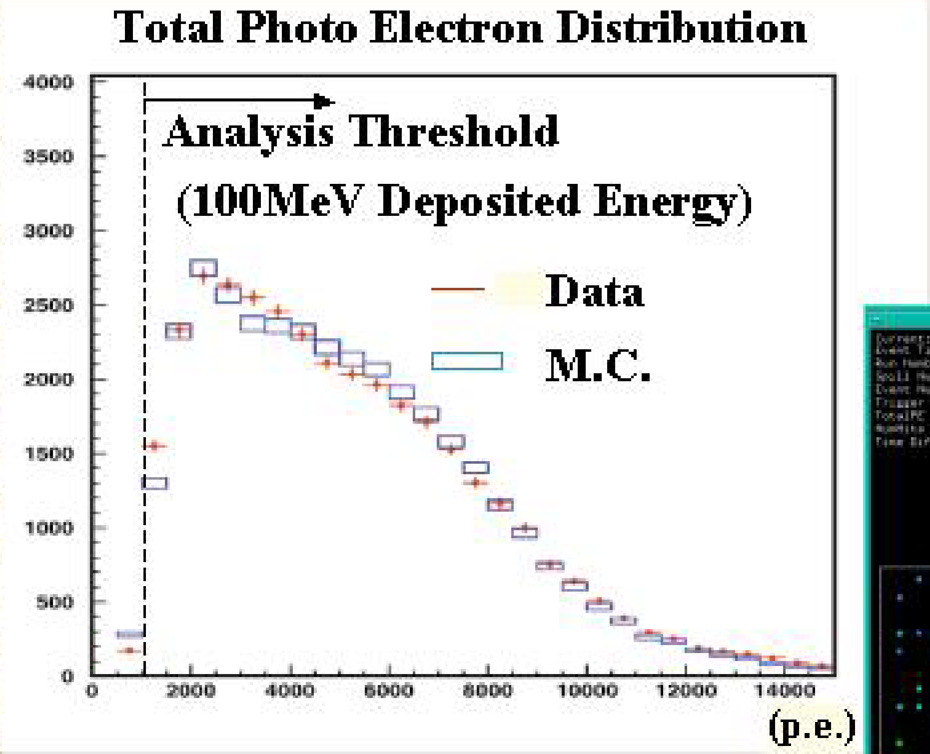
Near Site Neutrino Detectors



1kt:	Same Type Detector as SK	Neutrino Flux Measurement at Near
MRD:	Massive Large Area Coverage	Neutrino Beam Monitor
SciFi+MRD:	Fine Grained	Precise Neutrino Interaction Study

1kt as a Near Site Neutrino Detector

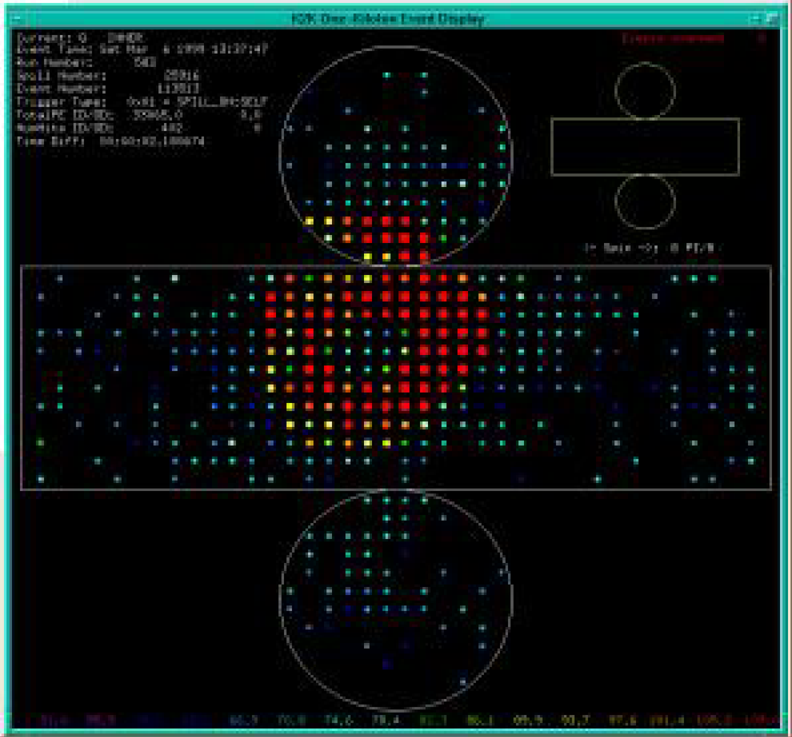
Same Type Detector as SK



Water Target,

Same Photo Coverage

with 680 20inc. PMT



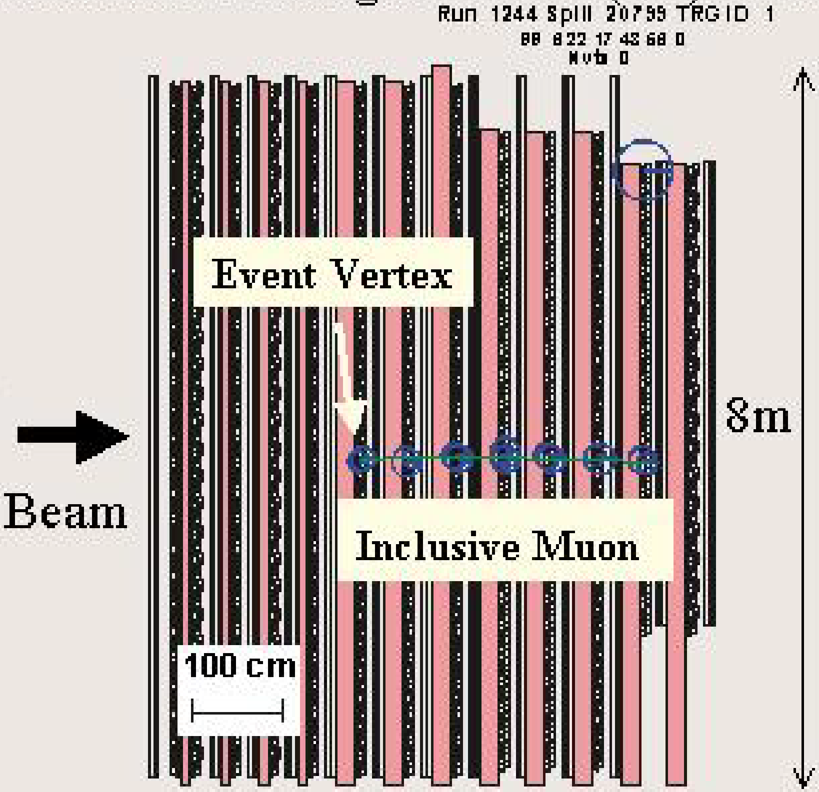
Fiducial Mass: 25ton

for r<2m, -2< z<0m

Event Rate : ~ 2/100pulses

Muon Range Detector (MRD) as a Neutrino Beam Monitor

Neutrino/Fe Charged Current(CC) Interaction



Fe /Drift tube Sandwich
(Fe: 10cm×4,20cm×8)
ΔE_{μ}=150MeV

Large area coverage
Vertex Distribution
Mom. and Angle of Inclusiveμ

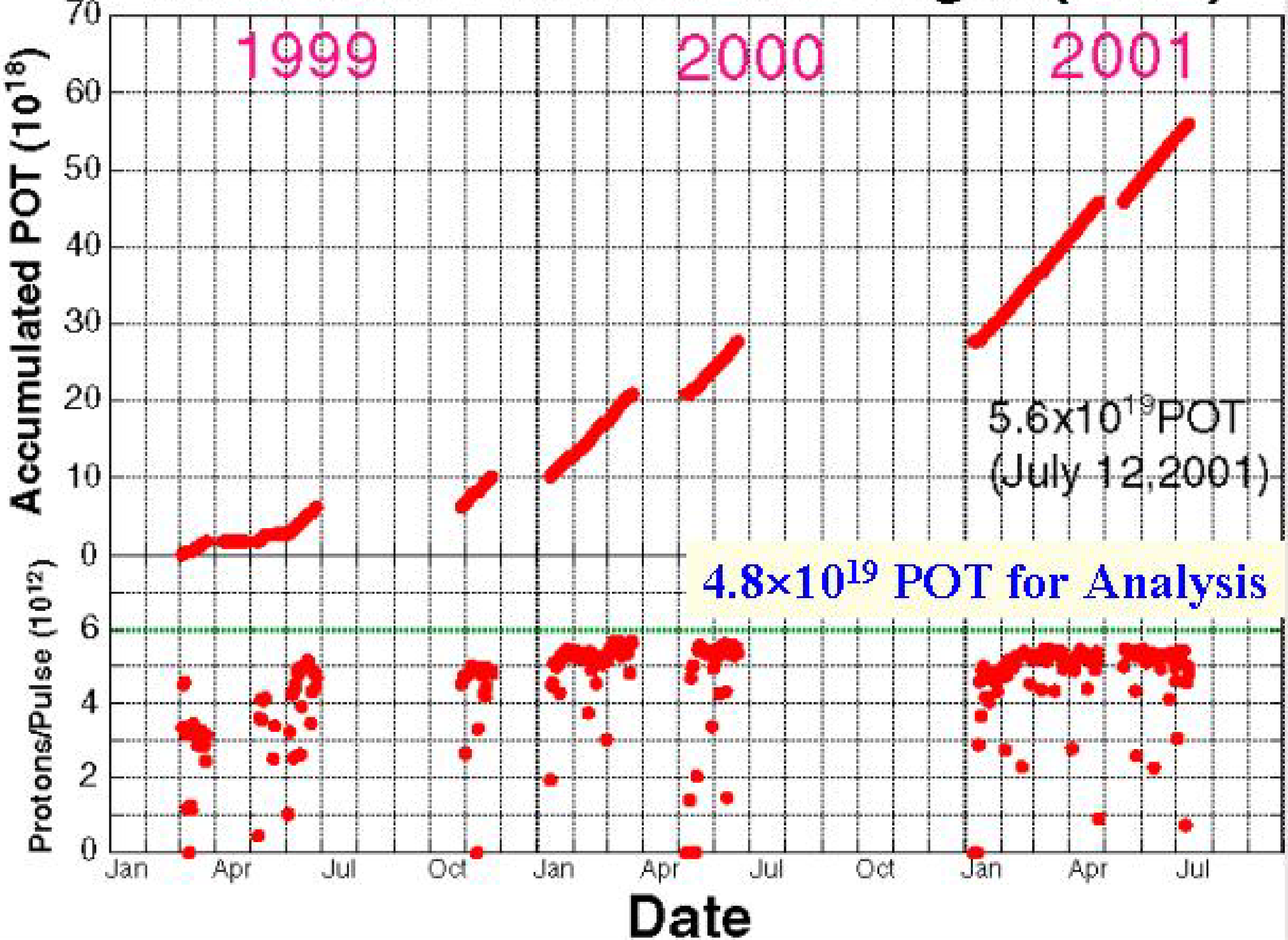
High Mass
329ton for r<3m
High Statistics (~ 5/100pulses)

Good Neutrino Beam Monitor
(Stability of Direction, Spectrum and Intensity)

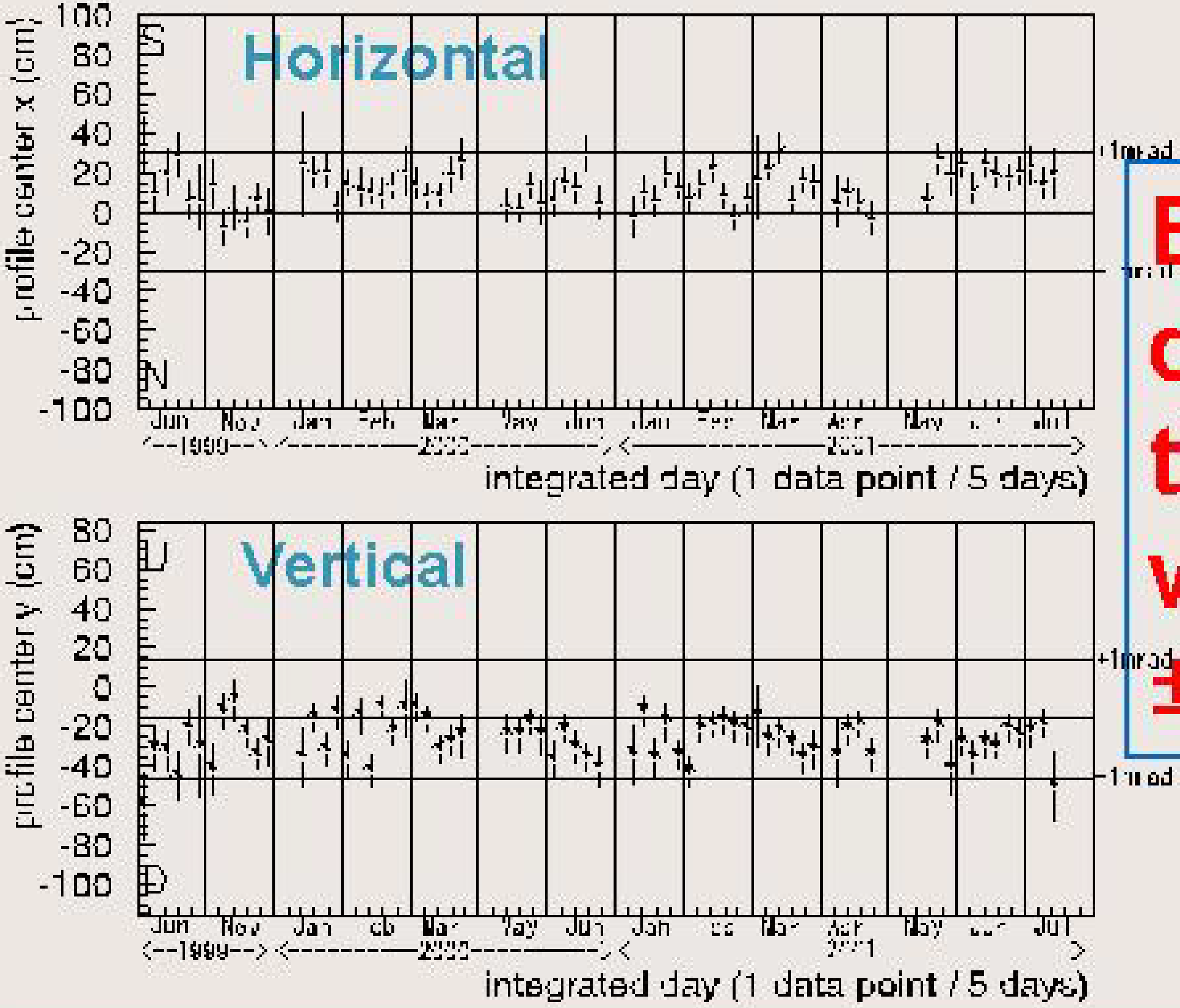
2. New Results

Based on data accumulated
between June 1999 and July 2001

Delivered Protons on Target (POT)

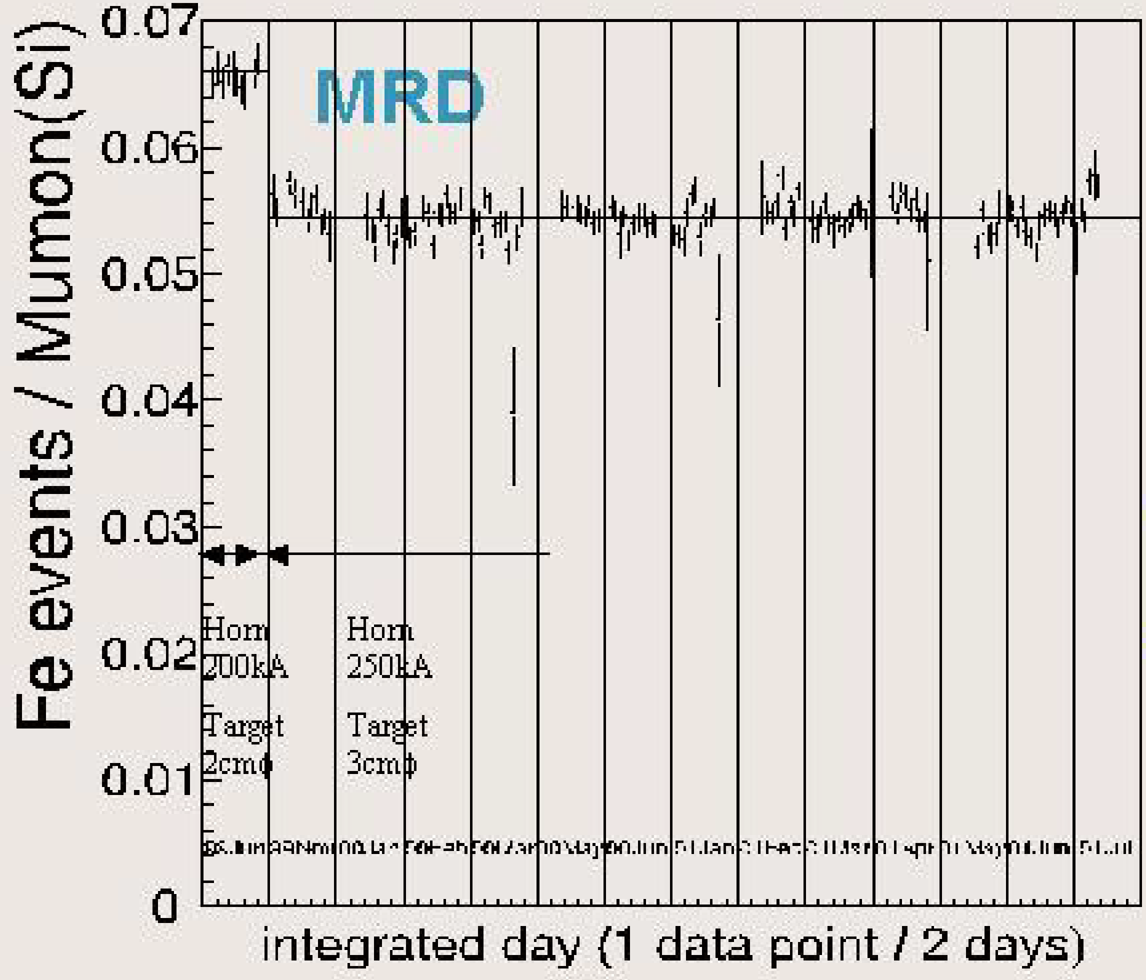


Profile Center Stability (MRD)



Beam is directed to SK within ±1mrad

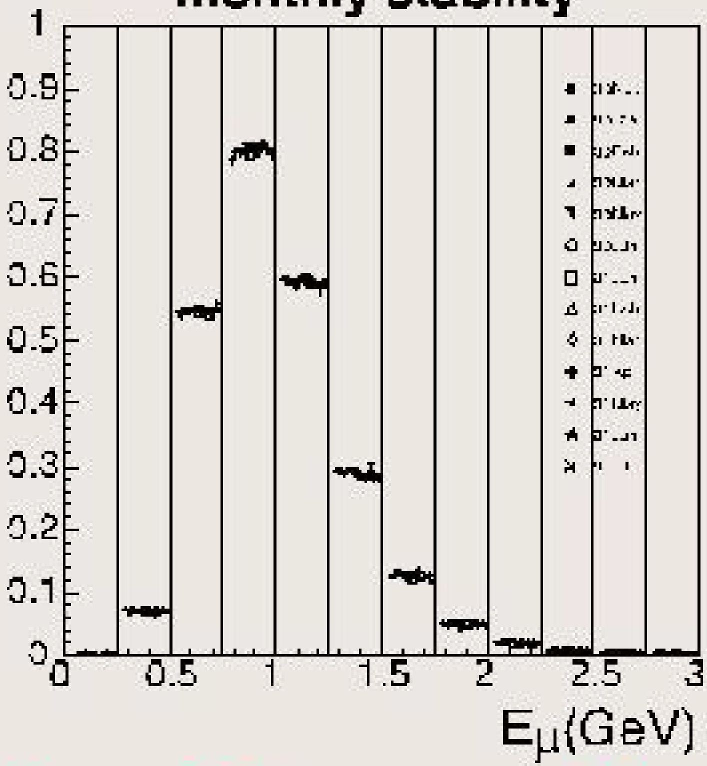
Event Rate(MRD) / Mumon



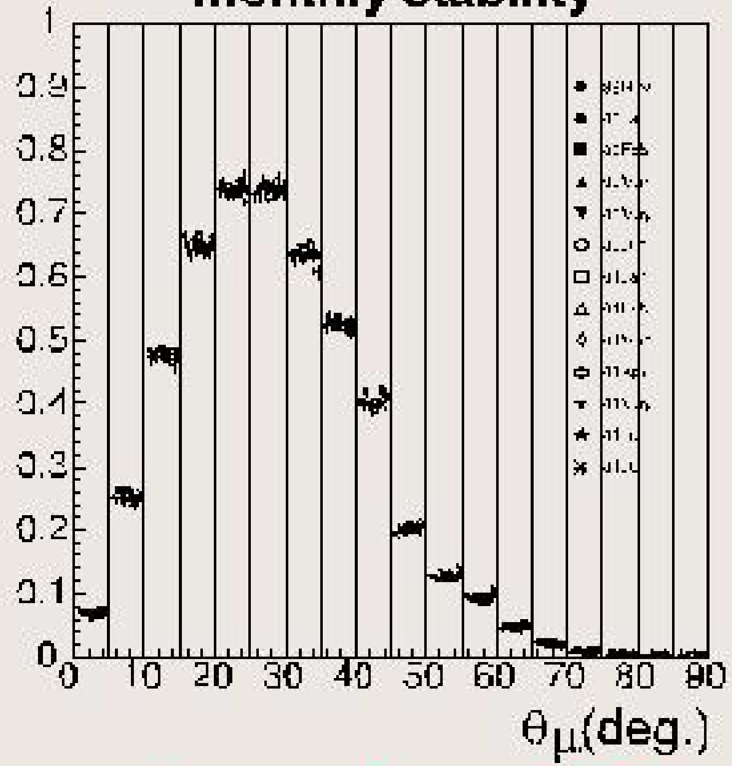
Stable

Muon Energy Angle Stability (MRD)

Muon energy monthly stability

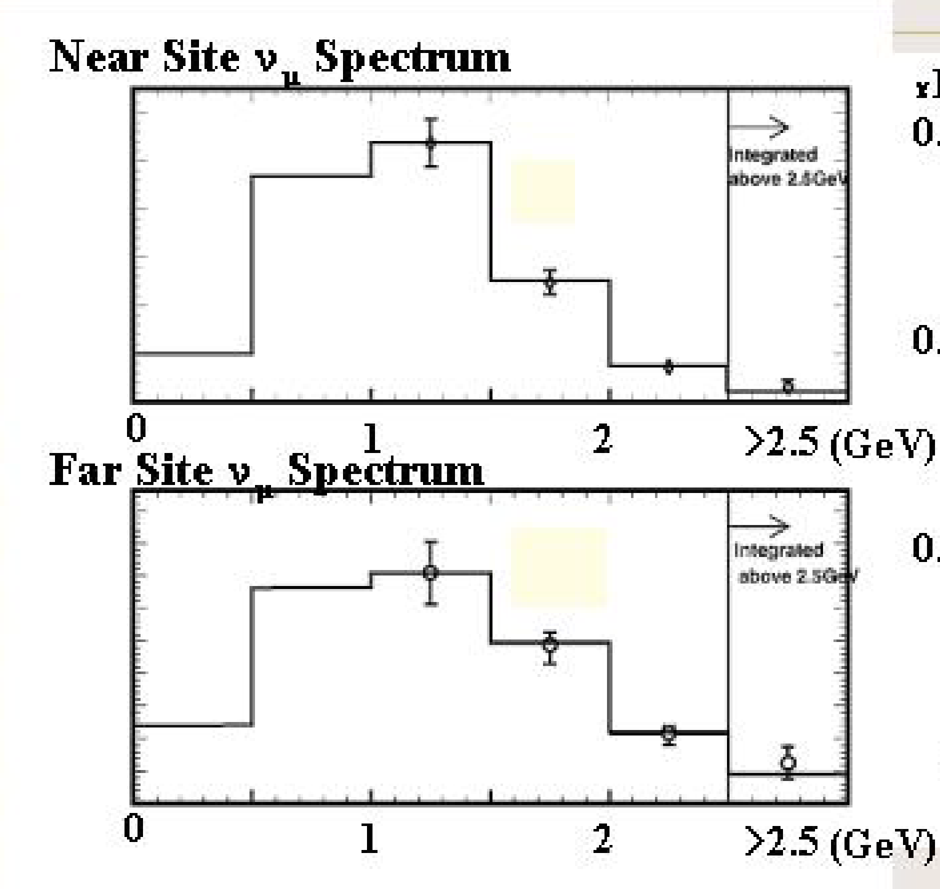


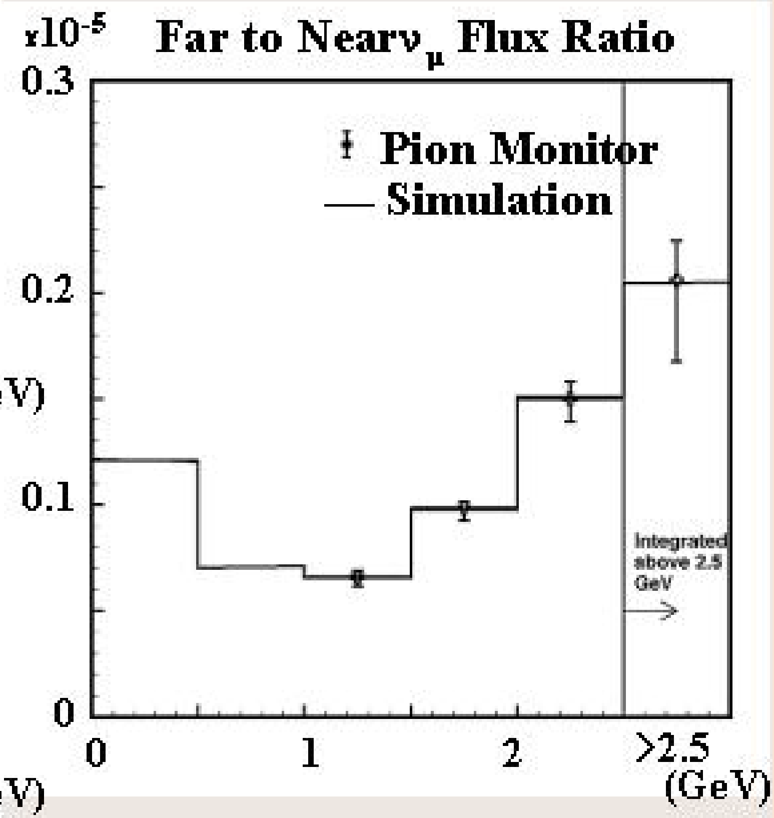
Muon angle monthly stability



Implying neutrino spectrum is stable

Inferred Neutrino Energy Spectrum at Far/Near by Pion Monitor



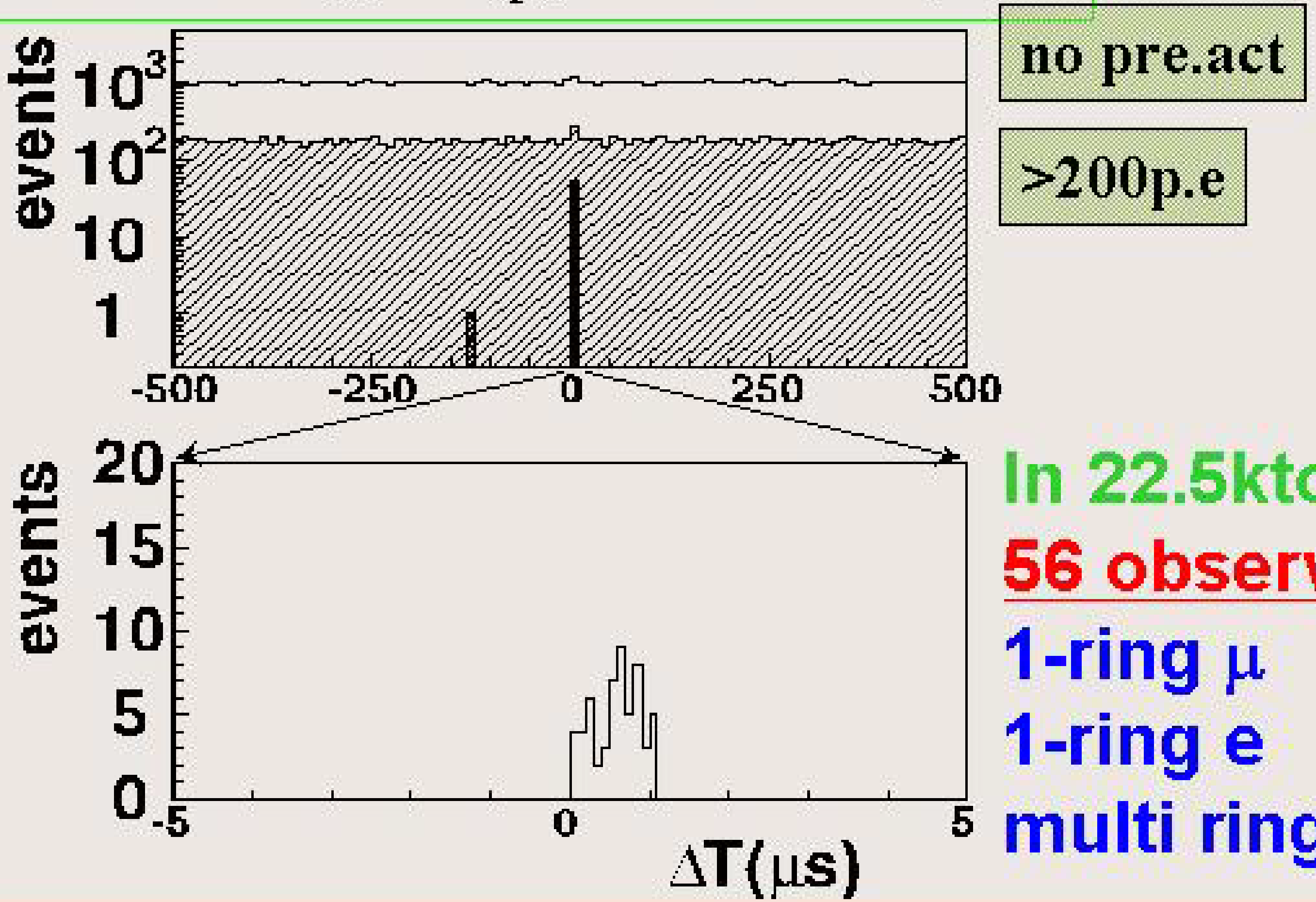


Simulation is Validated by Pion Monitor Measurement

Evaluation of Far/Near Uncertainty is Based on this Measurement

SK Events

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



In 22.5kton

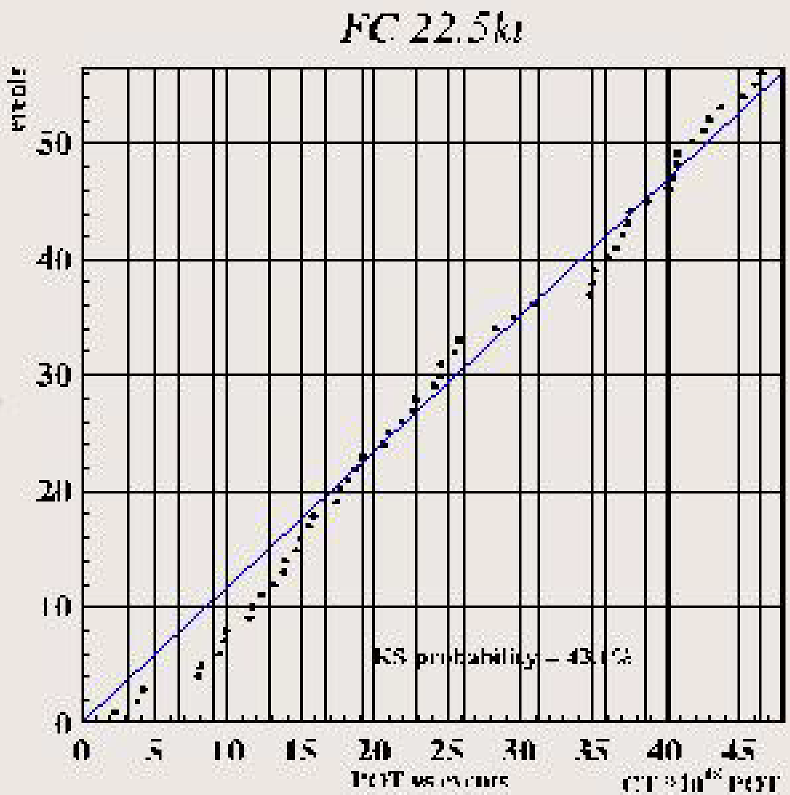
56 observed

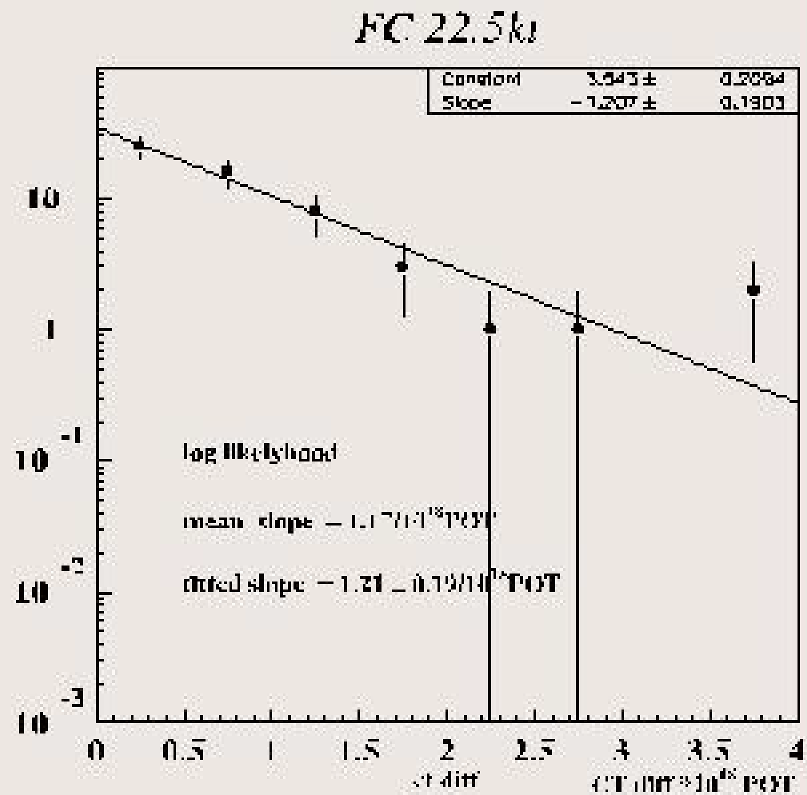
1-ring μ 30

1-ring e 2

multi ring 24

SK Events vs. POT





History of K2K and the New Result

	June1999 -July 2000	June1999 -April 2001	June1999 -July 2001 NEW
#Observed	28	44	56
#Expected	38	64	$80.6 \pm 0.3(\text{stat.})^{+7.3}_{-8.0}$

The result:

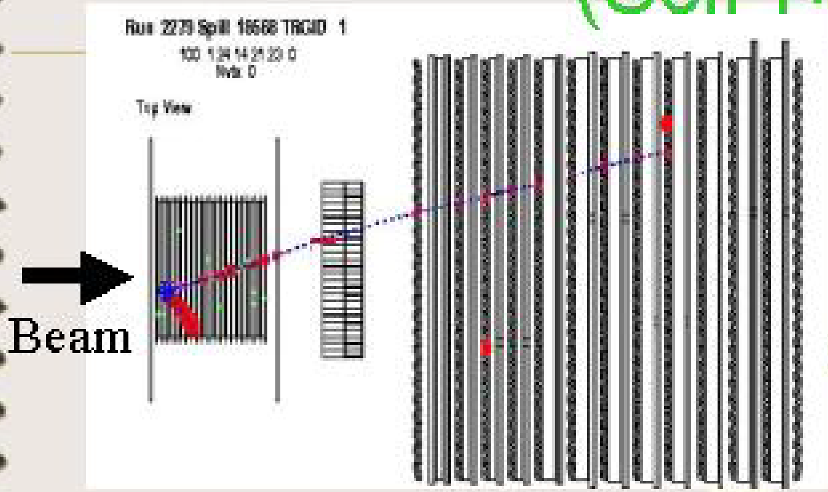
The probability of null oscillation scenario is **<u>less than 3%</u>** .

Method of a long-baseline ν experiment has been established.

- **<u>Beam monitoring and handling</u>** towards the detector 250km away.
- **<u>Synchronization</u>** of Far detector with an accelerator by GPS.
- Spectrum and Flux **<u>Extrapolation</u>** from Near to Far.

Work in Progress

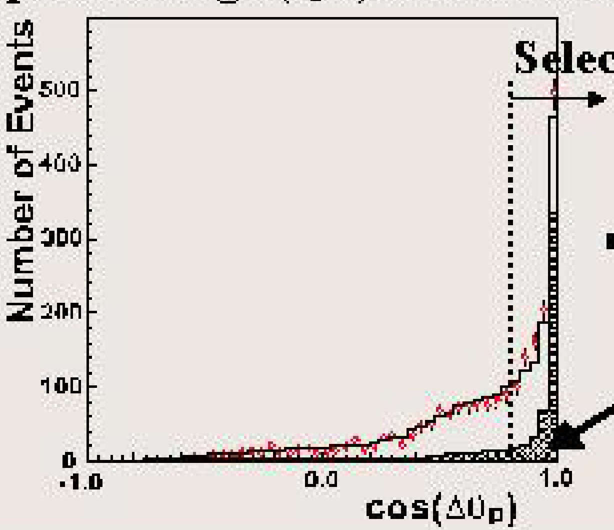
Near Site Neutrino Spectrum Measurement (SciFi+MRD)



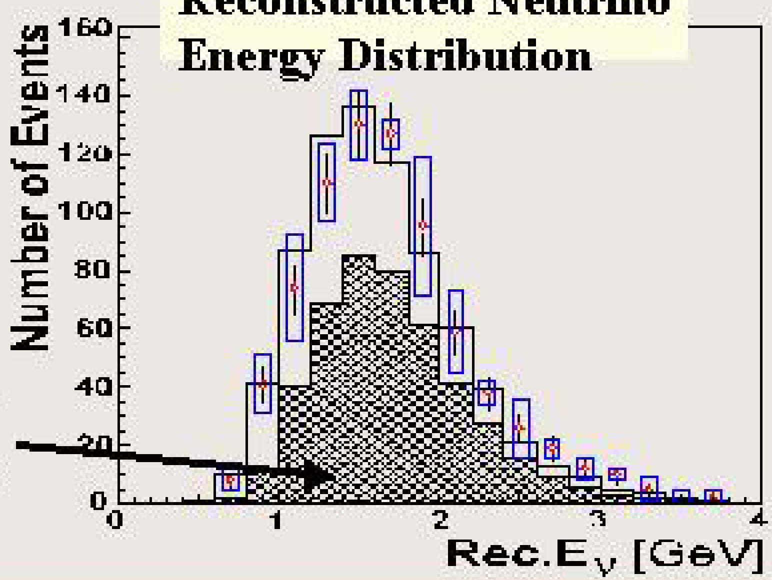
Water Target (+20% Al)
Pos. Resolution ~1mm
Fiducial Mass : 5.9 ton
Event Rate ~ 1/1000pulses

Suitable for Studying Neutrino Int., e.g. $\sigma_{QE}/\sigma_{non\text{-}QE}$

Expected Angle(QE)-Measured Angle

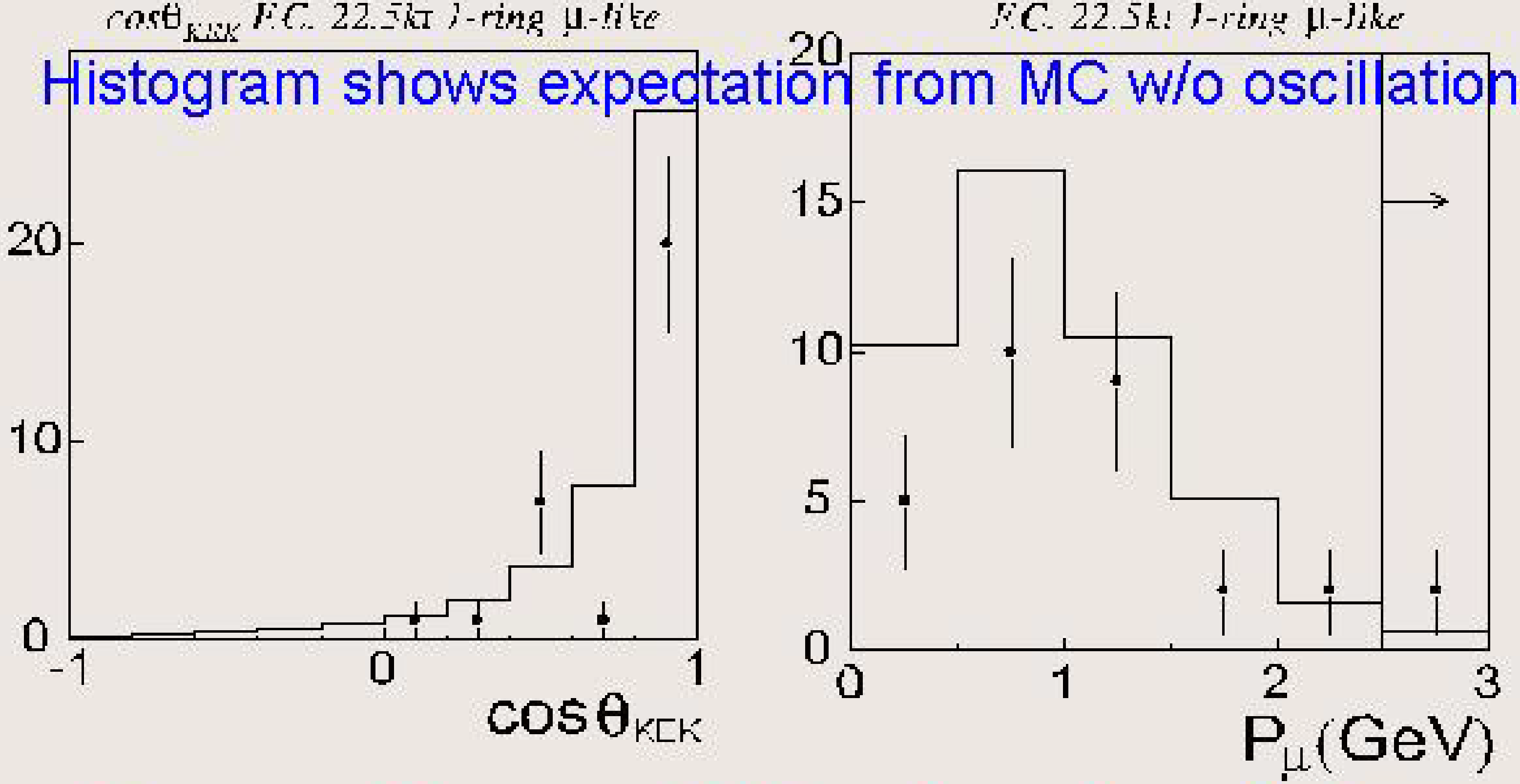


Reconstructed Neutrino Energy Distribution



Angle and Momentum of Muon-like Events at SK

Histogram shows expectation from MC w/o oscillation

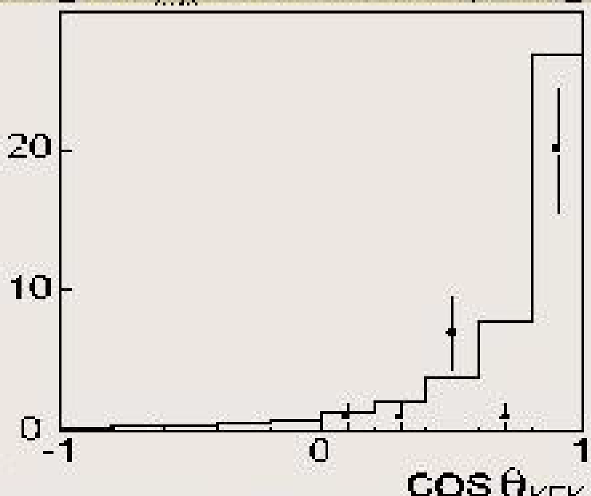


Sys. err. in expectation is under study using near detector information.

Work in Progress

Observed Neutrino Spectrum at SK

Angular Distribution of Single-Ring μ

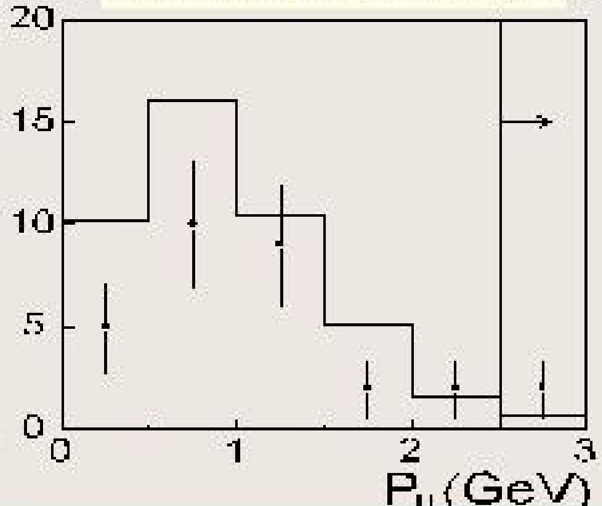


Statistical Uncertainty Only !!

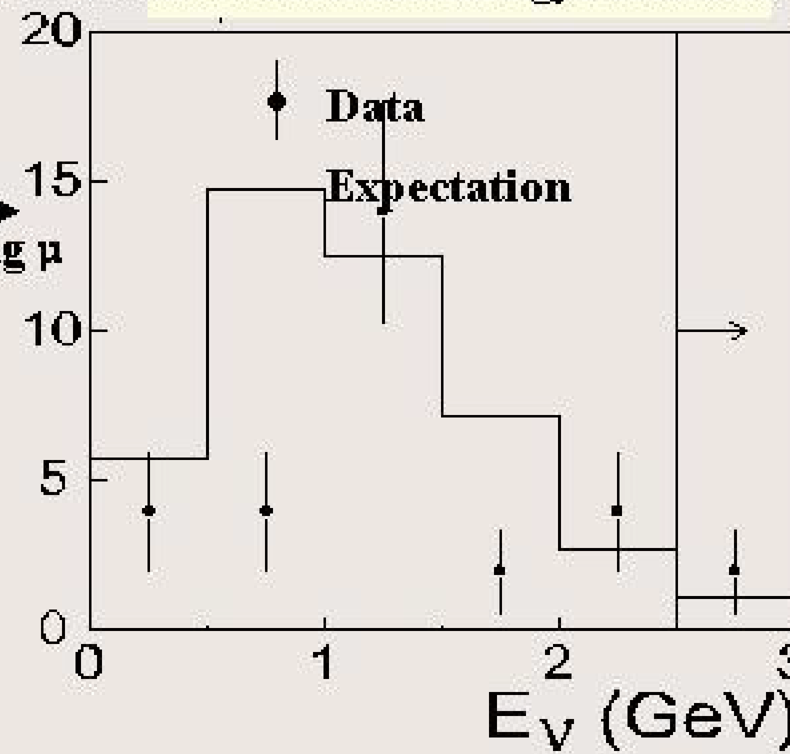
Evaluation of Systematic Uncertainty

inc. Bin by Bin Correlation is Necessary !!

Momentum Distribution of Single-Ring μ

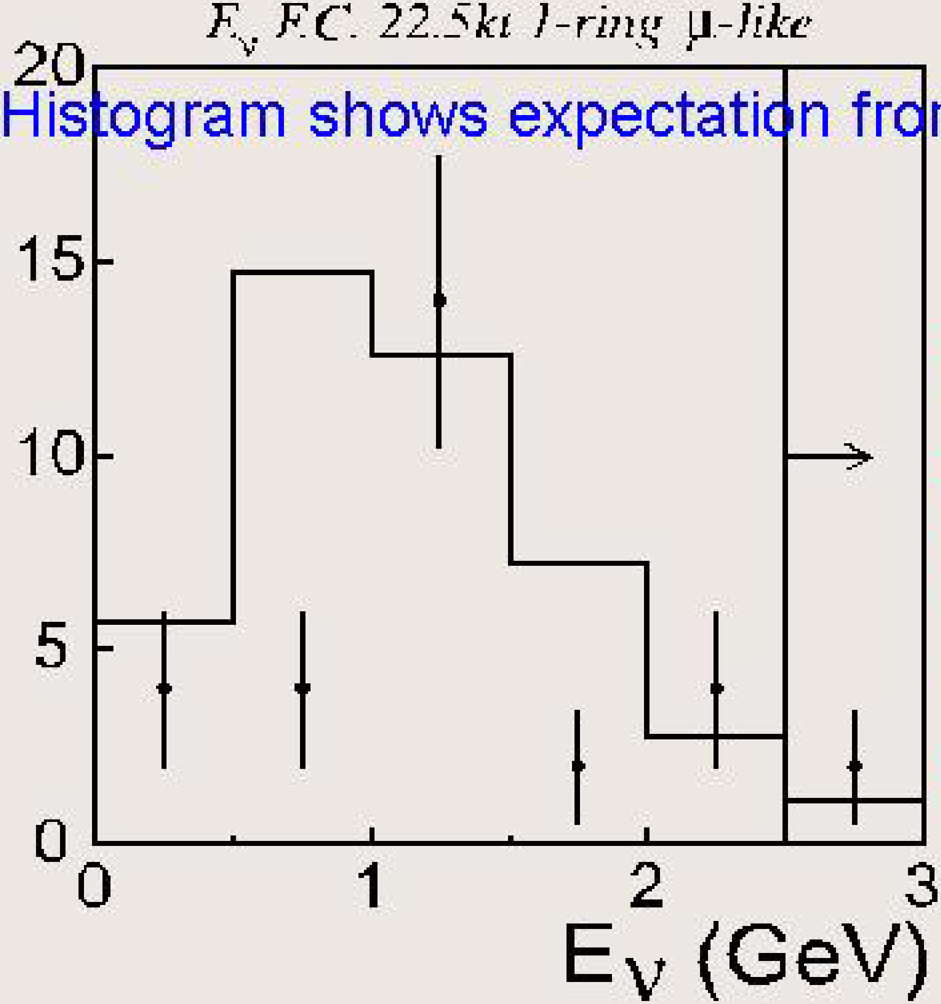


Reconstructed Neutrino Energy Distribution



Work in Progress

Reconstructed Eν at SK



Histogram shows expectation from MC w/o oscillation

Full spectrum analysis is under way using all information.

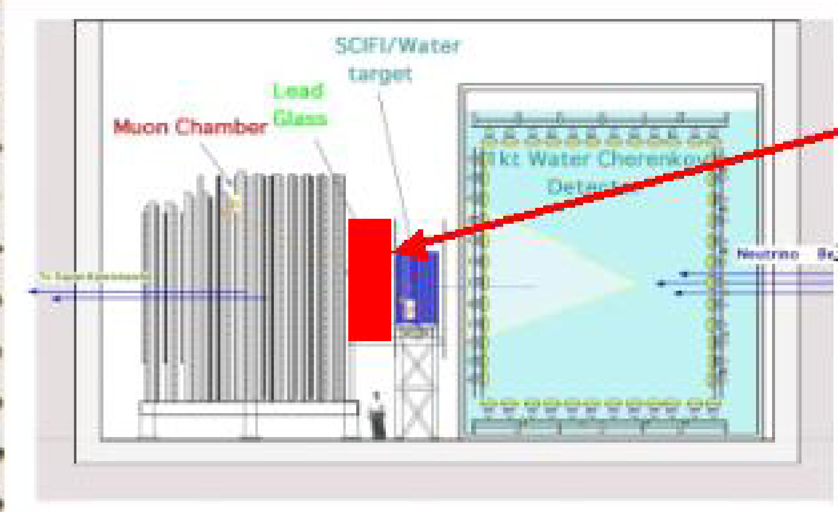
3. Near Detector Upgrade

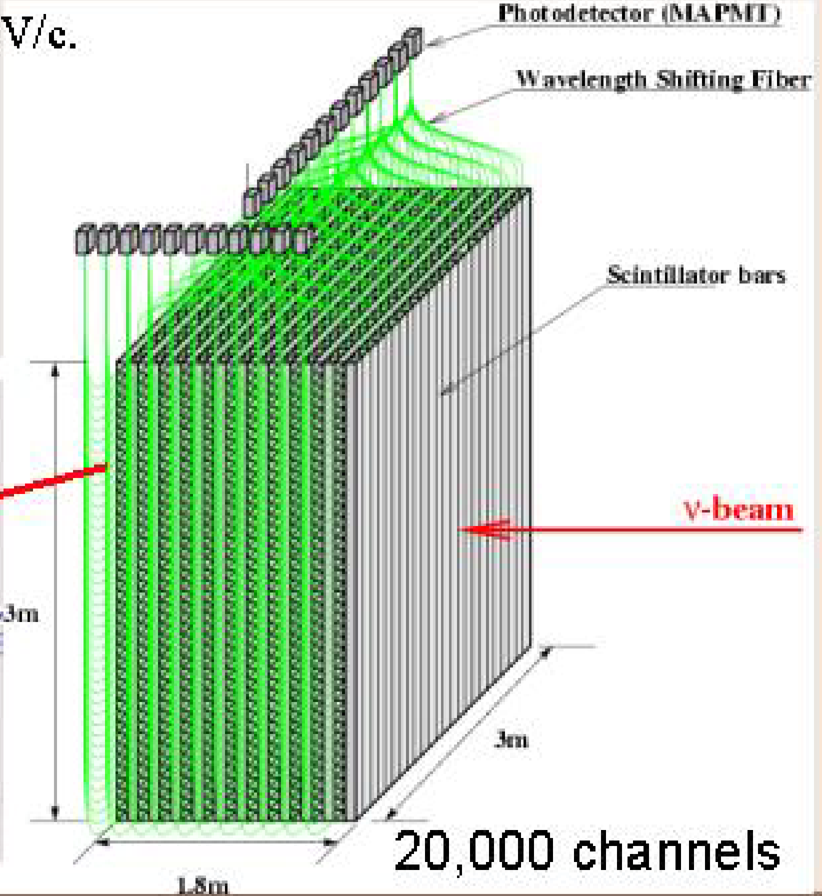
•K2K will install another brand new near detector **in summer 2003**.

L=250km, $\delta m^2=3\times10^{-3}$.....E$\nu$ ~ 0.6GeV

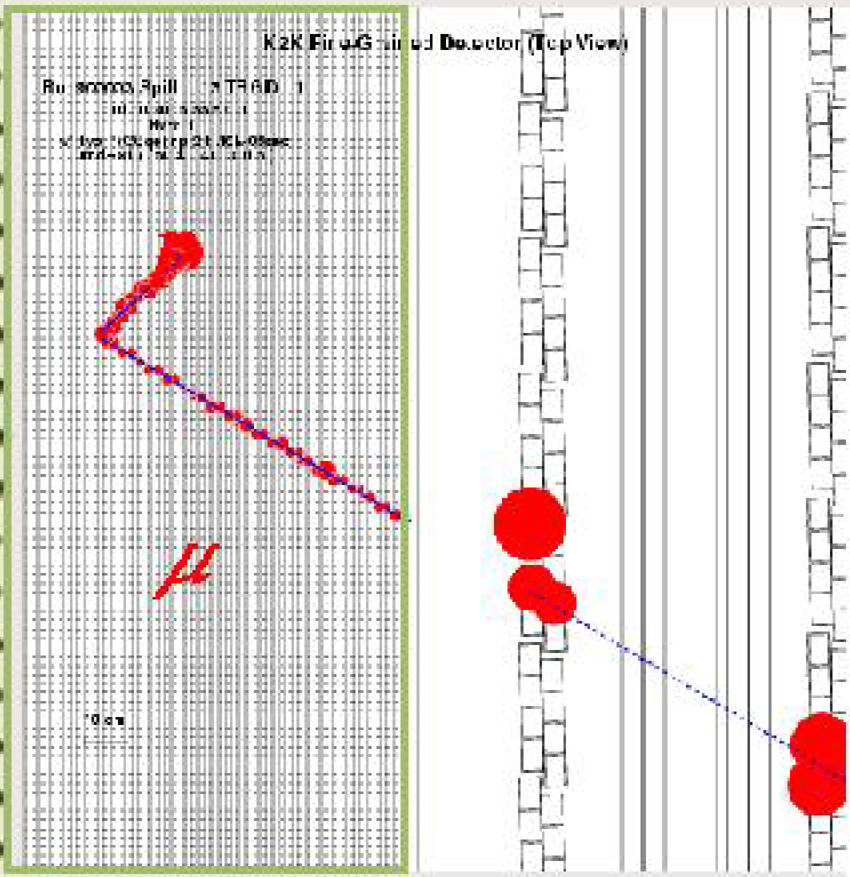
Full active (solid) Scintillator tracker (SCIBAR)

- 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.
- Fine segments ($1\times2\times300\text{cm}^3$).

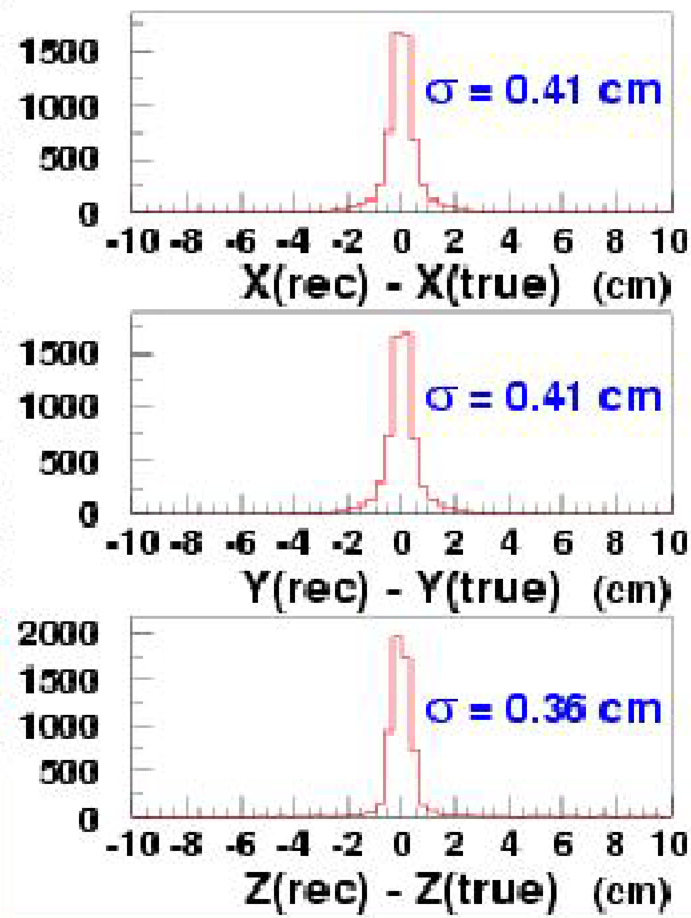




CC-QE Event Display (SCIBAR)



Tracking Performance



4. Run Plan

- Firmly to establish neutrino oscillation, K2K will accumulate **10^{20} POT** (additional **18 month run**).
- Super-K is being rebuilt with a reduced PMT density. Goal is within 1 year.
- After the Super-K rebuilt, we want to accumulate data as quick as possible. K2K can run for **more than 7 month** in a year.
  - The horns are sustained more than **8 M pulses**.
- The upgrade detector, Full Active Scintillator Tracker (SCIBAR), will be installed and be ready by summer 2003.

5. Summary

- The new result is:

  #Events=56 for **#expect=80.6±0.3(stat.)$^{+7.3}_{-8.0}$(sys.).**

  Probability of null-oscillation scenario is <3%CL.
- We hope that Super-Kamiokande can be **rebuilt within one year**.
- K2K wants to achieve **10^{20} POT** (additional **18 month run**) to establish ν oscillation definitely.
- The new **full active scintillator tracker** will be installed **in summer 2003** to measure ν spectrum precisely and to study ν interactions.