Results from K2K experiment.

K2K Collaboration.

KEK

Yoshinari Hayato

1. Introduction

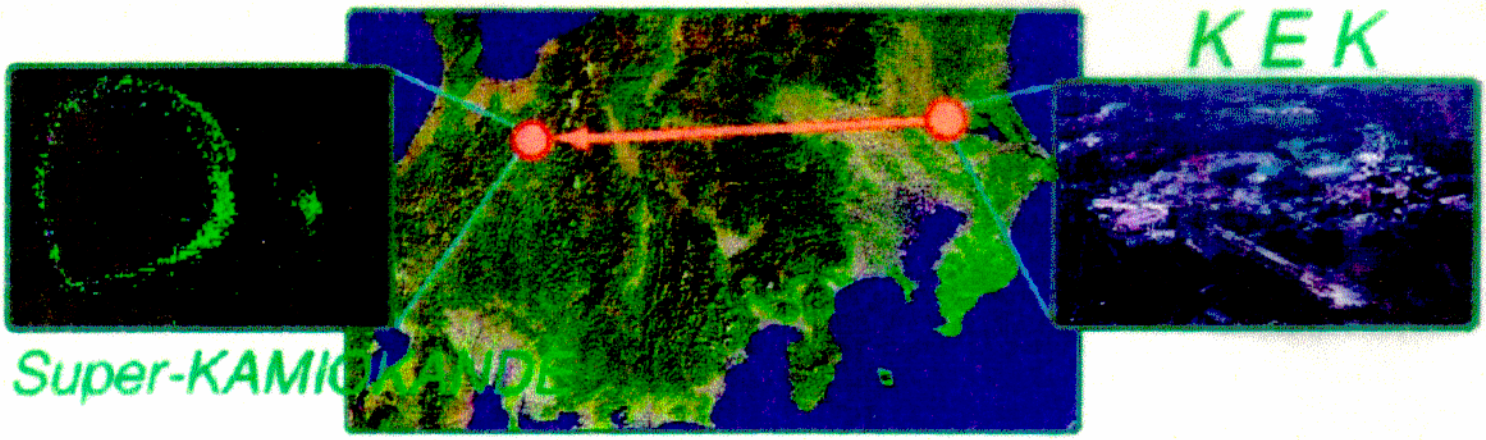
2. Results

- π-monitor
- μ-monitor
- Water Cherenkov detector
- ν drift chamber
- Scintillating fiber tracker
- Super Kamiokande

3. Summary

1. Introduction

K2K. Long baseline ν oscillation experiment



ν_μ beam from 12 GeV PS @ KEK

(Contamination of ν_e < a few %)

Beam monitors & ν detectors @ KEK.

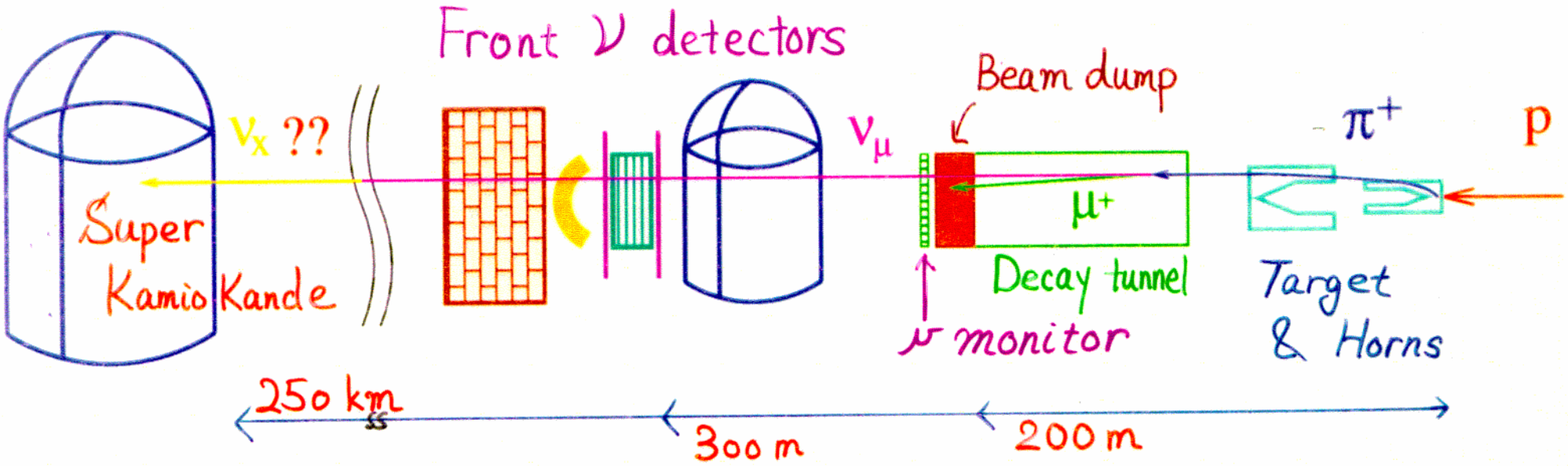
↓

Super-Kamiokande

$\langle E_\nu \rangle \sim 1.4$ GeV.

$L = 250$ Km.

$\Rightarrow \Delta m^2 \sim 10^{-2} \sim 2 \times 10^{-3}$ eV^2

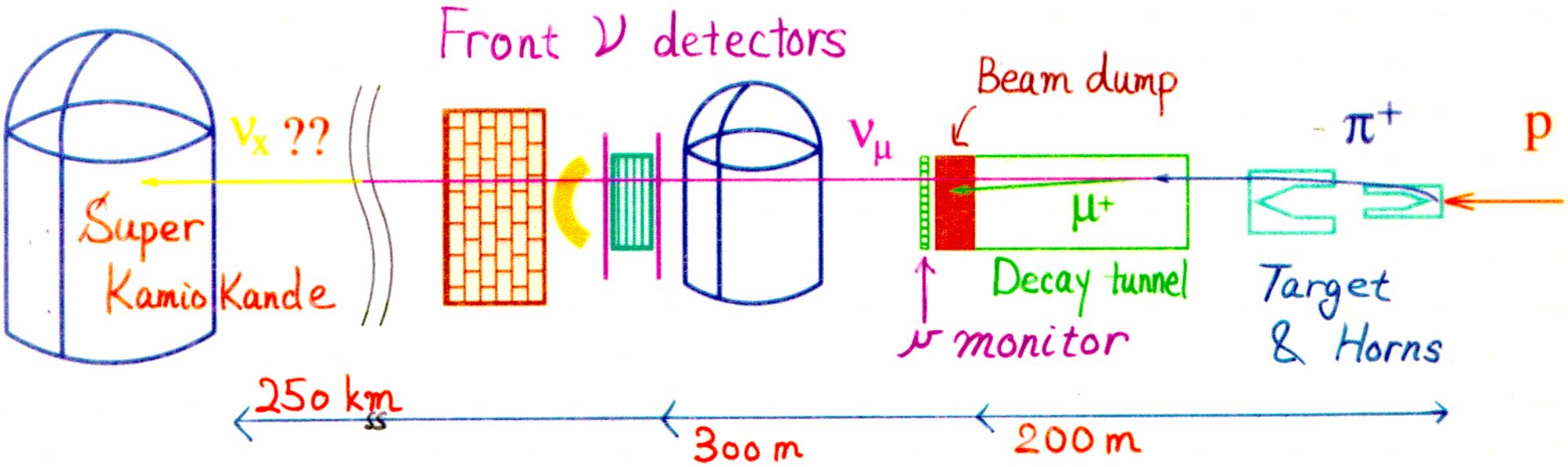


Proton beam 12GeV. Every 2.2 sec, ~5.5×10^{12} protons of target/spill.
1 spill ~ 1.1 μs.

Target Al. 30 mm φ × 660 mm. (20mm φ × 660mm for June'99)

Horns. 250kA. (200kA for June, '99)

Alignment (beamline) GPS measurements. ⇒ less than 0.01 mrad.

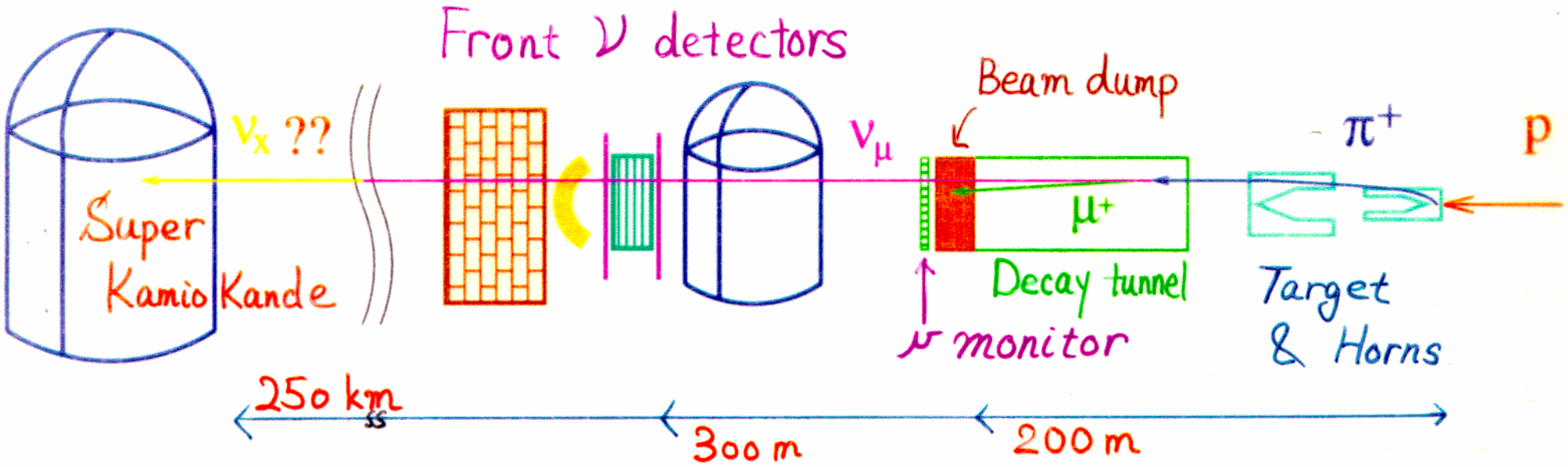


Beam Monitors

primary protons. Current Transformer (CT).

Secondary particles. π monitor → ν spectrum & ν flux ratio (ϕ_{FD}/ϕ_{SK}) prediction.

ν monitor → Direction of ν Spill by Spill.



Front ν detectors.

1 kt water Č detector.

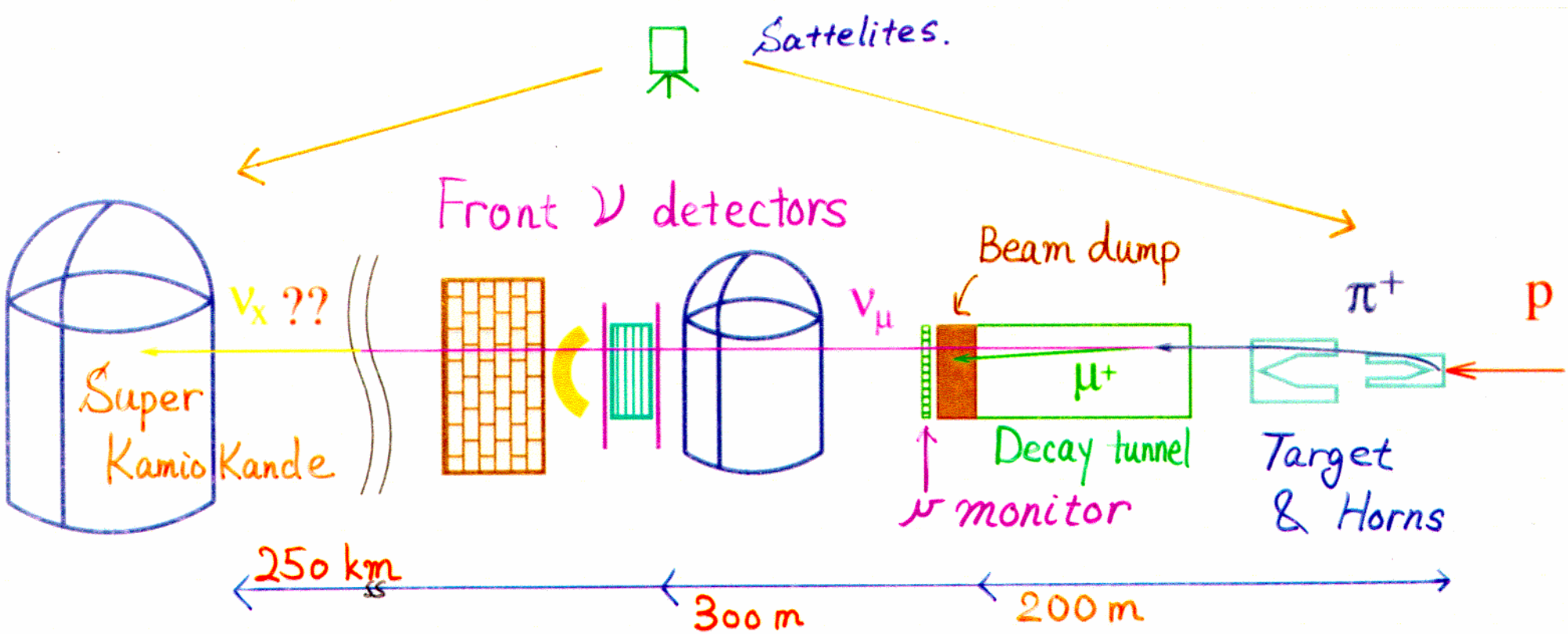
H_2O target.
Same type (S.K.). → Smaller Systematic errors.

Scintillating Fiber tracker

H_2O target
Fine vertex resolutions.

ν-drift chamber

Fe target
Large mass = High stat.



Event selection

⇒ G.P.S. → timing information. (drift ≪ 100 ns)

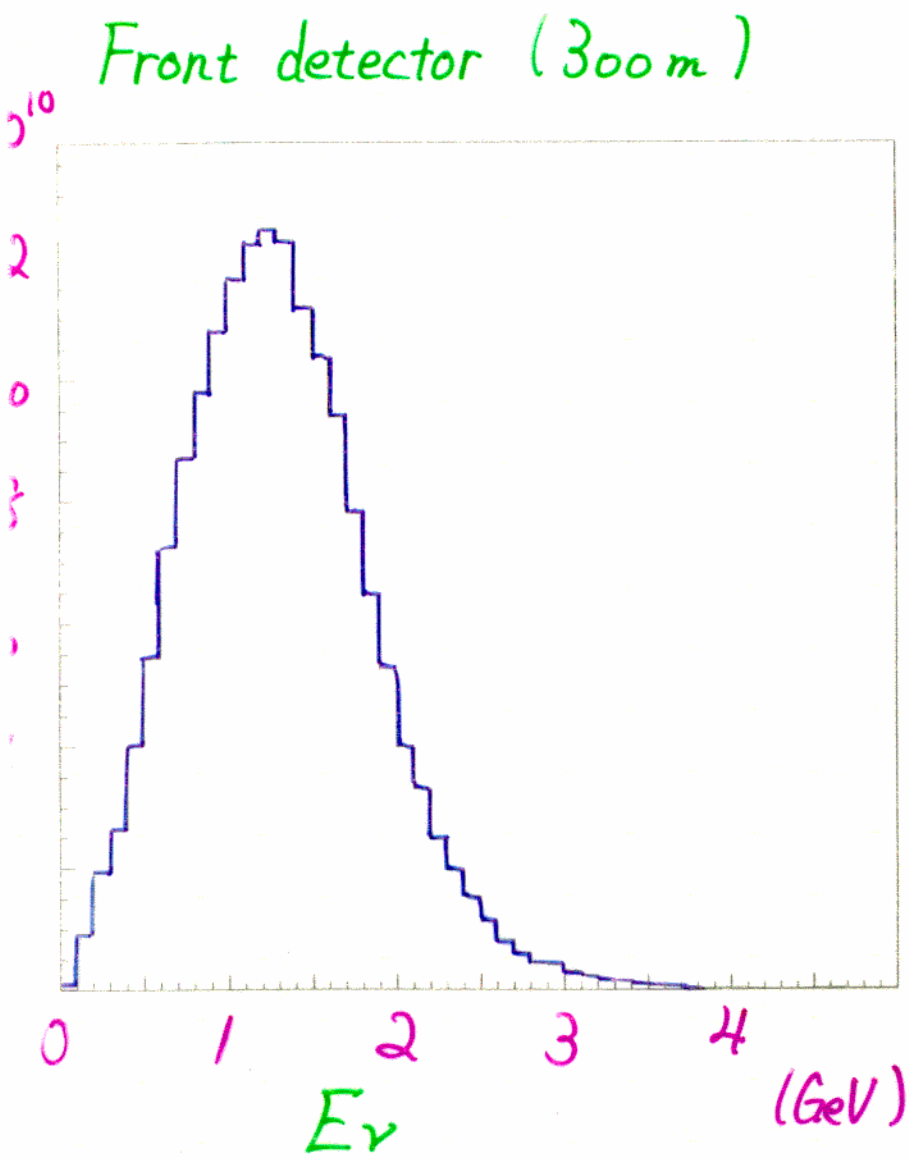
timestamp → beam spills (T_{KEK})

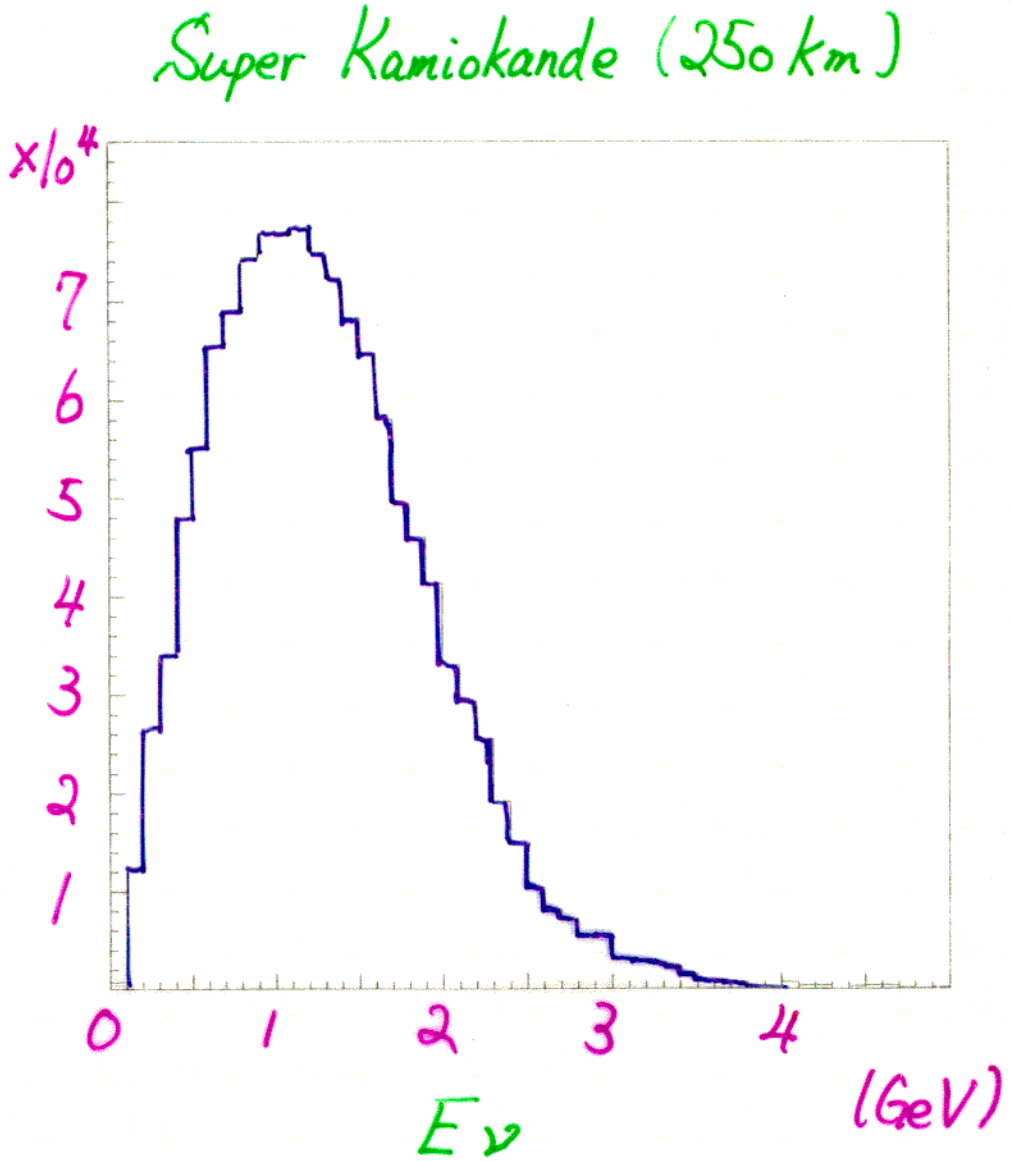
→ all S.K. events. (T_{SK})

→ $\Delta T \equiv T_{SK} - T_{KEK} - T_{TOF}$

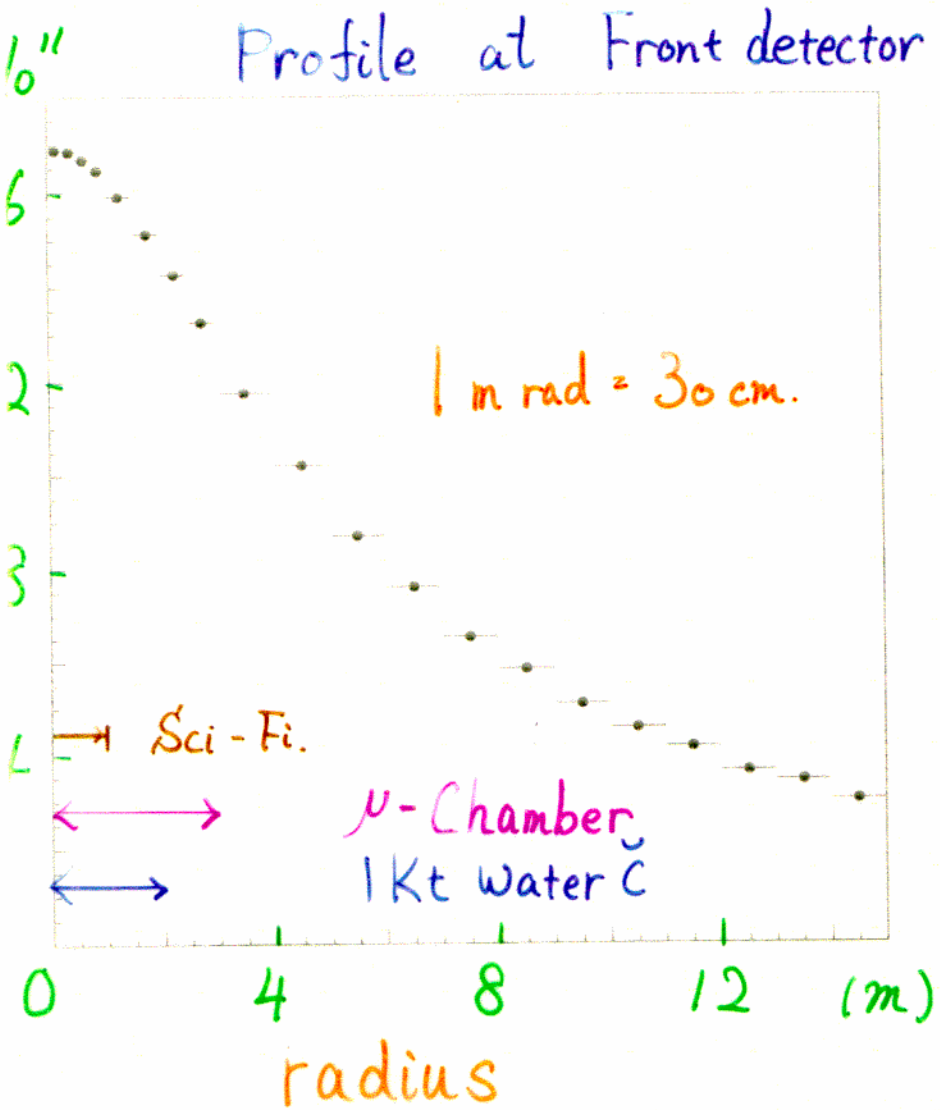
→ Select events

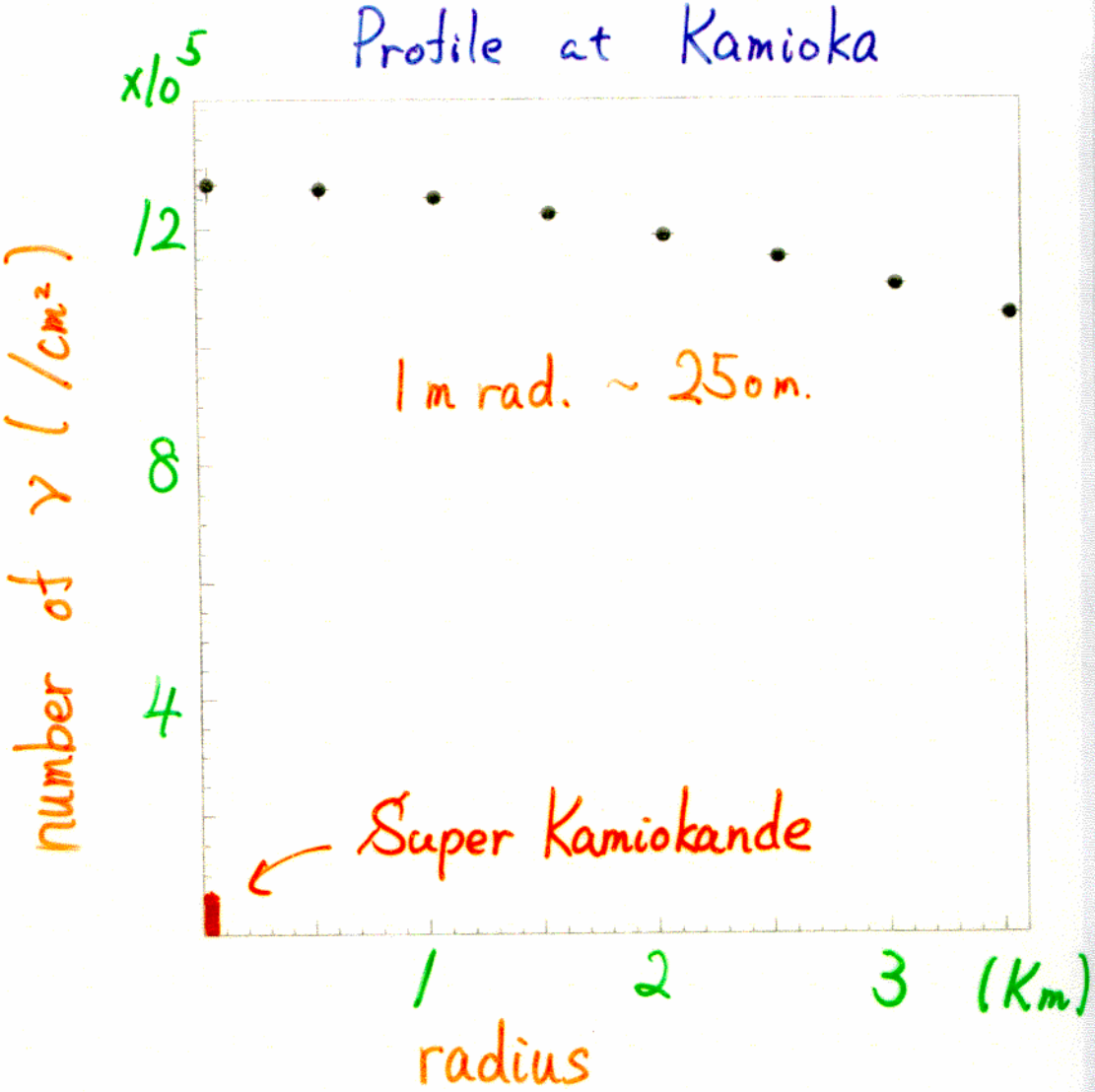
Energy spectrum of ν (Monte-Carlo)





Profile of ν





What we need to know...

- ν energy spectrum
  - Monte-Carlo
    - ★ guaranteed by π-monitor ($E_\nu \geq 1$ GeV)
    - ★ confirmed by front detectors.
- ν beam direction
  - GPS measurements ≤ 0.01 mrad.
  - ν-monitor. (spill by spill)
  - ν-drift chamber (day by day)
    - ★ direct measurement of ν-interactions

ν absolute flux

- Front detectors.
  - 1kt water Čherenkov detector. (reference)
  - Scintillating fiber tracker
    - → Water target.
  - ν-drift chamber
    - → Fe target, large volume area

Expected # of events. @ S.K.

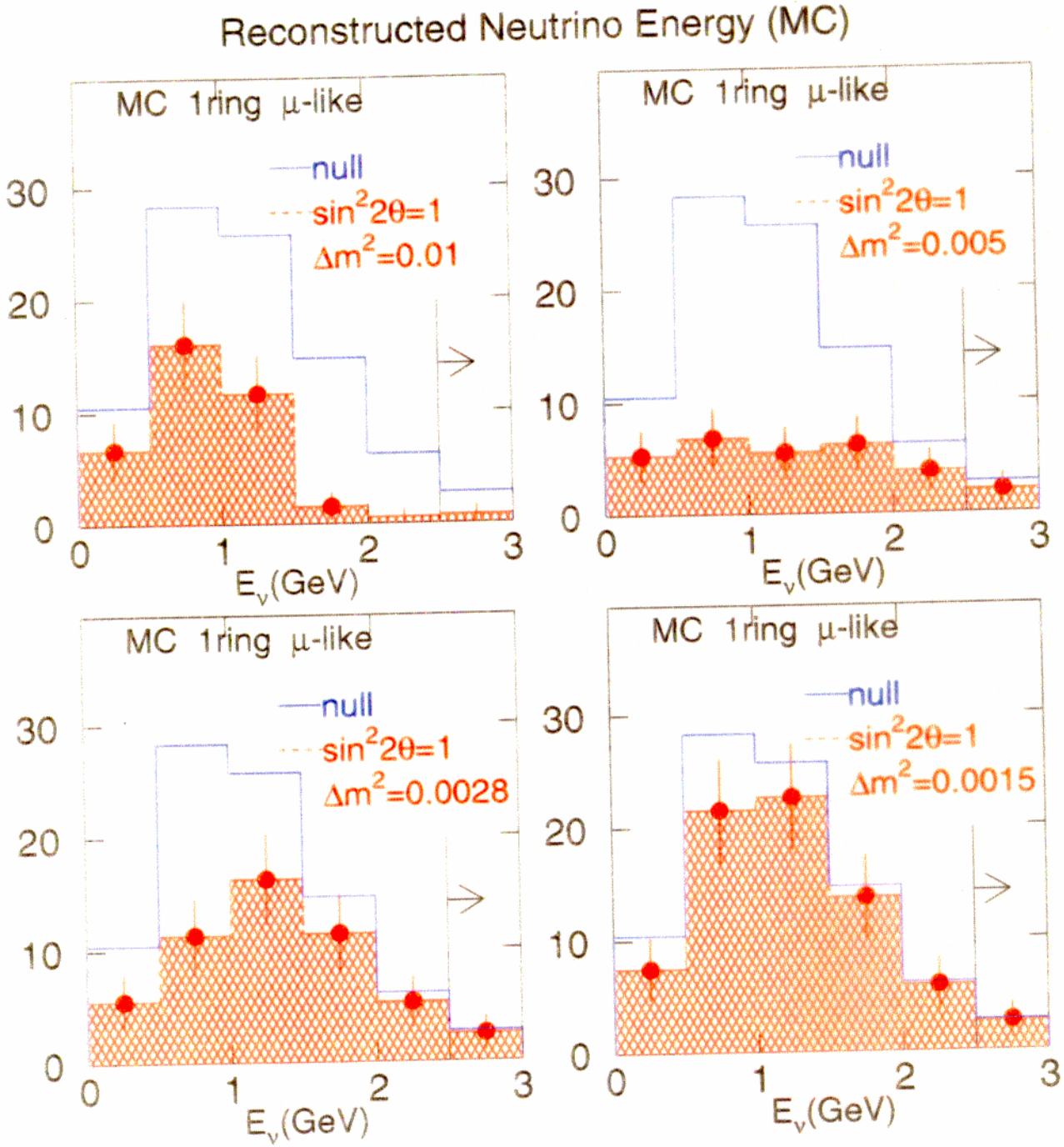
Extrapolation of ν-flux

Monte-Carlo.

★ guaranteed by π-monitor.

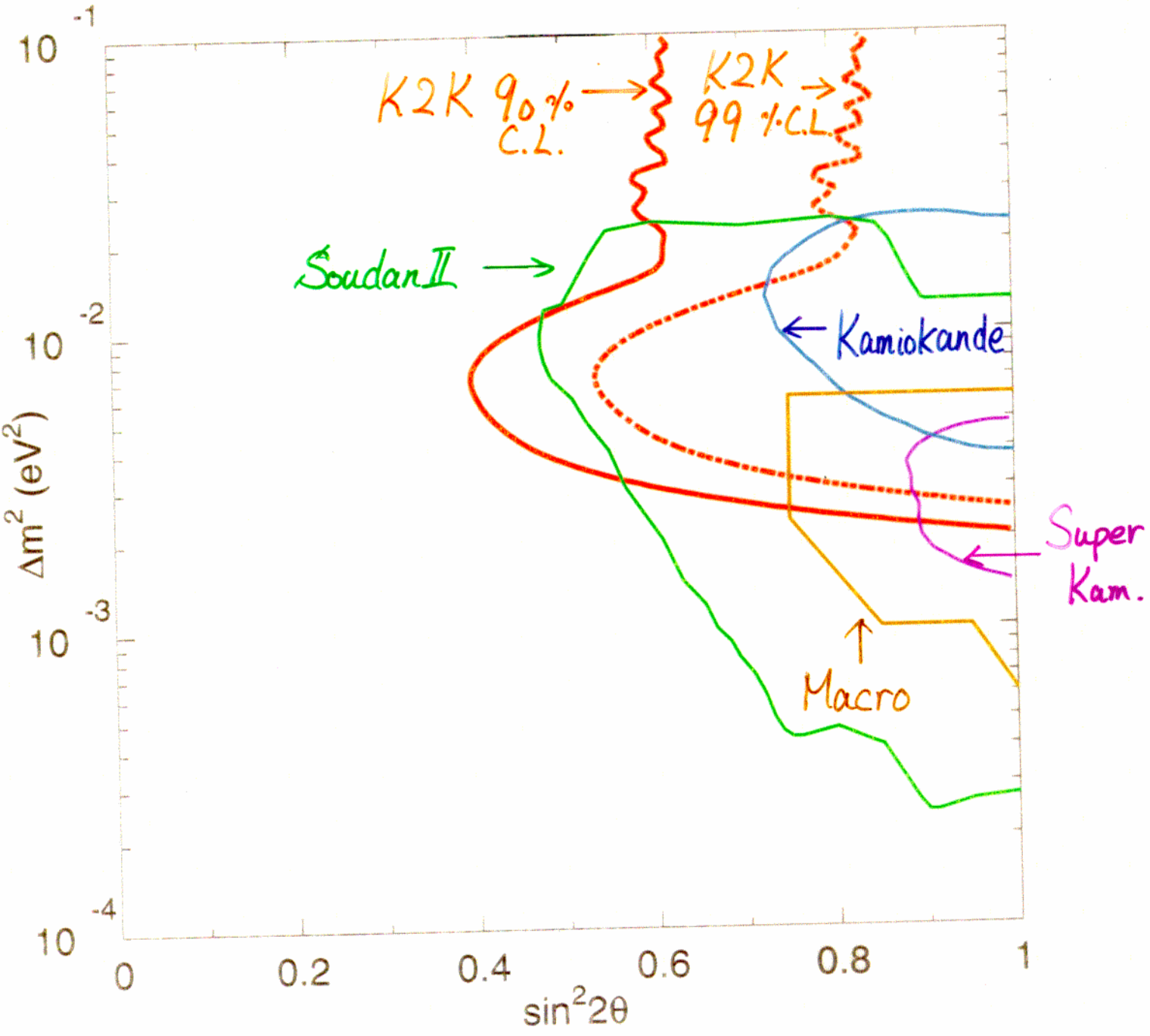
Energy spectrum of ν at Super Kamiokande

10^{20} protons on target



Sensitivity plot of K2K experiment

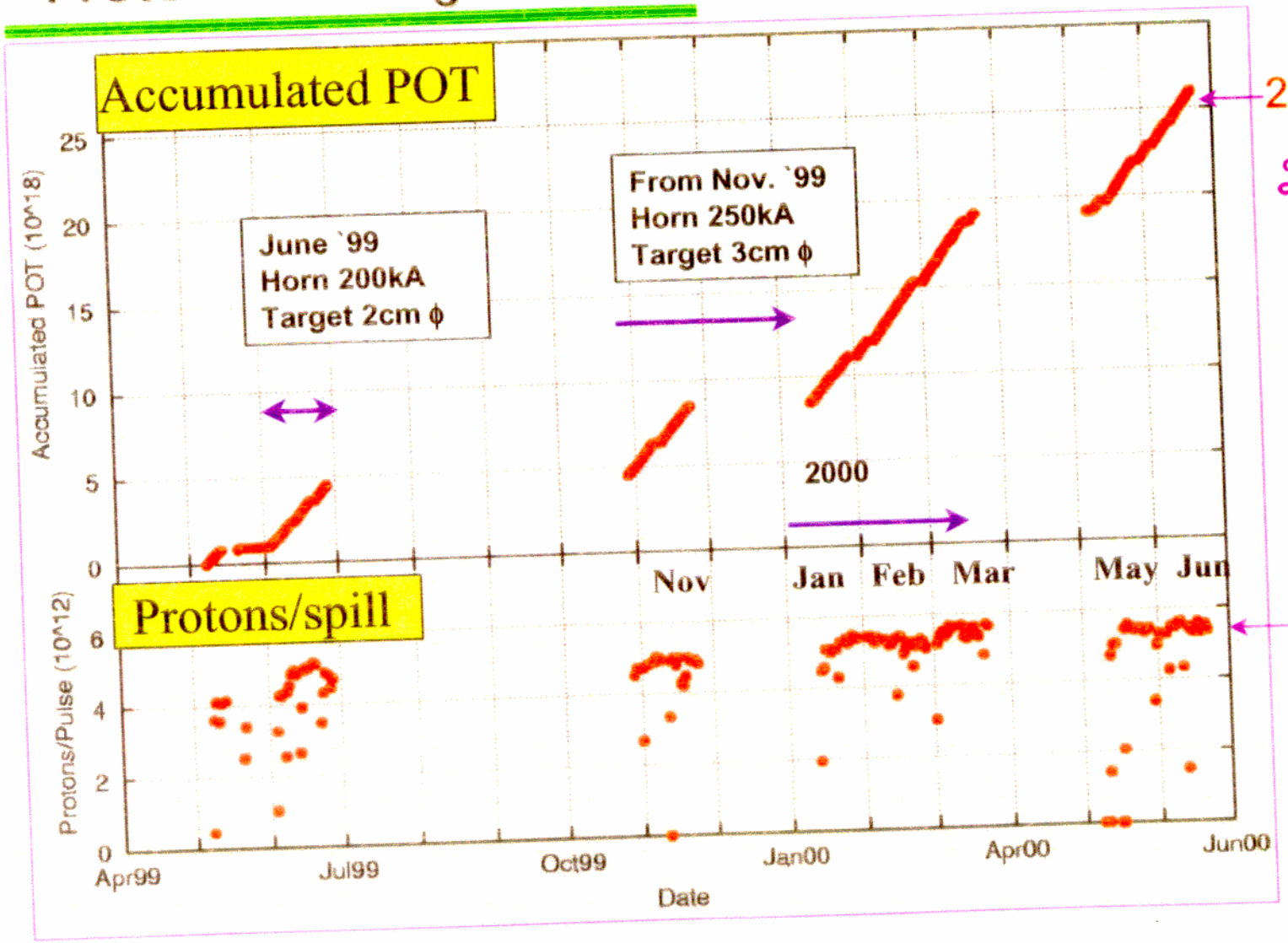
(10^{20} p.o.t.)



2. Results.

Delivered.

Protons on Target (POT)



2.6×10^{19} POT

2.3×10^{19} p.o.t. USEd in the analysis.

5.5×10^{12} protons/spill

π monitor.

Threshold Gas Cherenkov type detector

measure momentum
angular distributions of π.

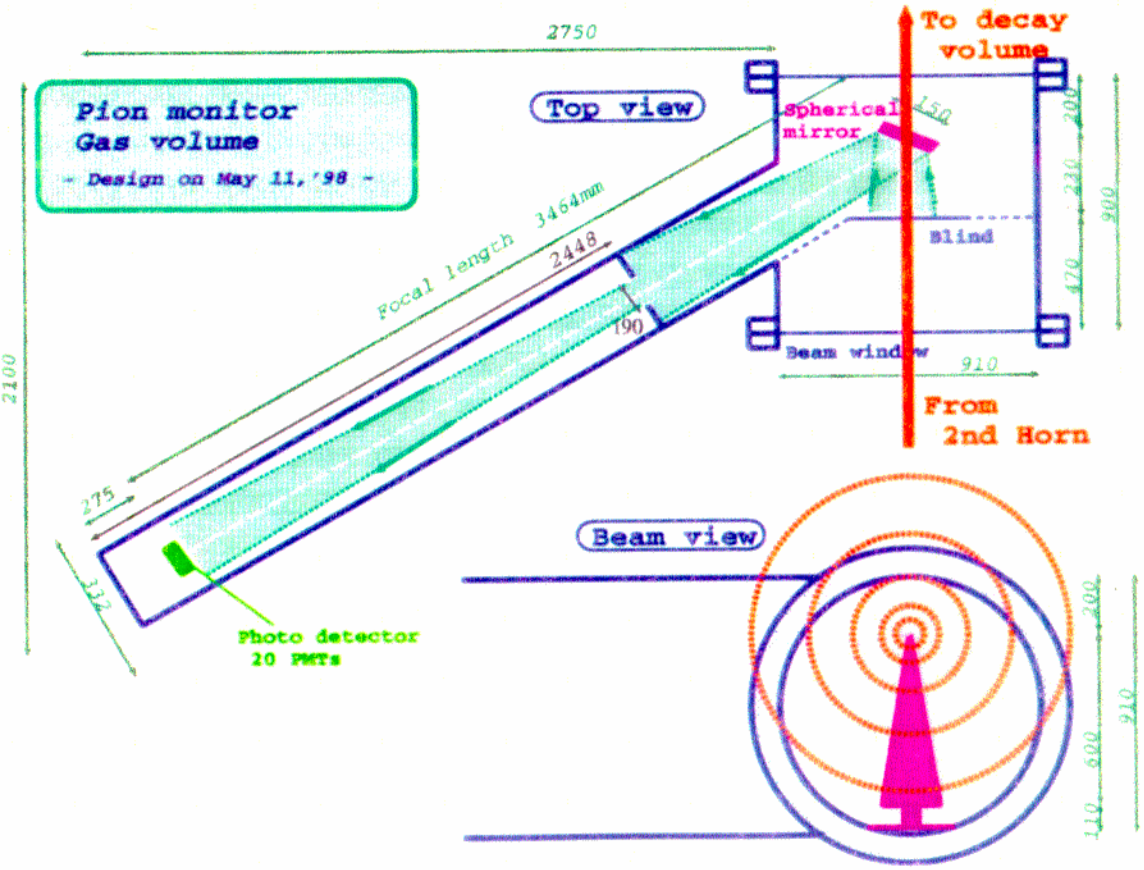
$\Rightarrow$ ν spectrum at front detector & S.K.

ν flux ratio. (Φ_{SK}/Φ_{KEK})

as a function of ν energy

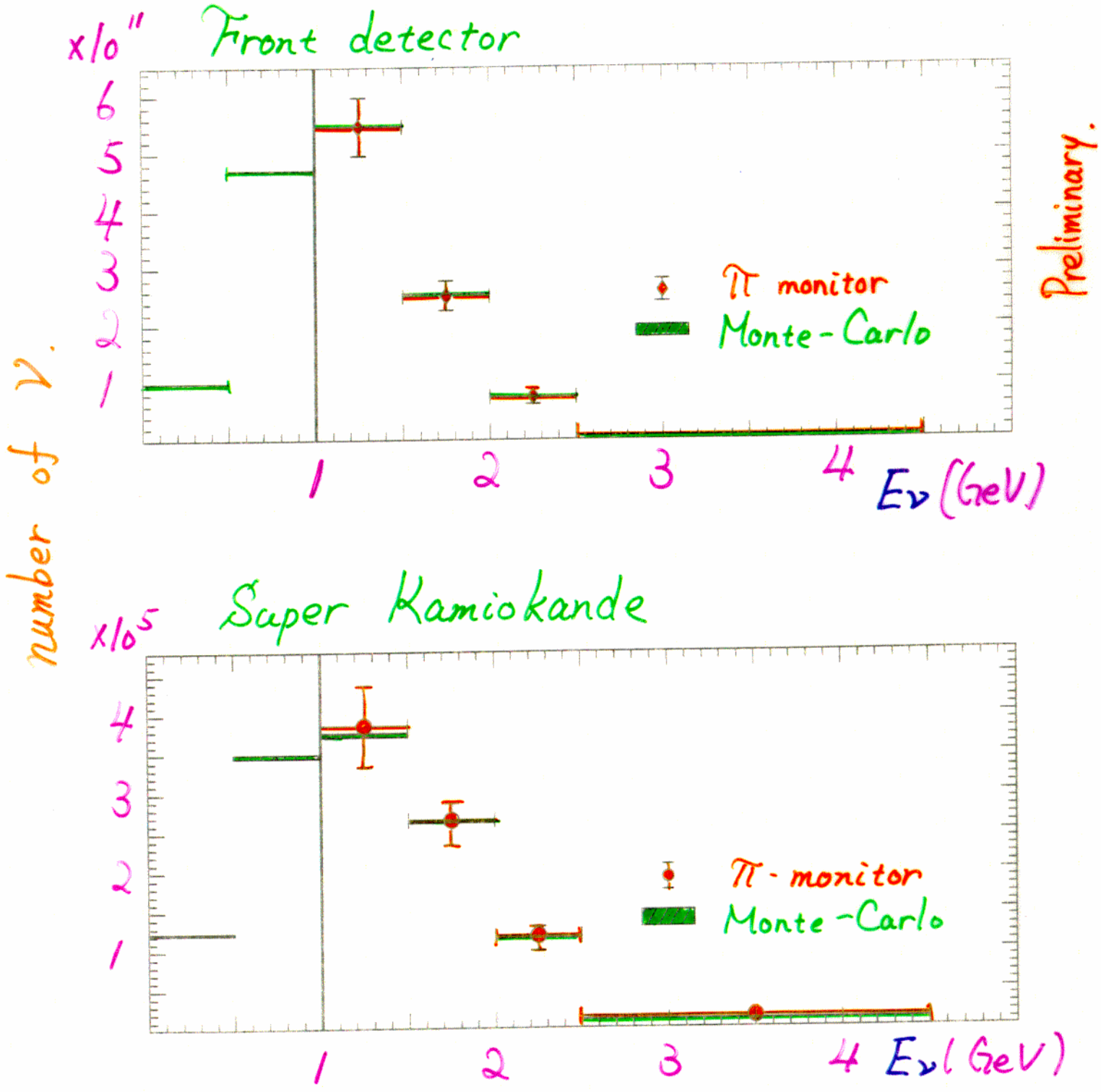
can be predicted.

$(E_\nu \gtrsim 1\ GeV)$



Predicted energy spectrum of ν

π monitor



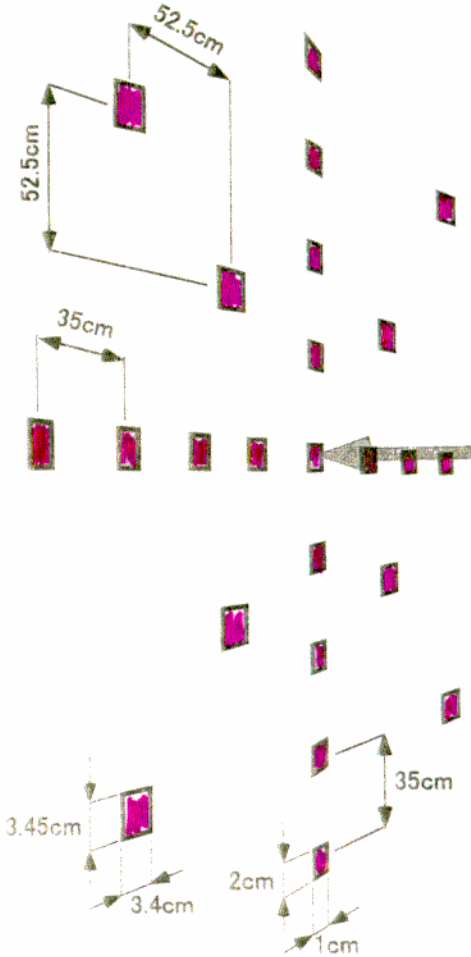
ν-monitor

Large area Ionization chamber
& Si-pad detectors.

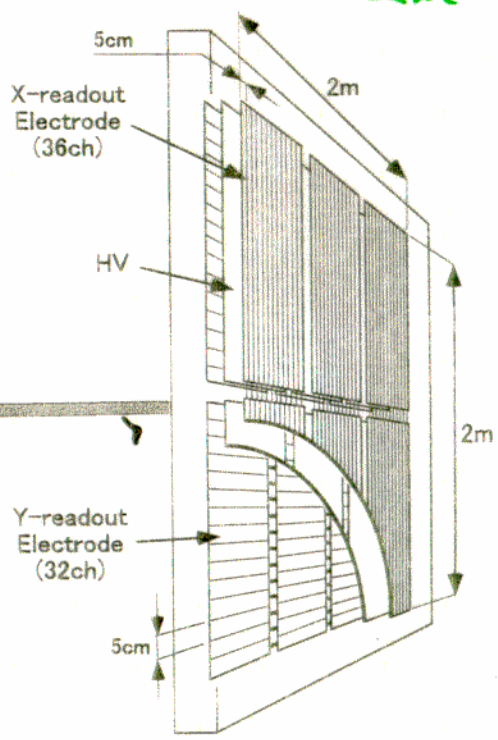
measure profile of ν after beamdump.
spill by spill

$\Rightarrow$ direction of the beam
can be monitored.

Si pad detectors



Ionization chamber
2m x 2m



μ-SPIC

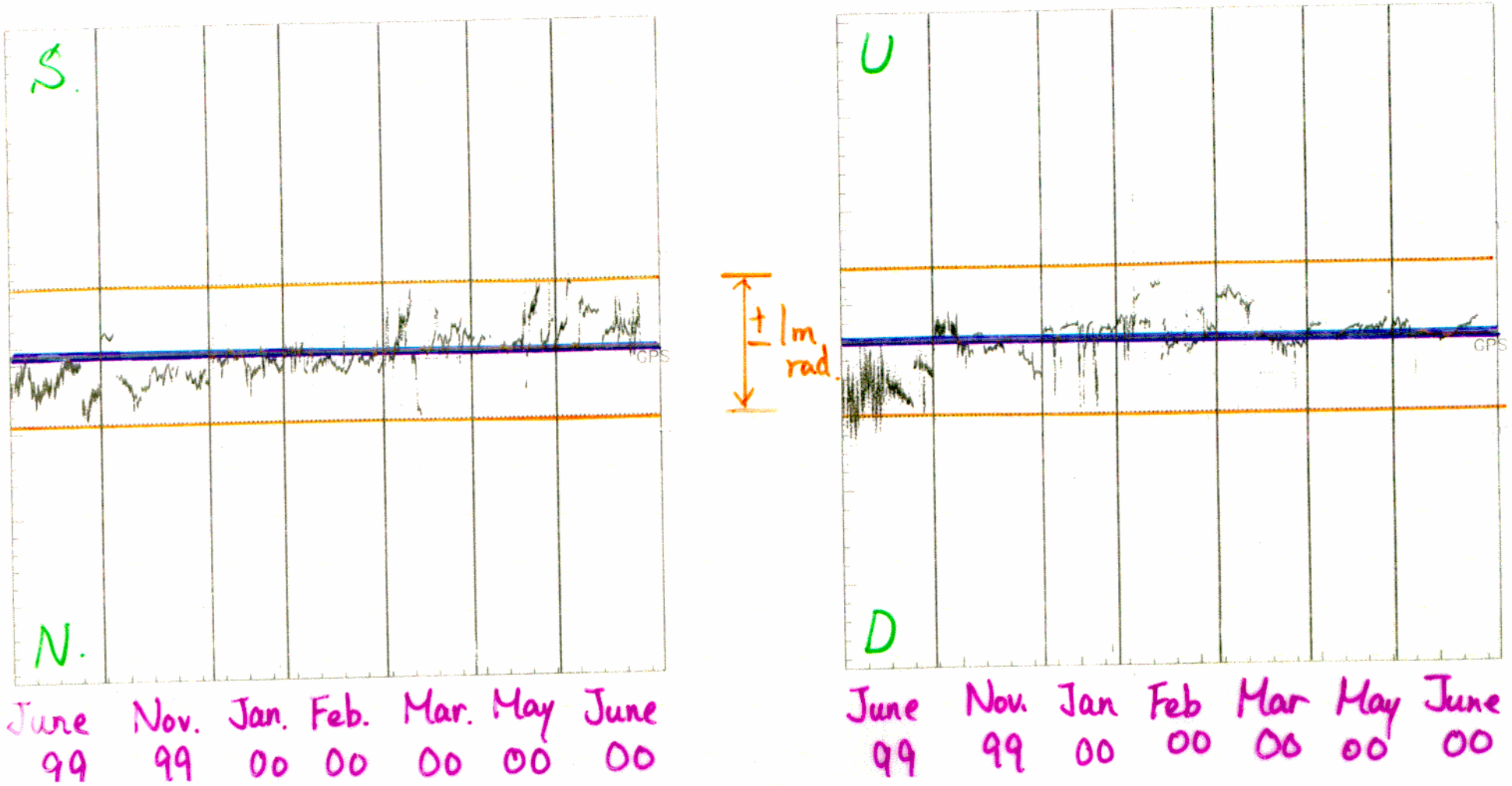
Mu2

Center of ν measured by ν-monitor

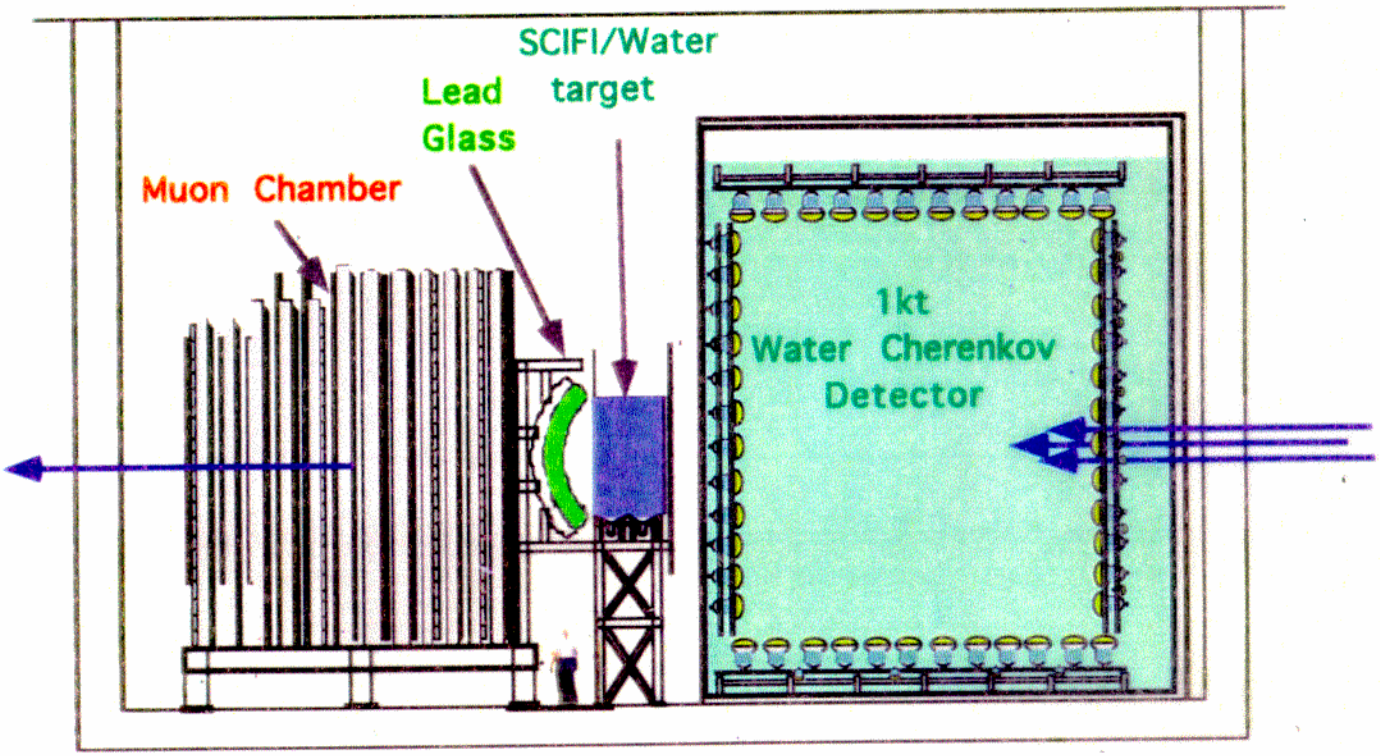
$\Rightarrow$ direction of ν beam.

($E_\nu \gtrsim 5.5$ GeV.)

—: GPS Center —: $\pm$ 1 m rad.



Front ν detectors.



1 kt water Cherenkov detector.

680 20inch PMTs.

Fid. mass ~ 50 tons. ($r < 2m$)

measure eventrate at KEK.

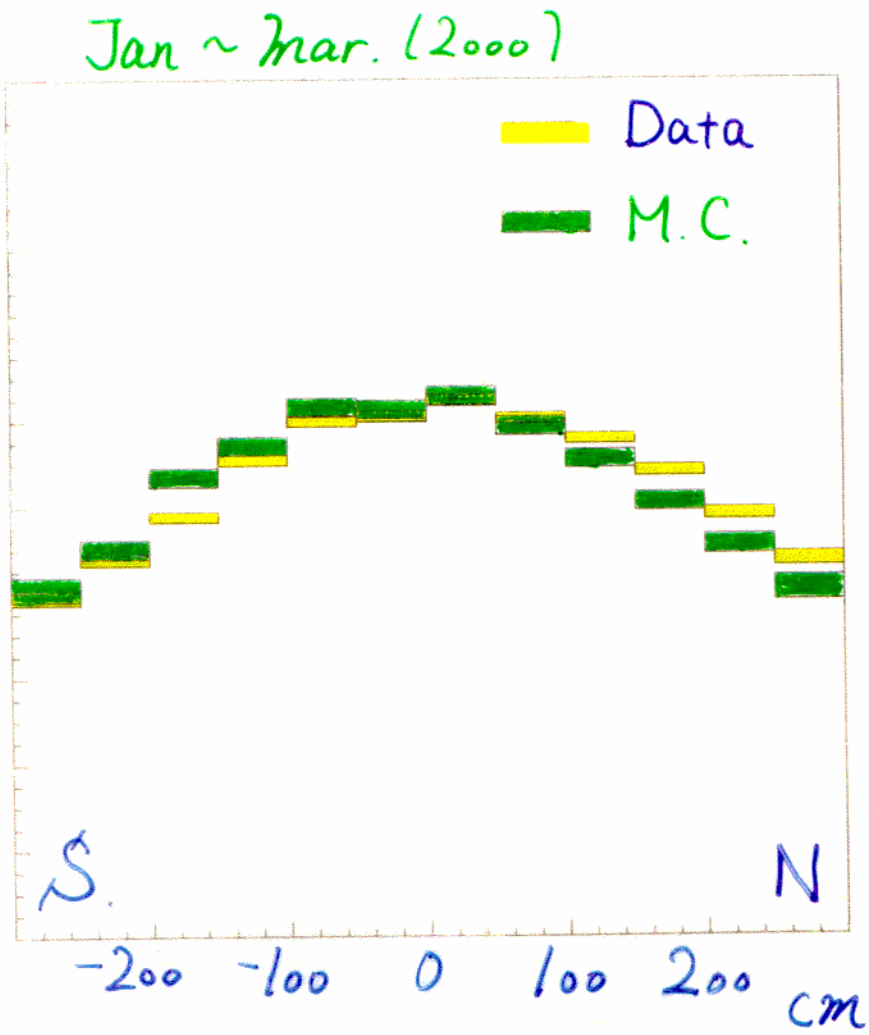
↓

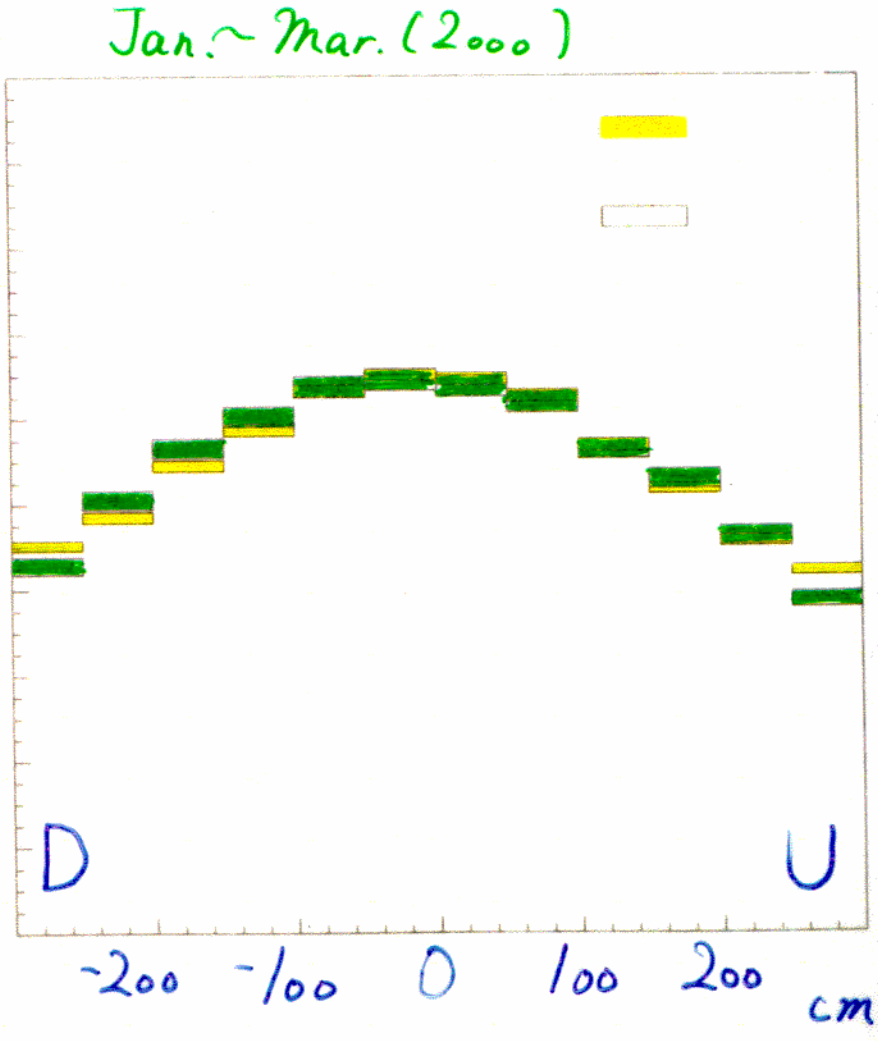
absolute flux estimation.

☆ Same type of the detector as S.K.

→ Small systematic errors.

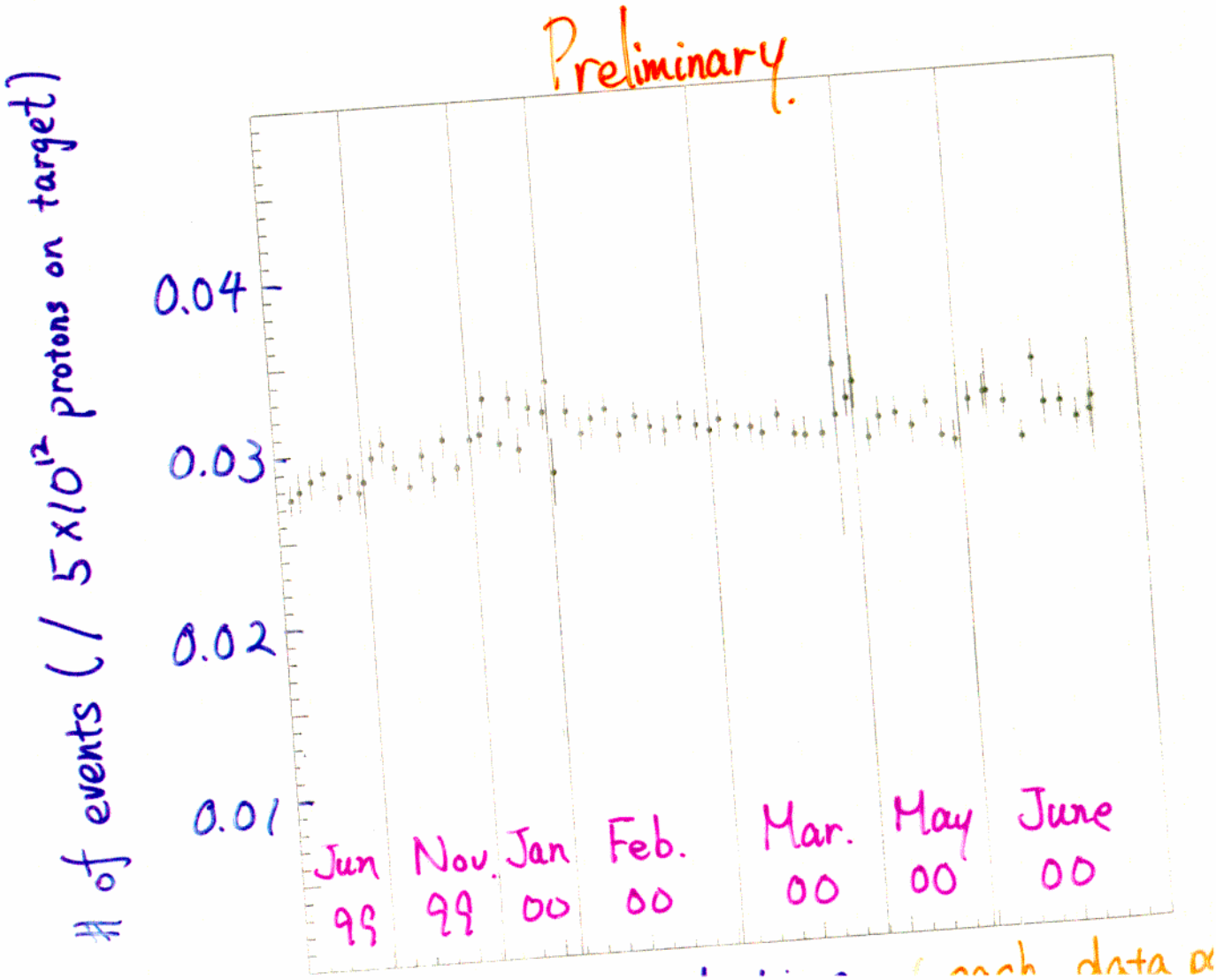
ν profile (1kt water Cherenkov detector)





Stability of event rate (1/kt water Cherenkov detector)

⇒ Estimate expected # of events @ S.K.
(normalization)



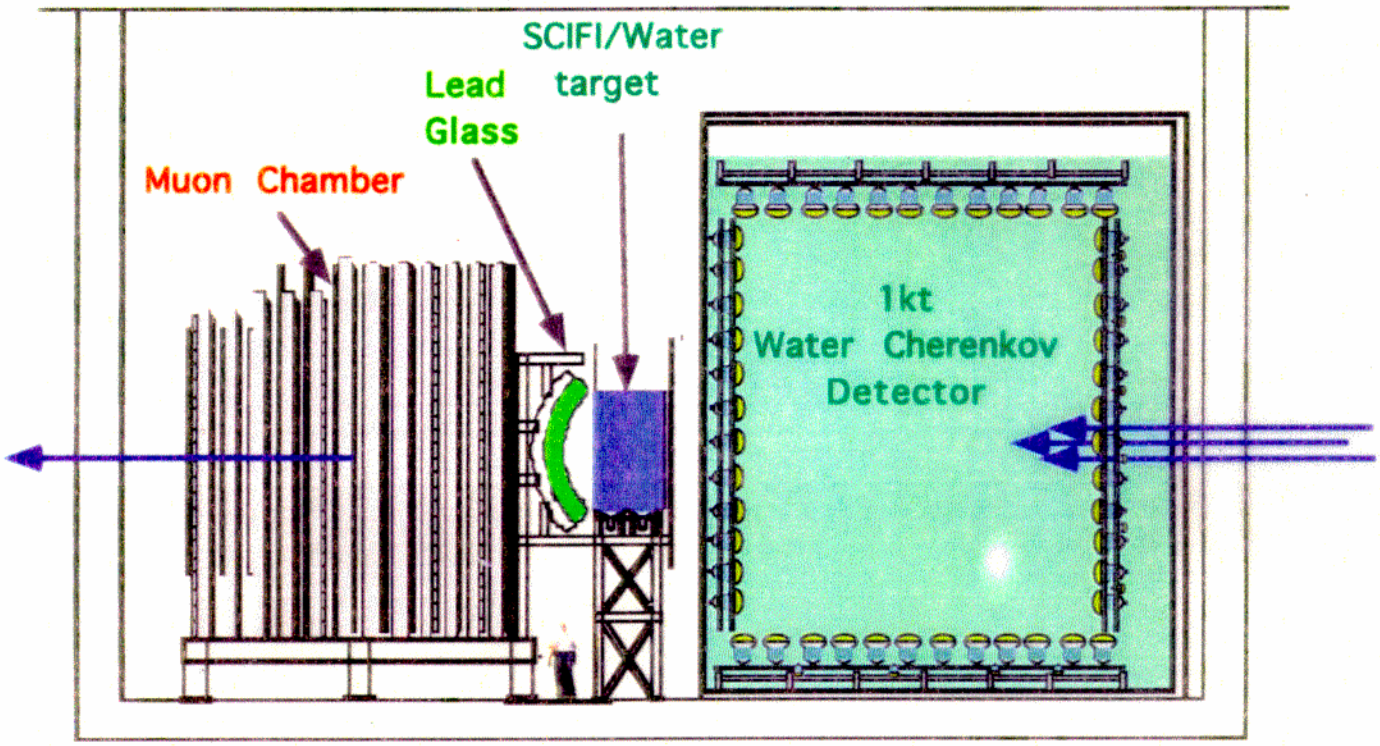
Expected number of events @ Super-Kamiokande

$$N_{SK} = N_{FD} \times \frac{\eta_{SK}}{\eta_{FD}} \times \frac{M_{SK}}{M_{FD}} \times \frac{L_{SK}}{L_{FD}}$$

N_{FD}	Number of observed ν events @ Front detector(s)
$\frac{\eta_{SK}}{\eta_{FD}}$	Far/Near event ratio. $\eta \equiv \int \phi \times \sigma \times \varepsilon \, dE_\nu$
	ϕ: flux
	σ: cross-section
	ε: detection efficiency
$M_{SK,FD}$	Fiducial masses of SK and F.D.
$L_{SK,FD}$	Used 'Protons of Target' of S.K and F.D.

$$\Longrightarrow \quad N_{SK} = 40.3 \, {}^{+4.7}_{-4.6} \text{ (events.)}$$

Front ν detectors.



ν-drift chamber

12 layers of Fe plates. (10cm x 4layers
+ 20cm x 8 layers)

Fid. mass ~3/2 tons. ($r < 3$ m)

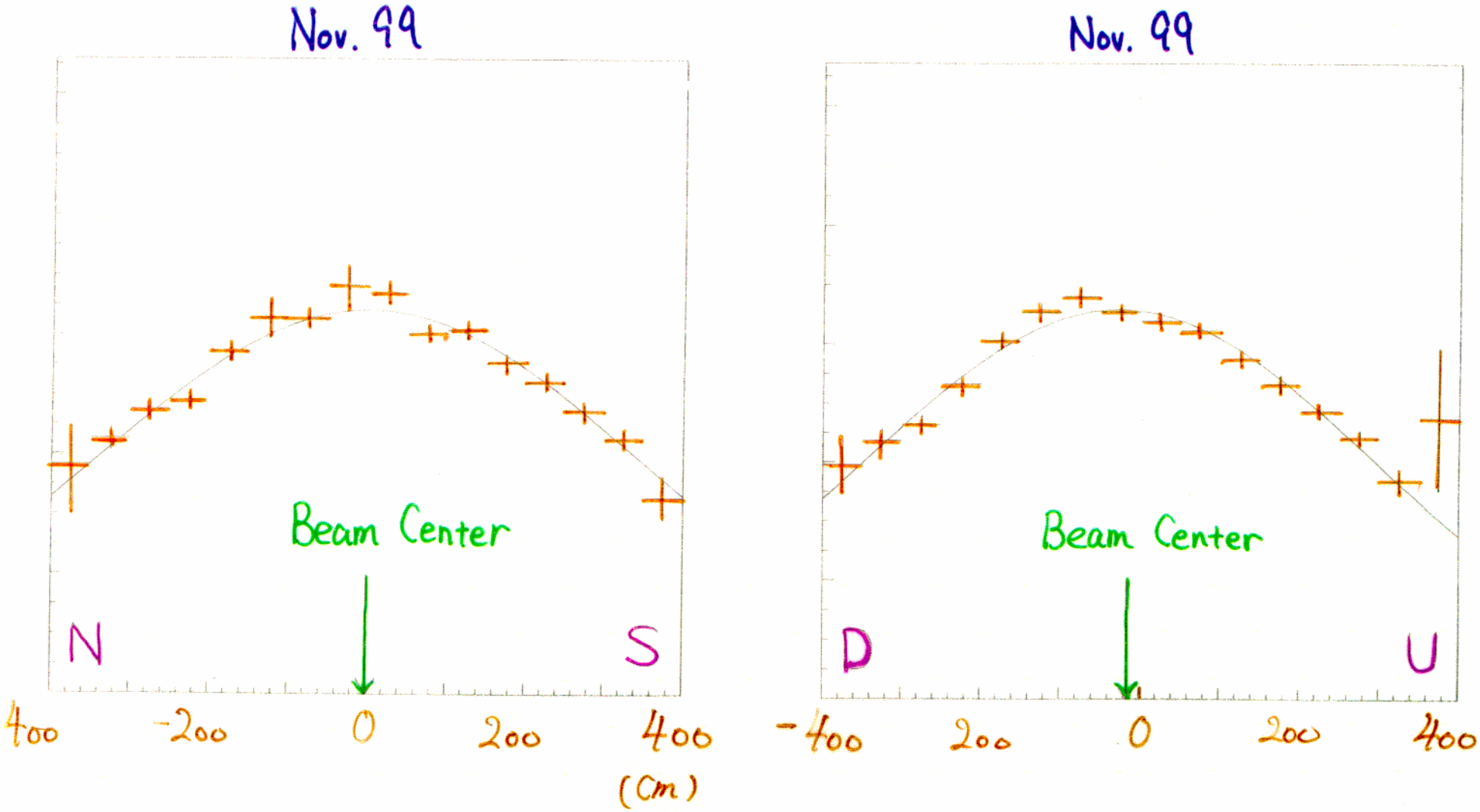
measure profile of ν directly at KEK

momentum & angle of ν from charged current ν int.

eventrate

High stat. → monitor Stability of ν beam.

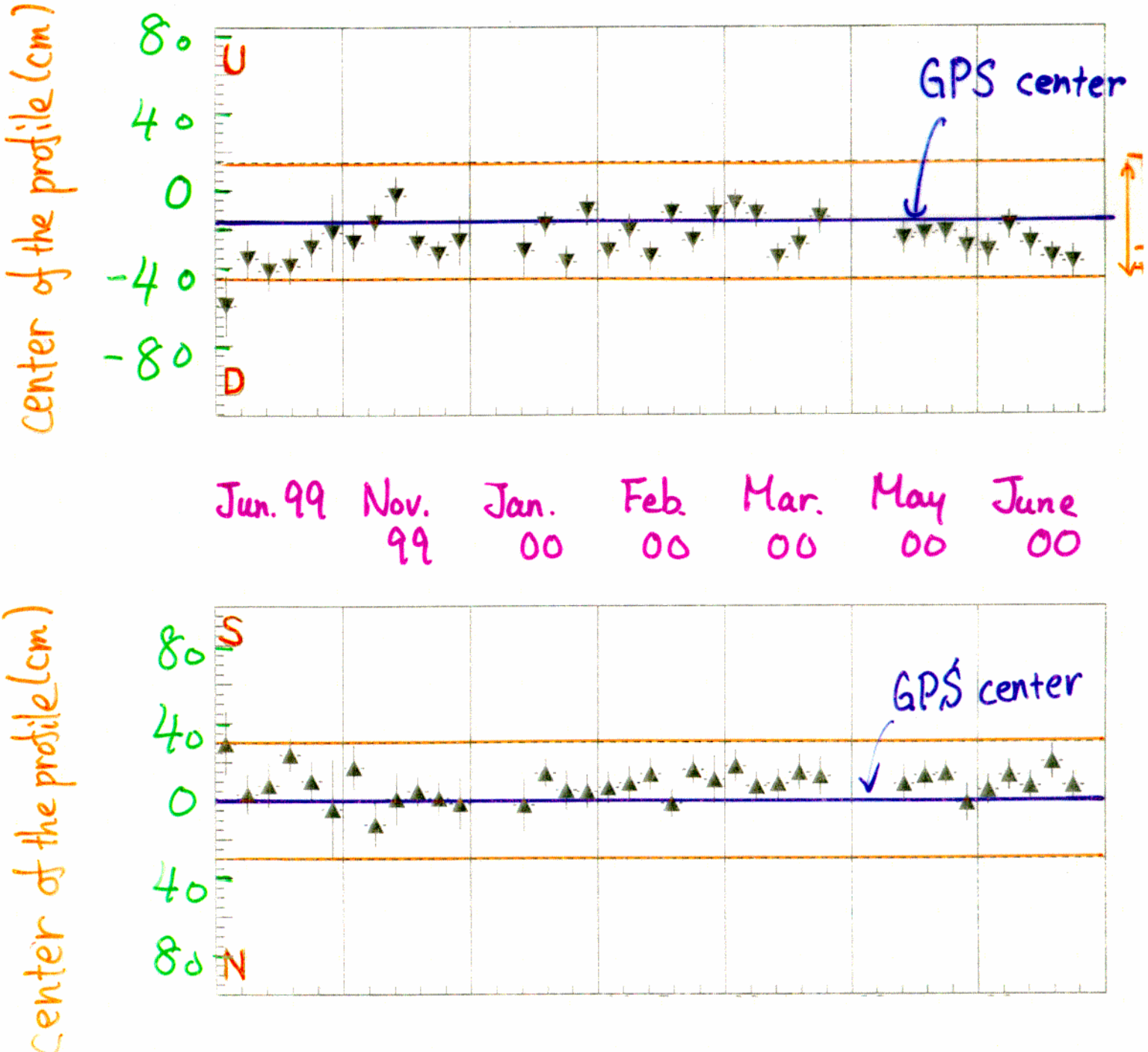
ν profile (μ-drift chamber)



Stability of ν profile (ν-drift chamber)

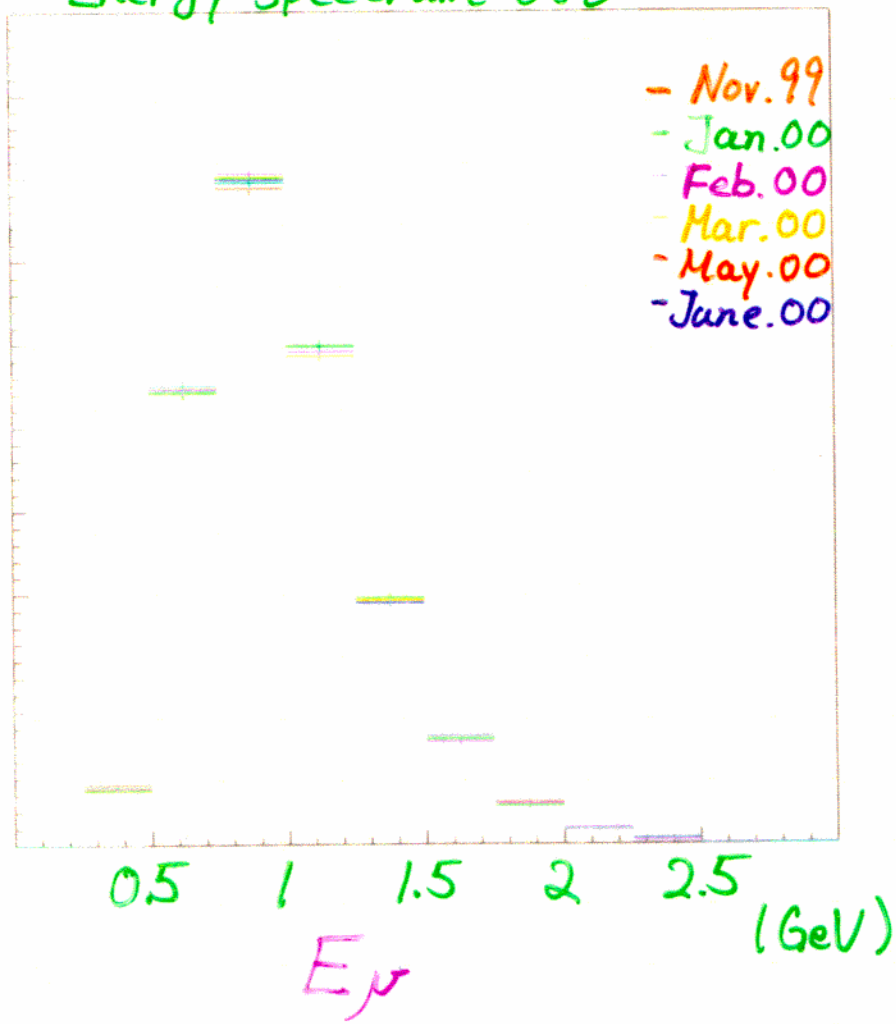
within 1m rad.

confirmed by γ interactions.

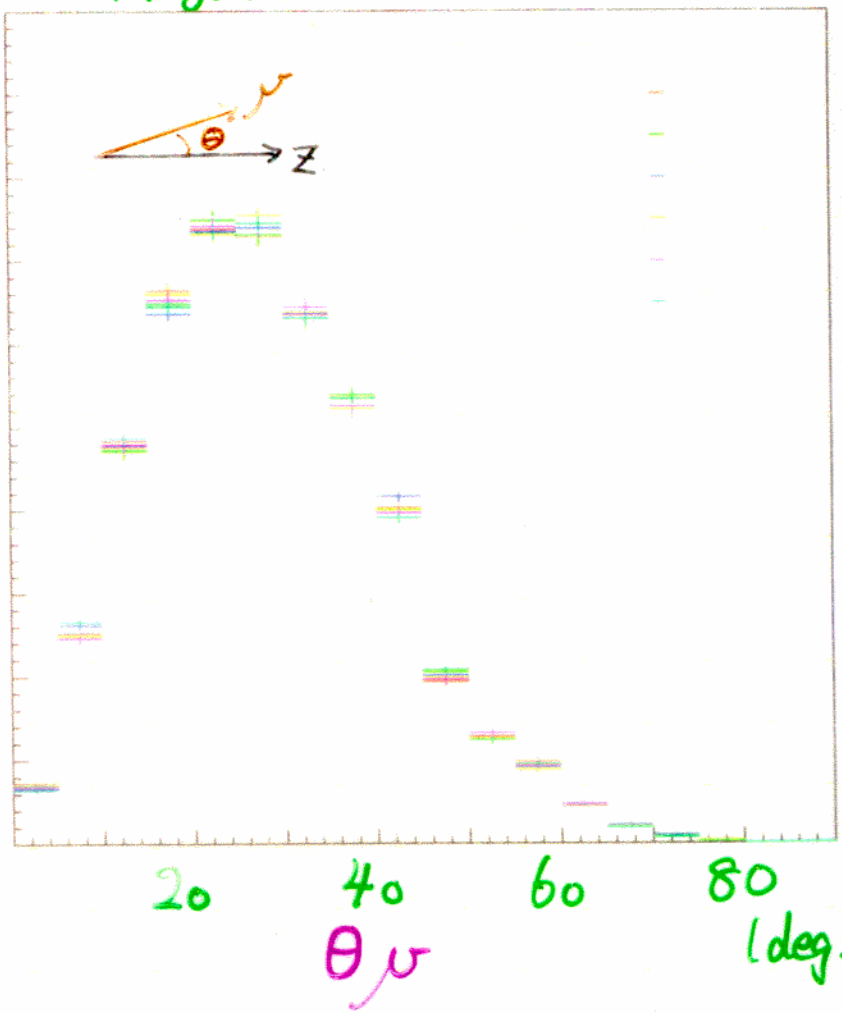


Stability of momentum and angular distributions of ν-induced μ. (μ-drift chamber)

Energy spectrum of ν



Angular distribution

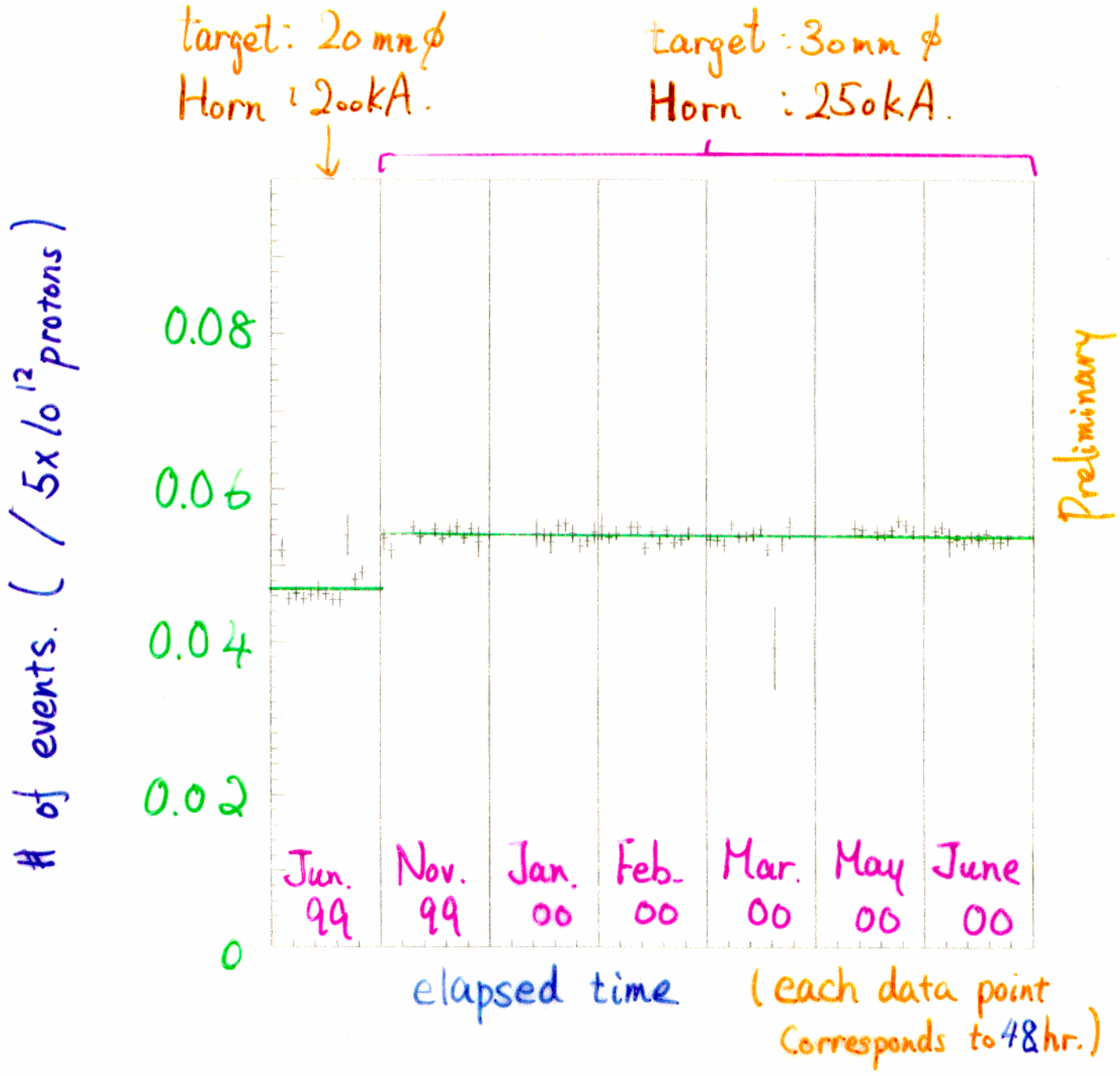


Stability of ν induced event rate

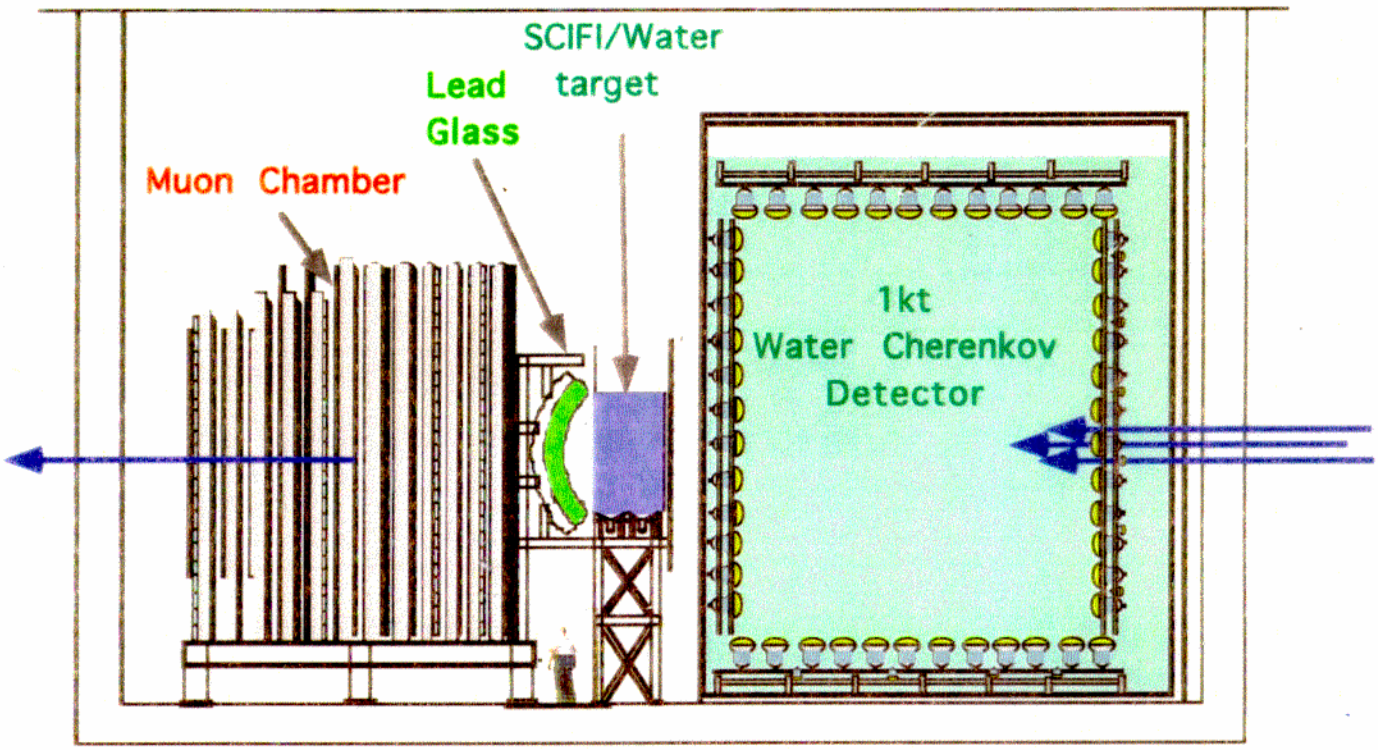
(ν-drift chamber)

$\Rightarrow$ Very stable.

confirmed by ν interactions.



Front ν detectors.



Scintillating fiber tracker

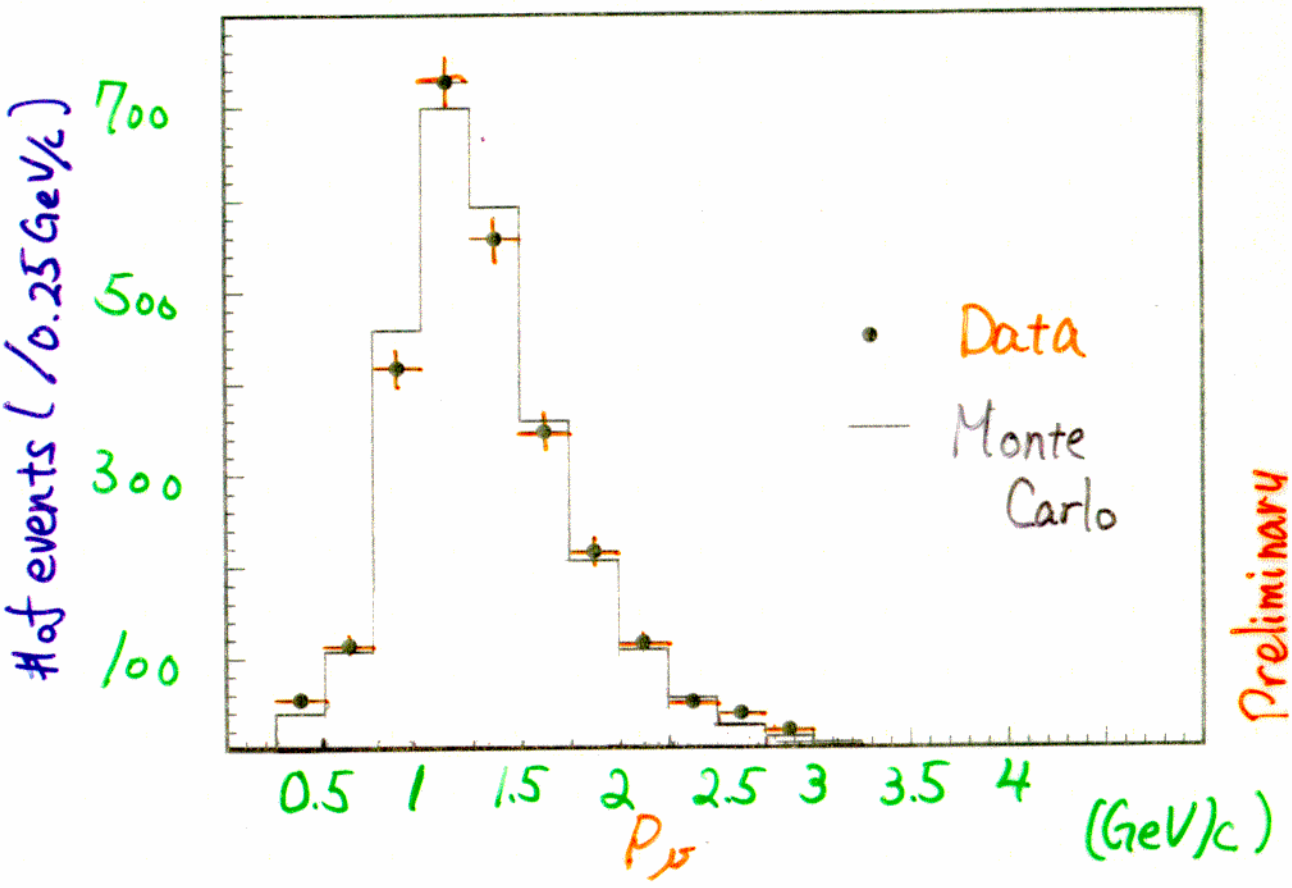
19 layers of water containers. (6cm/layer)

20 layers of Scintillation fiber planes.

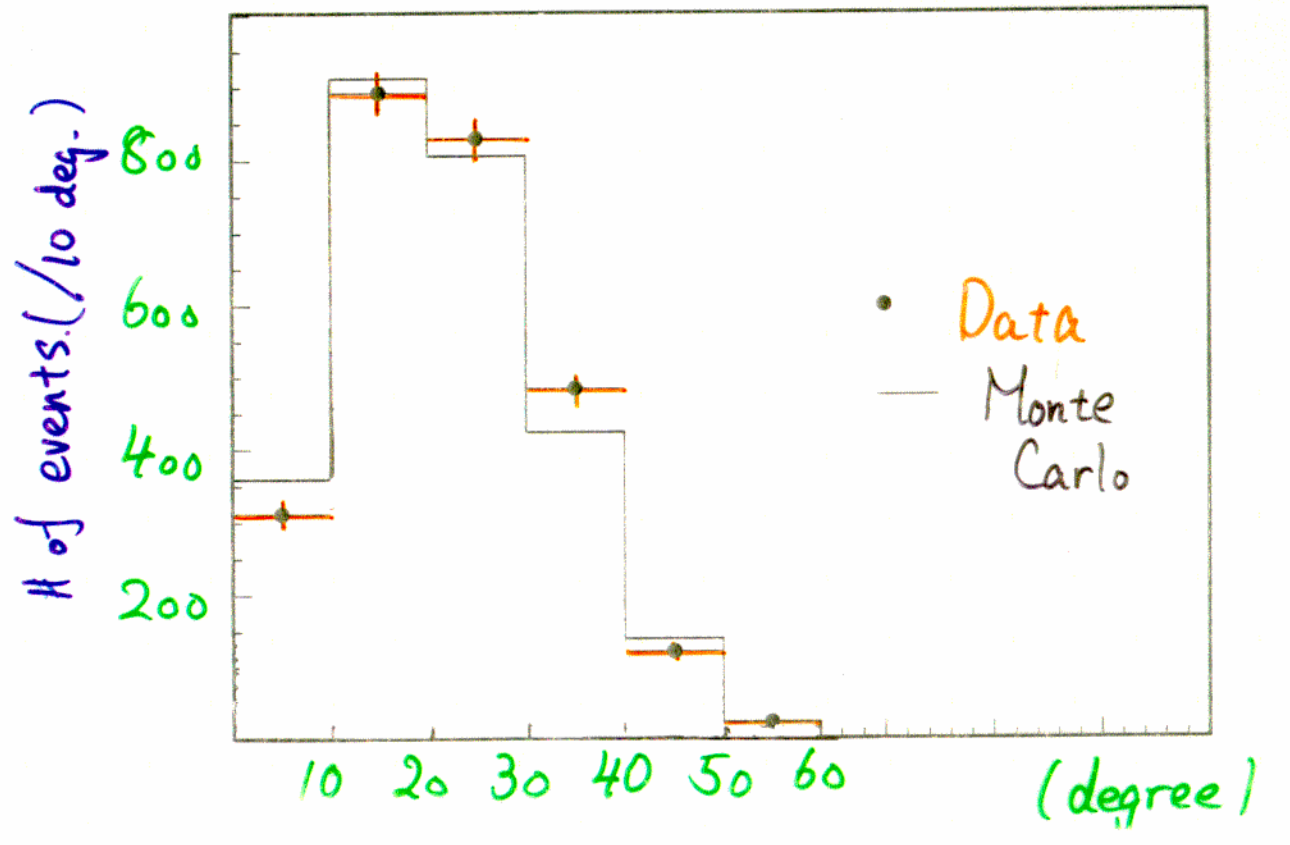
Fid. mass ~ 5 tons. ($r < 1m$)

- Fine vertex resolution. ($\leq 1mm$)
- H_2O target. → Independent measurements of ν-H_2O interactions.
- Multiple tracks can be observed.

Reconstructed momentum and angular distribution of ν. (Sci-fi tracker with ν drift chamber



Nov. 99 ~ June. 06

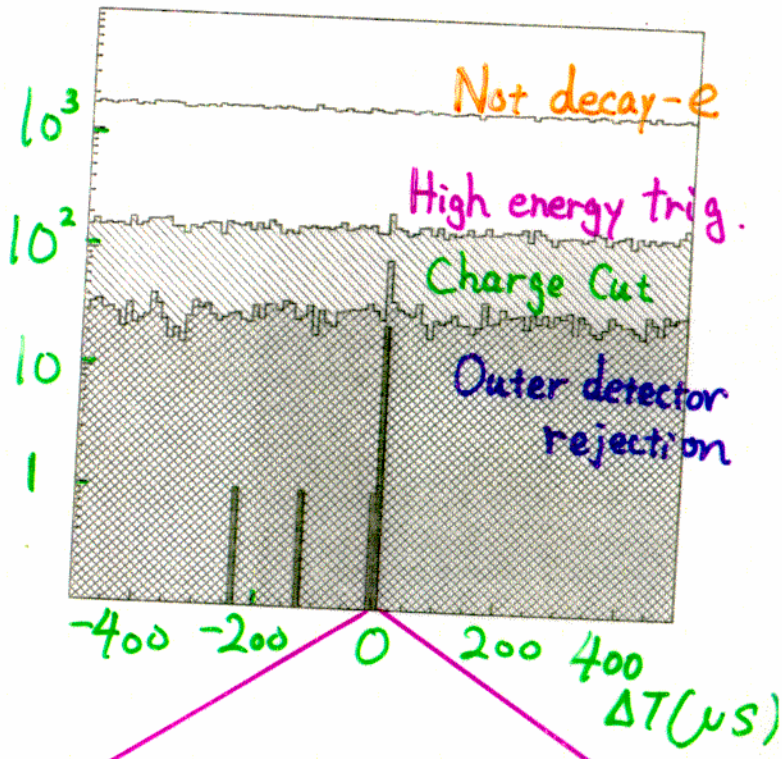


Event reduction at Super-Kamiokande

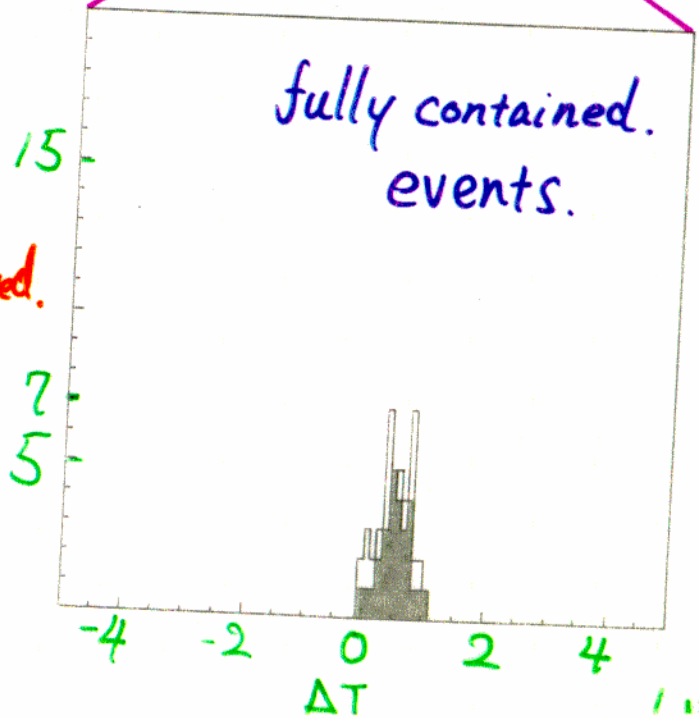
Use GPS timing information
to select candidate events.

$$\Delta T \equiv T^{GPS}_{SK} - T^{GPS}_{KEK} - TOF(KEK \cdot SK)$$

Require
$-0.2 < \Delta T < 1.3$ (μs)

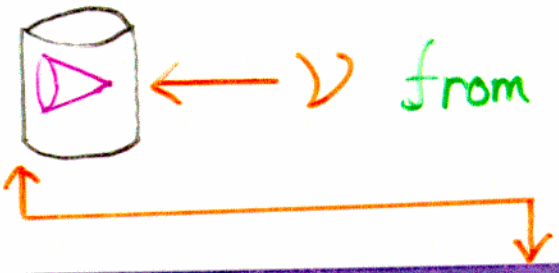


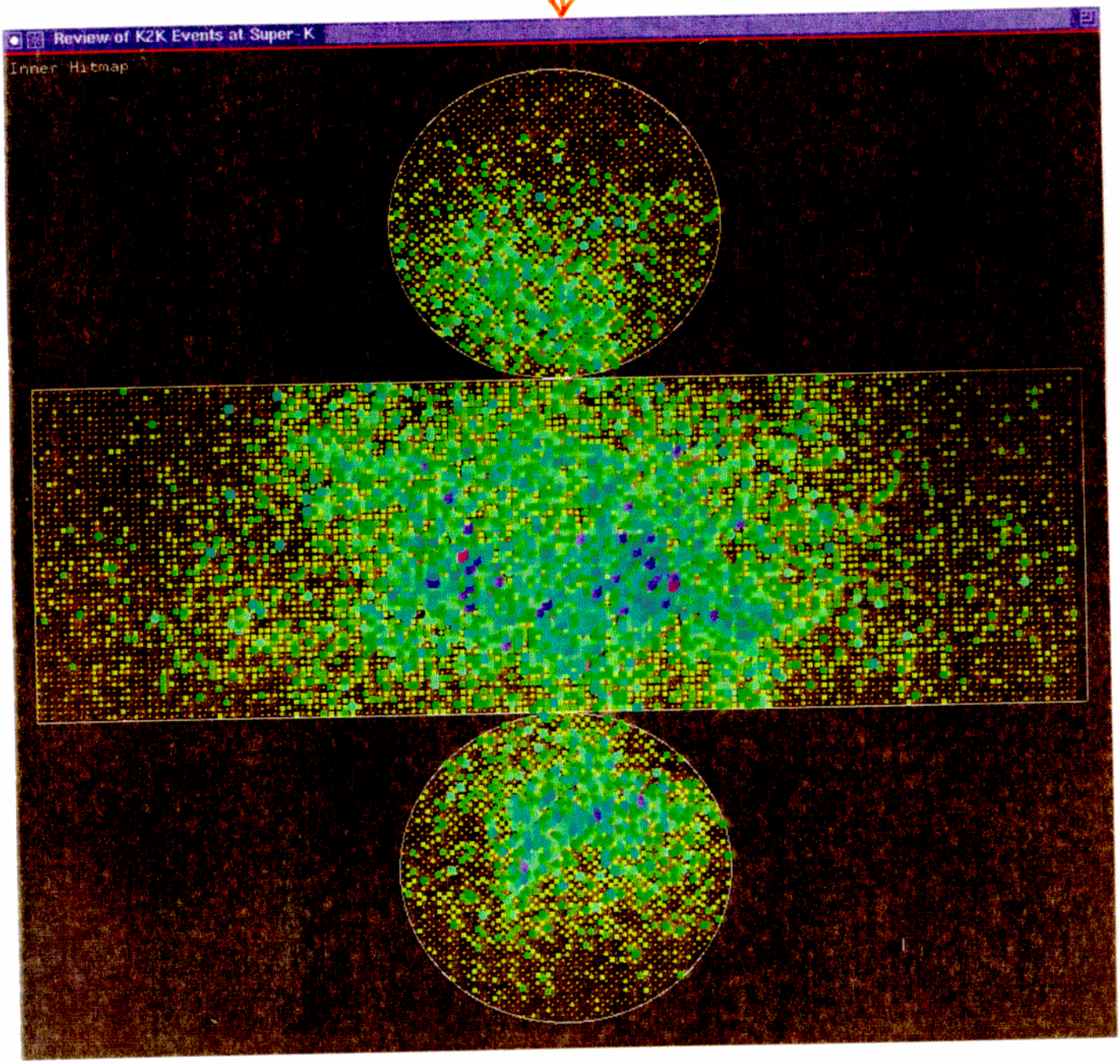
27 Fully contained in-Fiducial volume events are observed.



Integrated Charge of K2K events.

at Super-Kamiokande

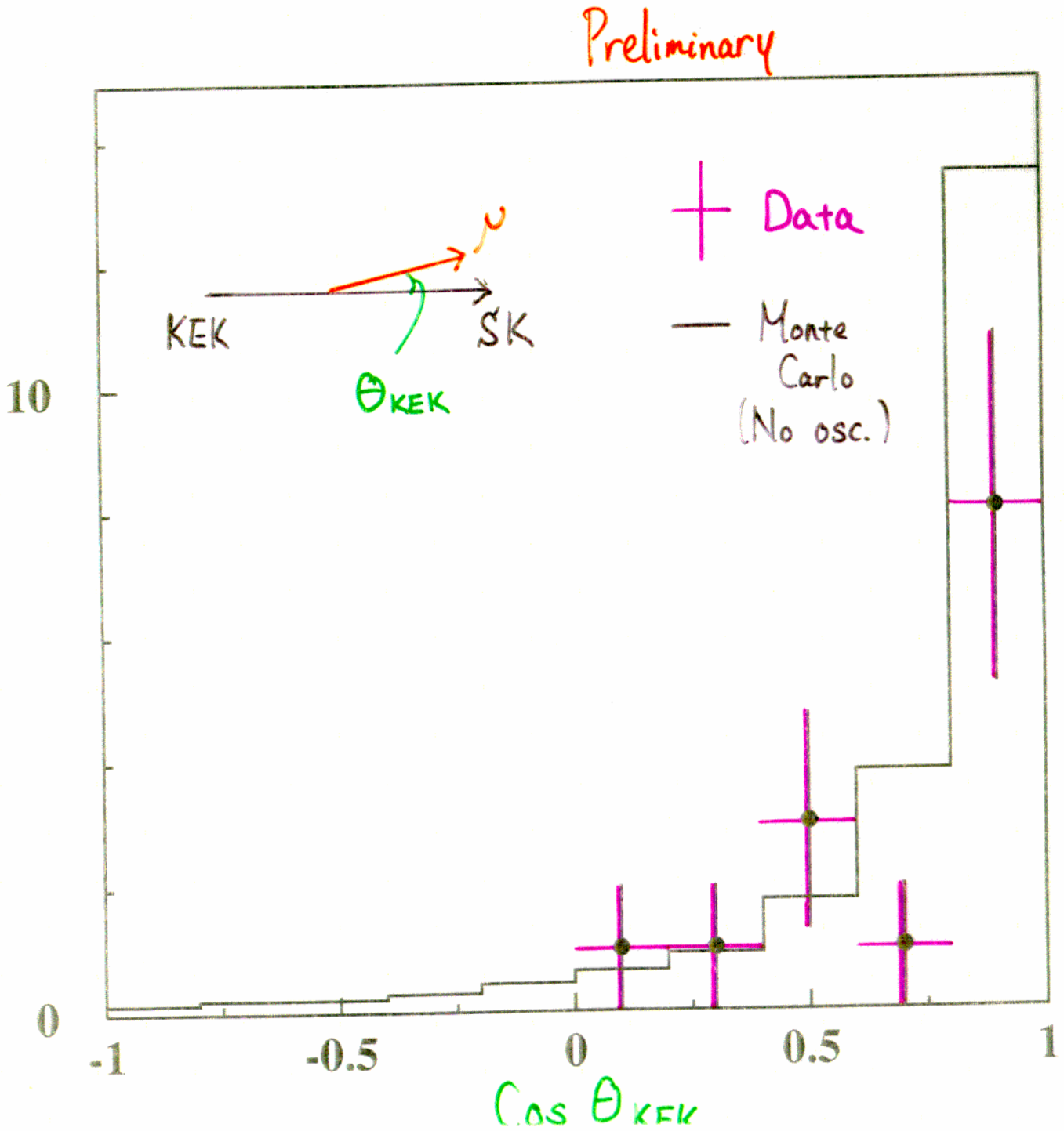




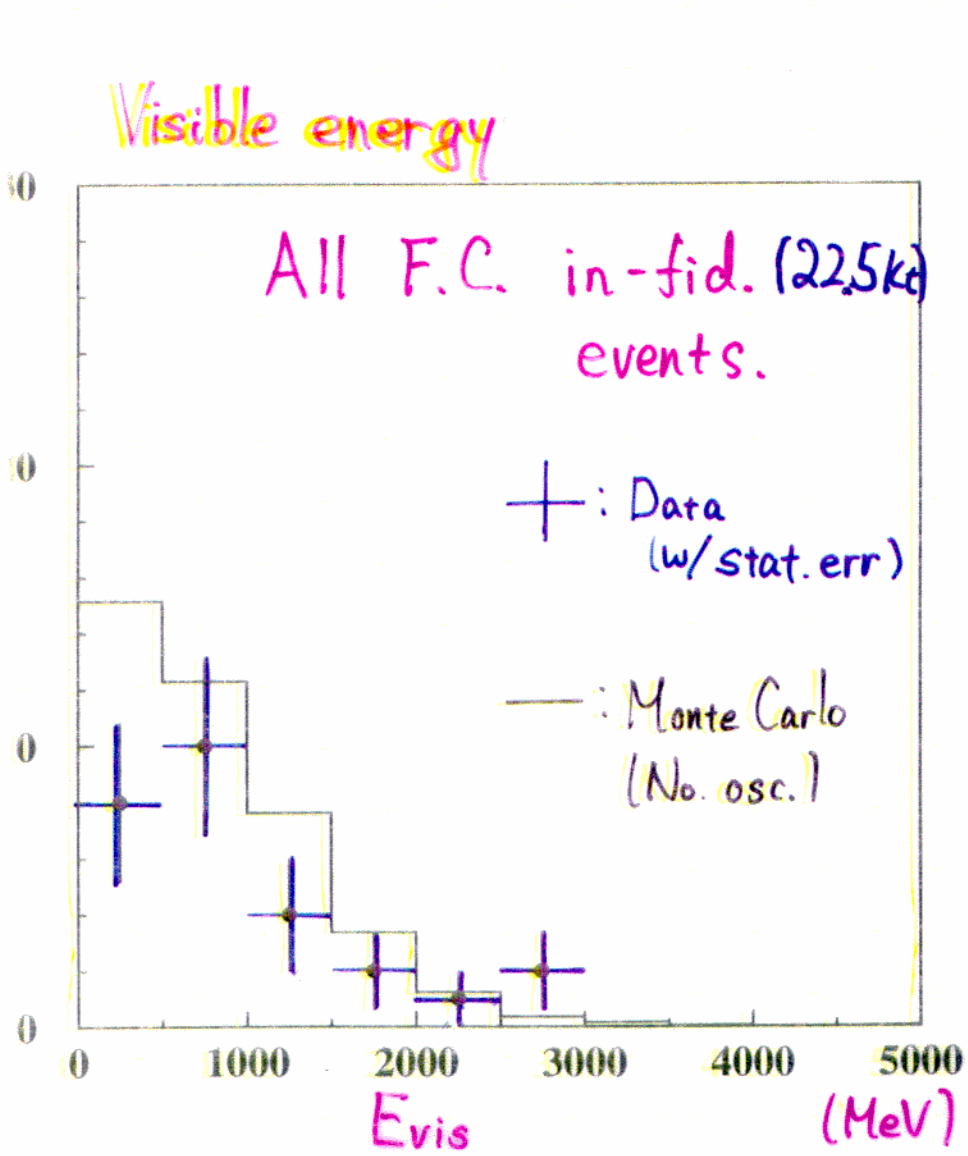
Reconstructed direction of ν (Super-Kamiokande)

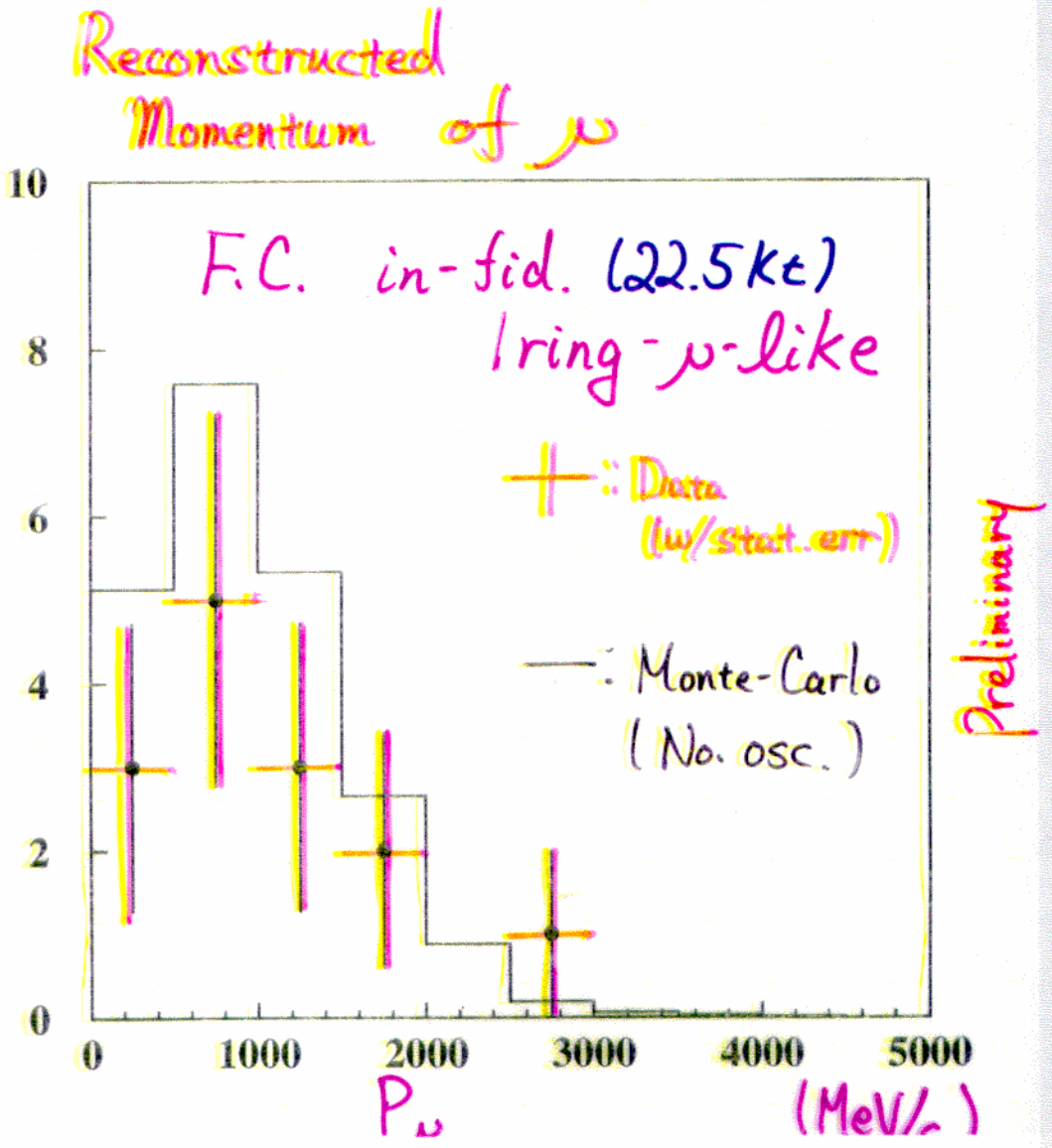
vertex inside the fiducial volume (22.5Kt)

1 ring, ν-like events.



Visible energy & reconstructed momentum of ν (Super Kamiokande)





of observed events and expected events 1999/06-2000/06

	Obs.	Exp.	$\Delta m^2(\times 10^{-3} eV^2)$ 3	5	7
FC 22.5kt	27	$40.3\ ^{+4.7}_{-4.6}$	$26.6\ ^{+3.4}_{-3.3}$	$17.8\ ^{+2.3}_{-2.2}$	$14.9\ ^{+1.9}_{-1.9}$
1-ring	15	24.3±3.6	14.4±2.3	9.4±1.5	8.6±1.4
μ-like	14	21.9±3.5	12.4±2.1	7.5±1.3	6.8±1.2
e-like	1	2.4±0.5	2.1±0.4	1.9±0.4	1.8±0.4
multi ring	12	16.0±2.7	12.2±2.1	8.4±1.5	6.3±1.1
out-of-FV	16	17.2	11.2	7.6	6.7

3. Summary.

ν beam 2.3×10^{19} p.o.t.

- direction < 1 mrad.
  - confirmed by ν-monitor
  - and ν profile
- spectrum
  - Monte-carlo expectations
  - confirmed by π-monitor.
  - Good agreements with ν-detectors.
- eventrate
  - Consistent results from
  - 3 front detectors.
- time variations of ν profile & spectrum
  - → Very stable
  - checked by ν-drift chamber

GPS system (timing)
checked with Atomic clock.

Expected # of events @ Super Kamiokande

$40.3^{+4.7}_{-4.6}$

Observed # of events @ Super Kamiokande

27 (Fully contained in-fid. volume)

$\Rightarrow$ 2σ off from expected # of events.

We will start the next run from Jan. 2001.!!

Tokyo U., ~~ICRR~~ ICRR
S. Fukuda, Y. Fukuda, M. Ishitsuka, S. Ishizuka, Y. Itow, T. Kajita, J. Kameda, K. Kaneyuki, K. Kobayashi, Y. Koshio, M. Miura, S. Moriyama, M. Nakahata, S. Nakayama, Y. Obayashi, A. Okada, N. Sakurai, M. Shiozawa, Y. Suzuki, H. Takeuchi, Y. Takeuchi, Y. Totsuka, S. Yamada
KEK, Tsukuba
Y. Hayato, T. Ishida, T. Ishii, H. Ishino, E.J. Jeon T. Kobayashi, S.B. Lee, K. Nakamura, Y. Oyama, H. Park, M. Sakuda
Kobe U.
S. Aoki, K. Fujii, T. Hara, T. Iwashita, M. Kohama, G. Kume, M. Onchi, T. Otaki, K. Satoh, A. Suzuki, M. Takatsuki, K. Takenaka, Y. Tanaka
Kyoto U.
T. Inagaki, I. Kato, S. Mukai, T. Nakaya, K. Nishikawa, N. Sasao, A. Shima, Hk. Yokoyama
Niigata U.
K. Miyano, M. Nakamura, N. Tamura
Okayama U.
I. Nakano
Osaka U., Inst. Phys.
M. Yoshida
Science U.,Tokyo
T. Kadowaki, S. Kishi, Hm. Yokoyama
Tohoku U.
T. Hasegawa, T. Maruyama
Chonnam National U.
J.H. Choi, H.I. Jang, J.S. Jang, J.Y. Kim, I.T. Lim, S.H. Lim
Dongshin U.
M.Y. Pac
Korea U., Tokyo
S.J. Hong, C.O. Kim, S.K. Park
Seoul National U.
H.C. Bhang, B.J. Kim, H.I. Kim, J.H.Kim a S.B.Kim a H. So, J.H. Yoo
Warsaw U.
Danka Kielczewska
Boston U.
Ed Kearns, Kate Scholberg, Jim L. Stone, Larry R. Sulak, C. Walter
UC, Irvine
David Casper, Wojciech Gajewski, William R. Kropp, Shunichi Mine, Hank W. Sobel, Mark Vagins
Hawaii U.
Atsuko Kibayasi, John Learned, Shige Matsuno
SUNY, Stony Brook
Jim Hill, Chang Kee Jung, Kai Martins, C. Mauger, Clark McGrew, Eric Sharkey, Chiaki Yanagisawa
Washington U., Seattle
Hans Berns, Steve Boyd, Andy Stachyra, Jeff Wilkes