

July 4, 2002
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Translation from Near to Far at K2K

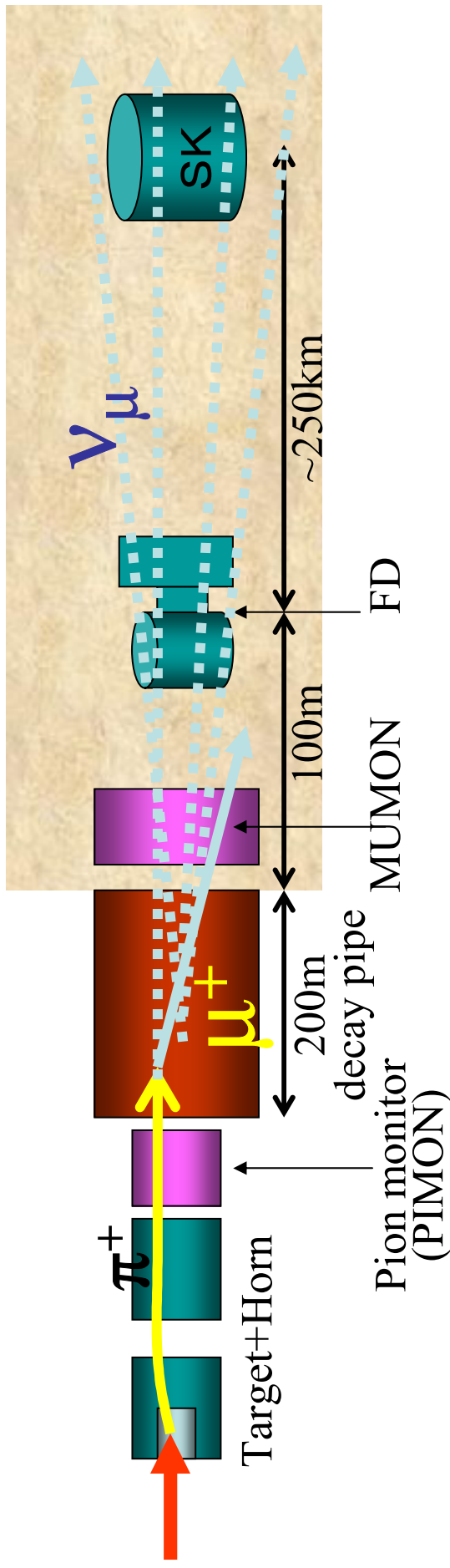
T.Kobayashi
IPNS, KEK

for K2K beam monitor group

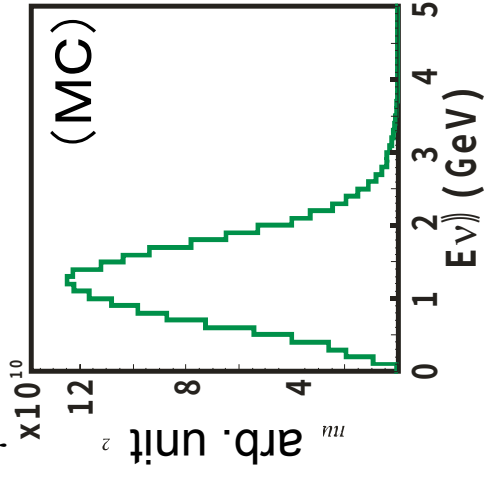
(K.Nishikawa, T.Hasegawa, T.Inagaki,
T.Maruyama, T.Nakaya,)

Especially for T.Maruyama(KEK→Chicago) who
played major role in PIMON
construction/measurement/analysis

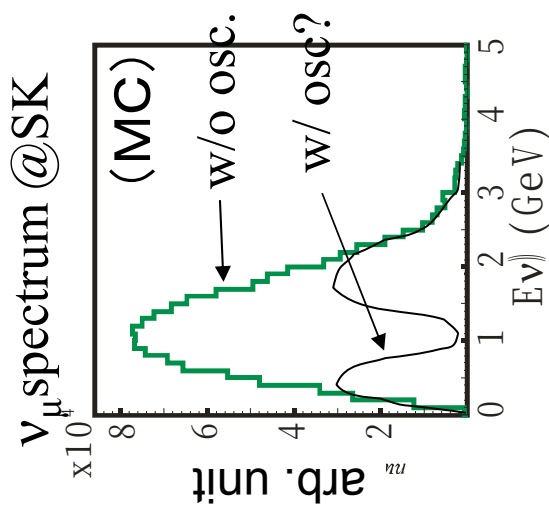
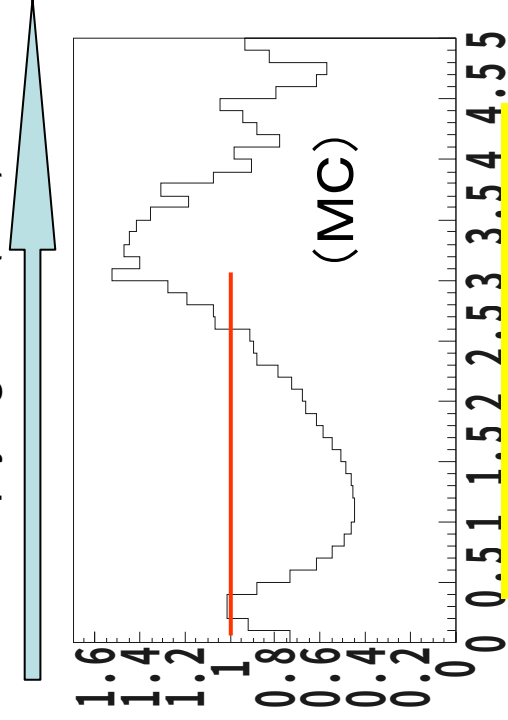
Strategy of K2K



ν_μ spectrum@production



Extrapolate by
multiplying ratio($\neq 0$)



What's new in the treatment of far/near extrapolation

- Before
 - Observable for osc. analysis:
 - total # of events
 - added syst. error from each energy bins linearly (= 100% positive correlation) to be safe.
- New
 - Observables for osc. analysis
 - total # of events,
 - E_ν^{rec} spec. shape for 1-ring μ -like events
 - Correlation for far/near ratio btw energy bins are taken into account

Far/Near ratio in oscillation analysis (method1)

Maximum Likelihood Method

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

systematics parameters

$$f = (f_{\Phi}, f_{nQE}, \underset{\substack{\uparrow \\ \text{spec}}}{f_{F/N}}, f_{\varepsilon sk}, f_{Esk}, f_{n6}, f_{n11})$$

$f_{F/N}$ is highlighted in a red circle.
 $f_{\varepsilon sk}$ is labeled "Far/near" (yellow box) and "efficiency".
 f_{Esk} is labeled "SK Energy scale".
 f_{n6} and f_{n11} are labeled "Overall Norm Error".

For Jun99 and Nov99-₄

Normalization term

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

$$N_{exp} = N_{KT}^{obs} \cdot \frac{N_{SK}^{MC}(f, P_{osc})}{N_{KT}^{MC}(f)}$$

$$= N_{KT}^{obs} \cdot \frac{\sum_{i,j} f_{\Phi i} \boxed{f_{F/Ni}} \cdot \Phi_{SK}^{MC}(E_i) P(\Delta m^2, \sin^2 2\theta) \cdot (f_j \sigma_{ij}) \cdot \mathcal{E}_{ij}^{SK}}{\sum_{i,j} f_{\Phi i} \cdot \Phi_{KT}^{MC}(E_i) \cdot (f_j \sigma_{ij}) \cdot \mathcal{E}_{ij}^{KT}}$$

i : energy bin index

j : processes (=QE, nQE)

Spectrum meas. in FD($f_{\Phi i}$) cancels first order
but far/near ratio $f_{F/N}$ does not.

E_ν^{rec} spectrum shape term for FC

1Rμ

$$L_{shape} \equiv \prod_{i=1}^{29} P(E_i^{rec})$$

Total 29 events
for **Nov99~** data

P : reconstructed E_ν distribution for 1Rμ (gen'ed by using MC)

$$P(E_\nu^{rec}) = \int \Phi_{SK}(E_\nu^{true}) \cdot \left[\sigma_{QE}(E_\nu^{true}) \cdot \mathcal{E}_{QE}^{1R\mu}(E_\nu^{true}) \cdot r_{QE}(E_\nu^{rec}, E_\nu^{true}) + f_{nQE} \sigma_{nQE}(E_\nu^{true}) \cdot \mathcal{E}_{nQE}^{1R\mu}(E_\nu^{true}) \cdot r_{nQE}(E_\nu^{rec}, E_\nu^{true}) \right] dE_\nu^{true}$$

Detector response from MC

$$\Phi_{SK}(E_\nu^{true}) = (f_\Phi^{meas} \Phi_{FD}^{MC}) \cdot (f_{F/N} R) \cdot P_{osc}(\sin^2 2\theta, \Delta m^2)$$

Systematic constraint term

$$\begin{aligned}
 L_{\text{syst}} \equiv & \exp\left(-\Delta f_{\Phi, nQE}^T \cdot M_{FD}^{-1} \cdot \Delta f_{\Phi, nQE} / 2\right) \\
 & \times \exp\left(-\Delta f_{F/N}^T \cdot M_{F/N}^{-1} \cdot \Delta f_{F/N} / 2\right) \\
 & \times \exp\left(-\Delta f_{\text{ESK}}^T \cdot M_{\text{ESK}}^{-1} \cdot \Delta f_{\text{ESK}} / 2\right) \\
 & \times \exp\left(-f_{n6}^2 / 2\sigma_{n6}^2\right) \cdot \exp\left(-f_{n11}^2 / 2\sigma_{n11}^2\right) \\
 & \times \exp\left(-\Delta f_{\text{Esk}}^2 / 2\sigma_{\text{Esk}}^2\right)
 \end{aligned}$$

Far/near ratio

$$\Delta f \equiv f - 1$$

$M_{\text{FD}}, \mathbf{M}_{\pi}, M_{\text{SK}}$: error matrix of syst. errors.
 σ_{n6} : overall norm. err. for Jun99 ($=+0.80-0.68$ evts)
 σ_{n11} : overall norm. err. for Nov99~ ($=5.34\%$)
 σ_{Esk} : SK Energy scale error (3%)

Questions

- Central values of far/near ratio (relative to MC prediction)

$$f_{\text{F/Ni}}$$

- Correlation of far/near ratio btw. energy bins (error matrix)

$$M_{\pi}$$

A tool:Pion Monitor (PIMON)

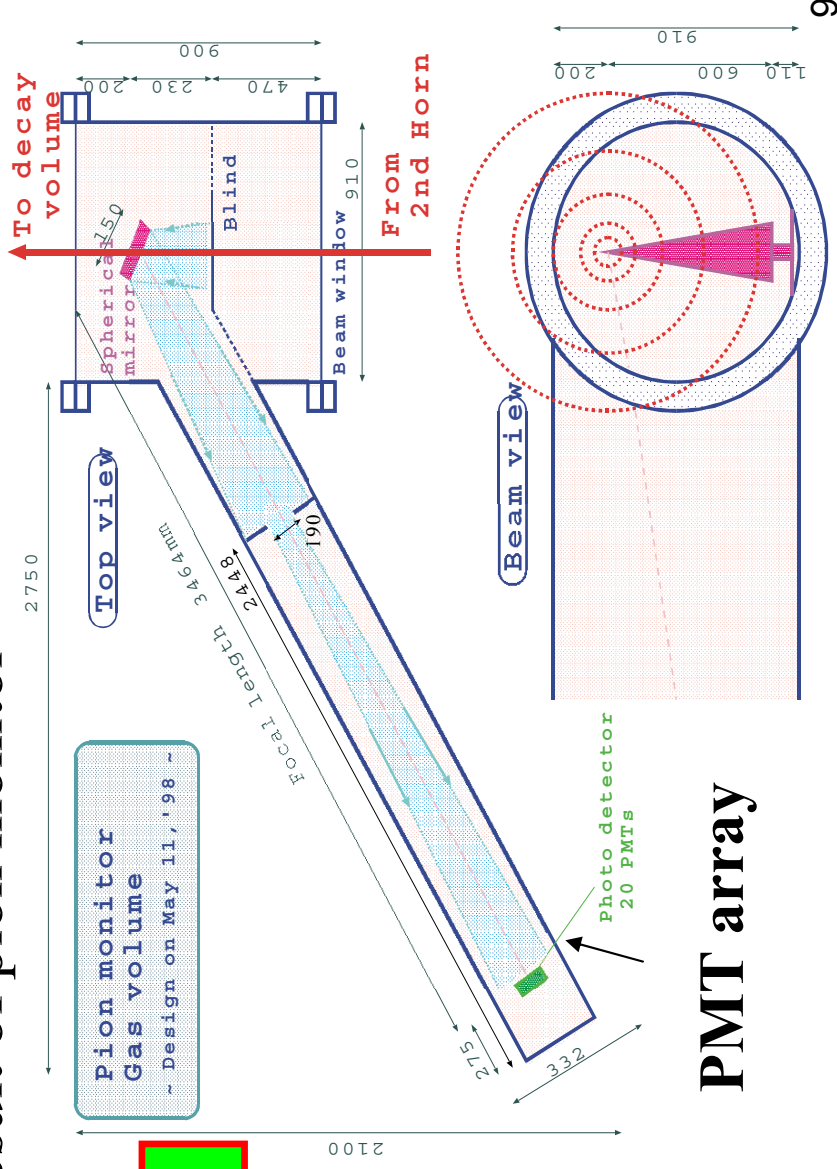
$N(p_\pi \theta_\pi) \rightarrow$ Neutrino flux $\Phi(E_\nu)$ at any distance
using **only decay kinematics**

$$R(E_\nu) \equiv \Phi_{SK}(E_\nu) / \Phi_{FD}(E_\nu)$$

as a result of pion monitor

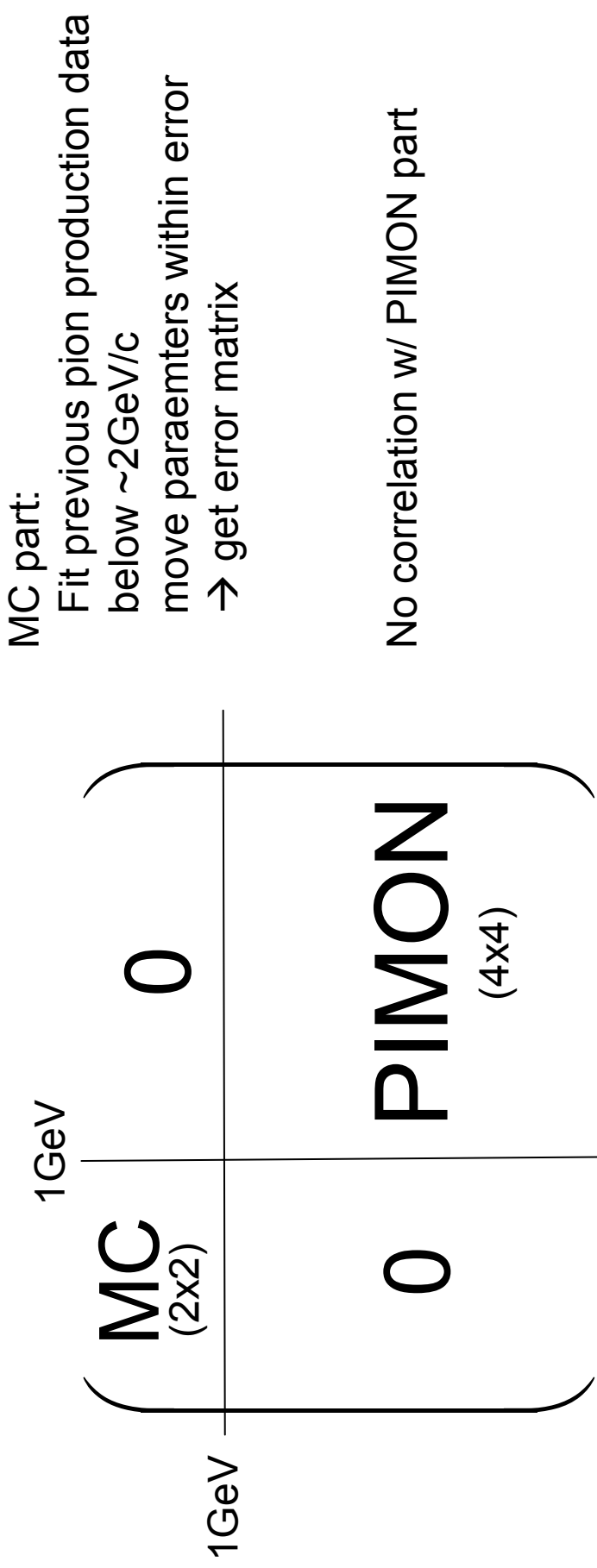
Gas Cherenkov detector

to avoid signal from
12GeV protons
 $\rightarrow$ insensitive to p_π
<2GeV ($E_\nu < 1\text{GeV}$)

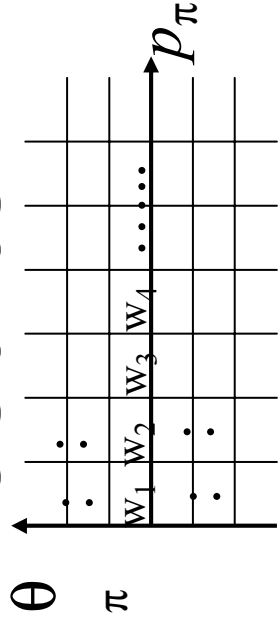
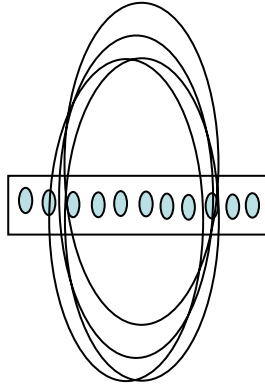


Strategy to obtain $f_{F/N}$, error matrix

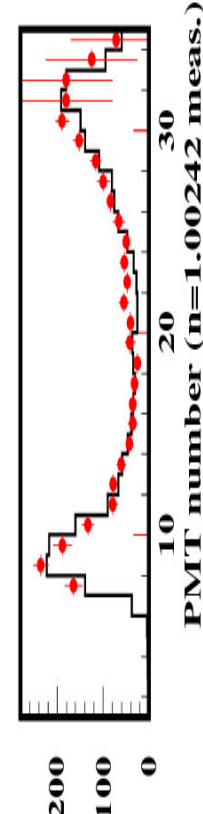
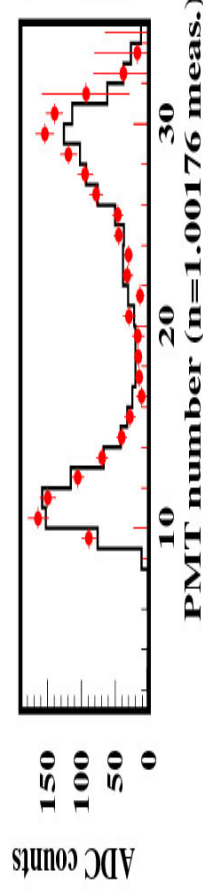
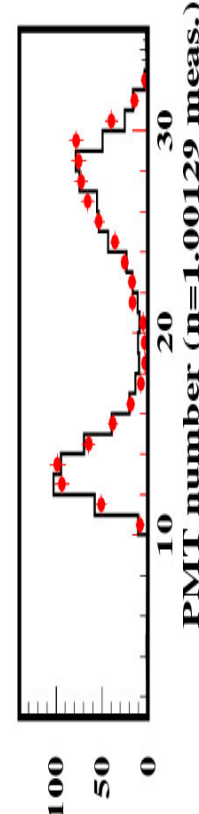
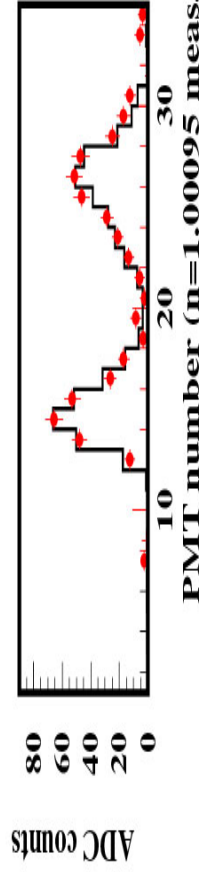
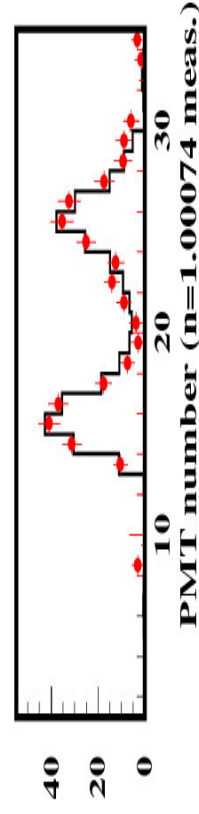
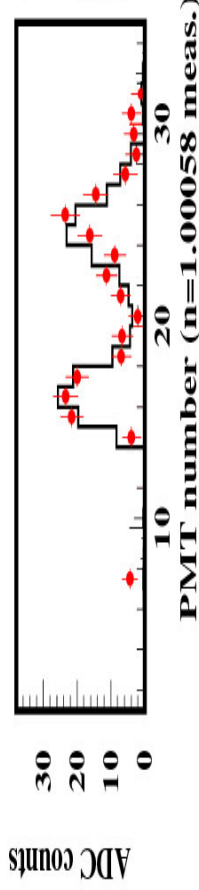
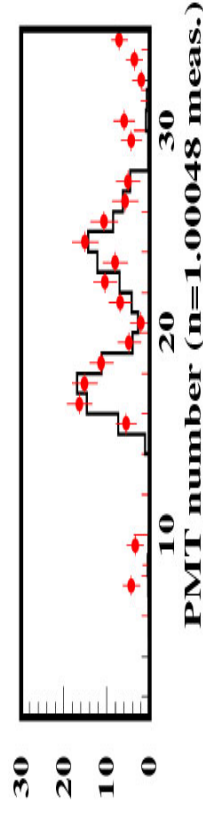
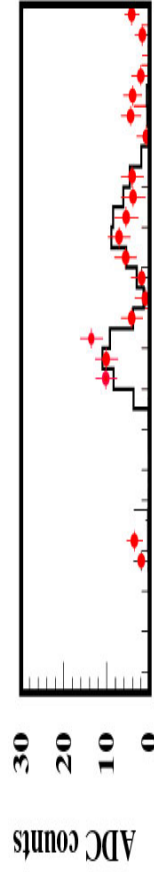
- Above 1GeV $\rightarrow$ PIMON
- Below 1GeV $\rightarrow$ Beam MC(Sanford-Wang parameterization fitted to previous data) validated by PIMON measurement at $>1\text{GeV}$
- Error matrix



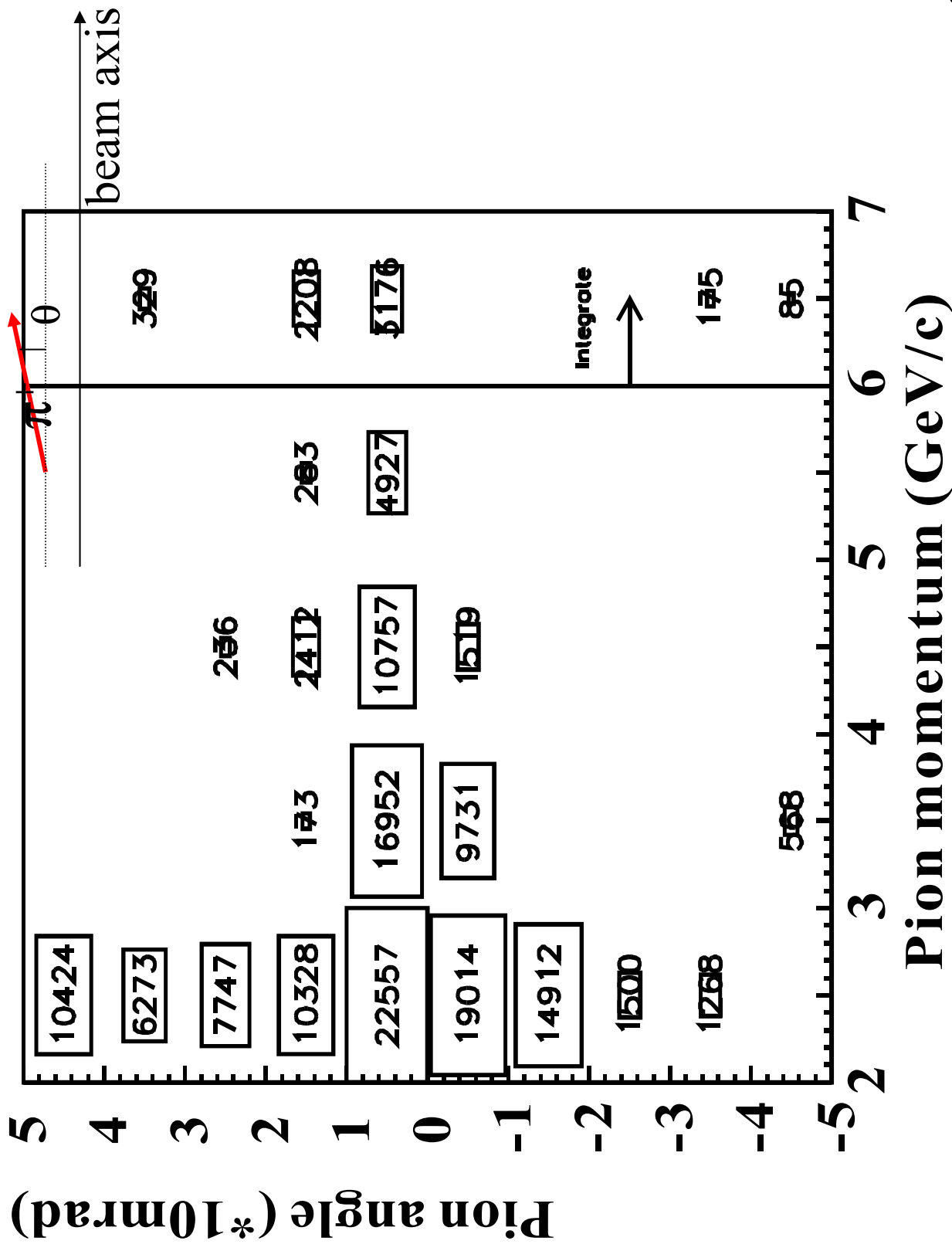
Pion Monitor Results



Pion Monitor Fitting (November)



Pion Monitor Result(relative weight)

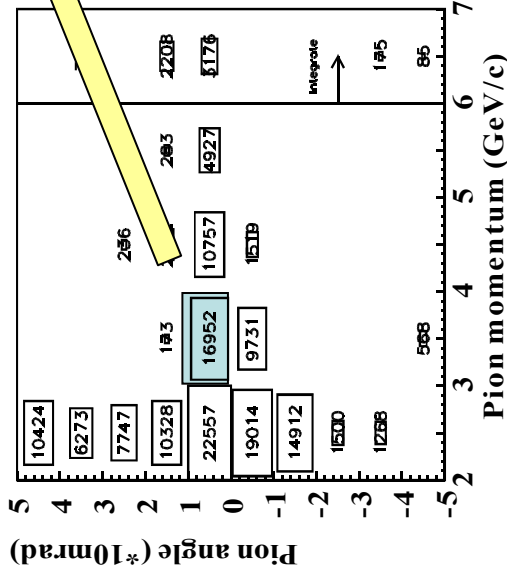


Pion distribution to far/near ratio

(incl. error matrix)

From PIMON fitting

Relative weight $W_i (i=1 \sim 50)$



Contribution to ν flux from each p - θ bin (by MC. To 1st order, depend only on decay kinematics & geometry

$$\Phi_i^{FD,SK} = \sum_{j=1}^{50} \phi_i^{FD,SK}(W_j)$$

FD,SK flux

Ratio as func. of weights

$$R_i = \Phi_i^{SK}(W) / \Phi_i^{FD}(W)$$

$$U_{ij} = \frac{dR_j}{dW_i}$$

Dependence of R on W (50x4 matrix)

50x50 error matrix on weight

$$E_{ij}^{\pi}$$

$$E^R = U^T \cdot E^{\pi} \cdot U$$

Error matrix transformation from π weight $\rightarrow$ far/near ratio

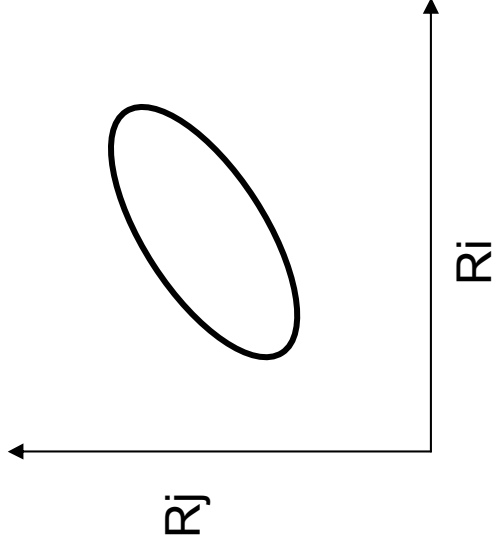
$$(4 \times 4) \quad (4 \times 50) \quad (50 \times 50) \quad (50 \times 4)$$

Other systematic errors

Errors on spectrum ratio (Nov.)
Fitting error
PMT saturation correction
PMT relative gain correction
Mirror reflectivity
Refractive index measurement
Wave length dep. of the ref. index
Low and high beam intensity
Pion monitor alignment
Injection point of protons
Beam stability (pion monitor run)
Horn magnetic field uncertainty
Subtraction of BKG radiation component
Subtraction of EM shower component
Fitting method
Pion beam profile (fitting function)
Pion decay before pion monitor
Pion beam profile (pion absorption)
Bin size of pion kinematics
Beam stability (normal run)
Hadron model (MC)
Total

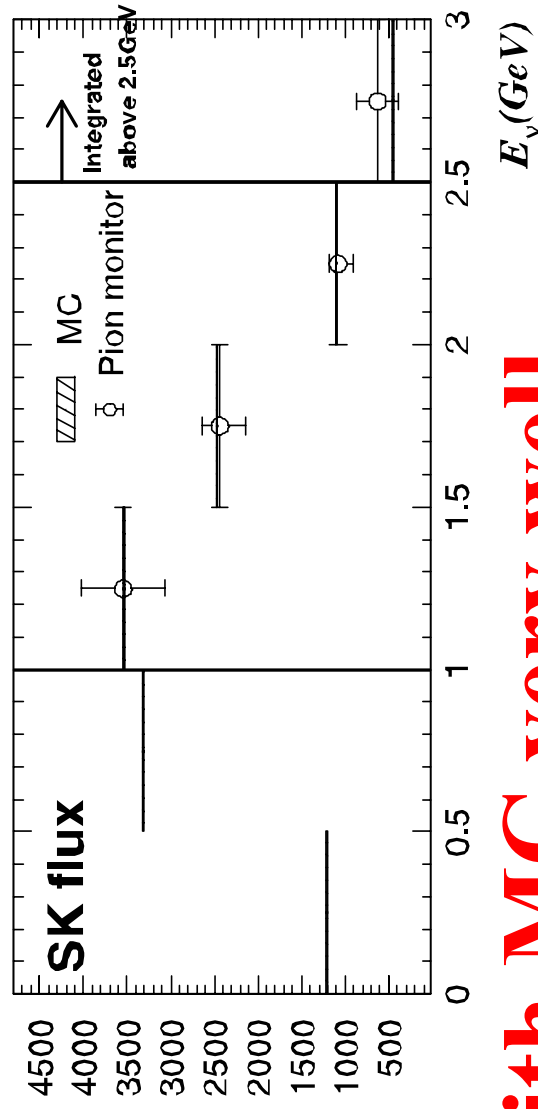
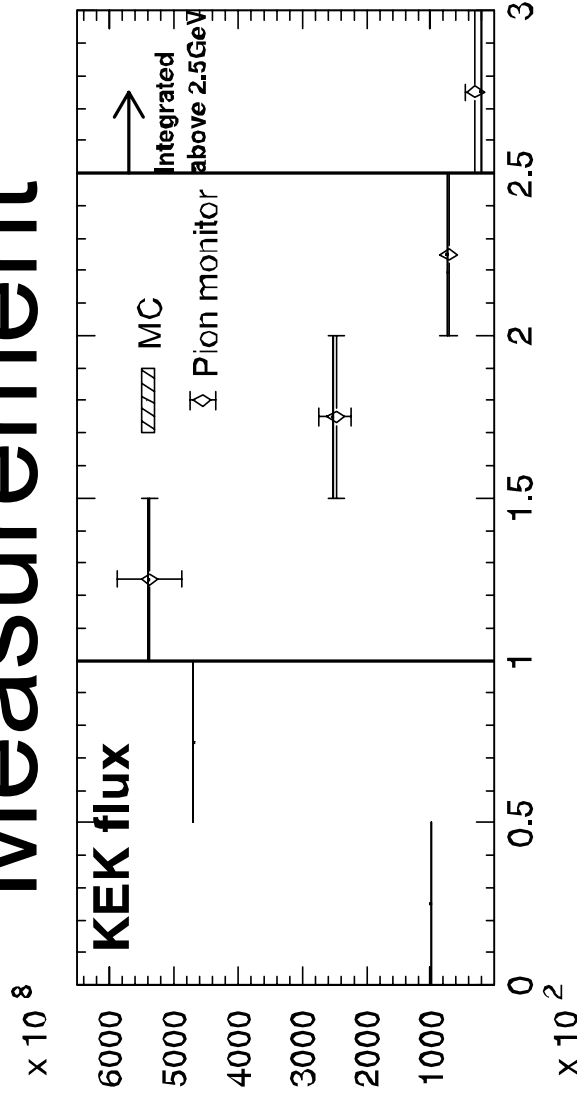
→ treated in matrix form as described

1. move syst. parameter within error
2. Check correlation btw energy bins



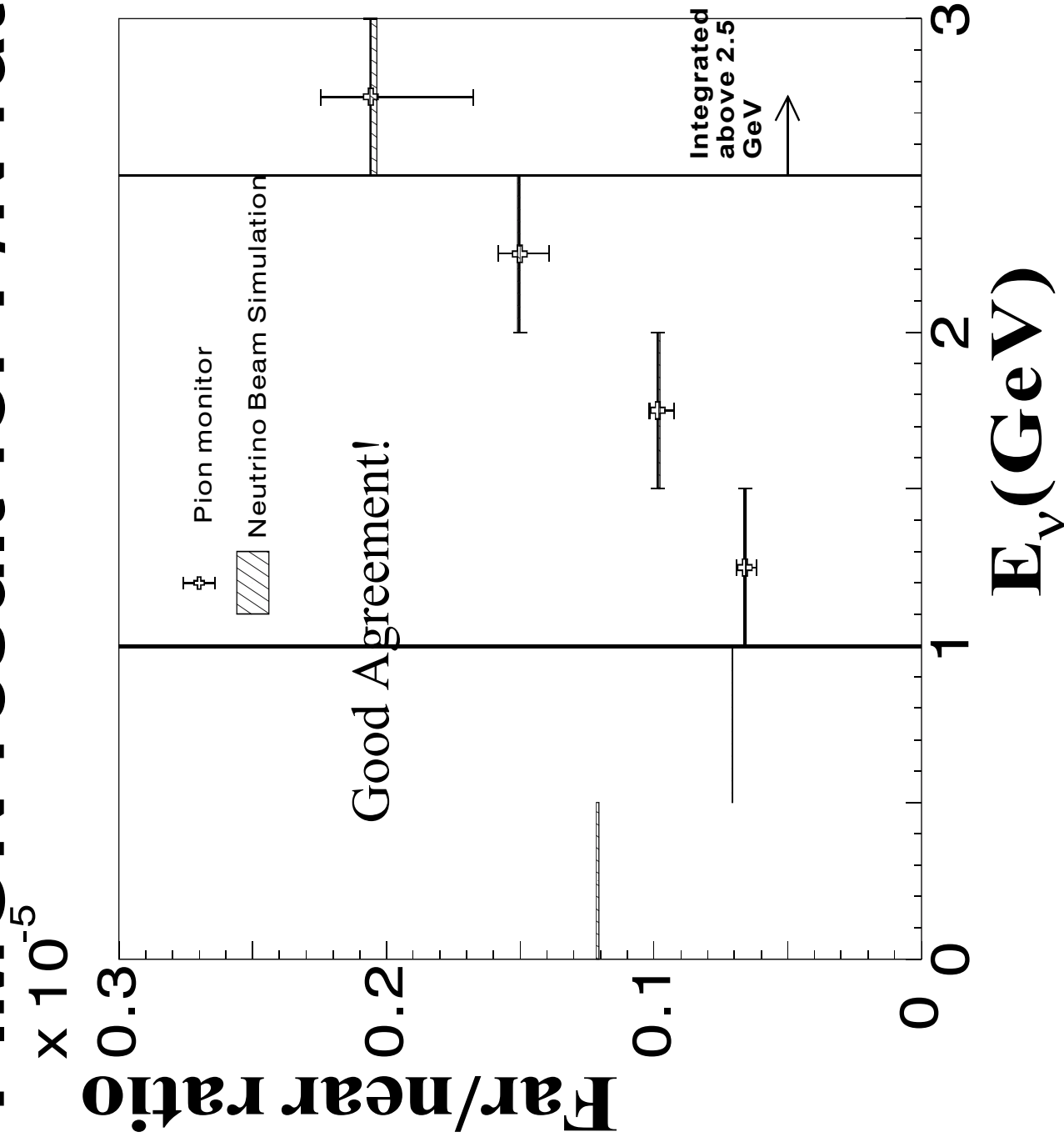
ν_μ spectra from Pion Monitor

Measurement



Agree with MC very well.

PIMON result for F/N ratio



Far/Near Error Matrix

“sqrt” of error matrix (%)

$$\text{sign}(M_{ij}) \cdot \sqrt{M_{ij}}$$

*****		SQRT (FAR/NEAR ERROR MATRIX)		*****	
		SQRT (FAR/NEAR ERROR MATRIX)		*****	
2.5696	-1.6432	0.0000	0.0000	0.0000	0.0000
-1.6432	4.2591	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	6.5322	2.3973	-1.7861	-4.0187
0.0000	0.0000	2.3973	10.4307	9.5315	4.9528
0.0000	0.0000	-1.7861	9.5315	11.0833	7.2229
0.0000	0.0000	-4.0187	4.9528	7.2229	12.1552
0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-

Beam MC

PIMON

Summary of systematic errors on total # of events w/o osc.

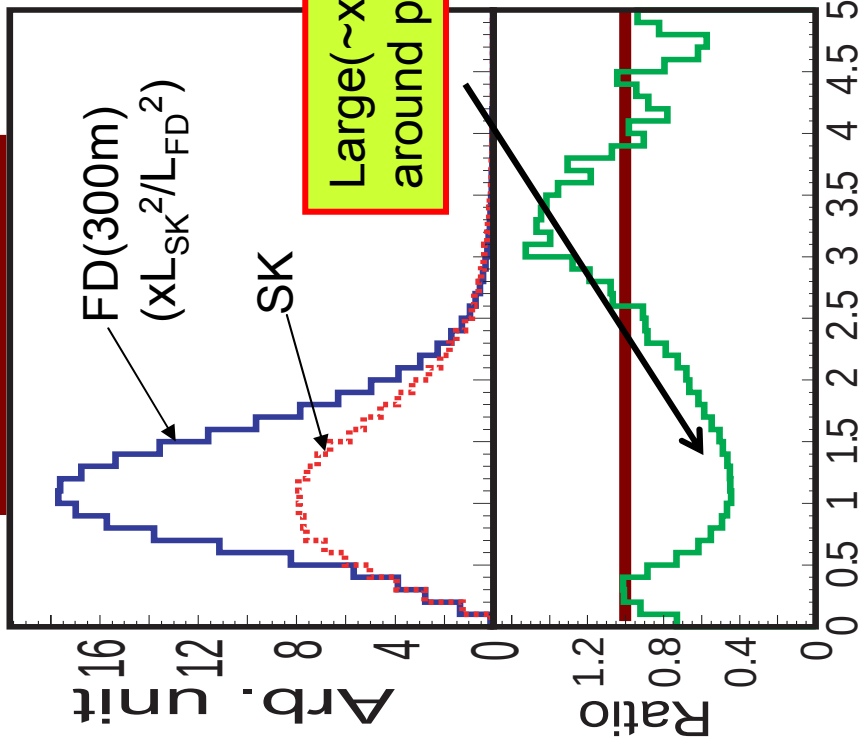
Center: 80.1evts		(%)
Jun99 (4.55evts)	Total	+1.0% -0.9%
Nov99~ (75.5evts)	Spectrum	+0.6% -0.6%
	nQE/QE	+0.5% -1.1%
	Far/Near	+4.9% -5.0%
	Norm	5.0%
Total		+7.7% -6.7%

Summary

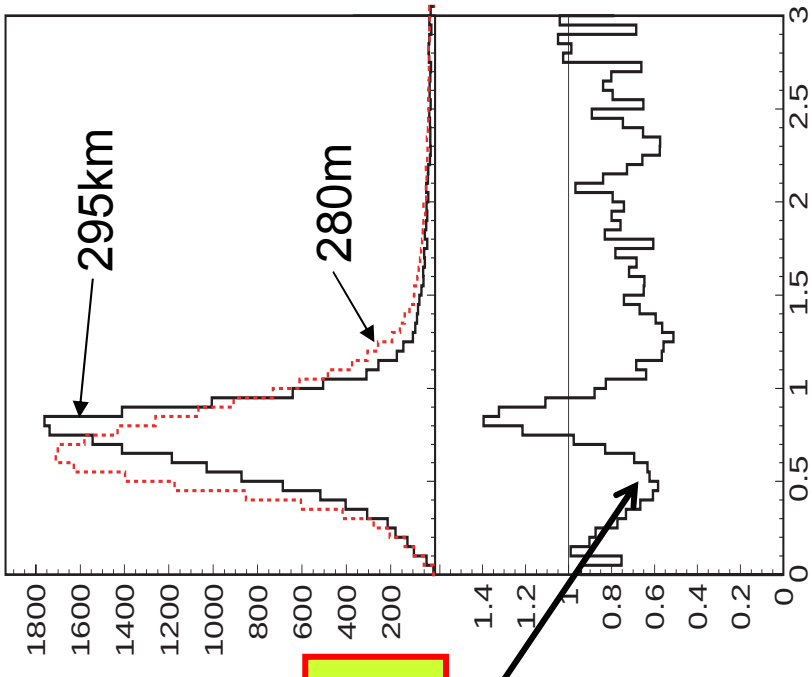
- K2K uses pion distribution measured in-situ ($>1\text{GeV}$) and beam MC ($<1\text{GeV}$) for spectrum extrapolation
- The beam MC is validated by the PIMON measurements
- Correlation of far/near ratio btw energy bins is taken into account (instead of linear sum = 100% positive correlation)
- Still far/near ratio is major source of systematic error
- Expect precise data from HARP (measurement in Aug.26~). Many many thanks to HARP collaborators

Syst. error: far/near spectrum diff.

K2K case (MC)

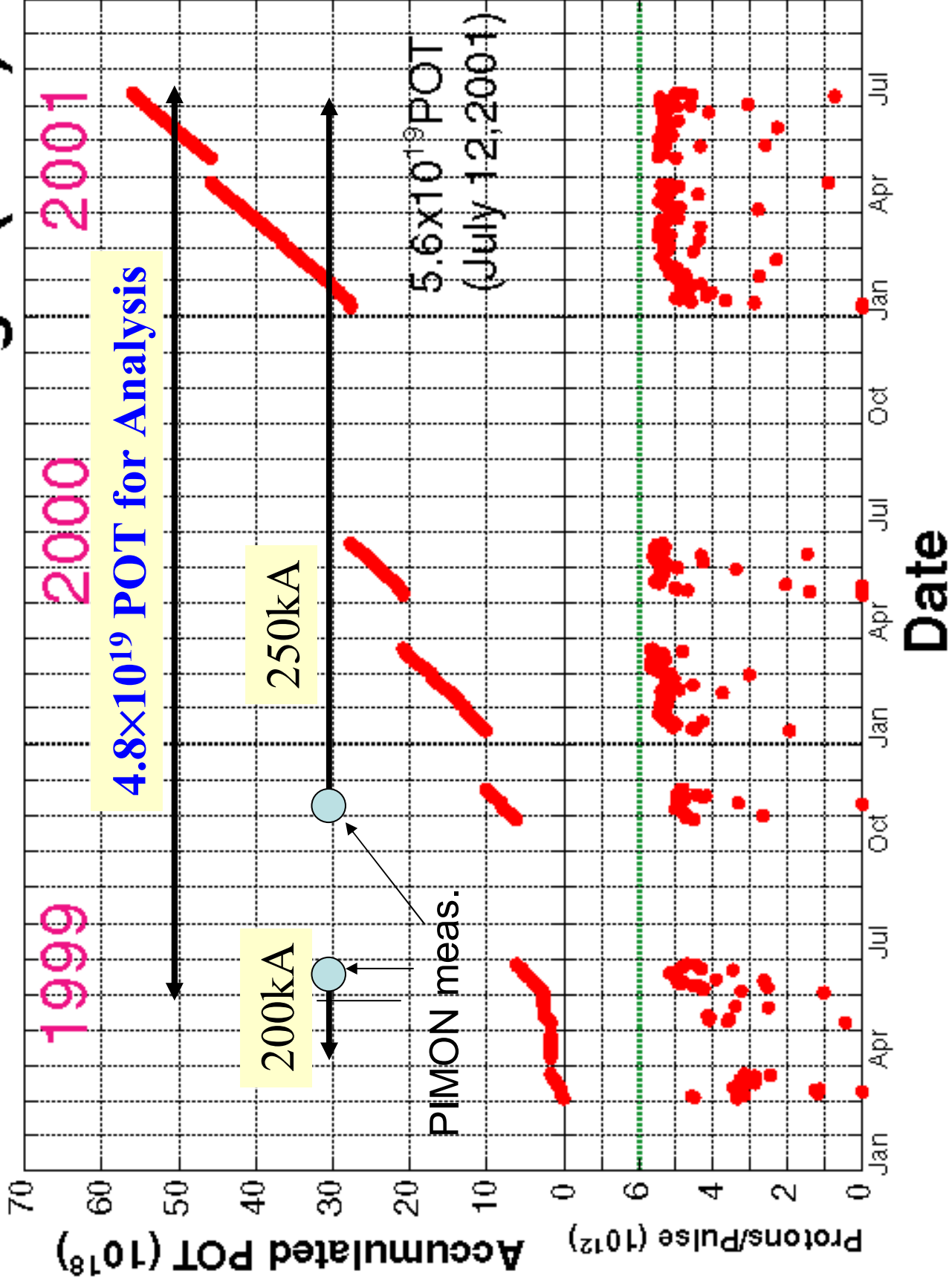


Typical OA beam(80mDV)

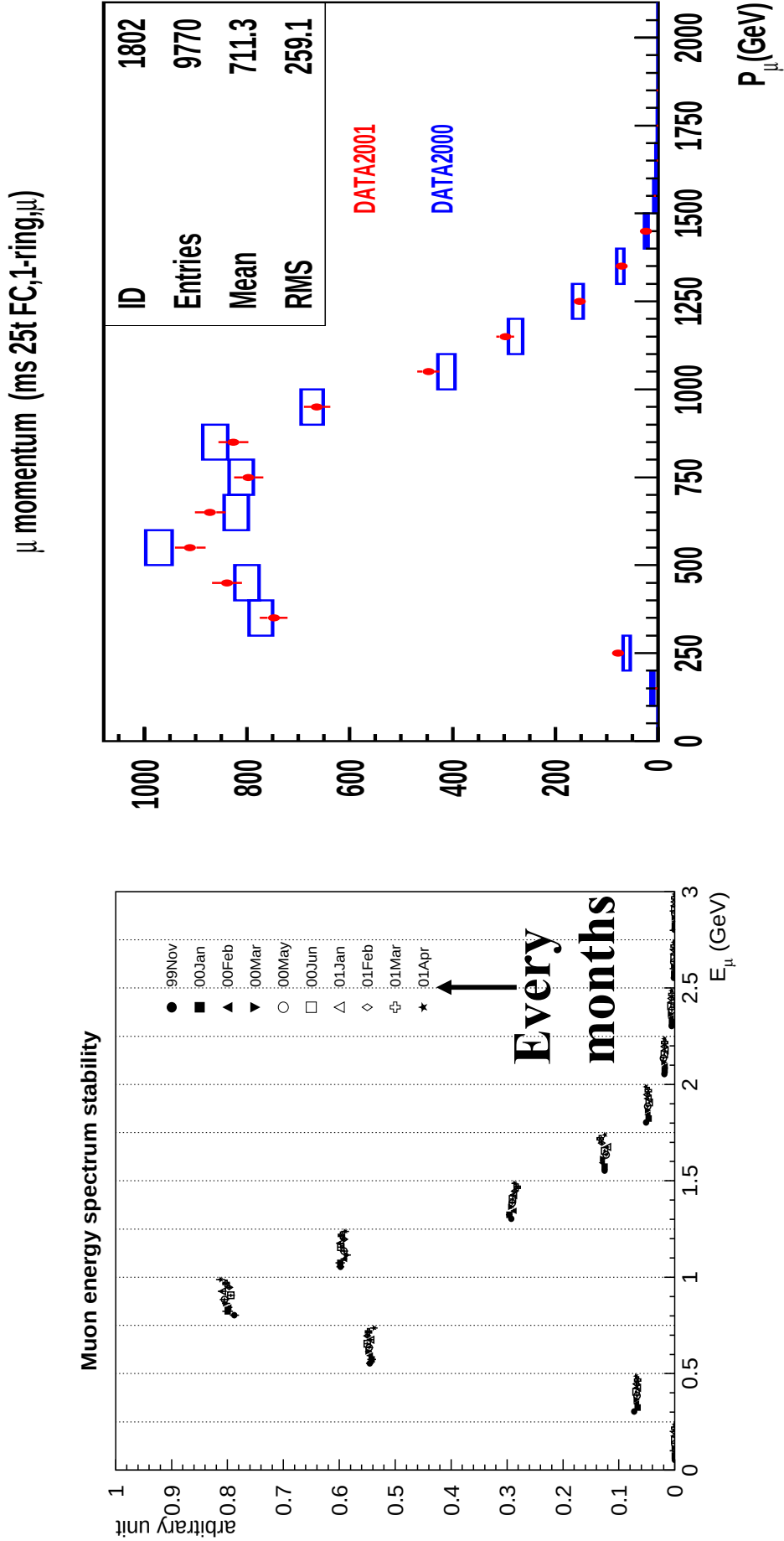


Important not only for ν_μ disappearance,
but also for **sig/BG estimation for ν_e search**

Delivered Protons on Target (POT)



Stability of μ -Energy Spectrum

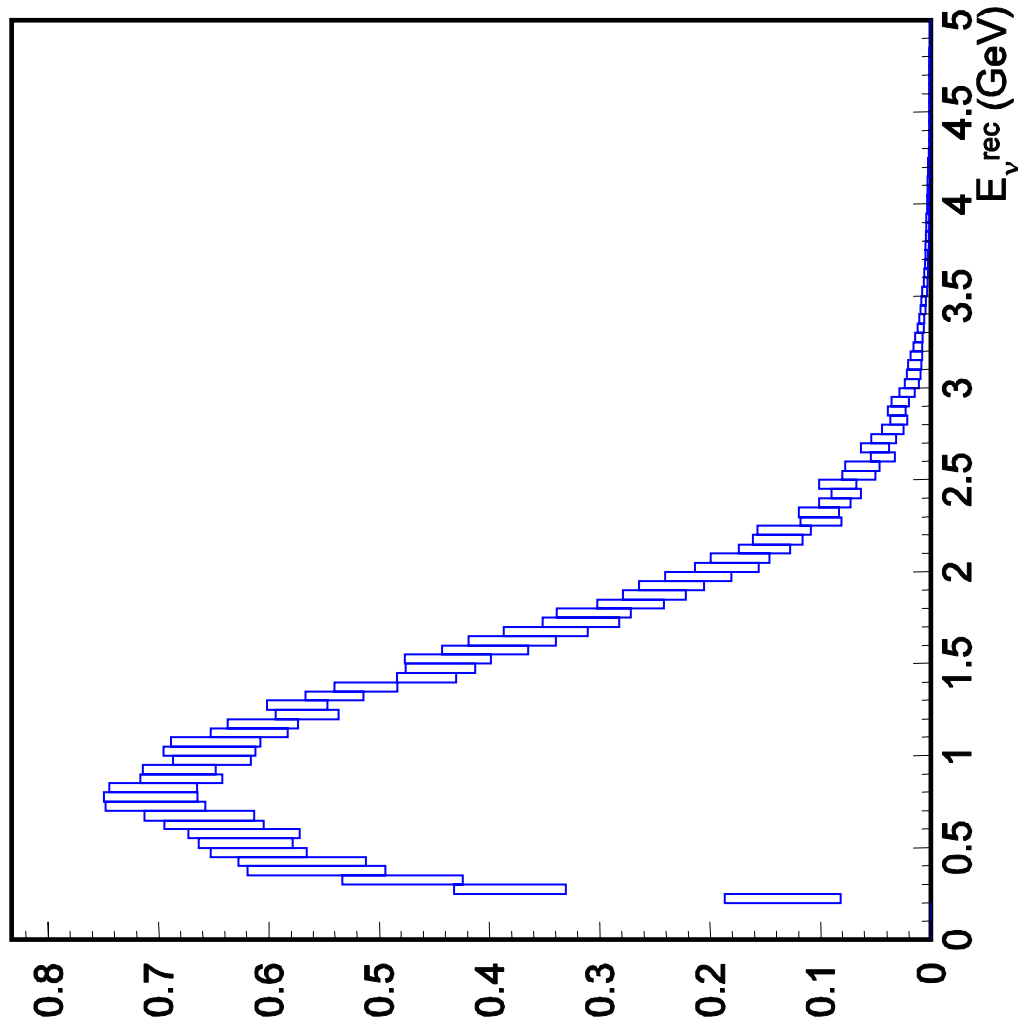


**Muon Energy of
MRD events**

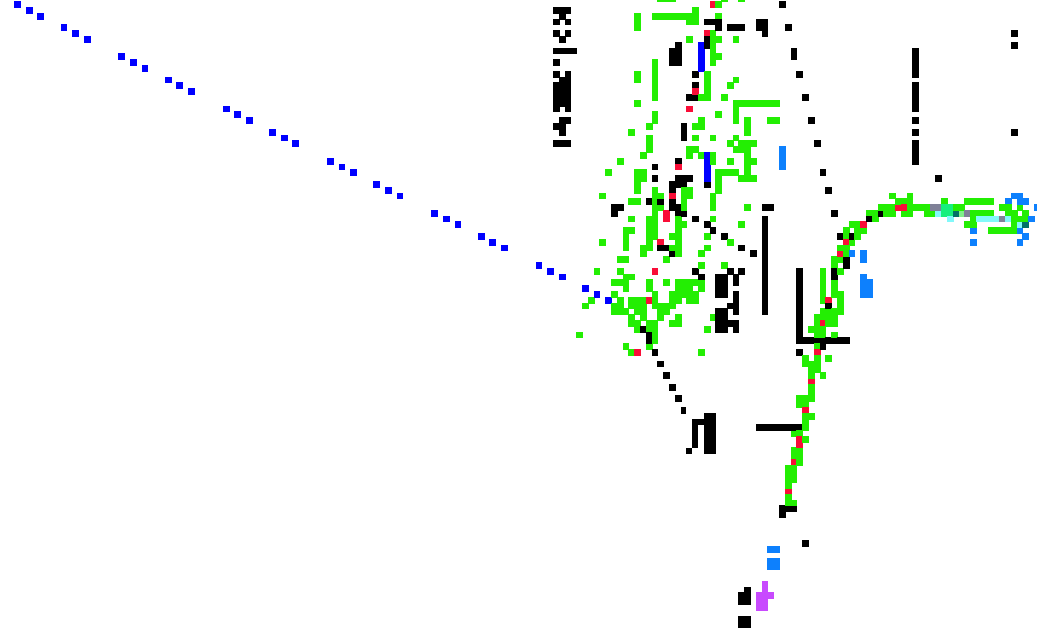
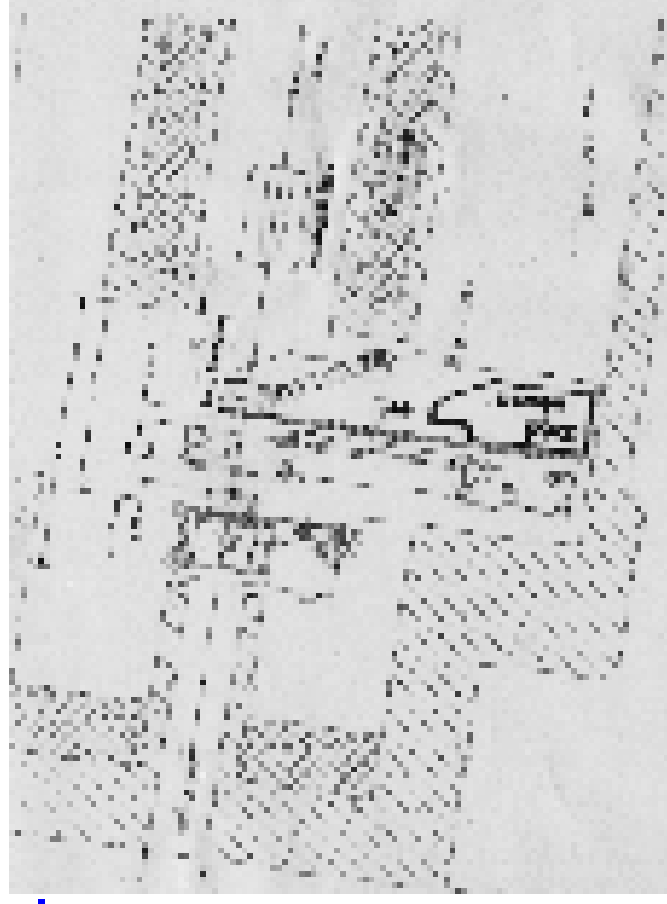
**Muon Energy in
KT on '01, '00**

Exp'd E_{ν}^{rec} spectrum for $1R\mu$ estimated by FD measurements

Initial $1R\mu$ spectrum w/ all syst. err. incl. Escal



PIMON in target station



After Homing system

- Pious are free from magnetic field.
(clarity with well known kinematics)

Pion monitor analysis

using θ_π - p_π plane)

A. 50 kinematic bins are prepared in θ_π - p_π plane.

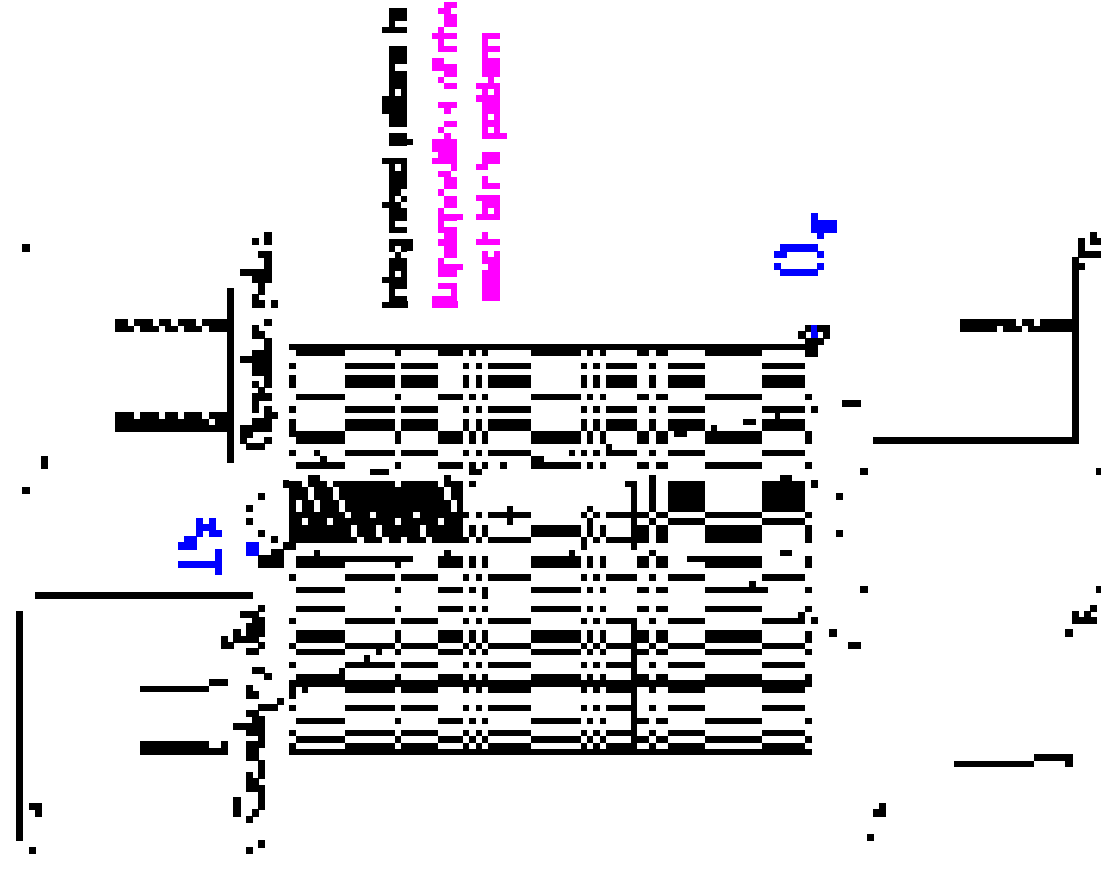
$-50 < \theta_\pi < 50 \text{ mrad}$
 (10 mrad step: 10 bins.)

$2 < p_\pi < 10 \text{ GeV/c}$
 (2 < 10 GeV/c step: 4 bins
 > 10 : integrated : 1 bin)

B. Reconstruct pion kinematics using fl. 4 each bin has each Cherenkov photon dist.)

C. Predict neutrino spectrum from pion kinematics.

(Each bin has each neutrino energy!)



K2K osc. analysis overview

