K2K Eν spectrum measurement and ν interaction model

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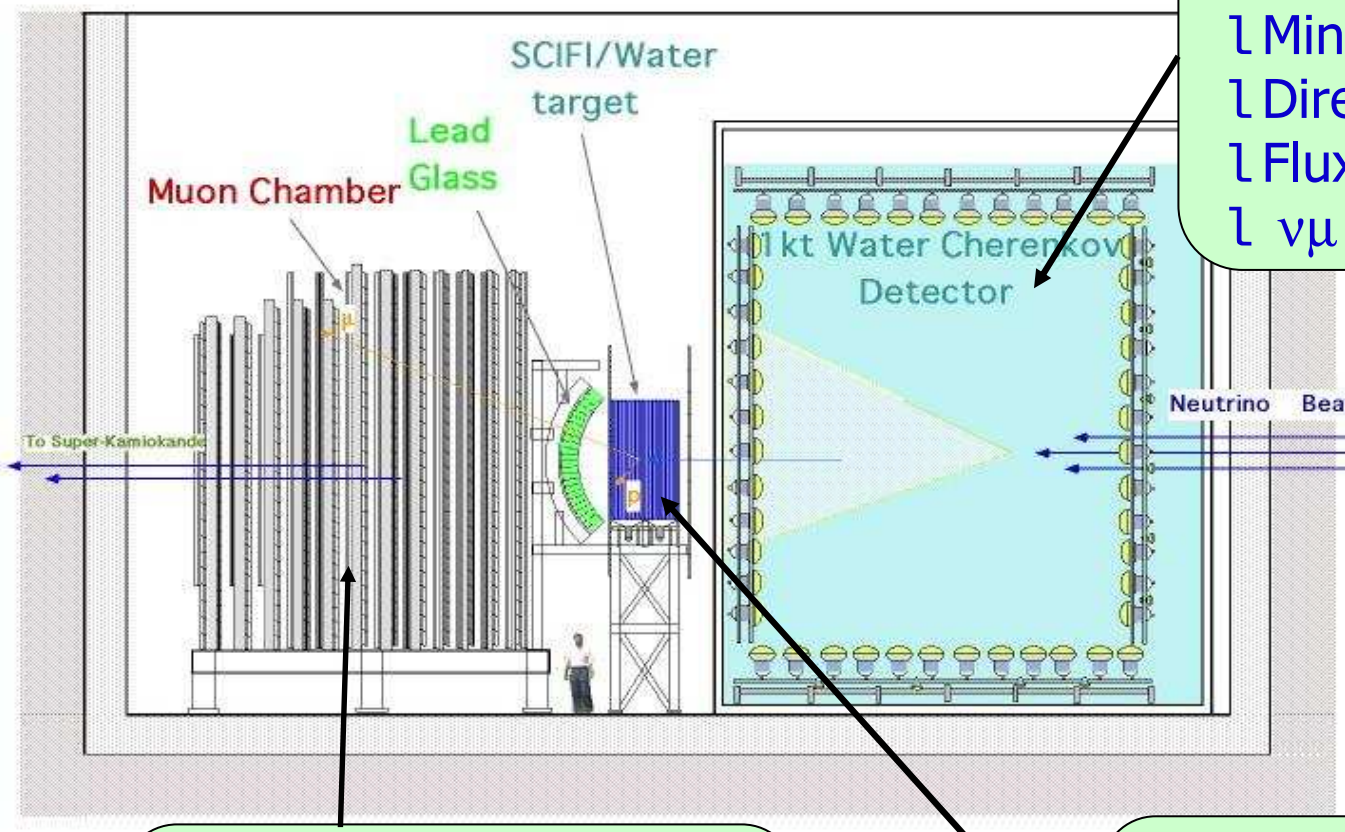
NuInt02@UCIrvine,12Dec,02

Motivation & Outline

- K2K Eν spectrum is determined by two near detectors
  - 1kt water Cherenkov detector
  - Fine Grain Detector
- ν interaction model ("NEUT") needs to be tuned to derive Φ(Eν) from measured quantity Φ(Eν)xσ(Eν)
  - Also check ν interaction model used in Super-K
- 4 CC sample (1kt+FGD) to determine Φ(Eν)
  - 1kt : 1-ring μ-like FC
  - FGD:1-track, 2-track QE-enriched, 2-track nQE-enriched
- Adjust ν interaction model, then fit Φ(Eν) ⇨ **Many talks@NuInt01**
  - This is one explanation of our data
  - Oscillation analysis is robust against adjustment ⇨ **C.Walter@NuInt02**
- Check consistency with other 1kt nQE-sample
  - 2-ring μμ(=μπ), 3-ring μπ^0 (nQE-rich sample)

K2K Front Detector



1kt water Cherenkov

- Miniature of Super-K
- Direct comparison to SK
- Flux normalization
- $\nu\mu$ spectrum < 1GeV

ν_μ

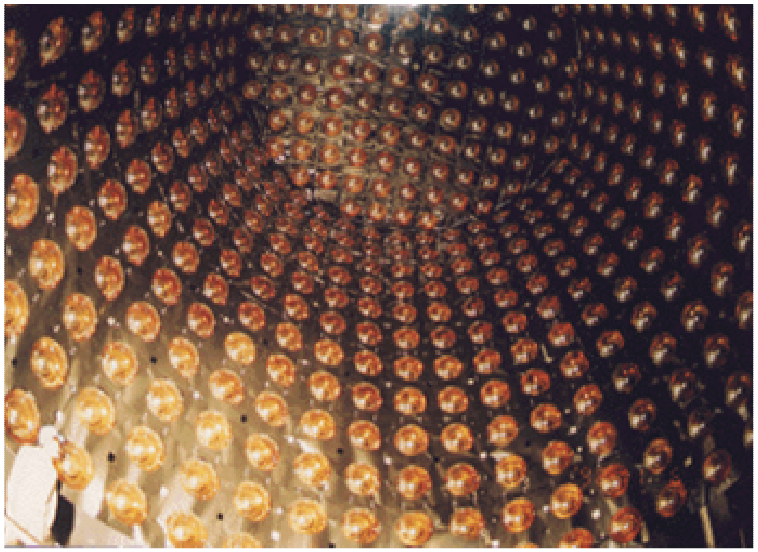
MRD

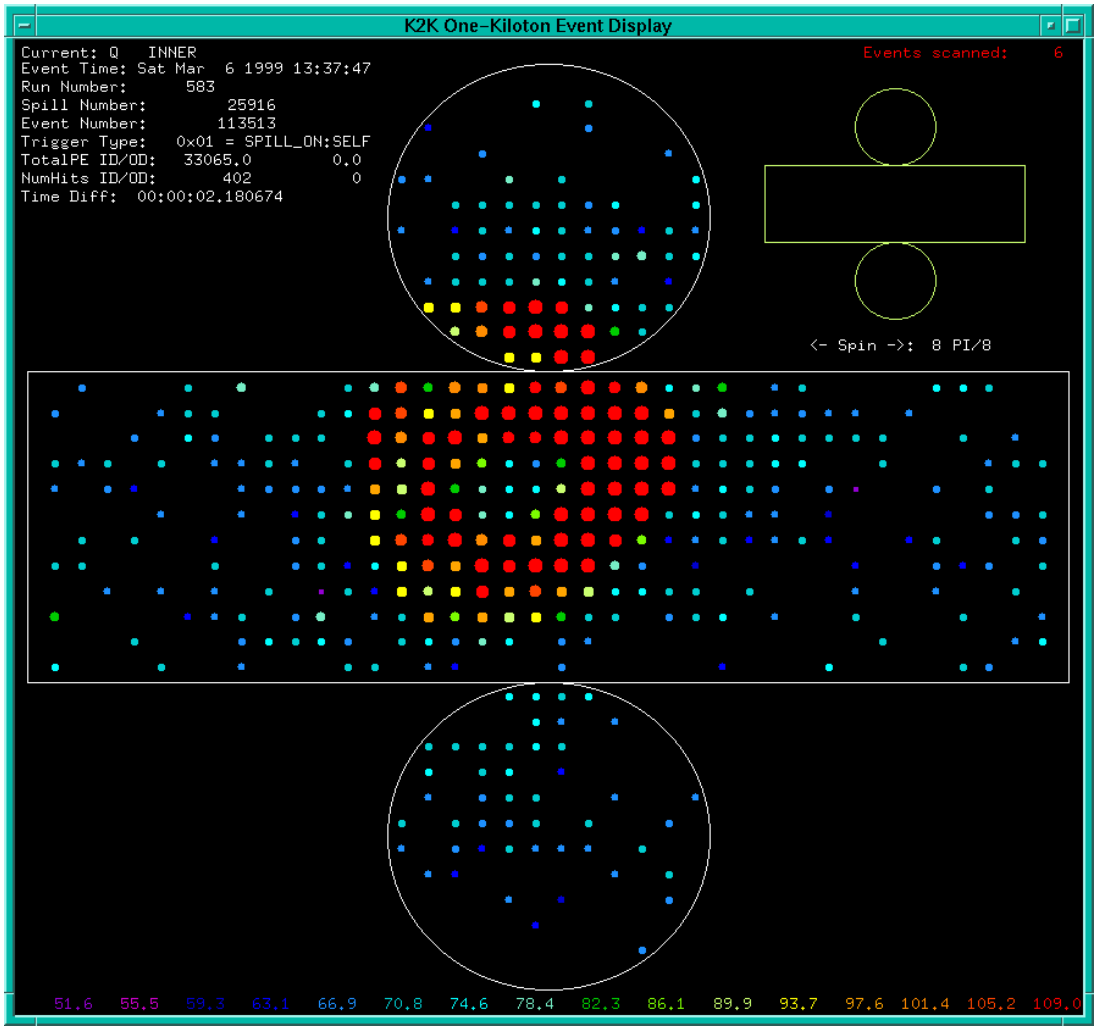
- drift tubes + Fe
- Huge mass, Large area
- profile, spectrum, their stability

SCIFI

- SCFI tracker + water
- Fine vertex tracking
- $\nu\mu$ spectrum

Water Cherenkov Detector (1kt)

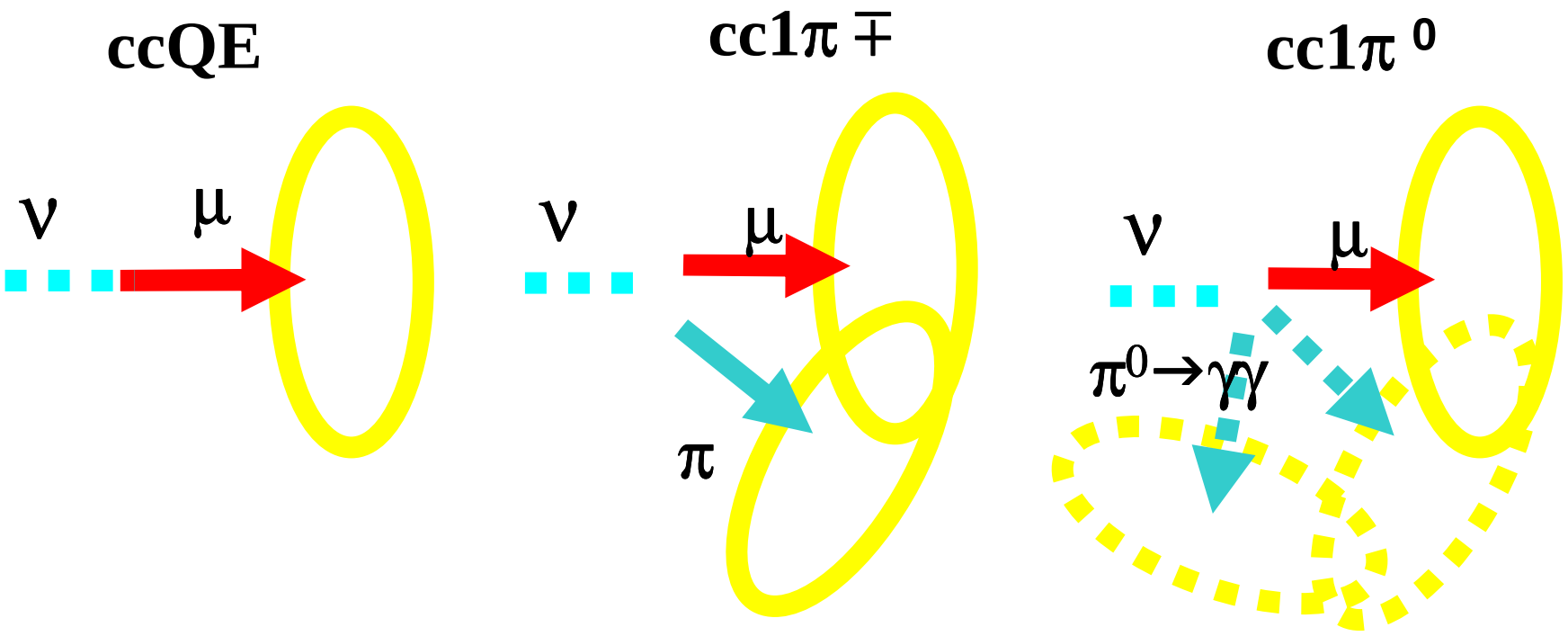




- A miniature of Super-Kamiokande detector with 1/50 volume
- 680 20" PMTs with 70cm spacing (same as Super-K)
- Inner Volume : 496 tons
  Fiducial Volume : 25.1 tons
  (r=2m cylindrical volume along beam)

Typical 1-ring FC μ-like event

1kt event topology based on ring counting



1-Ring μ

2-Ring μπ (μμ)

3-Ring μπ^0

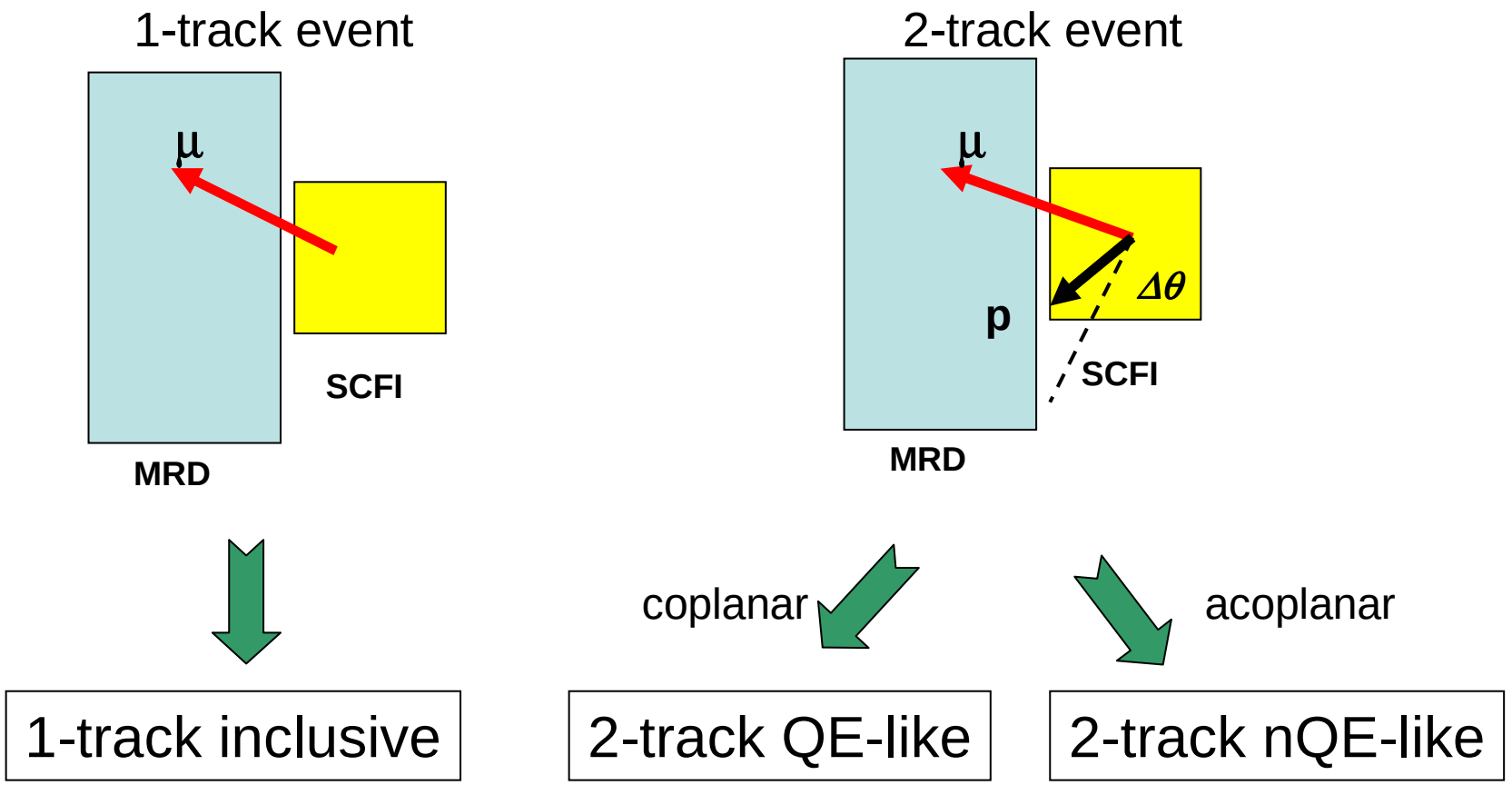
Fraction of NEUT modes:

	μ	$\mu\mu$	$\mu\pi^0$	π^0
CCQE	53%	11%	3%	0.3%
CC1 π	34%	58%	38%	7%
CCcohe π	2%	4%	0.7%	0.1%
CCother	8%	21%	44%	8%
NC1 π	2%	3%	5%	50%
NCcohe π	0.03%	0%	0.2%	12%
NCother	1%	3%	9%	24%

For 1kt sample

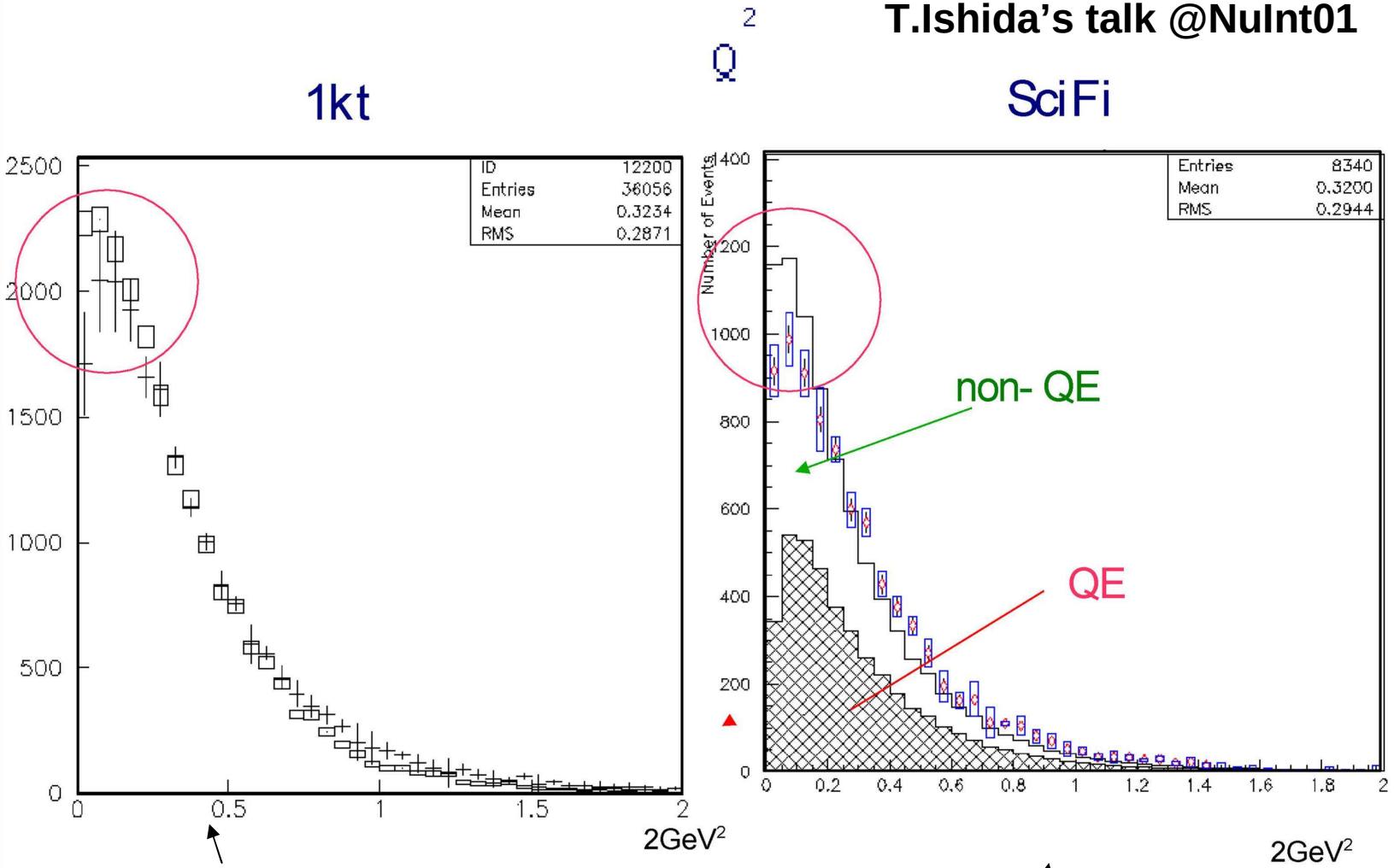
C.Mauger@NuInt01

FGD (SCFI target+MRD)



Low-Q2 suppression or Larger M_A?

T.Ishida's talk @NuInt01



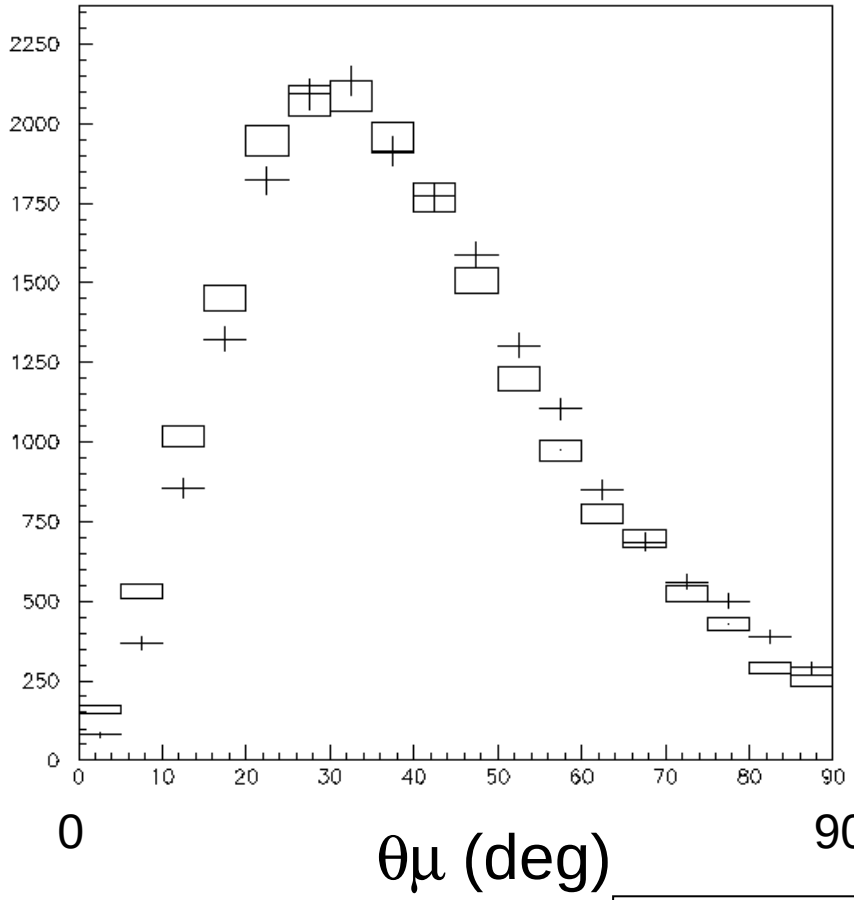
* Errors shown here is an energy scale error (±5%)
* Nuclear binding energy is not taken into account..

* Errors shown here is a typical energy scale error (±3%).
* Nuclear binding energy B = - 30MeV (for Oxygen) is taken into account.

Angular distribution of μ

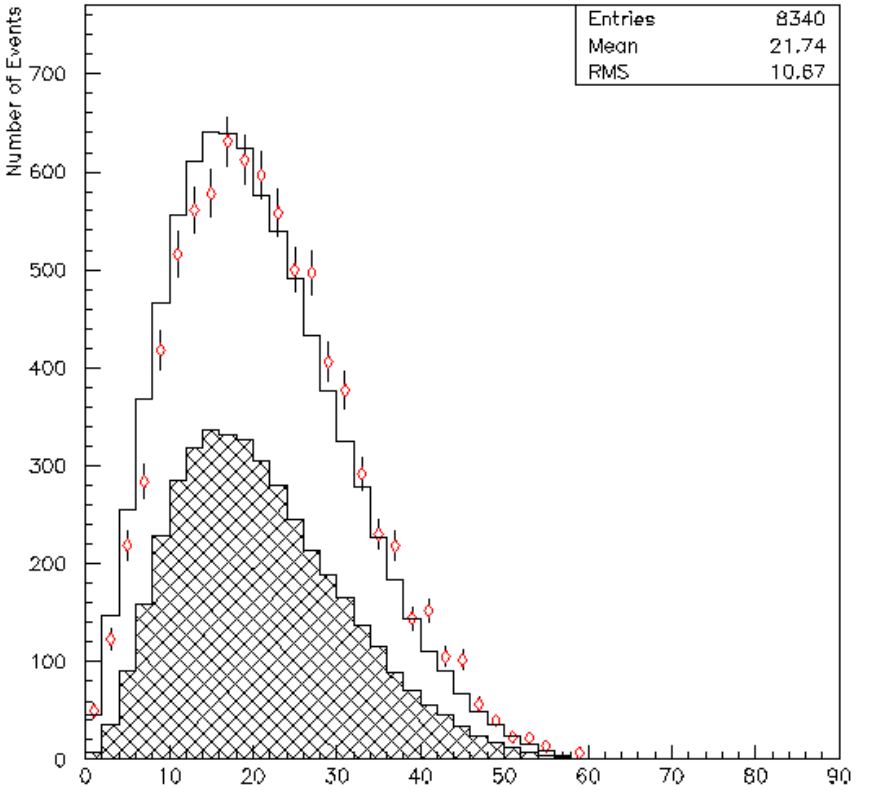
Taken from Ishida@NuInt01

1kt 1-Rμ-like θ μ



0 θμ (deg) 90

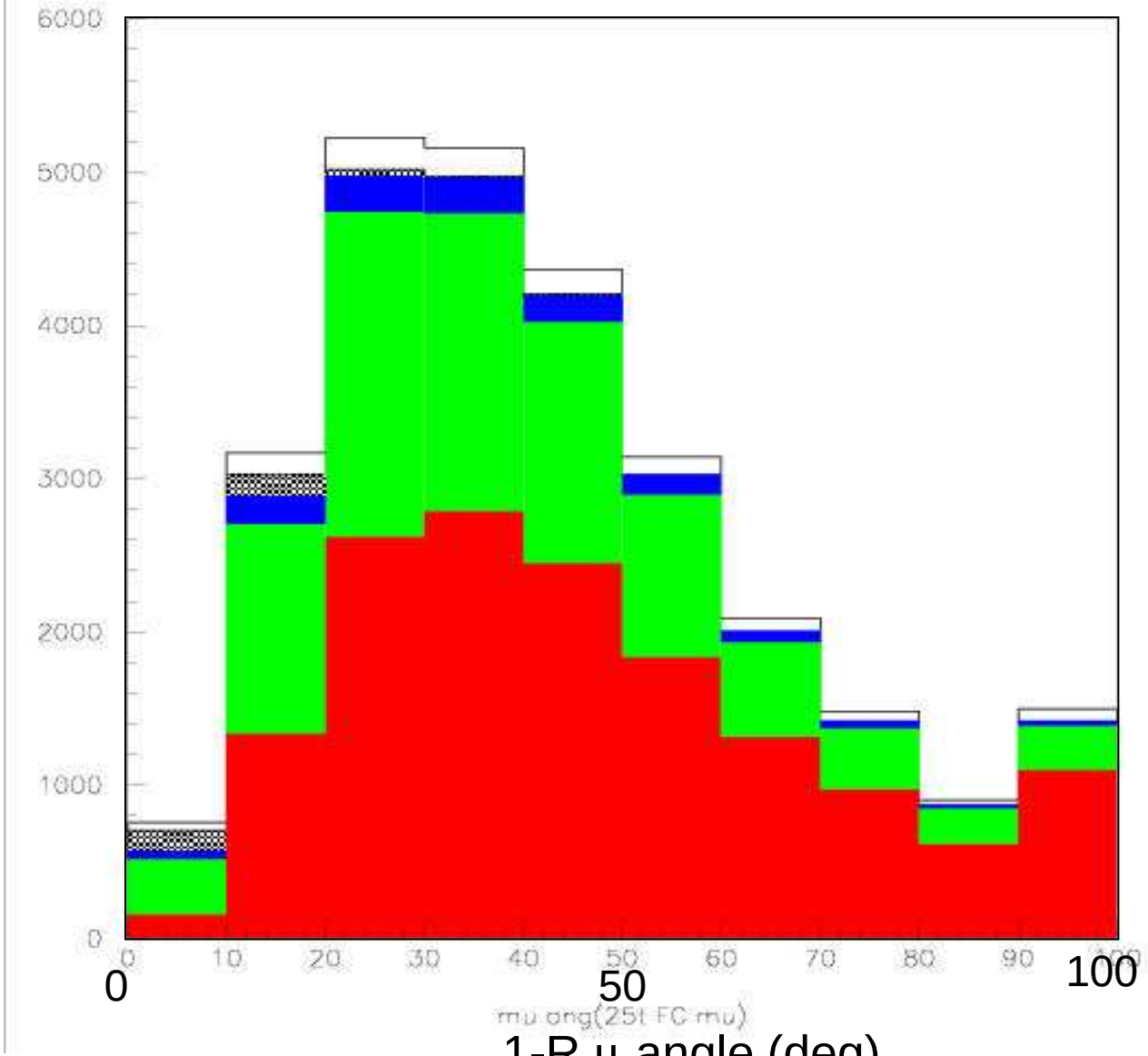
FGD 1-track θ μ



0 θ μ (deg) 90

Statistical error only

Mode fraction in 1kt 1-Rμ



NEUT (The ν interaction model)

See Hayato@NuInt01 for detail

ν interaction vertex

- Quasi elastic
  - ν N → l N' (l: lepton)
- Single π producion

  (based on Rein&Sehgal)
  - ν N →l N'π,(η,K) (resonance)
  - ν^{16}O → l ^{16}Oπ (coherent)
- Deep inelastic

  (GRV94)
  - ν N → l X$\pi\pi\pi$…

Nuclear effect

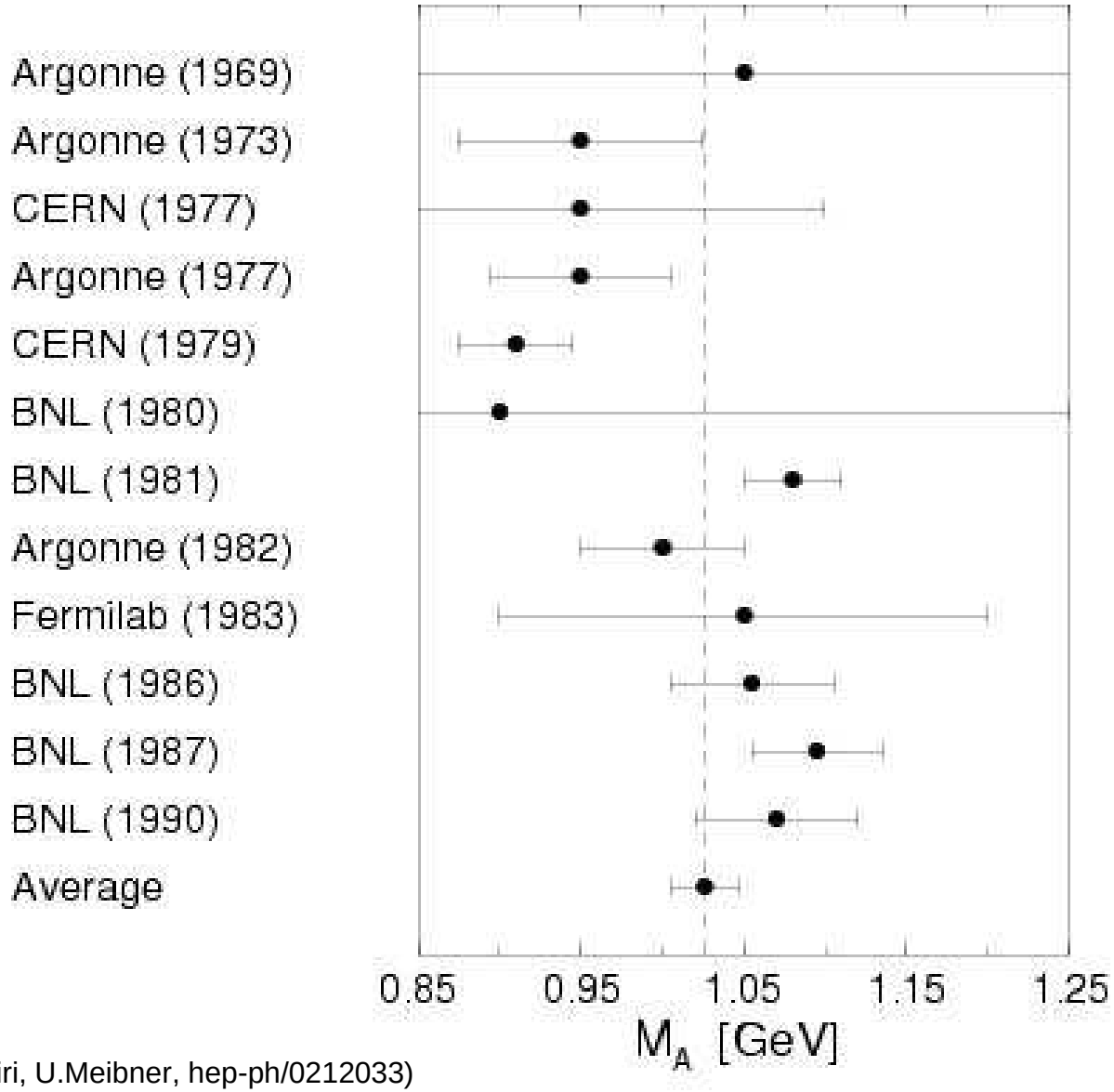
- p ,π rescattering absorption, exchange inside a nucleus
- Nuclear potential
- Pauli blocking
- Fermi motion

Adjustment of NEUT parameters

- QE : M_A=1.11 (instead of 1.01, survey 1.0 ~ 1.11)
- 1π : M_A=1.21 (instead of 1.01, survey 1.0~1.5)
- Coherent π :
  - J.Marteau et al., NIM A451(2000)
  - Use Rein&Sehgal, but cross section is scaled by ~0.5
- Multi-π :
  - A.Bodek et al., hep-ex/0203009
  - Re-scale by $q^2/(q^2+0.188)$
- (nQE/QE ratio)
  - Later fitted as a free parameter, found to be =0.93

Re-weight distributions according to the above adjustments

M_A? For QE



(V.Bernard, L.Elouadrhiri, U.Meibner, hep-ph/0212033)

M_A? for 1π production

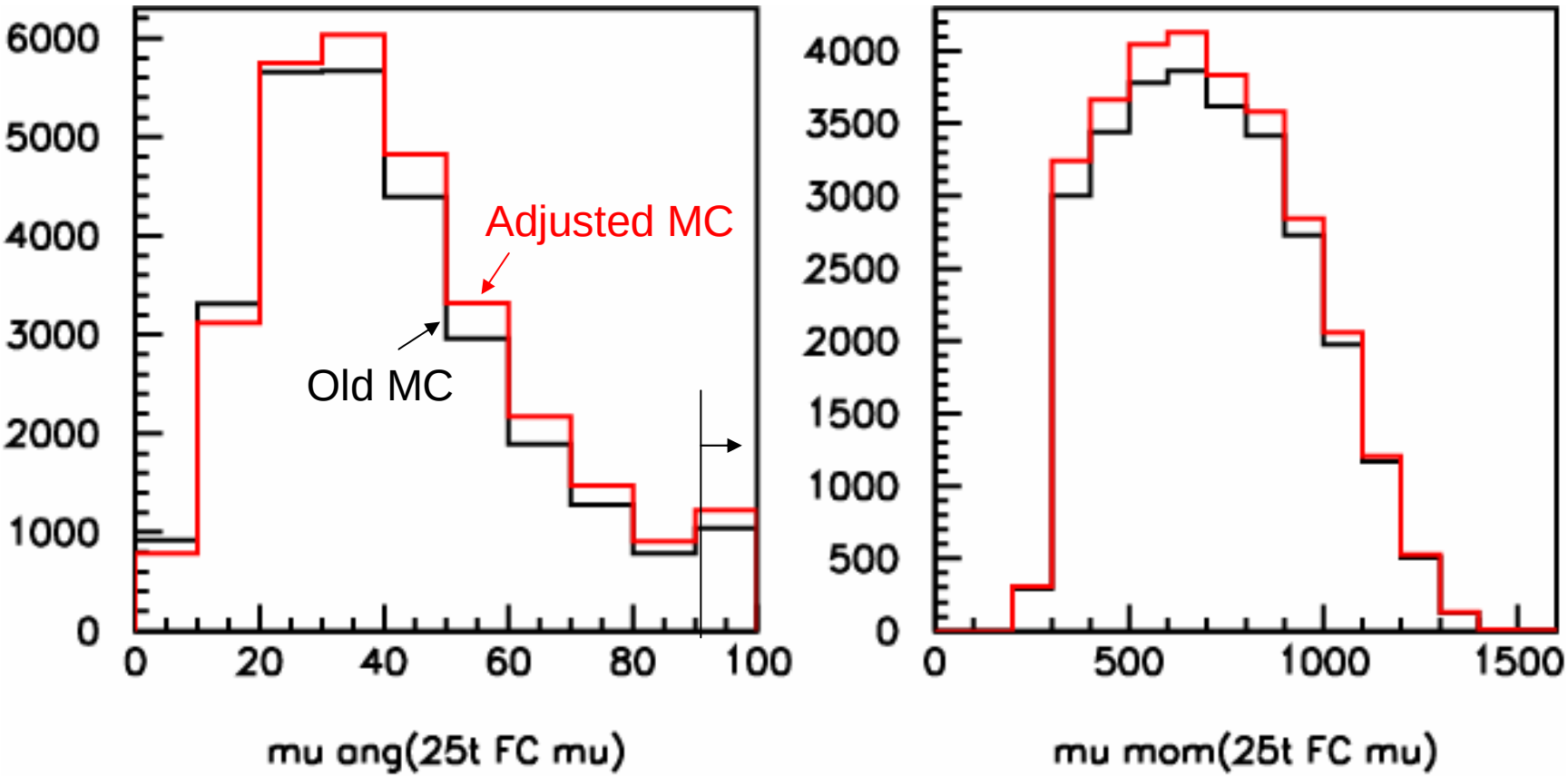
G.T.Joneset et al., Z.Phys. C43(1989)527-540

Model	Value of m_A(GeV)	Fitted quantity	Reaction
MA1	$1.25^{+0.15}_{-0.13}$ ⇐	Q^2 distribution, $Q^2<1$ GeV^2	$\nu p \to \mu^- p \pi^+$
	$1.43^{+0.07}_{-0.09}$ ⇐	Q^2 distribution, $Q^2<3$ GeV^2	
SvH	1.15 ± 0.10 ⇐	Q^2 distribution, $Q^2<3$ GeV^2	
SvH	0.85 ± 0.10	$\sigma(E_\nu^L)$	$\nu p \to \mu^- p \pi^+$
SvH	1.28 ± 0.11 ⇐	Q^2 distribution, 0.1 GeV^2 $<Q^2<3$ GeV^2	$\nu d \to \mu^- p \pi^+ (n)$
RS	0.96 ± 0.08	$\sigma(E_\nu^L)$	$\bar{\nu} d \to \mu^+ p \pi^- (n)$, $\bar{\nu} d \to \mu^+ n \pi^- (p)$
RS	1.01 ± 0.10	$\sigma(E_\nu^L)$, $W<1.6$ GeV	$\nu p \to \mu^- p \pi^+$
RS	1.05 ± 0.09	$\sigma(E_\nu^L)$, $W<2$ GeV	$\bar{\nu} p \to \mu^+ p \pi^-$
MA2	1.31 ± 0.12 ⇐	Q^2 distribution, $Q^2<1$ GeV^2	$\nu p \to \mu^- p \pi^+$, $\bar{\nu} p \to \mu^+ p \pi^-$

Q^2-fit favors larger M_A than σ(E) does?

Old NEUT vs Adjusted NEUT

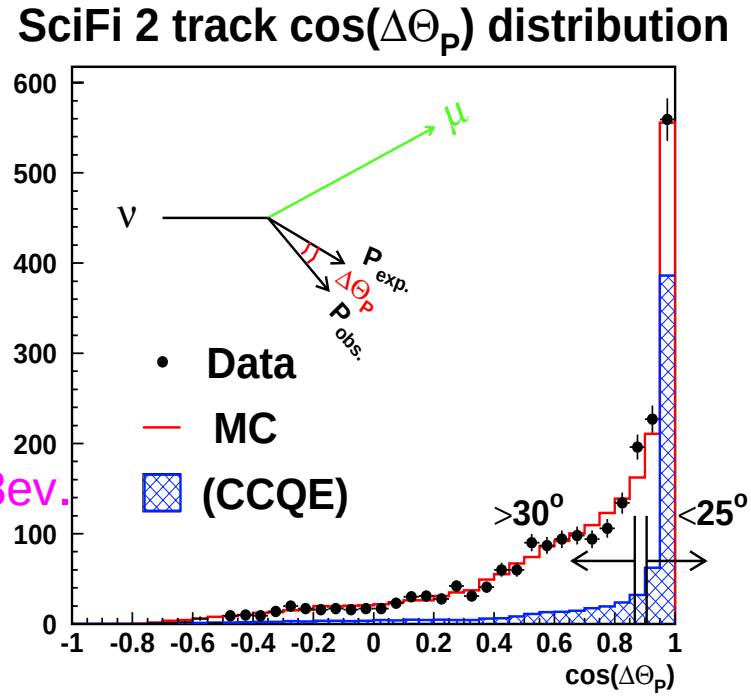
(Please ignore absolute normalization here)



For 1-ring FC μ-like sample

Data Set for Spectrum Measurements

- 1KT : P_μ<1.5GeV/c, 4π acceptance
  - Fid.25ton 1-ring μ-like FC : 22,476ev.
- SciFi : P_μ>1GeV/c, θ_μ<60deg.
  - 1-track μ-like (MRD 3D+1L) : 5963ev.
  - 2-track QE-enriched ($\Delta\theta_p$<25deg.) : 764ev.
  - 2-track nonQE-enriched ($\Delta\theta_p$>30deg.) : 1288ev.
- PIMON
  - π (p,θ) distribution ⇒ Neutrino Spectrum (>1GeV)



Fitting Parameters

E_ν : 8 bins, nonQE/QE ratio : 1

(+ normalization, detector systematic parameters)

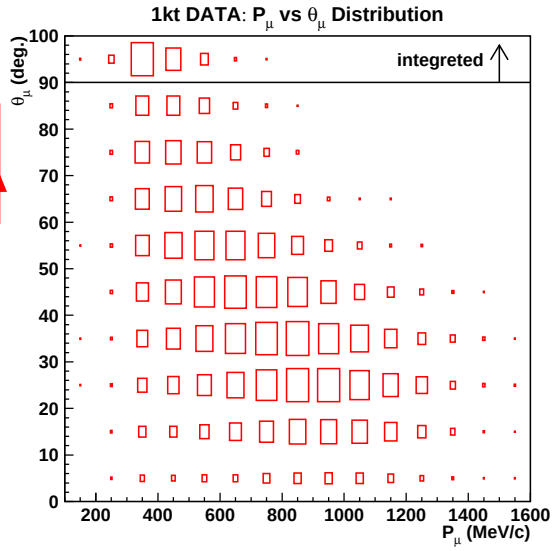
See K2K spectrum analysis paper in hep-ex

Eν spectrum fitting

Fitting parameters: f_{1-8} , R_{nqe}

χ^2-fitting : $\chi^2_{\mathrm{merged}} = \chi^2_{\mathrm{1kt}} + \chi^2_{\mathrm{SciFi}}$

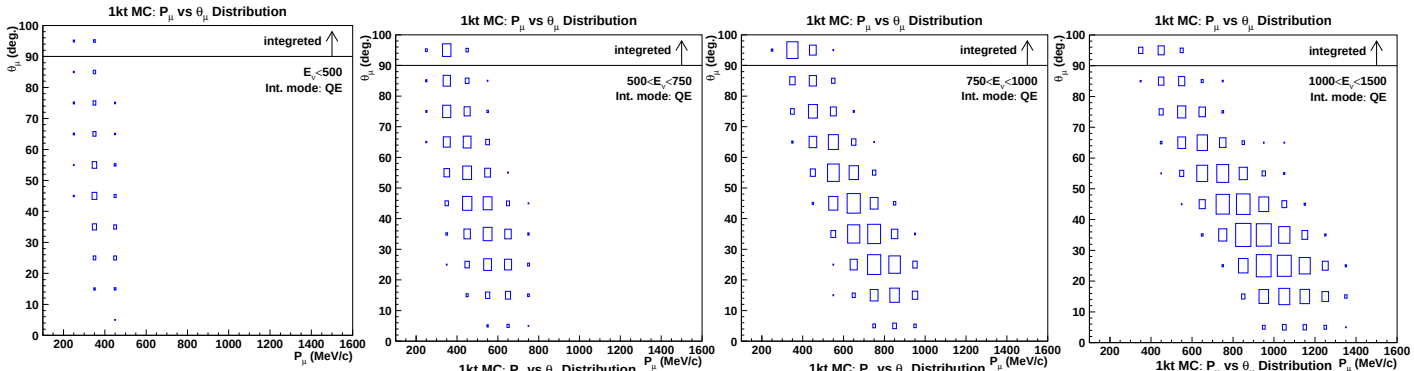
DATA



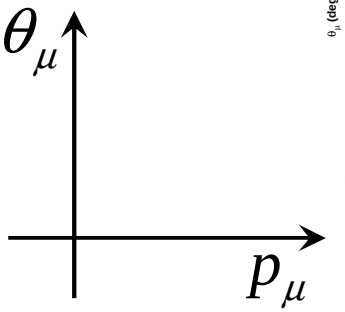
MC templates (8bins x 2)

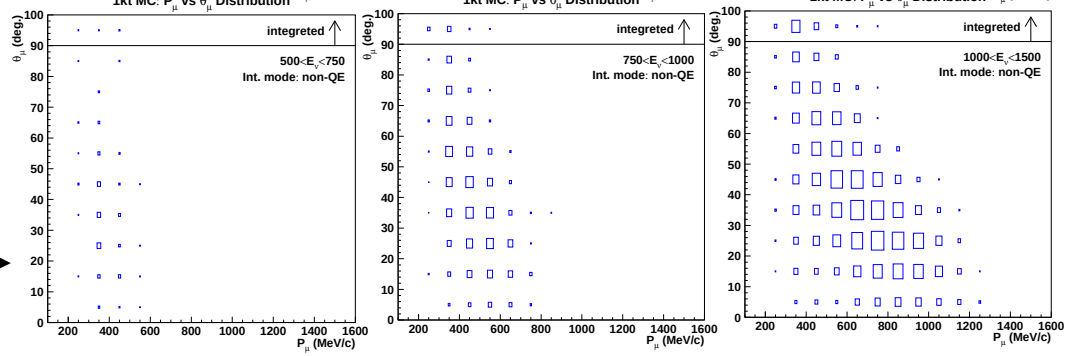
E_ν^{true} : 0.0 – 0.5 | 0.5 – 0.75 | 0.75 – 1.0 | 1.0 – 1.5

QE

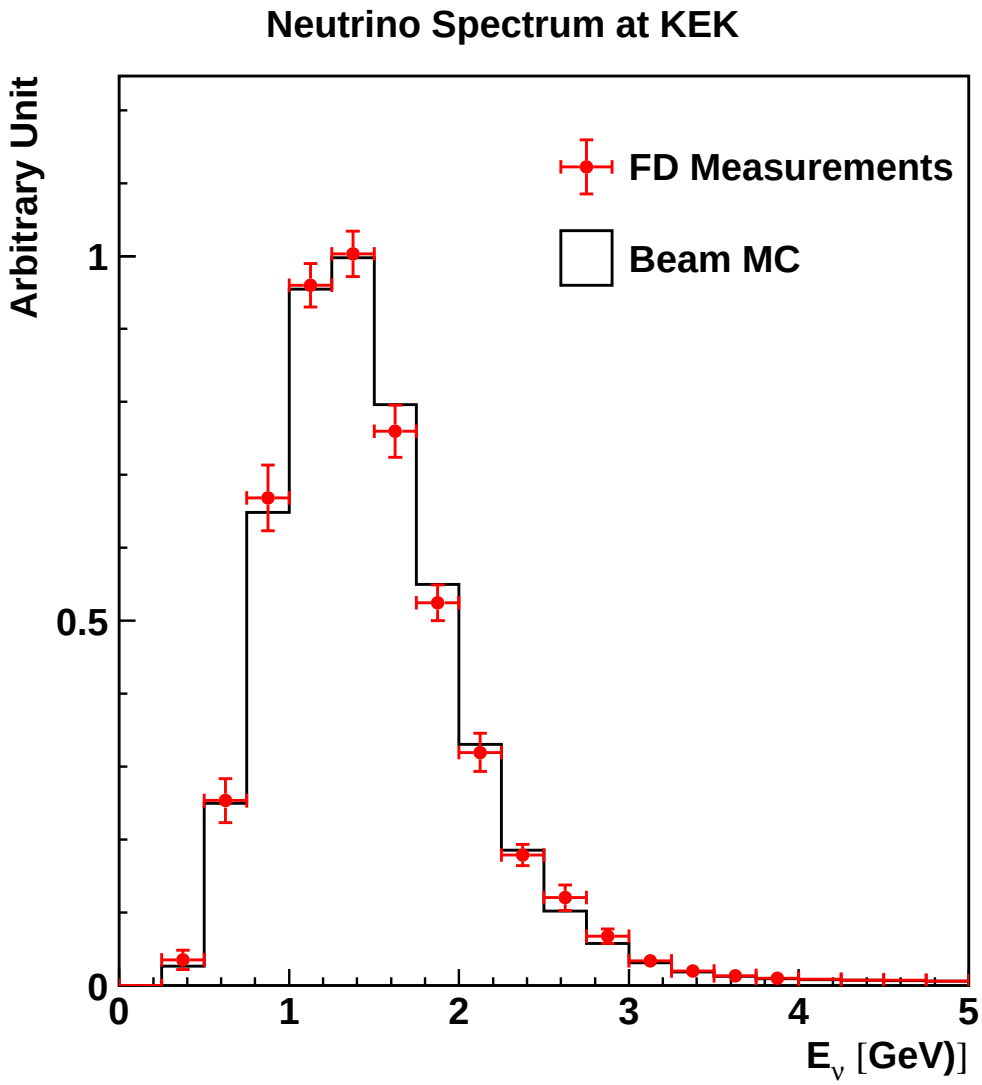


non-QE

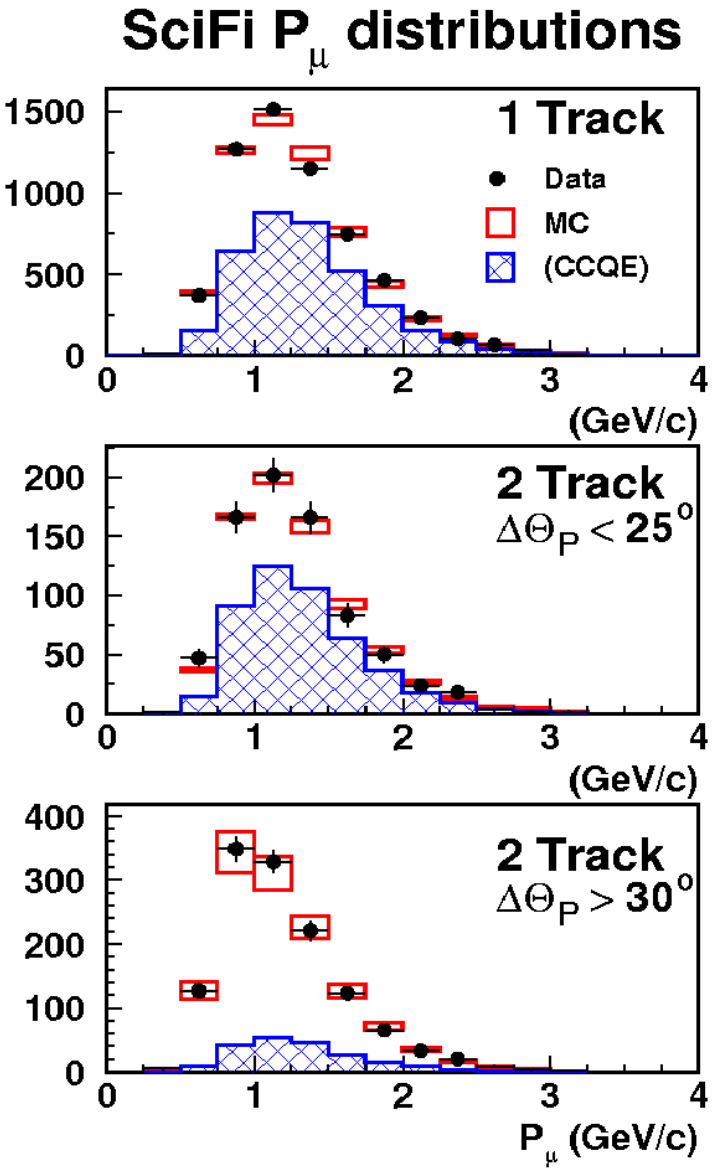


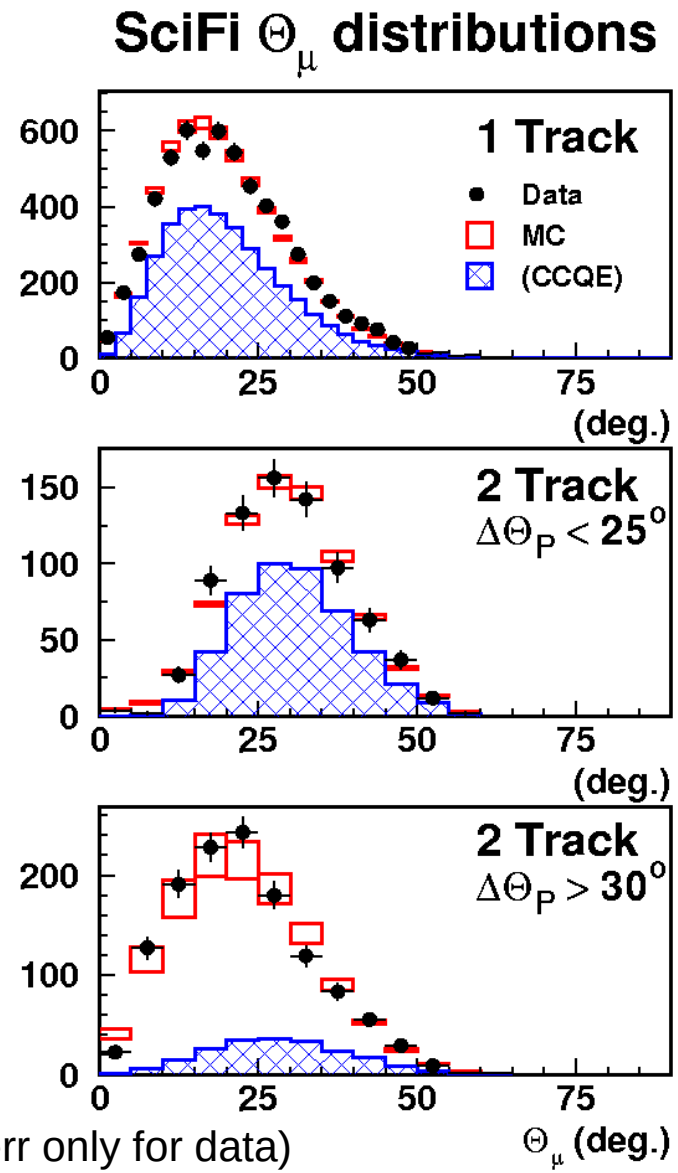


Results of Fitting :Eν Spectrum



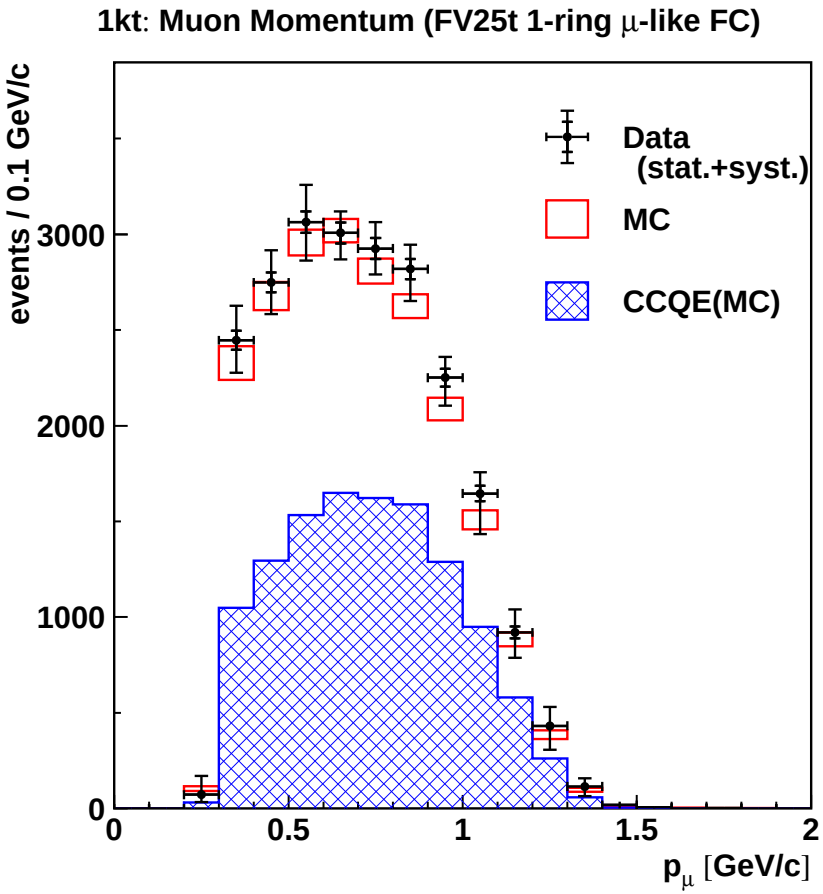
Results of Fitting : SciFi

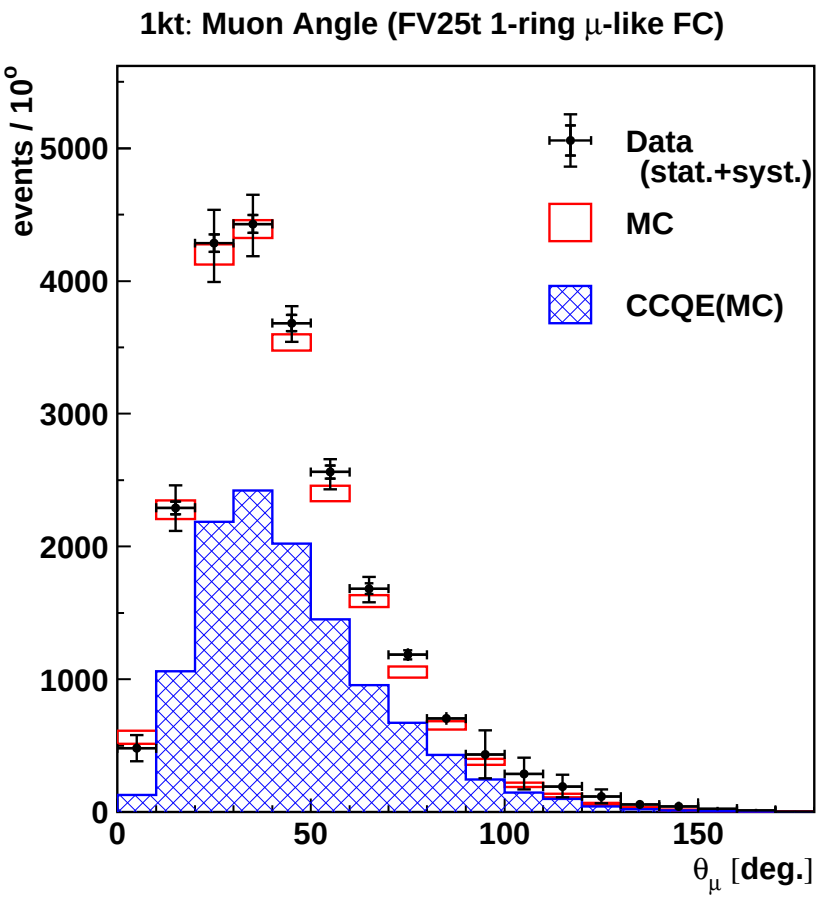




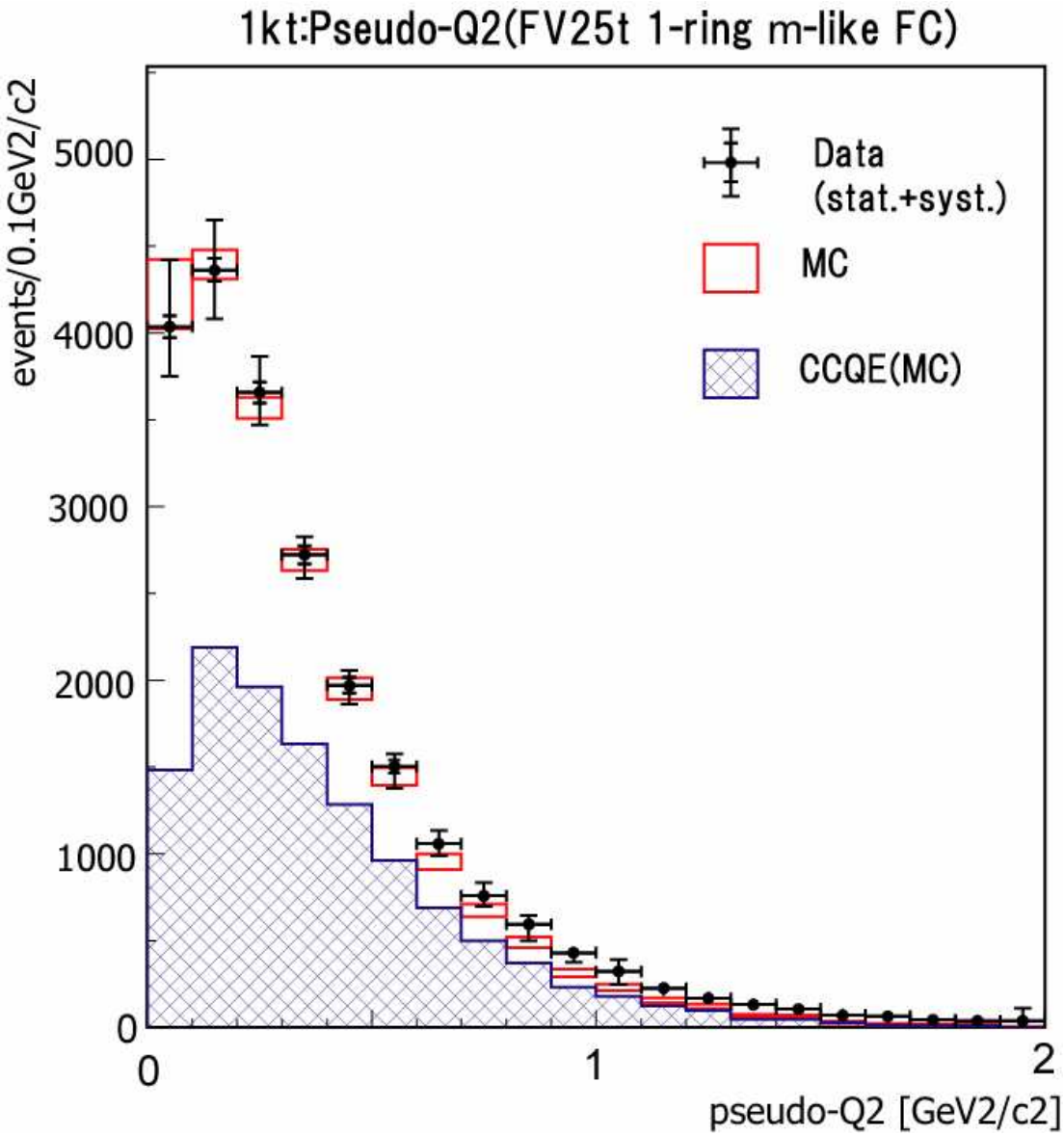
(Stat err only for data)

Results:1KT 1-R μ sample



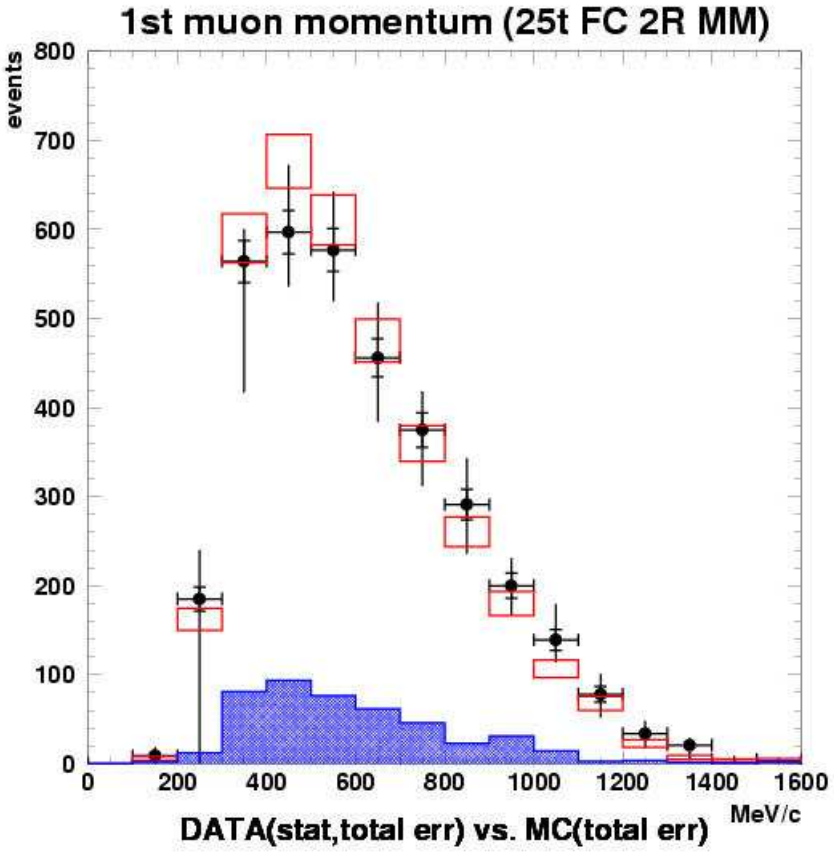


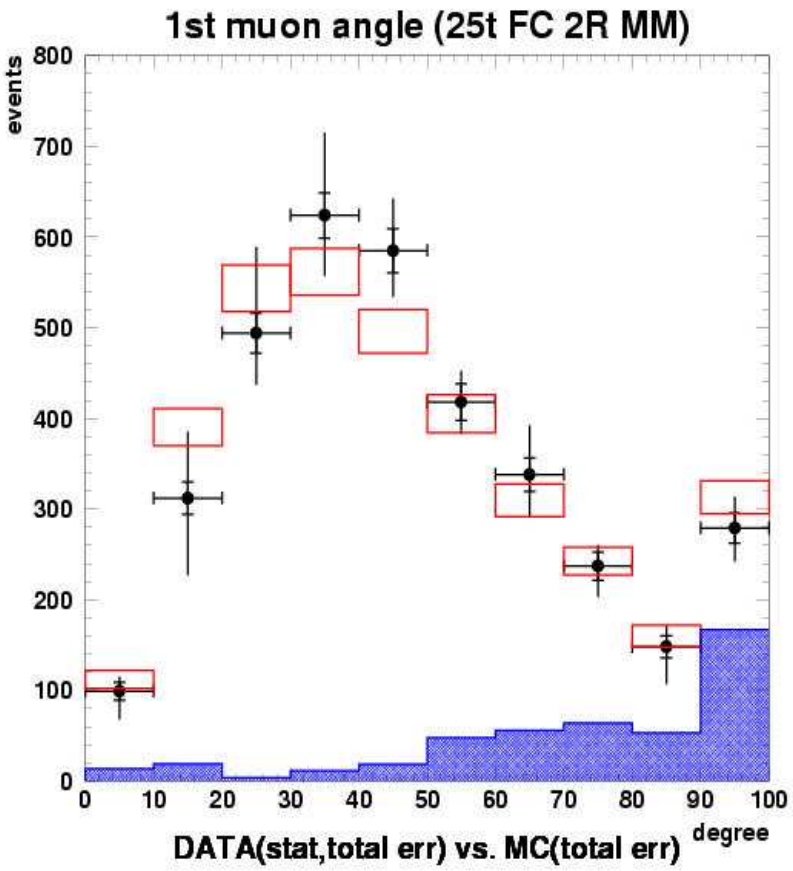
Results: Q^2 of 1kt 1-R μ



Check with 1kt nQE sample

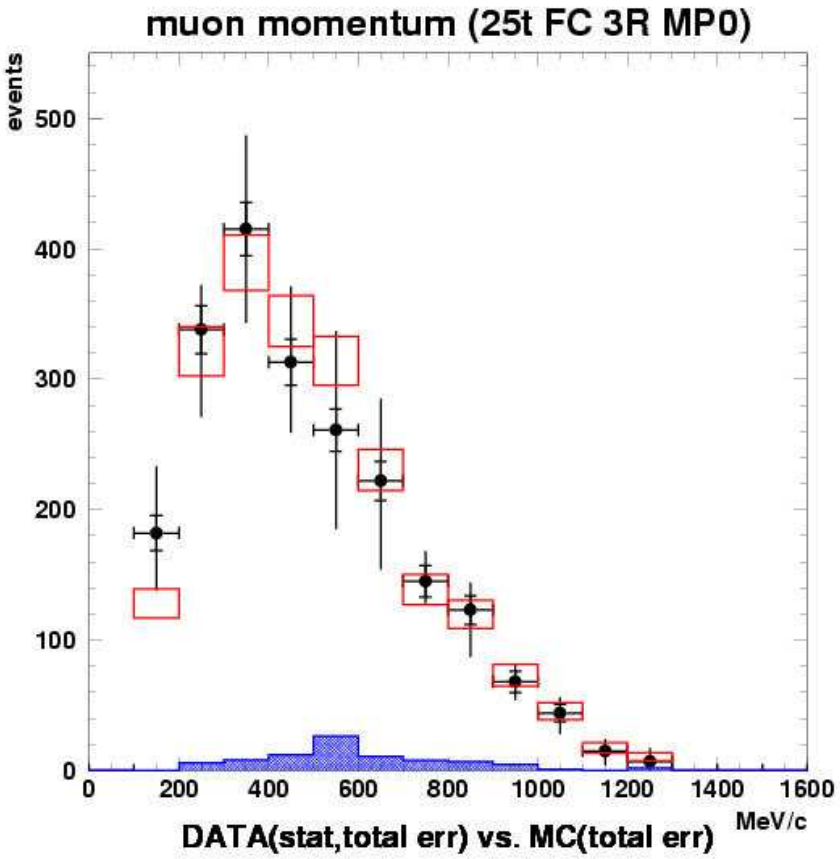
2-R μπ sample

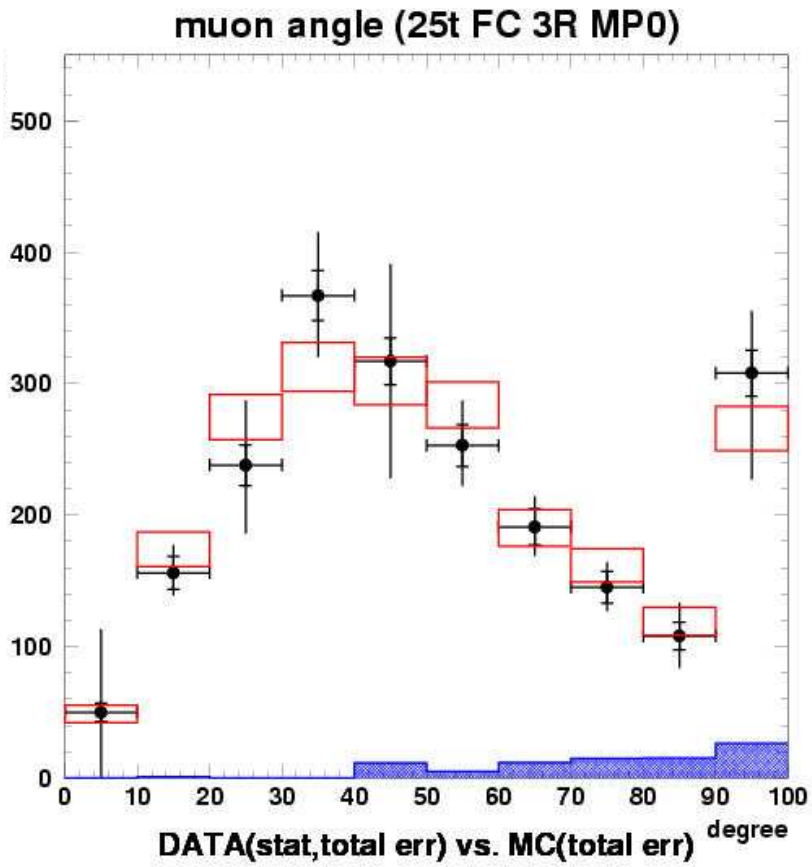




Preliminary

3-R $\mu\pi^0$ sample

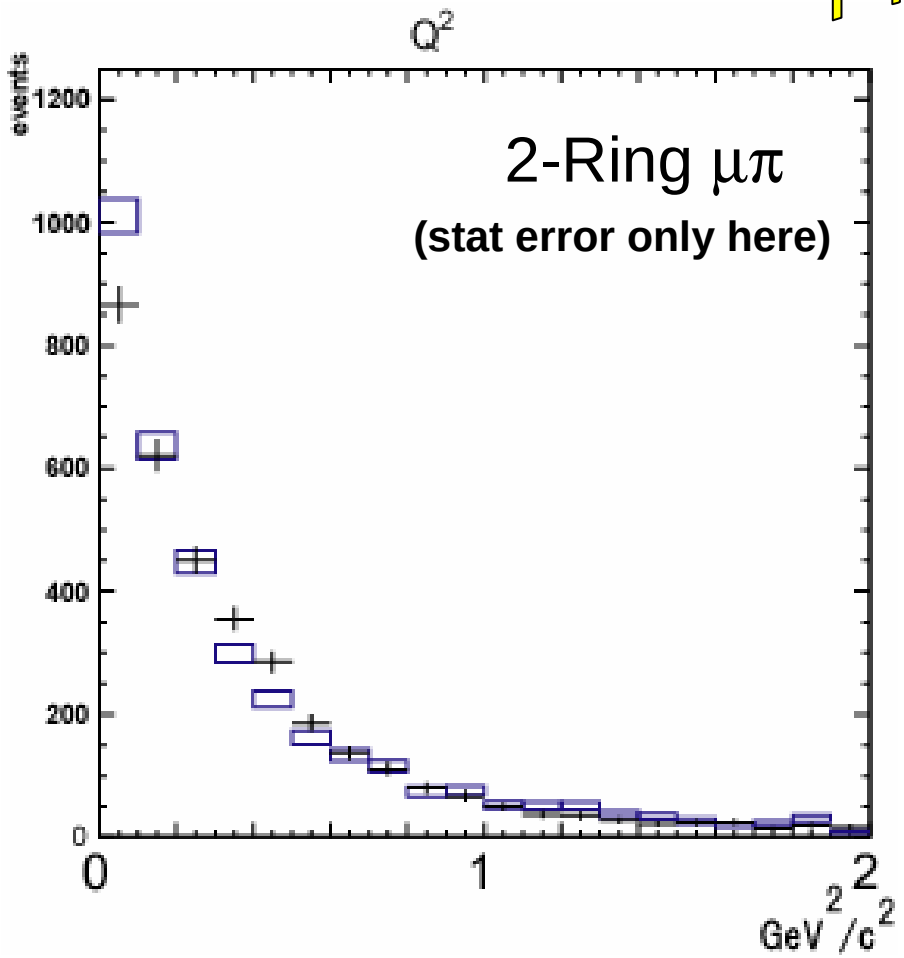


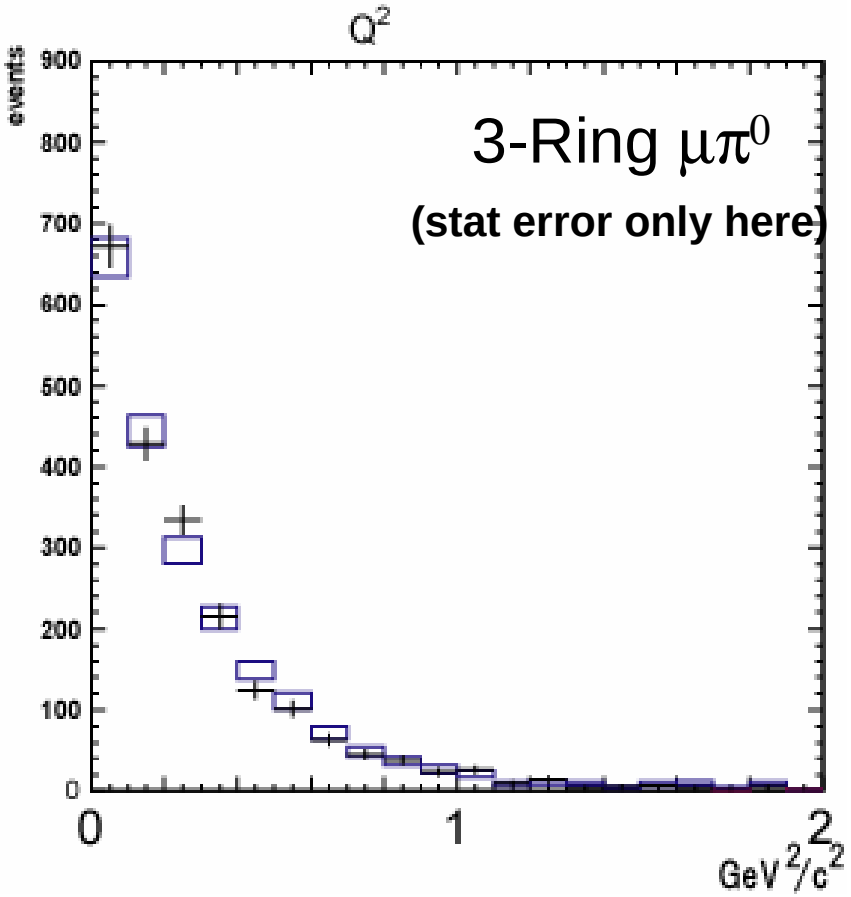


Preliminary

Pseudo-Q^2 for 1kt 2R$\mu\pi$ 3R$\mu\pi^0$

Preliminary





Summary

- K2K Eν spectrum is determined by two near detectors
  - 1kt water Cherenkov detector
  - Fine Grain Detector
- ν interaction model (“NEUT”) is adjusted to cope with low-Q^2 behavior
  - Larger MA for QE(=1.11) and 1π(=1.21)
  - Re-scaling for DIS (Bodek’s)
  - Smaller coherent production (Marteau’s)
- These modification reasonably explain various distributions
  - 1kt 1-R m-like, 2-R μμ, 3-Rμπ^0, FGD 1track, 2track
  - This is the current best explanation.
  - Another explanation ? (Paschos’s idea ?)