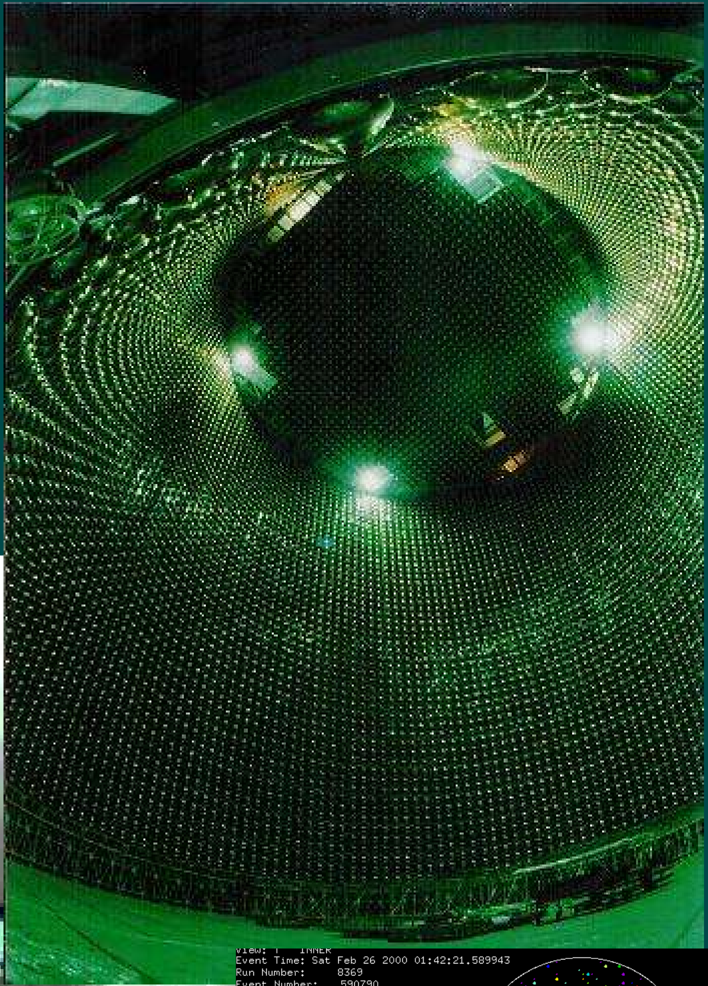
Risultati recenti in K2K

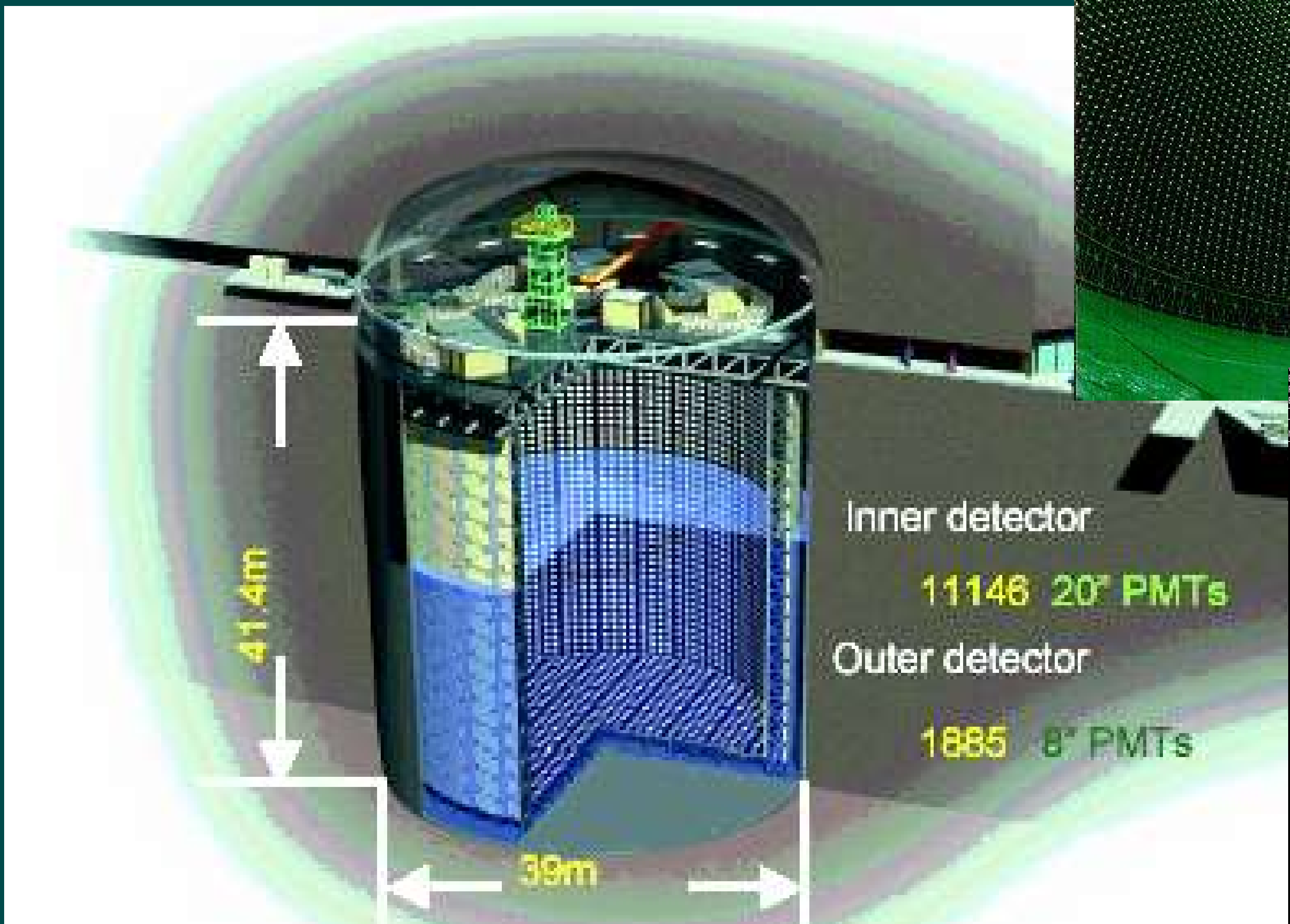
Layout dell'esperimento
Contributo di Roma
Nuovi(*) risultati di oscillazione

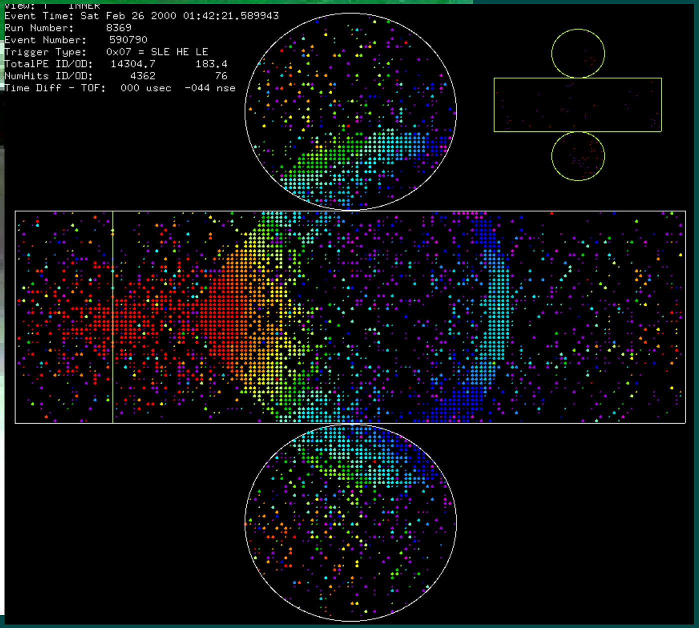
(*) DISCLAIMER: risultati preliminari in corso di pubblicazione

KEK neutrino beam

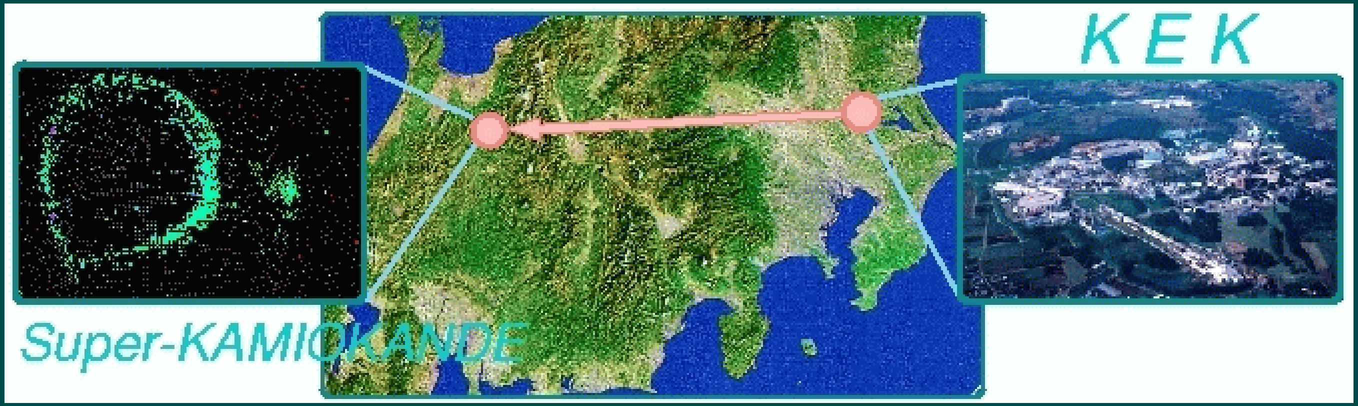
Super-Kamiokande







K2K Collaboration



K2K-I   Japan, Korea, Poland and USA.

K2K-II   in 2002 joined by Canada, France, Italy, Russia, Spain and Switzerland.

Also the core of the T2K proto-collaboration.

Roma in K2K-II

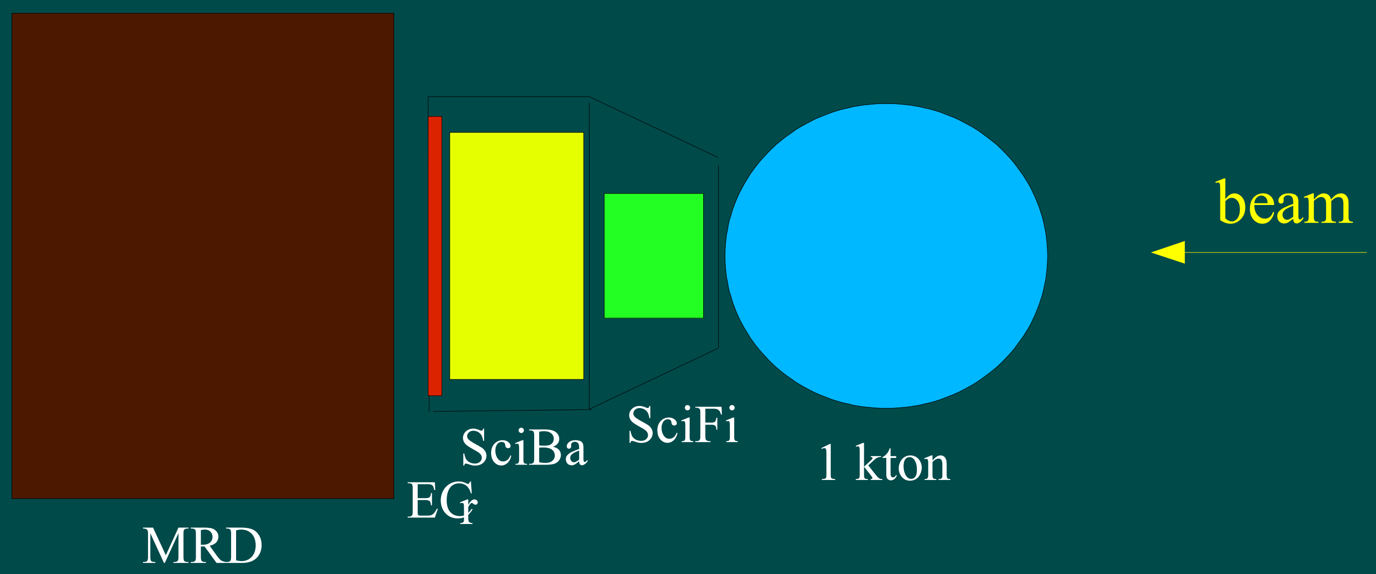
- Partecipazione a K2K-II sin dall'inizio (novembre 2002).
- Corresponsabilità nel nuovo rivelatore SciBar.
- Responsabilità dell'Electron Catcher (EC).
- Una membership nel Convener Board.
- Contributo all'analisi dei dati.
- Futuro (T2K).

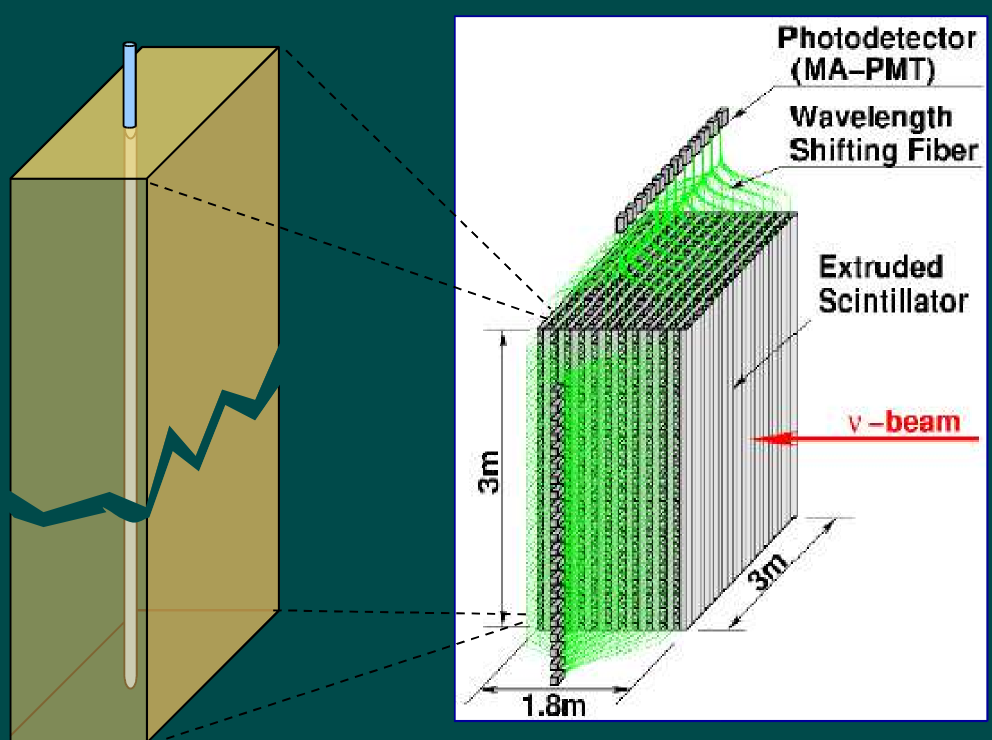
Composizione del gruppo

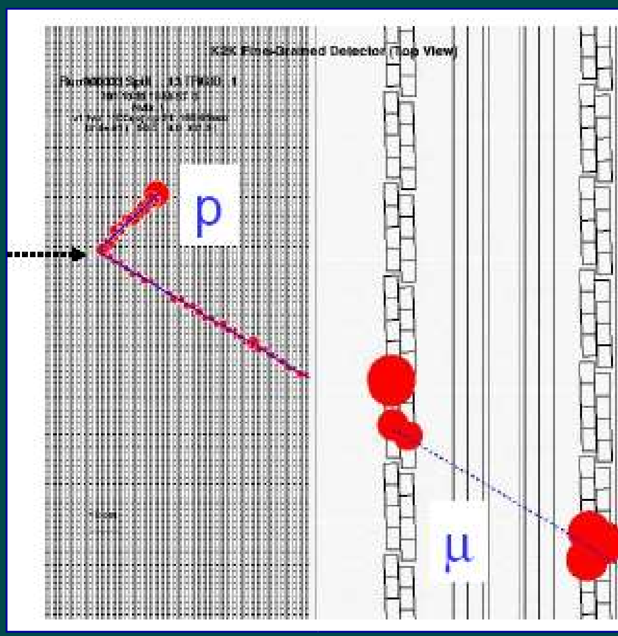
F.Cidronelli(2), U.Dore, C.Gargiulo(1), A.Iacoangeli(2), P.F.Loverre, L.Ludovici, A.Maslennikov(2), C.Mariani, F.Pulcinella(2), M.Zullo(1)

(1) Servizio di Progettazione Meccanica
(2) Supporto tecnico

K2K-II upgrade (SciBar+EC)







SciBar motivation

Physics capabilities

Study low energy ν interactions with high granularity

Event classification (proton visible)

High statistic (16t mass, intense beam)

Physics output

Quasi-elastic vs non-quasi elastic cross section

π^o cross section

Improve K2K systematic

T2K training

EC motivation

Physics capabilities

Longitudinal containment (85% at 3GeV)

Energy reconstruction (14%/$\sqrt{E}$)

electron vs (muon or pion) ID

π^{o} reconstruction

Physics output

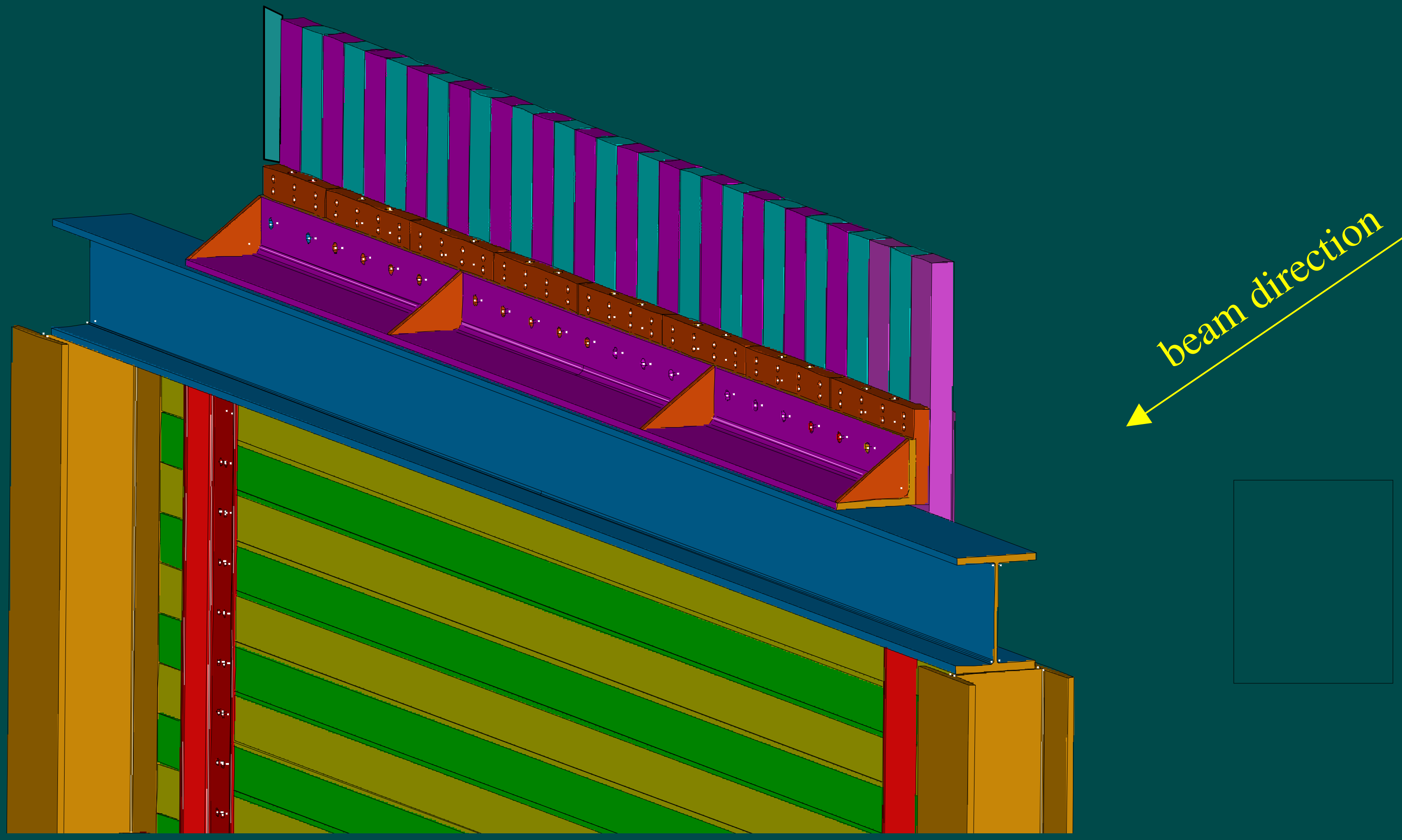
ν_e energy spectrum

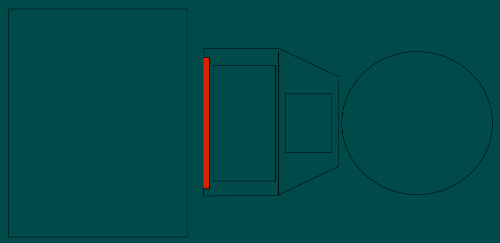
π^{o} statistic

Enhance PID and event classification

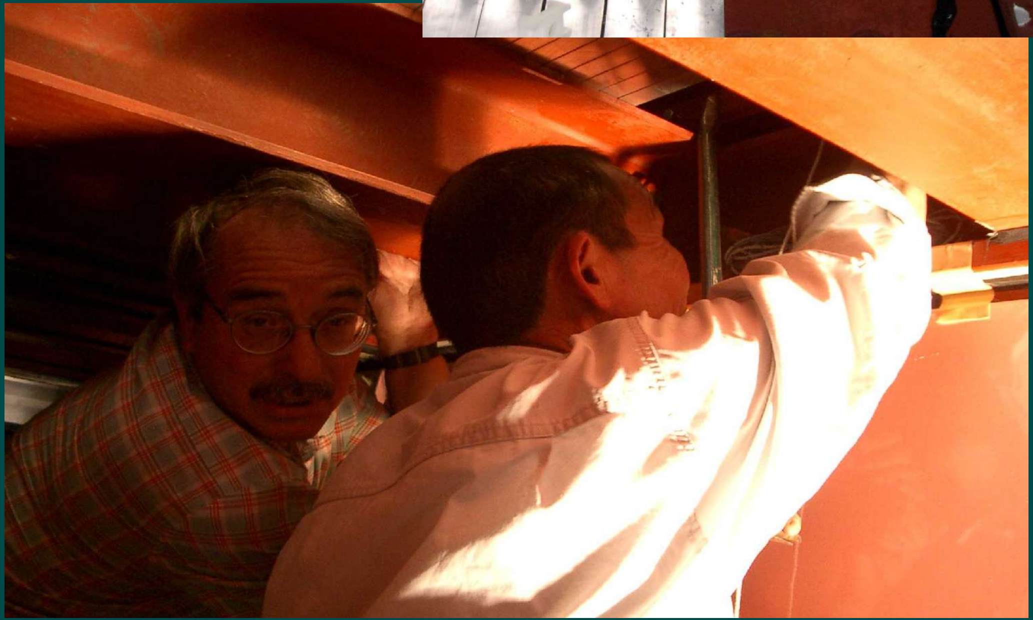
EC structure

- Two orthogonal planes just downstream of SciBar (4 Xo), providing energy reconstruction and cluster positions in both transverse projections (11 Xo and 0.38 λint).
- 30 horizontal modules (60 readout cells) and 32 vertical modules (64 readout cells).
- The fibers in each readout cell (4x4x265cm) are bundled both side to 248 PMTs.
- Readout by VME ADC (CAEN V792).



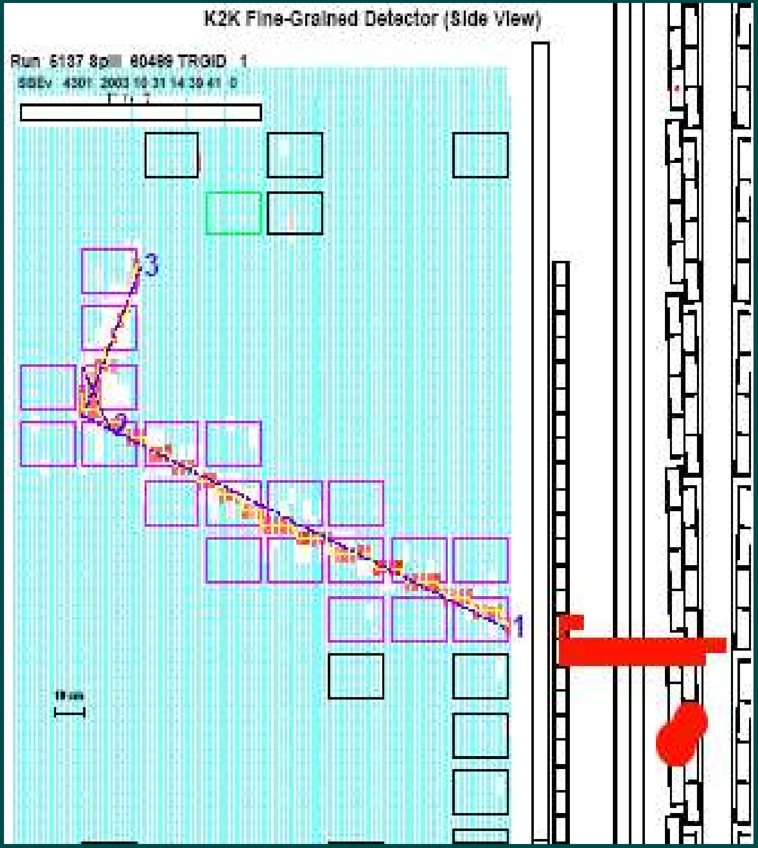




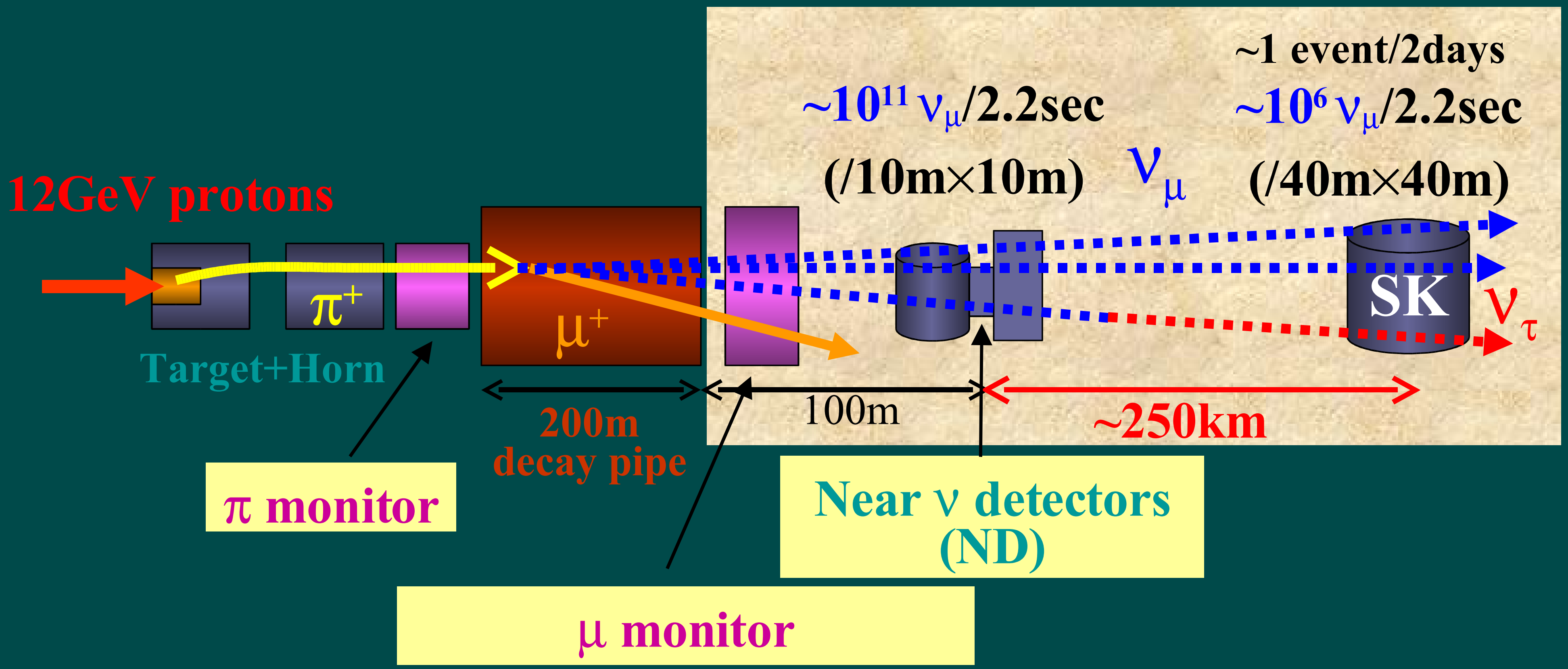

PRELIMINARY

ν_e measurement (Rome)



- Select interactions in main SciBar and use EC for electron ID
- 27 ν_eQE candidates found, out of which 10 have a visible recoil proton
- Analysis of efficiency and background in progress
- 10-15% statistical error on ν_e/ν_μ including the coming data sample.

K2K Conceptual Setup

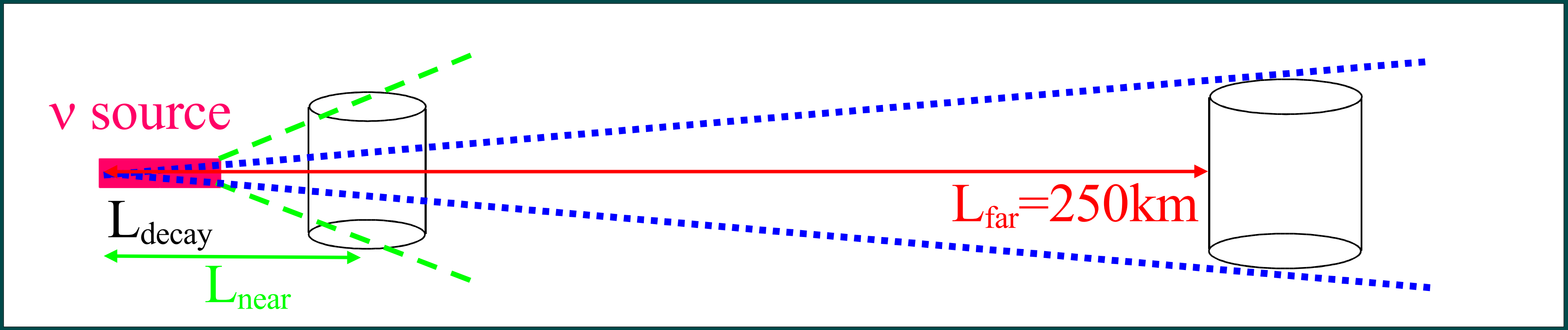


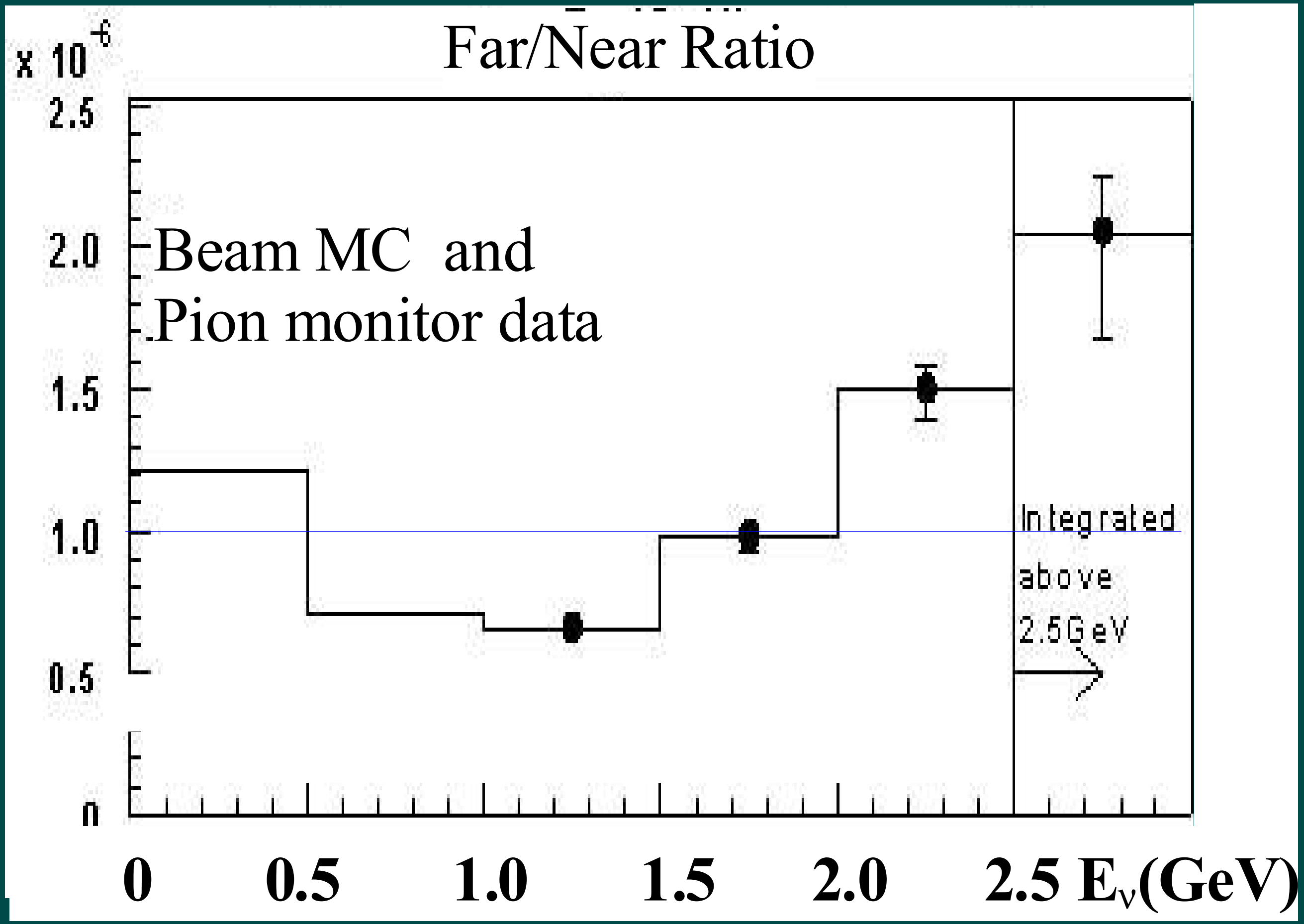
Signal of ν oscillation in K2K

Reduction of ν_μ events

Distortion of ν_μ energy spectrum

Far/Near Ratio

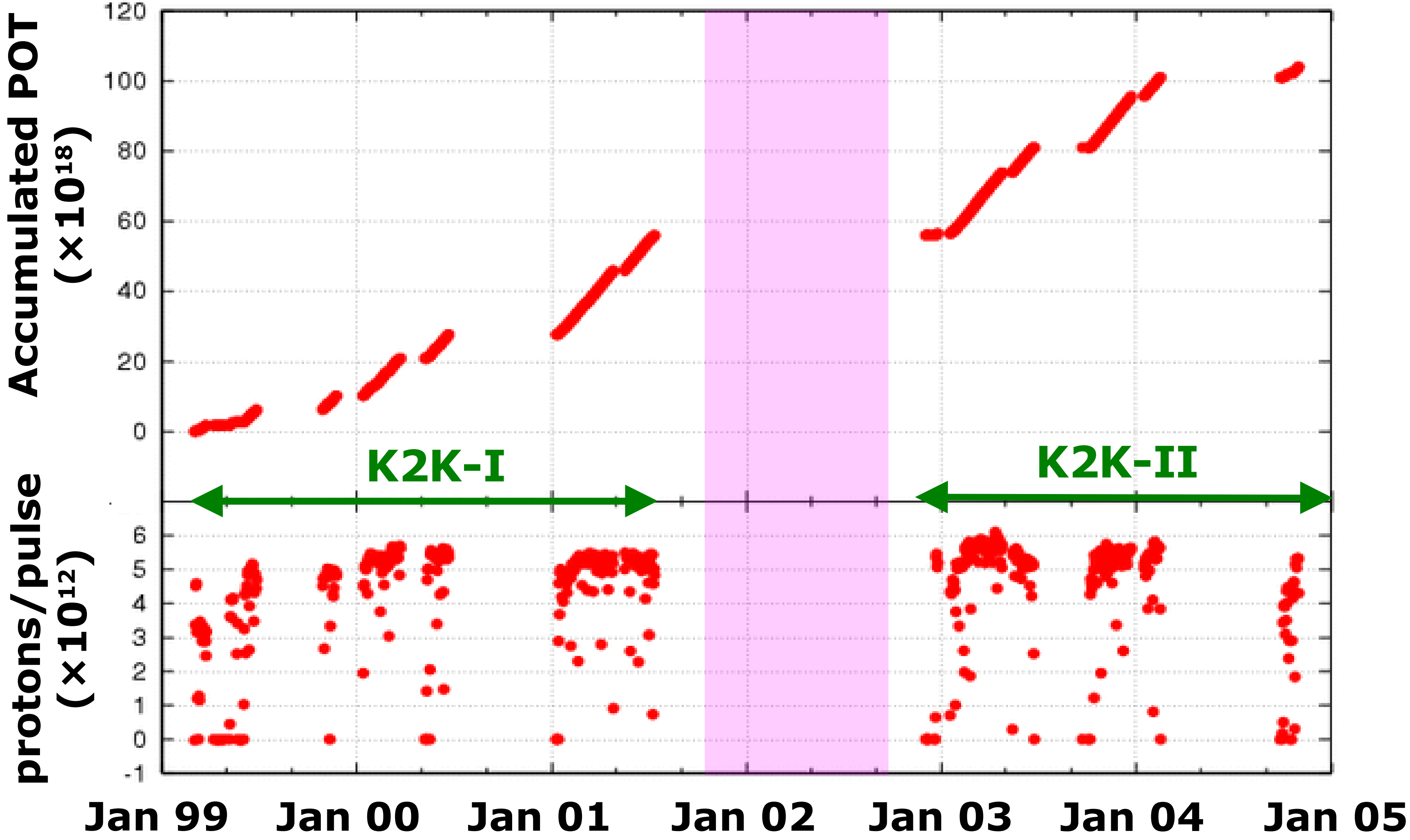




$R = f(E_\nu) \neq (L_{near}/L_{far})^2 \sim 10\text{-}6$

for $L_{near} \approx L_{decay}$

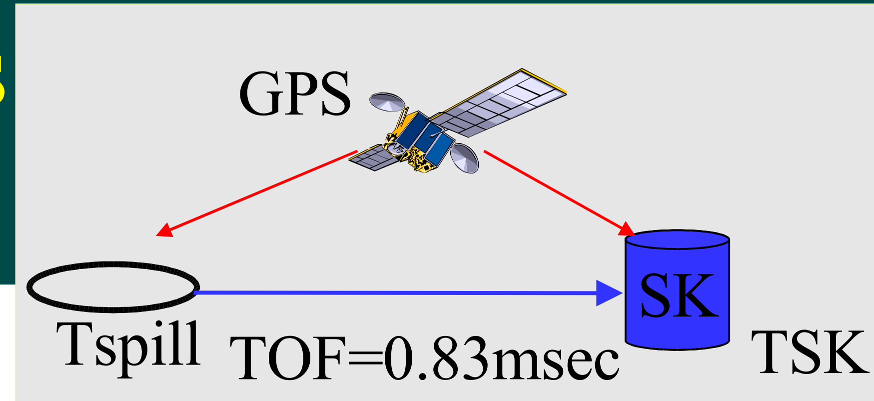
Proton on Target (PoT)

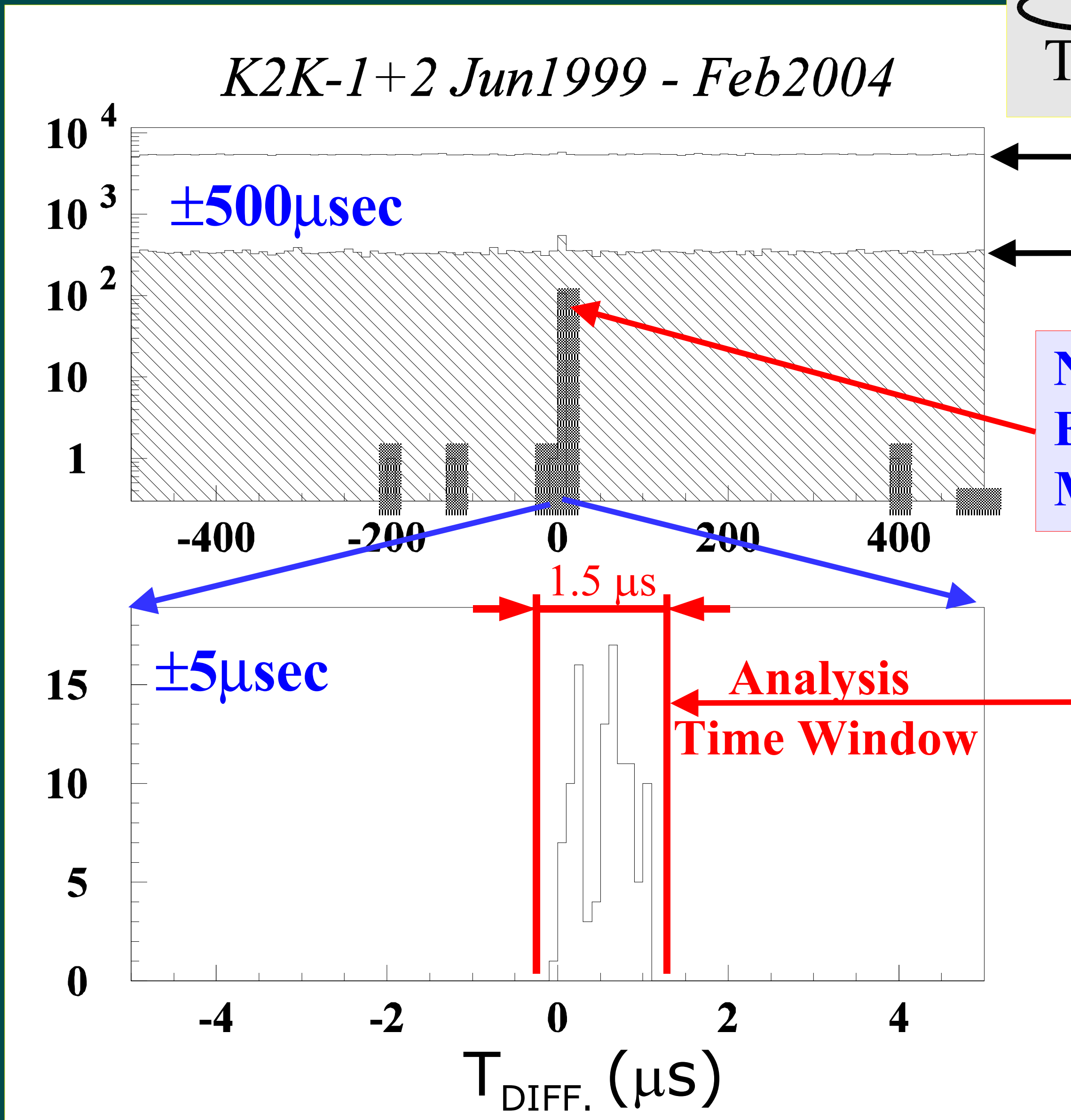


$10.1\ 10^{19}$ PoT delivered

$8.9\ 10^{19}$ PoT for physics analysis

SuperKamiokande Events





Decay electron cut.

≥20MeV Deposited Energy

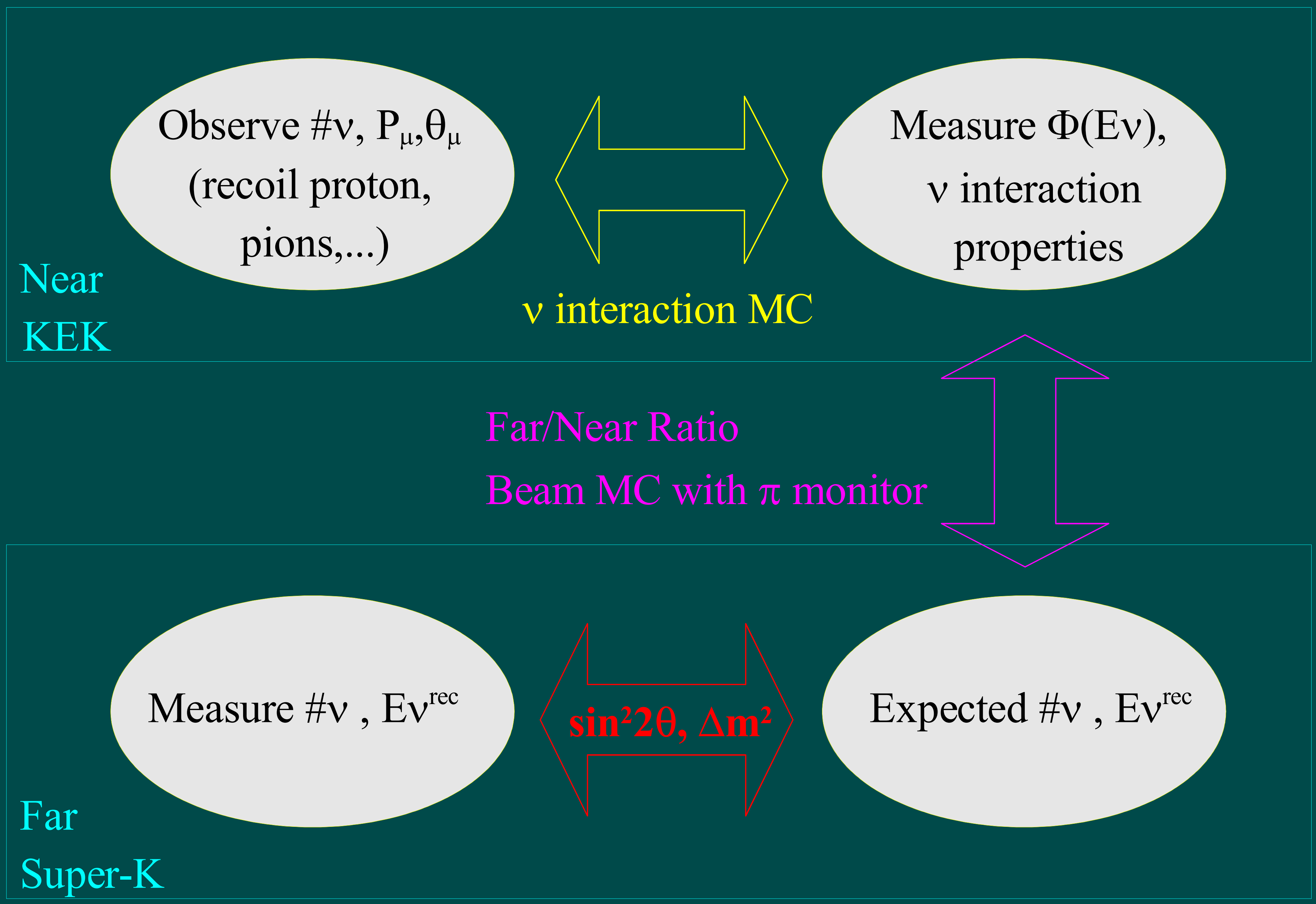
No Activity in Outer Detector
Event Vertex in Fiducial Volume
More than 30MeV Deposited Energy

$-0.2 < T_{SK} - T_{spill} - TOF < 1.3\mu sec$

107 events

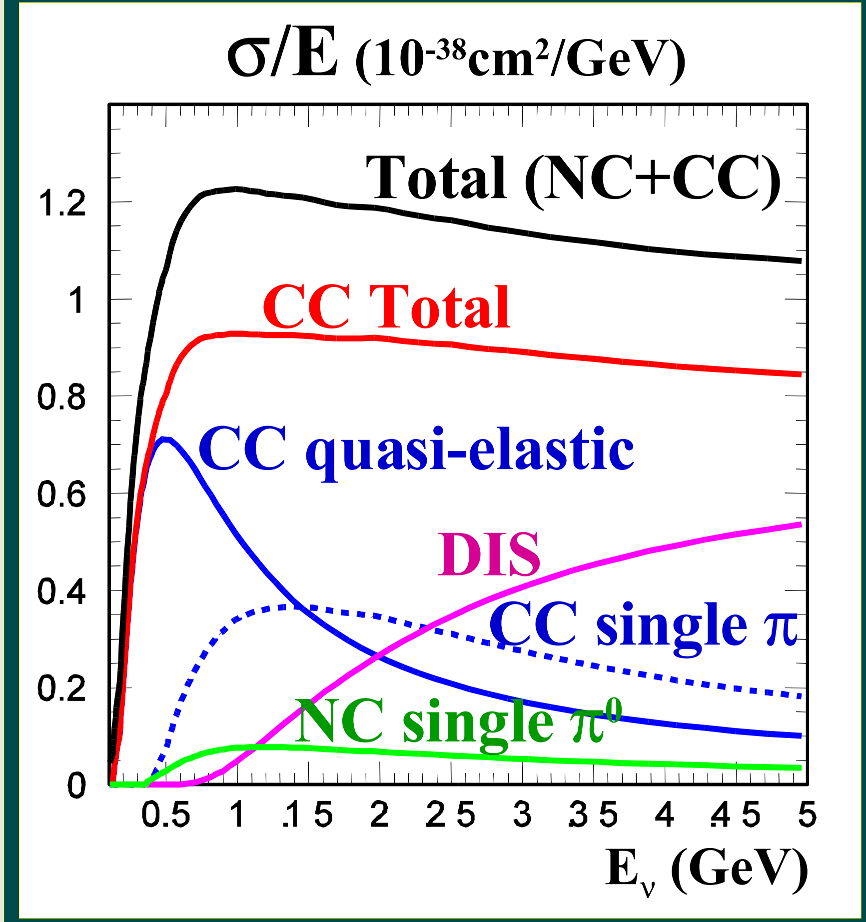
(BG: 1.6 events within ±500μs
2.4×10^{-3} events in 1.5μs)

Analysis Strategy

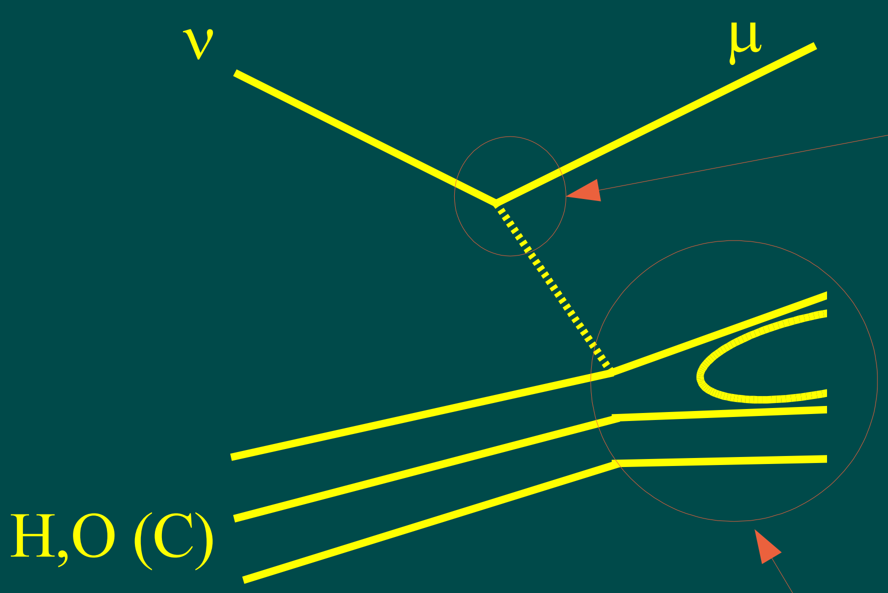


Neutrino Interaction MC (NEUT)

- **CC quasi elastic (CCQE)**
  - Smith and Moniz with M_A=1.1GeV
- **CC (resonance) single π(CC-1π)**
  - Rein and Sehgal's with M_A=1.1GeV
- **DIS**
  - GRV94 + JETSET with Bodek and Yang correction.
- **CC coherent π**
  - Rein&Sehgal with the cross section rescale by J. Marteau
- **NC**
- **Nuclear effects: oxygen, carbon**



Low Energy ν Interactions



Lepton Kinematics

- Nucleons: QE dominates but resonance and DIS has to be added and combined at low W
- Nucleus: Fermi motion, Pauli blocking, binding, EMC, shadowing, spectral functions

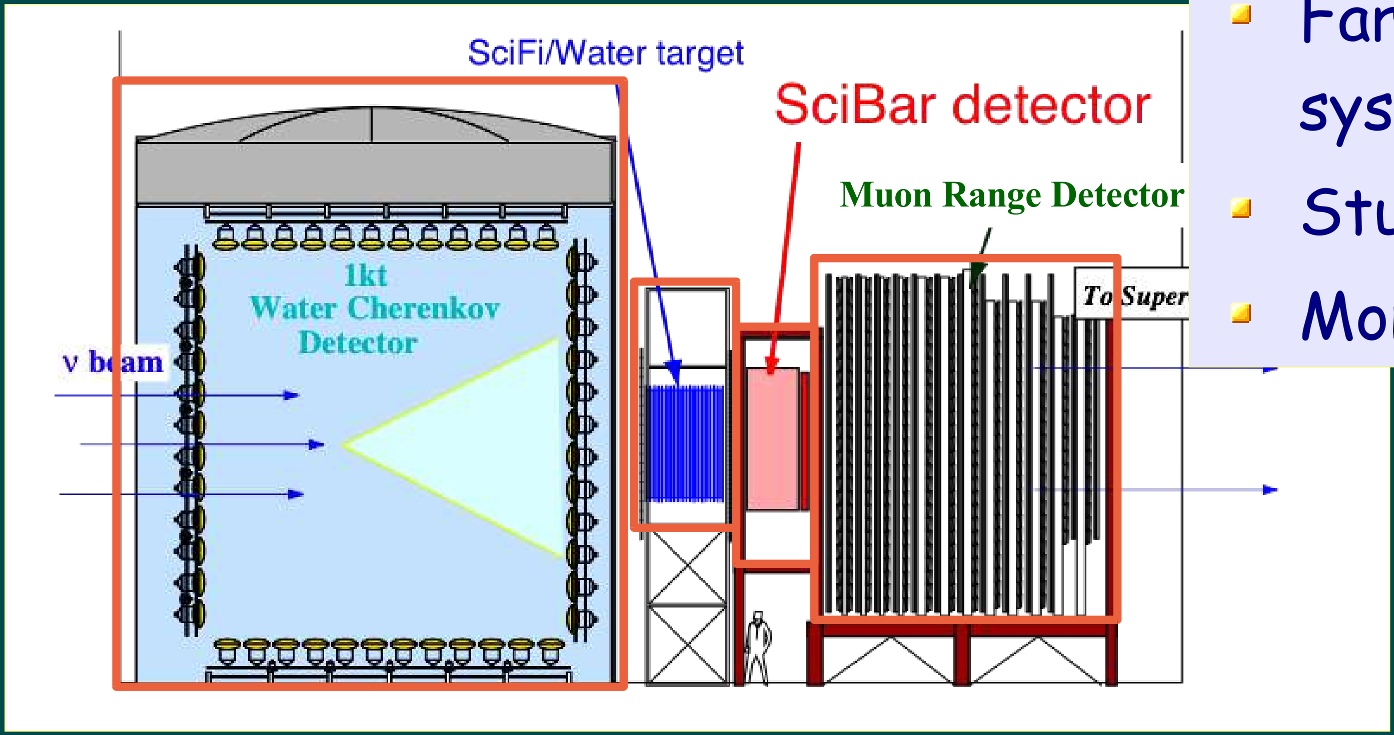
Hadronic system.

- Nucleons: validity of resonance models (Rein-Seghal), low invariant mass DIS hadronisation.
- Nucleus: intranuclear scattering and reinteractions

NUINT workshops. (NUINT04 at LNGS).

Near Detector Layout

- 1KT Water Cherenkov (1KT)
- Scintillating-fiber/Water sandwich (SciFi)
- Lead Glass calorimeter (LG) before 2002
- Scintillator Bar Detector (SciBar) after 2003
- Muon Range Detector (MRD)



- Measure neutrino flux
- Far/Near: detector systematics, C vs O
- Study ν properties
- Monitor ν beam stability

1KT: Neutrino Flux Extrapolation

- Water Cherenkov replica of Super-K (scale 1/50, ~1/1000 fiducial)
- Most of detector systematics cancel in the extrapolation

$$N_{SK}^{exp} = N_{KT}^{obs} \bullet \boxed{\frac{\int \Phi_{SK}(E_\nu)\sigma(E_\nu)dE_\nu}{\int \Phi_{KT}(E_\nu)\sigma(E_\nu)dE_\nu}} \bullet \frac{M_{SK}}{M_{KT}} \bullet \frac{\varepsilon_{SK}}{\varepsilon_{KT}}$$

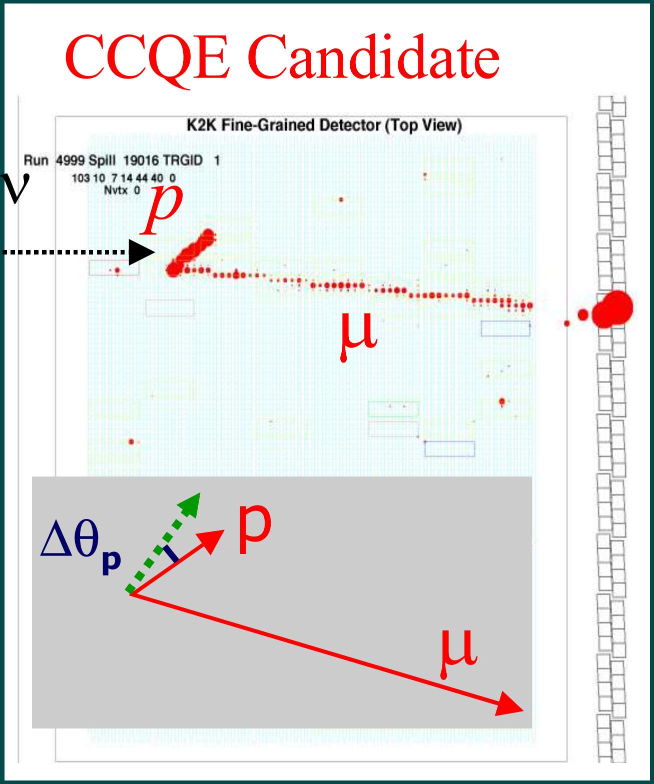
≡Far/Near Ratio ~1×10^{-6} (from MC)

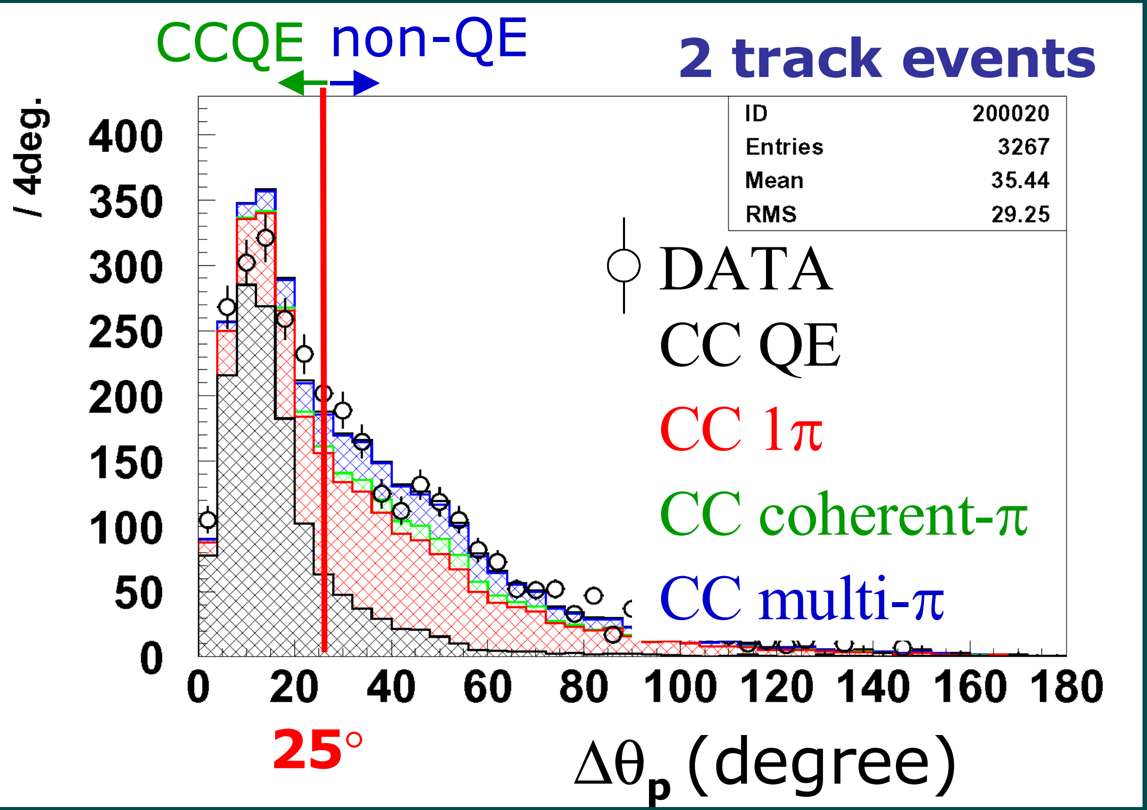
M: Fiducial mass	M_{SK}=22,500ton,	M_{KT}=25ton
ε: efficiency	$\varepsilon_{SK\text{-}I(II)}$=77.0(78.2)%,	ε_{KT}=74.5%

$N_{SK}^{exp} = 150.9\,^{+11.6}_{-10.0}$ ⟷ $N_{SK}^{obs} = 107$

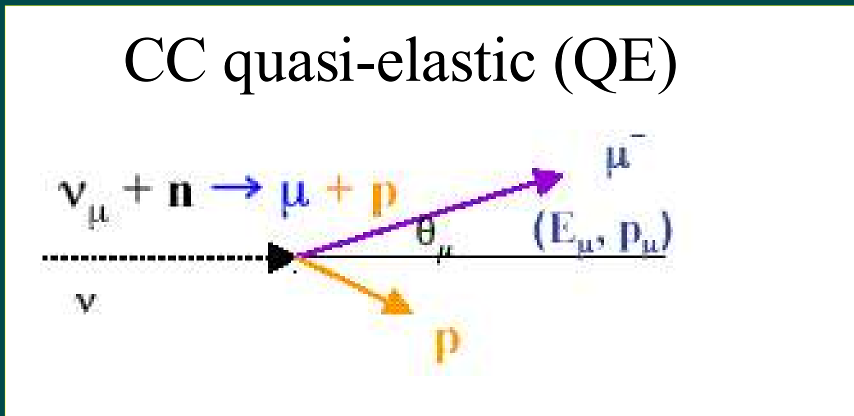
SciBar: QE vs nonQE study

- Fully active fine-grained detector
- Low energy proton visible
- Study (enriched) QE and nonQE samples

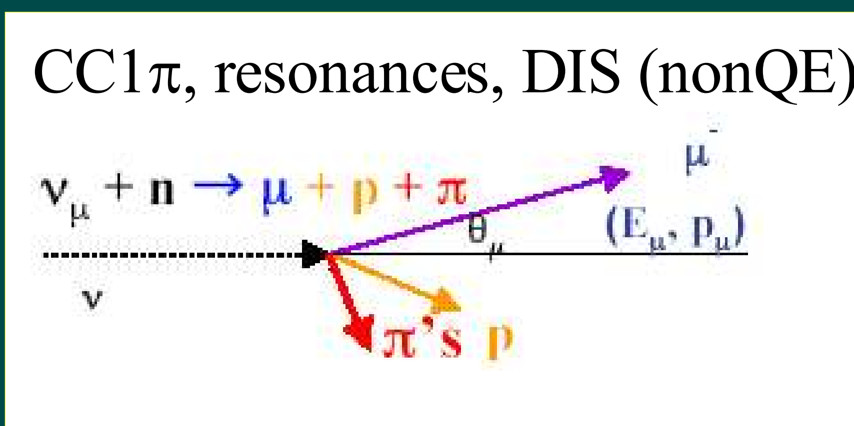


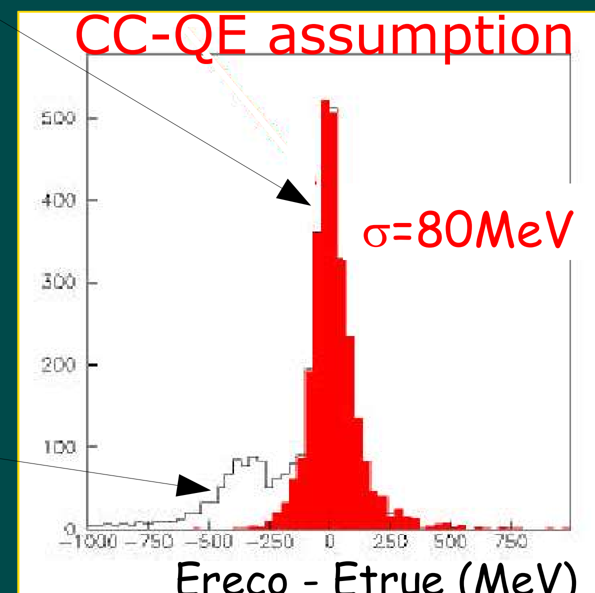


Neutrino Energy Reconstruction



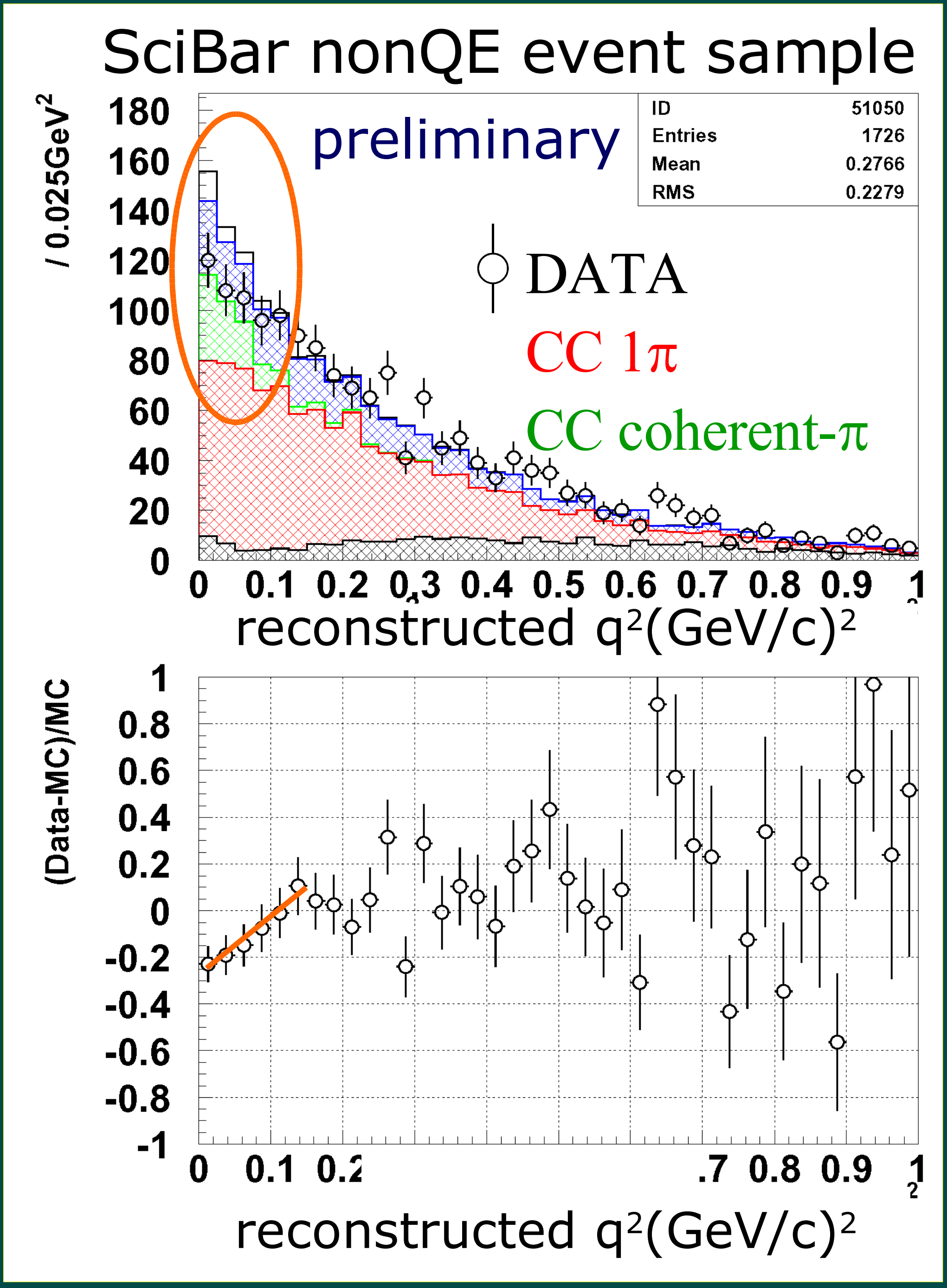
$$E_\nu^{rec} = \frac{(m_N - V)E_\mu - m_\mu^2/2 + m_N V - V^2/2}{(m_N - V) - E_\mu + p_\mu \cos\theta_\mu}$$





Hint of Forward Muon Deficit from K2K data

- Small angle, small q^2 deficit.
- Observed by all near detectors
- Most clear in 2 tracks, nonQE samples
- Two phenomenological models fit this deficit:
  1. CC-1π suppression of q^2/A for events with $q^2<A$. SciBar nonQE sample: $A=0.10\pm0.03(GeV/c)^2$
  2. NO coherent π
- The oscillation analysis is insensitive to the choice.



Near Detector Spectrum Measurement

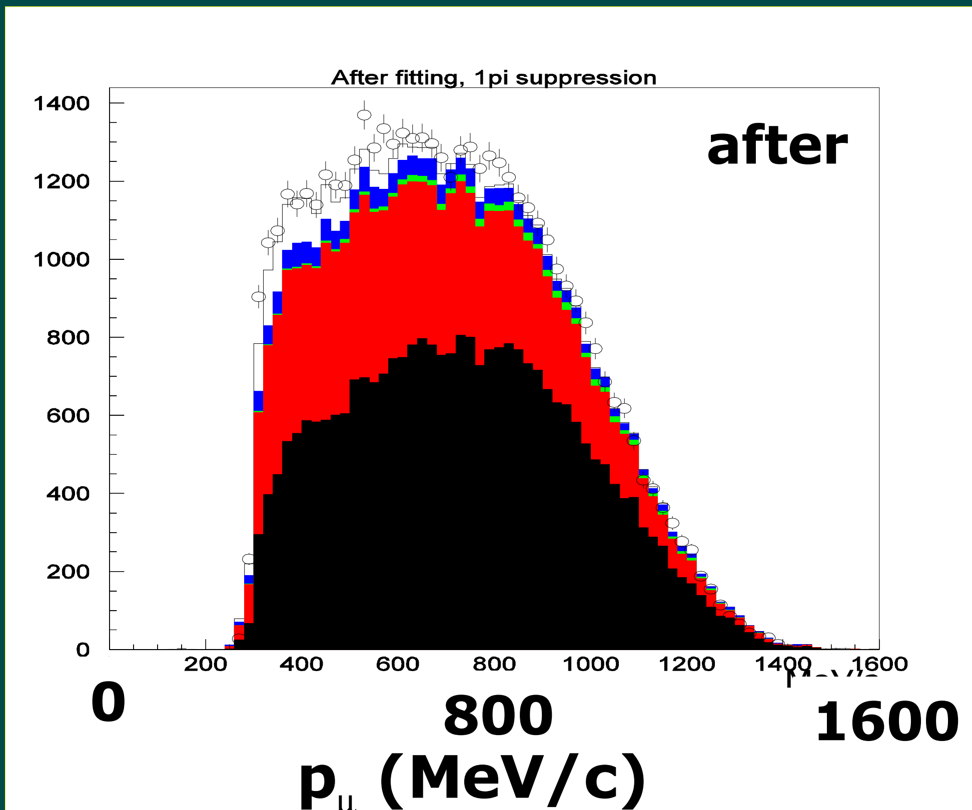
- 1KT Water Cherenkov detector (H,O target)
  1. Fully contained one-ring muon-like sample
- SciFi fiber tracker (H,O target)
  2. Single-muon track sample
  3. Two-track QE sample ($\Delta\theta_p$<25°)
  4. Two-tracks nonQE sample ($\Delta\theta_p$>30°)
- SciBar fine-grained scintillator (HC target)
  5. Single-muon track sample
  6. Two-track QE sample ($\Delta\theta_p$<25°)
  7. Two-tracks nonQE sample ($\Delta\theta_p$>25°)

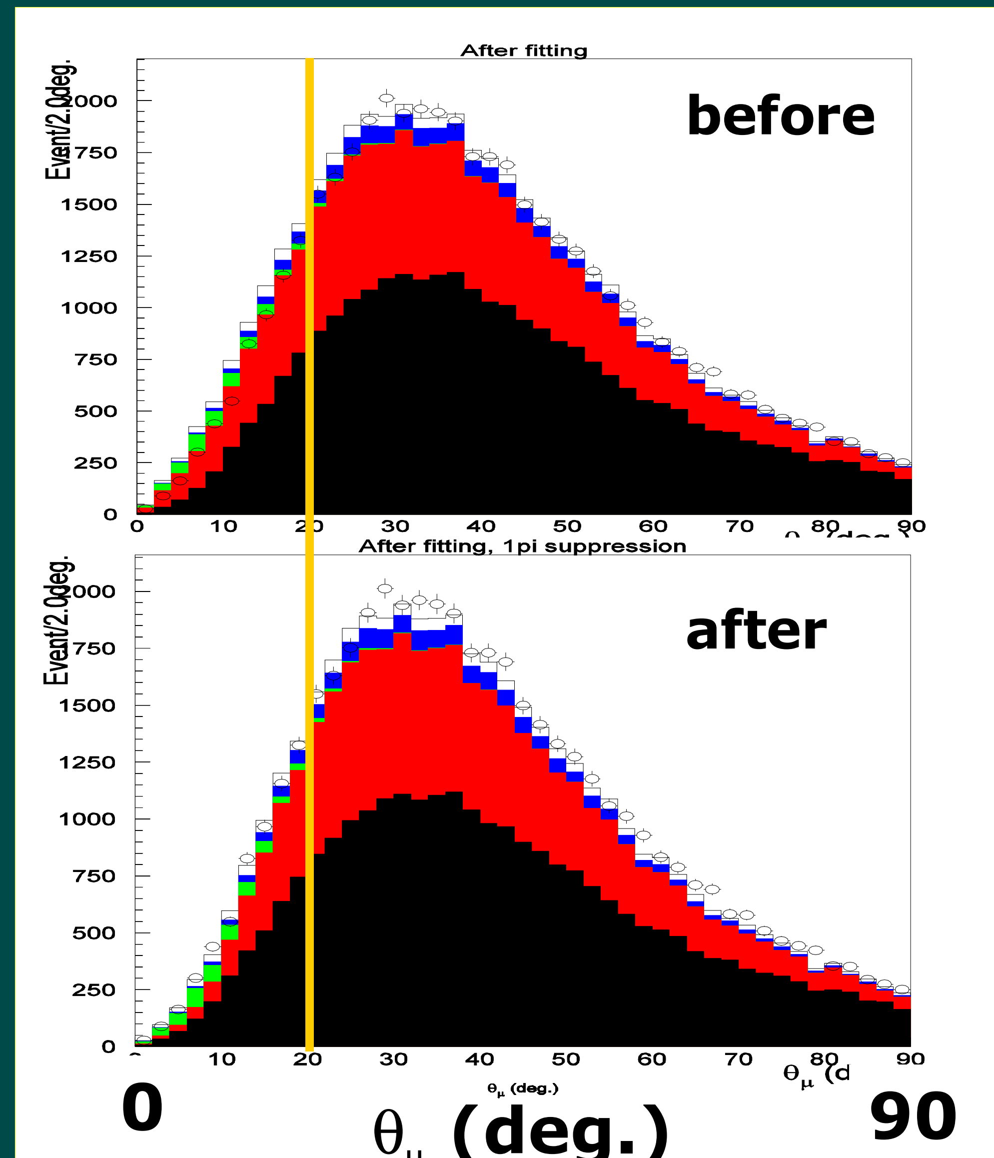
For each event we measure P_μ,Θ_μ

After the low q2 correction, all data samples agree with MC

Example: Pμ and Θμ from 1KT

1-ring μ-like after the CC1π low q^2 correction





1KT 1-ring μ-like sample

Black is quasi-elastic

Red is single pion

Neutrino Spectrum from Pμ, Θμ

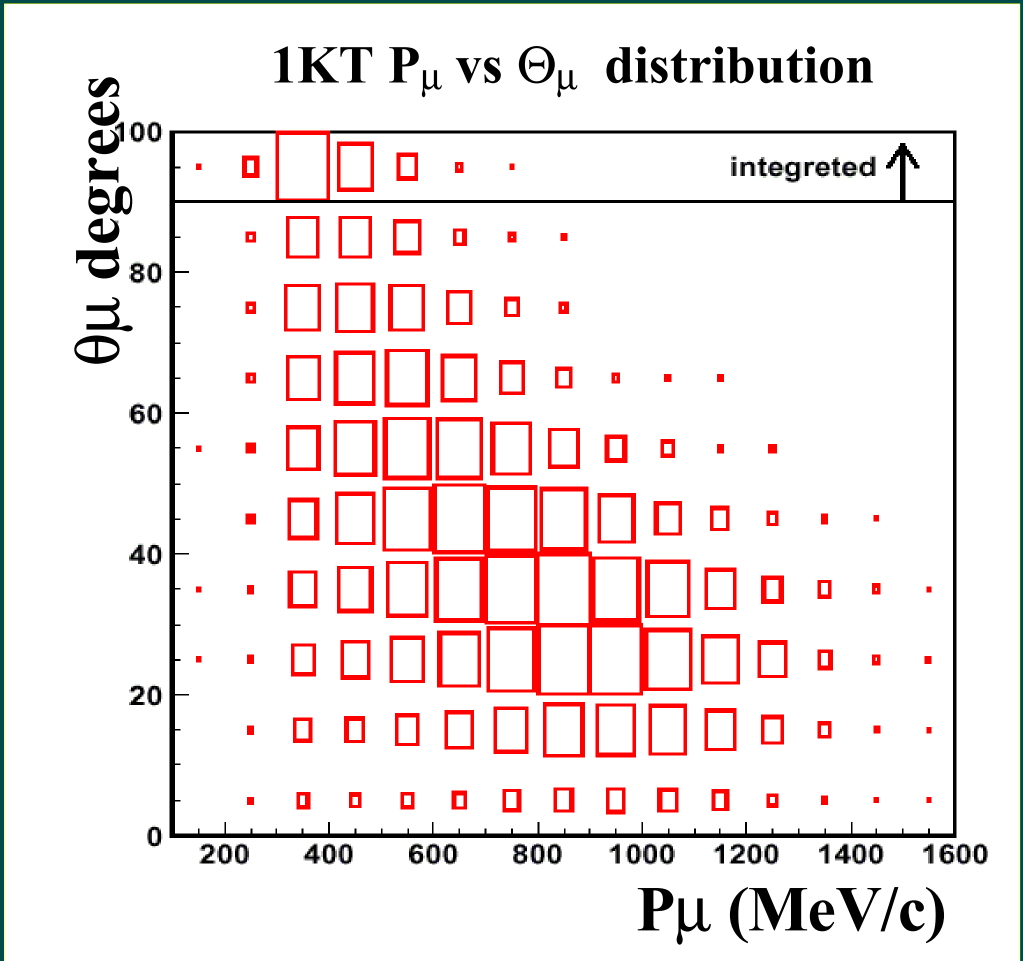
Free parameters of the fit

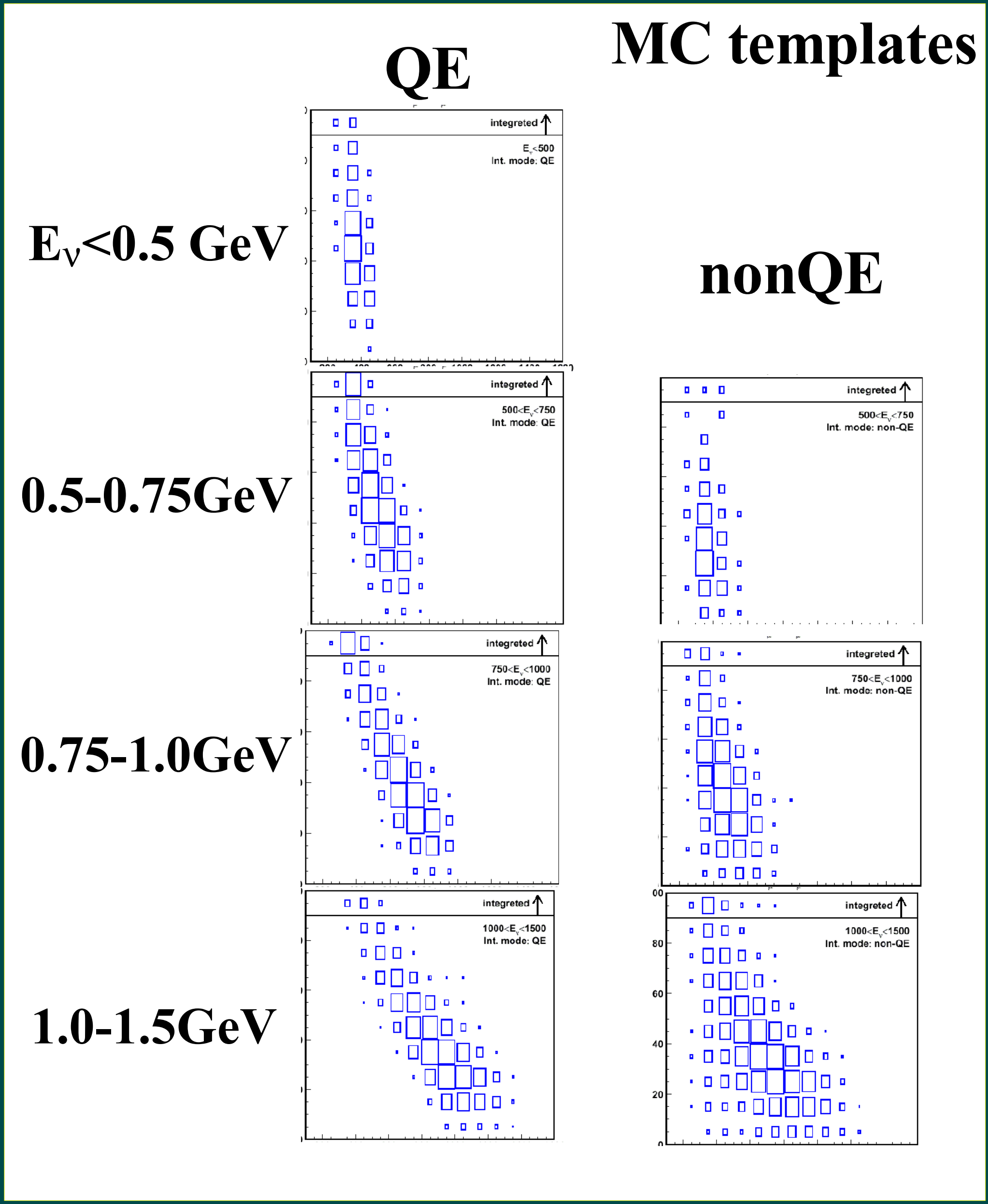
- flux in 8 energy bins $\Phi(E\nu)$
- nonQE/QE
- detector uncertainties (energy scale, efficiencies,...)
- nuclear effect uncertainties (proton and pion rescattering)

Strategy

- fit $\Phi(E\nu)$ flux without low angle data
- apply either low q^2 $CC1\pi$ or coherent pion suppression
- fit nonQE/QE for the entire angular range
- Use $\Phi(E\nu)$, nonQE/QE to calculate the spectrum at Super-K

Example of Spectrum fit





Free parameters of the fit:

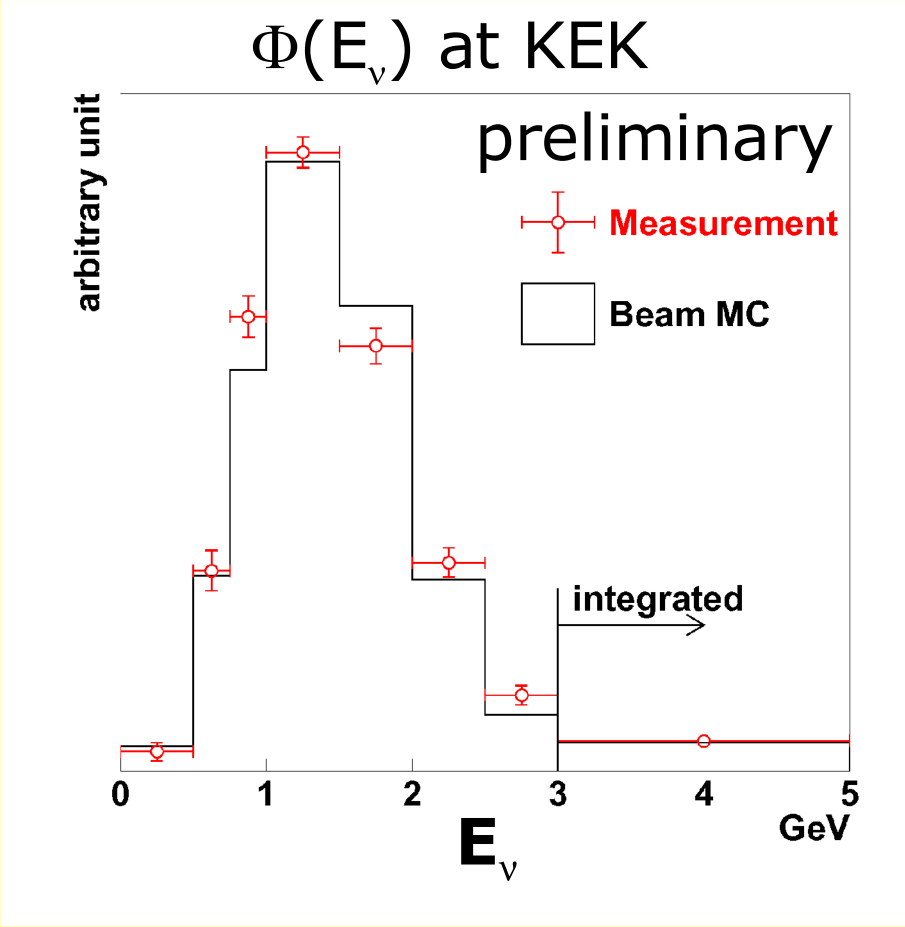
relative flux $\Phi(E\nu)$ (8 bins)

ratio nonQE/QE

Spectrum Fit Results

$\Phi1$ (Eν < 500)	= 0.78 ± 0.36
$\Phi2$ (500≤ Eν < 750)	= 1.01 ± 0.09
$\Phi3$ (750≤ Eν <1000)	= 1.12 ± 0.07
$\Phi4$ (1000≤ Eν <1500)	= 1.00
$\Phi5$ (1500≤ Eν <2000)	= 0.90 ± 0.04
$\Phi6$ (2000≤ Eν <2500)	= 1.07 ± 0.06
$\Phi7$ (2500≤ Eν <3000)	= 1.33 ± 0.17
$\Phi8$ (3000≤ Eν)	= 1.04 ± 0.18
nonQE/QE	= 1.02 ± 0.10

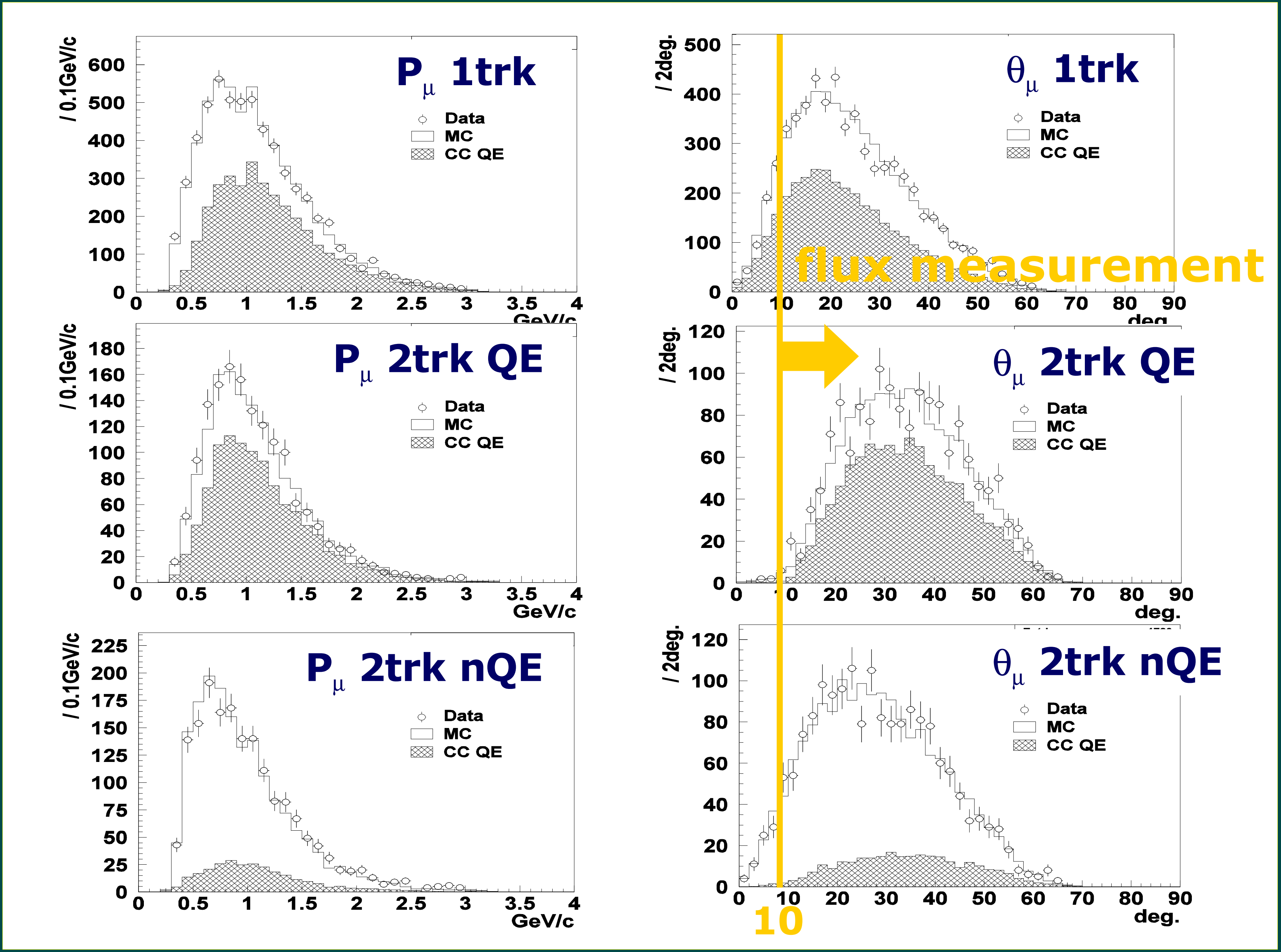
χ^2=638.1 for 609 *d.o.f*



The nonQE/QE error of is determined from the variation with different fit criteria:

nonQE/QE = 0.95 ± 0.04 with standard angular cut.
nonQE/QE = 1.02 ± 0.03 with single pion suppression
nonQE/QE = 1.06 ± 0.03 with no coherent pion

Example: SciBar Data with Measured Spectrum



Oscillation Analysis

$$L(\Delta m^2, \sin 2\theta, f^x)$$
$$= L_{norm}(\Delta m^2, \sin 2\theta, f^x) \cdot L_{shape}(\Delta m^2, \sin 2\theta, f^x) \cdot L_{syst}(f^x)$$

- Total Number of neutrino events
- Reconstructed E_ν^{rec} spectrum shape for 1-ring μ-like events
- Systematic error terms, f^x

Systematic error terms include: normalisation, flux, nonQE/QE ratio, pion monitor and beam MC constraints, Super-K systematic uncertainties.

K2K/Super-K Data Sample

preliminary

K2K-all (K2K-I, K2K-II)	DATA (K2K-I, K2K-II)	MC (K2K-I, K2K-II)
FC 22.5kt	**107** (55, 52)	**150.9** (79.1*, 71.8)
1-ring	**67** (33, 34)	**93.7** (48.6, 45.1)
1-ring μ-like	**57** (30, 27)	**84.8** (44.3, 40.5)
1-ring e-like	**10** (3, 7)	**8.8** (4.3, 4.5)
Multi Ring	**40** (22, 18)	**57.2** (30.5, 26.7)

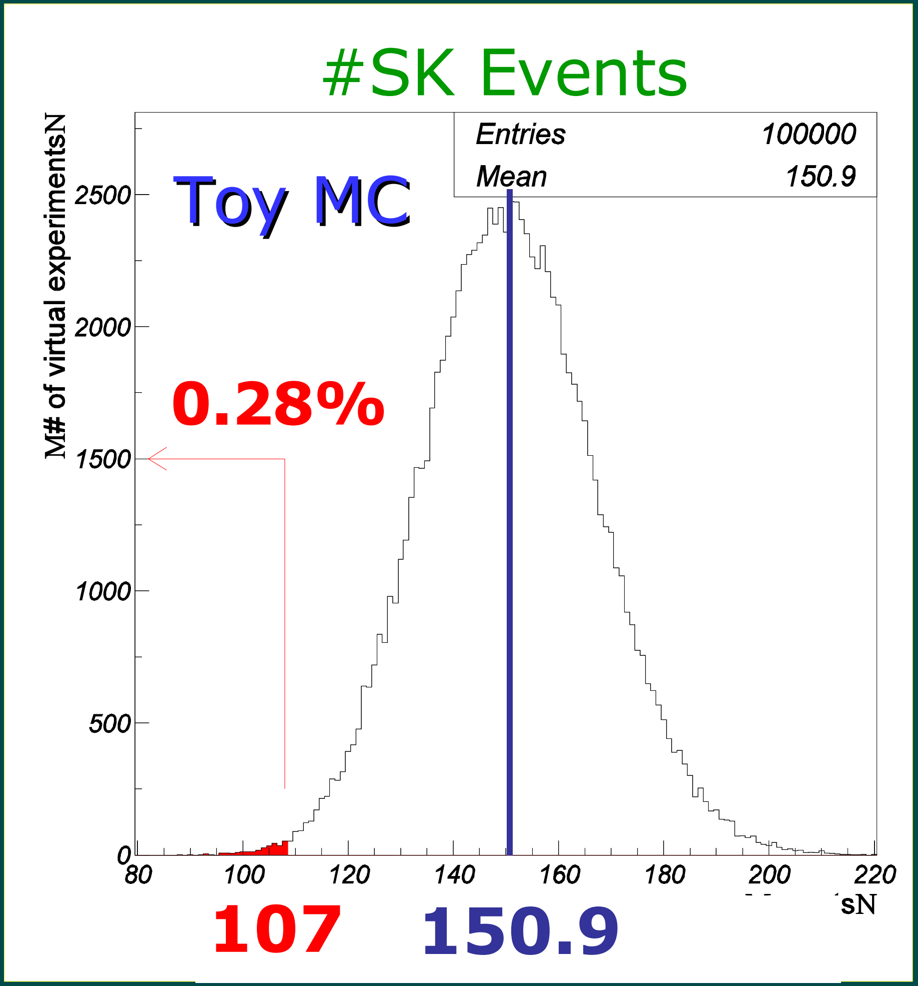
K2K-I 47.9 10^{18} PoT
K2K-II 41.2 10^{18} PoT

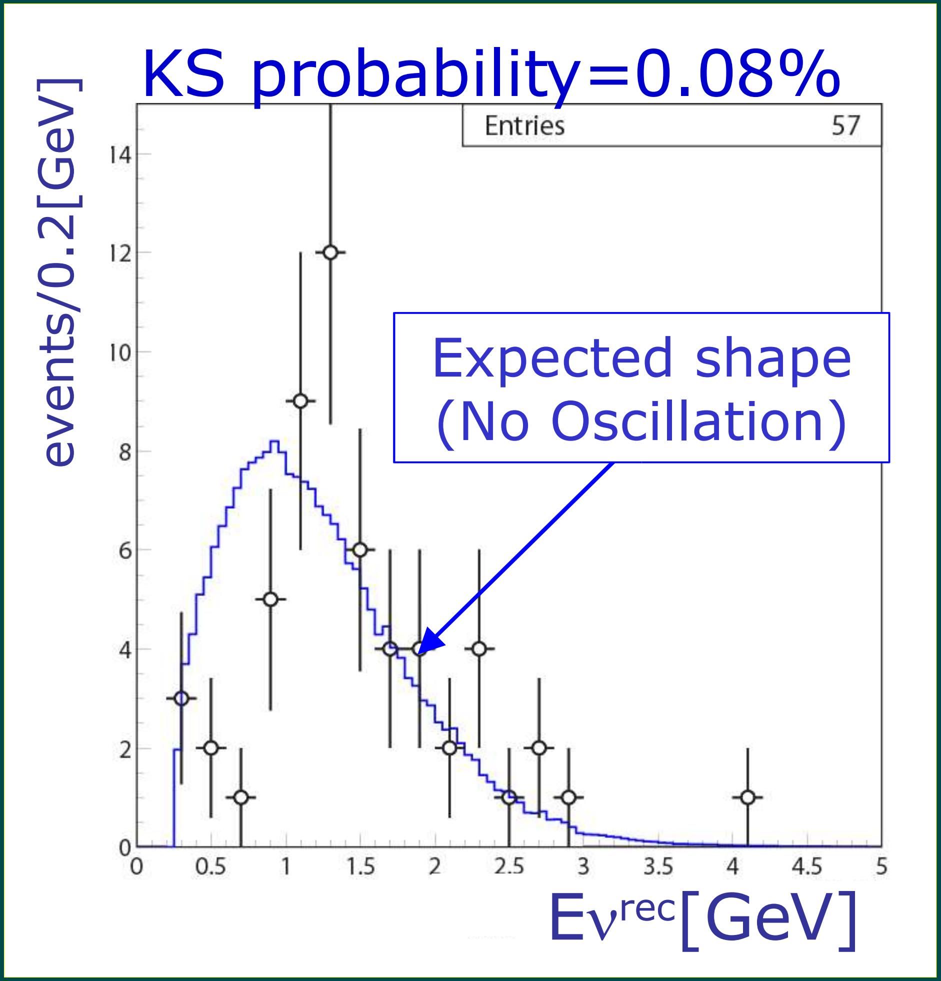
*Updated with respect to previous analysis

Compare with Null Oscillation

$$L_{norm}(f^x)$$

$$L_{shape}(f^x)$$



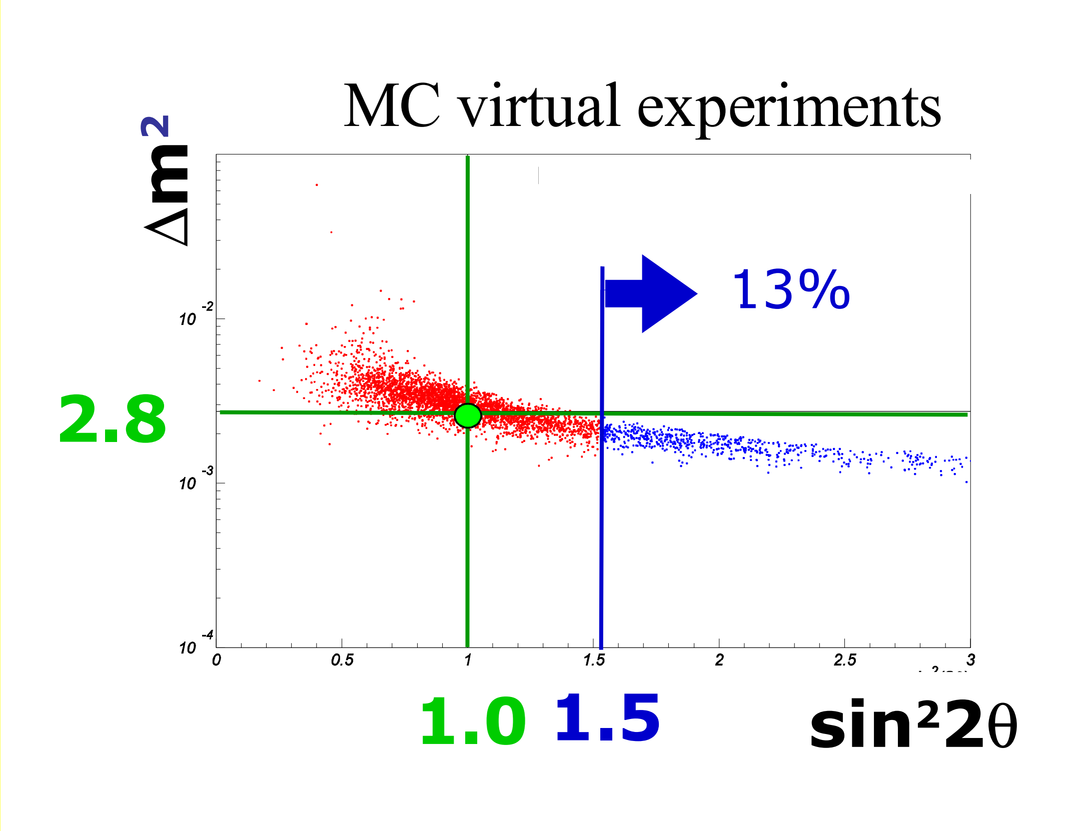


Best Fit of Oscillation Parameters

Best fit in the physical region:
$\sin^2(2\theta)=1.0$ $\Delta m^2=2.79\ 10^{-3}\ eV^2$

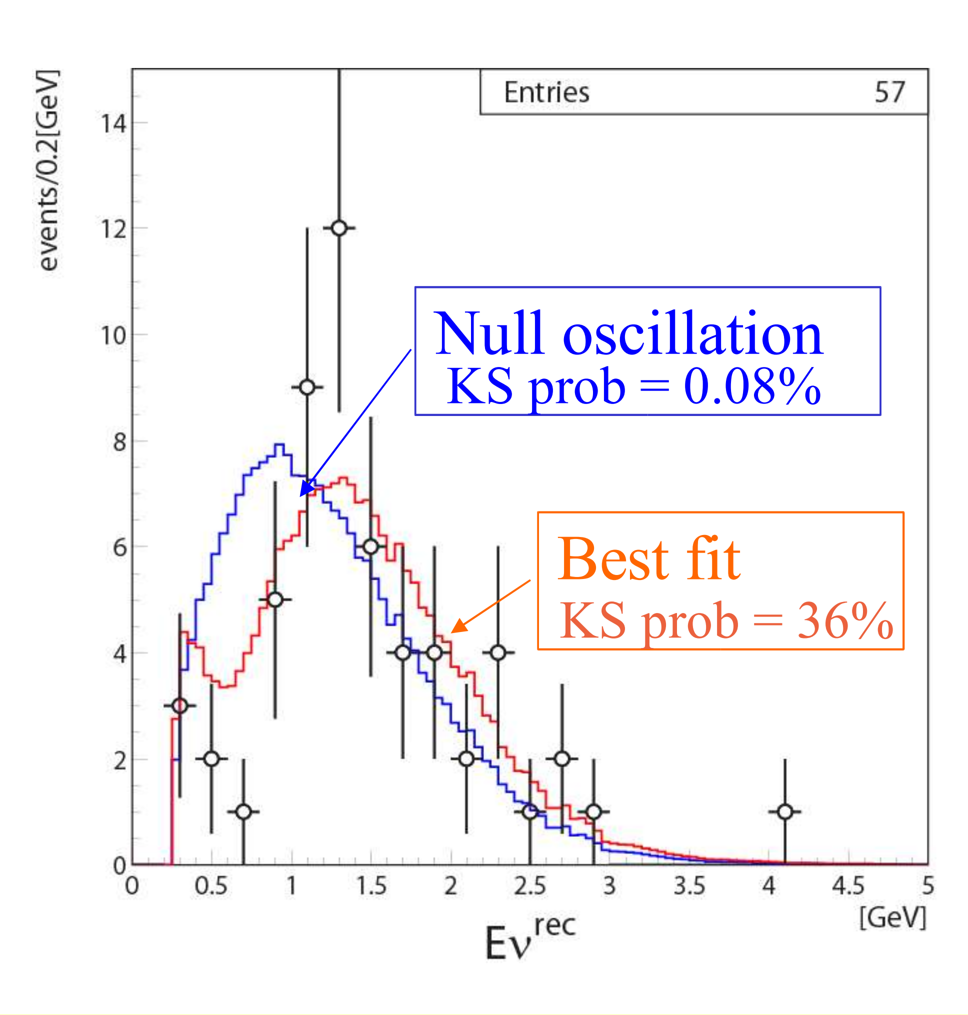
Highest likelihood for:
$\sin^2(2\theta)=1.51$ $\Delta m^2=2.19\ 10^{-3}\ eV^2$

The difference in these two fits is $\Delta Log=0.64$



A value $\sin^2(2\theta)>1.51$ can occur, due to a statistical fluctuations, with a probability of 13%.

Fit and Data are Consistent



Best likelihood for:

$\sin^2 2\theta = 1.51$

$\Delta m^2\,[eV^2] = 2.19\times10^{-3}$

$\mathrm{Prob}\{\sin^2 2\theta > 1.5\}|_{\mathrm{BestFit}} = 13\%$

Best fit (physical region):

$\sin^2 2\theta = 1.00$

$\Delta m^2\,[eV^2] = 2.79\times10^{-3}$

Expected neutrino interactions at the best fit is 103.8, to be compared with 107 observed.

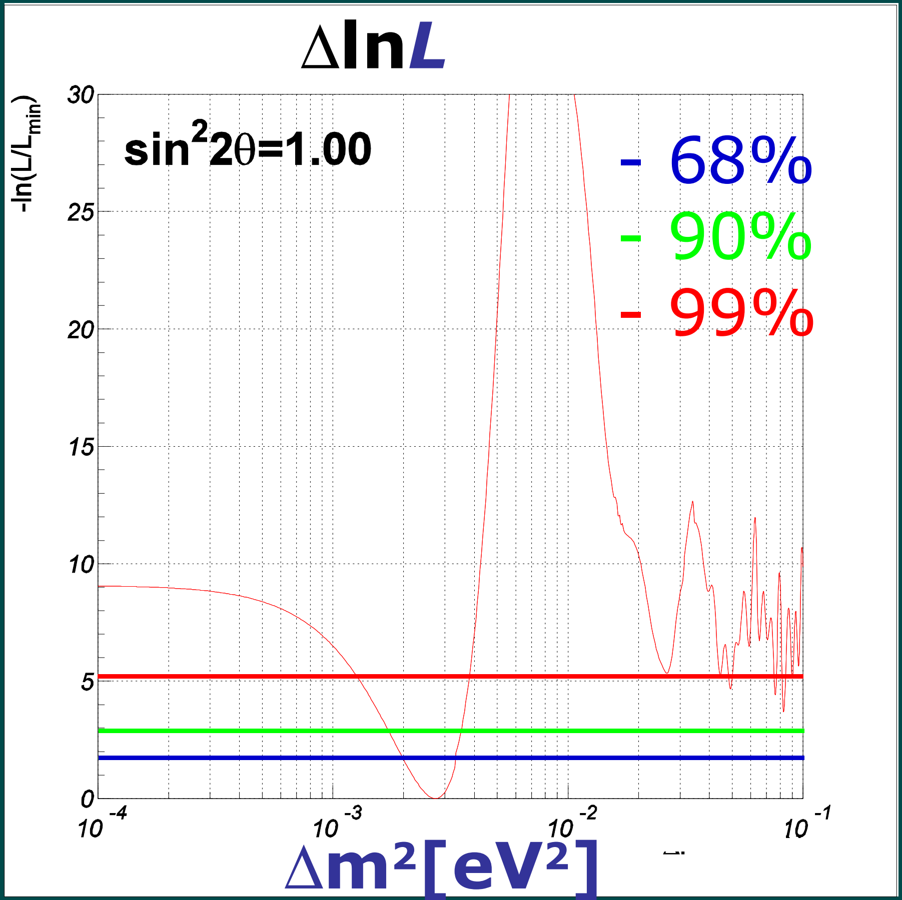
From LogL differences w.r.t. the best fit:

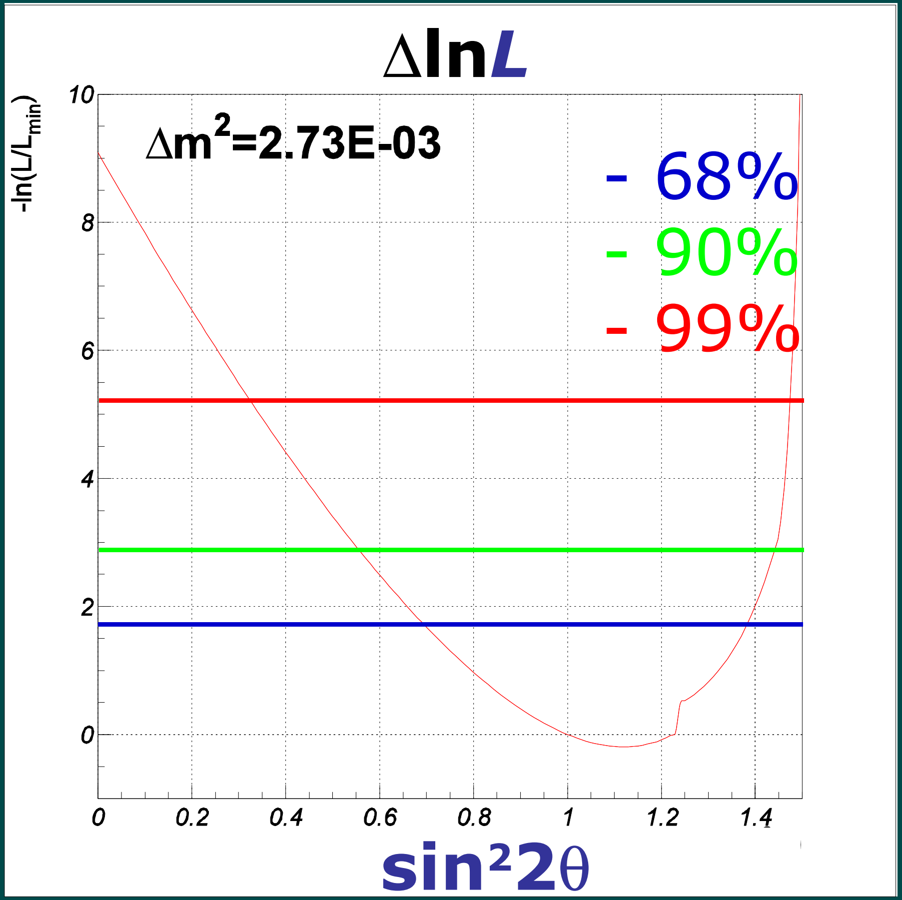
Prob{No Oscill} = 0.0050% (4.0σ) (shape+norm.)

= 0.74% (2.6σ) (shape only)

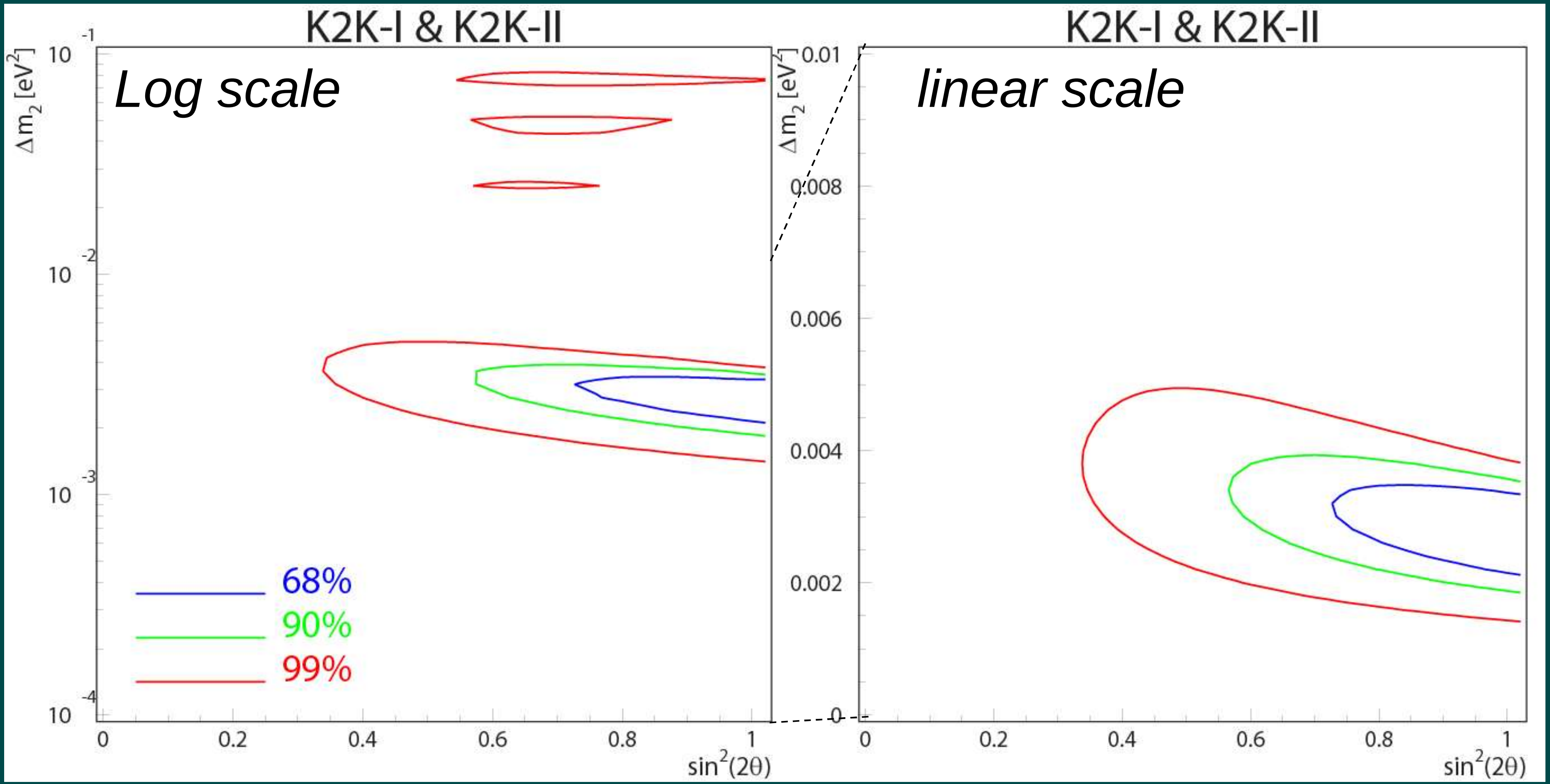
= 0.26% (3.0σ) (norm. only)

Likelihood Distribution





Allowed Region

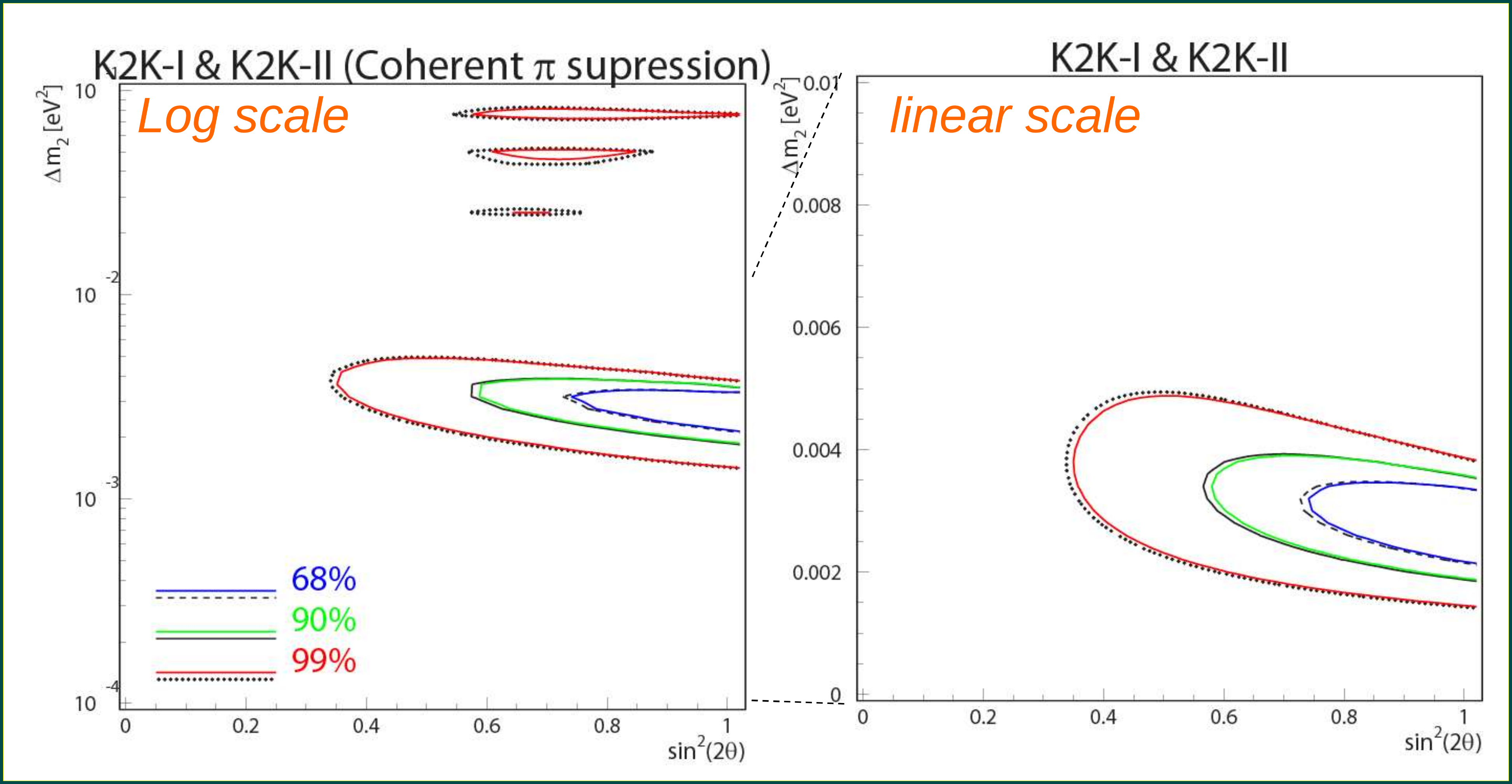


Δm^2 @ $\sin^2 2\theta = 1$:

$2.1 < \Delta m^2 < 3.4$ [eV]$\times 10^3$ @68%

$1.9 < \Delta m^2 < 3.6$ [eV]$\times 10^3$ @90%

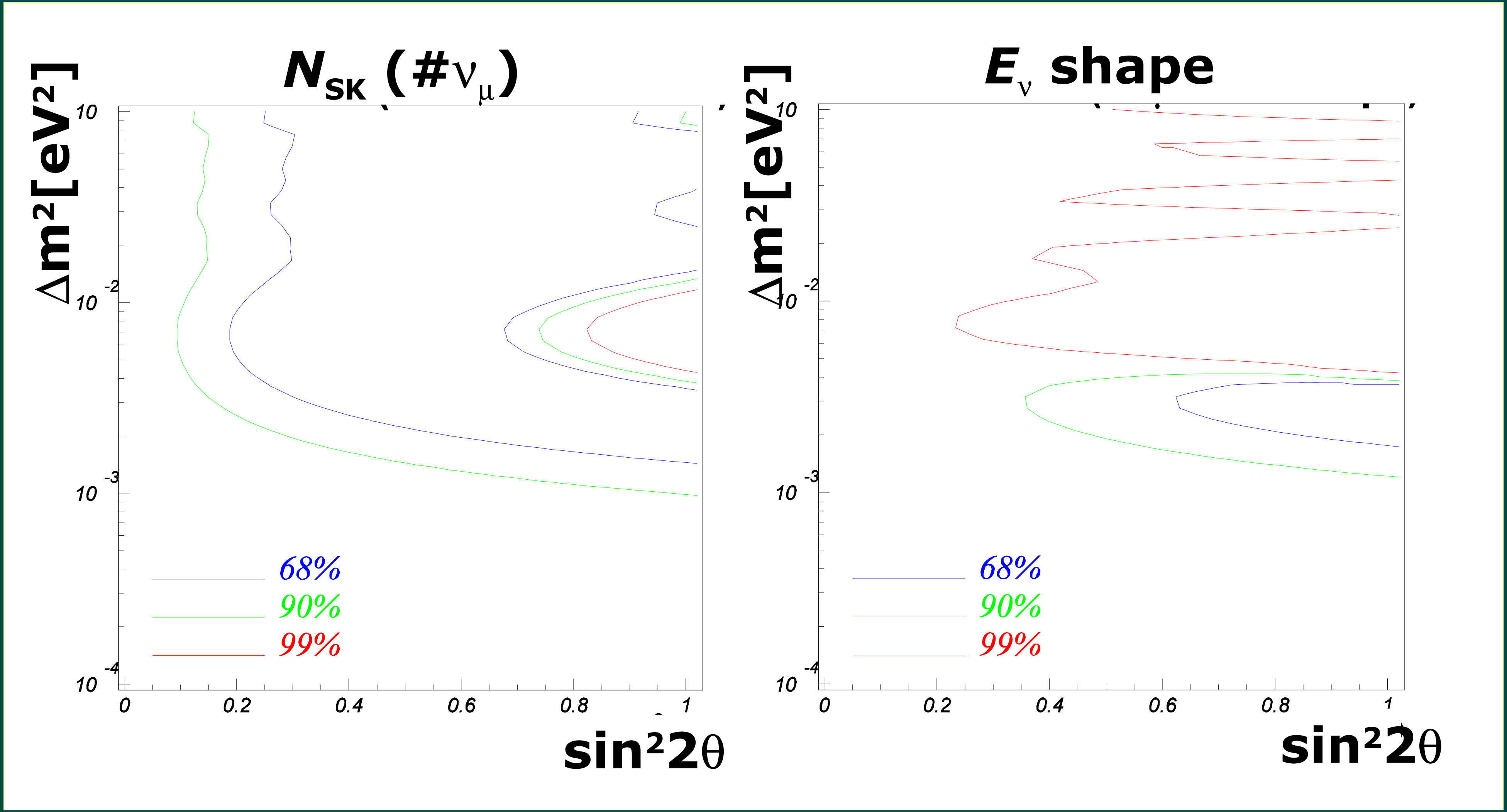
Single vs coherent pion suppression



Mono: single pion suppression
Color: coherent pion suppression

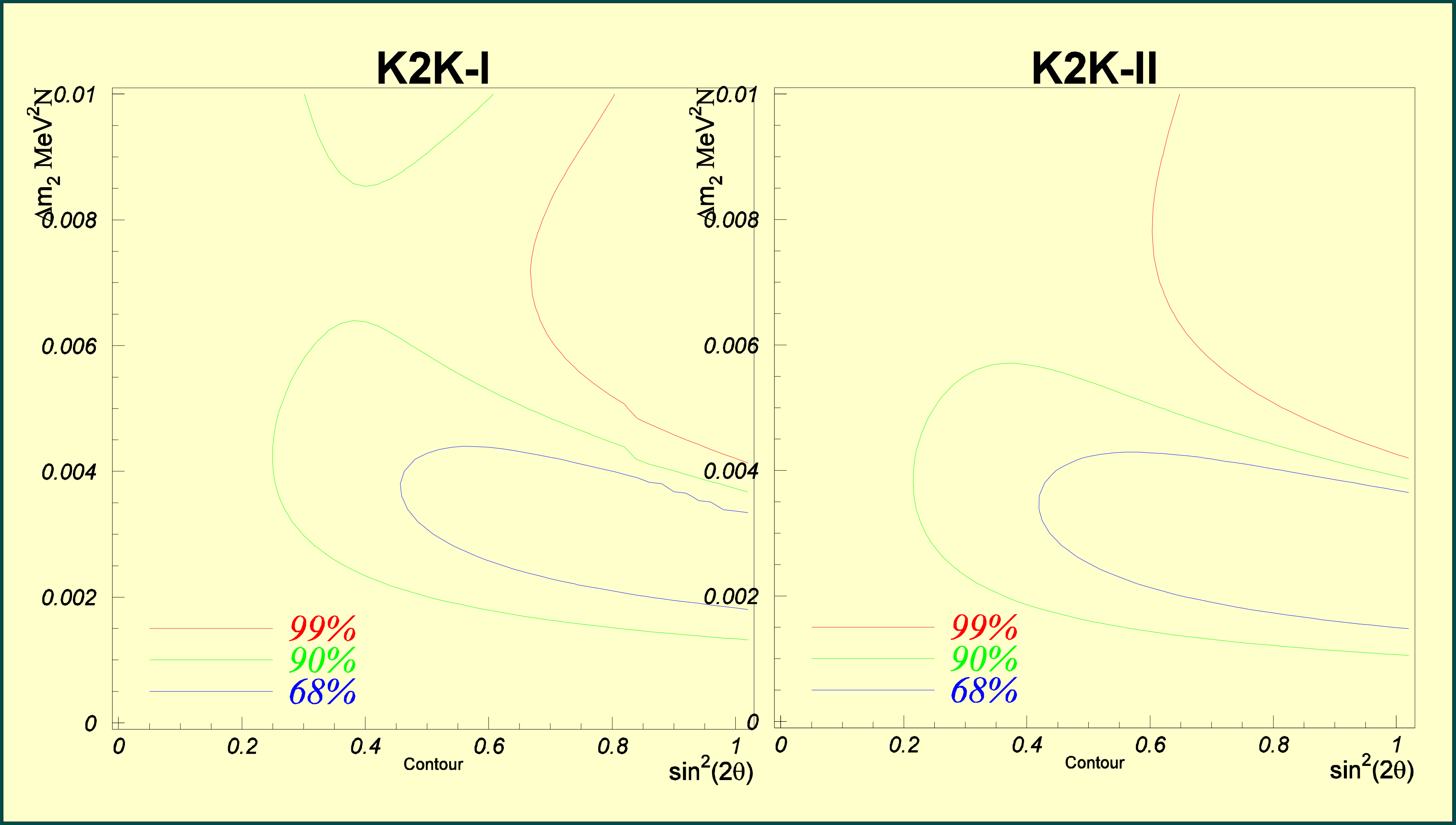
Almost no difference. Single pion suppression more conservative

Disappearance vs Spectrum Distortion



Disappearance of ν_μ and the distortion of E_ν spectrum give consisten allowed regions.

K2K-I and K2K-II Comparison



Analyses in Progress/Perspective

- Forward muons (low q^2) deficit. Resonant pion vs coherent pion suppression.
- Neutral pion production cross-section. (Roma)
- Electron neutrino flux. (Roma)
- $\nu_\mu \rightarrow \nu_e$ oscillation.
- CCQE form factor (M_A)measurement.
- "Observation of neutrino oscillation" (increased statistic, improved systematic).

Summary

With 8.9 10^{19} proton on target

A neutrino flux deficit is observed

An energy spectrum distortion is seen

K2K confirms neutrino oscillation at 4σ level