Neutrino interaction at K2K

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for the K2K collaboration

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  and neutrino interaction studies in K2K
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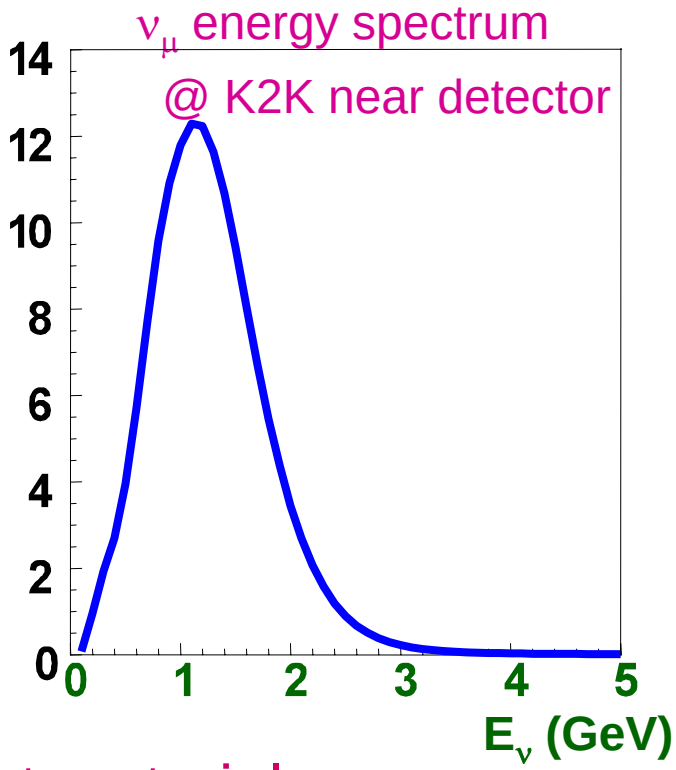
Introduction

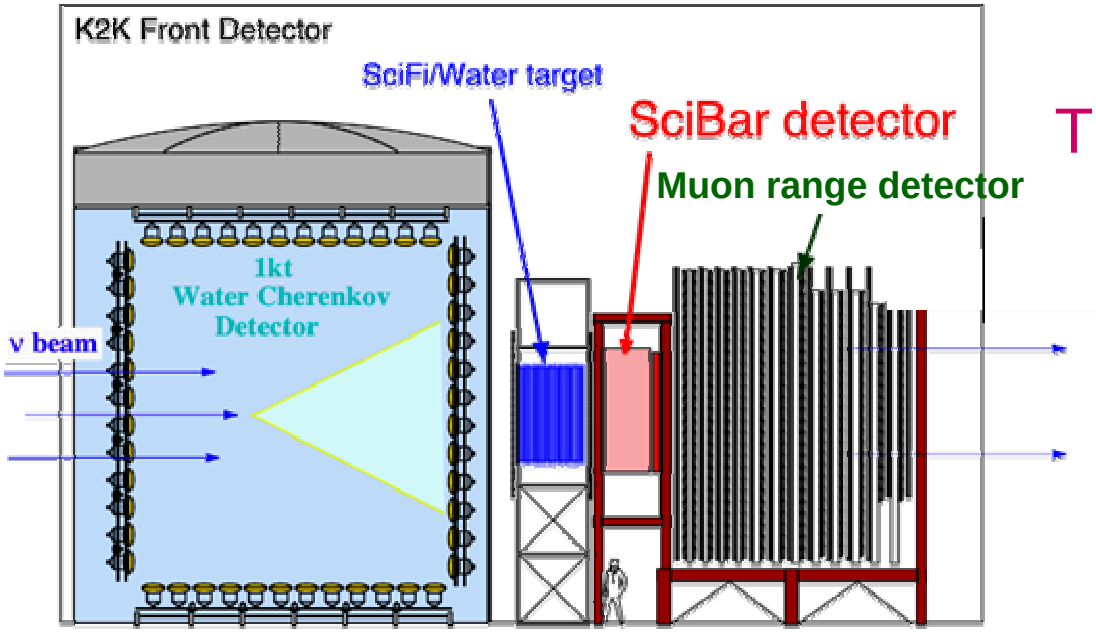
K2K Neutrino beam

E_ν ~ 1GeV

Almost pure ν_μ beam (~98%)

It is possible to investigate
various neutrino interactions
with the K2K near detectors.





Target material

Water (H,O)

1kt water Cherenkov detector

SciFi detector

Scintilator (H,C)

SciBar detector

Iron

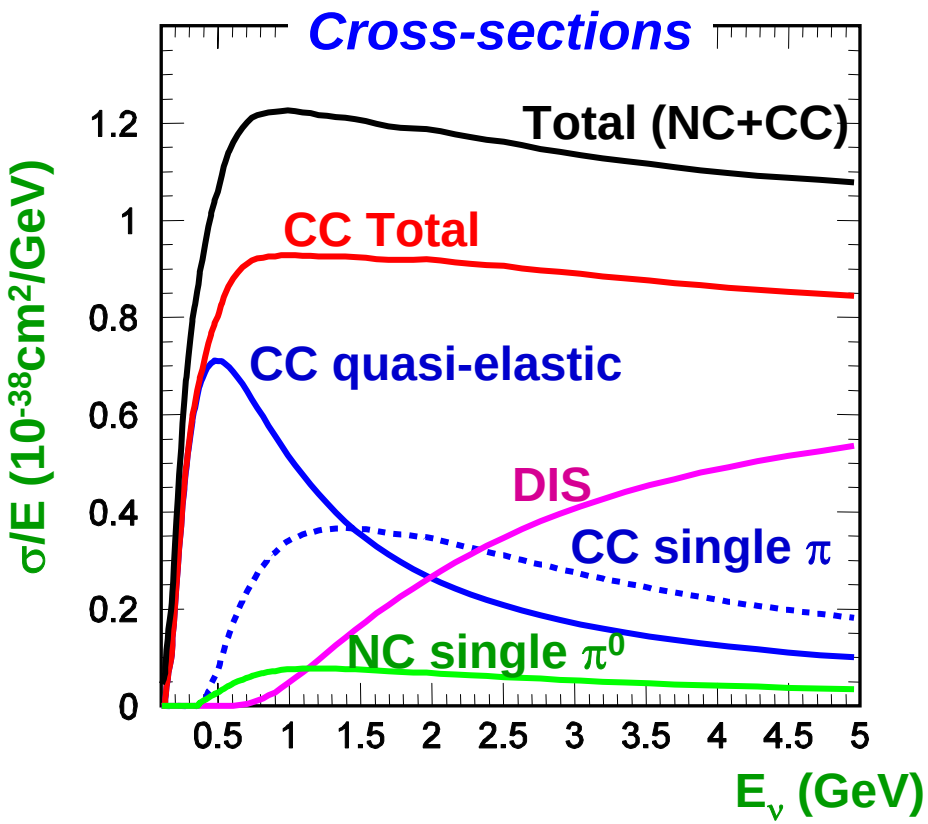
MRD

Introduction

Neutrino interactions around 1GeV region

Charged current quasi-elastic scattering (CCQE)	$\nu_\mu + n \rightarrow \mu^- + p$
Neutral current elastic scattering	$\nu_\mu + N \rightarrow \nu + N$
Single π,η,K resonance productions	$\nu_\mu + N \rightarrow l + N' + \pi\ (\eta,K)$
Coherent pion productions	$\nu_\mu + O \rightarrow l + X + \pi$
Deep inelastic scattering	$\nu_\mu + N \rightarrow l + N' + m\pi\ (\eta,K)$

(*l* : lepton, N,N' : nucleon, m : integer)



It is also important
to take into account
nuclear effects.
Mesons (especially π)
and
protons interactions
in target nucleus.
(Oxygen, Carbon ..)

Neutrino flux measurements and neutrino interaction studies at K2K

Charged Current Quasi-Elastic scattering ($\nu_\mu + n \rightarrow \mu^- + p$) is very useful to measure the energy spectrum of neutrino.

For the neutrino energy spectrum measurements, we also changed the neutrino interaction models and parameters (CCQE, Single π, coherent π, DIS..) and search for the best combination.

Fit the momentum and direction of μ.

↓

Study the neutrino interactions

Neutrino flux measurements and neutrino interaction studies at K2K

1) 1kt water Cherenkov detector

4π detector

Possible to distinguish forward going particles from backward going particles.

Momentum threshold of **proton** ~**1.2**GeV/c

→ Use "1ring μ-like" events

→ { Fraction of **quasi-elastic** scattering event ~50%
Efficiency is getting smaller @ $\mathbf{P_\mu > 1GeV/c}$

2) SciFi detector

Possible to **identify quasi-elastic scattering** events by using the **proton tracks**

a) 1track sample (CCQE ~60%, 1π ~30%)

b) 2track CCQE sample (CCQE ~60%, 1π ~30%)

c) 2track non-CCQE sample (CCQE ~15%, 1π ~51%, DIS ~ 25%, Coh.π ~7%)

Neutrino flux measurements and neutrino interaction studies at K2K

Observation:

Number of forward going particle is smaller than expected.

(Deficit in the small q^2 region)

- Charged current quasi-elastic scattering M_A=1.1GeV/c^2
- Single π production M_A=1.1GeV/c^2 (1.2GeV/c^2)
- DIS correction (Suggested by A. Bodek and U. K. Yang.)

  Nucl.Phys.Proc.Suppl.112:70-76,2002

  This correction to PDF suppress small q^2 interactions.
- Coherent π production cross-section

  μ from coherent π production → Forward peaking

  Use the calculation done by Marteau.

  σ is ~30% smaller in the low energy region compared to the calculation by Rein & Sehgal.

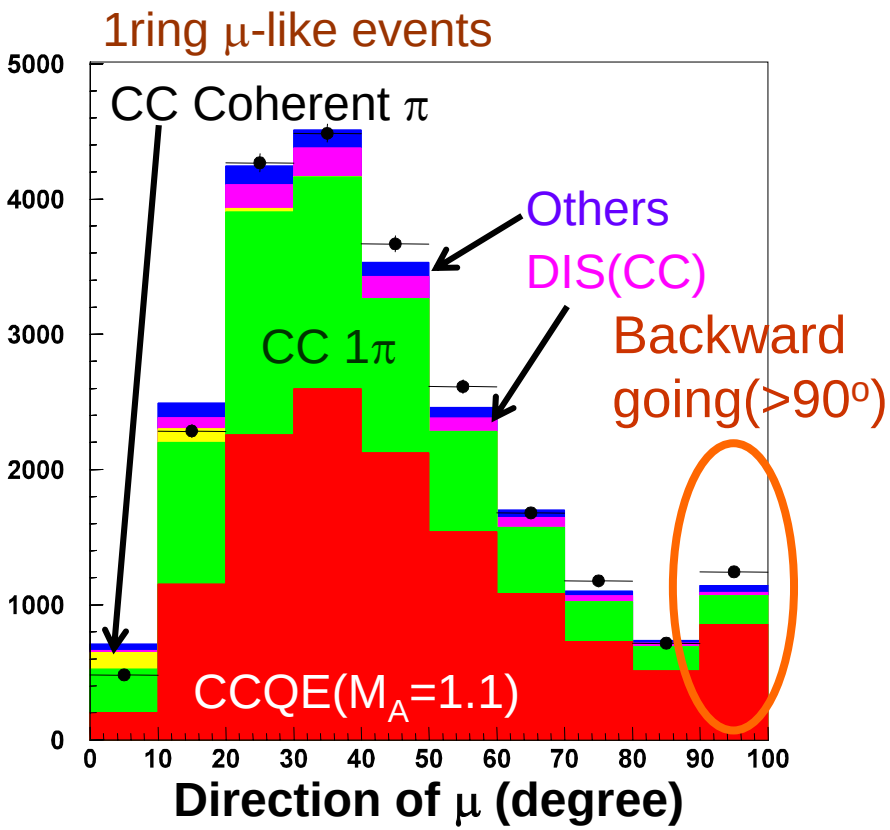
Charged current quasi-elastic scattering

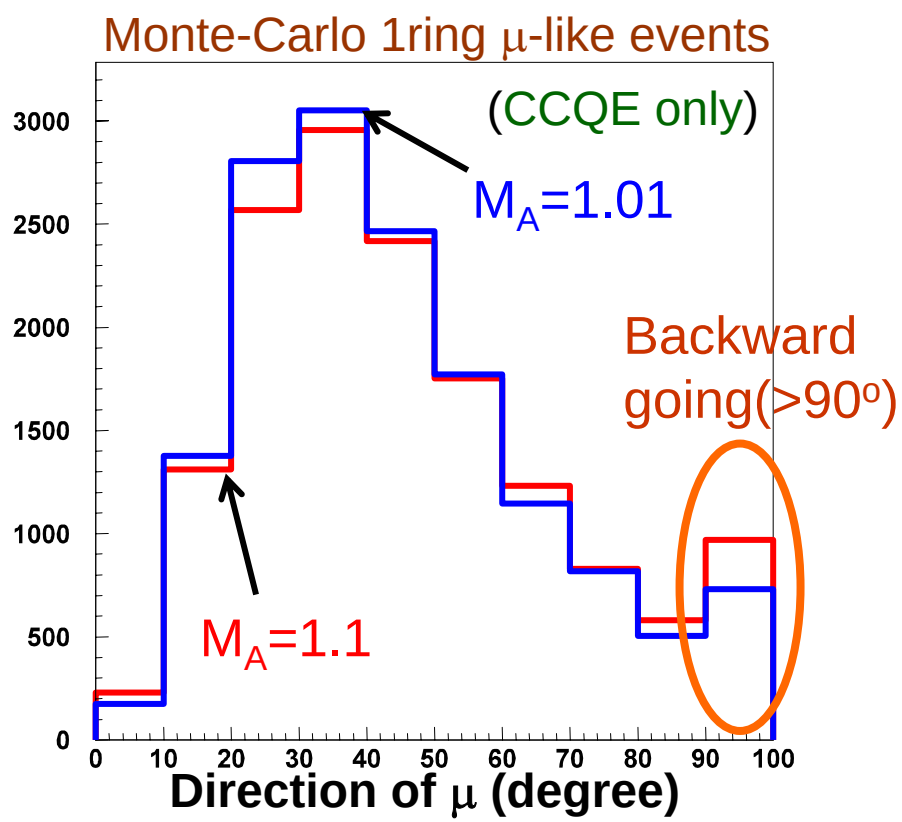
Larger M_A value (~ 1.1 GeV/c^2) was favored.

1ring μ-like sample (from the 1kt detector)

The number of backward going μ agrees well if we take M_A=1.1GeV/c^2.

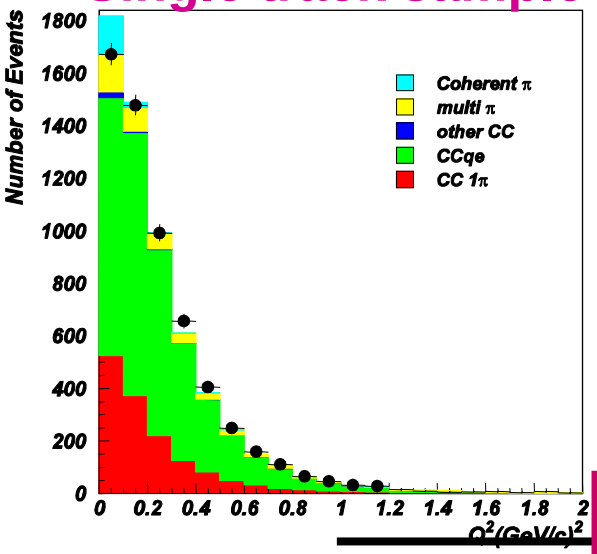
(The backward going region is dominated by CCQE events)



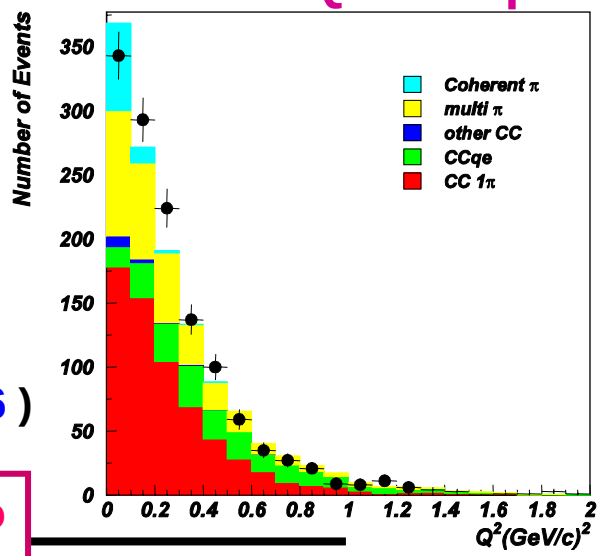


Reconstructed q^2 distributions [SciFi detector]

Single track sample



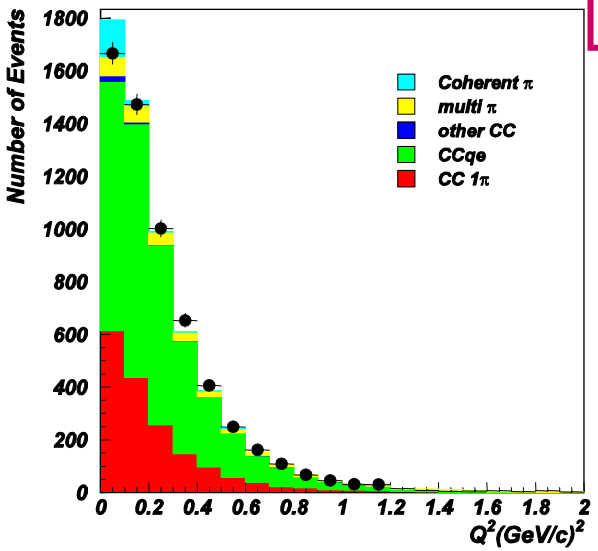
2trk non-QE sample

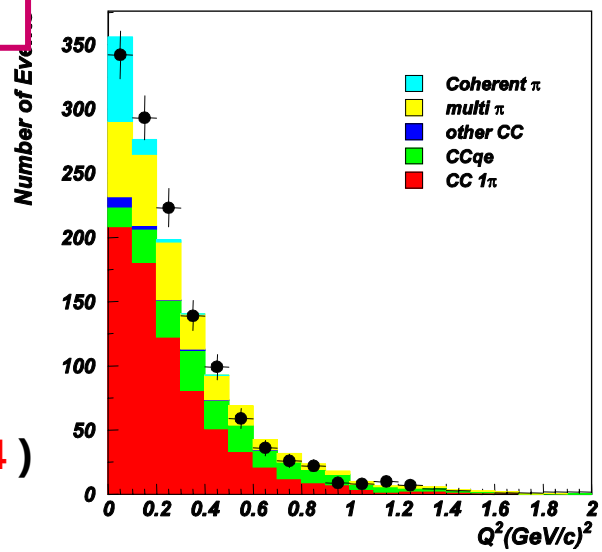


Without DIS correction
coherent π production cross-section
Rein&Sehgal

(relative normalization
σ(nQE)/σ(QE) = 0.86)

Fit neutrino flux & nonQE QE ratio for each combinations





With DIS correction
coherent π production cross-section
Marteau

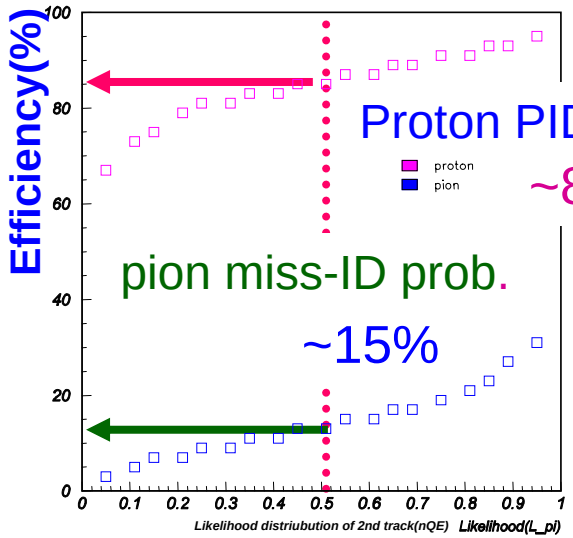
(relative normalization
σ(nQE)/σ(QE) = 1.04)

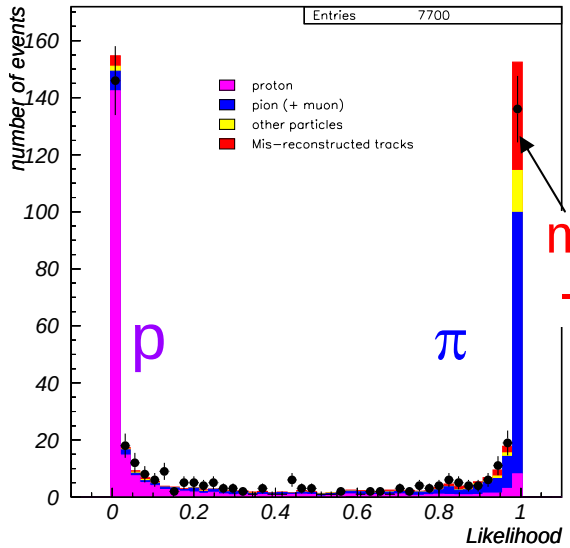
Including these corrections, fit results get better
but still some discrepancies exist in the small q^2 region.

Further study of coherent π productions w/SciFi

In order to select the coherent π production events,
apply PID to the second tracks.

(Use dE/dx difference between p and π.)

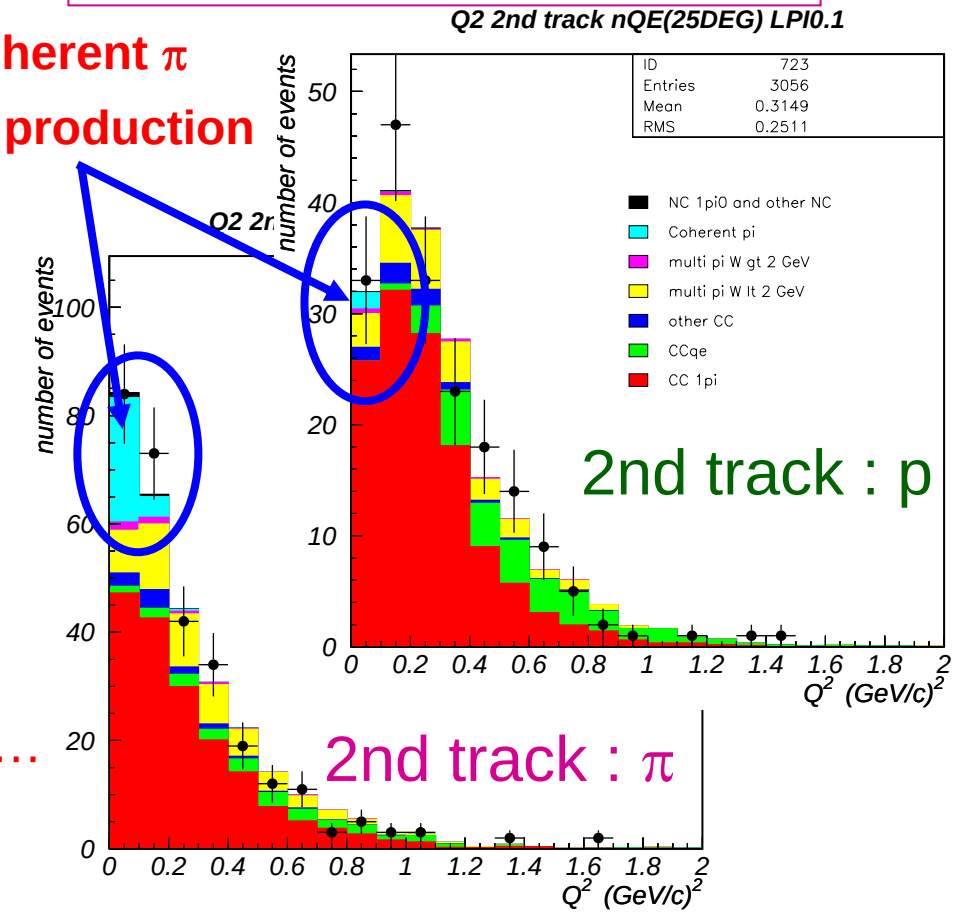




miss
-reconstructed…

2track non-QE samples

Coherent π production



(Need to optimize the reconstruction tools.)

NC π^0 measurements in 1kt detector

Neutral current single π^0 production

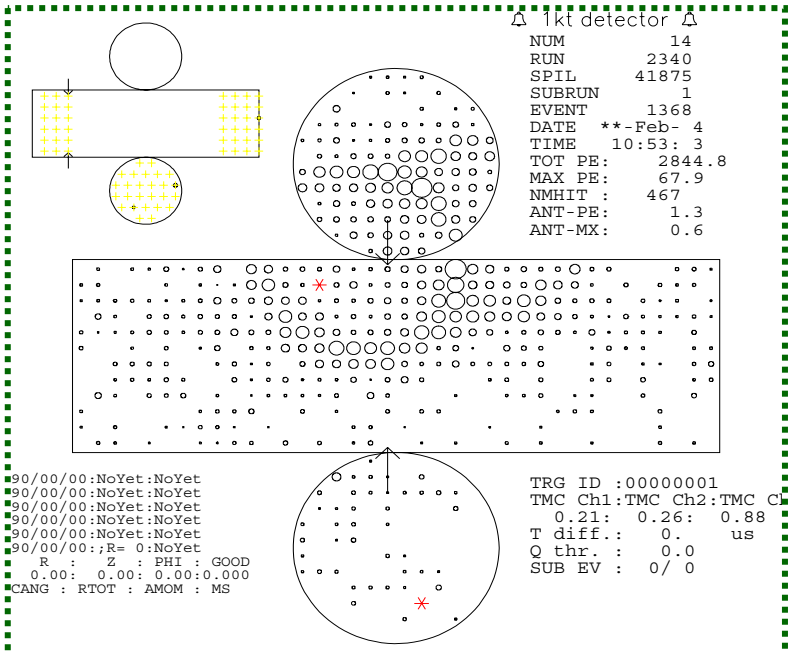
$\nu + N \rightarrow \nu + N + \pi^0$

Observable in 1kt : π^0

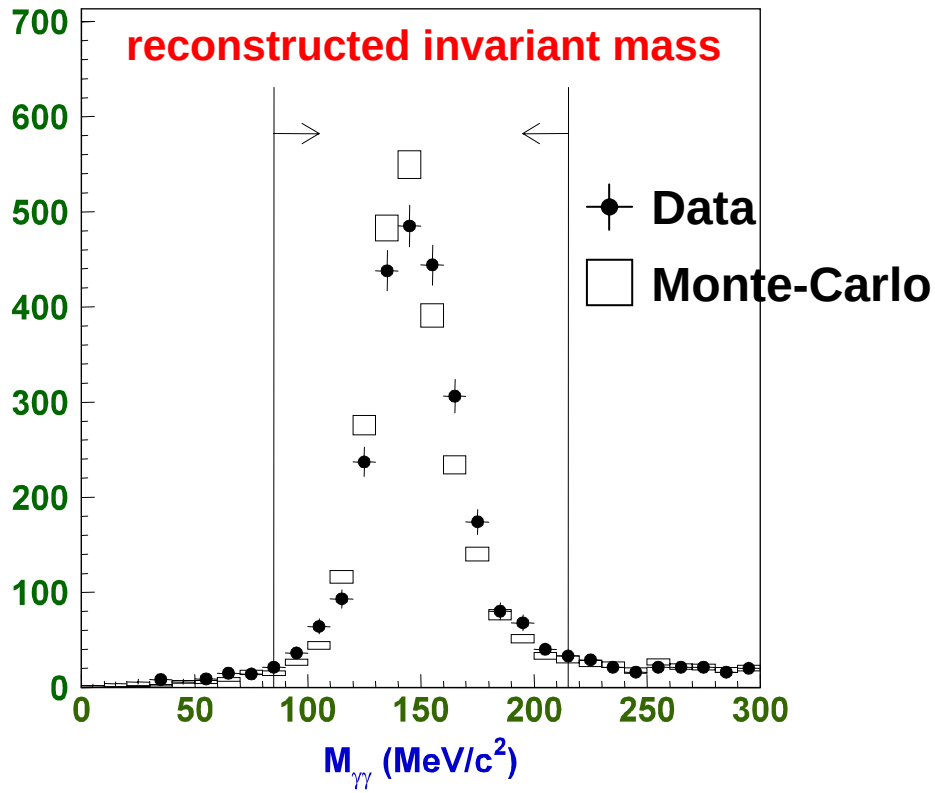
(Cherenkov threshold of proton > 1GeV/c)

2 γs from π^0 are identified as 2 electron like rings

$\rightarrow$ reconstruct invariant mass



Typical π^0 candidate



NC π^0 measurements in 1kt detector

1kt water Cherenkov detector

has high efficiency in finding low energy π^0.

π^0 sample selection criteria

- 2 e-like rings
- reconstructed mass 85~215MeV/c^2

- detection efficiency of π^0 ~49%
- 86% from NC interactions

(~60% from NC resonance meson production)

Contamination from charged current

→ low momentum μ ($P\mu$ < 200MeV/c)

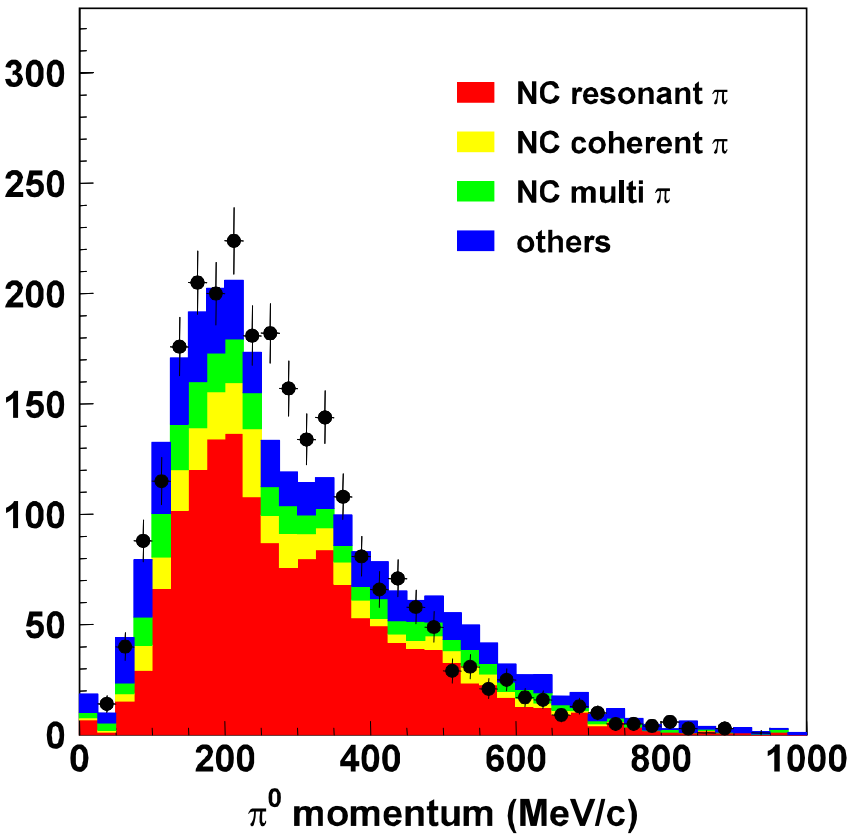
can not be identified.

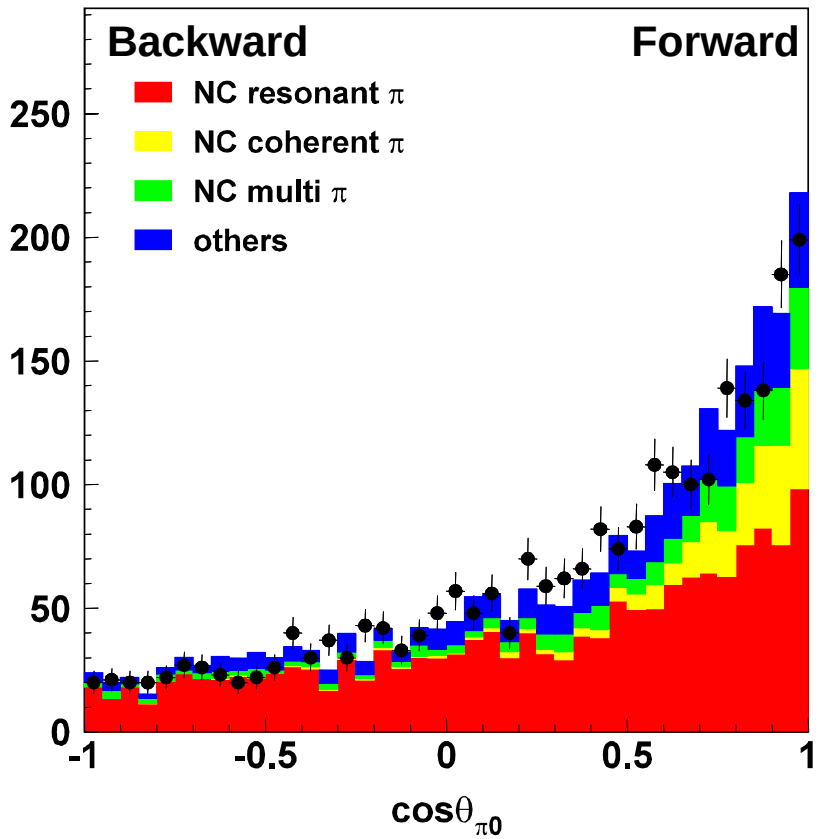
Pions generated in Oxygen interacts with nucleons.

(Inelastic scatterings, charge exchange and absorption in Oxygen are considered in Monte-Carlo simulation program)

NC π^0 measurements in 1kt detector

momentum and direction of π^0





Both distributions agree quite well with Monte-Carlo.

Still some discrepancies exist in the momentum distributions.

(250~350MeV/c, 350~750MeV/c)

NC π^0 measurements in 1kt detector

Cross-section of NC π^0 production

Use single ring μ-like events as a reference.

π^0

25t fiducial (r<2m, -2m<z<0m)
2 ring FC events, both e-like
$M_{\gamma\gamma}$ = 85 – 215 MeV/c^2

μ

25t fiducial (r<2m, -2m<z<0m)
1 ring FC events, μ-like

K2K Data set : 3.2E19 POT

GOOD Agreement !

	Data	MC(*)
π^0	2496	2582.3
1-R FC μ	22612	22545.2
π^0/μ	**0.110** ± 2% ± 8% (stat) (sys)	**0.115** ± ~30% (sys)

Detector systematic
- **Particle ID**
- **Ring counting, etc..**

Neutrino interaction model
- **NC/CC ratio**
- **Secondary interactions of π, etc..**

The error was reduced by this measurement

(*) **Same version for the oscillation analysis paper.**
normalized by number of total events in 25t fiducial

New neutrino detector "SciBar"

Installed in the summer 2003

- **Full Active tracking detector**

  Extruded scintillator

  with WLS fiber readout

  Cell size : **2.5 x 1.3** x 300cm^3

  Light yield :**7~20p.e.** /MIP/cm

  (2 MeV)

  → { **reconstruct vertex**
  identify the interaction

- **High efficiency**

  even for the **short tracks**

- Can detect

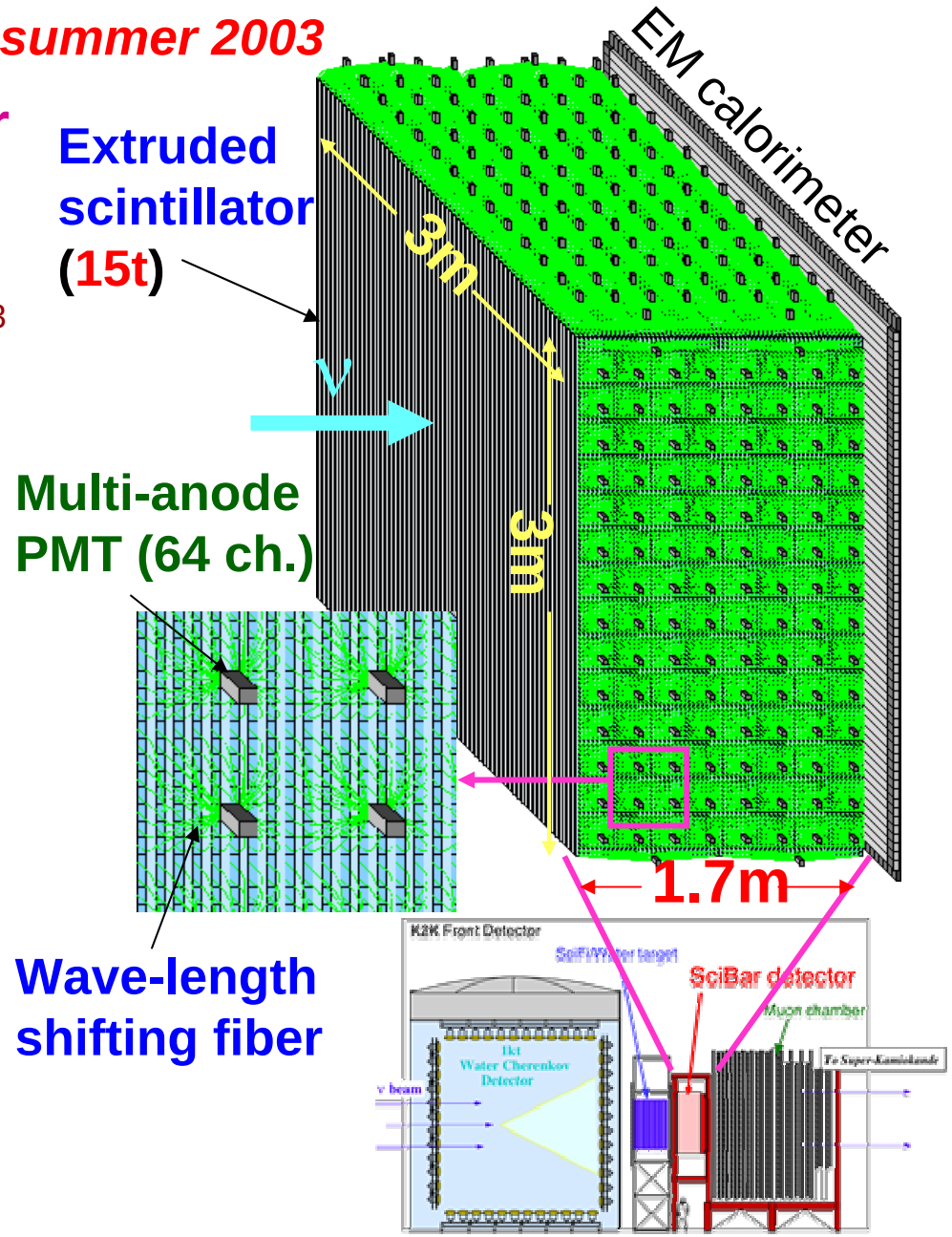
  low momentum protons

  down to ~**350 MeV/c**.

- **PID (p/π)**

  & momentum measurement

  by **dE/dx**.



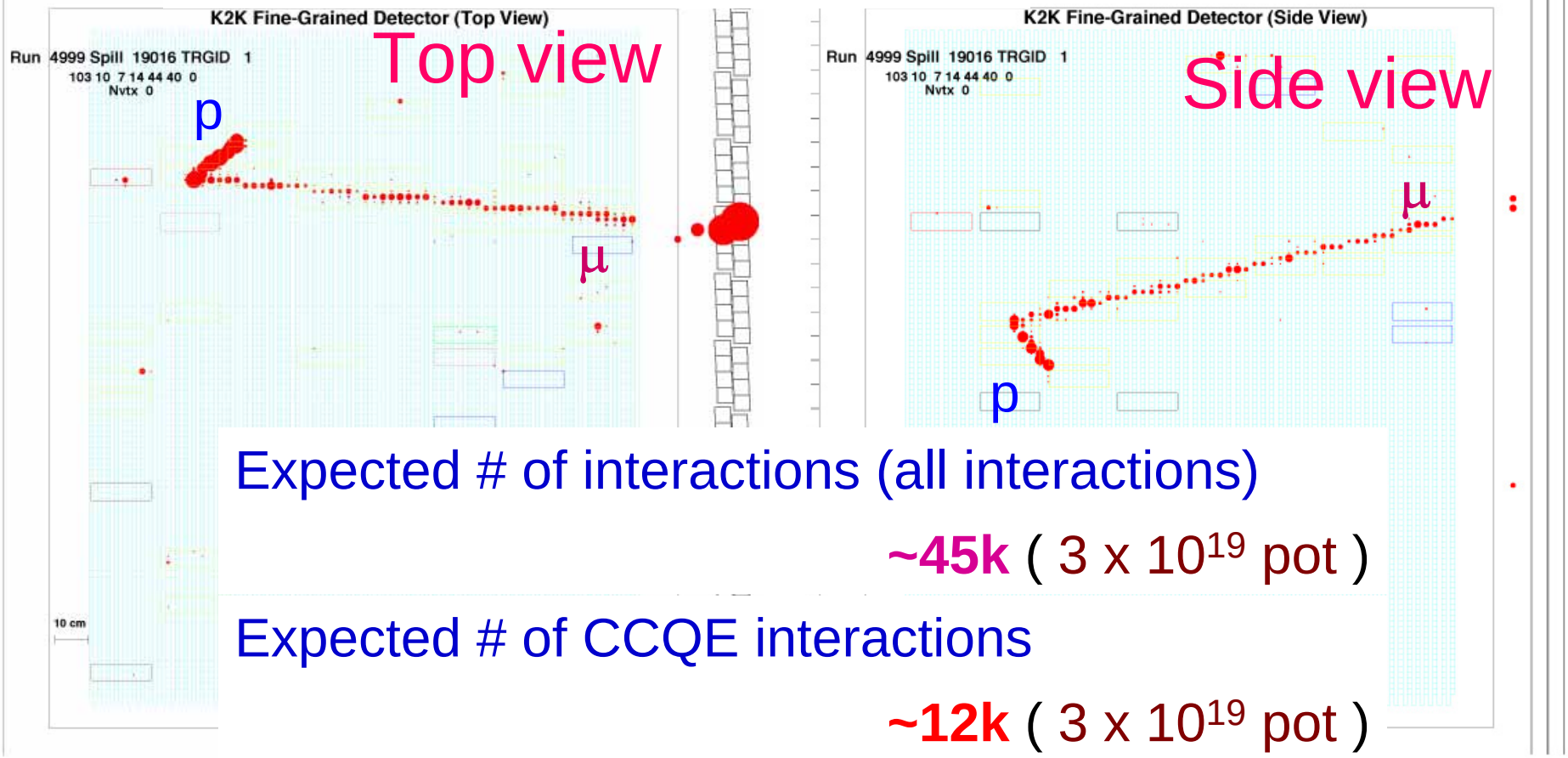
Event observed by the “SciBar” detector

Charged current quasi-elastic event candidate

Size of each circle proportional to the ADC count.

~ energy deposit in each cell.

dE/dx for the shorter track is larger → **proton like.**



Expected # of interactions (all interactions)

~45k (3 x 10^{19} pot)

Expected # of CCQE interactions

~12k (3 x 10^{19} pot)

Performance of the "SciBar" detector

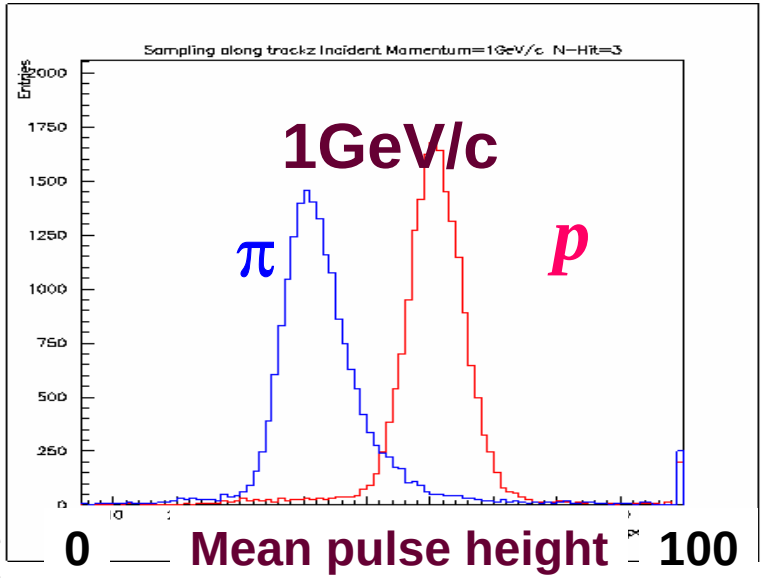
- **PID (p/π)**
- **momentum measurement**
  by **dE/dx ~ Pulse height**.

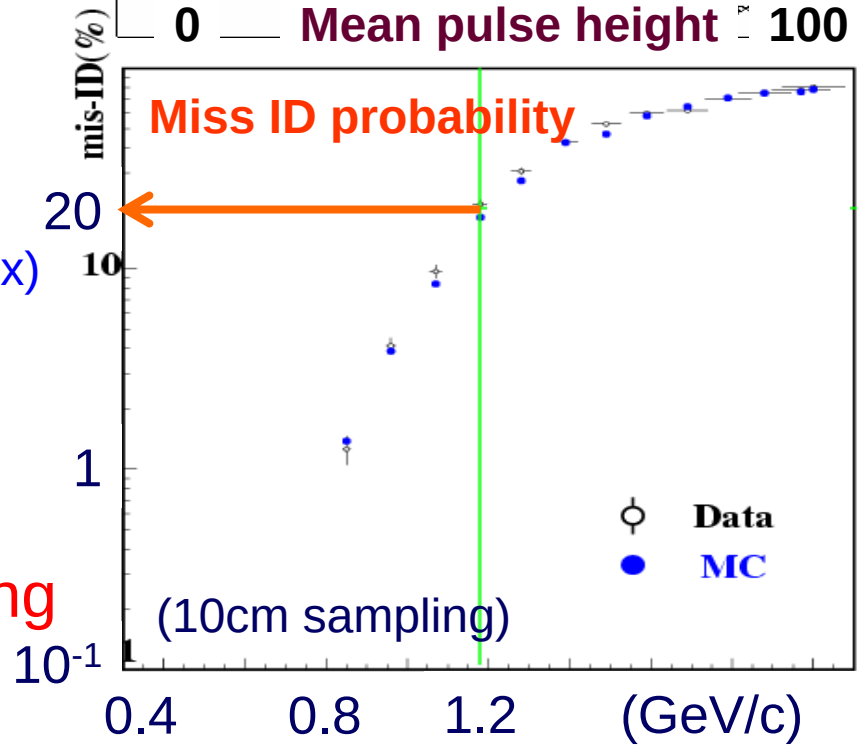
Results from the beam test

- p/π miss ID probability
  less than 20% below 1.2GeV/c
- Momentum reconstruction
  of proton by dE/dx
  Δp/p within 10%
  (using 10cm of dE/dx)

- **Low momentum (short track)**
  proton identification

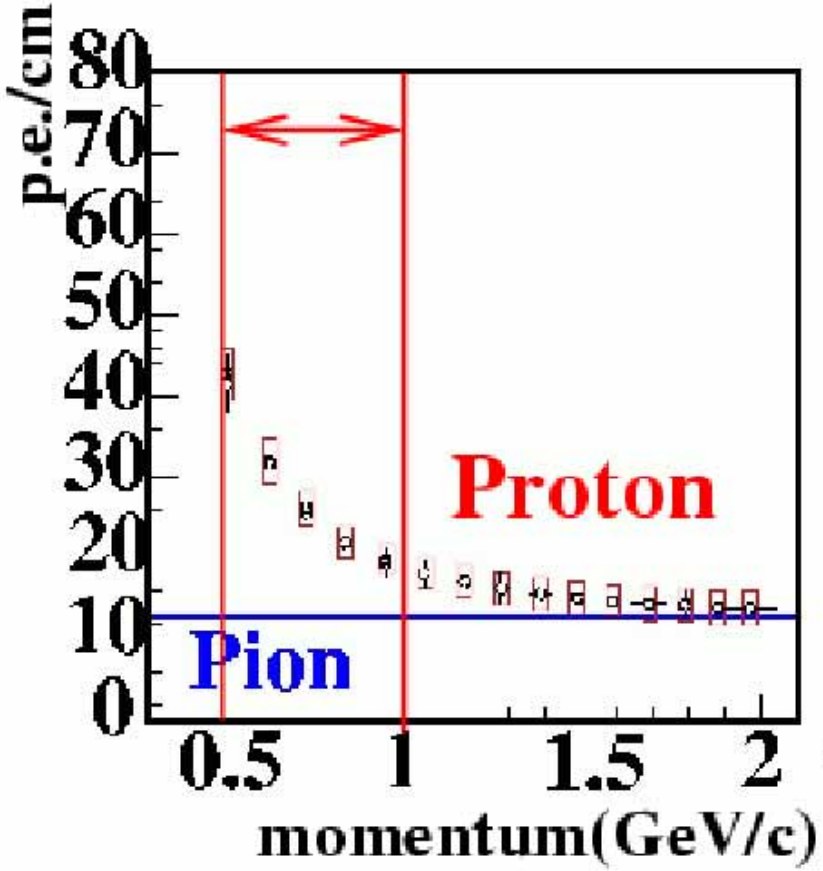
High efficiency in finding/identifying
the low energy CCqe events

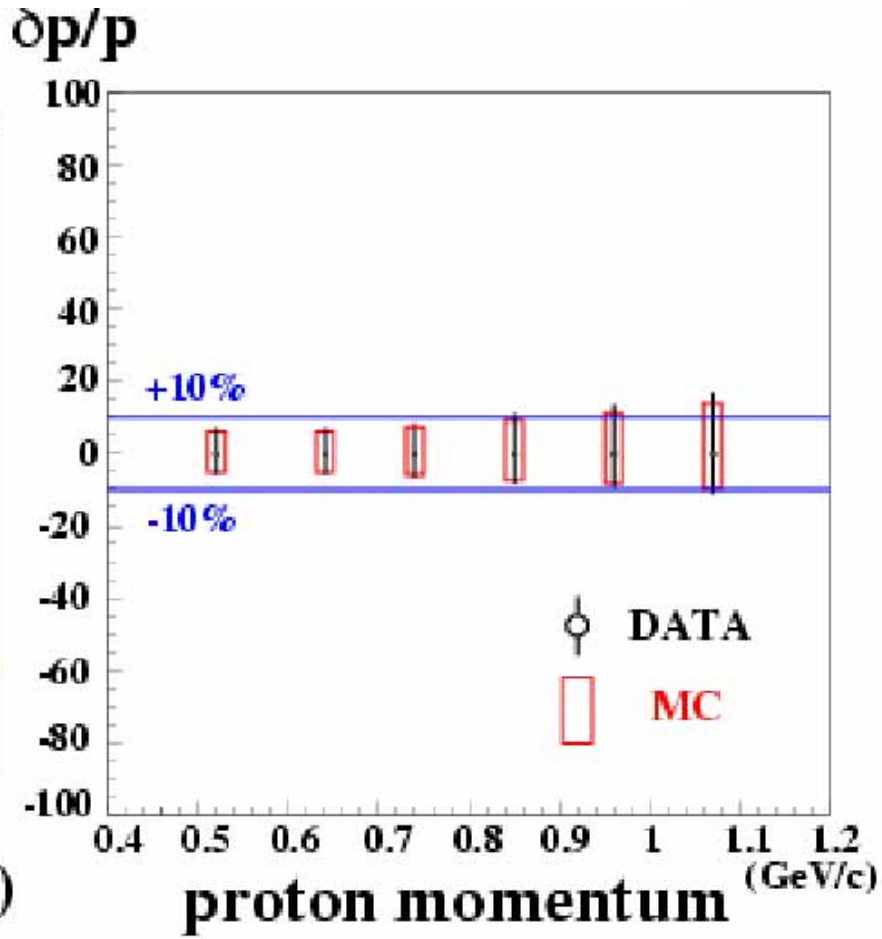




Performance of the “SciBar” detector

proton momentum reconstruction





Proton momentum can be estimated within 10% using only 10cm dE/dx info.

Summary

- K2K near neutrino detectors accumulated
  large number of neutrino events around 1GeV.
- We have studied the neutrino interaction models
  and their parameters.
- The overall agreements between the data and
  Monte-Carlo simulations are quite well.
  Still, some discrepancies are observed.
  (Especially in the small reconstructed q^2 region.)
- Lead Glass detector has been removed (Summer 2002)
  and the new detector “SciBar” was installed (Summer 2003).

  Possible to lower the energy threshold
  for the quasi-elastic scattering events.
  Investigate other neutrino interactions more in detail.