Measurement of charged current charged single pion production in SciBooNE

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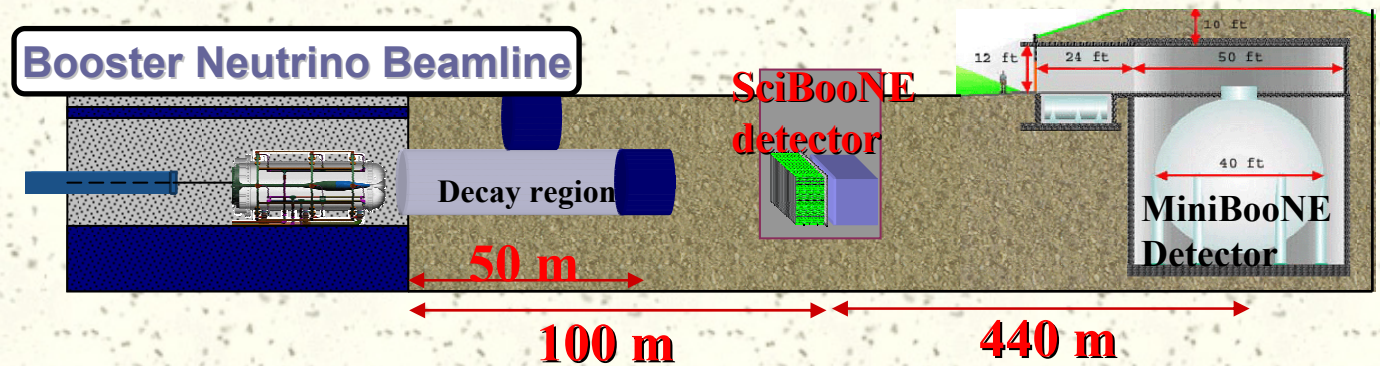
SciBooNE (FNAL E954) experiment



- Precise measurements of neutrino- and antineutrino-nucleus cross sections near 1 GeV
  - Essential for future neutrino oscillation experiments
- Neutrino energy spectrum measurements
  - MiniBooNE/SciBooNE joint ν_μ disappearance
  - ν_e constraint for MiniBooNE

SciBooNE collaboration

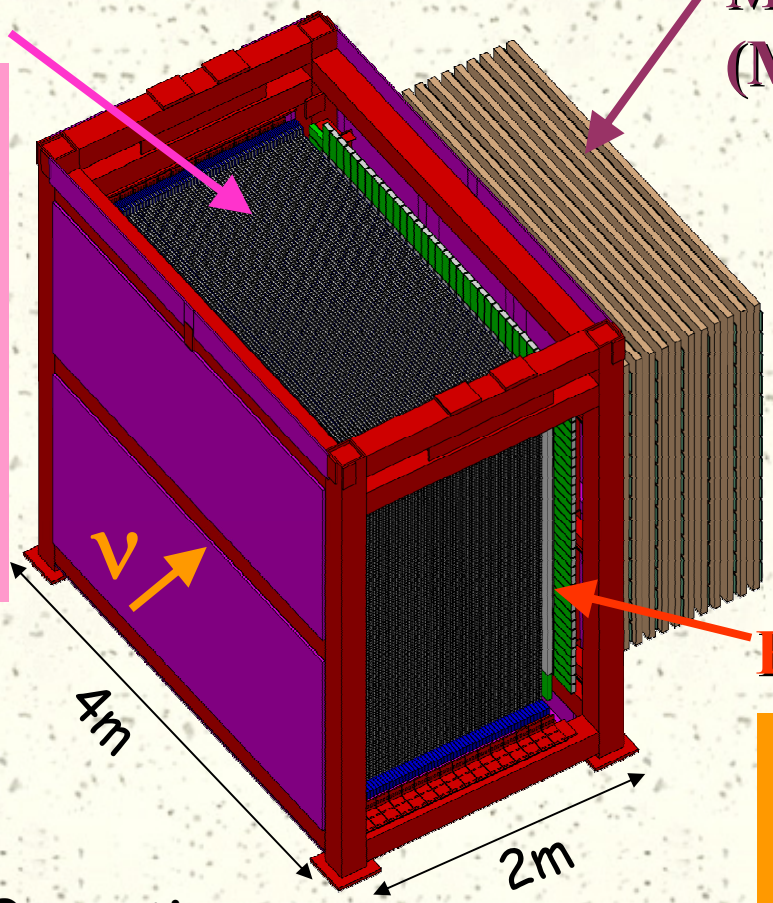
- Universitat Autonoma de Barcelona
- University of Cincinnati
- University of Colorado
- Columbia University
- Fermi National Accelerator Laboratory
- High Energy Accelerator Research Organization (KEK)
- Imperial College London*
- Indiana University
- Institute for Cosmic Ray Research
- Kyoto University*
- Los Alamos National Laboratory
- Louisiana State University
- Purdue University Calumet
- Università degli Studi di Roma and INFN-Roma
- Saint Mary's University of Minnesota
- Tokyo Institute of Technology
- Universidad de Valencia

~70 physicists from 5 countries

SciBooNE detectors

SciBar

- scintillator tracking detector
- 14,336 scintillator bars (15 tons)
- Neutrino target
- detect all charged particles
- p/π separation using dE/dx



Muon Range Detector (MRD)

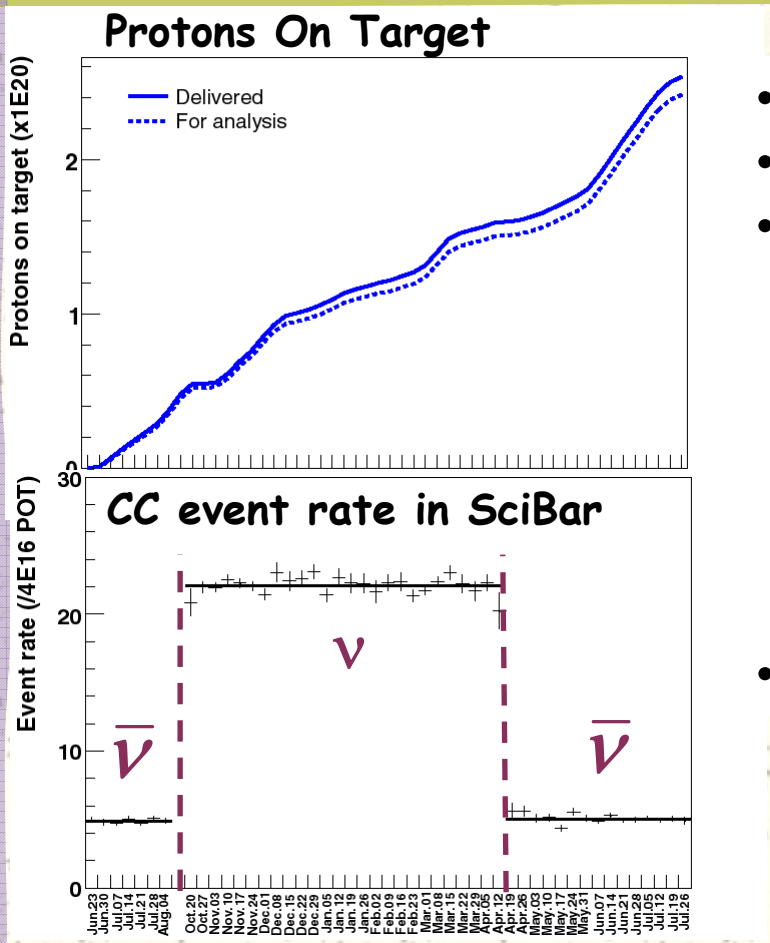
- 12 2”-thick steel + scintillator planes
- measure muon momentum with range up to 1.2 GeV/c

Electron Catcher (EC)

- spaghetti calorimeter
- 2 planes (11 X_0)
- identify π^0 and ν_e

DOE-wide Pollution Prevention Star (P2 Star) Award

Data-taking



- started in June 2007
- collected 2.4×10^{20} POT (July 27)
- 95% data efficiency

  - Neutrino data : 0.99×10^{20} POT completed!
  - Antineutrino data: 1.43×10^{20} POT accumulating!

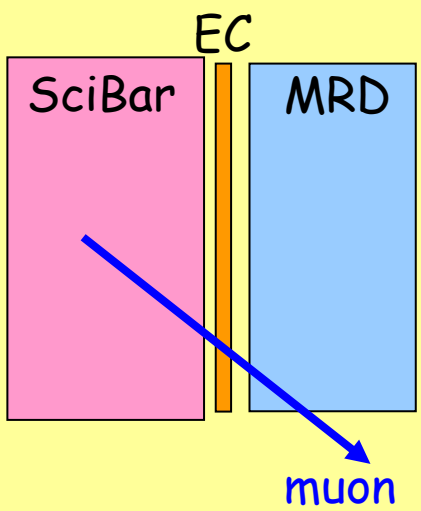
- will finish taking data on August 18th

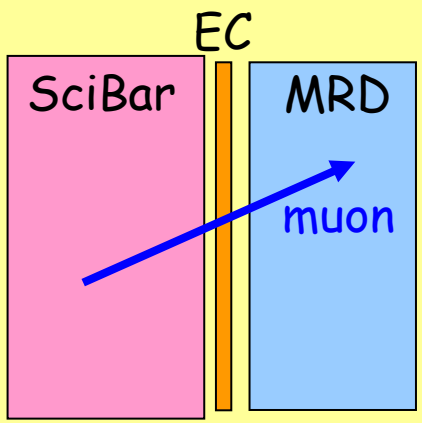
Preliminary results from full neutrino data set are presented

Neutrino spectrum measurement

Neutrino energy spectrum measurement using CC-inclusive sample

<u>SciBar-MRD matched event</u> (~30k events)



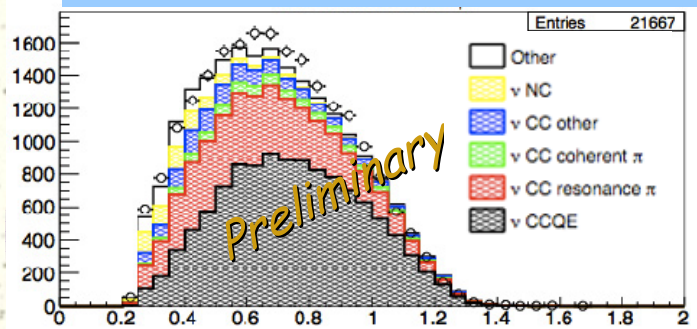


MRD stopped event (~22k events)
(muon contained in MRD)

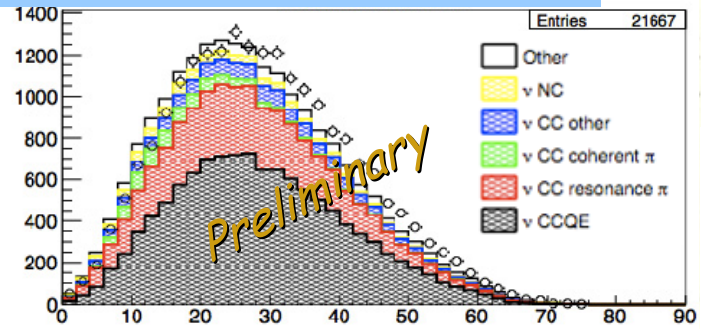
96% pure CC-inclusive sample

Neutrino spectrum measurement

Muon kinematics of MRD stopped sample



Pμ (GeV/c)

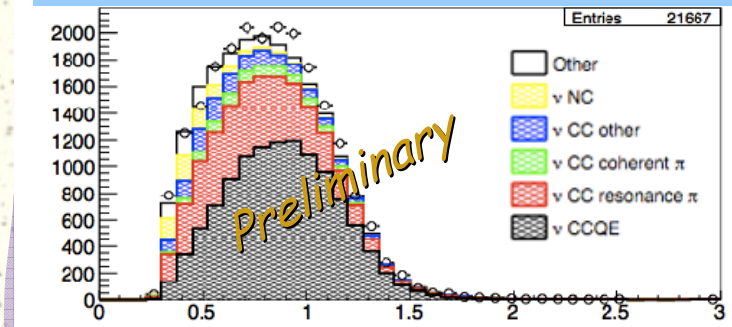


θμ (degree)

Y.Nakajima

$\sigma(P\mu)$~50MeV/c
$\sigma(\theta\mu)$~0.9degree
M_A=1.1 GeV/c^2

Reconstructed Eν assuming CC-QE



$E\nu^{rec}$ (GeV)

MC is normalized to SciBar-MRD matched sample

Fit Pμ, θμ distribution to get neutrino spectrum for ν_μ disappearance

Result will come soon

CC-1π^+ measurement in SciBooNE

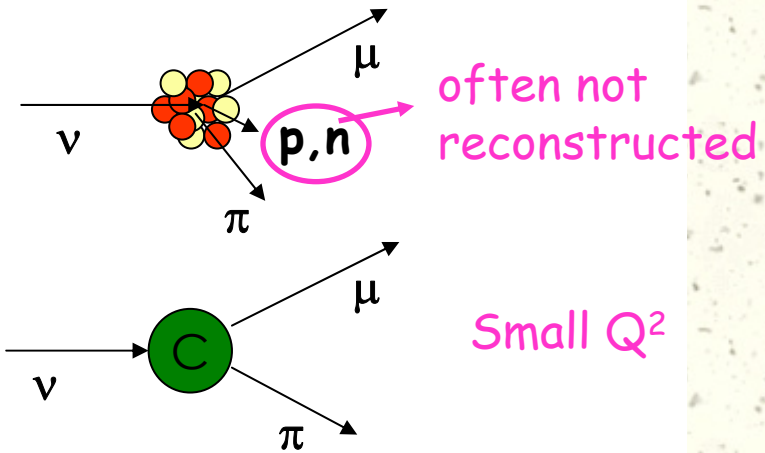
Charged current single charged pion (CC-1π^+) production

CC-resonant π production

- $\nu + p \rightarrow \mu + p + \pi^+$
- $\nu + n \rightarrow \mu + n + \pi^+$

CC-coherent π production

$\nu + C \rightarrow \mu + C + \pi^+$



signal

2 MIP-like tracks (a muon and a pion)

Physics Motivation

- Dominant background process to ν_μ disappearance measurement
- Need precise measurement in the 1 GeV region

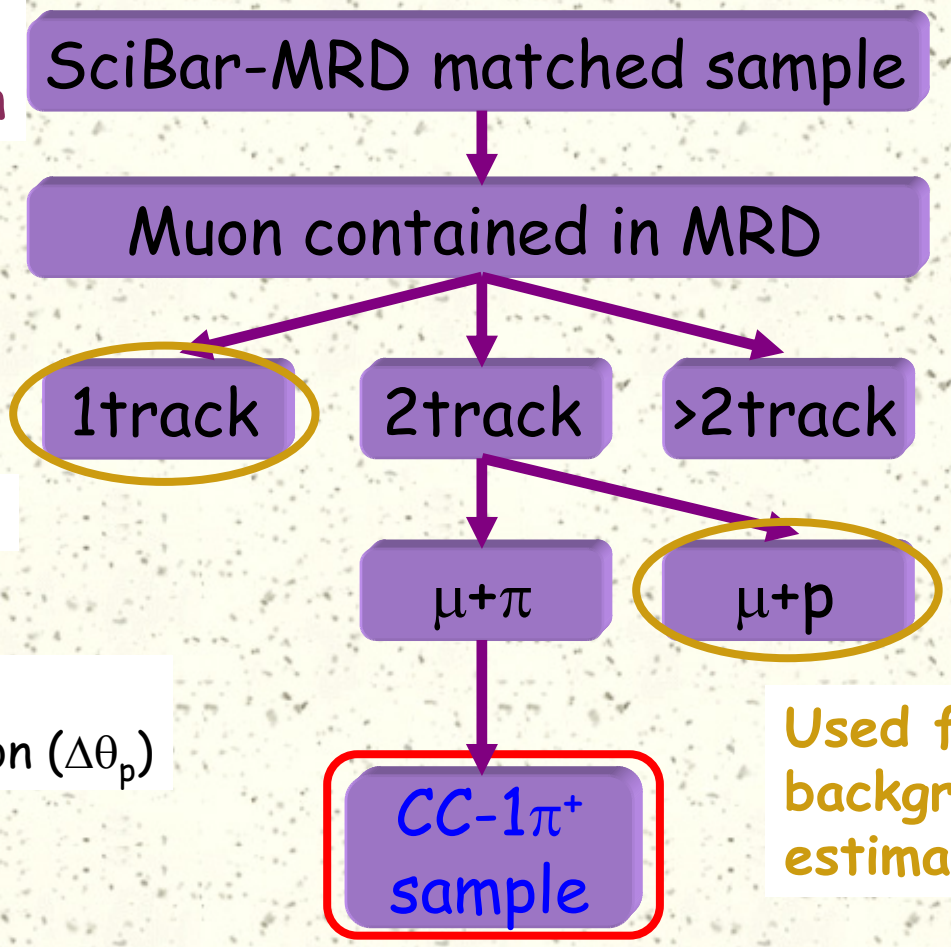
CC-1π^+ event selection

Define MC normalization

Number of tracks from a common vertex

Particle ID using dE/dx

CCQE rejection using non-muon track direction ($\Delta\theta_p$)



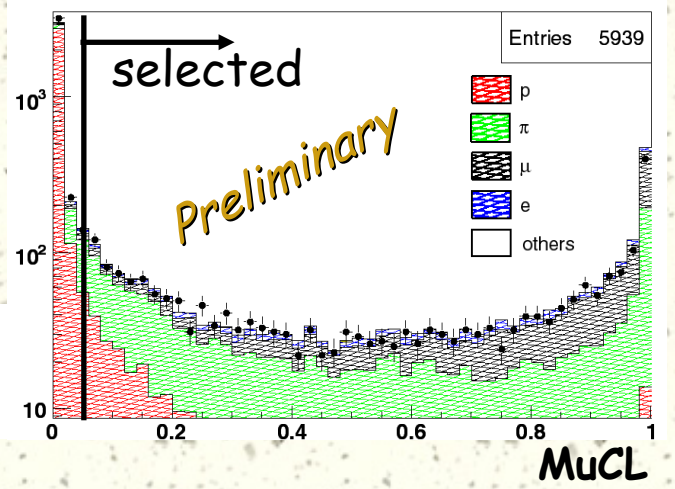
Used for background estimation

CC-1π^+ event selection (cont'd)

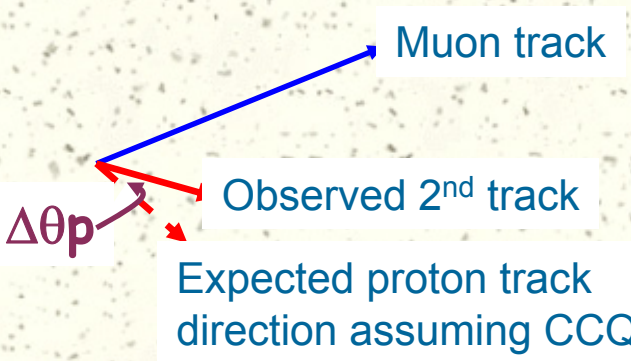
Particle ID using dE/dx

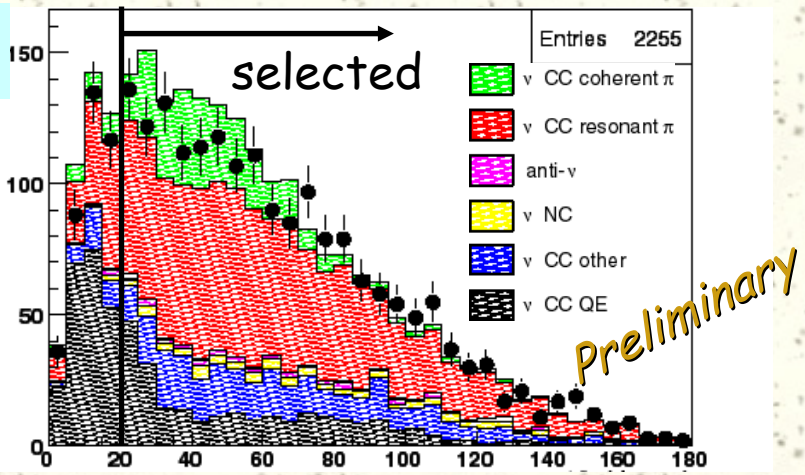
Construct "Muon Confidence Level" to separate proton from muon/pion

MuCL distribution of 2nd track



CCQE rejection based on $\Delta\theta p$

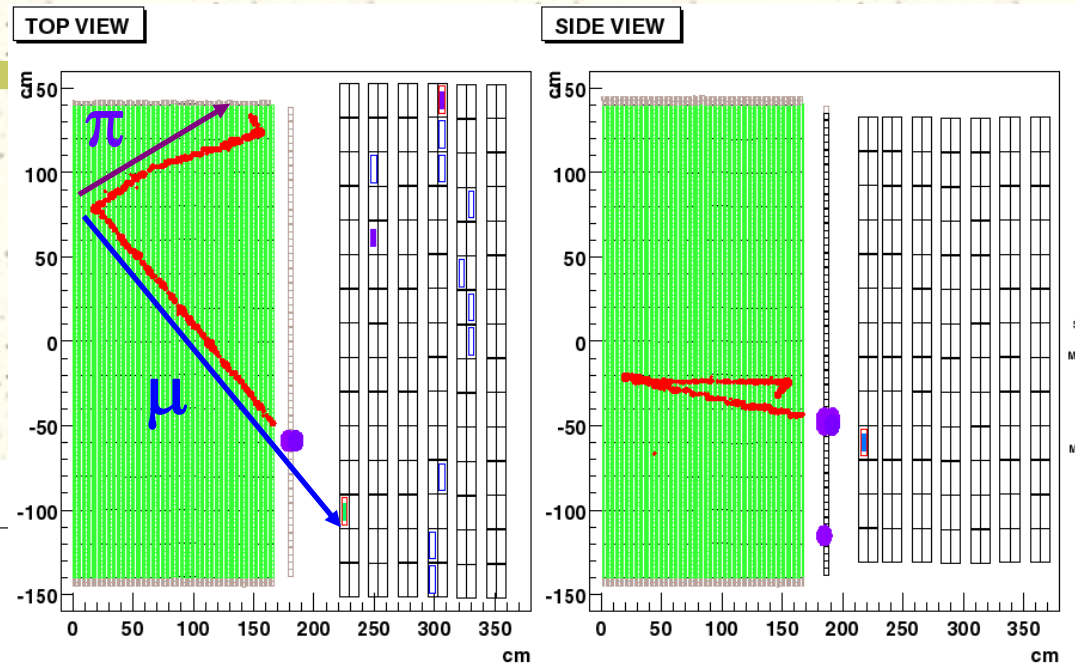




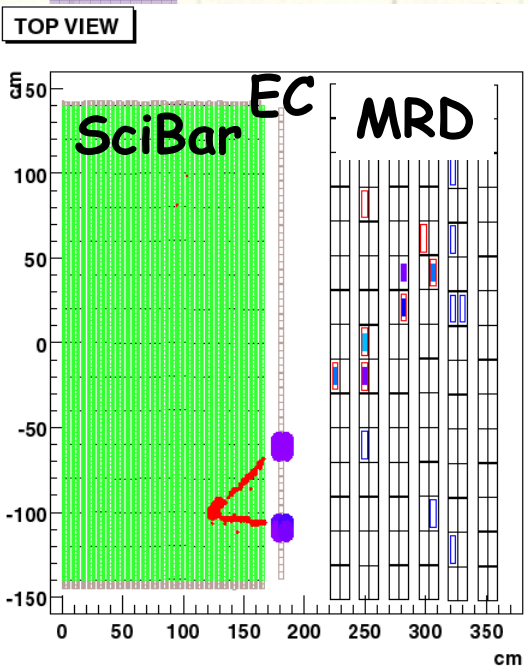
CCQE contamination 20%→13%

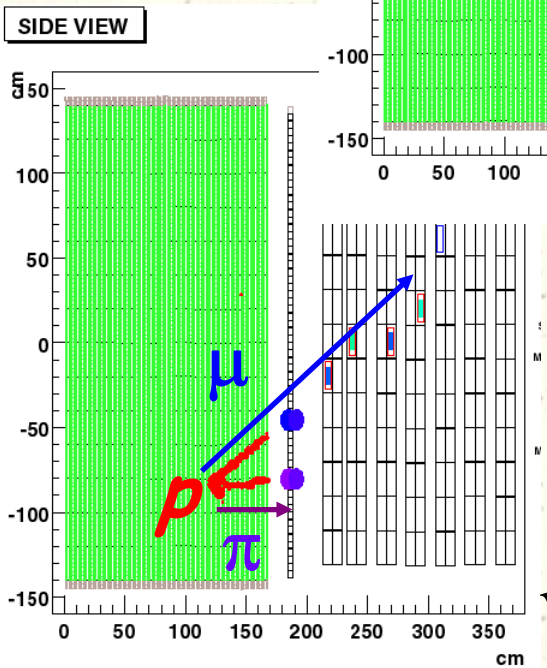
CC-1π^+ event candidates

SciBooNE DATA



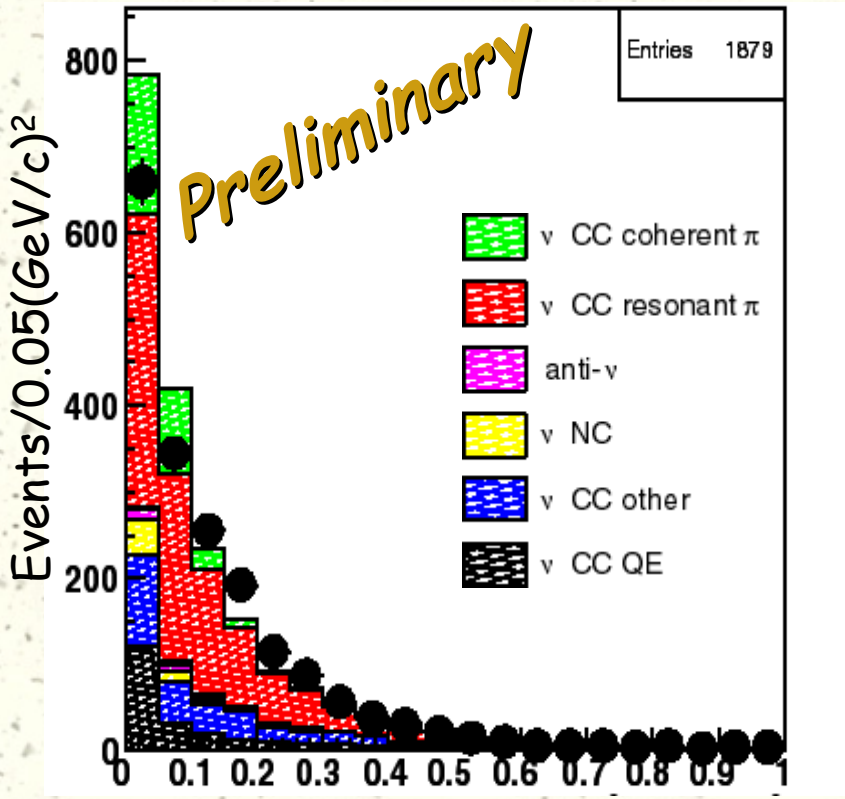
$\nu n \rightarrow \mu n \pi$ candidate





$\nu p \rightarrow \mu p \pi$ candidate

CC-1π^+ sample



Reconstructed Q^2 $(GeV/c)^2$ assuming CC-QE

~80% pure $\mu+\pi$ sample

CC-1π^+ fraction in the sample

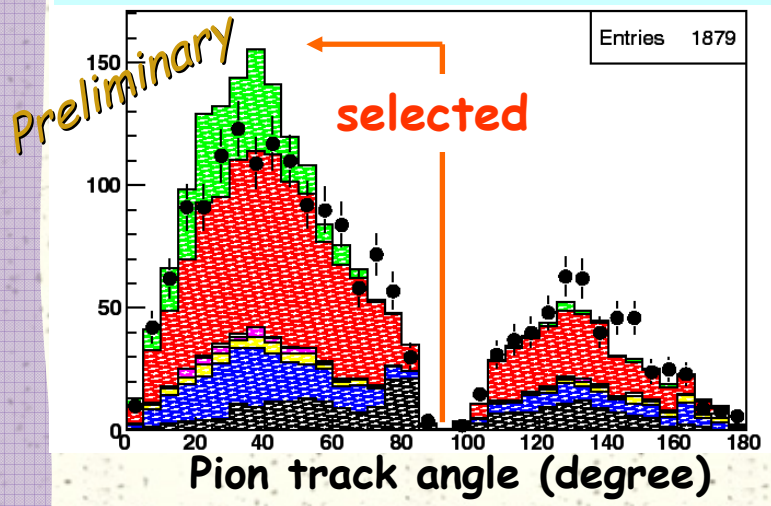
$\nu p \rightarrow \mu p \pi$	34%
$\nu n \rightarrow \mu n \pi$	11%
CC-coherent π	15%

Observed DATA deficit in low Q^2 region

Separate CC-coherent π from CC-resonant π using its characteristic kinematics

Extracting CC-coherent π

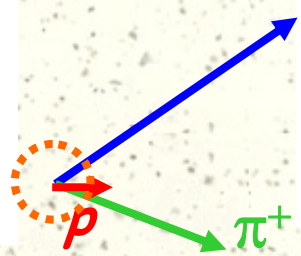
Direction of the pion track

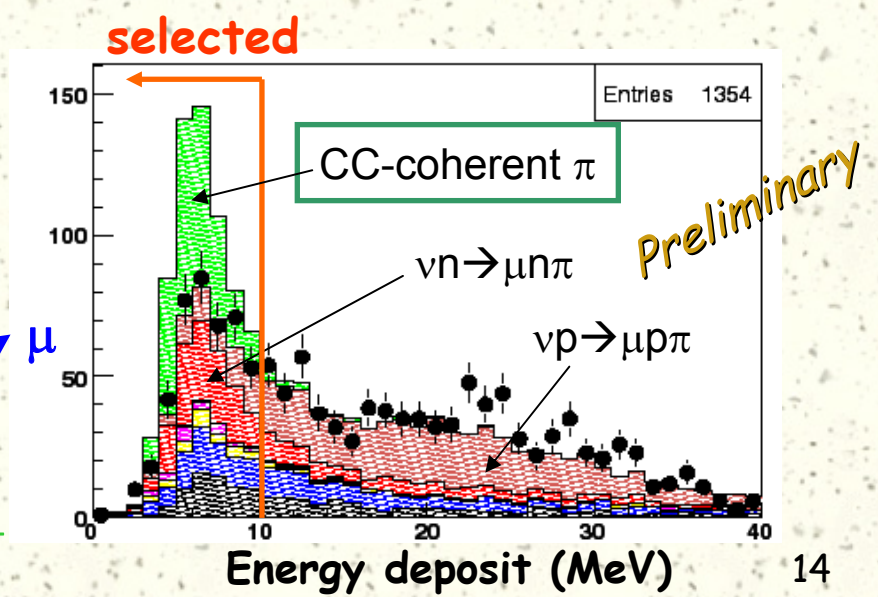


Events with a forward-going Pion track are selected

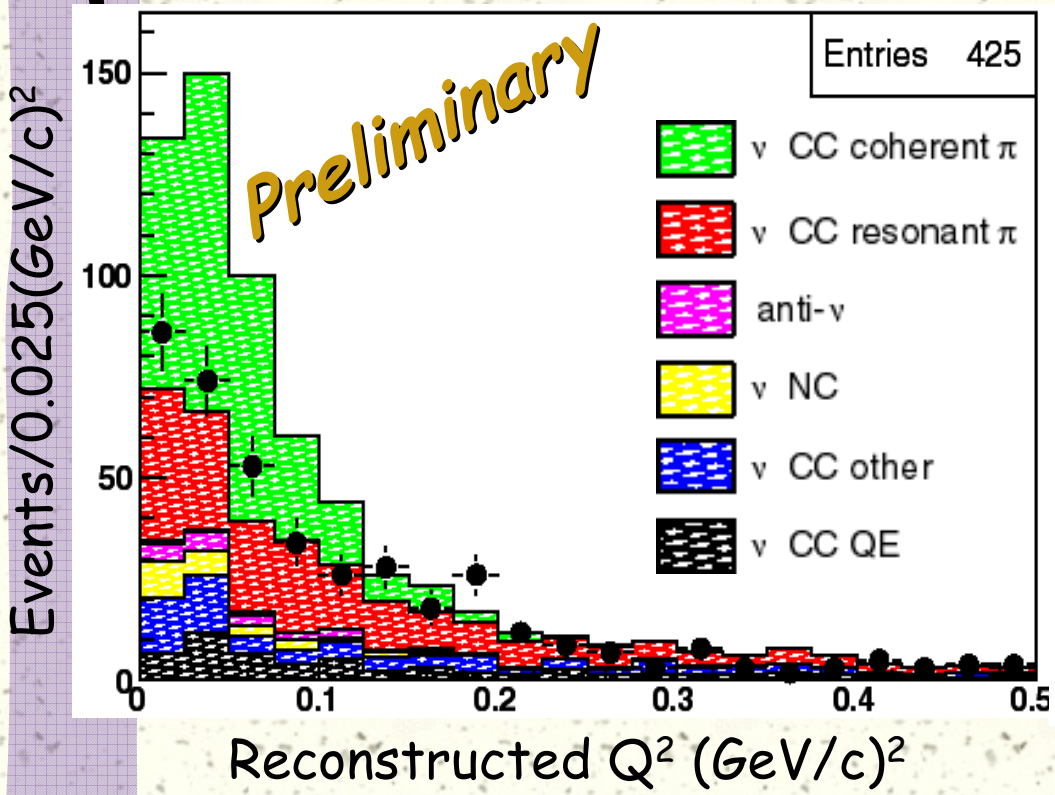
Vertex activity

Low energy proton is identified as a large energy deposit around the vertex





Final CC-coherent π sample



* Systematic error on background estimation is not included yet

Observed CC-coherent π sample in SciBooNE contains fewer events than our MC simulation, which is based on the Rein&Sehgal model (2007)

CC-coherent π

Efficiency 13%

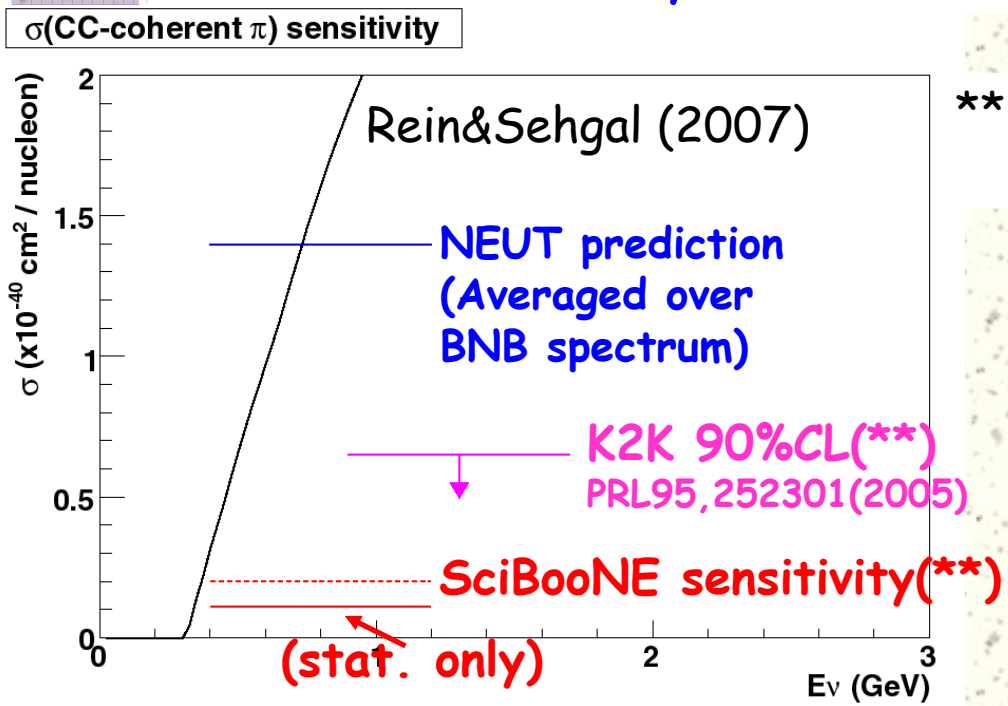
Purity 40%

SciBooNE sensitivity to σ(CC-coherent π)/σ(CC) ratio

SciBooNE sensitivity

σ(CC-coherent π)/σ(CC)~0.3x10^{-2} (*)
(sensitive down to ~10% level of the MC prediction)

*Included only detector systematic error



** Interpreted from cross section ratio using σ(CC) prediction

MiniBooNE NC-coherent π^0 (<Eν>~0.8GeV)
Phys.Lett.B664,41(2008)
(NC-coherent π)/(NC exclusive π^0)
=(19.5+/-1.1+/-2.5) %
65% of the Rein&Sehgal model

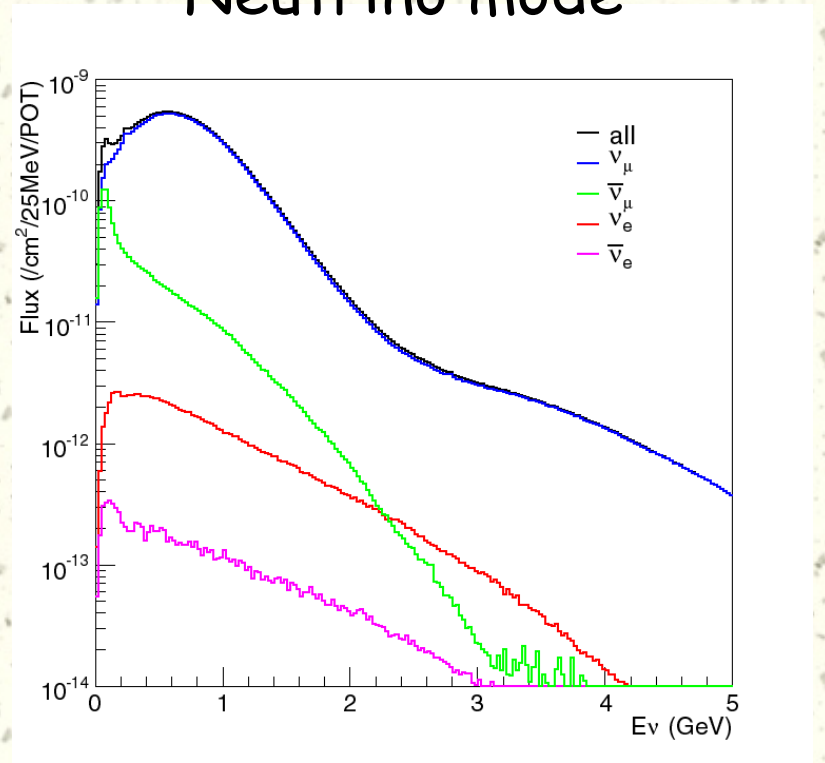
Summary

- SciBooNE measures neutrino and antineutrino cross sections near 1 GeV
- CC-1π^+ measurement in SciBooNE
  - Essential for future neutrino oscillation experiment
  - Observed fewer events in CC-coherent π sample than prediction
- Results will come soon
  - Many analyses (CCQE, CCπ^0, NCπ^0, NCelastic, ν_μ disappearance, ν_e etc.) are on-going
  - Antineutrino measurements

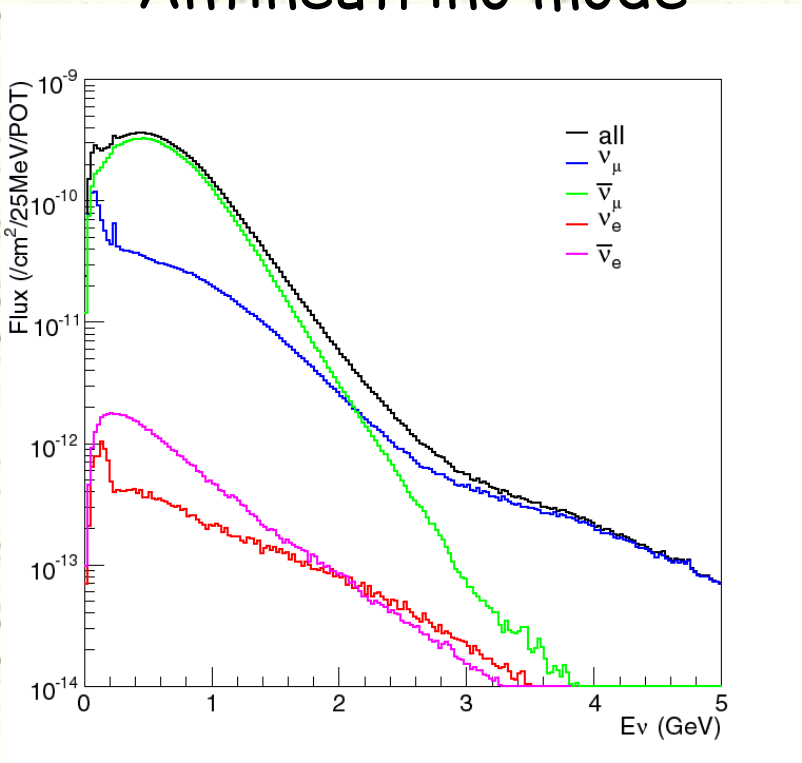
Backup slides

Booster neutrino beam

Neutrino mode

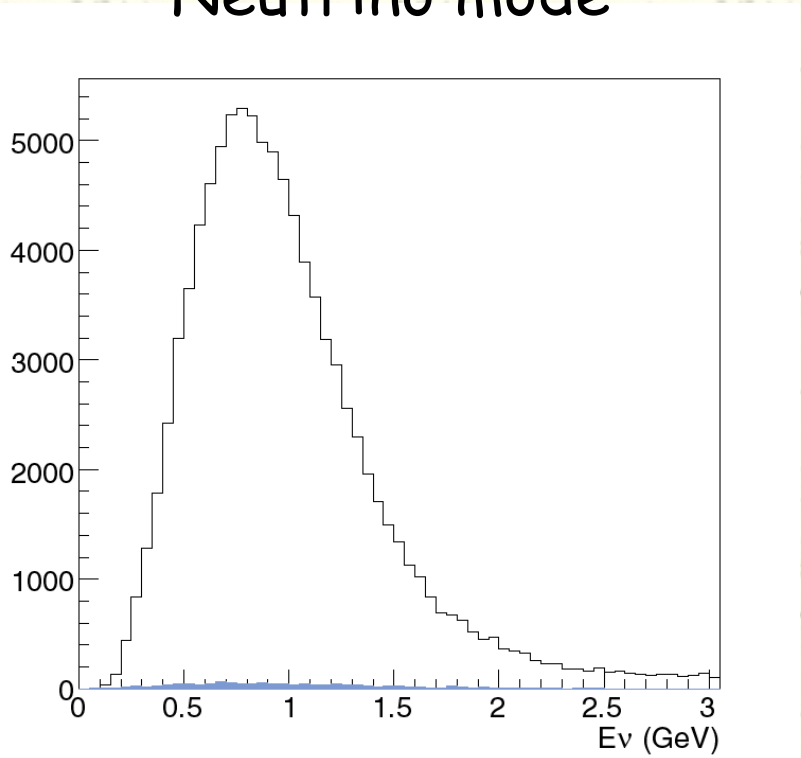


Antineutrino mode

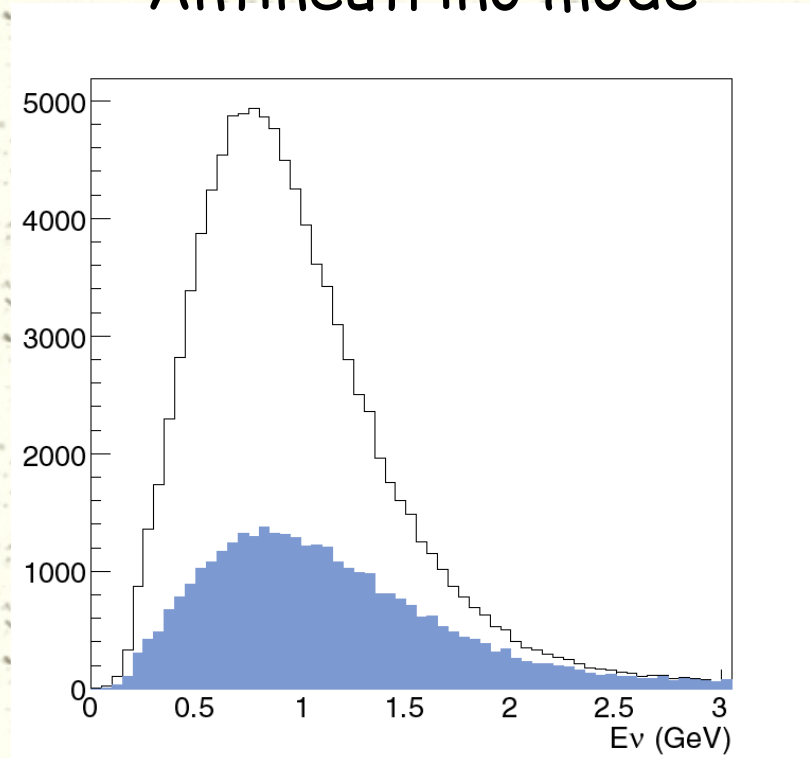


Neutrino energy distribution (cross section weighted)

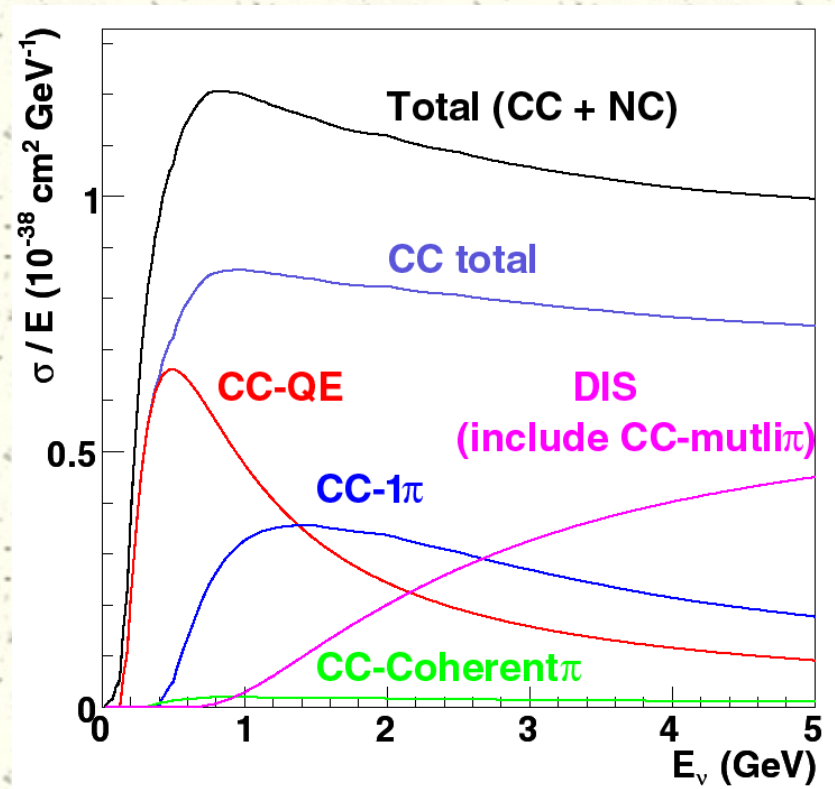
Neutrino mode



Antineutrino mode



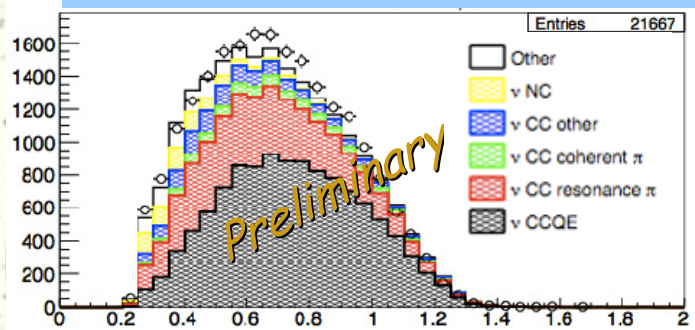
NEUT simulation



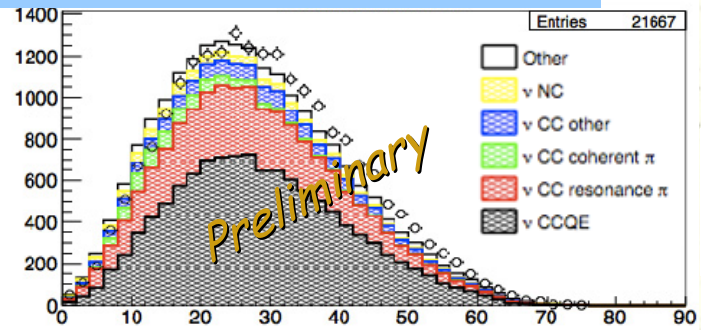
- QE
  - Llewellyn Smith
  - Smith & Moniz
  - M_A=1.1GeV/c^2
  - P_F=217MeV/c, E_B=27MeV
- 1π
  - Rein & Sehgal w/ lepton mass corr.
  - M_A=1.1 GeV/c^2
- DIS
  - GRV98
  - Bodek & Yang corr.
- Nuclear effects

CC-inclusive measurement

Muon kinematics of MRD stopped sample



Pμ (GeV/c)

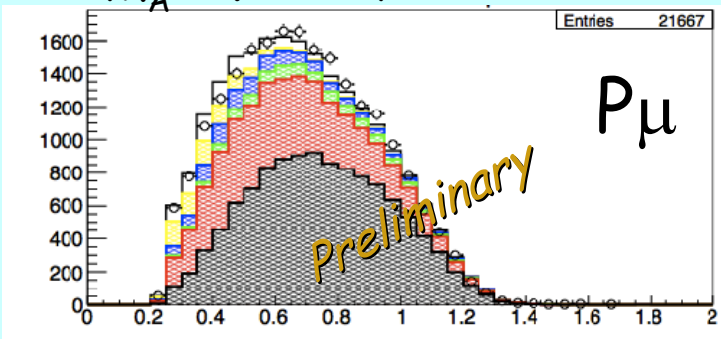


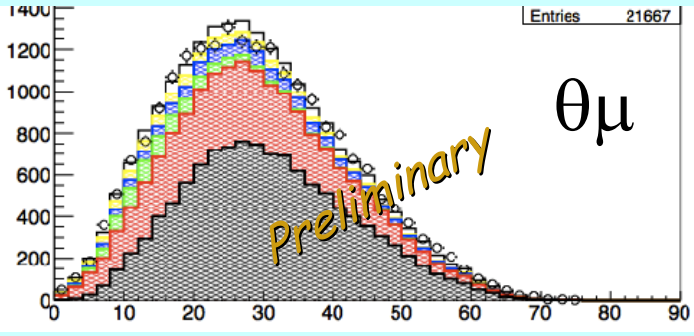
θμ (degree)

Y.Nakajima

σ(Pμ)~50MeV/c
σ(θμ)~0.9degree

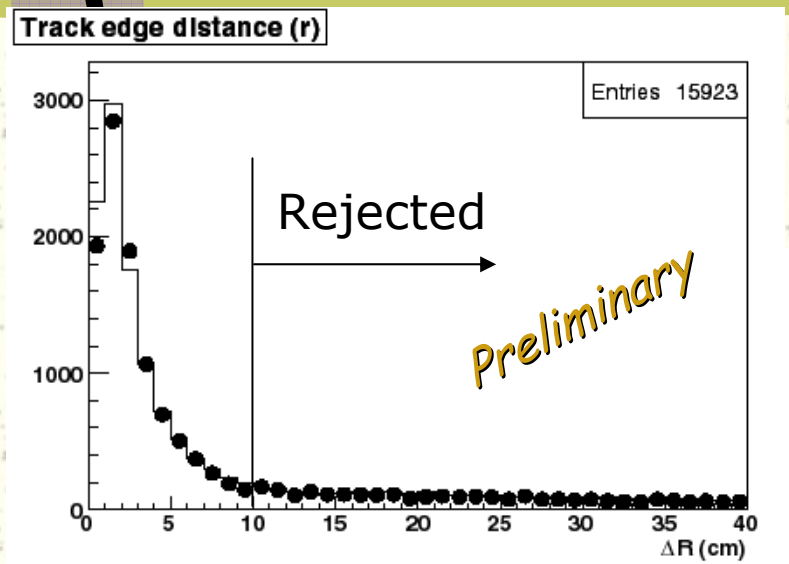
MiniBooNE Pauli blocking parameter κ=1.019
M_A= 1.2 GeV/c^2

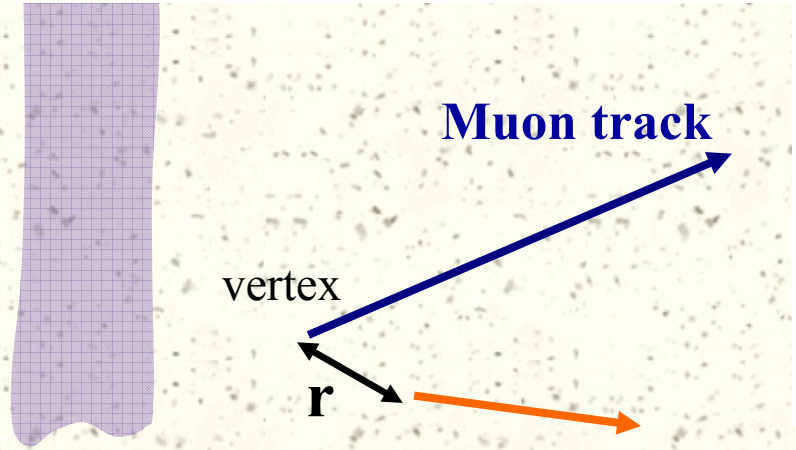


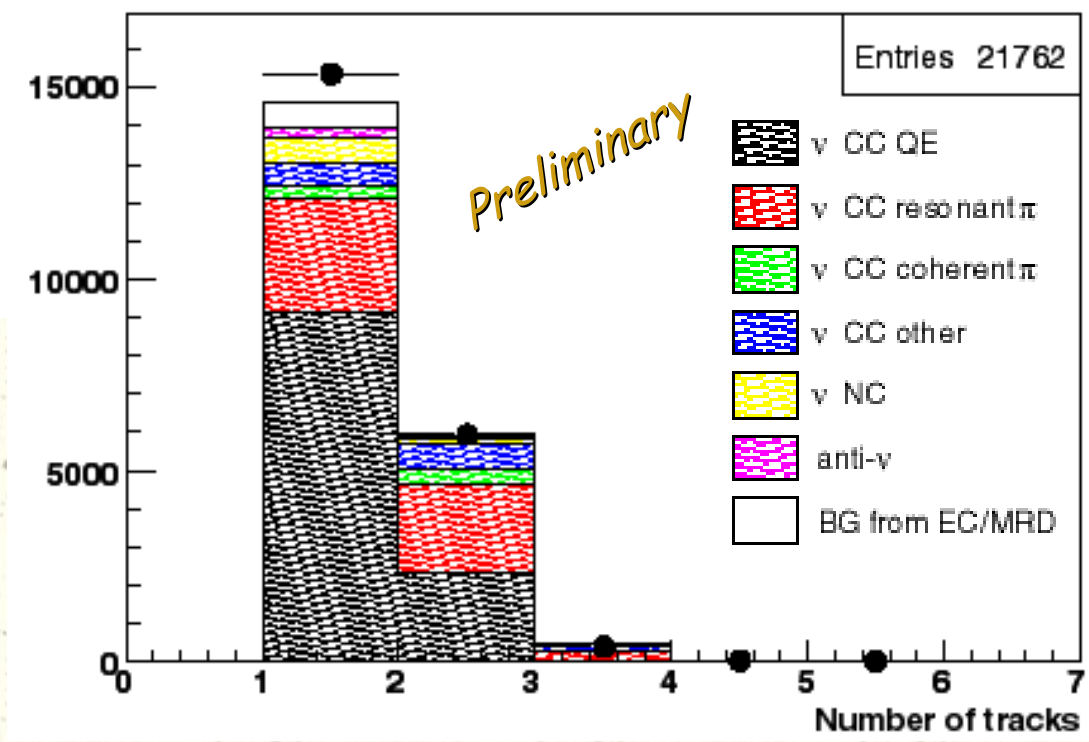


Better agreement!

of tracks from the vertex (MRD stopped sample)

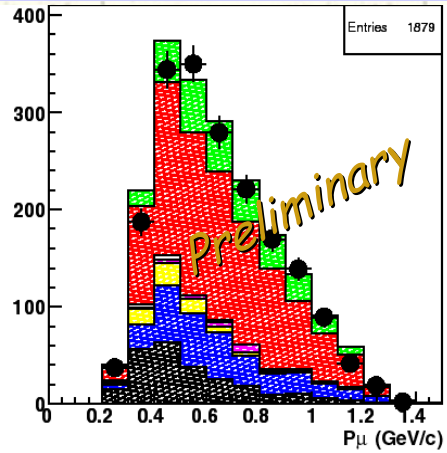




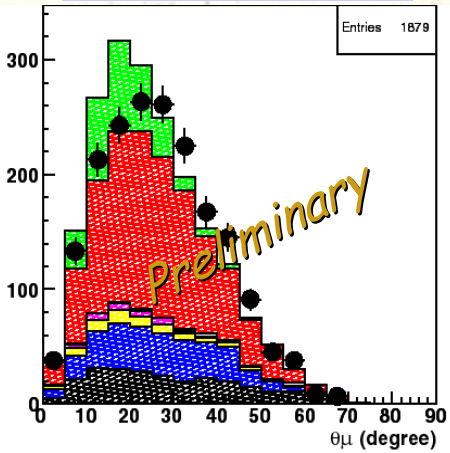


CC-1π^+ distributions

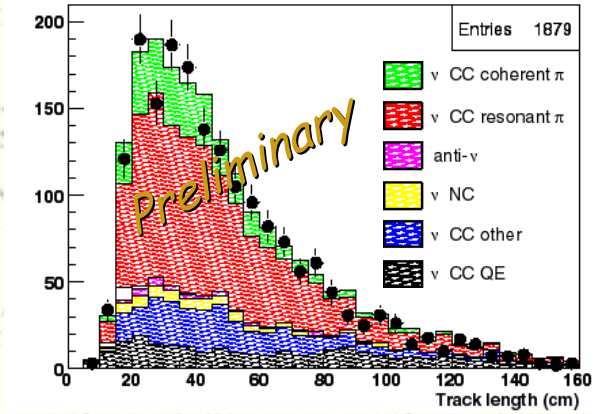
Muon momentum



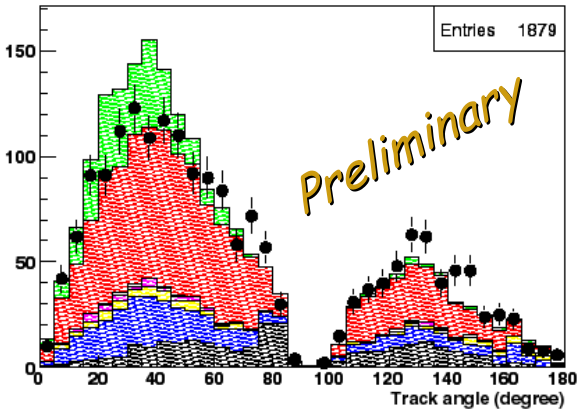
Muon angle



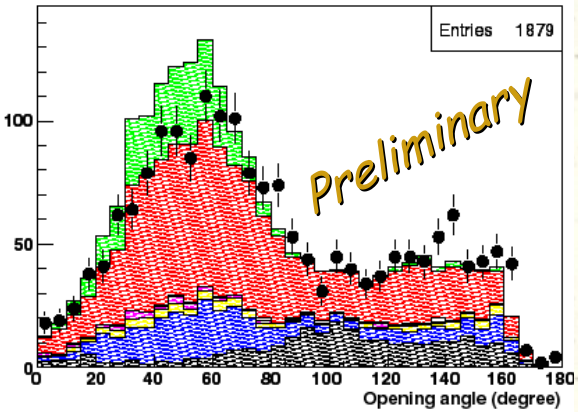
2nd track length



2nd track angle

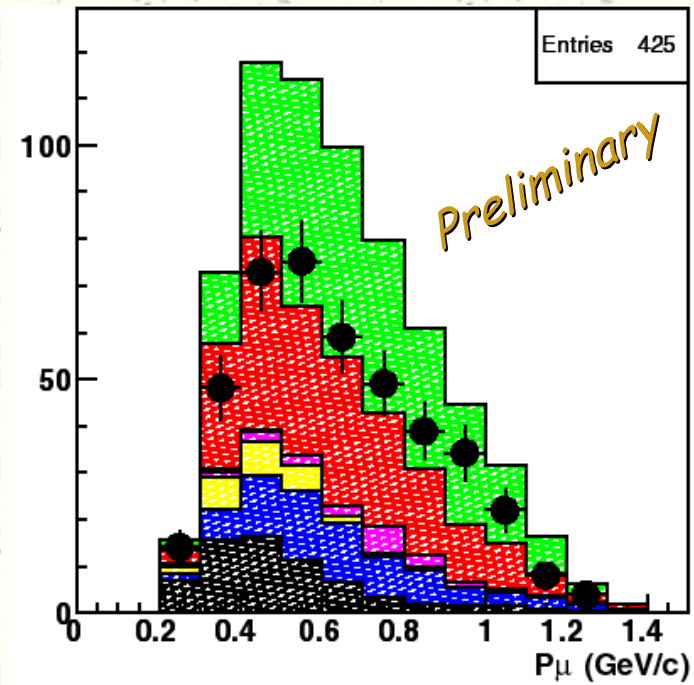


Opening angle

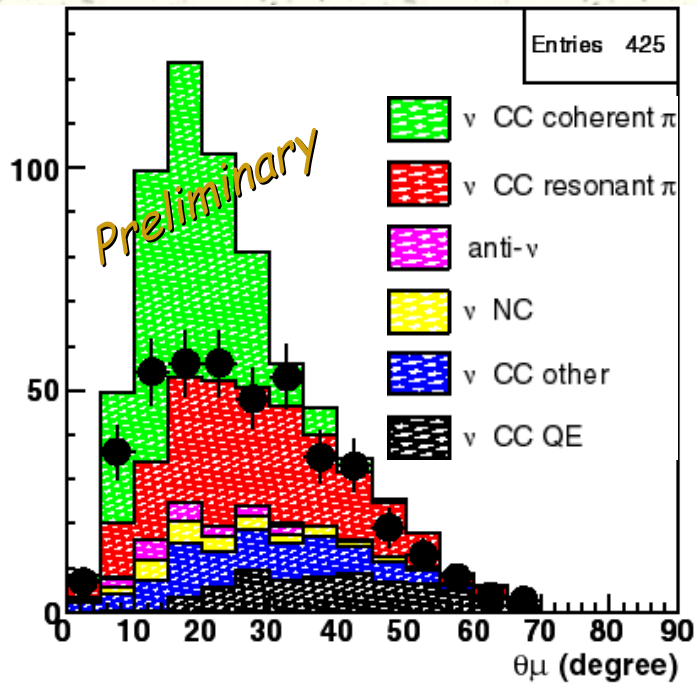


CC-coherent π sample

Muon momentum



Muon angle



CC-1π^+ event selection summary

Preliminary

	DATA	MC	$\nu p \rightarrow \mu p \pi$ efficiency	$\nu n \rightarrow \mu n \pi$ efficiency	Coherent π efficiency
Generated in FV		140,033	100%	100%	100%
MRD matched	30,337	30,337	25.4%	24.2%	49.4%
MRD stopped	21,762	21,041	18.5%	16.7%	36.7%
2 track	5,939	5,898	8.2%	5.8%	19.0%
$\mu+\pi$ (MuCL>0.05)	2,255	2,388	3.8%	4.8%	15.8%
$\Delta\theta_p$>20 degree	1,879	1,972	3.4%	4.3%	14.1%

CC-resonant π
- $\nu p \rightarrow \mu p \pi$ 34%
- $\nu n \rightarrow \mu n \pi$ 11%

CC-coherent π 15%

Backgrounds
CC-QE 13%
CC-multi π 12%

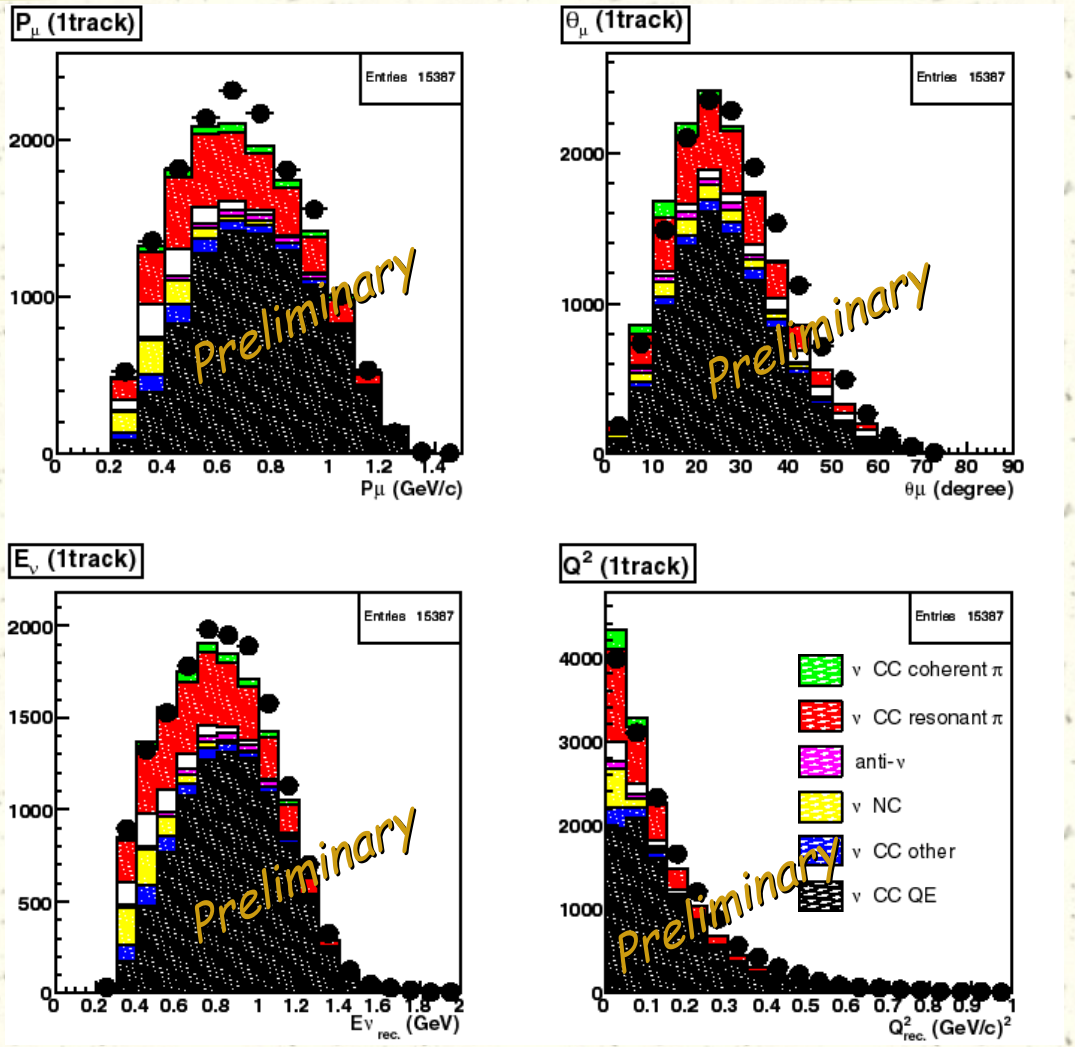
CC-coherent π event selection summary

CC-1π+ selection

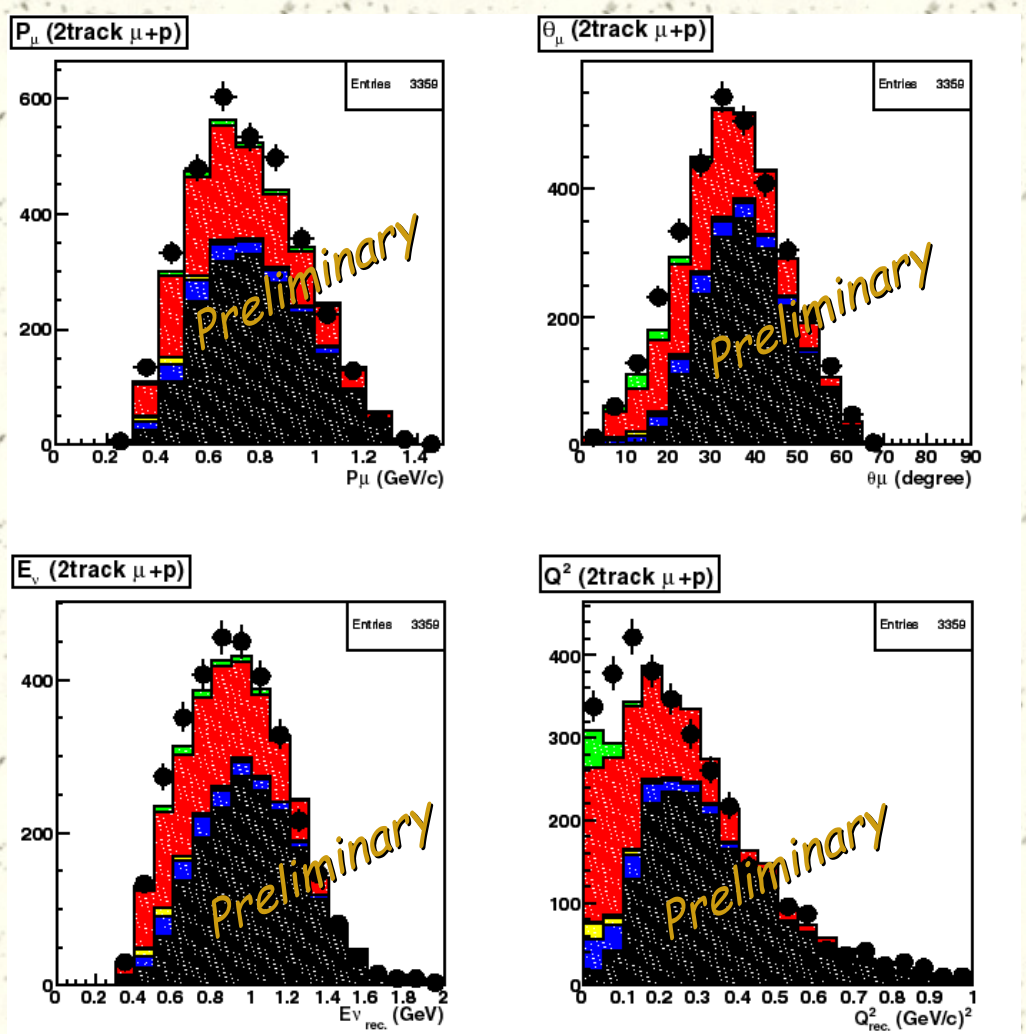
Coherent π

Preliminary	DATA	MC		Coherent π efficiency	Coherent π purity
		coherent	Others		
Generated in FV		2,119	137,914	100%	1.5%
MRD matched	30,337	1,047	29,290	49.4%	3.5%
MRD stopped	21,762	777	20,264	36.7%	3.7%
2 track	5,939	402	5,496	19.0%	6.8%
$\mu+\pi$ (MuCL<0.05)	2,255	334	2,054	15.8%	14%
$\Delta\theta_p$>20 degree	1,879	300	1,672	14.1%	15%
θ_π<90 degree	1,354	284	1,229	13.4%	19%
No vertex activity	425	266	395	12.6%	40%

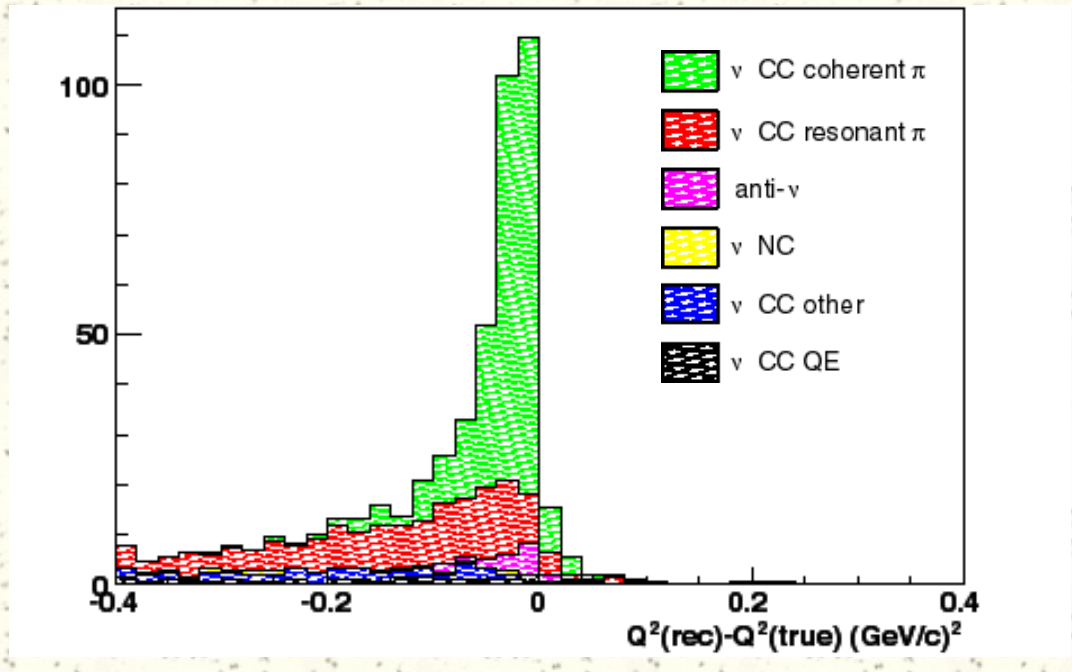
1track sample



2track μ+p sample



Q^2 resolution of CC-coherent π sample

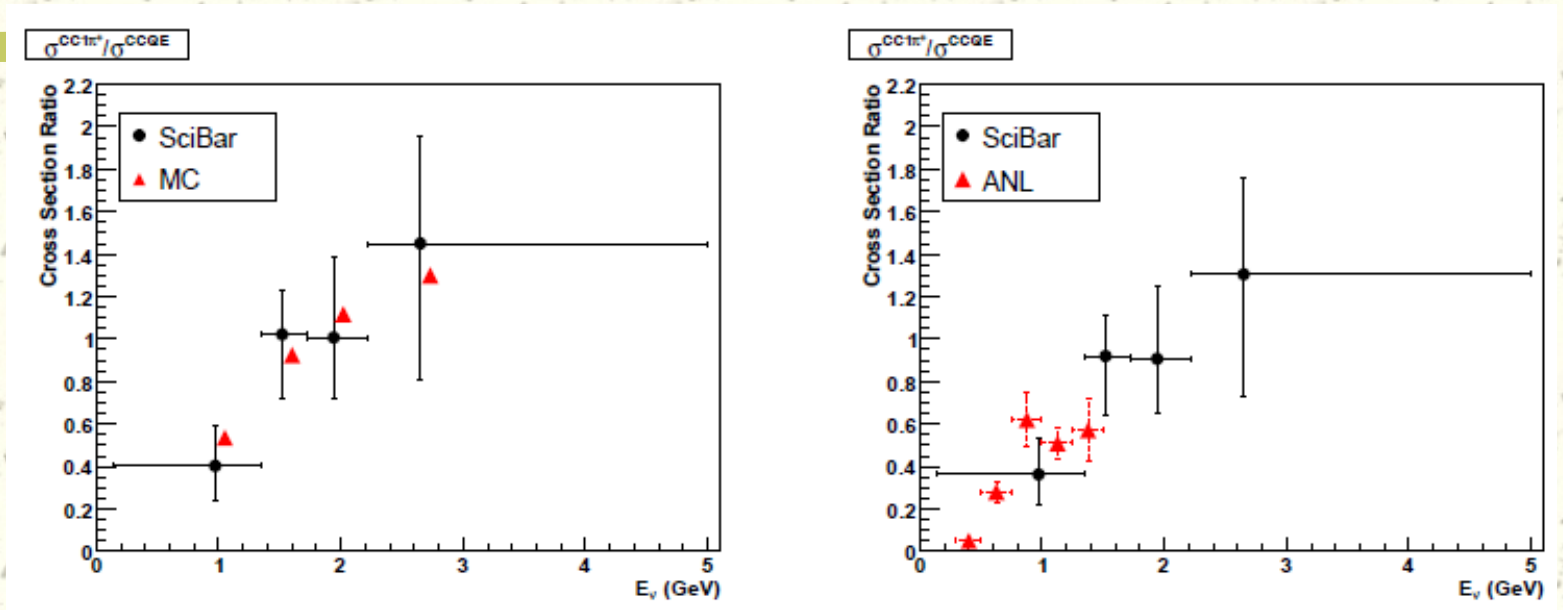


Q2 resolution of CC-coherent π events

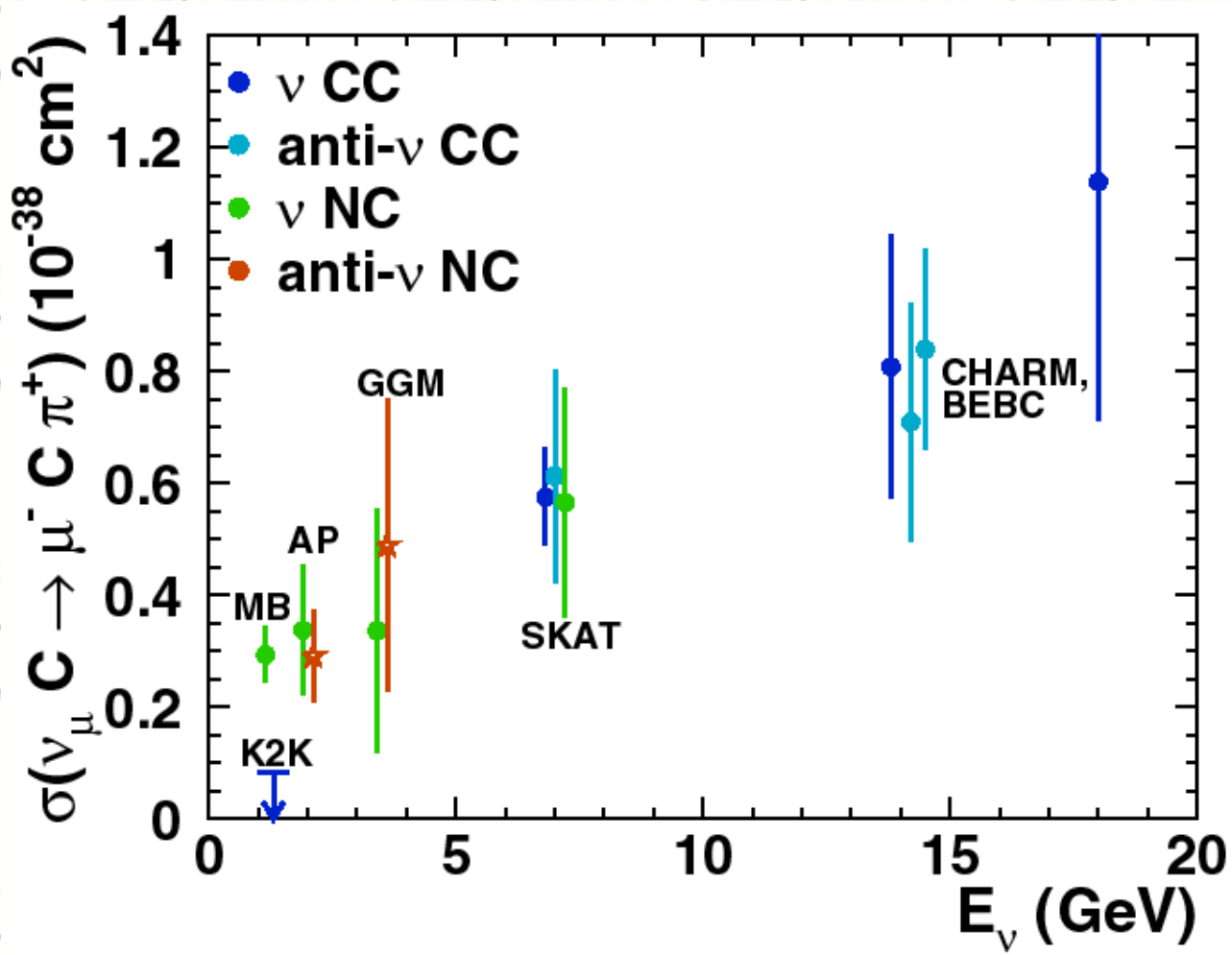
Mean: -0.024 $(GeV/c)^2$

Sigma: 0.016 $(GeV/c)^2$

K2K result on CC-resonant π^+



Energy Range (GeV)	Cross Section Ratio $R_e = \frac{\sigma_e^{CC1\pi^+}}{\sigma_e^{CCQE}}$
>0.00	$0.734 \pm 0.086(\text{fit})^{+0.076}_{-0.103}(\text{nucl})^{+0.079}_{-0.073}(\text{syst})$
0.00-1.35	$0.402 \pm 0.111(\text{fit})^{+0.079}_{-0.071}(\text{nucl})^{+0.131}_{-0.092}(\text{syst})$
1.35-1.72	$1.022 \pm 0.167(\text{fit})^{+0.072}_{-0.217}(\text{nucl})^{+0.107}_{-0.139}(\text{syst})$
1.72-2.22	$1.007 \pm 0.214(\text{fit})^{+0.209}_{-0.065}(\text{nucl})^{+0.241}_{-0.173}(\text{syst})$
>2.22	$1.450 \pm 0.324(\text{fit})^{+0.200}_{-0.272}(\text{nucl})^{+0.330}_{-0.480}(\text{syst})$

arXiv:0805.0186

Other coherent π measurements