

SciBooNE Experiment

Hide-Kazu TANAKA

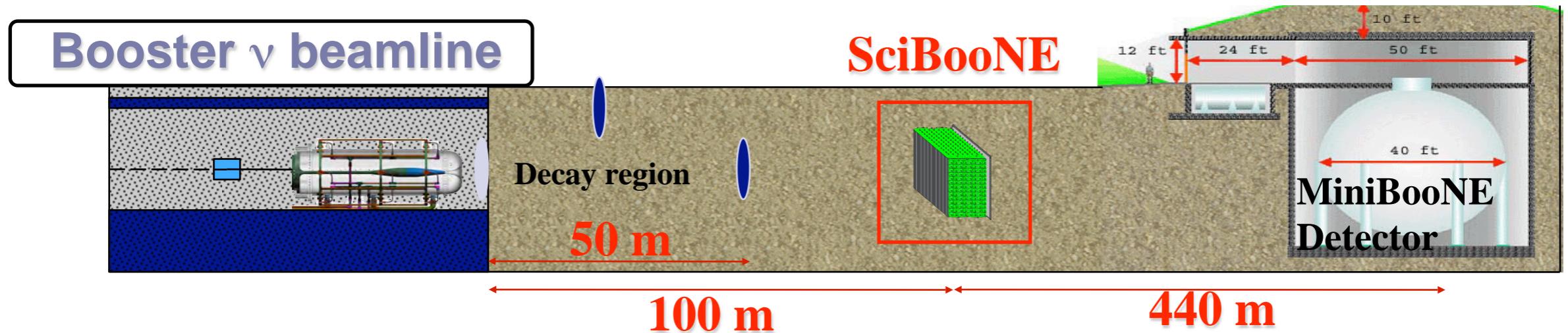
Columbia University / MIT

Outline

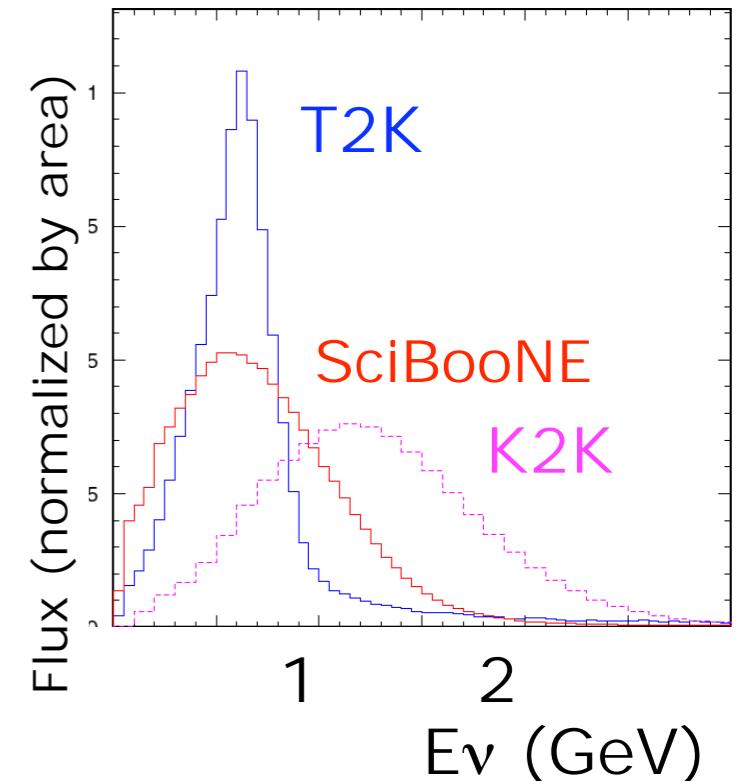
- SciBooNE experiment
- First results from SciBooNE
 - Coherent π production measurement
 - Published in Phys. Rev. D78:112004,2008
- Summary

SciBooNE Experiment

(K2K-SciBar detector at FNAL Booster Neutrino Beam line)



- Precise measurements of neutrino- and antineutrino-nucleus cross sections ~ 1 GeV
- Essential for neutrino oscillation experiments
- MiniBooNE / SciBooNE joint analysis
→ Search for ν_μ disappearance

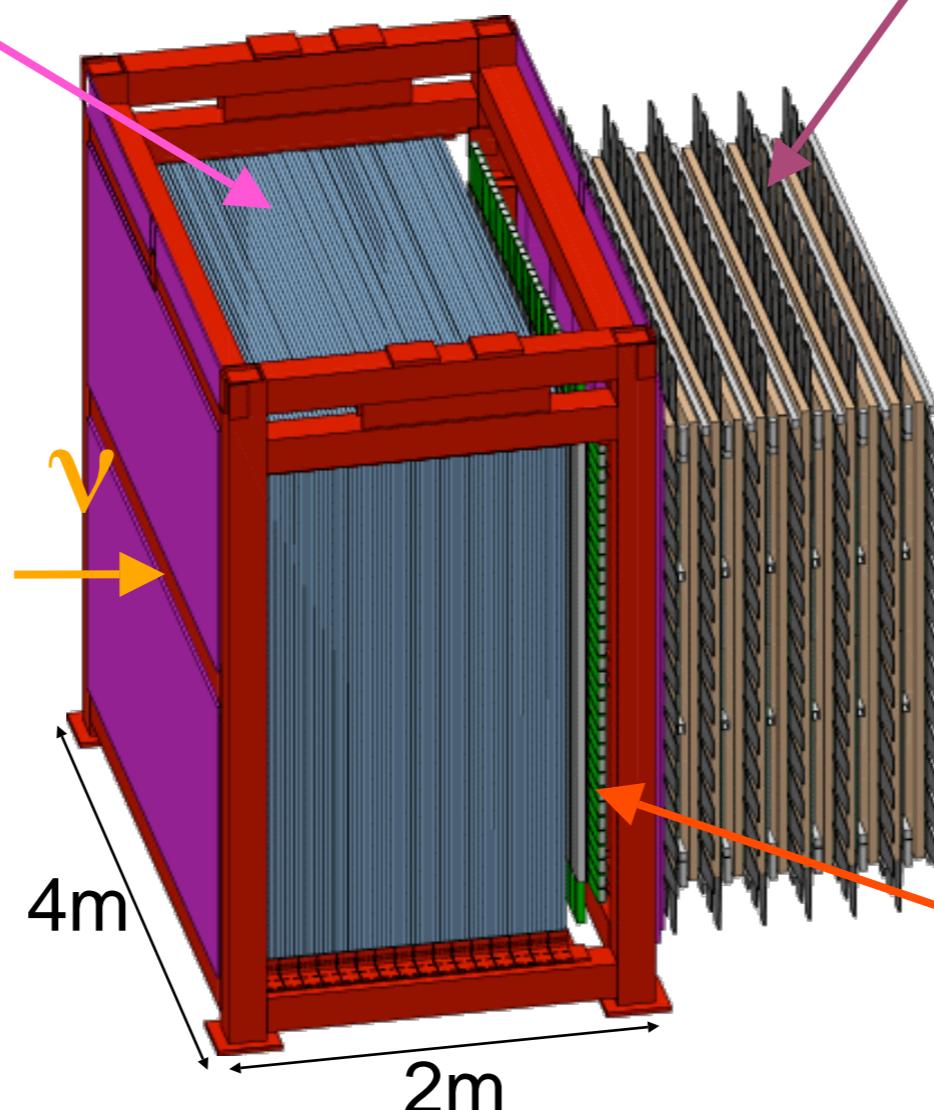


SciBooNE detector

SciBar

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

Used in K2K experiment



Muon Range Detector (MRD)

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

Parts recycled from
Past experiment

Electron Catcher (EC)

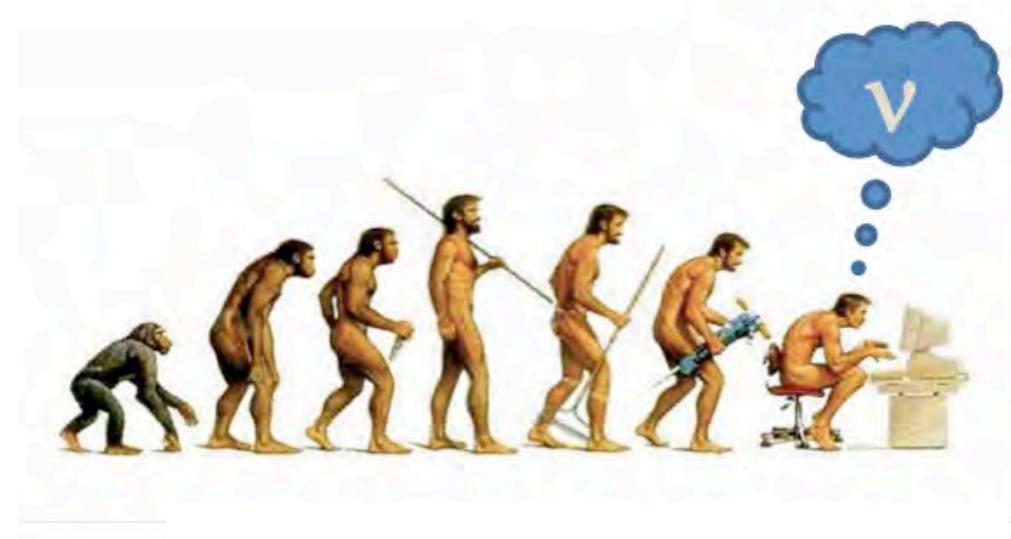
- spaghetti calorimeter
- 2 planes ($11 X_0$)
- identify π^0 and ν_e

Used in CHORUS, HARP and K2K

DOE-wide Pollution Prevention
Star (P2 Star) Award

SciBooNE Timeline

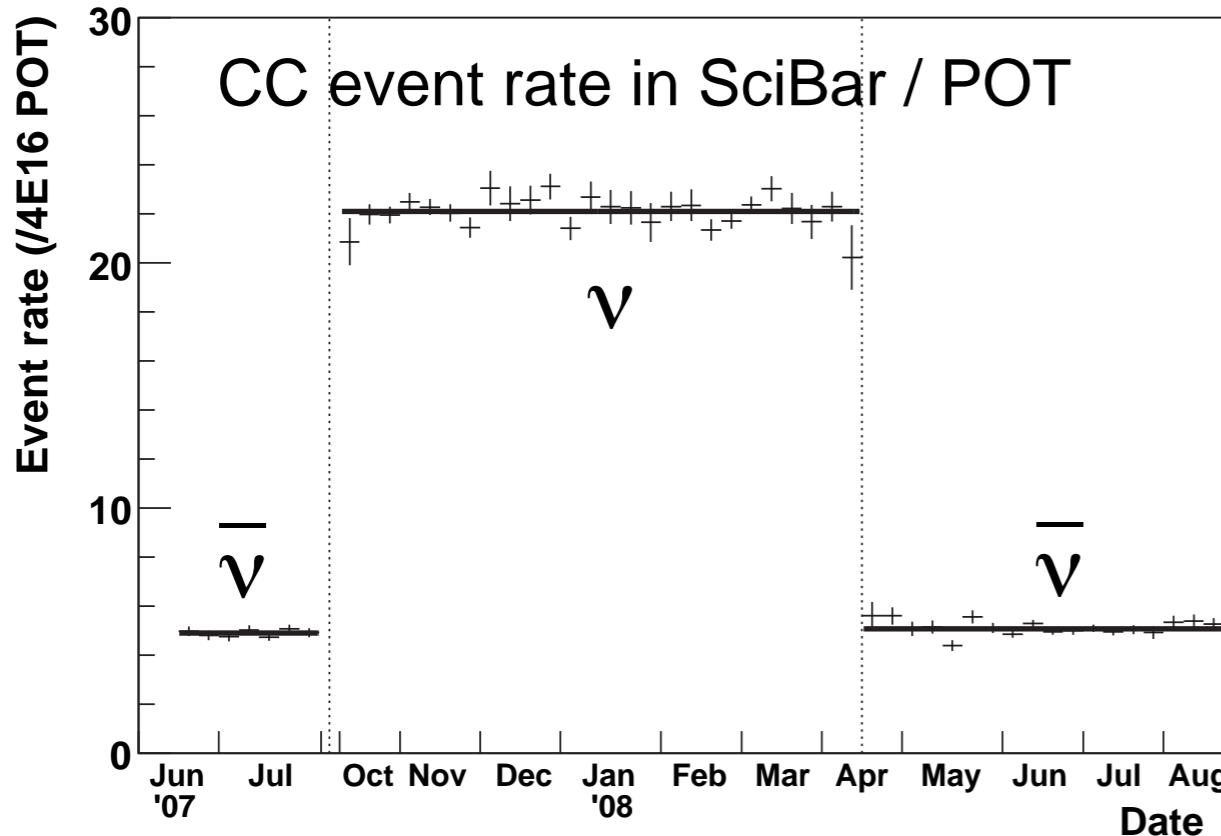
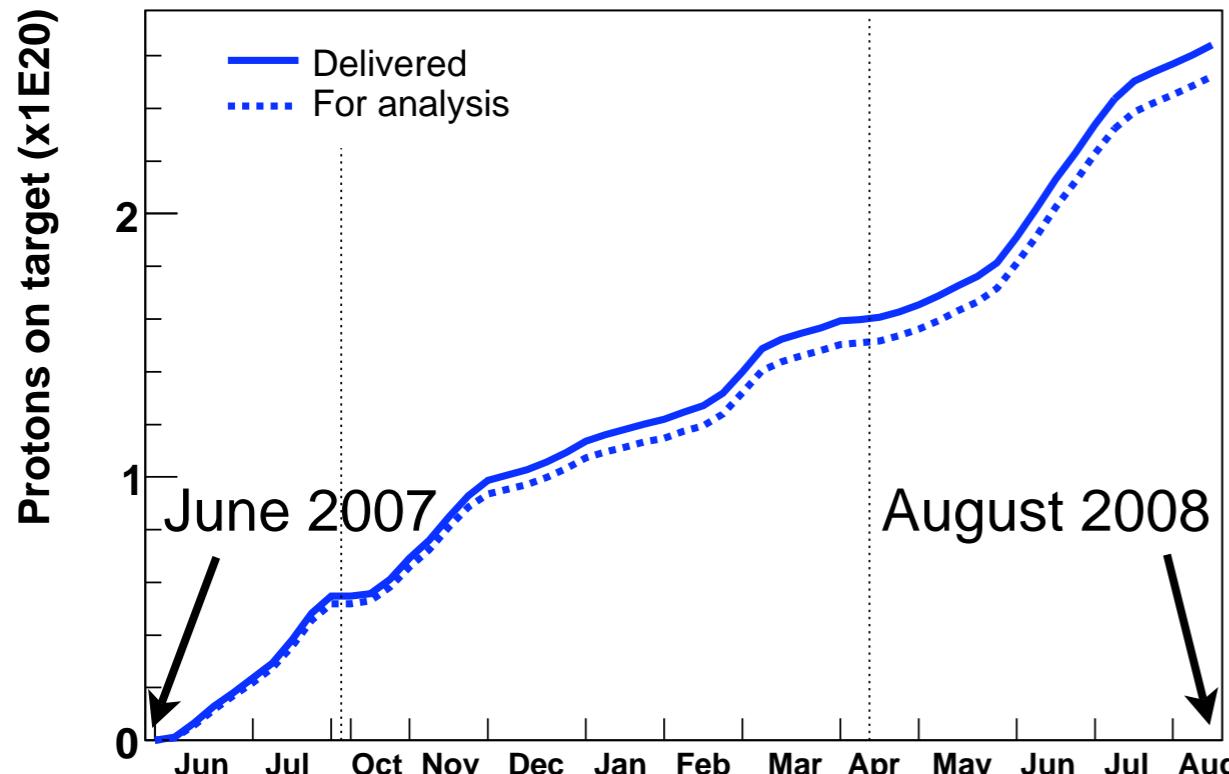
- **2005, Summer - Collaboration formed**
- 2005, Dec - Proposal approved
- 2006, Jul - Ship detectors to FNAL
- 2006, Sep - Groundbreaking
- 2006, Nov - EC Assembly
- 2007, Feb - SciBar Assembly
- 2007, Mar - MRD Assembly
- 2007, Mar - Cosmic Ray Data
- 2007, Apr - Detector Installation
- 2007, May - Commissioning
- **2007, Jun - Start data taking ($\bar{\nu}$ mode)**
- 2007, Oct - Neutrino Data Run
- 2008, Apr - Antineutrino Data Run
- **2008, Aug - Complete data taking**
- 2008, Aug - SciBooNE decommissioning
- **2008, Nov - First physics results**



Three years
from
formation to
the first results!

Data set

Number of Protons on target (POT)



2.52×10^{20} POT in total

- neutrino : 0.99×10^{20} POT
- antineutrino: 1.53×10^{20} POT

POT: Protons On Target

Results with full neutrino data set will be presented in this talk.

Physics Topics

- ν Charged Current
 - CC inclusive (ν_μ flux measurement)
 - CC-QE
 - CC- $1\pi^+$
 - CC- π^0
 - CC- ν_e (ν_e flux measurement)
- ν Neutral Current
 - NC- π^0
 - NC-elastic
- $\bar{\nu}$ CC analysis
- Short-baseline ν_μ disappearance search with MiniBooNE

Physics Topics

- ν Charged Current
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First physics result from SciBooNE
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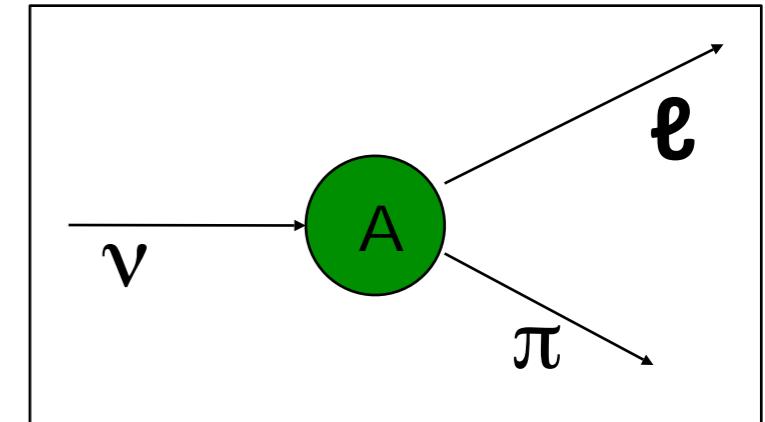
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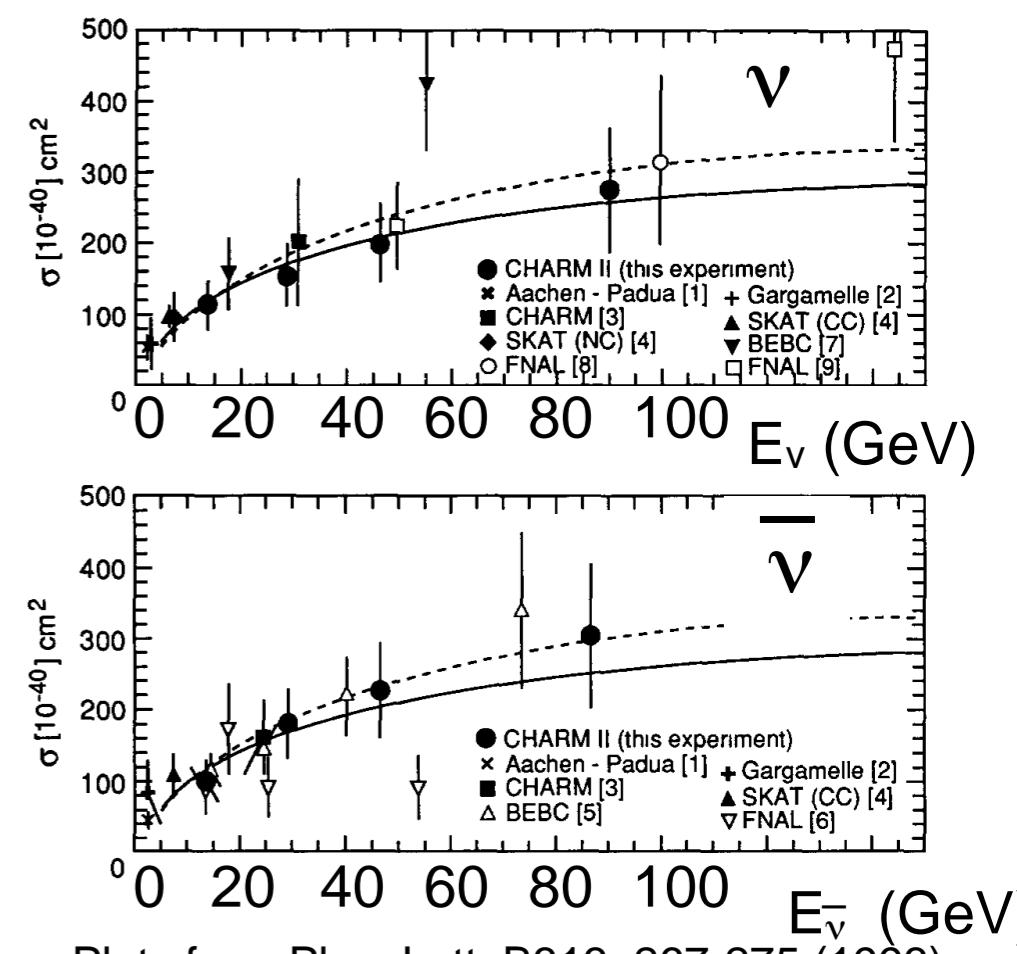
Coherent pion production

- Neutrino interacts with nucleus coherently, producing a pion
- No nuclear breakup occurs

Charged Current (CC): $\nu_\mu + A \rightarrow \mu + A + \pi^+$
Neutral Current (NC): $\nu_\mu + A \rightarrow \nu_\mu + A + \pi^0$



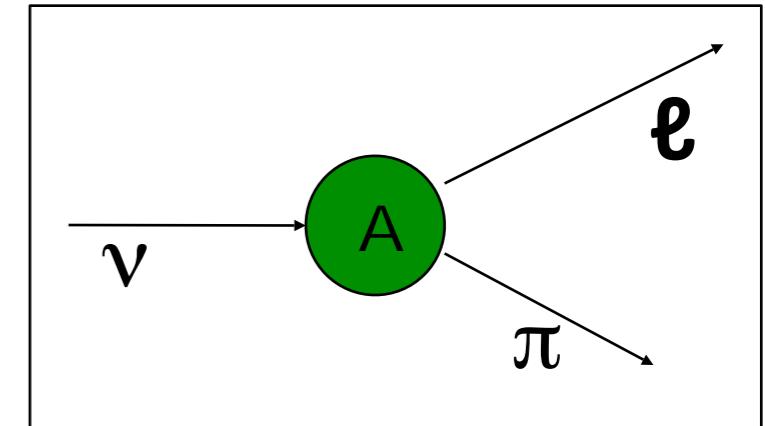
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Coherent pion production

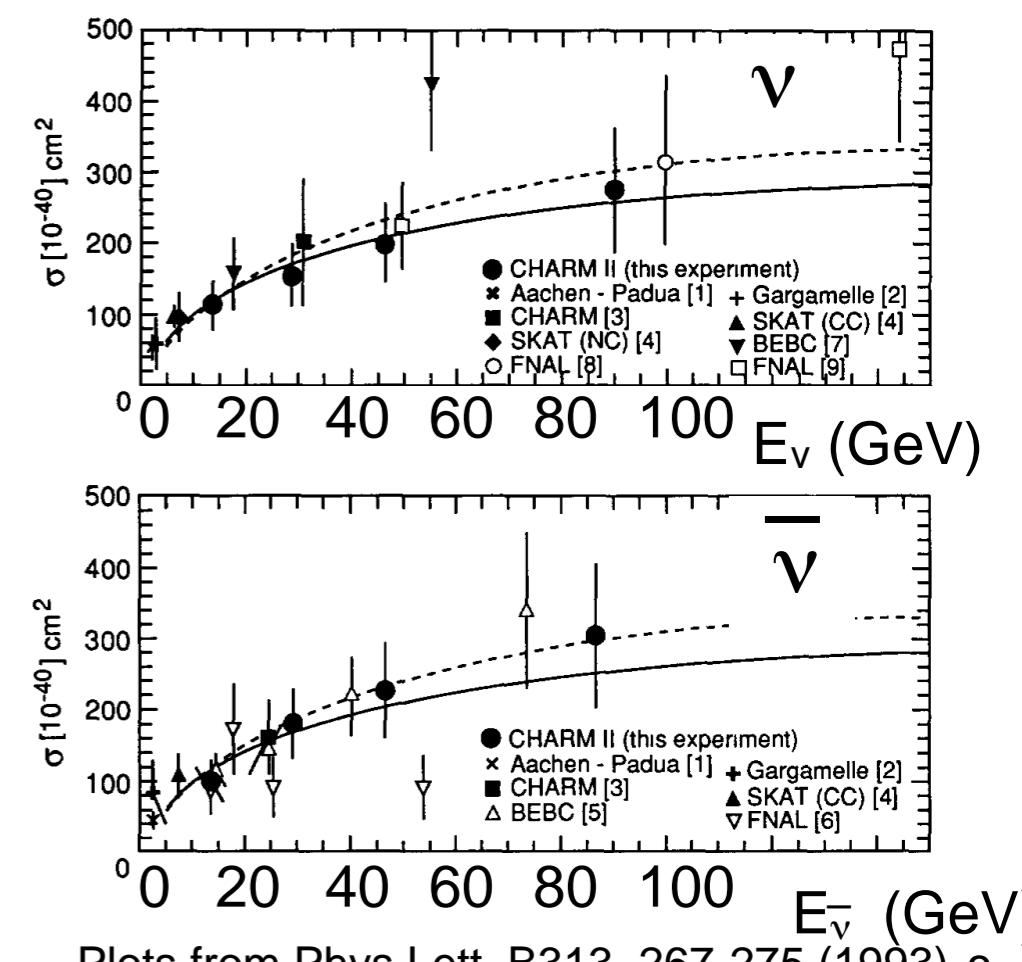
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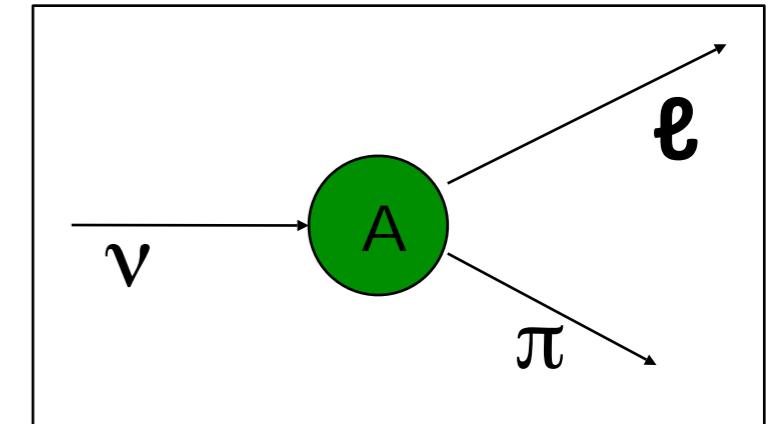
Recent new results at low energy (~1GeV) from **K2K** and **MiniBooNE(MB)**:



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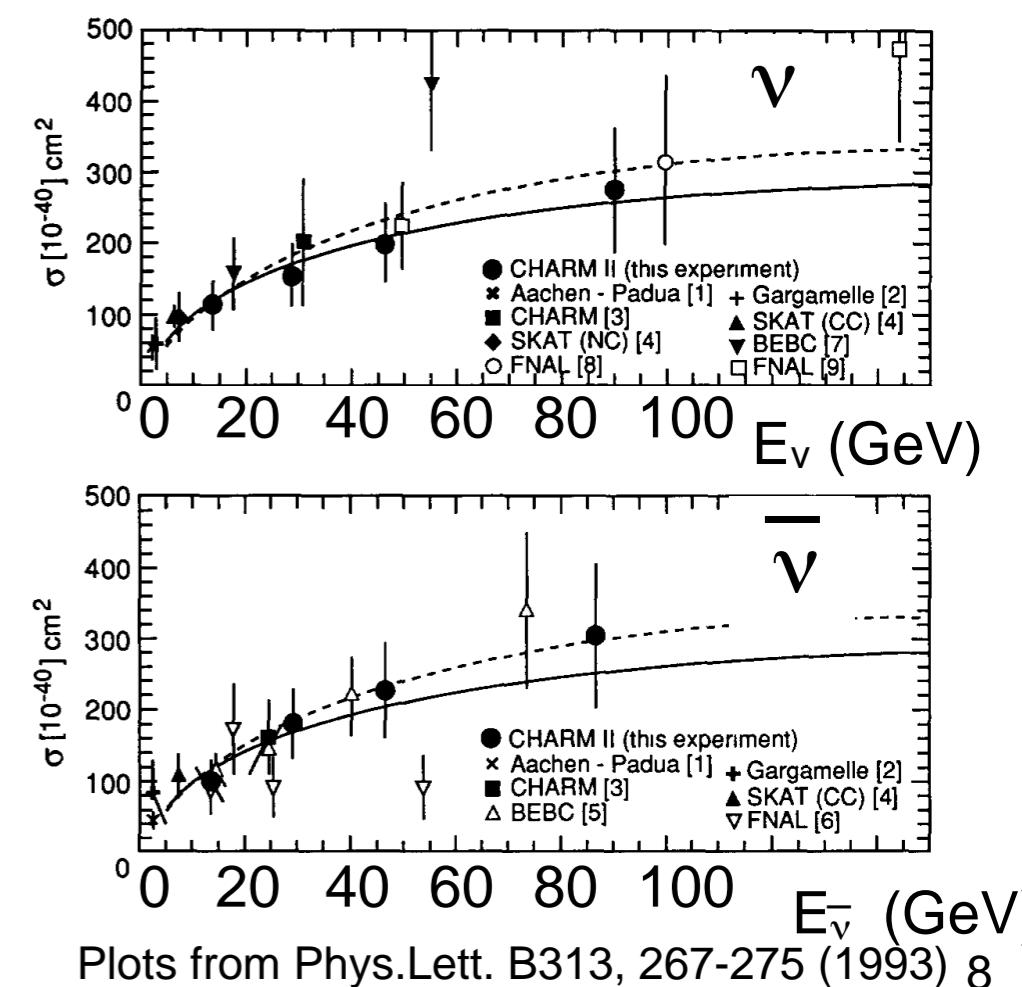


There are several measurements at **high energy region (E_ν : 2~100GeV)** in past.

Recent new results at low energy (~1GeV) from **K2K** and **MiniBooNE(MB)**:

- **K2K**: CC coherent π^+ is **NOT** observed
- **MB**: NC coherent π^0 is observed

Consistent? → New results from SciBooNE

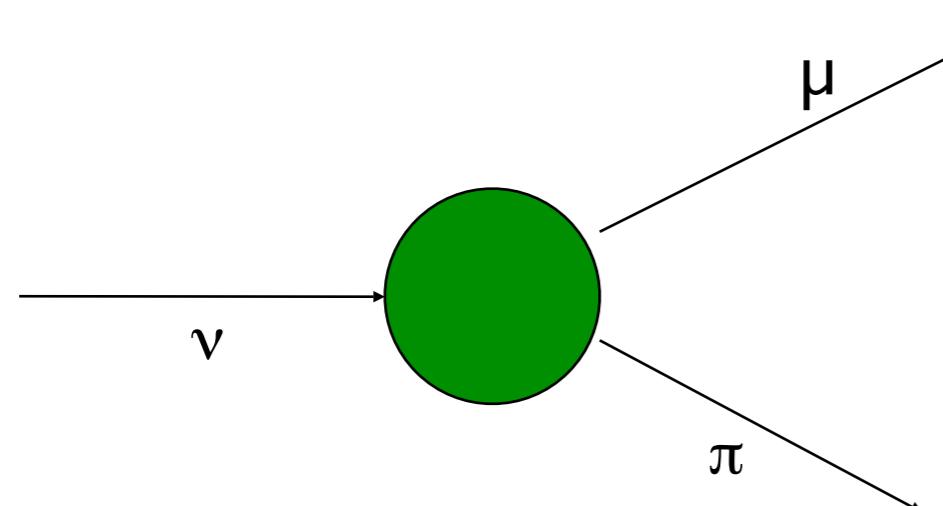


CC coherent π signature

Signal

CC-coherent π ($\nu+A \rightarrow \mu+A+\pi$)

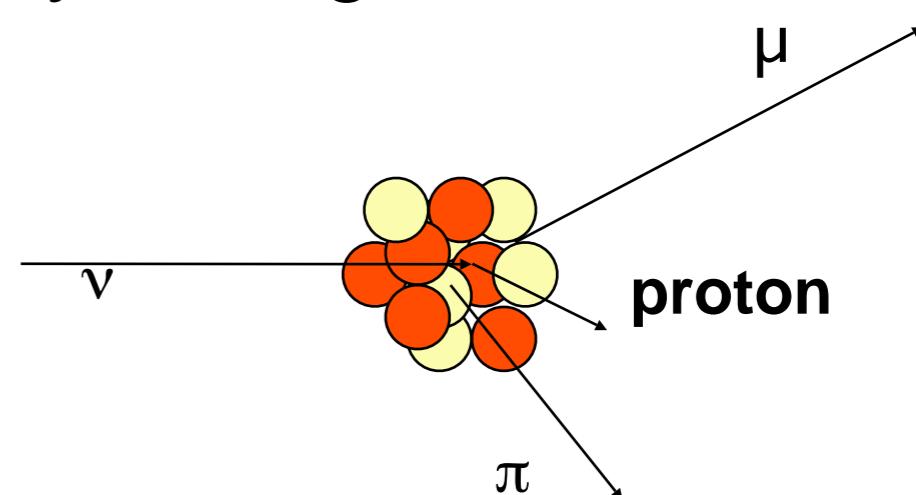
~1% of total ν interaction
(according to Rein-Sehgal model)



Background

CC-resonant π ($\nu+p \rightarrow \mu+p+\pi$)

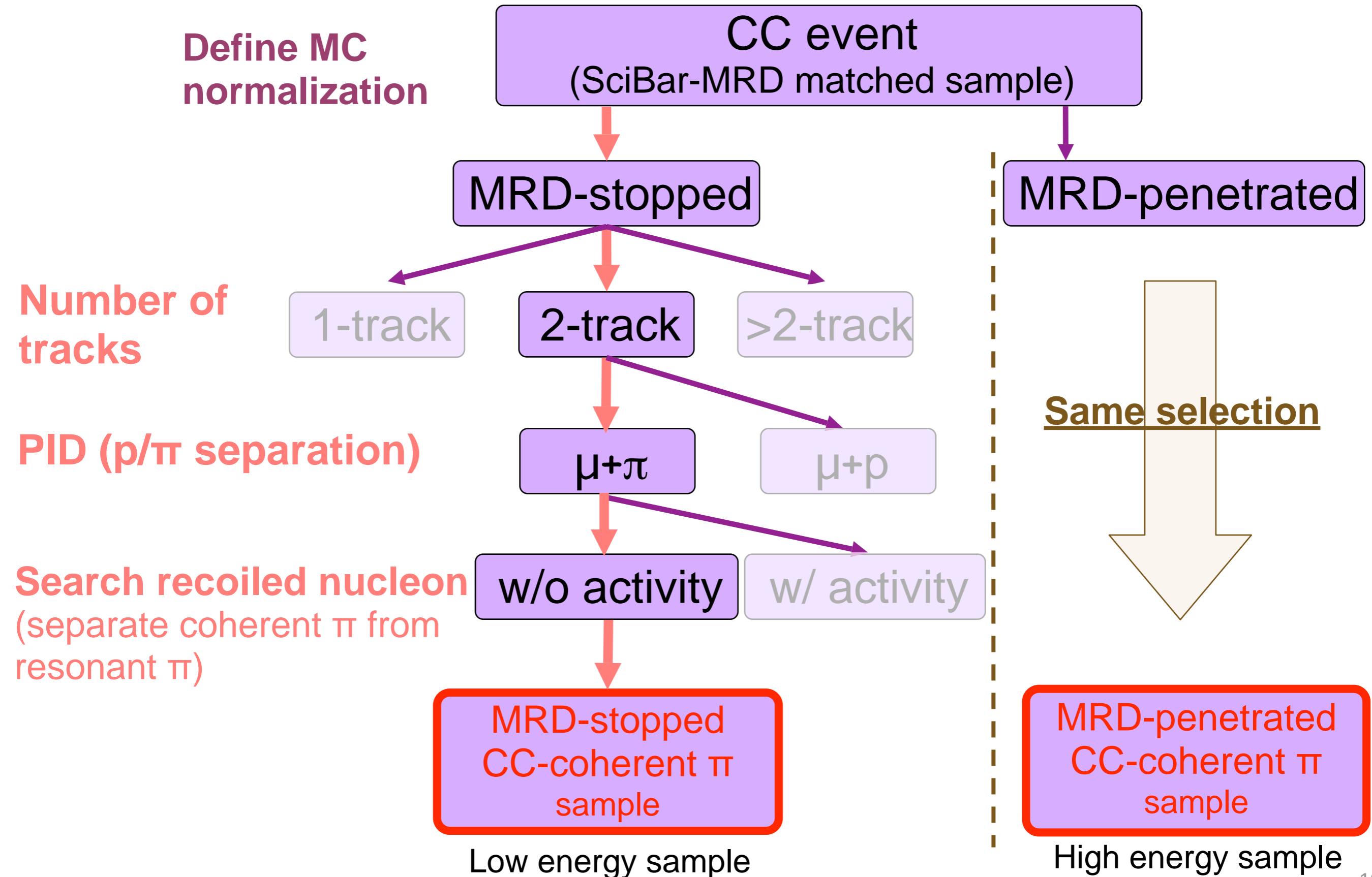
Predominant process in ~1GeV.
Mainly through Δ resonance.



Coherent π signature

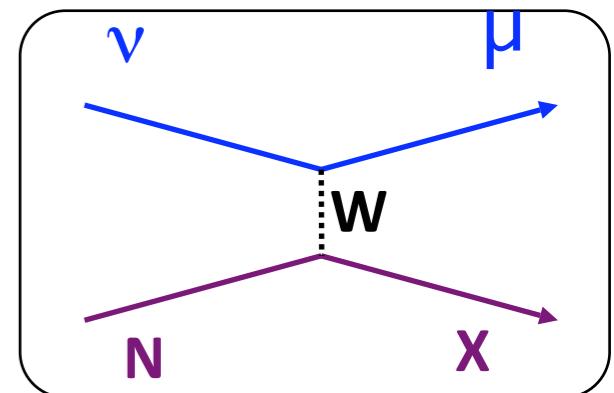
- One muon and one pion in the final state
- No recoiled nucleon nor nuclear breakup
- No “vertex activity”
- Low momentum transfer (small Q^2)

Event classification



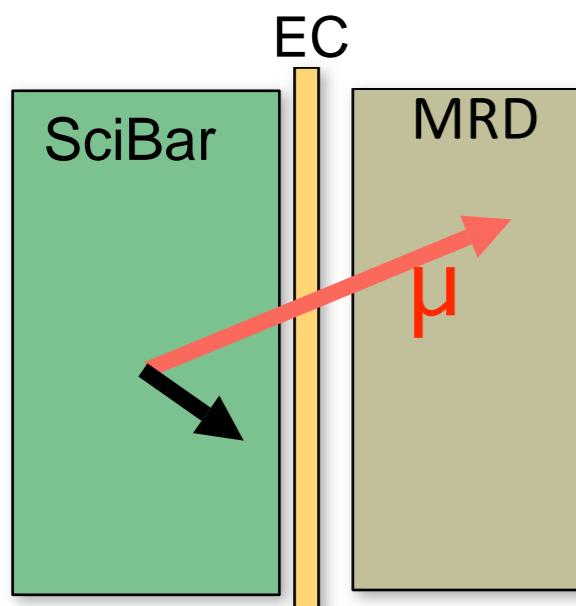
Charged Current (CC) event selection

- Muon is identified using MRD
- The track should start from SciBar fiducial volume
 - **SciBar-MRD matched track \equiv muon track**

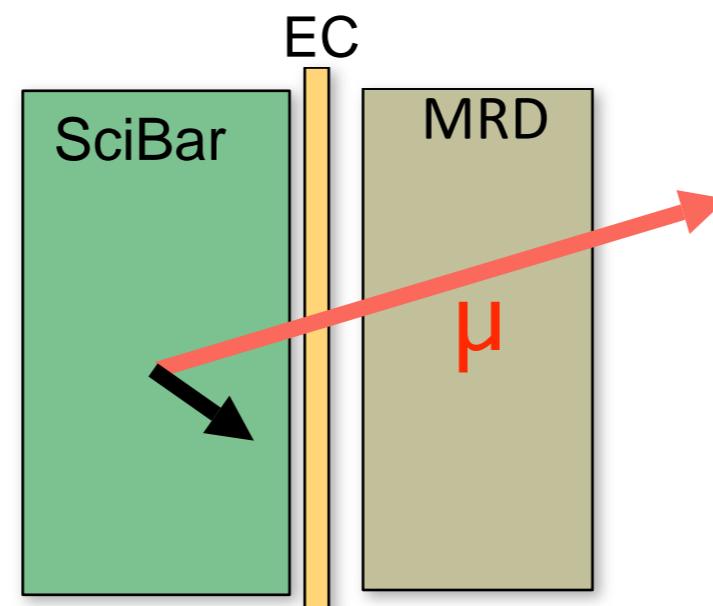


SciBar-MRD matched event (~30k events)

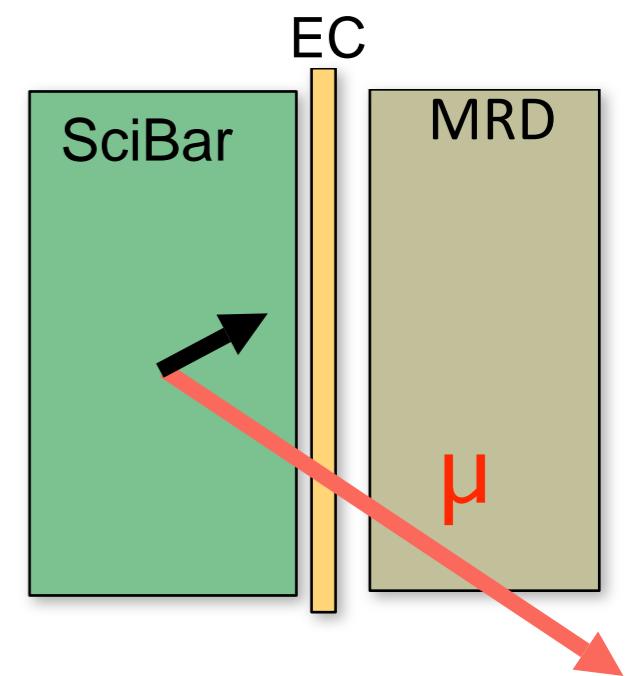
MRD-stopped
(low-energy sample)



MRD-penetrated
(high-energy sample)

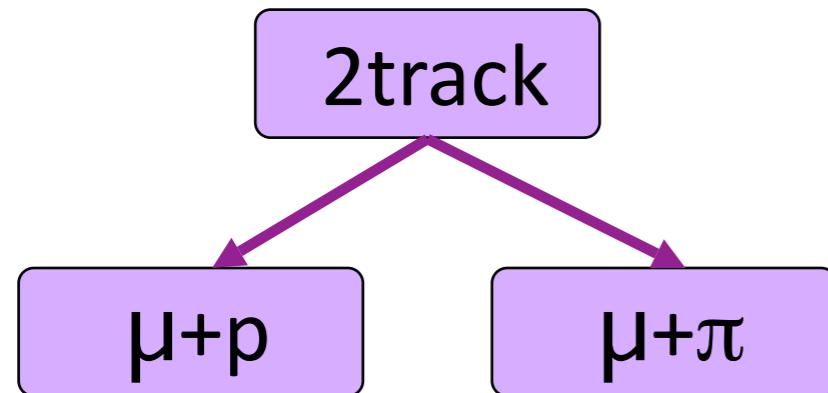


MRD-side escaped

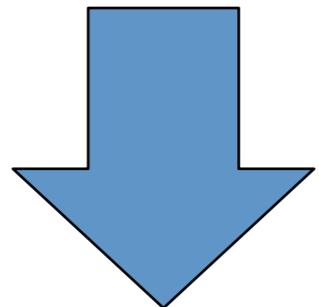


93% pure CC ($\nu+N \rightarrow \mu+X$) sample

Particle identification



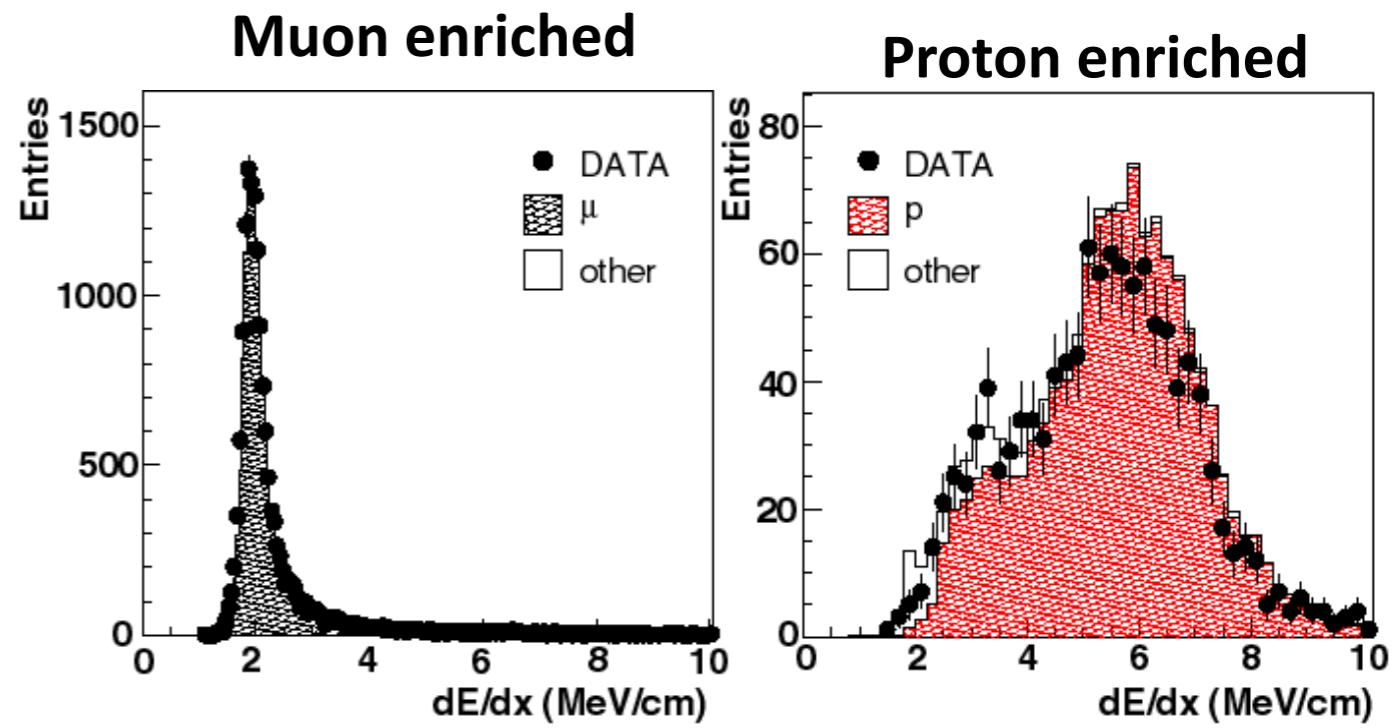
Particle ID using dE/dx in SciBar



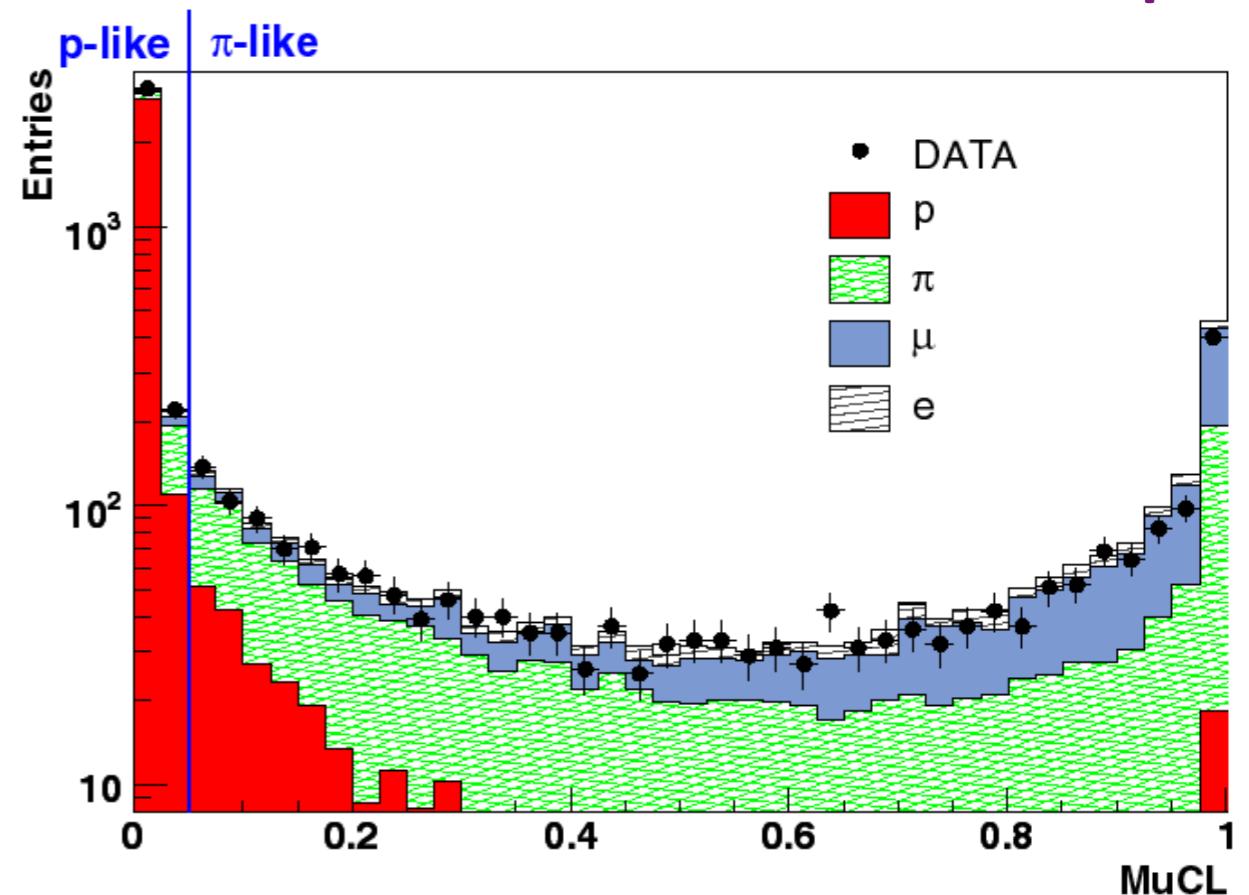
“Muon confidence level” (MuCL)

$\text{MuCL} > 0.05 \rightarrow \text{MIP-like } (\mu, \pi)$
 $< 0.05 \rightarrow \text{proton-like}$

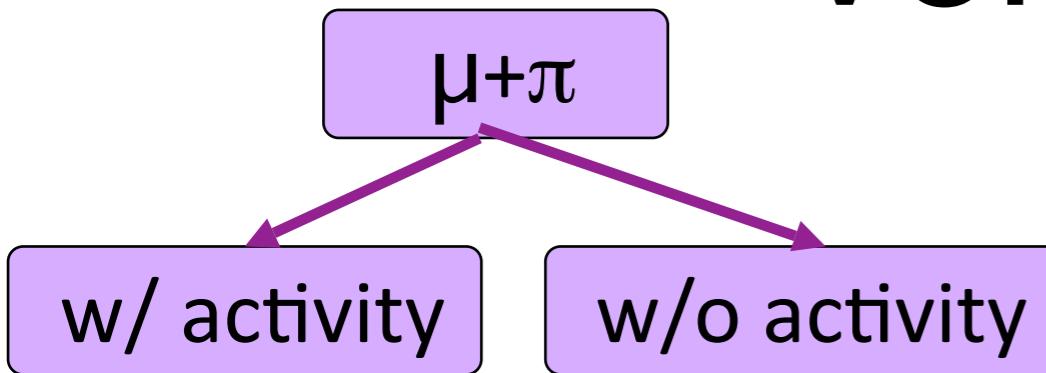
$\text{MuCL} > 0.05$ for 2nd tracks:
~90% p rejection
84% π efficiency



MuCL for 2nd track in 2-track sample

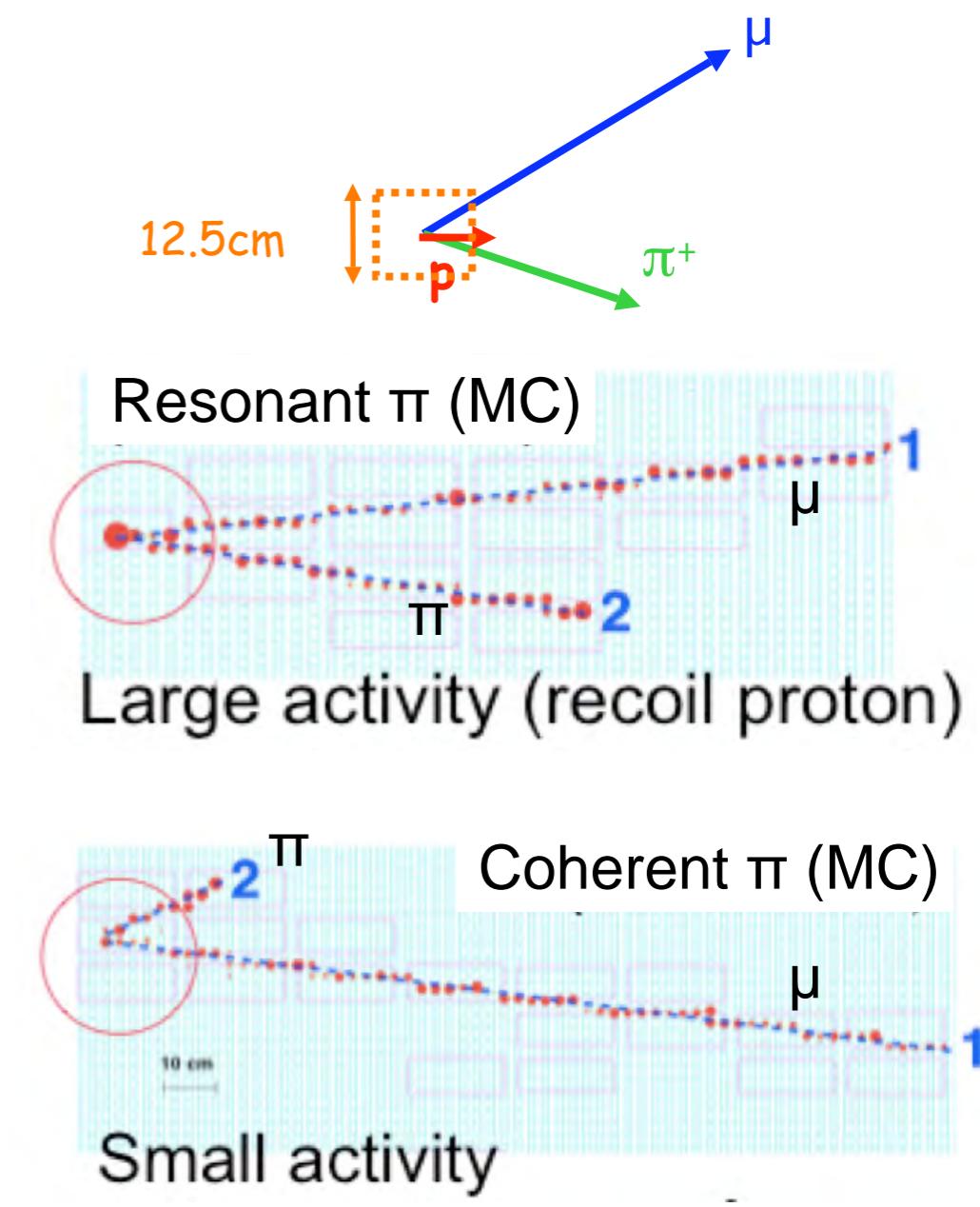
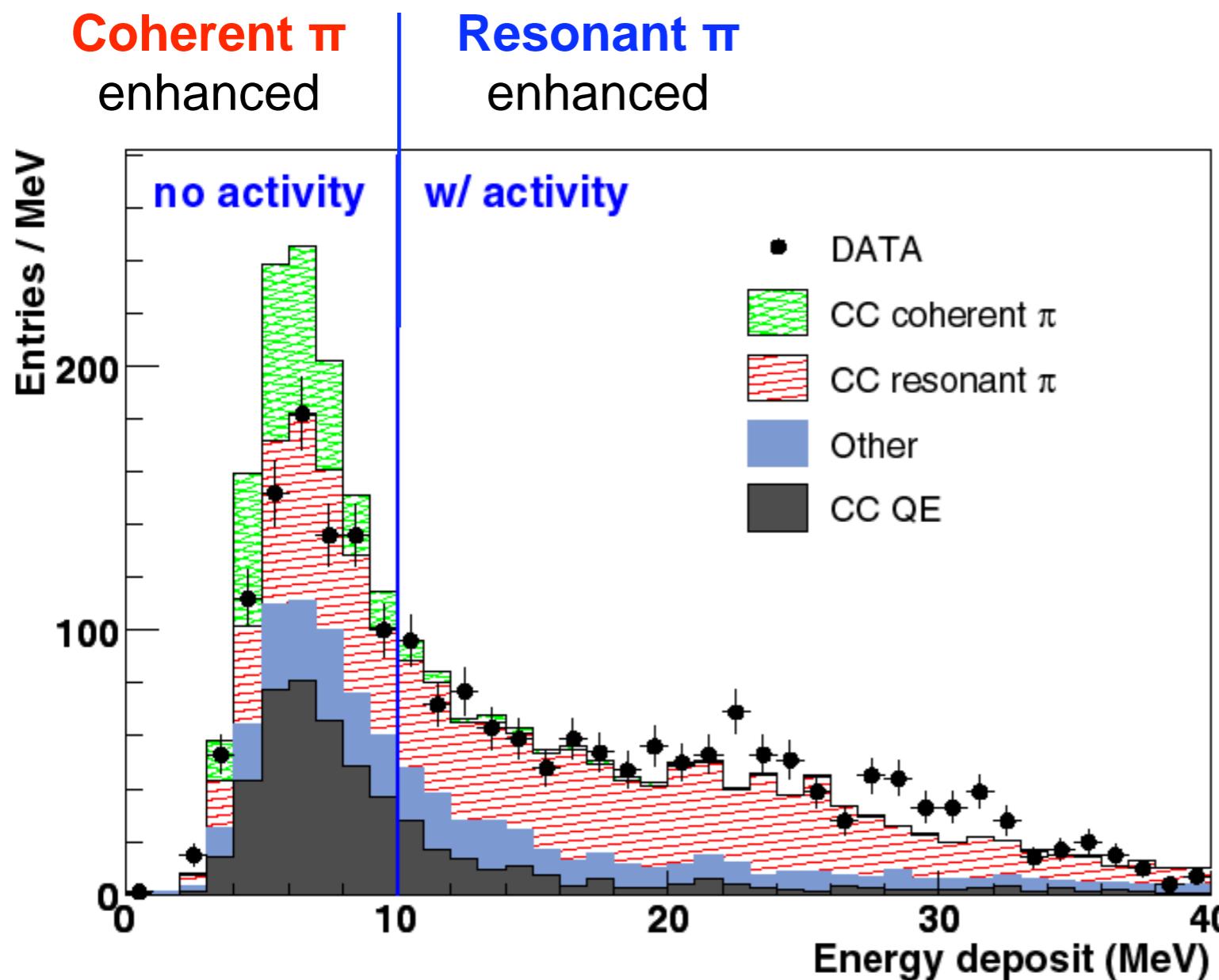


Vertex activity



Resonant π have recoiled proton while coherent π do not.

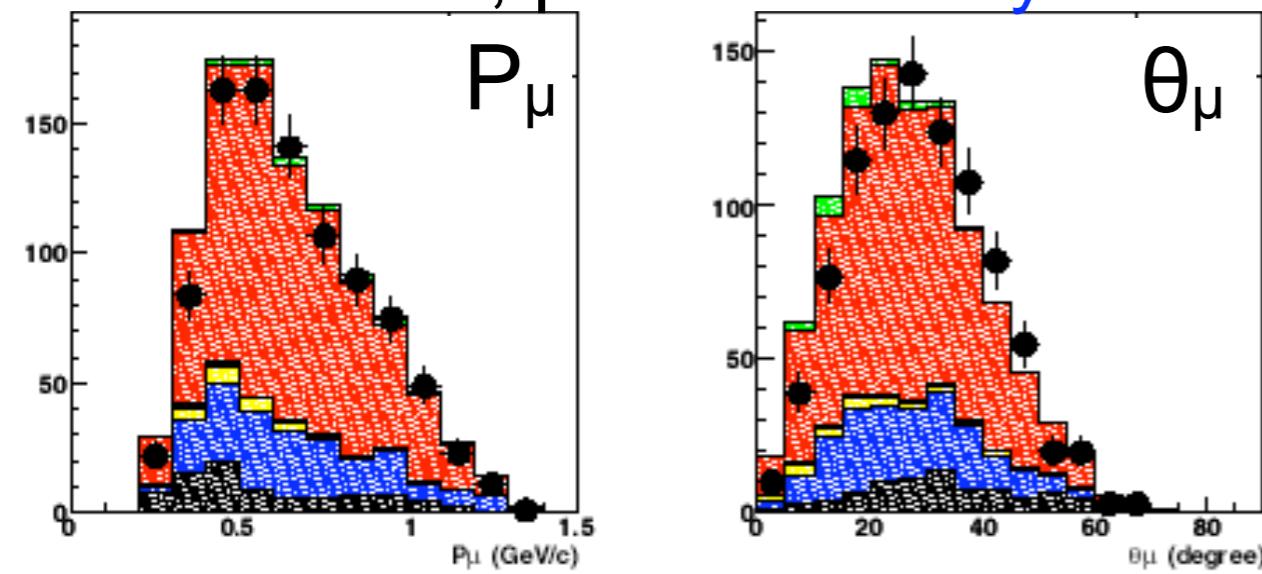
Low energy proton make energy deposit around vertex = “vertex activity”



$\mu + \pi$, w/ and w/o activity

Resonant π enhanced

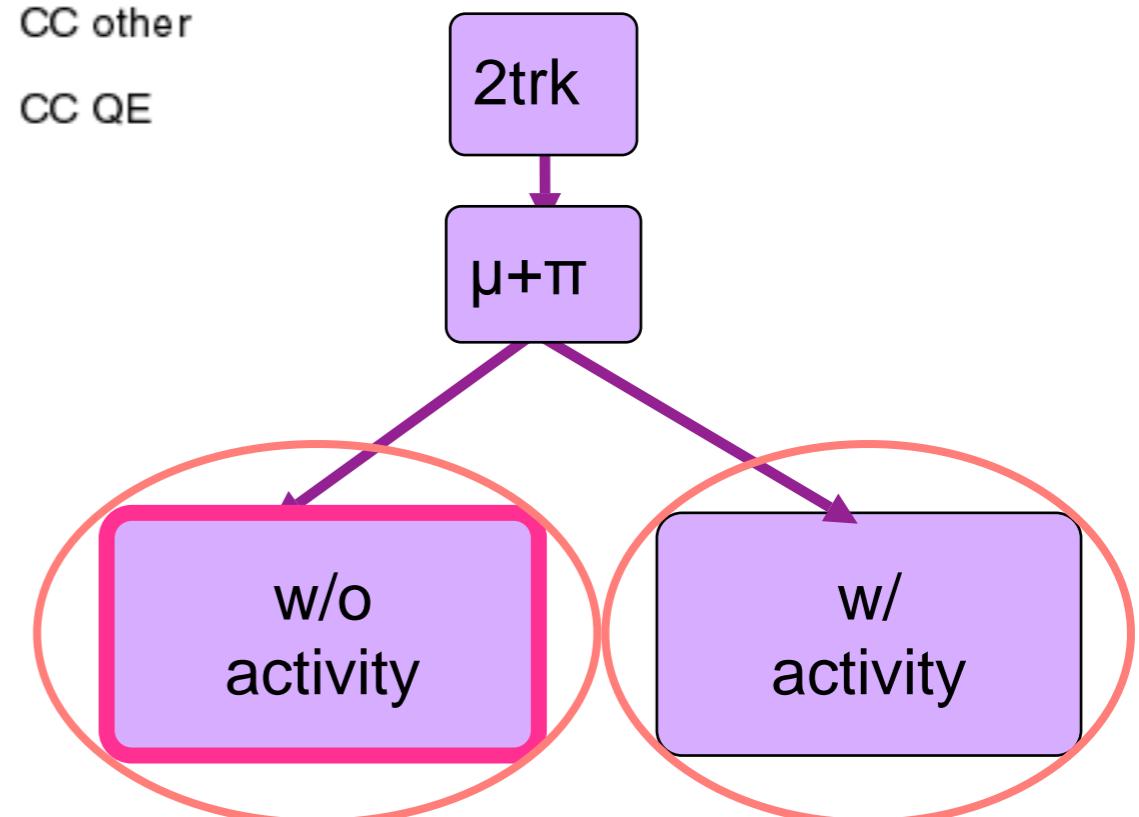
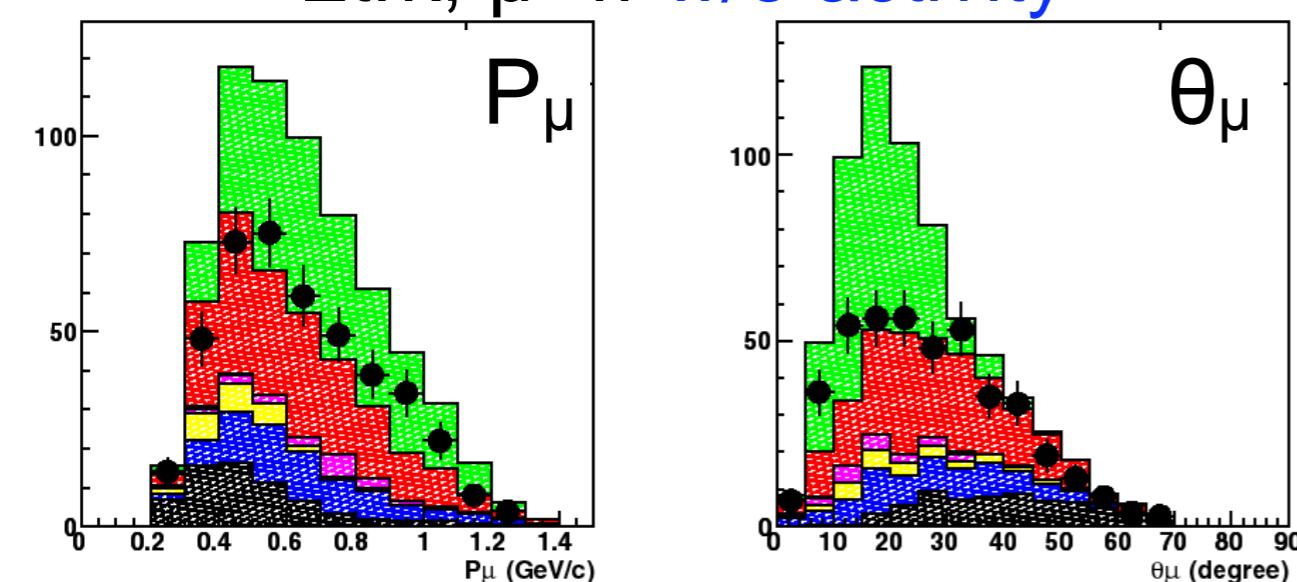
2trk, $\mu + \pi$ w/ activity



- v CC coherent π
- v CC resonant π
- anti-v
- v NC
- v CC other
- v CC QE

Coherent π enhanced

2trk, $\mu + \pi$ w/o activity



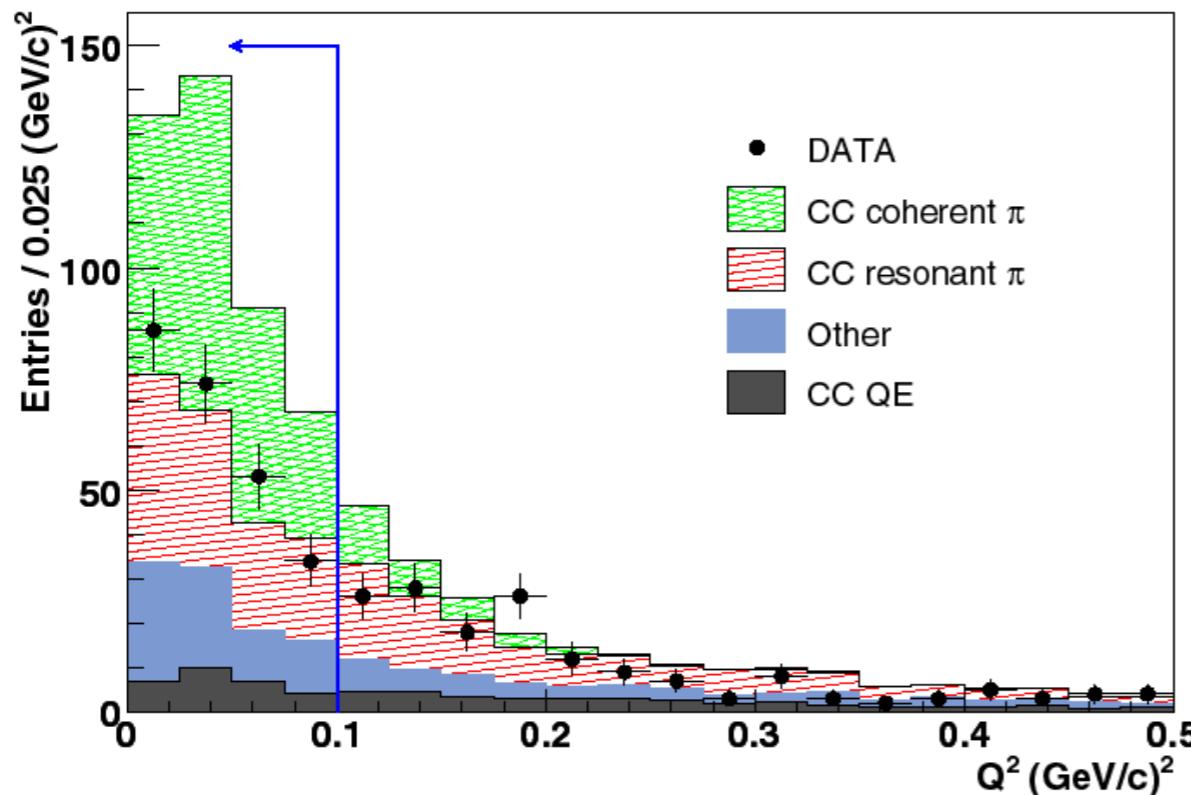
→ Evaluate # of coherent π events in data.

"with activity": resonant π ~60%

"without activity": coherent π ~40%

CC coherent pion sample ($Q^2 < 0.1$ (GeV/c) 2)

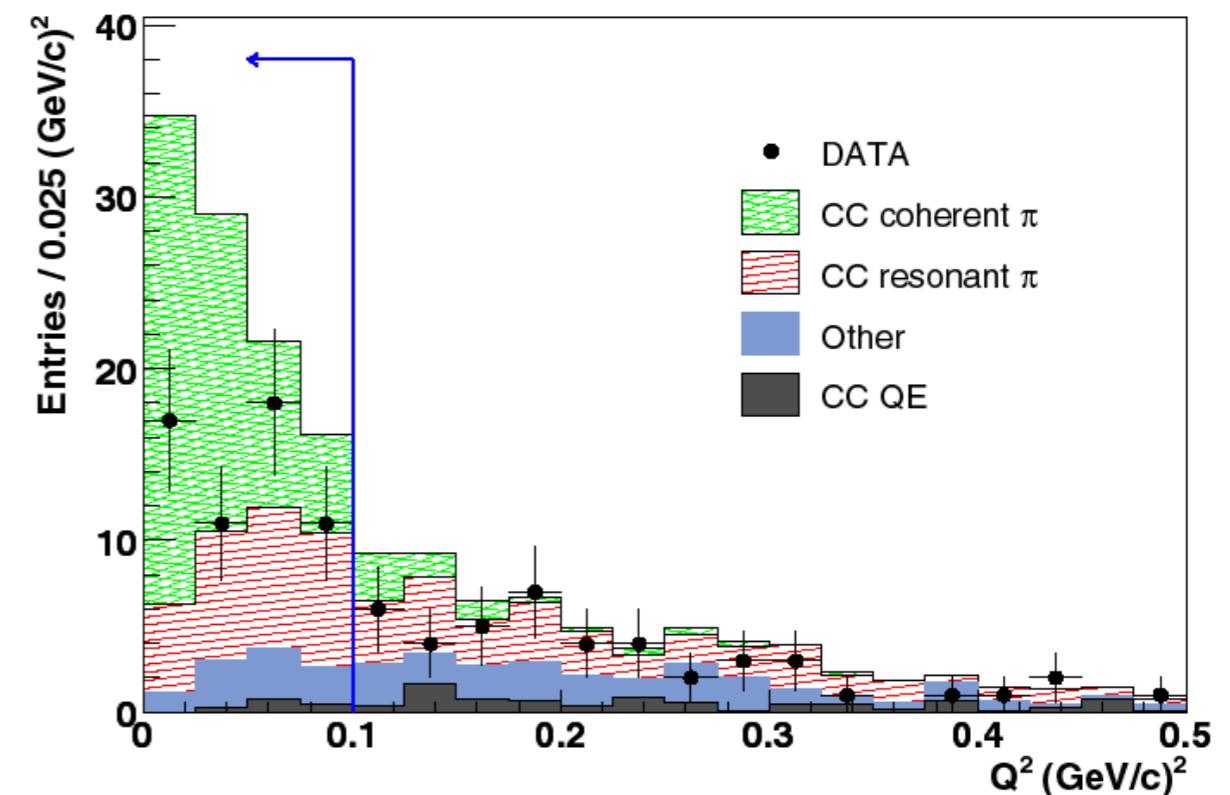
MRD stopped sample
 $\langle E\nu \rangle = 1.1 \text{ GeV}$



247 events selected

BG expectation
228+/-12 events

MRD penetrated sample
 $\langle E\nu \rangle = 2.2 \text{ GeV}$



57 events selected

BG expectation
40+/-2.2 events

Results

To minimize the uncertainty on neutrino flux,
we measure $\sigma(\text{CC coherent } \pi)/\sigma(\text{CC})$ cross section ratio.

MRD stopped sample

$\langle E\nu \rangle = 1.1 \text{ GeV}$

$\sigma(\text{CC coherent } \pi)/\sigma(\text{CC})$

$$= (0.16 \pm 0.17(\text{stat})^{+0.30}_{-0.27}(\text{sys})) \times 10^{-2}$$

MRD penetrated sample

$\langle E\nu \rangle = 2.2 \text{ GeV}$

$\sigma(\text{CC coherent } \pi)/\sigma(\text{CC})$

$$= (0.68 \pm 0.32(\text{stat})^{+0.39}_{-0.25}(\text{sys})) \times 10^{-2}$$

No evidence of CC coherent pion production is found

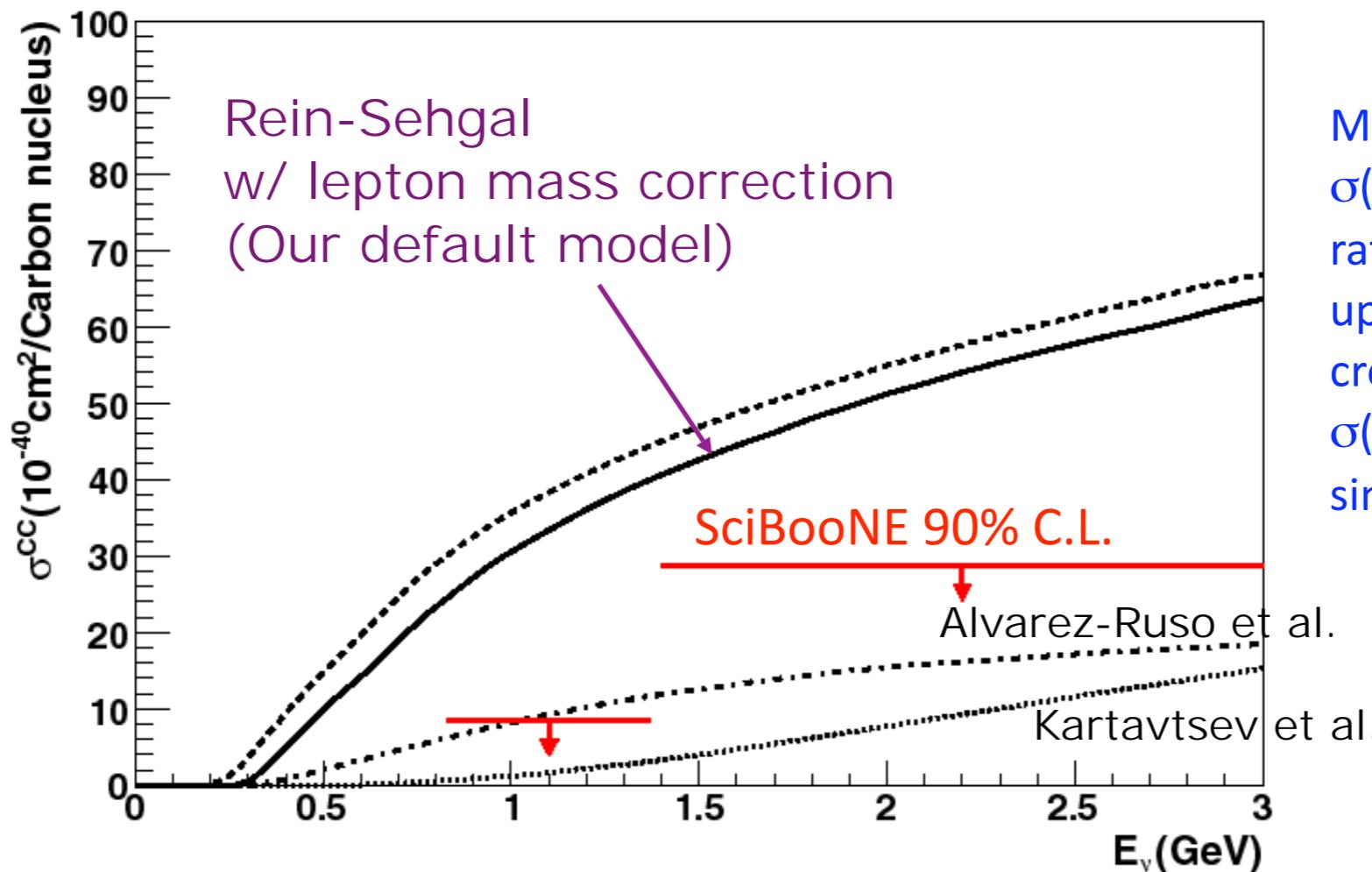


90% CL upper limit (Bayesian)

$\sigma(\text{CC coherent } \pi)/\sigma(\text{CC}) < 0.67 \times 10^{-2}$ for $\langle E\nu \rangle = 1.1 \text{ GeV}$
 $< 1.36 \times 10^{-2}$ $\langle E\nu \rangle = 2.2 \text{ GeV}$

Discussion (1)

Comparison with theoretical models



Five new theoretical models were proposed to explain recent low energy results (in last a few months)

- [1] J.E. Amaro, E. Hernández, J. Nieves, M. Valverde, Phys.Rev.D79:013002,2009. (**Nov 2008**)
- [2] Ch. Berger, L. M. Sehgal, arXiv:0812.2653 [hep-ph] (**Dec 2008**)
- [3] T. Leitner, U. Mosel, S. Winkelmann, arXiv:0901.2837 [nucl-th] (**Jan 2009**)
- [4] S. X. Nakamura *et al*, arXiv:0901.2366 [nucl-th] (**Jan 2009**)
- [5] E. A. Paschos, Dario Schalla, arXiv:0903.0451 [hep-ph] (**Mar 2009**)

(cf. SciBooNE coherent π paper became available in archive **Nov. 2008**)

Discussion (2)

Comparison with other experimental results

- **SciBooNE** results
 - $\sigma(\text{CC coh } \pi)/\sigma(\text{CC}) < 0.67 \times 10^{-2}$ for $\langle E_\nu \rangle = 1.1 \text{ GeV}$
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- Comparison with **K2K**?

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 - Comparison with **K2K**?
 - $\sigma(\text{CC coh } \pi)/\sigma(\text{CC}) < 0.60 \times 10^{-2}$ for $\langle E\nu \rangle = 1.3 \text{ GeV}$
- Consistent with K2K

NOTE: K2K used 90% C.L. upper limit with “mean+1.28x σ ”,
SciBooNE used Bayesian 90% C.L.

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 - MiniBooNE: NC coherent π^0

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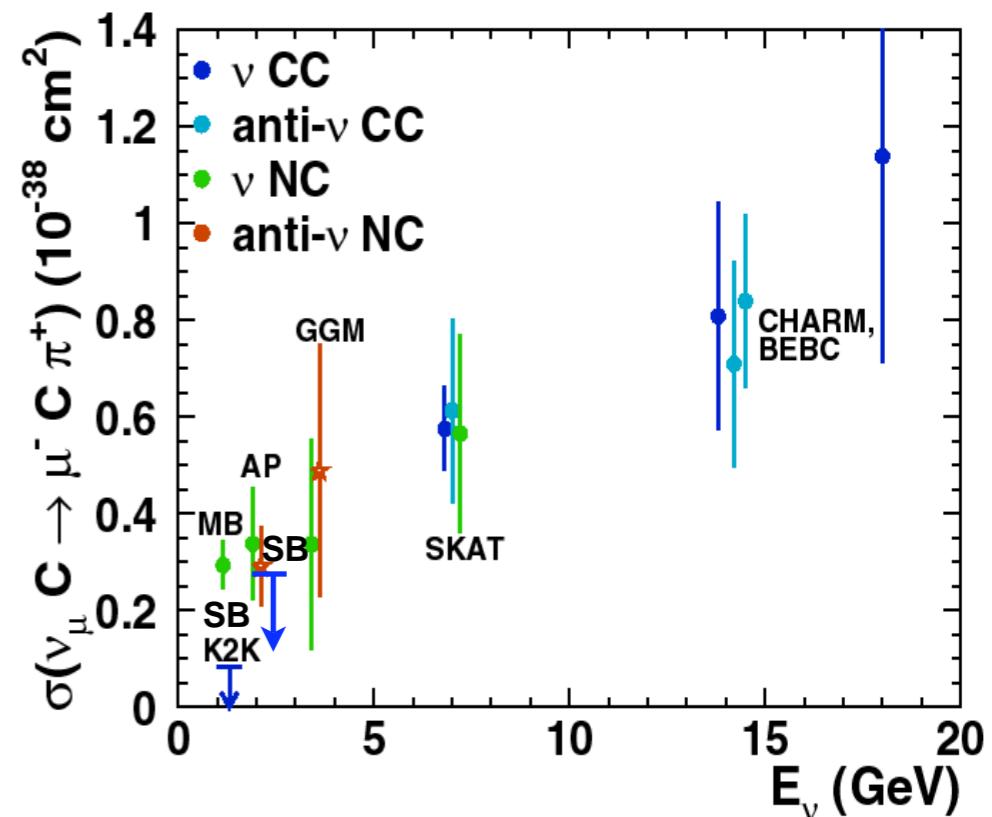
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- Comparison with **MiniBooNE**?

- MiniBooNE: NC coherent π^0

Other measurements at
higher neutrino energy



Discussion (2)

Comparison with other experimental results

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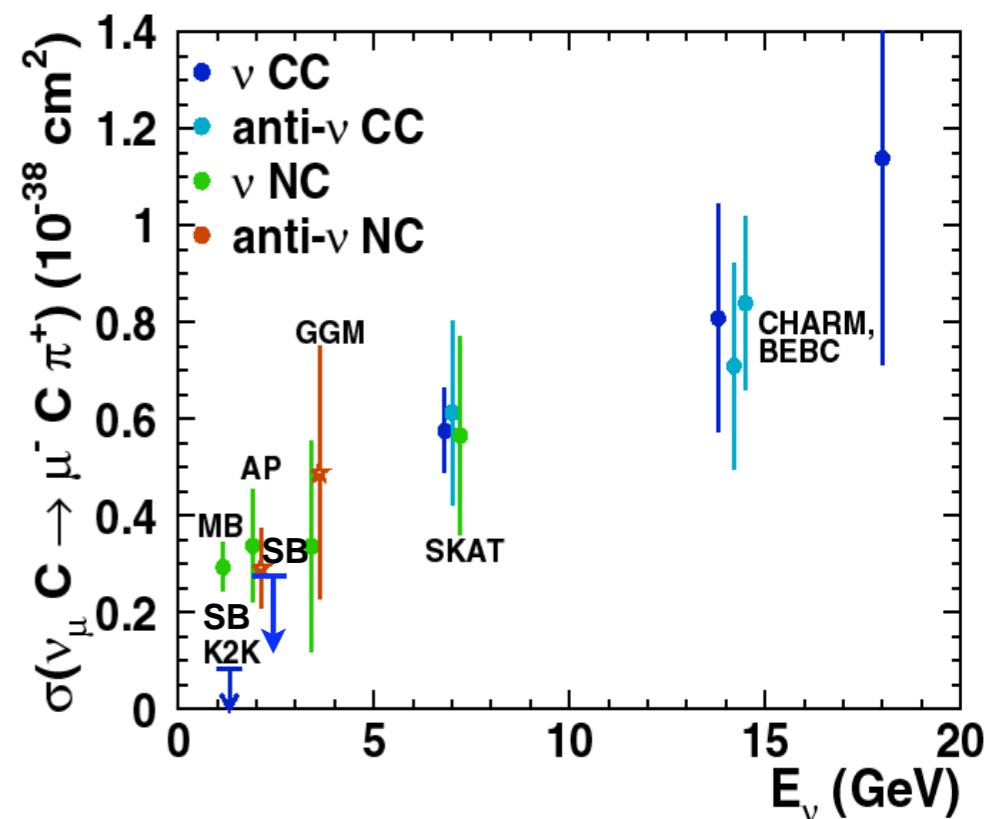
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- MiniBooNE: NC coherent π^0
- Comparison will be model-dependent.

Other measurements at
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Discussion (2)

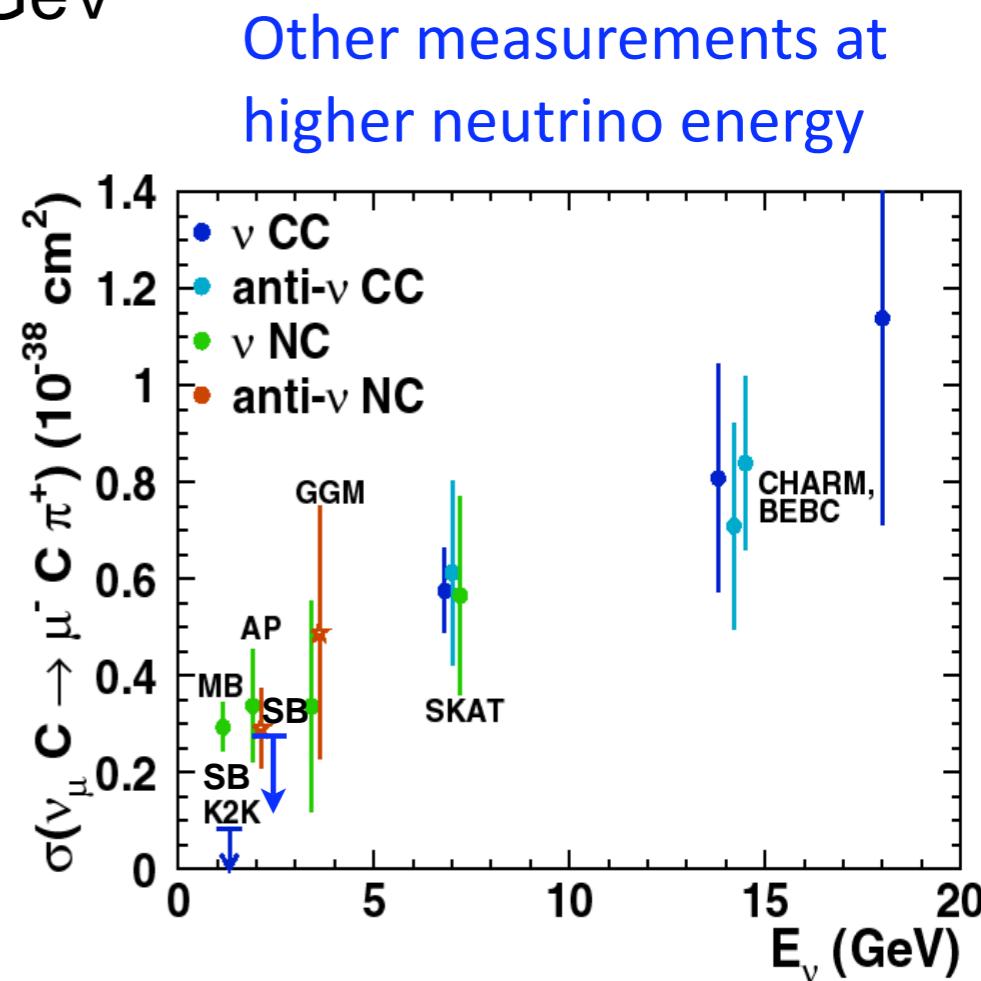
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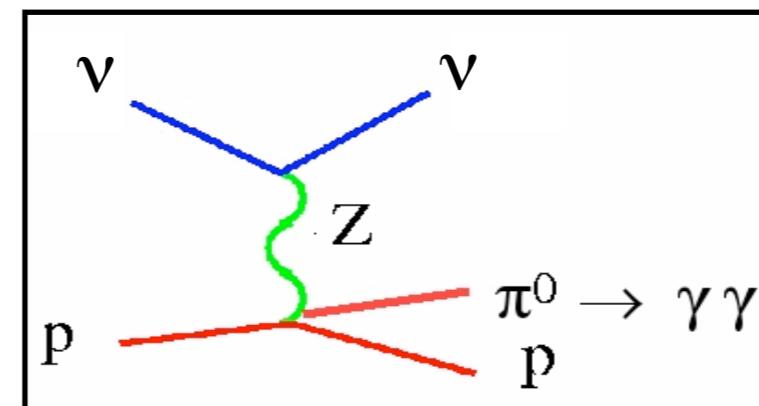
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- Comparison with **MiniBooNE**?
 - MiniBooNE: NC coherent π^0
 - Comparison will be model-dependent.
- SciBooNE can measure NC- π^0 !

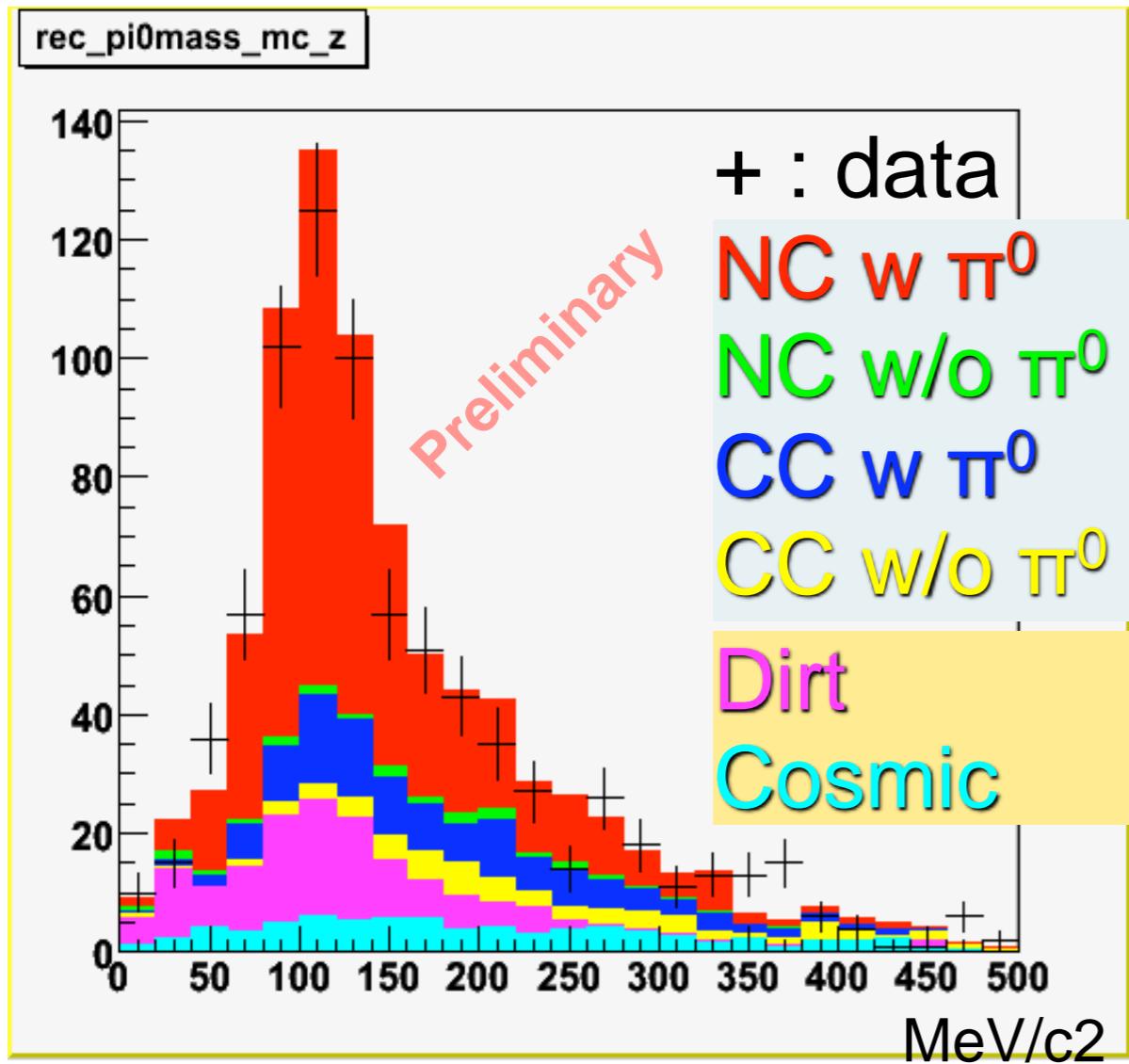


NC- π^0 reconstruction

Neutral Current
 π^0 production



Reconstructed 2γ Mass



Clear π^0 mass peak!
SciBar can reconstruct π^0 !!

~850 event are selected
~460 NC- π^0 events

NC- π^0 analysis is in progress.

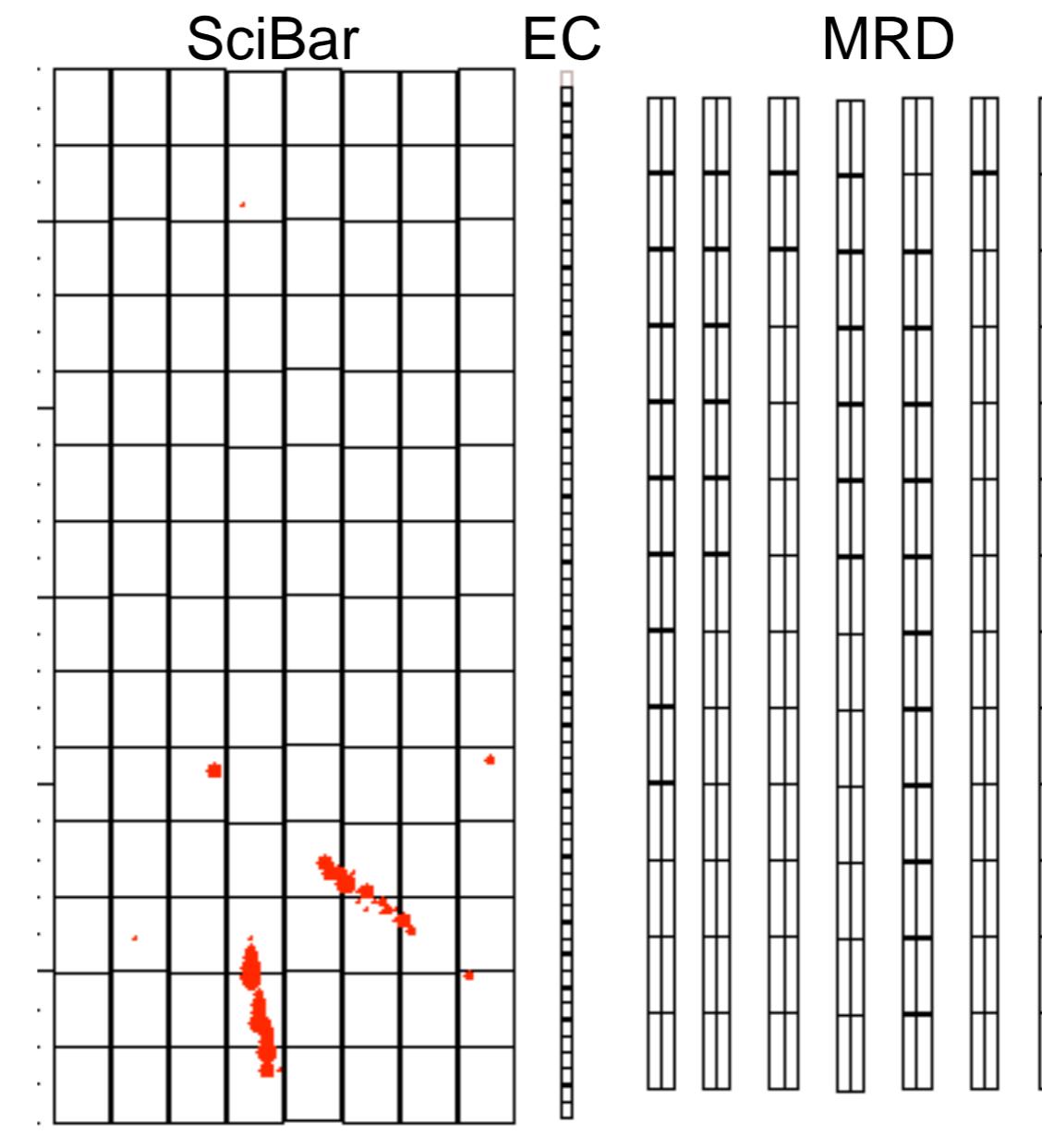
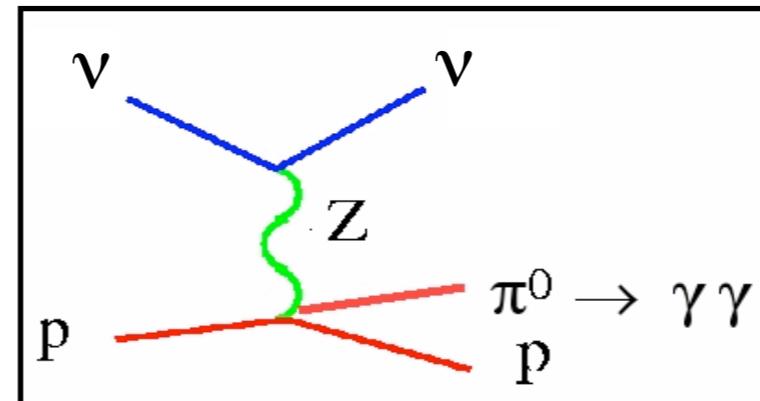
Summary

- SciBooNE measures neutrino and antineutrino cross sections near 1 GeV
 - Essential for long baseline neutrino oscillation experiment
- **First physics results from SciBooNE**
 - No evidence of CC coherent π production is found
 - Published: Phys. Rev. D78:112004,2008
- Many analyses are in progress
 - ν CC-QE, CC π^0 , NC π^0 , NC-elastic, $\bar{\nu}$ CC
 - ν_μ disappearance search
- **Many results will be in this year.**

Backup

NC- π^0 candidate in SciBooNE

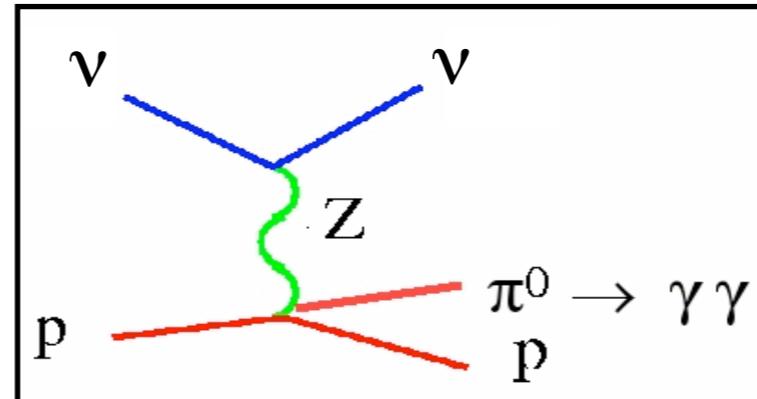
Neutral Current
 π^0 production



● : SciBar hit, area \propto energy deposit

NC- π^0 candidate in SciBooNE

Neutral Current
 π^0 production

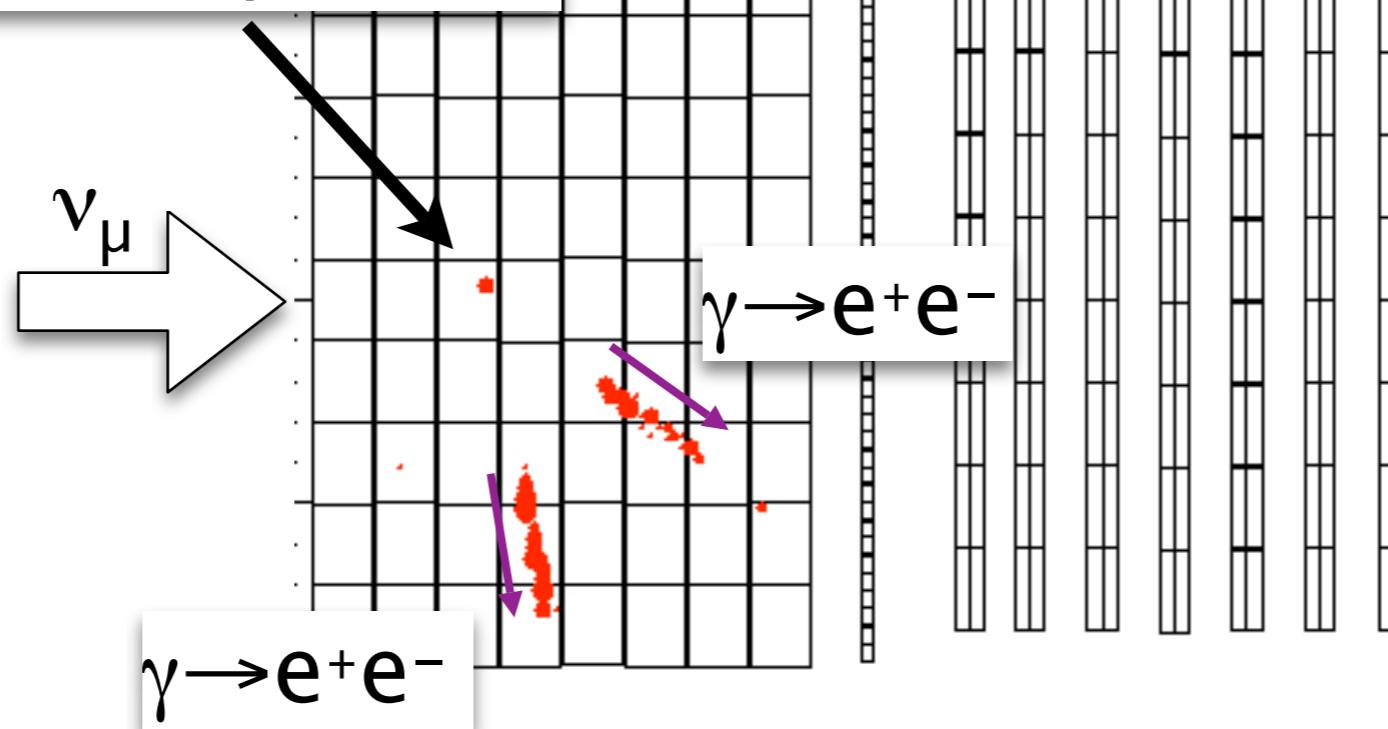


SciBar

EC

MRD

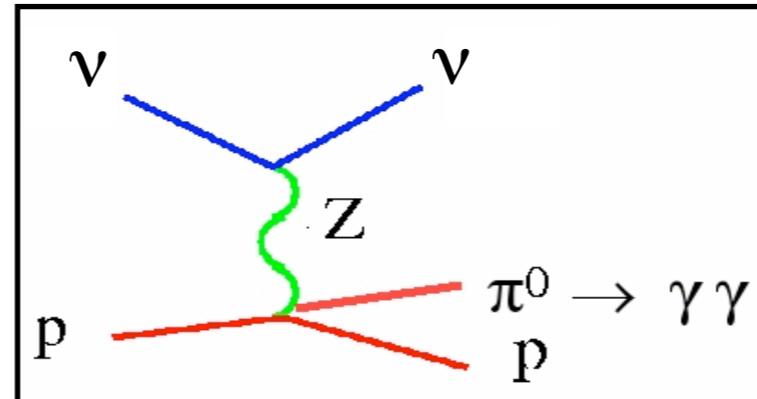
Recoiled proton?



: SciBar hit, area \propto energy deposit

NC- π^0 candidate in SciBooNE

Neutral Current
 π^0 production



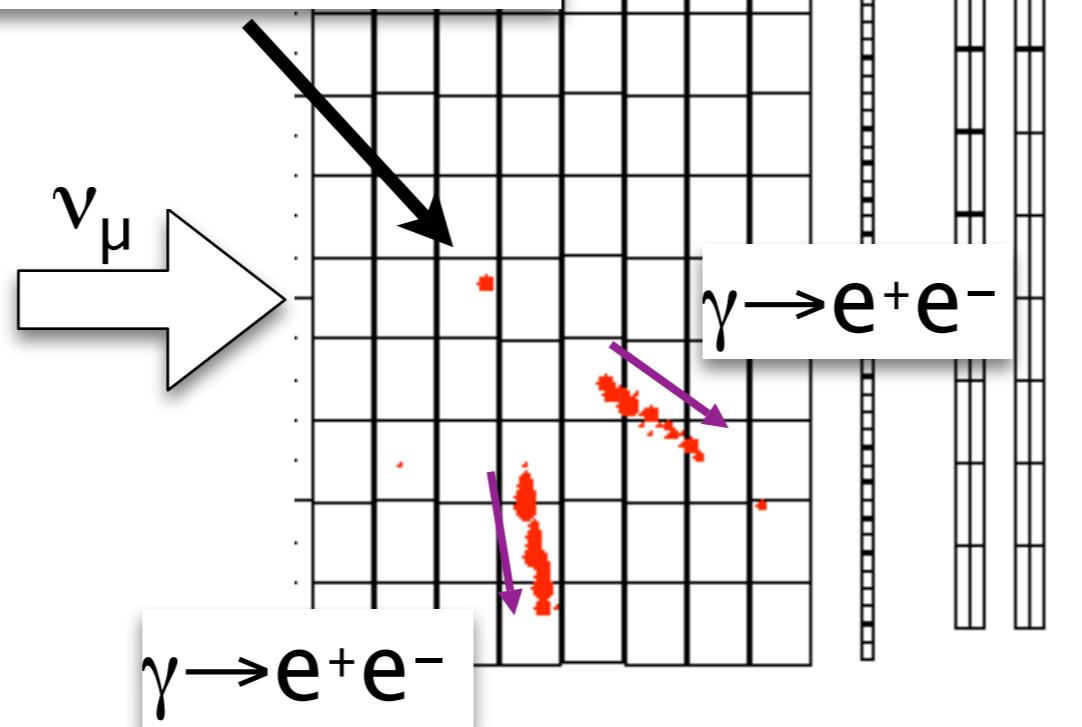
$\nu + p \rightarrow \nu + p + \pi^0 ?$
(resonant π^0)

SciBar

EC

MRD

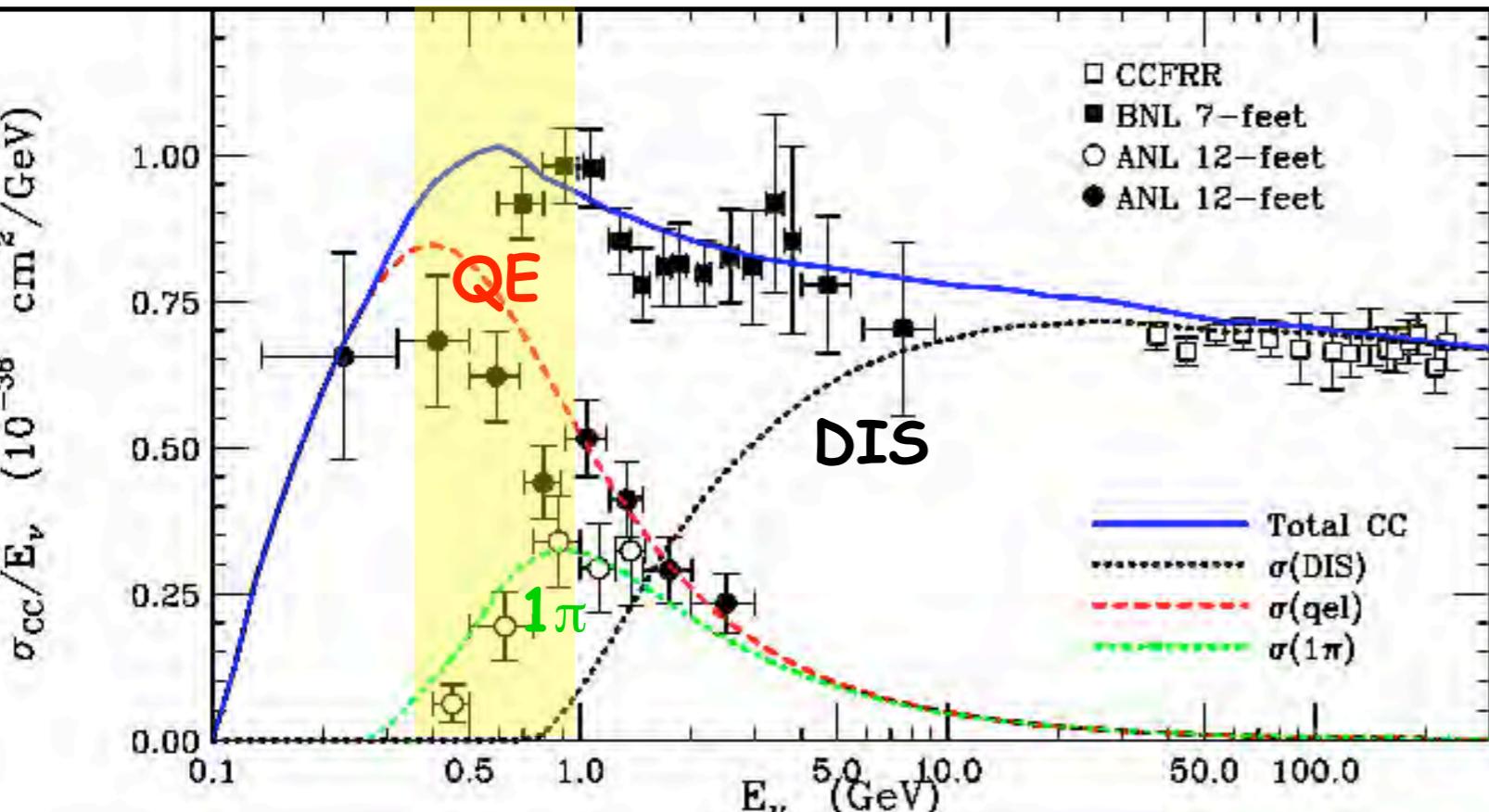
Recoiled proton?



● : SciBar hit, area \propto energy deposit

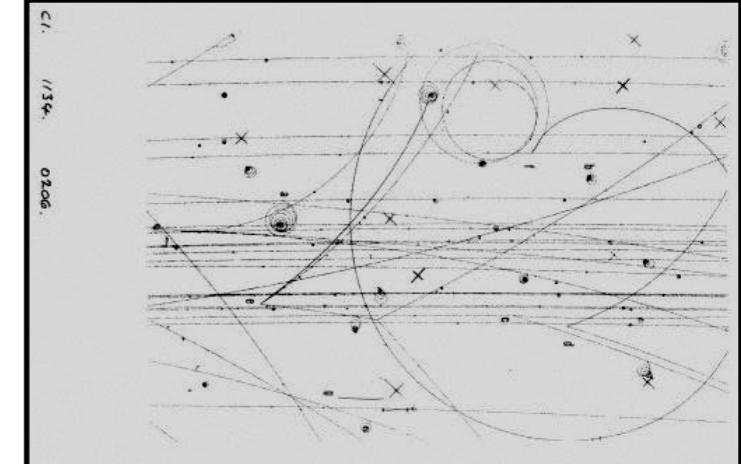
σ_ν : Unexplored areas in Neutrino physics

σ_ν in this E range of interest:



↑
MINOS, NINERvA (NUMI)
↑
K2K, NOvA

MiniBooNE, T2K, SciBooNE
↔ Super-K atmospheric ν



- Data from '70~'80
 - Low statistics
 - Systematic Uncertainties (ex. flux)
- Final State Interaction (Nuclear effects)
 - π/p/n absorption/scattering, shadowing, low Q^2 region
 - Not well-modeled
- New data from K2K & MiniBooNE
- More data at ~1GeV with fine grained resolution will advance Neutrino Physics.

Impact σ_ν on oscillation measurement (T2K case)

- ν_μ disappearance ($\nu_\mu \rightarrow \nu_X$)

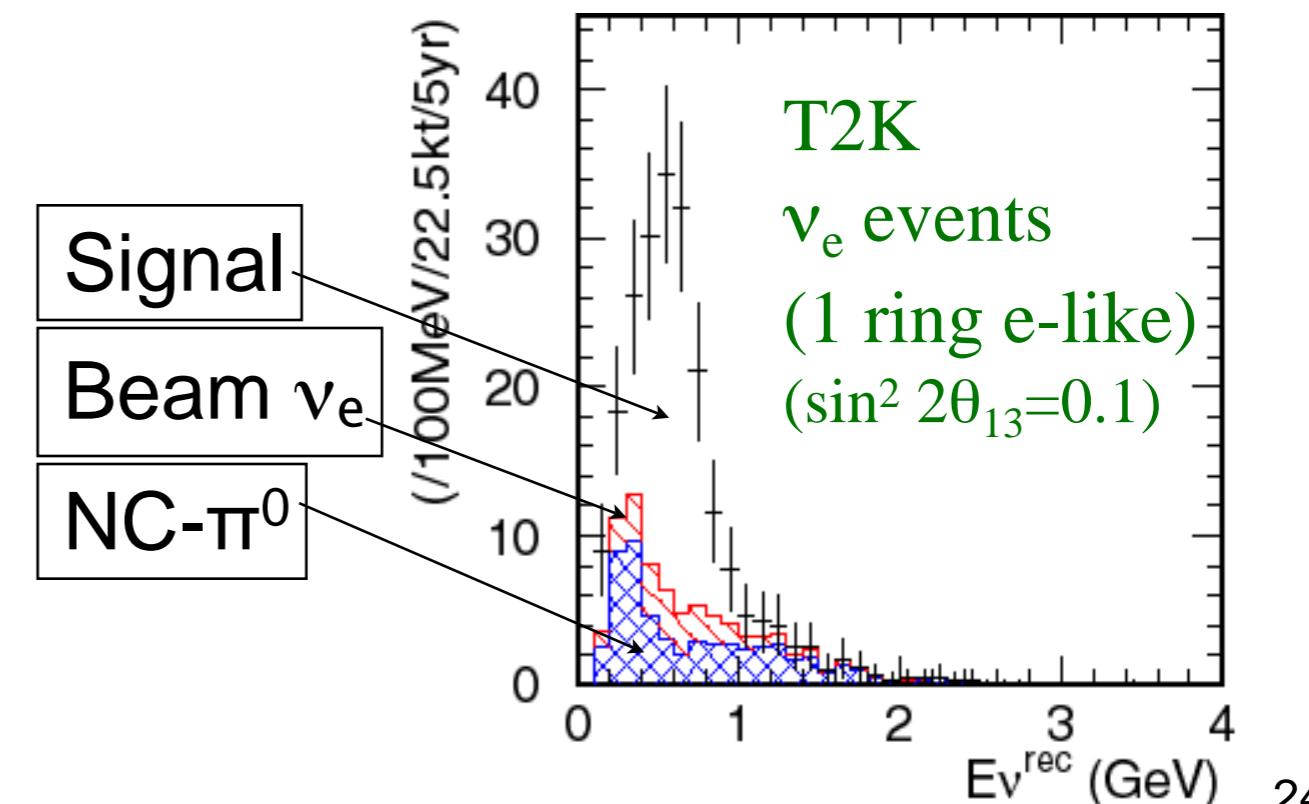
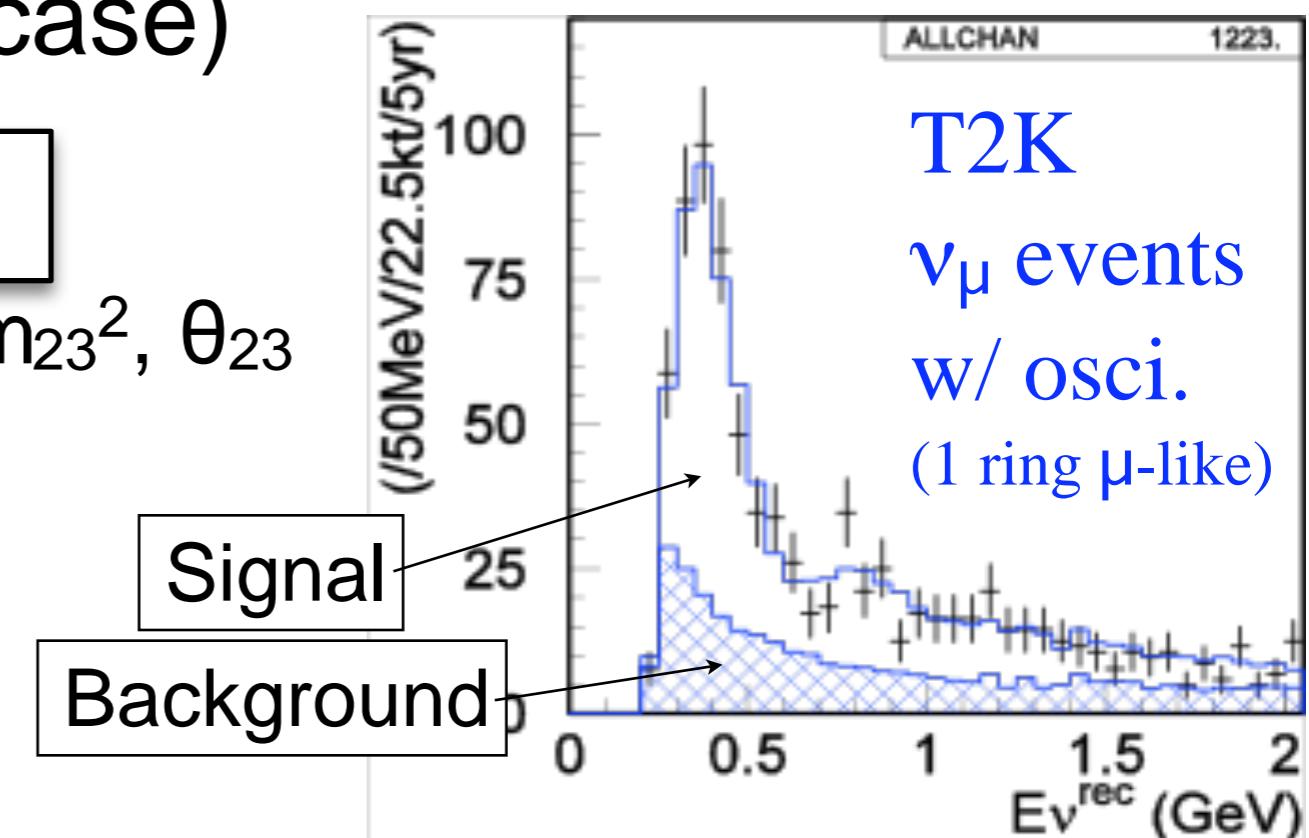
- Precision measurement of Δm_{23}^2 , θ_{23}
- Signal: ν_μ CC-QE
- Background: mainly CC- $1\pi^+$

- ν_e appearance ($\nu_\mu \rightarrow \nu_e$)

- Search for θ_{13}
- Signal: ν_e CC-QE
- Background:
 - Intrinsic beam ν_e
 - NC- π^0

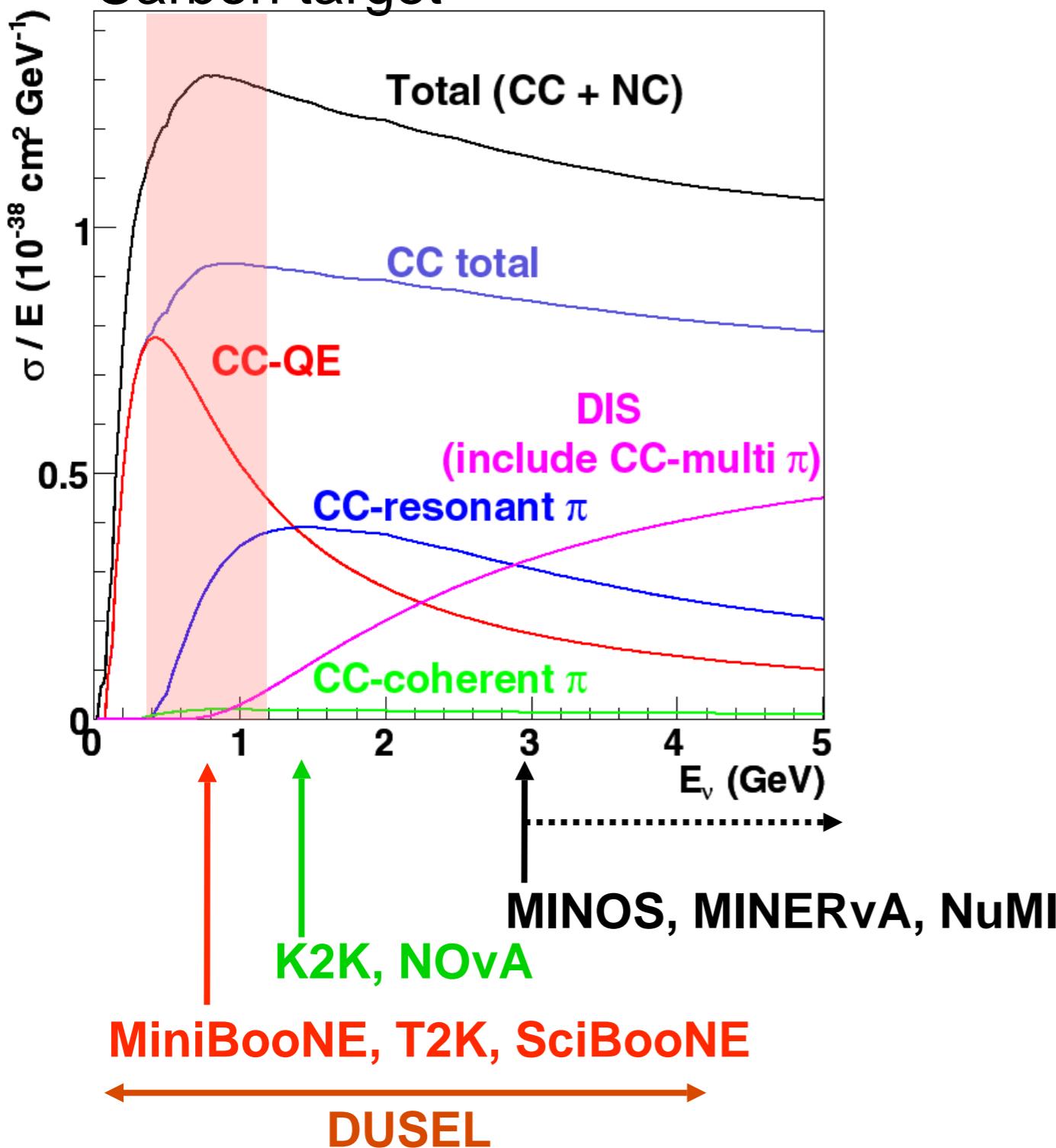
- Search for CP violation

- $\bar{\nu}$ cross sections



Neutrino cross section (NEUT prediction)

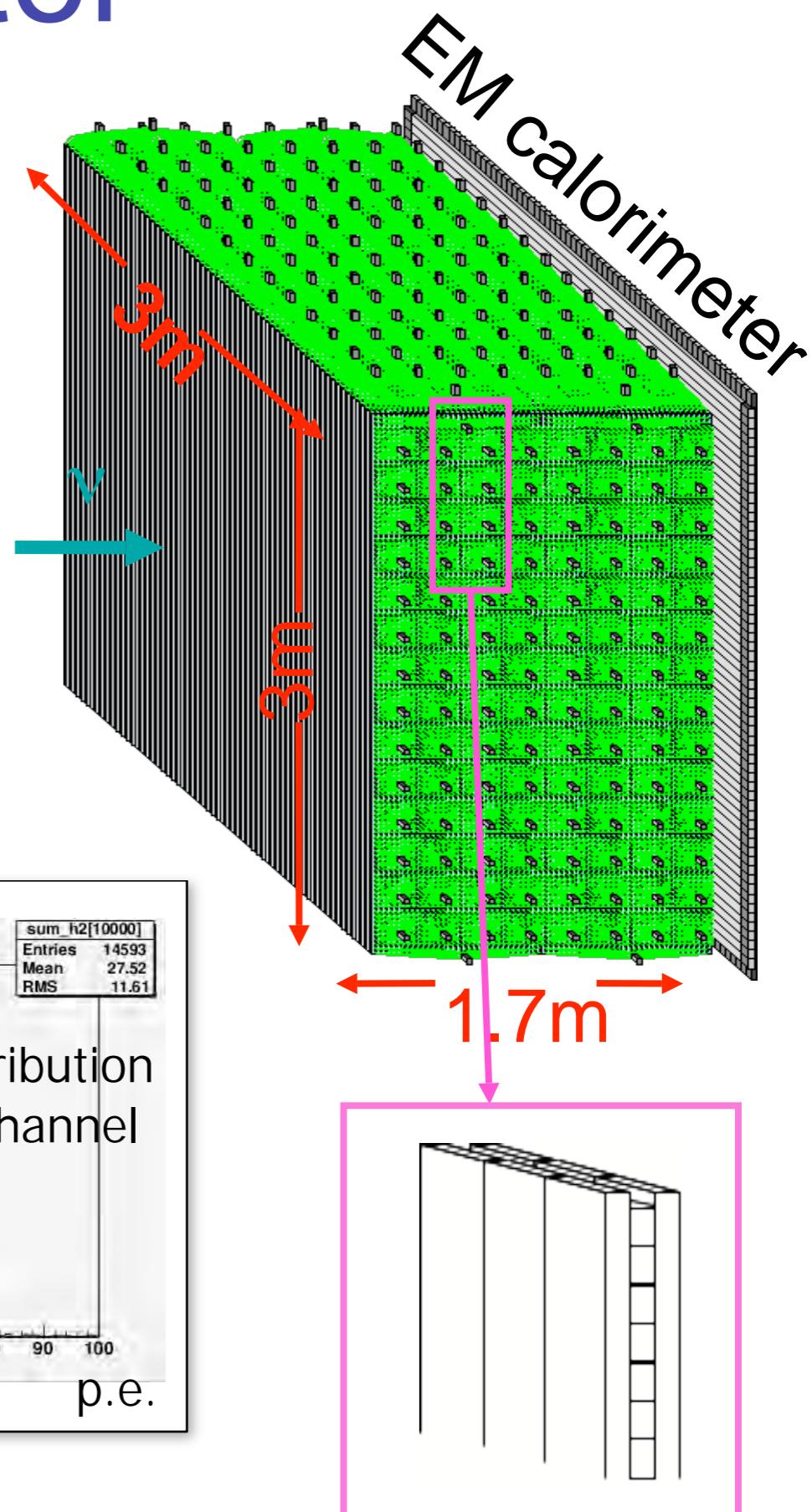
Carbon target



- QE
 - Llewellyn Smith, Smith-Moniz
 - $M_A=1.2 \text{ GeV}/c^2$
 - $P_F=217 \text{ MeV}/c, E_B=27 \text{ MeV}$ (for Carbon)
- Resonant π
 - Rein-Sehgal (2007)
 - $M_A=1.2 \text{ GeV}/c^2$
- Coherent π
 - Rein-Sehgal (2006)
 - $M_A=1.0 \text{ GeV}/c^2$
- DIS
 - GRV98 PDF
 - Bodek-Yang correction
- Intra-nucleus interactions

SciBar Detector

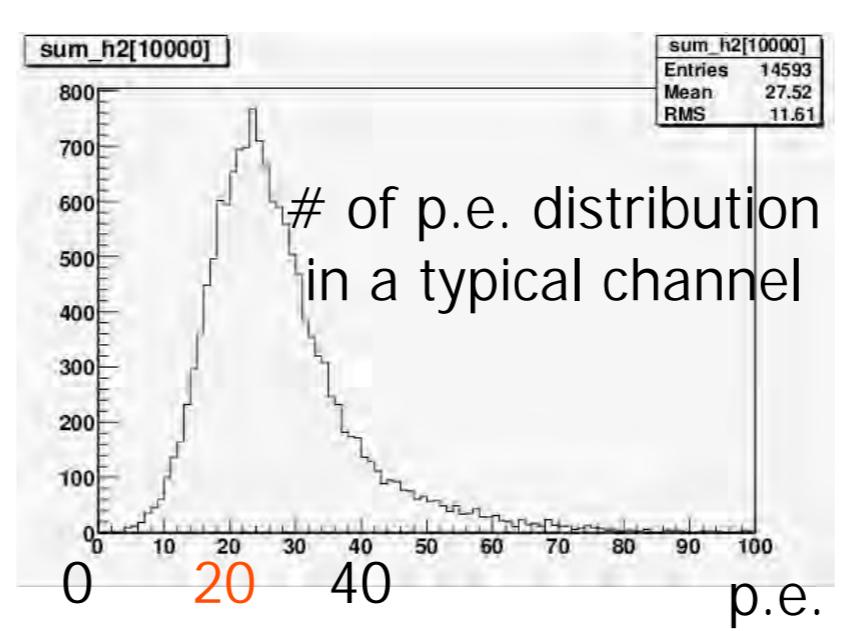
- Fully active target & tracking detector
 - Extruded scintillators with WLS fiber readout with Multi-Anode PMT (64 ch)
 - $2.5 \times 1.3 \times 300 \text{ cm}^3$ cell
 - ~15,000 channels
- Total 15 tons, Fiducial volume: ~10 tons
- Distinguish a proton from a pion by dE/dx



Detector performance

(SciBooNE cosmic ray data)

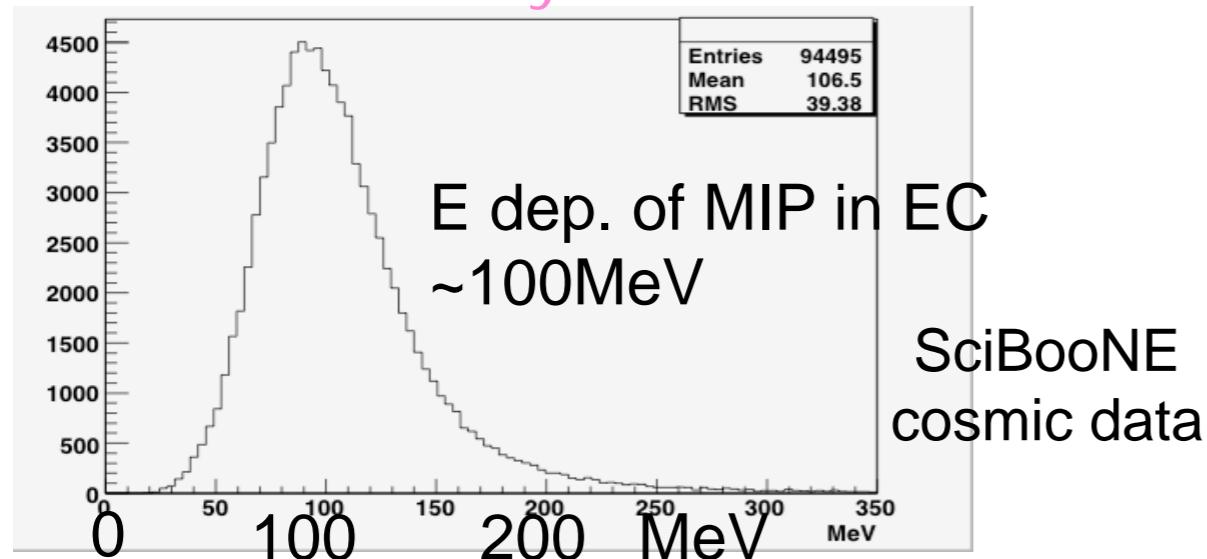
- Light yield for MIP:
~20 p.e./ 1.3cm
- Hit finding efficiency: **~99.9%**



Electron Catcher (EC)

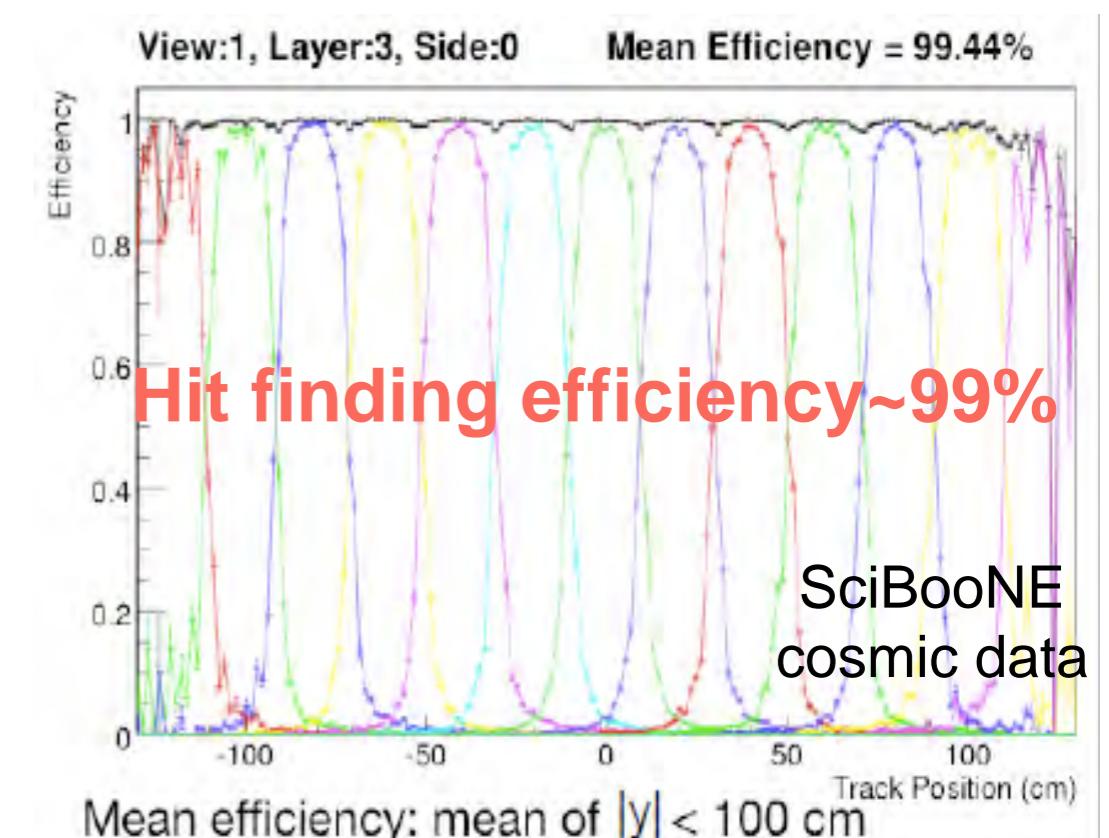
- EM calorimeter
- Electron, gamma ID
- 1mm scintillation fibers in the grooves of lead foils
- 2 planes (total $11X_0$)
- Expected resolution $14\%/\sqrt{E}$

dE/dx distribution for cosmic ray muons



Muon Range Detector (MRD)

- Measure μ momentum with range
 - momentum up to $1.2\text{GeV}/c$
- Iron Plate
 - 2" thick x 12 planes
- Scintillator Plane
 - 13 planes alternating horizontal and vertical planes



Tuning MC simulation

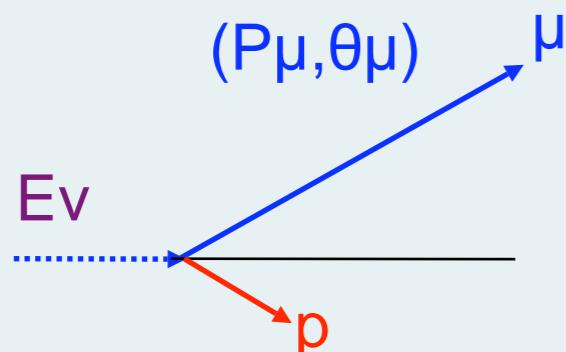
To constrain systematic uncertainties due to

- detector responses
- nuclear effects (final state interaction)
- neutrino interaction models
- neutrino energy spectrum (flux)

Q^2 distributions of sub-samples are fitted to data

$$Q_{rec}^2 = 2E_\nu^{rec}(E_\mu - p_\mu \cos \theta_\mu) - m_\mu^2$$

Q^2 reconstruction assuming CC-QE ($\nu + n \rightarrow \mu + p$) interaction

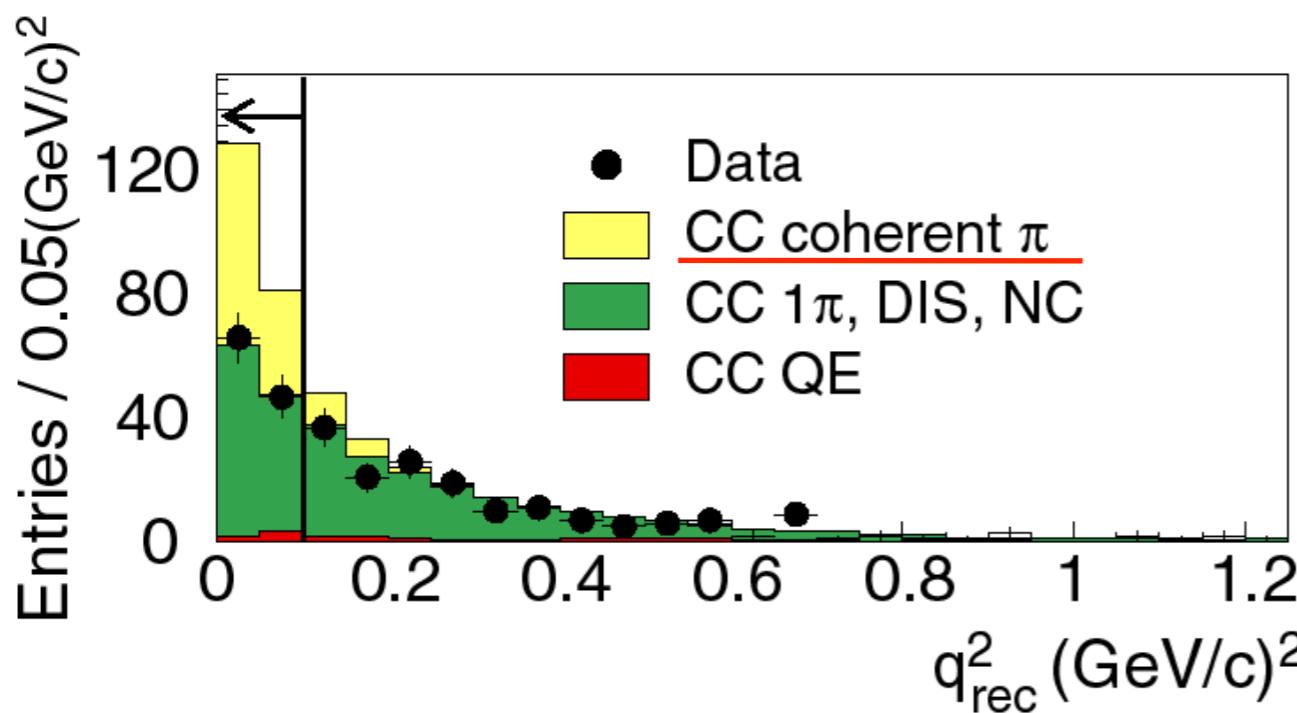


$$E_\nu^{rec} = \frac{1}{2} \frac{M_p^2 - m_\mu^2 - M_n^2 + 2E_\mu M_n}{M_n - E_\mu + p_\mu \cos \theta_\mu}$$

Recent results at low energy ($\sim 1\text{GeV}$)

ν CC coherent π^+

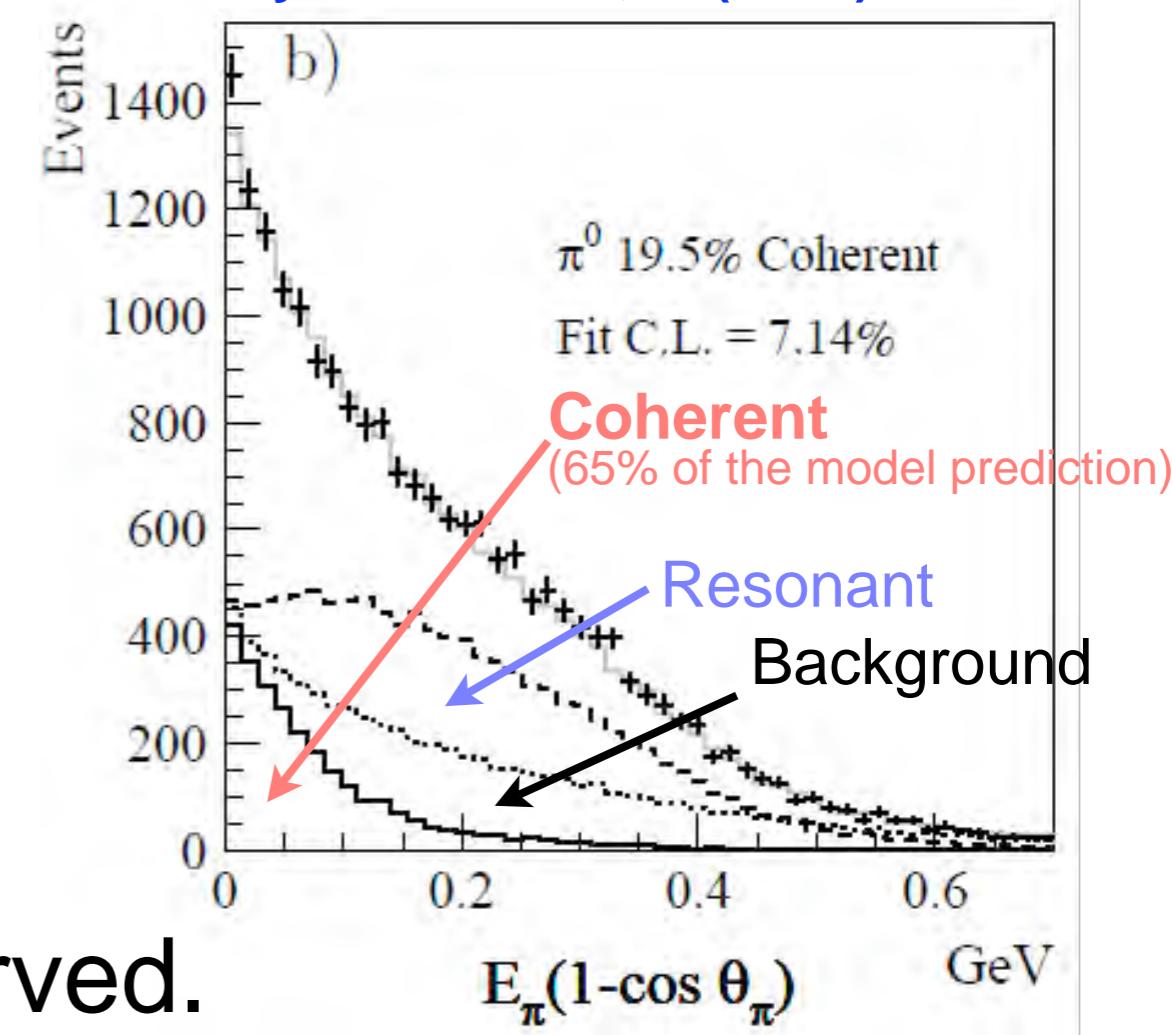
K2K,
Phys.Rev.Lett. 95,252301 (2005)



- CC-coherent π^+ is **NOT** observed.
- NC-coherent π^0 is observed.

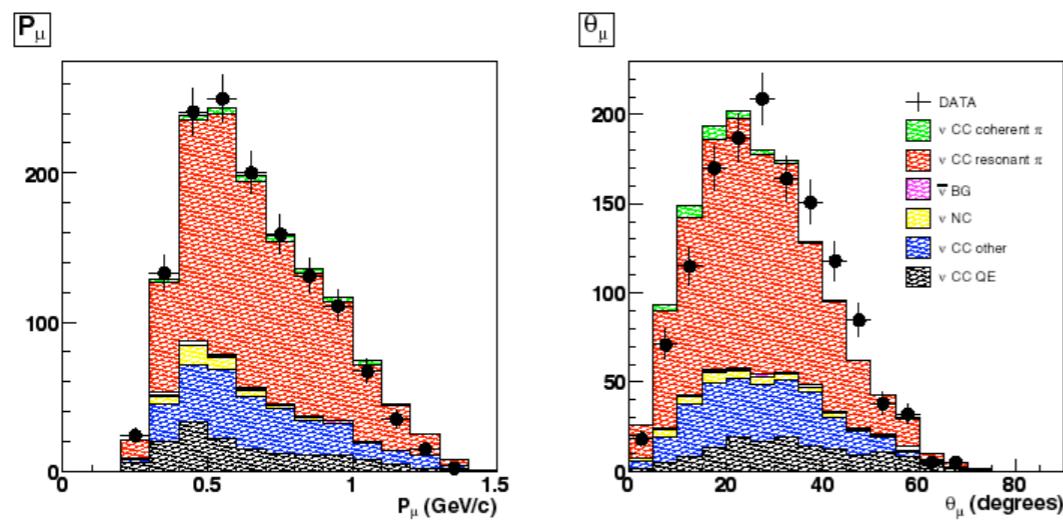
ν NC coherent π^0

MiniBooNE,
Phys.Lett. B664,41 (2008)

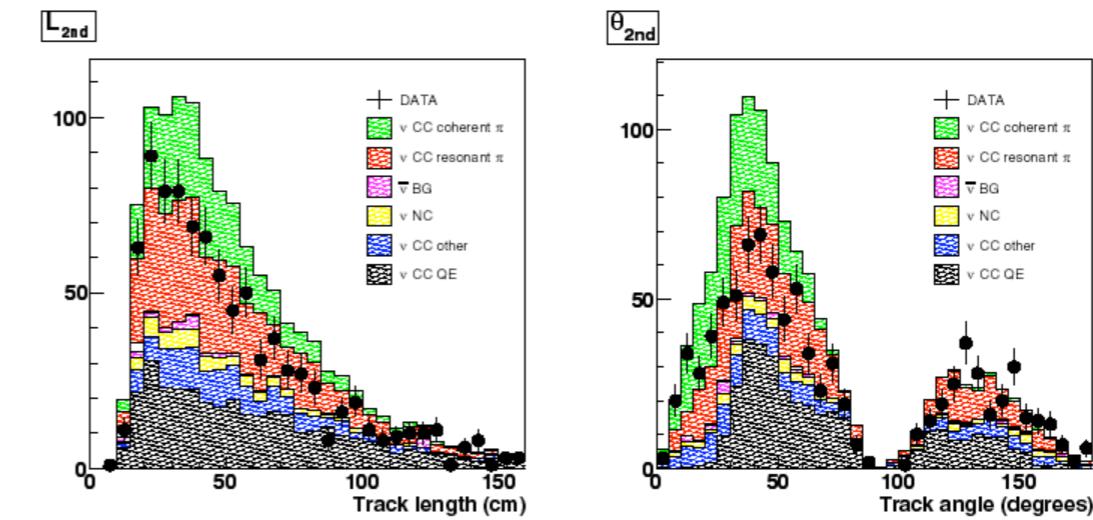
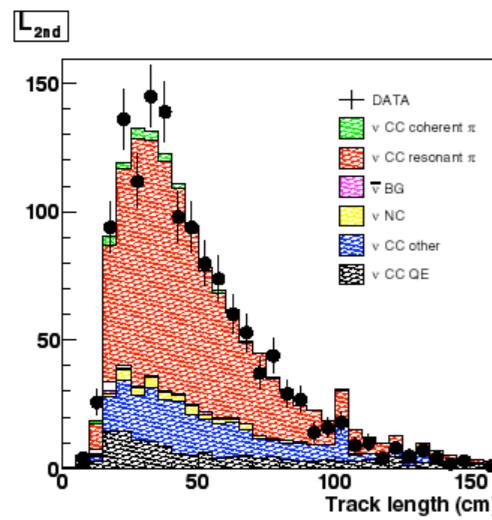
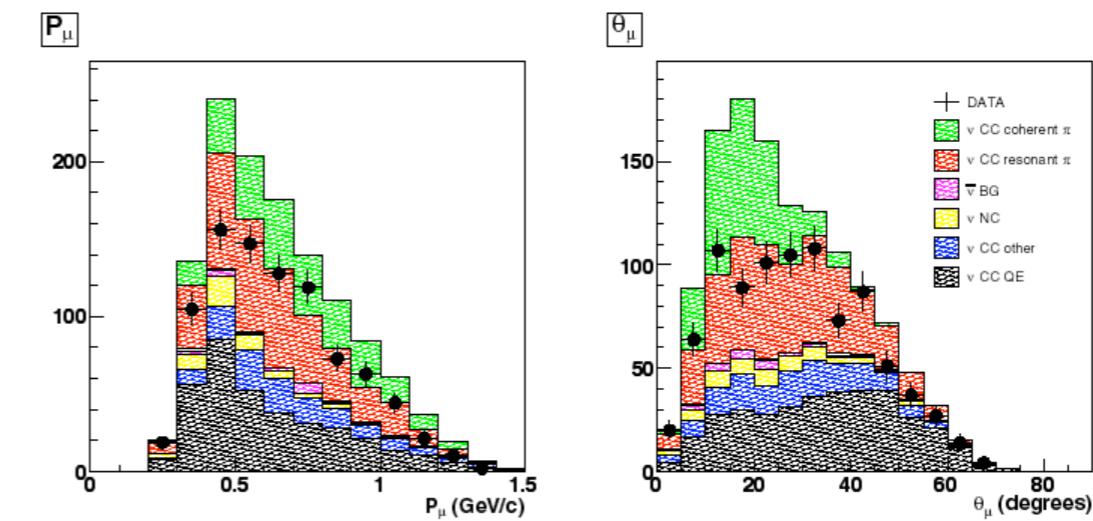


Kinematic distributions

$\mu + \pi$ w/ vertex activity

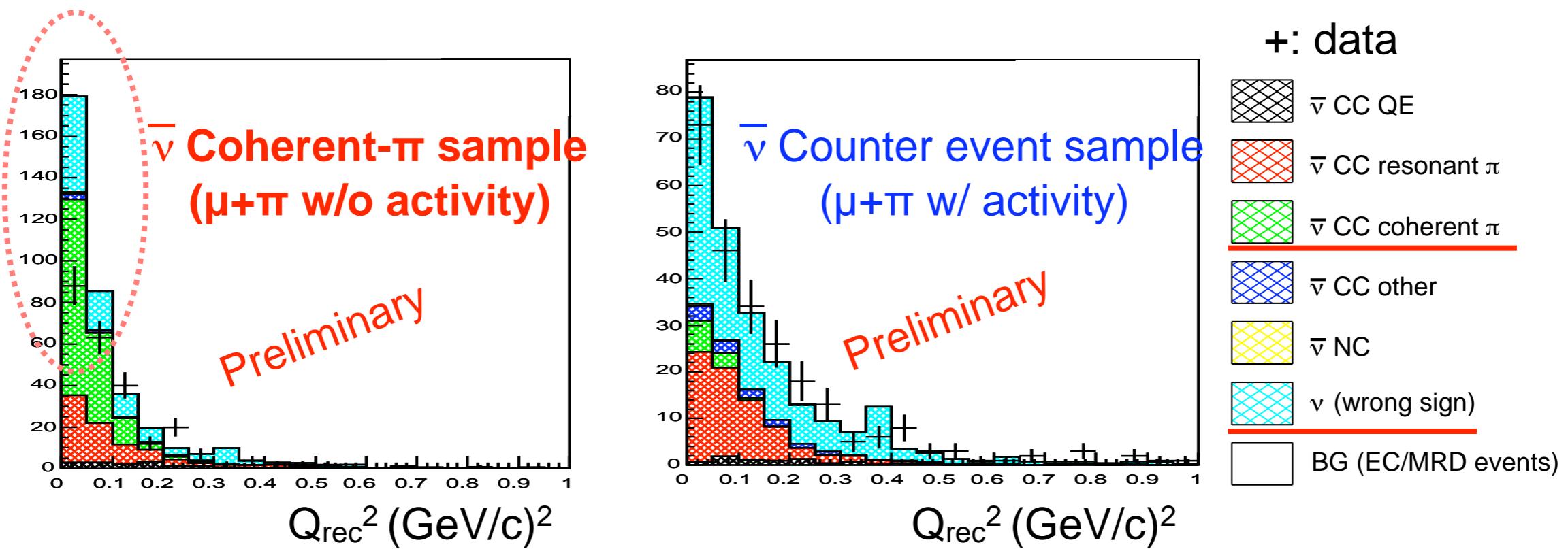


$\mu + \pi$ w/o vertex activity



$\bar{\nu}$ coherent π

Used the same selection criteria as ν coherent π
(NOTE: no syst. error included, no MC tuning yet)



$\bar{\nu}$ coherent π sample also show data deficit at low Q^2 region.

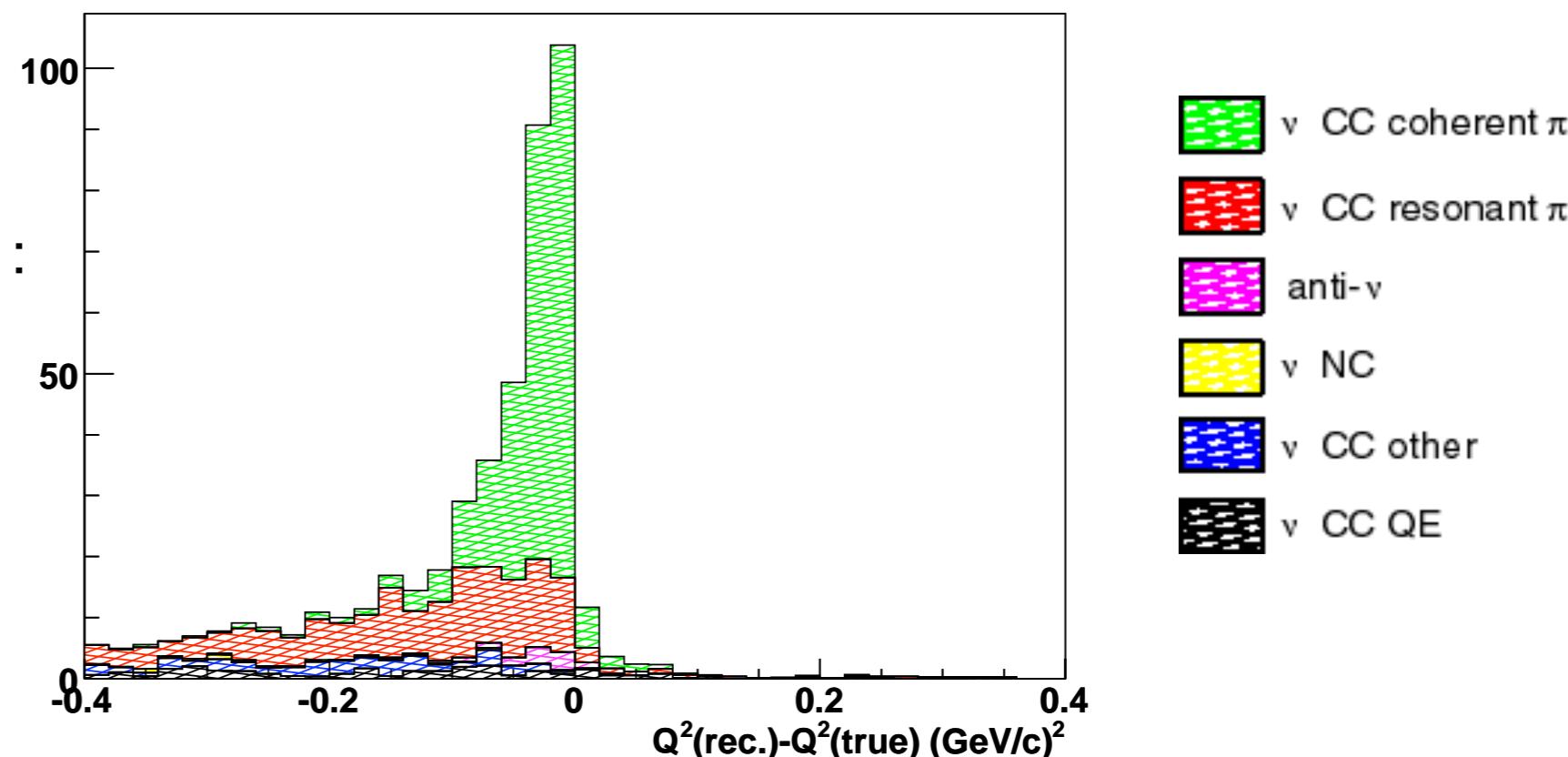
But $\bar{\nu}$ sample has large fraction of ν (wrong sign) background.
→ Need to understand the wrong sign background first.

Q^2 resolution (coherent π)

Q^2 resolution of CC-coherent π :

Mean: -0.024 (GeV/c)^2

Sigma: 0.016 (GeV/c)^2



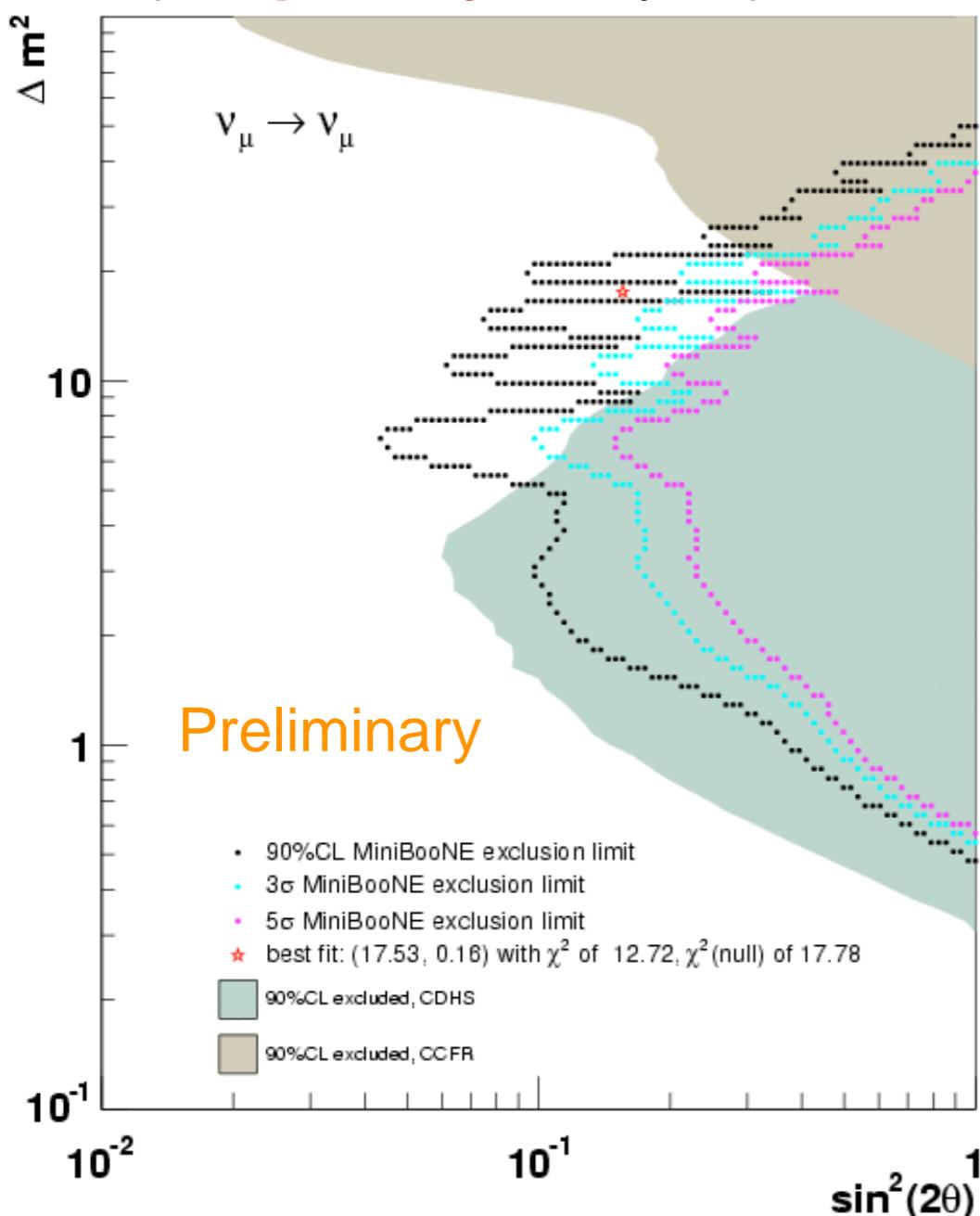
Assume CC-QE

$$Q_{\text{rec}}^2 = 2E_\nu^{\text{rec}}(E_\mu - p_\mu \cos \theta_\mu) - m_\mu^2$$

$$E_\nu^{\text{rec}} = \frac{1}{2} \frac{(M_p^2 - m_\mu^2) - (M - n - V)^2 + 2E_\mu(M_n - V)}{(M_n - V) - E_\mu + p_\mu \cos \theta_\mu}$$

ν_μ disappearance measurement

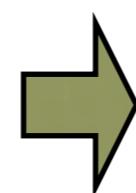
Result of MiniBooNE-only
 ν_μ disappearance search
(shape only analysis)



3+2 models (5 flavor neutrinos) have large mixing and prefer the region where experiment is not explored yet.

G. Karagiorgi et al, Phys.Rev.D75:013011,2007. hep-ph/0609177

- MiniBooNE/SciBooNE joint ν_μ disappearance search
 - Share beamline
 - Share target material



Constraint for flux and cross-sections at MiniBooNE (Shape + Normalization)

Flux prediction

- Constraint v flux with SciBooNE CC samples
- Data prefer higher flux around 1 GeV and lower at high-energy region than MC prediction.
- Next:
 - Take detector/cross-section error into account.

→ Flux comparison with MiniBooNE

MiniBooNE/SciBooNE joint ν_μ disappearance search is in progress.

Only beam related errors are taken into account

