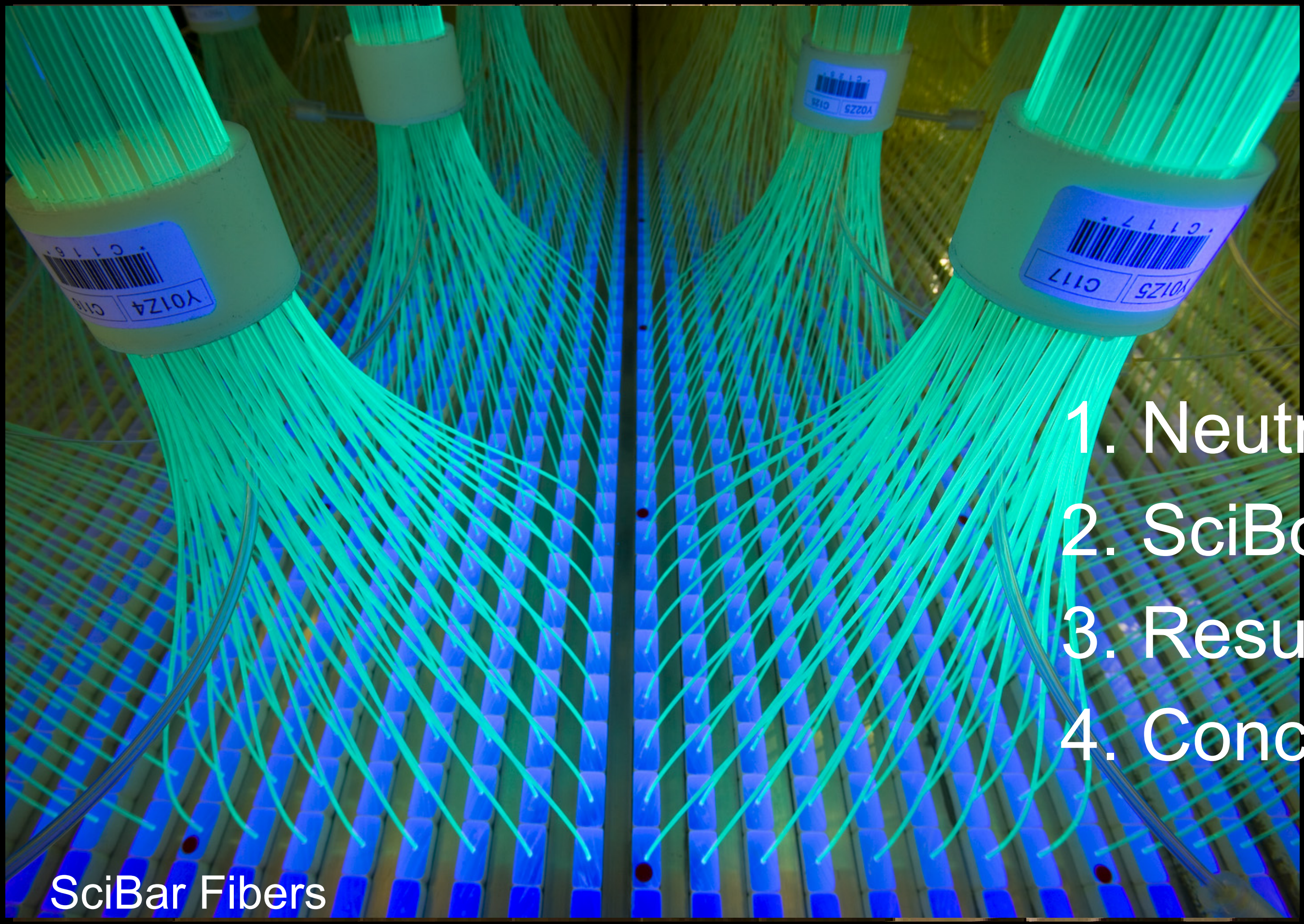
SciBooNE

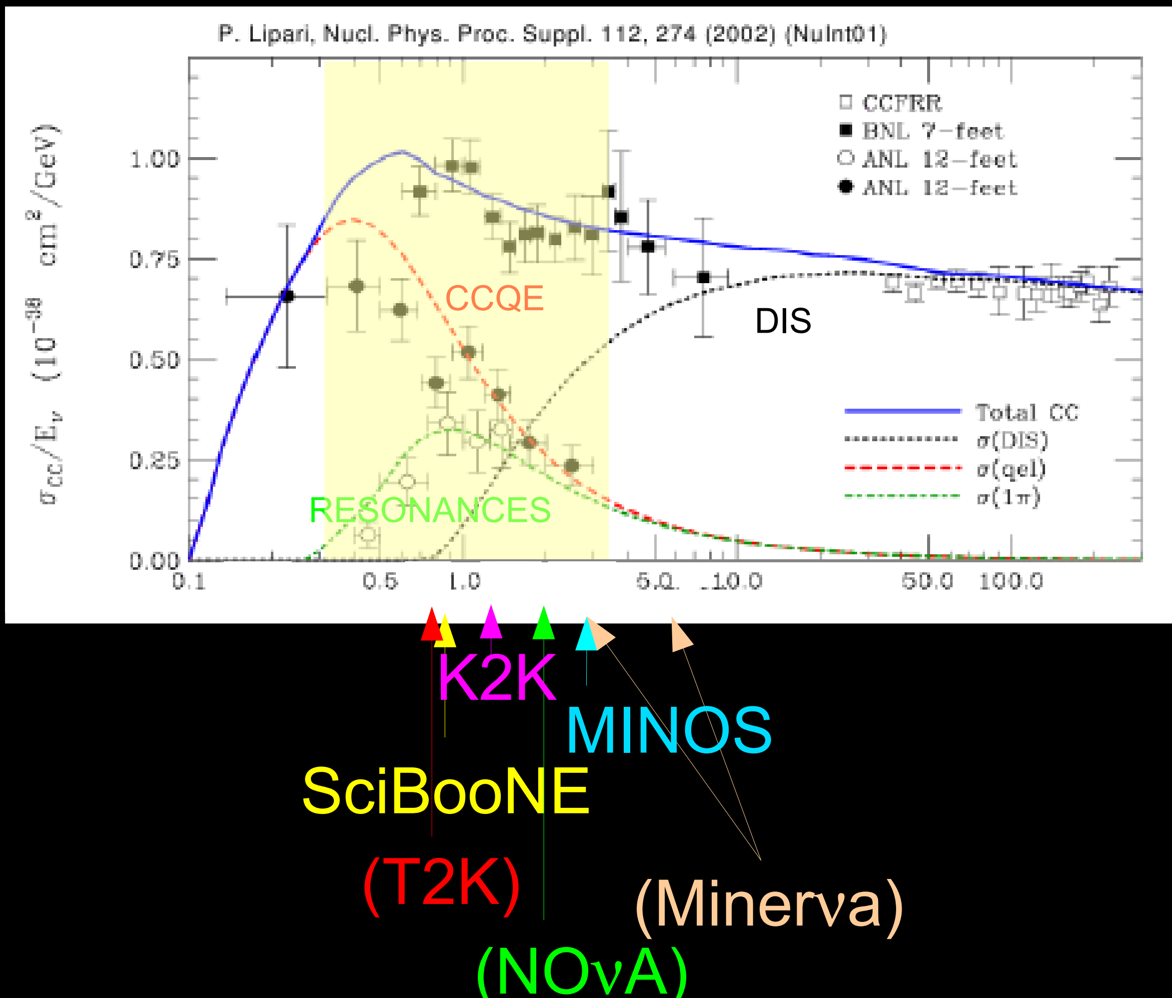


Outline

1. Neutrino cross-sections
2. SciBooNE experiment
3. Results
4. Conclusions

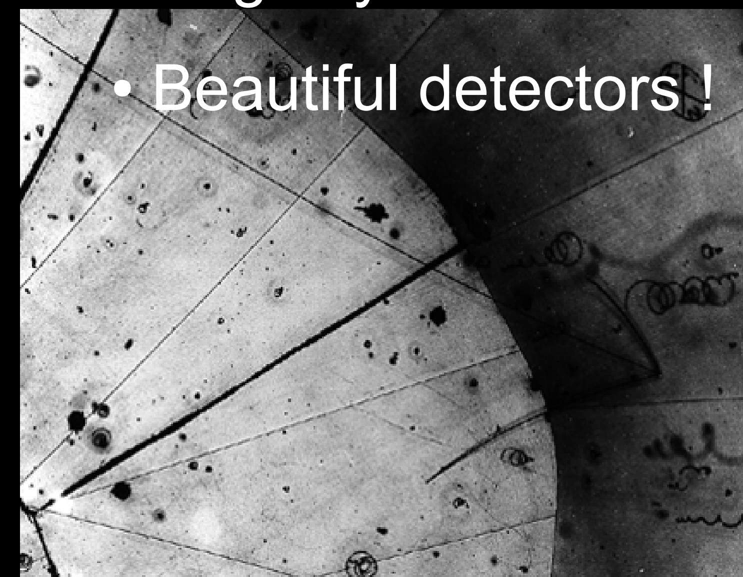
L.Ludovici – INFN Roma @ GDR neutrino, LPNHE Paris
April 27th-28th, 2009

Low (~1GeV) ν Cross-Sections



Old data 1970-1980s:

- Low statistics
- Large systematics
- Beautiful detectors !



Current phenomenological models are not constrained by experimental data with enough precision for the next generation oscillation experiments

Need to improve our understanding of low energy ν-Nucleus interactions

Low energy neutrino cross-section open issues

CC Quasi-Elastic Scattering

- M_A
- Q^2 distribution
- Low Q^2 region

Single π production

- M_A, Q^2 distribution, low Q^2 region
- Coherent π production (CC vs NC)
- π° momentum

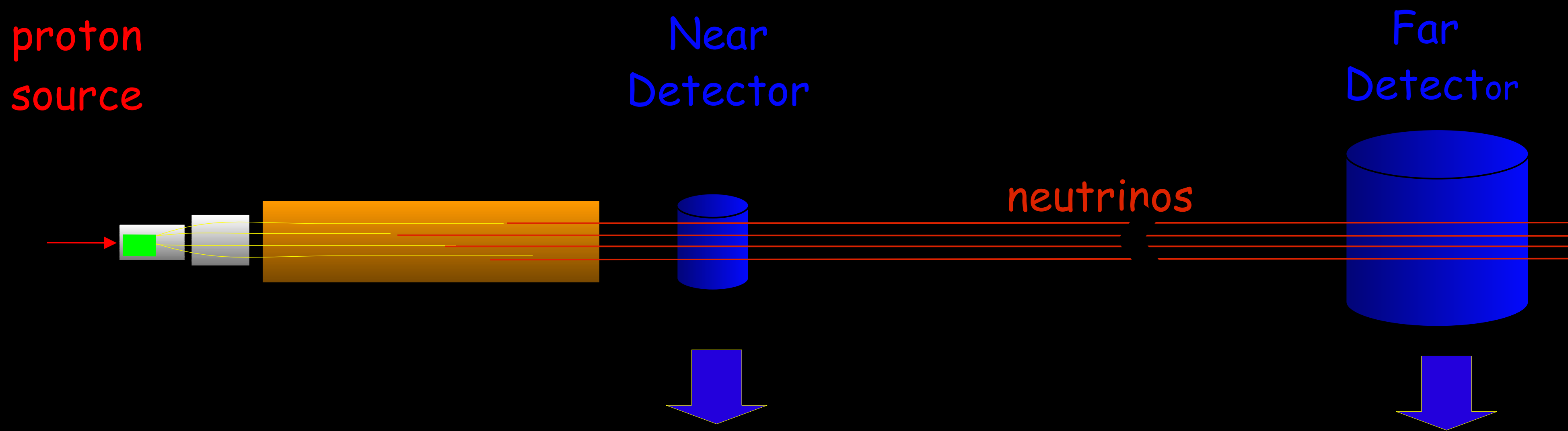
Low energy ν_e (not $\overline{\nu}_e$) MiniBooNE excess (?)

...

CC1$\pi \rightarrow$ background to ν_μ disappearance

NC$\pi^\circ \rightarrow$ background to $\nu_\mu \rightarrow \nu_e$ searches

LBL Near-Far Strategy



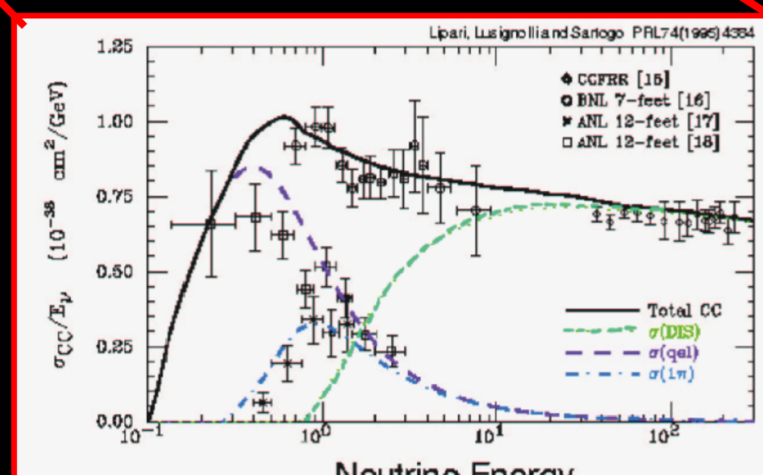
Event rate

Event rate

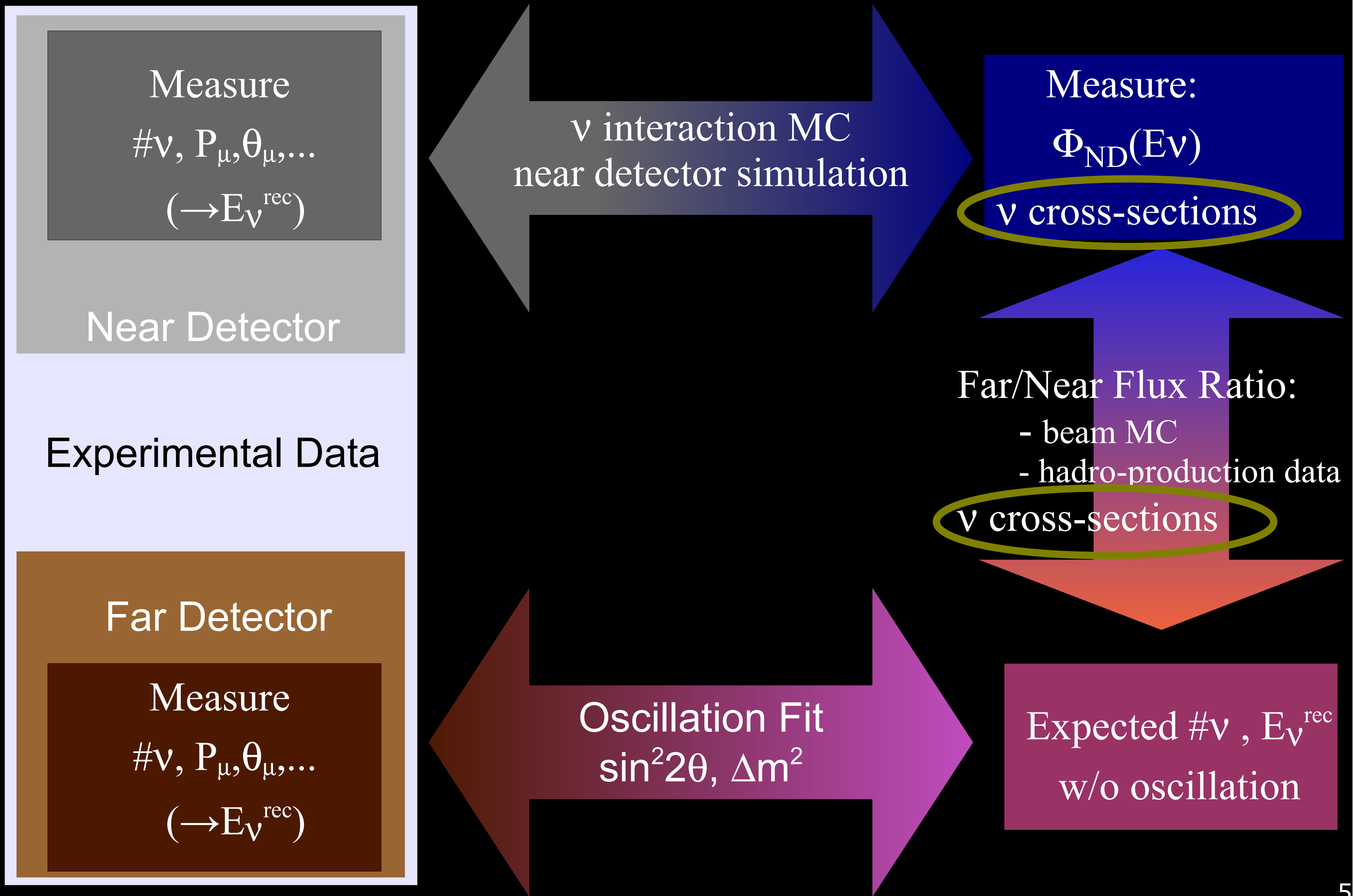
$$\sigma(E) \times \Phi_\nu^{Near}(E) \Leftrightarrow \sigma(E) \times \Phi_\nu^{Far}(E)$$

$\Phi_\nu(E)$

- Beam monitoring
- Beam simulation
- Hadroproduction data
- ...



LBL Near-Far Strategy



SciBooNE: why ?

Precise σ measurements

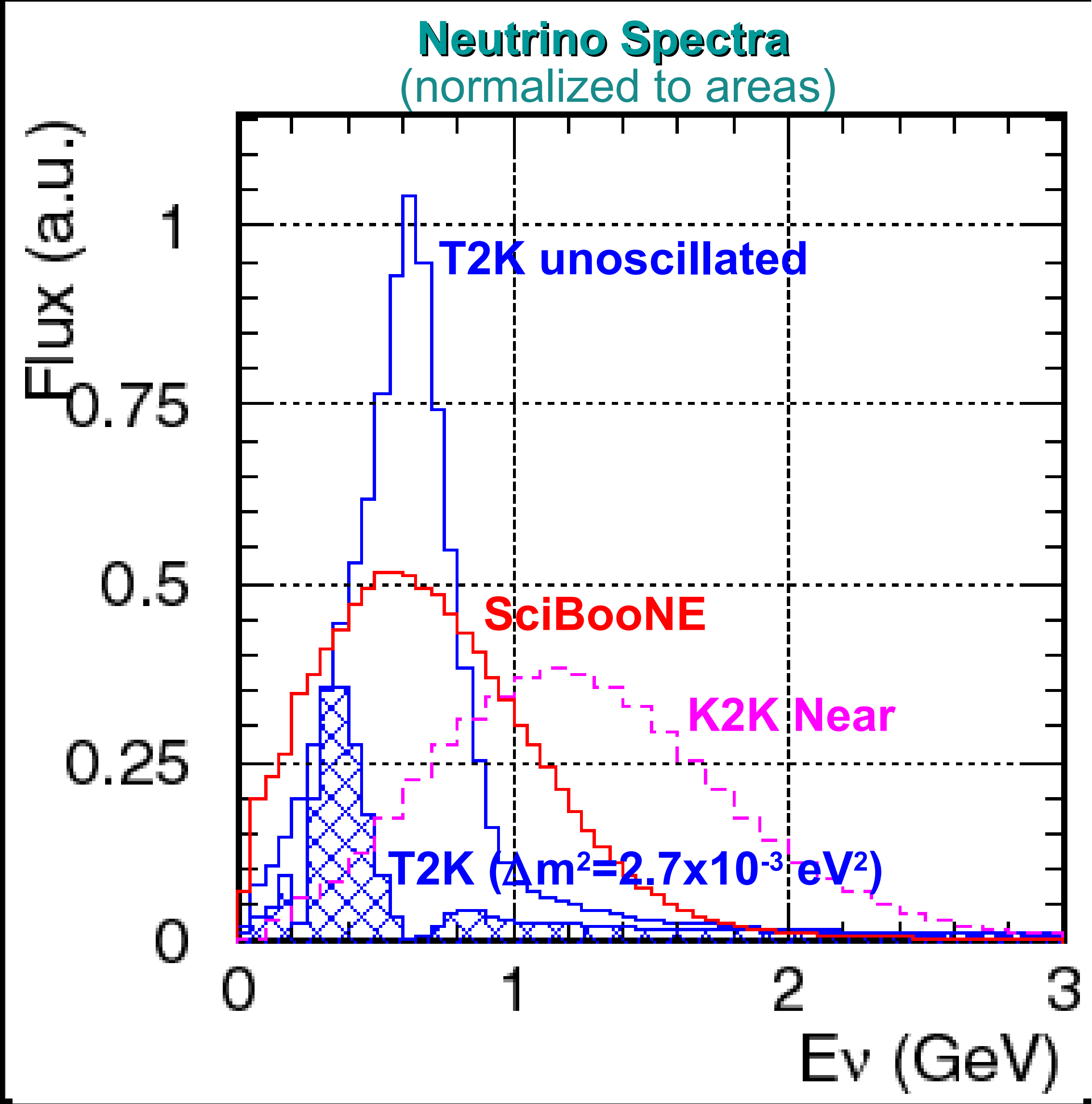
CC-QE

CC-coherent π

CC-1π

NC-π^0

Similar neutrino energy as T2K



Anti-neutrino σ measurements

CC-QE

CC-coherent π

....

Poor experimental data

Measurements joint with MiniBooNE

Flux x σ measurement (WS, ν_μ disapp.,..)

Beam ν_e contamination

Neutrino Interaction MC (NEUT)

CC quasi-elastic (CCQE)

- Llewellyn Smith, Smith-Moniz with M_A=1.2GeV/c^2
- Fermi gas model with P_F=217MeV/c, E_B=27MeV (Carbon)

CC (resonance) single π (CC1π)

- Rein-Seghal(2007), M_A=1.2GeV/c^2

DIS

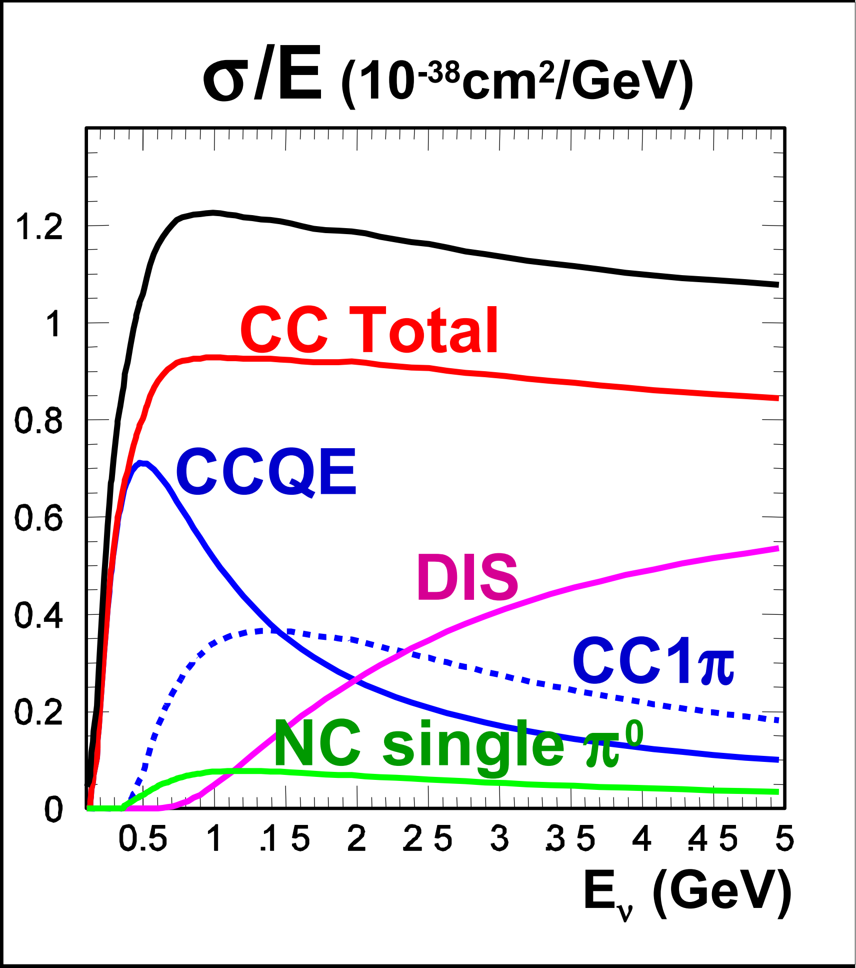
- GRV98 PDF
- Bodek-Yang corrections

CC coherent

- Rein-Sehgal(2006), M_A=1.0GeV/c^2

Neutral Currents

Nuclear effects



SciBooNE: how ?

After K2K end of run (Nov. 2004), where available at KEK SciBar (a fully active tracker and neutrino target) and EC (a lead and fibers “spaghetti” calorimeter adding longitudinal energy containment for electron and $\pi°$).

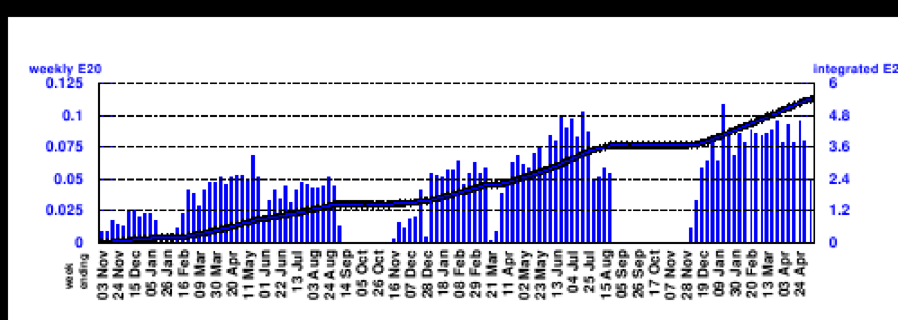
Since installation in K2K (Oct. 2003), 2.2 10^{19} PoTs were taken, producing results on neutrino cross-section (no anti-nu).

A new experimental campaign to measure (anti-)neutrino cross-sections was possible with the addition of a downstream muon detector and the availability of a neutrino beam.

The Booster Neutrino Beam at Fermilab could provide 2 10^{20} PoTs, half in neutrino and half in anti-neutrino mode.

End of 2005 $\rightarrow$ Letter of Intent to FNAL PAC.

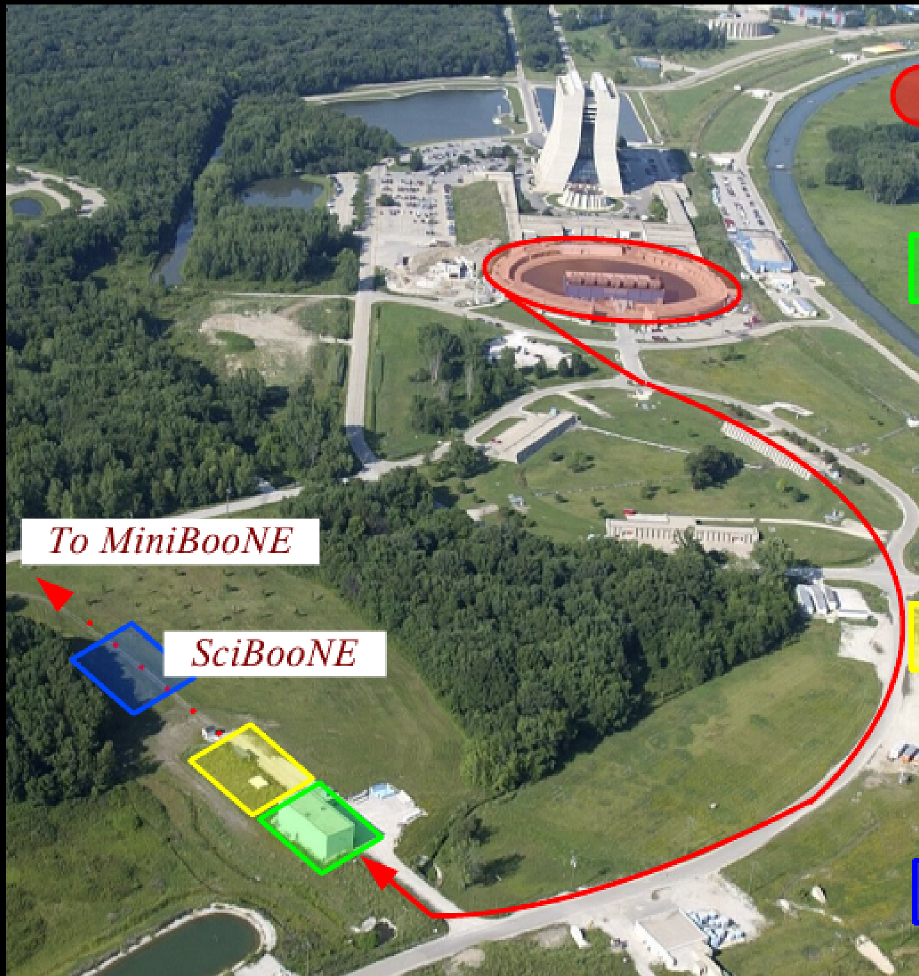
SciBooNE: where ?



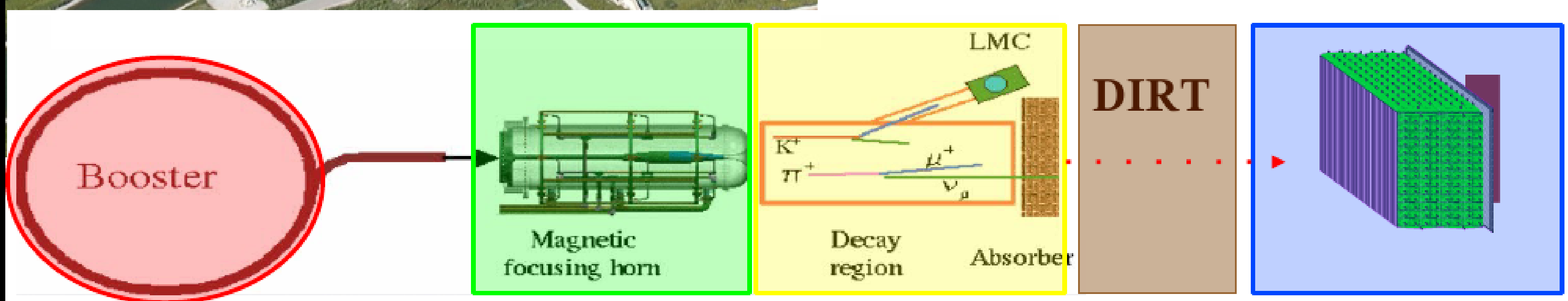
FNAL Booster Neutrino Beam

1÷2 10^{20} PoT/year

SciBooNE at Fermilab



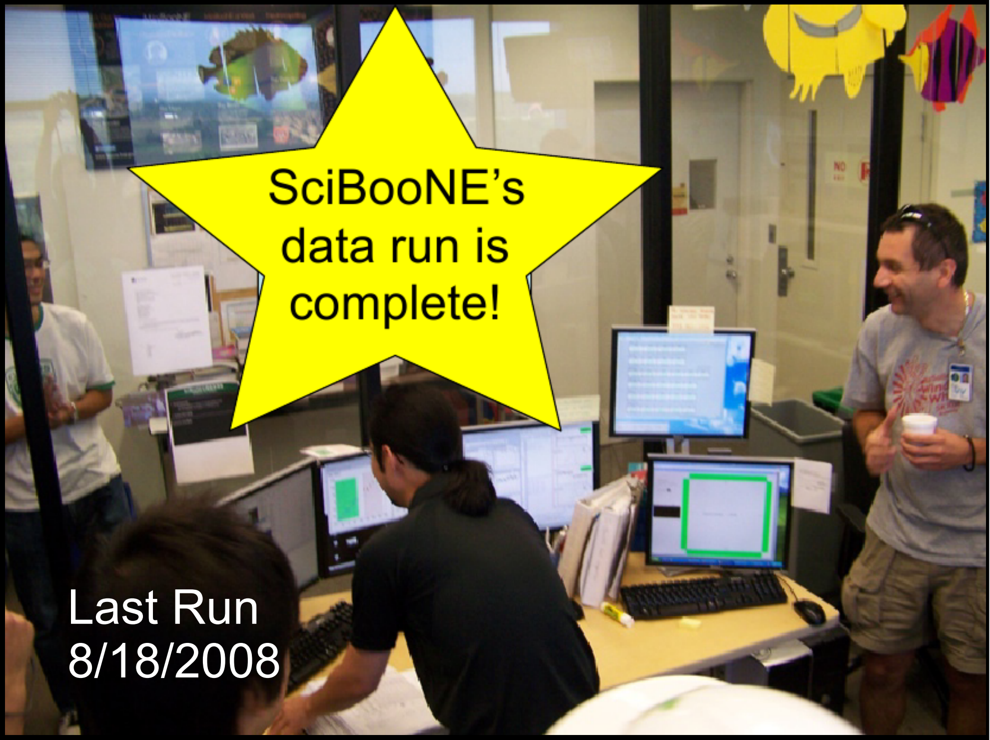
- Booster Proton accelerator
  - 8 GeV protons sent to target
- Target Hall
  - Beryllium target: 71cm long 1cm diameter
  - Resultant mesons focused with magnetic horn
  - Reversible horn polarity
- 50m decay volume
  - Mesons decay to μ & ν_μ
  - Short decay pipe minimises $\mu \rightarrow \nu_e$ decay
- SciBooNE located 50m from Absorber



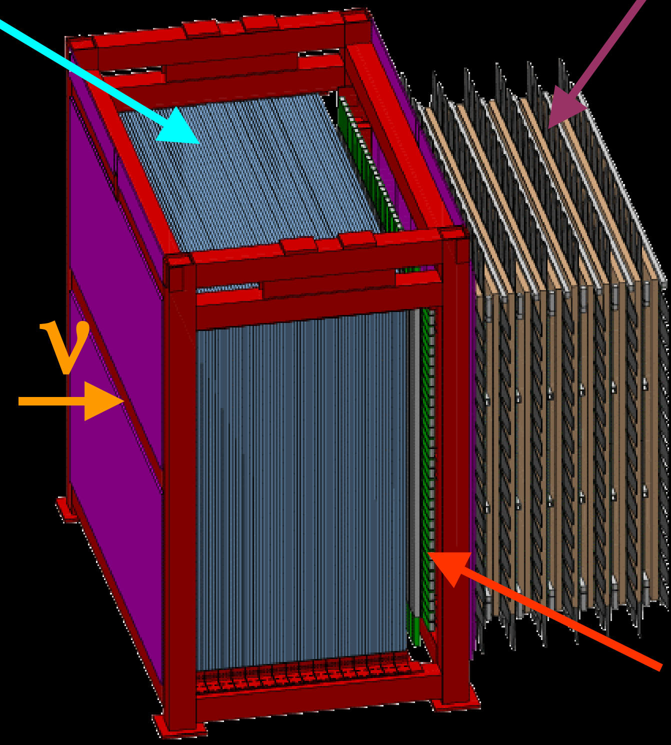

Ground breaking
9/20/06


Detector Assembly
12/20/2006


MRD (SciBooNE)
4/23/07


SciBooNE's data run is complete!
Last Run
8/18/2008

SciBooNE detector



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

Built for K2K

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

Built for SciBooNE with parts recycled at FNAL

- Lead+Fibers "spaghetti" calorimeter
- 2 planes, horizontal+vertical (11 Xo)
- PID and containment for π° and ν_e

Built for K2K re-cycling modules originally constructed for CHORUS

The "Green" Experiment

Fermilab Today | Monday, April 7, 2008

SciBooNE wins DOE-wide award for pollution prevention

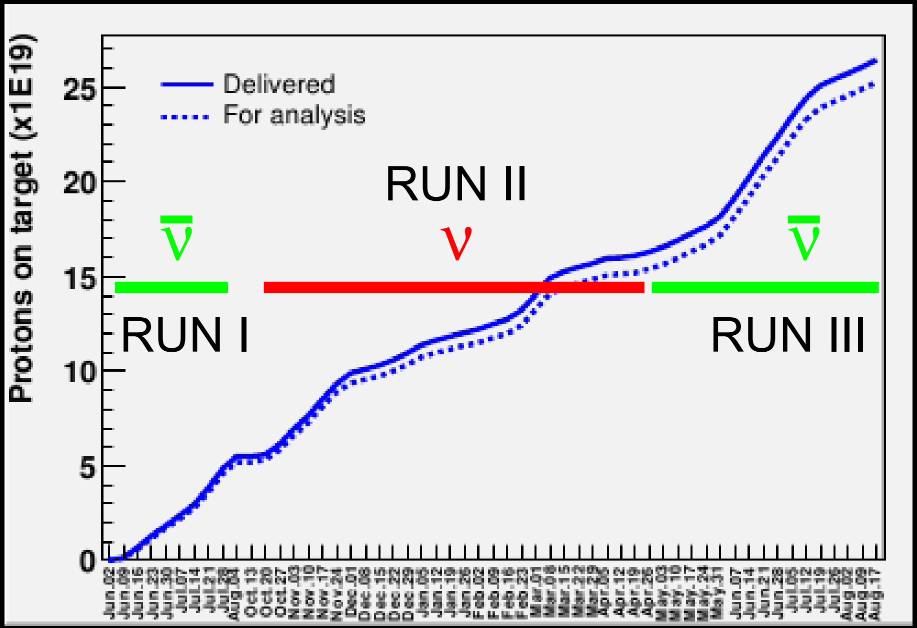
Camillo Mariani (top) and Lucio Ludovici (middle), both from University of Rome, La Sapienza, and Chris Richardson and John Cornele, both of Fermilab, install re-used electromagnetic calorimeter modules into an element of the SciBooNE experiment.

The SciBooNE experiment, which is tucked away in a small cement building no larger than a commercial elevator shaft, recently stood out in the national spotlight. Federal officials recently named SciBooNE a recipient of a DOE-wide Pollution Prevention Star (P2 Star) Award for its reuse of existing materials.

DOE-wide Pollution Prevention Star (P2 Star) Award

Hardware re-cycling reduced the experiment from 4.5 to 1.2 M$

SciBooNE Data Taking

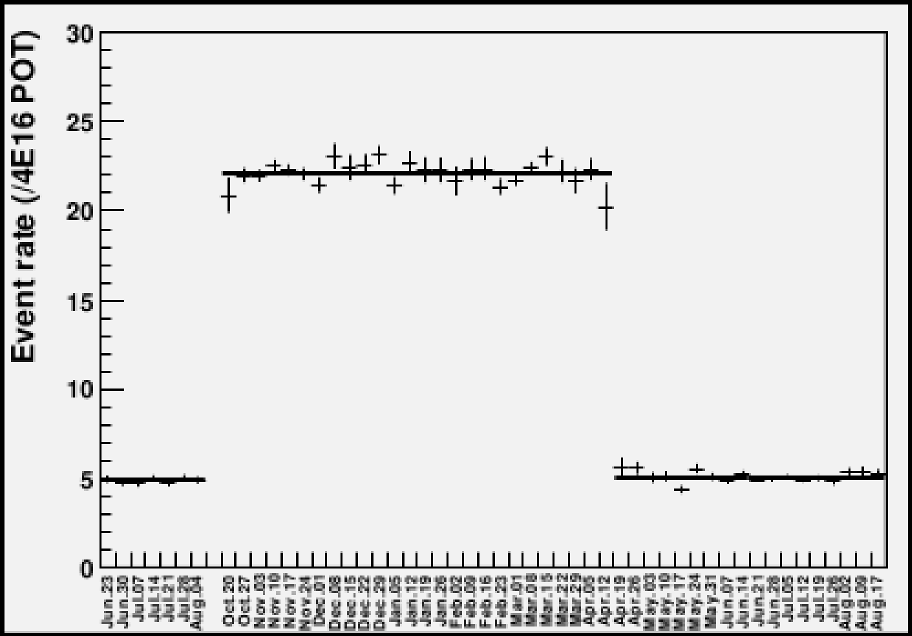


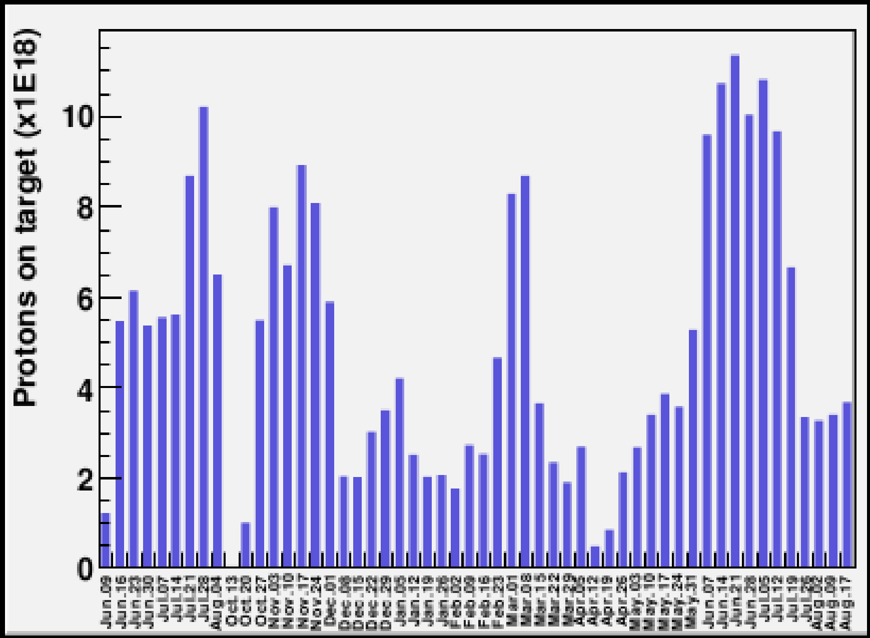
Started June 2007

Ended Aug. 18th, 2008

Collected for analysis 2.52E20 PoT:

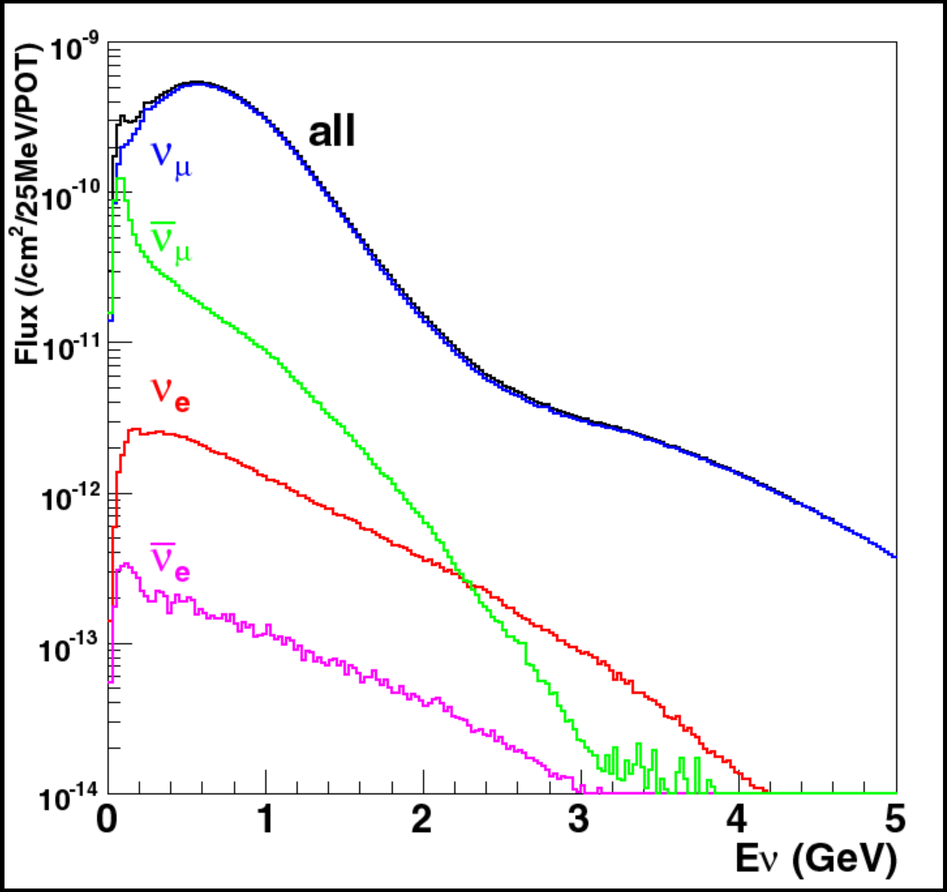
Neutrino data 0.99E20 PoT
Anti-neutrino data 1.53E20 PoT





Booster Neutrino Beam (BNB)

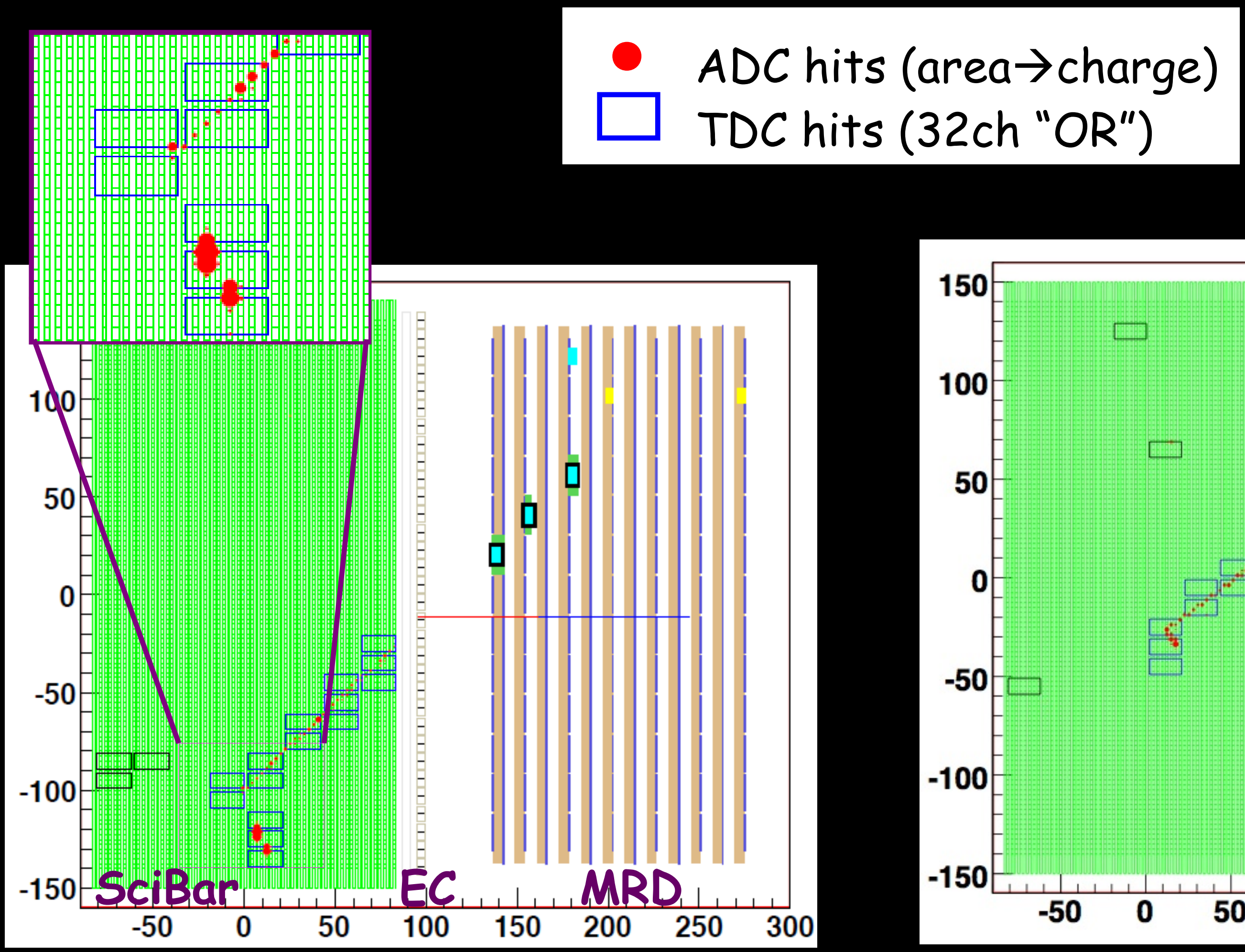
Expected neutrino spectrum at SciBooNE (neutrino mode)

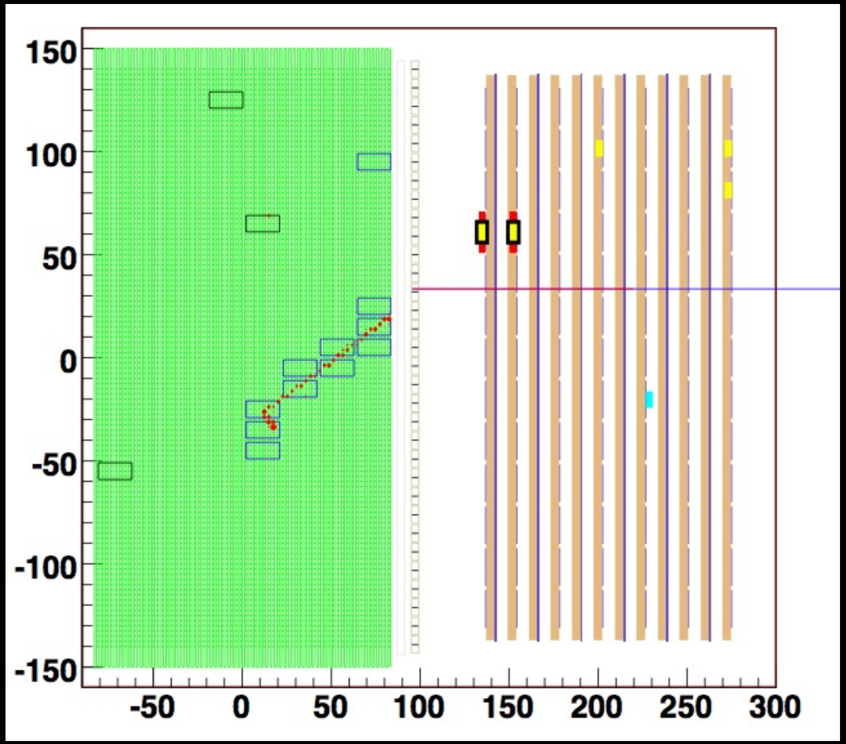


- mean neutrino energy: $\langle E\nu \rangle \sim 0.7$ GeV
- 93% pure νμ beam
  $\overline{\nu\mu}$ (6.4%)
  $\nu e + \overline{\nu e}$ (0.6%)
- the anti-neutrino beam is obtained by reversing the horn polarity

Event Display

Real SciBooNE Data





anti-νμ CC-QE candidate
(νμ + p → μ + n)

νμ CC-QE candidate
(νμ + n → μ + p)

SciBooNE Analysis Topics

CC-coherent pion ⇐ Today

Flux measurement

Joint SciBooNE/MiniBooNE oscillation analysis

CC Quasi Elastic

CC $1\pi^+$

NC $\pi°$ production

CC $\pi°$ production

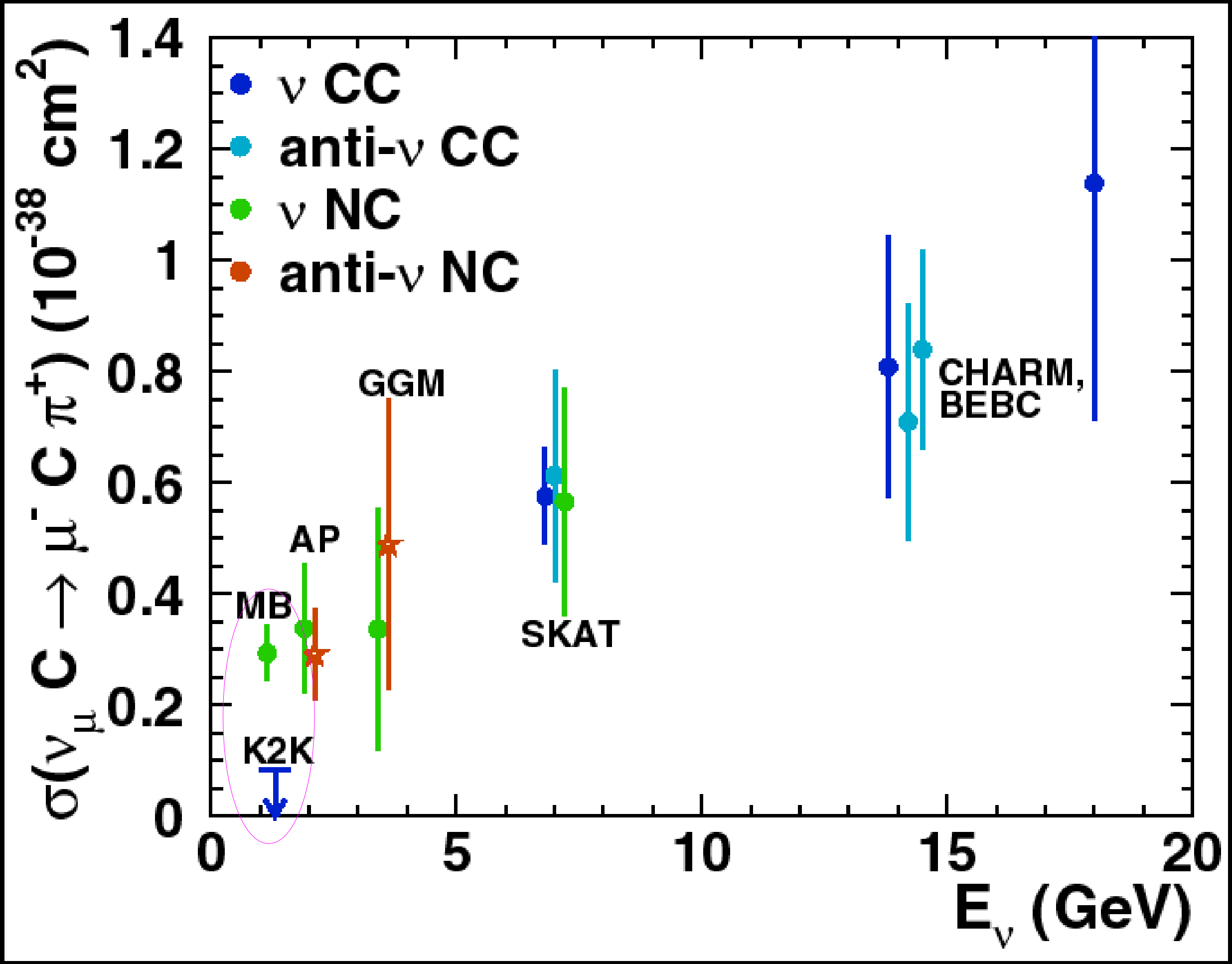
NC elastic

Beam ν_e spectrum

...

Excellent training for a new generation of neutrino physicists !

Coherent pion production



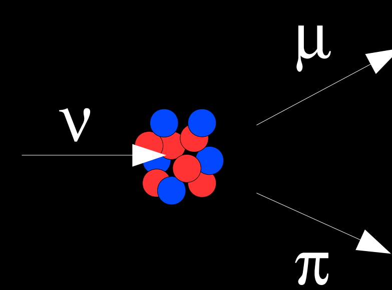
Scaled to CC coherent on Carbon assuming:

- $A^{2/3}$ dependence
- $\sigma(CC)=2\sigma(NC)$
- $\sigma(\nu\mu)=\sigma(\bar{\nu}\mu)$

CC coherent π^+

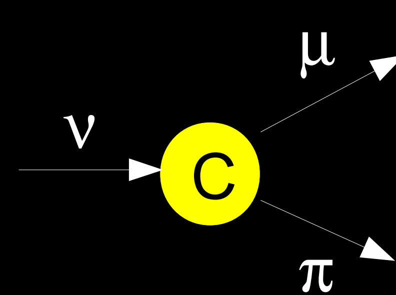
CC-resonant π^+ production

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

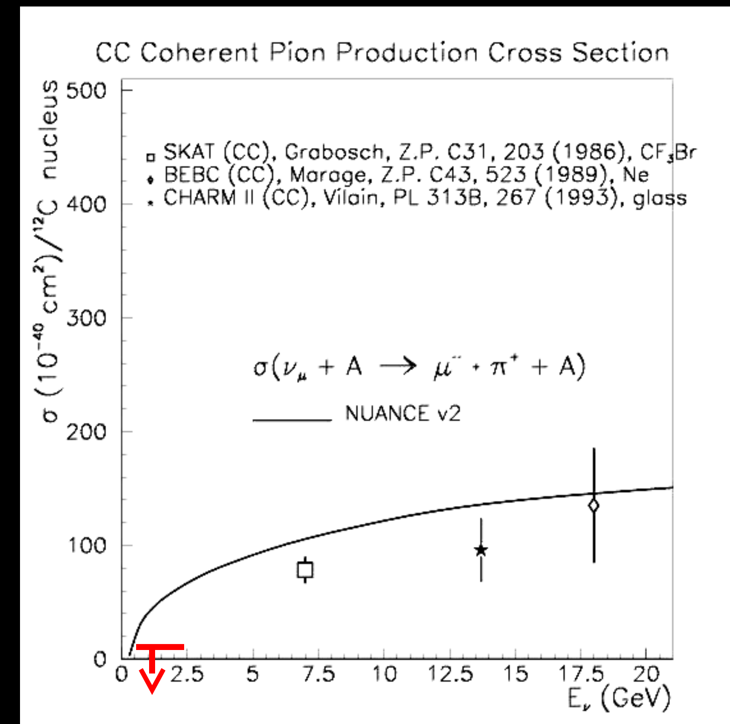


CC-coherent π^+ production

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



G.Zeller



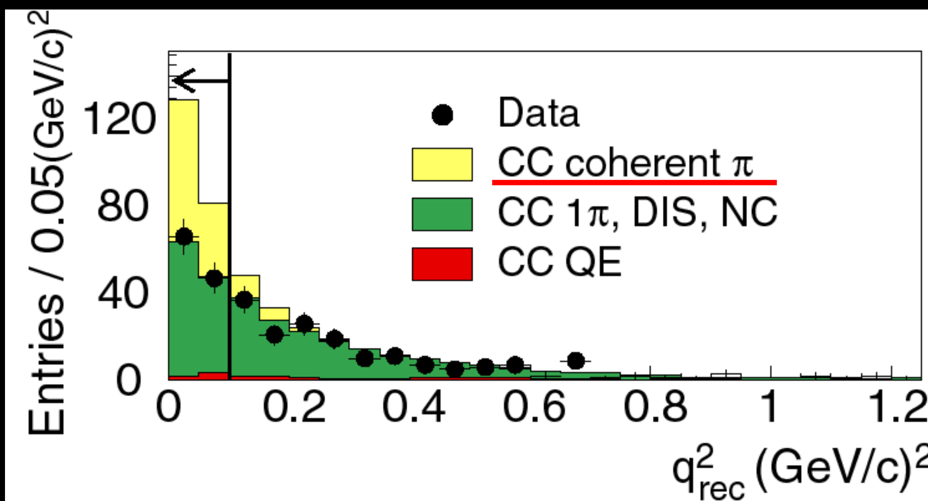
K2K observed a large suppression of CC pion coherent production

At <En>=1.3 GeV $\sigma(\text{CC-coherent})/\sigma(\text{CC}) < 0.6\ 10^{-2}$ at 90%CL

K2K Coll., PRL 95:252301 (2005)

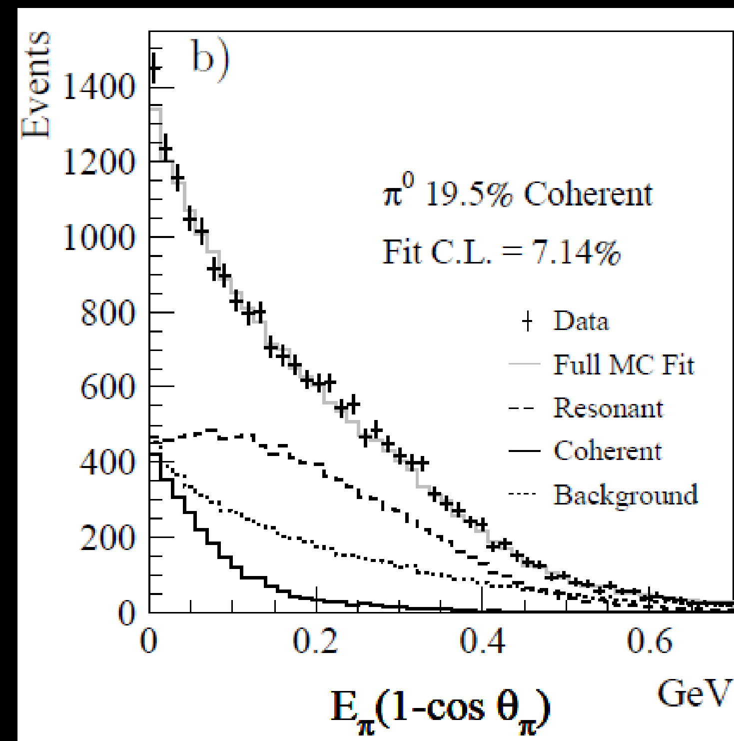
CC and NC coherent pion

CC coherent π+ (K2K)
Phys.Rev.Lett. 95,252301 (2005)



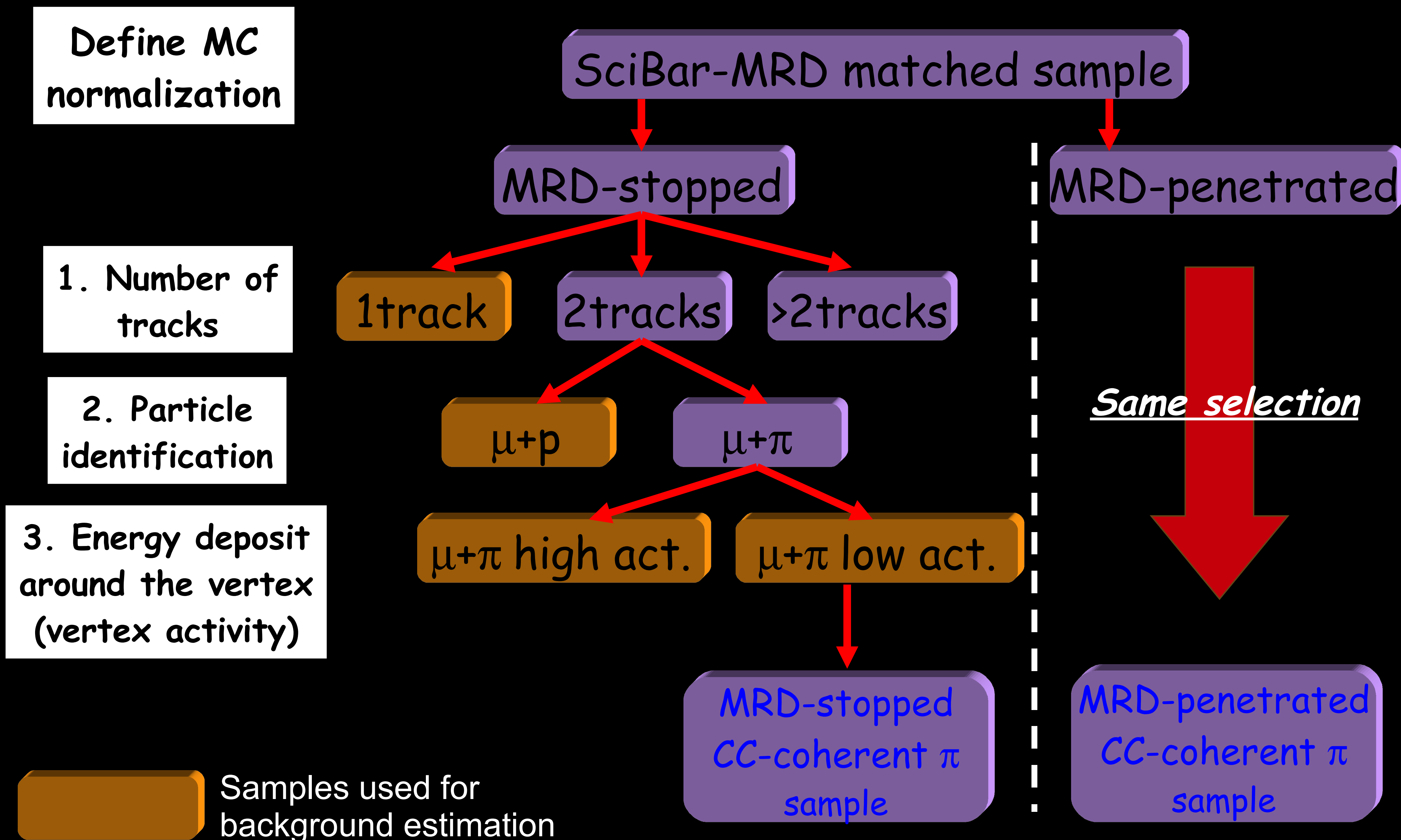
No evidence of CC coherent pion production at <Eν>=1.3 GeV
σ(CC coherent π)/σ(CC)<0.60×10^{-2} (90%CL)
(corresponding to 23% of the MC prediction)

NC coherent π° (MiniBooNE)
Phys.Lett. B664,41 (2008)



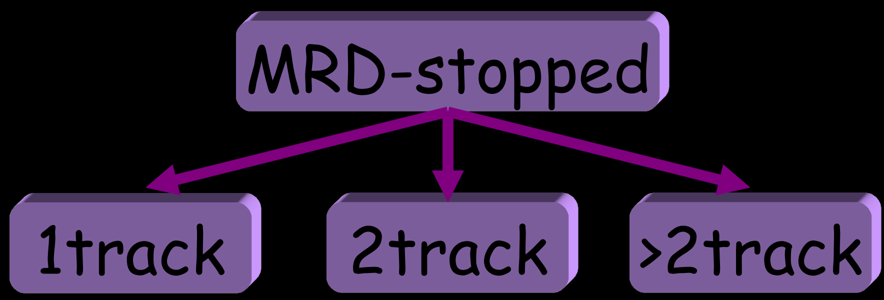
First observation of NC coherent pion production at Eν<2GeV
19.5% of π° coherent over π° all
(65% of the MC prediction)

CC coherent: event samples

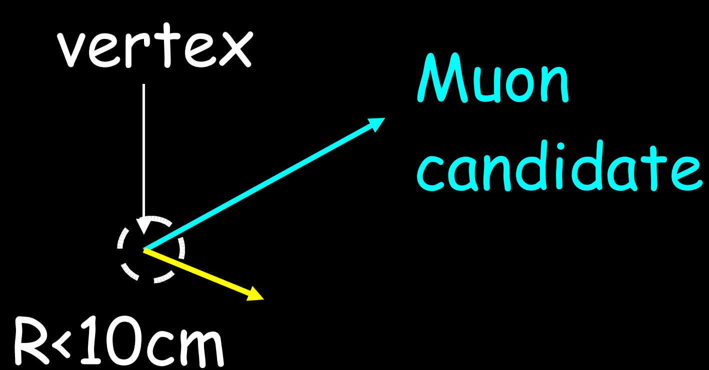


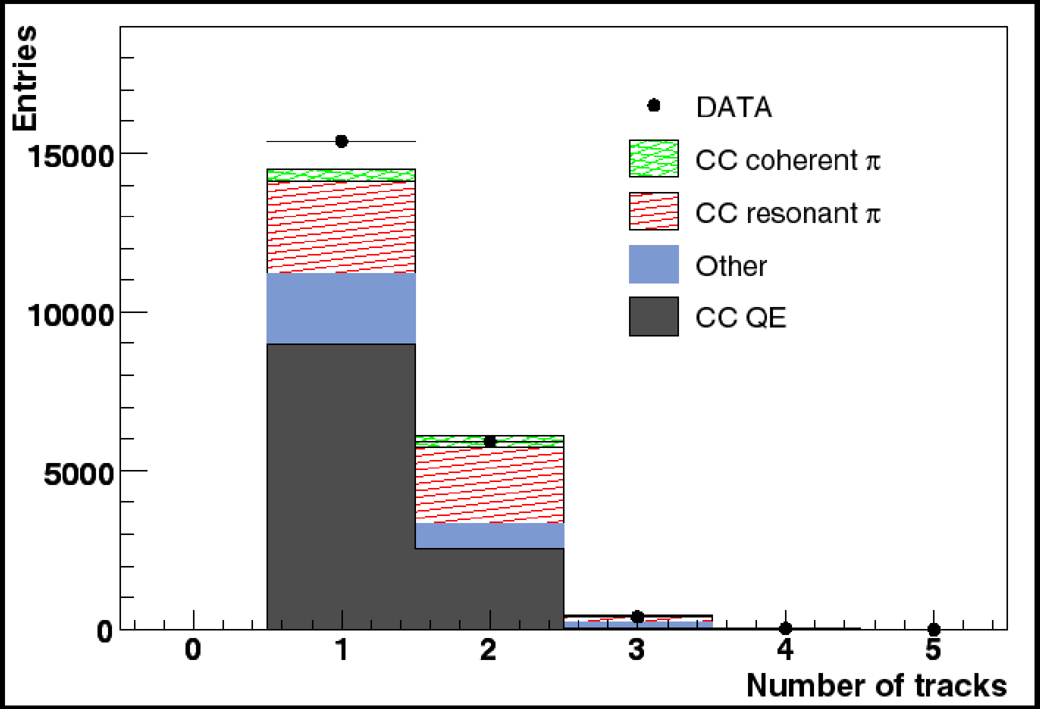
Samples used for background estimation

1. Number of tracks



Search for tracks close to the vertex (R<10cm)





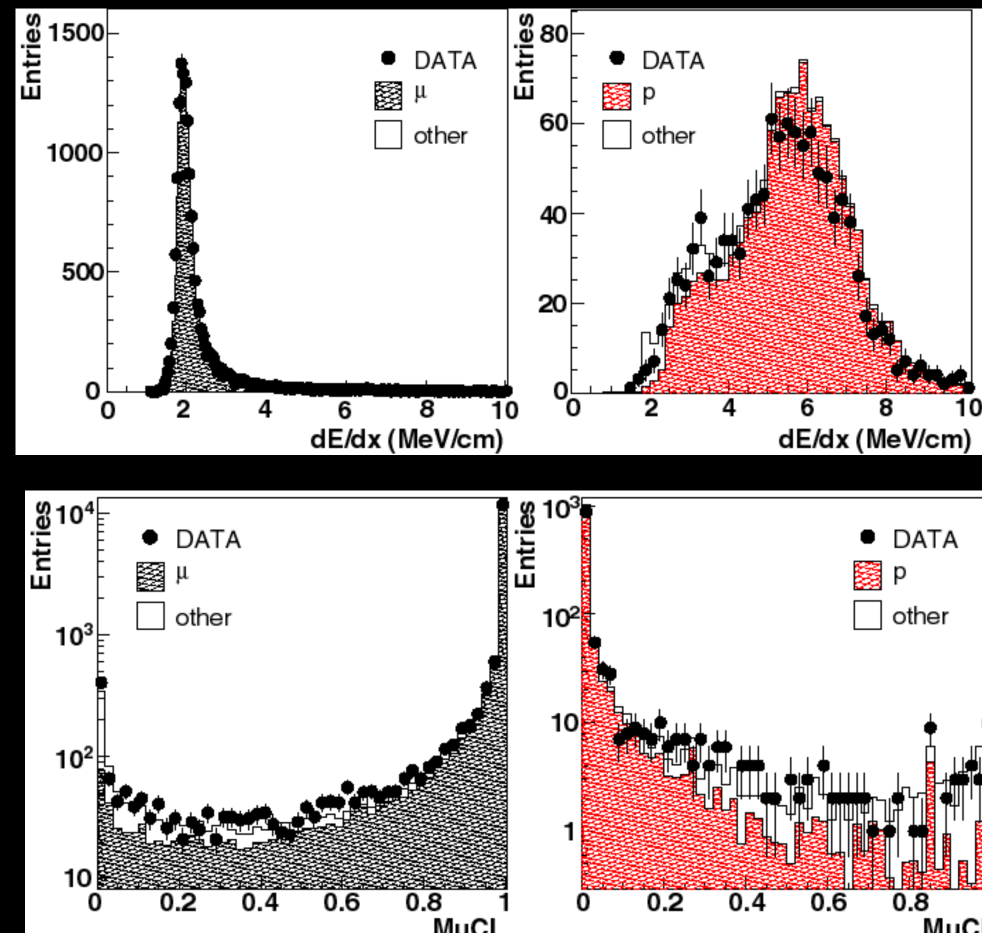
2. Particle ID

Particle ID using dE/dx in SciBar

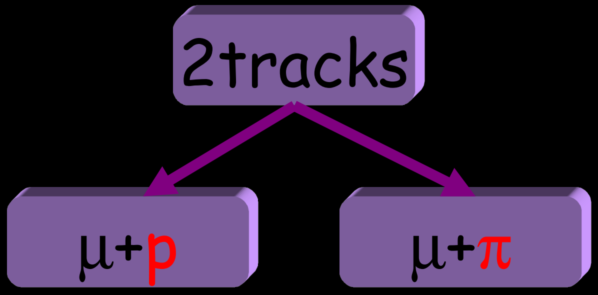
Muon Confidence Level (MuCL)

MuCL >0.05 → muon-like
<0.05 → proton-like

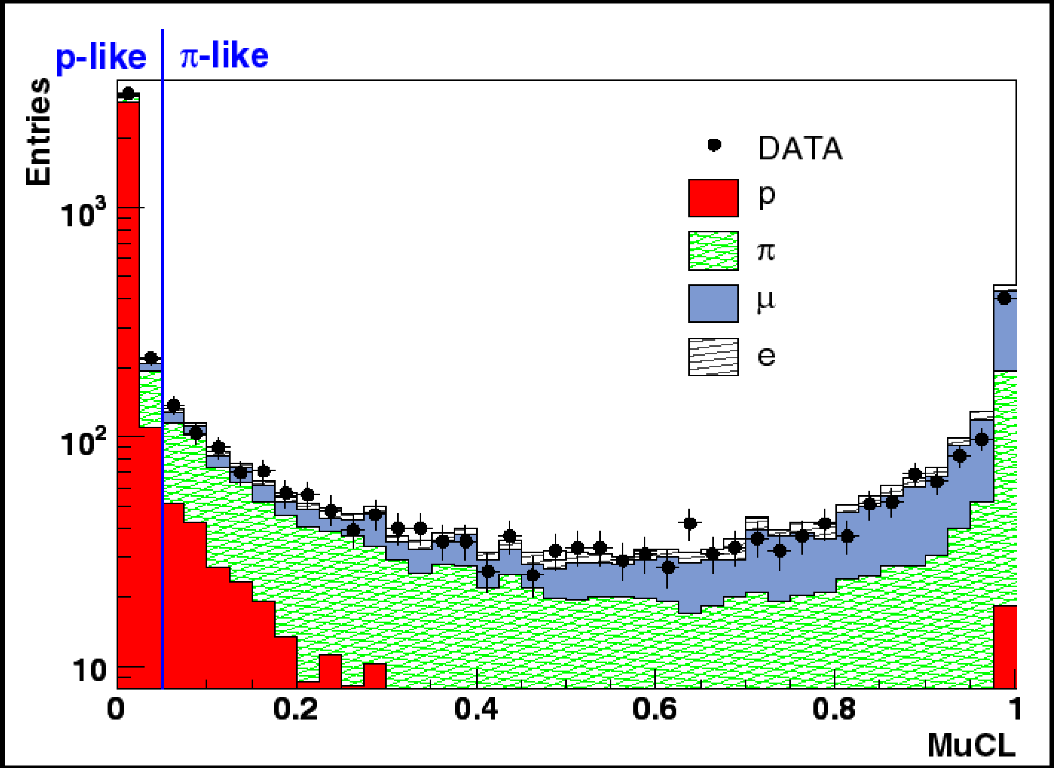
Mis-ID probability
Muon: 1.1%
Proton: 12%



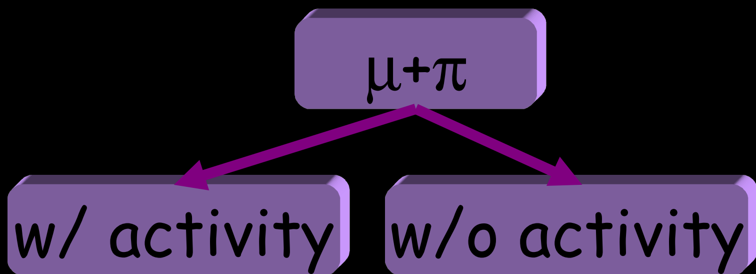
2. Particle ID (cont'd)



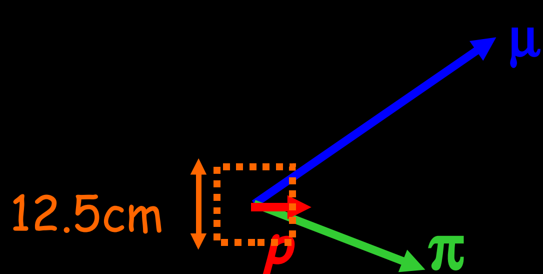
p/π separation with MuCL for 2nd track in 2-tracks events

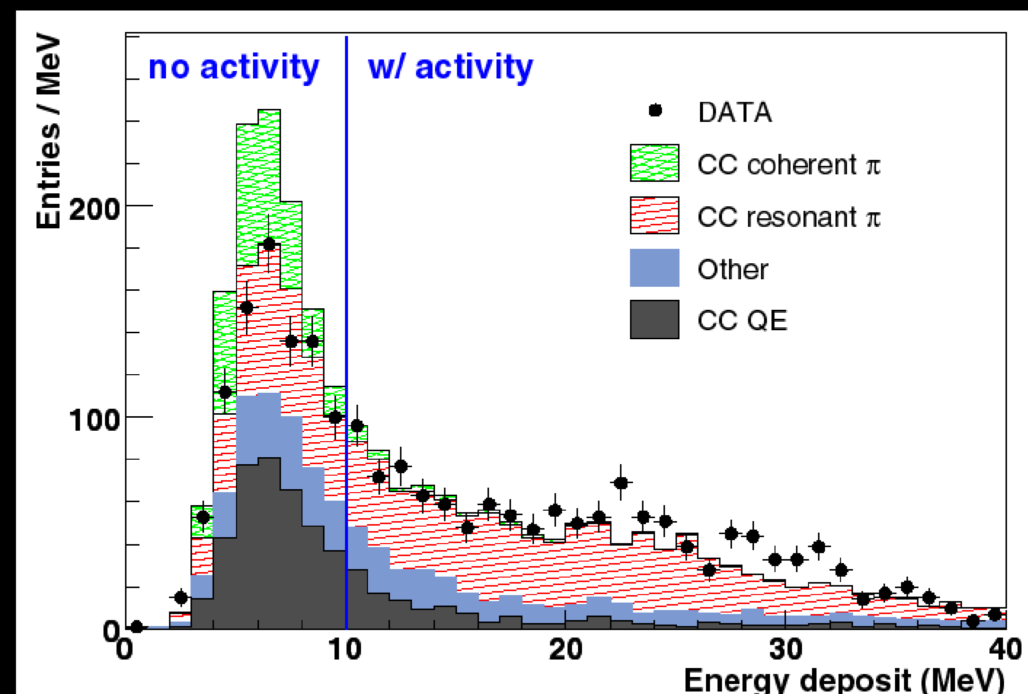


Vertex activity



Low energy protons are detected as a large energy deposition around the vertex



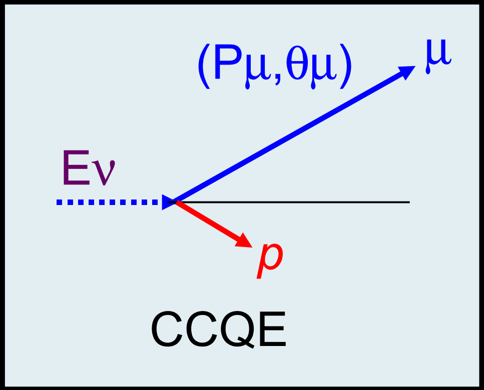


MC tuning

MC distributions of reconstructed Q^2 for different sub-samples are simultaneously fitted to data to constrain systematic uncertainties due to:

- detector response
- nuclear effects
- neutrino interaction models
- neutrino energy spectrum

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



$$E_\nu^{rec} = \frac{1}{2}\frac{(m_p^2 - m_\mu^2) - (m_n - V)^2 + 2E_\mu(m_n - V)}{(m_n - V) - E_\mu + p_\mu \cos\theta_\mu}$$

V=27 MeV nuclear potential

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

MC tuning parameters

R_{norm} : MRD stopped sample normalization
R_{res} : CC resonant pion cross section factor
R_{other} : Other nonQE (mainly DIS) cross section factor
$R_{2trk/1trk}$: Migration between 2track / 1track samples
$R_{p/\pi}$: Migration between μ+p / $\mu+\pi$ samples
R_{act} : Migration between low/high vertex activity samples
R_{pscale} : Muon momentum scale
Kappa : Pauli-suppression for CCQE $E_{lo} = \kappa(\sqrt{p_F^2 + m_p^2} - \omega + E_B)$

k>1, Elo lowest integration bound on initial nucleon energy

$$\chi^2 = \chi^2_{\text{dist}} + \chi^2_{\text{sys}}$$

$$\chi^2_{\text{dist}} = 2\sum_{i,\ j}\left(N^{\text{exp}}_{ij} - N^{\text{obs}}_{ij} + N^{\text{obs}}_{ij} \times \ln\frac{N^{\text{obs}}_{ij}}{N^{\text{exp}}_{ij}}\right)$$

$$\chi^2_{\text{sys}} = (\boldsymbol{P_{sys}} - \boldsymbol{P}_0)\boldsymbol{V}^{-1}(\boldsymbol{P_{sys}} - \boldsymbol{P}_0)$$

$$\boldsymbol{P_{sys}} = \begin{pmatrix} R_{\text{res}} \\ R_{\text{2trk/1trk}} \\ R_{p/\pi} \\ R_{\text{pscale}} \end{pmatrix}, \quad \boldsymbol{P}_0 = \begin{pmatrix} 1 \\ 1 \\ 1 \\ 1 \end{pmatrix}$$

Covariance matrix (R_{res}, $R_{2trk/1trk}$, $R_{p/\pi}$, R_{pscale})

$$\boldsymbol{V} = \begin{pmatrix} (0.20)^2 & -(0.09)^2 & +(0.10)^2 & 0 \\ -(0.09)^2 & (0.09)^2 & -(0.07)^2 & 0 \\ +(0.10)^2 & -(0.07)^2 & (0.15)^2 & 0 \\ 0 & 0 & 0 & (0.02)^2 \end{pmatrix}$$

Fitting parameters (cont'd)

1-track:

$$N^{\text{exp}}_{i,\ \text{1trk}} = R_{\text{norm}} \cdot \left[n^{\text{QE}}_{i,\text{1trk}} + R_{\text{res}} n^{\text{res}}_{i,\text{1trk}} + R_{\text{other}} n^{\text{other}}_{i,\text{1trk}} \right]$$

μ+p:

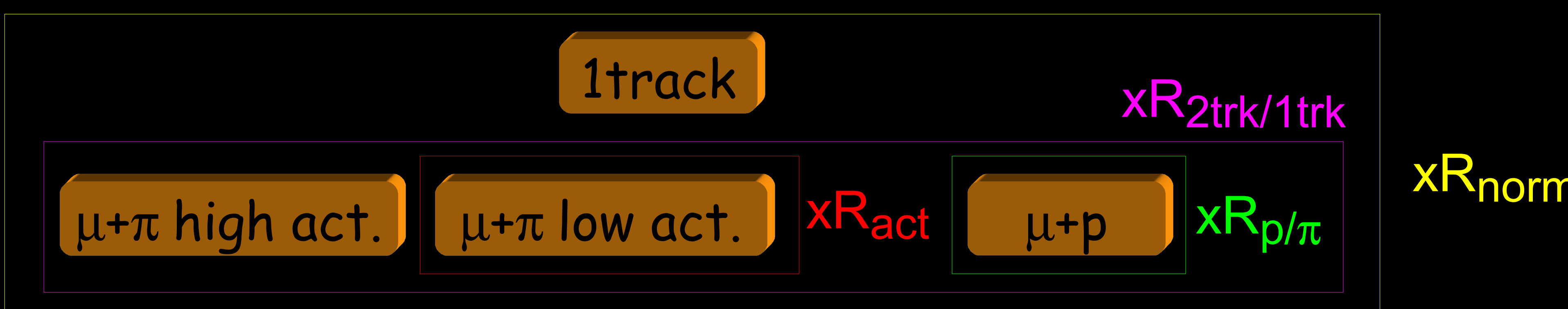
$$N^{\text{exp}}_{i,\ \mu p} = R_{\text{norm}} \cdot R_{\text{2trk/1trk}} \cdot R_{p/\pi} \cdot \left[n^{\text{QE}}_{i,\mu p} + R_{\text{res}} n^{\text{res}}_{i,\mu p} + R_{\text{other}} n^{\text{other}}_{i,\mu p} \right]$$

μ+π High activity:

$$N^{\text{exp}}_{i,\ \mu\pi\text{H}} = R_{\text{norm}} \cdot R_{\text{2trk/1trk}} \cdot \left[n^{\text{QE}}_{i,\mu\pi\text{H}} + R_{\text{res}} n^{\text{res}}_{i,\mu\pi\text{H}} + R_{\text{other}} n^{\text{other}}_{i,\mu\pi\text{H}} \right]$$

μ+π Low activity:

$$N^{\text{exp}}_{i,\ \mu\pi\text{L}} = R_{\text{norm}} \cdot R_{\text{2trk/1trk}} \cdot R_{\text{act}} \cdot \left[n^{\text{QE}}_{i,\mu\pi\text{L}} + R_{\text{res}} n^{\text{res}}_{i,\mu\pi\text{L}} + R_{\text{other}} n^{\text{other}}_{i,\mu\pi\text{L}} \right]$$



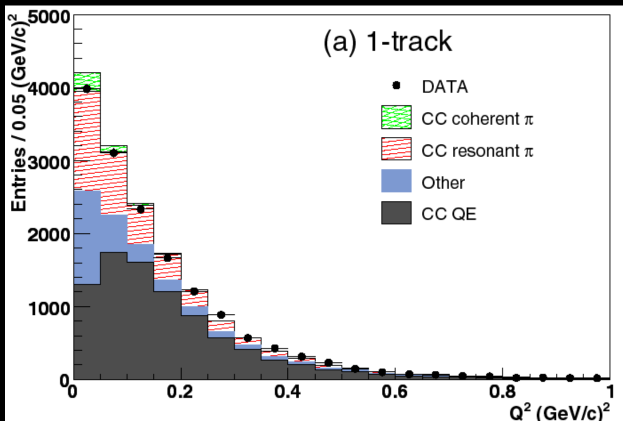
MC tuning fit result

Parameter	Value	Error
R_{norm}	1.103	0.029
$R_{2trk/1trk}$	0.865	0.035
$R_{p/\pi}$	0.899	0.038
R_{act}	0.983	0.055
R_{pscale}	1.033	0.002
R_{res}	1.211	0.133
R_{other}	1.270	0.148

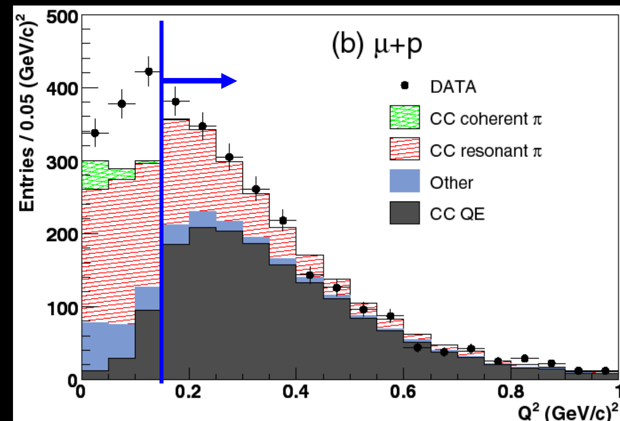
Parameter Value Error

Reconstructed Q^2 distributions after fit

1-track

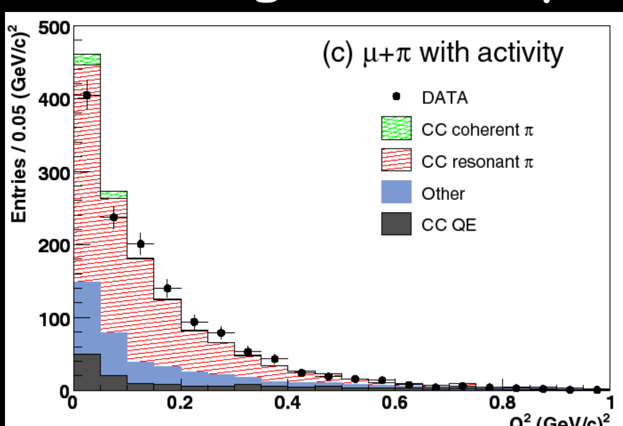


μ+p

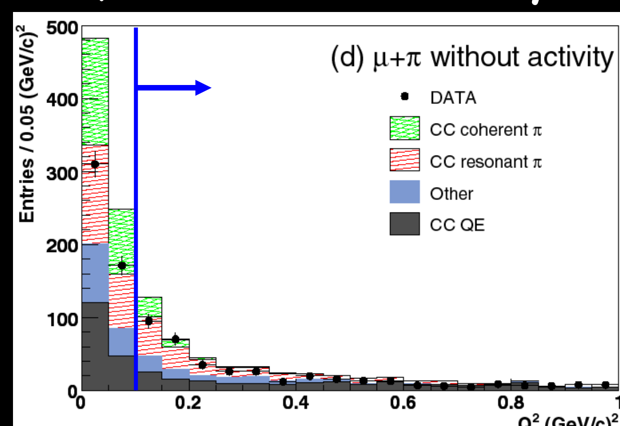


low Q^2 region in μ+p events is excluded from fitting

μ+π high activity



μ+π low activity



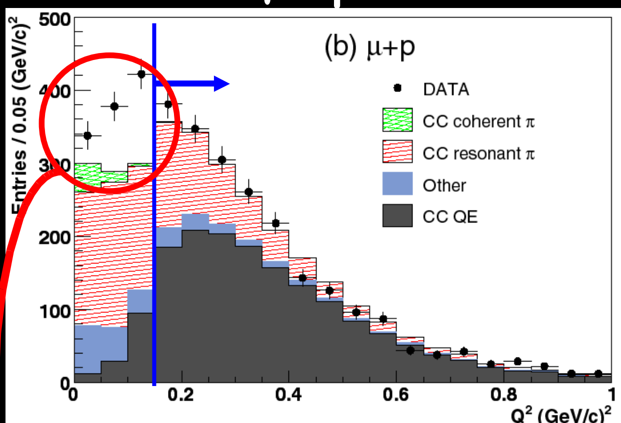
CC coherent π signal region is excluded from fitting

Before fit : χ_2/ndf = 473/75 = 6.31

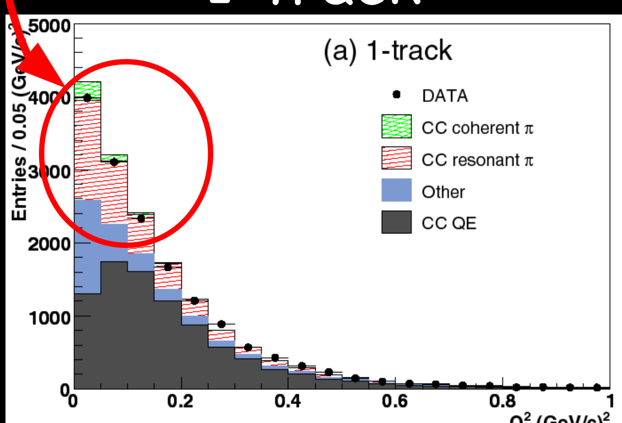
After fit : χ_2/ndf = 117/67 = 1.75

Data excess in μ+p sample

μ+p



1-track

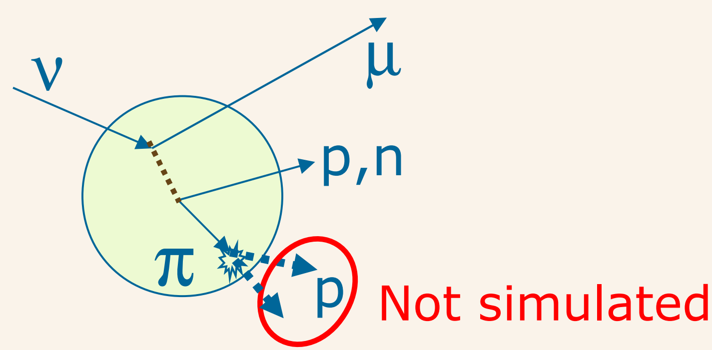


Features of excess events

- proton candidate goes at large angle
- additional activity around the vertex

Candidate

CC resonant pion events in which the pion is absorbed in the target nucleus



In MC such events are reconstructed As 1-track events

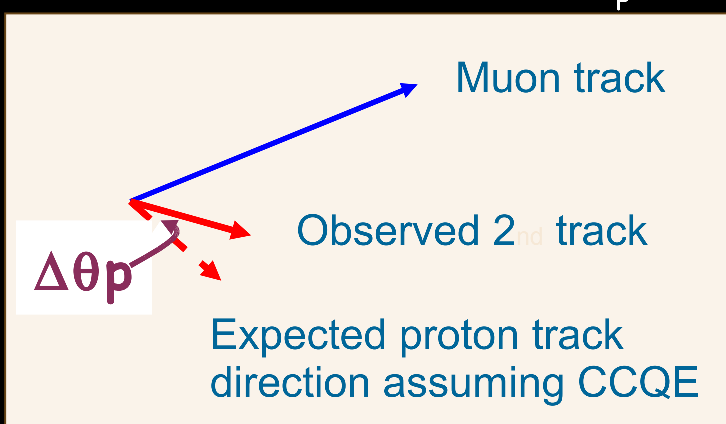
It is not expected to affect CC coherent pion measurement

Coherent pion kinematical cuts

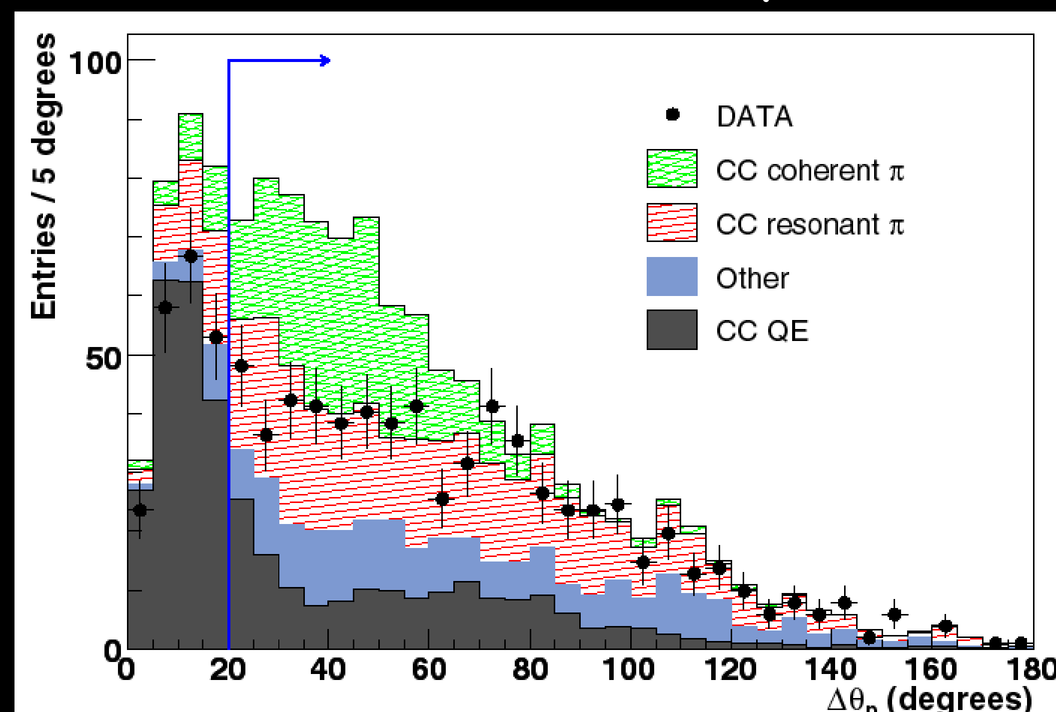
1. CC QE rejection: $\Delta\theta_p > 20°$

2. CC resonant π rejection: $\theta_\pi < 90°$

kinematical variable $\Delta\theta_p$



μ+π low activity



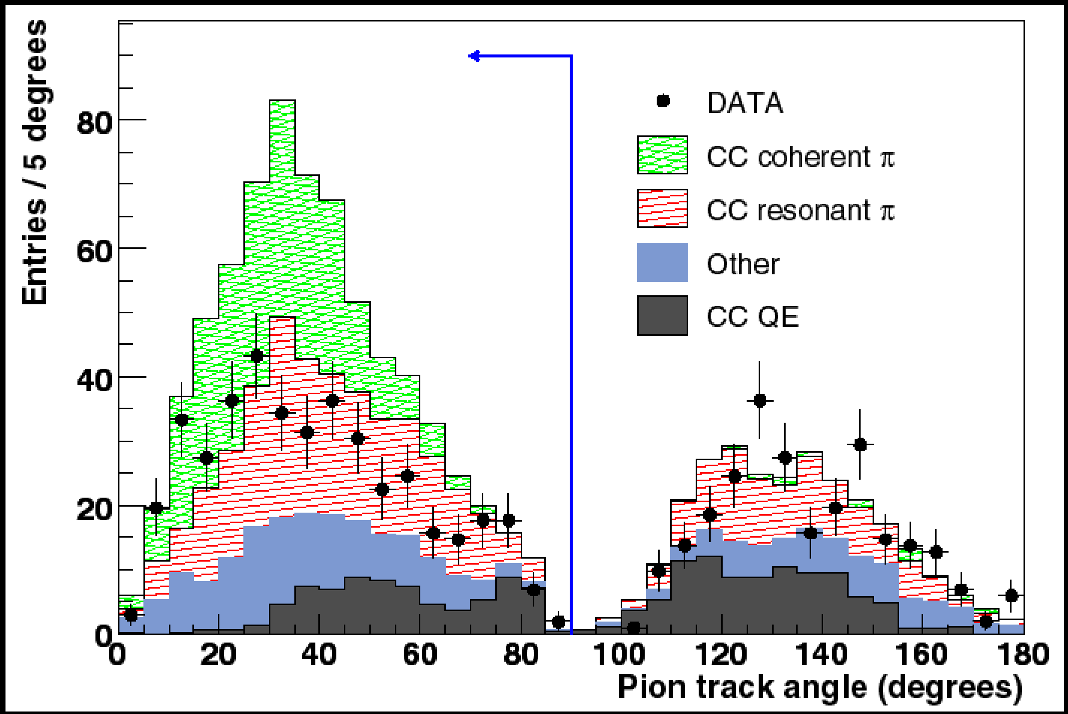
Coherent pion kinematical cuts

1. CC QE rejection: $\Delta\theta_p > 20°$

2. CC resonant π rejection: $\theta_\pi < 90°$

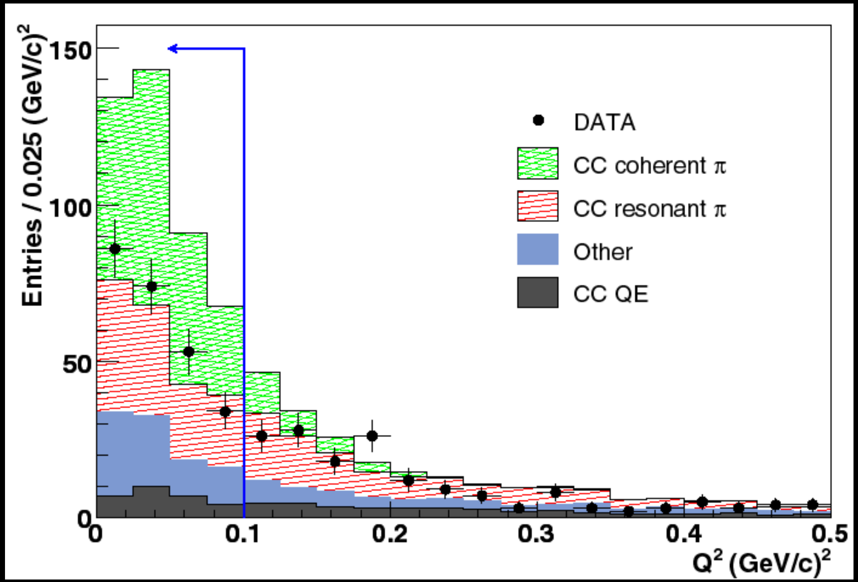
Event with a forward-going pion candidate are selected

$\mu+\pi$ low activity



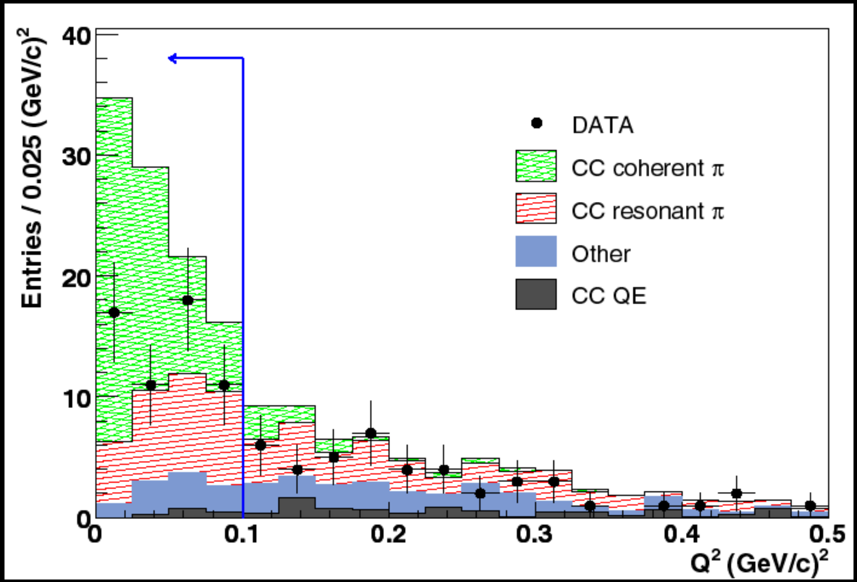
CC coherent pion sample $Q^2<0.1$ (GeV/c)^2

MRD stopped sample
<Eν>= 1.1 GeV



247events selected
BG expectation: 228 ± 12 events

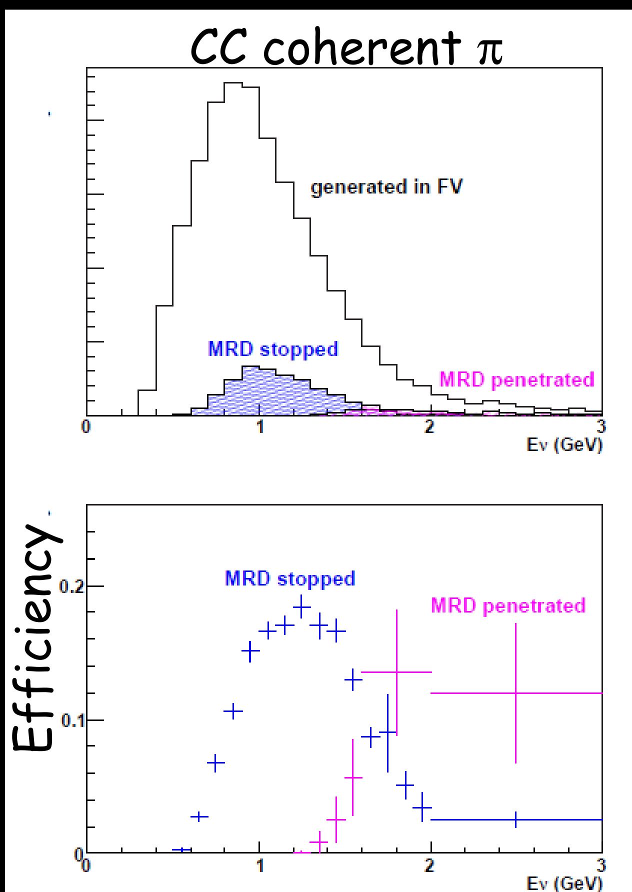
MRD penetrated sample
<Eν>= 2.2 GeV

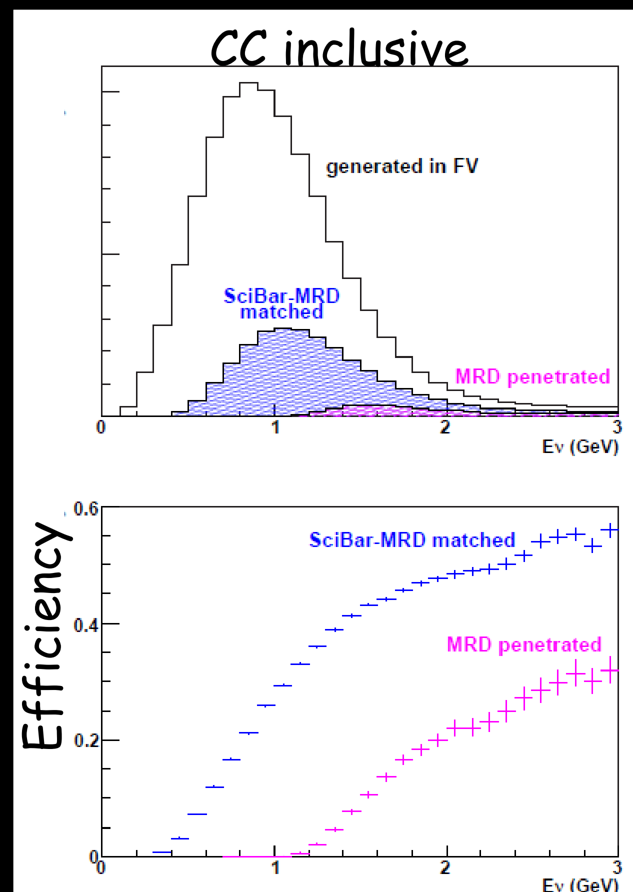


57events selected
BG expectation 40 ± 2.2 events

σ(CC coherent π)/σ(CC) cross section ratio

Measure σ(CC coherent π)/σ(CC) cross section ratio in order to reduce sytematic from neutrino flux uncertainty





CC inclusive samples are chosen so that they cover similar neutrino energy range as coherent π samples

Results

MRD stopped sample $\langle E\nu\rangle$= 1.1 GeV	$\sigma(\text{CC coherent } \pi)/\sigma(\text{CC})$ $= (0.16 \pm 0.17(stat)^{+0.30}_{-0.27}(sys)) \times 10^{-2}$
MRD penetrated sample $\langle E\nu\rangle$= 2.2 GeV	$\sigma(\text{CC coherent } \pi)/\sigma(\text{CC})$ $= (0.68 \pm 0.32(stat)^{+0.39}_{-0.25}(sys)) \times 10^{-2}$

No evidence of CC coherent pion production is found

90% CL upper limit

$\sigma(\text{CC coherent } \pi)/\sigma(\text{CC}) < 0.67\times10^{-2}$ for $\langle E\nu\rangle$=1.1 GeV

$< 1.36\times10^{-2}$ $\langle E\nu\rangle$=2.2 GeV

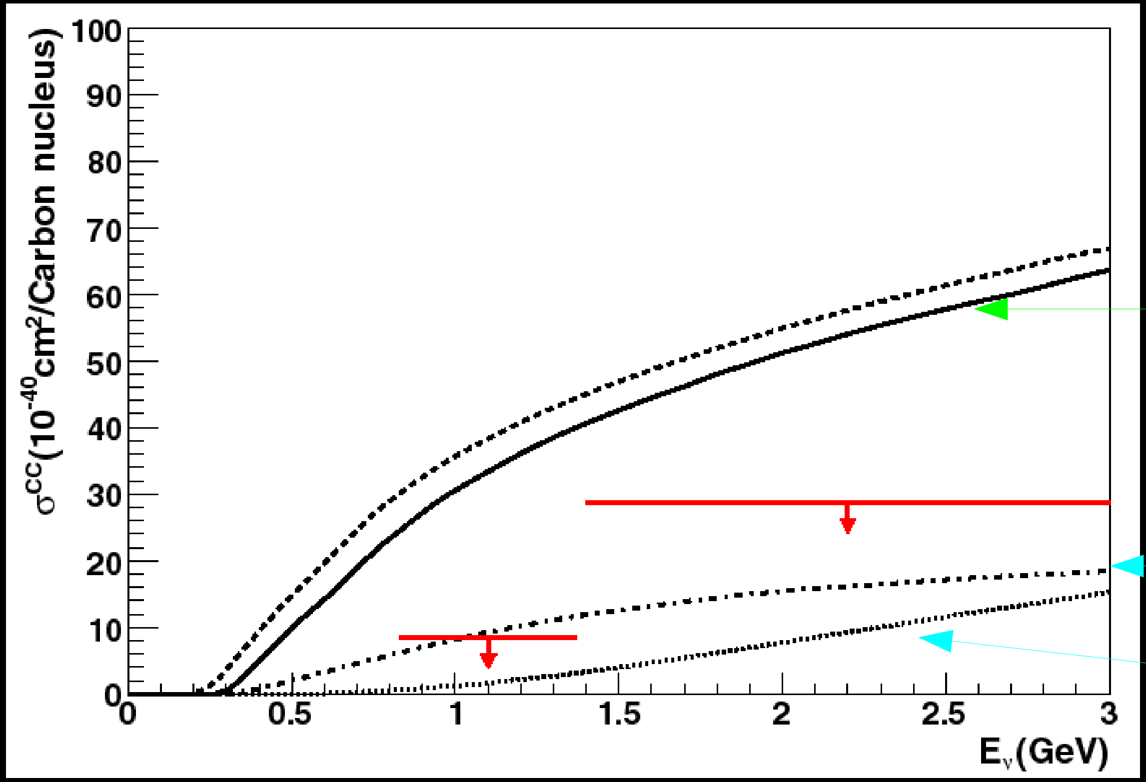
arXiv:0811.0369, Phys.Rev. D78:112004 (2008)

consistent with K2K result

$\sigma(\text{CC coherent } \pi)/\sigma(\text{CC}) < 0.60\times10^{-2}$ for $\langle E\nu\rangle$=1.3 GeV

Results

Upper limits on σ(CC coherent π)/σ(CC) cross section ratios are converted to upper limits on absolute cross sections by using σ(CC) predicted by MC simulation



Rein-Sehgal with lepton mass correction (Our default)

Singh et al.

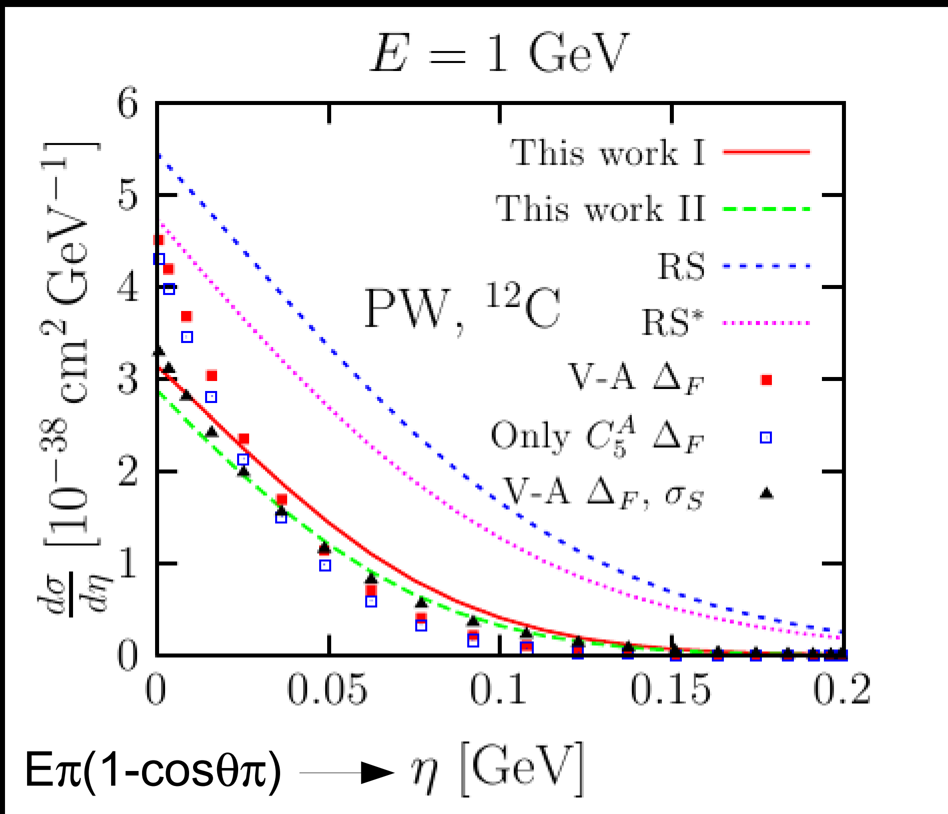
Alvarez-Ruso et al.

Systematic errors

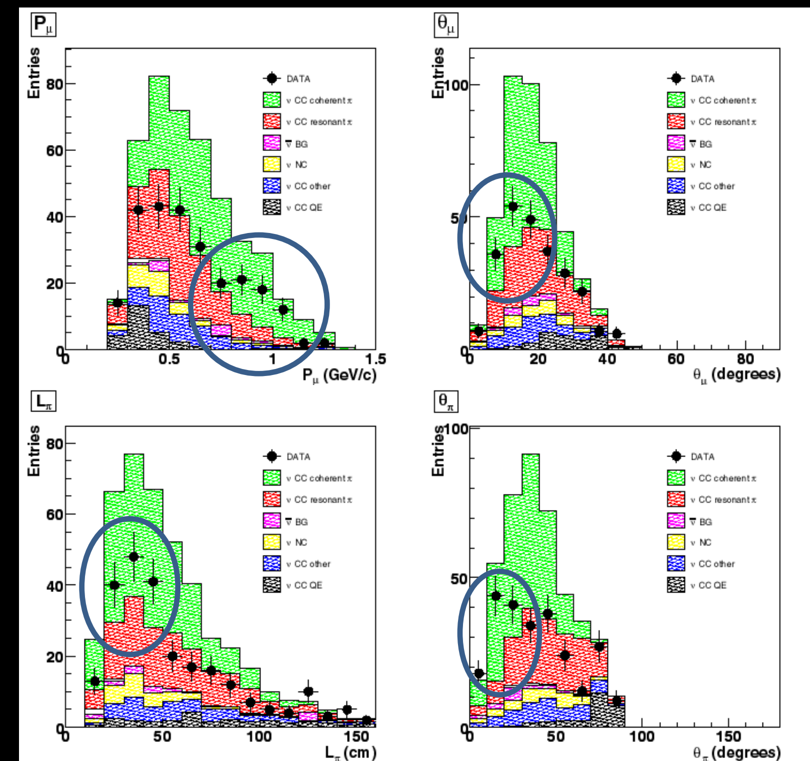
	MRD stopped Error ($\times 10^{-2}$)	MRD penetrated Error ($\times 10^{-2}$)
Detector response	+0.10 / -0.18	+0.18 / -0.18
Nuclear effect	+0.20 / -0.07	+0.19 / -0.09
Neutrino interaction model	+0.17 / -0.04	+0.08 / -0.04
Neutrino beam	+0.07 / -0.11	+0.27 / -0.13
Event selection	+0.07 / -0.14	+0.06 / -0.05
	MRD stopped Error ($\times 10^{-2}$)	MRD penetrated Error ($\times 10^{-2}$)

Outlook for CC coherent

E.Hernandez et al, arXiv:0903.5285



Preliminary K.Hiraide, PhD Thesis



Our data and recent theoretical works suggest kinematics of coherent pion different from Rein-Seghal: pion less energetic and more peaked forward.

Same effect is observed in a preliminary study of coherent production in our anti-neutrino data.

Implications for CCπ coherent (SciBooNE) vs NCπ coherent (MiniBooNE) ?

Conclusions & Outlook

SciBooNE data taking finished successfully

First result published (Phys.Rev. D78:112004, 2008)

- no evidence for coherent pion production in neutrino CC interactions
- coherent pion kinematic different from existing models ?

Many cross-section measurements on going

- CC-QE, CC-1π, NC-1π, NC-elastic

Neutrino flux measurement (compare with MiniBooNE)

- absolute cross-section measurements
- flux prediction for MiniBooNE (a.k.a. joint oscillation analysis)

Anti-neutrino cross-sections also coming soon