SciBooNE Experiment

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Columbia University

JSPS Research Fellow

Mar 19, 2008 Seminar at Imperial College London

Formal Friday (Wednesday)

SciBooNE tradition

Outline

- What's SciBooNE?
- Introduction
- SciBooNE Experiment
- Timeline & Current Status
- Summary

What's SciBooNE?

- Neutrino experiment at Fermilab (E954)
- Precision measurement of ν and $\bar{\nu}$-nucleus cross section around 1GeV.
  - Important for T2K and other oscillation experiment.

SciBooNE

SciBooNE Collaboration

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

5 countries 17 institutions

Spokespeople:
M.O. Wascko (Imperial), T. Nakaya (Kyoto)

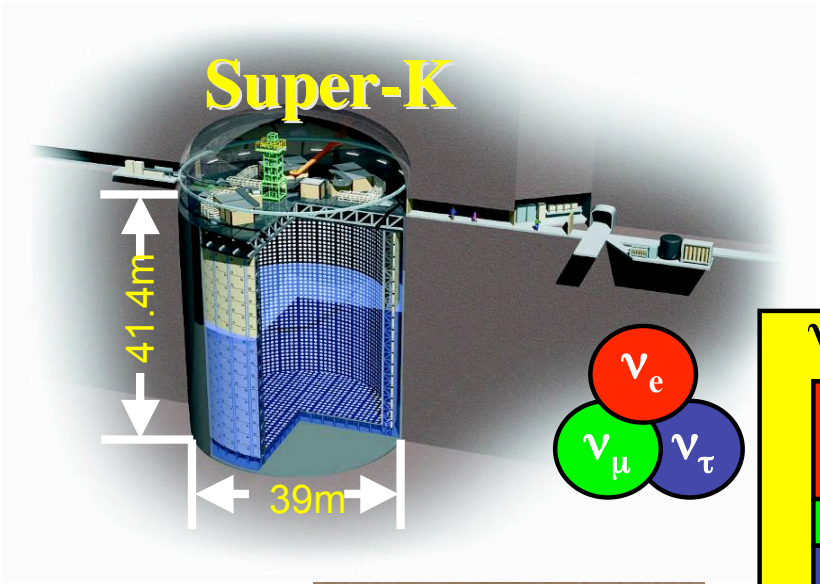
SciBooNE on the front line…

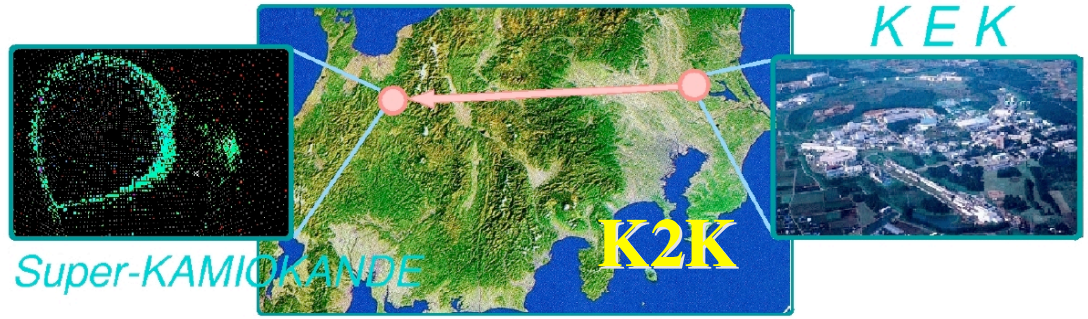
Young experiment!

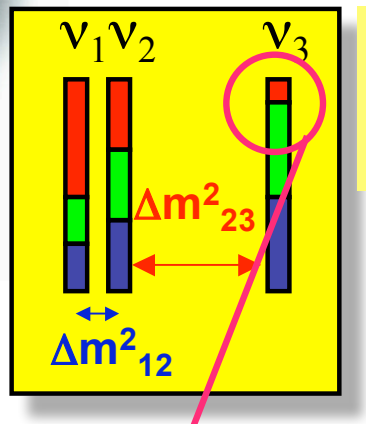
SciBooNE social club @Fermilab

Introduction

Neutrino Oscillations 1998~

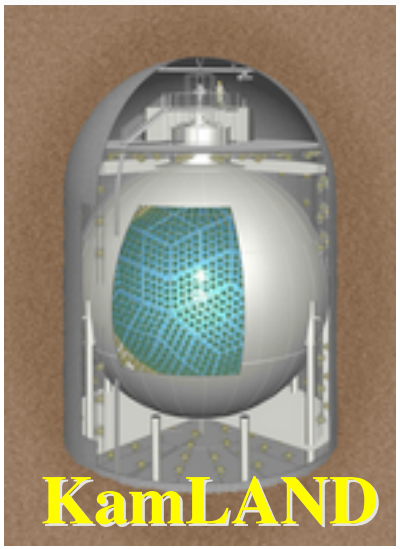


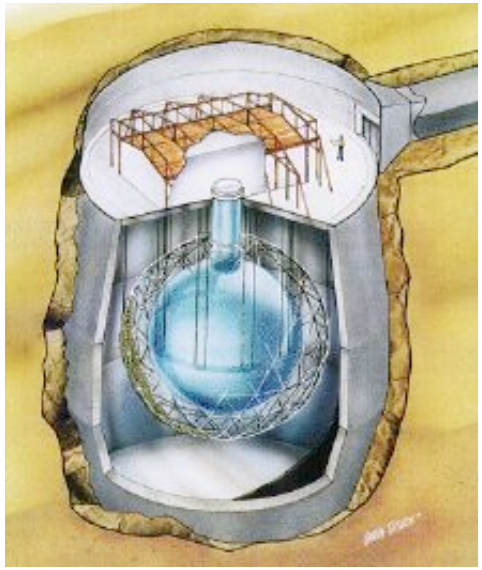


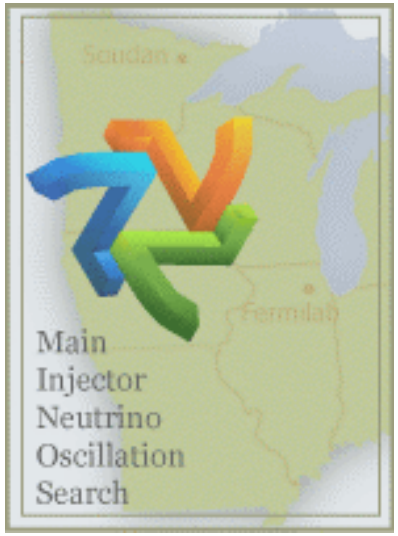


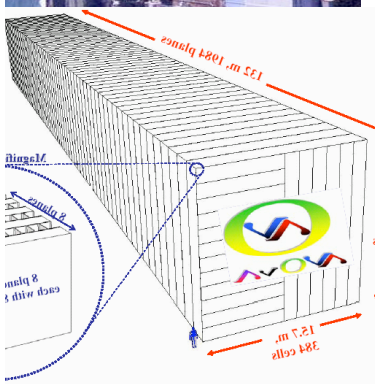
Neutrino masses (Δm_{12}^2, Δm_{23}^2)
Mixing Angles (θ_{12}, θ_{23})

$\theta_{13} \rightarrow \delta$

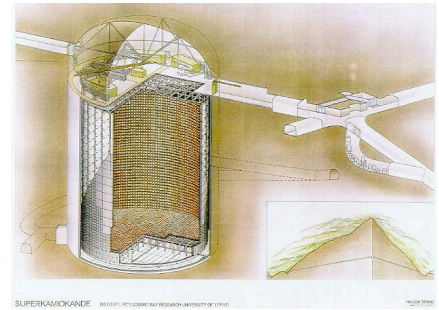








Next step…



ν_e ν_μ ν_τ

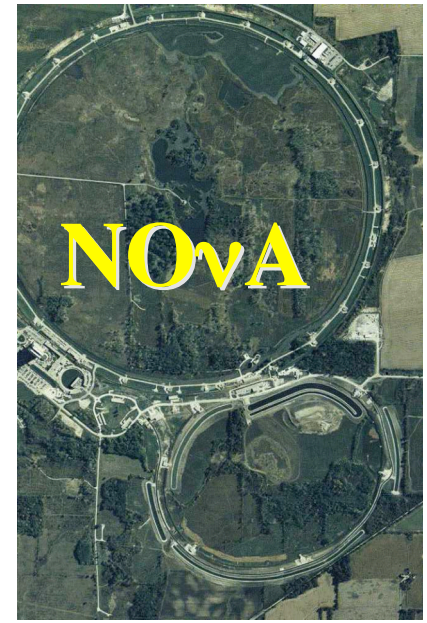
$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = U_{MNS} V_M^{CP} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

$$c_{ij} = \cos\theta_{ij}$$
$$s_{ij} = \sin\theta_{ij}$$

ν_1 ν_2 ν_3

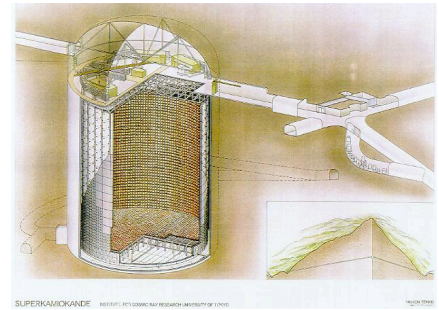
$$U_{MNS} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \times \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{-i\delta} & 0 & c_{13} \end{pmatrix} \times \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

atmospheric **Cross Mixing** solar



- Discover the last oscillation channel
  - θ_{13}
- CP violation in the lepton sector $(\nu,\bar{\nu})$
  - δ
- Mass hierarchy
  - **The sign of Δm_{23}^2**
- Test of the standard ν oscillation scenario (U_{MNS})
  - Precise measurements of ν oscillations ($\pm\Delta m_{23}^2$, θ_{23})

Next step…



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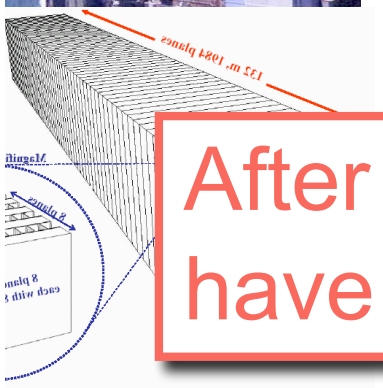
$$c_{ij} = \cos\theta_{ij}$$
$$s_{ij} = \sin\theta_{ij}$$

ν_1 ν_2 ν_3

$$\begin{pmatrix} 1 & 0 & 0 \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \end{pmatrix}$$



After the discovery, ν oscillation studies have come to a parameter measurement

- Discover the last oscillation channel
  - θ_{13}
- CP violation in the lepton sector $(\nu,\bar{\nu})$
  - δ
- Mass hierarchy
  - **The sign of Δm_{23}^2**
- Test of the standard ν oscillation scenario (U_{MNS})
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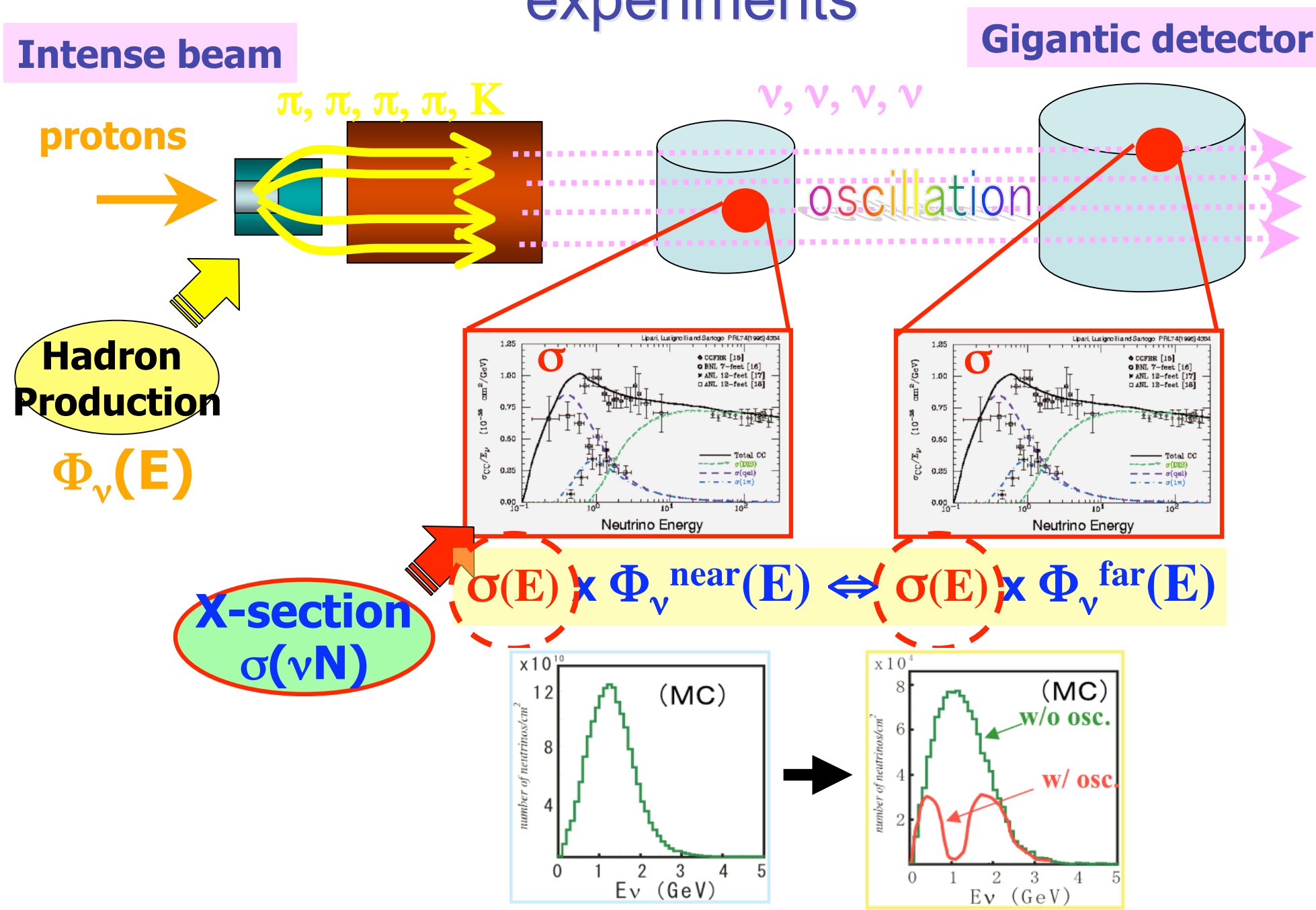
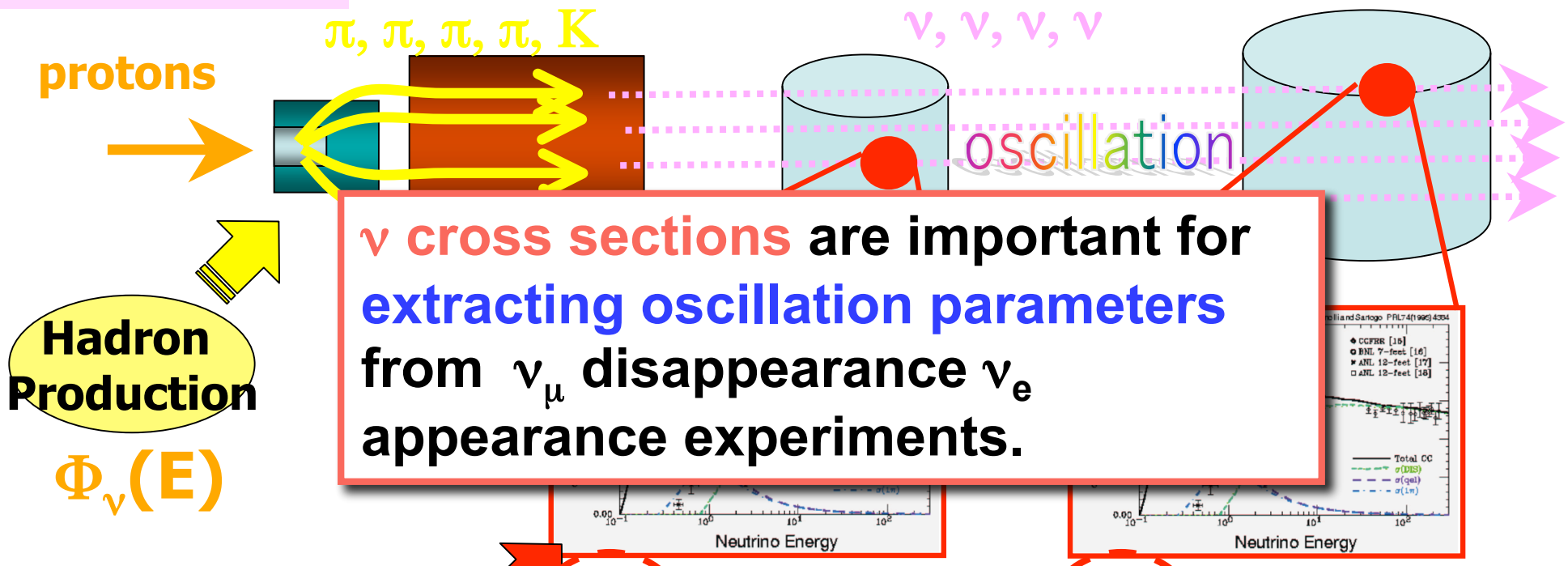
Strategy of accelerator ν oscillation experiments



Strategy of accelerator ν oscillation experiments

Intense beam

Gigantic detector



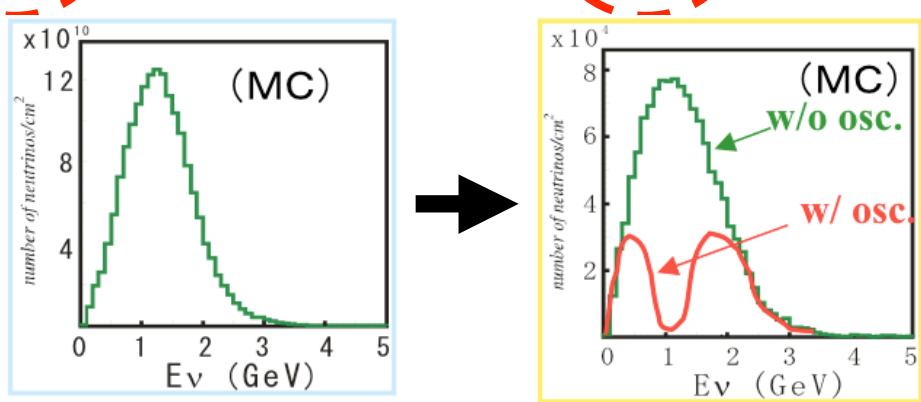
Hadron Production

$\Phi_\nu(E)$

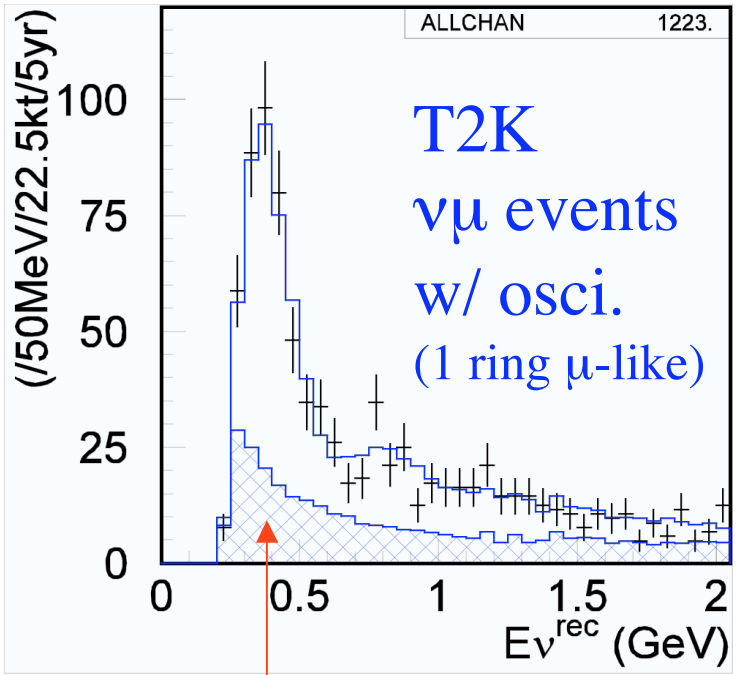
ν cross sections are important for extracting oscillation parameters from ν_μ disappearance ν_e appearance experiments.

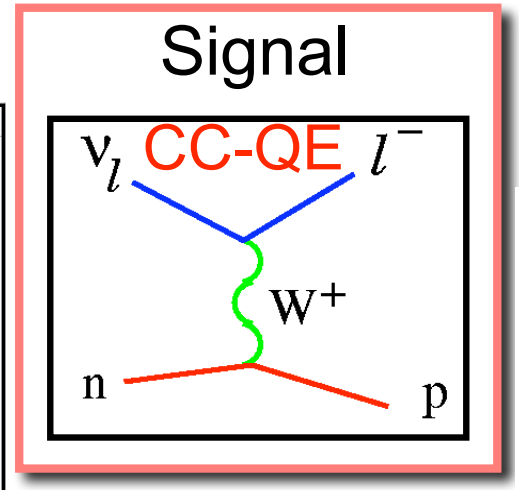
X-section σ(νN)

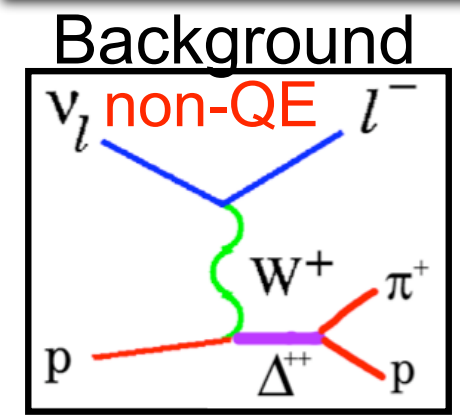
$$\sigma(E) \times \Phi_\nu^{near}(E) \Leftrightarrow \sigma(E) \times \Phi_\nu^{far}(E)$$



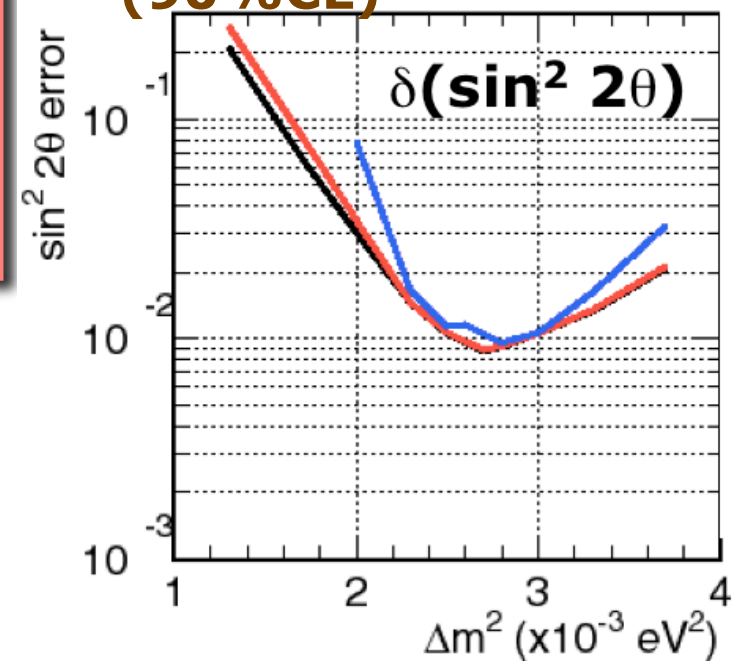
Impact of ν cross section







ν_μ disappearance measurement error (90%CL)



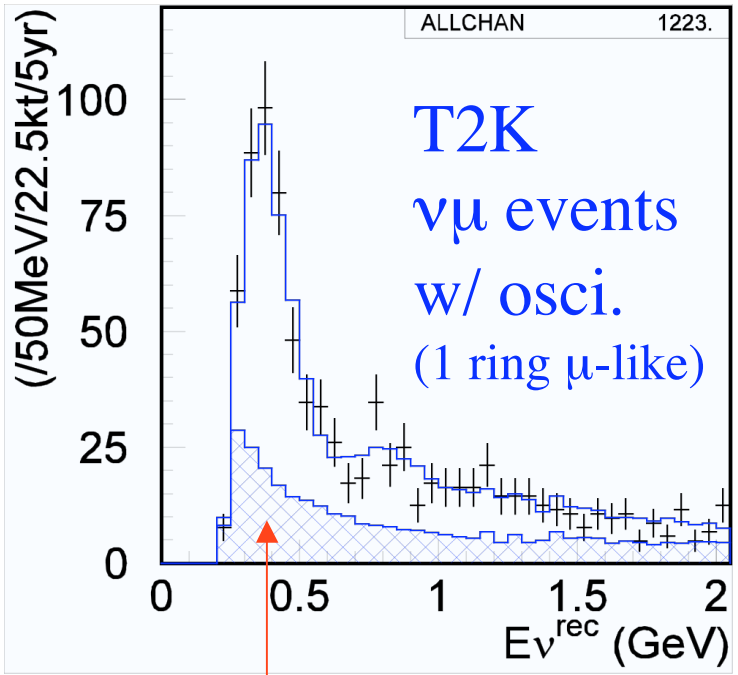
— stat. only
— δ(non-QE/QE)= 5%
— δ(non-QE/QE)=20%

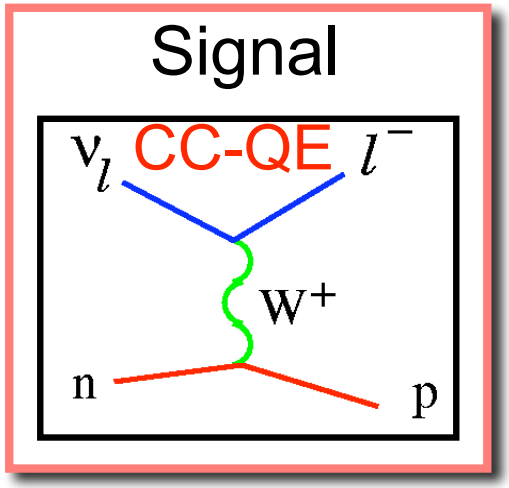
–Signal: **CC-QE**
(ν+n→μ+p; Energy Reconstruction from μ kin.)
–Background: **non-QE;** Mainly **CC-1π⁺**
ν+N→μ+π+N')

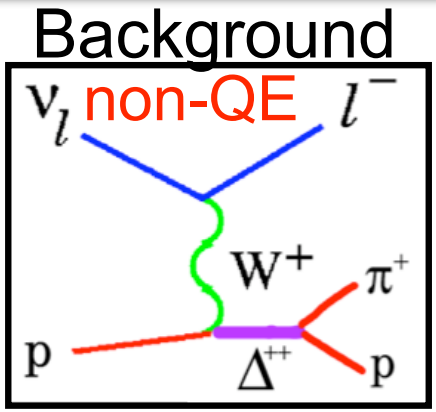
ν oscillation measurement requires precise knowledge on background.

T2K requires 5% level knowledge on nonQE/QE

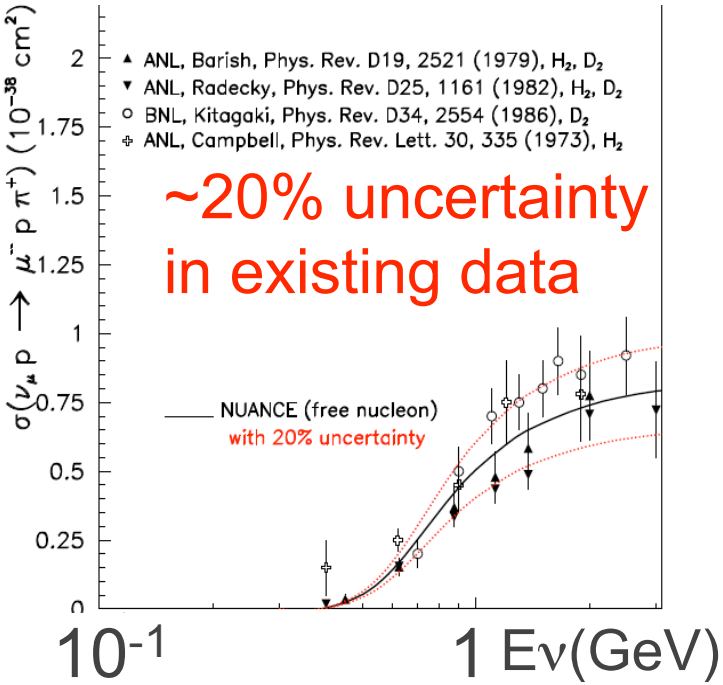
Impact of ν cross section







CC-1π+ cross section



–Signal: **CC-QE**
(ν+n→μ+p; Energy Reconstruction from μ kin.)

–Background: **non-QE;** Mainly **CC-1π+**
ν+N→μ+π+N')

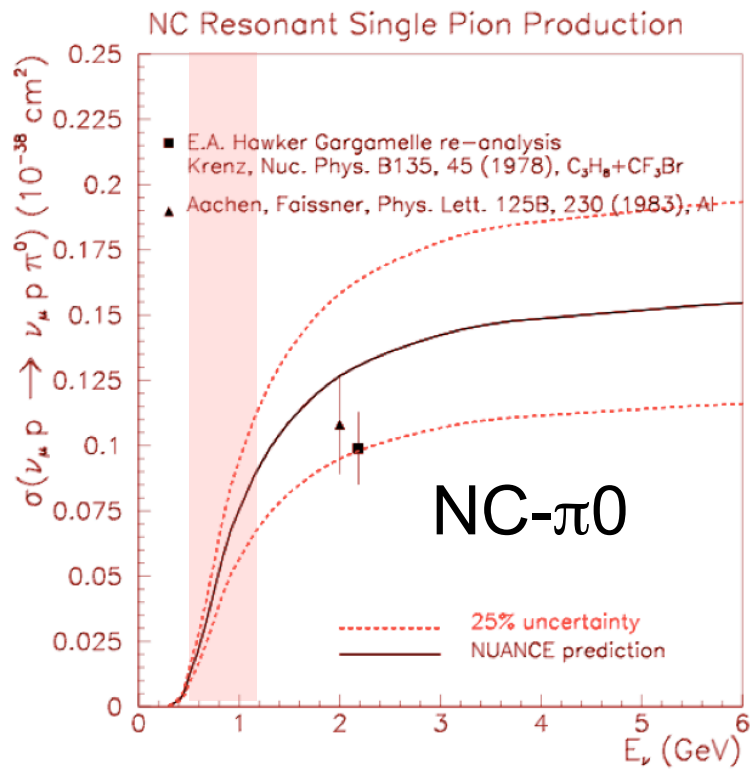
ν oscillation measurement requires precise knowledge on background.

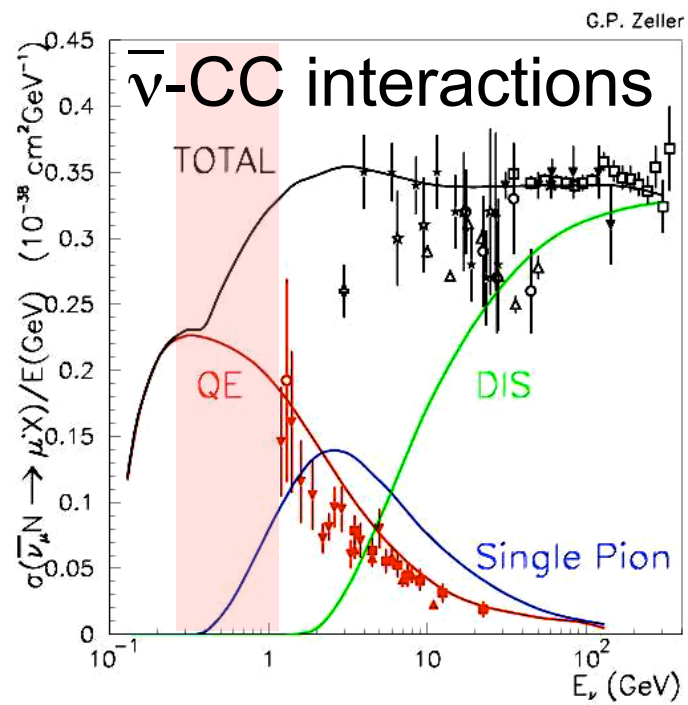
Need new measurement of non-QE cross sections

Other $\nu/\bar{\nu}$ interactions

- Neutral current π^0 production (ν+N→ ν+π^0+N')
  - ← Background for ν_e appearance search

- Anti-neutrino interactions
  - No measurement below 1GeV
  - ← Important for $\bar{\nu}$ oscillation study (CPV) in T2K-II

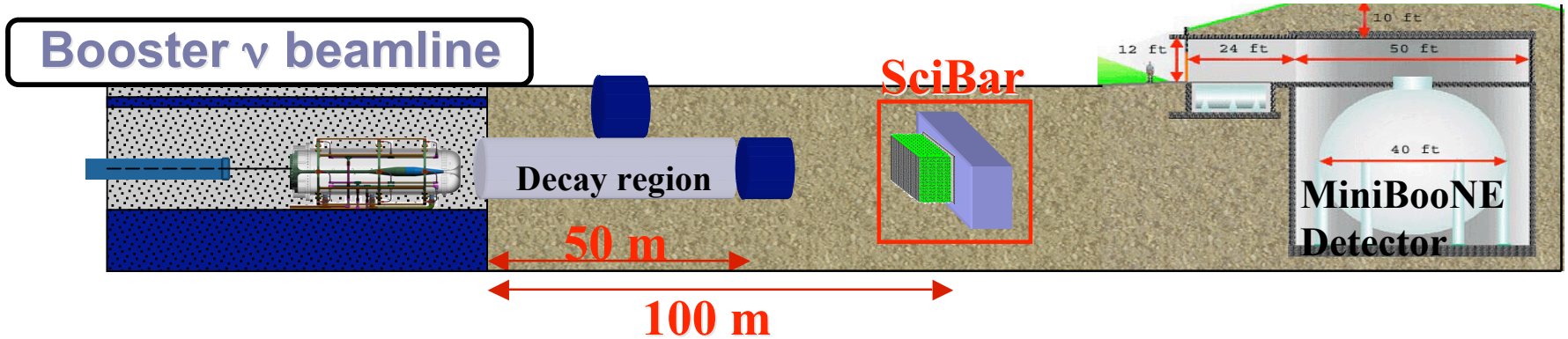




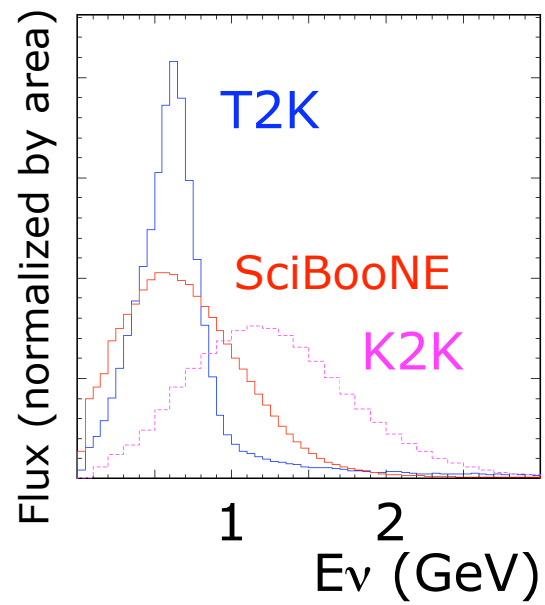
SciBooNE Experiment

SciBooNE Experiment

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

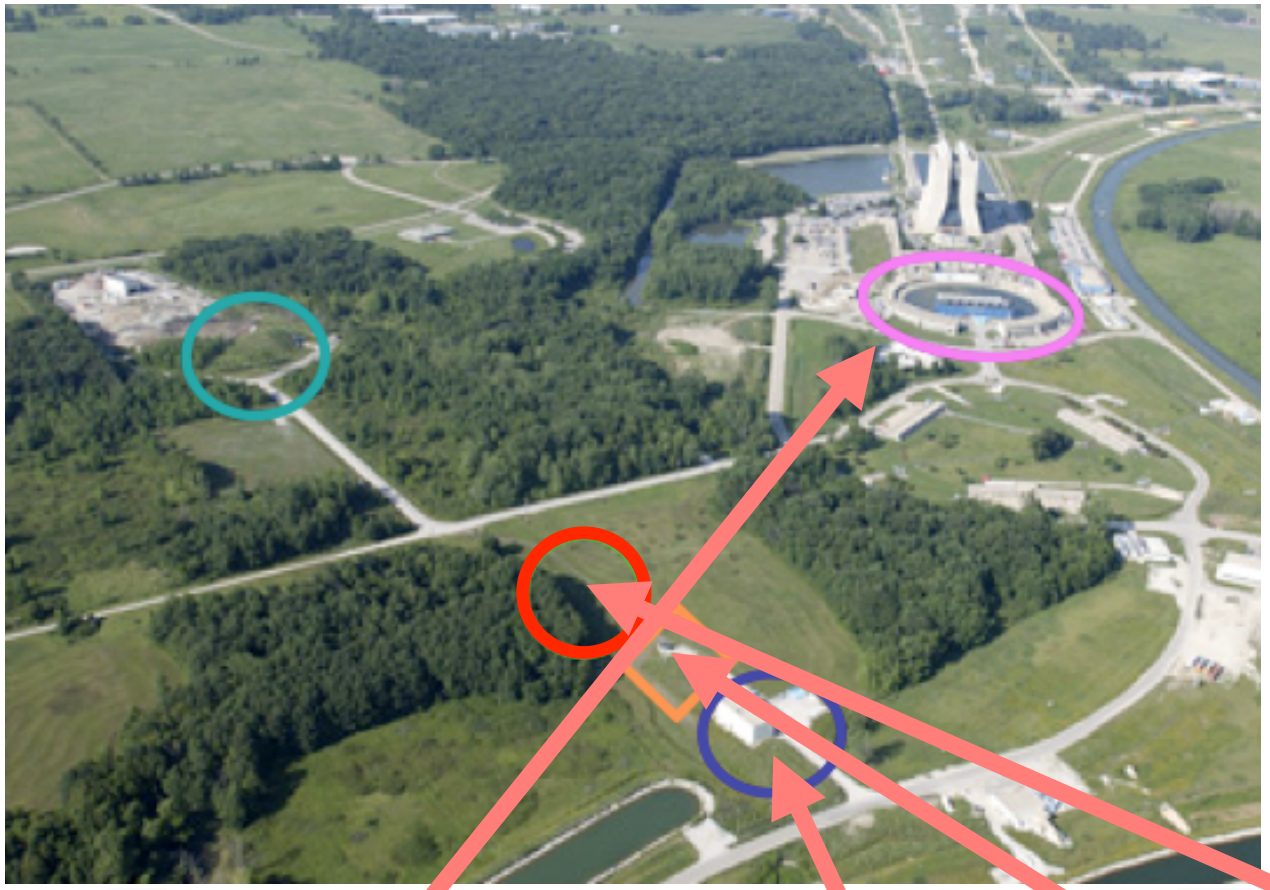


- Precision measurement of ν & ν-bar cross sections at ~1GeV.
- **SciBar:**
  - Originally K2K-near detector
  - Shipped to FNAL
  - SciBar = active target && fine grained tracking detector
- **BNB: Intense & low energy ν beam**
  - Eν good match to T2K
  - Quick & high stat. measurement (SciBooNE results before T2K starts)
  - ν and $\bar{\nu}$ beam
- MoniBooNE near detector

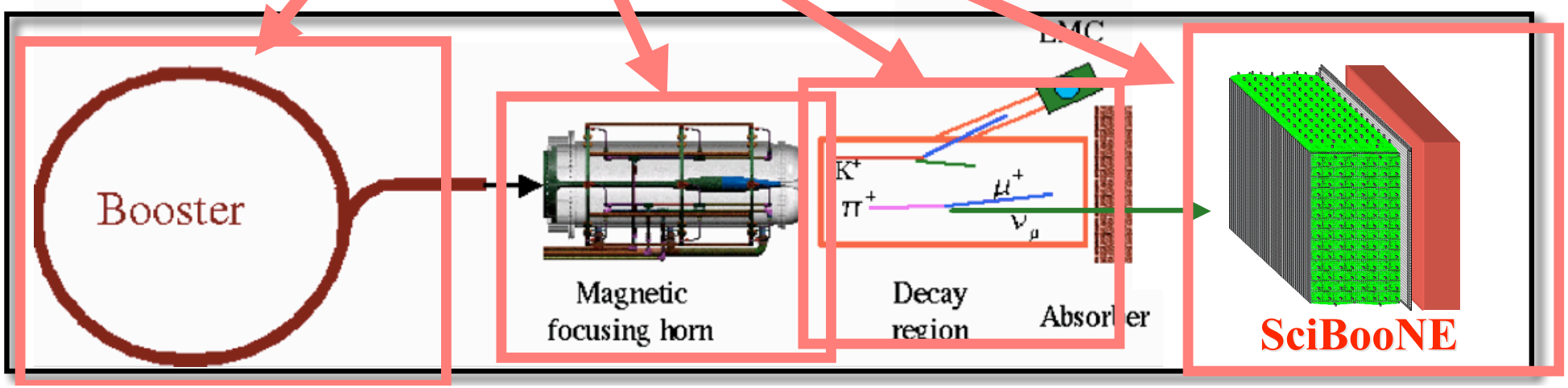


Booster Neutrino Beam (BNB)

FNAL Booster Neutrino Beam (BNB)

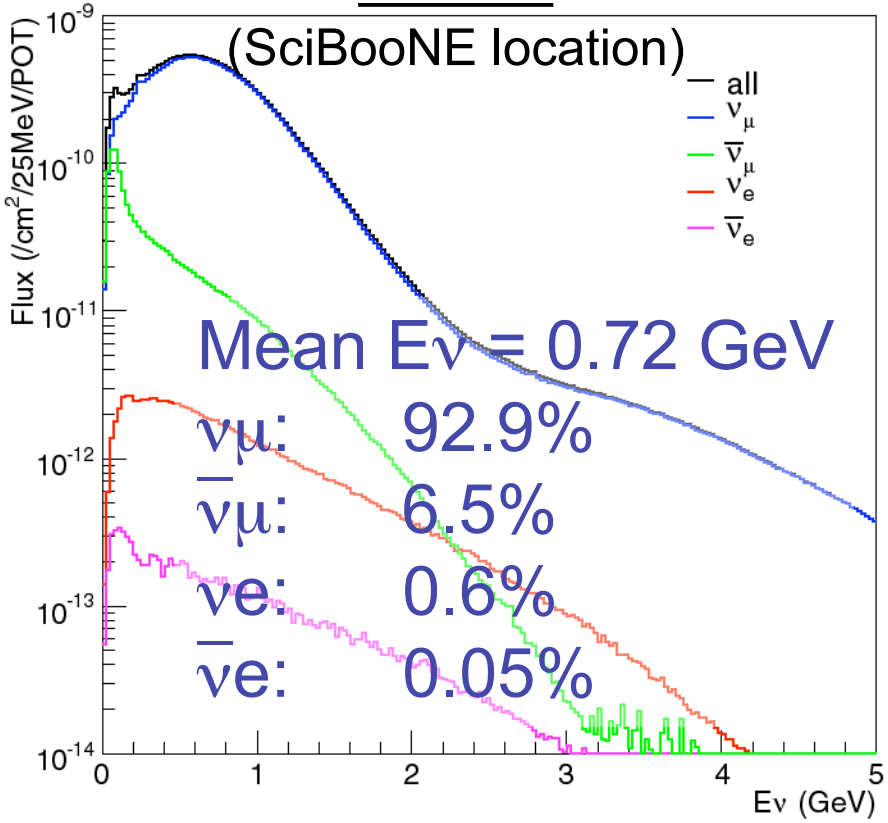


- 8 GeV protons from Booster
- Protons hit beryllium target (71 cm long, 1 cm diameter) within a magnetic focusing horn and produce mesons
- The mesons decay into neutrinos in 50m decay region
- Neutrinos are observed in SciBooNE (100m) and MiniBooNE (541m)

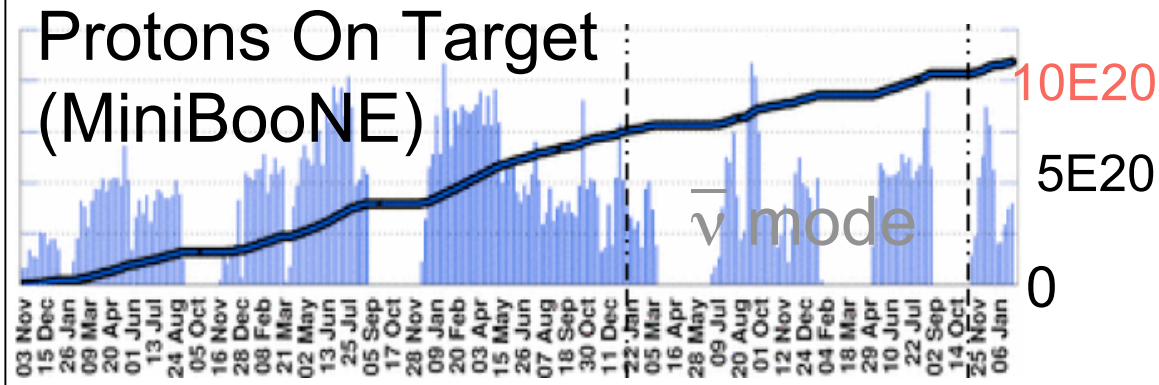


Neutrino Beam Specification

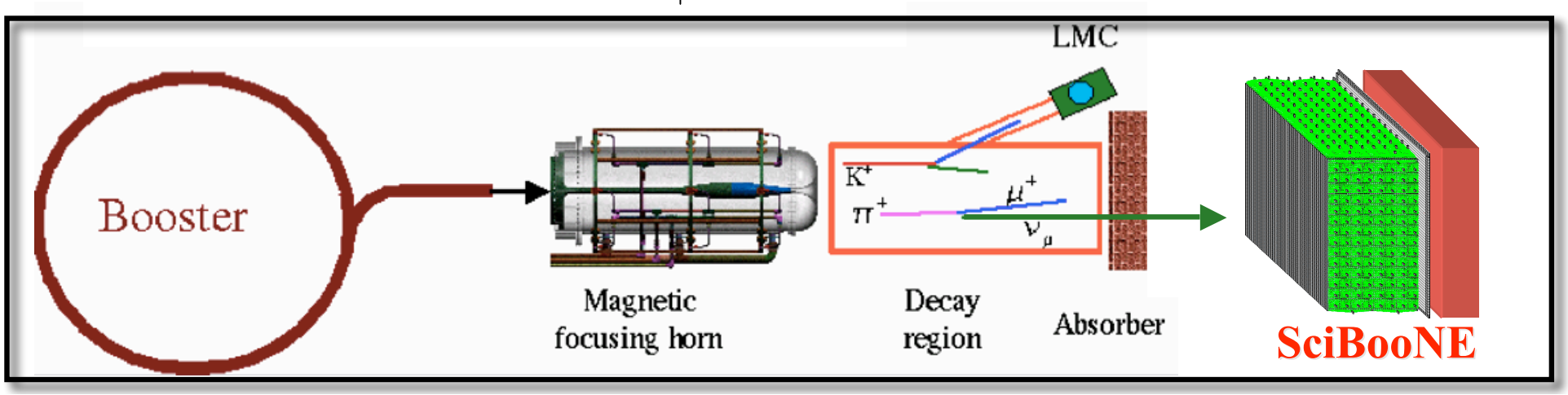
ν Flux



Intensity



- Intense ν beam.
  - 1E21 POT/5 years (2002~) (~2E20/year)
- ν̄ mode too



SciBooNE Projected POT
of expected $\nu/\bar{\nu}$ events

- ~1 year run = 2×10^{20} POT

- Neutrino run (~1×10^{20} POT)
  cf. K2K-SciBar (0.2×10^{20} POT): ~25,000 ν_μ

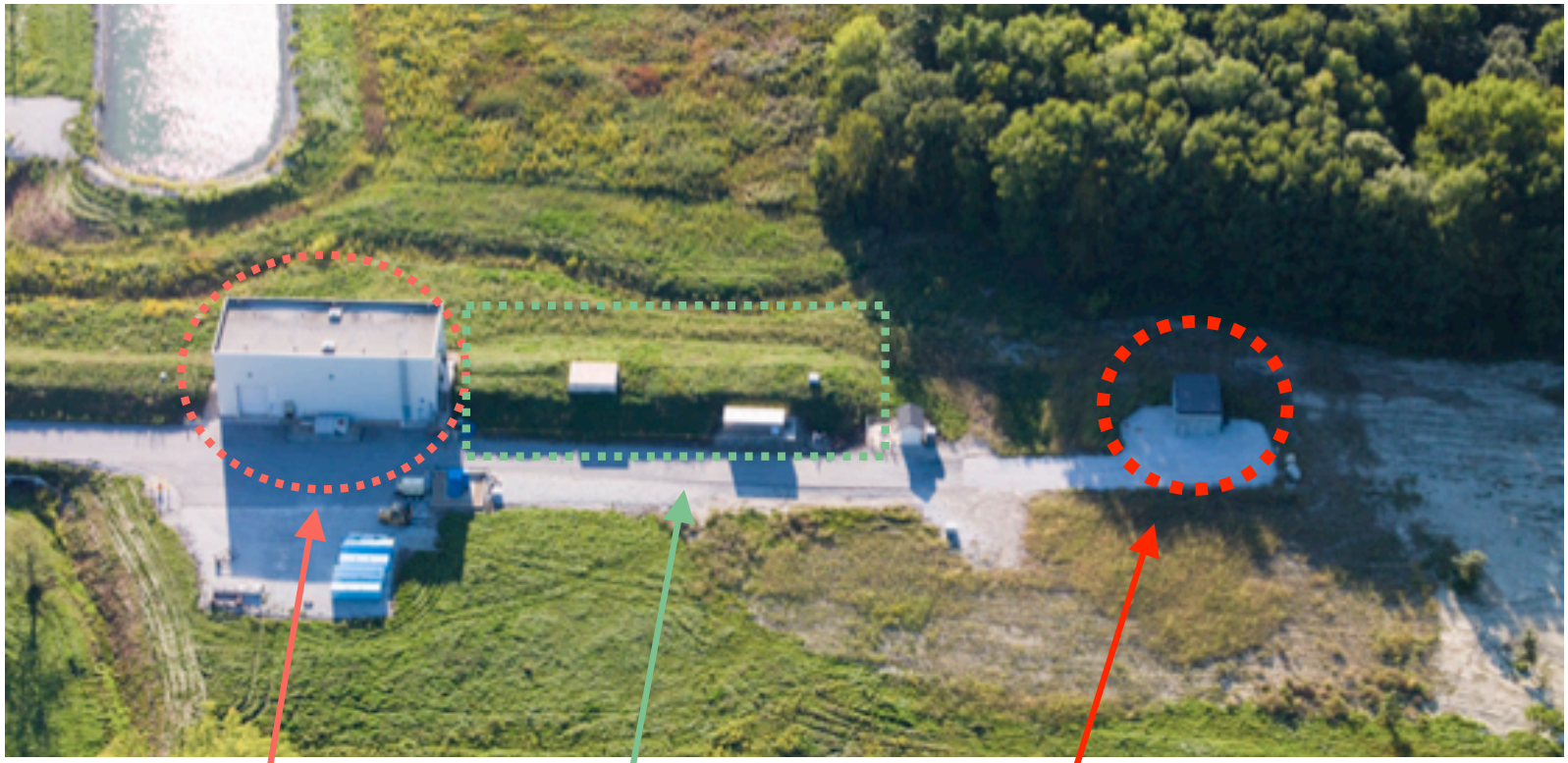
# of interactions
in Fiducial Volume
ν_μ **~156,000**
ν_e**~ 1,400**

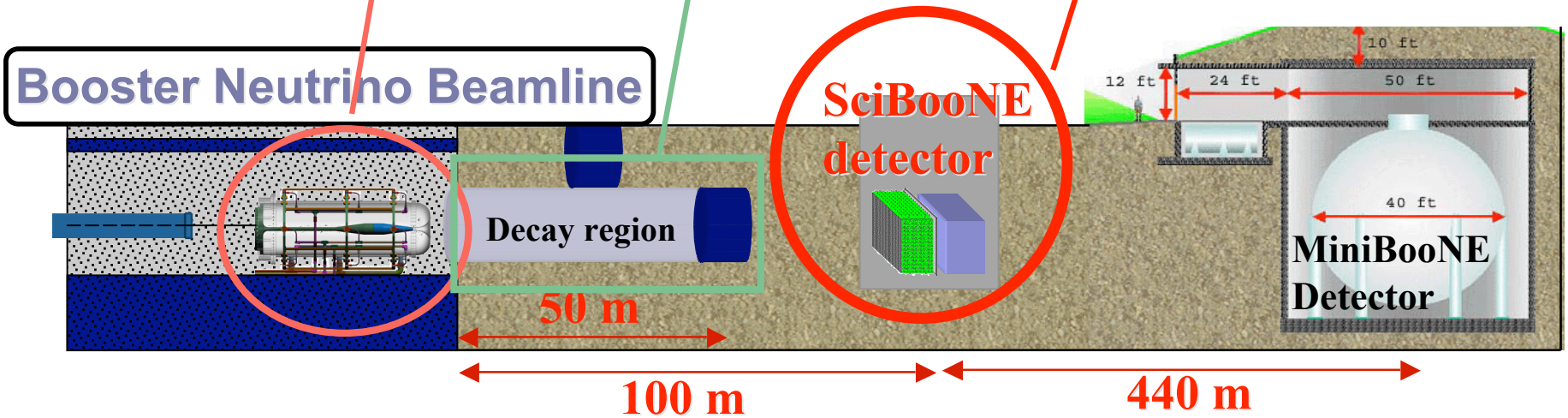
- Anti-neutrino run (~1×10^{20} POT)
  cf. K2K-SciBar: no measurement

# of interactions in FV
$\bar{\nu}_\mu$ **~27,000**
ν_μ **~15,000**

SciBooNE Detectors

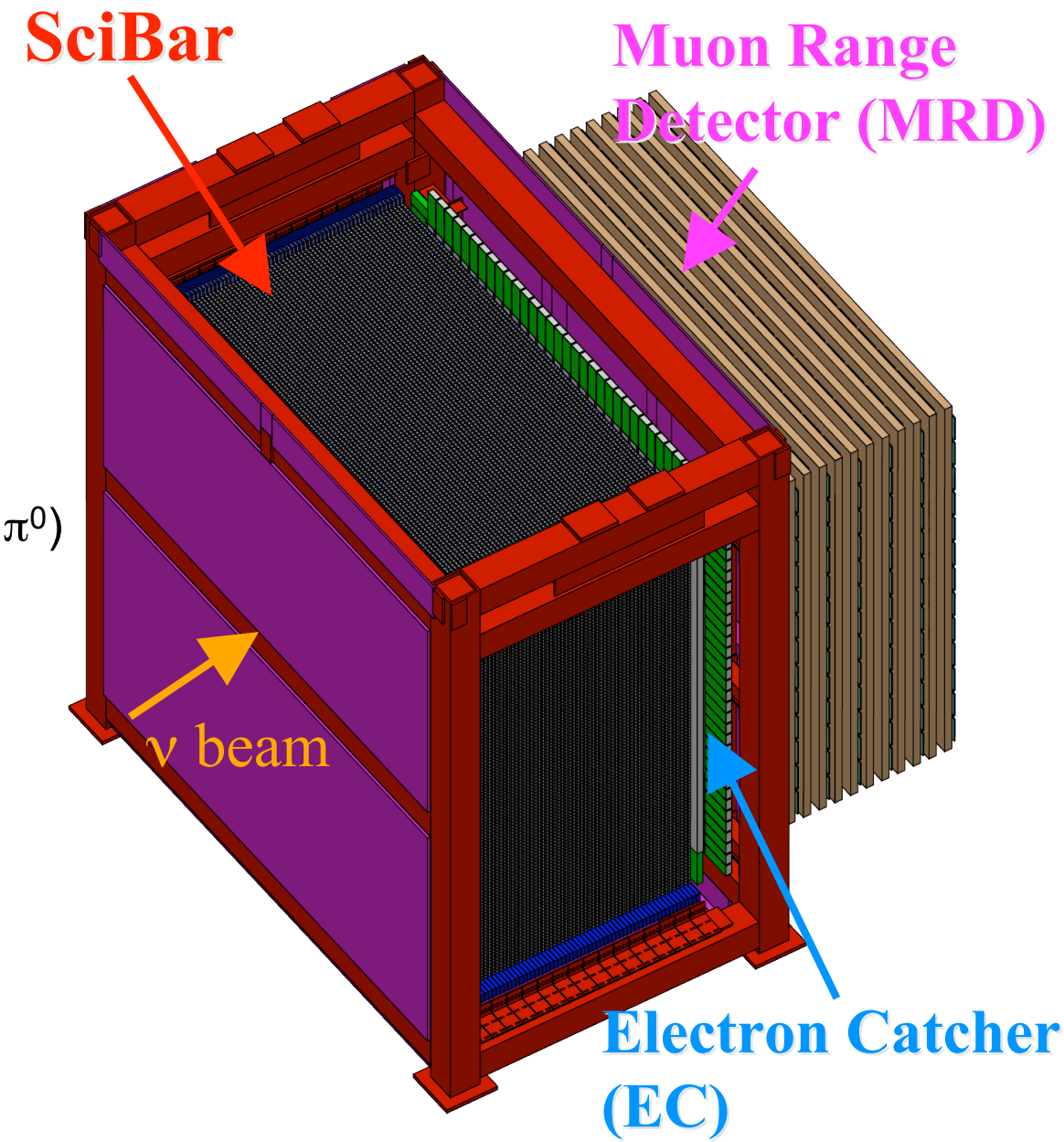
BNB + SciBooNE detector





SciBooNE Detectors

- SciBar Detector
  - Fully active neutrino target
  - Tracking
  - Shipped from KEK, Japan
- Electron Catcher (EC)
  - Electron identification (for ν_e, π^0)
  - Used CHORUS and K2K
  - Charged by Italy group
  - Shipped from KEK, Japan
- Muon Range Detector (MRD)
  - Muon identification
  - Momentum measurement
  - Newly built at FNAL

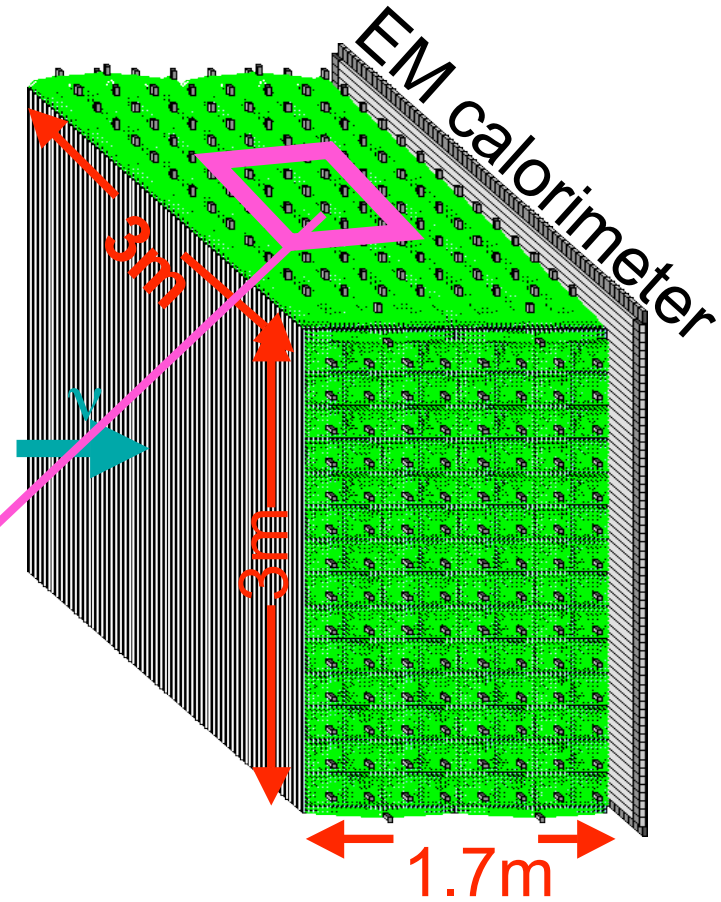


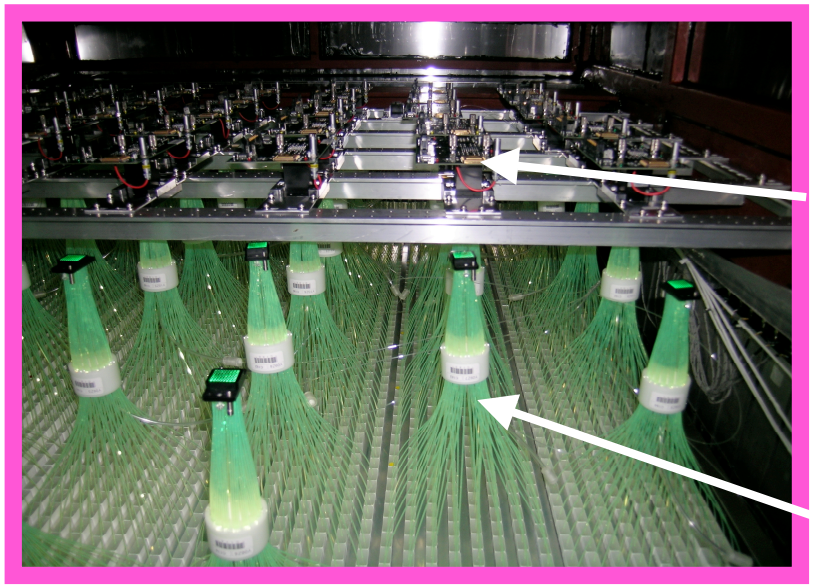
SciBar Detector

- Extruded scintillators with WLS fiber readout
- Scintillators are the neutrino target
- 2.5 x 1.3 x 300 cm^3 cell
- ~15000 channels
- Total 15 tons, Fiducial volume: ~10 tons
- Identify short tracks (>8cm)
- Distinguish a proton from a pion by dE/dx

➔High track finding efficiency (>99%)

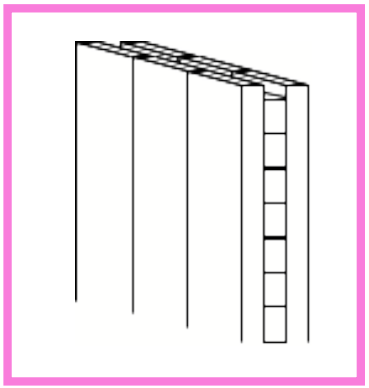
➔Clear identification of ν interaction process





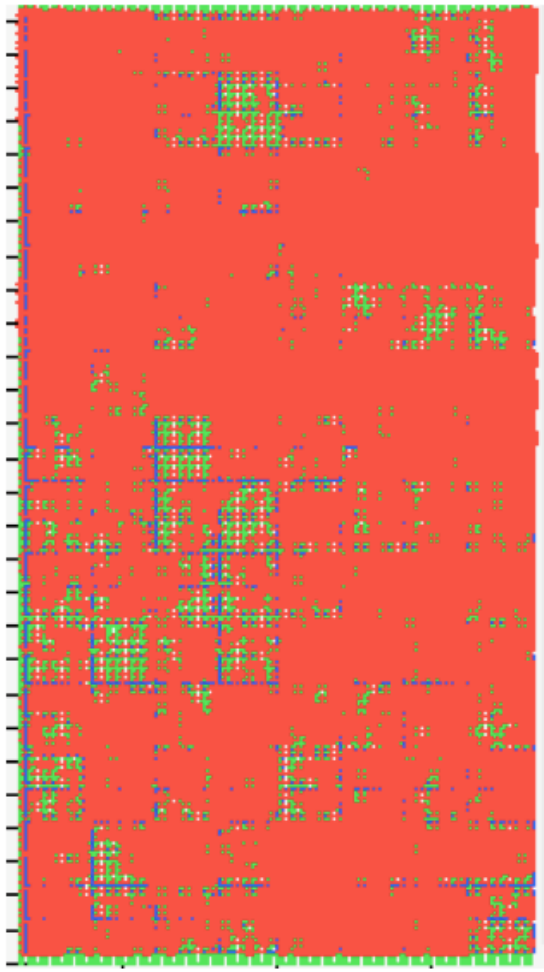
Multi-Anode PMT
(64 channels)

Wave-Length
Shifting fiber

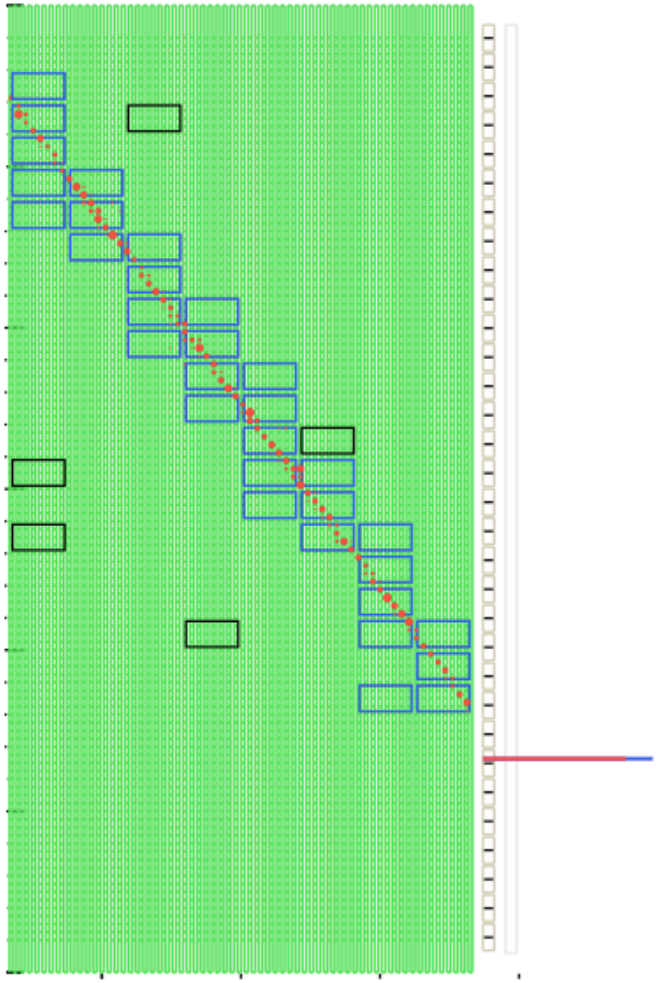


SciBar calibration

- Two sources: <u>LED</u> and <u>cosmic rays</u>
- Taken between beams



LED event display



Cosmic ray

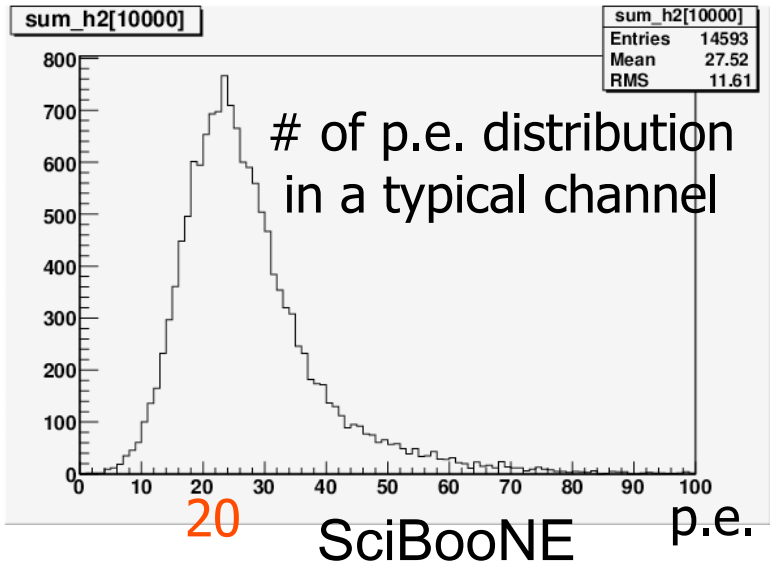
●: SciBar hit, area∝charge

Box: TDC hits (32ch OR-ed)

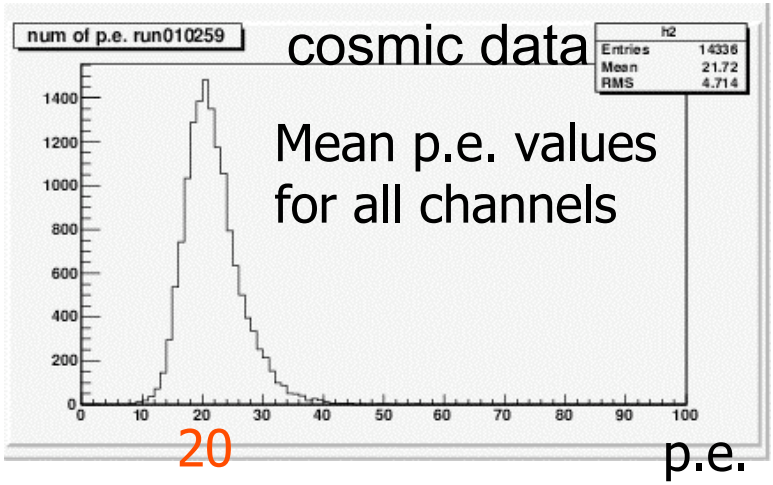
Basic Performance of SciBar Detector

- Light yield for MIP
  - **~20 p.e./ 1.3cm**
    (average over all channels)

- Hit finding efficiency (cosmic)
  - Horizontal plane: **99.9%**
  - Vertical plane : **99.8%**



SciBooNE
cosmic data

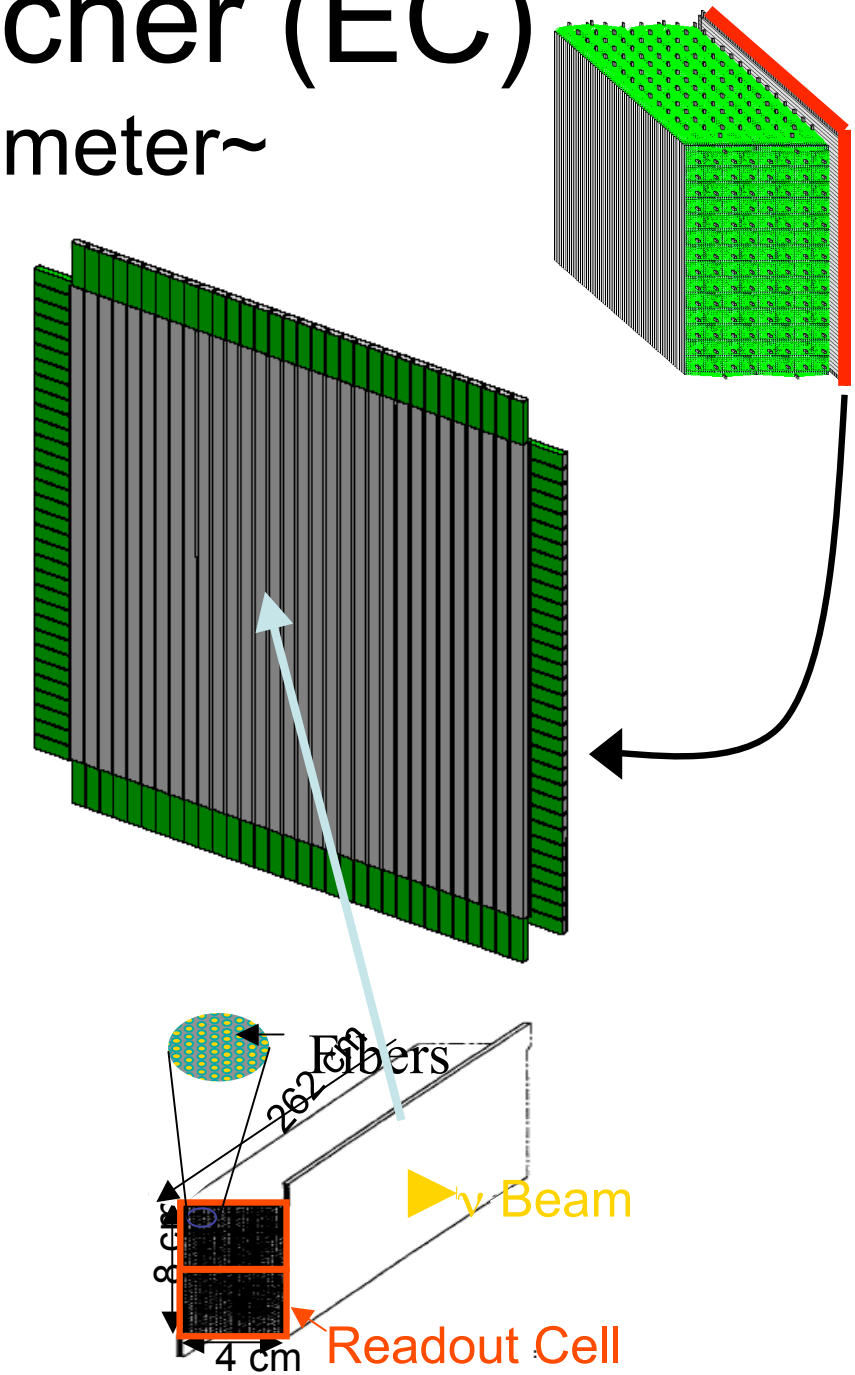


Electron Catcher (EC)

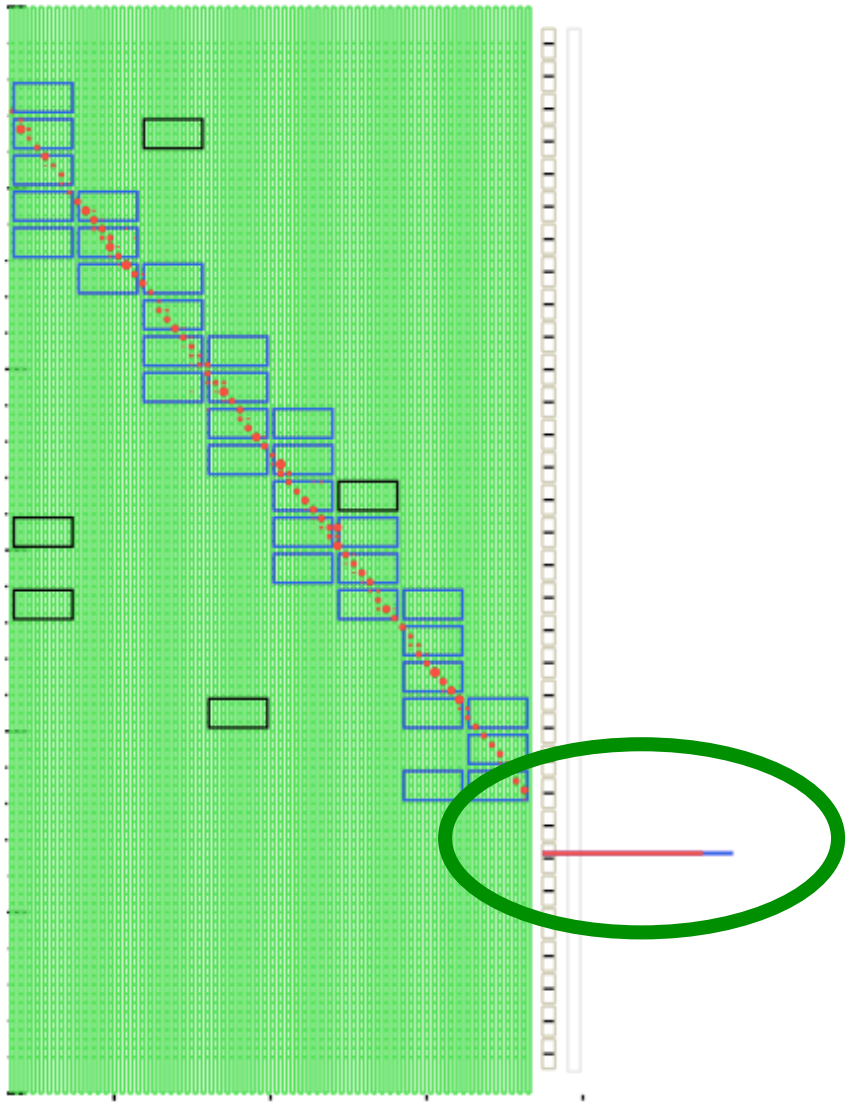
~EM Calorimeter~

- Electron / gamma ID
- "Spaghetti" calorimeter re-used from CHORUS
- 1mm diameter fibers in the grooves of lead foils
- 4x4cm^2 cell read out from both ends
- 2 planes (11X_0)

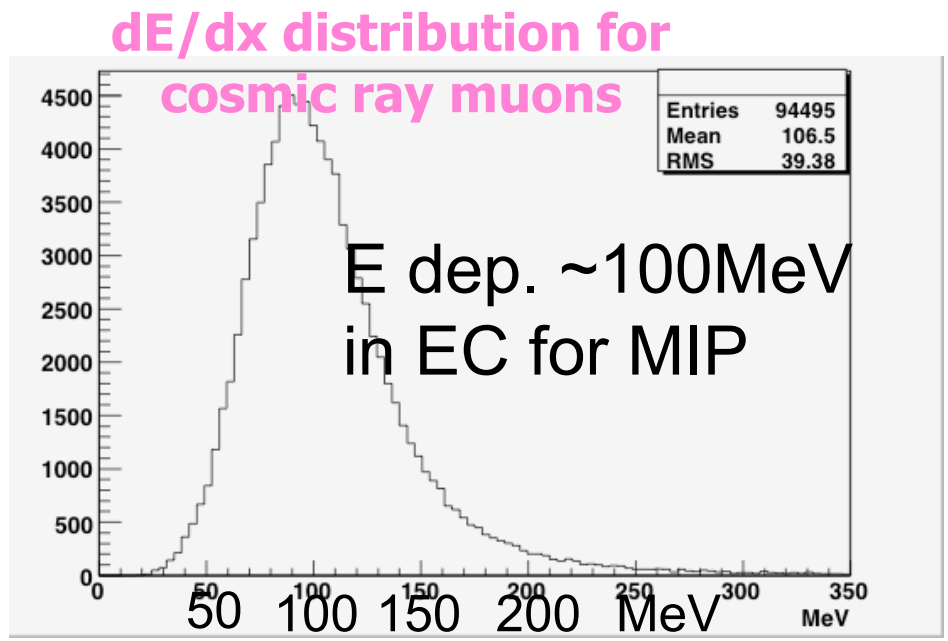
  Horizontal: 32 modules
  Vertical : 32 modules
- Total 256 readout channels
- Expected resolution 14%/$\sqrt{E}$



EC Cosmic Data



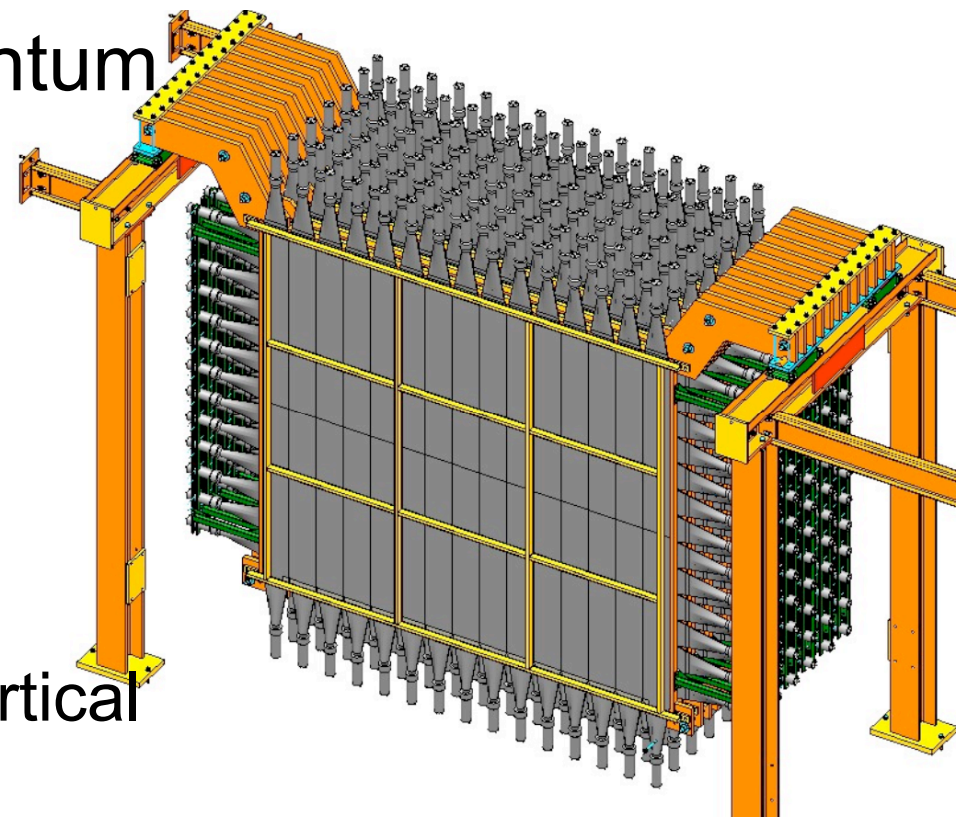
Cosmic ray



SciBooNE
cosmic data

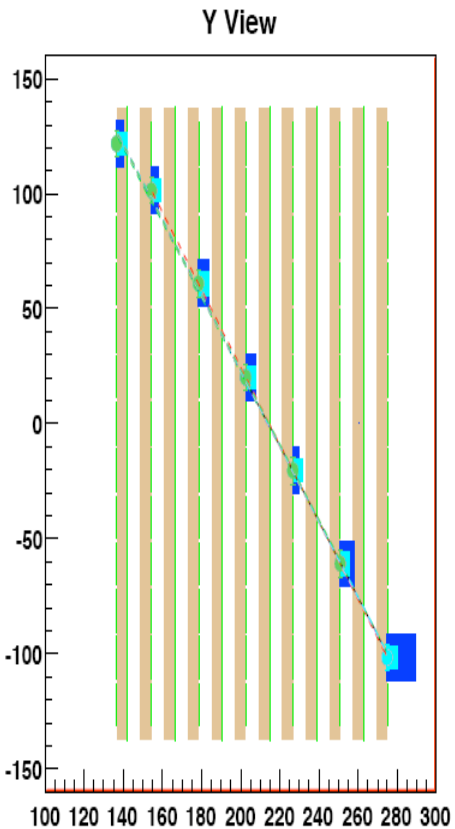
Muon Range Detector (MRD)

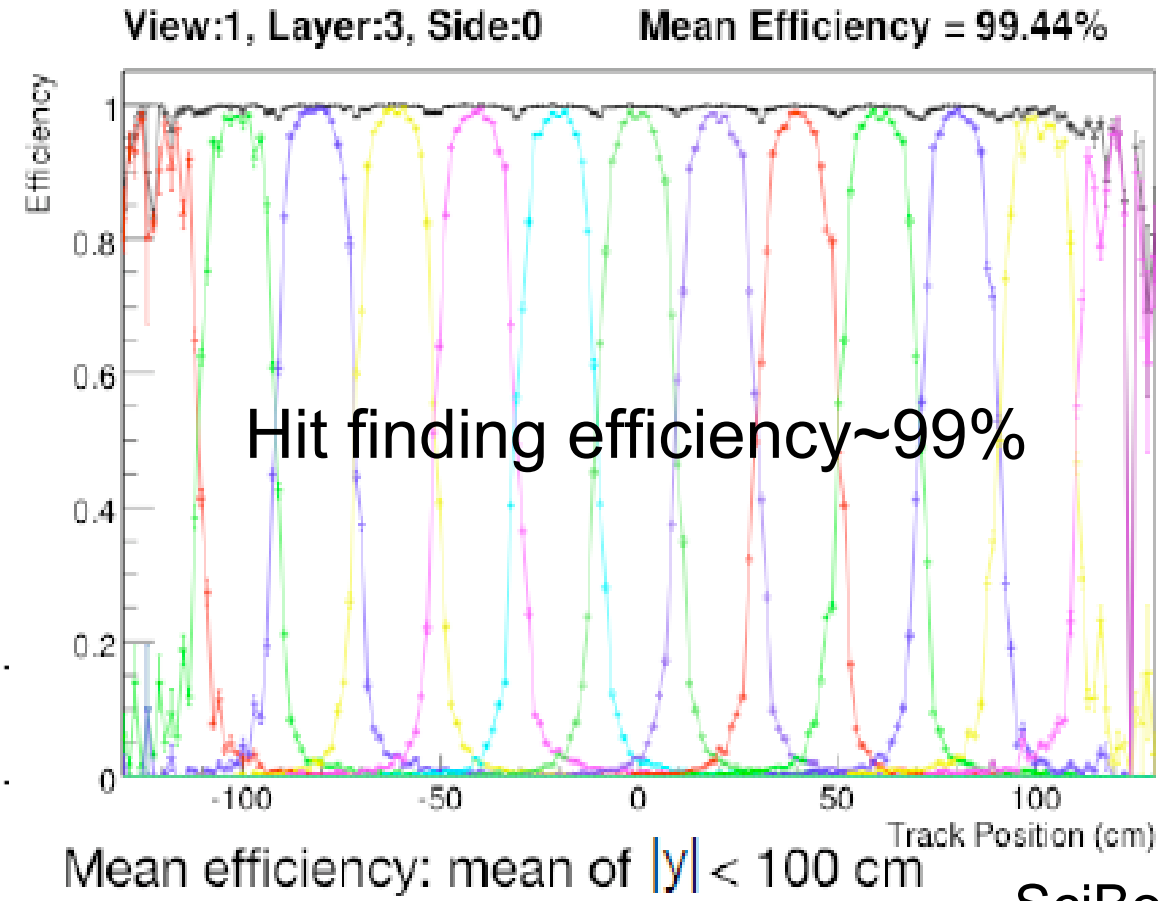
A new detector built with the used scintillators, iron plates and PMTs to measure the muon momentum up to 1.2 GeV/c.



- Iron Plate
  - 305x274x5cm^3
  - Total 12 layers
- Scintillator Plane
  - Alternating horizontal and vertical planes
  - Total 362 channels

MRD Cosmic Data

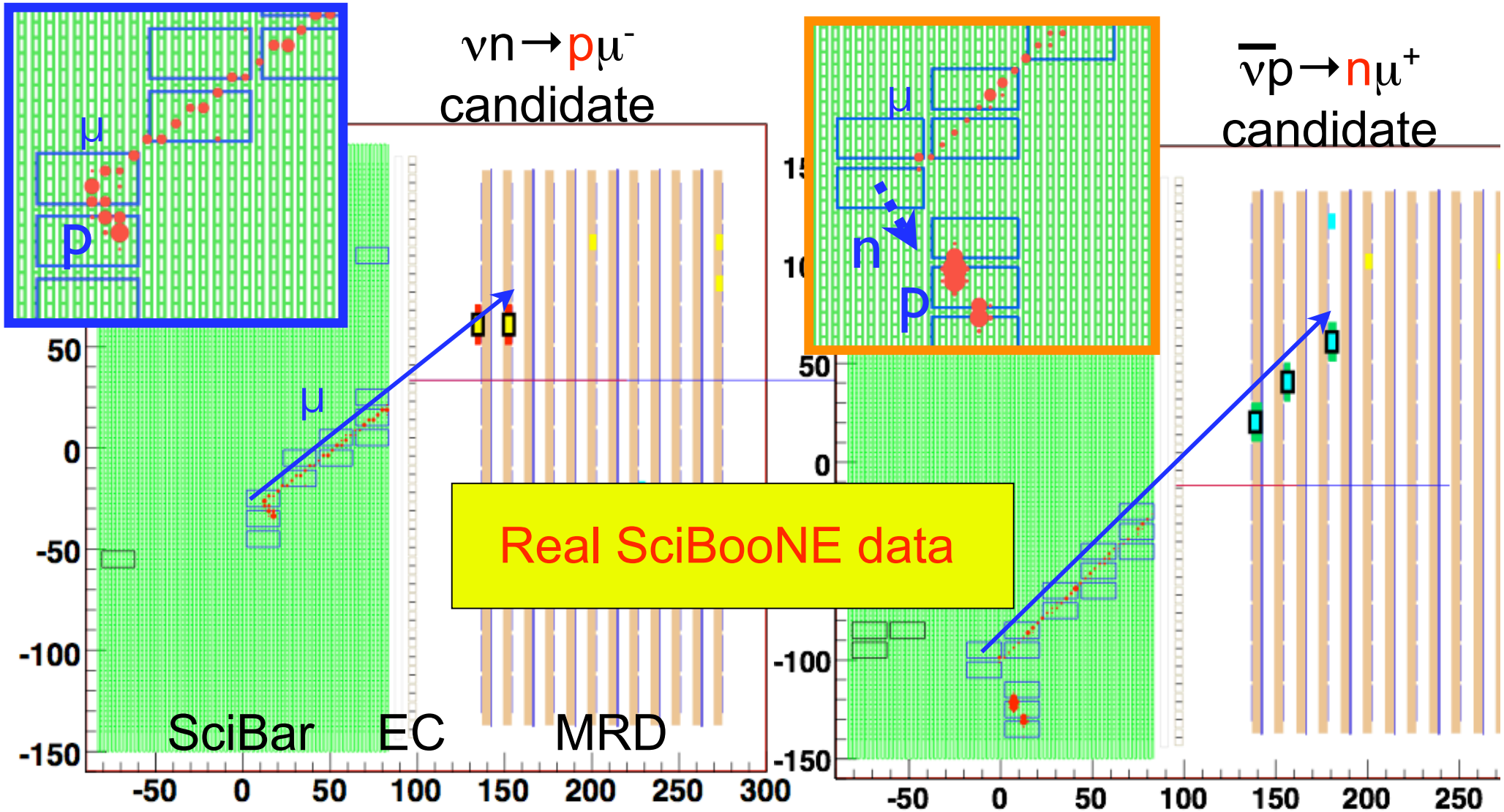




Hit finding efficiency of a typical horizontal plane

SciBooNE cosmic data

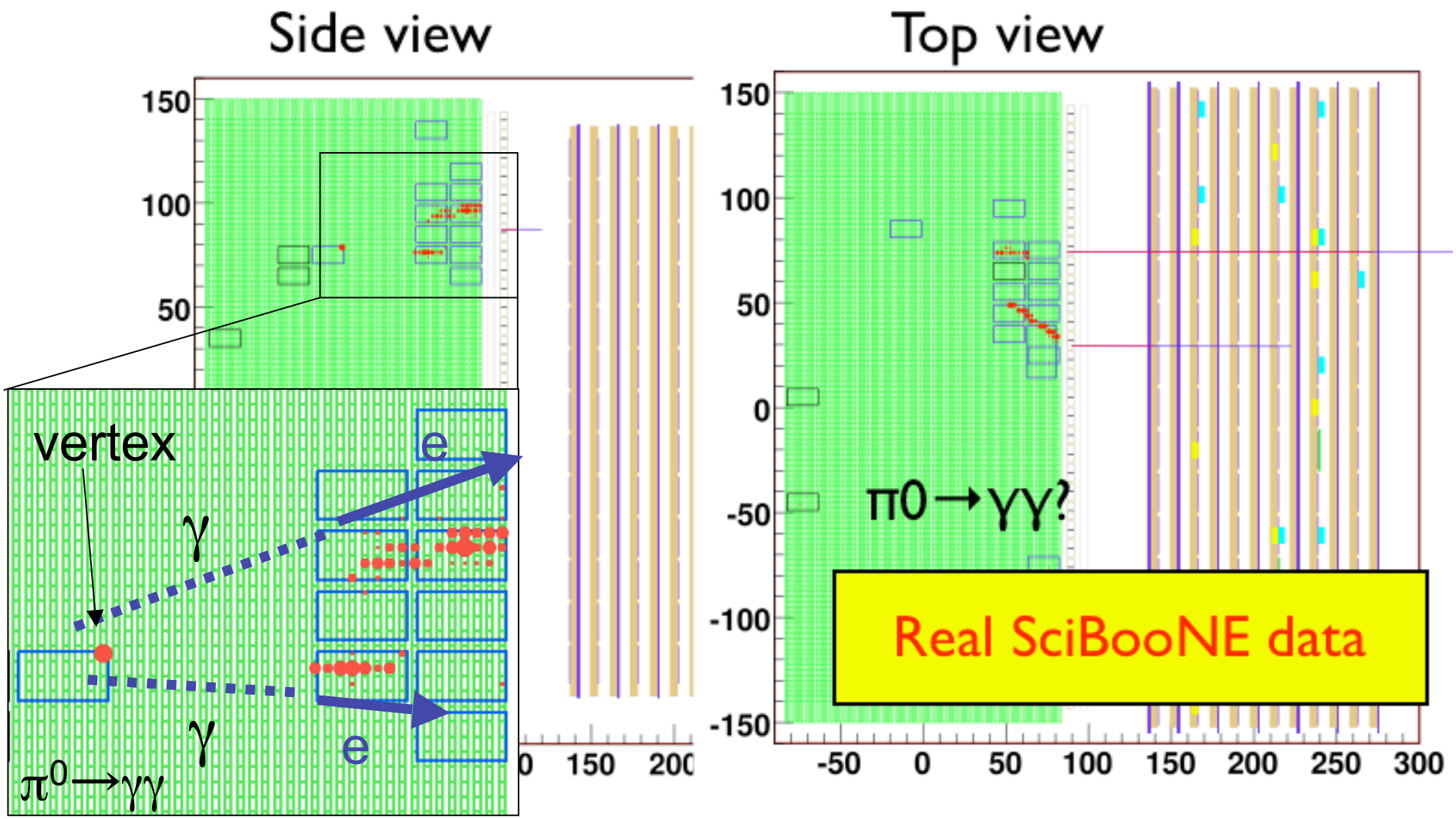
ν and $\bar{\nu}$ CCQE event candidates



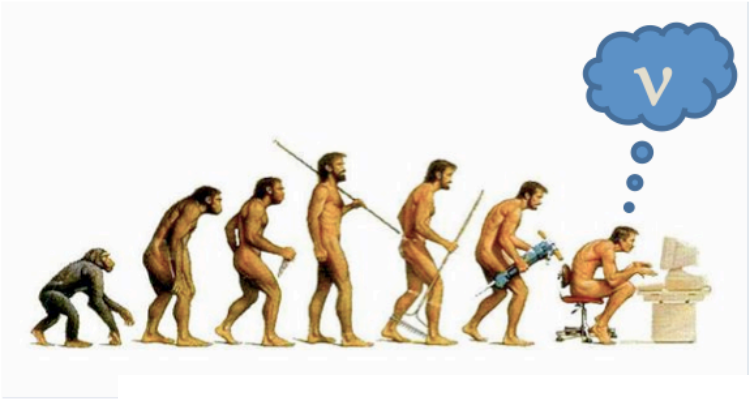
●: SciBar hit, area∝energy deposit

NC-π^0 event candidate

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

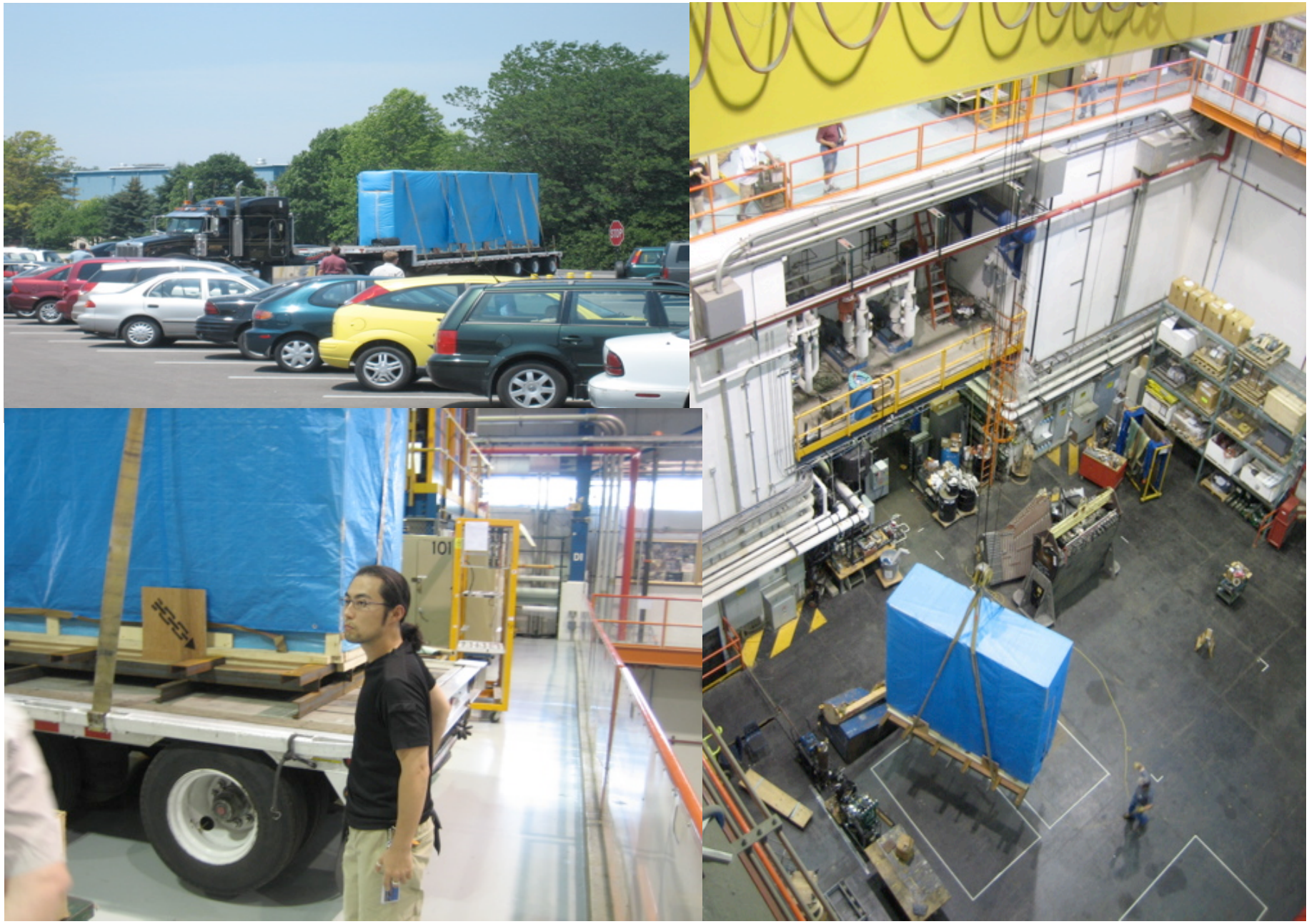


SciBooNE Timeline



- 2005, Summer - Collaboration formed
- 2005, Dec - Proposal
- 2006, Jul - Detectors move 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 - Anti-Neutrino Data Run
- 2007, Oct - Neutrino Data Run

Two years from formation to first data!

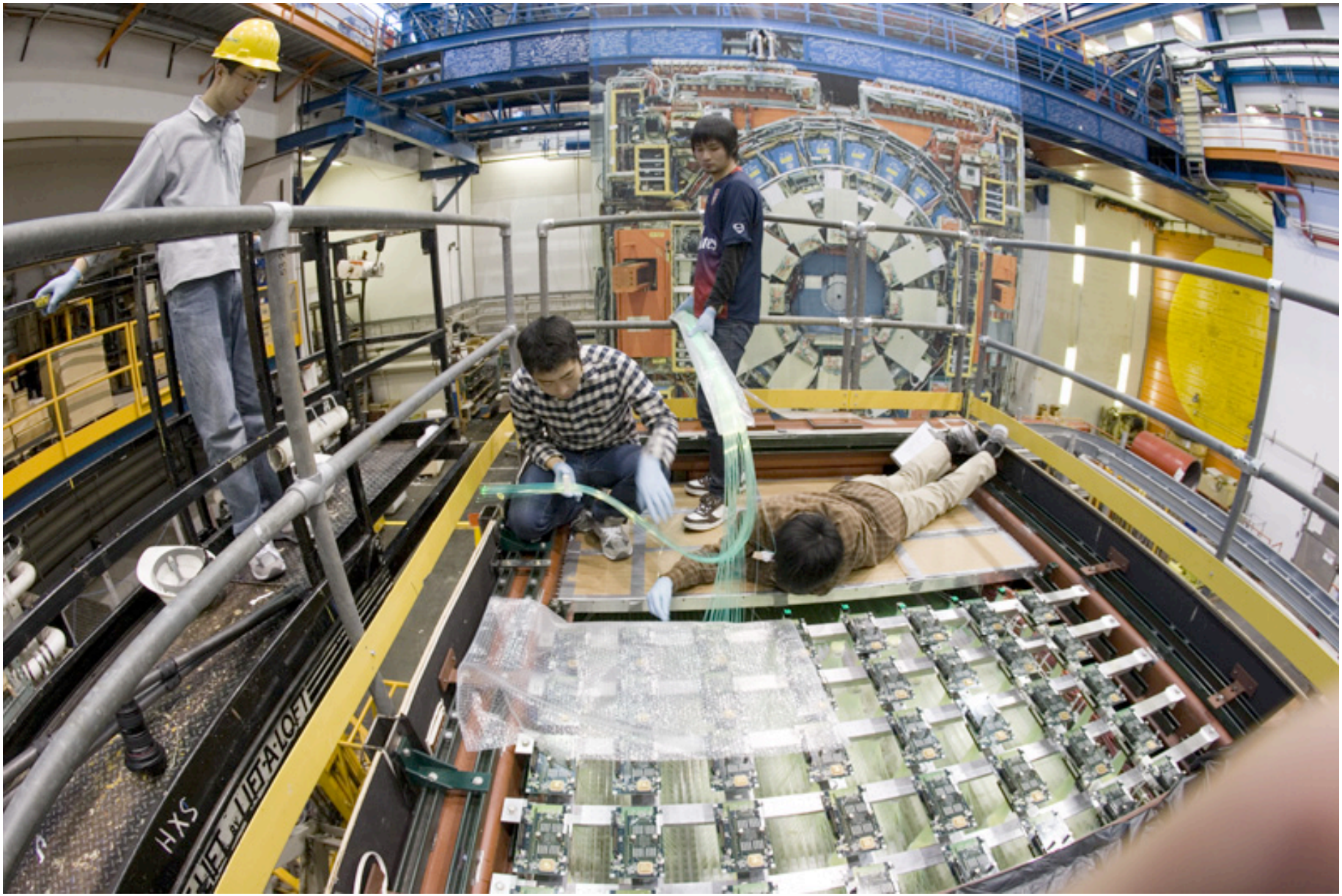


Detectors arrived at Fermilab (July, 2006)

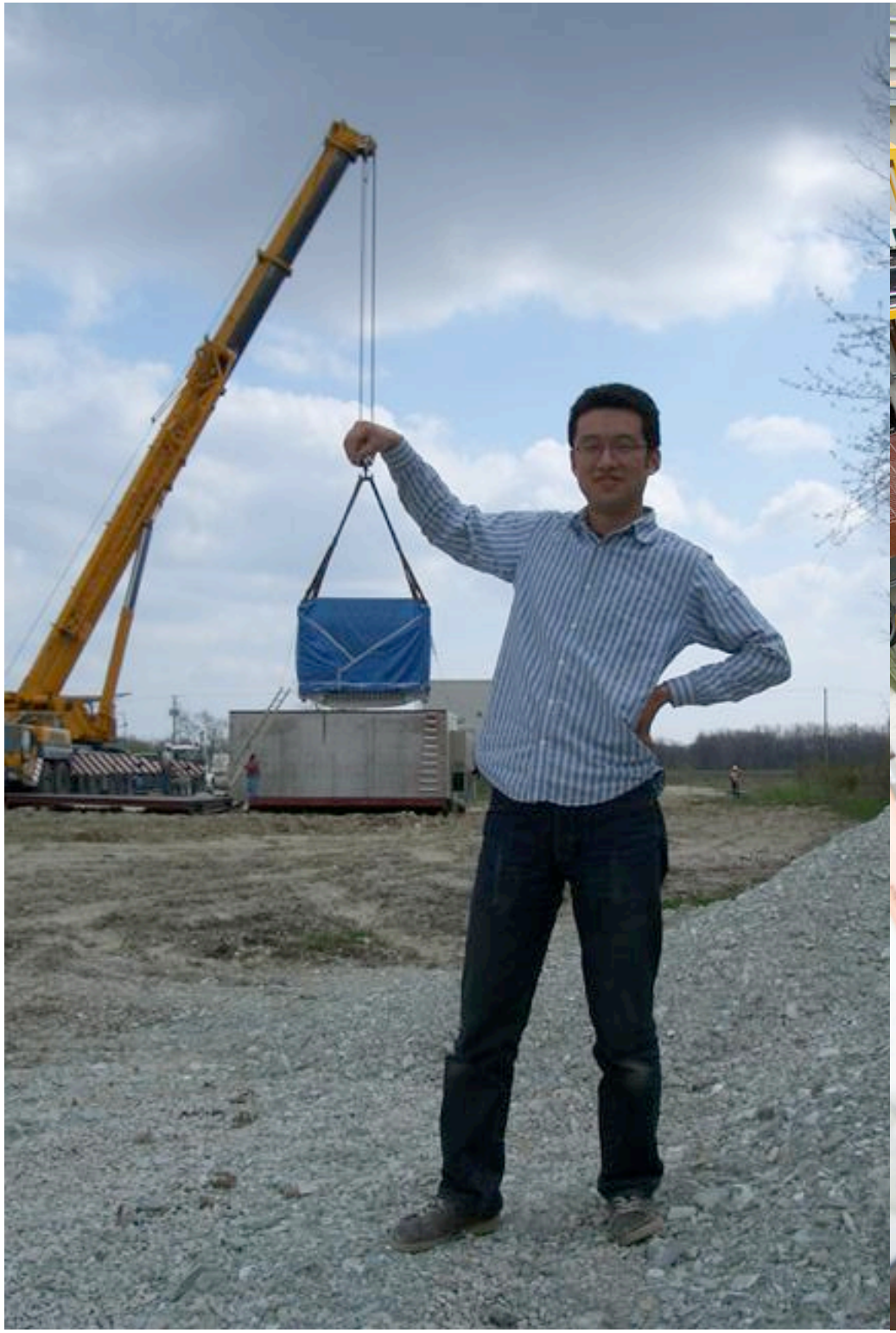
Civil construction of detector hall (September, 2007)

Ground breaking ceremony

MRD construction (January, 2007)



SciBar construction (January, 2007)



April, 2007

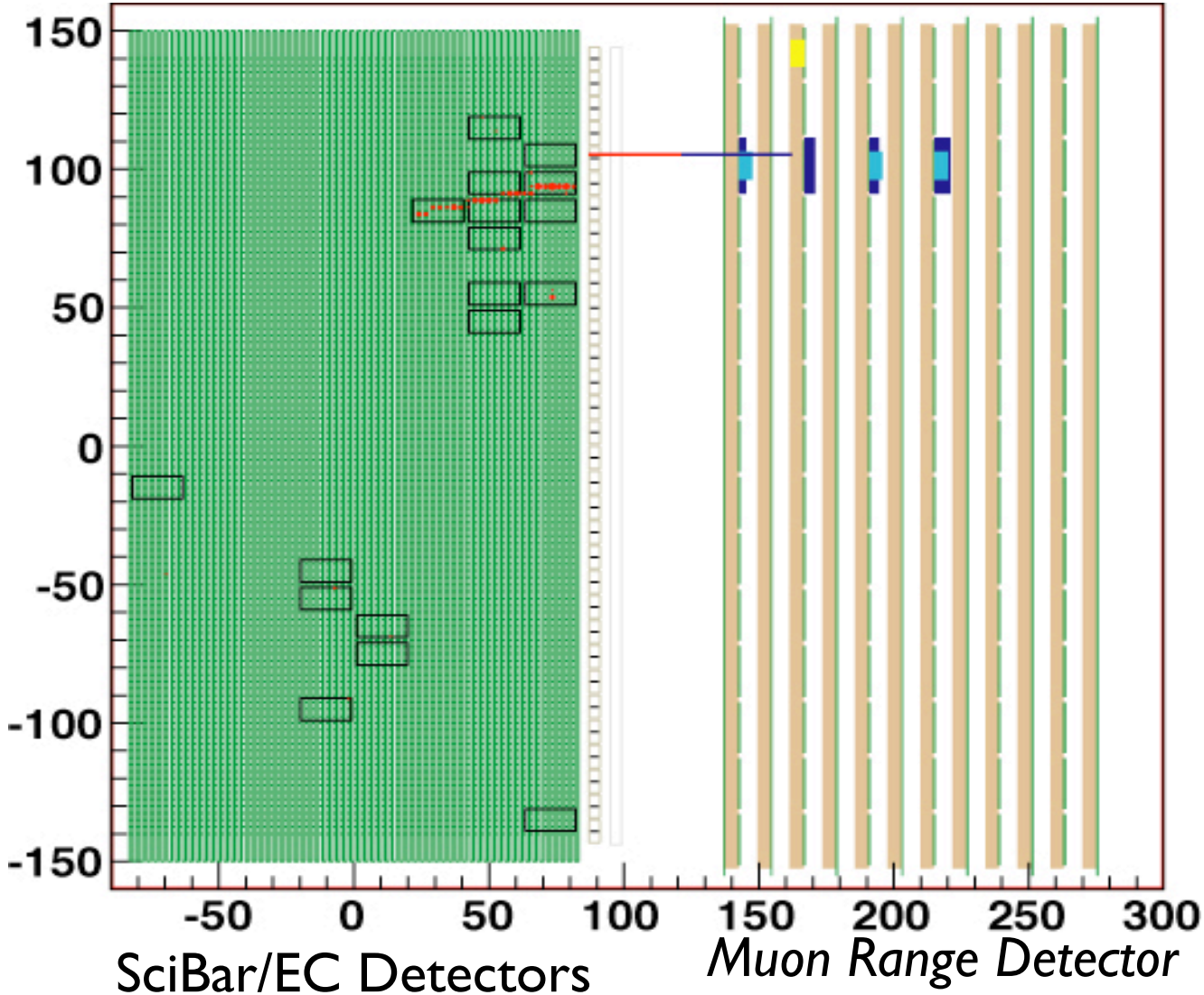
May, 2007

SciBar/EC Detectors

Muon Range Detector

First Neutrino Event

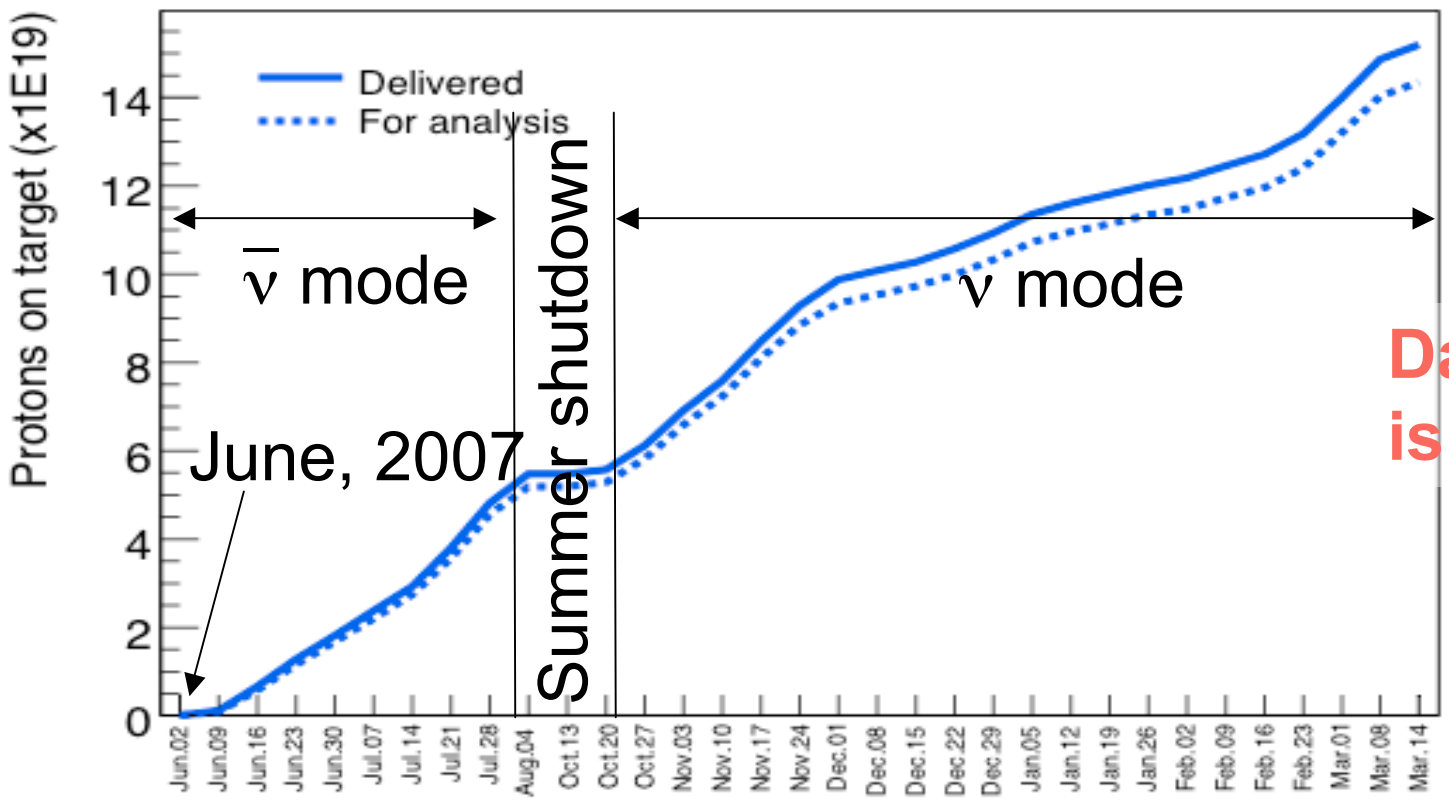
($\bar{\nu}$ mode)



●: SciBar hit, area∝energy deposit

Data taking status

- Projected Protons On Target (POT): 2E20
- Total collected POT: 1. 46E20
  - ν: 9.2E19 (goal: 1E20)
  - $\bar{\nu}$: 5.4E19 (goal: 1E20)
- Averaged detector live time fraction: 94%



Data taking is ongoing.

Status of Analyses

- Neutrino data (not $\bar{\nu}$ data, in this talk)
- ~77% of all projected ν data (POT) is used
  - 84% (~7.7E19POT) of all collected ν data

Analyses of ν interaction

<u>Several analyses are in progress</u>

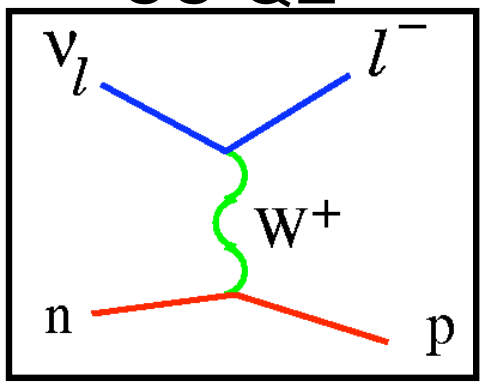
- Charged Current
  - CC inclusive (Yasuhiro N.)
  - CC-QE (Jose A. and Joe W.)
  - CC-1π (Katsuki H.)
  - CC-π^0 (Joan C.)
- Neutral Current
  - NC-π^0 (Yoshinori K.)
  - NC-elastic (Hideyuki T.)
- ν_μ disappearance (Kendall M.)

Charged Current analyses

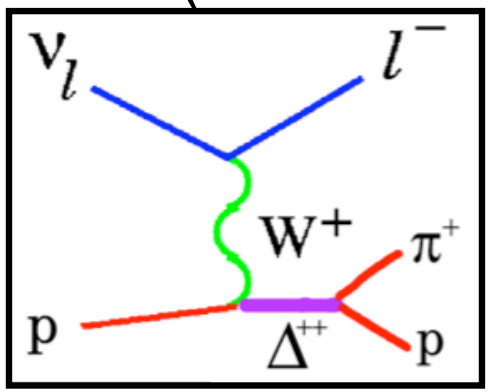
- CC, CC-1π, CC-QE

Feature of CC event at SciBooNE

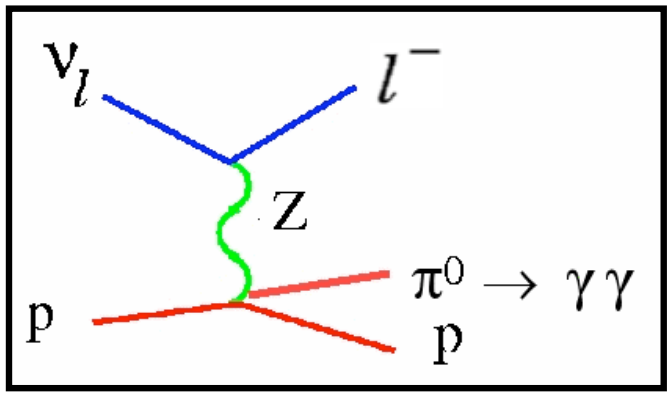
CC-QE



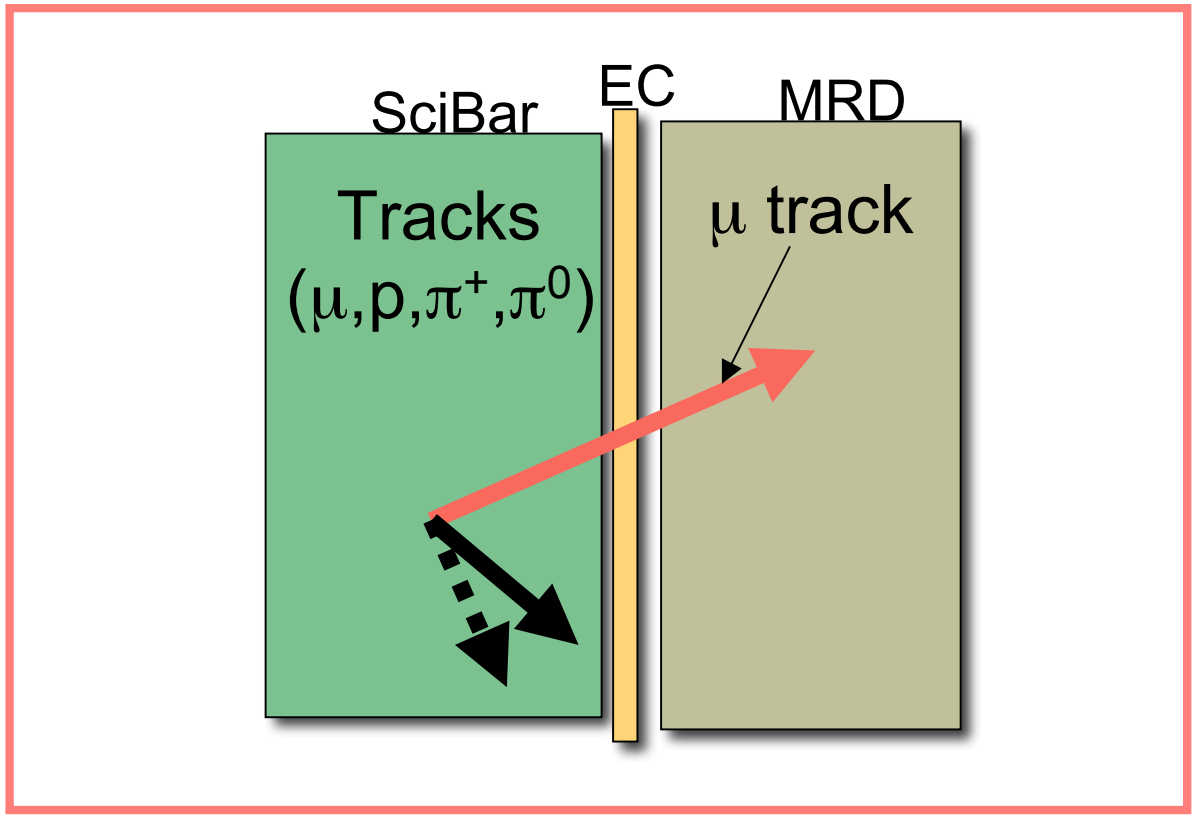
CC-1π (resonance)



CC-π^0

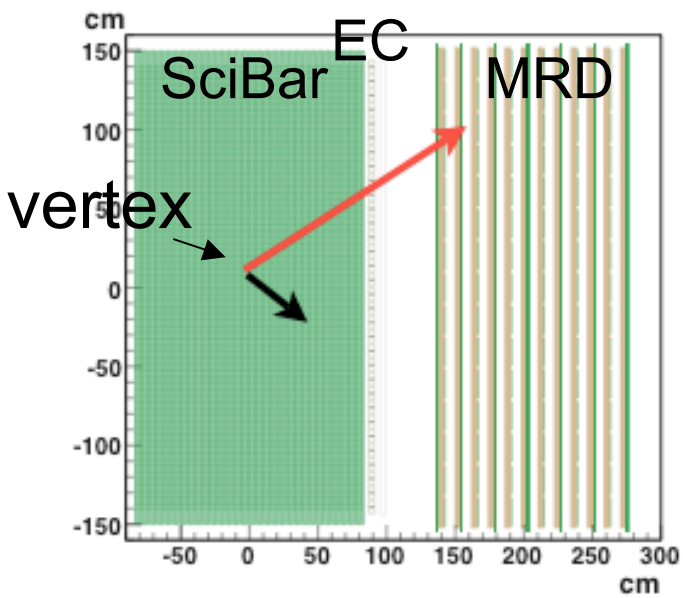


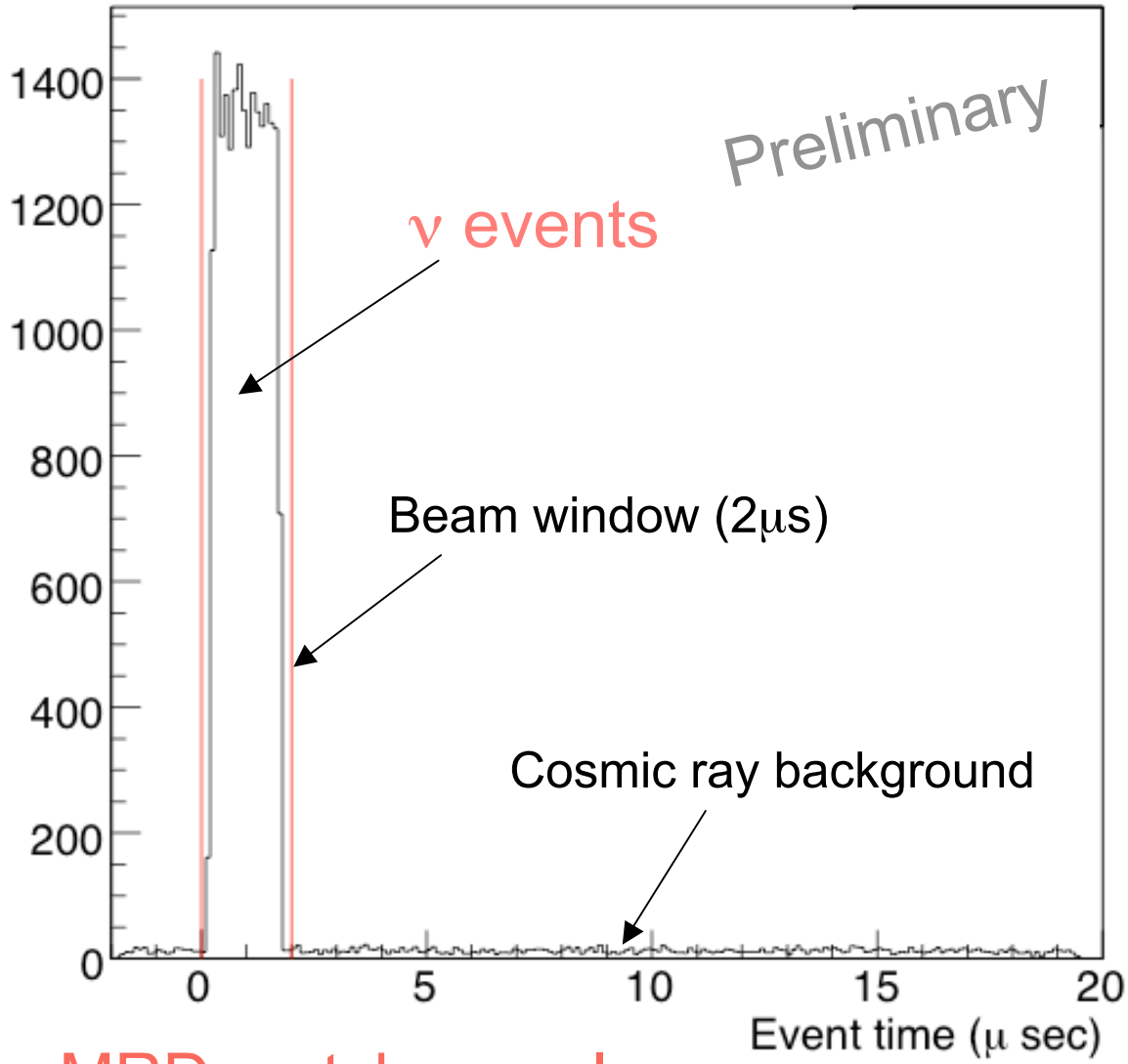
- Muon = SciBar-MRD matched track



ν events timing distribution

- Beam window: 2usec (1.6us beam spill)
- Requiring SciBar-MRD match, cosmic ray background contamination <0.5%

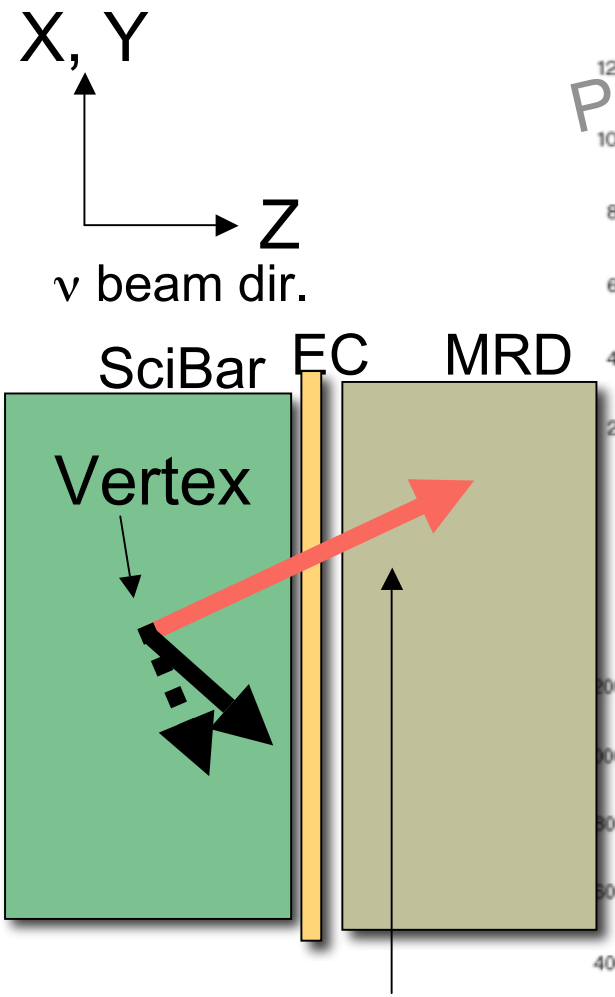




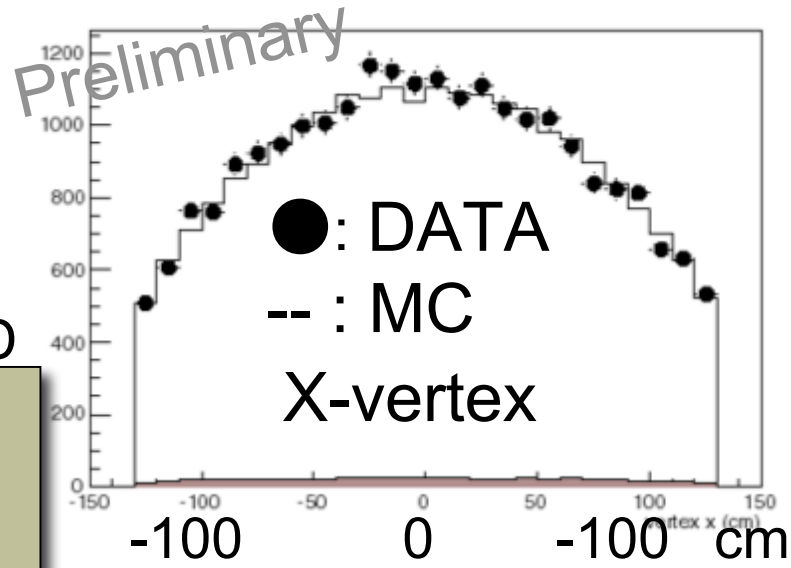
SciBar-MRD match sample:
CC purity: 96%

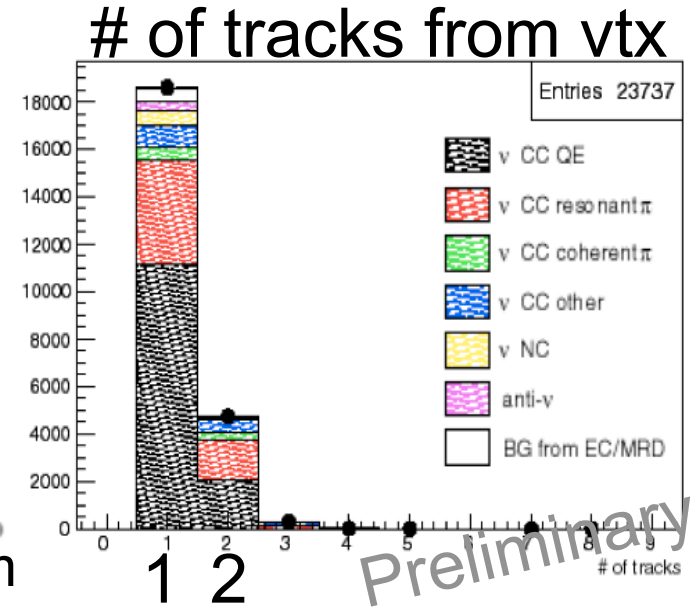
Vertex and # of tracks

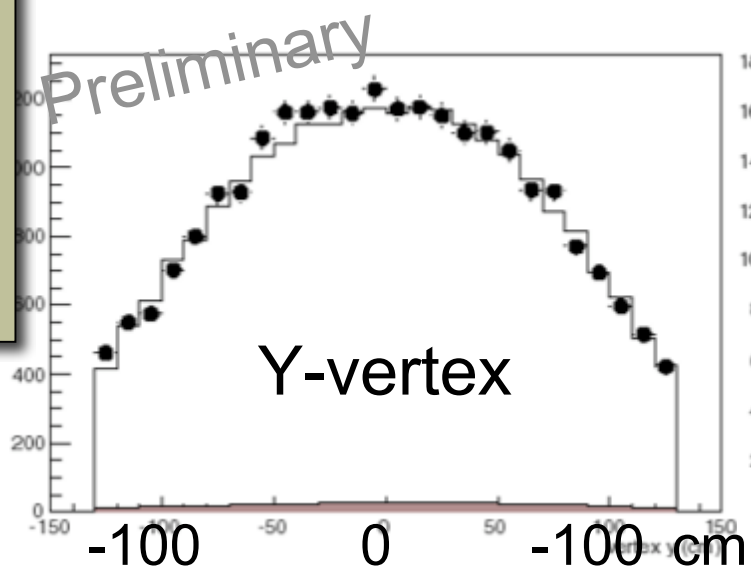
Sample: SciBar-MRD track matched event

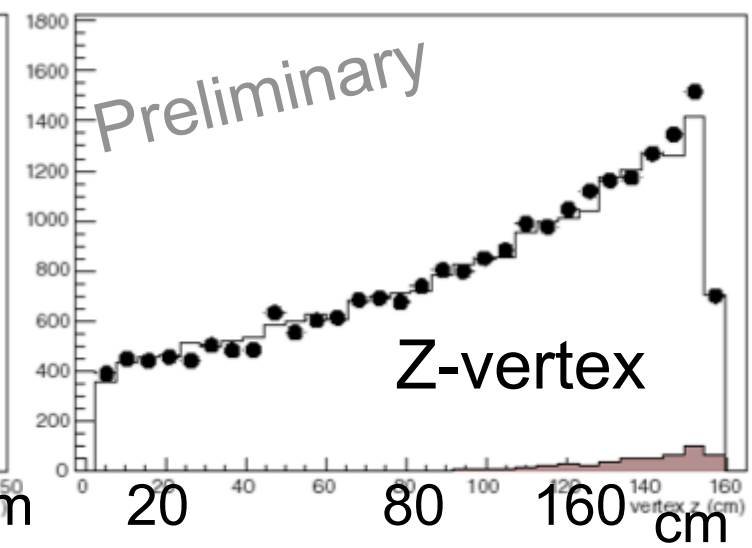


SciBar-MRD matched trk (Muon track)

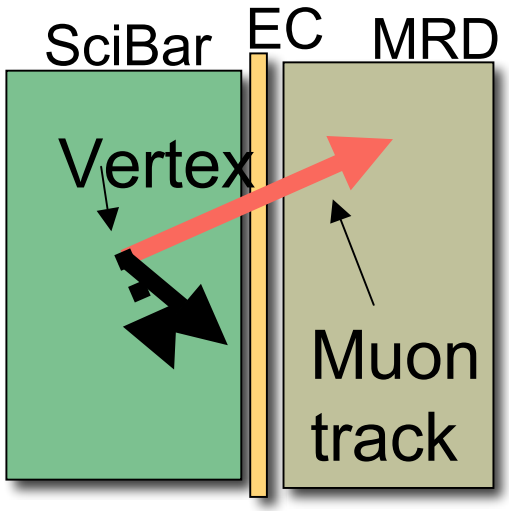








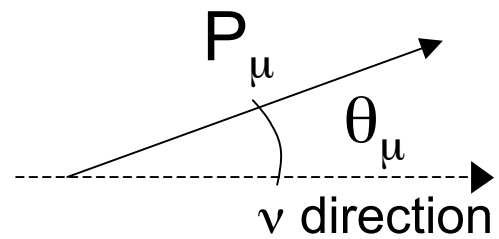
Y. Nakajima



Muon distribution

preliminary results

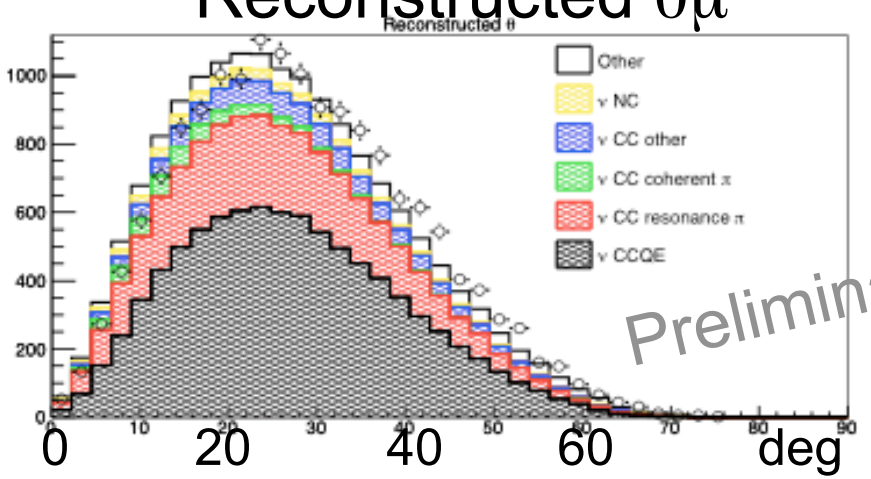
Y. Nakajima



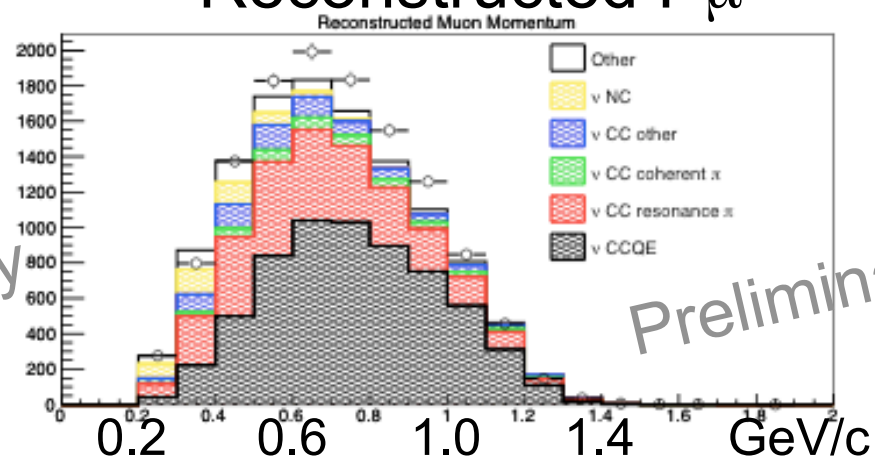
Sample: events μ stopped inside the MRD

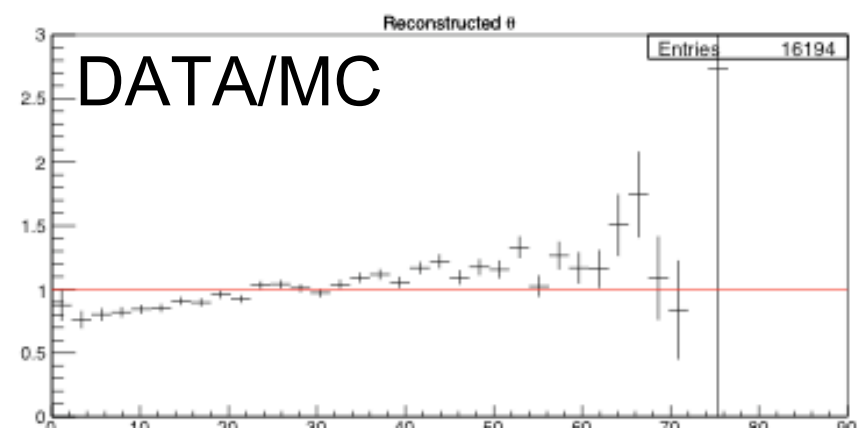
(MC samples: normalized by # of MRD match events)

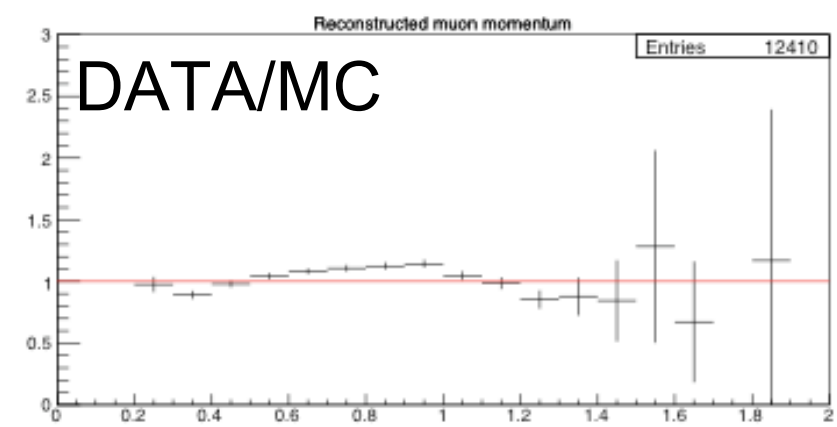
Reconstructed θμ



Reconstructed Pμ





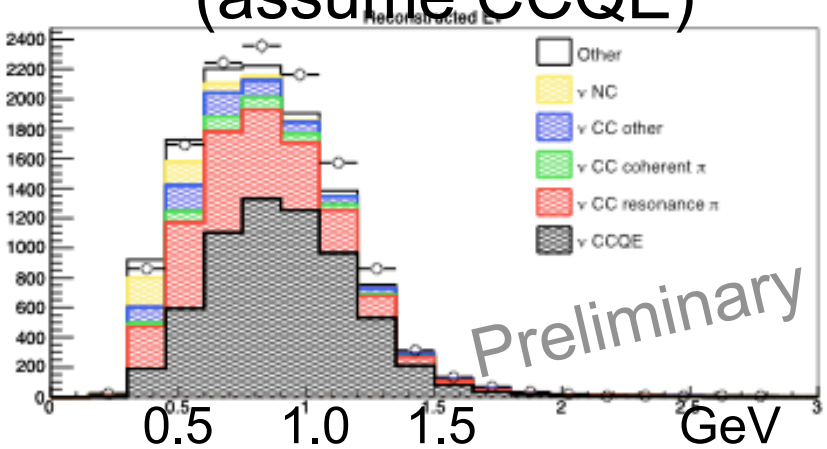


Event kinematics

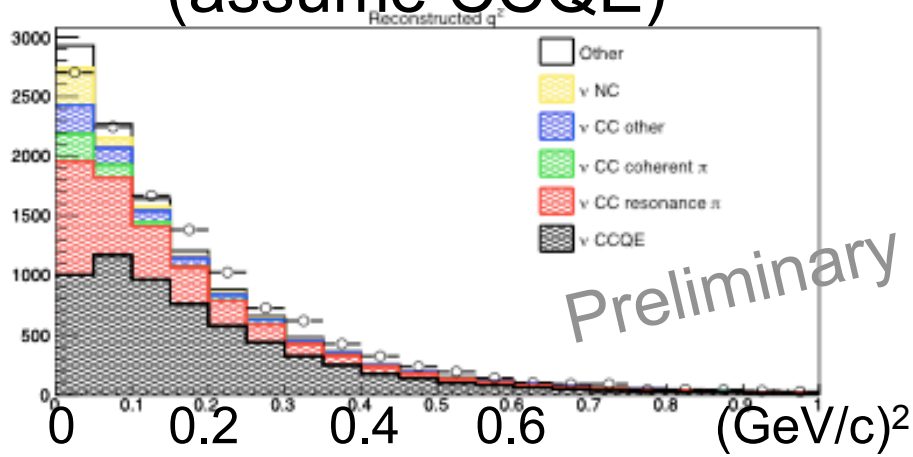
Y. Nakajima

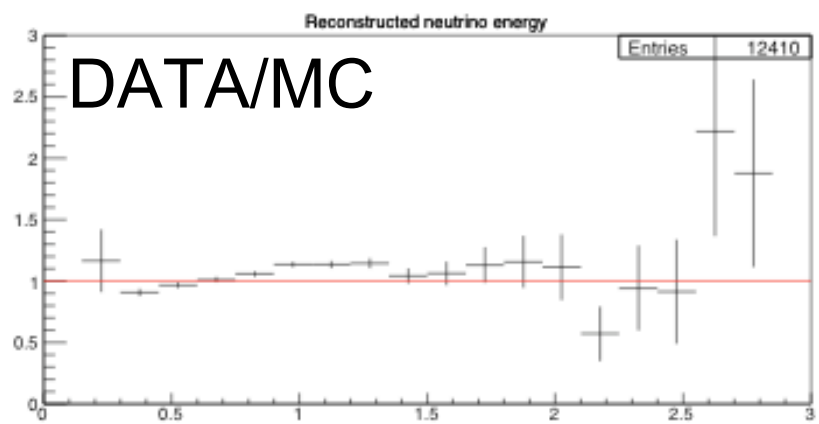
preliminary results

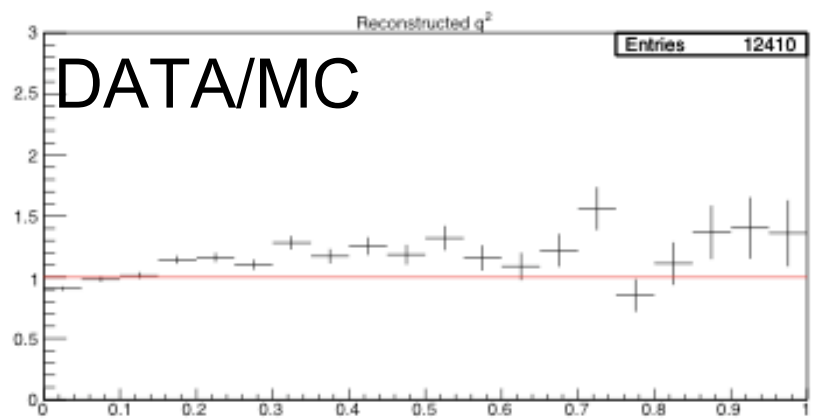
Reconstructed Eν (assume CCQE)

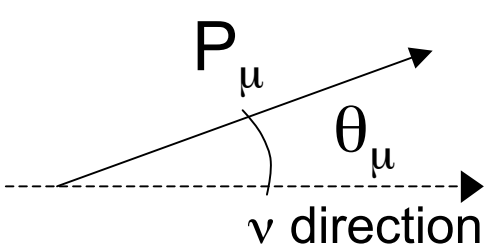


Reconstructed Q^2 (assume CCQE)









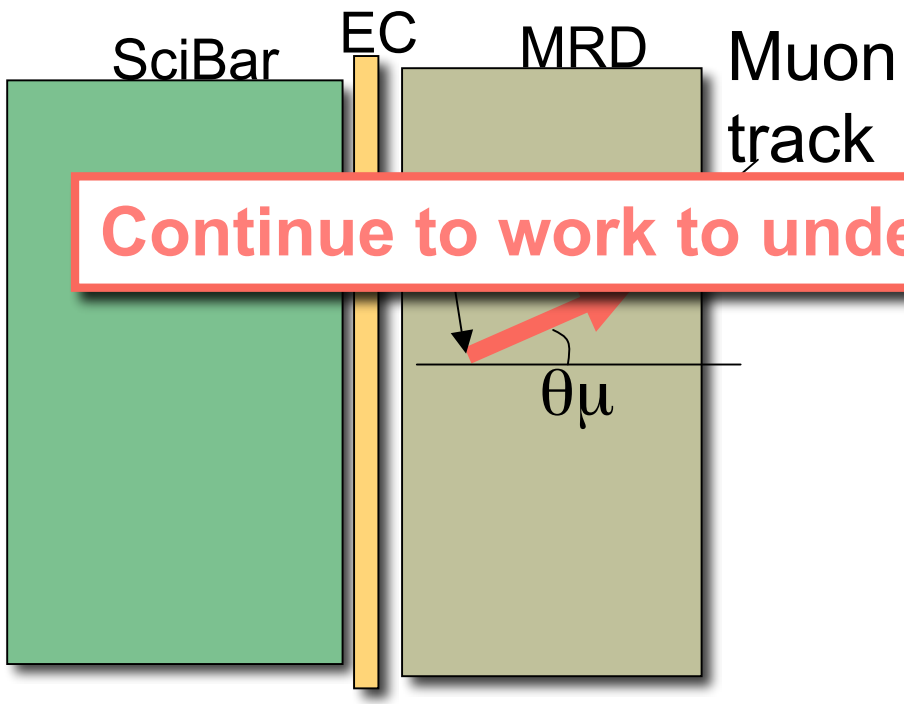
$$E_\nu^{rec} = \frac{m_n E_\mu - m_n^2/2}{m_n - E_\mu + P_\mu \cos\theta_\mu}$$

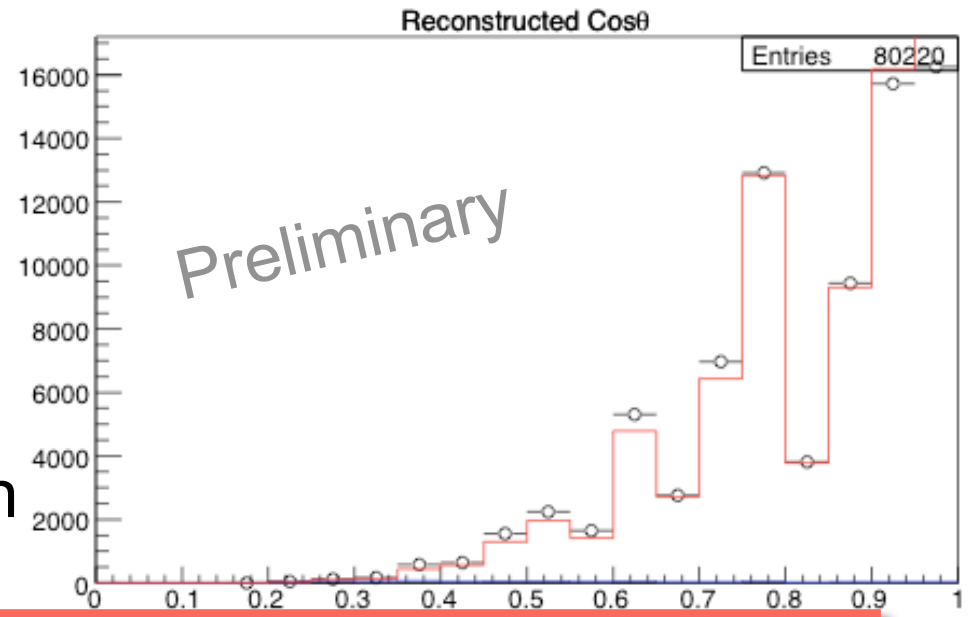
Assume CC-QE

Y. Nakajima

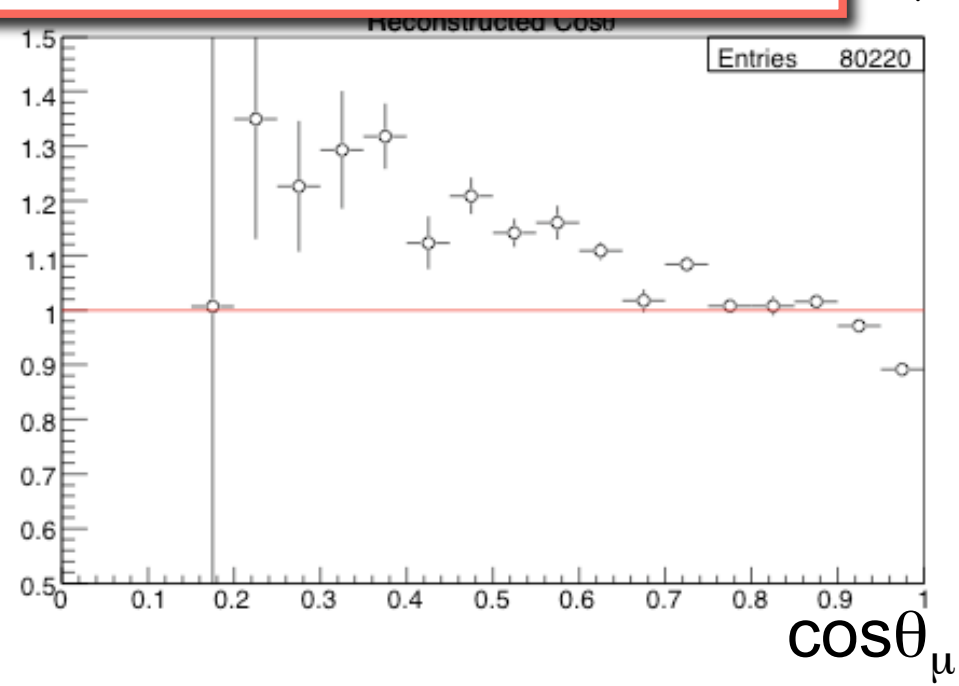
Independent Check on μ angle

- **ν events inside MRD**
- (SciBar not used for this sample)





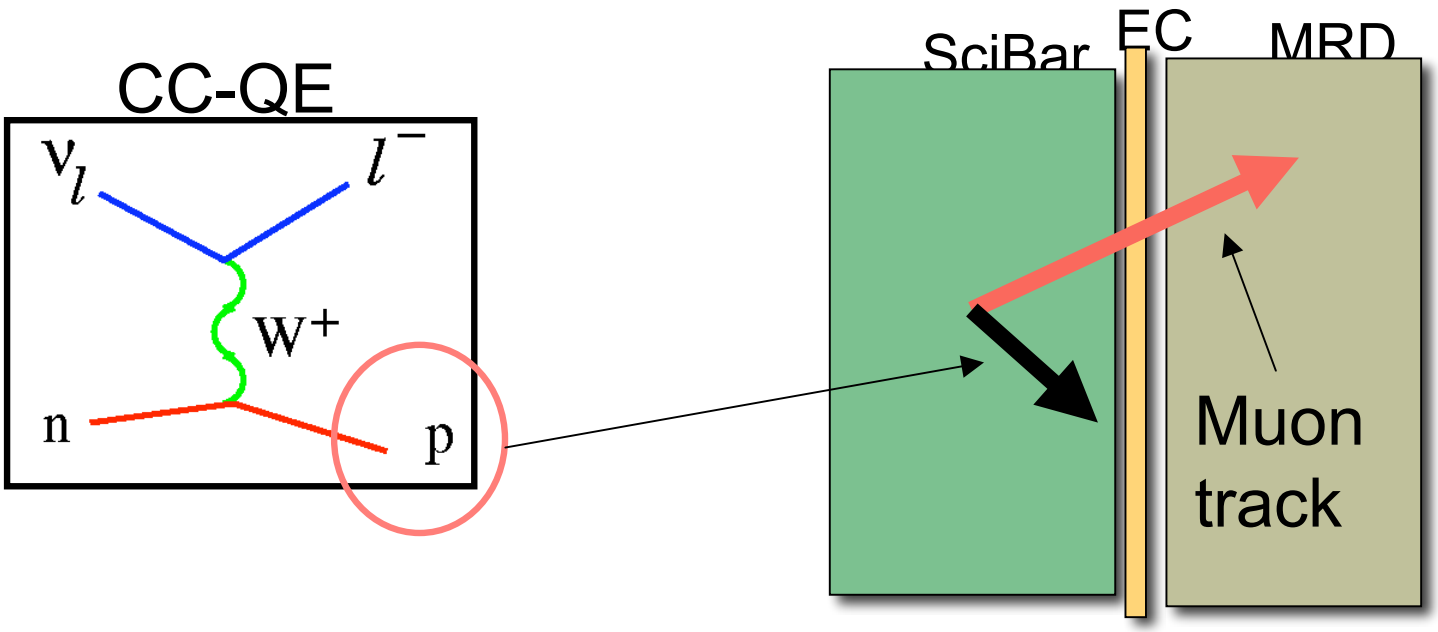
Continue to work to understand muon distribution



Data/MC disagreement is not caused by detector effect.

??Physics??

CC-Quasi Elastic

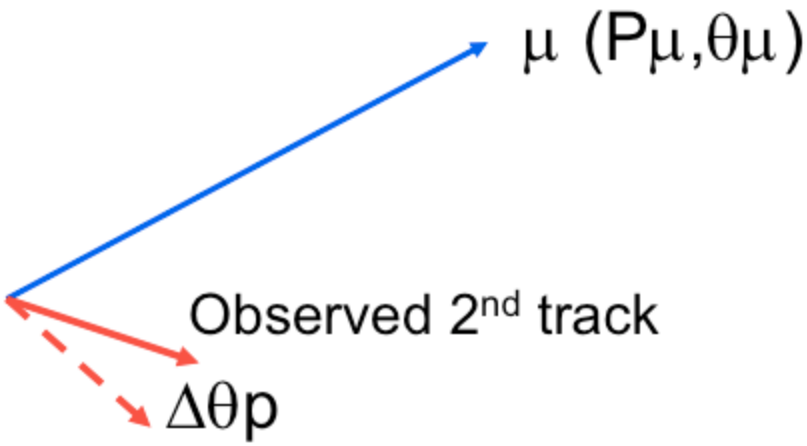


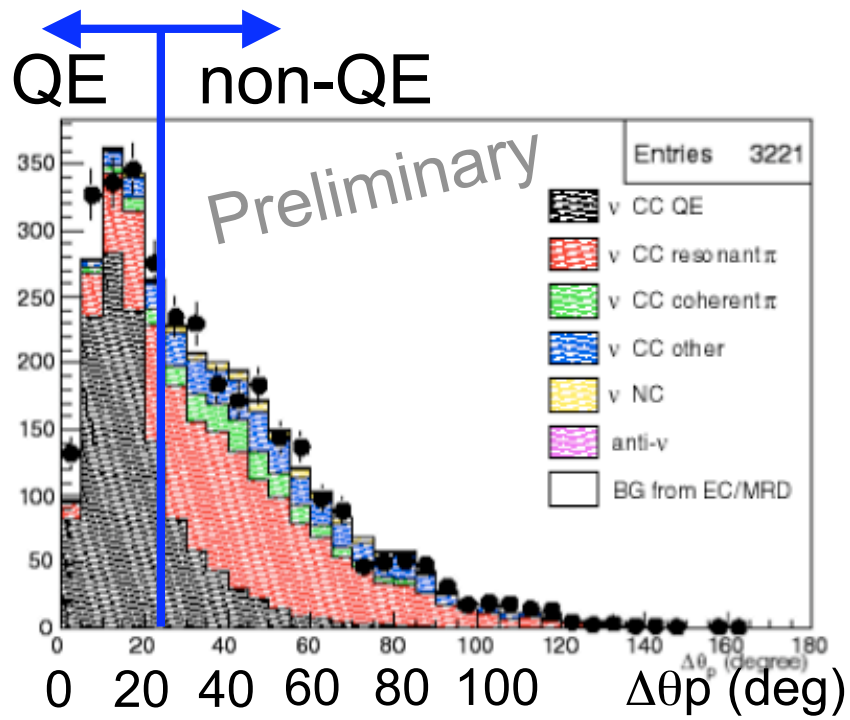
- Signature: muon + proton (2 track event)
- By looking at proton kinematics, separate CC-QE from other interactions.

CC-QE and non-QE separation: Δθp

K. Hiraide

Opening angle between observed 2nd track and expected proton track assuming CCQE.

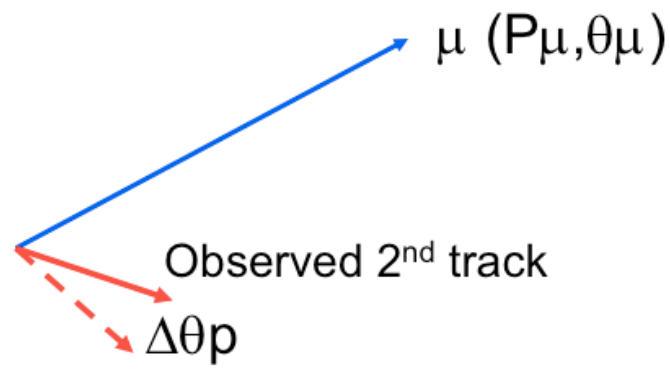




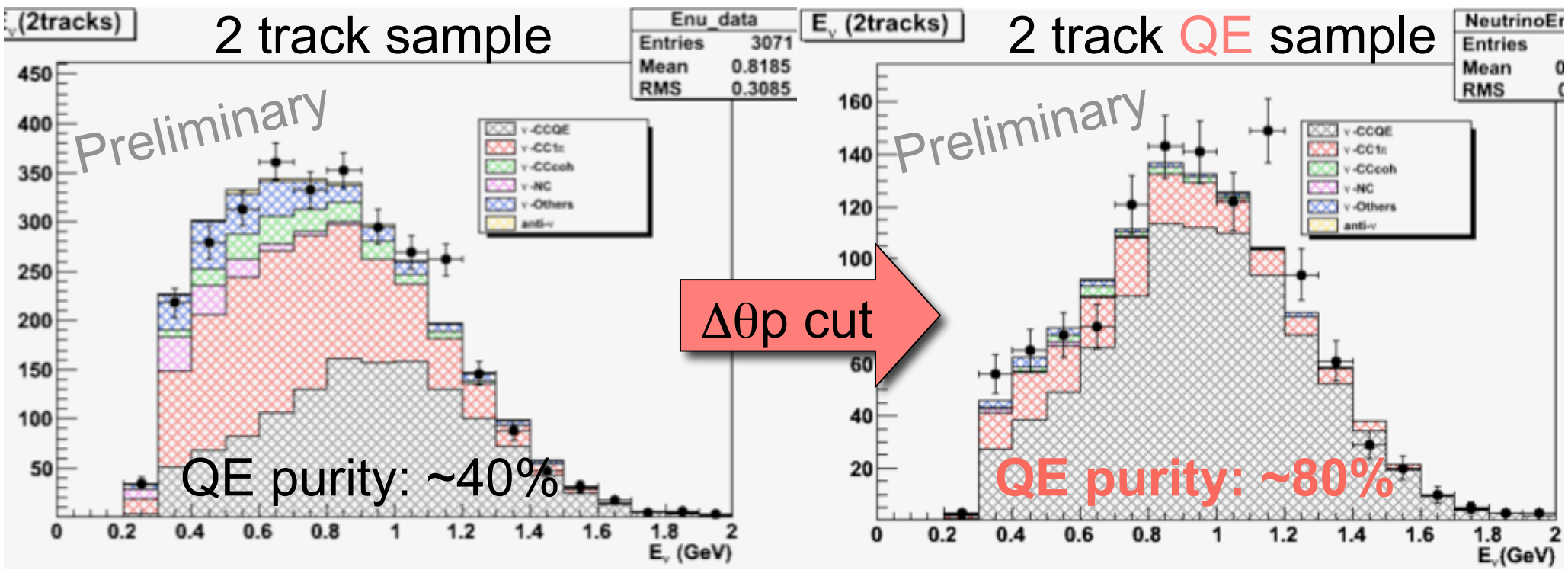
CC-QE

$\nu + p \rightarrow \mu + p$

Opening angle between observed 2nd track and expected proton track assuming CCQE.



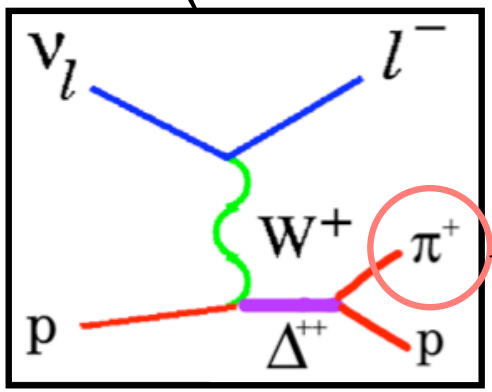
Jose Luis Alcaraz Aunion

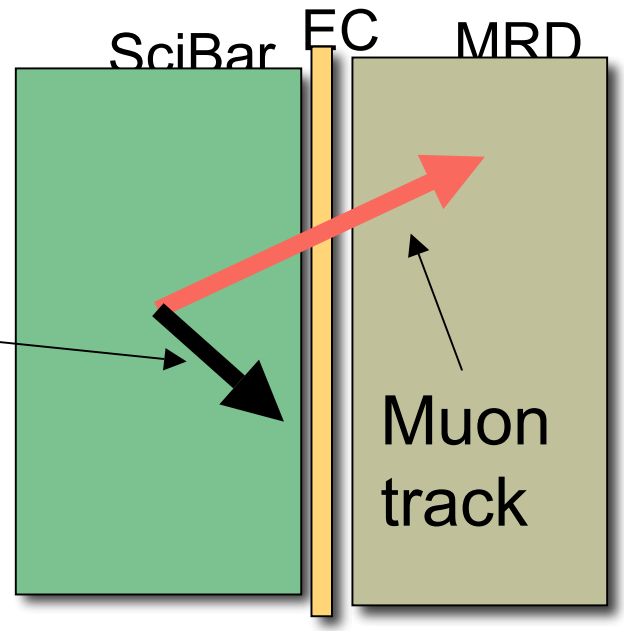


CC-$1\pi^+$

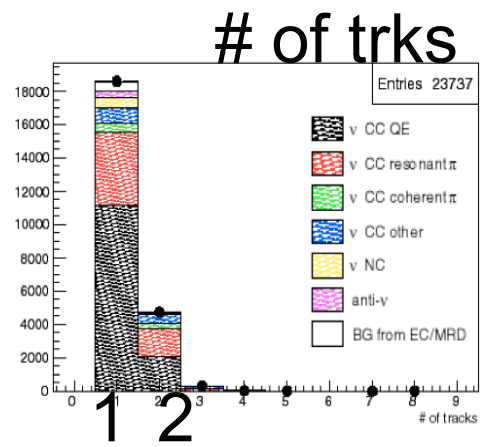
$\nu + p \rightarrow \mu + \pi + p$

CC-1π (resonance)



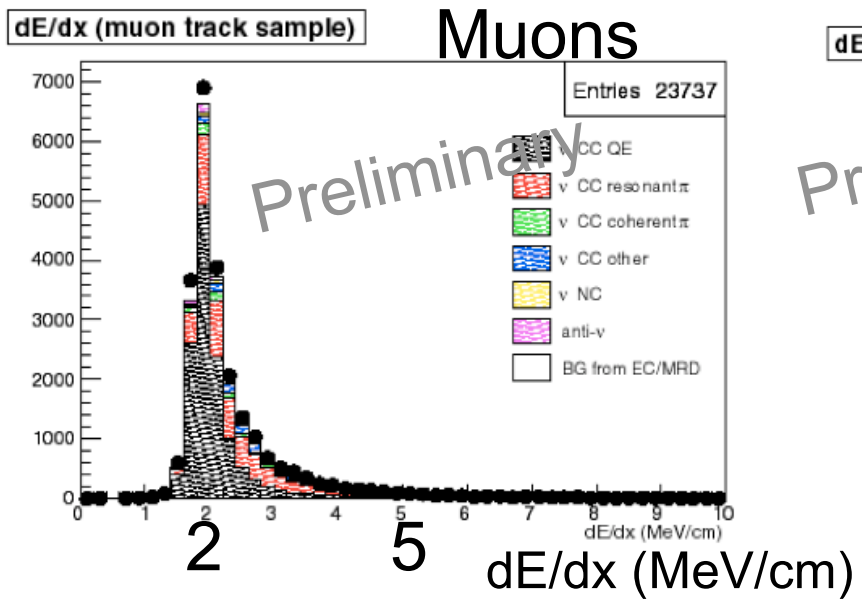


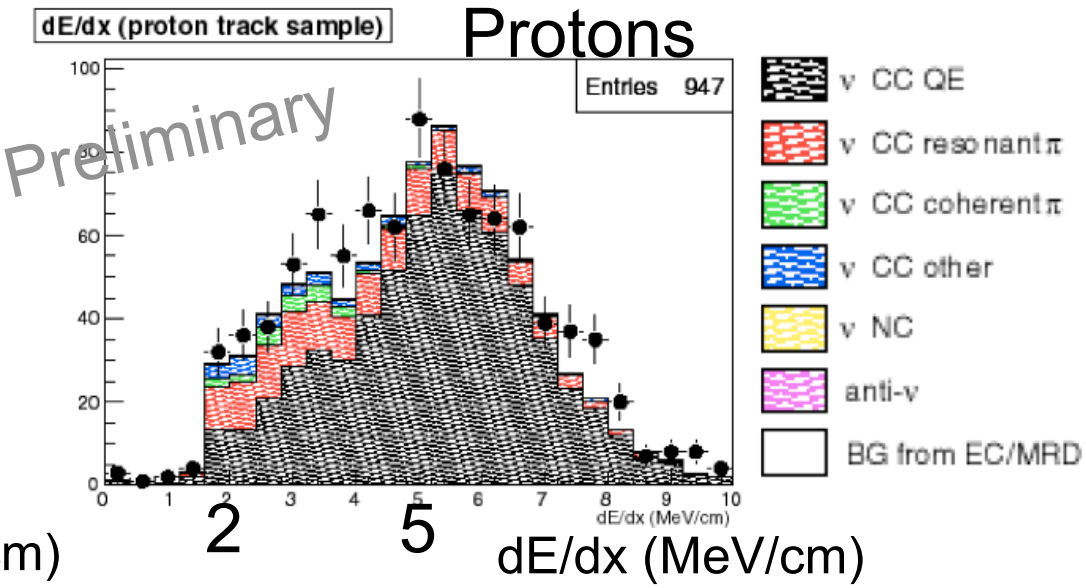
- Signature: muon + pion
  - CC-1π event: $\nu + p \rightarrow \mu + \pi + p$
  - 2 track event

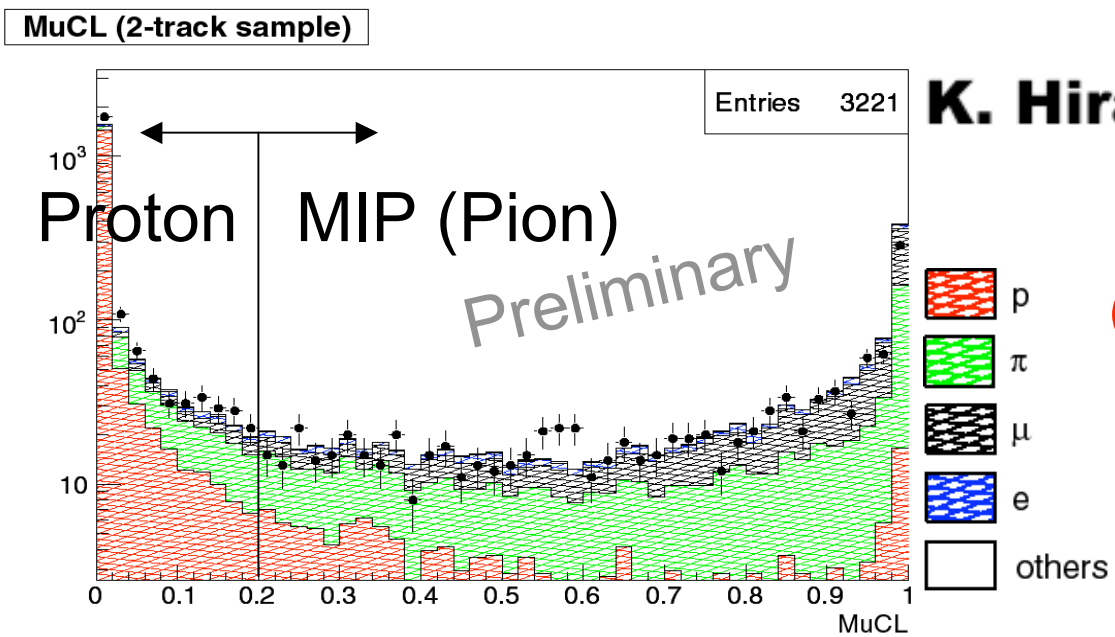


- By $\Delta\theta p$ & PID for 2nd track (π or p) separate CC-π from other ints.

Particle ID with dE/dx





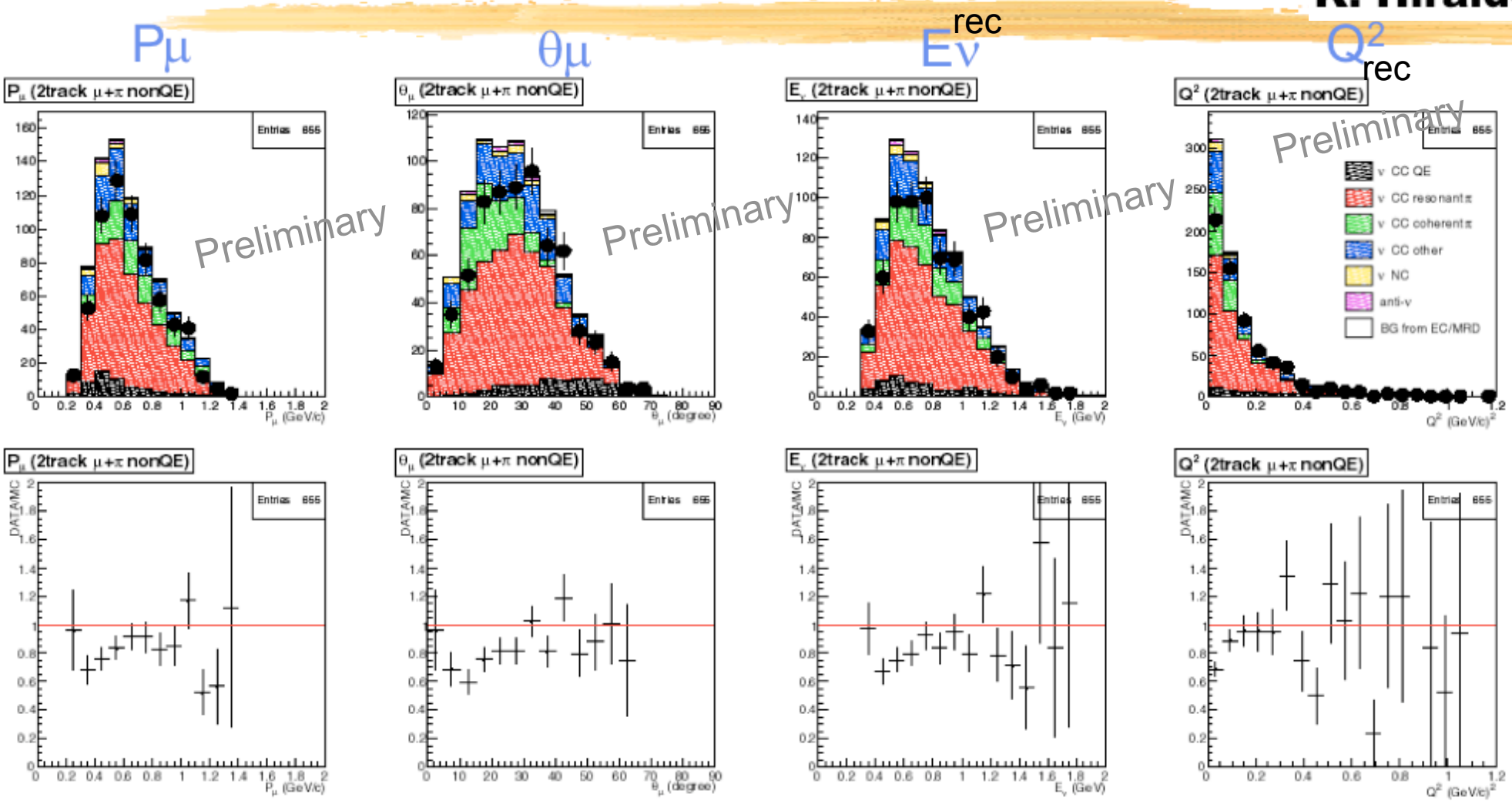


K. Hiraide

Proton mis-ID as pion = 7.2%
(Pion track efficiency = 74%)

CC-1π^+ (ν+N→μ+π+N') sample

K. Hiraide

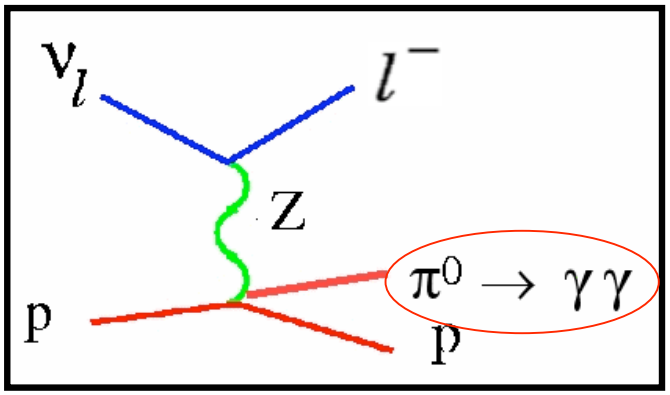


- Inclusive CC-1π
  - CC-resonance
  - CC-coherent
  - ….

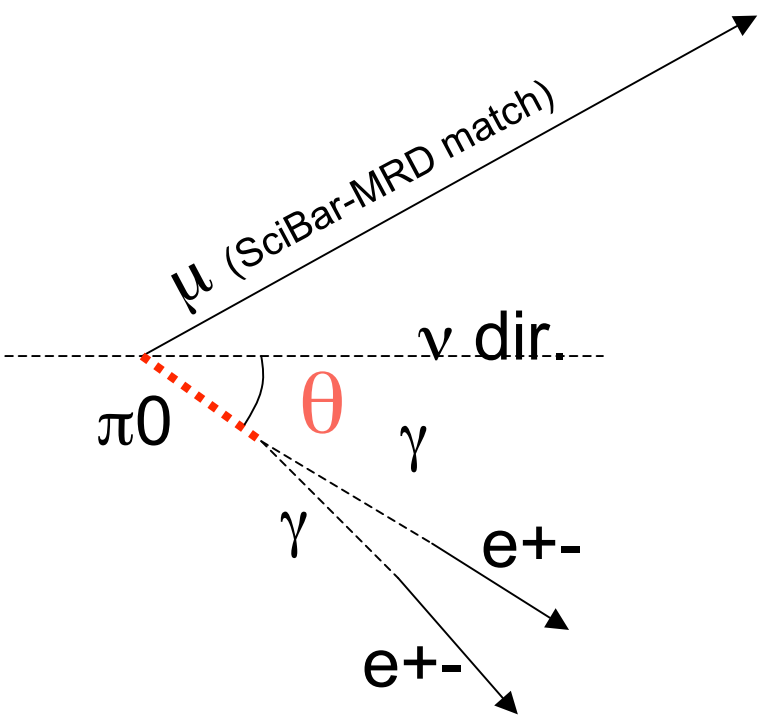
CC-π^0

$\nu + p \rightarrow \mu + p + \pi 0$

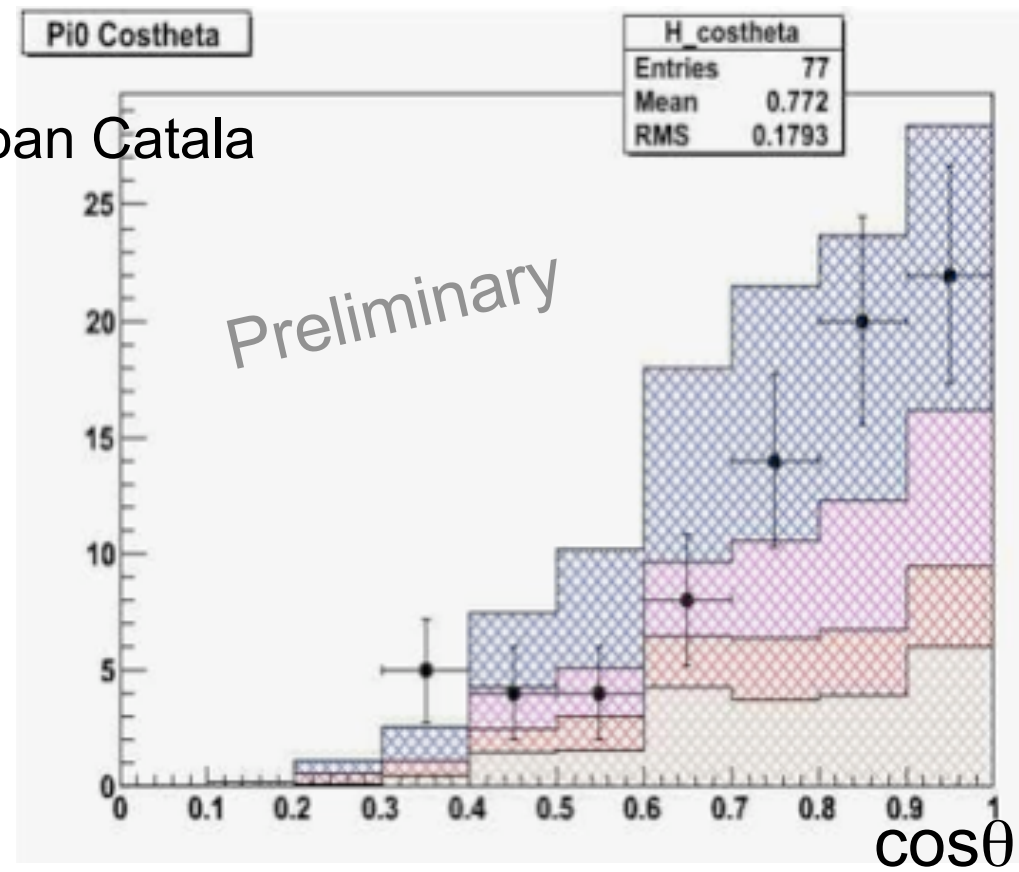
CC-π^0



- 3 track sample: $\mu + 2\gamma$ (from $\pi 0$)
- Reconstructed π^0 angle respect to ν-beam

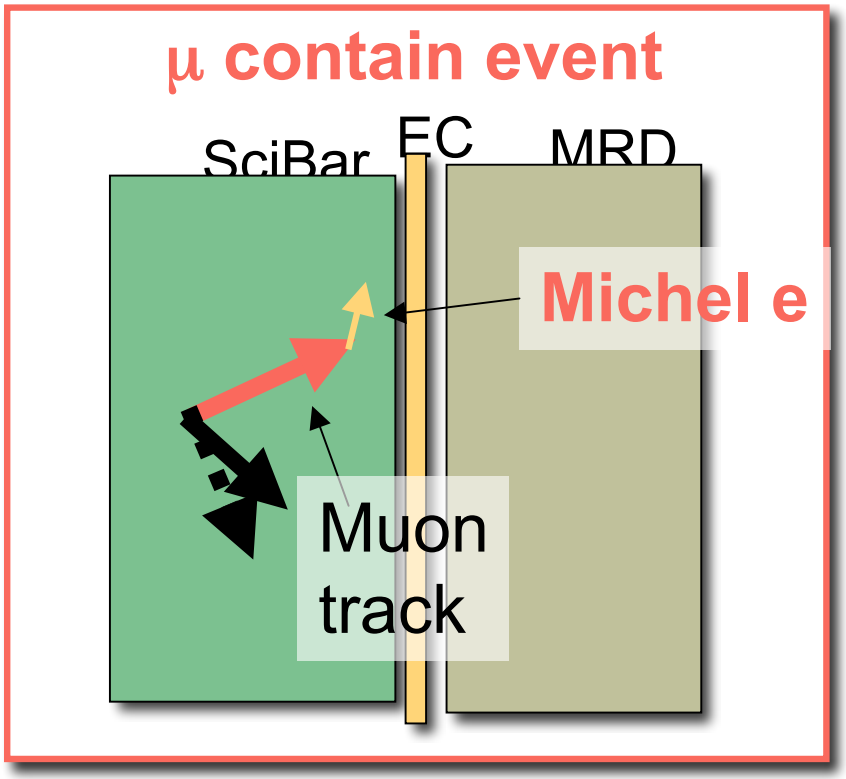


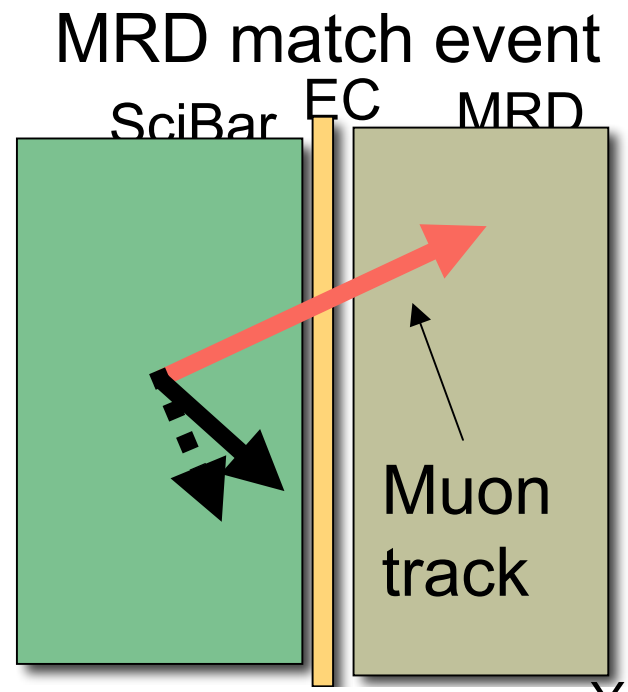
Joan Catala



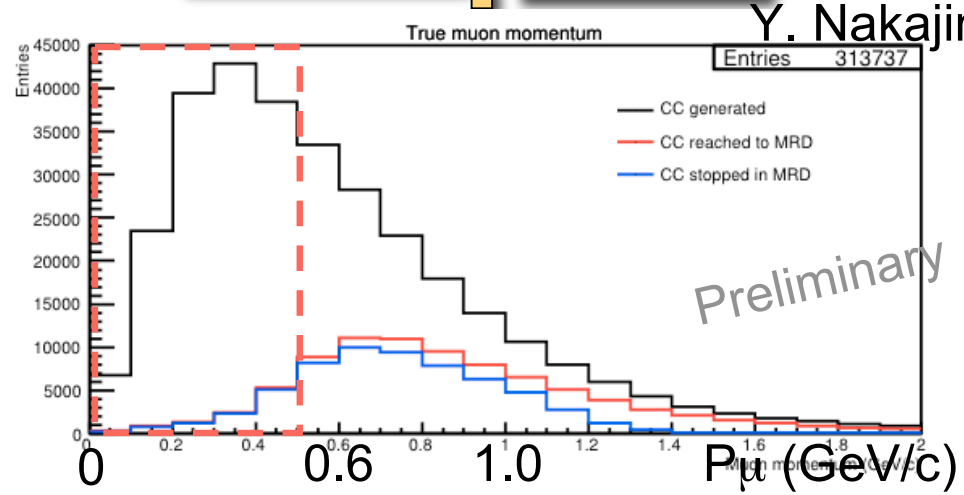
Advanced CC event sample

- So-called "μ contained (in SciBar) event"





Y. Nakajima



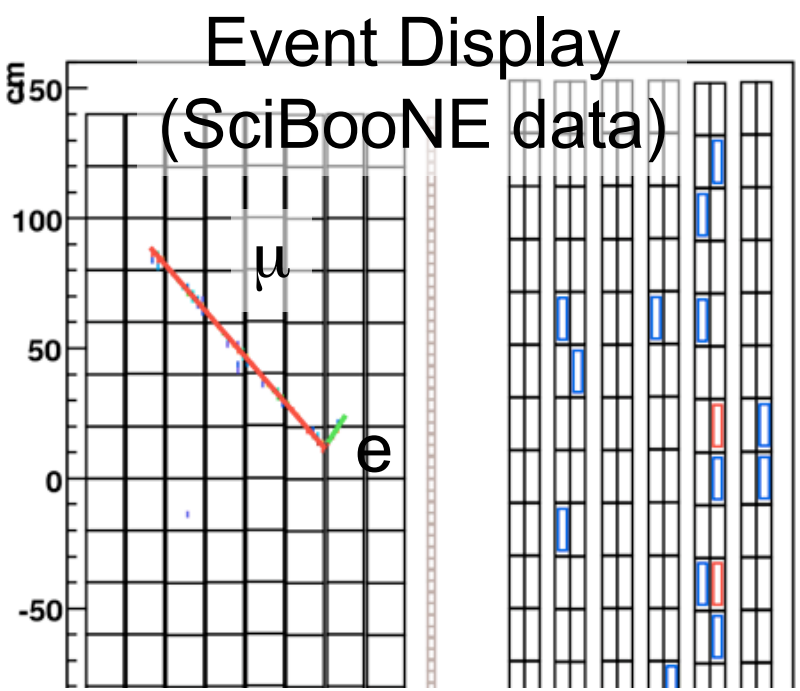
Muon stopped inside SciBar.

Corresponds to low energy events.

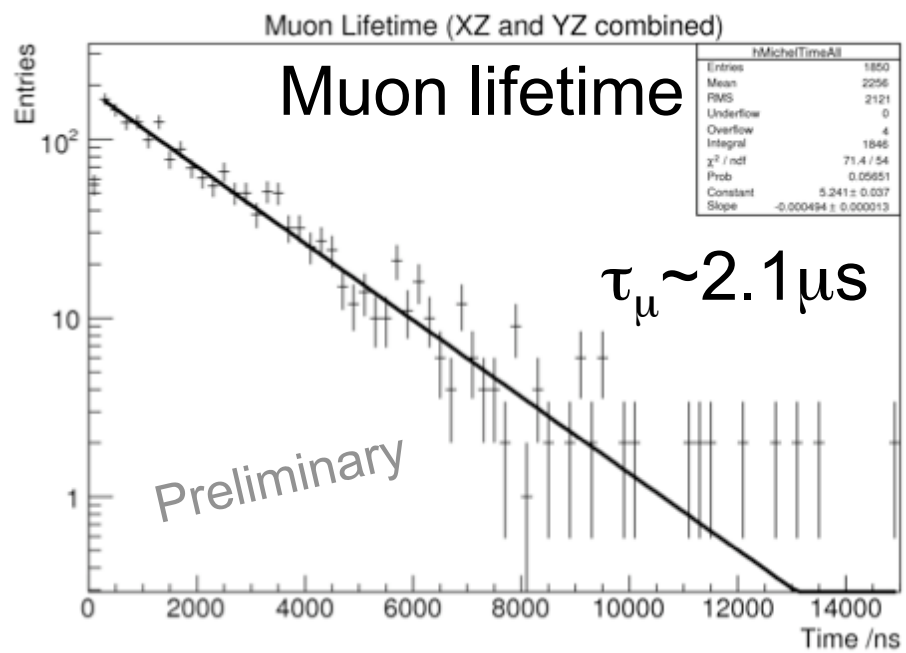
For muon ID, Michel decay electron can be used.

Muon ID for contain event:
Michel electron tagging

- Tag Michel electron with TDC info (multi-hit):
  - TDC hits of muon and Michel electron
- Clear signature of muon Michel decay



Joseph Walding



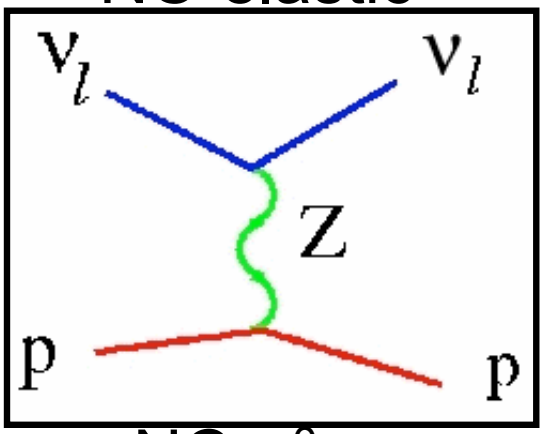
Neutral Current Analyses

NC-π^0, NC-elastic

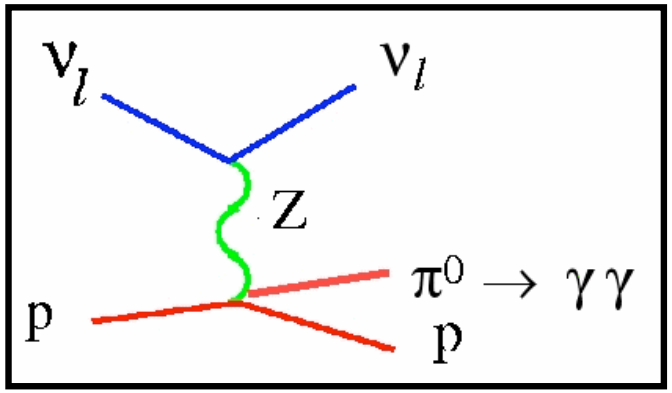
Feature of NC event at SciBooNE

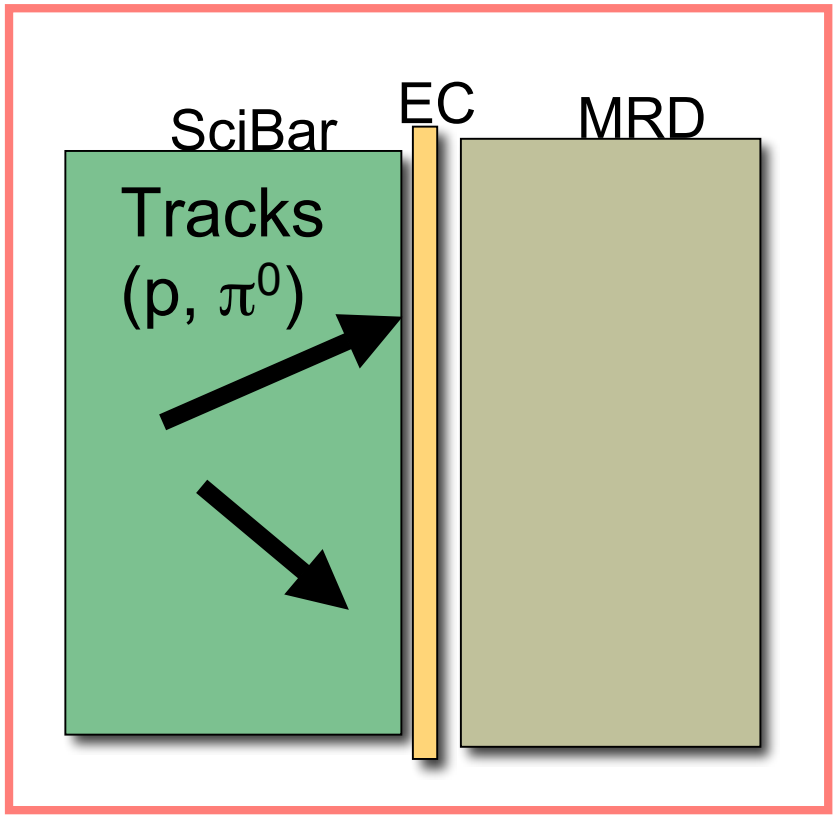
- No muon = No SciBar-MRD match track
- All tracks contained in SciBar

NC-elastic



NC-π^0

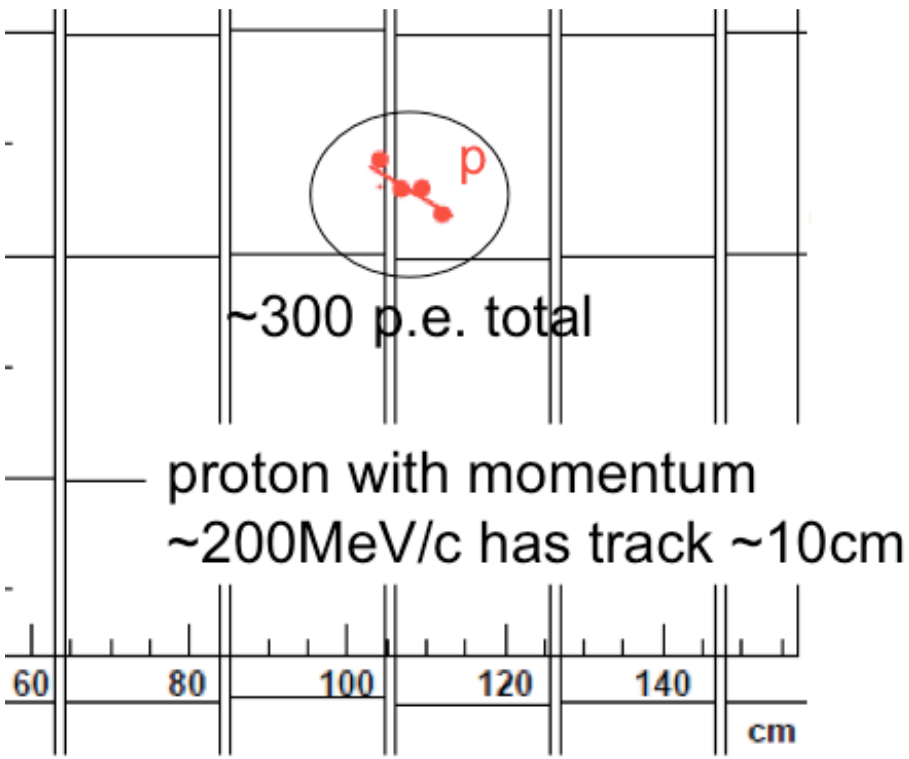




NC-elastic

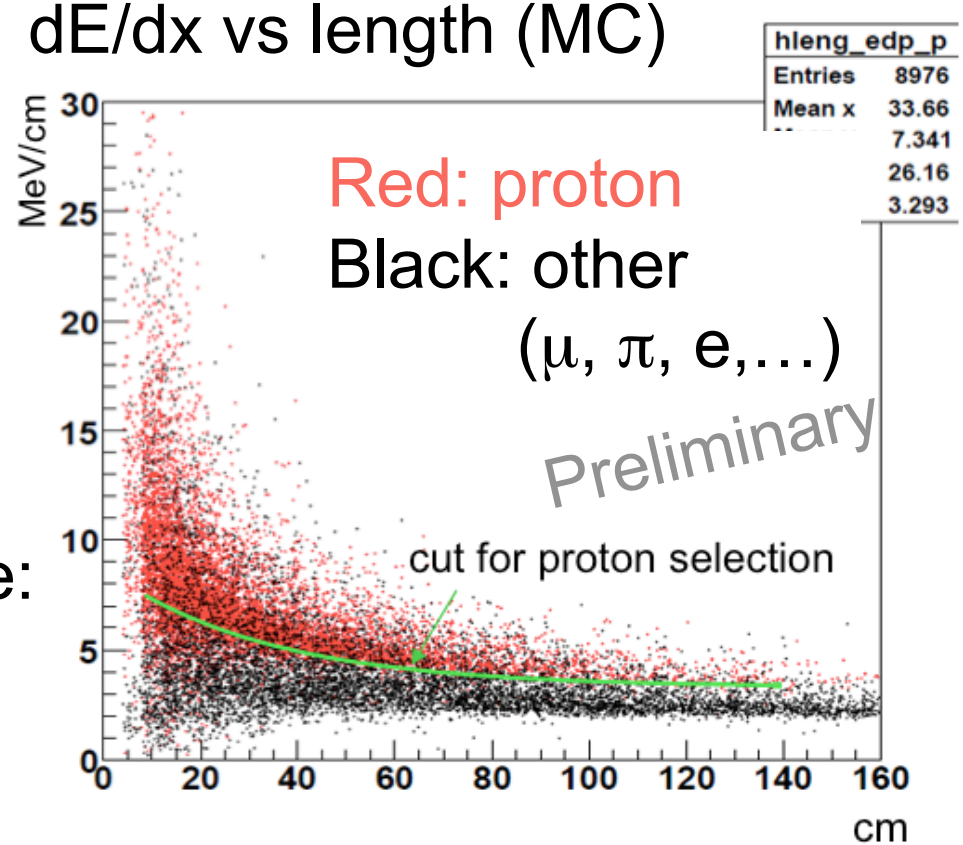
$\nu + p \rightarrow \nu + p$

H. Takei



- Only <u>1 proton track</u> contained in SciBar

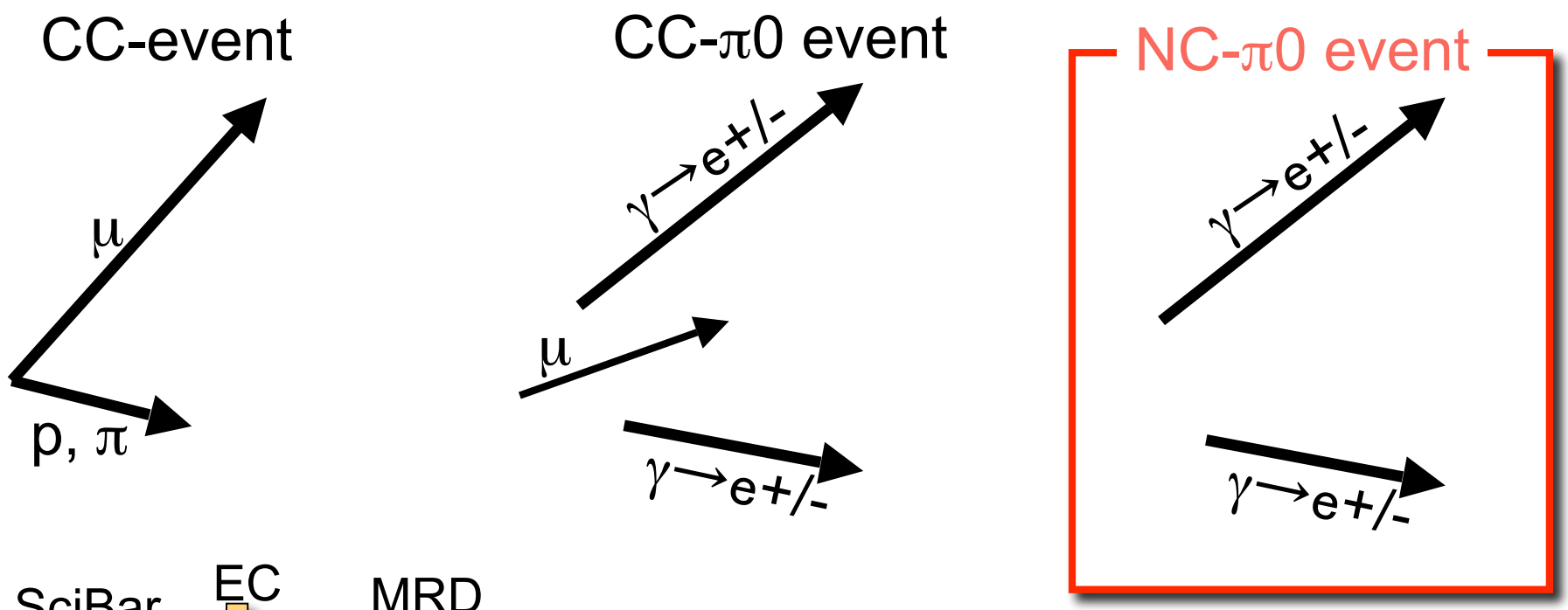
dE/dx vs length (MC)

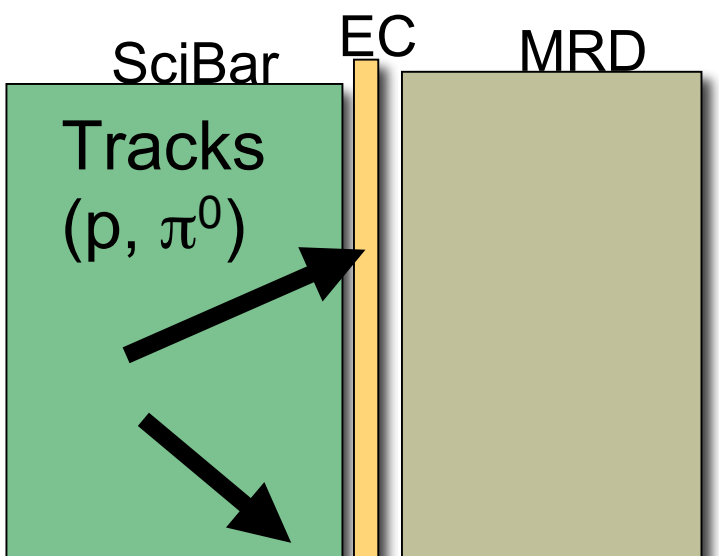


Proton selection performance:
Efficiency: ~83%
Purity: 77%

NC-π0

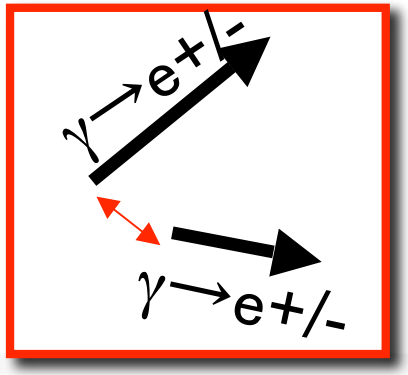
$$\nu + p \rightarrow \nu + \pi^0$$





- In order to select NC-π^0

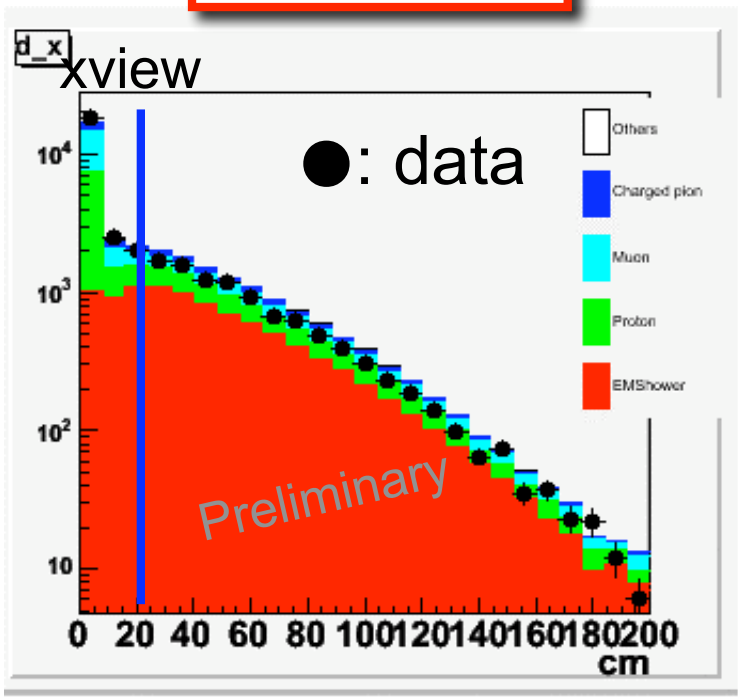
  ➔Reject: μ, π, p



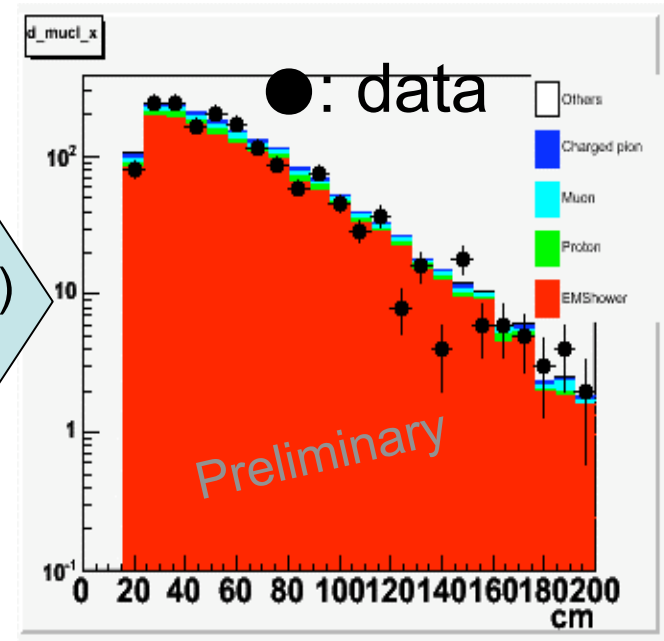
NC-π0

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

Y. Kurimoto



Reject:
Trk distance
Muon (by Michel e)
Proton (by PID with dE/dx)



Hist: MC

EMShower

NCπ0 (19%), CCπ0(17%)

Proton (19%)

Muon (17%)

Hist: MC

EMShower

NCπ0 (47%), CCπ0 (12%)

Proton (7%)

Muon (6%)

And…

- In this talk, I just showed “key” plots in each analysis
- Probably, you have a lot of questions…
- Meet SciBooNE students and talk with them!!

Summary → Introduction

- SciBooNE Experiment is ν experiment at FNAL
  - Precision measurement of ν & ν-bar cross sections at ~1GeV
  - Use SciBar and Booster Neutrino Beamline
  - Data taking have been started June, 2007
    - Through Aug. 2007: Antineutrino mode
    - Started Oct. 2007: Neutrino mode

- SciBooNE has excellent capability to study several neutrino interactions.

- Several physics analyses are in progress.
  - First results in this summer.