SciBooNE

a ν Experiment at Fermilab

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Outline

Neutrino Mixing/Oscillations

- Oscillation Measurements Status/Future
- Input to Oscillation Measurements

The SciBooNE Experiment

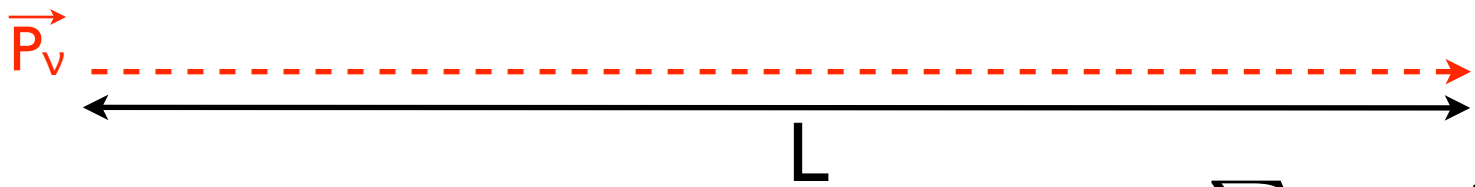
- SciBooNE Physics
- Detector & Performance
- Status and Schedule
- Preview of Data

Summary

Neutrino Mixing/Oscillations

Example:

- Simple, 2 state quantum mechanical system:



$$|\nu_\alpha(0)>=\sum_i U^*|\nu_i> \qquad |\nu_\alpha(L)>=\sum_i U^*_{\alpha,i}e^{-i(m_i^2/2E)L}|\nu_i>$$

$$U=\begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}$$

Assumptions:

- $E_\nu >> m_\nu$

$$P(\nu_\alpha\to\nu_\beta)=|<\nu_\alpha|\nu_\beta>|^2\approx\sin^2 2\theta\sin^2\left(1.27\frac{\Delta m^2 L}{E}\right)$$

For fixed Δm^2, P_{osc} depends on L/E

- modifies number of ν_α observed at L
- modifies $E(\nu_\alpha)$ observed at L

3 Component Oscillations/Mixing

Mixing similar to quark Cabibbo-Kobayashi-Maskawa (CKM) matrix

- 3 angles
- 1 phase (CP violating)
- Assuming no Majorana neutrinos ($\nu = \overline{\nu}$)

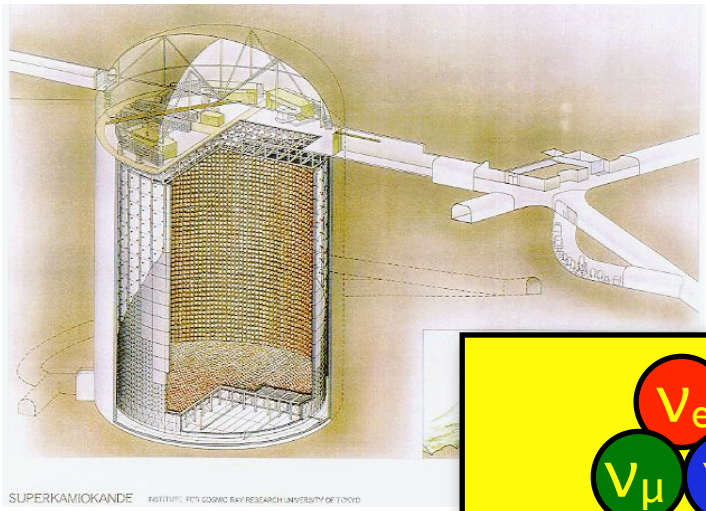
$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

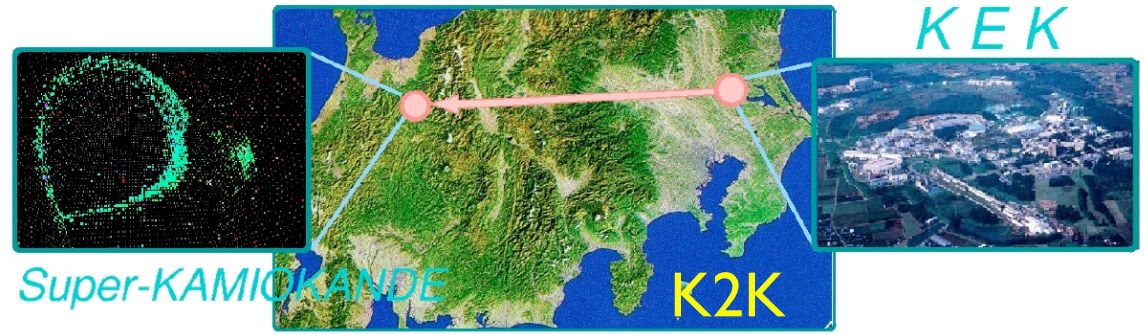
$$c_{ij} = \cos\theta_{ij}$$
$$s_{ij} = \sin\theta_{ij}$$

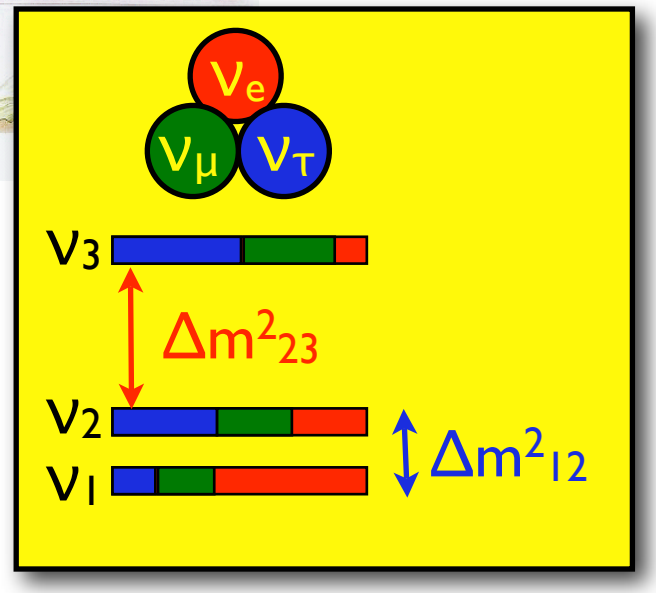
phase allows for CP violation

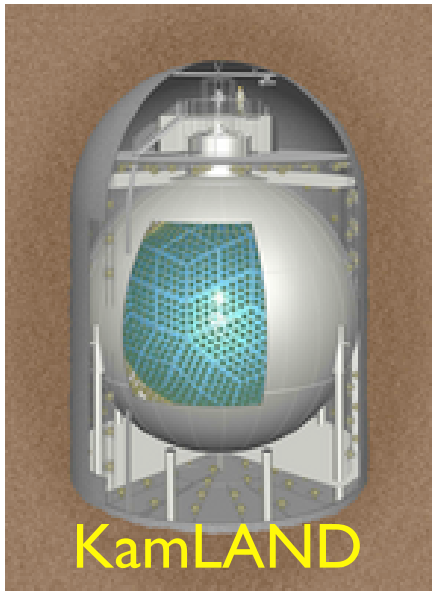
Neutrino Oscillations (1998 - 2005)

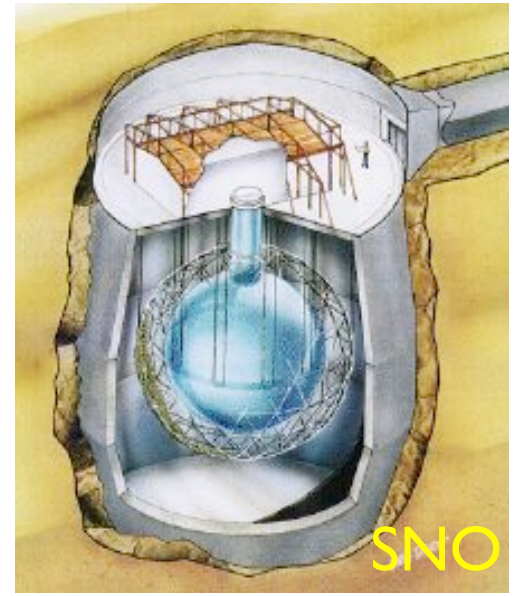
Super-Kamiokande









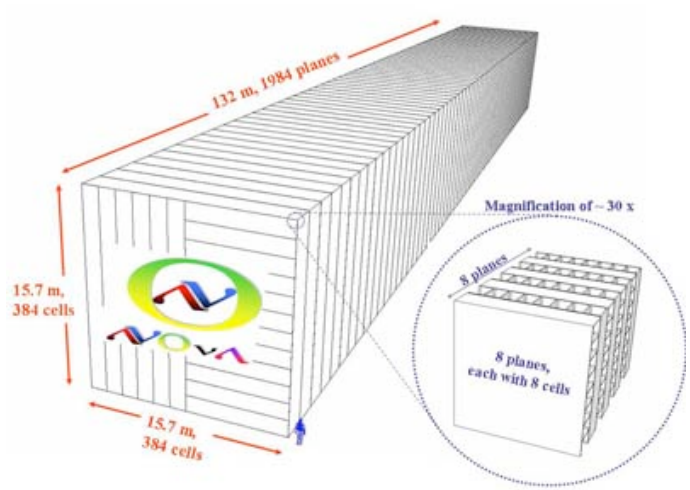


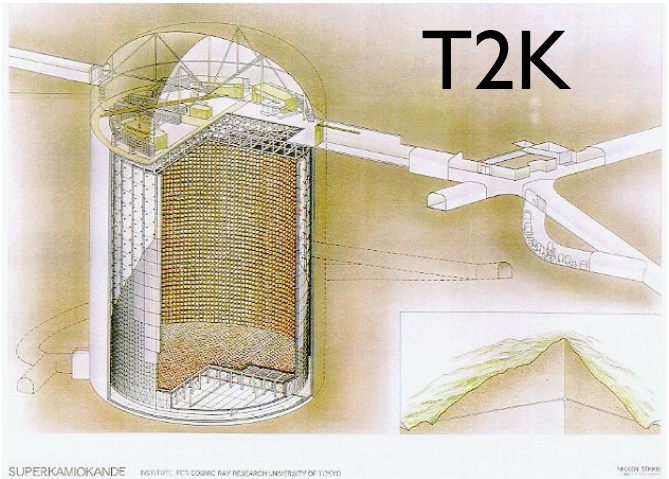
Measurements establish:

- Neutrino Masses (Δm^2_{12}, Δm^2_{23})
- Mixing Angles (θ_{12},θ_{23})

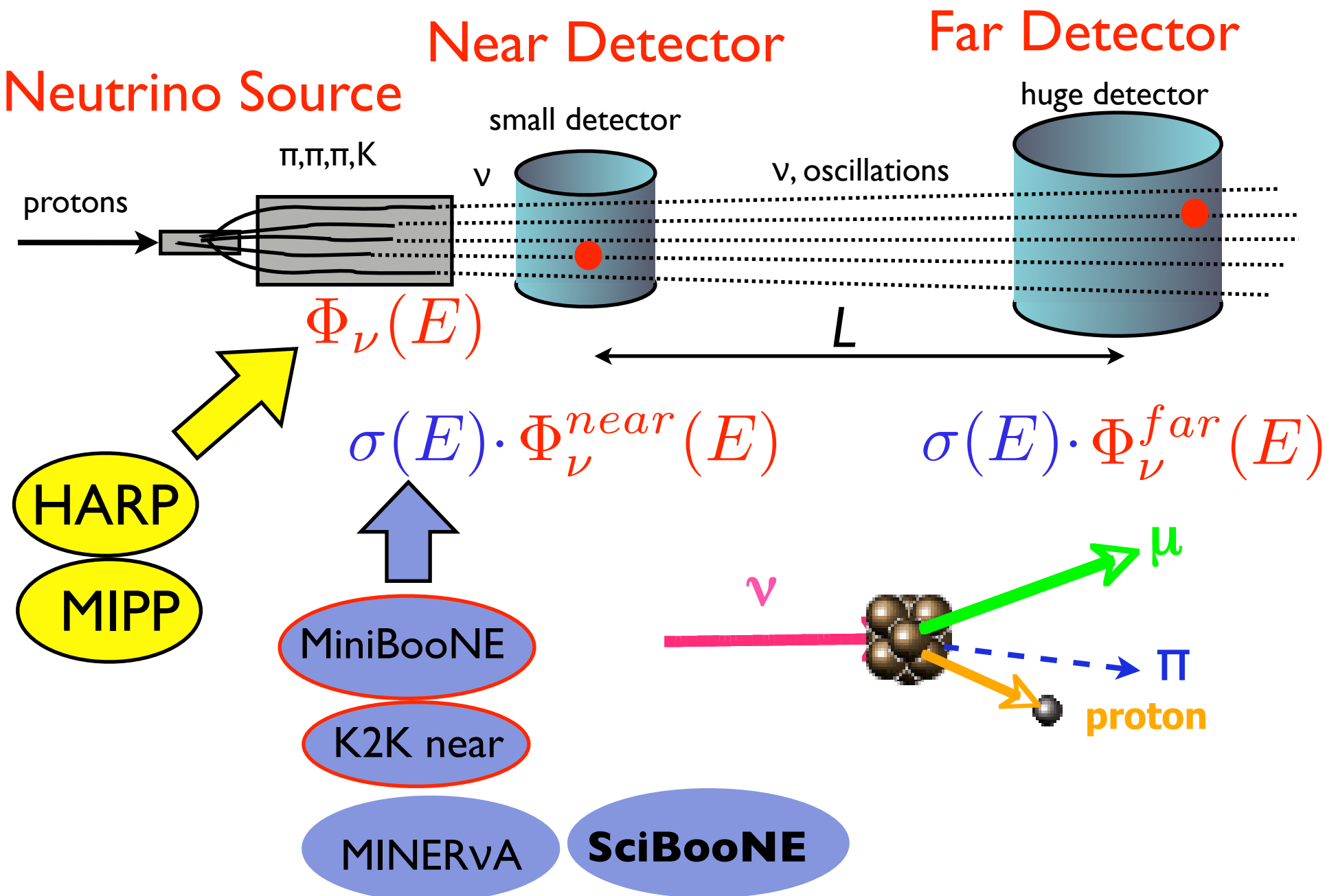
Next Step (2006 - 2015)

- Measure the last oscillation channel
  - θ_{13}
- CP violation in lepton sector (ν, $\bar{\nu}$)
  - δ
- Mass heirarchy
  - sign of Δm^2_{23}
- Test of standard ν oscillation scenario (U_{MNS})
  - Precise measurements of ν oscillations (Δm^2_{23}, θ_{23})



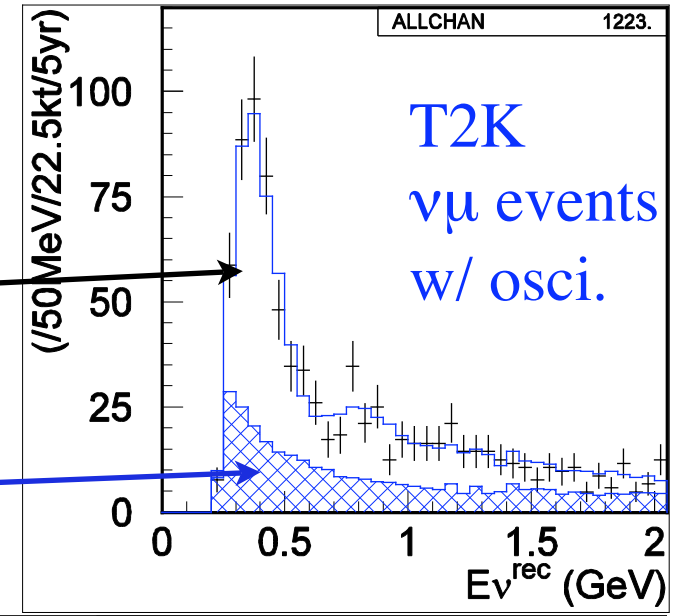


Accelerator based ν Oscillations

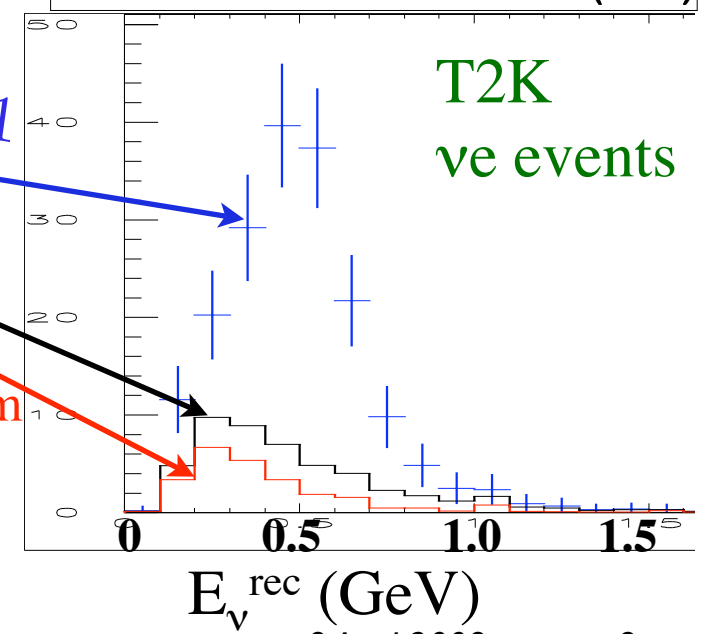


Impact of Neutrino Cross Sections on Oscillation Measurements

- $\nu_\mu \rightarrow \nu_\mu$: precision measurements (θ_{23} and Δm_{23}^2)
  - Signal: CC-QE ($\nu+n \rightarrow \mu+p$)
    - Energy Reconstruction from μ kinematics
  - Background: Mainly CC-1$\pi^\pm$ ($\nu+N \rightarrow \mu+\pi+N'$)
    - Cross section with **the visibility of π**
- $\nu_\mu \rightarrow \nu_e$: search for θ_{13}
  - Signal: CC-QE ($\nu+n \rightarrow e+p$)
  - Background
    - Beam ν_e
    - NCπ^0
      - Cross section as a function of the momentum



$\sin^2 2\theta_{13} = 0.1$

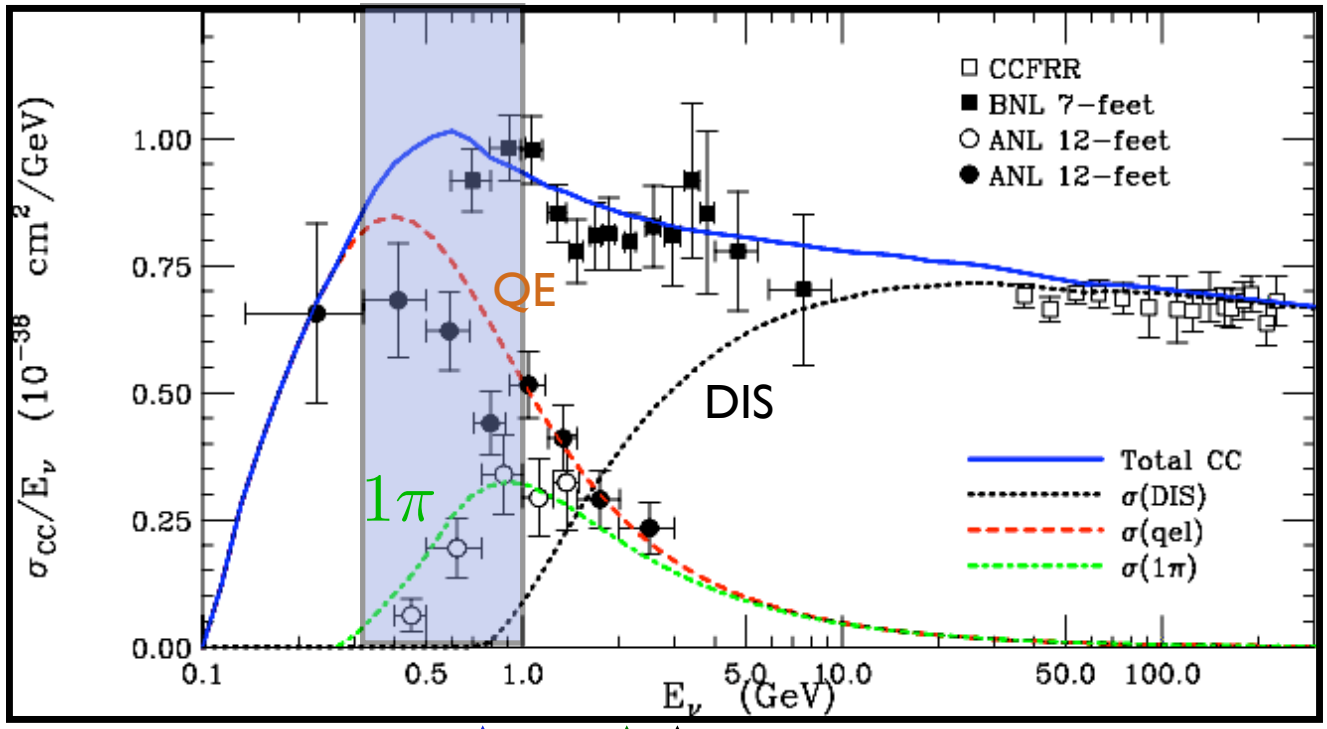


Anti-neutrinos for CP violation study

Unexplored Areas of Neutrino Physics

- **Data from old experiments** (1970~1980)
  - Low statistics
  - Systematic Uncertainties
- **Nuclear effects** (π/p/n absorption/scattering, shadowing, low Q^2 region)
  - Not well-modeled
- **New data** from MiniBooNE & K2K revealing surprises
- **More data at 1GeV with fine grained resolution will advance Neutrino Physics.**

σ_ν energy range of interest



MINOS, NuMI

K2K, NOνA

MiniBooNE, T2K, SciBooNE

Super-K atmospheric ν

Existing Cross Section Measurements

What's Missing from K2K and MiniBooNE Cross Section Measurements?

- Good Q^2 resolution to understand nuclear effects
  - Need true nuclear models in Monte Carlo
- Resonant/coherent separation for background measurements
- Multiparticle final states
- Antineutrino measurements
- Absolute σ measurements for non-QE channels

Needed to tune neutrino cross section Monte Carlos

All needed for next generation oscillation measurements

Prototype Experiment

Fine-segmented tracking detector with an intense low energy neutrino beam.

- SciBar Detector
  - + Well working tracking detector in K2K
  - + Fine granularity (2.5x1.3 cm^2) Fully Active
  - + Particle ID capability
- FNAL Booster Neutrino Beam
  - + Intense, low energy (~ 1 GeV) beam
  - + Both neutrinos and anti-neutrinos.
  - + Beam well-understood from hadron production experiments (HARP/BNL-E910).

SciBooNE Experiment

What is SciBooNE?

- A new Fermilab experiment to measure cross sections in the booster neutrino beam.
- Small, cheap, focused, short time scale experiment.

How to make a small, cheap focused short time scale experiment

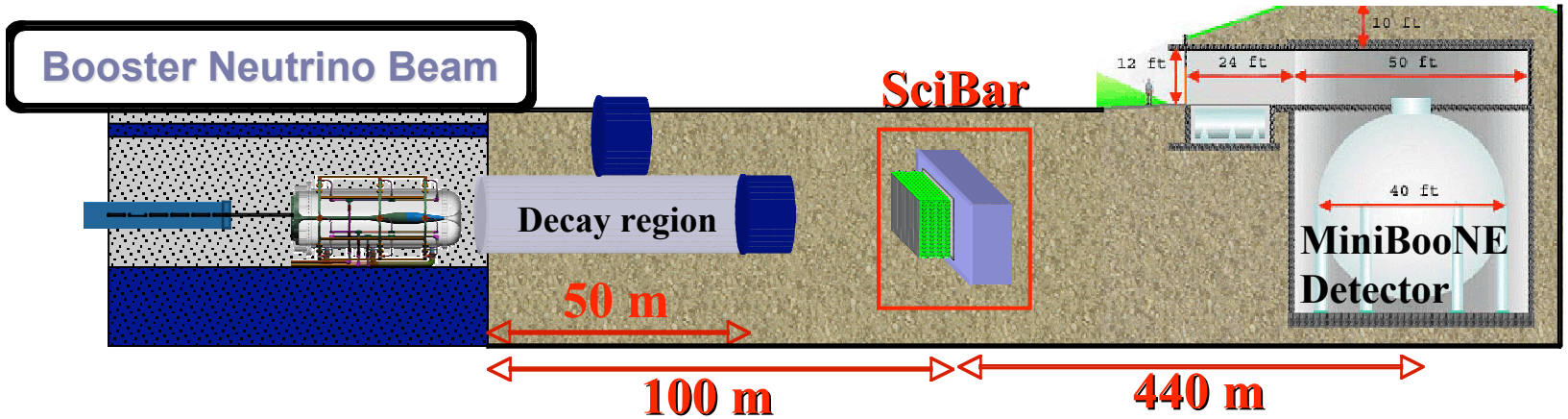
- Re-cycle detector materials from previous experiments.
- Use an existing beam line
- Young, highly motivated collaboration

SciBooNE Collaboration

- Universitat Autonoma de Barcelona
- University of Cincinati
- University of Colorado
- Columbia University
- Fermilab
- KEK
- Imperial College London
- Indiana University
- Institute for Cosmic Ray Research
- Kyoto Univerisity
- Los Alamos
- Louisiana State University
- Purdue University, Calumet
- Sapienza Universita di Roma
- St Mary's University of Minnesota
- Tokyo Institute of Technology
- Universidad de Valencia

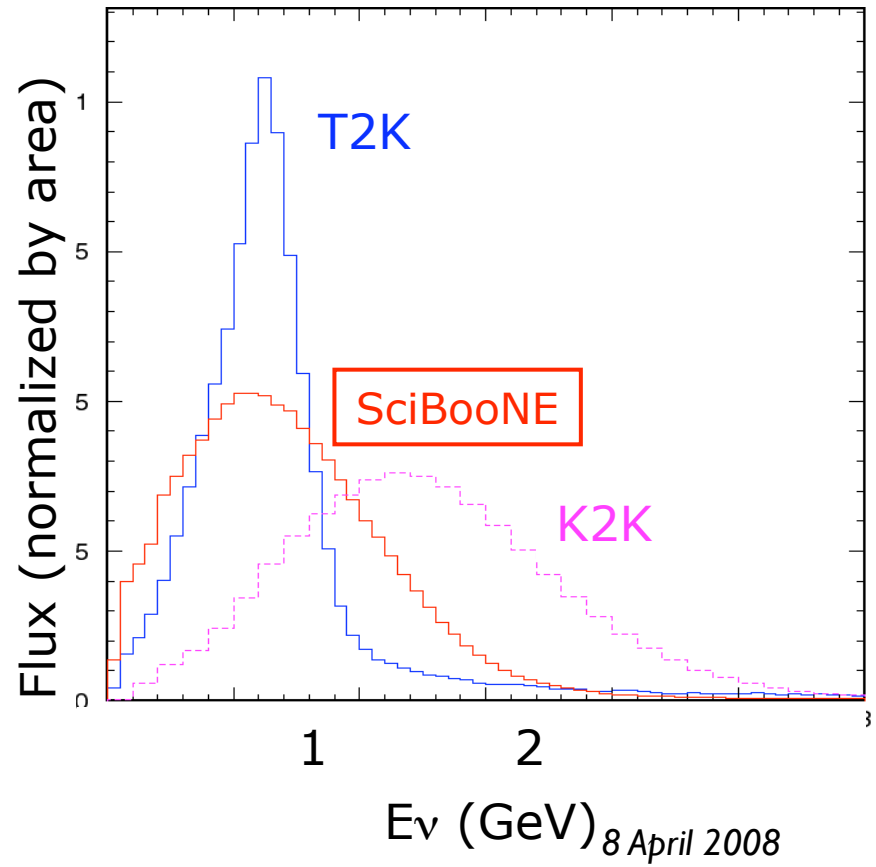
17 Institutions 5 Countries

SciBooNE Experiment

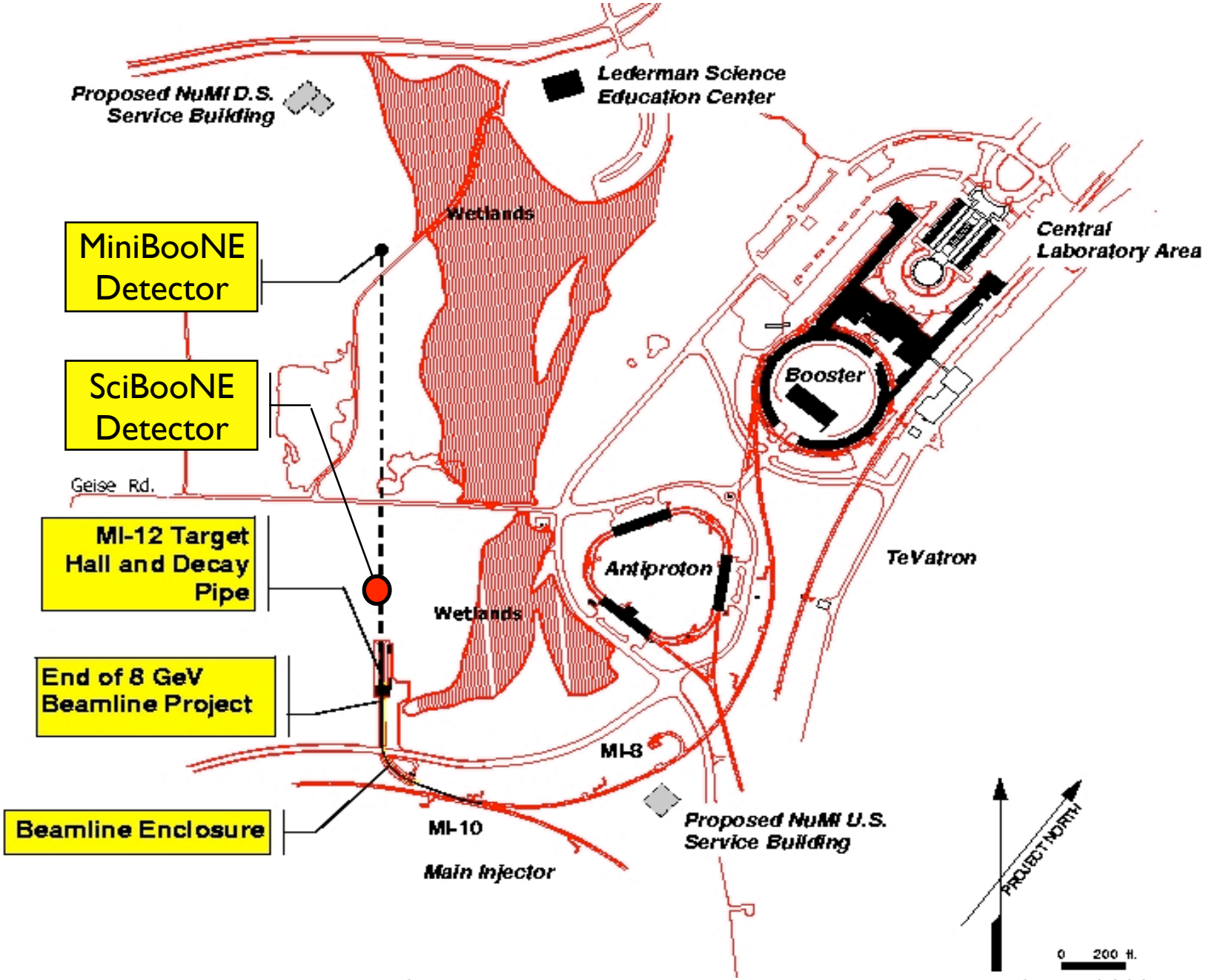


Booster Neutrino Beam

- 8 GeV protons on Be target
- Horn focuses 1 charge sign (π,K)
- π,K decay to neutrinos
- Undecayed beam & daughter particles stopped
- Neutrino spectrum similar to T2K

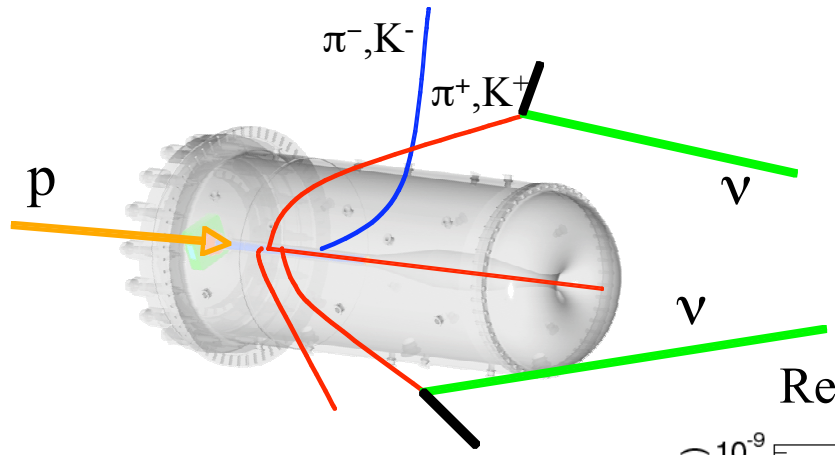


SciBooNE Location

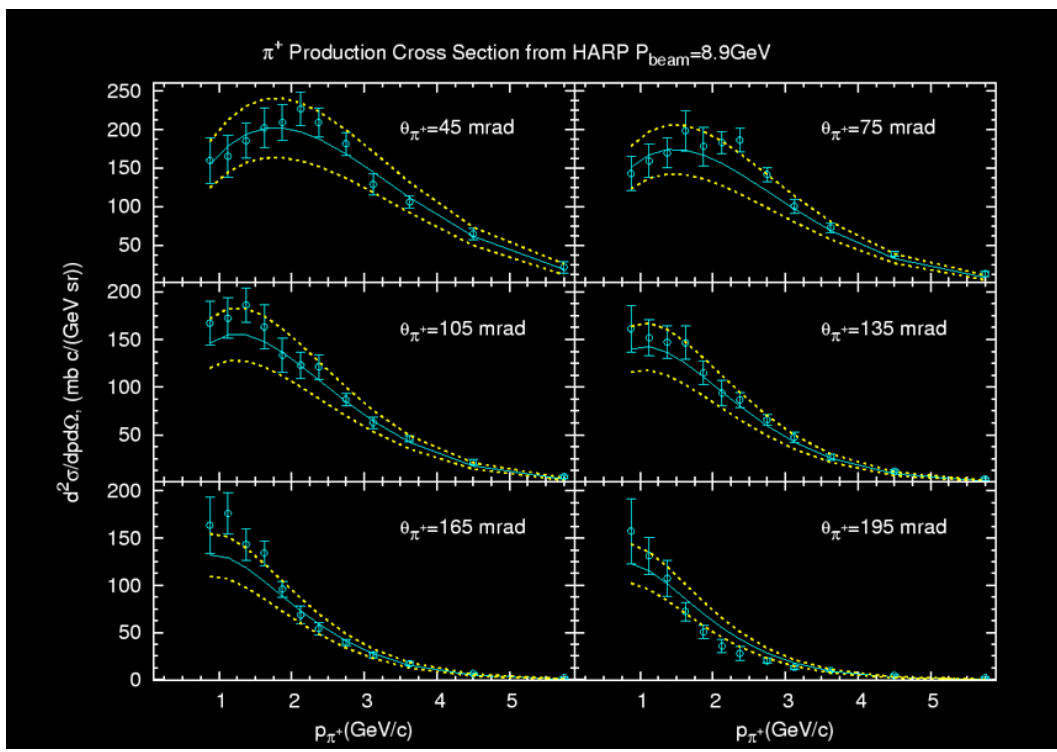


FNAL Booster Neutrino Beam

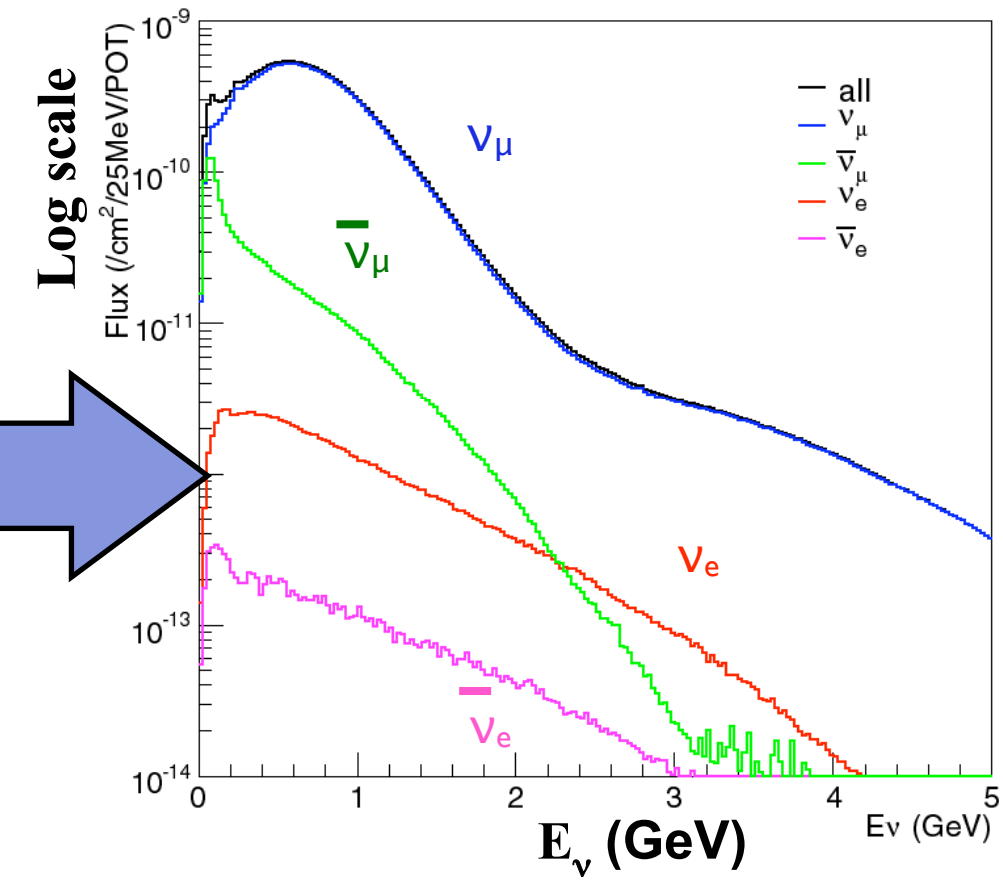
Reversable horn



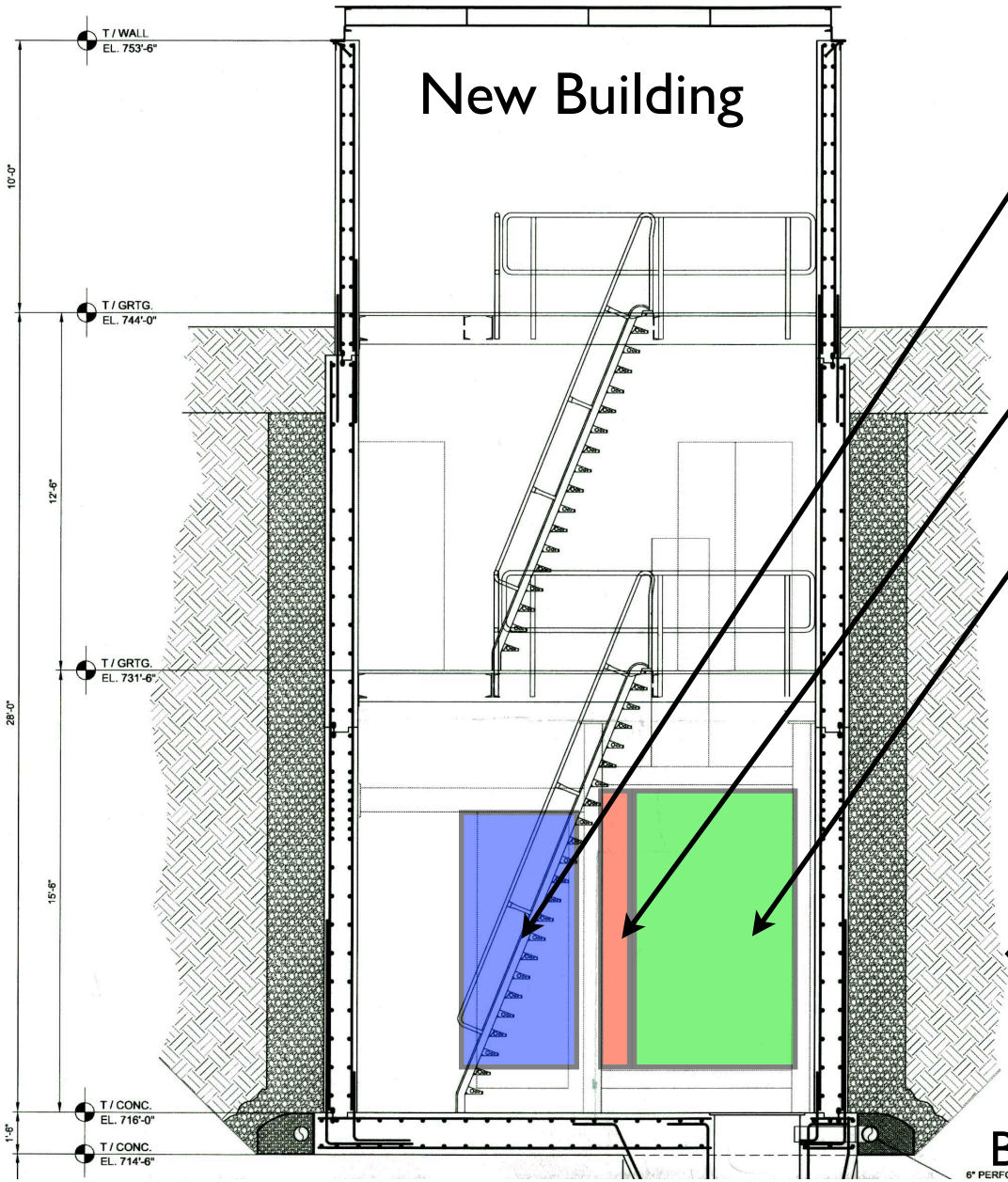
p Be → π+X
Cross Section



Relative neutrino fluxes



Recycled Detectors



Detector:

Muon Range Detector
- re-used scintillator (E605)
- re-used steel plates (E605)
- re-use PMTs (KTeV, NuTeV, etc.)

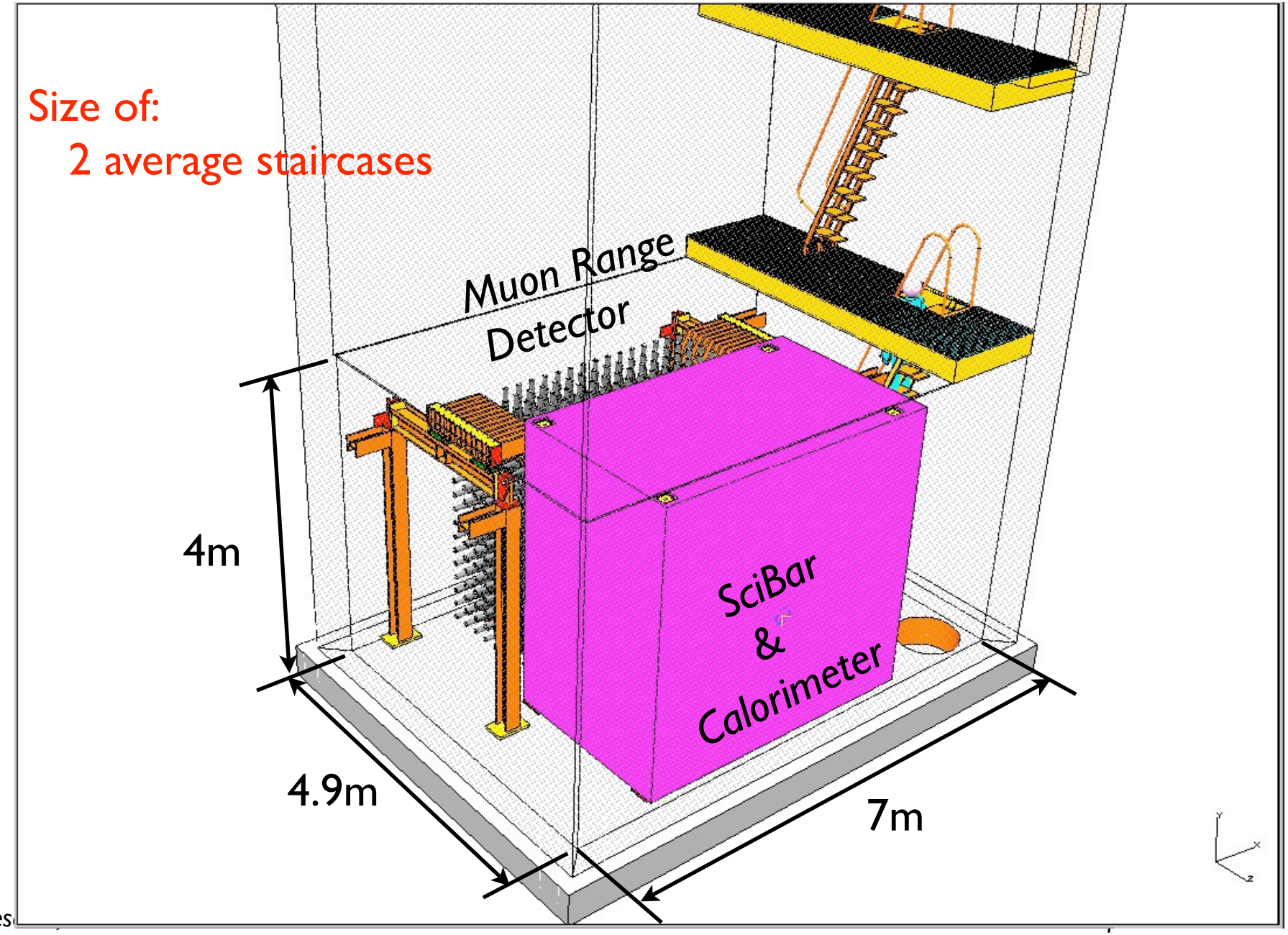
Electromagnetic Calorimeter
- re-used from K2K/CHORUS

SciBar (target/tracker)
- re-used from K2K

Booster Neutrino Beam

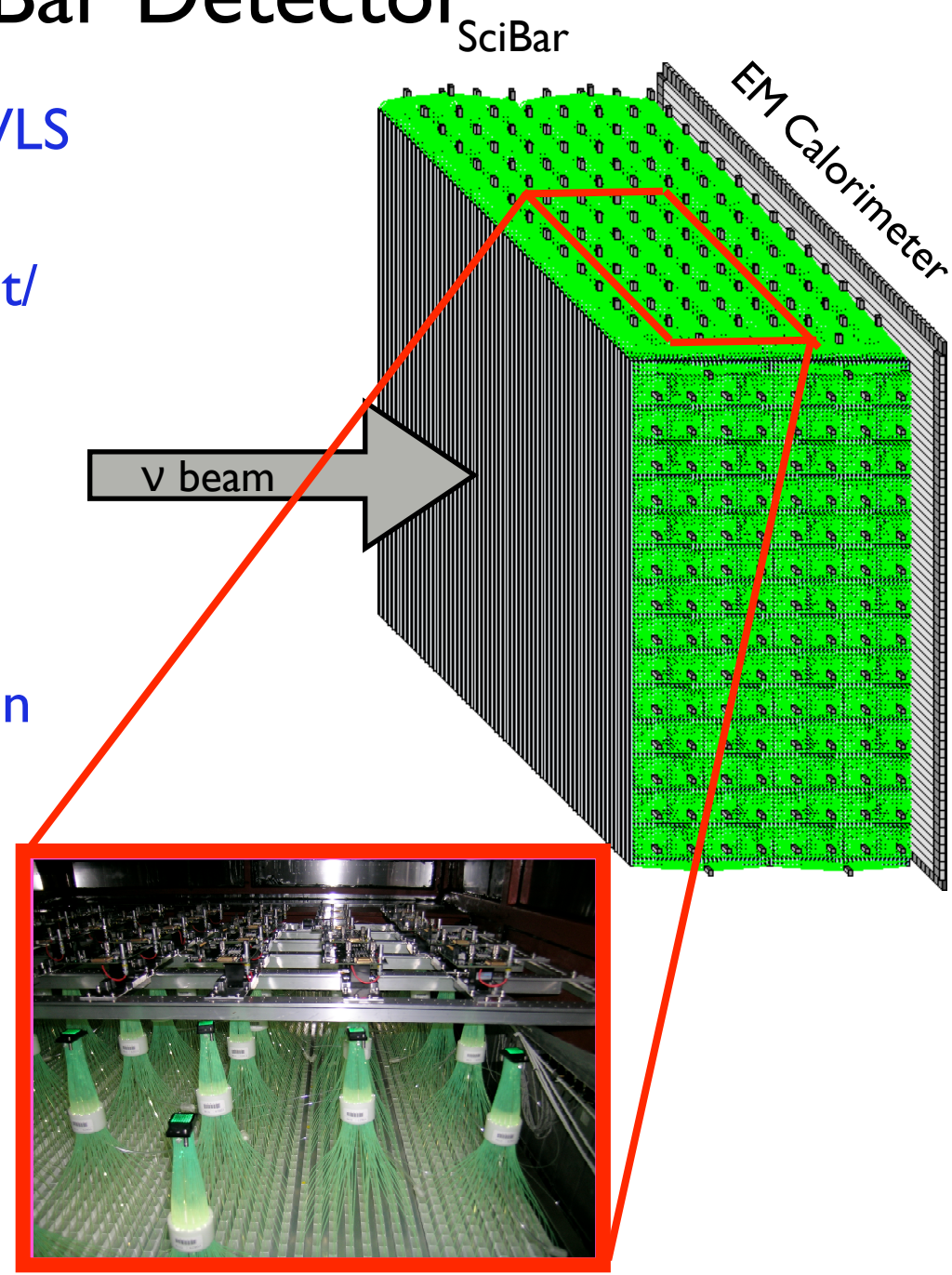
Building Dimensions: 19'x26'x28' deep

3D View of SciBooNE

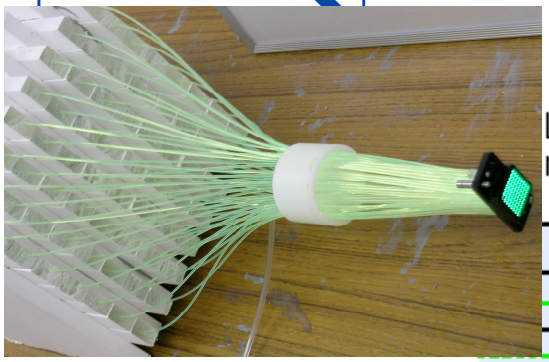


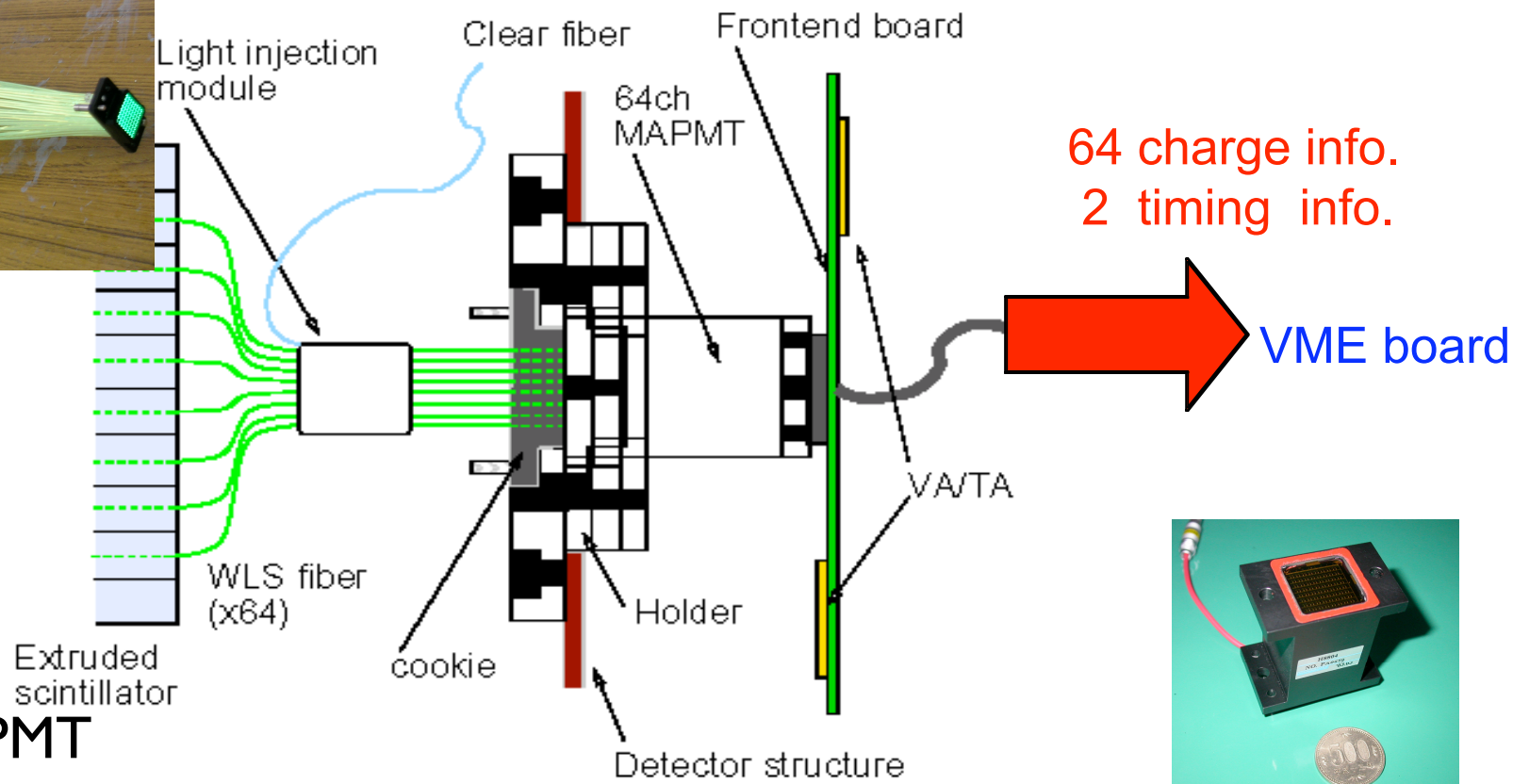
SciBar Detector

- Extruded scintillator with WLS fiber readout
- Scintillator is neutrino target/ tracker
- 2.5 x 1.3 x 300 cm3 cells
- 14,400 channels
- detect short tracks (> 8cm)
- Distinguish proton from pion using dE/dx
- Total 15 tons
- High track finding efficiency (>99%)
- Clear identification of ν interaction process



SciBar Readout





Multi-Anode PMT

- 2x2 mm^2 pixel (3% cross talk @ 1.5mm dia.)
- Gain uniformity (20% RMS)
- Good Linearity (~200 p.e. @ gain = 6×10^5)

VA/TA Readout

- ADC for all 14,400 channels
- TDC for 450 sites (32 channel-OR)

Electron Catcher

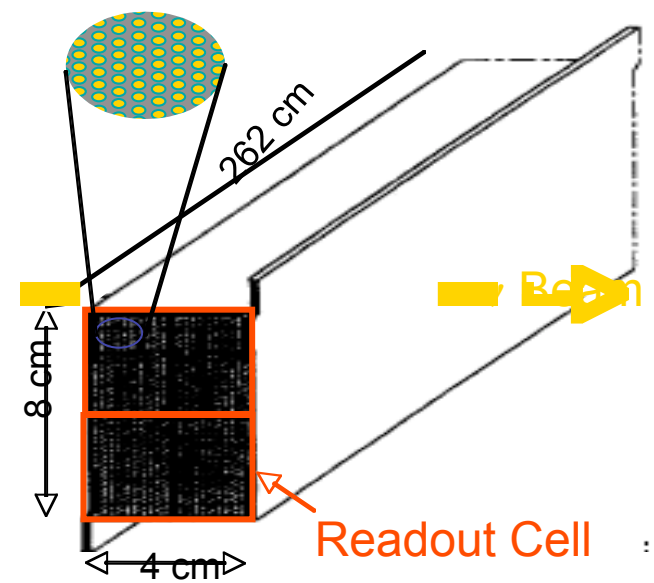
Spaghetti Calorimeter

- re-used from CHORUS
- 1 mm diameter fibers in grooves between lead foils
- 4x4 cm^2 cell read out from both ends
- 2 planes ($11X_0$)

  Horizontal: 32 modules

  Vertical: 32 modules

- Expected resolution $14\%\sqrt{E}$
- Linearity: better than 10%
- Total 256 channels

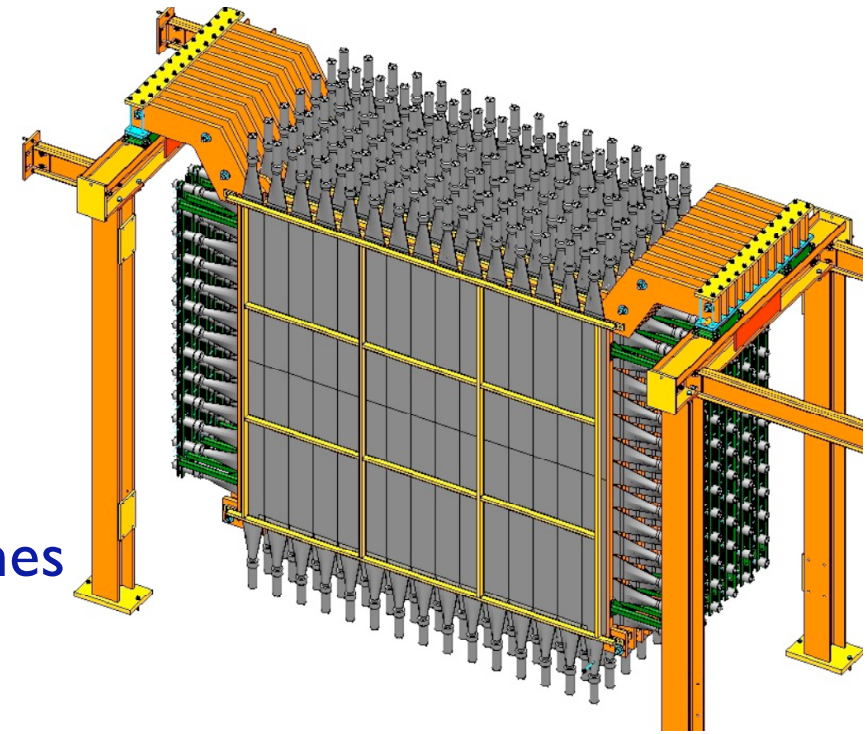


Readout

- Differential PMT signal read using CAEN ADC (VME)

Muon Range Detector

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



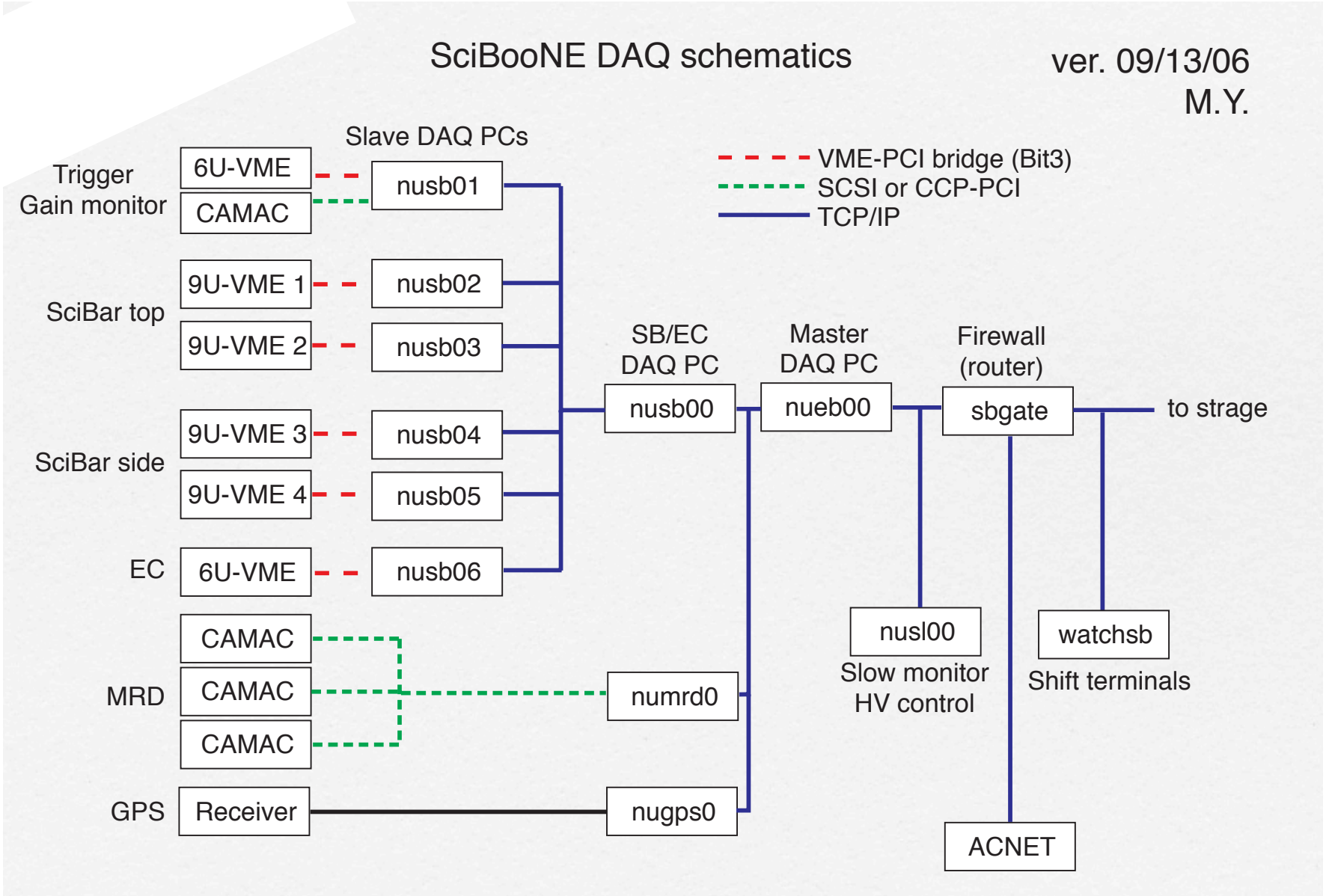
Detector:

- Iron Plate 305 x 247 x 5 cm^3
- Total 13 layers
- Scintillator for detector
- Alternating horizontal and vertical planes
- Total 362 channels

Readout:

- Lecroy FERA ADC/TDC (CAMAC)

DAQ


SciBooNE DAQ schematics
ver. 09/13/06
M.Y.
Slave DAQ PCs
VME-PCI bridge (Bit3)
SCSI or CCP-PCI
TCP/IP
Trigger
Gain monitor
6U-VME
CAMAC
nusb01
SciBar top
9U-VME 1
9U-VME 2
nusb02
nusb03
SciBar side
9U-VME 3
9U-VME 4
nusb04
nusb05
EC
6U-VME
nusb06
MRD
CAMAC
CAMAC
CAMAC
numrd0
GPS
Receiver
nugps0
SB/EC
DAQ PC
nusb00
Master
DAQ PC
nueb00
Firewall
(router)
sbgate
to strage
nusl00
Slow monitor
HV control
watchsb
Shift terminals
ACNET

SciBooNE Physics

2 year run, 2×10^{20} protons on target (POT)

Neutrino Run (1.0×10^{20} POT):

- CC-$1\pi^+$ cross section
- CC-$1\pi^0$ cross section
- Intrinsic ν_e contamination

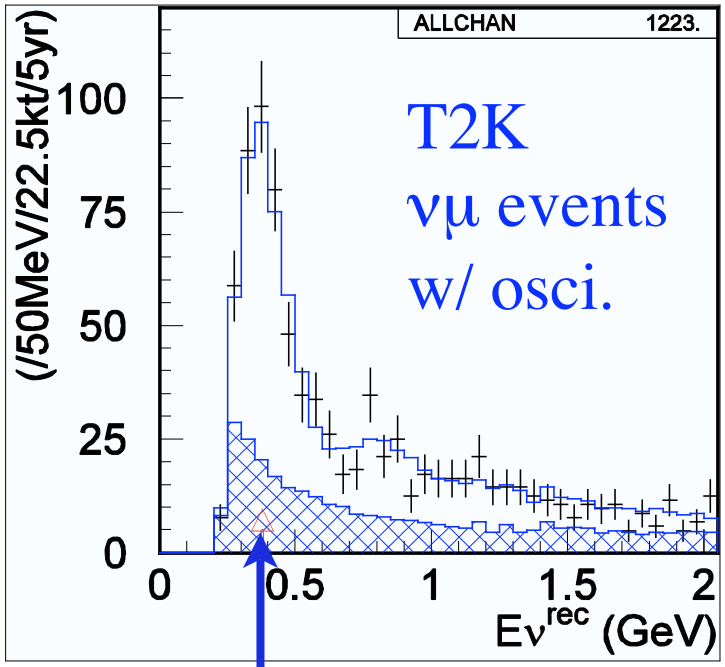
interactions in F.V.
$\nu_\mu \sim 81{,}000$
$\nu_e \sim 17{,}000$
(cf. $\nu_\mu \sim 25{,}000$ K2K)

Anti-neutrino run (1.0×10^{20} POT)

- CC-QE cross section
- neutrino background contamination
- CC- coherent π cross section

interactions in F.V.
$\bar{\nu}_\mu \sim 7{,}500$

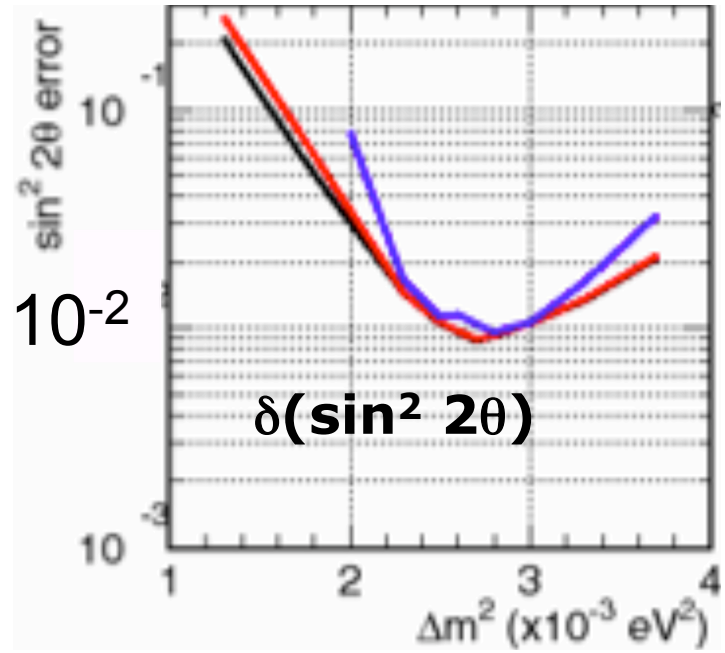
CC-1π⁺ Measurement



–Signal: CC-QE ($\nu+n\rightarrow\mu+p$)
(Energy Reconstruction from μ kin.)

–Background: Mainly CC-1π⁺
($\nu+N\rightarrow\mu+\pi+N'$)

ν_μ disappearance measurement error (90%CL)

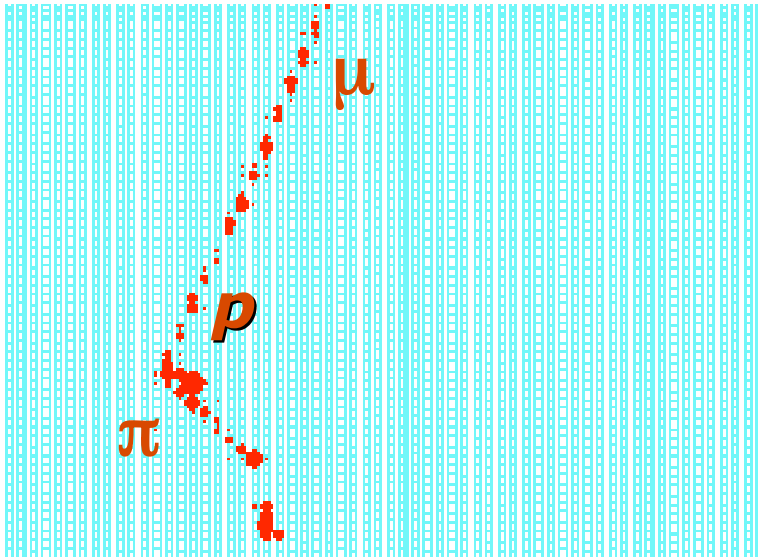


stat. only
δ(nQE/QE)= 5%
δ(nQE/QE)=20%

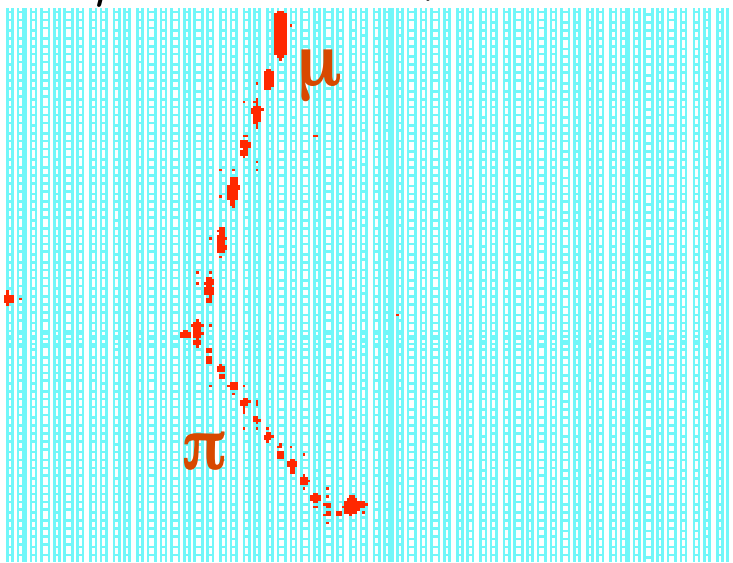
T2K needs to know uncertainty of nonQE/QE at ~5% level.

CC-1π⁺ at SciBooNE

$$\nu_\mu + p \rightarrow p\mu^-\pi^+$$



$$\nu_\mu + n \rightarrow n\mu^-\pi^+$$



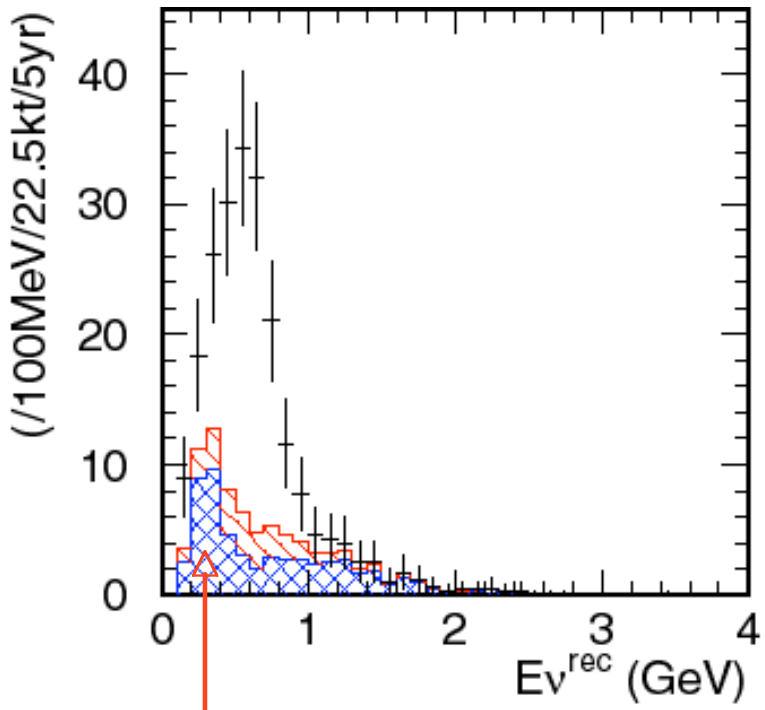
Vertex requirements allow clear separation between proton and neutron interactions

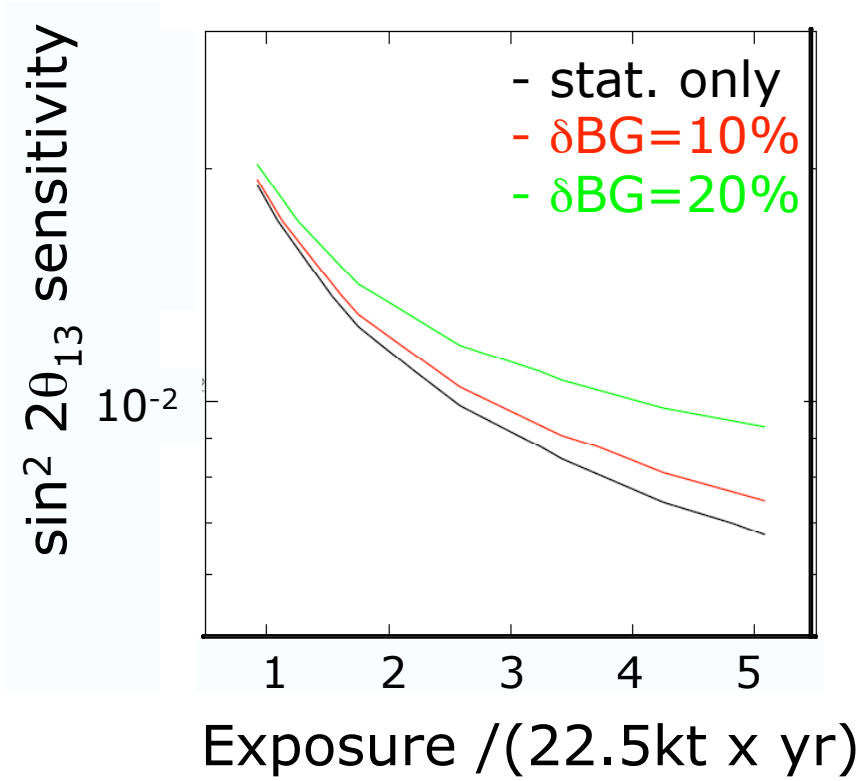
Expect ~1400 CC-1π⁺ events

~5% measurement

NC-1π^0 Measurement

NC-1π^0 dominant background for ν_e appearance search



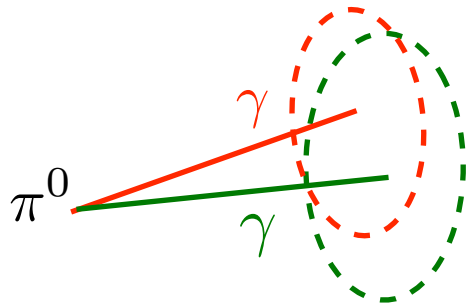


- Signal: CC-QE (ν+n→e+p)
- Background
  - Beam ν_e
  - NCπ^0

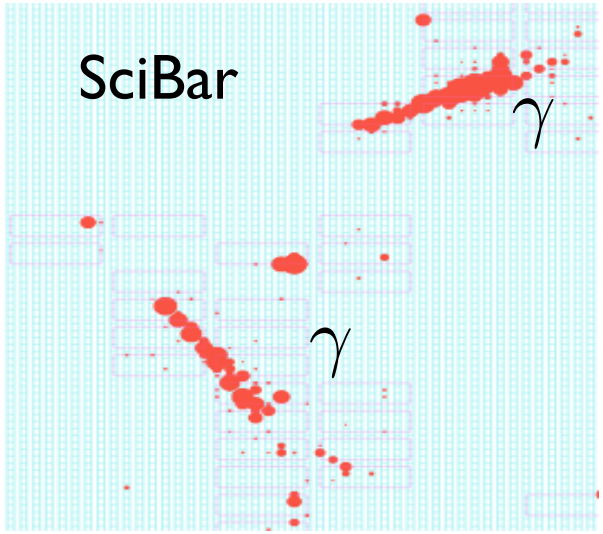
T2K needs ~10% uncertainty on NC-1π^0 cross section

NC-1π^0 at SciBooNE

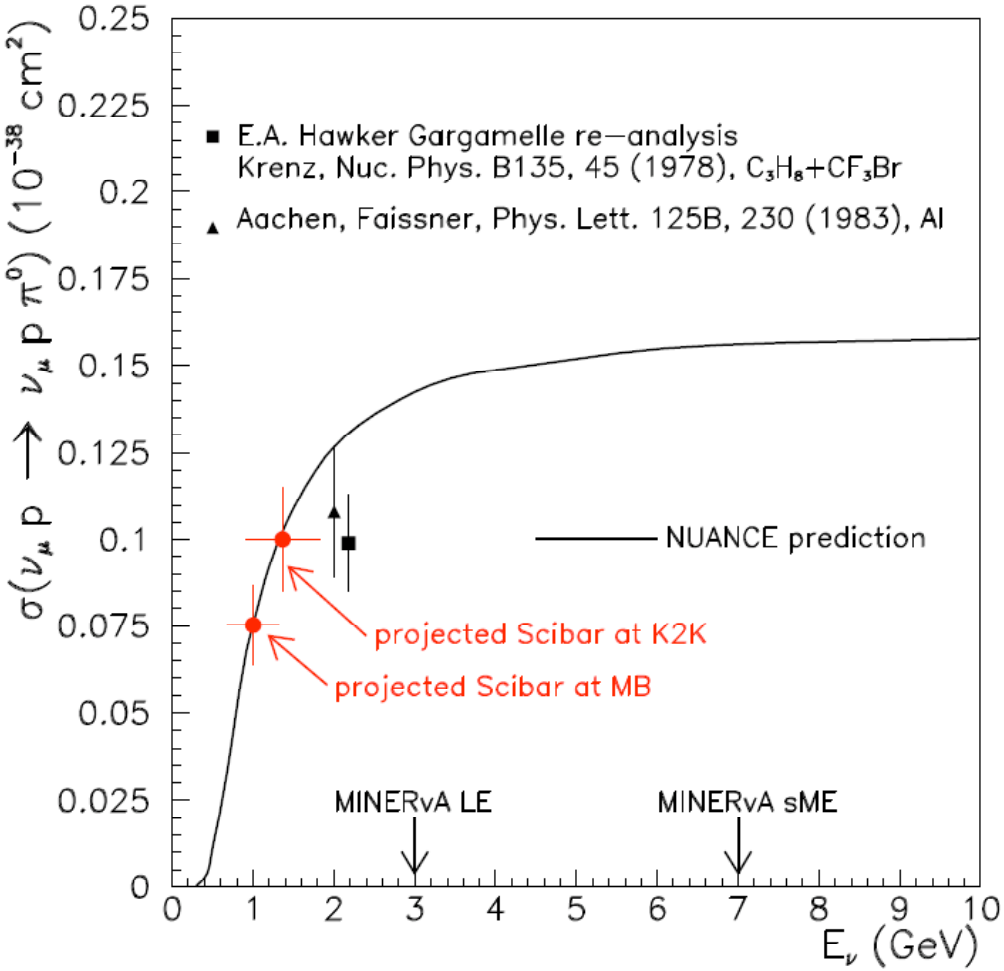
Super Kamiokande



Overlapping Cerenkov Rings



γ track separation

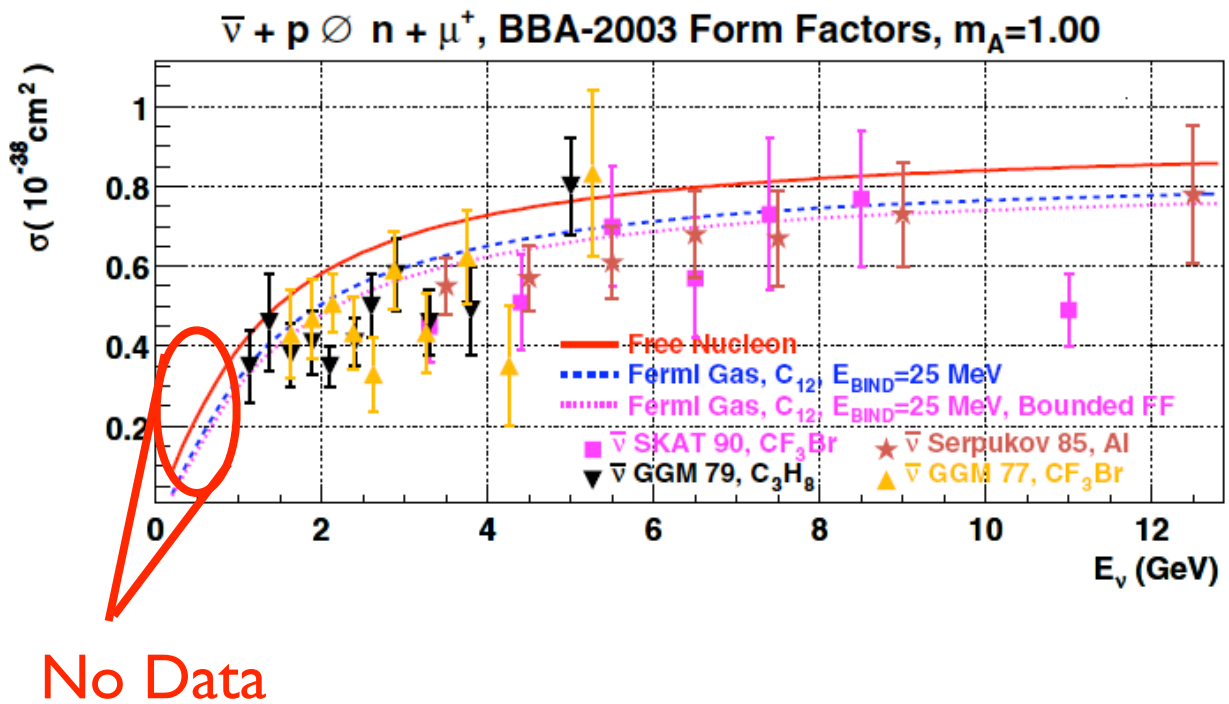


SciBooNE (0.8GeV) and K2K (1.3GeV) results provide the first mapping of energy dependence of the cross section below 2GeV.

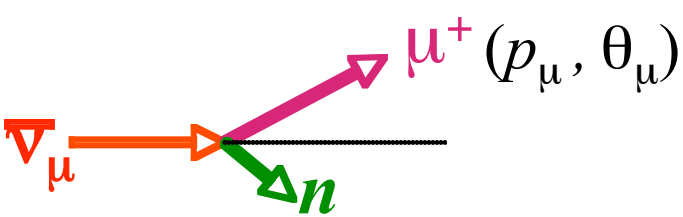
Anti-neutrino CCQE Measurement

Physics motivation

- Important for T2K phase-II
  - CP violation search
- Free proton scattering: check of nuclear model



No Data



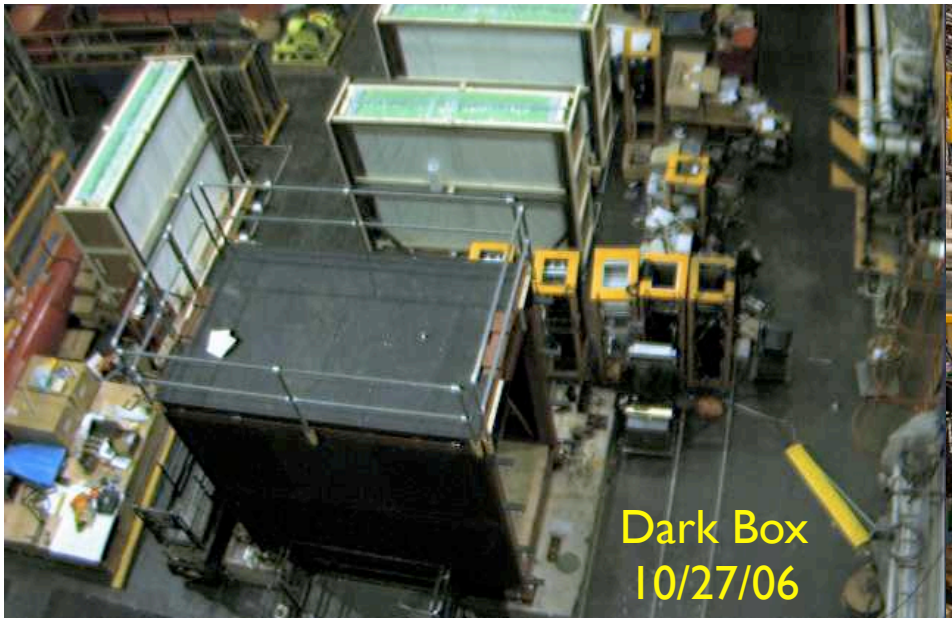
Expect ~9,000 CCQE events after cuts, 80% purity

SciBooNE Civil Construction

SciBar

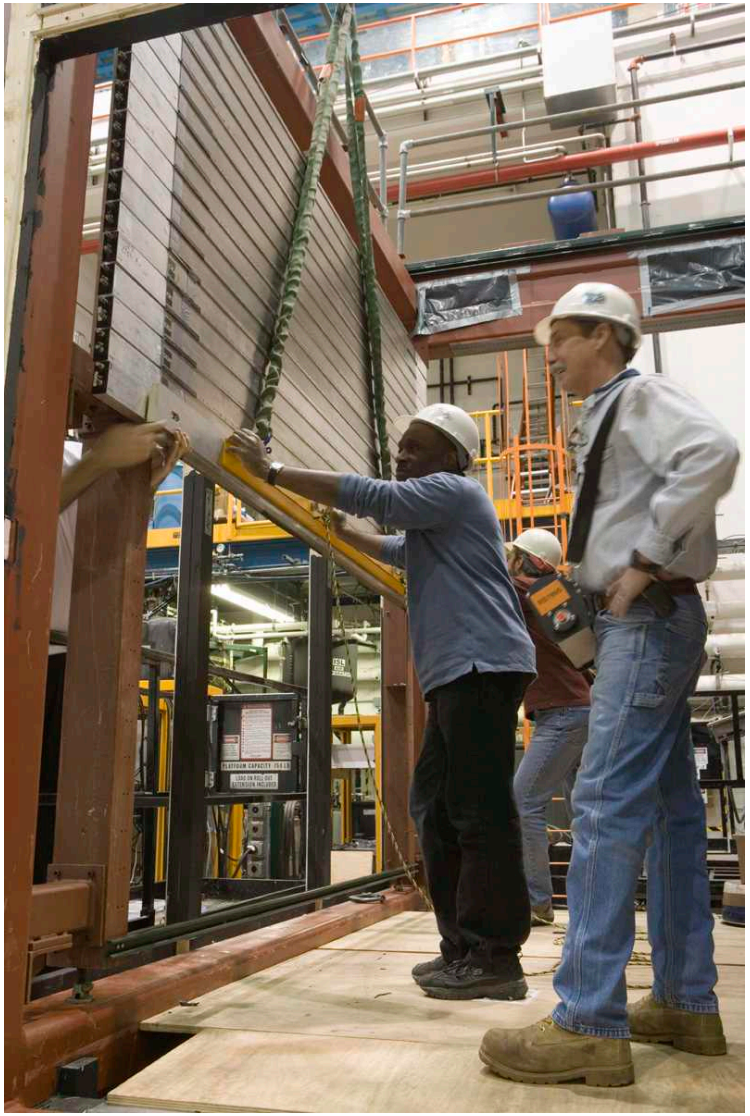
SciBar arrives at CDF
7/17/06

Support structure arrives
7/17/06


Dark Box
10/27/06

Last Module
12/6/06

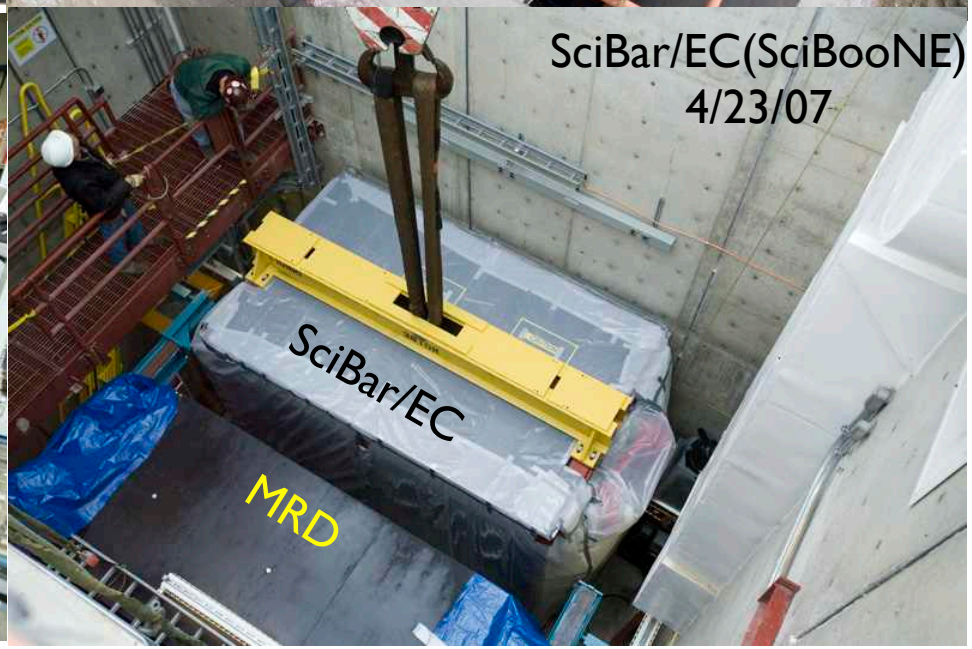
EM Calorimeter



Downstream layer sees cosmic ray signals 12/4/06

Muon Range Detector

SciBooNE Installation

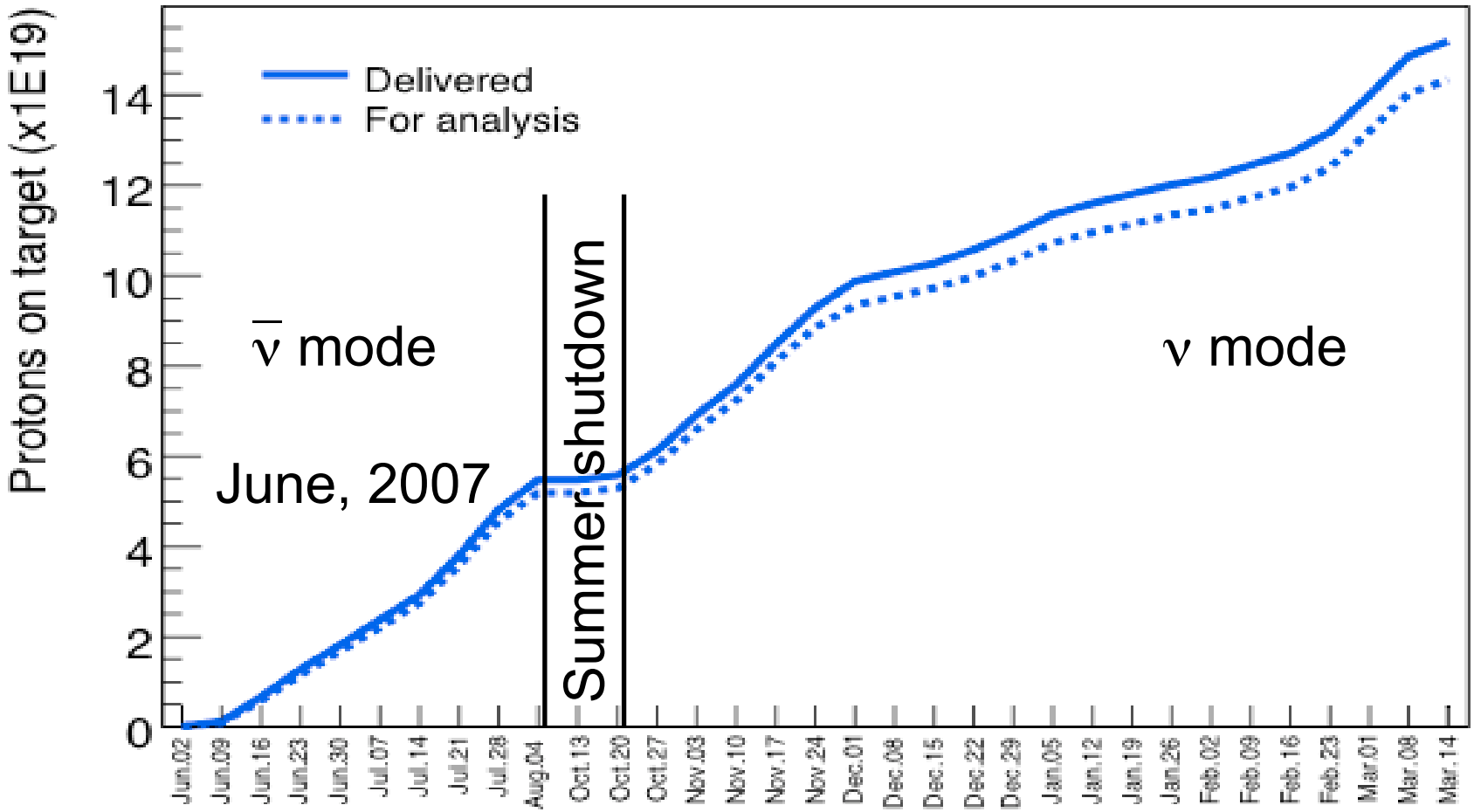


Schedule

Mar. 2005	K2K Ends
Nov. 2005	Submit proposal to FNAL
Dec. 2005	Proposal Approved
Feb. 2006	SciBar/EC disassembled
Jun. 2006	Ship detectors to FNAL
Jul. 2006	Detectors @ FNAL
Sep. 2006	Civil construction starts
Nov. 2006 - Feb. 2007	Detector assembly/staging
Feb. - Apr. 2007	Installation
May 2007	Commissioning
Jun. - Oct. 2007	Anti-neutrino data taking
Oct. 2007 - Apr. 2008	Neutrino data taking
Apr. 2008 - Aug. 2008	Anti-neutrino data taking

SciBooNE Data Taking

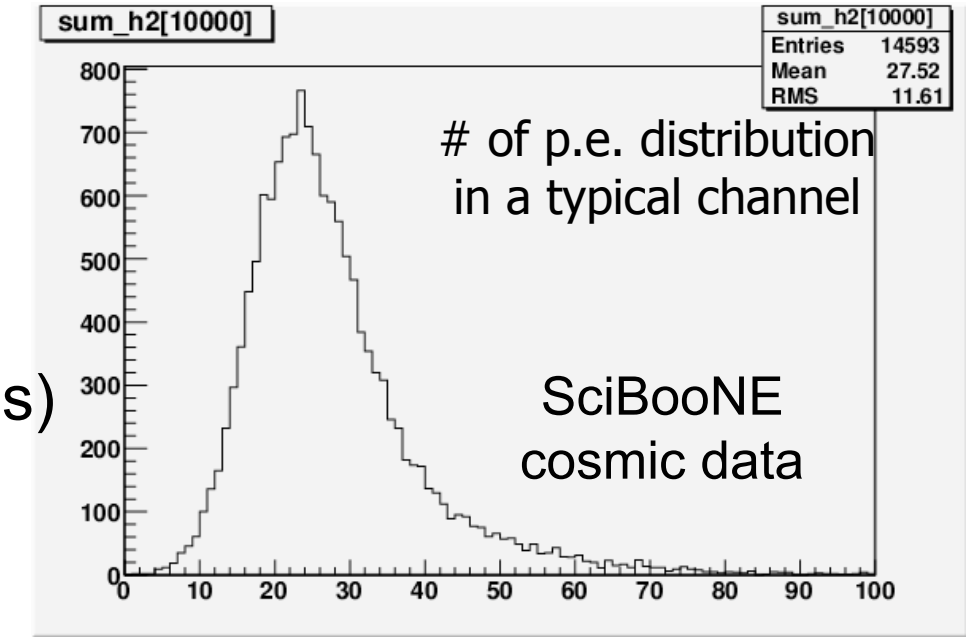
- Projected Protons On Target (POT): 2E20
- Total collected POT: 1. 46E20
  - ν: 9.2E19 (goal: 1E20)
  - $\bar{\nu}$: 5.4E19 (goal: 1E20)
- Averaged detector live time fraction: 94%

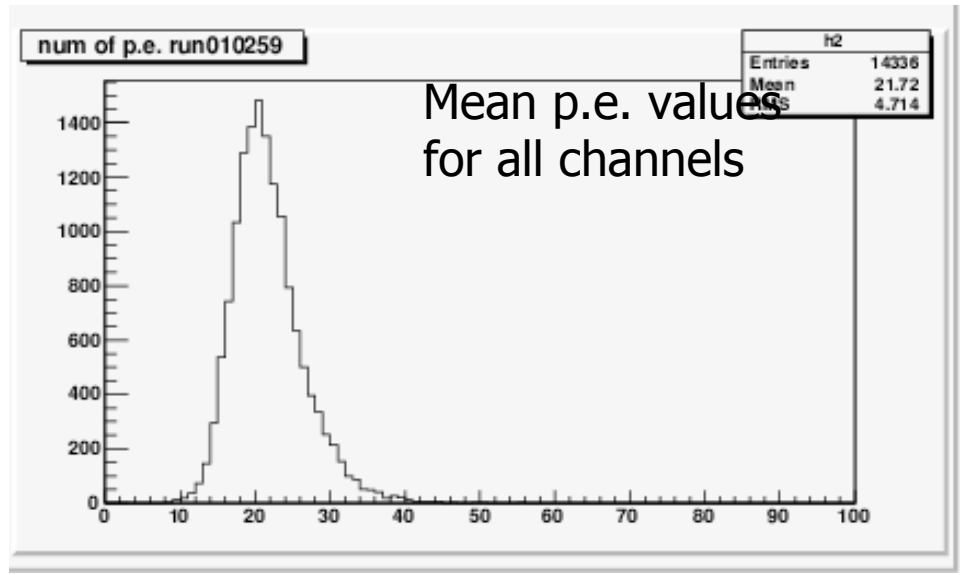


SciBar Detector Performance

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

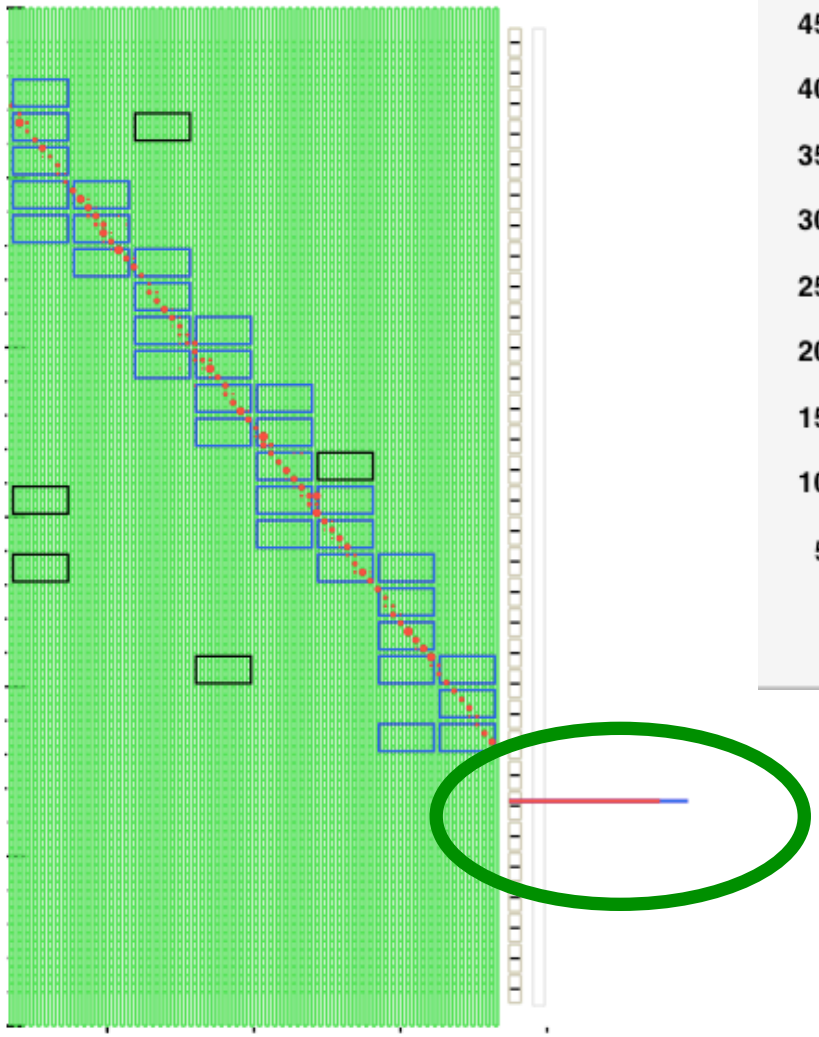
- Hit finding efficiency (cosmic)
  - Horizontal plane: **99.9%**
  - Vertical plane : **99.8%**



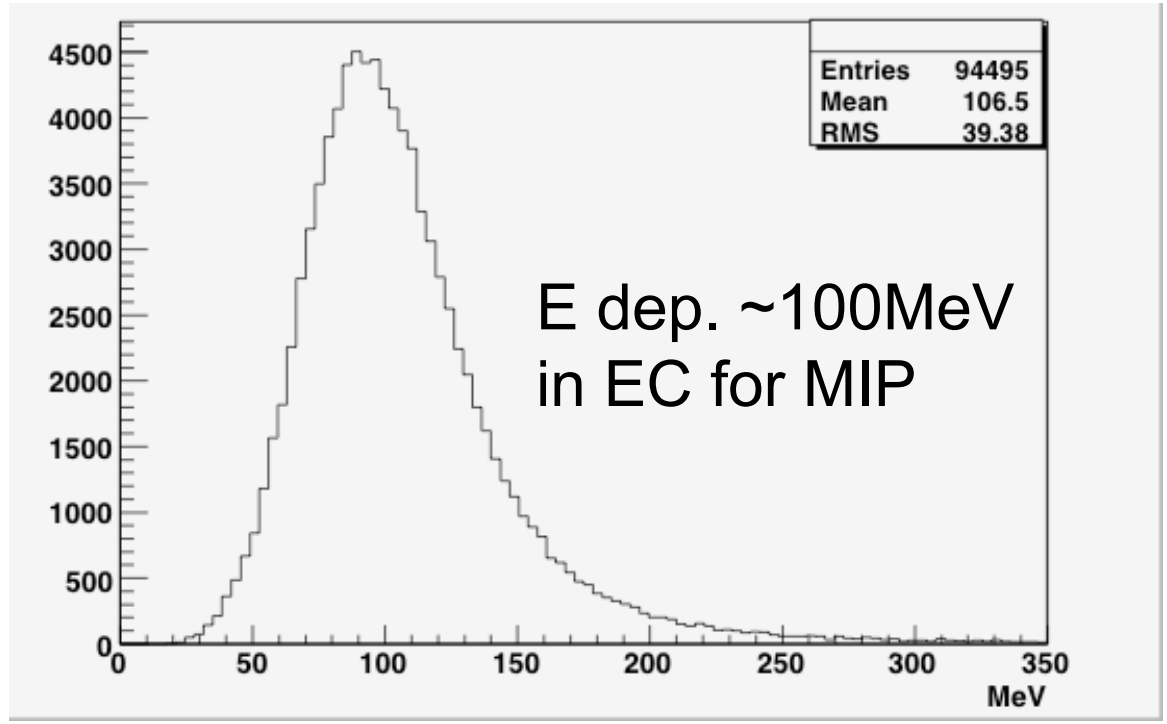


EC Cosmic Data

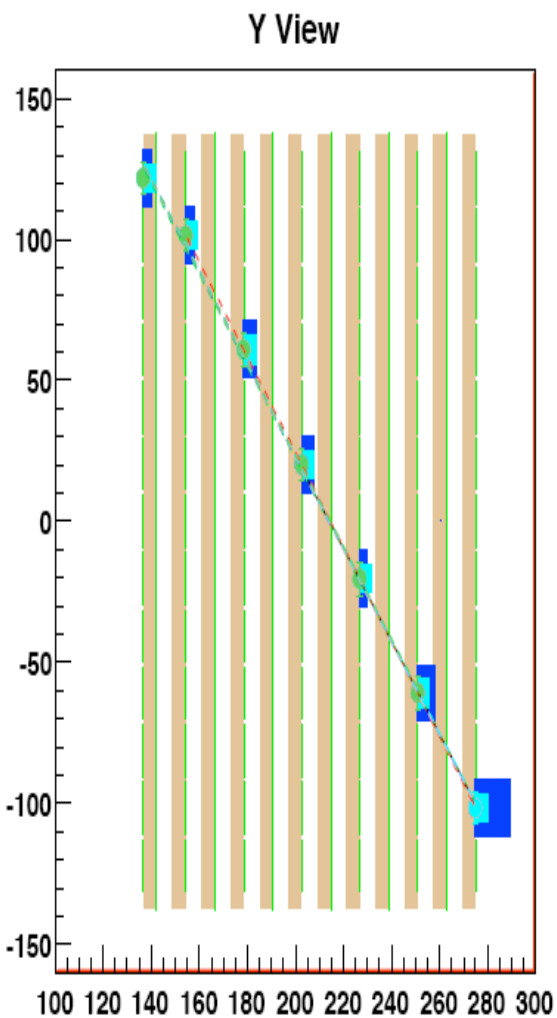
Cosmic ray

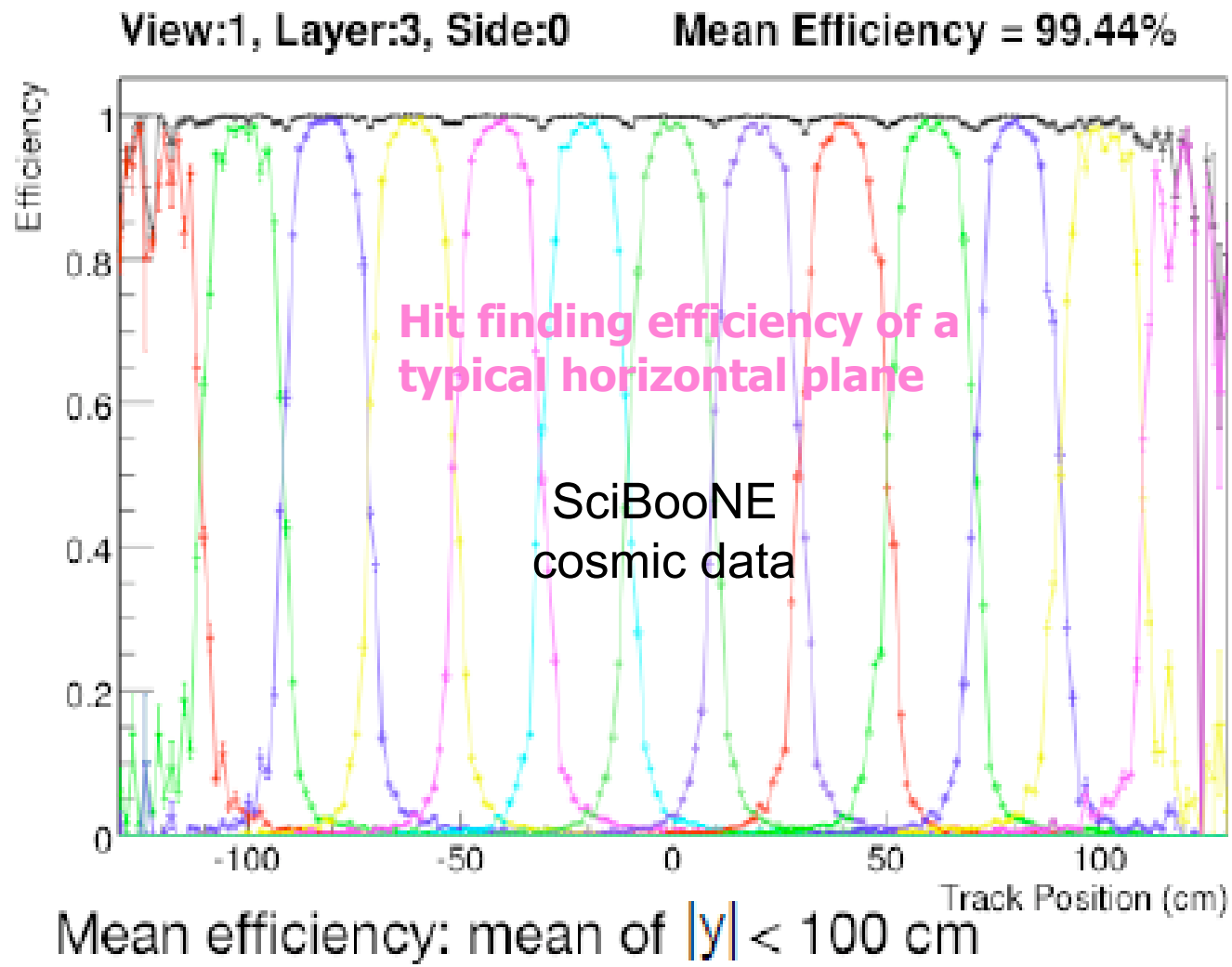


SciBooNE
cosmic data

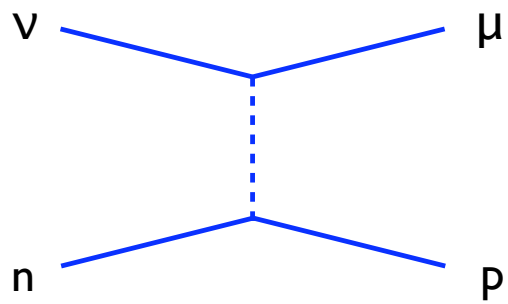


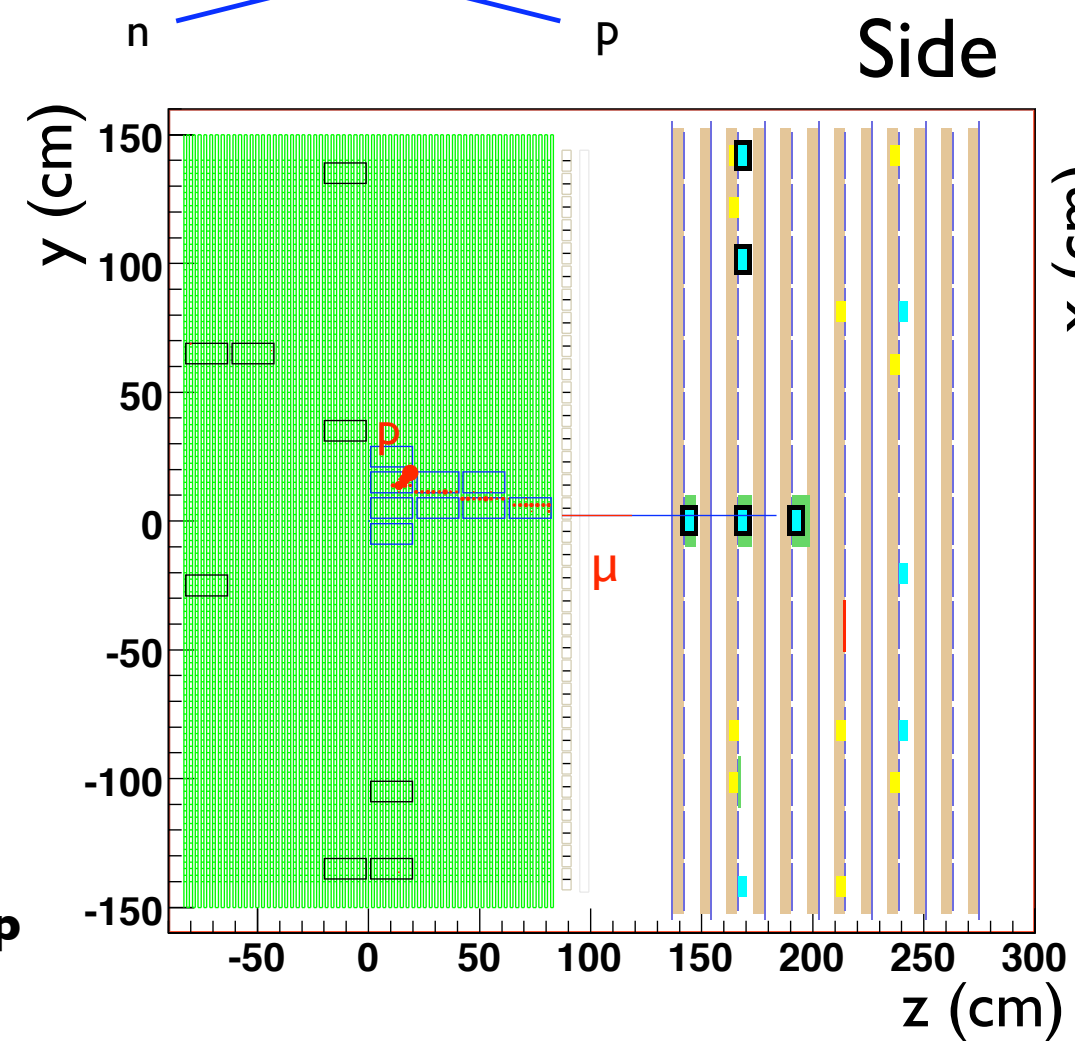
MRD Cosmic Data

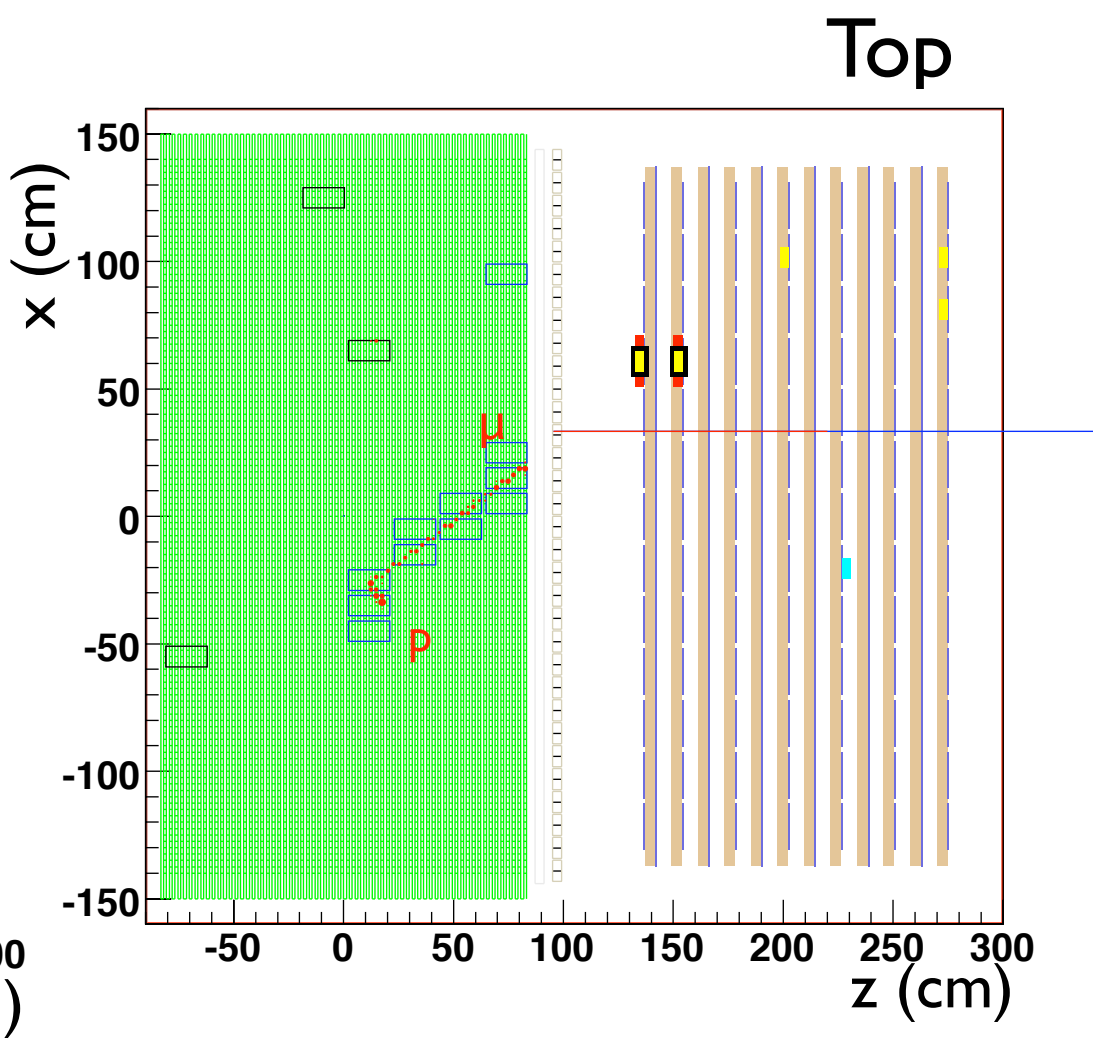




CCQE SciBooNE Data

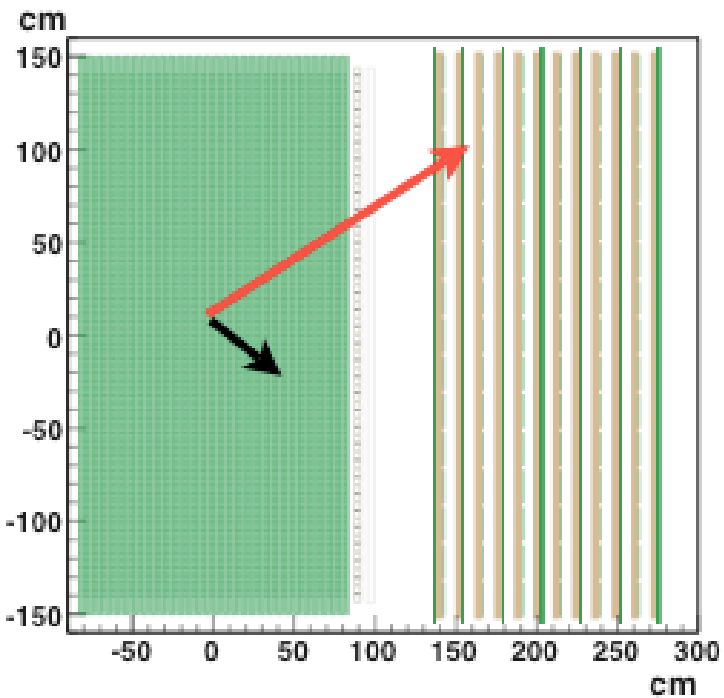


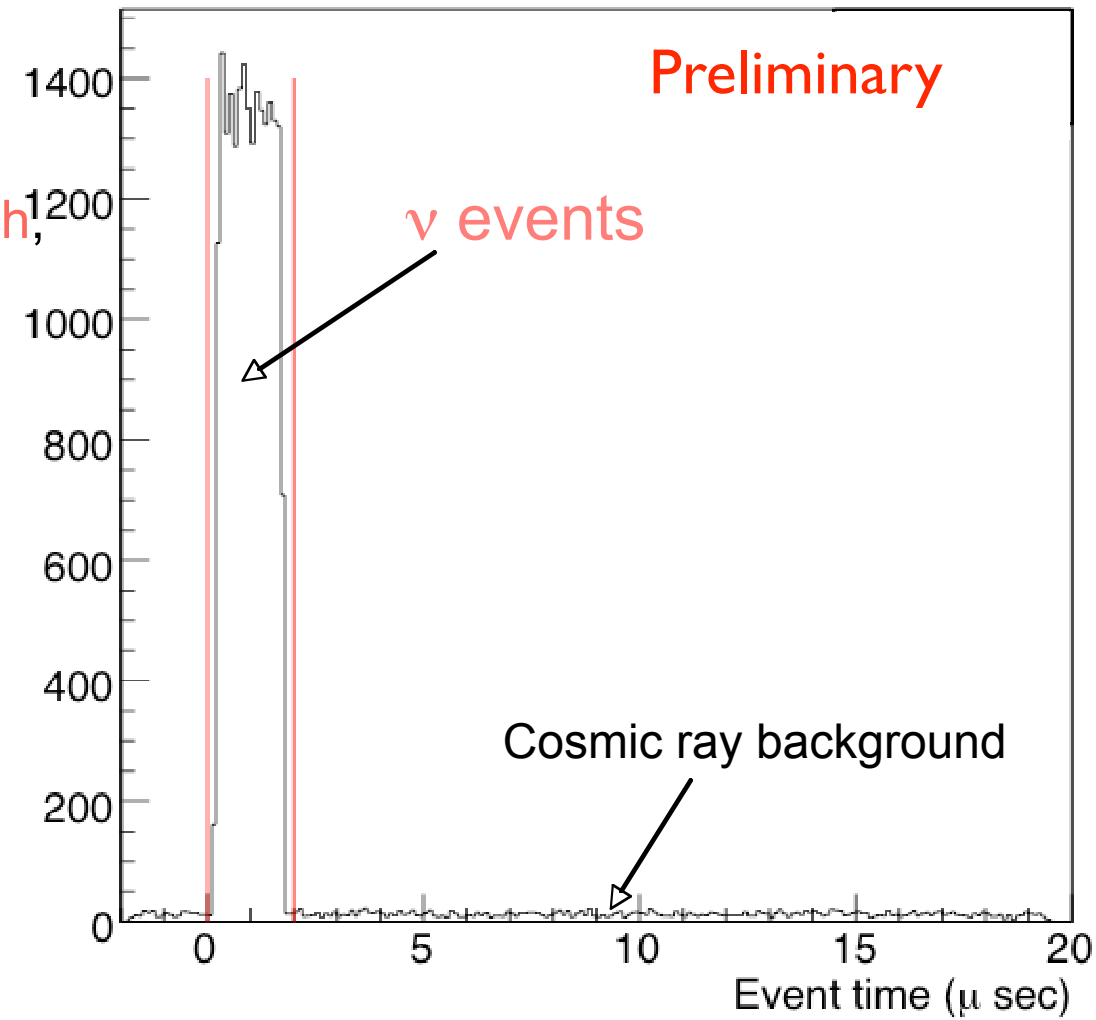




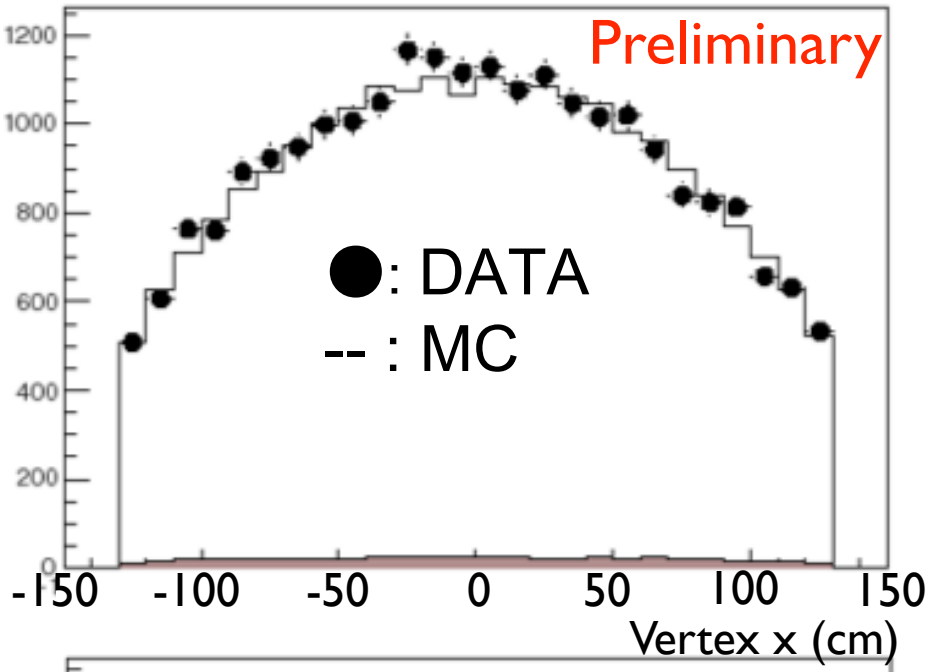
CC Reconstruction

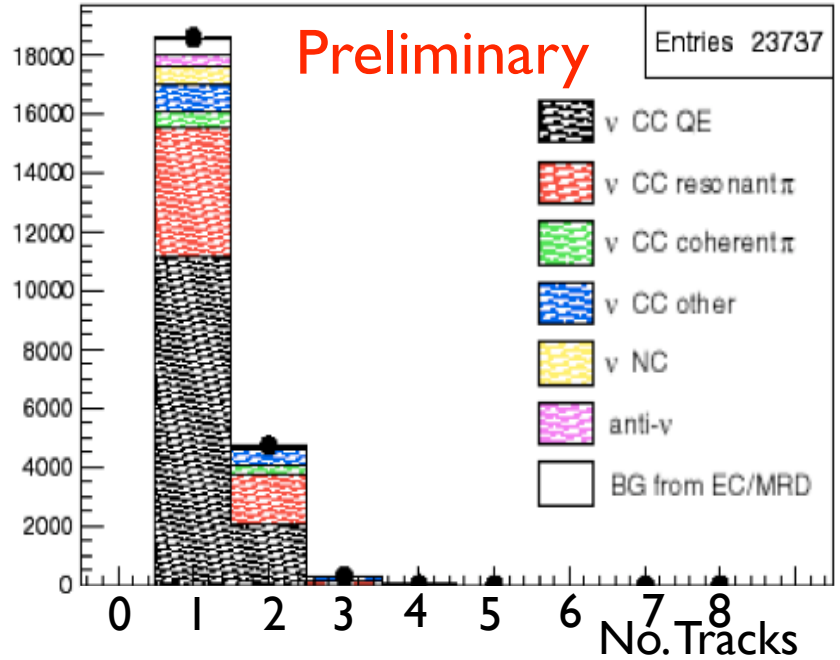
- Beam window: 2usec (1.6us beam spill)
- Requiring SciBar-MRD match, cosmic ray background contamination <0.5%

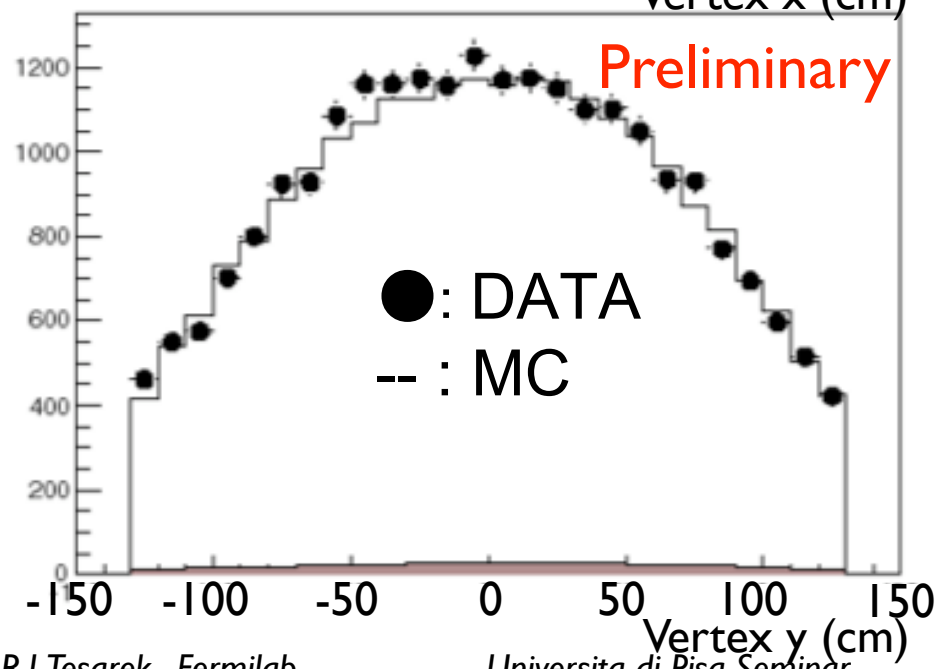


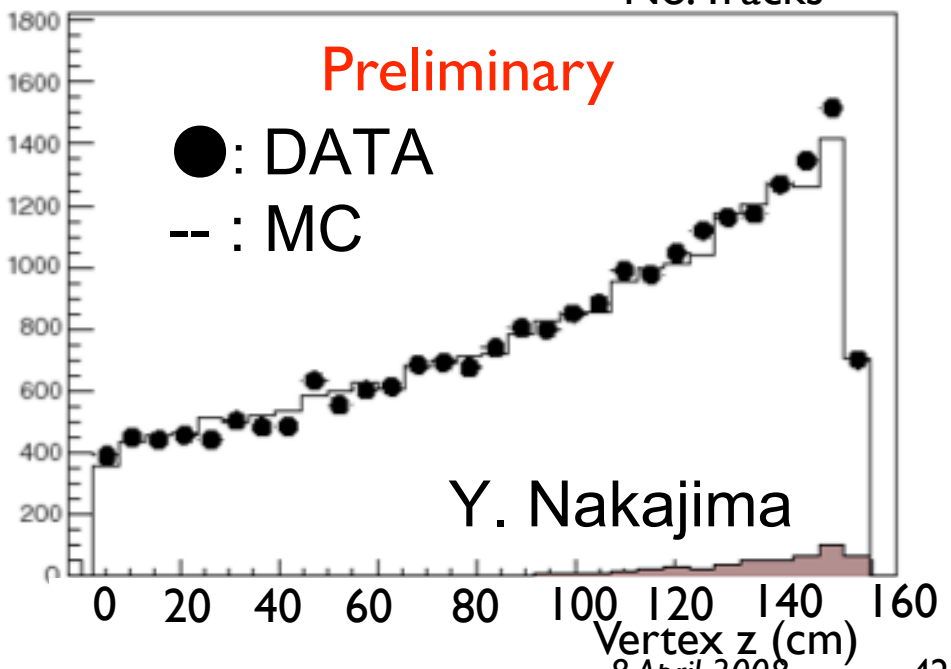


Reconstructed Tracks





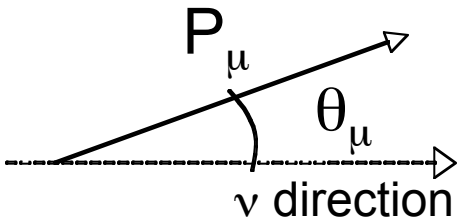


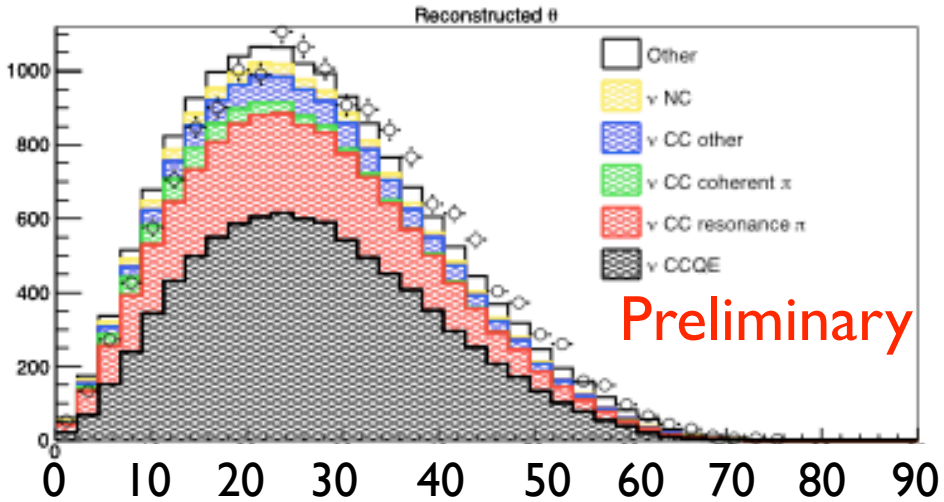


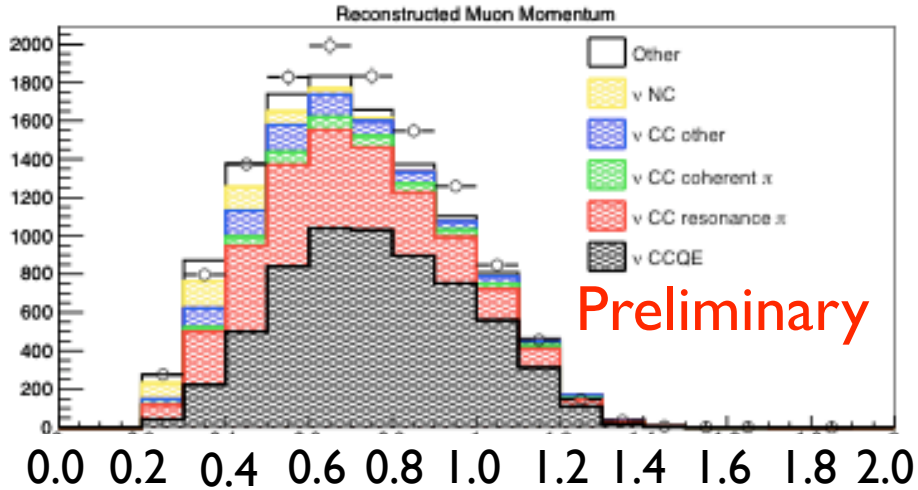
Muon Distributions

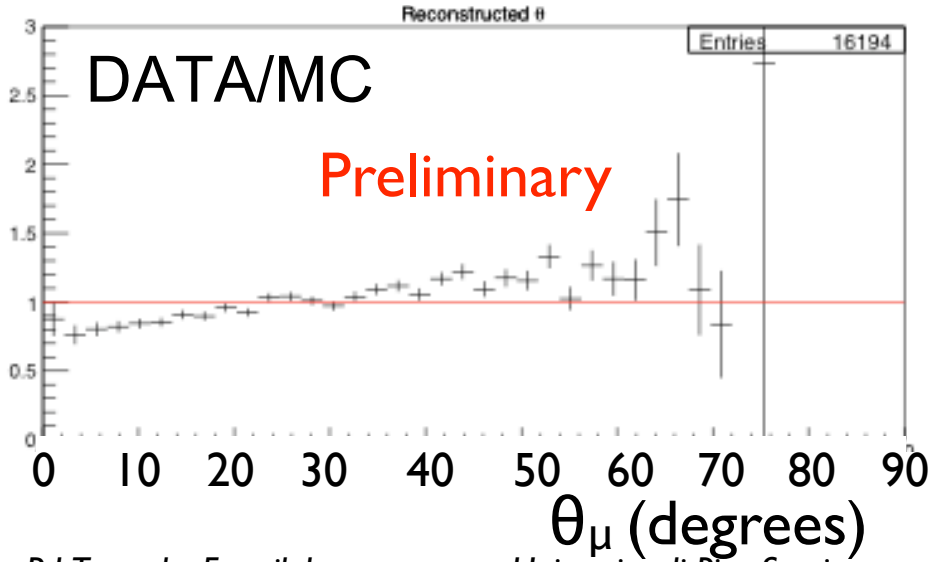
Sample: events μ stopped inside the MRD

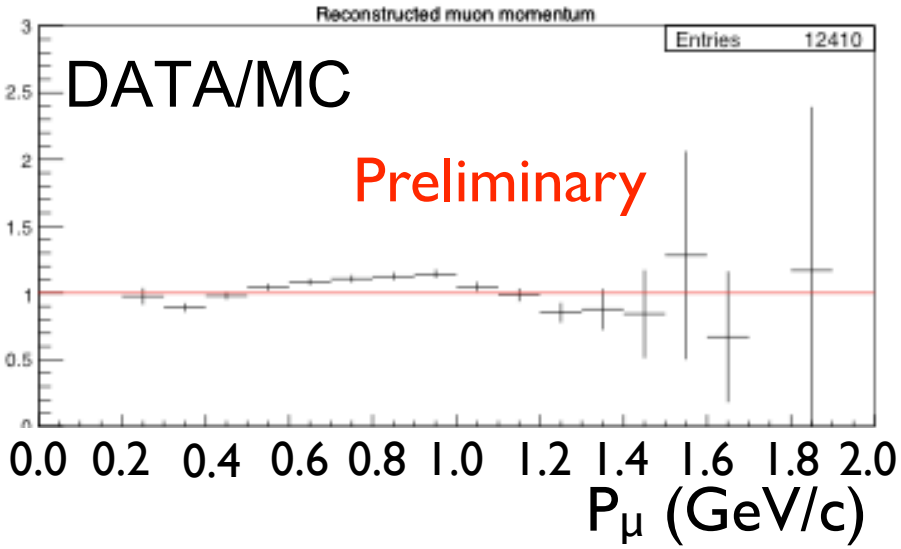
(MC samples: normalized by # of MRD match events)







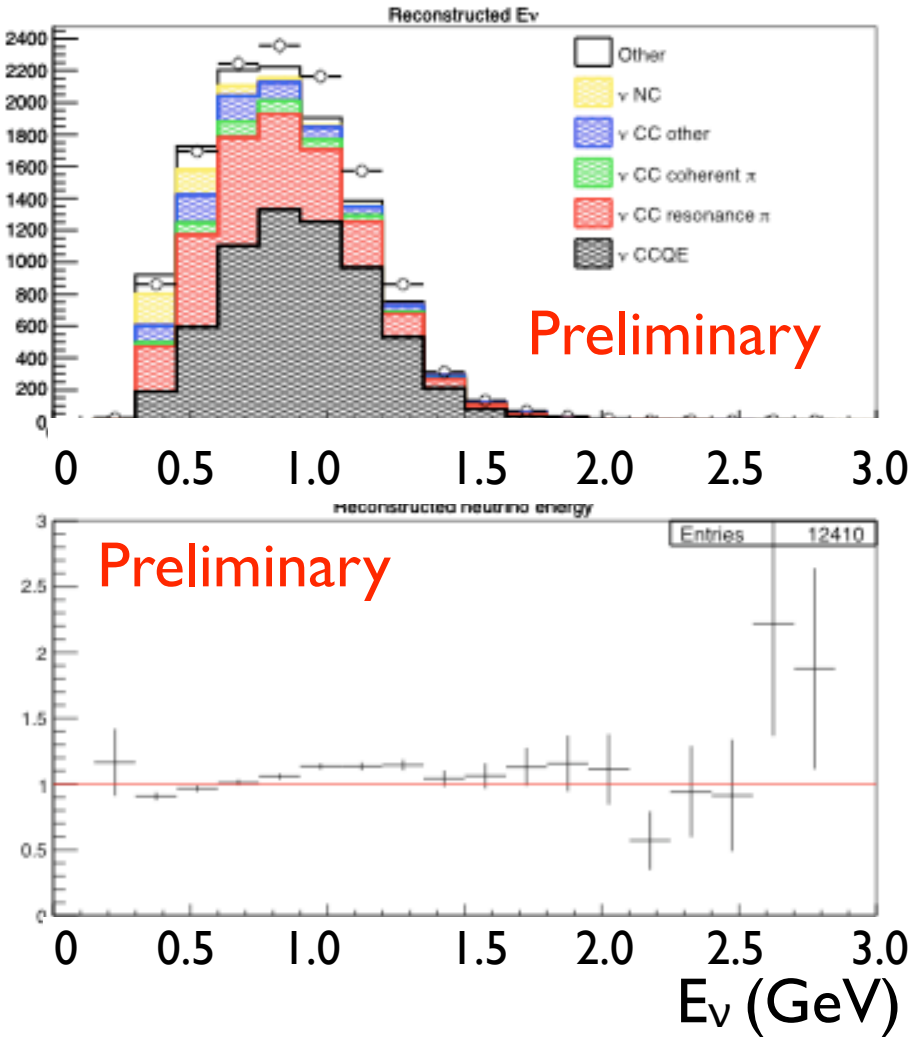




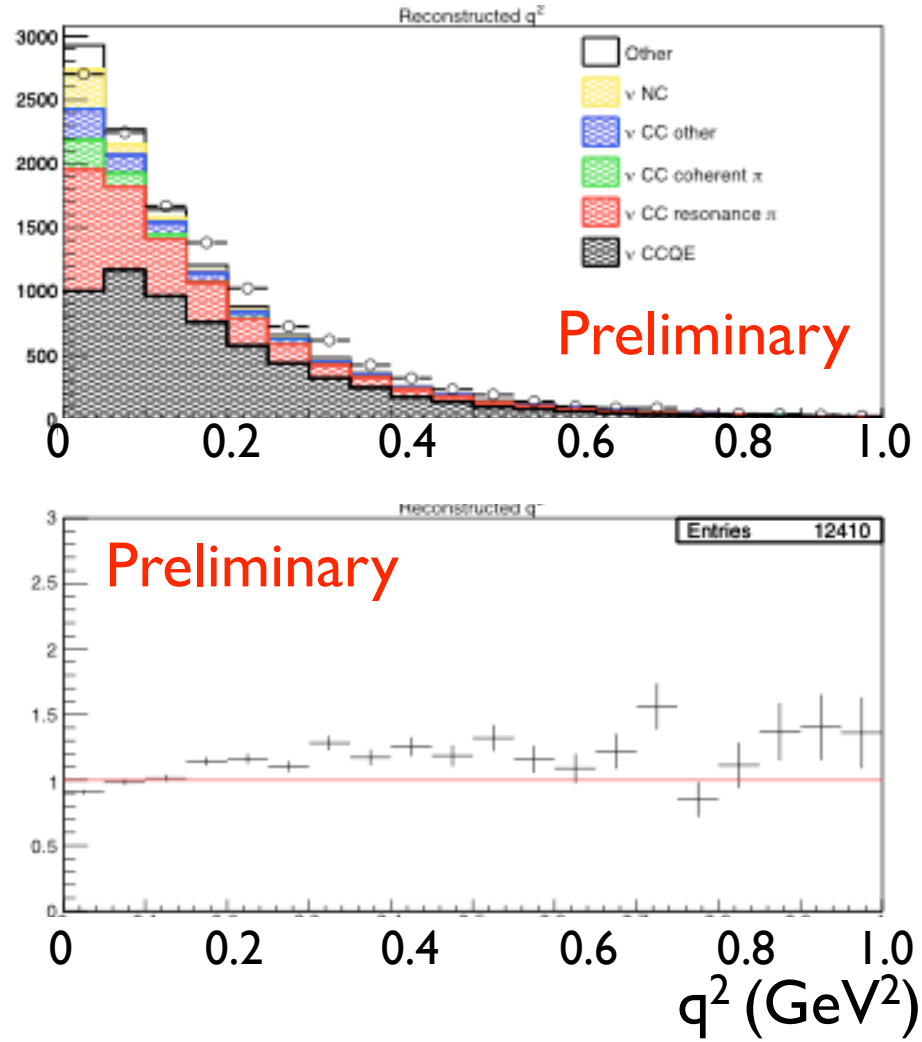
CCQE Kinematics

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

Reconstructed E_ν



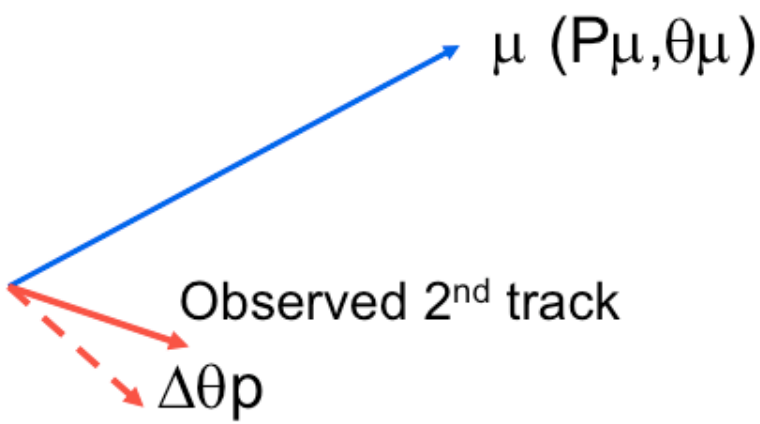
Reconstructed q^2

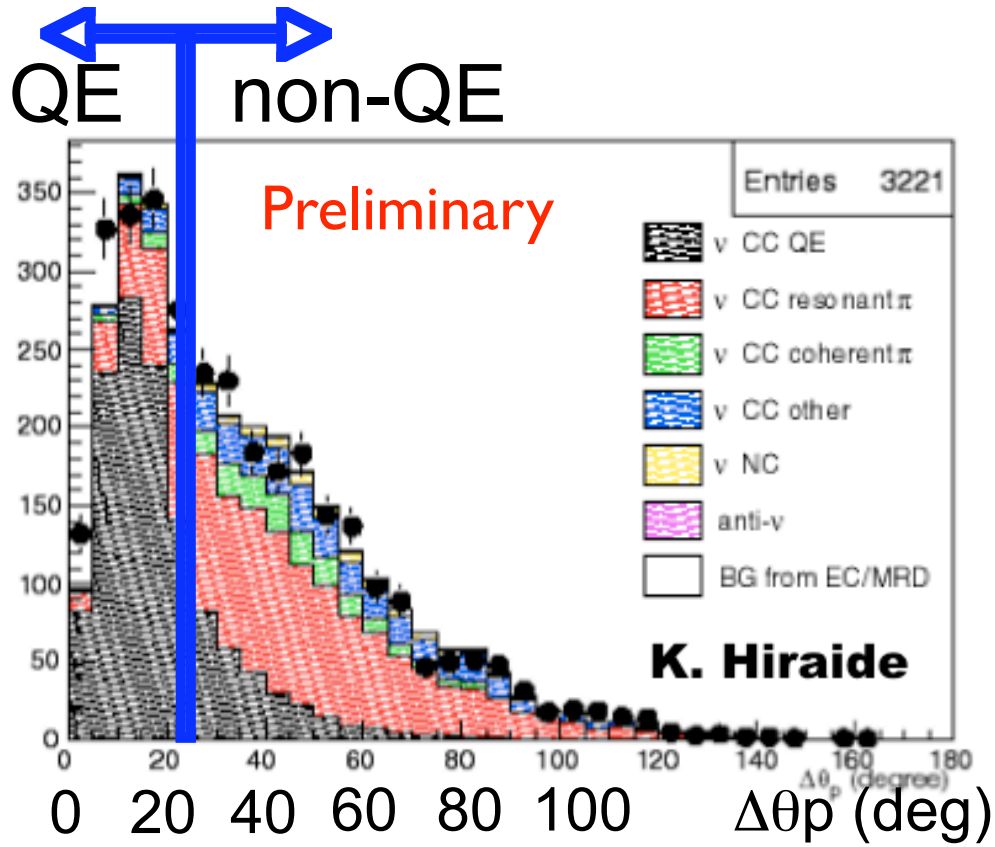


Y. Nakajima

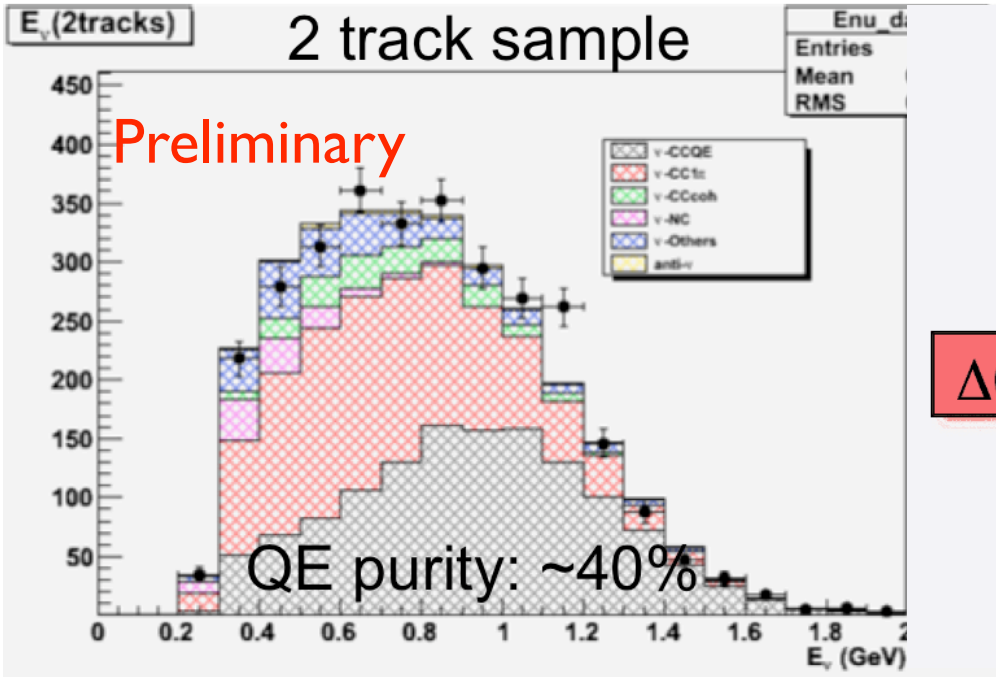
CC-QE and CC-nonQE Separation

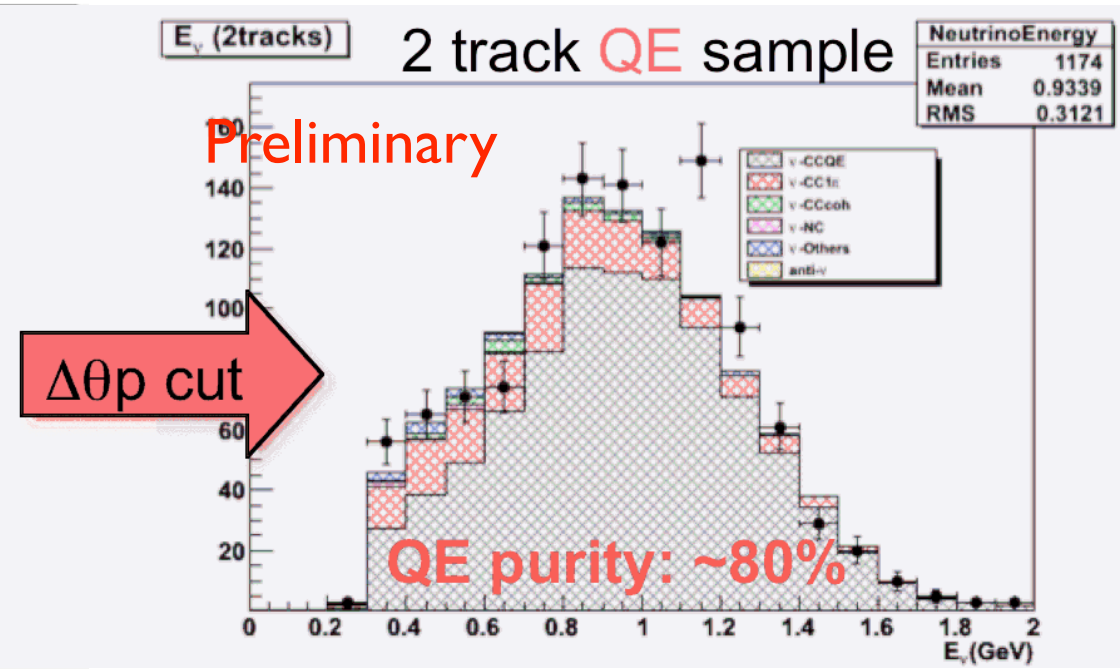
Opening angle between observed 2nd track and expected proton track assuming CCQE.





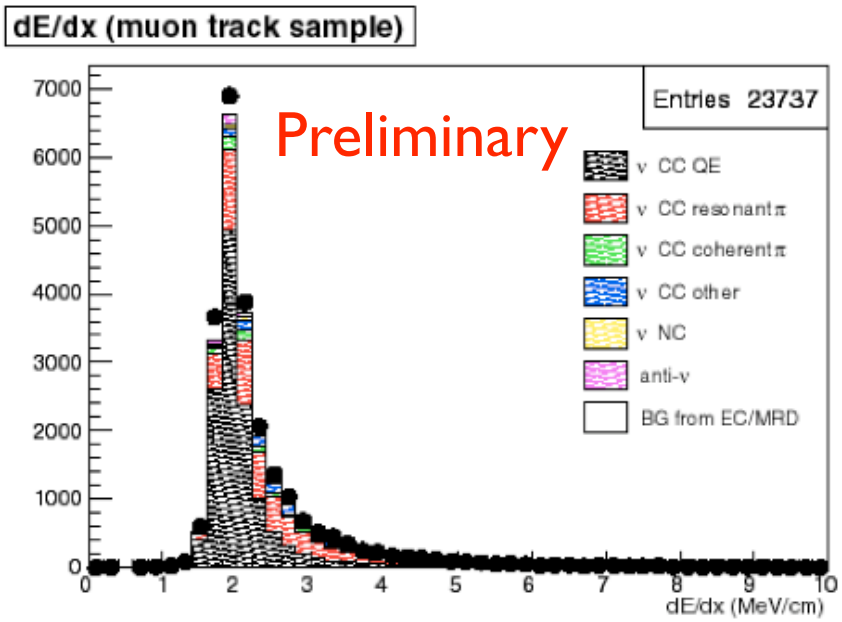
CCQE Selection/Purity

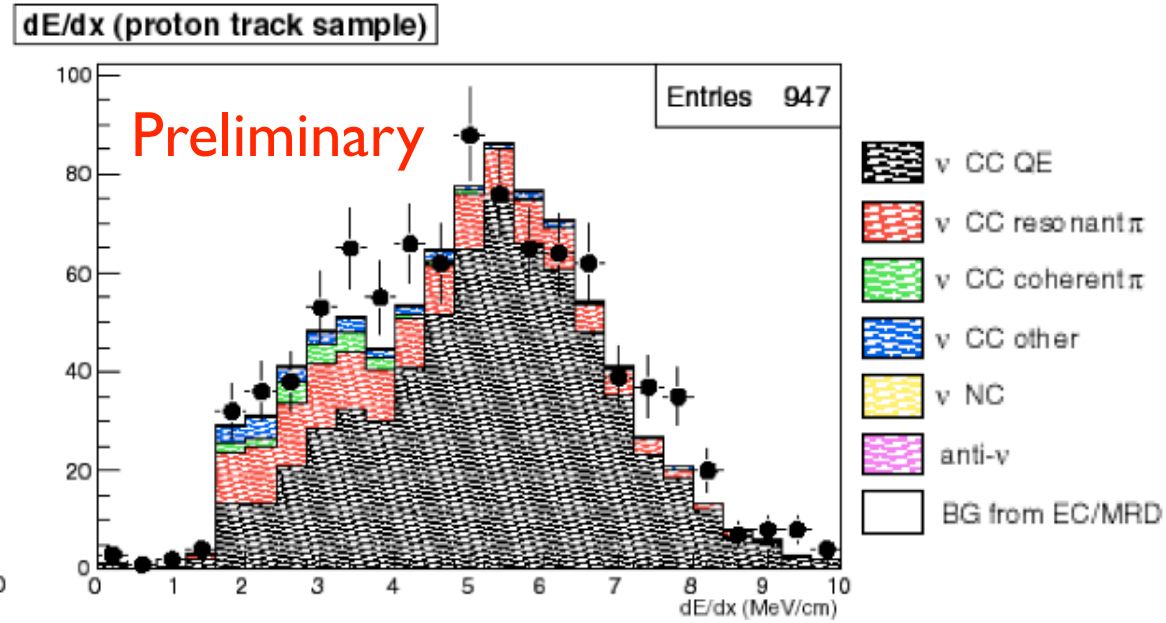


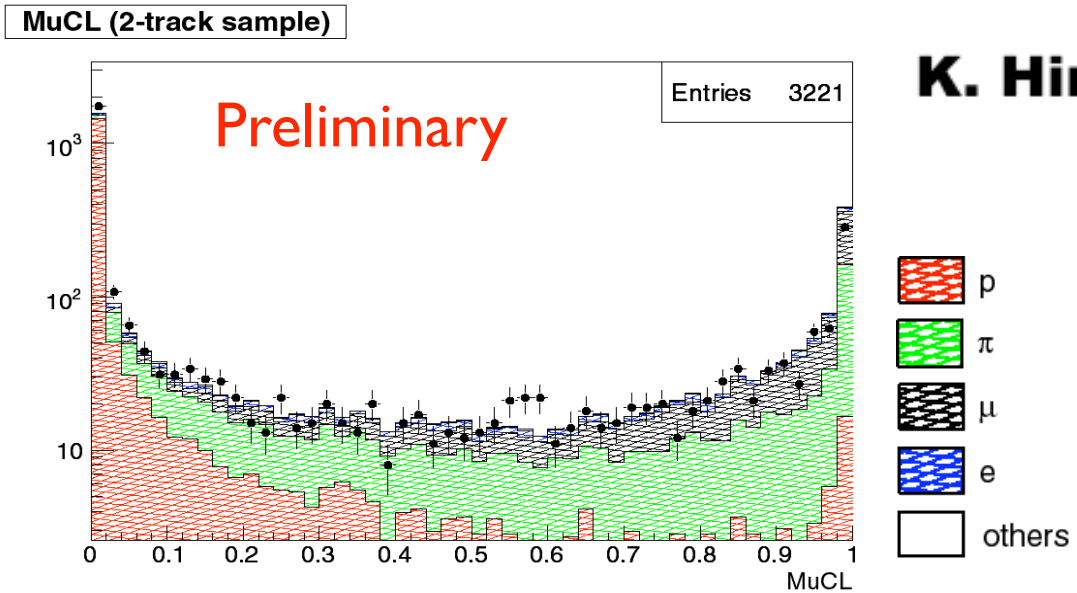


Jose Luis Alcaraz Aunion

Particle ID Using dE/dx





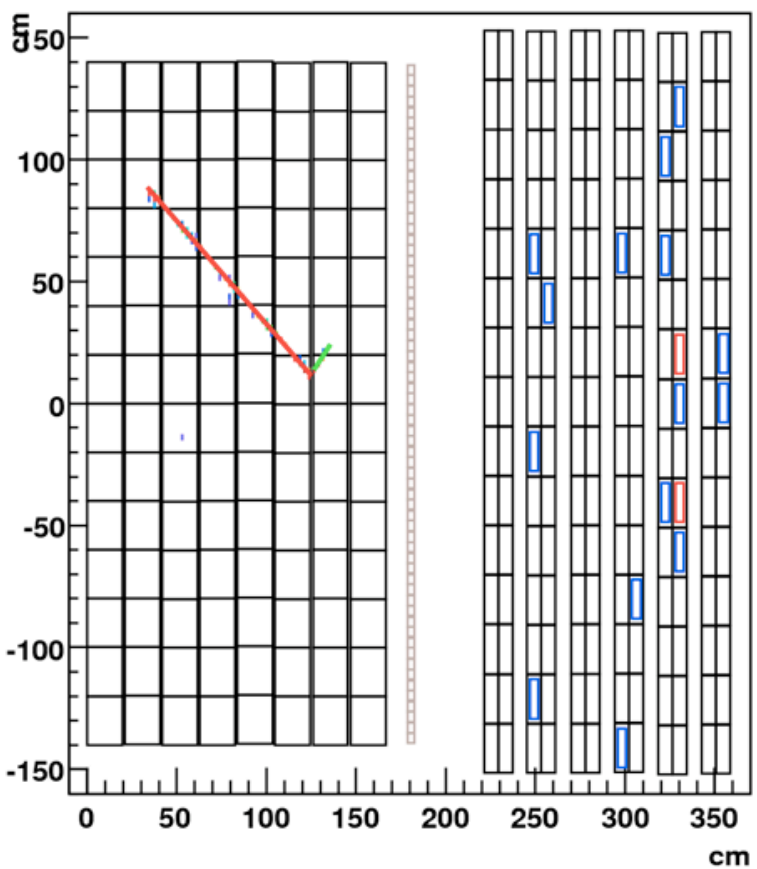


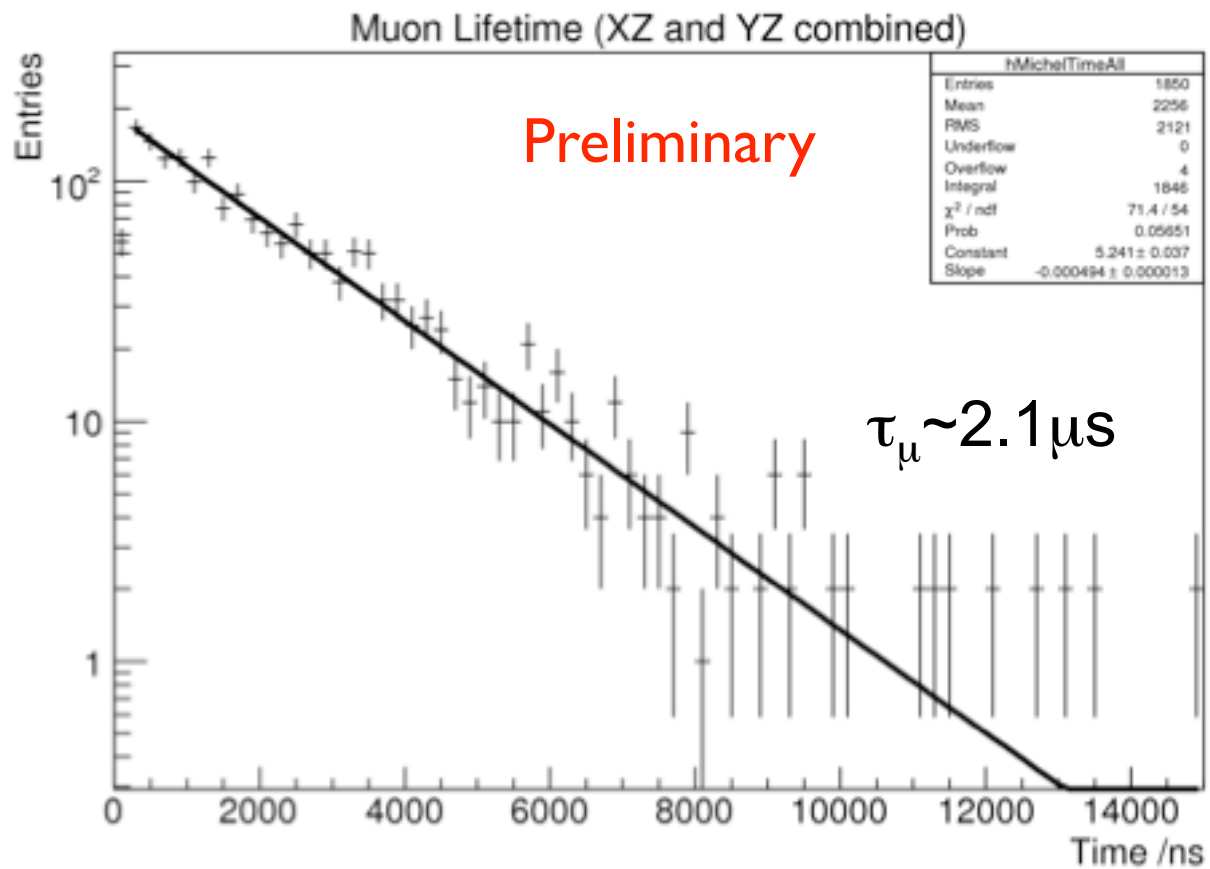
K. Hiraide

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

Stopped μ in SciBar

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

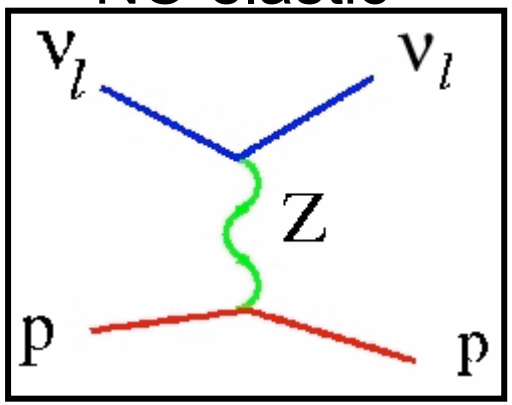




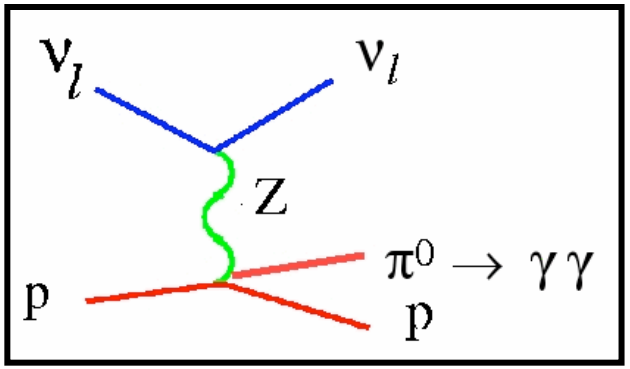
Neutral Current Analysis

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

NC-elastic

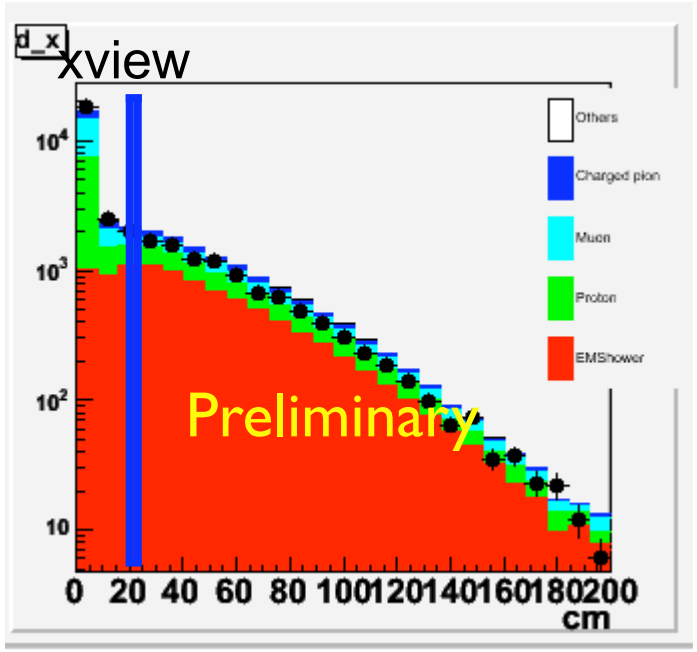


NC-π^0

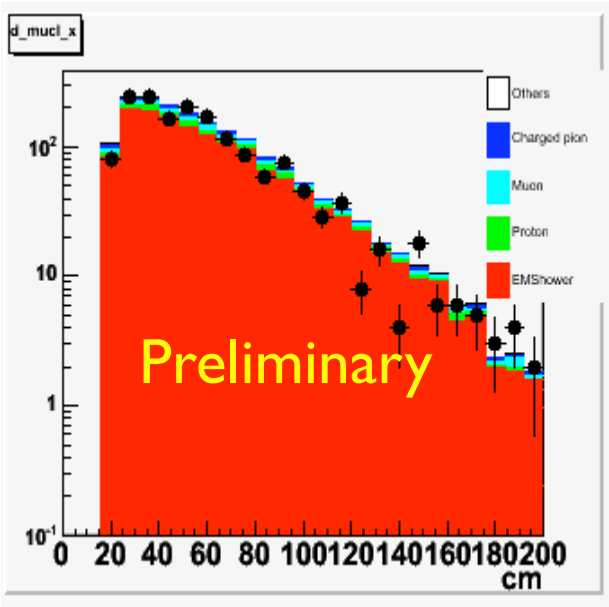


NC π^0

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



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



EMShower

NCπ0 (19%), CCπ0(17%)

Proton (19%)

Muon (17%)

EMShower

NCπ0 (47%), CCπ0 (12%)

Proton (7%)

Muon (6%)

Summary/Outlook

SciBooNE Physics

- Measure nu cross sections before T2K experiment
- Reduce uncertainties in MiniBooNE analysis
- Following NASA (smaller, faster, cheaper)

Status

- Construction complete at start of summer 2007
- 75% of expected data in hand
  - 100% of neutrino data on tape
  - 50% of anti-neutrino data on tape
- Detectors performing well
- Expect first results this summer

Young Collaboration

References

SciBooNE:

http://www-sciboone.fnal.gov

SciBooNE Proposal: hep-ex/0601022 v1

SciBar (K2K):

K. Nitta, *et al.,* (K2K SciBar group) Nucl. Instrum. and Meth. **A535** (2004) 147-151. hep-ex/040623

M. Hasegawa, *et al.,* (K2K Collaboration), Phys. Rev. Lett. **95**(2005) 252301. hep-ex/0506008

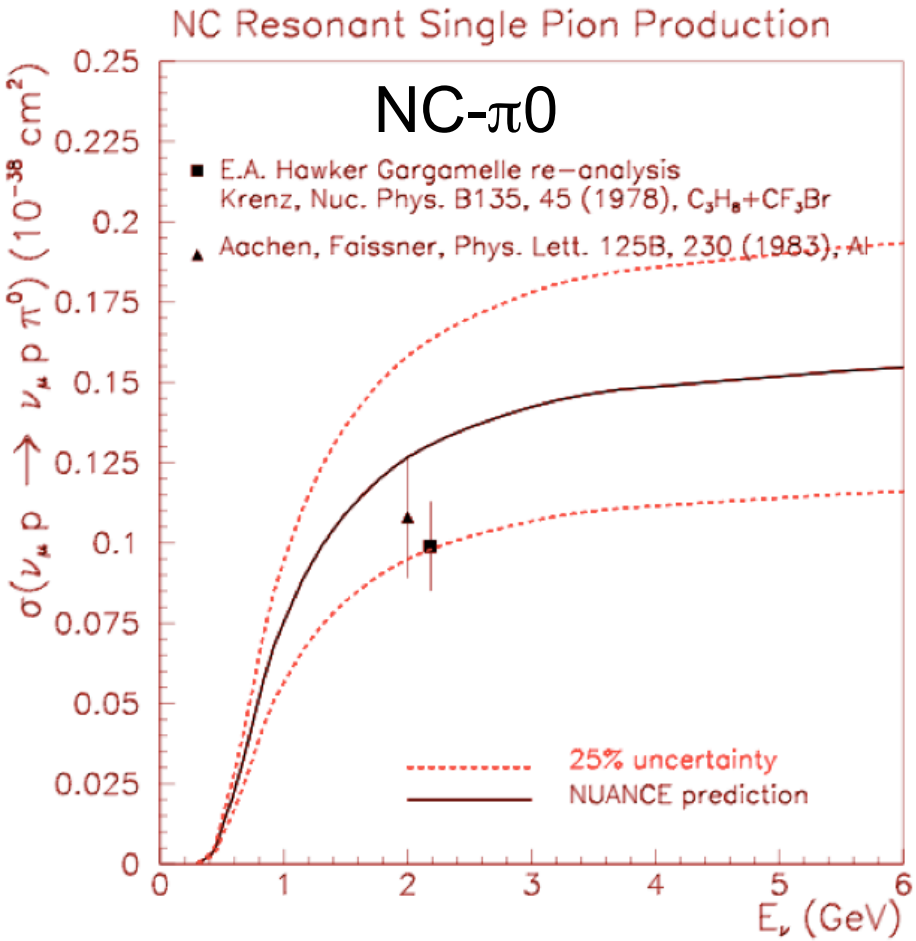
M.H. Ahn, *et al.,* (K2K Collaboration), Phys.Rev. **D74**(2006) 072003, hep-ex/0606032

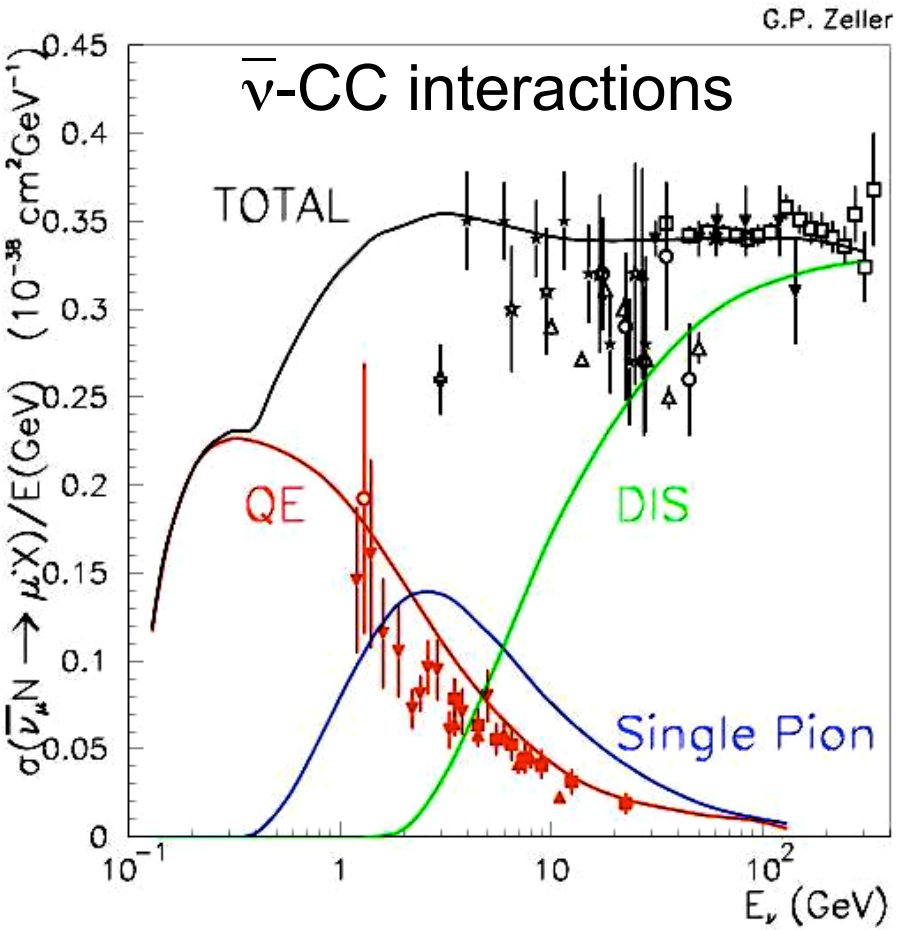
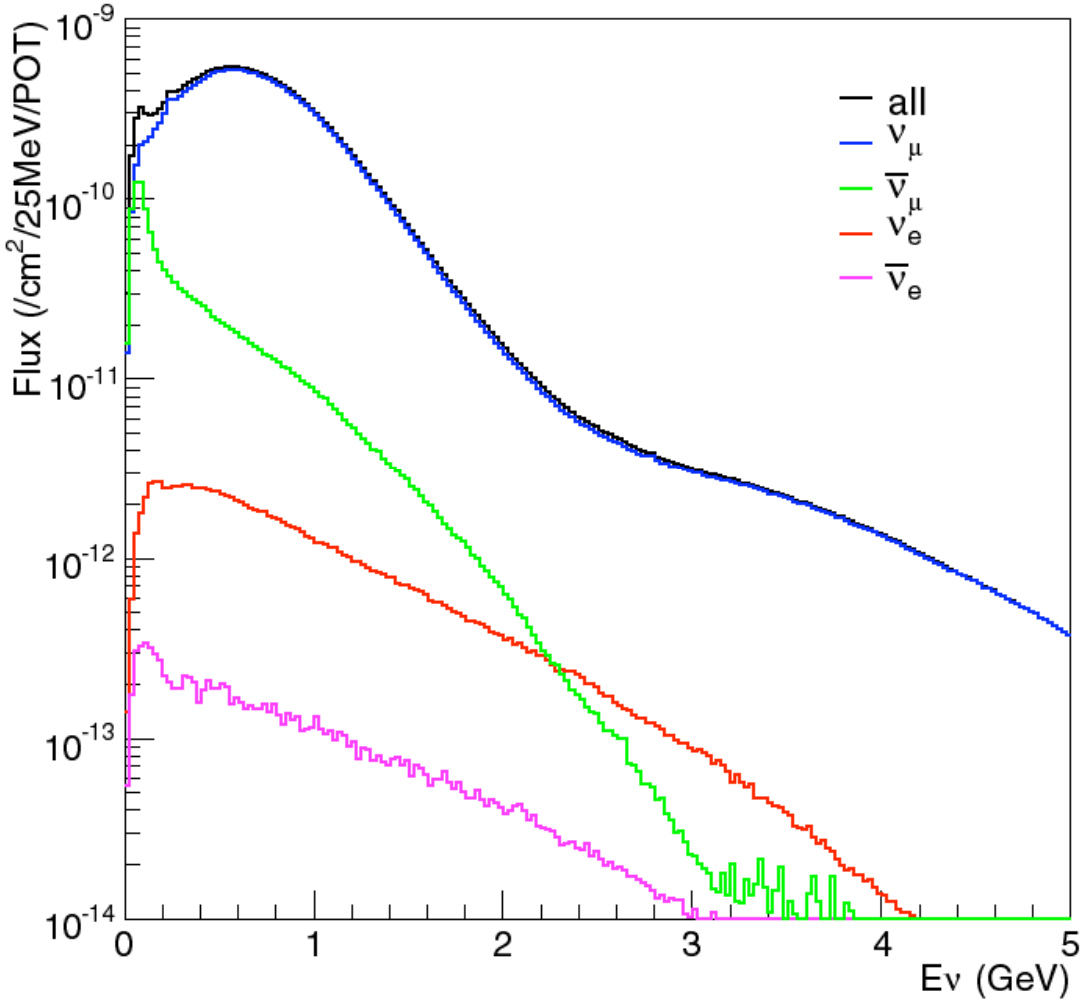
E. Aliu, *et al.,* (K2K Collaboration, Phys.Rev.Lett **94**(2005)081802. hep-ex/0411038.

MiniBooNE (Booster Neutrino Beam):

I.Stancu, *et al.,* (MiniBooNE Collaboration) (2001) **FERMILAB-TM-2207**.

Back up slides


NC Resonant Single Pion Production
NC-π0
E.A. Hawker Gargamelle re-analysis
Krenz, Nuc. Phys. B135, 45 (1978), C3H8+CF3Br
Aachen, Faissner, Phys. Lett. 125B, 230 (1983), Al
25% uncertainty
NUANCE prediction
σ(νμ p → νμ p π0) (10-38 cm2)
Eν (GeV)


G.P. Zeller
ν̄-CC interactions
TOTAL
QE
DIS
Single Pion
σ(ν̄μN → μ+X)/E(GeV) (10-38 cm2GeV-1)
Eν (GeV)

Booster Neutrino flux