SciBooNE (FNAL E954)

Study of neutrino cross sections in the GeV region.

T. Nakaya (Kyoto)

for the SciBooNE collaboration

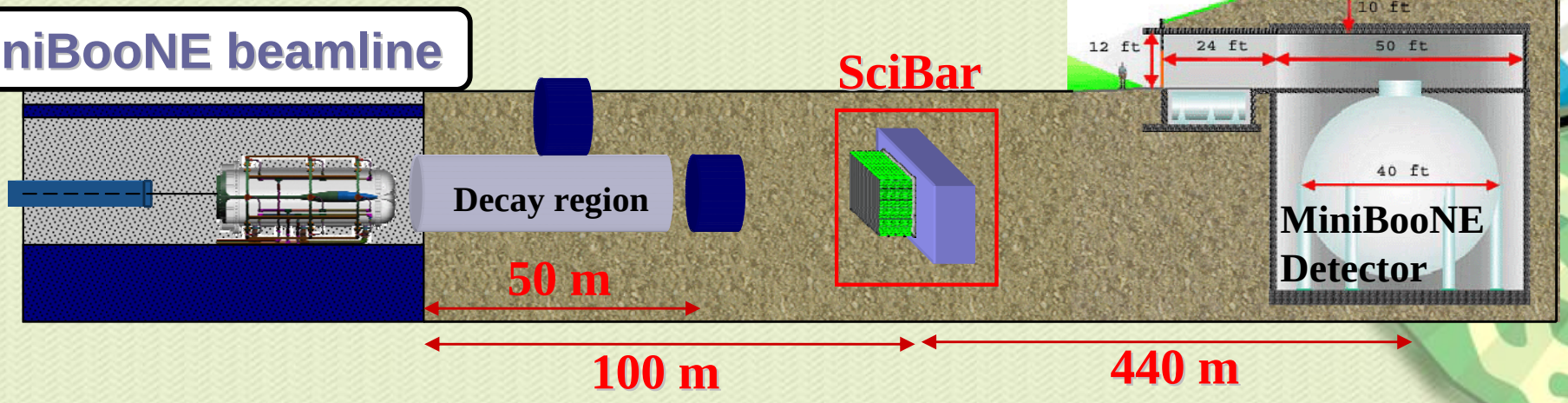
Outline

- Introduction to SciBooNE
- SciBooNE Physics
- SciBooNE Detector and Beam
- SciBooNE Status
- Summary

1. Introduction to SciBooNE

- A new approved experiment to measure the neutrino and anti-neutrino cross sections at the FNAL Booster Neutrino Beam line

MiniBooNE beamline

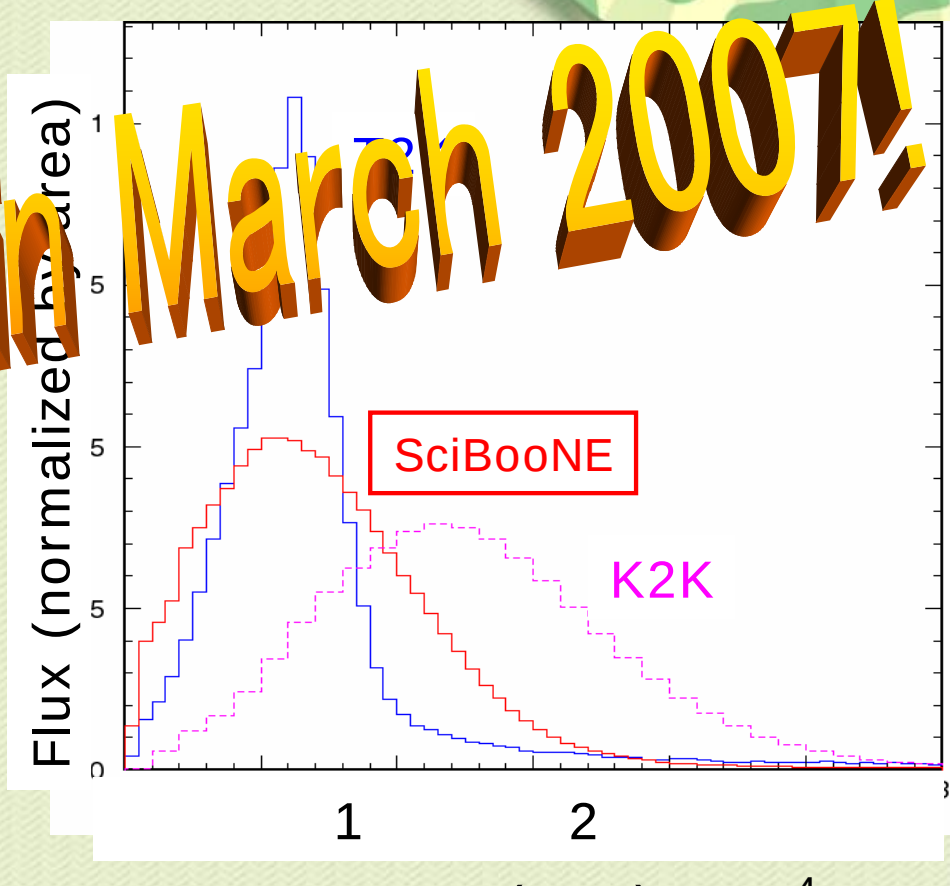


- Precision study of neutrino cross sections for T2K.
- Anti-neutrinos
  - Unexplored phys… to … improv… … detector.

The experiment will start in March 2007!

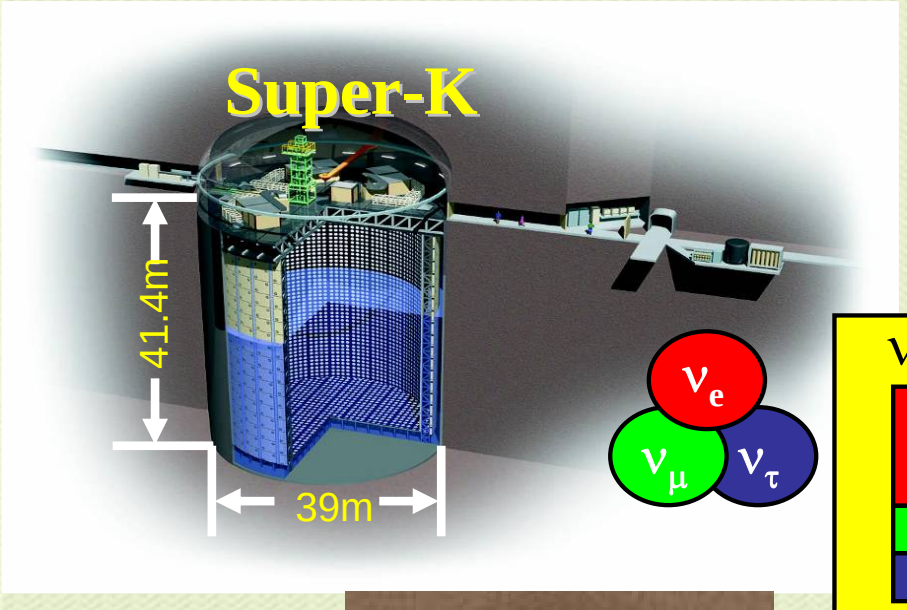
K2K-SciBar + FNAL-BNB

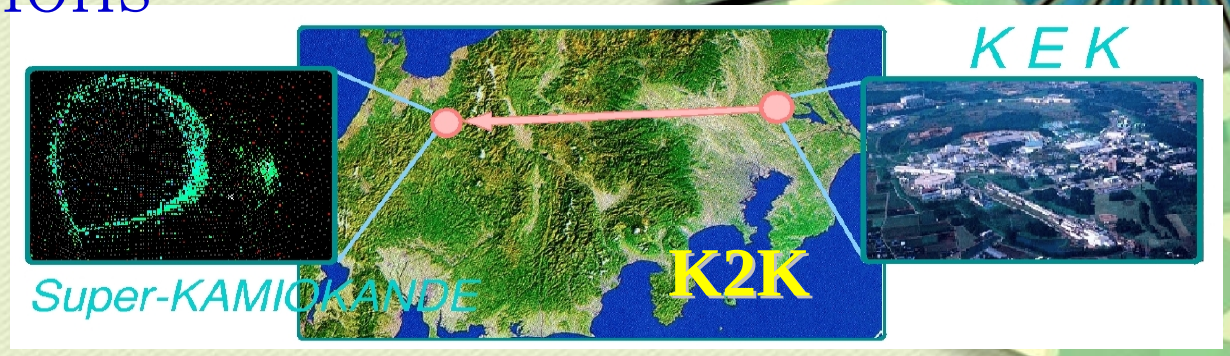
- Well developed Detector
- Most intense low energy neutrino beam.

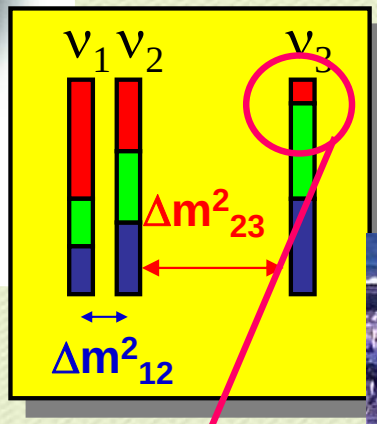


2. SciBooNE Physics

- For neutrino oscillations

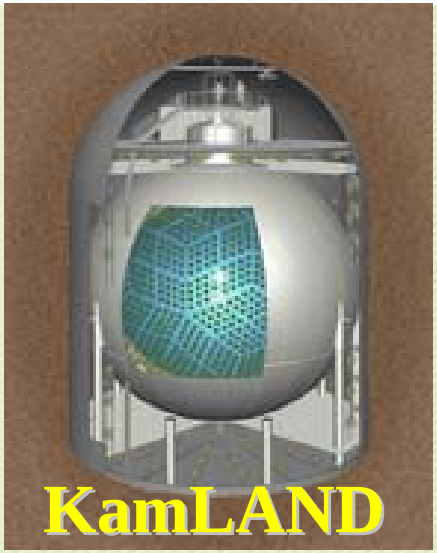






Neutrino masses (Δm_{12}^2, Δm_{23}^2)
Mixing Angles (θ_{12}, θ_{23})

$\theta_{13} \rightarrow \delta$



Strategy of accelerator ν oscillation experiments.

Intense beam

Gigantic detector

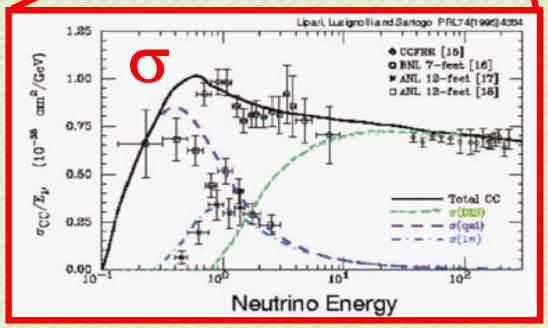
protons

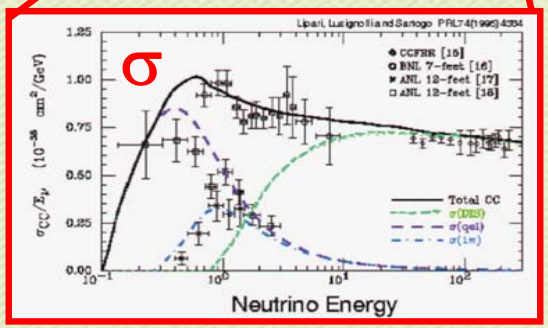
π, π, π, π, K

oscillation

ν, ν, ν, ν

$\Phi_\nu(E)$





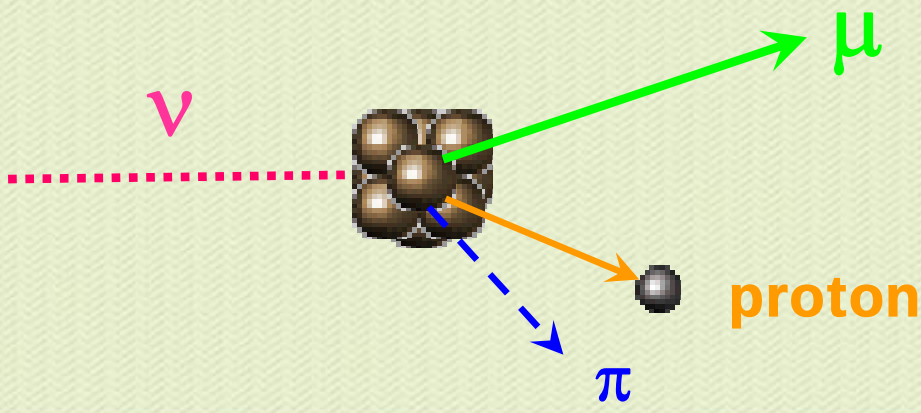
$\sigma(E)\cdot\Phi_\nu^{near}(E) \Leftrightarrow \sigma(E)\cdot\Phi_\nu^{far}(E)$

MiniBooNE

K2K-ND

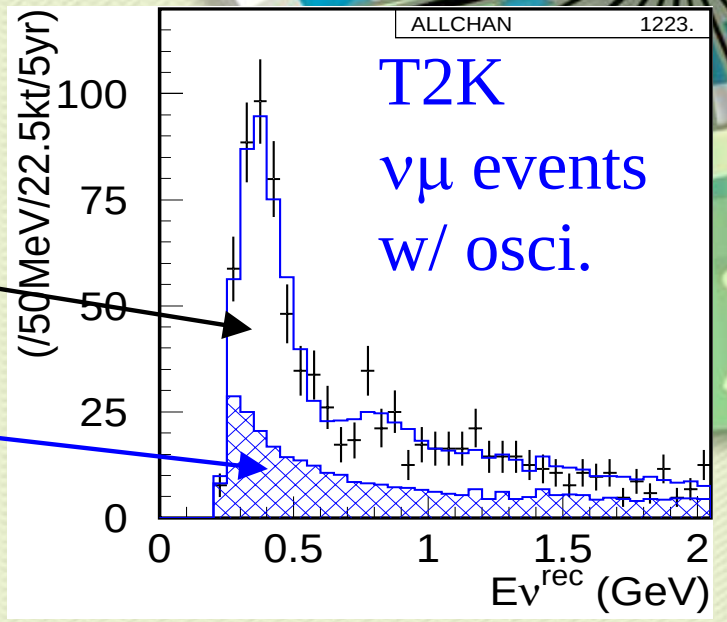
SciBooNE

MINERνA

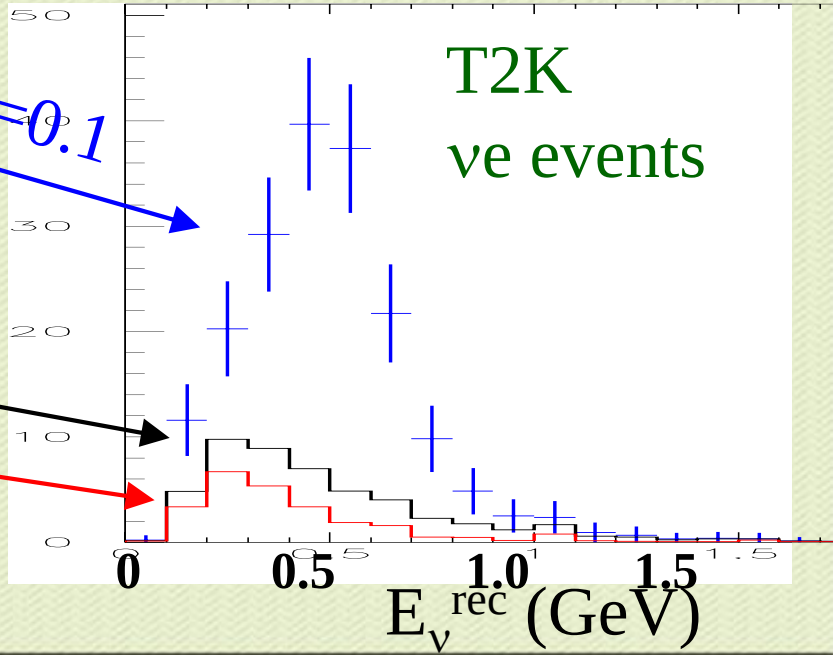


Impact of Neutrino Cross sections on oscillation measurements

- $\nu_\mu \rightarrow \nu_\mu$: 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

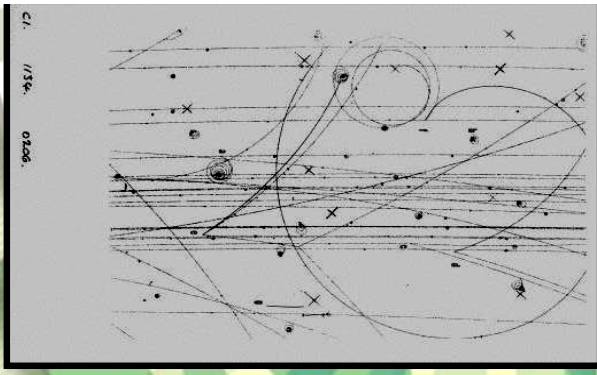


- $\nu_\mu \rightarrow \nu_e$: search for θ_{13}
  - Signal: CC-QE ($\nu + n \rightarrow e + p$)
  - Background
    - Beam ν_e
    - NCπ^0
      - Cross section as a function of the momentum

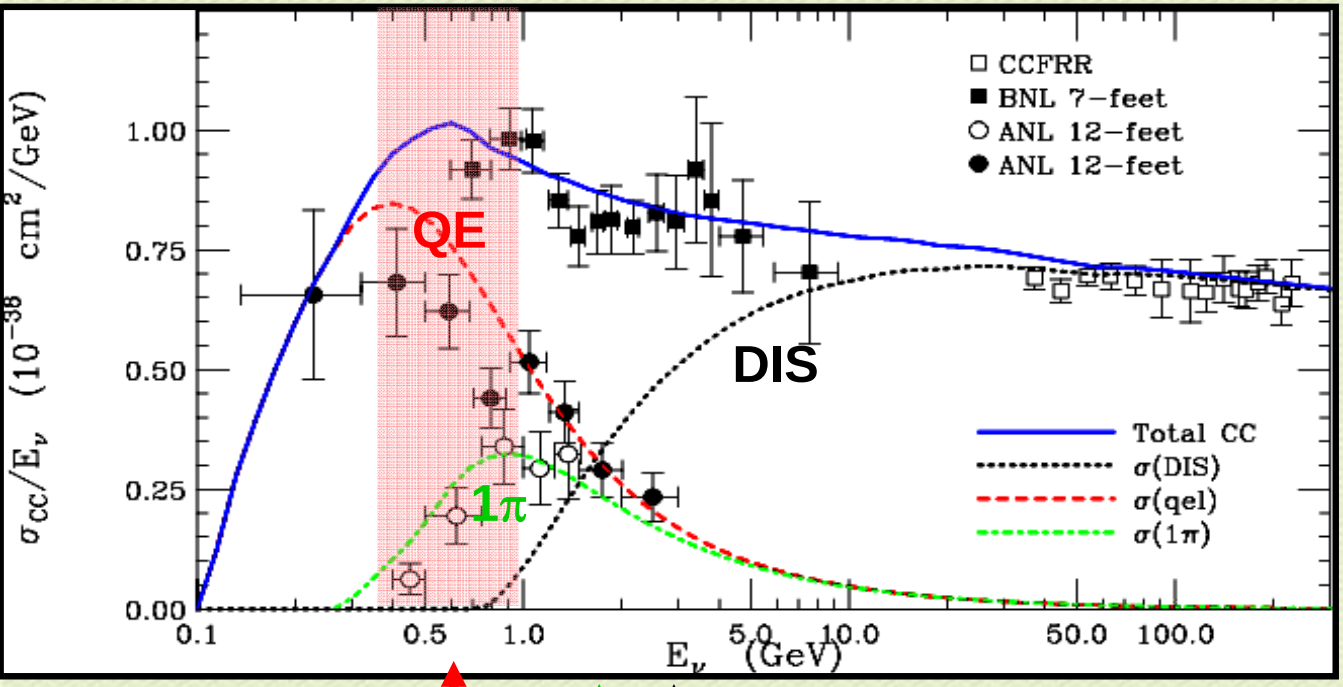


Anti-ν for CP violation study

Unexplored Areas of Neutrino Physics



σ_ν in this E range of interest:



MINOS, NuMI

K2K, NOvA

MiniBooNE, T2K, SciBooNE

Super-K atmospheric ν

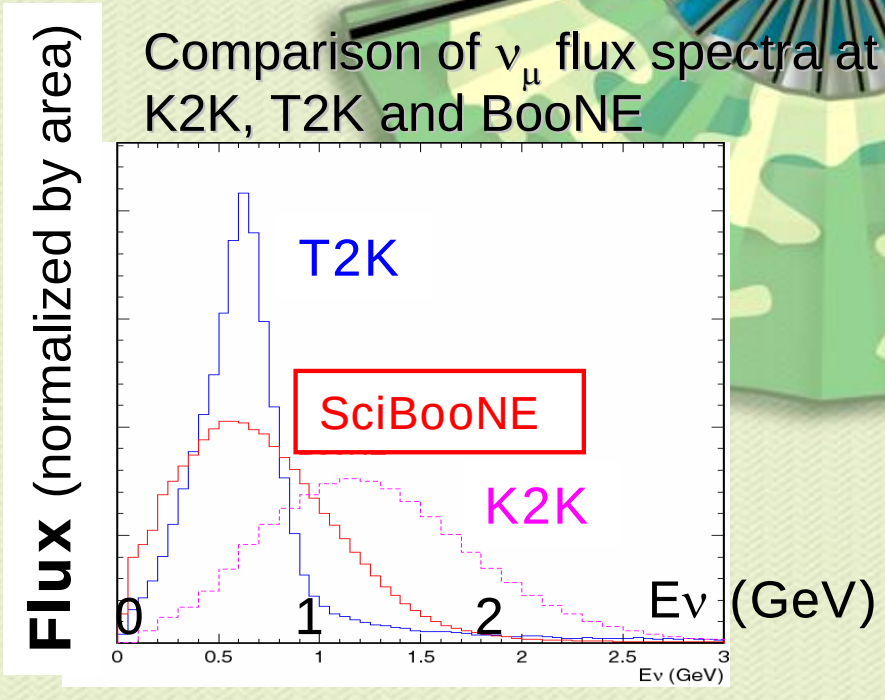
- **Data from old experiments** (1970~1980)
  - Low statistics
  - Systematic Uncertainties
- **Nuclear effects** (π/p/n absorption/scattering, shadowing, low Q^2 region)
  - Not well-modeled
- **New data** from MiniBooNE & K2K revealing surprises
- **More data at 1GeV with fine grained resolution will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

Anti-ν cross section is in a poor situation.

Neutrino Measurements (~5% precision)

- Measurements
  - CC-1π cross section
  - CCQE σ,M_A measurement
  - NC π^0 measurement
  - Search for CC coherent π
  - Search for NC coherent π^0
  - Search for radiative Delta decay (ν+N$\rightarrow\mu$+N'+γ)
  - Intrinsic ν_e flux for BNB ($\nu_\mu\rightarrow\nu_e$ appearance search)
  - Unoscillated $\Phi_\nu\times\sigma$ for BNB ($\nu_\mu\rightarrow\nu_\mu$ disappearance search)

Comparison of ν_μ flux spectra at K2K, T2K and BooNE



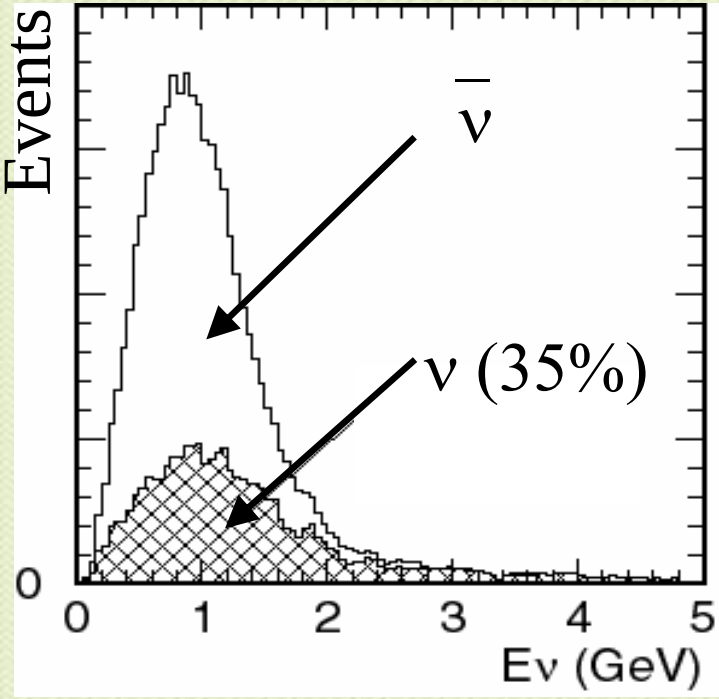
Cross checks

Study ν interactions to improve MC modeling of low E νs for precision physics

$\bar{\nu}$ Measurements (~10% precision)

- CCQE measurement.
  - Negligible BG from ν.
  - Energy Dependence of σ and M_A
- CC-1π cross section with M_A.
- NC π^0 measurement
  - Also $\nu+p \rightarrow \nu+p+\pi^0$ exclusive final-state search
- Search for CC coherent π
- Search for NC coherent π^0
- Search for radiative Delta decay ($\nu+N \rightarrow \mu+N'+\gamma$)
- Hyperon production in anti-ν mode
- Energy dependence of ν contamination of BNB anti-ν mode.

Reversible current horn



3. SciBooNE Detector and Beam

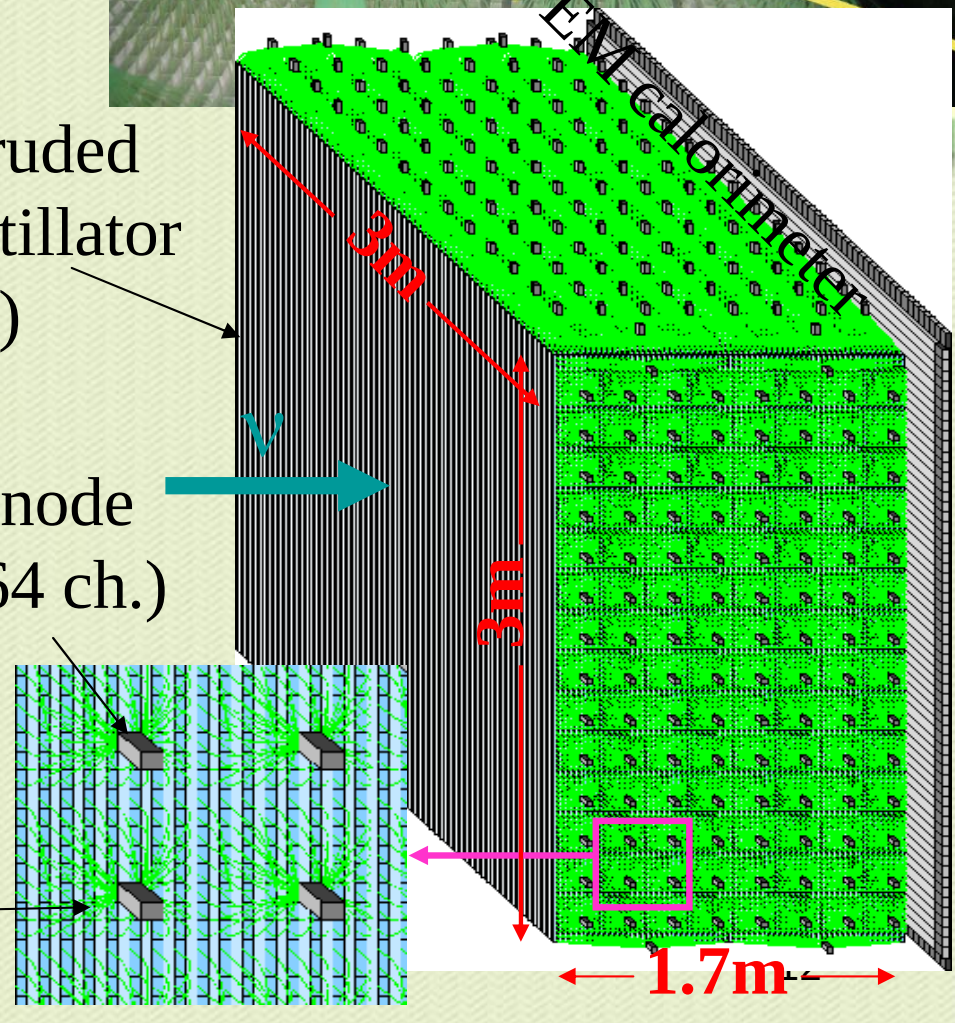
- *Detectors*
  - K2K-SciBar Detector
  - K2K/CHORUS Electron Calorimeter
  - Muon Range Detector (newly built)
- *FNAL Booster Neutirno Beam*
  - Both neutrinos and anti-neutrinos
  - High Intensity (~2E20 POT/year)
  - Low energy matching with the T2K ν energy

SciBar Detector

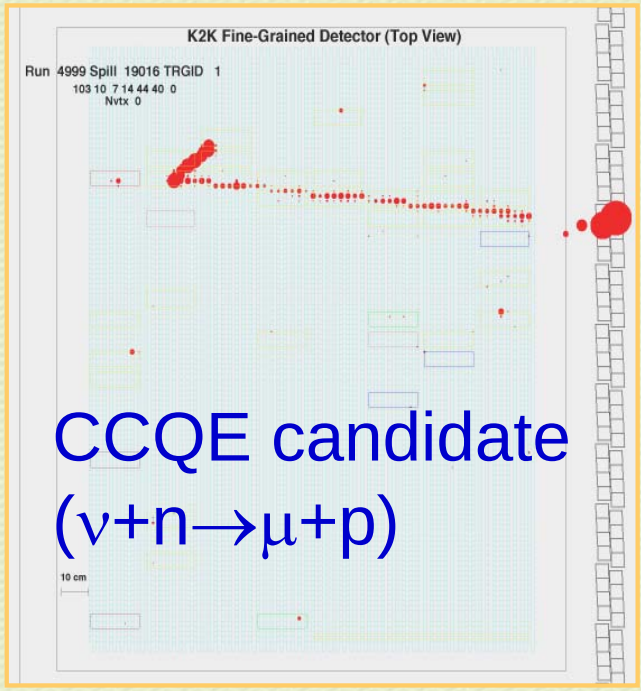
- **Extruded scintillators with WLS fiber readout**
- **The scintillators are the neutrino target**
- **2.5 x 1.3 x 300 cm^3 cell**
- **~15000 channels**
- **Detect short tracks (>8cm)**
- **Distinguish a proton from a pion by dE/dx**
- **Total 15 tons**

➔High track finding efficiency (>99%)

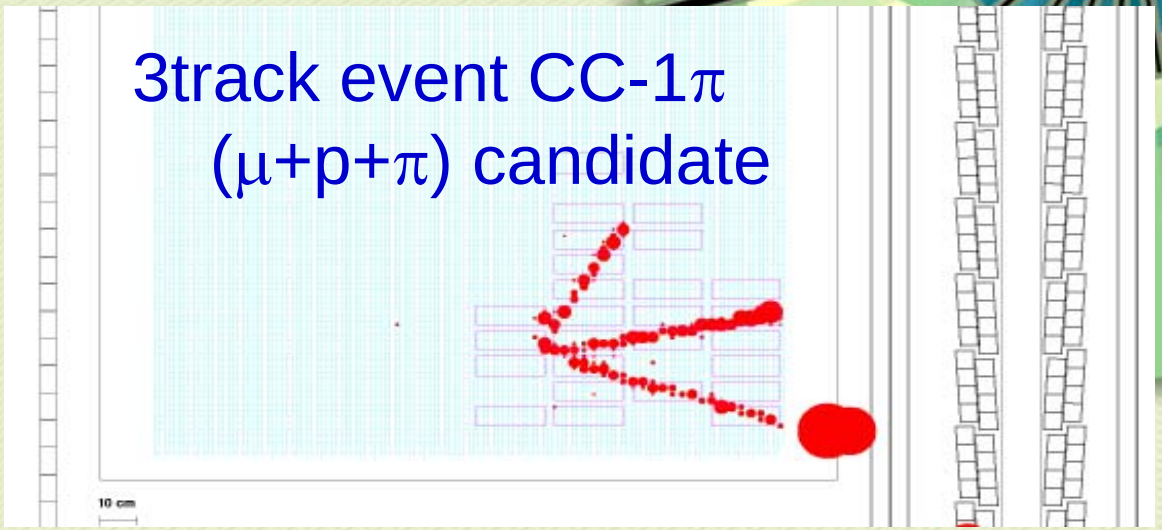
➔Clear identification of ν interaction process



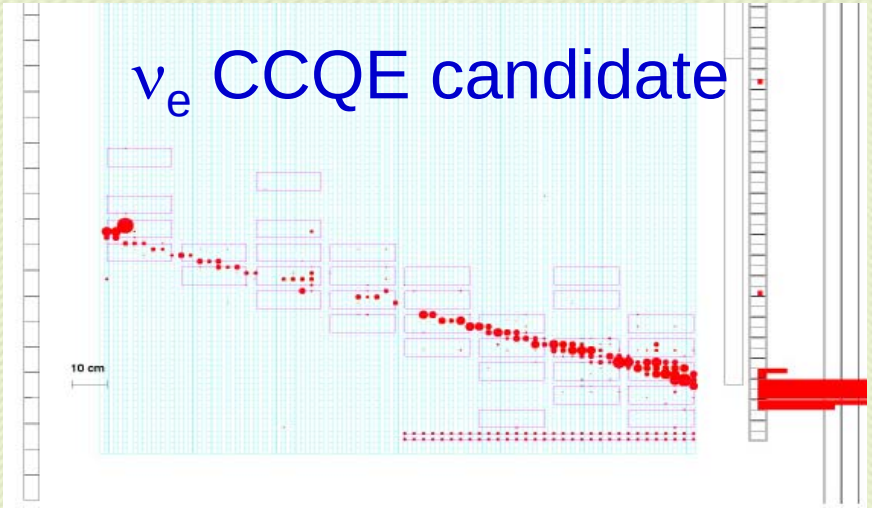
SciBar-Shots (15k pixels) in K2K



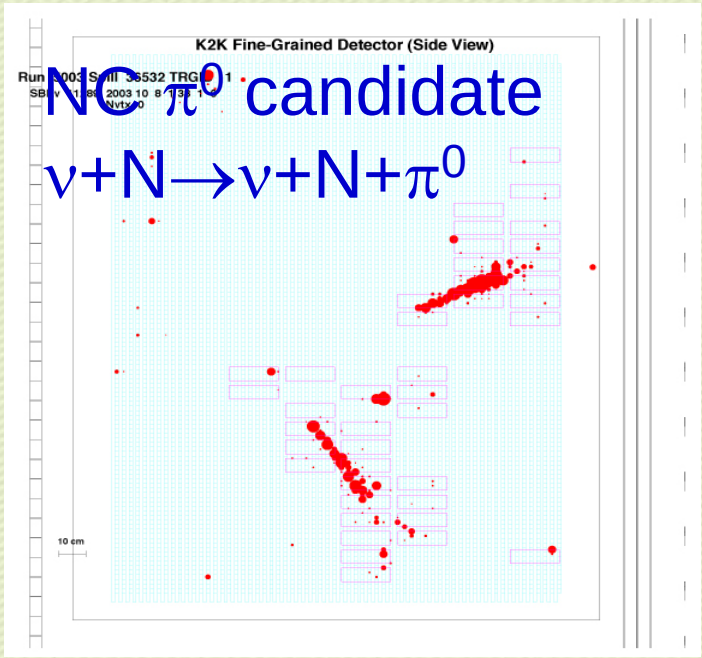
CCQE candidate
($\nu+n \rightarrow \mu+p$)



3track event CC-1π
($\mu+p+\pi$) candidate



ν_e CCQE candidate



NC π^0 candidate
$\nu+N \rightarrow \nu+N+\pi^0$

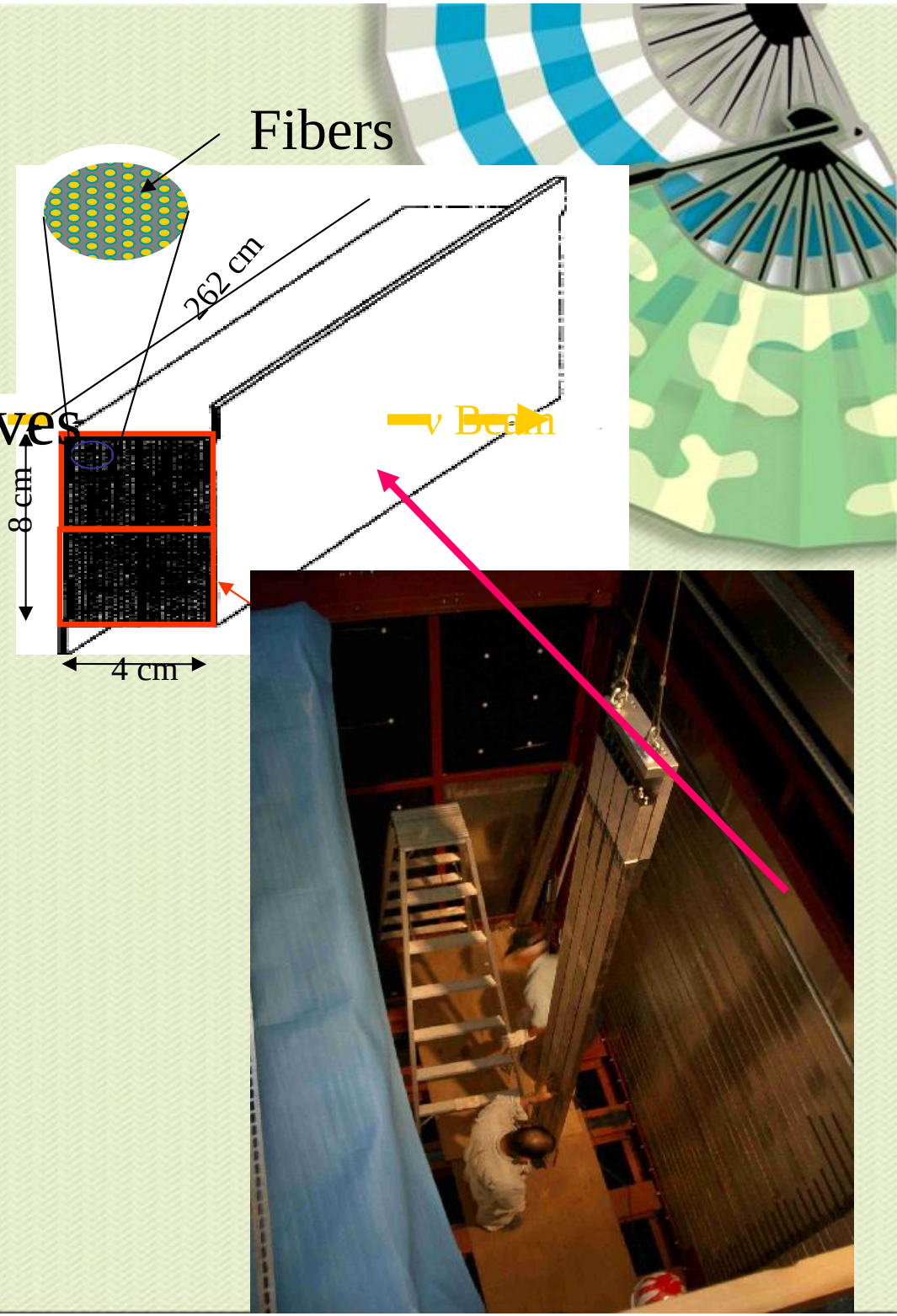
Sony Cyber-shot
(6M pixels)

Electron Catcher

- "spaghetti" calorimeter re-used from CHORUS
- 1mm diameter fibers in the grooves of lead foils
- 4x4cm^2 cell read out

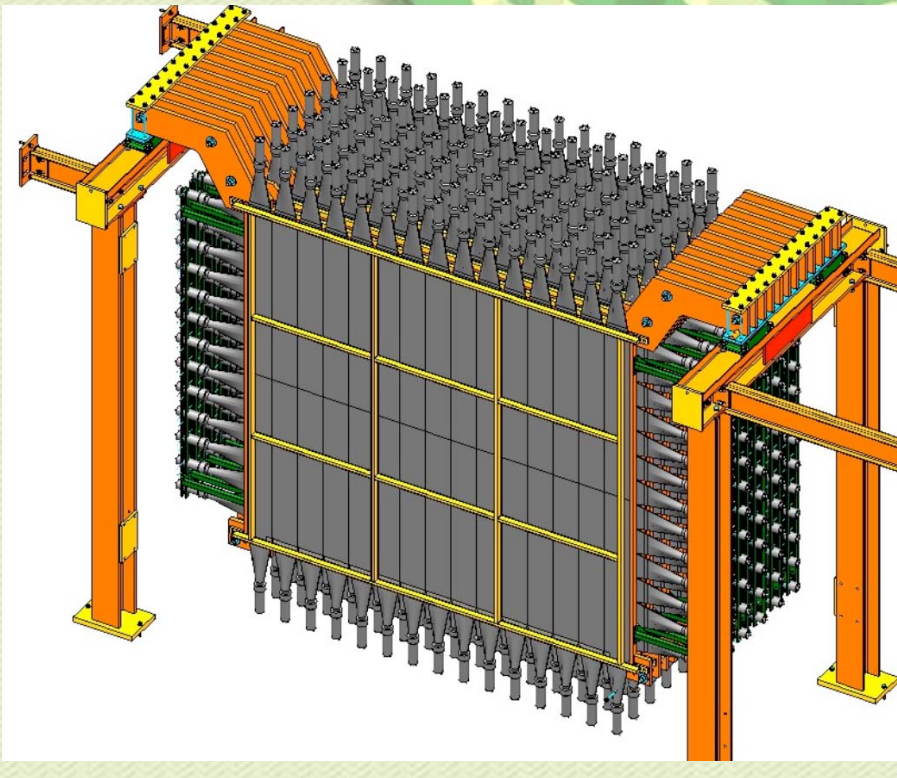
  from both ends
- 2 planes ($11X_0$)

  Horizontal: 30 modules
  Vertical : 32 modules
- Expected resolution $14\%\sqrt{E}$
- Linearity: better than 10%



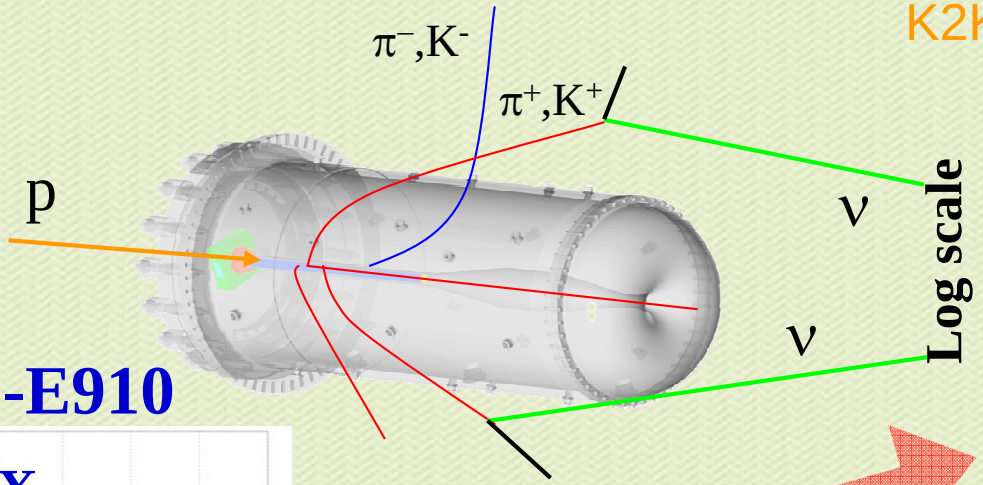
Muon Range Detector (MRD)

- 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
    - 305×247×5cm^3
    - Total 13 layers
  - Scintillator planes
    - Alternating horizontal and vertical planes.
    - Total 362 channels

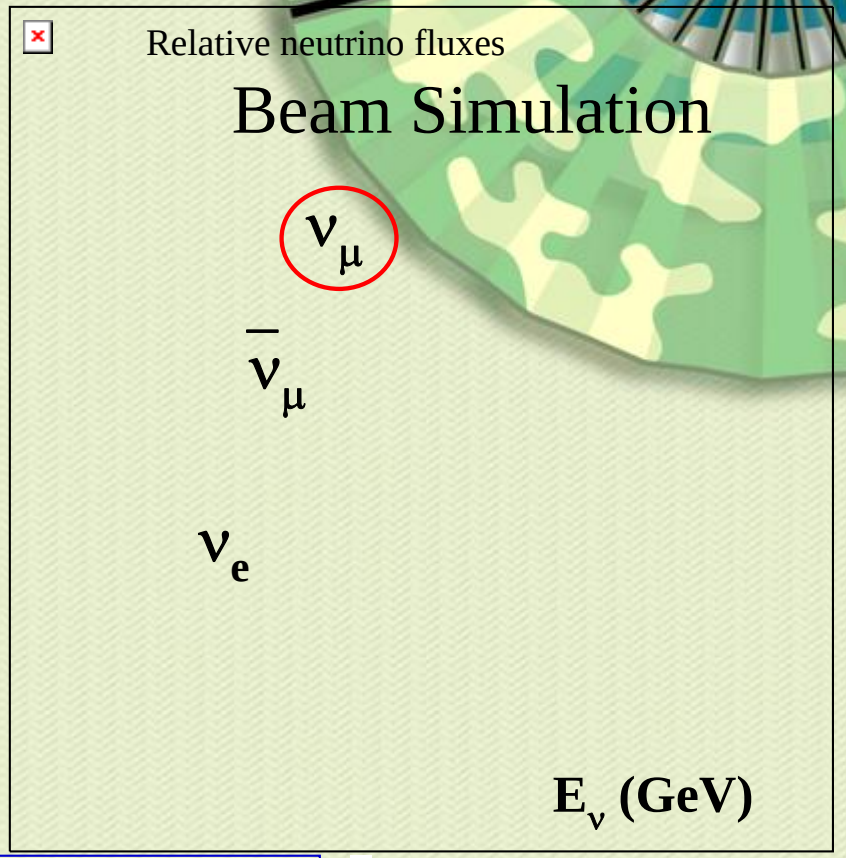


FNAL BNB (2E20 protons for SciBooNE)

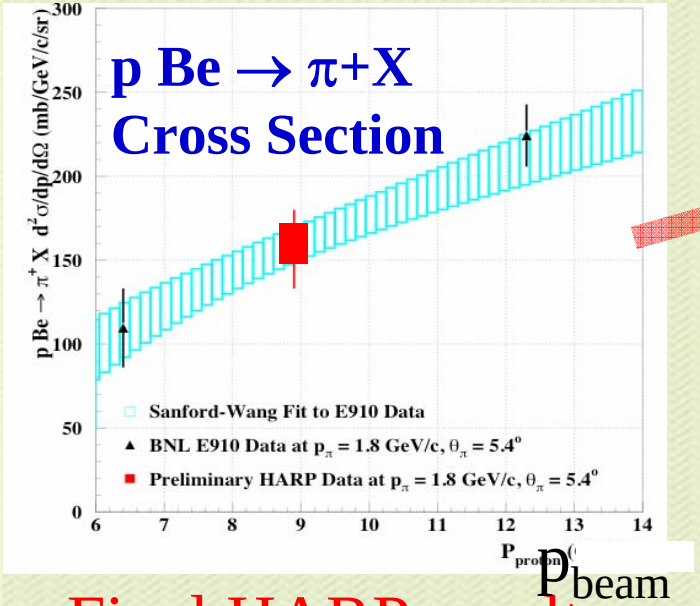
K2K-SciBar Data: ~0.2E20 protons



Log scale



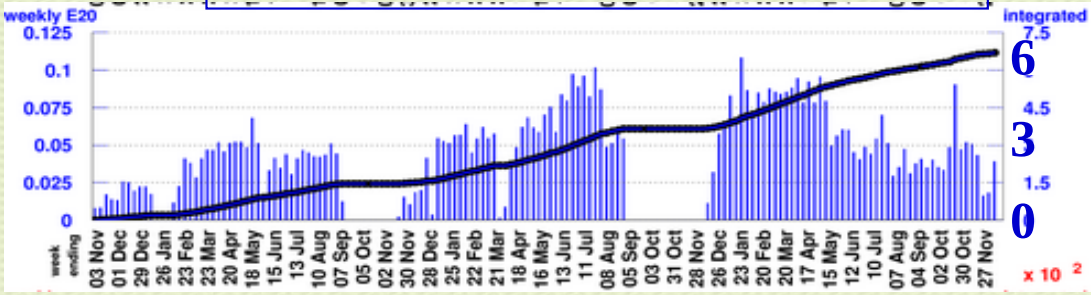
From BNL-E910



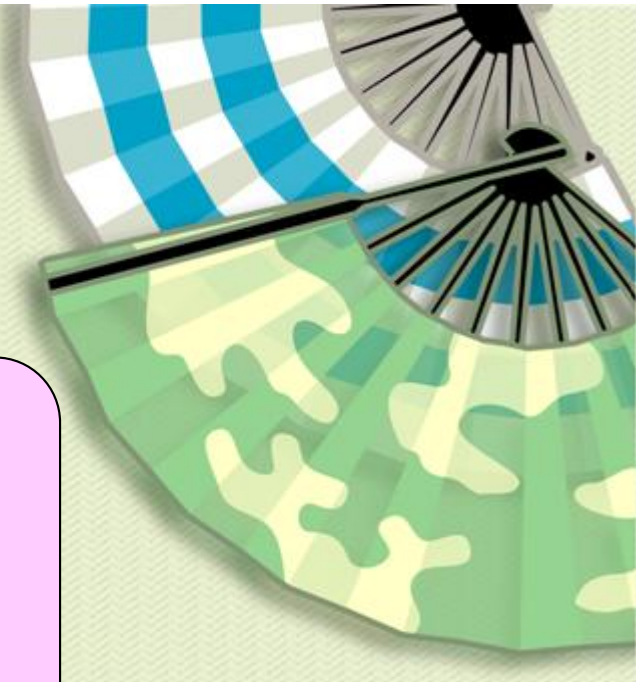
p_{beam}

Final HARP results is coming.

6.7E20 Protons/3 years



SciBooNE Events



- Neutrino run (~1×10^{20} POT)

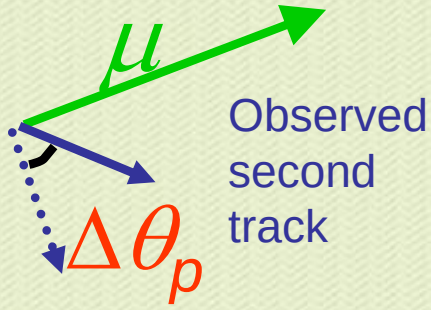
# of interactions
in 10 ton Fiducial Volume
ν_μ ~**156,000**
ν_e~ **1400**

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

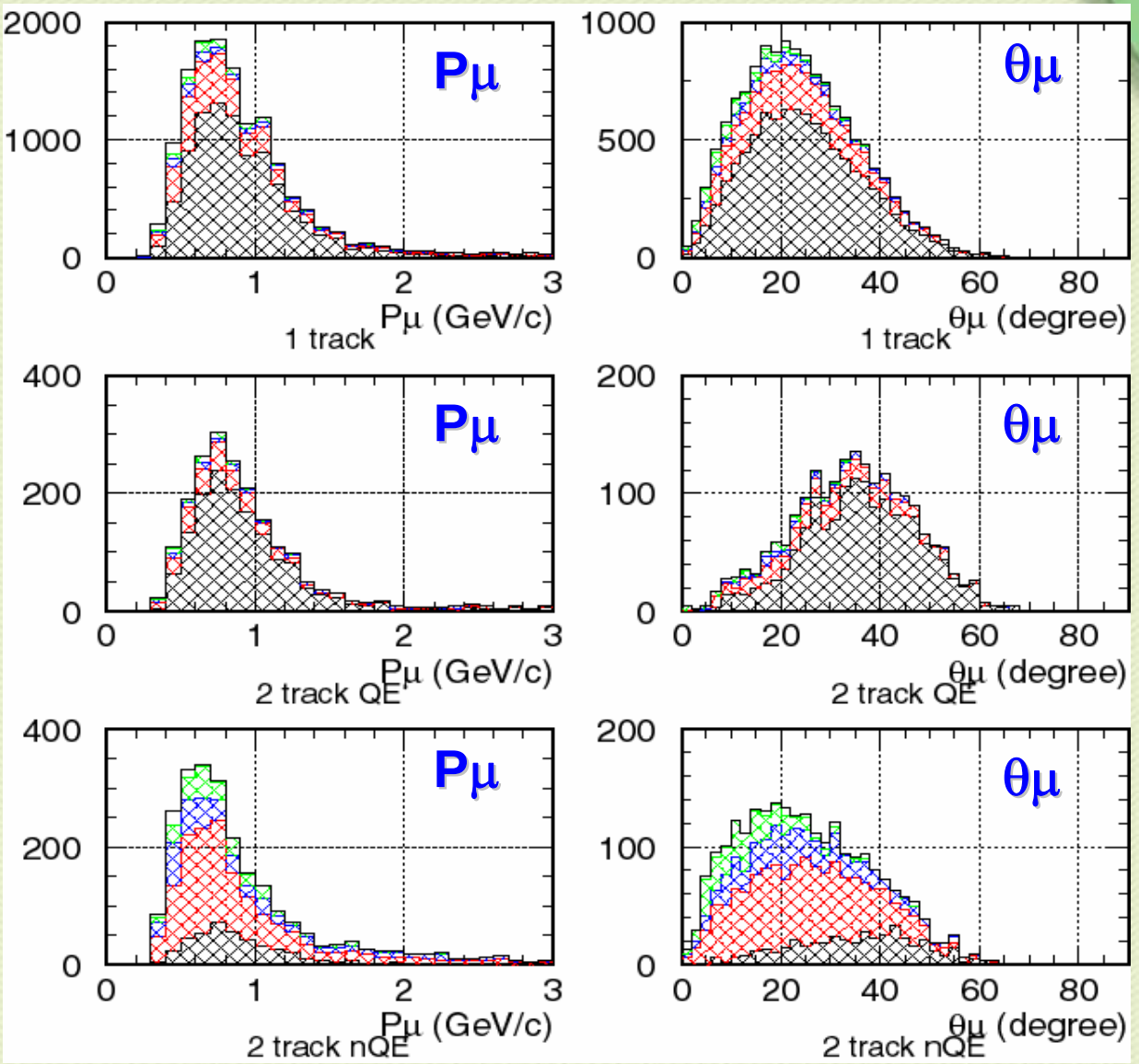
- Anti-neutrino run (~1×10^{20} POT)

# of interactions in FV
$\overline{\nu}_\mu$ ~**26,000**
ν_μ ~**14,000**

CC Event Selection with MRD matching (0.5E19 POT)



Expected direction assuming CCQE



CC-QE
CC-1π
CC-coh. π
CC-multi π

1 track

~13,500 events
QE~67%

2 track QE

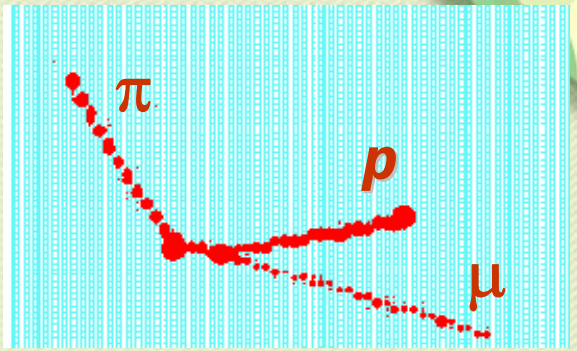
~1,970 events
QE~76%

2 track non-QE

~2,360 events
CC-1π~49%

CC−1π^+ measurement

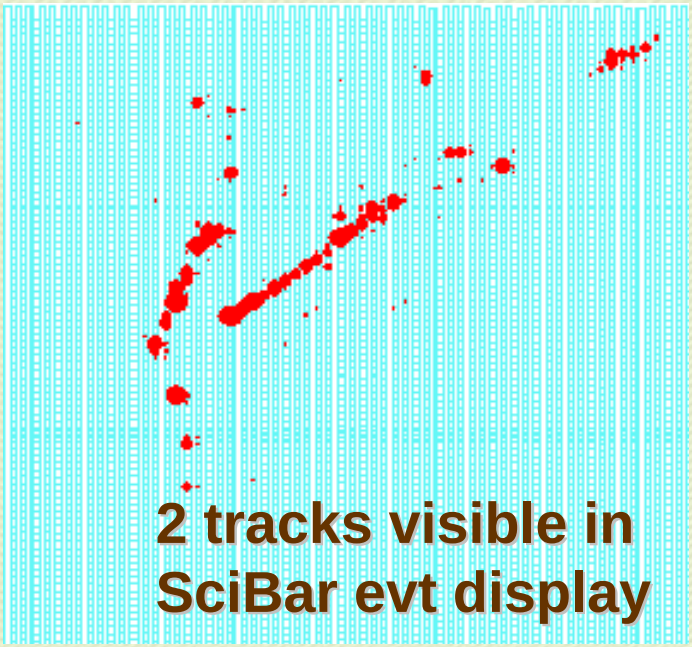
- CC−1π+ signature:
  - 2 MIP−like tracks



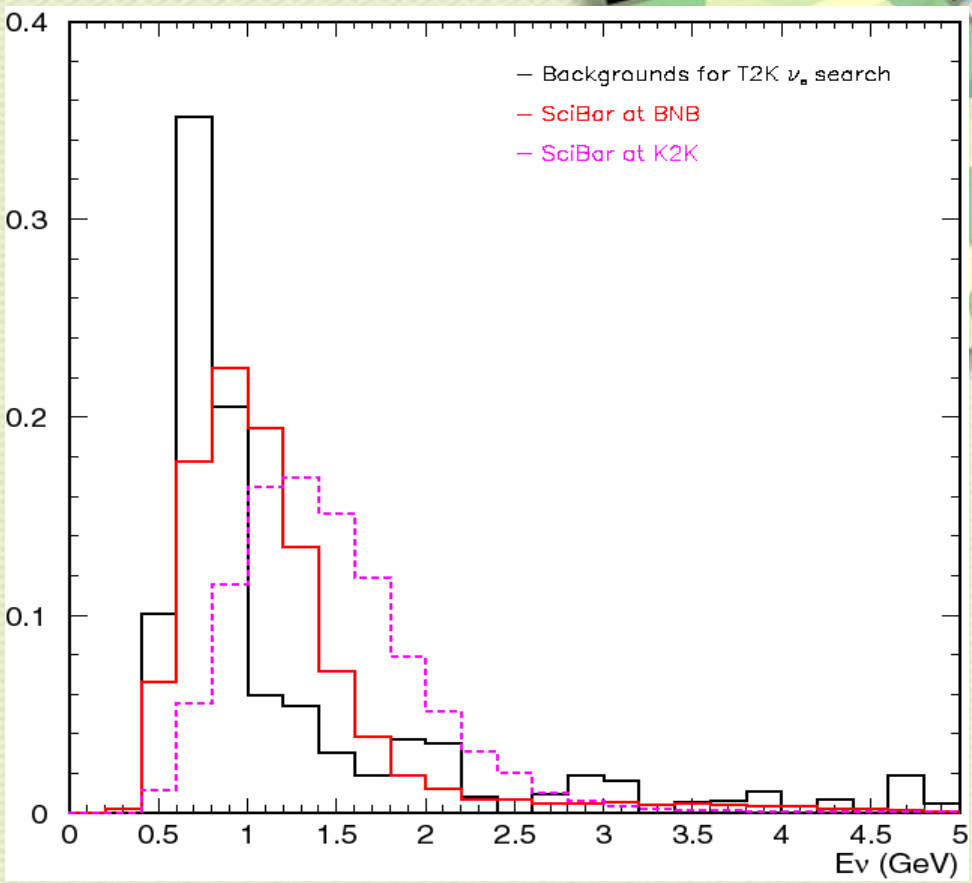
- Vertex activity cuts:
  - separate ν+p→μ^-pπ^+
  - from ν+n→ μ^+nπ^+

Statistics and systematics Sufficient for ~5% measurement

NC-1π^0 measurement



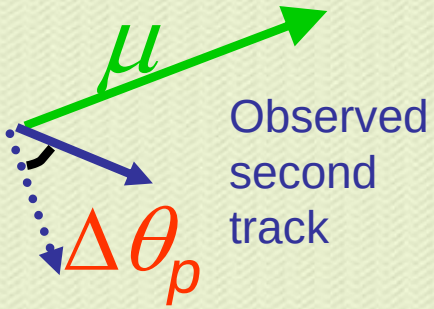
2 tracks visible in SciBar evt display



200~700MeV/c π^0s

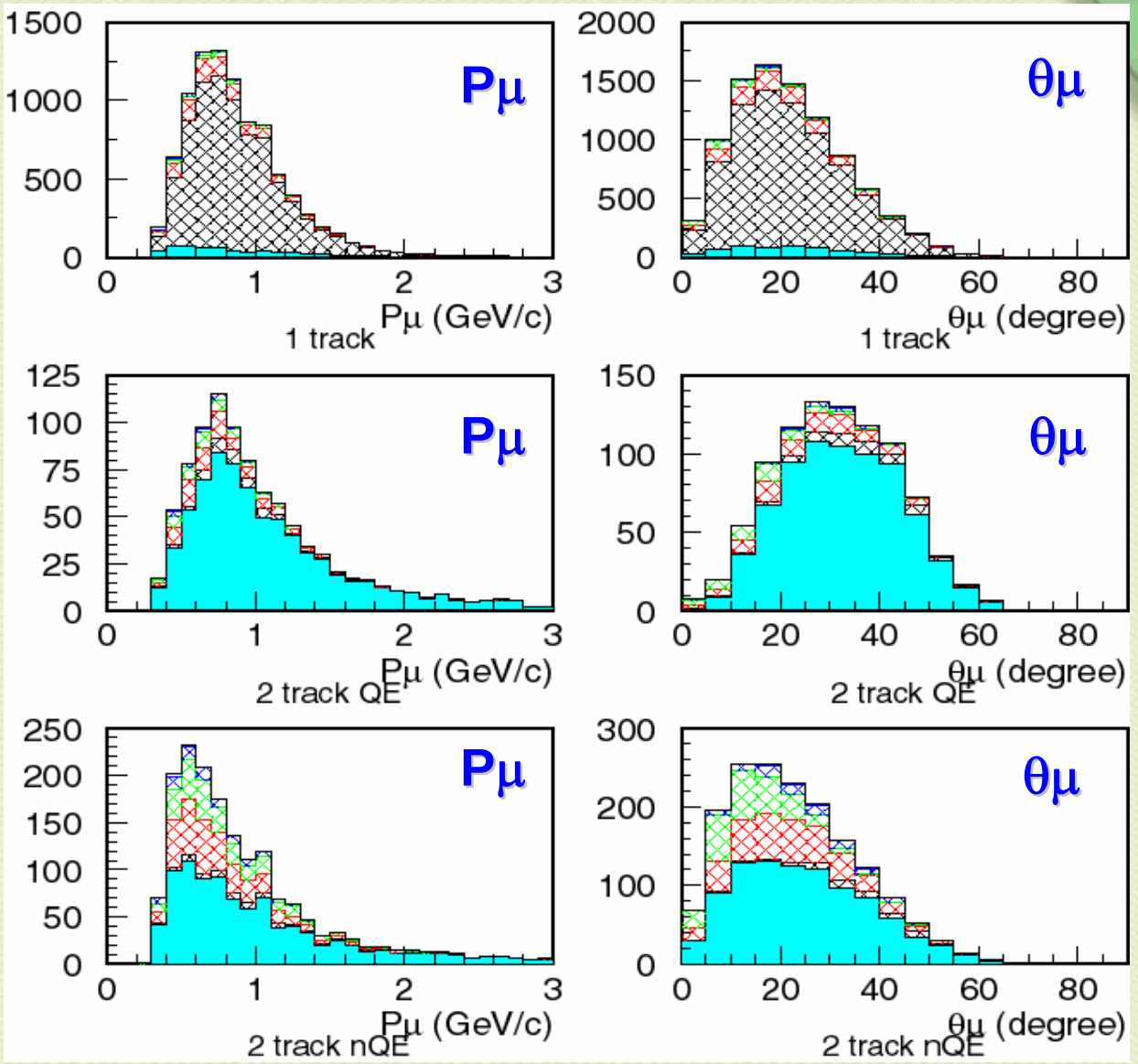
SciBooNE expects to make a 10% measurement

Identifying anti-ν CC Events (w/MRD) w/ vertex activity cut



Expected direction assuming CCQE

CC-QE
CC-1π
CC-coh. π
CC-multi π
ν_μ BG



1 track

~9,300 events
QE~80%
ν_μ BG=7%

2 track QE

~910 events
ν_μ BG~80%

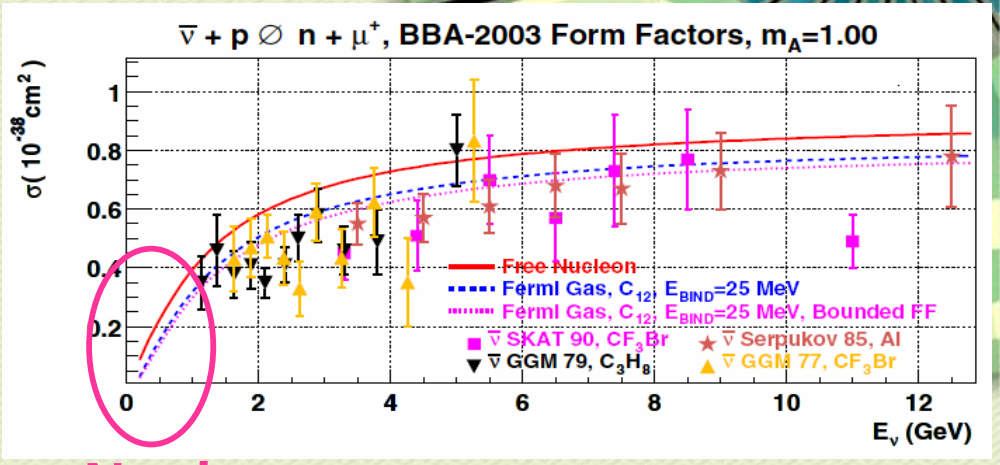
2 track non-QE

~1,700 events
ν_μ BG~56%
CC-1π~21%
CC-coh. π~15%

Antineutrino CCQE measurement

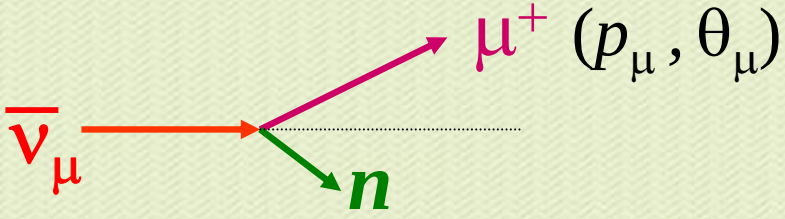
Physics motivation

- Important for T2K phase-II
  - CP violation search



No data

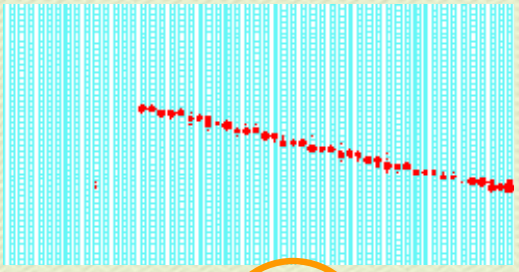
CC-QE: $\bar{\nu}_\mu + p \rightarrow \mu^+ + n$

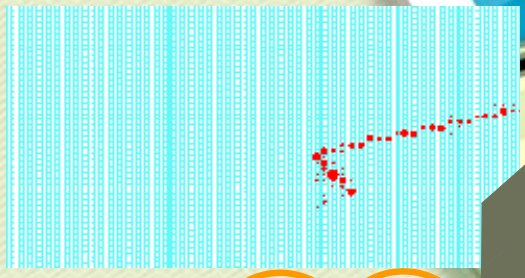


- **Detected as a 1-track event in SciBar**
- **Excellent ν energy, Q^2 resolution**

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

BNB Wrong Sign Backgrounds



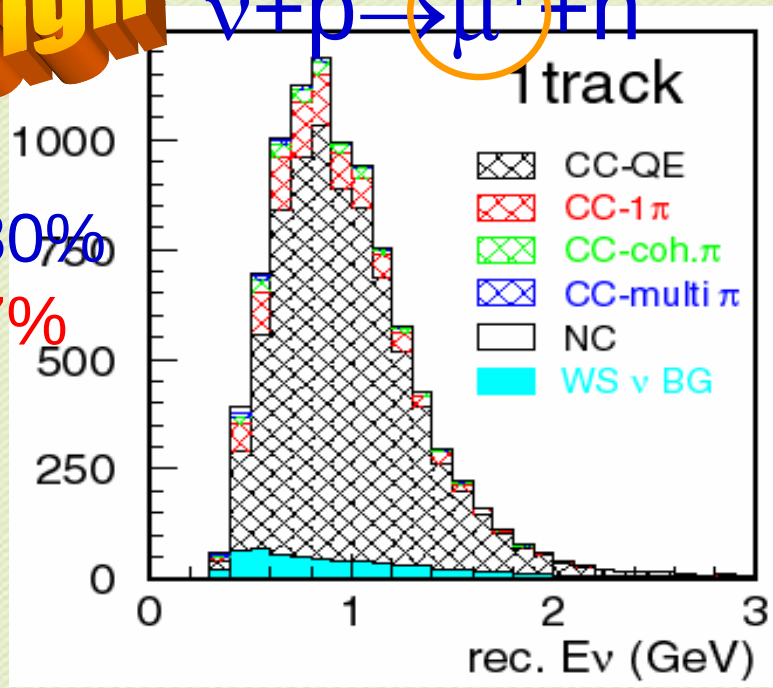


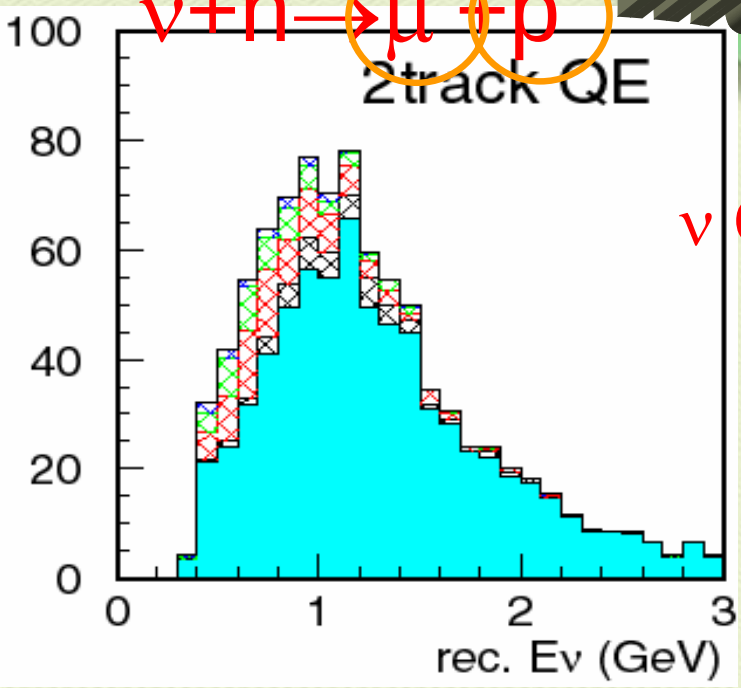
$\bar{\nu}+p \rightarrow \mu^{+}+n$

$\nu+n \rightarrow \mu^{-}+p$

$\bar{\nu}$ QE: ~80%

ν BG: ~7%





ν QE: ~80%

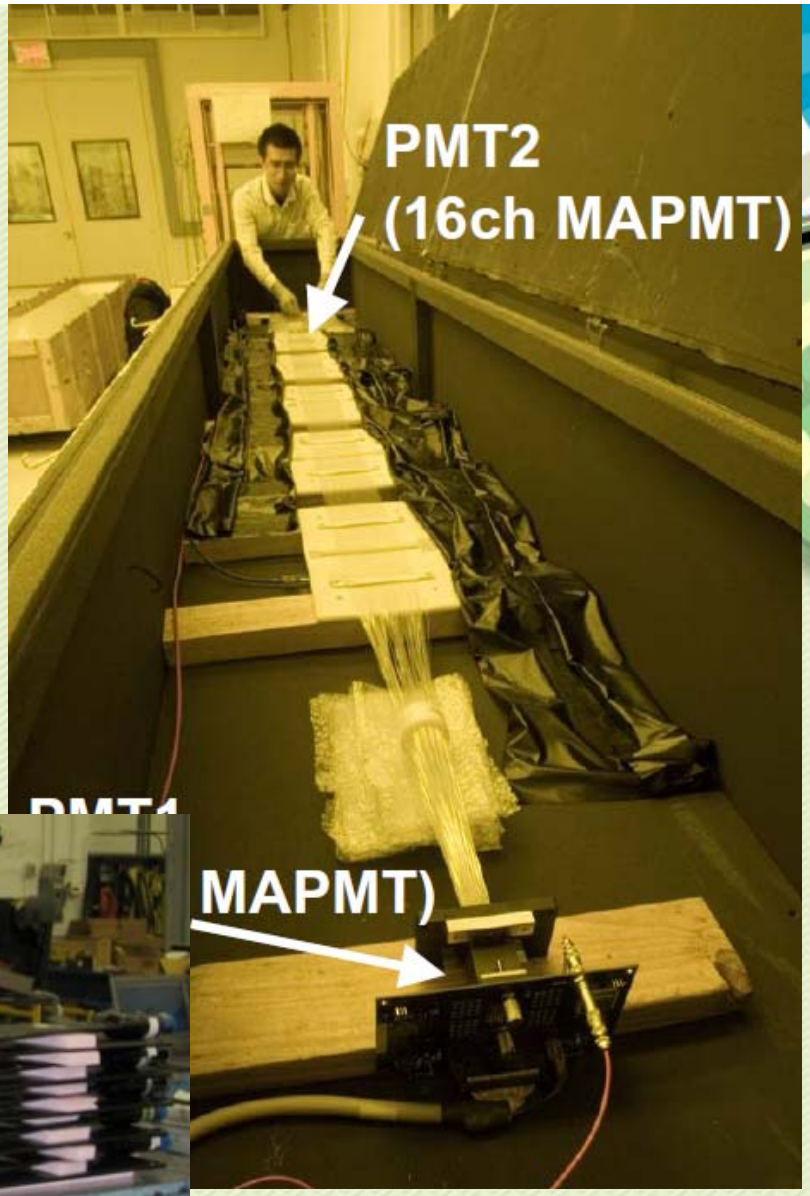
4. SciBooNE Status

- Timeline:
  - Summer 2006: Collaboration formed.
  - Nov. 2005: Proposed
  - **Dec. 2005: Approved**
  - Jul. 2006: Detectors arrived
  - **Aug. 2006 Civil construction contract**
  - Fall 2006; Detector Assembly **NOW**
  - Dec. 2006: Detector hall complete
  - Jan. 2007: Installation
  - Feb. 2007: Commissioning
  - **Mar. 2007: Beam data.**

Status

- The hall is under construction.
- The detectors: SciBar and EC are under construction at the CDF hall.
- MRD will be constructed at Lab-F
  - The scintillator counters are under productions, and 270 counters are built and 180 are tested.

We are on schedule with a little delay.

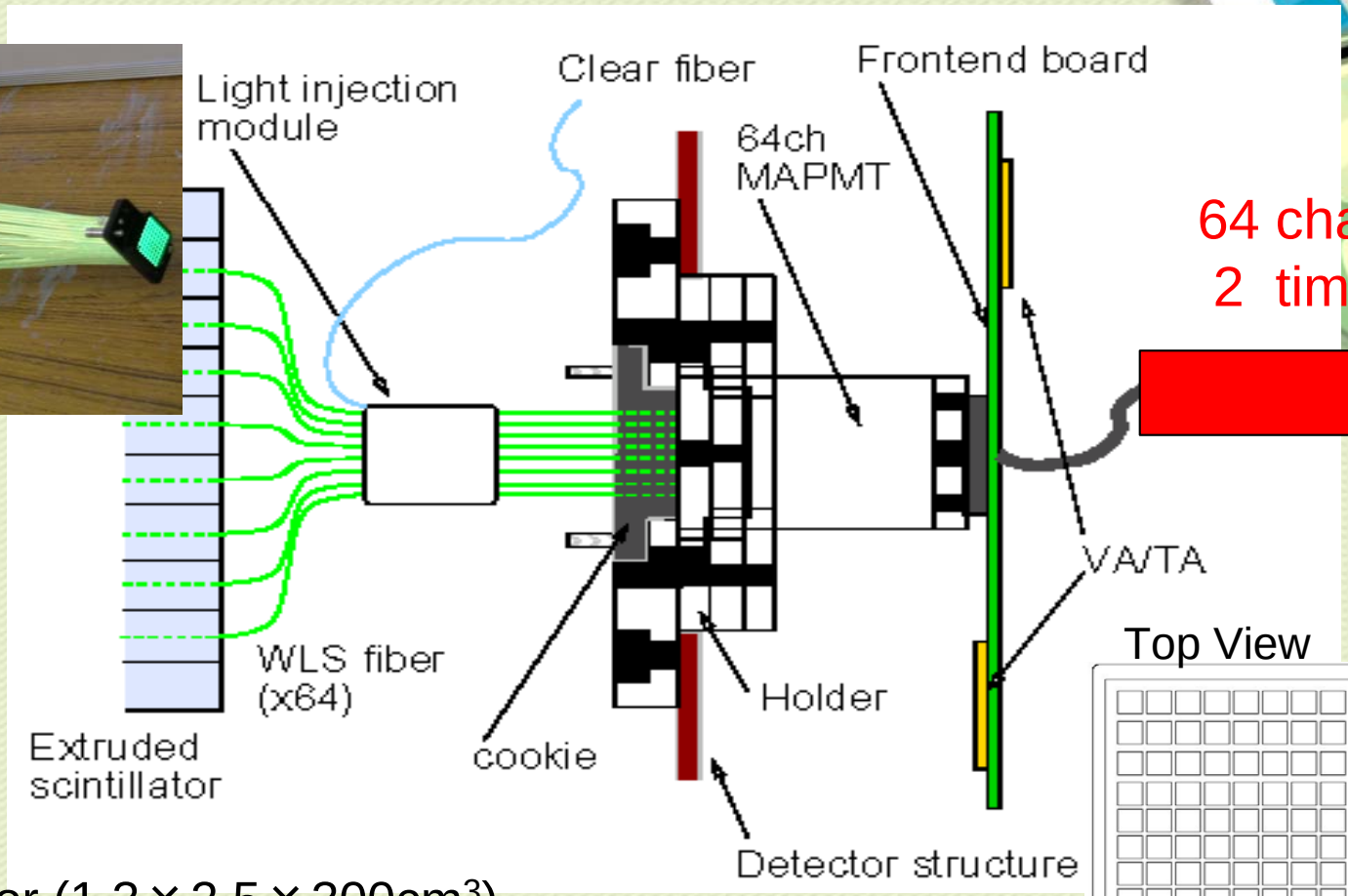

PMT2
(16ch MAPMT)
MAPMT)

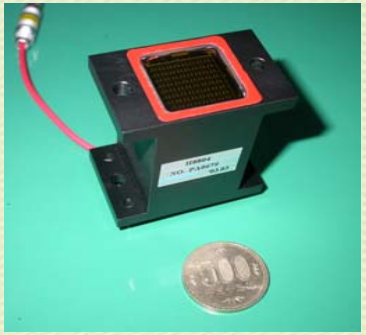
5. Summary

- SciBooNE is a new dedicated experiment to study neutrino interactions with nucleus by using both neutrino and anti-neutrino beams.
- SciBooNE is under preparation to start taking data on March 2007.
- It is an exciting time now to look at the detectors and construction if you are at FNAL.
  - You are welcome!
- We will collect the most precise neutrino interaction data at the energy of 1 GeV soon.

BackUp

SciBar Components





Extruded Scintillator ($1.3 \times 2.5 \times 300 cm^3$)
- made by FNAL (same as MINOS)

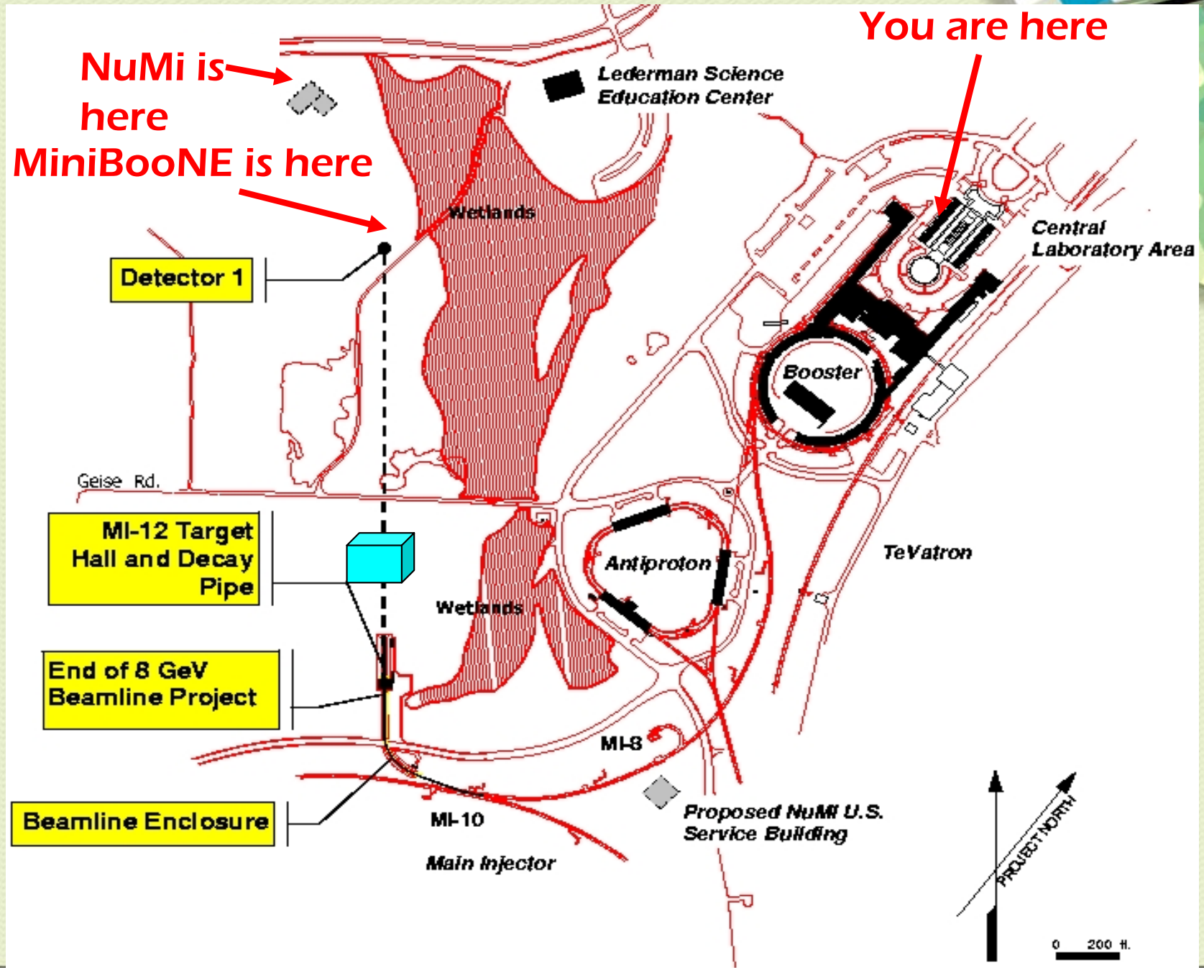
Wave length shifting fiber (1.5mmΦ)
- Long attenuation length (~350cm)

→ Light Yield : 18.9p.e./cm/MIP

Multi-Anode PMT
- $2 \times 2 mm^2$ pixel (3% cross talk @1.5mmΦ)
- Gain Uniformity (20% RMS)
- Good linearity (~200p.e. @6×10^5)

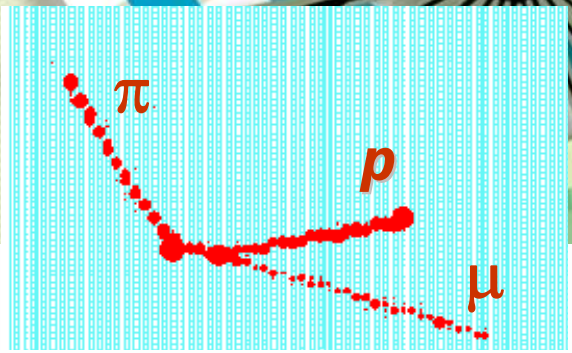
Readout electronics with VA/TA
- ADC for all 14,400 channels
- TDC for 450 sets (32 channels-OR)

Fermilab Accelerator Complex



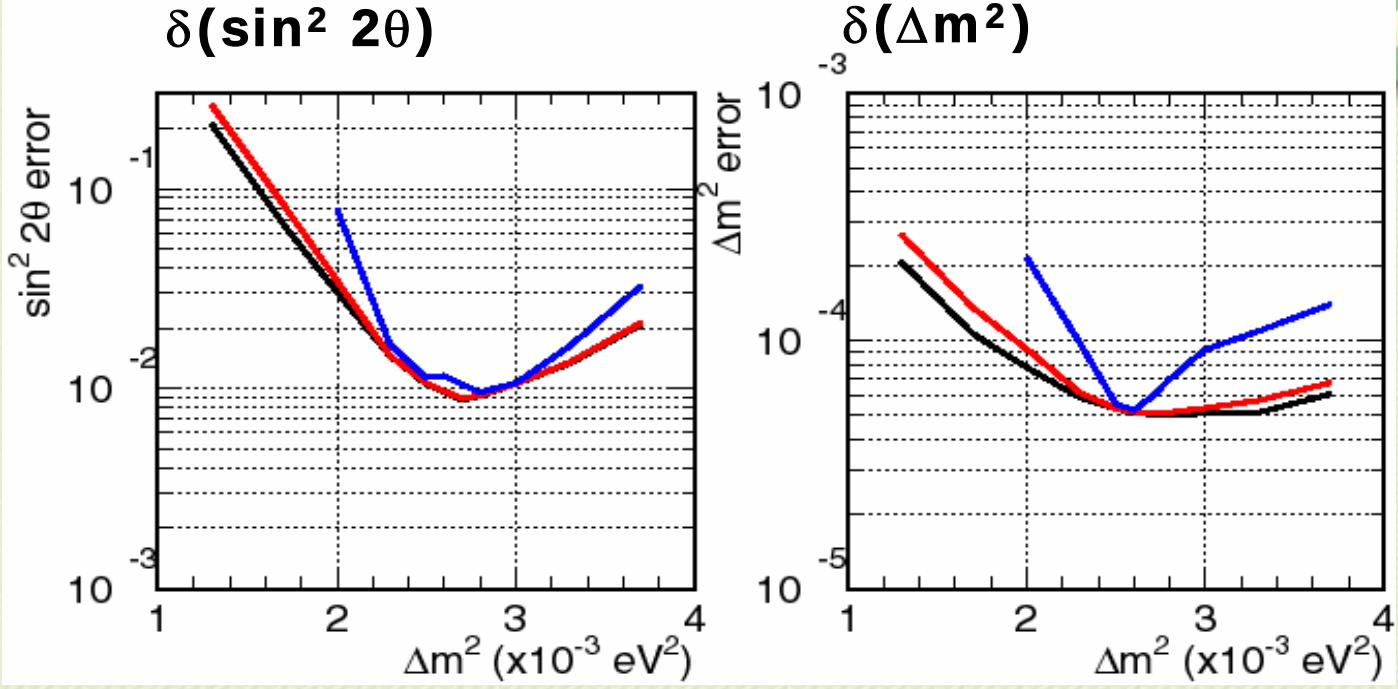
CC-1π^+ measurement

- Non-QE events: dominant background for ν_μ disappearance
  - At BNB energies, non-QE BG dominated by CC1π^+
  - T2K needs uncertainty of nonQE/QE to ~5%



ν_μ disappearance measurement error (90%CL)

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



CC-1π^+ signature:
2 MIP-like tracks

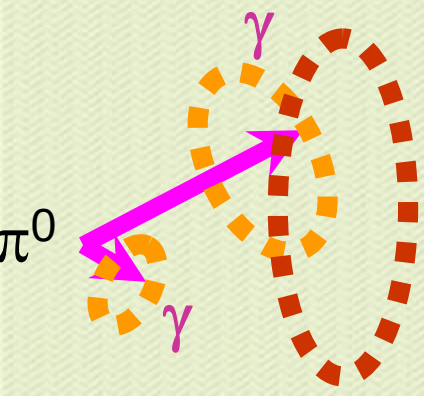
Vertex activity cuts:
separate $\nu+p\rightarrow\mu^-p\pi^+$ from $\nu+n\rightarrow\mu^+n\pi^+$

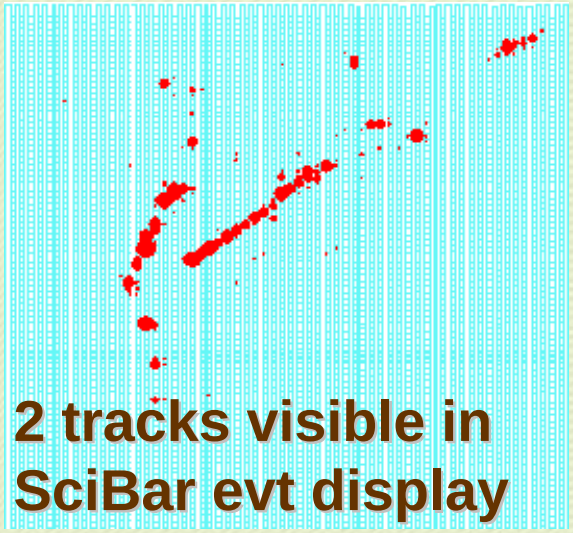
Statistics and systematics Sufficient for ~5% measurement

NC-1π^0 measurement

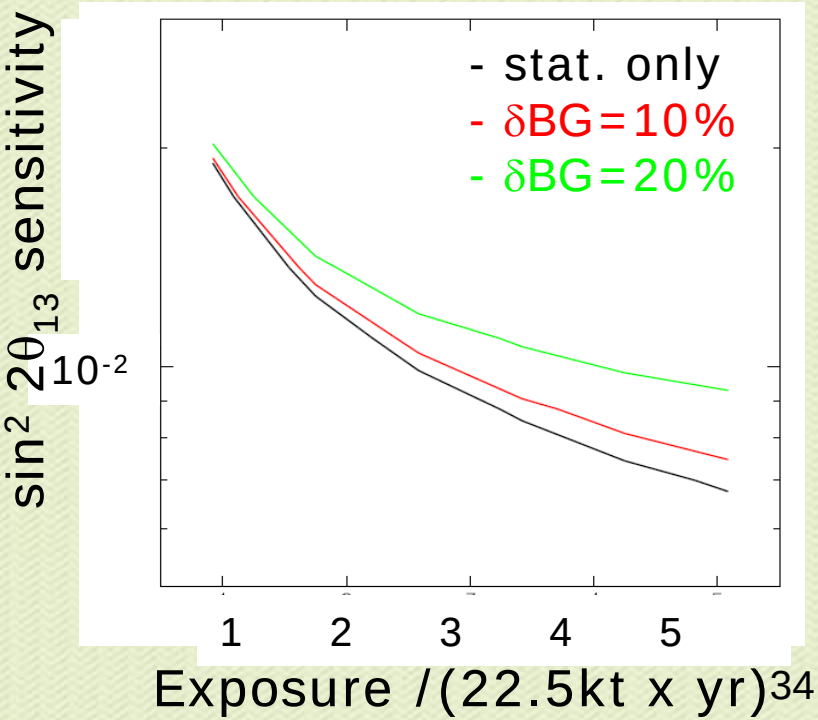
- Dominant background to ν_e appearance in any experiment
  - Overlapping rings, or back-to-back decay
  - T2K needs NC1π^0 cross section to be known to 10% level

2-ring merged to 1-ring in Cherenkov detector

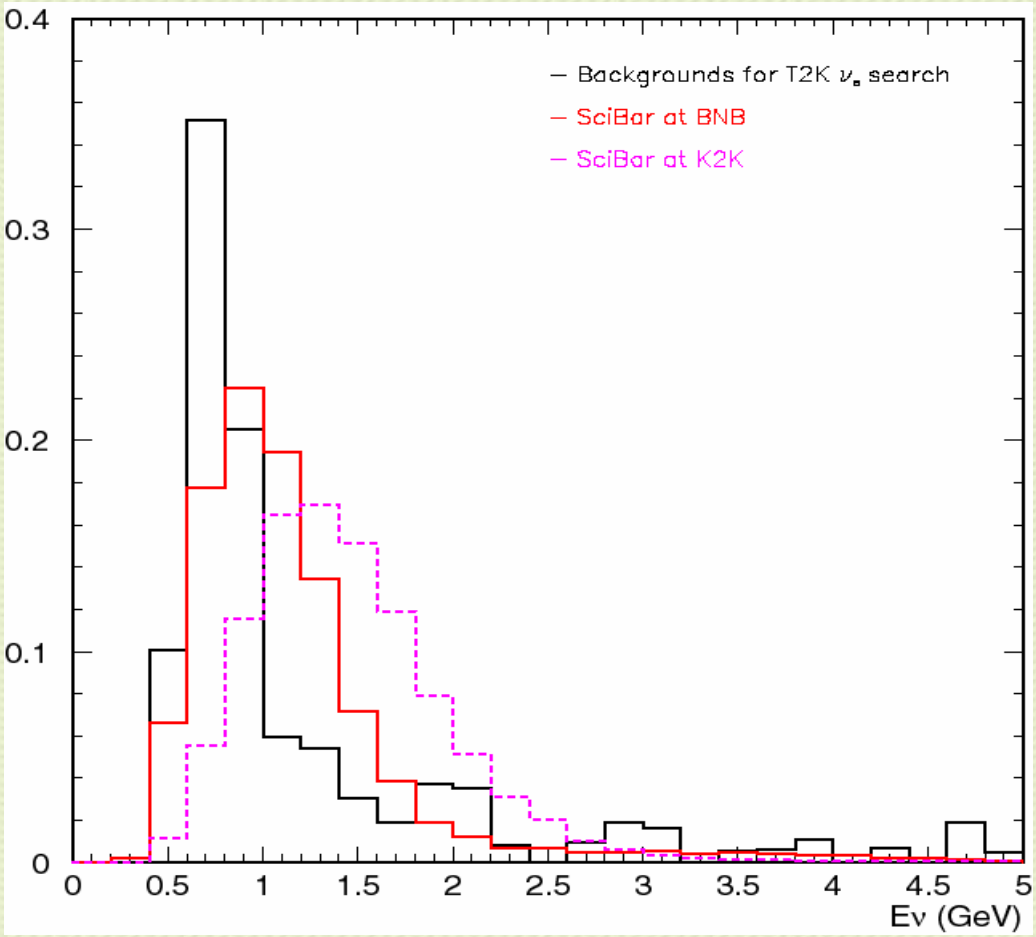




200~700MeV/c π^0s



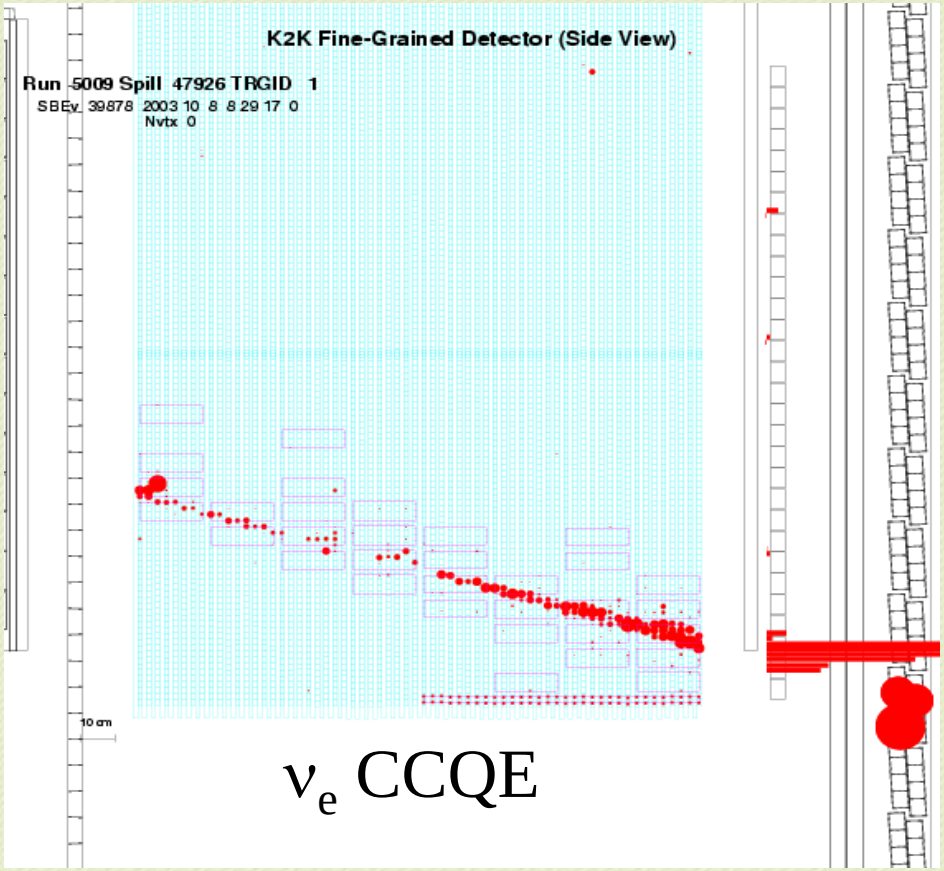
NC-1π^0 measurement (cont'd)



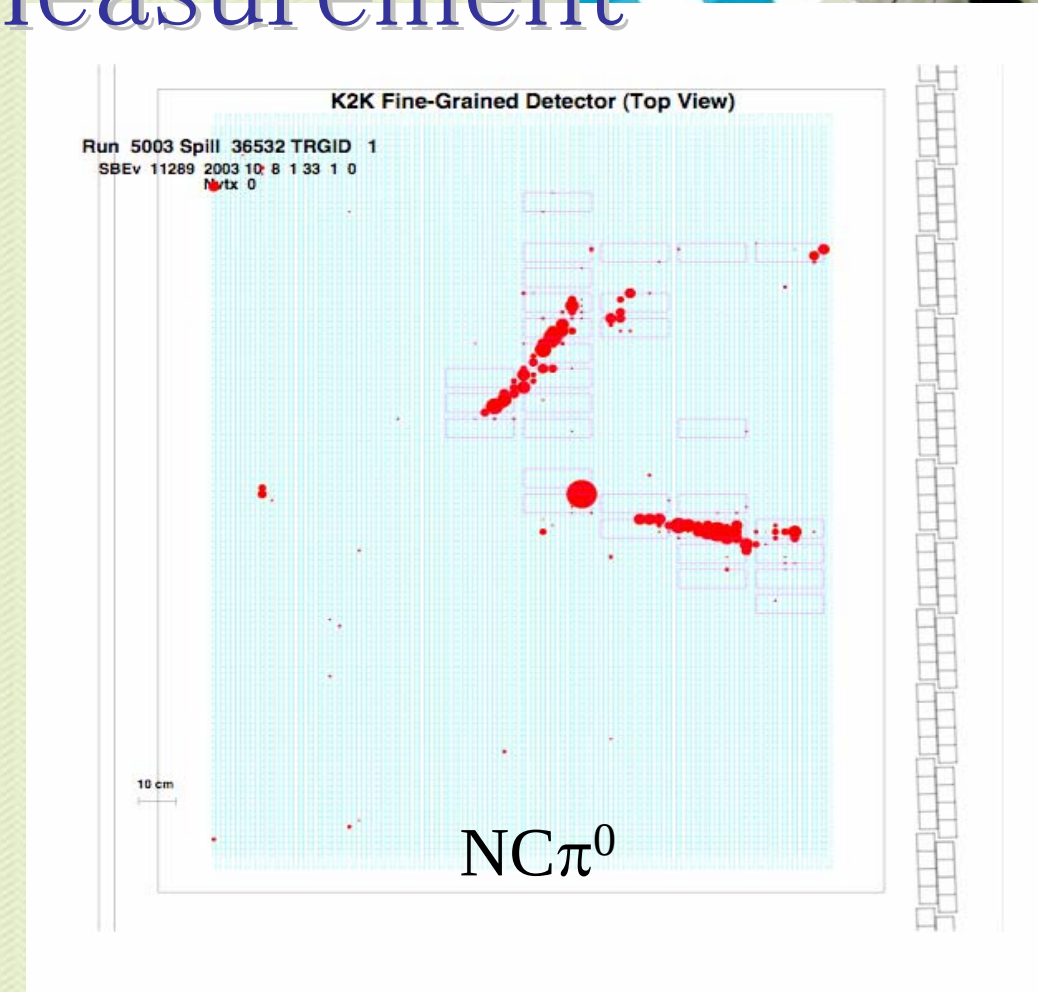
SciBooNE expects to make a 10% measurement

Measurement at energy that is crucial for T2K NC1π^0 BGs

BNB Intrinsic ν_e Measurement



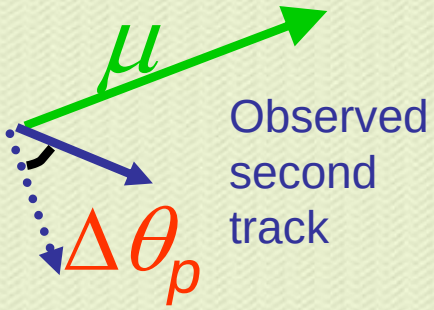
ν_e CCQE



NCπ^0

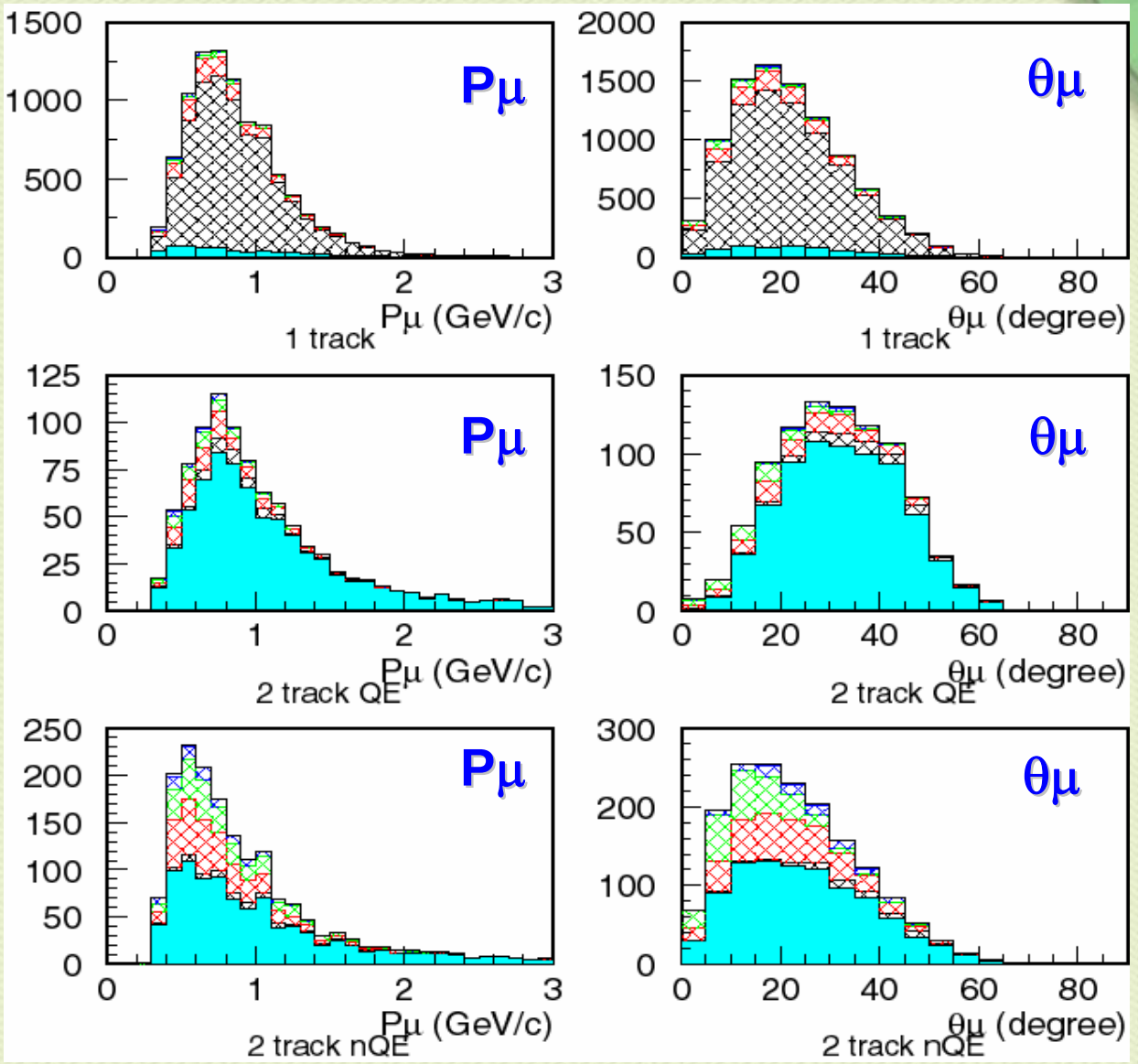
- Electron catcher provides good electromagnetic ID and energy resolution
  - Can use dE/dx in SciBar as well
- Expect to directly measure ν_e flux to 10–20% in ν mode
  - Assuming current efficiency/purity

Identifying CC Events (w/MRD) w/ vertex activity cut



Expected direction assuming CCQE

CC-QE
CC-1π
CC-coh. π
CC-multi π
ν_μ BG



1 track

~9,300 events
QE~80%
ν_μ BG=7%

2 track QE

~910 events
ν_μ BG~80%

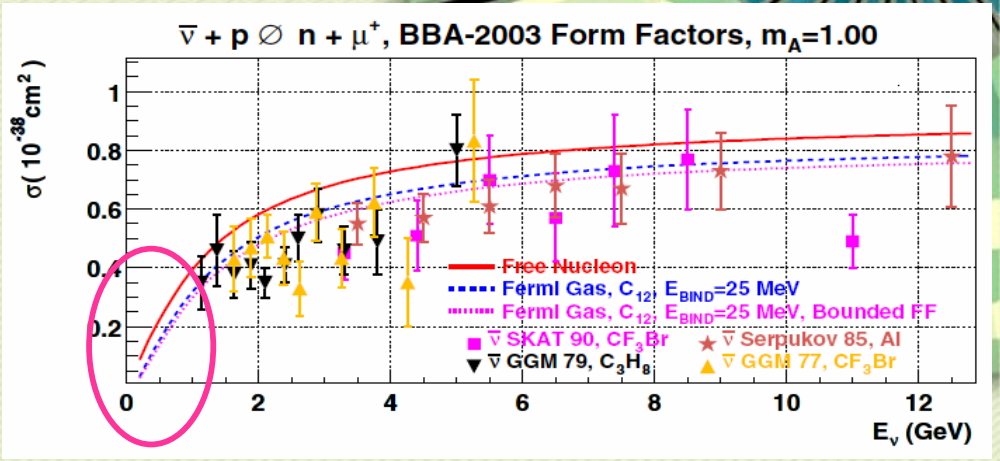
2 track non-QE

~1,700 events
ν_μ BG~56%
CC-1π~21%
CC-coh. π~15%

Antineutrino CCQE measurement

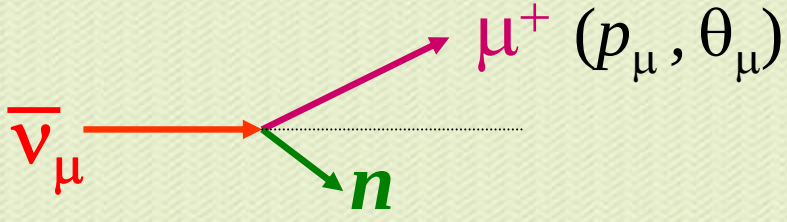
Physics motivation

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



No data

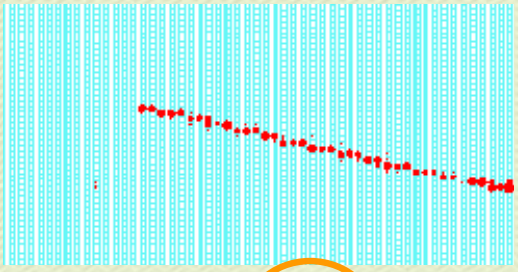
CC-QE: $\bar{\nu}_\mu + p \rightarrow \mu^+ + n$

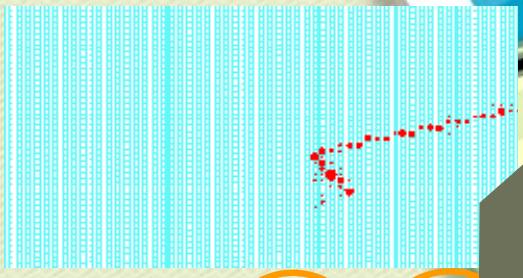


- **Detected as a 1-track event in SciBar**
- **Excellent ν energy, Q^2 resolution**

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

BNB Wrong Sign Backgrounds



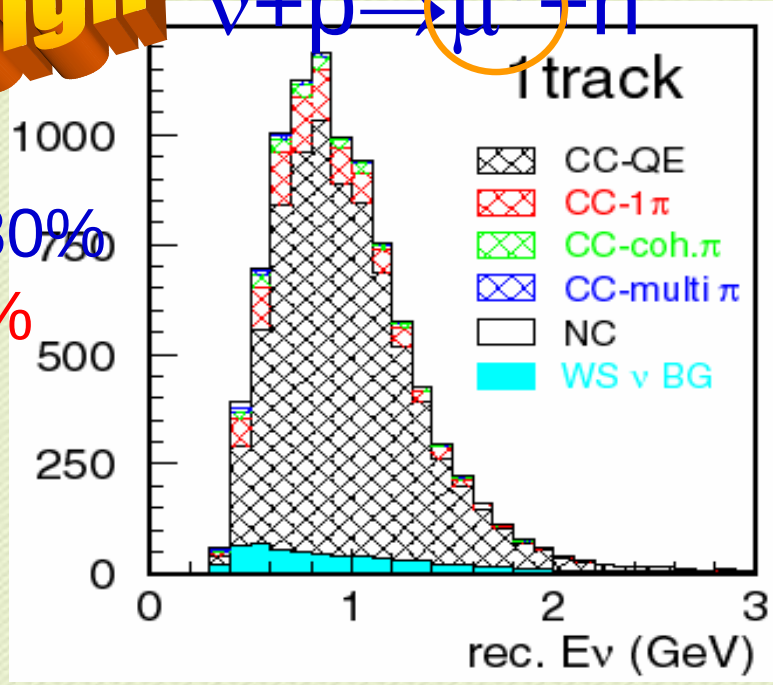


Right Sign

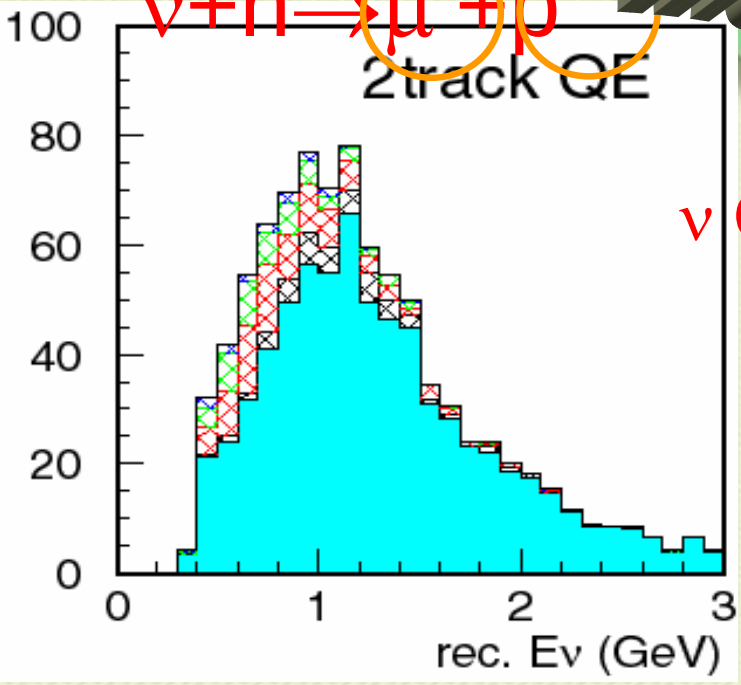
$\bar{\nu}+p \Rightarrow \mu^{+}+n$

$\bar{\nu}$ QE: ~80%

ν BG: ~7%



$\nu+n \Rightarrow \mu^{-}+p$



Wrong Sign

ν QE: ~80%

- MB: ~15% uncertainty on WS BG in 4 bins (0-1.5 GeV)
- SB: ~7.5% stat. err. in 2 track sample in 4 bins (0-1.5 GeV)

Radiative Δ Decay

- $\Delta \rightarrow N\gamma$ is a background for $\bar{\nu}_e, \nu_e$ appearance (NOνA too!)
  - BR: 15% uncertainty
  - Never measured in ν production
- Event signature
  - NC: recoil proton and detached photon track
  - CC: muon and recoil proton with shared vertex and photon with detached vertex
  - Each case: photon and proton tracks should be consistent with decay of Δ mass particle
  - π^0s provide calibration sample for photon tracks
- Expect ~ 45 events after cuts in total run (ν and $\bar{\nu}$ mode)
- Would be first observation of neutrino induced Δ radiative decay
  - Very powerful detector!