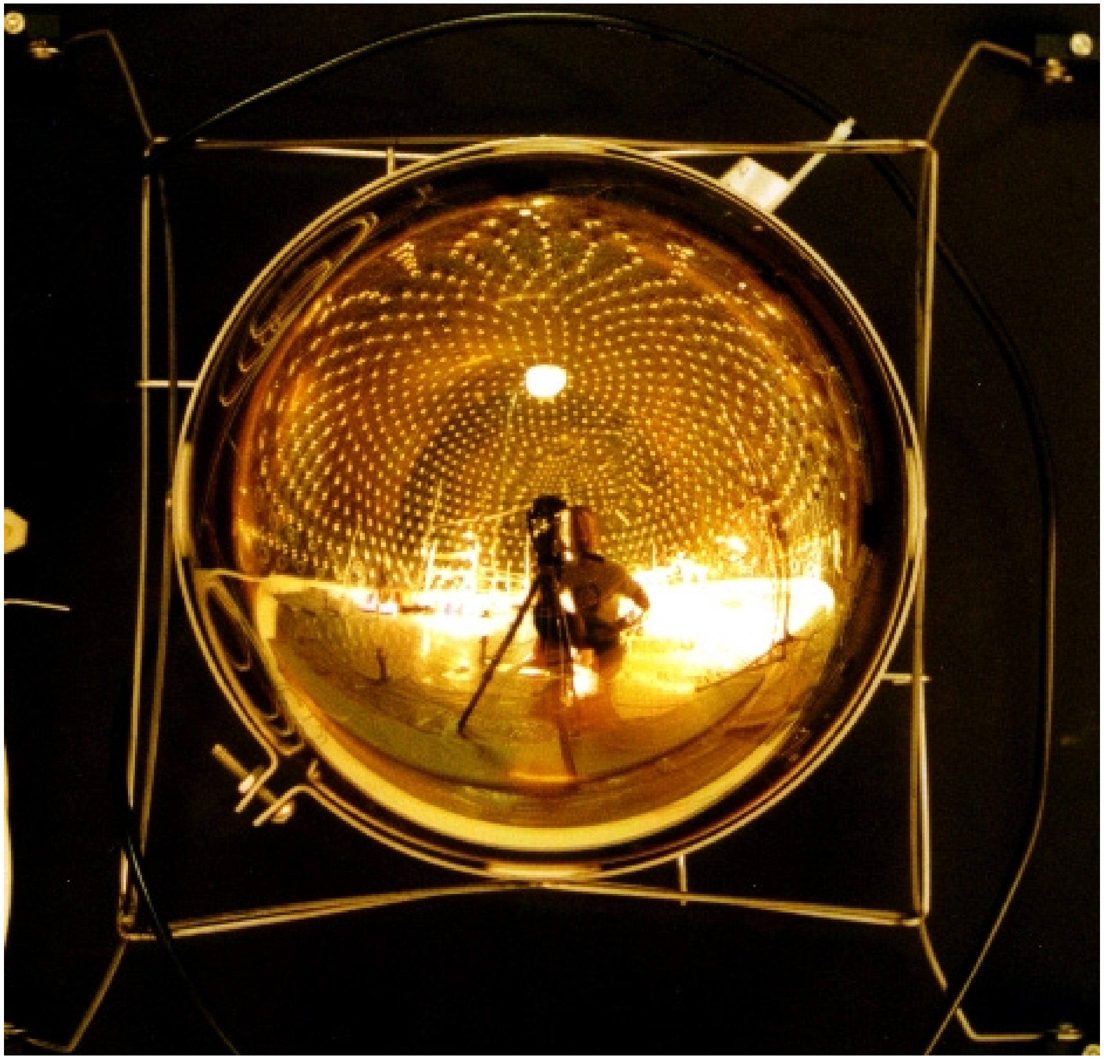


MiniBooNE

Hirohisa A. Tanaka
Princeton University

Weak Interactions and Neutrinos Workshop 2003 (Lake Geneva, WI)

Overview:

BooNE: Booster Neutrino Experiment

- The Beam
- The Detector and Calibration Devices
- Beam Data
- Conclusions

See Andrew Bazarko's talk for oscillation discussion

BooNE is for Booster:

The Fermilab Booster:

- 8 GeV protron synchrotron

Provides protons for:

- MiniBooNE
- Main Injector
  Antiprotons, Tevatron
  120 GeV Fixed Target, NuMI

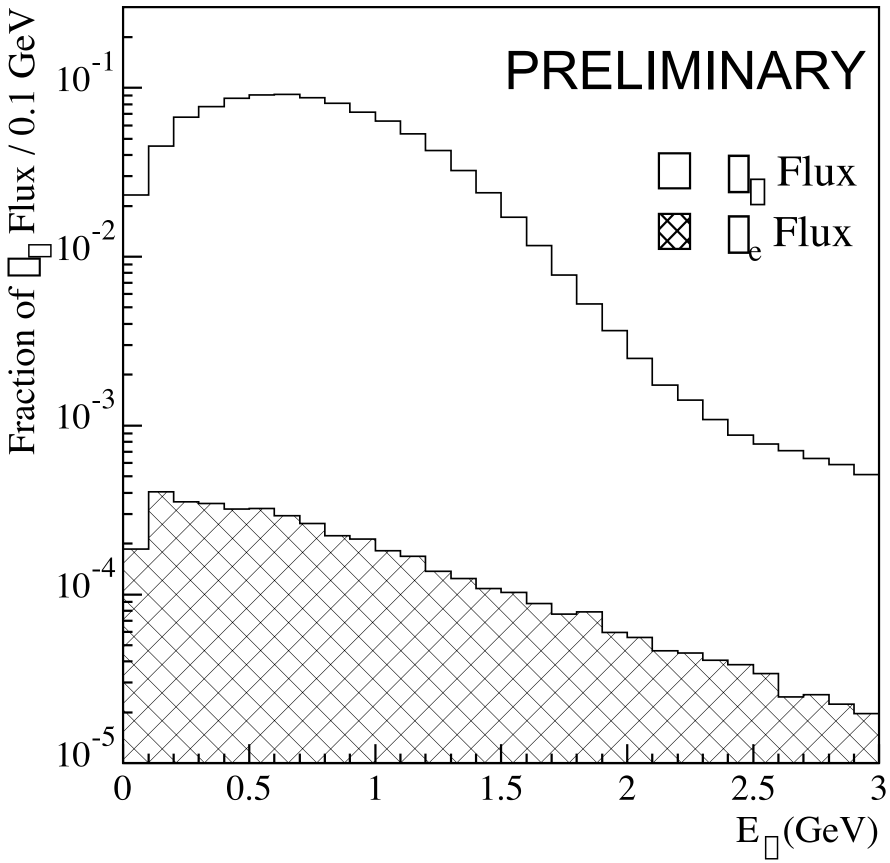
MiniBooNE beamline

- $1.6\ \mu$sec p batch on Be
- Electromagnetic Horn $(+)$
  Focus 2ndary particles
- 50 m decay region $\pi^+ \rightarrow \mu^+ \nu_\mu$

Design Performance

- 5×10^{12} p/batch at 5 Hz
- 5×10^{20} POT/year

BooNE is for Neutrino:

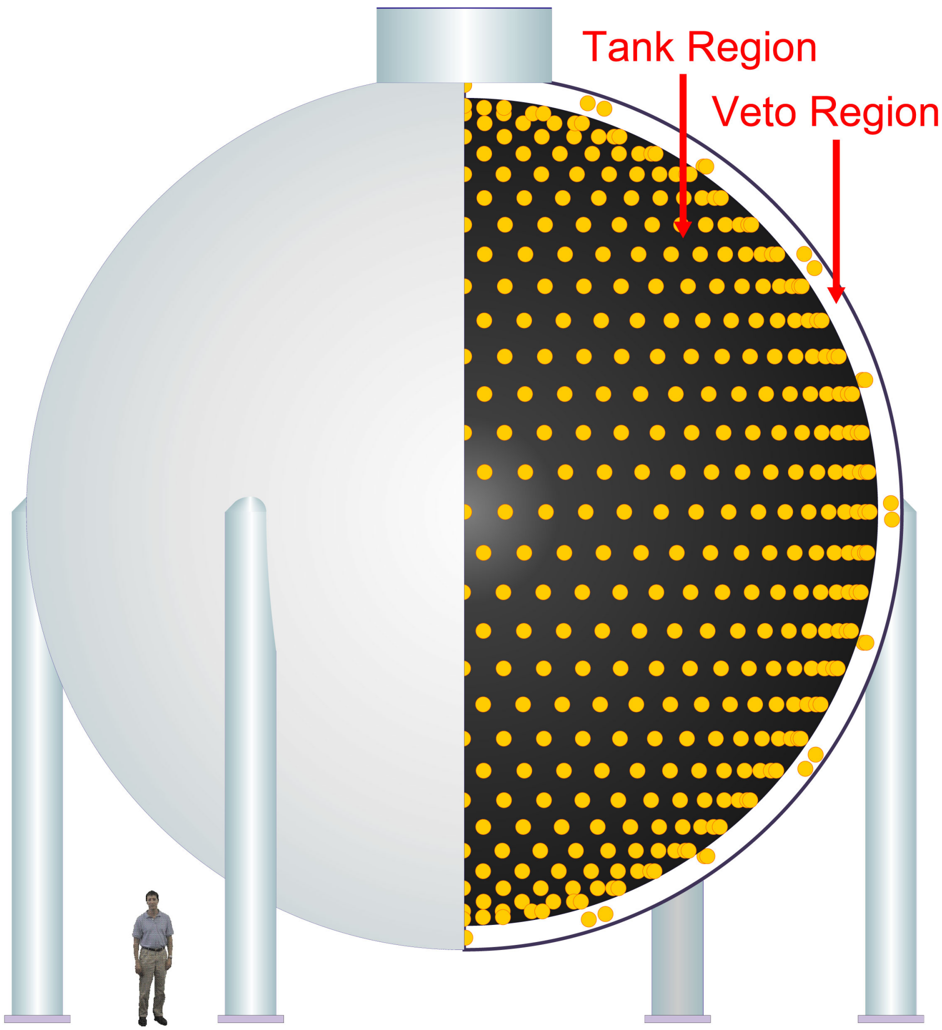


Predicted Neutrino Flux:

- Sanford-Wang parameterization: Global fit to $p-$ Be π^+ data
- Kaons from MARS
- Dominant Processes at $\sim 1\,\mathrm{GeV}$:
  - CC Quasi-elastic
  - NC Elastic
  - Resonance

Comparable energies to Off-Axis proposals

BooNE is for Experiment:

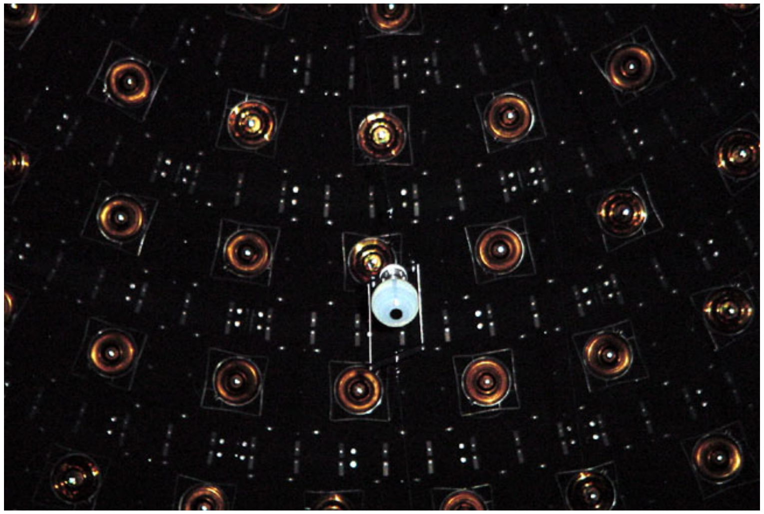


MiniBooNE:

- 540 m from target
- 6.1 m radius sphere
  Mineral oil target
- Optical barrier at 575 cm
  - Inner "Tank" region
  - Outer Veto region
- 1280 8" PMTs in Tank (10%)
- 240 8" PMTs in Veto

Detect neutrino interactions via Č and Scintillation light

Calibration Devices:



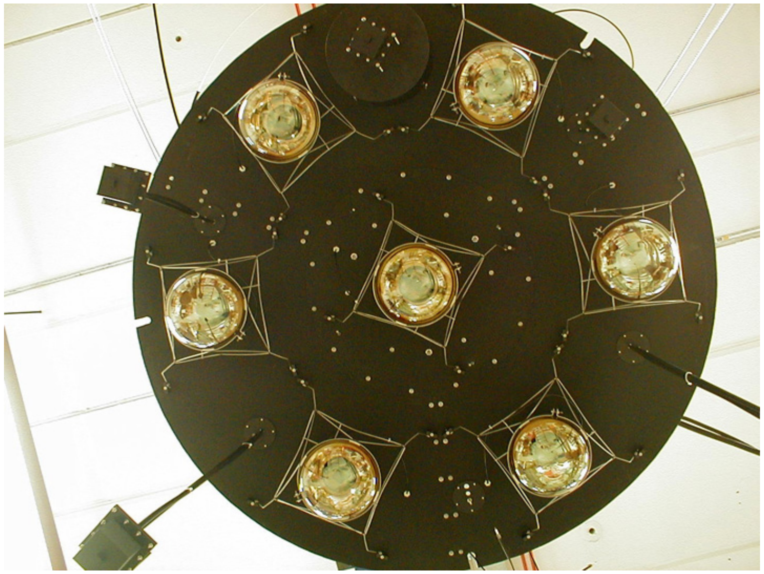
Laser Flask:

- Prompt monochromatic light
  Pulsed via 397 and 438 nm laser
- Varying intensity
  sub-1 p.e. $\longrightarrow$ multi p.e.
- Varying location
  Four flasks + bare fiber in detector.
  Study PMT hit reconstruction
  Study oil optical properties.

Muon Tracker + Cubes:

- Muon Hodoscope above detector
  Four layers of scintillator bars
  Independent track reconstruction
- Scintillator Cube
  Seven cubes throughout detector
  Independent vertex reconstruction

Stopping muons with precisely known pathlength



The Collaboration

University of Alabama	Y.Liu, I.Stancu
Bucknell University	S.Koutsoliotas
University of Cincinnati	E.Hawker, R.A.Johnson, J.L.Raaf
University of Colorado	T.Hart, R.H. Nelson, E.D.Zimmerman
Columbia University	A. Aguilar-Arevalo, L.Bugel, J.M.Conrad, J.Formaggio, J.Link, J.Monroe, D. Schmitz, M.H.Shaevitz, M.Sorel, G.P. "Sam" Zeller
Embry Riddle Aeronautical University	D.Smith
Fermi National Accelerator Laboratory	L.Bartoszek, C.Bhat, S.J.Brice, B.C.Brown, D.A.Finley, B.T.Fleming, R.Ford, F.G.Garcia, P.Kasper, T.Kobilarcik, I.Kourbanis, A.Malensek, W.Marsh, P.Martin, F.Mills, C.Moore, P.Nienaber, E.Prebys, A.D.Russell, P.Spentzouris, R.Stefanski, T.Williams
Indiana University	D.C. Cox, J.A. Green, H.Meyer, R.Tayloe
Los Alamos National Laboratory	G.T.Garvey, C. Green, W.C.Louis, G.McGregor, S. McKenney, G.B.Mills, V.Sandberg, B.Sapp, R.Schirato, R.Van de Water, N. Walbridge, D.H.White
Louisiana State University	R.Imlay, W.Metcalf, M.Sung, M.Wascko
University of Michigan	J.Cao, Y.Liu, B.P.Roe
Princeton University	A.O.Bazarko, P.D.Meyers, R.B.Patterson, F.C.Shoemaker, H.A.Tanaka

Neutrino Data:

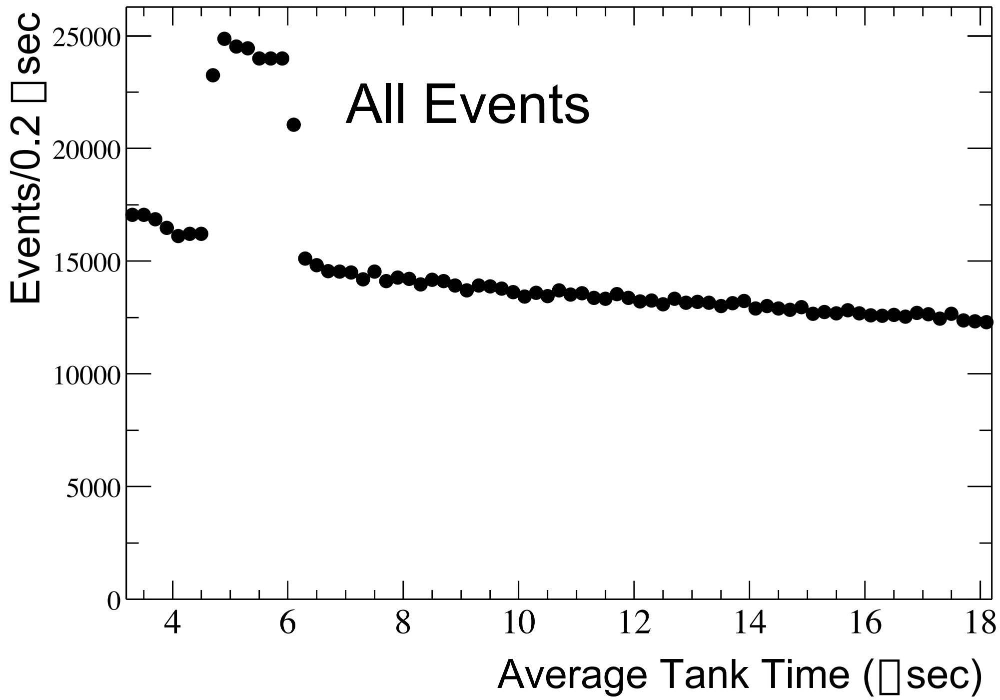
- Inclusive distributions
- Charged Current quasi-elastic scattering
- Neutral Current elastic scattering
- Neutral Current π^0 production

$\sim 1 \times 10^{20}$ protons-on-target analyzed

Comparisons to Monte Carlo are relatively normalized.

See Andrew Bazarko's talk for discussion on Oscillation Analysis

Neutrino Events!



Beam Events:

- Arrive in 1.6 μsec window $[4.6, 6.2]$ μsec
- Event time: From average of tank hits
- Excess is clearly seen

Backgrounds:

- Cosmic Muons
- Decay electrons

Event time is calculated from "subevent": First cluster of > 10 hits contiguous in time.

Backgrounds can be eliminated with multiplicity cuts (Tank/Veto PMT Hits).

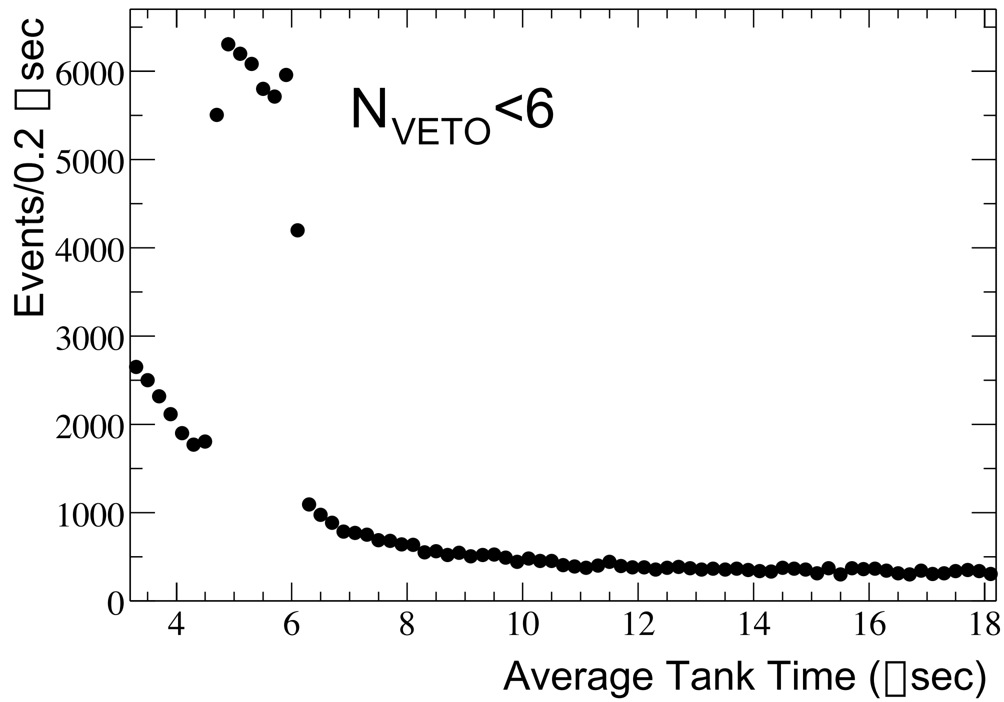
Neutrino Events!

Veto cut eliminates cosmic μ:

- Single MIP ~ 18 hits
  Most are throughgoing.
- Eliminate with $N_{VETO} < 6$

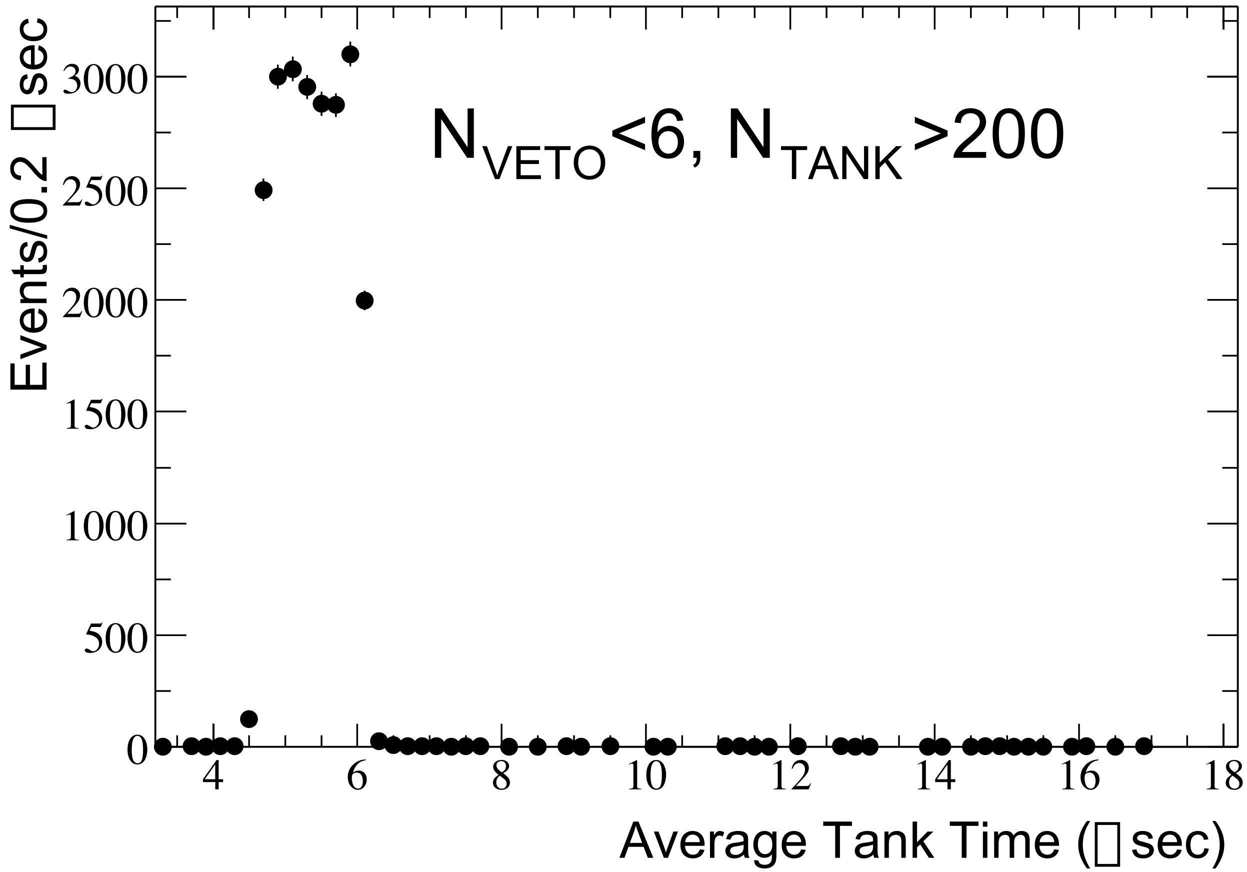
Remaining Background:

- Decay electrons (< 200 Hits)
  Muon enters before window.
- Env./Noise (< 20 Hits)



Remaining background eliminated with Tank Multiplicity cut.

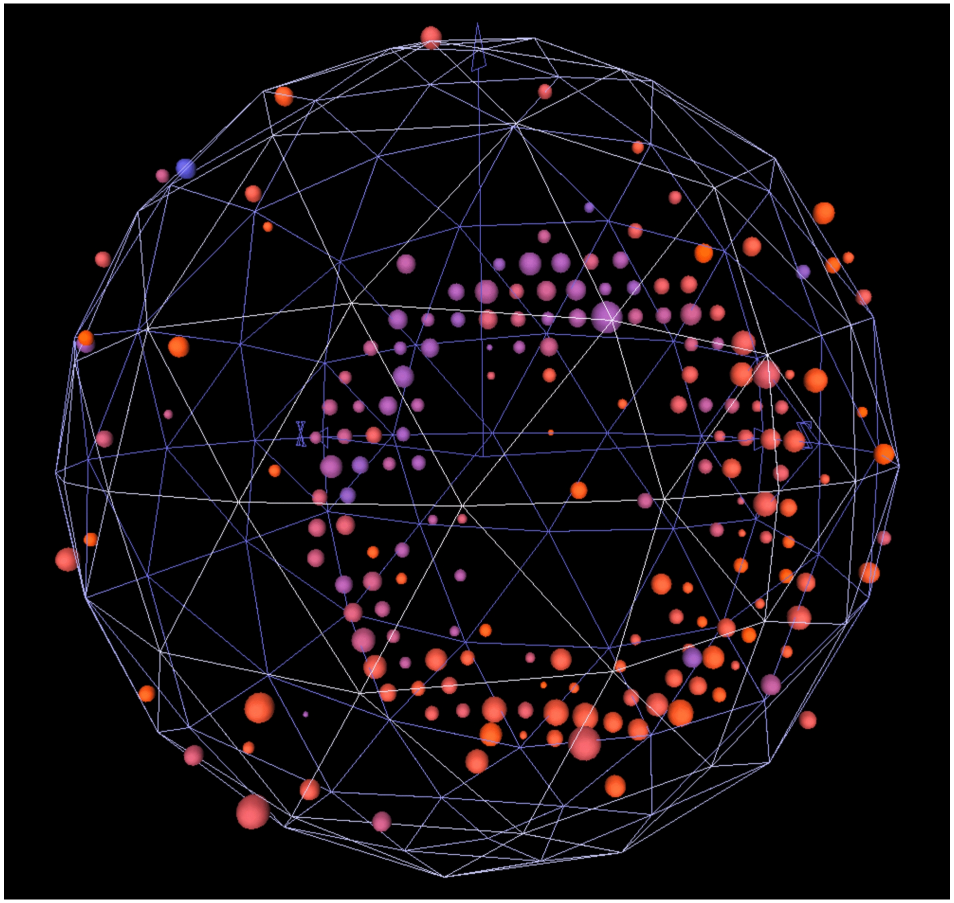
Neutrino Events!



Remaining background eliminated with $N_{TANK} > 200$. S/B > 1000

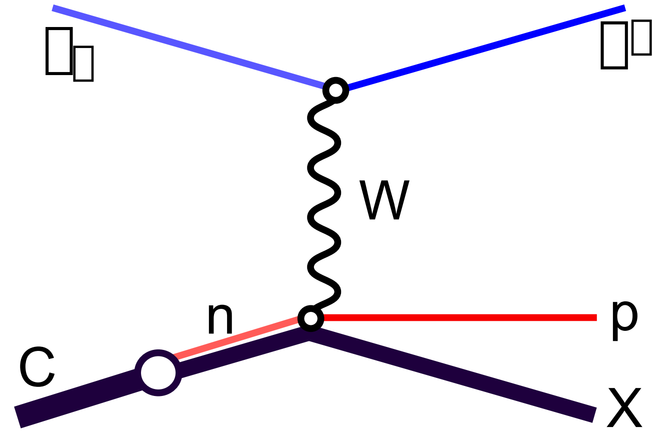
$\sim 150K$ "clean" candidates in $\sim 1.5 \times 10^{20}$ protons-on-target
Approximately $50\%/50\%$ CC Quasi-elastic/Single Pion

ν_μ Quasi-Elastic Events:



Size of Ball = Charge

Red = early, Blue = late



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

- Abundant (40%)
- Simple topology:
  one muon-like ring
  proton rarely above Č threshold
- Obtain E_μ, θ_μ from fit

Selecting Quasi-Elastic Events:

Selection

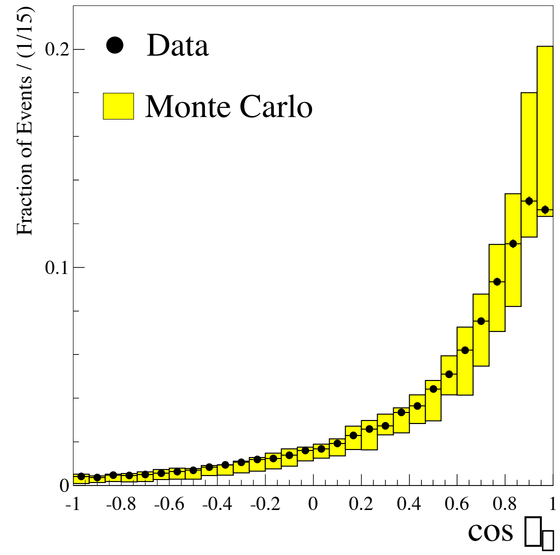
- Single μ-like ring, decay electron
  - Ring profile/sharpness
  - Time of hits
  - Minimize energy bias

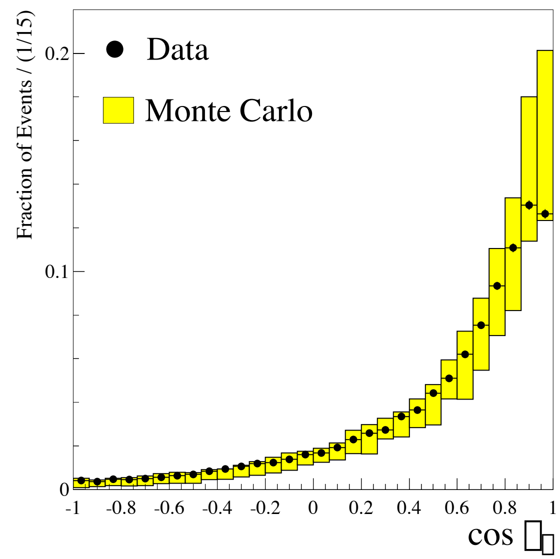
  $\longrightarrow$ Fisher discriminant

- MC indicates $\sim 88\%$ purity
  Some background is irreducible

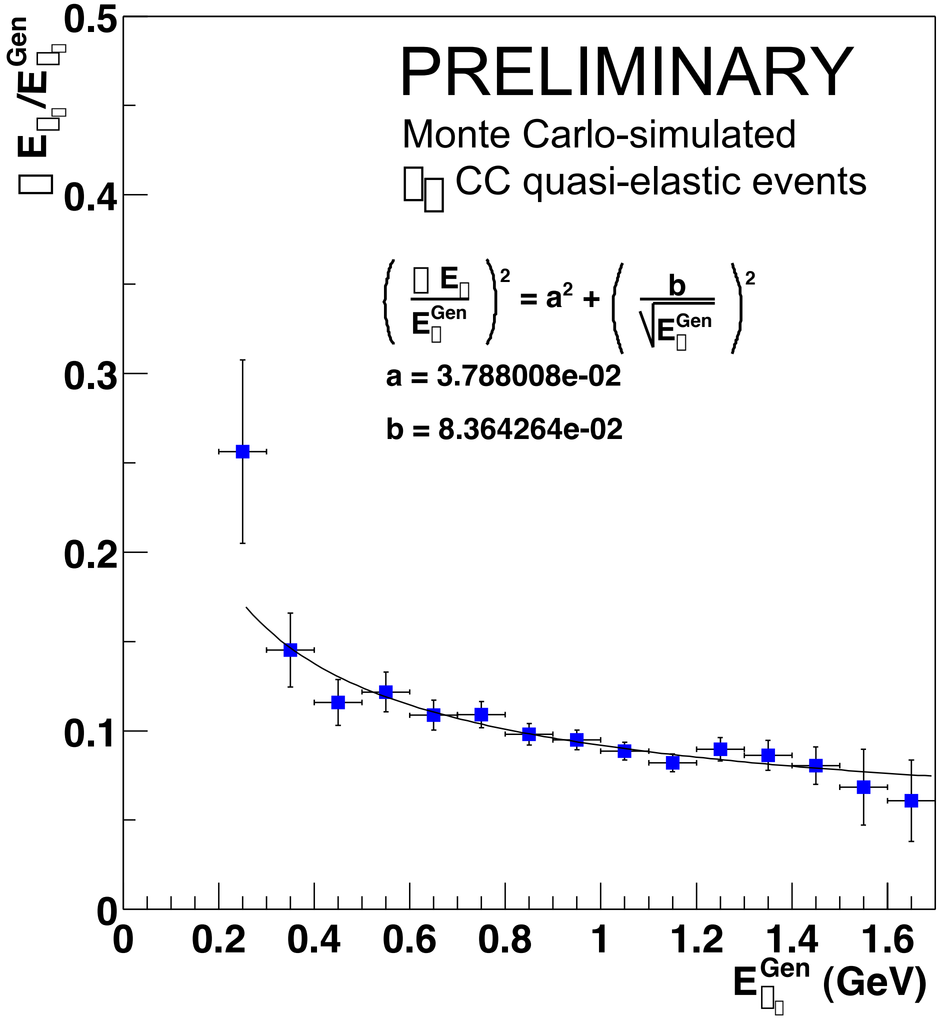
- Relatively well-known cross section

$\longrightarrow$ cross-check of flux prediction
$\sim 28K$ CC QE candidates





Neutrino Energy:



Kinematic Reconstruction:

Assume:

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

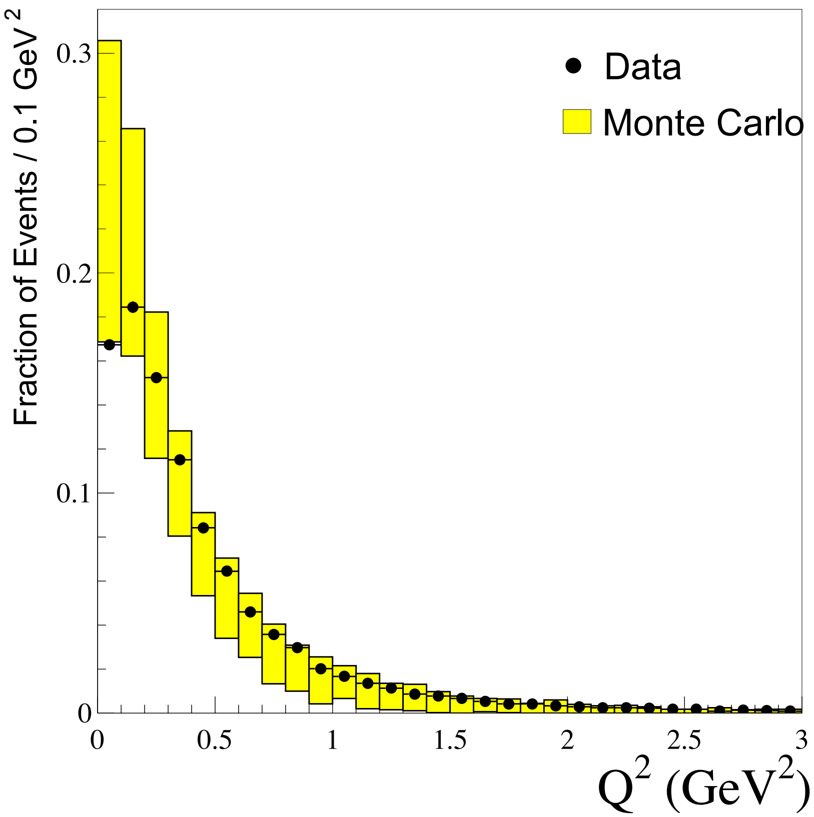
$\rightarrow$ obtain E_ν via E_μ, θ_μ

Account for:

- Binding energy
- Muon mass
- Č threshold

$\sim 10\%$ resolution for $E_\nu > 500\,\mathrm{MeV}$

Q^2 and E_ν :

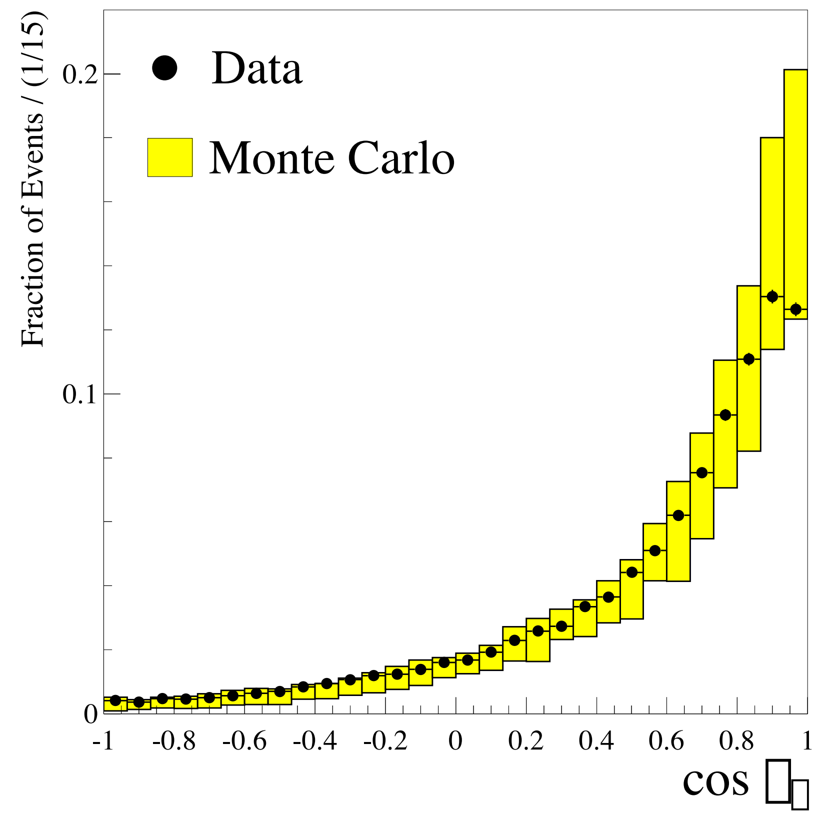


$$Q^2 = -(p_\nu - p_\mu)^2$$

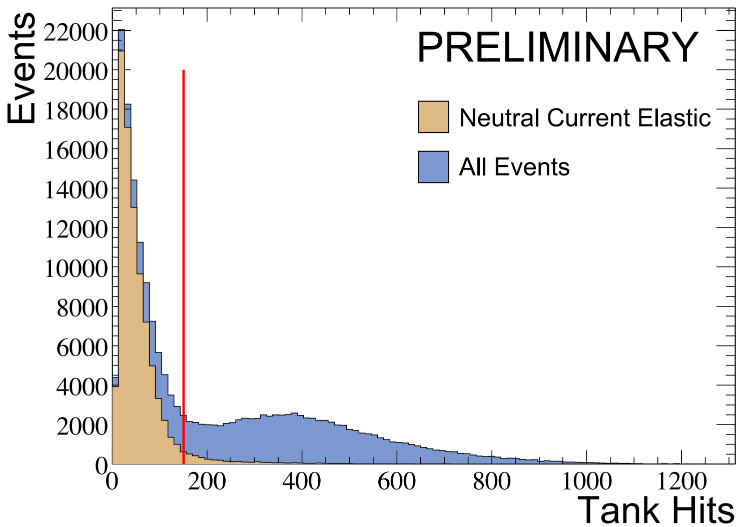
- Form factors ($f_{1,2}$, g_1) depend on Q^2
- Nuclear effects at low Q^2

E_ν (Incident Neutrino Energy):

- Measures incident flux



Neutral Current Elastic Scattering:

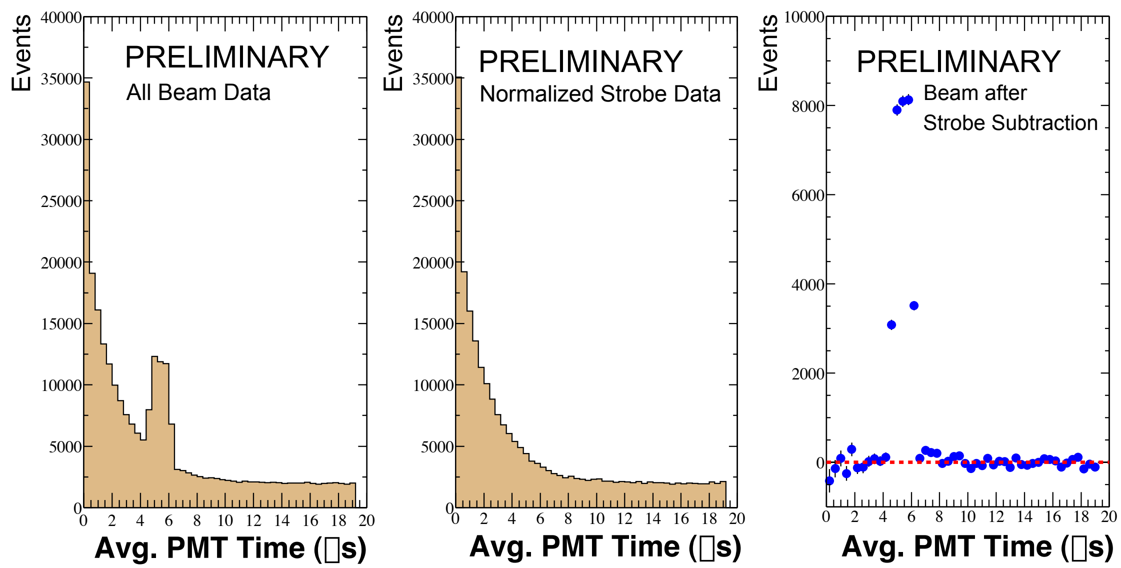


$$\nu_\mu + (p/n) \rightarrow \nu_\mu + (p/n)$$

- Typically sub-Č:
  Dominated by scintillation
- low N_{TANK}, large late light fraction
- Large cross section $(\sim 15\%)$
- Sensitive to strange spin component

Background subtraction:

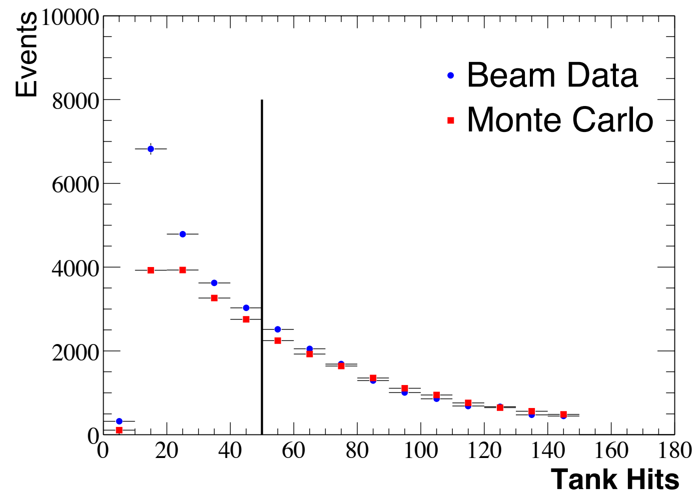
- Beam excess clearly visible
  Non-beam background
  - Decay electrons
  - Environmental
- Subtract with random triggers

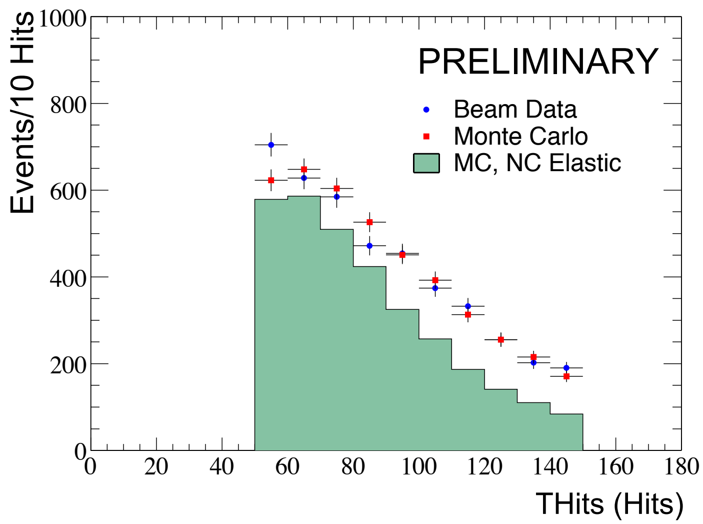


Neutral Current Hit Spectrum:

Low multiplicity events:

- Strobe background subtraction
- Unknown component $N_{TANK} < 30$
- 50 hit threshold for vertex fit
  Normalize MC to $N_{TANK} > 50$ yield





Late light Selection:

- Fit event vertex for $N_{TANK} > 50$ events
- Calculate fraction of late hits
- Select events with significant late light

Agreement for $N_{TANK} > 50$ with/without late light cut.

Neutral Current π^0 Production:

Physics Interest:

- Background for ν_e
- Limits on Sterile ν

Primary Mechanisms:

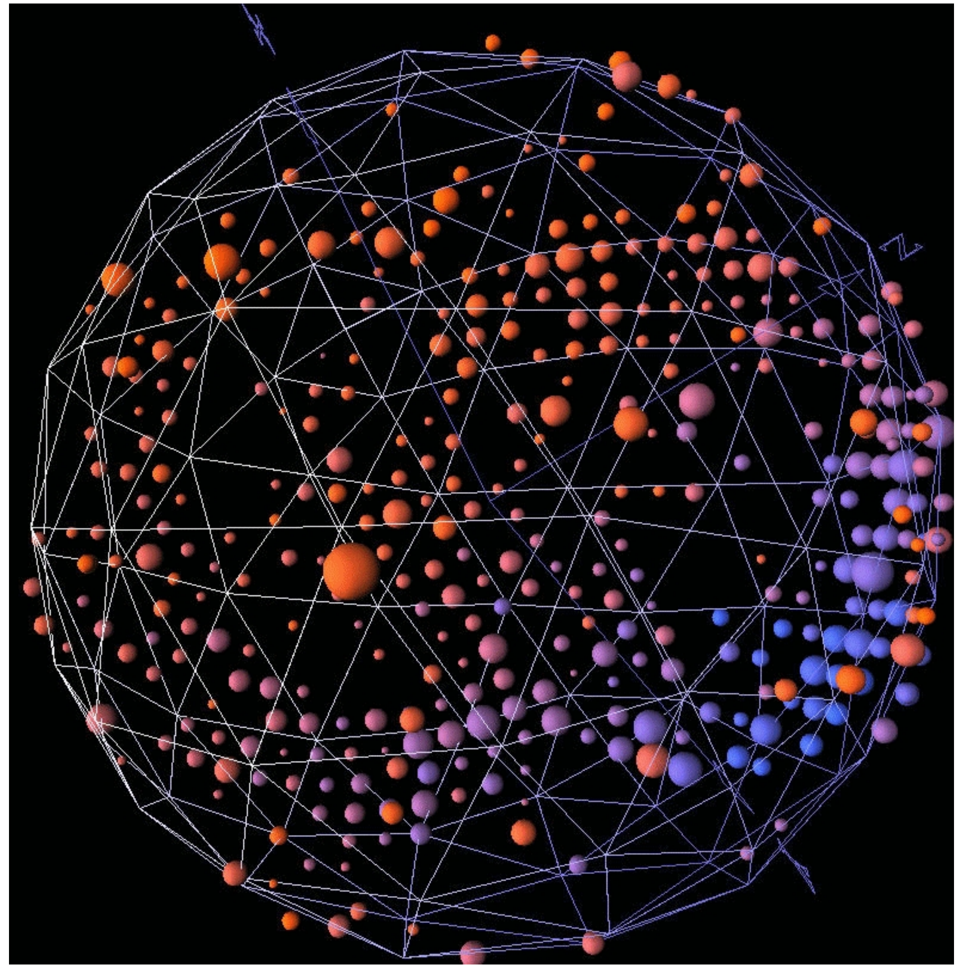
- Resonance:

  $\nu + (p/n) \rightarrow \nu + \Delta$

  $\Delta \rightarrow (p/n) + \pi$

- Coherent:

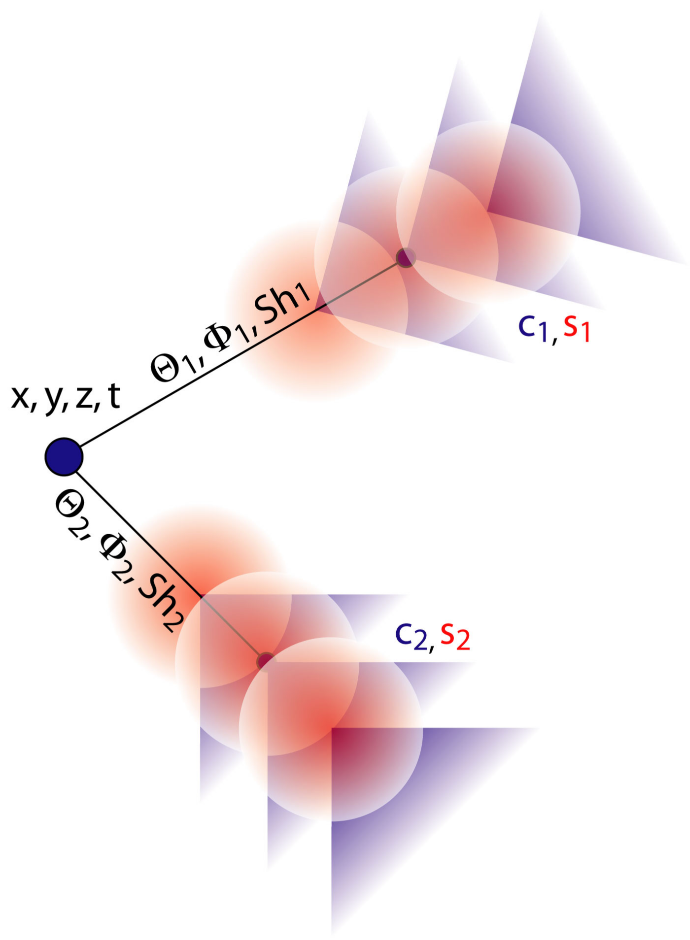
  $\nu + \mathrm{C} \rightarrow \nu + \mathrm{C} + \pi^0$



Size of Ball = Charge

Red = early, Blue = late

Reconstructing Two Ring Events:



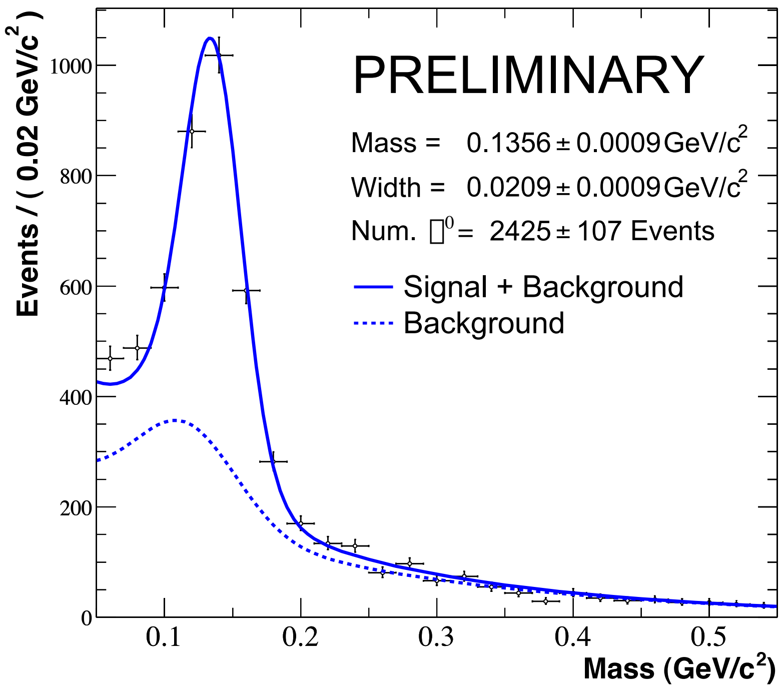
Blue: Cherenkov Light

Red: Scintillation

- Fourteen parameter fit:
  - Vertex of decay (4)
  - Direction of photons (4)
  - Mean emission points (2)
  - Č/Sci Intensity(4)
- Kinematics from Č Intensity
  - $mc^2 = \sqrt{2E_1E_2(1 - \cos\theta_{12})}$
  - $\vec{p} = E_1\hat{u}_1 + E_2\hat{u}_2$

  $E_1,\ E_2$ derived from Č rings.
- No (e/μ) Ring Identification

Inclusive Mass Distribution:



Event Selection:

- No decay electrons
- $N_{TANK} > 200,\ N_{VETO} < 6$
- $E_1,\ E_2 > 40\,\mathrm{MeV}$

Signal shape from Res.+Coh. π^0s

Background shape from Monte Carlo (Contains π^0s from FSI, etc.)

Bin data in kinematic quantities:

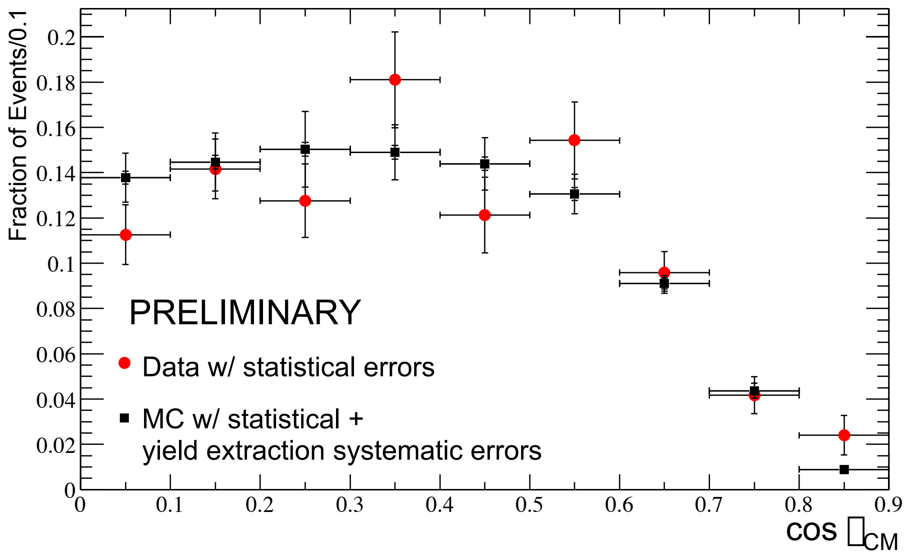
- Momentum (p_{π^0})
- Angle relative to beam ($\cos\theta_{\pi^0}$)
- CM Decay angle ($\cos\theta_{CM}$)

EML Fit to extract signal yield

Extract binned yields

$\longrightarrow$ Get distribution

π^0 Angular Distributions:



π^0 CM Decay Angle

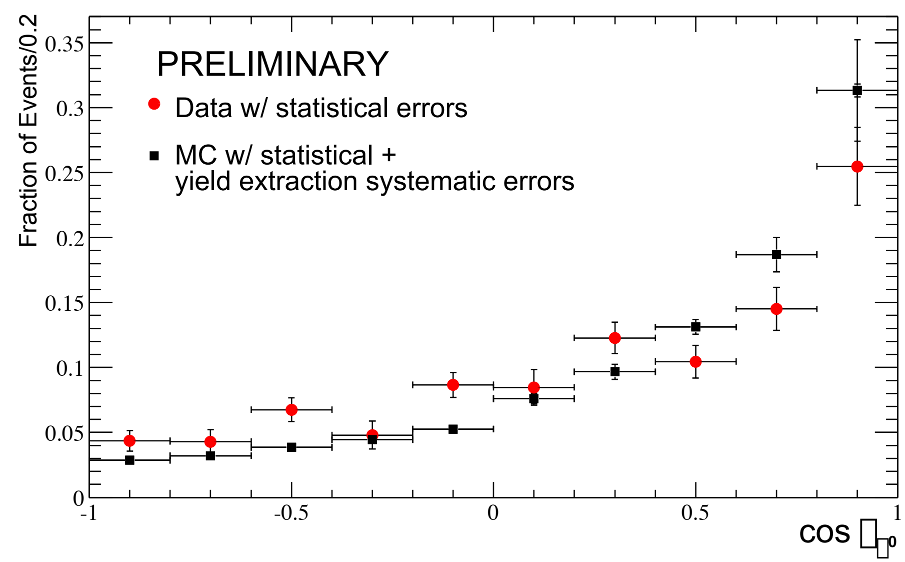
- Should be flat (pseudoscalar)
- Distorted by E_γ cut, inefficiency
- Probes inefficiencies from: asymmetry, ring merging

π^0 Lab Production Angle

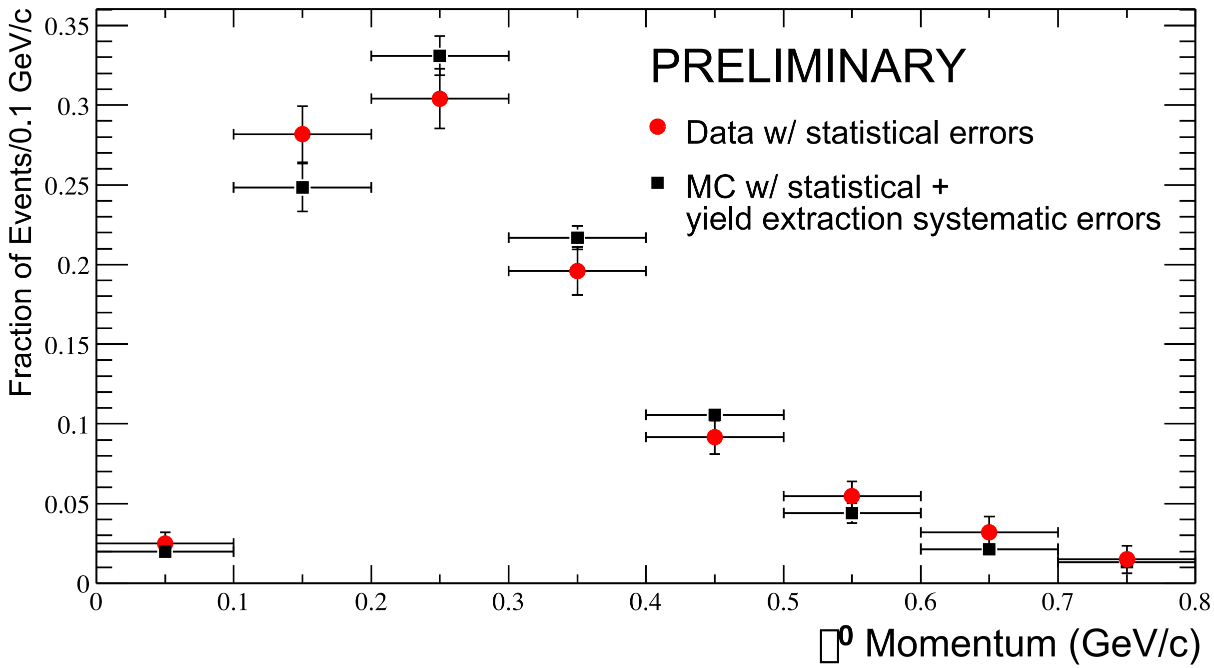
Sensitive to production mechanism

- Coherent is highly forward peaked
- Resonance is less forward-peaked

MC assumes Rein-Sehgal cross-sections



π^0 Momentum Distribution :



Higher Momentum means:

- Energy asymmetry
- Smaller opening angle

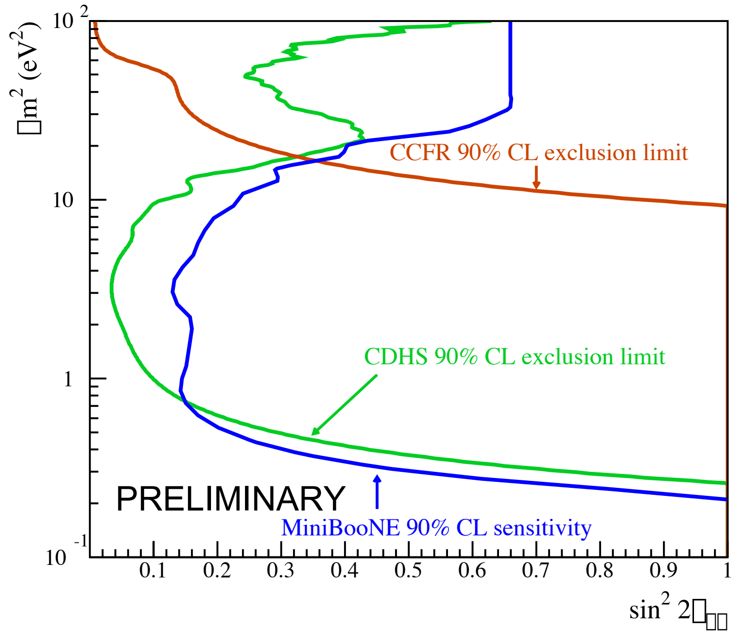
Harder to Reconstruct

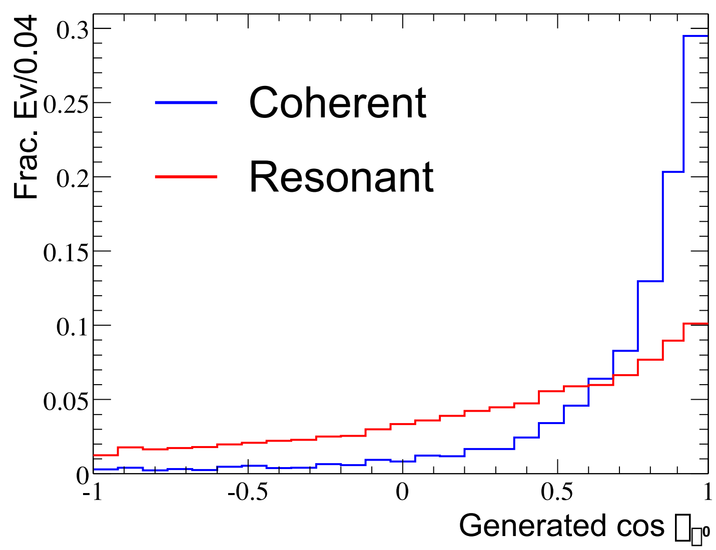
Physics Outlook:

- CC Quasi-Elastic:
  Compare with flux predictions $\rightarrow$
  ν_μ disappearance analysis.
  Probe low Q^2 region

- Neutral Current Elastic:
  Measure σ_{NC}/σ_{CC} vs. Q^2
  Probe Δs.

- NC π^0 Production:
  Cross-section measurement
  Background extrapolation
  Analyze coherent contribution





Conclusions:

- MiniBooNE has been taking beam for ~ 1 year.
  - 1.5×10^{20} protons-on-target
  - $150K$ contained neutrino candidates
- Detector is working as expected.
- Reconstruction algorithms working well
- First sample of neutrino physics

More to come!