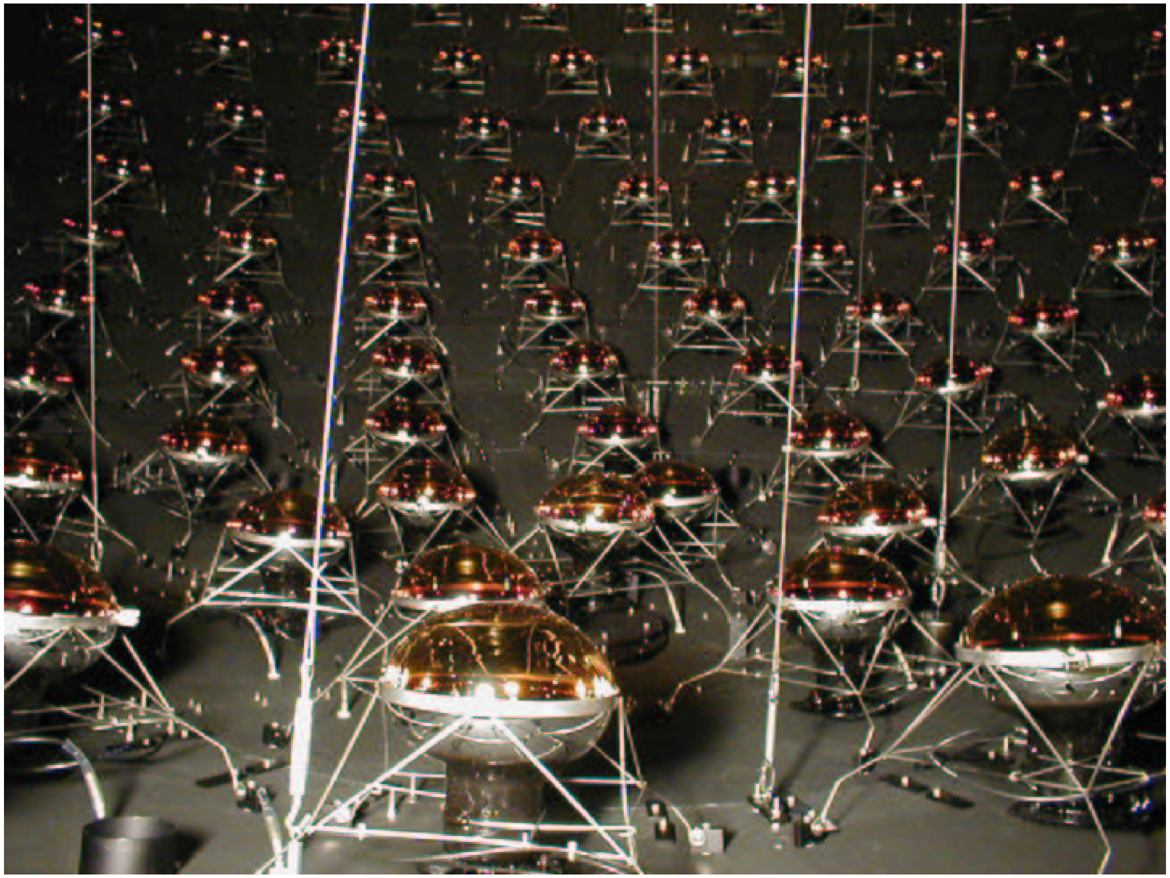
MiniBooNE

Steve Brice
Fermilab



Overview

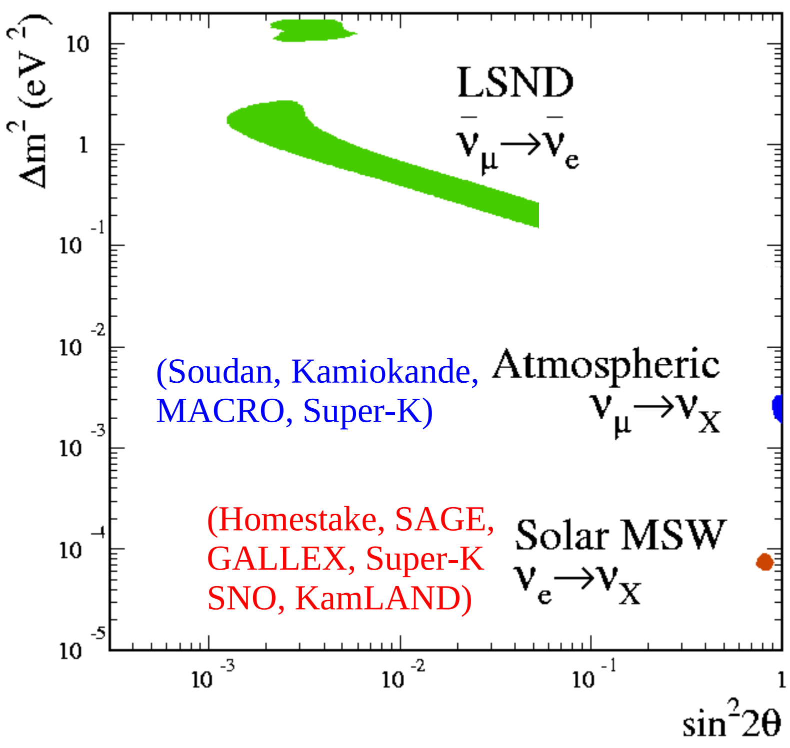
MiniBooNE Beam

MiniBooNE Detector

Neutrino Analyses

Summary

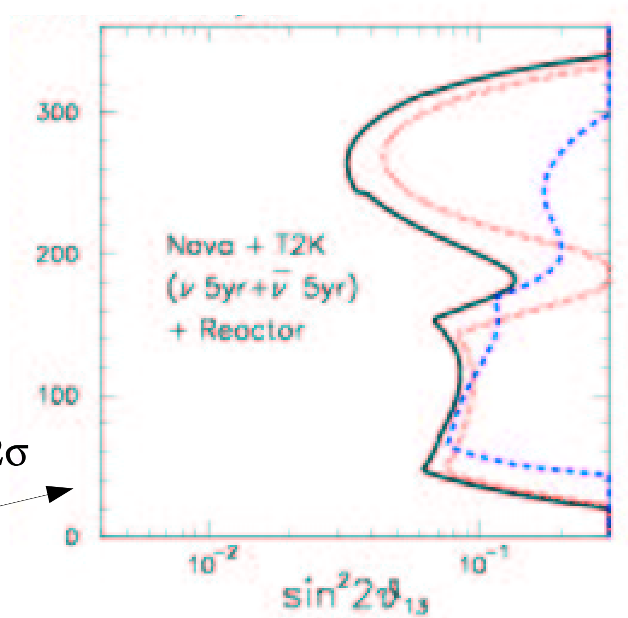
Current Oscillation Signals



- Unconfirmed
  - $\Delta m^2_{LSND} \sim$ 0.1-10 eV^2
- Well established measurements
  - $\Delta m^2_{atm} \sim 2 - 3 \times 10^{-3}$ eV^2
  - $\Delta m^2_{solar} \sim 7 \times 10^{-5}$ eV^2

Implications

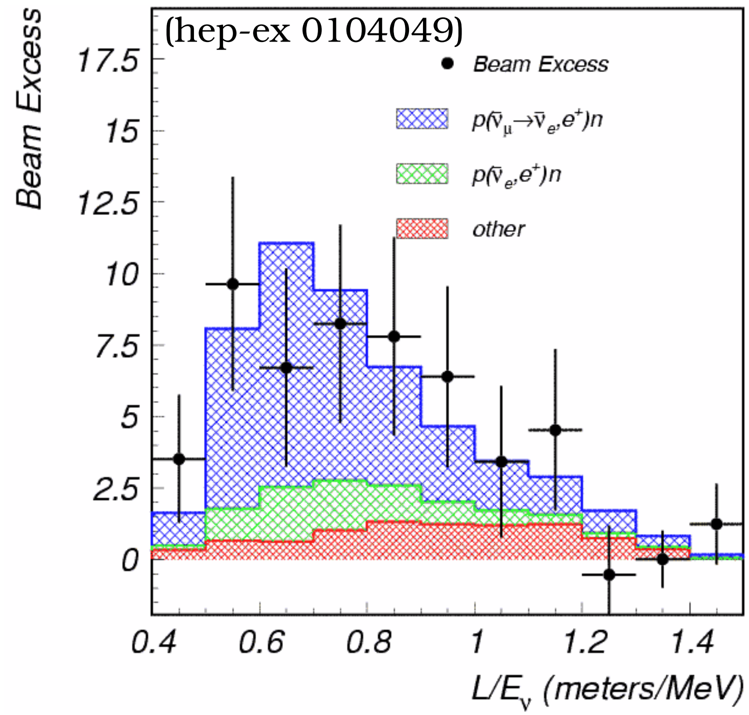
- 3 active, light neutrinos (Z width from LEP)
- But $\Delta m^2_{solar} + \Delta m^2_{atm} \neq \Delta m^2_{LSND}$
- If all 3 measurements are oscillations something fundamental has to give
- Sterile neutrino(s) are one possibility
  - add extra neutrino flavours, but don't allow them to interact weakly
- Also affects offaxis sensitivity



Sensitivity to exclude Null CP signal at 2σ
Black: No MiniBooNE Signal
Red: if CPC MiniBooNE signal
Blue: if CPV MiniBooNE signal

The LSND Result

- LSND:
  - Excess of $\bar{\nu}_e$ events in a $\bar{\nu}_\mu$ beam
  - $87.9 \pm 22.4 \pm 6.0$ over background
  - $\sim 4\sigma$ evidence for ν oscillation



- To Check LSND you want
  - Experiment with
    - different systematics
    - higher statistics
    - similar L/E
- ➤ MiniBooNE

The Collaboration

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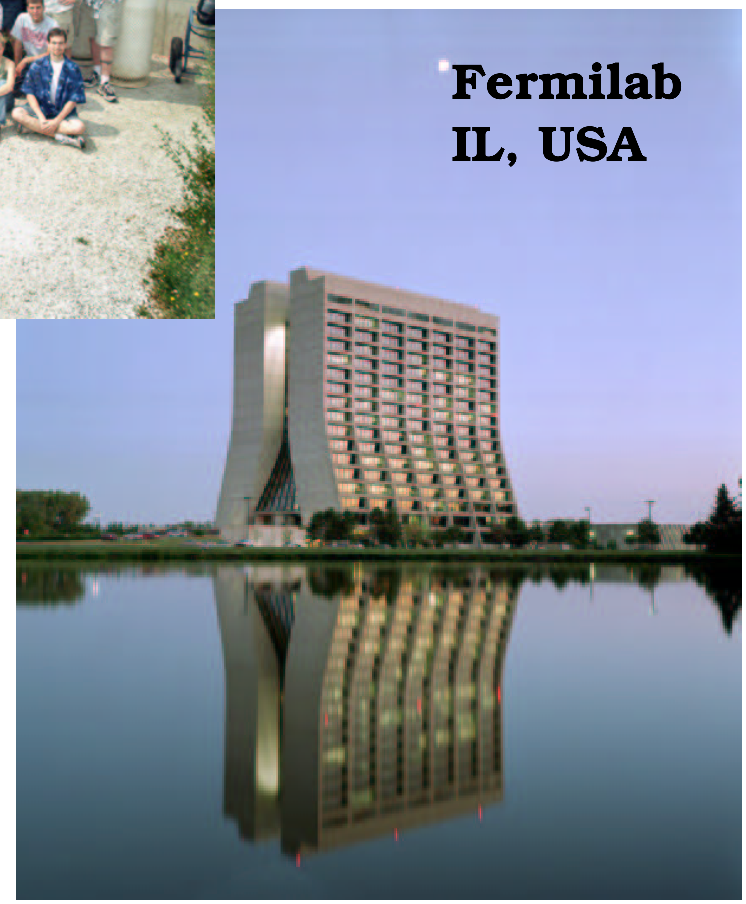
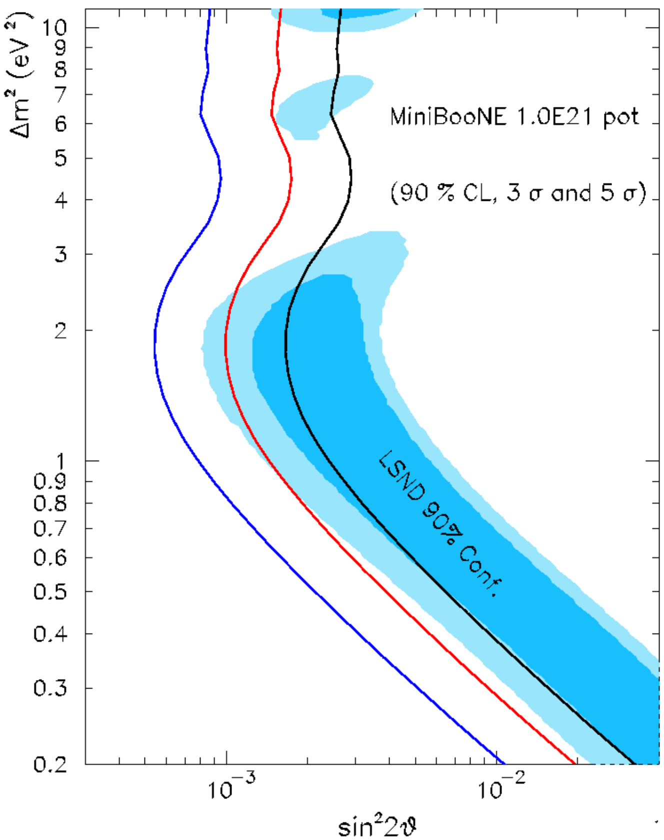
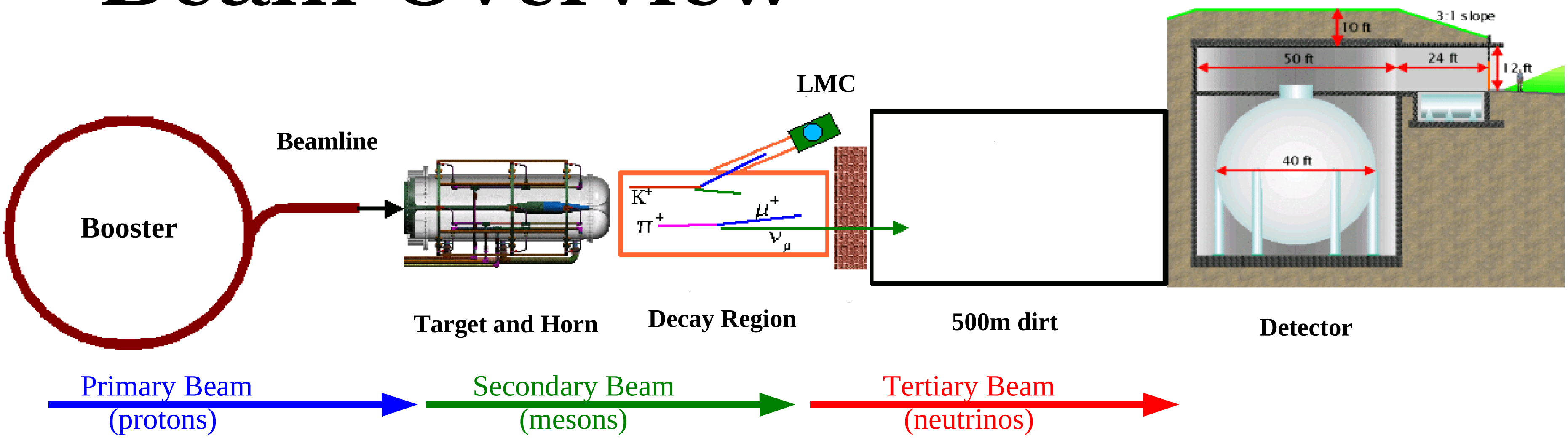


MiniBooNE Goal



- Search for ν_e appearance in a ν_μ beam
  - L=540 m ~10x LSND
  - E~500 MeV ~10x LSND
- Aim to be definitive
  - cover LSND 90% conf region at 4-5σ
  - this needs ~10^{21} delivered protons

Beam Overview



Primary Beam

- 8 GeV protons from Booster
- Into MiniBooNE beamline

Secondary Beam

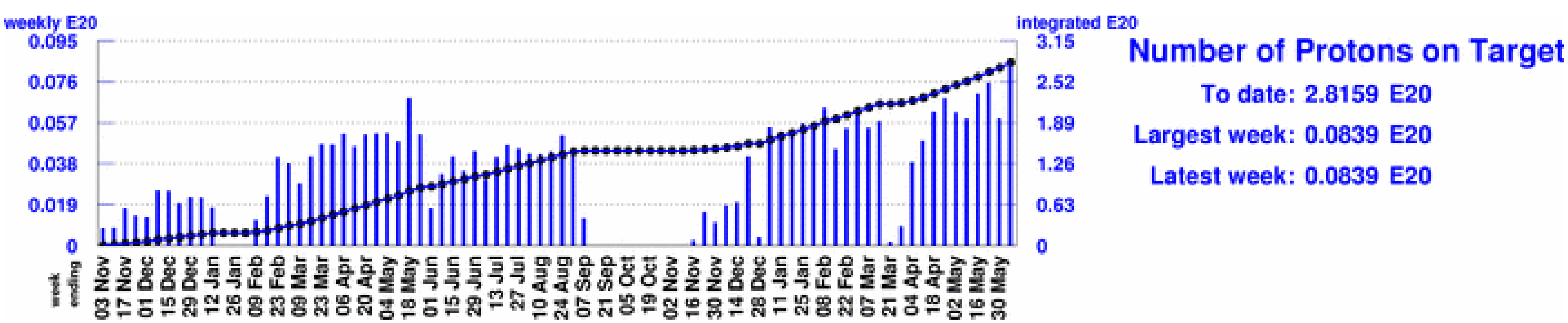
- Mesons from protons striking Be target
- Focused by magnetic horn

Tertiary Beam

- Neutrinos from meson decay in 50m pipe
- Pass through 500m dirt (and oscillate?) to reach detector

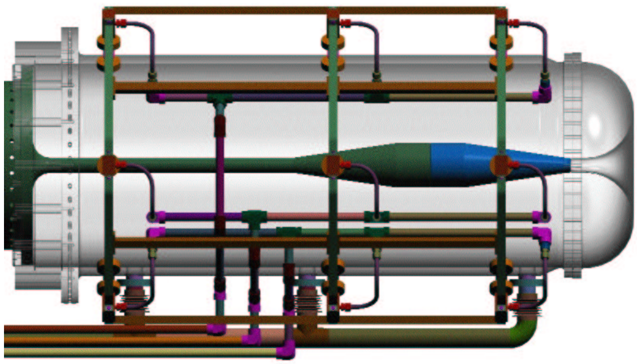
Booster Performance

- In its 30 years the Fermilab Booster has never worked this hard
- Currently average …
  - ~ 6×10^{16} protons/hour
- Have reached 28% of total protons needed

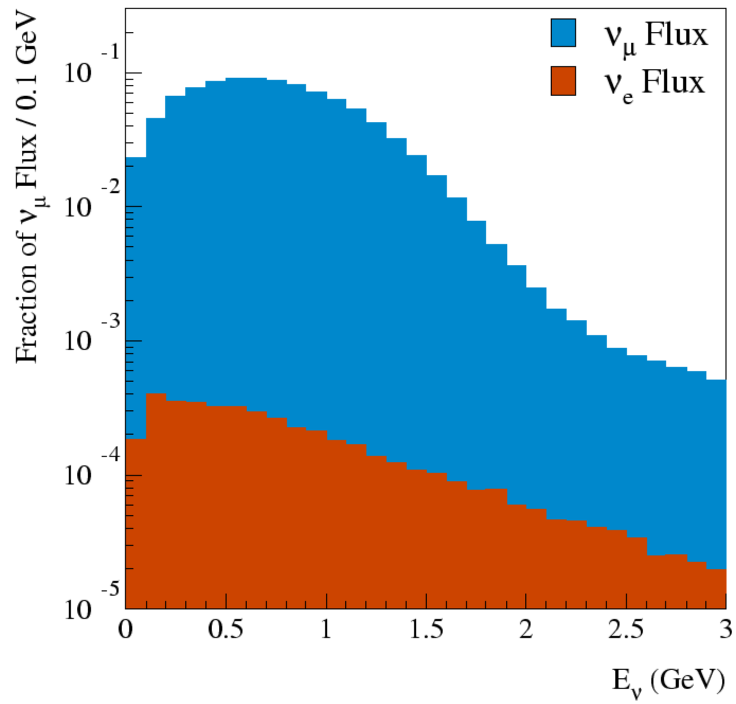


Horn, Target & Fluxes

- Protons impinge on 71cm long, Be target
- Horn focusing of secondary beam increases ν flux by factor of ~5
- 170 kA pulses, 143μs long at ~5 Hz
- Has performed flawlessly with ~80 million pulses to date

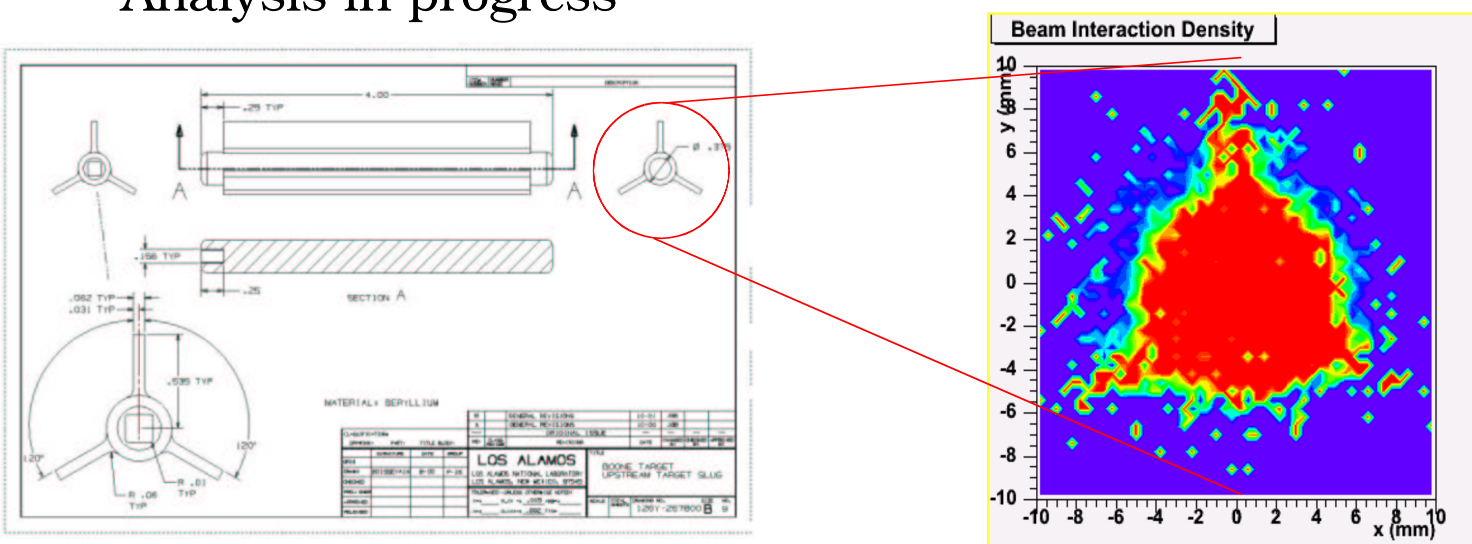


- Main ν_μ flux from $\pi^+ \rightarrow \mu^+ \ \nu_\mu$
- Intrinsic ν_e flux from
  - $\mu^+ \rightarrow \nu_\mu \ e^+ \ \nu_e$
  - $K^+ \rightarrow \pi^0 \ e^+ \ \nu_e$
  - $K^0_L \rightarrow \pi^- \ e^+ \ \nu_e$
- Understand fluxes with multiple monitoring systems



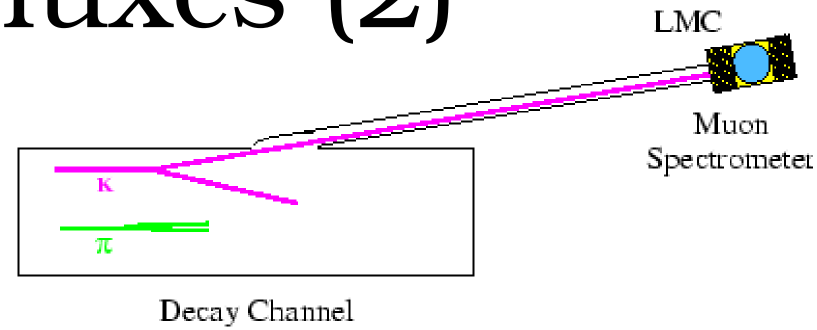
Understanding ν Fluxes (1)

- E910 @ BNL + previous world data fits
  - Basis of current MB π production model
- HARP @ CERN
  - Measure π & K production from 8 GeV p beam
  - MB target slugs - thin and thick targets
  - Analysis in progress

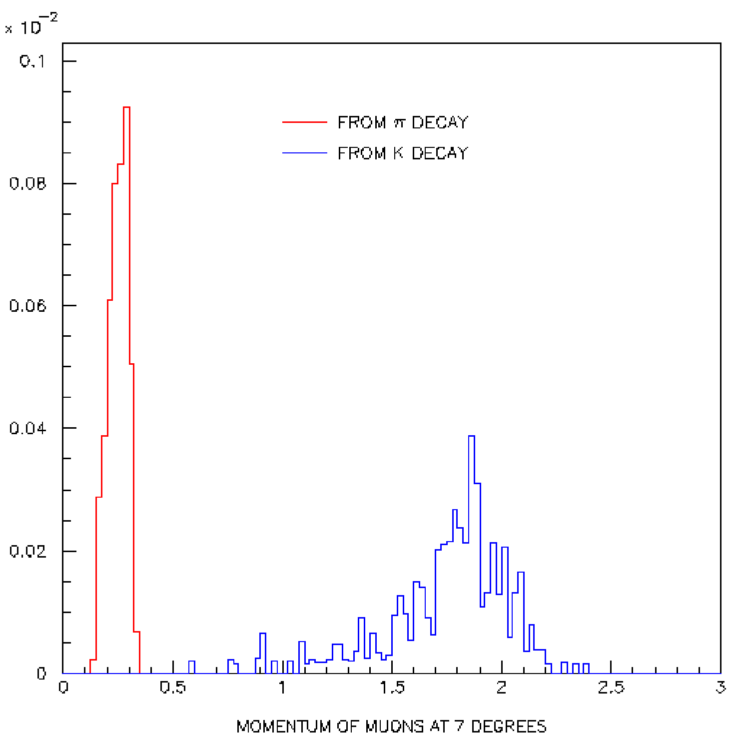


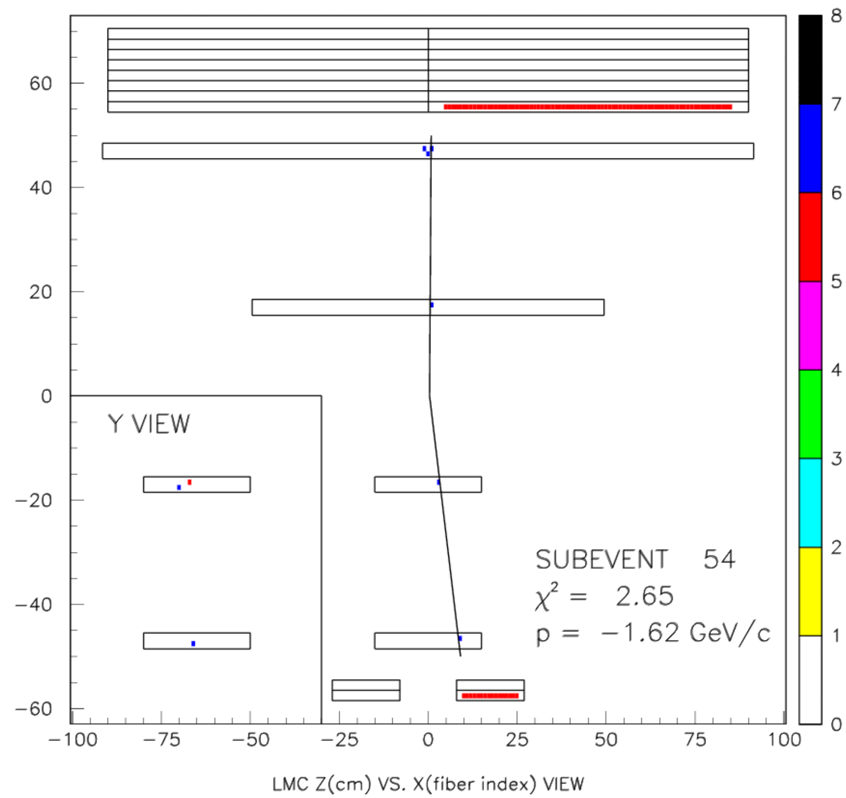
Understanding ν Fluxes (2)

- LMC muon spectrometer
  - K decays produce wider angle muons than π decays
  - Scintillating fibre tracker 7 degrees off axis

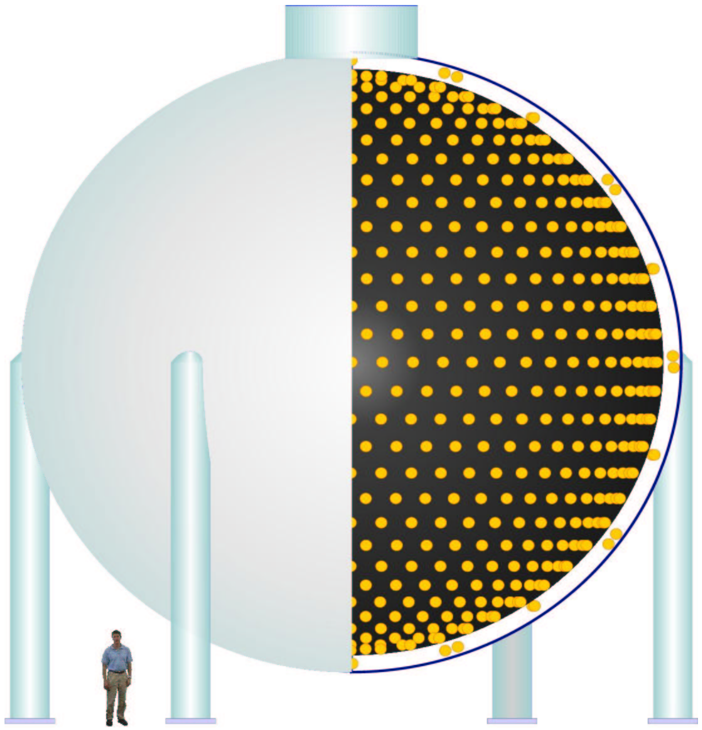


- LMC triggered from beam-on-target signal

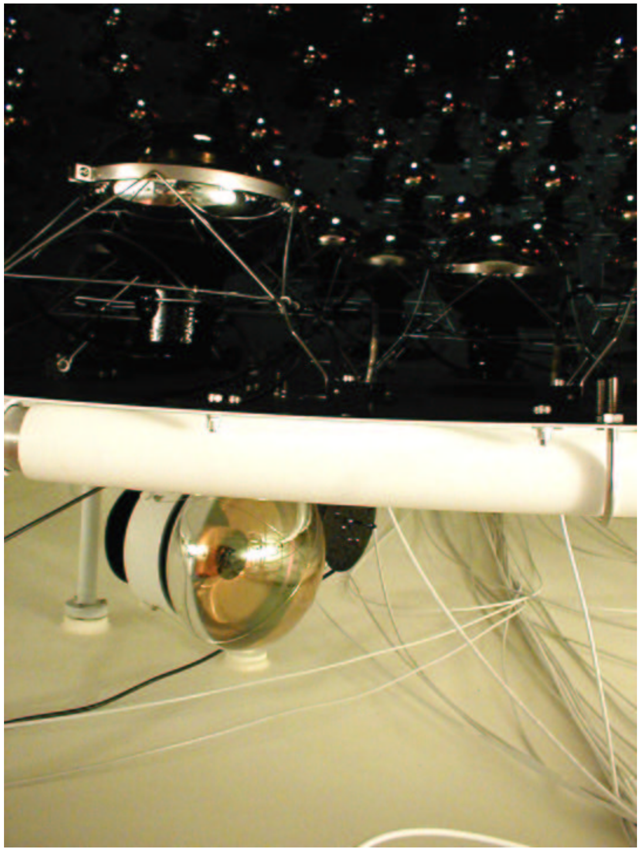




Detector Overview

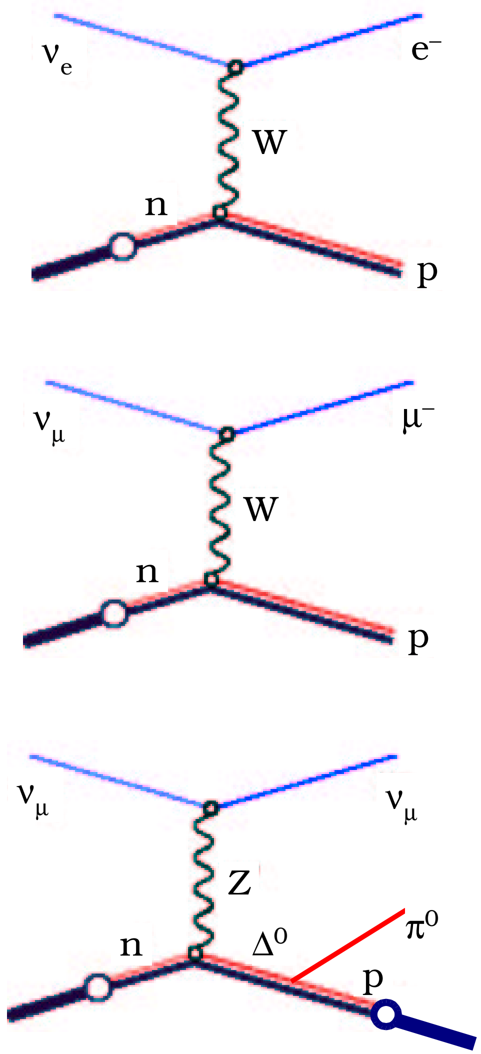


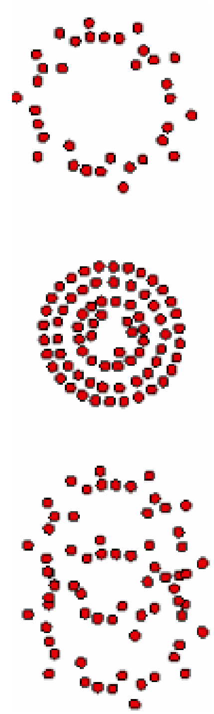
- 12m diameter sphere
- Filled with 950,000 litres of pure mineral oil



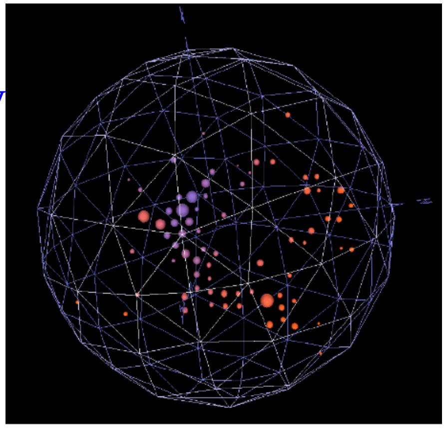
- Light tight inner region with 1280 8” PMTs (10% coverage)
- 240 PMTs in outer veto region
- Neutrino interactions in oil produce
  - Prompt Čerenkov light
  - Delayed scintillation light

Particle ID

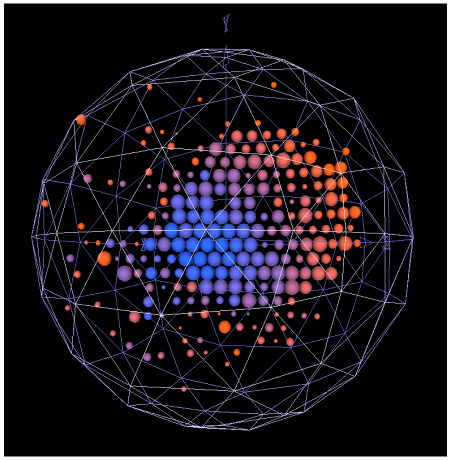




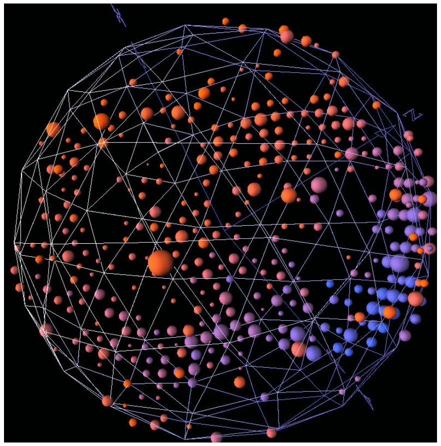
Michel e from μ decay candidate



Beam μ candidate



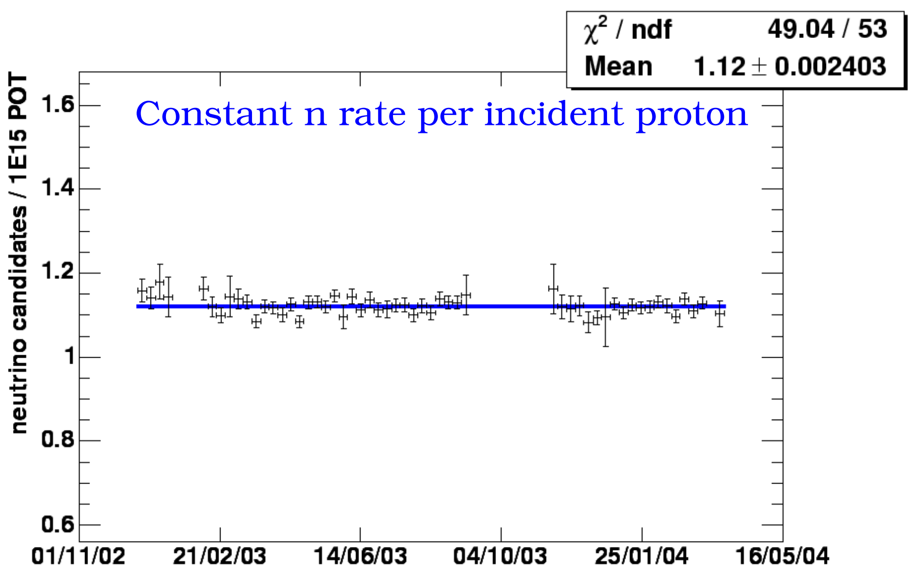
Beam π^0 candidate

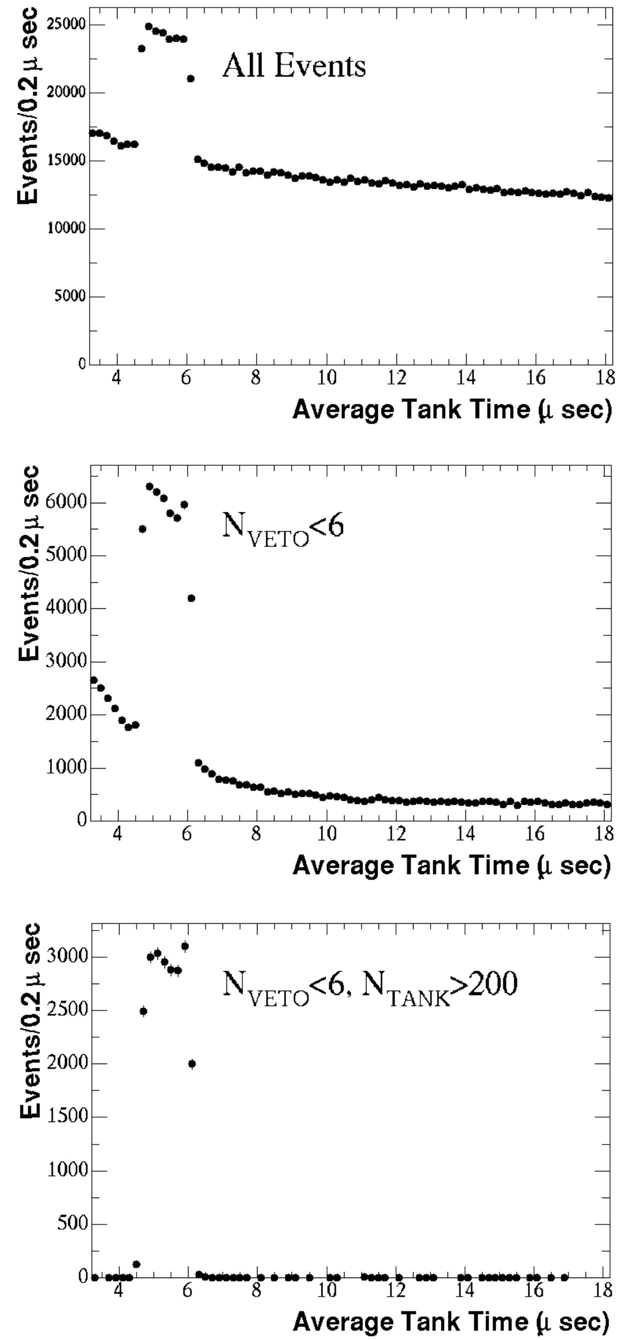


- Identify electrons (and thus candidate ν_e events) from characteristic hit topology

Neutrino Candidates

- DAQ triggered on beam from Booster
- Detector read out for 19.2 μs
- ν pulse through detector lasts 1.6 μs
- With a few very simple cuts non-neutrino/neutrino rate is ~10^{-3}

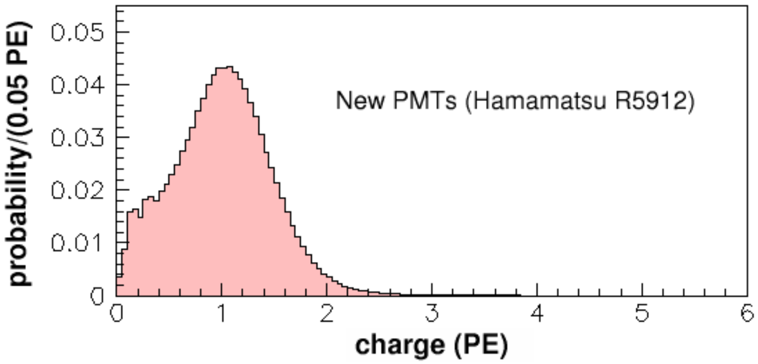




- ν event every 1.5 minutes, ~300k to date

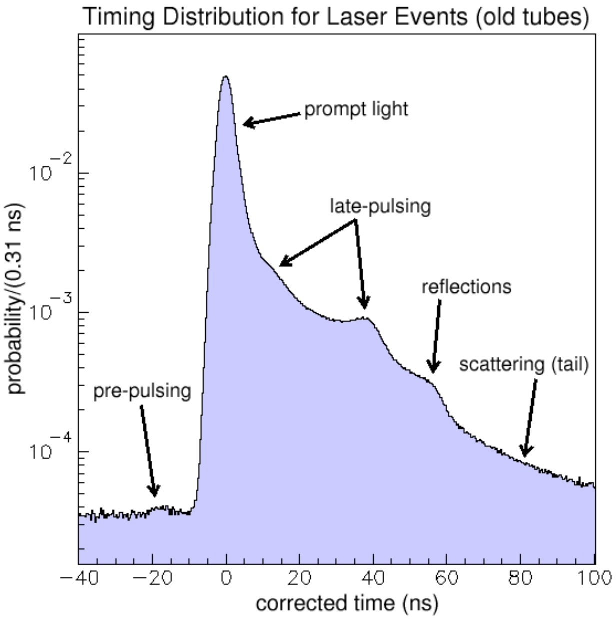
Laser Calibration System

- 4 Flasks distributed about the tank
- Measure tube charge response (needed for energy measurement)



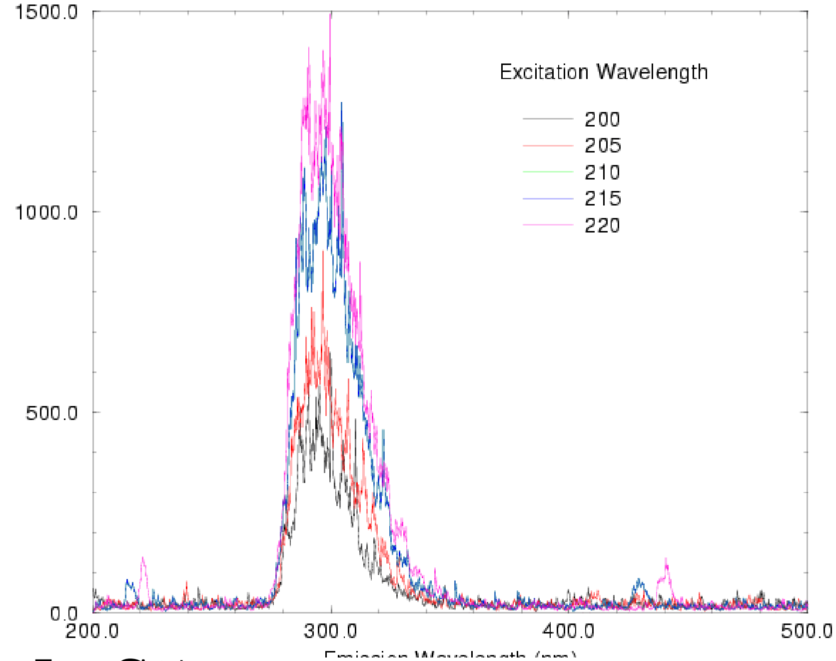
- Fully automated calibration system
- New calibration every 4 days

- Measure tube timing response (needed for event reconstruction)



Optical Model

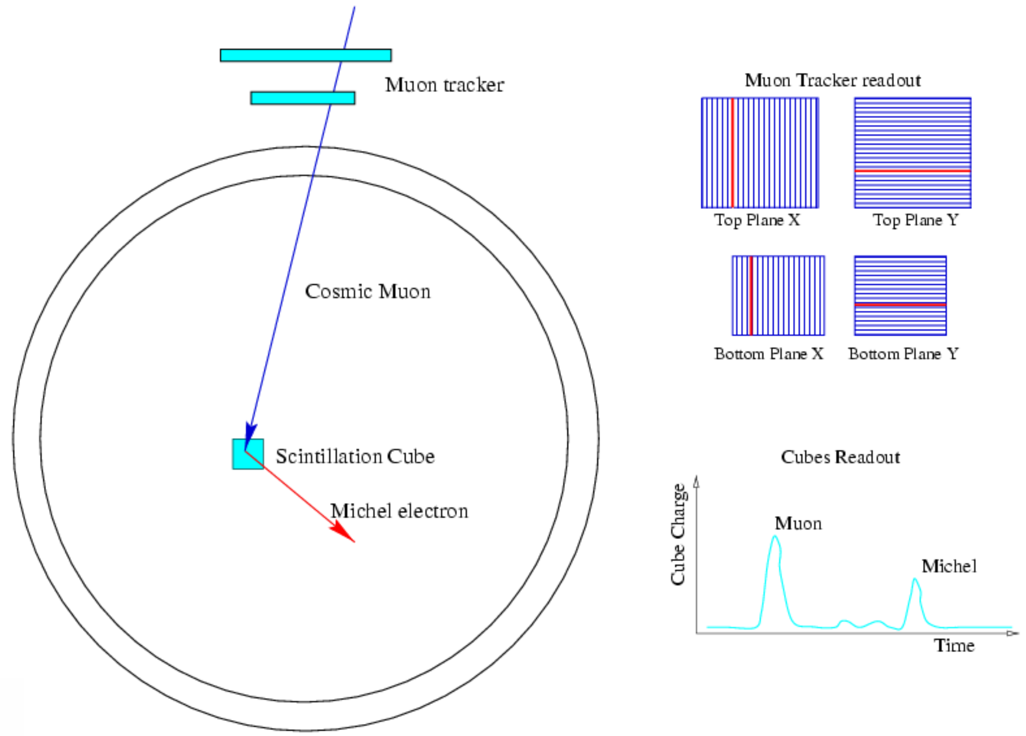
- Light Creation
  - Cerenkov – well known
  - Scintillation
    - yield
    - spectrum
    - decay times
- Light Propagation
  - Fluoresence
    - rate
    - spectrum
    - decay times
  - Scattering
    - Rayleigh (λ^4, $1+\cos^2\theta$)
    - Particulate (Mie)
  - Absorption

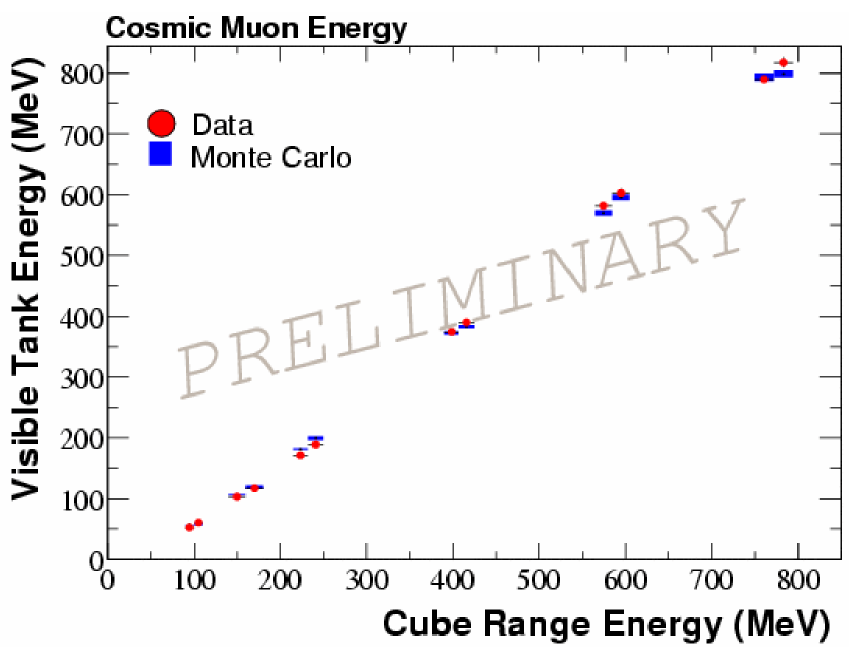


- In Situ
  - Cosmics muons, Michel electrons, Laser
- Ex Situ
  - Scintillation from p beam (IUCF)
  - Scintillation from cosmic μ (Cincinnati)
  - Goniometry (Princeton)
  - Fluorescence Spectroscopy (FNAL)
  - Time resolved spectroscopy (JHU)
  - Attenuation (Cincinnati)

Muon Tracker and Cubes

- Muon tracker system provides muons of known direction in the tank
- Key to understanding energy and reconstruction



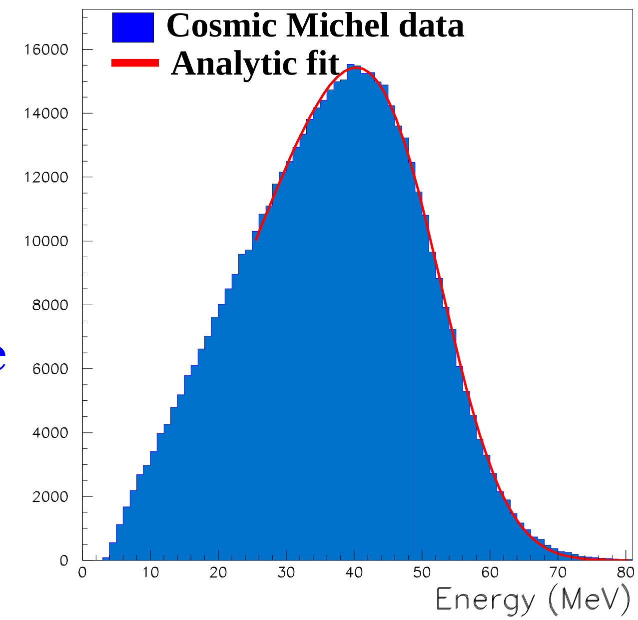


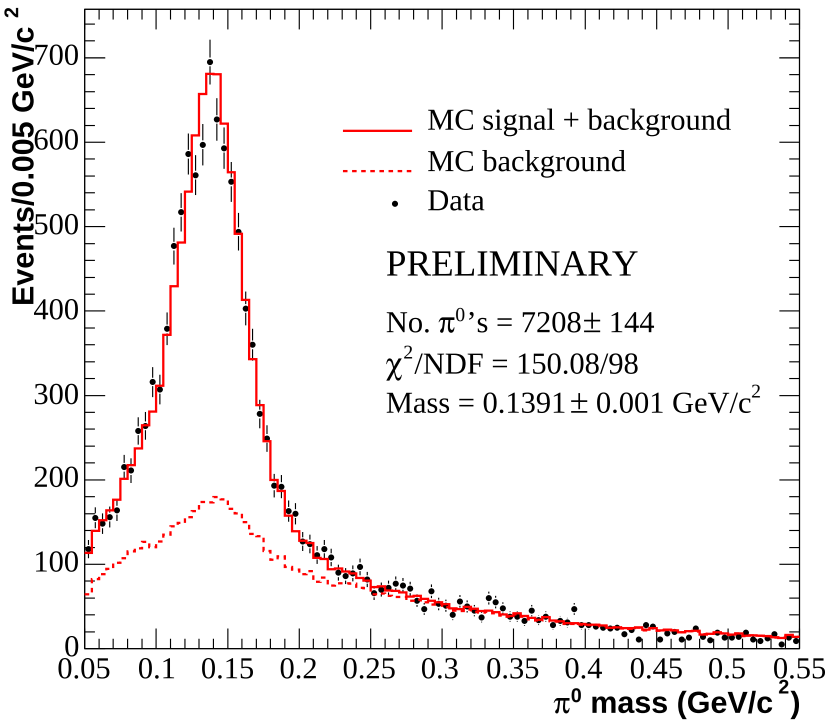
- 7 Scintillator cubes throughout the tank
- Provide muons & Michel electrons of known position

Electron Energy Response

Michel Electrons from Cosmic μ Decays

- Used to set energy scale



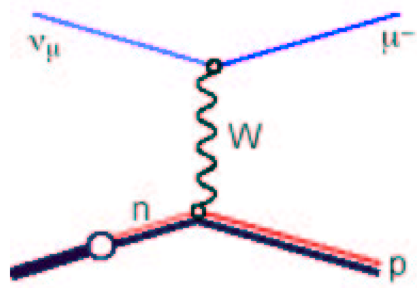


π^0 Mass Reconstruction

- In Beam Time window
- Tank hits > 200, Veto hits < 6
- In fiducial volume
- Both rings > ~40MeV and well separated

ν_μ Analyses

CC quasi-elastic



Use to understand ν_e CCQE cross-section

NC π^0 production

resonant:

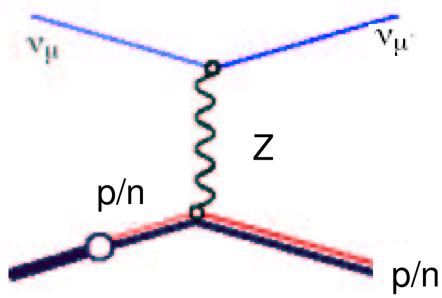
$$\nu + (p/n) \rightarrow \nu + \Delta$$
$$\Delta \rightarrow (p/n) + \pi$$

coherent:

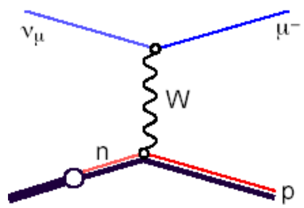
$$\nu + \mathrm{C} \rightarrow \nu + \mathrm{C} + \pi^0$$

background to ν_e appearance

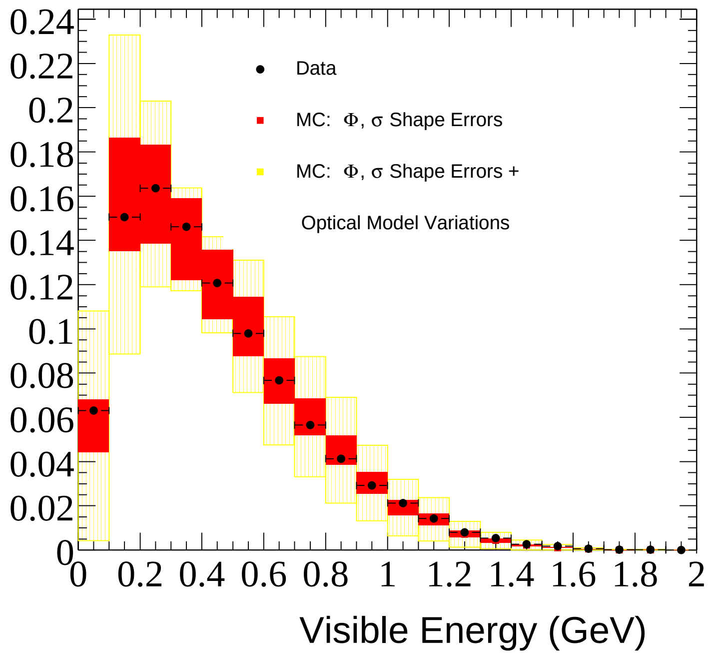
NC elastic



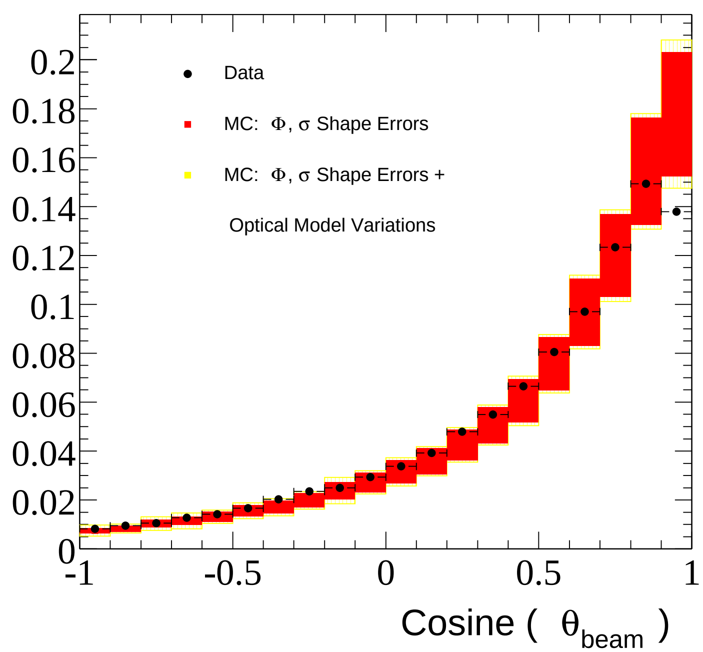
Use to understand lower vertex

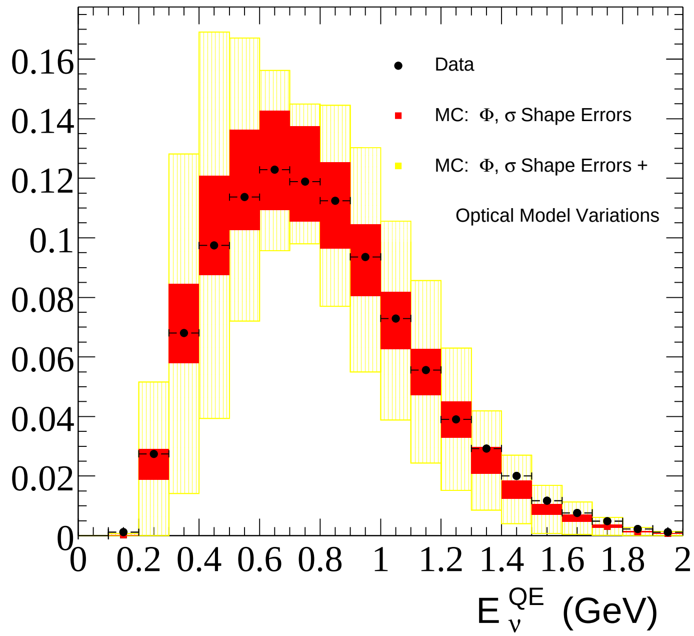


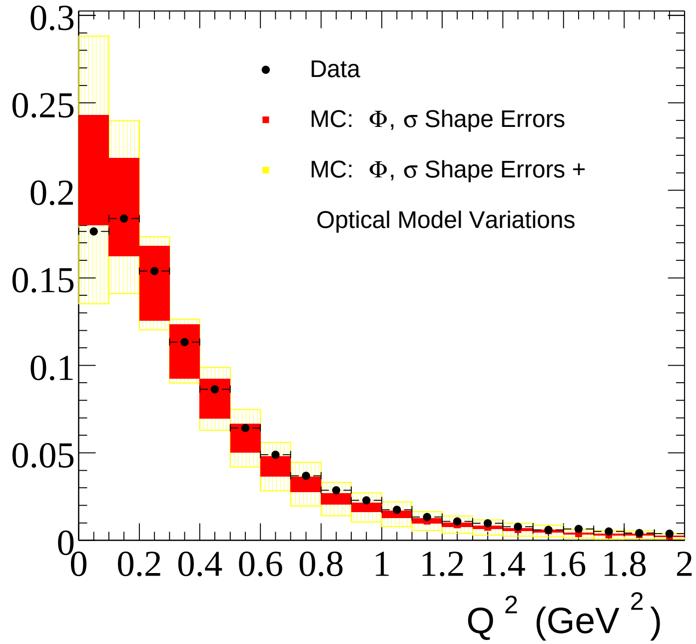
Charged Current QE



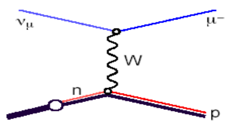
- Selection:
  - Cosmic ray cuts
  - Single μ-like ring
  - Topology
- MC & Data relatively normalized.
- Red Band: MC 1σ uncertainty from…
  - flux shape
  - cross-section
- Yellow Region: idea of variation from…
  - optical properties (atten. length, scintillation, scattering, …)







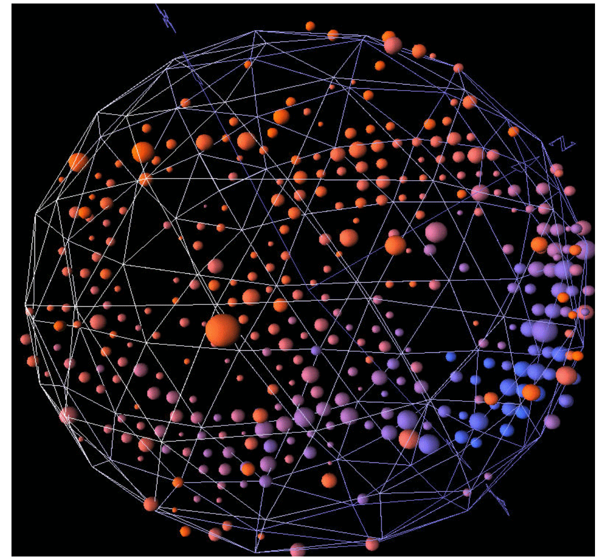
CCQE Reconstruction

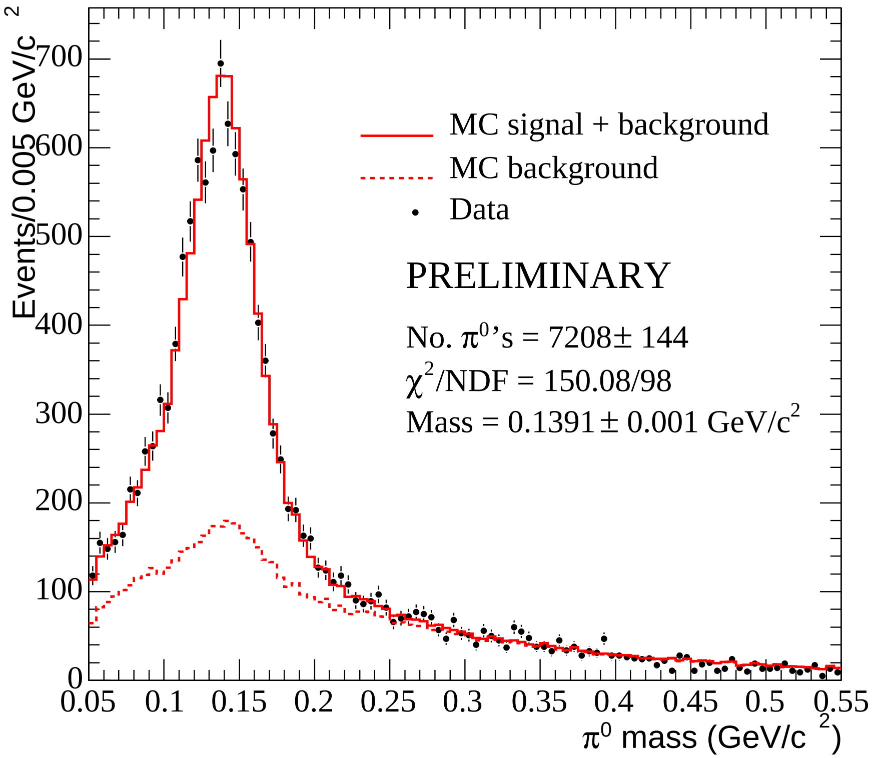
- Assume:  (CCQE)

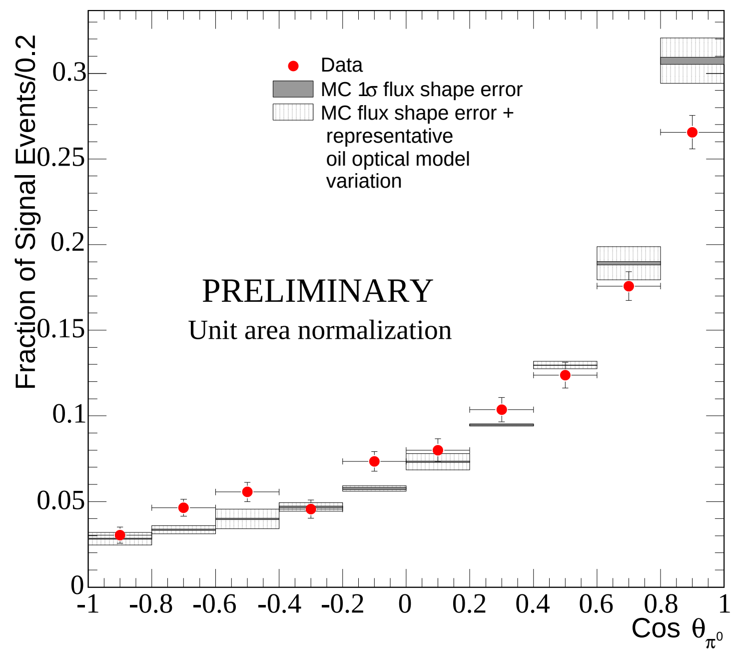
- Get E_ν^{CCQE} and Q^2 from E_μ, θ_μ
- Sensitive to ν_μ disappearance

NC π^0

- Ntank > 200, Nveto < 6, Fid.Vol.
- No Michel electron
- Clear 2-ring fit on all events
- Each ring: $E_{\gamma 1}$, $E_{\gamma 2}$ > 40 MeV.



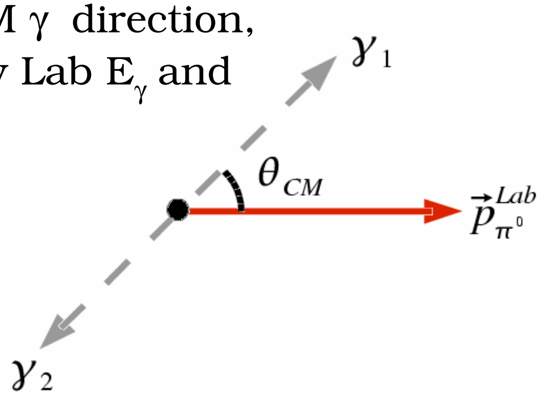


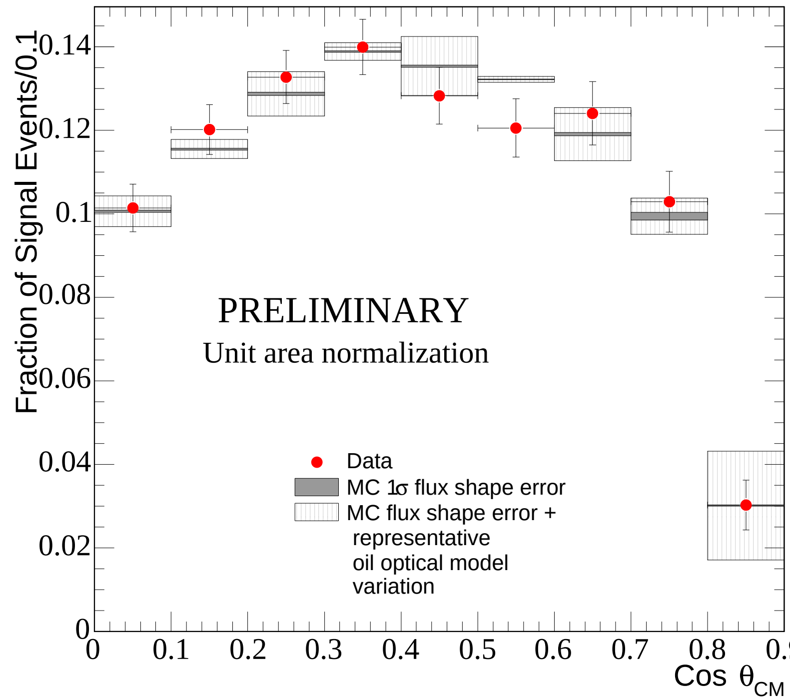


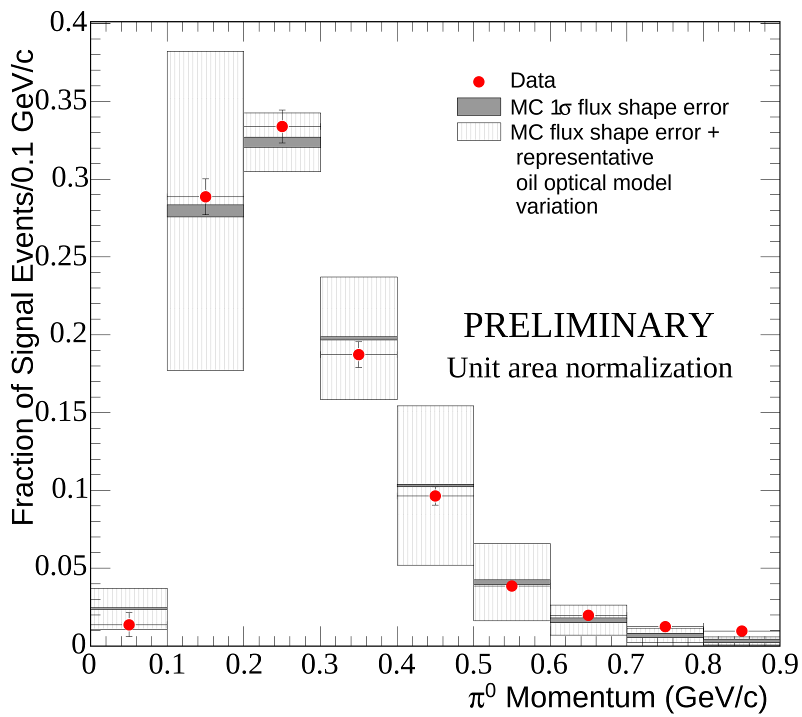
Signal yield extracted from fit with background MC.

π^0 Variables

No preferred CM γ direction, but distorted by Lab E_γ and 2 ring cuts.

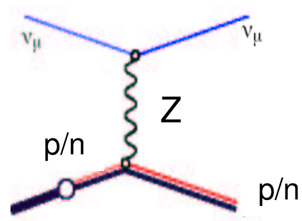


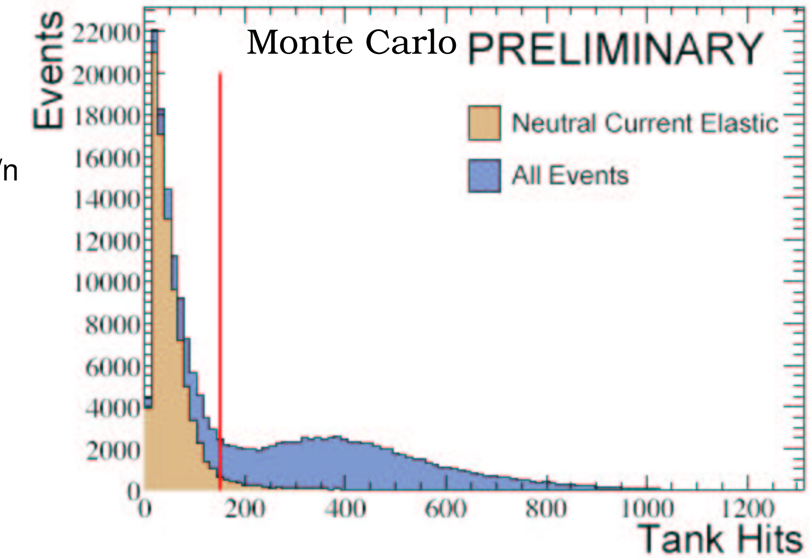




High Momentum tail
- from ν flux
- distorted by 2 ring cut

NC Elastic Scattering



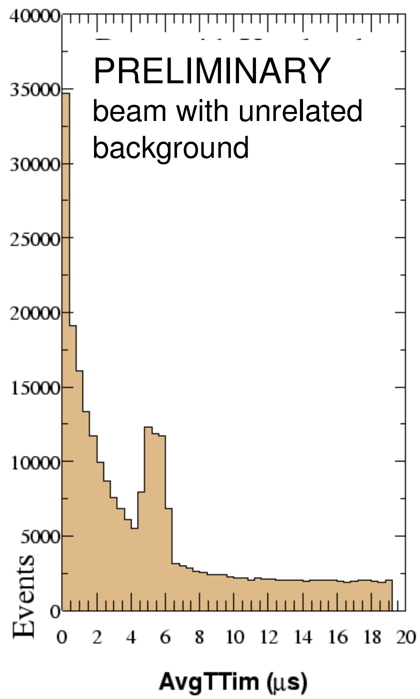


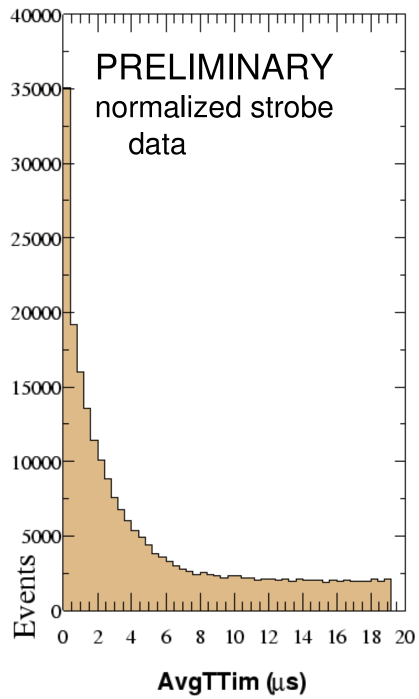
Select N_{TANK} < 150

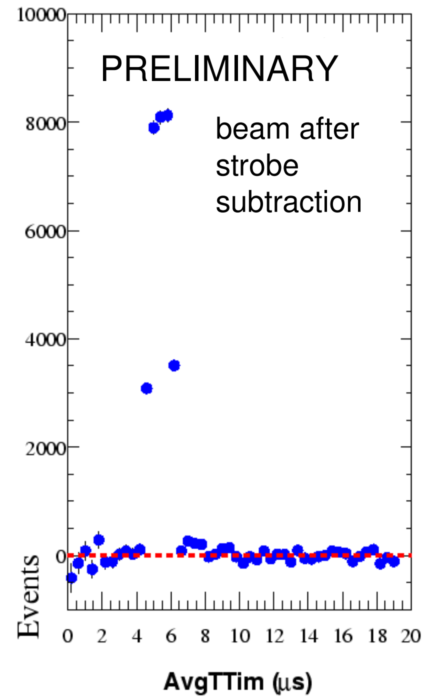
N_{VETO}< 6

clear beam excess

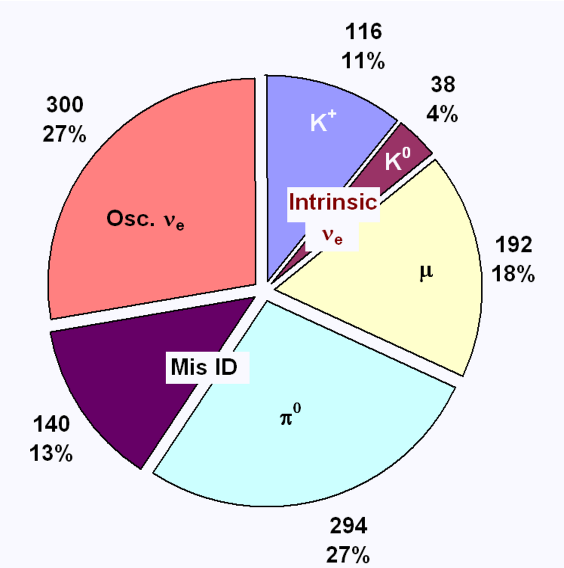
use random triggers to subtract non-beam background







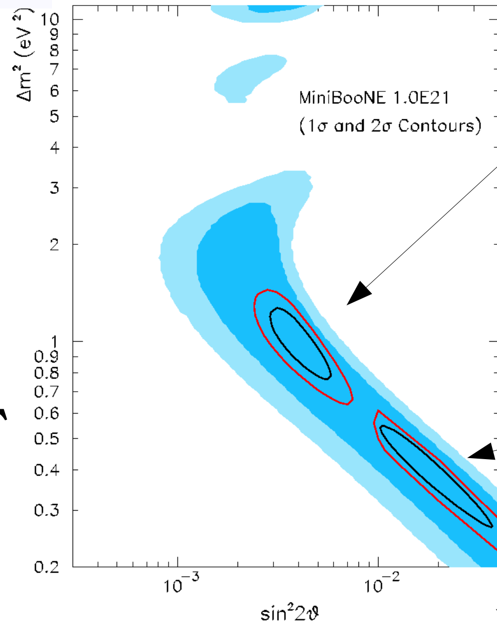
Updated Appearance Sensitivity

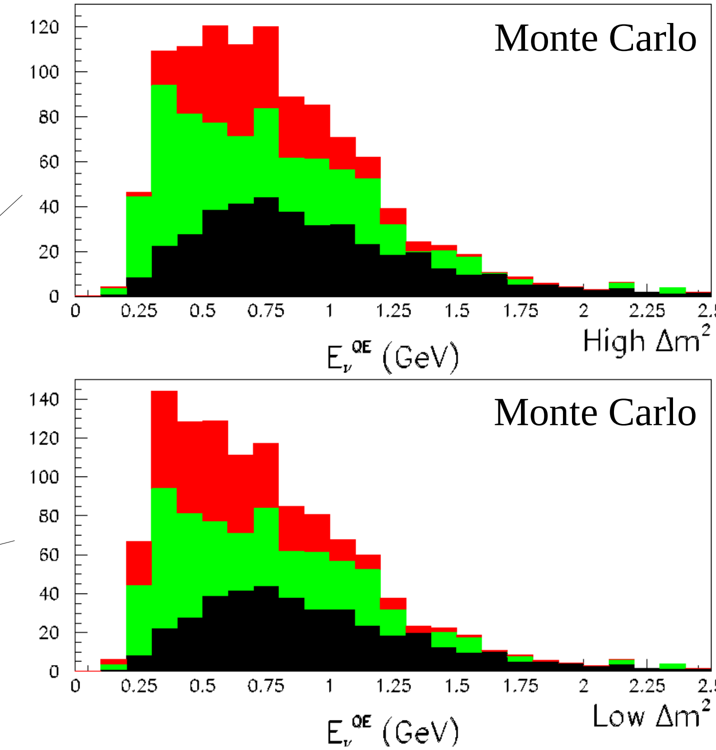


- ν_e signal and background breakdown

- ν_e signal events
- NC π^0 misIDs
- Beam ν_e events

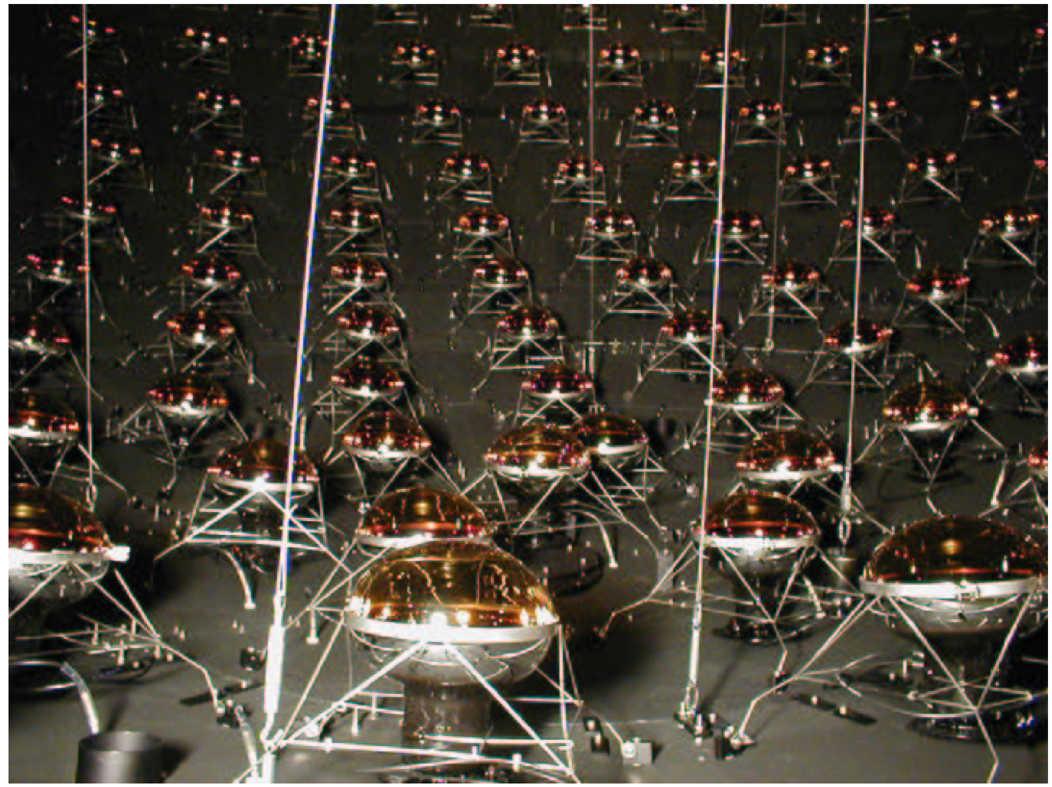
- Reasonable signal separation with 10^{21} POT





Summary

- All hardware systems working well
- We're at 28% of 10^{21} protons on target
- Already amassed world's largest ν dataset in ~1GeV range
- Sample of neutrino physics shows that reconstruction and analysis algorithms are working well



- ν_e appearance analysis should be ready in time for 10^{21} POT. Hopefully in 2005