MiniBooNE

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Neutrino Factory 2004 Osaka, Japan

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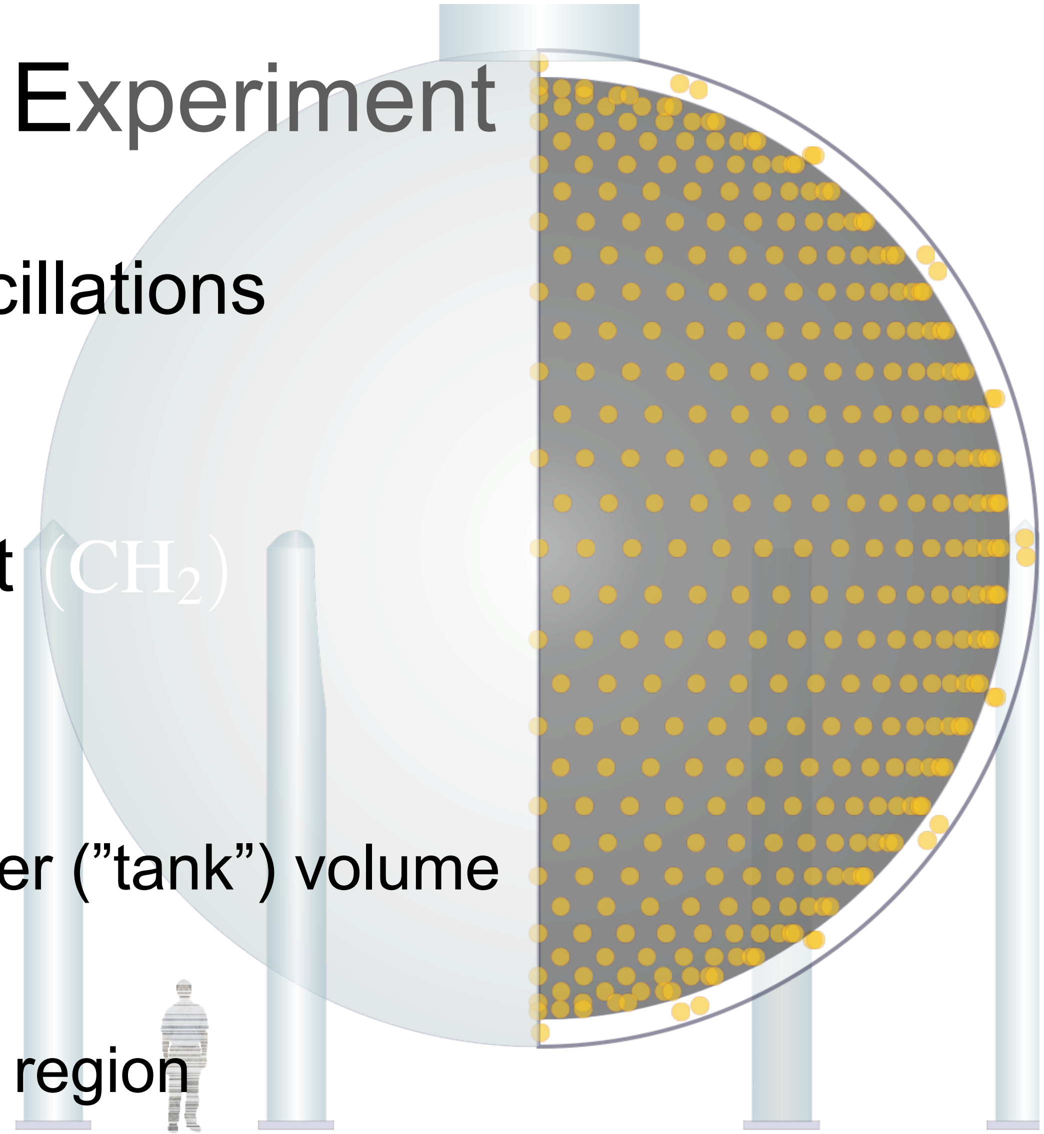
MiniBooNE:

Mini Booster Neutrino Experiment

- A search for oscillations
  -
- 800 ton mineral oil target (CH_2)
  - 610 cm radius
  - Optical barrier at 5.75 m
  - 1280 photomultipliers in inner ("tank") volume 5500 cm radius, 445 tons
  - 240 photomultipliers in veto region

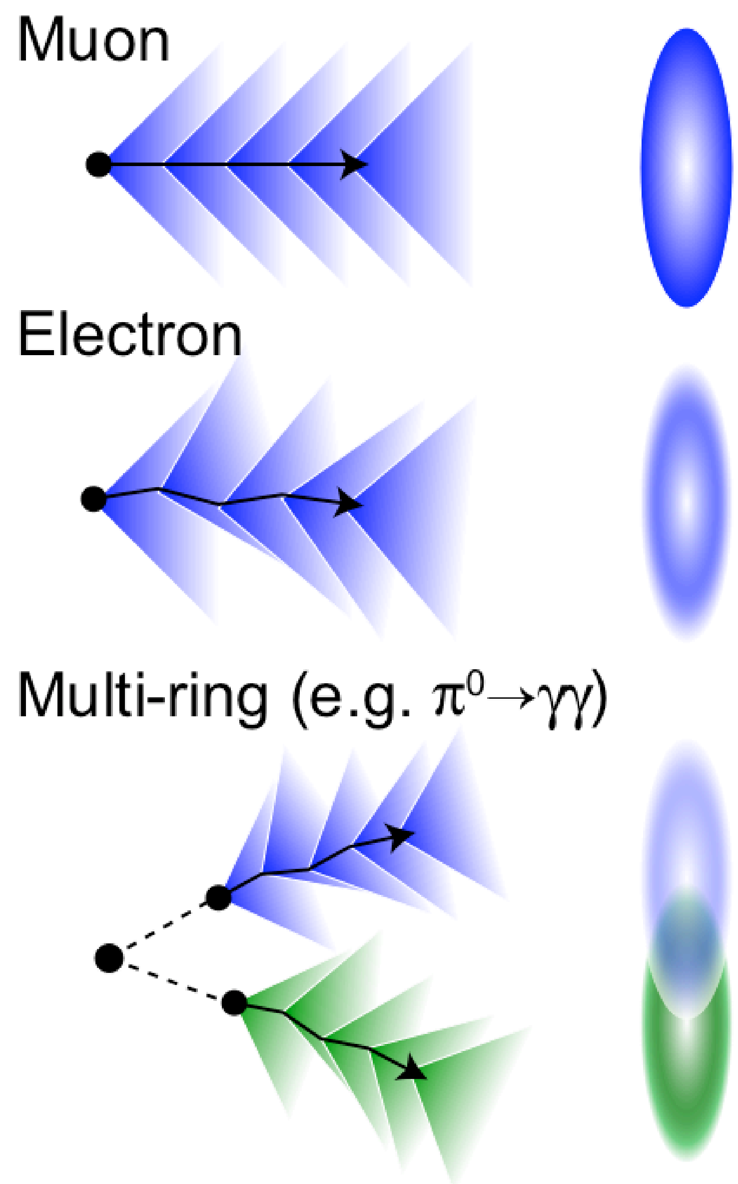


Detect neutrino interactions with

Detecting Neutrino Interactions

Cherenkov radiation:

- Charged particles with produce cone of radiation
- Minimum ionizing particles (muons)
  sharp-edged rings
- Electrons (Photons)
  multiply scatter, shower, convert, etc.
  more diffuse rings
- Multiple particles:
  reconstruct by identifying multiple rings

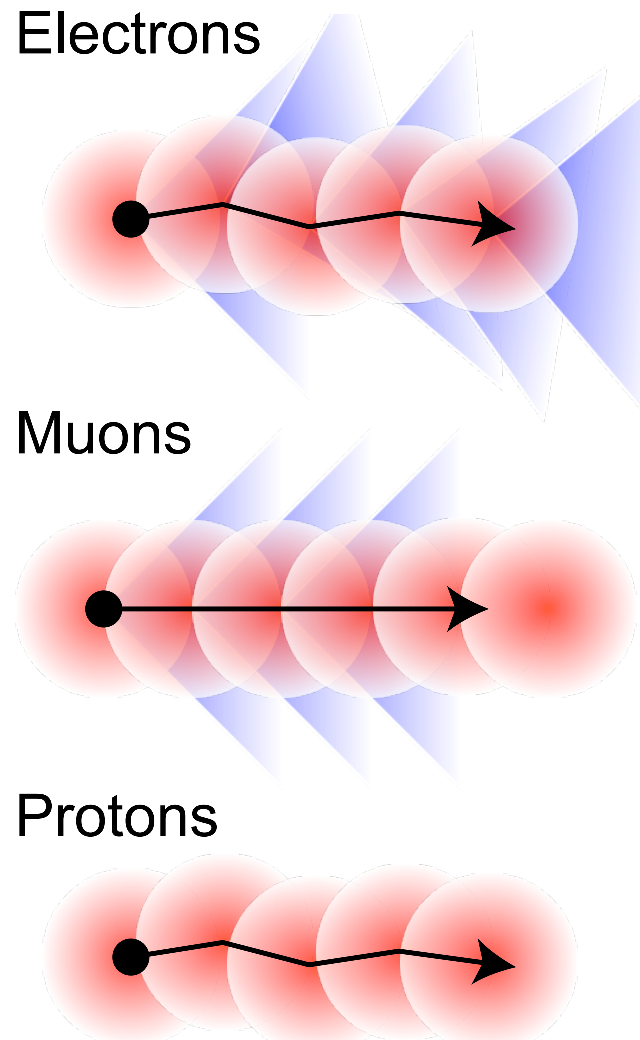


Detecting Neutrino Interactions

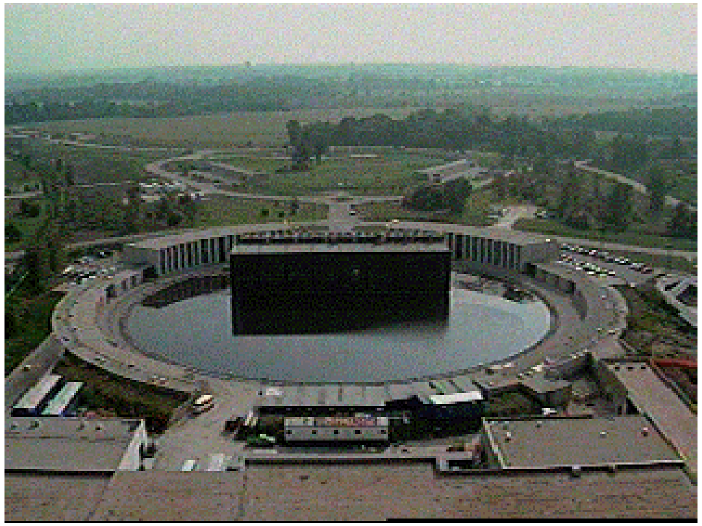
Scintillation

- Charged particles “scintillate”
  Molecules absorb and reemit light
- Scintillation light is
  - isotropic
  - delayed:
    emitted with characteristic lifetime
- Particles scintillate below C threshold
  - Same momentum but different mass
    Different ratios of C/Sci light.

Note: mineral oil is not doped



The Proton Beam:



The Fermilab Booster

- 8 GeV proton synchrotron
- Provides in 1.6 μsec "batch"
- Rate of 5 Hz to MiniBooNE beamline
- 9 x 10^{16} pph to beamline

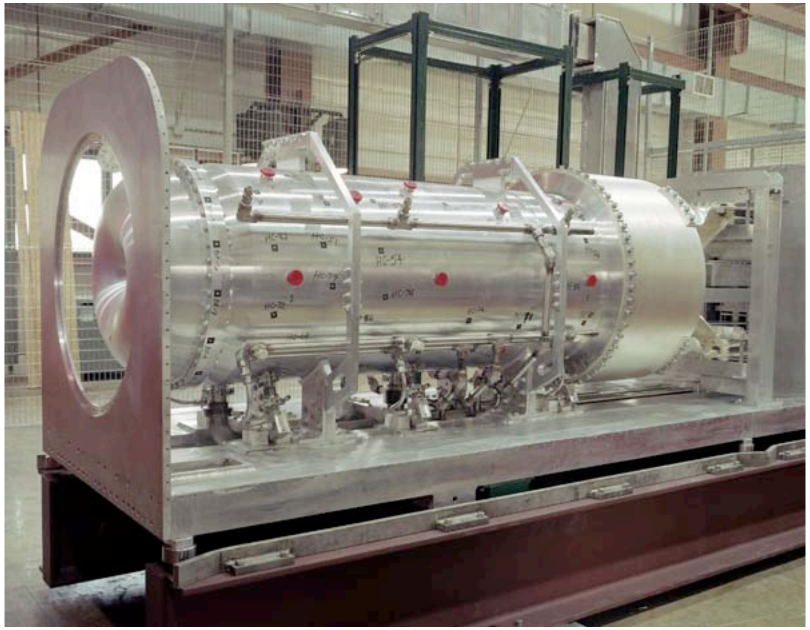
Typically at (3-4)x10^{16} pph, now (6-8) x 10^{16} pph

Neutrinos:

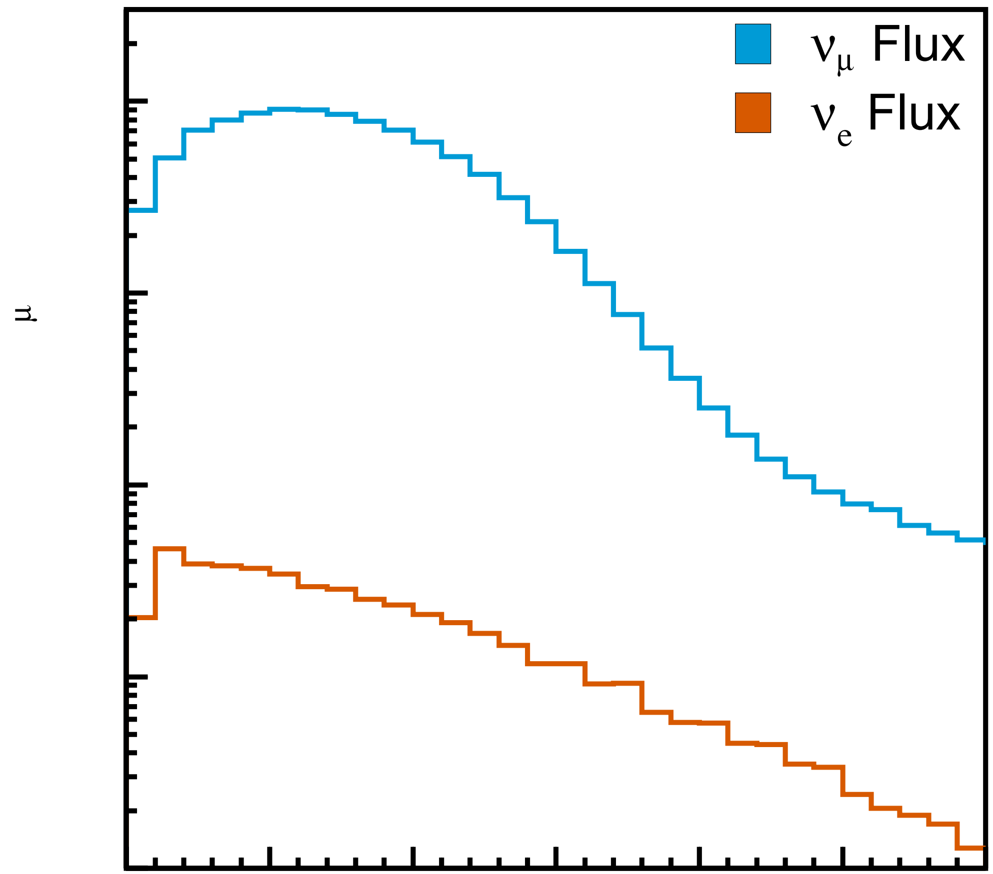
Protons incident on 71 cm Be target
produced in interactions

Positive secondaries focussed by horn

Decay in 50 m region:



The Neutrino Beam



Predicted energy spectrum

Predicted Neutrino Flux

- σ Pion production determined from global fit to data (includes E910)
- High purity beam
  - ~0.5% contamination from:
    - Kaons produced at target (K_{e3})
    - μ decays from pion decay
-

540 m baseline to detector

Neutrino Oscillations

- "Atmospheric": $\nu_\mu \to \nu_x$ disappearance
  Strong Evidence for oscillations:
  $$\Delta m^2 \sim 2.5 \times 10^{-3}\text{eV}^2,\ \sin^2 2\theta \sim 1$$
  Zenith angle distortion (Super-K, Kamiokande, IMB, MACRO)

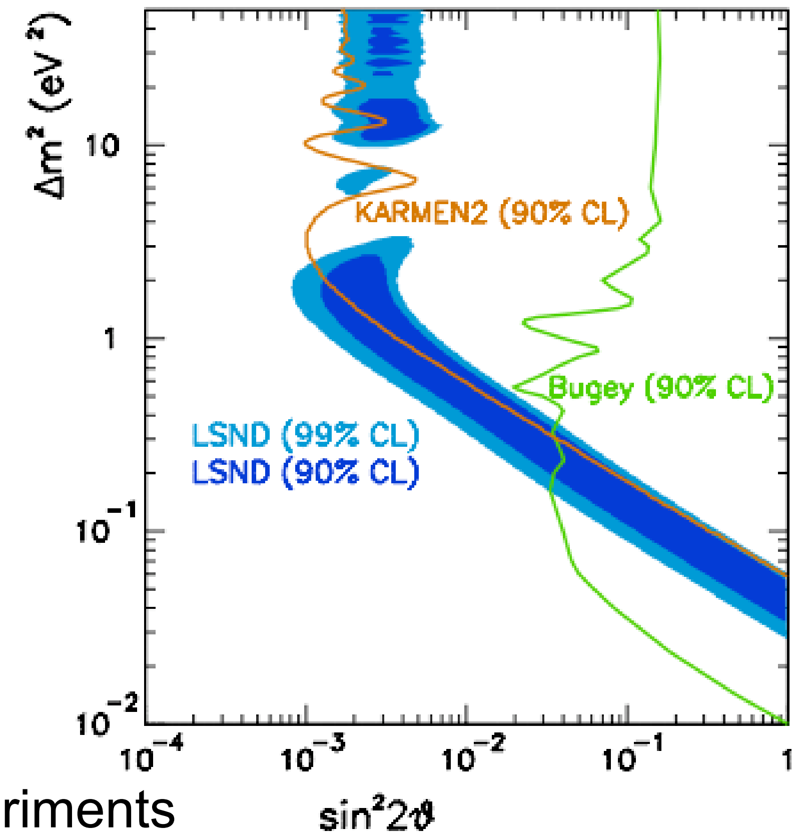
  Evidence in LBL accelerator neutrinos (K2K)

- "Solar": $\nu_e \to \nu_\alpha$ disappearance
  Strong evidence for neutrino oscillations:
  $$\Delta m^2 \sim 8 \times 10^{-5}\text{eV}^2,\ \tan^2\theta \sim 0.4$$
  Homestake, Super-Kamiokande, SNO (NC)

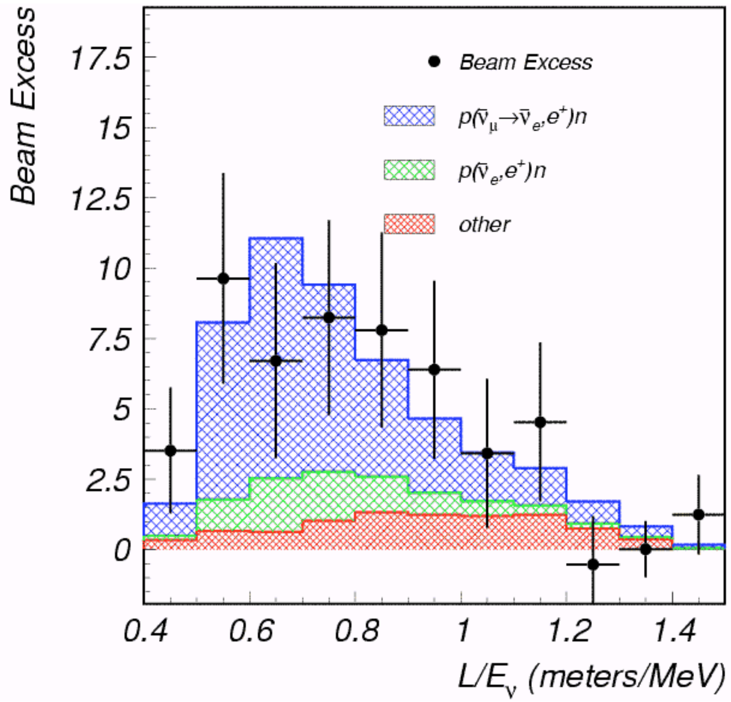
  Strong evidence from reactors (KamLAND)

- LSND: $\bar{\nu}_\mu \to \bar{\nu}_e$ appearance:
- $\Delta m^2 \sim (10^{-1} - 10^{1})\text{eV}^2,\ \sin^2 2\theta \sim 10^{-4} - 10^{-2}$

  Unconfirmed, but not excluded by other experiments



The LSND Signal:



Search for excess in beam

- Stopped pion beam produces pure
- Detect , via double coincidence
- Excess of events
- Oscillation probability: %

A challenge to the Standard Model:

Three active neutrinos cannot accommodate the observed oscillations

At least one interpertation of results is wrong, or

something in the Standard Model has to give

MiniBooNE: maximally sensitive to LSND

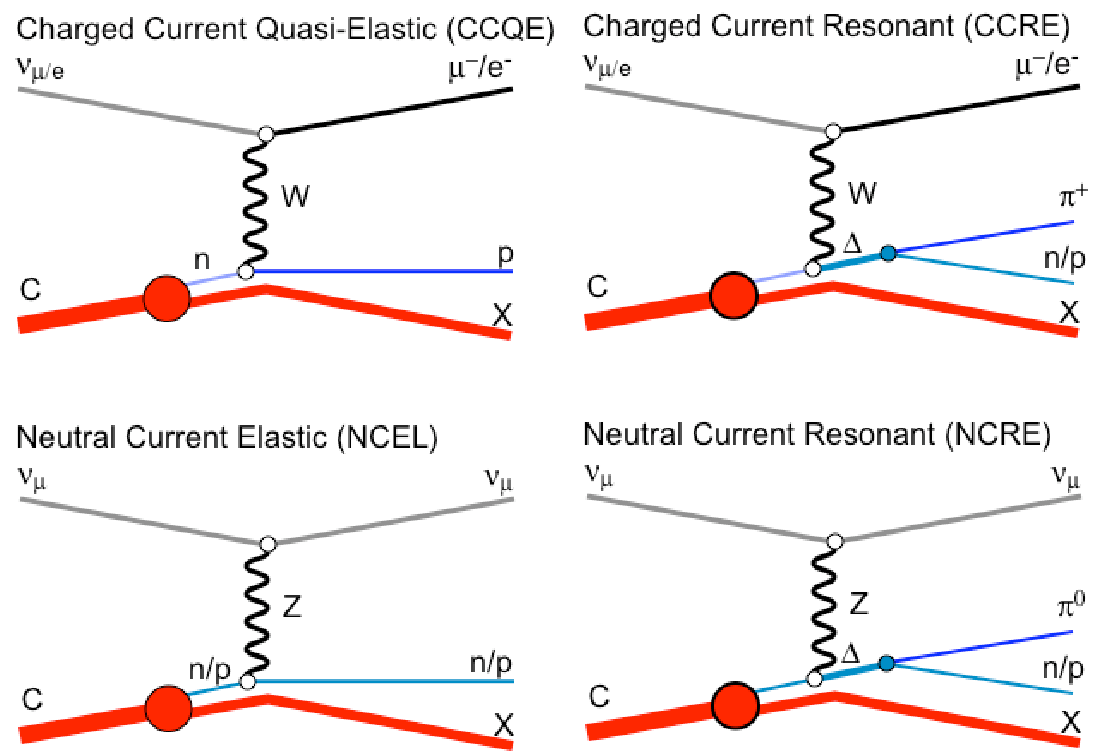
same L/E ~ (540 m/ 800 MeV) ~ 1 m/MeV

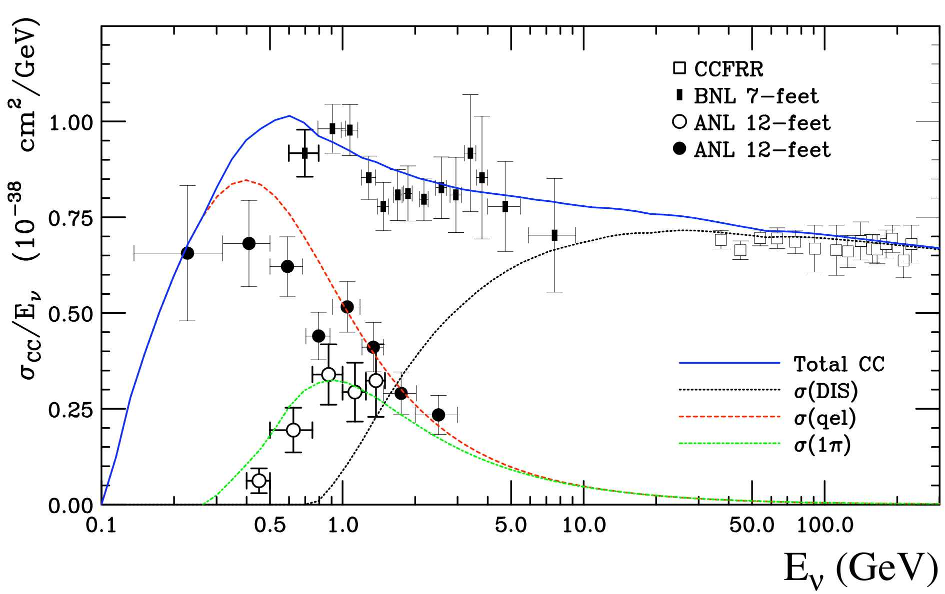
but searches for the same physics in a systematically different fashion

Neutrino Physics at 1 GeV

Primary Interactions:

- CC Quasi-Elastic (40%)
- NC Elastic (15%)
- CC Resonance (25%)
- NC Resonance (10%)





Other Interactions:

Multi pion production

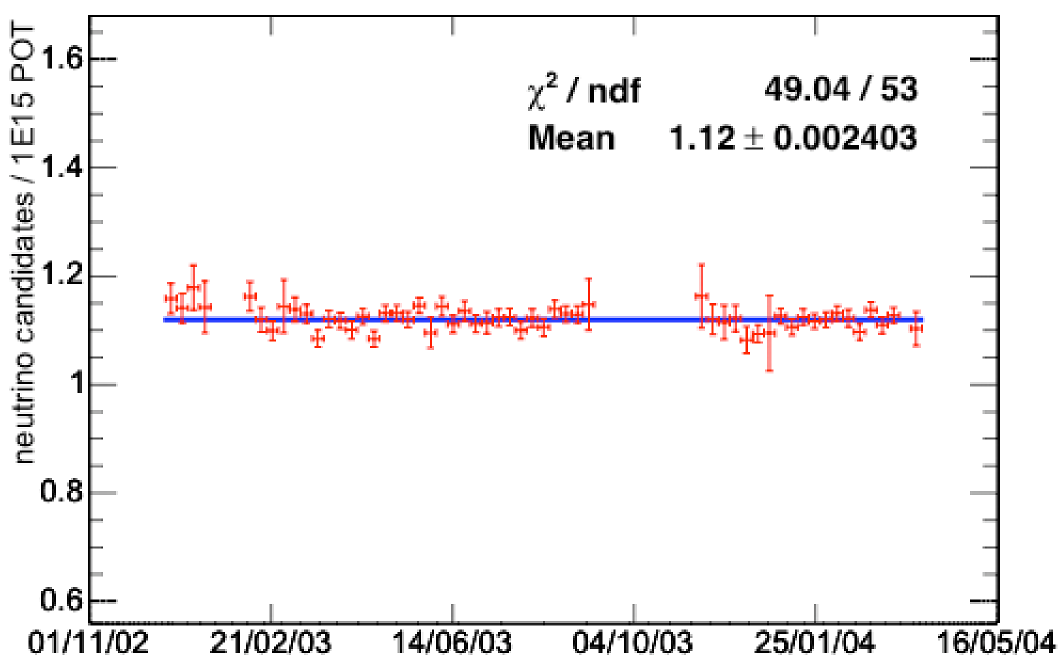
Deep-inelastic scattering

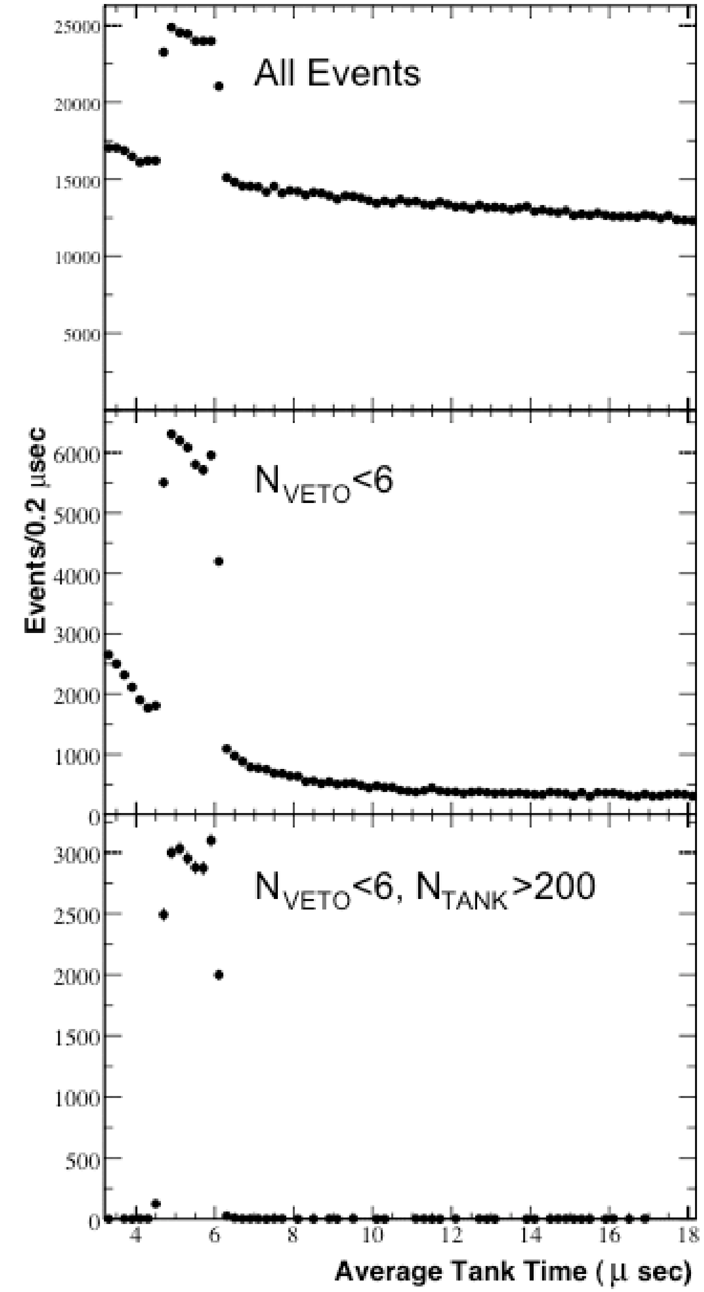
Coherent pion production

Beam Data: Cosmics

Beam arrives in 1.6 μsec window

- Clear beam excess without any selection
- N_{VETO}<6 eliminates cosmic muons
- N_{TANK}>200 eliminates Michel electrons (μ DAR)





3.2x10^{20} protons-on-target, 350K neutrino candidates

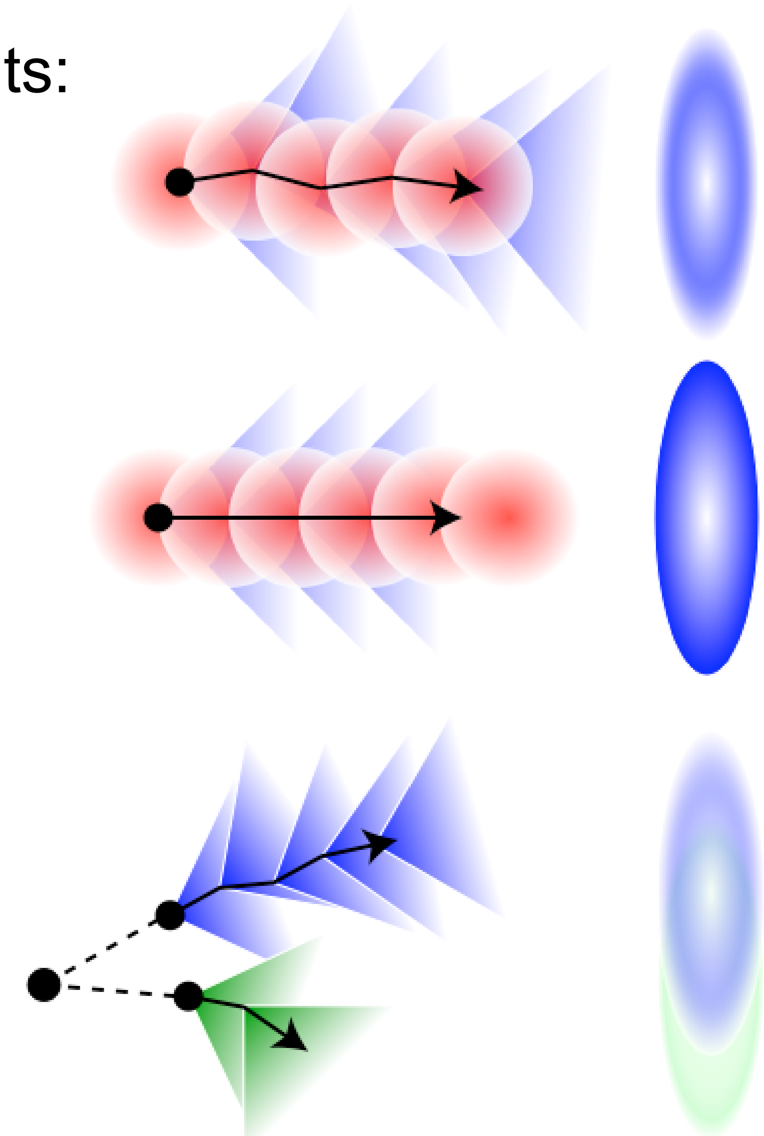
Searching for Oscillations:

Search for by looking for excess of CCQE events

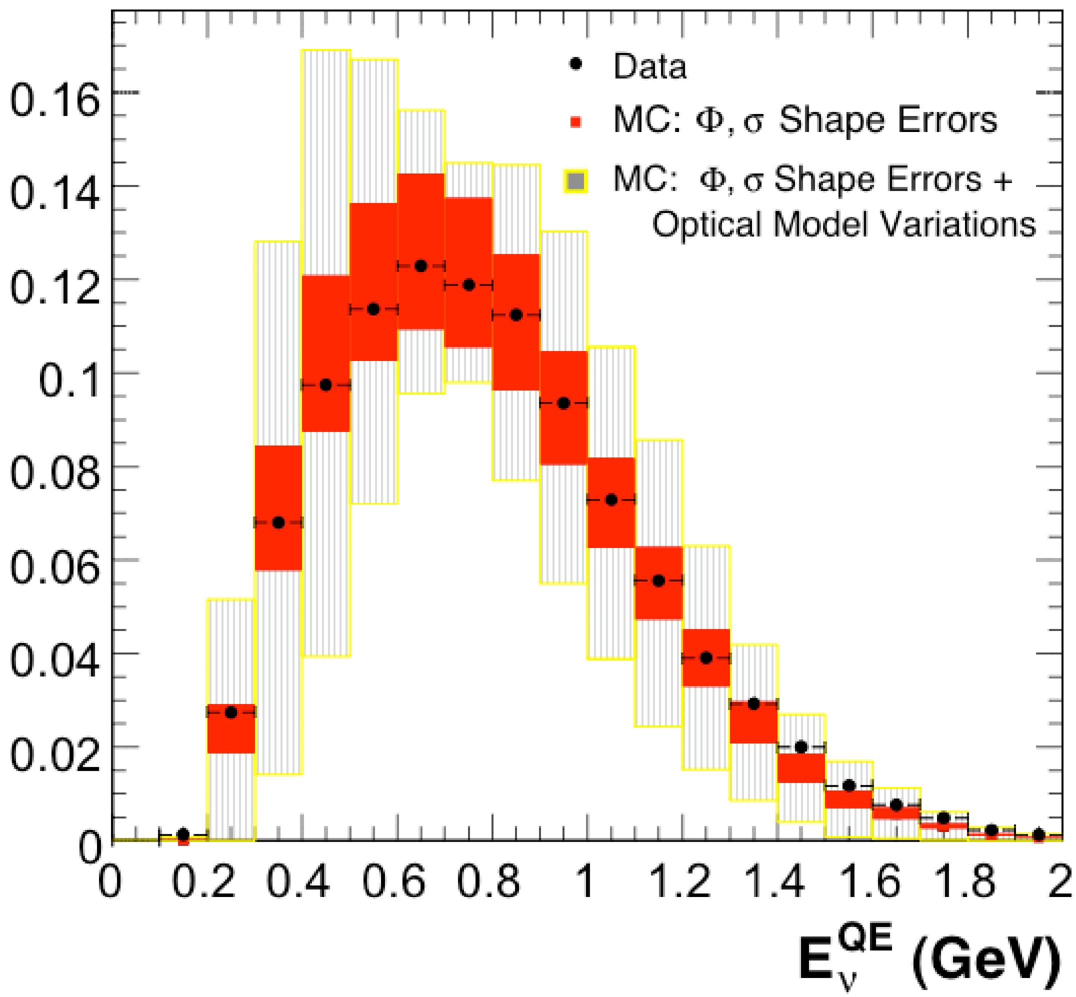
- Charged current quasi-elastic events:
  - Simple single ring topology
  - σ well-known cross sections
  - l Outgoing lepton tags neutrino flavor
- Backgrounds:
  - charged current events

    (large number of single ring events)
  - Neutral current production

    (gammas produce e-like rings)
  - Intrinsic in the beam



CC Quasi-Elastic Events



Selected based on:

- Ring profile
- Time profile of hits

88% purity

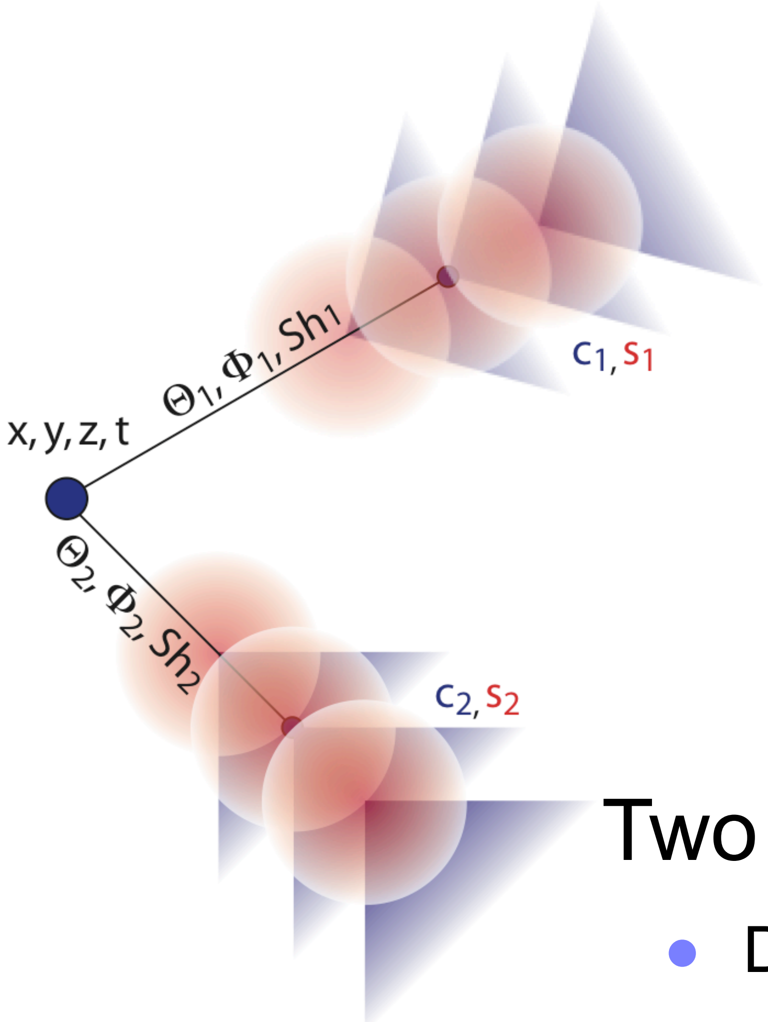
Neutrino energy based on

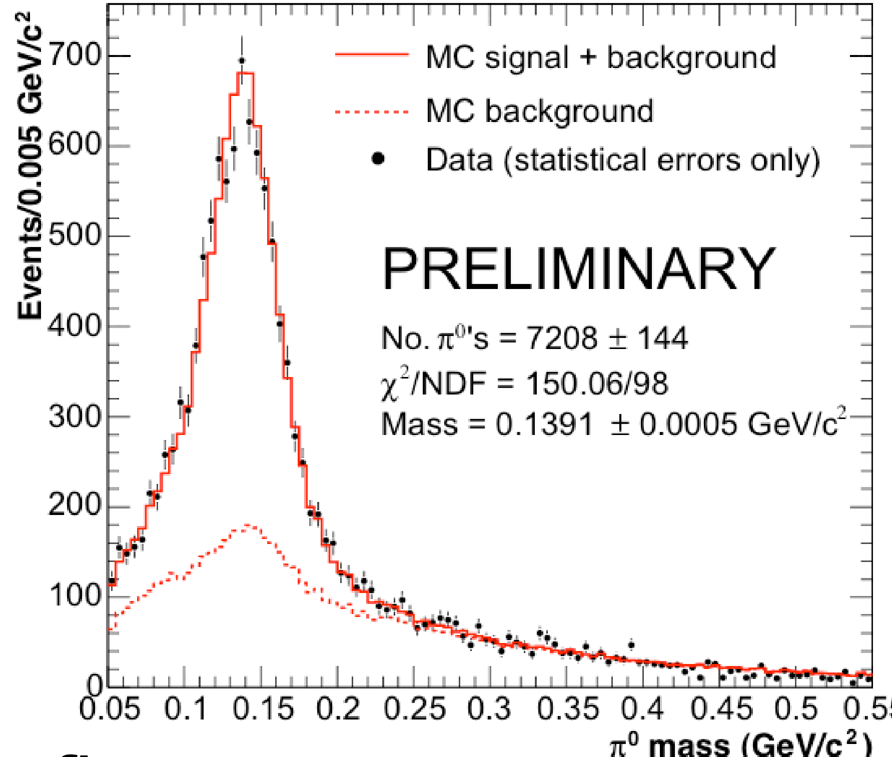
- Energy, angle of muon
- Two body kinematics

28K events selected

Compare predicted neutrino energy spectrum
CCQE process has abundant, well known rate

Neutral Current π^0 events





Two ring fit:

- Determine energy, direction of each ring
- Determine kinematics of decay

Dominant reducible background to oscillation search

Experimental Challenges

Background suppression

- Based on event topology
  - Ring/spatial profile
  - Time profile (prompt versus delayed)
- Requires excellent understanding of:
  - σ Cross sections of signal and background processes
  - Detector behavior (mineral oil and PMT behavior)

The neutrino beam:

- K Background from intrinisic (irreducible)
- π Spectrum to evaluate oscillation profile

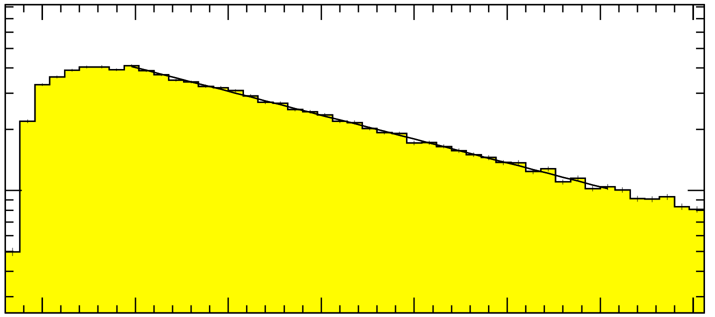
Need excellent understanding of target particle production and flux

Measure ex-situ with in-situ crosschecks

Mineral Oil Properties

Two production mechanisms:

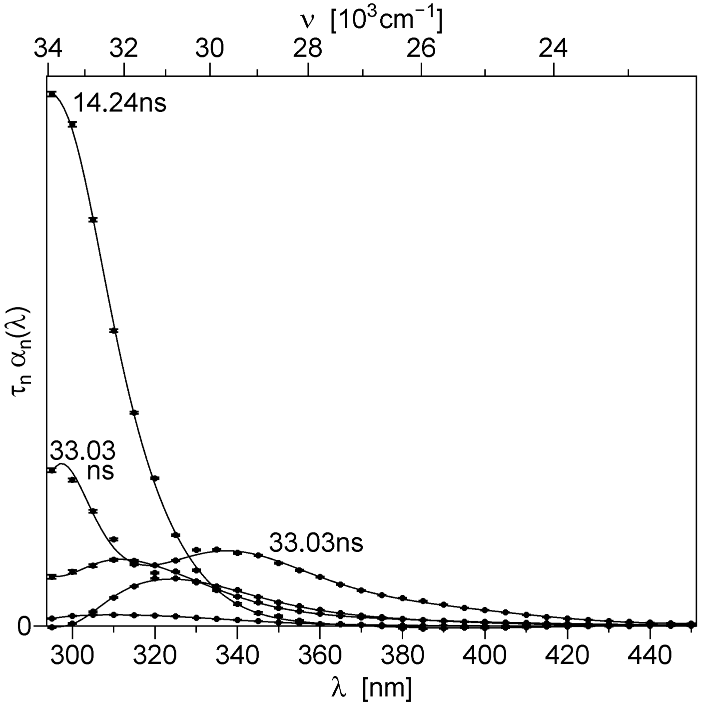
- Cherenkov radiation
- Scintillation:
  - IUCF measurement of time and rate
  - Spectrum measurement in progress



IUCF scintillation lifetime measurement

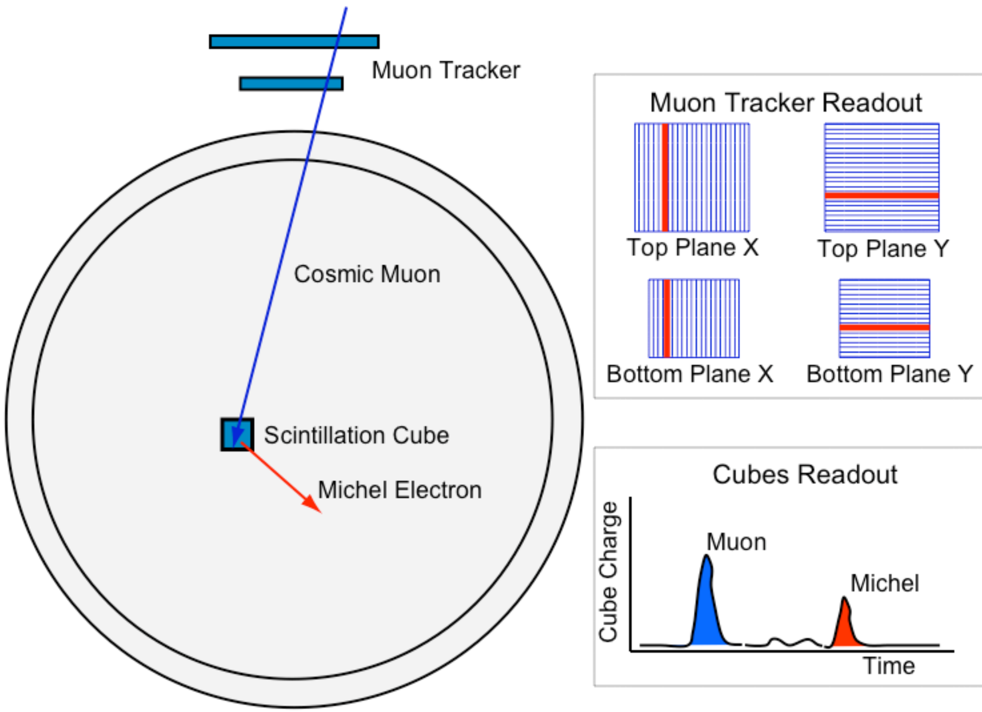
Processes in Propagation

- Scattering (primarily Rayleigh):
  - Goniometer: angle and rate
  - Fluorimeter: rate and Raman scattering
- Fluorescence:
  - Time-resolved measurements
  - Excitation and emission from fluorimeter
- Attenuation/Extinction
  - Transmission measurements (1 cm-1 m)



JHU time-resolved fluoroscopy

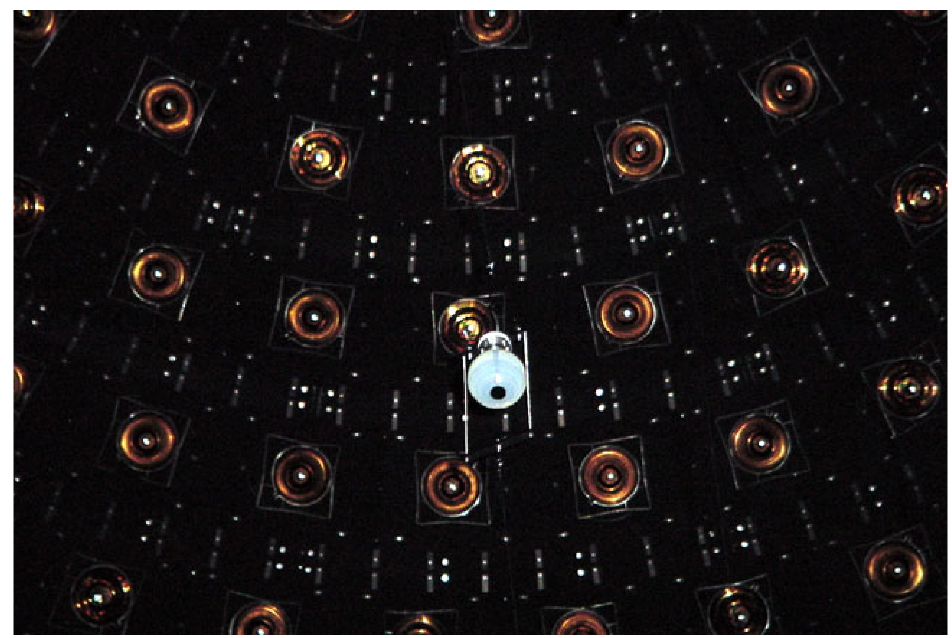
Detector Calibration Systems



Tracker/Cube System

- Scintillator hodoscope
- Seven scintillator cubes at various depths

Muons with well known pathlength



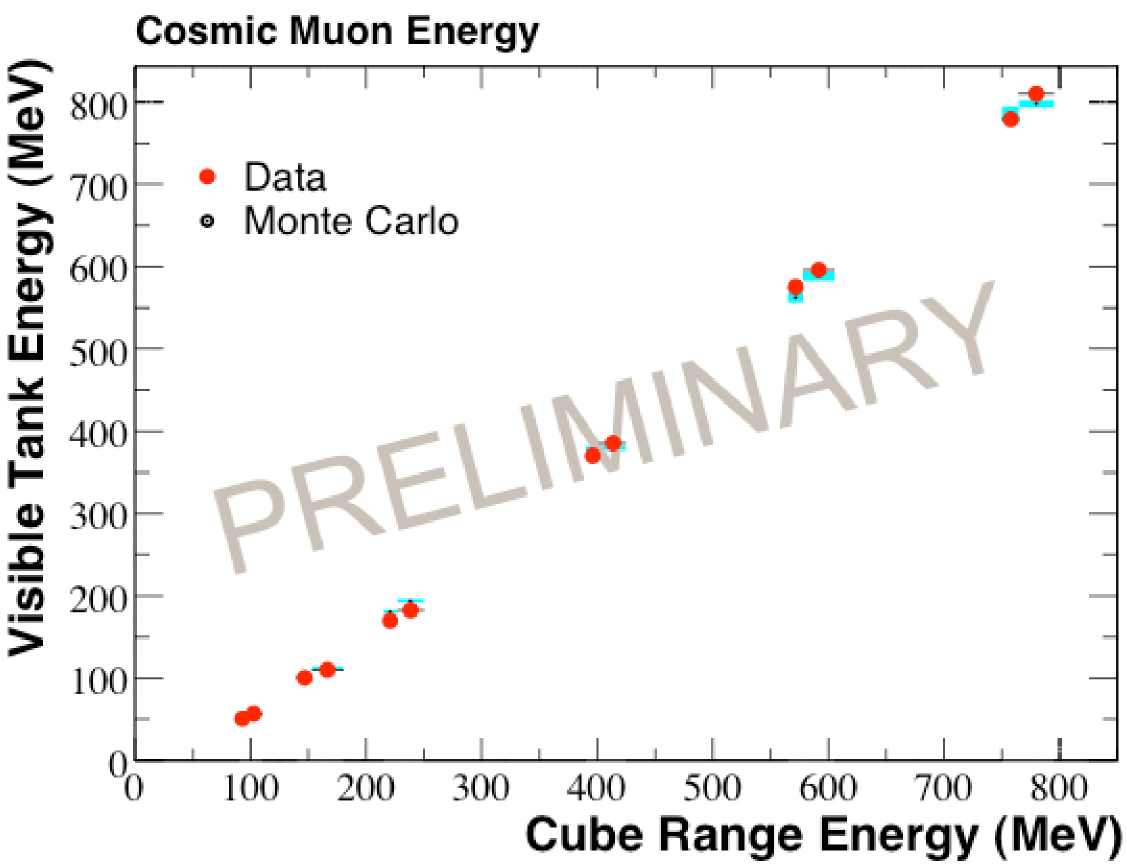
Laser Flask System:

397 and 438 nm pulsed lasers

4 Ludox flasks scatter light

1 bare fiber (collimated light)

Energy Scale:



Tracker/Cube reconstructed muons

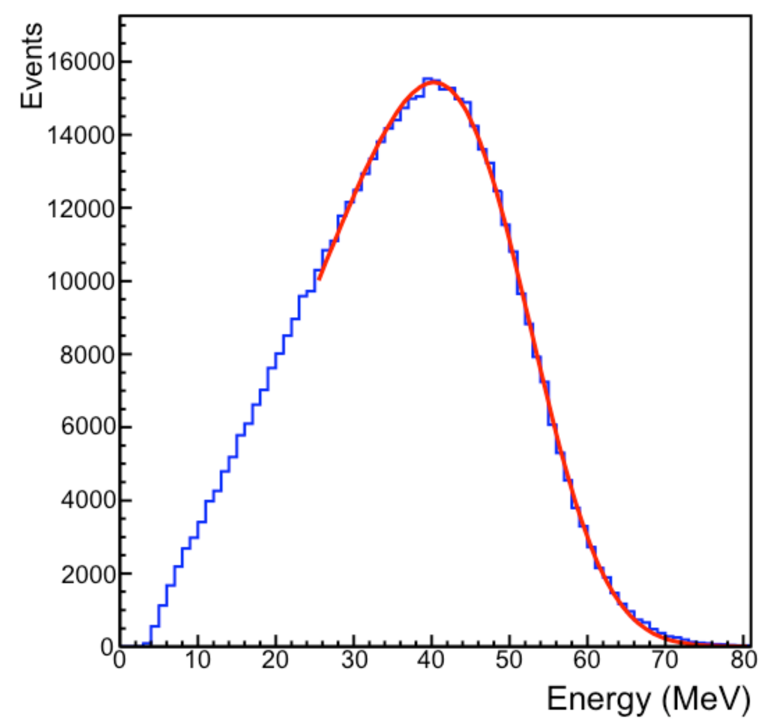
- Energy estimate from pathlength and dE/dx
- Compared with reconstructed energy

Michel electrons:

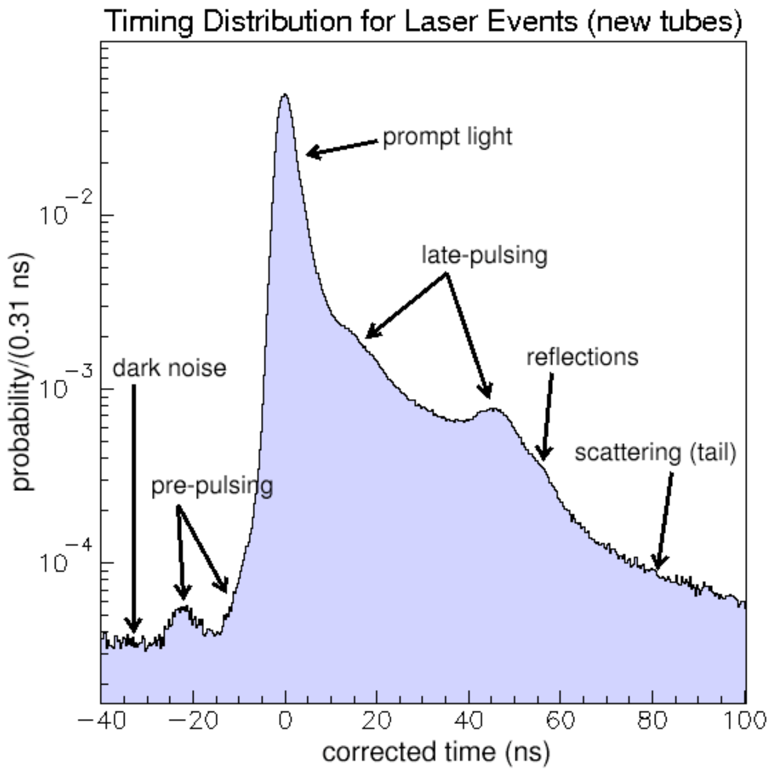
Decay of stopped muons

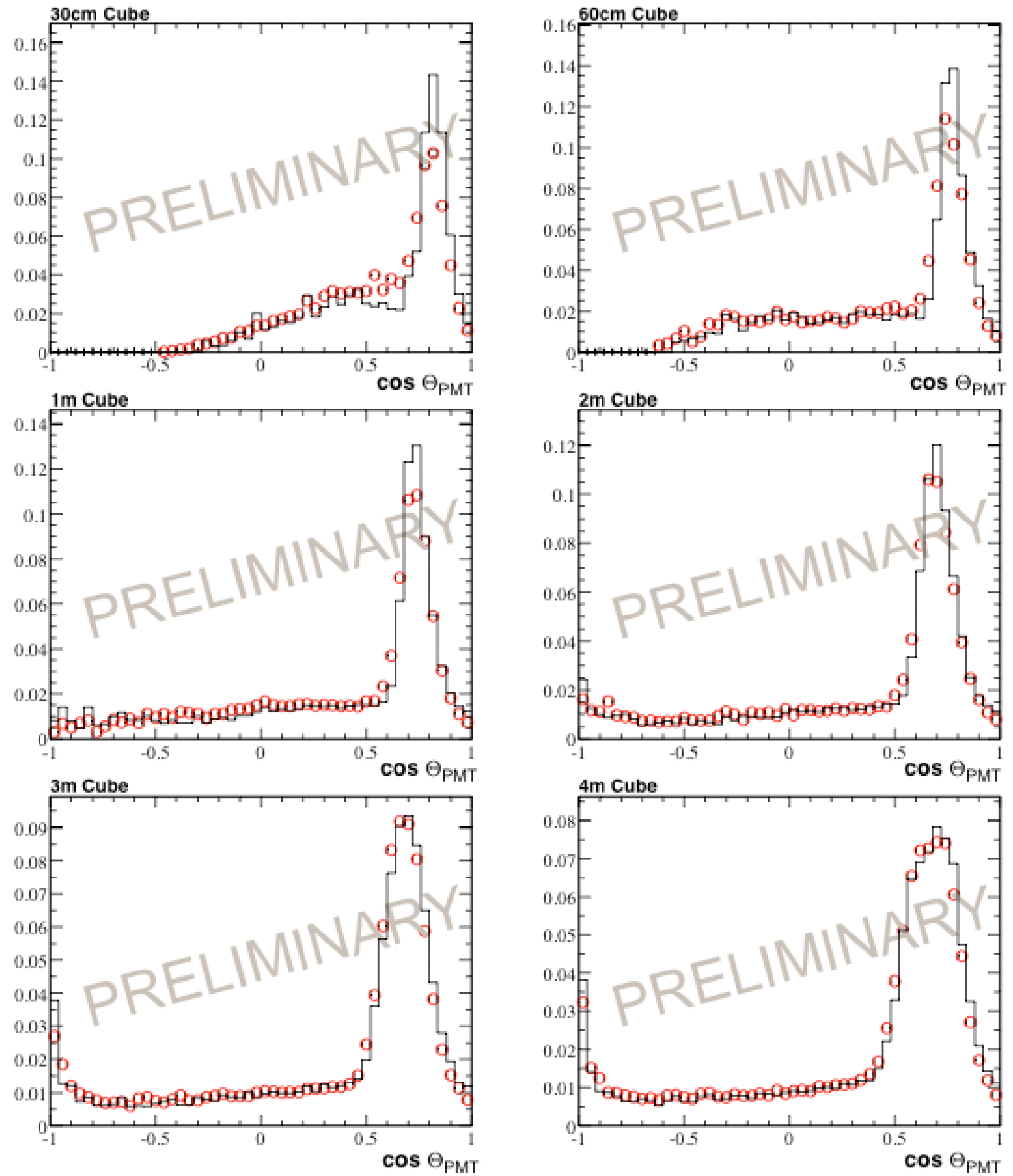
Well-defined energy spectrum

Reconstructed energy compared with theory and resolution model



Space/Time Distribution





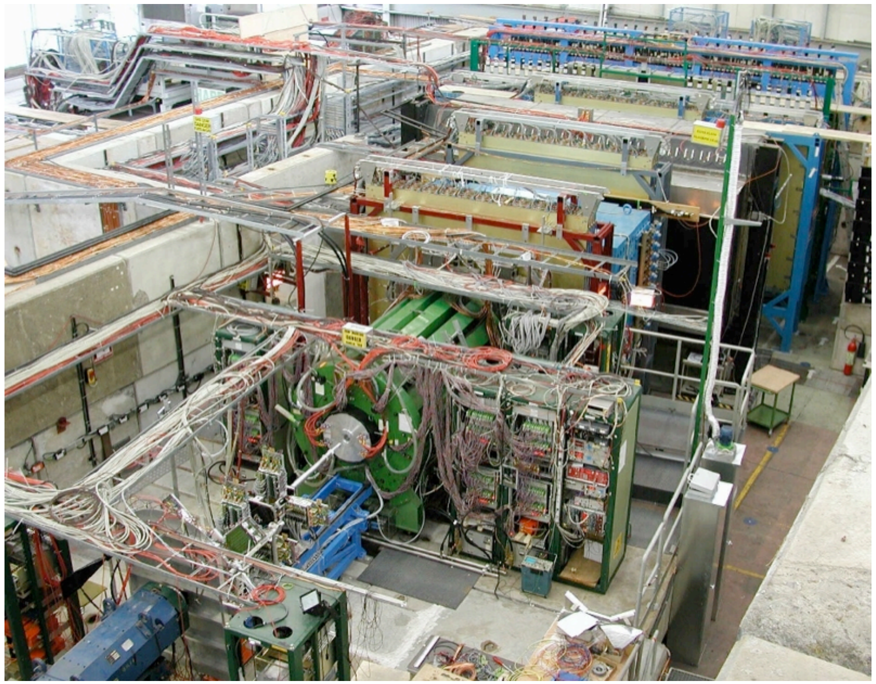
Laser data:

- Scattering and PMT response from time profile

Tracker/Cube Muons:

- Scintillation/Fluorescence from time and angular distribution

HARP: Secondary Particle Production



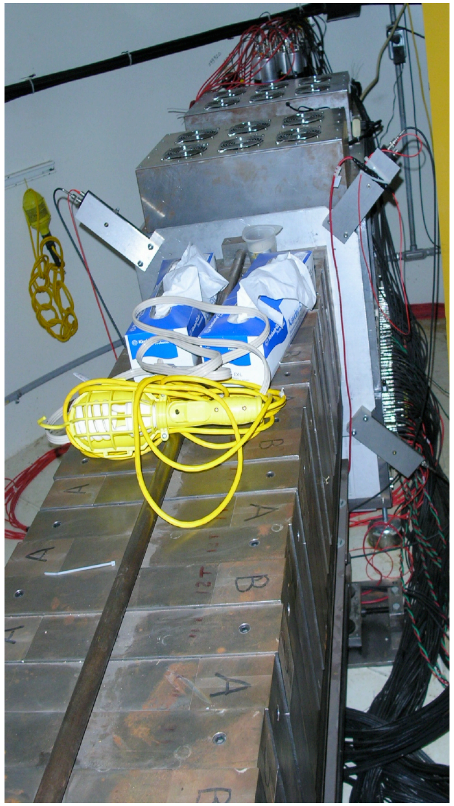
Dedicated Measurement:

- 8 GeV protons on Be
  - Replica targets
    0.1, 0.5 and 1 interaction length
- Tracking (TPC, Drift Chambers)
  Particle ID (TOF and Cherenkov)

Precision Pion and Kaon production measurement

- Spectrum and rate of incident neutrino flux
- Backgrounds from intrinsic (Kaon decay)

The Little Muon Counter (LMC)

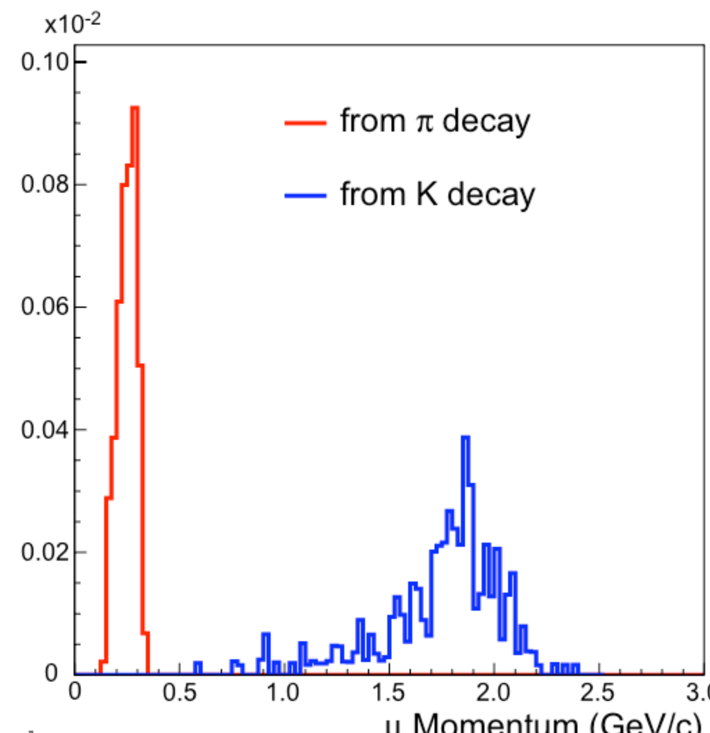


Decay Region Monitor:

- Wide angle (7°), high *p* (2 GeV/c) muons
- Kaon decays in the decay pipe.

Detector:

- Collimator to select angle range
- Fiber tracker/magnet
- Range stack



Detector installed:

Analysis in progress

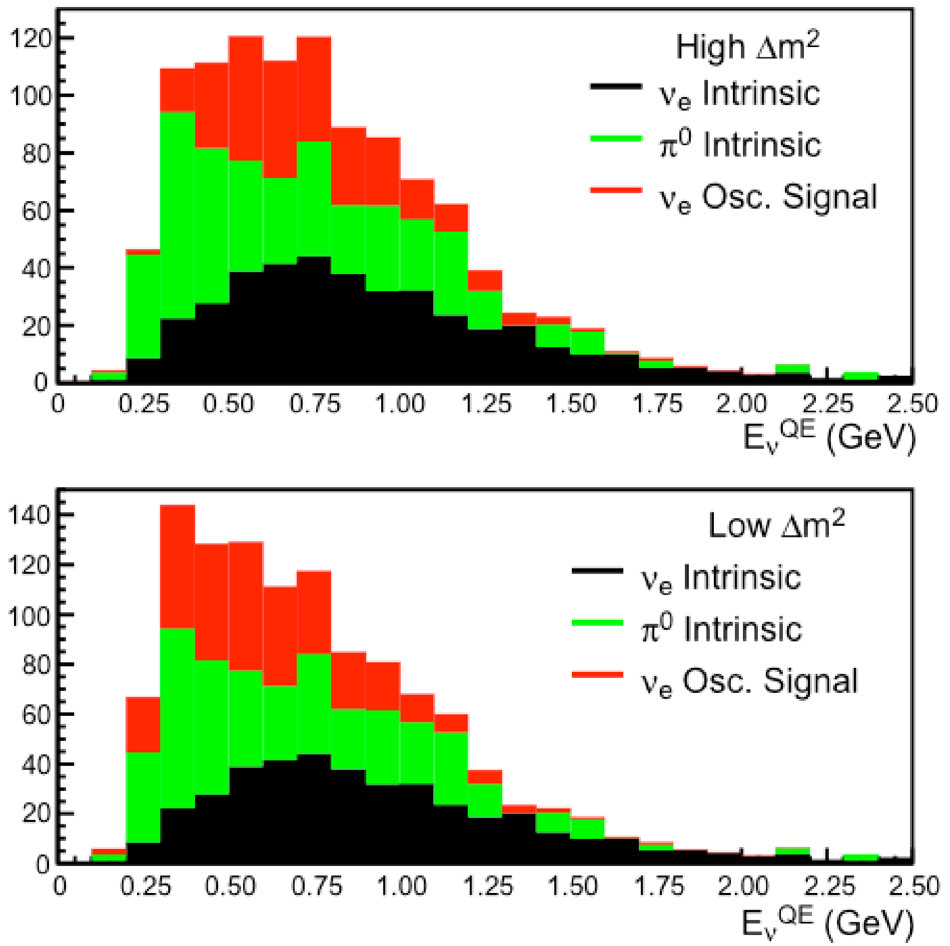
Expected Signal/Backgrounds

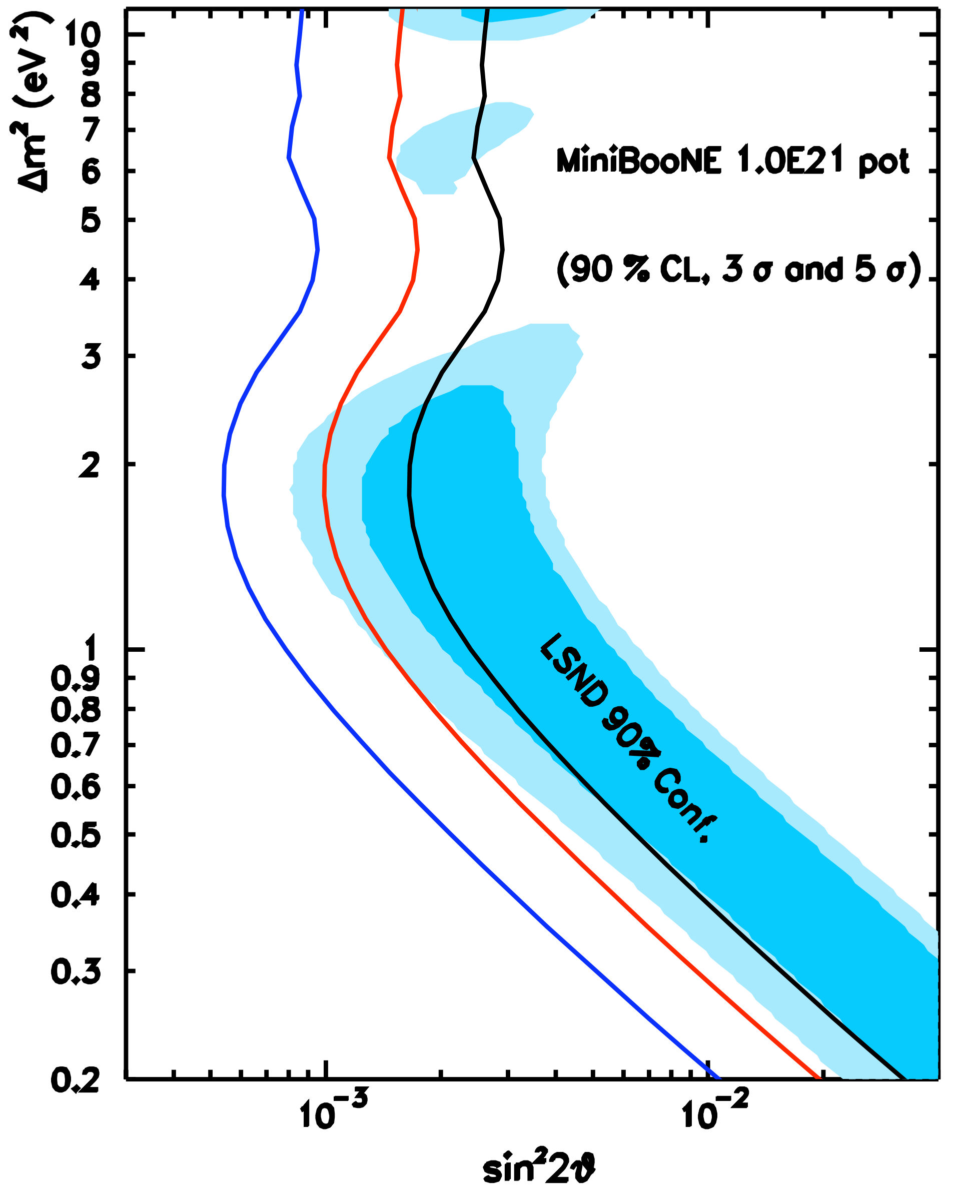
Process	All Events	After Selection
CC quasi-elastic	553,000	8
NC	110,000	290
Radiative decay	1,080	80
Intrinsic	2,500	350
Oscillation Signal	1,500	300
Signal/Background		300/780=0.38

For 10^{21} protons-on-target

NC π^0 is dominant reducible background

Sensitivity

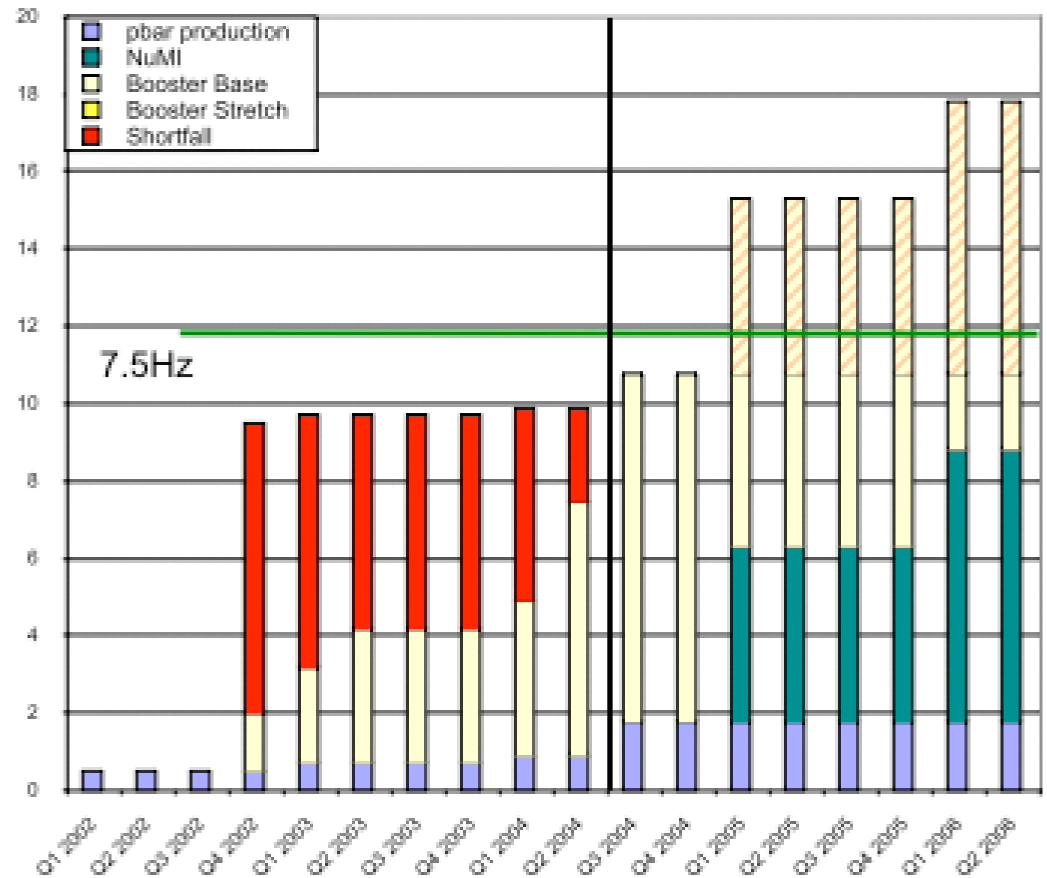




Sensitivity for 10^{21} protons-on-target

Expect 4.5×10^{20} protons by end of 2004

Booster Performance



Recent Progress:

- Collimator in use
- Other improvements kicking in
- Peak of >8.0x10^{16} pph to MiniBooNE (~90% design)

Booster output now exceeds initial NuMI + stacking demand

- Protons to MiniBoonE after 2005

Summary

MiniBooNE:

Confirm/refute LSND evidence for neutrino oscillations

- ! Confirmation would have dramatic implications for neutrino physics

Accumulated 3.2×10^{20} pot

- 350K neutrino interactions
- Detector/reconstruction functioning well
- Beamline functioning well (>80 million horn pulses)

Current Activities

- Systematic studies to improve understanding of beam/detector
- σ Broad range of cross section studies (see talk)
- Accumulating data: Booster approaching design intensity