MiniBooNE

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LSND Result

- **LSND Result:**

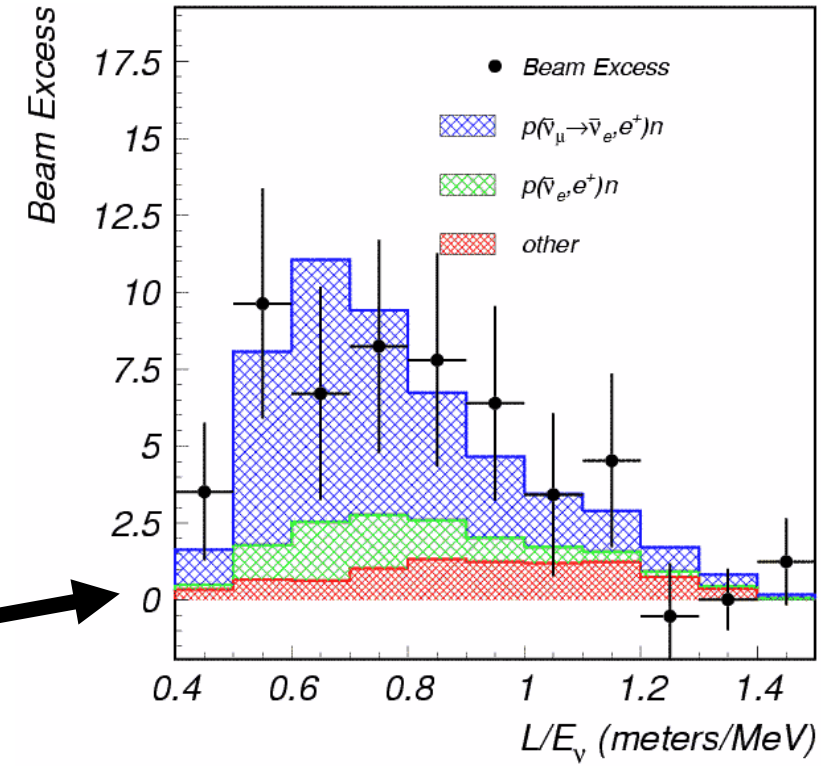
$$87.9 \pm 22.4 \pm 6.0 \ \overline{\nu}_e \text{ candidate excess } (3.8\sigma)$$

- **If interpreted in terms of oscillations:**

$$\langle P(\overline{\nu}_\mu \rightarrow \overline{\nu}_e) \rangle = (0.264 \pm 0.067 \pm 0.045)\%$$

- **L/E distribution of the excess agrees well with oscillation hypothesis:**

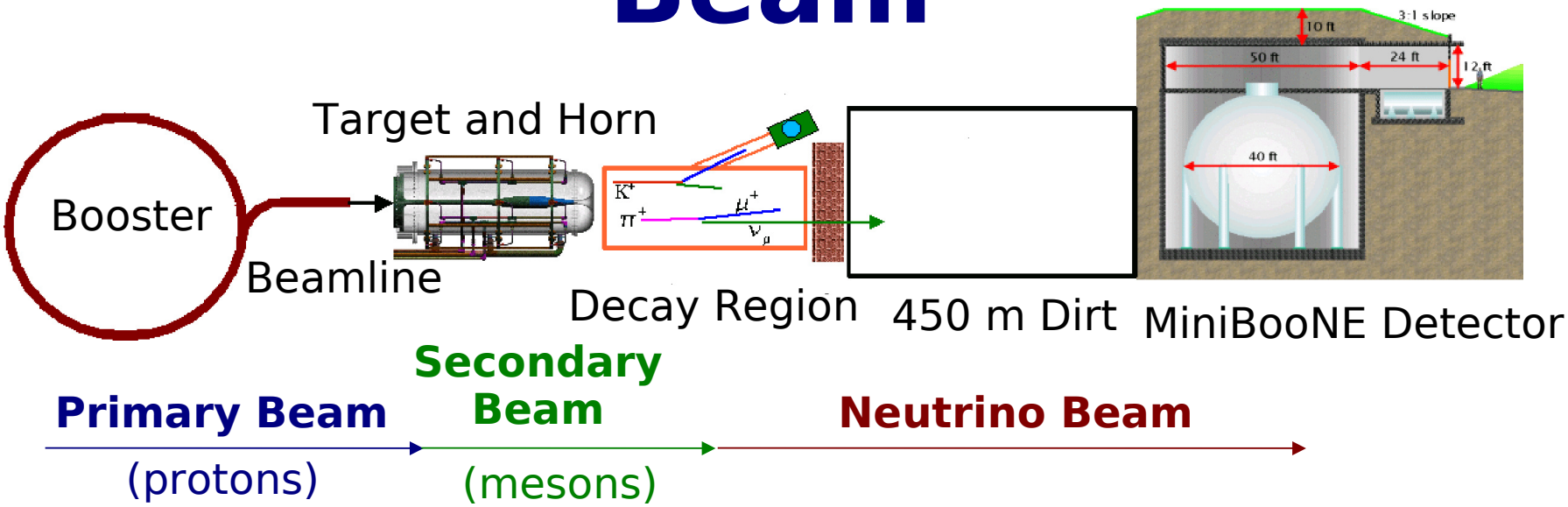
  - Backgrounds in **red**, **green**
  - Fit to oscillation signal in **blue**



MiniBooNE goal: confirm or refute the LSND evidence in a **definitive** and **independent** way, with

- Different systematics
- Higher statistics

Beam

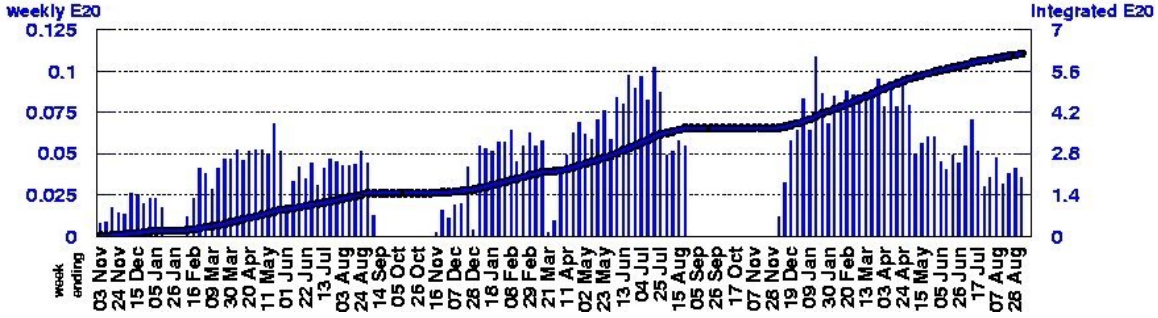


Primary Beam: 8 GeV protons from Booster, $8 \cdot 10^{-6}$ duty factor

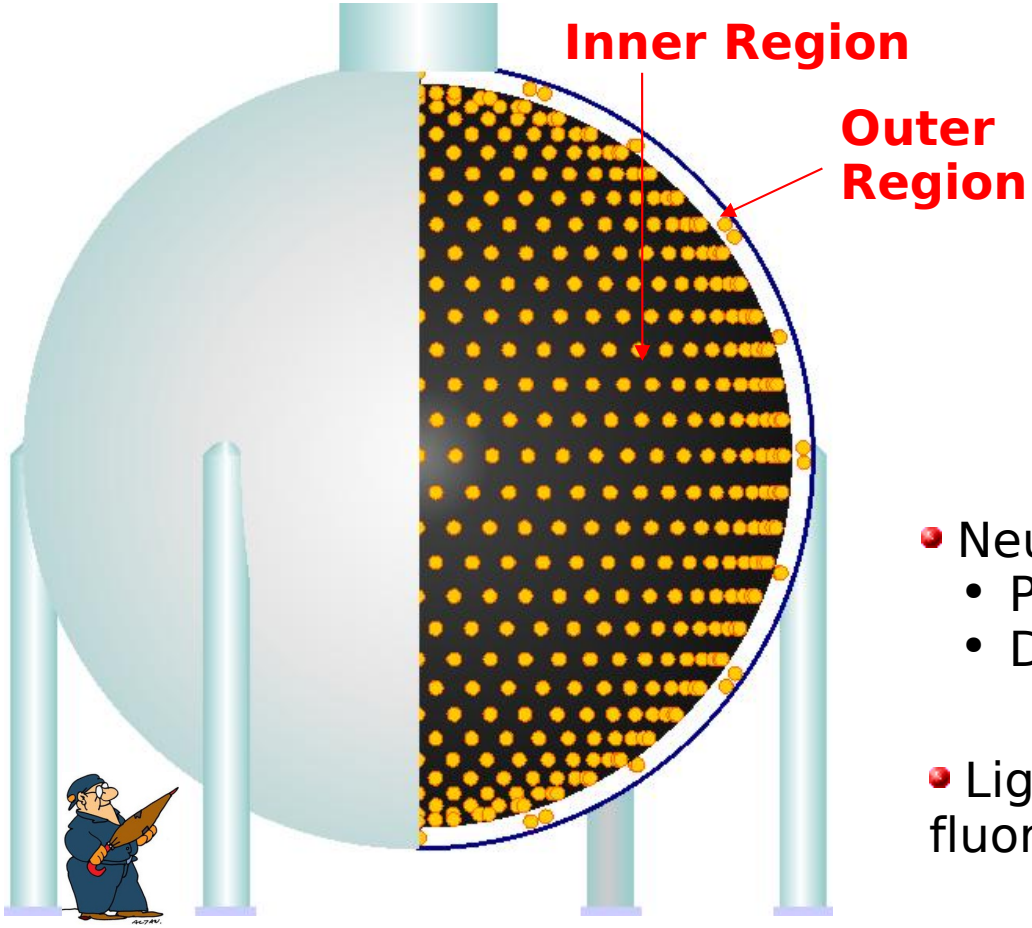
Secondary Beam: mesons are produced from protons striking Be target, focused by horn, and monitored by "Little Muon Counters" (LMC)

Neutrino Beam: neutrinos from meson decay in 50m pipe, pass through 450m of dirt (and oscillate?) to reach MiniBooNE detector

Number of accumulated protons on target: $6.2 \cdot 10^{20}$



Detector

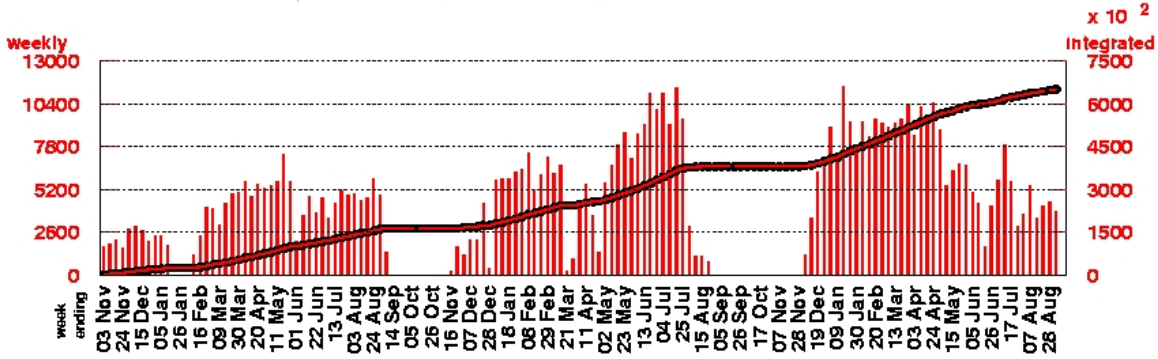


- 12 m in diameter sphere filled with 800 t of undoped mineral oil
- Light tight inner region with 1280, 20 cm diam., PMTs (10% coverage)
- 240 PMTs in veto region (>99.9% veto efficiency)

- Neutrino interactions in oil produce:
  - Prompt, ring-distributed, Cerenkov light
  - Delayed, isotropic, scintillation light

- Light transmission affected by: fluorescence, scattering, absorption

Number of accumulated neutrino interactions: $6.5 \cdot 10^5$

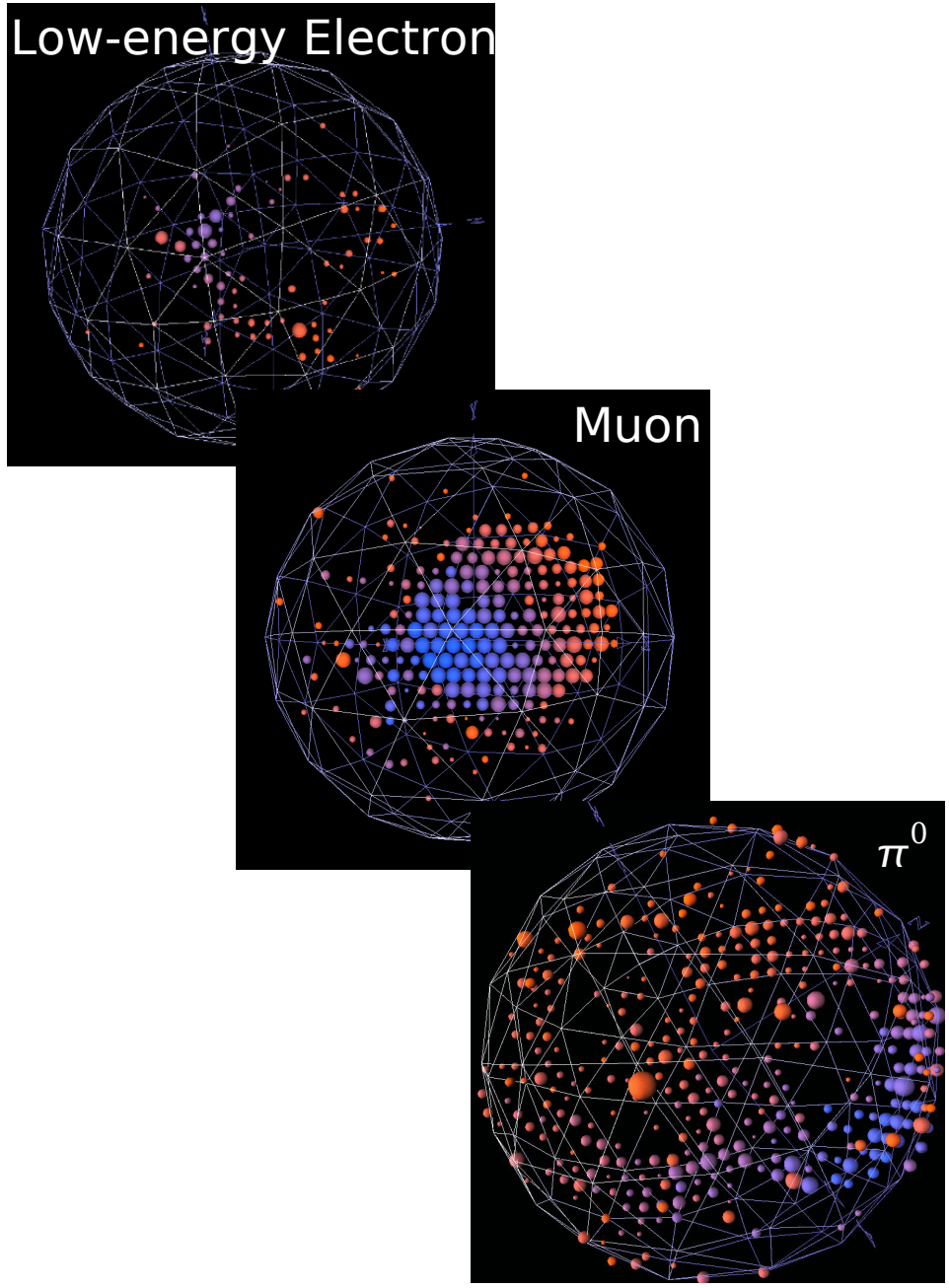


Reconstruction and PID

- **Measure photoelectrons from optical photons reaching the PMT surface:**
  - Total charge
  - Spatial distribution
  - Time distribution

- **Event Reconstruction:**
  - Correlated electrons from muon decays
  - Neutrino interaction vertex
  - Direction, spatial extent, and energy of Cerenkov tracks
  - Separate amounts of Cerenkov and scintillation light
  - For CCQE, full event kinematics: neutrino energy, Q^2, etc.

- **Particle ID:** distinguish $e/\mu/\pi^0$



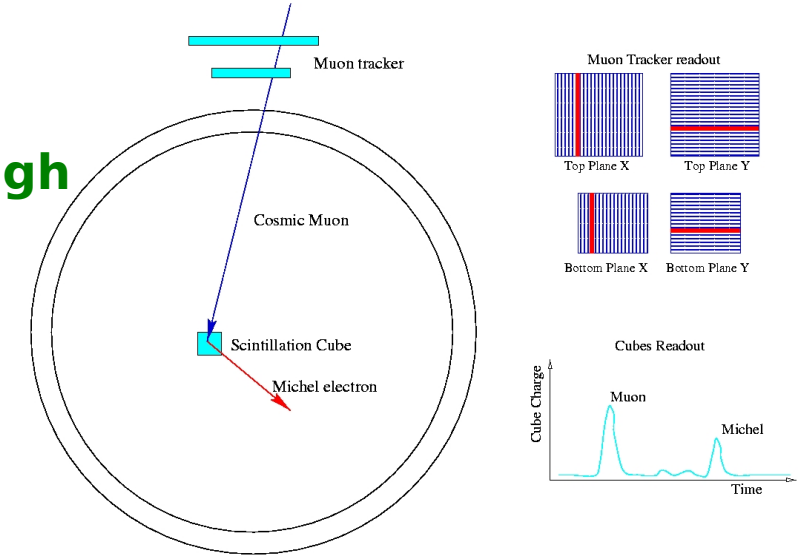
Calibration Samples

Laser calibration sample: prompt, isotropic light source

- PMT hit reconstruction: PMT time/charge resolution, pre/afterpulsing
- Oil optical properties: absorption, surface reflections, scattering

Muon calibration sample: cosmic rays through tracker, and stopping in scintillation cubes

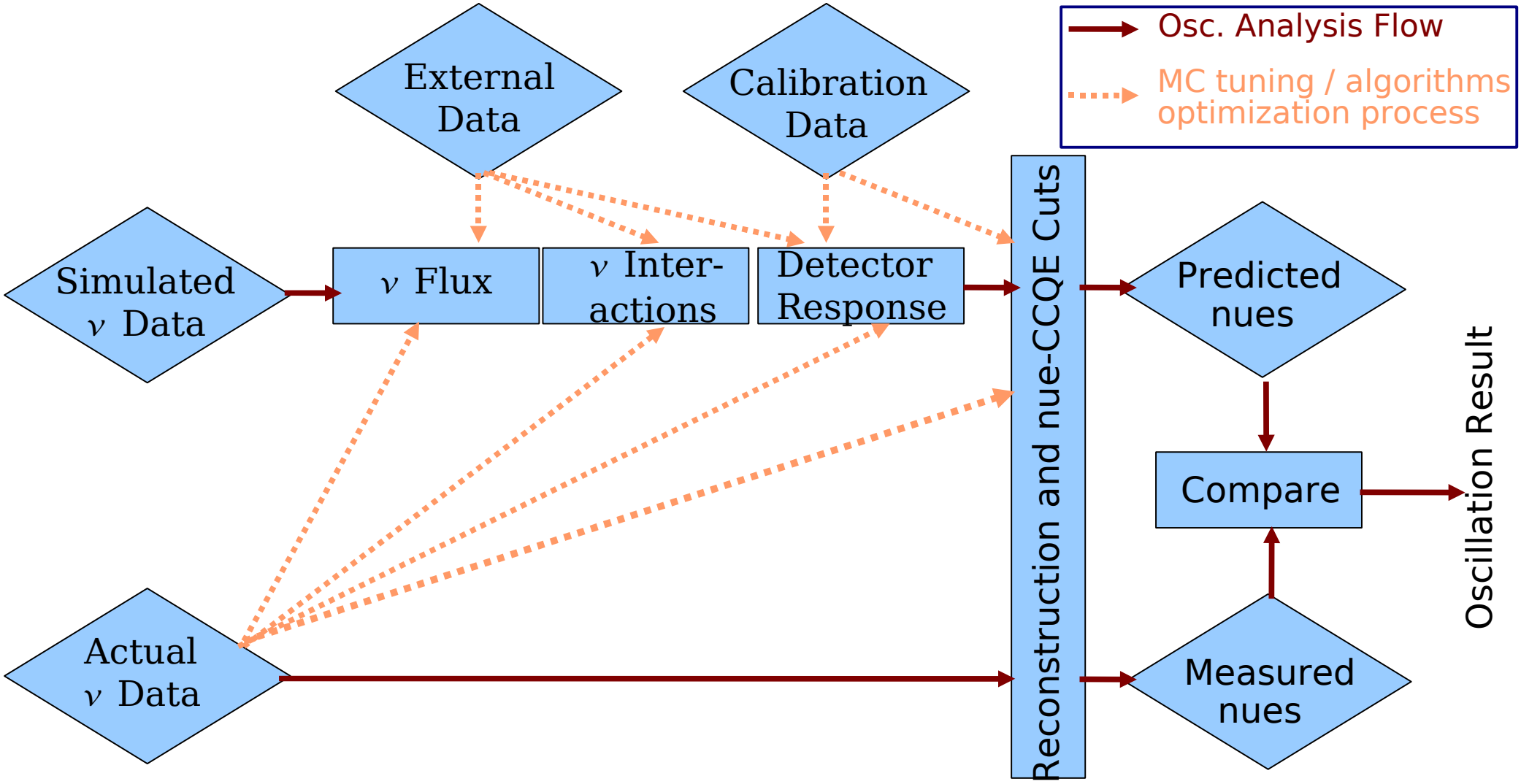
- Muons of known direction, decay vertex, pathlength, deposited energy up to 700 MeV



Electron calibration sample: Michel electrons from muon decays at rest

- Known energy spectrum between 0 and 52.3 MeV
- Energy reconstruction accuracy at 52.3 MeV: 14% ⇒ fix energy scale

Muon-to-Electron Neutrino Oscillation Analysis



Will now give a flavour of ongoing MC tuning / algorithms optimization process, necessary for oscillation results

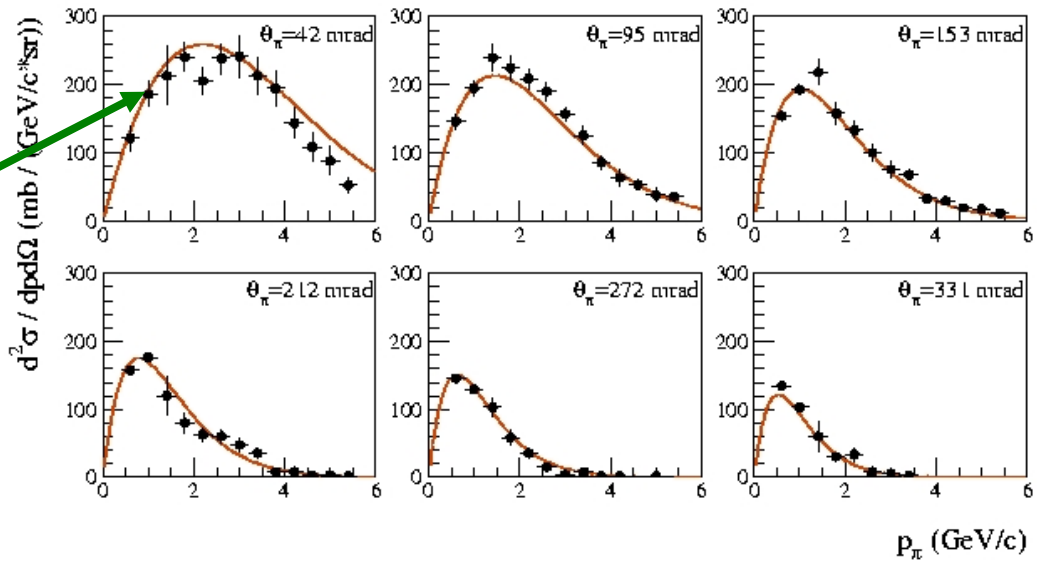
Neutrino Flux

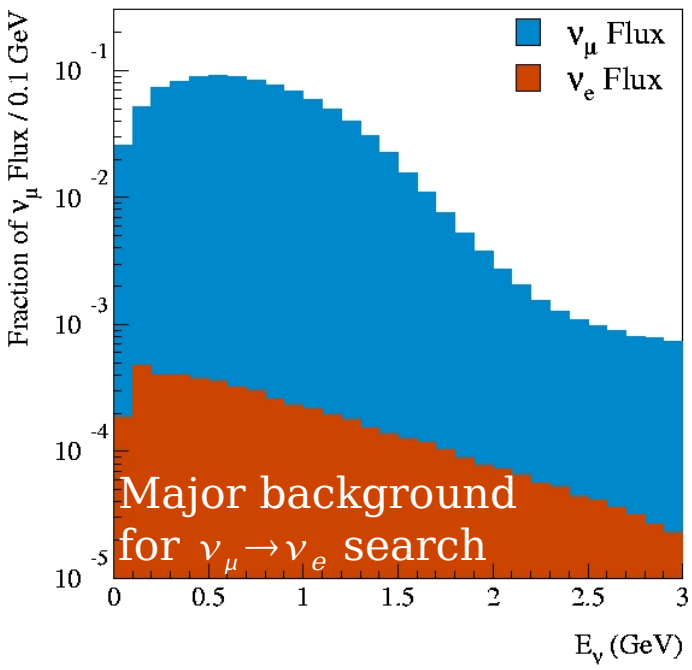
- **Tool is GEANT4 description of the beamline, simulating:**
  - Primary protons, geometry, materials and horn B-field
  - Interactions, focusing, decays of baryons, mesons, muons

- Pion/kaon production data on beryllium is the most important external physics input to the simulation

BNL E910 pion production data at 12.3 GeV/c

CERN HARP pion production data to be used soon! See A. Guglielmi's talk, this session



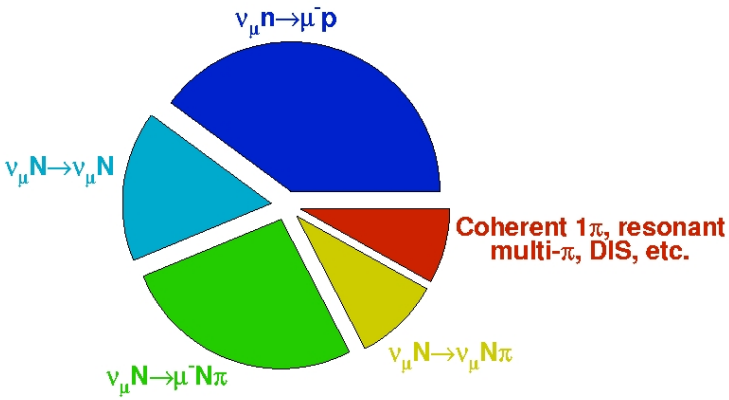


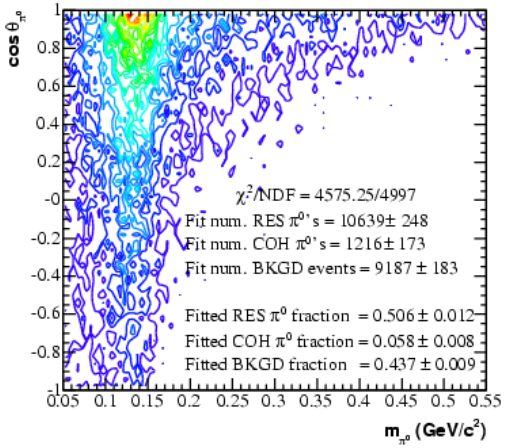
- Overall muon neutrino flux normalization, and electron neutrino flux component from muon decay, tuned on MiniBooNE CCQE neutrino data

- Electron neutrino flux component from kaon decay will be tuned on MiniBooNE LMC monitoring data and high-energy CCQE neutrino data

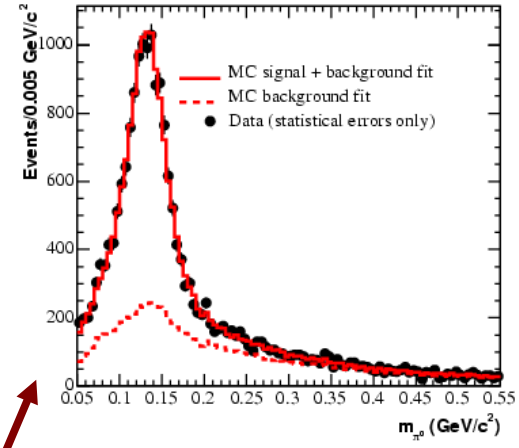
Neutrino Interactions

- **Tool is NUANCE cross-section generator**, simulating all relevant elastic, resonant, and coherent neutrino processes, including detailed treatment of Carbon nuclear effects:





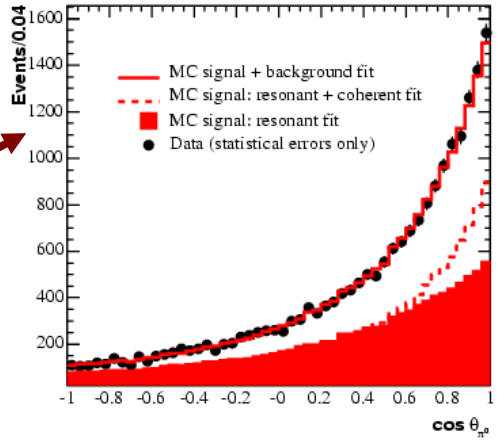
- **External constraints used in the simulation:**
  - Free nucleon cross-sections from neutrino data
  - Nuclear model from electron data
  - Final state interactions from pion/proton scattering data



- Major background for oscillation search:

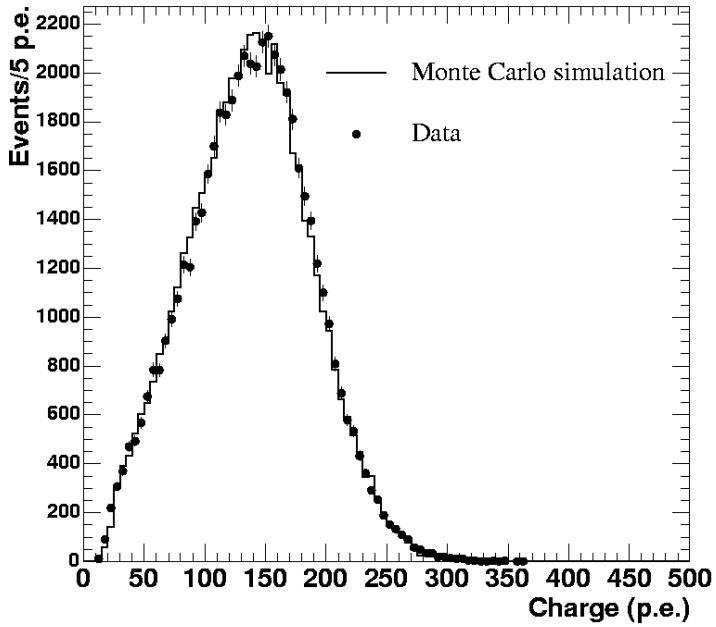
NCPi0 events where Pi0 is misidentified as electron

- Resonant and coherent NCPi0 cross-sections will be tuned on the MiniBooNE NCPi0 data sample

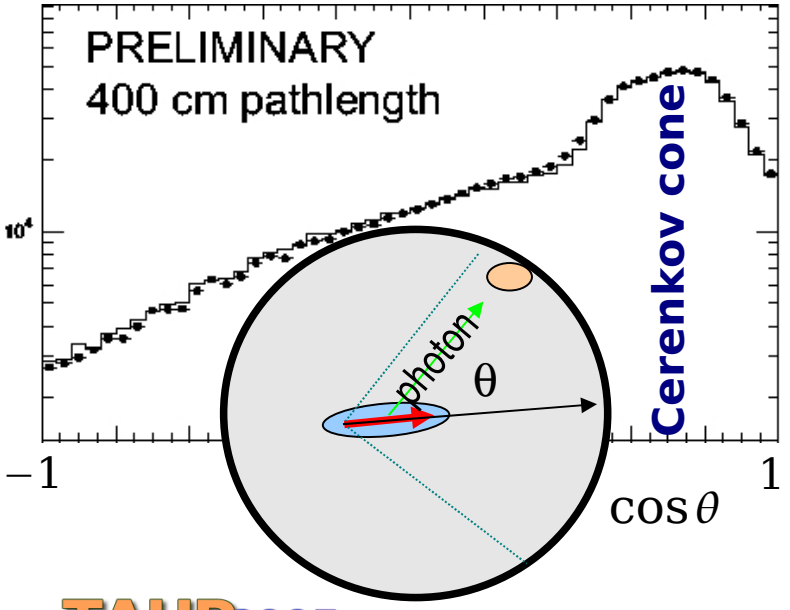


Detector Response

- **Tool is GEANT3 description of the detector and calibration devices, with detailed simulation of:**
  - Optical model: light production and transmission mechanisms in MiniBooNE mineral oil
  - PMT charge/time response



- **Tabletop measurements constraining critical optical model parameters:**
  - Time-resolved fluorescence
  - Rayleigh/Raman scattering
  - Light attenuation .vs. wavelength



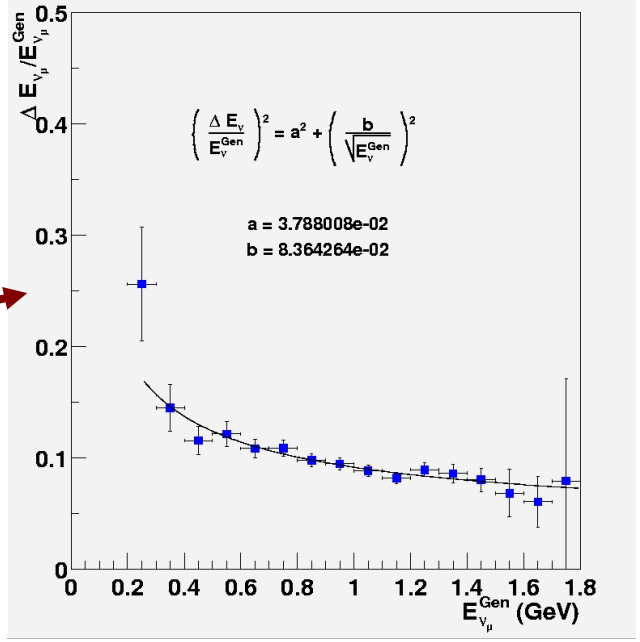
- **Overall tuning accomplished with MiniBooNE calibration data:**
  - Total PMT charge distribution, for Michel electrons from muon decays at rest
  - Angular distribution of detected light, for cosmic ray muons of known direction

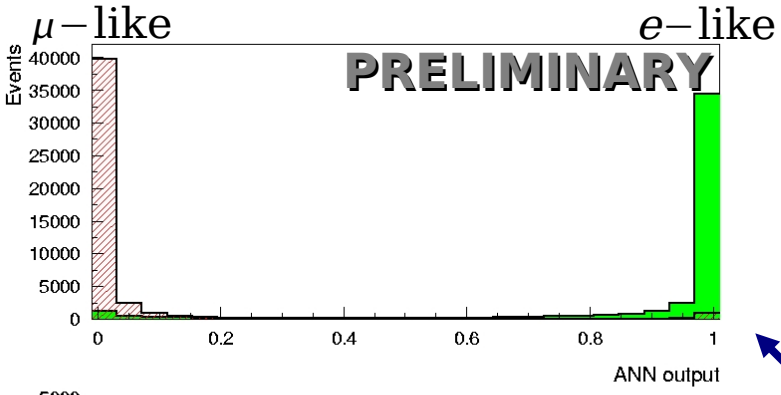
Reconstruction and PID

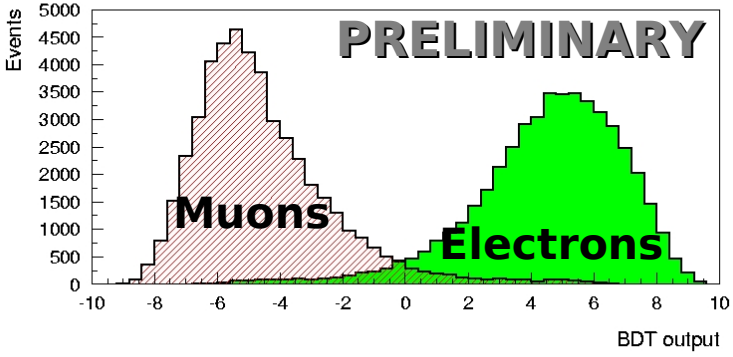
- Various algorithms (MLL, ANN, BDT) used to optimize reconstruction/PID, to achieve good:
  - **Reconstruction accuracy**
  - **Robustness**
  - **Efficiency of PID separation**

- **Reconstruction accuracy example:**

~10% resolution on neutrino energy reconstruction, **predicted** for muon neutrino CCQE interactions, for algorithm chosen for oscillation analysis





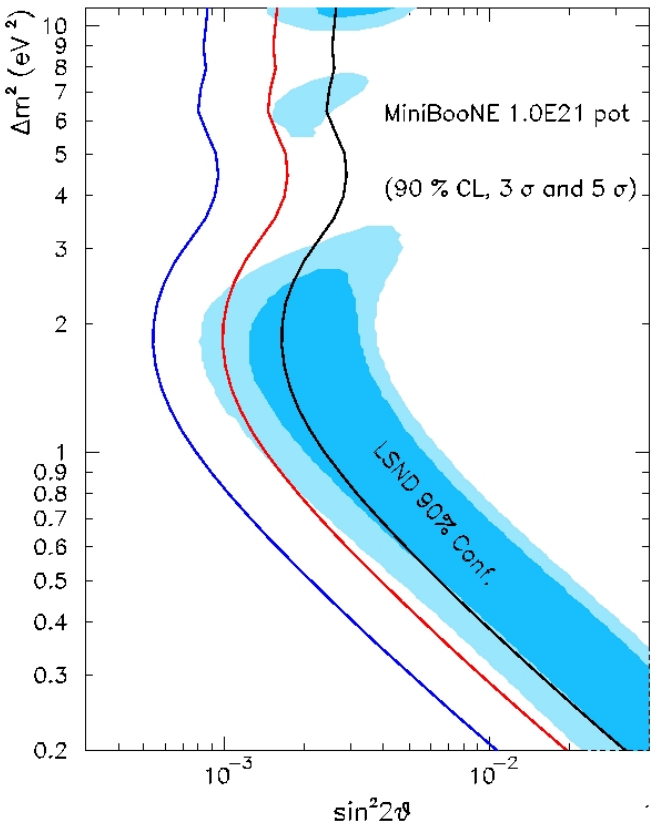


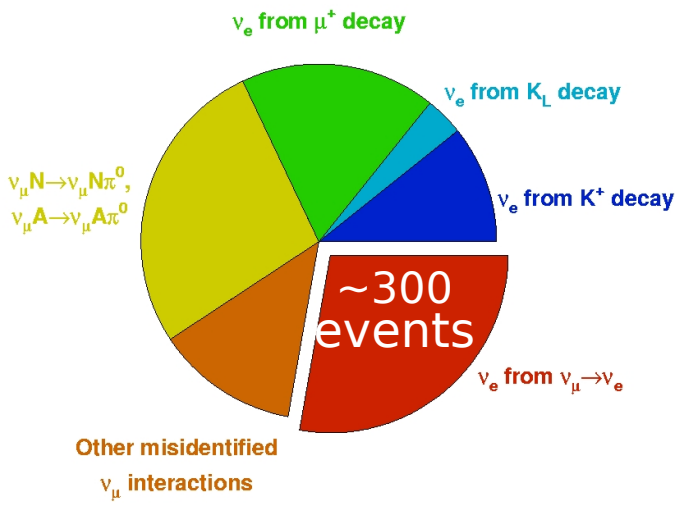
- **Efficiency of PID separation example:**

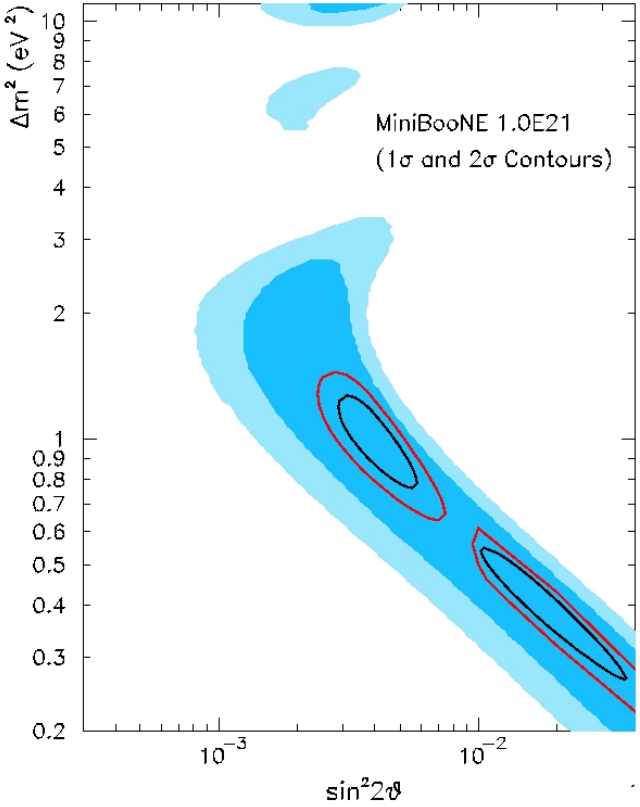
muon / low-energy electron identification, **measured** with cosmic ray muons and associated decay electrons, for two PID algorithms under study

Oscillation Sensitivity

For 10^{21} protons on target, including systematic error estimates, and neutrino energy fit







If LSND is wrong, 4 σ sensitivity to entire LSND 90% CL allowed region

If LSND is right, should see 5 σ excess at LSND central value, and have some Δm^2 discrimination

Conclusions

Basic ingredients for MiniBooNE muon-to-electron neutrino oscillation analysis are already in place:

- A fully calibrated detector
- Over 0.6 million neutrino interactions detected
- Well-tested Monte Carlo and reconstruction tools
- Understanding of key analysis issues

The devil is in the details. Ongoing efforts on:

- Fine-tuning of MC and reconstruction/PID tools, for best possible performance and accurate predictions
- Evaluating and reducing systematic uncertainties
- Devising consistency checks and increase analysis robustness

Schedule:

- The MiniBooNE electron neutrino appearance analysis is a blind analysis
- Oscillation results will be published shortly after the box will be opened
- Current estimate is not before the end of 2005
- First oscillation results should address LSND signal in a defnitive way
- Similar timescales for neutrino cross-section results (NCPi0, CCPi+)