First Oscillation Results from MiniBooNE

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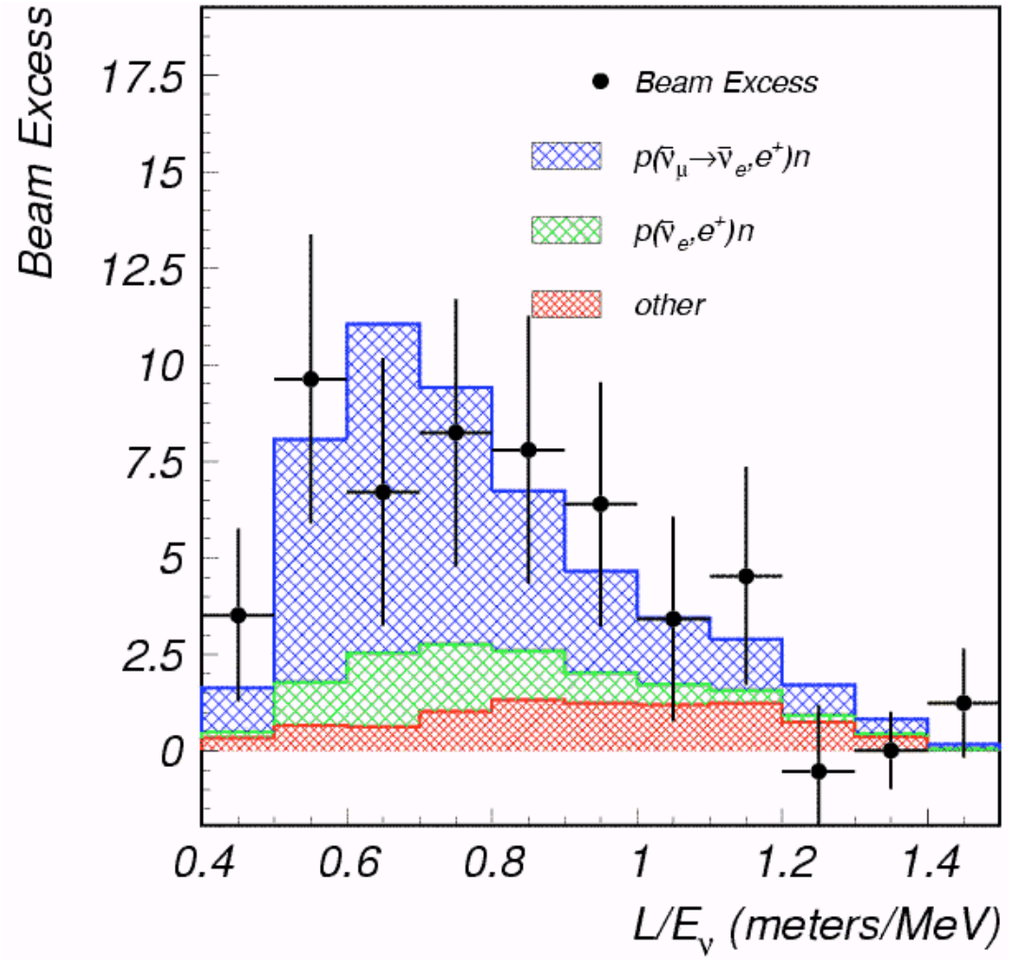
LSND Oscillations:



Evidence for $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillations

Stopped π^+ beam produces $\bar{\nu}_\mu$

Č/*n*-capture signature

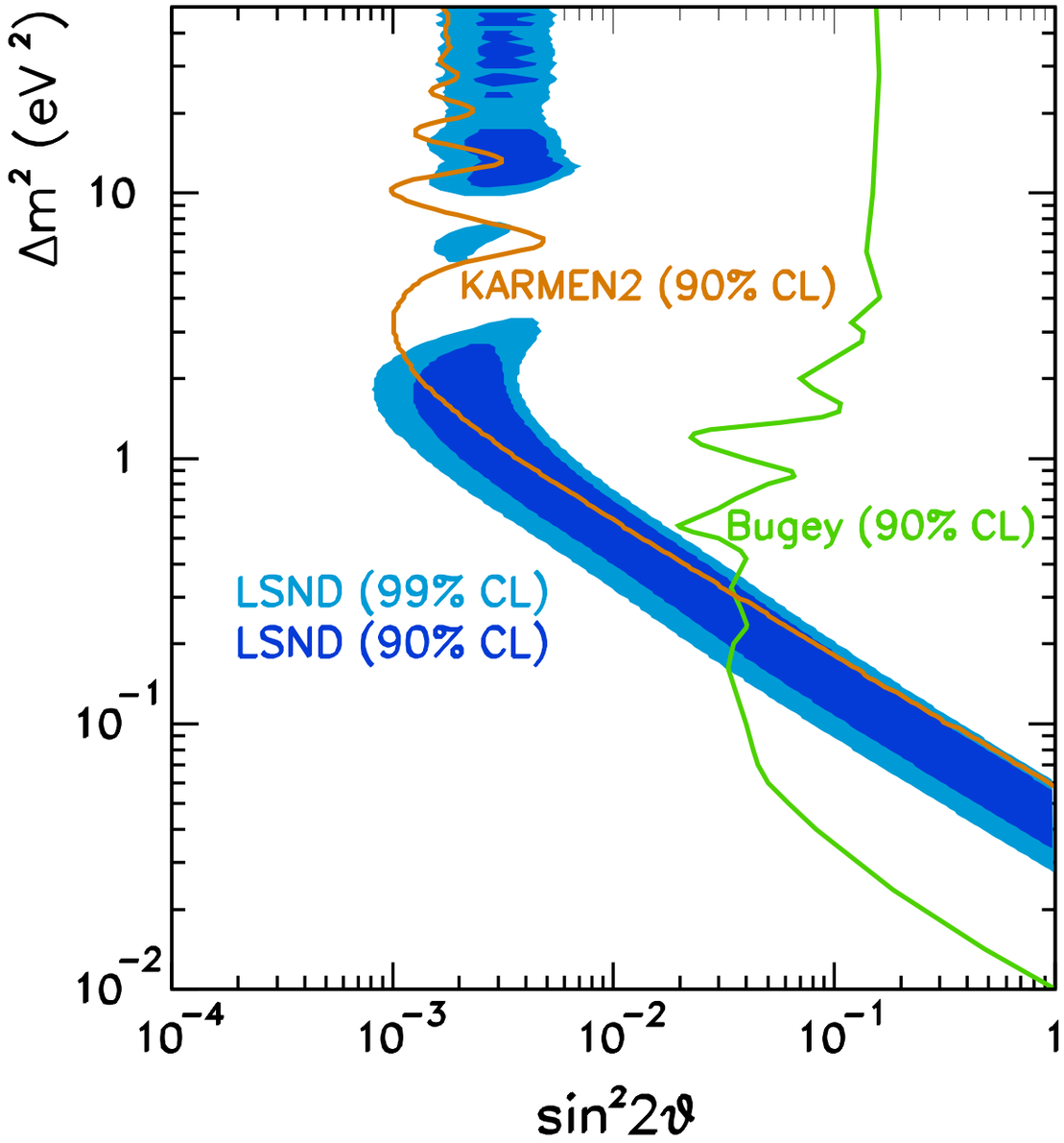
Excess of 87.9 ±22.4 ±6.0 events

Neutrino oscillations with

- $\Delta m^2 \sim 0.1\text{-}10\ eV^2$ (L/E~ 1 km/GeV)
- $\sin^2 2\theta \sim 0.001\text{-}0.04$ (0.25%)

New mode not consistent with atmospheric/solar: need new physics!

Unconfirmed by other experiments



The MiniBooNE Collaboration

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University of Michigan
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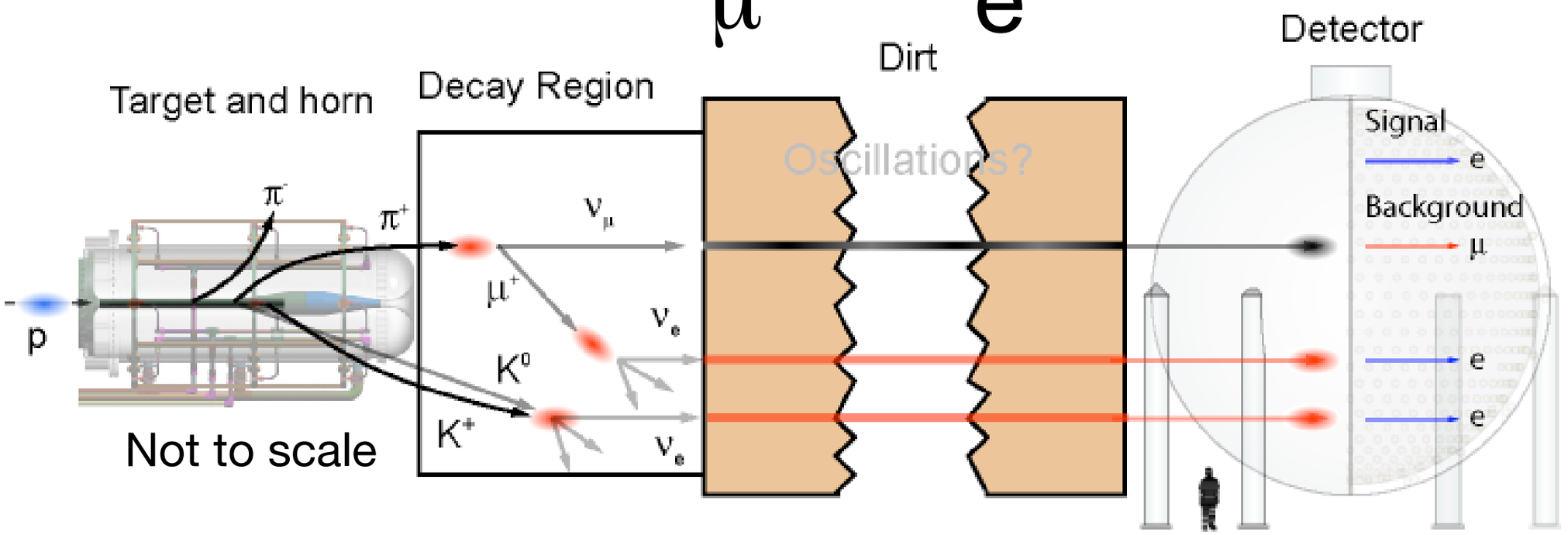
Saint Mary's University of Minnesota
Virginia Polytechnic Institute
Western Illinois University
Yale University

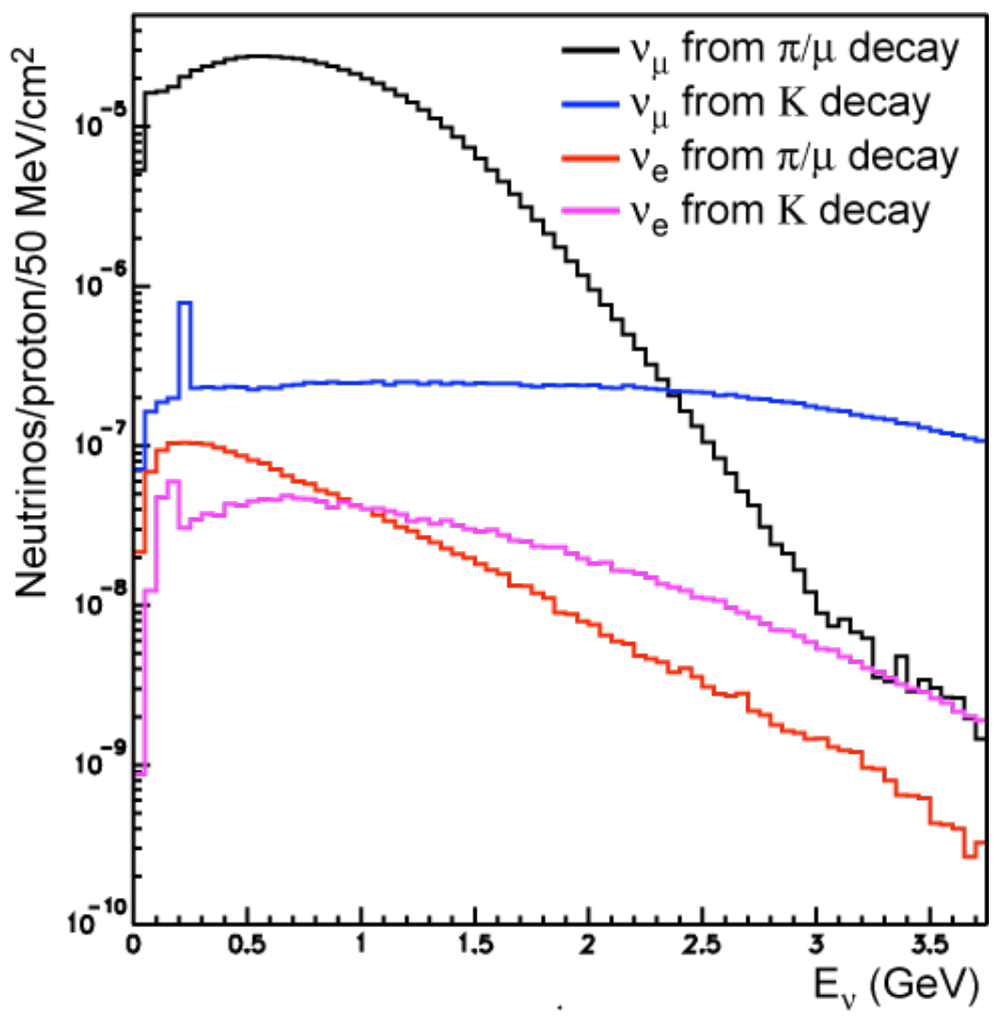
MiniBooNE: $\nu_\mu \rightarrow \nu_e$ search



- Beam: 8 GeV protons on Be
  Produce ~0.8 GeV ν_μ beam
  540 m baseline
  5.58 x 10^{20} POT for analysis
- Detector: 800 ton sphere of mineral oil
  550 cm inner "tank" region (1280 PMT)
  Outer "veto" region (240 PMTs)

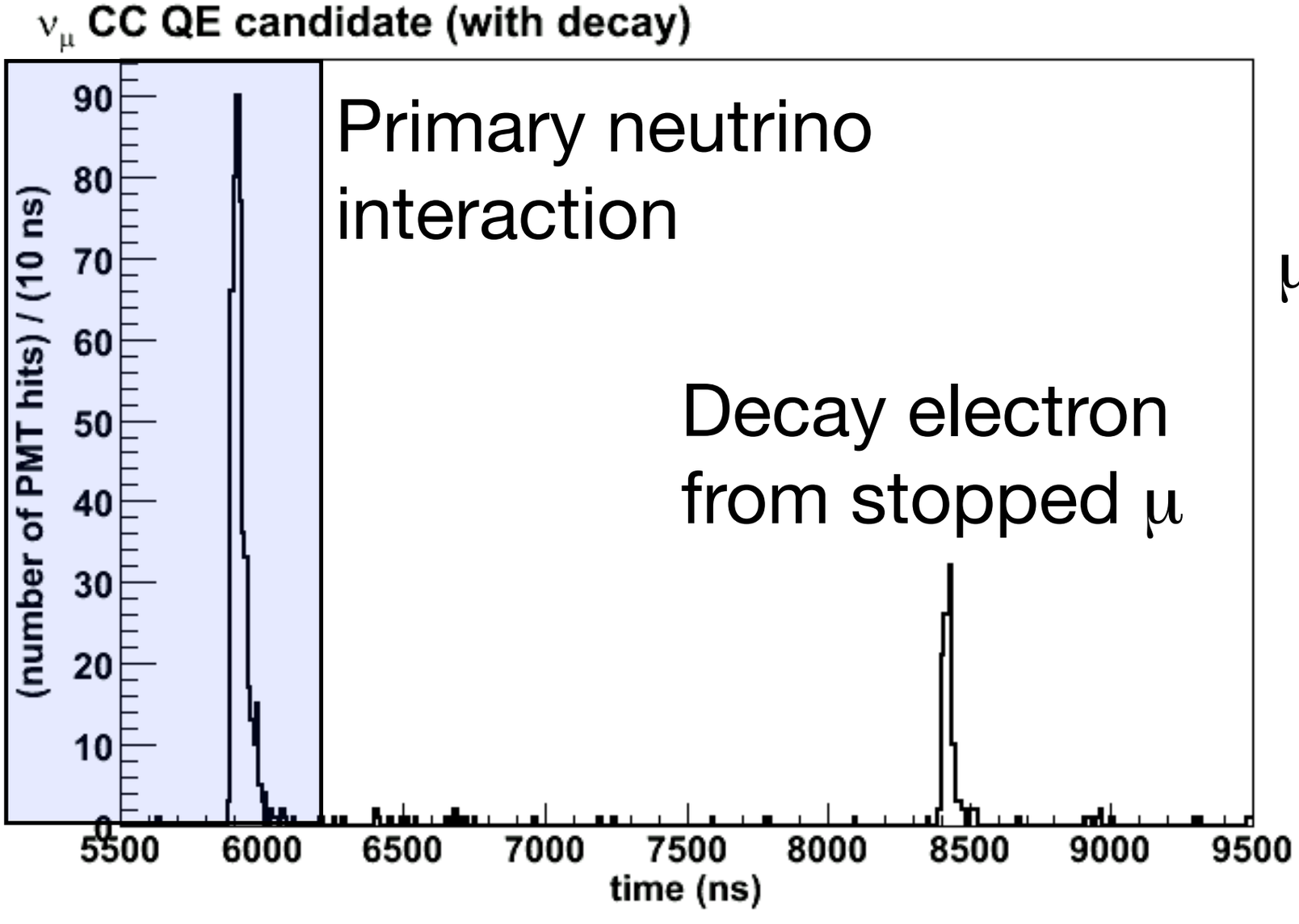
Detect ν interactions via Č/Scintillation

Search for $\nu_\mu \rightarrow \nu_e$, L/E~1 km/GeV



Neutrino events: Time profile

- PMT activity in each and every beam spill recorded
- Clusters of PMT hits in time identified



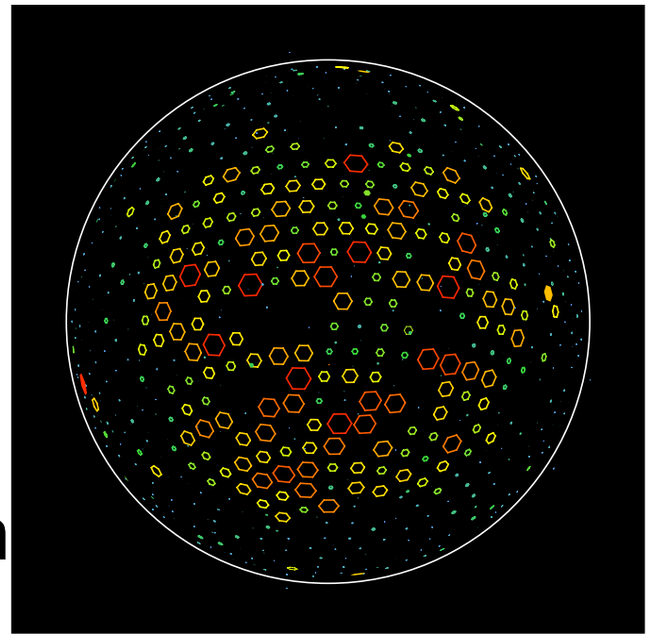
μ decay-at-rest

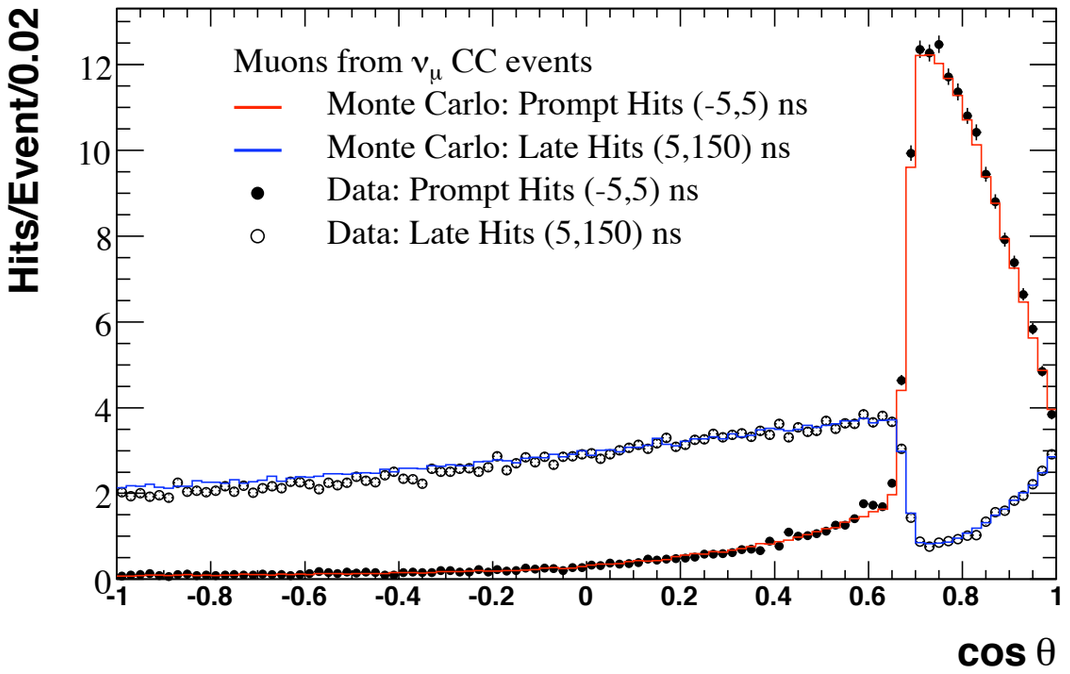
- 0-53 MeV electron
- <200 PMT hits
- Independently tags presence of muon in event $\Rightarrow \nu_\mu$ CC

Events: Spatial Profile

Muons:

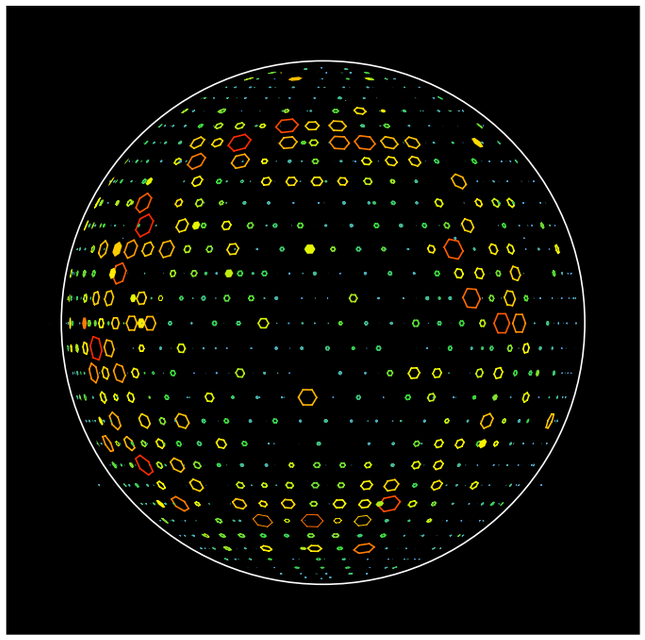
- Constant energy loss
- Extended Č emission
  L (cm) ~ 2 E(MeV)
  ~5 m for 1 GeV muon

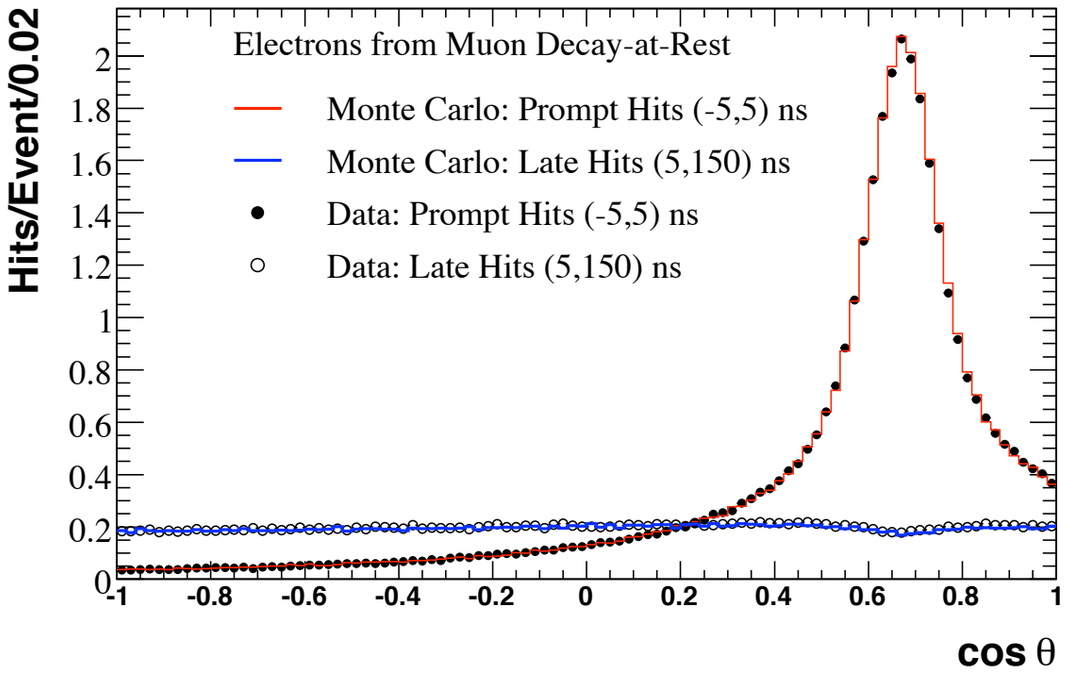




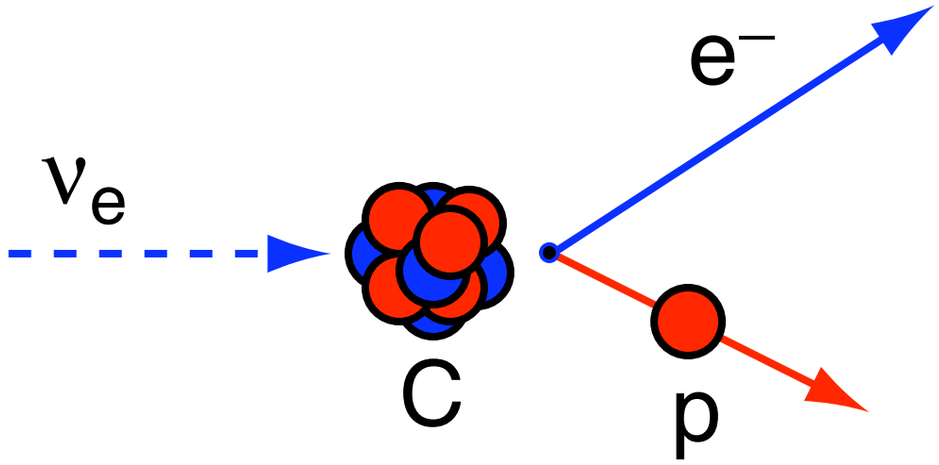
Electrons:

- EM cascade (bremsstrahlung, etc.)
- diffuse ring
- shorter for ~1 GeV





Signal and Backgrounds:



Signal: ν_e CCQE

- ~10^3 ν_e oscillation events
- ~10^6 background ν_μ events

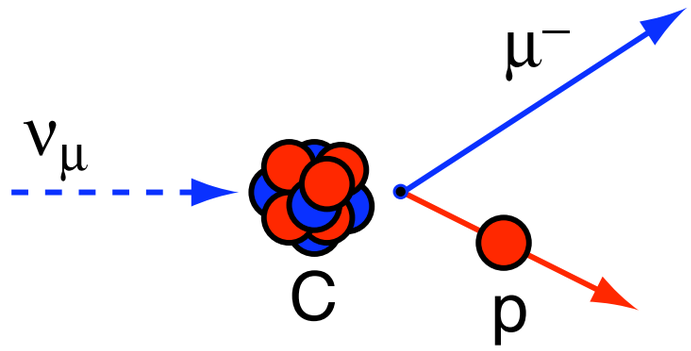
Reducible:

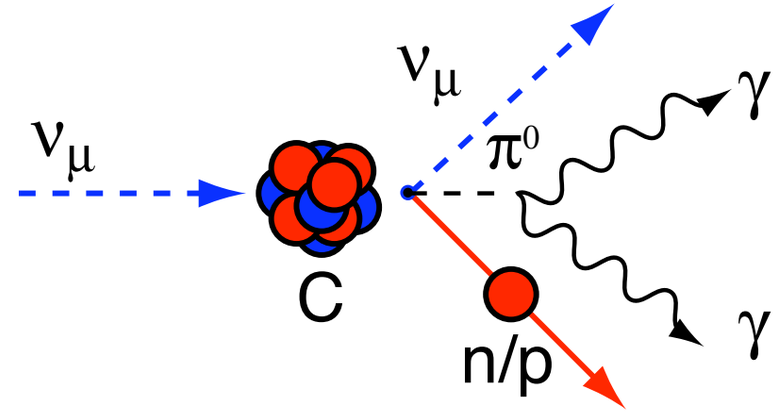
Single ring muon events

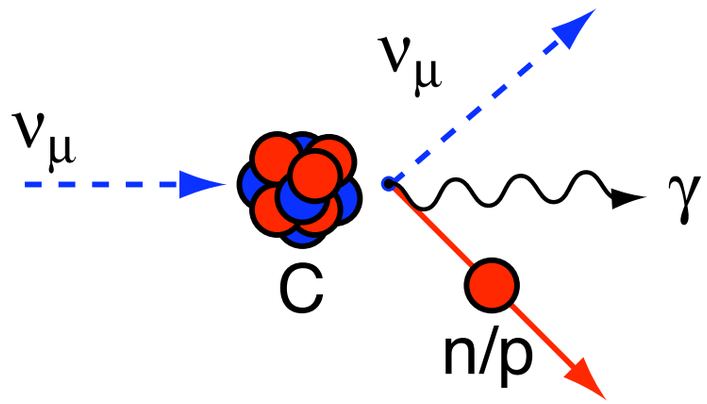
NC π^0 (1 or 2 e-like rings)

$\Delta \rightarrow N\gamma$ decay (1 e-like ring)

(photons shower like electrons)

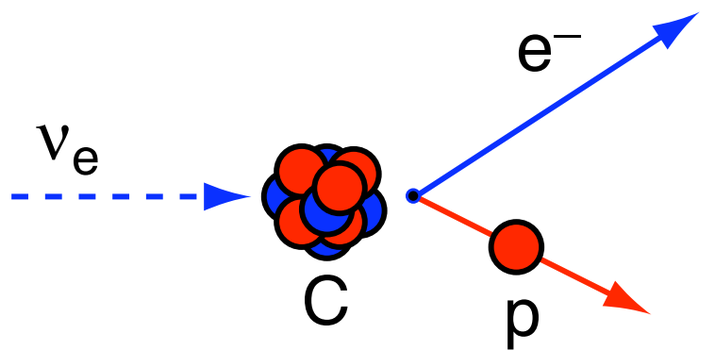






Irreducible/Intrinsic:

Genuine ν_e events in beam from kaon/muon decay



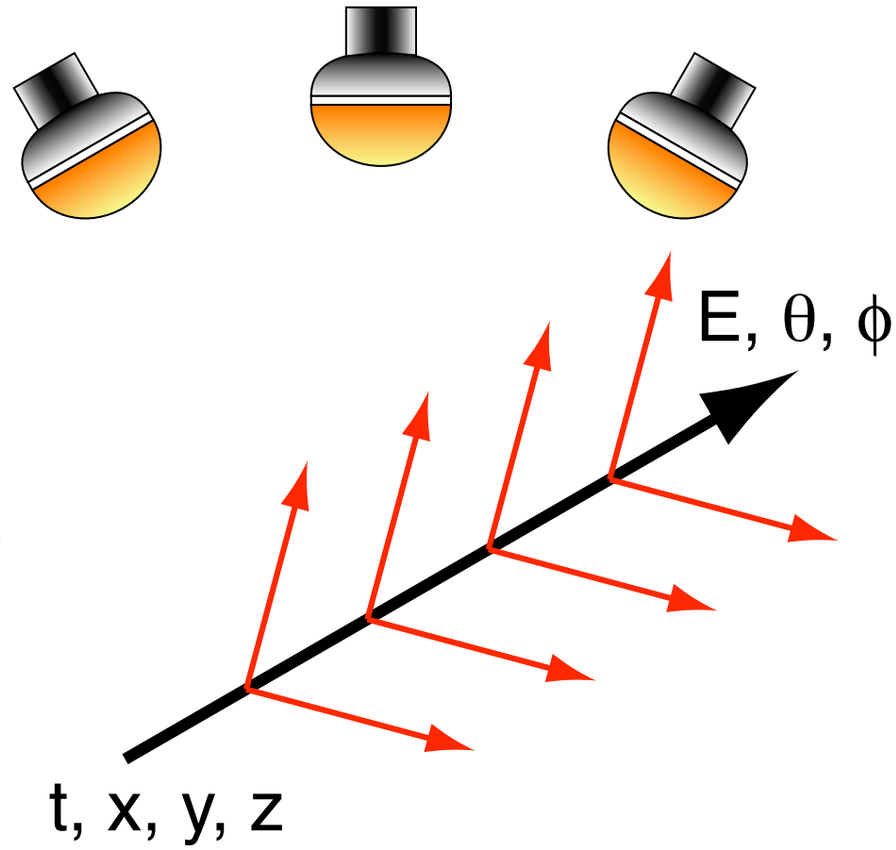
Event reconstruction

"Event": 1280 PMT signals of charge/time

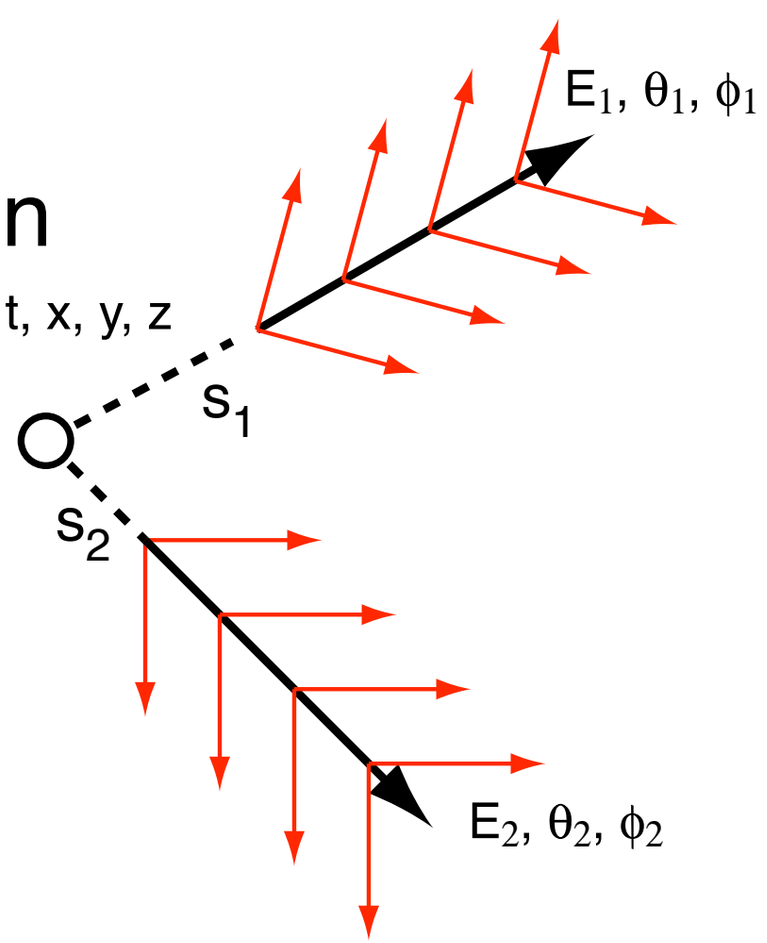
"Reconstruct" event under a hypothesis

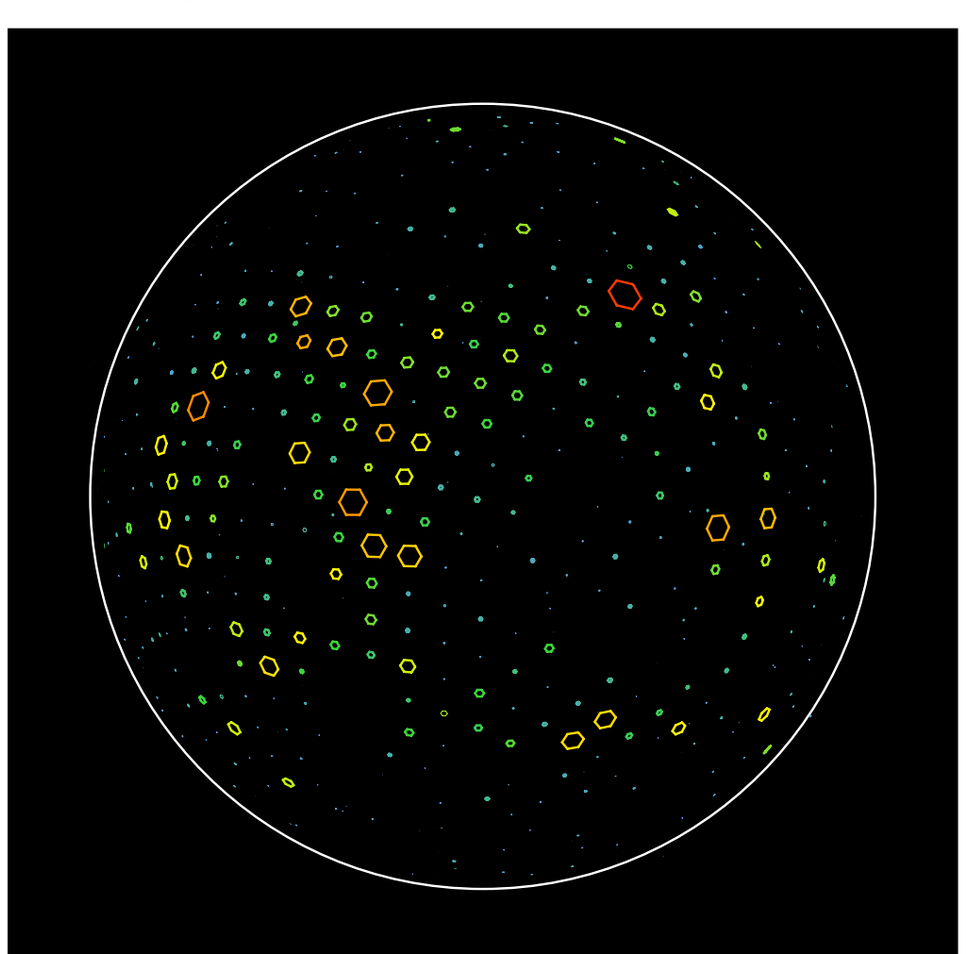
- single electron/muon track
- 7 parameter model predicts Q/T on PMTs
- Likelihood w.r.t actual Q/T calculated

Maximize likelihood to get parameters



Two track "π^0" fit incorporating photon conversion lengths



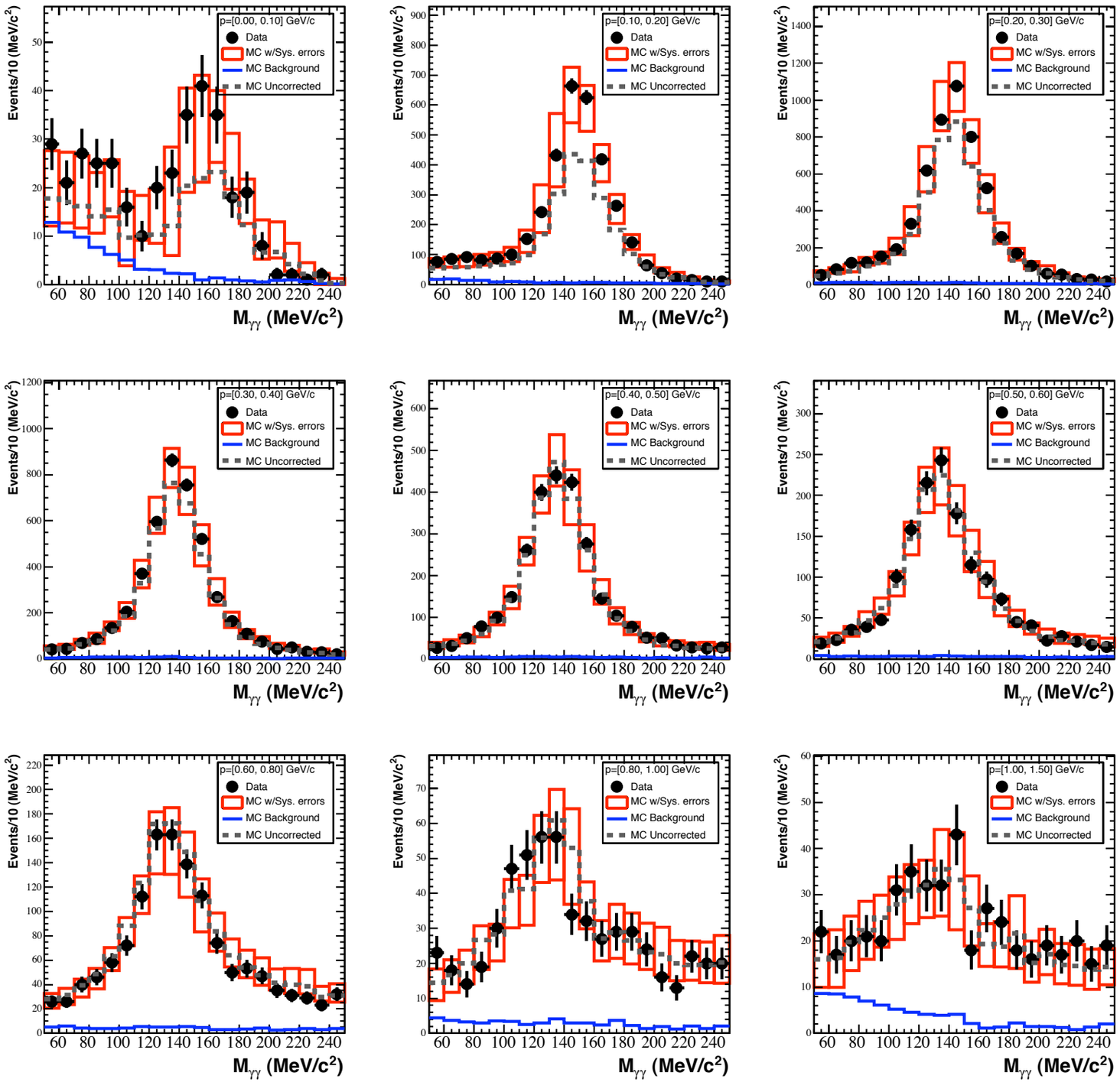


π^0 Rate and Spectrum

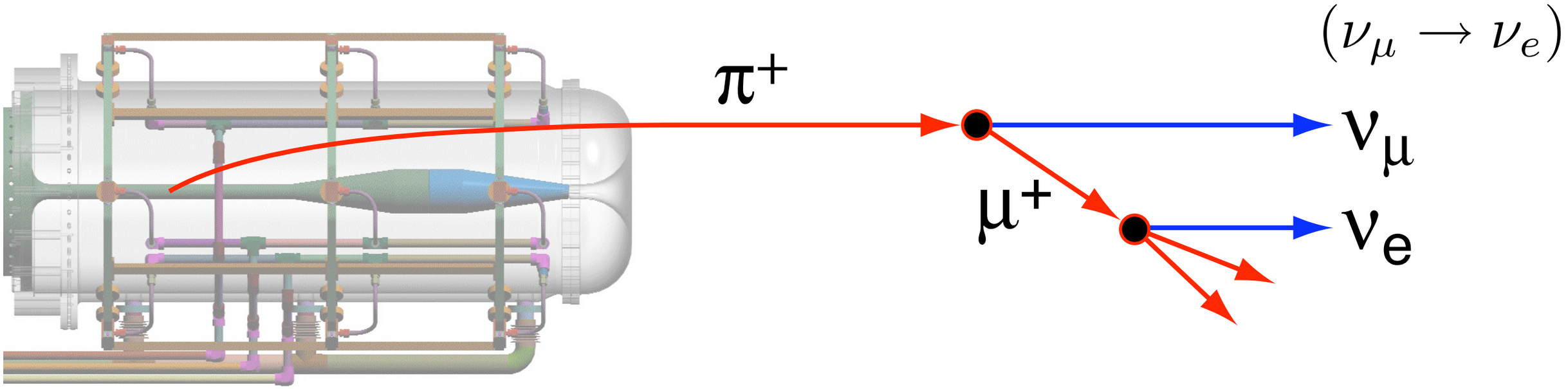
2T Mass distribution

- Measurement of π^0 production rate and spectrum.

Dominant Misidentification Background



Internal Constraints: ν_μ CCQE:



If we measure the rate of ν_μ CCQE in the detector:

The $\pi^+ \rightarrow \mu^+ \rightarrow \nu_e$ background (largest single source)

- comes from the same π^+ that produced ν_μ CCQE
- π^+ decays must be forward: tight relation between E_π and E_ν
- Uncertainties in π^+/μ^+ production pushed to higher order

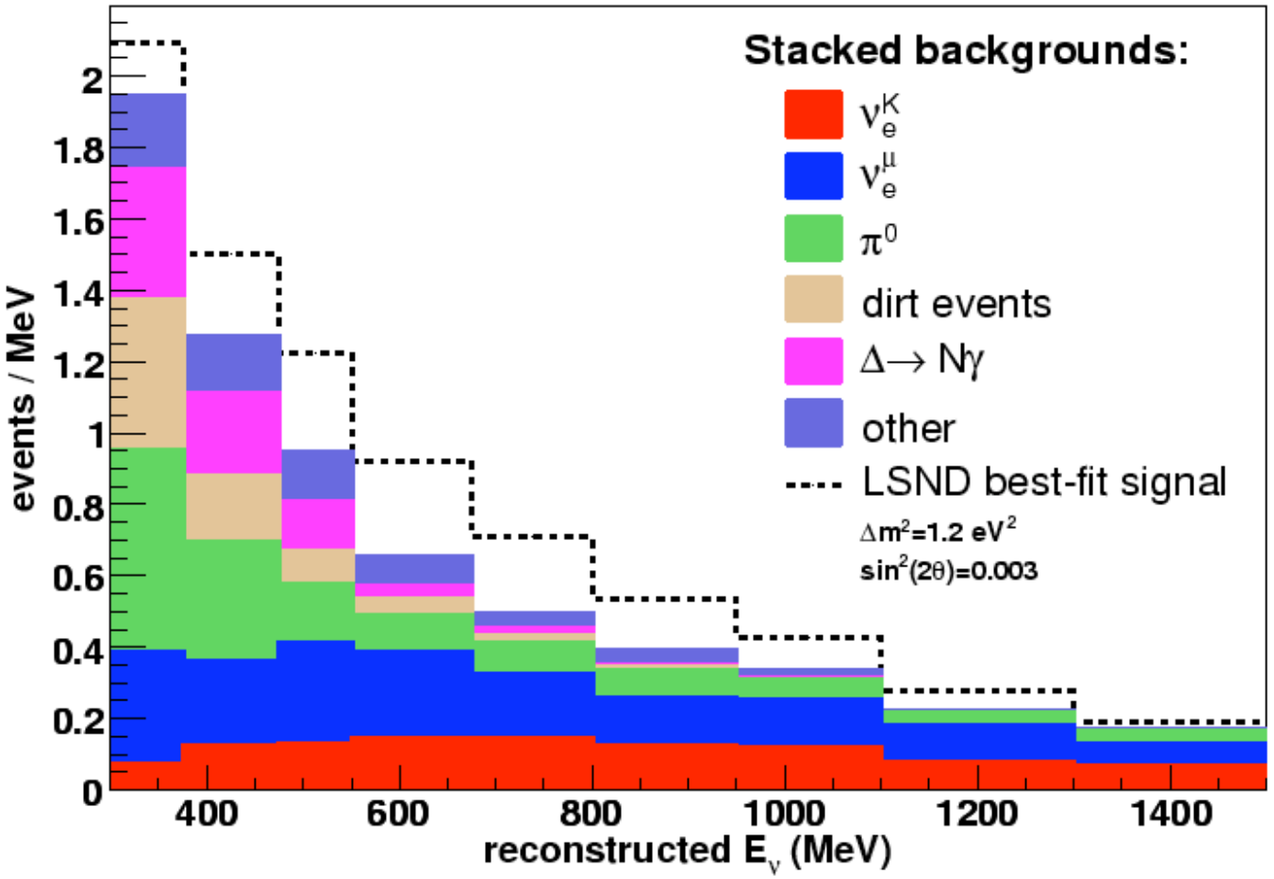
Signal: Oscillation ν_e are from the same ν_μ

ν_e Candidate Selection

Requirements:

- No decay electron (supress ν_μ CC)
- No activity in the veto PMTs (< 6 hits)
- Tank PMTs above μ-DAR endpoint ~53 MeV (>200 hits)
- Not too close to the wall (vertex < 500 cm, end < 488 cm)
- Likelihood ratios
  - e fits better than μ
  - e fits better than π^0
- Mass is not consistent with π^0 (135 MeV/c^2)
- Reconstructed neutrino energy between 475-3000 MeV

Expected Background



Signal:

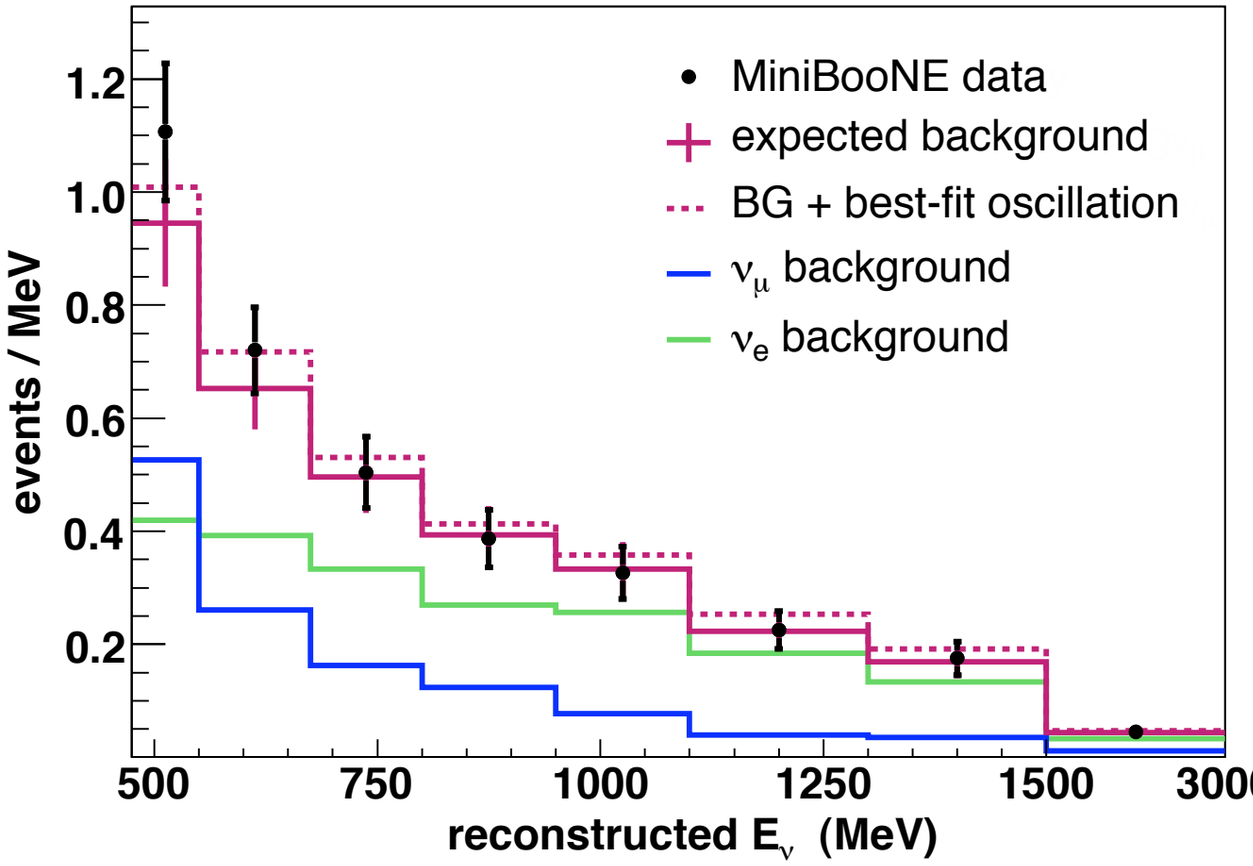
LSND Best fit expectation = 126

475-1250 MeV

Source	Events
π^0 contained	55
π^0 escape	7
Radiative Δ	20
Dirt Interactions	17
Other	33
ν_e (μ decay)	132
ν_e (K decay)	94
Total	358

- Signal/Background ~1/3 at LSND central value
- Comparable contributions from intrinsic/reducible background

Unblinded Data:

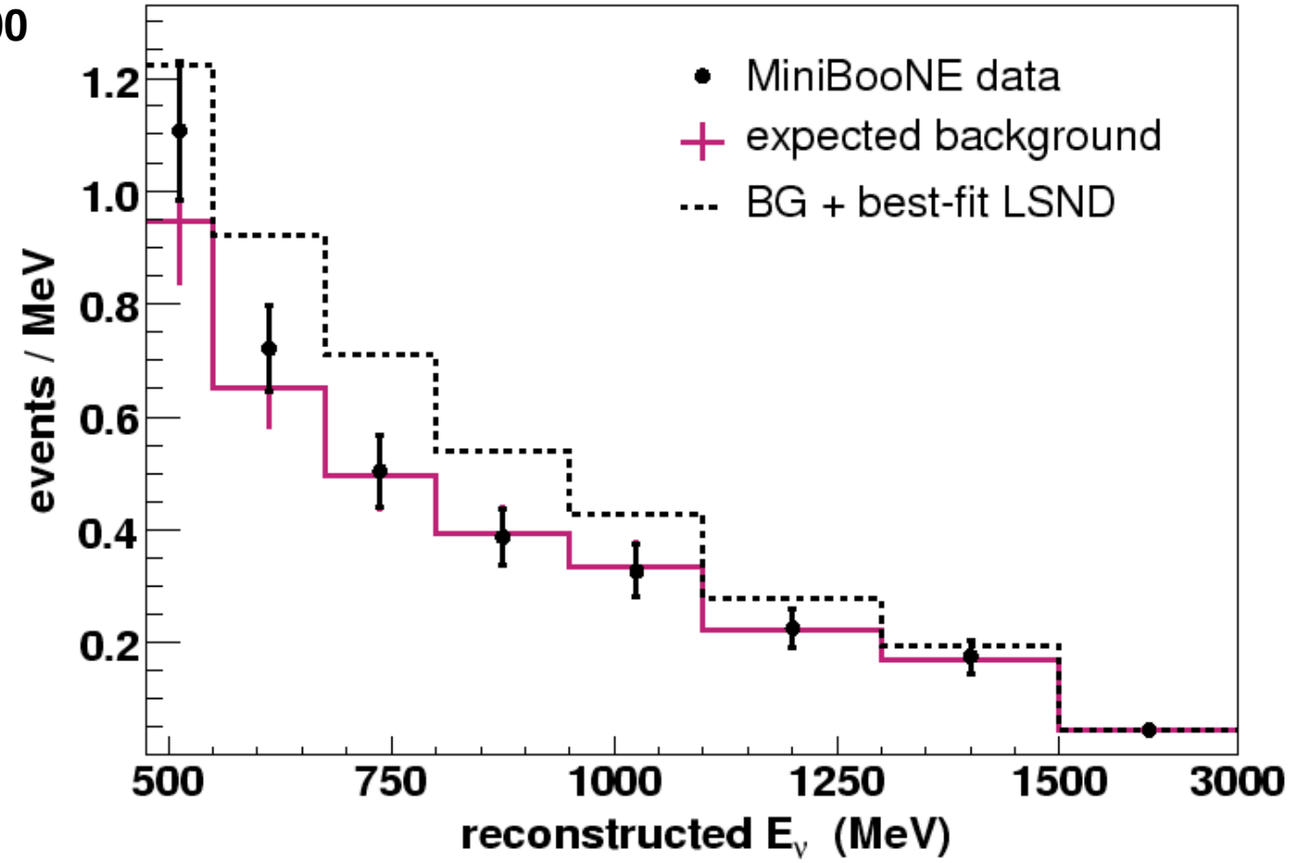


475-1250 MeV event count

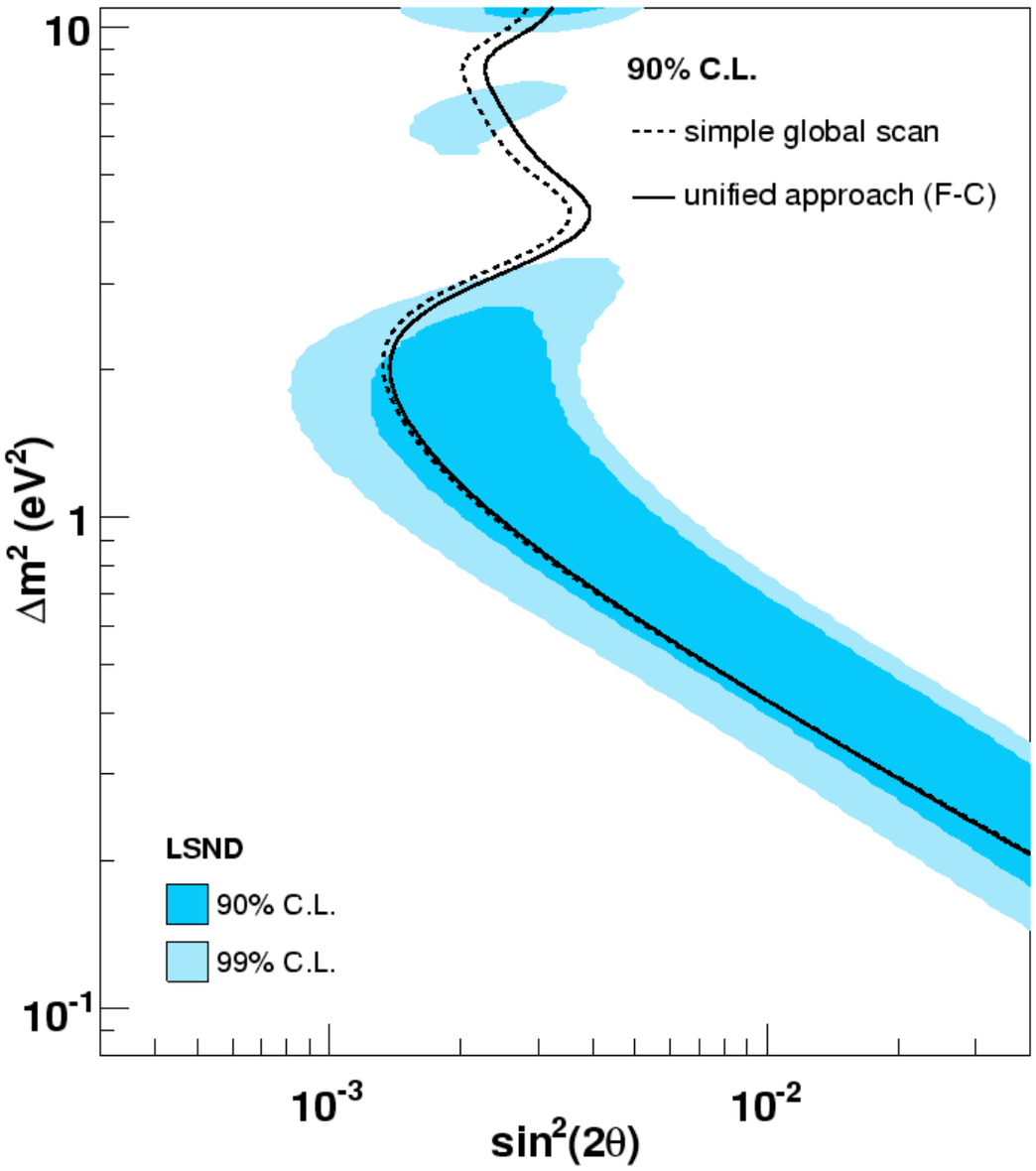
- Observed: 380 events
- Expect: 358 ± 19(stat) ±35(sys)
- 0.55 σ over background

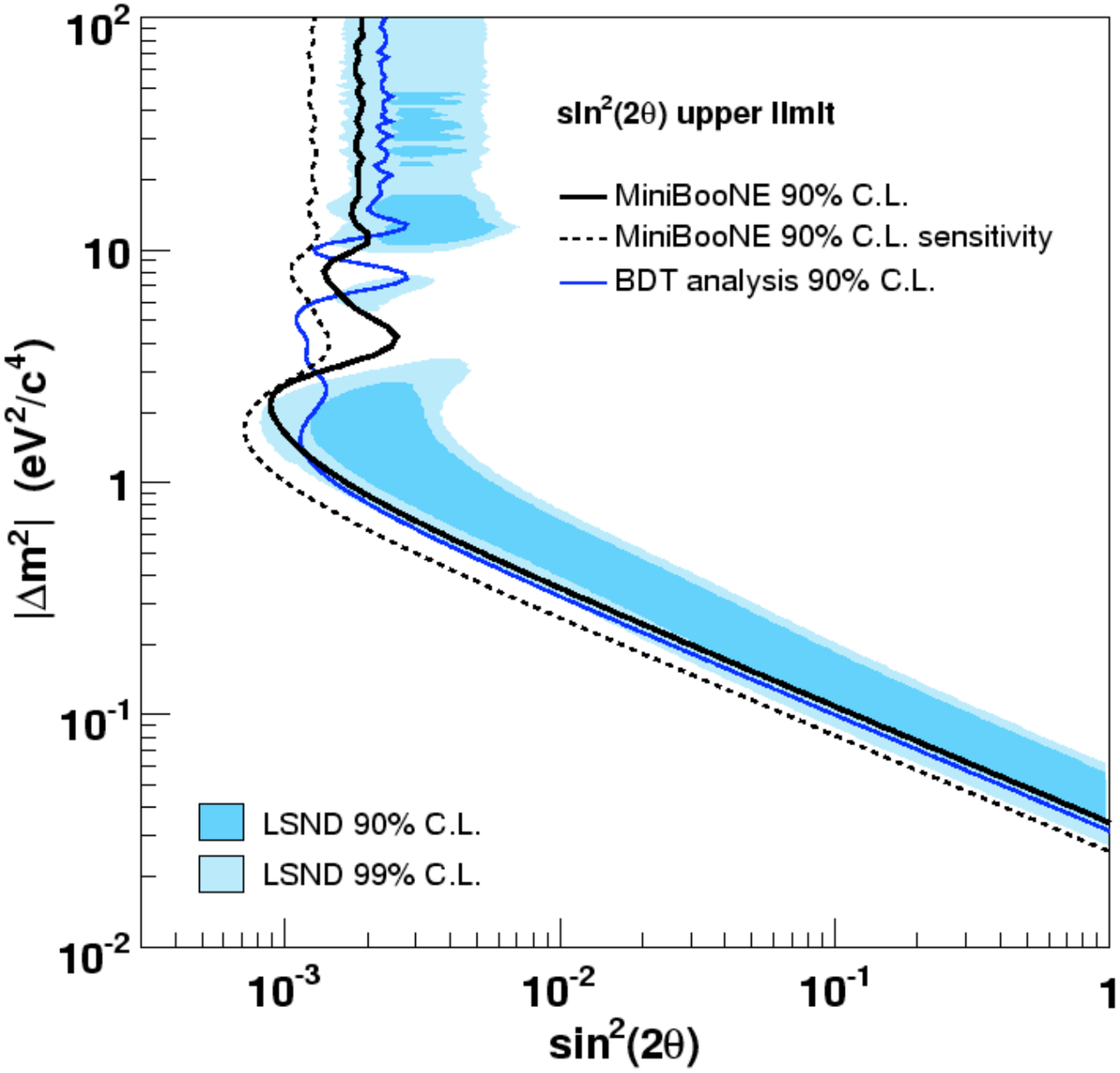
Best Fit Parameters

- $\sin^2 2\theta = 1.1 \times 10^{-3}$
- $\Delta m^2 = 4.1\ eV^2/c^4$
- $\chi^2_{null} - \chi^2_{best} = 0.94$
- $\chi^2_{LSND} - \chi^2_{best} = 13.7$



Oscillation Parameter Exclusion

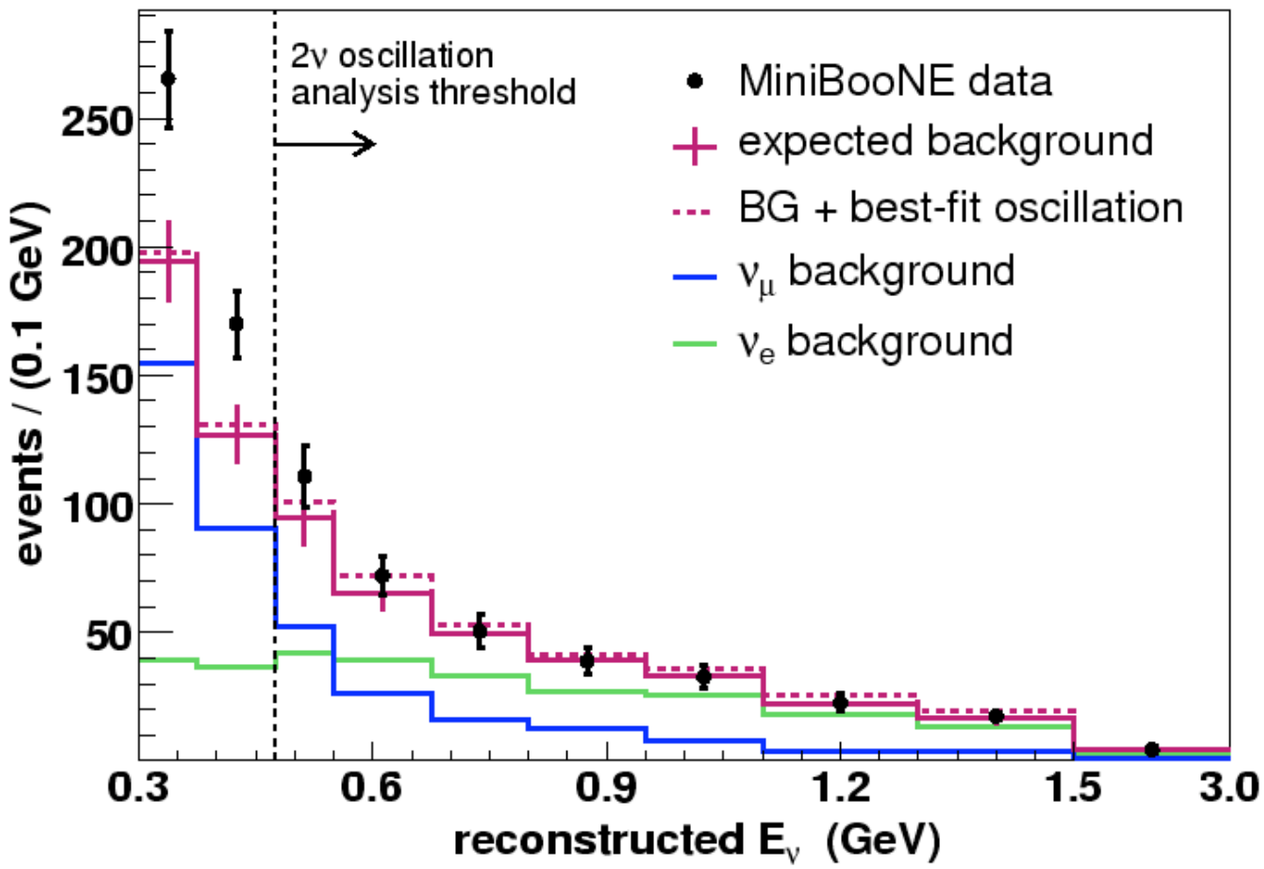




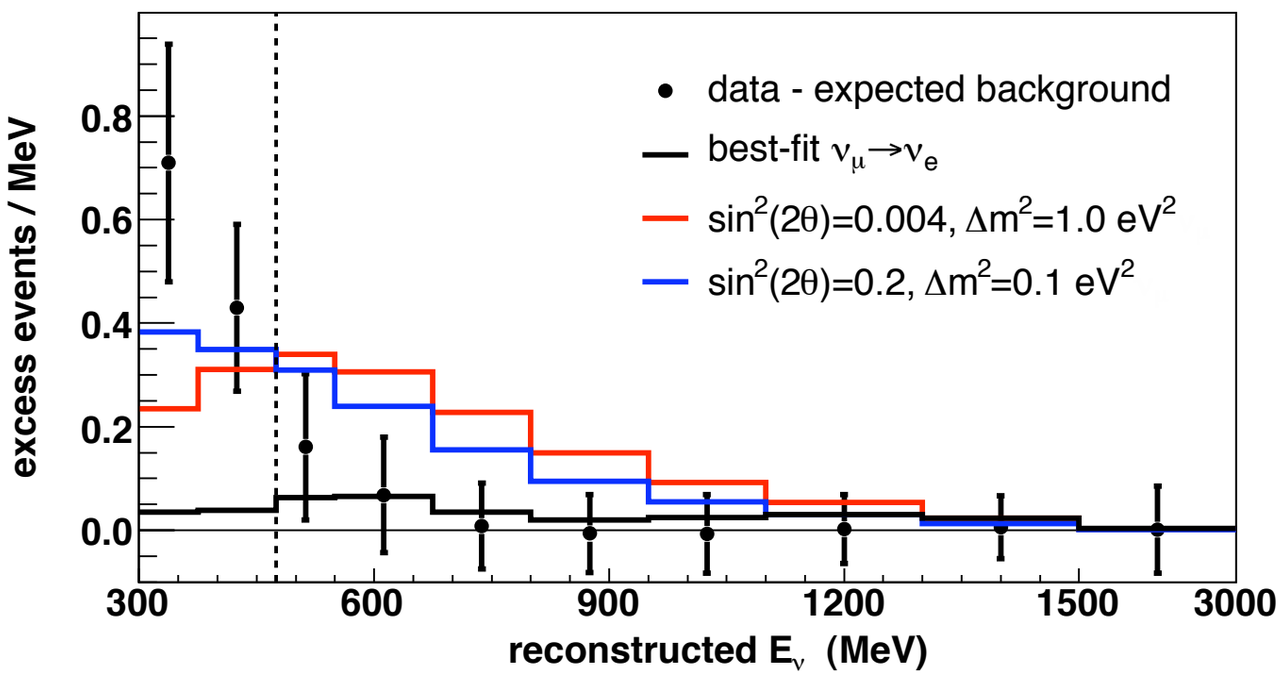
- Boosted Decision Tree analysis gives similar limits

Below 475 MeV:

- A discrepancy at low energies
- Currently under investigation



Spectrum



Excess over background:
Lower $\Delta m^2 \Rightarrow$ softer spectrum
0.1 eV^2 is CHOOZ bound

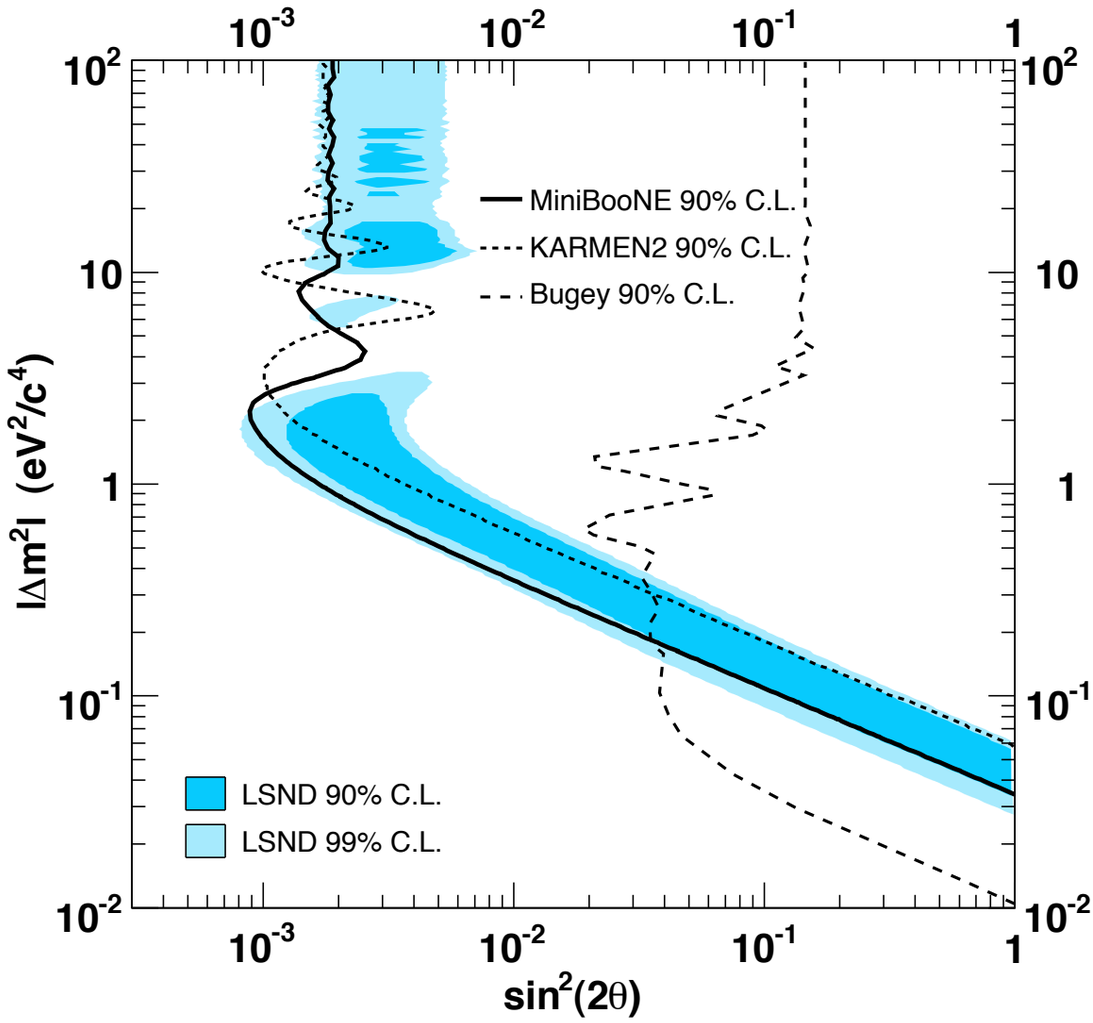
Summary:

MiniBooNE:

Search for $\nu_\mu \rightarrow \nu_e$ with $\Delta m^2 \sim 1$ eV^2 indicated by LSND

- Low-E under investigation
- No significant excess in analysis region
- Inconsistent with LSND with one Δm^2
- Investigating more elaborate models

(e.g. Maltoni and Schwetz hep-ph/07050107
2 or 3 sterile neutrinos with CP violation)



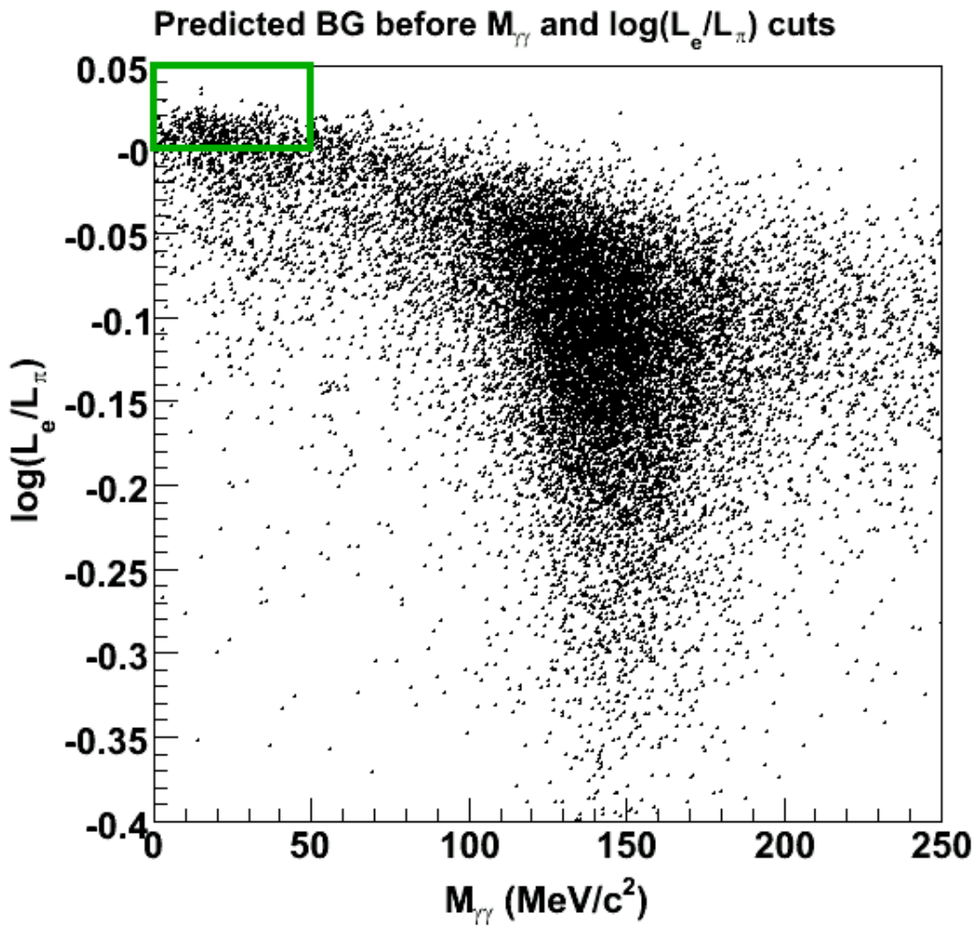
Sideband Studies

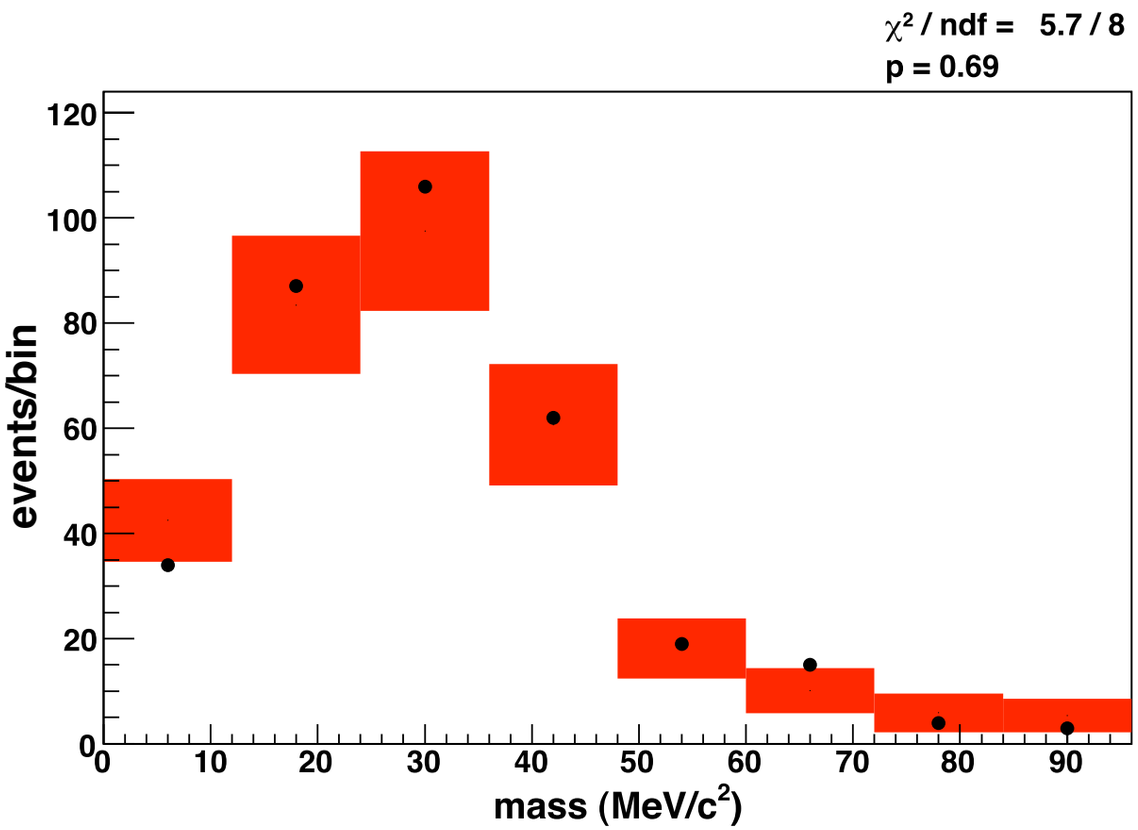
Apply all cuts except one:

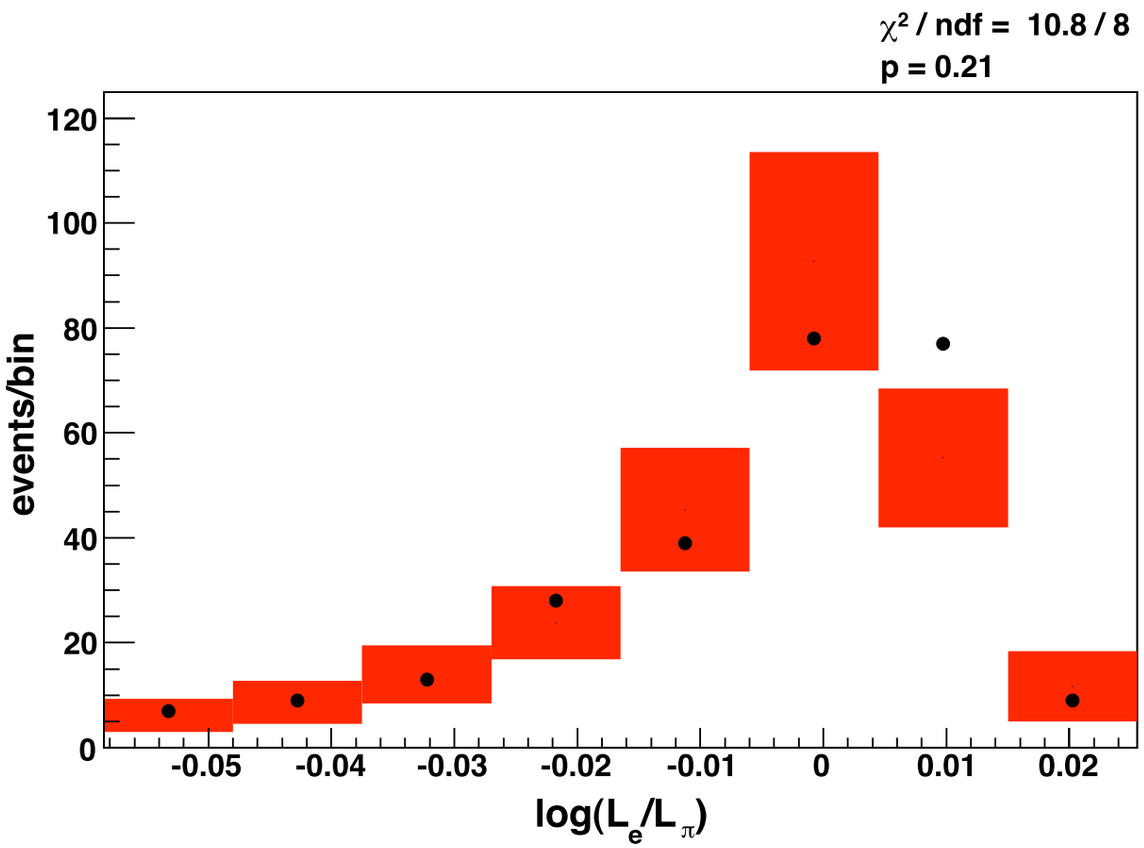
- invert (approx.) that cut

Left: Invert L(e/π), look at $M_{\gamma\gamma}$

Right: Invert $M_{\gamma\gamma}$, look at L(e/π)



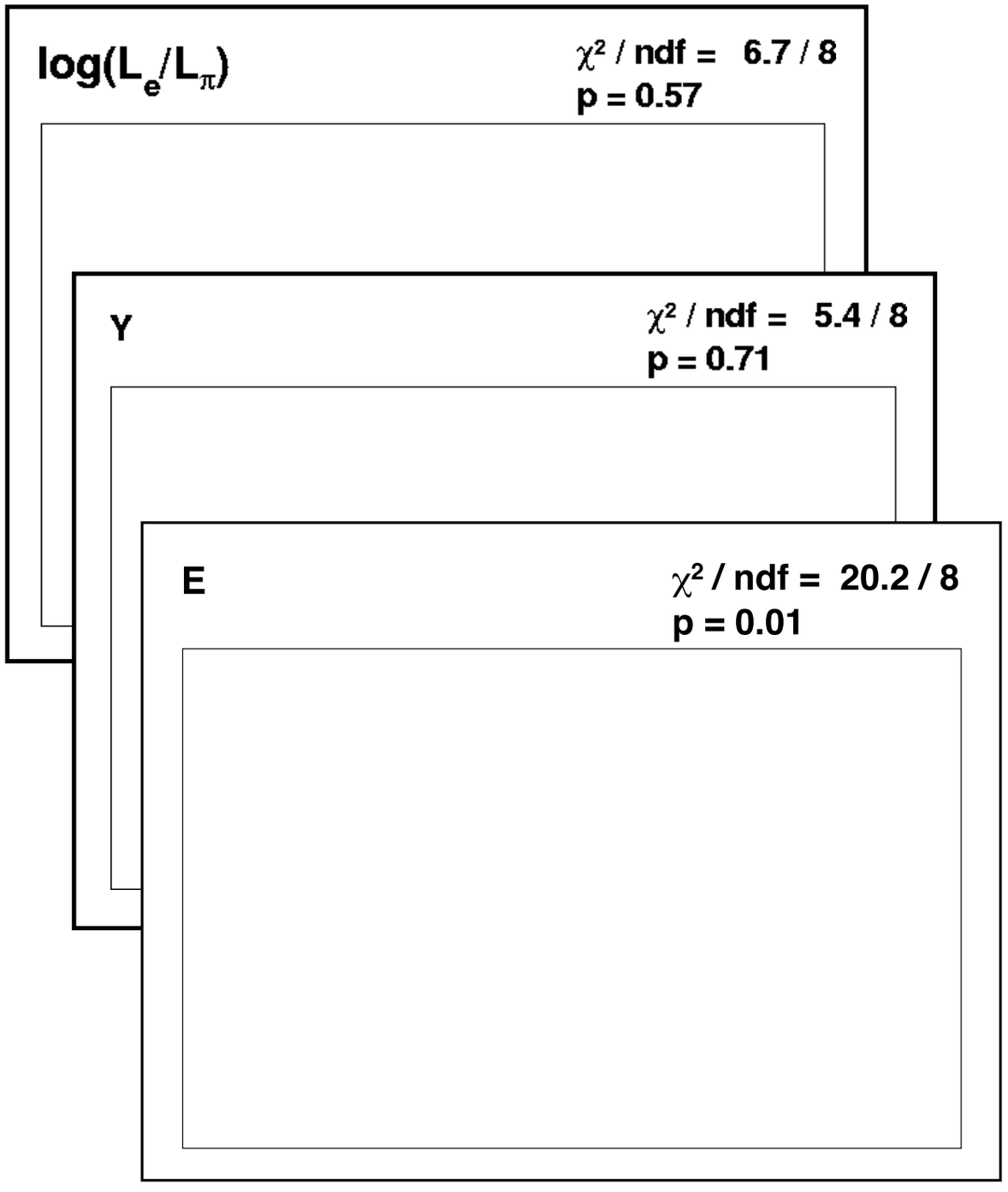




Stepwise Unblinding:

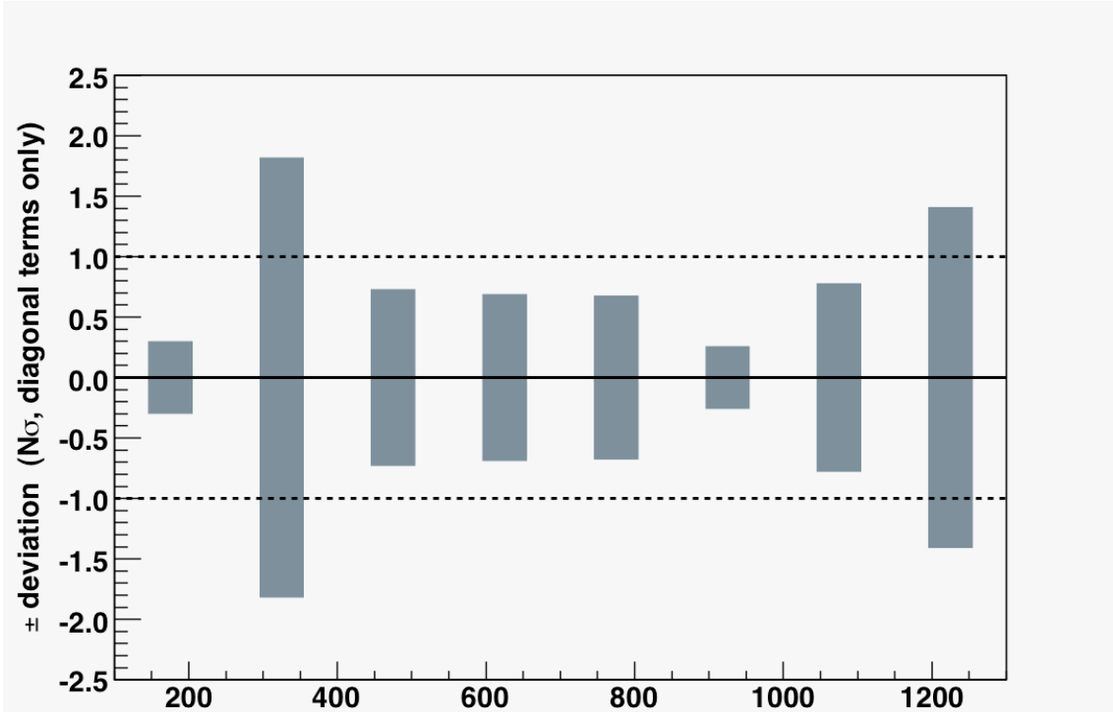
- Blind χ^2 Test:
  Fit E_ν distribution data to an oscillation hypothesis.
- Report χ^2 on diagnostic distributions accounting for the unknown best-fit signal
- Most quantities: good agreement
  Visible energy: poor χ^2

  Re-examine backgrounds/errors

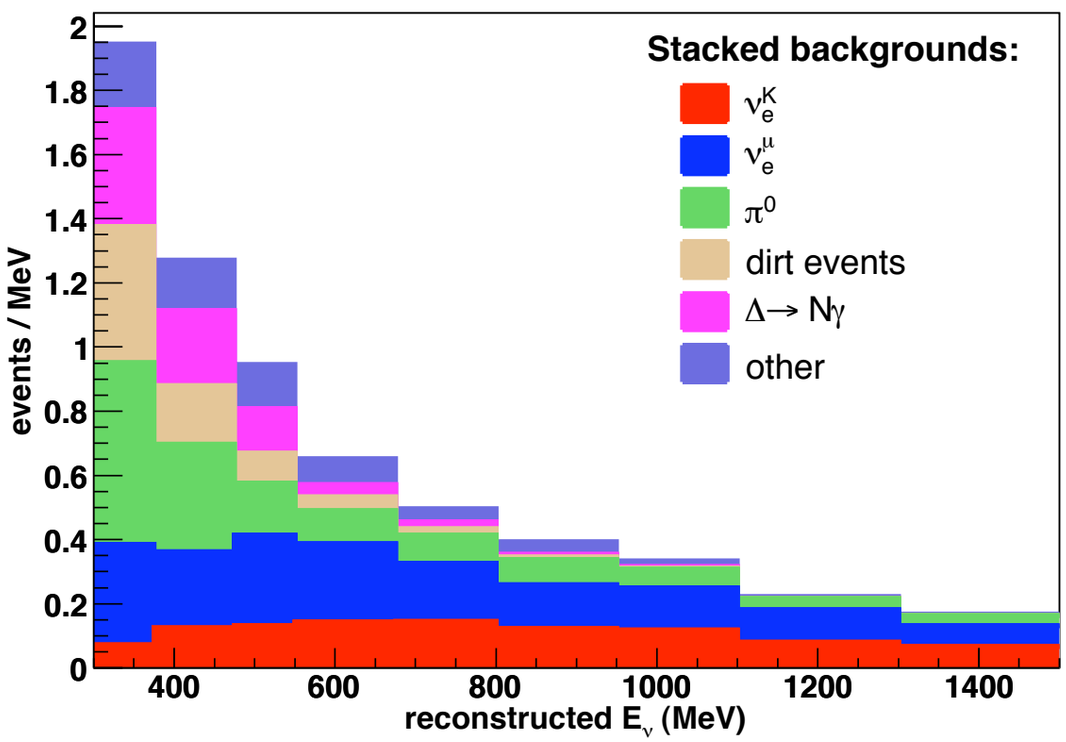


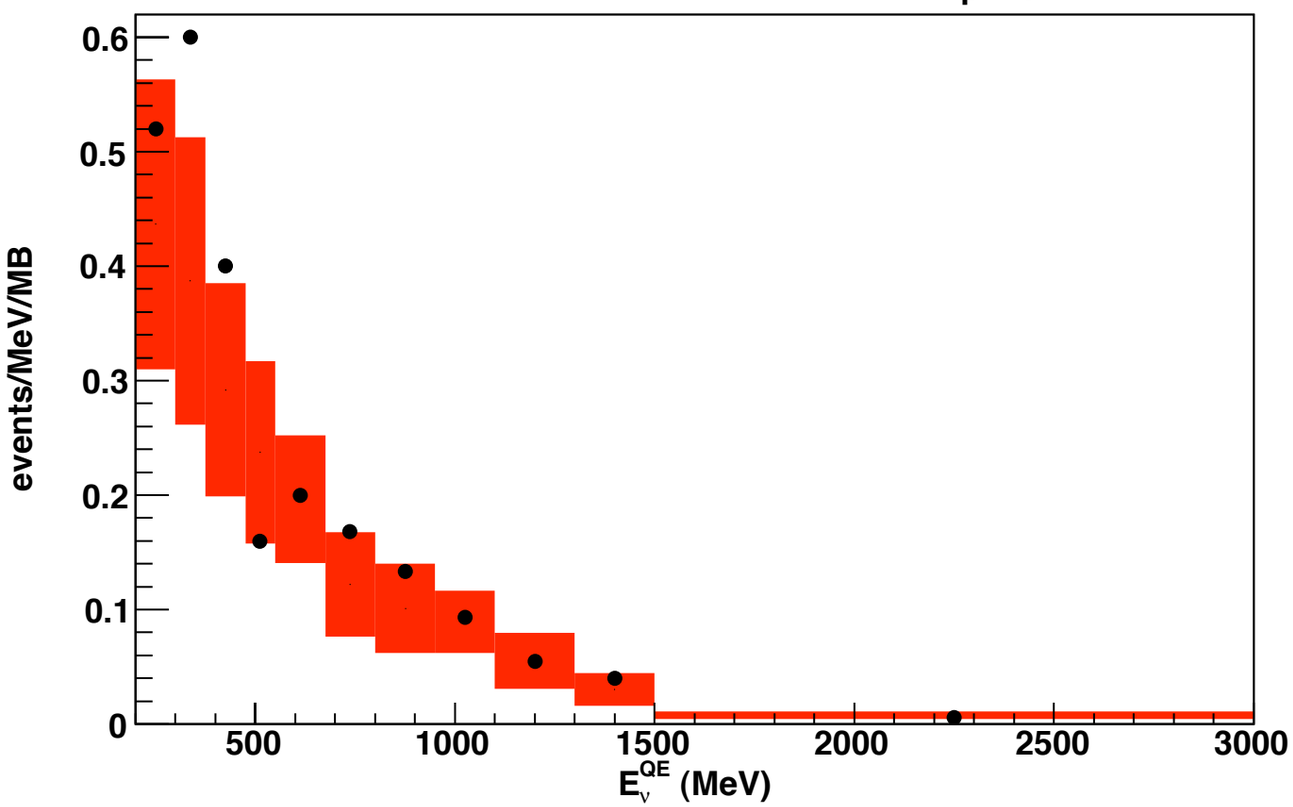
Low Energy?

- Suspect low energy:
  Look at unsigned deviation of data relative to best fit (blind to excess/deficit)
- MC indicates backgrounds pile up in this region.

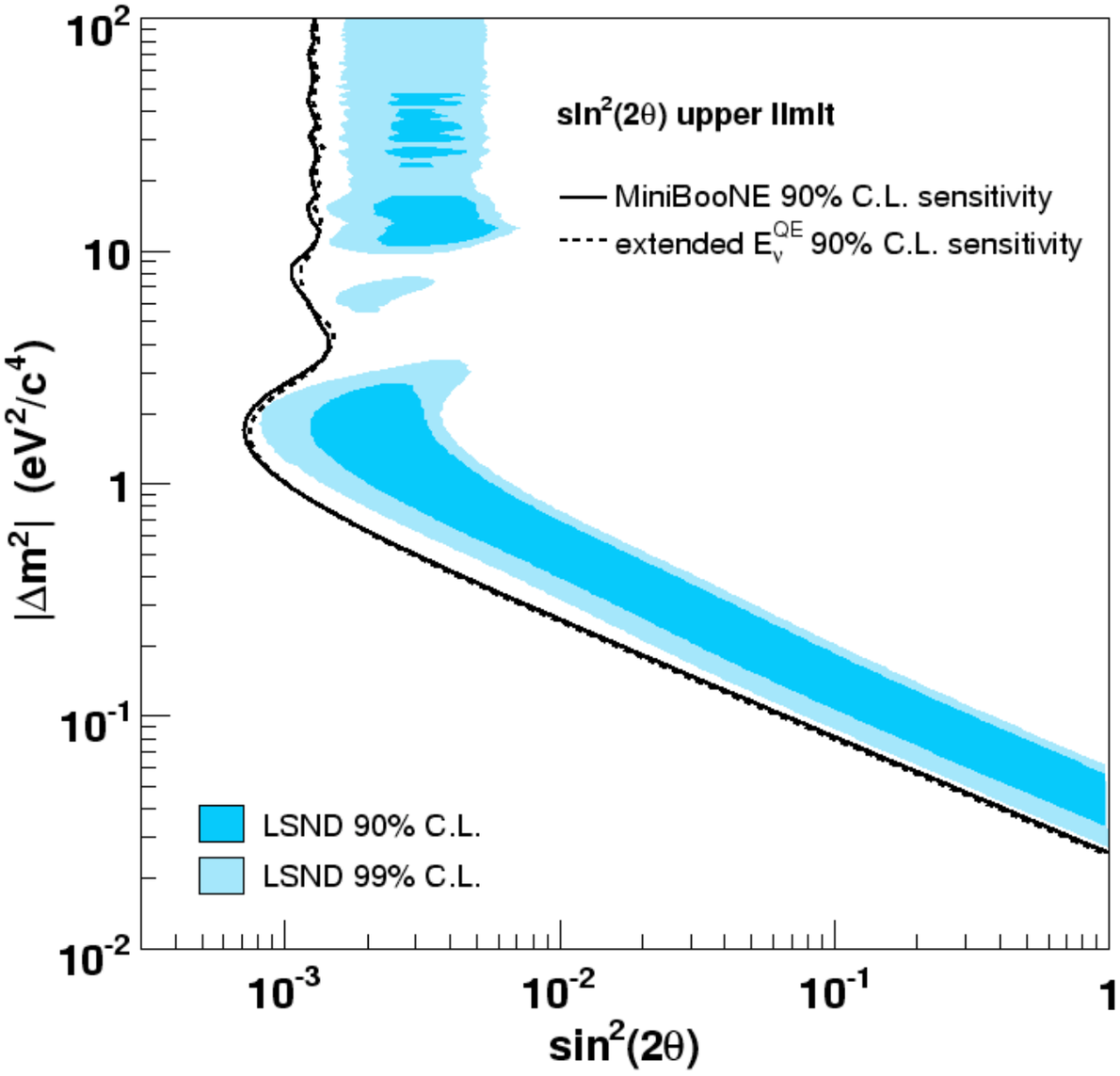


- Increase E_ν cut to 475 MeV





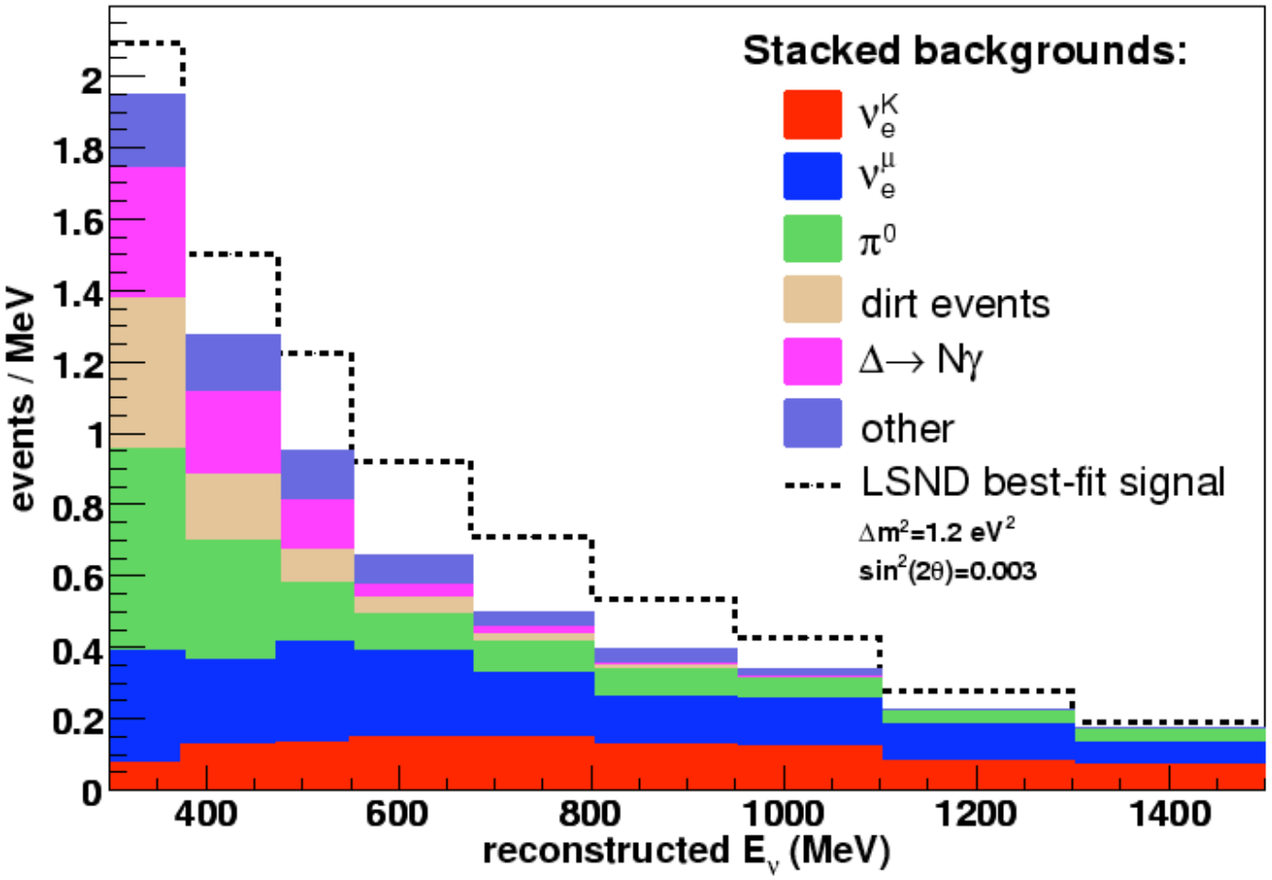
Increase E_ν Threshold:

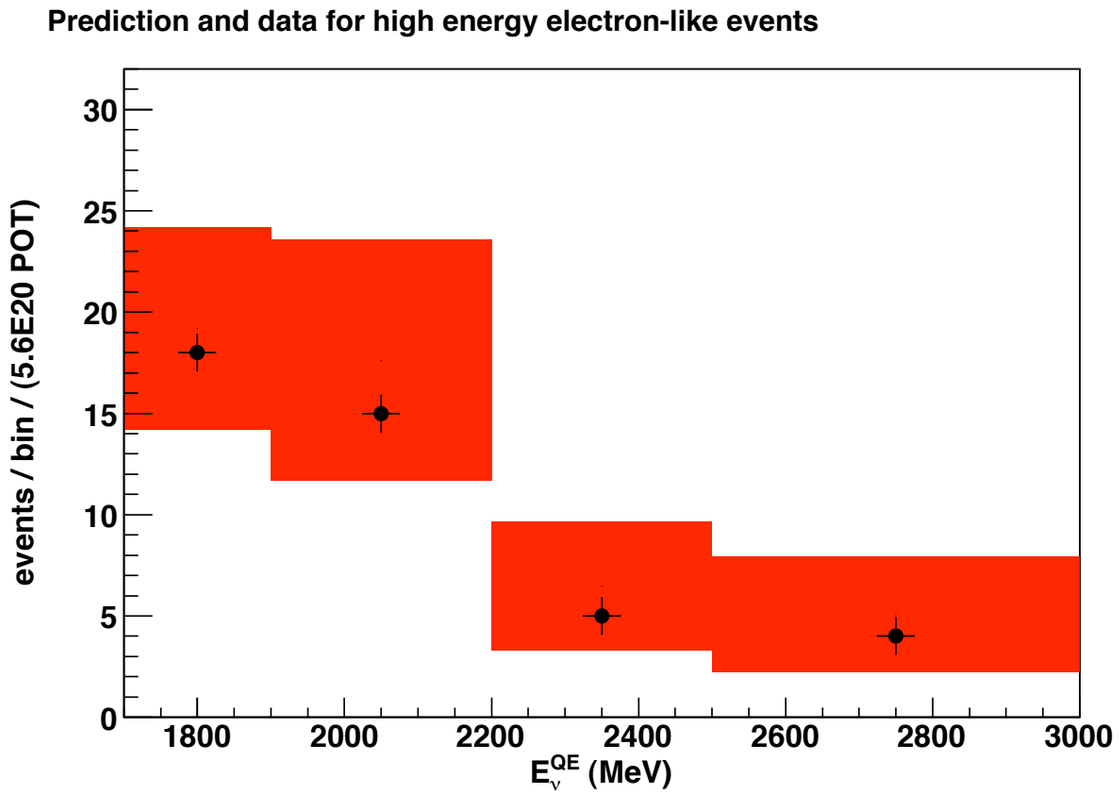


- No loss of sensitivity with increased threshold
- Sidebands also suggest issue at low energy

Re-check Data/MC agreement:
Everything is okay

More Cross checks



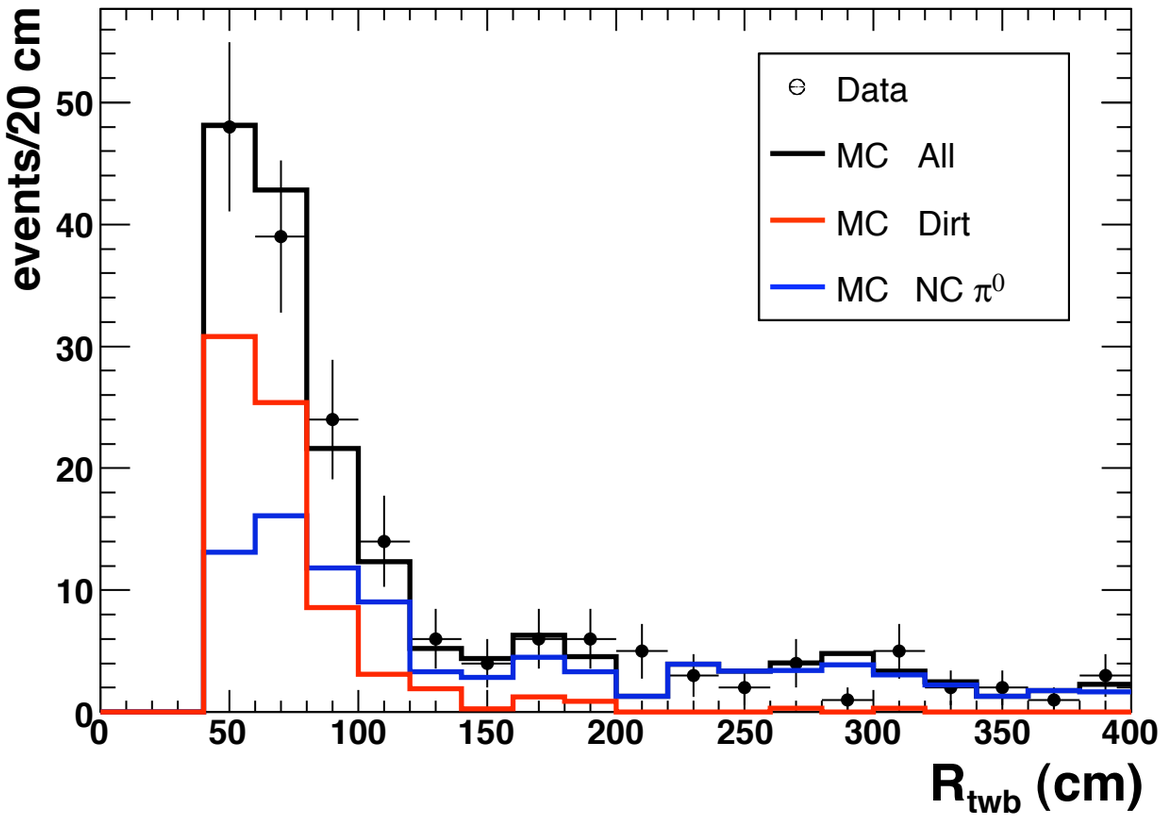


High energy region:

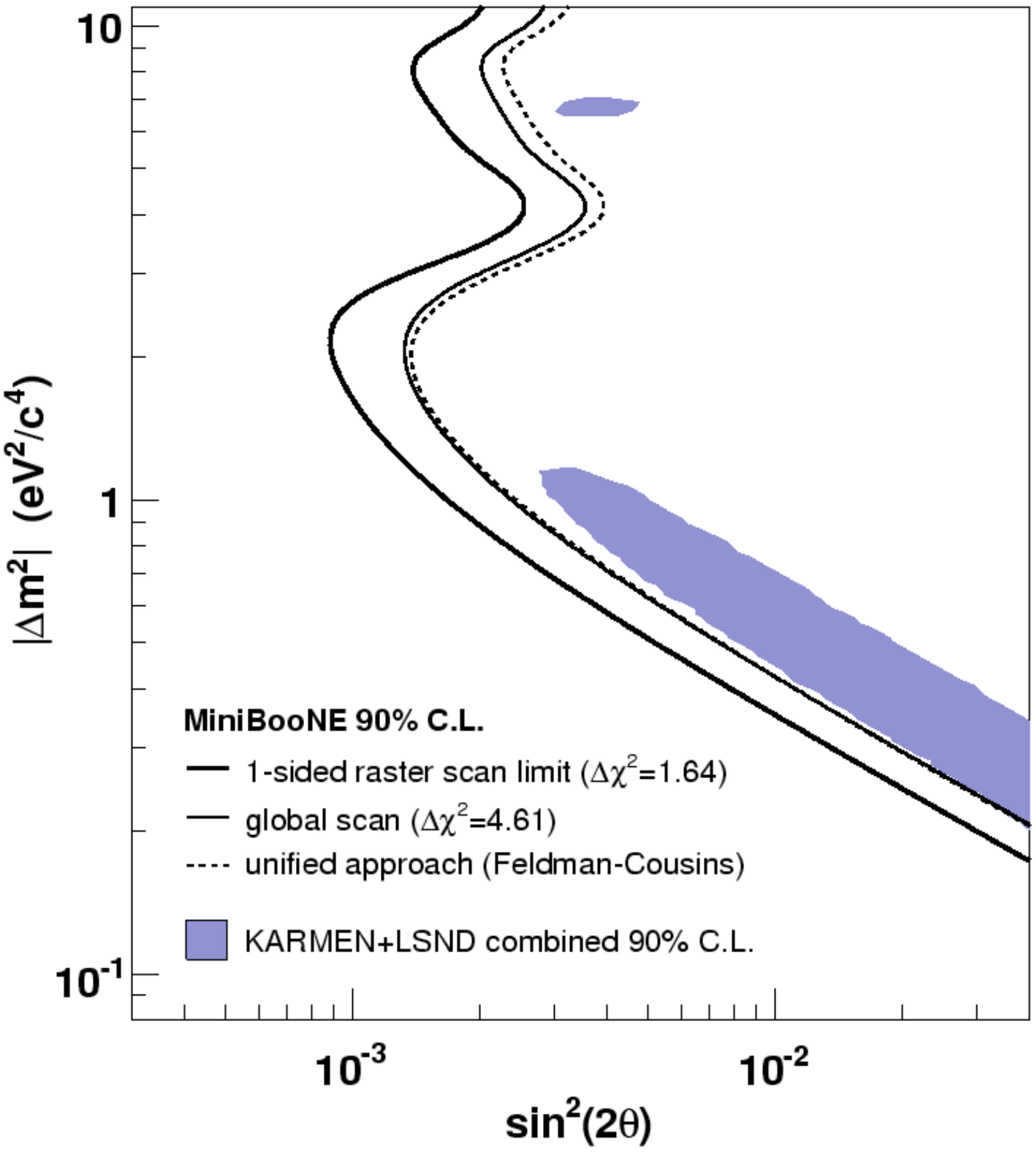
- Predominantly ν_e, but small contribution from possible signal

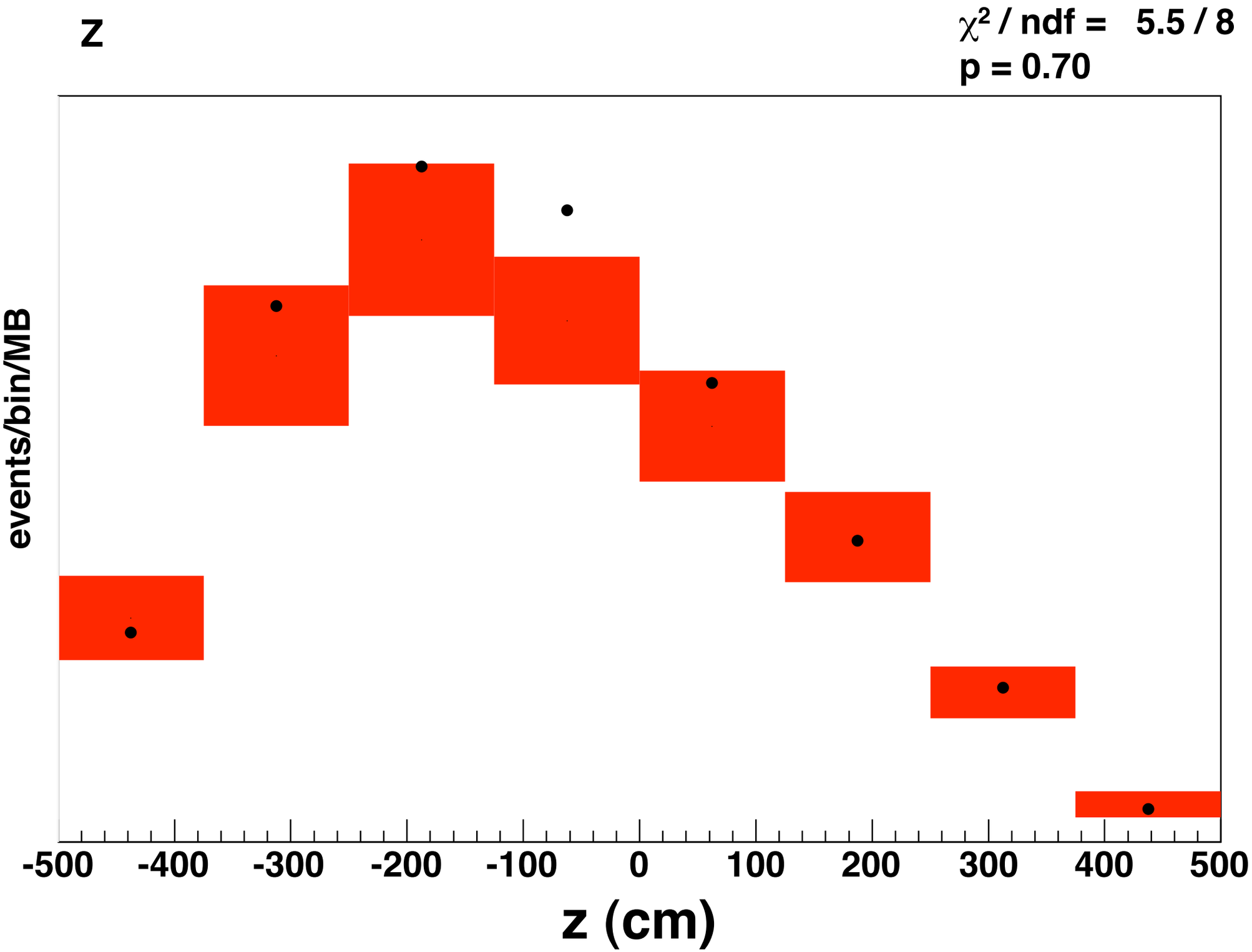
Large Radius:

- Enhanced dirt contribution



LSND/KARMEN Joint Analysis

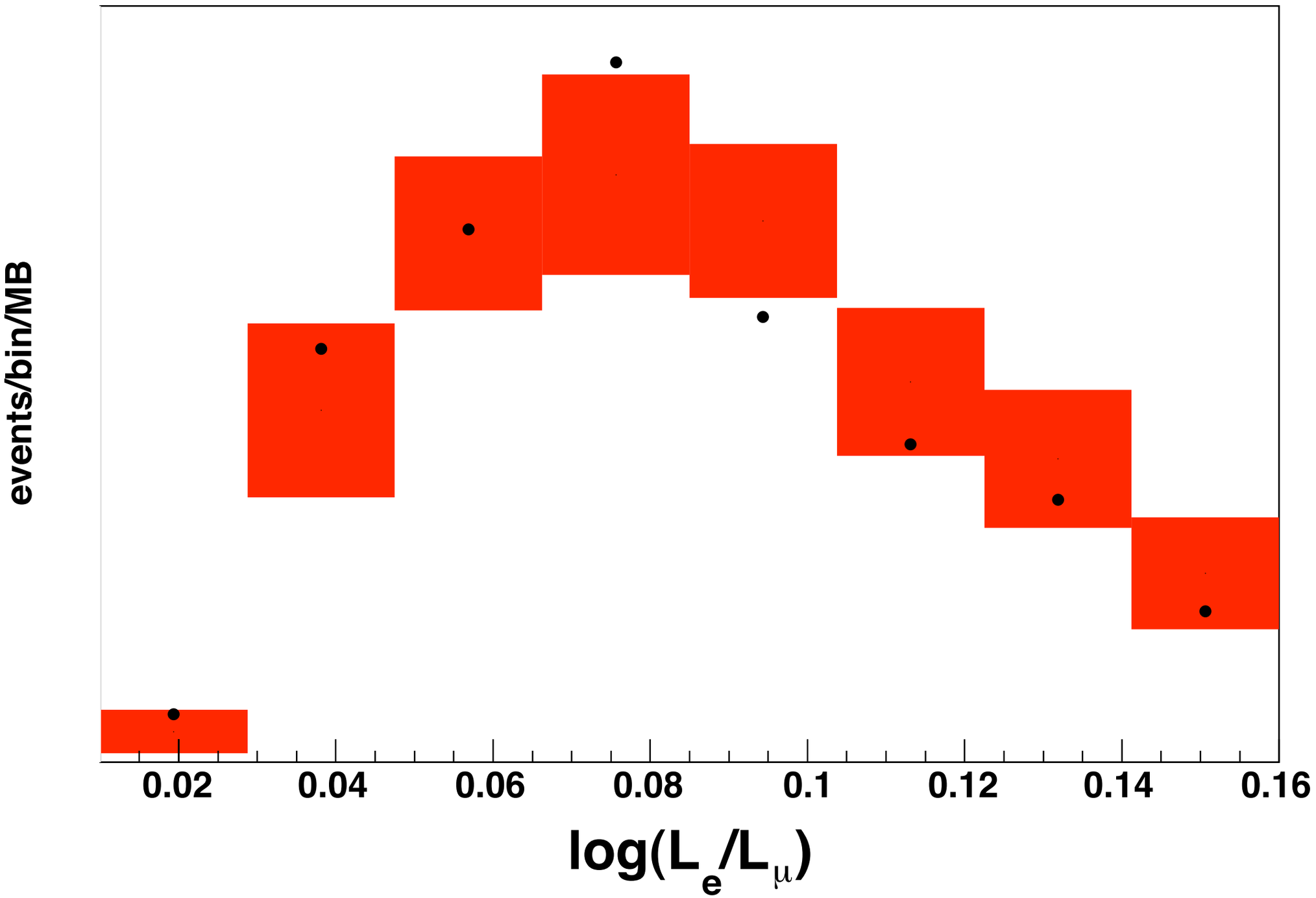




- Warning: strongly correlated errors

log(L_e/L_μ)

χ^2 / ndf = 7.2 / 8
p = 0.51



log(L_e/L_π)

χ^2 / ndf = 9.7 / 7
p = 0.21