First Neutrino Oscillation Results from MiniBooNE and Future Run Plans

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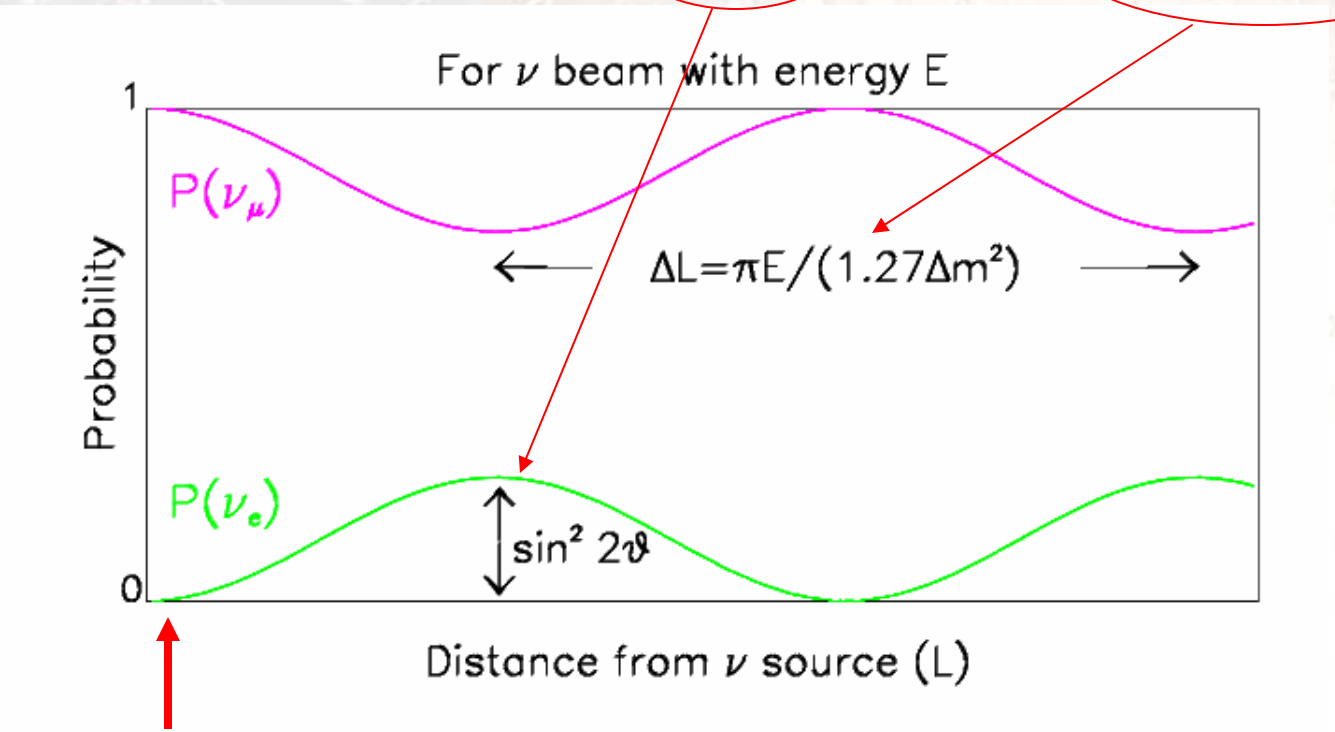
LANL, P-25

A Neutrino Oscillation Primer

$$\text{Oscillation Probability} = \sin^2 2\theta \quad \sin^2(1.27\Delta m^2 L/E)$$

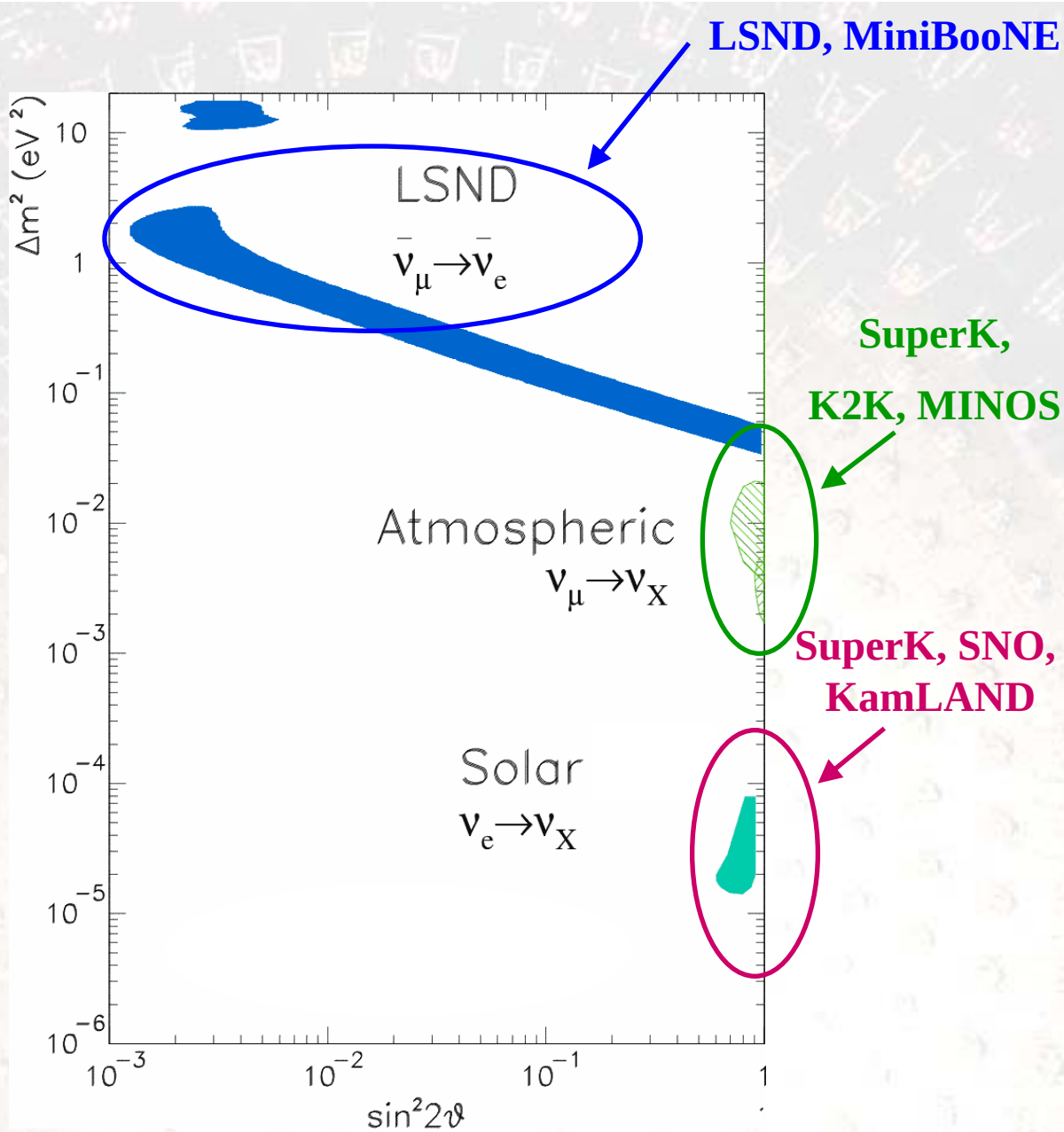


Start with pure ν_μ flavor eigenstate

Neutrinos must have mass for oscillations to occur

Areas explored by current experiments:

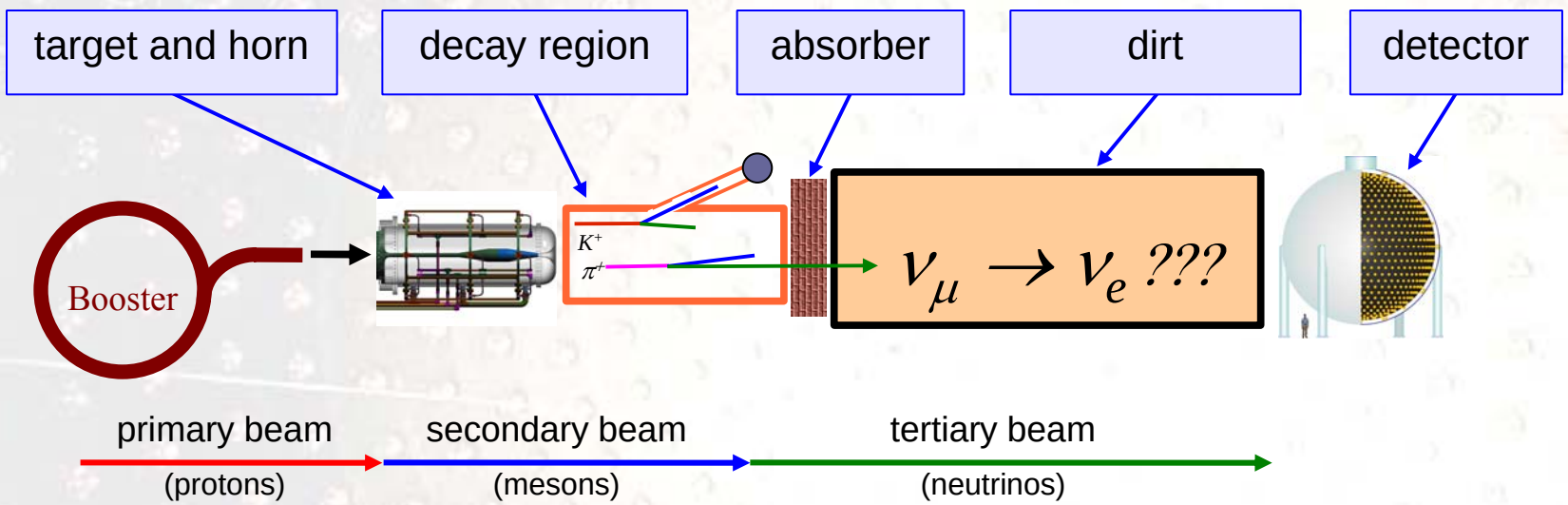
- LSND Δm^2
  - The purpose of MiniBooNE is to verify this result
- Atmospheric Δm^2
  - Verified by K2K and Minos accelerator experiments
- Solar Δm^2
  - Verified by the KAMLAND reactor experiment



The MiniBooNE Experimental Design:

While keeping L/E~1 m/MeV, as in LSND, MiniBooNE design changes the backgrounds, energy range, & event signature from the LSND case.

$$P(\nu_\mu \rightarrow \nu_e) = \sin^2 2\theta \, \sin^2(1.27\Delta m^2 L/E)$$

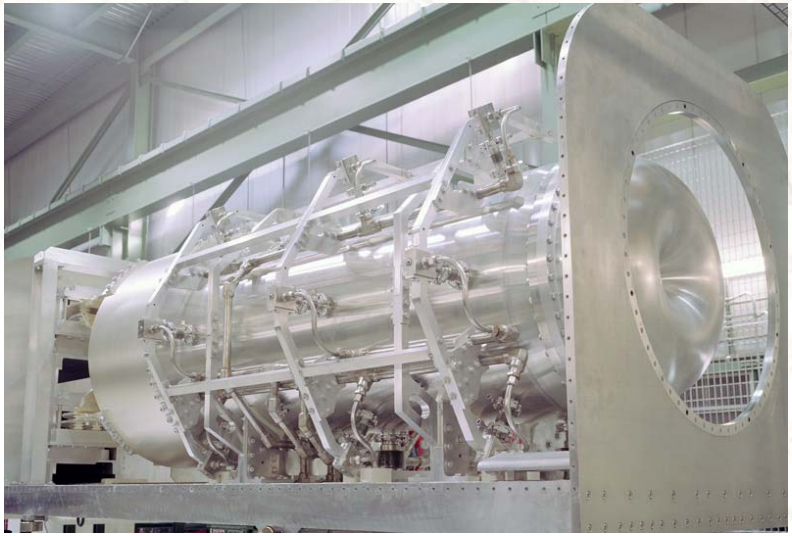


Order of magnitude higher energy (~500 MeV) than LSND (~30 MeV)

Order of magnitude longer baseline (~500 m) then LSND (~30 m)

MiniBooNE extracts beam from the 8 GeV Booster

Delivered to a 1.7 λ Be target



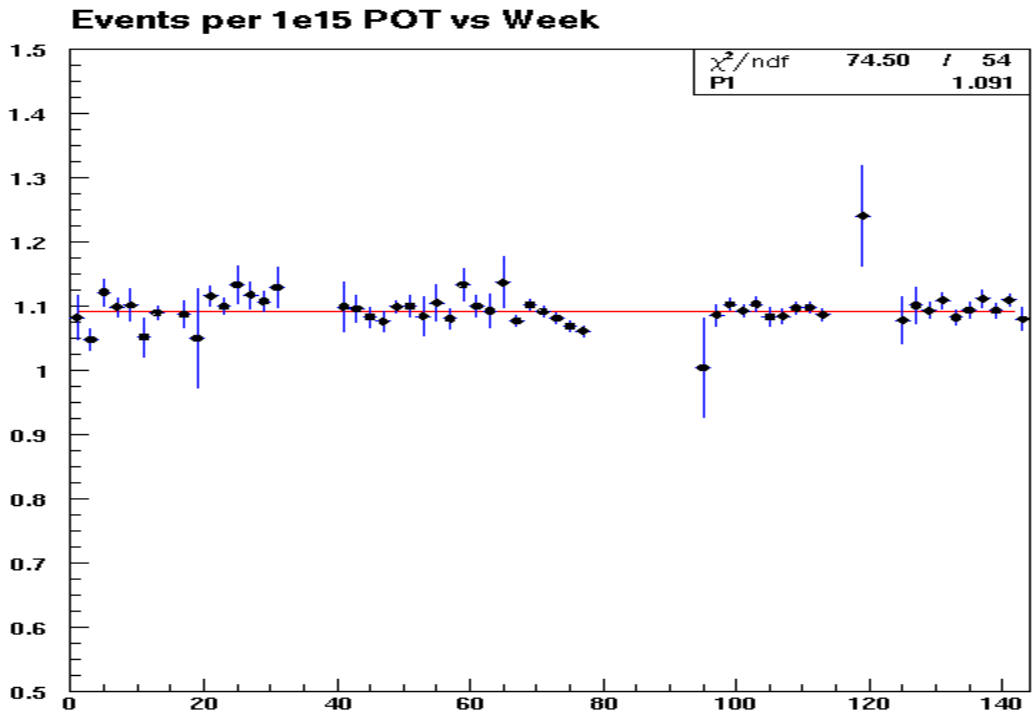
within a magnetic horn (2.5 kV, 170 kA) that (increases the flux by ×6)

4×10^{12} protons per 1.6 μs pulse delivered at up to 5 Hz.

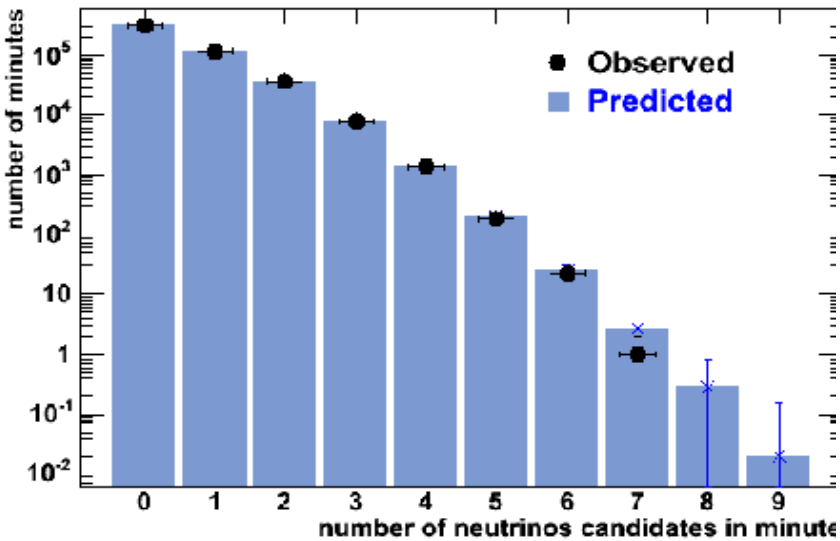
6.3×10^{20} POT delivered.

Results correspond to $(5.58 \pm 0.12) \times 10^{20}$ POT

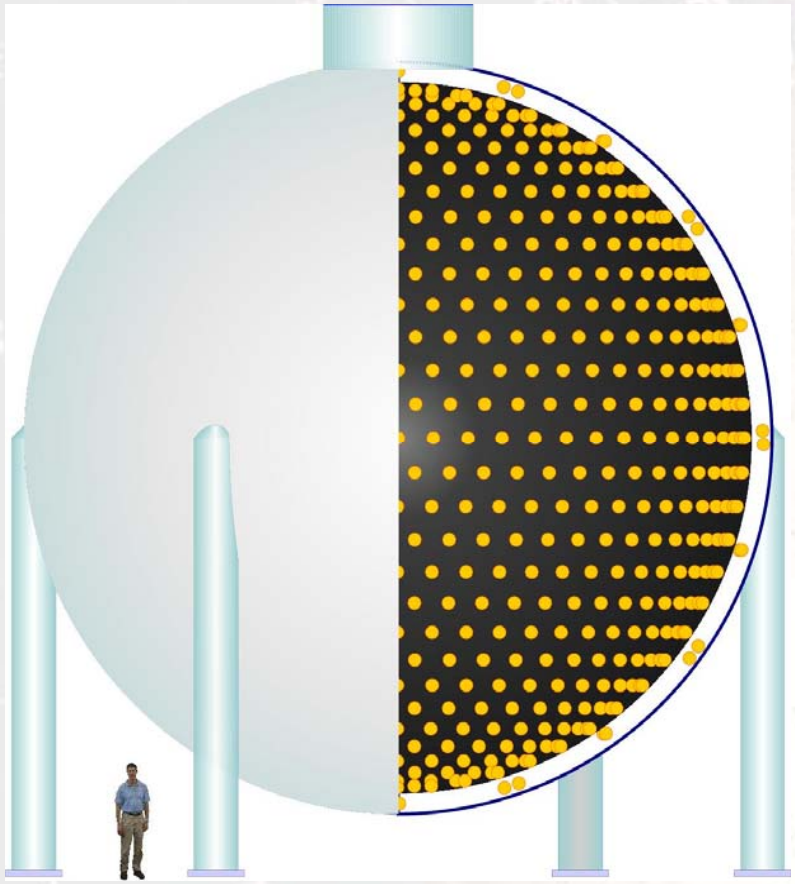
Beam and Detector stability: Neutrino events per proton-on-target



Observed and expected events per minute



The MiniBooNE Detector



- 541 meters downstream of target
- 3 meter overburden
- 12 meter diameter sphere

  (10 meter "fiducial" volume)

  - Filled with 800 tons

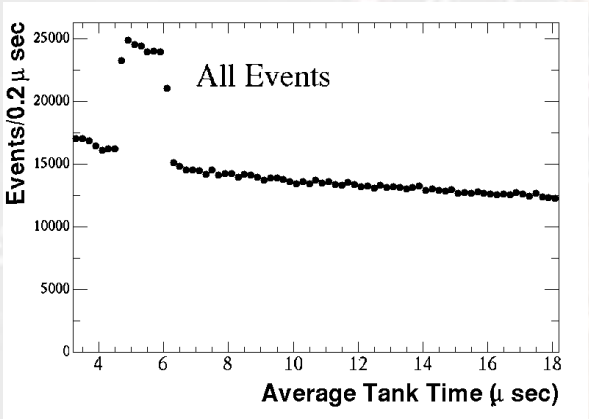
    of pure mineral oil (CH_2)

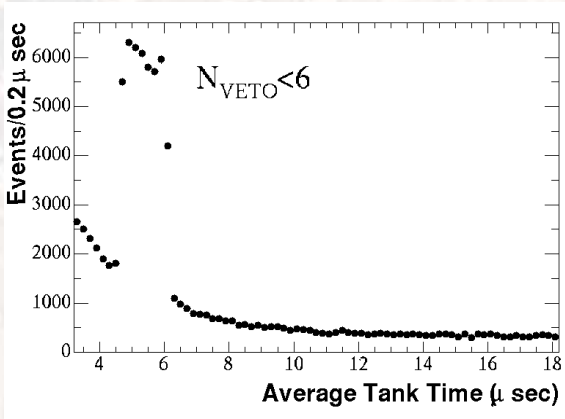
    (Fiducial volume: 450 t)
  - 1280 inner phototubes,

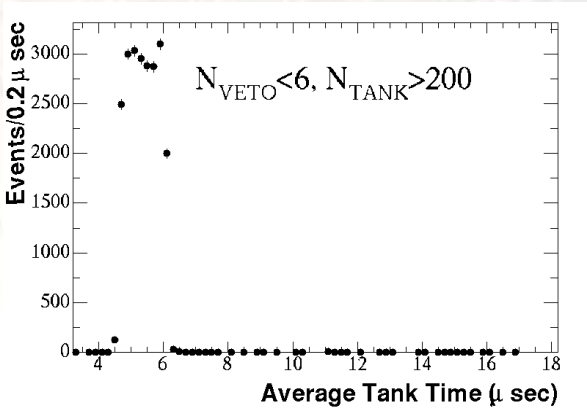
    240 veto phototubes
  - Simulated with a Geant3 Monte Carlo

A 19.2 μs beam trigger window encompasses the 1.6 μs spill

Tank time for first subevent







Raw data

Veto<6 removes Cosmic ray muons leaving " Michel electrons" ($\mu \rightarrow \nu_\mu \nu_e e$)

Tank Hits > 200 (equivalent to energy) removes Michel electrons, which have 52 MeV endpoint

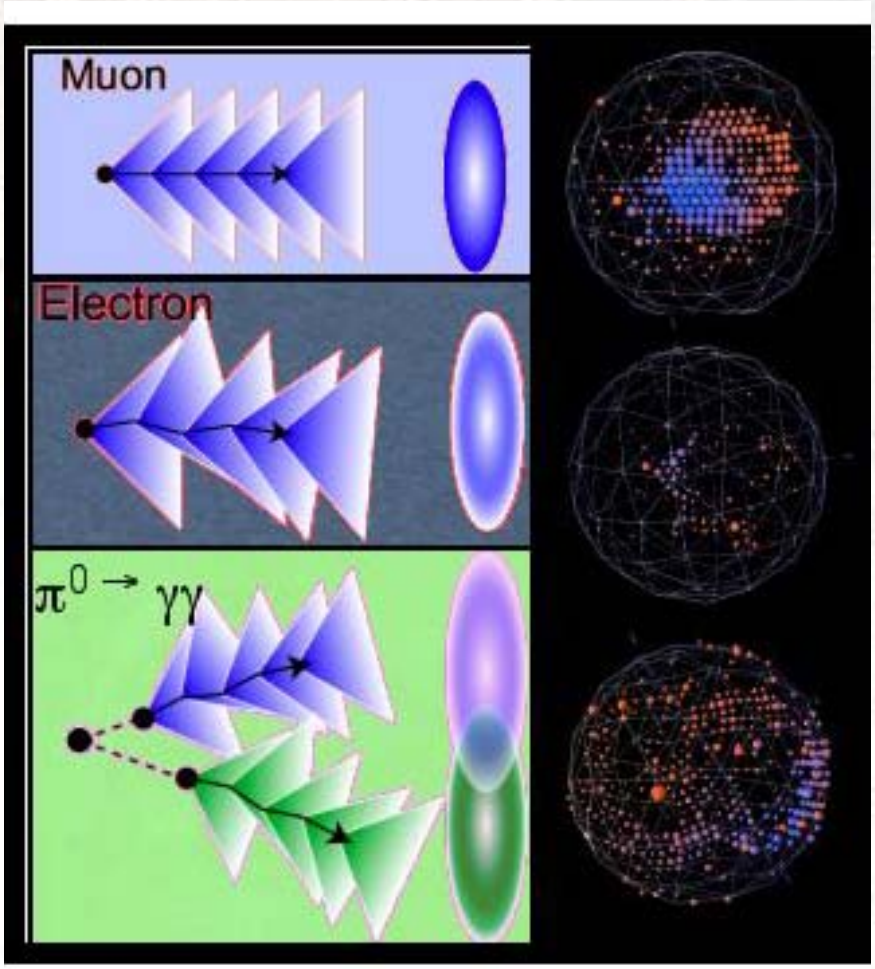
MiniBooNE is a Cerenkov Light Detector:

The main types of particles our neutrino events produce:

Muons (or charged pions):
Produced in most CC events.
Usually 2 or more subevents
or exiting through veto.

Electrons:
Tag for $\nu_\mu \rightarrow \nu_e$ CCQE signal.
1 subevent

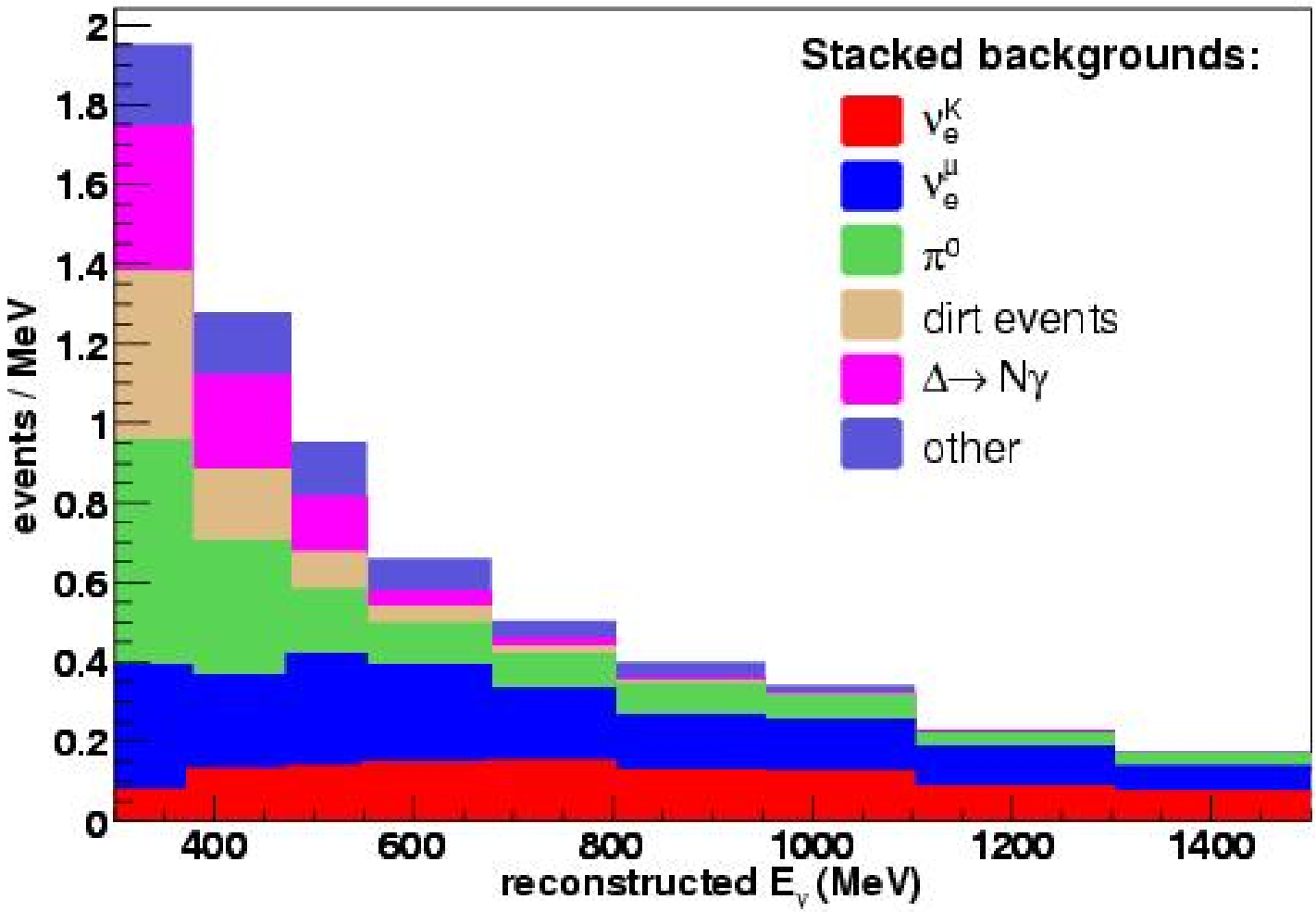
π^0s:
Can form a background if one photon is weak or exits tank.
In NC case, 1 subevent.



Summary of predicted backgrounds for the initial MiniBooNE result:

Process	Number of Events
Beam Unrelated	2
ν_μ CCQE	10
$\nu_\mu e \rightarrow \nu_\mu e$	7
Miscellaneous ν_μ Events	13
NC π^0	62
NC $\Delta \rightarrow N\gamma$	20
NC Coherent & Radiative γ	< 1
Dirt Events	17
ν_e from μ Decay	132
ν_e from K^+ Decay	71
ν_e from K_L^0 Decay	23
ν_e from π Decay	3
Total Background	358
0.26% $\nu_\mu \rightarrow \nu_e$	(example signal) 163

Backgrounds as a Function of Reconstructed Energy



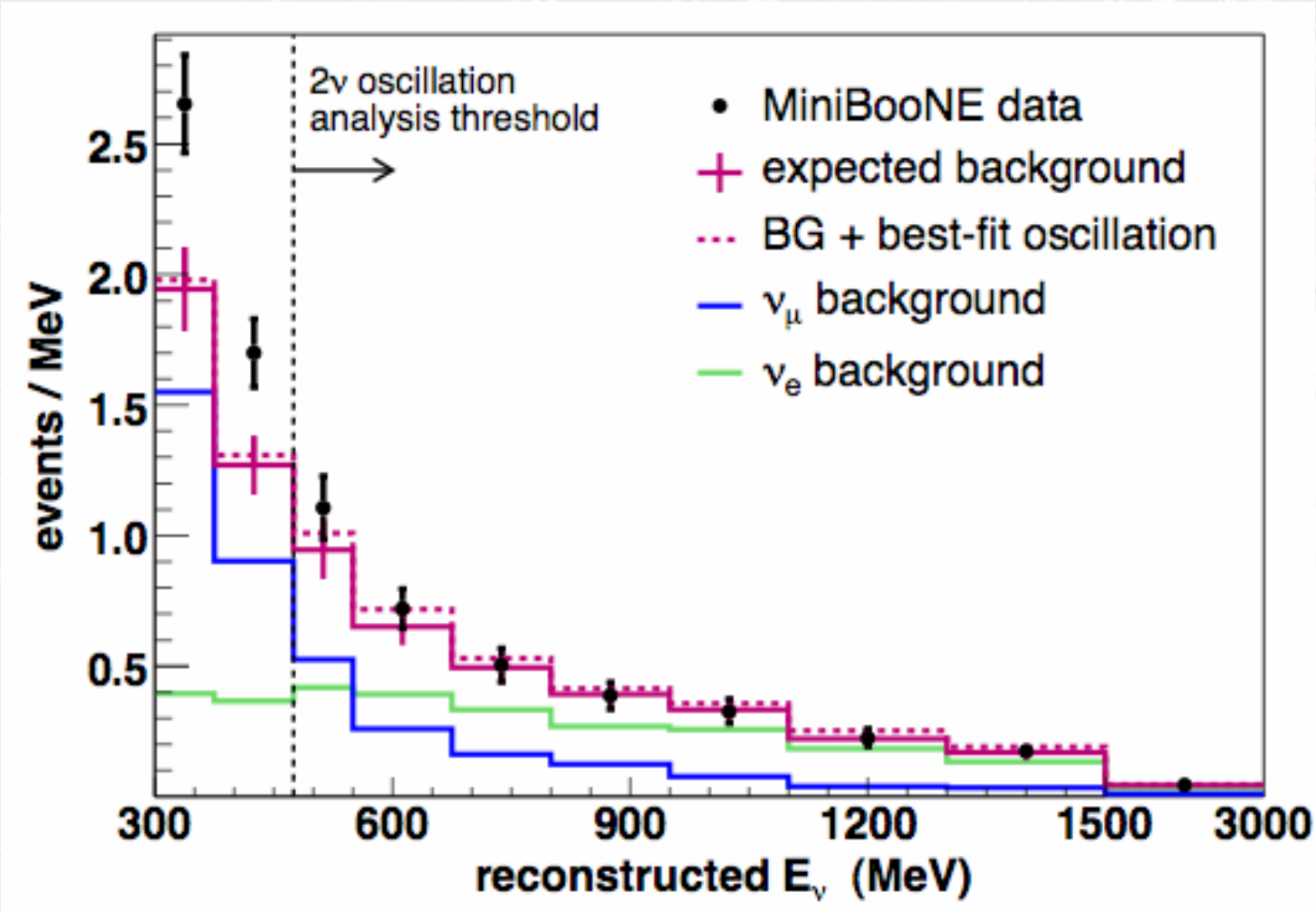
Event counting result: $475 < E_\nu^{QE} < 1250$ MeV

Measured data: 380 events

Null expectation: 358 ±19 (stat) ± 35 (sys) events

significance:
0.55 σ

$\nu_\mu \rightarrow \nu_e$ hypothesis fit result: 475 – 3000 MeV

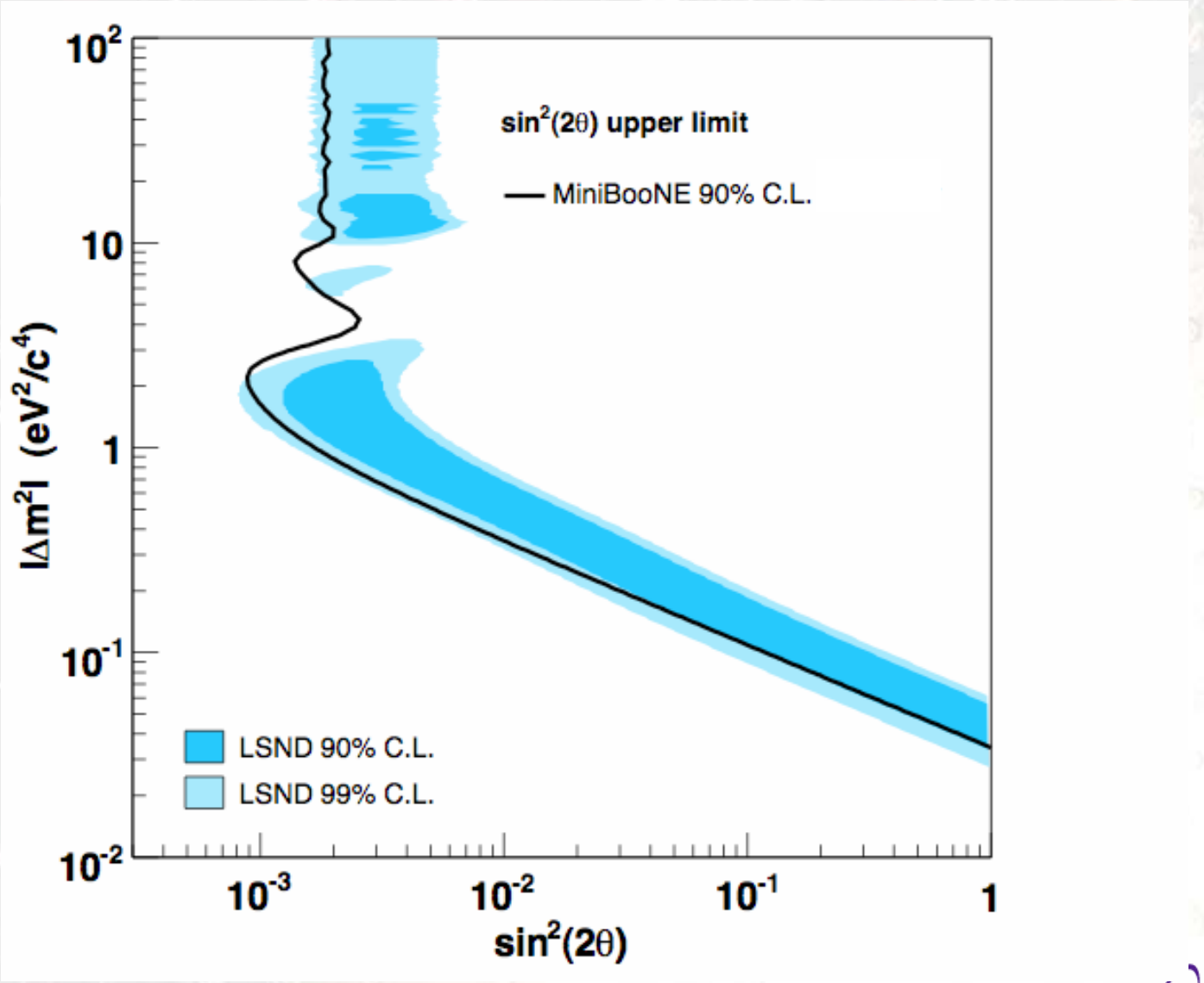


Error bars are the diagonal elements of the error matrix.

Fit errors for >475 MeV:
Normalization 9.6%
Energy scale: 2.3%

Best Fit (dashed): $(\sin^2 2\theta, \Delta m^2) = (0.001, 4\ \mathrm{eV}^2)$
Probability of Null Fit: 93%
Probability of Best Fit: 99%

MiniBooNE 2-neutrino model 90%CL limit:

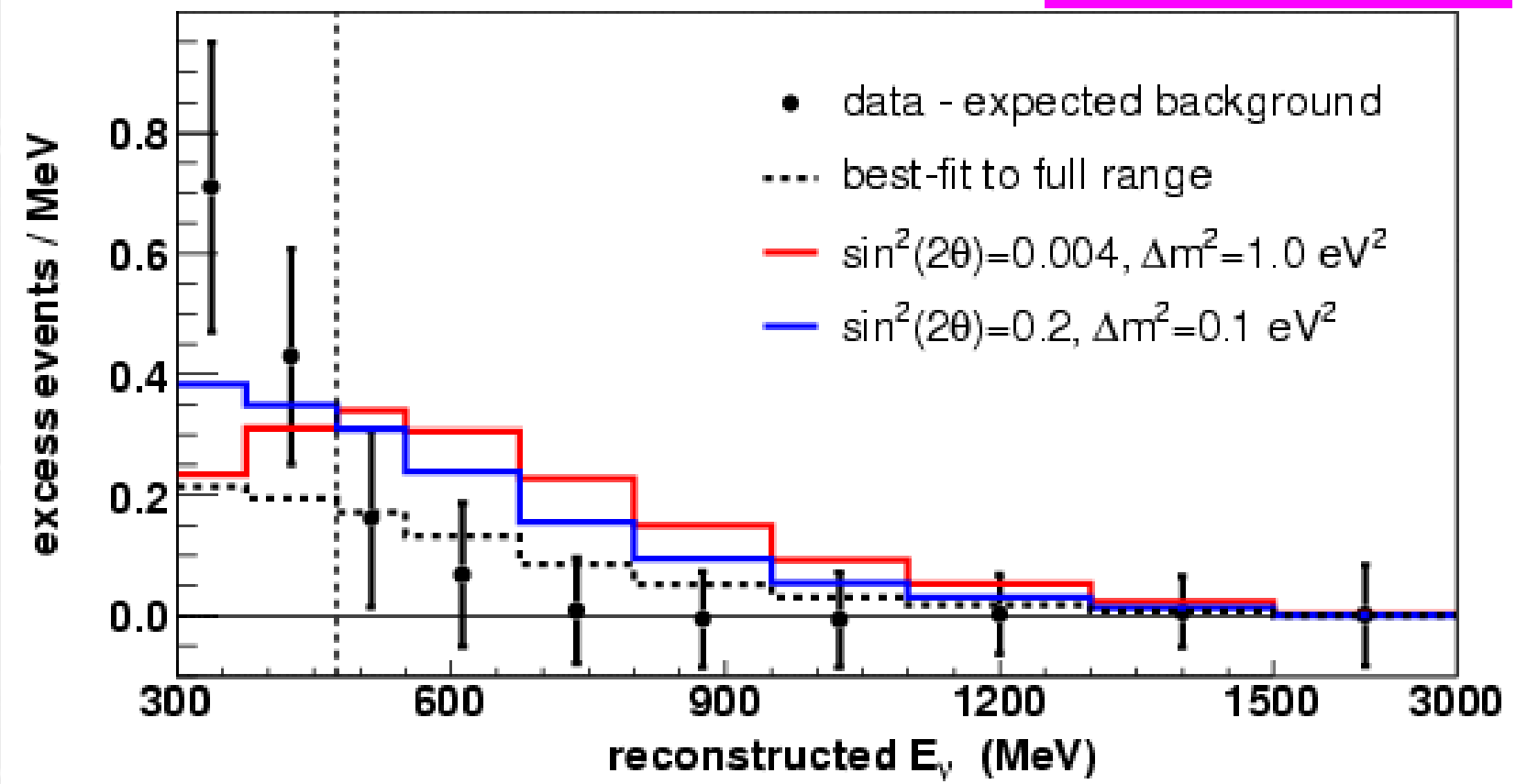


Fit to the full energy range: > 300 MeV

Best Fit (dashed): $(\sin^2 2\theta, \Delta m^2) = (1.0, 0.03\ eV^2)$

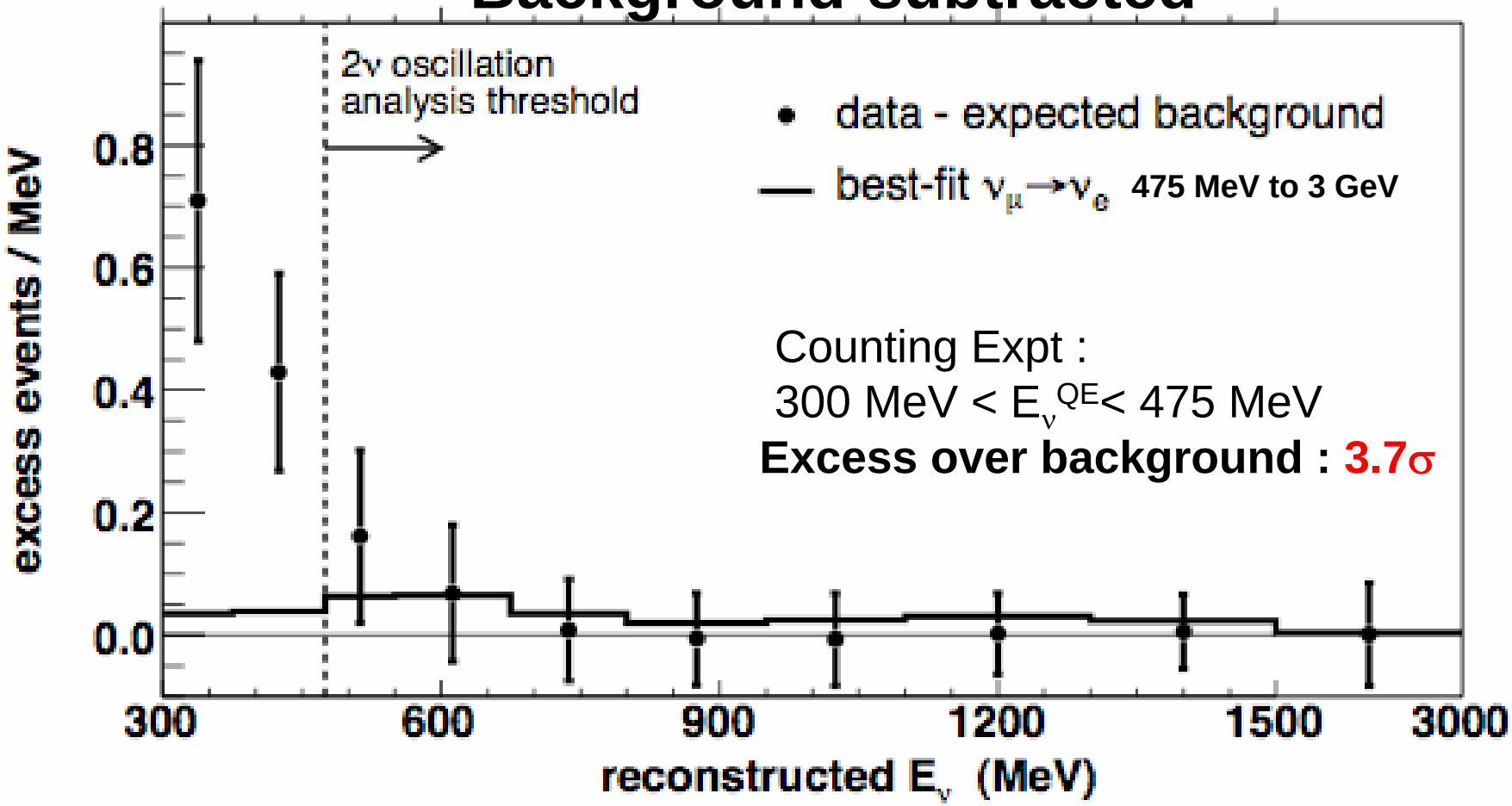
χ^2 Probability: 18%, Null Hypothesis= 3%

Excluded by Bugey!



Observed Event Distribution

Background-subtracted



Counting Expt :
300 MeV < E_ν^{QE}< 475 MeV

Excess over background : 3.7σ

Conclusions of Oscillation Analysis:

⇒A simple 2-neutrino appearance-only model of LSND disagrees with the shape as a function of energy.

⇒The low energy excess of events requires further investigation.

⇒ We will investigate other explanations, including unexpected behavior of low energy cross sections.

Future Analysis Plans

- Understand low E excess, if not a background, then has huge physics implications:
  - Sterile neutrinos.
  - (3+2)CP models.
  - Lorentz violation.
  - Extra dimensions (ya, for real!)
- Numerous cross section measurements.

Future Run Plans

- SciBooNE running after 2007 shutdown
  - 1E20 POT neutrino mode.
  - 1E20 POT antineutrino mode.
- MiniBooNE will seek approval from PAC and 2nd floor to run concurrently with SB.
- Will most likely ask for a further ~4E20 POT in antineutrino mode to make a significant oscillation measurement with antineutrinos.
  - Test LSND directly, and test CP and CPT oscillation models.

THANKS!

- Without the efforts of the Proton source group, none of the physics measurements made by MiniBooNE would have been possible!
- You should take great pride in these results, as they are the direct result of your outstanding efforts!!