MiniBooNE and BooNE

1. MiniBooNE Appearance Results
2. Other Anomalies
3. Resolution: The BooNE Proposal
4. Conclusions

Geoffrey Mills
Los Alamos National Laboratory
SBNP Workshop
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Synopsis:

- A number of anomalies are appearing in neutrino data in the region of $\Delta m^2 \sim$ an eV^2
- Predominantly from single detector experiments…
- There is some possibility that the effects are due to oscillations between sterile neutrinos and active neutrinos
- A definitive experiment is warranted
- BooNE would be such an experiment

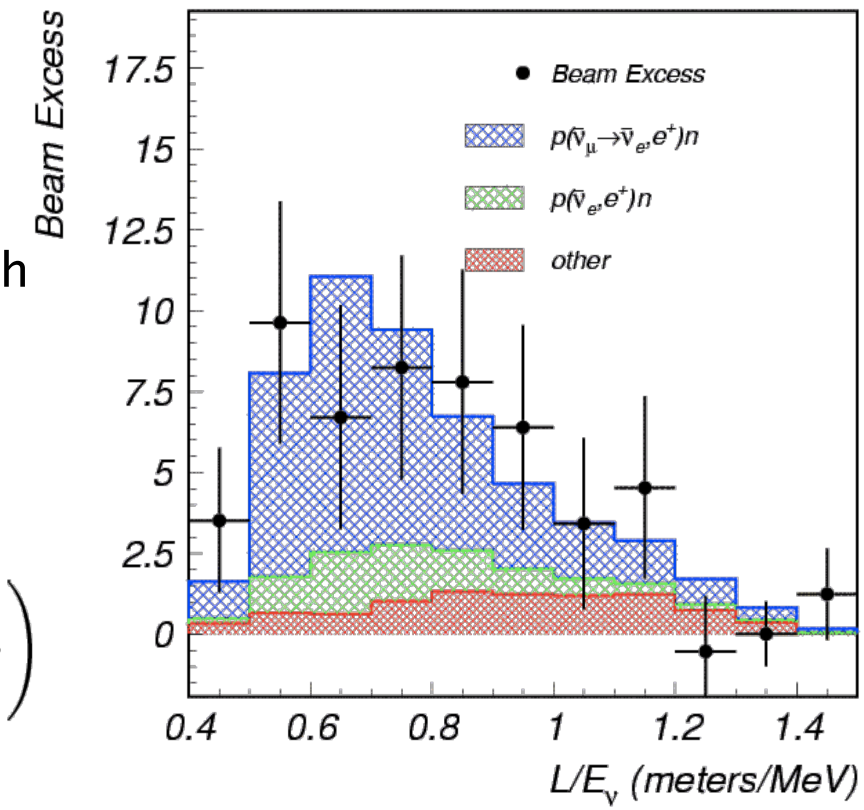
Anomalies in Neutrino Data

Motivation….

Excess Events from LSND still remain:

- LSND found an excess of $\overline{\nu}_e$ in $\overline{\nu}_\mu$ beam
- Signature: Cerenkov light from e^+ with delayed n-capture (2.2 MeV)
- Excess: 87.9 ± 22.4 ± 6.0 (3.8s)
- *The data was analysed under a two neutrino mixing hypothesis**

$$P(\overline{\nu}_\mu \to \overline{\nu}_e) = \sin^2(2\theta)\sin^2\left(\frac{1.27\, L\, \Delta m^2}{E}\right)$$
$$= 0.245 \pm 0.067 \pm 0.045\ \%$$



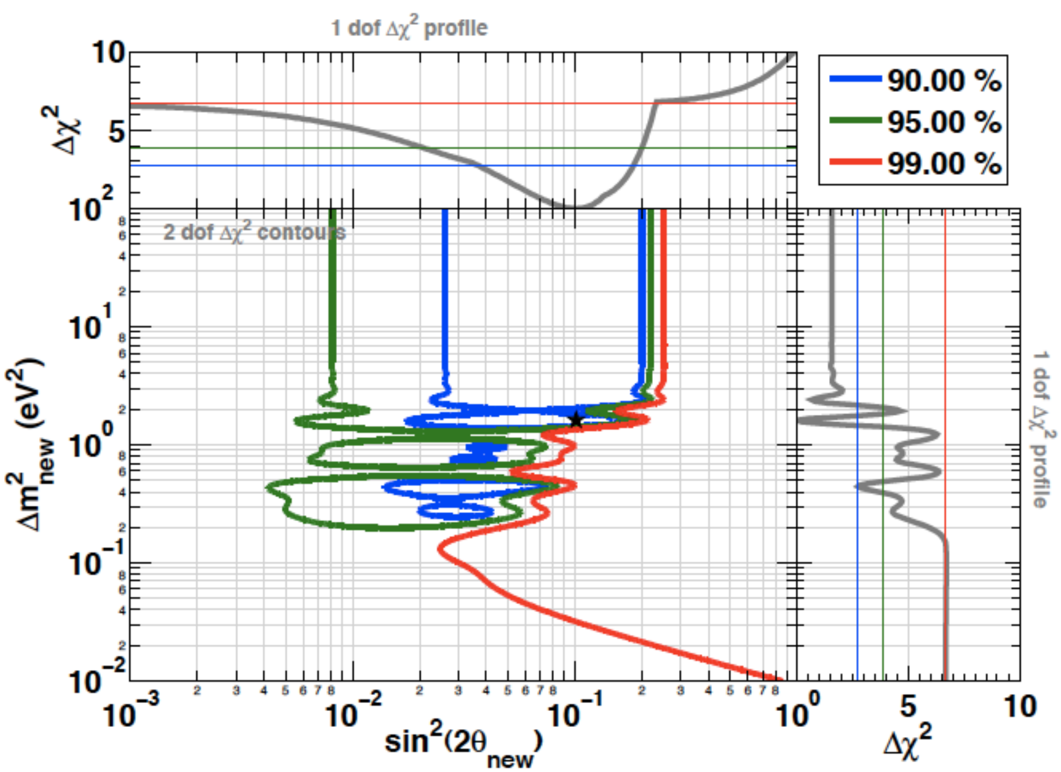
KARMEN at a distance of 17 meters saw no evidence for oscillations →low Δm^2

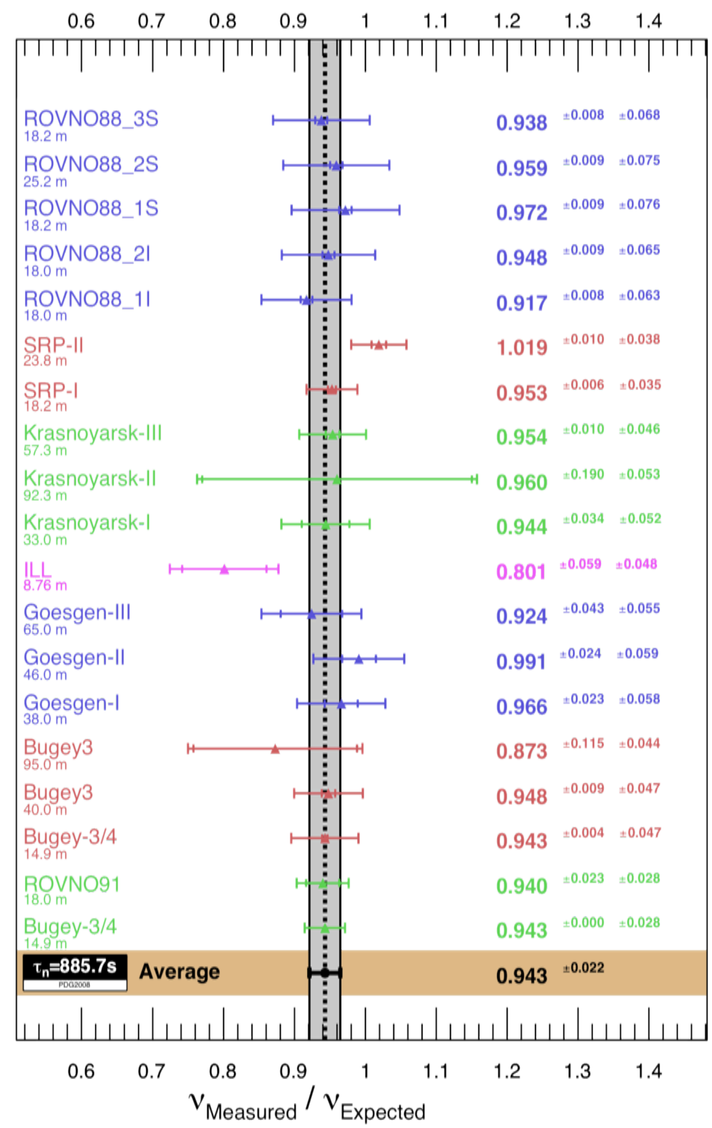
Reactor Anomaly in $\bar{\nu}_e$ Data

- Inclusion of new beta decay estimates in reactor flux calculations
- Increases expected flux

  Best fit: 0.943 ± 0.023

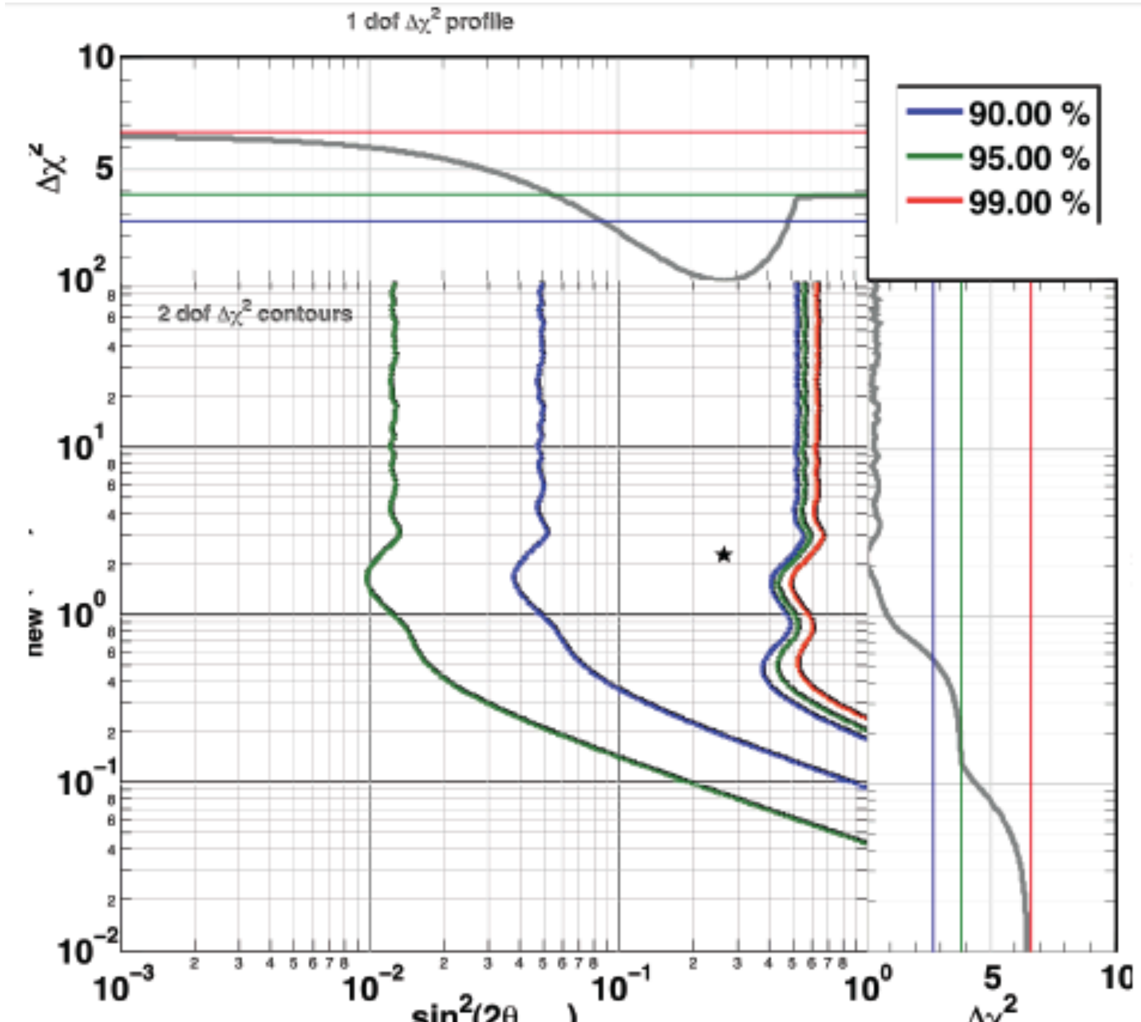
  P_{osc}~10%, Δm^2~1 eV^2





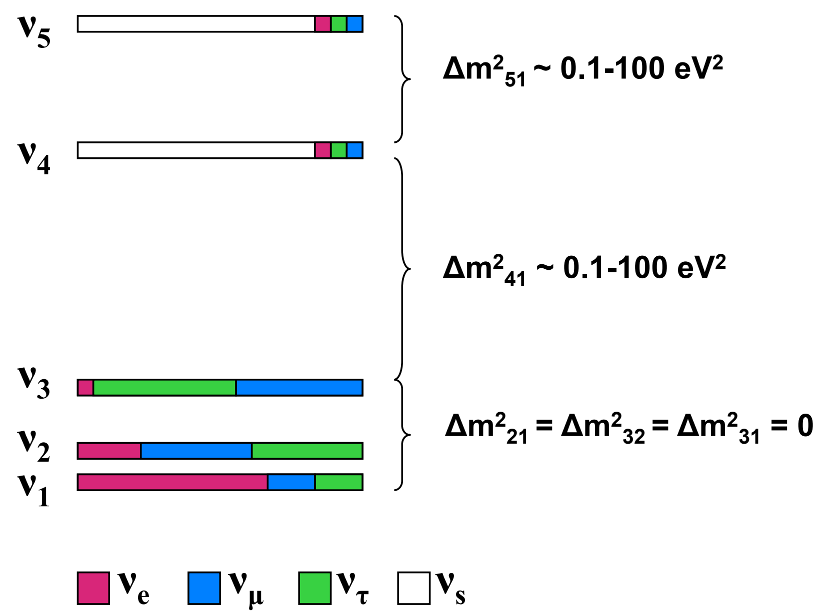
Gallium Source Anomaly in ν_e Data

- Observed too few ν_e interactions observed from an electron capture source



Can the anomalies be due to a more complicated oscillation picture?

- Sterile neutrino models
  - 3+2 → next minimal extension to 3+1 models



•2 independent Δm^2

•4 mixing parameters

•1 Dirac CP phase which allows difference between neutrinos and antineutrinos

Oscillation probability:

$$P(\overset{(-)}{\nu}_\mu \rightarrow \overset{(-)}{\nu}_e) = 4|U_{\mu 4}|^2|U_{e4}|^2\sin^2 x_{41} + 4|U_{\mu 5}|^2|U_{e5}|^2\sin^2 x_{51} +$$
$$+\, 8\,|U_{\mu 5}||U_{e5}||U_{\mu 4}||U_{e4}|\sin x_{41}\sin x_{51}\cos(x_{54}\pm\varphi_{45})$$

$$\Delta m^2_{\bar{\nu}} \overset{?}{=} \Delta m^2_{\nu}$$

Cosmology Fits for the Number of Sterile Neutrinos

•CMB + LSS + ΛCDM

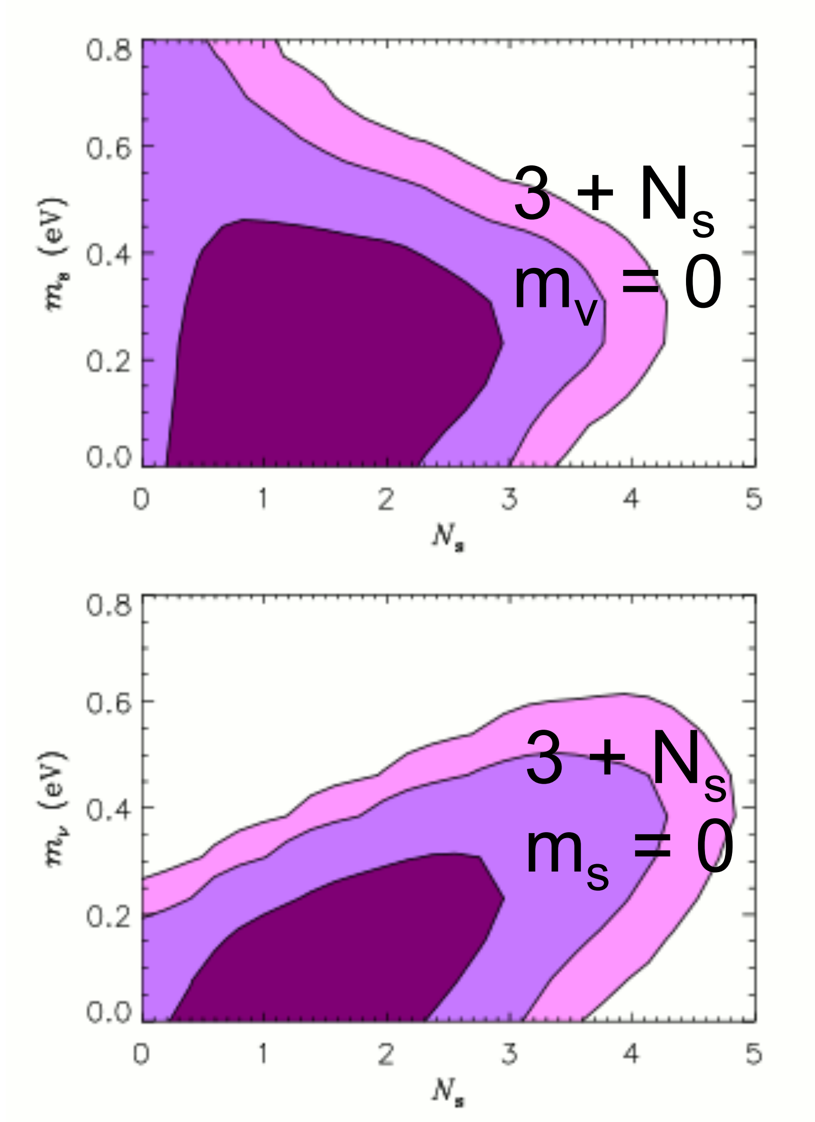
N_s= 1.6 ± 0.9

Hamann, Hannestad, Raffelt, Tamborra, Wong, PRL 105 (2010) 181301

• BBN:

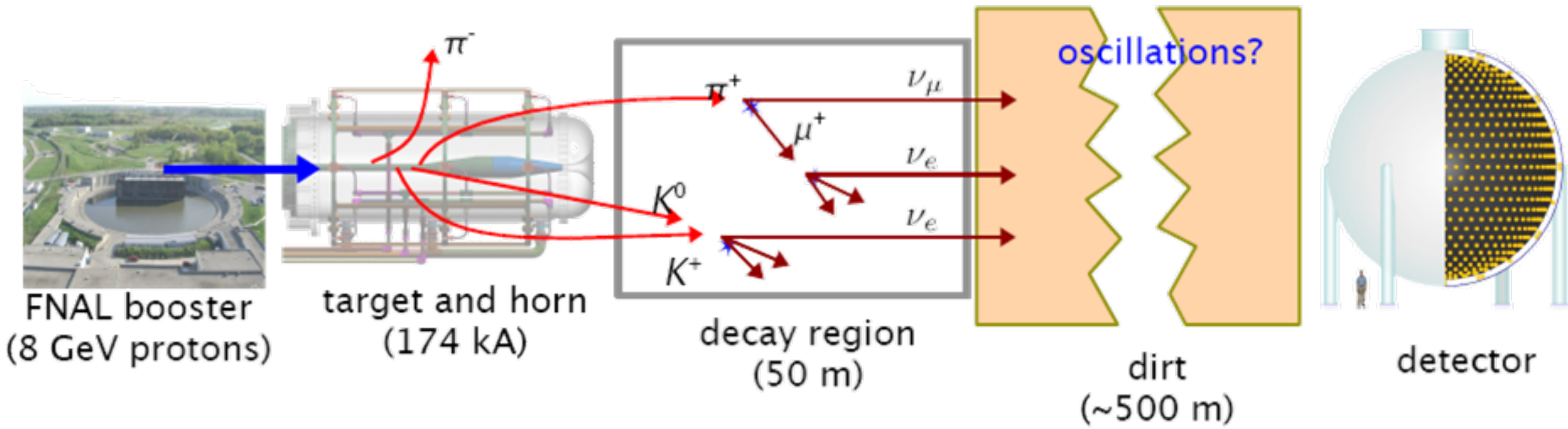
N_s= 0.64 ± 0.4

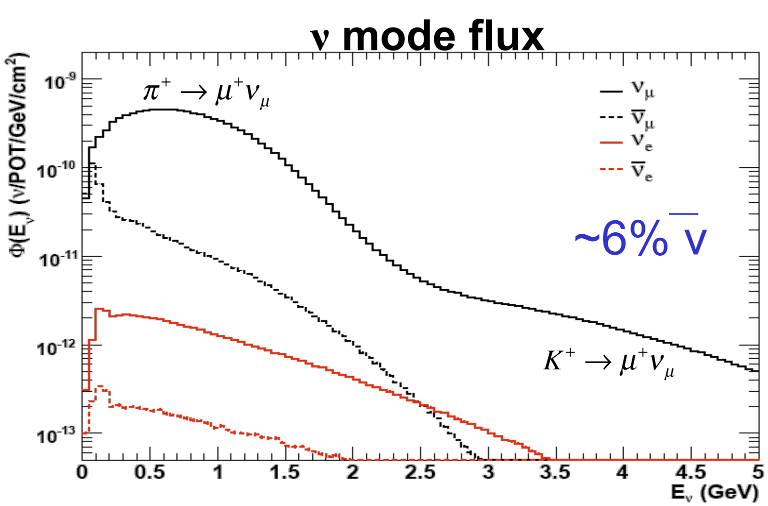
Izotov, Thuan, ApJL 710 (2010) L67

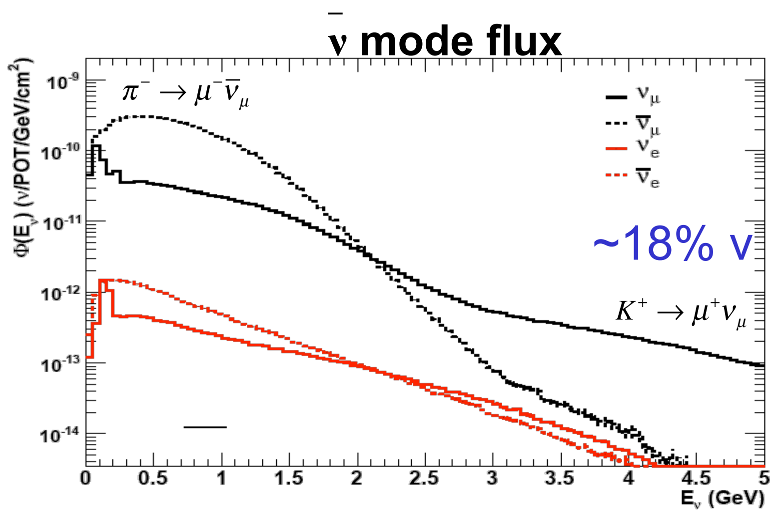


MiniBooNE Data

MiniBooNE looks for an excess of electron neutrino events in a predominantly muon neutrino beam





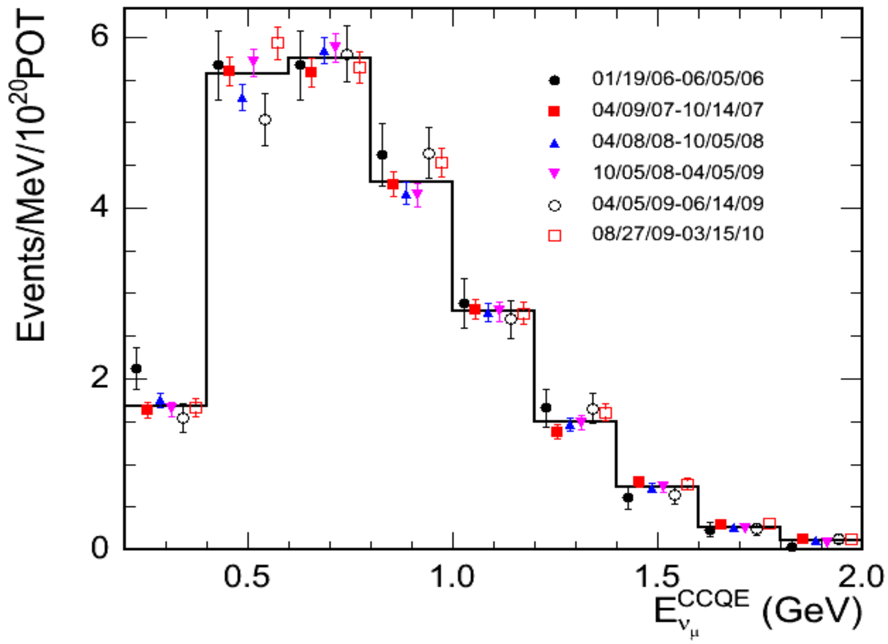


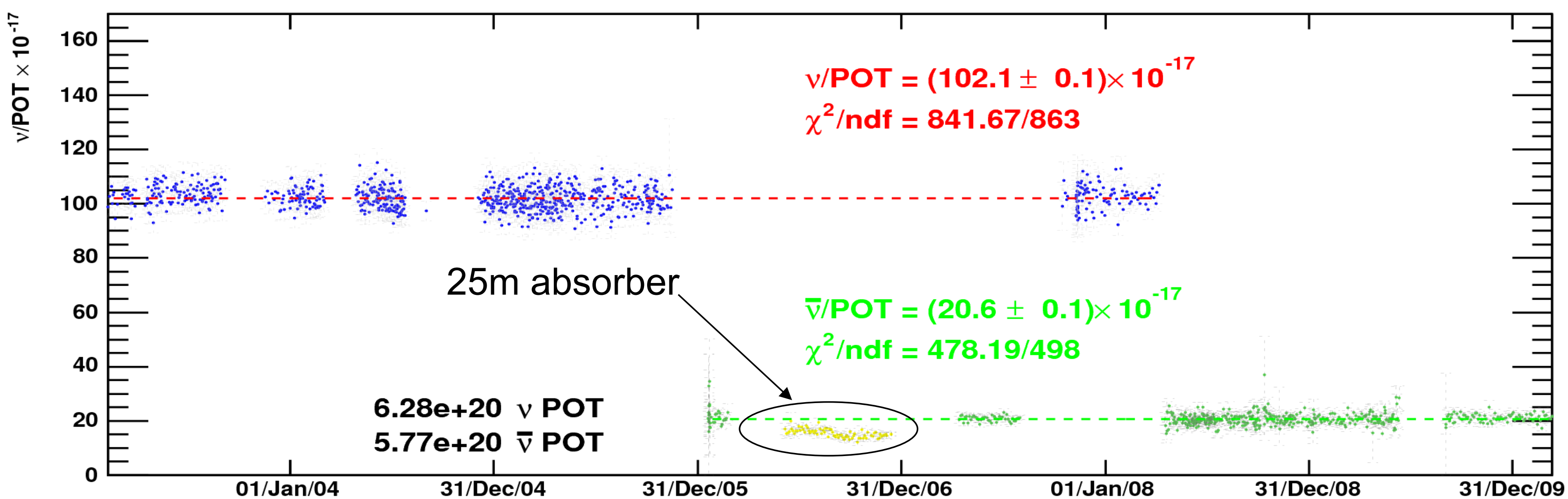
neutrino mode: $\nu_\mu \to \nu_e$ oscillation search

antineutrino mode: $\bar{\nu}_\mu \to \bar{\nu}_e$ oscillation search

Data stability

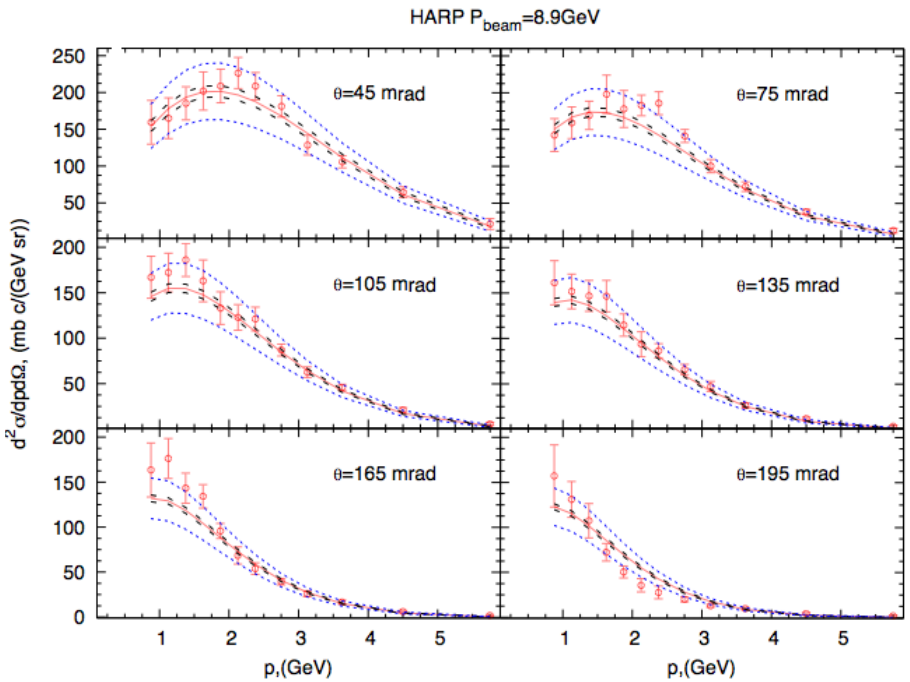
- Very stable throughout the run





Meson production at the Proton Target

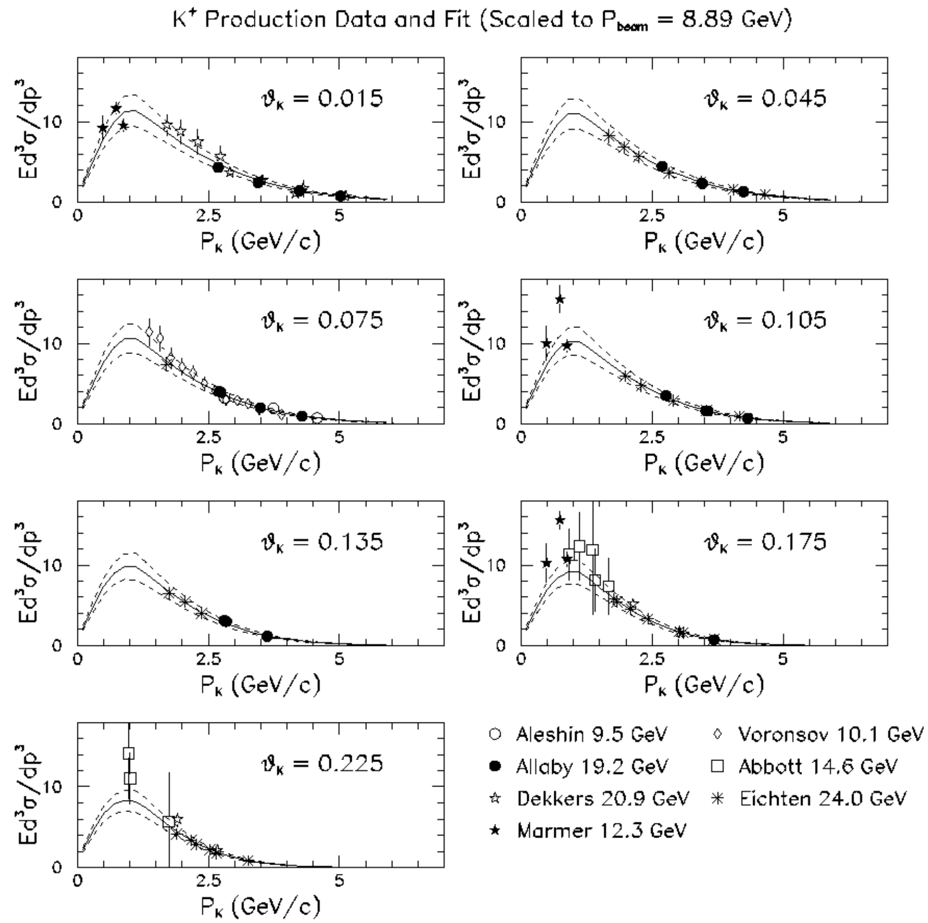
Pions(+/-):



HARP collaboration,
hep-ex/0702024

- MiniBooNE members joined the HARP collaboration
  - 8 GeV proton beam
  - 5% Beryllium target
- Spline fits were used to parameterize the data.

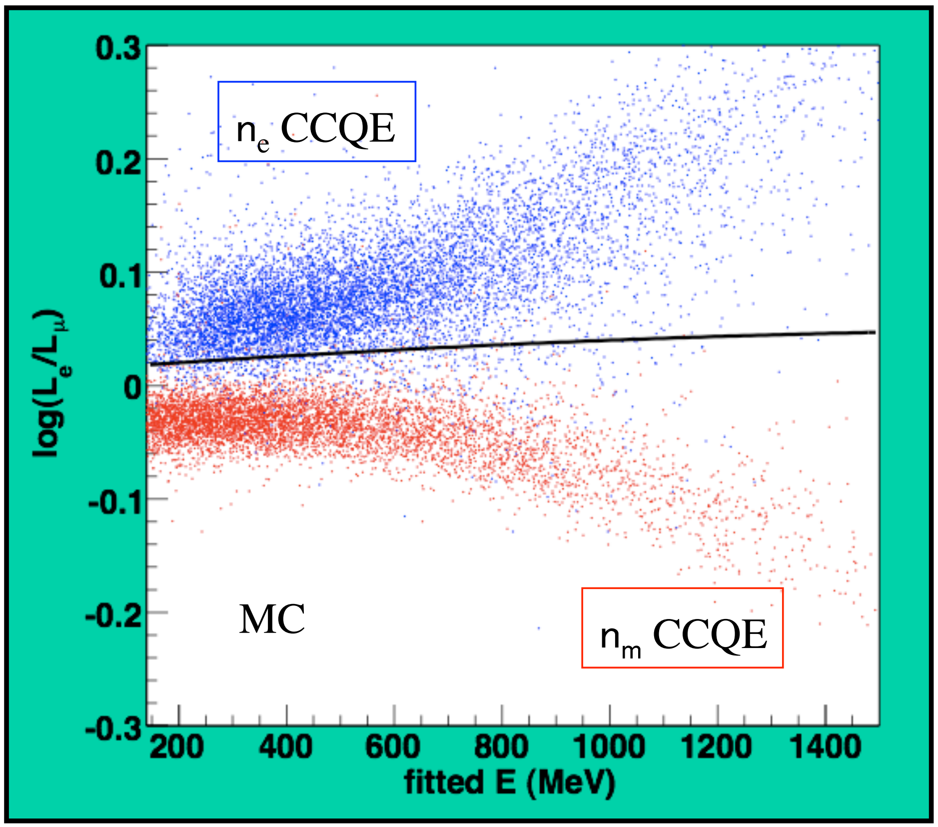
Kaons:



- Kaon data taken on multiple targets in 10-24 GeV range
- Fit to world data using Feynman scaling
- 30% overall uncertainty assessed

Separating muon-like and electron-like events by using a likelihood ratio technique

$\log(L_e/L_m)>0$ favors electron-like hypothesis



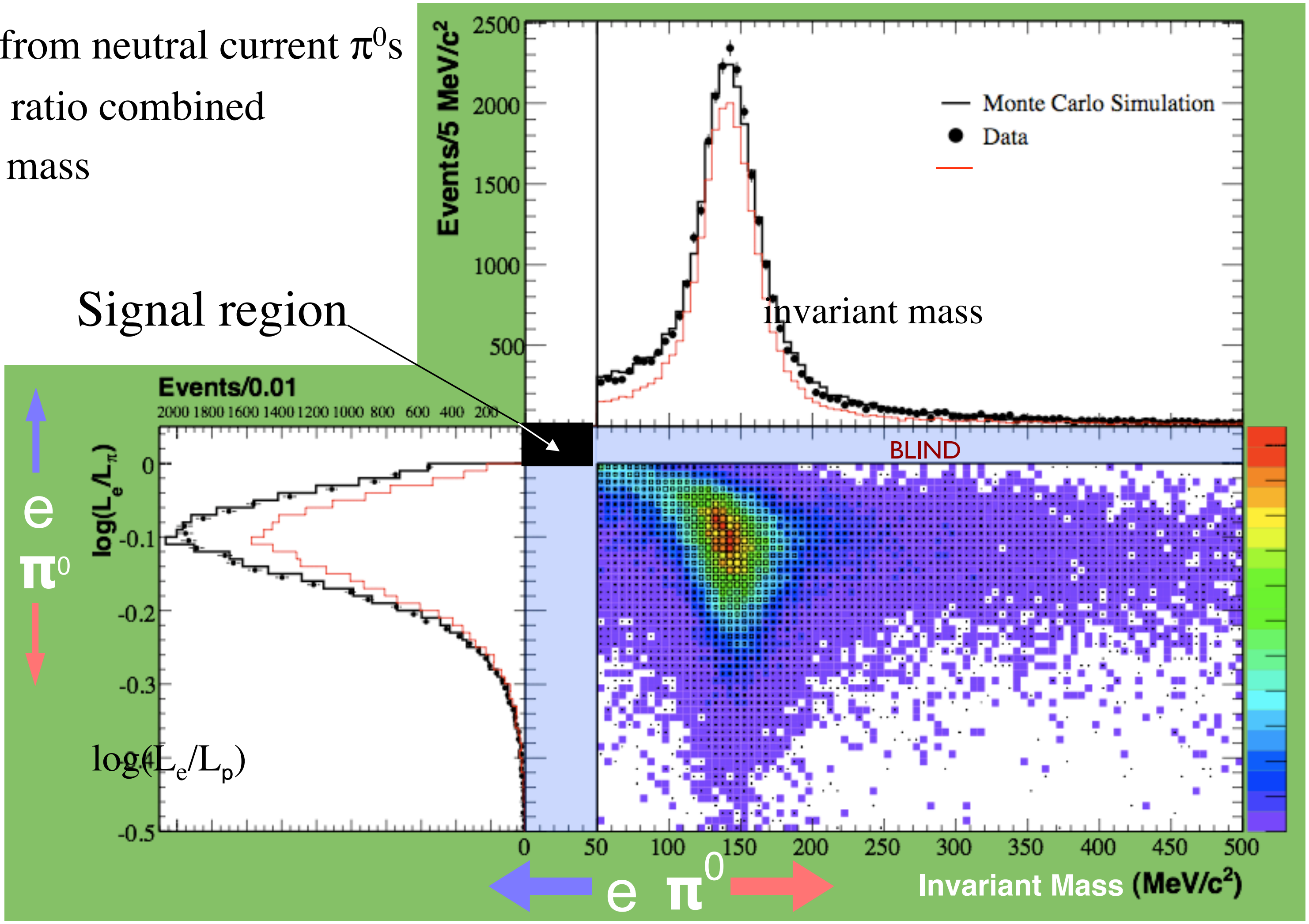
Note: photon conversions are electron-like.
This does not separate e/π^0.

Separation is clean at high energies where muon-like events are long.

Analysis cut was chosen to maximize the $\nu_\mu \rightarrow \nu_e$ sensitivity

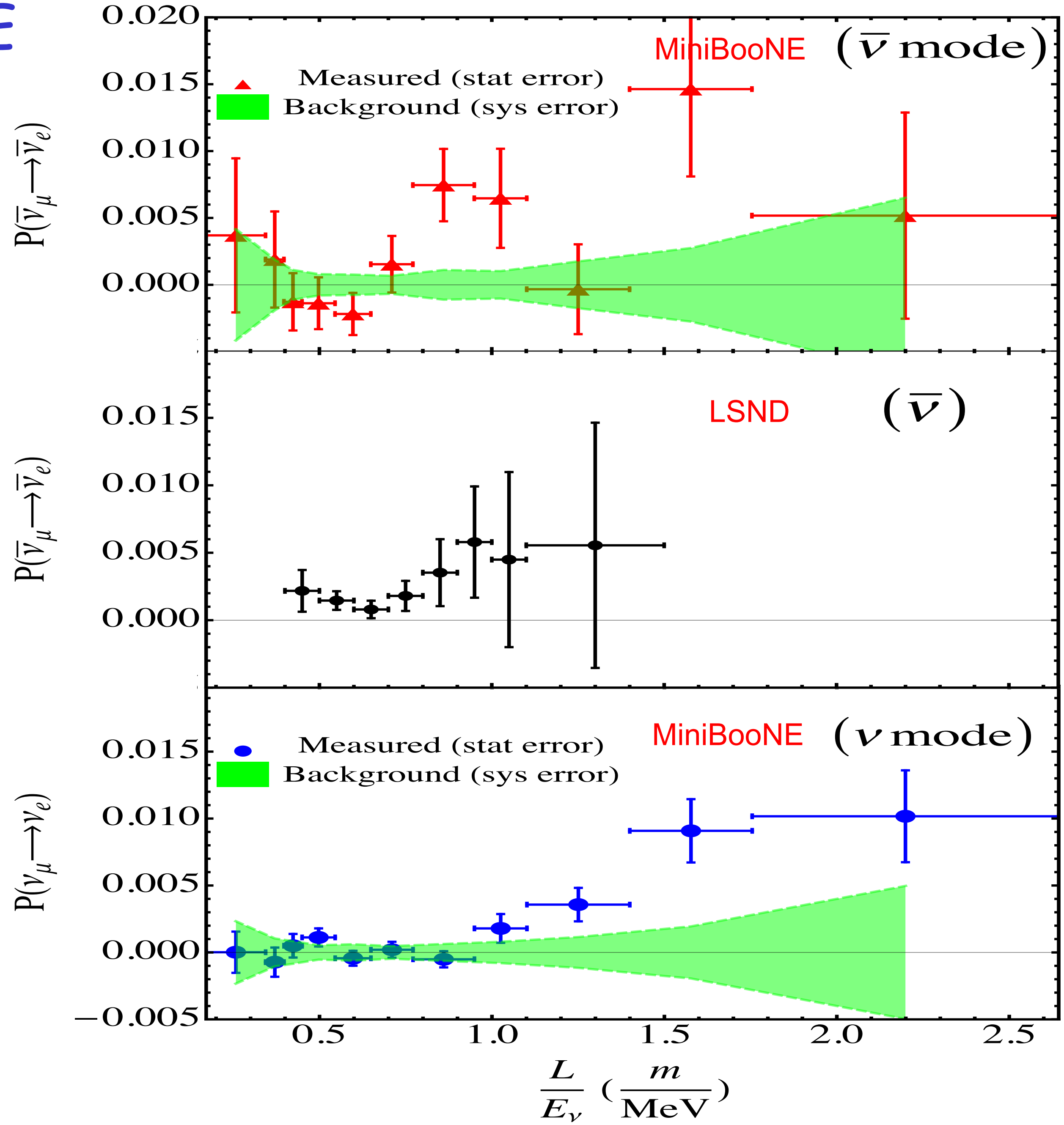
Reconstruction of NC π^0 events

Separating electrons from neutral current π^0s by using a likelihood ratio combined with the $\gamma\gamma$ invariant mass

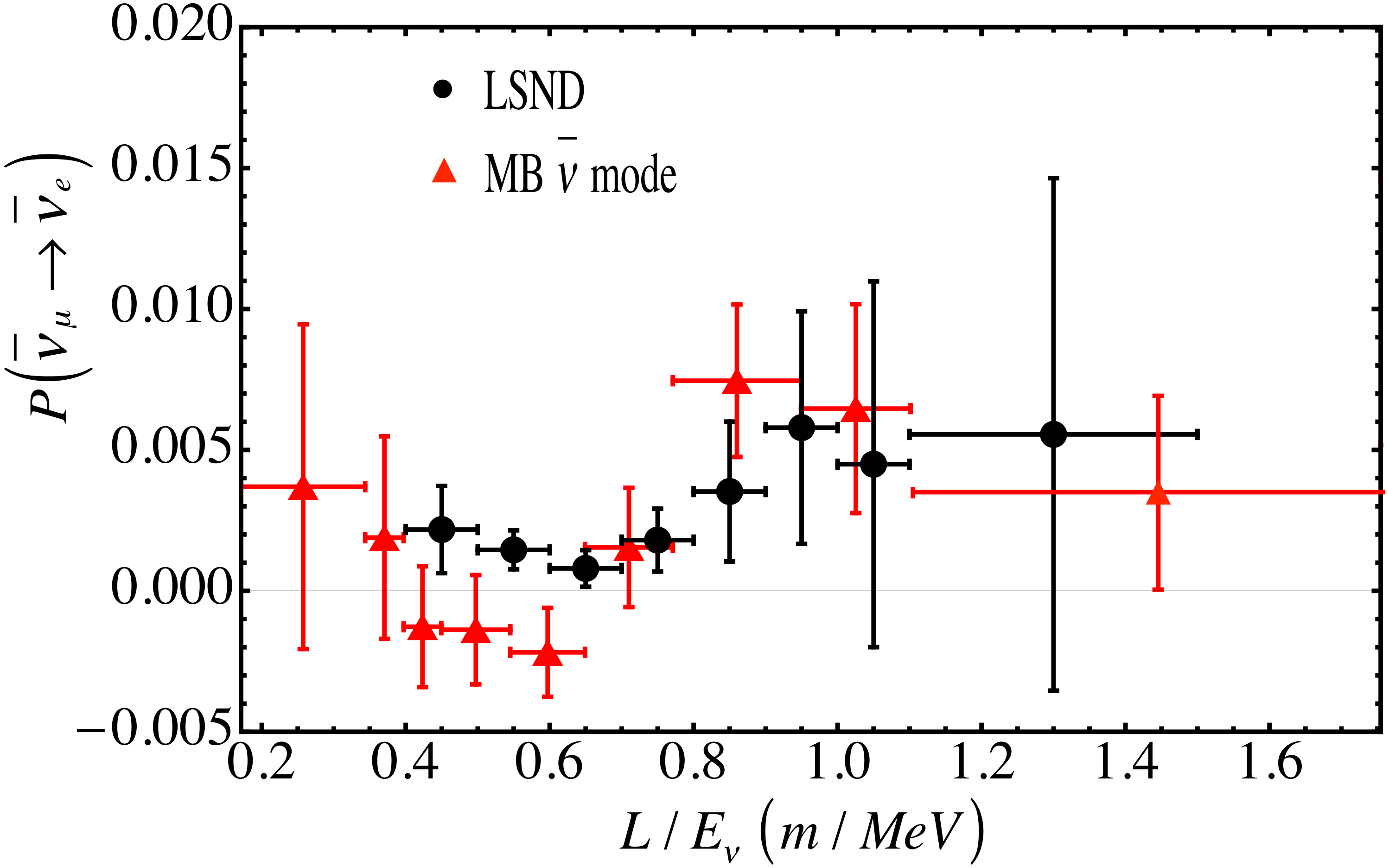


Data plotted vs L/E

5.66×10^{20} POT
(> 1×10^{21} to date)

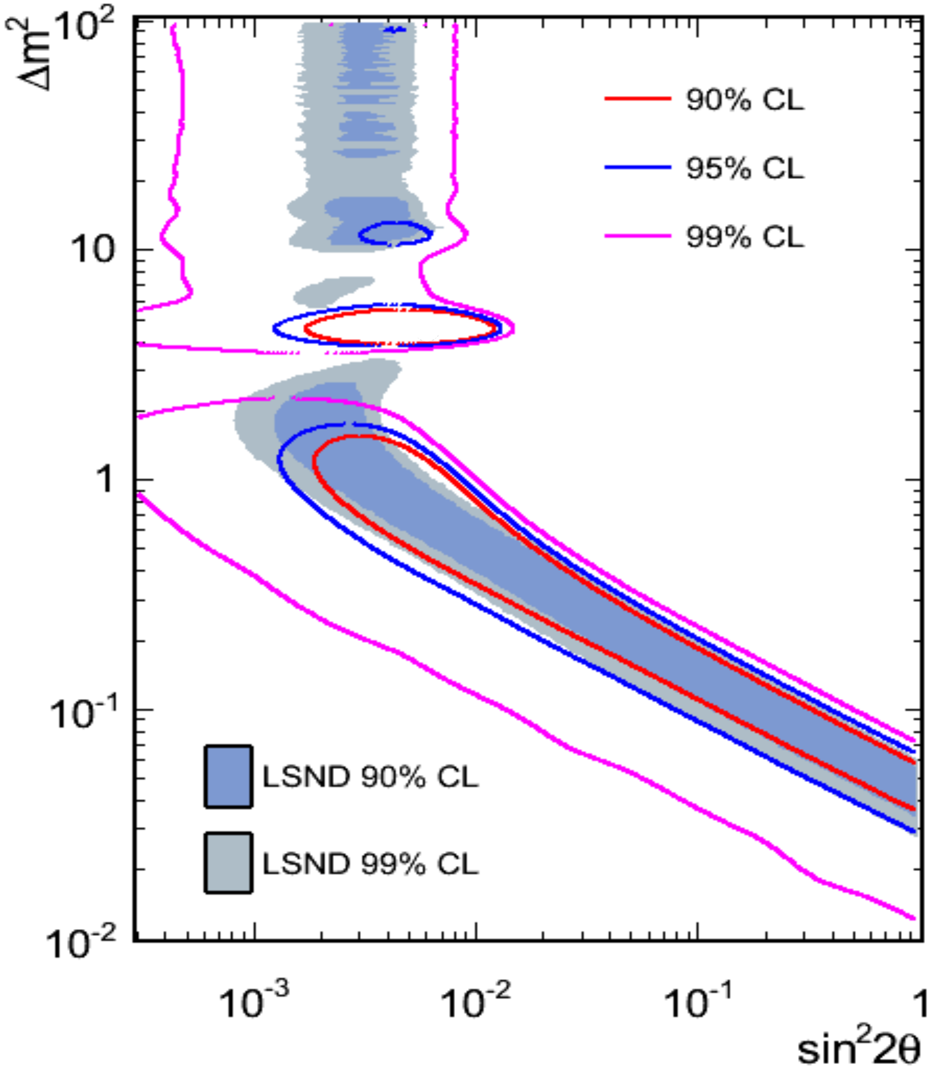


Direct MiniBooNE-LSND Comparison of $\bar{\nu}$ Data



Antineutrino mode MB results Full Energy Range

- Results for **5.66E20 POT**
- Maximum likelihood fit in *simple 2 neutrino model*
- Null excluded at 99.5% with respect to the two neutrino oscillation fit



Conclusions (I)

- Significant ν_e (~3 σ) and $\bar{\nu}_e$ (~2.75 σ) excesses above background are emerging in both neutrino mode and antineutrino mode in MiniBooNE

- Antineutrino mode: statistical errors dominate (more data?)

- MiniBooNE plans has now accumulated > 10^{21} protons on target in anti-neutrino mode and we hope to release results this summer

- Difficulties remain:
  - Cannot determine whether excesses are due to an oscillation phenomena because MiniBooNE has only one detector
  - Need to vary E *and* L

Long-Baseline News, May 2010:

" *** LSND effect rises from the dead… "

BooNE

A Letter of Intent to Build a MiniBooNE Near Detector:BooNE

October 12, 2009

I. Stancu
University of Alabama, Tuscaloosa, AL 35487

Z. Djurcic
Argonne National Laboratory, Argonne, IL 60439

D. Smith
Embry-Riddle Aeronautical University, Prescott, AZ 86301

R. Ford, T. Kobilarcik, W. Marsh, & C. D. Moore
Fermi National Accelerator Laboratory, Batavia, IL 60510

J. Grange, B. Osmanov, & H. Ray
University of Florida, Gainesville, FL 32611

G. T. Garvey, J. A. Green, W. C. Louis, C. Mauger, G. B. Mills, Z. Pavlovic,
R. Van de Water, D. H. White, & G. P. Zeller
Los Alamos National Laboratory, Los Alamos, NM 87545

W. Metcalf
Louisiana State University, Baton Rouge, LA 70803

B. P. Roe
University of Michigan, Ann Arbor, MI 48109

A. A. Aguilar-Arevalo
Instituto de Ciencias Nucleares, Universidad Nacional Autnoma de México, México D.F. México

arXiv:0910.2698v1 [hep-ex] 14 Oct 2009

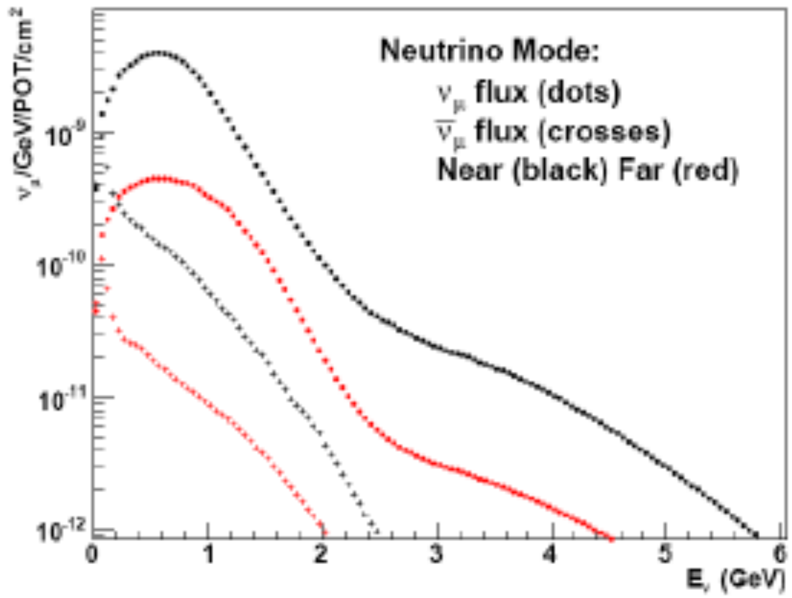
BooNE

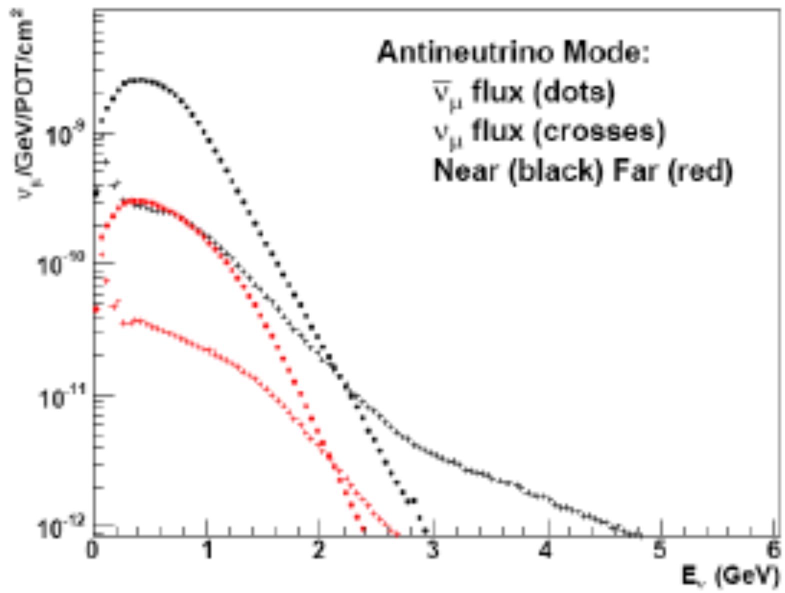
- Cloning a MiniBooNE detector for ~200m
  - Letter of Intent: arXiv:0910.2698
  - Accumulate a sufficient data sample in < 1 year
  - will dramatically reduce errors in neutrino mode, the 3σ low energy excess has a ~ 6σ significance with statistical errors only.
  - Many short runs for checking systematic effects would be possible, as was done for MINOS (e.g. 25 meter absorber, different horn currents) .

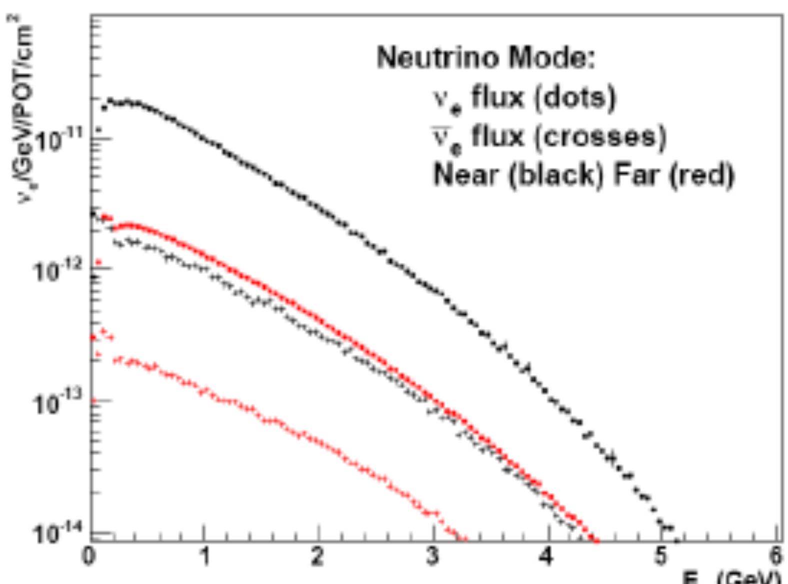
New Location at 200 meters from BNB Target

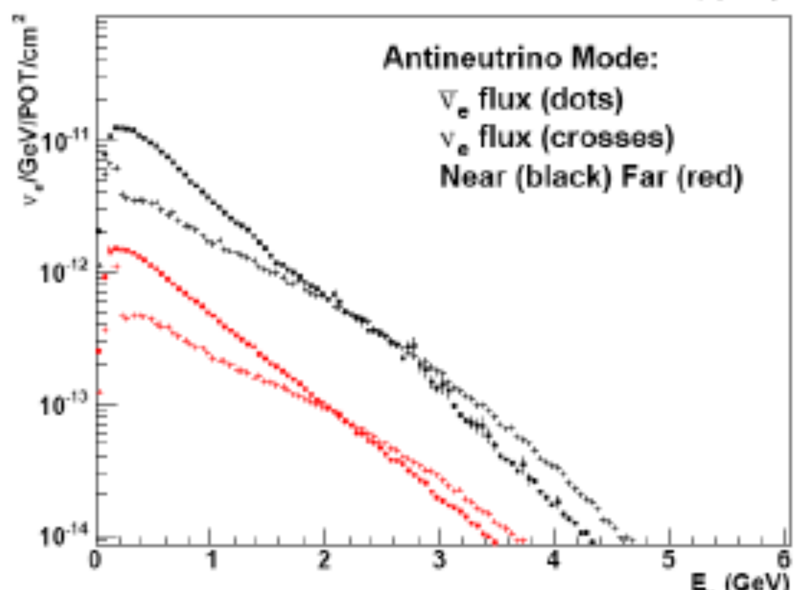
Geoffrey Mills - Los Alamos

Neutrino Fluxes at Near and Far Locations



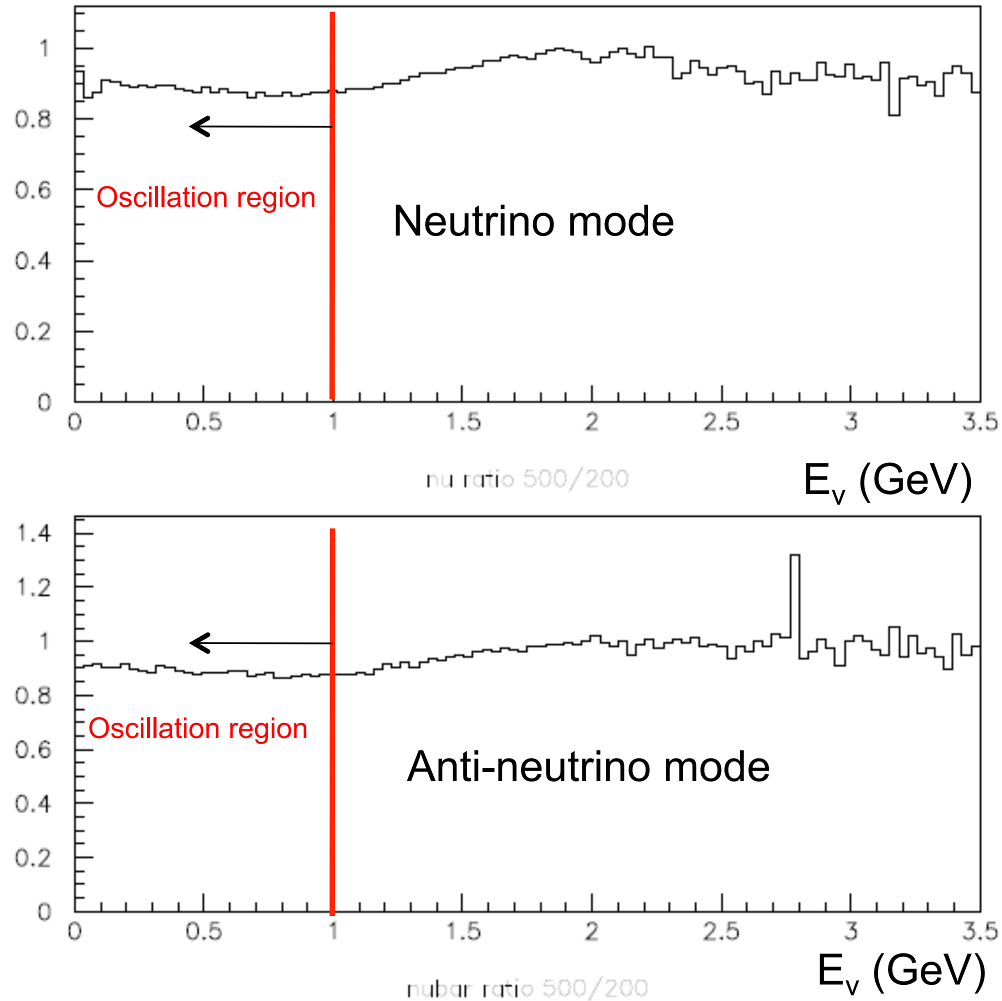




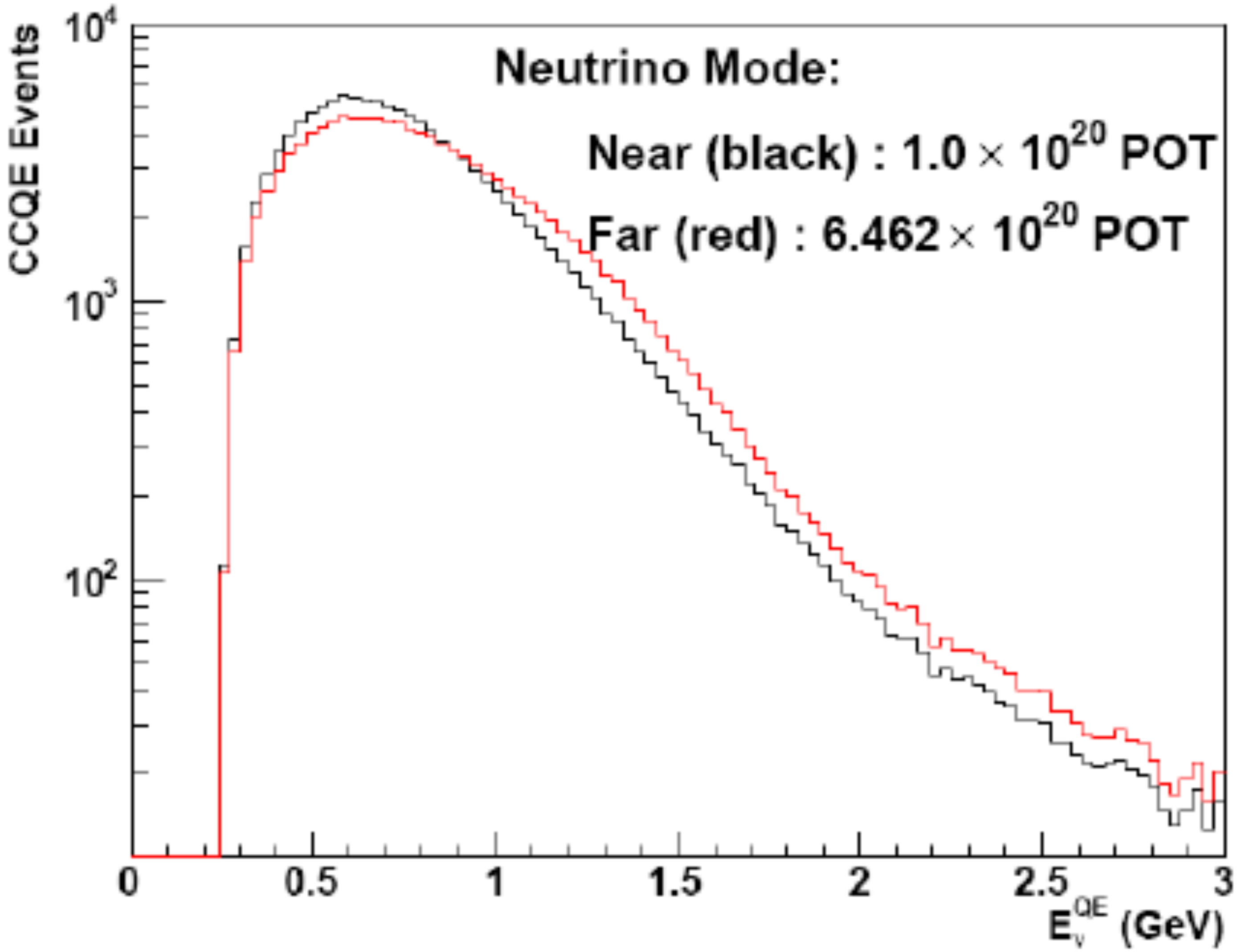


Far to Near Neutrino Flux Ratios at 200 m

MiniBooNE Far/Near fluxes
Scaled by $1/r^2$

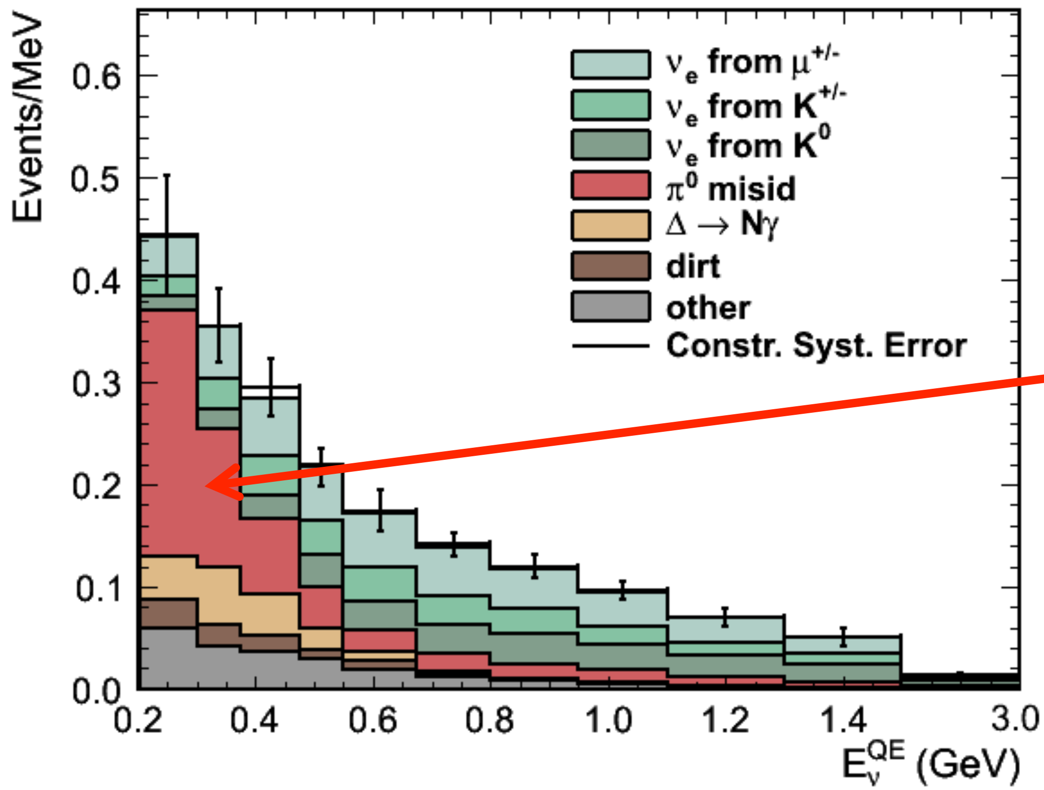


ν_μ Charged Current Event Rates Near and Far



Quasi elastic event rates

Background prediction $\bar{\nu}$ mode



5.66e20 Protons on Target			
	200-475	475-1250	
$\mu^{\pm}$	13.45	31.39	Intrinsic ν_e
$K^{\pm}$	8.15	18.61	
K^0	5.13	21.2	
Other ν_e	1.26	2.05	
NC π^0	41.58	12.57	
$\Delta \rightarrow N\gamma$	12.39	3.37	Mis-ID
dirt	6.16	2.63	
ν_μ CCQE	4.3	2.04	
Other ν_μ	7.03	4.22	
Total	99.45	98.08	

$\bar{\nu}_e$ Background Uncertainties

Uncertainty (%)	200-475MeV	475-1100MeV
π^+	0.4	0.9
π^-	3	2.3
K^+	2.2	4.7
K^-	0.5	1.2
K^0	1.7	5.4
Target and beam models	1.7	3
Cross sections	6.5	13
NC π^0 yield	1.5	1.3
Hadronic interactions	0.4	0.2
Dirt	1.6	0.7
Electronics & DAQ model	7	2
Optical Model	8	3.7
Total	13.4%	16.0%

- Unconstrained $\bar{\nu}_e$ background uncertainties
- Biggest contributors:
  - Detector response
  - Cross sections

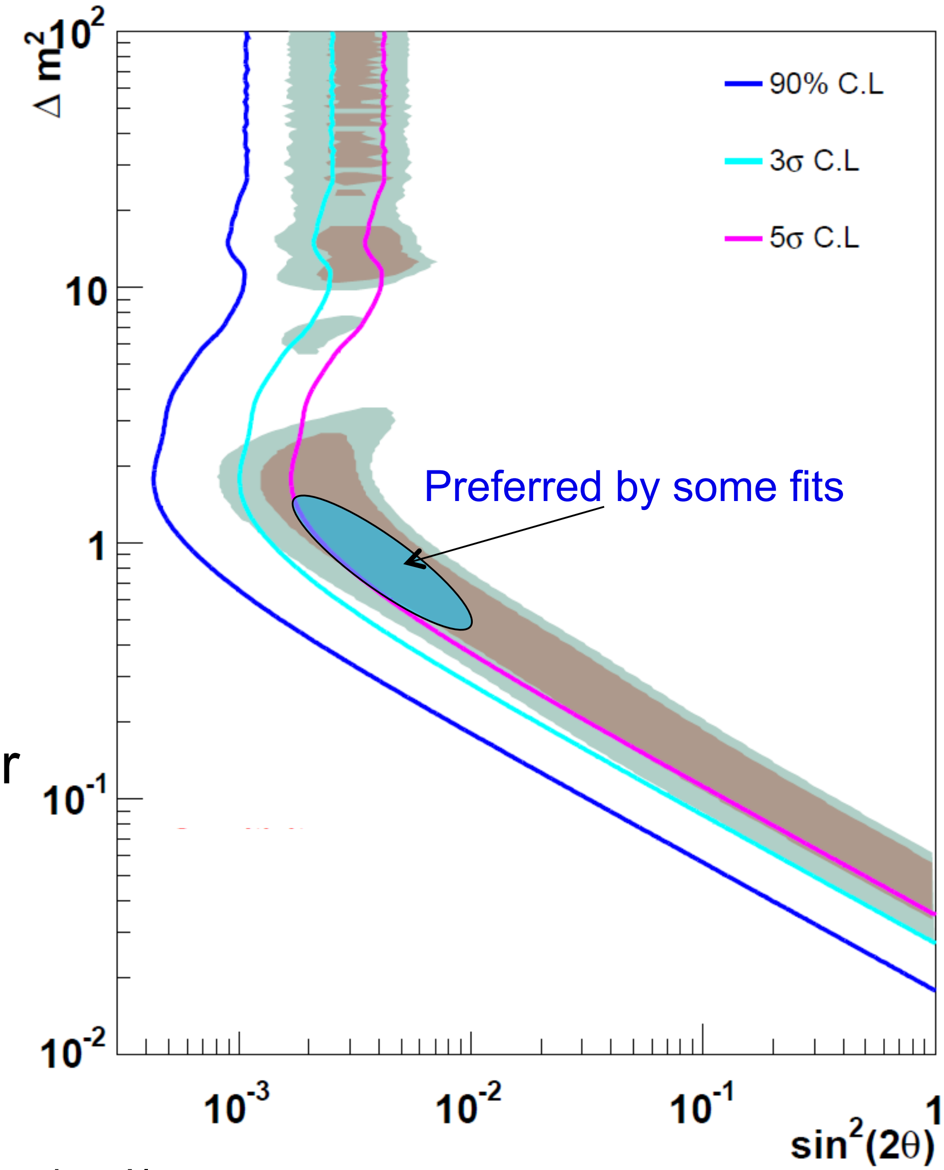
($\bar{\nu}_\mu$ constrained error ~10%)

BooNE Performance

- Use full MiniBooNE sensitivity machinery
  - Use identical detector response (fully correlated errors)
  - 1×10^{20} POT per mode (2×0.5 years at current rates)
  - Reweight MC events for fluxes at 200 meters
  - Full oscillation analysis package applied

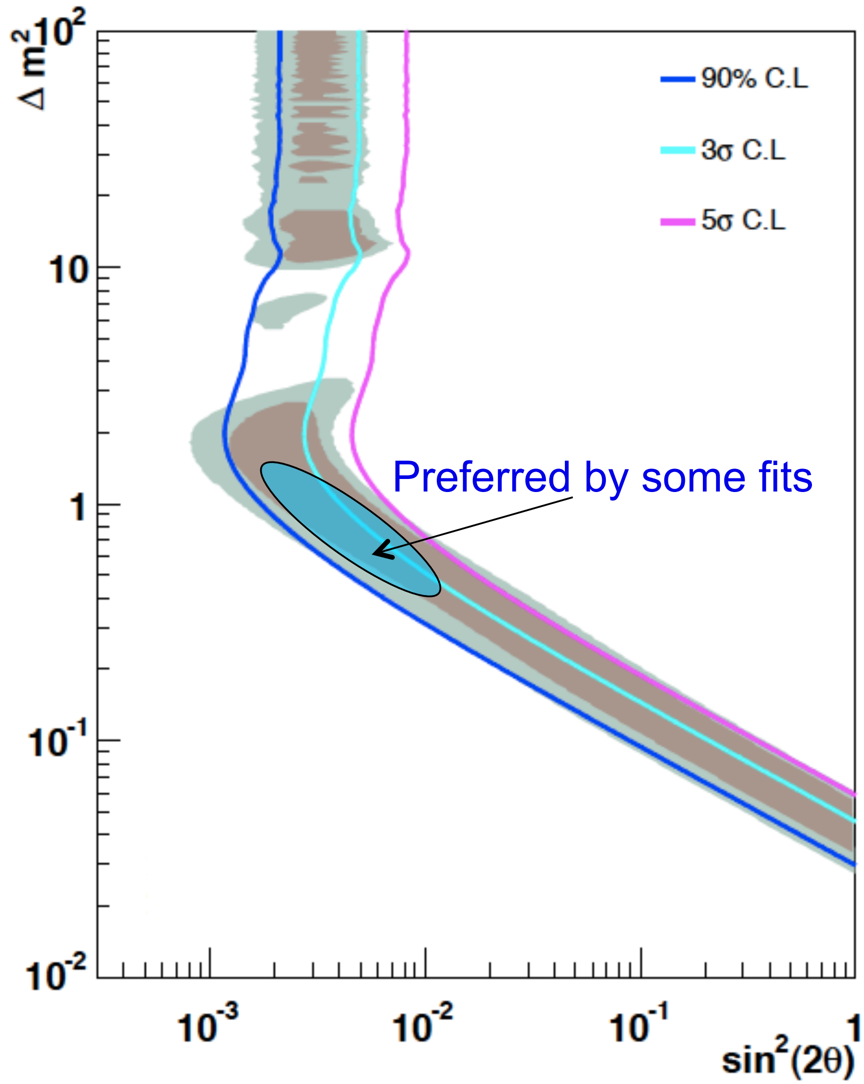
Sensitivity with Near/Far Comparison

- Near/Far comparison sensitivity
  - Near location at 200 meter
    - ✓ 1×10^{20} pot ~1 yr of running
  - Full systematic error analysis
    - ✓ Flux, cross section, detector response

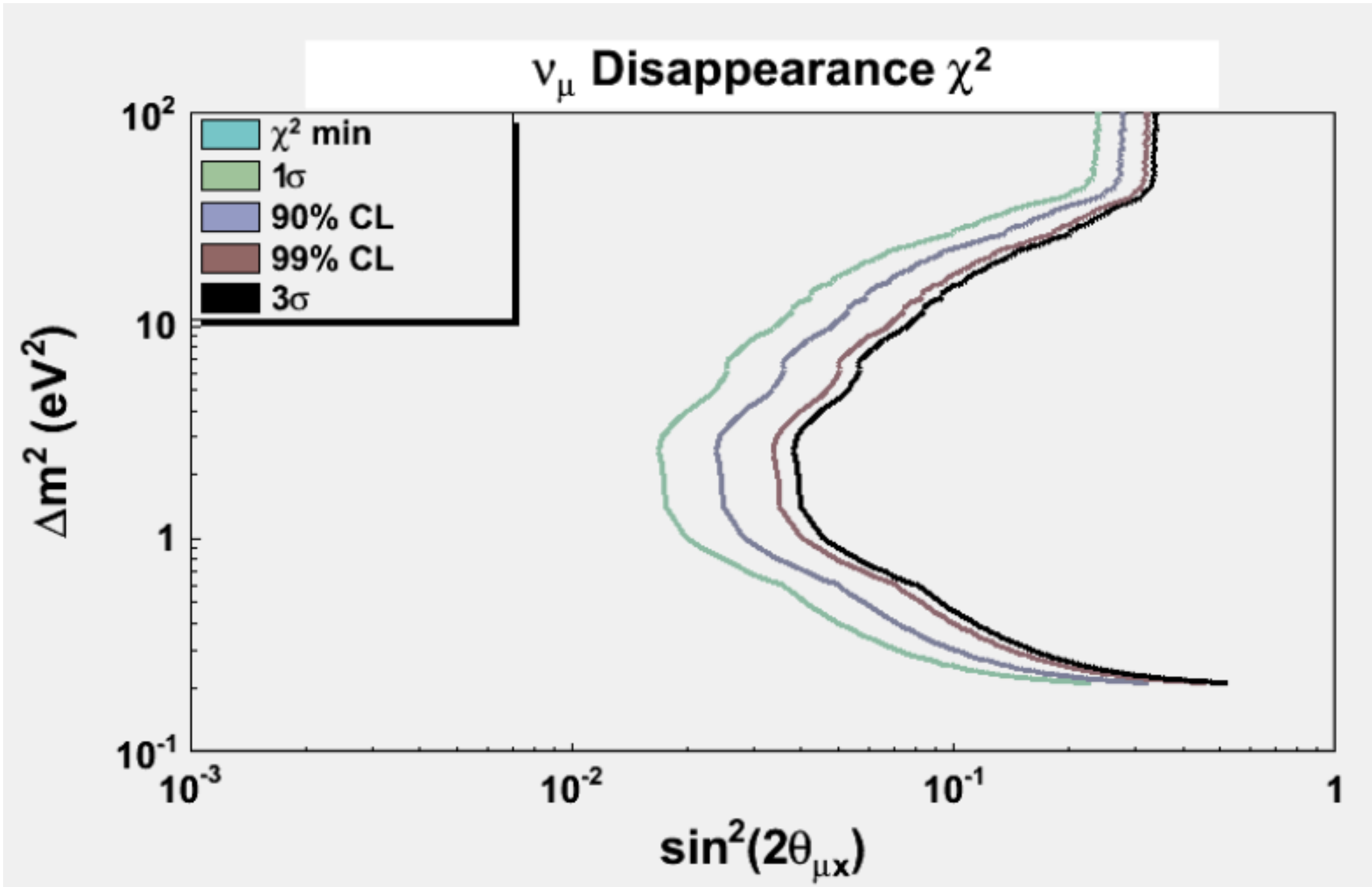


Sensitivity with Near/Far Comparison Anti-nu Mode

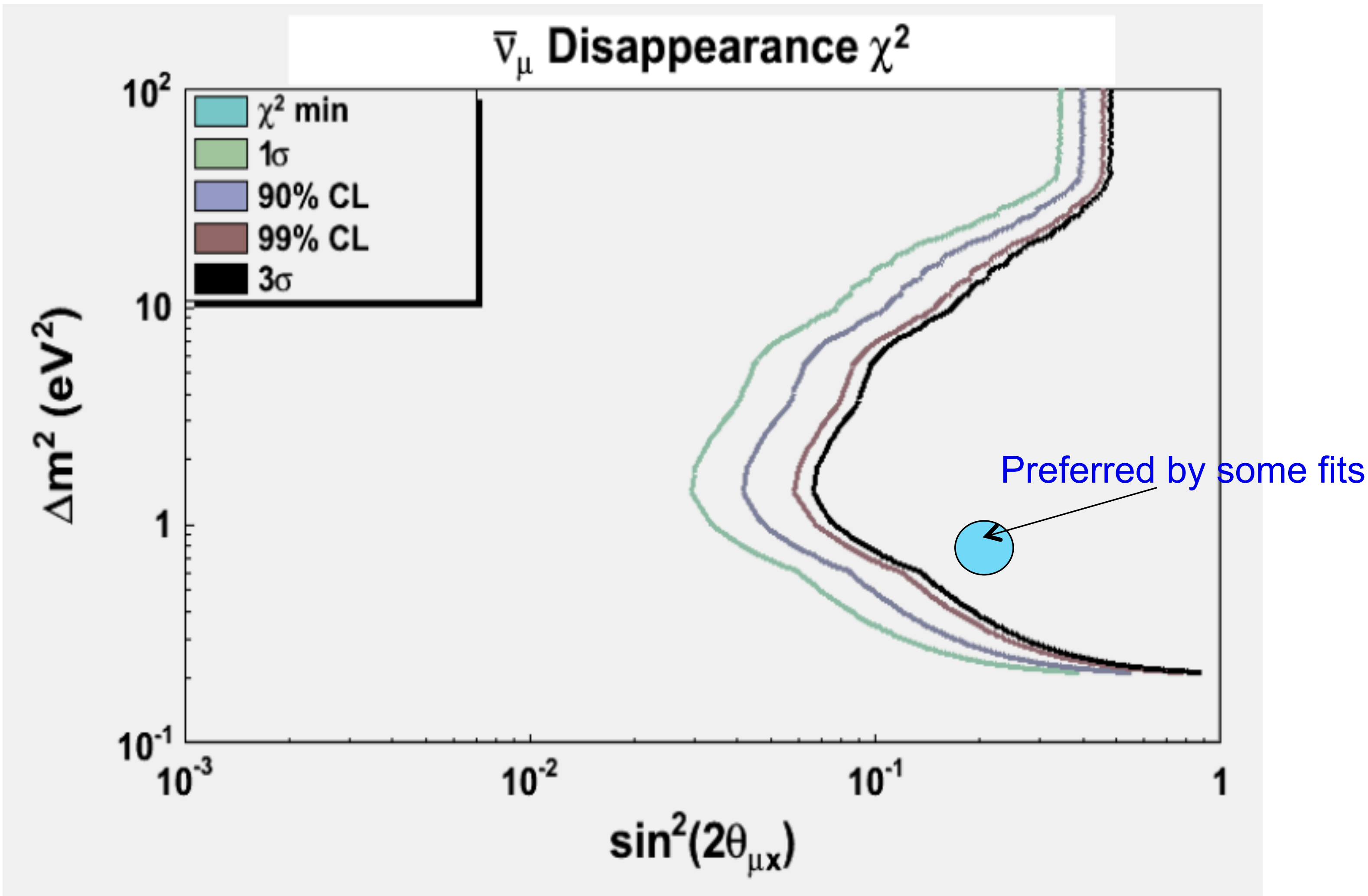
- Near/Far comparison sensitivity
  - ➢Near location at 200 meter
    - ✓ 1×10^{20} pot ~1 yr of running
  - ➢ Full systematic error analysis
    - ✓Flux, cross section, detector response



Neutrino Disappearance Sensitivity with Detector at 200 Meters



Antineutrino Disappearance Sensitivity with Detector at 200 Meters



Conclusions and Outlook

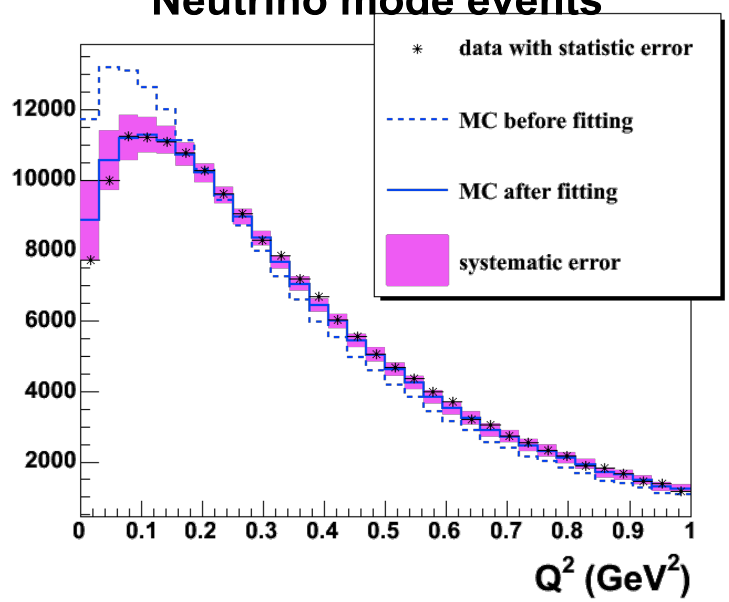
- Significant ν_e (3 σ) and $\bar{\nu}_e$ (2.75 σ) excesses above background are emerging in both neutrino mode and antineutrino mode in MiniBooNE
  - The two modes do not appear to be consistent with a simple two flavor neutrino model
  - Neutrino mode systematic errors dominate (near detector?)
  - Antineutrino mode statistical errors dominate (more data?)
  - MiniBooNE plans accumulate more data until the 2012 shutdown
- BooNE proposal:
  - Cloning or cannibalizing MiniBooNE at a near position following the $\bar{\nu}$ run
  - Cost ~ 10M$ for new detector, 5M$ reusing the existing MiniBooNE detector.
  - Data can be accumulated in < 1 yr at present proton delivery rates

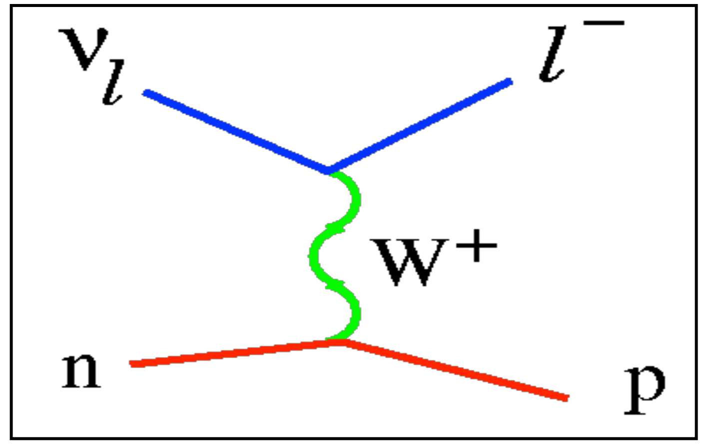
BACKUP

Benchmark Reaction: Charged Current Quasi Elastic (CCQE)

Normalizes our (flux × cross section)

Neutrino mode events





We adjust the parameters of a Fermi Gas model to match our observed Q^2 Distribution.

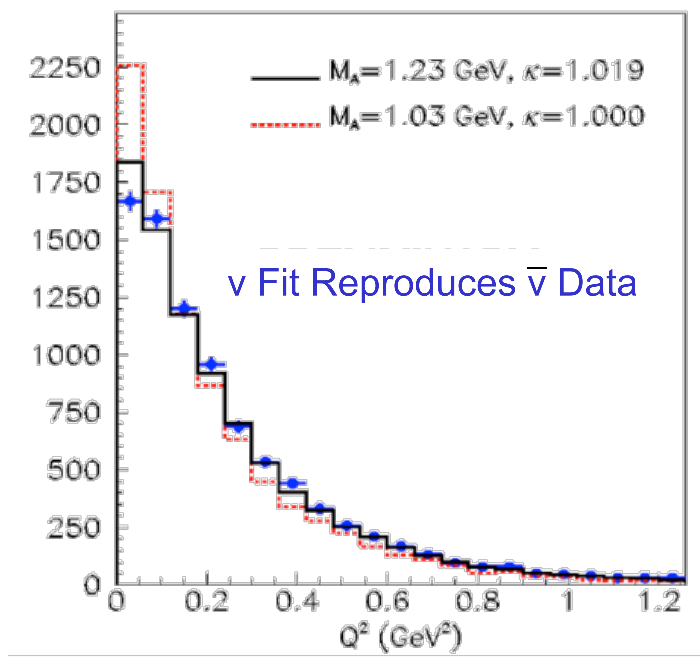
Fermi Gas Model describes CCQE n_m data well

$M_{A,eff}$ = 1.23+-0.20 GeV

$\varkappa$ = 1.019+-0.011

Also used to model ν_e and $\overline{\nu_e}$ interactions

Antineutrino mode events

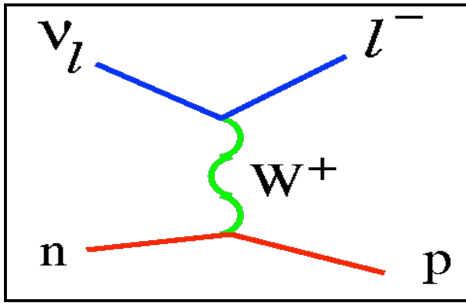


MiniBooNE Detects Cherenkov Light

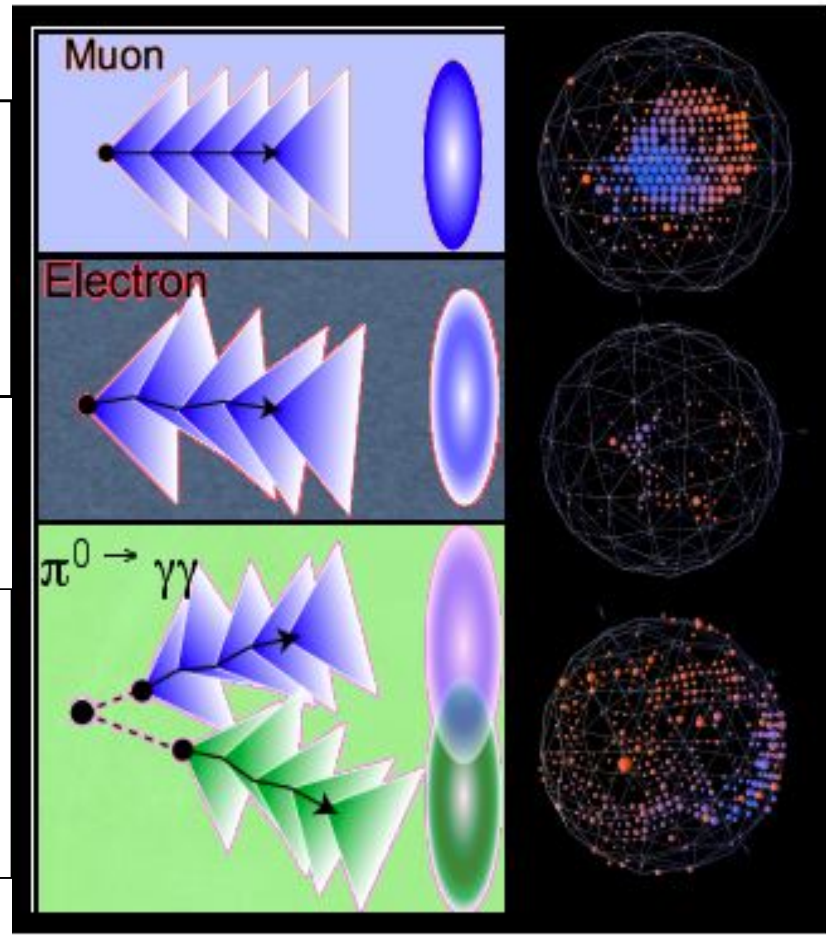
Pattern of Cerenkov Light Gives Event Type

The most important types of neutrino events in the oscillation search:

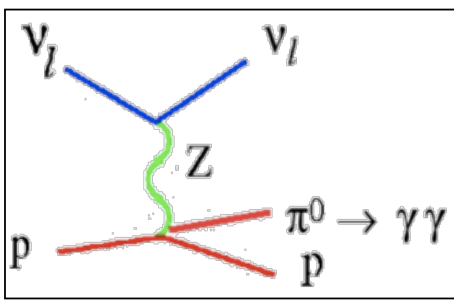
Background Muons (or charged pions):
Produced in most CC events.
Usually 2 or more subevents
or exiting through veto.



Signal and Background
Electrons (or single photon):
Tag for :$\nu_\mu \rightarrow \nu_e$ CCQE signal.
1 subevent



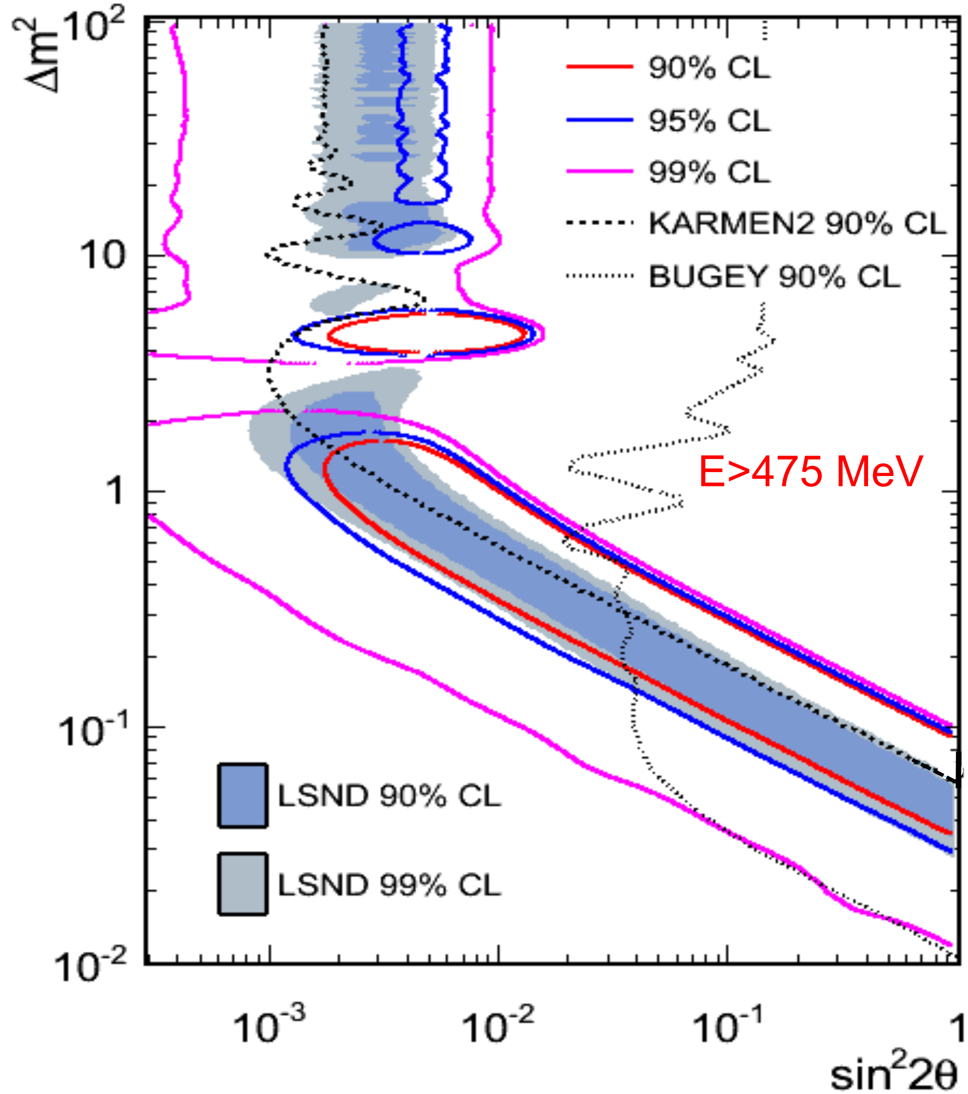
Background π^0s:
Can form a background if one
photon is weak or exits tank.
In NC case, 1 subevent.



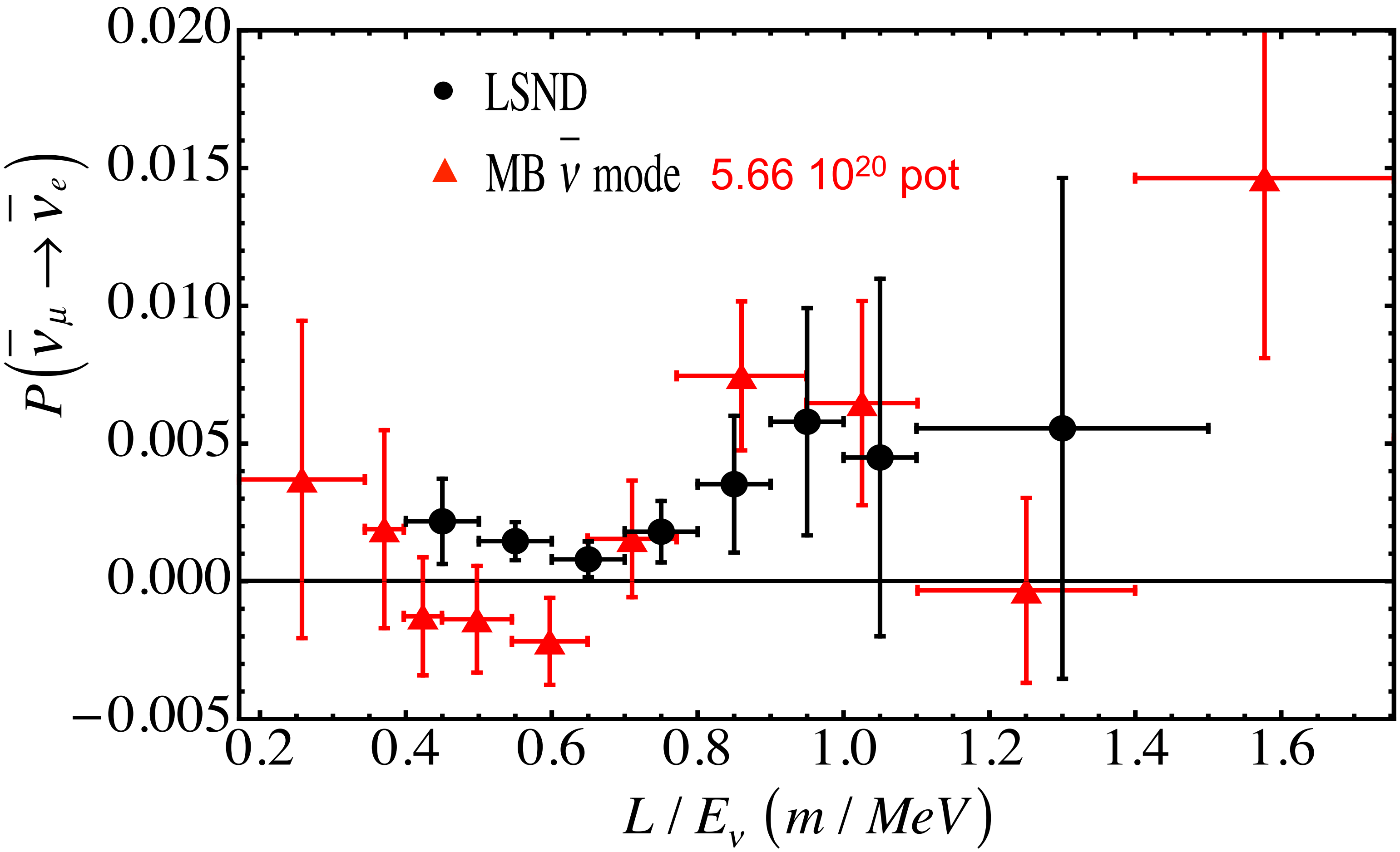
Antineutrino mode MB results for E>475 MeV

(E>475 avoids question of low energy excess in nu-mode)

- Results for **5.66E20 POT**
- Maximum likelihood fit for *simple two neutrino model*
- Null excluded at 99.4% with respect to the two neutrino oscillation fit.



Direct MiniBooNE-LSND Comparison of $\bar{\nu}$ Data



Near/Far Sensitivity for Several Distances

- 150 m : 0.6×10^{20} POT
- 200 m : 1.0×10^{20} POT
- 250 m : 1.5×10^{20} POT
- 300 m : 2.0×10^{20} POT

•Near/Far comparison relatively insensitive to detector distance for roughly the same number of events

> ➢ 200 meters gives similar flux shapes