First Oscillation Results From MiniBooNE

Martin Tzanov
University of Colorado

Double Beta Decay and Neutrinos Workshop 2007
Osaka, 2007

Outline

- Introduction
- MiniBooNE experiment.
- Oscillation analysis.
- First oscillation result.
- Conclusions.

LSND Experiment

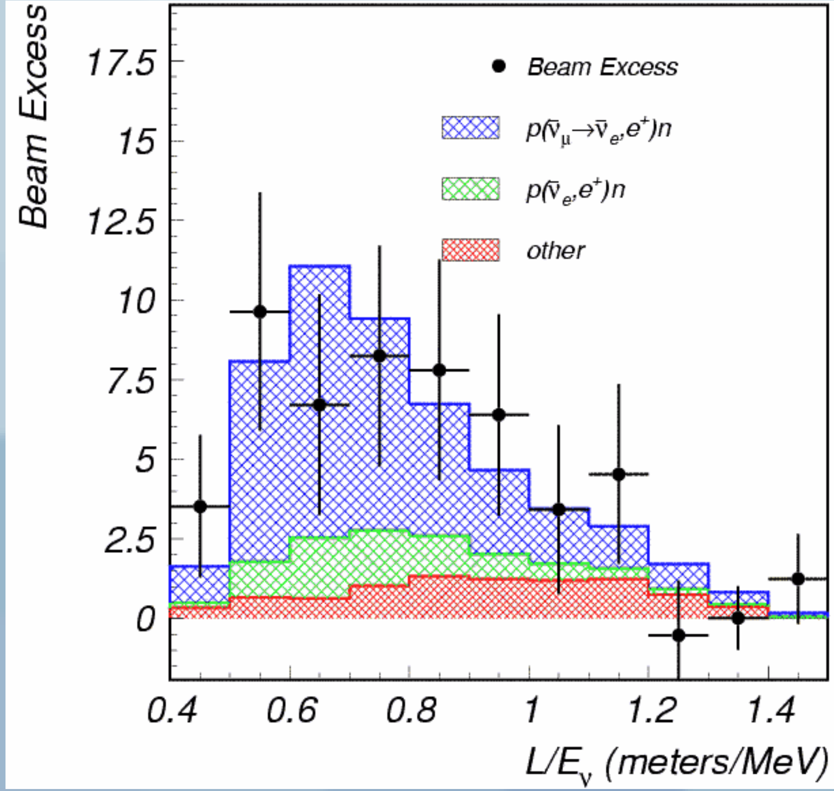
Liquid Scintillator Neutrino Detector at Los Alamos Meson Physics Facility (LAMPF) accelerator

- Neutrino source: stopped pion and muon decays
- Search for $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillations

- L = 30 m, E = 30-53 MeV

Observed excess:
- an excess of $\bar{\nu}_e$ events in a $\bar{\nu}_\mu$ beam,
  87.9 ± 22.4 ± 6.0 (3.8σ)

- which can be interpreted as $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillations:



Points -- LSND data
Signal (blue)
Backgrounds (red, green)

LSND Oscillation Signal

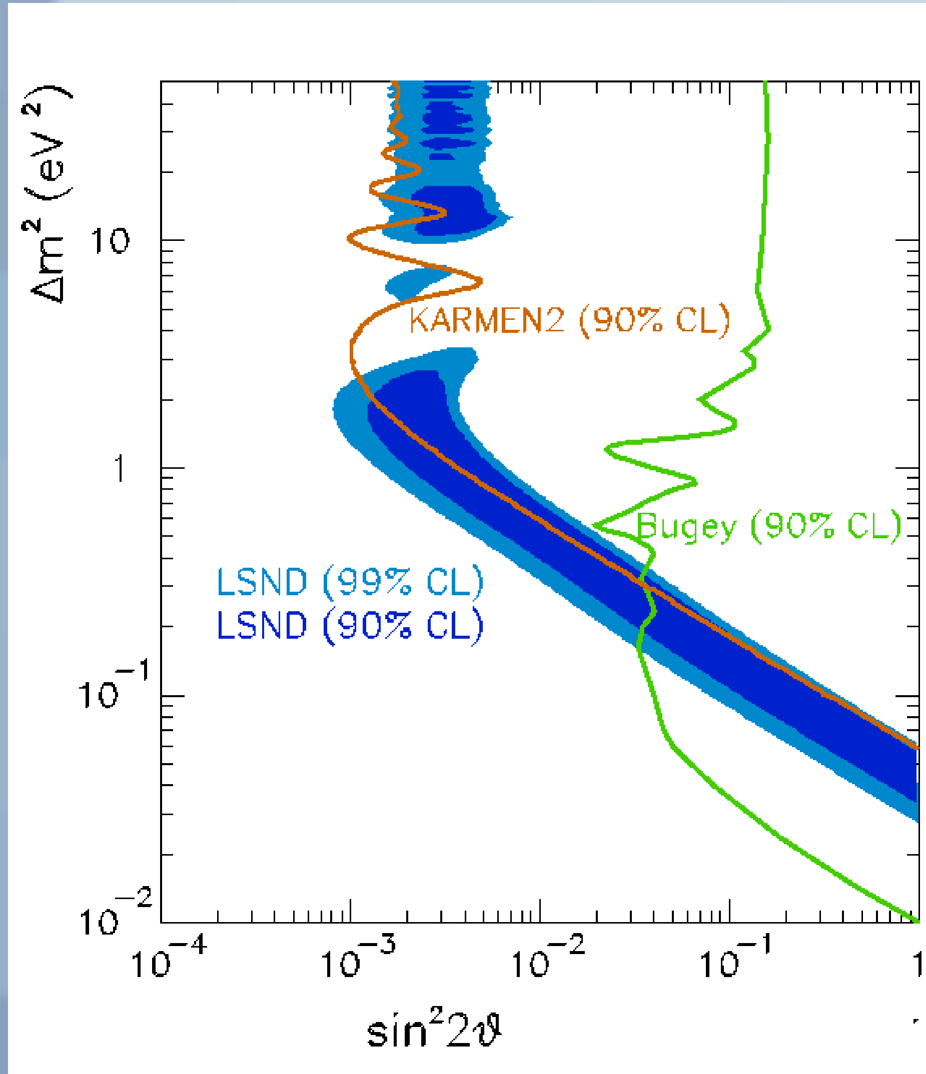
LSND observed excess in the context of two-neutrino oscillation:

$$P(\overline{\nu}_\mu \rightarrow \overline{\nu}_e) = (2.5 \pm 0.6_{stat} \pm 0.4_{syst}) \times 10^{-3}$$

Comparison with KARMEN and **Bugey** given the same oscillation model

Joint analysis with Karmen2:
64% compatible

Church, et al., PRD 66, 013001



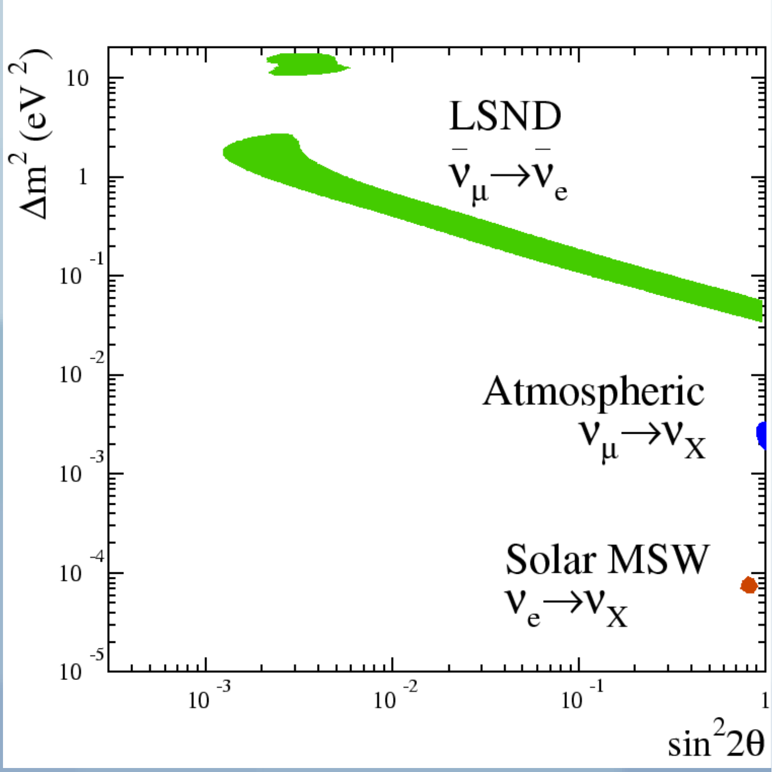
Neutrino Oscillations – Pre MiniBooNE

In three neutrino model two Δm^2 constrain the third:

- $\Delta m_{13}^2 = \Delta m_{12}^2 + \Delta m_{23}^2$

LSND	$\Delta m^2 > 0.1 \mathrm{eV}^2$	$\bar{\nu}_\mu \leftrightarrow \bar{\nu}_e$
Atmos.	$\Delta m^2 \approx 2 \times 10^{-3} \mathrm{eV}^2$	$\nu_\mu \leftrightarrow \nu_?$
Solar	$\Delta m^2 \approx 10^{-4} \mathrm{eV}^2$	$\nu_e \leftrightarrow \nu_?$

- 3 neutrino masses can not reconcile an order of magnitude difference in the 3 Δm^2.



Is there fourth neutrino?

- Z^0 boson resonance width measurements is consistent with only 3 weakly interacting neutrinos.

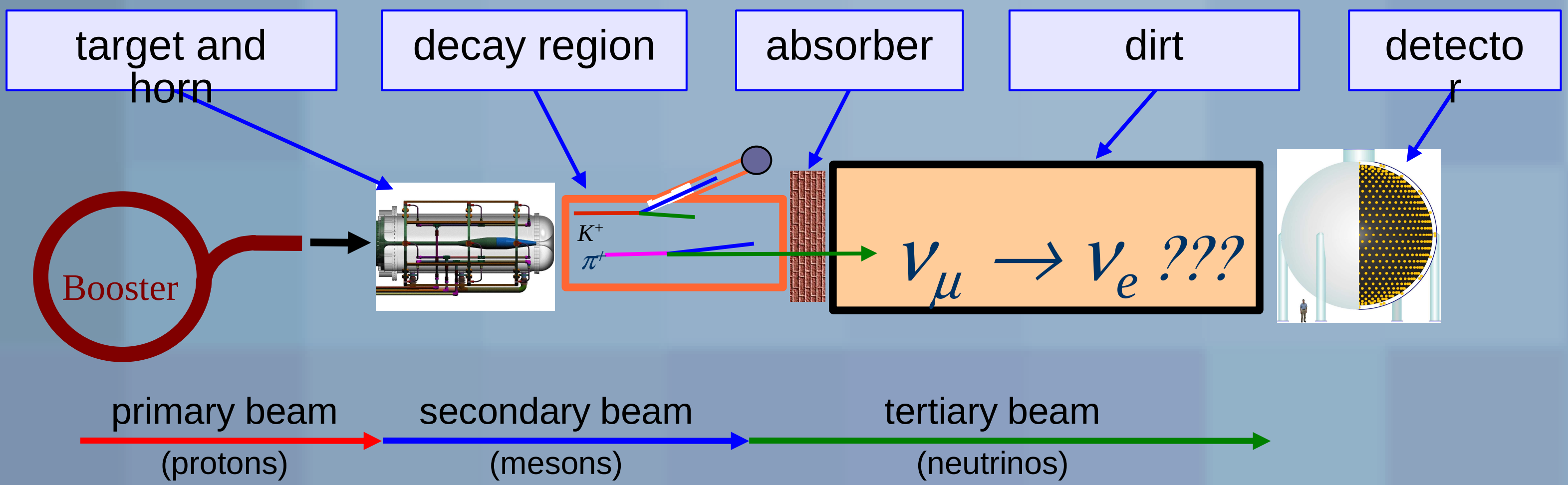
Possible solutions

- Sterile neutrino sector.
- Discover one of the three is not oscillations.

MiniBooNE Experiment – E898 at Fermilab

Test of LSND within the context of $\nu_\mu \rightarrow \nu_e$ appearance only is an essential first step:

- Keep the same L/E
- Higher energy and longer baseline – E=0.5 – 1 GeV; L=500m
- Different beam
- Different oscillation signature $\nu_\mu \rightarrow \nu_e$
- Different systematics
- Antineutrino-capable beam

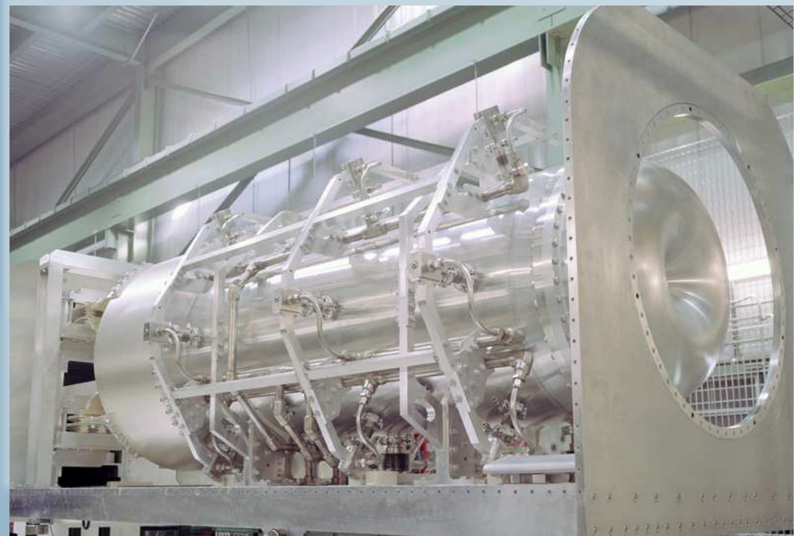


MiniBooNE Collaboration

A. A. Aguilar-Arevalo, A. O. Bazarko, S. J. Brice, B. C. Brown, L. Bugel, J. Cao, L. Coney, J. M. Conrad, D. C. Cox, A. Curioni, Z. Djurcic, D. A. Finley, B. T. Fleming, R. Ford, F. G. Garcia, G. T. Garvey, J. A. Green, C. Green, T. L. Hart, E. Hawker, R. Imlay, R. A. Johnson, P. Kasper, T. Katori, T. Kobilarcik, I. Kourbanis, S. Koutsoliotas, J. M. Link, Y. Liu, Y. Liu, W. C. Louis, K. B. M. Mahn, W. Marsh, P. S. Martin, G. McGregor, W. Metcalf, P. D. Meyers, F. Mills, G. B. Mills, J. Monroe, C. D. Moore, R. H. Nelson, P. Nienaber, S. Ouedraogo, R. B. Patterson, D. Perevalov, C. C. Polly, E. Prebys, J. L. Raaf, H. Ray, B. P. Roe, A. D. Russell, V. Sandberg, R. Schirato, D. Schmitz, M. H. Shaevitz, F. C. Shoemaker, D. Smith, M. Sorel, P. Spentzouris, I. Stancu, R. J. Stefanski, M. Sung, H. A. Tanaka, R. Tayloe, M. Tzanov, M. O. Wascko, R. Van de Water, D. H. White, M. J. Wilking, H. J. Yang, G. P. Zeller, E. D. Zimmerman

University of Alabama
Bucknell University
University of Cincinnati
University of Colorado
Columbia University
Embry Riddle University
Fermi National Accelerator Laboratory
Indiana University
Los Alamos National Laboratory
Louisiana State University
University of Michigan
Princeton University
Saint Mary's University of Minnesota
Virginia Polytechnic Institute
Western Illinois University
Yale University

Booster and Magnetic Horn

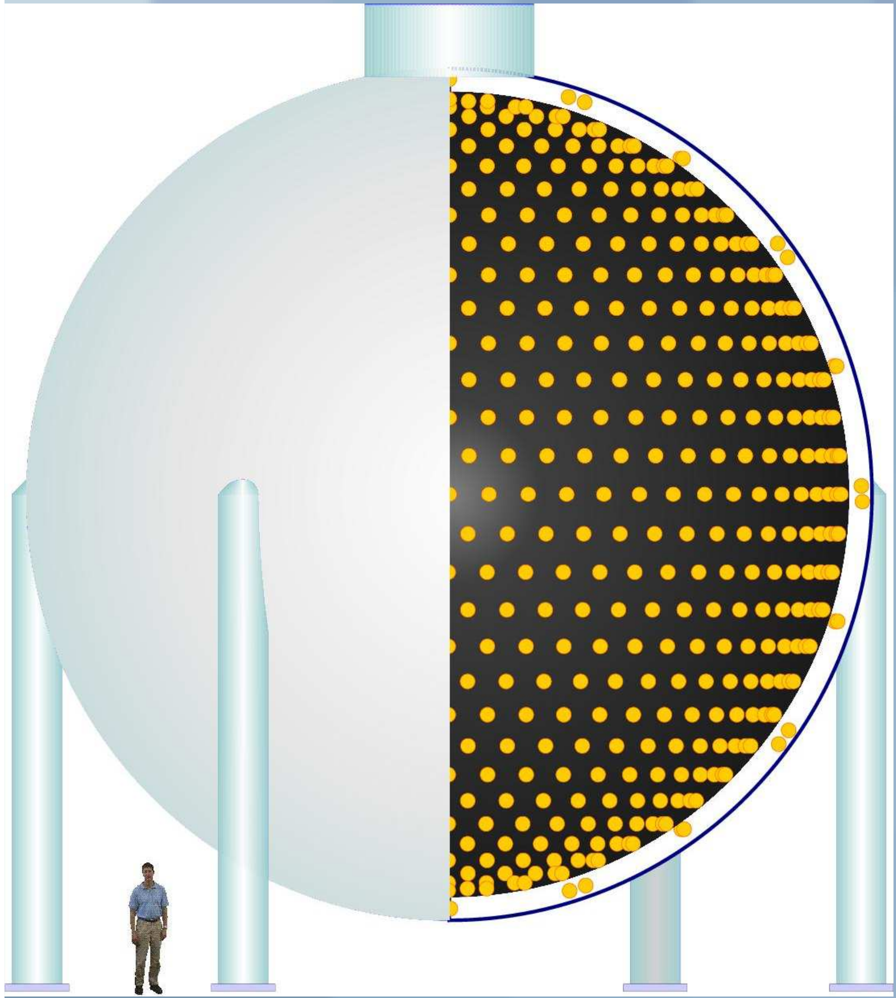


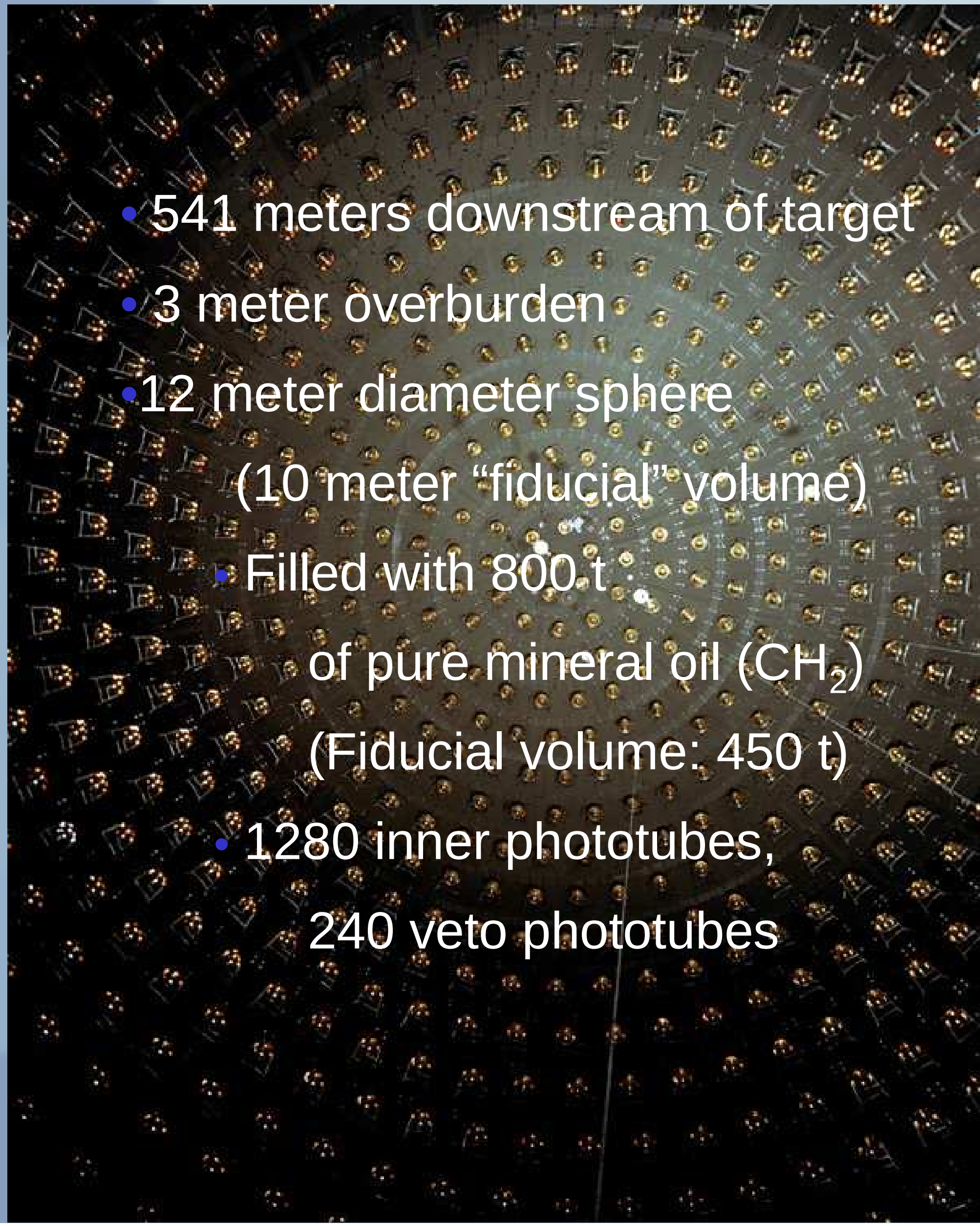
- MiniBooNE extracts beam from the 8 GeV Booster
- 4×10^{12} protons per 1.6 μs pulse delivered at up to 5 Hz.

6.3×10^{20} POT delivered.

Delivered to a 1.7λ Be target inserted into a magnetic horn (2.5 kV, 174 kA) that (increases the flux by $\times$6)

The MiniBooNE Detector





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

  (10 meter "fiducial" volume)

  - Filled with 800 t

    of pure mineral oil (CH_2)

    (Fiducial volume: 450 t)

  - 1280 inner phototubes,

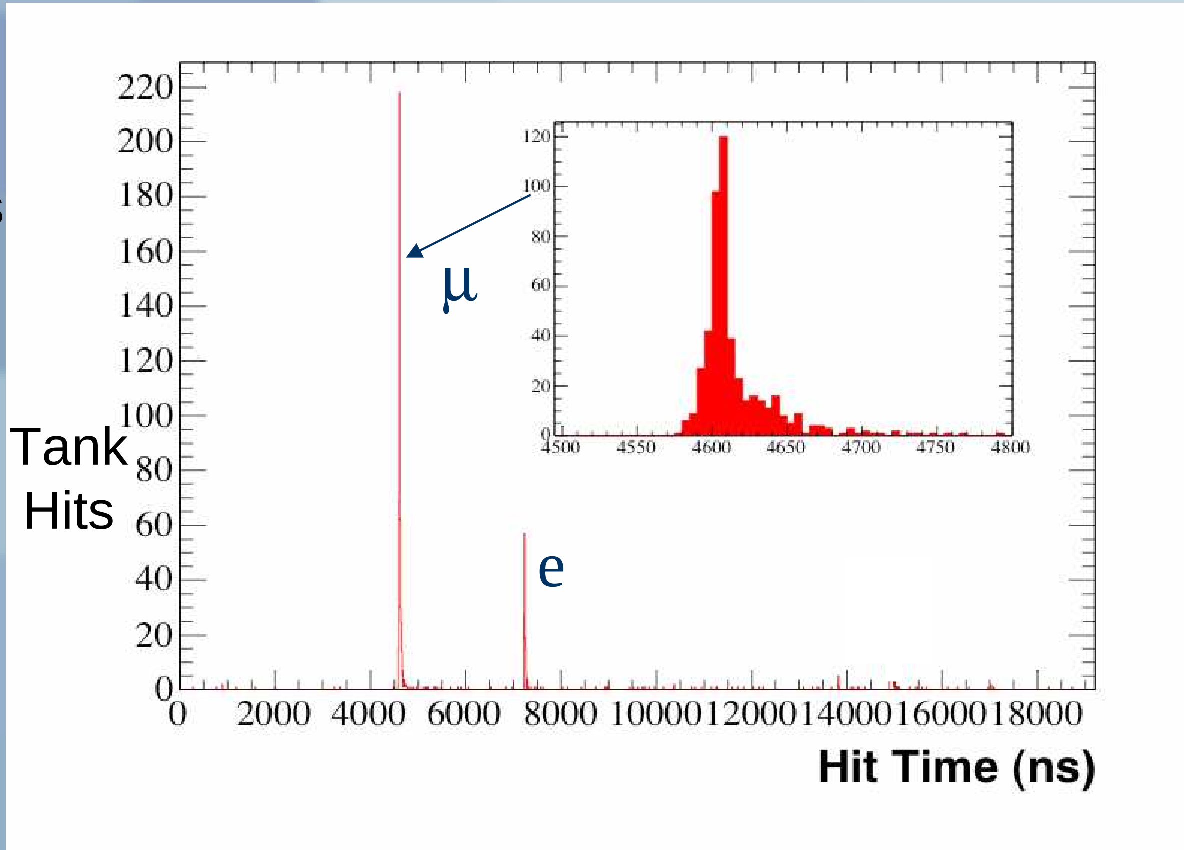
    240 veto phototubes

Timing and Subevents

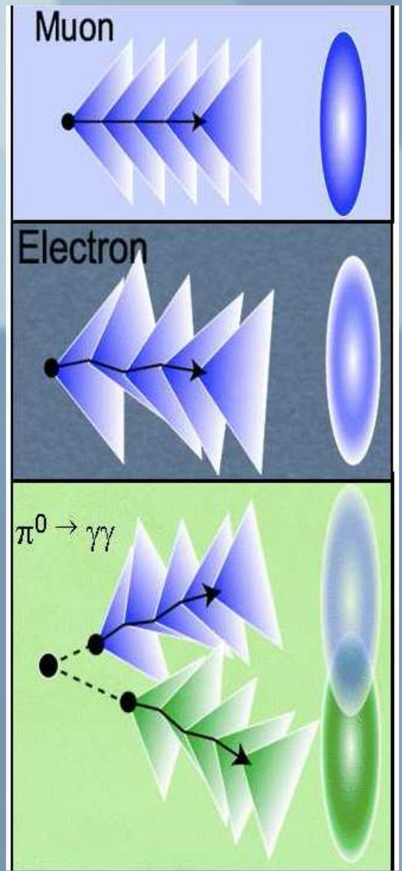
A 19.2 μs beam trigger window
- encompasses the 1.6 μs spill
- starts 4 μs before the beam

Subevent:
Multiple hits within a ~100 ns window form "subevents"

Most events are from ν_μ CC interactions (ν+n $\rightarrow$ μ+p) with characteristic two "subevent" structure from stopped $\mu \rightarrow \nu_\mu \nu_e e$



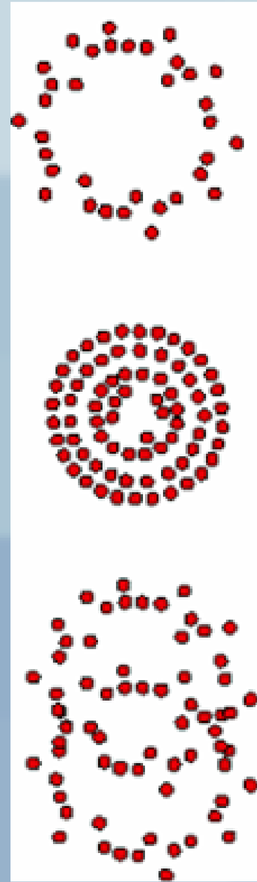
Event Topologies in MiniBooNE Detector



Electron/photon event – fuzzy ring
- short track, large scattering
- γ converts and looks like electrons

Muon event
- long track, small scattering

π^0 event – two fuzzy rings



Oscillation Analysis

- Neutrino flux model.
- Neutrino cross sections model.
- Detector response model.
- Particle ID and reconstruction
- Systematic errors and checks
- Oscillation fit

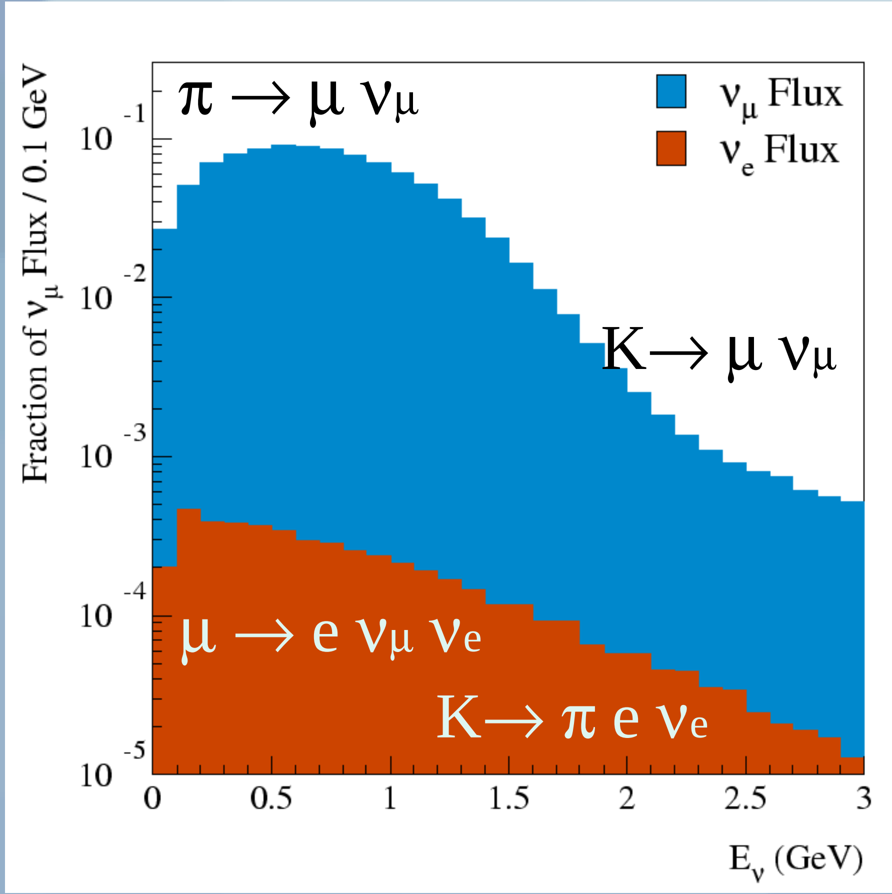
Neutrino Flux Prediction

- GEANT4 based Monte Carlo simulates the neutrino flux in MiniBooNE beamline,
- high purity ν_μ beam – 99%,
  small ν_e component – intrinsic ν_e
  - background for ν_e appearance

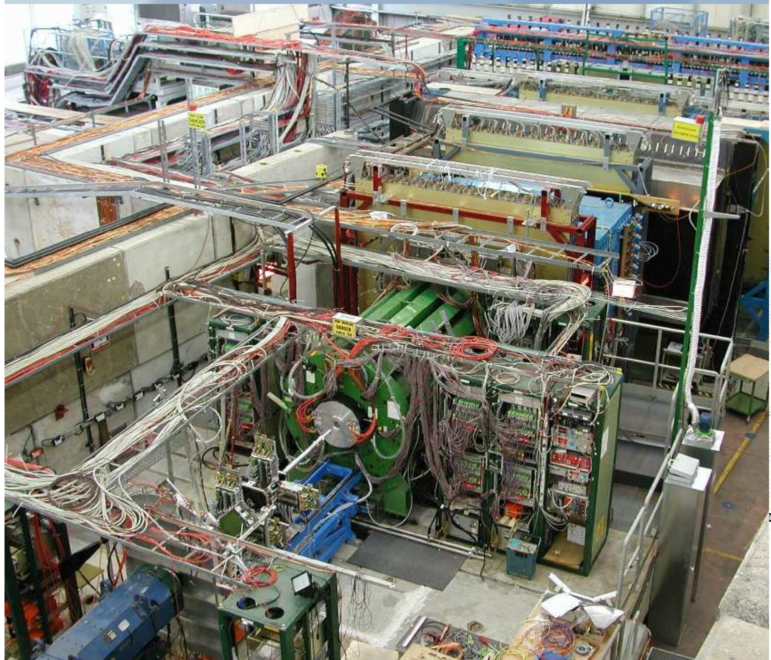
  $\nu_\mu \to \nu_e$, $\nu_e/\nu_\mu = 0.5\%$
- "Intrinsic" $\nu_e + \bar{\nu}_e$ sources:

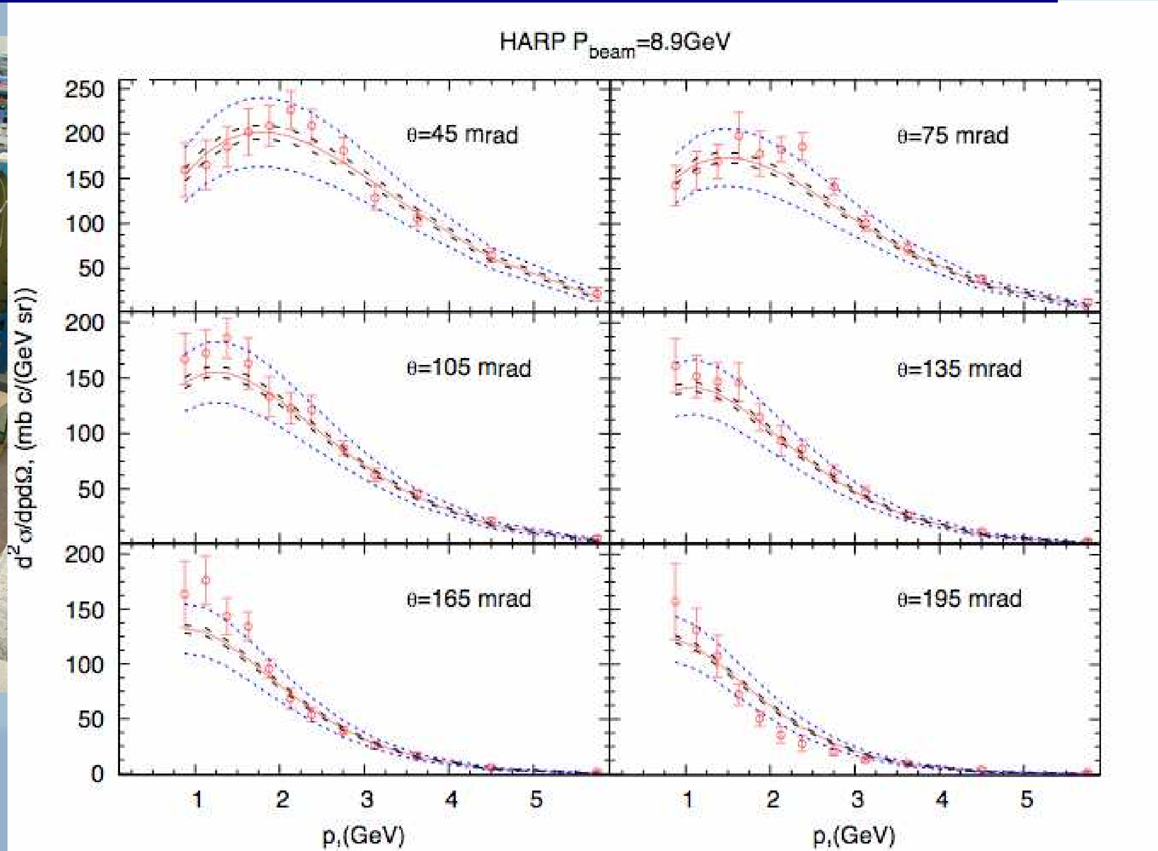
$\mu^+ \to e^+ \bar{\nu}_\mu \nu_e$	(52%)
$K+ \to \pi^0 e^+ \nu_e$	(29%)
$K^0 \to p\ e\ \nu_e$	(14%)
Other	(5%)

- Antineutrino content: 6%



π^+ Production Cross Section from HARP





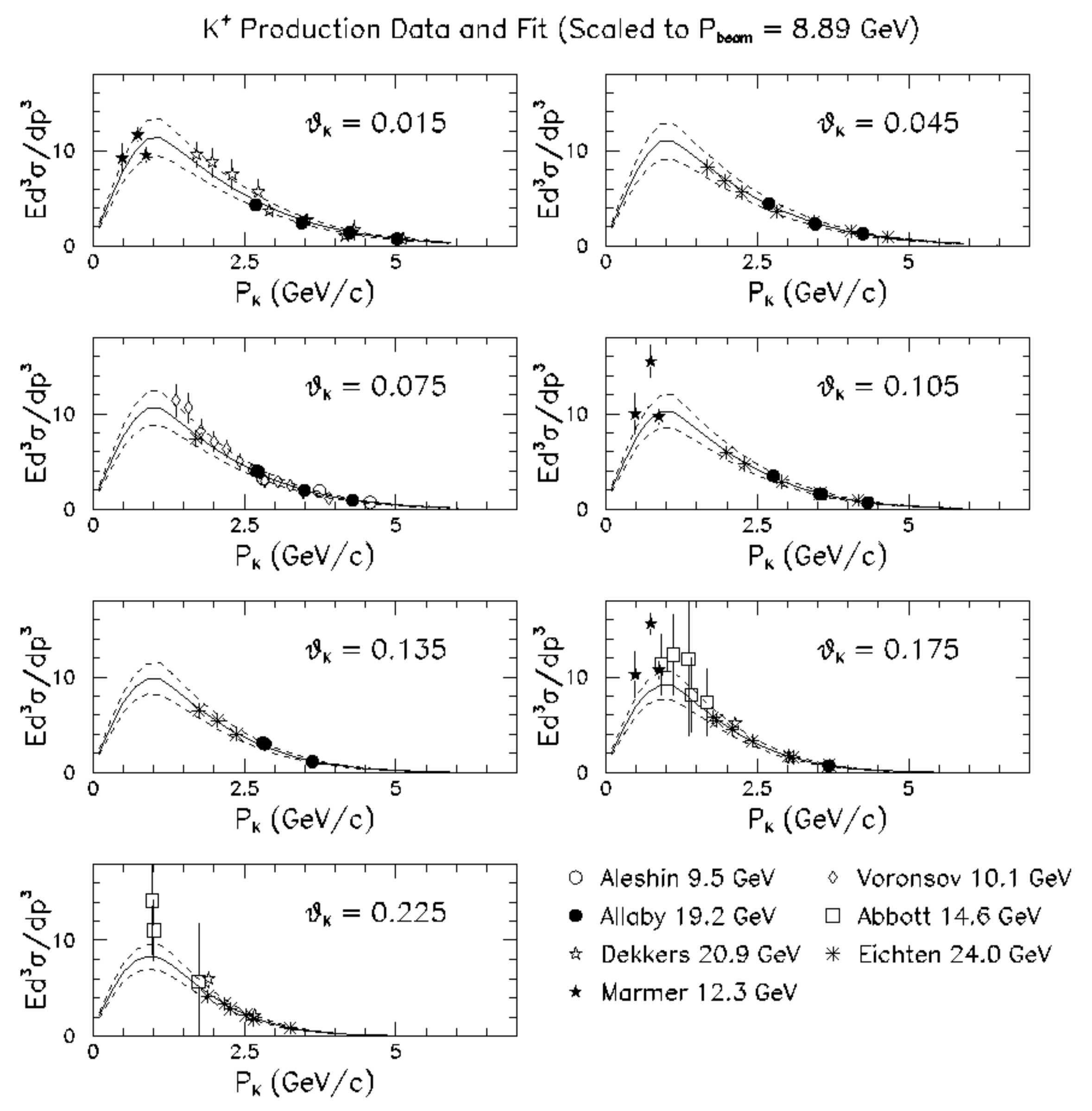
π^+ production cross section
is parameterized from a fit
to HARP π^+ production cross section,
using the standard Sanford-Wang
parameterization.

HARP collaboration,
hep-ex/0702024

HARP (CERN) measured the π^+
production cross section
- 5% λ Beryllium target
- 8.9 GeV proton beam
momentum

K Production Cross Section

- K^+ production cross section is parameterized from a fit to external data with beam momentum from 10-24 GeV.
- Feynman Scaling function is used parameterization.
- SW parameterization was also used and it's completely covered by the FS uncertainty.

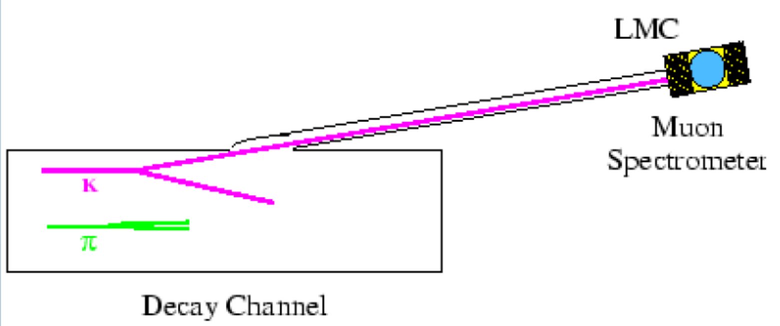


data -- points
dash --total error
(fit ⊕ parameterization)

- K^0 cross section is also parameterized from external data using SW.

K^+ Production Limit from LMC

LMC - **off-axis muon spectrometer viewing the decay pipe at 7º.**

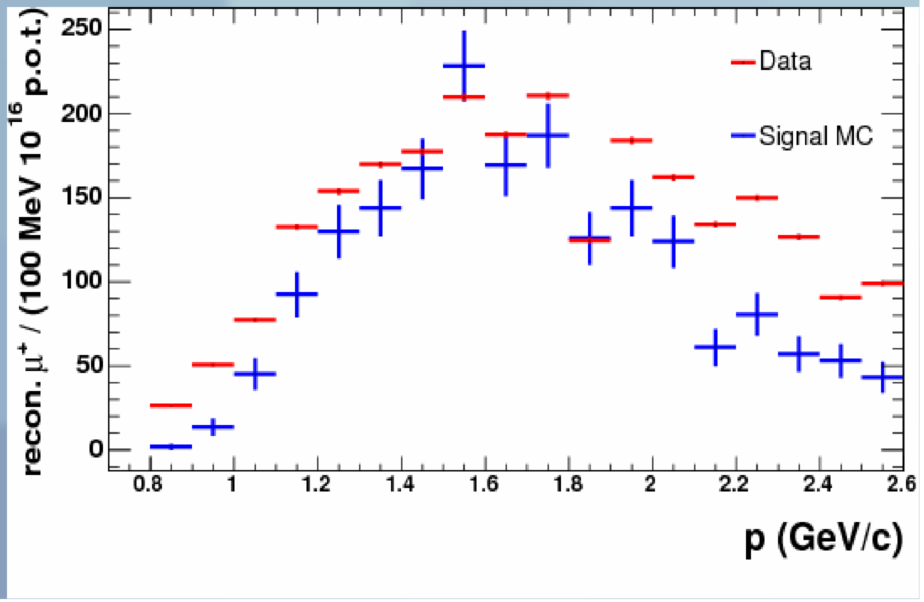


- **High-p_T μ's come from K^+ decays; Low-p_T μ's come from π^+ decays**

- **Effective |p| separation at this angle.**

Constraint on the K^+ flux normalization:

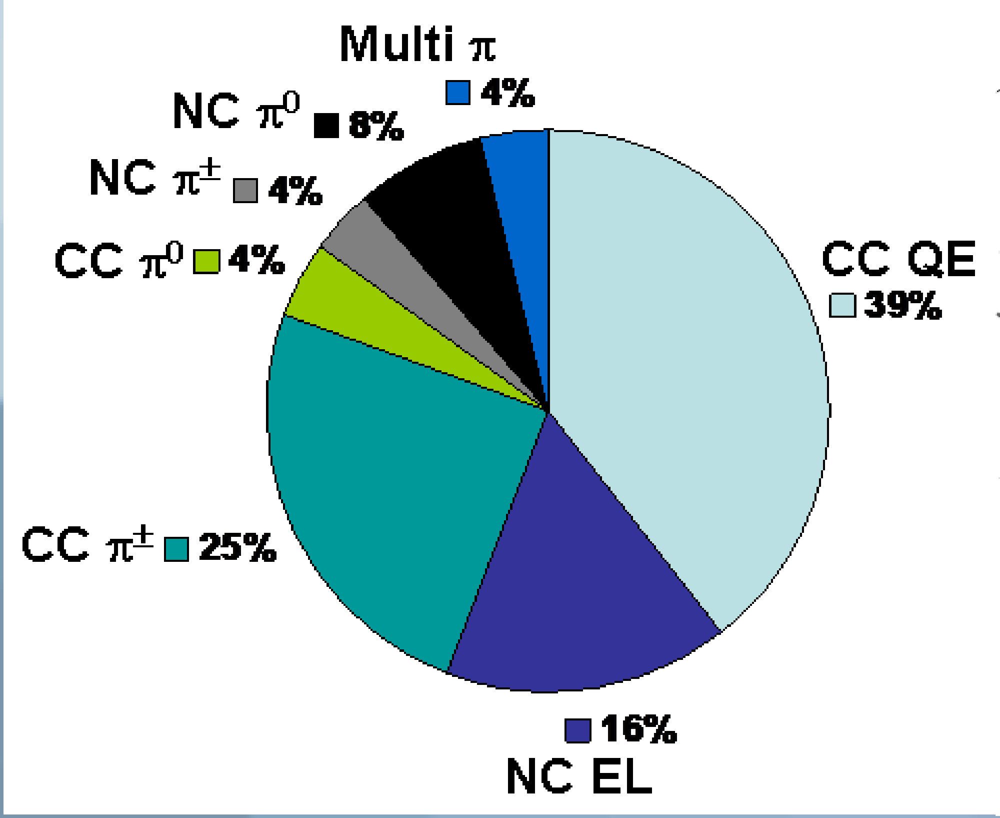
- **MC simulates p and K decays.**
- **No hadronic interaction backgrounds simulated.**
- **Plot shows data vs MC for well-identified muons in a region where we expect low backgrounds.**



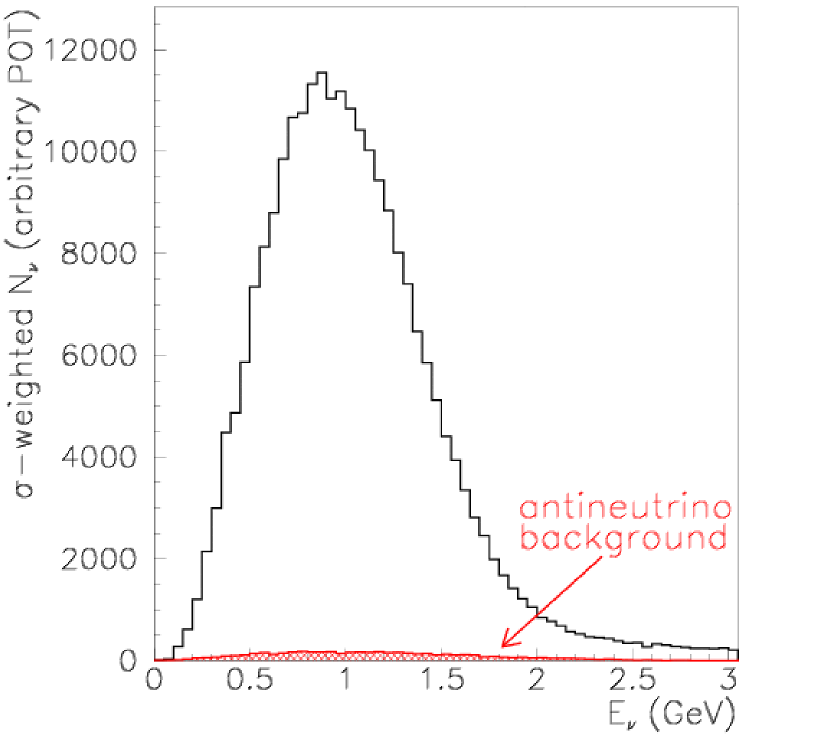
The upper limit on the K^+ flux normalization is 1.32.

Neutrino Cross Section Model - NUANCE

D. Casper, NPS, 112 (2002) 161



Predicted event type fractions.

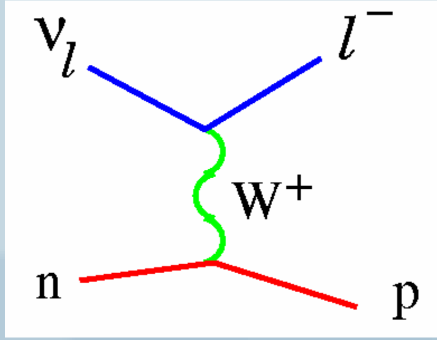


Predicted neutrino energy spectrum

Charge Current Quasielastic

Golden mode for oscillation search

$$\nu_l n \rightarrow l^- p$$



- Clean signature in the detector.
- Neutrino energy is reconstructed from the reconstructed momentum and angle of the charged lepton.

$$E_\nu^{CCQE} = \frac{m_N E_l - \frac{1}{2} m_l^2}{m_N - E_l + p_l \cos\theta_l}$$

$$Q^2 = -2E_\nu (E_l - p_l \cos\theta_l) + m_l^2$$

- Nuclear target
- Nucleon is not excited

Tuning the Cross Section Model - QE

Default NUANCE model QE Q^2 distr. shows discrepancy with data.
- reported by K2K (1kt) as well

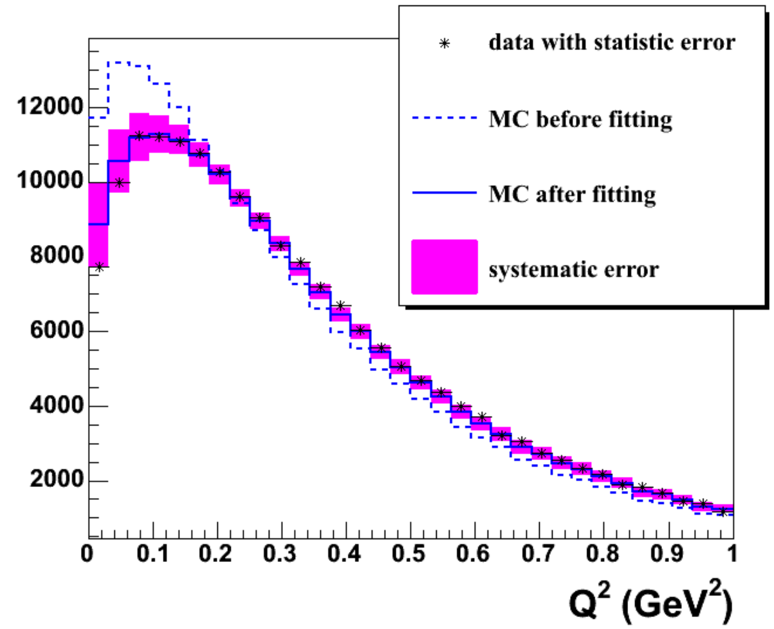
From Q^2 fits to MB ν_μ CCQE data:
- M_A^{eff} -- effective axial mass
- E_{lo}^{SF} -- Pauli Blocking parameter

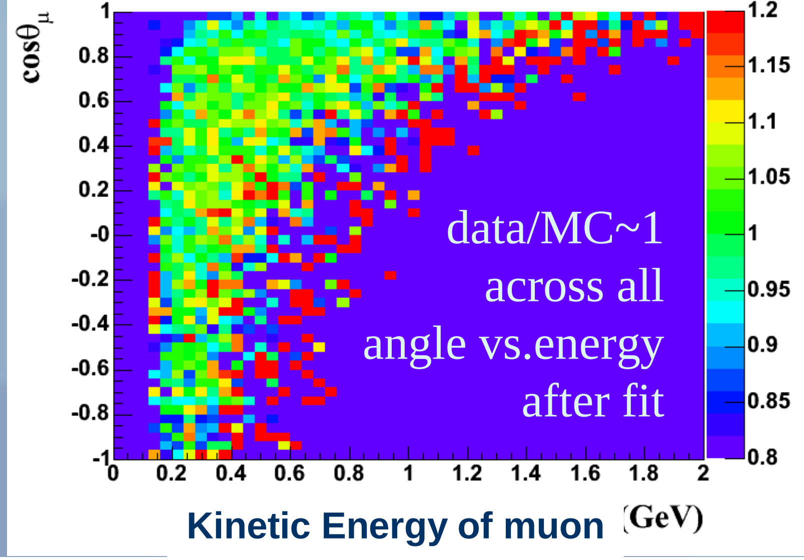
From electron scattering data:
- E_B -- binding energy
- p_F -- Fermi momentum

Submitted for publication to PRL:

e-Print: arXiv:0706.0926

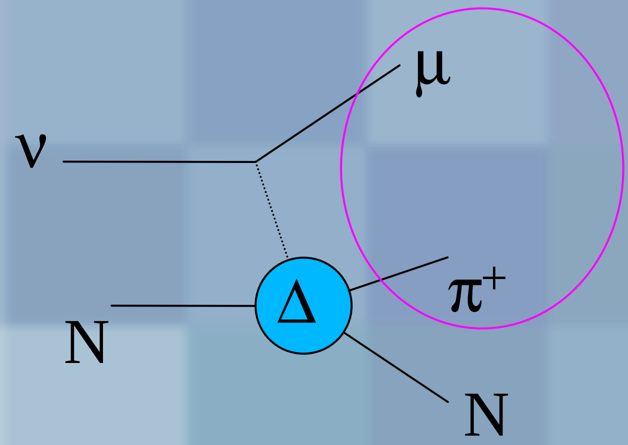
Measurement of Muon Neutrino Quasi-Elastic Scattering on Carbon.





Δ Resonance Production

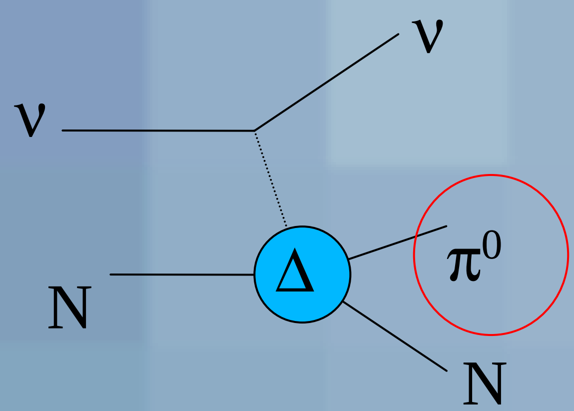
25%



$CC\pi^+$

Easy to tag due to 3 subevents. Not a substantial background to the oscillation analysis.

8%



$NC\pi^0$

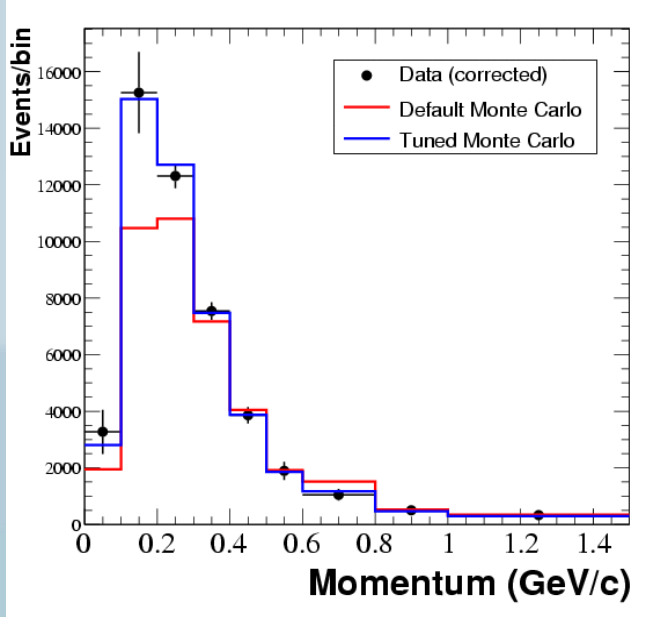
The π^0 decays to 2 photons, which can look "electron-like" mimicking the signal.

<1% of π^0 contribute to background.

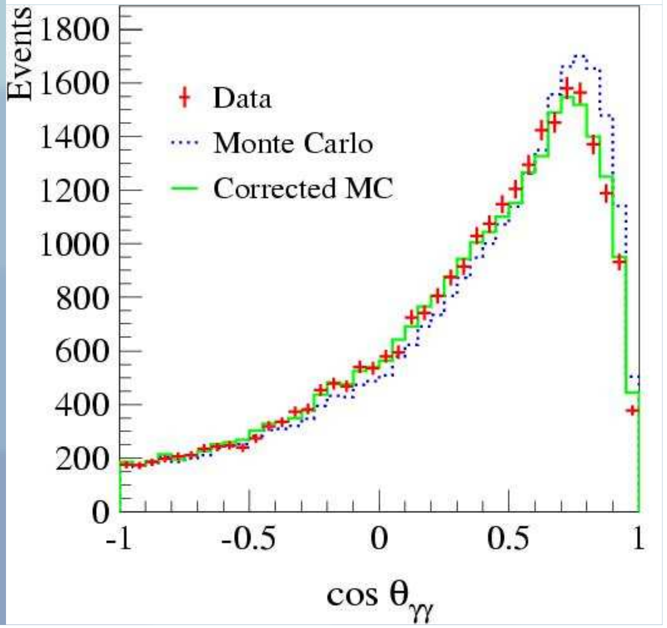
(also decays to a single photon with 0.56% probability)

Constraining NC Δ Resonance

- Fully reconstructed π^0 events sample constrains the total NC Δ rate.
- Re-weight the MC π^0 using the measured momentum distribution and total rate.
- Reduces the uncertainty of the π^0 mis-ID/misreconstructed background.
- It constrains also Δ–>Nγ



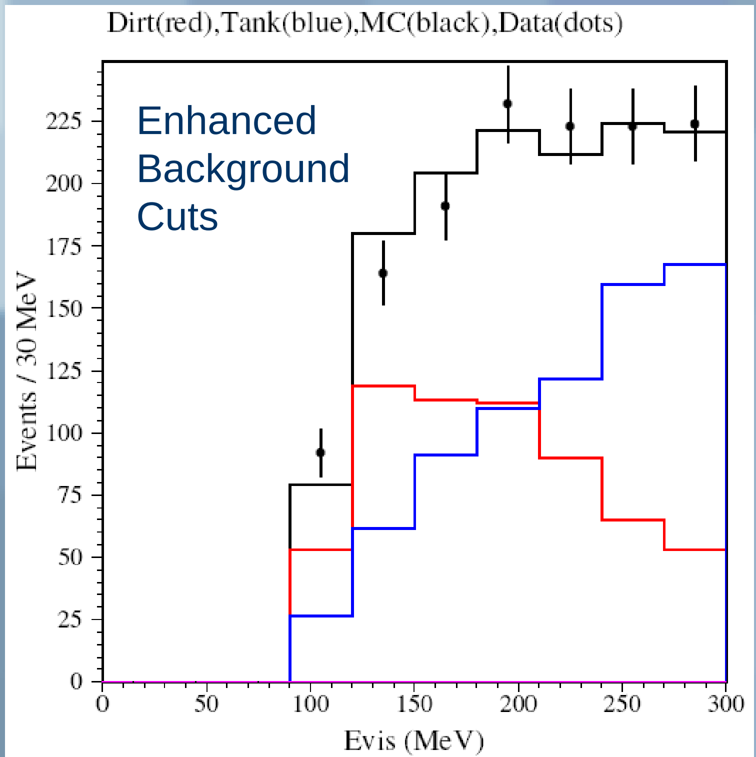
Reweighting improves agreement in other variables, e.g.⇒

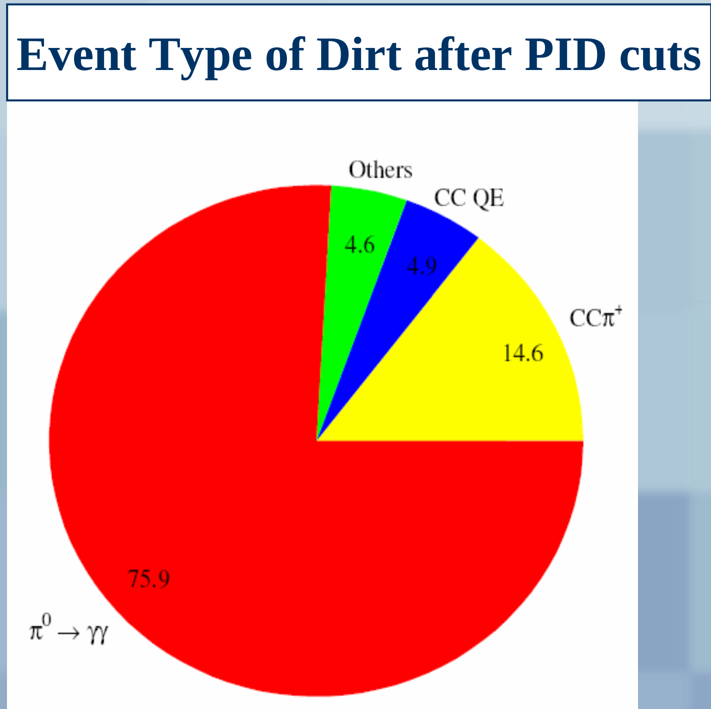


External Backgrounds

"Dirt" Events

ν interactions outside of the detector $N_{data}/N_{MC} = 0.99 \pm 0.15$





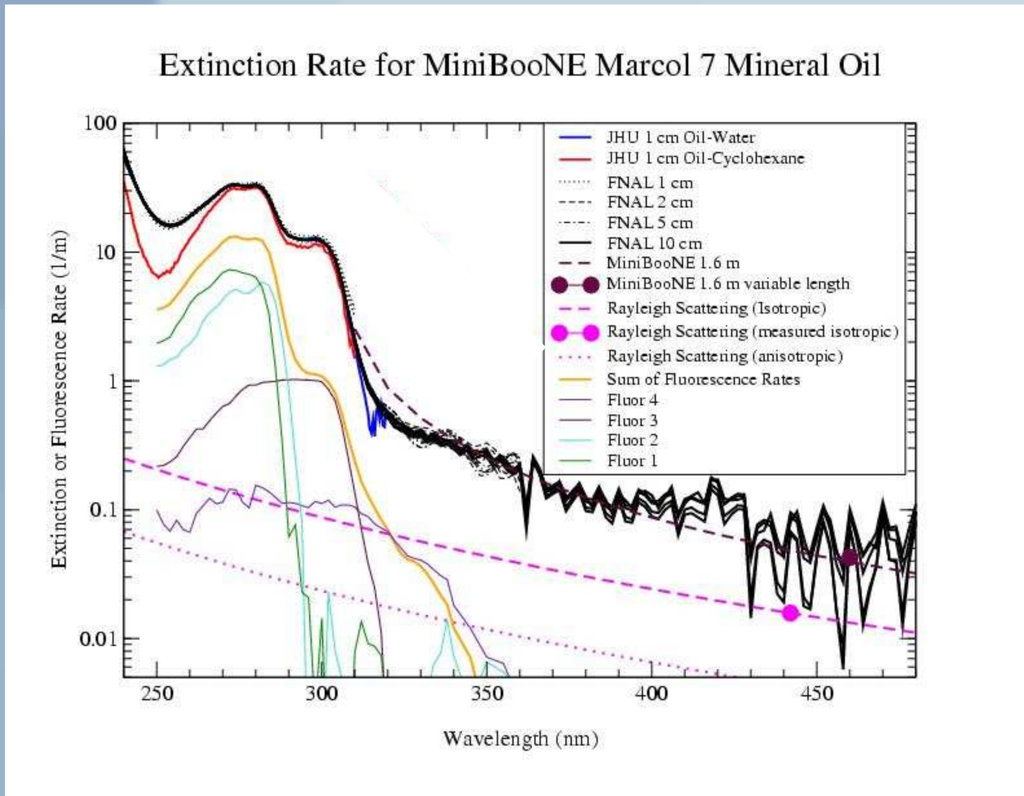
Cosmic Rays: Measured from out-of-beam data: 2.1 ± 0.5 events

Detector "Optical" Model

Primary light sources

- Cherenkov
    - Emitted promptly, in cone known wavelength distribution
- Scintillation
    - Emitted isotropically
    - Several lifetimes, emission modes
    - Studied oil samples using Indiana Cyclotron test beam
    - Particles below Cherenkov threshold still scintillate

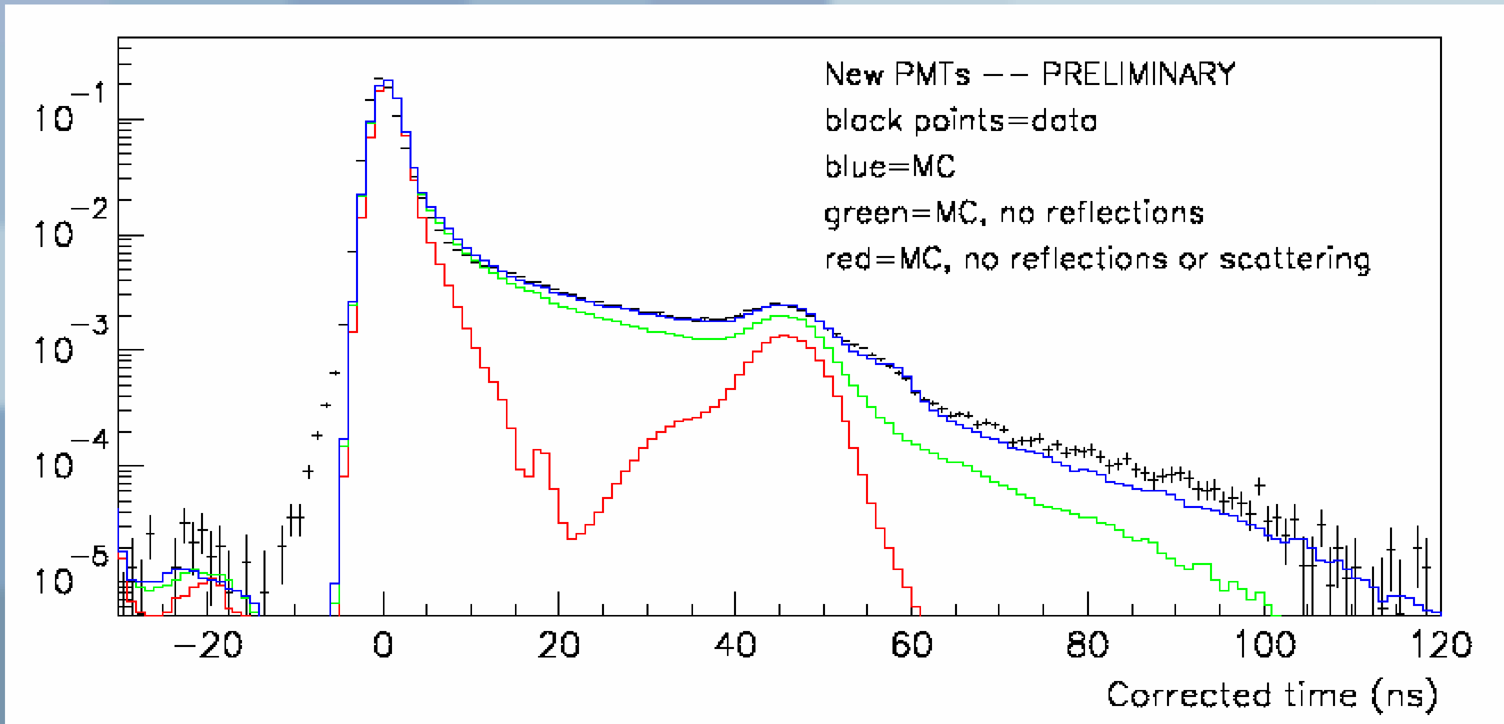
We have developed 39-parameter "Optical Model" based on internal calibration and external measurement



Optical properties of oil, detectors:

- Absorption (attenuation length >20m at 400 nm)
- Rayleigh and Raman scattering
- Fluorescence
- Reflections

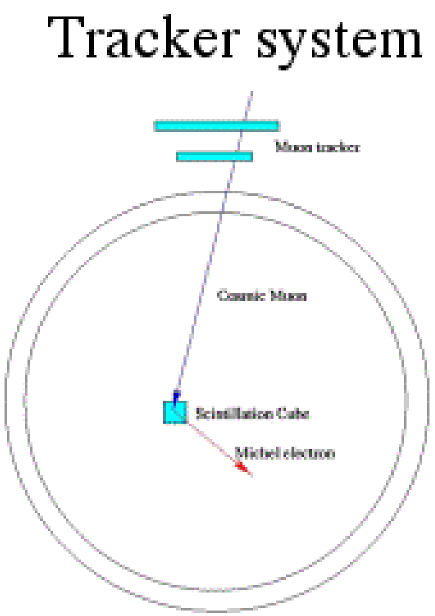
Detector "Optical" Model

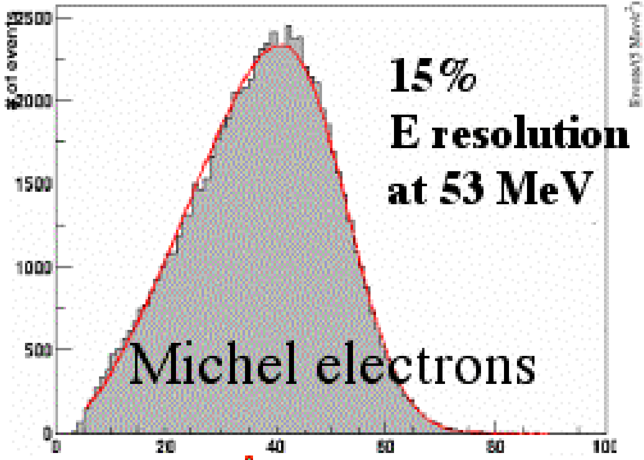


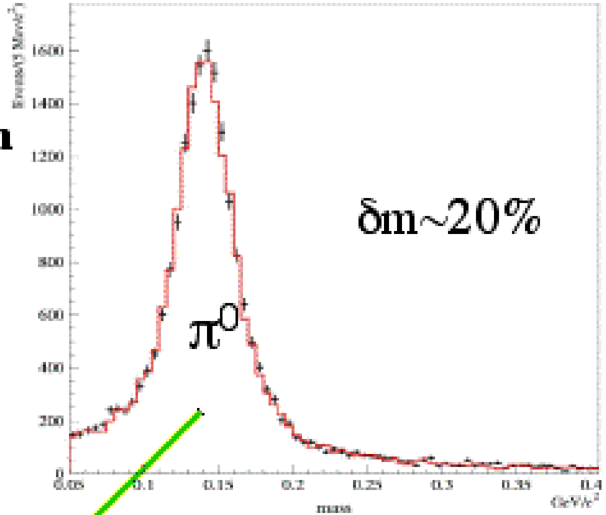
Timing distribution for PMT hits

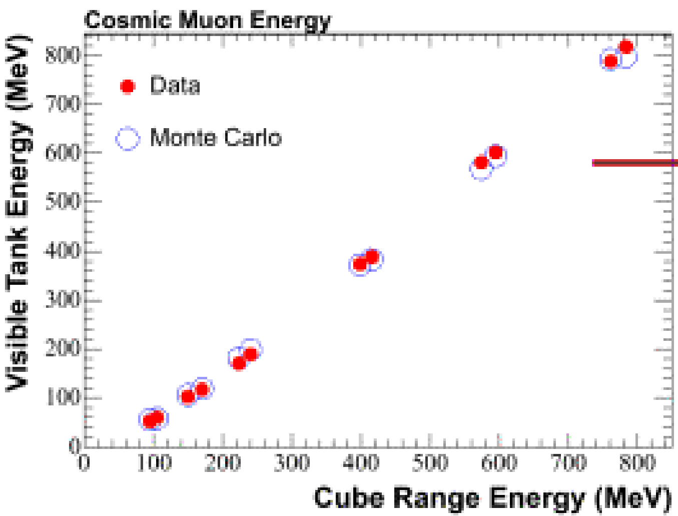
- Calibration laser source inside tank
- Monte Carlo with full optical model describes most of the timing structure

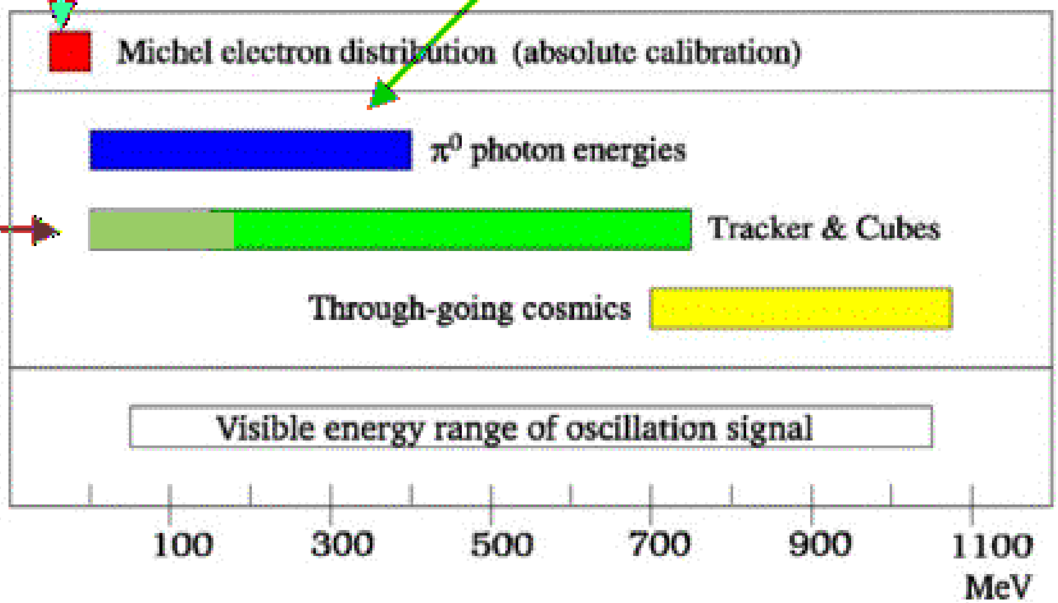
Detector Callibration











Events Reconstruction and Particle ID

Two parallel approaches to PID analysis:

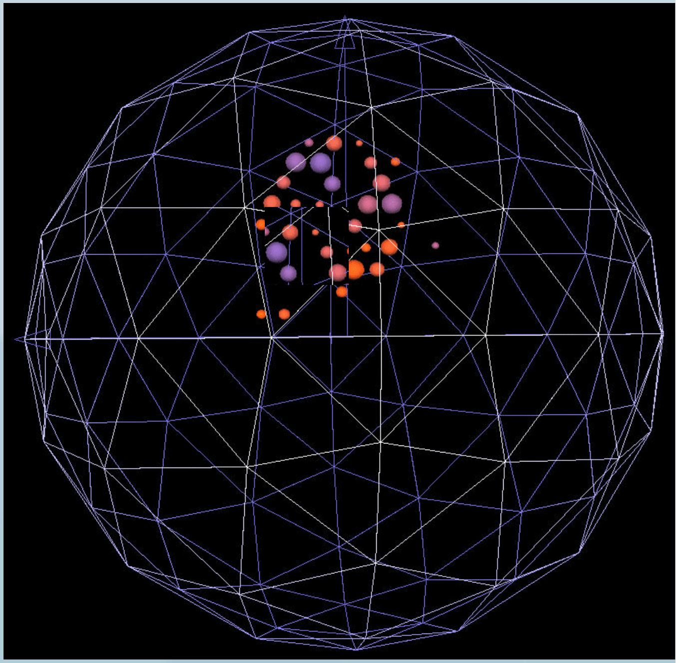
Track/likelihood-based (TB)

PID is based on log-likelihood ratios of different particle hypotheses.

Boosted decision trees (BDT)

PID is based on algorithm extracting collective information from a large number of low level variables.

Blind Analysis



MiniBooNE is searching for a small but distinctive event signature.

Blind region:
- Electron-like events were sequestered
  - about 1% of the in-beam events.

The rest 99% of in beam events
- At the beginning highly restrictive.

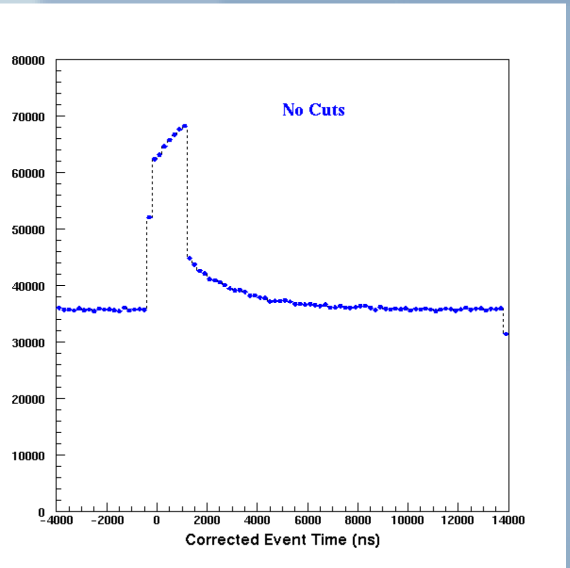
- Rule for cuts to sequester events:
  <1σ signal outside of the box

- Look closer and closer to the box as the PID and MC became more and more trustworthy.

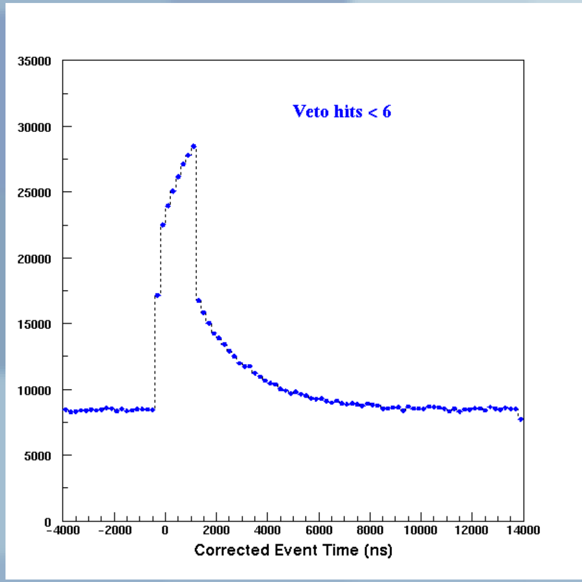
Finally box was opened in series of steps.

Eliminating Cosmic Background

Progressively introducing cuts on the time window:

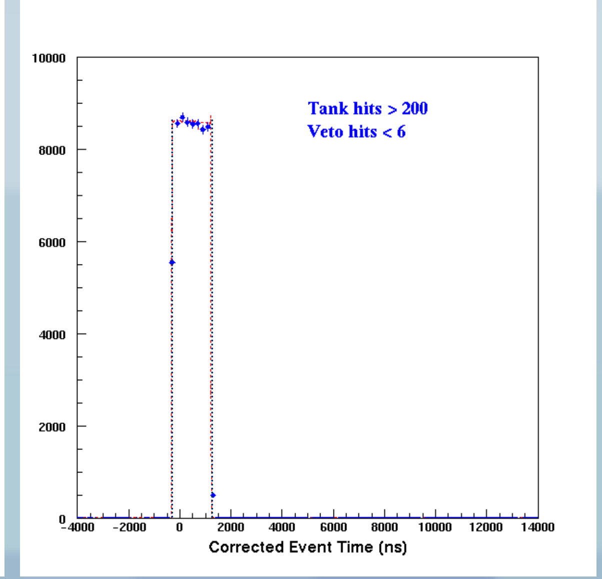


Raw data



Veto<6 removes through-going cosmics

This leaves "Michel electrons" ($\mu \rightarrow \nu_\mu \nu_e e$) from cosmics



Tank Hits > 200 (effective energy cut) removes Michel electrons, which have 52 MeV endpoint.

Analysis Precuts

Precuts:

Only 1 subevent

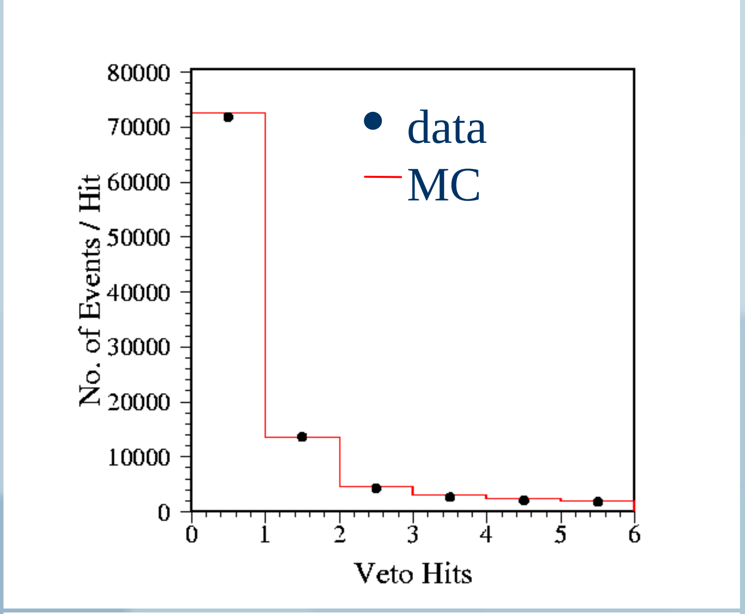
Veto hits < 6

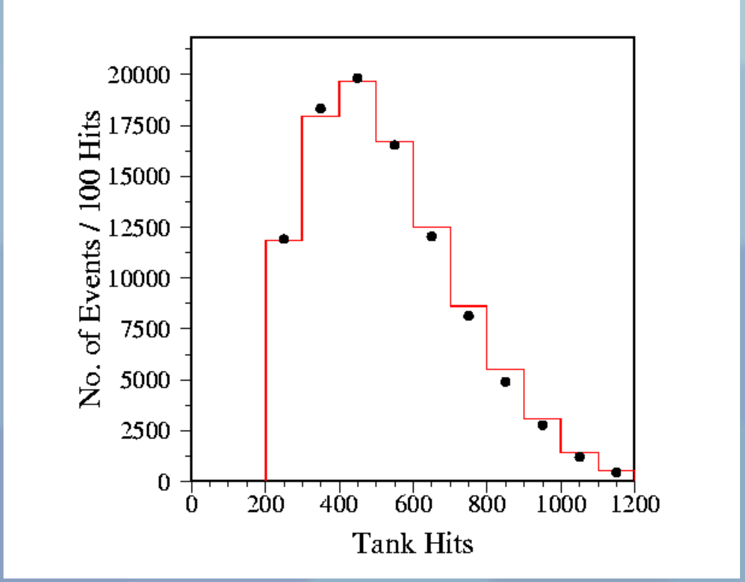
Tank hits > 200

And a radius precut:

R<500 cm

(where reconstructed R is algorithm-dependent)





Track-Based Analysis
Track Reconstruction

Predicts the probability for each tube to be "hit" based on the average number photo electrons (PE).

- detailed calculation of the PE, given the optical properties of the detector and the particle parameters (parameters in the fit), accounting for:
  - Non-uniform light source.
  - Prompt light
  - Delayed light
  - Indirect light
  - Angular profile of the produced light.

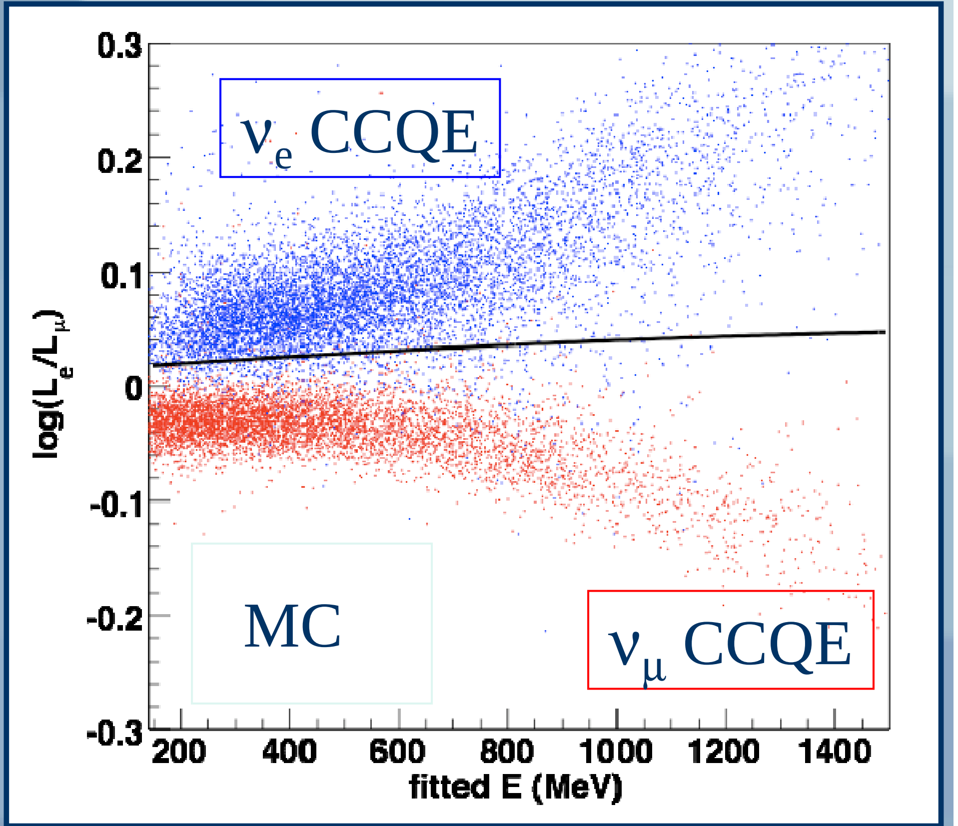
Several track hypothesis:

- a single track (μ,e) is parameterized with 7 parameters – (x^0, y^0, z^0, T^0, E^0, θ^0, ϕ^0)
- two track fit to π^0 hypothesis includes additionally γ_1, γ_2 conversion lengths, energy and direction of γ_2 π^0 mass.

Perform likelihood fits to each event with different particle hypothesis (μ, e, π^0 -> 2 γ with and without π^0 mass constraint).

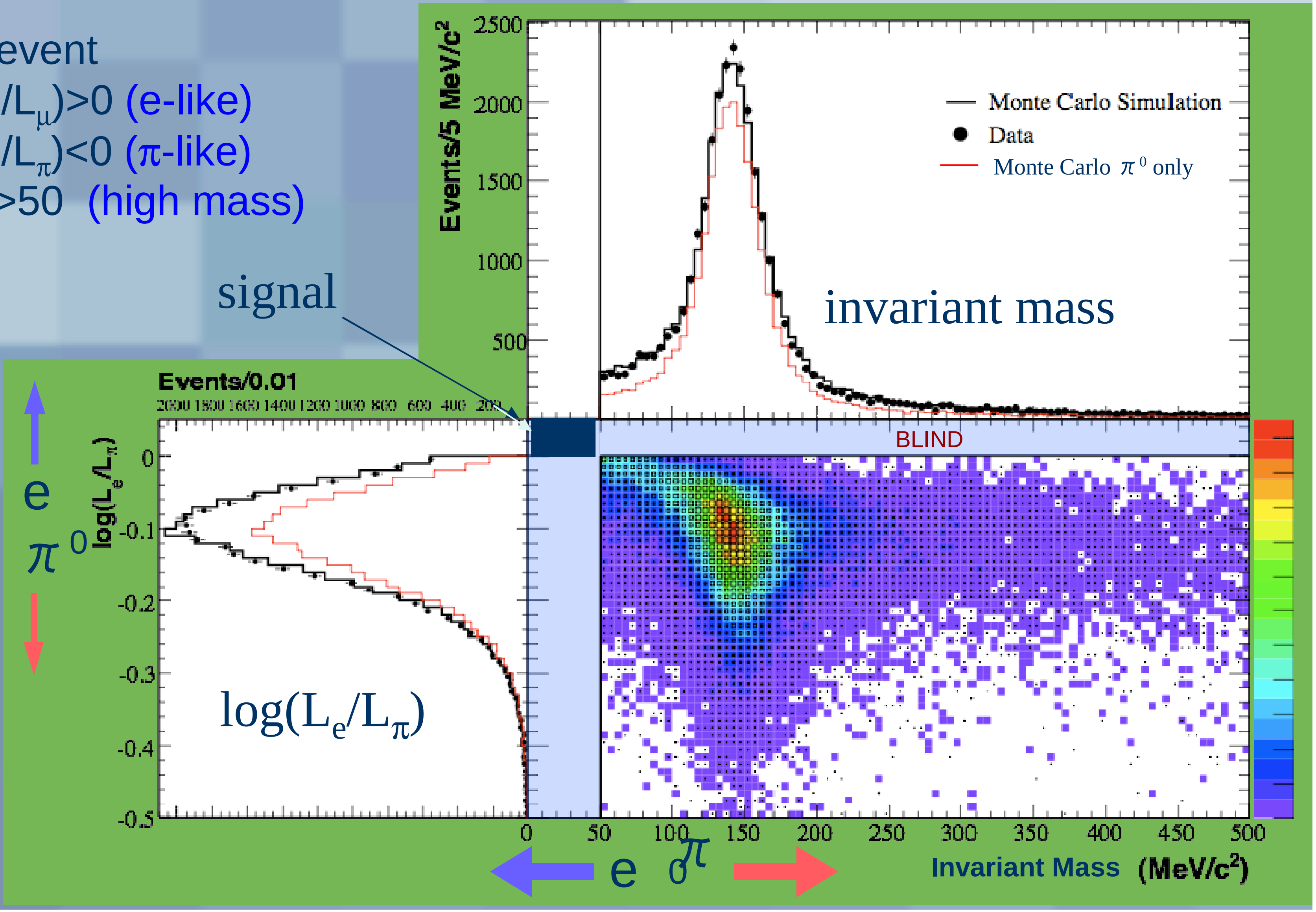
Track-Based Analysis
Rejecting Muon-like Events

- Single track fit to muon and electron hypothesis
- $\log(L_\varepsilon/L_\mu)>0$ selects electron hypothesis.
- The cut is a quadratic function with energy, optimizing oscillation sensitivity.
- Separation is clean at high energies where muon-like events are long.

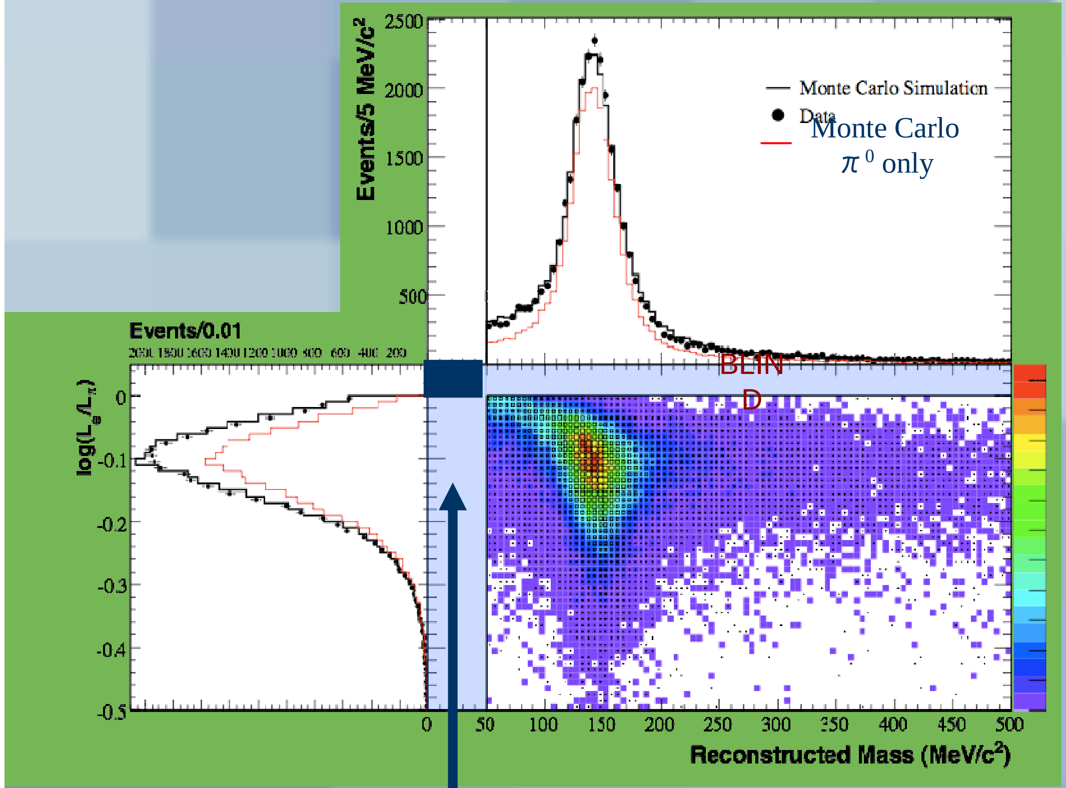


Track-Based Analysis
Test of e/π^0 Separation

1 subevent
$\log(L_e/L_\mu)>0$ (e-like)
$\log(L_e/L_\pi)<0$ (π-like)
mass>50 (high mass)



Track-Based Analysis
Checking the Sidebands

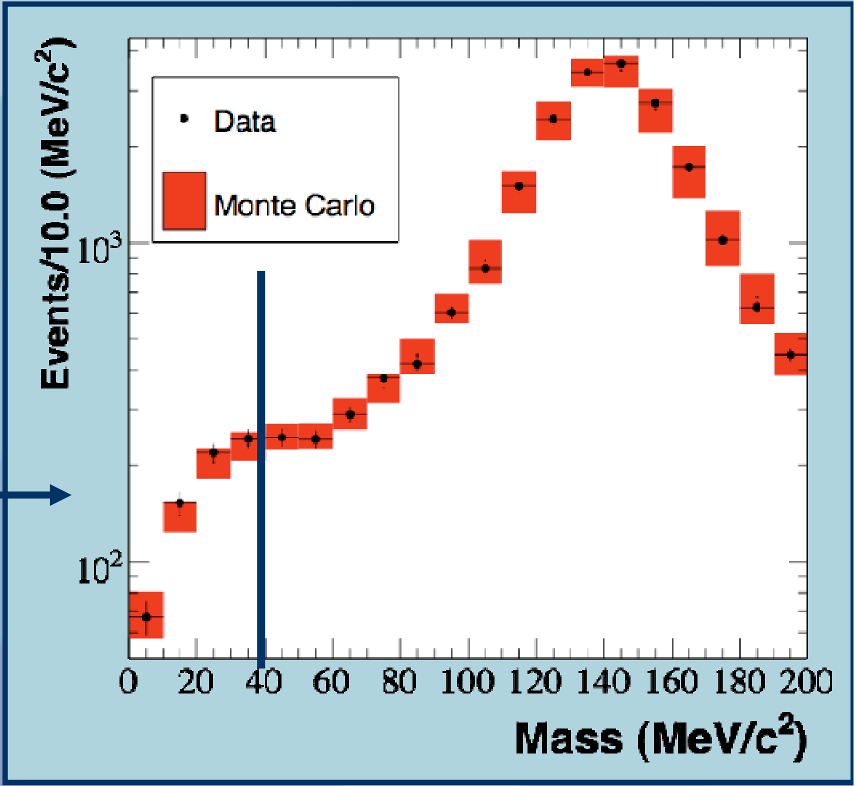


1 subevent

log(L_e/L_μ)>0 (e-like)

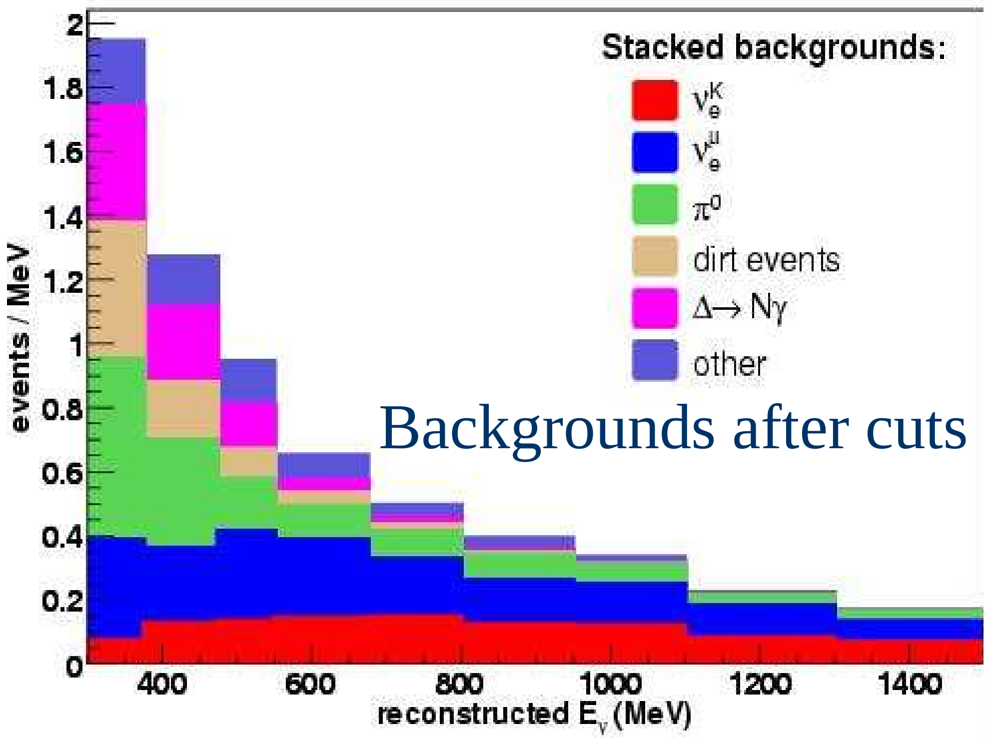
log(L_e/L_π)<0 (π-like)

mass<200 (low mass)



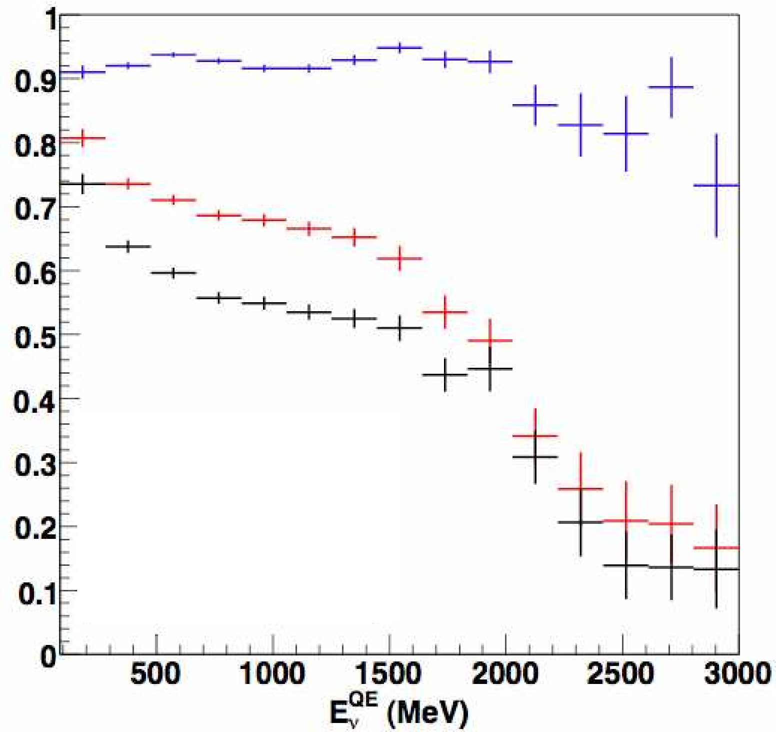
χ^2 Prob for mass<50 MeV ("most signal-like"): 69%

Track-Based Analysis
Predicted Background and Signal Efficiency



Backgrounds after cuts

Efficiency:



"Precuts" +
$Log(L_e/L_\mu)$ +
$Log(L_e/L_\pi)$ +
Invariant mass

Boosted Decision Tree Analysis (BDT)

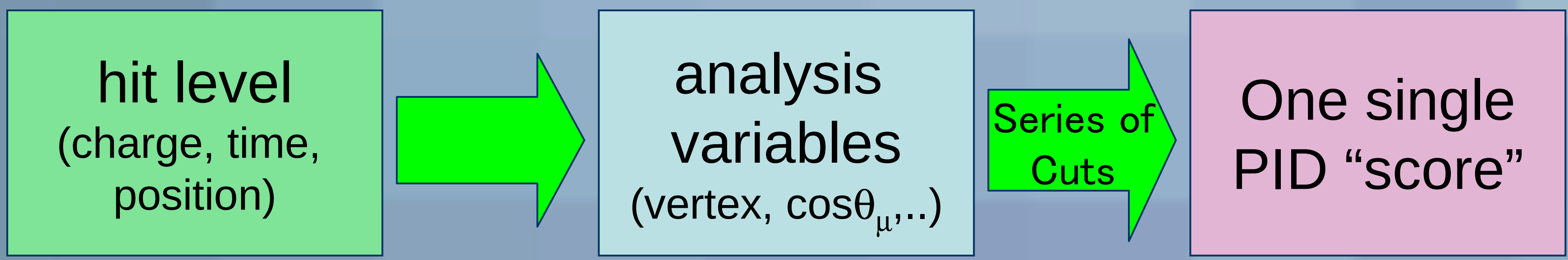
- An algorithm optimized to combine many weakly discriminating variables into one that provides powerful separation
  B. Roe et al., Nucl. Inst. Meth. ***A543*** *577 (2005)*

- Procedure for building a “decision tree”:

    - Find the variable separating signal and background best.

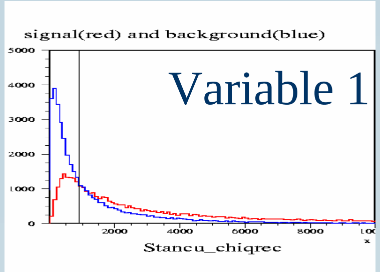
    - for each of the two subsets repeat the process.

    - final nodes are called leaves (can not be further separated).



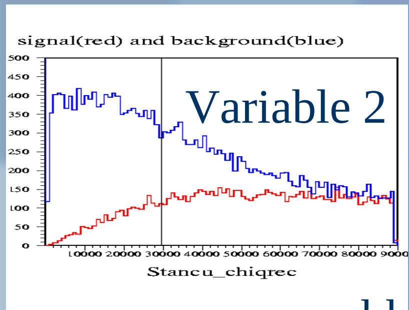
Decision Tree

(N$_{signal}$/N$_{bkgd}$)



bkgd-like

signal-like



9755/23695

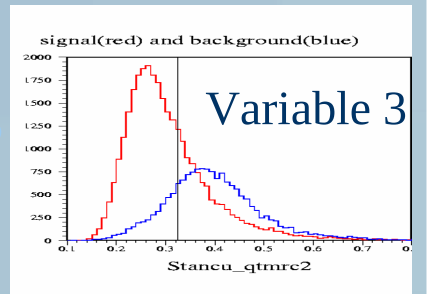
bkgd-like

sig-like

1906/11828

7849/11867

30,245/16,305



sig-like

bkgd-like

20455/3417

9790/12888

etc.

This tree is one of many possibilities...

Boosted Decision Tree

- A set of decision trees can be developed, each re-weighting the events to enhance identification of backgrounds misidentified by earlier trees   ("boosting")

- For each tree, the data event is assigned
  - +1 if it is identified as signal,
  - -1 if it is identified as background.

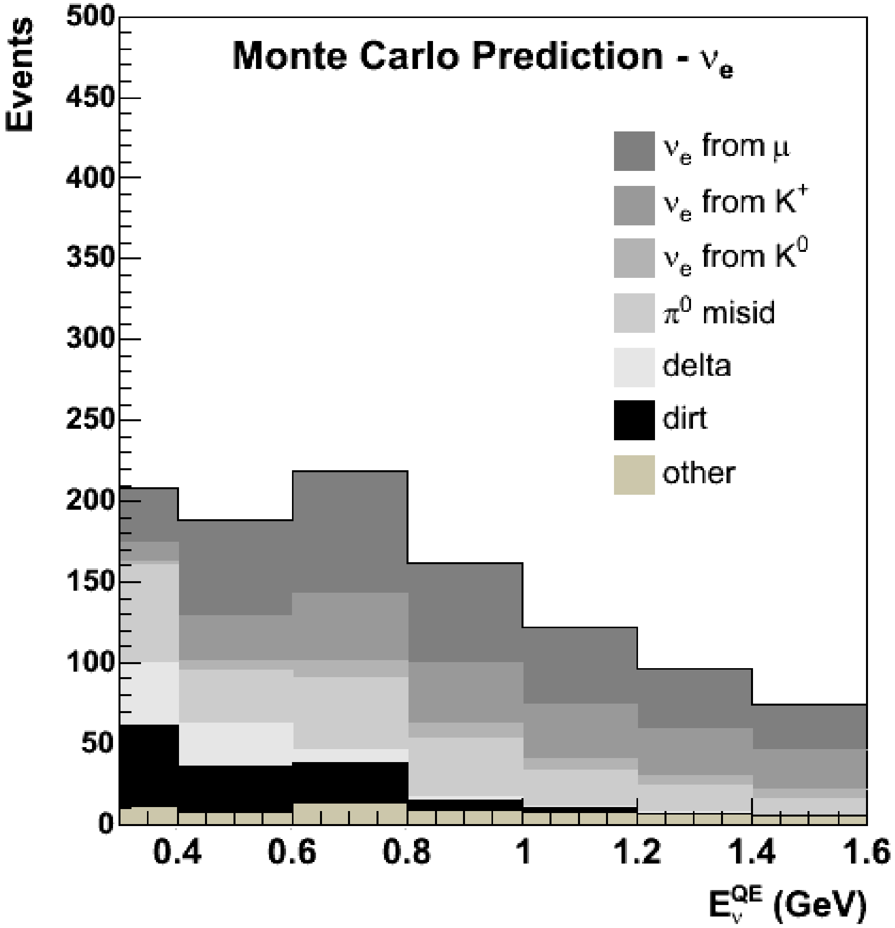
The total for all trees is combined into a "score"

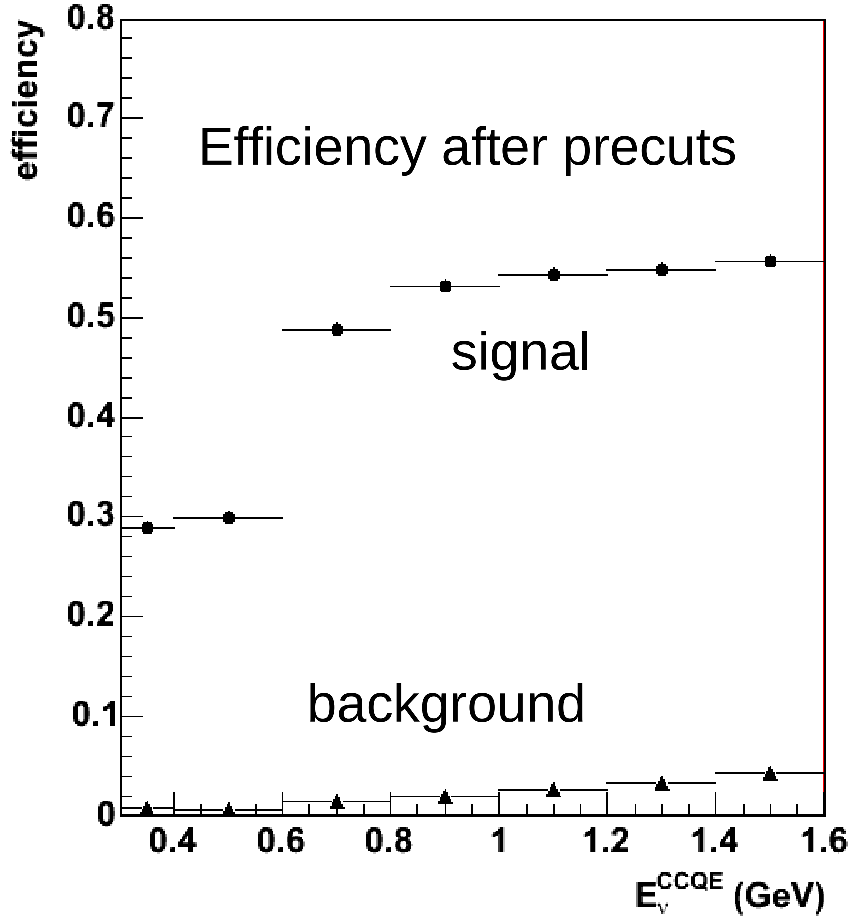
Background-like

Signal-like

Background and Signal Efficiency of BDT

Analysis cuts on PID score as a function of Energy

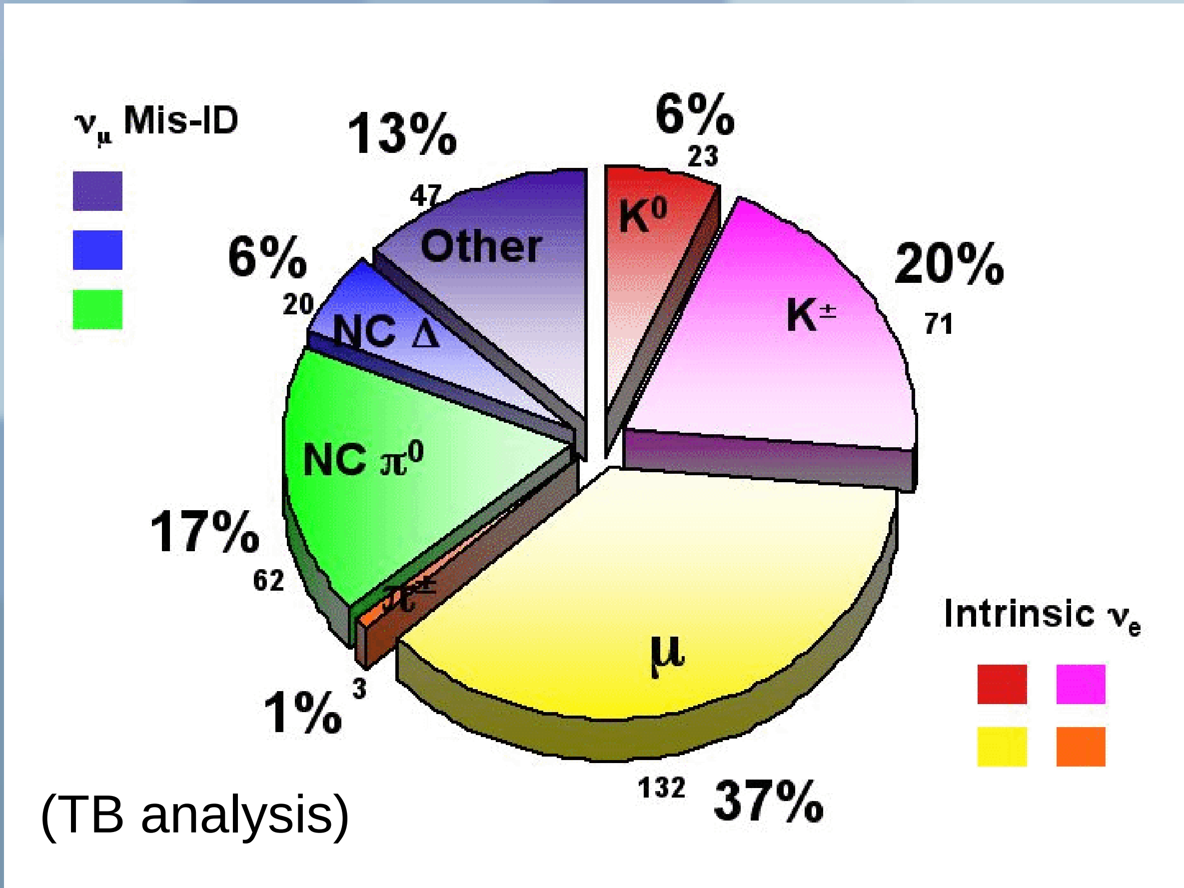




Uncertainties, Constraints and Sensitivity

Background Components

We have two categories of backgrounds:



Predictions of the backgrounds are among the nine sources of significant error in the analysis

Systematic Uncertainties

Source of Uncertainty On ν_e background	Track Based /Boosted Decision Tree error in %	Checked or Constrained by MB data	Further reduced by tying ν_e to ν_μ
Flux from π^+/μ^+ decay	6.2 / 4.3	√	√
Flux from K^+ decay	3.3 / 1.0	√	√
Flux from K^0 decay	1.5 / 0.4	√	√
Target and beam models	2.8 / 1.3	√	
ν-cross section	12.3 / 10.5	√	√
NC π^0 yield	1.8 / 1.5	√	
External interactions ("Dirt")	0.8 / 3.4	√	
Optical model	6.1 / 10.5	√	√
DAQ electronics model	7.5 / 10.8	√	

Cross Section Uncertainties

(Many are common to ν_μ and ν_e and cancel in the fit)

Parameter	Error/Value	Source
M_A^{QE}, E_{lo}^{SF} QE σ norm	6%, 2% (stat+bkg) 10%	MB ν_μ CCQE MB ν_μ CCQE
NC π^0 rate Δ–> Nγ rate	few % (depends on p_π) ~10%	MB NC π^0 data MB NC π^0 data, BR
E_B, p_F σ DIS	9 MeV, 30 MeV 25%	External data External data

Error Propagation

Use "Multisim" technique for error propagation:

- **vary the parameters according to a full covariance matrix and obtain MC for each parameter set (ensemble of MC experiments).**

Optical model:

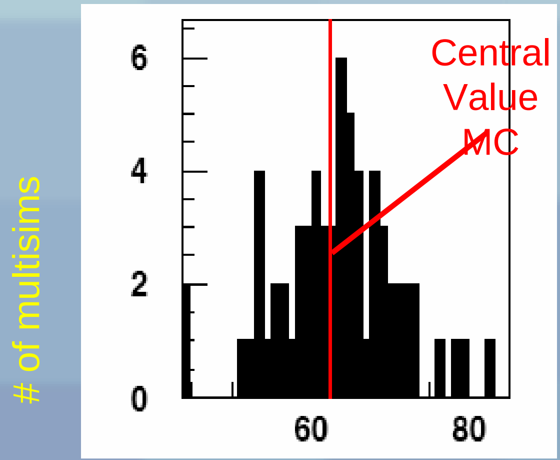
- **depends on 39 parameters such as absorption, scintillation, etc.**
- **ensemble of 70 full GEANT MC "experiments" to map the space of detector responses to the parameters.**

Other:

- **Flux and neutrino cross-section parameter variations do not affect the hit distributions for a given event, only the probability of that event occurring in the first place**
- **ensemble of 1000 MC by reweighting the same MC events: reduced MC statistics error and greatly reduced CPU usage.**

Example of multisim outputs in a single osc. bin:

70 Optical Model multisims



events passing signal cuts in bin $500<E_{\nu}^{QE}<600$ MeV

Error Matrix Calculation

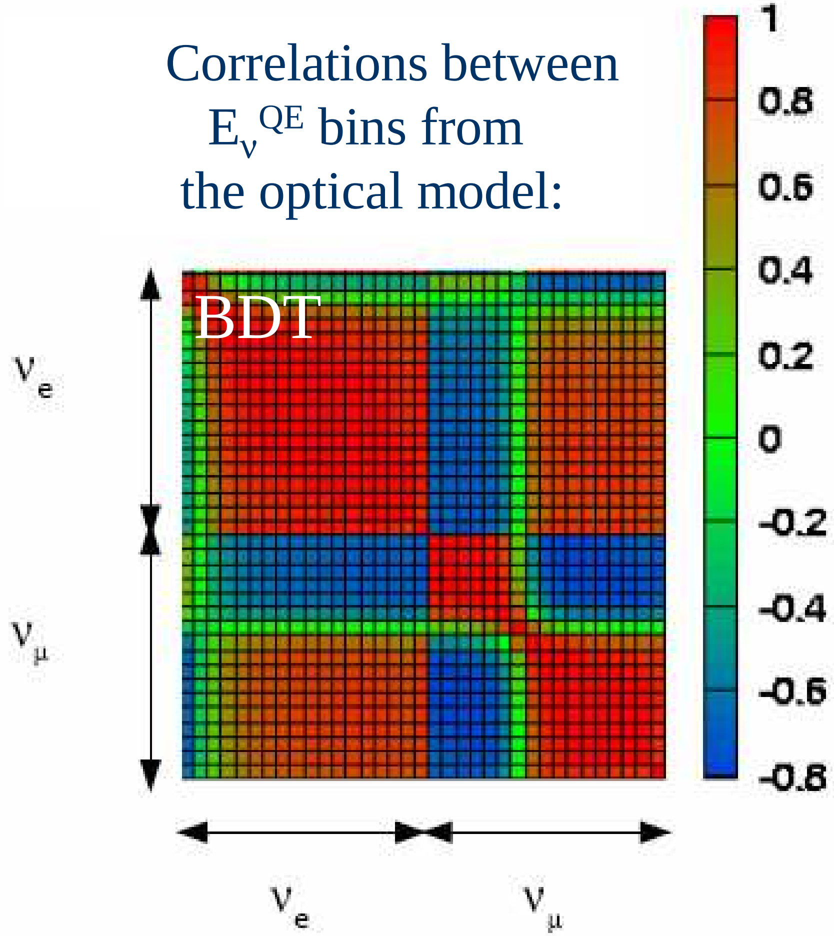
$$E_{ij} \approx \frac{1}{M} \sum_{\alpha=1}^{M} \left(N_i^{\alpha} - N_i^{MC}\right)\left(N_j^{\alpha} - N_j^{MC}\right)$$

- N is number of events passing cuts
- MC is standard monte carlo
- α represents a given multisim
- M is the total number of multisims
- i,j are E_ν^{QE} bins

Total error matrix
is sum from each source.

TB: ν_e-only total error matrix
BDT: ν_μ-ν_e total error matrix

Correlations between
E_ν^{QE} bins from
the optical model:



Predicted Background Content (TB)

	Process	Number of Events
MisIDs	ν_μ CCQE	10 ± 2
	$\nu_\mu e \to \nu_\mu e$	7 ± 2
	Miscellaneous ν_μ Events	13 ± 5
	NC π^0	62 ± 10
	NC $\Delta \to N\gamma$	20 ± 4
	NC Coherent & Radiative γ	< 1
	Dirt Events	17 ± 3
Intrinsic ν_e	ν_e from μ Decay	132 ± 10
	ν_e from K^+ Decay	71 ± 26
	ν_e from K^0_L Decay	23 ± 7
	ν_e from π Decay	3 ± 1
	Total Background	358 ± 35
LSND signal	0.26% $\nu_\mu \to \nu_e$	163 ± 21

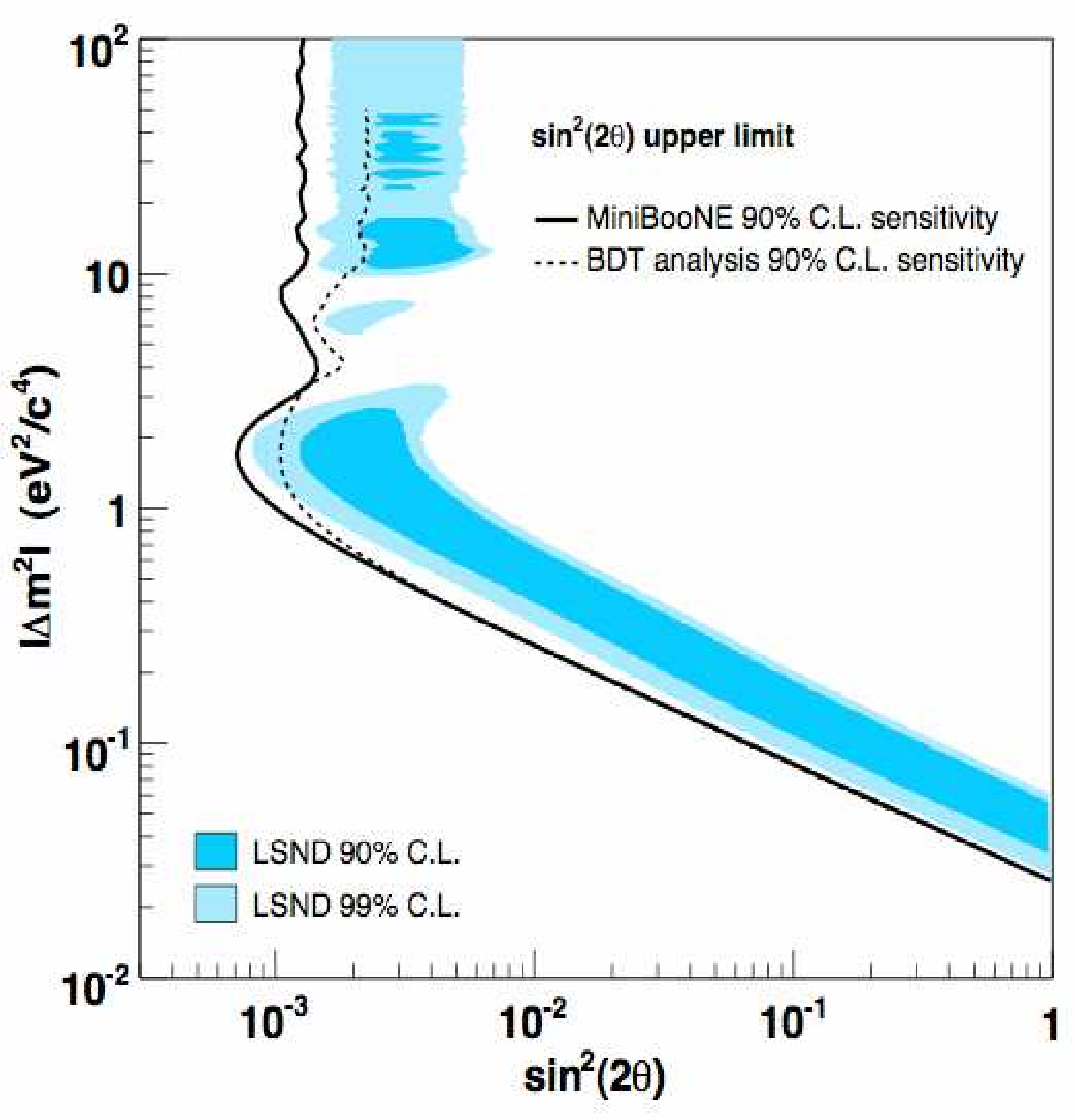
MiniBooNE Sensitivity

- Track-based analysis has slightly better sensitivity to 2-neutrino oscillations.

- Therefore it's the PRIMARY MiniBooNE result.

This is the culmination of the analysis

Next step: UNBLINDING
Procedure in steps.



Set using $\Delta\chi^2$=1.64 @ 90% CL

First Oscillation Results

Unblinding Steps

After applying all analysis cuts:

1. Fit sequestered data to an oscillation hypothesis, returning no fit parameters. Return the χ^2 of the data/MC comparison for a set of diagnostic variables.

2. Open up the plots from step 1. The Monte Carlo has unreported signal. Plots chosen to be useful diagnostics, without indicating if signal was added.

3. Report the χ^2 for a fit to E_ν^{QE} , without returning fit parameters.

4. Compare E_ν^{QE} in data and Monte Carlo, returning the fit parameters.
   At this point, the box is open (March 26, 2007)

Setting Low Energy Cut

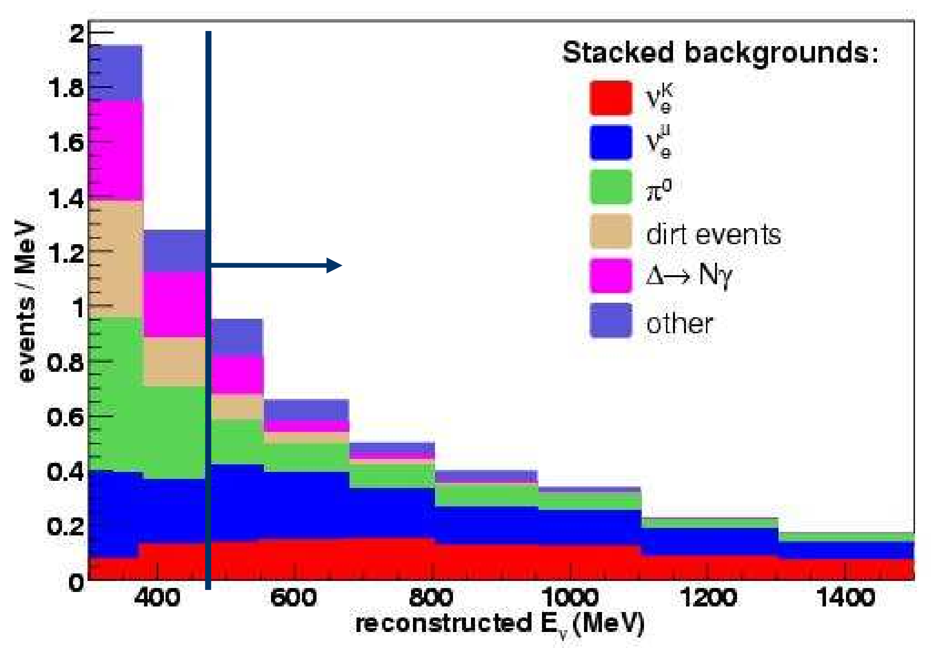
All analysis variables were returned with good probability (Step 1) except TB analysis χ^2 Probability of $E_{visible}$ (not E_ν^{QE}) fit: 1%

- We re-examined our background estimates using sideband studies
  - *We found no evidence of a problem*

- However, knowing that backgrounds rise at low energy,
  We tightened the cuts for the oscillation fit (TB only):

$E_\nu^{QE} > 475$ MeV

We agreed to report events over the original full range:
$E_\nu^{QE} > 300$ MeV



Counting Experiment

The Track-based $\nu_\mu \rightarrow \nu_e$ Appearance-only Result:

Counting Experiment: $475 < E_\nu^{QE} < 1250$ MeV

data: 380 events
expectation: 358 ±19 (stat) ± 35 (sys) events

significance:
0.55 σ

No evidence of oscillations

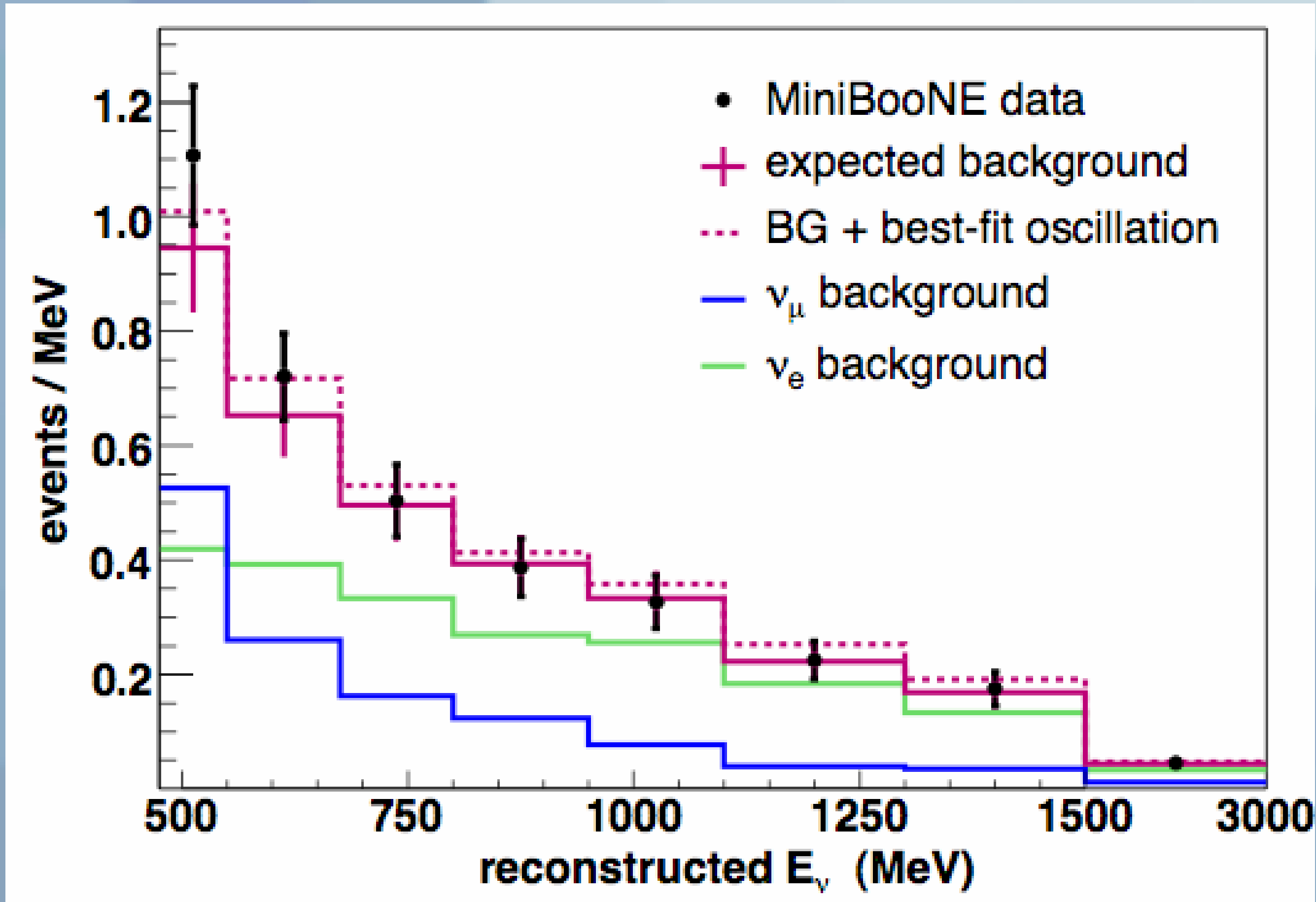
Energy Fit

Track Based energy dependent fit results:

- Data are in good agreement with background prediction.
- Best Fit (dashed): $(\sin^2 2\theta, \Delta m^2) = (0.001, 4\ \text{eV}^2)$

Error bars are diagnonals of error matrix.

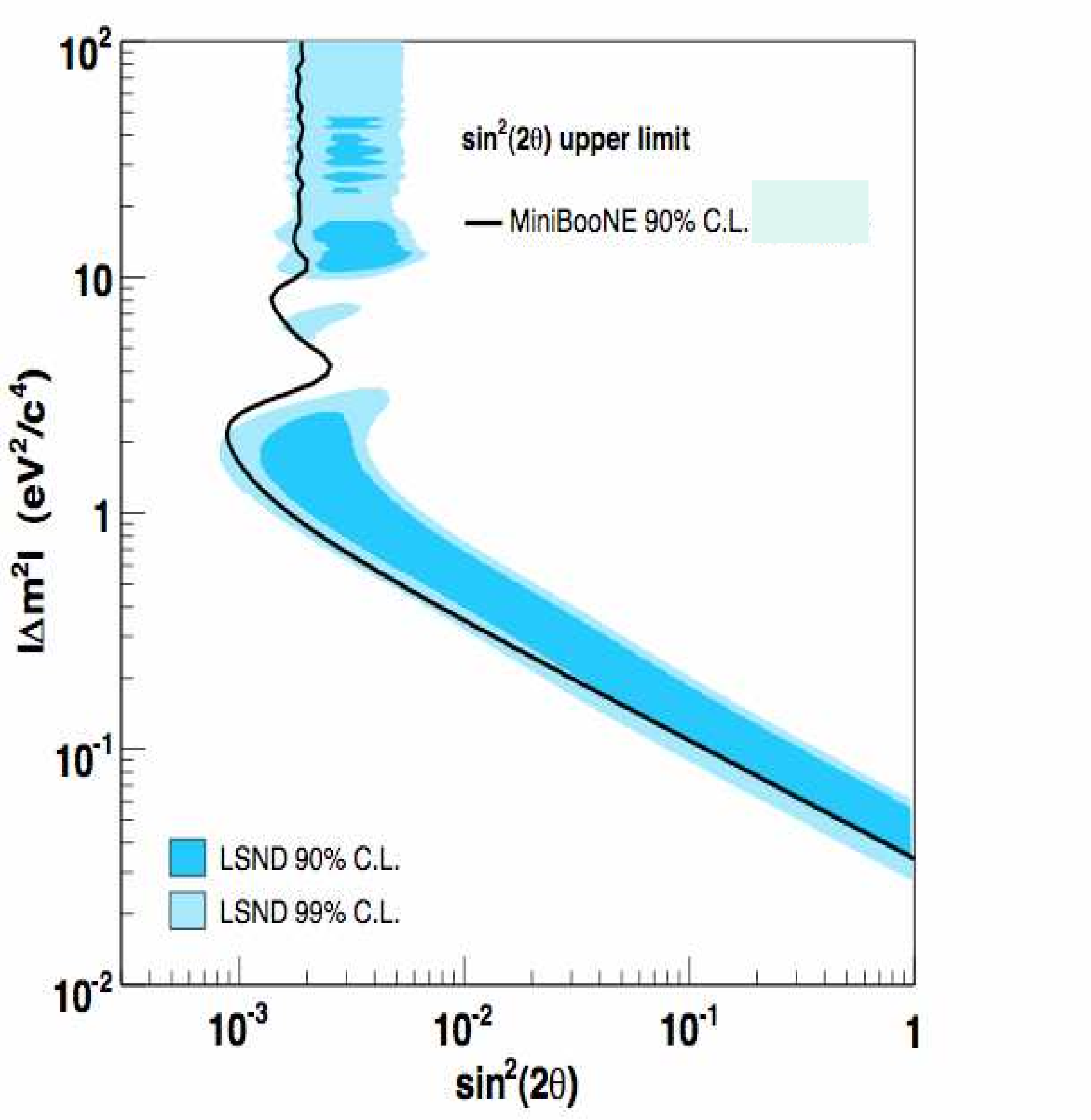
Fit errors for >475 MeV:
Normalization 9.6%
Energy scale: 2.3%



Oscillation Limit

- The result of the $\nu_\mu \to \nu_e$ appearance-only analysis is a limit on oscillations.
- χ^2 probability, null hypothesis: 93%

Energy fit: $475 < E_\nu^{QE} < 3000$ MeV



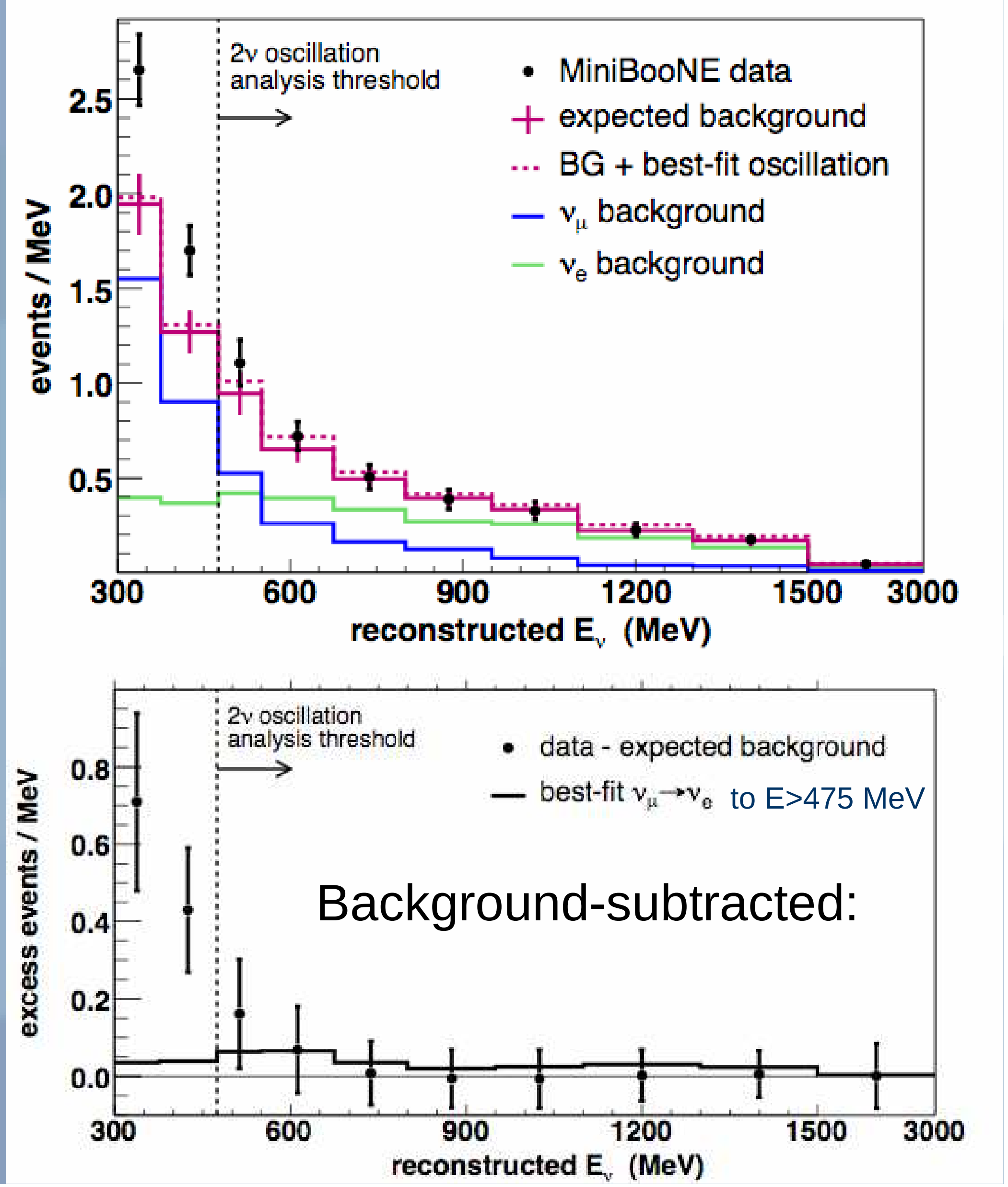
Full Spectrum

Full energy range:

- $300<E_n^{QE}<3000$ MeV

96 ± 17 ± 20 events above background, for $300<E_\nu^{QE}<475$MeV

Deviation: 3.7σ

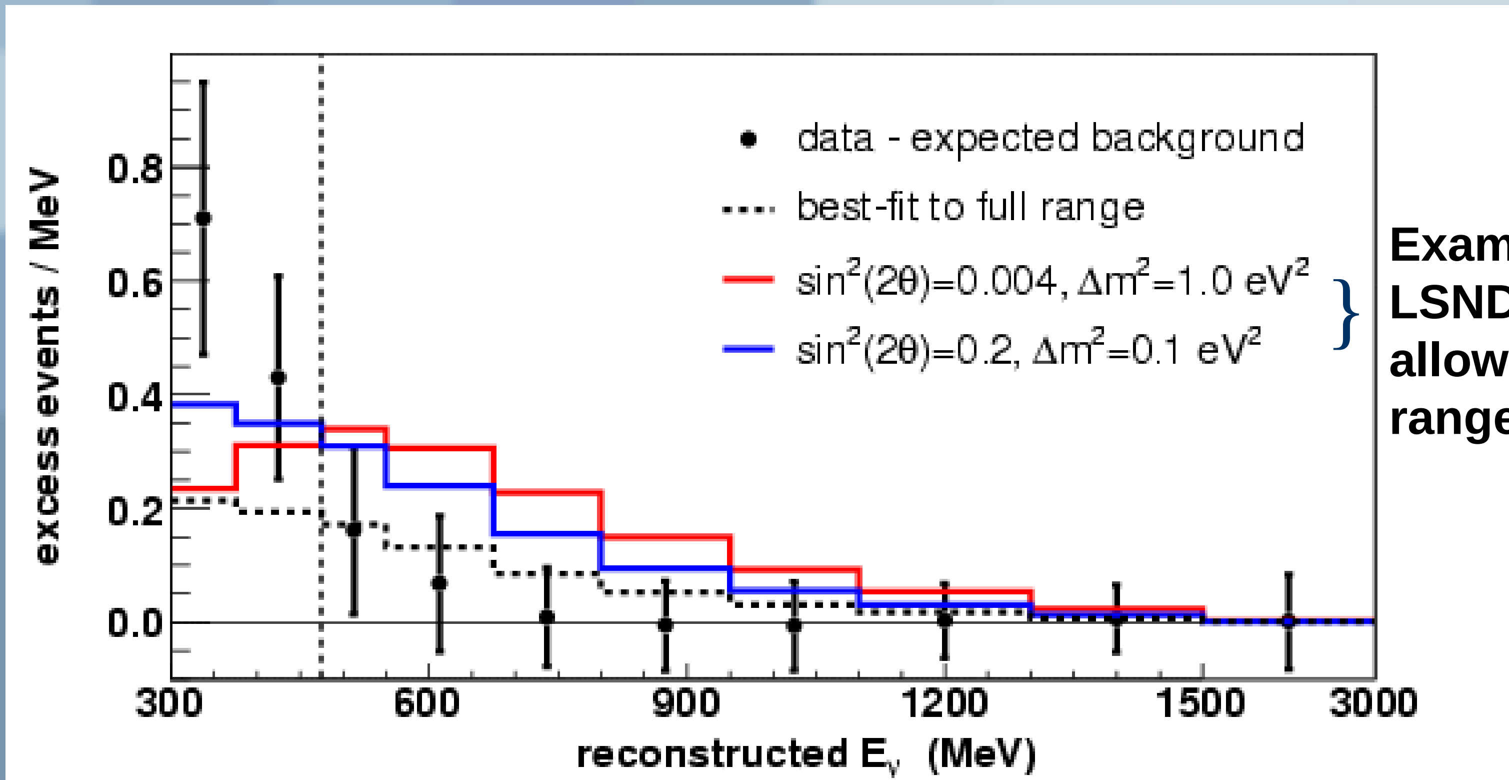


Energy Fit to Full Spectrum

Fit to the > 300 MeV range:

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

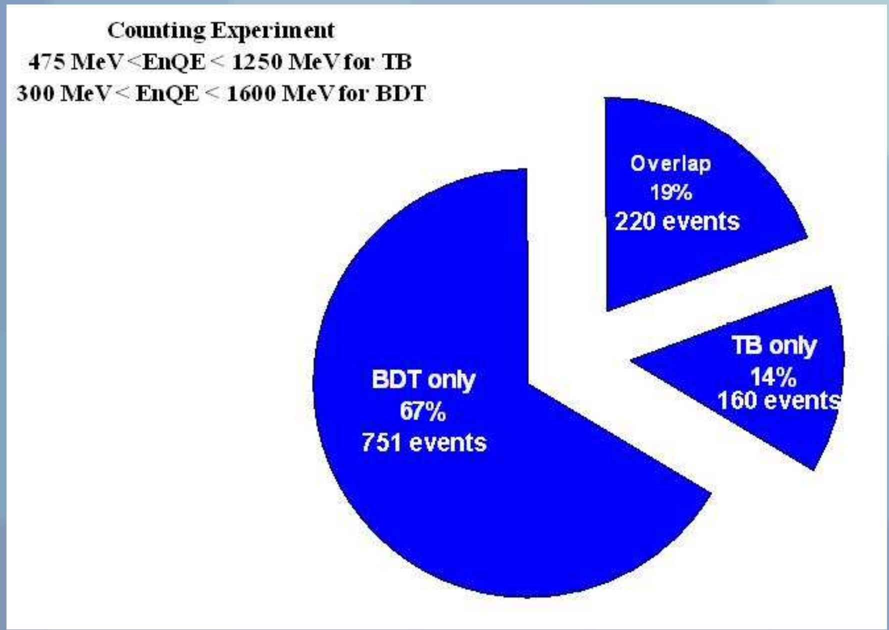
χ^2 Probability: 18%



} **Examples in LSND allowed range**

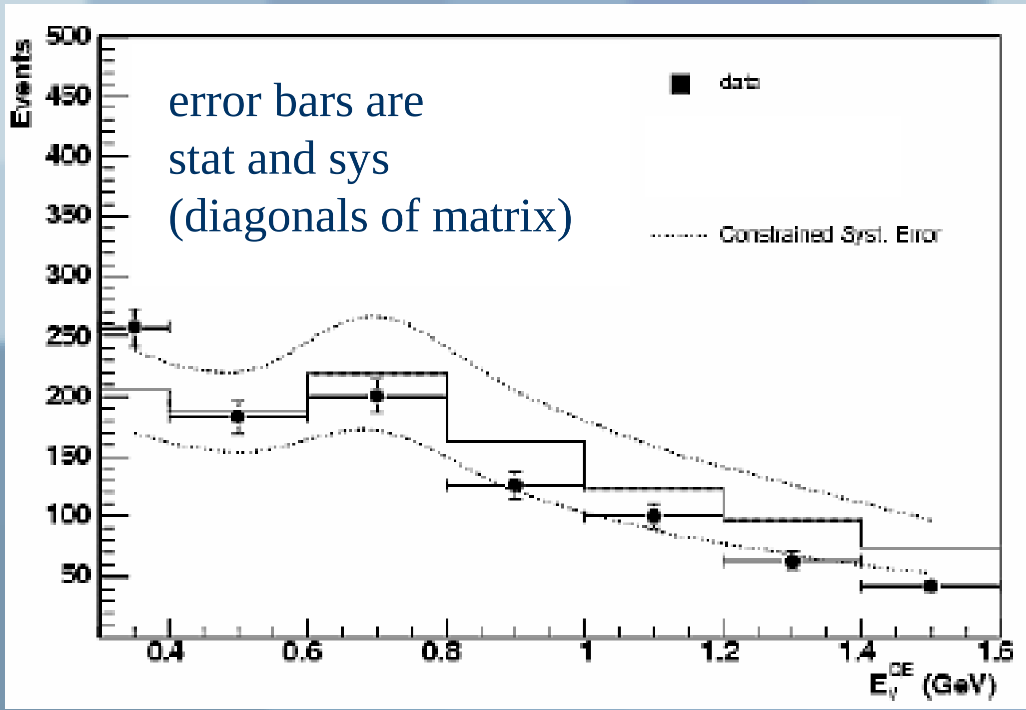
BDT Counting Experiment

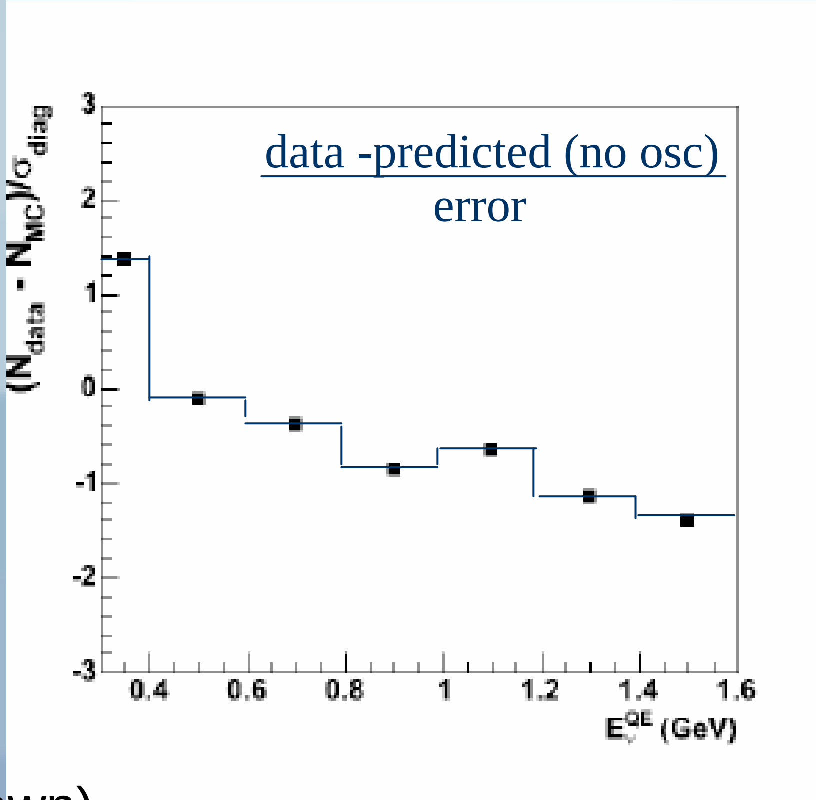
Counting Experiment: $300<E_\nu^{QE}<1600$ MeV
data: 971 events
expectation: 1070 ±33 (stat) ± 225 (sys) events
significance: –0.38 σ



BDT Energy Fit to Full Spectrum

Boosted Decision Tree E_ν^{QE} data/MC comparison:





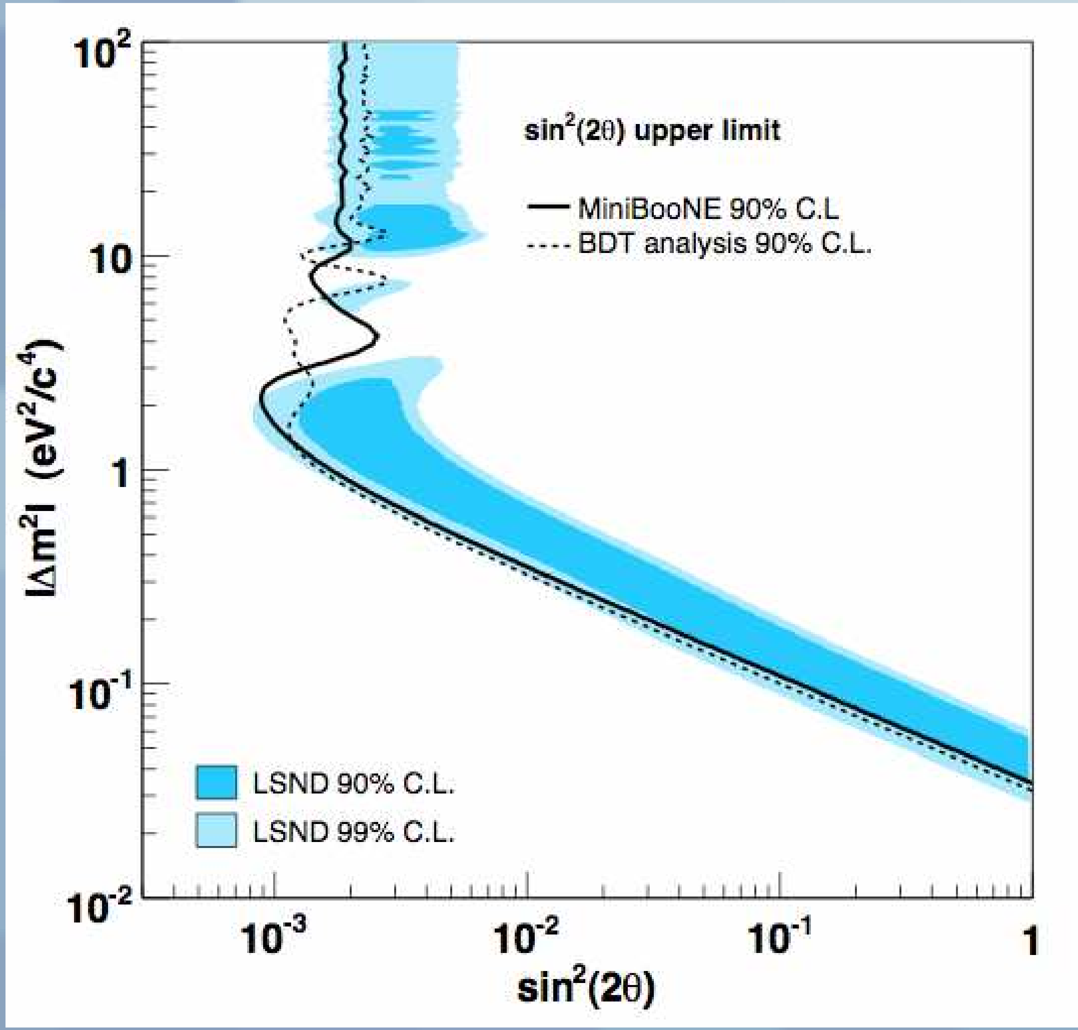
(sidebands used for constraint not shown)

Comparison of the Limits

• Energy-fit analysis:
  solid: TB
  dashed: BDT

• Independent analyses are in good agreement.

TB is still the primary analysis



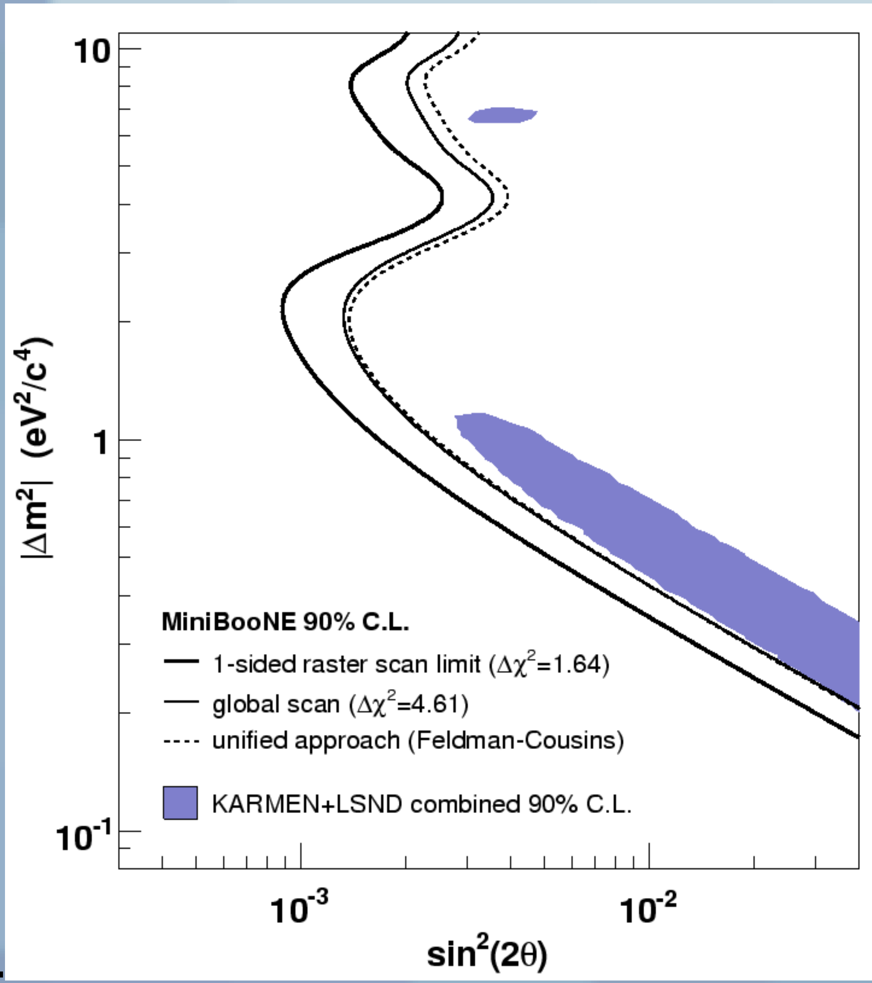
Different Limit Definitions

1) There are various ways to present limits:
   - Single sided raster scan (historically used, presented here)
   - Global scan
   - Unified approach (most recent method)

2) This result must be folded into an LSND-Karmen joint analysis.

Church, et al., PRD 66, 013001

We will present a full joint analysis soon.



MiniBooNE-LSND Compatibility Test

- For each Δm^2, determine the MB and LSND measurement:

  $z_{MB} \pm \delta z_{MB}$, $z_{LSND} \pm \delta z_{LSND}$

  where $z = \sin^2(2\theta)$ and δz is the 1σ error

- For each Δm^2, form χ^2 between MB and LSND measurement

$$\chi_0^2 = \frac{(Z_{MB} - Z_0)^2}{\sigma_{MB}^2} + \frac{(Z_{LSND} - Z_0)^2}{\sigma_{LSND}^2}$$

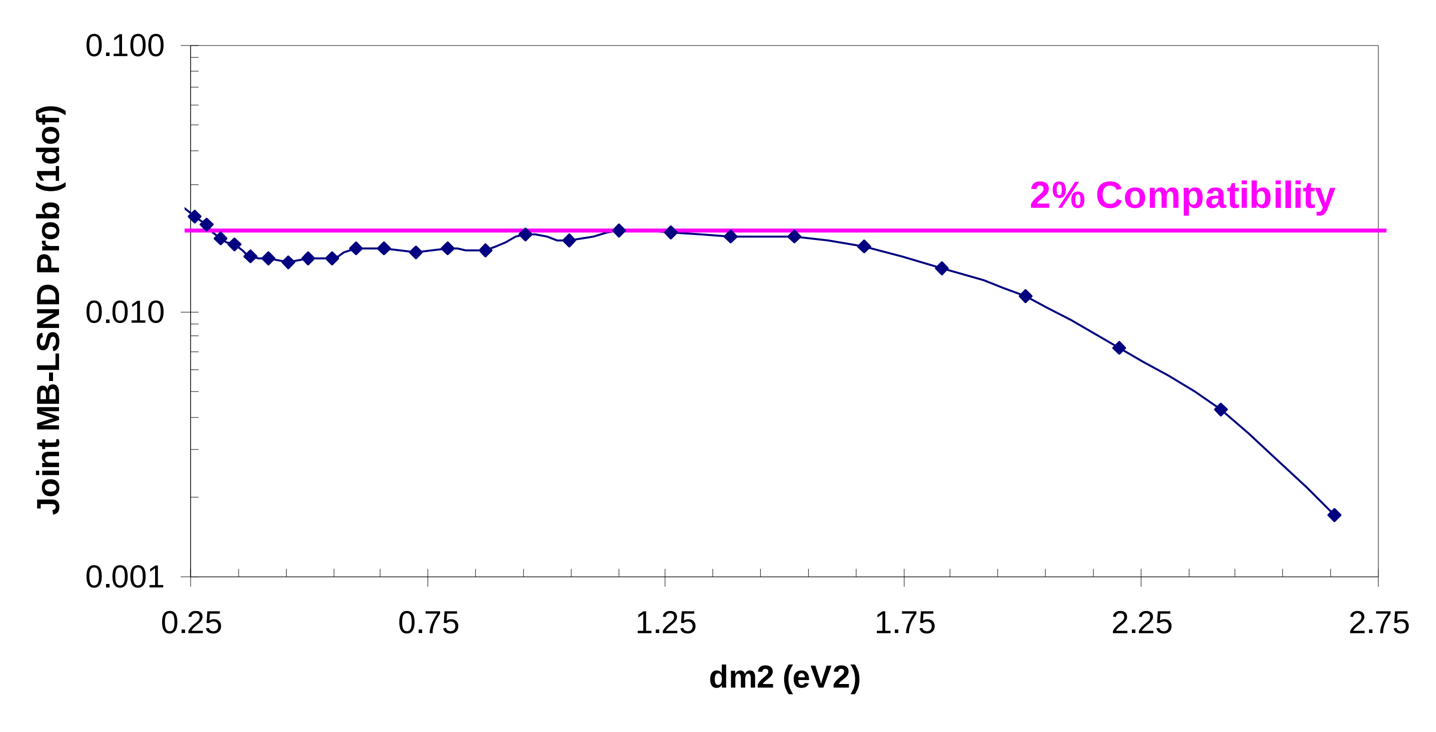
- Find z_0 that minimizes χ^2

  (weighted average of two measurements) and this gives χ^2_{min}

- Find probability of χ^2_{min} for 1 dof;

  this is the joint compatibility probability for this Δm^2

MiniBooNE-LSND Compatibility



MiniBooNE is incompatible with a
$\nu_\mu \rightarrow \nu_e$ appearance only interpretation of LSND
at 98% CL

Future

More papers supporting this analysis will follow,
in the near future:

- $NC\pi^0$ production
- MiniBooNE-LSND-Karmen joint analysis

Further analyses of the neutrino data,

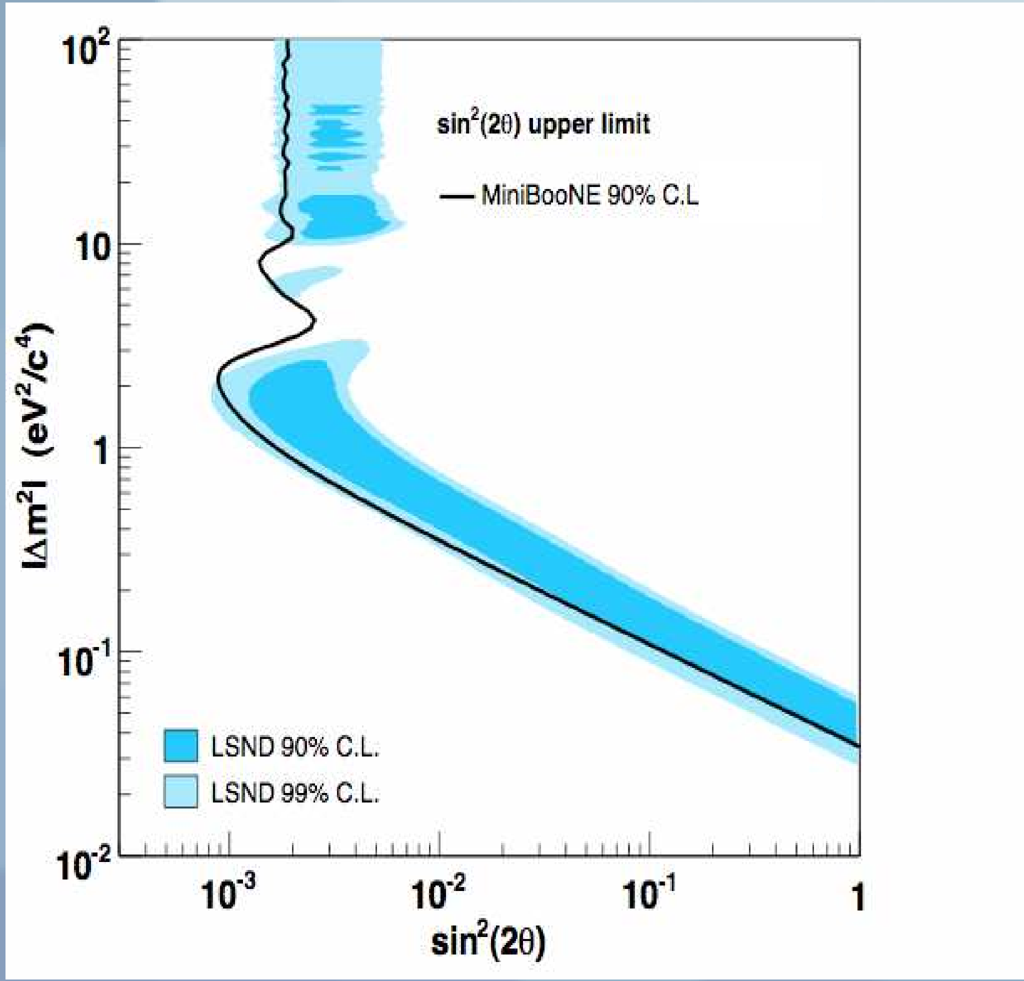
- Combined TB and BDT analysis,
- more exotic models for the LSND effect,
- Neutrino cross sections.

MiniBooNE is presently taking data in antineutrino mode.

Conclusions

- The observed reconstructed energy distribution is inconsistent with a $\nu_\mu \rightarrow \nu_e$ appearance-only model
- Therefore we set a limit on ν_μ->ν_e appearance

- Data show discrepancy vs. background at low energies, but spectrum is inconsistent with two-neutrino oscillation.



Accepted for publication in PRL:

e-Print: arXiv:0704.1500

A Search for electron neutrino appearance at the Δm^2 ~ 1 eV^2 scale.

Acknowledgements

Our thanks to DOE, NSF and Fermilab