MiniBooNE

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for the MiniBooNE collaboration

XLIInd Rencontres de Moriond 2007
Electroweak Interactions and Unified Theories

Outline

- Purpose
- Experiment
- Oscillation fit
  - Data samples
  - Uncertainties
  - Constraining backgrounds
- Summary

No Results section... so I will not present oscillation results today.

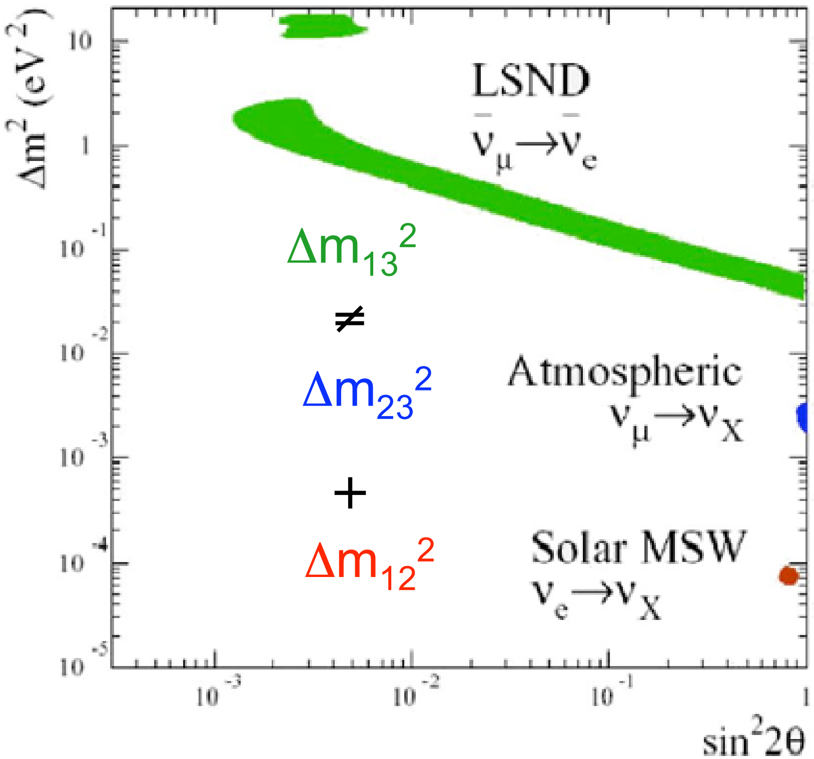
However, I will tell you about the complete pieces of the oscillation analysis.

Purpose

Prob(osc) = $\sin^2 2\theta \sin^2 (1.27\ \Delta m^2\ L/E)$

fix L,E and fit for Δm^2 , $\sin^2 2\theta$

For MiniBooNE, Prob(osc) ~ 0.25%



Three independent Δm^2 implies:

- One of the three measurements is wrong or
- BSM physics, the current favored solution would be additional "sterile" neutrinos involved in oscillations

The solar and atmospheric oscillations have been confirmed by multiple experiments

MiniBooNE's goal is to confirm or refute LSND's measurement of ν_μ to ν_e oscillations

- Similar L/E as LSND, but different beam (1GeV) and baseline (0.5 km)
- Different systematics, event signatures than LSND

The MiniBooNE Collaboration

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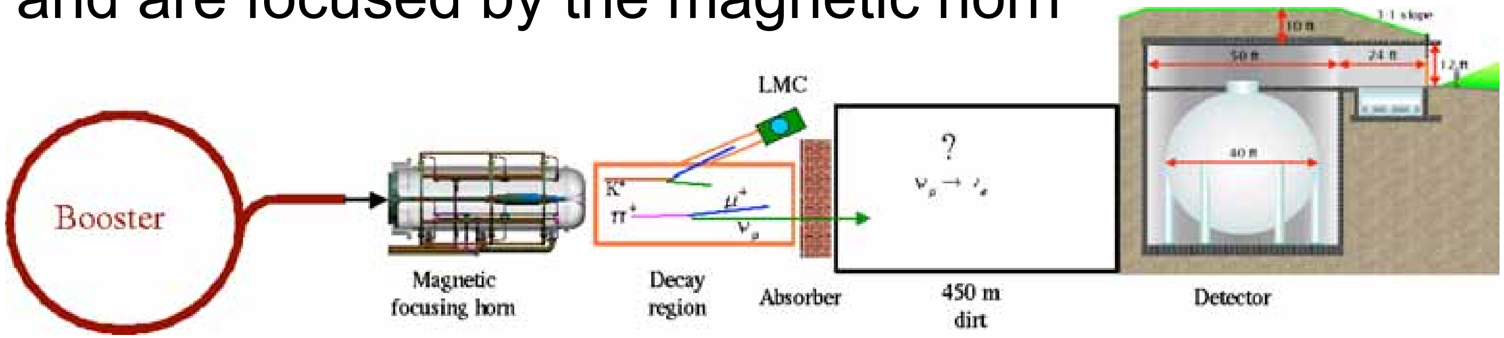
MiniBooNE Experiment

- 8.9 GeV/c protons hit a Be target
- mesons are produced, predominantly π^+ and some K^+, and are focused by the magnetic horn

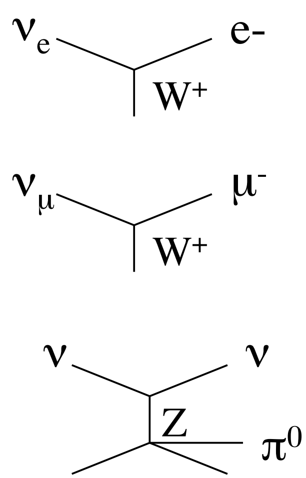


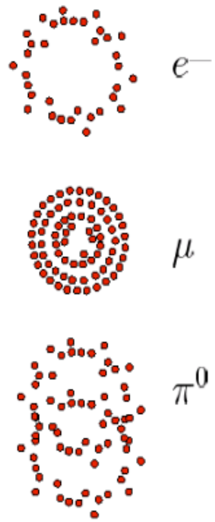
- The neutrinos from meson decay are observed in the ~1kton, mineral oil Cherenkov detector
  - 12 m diameter sphere, with 1280 PMTs in inner region, 240 PMTs in outer 'veto' region (10% PMT coverage)

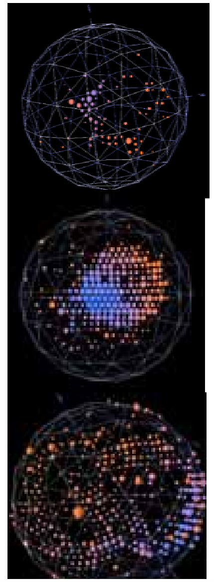
Events in MiniBooNE

Use hit topology, timing to determine event type

- Outgoing lepton implies flavor of neutrino for charged current events
- Reconstructed quantities: track length, angle relative to beam direction
- Fundamental: timing, charge of hits, early/late hit fractions
- Geometry: position from wall of tank

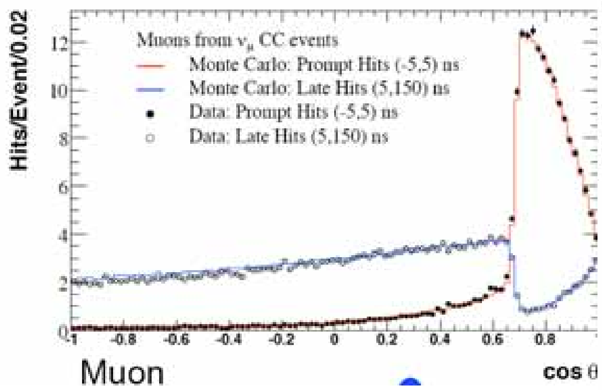


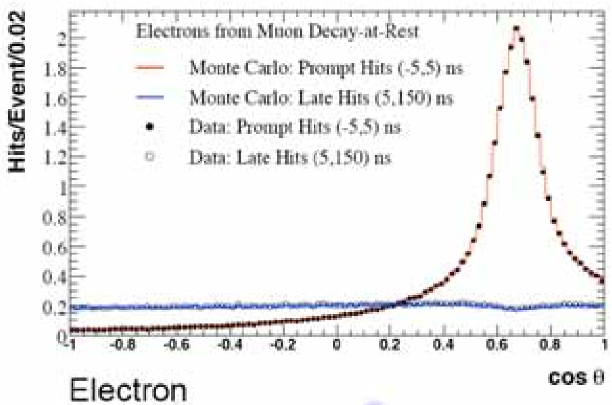




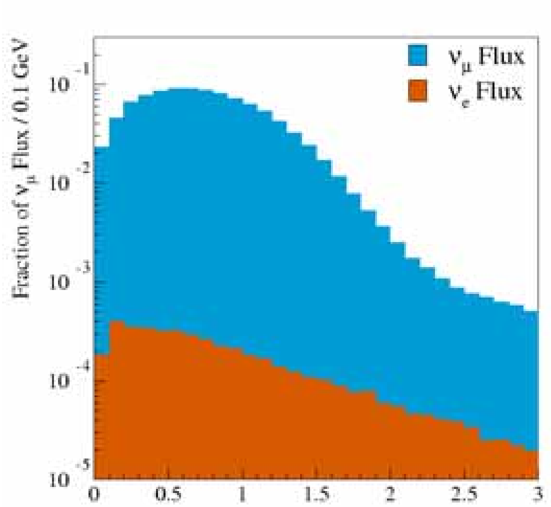
Additional information in scintillation light

- ~25% of the light in the tank due to mineral oil
- Unlike prompt Cherenkov light, scintillation light is delayed
- Amount depends on particle type





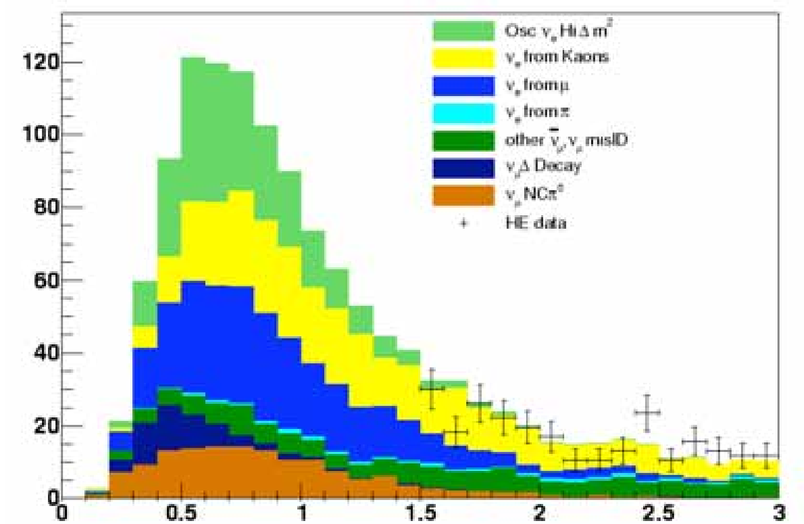
ν_e appearance



ν_μ E_ν(QE)

0.5% intrinsic ν_e

ν_e selection cuts



Signal E_ν(QE)

($\Delta m^2=1eV^2$, $\sin^2 2\theta=0.004$)

Background

- misidentified ν_μ (mainly π^0s)
- ν_e from μ^+ decay
- ν_e from K^+, K^0, π^+ decay

Do the ν_μ oscillate into ν_e ?

- Produce ν_μ
- Select ν_e
- Observe an excess or not?

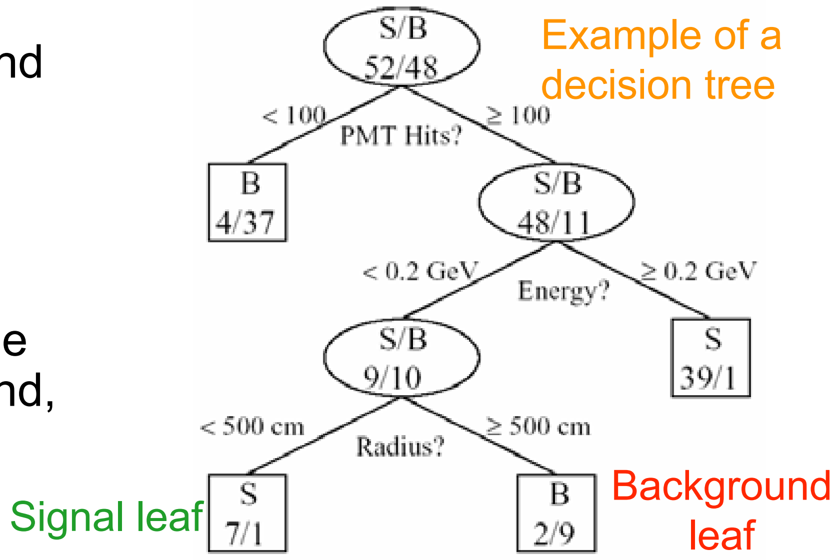
ν_e selection cuts: particle identification (PID)

Two PID algorithms used:

- Likelihood based analysis: e/μ, e/π^0 and $m_{\pi 0}$ cuts
- A "boosted decision tree" algorithm to separate e, μ, π^0

A decision tree is similar to a neural net

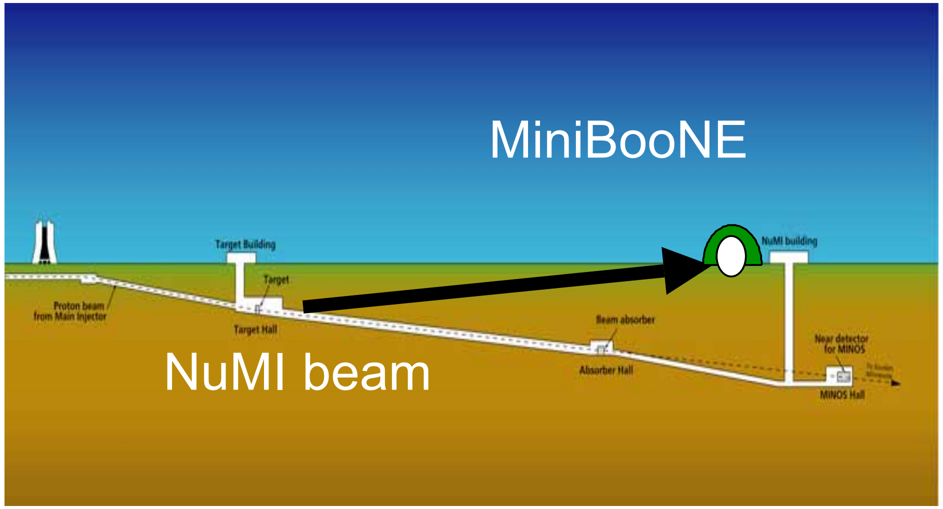
- Cut first on the variable which gives the most separation of signal to background, at the point where it gives the most separation. Then cut on next best variable...

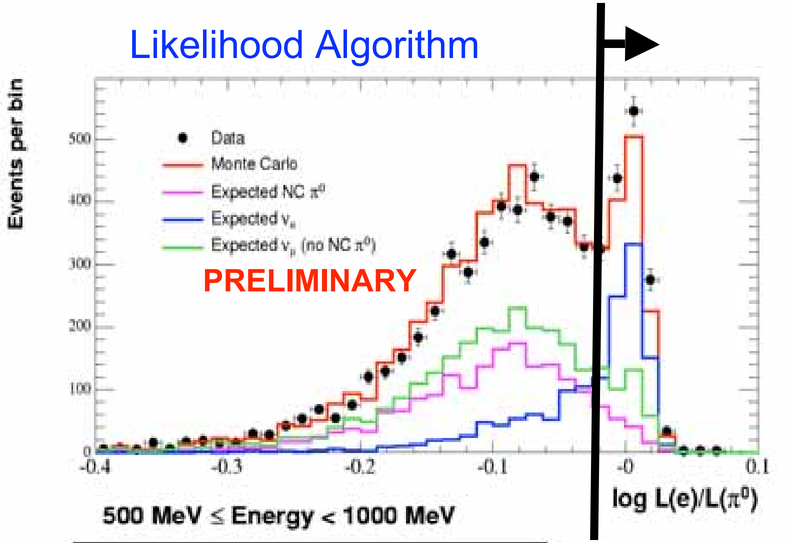


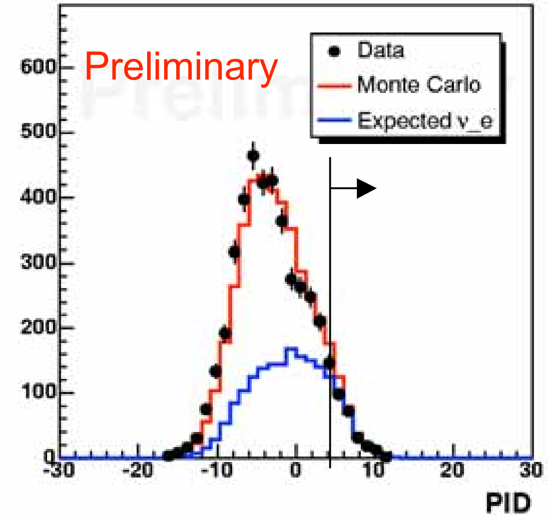
"Boosting" is a method to additionally separate signal from background, by weighting events

- Increase weight of misclassifed events in current tree, and remake tree. Repeat ~100-1000x. Sum all the trees, by counting events on signal leaves as +1, and -1 otherwise. This forms the PID variable.

ν_e selection cuts: particle identification (PID)





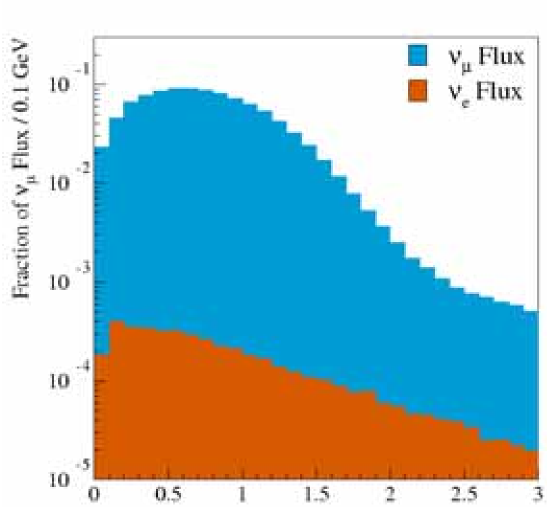


Boosted Decision Tree Algorithm

Vet both algorithms on NuMI beam offaxis neutrino sample

- Neutrinos produced at an angle of ~100mr from Minos neutrino beamline (NuMI) direction can be detected in MiniBooNE
- This sample has substantial ν_e content with similar energy to our oscillation sample

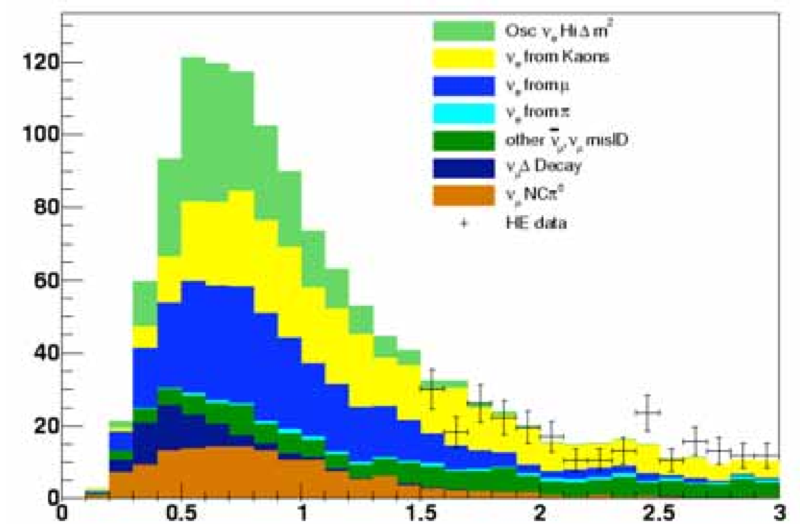
ν_e appearance



ν_μ E_ν(QE)

0.5% intrinsic ν_e

ν_e selection cuts



Signal E_ν(QE)

(Δm^2=1eV^2, $\sin^2 2\theta$=0.004)

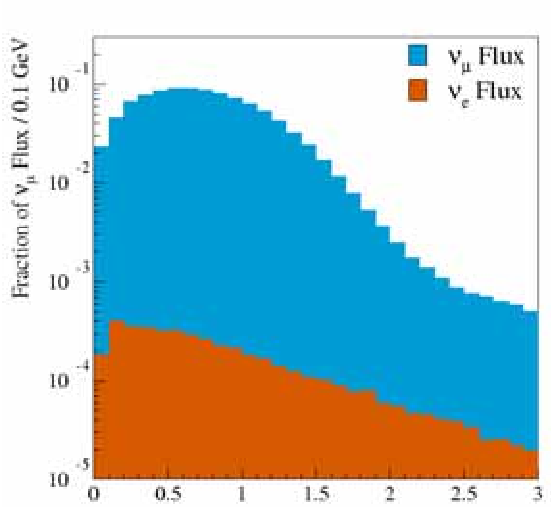
Background

- misidentified ν_μ (mainly π^0s)
- ν_e from μ+ decay
- ν_e from K+, K^0, π+ decay

<u>What affects the observed ν_e rate?</u>

- flux uncertainty
- cross section uncertainty
- detector effects
- ν_μ misidentified as ν_e

ν_e appearance



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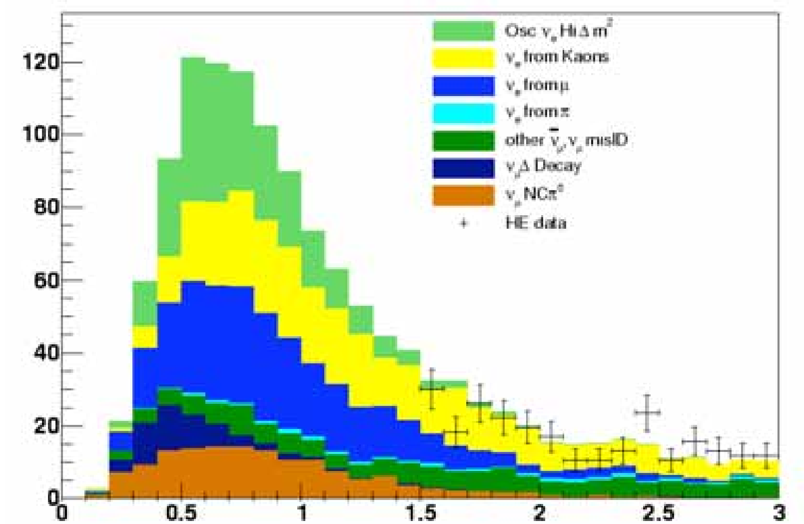

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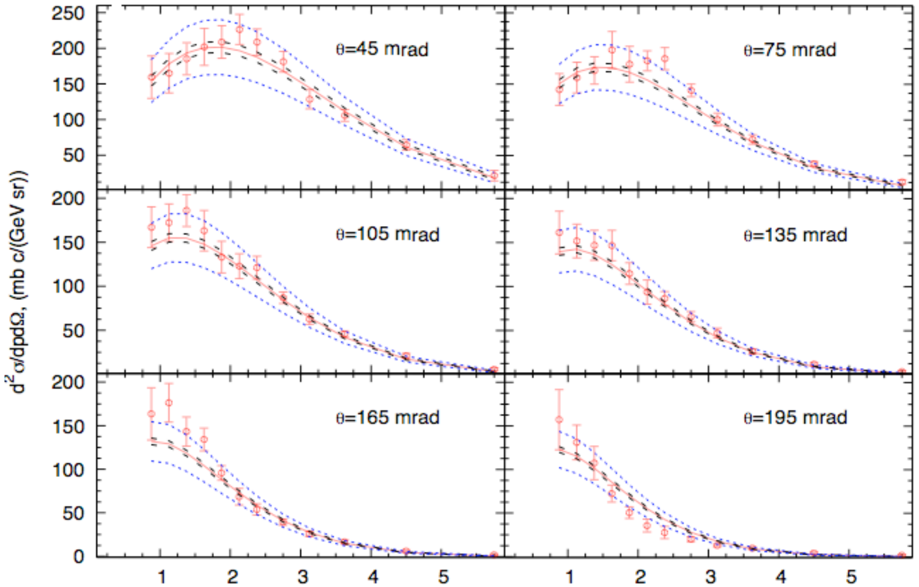
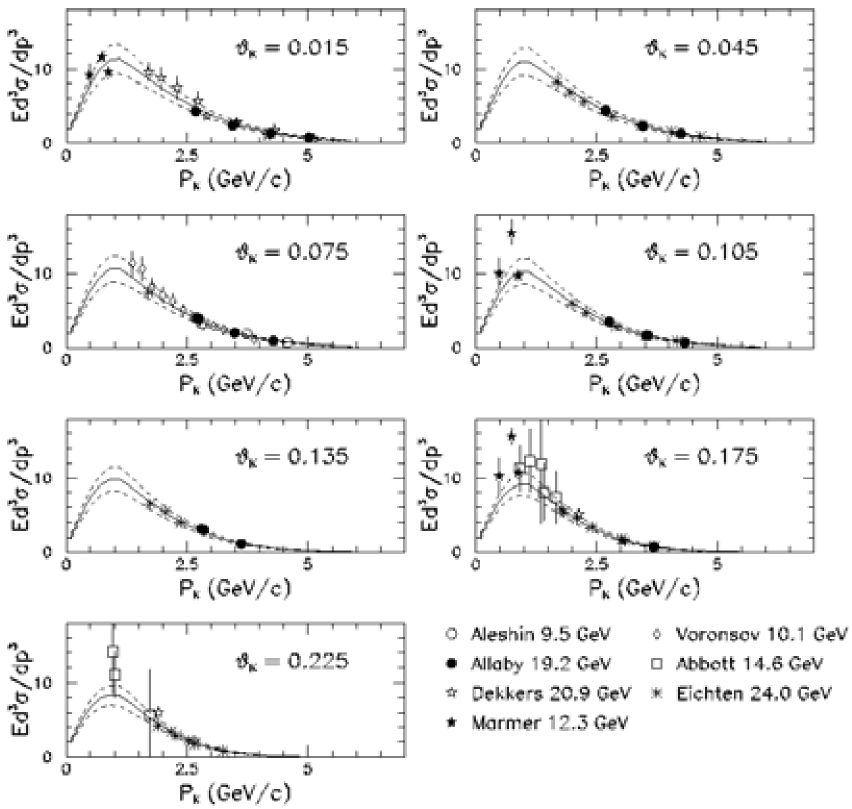
Flux: π^+ and K^+ production

HARP 8.9 GeV/c pBe π^+ production

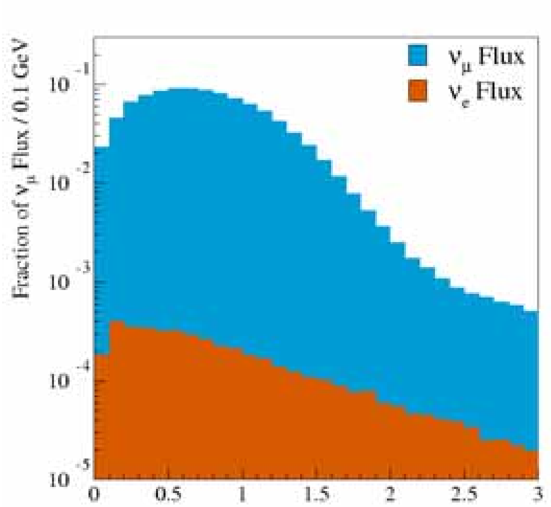


External measurements of pBe K^+ production from 9.5 to 24 GeV, scaled to 8.9 GeV/c



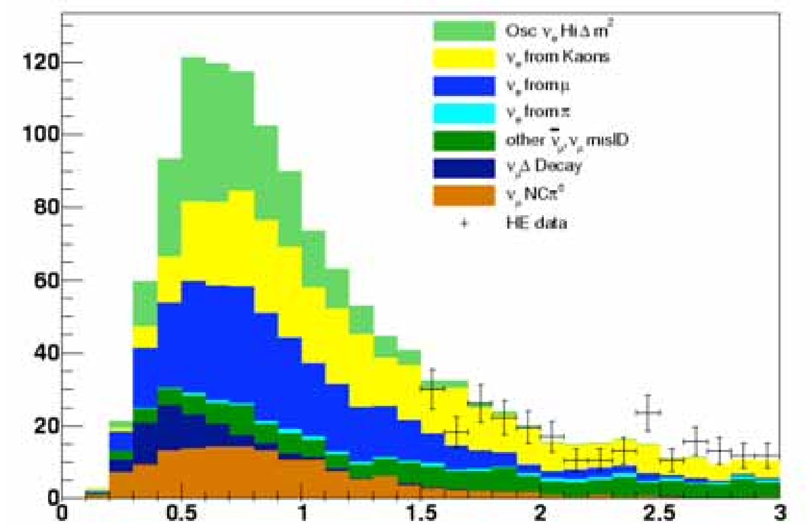
- For π^+, K^+ ,and K^0 production use a parameterization to fit the existing data
- Errors set to cover the spread of data points as well as parameterization uncertainties

ν_e appearance



ν_μ E_ν(QE)

ν_e selection cuts



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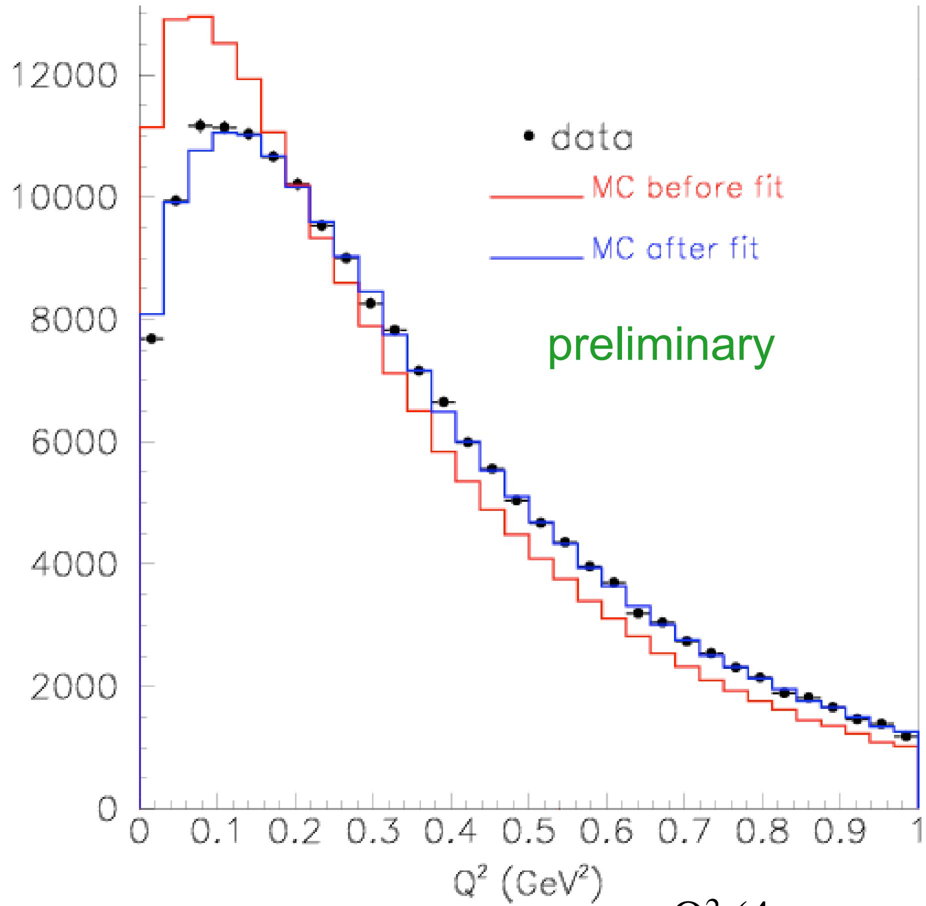
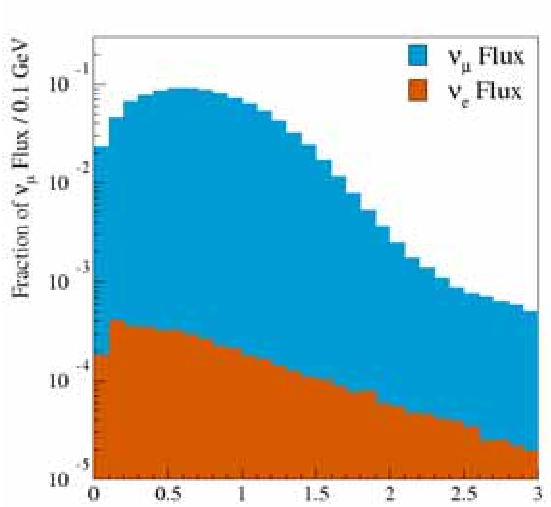
Cross Sections

- Differential cross section for quasi-elastic scattering determined from MiniBooNE CCQE ν_μ data
- Shape fits are performed to observed data Q^2 distribution using a relativistic-Fermi-gas model
- Two parameters (and their uncertainties) are determined:
  - Axial mass parameter, M_A
  - A Pauli blocking parameter
- Fit also agrees well with neutrino energy distributions
- Other cross sections (i.e. CC1π) are determined from MiniBooNE data combined with previous external measurements



Q^2 (4-momentum transfer)

ν_e appearance



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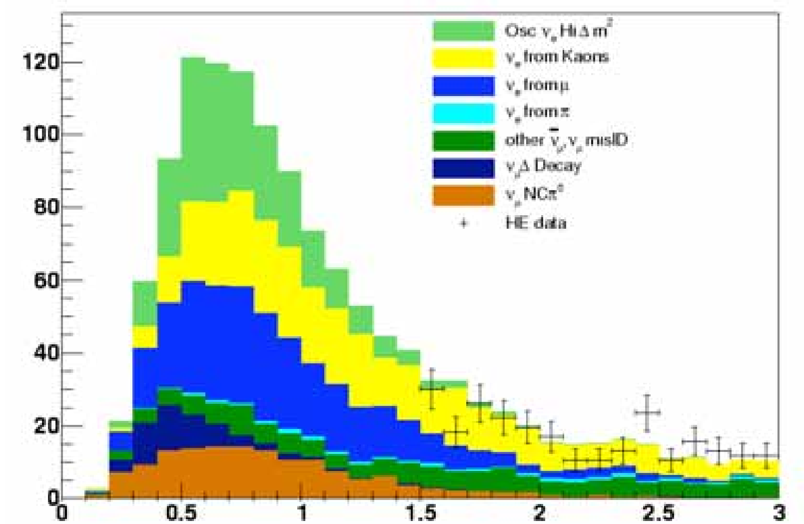

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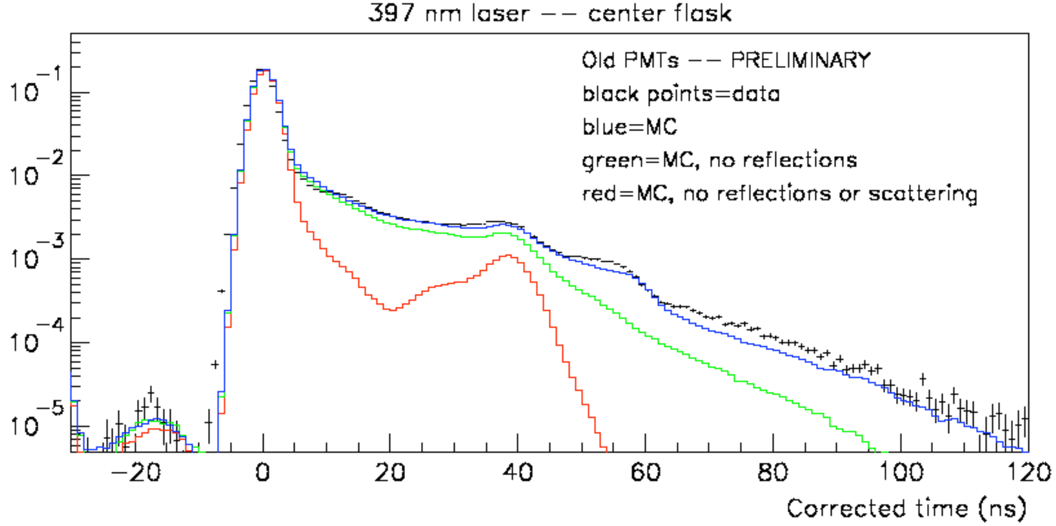
Model of light propagation in mineral oil

Dominant light source is well understood Cherenkov light

Also must model:

- Scintillation
  - yield, spectrum, decay times
- Fluorescence (absorption and reemision of Cherenkov light)
  - rate, spectrum, decay times
- Scattering
  - Rayleigh, Raman, Particulate (Mie)
- Absorption
- Reflection
  - tank walls, PMT faces
- PMT effects
  - single pe charge response, charge linearity



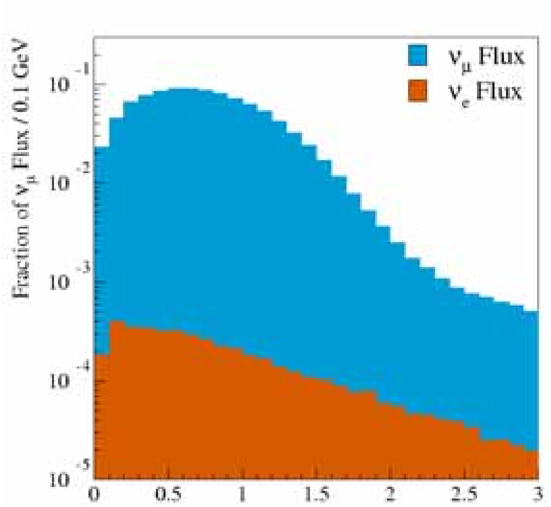
External measurements

- Scintillation from p beam (IUCF)
- Scintillation from cosmic μ (Cincinnati)
- Fluorescence Spectroscopy (FNAL)
- Time resolved spectroscopy (JHU, Princeton)
- Attenuation (Cincinnati)

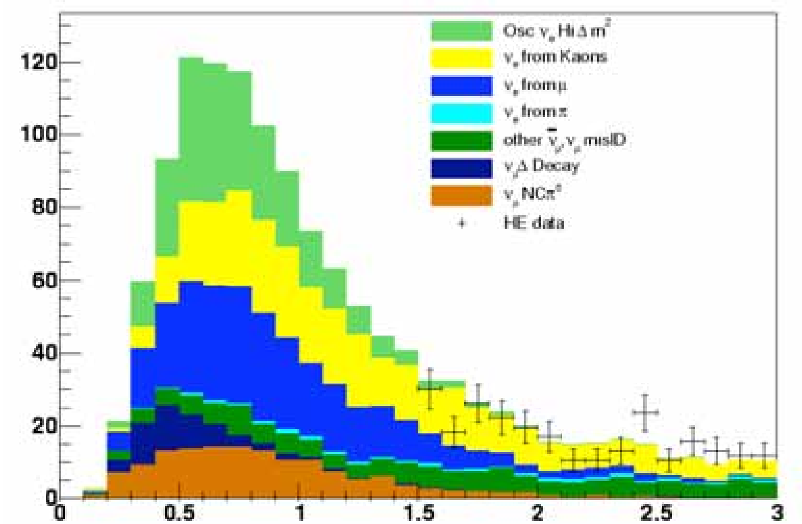
Internal measurements

- Cosmic muons and decay electrons, Laser flasks

ν_e appearance



ν_e selection cuts



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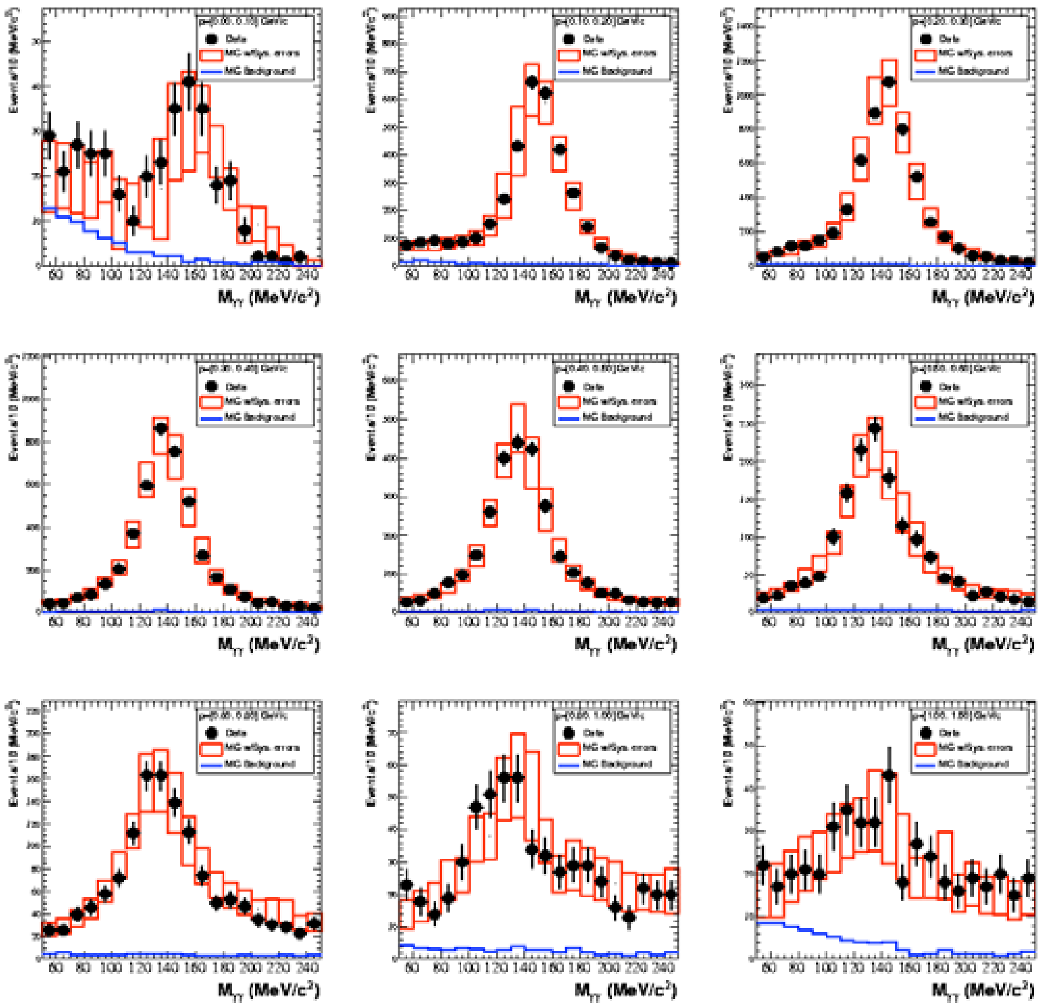
ν_μ misidentification (π^0s)

- Measure π^0s in MiniBooNE
  - very pure (~90%) sample
- Compare the observed π^0 rate to the MC as a function of π^0 momentum, and make a correction factor
- Reweight the misidentified π^0s based on their momentum by this correction factor
- Can also correct radiative events $\Delta \rightarrow N + \gamma$ as the photon spectrum is very close to the π^0 momentum shape

$M_{\gamma\gamma}$ Mass Distribution for Various $p_{\pi 0}$ Momentum Bins



"Combined" Oscillation Fit

Do a combined oscillation fit to the observed ν_μ and ν_e energy distribution for data vs prediction

$$\chi^2 = \begin{pmatrix} \Delta_i^{\nu_e} & \Delta_i^{\nu_\mu} \end{pmatrix} \begin{pmatrix} M_{ij}^{e,e} & M_{ij}^{e,\mu} \\ M_{ij}^{\mu,e} & M_{ij}^{\mu,\mu} \end{pmatrix}^{-1} \begin{pmatrix} \Delta_j^{\nu_e} \\ \Delta_j^{\nu_\mu} \end{pmatrix}$$

where $\Delta_i^{\nu_e} = \mathrm{Data}_i^{\nu_e} - \mathrm{Pred}_i^{\nu_e}(\Delta m^2, \sin^2 2\theta)$ and $\Delta_i^{\nu_\mu} = \mathrm{Data}_i^{\nu_\mu} - \mathrm{Pred}_i^{\nu_\mu}$

Systematic (and statistical) uncertainties in $(M_{ij})^{-1}$ matrix

- Covariance matrix includes correlations between ν_e and ν_μ events

Exploit these correlations to constrain ν_e sample backgrounds

- This is much like a "near to far" ratio, a ratio of ν_e / ν_μ
- With a 0.25% probability of oscillation, the ν_μ are an unoscillated "near" sample, while the ν_e are the oscillated "far" events
- The ratio cancels what systematics are the same for the two samples
- Combined fit also reduces ν_e uncertainties using high stat ν_μ events

Constraining ν_e with ν_μ: ν_e from μ^+

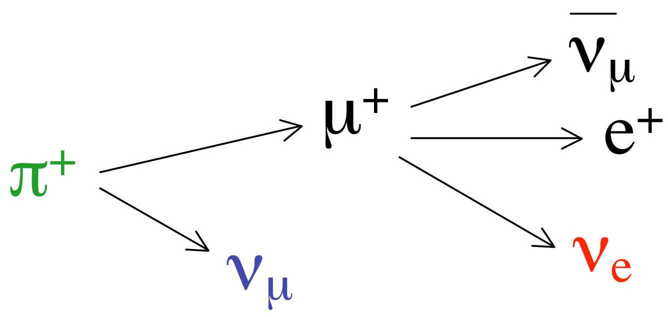
Without employing a link between ν_e and ν_μ , ν_e from μ^+ would have all aforementioned errors: flux, cross section, detector uncertainties

However, for each ν_e produced from a μ^+, there was a corresponding ν_μ and we observe that ν_μ spectrum

This is true here because the pion decay is very forward

Therefore, we know that some combination of cross sections, flux, etc errors are excluded by our own data, and so the error is reduced

This is what the combined final fit does for us above just a ν_e fit



$E\,\nu_\mu \sim 0.43\, E\pi / (1 + \gamma^2\theta^2)$

for small θ

$E\pi$ restricts possible $E\nu_e$

Summary

- MiniBooNE employs a blind analysis, so one cannot directly look at ν_e where there could be oscillation
- However, we can learn about the oscillation region in our own detector through:
  - ν_μ sample $\Longrightarrow$ ν_e from μ^+, K^+
  - π^0 sample $\Longrightarrow$ misID π^0
  - ν_e events just above the oscillation region and NuMI ν_e sample $\Longrightarrow$ PID, ν_e from K^+
  - Calibration sources (laser flasks, cosmic ray muons and decay electrons) $\Longrightarrow$ light in our detector
- We are working through a list of cross checks and questions posed by the collaboration before presenting results