Neutrinos from kaon decay in MiniBooNE

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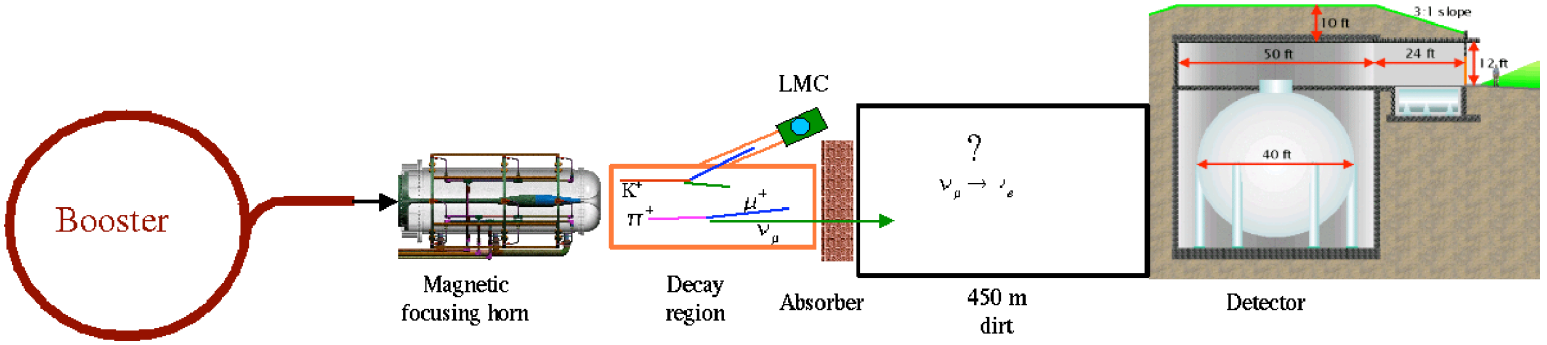
- MiniBooNE beamline overview
- Kaon flux predictions
- Kaon measurements in MiniBooNE
  - high energy events
- Summary

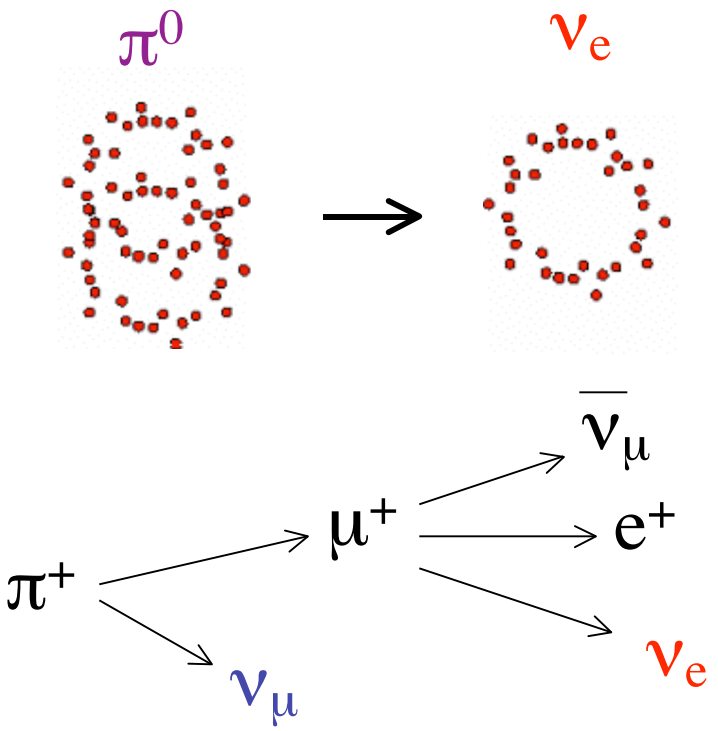
MiniBooNE beamline



- MiniBooNE is searching for ν_μ to ν_e oscillations
  - Produce a beam of ν_μ, look for ν_e
- 8 GeV protons hit Be target, producing:
  - π+ (primary source of ν_μ)
  - K+/- (decay to ν_μ, ν_e)
  - K^0 (decay to ν_e)

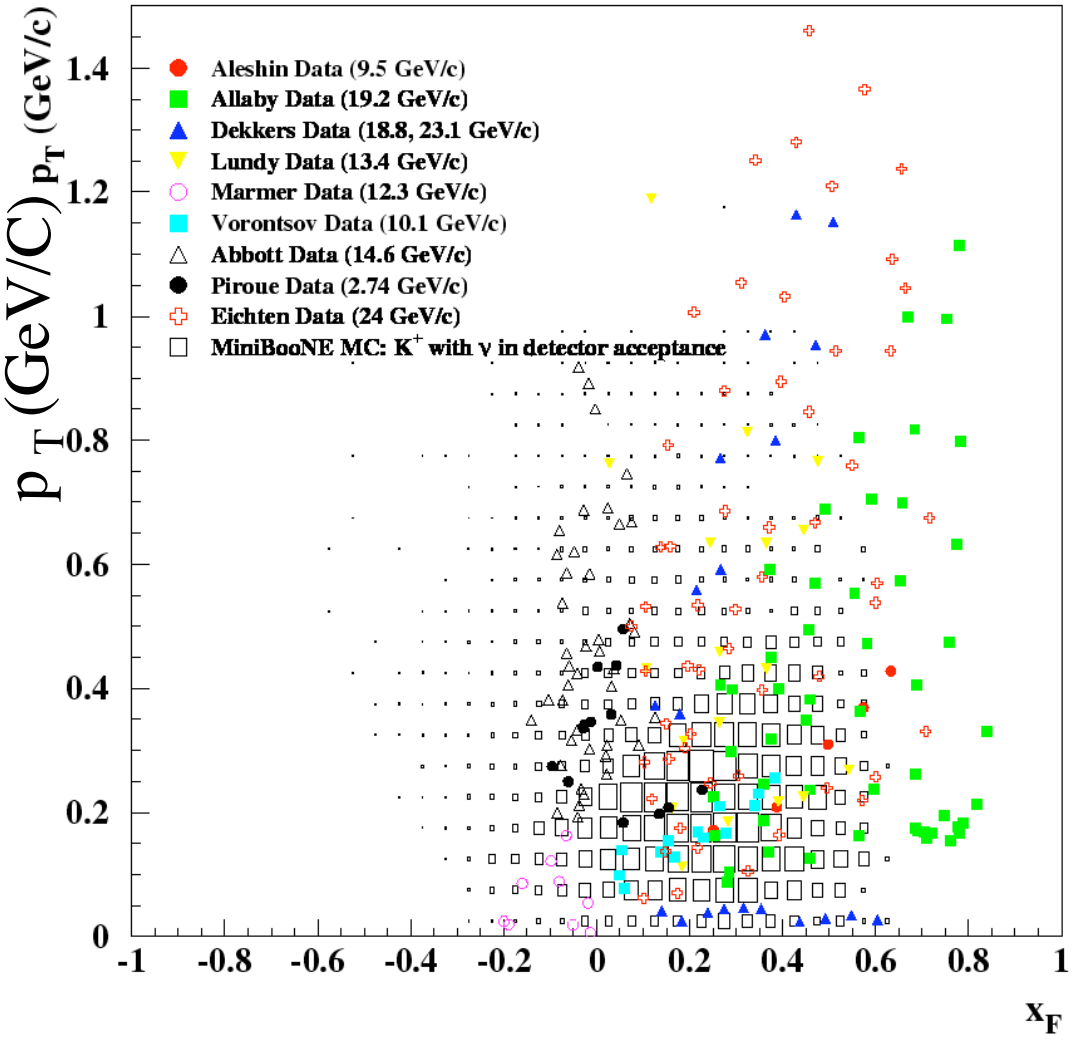
Oscillation search backgrounds

- Three major backgrounds:
  - misID'd π^0s
    - constrained by observed π^0s
  - ν_e from muon decay
    - muon produced for each ν_μ, constrained via ν_μ spectrum
  - ν_e from kaon decay



K+ flux predictions

- All flux predictions are from a parameterized fit to external data with uncorrelated uncertainties
- K+ external data shown here in transverse momentum (p_T) vs x_F
  - Feynman x, the longitudinal momentum / maximum allowed longitudinal momentum
  - Currently use Aleshin, Abbot, Eichten, Piroue and Vorontsov data



x_F

Measurements of kaons in MiniBooNE

- MiniBooNE is a blinded analysis:
  - we can't look at ν_e -like events at energies where there might be oscillation events
  - must measure kaons outside the signal region and extrapolate

Measurements of kaons in MiniBooNE

- Measure kaons via muons: Little Muon Counter (LMC)
  - –Large angle muons are predominantly from kaon decays (higher allowed p_T for muons from kaons)
  - –Count muons at 7° angle from decay pipe and determine corresponding kaon rate
- Measure kaons via neutrino events: high energy "box"
  - –A neutrino from a kaon will have a higher energy than if it came from a pion of the same momentum
  - –Highest energy tank events tend to be from K+
  - –Directly measure ν_e background in different energy region

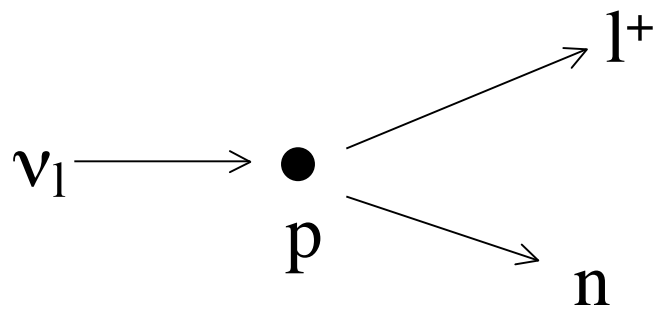
Neutrino Events in MiniBooNE

- 12 m diameter light detector filled with mineral oil
  - 1280 PMTs in inner region
  - 240 PMTs in outer "veto" region
- Neutrino events emit Cherenkov light in a characteristic pattern for different events
  - Muons have long tracks, constant light over distance
  - Electrons have shorter tracks; scattering causes the ring to be "fuzzier"

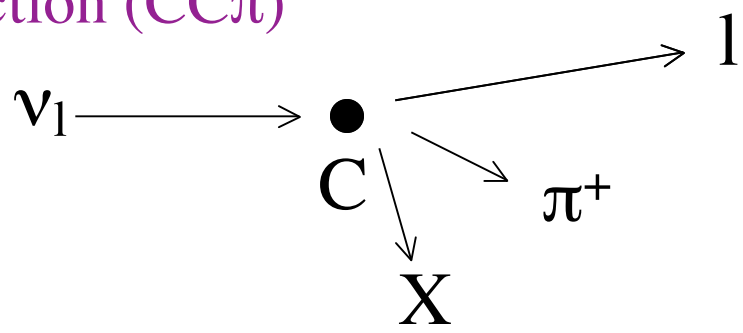
Neutrino Interactions

- Charged Current Quasi-elastic (CCQE)
  - Energy of neutrino is related to the outgoing leptons' energy and angle

$$E\nu(QE) = \frac{m_p E_l - m_l^2/2}{m_p - E_l + \sqrt{(E_l^2 - m_l^2)}\cos\theta_\mu}$$



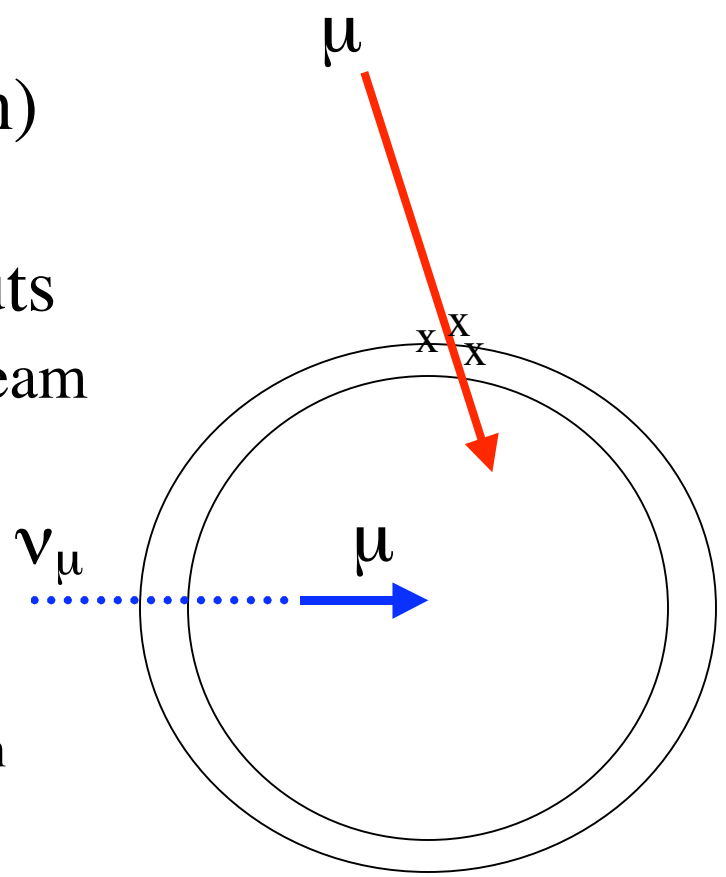
- Charged Current Pion production (CCπ)



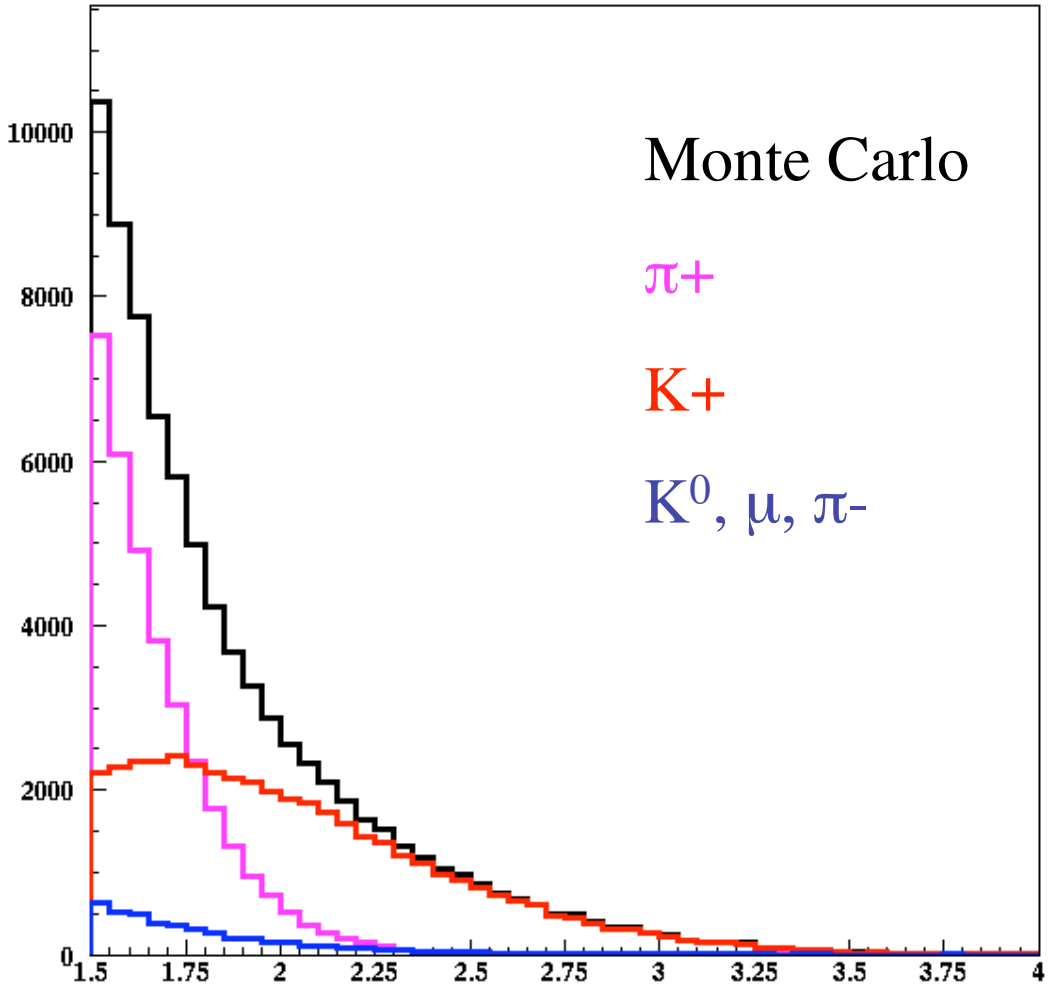
High Energy Box

Event selection:

- Event is in time with the beam
- Has a Eν(QE) (assuming muon) > 1.5 GeV, < 4 GeV
- Passes cosmic ray reduction cuts
  - within forward cone along the beam direction
  - Veto hits less than 30
  - Entering cluster hits less than 1
    - Less than 1 hit in the veto corresponding to the track direction



High Energy Box



1.5 GeV

Eν (QE) in GeV

Predominantly π+ below 2 GeV, predominantly K+ above

High Energy Box: ν_μ events

- Look at CCQE, CC π+ ν_μ events as a check of π+, K+
  - long tracks consistent with muon
  - veto hits<6 (contained)

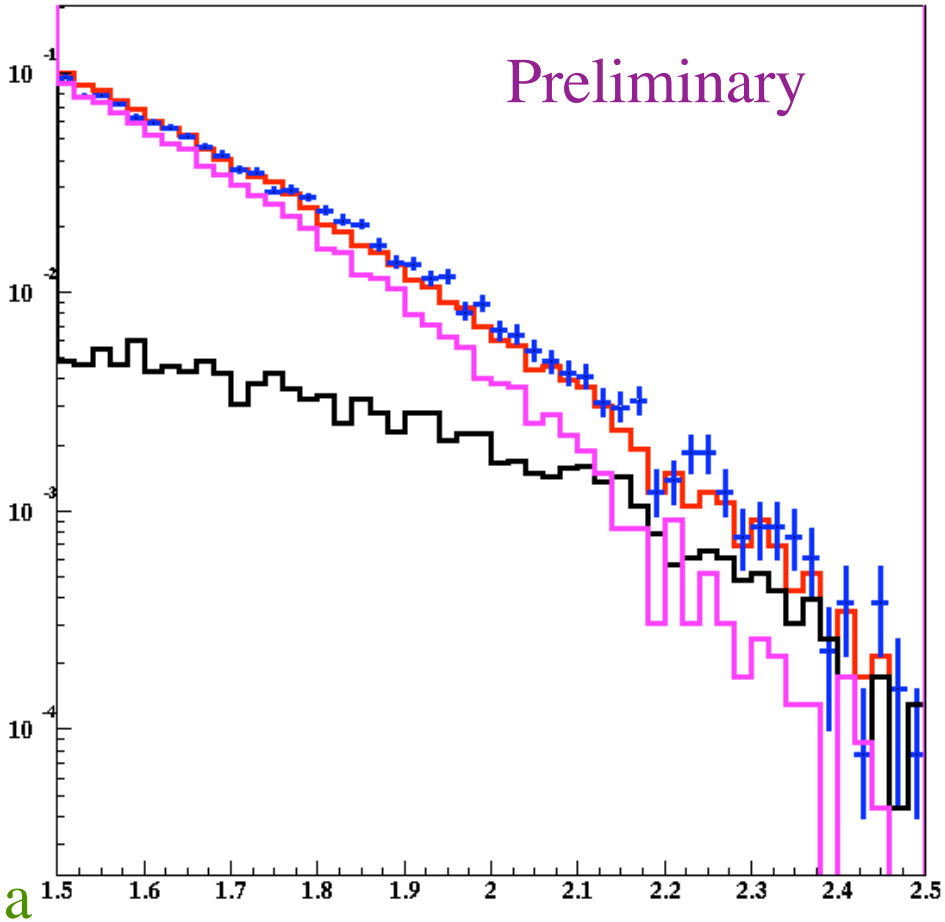
Total MC Data(stat only)

π + K+

Note: All plots are relatively normalized to 1

Absolutely normalized plots show a normalization difference of ~50%

=> MiniBooNE is working on this



1.5 GeV

Eν(QE) in GeV

logarithmic scale

High Energy Box: ν_μ events

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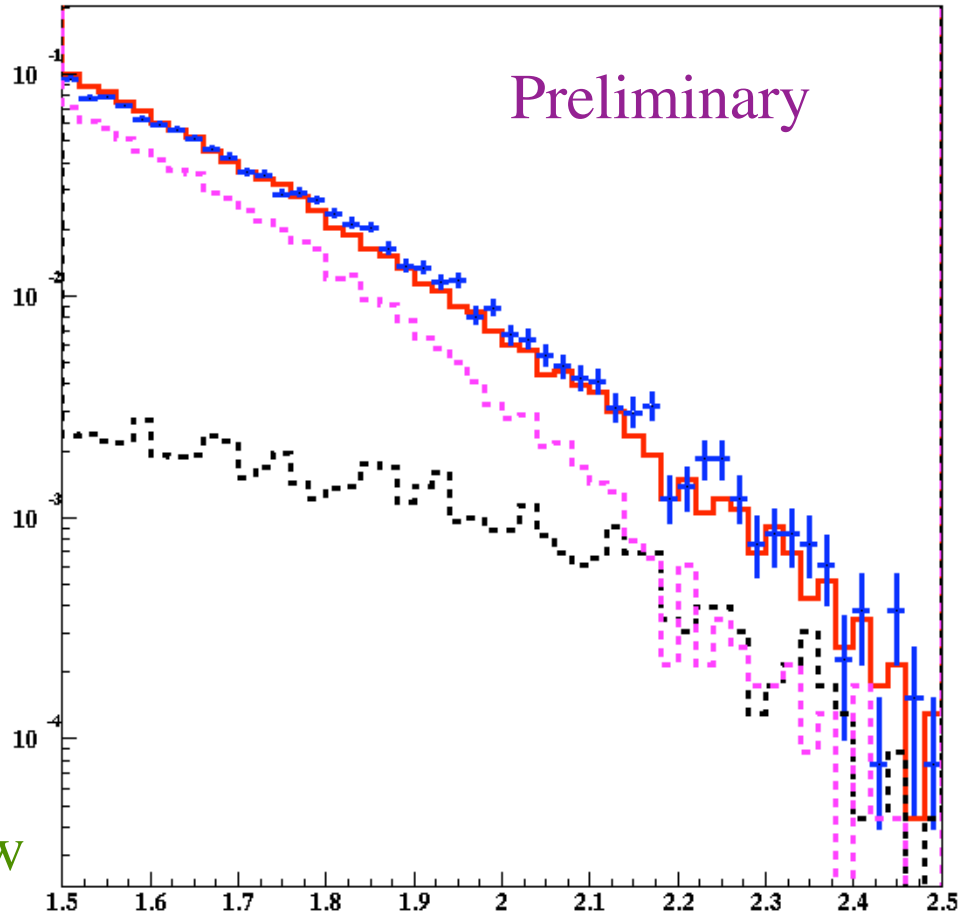


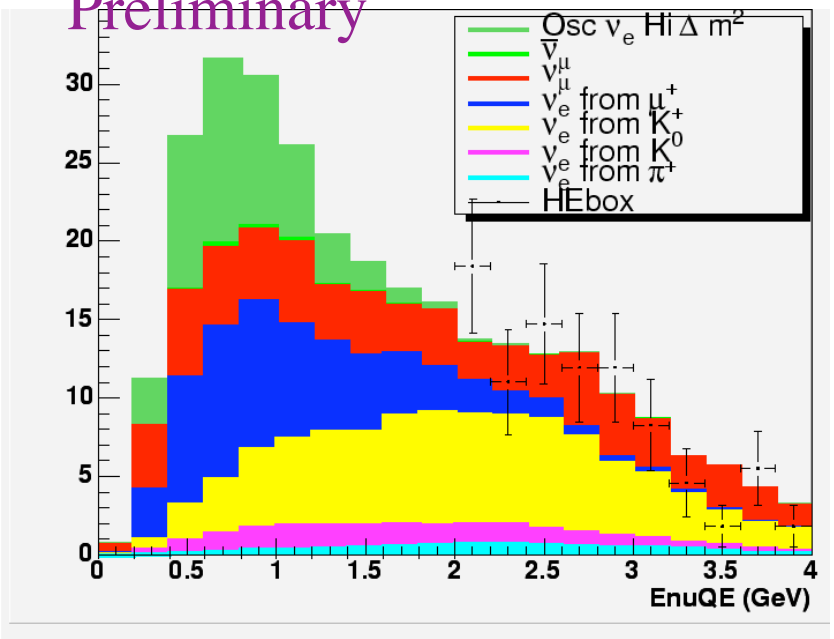
1.5 GeV Eν(QE) in GeV

logarithmic scale

High Energy Box: ν_e events

- Look at CCQE ν_e events as a check of all ν_e backgrounds
  - run the ν_e PID prepared for the oscillation analysis on this sample

Preliminary



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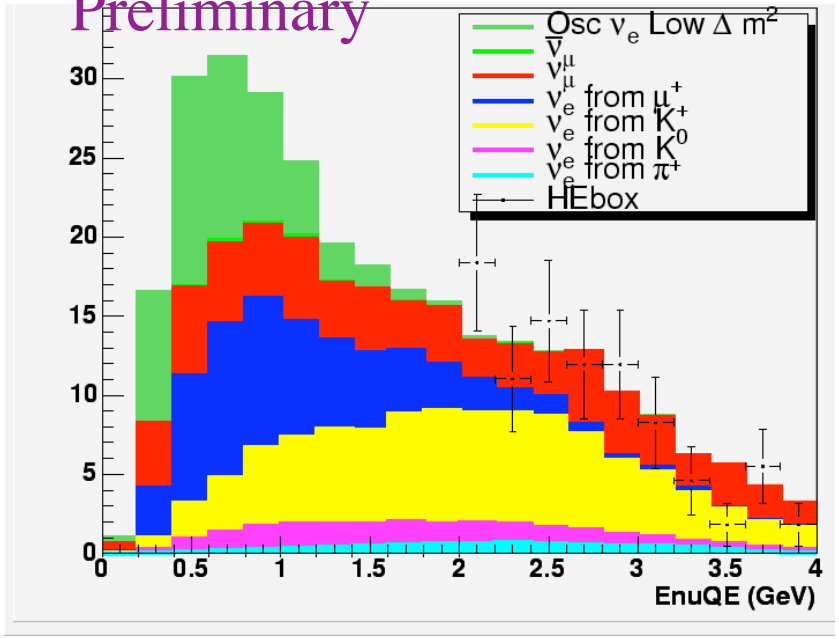

Oscillation K+ misID K^0 μ π+

HE box data (stat only)

Eν(QE) (electron) GeV

High Energy Box: ν_e events

- Look at CCQE ν_e events as a check of all ν_e backgrounds
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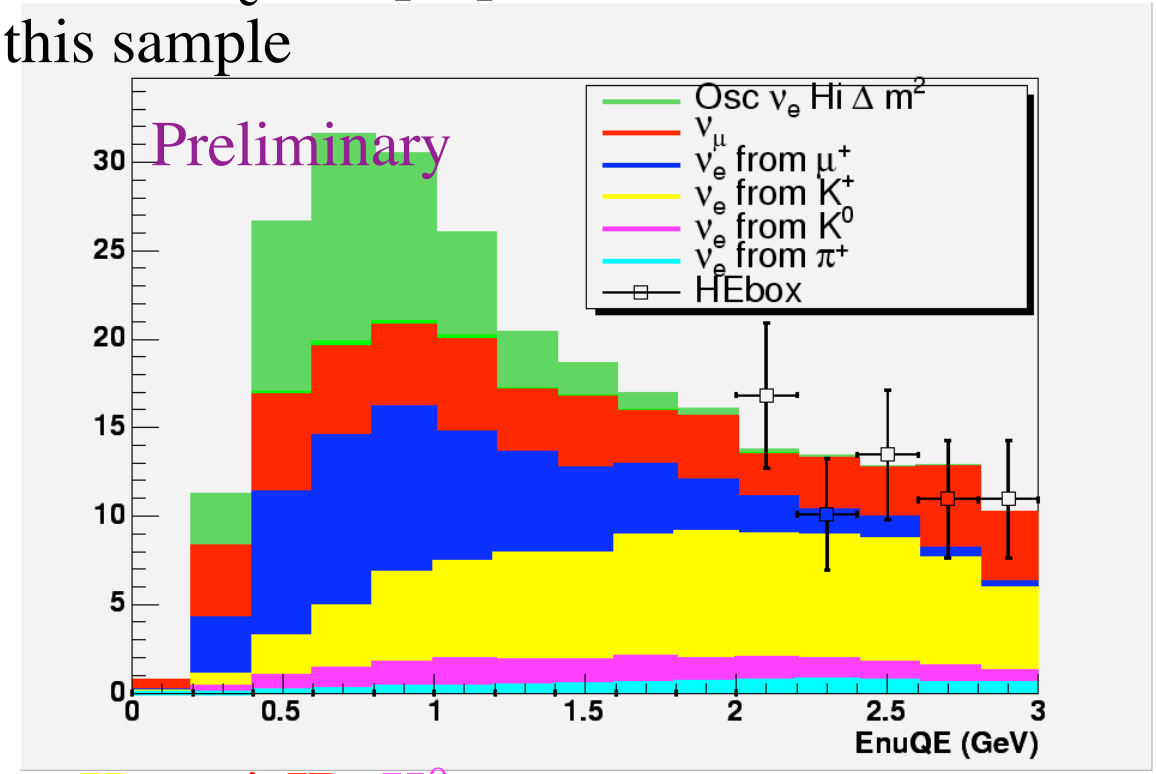

Oscillation K+ misID K^0 μ π+

$E\nu$(QE) (electron) GeV

HE box data (stat only, 3.25e20 pot)

Using the HE box

- The different event samples in the HE provide checks of the predicted neutrino from kaon rate
  - Example: CCQE contained events:
    - 2 subevents, decay michel electron energy <70 MeV, veto hits < 6, muon-like track
    - ~11K data events for 5e20 pot, 82% CCQE, 15% CCπ
    - 17% error due to cross sections, 5% due to flux, 7% optical model

Summary

- MiniBooNE is searching for ν_μ to ν_e oscillations
  - Observing these oscillations depends on understanding the content of the neutrino beam
- The HE box and LMC provide MiniBooNE with checks using the same beamline of the kaons
  - Check of K+ μ from the LMC
  - Check of π+, K+ ν_μ from HE box CCQE, CCpi muon-like events
  - Check of K^0, K+ ν_e from HE box CCQE electron-like events