Constraining neutrinos from kaon decay in MiniBooNE

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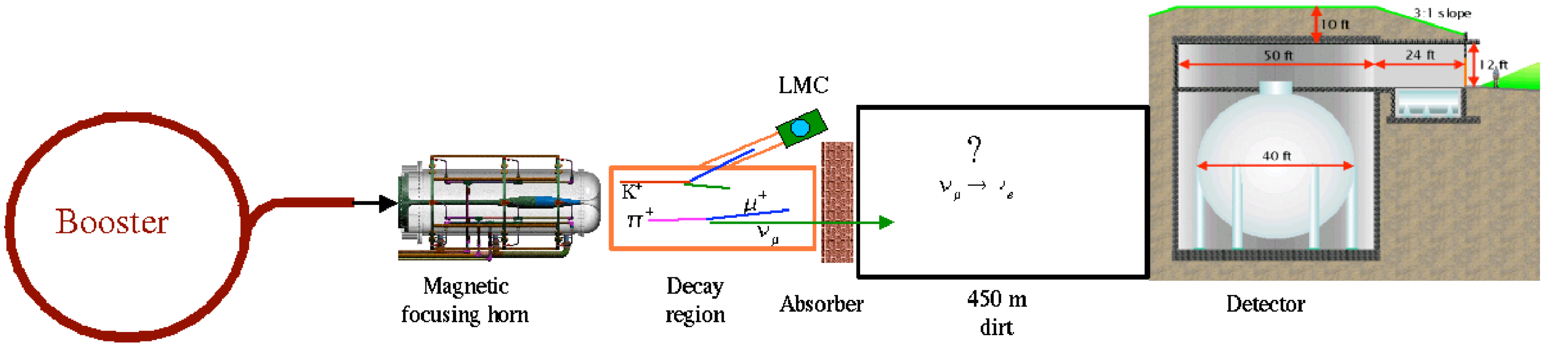
- Oscillation backgrounds
- Kaon measurements in MiniBooNE
  - high energy ν_μ events from K+
- Summary

MiniBooNE beamline

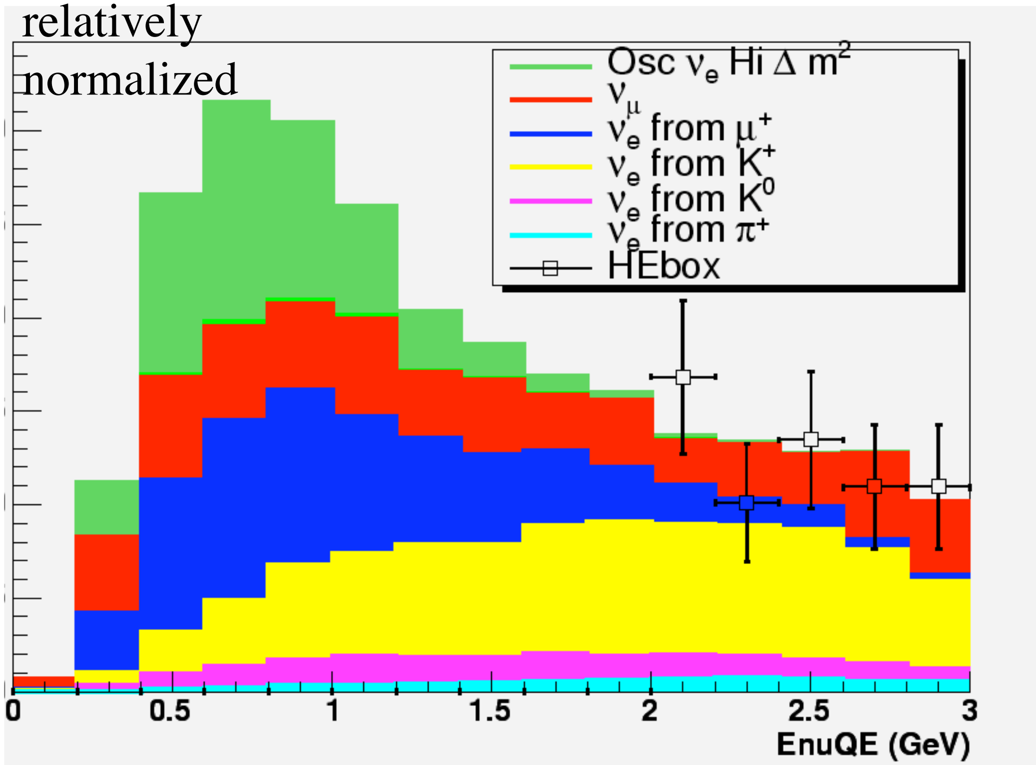


Pop Quiz!

Protons hit Be target, producing:

- a) π+ (primary source of ν_μ)
- b) K+ decay to ν_μ , ν_e
- c) K^0 decay to ν_μ, ν_e
- d) all of the above

Oscillation search



Events in E_ν(QE) bins after oscillation selection cuts

- shape subject to change as final cuts are decided

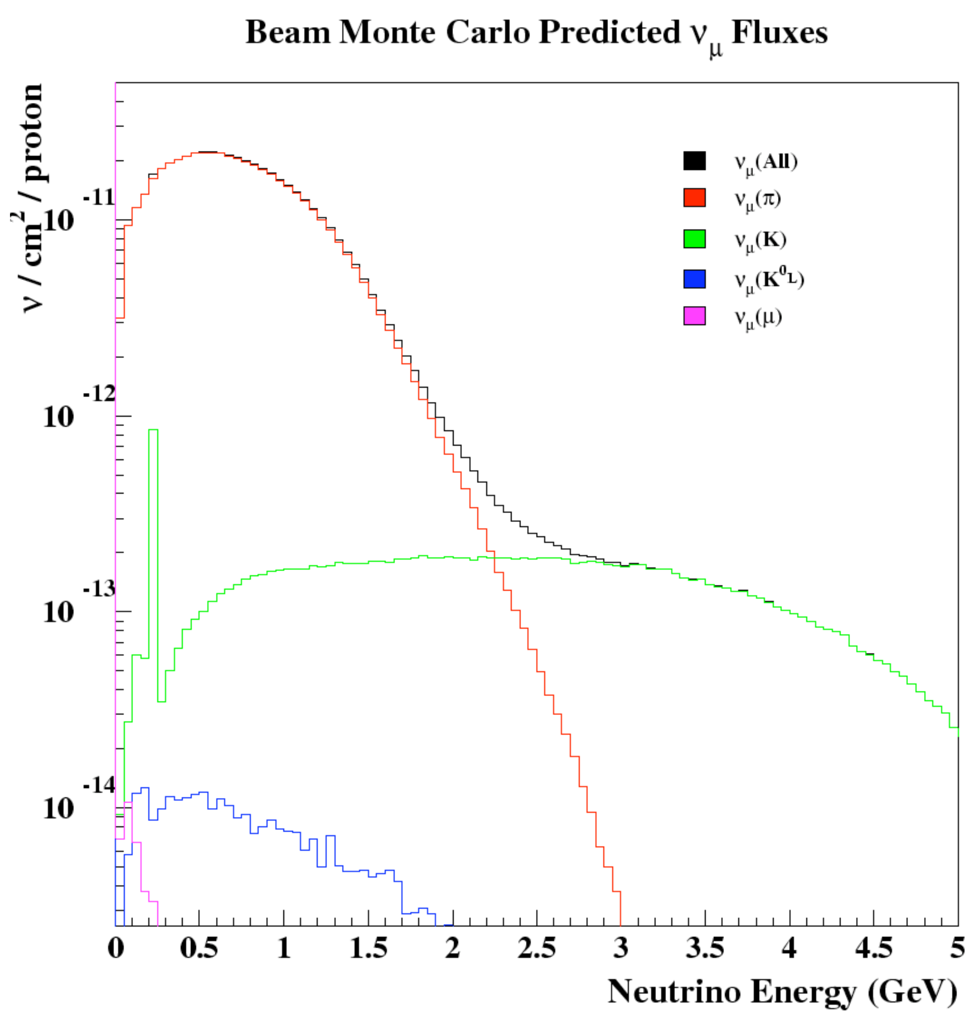
Signal (Δm^2=1eV^2, $\sin^2 2\theta$=0.004

Background

- misidentified ν_μ (mainly π^0s)
  - constrained by observed π^0s
- ν_e from muon decay
  - muon produced for each ν_μ
  - constrained via ν_μ spectrum because π decay is very forward
- ν_e from K+, K^0, π+ decay
  - K^0, π+ external data parameterization and errors are sufficient
  - Must measure K+ normalization due to uncertainties in production

this talk

Measuring neutrinos from K+



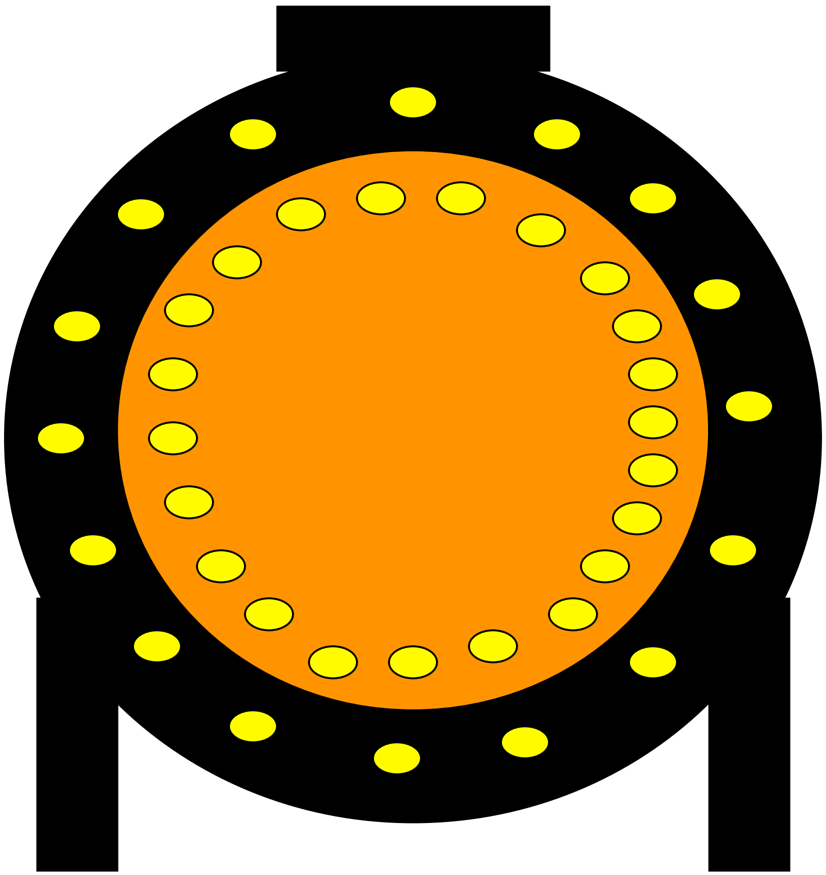
Neutrinos from K+ are buried under neutrinos from π+ except at high energies

⇒ Look at highest energy events in MiniBooNE

⇒ Search for K+ ν_μ events

Rate of ν_μ larger than ν_e ; different backgrounds

The MiniBooNE detector



12 m diameter light detector filled with mineral oil

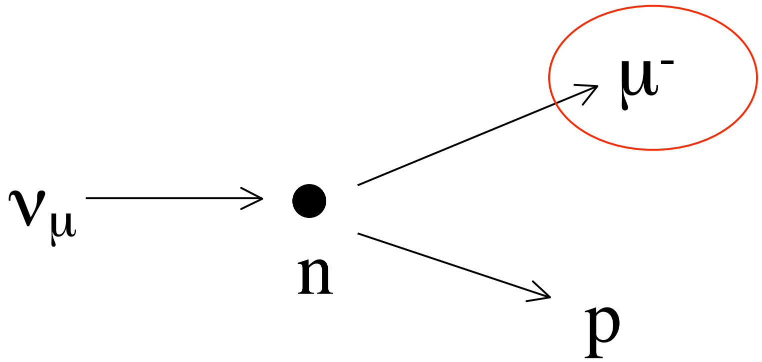
- 1280 PMTs in inner region
- 240 PMTs in outer "veto" region

ν_μ events appear as Cherenkov rings

- Energy based on the charge read out from the PMTs response to light in the tank
- Track length is derived from the geometry of the Cherenkov ring

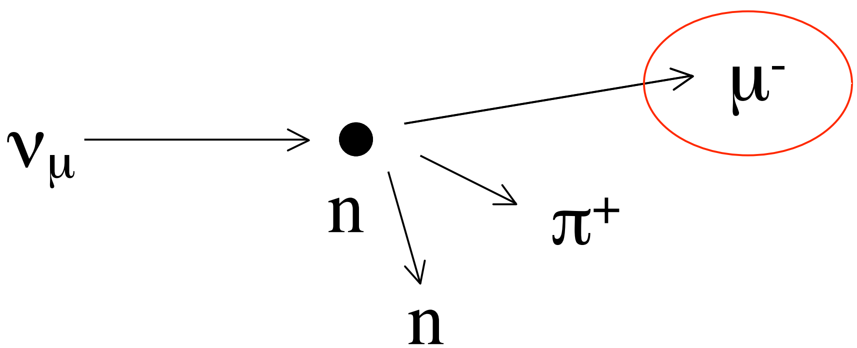
Neutrino Interactions

- Charged Current Quasi-elastic (CCQE)



Both of these interactions have a primary μ, which we will use to identify ν_μ from K+ decay

- Charged Current single pion production ($CC\pi^+$)



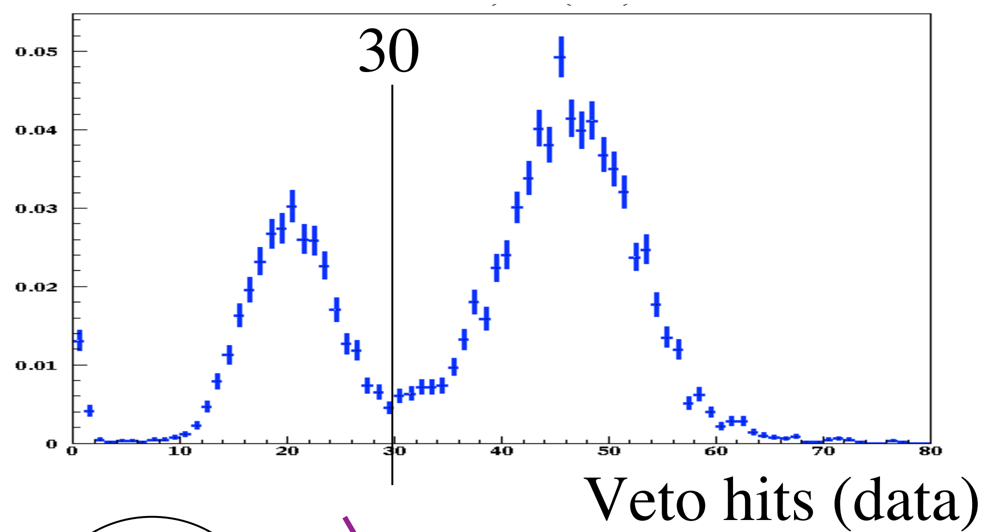
Selecting ν_μ events at high energy

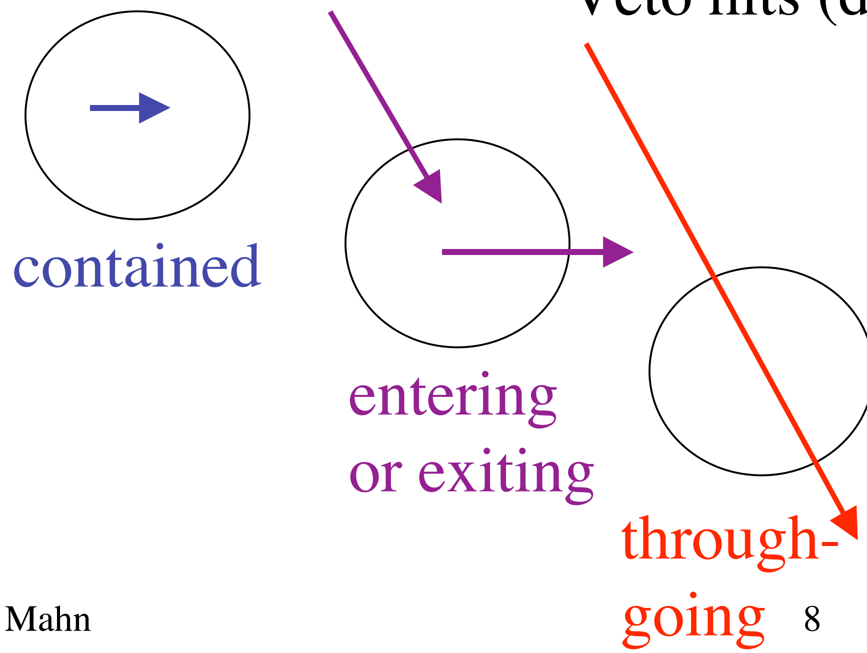
Basic cuts:

- Event is in time with the beam
- Observed energy in inner detector > 2 GeV
  - Predominantly K+ decay neutrino events
- Event is in the forward direction of the beam
- Passes cosmic ray reduction cuts
  - want ν_μ from CC events, not cosmic ray muons

Cosmic ray reduction cuts (I)

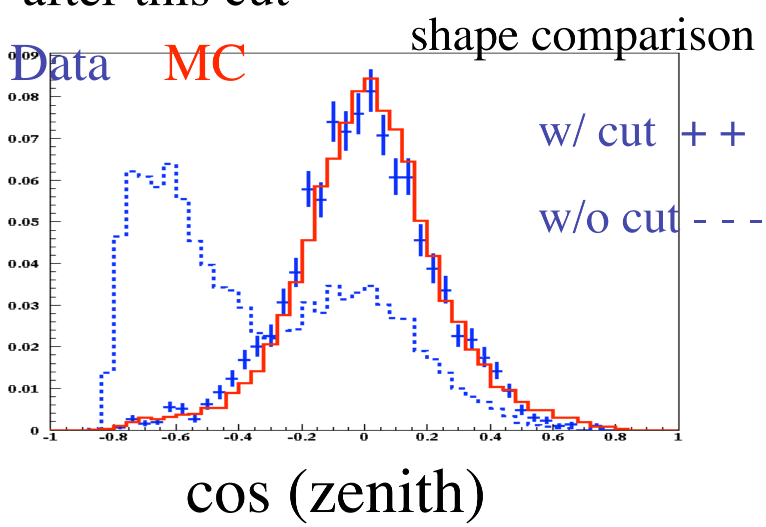
- Veto hits < 30
  - Veto hits < 6 are "contained" and have no cosmic ray contamination
  - > 30 hits are through going cosmic rays that enter and exit the inner tank
- Why not consider only contained events?
  - Requiring containment is an effective energy cut; many K+ neutrino events exit the inner tank
  - Must separate incoming cosmic rays from exiting neutrino events

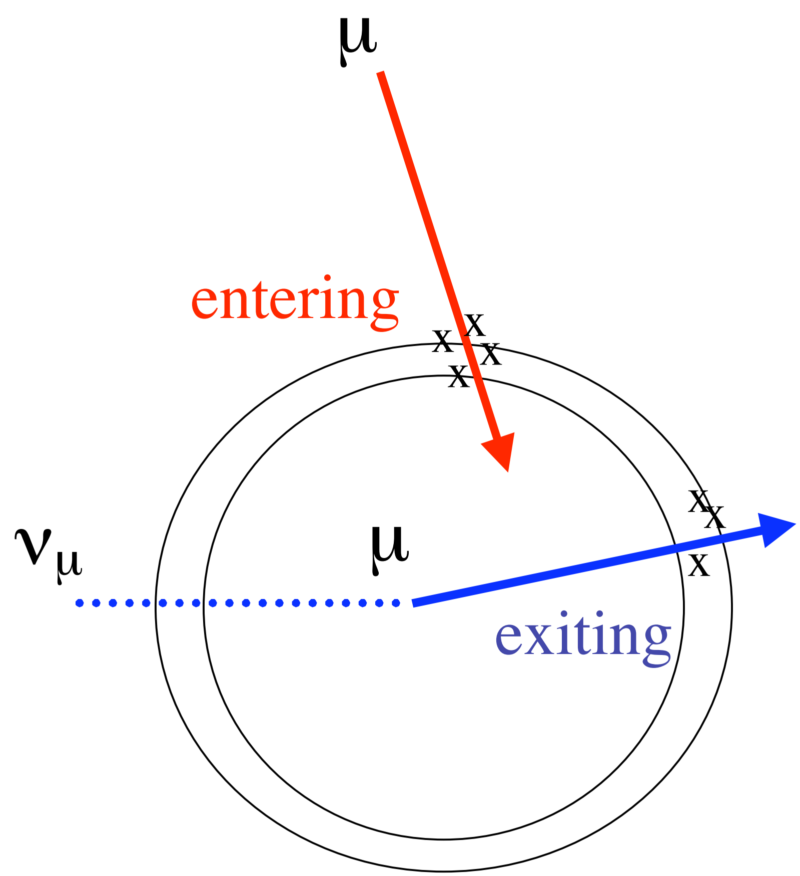




Separating entering cosmic rays from exiting neutrino events

- Entering cluster hits less than 5
  - "Entering cluster": hits in the veto that are consistent with the direction of the observed track
  - No excess of events in veto hits, downward direction are observed after this cut

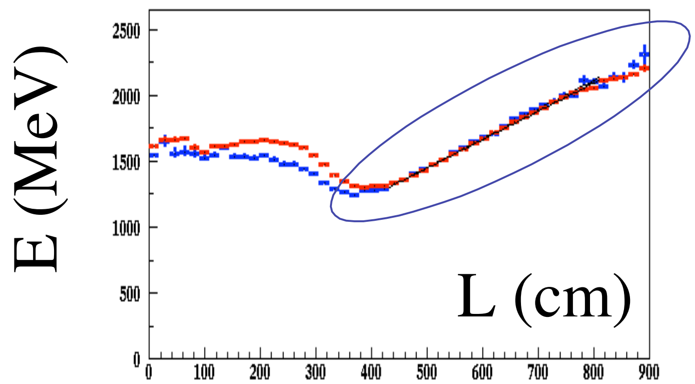




Selecting ν_μ CCQE, CCπ+ events

Select events consistent with a muon

- Form a variable, E_L, which is an energy based on the track length
- Select events with a small difference between E_L and the observed energy, E
- These events are mainly CCQE,CCπ+

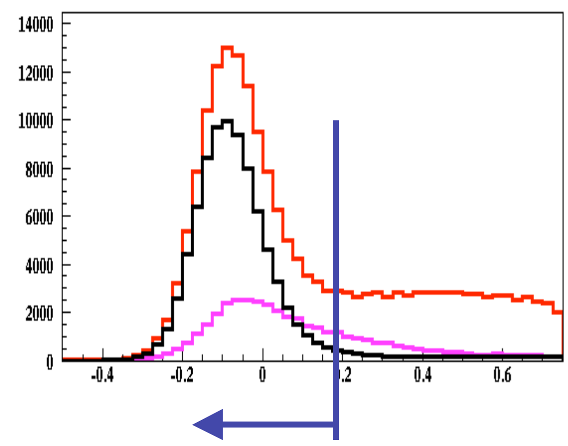


Data MC

E_L=2*L+370

MC CCQE CCπ+

$(E- E_L) / E$
< 0.2



Characteristics of the high energy ν_μ from K+ sample

- 76% CCQE/CCπ+ ν_μ from K+ decay
- 24% background events
  - primarily from ν_μ from π+ decay and CC π^0 events
- Neutrino energies between 2-3 GeV

This sample sets the normalization of the ν_e from K+ decay in the oscillation sample

Shape of the K+ intrinsic ν_e flux in the oscillation sample is given by external data Sanford-Wang parameterization

Current (not final) systematics

Statistical uncertainty = 5%

Detector (light propagation model, PMT response, etc) = 10%

- expected to decrease with recent work

Cross section uncertainty = 13%

- MA(QE), Fermi momentum in the nucleus, binding energy, etc; to be constrained further by our analysis of CCQE ν_μ events at lower energies

Flux uncertainties = 7 %

- pion, kaon Sanford-Wang fit uncertainties, does not include parameterization error

Beam uncertainties = 2%

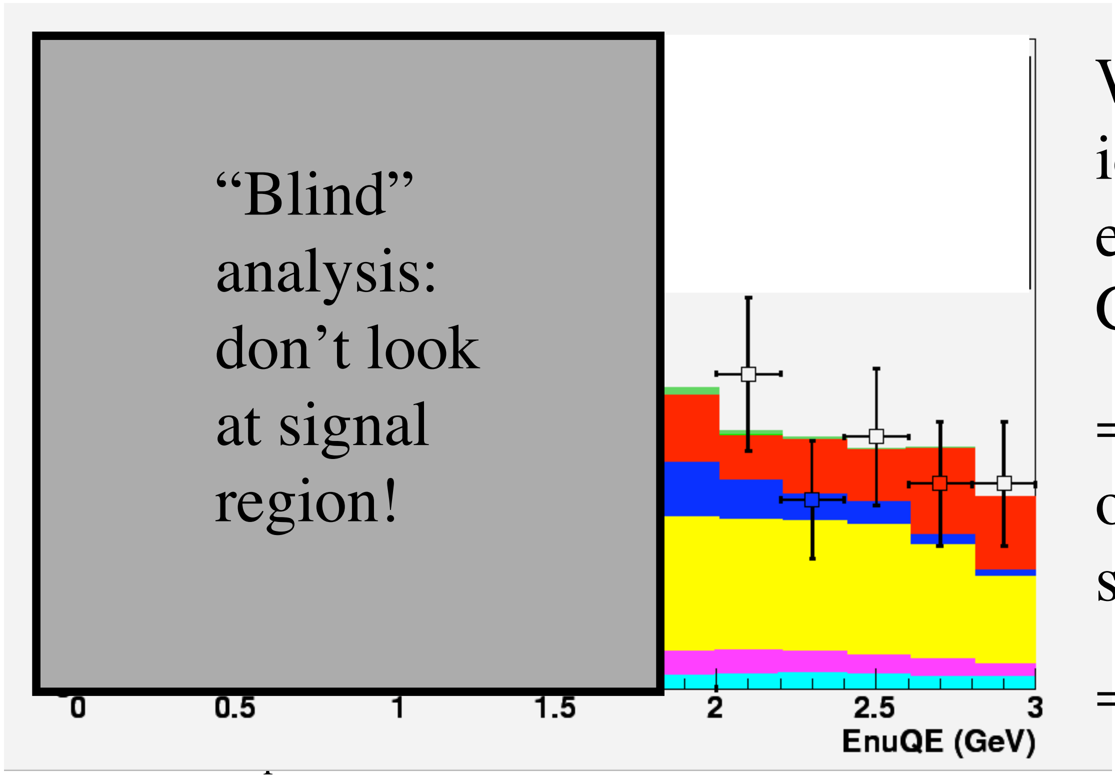
- skin depth, horn current variations, does not include p.o.t. uncertainty

Other ways to measure neutrinos from K+

- Measure muons from K+ via LMC (Little Muon Counter)

  ⇒ consistent with HE ν_μ sample

- Apply ν_e selection cuts for oscillation analysis to high energy region



With current particle identification, less than half events are from K+ (~1/3 CCQE K+ ν_e)

⇒ depends on understanding of HE backgrounds which is still being actively worked on

⇒ use as cross check

Summary

- The observation of ν_μ to ν_e oscillations depends on the understanding of the ν_e in the beam from K+
- The high energy ν_μ sample and LMC provide MiniBooNE with a normalization for these intrinsic ν_e events from K+