Current Status of Short-Baseline Neutrino Experiments

H. Ray

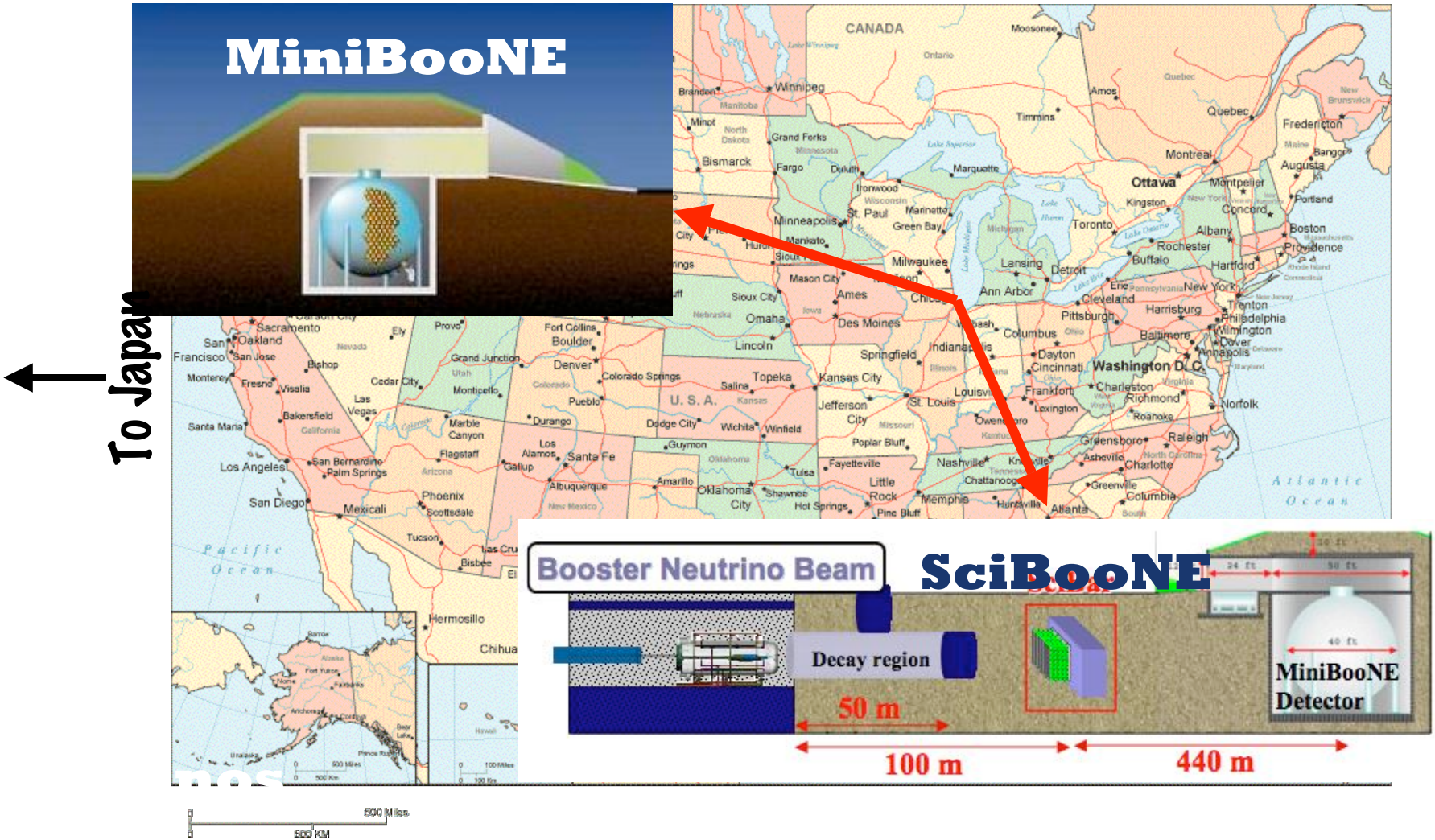
Los Alamos National Laboratory

Short-Baseline Experiments

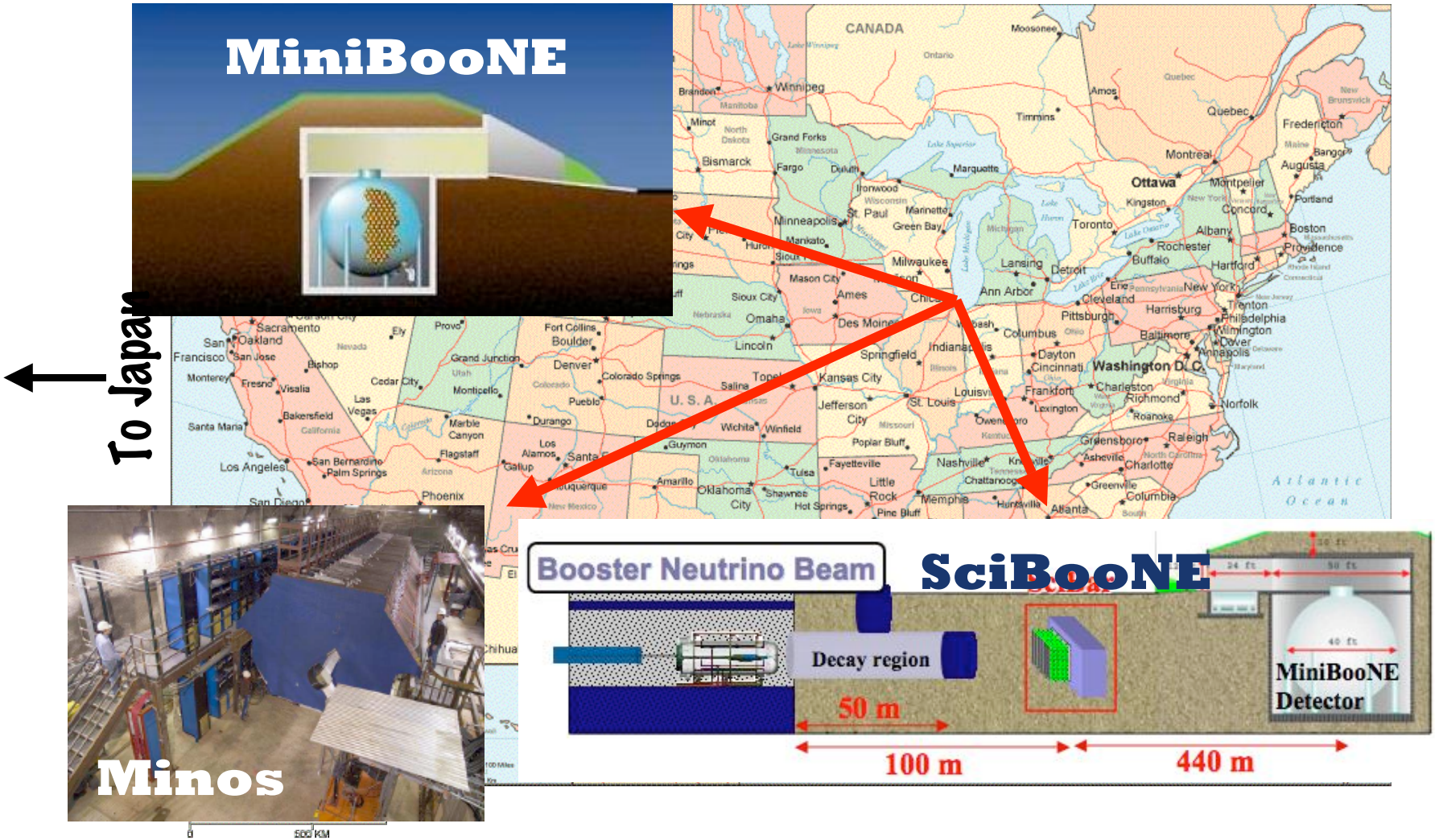
To Japan

Short-Baseline Experiments

Short-Baseline Experiments

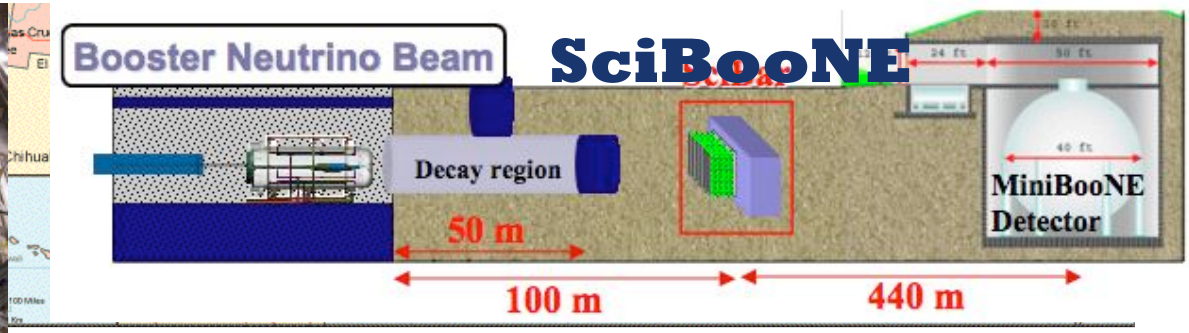


Short-Baseline Experiments

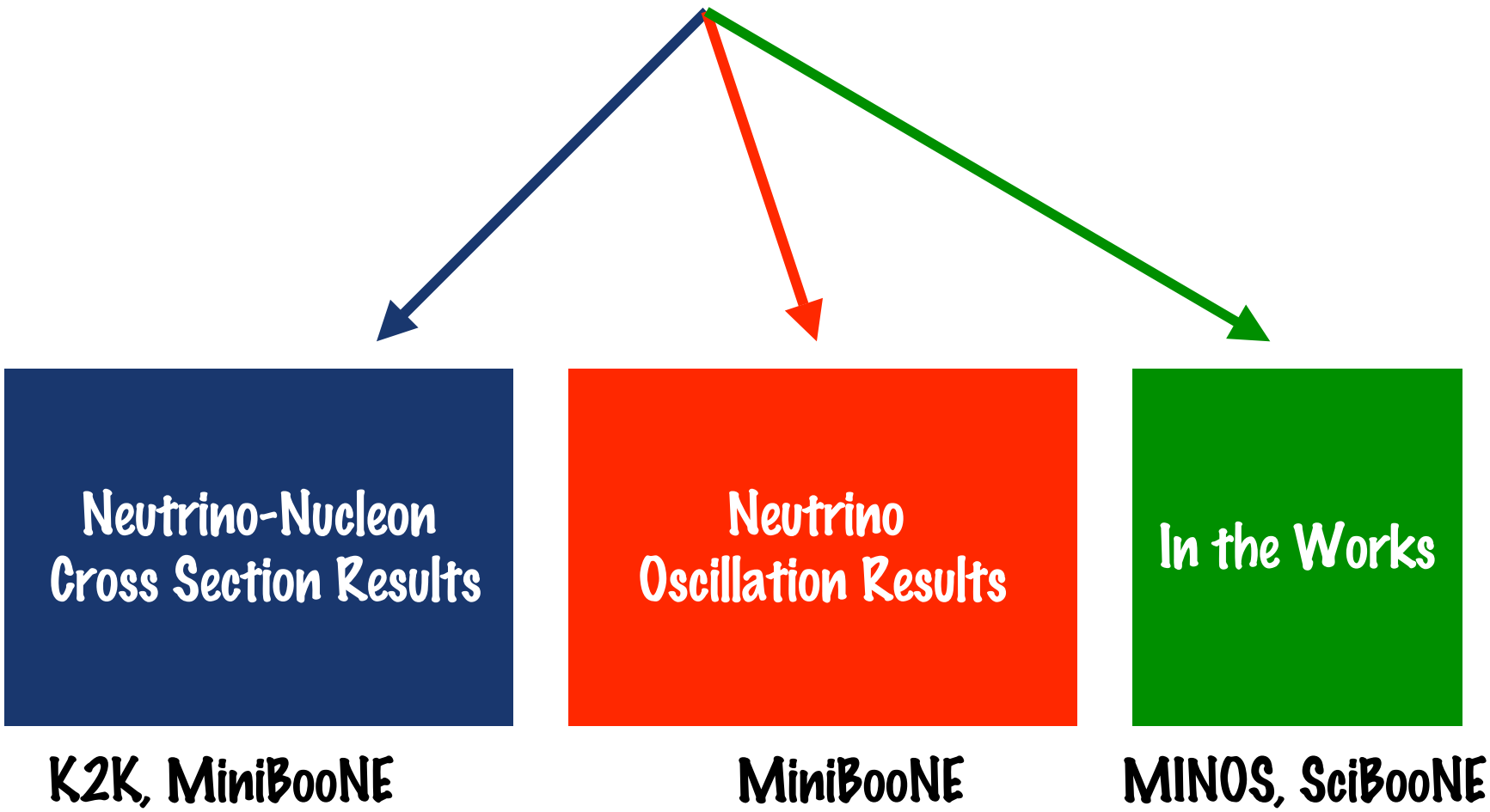


Short-Baseline Experiments

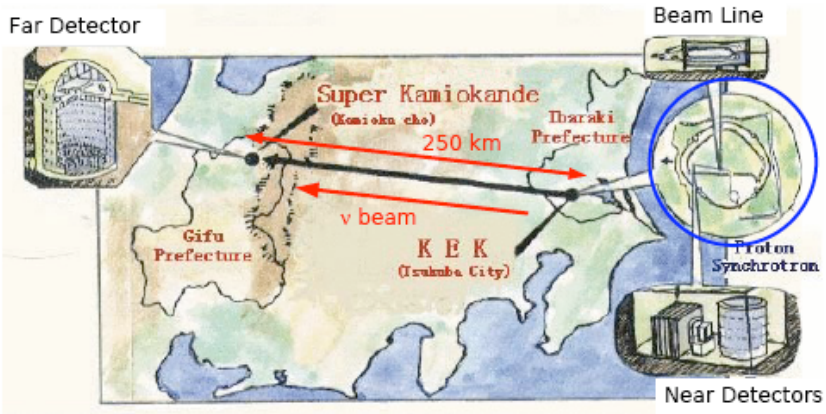
To Japan

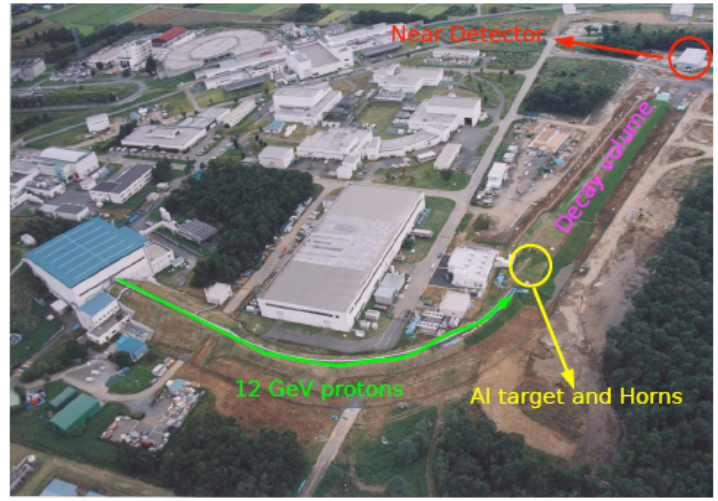


Short-Baseline Experiments



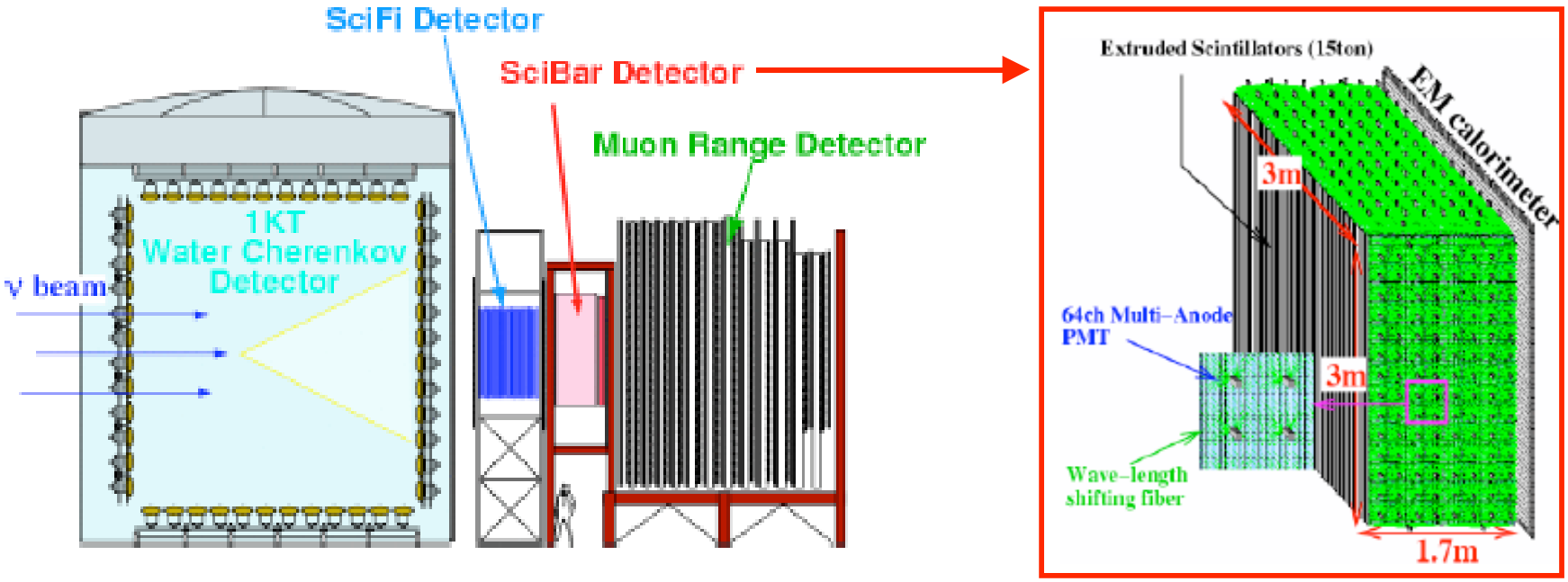
K2K





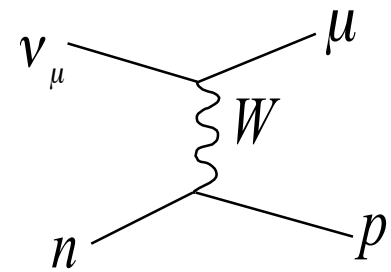
- 12 GeV protons + Al target
- Magnetic focusing horns, run in neutrino mode
- Focus π^+ into decay volume. DIF, beam dump
- E_ν = 1 to 1.5 GeV

K2K Near Detector



- SciFi : 19 layers of water in Al tanks, each layer has 1 hor. & 1 vert. sheet of scintillating fiber
- SciBar : fully active C tracker w/ Pb +scint fiber calorimeter at end
- MRD : 12 layers of Fe, 13 sets of vert. & hor. drift tube layers

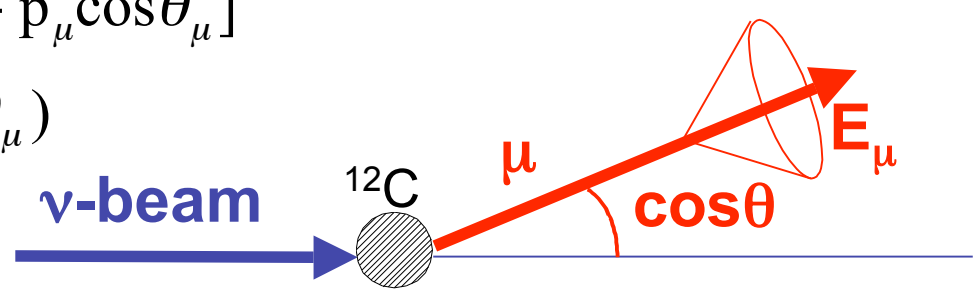
Charged-Current Quasi-Elastic Events



- All kinematics are specified from 2 observables
  - ⇒ Muon energy (E_μ) and muon scattering angle (θ)
- Reconstruct neutrino energy (E_ν) and 4-momentum transfer (Q^2) using these observables

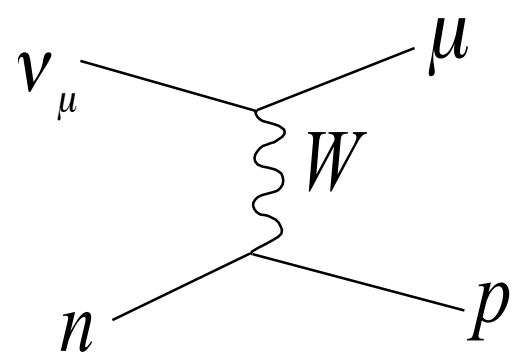
$$E_\nu = \frac{2(M - E_B)E_\mu - (E_B^2 - 2ME_B + m_\mu^2 + \Delta M^2)}{2[(M - E_B) - E_\mu + p_\mu \cos\theta_\mu]}$$

$$Q^2 = -m_\mu^2 + 2E_\nu(E_\mu - p_\mu \cos\theta_\mu)$$



Charged-Current Quasi-Elastic Events

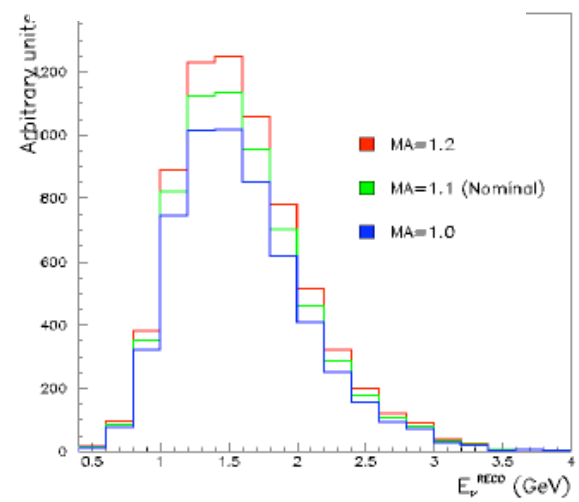
- CCQE cross section depends on axial and vector form factors



- Axial form factor assumed to follow a dipole approximation, which depends on the axial mass (M_A)

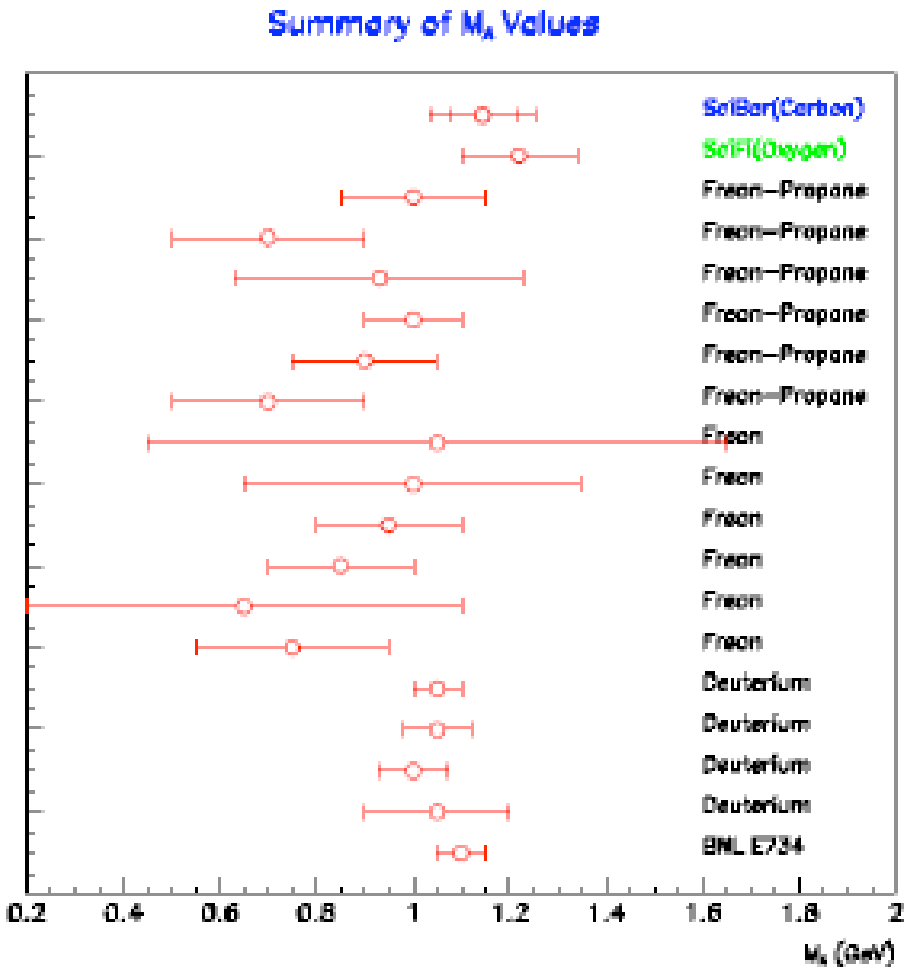
$$F_A(q^2) = \frac{F_A(0)}{(1+q^2/M_A^2)^2}$$

- M_A has large impact on total cross section, 4-momentum transfer (Q^2), reconstructed neutrino energy (E_ν)



K2K CCQE Results

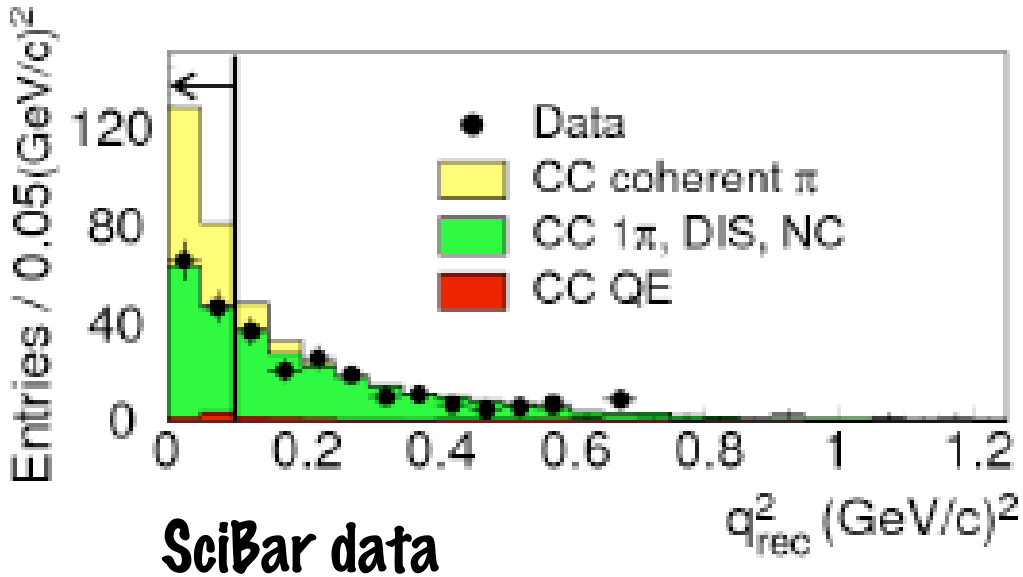
- Measured M_A using SciFi and SciBar detectors
  - ⇒ Phys. Rev. D74:052002,2006
- SciFi : M_A = 1.20 ± 0.12 GeV (stat + syst)
- SciBar : M_A = 1.144 ± 0.077 GeV (fit) + 0.078 - 0.072 (syst)



K2K CC Single Pion Results

- Coherent or Resonant production mechanism
  - ⇒Resonant = pion produced through the production and decay of a resonant state (ie Deltas)
  - ⇒Coherent = neutrino interaction involves the entire nucleus

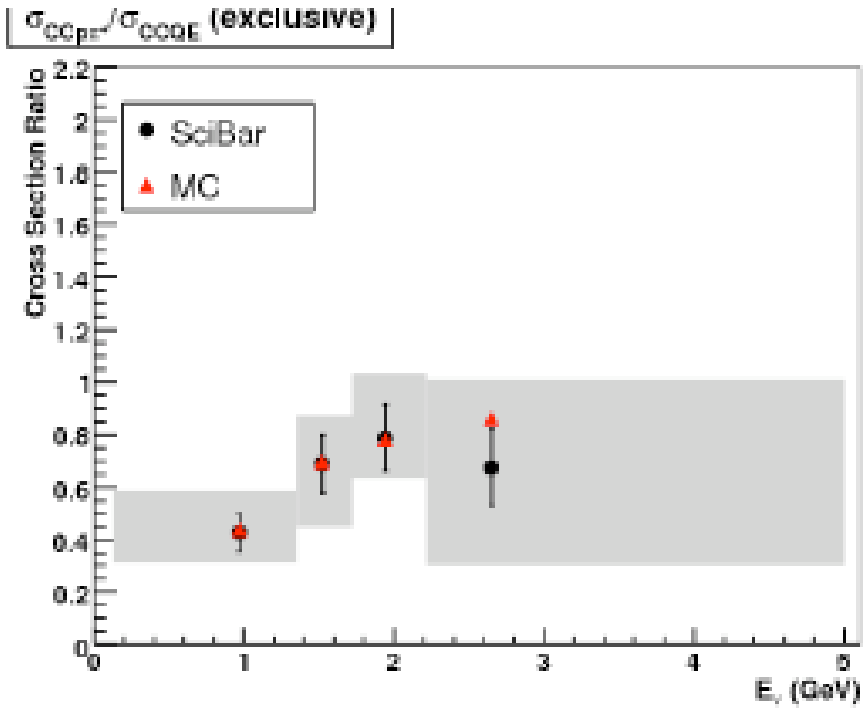
- Upper limit of 0.60×10^{-2} at 90% CL for CC coherent π^+
  - ⇒ PRL 95, 252301 (2005)

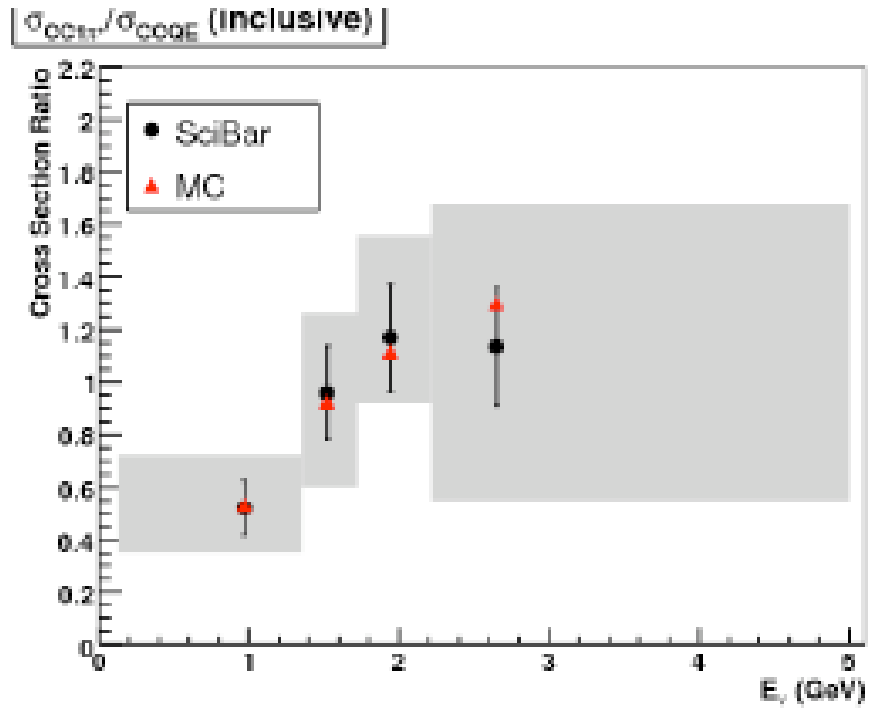


SciBar data

K2K CC Single Pion Results

- Measure the inclusive (CC1π^+) and exclusive (CCpπ^+) resonant single pion production

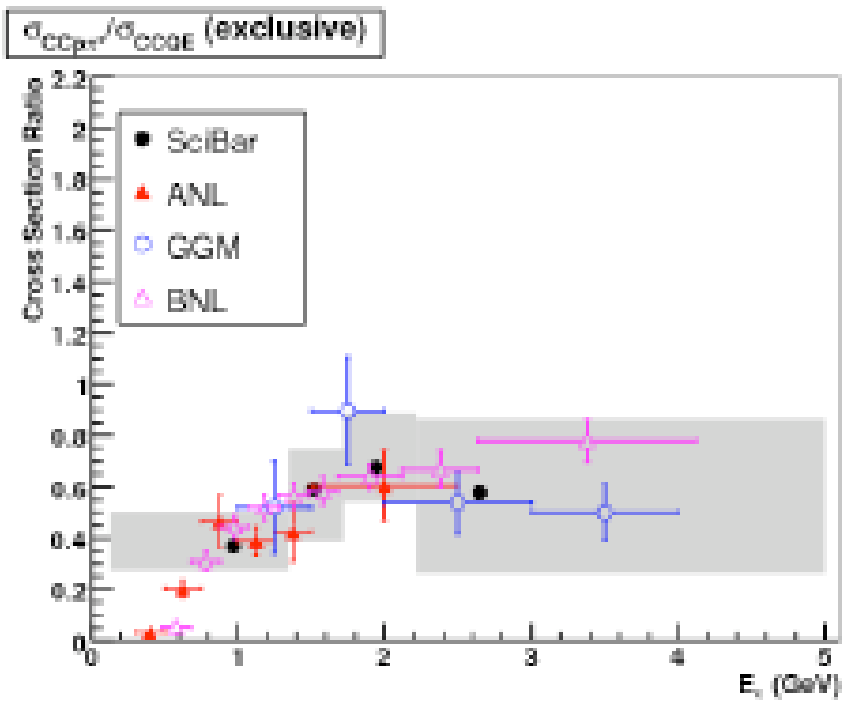


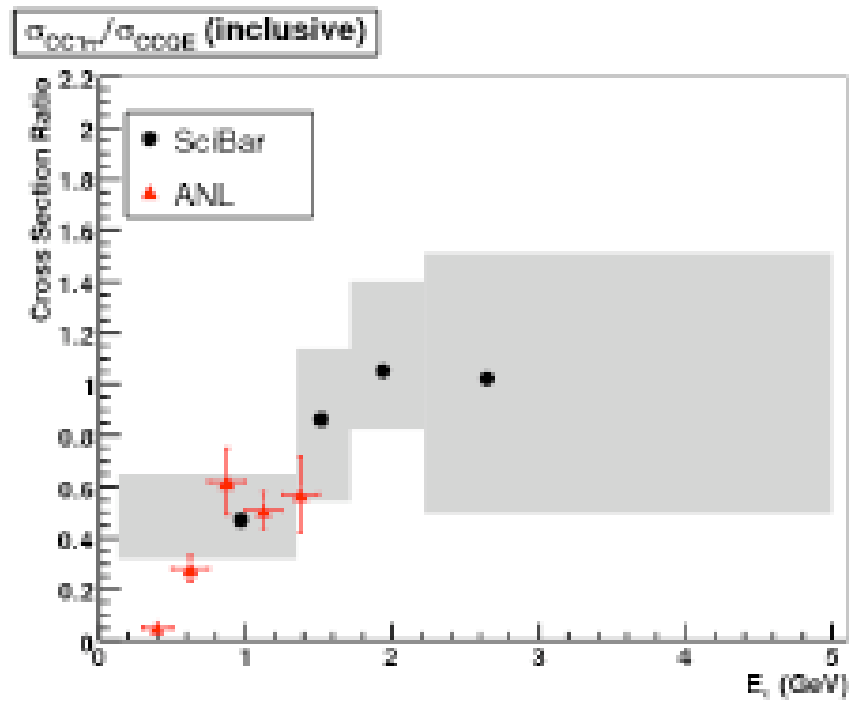


Results submitted for publication this summer

K2K CC Single Pion Results

- Measure the inclusive (CC1π^+) and exclusive (CCpπ^+) resonant single pion production

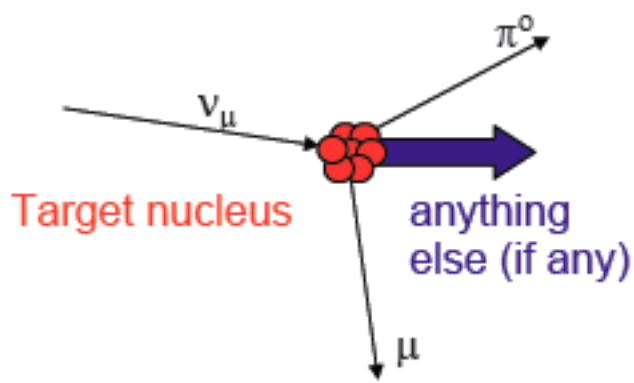




Results submitted for publication this summer

K2K Neutral Pion Results

- CC π^0 inclusive cross section measurement
  - ⇒ PRD in preparation
- Measurement larger than MC expectations
- CC π^0 > MC, CC1π^+ same as MC
  - ⇒ 30 ± 18% excess of multi-pion events in data over MC



K2K Neutral Pion Results

- CC π^0 inclusive cross section measurement
  - $\Rightarrow$ PRD in preparation
- Measurement larger than MC expectations
- CC π^0 > MC, CC1π^+ same as MC
  - $\Rightarrow$ 30 ± 18% excess of multi-pion events in data over MC

$$\frac{\sigma_{CC\pi^0}}{\sigma_{CCQE}} = 0.306 \pm 0.023\,(stat.)^{+0.023}_{-0.021}\,(syst.)$$

$$\frac{\sigma^{MC}_{CC\pi^0}}{\sigma^{MC}_{CCQE}} = 0.220 \pm 0.001(stat.) \pm 0.043$$

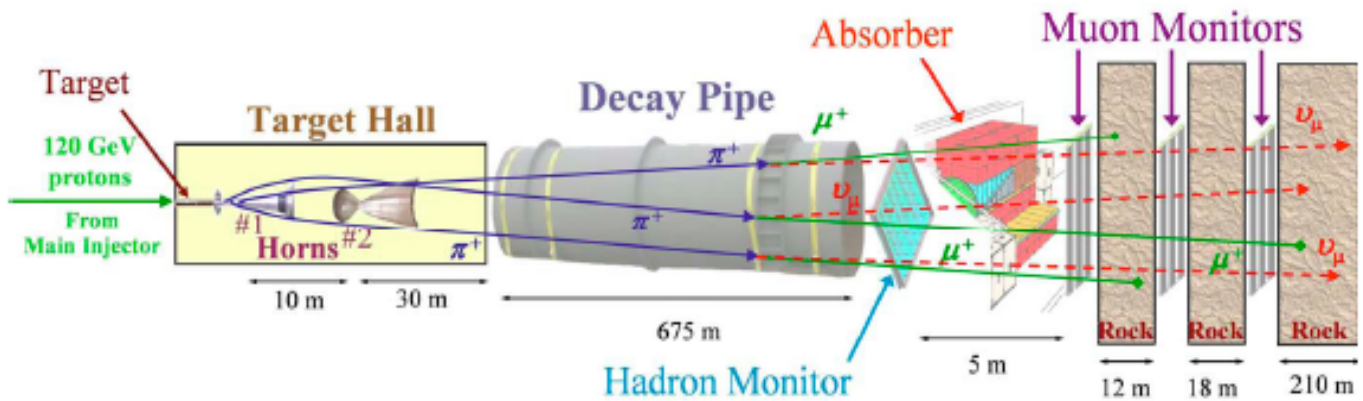
K2K Neutral Pion Results

- CC π^0 inclusive cross section measurement
  - $\Rightarrow$ PRD in preparation
- Measurement larger than MC expectations
- CC π^0 > MC, CC1π^+ same as MC
  - $\Rightarrow$ 30 ± 18% excess of multi-pion events in data over MC

$$\frac{\sigma_{CCmulti-\pi}}{\sigma_{CCQE}} = 0.465 \pm 0.029(stat.) \pm 0.056(syst.)$$

$$\frac{\sigma^{MC}_{CCmulti-\pi}}{\sigma^{MC}_{CCQE}} = 0.358 \pm 0.001(stat.)$$

MINOS

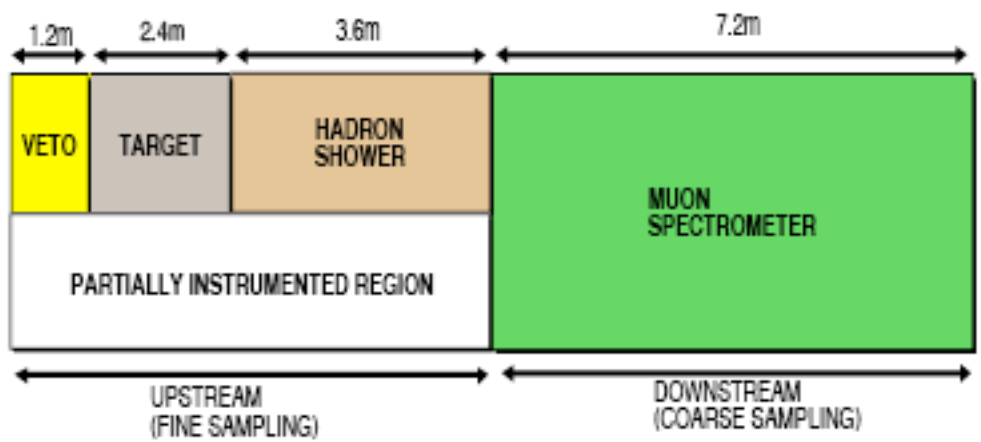


- 120 GeV protons + graphite target
- Magnetic focusing horns, run in neutrino mode
- Focus π^+ into decay volume. DIF
- Moveable target relative to horn = tune neutrino E spectrum (~3 to 10 GeV)

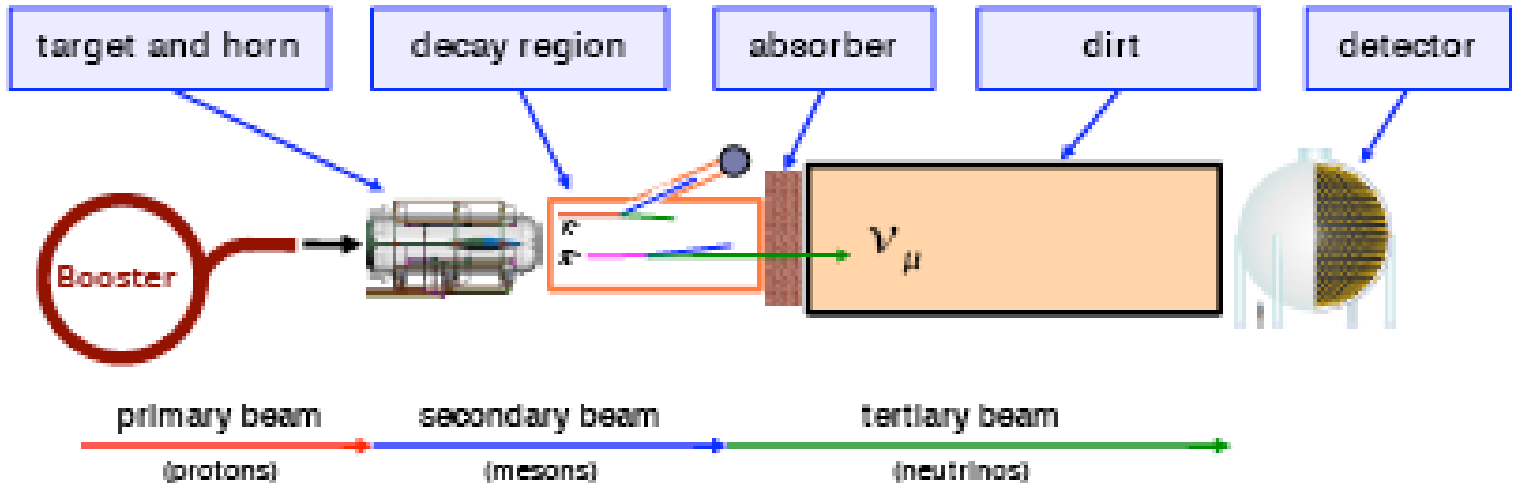
Minos Near Detector

- 1 km from target
- Steel and scintillator tracking calorimeter

- CCQE M_A fit
- DIS cross section
- NC π^0 coherent production
  - ⇒First NC measurement on a heavy target!



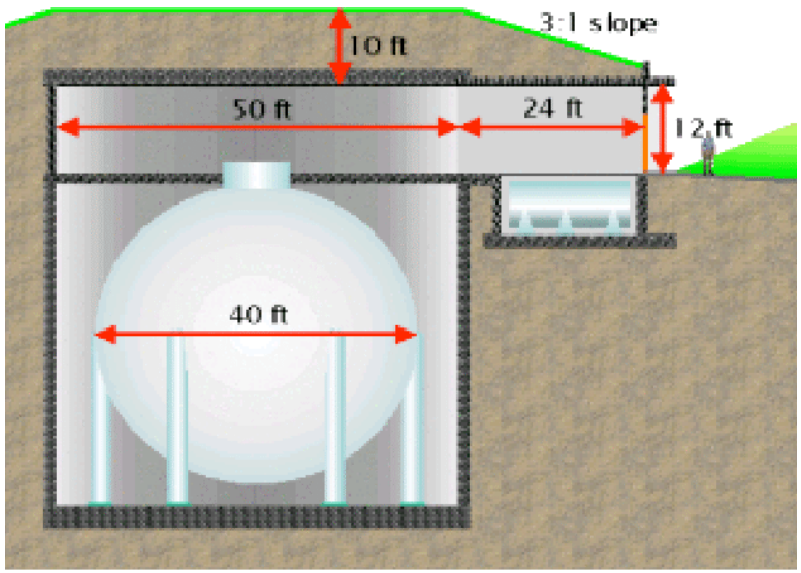
MiniBooNE Neutrino Beam



- 8 GeV beam of protons + Be target
- Magnetic focusing horn dictates beam type (nu, anti-nu)
- Mesons decay into the neutrino beam seen by the detector

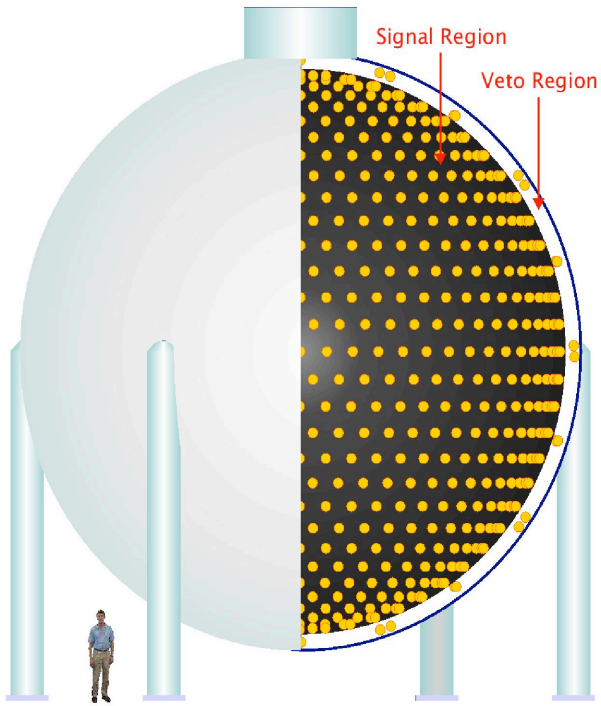
  $\Rightarrow K^+ / \pi^+ \rightarrow \mu^+ + \nu_\mu$
- MiniBooNE L/E = 0.5 km / 0.8 GeV

MiniBooNE Detector



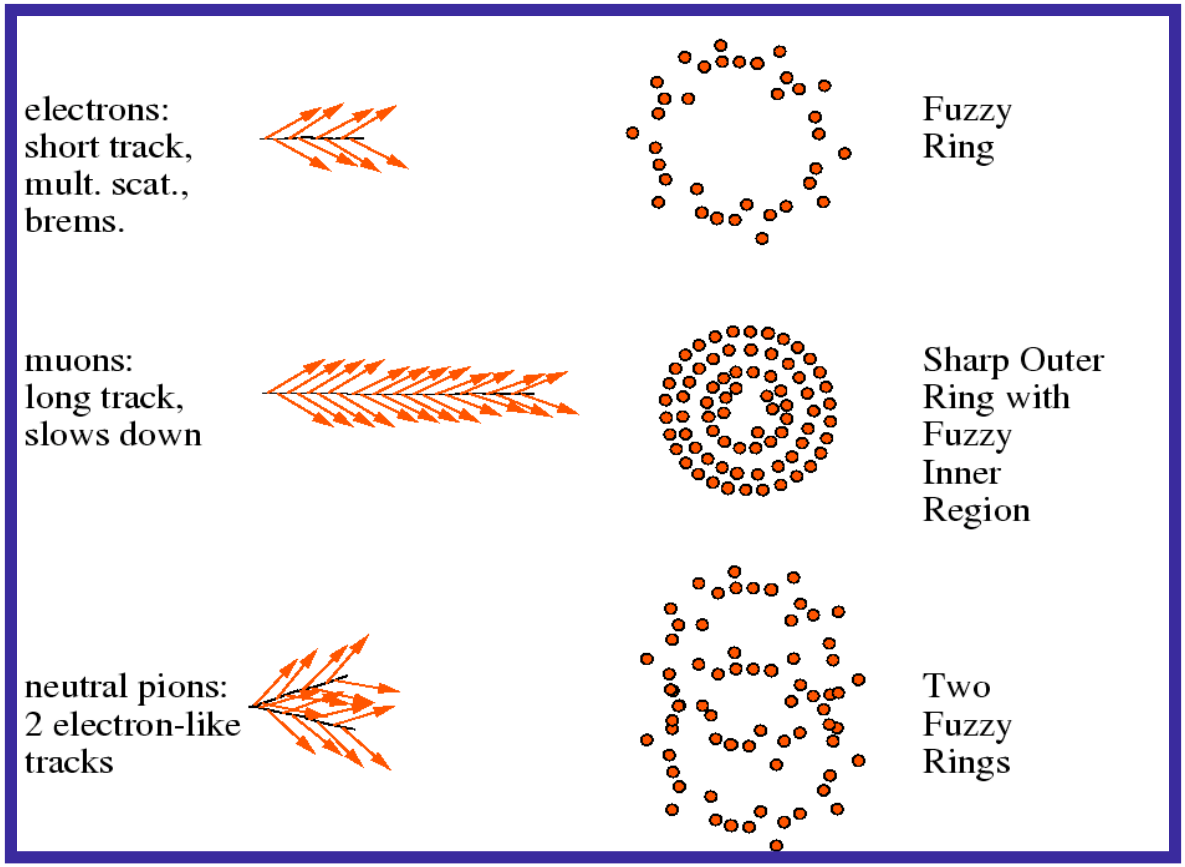
Detector

MiniBooNE Detector

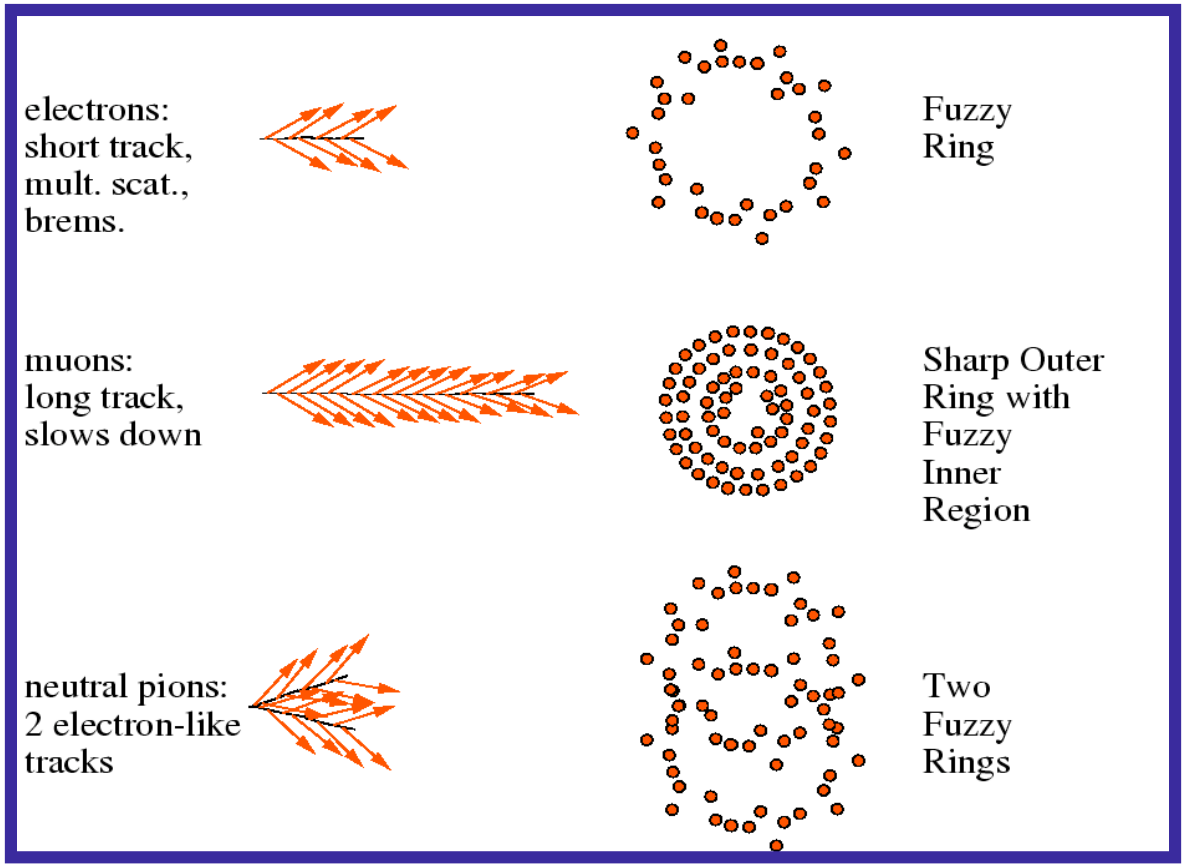


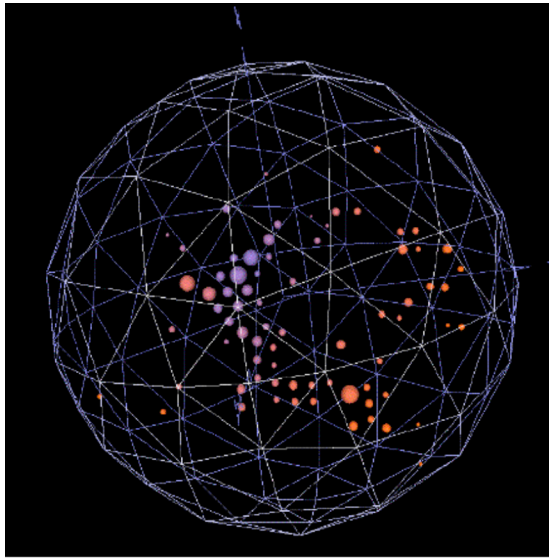
- 12.2 meter diameter sphere
- Pure mineral oil
- 2 regions
  - ⇒Inner light-tight region, 1280 PMTs (10% coverage)
  - ⇒Optically isolated outer veto-region, 240 PMTs

Event Signature

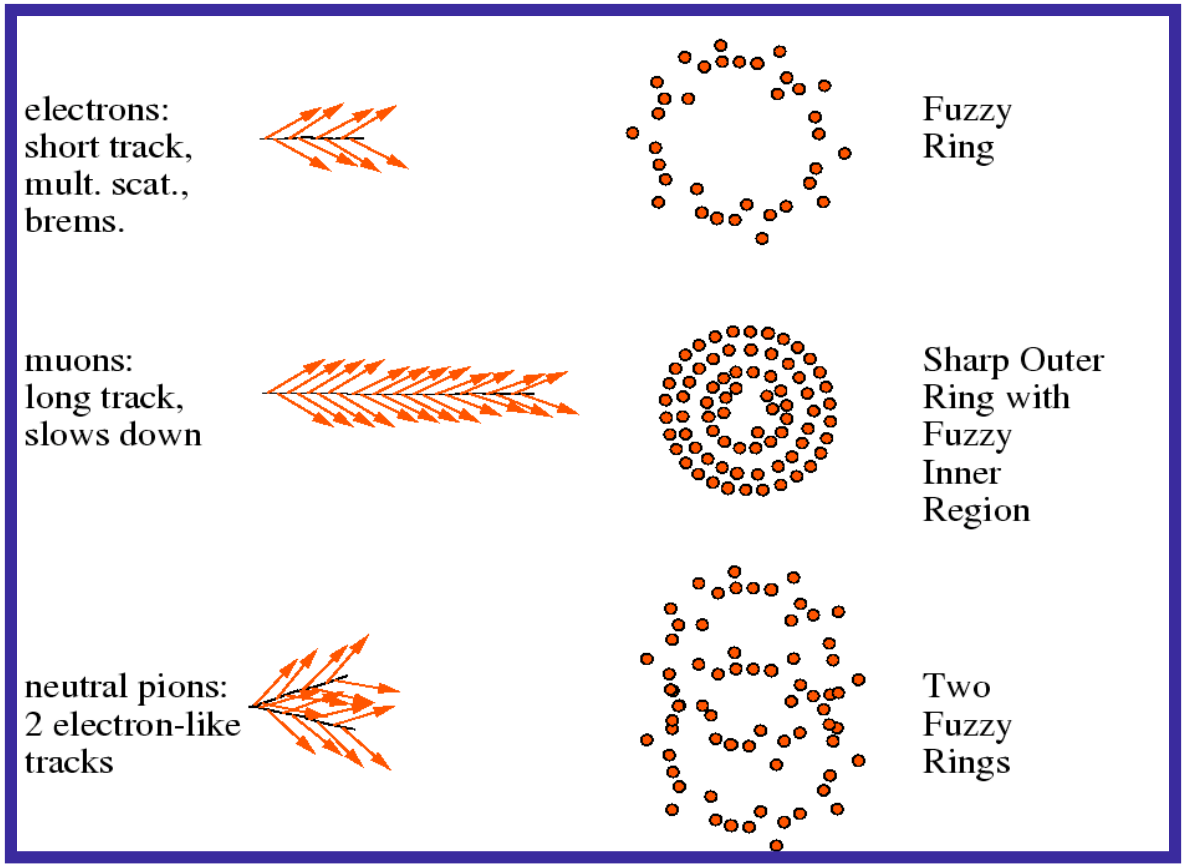


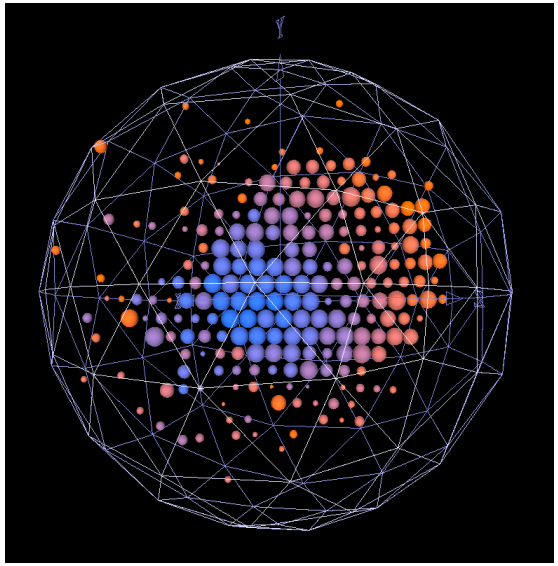
Event Signature



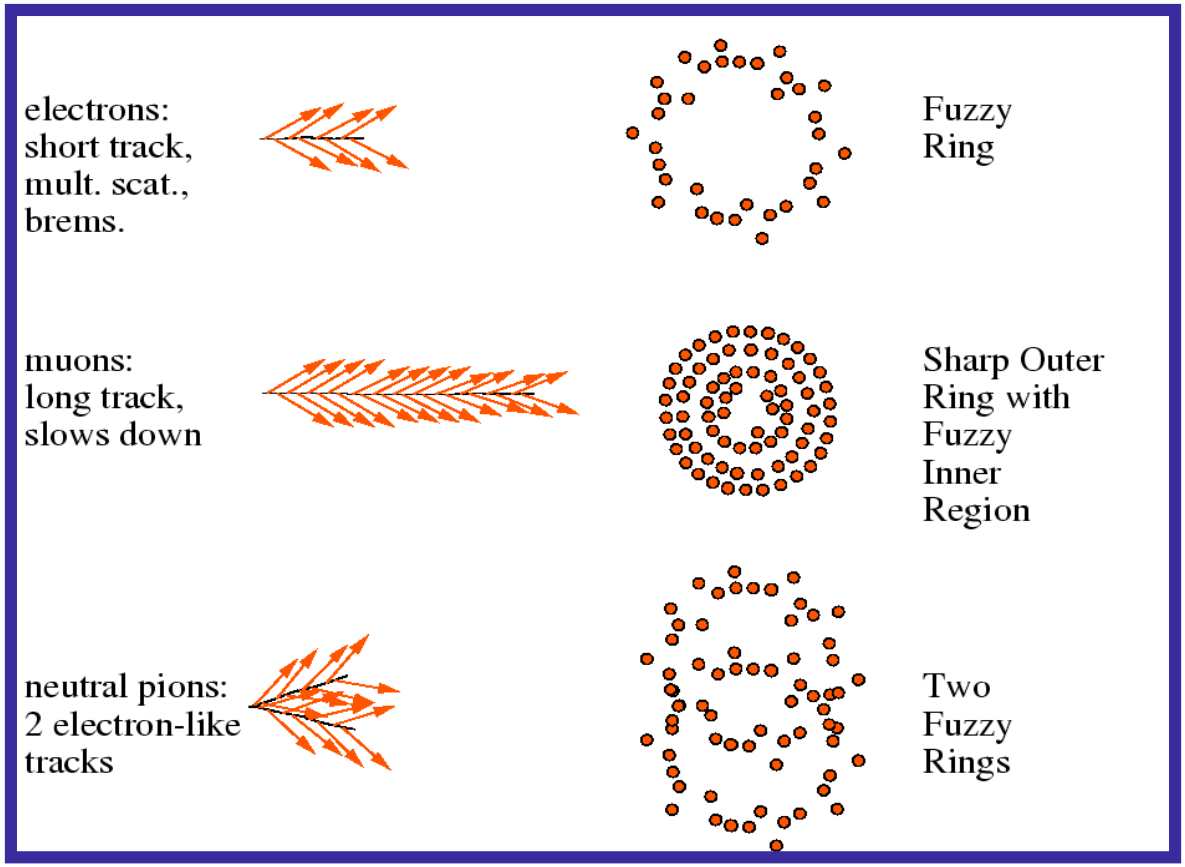


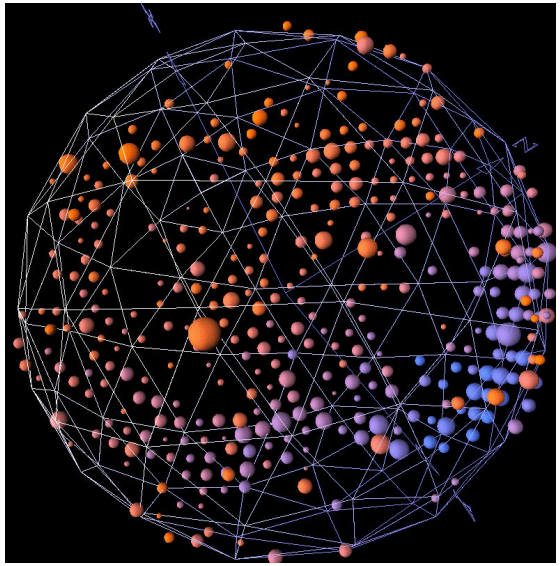
Event Signature





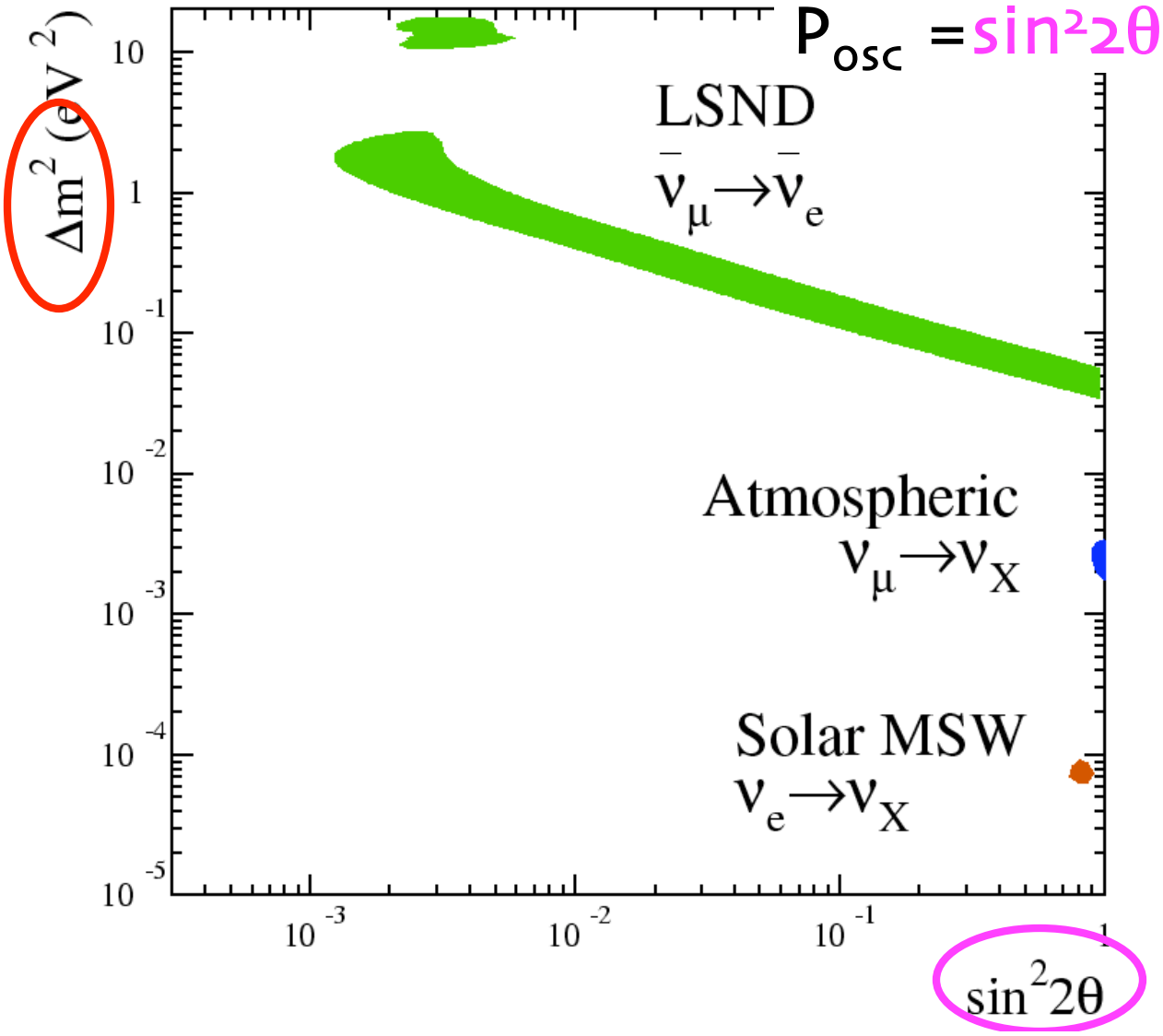
Event Signature





Current Oscillation Status

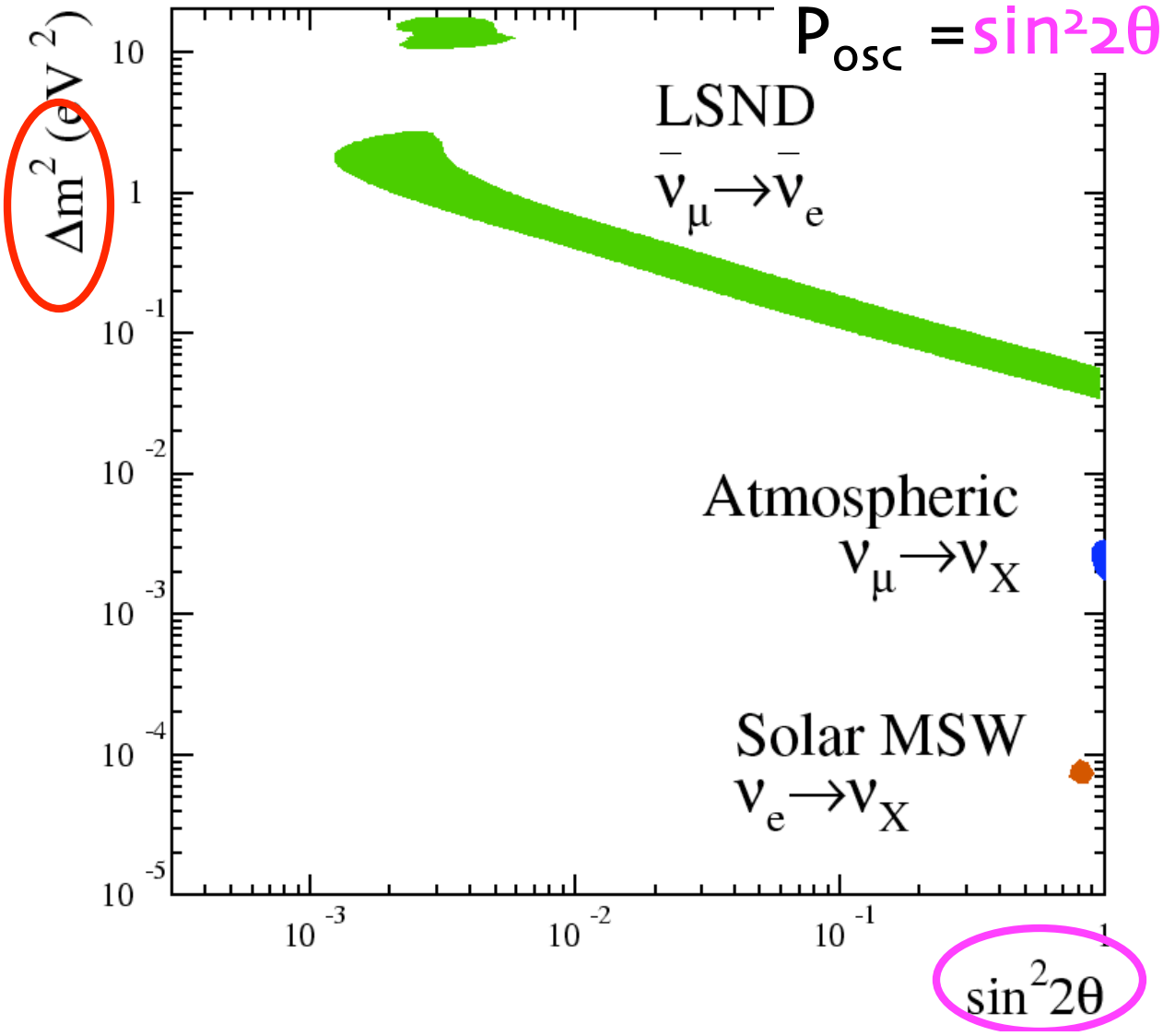
$$P_{osc} = \sin^2 2\theta \, \sin^2\left(\frac{1.27\,\Delta m^2 L}{E}\right)$$

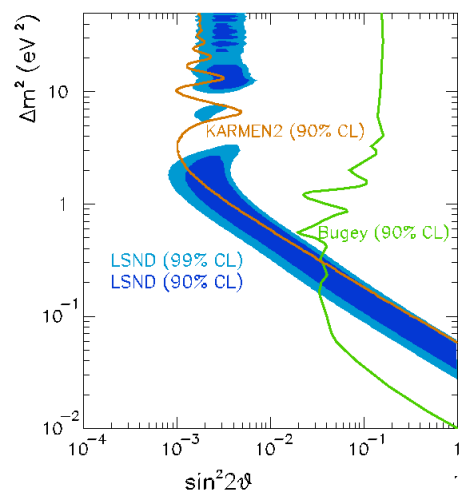


$$\Delta m^2_{ab} = m_a^2 - m_b^2$$

Current Oscillation Status

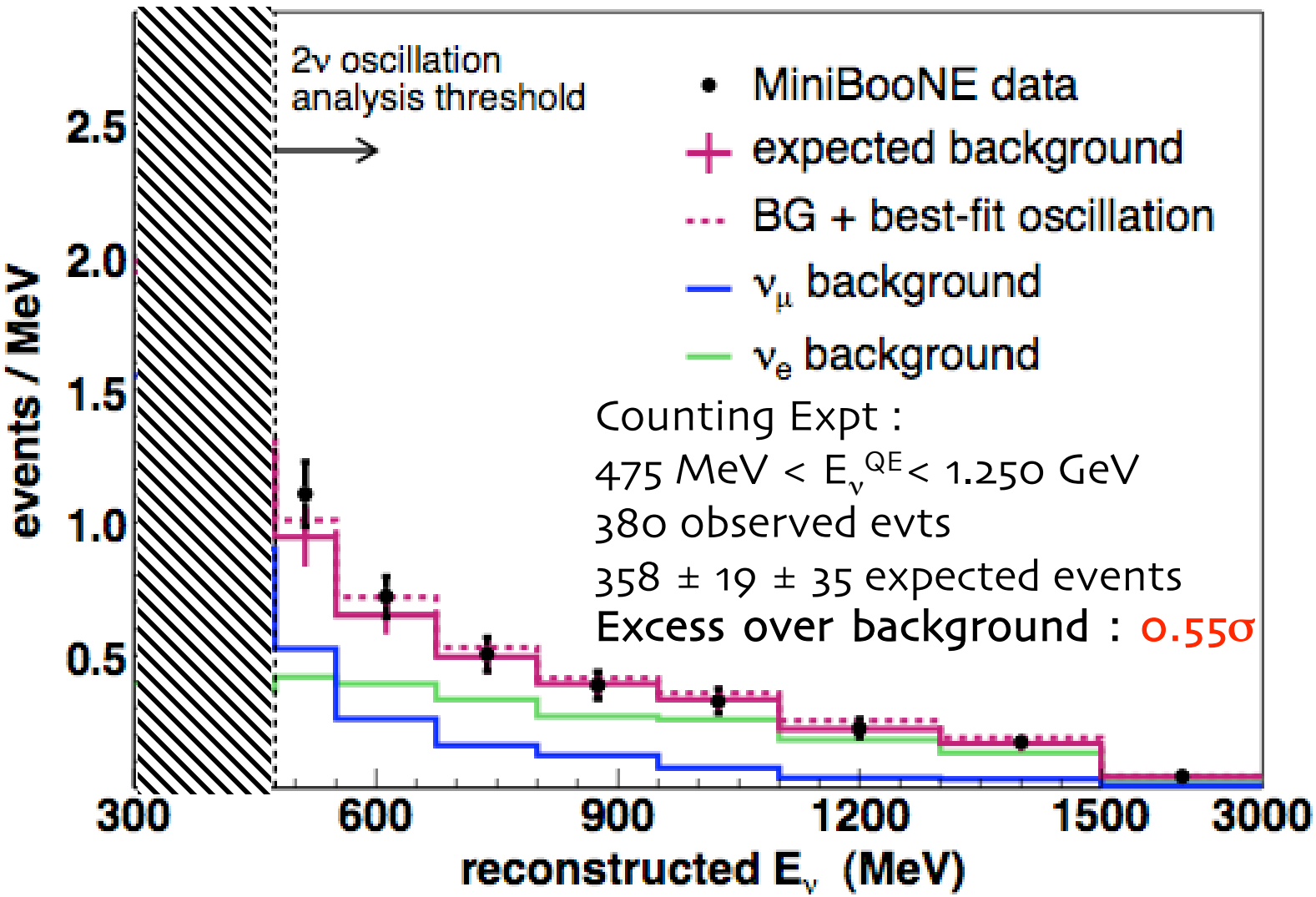
$$P_{osc} = \sin^2 2\theta \, \sin^2\left(\frac{1.27\,\Delta m^2 L}{E}\right)$$





$$\Delta m^2_{ab} = m_a^2 - m_b^2$$

Observed Event Distribution



Counting Expt :

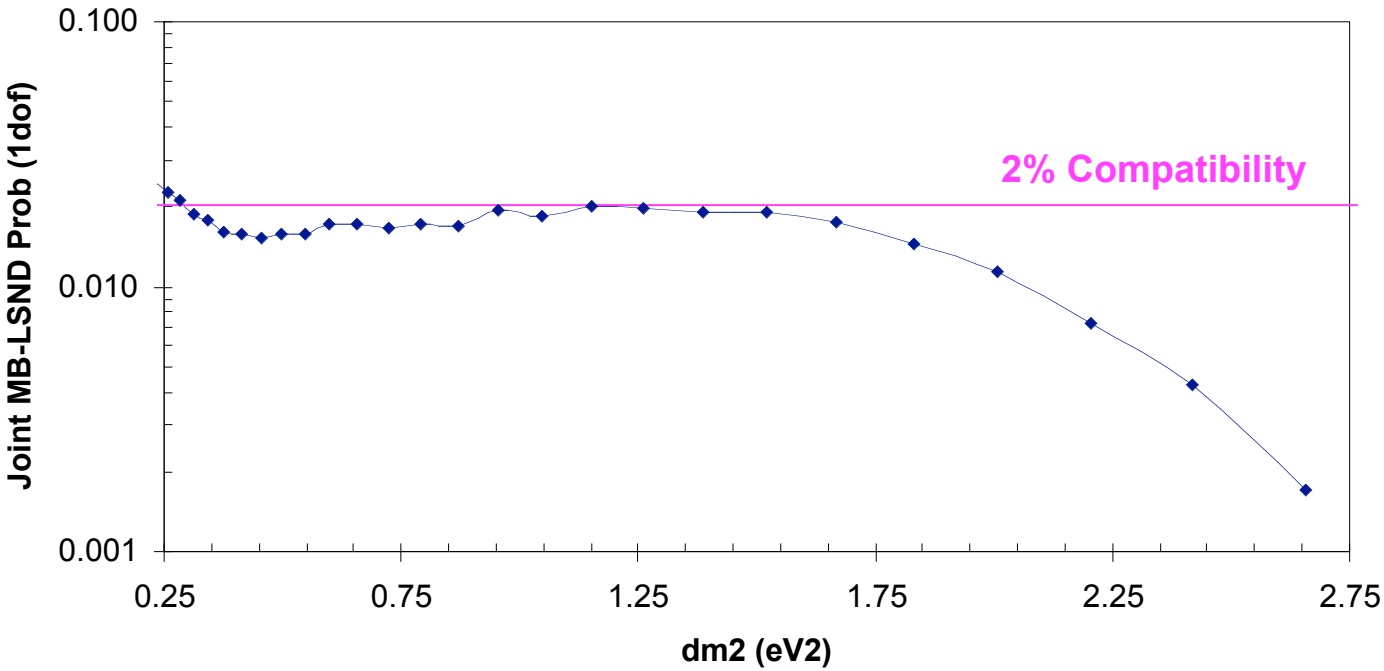
475 MeV < E_ν^{QE} < 1.250 GeV

380 observed evts

358 ± 19 ± 35 expected events

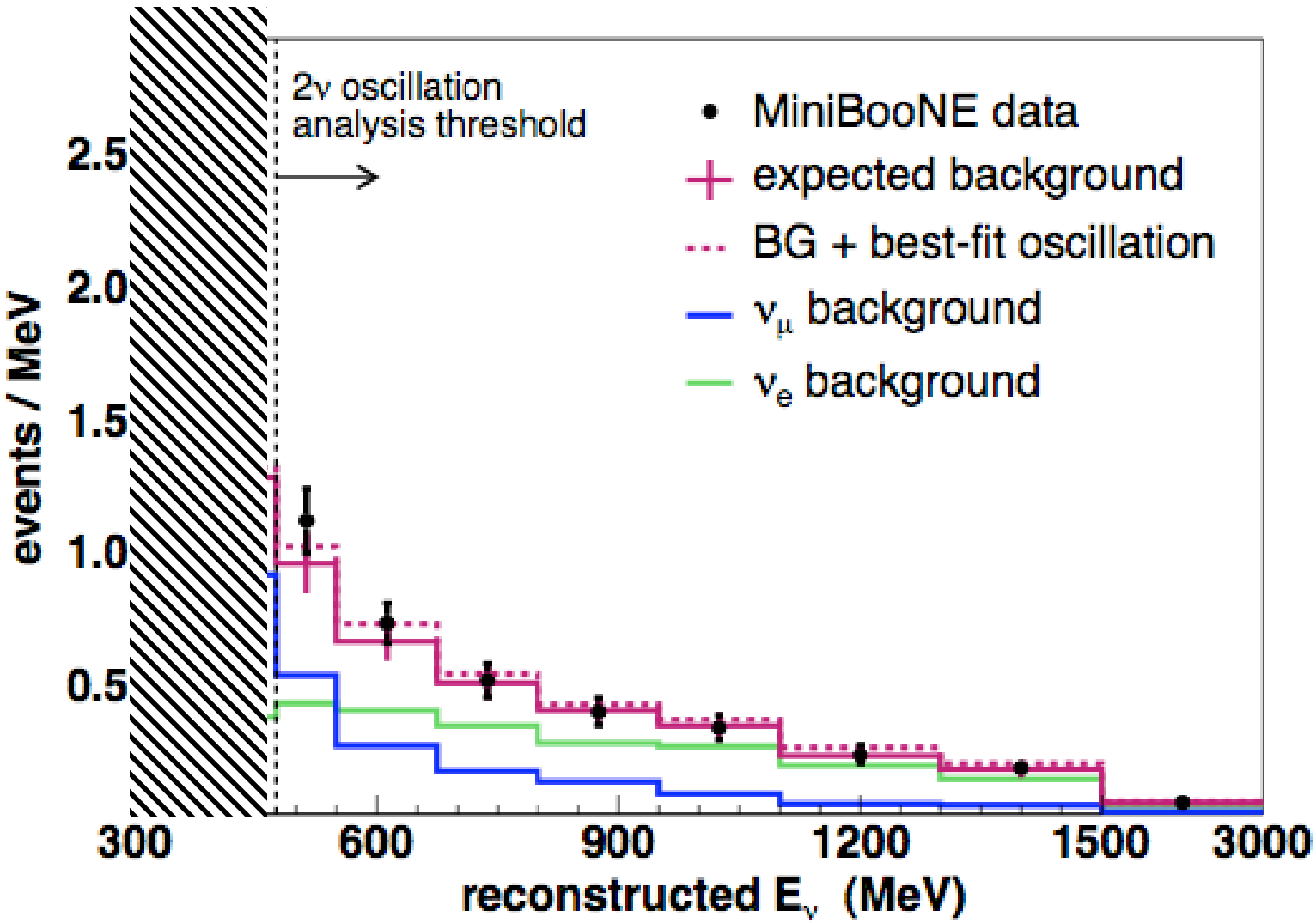
Excess over background : 0.55σ

MB-LSND Compatibility

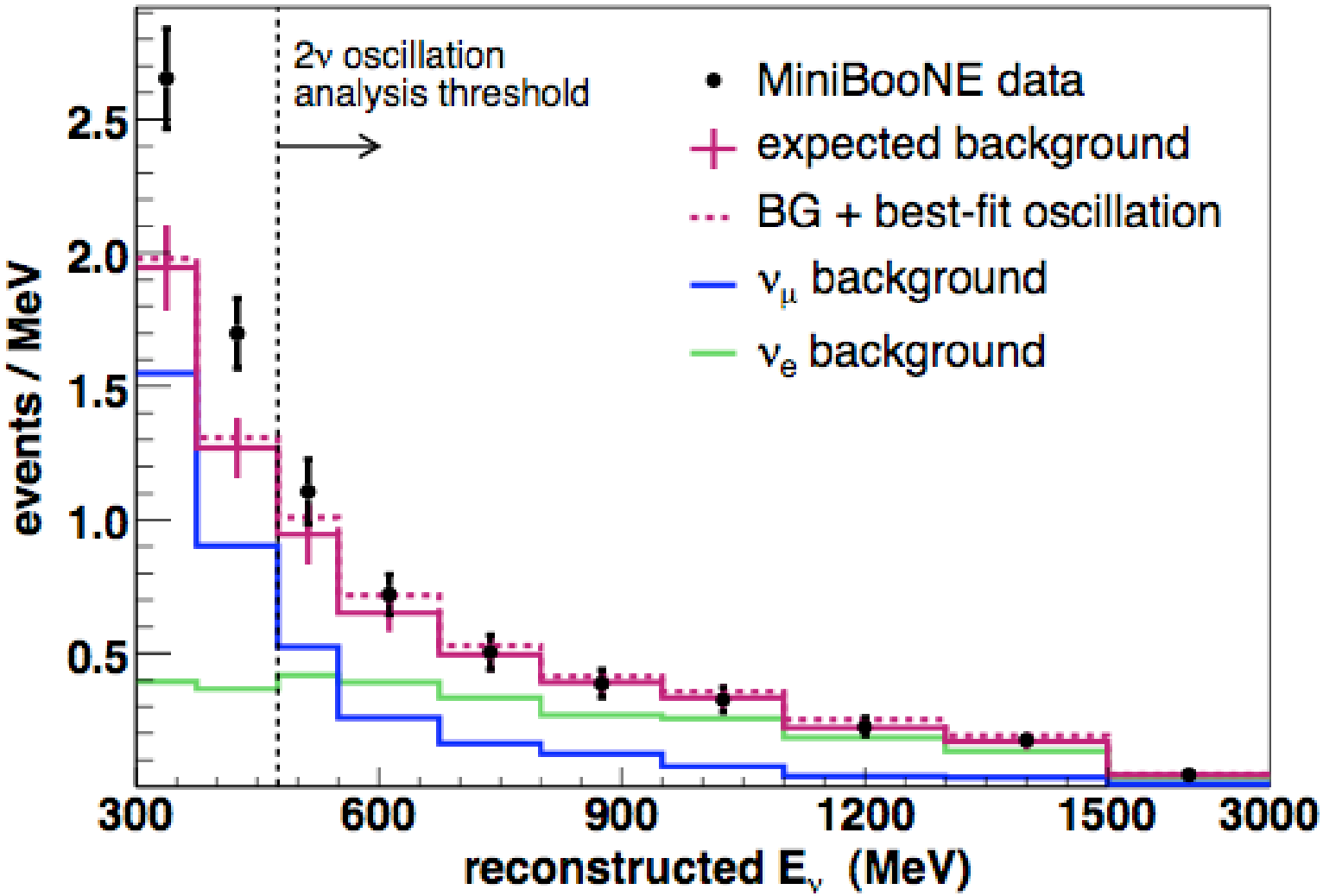


MiniBooNE is incompatible with a $\nu_\mu \rightarrow \nu_e$ appearance only interpretation of LSND at 98% CL

Observed Event Distribution

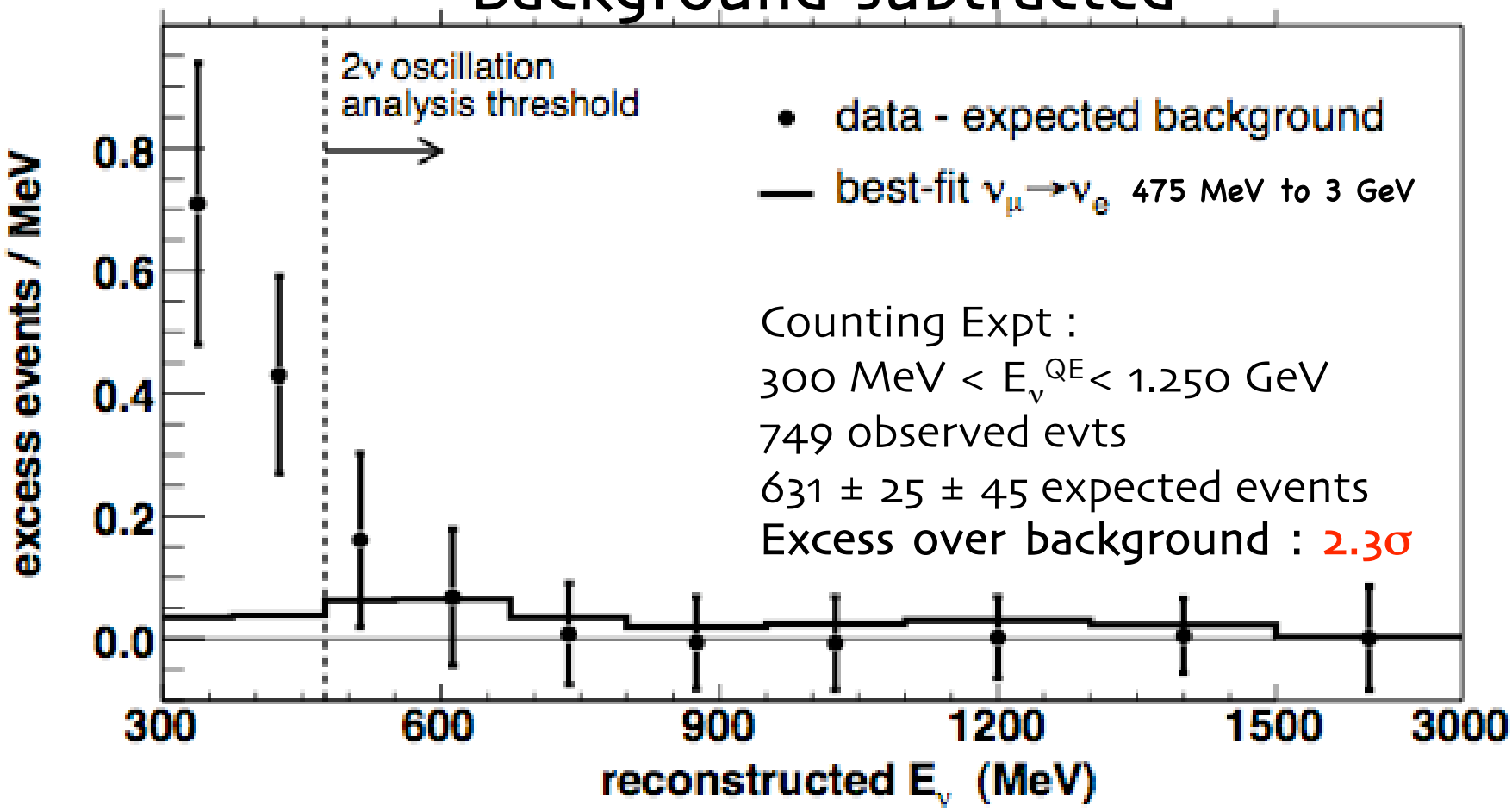


Observed Event Distribution



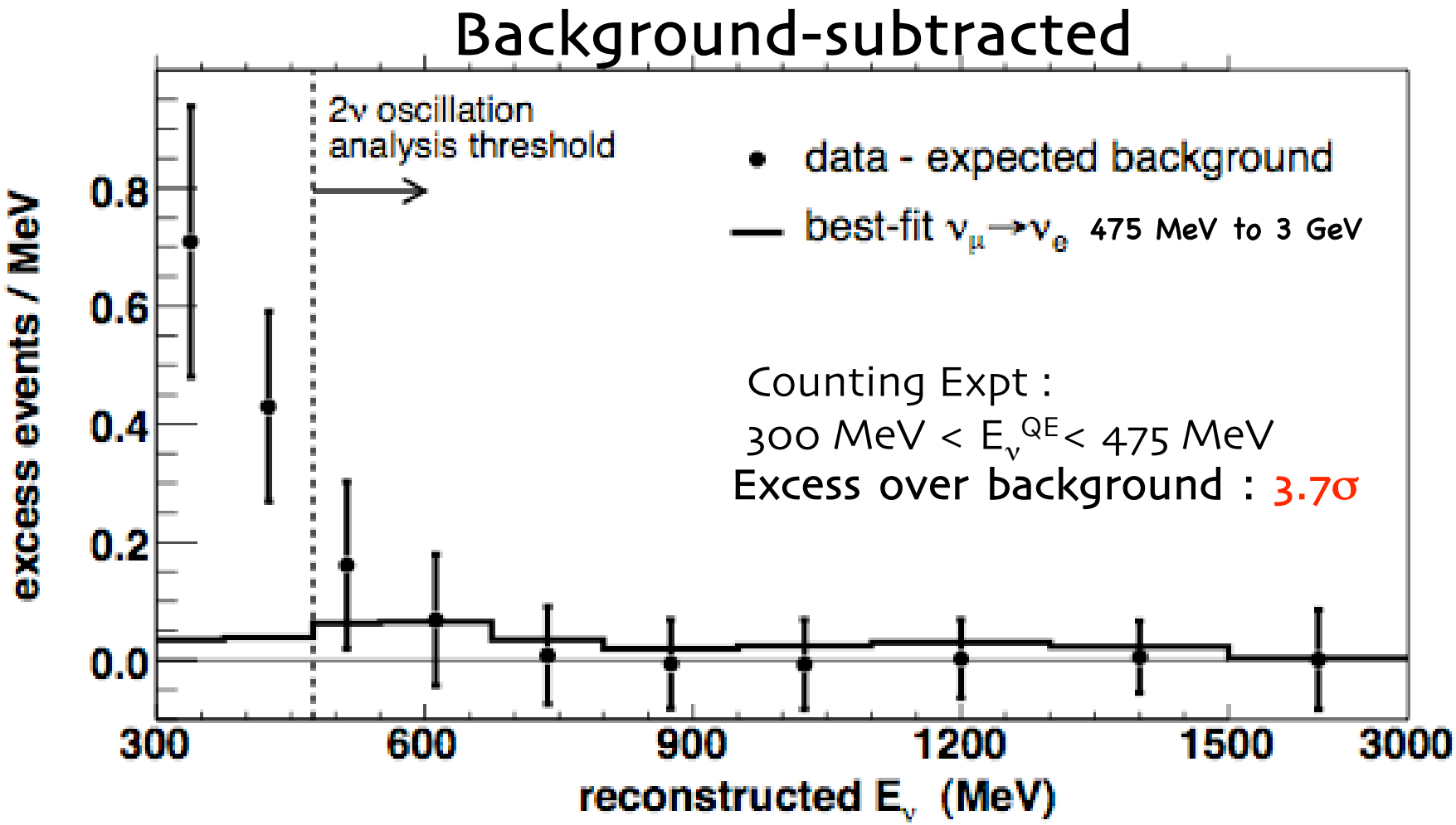
Observed Event Distribution

Background-subtracted



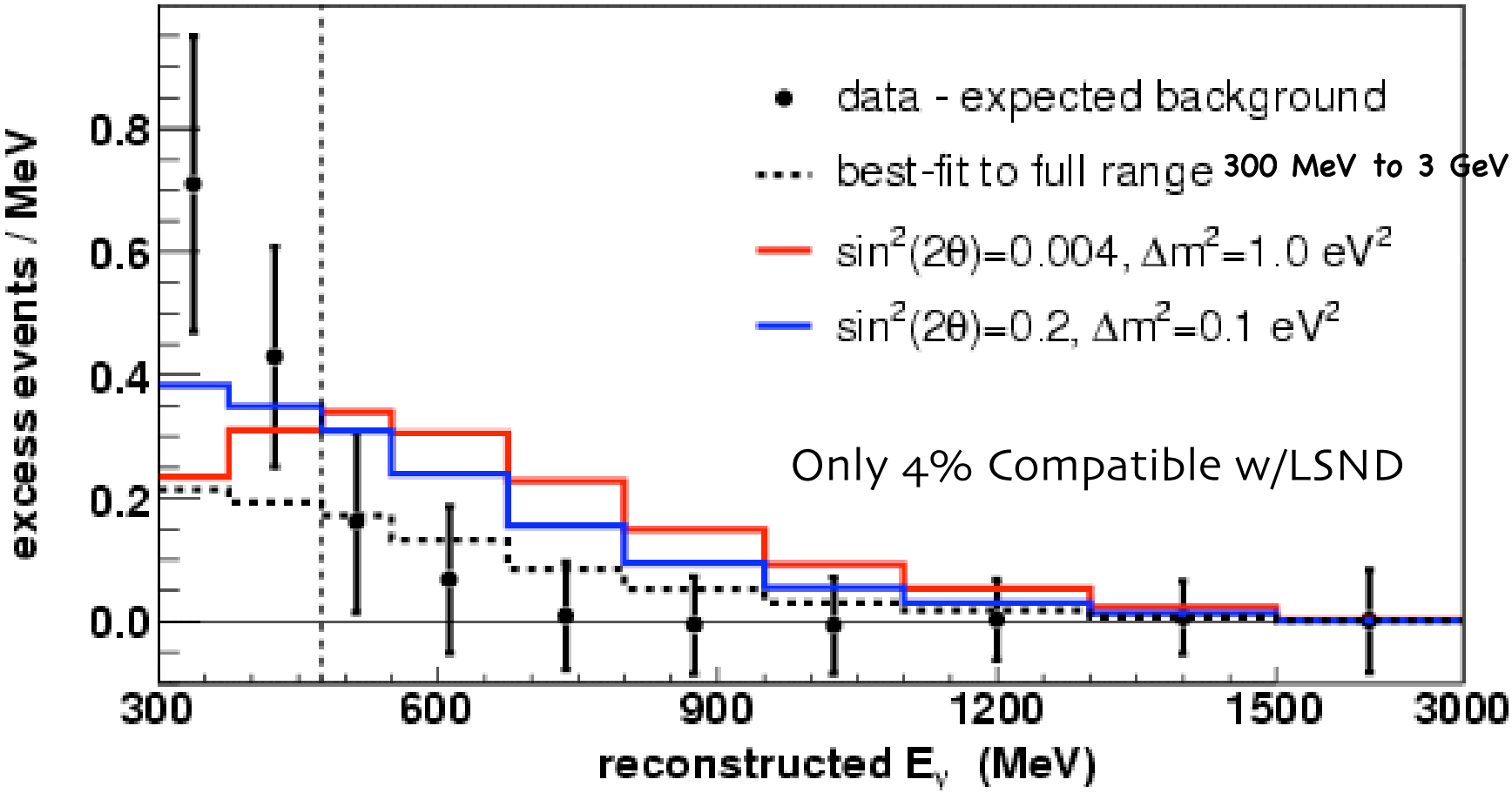
Counting Expt :
300 MeV < E_ν^{QE} < 1.250 GeV
749 observed evts
631 ± 25 ± 45 expected events
Excess over background : 2.3σ

Observed Event Distribution

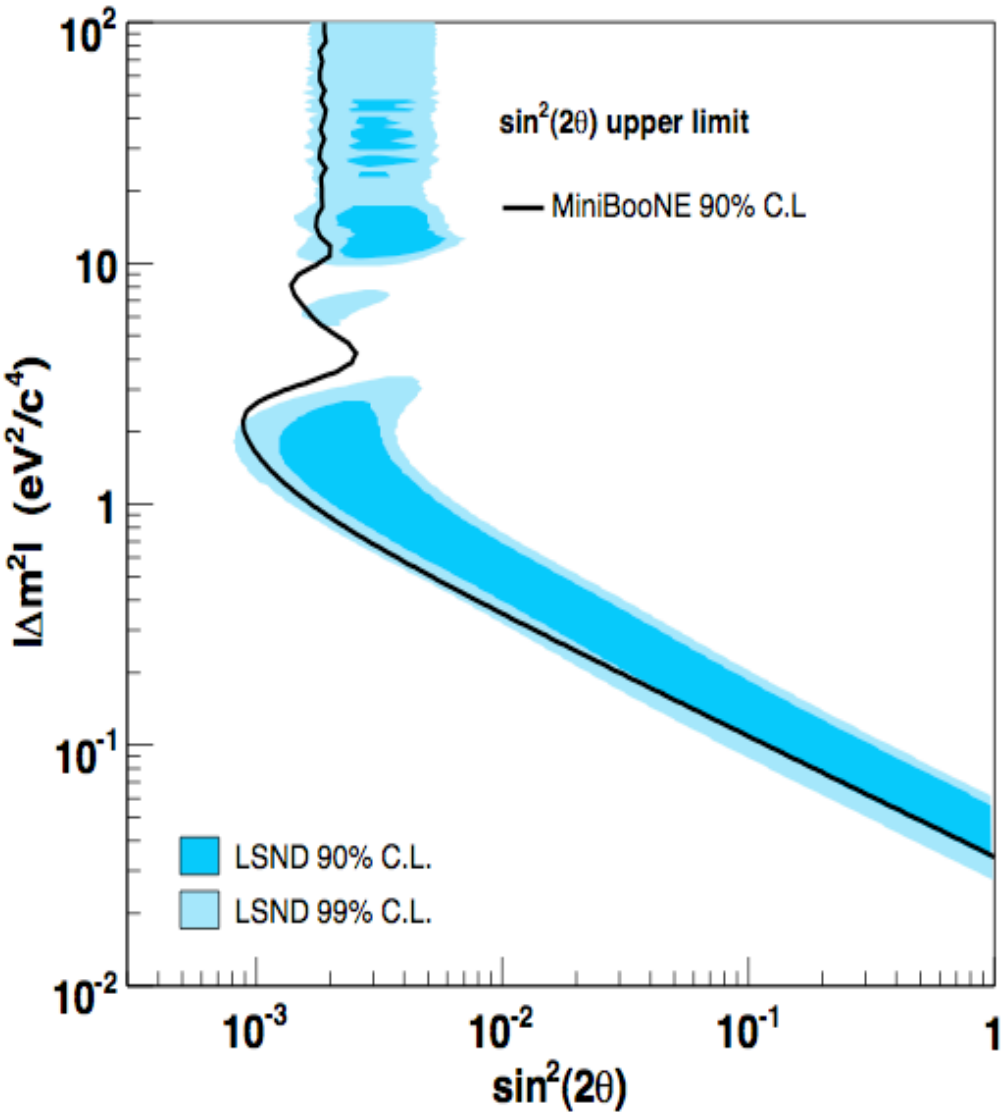


Observed Event Distribution

Background-subtracted



MiniBooNE Oscillation Results



- MiniBooNE does not observe an excess of events consistent with a CP conserving, 2-neutrino oscillation hypothesis
- Any conclusions drawn about the low E events will have no effect on the oscillation result

Phys. Rev. Lett 98, 231801 (2007)

MiniBooNE Cross Sections

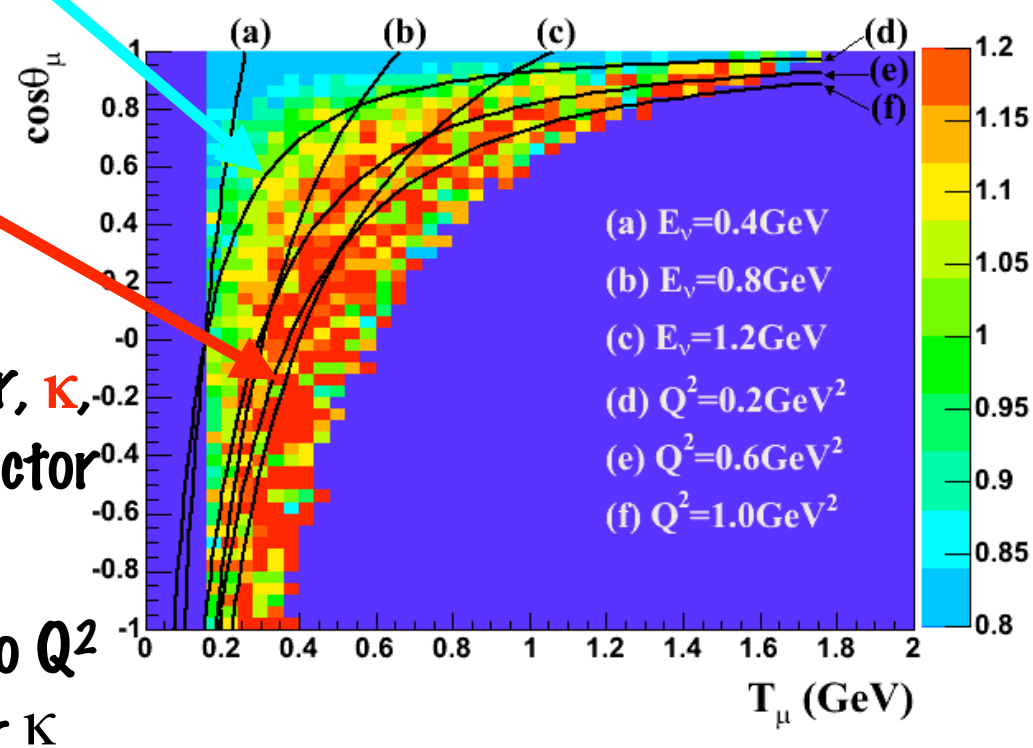
- On the way to the oscillation result several important measurements were performed
  - ⇒CCQE axial-mass measurement
  - ⇒NCE cross section
  - ⇒NCπ^0 coherent production rate

- Also have a growing anti-neutrino data set
  - ⇒CCQE anti-neutrino analysis
  - ⇒NCπ^0 coherent production rate in anti-neutrinos

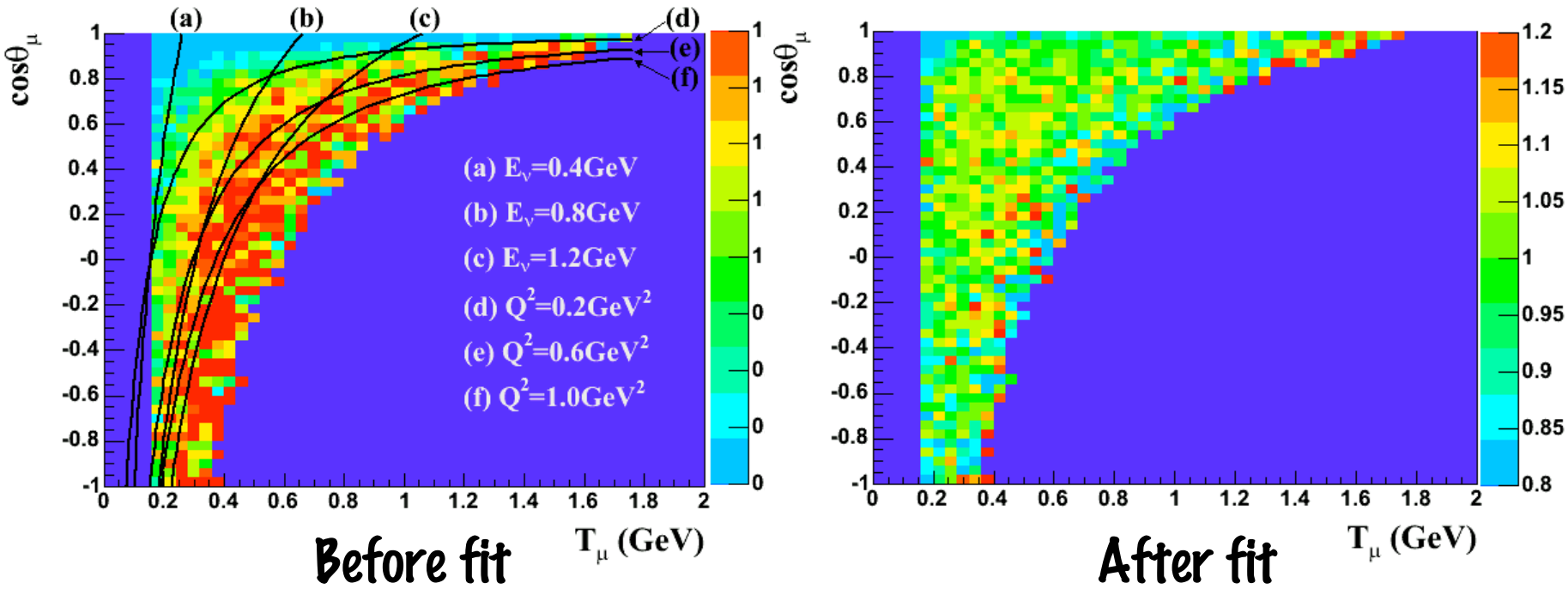
MiniBooNE CCQE Results

- Deficit in data at low Q^2
  - ⇒ Pauli blocking
- Excess in data at high Q^2
  - ⇒ Axial mass M_A
- Introduce a new parameter, κ, as a Pauli-blocking scale factor
- Perform simultaneous fit to Q^2 distribution, allowing M_A & κ to float

Data/MC Ratio



MiniBooNE CCQE Results



- M_A= 1.23 ± 0.20 (stat + syst)
- κ = 1.019 ± 0.011 (stat + syst)
- Fitting for Q^2 shores up agreement across the board in all variables

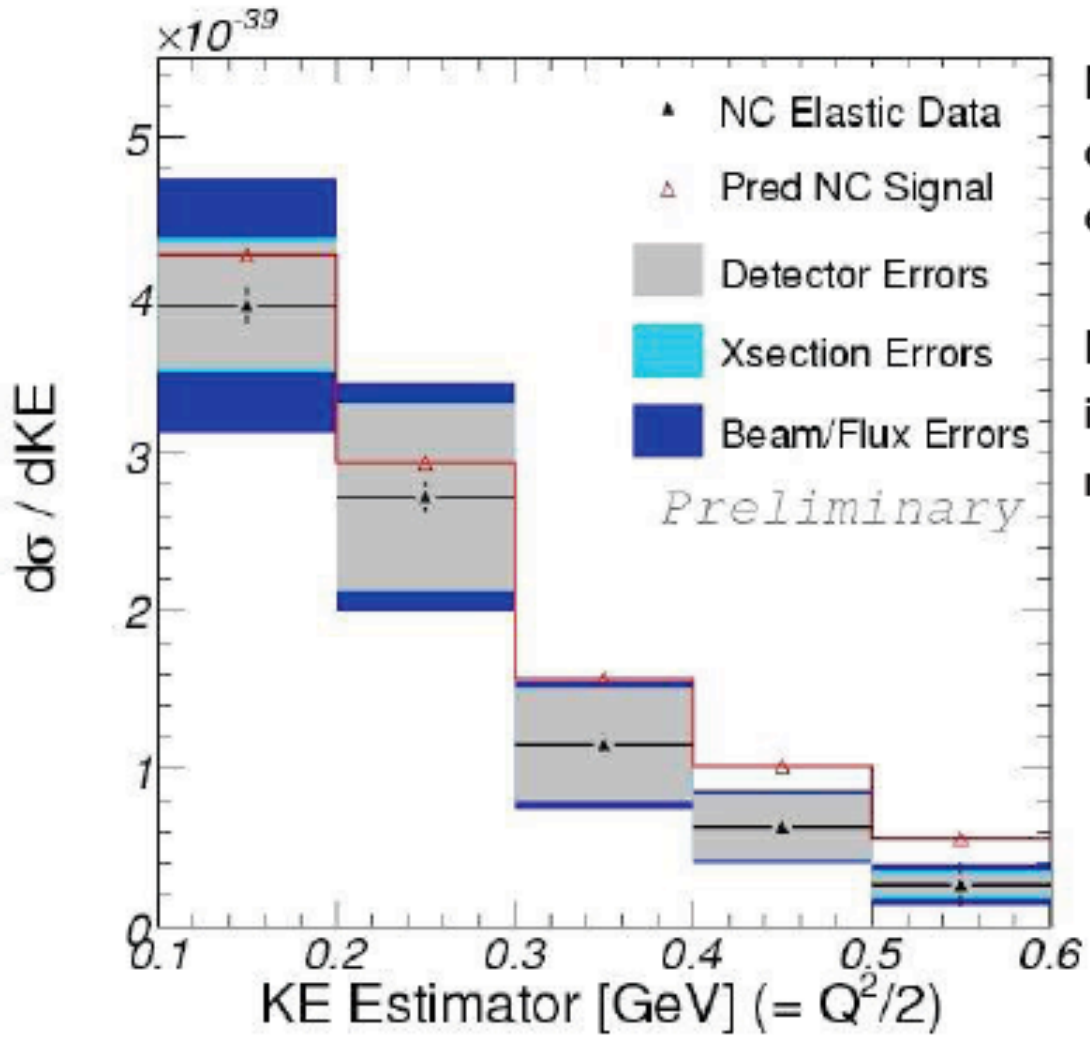
hep-ex/0706.0926

MiniBooNE NCE Results

- Use neutral current elastic scattering events to probe the isoscalar structure of the nucleon
- This analysis is complementary to the electron-nucleon DIS measurements

MiniBooNE NCE Results

NC Elastic Differential Cross Section in MiniBooNE

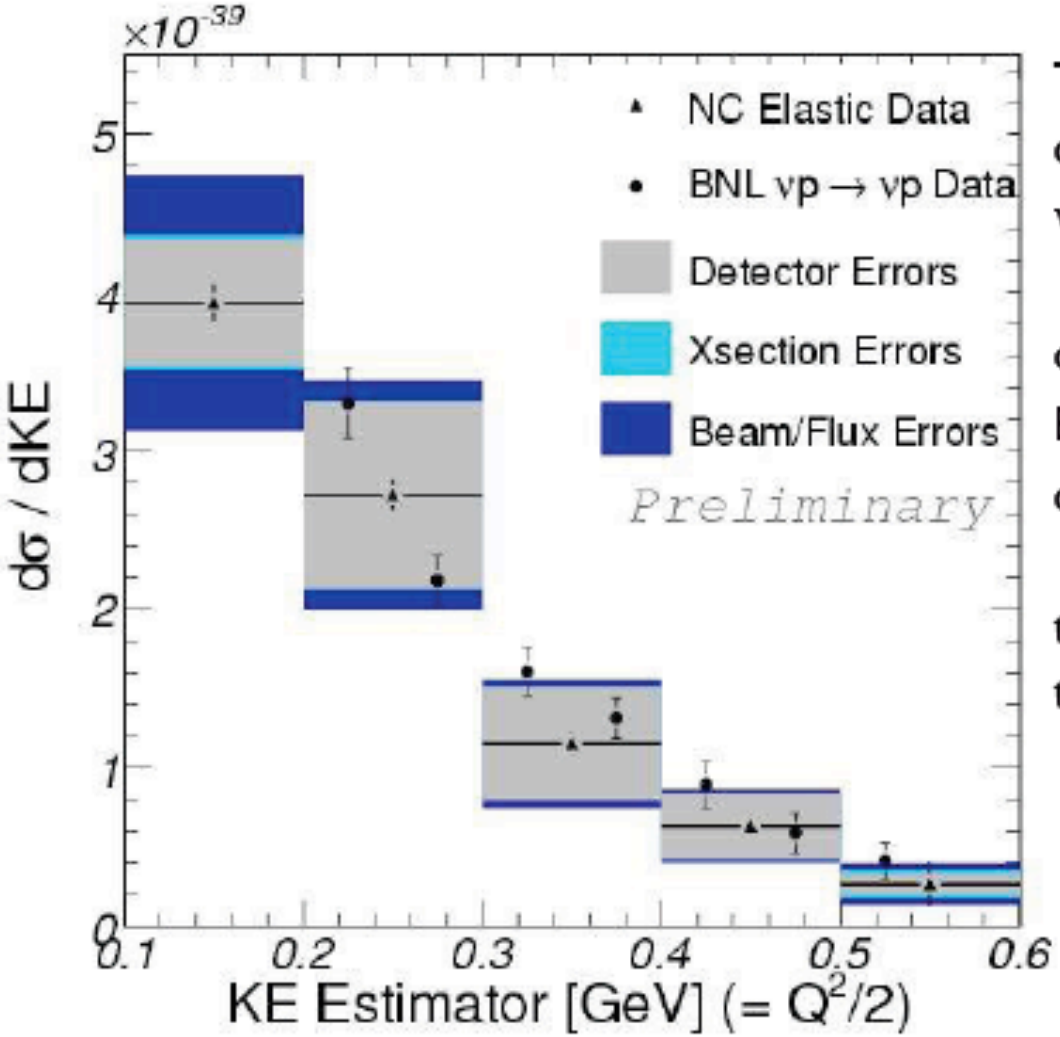


MiniBooNE NC elastic data with systematic errors.

Monte Carlo prediction is absolutely (POT) normalized to the data.

MiniBooNE NCE Results

NC Elastic Differential Cross Section in MiniBooNE & BNL 734



The same MiniBooNE cross section $\nu N \rightarrow \nu N$

overlaid by the BNL 734 $\nu p \rightarrow \nu p$ cross section

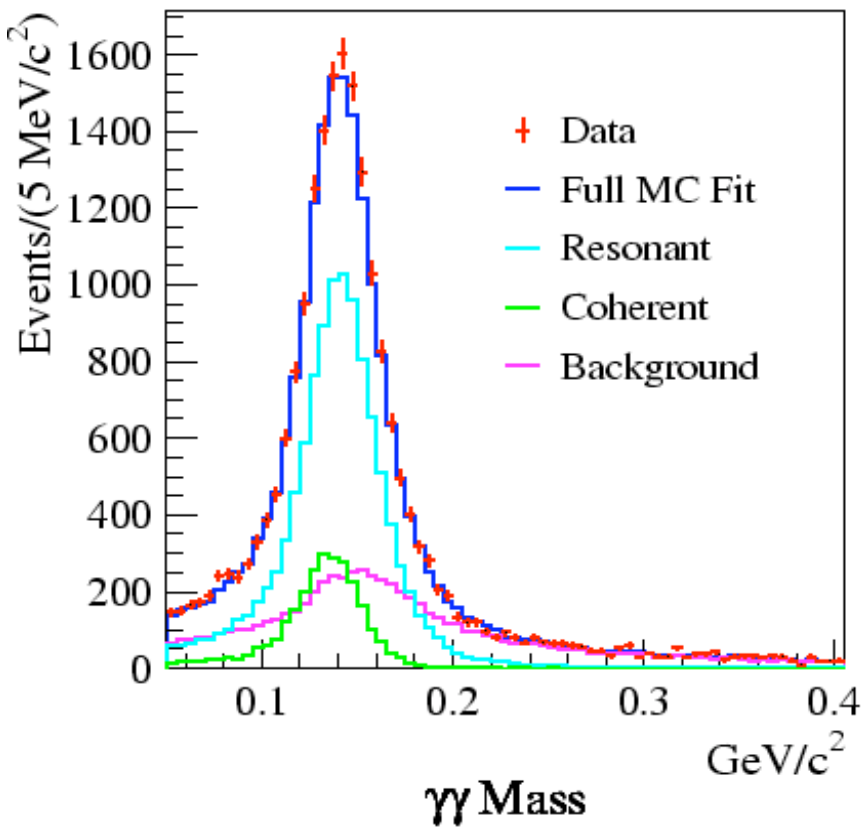
transformed from Q^2 to KE:

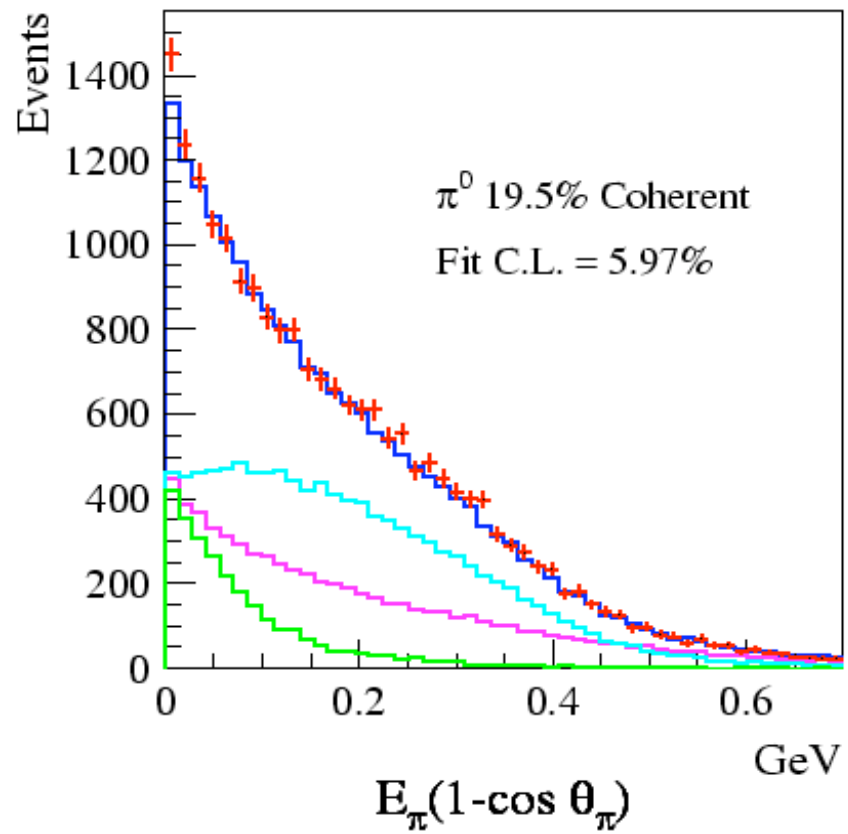
$(KE = Q^2 / 2m_p)$

MiniBooNE NCπ^0 Results

- Focused on oscillation result
- Need to know total π^0 production in bins of true π^0 momentum
- Need to know coherent contribution to π^0 production
- Use observed π^0 production to fix the Monte Carlo & provide a better estimate of π^0 mis-id
  - $\Rightarrow$Dominant background to oscillation analysis

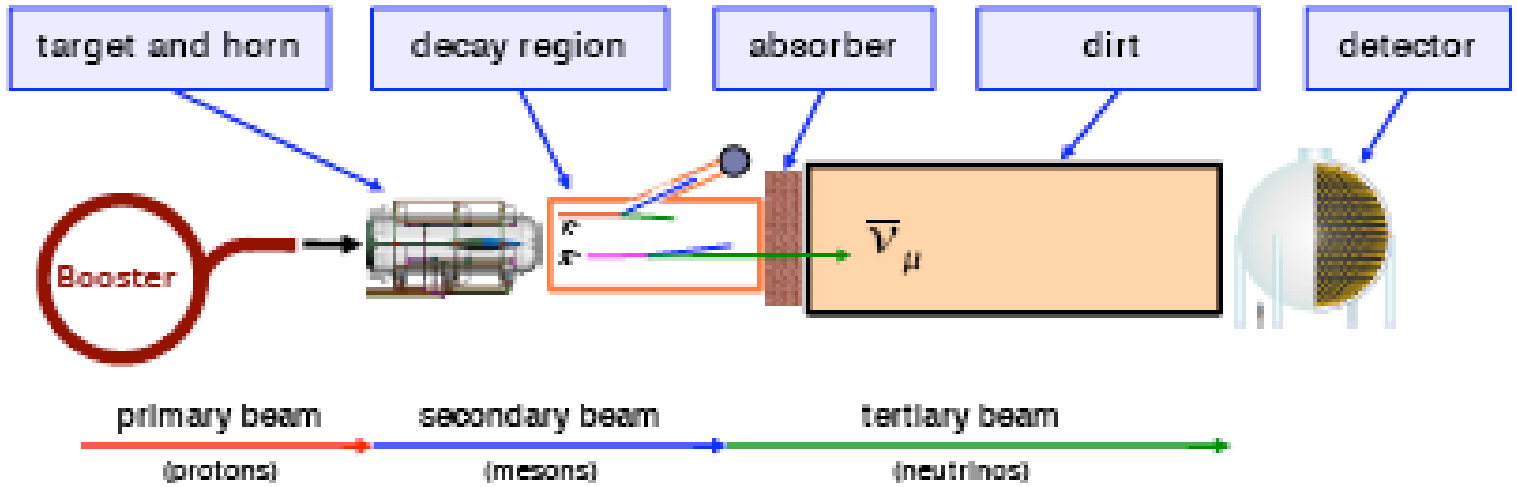
MiniBooNE NCπ^0 Results





➡ MiniBooNE finds 19.5 ± 1.1% of all NCπ^0 production is coherent

MiniBooNE Anti-Neutrino Beam

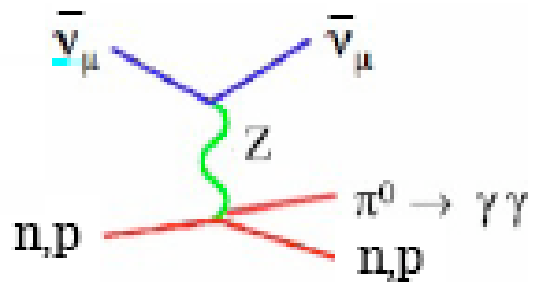


- 8 GeV beam of protons + Be target
- Magnetic focusing horn dictates beam type (nu, anti-nu)
- Mesons decay into the neutrino beam seen by the detector

  $\Rightarrow K^- / \pi^- \rightarrow \mu^- + \bar{\nu}_\mu$
- MiniBooNE L/E = 0.5 km / 0.8 GeV

MiniBooNE NCπ^0 Anti-ν Results

- Only 1 published measurement of the absolute rate of NCπ^0 anti-ν production
  - $\Rightarrow$25% uncertainty @ 2 GeV

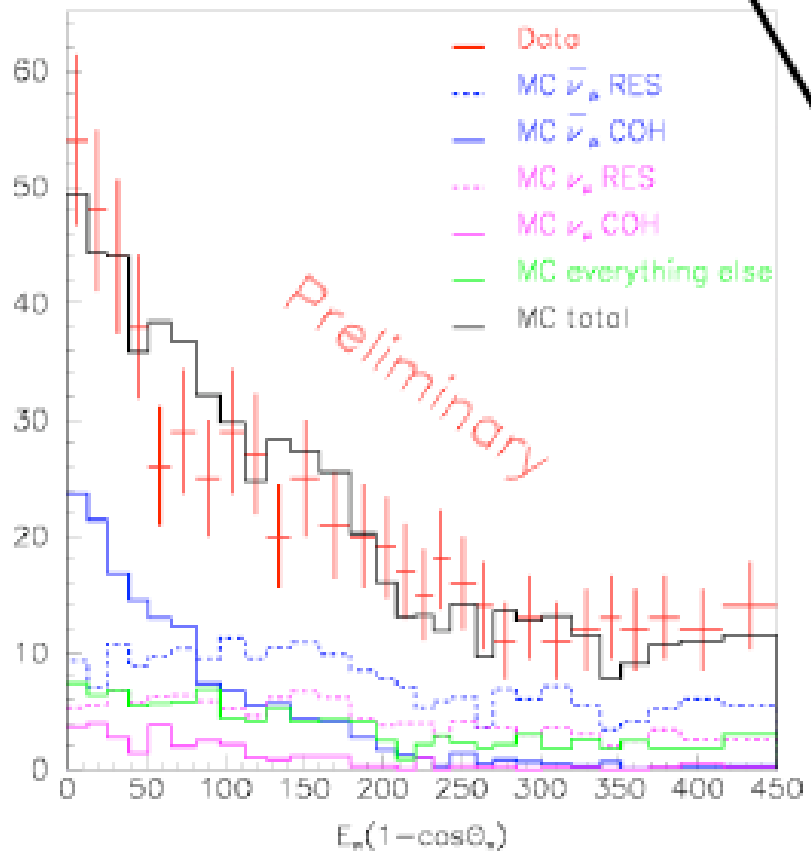


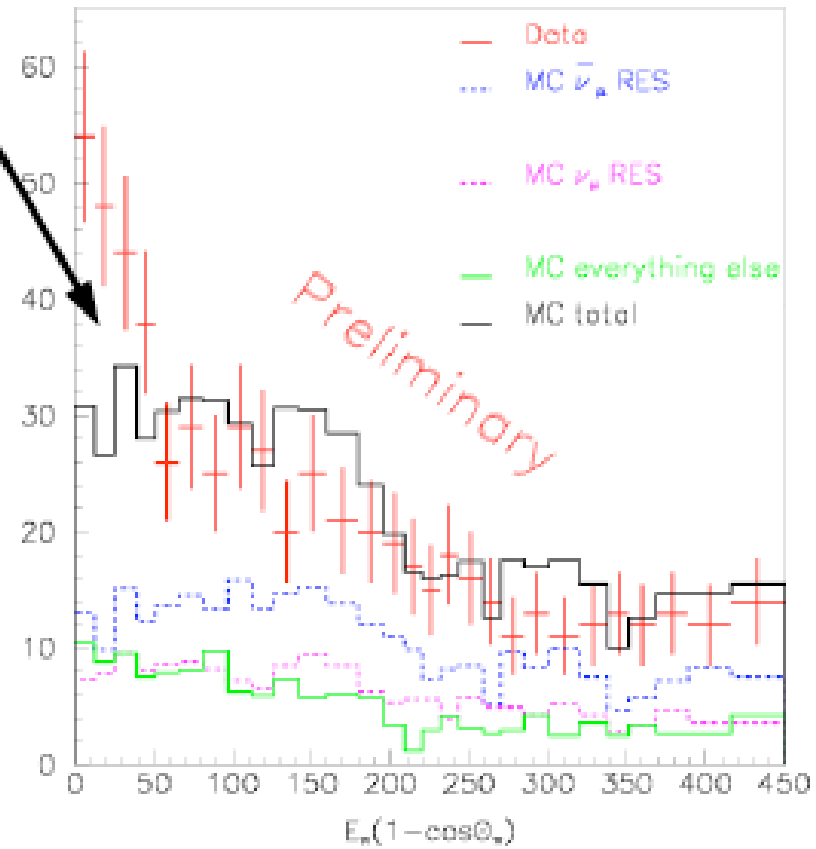
- Current theoretical models can vary by up to an order of magnitude in predictions of coherent production at low E

- Worlds largest π^0 anti-ν sample (~900 events)

MiniBooNE NCπ^0 Anti-ν Results

Suggestive of antineutrino
NC coherent π^0 production

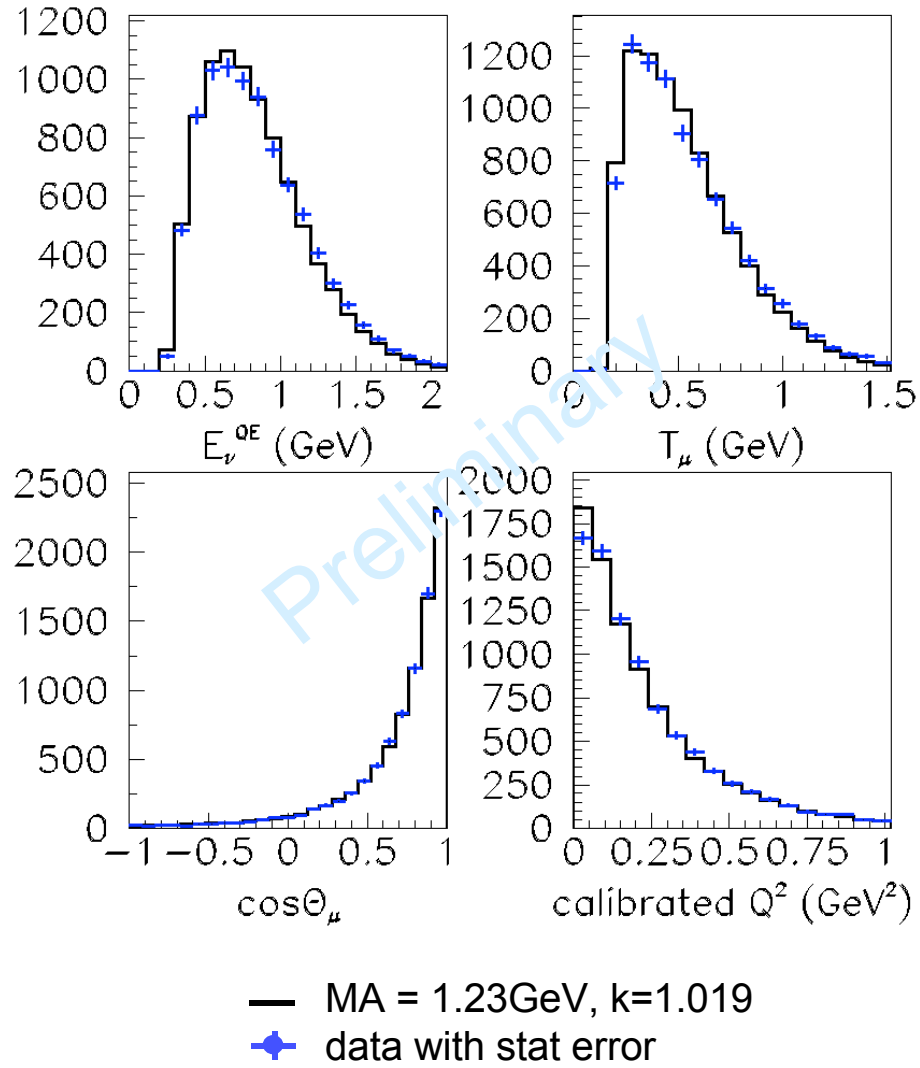




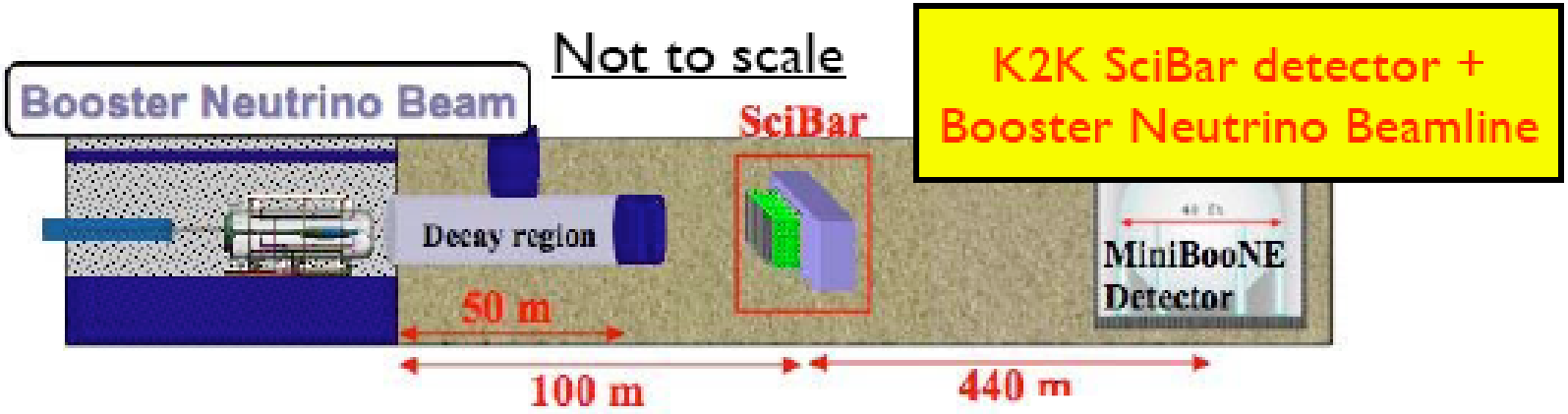
No COH contribution

MiniBooNE CCQE Anti-ν Results

- Use same event selection as neutrino CCQE analysis
  ⇒ ~9K events
- Use values of M_A, Pauli blocking scale factor found from fit to nu CCQE data
- Excellent data to MC agreement in anti-ν mode

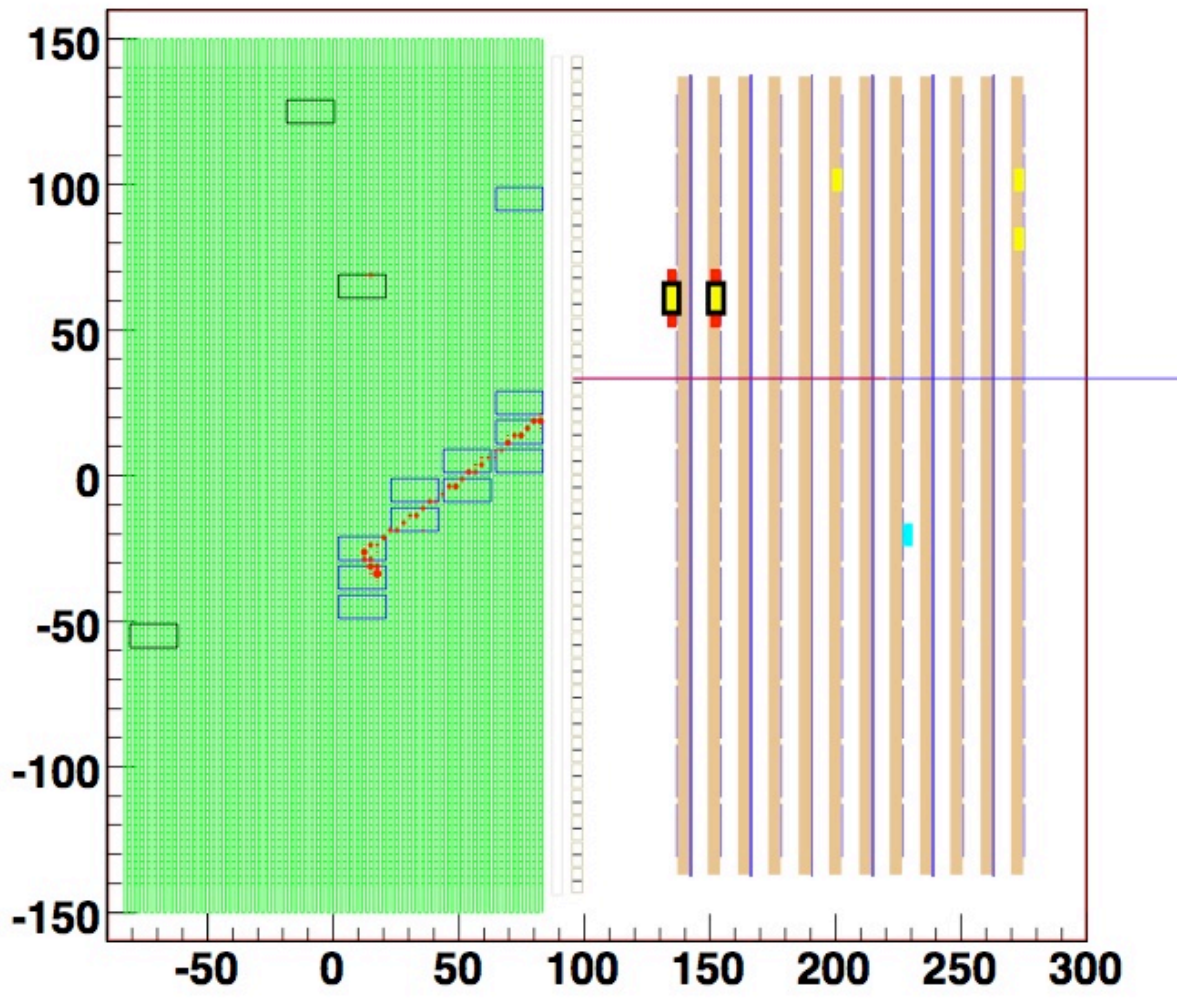


SciBooNE



- Precise neutrino-nucleus cross section measurements for T2K
- Anti-neutrino cross section measurements
- June 8th = Started commissioning with full detector!

SciBooNE First Events!



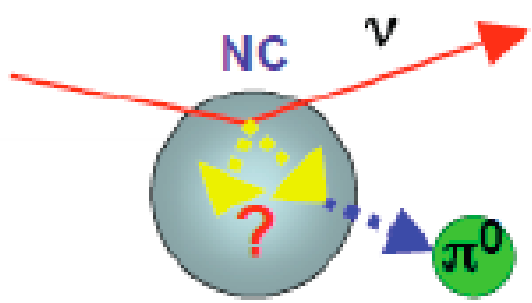
Final Remarks

- It's been an exciting year for short-baseline neutrino experiments!
- K2K cross sections
- MiniBooNE oscillation result
- MiniBooNE cross sections (some worlds first!)
- Minos on track to several firsts as well
- SciBooNE is up and running

Random Backup Slides

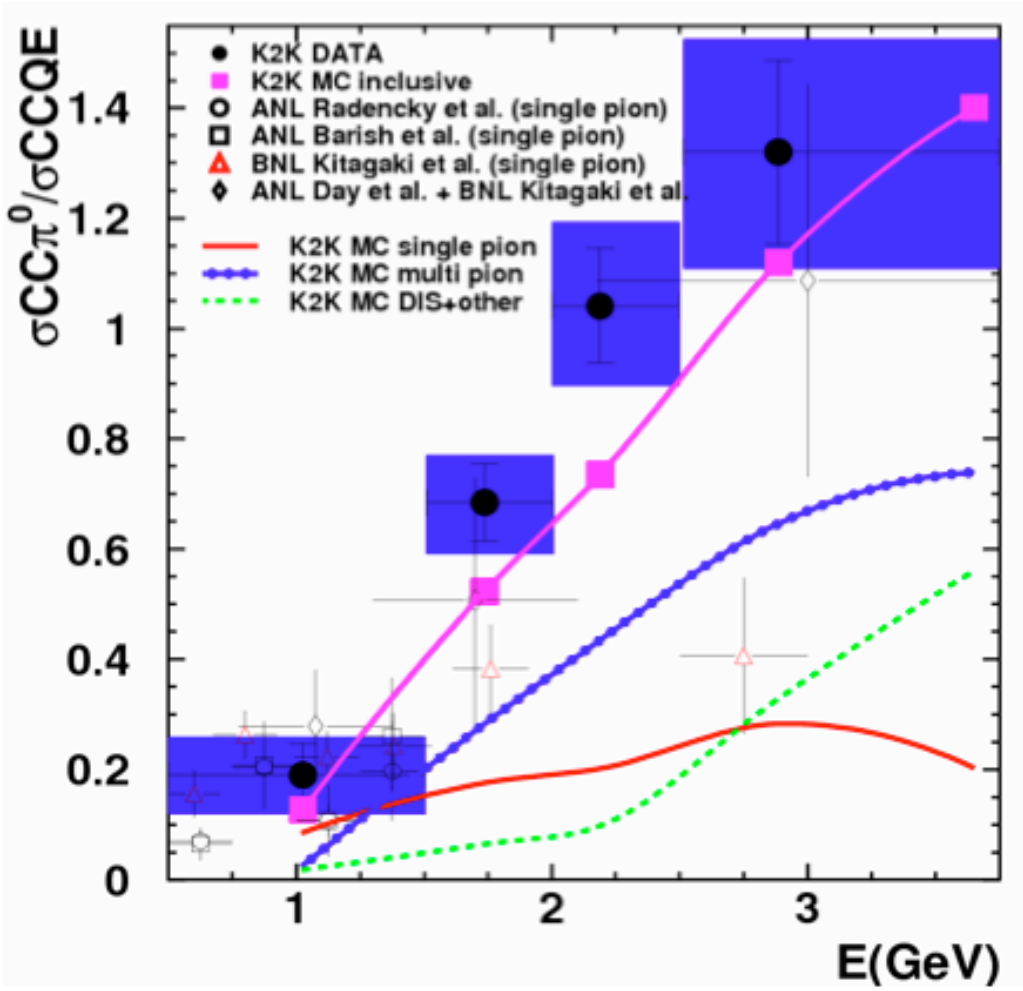
K2K Neutral Pion Results

- NC π^0 relative cross section published 2005
- High stat measurement, in good agreement with MC prediction

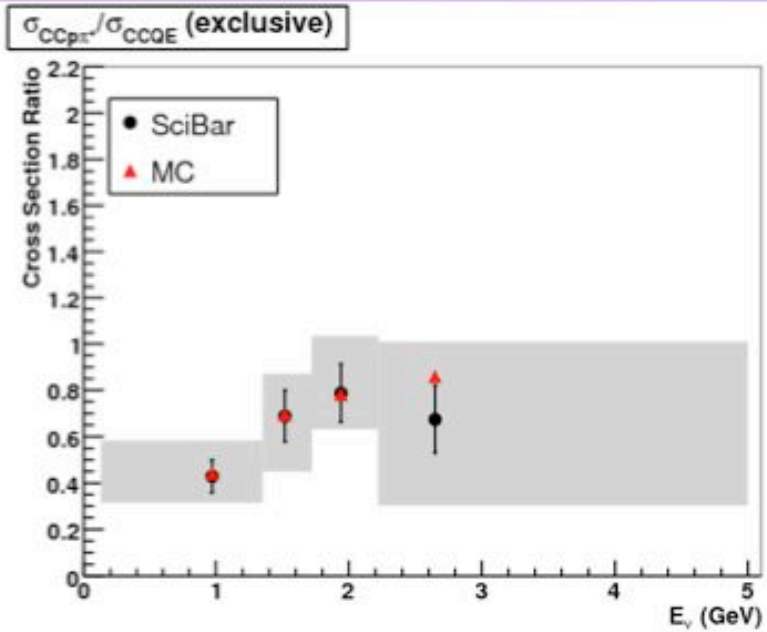


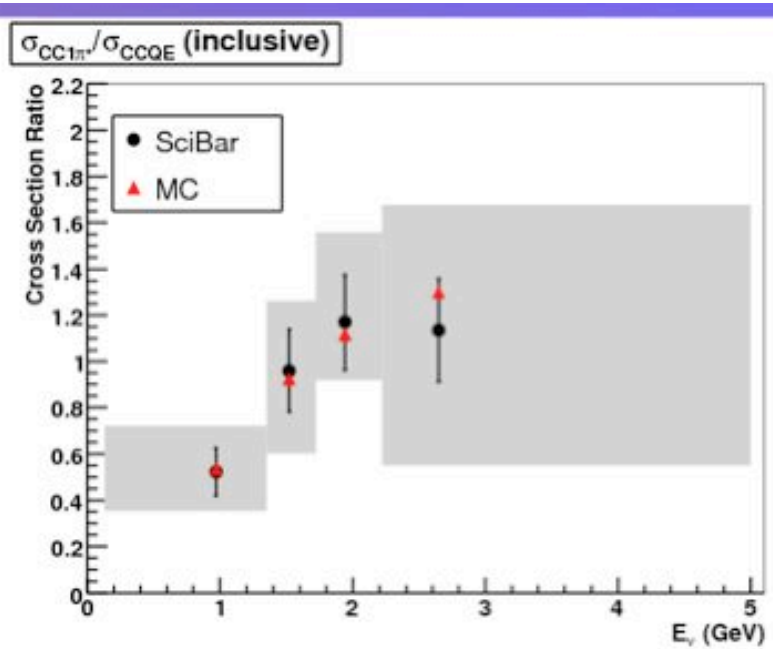
$$\frac{\sigma\, \mathrm{NC1}\, \pi^0}{\sigma\, \nu_\mu \mathrm{CC}} = 0.063 \pm 0.001\ (\mathrm{stat}) \pm 0.006\ (\mathrm{syst})$$

K2K Neutral Pion Results



K2K CC Single Pion Results

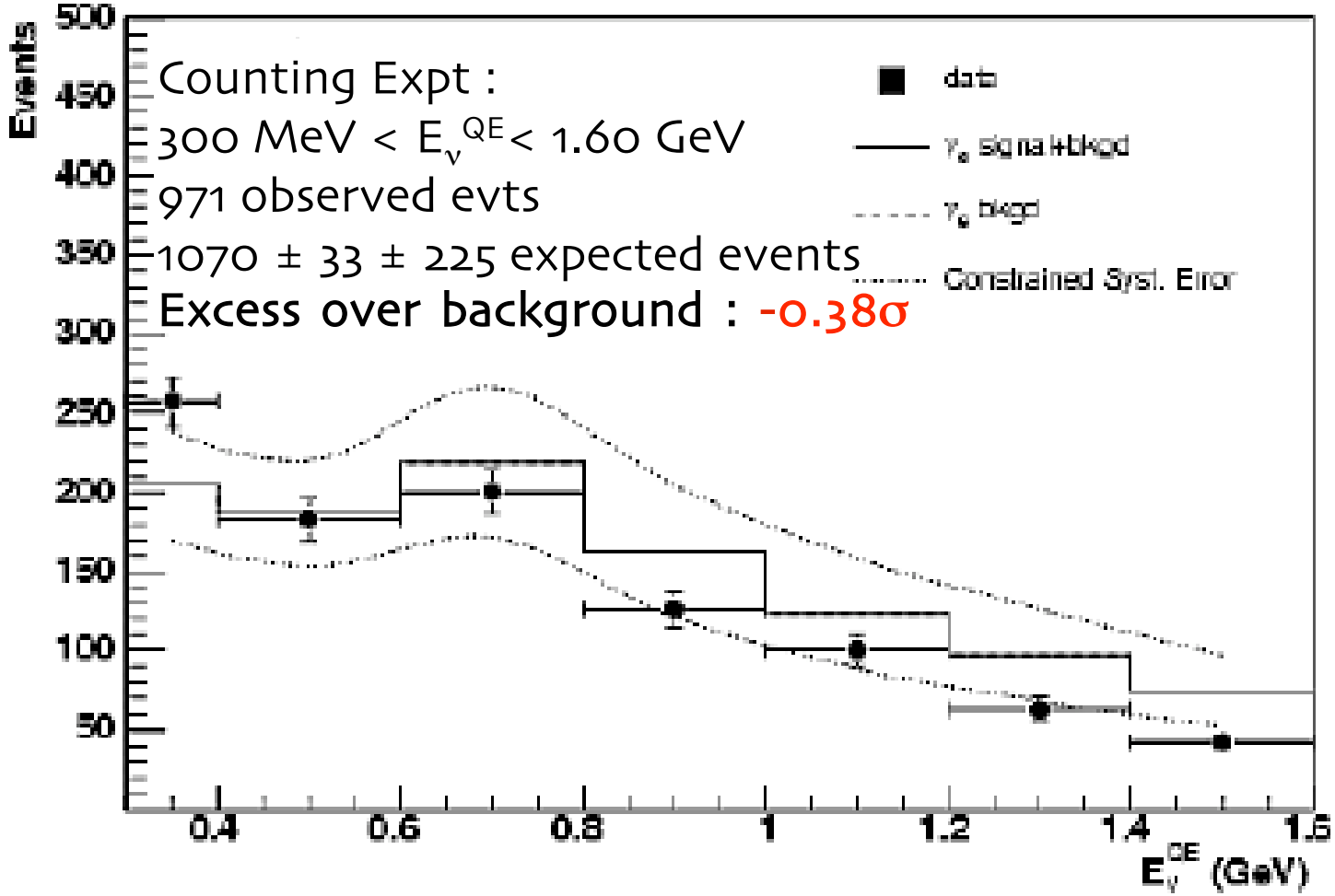




Energy Range (GeV)	Cross Section Ratio $R_e = \frac{\sigma_e^{CCp\pi^+}}{\sigma_e^{CCQE}}$
>0.00	$0.614 \pm 0.061(\text{stat.})^{+0.084}_{-0.028}(\text{nucl.})^{+0.087}_{-0.077}(\text{syst.})$
0.00-1.35	$0.429 \pm 0.071(\text{stat.})^{+0.070}_{-0.052}(\text{nucl.})^{+0.119}_{-0.073}(\text{syst.})$
1.35-1.72	$0.689 \pm 0.112(\text{stat.})^{+0.116}_{-0.147}(\text{nucl.})^{+0.085}_{-0.151}(\text{syst.})$
1.72-2.22	$0.788 \pm 0.126(\text{stat.})^{+0.156}_{-0.005}(\text{nucl.})^{+0.141}_{-0.093}(\text{syst.})$
≥2.22	$0.674 \pm 0.146(\text{stat.})^{+0.097}_{-0.138}(\text{nucl.})^{+0.286}_{-0.311}(\text{syst.})$

Energy Range (GeV)	Cross Section Ratio $R_e = \frac{\sigma_e^{CC1\pi^+}}{\sigma_e^{CCQE}}$
>0.00	$0.850 \pm 0.080(\text{stat.})^{+0.127}_{-0.039}(\text{nucl.})^{+0.119}_{-0.109}(\text{syst.})$
0.00-1.35	$0.522 \pm 0.103(\text{stat.})^{+0.089}_{-0.088}(\text{nucl.})^{+0.146}_{-0.098}(\text{syst.})$
1.35-1.72	$0.960 \pm 0.179(\text{stat.})^{+0.205}_{-0.208}(\text{nucl.})^{+0.129}_{-0.227}(\text{syst.})$
1.72-2.22	$1.170 \pm 0.206(\text{stat.})^{+0.260}_{-0.029}(\text{nucl.})^{+0.203}_{-0.142}(\text{syst.})$
≥2.22	$1.135 \pm 0.225(\text{stat.})^{+0.193}_{-0.218}(\text{nucl.})^{+0.456}_{-0.494}(\text{syst.})$

Observed Event Distribution



Counting Expt :

300 MeV < E_ν^{QE} < 1.60 GeV

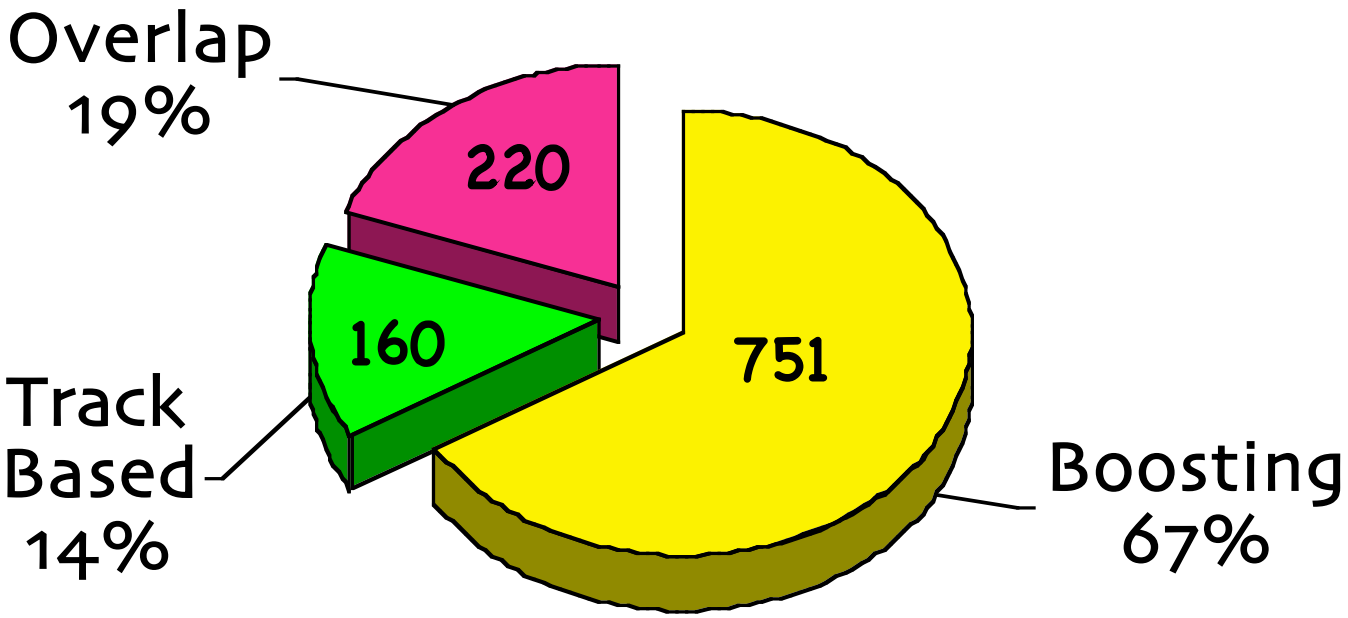
971 observed evts

1070 ± 33 ± 225 expected events

Excess over background : -0.38σ

Overlap of Events

Track Based : 475 MeV < E_ν^{QE} < 1.250 GeV
Boosting : 300 MeV < E_ν^{QE} < 1.60 GeV



MiniBooNE Cross Sections

- MiniBooNE has the world's largest neutrino data set in the few-GeV range
- MiniBooNE has the ability to make a huge impact in neutrino cross section measurements

Cross-Section Measurements

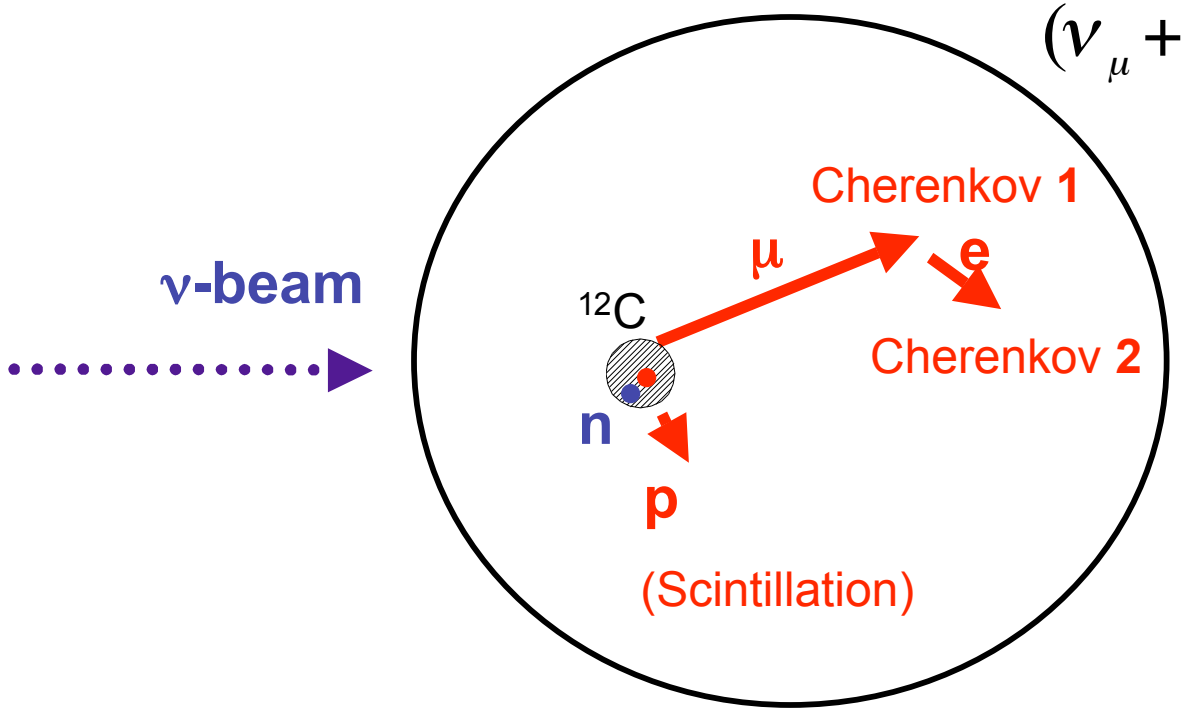
- Astrophysics
  - ⇒Low E relevant for supernovae, gamma bursts
  - ⇒Inelastic important for dynamics + nucelosynthesis
  - ⇒Coherent scattering could reveal info about neutron star structure
- Oscillation experiments
  - ⇒always measure flux*cross section
  - ⇒must be able to predict non-oscillated spectra and interpret distortions
  - ⇒entering a phase where the errors from xsec are ~= to stat errors from expts

CCQE events in MiniBooNE

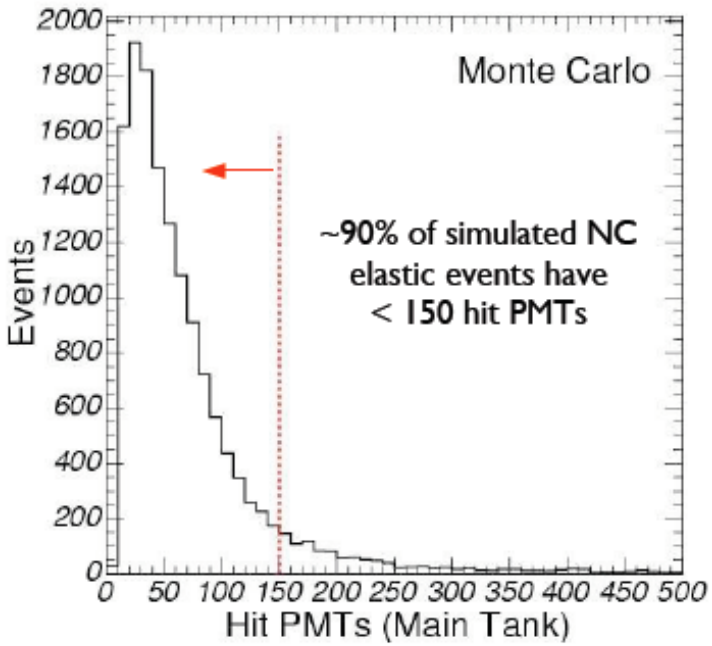
- ν_μ CCQE interactions are the most abundant and fundamental interactions in MiniBooNE
- ~40% of all neutrino interactions, 197K events with full neutrino data set

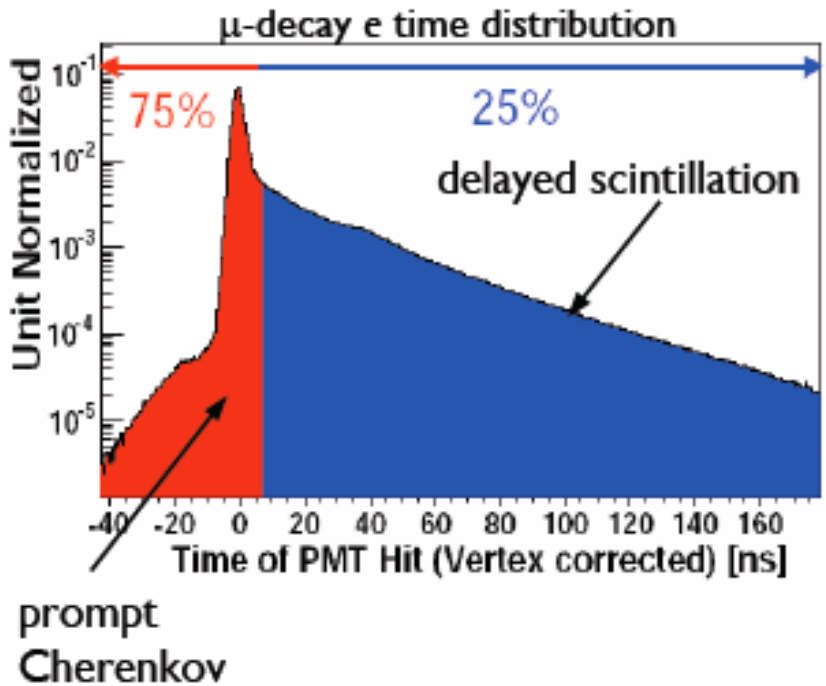
$$\nu_\mu + n \rightarrow p + \mu^-$$

$$(\nu_\mu + {}^{12}C \rightarrow X + \mu^-)$$



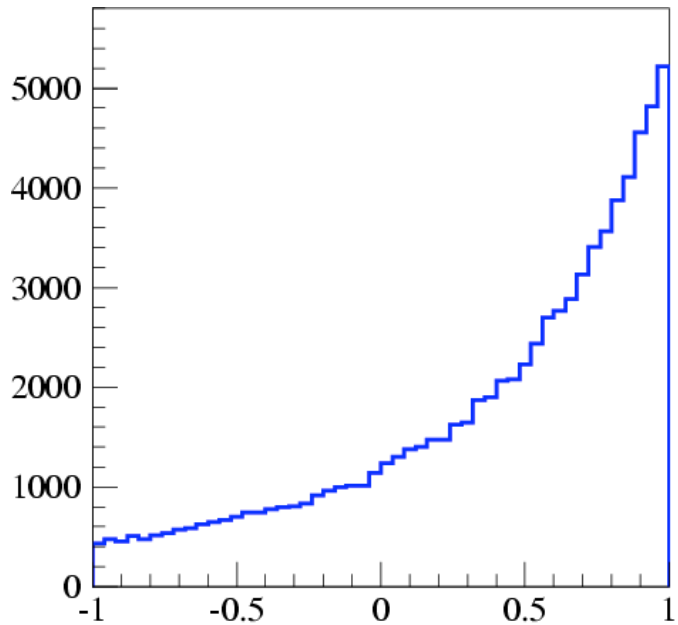
MiniBooNE NCE Results



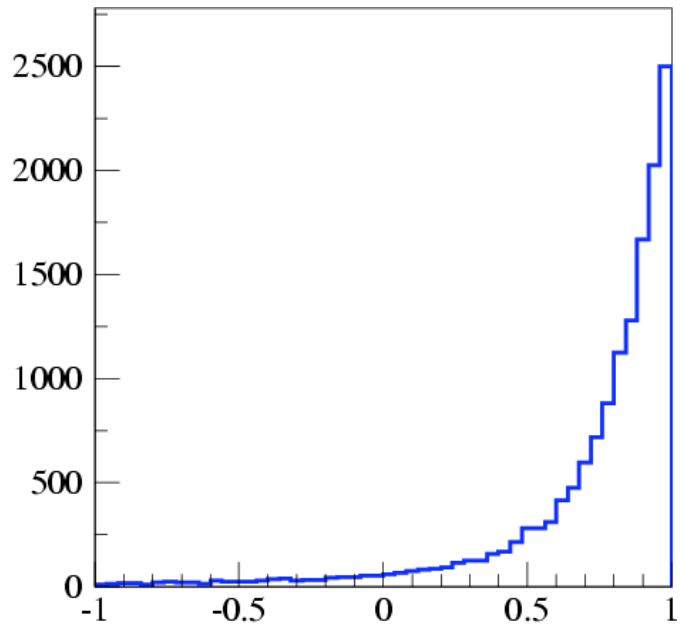


- NCE events are low energy, dominated by scintillation light
- Use ratio of prompt to delayed light to isolate NCE events

MiniBooNE NCπ^0 Results



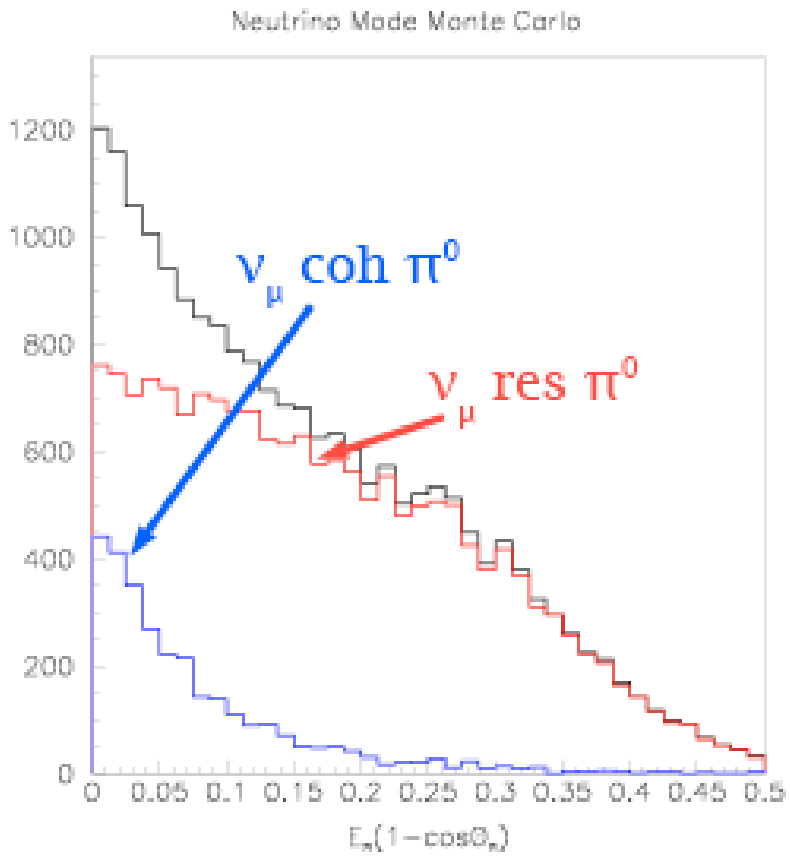
Resonant $\cos\theta_\pi$



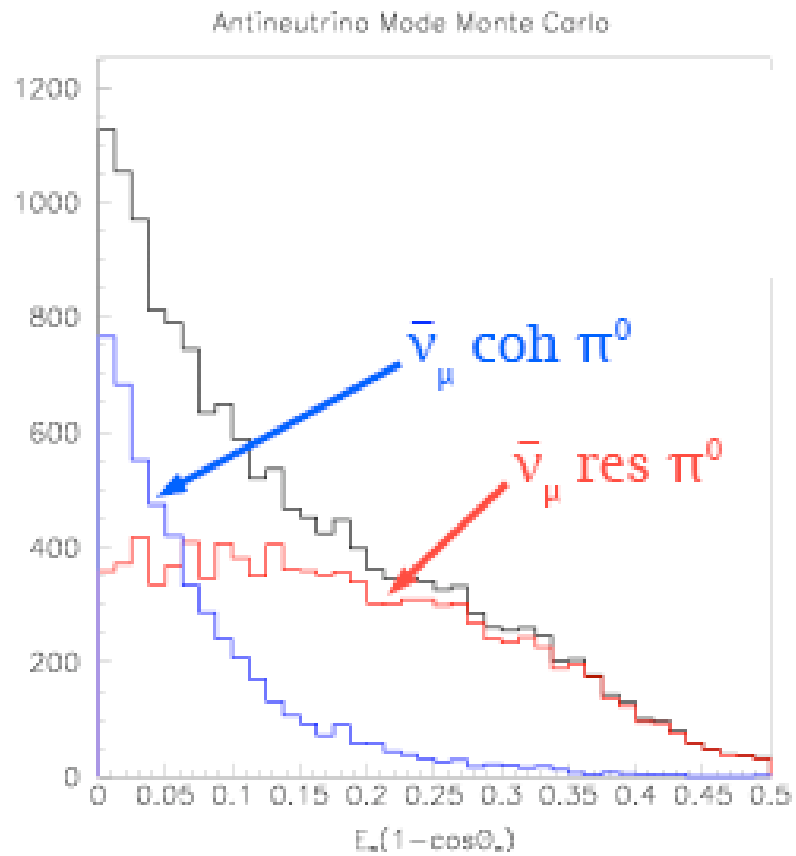
Coherent $\cos\theta_\pi$

- Can distinguish different production mechanisms through $\cos\theta_\pi$, the π^0 angle with respect to the beam direction
- Fit data in π^0 mass, E(1-cos), using three MC templates : resonant, coherent, background

MiniBooNE NCπ^0 Anti-ν Results

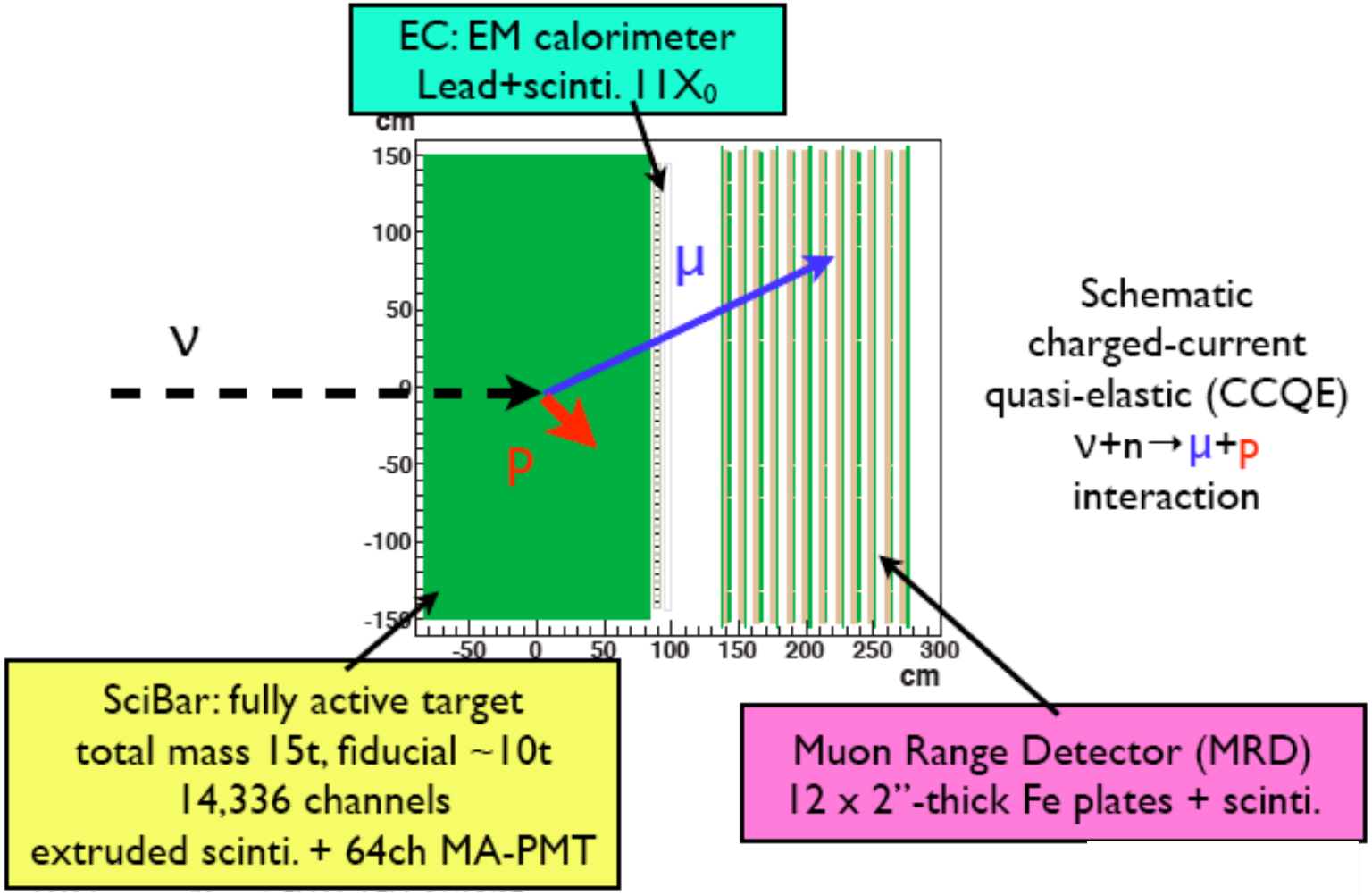


- 20% is coherent production



- 40% is coherent production
- "enhanced" coherent sample

SciBooNE



Schematic charged-current quasi-elastic (CCQE) $\nu + n \rightarrow \mu + p$ interaction