Search for Short-Baseline Muon Neutrino Disappearance at SciBooNE and MiniBooNE

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Fermilab New Perspectives Conference

June 2nd, 2009

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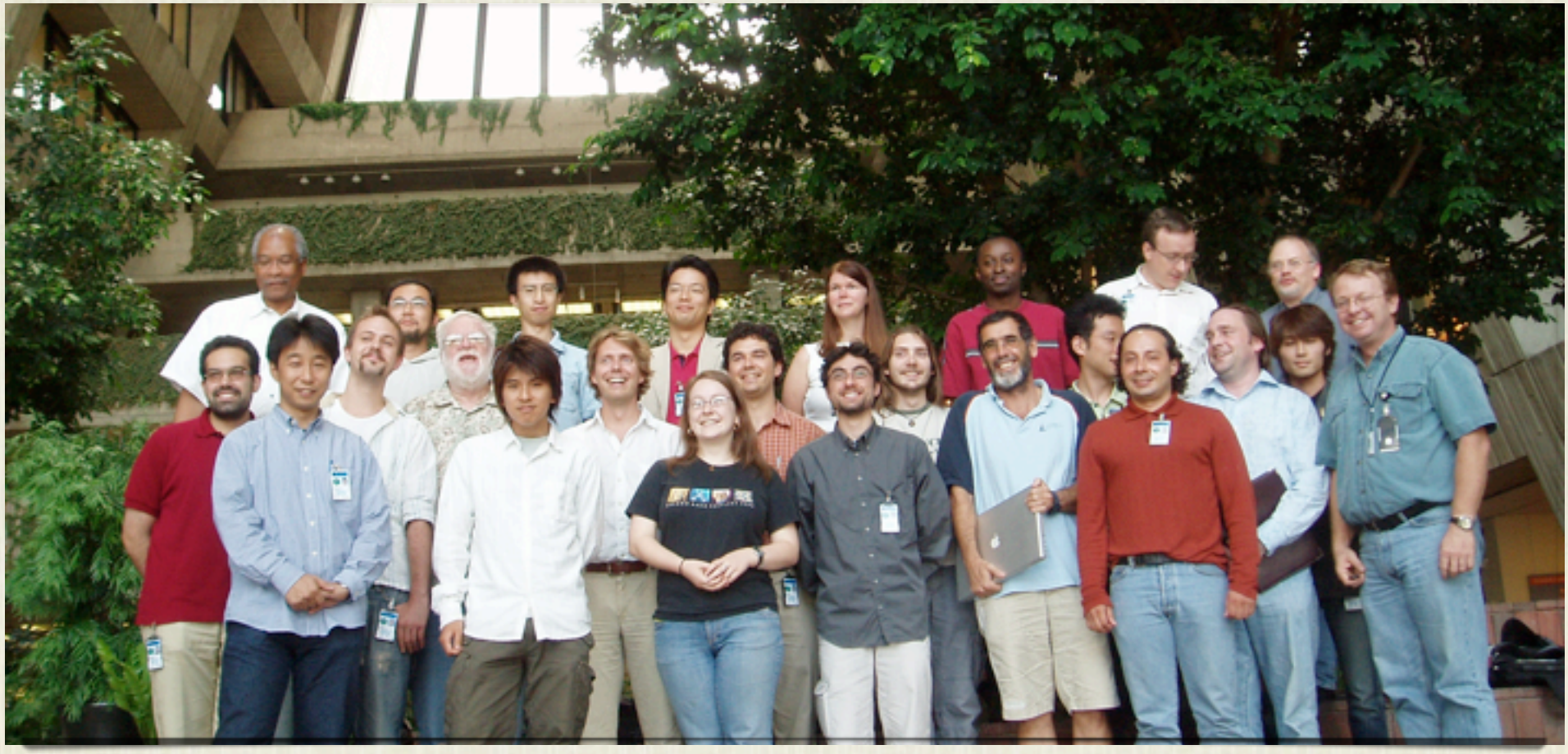


SciBooNE Collaboration Meeting August, 2006

Neutrino Oscillation

Neutrino Oscillation

- Neutrino flavor eigenstates and mass eigenstates are “mixed”
- Neutrinos change their flavor as a function of time (travel distance)

$$|\nu_\alpha(t=0)\rangle = \sum_i U_{\alpha i}\,|\nu_i\rangle\,.$$

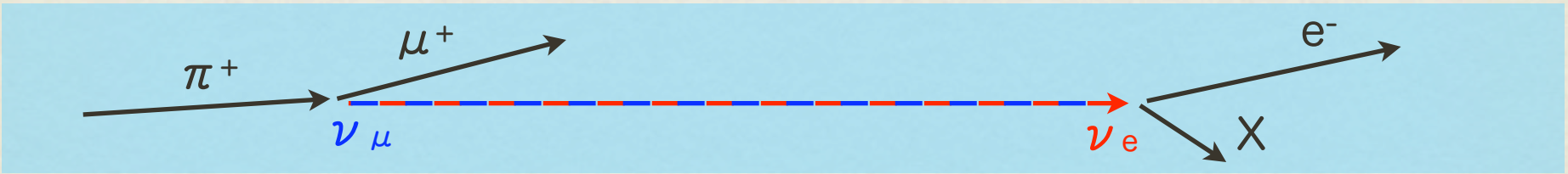
α = e, μ, τ (Flavor eigenstates)

i = 1, 2, 3 (Mass eigenstates)

$$U = \begin{pmatrix} 1 & & \\ & c_{23} & s_{23} \\ & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & & s_{13}e^{-i\delta} \\ & 1 & \\ -s_{13}e^{i\delta} & & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & \\ -s_{12} & c_{12} & \\ & & 1 \end{pmatrix}$$

MNS matrix

$s_{ij} = \sin\theta_{ij}, c_{ij} = \cos\theta_{ij}$



$$P_{\alpha\to\beta} = \left|\langle\nu_\beta(t)|\nu_\alpha(0)\rangle\right|^2$$

$$= \sin^2 2\theta \sin^2\left(\frac{1.27\Delta m^2[\mathrm{eV}^2]L[\mathrm{km}]}{E[\mathrm{GeV}]}\right)$$

θ : mixing angle

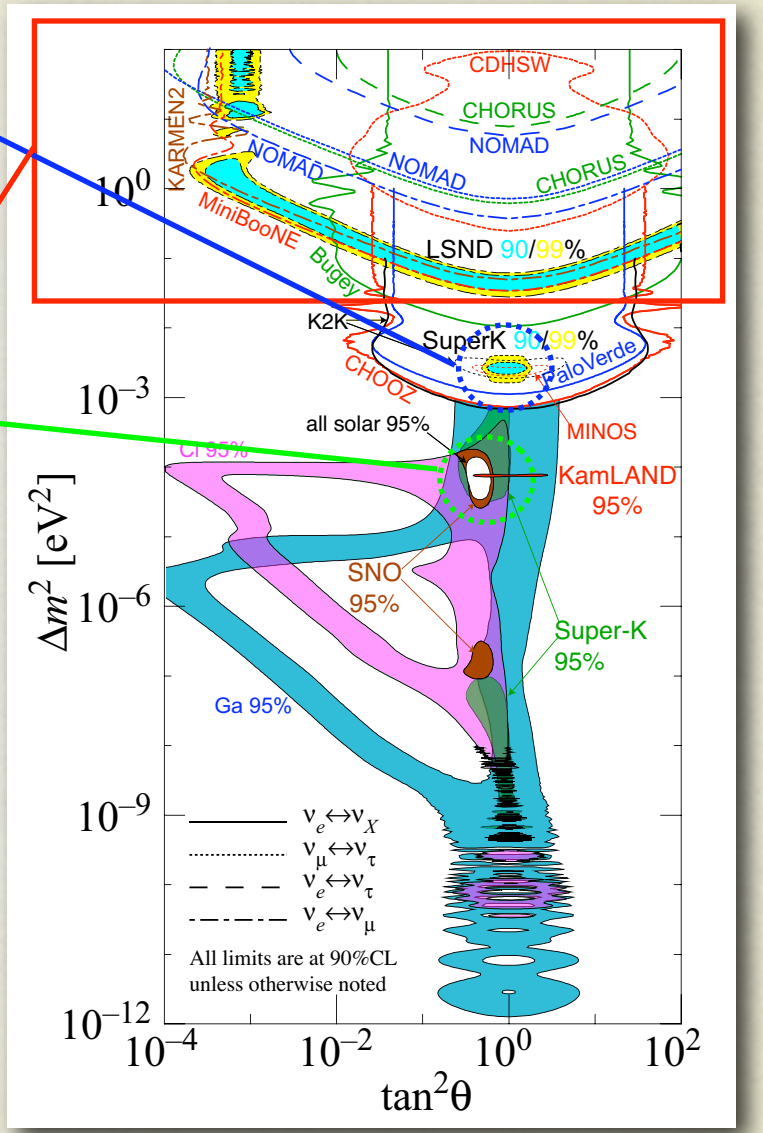
Δm^2 : Difference of mass squared

L : Travel distance

E : Neutrino Energy

Neutrino Oscillation Observations

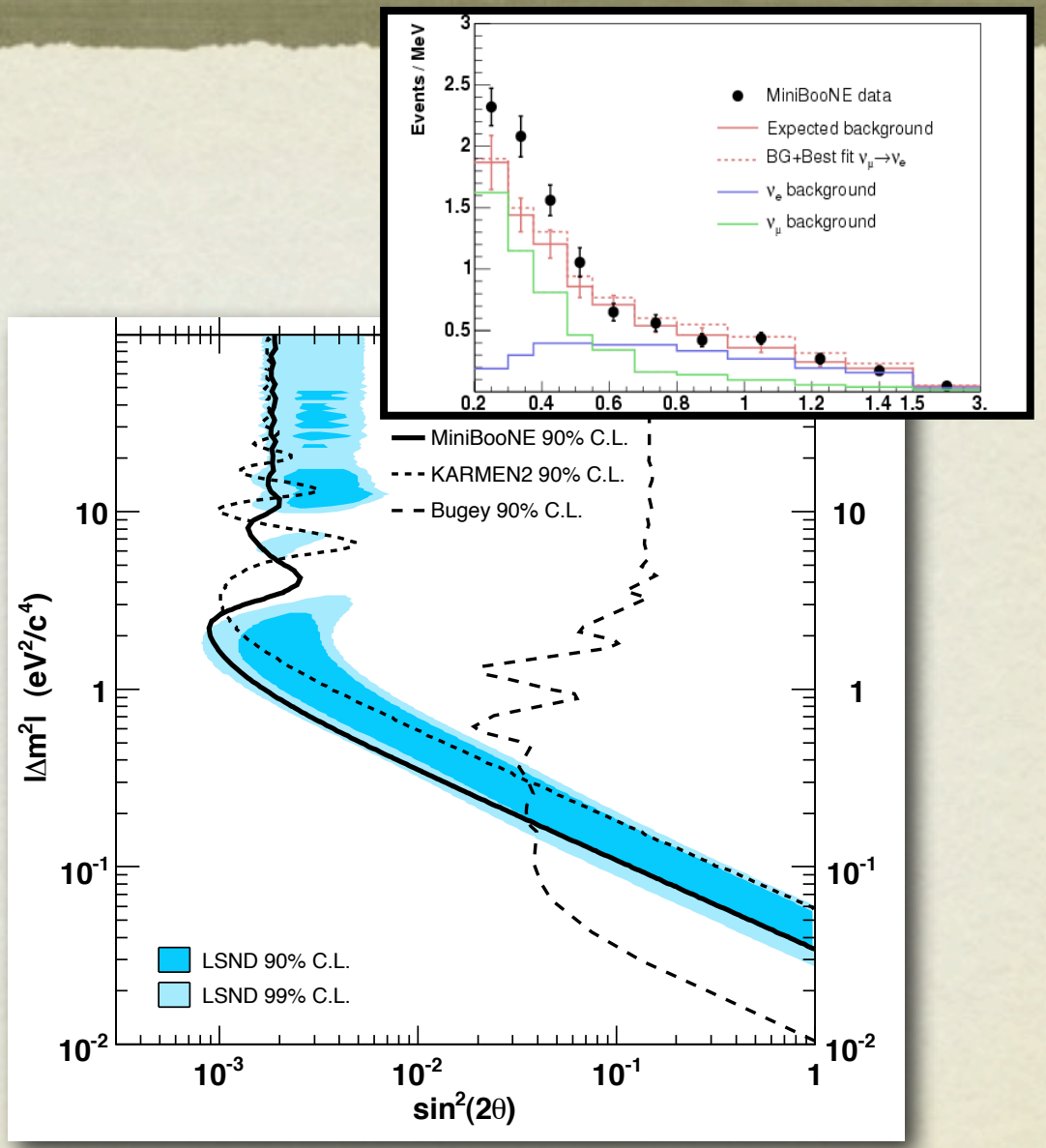
- Atmospheric region: $\Delta m^2 \sim 10^{-3}\ eV^2$
  - Super-K etc (Atmospheric neutrino)
  - K2K, MINOS (Accelerator neutrino)
- Solar region: $\Delta m^2 \sim 10^{-5}\ eV^2$
  - SNO, etc (Solar neutrino)
  - KamLAND (Reactor neutrino)
- High Δm^2 region: $\Delta m^2 \sim 1\ eV^2$
  - Observed at LSND ($\bar{\nu}_\mu \rightarrow \bar{\nu}_e$) experiment, but not confirmed other experiment.



However, only 2 Δm^2 regions are allowed in the current SM with 3 neutrino generations

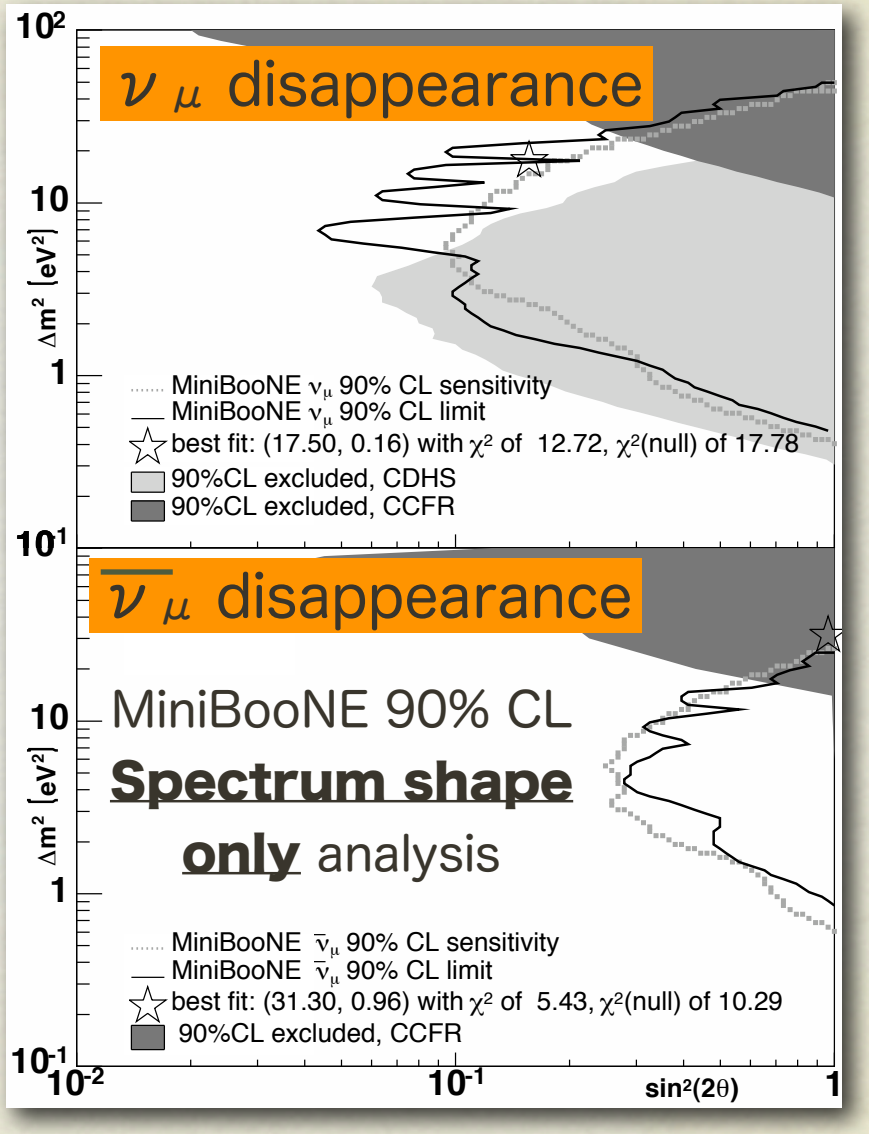
MiniBooNE's ν_e appearance search at $\Delta m^2 \sim 1 eV^2$

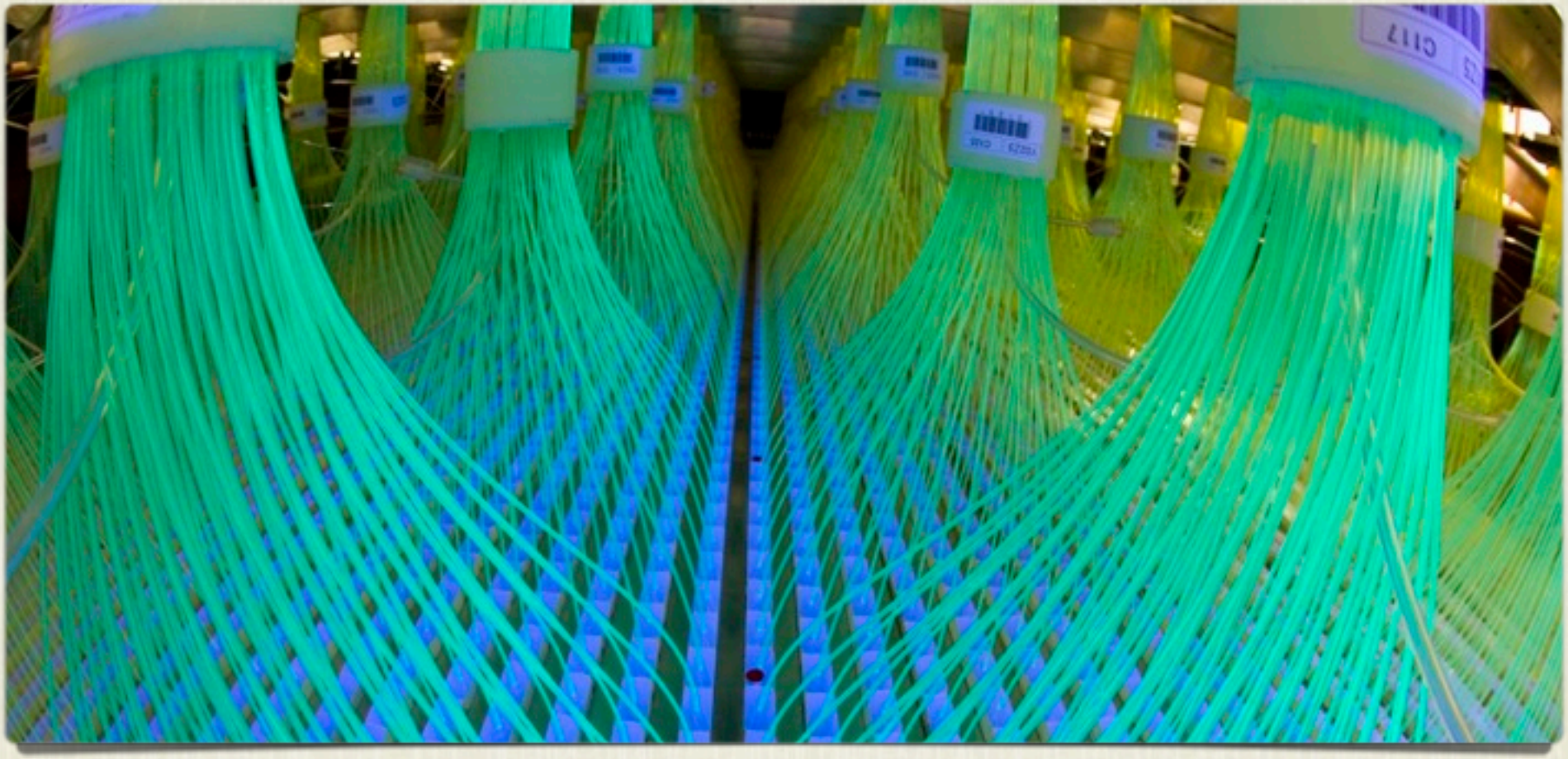
- Search for ν_e signal in ν_μ beam.
- ν_μ flux is used to normalize intrinsic ν_e backgrounds.
- No ν_e appearance signal is observed.
- LSND signal is ruled out if $P(\nu_\mu \rightarrow \nu_e) = P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$



MiniBooNE's ν_μ disappearance search at $\Delta m^2 \sim 1 eV^2$

- Search for non-standard model interaction.
  - Sterile neutrino, etc..
- MiniBooNE's first result is based on the spectrum shape only analysis.
  - Limited by large flux and x-section uncertainties.
- A near detector (SciBooNE) can strongly constrain flux and x-section errors.

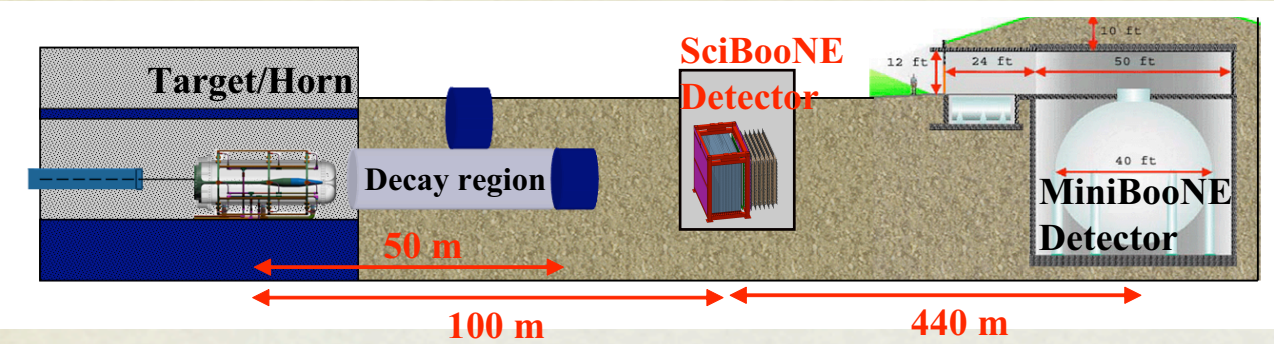




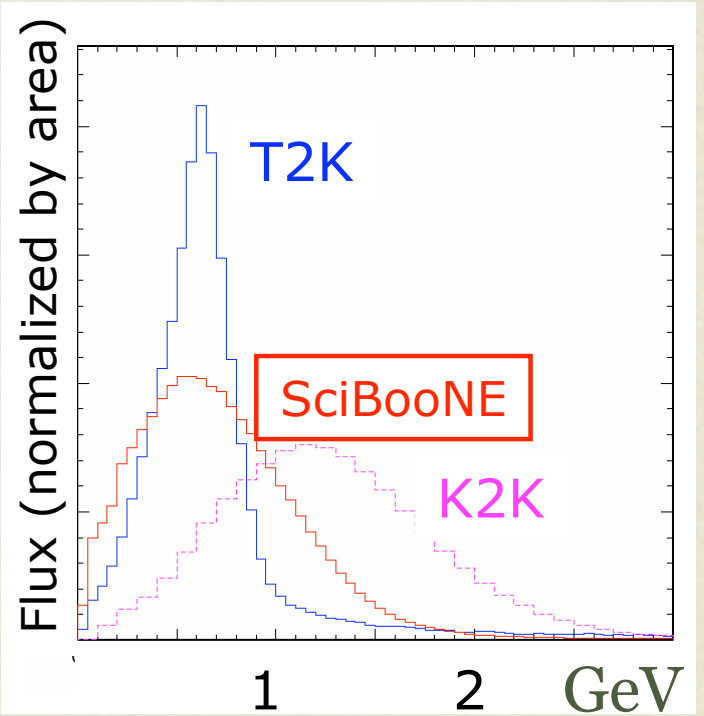
SciBar Detector

SciBooNE Experiment

Experimental Setup



- Fine-grained detector (SciBar) on the Fermilab Booster Neutrino Beamline.
- Cross section measurement for ~1 GeV neutrino and anti-neutrino
  - Essential for future neutrino oscillation measurements (T2K, etc)
- MiniBooNE near detector
  - Measure un-oscillated neutrino fluxes.



SciBooNE Collaboration

- Universitat Autonoma de Barcelona
- University of Cincinnati
- University of Colorado
- Columbia University
- Fermi National Accelerator Laboratory
- High Energy Accelerator Research Organization (KEK)
- Imperial College London*
- Indiana University
- Institute for Cosmic Ray Research
- Kyoto University*
- Los Alamos National Laboratory
- Louisiana State University
- Purdue University Calumet
- Università degli Studi di Roma and INFN-Roma
- Saint Mary's University of Minnesota
- Tokyo Institute of Technology
- Universidad de Valencia

~70 Physicist

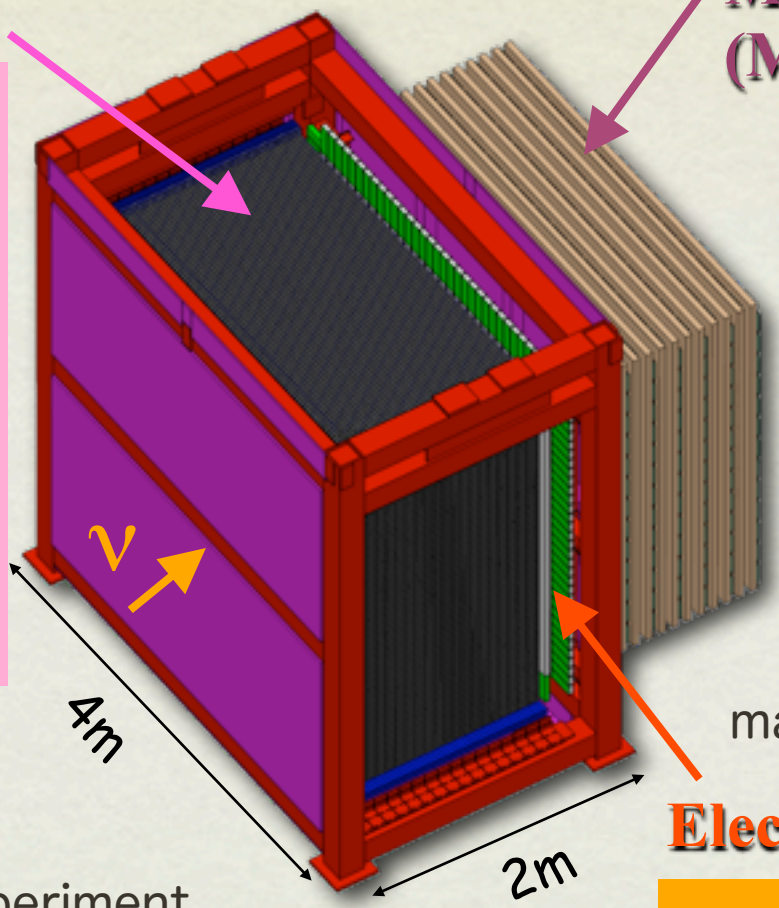
from 17 institutes, 5 countries

SciBooNE detector

SciBar

- scintillator tracking detector
- 14,336 scintillator bars (15 tons)
- Neutrino target
- detect all charged particles
- p/π separation using dE/dx

Used for K2K experiment. Shipped to and re-assembled at FNAL



Muon Range Detector (MRD)

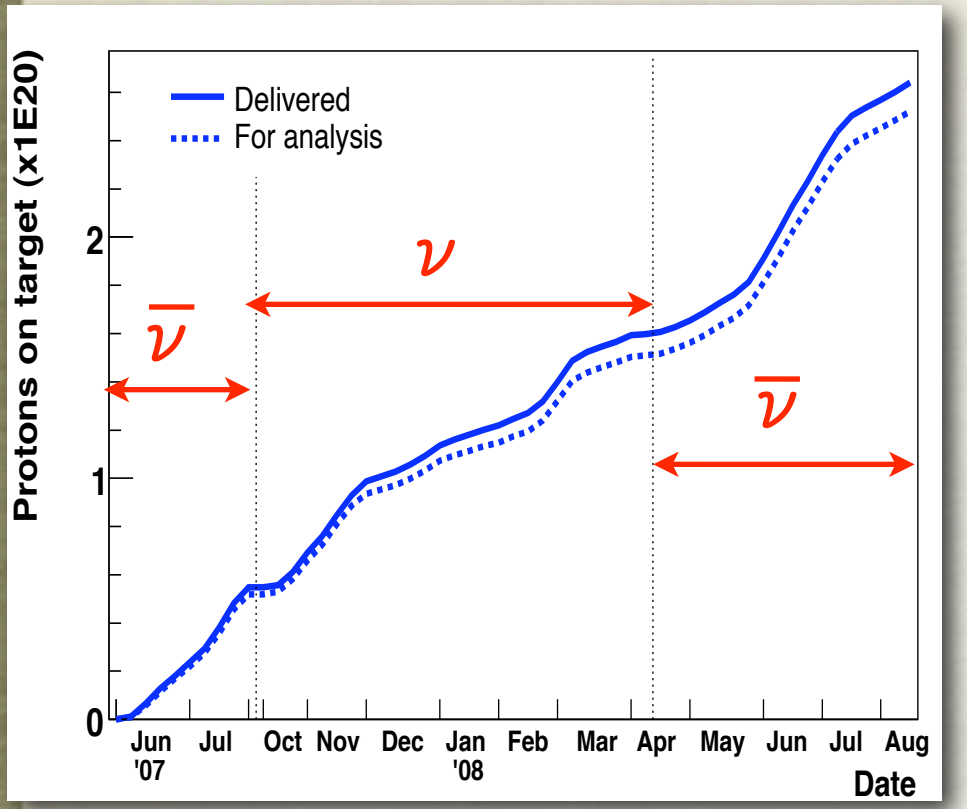
- 12 2"-thick steel + scintillator planes
- measure muon momentum with range up to 1.2 GeV/c

Newly built at FNAL with materials from past experiments

Electron Catcher (EC)

- spaghetti calorimeter
- 2 planes (11 X_0)
- identify π^0 and ν_e

SciBooNE Data Taking

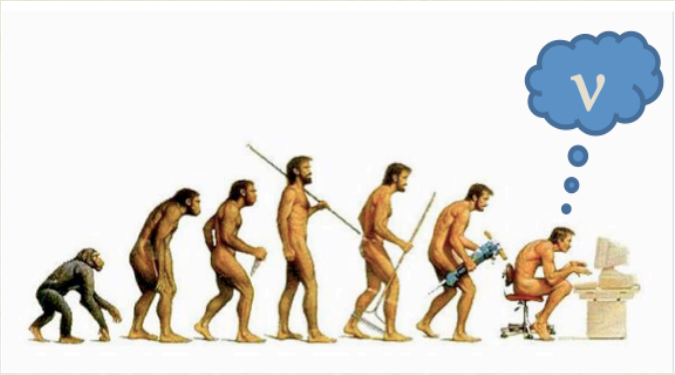


- Start beam data taking in June 2007
- Data taking completed in August 2008
- Stable data taking
- Total 2.52x10^{20} POT for analysis (95% of delivered)
  - Neutrino: 0.99x10^{20} POT
  - Anti-neutrino: 1.53x10^{20} POT

Results from full neutrino data set are presented today

SciBooNE Timeline

- 2005, Summer - Collaboration formed
- 2005, Dec - Proposal
- 2006, Jul - Detectors move to FNAL
- 2006, Sep - Groundbreaking
- 2006, Nov - Sub-detectors Assembly
- 2007, Apr - Detector Installation
- 2007, May - Commissioning
- 2007, Jun – Started Data-taking
- 2008, Aug – Completed data-taking
- 2008, Nov – 1st physics result



3 years from formation to 1st physics result

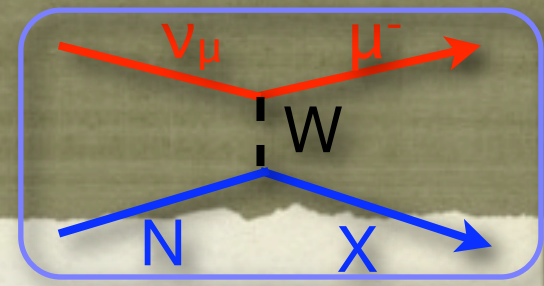
SciBooNE Detector Installation April, 2007

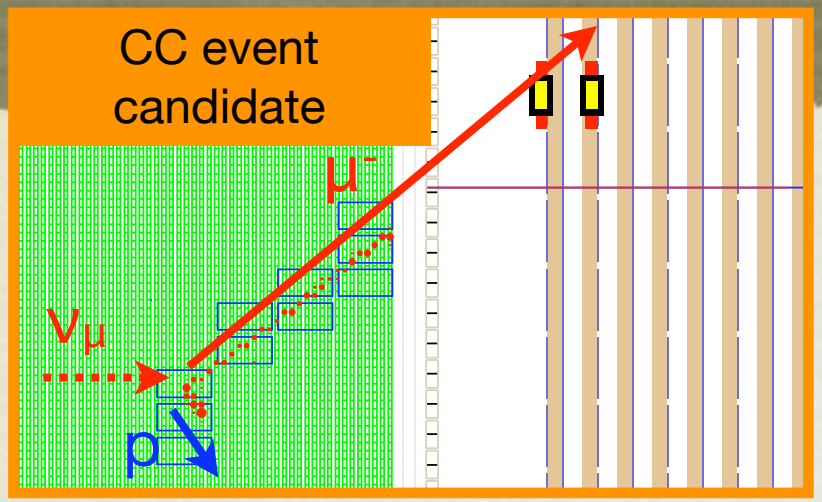
Flux Measurement at SciBooNE

Event Selection

SciBooNE

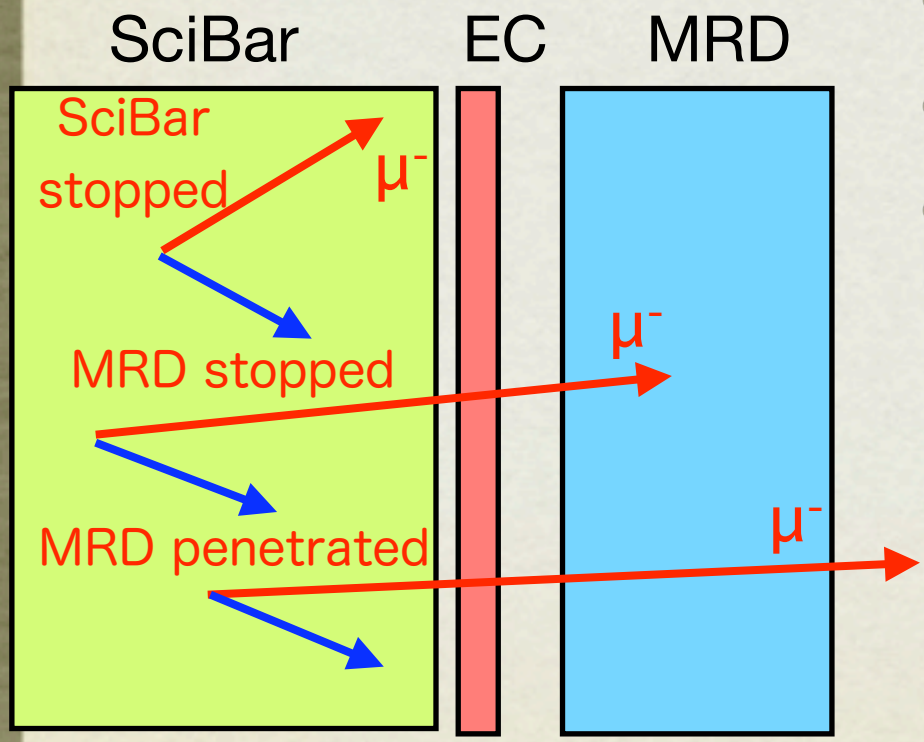
Use charged current inclusive sample

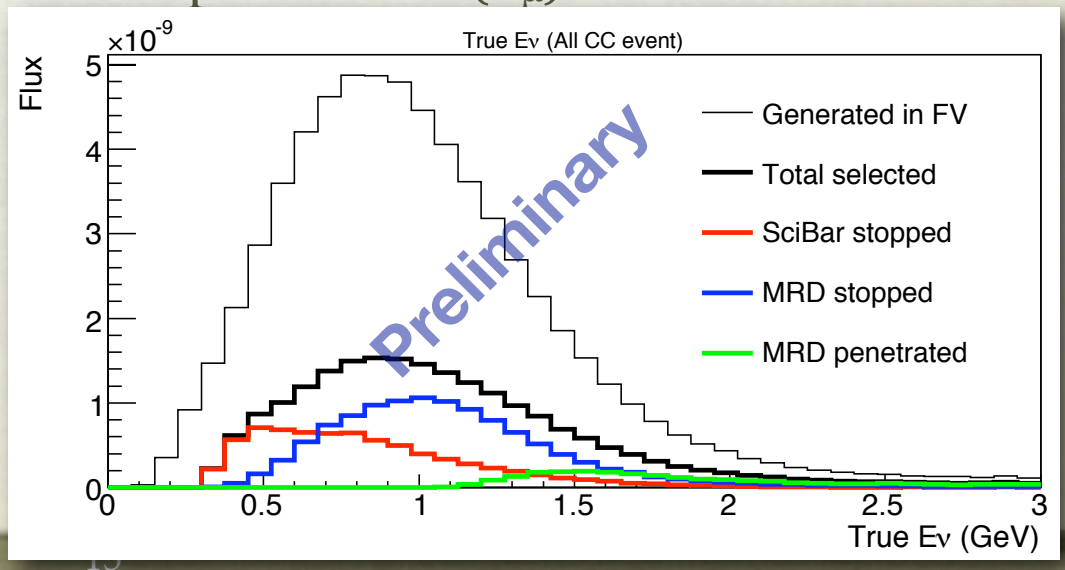




- Select MIP-like energetic tracks (P_μ>0.25GeV)
- Reject side-escaping muons.
- 3 samples:
  - SciBar-stopped (P_μ,θ_μ)
  - MRD-stopped (P_μ,θ_μ)
  - MRD-penetrated (θ_μ)

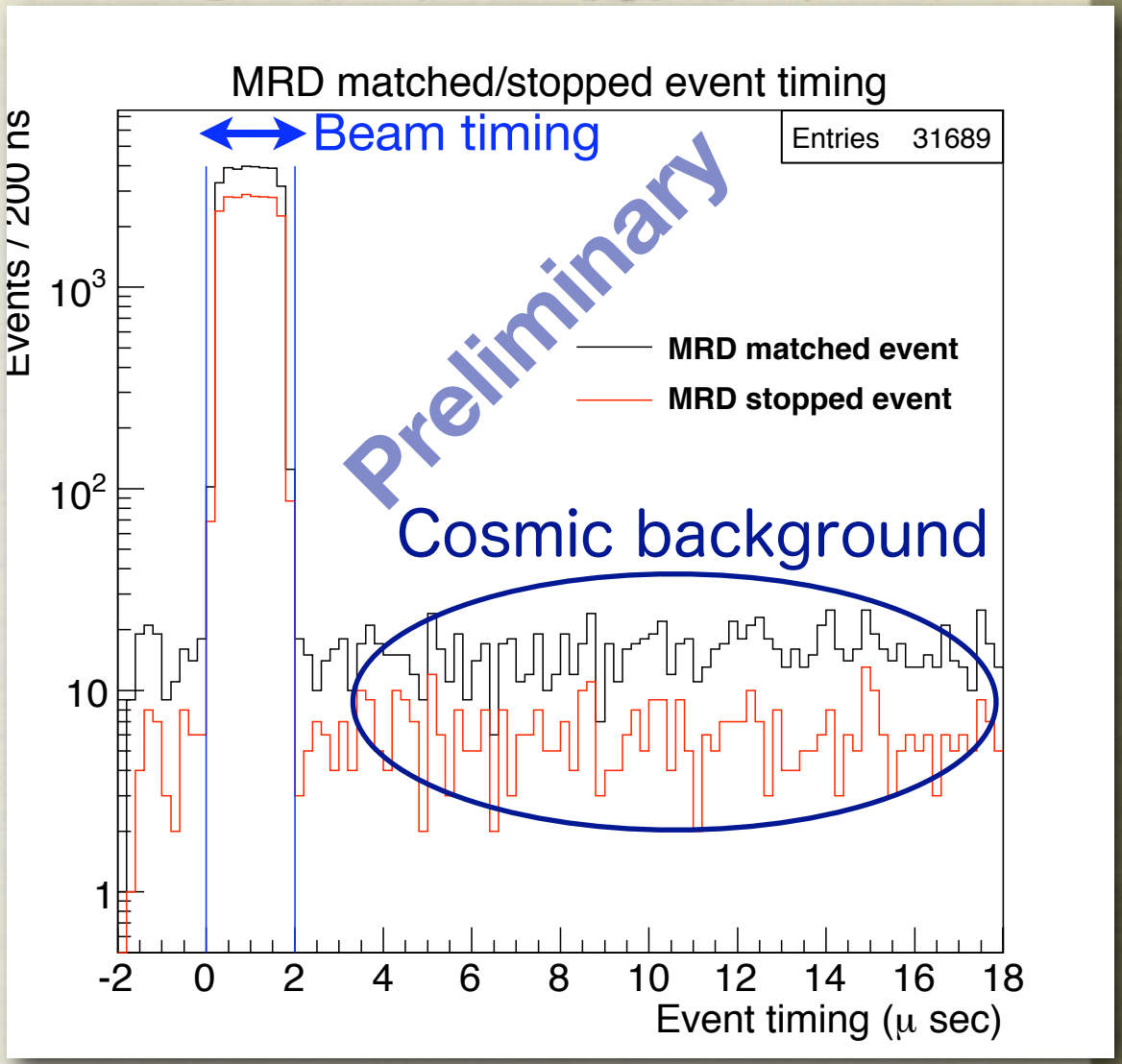
P_μ: Muon momentum reconstructed by its path-length
θ_μ: Muon angle w.r.t. beam axis





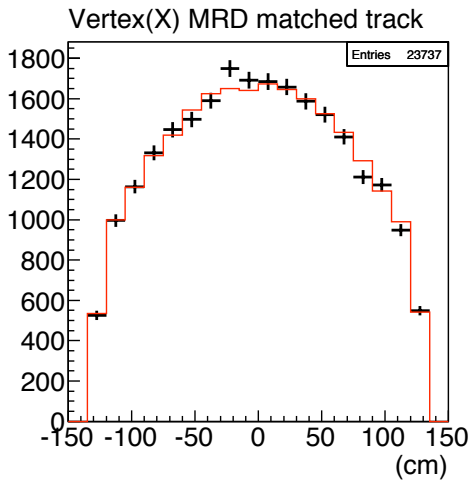
Event Selection (Timing)

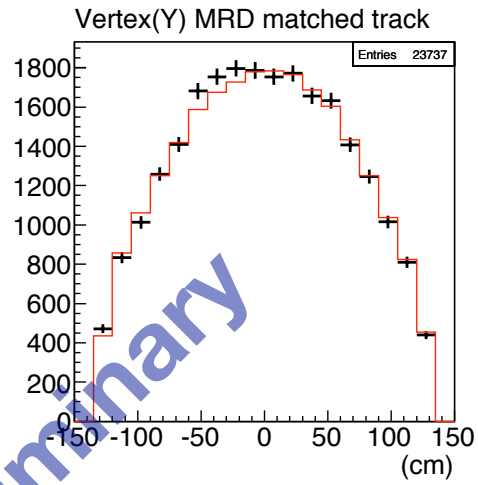
- 2 μsec beam timing window.
  - Less than 0.5% cosmic background contamination.
- ~14K SciBar-stopped events.
- ~20K MRD-stopped events.
- ~4K MRD-penetrated events.

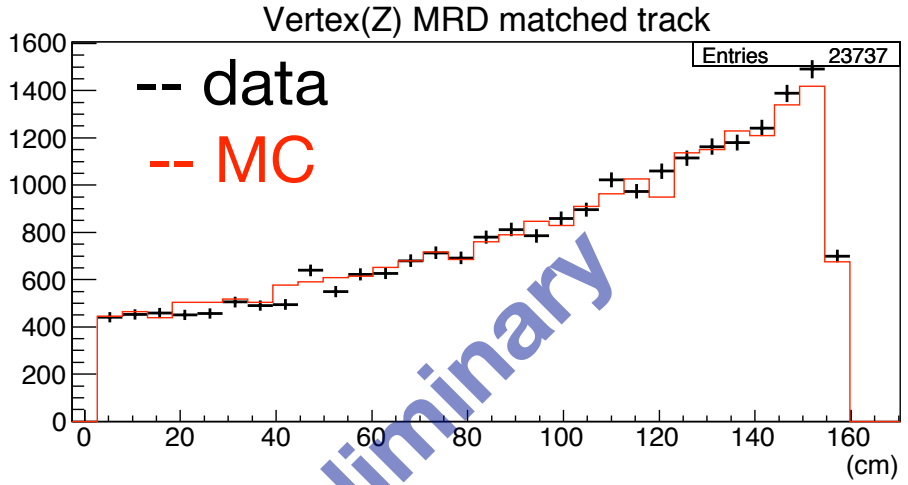


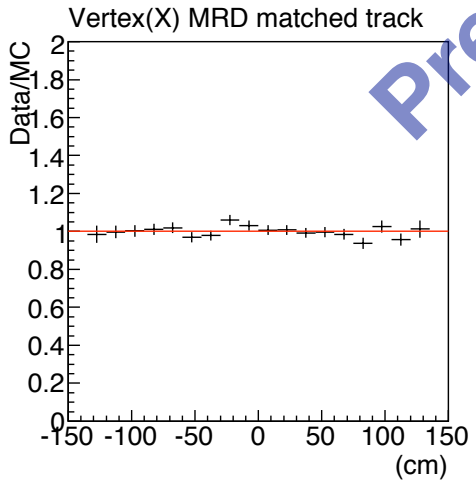
Reconstructed Interaction Vertices

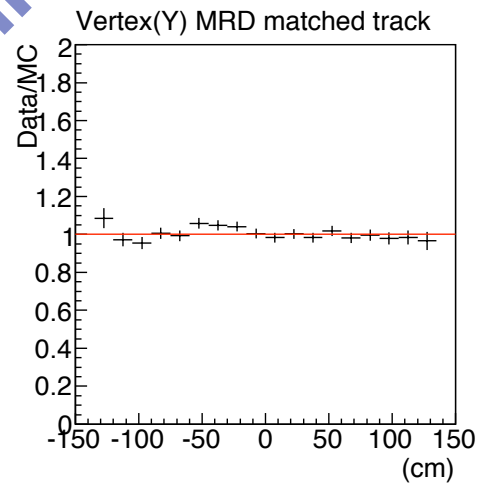
MRD matched muon (relatively normalized)

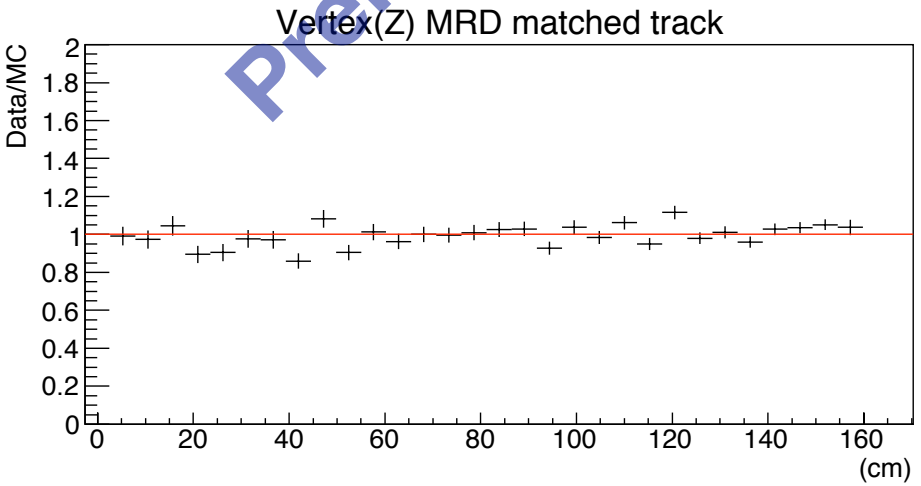












Preliminary

Preliminary

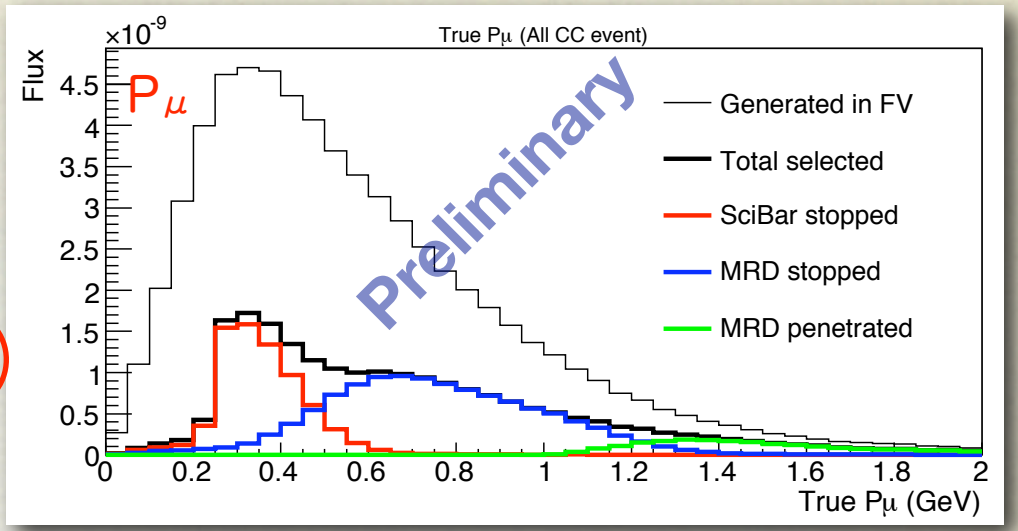
Extracting E_ν Spectrum

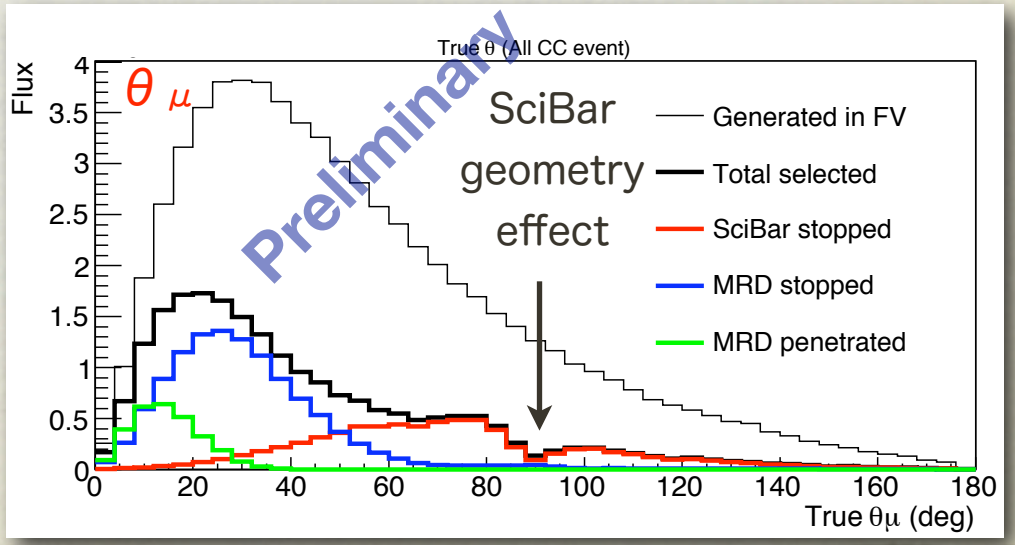
- Use muon kinematics to extract E_ν information

$$E_\nu = \frac{m_p^2 - (m_n - V)^2 - m_\mu^2 + 2(m_n - V)E_\mu}{2(m_n - V - E_\mu + p_\mu \cos\theta_\mu)}$$

(Assuming CC-quasi-elastic scattering)

- Good coverage of entire kinematic region with these 3 samples.



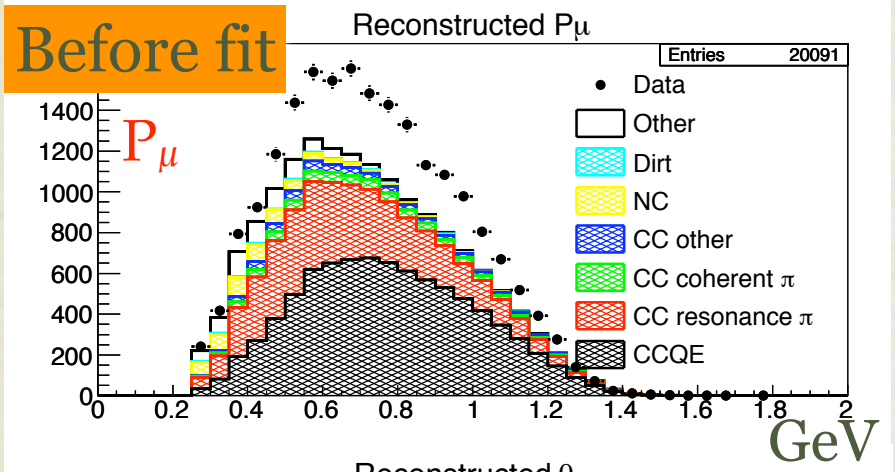


Spectrum Fitting

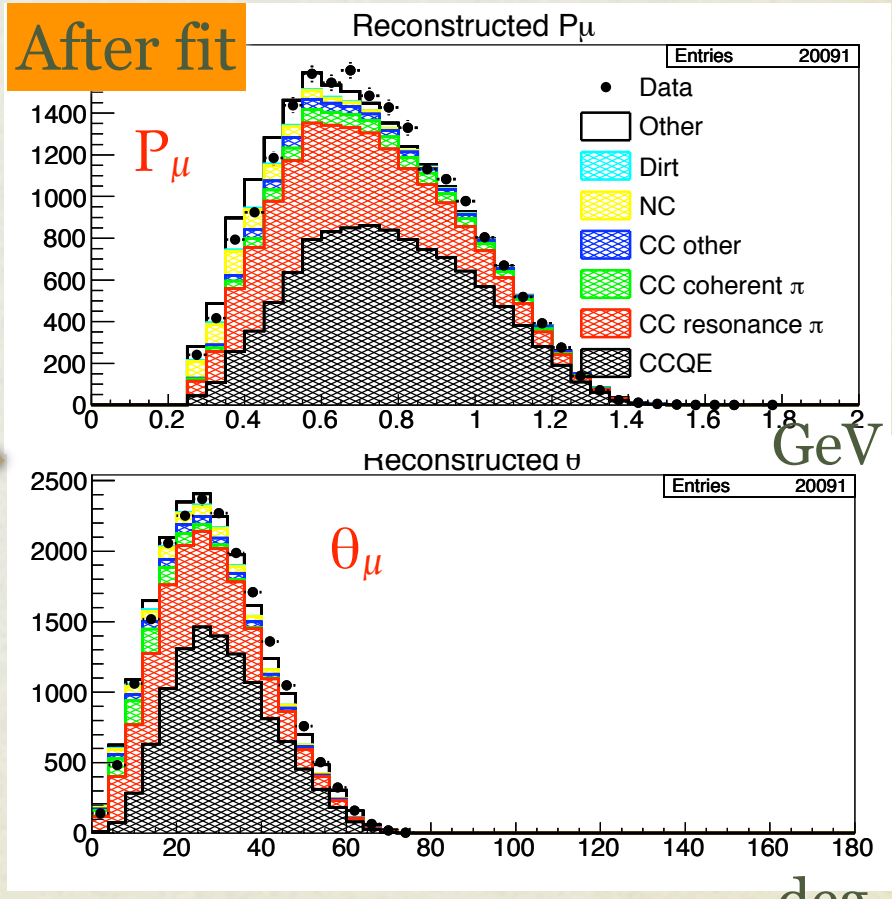
- Determine E_ν spectrum shape and normalization by fitting P_μ and θ_μ distributions.

MRD stopped muon (Absolute normalization)

Before fit

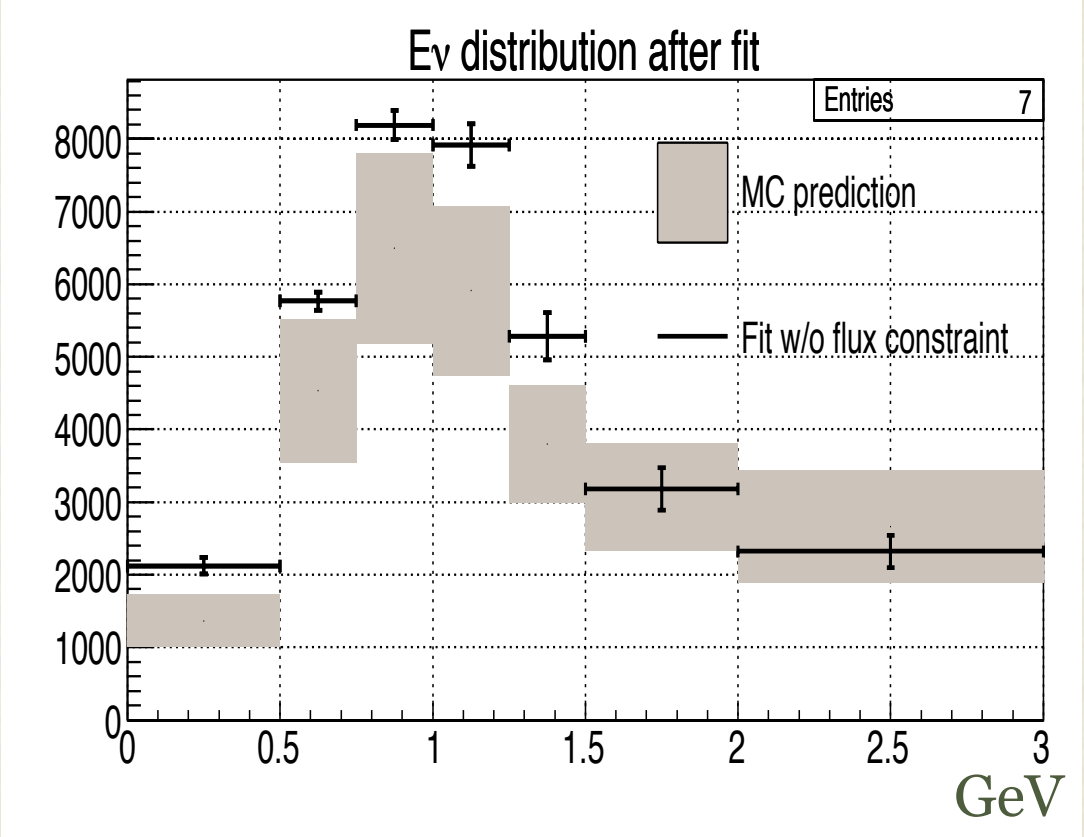


After fit



Flux Prediction at SciBooNE

- Originally ~20% flux and cross-section uncertainty.
- Measure the neutrino interaction rate at a few % uncertainty.
- We found the neutrino interaction rate is higher at ~1GeV than predicted by MC.

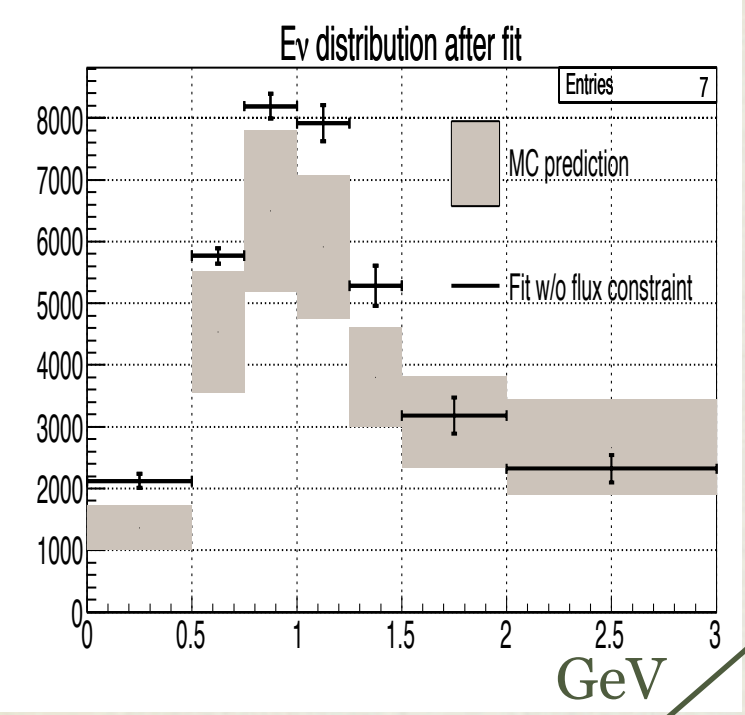


SciBooNE End of Run August, 2008

ν_μ Disappearance Joint Analysis

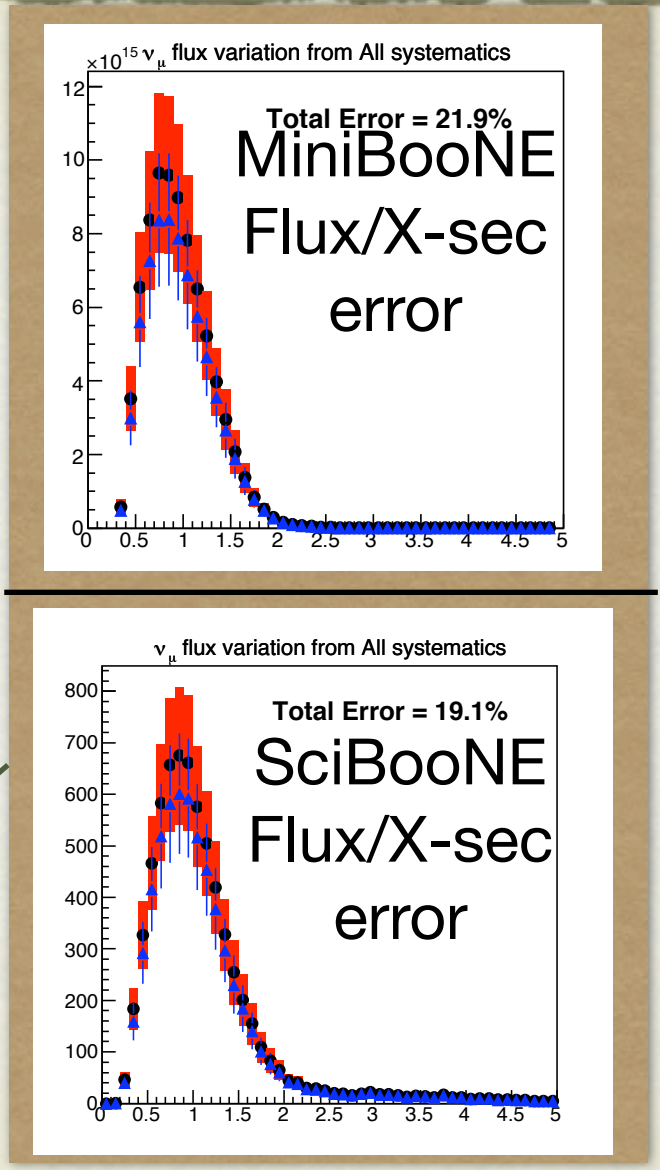
Flux Prediction at MiniBooNE

Start from fitted spectrum at SciBooNE



Multiply MiniBooNE/SciBooNE flux ratio and its systematic error

X



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MiniBooNE flux prediction

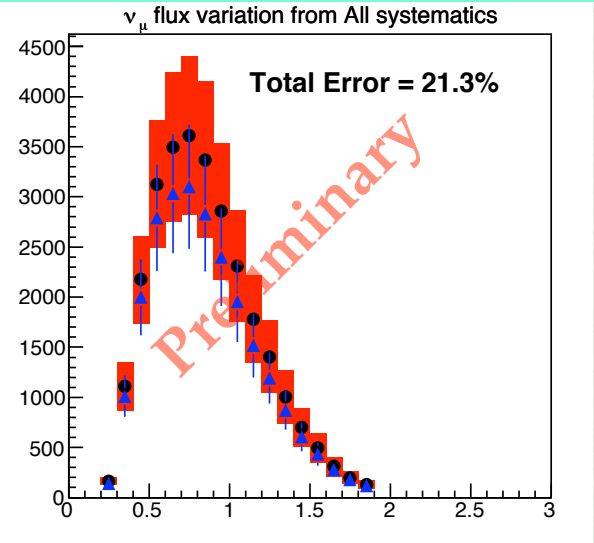
MiniBooNE Rec. E_ν prediction

Reconstructed E_ν at MiniBooNE

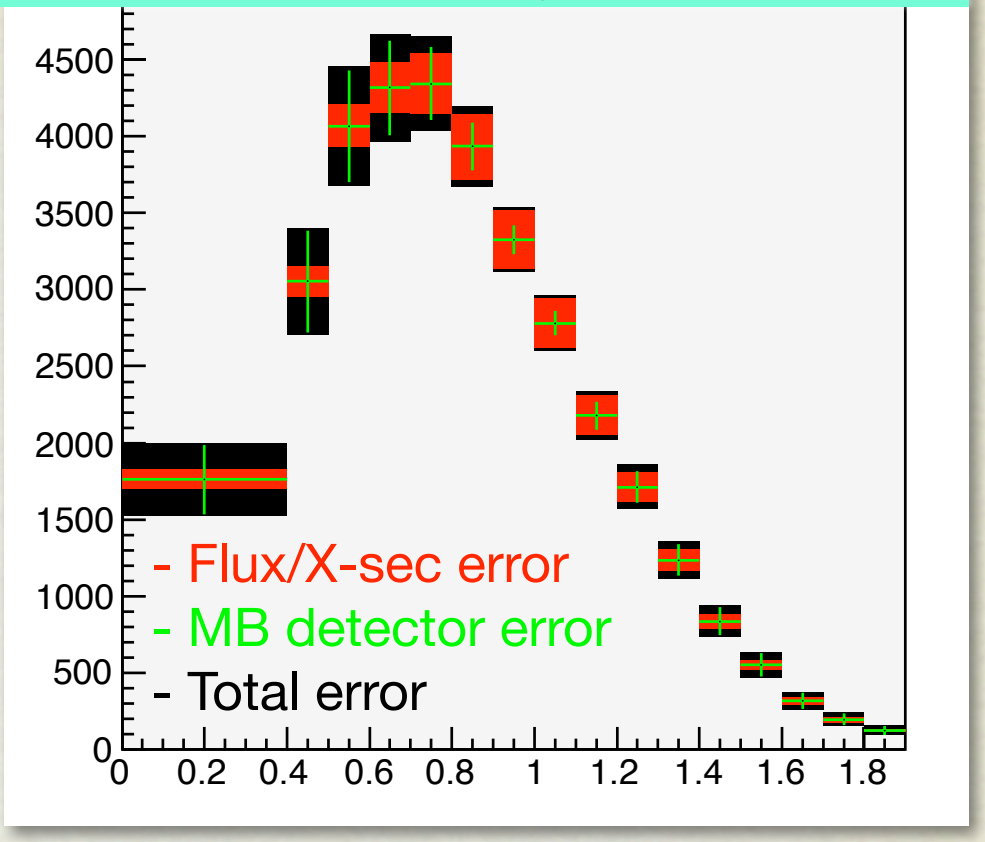
$$E_\nu = \frac{m_p^2 - (m_n - V)^2 - m_\mu^2 + 2(m_n - V)E_\mu}{2(m_n - V - E_\mu + p_\mu \cos\theta_\mu)}$$

- Reconstruct Enu assuming CC Quasi-Elastic scattering

Rec. E_ν w/o SciBooNE data



Rec. E_ν constrained by SciBooNE data



Uncertainty for MiniBooNE Rec Eν is reduced to ~5 % level

We fit this prediction to data to search for ν_μ disappearance

Conclusion

- SciBooNE experiment
  - Precise Cross-section measurement at ~1GeV
  - Neutrino flux measurements as a MiniBooNE near detector
- Search for short-baseline ν_μ disappearance
  - Search for non-standard model neutrino interactions.
  - Established the method to constrain MiniBooNE data by SciBooNE.
  - Joint SciBooNE-MiniBooNE ν_μ disappearance result will be released soon!
- There are many cross-section result from SciBooNE!
  - Search for CC coherent π^+ production (Phys. Rev. D78:112004,2008)
  - CC/NC (quasi) elastic Scattering
  - CC/NC 1π production
  - Anti-nu cross-sections
  - ν_e flux measurements

See Sam Zeller's talk at Users Meeting tomorrow 11:00~!