Search for Muon Neutrino Disappearance in a Short-Baseline Accelerator Neutrino Beam

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for the SciBooNE Collaboration

September 15th, 2009
WIN 09

Contents

- Introduction
  - Neutrino Oscillations
- Experimental Setup
  - Beamline
  - Detectors : SciBooNE and MiniBooNE
- Oscillation Analysis

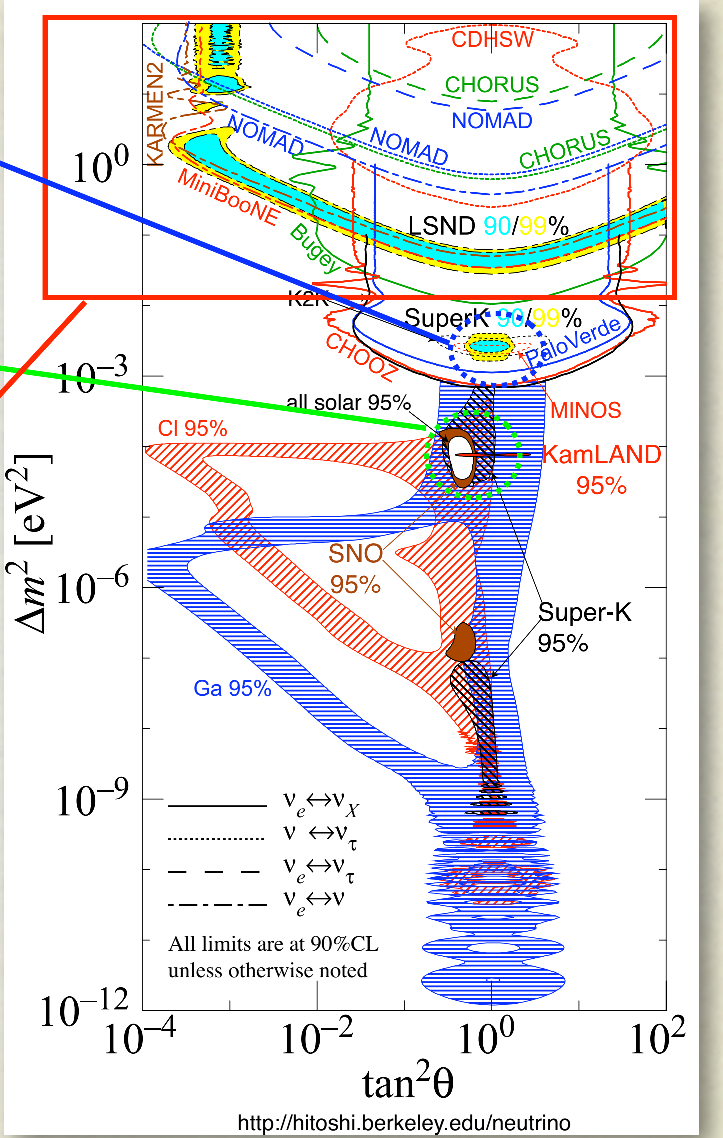
Introduction

Neutrino Oscillations

- Atmospheric region: $\Delta m^2 \sim 10^{-3}\ eV^2$
  - Super-K, K2K, MINOS, etc
- Solar region: $\Delta m^2 \sim 10^{-5}\ eV^2$
  - SNO, Super-K, KamLAND, etc.

Only 2 Δm^2 regions are allowed in the current SM with 3 neutrino generations

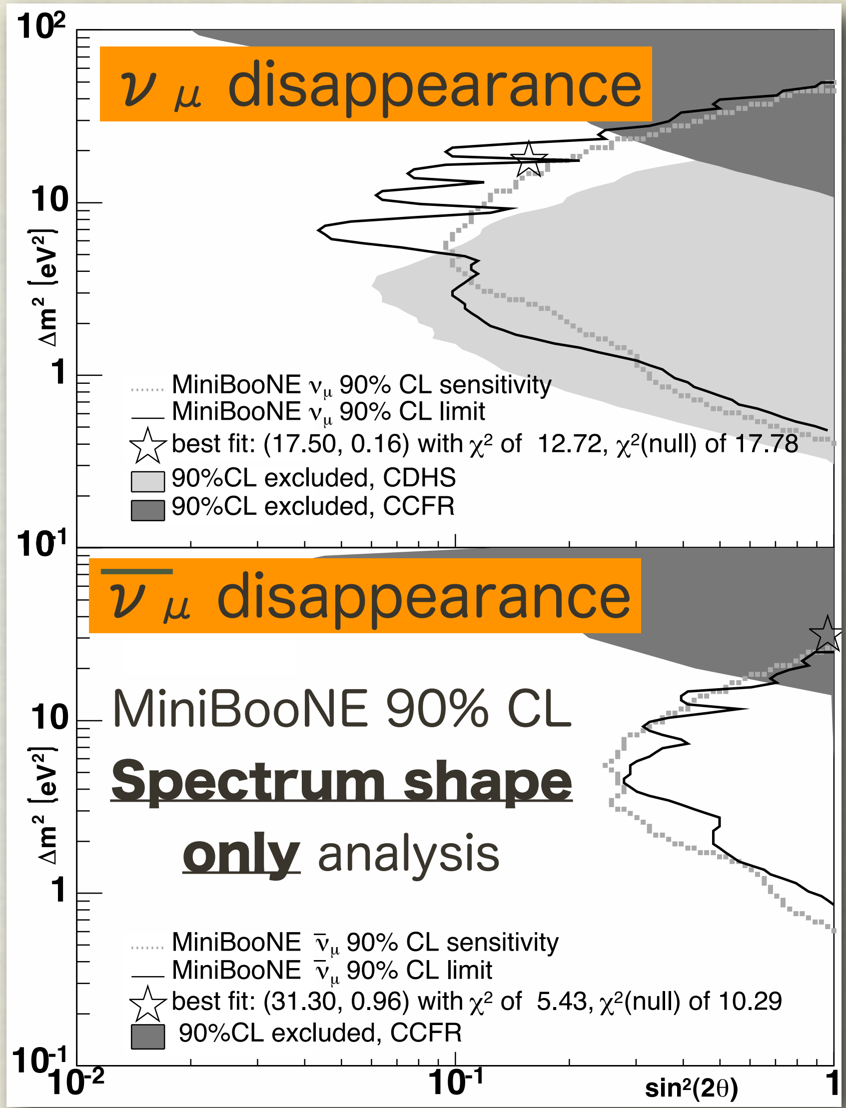
- High Δm^2 region: $\Delta m^2 \sim 1\ eV^2$
  - Observed at LSND ($\bar{\nu}_\mu \rightarrow \bar{\nu}_e$)
  - Ruled out by MiniBooNE if $P(\nu_\mu \rightarrow \nu_e) = P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$



Search for Muon Neutrino Disappearance at high Δm²

SciBooNE

- Search for exotic mode of neutrino oscillation
  - 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 can strongly constrain flux and x-section errors.



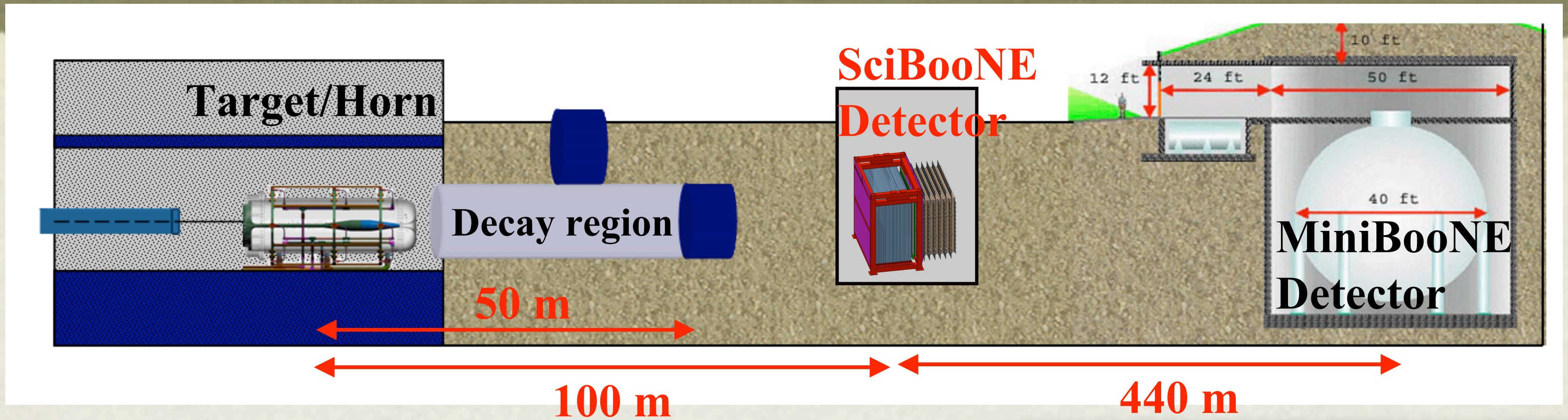
Phys. Rev. Lett. 103, 061802 (2009)

SciBooNE Detector Installation   April, 2007

Experimental Setup

Fermilab Booster Neutrino Beamline

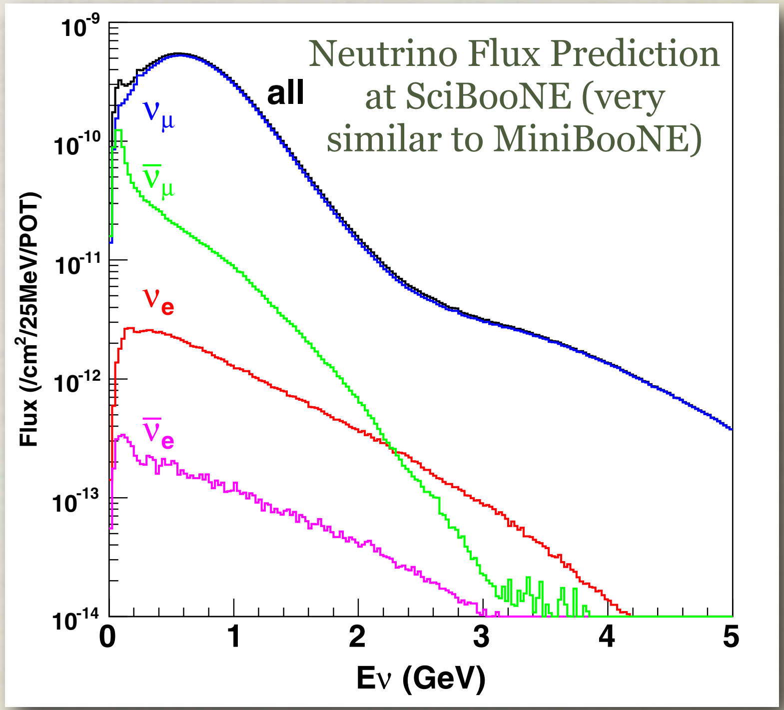
SciBooNE



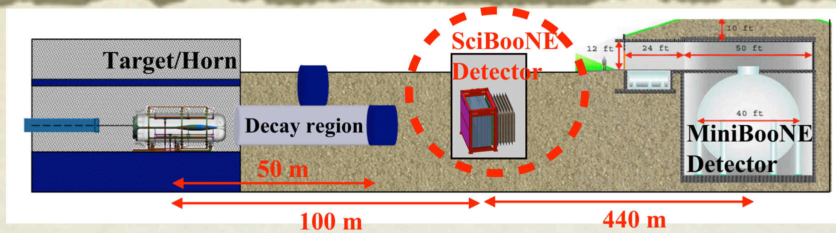
- High intensity Neutrino and Anti-Neutrino beam
  - $E_\nu \sim 1$ GeV
- Neutrino Fluxes are measured at 2 detectors: SciBooNE and MiniBooNE
  - L ~ 500m

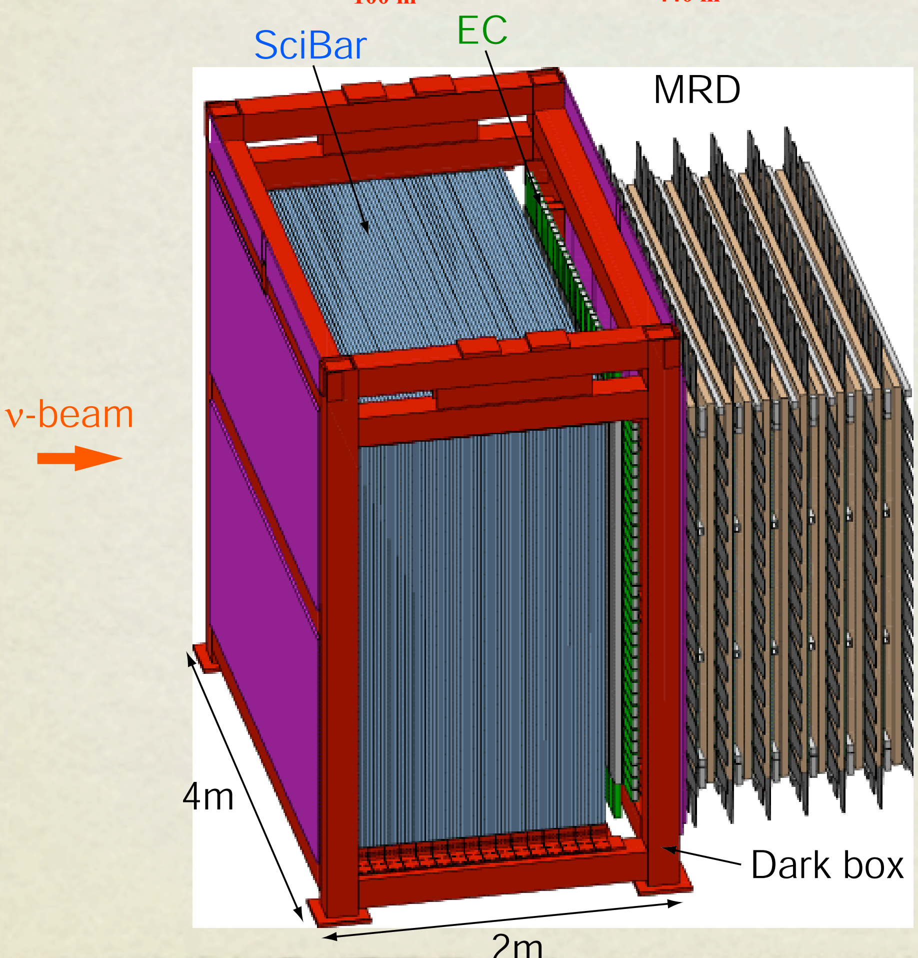
Sensitive to Oscillations at $\Delta m^2 \sim 1 eV^2$

$$P(\nu_\alpha \rightarrow \nu_\beta) = \sin^2 2\theta \sin^2\left(\frac{1.27\Delta m^2[\text{eV}^2]L[\text{km}]}{E[\text{GeV}]}\right)$$



SciBooNE Detector



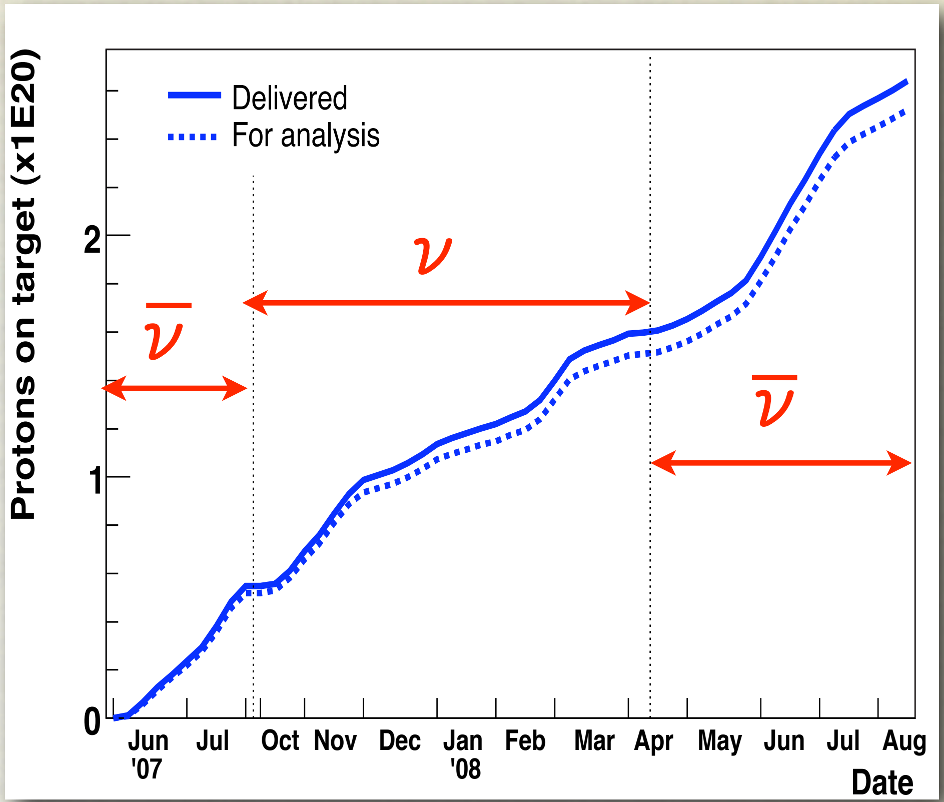


- SciBar:
  - Full active scintillator tracker (~14000 strips)
  - Neutrino Target
    - Fiducial volume: ~10 tons
    - Main component: CH
- Electron Catcher (EC)
  - “Spaghetti” type calorimeter
- Muon Range Detector (MRD)
  - Steel and scintillator sandwich
  - Measure muon momentum from its range

SciBooNE Data Taking

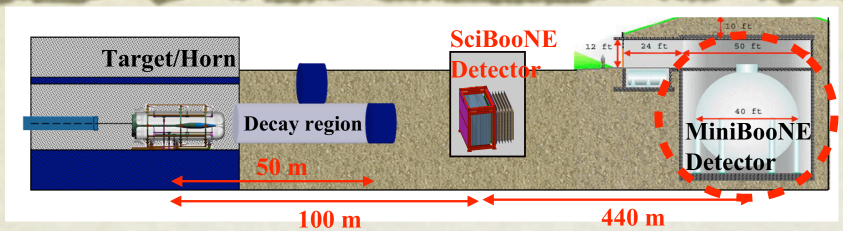
SciBooNE

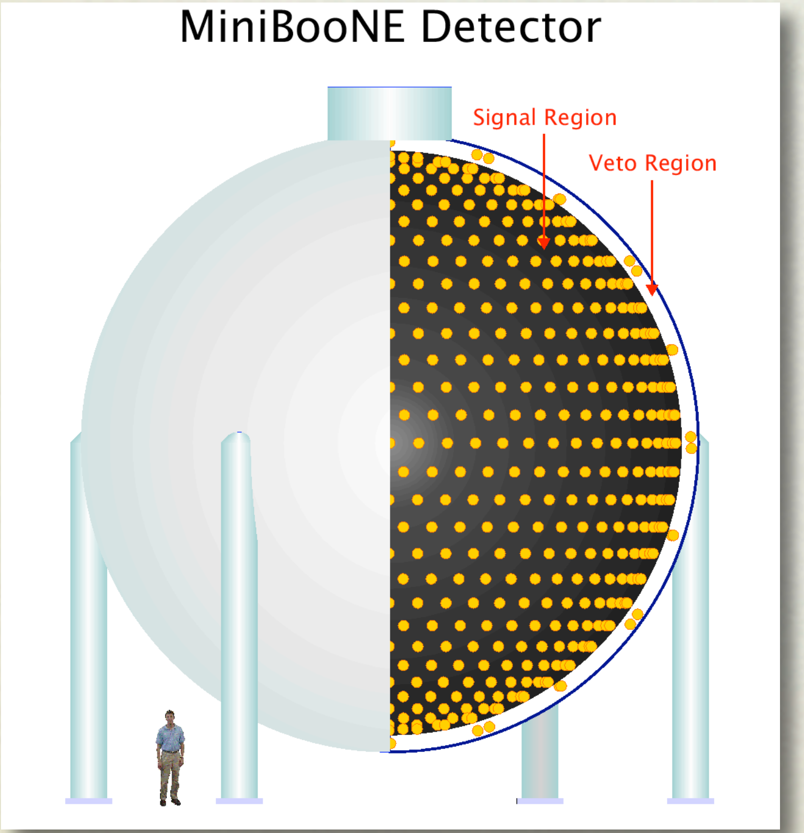
- Started beam data taking on July 2007
- Data taking completed in August 2008
- Stable data taking
- Tatal 2.52×10^{20} POT for analysis (95% of delivered)
  - Neutrino: 0.99×10^{20} POT
  - Anti-Neutrino: 1.53×10^{20} POT



Analysis of full neutrino data set are presented today

MiniBooNE Detector

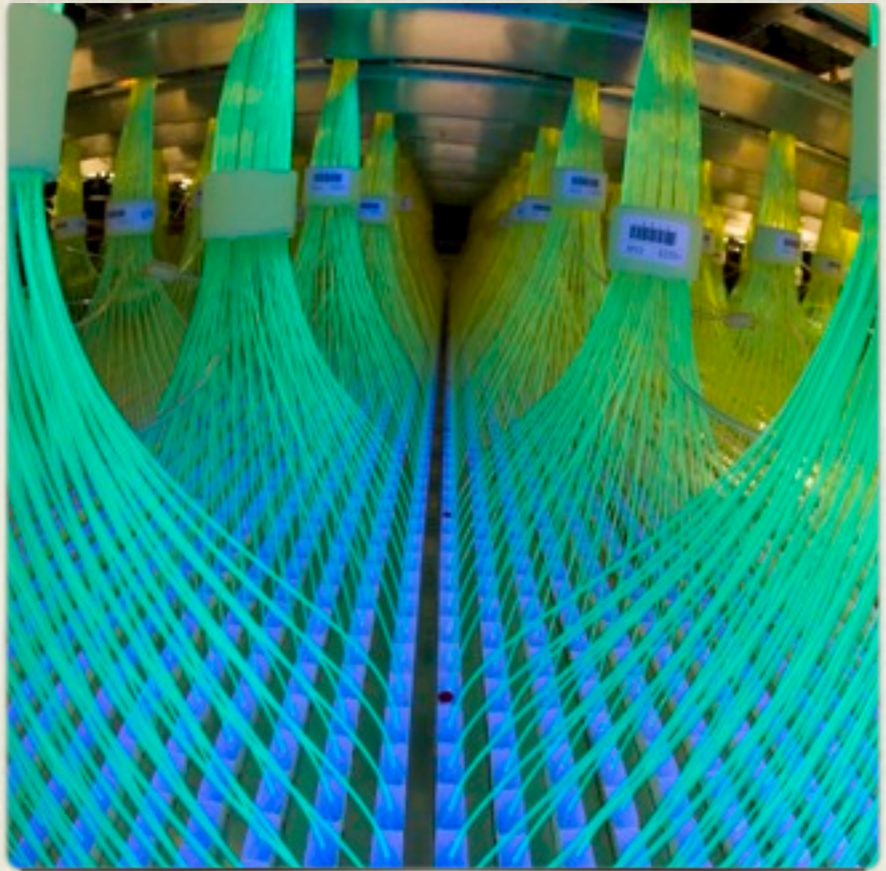




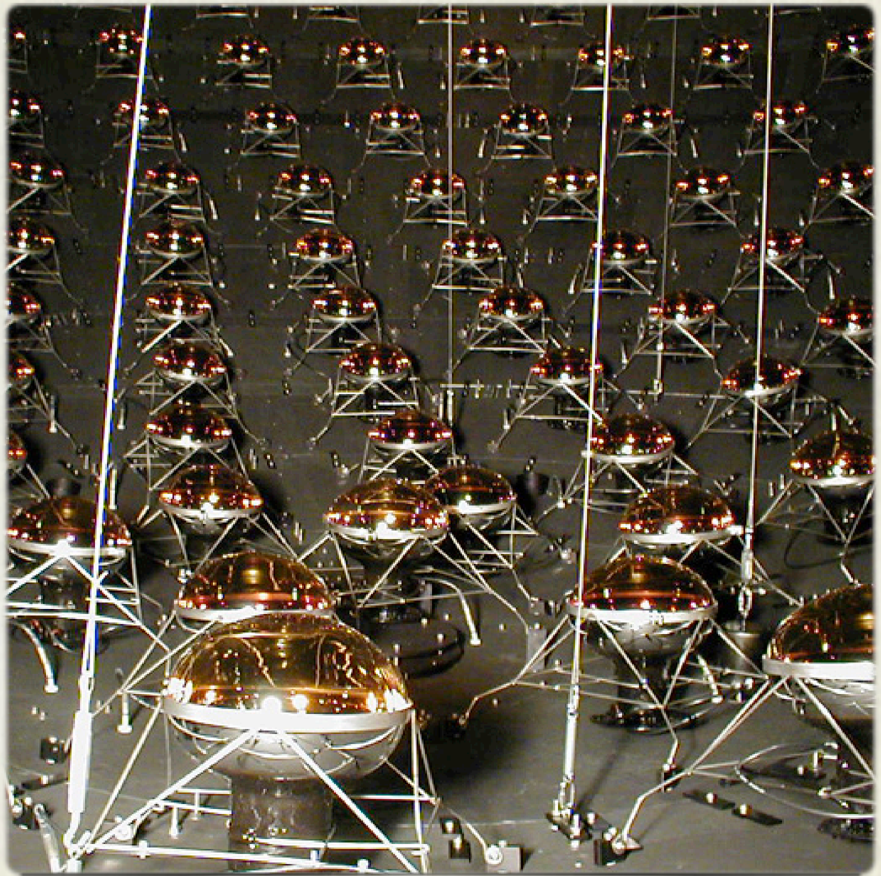
- Mineral oil Cherenkov detector
  - Select ν_μ by single muon and its decay-electron signal.
- Total mass: ~1k ton
- Main component: CH_2
- Taking beam data since 2002
  - 5.58×10^{20} POT (neutrino mode) + SB-MB overlap

2 detectors share the beam and the target material (both carbon)

Most of the systematic error cancels



SciBar detector at SciBooNE



MiniBooNE Detector

Oscillation Analysis

Analysis Overview

SciBooNE

2 Independent Analyses

Step-by-step

SciBooNE Data

↓ Spectrum fit

SciBooNE True E_ν

↓ Far/Near ratio

MiniBooNE True E_ν

↓

MiniBooNE Rec. E_ν Prediction

↕ Oscillation Fit

MiniBooNE Rec. E_ν Data

Advantage: Can see what physically happening and error size at each step

Simultaneous fit

SB + MB Rec. E_ν Data

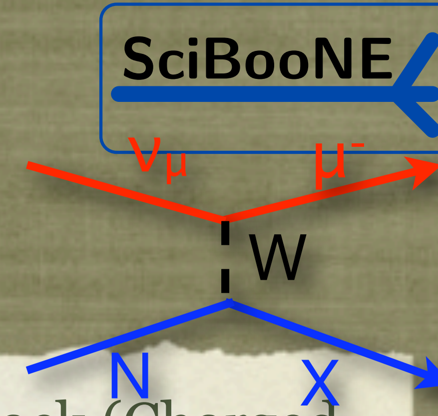
↕ Oscillation Fit

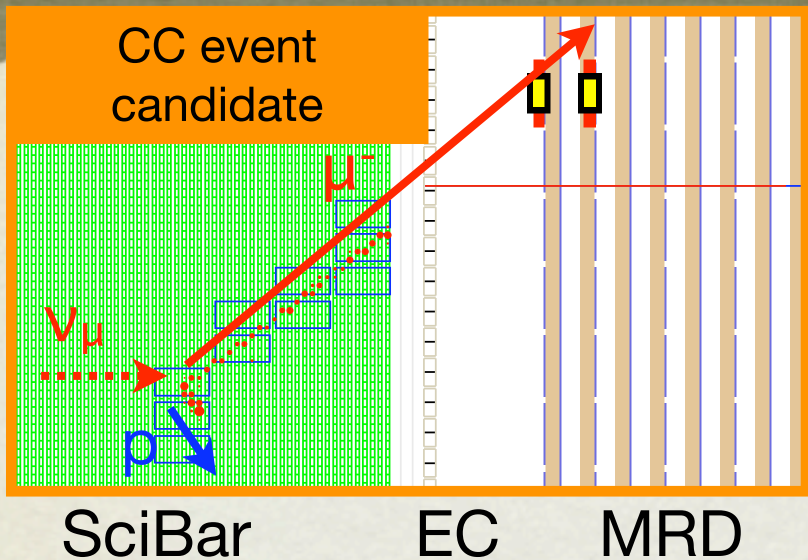
SB + MB Rec. E_ν Prediction

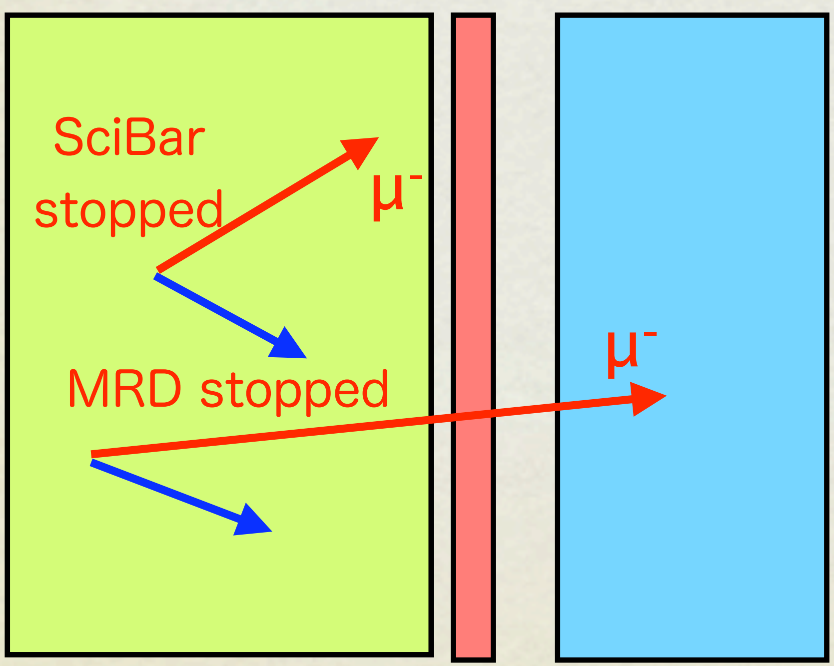
Advantage: Can include all correlation and minimize the systematic error

This talk will focus on "Step-by-step" analysis

SciBooNE ν_μ Selection

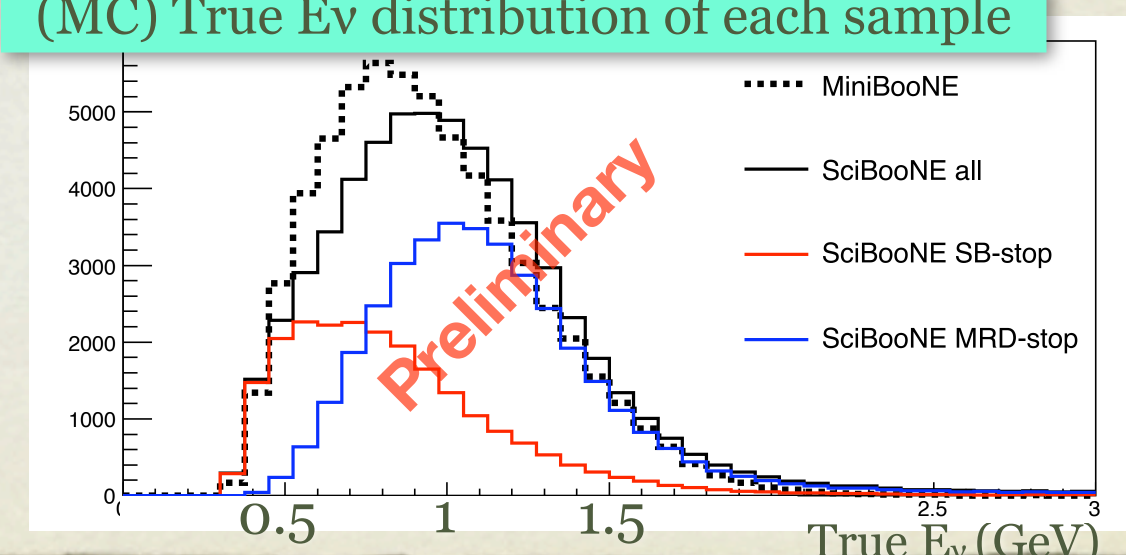


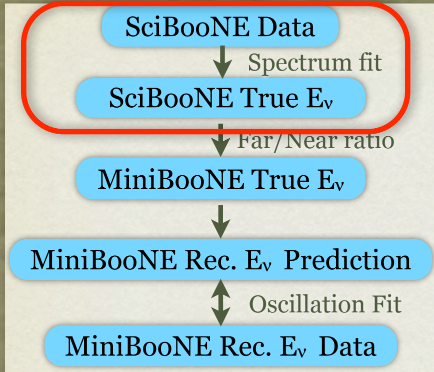




- Select events with muon track (Charged current inclusive sample)
- Muon selection
  - Muon-like energy deposit in SciBar
  - Require tracks stopped in the detectors
  - Require momentum > 0.25 GeV

(MC) True Eν distribution of each sample

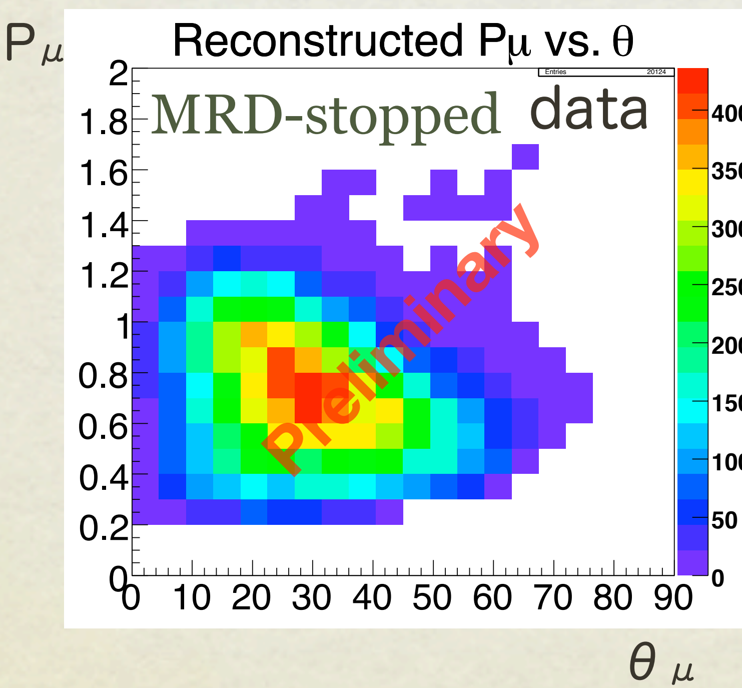




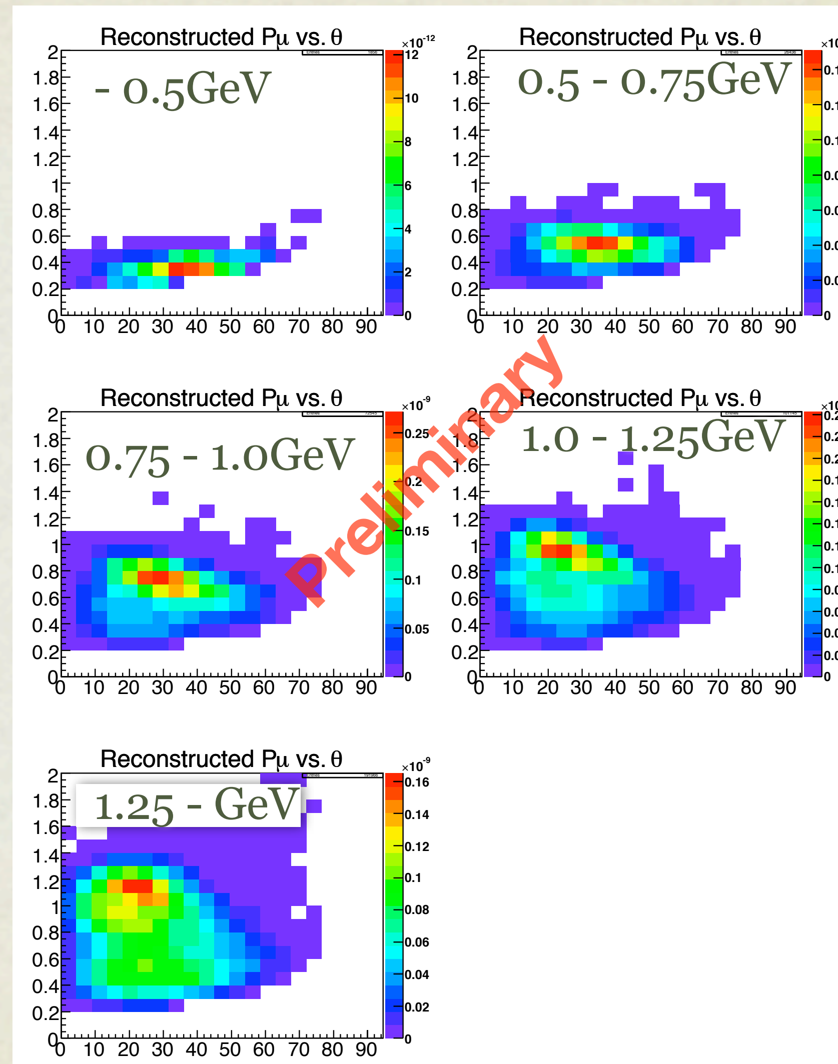
SciBooNE Spectrum Fitting (1)

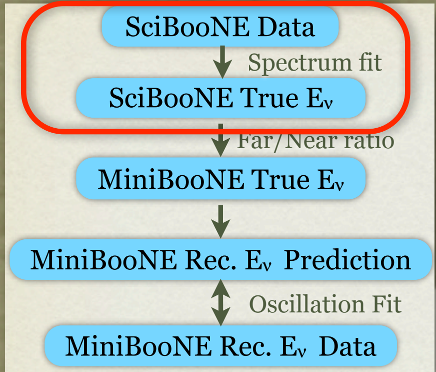
P_μ: Muon momentum reconstructed by its path-length
θ_μ: Muon angle w.r.t. beam axis

- Fit P_μ vs. θ_μ distributions.
- Determine MC scale factor for each true E_ν bins.



MC Templates (MRD-stopped)

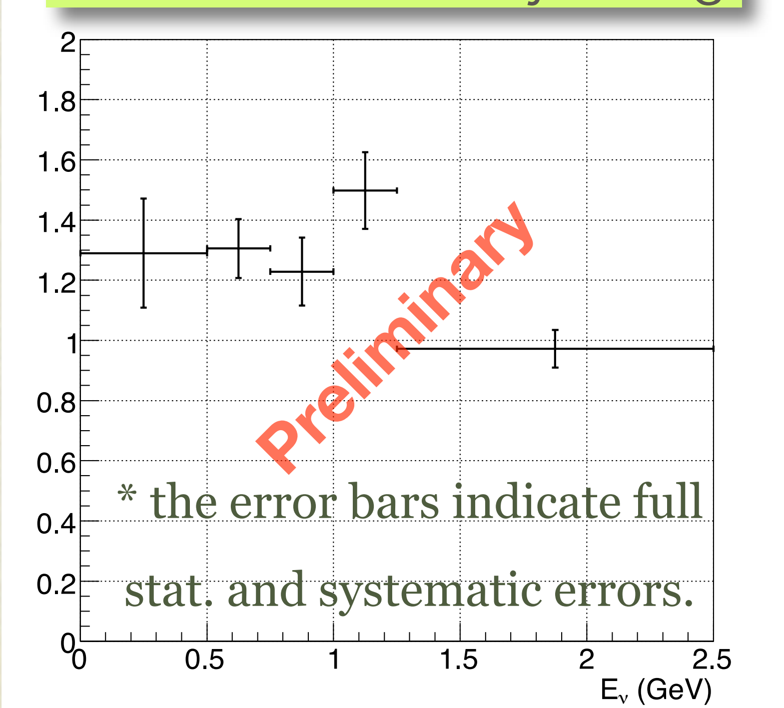




SciBooNE Spectrum Fitting (2)

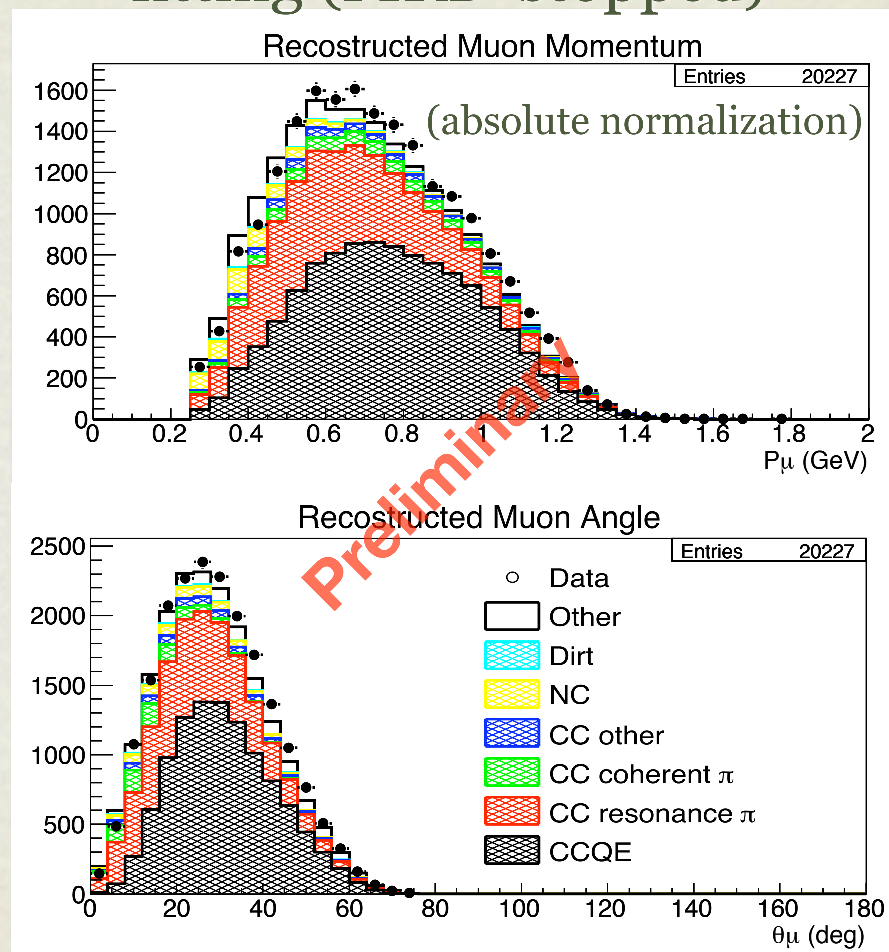
- Apply E_ν scale factor for the MC prediction.

(Absolute) E_ν scale factor obtained by fitting

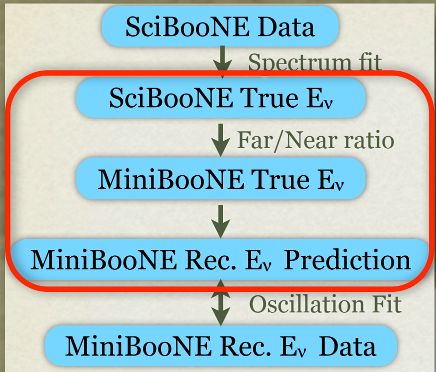


* the error bars indicate full stat. and systematic errors.

P_μ and θ_μ distribution after fitting (MRD-stopped)



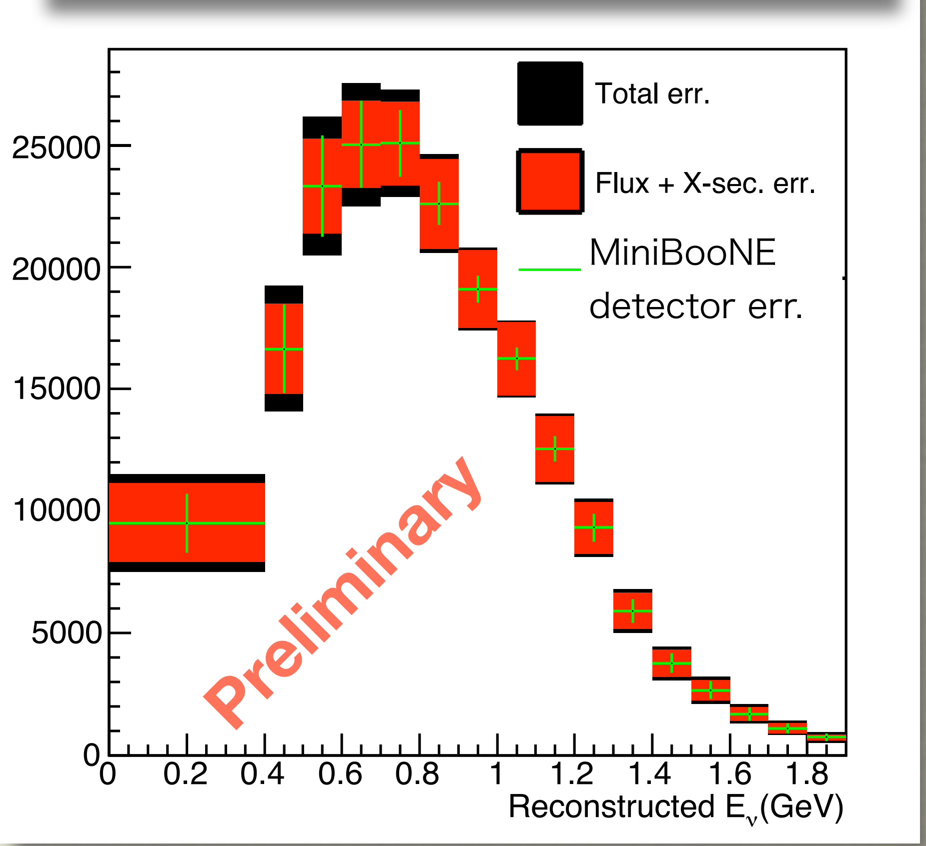
Good data and MC agreement

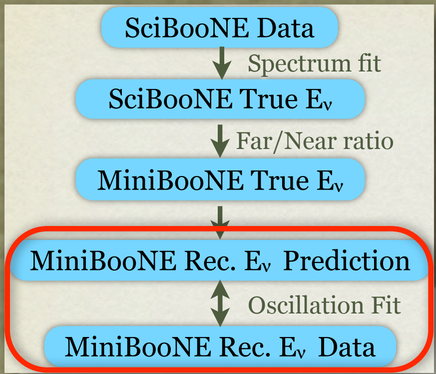


MiniBooNE Prediction

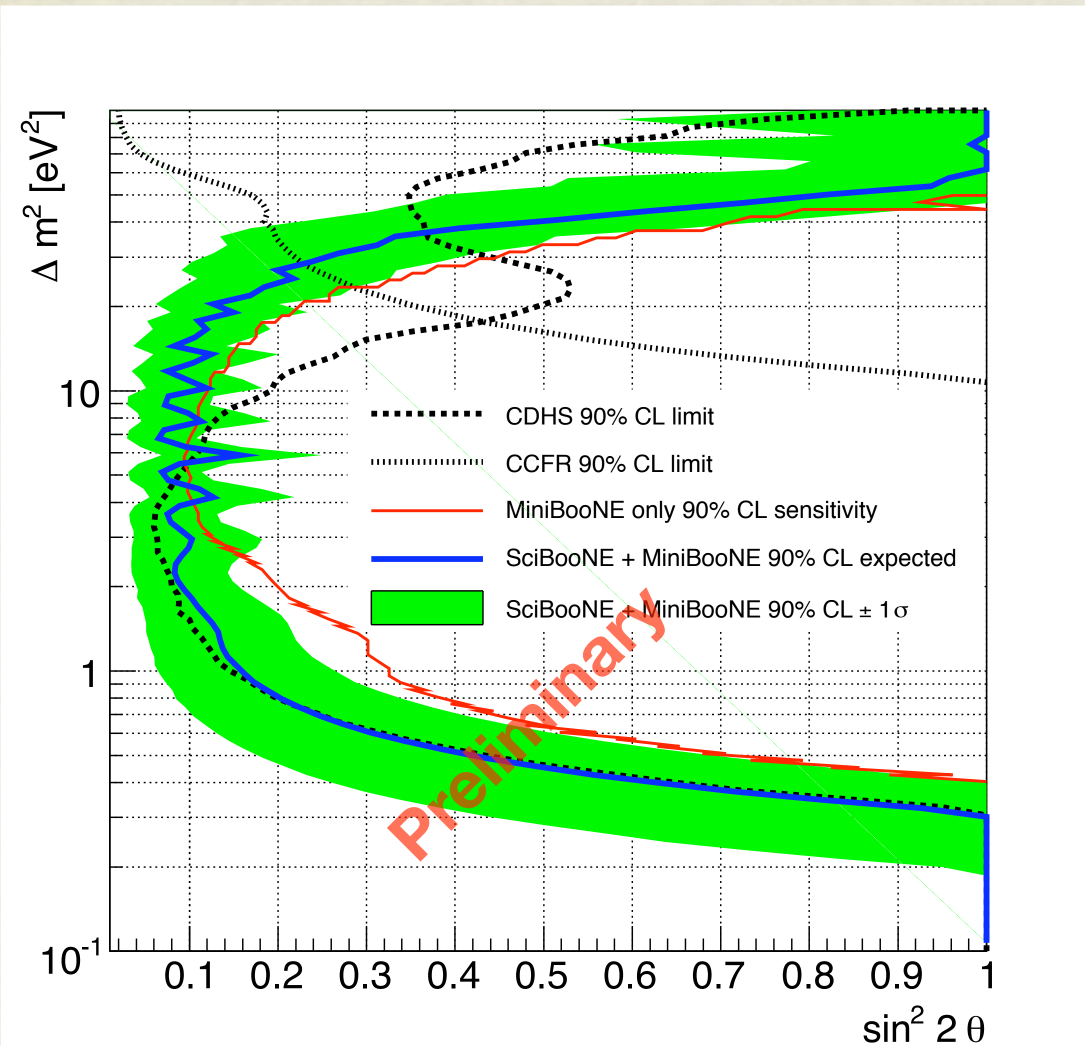
- Extrapolate measured spectrum from SciBooNE to MiniBooNE.
- Convert True E_ν → Rec. E_ν
- Systematic Errors
  - SciBooNE spectrum measurement uncertainty
  - Beam flux model
  - Cross-section model
  - MiniBooNE detector response

MiniBooNE reconstructed E_ν and its error expectation





Oscillation Sensitivity



- Sensitivity estimated by fitting simulated fake-experiments.
- Improved from MiniBooNE-only sensitivity especially at low-Δm^2 region, where absolute normalization is important.
- Final data fit result will be released soon!

SciBooNE

Summary and Prospects

- Search for neutrino disappearance at $\Delta m^2 \sim 1eV^2$
  - SciBooNE-MiniBooNE joint analysis.
  - Cover unexplored oscillation parameter region.
- Final data fit result will be released soon!
- Anti-neutrino analysis is also on-going.

Extra Slides

SciBooNE Collaboration

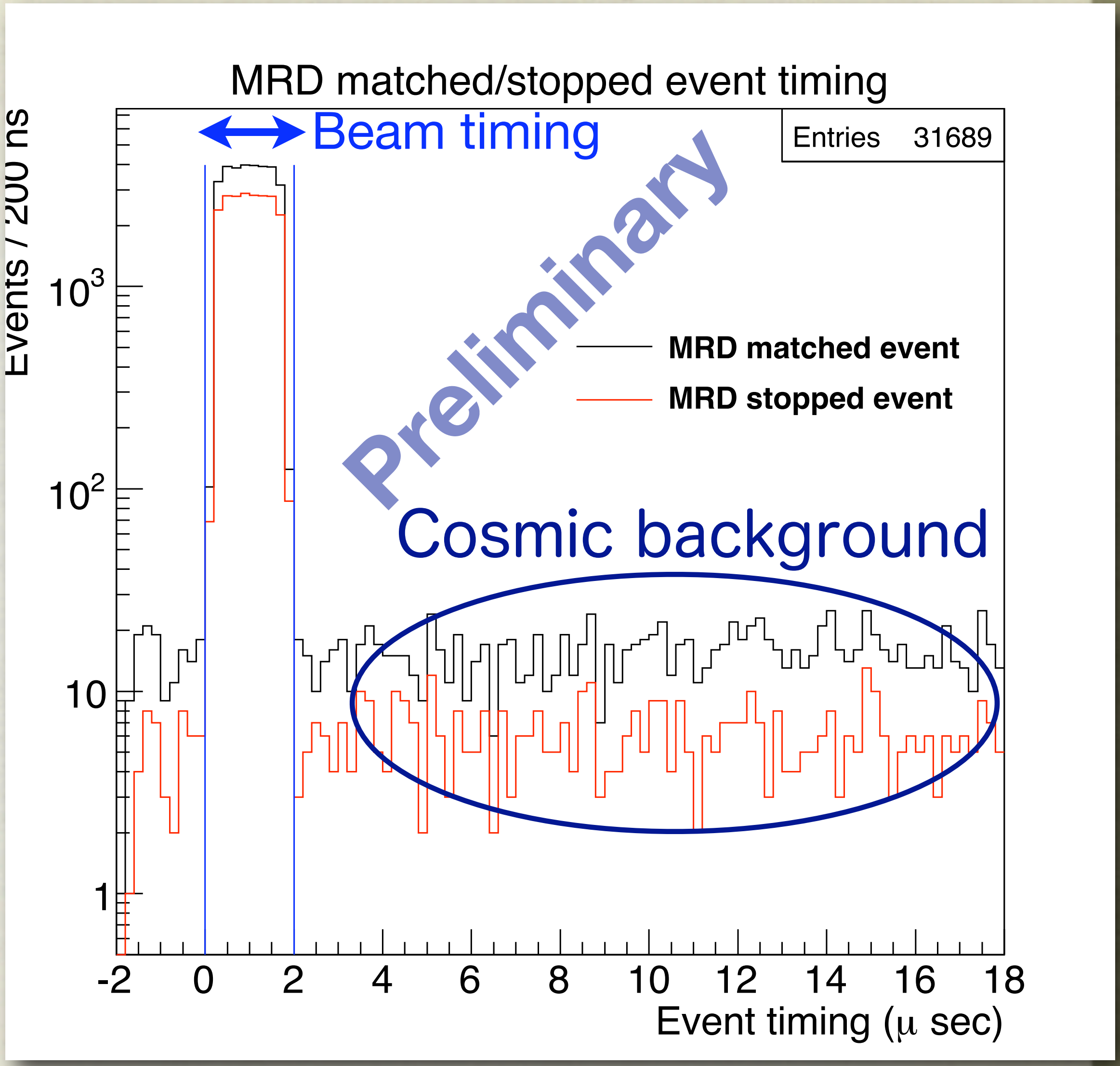
- Universitat Autonoma de Barcelona
- University of Cincinnati
- University of Colorado
- Columbia University
- Fermi National Accelerator Laboratory
- High Energy Accelerator Research Organization (KEK)
- Imperial College London*
- Indiana University
- Institute for Cosmic Ray Research
- Kyoto University*
- 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

Event Selection (Timing)

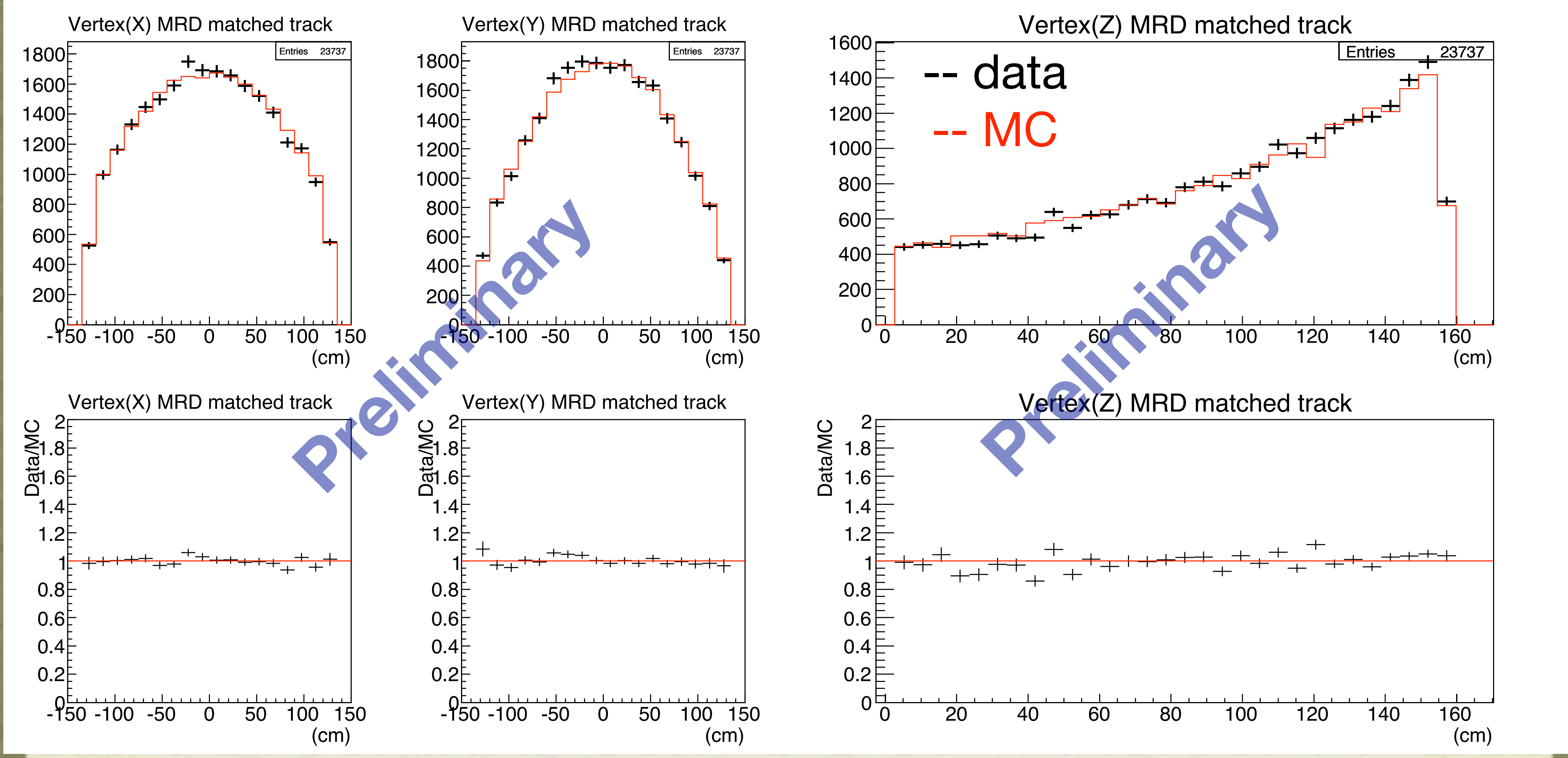
- 2 μsec beam timing window.
  - Less than 0.5% cosmic background contamination.
- ~14K SciBar-stopped events.
- ~20K MRD-stopped events.
- ~4K MRD-penetrated events.



Reconstructed Interaction Vertices

SciBooNE

MRD matched muon (relatively normalized)

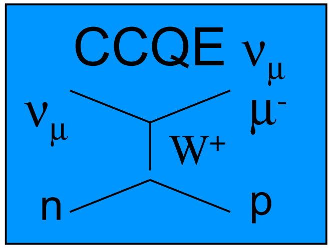


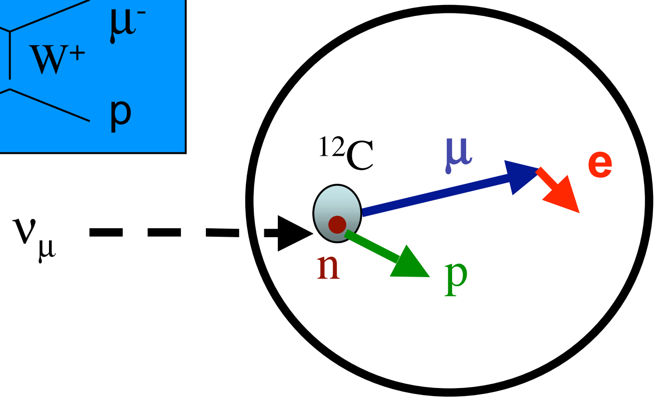
MiniBooNE ν_μ Selection

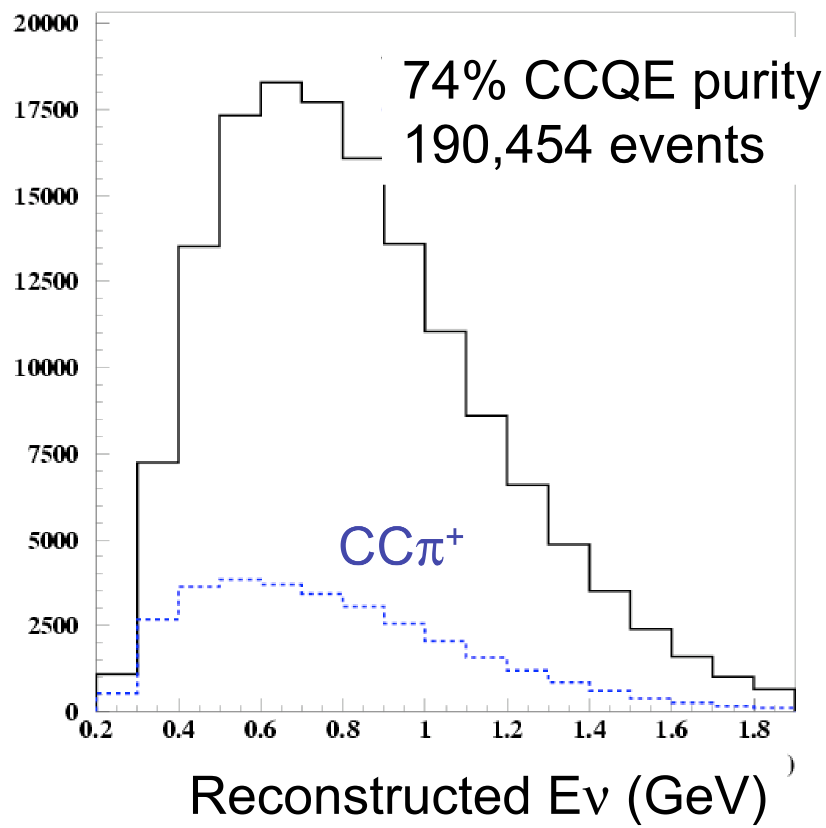
Selection of ν_μ candidates:

Tag single muon events and their decay electron

Background is $CC\pi^+$ where the pion is absorbed in nucleus or detector







22