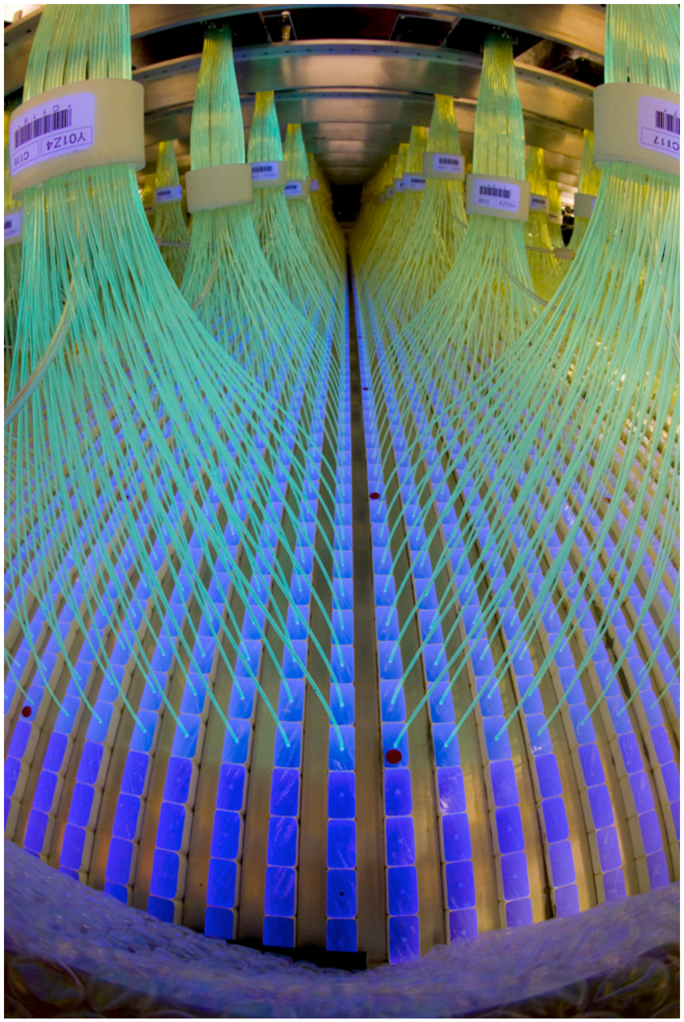
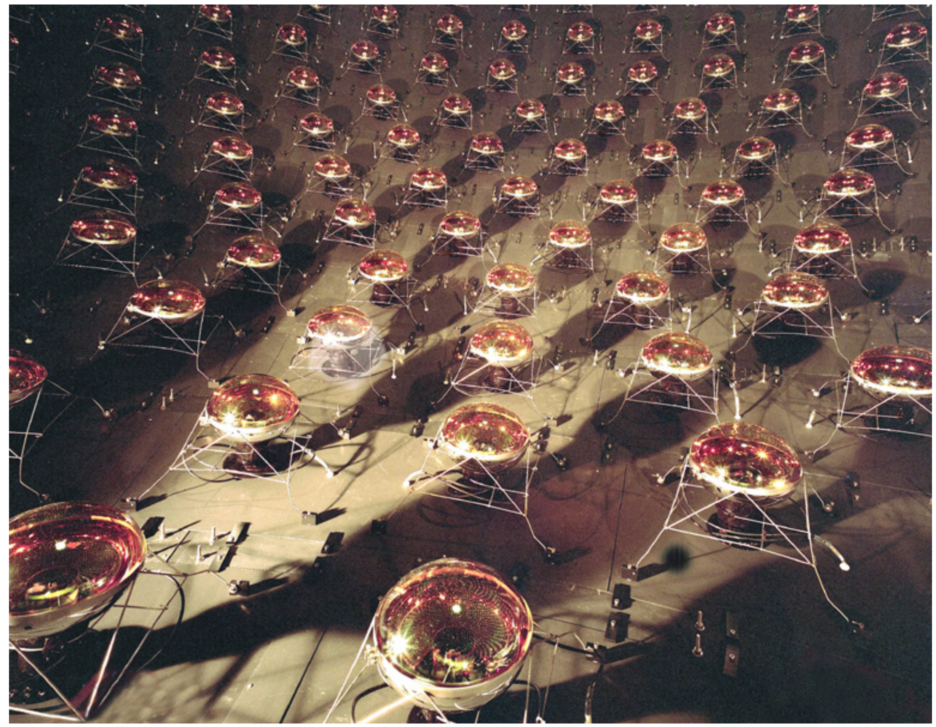
A search for ν_μ disappearance with:

SciBooNE



and

MiniBooNE



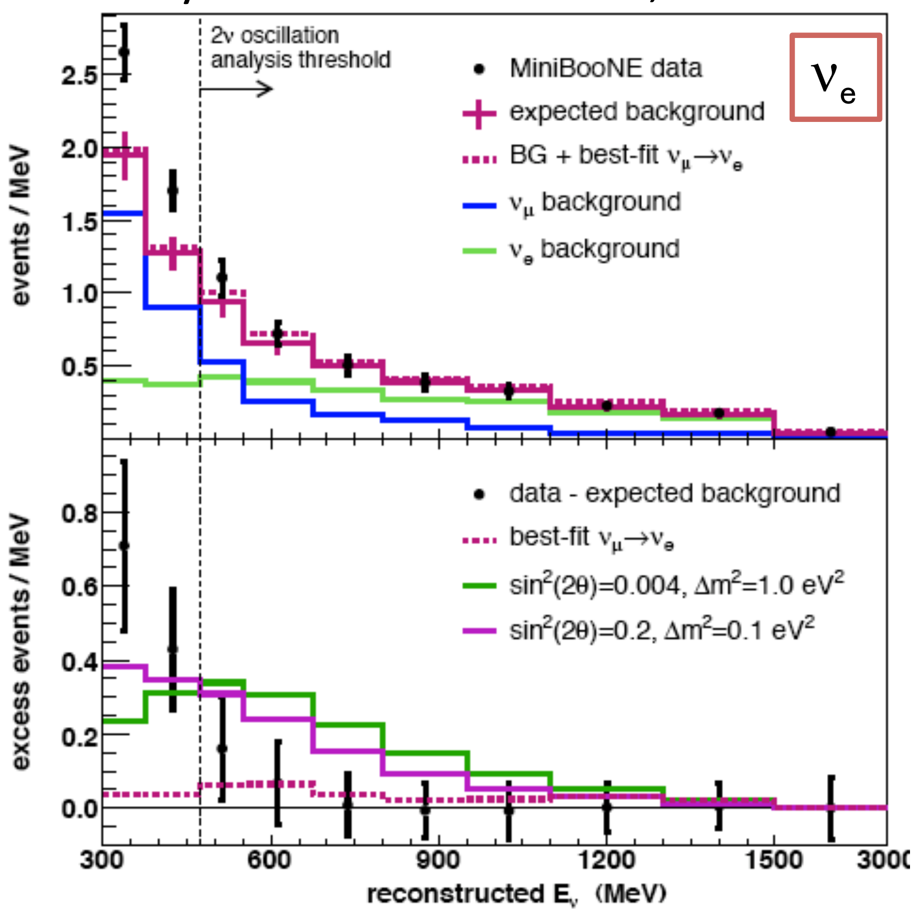
Kendall Mahn
TRIUMF
For the SciBooNE and MiniBooNE collaborations

Neutrino oscillations in 2011

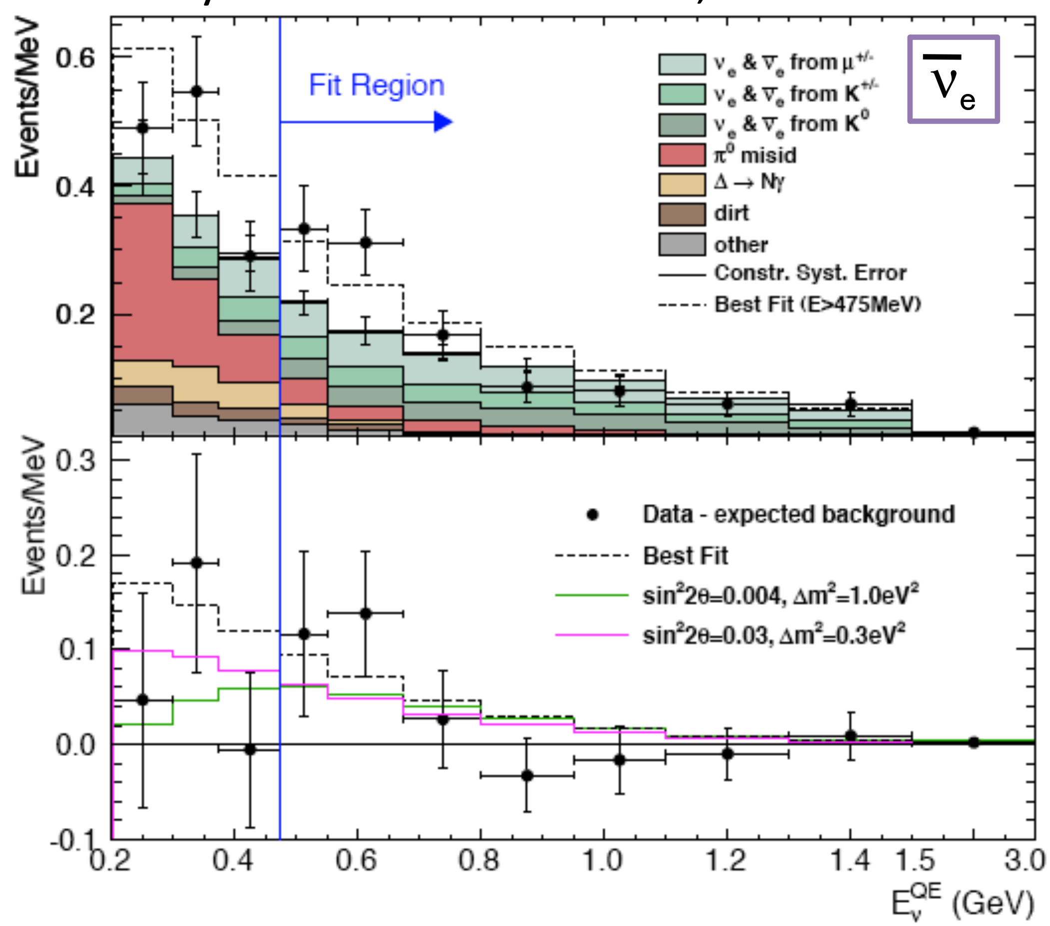
Neutrino oscillations thus far are consistent with three flavors of neutrinos which mix with the mass states according to a unitary matrix

Lack of $\nu_\mu \rightarrow \nu_e$ appearance but observation of $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ appearance at $\Delta m^2 \sim 1$ eV^2 by the MiniBooNE

Phys.Rev.Lett.98:231801,2007



Phys.Rev.Lett.105:181801,2010



ν_μ disappearance at $\Delta m^2 \sim 1\ eV^2$

Exotic physics is required to explain a difference between neutrinos and antineutrinos and the presence of an additional, large, mass splitting

Sterile neutrinos (with or without CPT violation)

G. Karagiorgi et al, Phys.Rev.D75:013011,2007. hep-ph/0609177

Barger, Marfatia, & Whisnant, Phys. Lett. B576 (2003) 303

Neutrino decay:

Palomares-Ruiz, Pascoli, Schwetz, JHEP 0509:048,2005. hep-ph/0505216

Extra dimensions:

Pas, Pakvasa, Weiler, Phys.Rev.D72:095017,2005. hep-ph/0504096

New, light gauge boson:

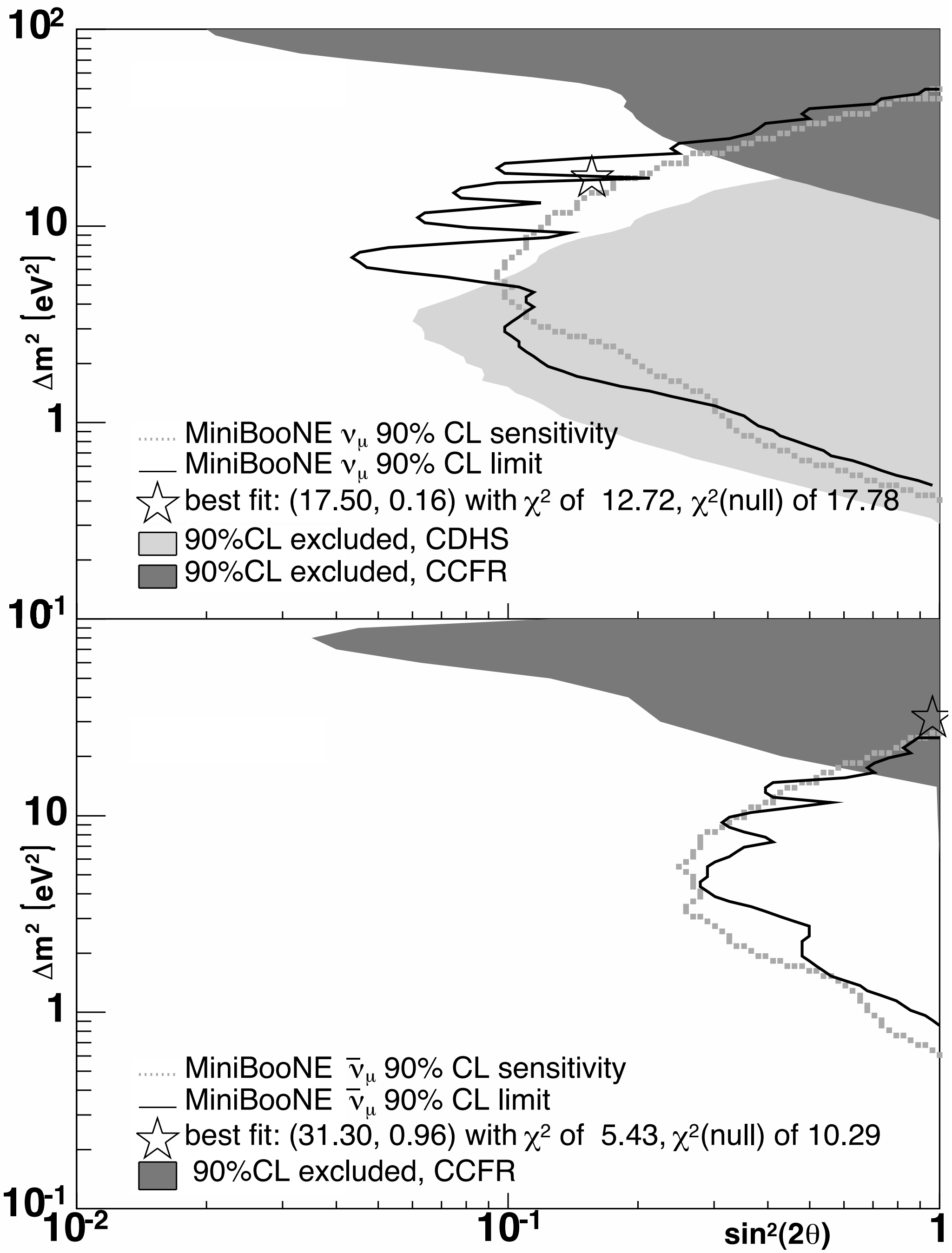
Nelson, Walsh Phys .Rev. D77 033001 (2008) hep-ph/0711.1363

Searches for $\nu_\mu \rightarrow \nu_s$ disappearance test the same physics as $\nu_\mu \rightarrow \nu_s \rightarrow \nu_e$ appearance

An observation of ν_μ disappearance at $0.1 < \Delta m^2 < 100\ eV^2$ would clarify the nature of any new physics

A lack of disappearance in the region would constrain new physics models

Existing measurements of ν_μ disappearance



Phys.Rev.Lett.103:061802,2009

MiniBooNE, CDHS, CCFR experiments observe no ν_μ disappearance (90%CL)

MiniBooNE, CCFR experiments observe no $\bar{\nu}_\mu$ disappearance (90%CL)

MiniBooNE-only results limited by neutrino flux and neutrino interaction uncertainties

Constrain these with a set of near detectors: SciBooNE
Same beamline, same neutrino target

The Booster Neutrino Experiments (BooNEs)

8 GeV/c protons from the Fermilab Booster strike a Be target

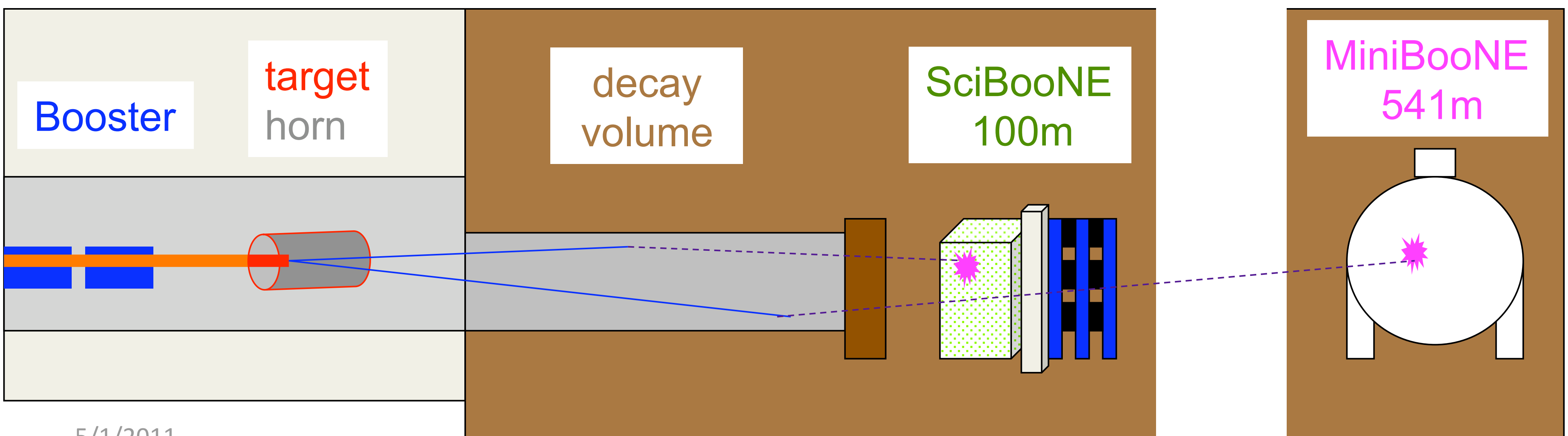
Pions and kaons are produced which decay to produce a neutrino beam

100m from the target are the SciBooNE detectors:

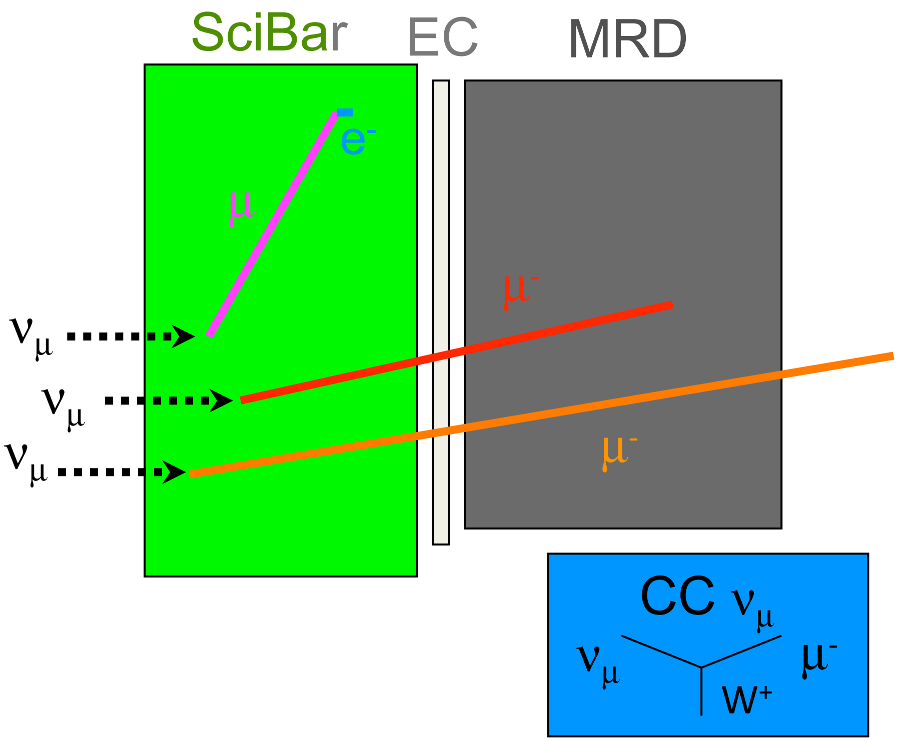
- 14,336 scintillator bar detector read out with WLS fibers attached to 64 channel MA-PMTs (SciBar)
- Lead and scintillator fiber electromagnetic calorimeter (EC)
- Iron and scintillator counter muon range detector (MRD)

541m from the target is the MiniBooNE detector

- 1kton mineral oil Cherenkov detector
- 1240 inner PMTs, 240 veto PMTs



Selecting CC ν_μ interactions in SciBooNE

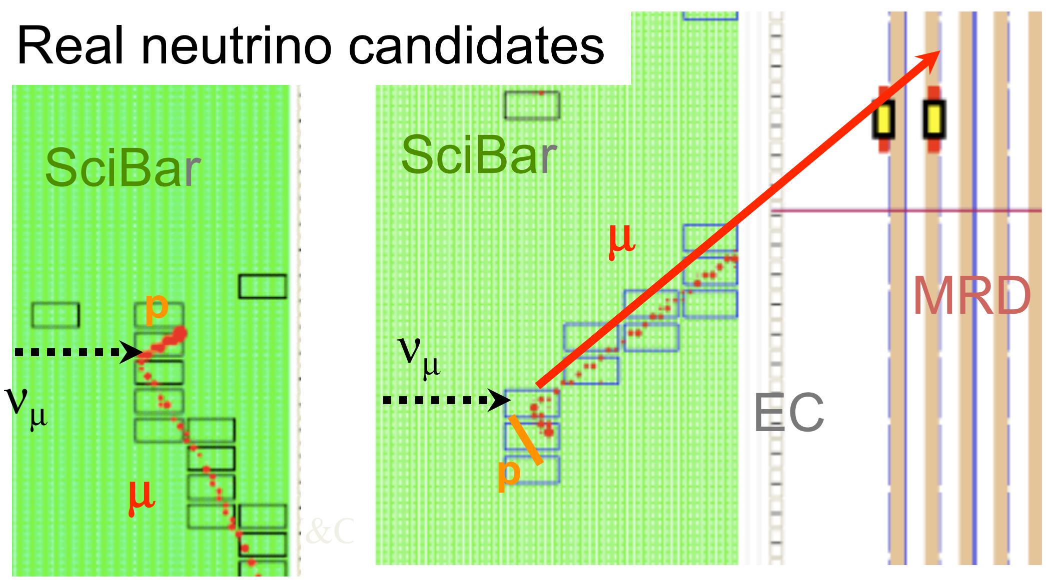


- Select events with the highest momentum track with a vertex in SciBar fiducial volume which pass data quality, beam timing cuts
- Events which also end in SciBar: "SciBar contained"

  Use energy loss in scintilator to select muon-like tracks

  p_μ>250 MeV/c reduces NC events

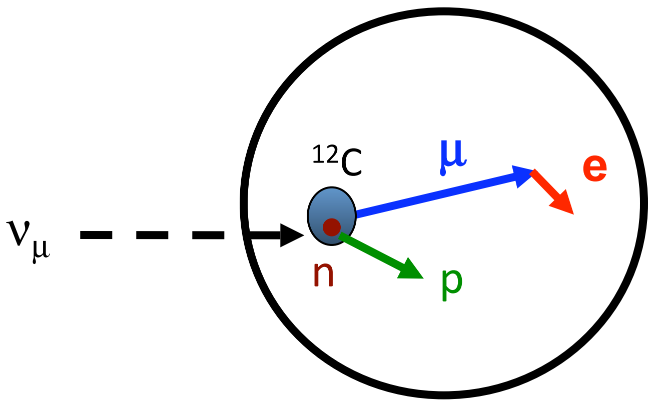
Real neutrino candidates



- Events which stop in the MRD: "MRD Stopped"
- Events which exit the end of the MRD: "MRD Penetrated"

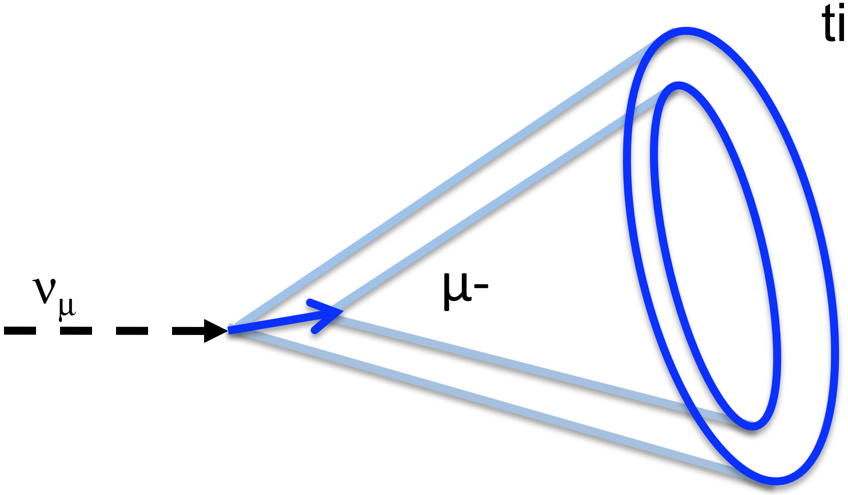
  Angular information only

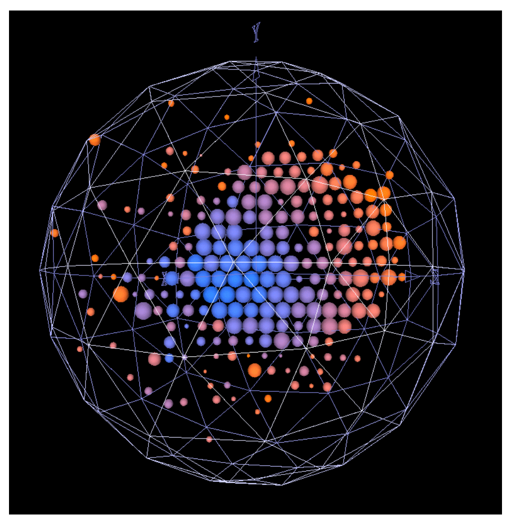
Selecting CCQE ν_μ interactions in MiniBooNE



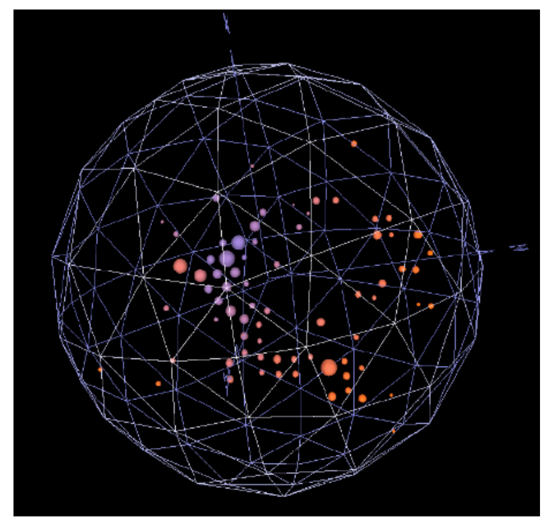
Tag single muon events and their decay electron

- Events produce Cherenkov light recorded by PMTs as hits (charge, time)
- Two sets of hits separated in time (**μ**, e)
- Minimal hits in the veto
- Require 1st set of hits above decay electron energy endpoint, 2nd set of hits below
- Endpoint of 1st track consistent with vertex of 2nd track
- Also require events within fiducial volume, beam timing and data quality selections





muon candidate



electron candidate

Disappearance analysis strategy

Use the CC ν_μ rate measured at SciBooNE to constrain the MiniBooNE ν_μ rate and test for disappearance

Two analysis methods:

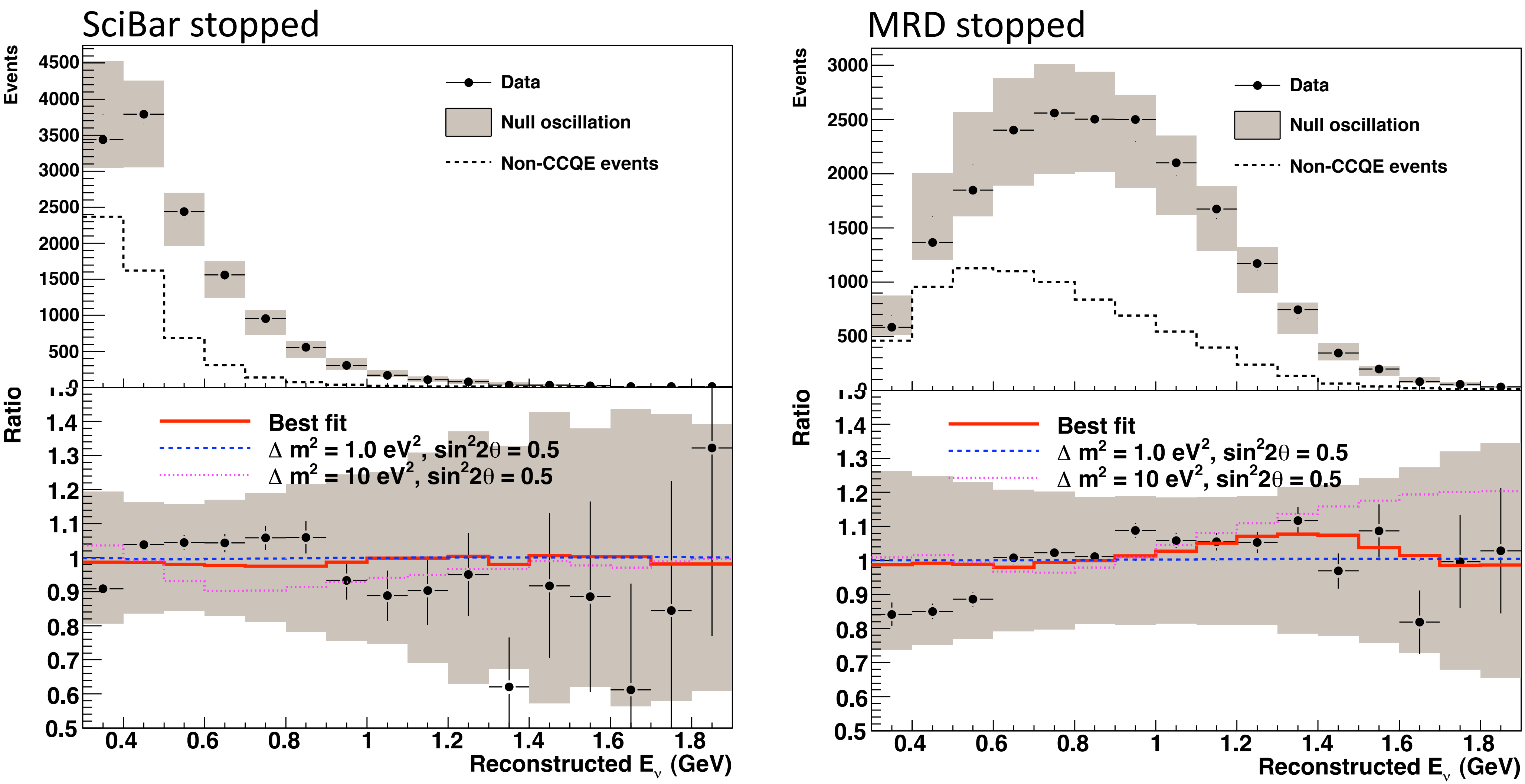
<u>Simultaneous fit</u>

1) Fit SciBooNE and MiniBooNE data simultaneously for oscillation
2) Constraint applied within fit, effectively removes systematic uncertainties shared by both detectors

<u>Spectrum fit</u>

1) Extract neutrino energy spectrum from SciBooNE data
   Phys.Rev.D83:012005,2011
2) Apply correction to MiniBooNE energy spectrum
3) Fit for oscillation at MiniBooNE
4) Systematics reduced by extraction process

SciBooNE CC ν_μ data set



First, test agreement of SciBooNE datasets

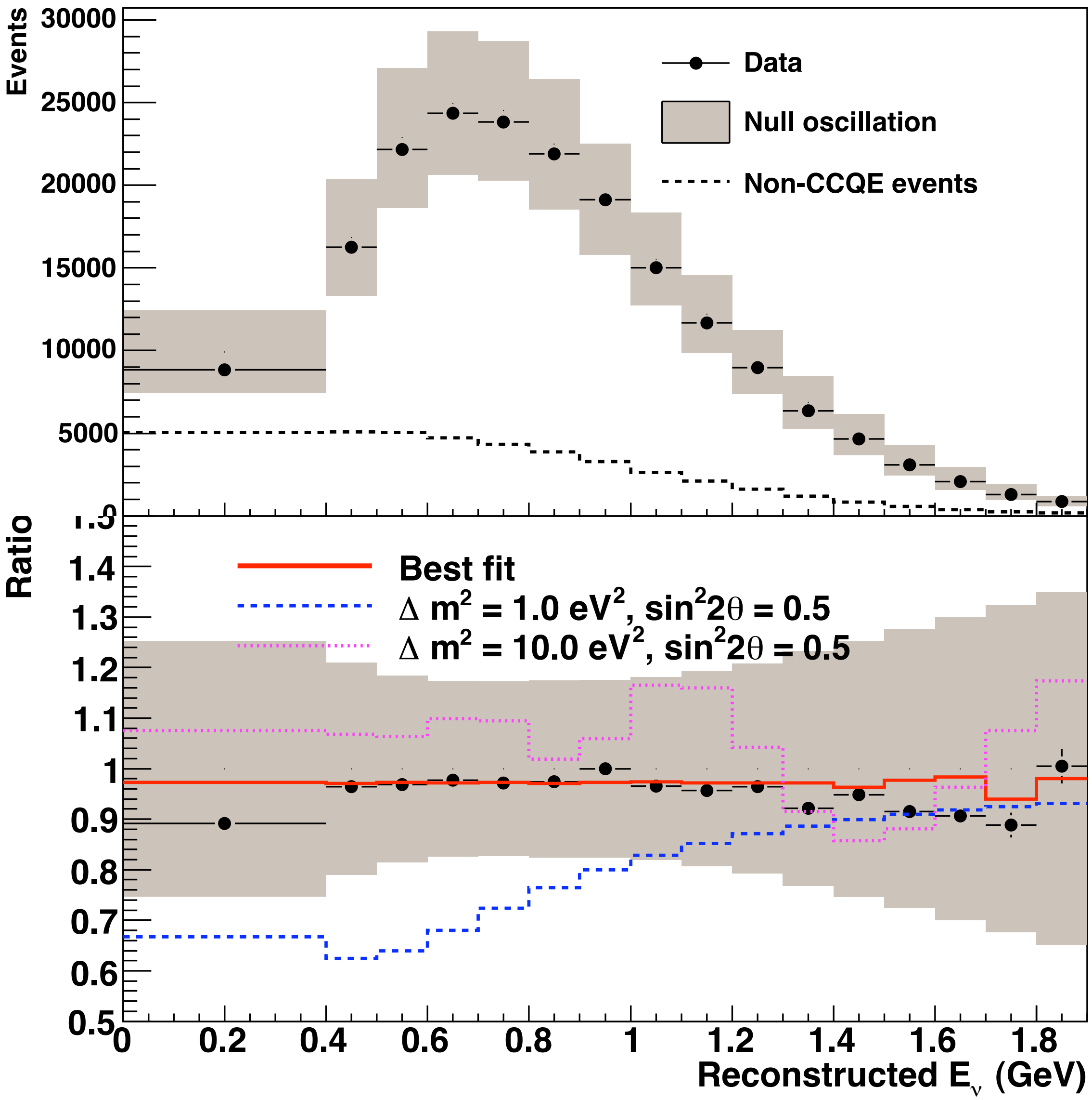
Above $\Delta m^2 > 2$ eV^2 , oscillation is possible at SciBooNE

No evidence for oscillation at SciBooNE

Uncertainties include neutrino flux, cross section and detector uncertainties

MiniBooNE CCQE ν_μ data set

MiniBooNE CCQE ν_μ data set
+ prediction (no oscillation)



Fit 16+16+16 bins in total = 48

χ^2 (null) = 45.1/ 48 (DOF)
χ^2 (best) = 39.5/ 46 (DOF)
At $\Delta m^2 = 43.7$ eV^2, $\sin^2 2\theta = 0.60$

$\Delta\chi^2 = \chi^2(\text{null}) - \chi^2(\text{best}) = 5.6$

$\Delta\chi^2$ (90% CL, null) = 9.3

Feldman Cousins frequentist technique used to determine $\Delta\chi^2$ statistic

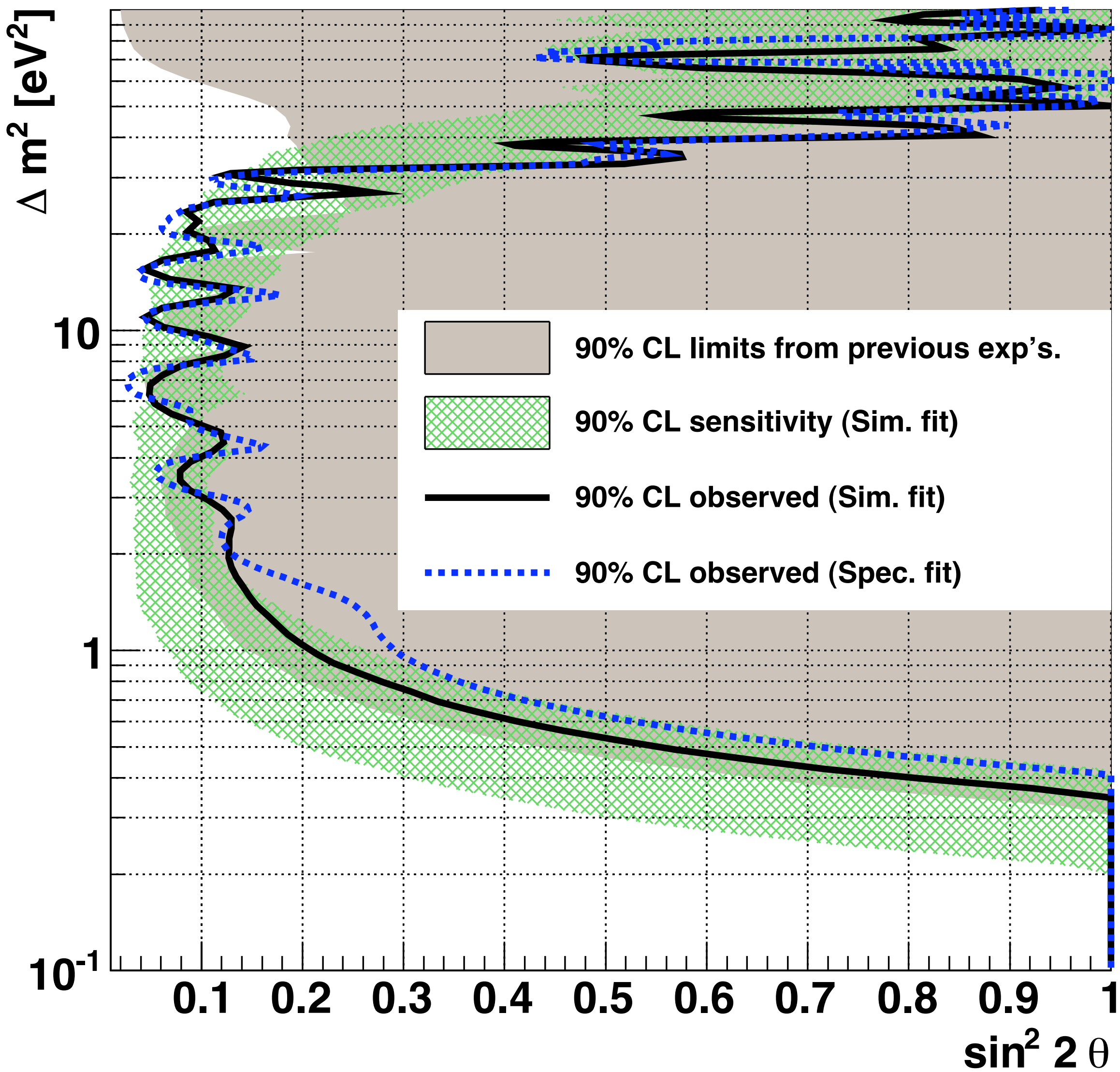
Results of ν_μ disappearance fit

Limits for simultaneous fit (black) and spectrum fit (blue)

Green hatched region indicates 68% of 90%CL limits to fake data with no underlying oscillation

Average of these limits is sensitivity, comperable for both analysis methods

Largest uncertainty is MiniBooNE detector systematics



<u>No disappearance at 90% CL observed for either method</u>

Conclusion

First joint venture of the SciBooNE and MiniBooNE experiments

A fit to SciBooNE and MiniBooNE data is consistent with no muon neutrino disappearance at 90%CL

- Two complementary methods have consistent results
- New exclusion region between $10 < \Delta m^2 < 30$ eV^2
- Provides additional constraints on exotic physics models, such as sterile neutrinos

SciBooNE took antineutrino data which will be used for a joint SciBooNE-MiniBooNE $\bar{\nu}_\mu$ disappearance analysis

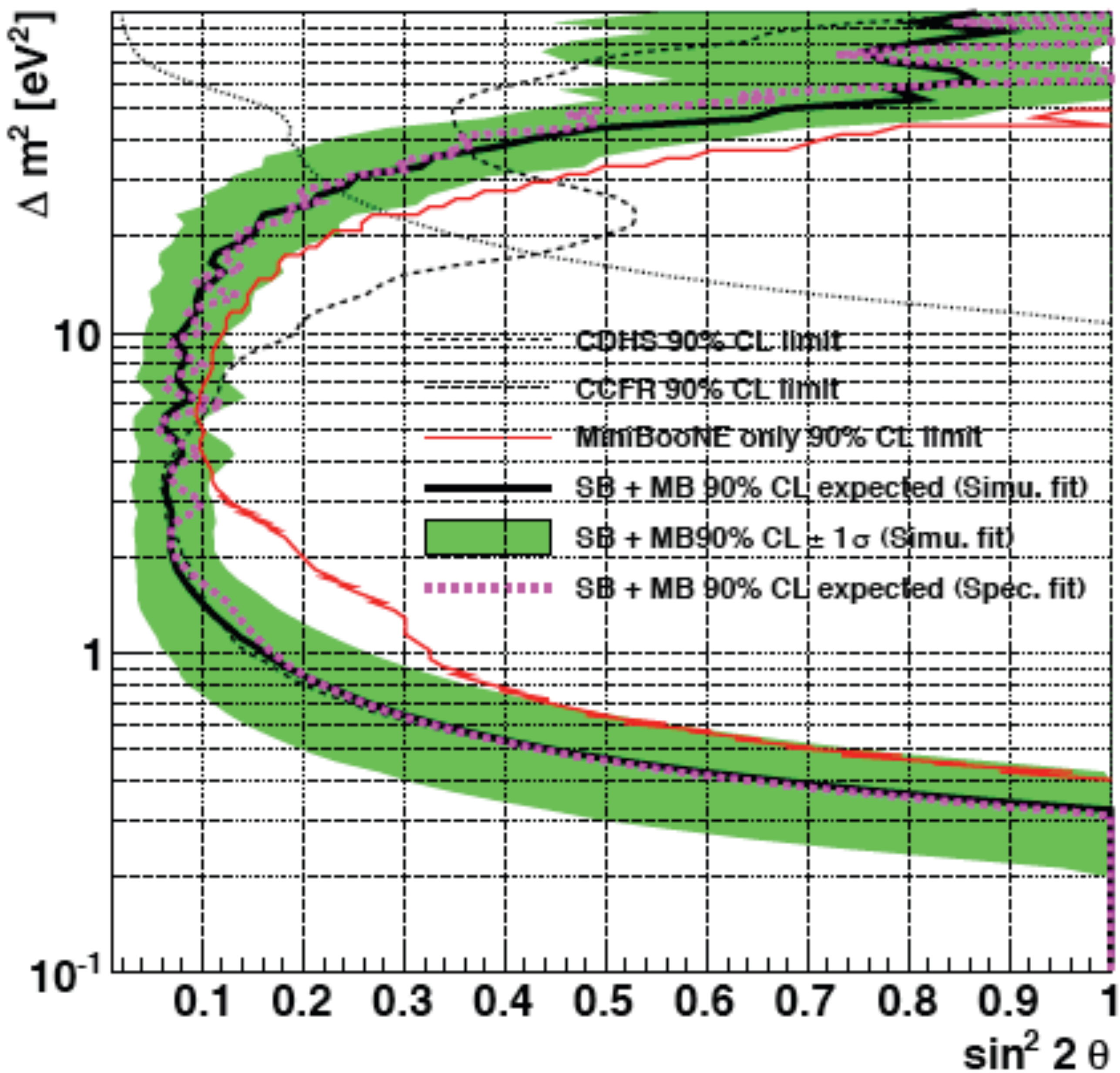
Backup slides

Sensitivity

Improvement over previous MiniBooNE-only analysis sensitivity

Two methods have similar sensitivities

Slightly better sensitivity for simultaneous fit



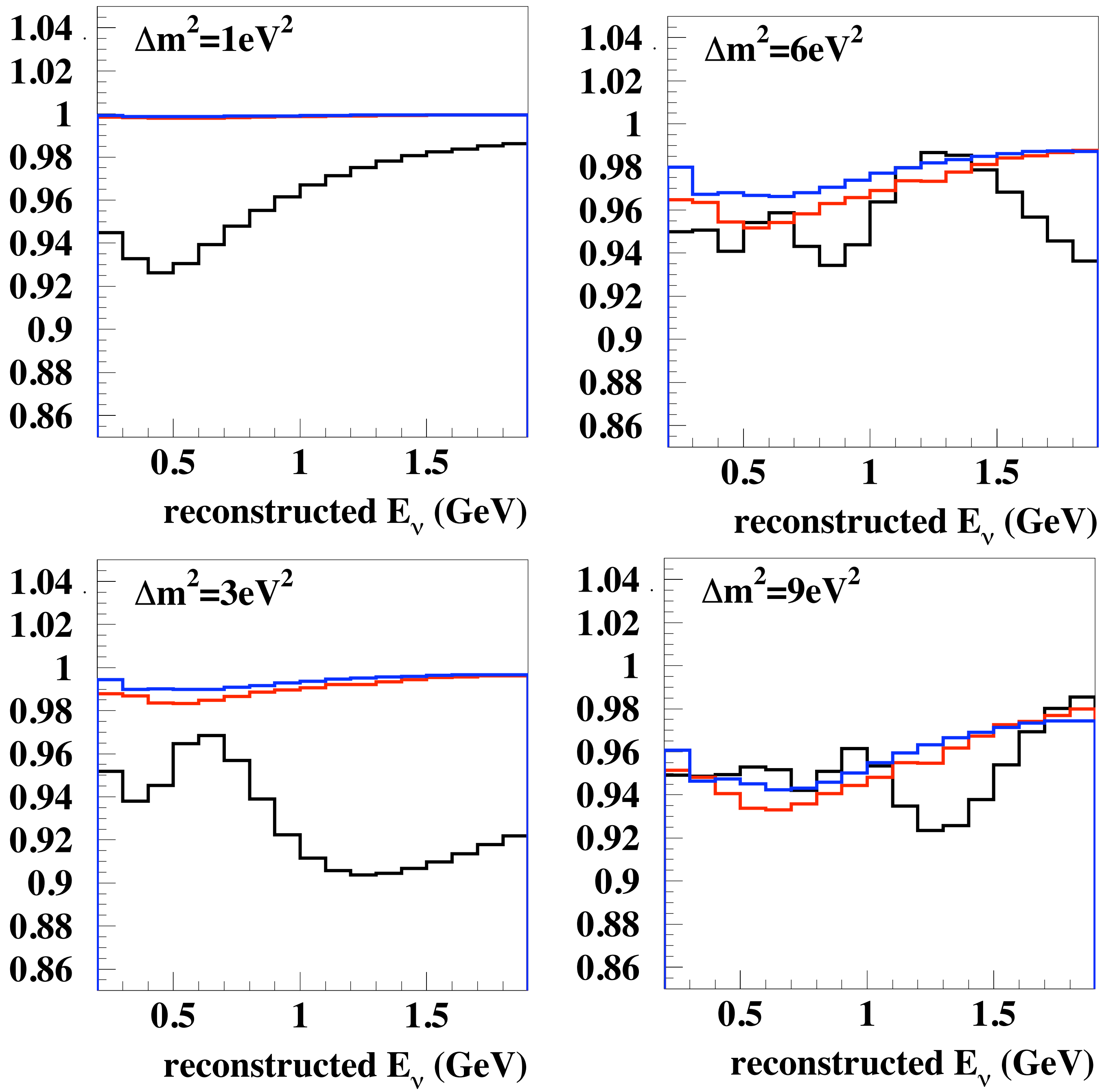
Oscillation probability

MiniBooNE CCQE ν_μ

SciBooNE MRD stopped

SciBooNE SciBar stopped

Oscillation at $\sin^2 2\theta = 0.10$
Includes range in L present at each detector



Spectrum fit method

Best fit: $\Delta m^2 = 41.5\ eV^2$
$\sin^2 2\theta = 0.51$

χ^2 (null) = 41.5/ 32 (DOF)
χ^2 (best) = 35.6/ 30 (DOF)

$\Delta\chi^2 = \chi^2(\text{null}) - \chi^2(\text{best}) = 5.9$

$\Delta\chi^2$ (90% CL, null) = 8.4
Estimated from frequentist techniques

No significant oscillation observed

MiniBooNE CCQE ν_μ dataset
+ prediction corrected from SciBooNE datasets (spectrum fit, reduced errors)