Sterile neutrino searches in US

Žarko Pavlović
Los Alamos National Laboratory

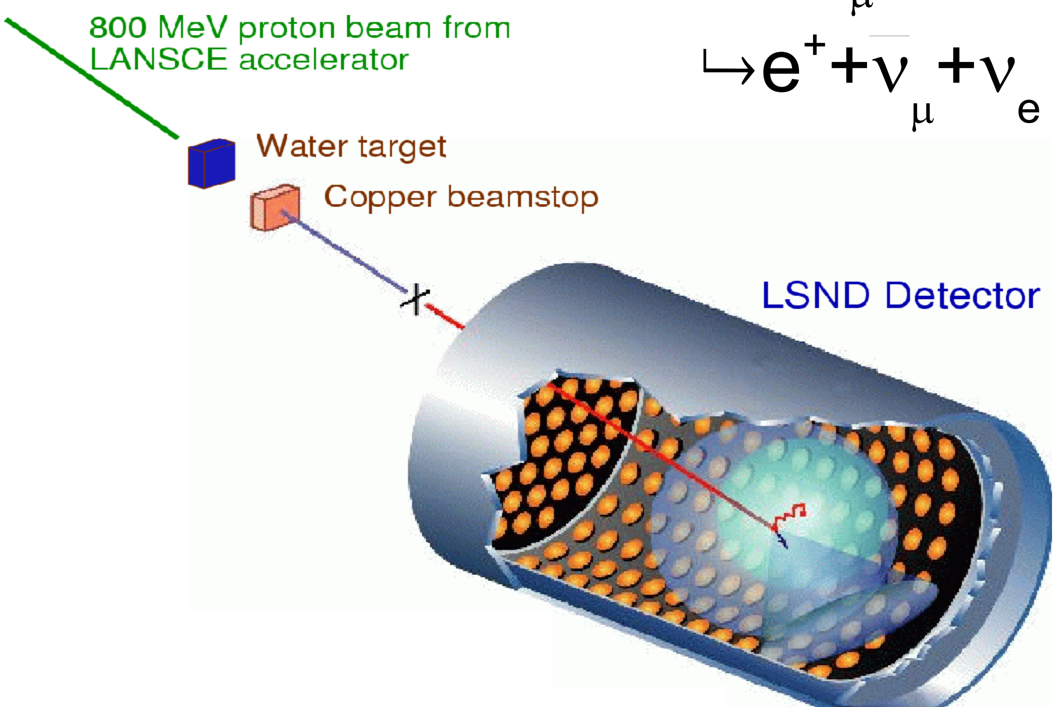
NuFact 2013 – IHEP, Beijing, China

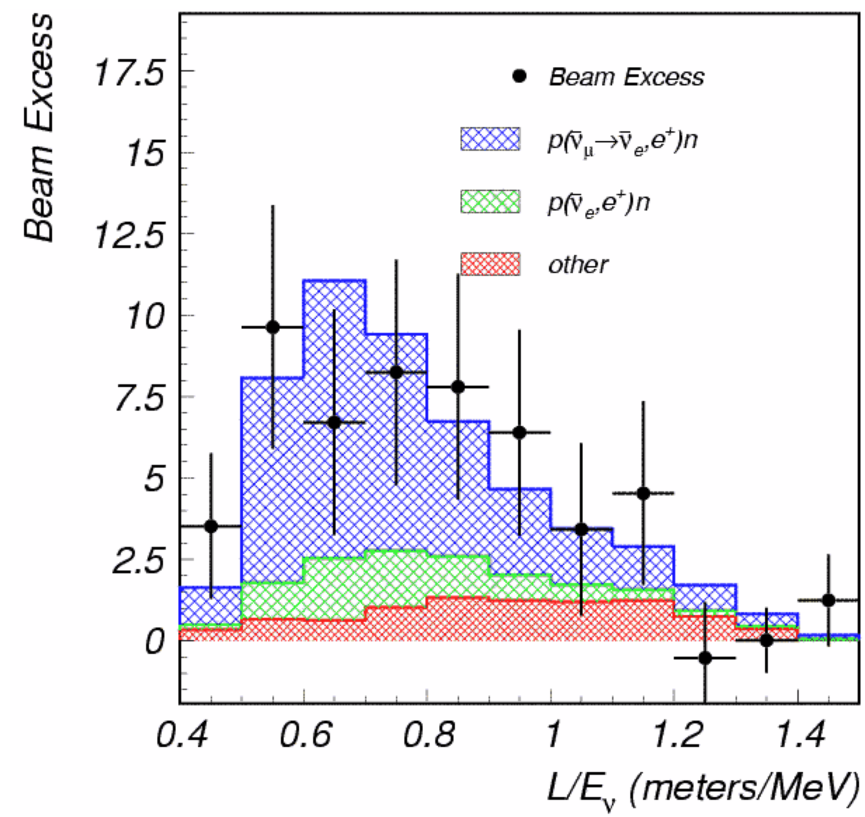
Quick overview of past results

LSND experiment

- Excess of $\bar{\nu}_e$ events in $\bar{\nu}_\mu$ beam : $87.9 \pm 22.4 \pm 6$ (3.8σ)
- $\bar{\nu}_e$ signature: Cherenkov light from e^+ with delayed n-capture
- Stopped pion beam

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$
$$\hookrightarrow e^+ + \bar{\nu}_\mu + \nu_e$$

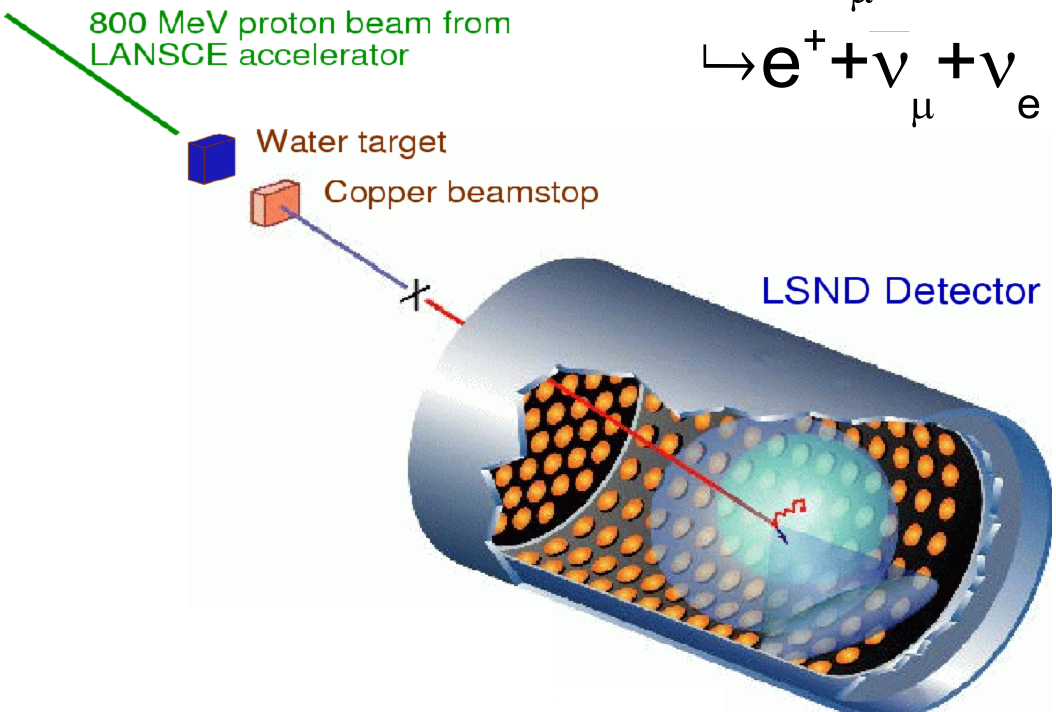


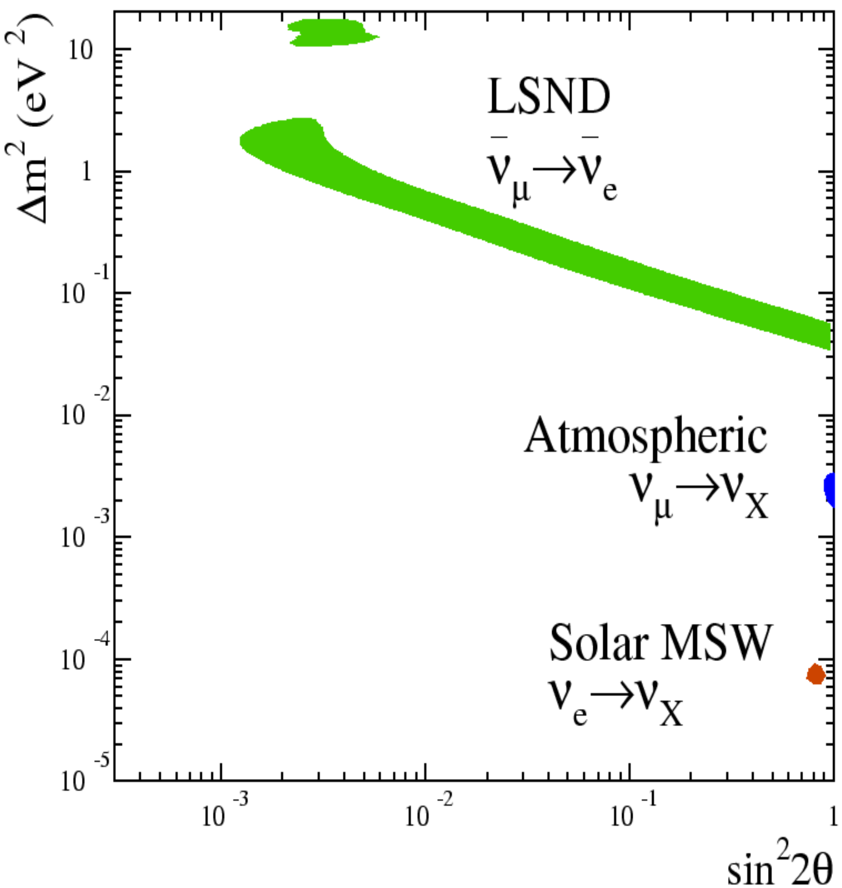


LSND experiment

- Excess of $\bar{\nu}_e$ events in $\bar{\nu}_\mu$ beam : 87.9 ± 22.4 ± 6 (3.8σ)
- $\bar{\nu}_e$ signature: Cherenkov light from e^+ with delayed n-capture
- Stopped pion beam

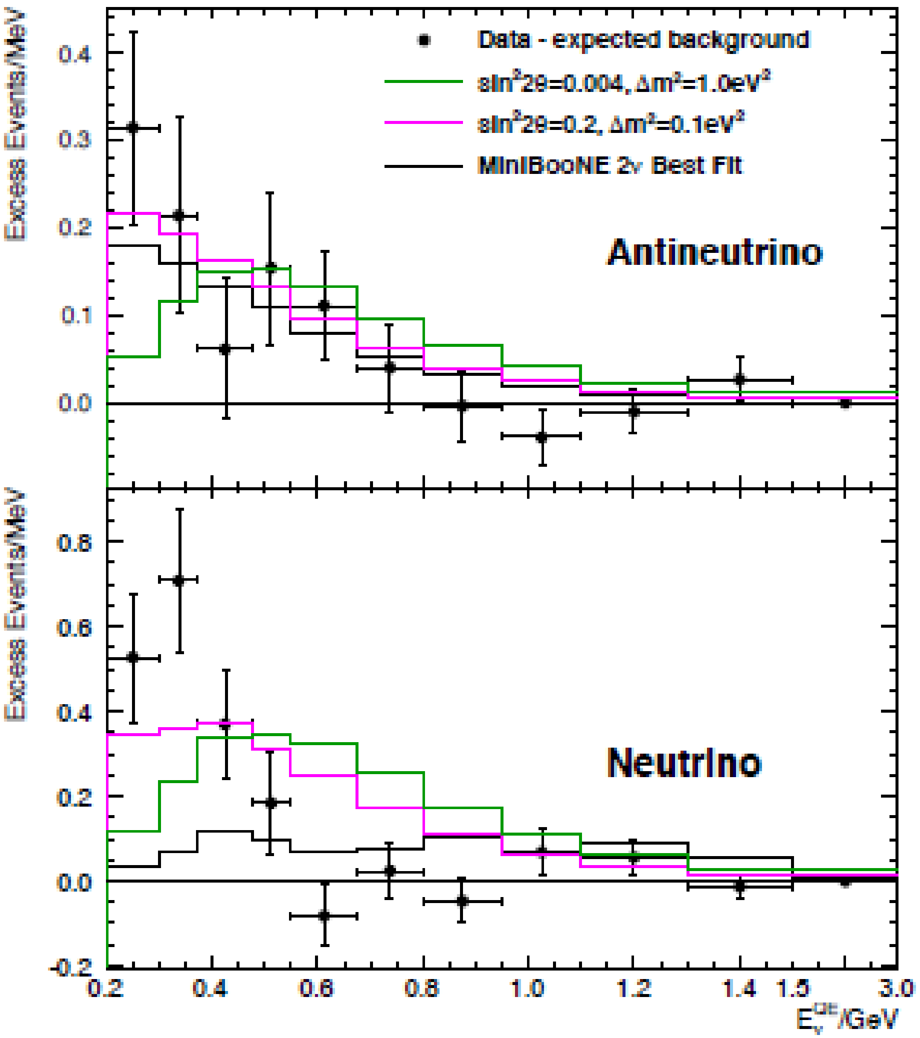
$$\pi^+ \to \mu^+ + \nu_\mu$$
$$\hookrightarrow e^+ + \bar{\nu}_\mu + \nu_e$$





MiniBooNE

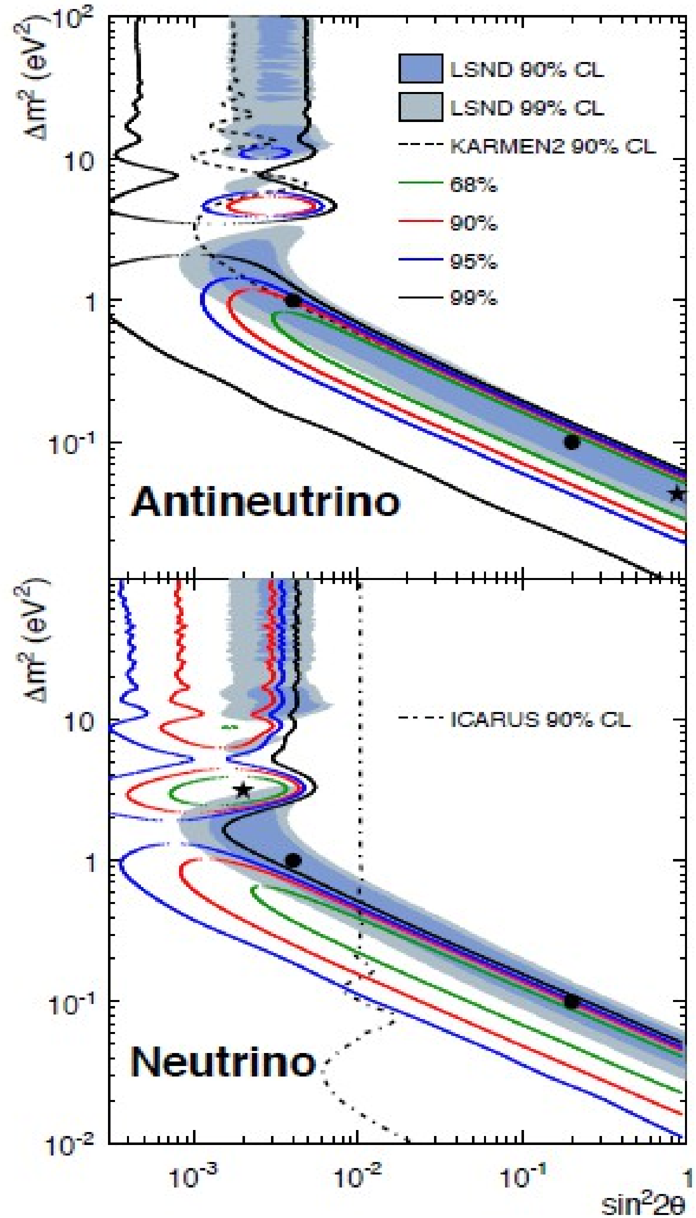
- Designed to test the LSND type oscillations
- Last year concluded its 10 year run
- 6.5e20 neutrino & 11.3e20 antineutrino mode
- Observed excess
  - Neutrino: 162 ± 47.8 (3.4σ)
  - Antineutrino: 78.4 ± 28.5 (2.8σ)



Phys. Rev. Lett. 110, 161801 (2013)

MiniBooNE

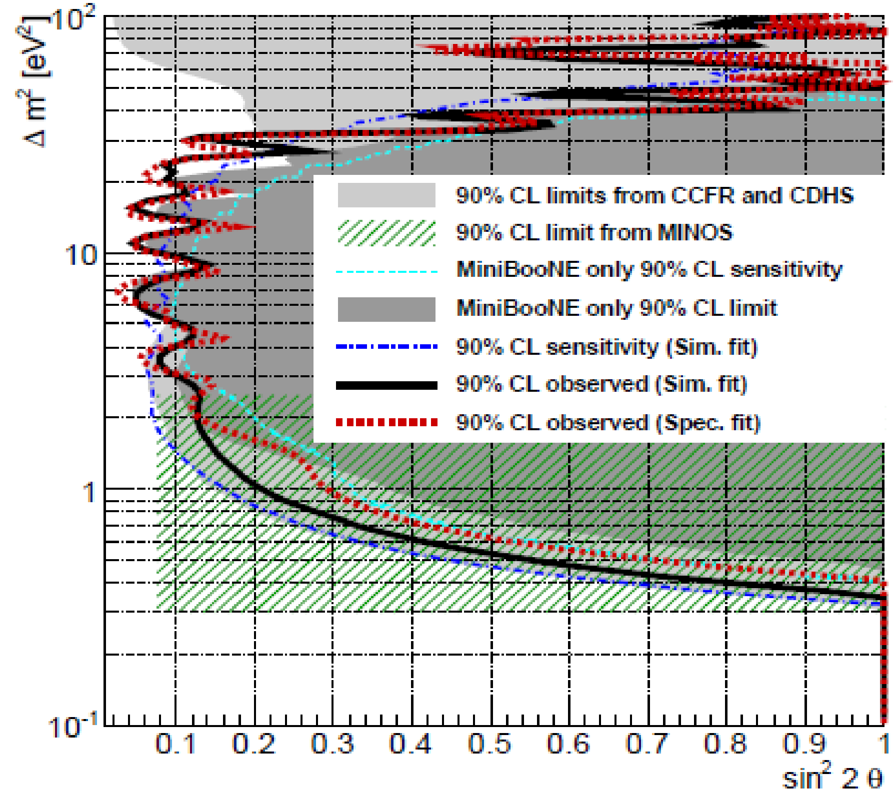
- Designed to test the LSND type oscillations
- Last year concluded its 10 year run
- 6.5e20 neutrino & 11.3e20 antineutrino mode
- Observed excess
  - Neutrino:
    162 ± 47.8 (3.4σ)
  - Antineutirno:
    78.4 ± 28.5 (2.8σ)

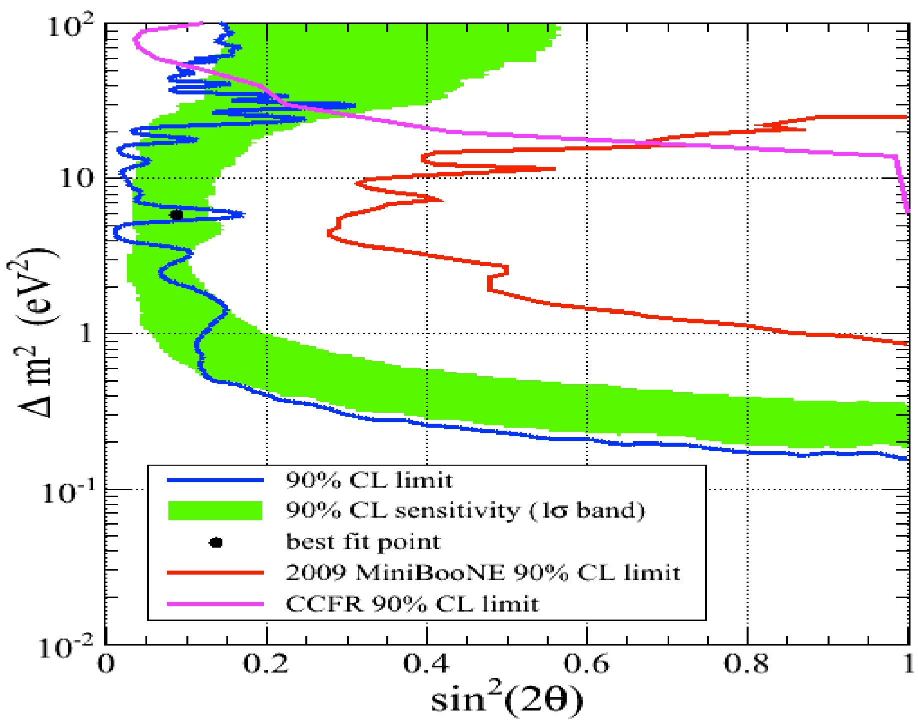


Phys. Rev. Lett. 110, 161801 (2013)

ν_μ & $\bar{\nu}_\mu$ Disappearance

- Not yet observed
- Some tension with appearance data – expect 5-10% disappearance
- MiniBooNE used SciBooNE as near detector

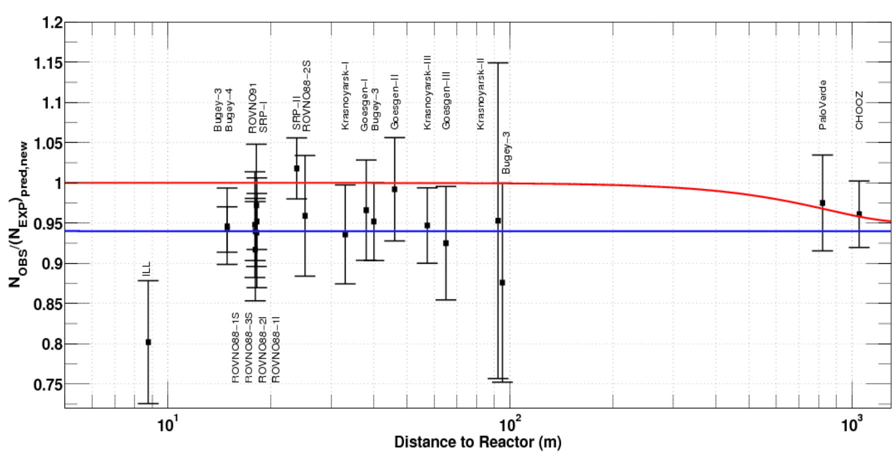




Reactor & Gallium anomalies

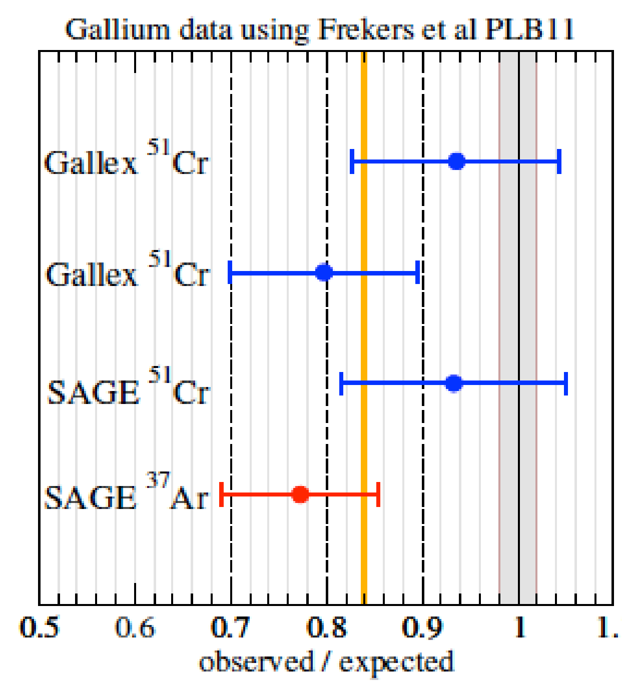
- 2011 update in calculated neutrino flux from reactors changed by ~+3%
- Average deviation observed with short baseline reactor experiments:

R=0.935 ± 0.024 (2.7σ)



- 4 calibration runs with intense radioactive sources
- Average deviation from prediction:

$R=0.84^{+0.054}_{-0.051}$ (2.9σ)



New results

MINOS

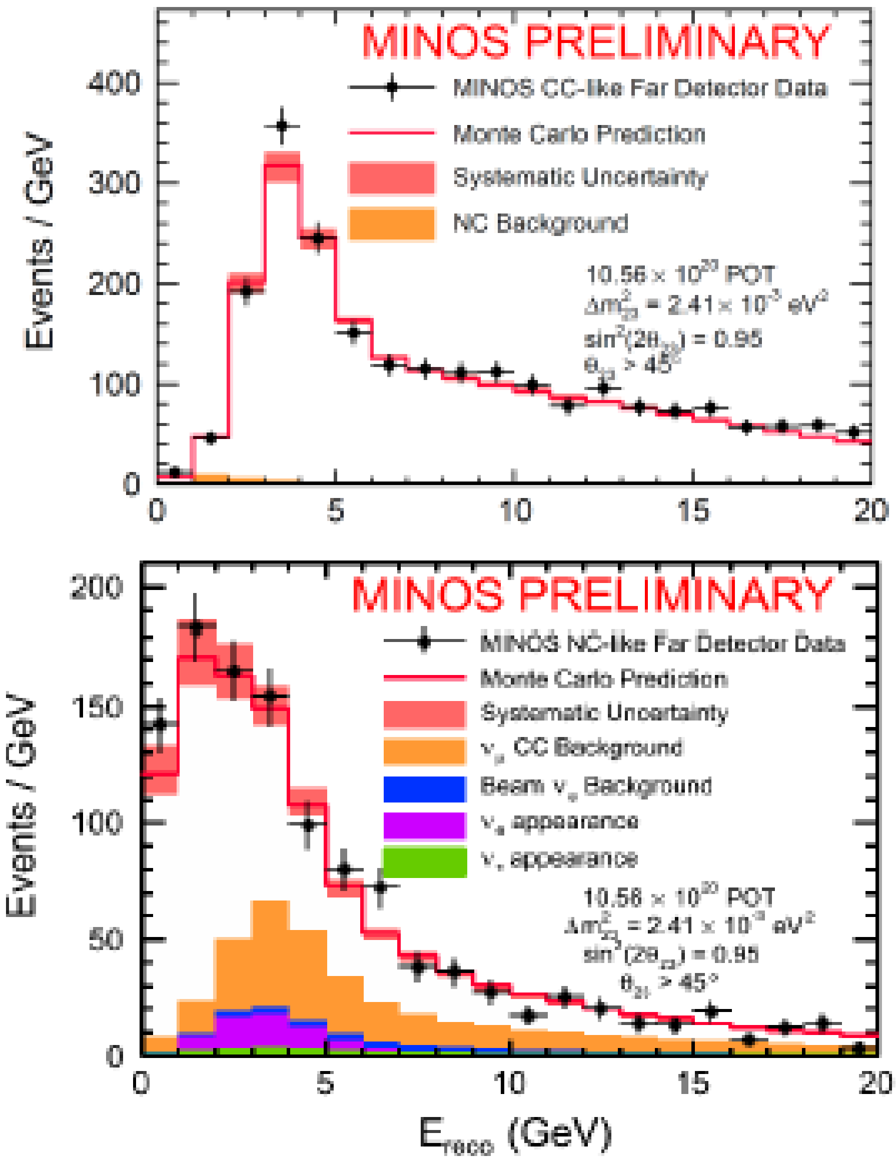
- Preliminary results of 4 flavor analysis shown last week at Fermilab W&C (J. Coelho)
- Looked for sterile oscillations at $\Delta m^2_{43}=0.5eV^2$
- Low energy neutrino mode data corresponding to 10.56e20
- Analysis:
  - Select NC and $(\nu_\mu + \bar{\nu}_\mu)$ CC interactions
  - Fit 4 parameters: $(\Delta m^2_{32}, \sin 2\theta_{23}, \sin^2\theta_{24}, \sin^2\theta_{34})$

MINOS results

- No evidence of sterile neutrino mixing at Δm^2_{43}=0.5eV^2
- Selected 2712 ν_μ CC candidate and 1221 NC candidates in far detector
- NC event counting:

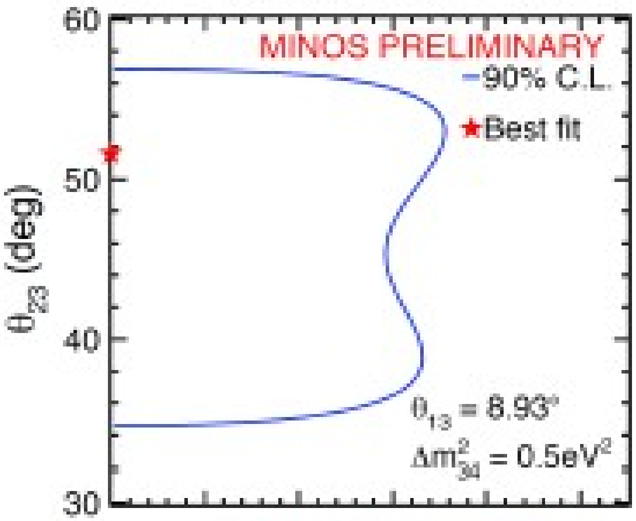
$$R = \frac{Data - CC_{Bkg}}{NC_{Pred}}$$

0-200 GeV: R=1.049+-0.076
0-3 GeV: R=1.093+-0.097
3-200 GeV: R=1.009+-0.095

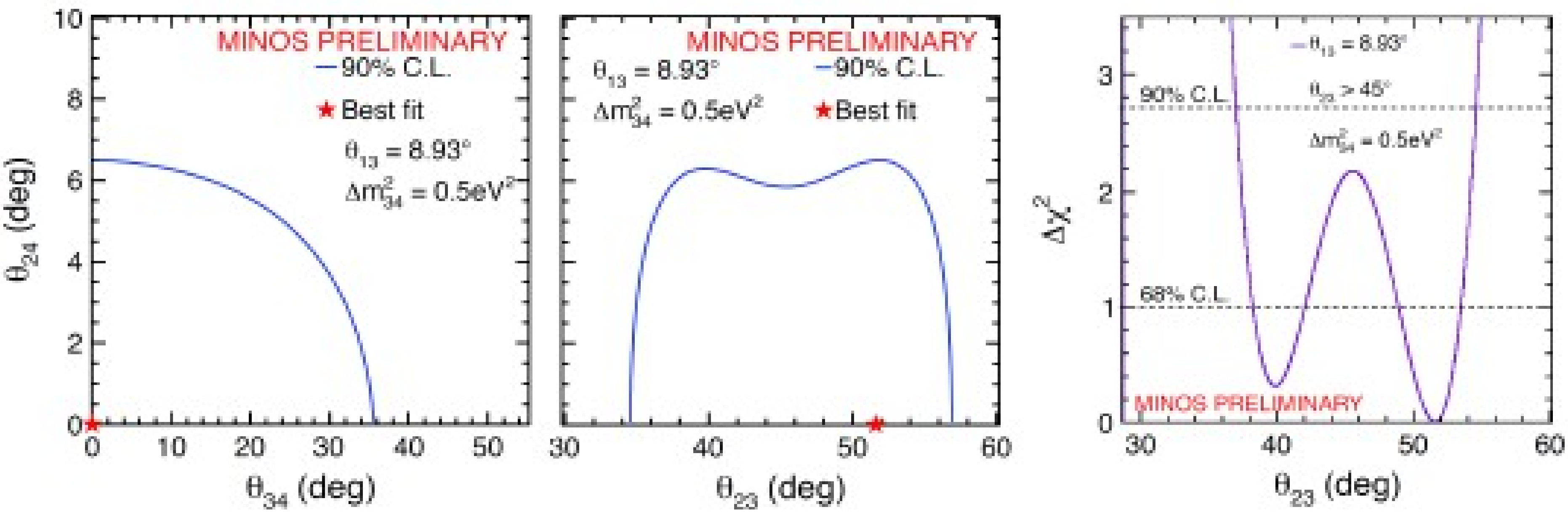


J. Coehlo, Fermilab W&C, 08/14/2013

MINOS results



- Sensitivity to ν_e appearance gives slight preference for $\theta_{23} > 45°$
- $\sin^2\theta_{24} < 0.0071$ ($\theta_{24} < 4.8°$) at 90% C.L.
- $\sin^2\theta_{34} < 0.17$ ($\theta_{34} < 24°$) at 90% C.L.



J. Coehlo, Fermilab W&C, 08/14/2013

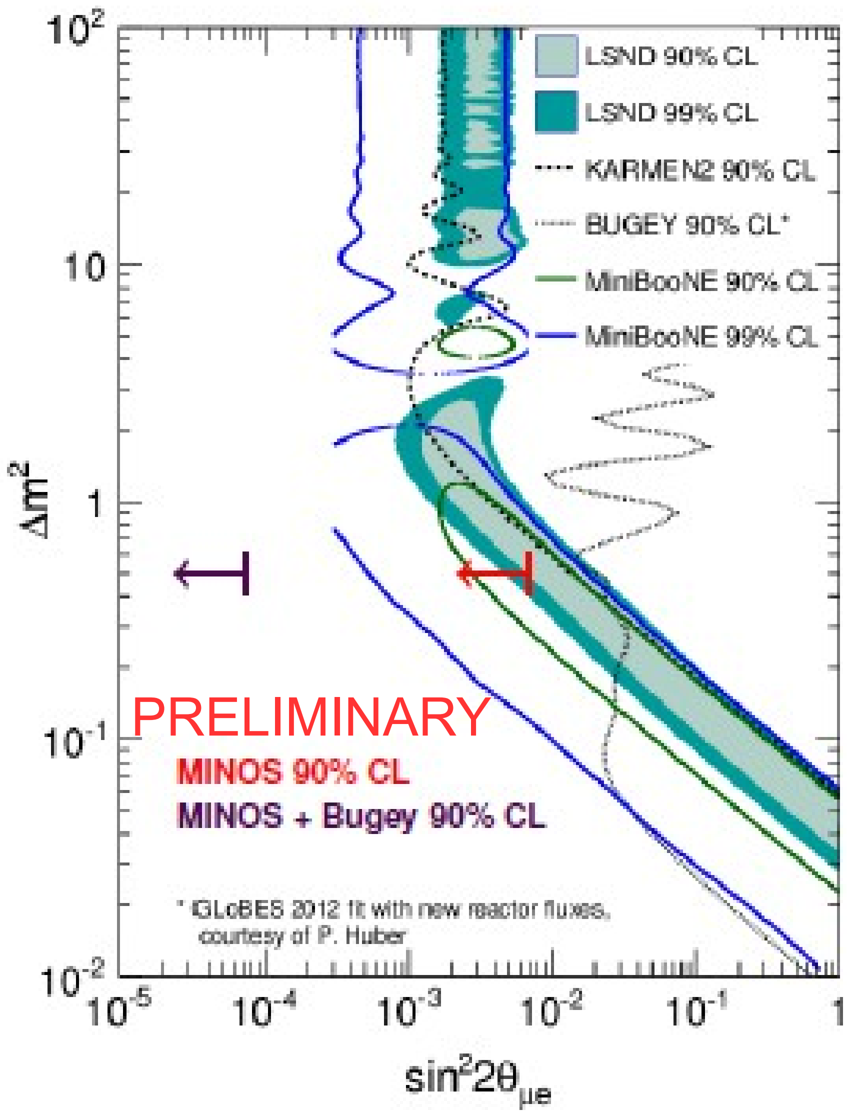
MINOS results

- At $\Delta m^2_{43} = 0.5$ eV^2:

  MINOS only:
  $\sin^2(2\theta^{\oslash}_{\mu e}) < 7.1 \times 10^{-3}$ at 90% C.L.

  MINOS + Bugey:
  $\sin^2(2\theta^{\oslash}_{\mu e}) < 7.7 \times 10^{-5}$ at 90% C.L.

- Observed limits stronger than the sensitivity due to small excess of events in data



J. Coehlo, Fermilab W&C, 08/14/2013

Near Future

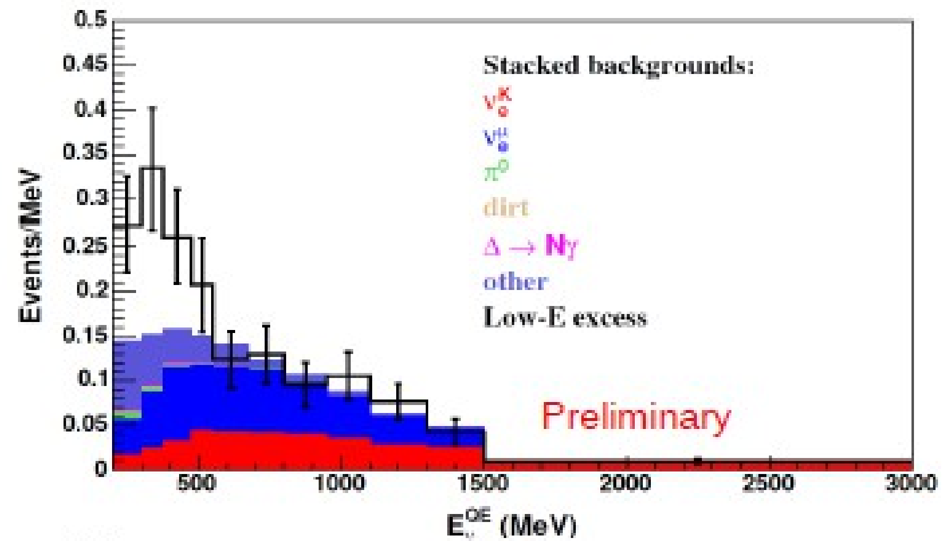
MicroBooNE

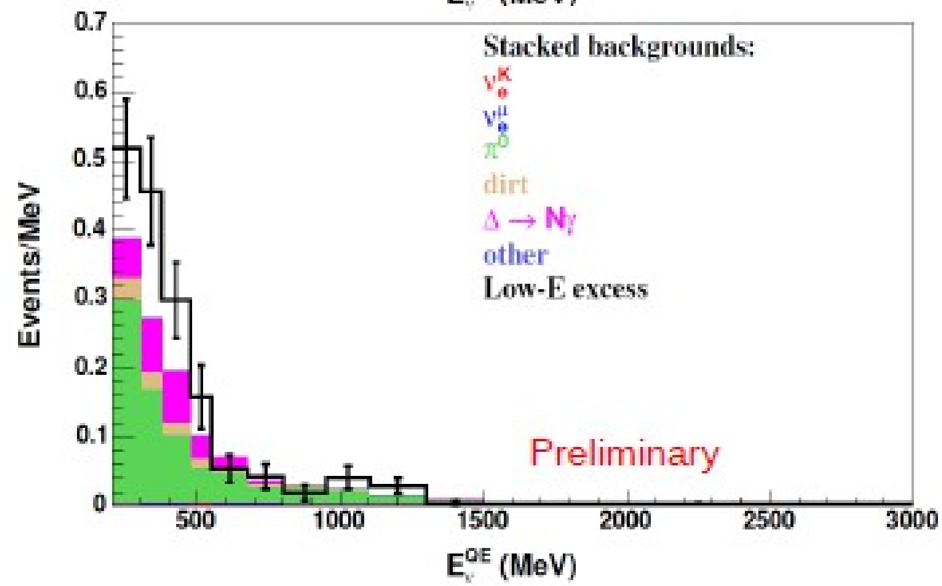
- LArTPC in BNB
- Scheduled to start running in 2014 and collect 6.6e20 POT in neutrino mode
- Study low energy excess observed with MiniBooNE
- Resolve between gamma and electron induced backgrounds

www-microboone.fnal.gov

MicroBooNE

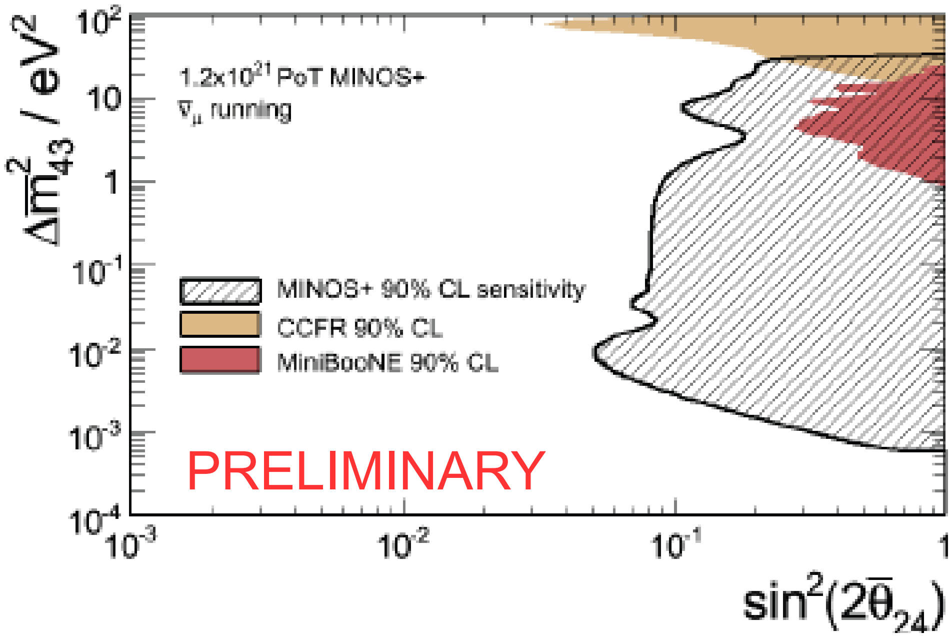
- Low energy excess will appear either in electron like (top) or gamma like sample (bottom)
- If electron like, expect excess:
  36.8 ± 6.4 (5.7σ)
- If gamma like, expect excess:
  36.8 ± 8.9 (4.1σ)

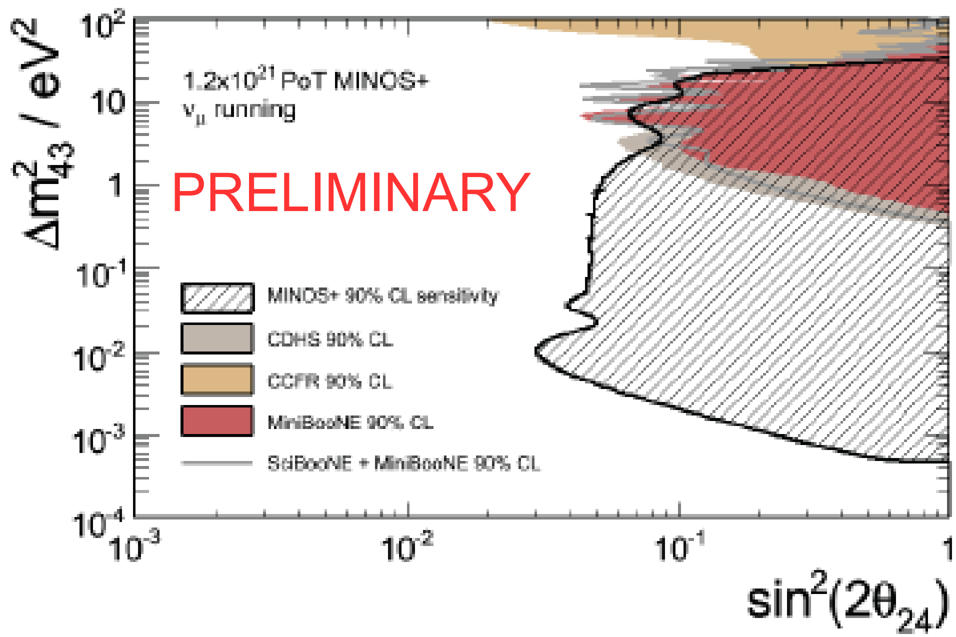




MINOS+

- Run MINOS detectors in NOvA era
- Start taking data over next few weeks
- Look for new physics in previously unexplored region
- 3000 far detector events per year in 4-10GeV region
- Sensitive to high Δm^2 oscillations

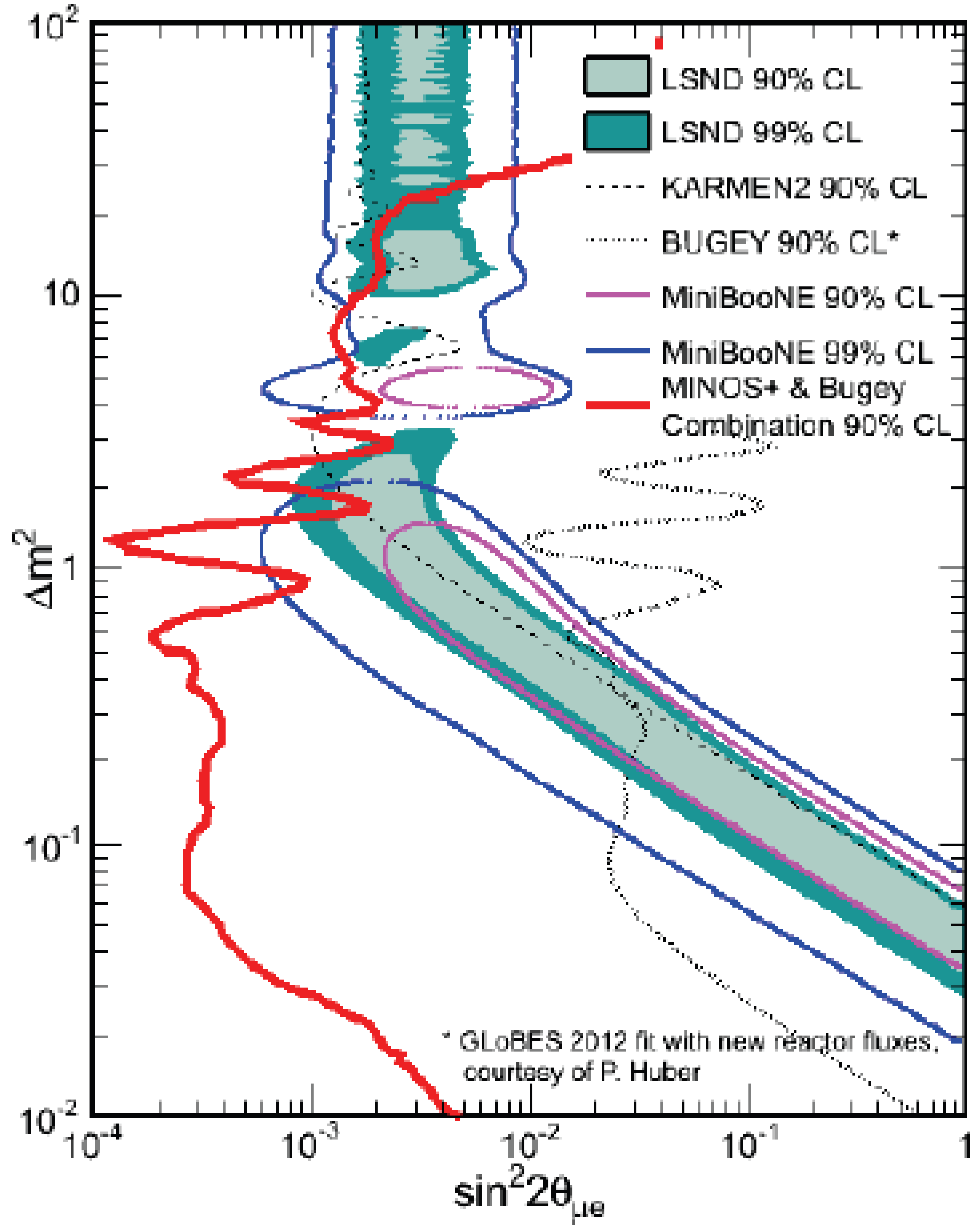




www-numi.fnal.gov/MinosPlus/minosPlus.html

MINOS+

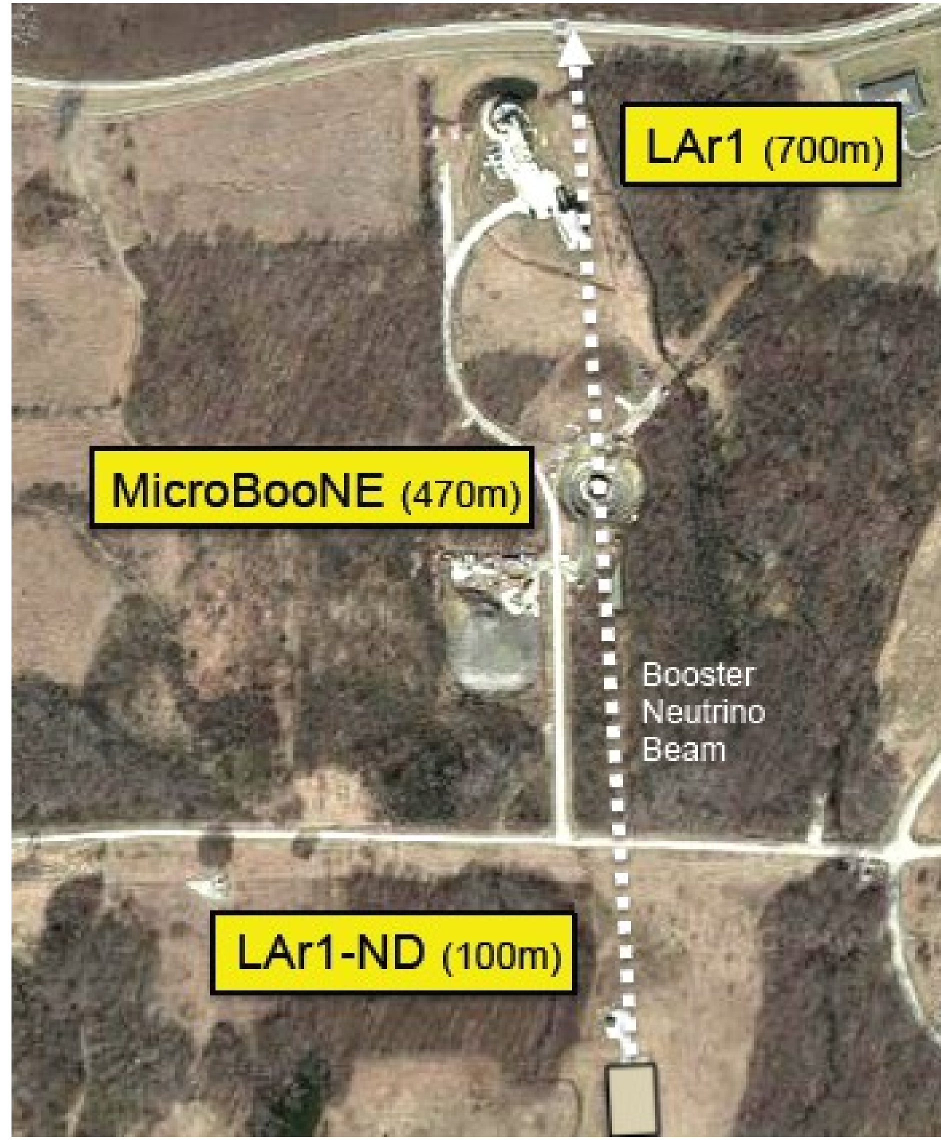
- Run MINOS detectors in NOvA era
- Start taking data over next few weeks
- Look for new physics in previously unexplored region
- 3000 far detector events per year in 4-10GeV region
- Sensitive to high Δm^2 oscillations



Proposals/LOIs/Ideas

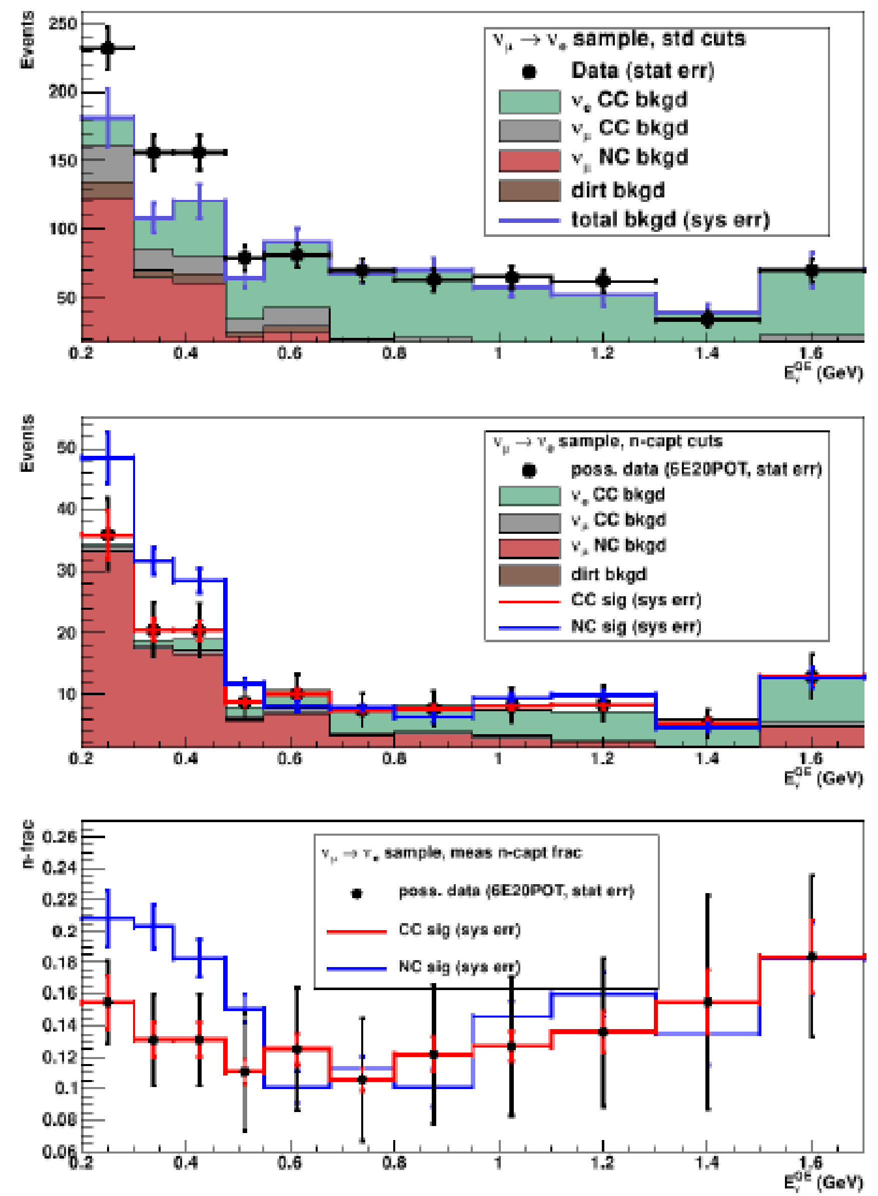
LAr1

- Run along MicroBooNE
- Definitive test of LSND and MiniBooNE both in neutrino and antineutrino mode
- Staged program
- Phase 1 detector@100m (40t fiducial)
  - study L/E dependence and ν_μ disappearance
- Phase 2 detector@700m (1kt)
  - test antineutrinos



MiniBooNE+

- Add scintillator to MiniBooNE to enable reconstruction of 2.2MeV gamma from n capture
  - True CC events have 1-10% neutrons
  - NC events have 50% neutrons (dominated by NC Δ with equal branch to p/n decay)
- Other physics goals
  - p to n ratio in NC elastic scattering to measure Δs (s-quark contribution to nucleon spin)
  - Measurement of ν_μC->μ^-N_{gs} tagged with N_{gs} beta decay (~15MeV endpoint enabled with scintillator); cross section known to ~2% near threshold allows a low-E flux test
  - Test of QE assumption in neutrino energy reconstruction

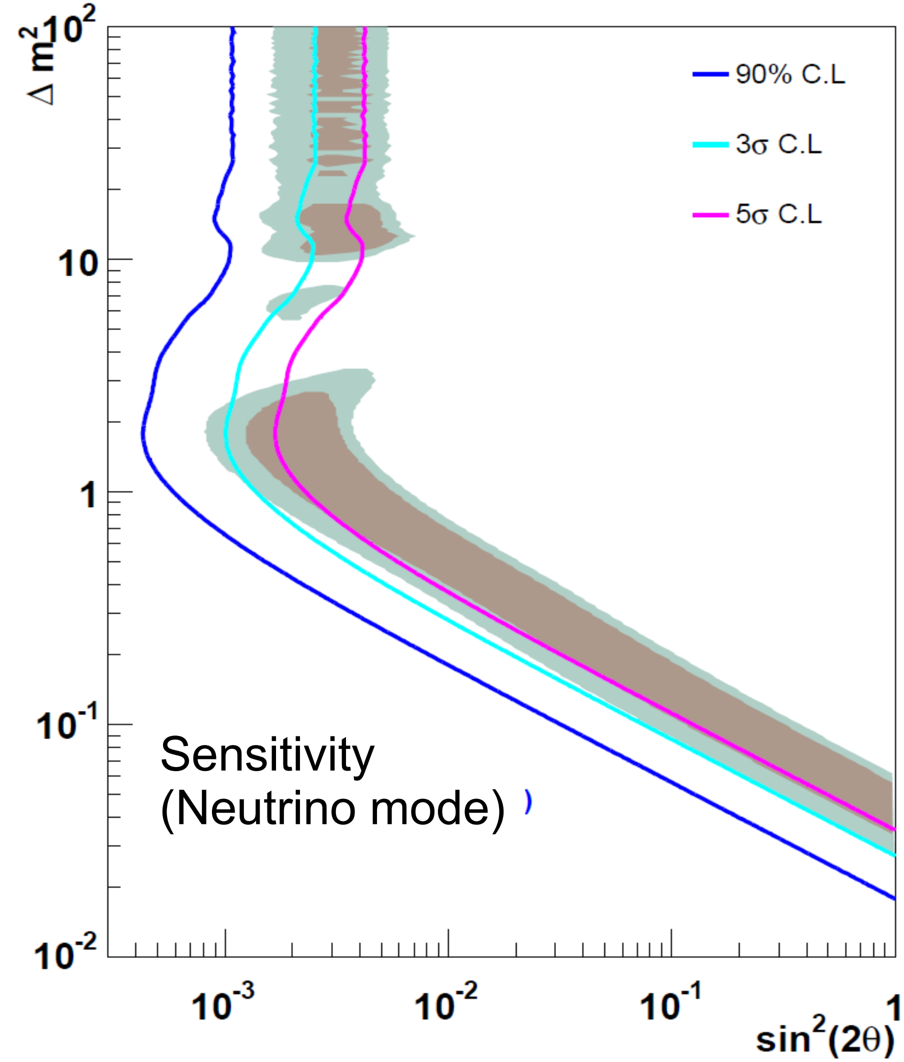


arxiv:1210.2296c

MiniBooNE II

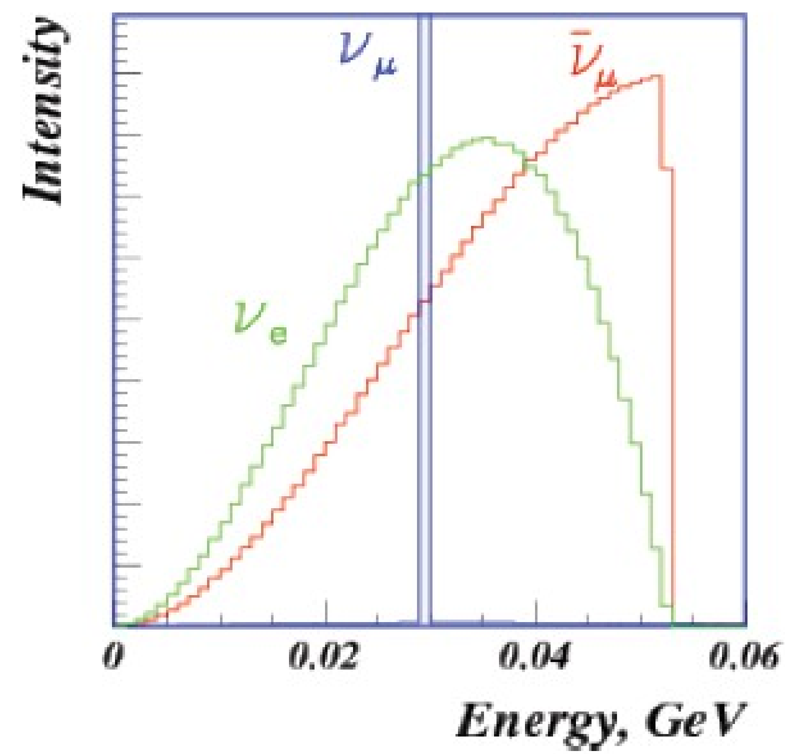
- Add MiniBooNE like detector at 200m to serve as near detector
- Study L/E dependence
- Gain statistics quickly, already have far detector data
- Analysis built on 10 years of running MiniBooNE detector

6.5e20 Far + 1e20 Near POT



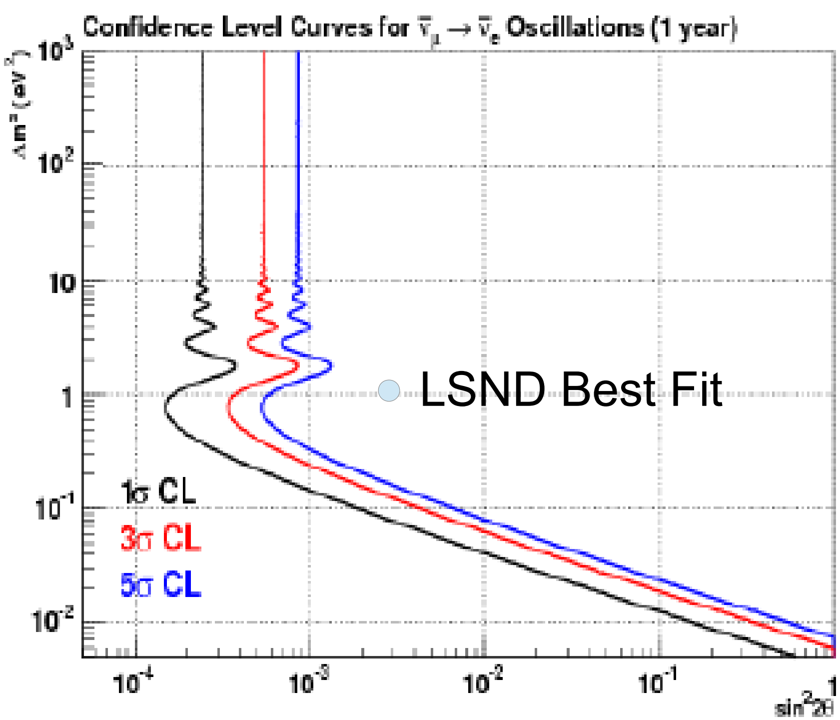
OscSNS

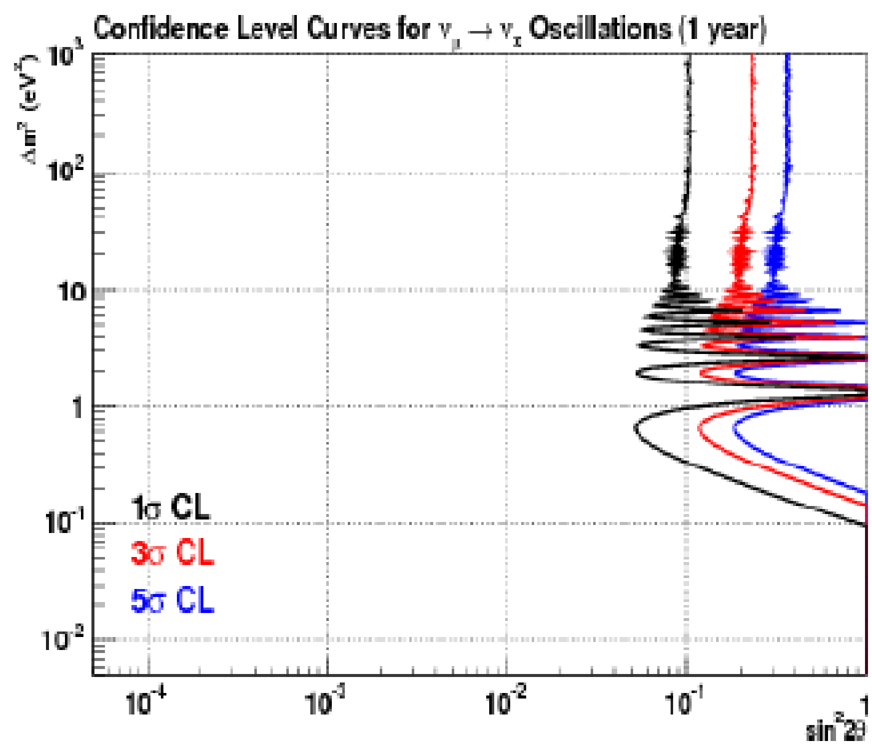
- Spallation neutron source at ORNL
  - Free source of neutrinos
  - 1GeV protons on Hg target (1.4MW)
- Well understood flux of neutrinos
- Decisive test of LSND appearance signal



OscSNS

- $\bar{\nu}_e$ appearance (left) and ν_μ disappearance sensitivity (right) for 1 year of running (100% beam on)

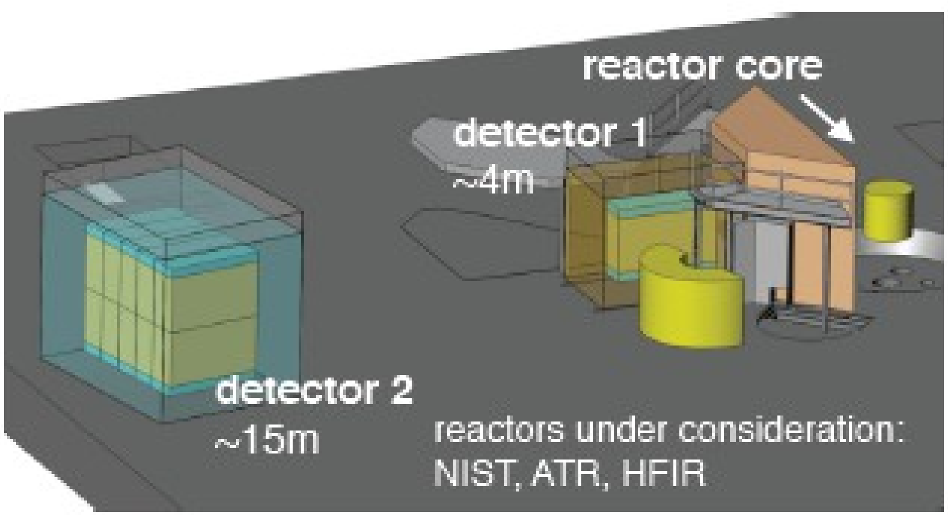


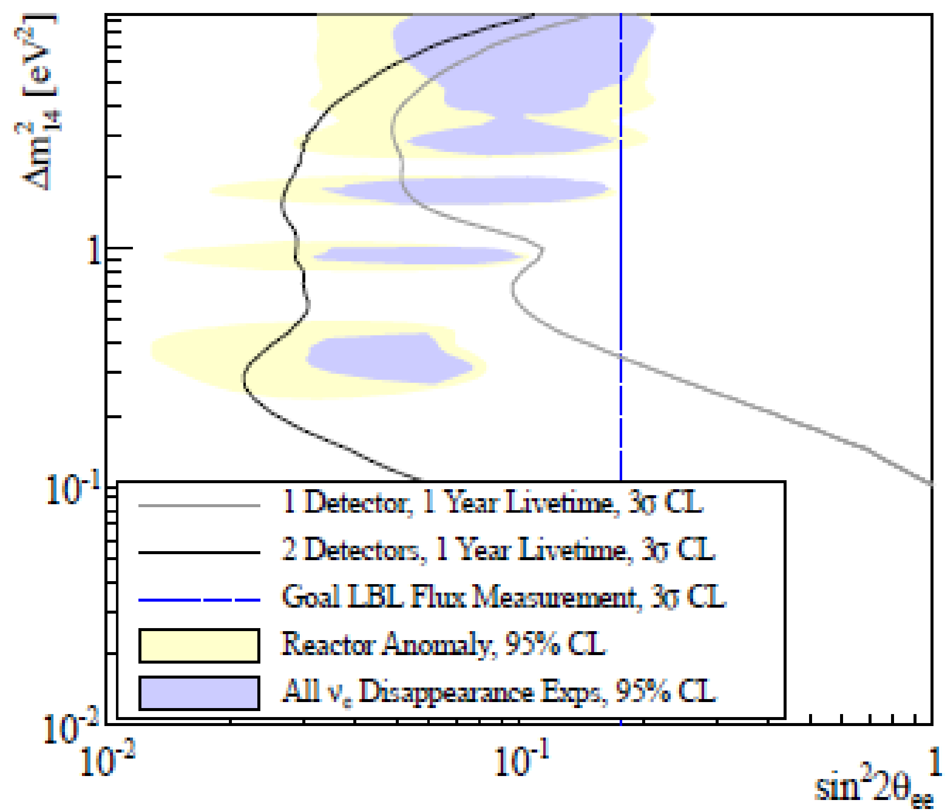


arxiv:1307.7097

US short baseline reactor experiment

- Demonstrate L/E dependence with 2 detectors





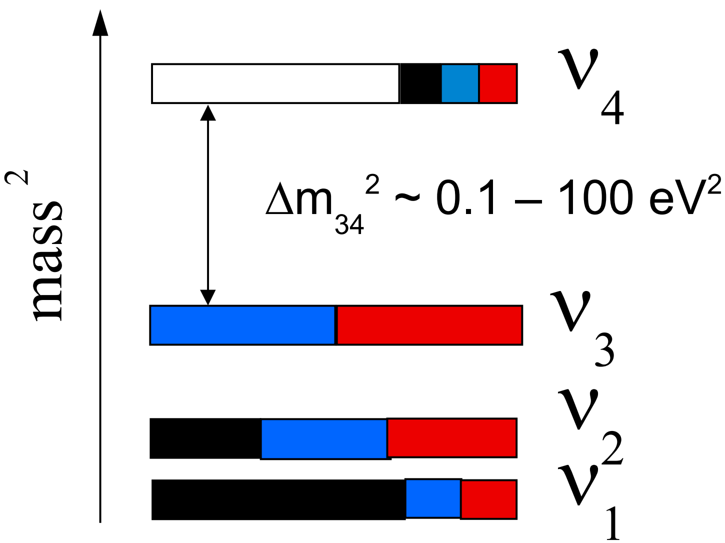
Mumm, Littlejohn, K.M.Heeger, arXiv:1307.2859 (2013)

Conclusion

- Short baseline anomalies: LSND, MiniBooNE, Gallium and Reactor
- Sterile neutrinos possible solution
- Important to find the physics behind these anomalies
- Need experiments to test:
  - Anomalies: MicroBooNE, OscSNS, MiniBooNE+
  - Sterile neutrinos hypothesis: MINOS+, LAr1, MiniBooNE II, US reactor
- For NuStorm see plenary talk by A. Bross (Sat 24 8:30am)

Backup

Sterile neutrinos



- Only 3 active neutrinos
- 3 active neutrinos +
  1 sterile neutrino

$$P(\nu_\mu \rightarrow \nu_e) = 4|U_{e4}|^2 |U_{\mu 4}|^2 \sin^2(1.27 \Delta m_{41}^2 L/E)$$

$$P(\nu_\mu \rightarrow \nu_e) = \sin^2 2\theta \sin^2(1.27 \Delta m^2 L/E)$$

- Model predicts same oscillation probability for neutrinos and anti-neutrinos