Searching for Physics
Beyond the Standard Neutrino Model
A Near Detector for MiniBooNE

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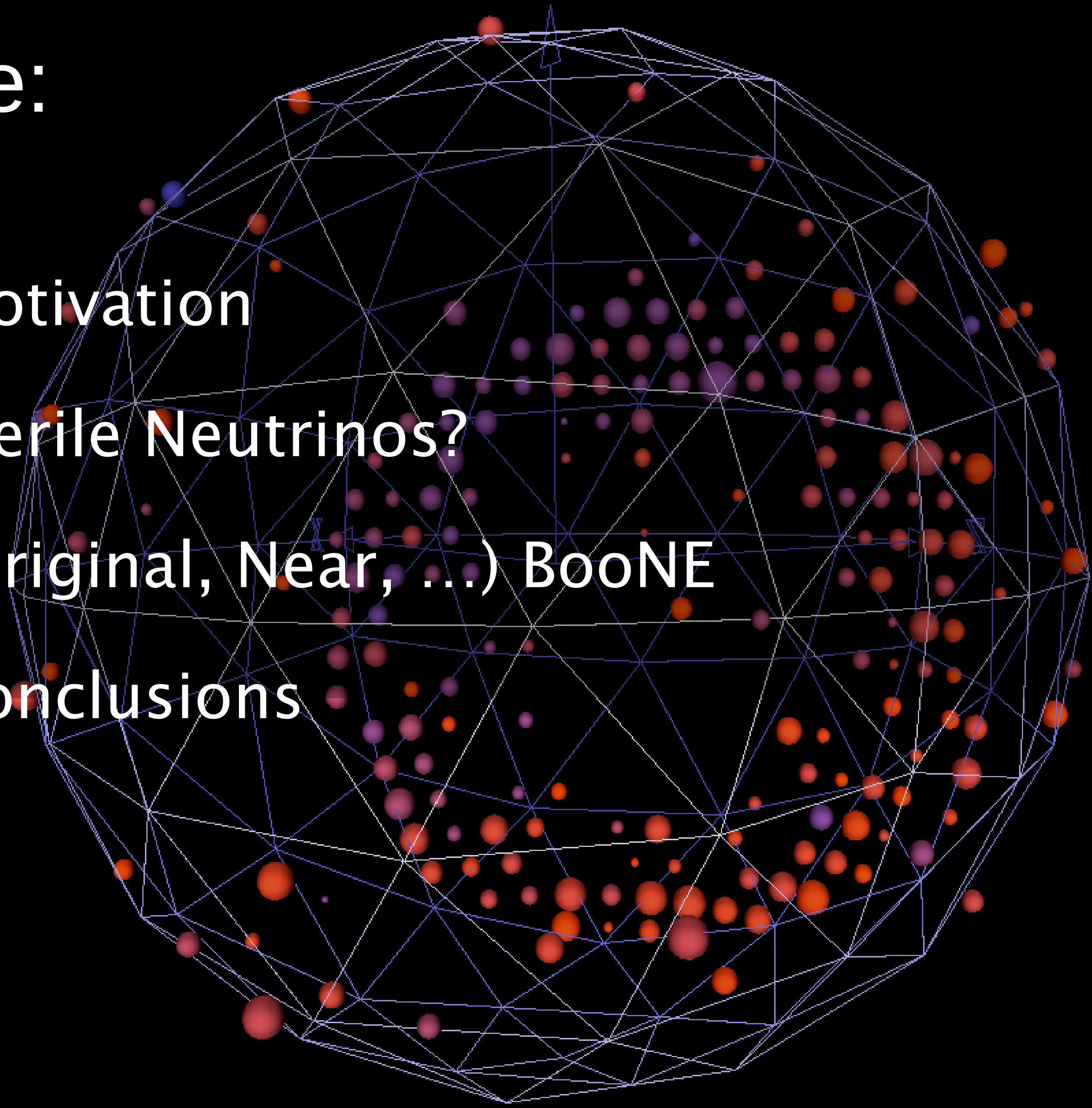
Outline:

1. Motivation
2. Sterile Neutrinos?
3. (Original, Near, ...) BooNE
4. Conclusions



Neutrino Oscillations

- The oscillation patterns between the 3 known active neutrino species have been demonstrated by a number of experiments over the last two decades:
  - SNO, Kamland
  - Super-K, K2K, MINOS

- Armed with that knowledge, measurements of neutrino behavior outside the standard 3 generations of active neutrinos indicate new physics:
  - LSND indicates that new physics may be operating

- Interpretations of such a non-standard result probe some deep theoretical issues, for example:
  - Light sterile neutrinos, neutrino decays, CP and/or CPT violation, Lorentz invariance, Extra dimensions

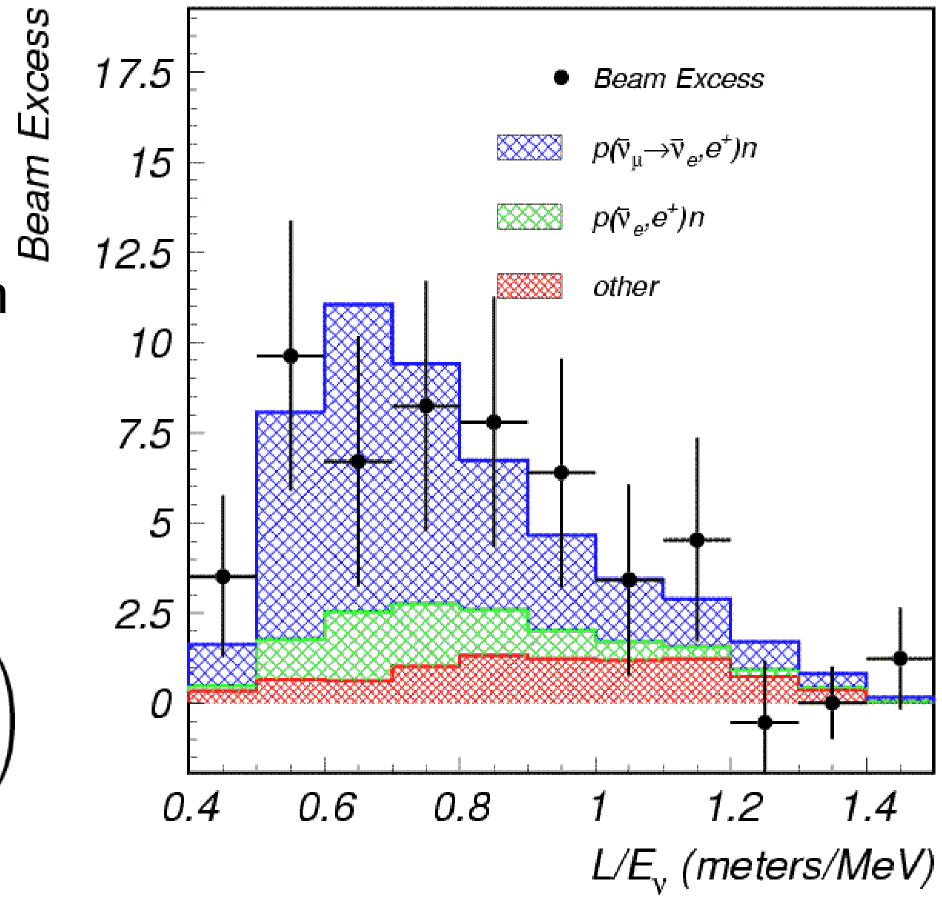
The investigation of neutrino oscillations at the <1% level is unique in its physics reach

Excess Events from LSND

- LSND found an excess of $\overline{\nu}_e$ in $\overline{\nu}_\mu$ beam
- Signature: Cerenkov light from e^+ with delayed n-capture (2.2 MeV)
- Excess: 87.9 ± 22.4 ± 6.0 (3.8σ)
- *The data was analysed under a two neutrino mixing hypothesis**

$$P(\overline{\nu}_\mu \to \overline{\nu}_e) = \sin^2(2\theta)\sin^2\left(\frac{1.27\, L\, \Delta m^2}{E}\right)$$

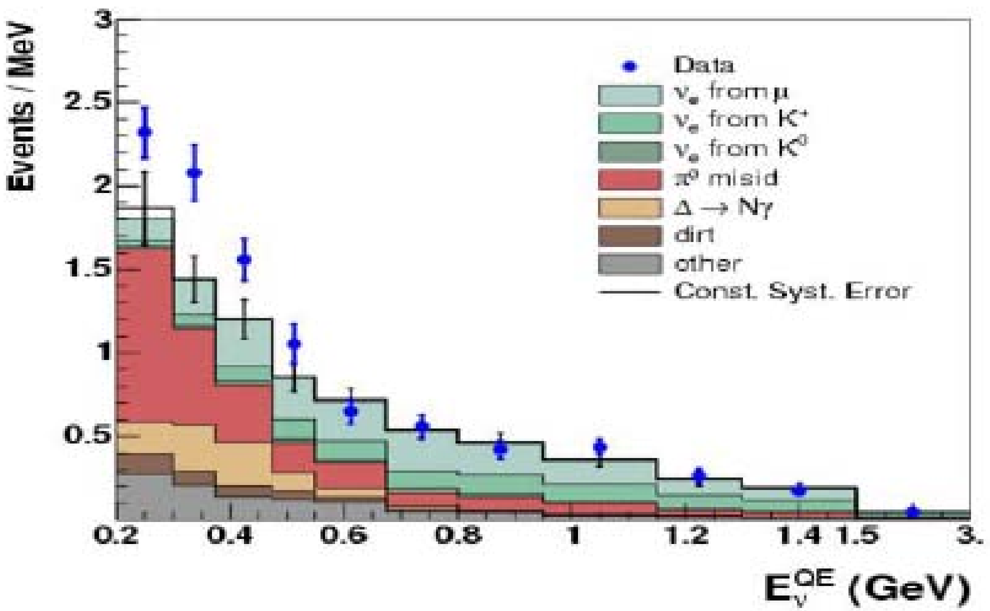
$$= 0.245 \pm 0.067 \pm 0.045\ \%$$



*at least 5 neutrinos are required to accommodate all experiments

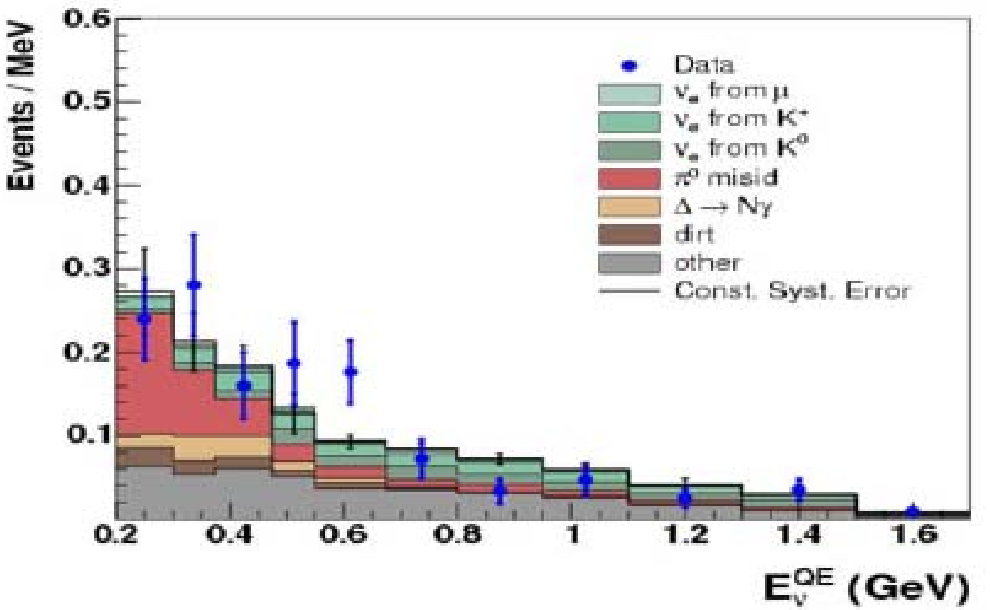
MiniBooNE Results

Neutrino Mode

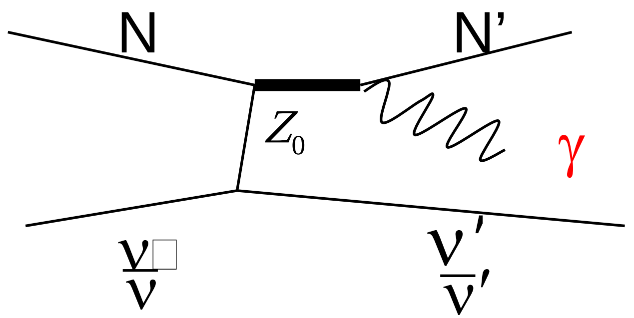


Anti-neutrino Mode

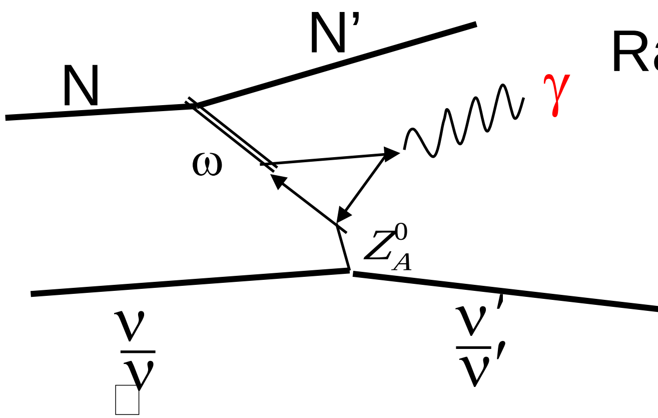
(Not yet sensitive to LSND)



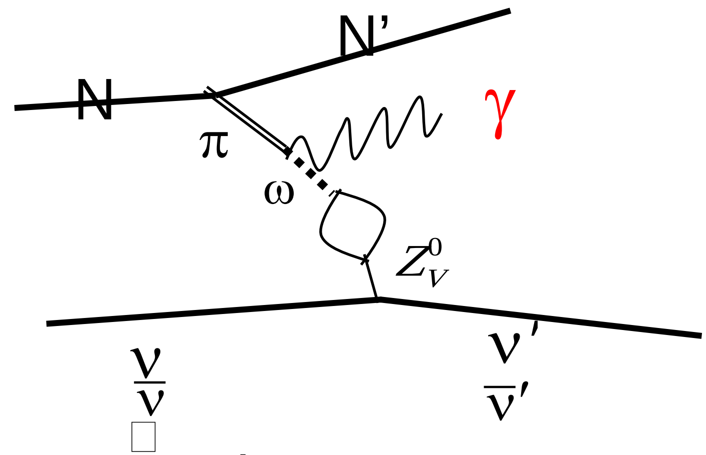
Backgrounds: Order(α x NC) , single photon FS



Radiative Delta Decay

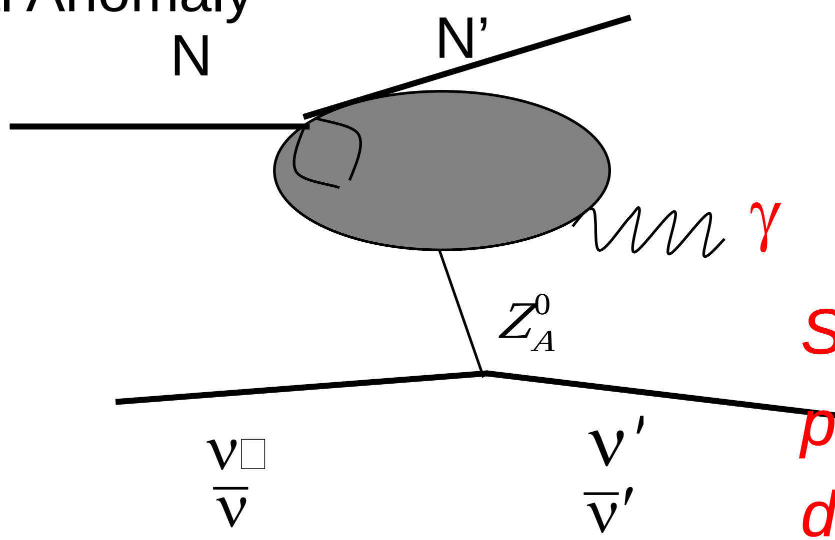


Axial Anomaly



Other PCAC

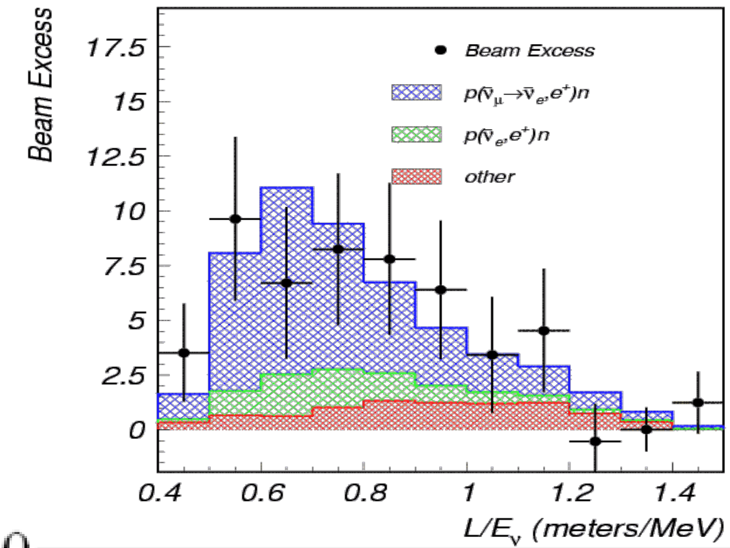
All order ($G^2\alpha\alpha_S$)



So far we have not found a process to account for the $\nu, \bar{\nu}$ difference. Work is in progress…

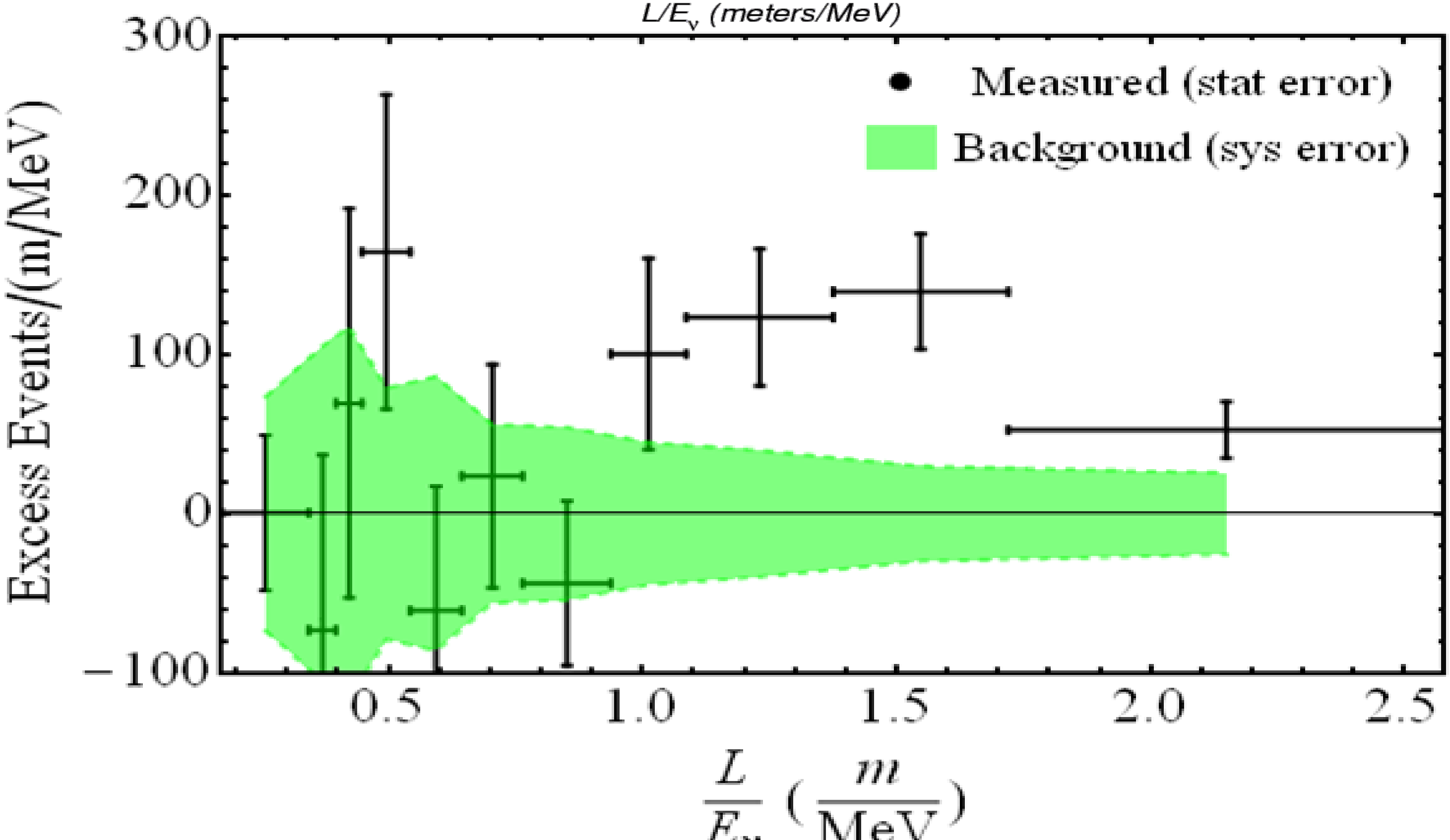
MiniBooNE and LSND Comparison

LSND
(anti-neutrino)

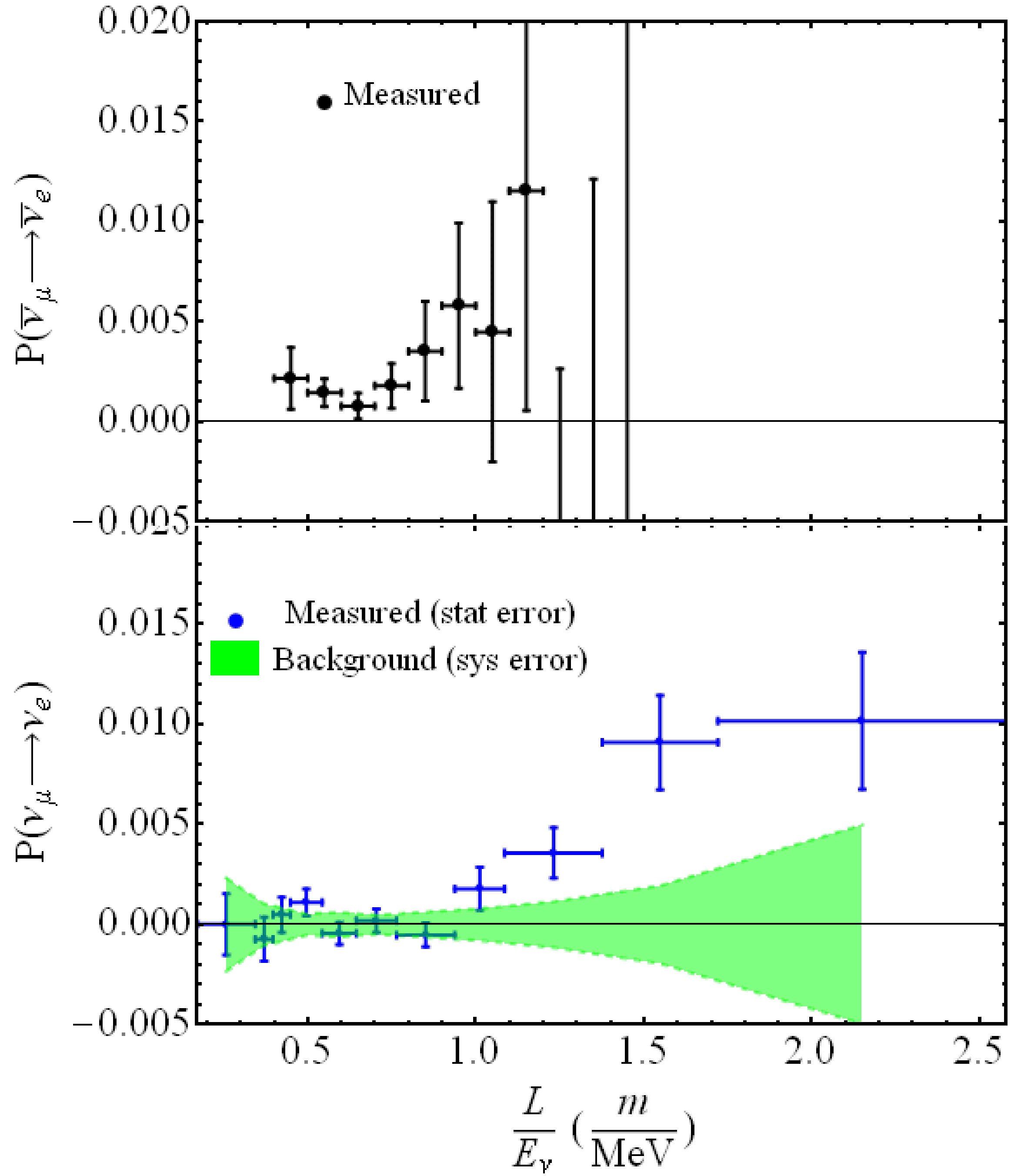


L/E ~ neutrino proper time
(in rest frame of neutrino)

MiniBooNE
(neutrino)



LSND and MiniBooNE oscillation probabilities



LSND and MiniBooNE oscillation probabilities

My own attempts to reconcile Data:

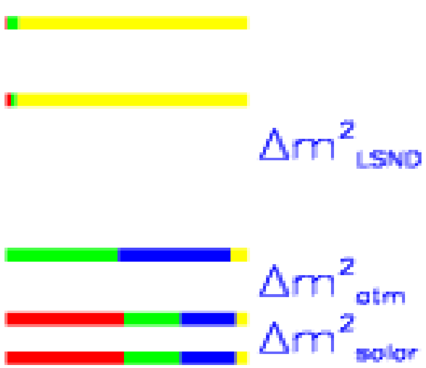
"high-low" solution

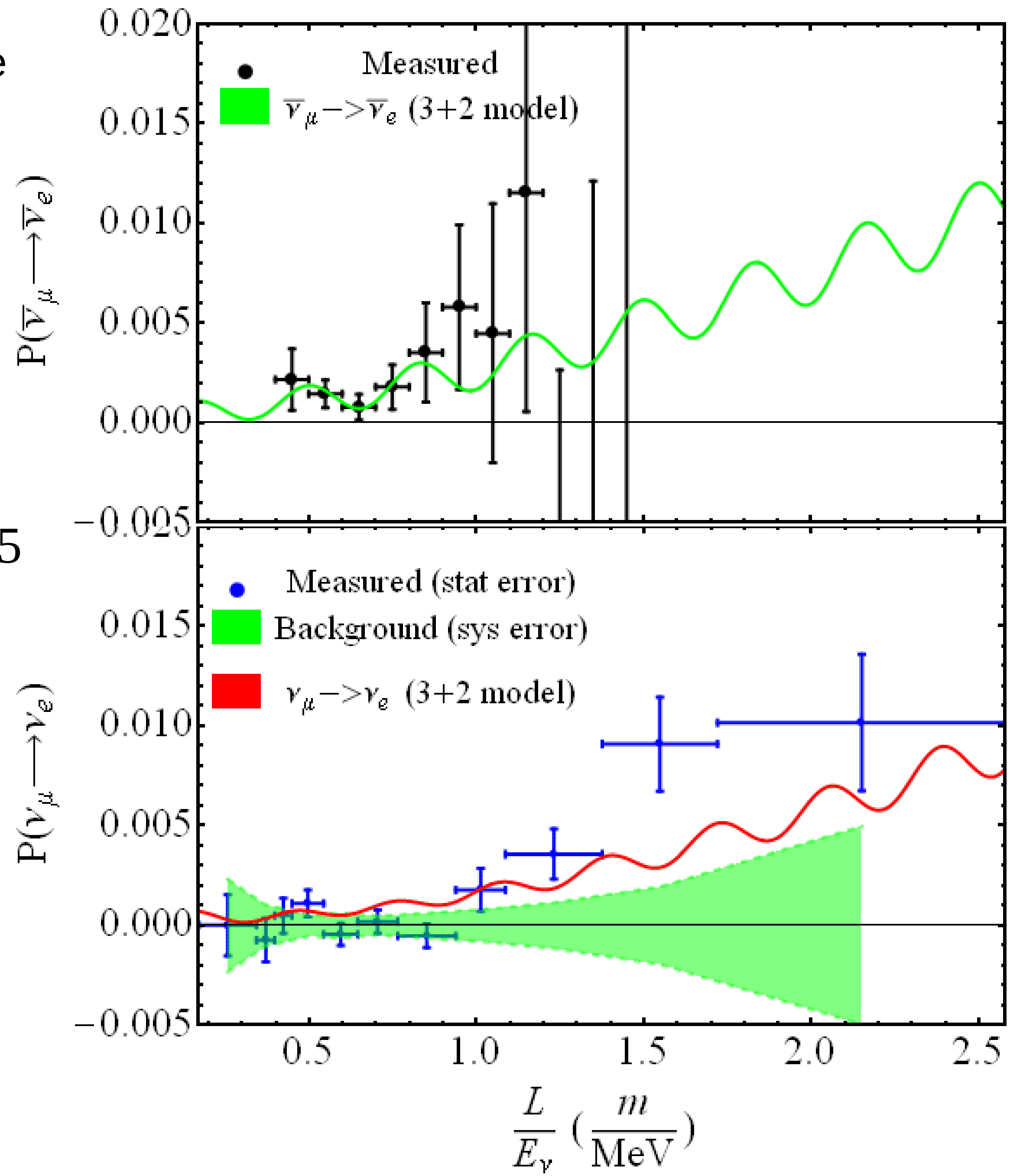
3+2 model (suggestive)

$$\Delta m_a^2 = 7.5\ \text{eV}^2, P_a = 0.015$$

$$\Delta m_b^2 = 0.25\ \text{eV}^2, P_b = 0.065$$

$$\phi_{CP} = 1.3\ \text{rad}$$





LSND and MiniBooNE oscillation probabilities

My own attempts to reconcile Data:

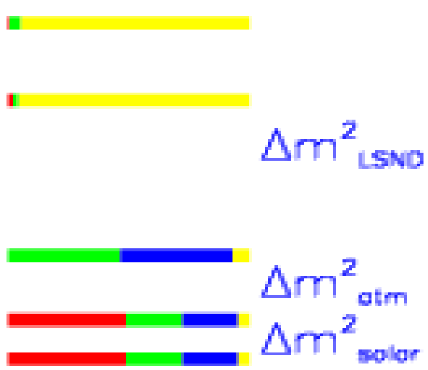
“low-low” solution

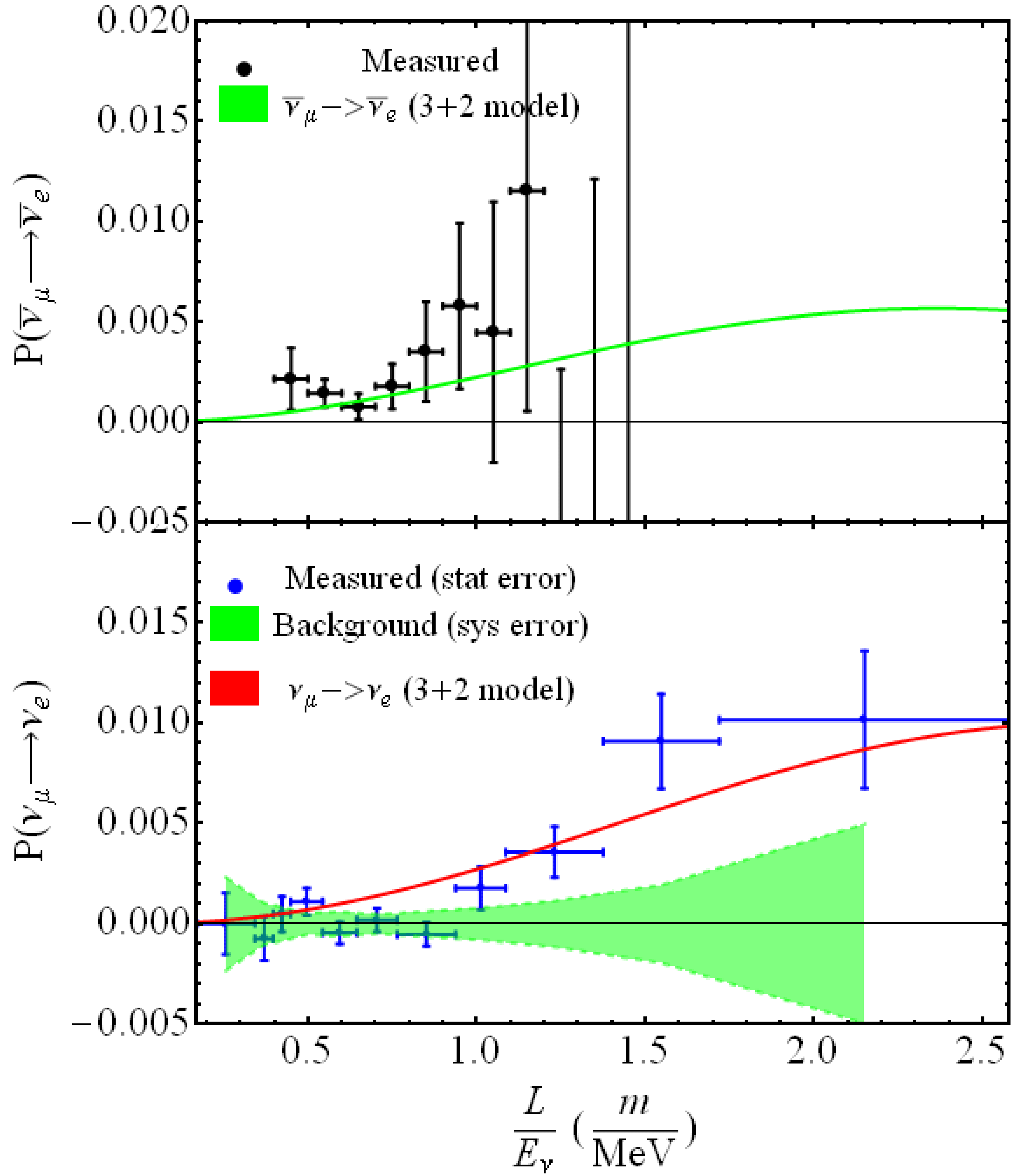
3+2 model (suggestive)

$\Delta m_a^2 = 0.5 \text{ eV}^2, P_a = 0.04$

$\Delta m_b^2 = 0.25 \text{ eV}^2, P_b = 0.025$

$\phi_{CP} = \frac{\pi}{2}$ rad

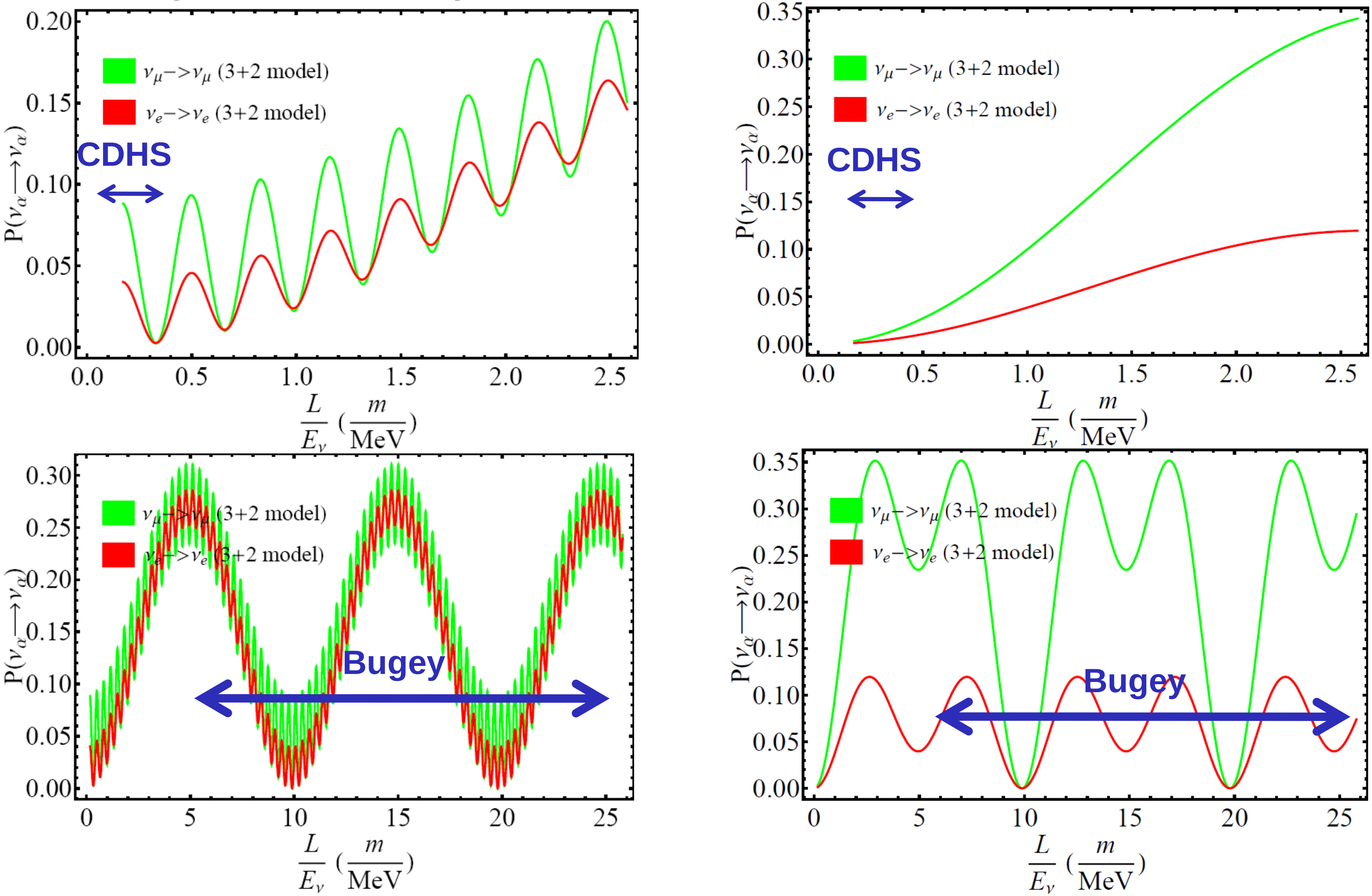




Disappearance oscillation probabilities

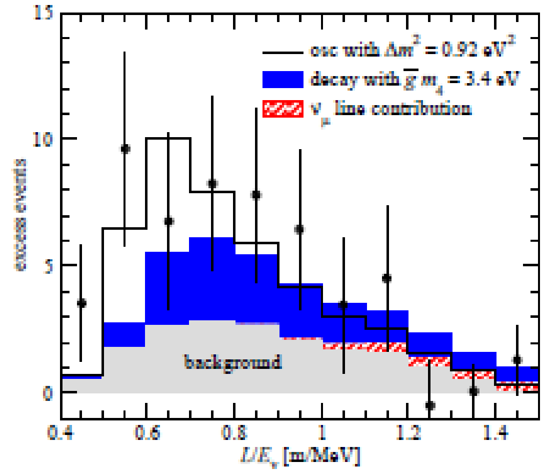
"high-low" 3+2 example

"low-low" 3+2 example

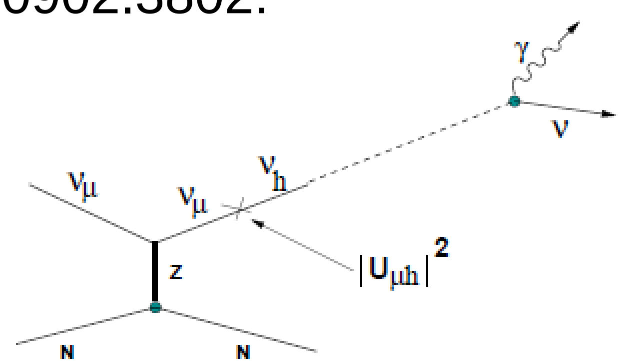


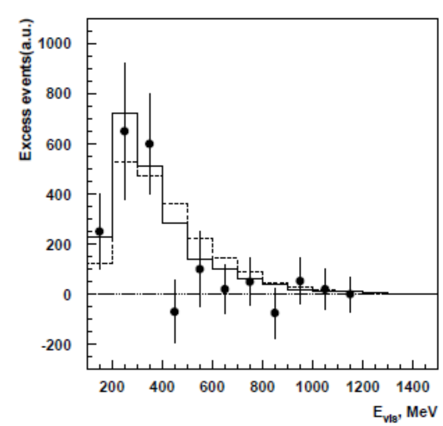
Neutrino Decays?

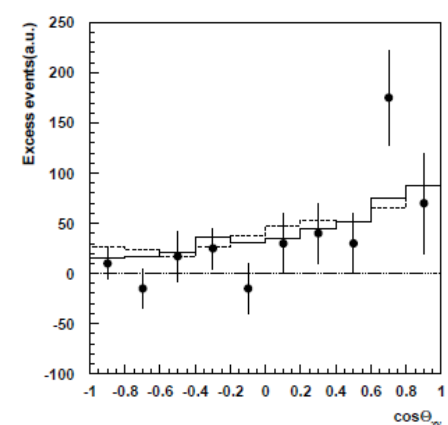
- With the addition of heavy sterile neutrinos the effects of sterile neutrino decays become important
- The combined effect has been shown to separately accommodate LSND and MiniBooNE results
  - arXiv:hep-ph/050521:



  - arXiv:0902.3802:







Resolving the MiniBooNE Low Energy Excess

- Moving the MiniBooNE detector to 200m (~4M$) (or building a new detector at 200m (~$8M$))
  - Accumulate a sufficient data sample in < 1 year
  - will dramatically reduce systematic errors (low energy excess is ~ 6 sigma significance with statistical errors only.
  - Can study L dependence of excess: backgrounds scale as 1/L**2, oscillation signal as $\sin^2(L/E)$, and decay as L/E.

- MicroBooNE (next talk…):
  - is a 70 ton liquid argon time projection chamber planned for the booster neutrino beam line
  - can differentiate single gamma-rays from electrons (MiniBooNE cannot do this)

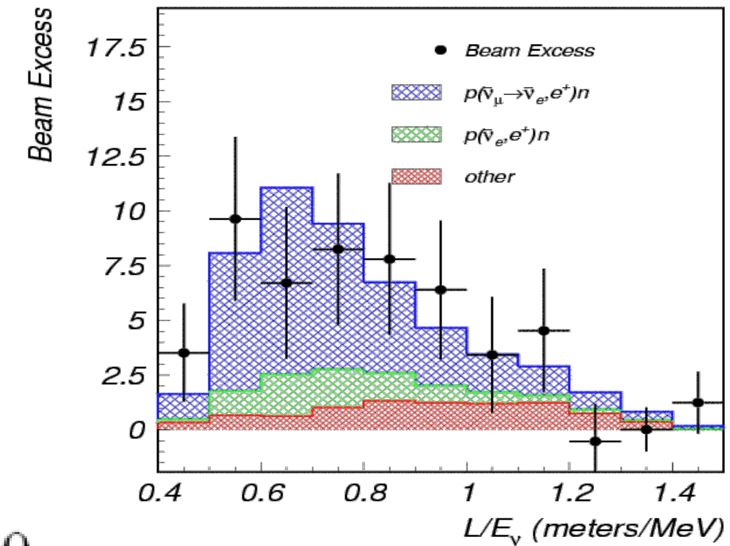
Near BooNE Detector

- In the low-e analysis we are dominated by systematic errors
  - The low-e excess is ~ 6 sigma statistically, but only ~3 sigma including systematic errors
    - it might be due to a unforeseen background or…
    - it might be due to new, non-standard physics

- Running MiniBooNE for 1 year at a position 200 meters would increase the data rate per pot x6 and:
  - *Make flux, cross section, and optical model systematic errors small in the 200 meter/500 meter comparison*
  - Demonstrate at ~ 5 sigma level whether or not the low-e excess depends on $1/L^2$ or (L,E) e.g. oscillations

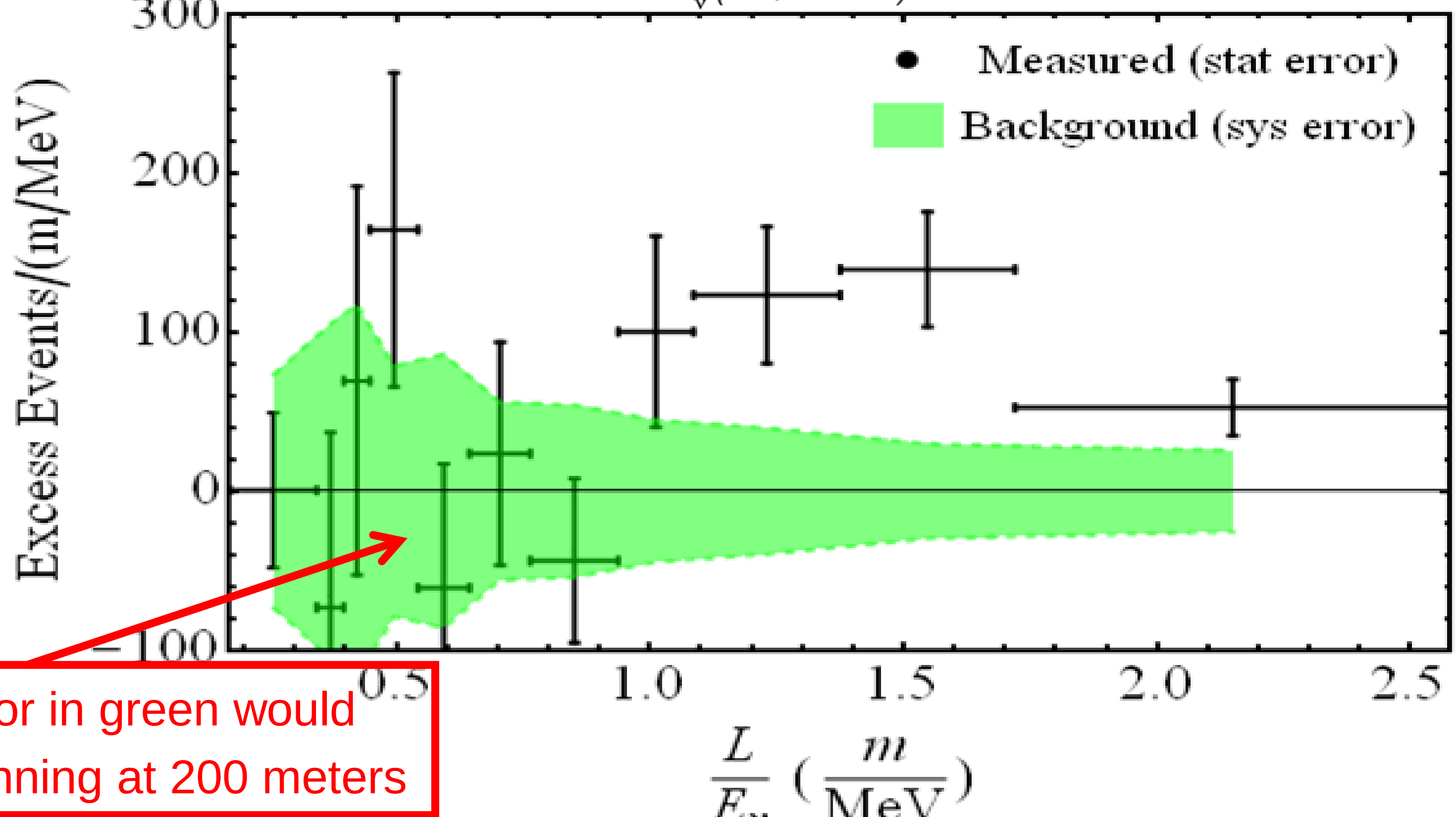
MiniBooNE at 200 meters

LSND
(anti-neutrino)



L/E ~ neutrino proper time
(in rest frame of neutrino)

MiniBooNE
(neutrino)



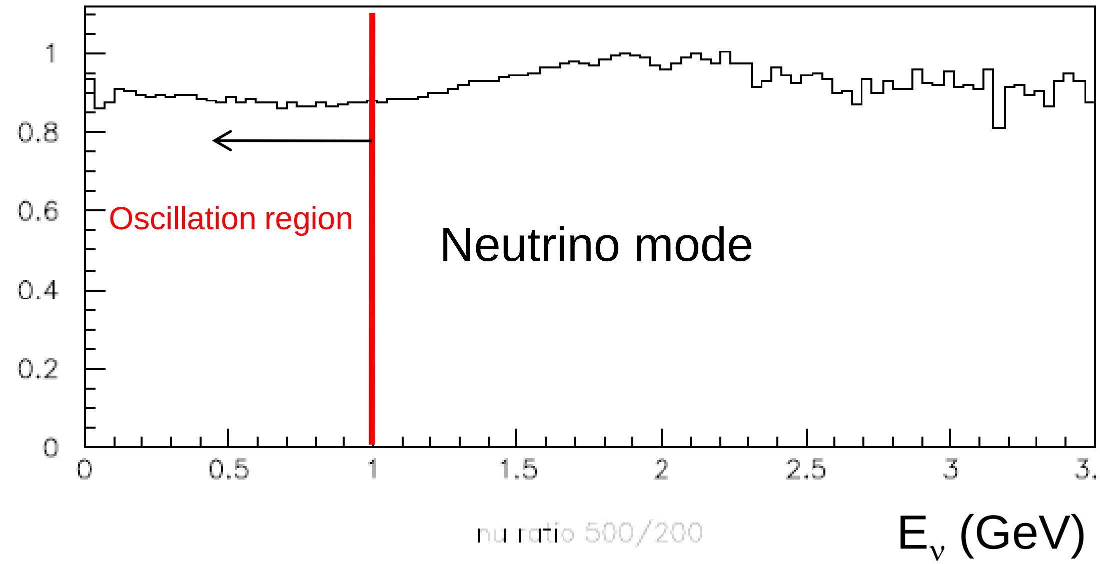
The systematic error in green would disappear after running at 200 meters

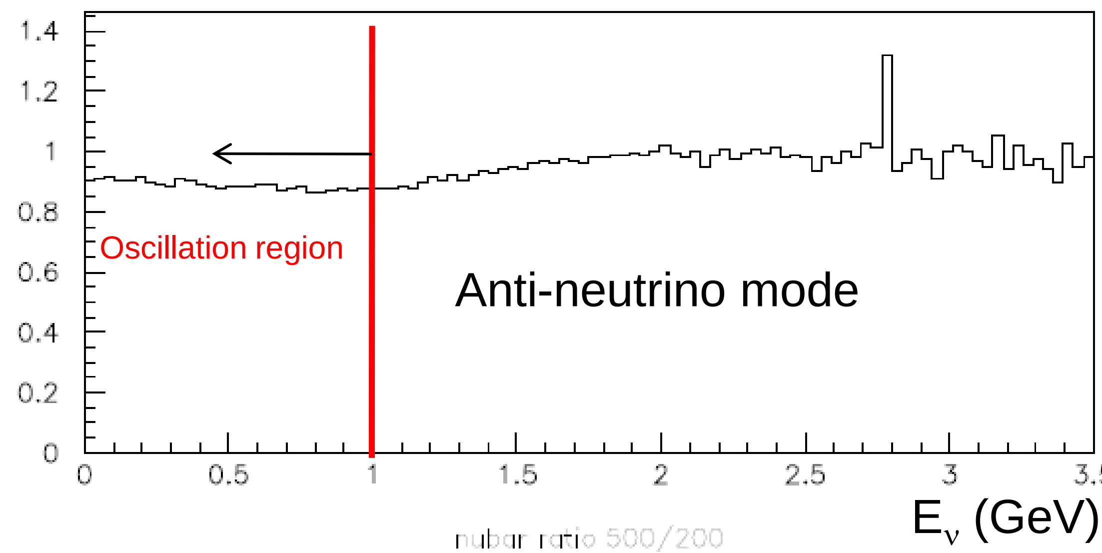
Systematic Errors :

- Neutrino Cross Sections
  - target material is the same (mineral oil)
- Detector Efficiencies
  - With the same detector, we should have nearly identical detection efficiencies
- Flux ?
  - the opening angles of neutrinos from pion or kaon decays are tens of mrad or greater
  - Most pions and kaons contribute to both the 200 and 500 meter fluxes

Far to Near Neutrino Flux Ratios at 200 m

MiniBooNE Far/Near fluxes
Scaled by $1/r^2$





Statistical Errors

- In order to achieve reasonable sensitivity ~ ½-1 year of running would be required for each focus
  - Current proton delivery rates of 2 x 10^{16} protons/hour give ~1.75×10^{20} protons/year
  - Current 6.5 σ statistical significance translates to ~5 σ statistical significance for one year of running in nu mode

Options for Near BooNE Detector

- Transport existing MiniBooNE detector (~80 tons) to new location 150-200 meters from BNB target (~4M$)
- Dismantle existing MiniBooNE detector and construct a new detector at 150-200 meters. (~4M$)
- Construct brand new detector at 150-200 meters (~8M$)

Lift of 260 ton Generator

Transporting 550 ton Coker Drum from ship to crane hook

Conclusion

- Moving MiniBooNE to 200 meters and running for one year would resolve whether or not the low-e excess is due to a (L,E) dependent phenomena at the ~ 5 sigma level
- It would also provide a high statistics, low systematic error numu/numu-bar disappearance measurement
- The timing of the project is ideal for post-antineutrino running in the BNB
- MicroBooNE will at the same time run to look for excess gamma events
- A “LSND”-like detector at the SNS (OscSNS) would directly test the LSND excess