Far Off-Axis NOvA Experiment

(Short baseline at Fixed L, variable E)

John Cooper
NOvA Project Manager

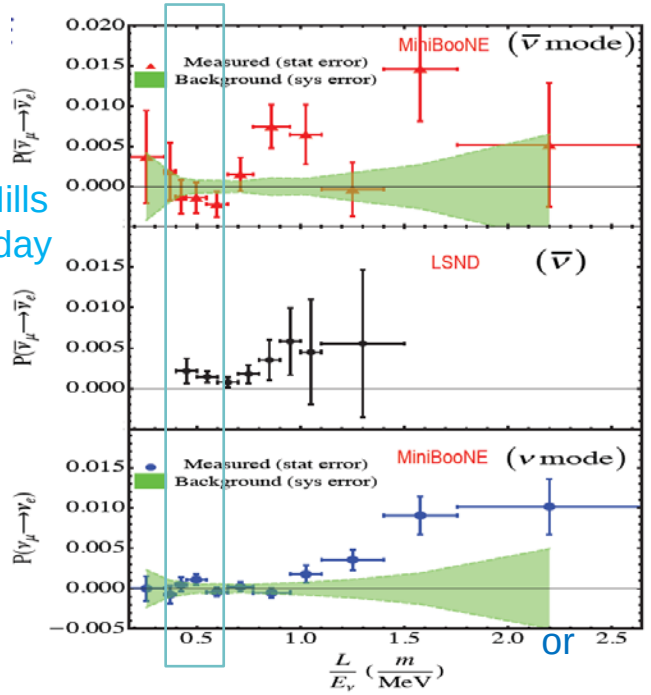
for

D. Bogert, L. Corwin, P. Derwent, W. Freeman,
P. Lucas, P. Lukens, M. Martens, M. Messier, T. Miao,
M. Muether, A. Norman, D. Perevalov, R. Ray,
P. Shanahan, R. Tesarek

Motivation for NOvA
to look for short baseline oscillations

- The NOvA Near Detector is ~ 0.8 km from the typical neutrino source point
- NOvA is in the NuMI Beam at an off-axis angle of 14.6 mrad
  - We see a beam energy ~ 2.0 GeV
- So, the NOvA Near Detector is in the L/E range around 0.3 – 0.5
- The LSND /MiniBooNE signals are in the L/E range 0.4 – 1.2
- What happens to the rest of the LSND signal assuming it is real?
  - It appears at larger L/E
  - We are at a fixed E, so it appears at larger L **downstream** of our Near Detector

From Geoffrey Mills talk yesterday



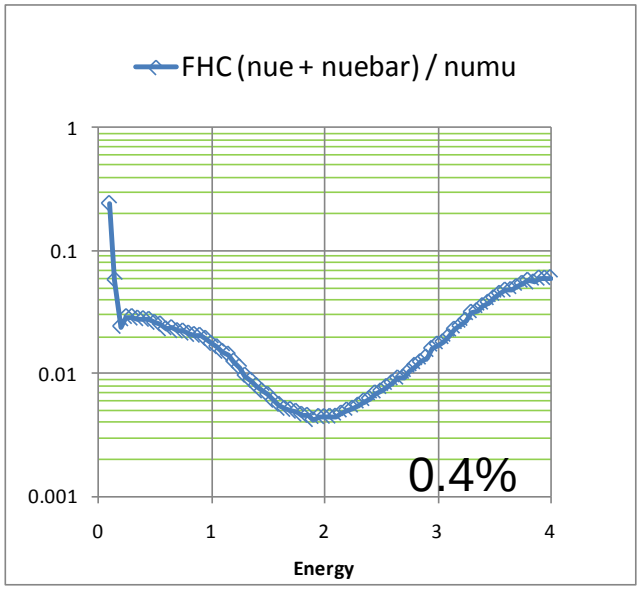
or

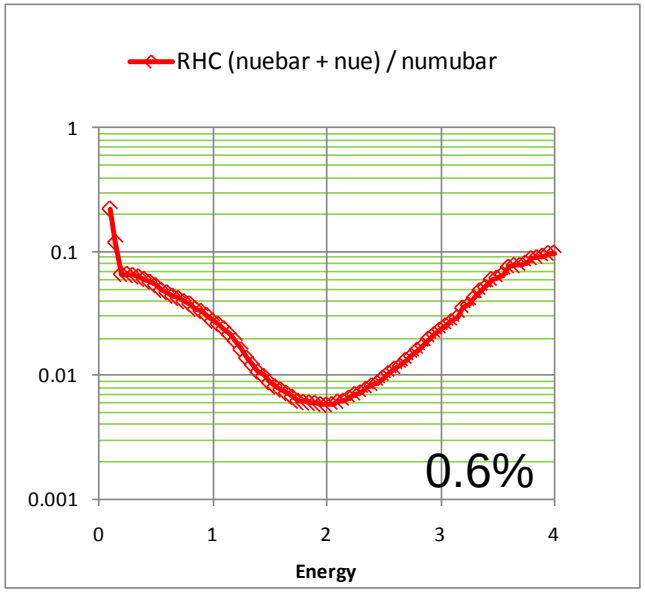
- Everything downstream of our Near Detector also survives to our Far Detector, 810 km away in Ash River, Minnesota
  - We would see "extra" ν_e events above the "ν_e beam background" that our Near Detector is supposed to measure.
  - This is the signal we are looking for in our θ_{13} search, and we may get it wrong.

- We noted all of this in our 2005 Proposal to the laboratory
  - And said we would have to move our Near Detector around to understand the effect.
  - We even noted we would have to do this if MiniBooNE saw only an anti-neutrino effect.

The oscillation is not a huge effect, but NOvA's electron neutrino background is also small

- LSND sees an oscillation probability of (0.264 ± 0.67 ± 0.45) % , a 3.8 σ effect.
  - I sometimes tweak my collaborators by suggesting since they have been prepared in the past to believe this is zero, they should also be prepared to believe it is at + 3.8 sigma = 0.53 %
- In any case, our (nue + nuebar) beam background is about this size.

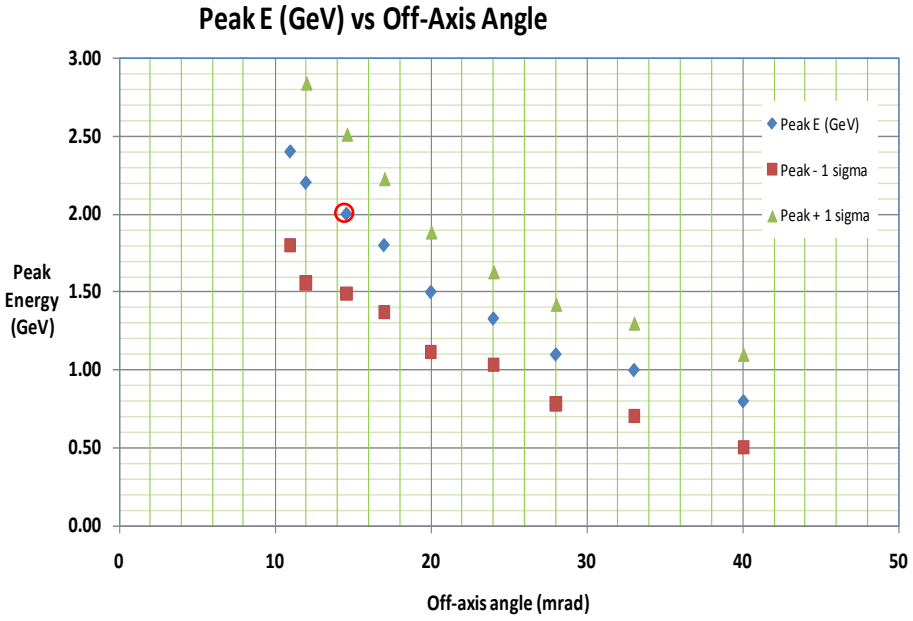


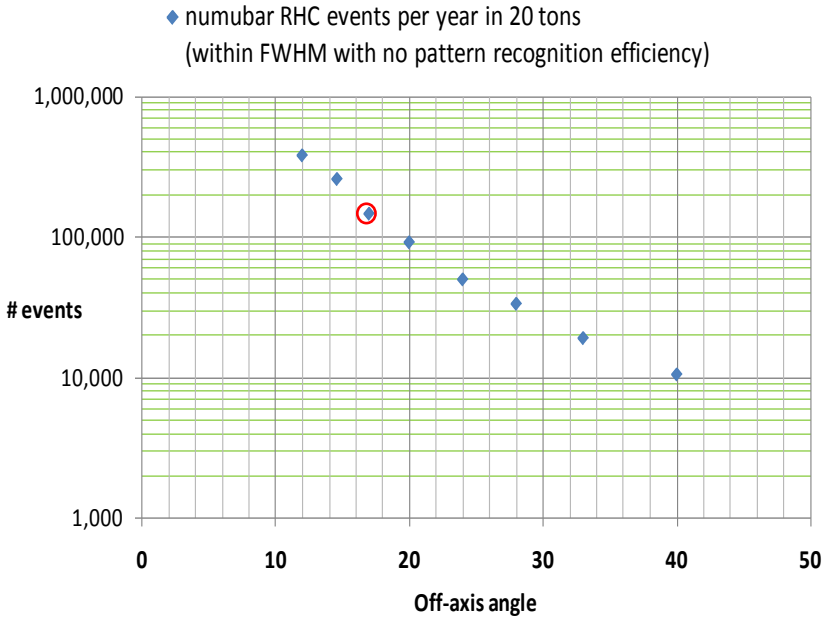


- We could effectively see twice as much "ν_e beam background", but fail to measure the extra part, instead calling it a signal at Ash River
  - This is still a small effect for NOvA (beam $\nu_e + \bar{\nu}_e$ are about 60% of our background in the Far Detector).
  - But in a possible scenario where all the upcoming θ_{13} searches might be competing for a new limit (no signal), understanding systematic errors like this would be necessary.

Additional Motivation for NOvA: We might make a measurement here!

- The idea is to exploit additional off-axis angles to get different E values
  - Energies in the range 2.5 GeV down to 0.8 GeV are accessible
    - Note narrow energy ranges for off-axis beams
  - Making L/E in the range 0.3 – 1.0 accessible
- Peak energy, FWHM, Number of $\overline{\nu}_\mu$ events within FWHM for a 1 year anti-neutrino run in 20 tons (NOvA Near fiducial volume) shown below





What could NOvA observe?

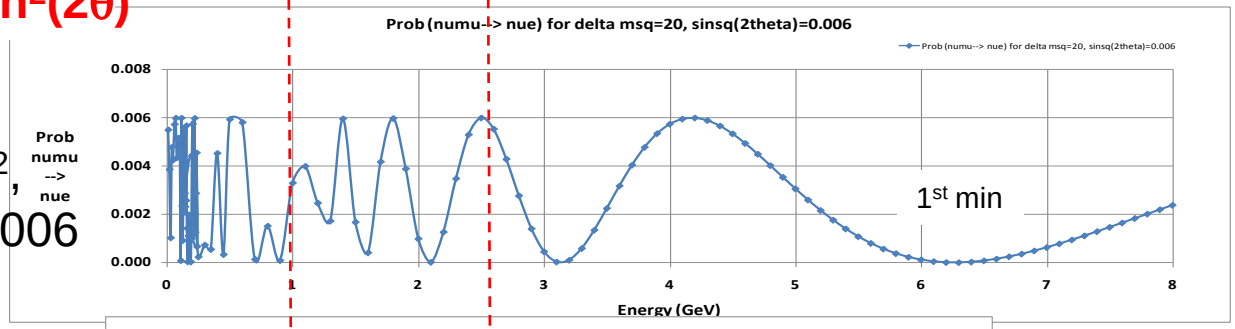
(In a 2 neutrino short baseline oscillation probability vs E_ν)

First, for exact L, look at the probability for numu → nue vs. E

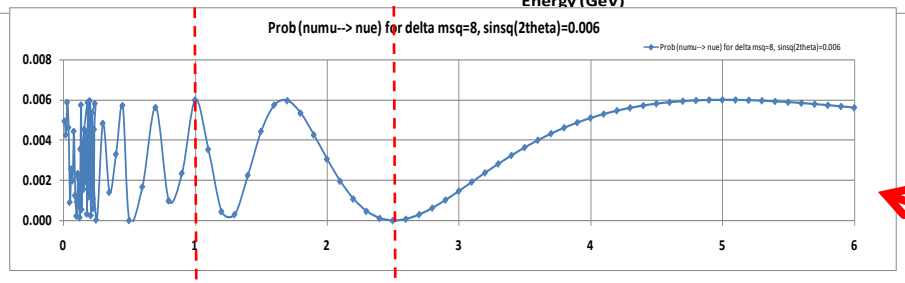
δm^2, $\sin^2(2\theta)$

Accessible E range

20 eV², 0.006

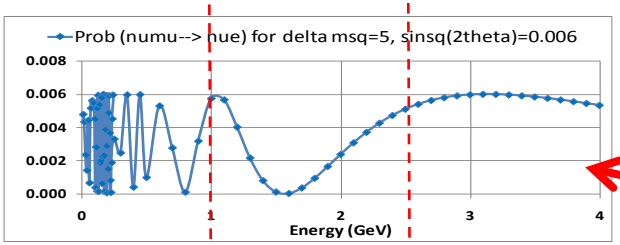


8 eV², 0.006



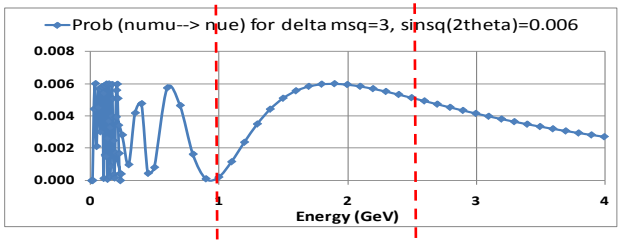
LSND best fit

5 eV², 0.006



LSND + MiniBooNE best fit

3 eV², 0.006



Parameter choice ~ guided by

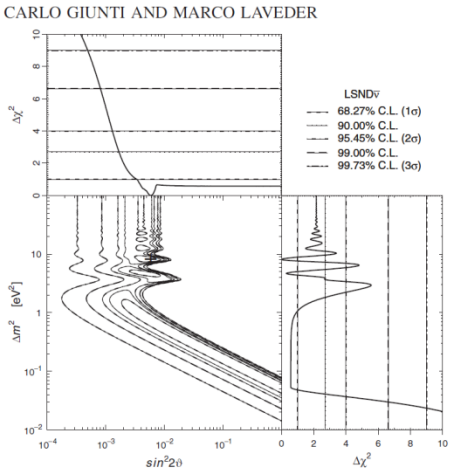


FIG. 2. Allowed regions in the $\sin^2 2\vartheta - \Delta m^2$ plane and marginal $\Delta\chi^2$'s for $\sin^2 2\vartheta$ and Δm^2 obtained from the fit of LSND antineutrino data. The best-fit point is indicated by a cross.

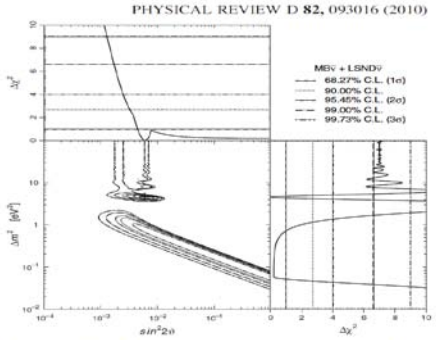


FIG. 3. Allowed regions in the $\sin^2 2\vartheta - \Delta m^2$ plane and marginal $\Delta\chi^2$'s for $\sin^2 2\vartheta$ and Δm^2 obtained from the combined fit of MiniBooNE (MB) and LSND antineutrino data. The best-fit point is indicated by a cross.

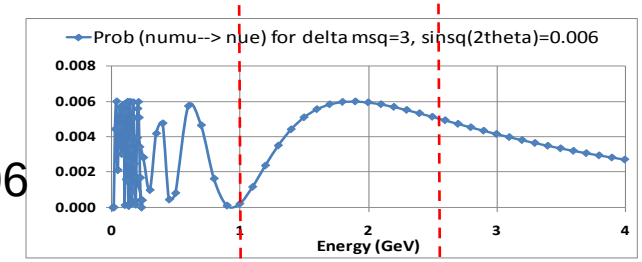
Further down the allowed parameter space **it gets harder** (no structure seen)

- Still for exact L, Probability for numu → nue vs. E

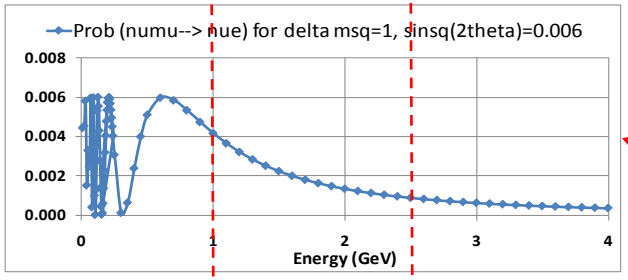
δm^2, $\sin^2(2\theta)$ ↓

Accessible E range

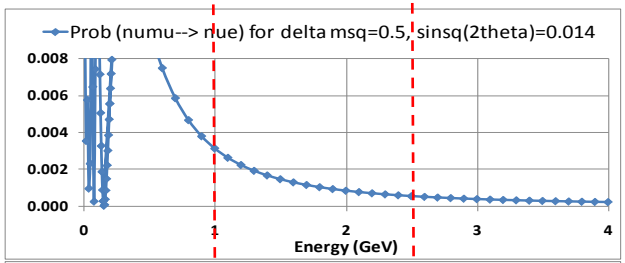
3 eV², 0.006



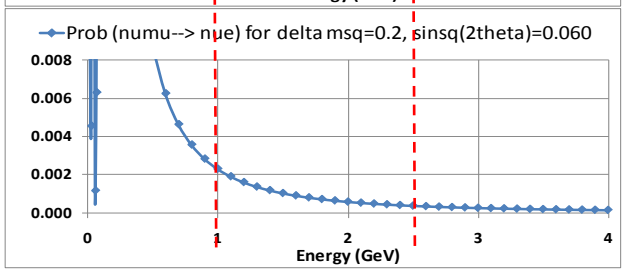
1 eV², 0.006



0.5 eV², 0.014



0.2 eV², 0.060



Parameter choice ~ guided by

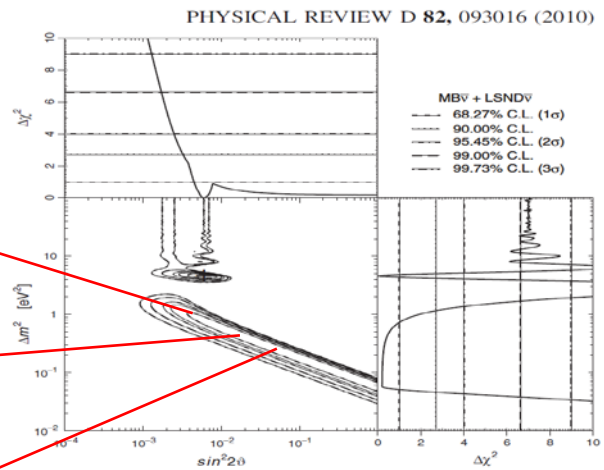
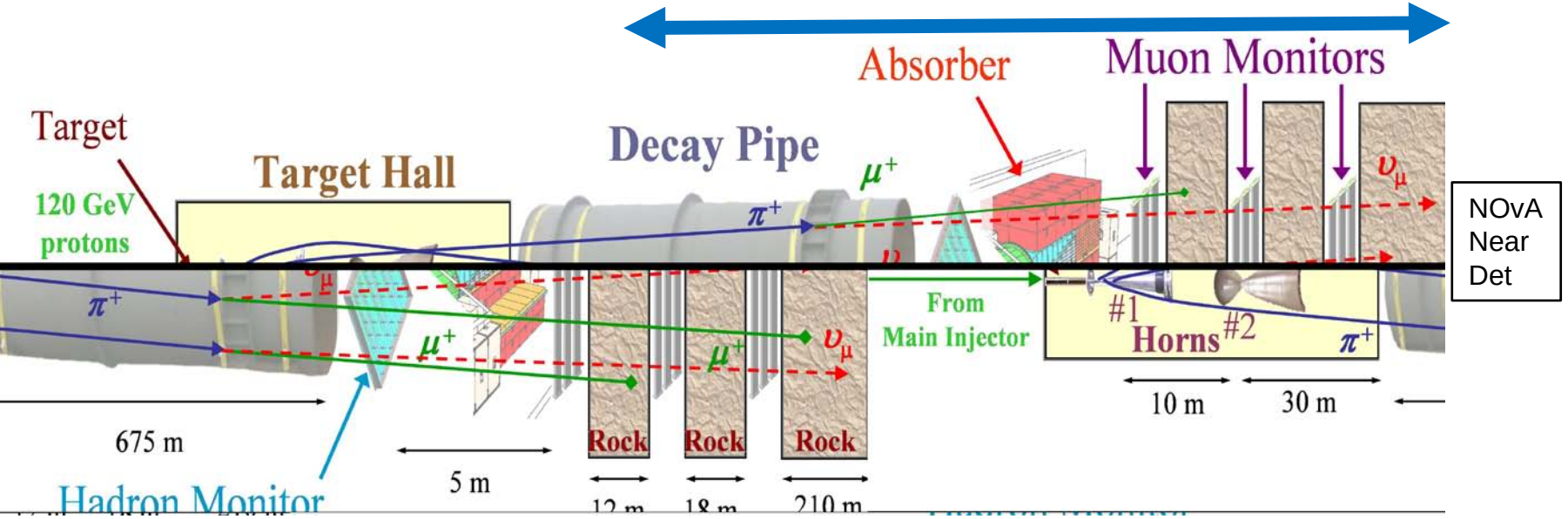


FIG. 3. Allowed regions in the $\sin^2 2\vartheta - \Delta m^2$ plane and marginal $\Delta\chi^2$'s for $\sin^2 2\vartheta$ and Δm^2 obtained from the combined fit of MiniBooNE (MB) and LSND antineutrino data. The best-fit point is indicated by a cross

How well do we do on L/E?

- NOvA's energy resolution for electron is $\sigma(E)/E = 0.06$
  - even better for QE events at $\sigma(E)/E = 0.04$
    - and QEs will be a majority of events <u>after reconstruction</u>
  - So binning in 100 MeV bins is reasonable
- But the previous slides were for exact L and that is not the case due to the long decay volume in NuMI
  - Typical origin for a neutrino is **0.8 km ± 0.2 km**

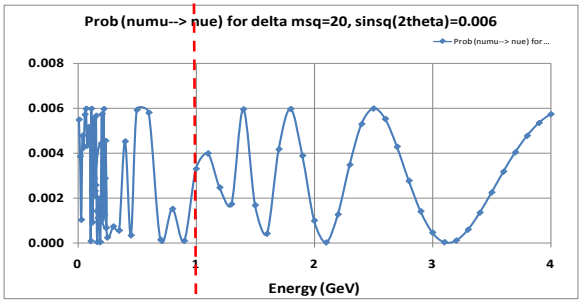


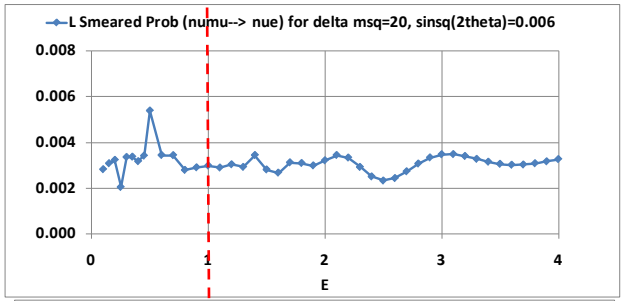
With a distribution of L values, the oscillation structure is nearly lost

δm^2, $\sin^2(2\theta)$

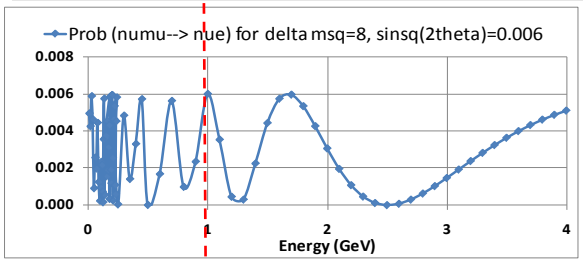
- Exact L
- L smeared 800±200

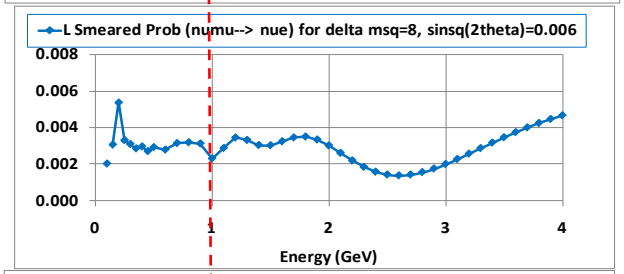
20 eV^2, 0.006



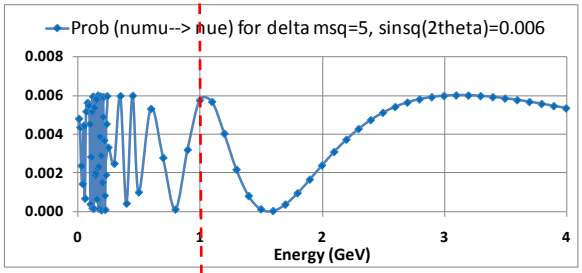


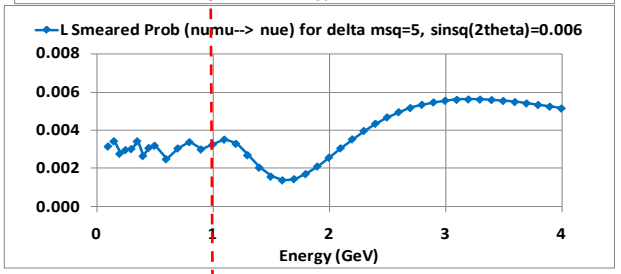
8 eV^2, 0.006



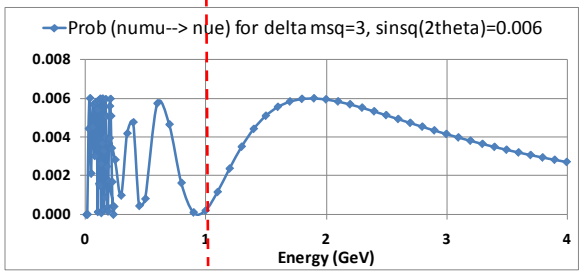


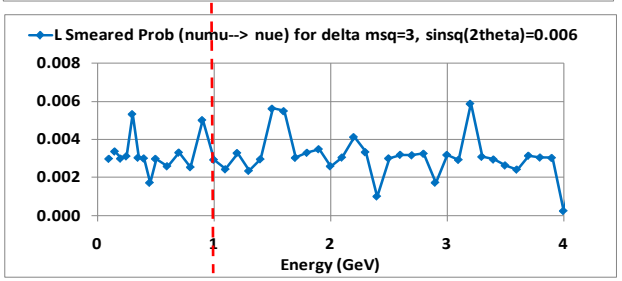
5 eV^2, 0.006





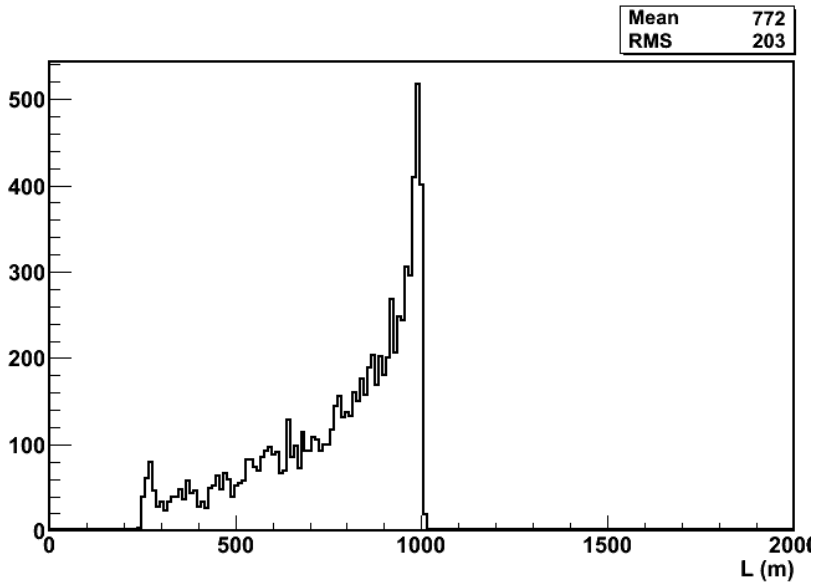
3 eV^2, 0.006

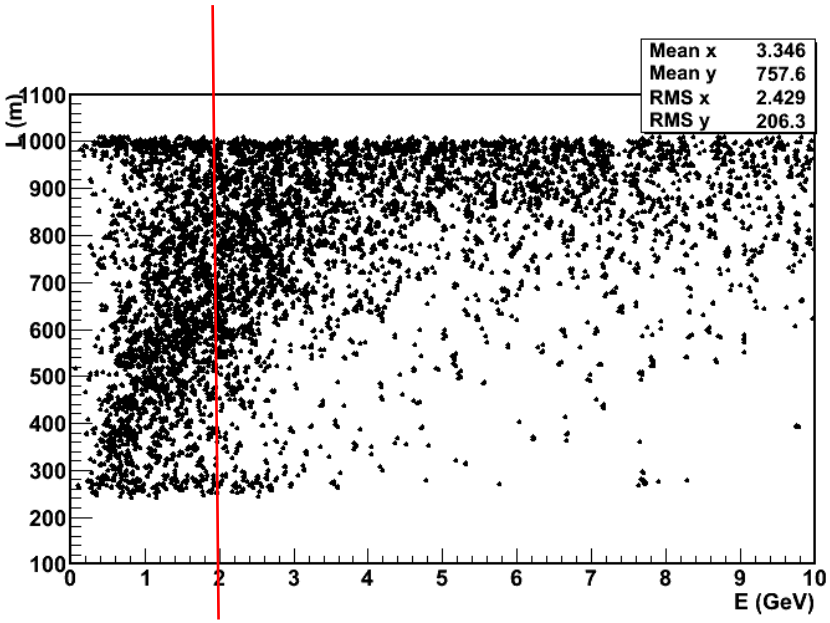




We can use an E vs. L correlation to recover the pattern

- At 14.6 mrad (2 GeV beam), see about a 10 meter change in mean L for every 100 MeV of energy

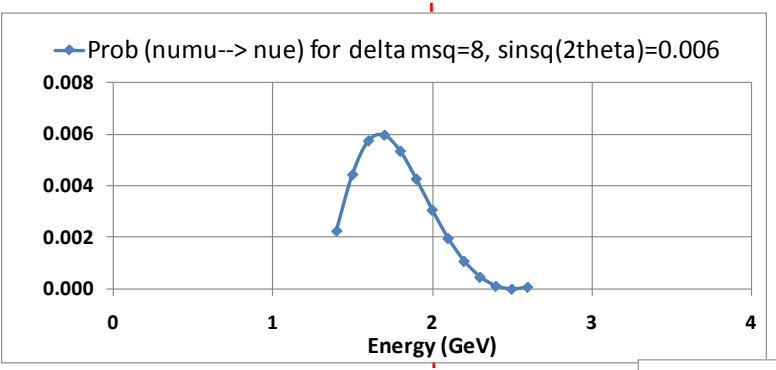




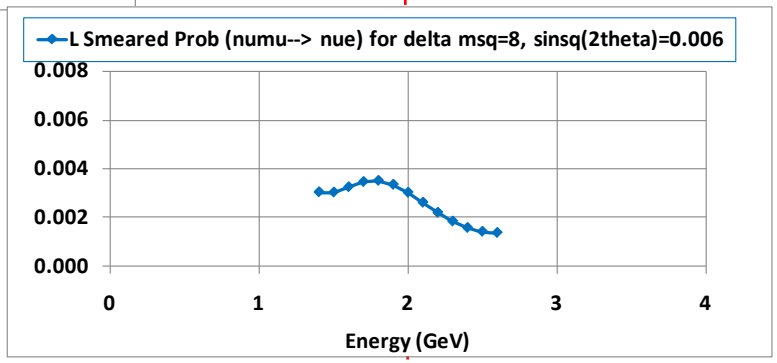
- The off-axis effect persists, giving a correlation.
  - Higher energy neutrinos come from farther away and are at a smaller off-axis angle to the detector.
  - Lower energy neutrinos come from closer and are at a larger off-axis angle.
- Using this correlation helps to recover the oscillation pattern (next slide)

An example for $\delta m^2 = 8\ eV^2$, $\sin^2(2\theta) = 0.006$

- Exact L

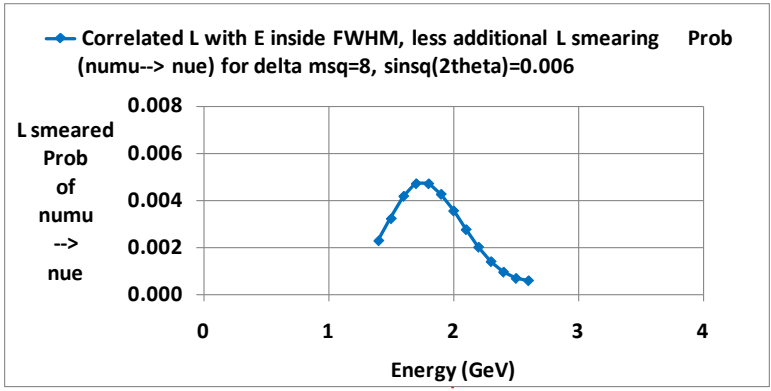


L smeared 800±200



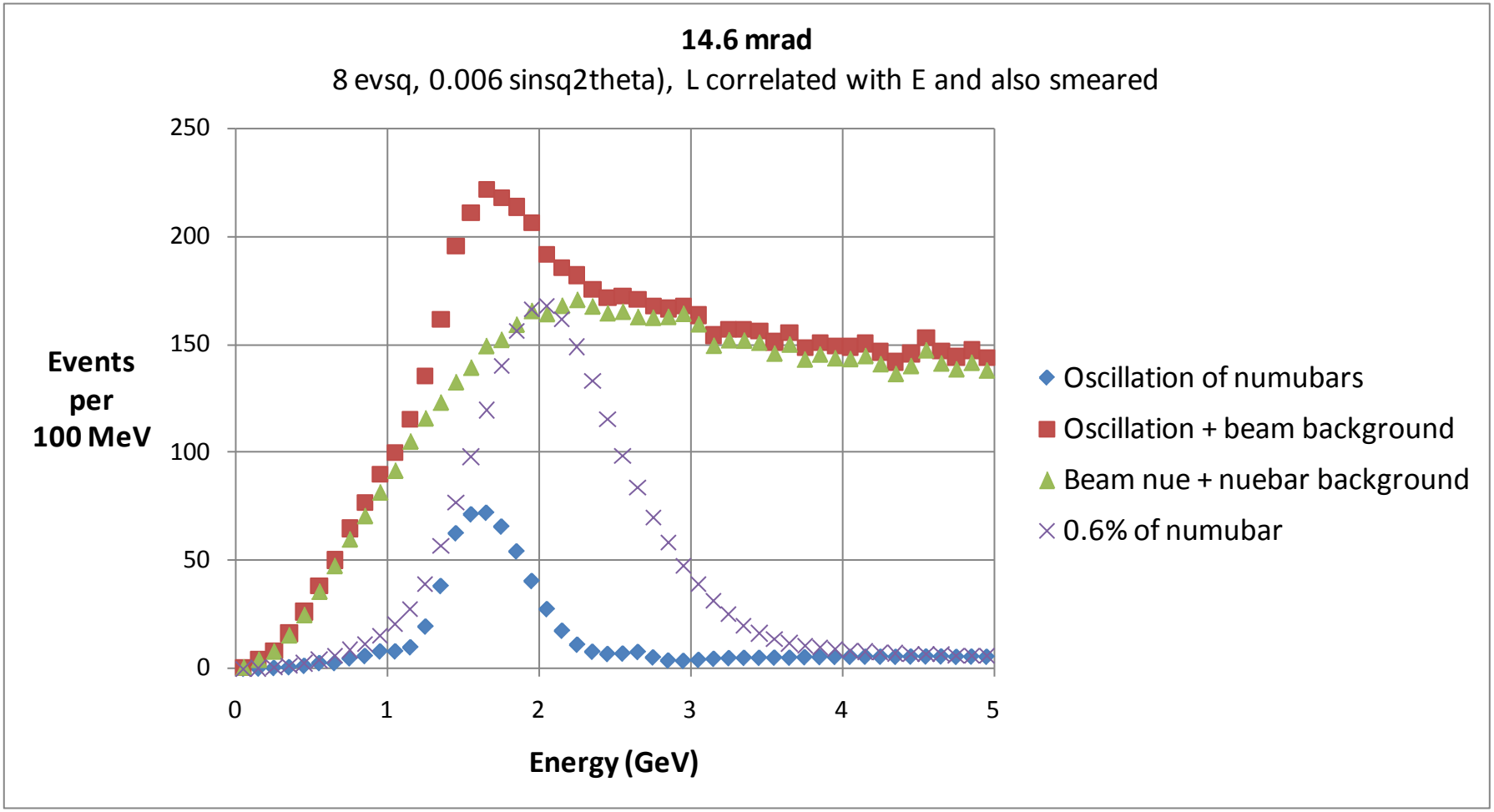
Correlated L
with L smeared ± 100 m

Inside FWHM at
14.6 mrad
(2.0 ± 0.6 GeV)



What we might see at 14.6 mrad for $\delta m^2 = 8\ eV^2$, $\sin^2(2\theta) = 0.006$

- Anti-neutrino running
- 3 years of data



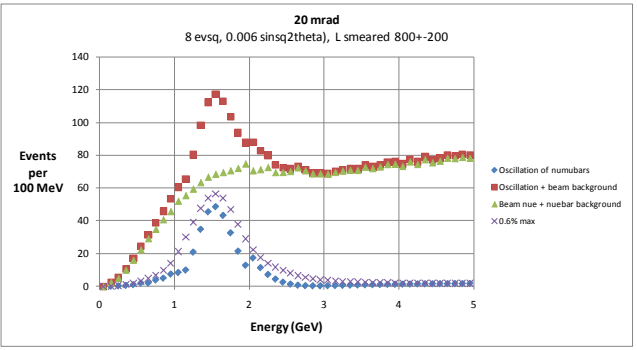
Add 1 year at 17 mrad and 2 yrs at 20 mrad

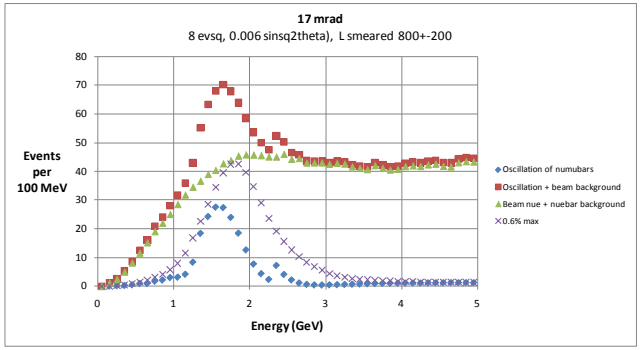
for δm^2,= 8 eV^2, $\sin^2(2\theta)$=0.006

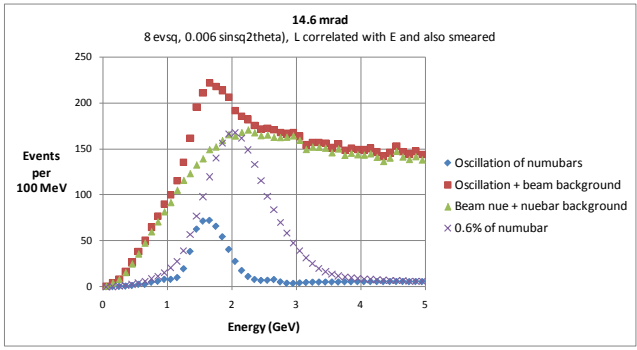
- 20 mrad
- 1.5 GeV peak

17 mrad
1.8 GeV peak

14.6 mrad
2.0 GeV peak



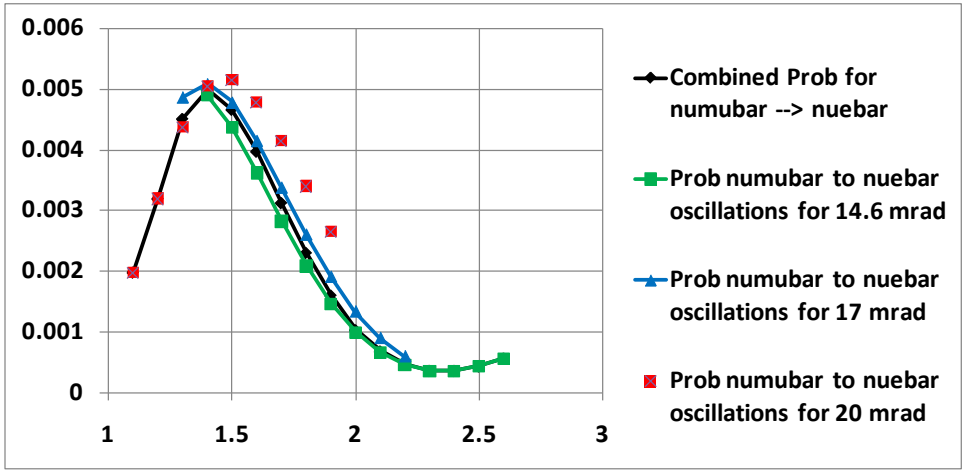




269 excess events

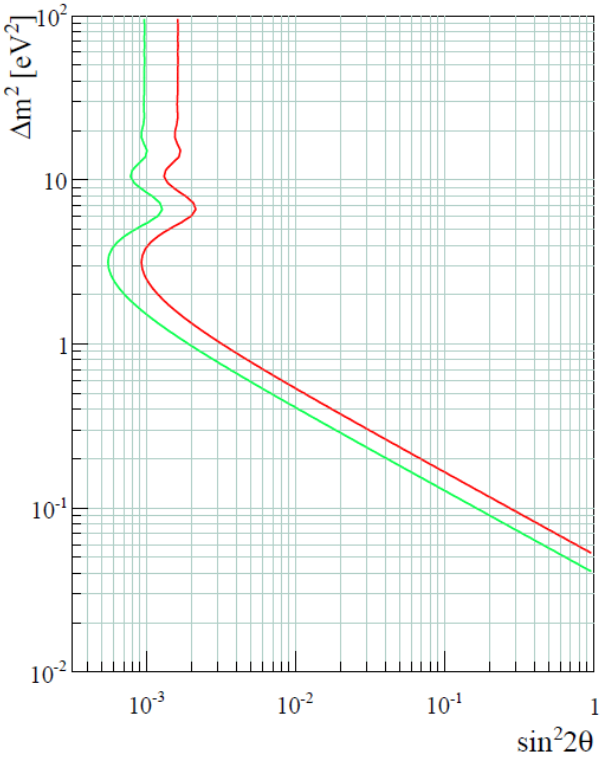
167 excess events

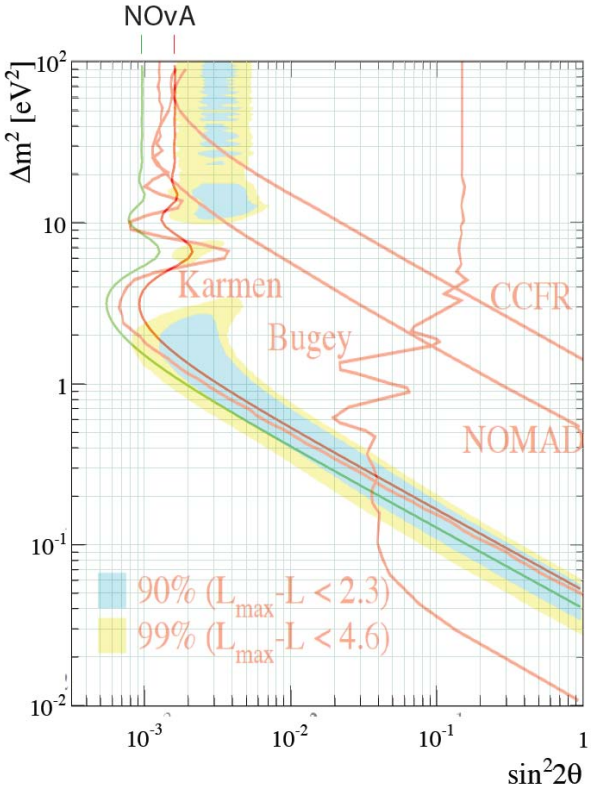
454 excess events



Some overnight fits

- These use only statistical errors, but with
  - Prob (NC→ signal) =2%
  - Prob (numu cc → signal = 36%
  - Anti-neutrinos only
  - 3 yrs at 14.6 mrad, 1 yr at 17 mrad, 2 yrs at 20 mrad as on previous slide
- Sensitivity:

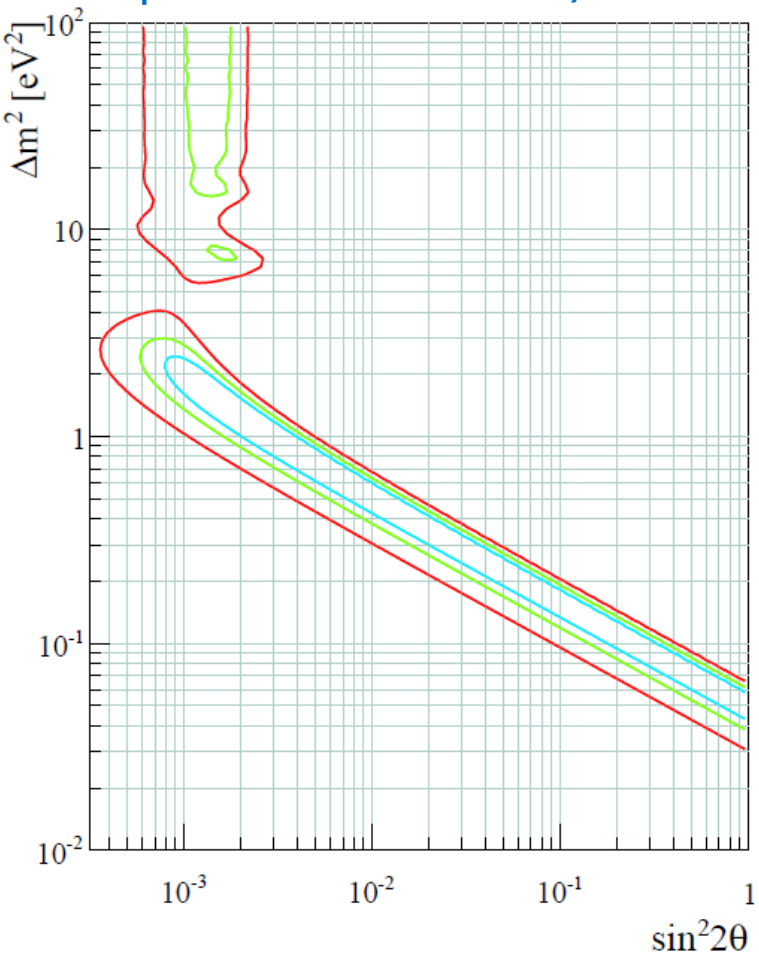




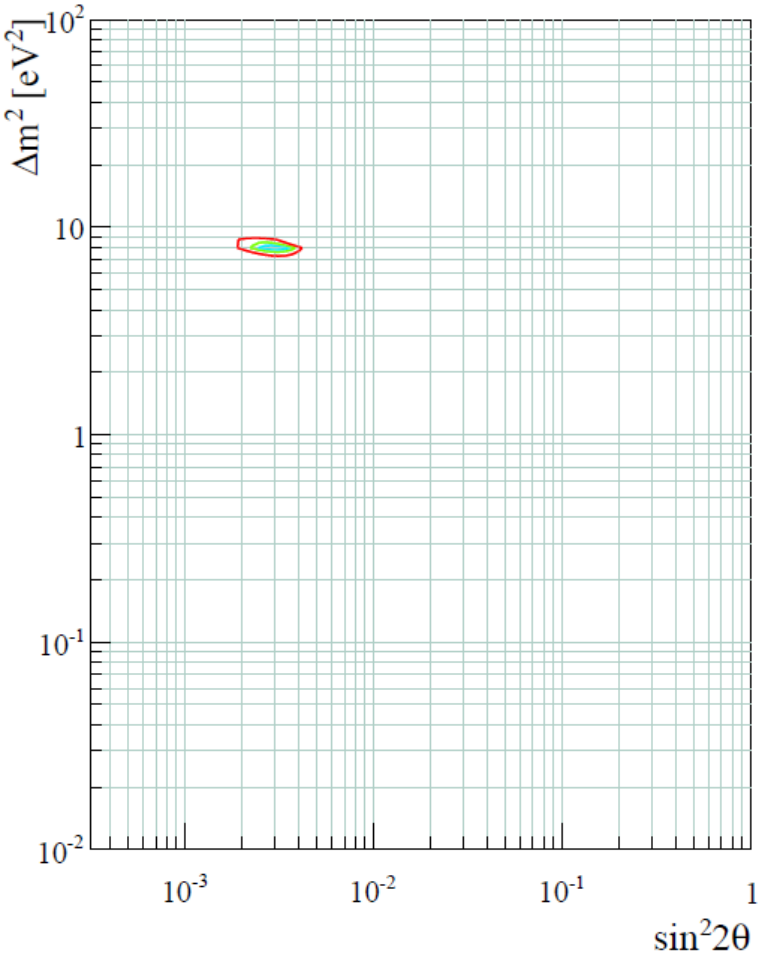
More overnight fits

- Still only statistical errors as on the previous slide

Possible measurement (68/90/99% CL) if true parameters at **0.003, 1 ev²**:

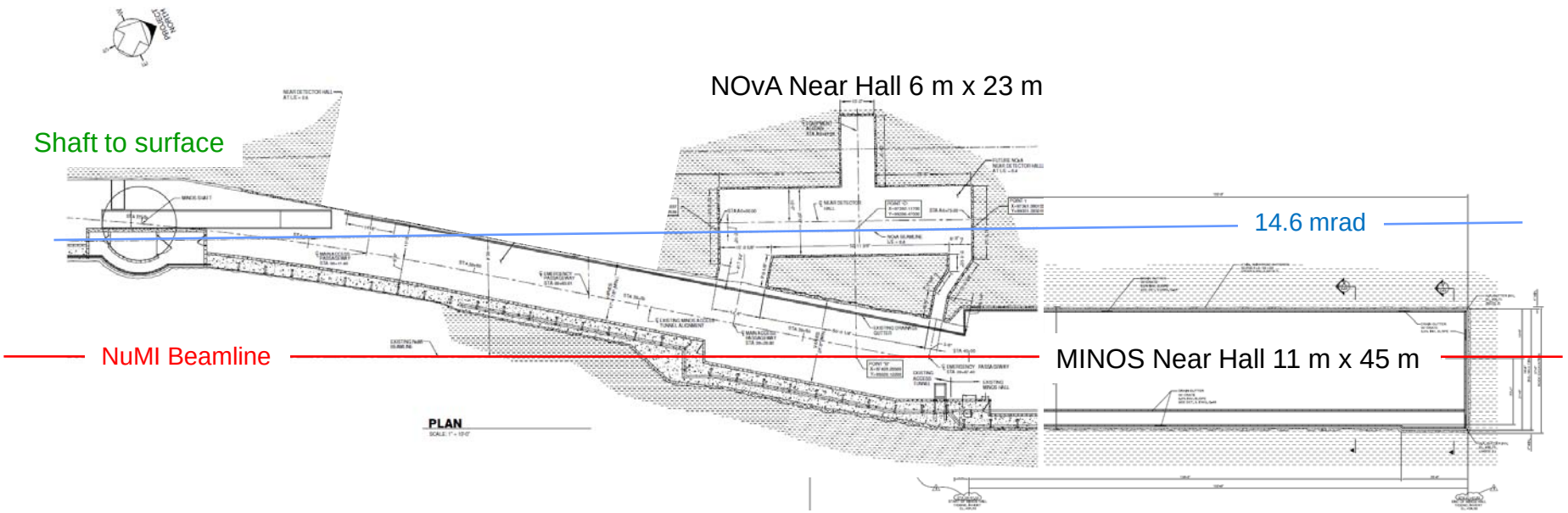


Possible measurement (68/90/99% CL) if true parameters at **0.003, 8 ev²**:



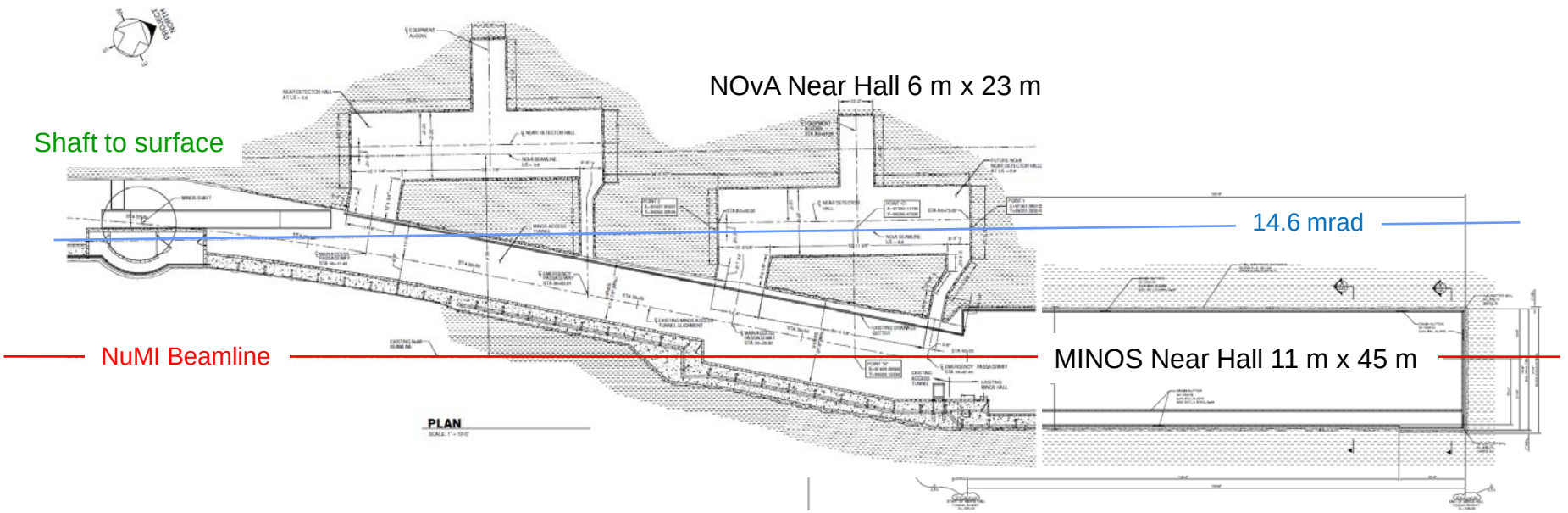
Some practical considerations: How to get further off-axis?

- Current NOvA Near Hall plan
- Problems for any expansion:
  - Narrow pillar (weak)
  - Existing tunnels and caverns limit new excavations
  - Detectors in existing caverns limit access for nearby construction



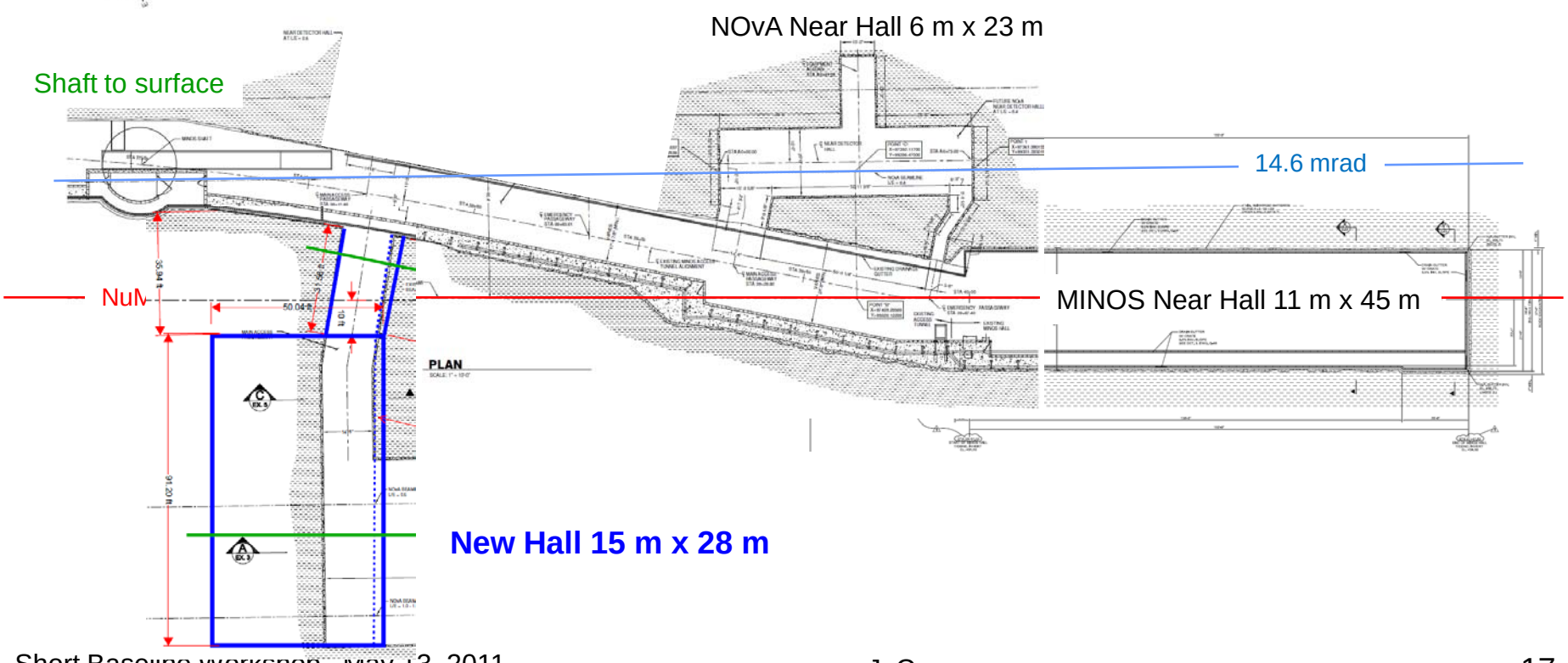
How to get further off-axis?

- Our A&E firm says we could duplicate current plan as shown
- Limited usefulness:
  - Another narrow pillar limits cavern width
  - Can only access one other off-axis angle at ≥ 24 mrad with L/E ≥ 0.6



How to get further off-axis?

- Our A&E firm also agrees we could go to the other side of the NuMI beamline and ~ duplicate the MINOS hall but at 90 degrees to the current MINOS hall
- **This is a hall at constant L, but with varying E**
  - Transverse width can be 28 m
  - **Angles from 12 – 35 mrad accessible to a NOvA Near Detector**
  - In this hall, envision a single NOvA Near Detector on a movable platform
    - Keeps detector cost low, but requires running time at multiple positions



Building a cavern is the critical path

- NOvA plans to build the current Near Cavern design during the March 2012 – Feb 2013 shutdown
- The current cavern comes with a ~ $ 2 M price tag just to mobilize a contractor above and below ground
  - If we build a second cavern in the same pass, we don't have to pay this $ 2 M a second time.
  - $ required for 2nd large cavern depends on final size which depends on more physics studies than we have done to date.

- A schedule for two caverns
  - Design for 1st ready soon
  - Go out for bids in Summer 2011
    - Bid for 2nd cavern may be an option based on a 50% design
    - Bid on # cubic yards, # rockbolts, area of concrete floor,…..
  - Start construction in March 2012
  - Decide on the option in Summer 2012
  - Completion in Summer 2013, then install detectors

NOvA Fixed L, Variable E Summary

- Need to measure LSND/ MiniBooNE effect or we may have an error in our ν_e background at Ash River.
- Opportunity to do additional physics
  - Search for / measure LSND / MiniBooNE effect
  - CC cross sections like MINERvA, but with a narrower energy band beam
    - This was also discussed in our 2005 Proposal.
  - NC ? Exotics?

- Pier Oddone is supportive of our efforts to do more Near Detector work vs. more mass at Ash River beyond our 14 kt "DOE Key Performance Parameter".
  - I believe we can convince DOE of these new "Objective Parameters" for Near Detector options based on the need to understand possible systematics in our θ_{13} search.
- All of this depends on the Project generating enough Management Reserve from our assigned risk-based contingency to do additional work.
  - I believe we can generate of order 15 M$ for this and other Near Detector items (e.g., see SciNOvA talk tomorrow) within our remaining 39M$ of contingency, if we manage our contingency carefully.
  - Building a new large off-axis cavern is key & the first available funds have to go to this purpose.

- Work to date was done by a few people, needs checking, but looks promising.
  - All of NOvA is pretty well consumed by getting 14 kt built at Ash River on schedule
- **If anyone's interest is piqued, please talk to us**
  - Spokespersons are Gary Feldman & Mark Messier.