The NOνA Experiment

WIN'05

Delphi

10 June 2005

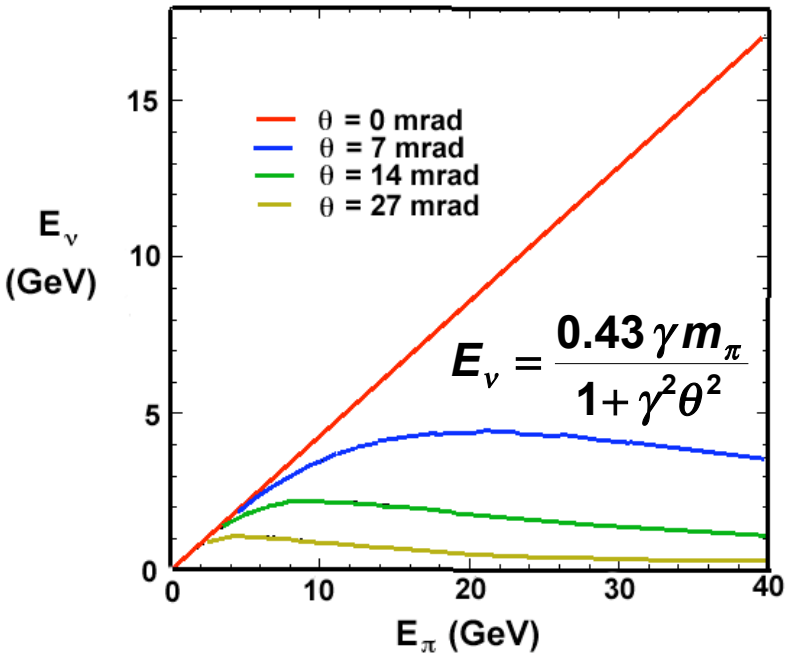
Gary Feldman

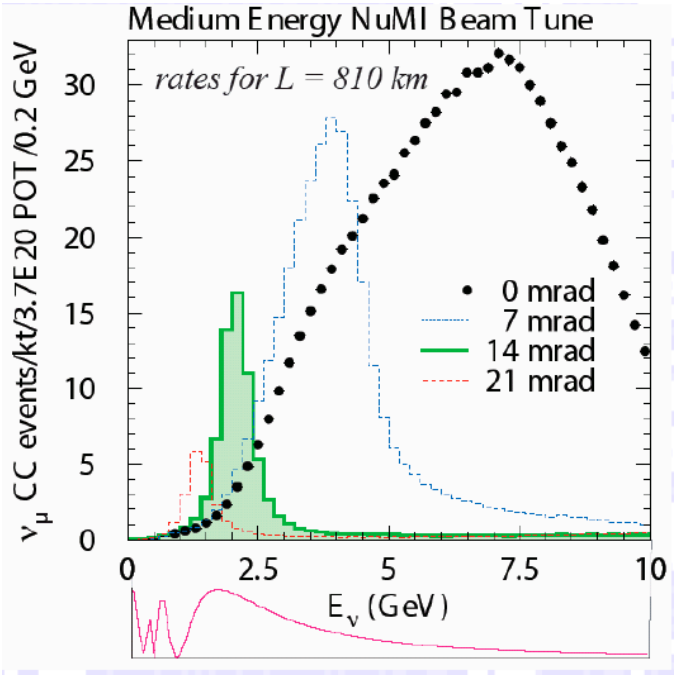
The NOνA Experiment
(NuMI Off-Axis ν_e Appearance Experiment)

- **NOνA is an approved Fermilab experiment optimized for measuring ν_e appearance with the goal of improving MINOS's $\nu_\mu \rightarrow \nu_e$ measurement by approximately an order of magnitude.**
- **The NOνA far detector will be**
  - **a 30 kT "totally active" liquid scintillator detector**
  - **located 15 mrad (12 km) off the NuMI beamline axis near Ash River, MN, 810 km from Fermilab**
- **The uniqueness of NOνA is the long baseline, which is necessary for determining the mass ordering of the neutrino states.**

Off-Axis Rationale

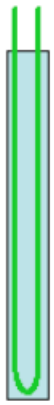
- **Both Phase 2 experiments, NOνA and T2K are sited off the neutrino beam axis. This yields a narrow band beam:**
  - **More flux and less background (ν_e's from *K* decay and higher-energy NC events)**

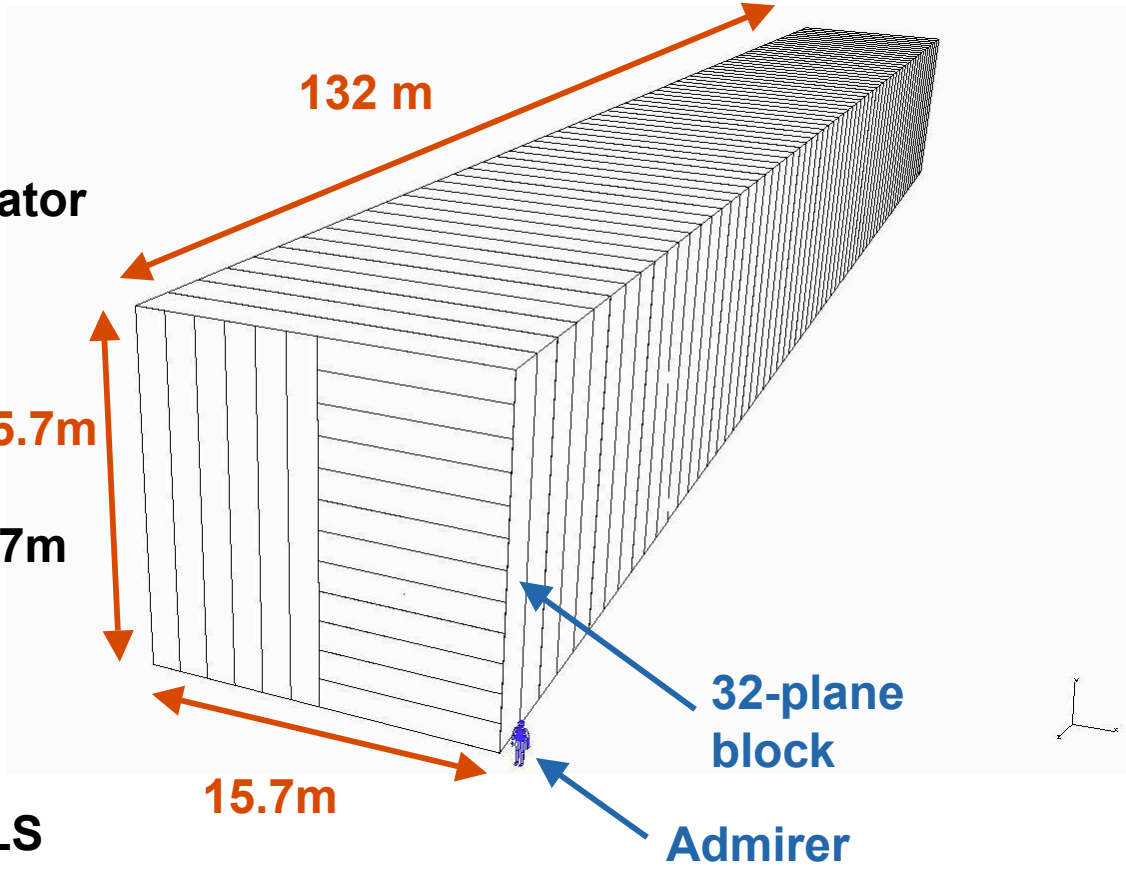




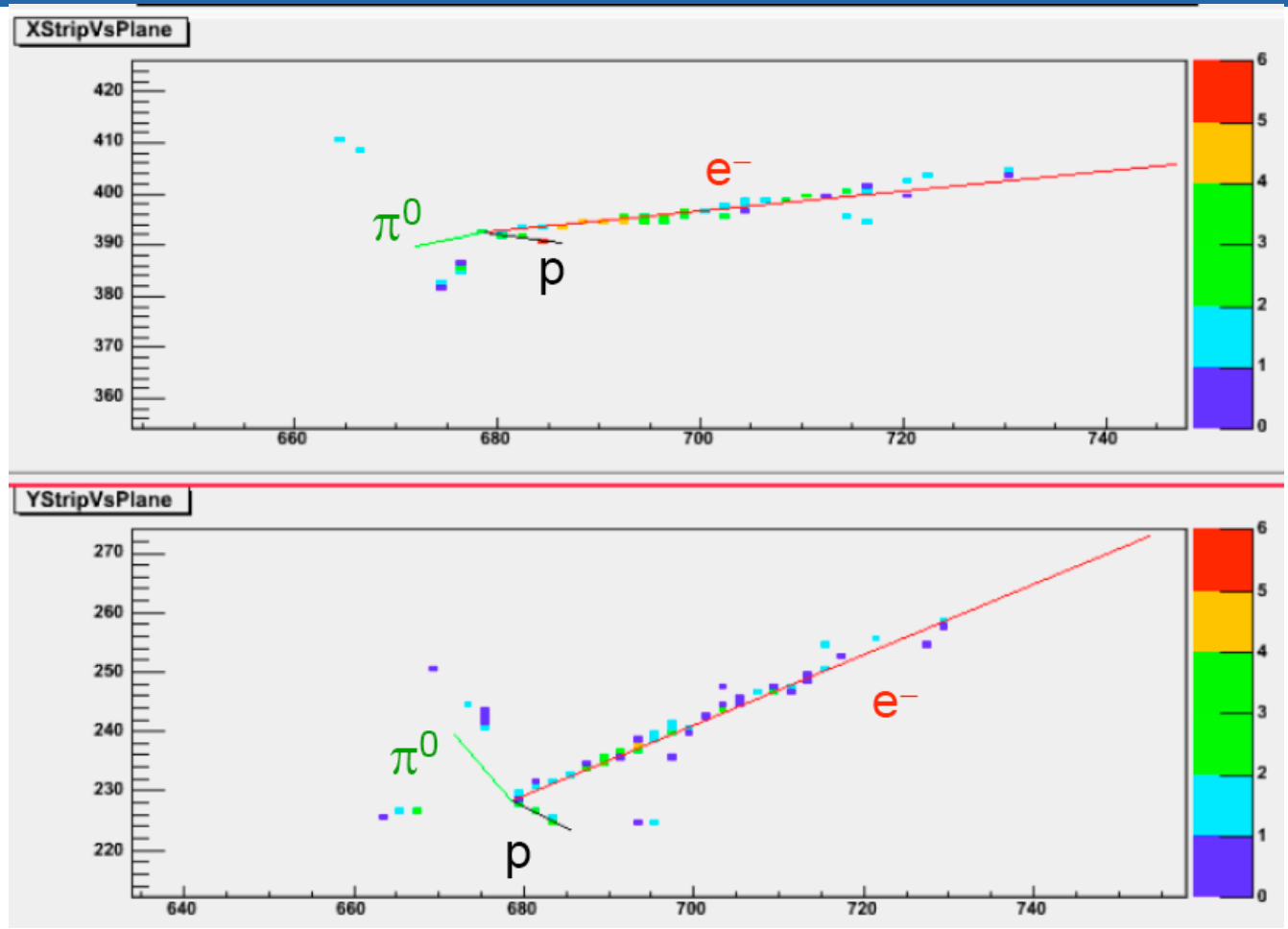
NOνA Far Detector

"Totally Active"
30 kT:
  24 kT liquid scintillator
  6 kT PVC
32 cells/extrusion
12 extrusions/plane
1984 planes
Cell dimensions:
  3.9 cm x 6 cm x 15.7m
  (0.15 X_0 thickness)
Extrusion walls:
  3 mm outer
  2 mm inner
U-shaped 0.8 mm WLS fiber into APD

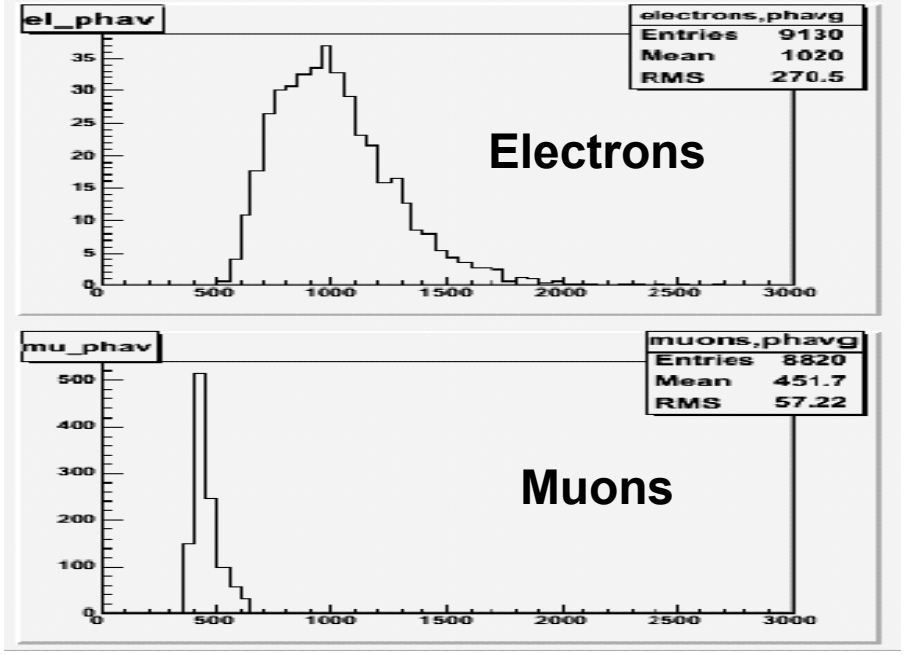




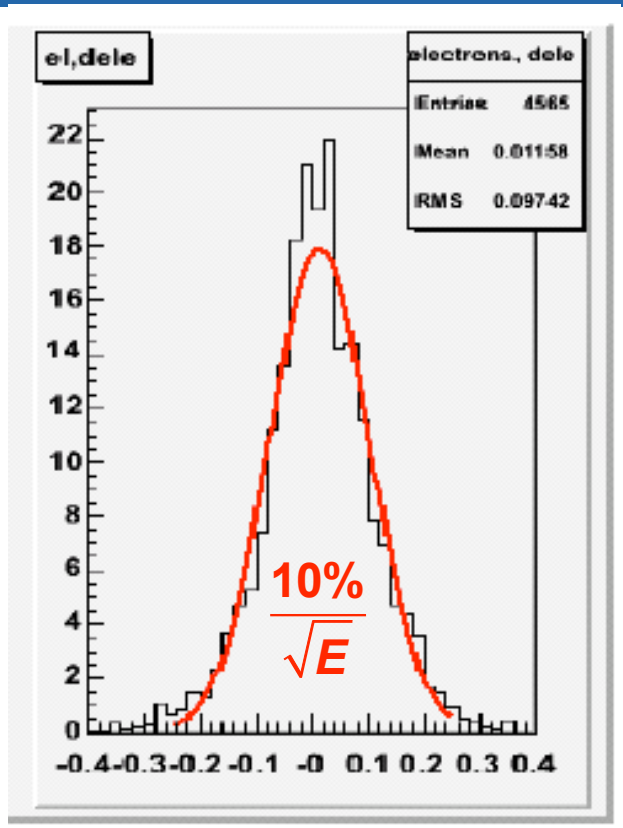
1.65 GeV $\nu_e N \rightarrow e p \pi^0$



Electron ID and Resolution



Average pulse height per plane



Electron resolution

How Does NOνA Meet Its Goals?

- **To get an order of magnitude improvement over MINOS for $\nu_\mu \rightarrow \nu_e$, NOνA**
  - **Reduces background and increases flux by going off axis**
  - **Increases mass by a factor of 6 (while reducing the cost/kiloton by a factor of 3)**
  - **Improves *e* identification and e/π^0 discrimination by**
    - **Increasing longitudinal sampling by a factor of 10 ($1.5\ X_0$ to $0.15\ X_0$)**
    - **Having a "totally active" calorimeter instead of a sampling calorimeter**

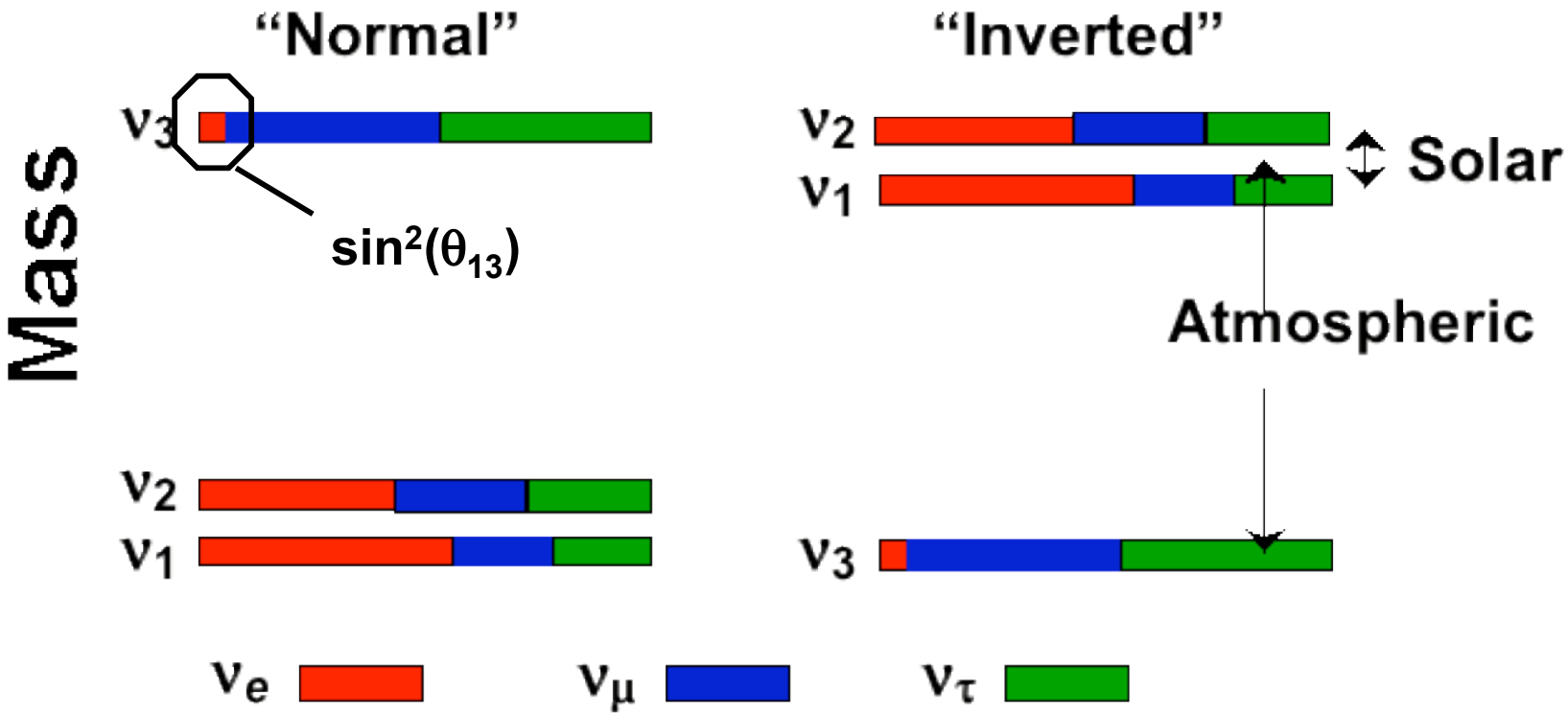
Change in NOνA Prospects

- The cancellation of the BTeV experiment caused a major change in the prospects for NOνA
  - Funds are available for medium size new initiatives
  - More protons are available
- DoE has signaled that it will prepare to put funds for NOνA in the FY07 budget
  - Pending NuSAG/P5 and OMB approval
- Strong Fermilab support
  - Only approved experiment in the post 2010 era

Post-Collider (~2009 and after) Proton Intensity Gains

- NOνA gains more than a factor of 2 from not having to make antiprotons:
  - 11/9 more Booster bunches available ⇒ factor of 1.22
  - Hide Booster filling time by filling the Recycler (2.2 s cycle time x 1.467s) ⇒ factor of 1.50
  - Lost time from transferring antiprotons ⇒ factor of 1.17
  - Total gain = (1.22)(1.50)(1.77) = 2.14
- Project 6.5 x 10^{20} pot/yr
- With a new Proton Driver, 25 x 10^{20} pot/yr
- Intermediate scenarios are being investigated

What Do We Know?



$P(\nu_\mu \rightarrow \nu_e)$ (in Vacuum)

- $P(\nu_\mu \rightarrow \nu_e) = P_1 + P_2 + P_3 + P_4$
  - $P_1 = \sin^2(\theta_{23}) \sin^2(2\theta_{13}) \sin^2(1.27\ \Delta m_{13}^2\ L/E)$ "Atmospheric"
  - $P_2 = \cos^2(\theta_{23}) \sin^2(2\theta_{12}) \sin^2(1.27\ \Delta m_{12}^2\ L/E)$ "Solar"
  - $P_3 = \mp J \sin(\delta) \sin(1.27\ \Delta m_{13}^2\ L/E)$
  - $P_4 = J \cos(\delta) \cos(1.27\ \Delta m_{13}^2\ L/E)$

  } Atmospheric-solar interference

where $J = \cos(\theta_{13}) \sin(2\theta_{12}) \sin(2\theta_{13}) \sin(2\theta_{23})$ x

$\sin(1.27\ \Delta m_{13}^2\ L/E) \sin(1.27\ \Delta m_{12}^2\ L/E)$

$P(\nu_\mu \rightarrow \nu_e)$ (in Matter)

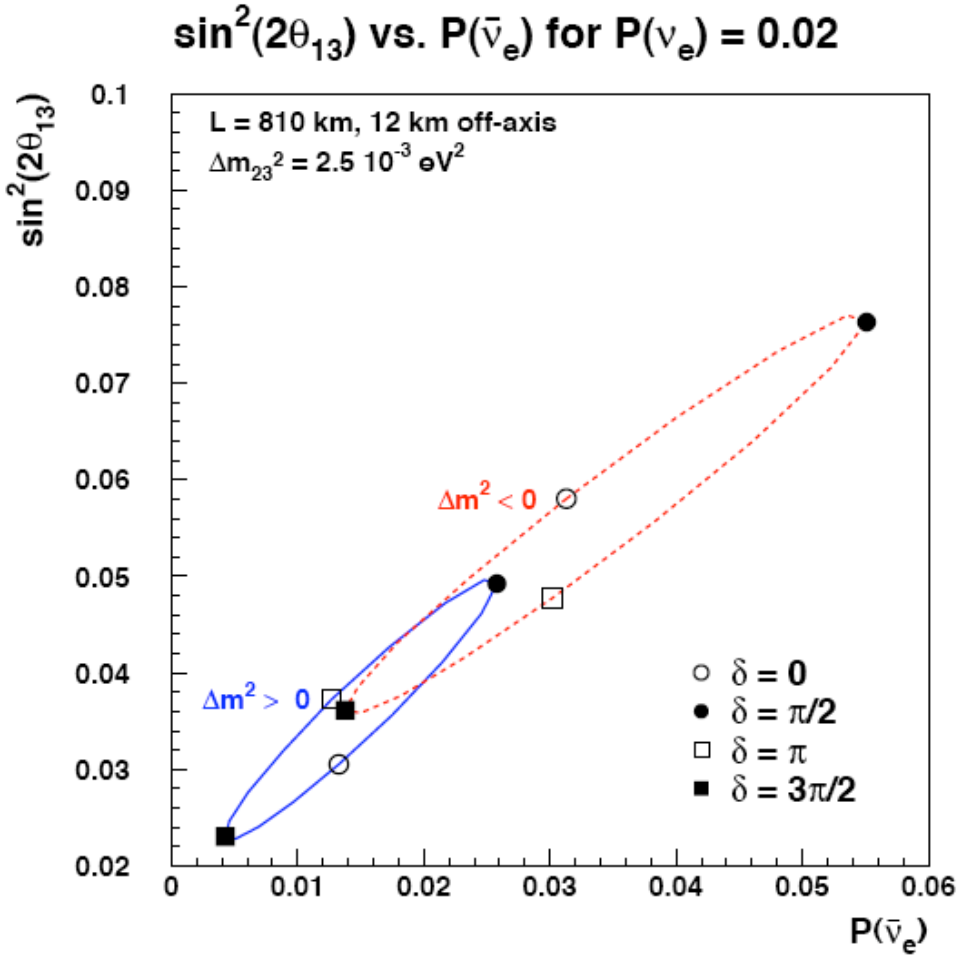
- In matter at oscillation maximum, P_1 will be approximately multiplied by $(1 \pm 2E/E_R)$ and P_3 and P_4 will be approximately multiplied by $(1 \pm E/E_R)$, where the top sign is for neutrinos with normal mass hierarchy and antineutrinos with inverted mass hierarchy.

$$E_R = \frac{\Delta m^2_{13}}{2\sqrt{2} G_F \rho_e} \approx 11\,\text{GeV}$$ for the earth's crust.

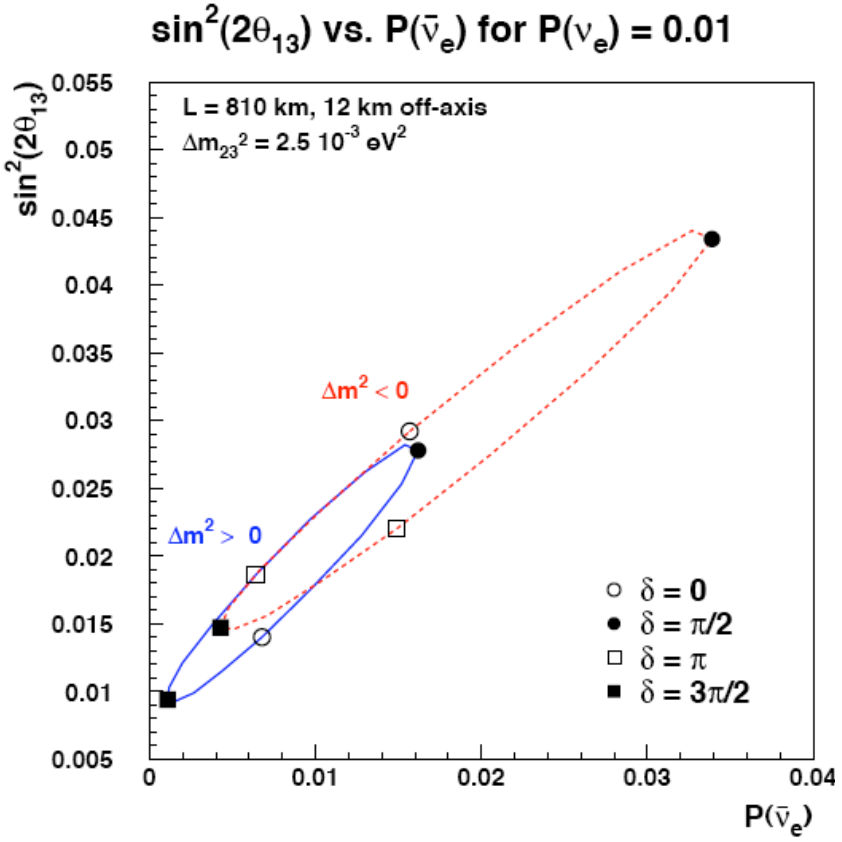
About a ±30% effect for NuMI, but only a ±11% effect for JPARC .

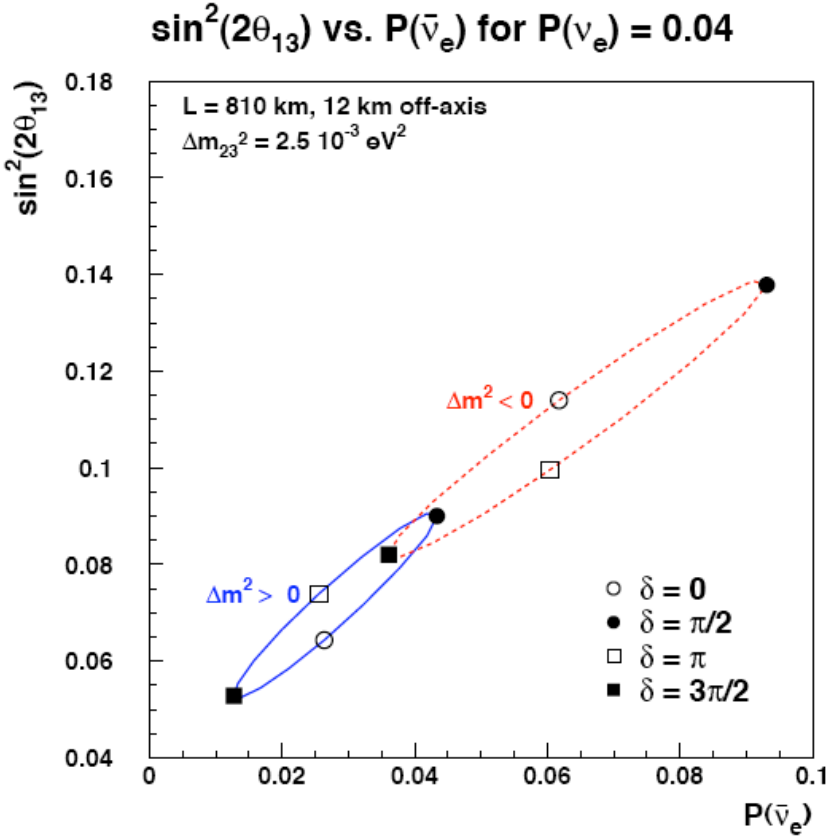
However, the effect is reduced for energies above the oscillation maximum and increased for energies below.

Parameters Consistent with a 2% $\nu_\mu \rightarrow \nu_e$ Oscillation

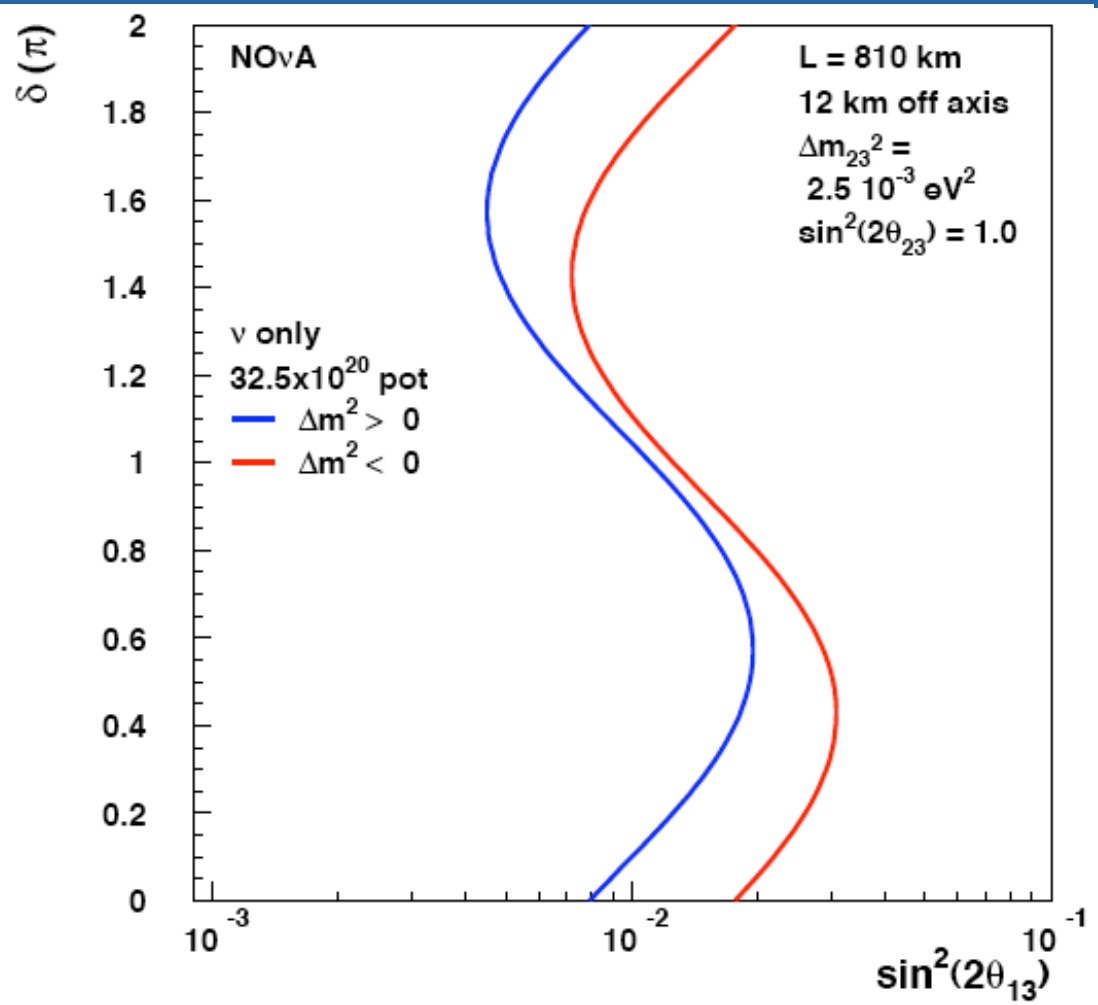


Parameters Consistent with Other Oscillation Probabilities



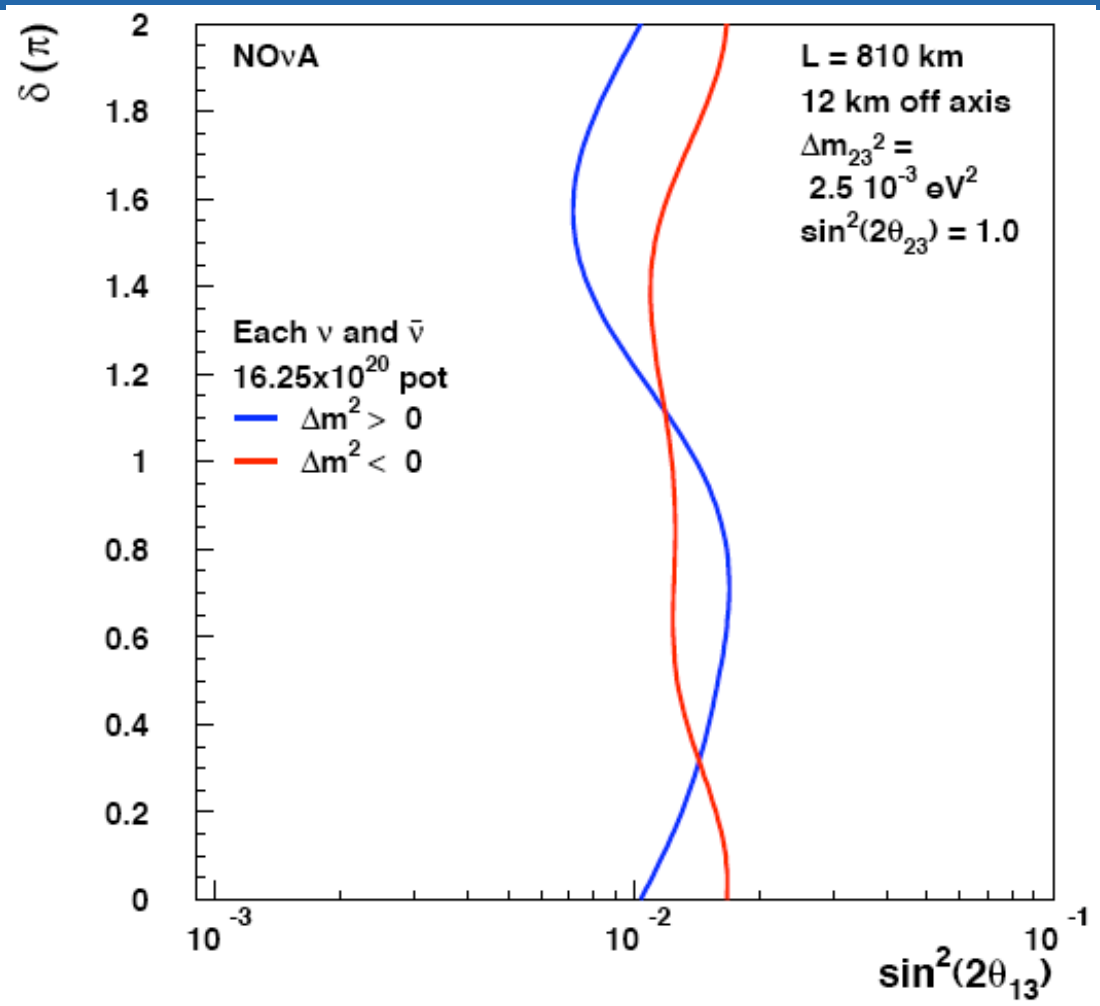


3 σ Sensitivity to $\theta_{13} \neq 0$



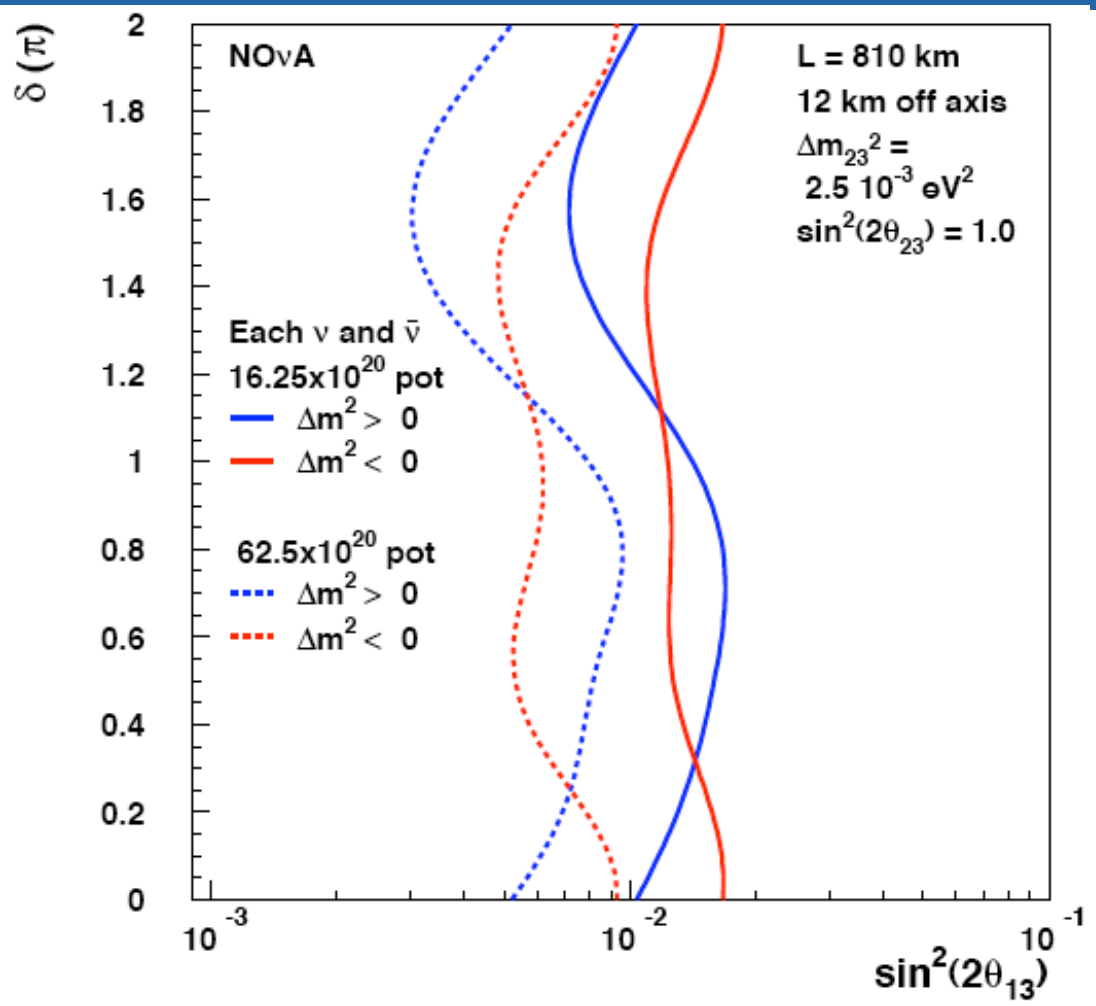
5 year ν only run

3 σ Sensitivity to $\theta_{13} \neq 0$



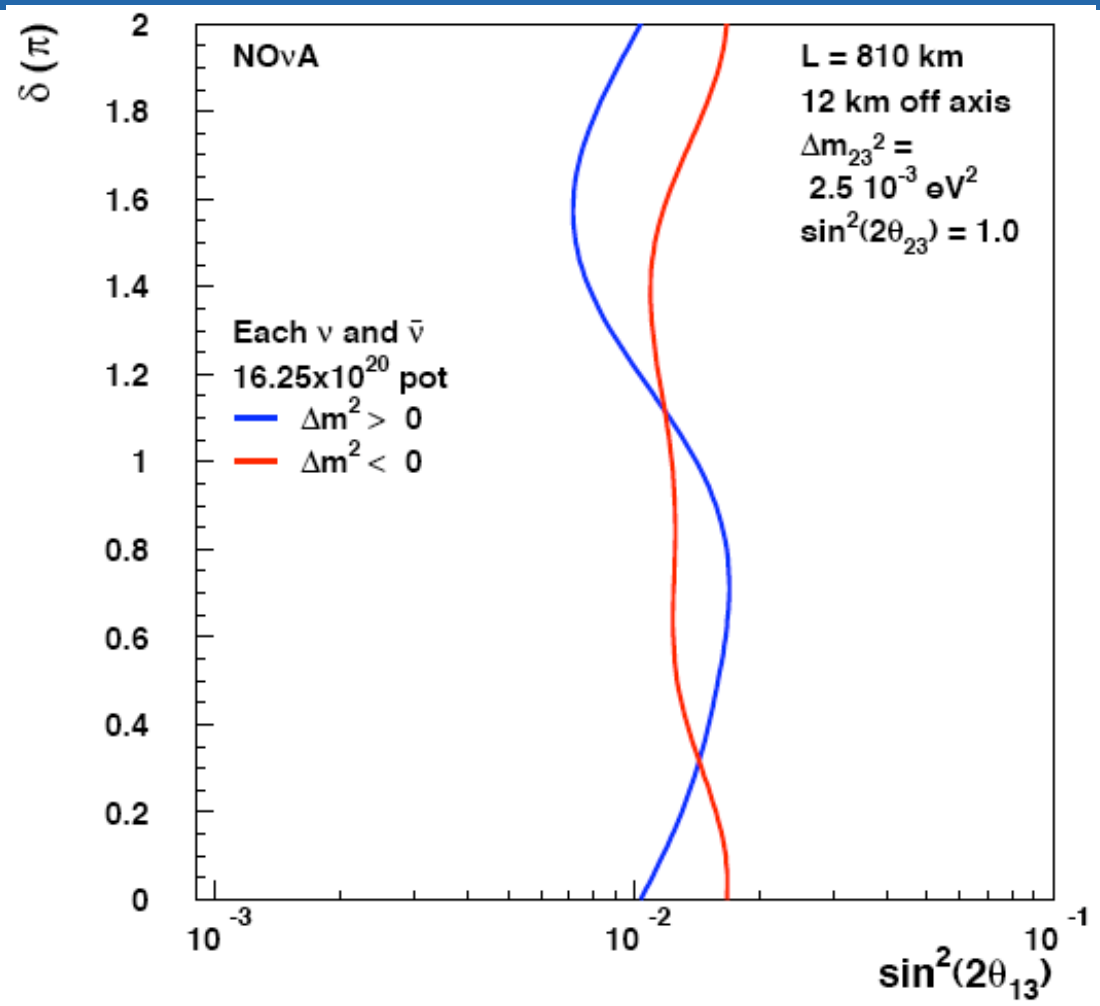
2.5 yr each ν and ν̄ run

3 σ Sensitivity to $\theta_{13} \neq 0$
Comparison with Proton Driver



2.5 yr each ν and $\bar{\nu}$ run

3 σ Sensitivity to $\theta_{13} \neq 0$



2.5 yr each ν and ν̄ run

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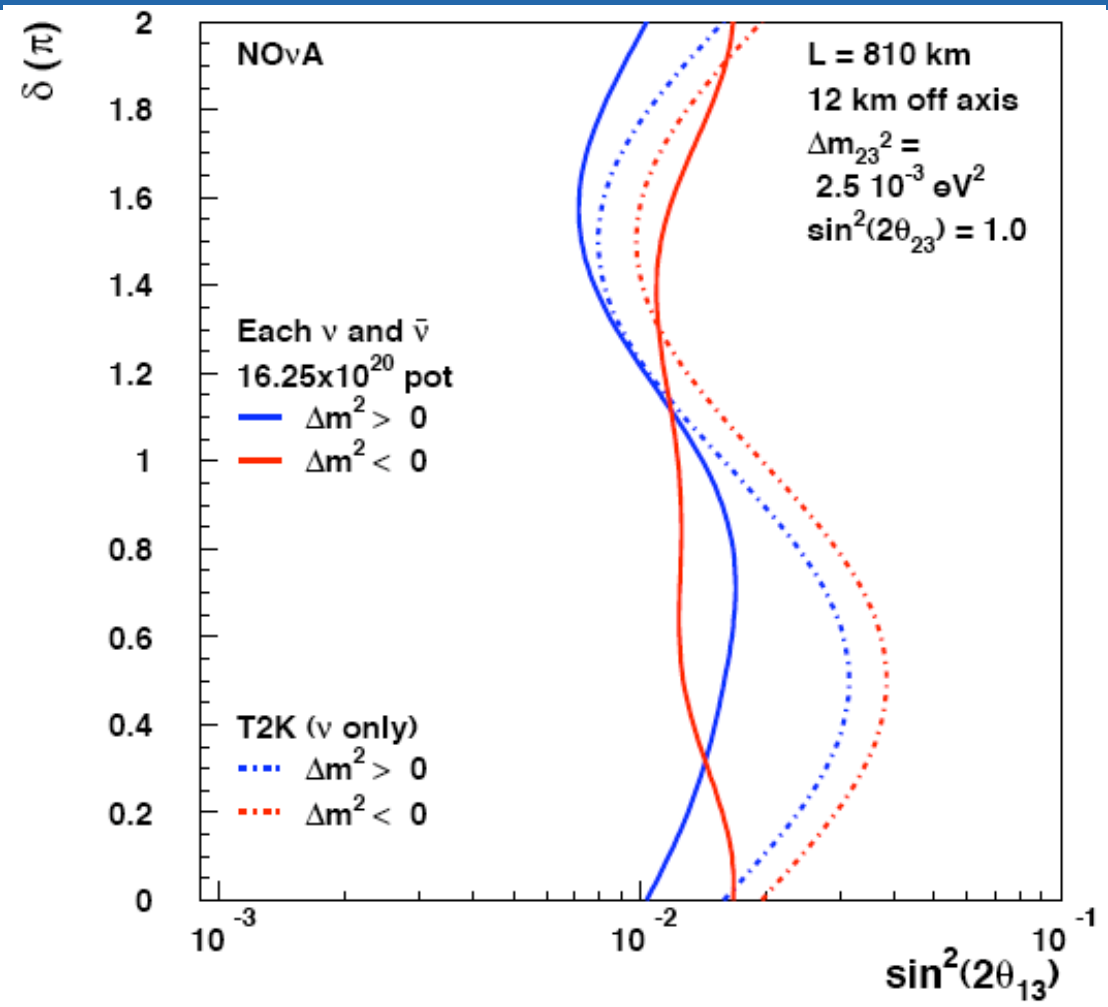

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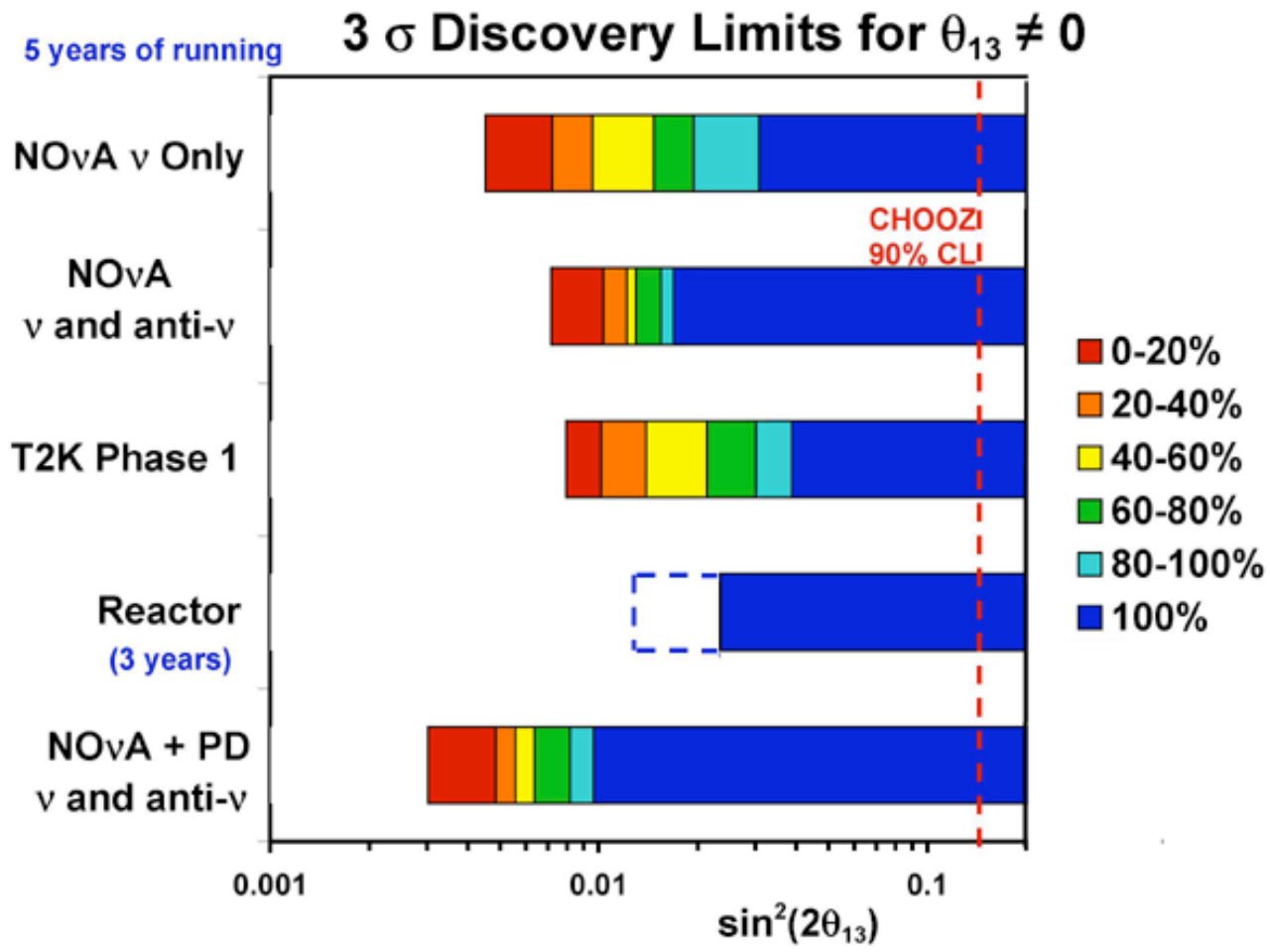


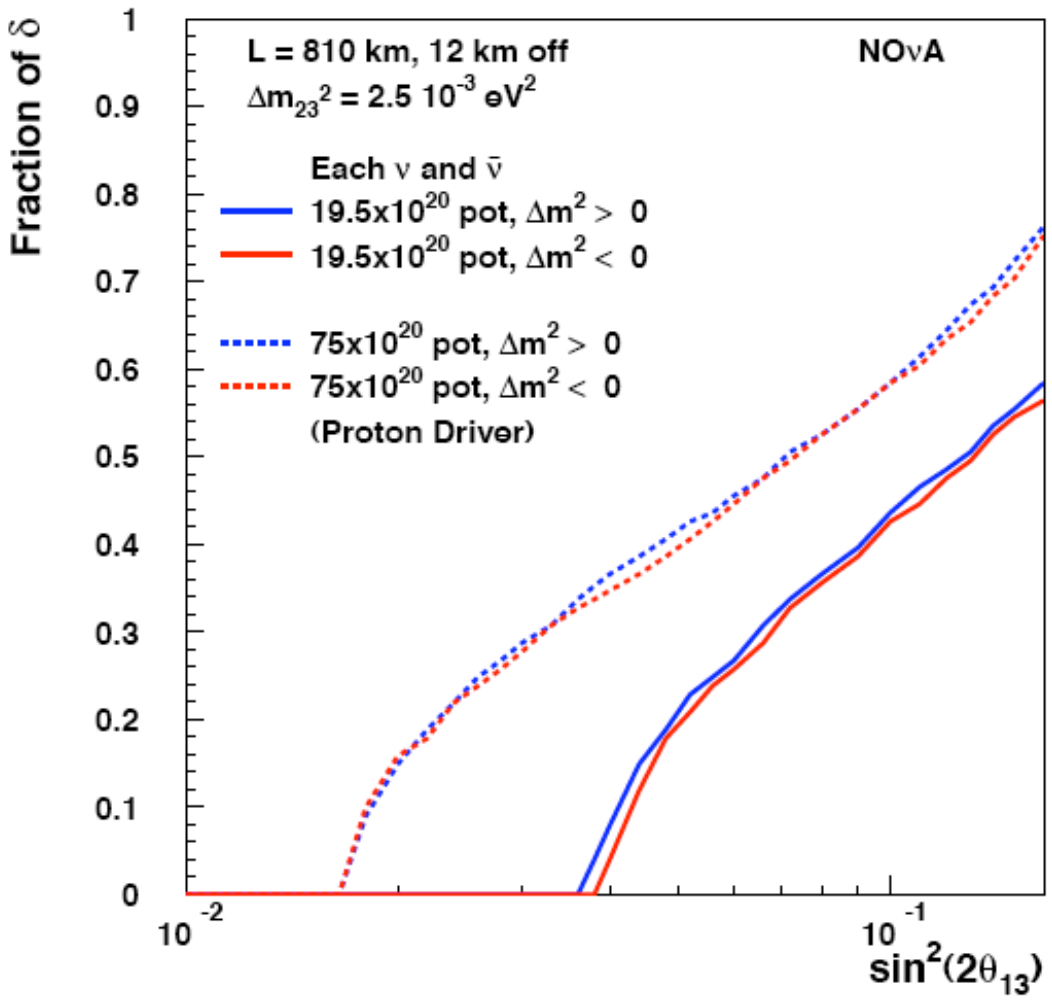
Importance of the Mass Ordering

- Window on very high energy scales: grand unified theories favor the normal mass ordering, but other approaches favor the inverted ordering.
- If we establish the inverted ordering, then the next generation of neutrinoless double beta decay experiment can decide whether the neutrino is its own antiparticle. However, if the normal ordering is established, a negative result from these experiments will be inconclusive.
- To measure CP violation, we need to resolve the mass ordering, since it contributes an apparent CP violation that we must correct for.

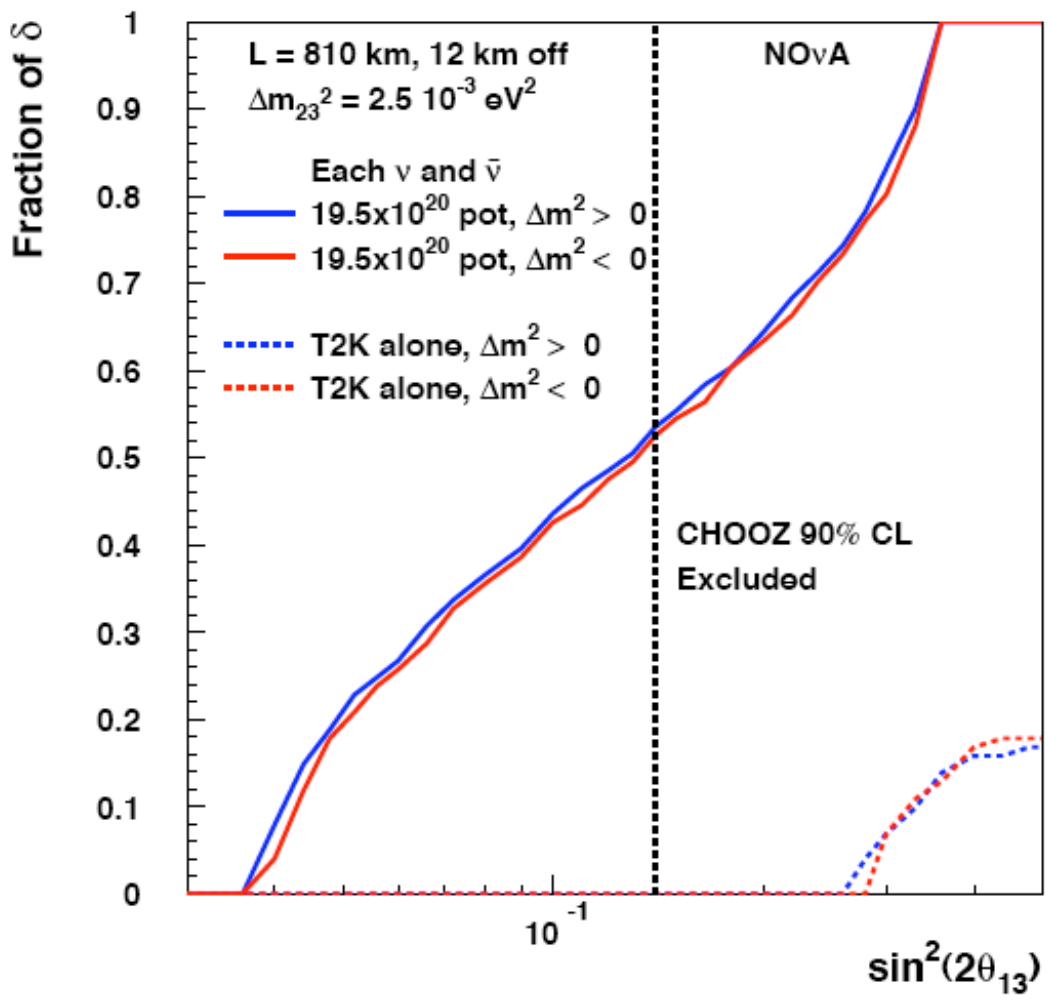
Role of NOνA in Resolving the Mass Ordering

- The mass ordering can be resolved only by matter effects in the earth over long baselines.
- NOνA is the only proposed experiment with a sufficiently long baseline to resolve the mass ordering.
- The siting of NOνA is optimized for this measurement.
- NOνA is the first step in a step-by-step program that can resolve the mass ordering in the region accessible to conventional neutrino beams.

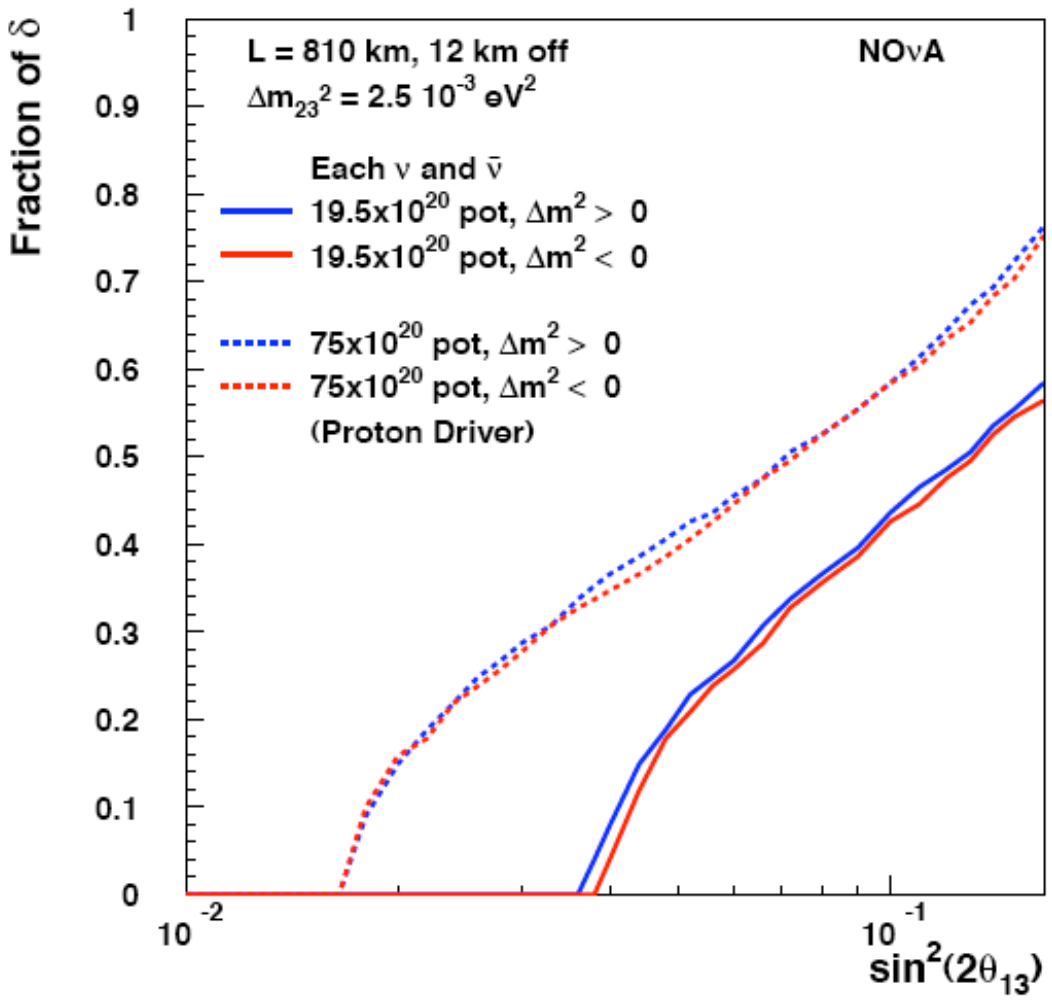
95% CL Resolution of the Mass Ordering



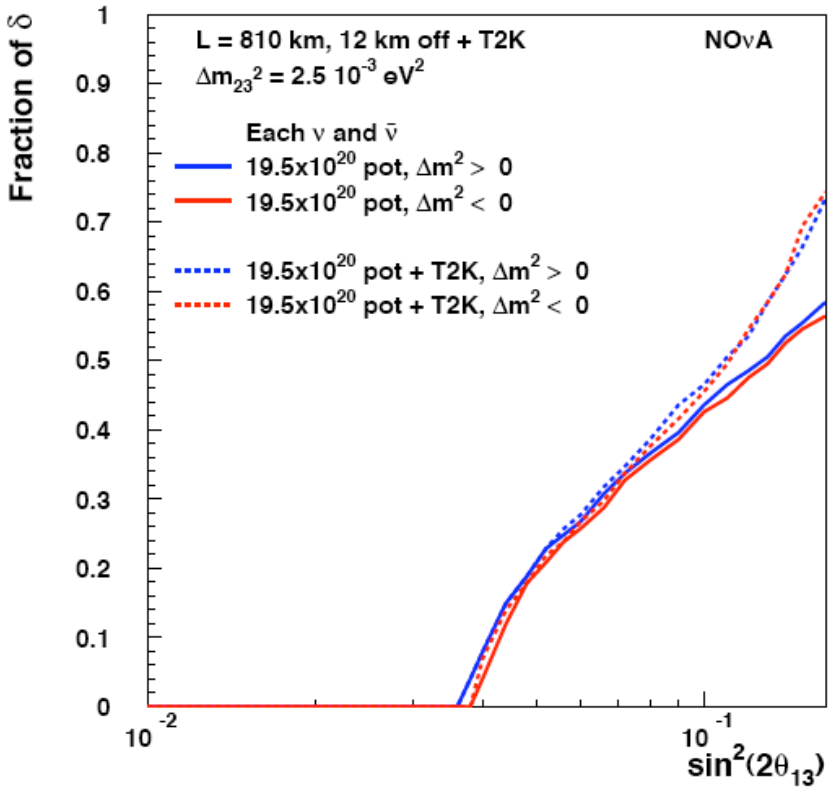
95% CL Resolution of the Mass Ordering



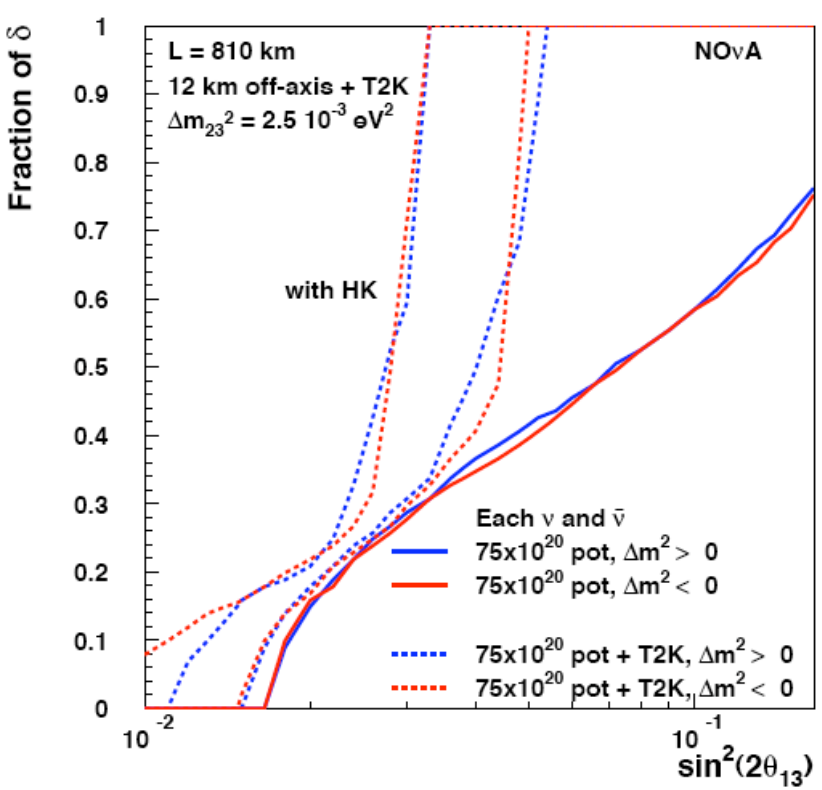
95% CL Resolution of the Mass Ordering



95% CL Resolution of the Mass Ordering

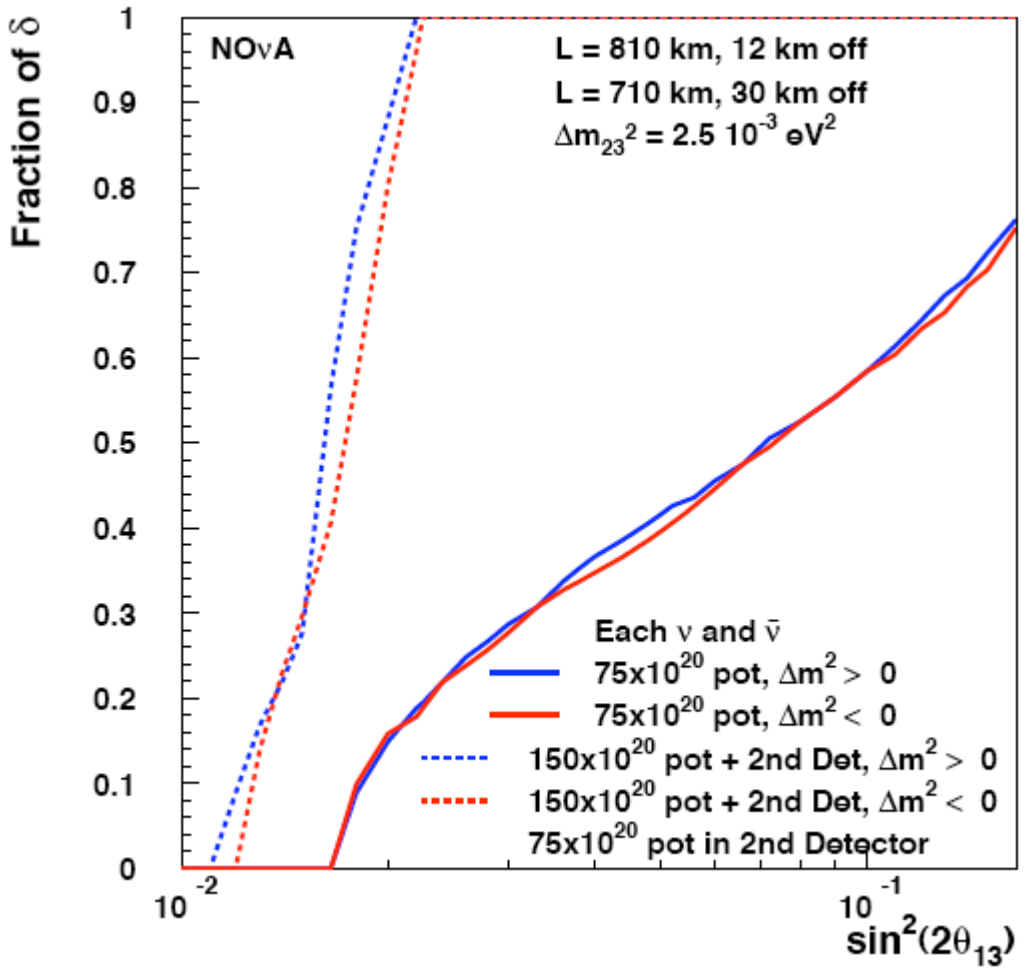


NOνA with T2K Phase 1



NOνA/PD with T2K Phase 2

95% CL Resolution of the Mass Ordering

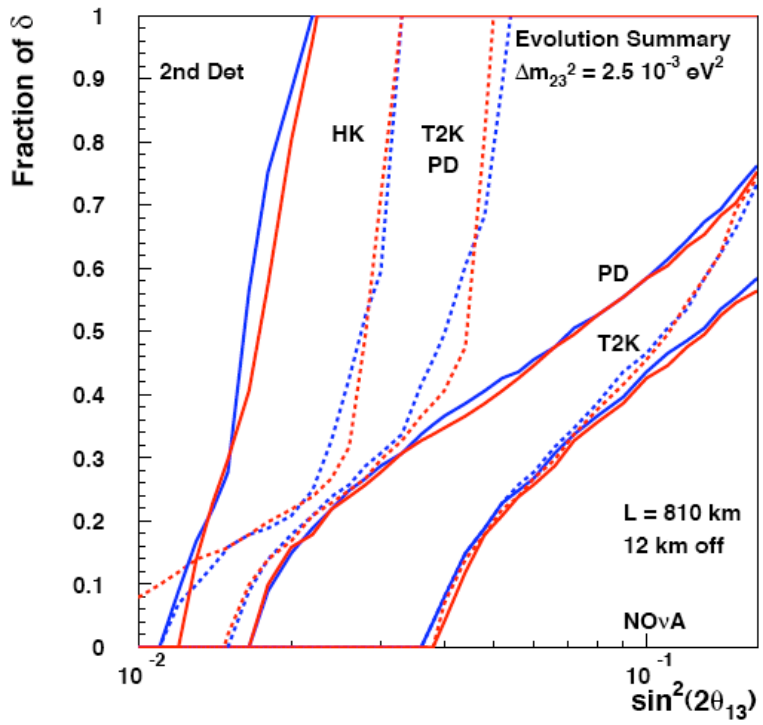


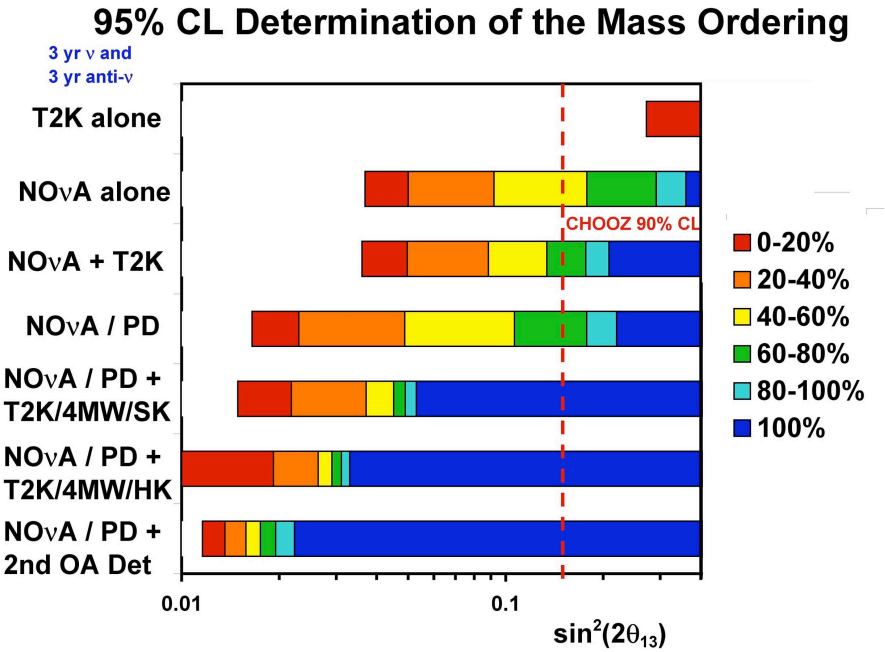
Scenario:

2 years into the PD run, realize the need for the 2nd off-axis detector. Build in 4 years, run for 6 years. Thus, 12 years running of NOνA with PD and 6 years of running the second detector.

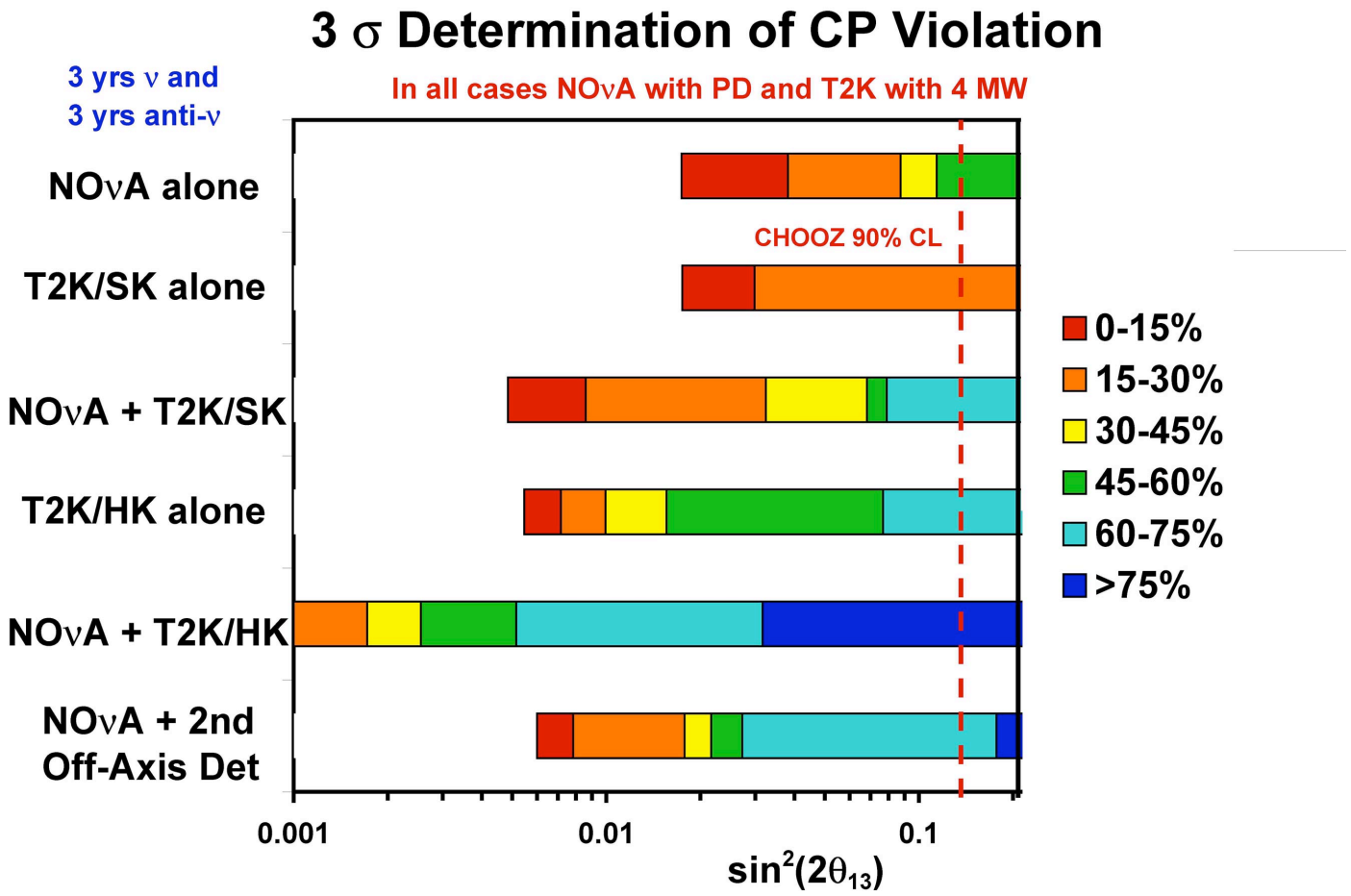
Several technologies possible for the 2nd detector. Use SK as a model for the calculation.

95% CL Resolution of the Mass Ordering: Summary

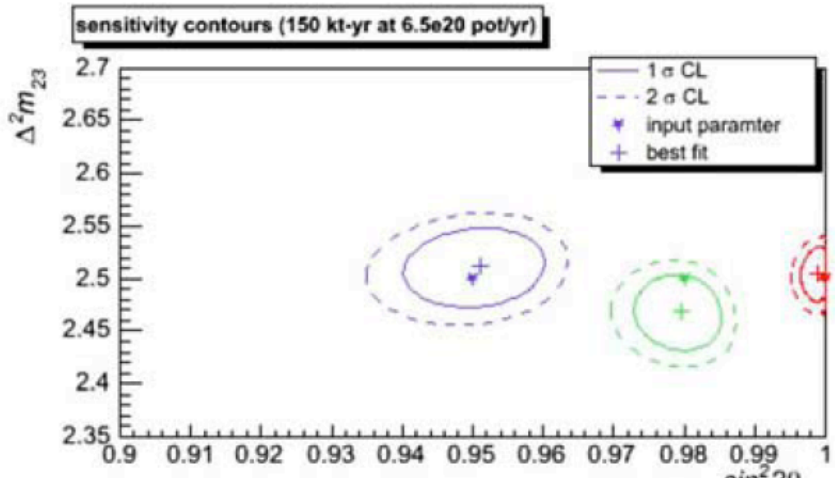




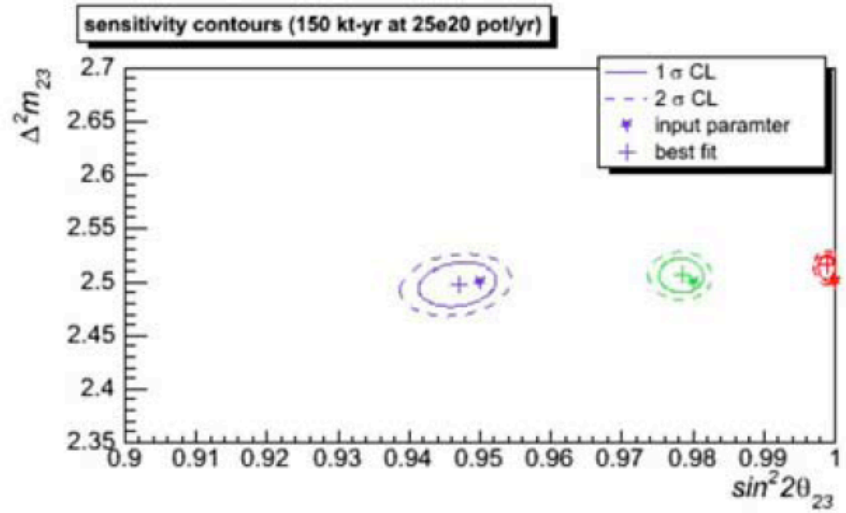
3 σ Determination of CP Violation



Measurement of Δm_{32}^2 and $\sin^2(2\theta_{23})$

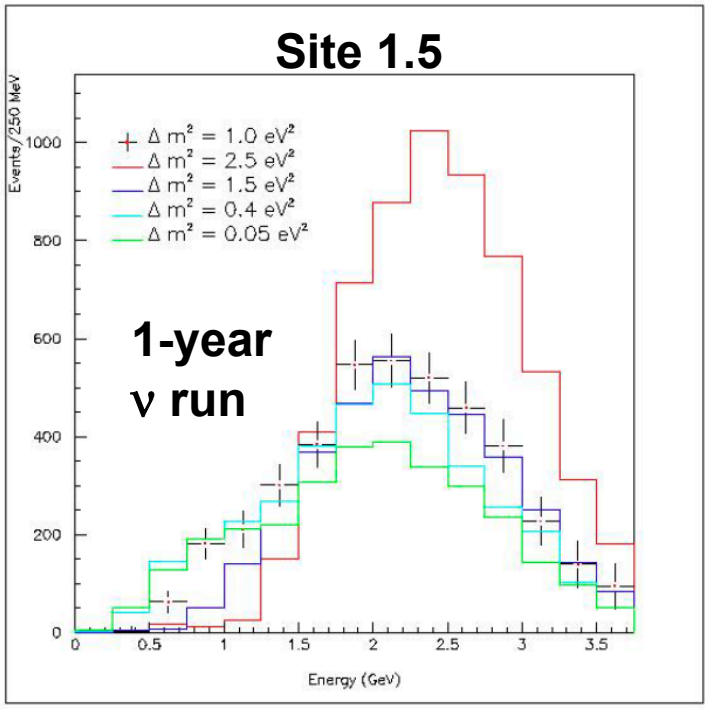


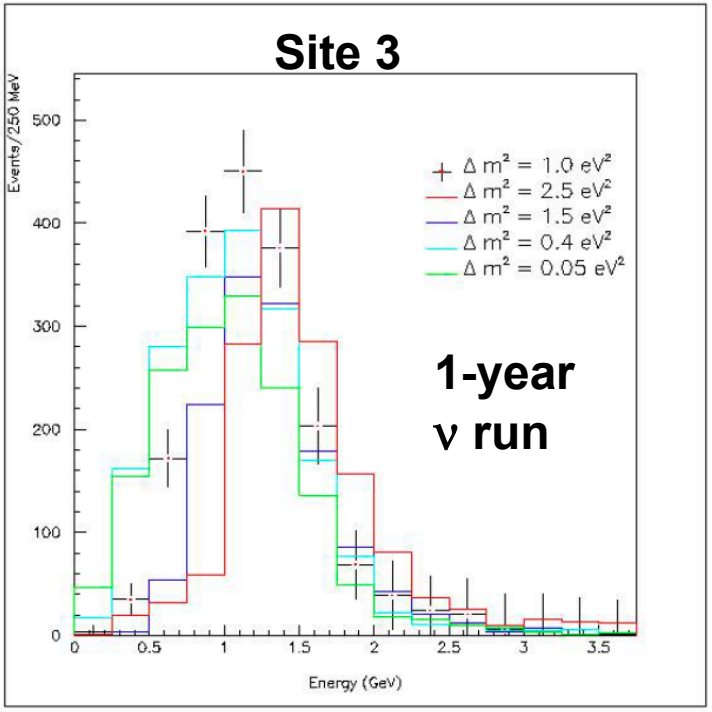
5-year ν run

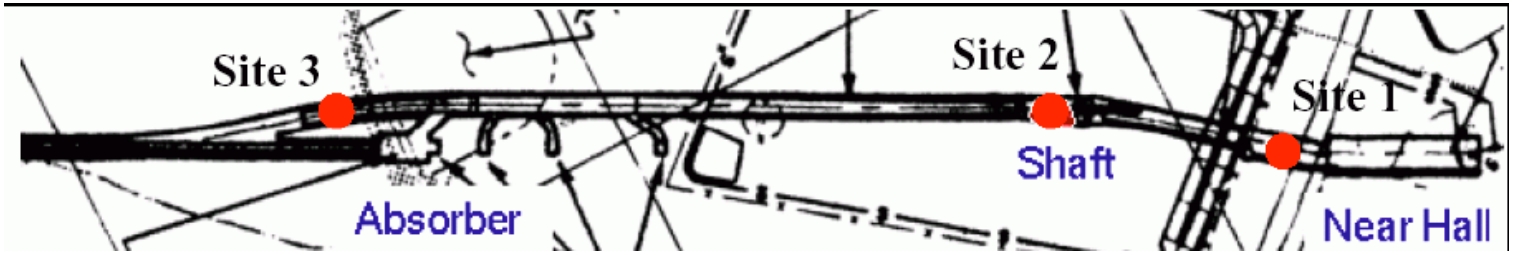


5-year ν run with Proton Driver

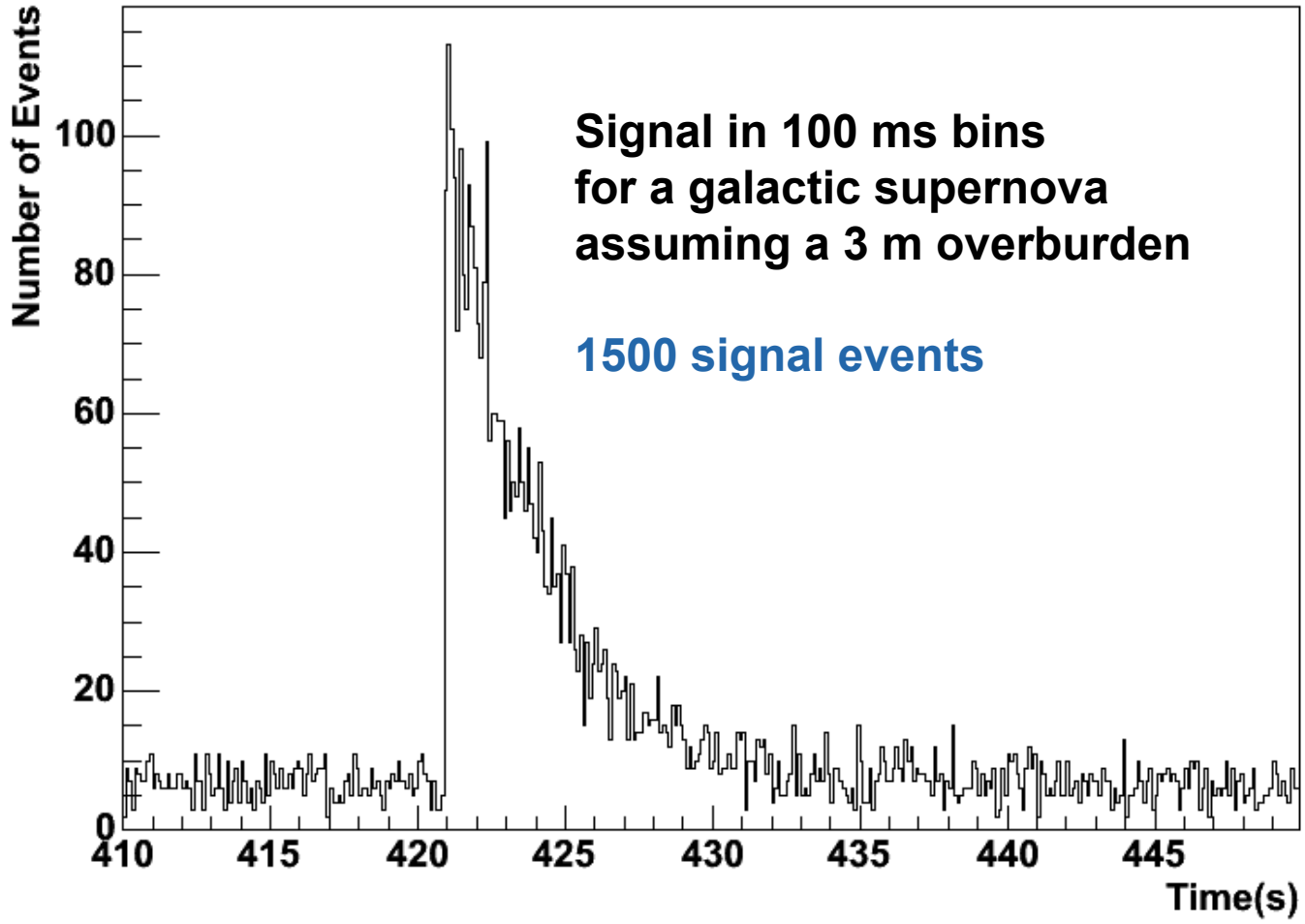
Study MiniBooNE Signal







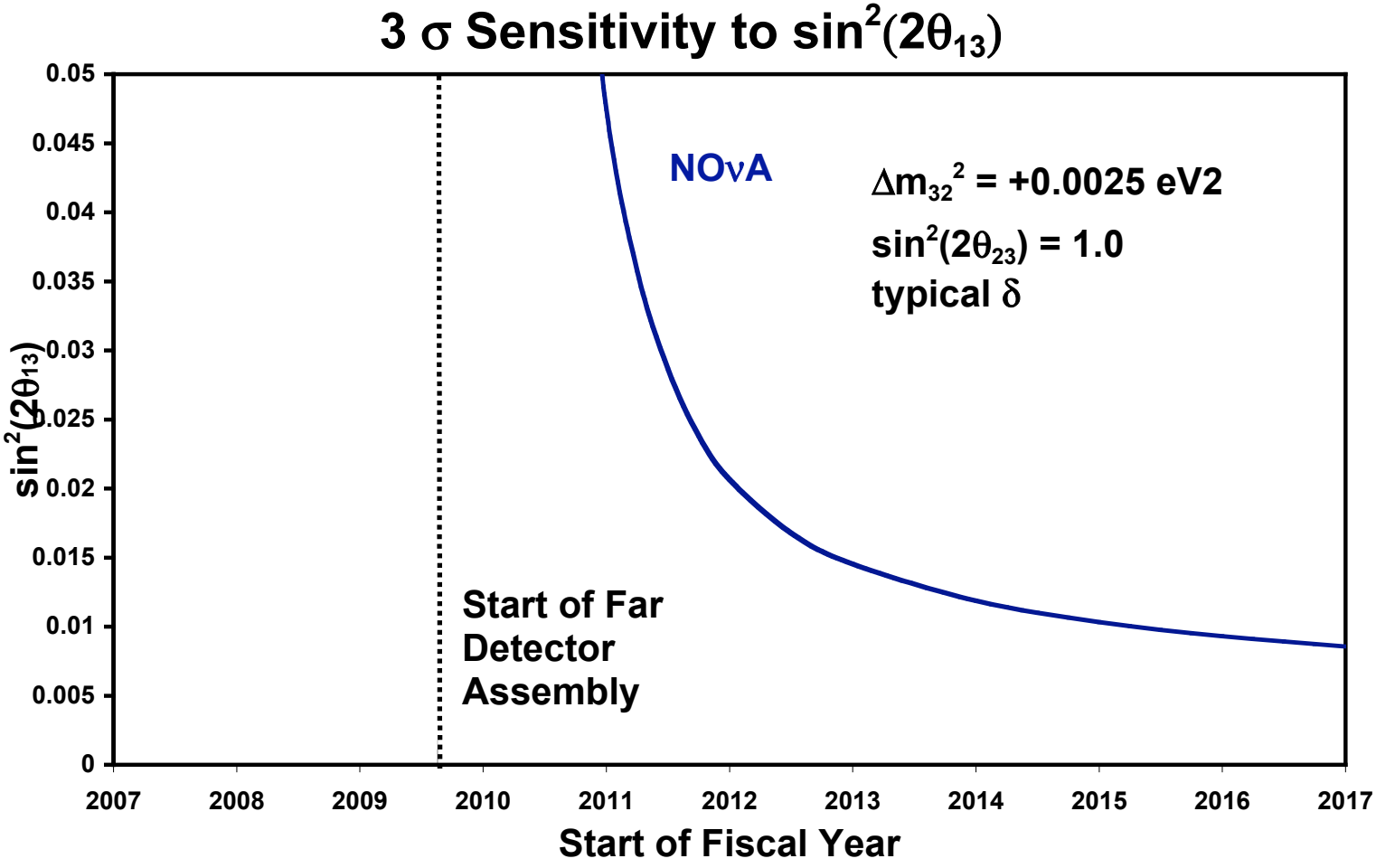
Sensitivity to a Galactic Supernova



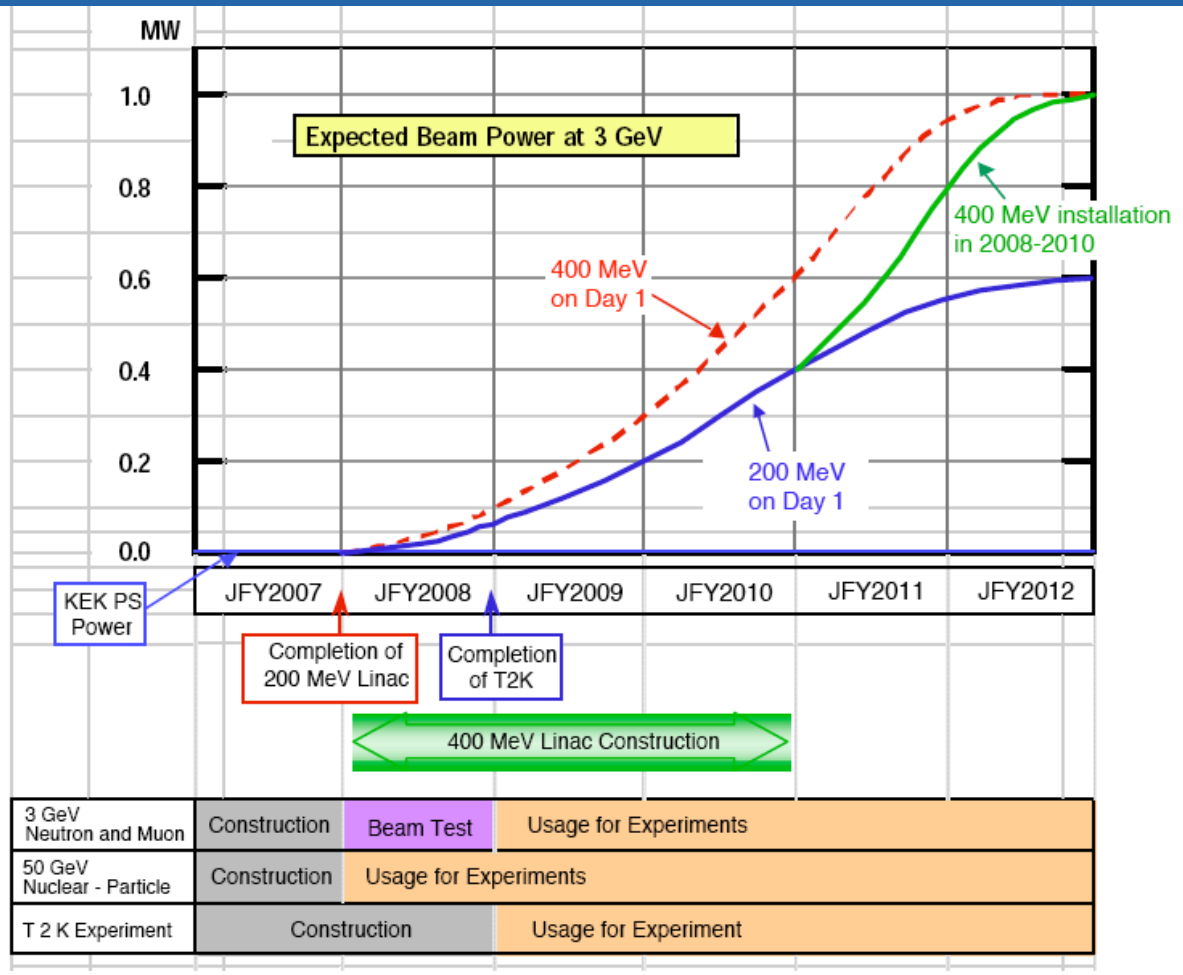
Schedule (10 of 29 Milestones)

Project start	Oct 2006
R&D prototype Near Detector complete	Mar 2007
Start Far Detector Building construction	Jul 2007
Start receiving packaged APDs	Oct 2007
Start extrusion module factories	Oct 2007
Start construction of Near Detector	Dec 2007
Start operation of Near Detector	Jul 2008
Start Far Detector assembly	May 2009
First kiloton operational	Oct 2009
Full 30 kilotons operational	Jul 2011

Sensitivity vs. Time

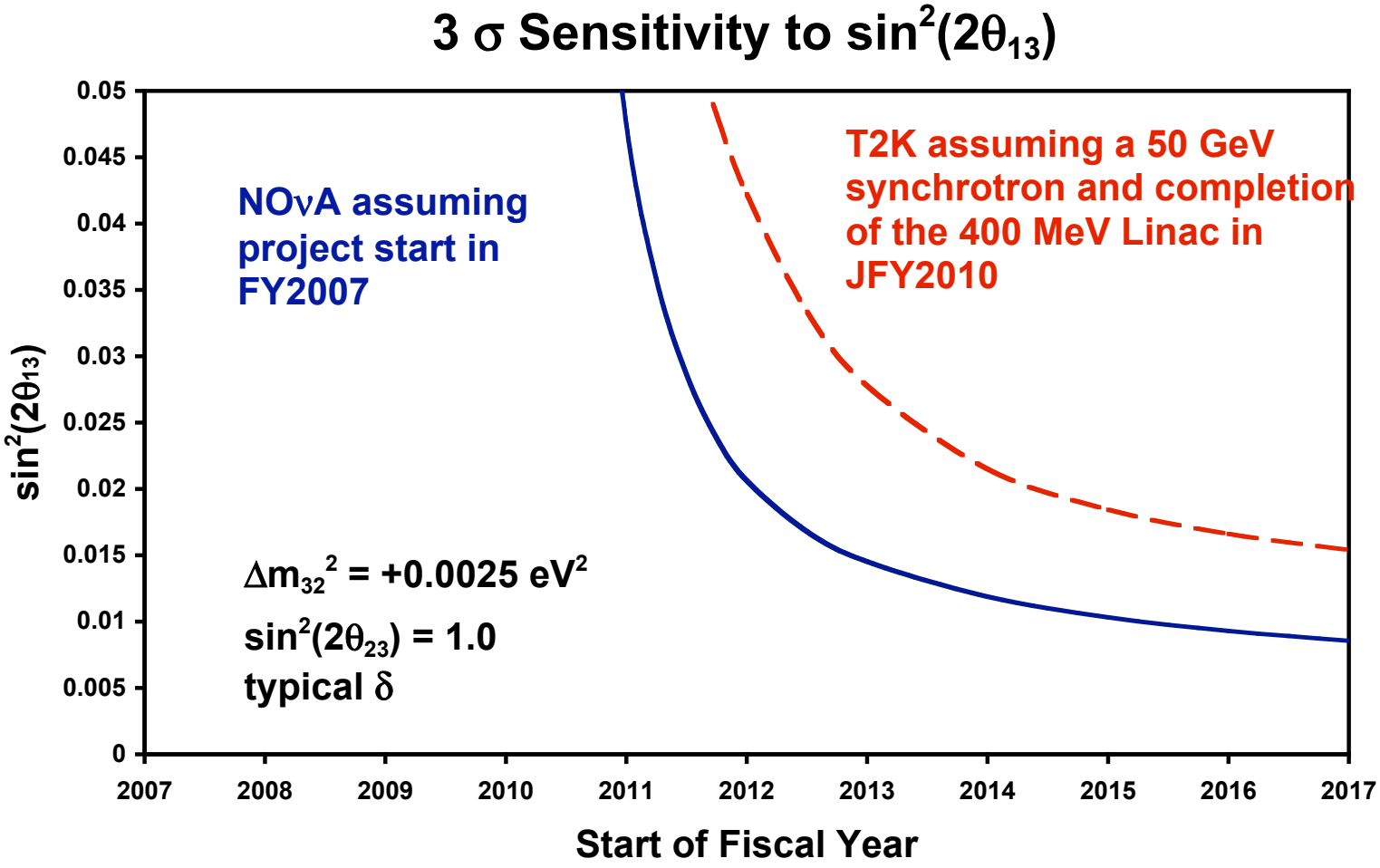


Assumed T2K Beam Power vs. Time



From S. Nagamiya, Feb 2005

Sensitivity vs. Time
Comparison to T2K



Conclusion

- **NOνA provides a flexible approach to studying all of the parameters of neutrino oscillations**
  - **A long baseline approach is crucial in the context of the world program.**
  - **NOνA is the first stage of a flexible program where each stage can be planned according to what has been learned in previous stages.**
  - **The NOνA physics reach is greater than other experiments being contemplated for the next few years.**
  - **The full range of the NOνA/NuMI program is comparable to that of other conventional approaches.**
  - **NOνA is the size project that can be started now.**