The Search for CP Violation and the Determination of the Neutrino Mass Hierarchy in NOνA and LBNE

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$\nu_\mu \rightarrow \nu_e$ Oscillations in Long-Baseline Experiments

- Now that $\theta_{13} \sim 9^\circ$ has been measured, the prospects for future long-baseline neutrino experiments to make some exciting discoveries are very bright!
- Long-baseline $\nu_\mu \rightarrow \nu_e$ experiments have the potential to simultaneously measure θ_{13}, δ_{CP}, sign(Δm_{31}^2), sign(θ_{23}-45°):

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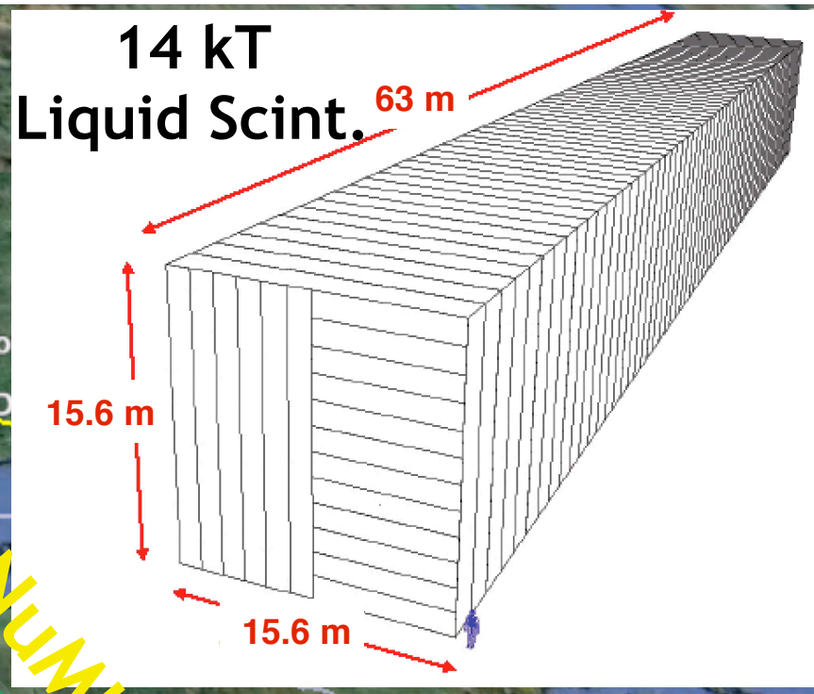
- The next generation experiments will require football/rugby field-sized detectors!

The NuMI Off-Axis ν_e Appearance (NOvA) Experiment

Ash River, MN
810 km, 14 mrad off-axis



Existing NuMI ν Beam from FNAL

Upgrade from 360 kW to 700 kW in progress

Nearly identical ~300 ton detector located at FNAL, 14 mrad off-axis & 1 km from source will measure ν spectrum before oscillations occur.

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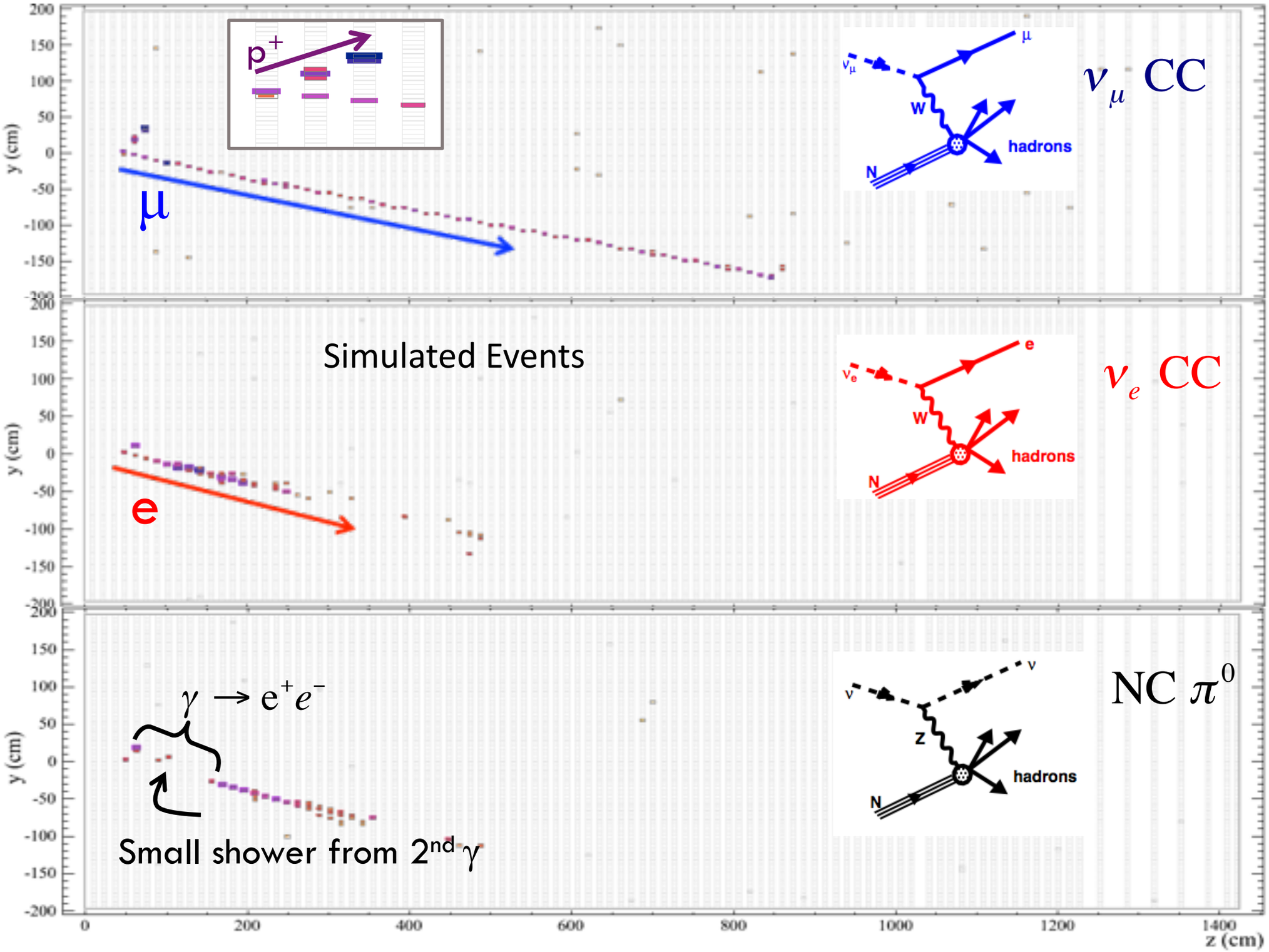
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2012 TerraMetrics

Distinguishing Neutrino Events in NOνA



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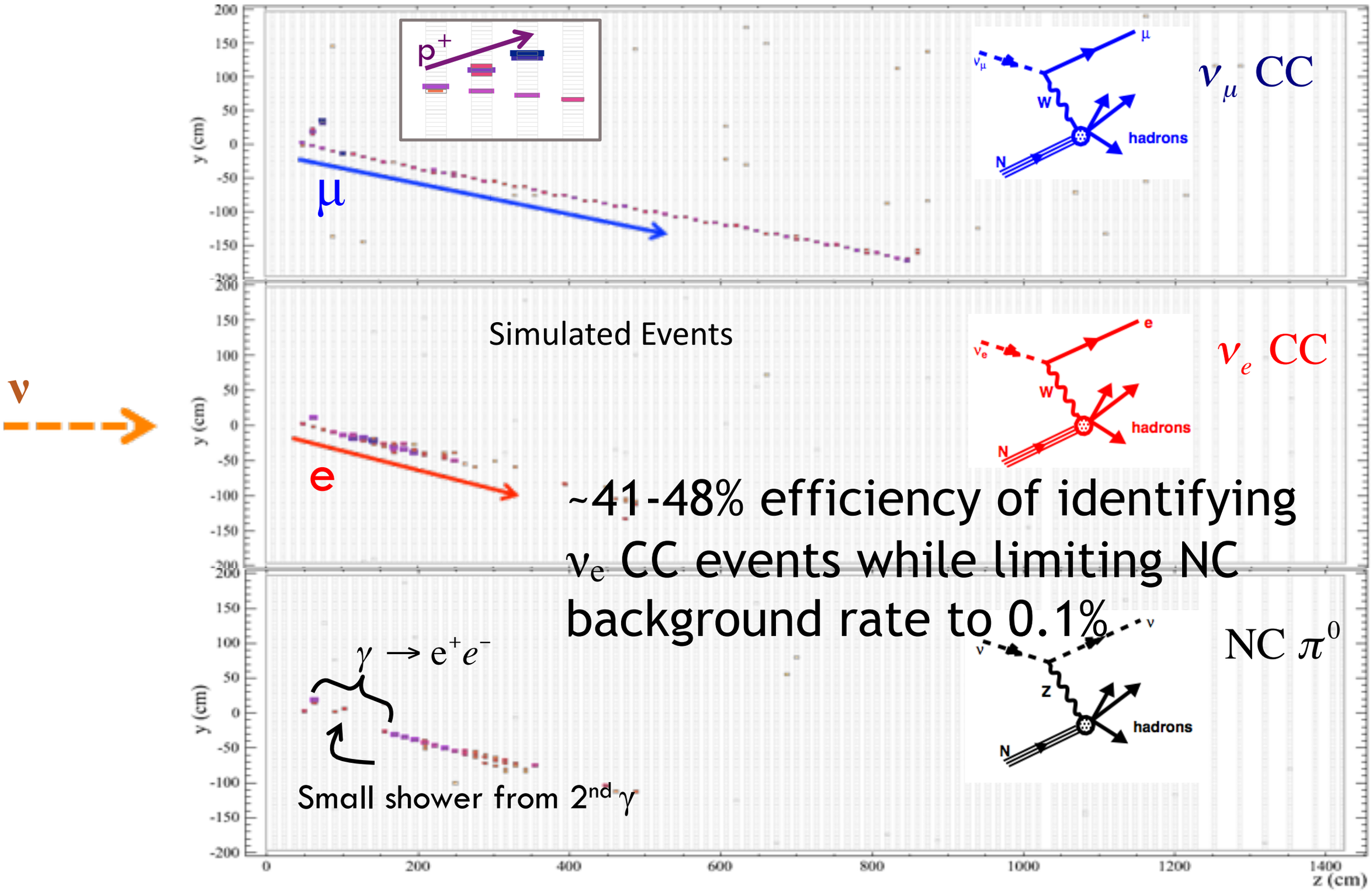
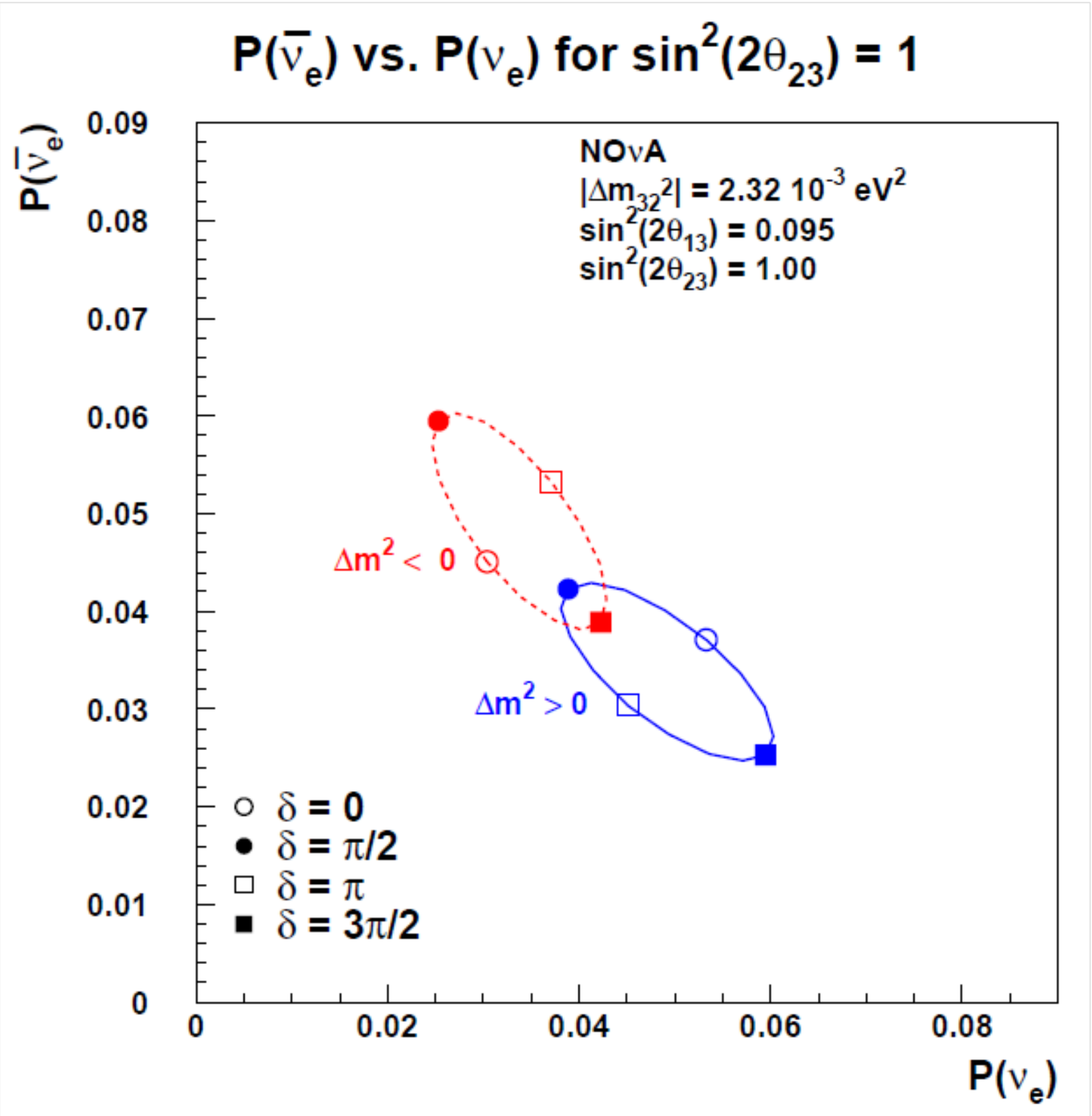


NOνA Measurements



- The strategy in NOνA is to compare the oscillation probability of $\nu_\mu \rightarrow \nu_e$ and $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$.

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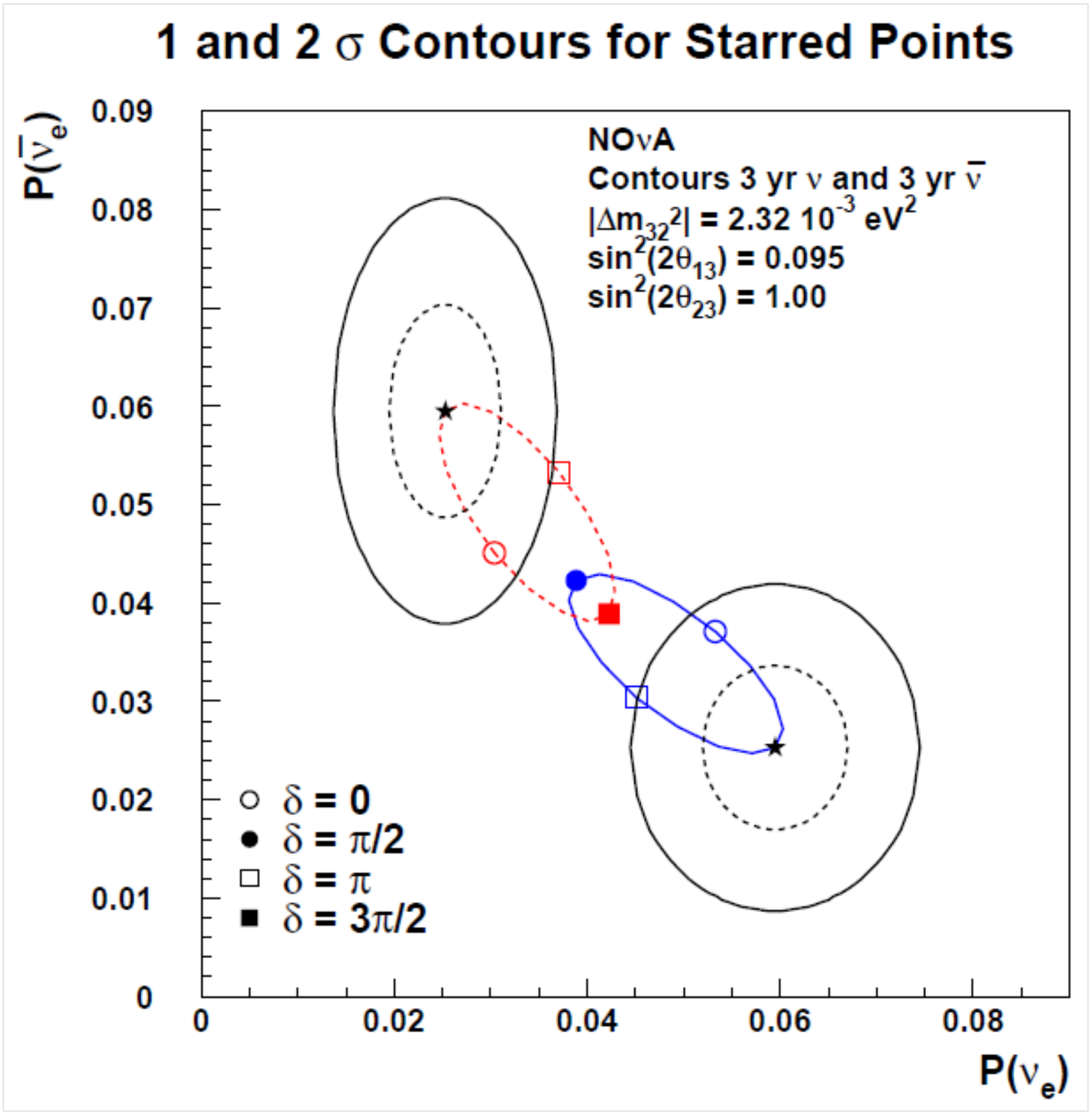

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- These cases represent best-case scenarios for determining the mass hierarchy after 3 years of running each mode each. Contours are 1- and 2-sigma measurements.

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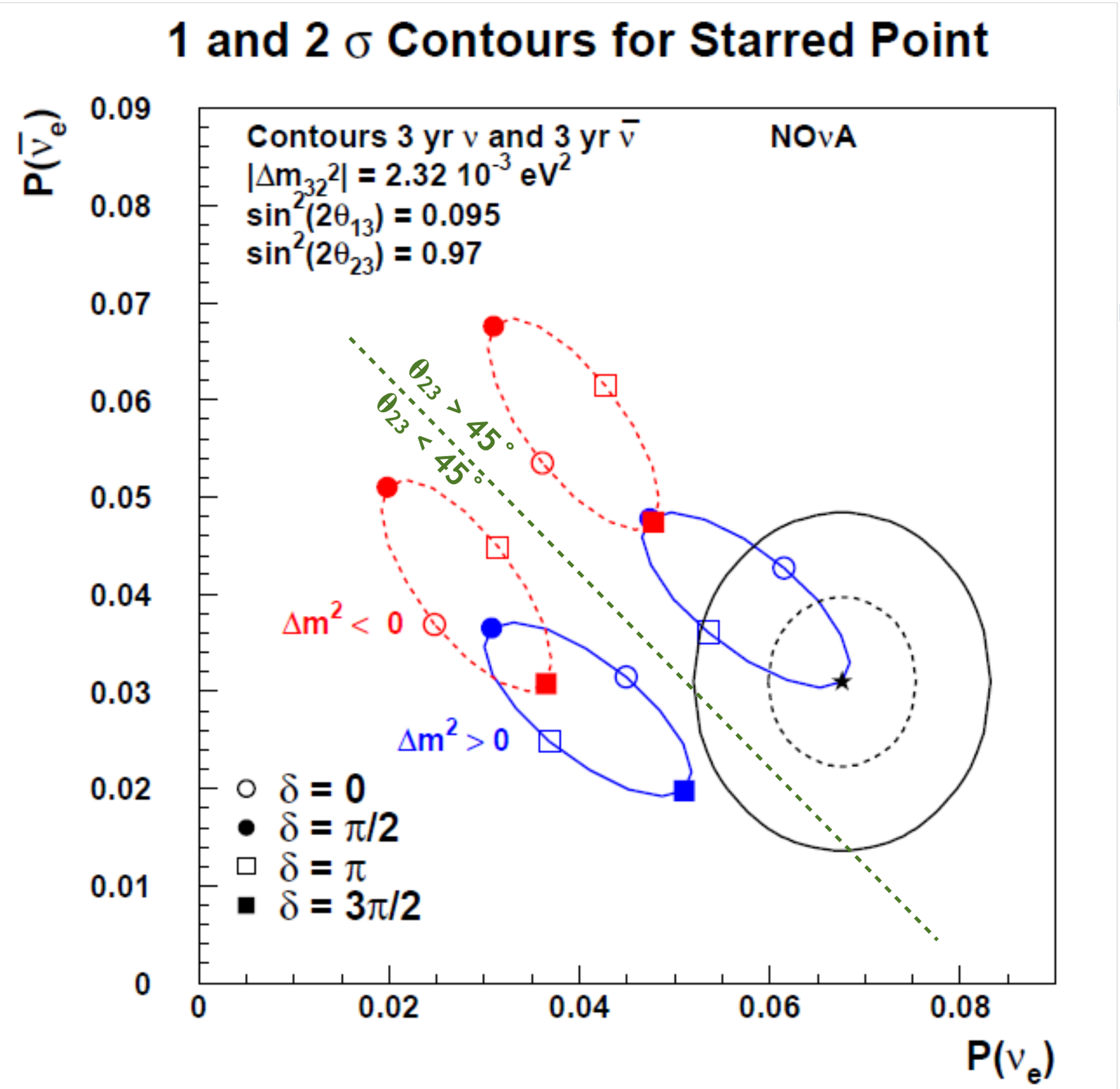
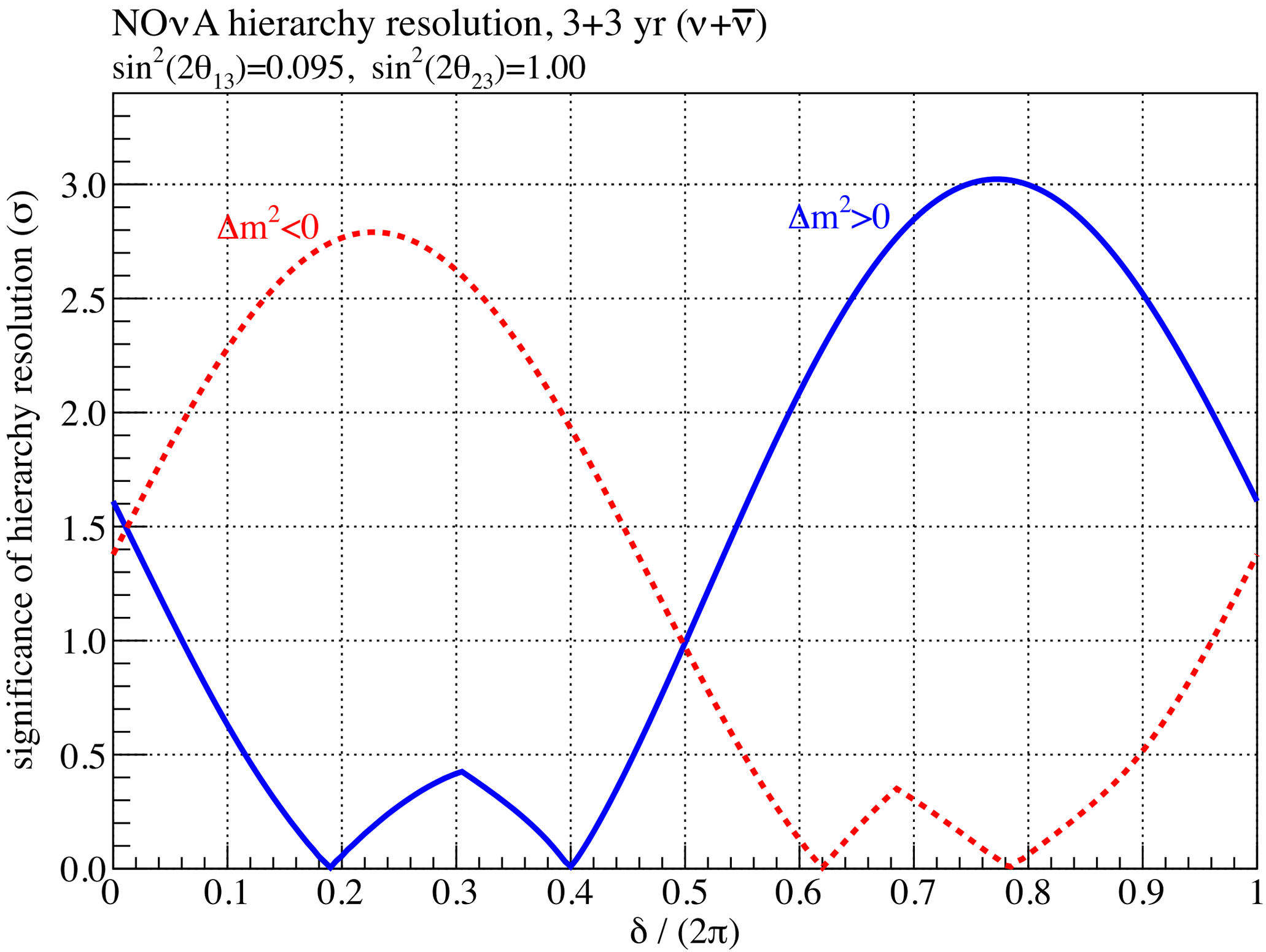


- The strategy in NOνA is to compare the oscillation probability of $\nu_\mu \rightarrow \nu_e$ and $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$.
- If θ_{23} is non-maximal, then we also have the capability of determining the octant; this tells us whether or not ν_μ couples more strongly to ν_2 or ν_3.

Resolution of Mass Hierarchy



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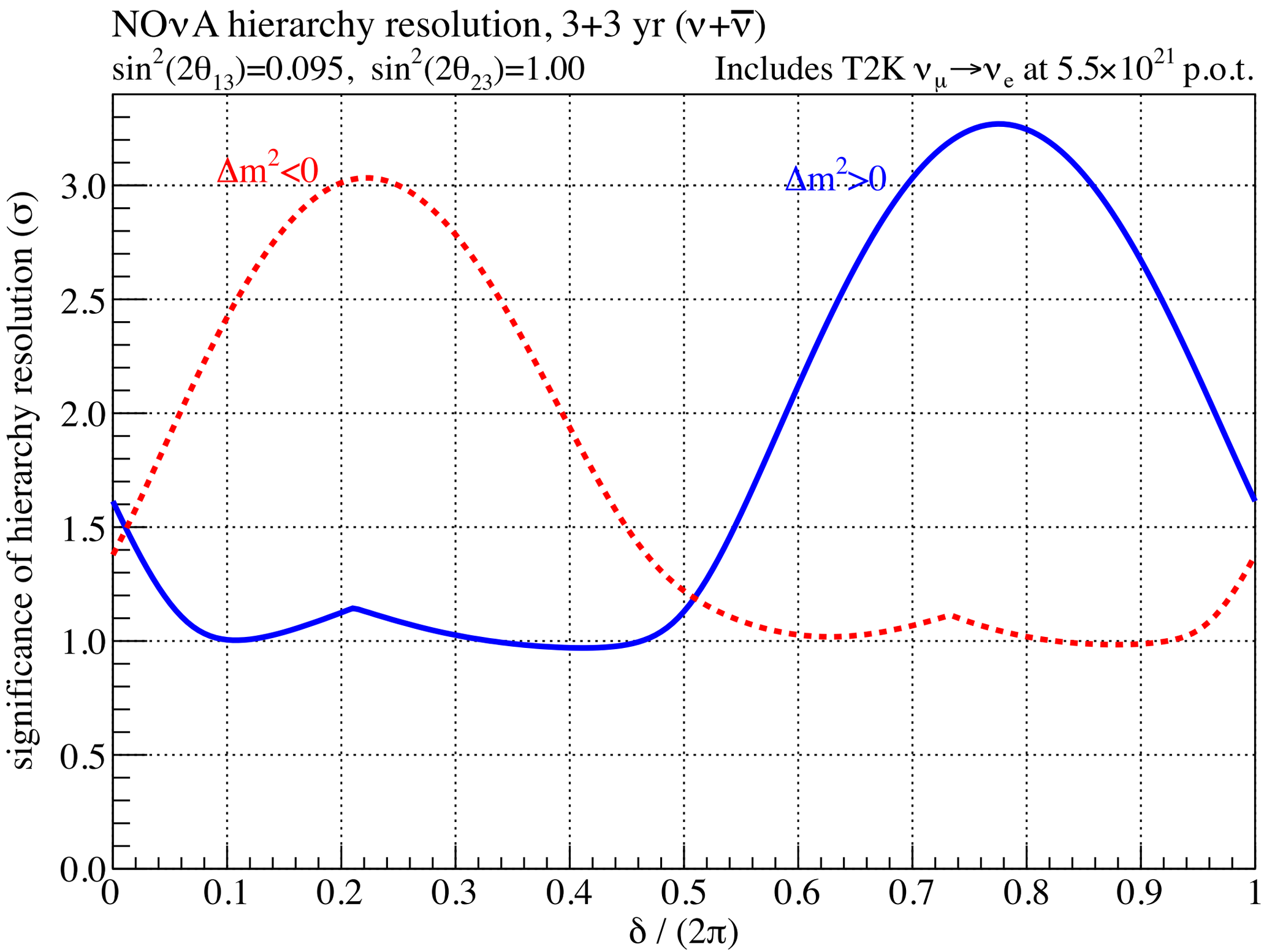
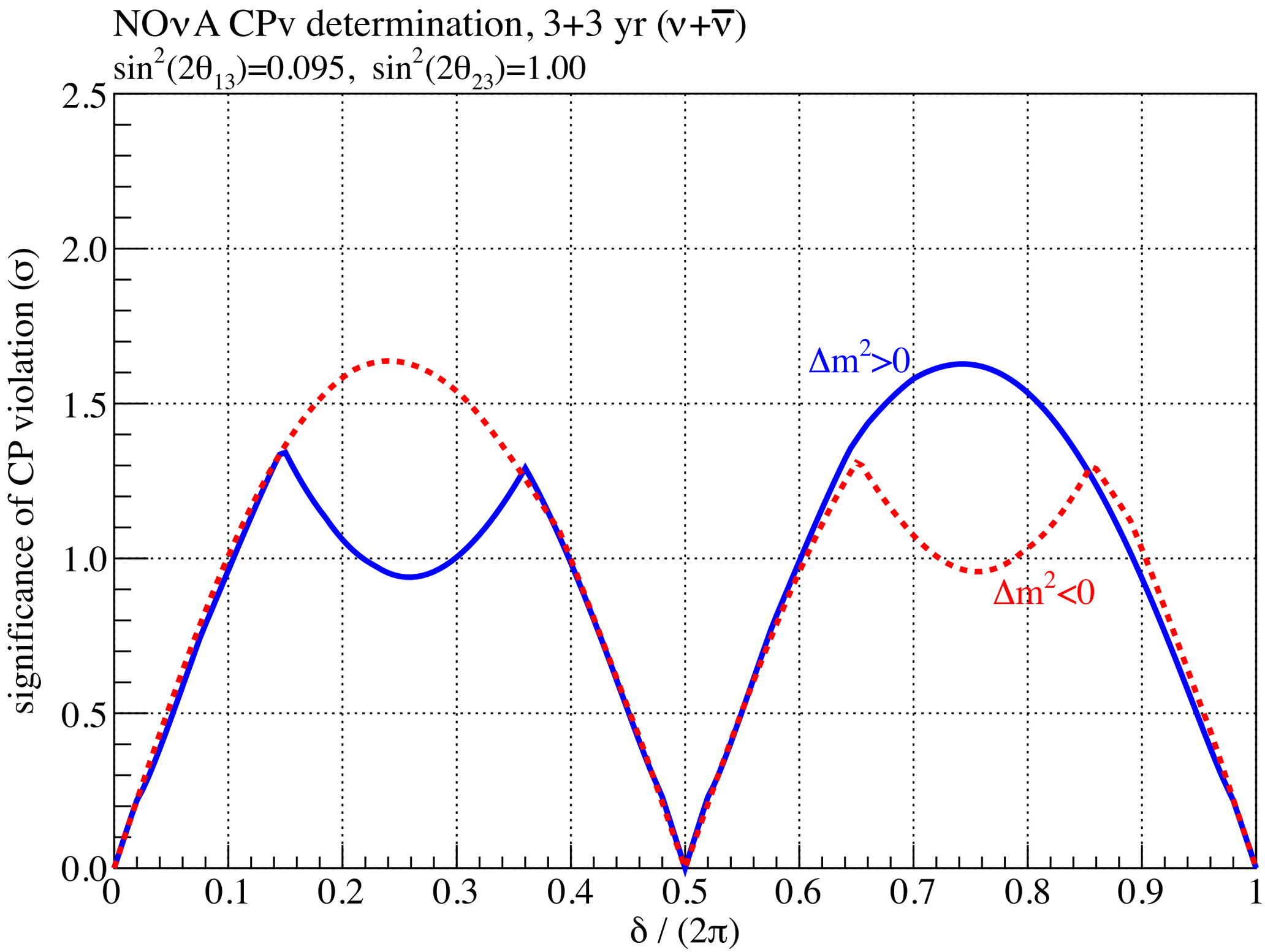


Measurement of CP-violation



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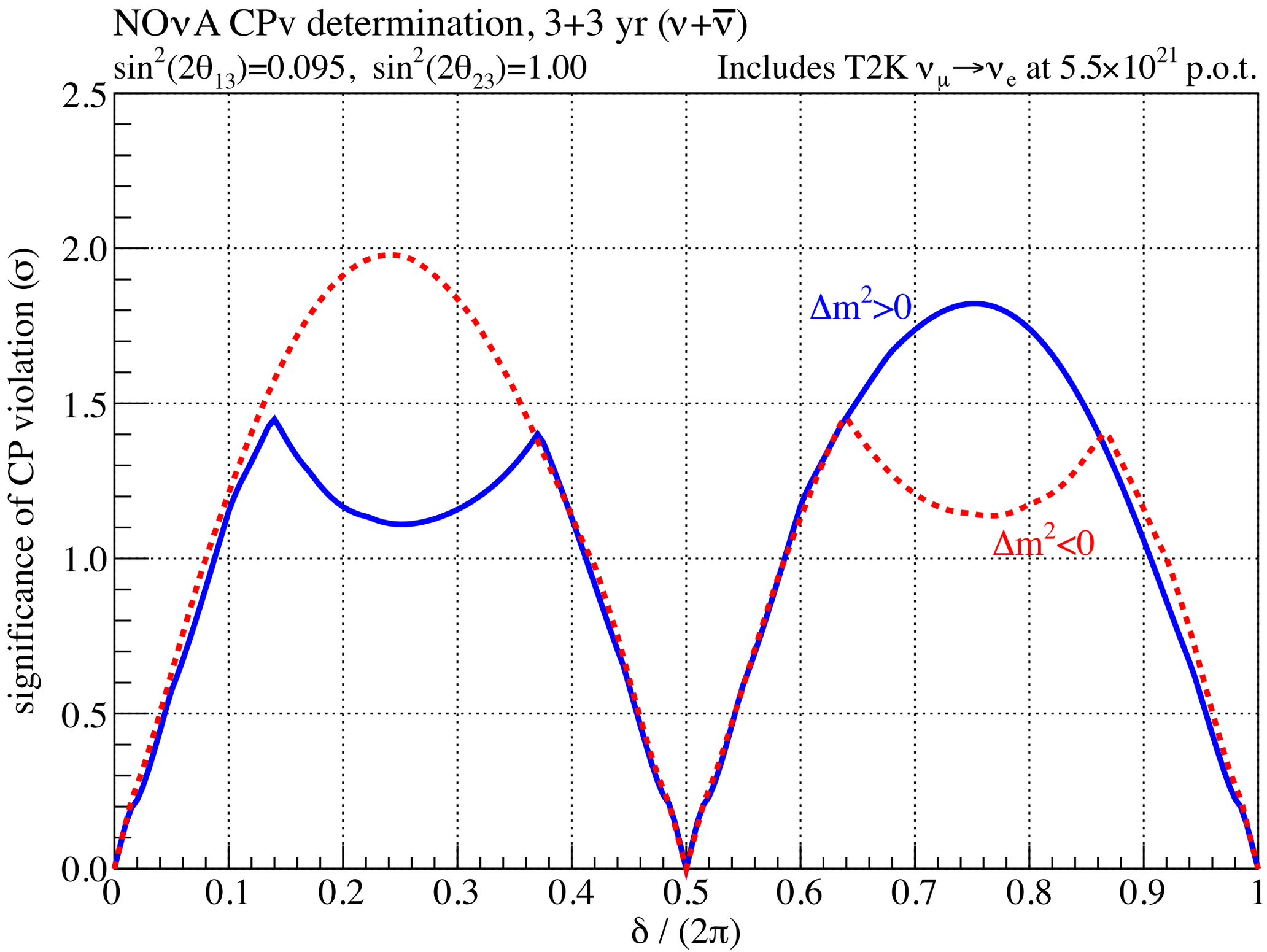
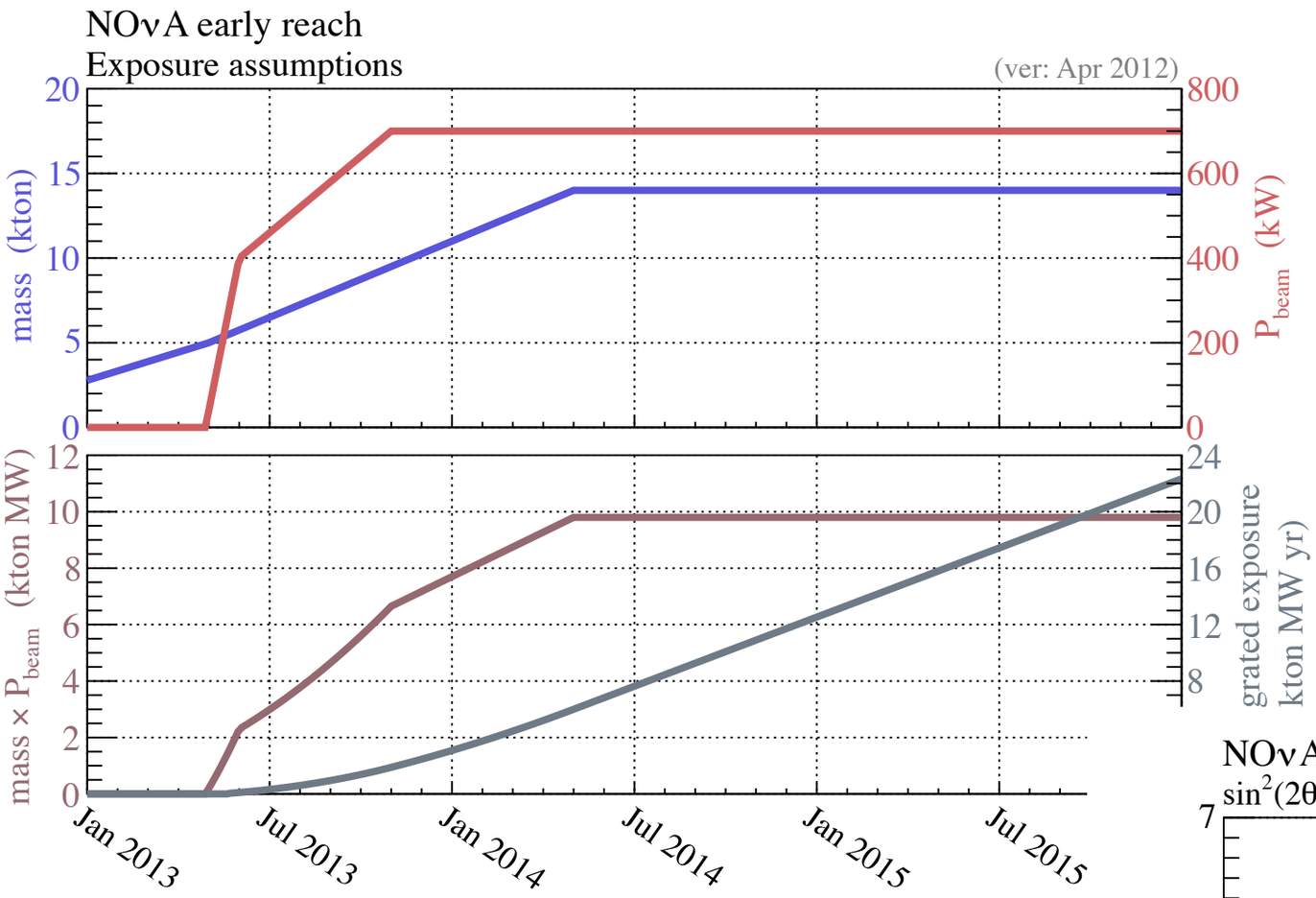
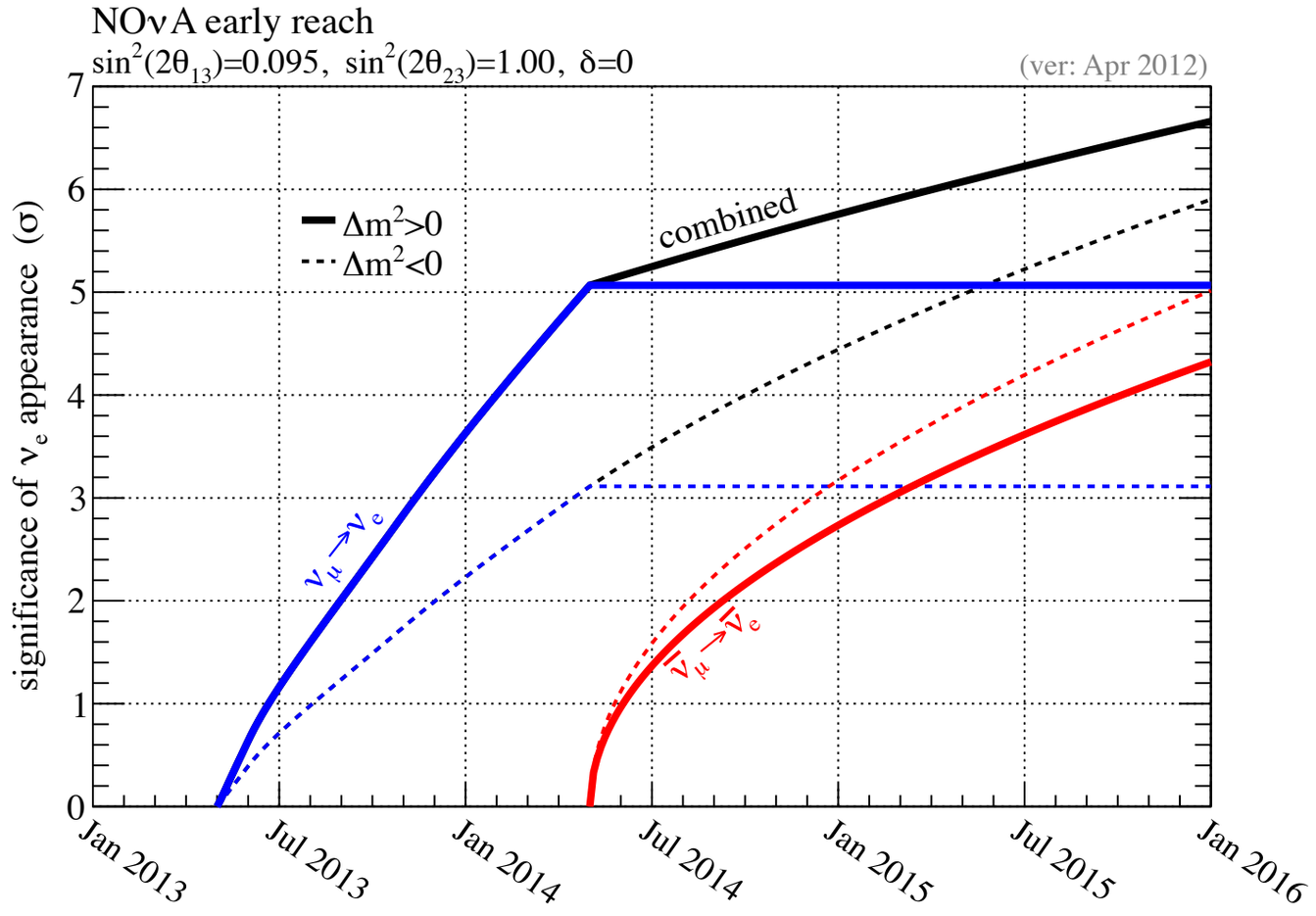


Project Timeline

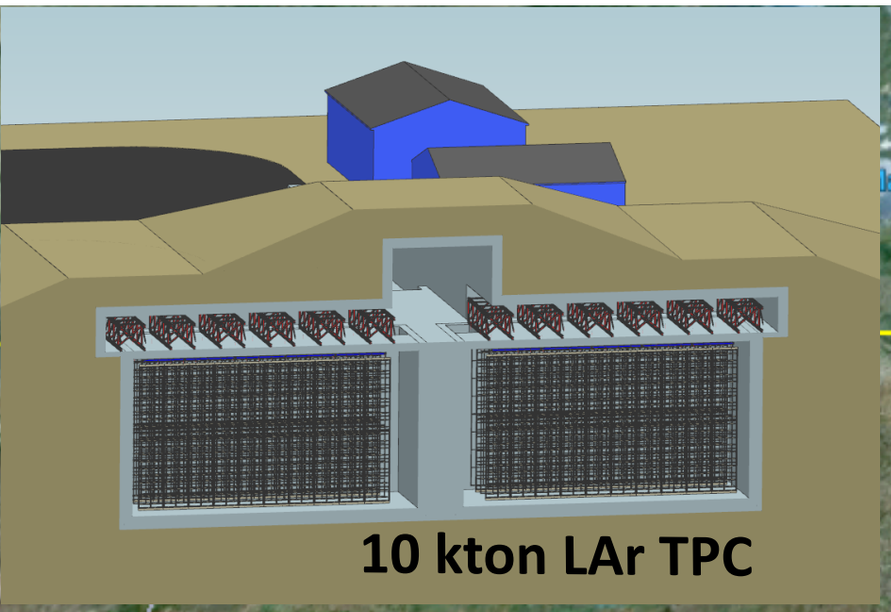


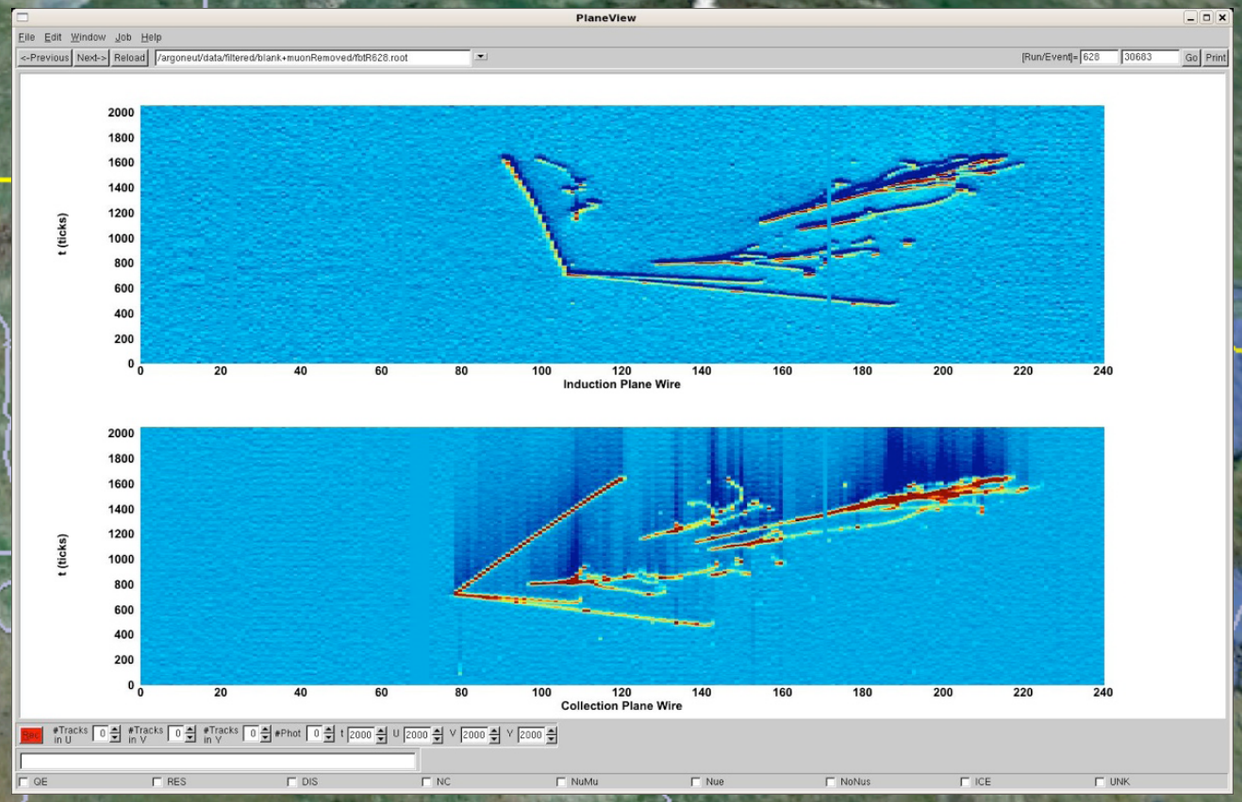
- Expect to have 5 kton built by the time beam returns in Spring of 2013 and we will be able to collect data as we build.
- Far detector to be complete by April 2014.
- Near detector to be complete in 2013.

- Partially instrumented prototype near detector built and operated on the surface for ~1.5 years. Continues to provide invaluable data!
- Accelerator upgrades are underway at FNAL and on-schedule.
- Preparations for far detector construction underway.



The Long-Baseline Neutrino Experiment (LBNE)





Lead, SD

1300 km, on-axis

New ν Beam from FNAL

700 kW initially, upgradable to 2.2 MW

Fermilab

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LBNE Reconfiguration

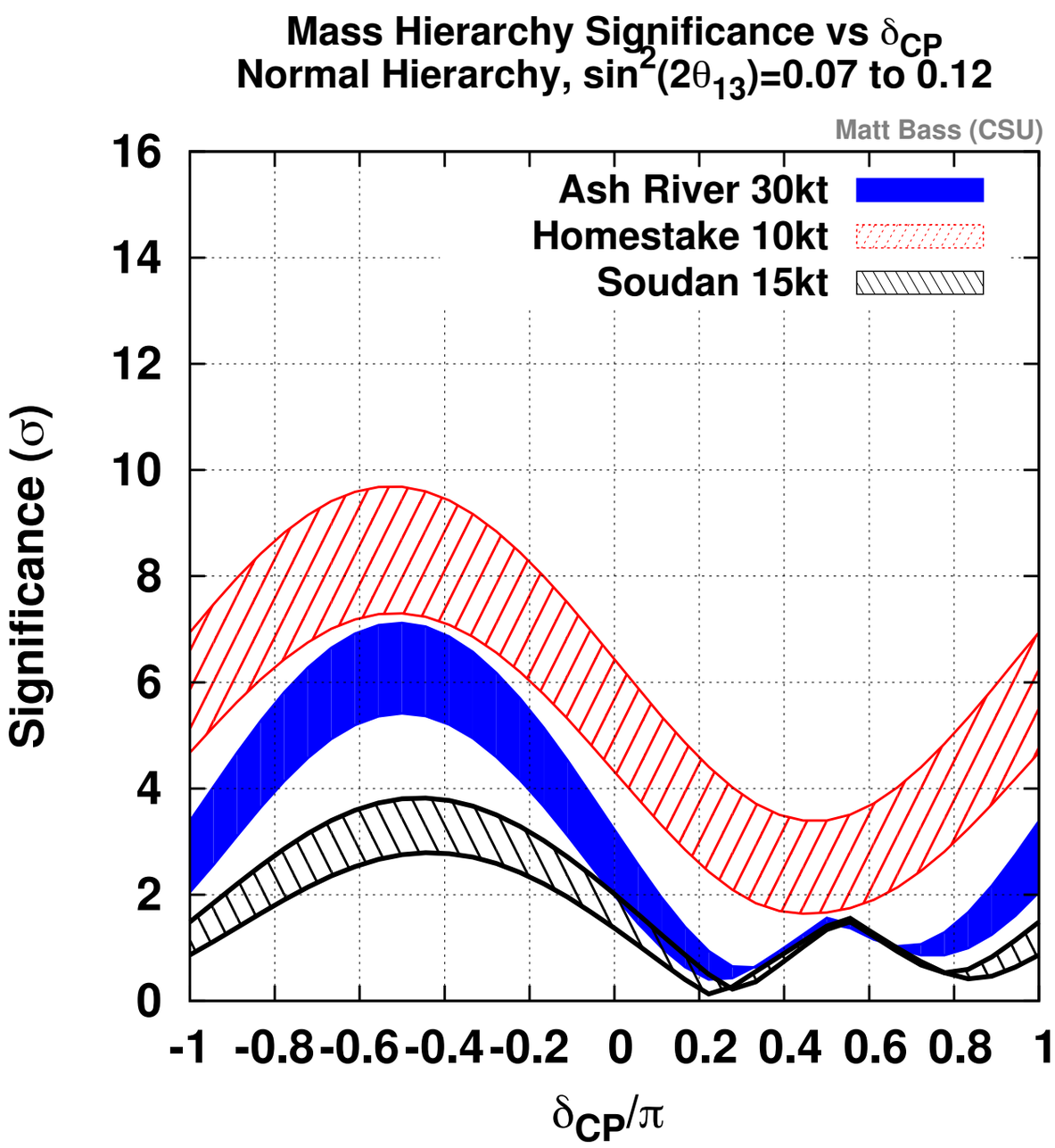
- December 2011: project management decided on a 34 kton LAr TPC located at the 4850' level at the Homestake Mine (Lead, SD). A new neutrino beamline capable of handling Project X level intensities (~2.2 MW) is part of the project.

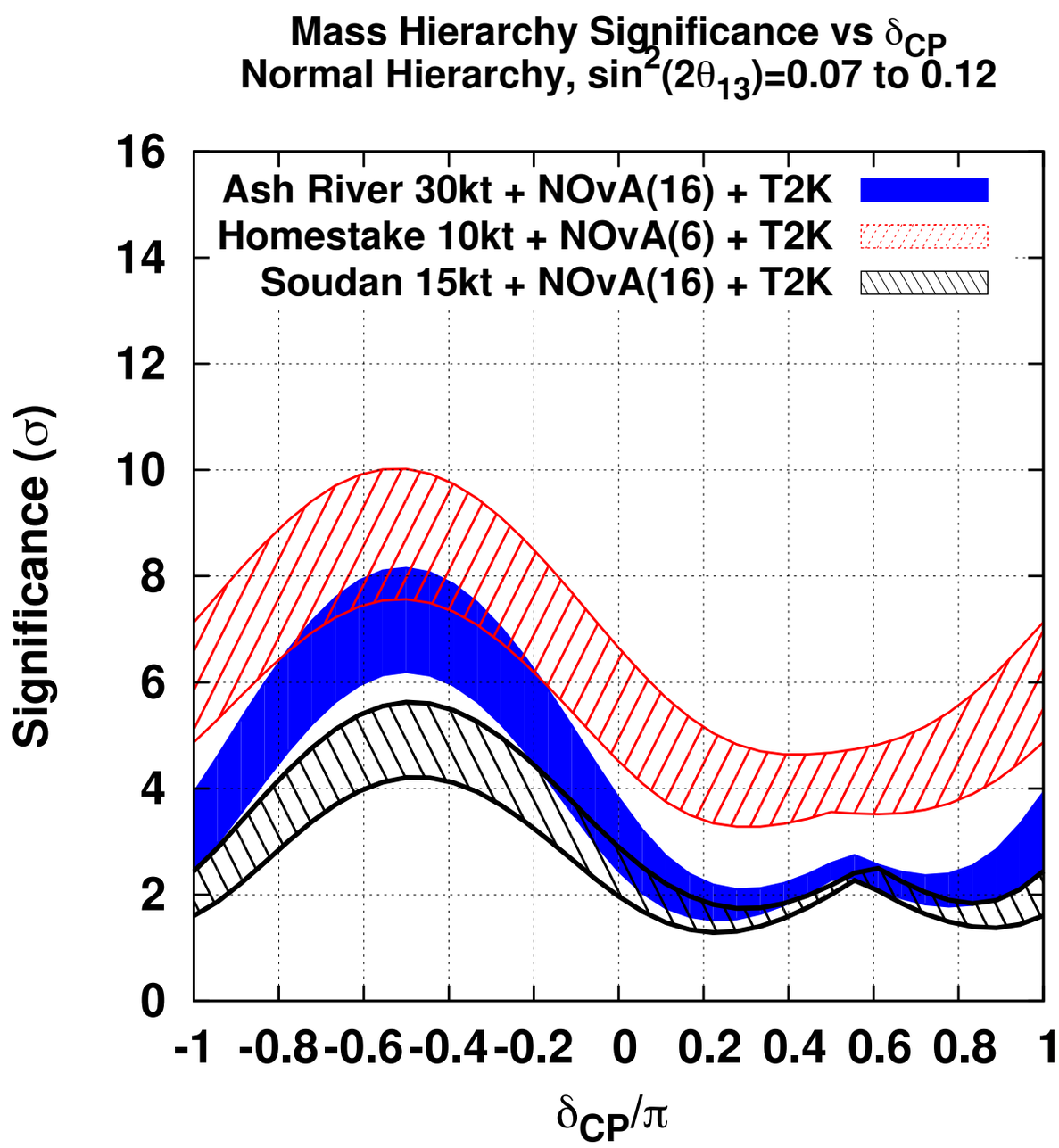
- March 19, 2012: DOE announced that it could not support the LBNE project as configured. Fermilab was tasked with developing "an affordable and phased approach that will enable important science results at each phase." [letter from W.F. Brinkman, DOE OSTP to Pier Odone, director of Fermilab]. Alternative options were also to be considered.

- A steering committee was formed and considered the impact and capabilities of three options (all w/ 10 years of running):
  - 30 kton LAr TPC surface detector at Ash River, 810 km baseline, 14 mrad off-axis from 700 kW NuMI beam
  - 15 kton LAr TPC underground detector at the 2340 ft. level in the Soudan Mine, 734 km baseline, on-axis along 700 kW NuMI beam
  - 10 kton LAr TPC surface detector at the Homestake Mine, 1300 km baseline, on-axis along new beamline

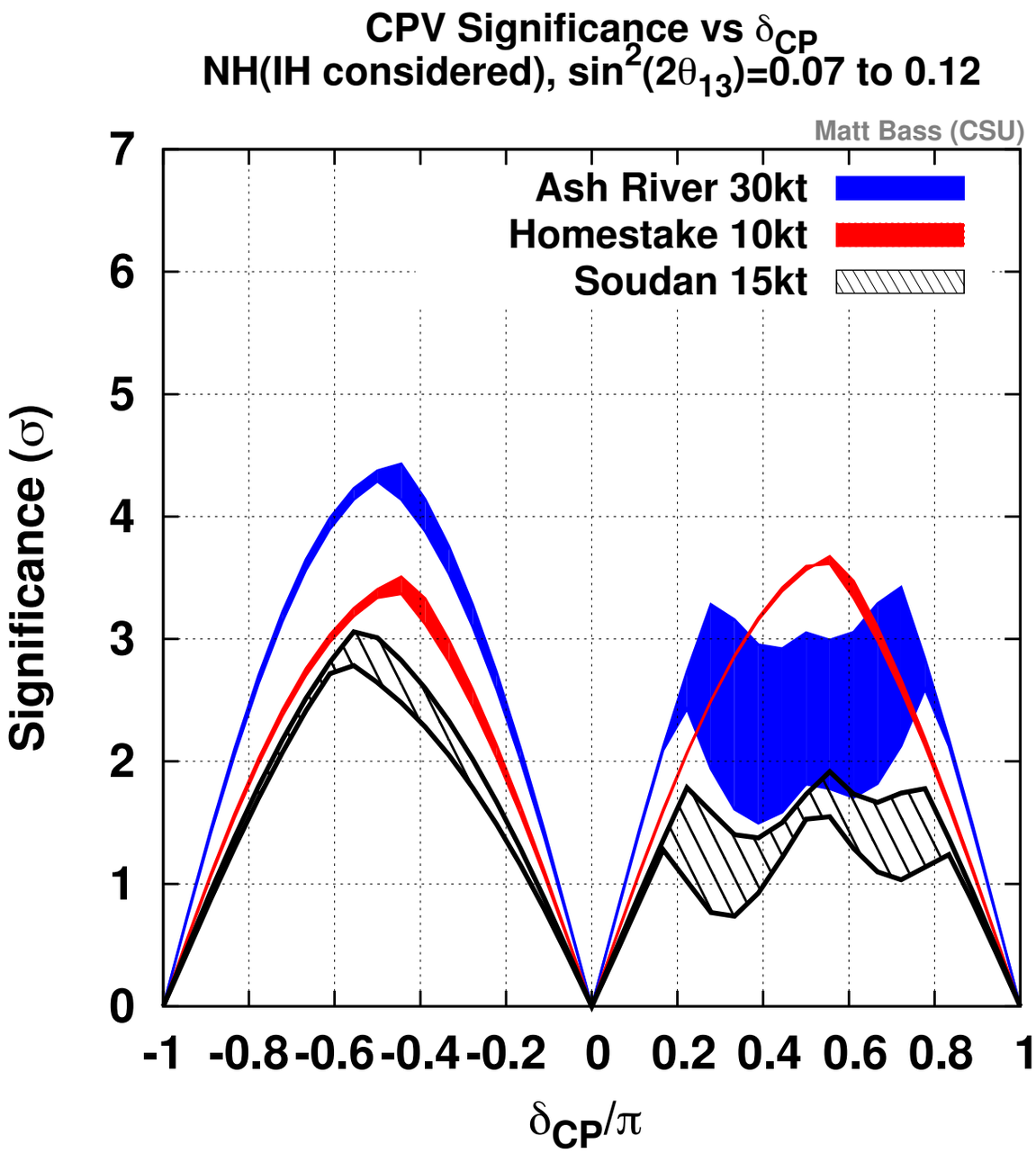
- The steering committee "strongly favored the option to build a new beamline to Homestake with an initial 10 kton LAr-TPC detector on the surface." [LBNE Reconfiguration Steering Committee Interim Report, http://www.fnal.gov/directorate/lbne_reconfiguration/index.shtml]

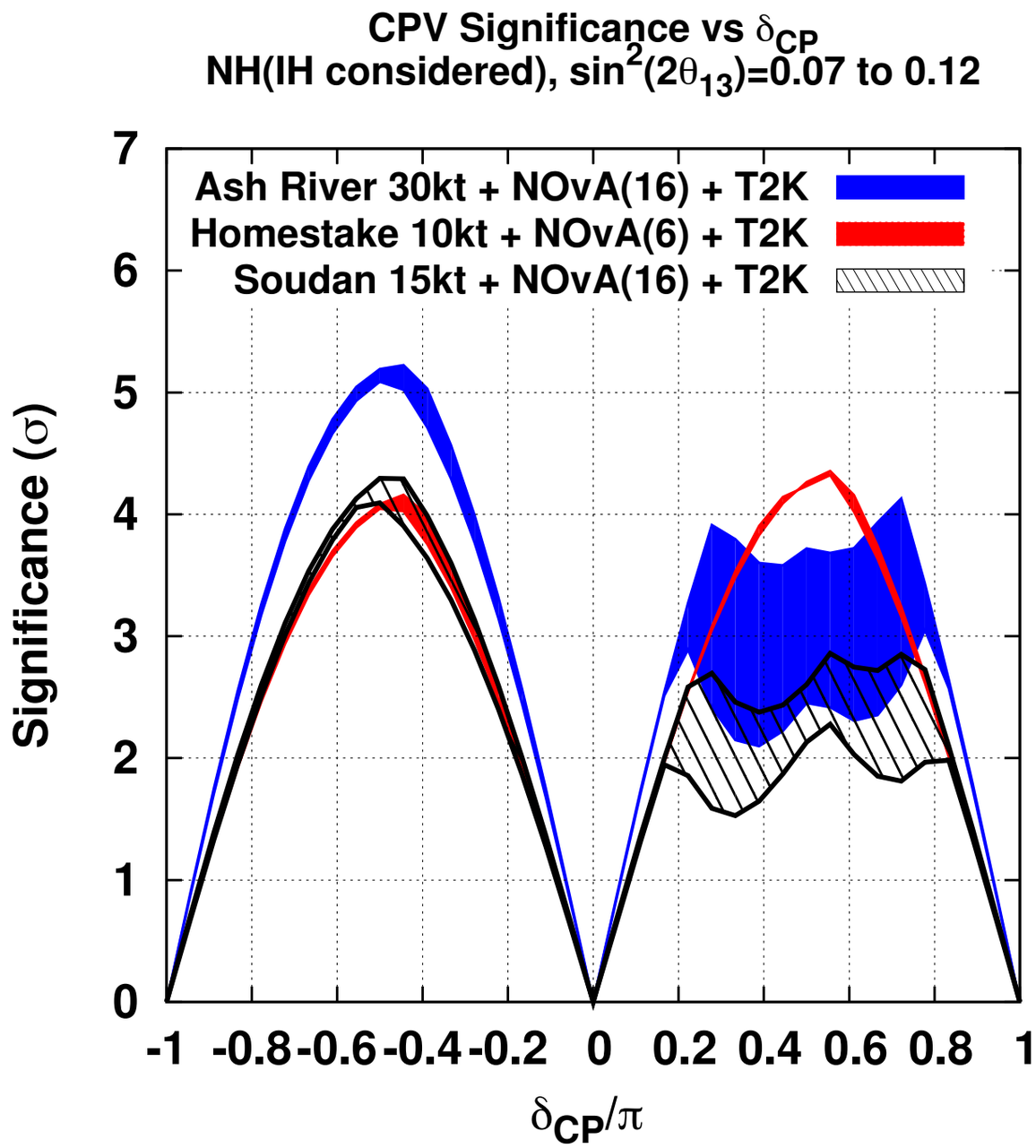
LBNE Resolution of Mass Hierarchy





LBNE Measurement of CP-violation





LBNE Status

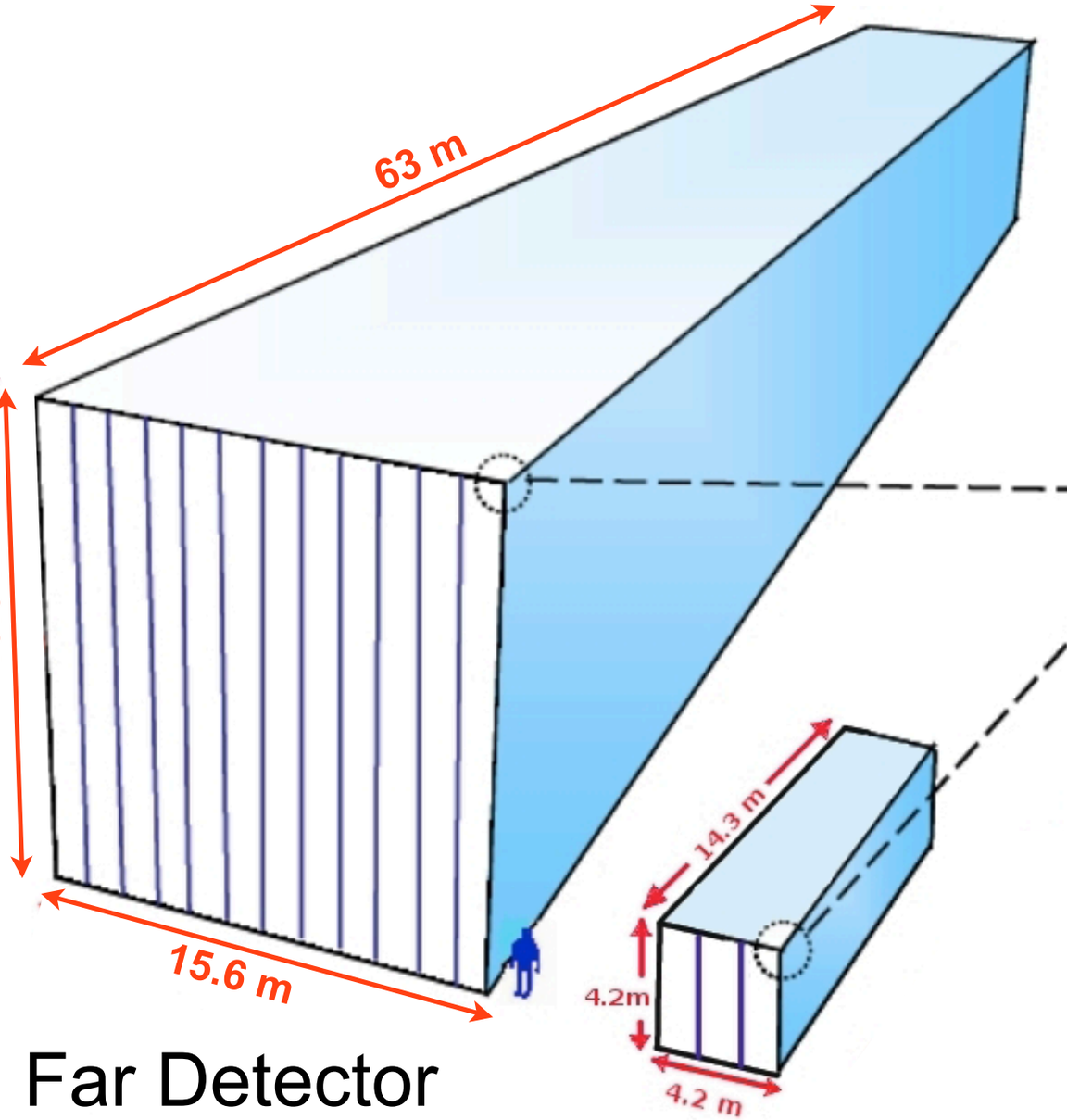
- LBNE Project management is moving forward with the Steering Committee's preference
- June 29, 2012: DOE authorized LBNE Project to proceed with planning a CD1 review later this year
- In the meantime, design work continues on the LAr TPC cryostat, wire planes, electronics, beamline, near detector, simulation and offline reconstruction tools, etc.
- Additional collaborators including international partners welcome!

Summary

- NOνA will make many important contributions to neutrino physics:
  - Measurement of θ_{13}
  - Important first information on the neutrino mass hierarchy and CP violating phase
  - Determination of the θ_{23} octant
  - More precise measurements of Δm_{32}^2 and $\sin^2(2\theta_{23})$
- NOνA is under construction:
  - surface prototype detector is operational, taking data, and has taught us many lessons
  - first far detector blocks will be installed and collecting cosmic ray data this fall
  - 1/3 FD expected to be complete by the time beam returns, full detector operational a year later
  - early physics results possible as early as 2014.
- LBNE has been reconfigured but still stands to do excellent physics while providing a path forward for future phases of the experiment:
  - mass hierarchy will be determined to within ~4 sigma regardless of the CP phase and mass hierarchy
  - capable of discovering CP violation

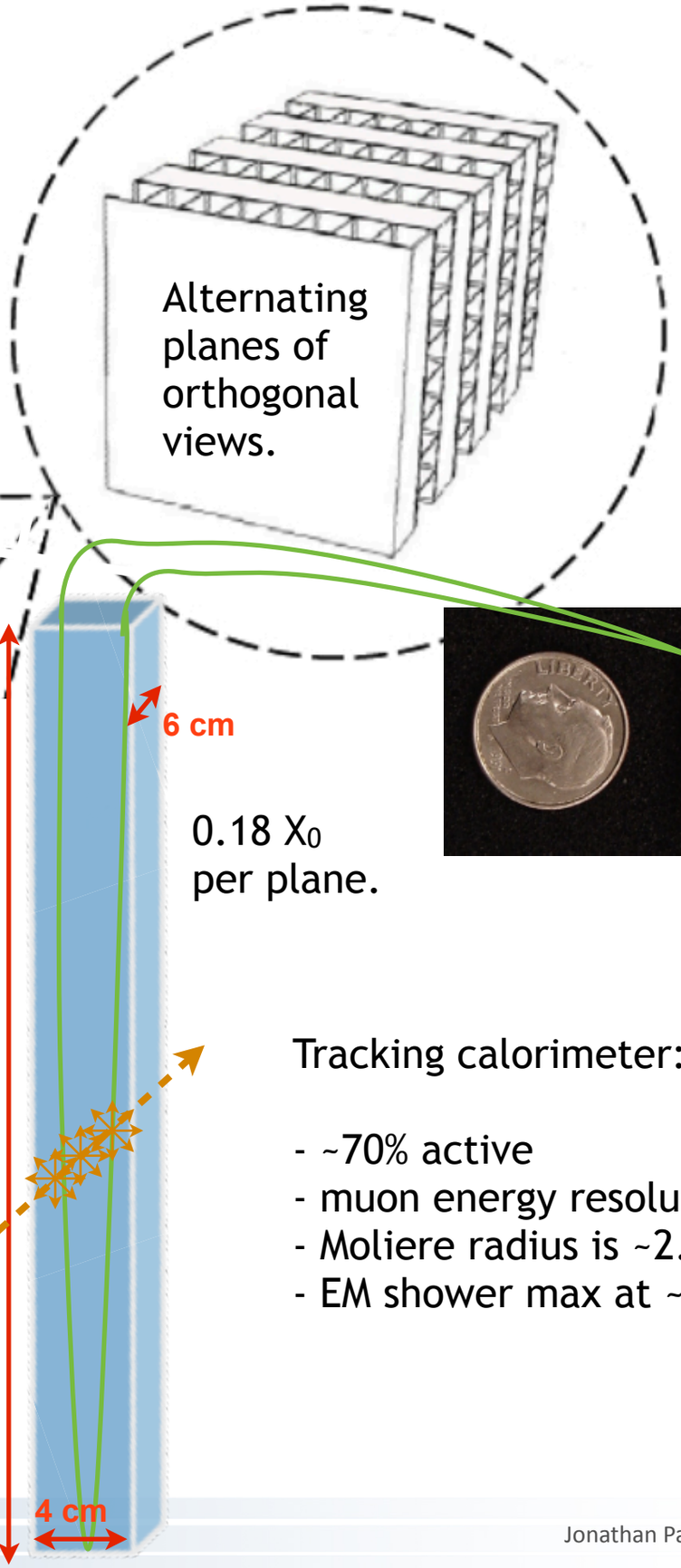
Backup Slides

The NOvA Detectors

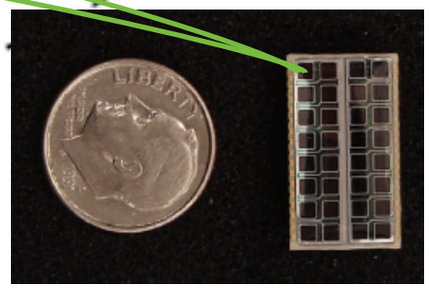


Far Detector

Near Detector



Wavelength-shifting fibers routed to a single cell on an Avalanche Photodiode (APD).

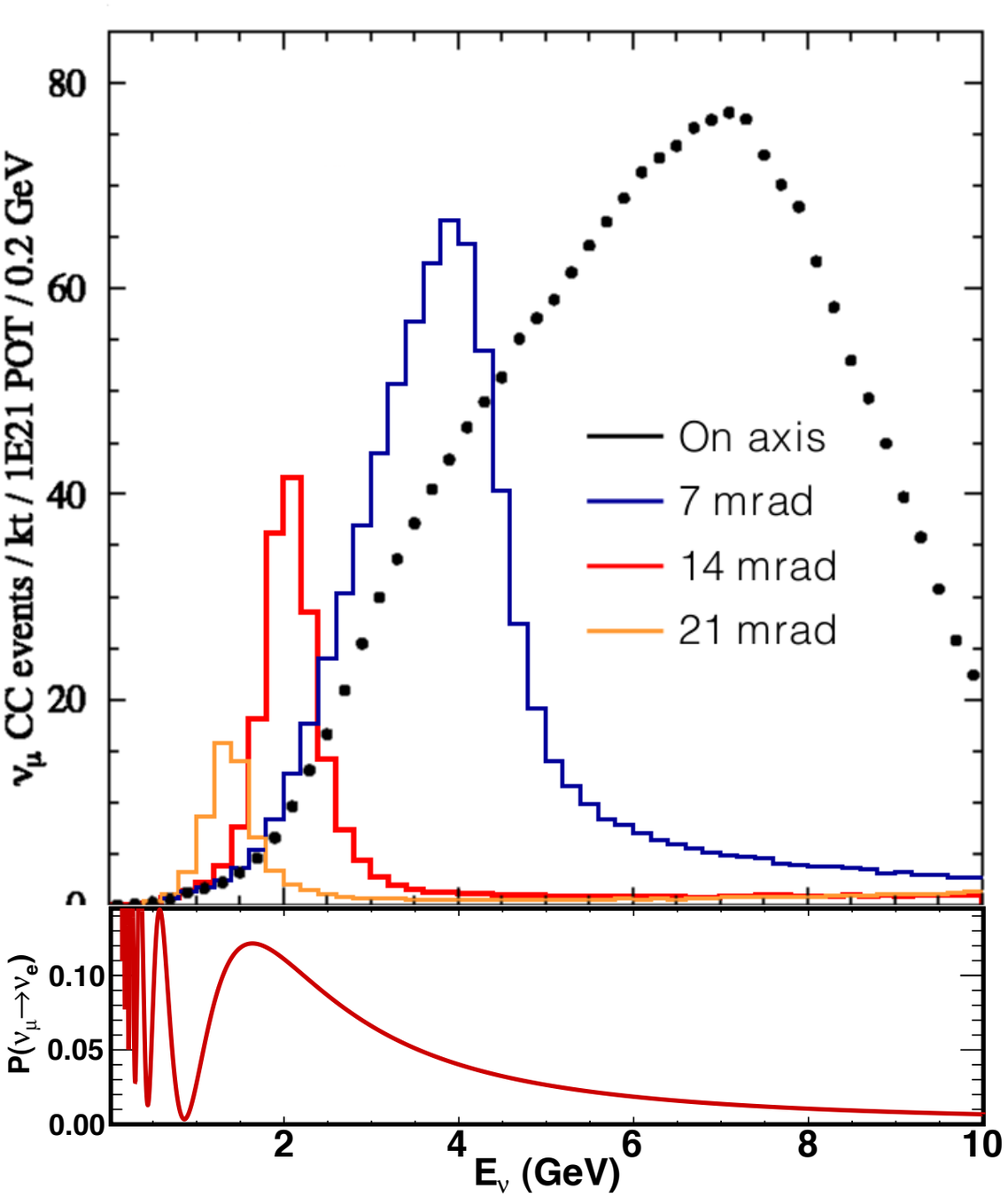


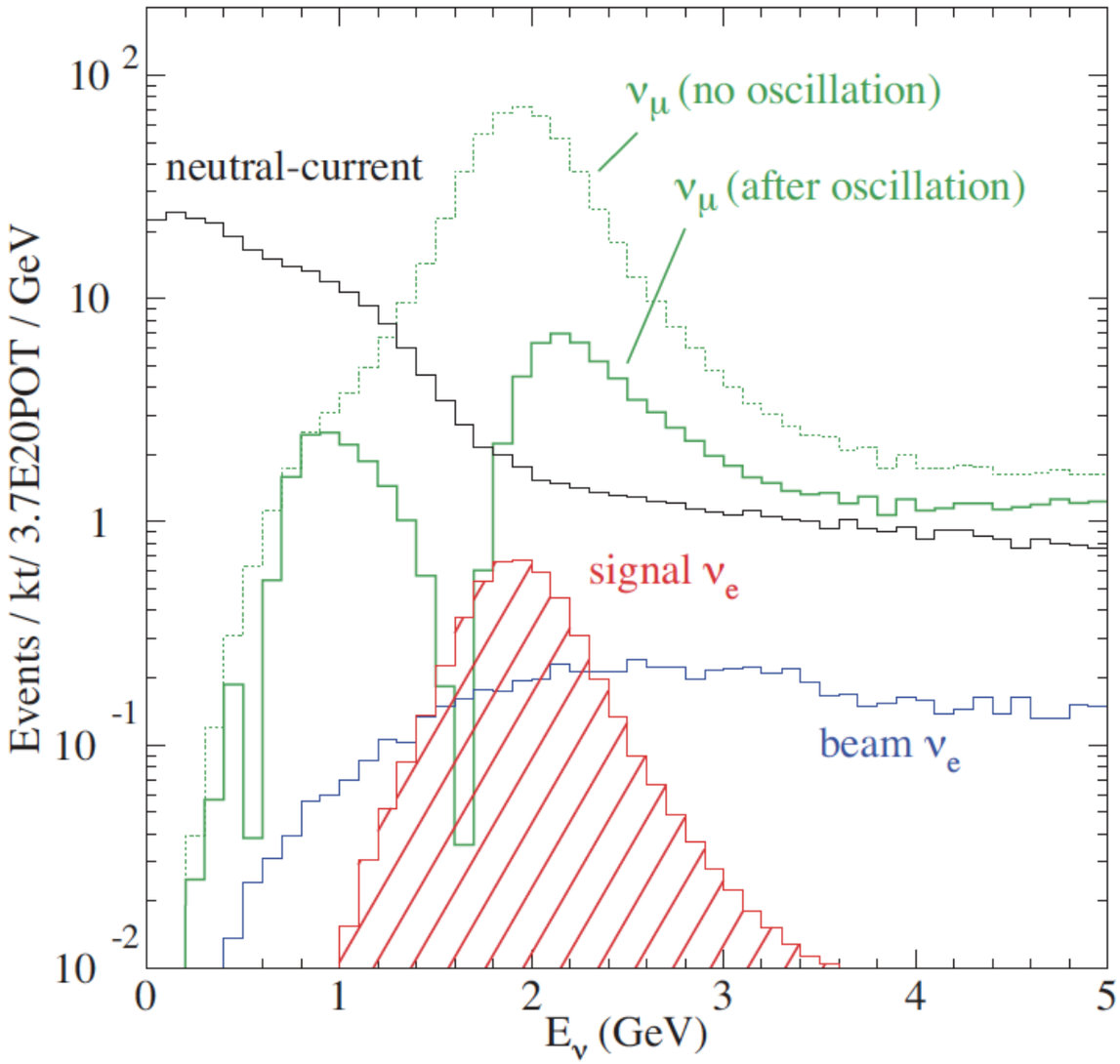
0.18 X_0 per plane.

Tracking calorimeter:

- ~70% active
- muon energy resolution (range): few %
- Moliere radius is ~2.5 cell widths
- EM shower max at ~5 X_0

NOvA - Why Go Off-Axis?



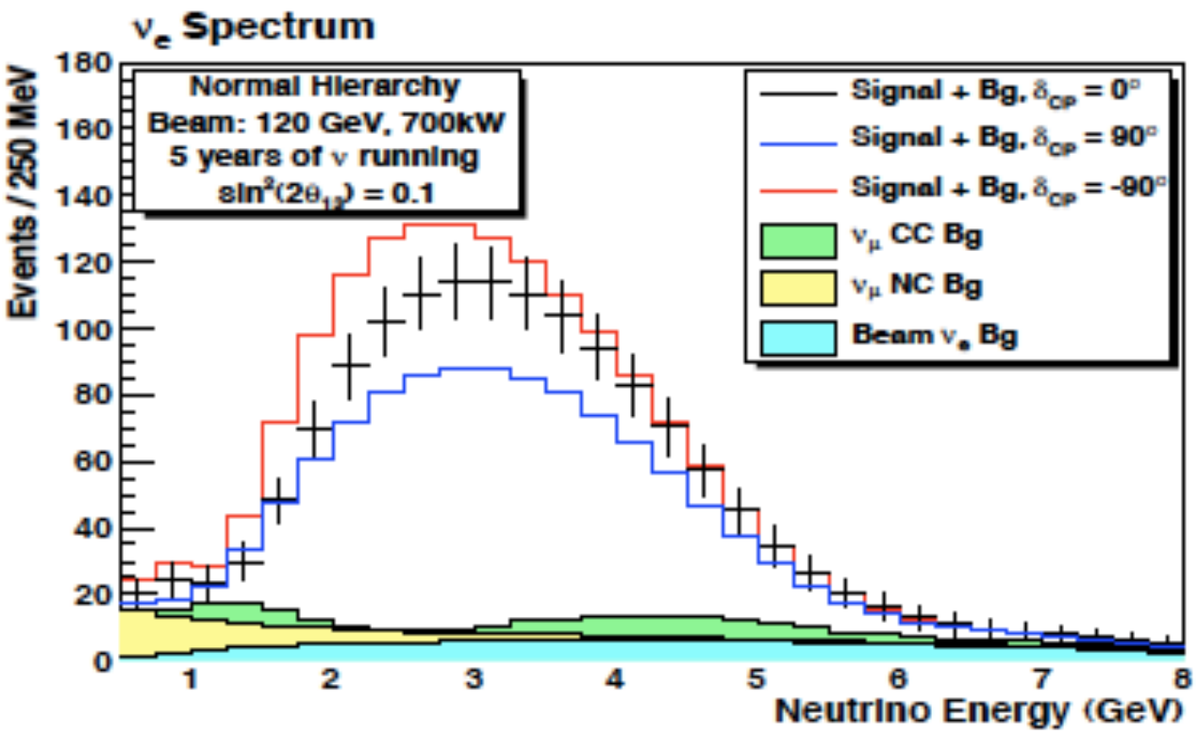


- Narrow-band beam, in conjunction with topology of final state particles, allows one to more easily reject potential backgrounds.

LBNE Beam Spectrum

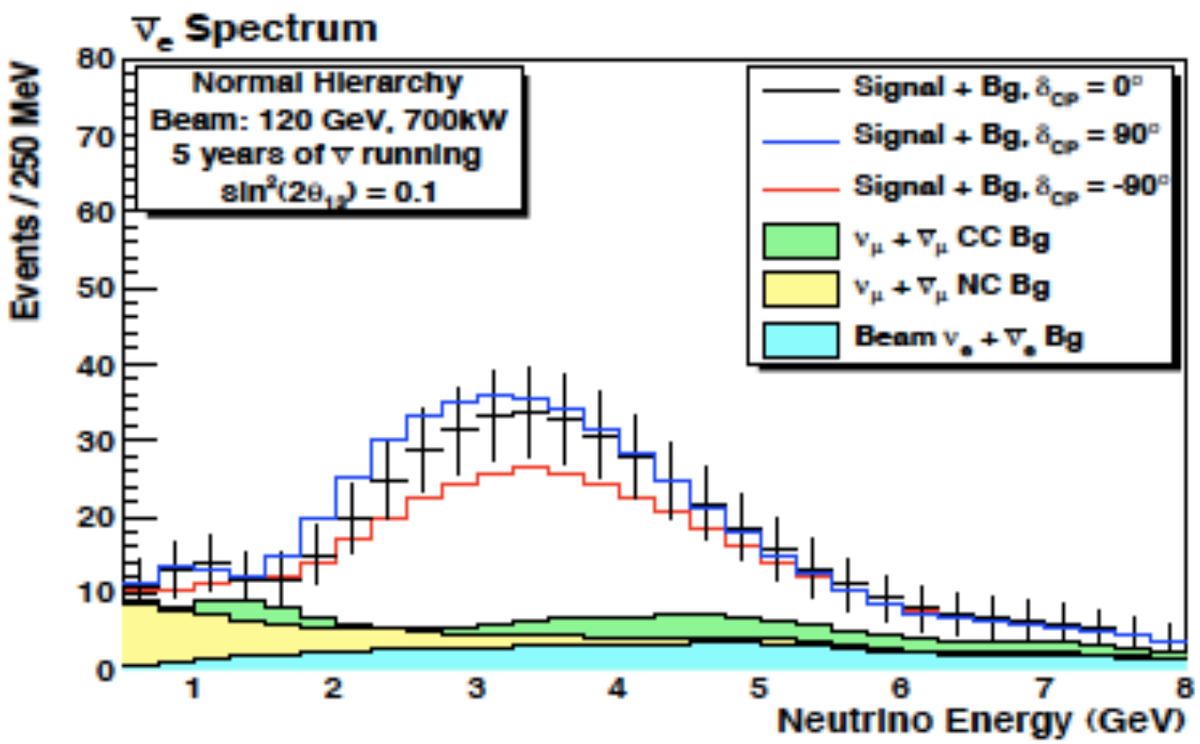
(assumes 34 kton LAr FD)

1300km, LBNE LE at Hmstk



SG: (1366,1157,889), BG: 317

1300km, LBNE LE at Hmstk



SG: (250,327,353), BG: 176

[M. Bishai, "Long Baseline Neutrino Physics Prospects with Project X"]