Plenary
NOvA Science Update

Mark Messier
Co-spokesperson

June 16, 2009

The NOvA Collaboration

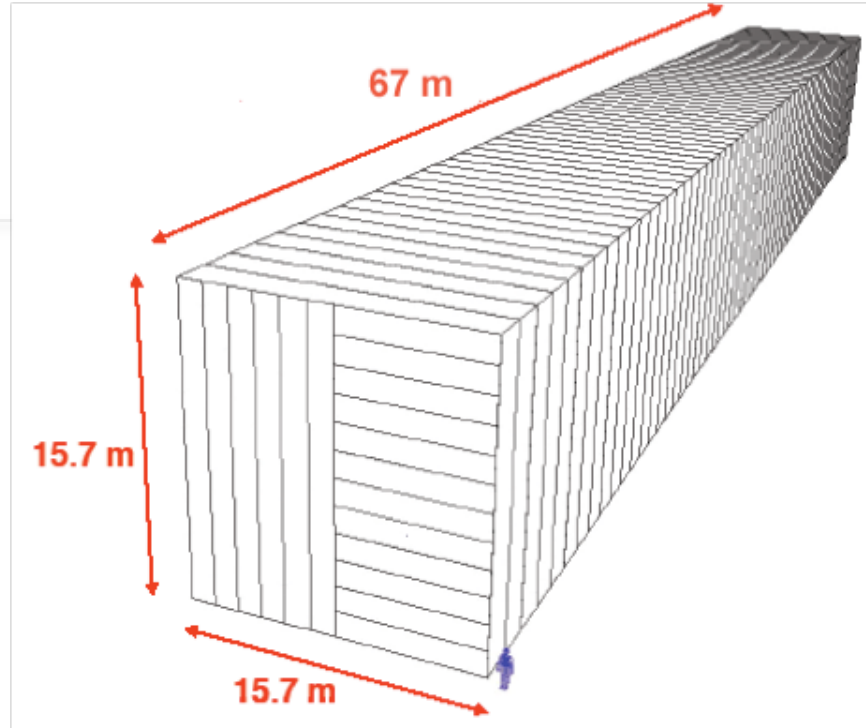
at Argonne National Lab, 25 April 2009

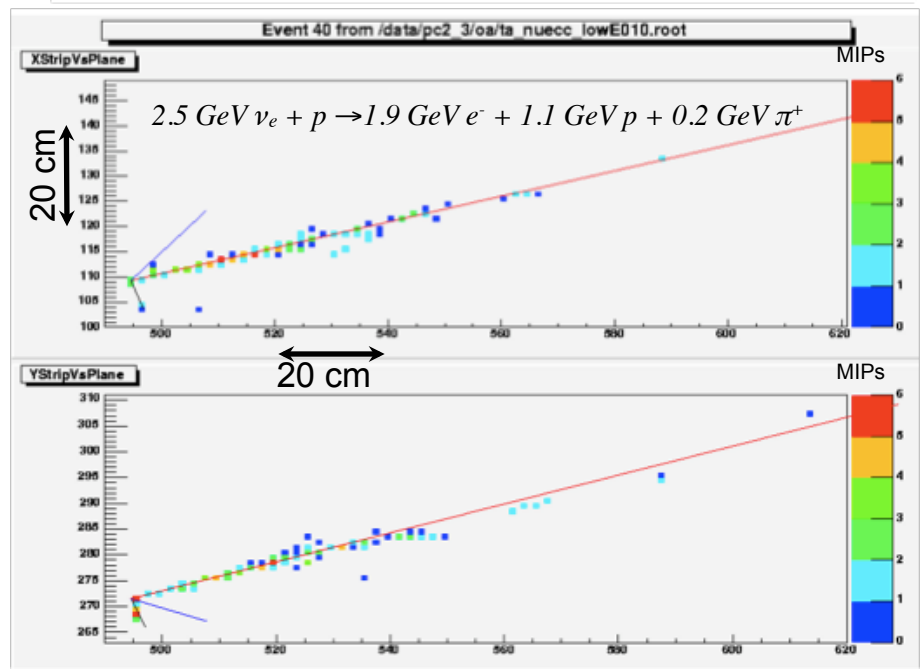
180 Scientists and Engineers from 26 Institutions

Argonne National Laboratory - University of Athens - California Institute of Technology - University of California, Los Angeles - Fermi National Accelerator Laboratory - Harvard University - Indiana University - Lebedev Physical Institute - Michigan State University - University of Minnesota, Duluth - University of Minnesota, Minneapolis - The Institute for Nuclear Research, Moscow - Technische Universität München, Munich - State University of New York, Stony Brook - Northwestern University - University of South Carolina, Columbia - Southern Methodist University - Stanford University - University of Tennessee - Texas A&M University - University of Texas, Austin - University of Texas, Dallas - Tufts University - University of Virginia, Charlottesville - The College of William and Mary - Wichita State University

The Experiment

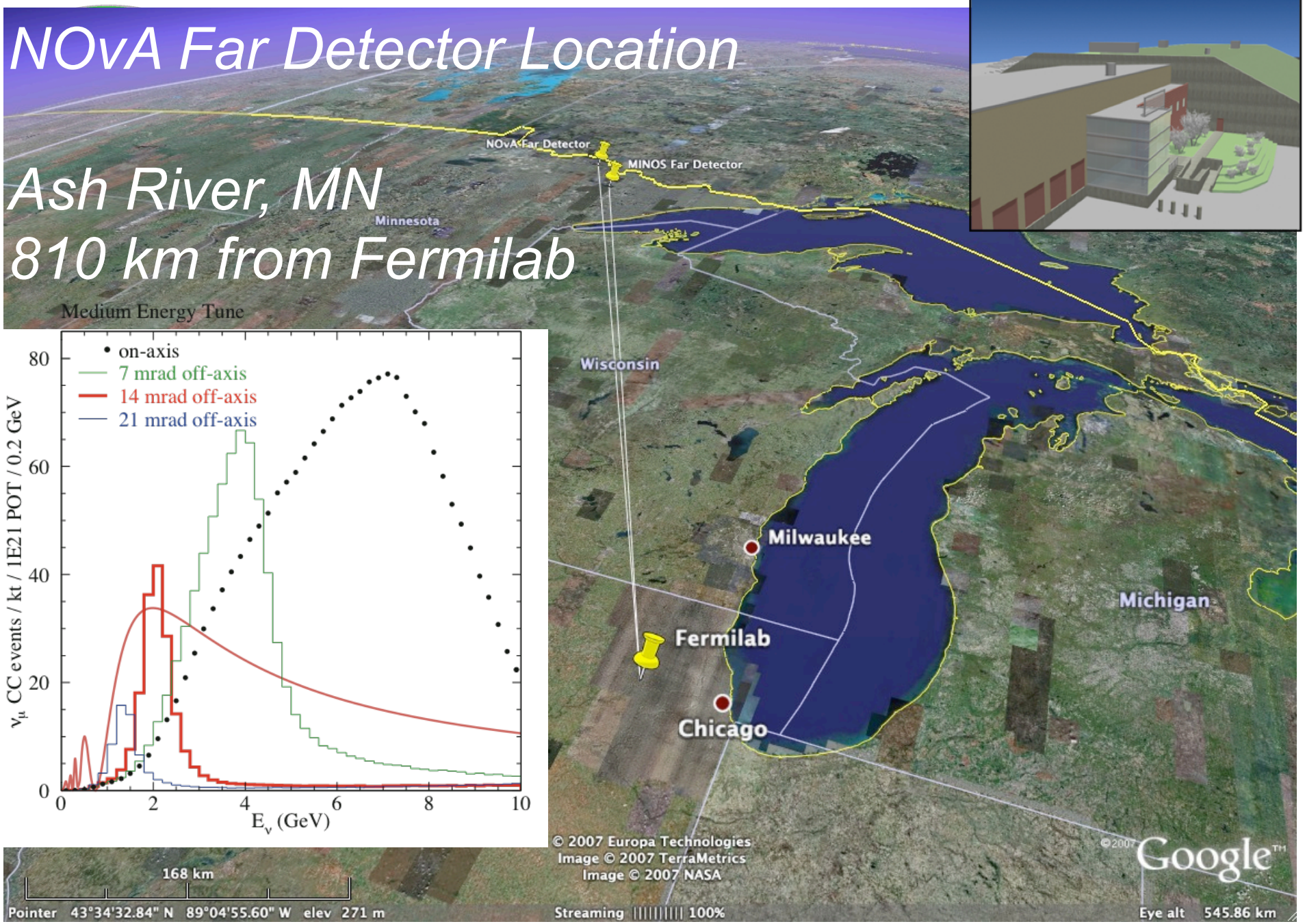
- NOvA is a second generation experiment on the NuMI beamline which is optimized for the detection of $\nu_\mu \rightarrow \nu_e$ and $\underline{\nu}_\mu \rightarrow \underline{\nu}_e$ oscillations
- NOvA is:
  - An upgrade of the NuMI beam intensity from 400 kW to 700 kW
  - A 15 kt "totally active" tracking liquid scintillator calorimeter sited 14 mrad off the NuMI beam axis at a distance of 810 km
  - A 215 ton near detector identical to the far detector sited 14 mrad off the NuMI beam axis at a distance of 1 km





NOvA Far Detector Location

Ash River, MN
810 km from Fermilab



Questions for the future

As the first chapter in the study of neutrino oscillations comes to an end, a new chapter begins. The great progress in neutrino physics over the last few decades raises new questions and provides opportunities for major discoveries. Among the compelling issues today:

1) What is the value of θ_{13}, the mixing angle between first- and third-generation neutrinos for which, so far, experiments have only established limits? Determining the size of θ_{13} has critical importance not only because it is a fundamental parameter, but because its value will determine the tactics to best address many other questions in neutrino physics.

2) Do neutrino oscillations violate CP? If so, how can neutrino CP violation drive a matter-antimatter asymmetry among leptons in the early universe (leptogenesis)? What is the value of the CP violating phase, which is so far completely unknown? Is CP violation among neutrinos related to CP violation in the quark sector?

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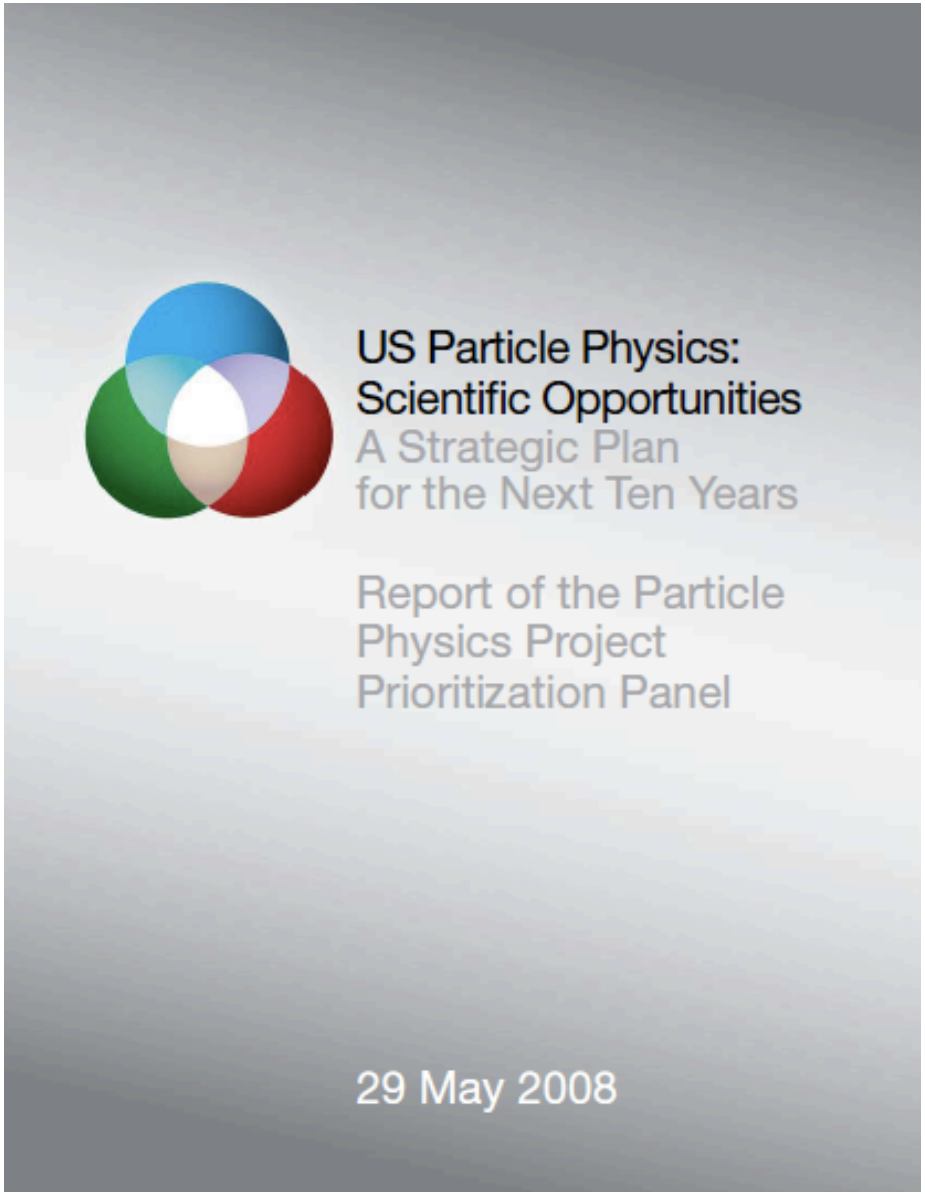
4) Is θ_{23} maximal (45 degrees)? if so, why? Will the pattern of neutrino mixing provide insights regarding unification of the fundamental forces? Will it indicate new symmetries or new selection rules?

5) Are neutrinos their own antiparticles? Do they give rise to lepton number violation, or leptogenesis, in the early universe? Do they have observable laboratory consequences such as the sought-after neutrinoless double beta decay in nuclei?

6) What can we learn from observation of the intense flux of neutrinos from a supernova within our galaxy? Can we observe the neutrino remnants of all supernovae that have occurred since the beginning of time?

7) What can neutrinos reveal about other astrophysical phenomena? Will we find localized cosmic sources of very-high-energy neutrinos?

8) What can neutrinos tell us about new physics beyond the Standard Model, dark energy, extra dimensions? Do sterile neutrinos exist?



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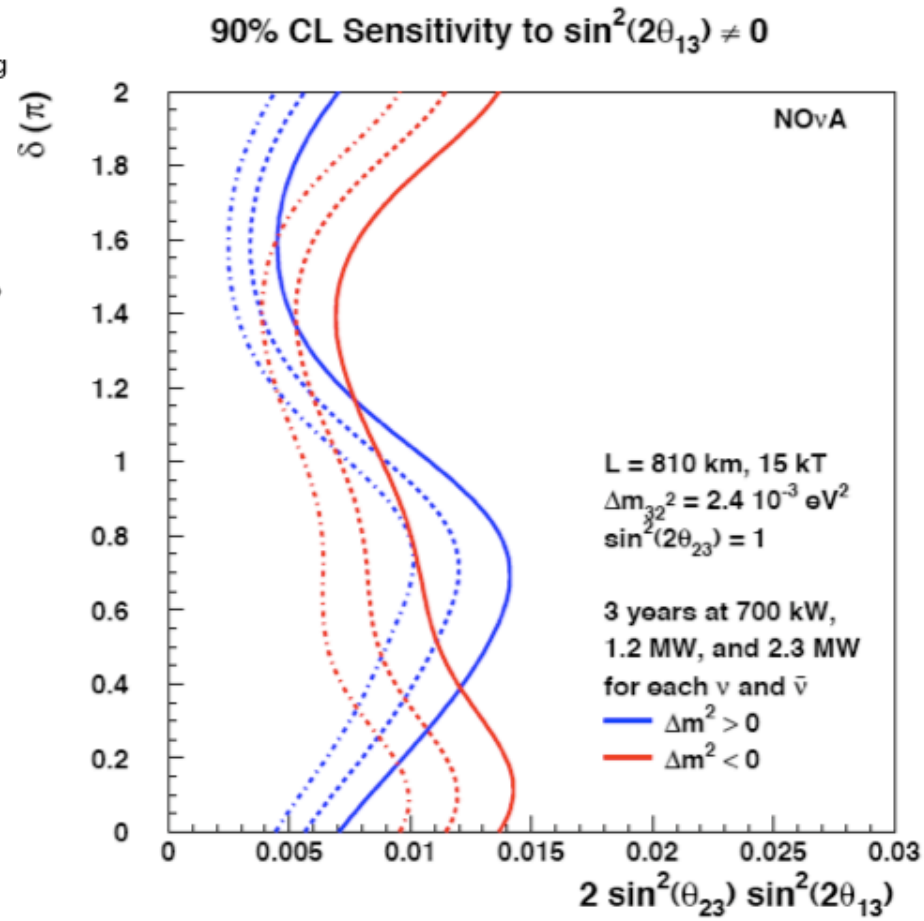

NOvA searches for electron neutrino appearance down to ~0.01 at 90% CL

excerpted from US Particle Physics: Scientific Opportunities. A Strategic Plan for the Next Ten Years. Report of the Particle Physics Project Prioritization Panel, May 2008

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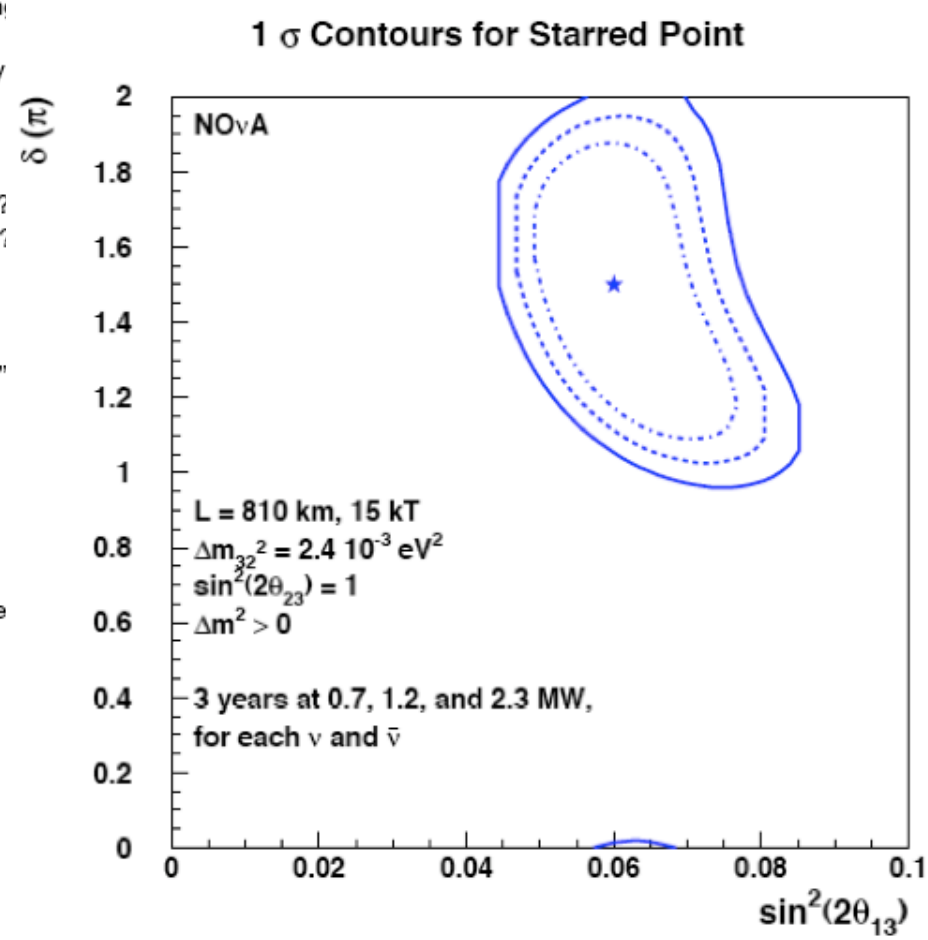

NOvA provides the first look into the CPV parameter space

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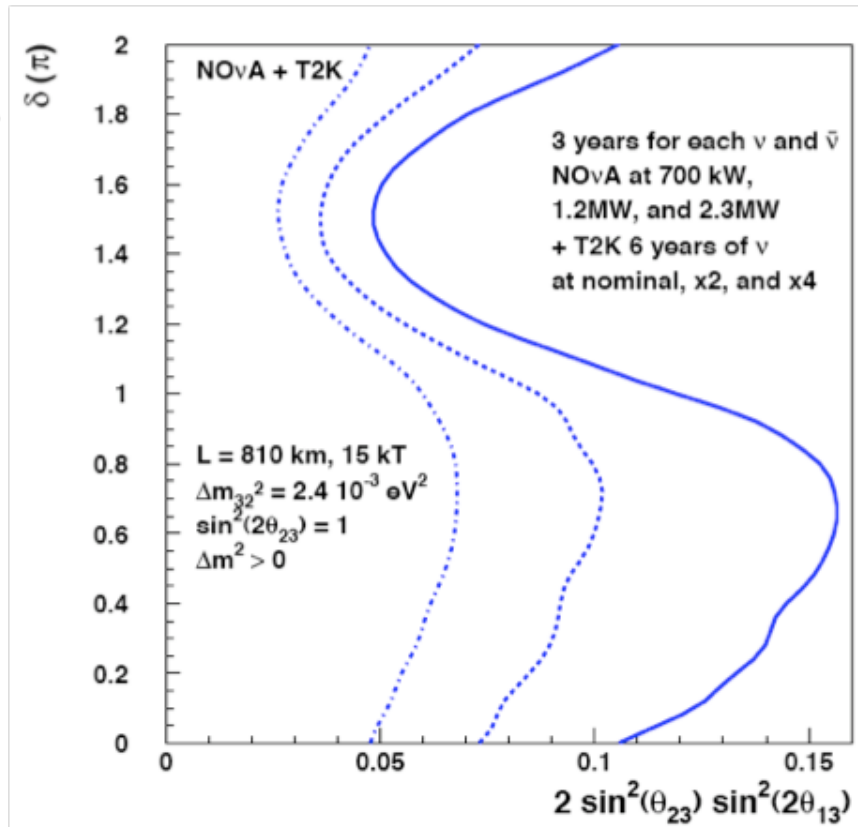

NOvA's long baseline makes it sensitive to the mass ordering

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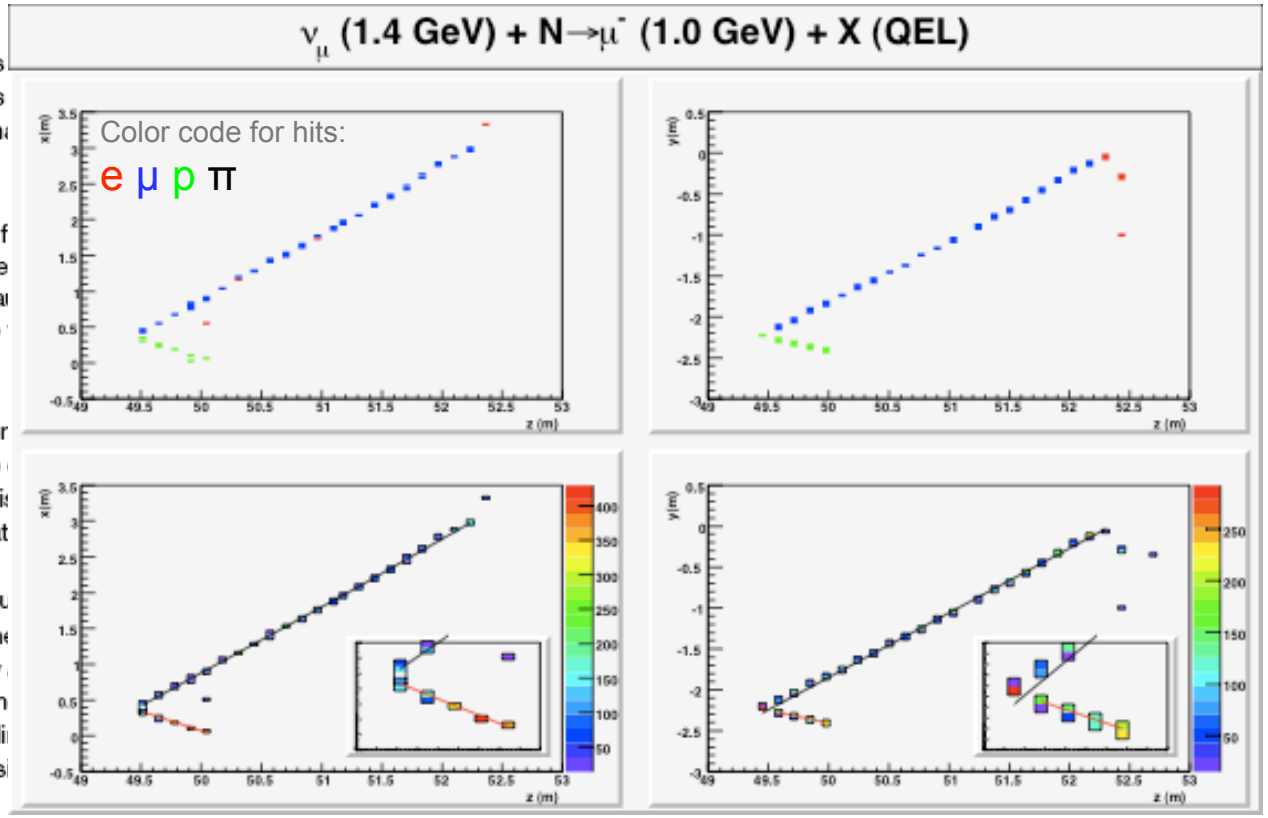

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4) Is θ_{23} maximal?

Because of its excellent energy resolution NOvA can make ~1% measurements of muon neutrino disappearance using quasi-elastic channel

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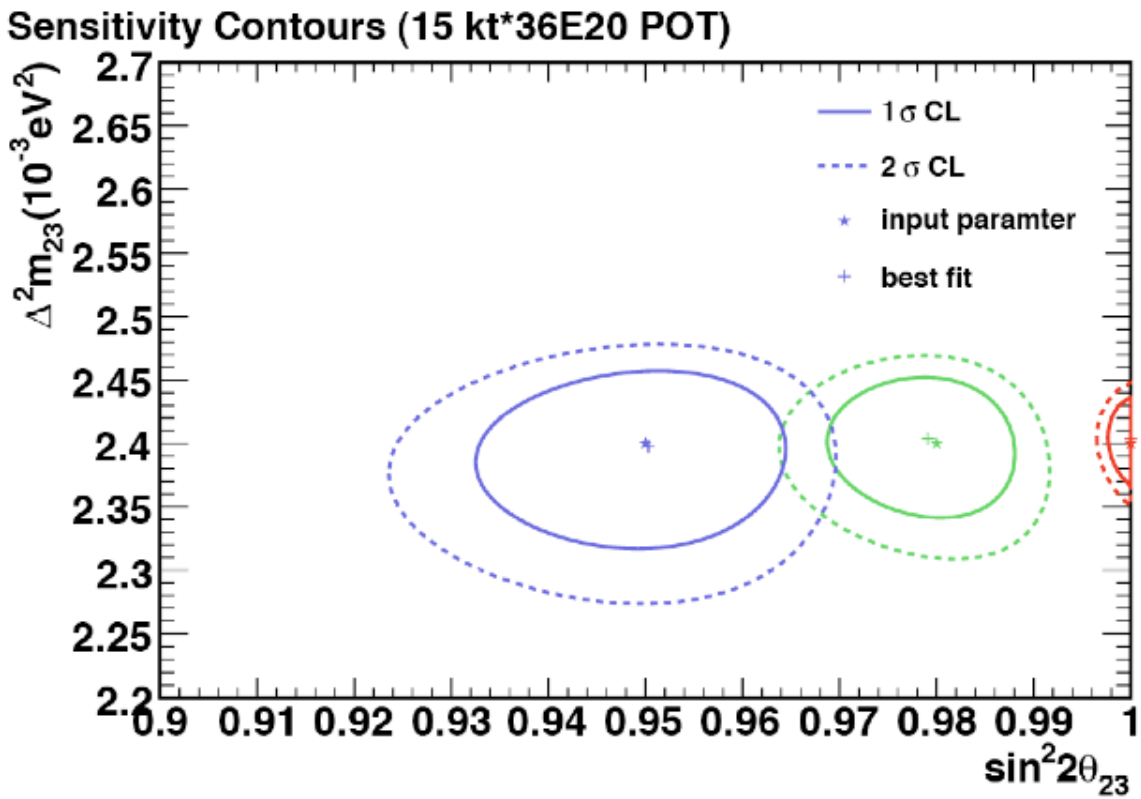

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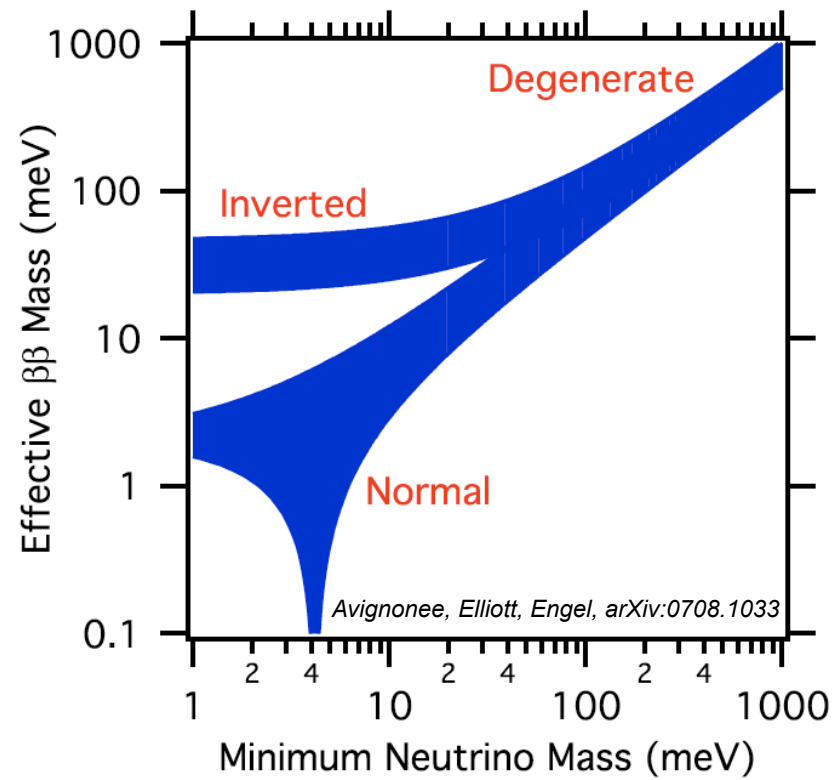

If NOvA establishes inverted hierarchy and next generation of 0νββ experiments see nothing, then it is very likely that neutrinos are Dirac particles

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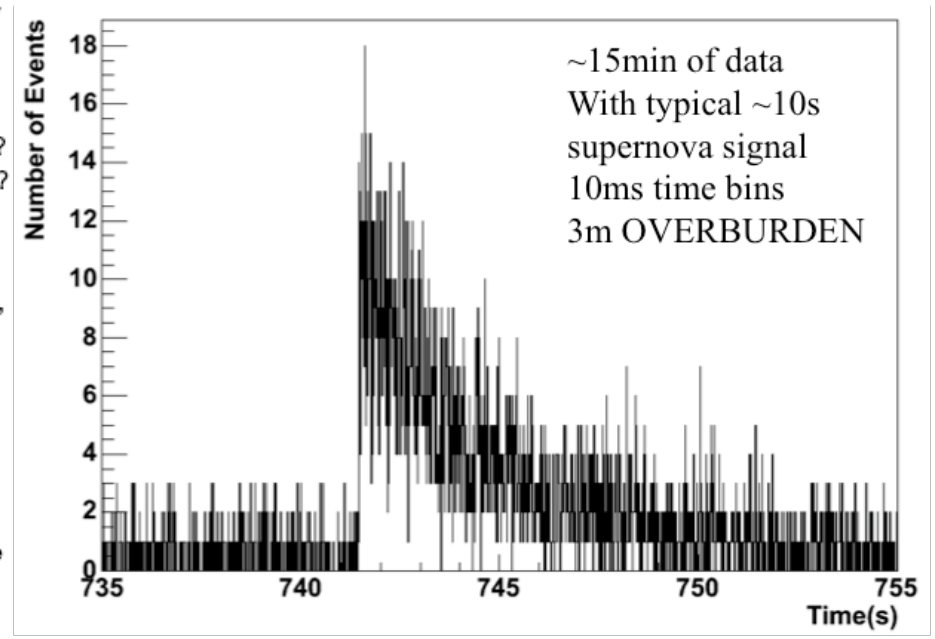

NOvA would see burst of 5000 events for a supernova at the center of the galaxy

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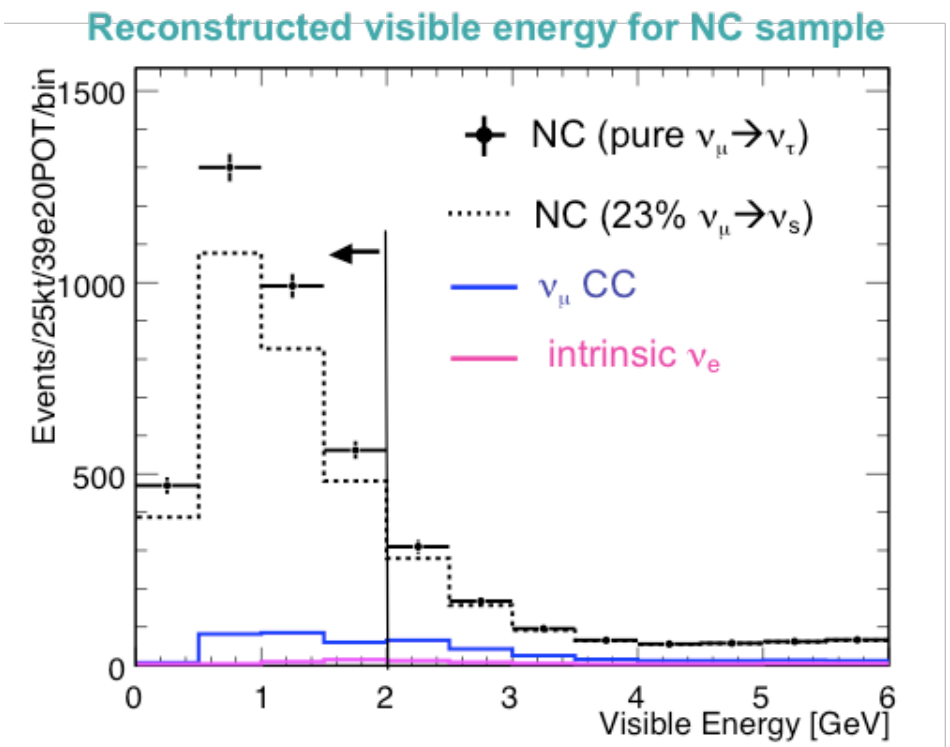

NOvA's granularity allows for clean neutral-current measurements facilitating searches for sterile neutrinos

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Part of my charge

- We would like the "NOvA Science Update" talk to explain the strategic position that NOvA will occupy as it starts up, with respect to the other neutrino experiments such as MINOS, Double CHOOZ, Daya Bay, K2K, T2K, etc. What limits or measurements are expected to exist at that time (mixing angle, mass differences, oscillations, CPV, etc.) and what will be NOvA's sensitivity for confronting them as the experiment evolves from partial to full operational capability? How is the competition expected to evolve as NOvA carries out its experimental mission?

What do we know now about θ_{13}?

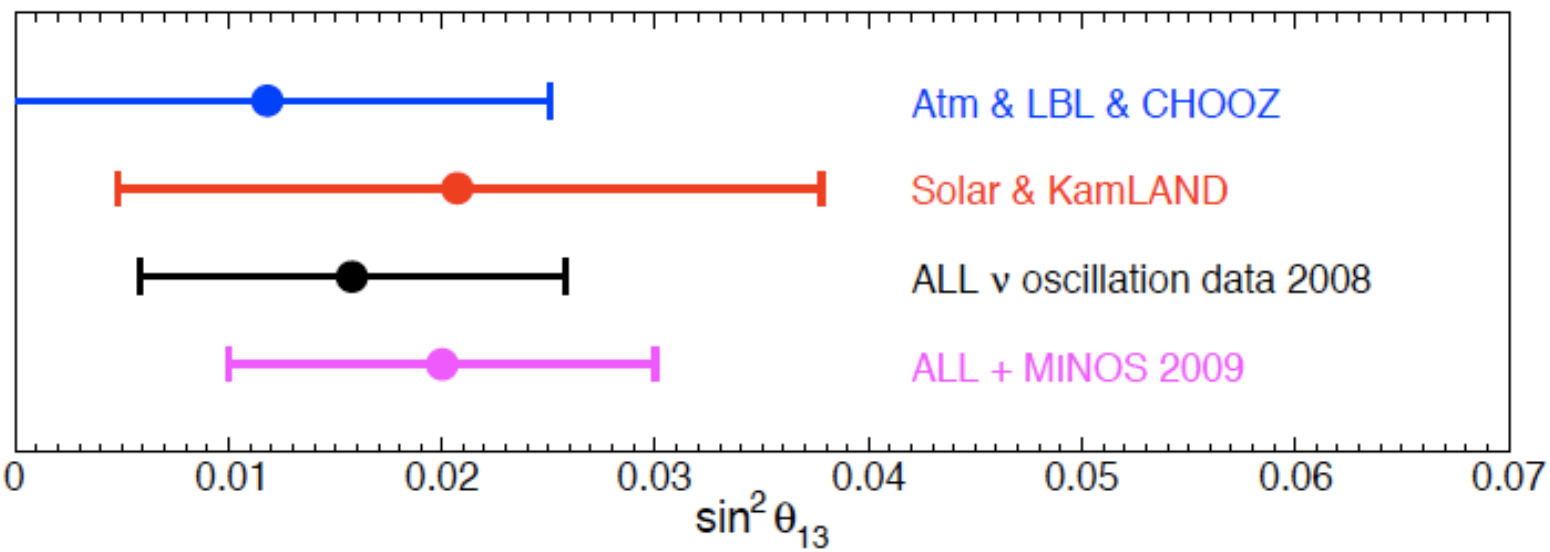
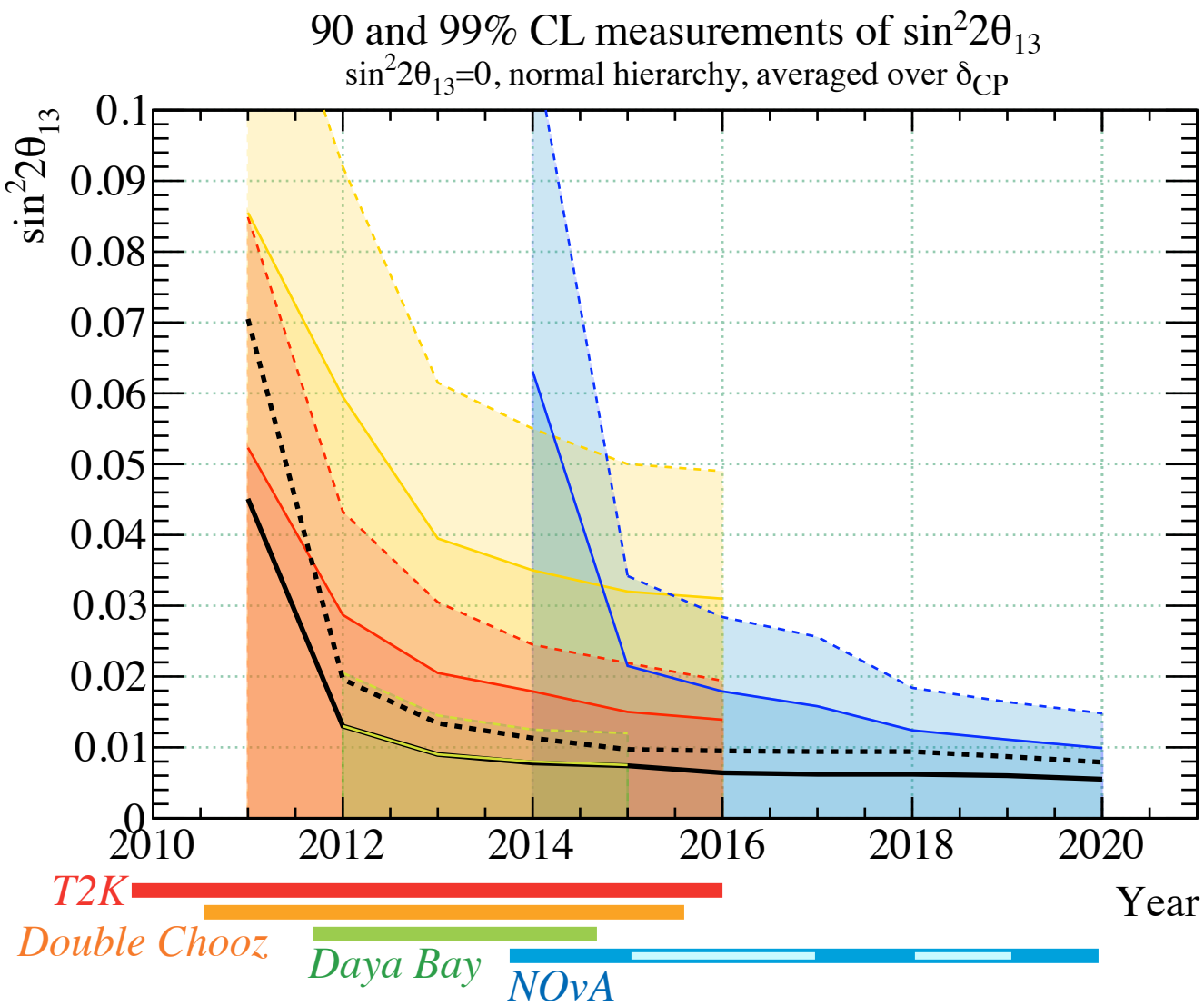


Figure 4: Hints of $\theta_{13} > 0$ from different data sets and combinations: 1σ ranges.

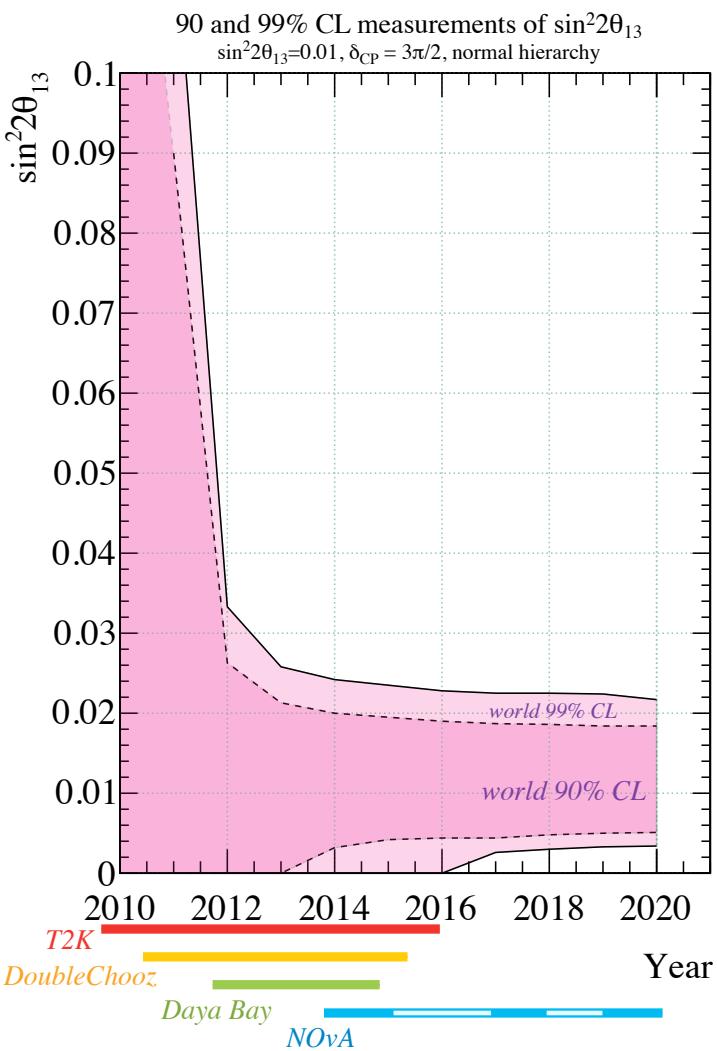
- Above: recent global fit to world data by Fogli et al. *(arXiv:0905.3549)*
- $\theta_{13} = 0$ disfavored by ~2 σ
- Central value $\sin^2\theta_{13} = 0.02$ or $\sin^2 2\theta_{13}=0.08$

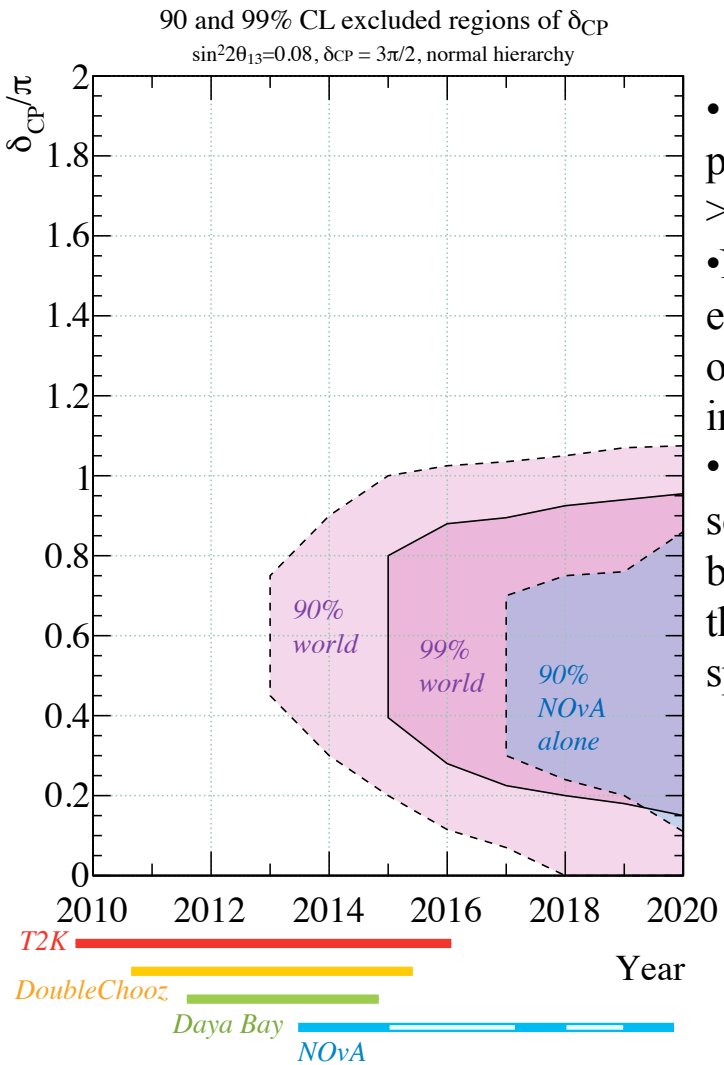
Progress toward $\theta_{13}>0$



Once Daya Bay reports (green curve), it dominates the combined sensitivity of all experiments (black curve) in the search for $\theta_{13}>0$

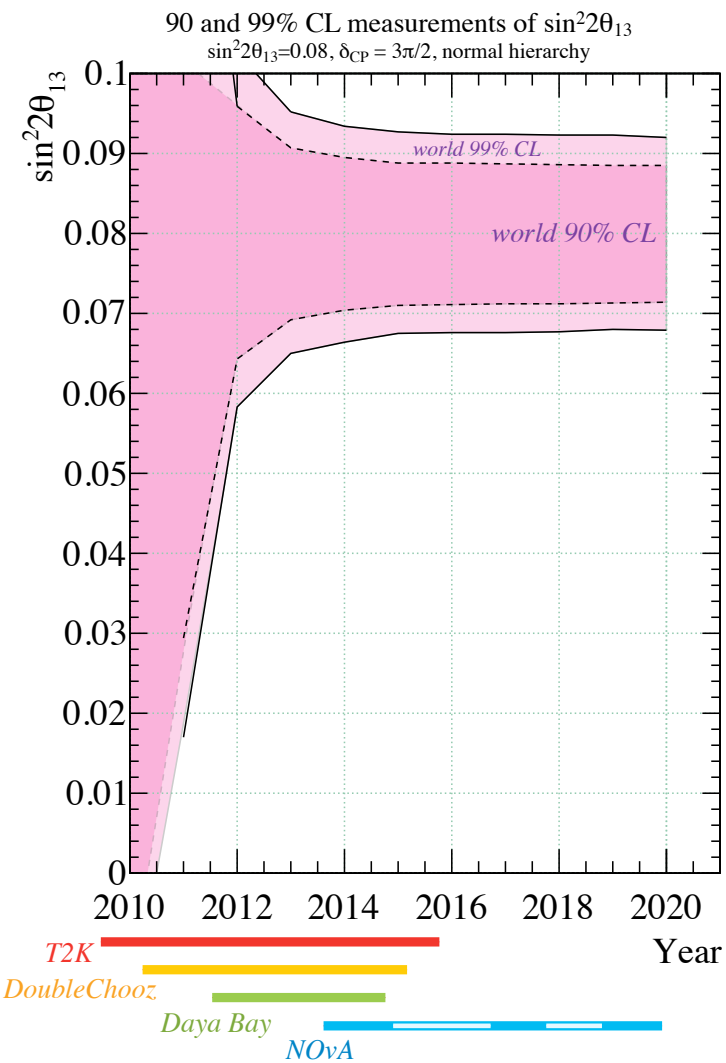
If $\sin^2 2\theta_{13}$=0.01

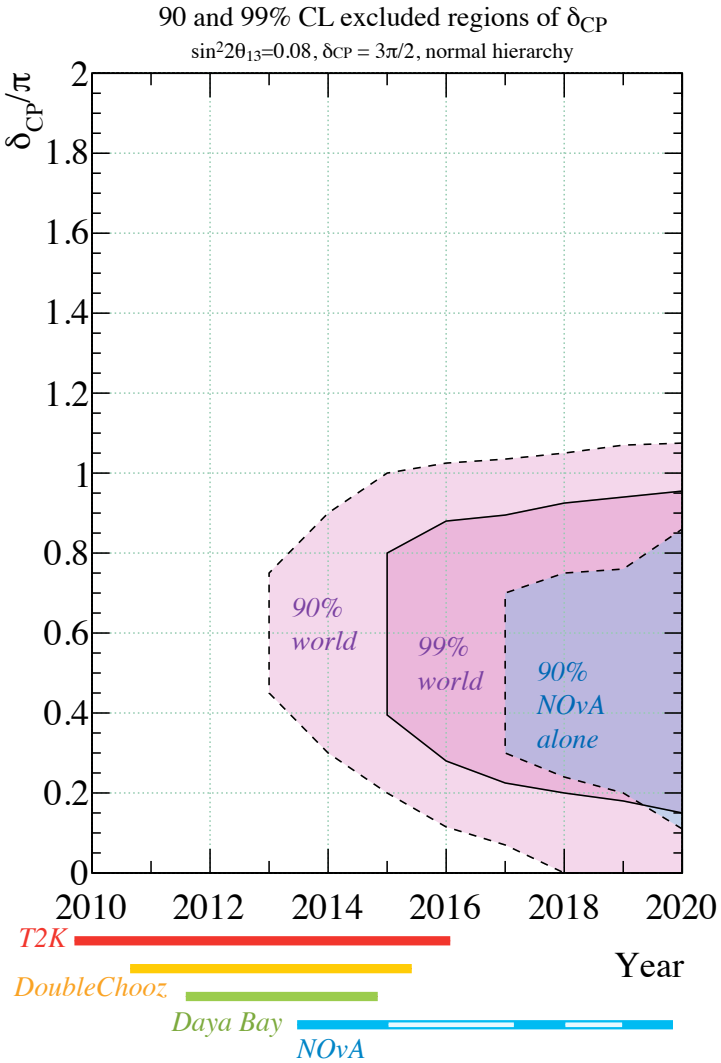




- Addition of NOvA pushes discovery past >99% CL
- NOvA is the only experiment which, on its own, provides any information about δ_{CP}
- T2K + Daya Bay have some small sensitivity, but with NOvA added this covers half the δ_{CP} space

If $\sin^2 2\theta_{13}$=0.08





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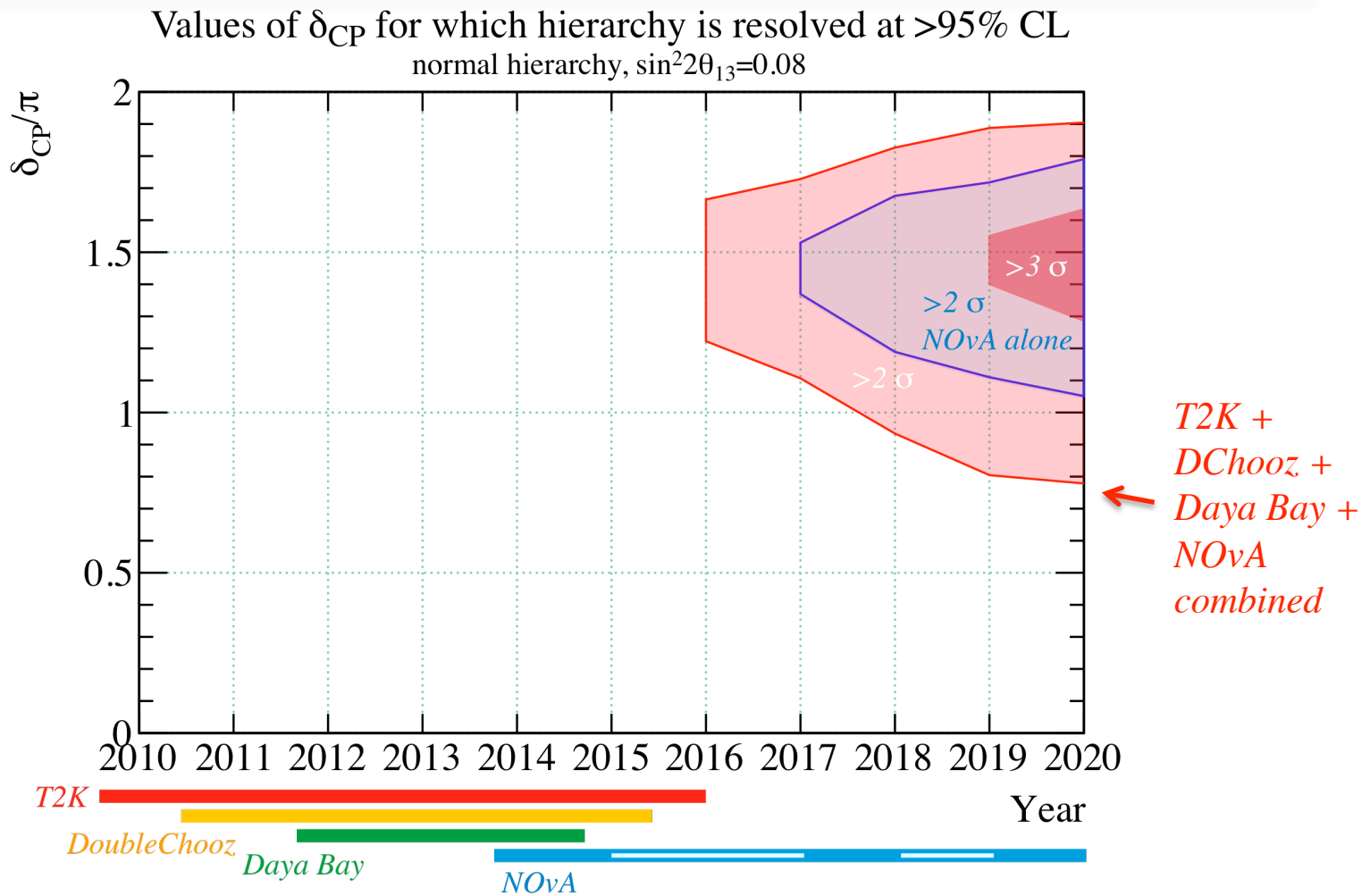
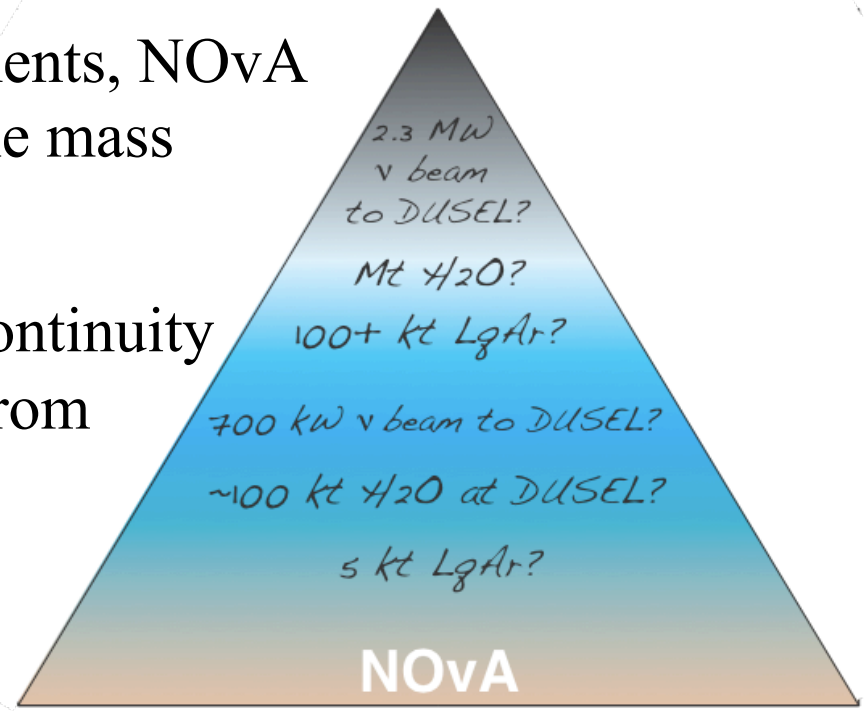
- T2K + Daya Bay have some sensitivity, but with NOvA added this covers >half the δ_{CP} space

Mass Hierarchy



- NOvA is the only experiment which, on its own, has sensitivity to hierarchy
- "World" sensitivity to mass ordering only turns when NOvA data is added
- If δ_{CP} is in "wrong" half of the plot we learn that with NOvA

NOvA is the foundation of the US accelerator neutrino program

- It addresses 7 of the 8 physics questions called out by P5 as the focus of the neutrino program over the next decade
- Among the next generation experiments, NOvA uniquely provides information on the mass hierarchy and CP phase
- NOvA provides the incentive and continuity to increase the NuMI beam power from 400 to 700 kW and ultimately to 2.3 MW
- Ensures a robust future program.