Cosmic Ray Physics with the NOνA Experiment

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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?

3) What are the relative masses of the three known neutrinos? Are they "normal," analogous to the quark sector, ($m_3>m_2>m_1$) or do they have a so-called "inverted" hierarchy ($m_2>m_1>m_3$)? Oscillation studies currently allow either ordering. The ordering has important consequences for interpreting the results of neutrinoless double beta decay experiments and for understanding the origin and pattern of masses in a more fundamental way, restricting possible theoretical models.

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?

1) NOνA searches for electron neutrino appearance down to $\sin^2 2\theta_{13}$ 0.01 at 90%

2) NOνA can rule out as much at 50% of the δ_{CP} parameter space

3) NOνA can test the mass hierarchy down to $\sin^2 2\theta_{13}$ =0.05

4) NOνA measures $\sin^2 2\theta_{23}$ to roughly 1%

5) If NOνA establishes the inverted hierarchy, then next generation of double beta decay experiments can determine if neutrinos are Dirac or Majoranna

6) NOνA will see roughly 5000 neutrinos during a supernova burst from the center of the galaxy

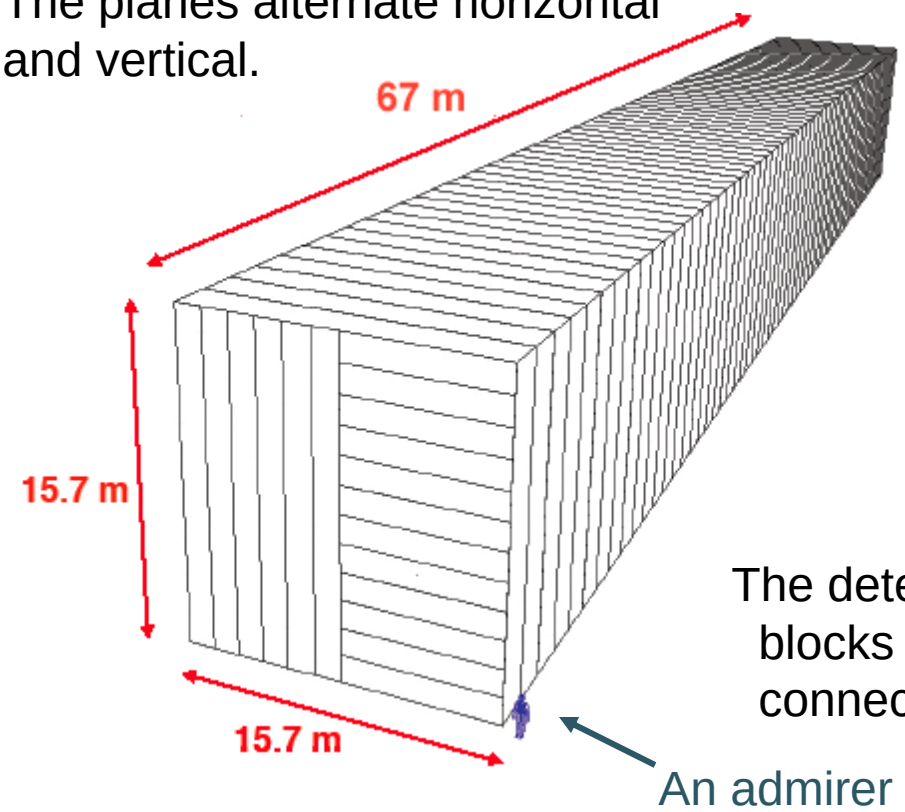
8) NOνA is twice as sensitive to the existence of sterile neutrinos than current experiments

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

Size of the NOνA Far Detector

The cells are made from 32-cell extrusions.

12 extrusion modules make up a plane. The planes alternate horizontal and vertical.

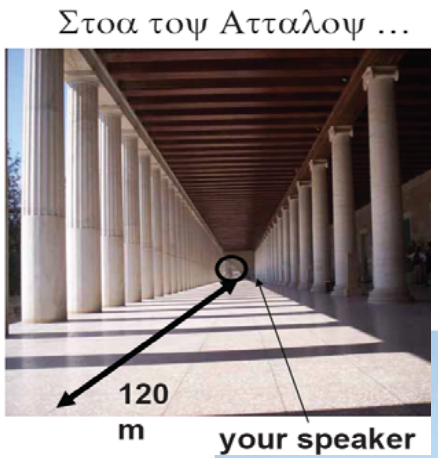


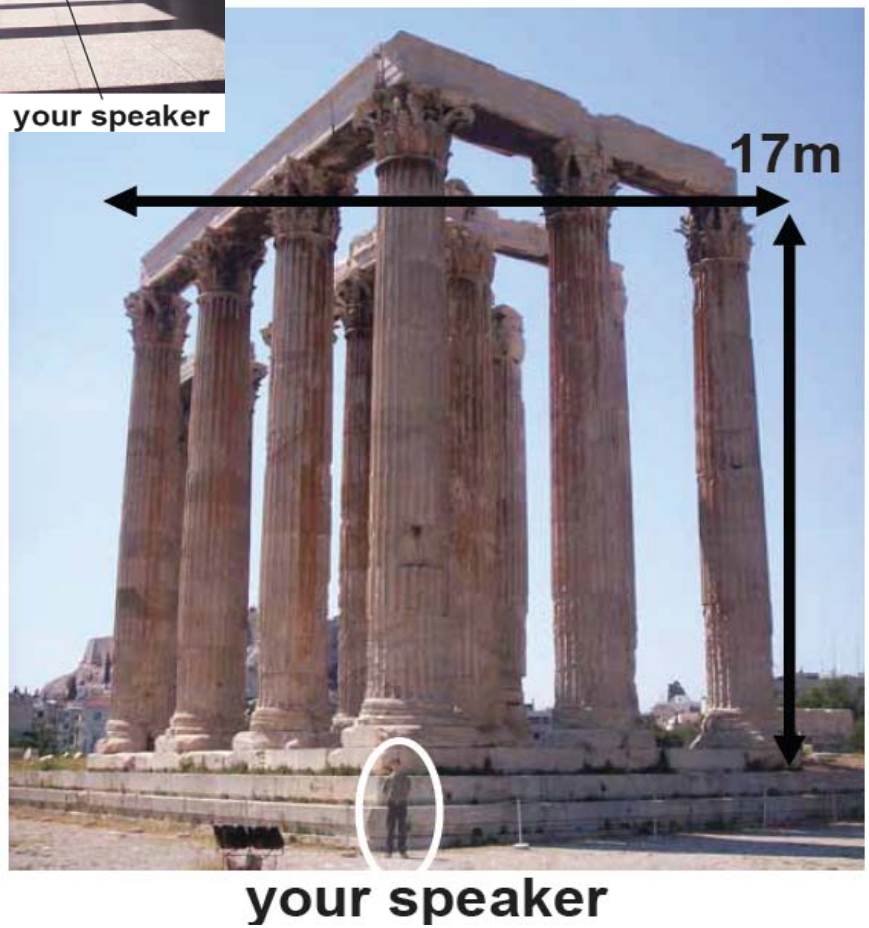
There are 1003 planes, for a total mass of 15 kT. There is enough room in the building for 18 kT, which can be built if we can preserve half of our contingency.

The detector can start taking data as soon as blocks are filled and the electronics connected.

Neutrino detectors, like NOvA, are getting very big

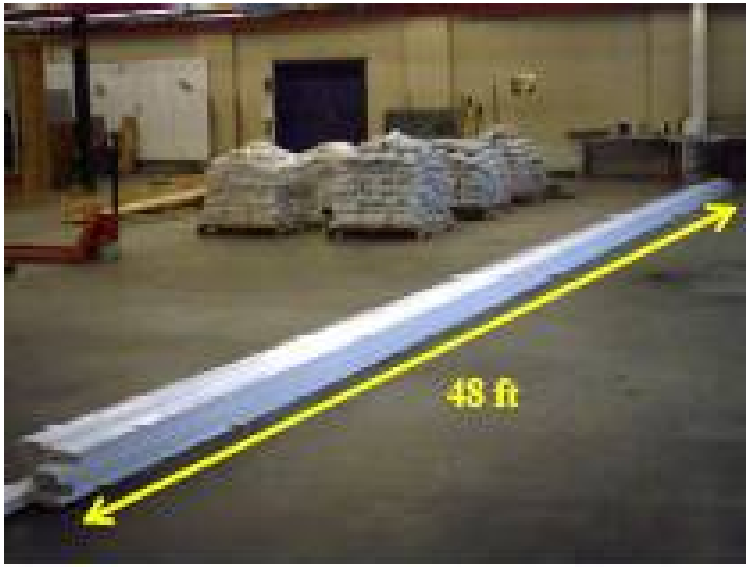
from Kevin Mcfarland - WIN meeting in Athens

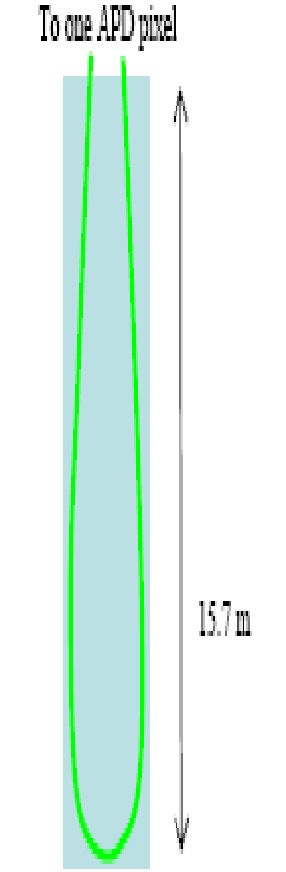


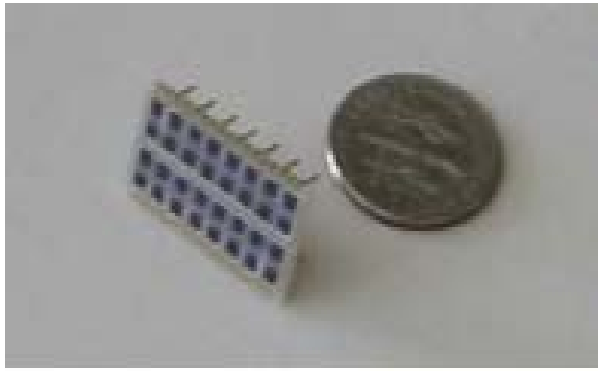


- Consider the Temple of the Olympian Zeus…
- 15.7m tall, just like NOvA!
  - a bit over ½ the length
- It took 700 years to complete
  - delayed for lack of funding for a few hundred years
- Fortunately construction technology has improved
  - has the funding situation?

NOνA Components



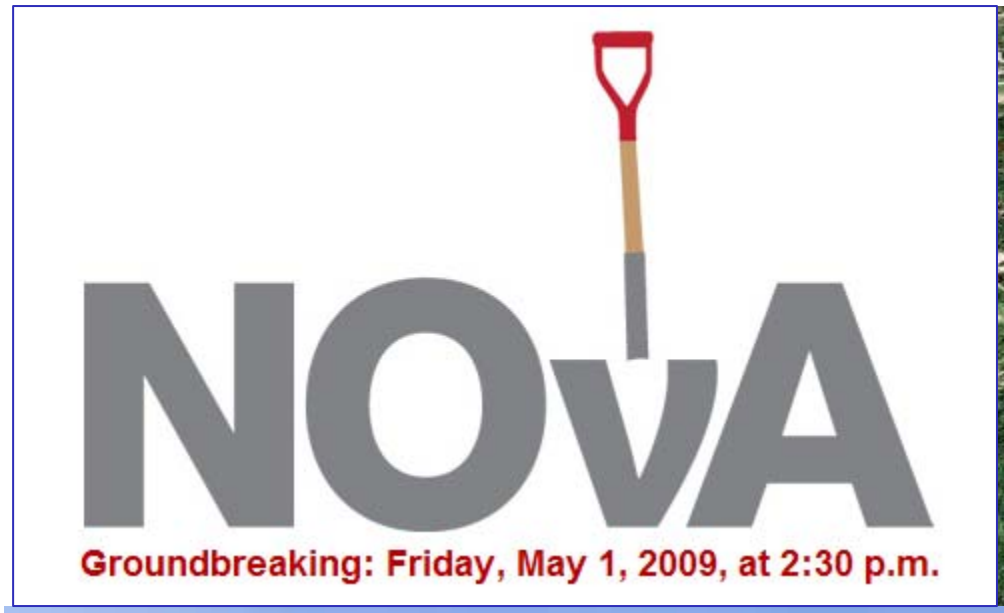




Prototype Construction 6/09

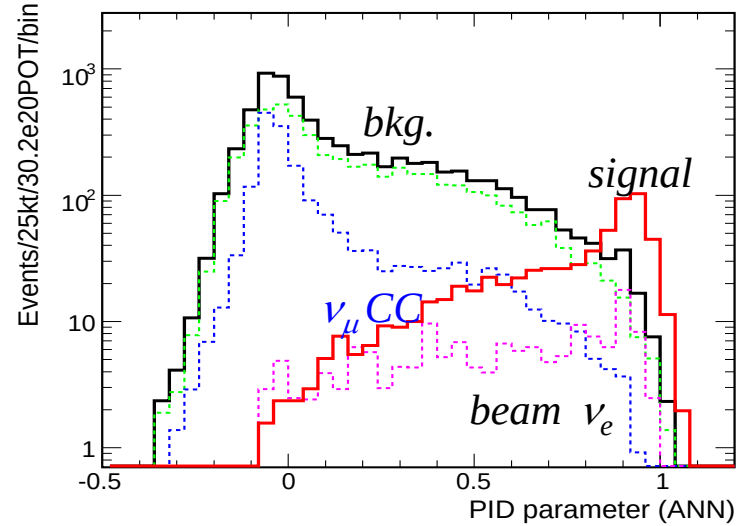
April 2009 NOνA meeting at Argonne

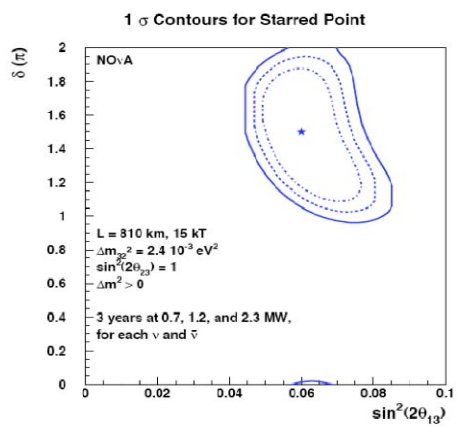
Far Site

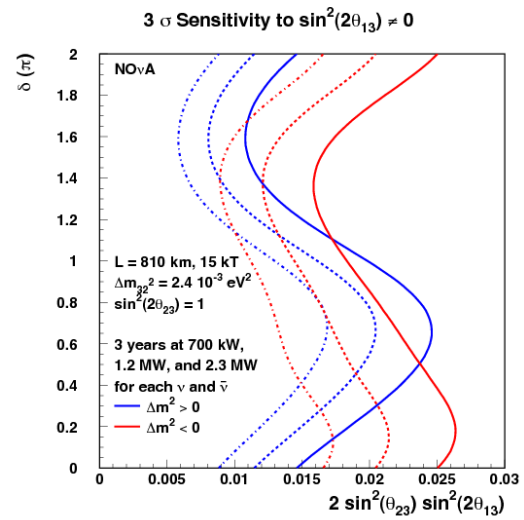


NOνA (Beam) Physics

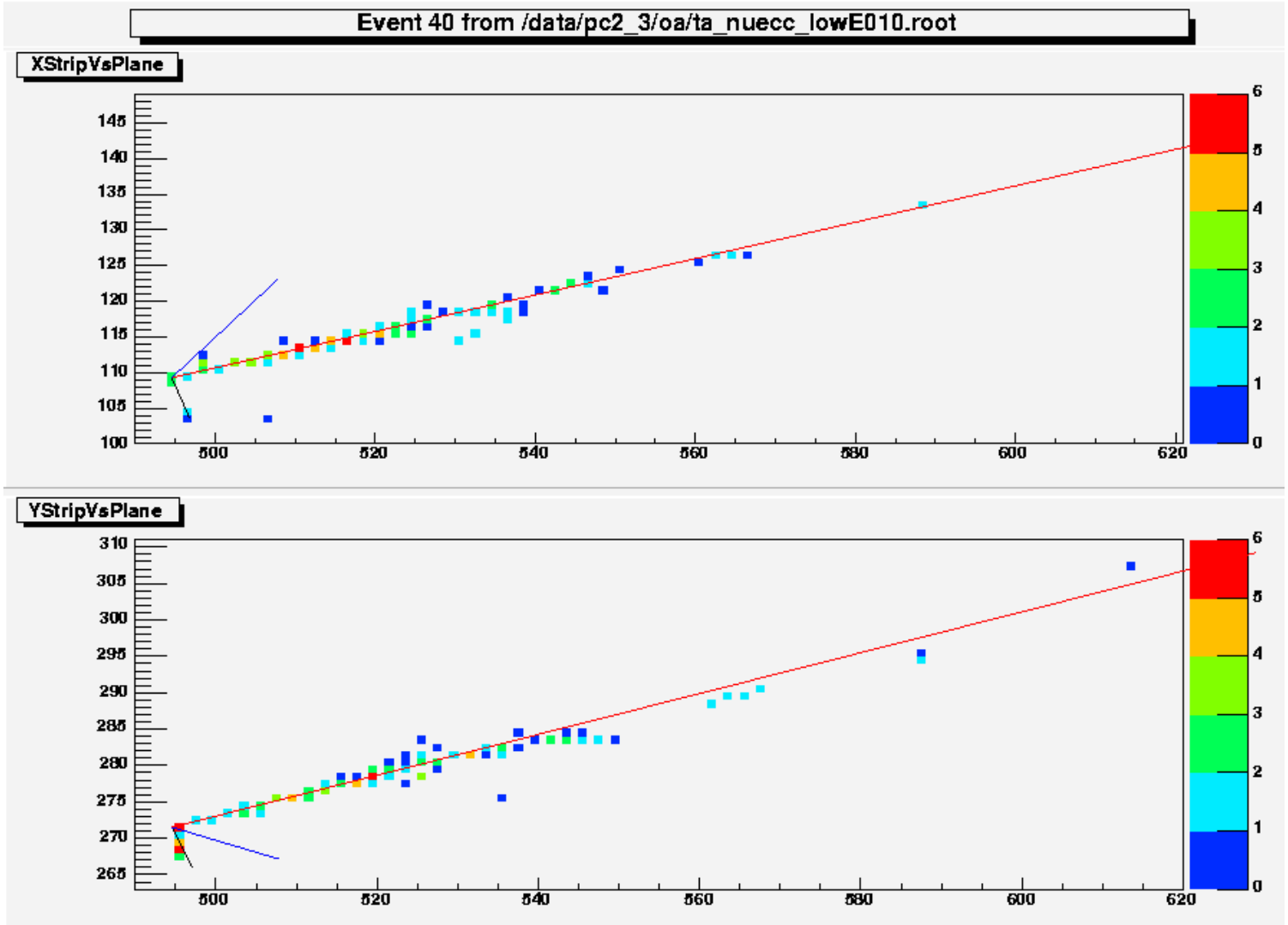
- ~20 variable Neural Net to separate the electron neutrinos from the background, mainly NC.
- Electron appearance is directly related to $\sin^2 2\theta_{13}$. Reach is close to an order of magnitude better than the current limit.
- If this parameter is within reach of NOvA then we will be able to resolve the mass hierarchy by running neutrinos and anti-neutrinos.
- Other NOvA goals include $\sin^2 2\theta_{23}$ by measuring muon neutrino disappearance and a CP violation measurement.







Simulated NOνA ν_e CC event

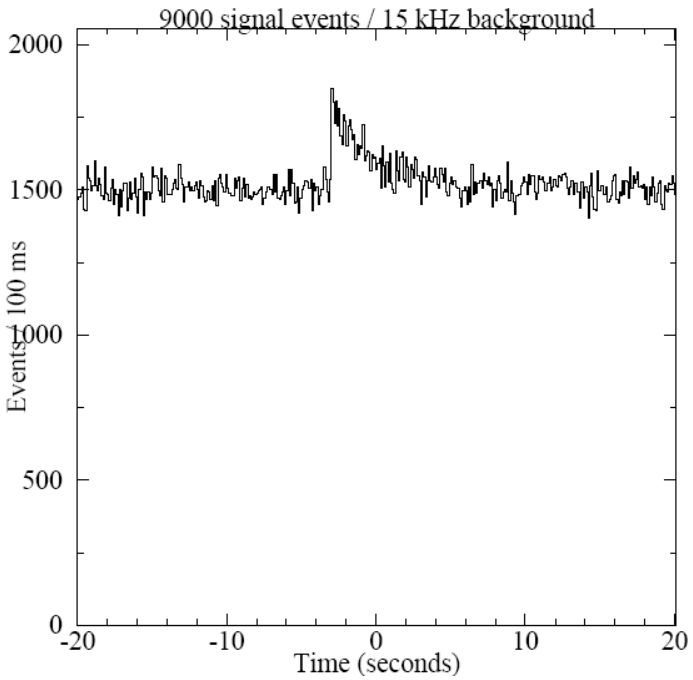


Cosmic Ray Capabilities

- Supernova ν
- Upward going atmospheric ν
- Multiple Muons
- Single and multiple hadrons in EAS and their correlations
- Horizontal μ from ν interactions deep in the atmosphere
- Fluctuations in air shower components
- Coincidences with an air shower array (not yet planned)

Supernovae & NOνA

- Could see increase in singles rate
- About half of the events are in the detectable energy range (20-40 MeV)
- Backgrounds
  - Radioactive dominates below 5 MeV; small 20-40 MeV
  - 100 Hz μ, should be easy
  - 25 Hz Michel e, may be tagged
  - Muon capture ^{12}B decay rate small above 20 MeV
- Could also use coincidence to see ν_e and anti-ν_e C



NOνA Detector Parameters

	Integration Prototype Near Detector (IPND)	Near Detector	Far Detector
Mass (metric tons)	84	222	15,000
Active Detector Size (width, height, length) in meters	(2.8, 4.1, 8.4)	(2.8, 4.1, 14.3)	(15.6, 15.6, 66.9)
Liquid scintillator required (gallons)	18,700	30,000	3,210,000
Number of 32 cell extrusion modules required	310	496	12,036
Number of extrusion modules seen by beam (horizontal by vertical)	3 by 2	3 by 2	12 by 12
Number of detector channels	9,892	15,904	385,152