NOvA

The NuMI Off-axis Neutrino Appearance Experiment

An international collaboration

Elisabeth Irina Pienpen Alberto Luis Ozan


NOvA Far Detector
MINOS Far Detector
Ontario
Minnesota
Wisconsin
Iowa
Milwaukee
Michigan
Fermilab
Chicago
© 2007 Europa Technologies
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168 km
Pointer 43°34'32.84" N 89°04'55.60" W elev 271 m
Streaming 100%
Eye alt 545.86 km

Neutrino oscillations

- Predicted by B. Pontecorvo in late 50s. Observed by the Homestake experiment in late 60s.

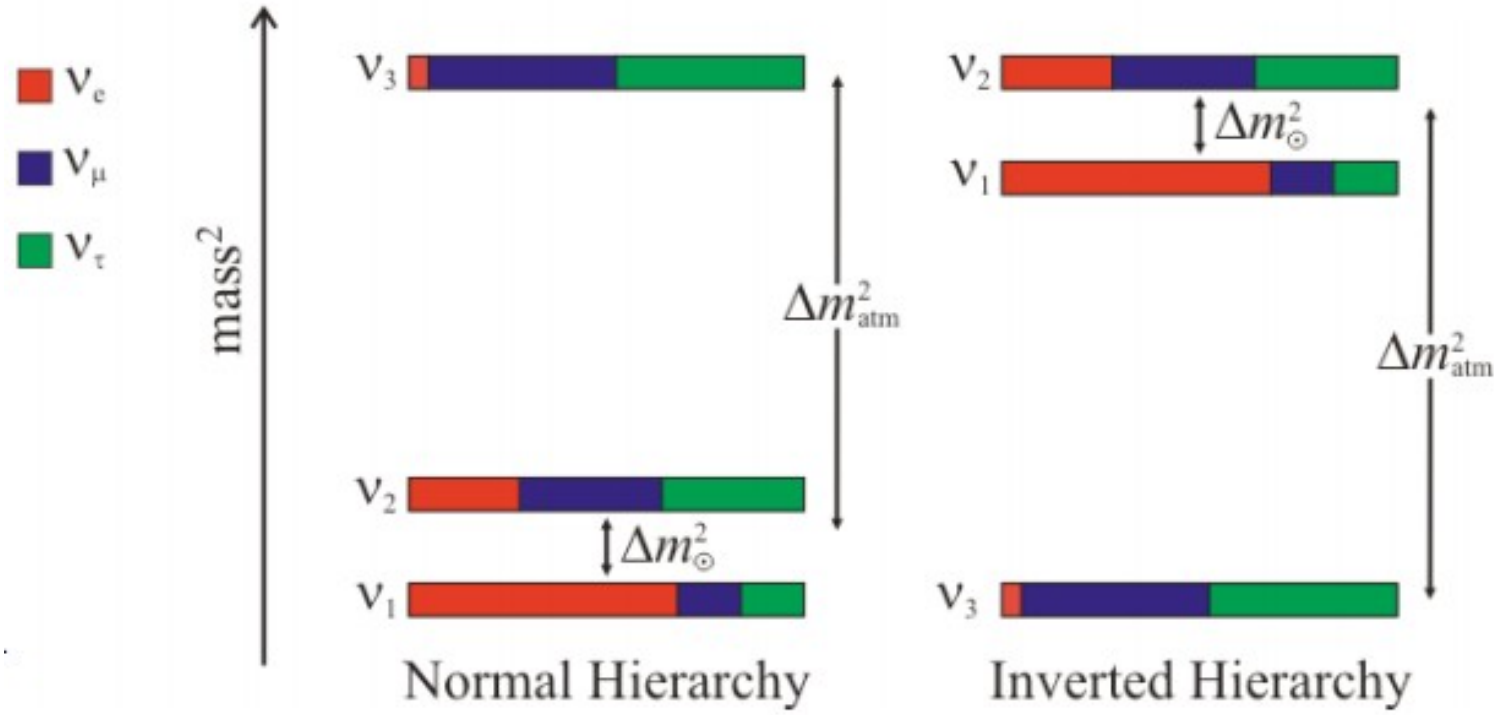
$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & -c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

- **SM**: ν (anti-ν) is massless and left (right) -handed
  - **Dirac**: need right-handed ν, vanishing coupling with gauge weak bosons (sterile neutrinos).
  - **Majorana**: violates the weak symmetry of the Lagrangian.
- In any case → need New Physics!

Mass hierarchy and CP-violation

- (Dis-)appearance probability given by PMNS matrix:

$$P_{\alpha\to\beta} = \delta_{\alpha\beta} - 4\sum_{i>j} Re(U^*_{\alpha i}U_{\beta i}U_{\alpha j}U^*_{\beta j})\sin^2\left(\frac{\Delta m^2_{ij}L}{4E}\right) + 2\sum_{i>j} Im(U^*_{\alpha i}U_{\beta i}U_{\alpha j}U^*_{\beta j})\sin\left(\frac{\Delta m^2_{ij}L}{2E}\right)$$



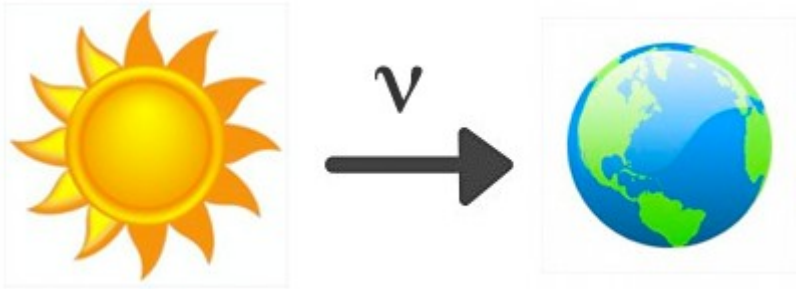
Open issues in ν-physics

- Dirac or Majorana
- Absolute scale of m(ν)
- Hierarchy (normal or inverted)
- Number of light neutrino families
- CP violation in lepton sector
- How do neutrinos fit into a picture of a GUT

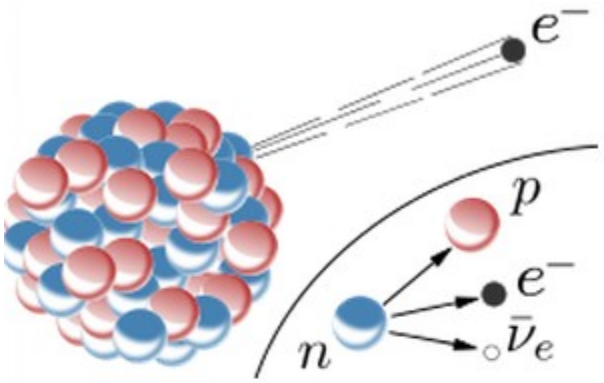
- NOνA will try to answer them!

Natural neutrino sources

- Supernovae
- Nuclear fusion powering the Sun



- Atmospheric: cosmic rays interacting with atomic nuclei in the atmosphere.
- Geologic: β decay of heavy nuclei.

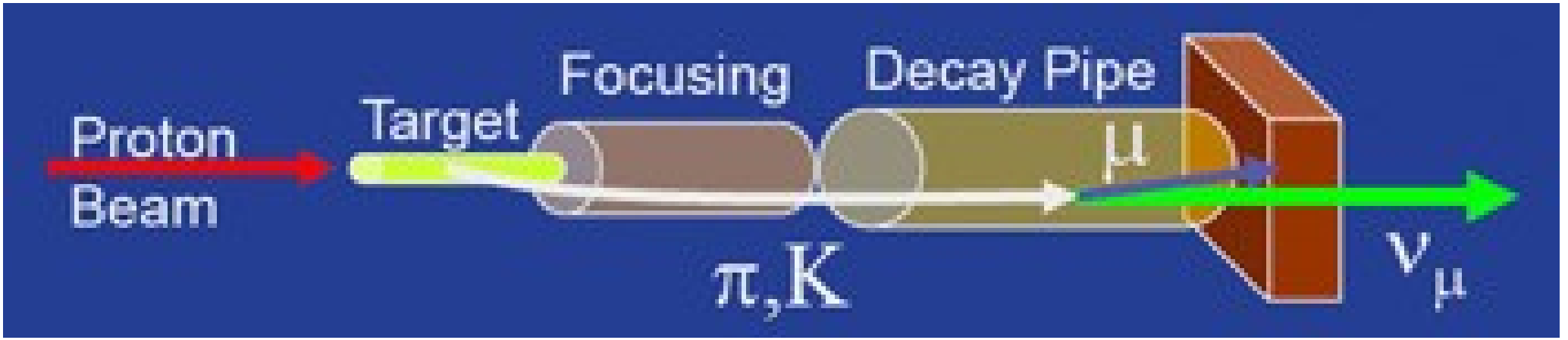


- Big Bang: Cosmic Neutrino Background (1.95 K).

Artificial neutrino sources

- Reactor: beta decay from reaction by-products.

- Accelerator: smash protons into a fixed target, choose the reaction products.



Classification of neutrino experiments

- Disappearance: attenuation of a ν beam primarily composed of a single flavor.
  - It is the only possible approach for low energy ν_e (solar or reactor neutrinos)
  - **1st evidence** of ν–oscillation, in **1998 at SuperKamiokande**, with atmospheric ν
- Appearance: search for interaction of neutrinos not present in original beam.
  - Typical examples of this approach are experiments with accelerators producing ν_μ beams
- Short baseline experiments: typically defined as L less than a few km, or E/L ~ 1
- Long baseline experiments: For experiments using accelerator ν as the source, the long-baseline means

$$E/L \approx \Delta m^2 \sim 2.5 \times 10^{-3}\ eV^2$$

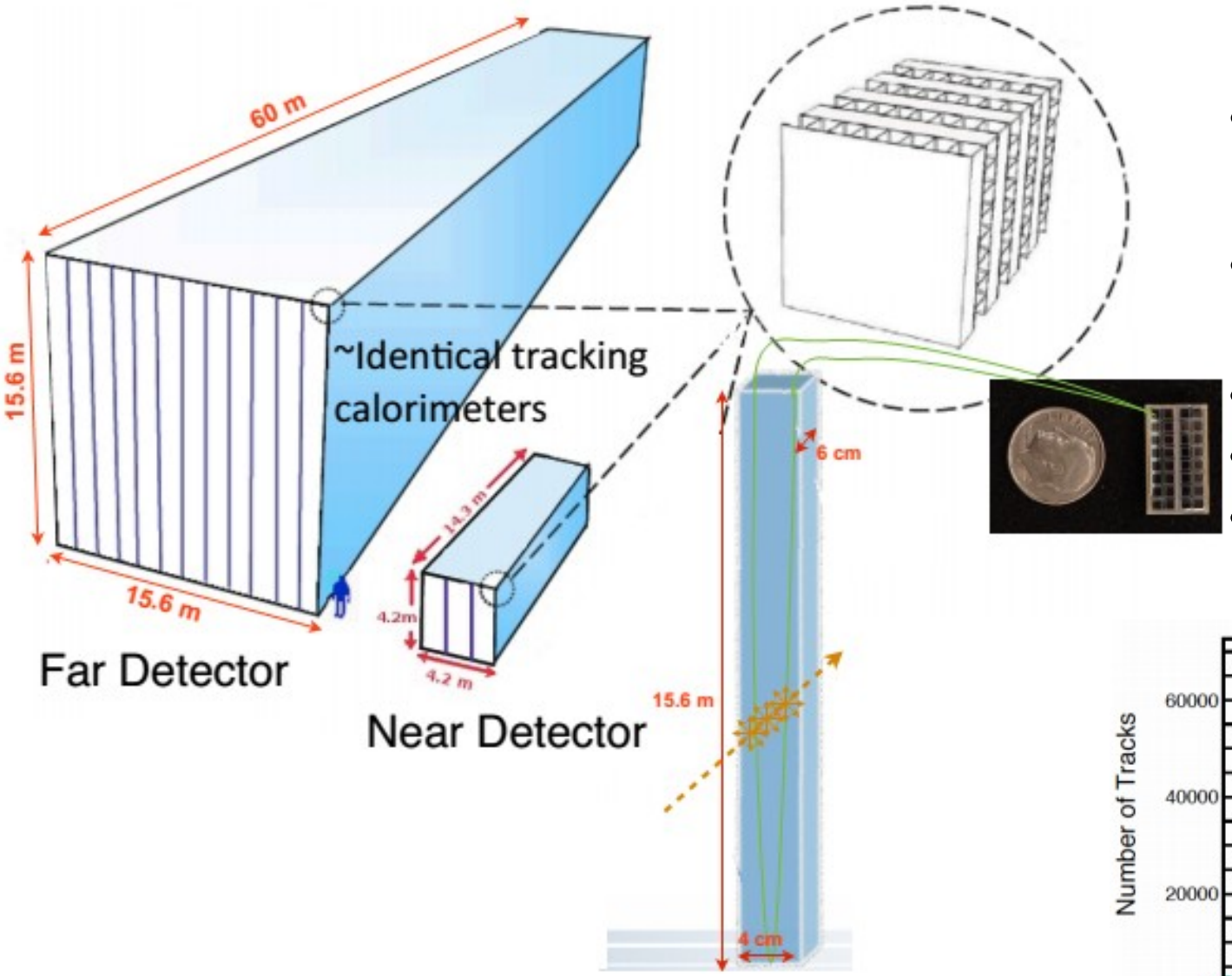
Neutrino oscillations landscape*

Parameter	Value (best fit ± 1σ)	Experiment
Δm^2_{21}	$(7.5 \pm 0.2) 10^{-5}$ eV^2	KamLAND
$\sin^2 2\theta_{12}$	0.857 ± 0.024	SNO
$\lvert\Delta m^2_{32}\rvert$	$(2.4 \pm 0.1) 10^{-3}$ eV^2	MINOS
$\sin^2 2\theta_{23}$	>0.95	SK atm + LBL
$\sin^2 2\theta_{13}$	0.095 ± 0.010	Reactor Experiments

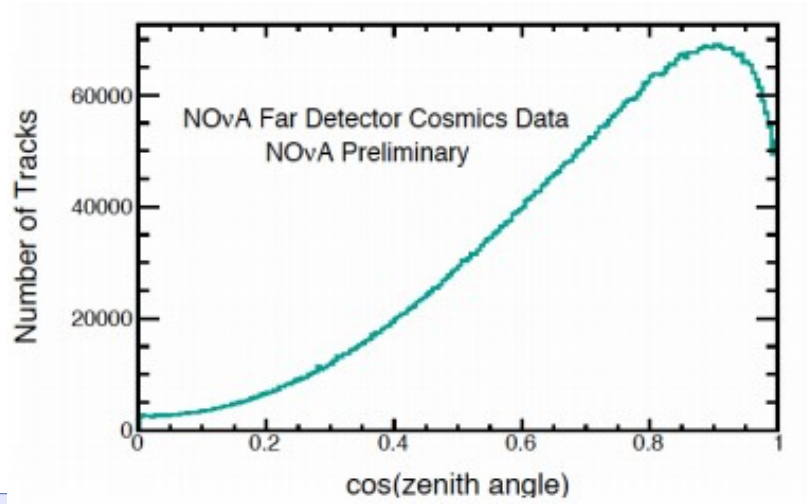
Still room for improvement on this measurements and still to be determined: δ_{CP} , θ_{23} octant, mass hierarchy...

* many experimental results available, only recent and most precise results listed

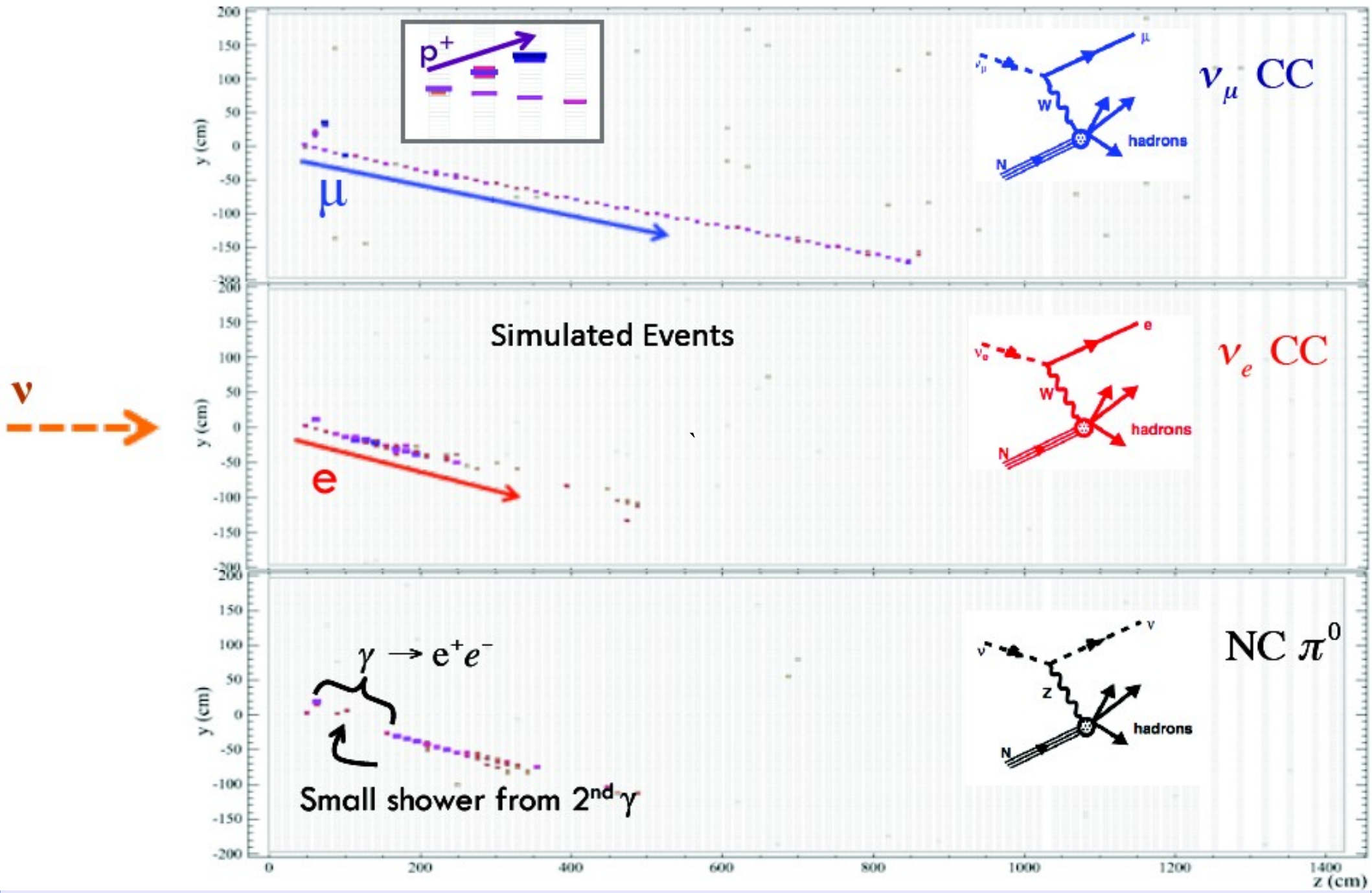
The NOvA Detectors



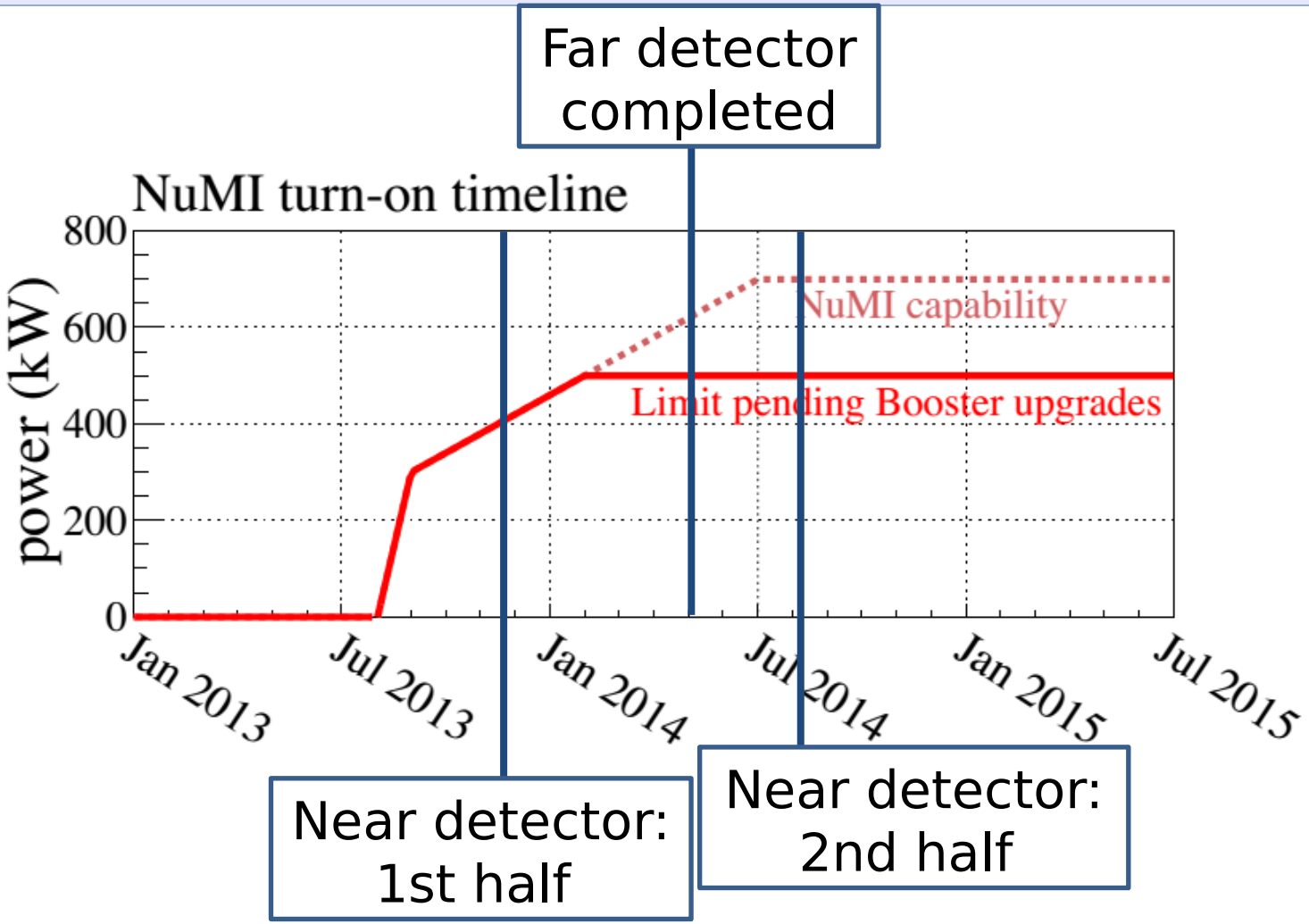
- Totally active detectors!
- (222+14000)t of liquid scintillator
- Avalanche photo diode read-out
- Low costs
- High efficiency
- First tests show convincing results

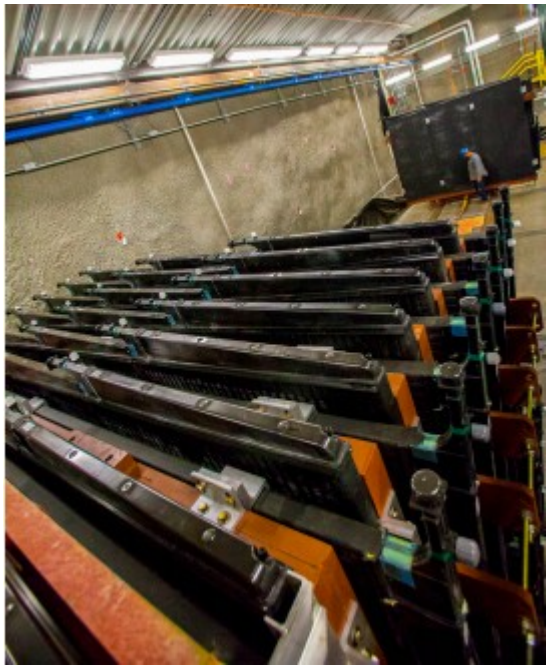


Event signature



Construction Timeline

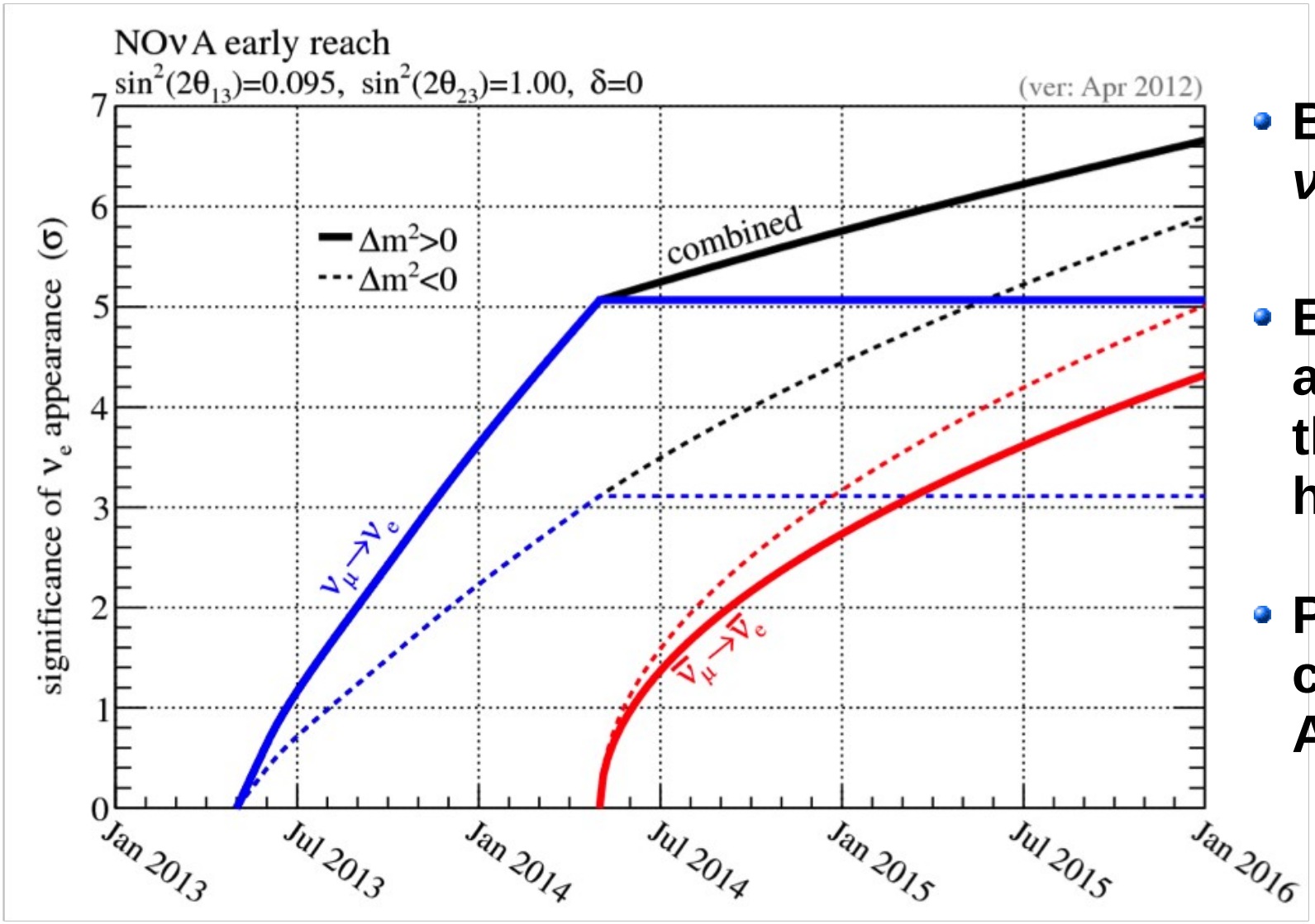




- Detectors under construction
- Completed in summer 2014

NOνA Goals

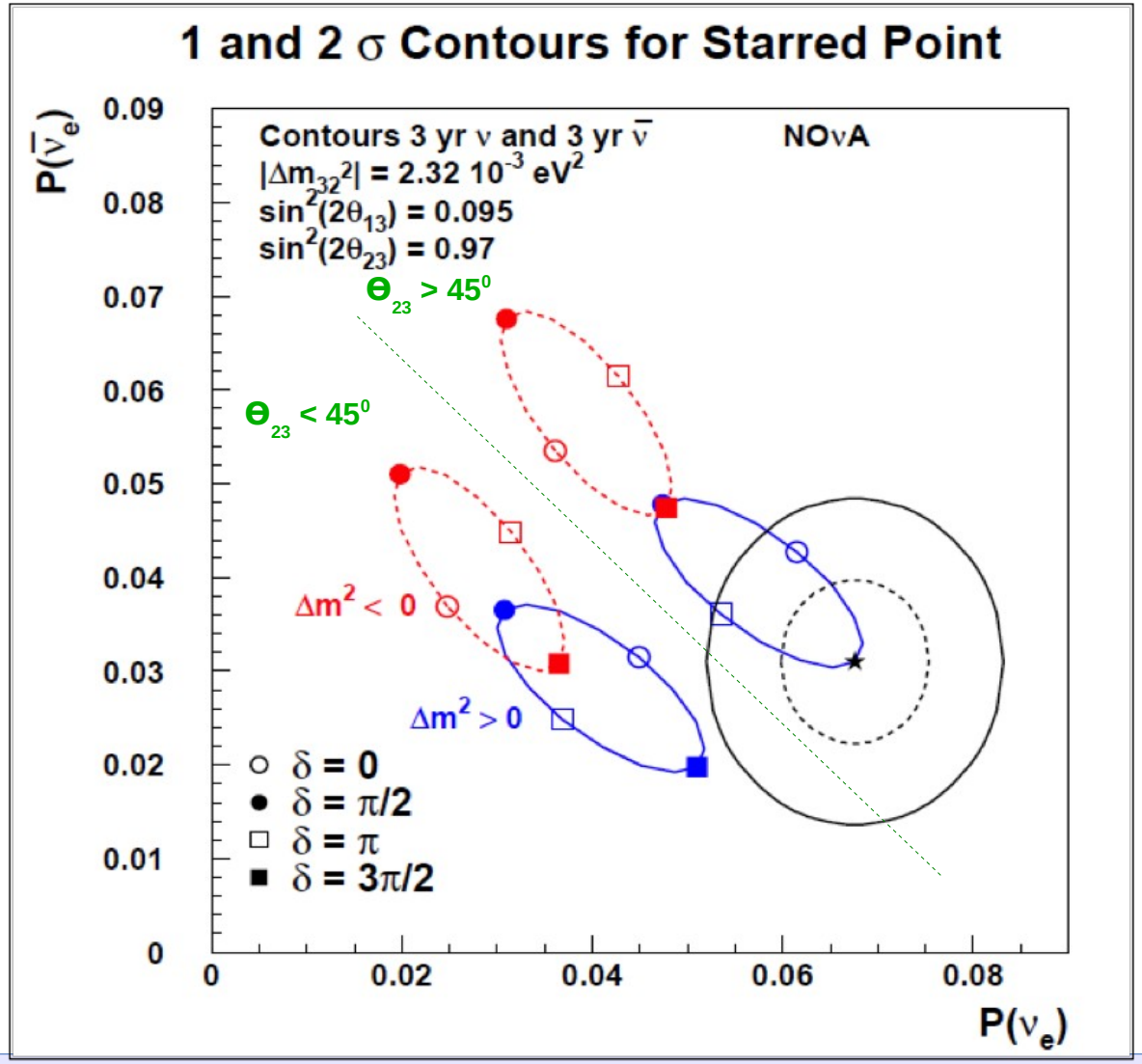
1. Measurement of θ_{13}



- By observing $\nu_\mu \rightarrow \nu_e$ oscillation
- Expect 5σ with an assumption of the normal mass hierarchy
- Possible to also combine with Anti-ν mode

NOνA Goals

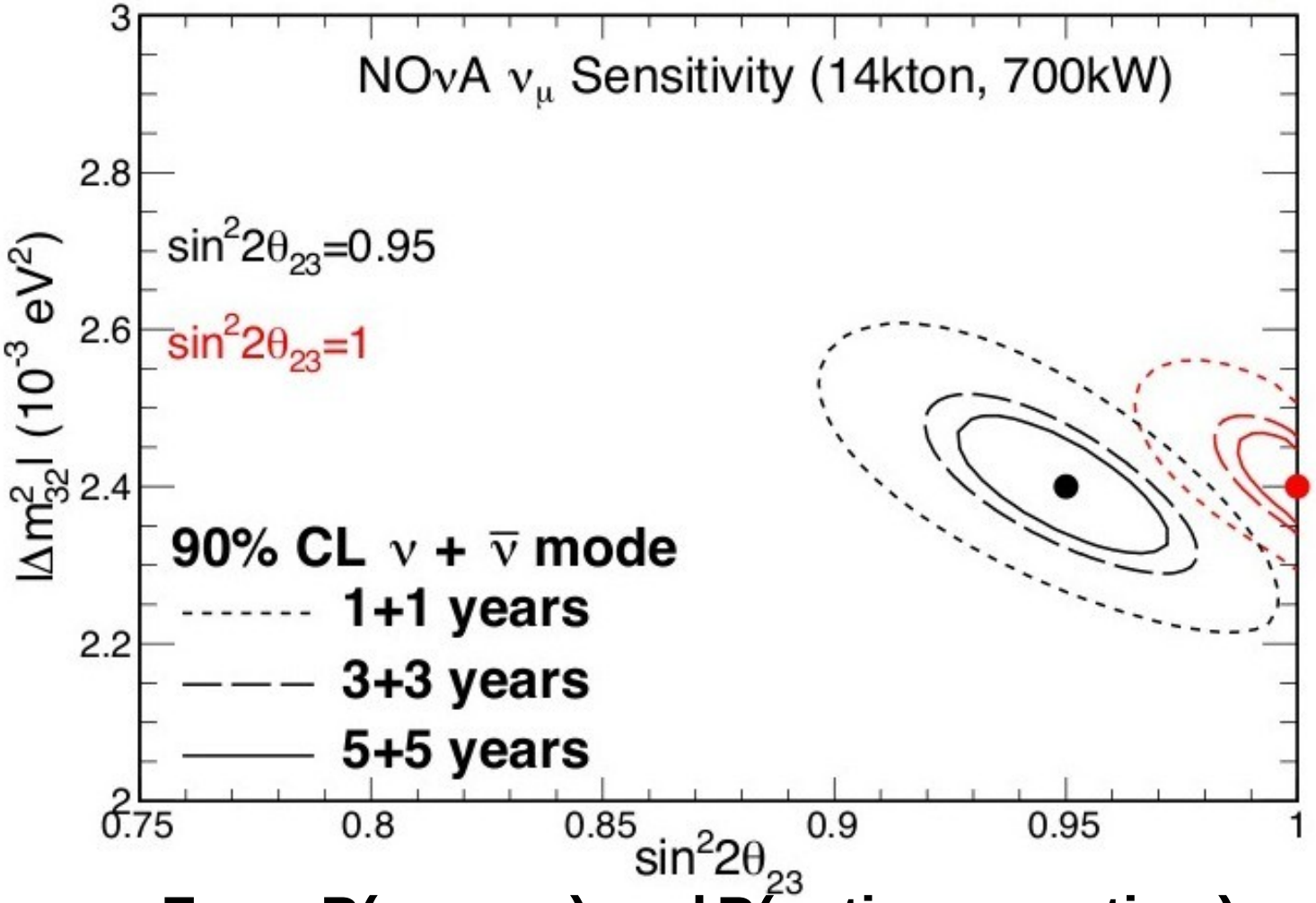
2. Information on the ν mass hierarchy and CP violating phase



- Compare $P(\nu_\mu \rightarrow \nu_e)$ to $P(\text{anti-}\nu_\mu \rightarrow \text{anti-}\nu_e)$
  - → $\Delta m^2 > 0$ or $\Delta m^2 < 0$
  - → δ_{CP}
  - → Isolate the sign of Θ_{23}

NOνA Goals

3) Precise measurements of $\sin^2(2\theta_{23})$



- From P($\nu_\mu \rightarrow \nu_\mu$) and P(anti-$\nu_\mu \rightarrow$ anti-ν_μ)

→ measure the $\sin^2(2\theta_{23})$ and determine the θ_{23} octant

Schedule

- Commissioning far detector since March 2013
- First kiloton instrumented on May 2013
- Near detector hall complete, installation to begin in July
- First beam in June 2013
- Finish module assembly and installation by early 2014
- Fully instrumented in summer 2014

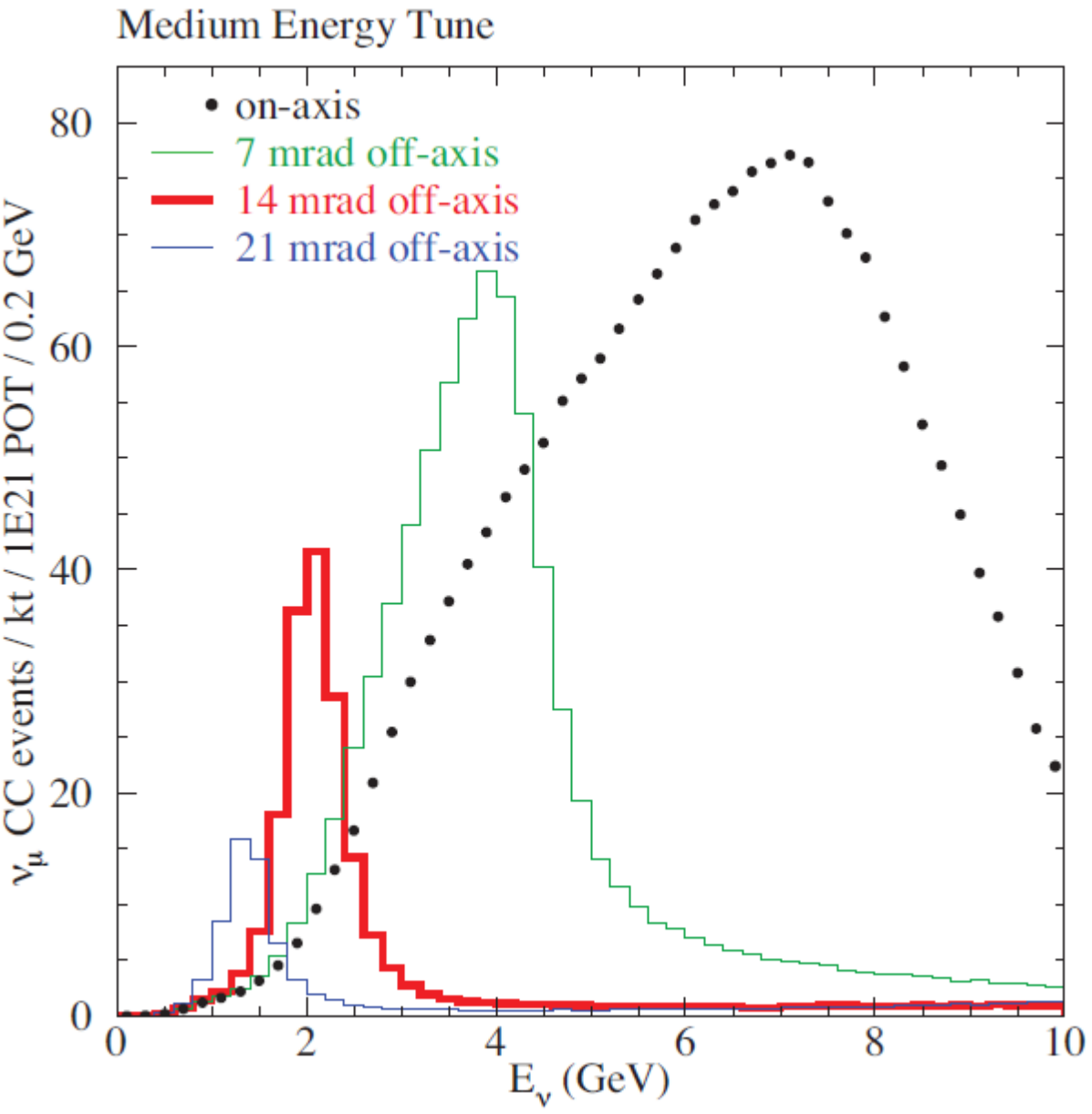
Prospects & outlook

- Collaboration with more than 180 members.
- Experiment fully operational on summer 2014.
- Promising and complete physics program, answer many fundamental questions.
- Plan 6 years of operation → significant physics results to be expected!.
- Support needed:
  - Finish construction.
  - Operation.
  - Man-power!

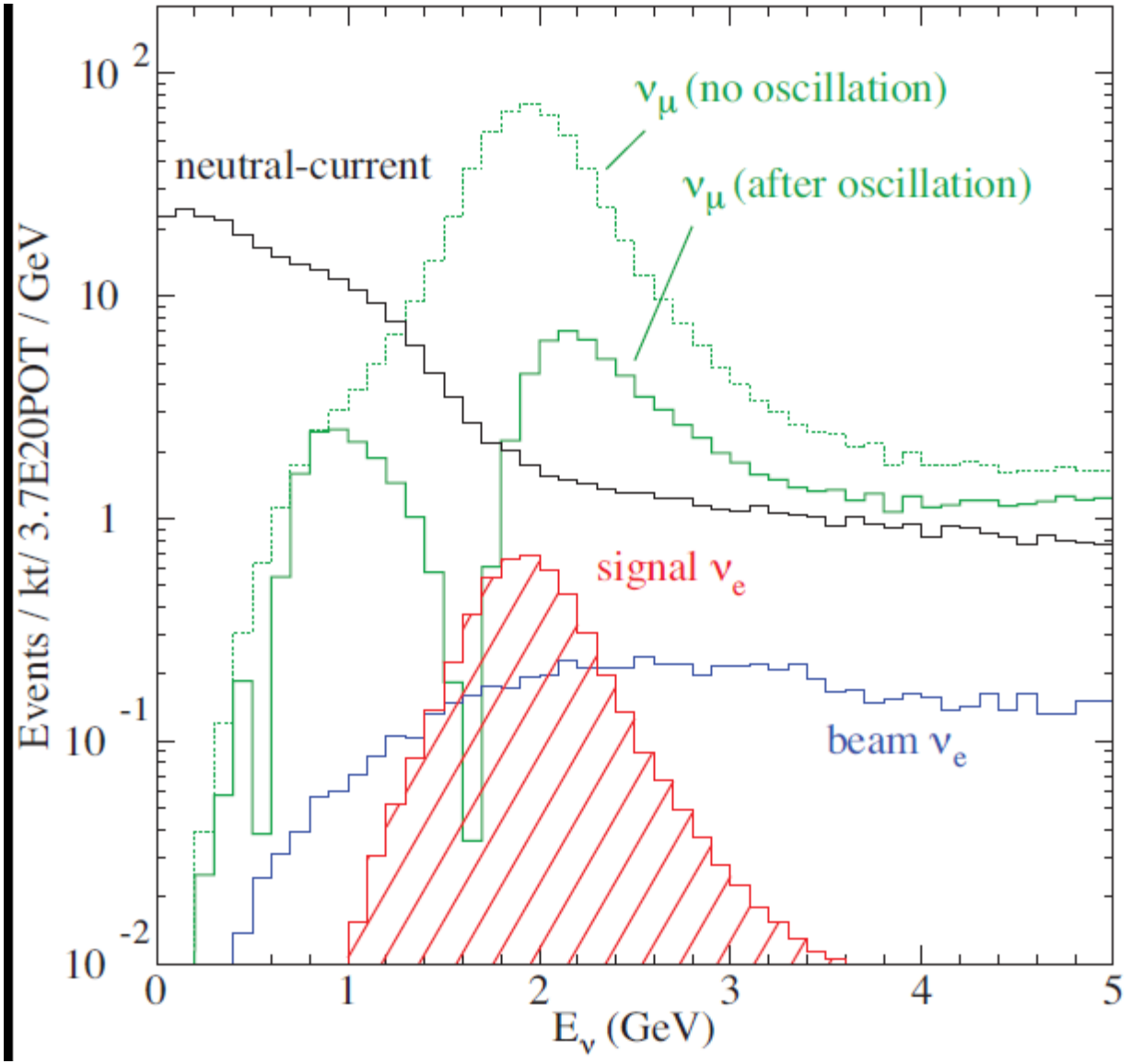
References

- June 2013 Fermilab Users Meeting 2013 Martin Frank The NOvA Experiment
- June 2013 Fermilab Users Meeting 2013 Satish Desai (poster) Status of the NOvA Experiment
- May 2013 WIPAC in Madison Wisconsin Xinchun Tian The NuMI Off-axis NuE Appearance Experiment

Backup


Medium Energy Tune
on-axis
7 mrad off-axis
14 mrad off-axis
21 mrad off-axis
ν_μ CC events / kt / 1E21 POT / 0.2 GeV
E_ν (GeV)
0
20
40
60
80
0
2
4
6
8
10

Backup


Events / kt/ 3.7E20POT / GeV
10^{2}
10
1
10^{-1}
10^{-2}
0
1
2
3
4
5
E_ν (GeV)
neutral-current
ν_μ (no oscillation)
ν_μ (after oscillation)
signal ν_e
beam ν_e