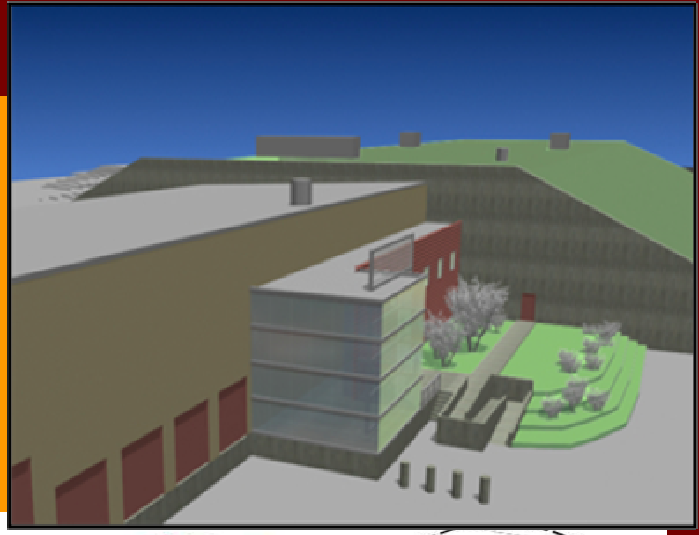
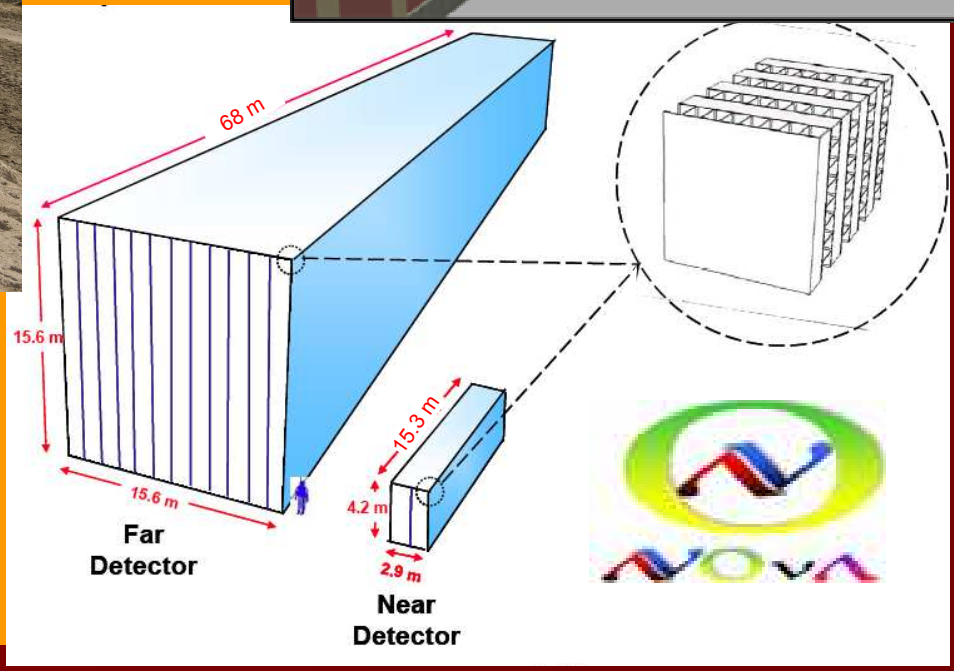


NOvA: θ_{13} & Beyond



Kregg Arms – University of Minnesota

10th Conference on the Intersections of Particle and Nuclear Physics

May 30, 2009

NOνA Long-Baseline Concept

- NOνA is designed to measure ν_e appearance at high precision
- Improve ν_μ disappearance measurement (Δm^2_{23} & $\sin^2 2\theta_{23}$)
- Sensitivity to neutrino mass hierarchy
- If ν_e appearance parameters ($\sin^2\theta_{13}$) large enough, find CP violation

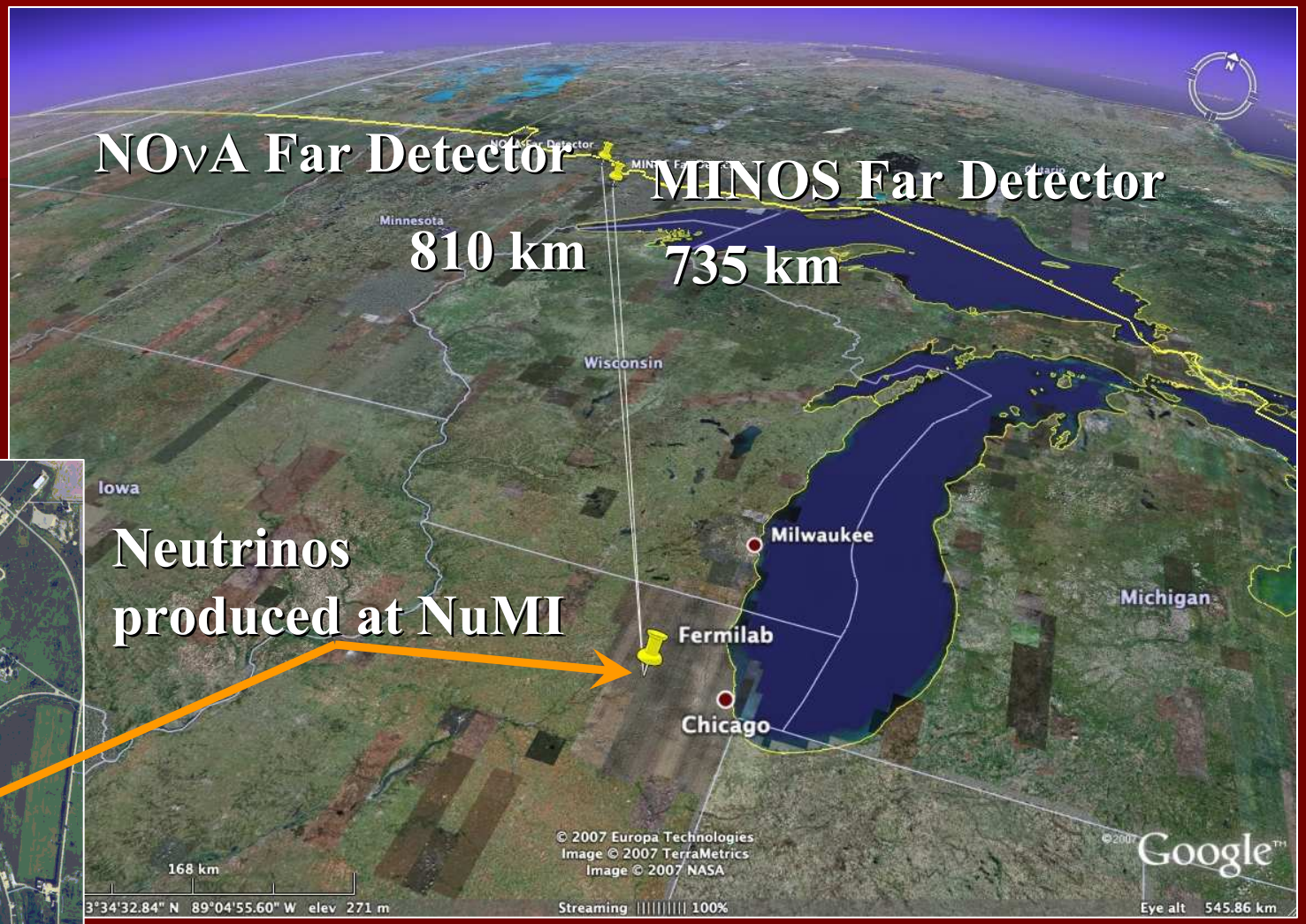
- To accomplish these goals, NOνA:
  - Will have more intense neutrino beam (275 kW → 700 kW)
  - Off-axis → lower backgrounds
  - Long baseline (810 km) at Ash River, MN (Voyaguers Nat'l Park)
  - 73% "active" detector
  - 15 kt total mass

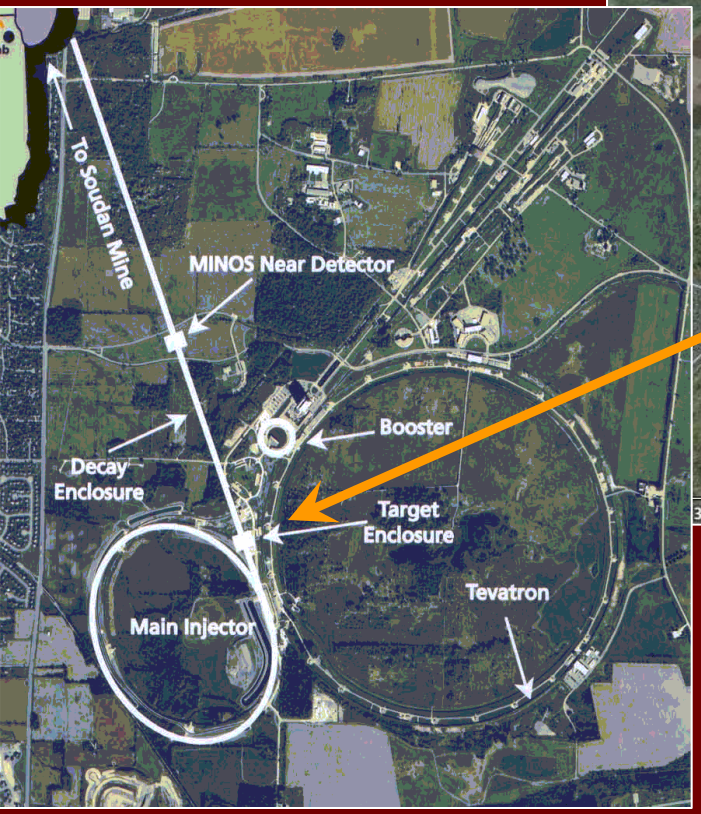
NOvA Collaboration

180+ Scientists/Engineers from 29 Institutions

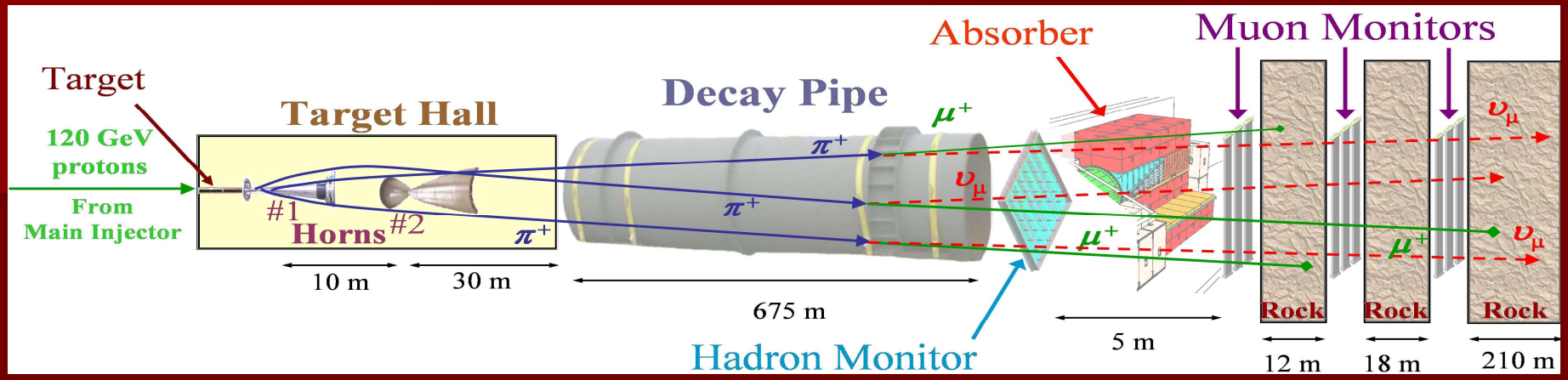
Argonne National Laboratory ● University of Athens ● California Institute of Technology ● University of California, Los Angeles ● Fermi National Accelerator Laboratory ● College de France ● Harvard University ● Indiana University ● Lebedev Physical Institute ● Michigan State University ● University of Minnesota, Duluth ● University of Minnesota, Minneapolis ● The Institute for Nuclear Research, Moscow ● Technische Universität München, Munich ● State University of New York, Stony Brook ● Northern Illinois University, DeKalb ● Northwestern University ● Ohio State University, Columbus ● Pontifícia Universidade Católica do Rio de Janeiro ● University of South Carolina, Columbia ● Southern Methodist University ● Stanford University ● 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

Neutrinos to Minnesota

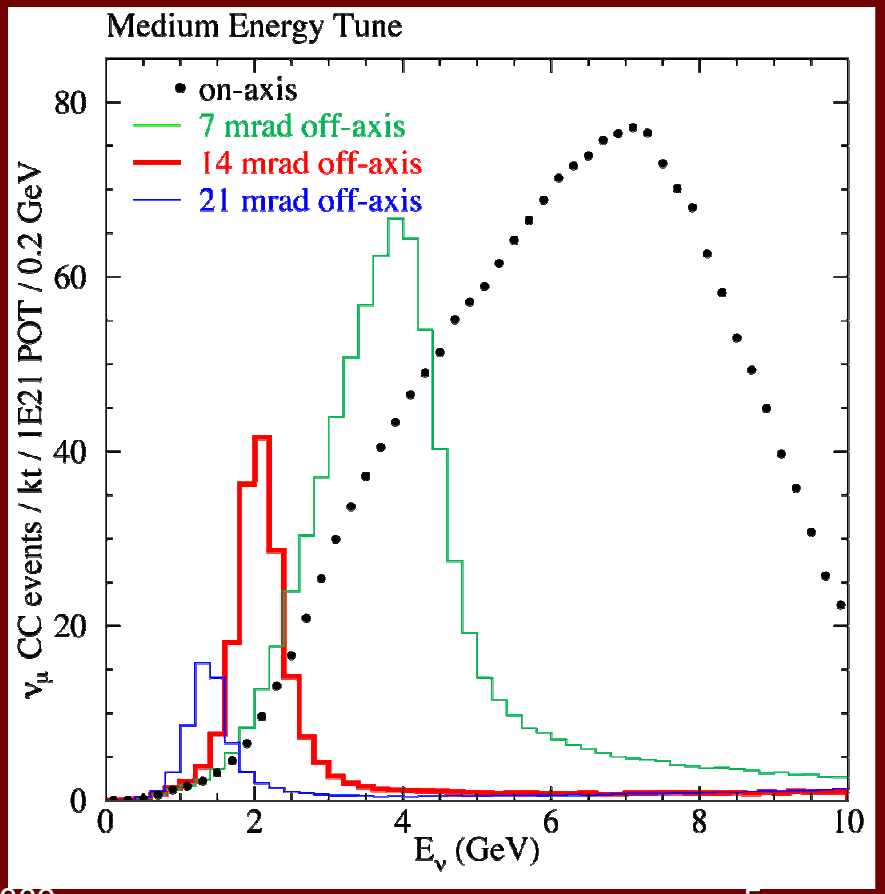




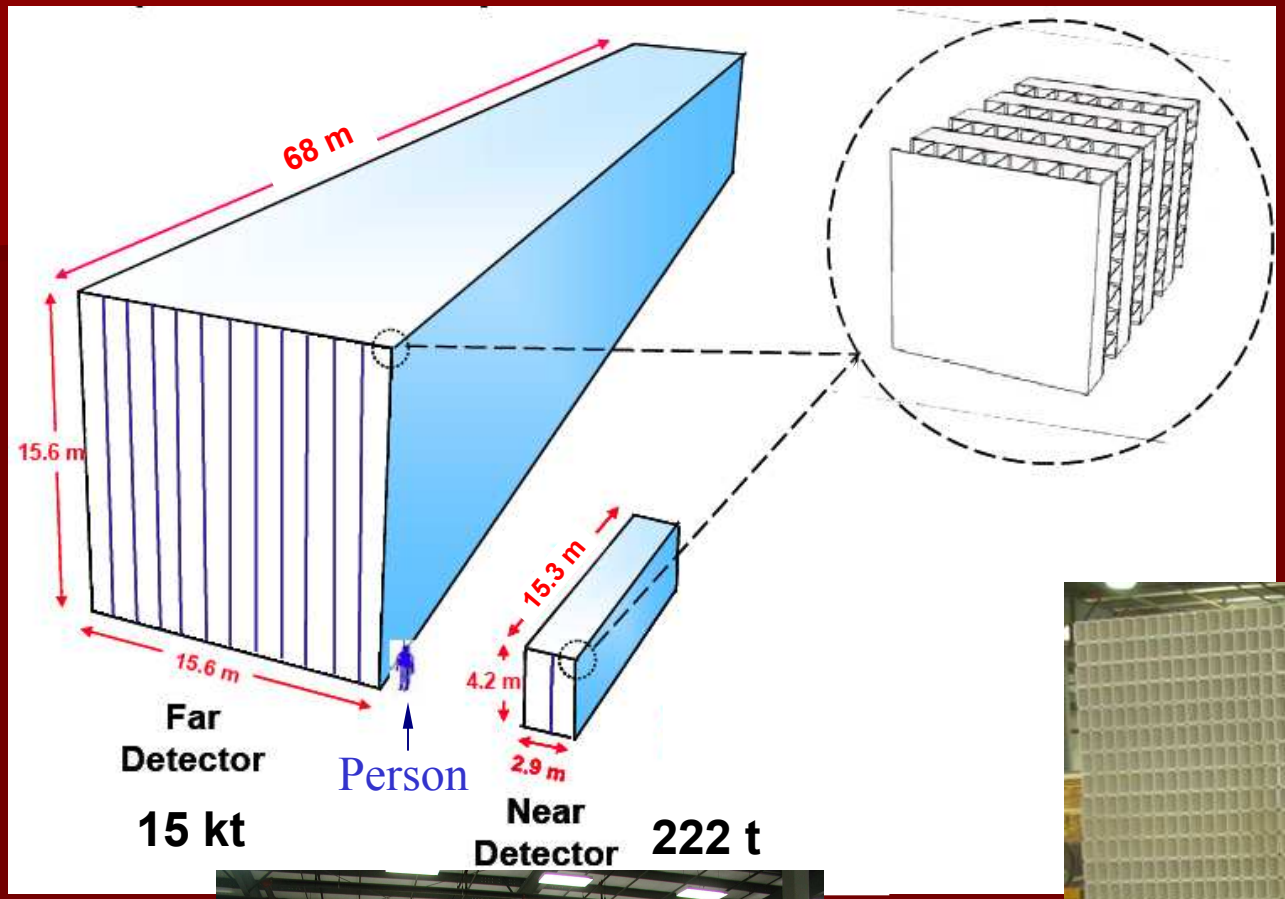
NuMI Beam Production



- Neutrino beam produced from 120 GeV protons striking a graphite target
- Beam performance:
  - 10μs spill every 1.3s
  - 4.9×10^{13} POT/spill
  - 700 kW beam power
  - ~3×10^{18} POTs/day → *6×10^{20} POTs/yr*
  - Plan to run 3yrs ν_μ & 3yrs $\bar{\nu}_\mu$
- NOνA will use ME beam 14 mrad off-axis



NOvA Detectors

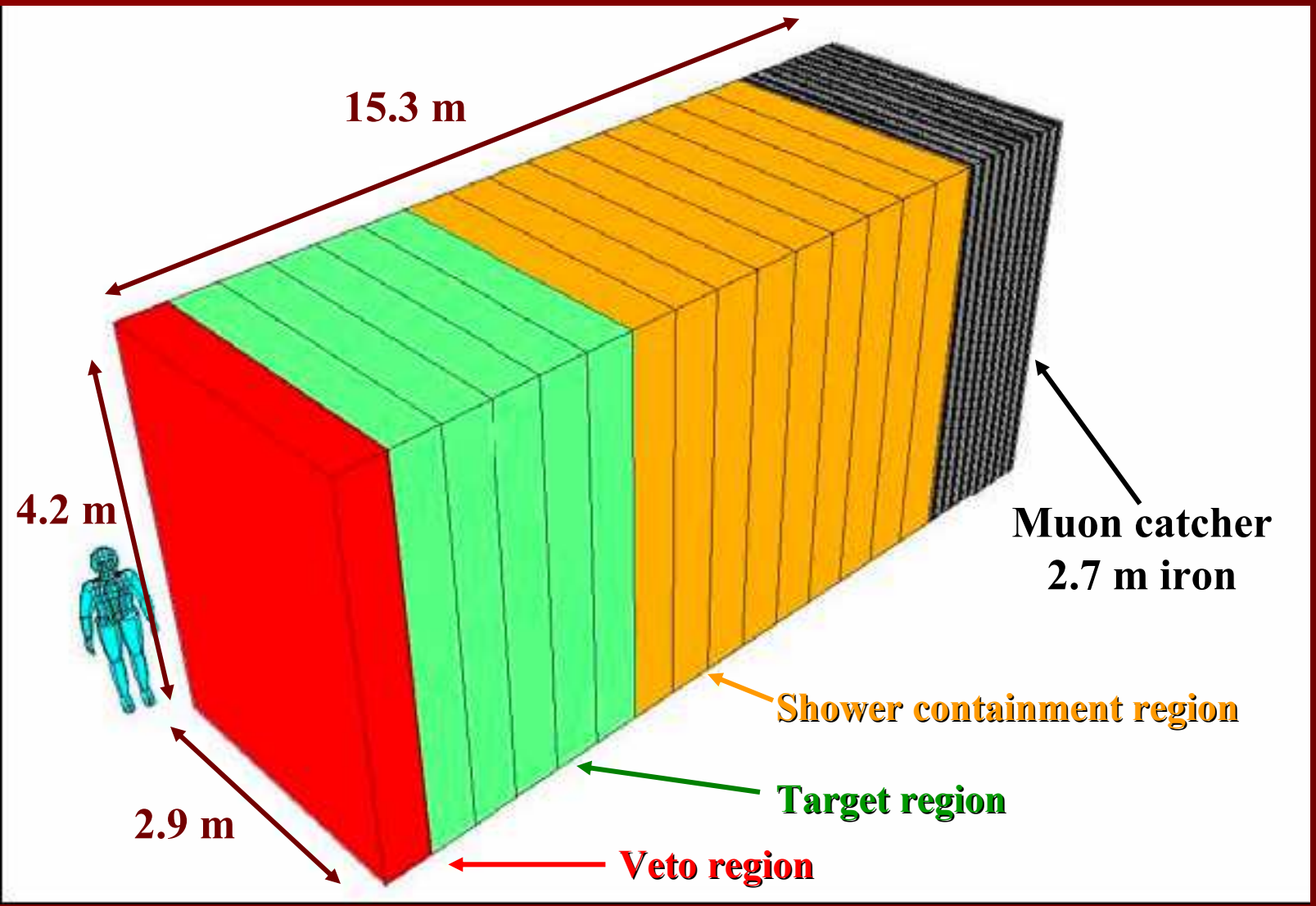


Planes consist of 32 cell PVC extrusions w/15% TiO_2

Planes alternate vertical & horizonal orientation

0.15 X_0 per plane

Near Detector



Test running with ND placed on the surface outside the MINOS surface building

Placed off-axis in the MINOS access tunnel for physics data-taking

222 t
125 t active
23 t fiducial

Far Detector

Extrusion modules are made from 32-cell extrusions

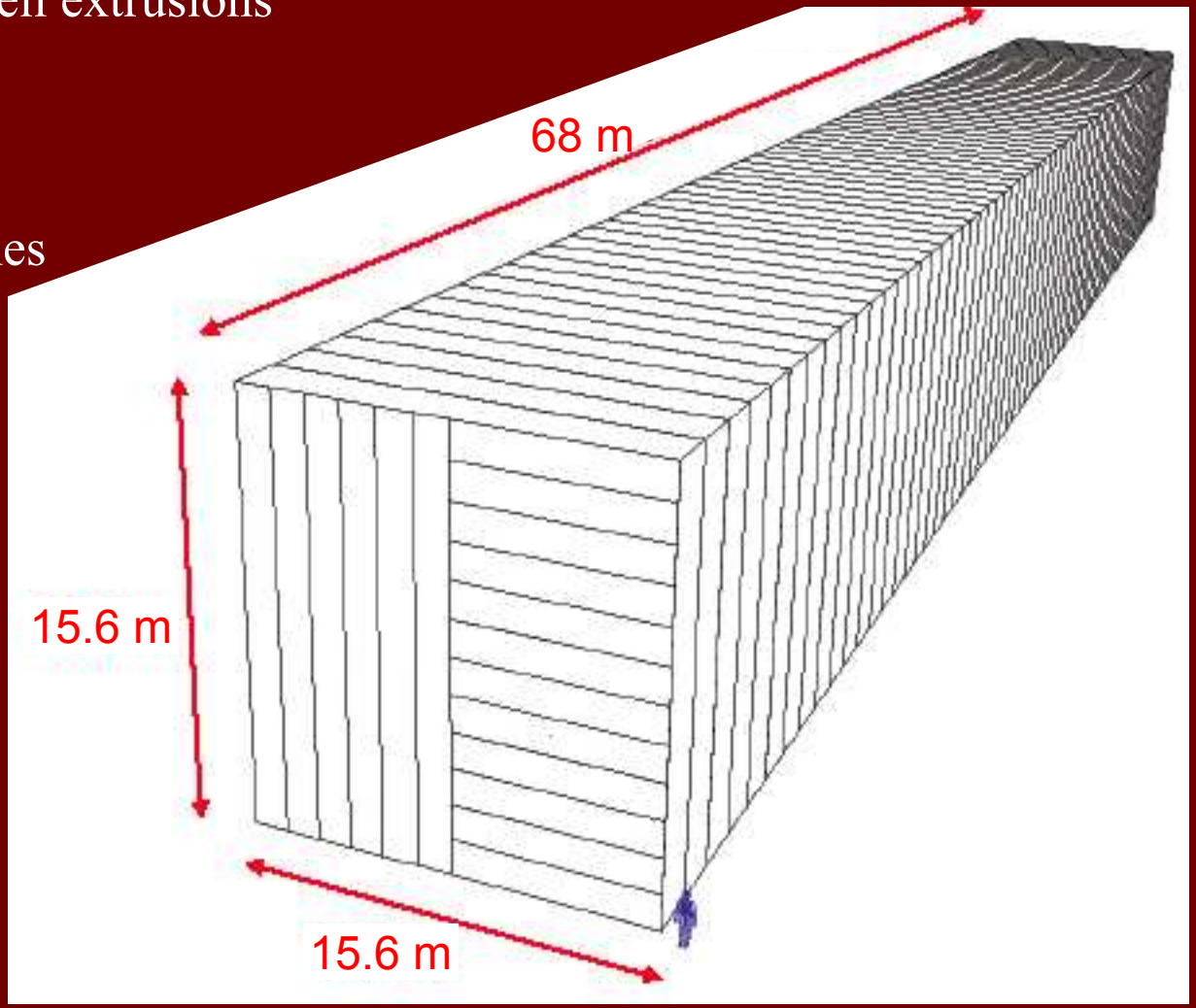
12 extrusion modules per plane

Alternating horizontal and vertical planes

1003 planes
= 12,036 modules
= 385,152 channels/cells

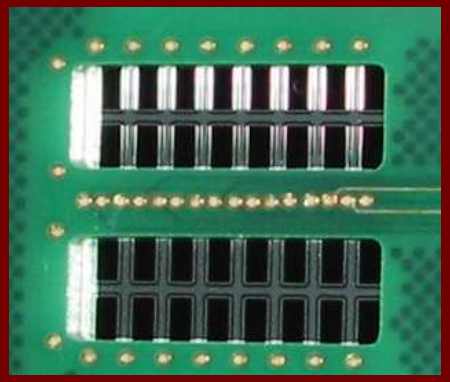
15 kt total mass

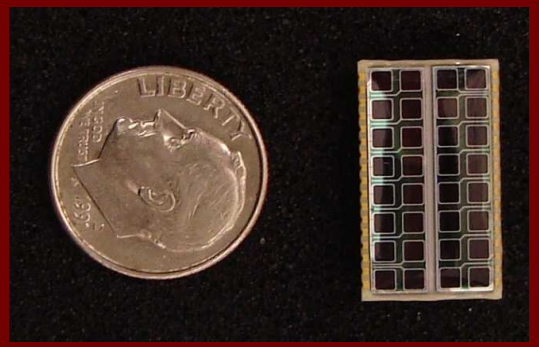
73% active volume

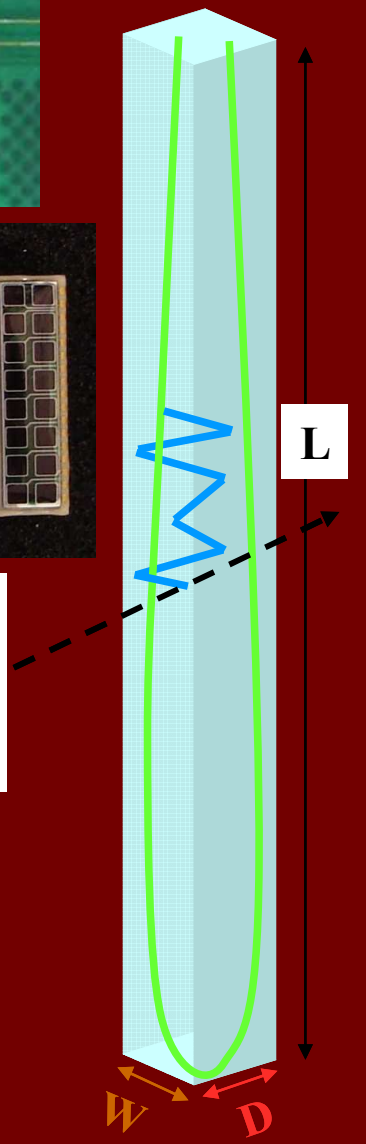


Detector Components

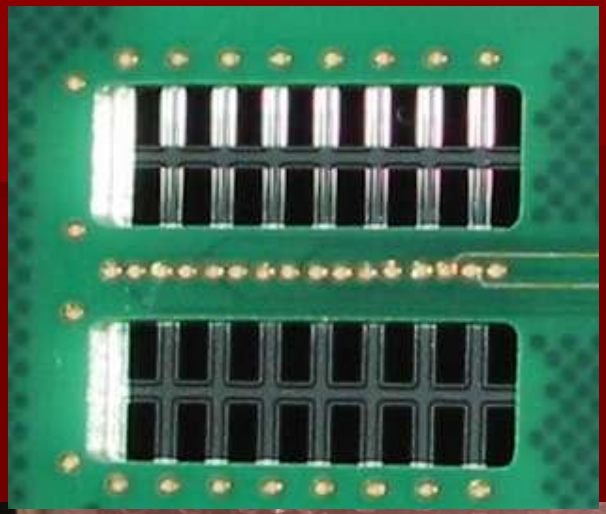
- Liquid scintillator (3 million gallons)
  - Contained in 3.9cm x 6.6 cm cells of length 15.6 meters
  - 3.9 cm as seen by the beam
- Cell walls are rigid PVC (5 kilotons)
  - Loaded with 15% anatase form of titanium dioxide
  - Diffuse reflection at walls keeps light near (within ~ 1 m) particle path
- Looped wavelength-shifting fiber collects light (13,000 km)
  - Fiber diameter 0.7 mm
  - Fiber shifts wavelength to ~ 520-550 nm along the fiber
- Avalanche photodiode (APD) converts light to electrical signal (13,000 devices, ea. 32 pixels)
  - 85% quantum efficiency



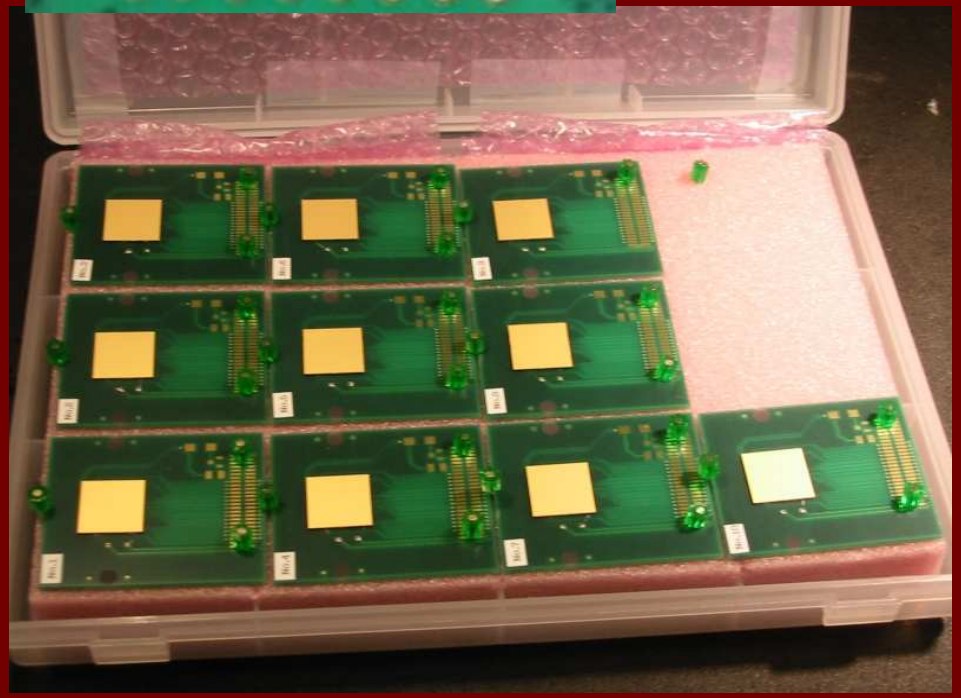


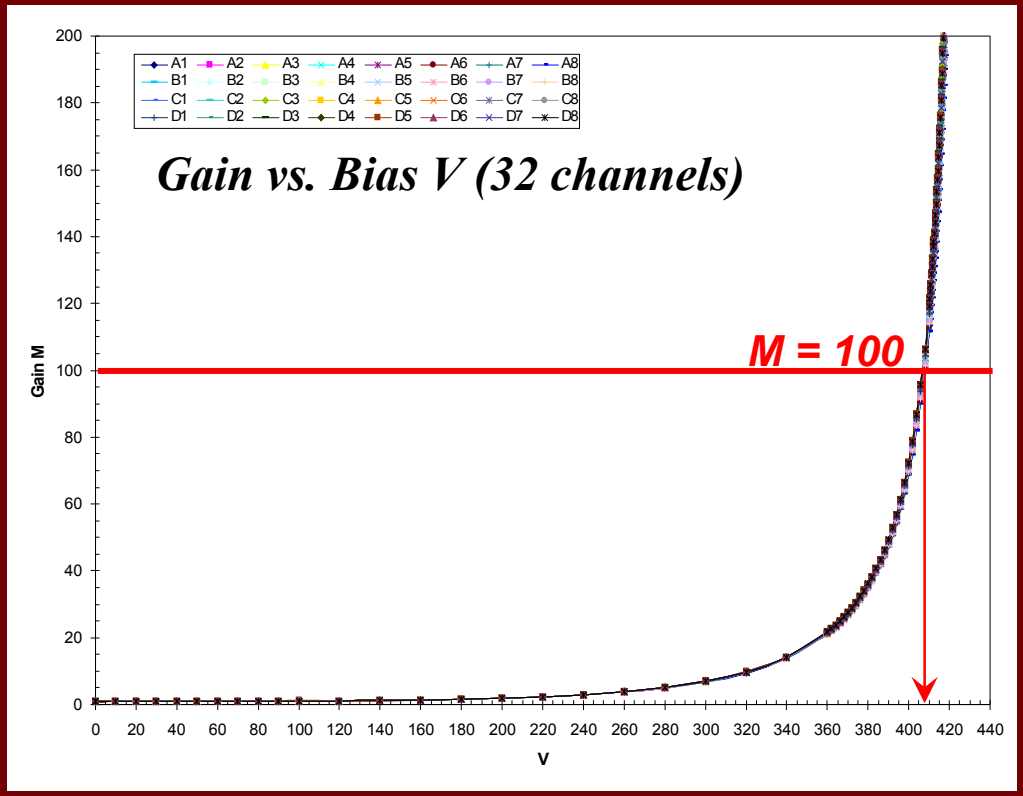


Avalanche Photodiodes



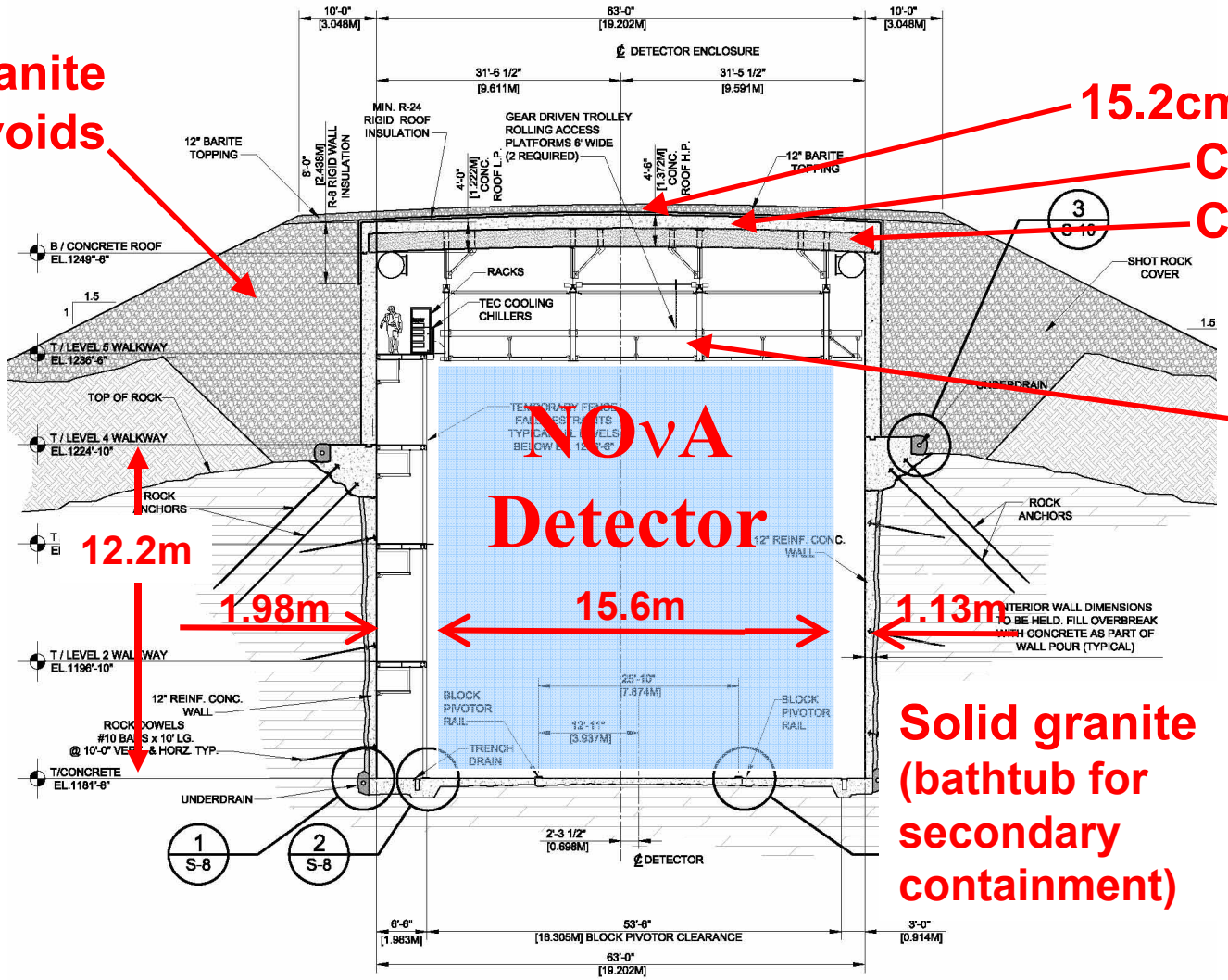
- Silicon solid-state device
- APDs have 85% quantum efficiency @ 520nm
- Operated at gain = 100 biased ~400V
- Low noise (< 2 p.e./channel @ –15 ºC)



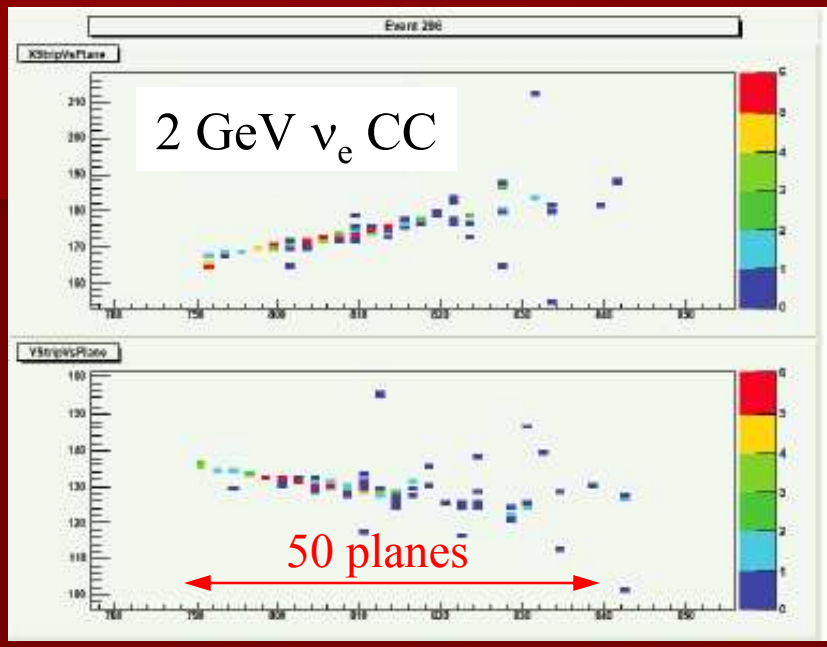


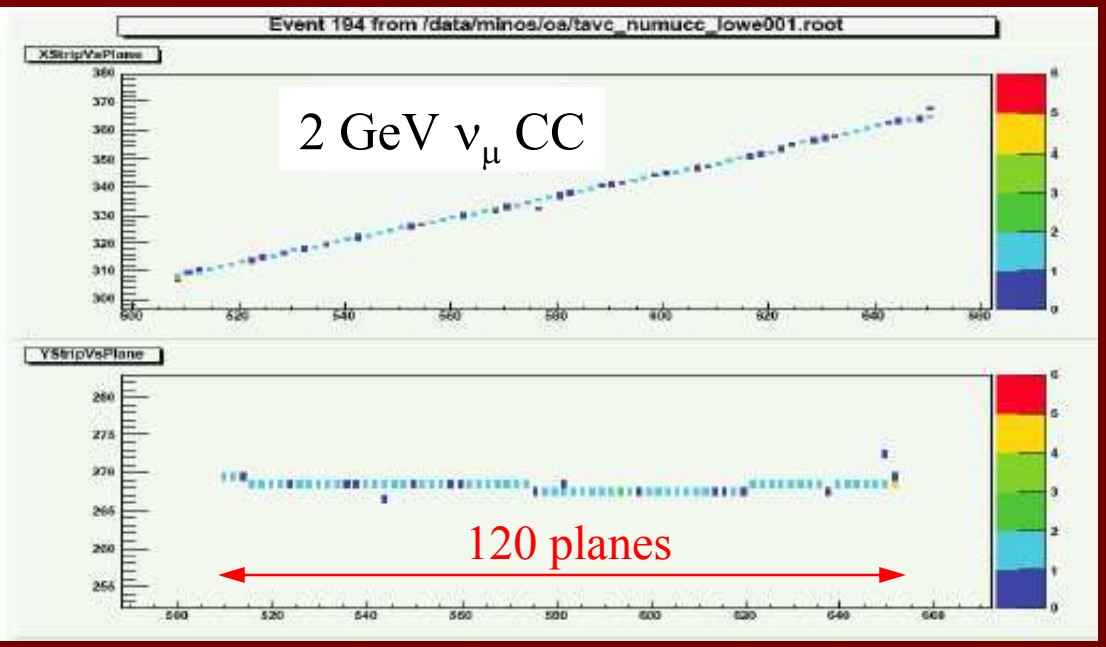
Groundbreaking

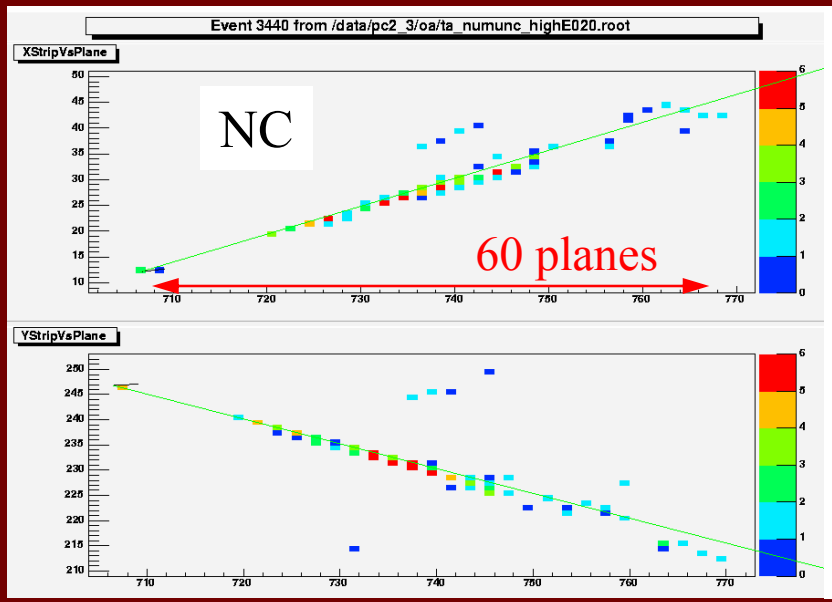
Site and Building



Event Topologies







$\nu_\mu N \rightarrow \nu_\mu p \pi^o$

E_ν = 10.6 GeV

E_p = 1.04GeV

$E_{\pi o}$ = 1.97GeV

Narrow off-axis beam provides improved discrimination between ν_e CC and NC events

Oscillation Probability

$P(\nu_\mu \rightarrow \nu_e) = P_1 + P_2 + P_3 + P_4$

$P_1 = \sin^2(\theta_{23}) \sin^2(2\theta_{13}) \sin^2(1.27\ \Delta m^2_{13}\ L/E)$

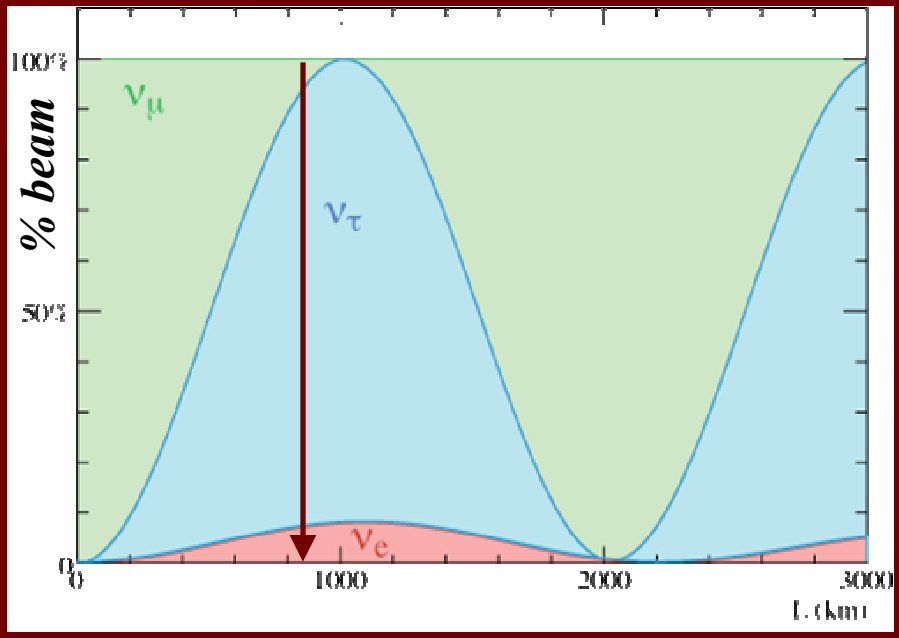
$P_2 = \cos^2(\theta_{23}) \sin^2(2\theta_{12}) \sin^2(1.27\ \Delta m^2_{12}\ L/E)$

$P_3 = J \sin(\delta) \sin(1.27\ \Delta m^2_{13}\ L/E)$

$P_4 = J \cos(\delta) \cos(1.27\ \Delta m^2_{13}\ L/E)$

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

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



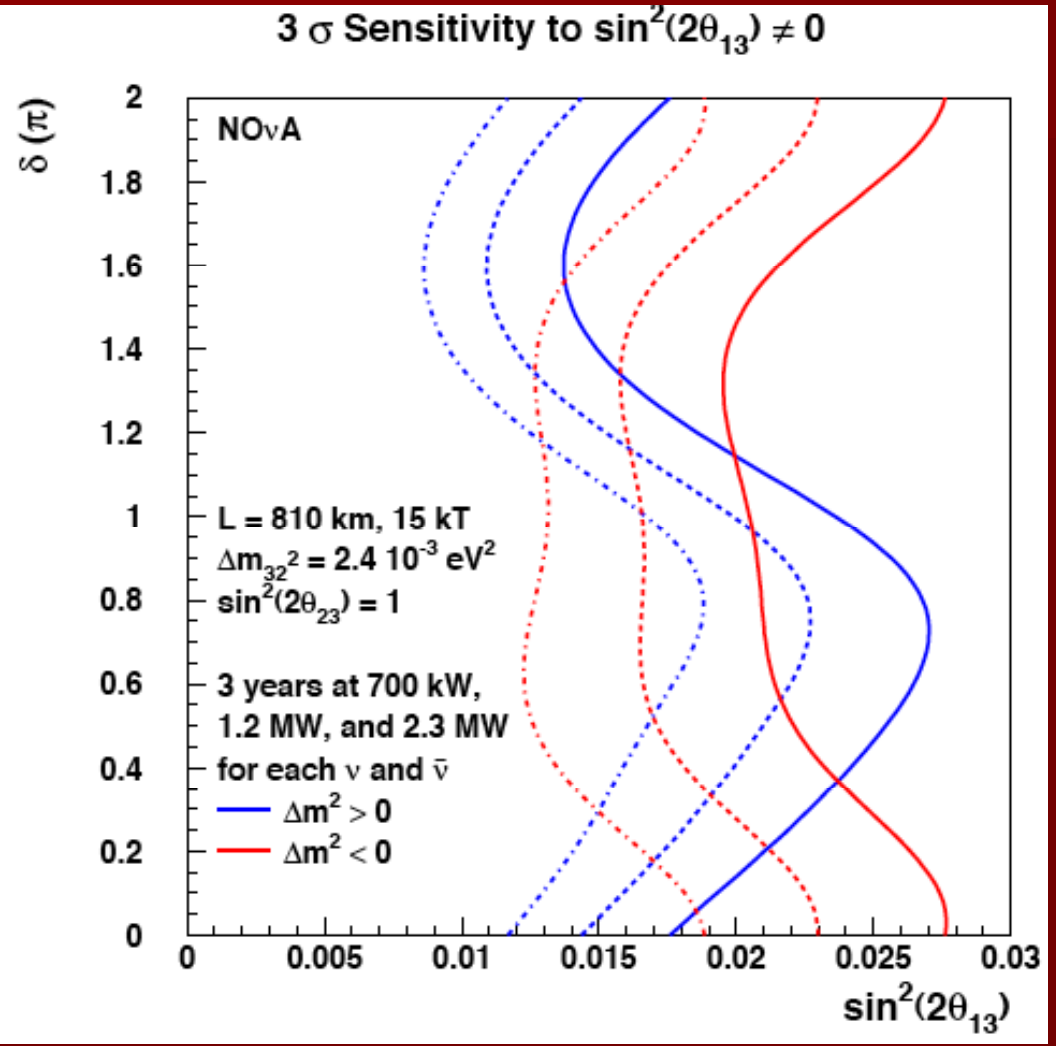
In matter at oscillation maximum, P_1 multiplied by $\sim(1 \pm 2E/E_R)$ and P_3 & P_4 will be multiplied by $\sim(1 \pm E/E_R)$, where the top sign is for neutrinos with normal mass hierarchy and antineutrinos with inverted mass hierarchy

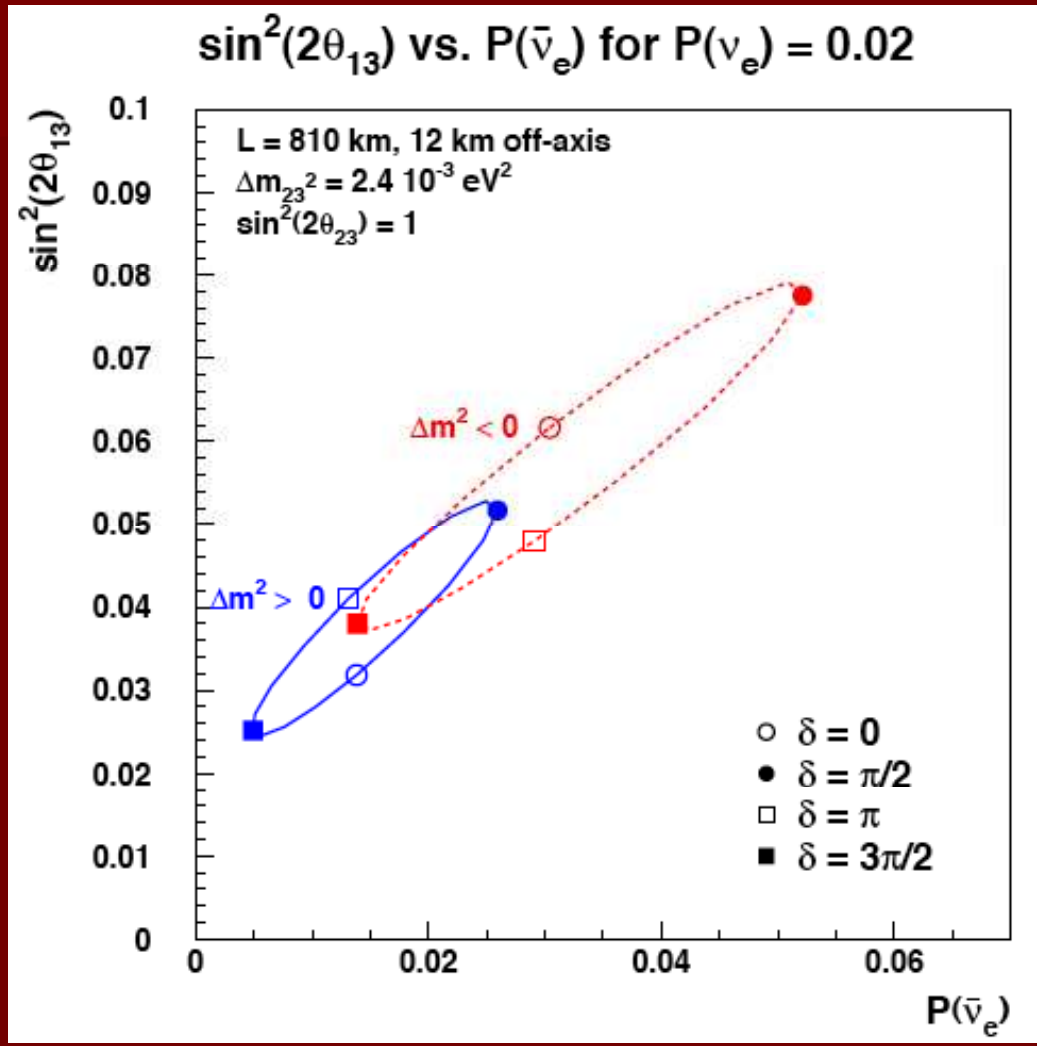
$E_R = \Delta m^2_{13}/[2\sqrt{2}G_F\rho_E] \approx 11$ GeV for earth's crust

About ±30% effect for NuMI, but only ±11% effect for T2K

Effect reduced for energies above oscillation maximum & increased for energies below

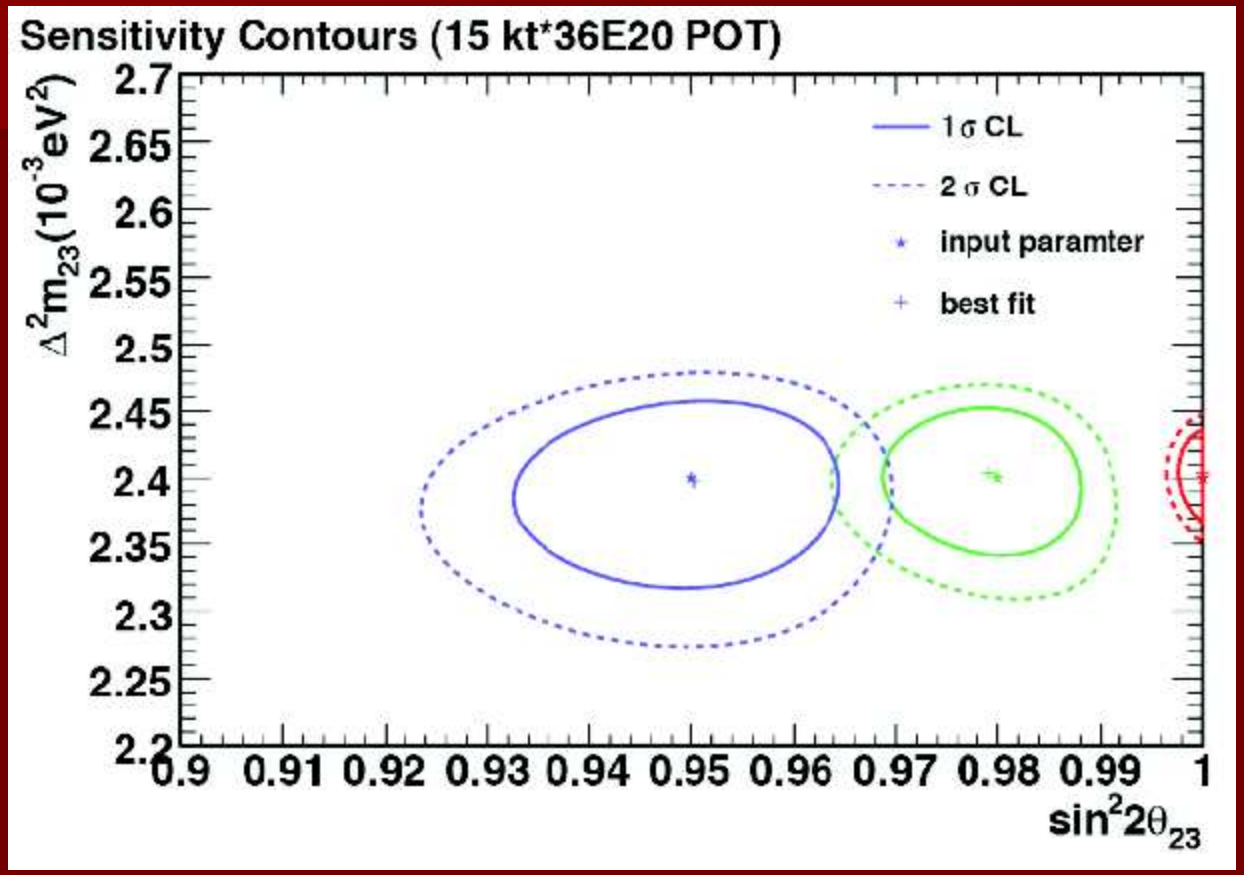
Sensitivity to $\sin^2 2\theta_{13}$ & δ





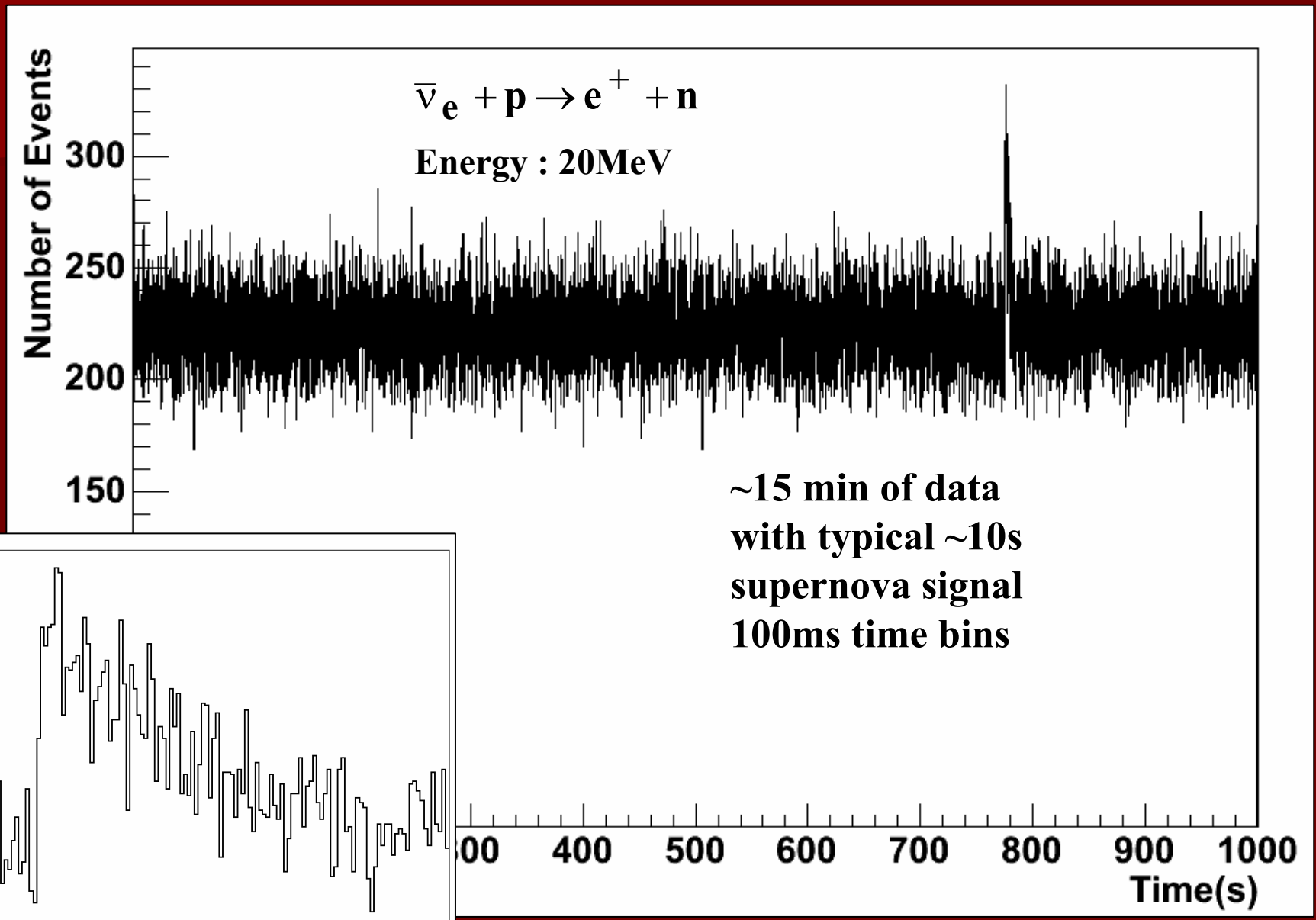
- Assume 3 years neutrino + 3 years anti-neutrino beam @ 0.7, 1.2, or 2.3 MW
- Unique sensitivity to neutrino mass hierarchy

Sensitivity to $\sin^2 2\theta_{23}$



- Assume 3 years neutrino + 3 years anti-neutrino beam @ 0.7, 1.2, or 2.3 MW
- NOνA can improve the precision of the $\nu_\mu \rightarrow \nu_\tau$ mixing angle by over an order-of-magnitude over MINOS

Possible Sensitivity to Supernova



Supernova sensitivity is beyond baseline project scope

NOvA Timeline

- ✓ May 2002: 1st Workshop
- ✓ April 2005: Fermilab PAC Approval
- ✓ February 2006: NuSAG report Recommends NOvA
- ✓ October 2006: P5 Recommends NOvA
- May 2007: DOE CD-1 Approved (Preliminary Baseline Range)
- November 2007: DOE CD-2 Review (Cost, Schedule, & Scope Baseline)
  - *Complete **Technical Design Report***
- ✗ December 17, 2007: US Congress Cuts Most Science Funding including FY08 NOvA
- ✓ May 2008: P5 Recommends NOvA, Except in Lowest Budget Scenario
- ✓ July 1, 2008: US Congress Passes Supplementary Appropriations Bill
  - ✓*M$9.23 Restored to NOvA Funding – On-Budget Project Activities Resume*
- September 15, 2008: DOE CD-2 Approved (Project Baseline)
- ✓ April 2009: NOvA Receives Recovery Act and FY09 Funding
- ✓ May 1, 2009: NOvA Far Detector Laboratory Groundbreaking
- ➢ **July 2009: DOE CD-3 Review (Full Construction Start)**

Detector Construction & Running:

- Expect ND data-taking *on the surface* starting spring 2010 → Move underground fall 2011
- Far Detector construction 2011 through 2013 → Data can start after first few kilotons

Summary

- NOνA is a next generation long-baseline experiment
- Order-of-magnitude improvement in sensitivity for $\sin^2 2\theta_{13}$
- Will yield significantly more precise Δm^2_{23} and $\sin^2 2\theta_{23}$
- Sensitivity to mass hierarchy and CP violation
- Physics sensitivity is complementary to T2K & reactor experiments
- Far detector site groundbreaking May 1, 2009
- ND data taking on the surface starting 2010 – Complete FD in 2013