NOvA Project Status
(NuMI Off-Axis ν_e Appearance)

ν_μ from NuMI oscillate to ν_e , 810 km away in Northern Minnesota

John Cooper
Project Manager

FRA Physics Visiting Committee
April 25/26 2008

NOvA Project History

- Last year at this time you heard from Ron Ray on OMB instructions to combine NOvA with the Accelerator 700 kW Upgrade within a TPC cap of $ 260 M.
  - We were aiming at 18 kilotons, down from the CD-1 value of 25 kt
- June 4-6, 2007 Director's Review for CD-2/3a
  - With all the details in the cost estimate, 18 kilotons came out $ 297 M, well outside the DOE TPC cap, implied we might afford only 14 kt.
  - Went back to look very hard for cost reductions, found ~fifty of them.
- August 21, 2007 Director's Review for CD-2/3a
  - Integral cost for 15 kilotons was below the cap of $ 260 M, but the cost profile did not quite match the funding profile
  - Documentation was about half there, so delayed Lehman Review by 5 wks
- October 23-25, 2007 DOE OHEP CD-2/3a Review
  - Integral cost and year by year obligation profile matched funding profile
  - 5,500 pages of documentation in place for review
  - Results: "judged that the project was ready for CD-2 but needed additional flexibility either in scope or cost.
    - **OHEP discussions gave us a new cap of $ 270 M & scope of 14 kilotons.**
    - **Instead of any changes to our contingency estimation (e.g. oil, escalation)**
    - **All our proposed CD-3a items were endorsed by this review.**

NOvA Project History

- November 26-30, 2007 DOE OECM CD-2 Review
  - Reviewed the same RLS and cost as OHEP in October ($ 260 M, 15 kt)
  - Documentation expanded to ~ 6,500 pages
  - Results: "The project can be successfully executed and the performance baseline validated once the project team resolves the 5 major findings and has an acceptable plan in progress to resolve the other 18 findings."
    - **All 5 major findings resolved in December, other 18 nearly completed.**

- **SCHEDULED, then cancelled:** December 19, 2007 DOE CD-2 ESAAB
  Energy Systems Acquisition Advisory Board
- **December 17 (Black Monday)** FY08 Omnibus Bill: "zero for NOvA"

- January, 2008: shutdown of project
  - Fermilab people assigned to other tasks, cannot charge time to "NOvA"
- **February, 2008: OHEP asks us to re-plan for FY09 start**
  - President's budget for FY09 has NOvA at $ 37 M
  - New funding profile from OHEP – next page
- **Passed 3rd Director's Review last week**, Lehman scheduled next week, EIR Follow-Up Review perhaps in early June (not yet scheduled)

New funding profile

	In $K	
Fiscal Year	Old funding profile	**New funding profile**
2006	2,780	2,780
2007	12,470	12,470
2008	36,050	**3,475**
2009	65,000	**37,000**
2010	73,220	**68,000**
2011	48,720	**71,220**
2012	31,760	**51,245**
2013	0	**31,810**
TOTAL	270,000	**278,000**

Essentially a one year slip in funding

+ $ 8 M escalation

CD-3a allows construction start

on a limited number of long leadtime items

Set at Feb 1, 2009

CD-3b is full funding

Set at Sept 30, 2009

Requires FRA EVMS certification by DOE-OECM

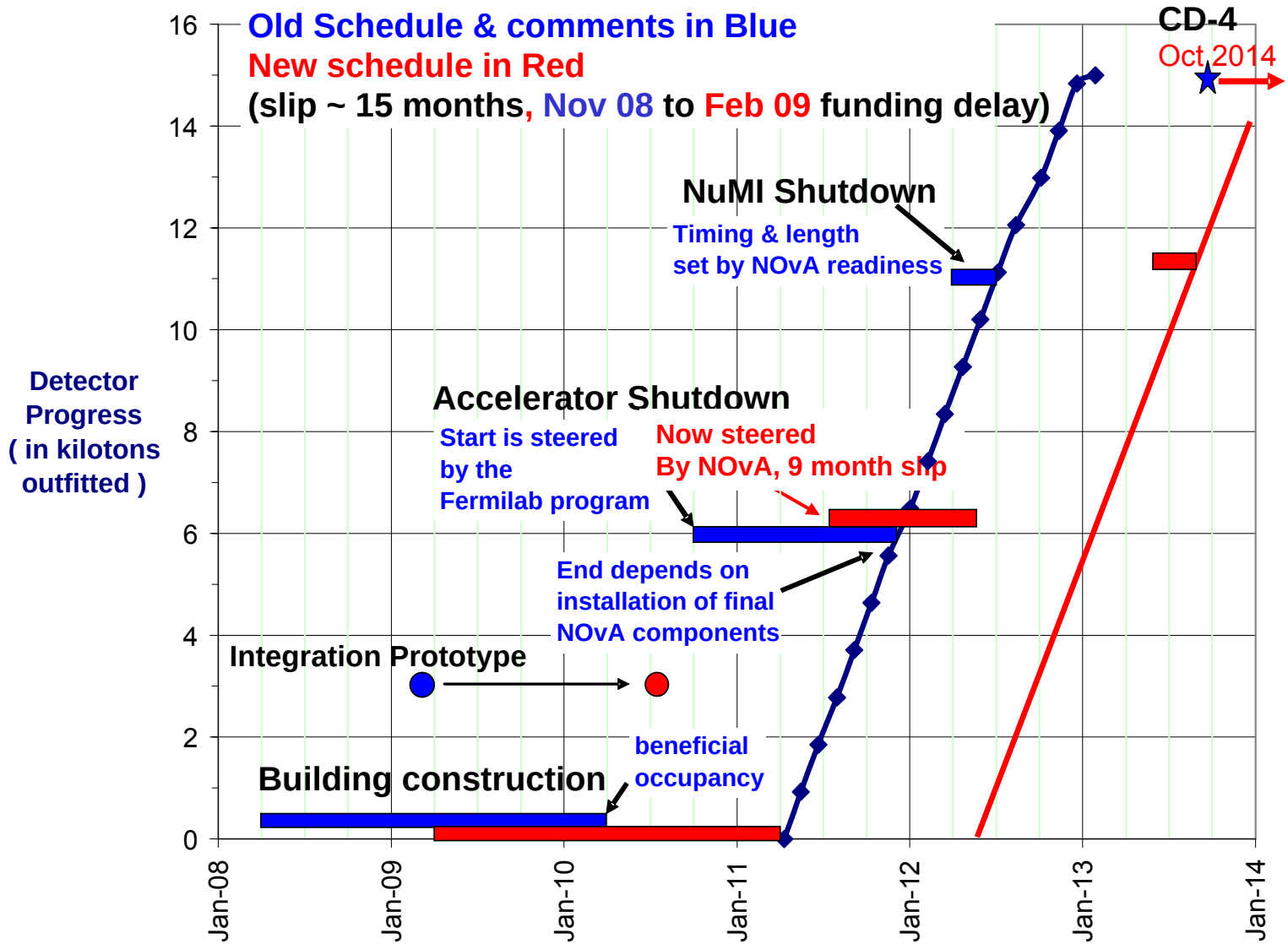
Four additional reviews

One done, 3 to go

NOvA Schedule: 2 Parallel Critical Paths

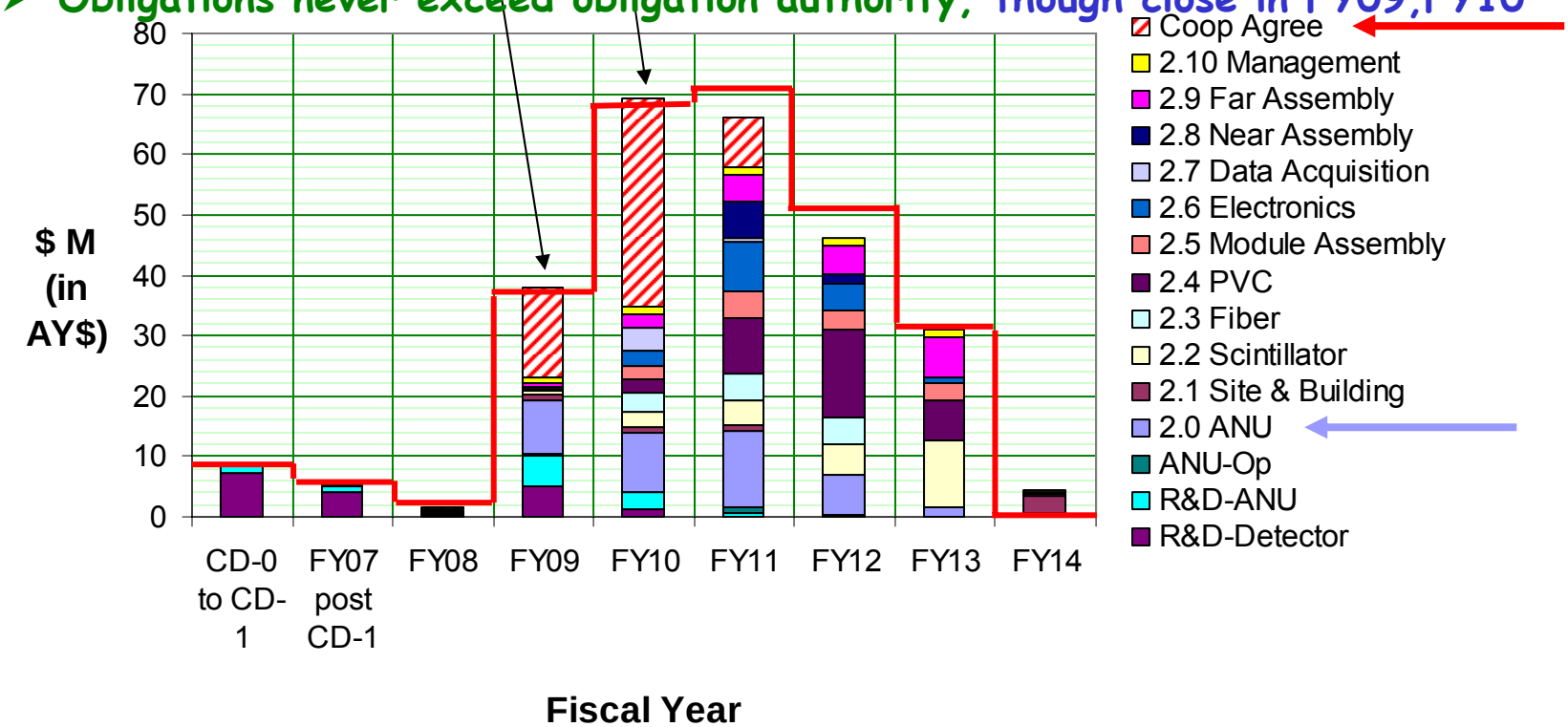
- We can't build the detector without a building at Ash River, Minn.
  - Therefore we must push the building as fast as possible from the start
  - We need CD-3a (Feb 1, 2009) for this (starts the access road to the site)
- Accelerator & NuMI Upgrades (WBS Level 2) uses a Fermilab Accelerator Division workforce, and all these people have additional operational responsibilities in the current Fermilab program
  - So we have a leveled resource, leveled from outside the project
  - Given the uncertainties, we must push the Accelerator & NuMI as hard as possible and use the workforce to the fullest extent when available
  - We need CD-3a here or these people will not have materials for the work
    - October Lehman Review agreed all these items are "ready for CD-3a"
    - Now in addition Kicker R&D is continued off-project
      - **Since the 1st kicker is a <u>Gap-Clearing Kicker</u> which will be used before NOvA exists. So 1st NOvA shutdown is delayed ~ 9 months.**
- These two facts mean we have to delay the start of the detector work and then ramp it up slowly to keep within the funding profile
  - So initially the detector people focus on a R&D Integration Prototype
    - **~ 90 tons, all of which gets re-used in the Near Detector**

Graphic Schedule



Obligation Profile (including contingency)

- TPC matches the $ 278 M guidance, base cost is for 14 kilotons
  - Contingency total is now increased from 30% to 36%, $ 70.1 M
  - Tagging 15th kiloton tasks in our RLS indicates a $ 5.9 M base cost per kt.
- DOE funding profile in red
  - Obligations in stacked histogram from Open Plan escalated using Cobra
  - Obligations never exceed obligation authority, though close in FY09,FY10



FY08 plan: Work towards Final Design/CD-3

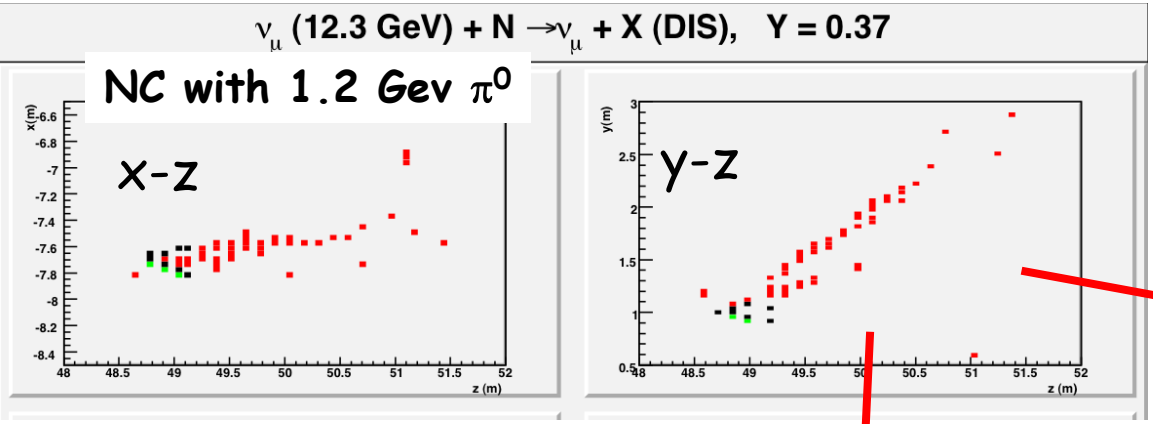
- We have about $ 2 M of FY07 carryover funding available
  - But in several colors which can't changed:
    Cooperative Agreement = $ 1 M R&D + MIE = ~$ 1 M
- We **may** get reprogrammed funds
  - Estimate ~$ 5 M would get us to a final design ready for CD-3
  - OHEP requires CD-2 finished
  - DOE requires a receptive Congress
- There **might** be a Supplementary Bill
  - We would then start building the 3.5 mile access road to the Ash River site starting in the middle of **this** summer, only 3-4 months behind the original schedule before the Omnibus Bill
  - Need FONSI, but our Environmental Assessment is now out for 30 day public comment, so this is possible

- FY09 funding **might conceivably** come before Feb 1?
- FY09 funding **could be less** than $ 37 M? P5 also back in the mix.
- FY09 funding **could be even more** than $ 37 M?
- Day to day uncertainty, perhaps no final answer for a year?

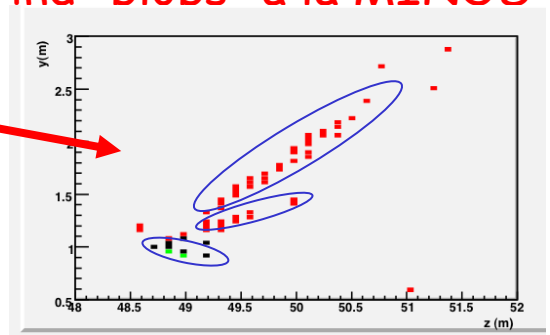
Technical Progress during the last year

- Accel Upgrades: Gap clearing kicker work proceeding off project
  - Kicker parts ordered
  - MI / Recycler radiation studies to plan shutdown work
  - Medium Energy horn placement studied and optimized 4 m upstream for 5% more beam.
- Site & Building: Road designed
  - EA out, NHPA Agreement in process for old railroad grade, potential archaeological finds
- Scintillator: Mixed 3800 gallons (mineral oil, pseudocumene, wave shifters), QA in process
- Fiber: Determined 300 ppm K27 dye is optimum in NOvA cell
- PVC: Have final resin mix with anatase TiO2, reflectivity OK
  - ~ 50 tons of 16 cell product extruded, Creep tests continue to look OK relative to design
  - Air cushion pallet system used at Extruder & ANL to unload 52 ft parts on & off truck
- Modules: Injection molded Manifolds design nearly complete
  - testing adhesive scheme: 3M-2216 next to scintillator, Plastic Welder with MMA outside that for strength
- Electronics & DAQ: Vertical Slice Test confirms photoelectron yield
  - ASIC back and being tested
  - Front End Board stopped in 3rd iteration, may restart
  - Data Control Module & Timing Control Unit final design in progress when stopped, restart?
- Near Detector: Cavern position settled
  - contracted with MHW (Harza) for rock evaluation on cavern parameters
  - Integration Prototype Near Detector will fit in MINOS Service Bldg with MINERvA
- Far Detector Assembly: Adhesive machine & vacuum lifter being assembled
  - Structure tests: 8 plane, 4 m high prototype tested at ANL full of water

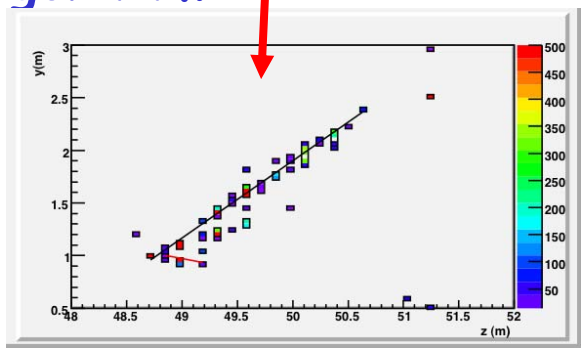
Off-Project Simulation Progress !



- **NEW Calorimetry Method** (Bob Bernstein, Fermilab)
  - Find "blobs" a la MINOS



- **Original Tracking Algorithm**
  - Find vertex *
  - Find tracks
  - Neural net
    - Energy
    - Event length (μ)
    - + more

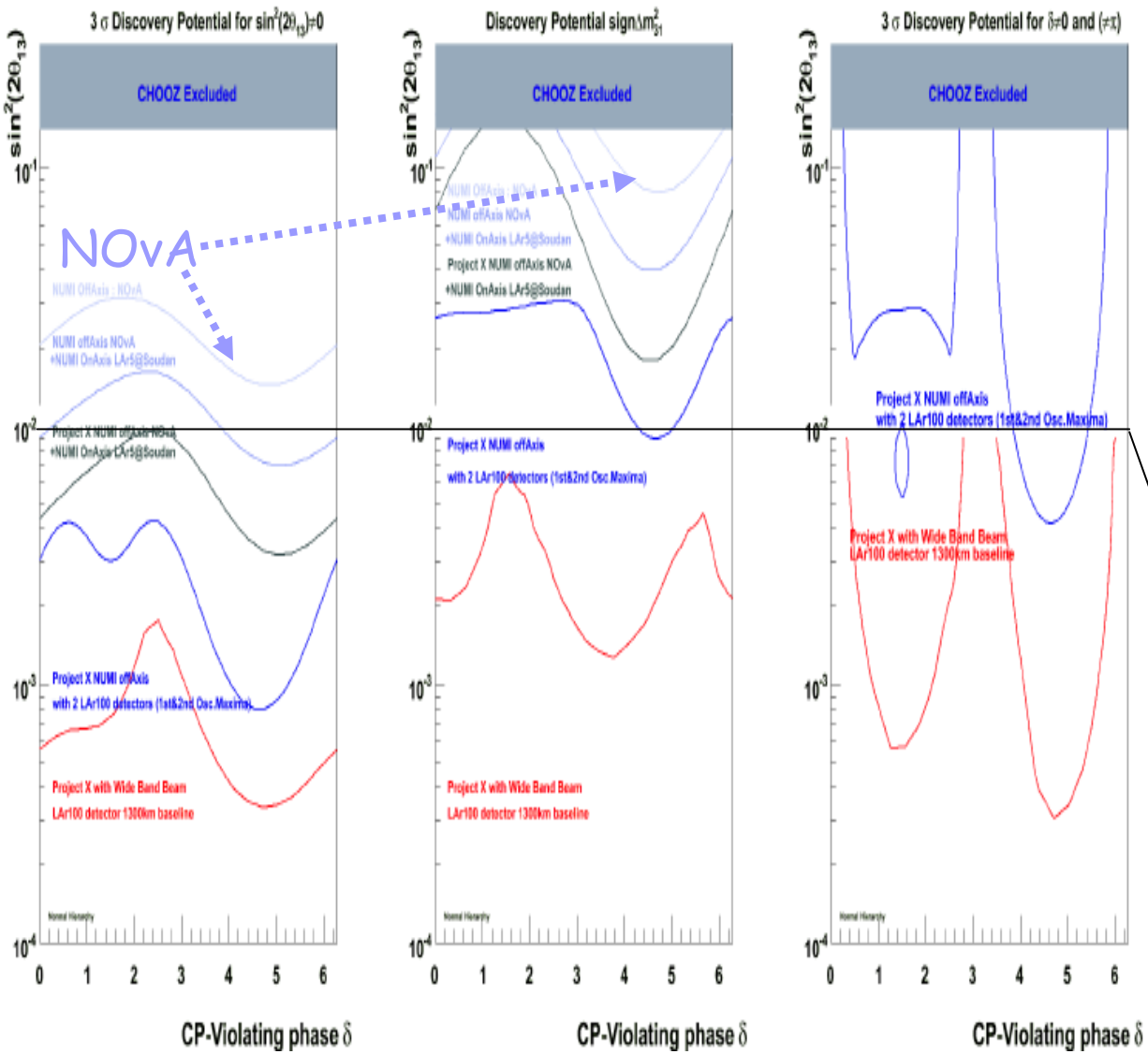


  - χ^2 for longitudinal & transverse electron shower profile using NOvA's fine granularity
  - X & Y views must match
  - Neural net, similar list

Net results: ν_e efficiency: Tracking = 24%, but Calorimetry = 35-37%
backgrounds: Tracking [NC = Beam ν_e], Calorimetery [NC < Beam ν_e]

EFFECTIVE MASS of NOvA increased: (36/24)*14 kt = 21 kt

Recent plots of θ_{13} may distort one's view



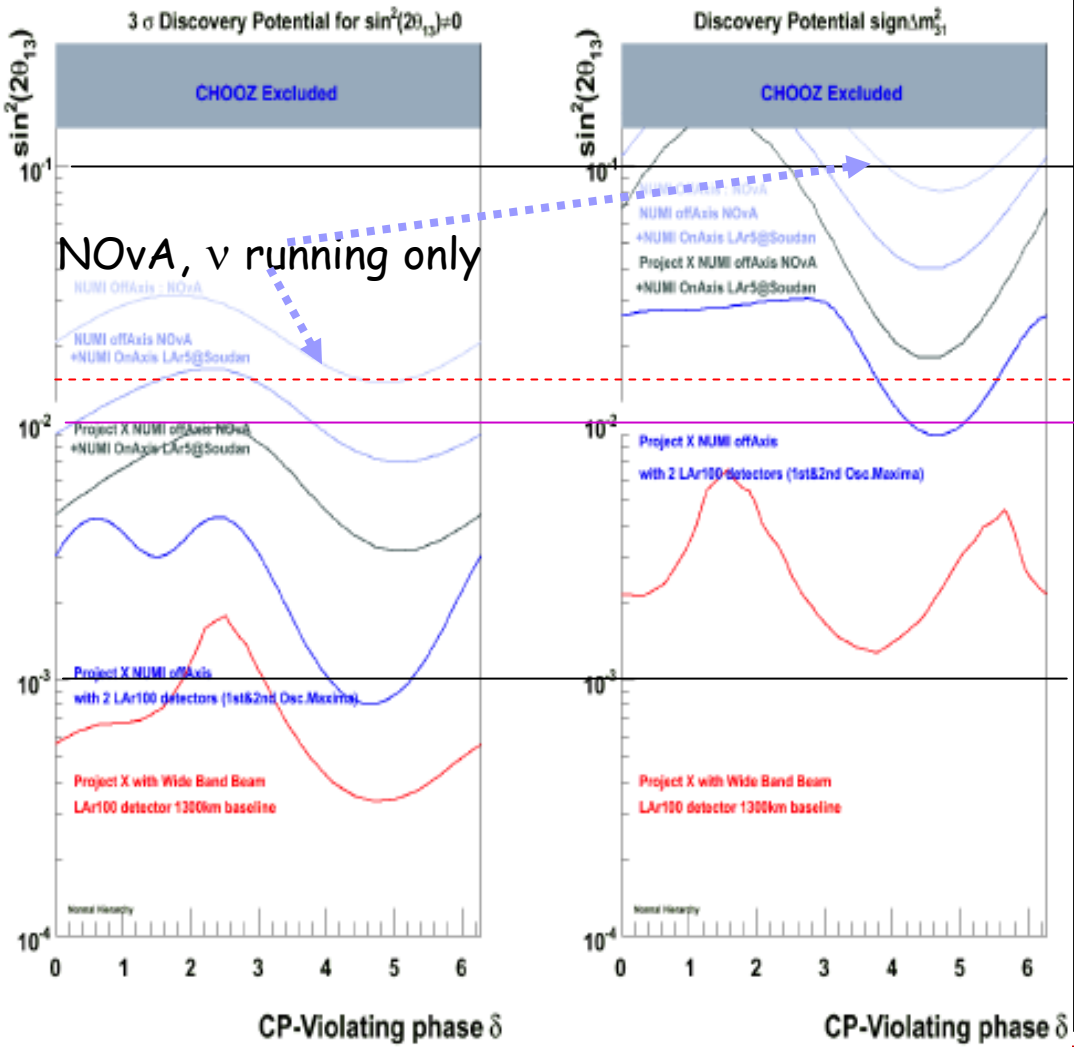
These plots are meant to show how one could build a phased neutrino program over time <u>if required</u> by the science.

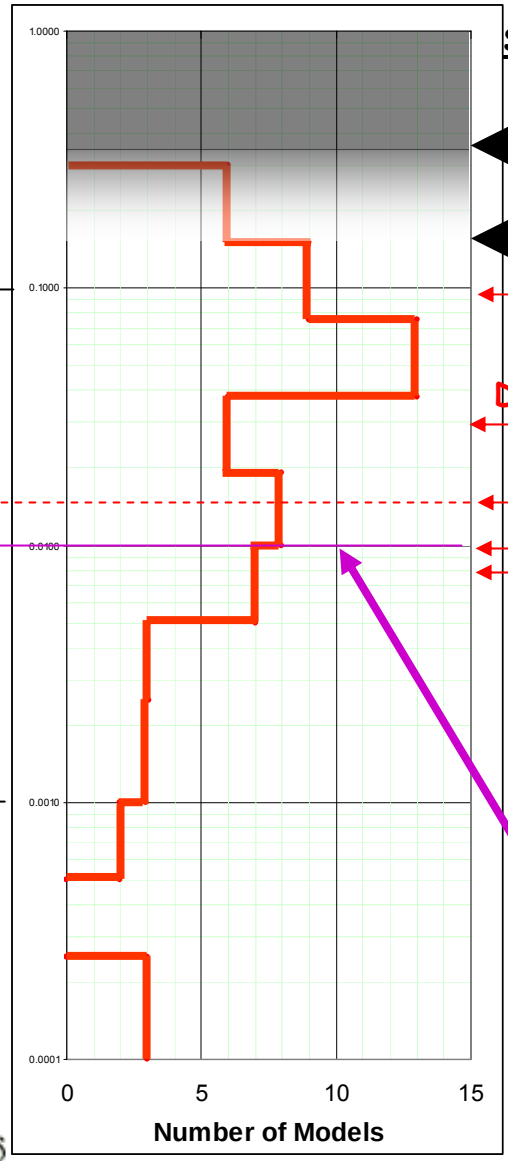
- But sometimes these plots take on a life of their own and leave the impression that NOvA can't measure much.

<u>NOT IN THE PLOT:</u>

- "CHOOZ Excluded" is overstated, showing a 1.28 sigma, 90% C.L.
- All concepts shown for neutrino running only, but NOvA plans to run anti-neutrinos as well
- There really is some theoretical guidance on $\sin^2(2\theta_{13})$, mostly in the first decade >0.01
  - Nice summary of 63 theory models by Albright & Chen, PR <u>D74</u> (2006), but watch for θ vs 2θ
- Multiple planned experiments actually complement one another & can be analyzed together for increased reach
- Δm^2 and δ-CP phase are linked, so information on one leads to information on the other

A different view





$\sin^2(2\theta_{13})$ reach

CHOOZ 3σ

CHOOZ 1.28σ

MINOS 1.28σ, 2009–10

Double CHOOZ 1.28σ, 2015

NOvA 1.28σ, ν,anti-ν 2019

T2K 1.28σ, 2013?

Daya Bay 1.28σ, 2016

(0.01 in ~ 2013?)

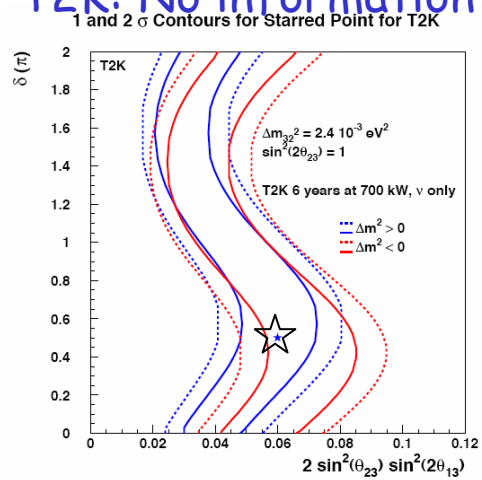
~ two-thirds of models have $\sin^2(2\theta_{13})>0.01$ which is ~ the ultimate reach for Daya Bay, T2K , & NOvA

NOvA + complementary experiments

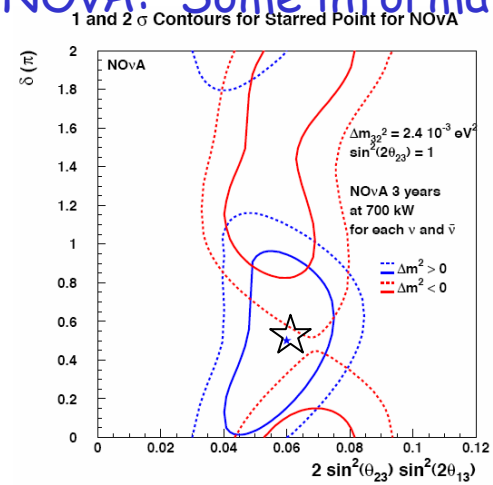
Note mass hierarchy (red vs. blue curves) and δ are linked

Case 1: δ vs. θ_{13} Contours: **Worst** Possible δ (☆) at $\sin^2(2\theta_{13})=0.06$

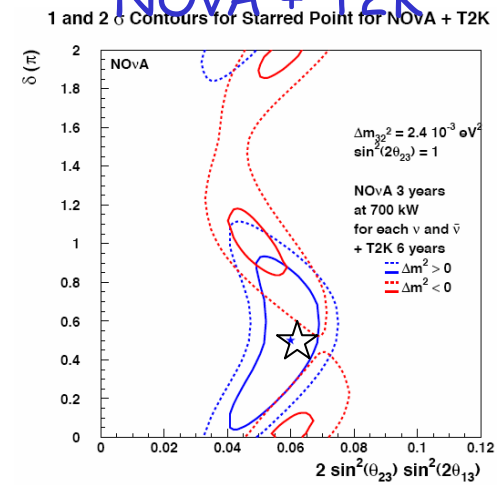
T2K: No information



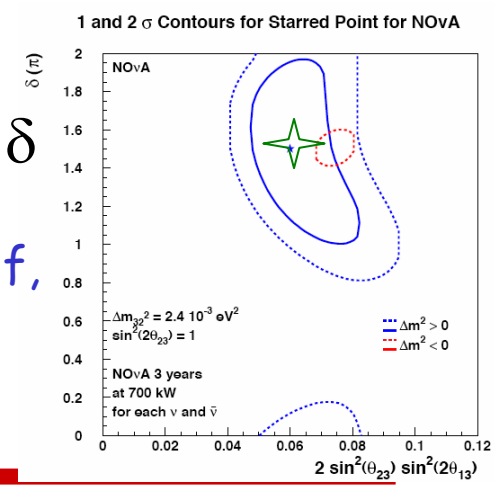
NOvA: Some information



NOvA + T2K



Case 2: δ vs. θ_{13} Contours: **Best** Possible (✧) δ

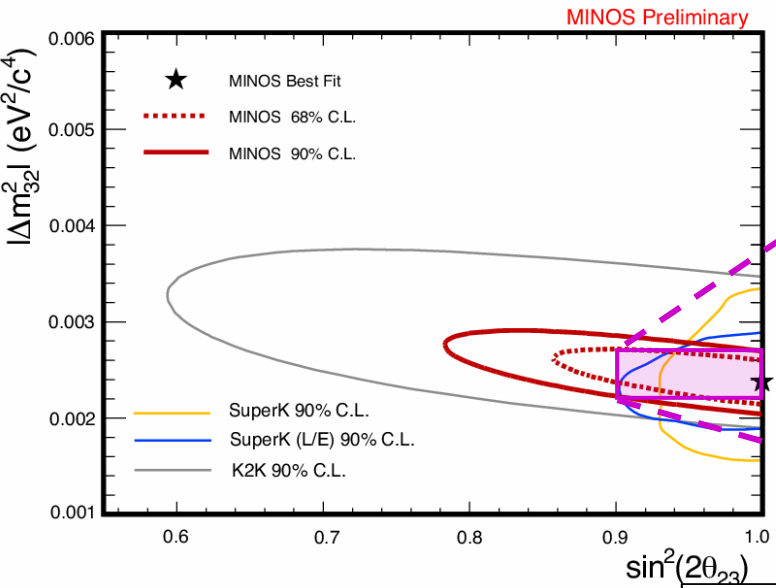


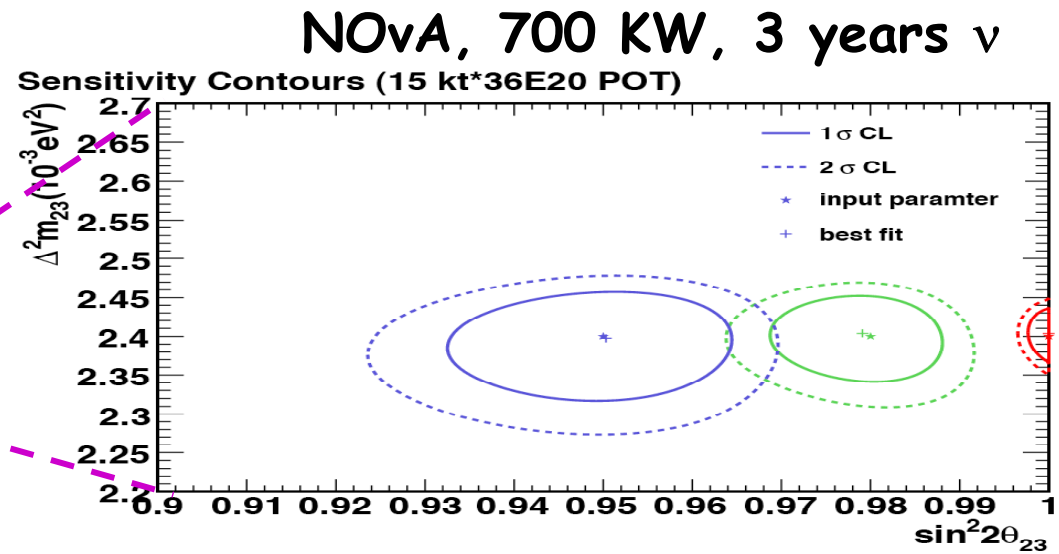
NOvA does a reasonable job by itself, favoring the appropriate hierarchy

What NOvA can do in various θ_{13} scenarios

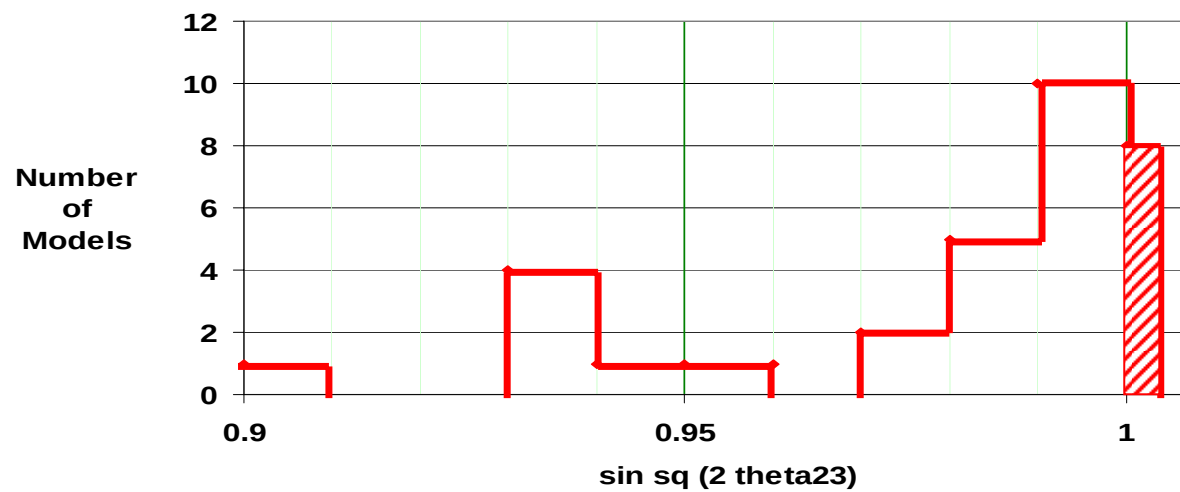
- $\sin^2(2\theta_{13}) \approx 0.1$
  - Determine the mass ordering for half of the δ space at the 1-3 σ level; combining with T2K, determine the mass ordering for the other half of the δ range at 1-2 σ level.
  - Exclude about half of the δ space at the 1-2 σ level.
  - Combining with Daya Bay, determine whether ν_3 couples more strongly to ν_μ or ν_τ at the 2 σ level if $\sin^2(2\theta_{23}) < 0.97$. (See G. Feldman talk at P5, Feb 08)
- $\sin^2(2\theta_{13}) \approx 0.06$
  - Determine the mass ordering for half of the δ space at the 1-2 σ level; combining with T2K, determine the mass ordering for the other half of the δ range at 1-2 σ level.
  - Exclude about half of the δ space at the 1-2 σ level.
  - Combining with Daya Bay, determine whether ν_3 couples more strongly to ν_μ or ν_τ at the 2 σ level if $\sin^2(2\theta_{23}) < 0.94$. (See G. Feldman talk at P5, Feb 08)
- $\sin^2(2\theta_{13}) \approx 0.03$
  - Determine the mass ordering for a quarter of the δ space at the 1 σ level.
  - Exclude about half of the δ space at the 1-2 σ level.
- $\sin^2(2\theta_{13}) \approx 0.01$
  - See a signal at the 1-3 σ level, confirming weak signals seen in other experiments. (Or, we might be another voice to sort out conflicting results from Double CHOOZ, Daya Bay, T2K)

NOvA contribution to θ_{23}





- Albright & Chen, PR D74 (2006) again
- 35 models
  - 8 have maximal mixing with $\sin^2(2\theta_{23})=1.0$, red cross-hatch
  - 27 do not
  - NOvA is capable and looking in the right space
    - MINERvA cross sections will help with this precision
    - ν_μ disappearance measurement



Reminders

- NOvA set out to design a $\nu_\mu \rightarrow \nu_e$ experiment that was an order of magnitude more sensitive than MINOS for this oscillation.
  - Experimental details & systematics are understood for this step size.
  - Only NOvA can contribute to Δm^2 and δ-CP phase among approved efforts.
- NOvA set out to minimize costs by using the existing NuMI facility for a follow-on experiment.
  - We shouldn't ignore the ~$ 225 M* the US taxpayers have put into NuMI.
- **NOvA timescale is real** (other concepts are NOT). *AY$ if start today
  - First workshop (5/02)
  - Final Proposal (3/05)
  - CD-0 (11/05)
  - CD-1 (5/06)
  - **CD-2** (6/08 ?)
  - CD-3 = $ (9/09 ?)

Takes at least 4.5 years
(DOE / OMB / Congress control the timescale -- other projects might dream to do better by ½ yr)

7.3 years

All other concepts are Between steps 1 and 2

Then still takes ~5 yrs to build anything

- **NOvA Cost Estimate is real** and reviewed @ CD-2.
  - other concepts are NOT there yet, so their costs are uncertain & low.
- NOvA continues to hope that P5 will not ignore these simple facts.

BACKUP SLIDES

NOvA mini-Review web page, April 17, 2008

NOvA Documents
- Document Database
- CDR
- Proposal

Reference
- P5 report
- NuSAG report
- CD0
- CD1

Director's Mini-Review of the NOvA Project, April 17, 2008

Link to the Directorate Web page for this review

Review Overview Information

- Technical Design Report (TDR)
- Project Parameter Sheets

Other Review Documents

- Key Assumptions [NEW]
- Project Execution Plan (PEP) [still updating]
- Acquisition Strategy
- Project Management Plan (PMP) [still updating]
- Acquisition Plan
- Quality Management Plan (QA)
- Risk Management Plan
  - Risk Summaries (includes high, medium & low) [NEW Management Risks]
- Integrated Safety Managment Program (ISM)
- Security Vulnerability Assessment
- Contingency Analysis Rules
- Configuration Management Plan
  - List of Managed Documents
  - Change Request List [NEW]
  - Change Request Report by Approval Status [NEW]
- Requirements Documents
- Monthly Reports [NEW months added with EVMS reports]
- Fermilab Guidance on Sustainable Buildings
  - NOvA Sustainble Building LEED checklist
  - Correspondence with Univ. of Minnesota on LEED [NEW]
- Design Reviews
  - Consolidated List of Comments with updated status [NEW]
- Value Management/Engineering documents

Other Review Documents (con't)

- MOUs [NEW Fermilab Directorate MOU], SOWs and Work Authorizations
- Environmental Assessment (EA) [NEW version submitted for 30 day public comment]
  - Tritium Reference Document
  - Accident Reference Document
- Minnesota EA Worksheet
- Updated Hazard Analysis - Detector [NEW]
- Updated Hazard Analysis - Accelerator
- draft PSAD
- Start-up Test Plan
- Earned Value Management System (EVMS)
  - NOvA specific EVMS
- Project Organization Chart
  - Responsibility Assignment Matrix [NEW]

Cost and Schedule from the RLS

- Guide to the Open Plan Views of the NOvA Schedule
- "Schedule on a page" [still updating]
- Budget and Contingency (R & D) [still updating]
- Budget and Contingency (Construction) [still updating]
- Activity Notes (R & D) [still updating]
- Activity Notes (Construction) [still updating]
- Gantt Chart (R & D) [still updating]
- Gantt Chart (Construction) [still updating]
- Basis of Estimate

- This webpage gives you access to
  - 45 different types of NOvA documents
  - 682 separate NOvA documents (443 are BOEs)
  - ~ 6,900 pages of documentation
    - **Up another 400 pages from the EIR in November**

EIR Major Findings & status

- (Major Finding) Increase the contingency to $60.8 million by incorporating the costs defined as MR into the project contingency.
  - DONE. The $696.2 k defined as Management Reserve (MR) during the EIR was subsequently incorporated into the project contingency. The contingency documented in the Project Management Plan (v37) and PEP of December 6, 2007 includes the MR amount, and future revisions will retain this
- (Major Finding) Consolidate the key project, technical, cost, and schedule assumptions into a single document.
  - This was done in a new document Key Cost, Schedule, Technical and Programmatic Assumptions for the NOvA Project NOVA-doc-2954
- (Major Finding) Identify the TPC consistent with DOE definition
  - The TPC was revised to be consistent with the expectation to include costs starting with CD-0, and this is documented in Project Management Plan (v37) and PEP of December 6, 2007.
- (Major finding) Review and clearly document the practice of not charging Fermilab scientist labor for what would appear to be direct labor on the project.
  - OHEP guidance on this practice has been documented and communicated, March 2008. See NOVA-doc-3083.
- (Major Finding) Make execution of the Fermilab / University of Minnesota MOU for implementation of the University of Minnesota/DOE Cooperative Agreement (CA) prior to CD-2 a high priority.
  - DONE. The Fermilab/University of Minnesota MOU for implementation of the University of Minnesota/DOE Cooperative Agreement was signed by all parties and executed. The MOU can be viewed at NOvA-doc-2824.

EIR finding. Status of Project EVMS

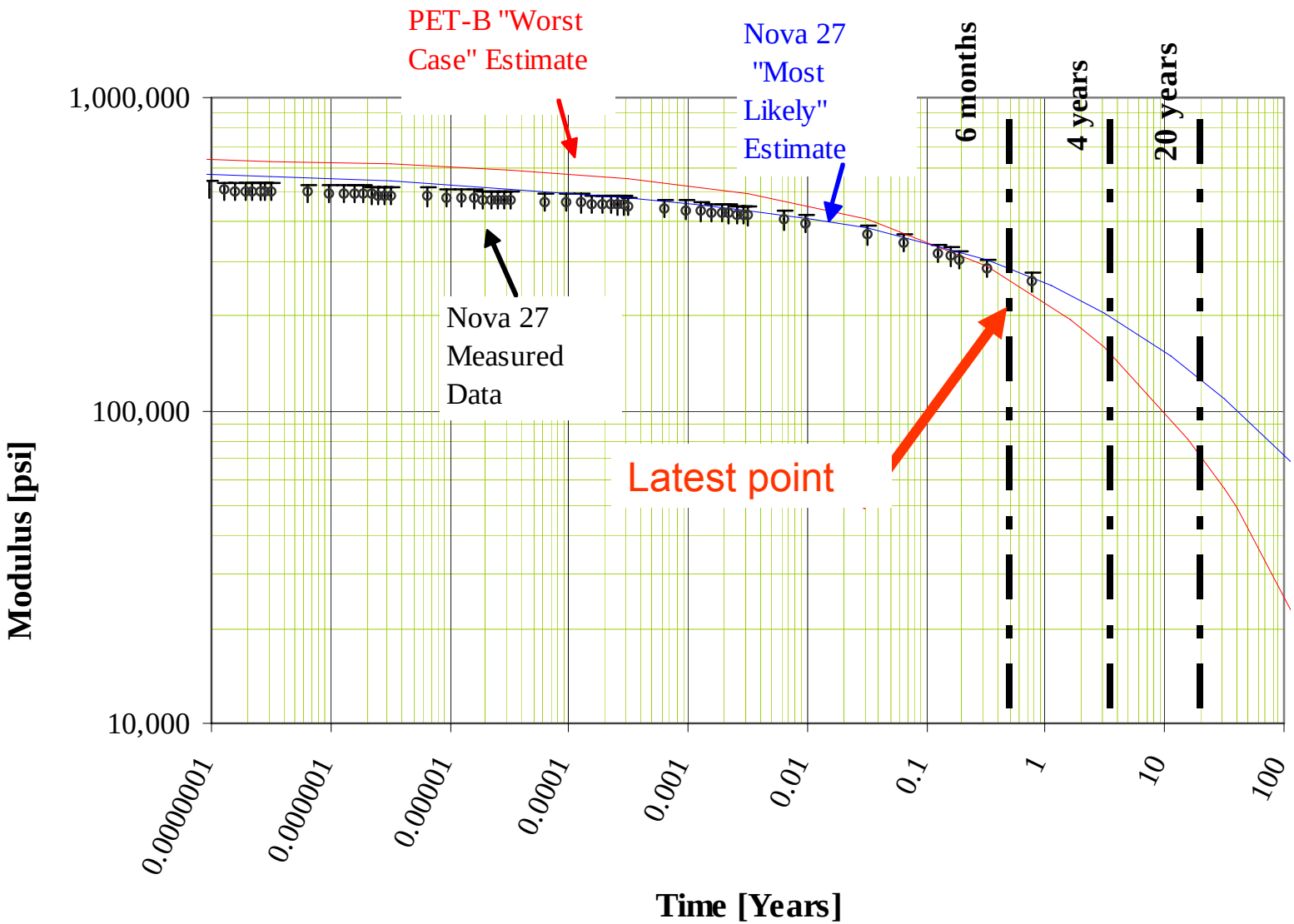
- (Finding) Ensure that the project controls system is completely "debugged" and capable of producing accurate EVMS reports prior to CD-2. If this cannot be done, obtain a written waiver from OECM that specifically allows a delay in EVMS reporting until the current errors can be corrected.
  - **The project controls system has been debugged** and used to generate EVMS Cost Performance Report data for a cumulative period and a Monthly period. This establishes capability for monthly updates and variance analysis using the NOvA EVMS data.
  - Details on next pages and in the February Monthly Report
    - We have statused 5 periods: May-July, Aug-Sept, Oct, Nov, Dec, 2007
    - We have produced CPI and SPI curves
    - We have produced WBS L2 reports
      - Starting in the Nov report, this includes the first costs from the CA (!)
    - We have done a milestone analysis
    - We have formally signed off on 24 Change Requests
    - We are tracking Change Requests in an Access database
    - We need to do formal variance analyses, hoping to do one for EIR
    - We have turned a formal crank to calculate EAC via the current effort to revise the schedule to meet the new profile.

Environmental Assessment Status

- The DOE NEPA Compliance Officer agreed to a final "pre-approval draft" EA on March 26
- DOE - FSO sent the draft out for public comment on March 27 with comments due by April 30.

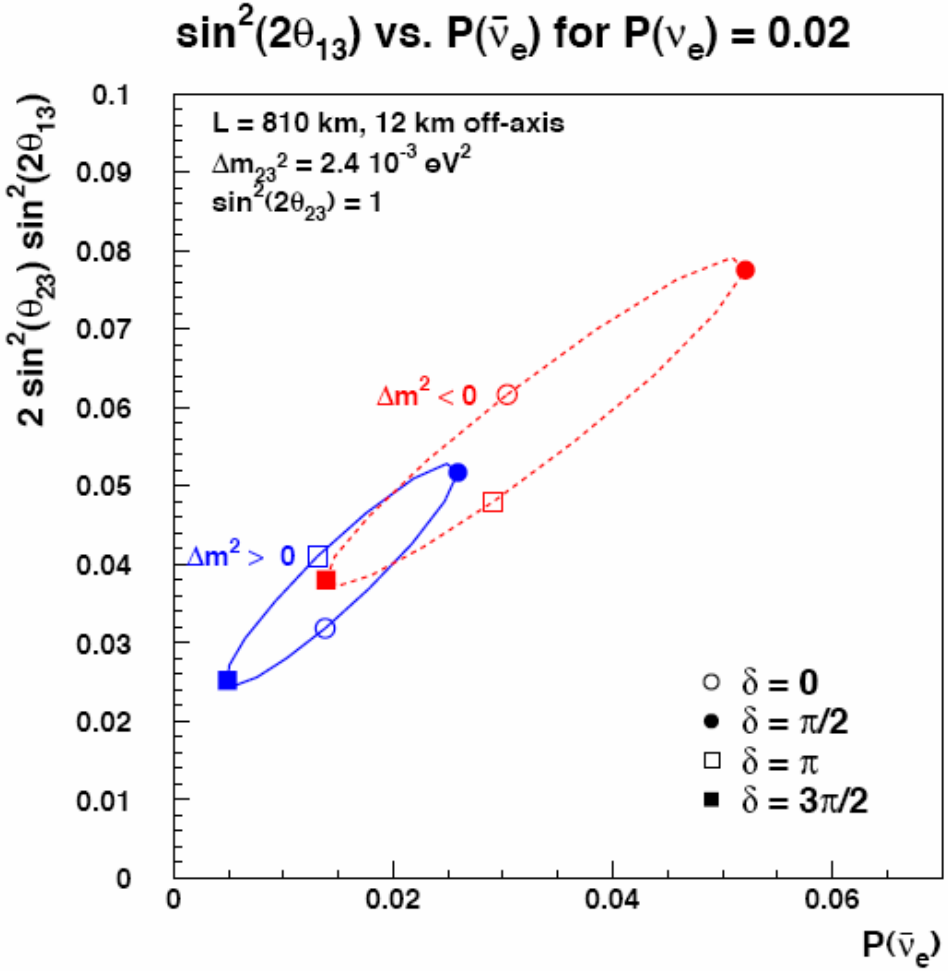
- As of Tuesday afternoon, April 22, DOE had received no comments.
  - Fermilab Public Relations had a few phone calls apparently prompted by the flyer sent to neighbors but on more general questions than the EA. One phone call was in support of the NOvA EA.

Creep properties of PVC still OK
we assume no worse than red curve at 20 years, seems to follow blue curve = most likely from consultant



Linkage of neutrinos and anti-neutrinos, of mass hierarchy & δ-CP phase

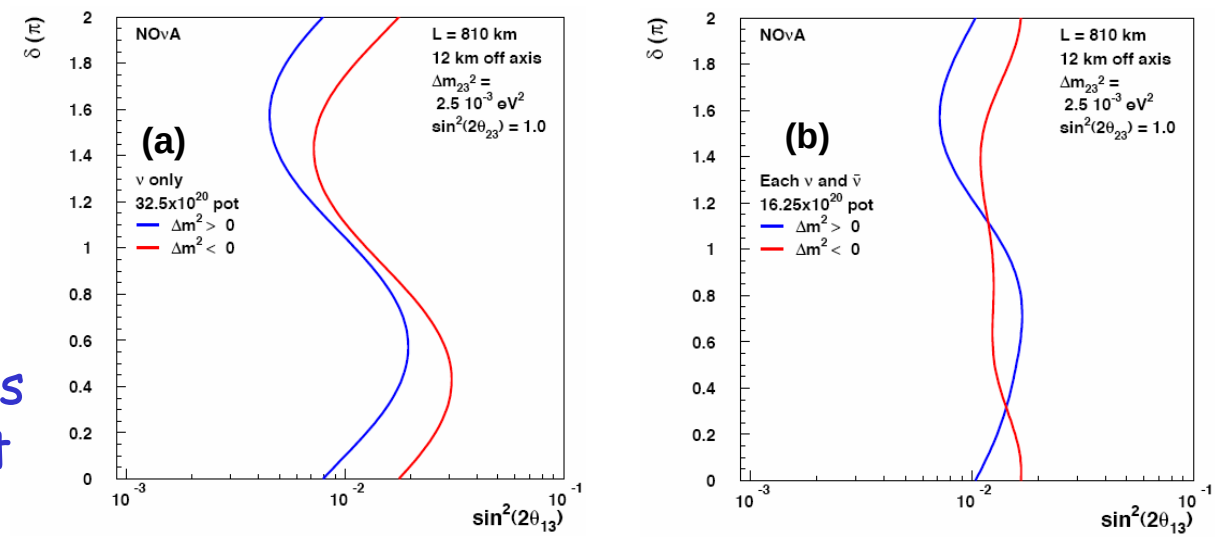
Parameters Consistent with a 2% $\nu_\mu \rightarrow \nu_e$ Oscillation Probability



NOvA neutrinos only vs. 50/50 ν and ν-bar

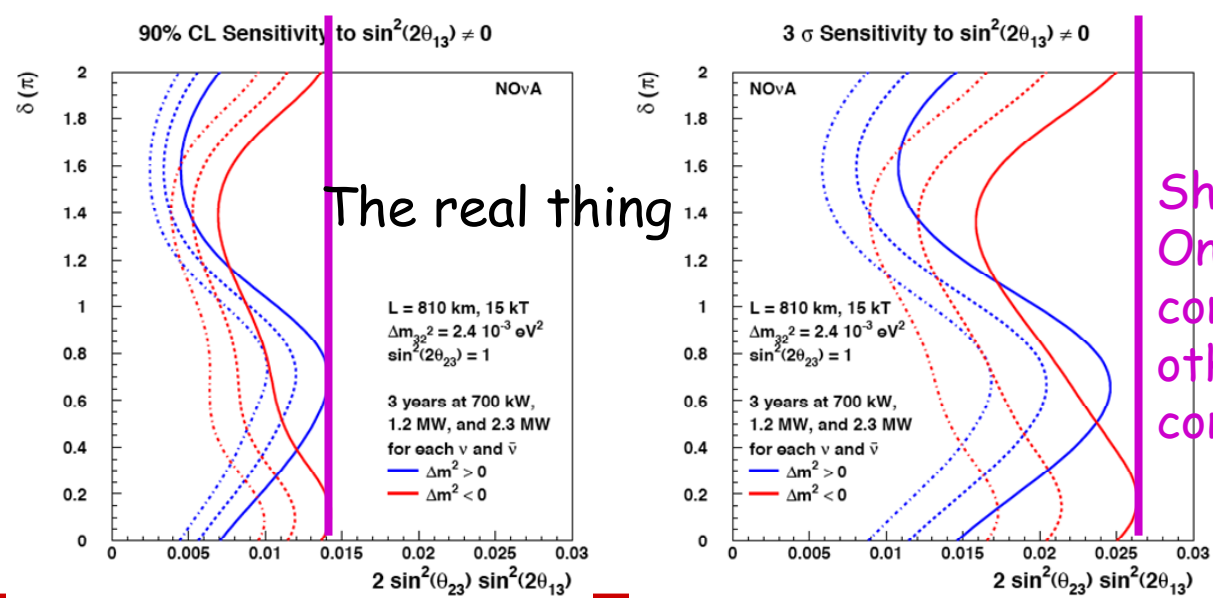
Old plots from our CDR, but show effect of ν vs. 50/50

The "wiggle" gets straightened out



Latest version of 50/50 with 3 beam power assumptions.

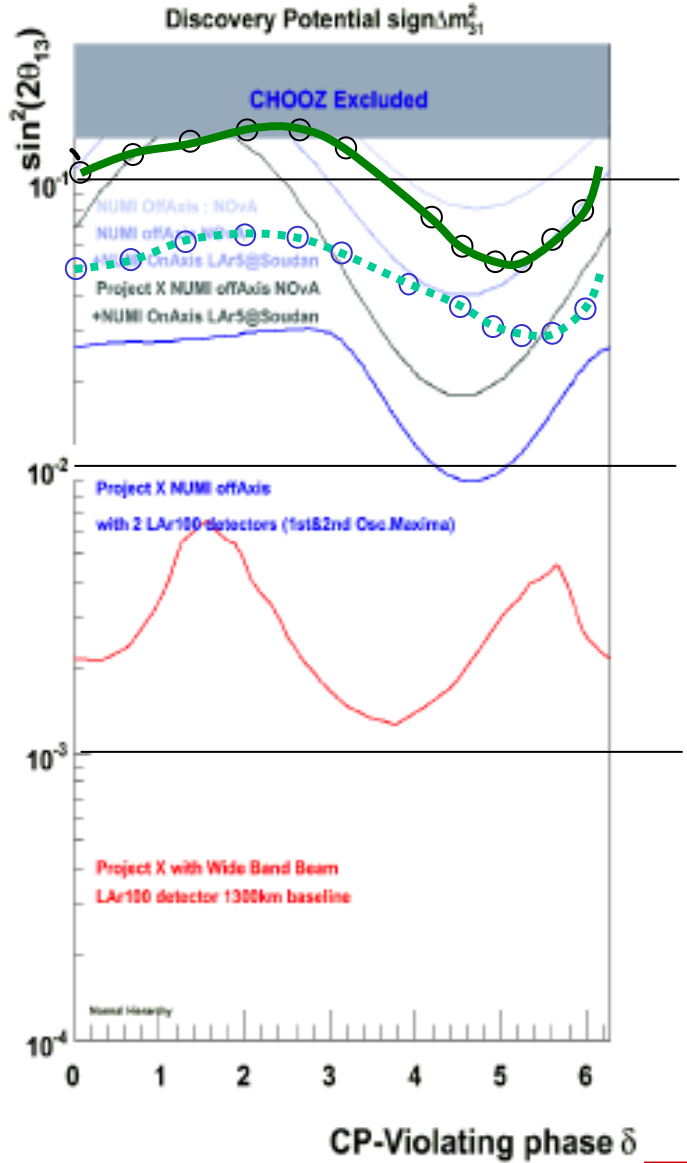
Solid lines are For 700 kW



The real thing

Shown On plot comparing other concepts

Mass hierarchy combining NOvA with T2K



700 kW, 6 yrs

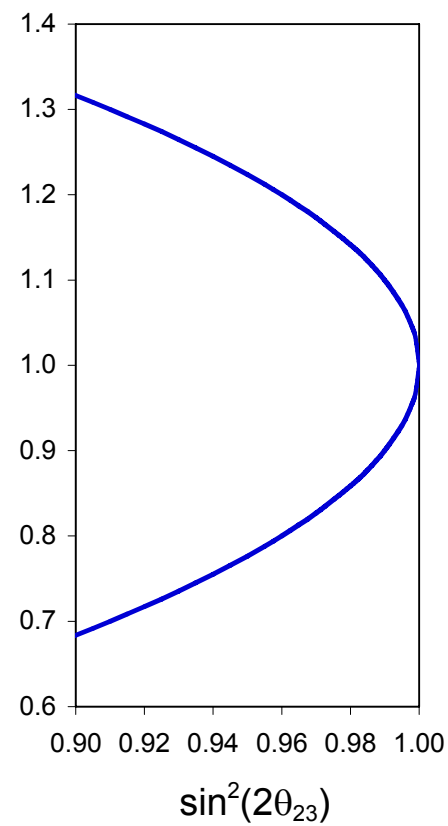
2.3 MW, 6yrs
T2K also x4 beam

Reactor vs. Accelerator

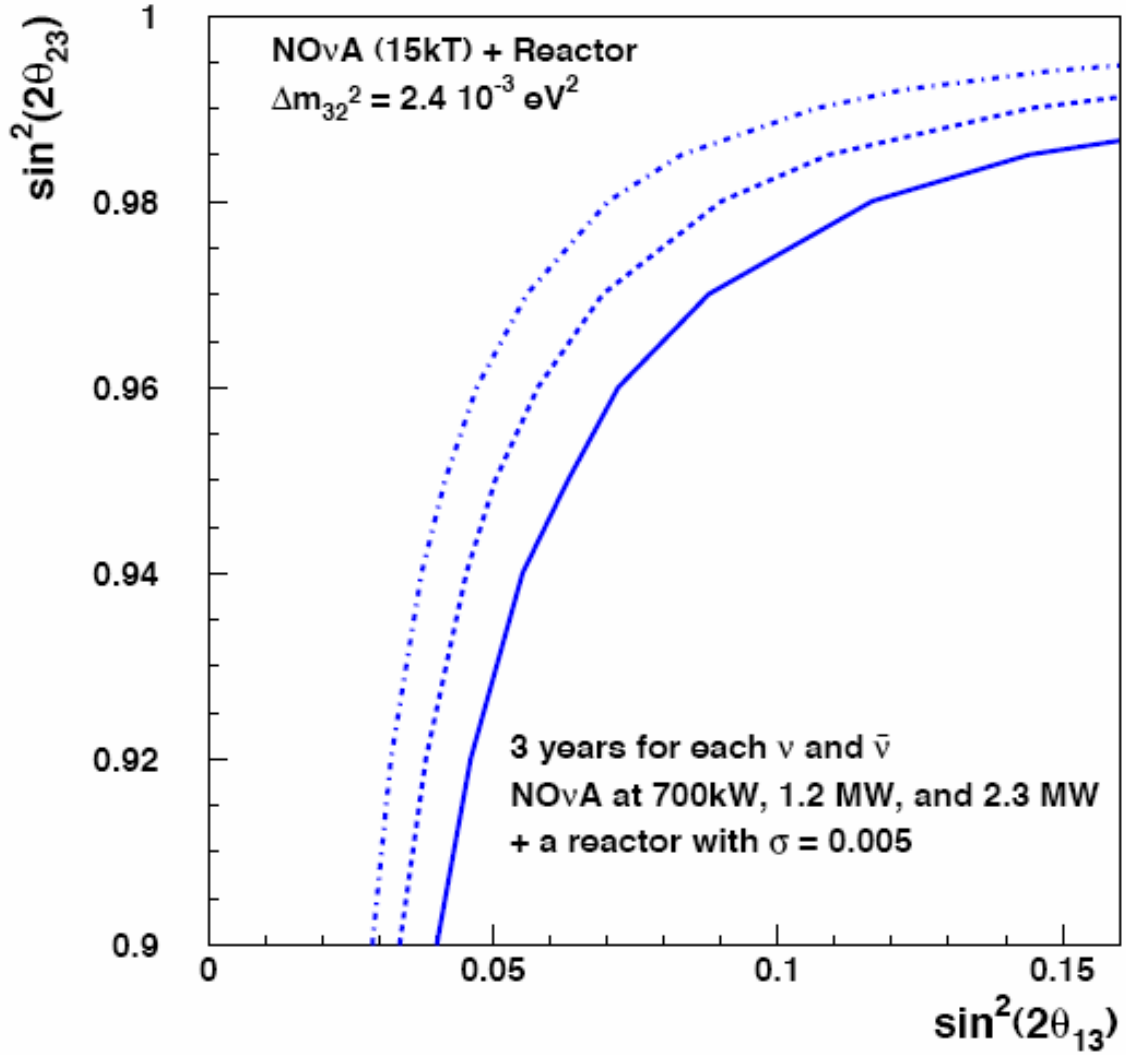
Reactor and accelerator experiments do not measure the same thing. Reactors are sensitive to $\sin^2(2\theta_{13})$, while accelerators are sensitive to $\sin^2(\theta_{23})\sin^2(2\theta_{13})$. If $\theta_{23} \neq \pi/4$, these quantities can be quite different.

The good news is that a comparison of NOνA and Daya Bay can break this ambiguity and determine whether ν_3 couples more to ν_μ or ν_τ.

$2\sin^2(\theta_{23})$ vs. $\sin^2(2\theta_{23})$



95% CL Resolution of the θ_{23} Ambiguity

The ambiguity can be resolved in the region below and to the right of the curves.

The sensitivity depends on the mass ordering, δ, and the sign of the ambiguity itself. The curves represent an average over these parameters.