NOvA Project

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Fermilab Institutional Review
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U.S. DEPARTMENT OF ENERGY

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NOvA CD-4 Deliverables

- Upgrade the Fermilab accelerator complex proton source from pre-NOvA 320 kW to a source capable of 700 kW
  - Paul Derwent is covering this in the parallel Accelerator breakout
- Build a new Far Detector Hall
  - At Ash River, Minnesota near the US-Canada border
  - The building is sized to hold an 18 kiloton detector
  - We have beneficial occupancy of the building (as of 13Apr2011)
- Build a 14 kiloton Far Detector at Ash River
  - This is a “Threshold Key Performance Parameter (KPP)”.
  - 18 kt is now authorized as an “Objective KPP” (as of 10Dec2010).
- Build a 222 ton Near Detector
  - Which will be underground at Fermilab in the MINOS tunnel
- R&D goal: Integration Prototype Near Detector
  - Now taking data on the surface near the MINOS Service building

Progress on the Ash River building

- Bare ground in June 2009; Hole in the ground + Service Building in July 2010
- Now complete, beneficial occupancy April 13, 2011.
  - Granite berm and Barite overburden in place
  - Retention pond, landscaping, fencing, interior outfitting, well water still in progress
  - Total cost ~ 34 M$ (claims settled), compare to estimate of 45 M$
    + 10M$ contingency at CD-2 in 2007 (ARRA funds came at the right moment)

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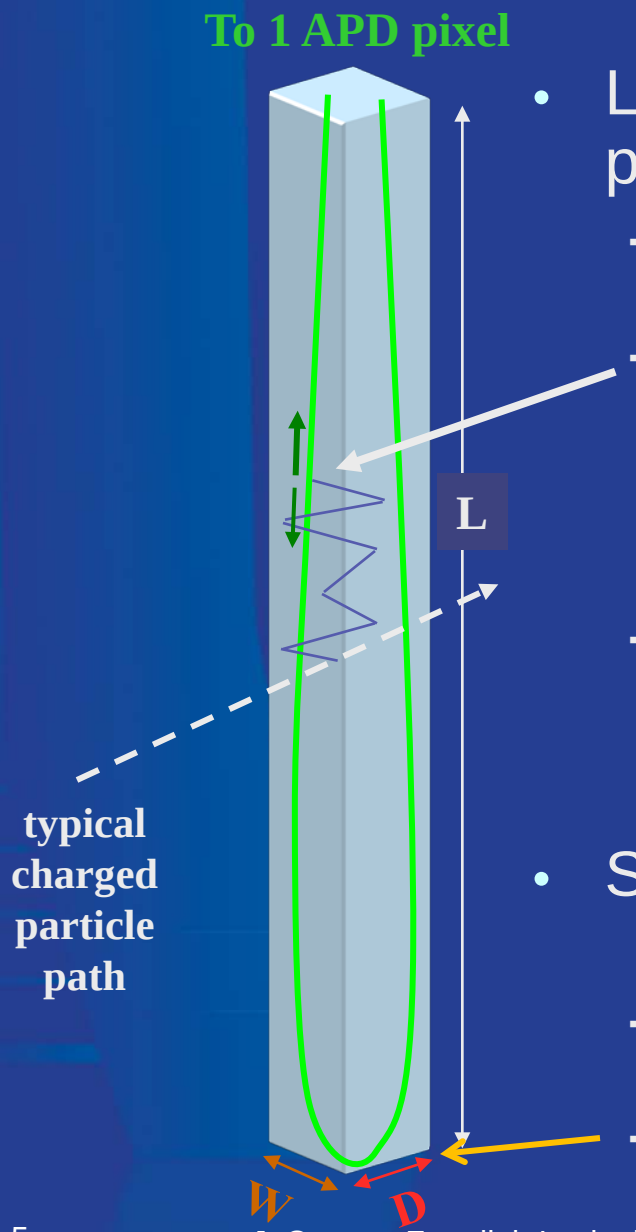
More Progress on Ash River Building

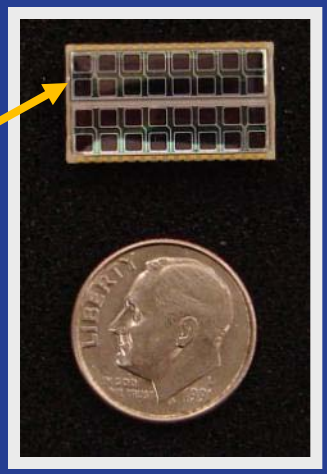
- June 2010:
  Rock bolts
  & concrete work
  in progress

- NOW -- Outfitting in progress
  - Movable access platforms at ceiling
  - South wall being leveled (needs to be flat)
  - Pivoter rails on floor
  - Movable platforms in Assembly area, ventilation for adhesive nearly done
  - 4 levels of catwalks with lights, detector power, cable trays

Reminder: NOvA Basic Detector Element



- Liquid scintillator in a highly reflective PVC plastic cell
  - Passage of charged particles through scintillator create light
  - Light bounces off reflective PVC walls until captured in a thin wavelength-shifting fiber
    - Typically light hits fiber within
      ~ 50 cm of particle path,
      ~ 8 reflections
  - The fiber is U-shaped and both ends terminate in one pixel of a 32-pixel avalanche photodiode (APD)



- Simple construction, just repeat 357,120 times
  - Cells are 15 m long (so they just fit in a 53 ft semi-trailer truck)
  - For vertical cells, pressure from liquid scintillator is 19 psi at bottom

Detector Progress: prototype Near Detector

- New Near Detector Building at Fermilab
  - 64 planes in place in July 2009, all 199 in place today
  - 30,000 gallons of scintillator in place, all PVC modules filled.
  - Front-end and Data Acquisition Electronics in place
    - Water cooling in place but not yet routinely on
  - Shortage of APDs (see next slide)
    - 83% of fiducial volume is live, 20% of shwr containment, 93% of μ catcher

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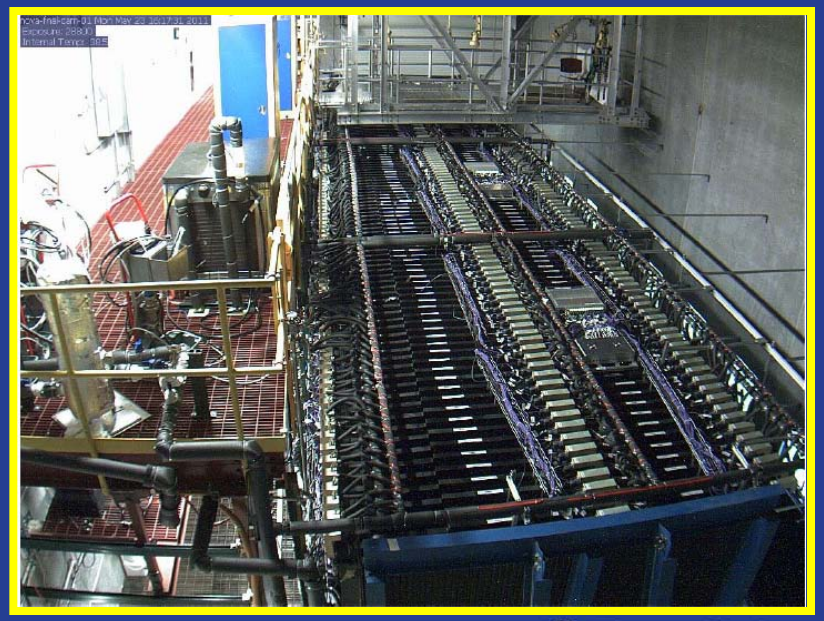
Detector Progress: prototype Near Detector

- We learned a tremendous amount while assembling this prototype – this will make Ash River assembly smoother.
  - Tested access issues (rolling platform prototype), tested fill machines
    - Found mechanical interferences – modified Ash River plans
  - Found problems with PVC module manifolds
    - cracks reported here last year, but all now repaired in place
  - Water system redesigned after installation & tests with original
  - Learned APDs must be installed with care
    - Cleanliness counts !
    - Now working to add protective coating from Hamamatsu
    - Added 3 mil shim to keep fibers away from APD surface
  - Noise from thermoelectric cooler circuit, now fixed with a cap board
  - Data Acquisition software was a huge effort -- Now performs with headroom, stress tests continue



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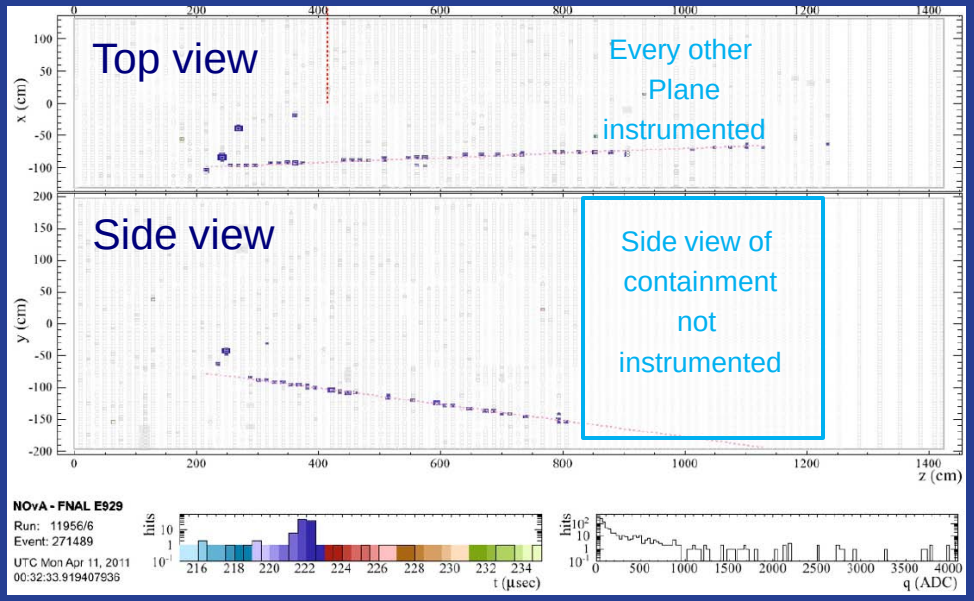
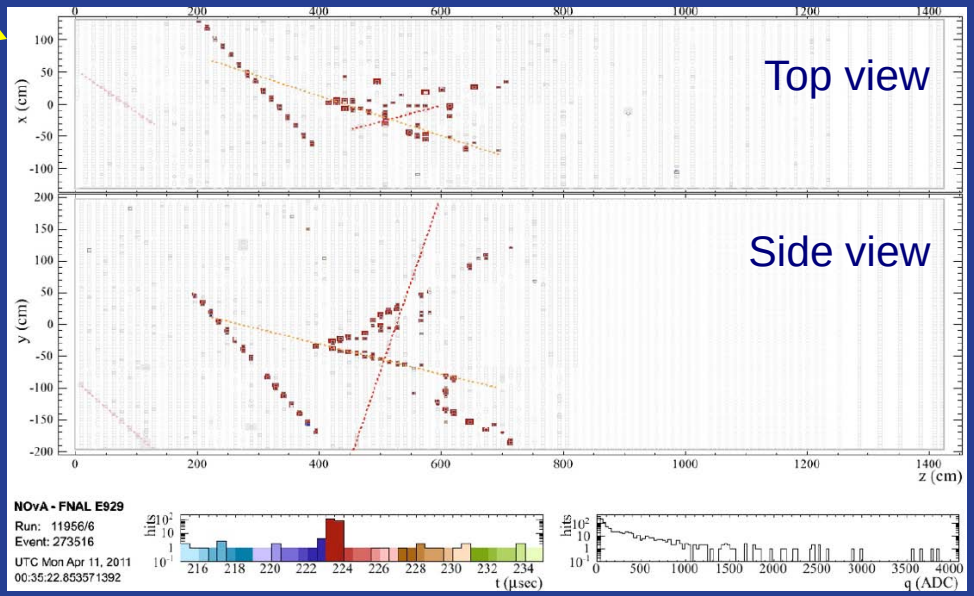
Detector Progress: prototype Near Detector

- **And we see neutrino events !**
- In NuMI neutrino mode
  - 110 mrad off-axis
  - First event seen on April 10, 2011
  - Now have about 150 in-time events
    - ν_μ CC
    - NC with multiple vertices
- In NuMI anti-neutrino mode
  - First event seen on Dec 15, 2010
  - Now have about 900 in-time events
- Booster anti-neutrino mode
  - 375 mrad off-axis
  - Events seen in March 2011
  - Now have > 200 in-time events





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Detector progress: Commodities

- Scintillator (~ 3.2 million gallons)
  - Mineral Oil contract with Renkert Oil (Riverdale, Illinois) (fixed price)
    - 120 railcars of Mineral Oil. First 3 railcars delivered (75,000 gallons)
    - Fixed price if crude oil is in the range $60 – $110 bbl.
    - Outside this range we pay an indexed price.
      - e.g. at $111/bbl would pay 22% more, have 30% contingency set aside
  - Pseudocumene, 155,000 gallons, 5% of mixture
    - 22 ISO tanks (international shipping method)
    - Also Renkert Oil, but here they are a broker with a Chinese firm.
    - Indexed price relative to Asian naptha (which follows crude oil)
  - Wave-shifting chemicals in hand (had these last year)
  - Toll blending P.O. just placed with Renkert Oil (but at Wolf Lake, Indiana)
    - $0.67 / gallon to blend + 600 K$ of infrastructure. This is a fixed price
    - 30,000 gallons blended as test (used in prototype Near Detector last fall)

- Wavelength Shifting Fiber (~12,000 kilometers)
  - Fiber from Kuraray in Japan, still delivering after earthquake.
  - 5,400 kilometers already delivered (44% complete vs. 12% last June)

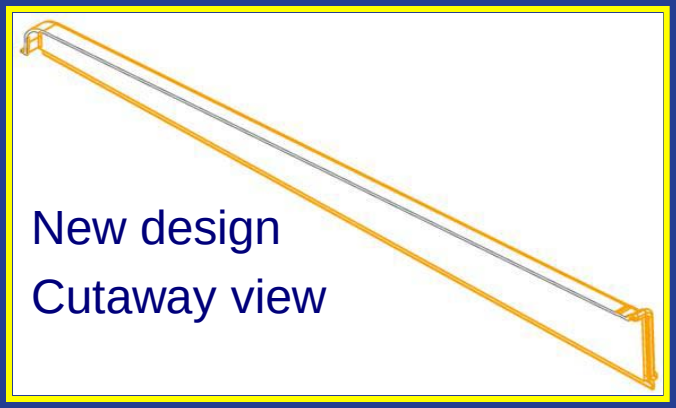
Detector progress: Commodities

- PVC Extrusions
  - ~ 23,000 required, 13.8 million pounds
  - PVC resin from PolyOne in Pasadena, Texas, fixed price $ 1.00 / lb
  - Extruding by Extrutech in Manitowoc, Wisconsin, fixed price $ 0.96 / lb
  - Have final die tuned, production started in January 2010
  - Have 1184 extrusions in hand which meet our specifications
    - Specs on 6-inch long parts cut between each 51 ft extrusion: part size checked optically, part tensile strength test, part performance under 200 psi hydraulic test, reflectivity checked
    - Part performance under 1 atmosphere pressure checked on every 51 ft extrusion

  - But we are still fighting some knitting problems and reflectivity problems which keep us from full rate production
    - Running at about 50% of full rate now, rest of the time is still R&D
    - Melt temperature low, need 370–390 deg , some is outside this range
    - Next step: change to more aggressive screws in extruder
    - Next step: slight modification to die for 16 of the 70 knit points
    - Next step: get TiO2 vendor to remove rutile form in all shipments

Detector Progress: PVC Module Production

- Module factory is at the University of Minnesota
- Major effort over the last year to understand the cracked manifold issue, then to redesign the part to avoid cracks
  - Simpler part, removed all stress points
  - Learned how to check new parts for hidden cracks using acoustic micro imaging (Sonolab Midwest), so can check a samples for quality



- New manifolds are due in July
- Other parts to match final extrusion size specifications come in later, so production to start in November 2011

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Detector Progress: Electronics

- Front End Board (FEB-4)
  - 400 assembled for Near Detector
- Components for FEBs at Ash River:
  - Avalanche Photo diodes (APDs)
    - Received 500 from Hamamatsu production for Near Detector
    - Hamamatsu yield was good enough for them to quote a cost of $350 each
    - About 20% were lost on installation
      - Oil incident, fibers hitting APD surface, general dust and whiskers
      - Unable to clean any & restore functionality for longer than a few days
      - Pursuing thin (20 micron) protective coating, cost still unknown but expected to be small compared to the $350 per part.
    - In most recent installation with more care, only 5% lost
  - Have ordered the low noise ASIC amplifiers
  - Have in hand all the ADCs
  - Starting to procure other parts (1 regulator unavailable ➔ version 4.1)

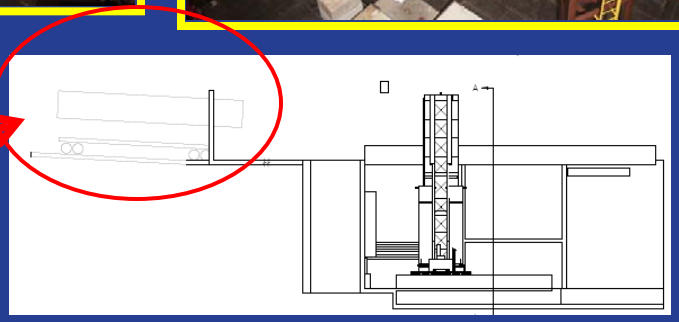
Detector Progress: Data Acquisition

- General Overview of progress during the last year:
  - System installed for Near Detector works
    - Software / Firmware took a long time to shakedown (Oct-Feb)
    - Have now sustained the rate expected at Ash River all the way through the data logger
    - Stress tests of system in progress during “no target” time
- Data Concentrator Modules (DCMs) (Each read out 64 FEBs)
  - 11 installed on Near Detector
  - Ash River version will have a faster version of PPC processor (25%), increased processor RAM to 2 GB, and a Larger FPGA
- Time Distribution Units (TDUs)
  - 3 are installed on Near Detector, no major changes for Ash River.
- Data Acquisition / Networking / Computers: All commercial items
- Power Distribution, Cables
  - Buying parts for Ash River now, testing at Univ of Virginia

Detector Progress: Assembly

- Another prototype still remains, the Full Height Engineering Prototype (FHEP) at Fermilab, CDF deep pit
  - The prototype Pivoter machine is complete and tested, Nov 11, 2010.
    - Have also tested repeatability of placing a fake block (unistrut outline with sensors)
  - Tests with full height PVC modules still to come in July
    - Will fill this block with water after positioning studies are complete

FHEP PVC Assembled at ANL, move to Fermilab



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Detector Progress: Assembly

- Added personnel to Ash River detector outfitting so the assembly people can concentrate on a smaller scope of work
  - 5 Outfitting workshops held during the last 6 months.
    - Refined realistic schedule based on Near Detector now in hand.
    - Cable trays, water cooling, electronics installation, scintillator filling,…
  - Ash River Pivoter designed and under construction
    - Simpler construction, now bolt together 30 separate table sections
    - Lower weldments, counterweights, pivot uprights, hydraulics in hand
    - 250 drawing bid package for assembly table out, bids due next week
  - Ash River assembly simplified
    - One kind of PVC module, all made of thick (4.5 mm) PVC vs. original plan with thin (3.0 mm thick) horizontal PVC modules
      - Increased safety factor in structure, 1.3 → 3.1, can fill immediately
    - All blocks will have 32 planes: **H**,V,H,V,….,H,V → 1st H will cause slight lean to south but < 0.5 inch after 20 years
      - Structure to be built with all blocks initially leaning south with nominal tilt of 1.0 inch ± 0.5 inch, avoids large gaps between blocks
      - Safety factor when leaning is 2.5 for filled blocks after 20 years

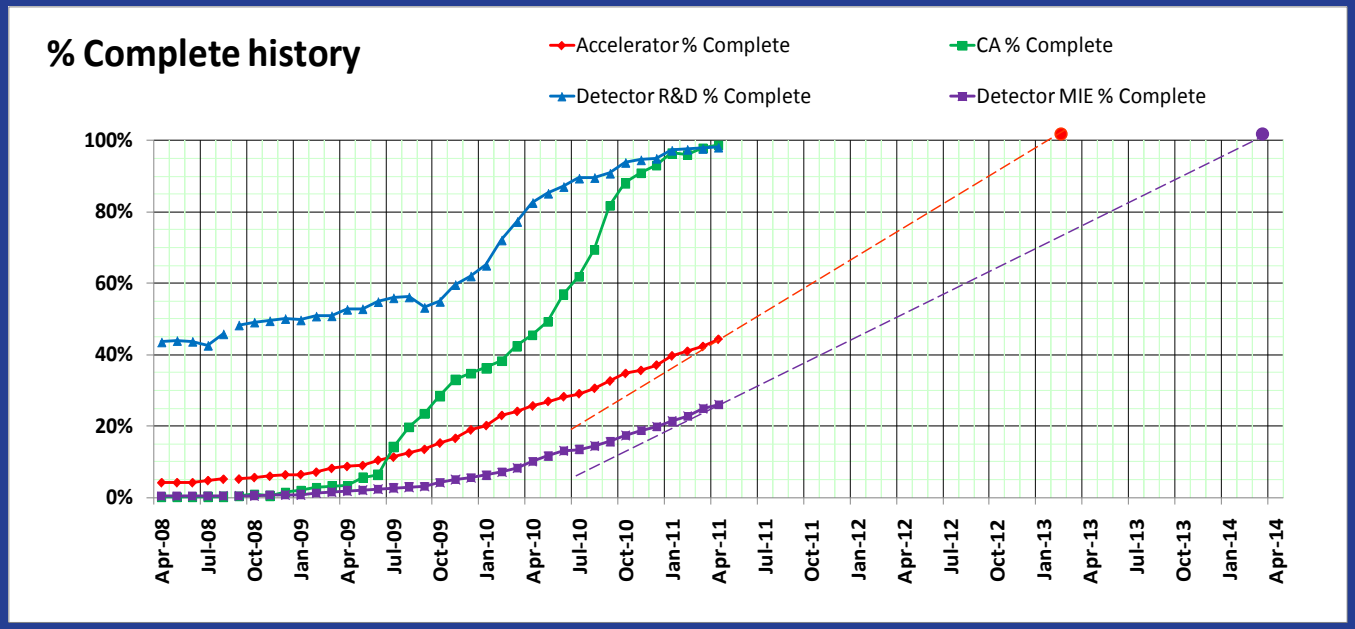
Project Progress: Financial Status

- Our Total Project Cost is 278 M$
- As of May 2011 have obligated 168 M$, costed 110 M$
  - The project is 70% obligated and 46% complete
    vs 29% complete last July
  - The Estimate at Completion = 244 M$, remaining 34 M$ is contingency
- Basic data in Funding, Obligations, BCWS, BCWP & ACWP,
  - BCWS = Budgeted cost of work Scheduled
  - BCWP = Budgeted cost of work Performed
  - ACWP = Actual cost of work Performed

Project Schedule

- We are in the middle of a multi-month effort to rework the Far Detector assembly schedule in every WBS into a more realistic estimate
  - Currently show a 130 day schedule slip relative to a year ago when we had 275 days of float between the last deliverable milestone of "Neutrino events seen in last superblock at Ash River" and CD-4.
    - 6 month slip primarily due to PVC module delays from additional R&D and redesign due to the manifold cracks, but also due to Pivoter design and construction delays
  - Attempting to recover some of the lost float during this re-planning.
- Expect:
  - Start detector construction at Ash River in January 2011
  - Accelerator shutdown for NOvA, March 2012 – Feb 2013
    Should have 1 block (0.5 kt) of the Far Detector operating just before the 2012 shutdown begins
  - At end of Accelerator shutdown, NOvA is operating about 60% of the Far Detector & the Accelerator is commissioning 700 kW beam.
  - CD-4 is November 2014

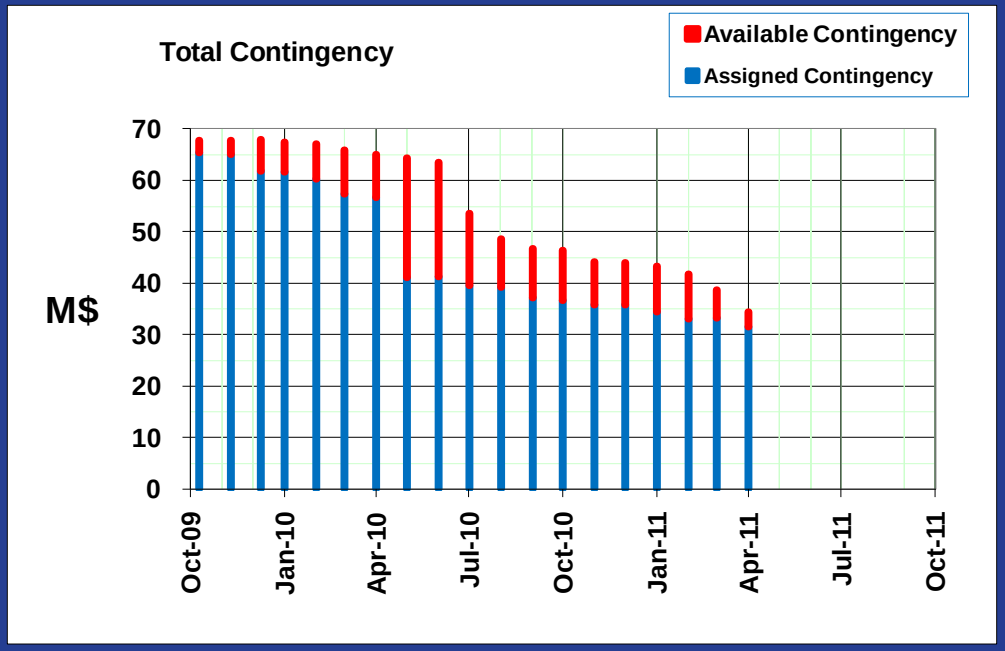
% Complete on the four basic parts of the Project



- Ash River building and Detector R&D are complete.
- Accelerator part of NOvA (discussed in the parallel session) is at 45%, finishes at the end of the 2012 accelerator shutdown
  - Need higher rate of work to get there – happens naturally in the shutdown.
  - **22 M$ to go**
- Detector part of NOvA at 26%, finishes in early 2014
  - **107 M$ to go**

Project Progress: Contingency Status

- Assigned contingency is assigned task by task according to risk
- Remaining contingency is "Available"
  - Increases unless tasks require more $ than in base budget + assigned cont.
    - e.g., when we get the final price for APDs
  - Decreases as we add forgotten tasks
    - e.g. add QA, change a design,…
- Currently stand at 34.4 M$ of contingency
- We have 26% Contingency on the remaining work.



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Contingency Use

- **First** we use Available contingency to reduce project risk, to hold the project schedule, or to advance the project schedule
  - We have done this many times during the last year. (thicker PVC example)
- But we still dream of using some of it for other things
  - Now authorized to build > 14 kilotons, up to 18 kt (~9 M$/ kt incl. contingency)
  - Also thinking about Near Detector items to address systematic issues
    - e.g. in a possible scenario where $\sin^2(2\theta_{13})$ is small and all experiments in the next round are chasing limits, not signals.
    - Larger Near Detector, 3 PVC modules wide instead of 2
      - Better event containment, can compare left/right samples to check the background we are extrapolating to Ash River
    - Another Near Detector, perhaps mobile in another larger hall to look for LSND / MiniBooNE effects at fixed L, variable E
      - Current Near Det at L/E = 0.4, but short baseline oscillation signals are above 0.4. Those events occur downstream of our Near Detector.
    - SciNOvA in front of our Near Detector.
      - Solid scintillator device (SciBooNE already took data) with half the cell size of NOvA to check our event pattern recognition & identification.
    - Testbeam NOvA module in an electron beam at Fermilab

SUMMARY

- The NOvA Project continues to make good progress.
- The project has sufficient funding and contingency
- The project schedule has slipped about 6 months, but we still have substantial float to CD-4 and funds to pursue work-arounds.

- **Still a major challenge ahead – fill this hall !**

Backup slides

Institutional contributions by WBS Level 2

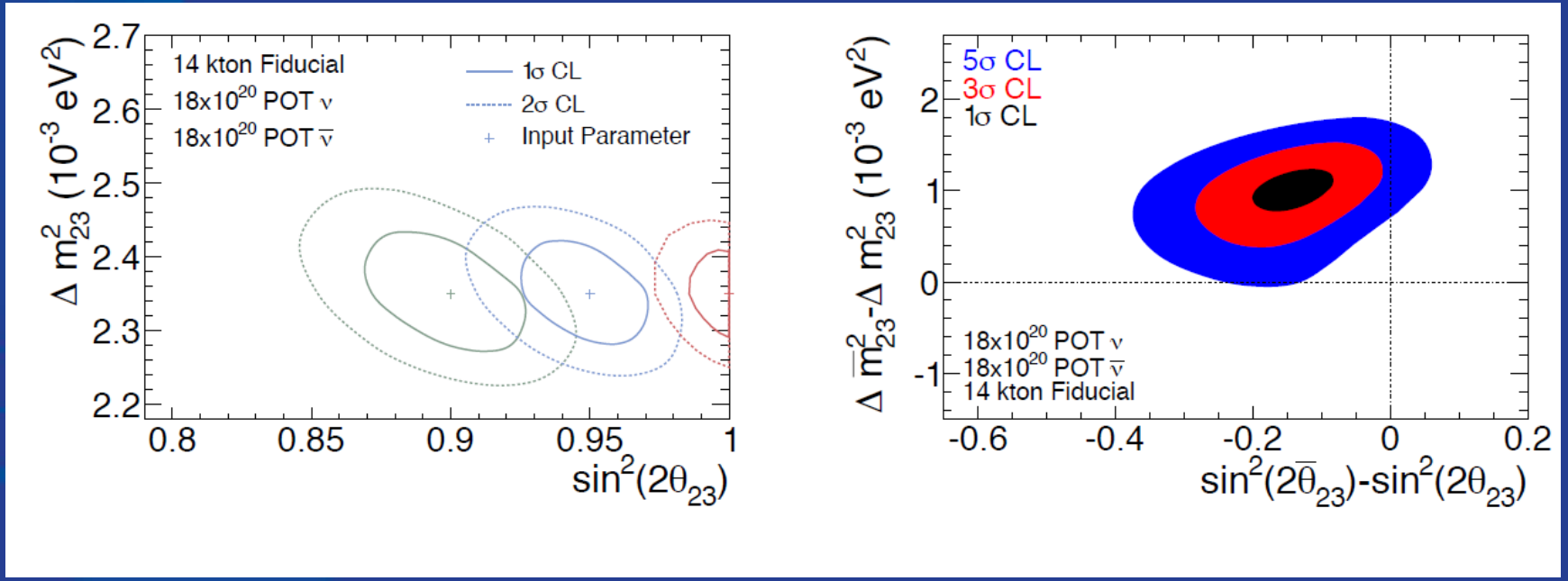
- Accelerator and NuMI Upgrades
  - **Fermilab**
- Site and Building
  - **Fermilab, U of Minnesota**
- Scintillator
  - **Indiana U**, Fermilab, Southern Methodist U
- Fiber
  - **Michigan State U**, U Texas Dallas
- PVC Extrusions
  - **ANL**, Fermilab, U of Minnesota
- Extrusion Modules
  - **U of Minnesota**
- Electronics
  - **Caltech, Harvard, U of Virginia**, Indiana, Tufts U, Fermilab, Minnesota
- Data Acquisition
  - **Fermilab**, Minnesota, Indiana, U of South Carolina, U of Minnesota Duluth
- Detector Assembly
  - **ANL, Fermilab,** Minnesota

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 2008)
- **$\sin^2(2\theta_{13}) \approx 0.06$**
  - 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 2008)
- **$\sin^2(2\theta_{13}) \approx 0.03$**
  - 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, RENO, T2K)**

MINOS neutrino / anti-neutrino asymmetry

- Sensitivity after 3 years each of neutrino and anti-neutrino beam
- If the MINOS neutrino / anti-neutrino result persists, this is the sensitivity of NOvA to the difference in the parameters



Off-Axis Beam