NOνA Project Overview

John Cooper
Project Manager

June 4, 2007

Project Overview

- Today's series of Plenary Talks are designed to walk through the NOvA Project and describe:
  - The NOvA Technical Design Report
    - ~ 600 pages - I hope you got a chance to read some of it.
    - Some sections are still "under construction".
    - In DOE language this is a "preliminary design" at about the 25 – 30% level as appropriate for CD-2
    - Some parts of NOvA have an "advanced technical design" at the 90 – 95% level for CD-3a
      - The prime example is the design of the access road to our Far Detector Site.
  - The NOvA Work Breakdown Structure (WBS) and Organizational Breakdown Structure (OBS)
  - The NOvA Cost & Schedule effort in Open Plan.
    - Critical Path, Milestones, Basis of Estimate, Risk,…
    - ~ 6,000 lines in the schedule

Project Overview

- At this report, our TDR and Cost & Schedule are not quite aligned
  - TDR talks of 18 kt,
  - Cost &Schedule needs to be tuned to a TPC of $260 M
    - It will be 14 kt for $ 260 M
      - » From simple scaling arguments
    - We first saw this roll-up late Saturday night
      - » Scrubbed it a bit <u>in both directions</u> with a few people for a few hrs, but it needs a lot more scrutiny
      - » I hope you can help us with your independent view in drill-downs into the Cost & Schedule
  - Since we've had no time to adjust, all of the documentation in this review will refer to 18 kt and its associated cost

Project Overview

- We depart from the traditional agenda a bit and jump right into the project details, then return at the end of the day to the scientific motivation
  - Partly because the Fermilab PAC, NuSAG, and P5 have already reviewed the science in depth
  - Partly so we can end the day of presentations by reminding ourselves why we want to do this project
    - When we get there, remember 18 kt for 6 years running is equivalent to 14 kt for 7.7 years

- For now note that we are looking for $\nu_\mu \rightarrow \nu_e$ oscillations at 2 GeV over a baseline 810 km from Fermilab
  - So the Far Detector needs to discriminate between electrons and muons but needs good rejection against neutral currents (with a π^o)
  - A Near Detector at Fermilab must measure the neutrino components in the NuMI beam before oscillations
  - We need all the beam we can get on the NuMI target

WBS/OBS

Project Work / Organizational Breakdown Structure

J. Cooper, Project Manager
R. Ray, Deputy Project Manager
N. Grossman, Associate Project Manager

- 2.0 **Accelerator & NuMI Upgrades (ANU)** — N Grossman, E. McCluskey, dep
- 2.1 **Far Site & Building** — S. Dixon
- 2.2 **Scintillator** — S. Mufson
- 2.3 **Fiber** — C. Bromberg
- 2.4 **PVC Extrusions** — R. Talaga
- 2.5 **PVC Modules** — K. Heller
- 2.6 **Electronics** & 2.7 **Data Acquisition** — L. Mualem
- 2.8 **Near Detector** & 2.9 **Far Detector Assembly** — D. Ayres
- 2.10 **Project Management**

WBS 2.x for the construction project, similar WBS 1.x for R&D/Ops

Project Office Staff:

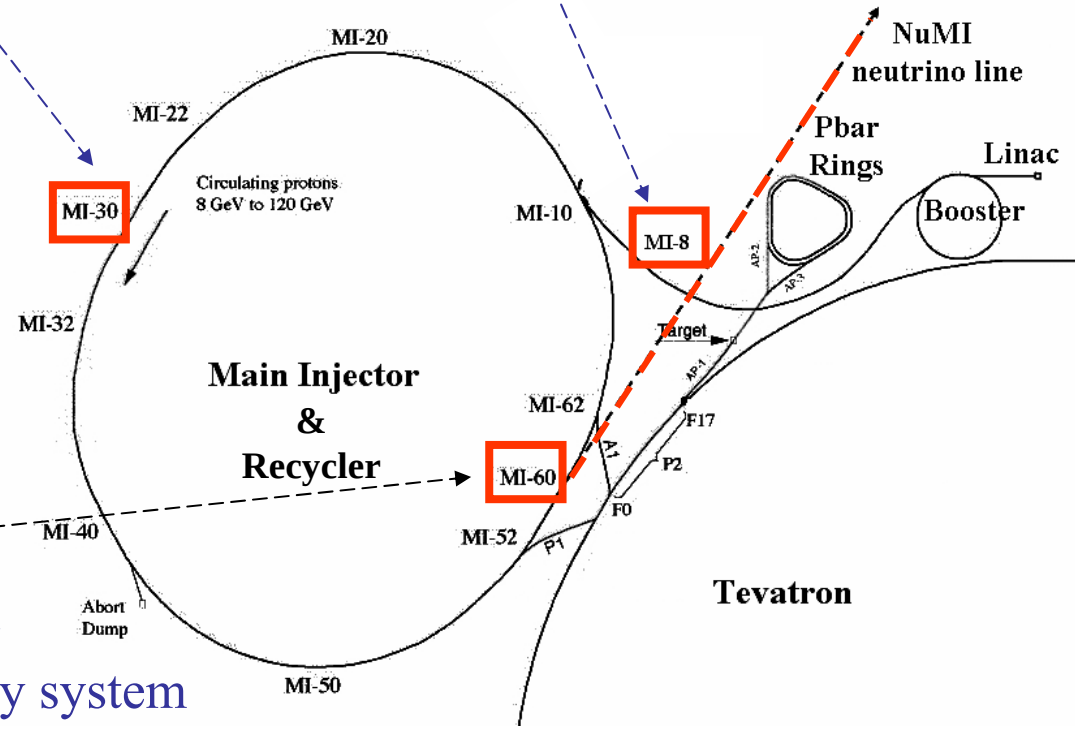
Dave Pushka, Mechanical Project Engineer
John Oliver, Electronics Project Engineer
Anna Pla-Dalmau, Project Chemist
Suzanne Pasek, Project Financial Officer
Bill Freeman, Project Scheduler
Ken Doman, ANU scheduler
Harry Ferguson, Assistant Project Scheduler
Keith Schuh, ES&H, EA, pSAD
Mike Andrews, ES&H for Accelerator side
Alan Wehmann, websites & document databases
Nancy Grossman, QA oversight
Elaine McCluskey, Configuration Control oversight
Jon Paley, databases

NOvA Components

- Upgrade the Fermilab accelerator complex proton source from pre-NOvA 320 kW to a source capable of 700 kW
  - Commissioning of the accelerator upgrades is not part of the project
- A new Far Detector Hall at Ash River, Minnesota near the US-Canadian border
- An 18 kiloton Far Detector
  - which gets assembled at Ash River
- A 200 ton Near Detector
  - which gets assembled underground in a small new cavern adjacent to the existing MINOS access tunnel
- An 88 ton Integration Prototype Near Detector
  - which gets assembled in the existing MINOS Service Building on the surface
  - This is the goal of the detector R&D work.

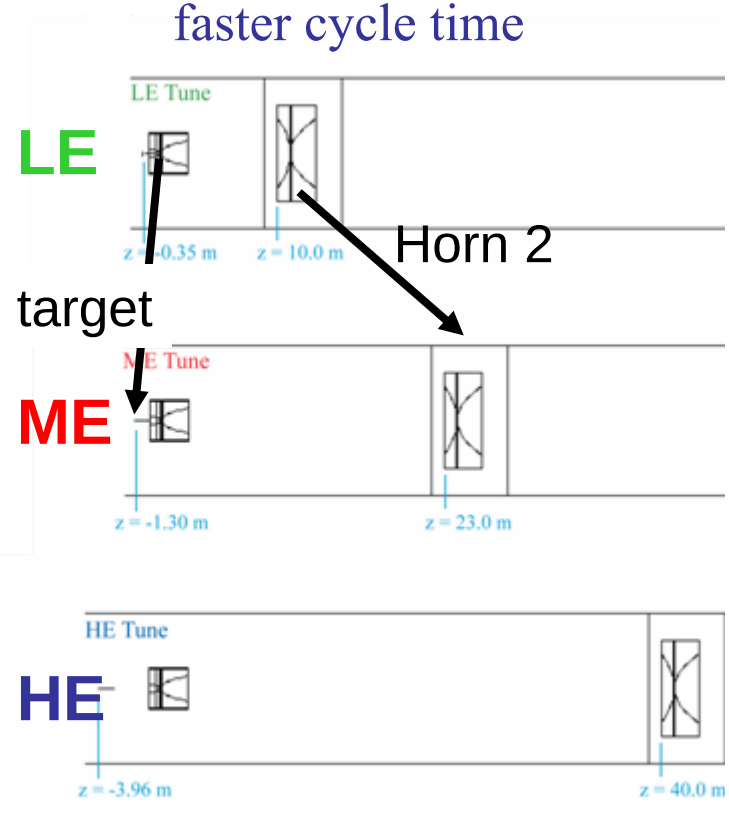
Accelerator and NuMI Upgrades

- Recycler
  - gets converted from anti-proton storage ring to a proton storage ring/ pre-injector into the Main Injector once the Tevatron Collider program ends
  - New injection line at MI-8, redirect from MI to Recycler
  - New extraction line at MI-30, from Recycler to MI
  - These lines (+ abort) require 5 new kicker systems
- Main Injector (MI)
  - Cycle time reduced from 2.2 sec to 1.5 sec since stack in Recycler
  - Reduce further to 1.33 seconds with 2 more RF stations at MI-60 204 GeV/sec → 240 GeV/sec
  - Upgrade one quad power supply system for increased ramp rate

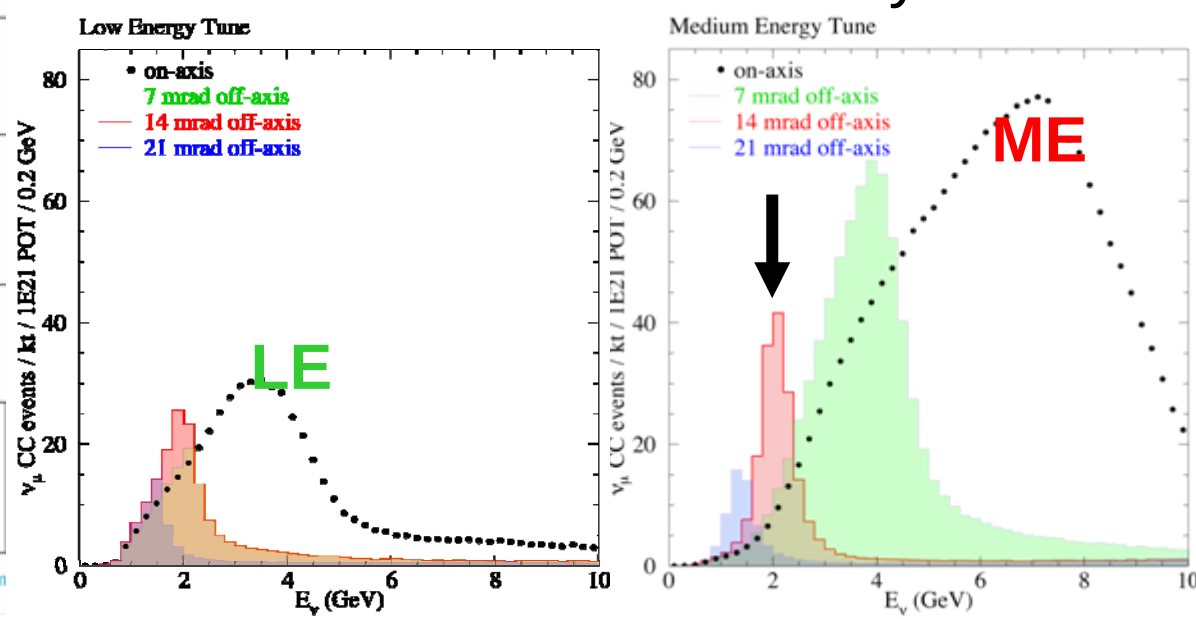


Accelerator and NuMI Upgrades

- NuMI Beamline
  - New Medium Energy target, upstream from current low energy target
  - Horn stripline extension so Horn #2 can move to medium energy position
  - Cooling modifications and power supply upgrades to handle the 700 kW and faster cycle time

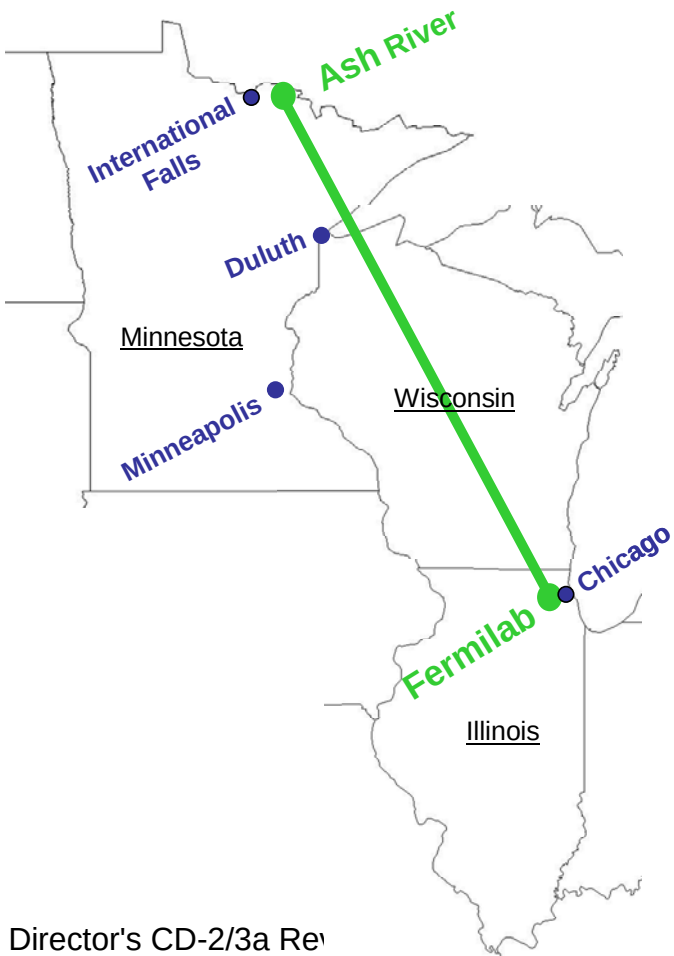


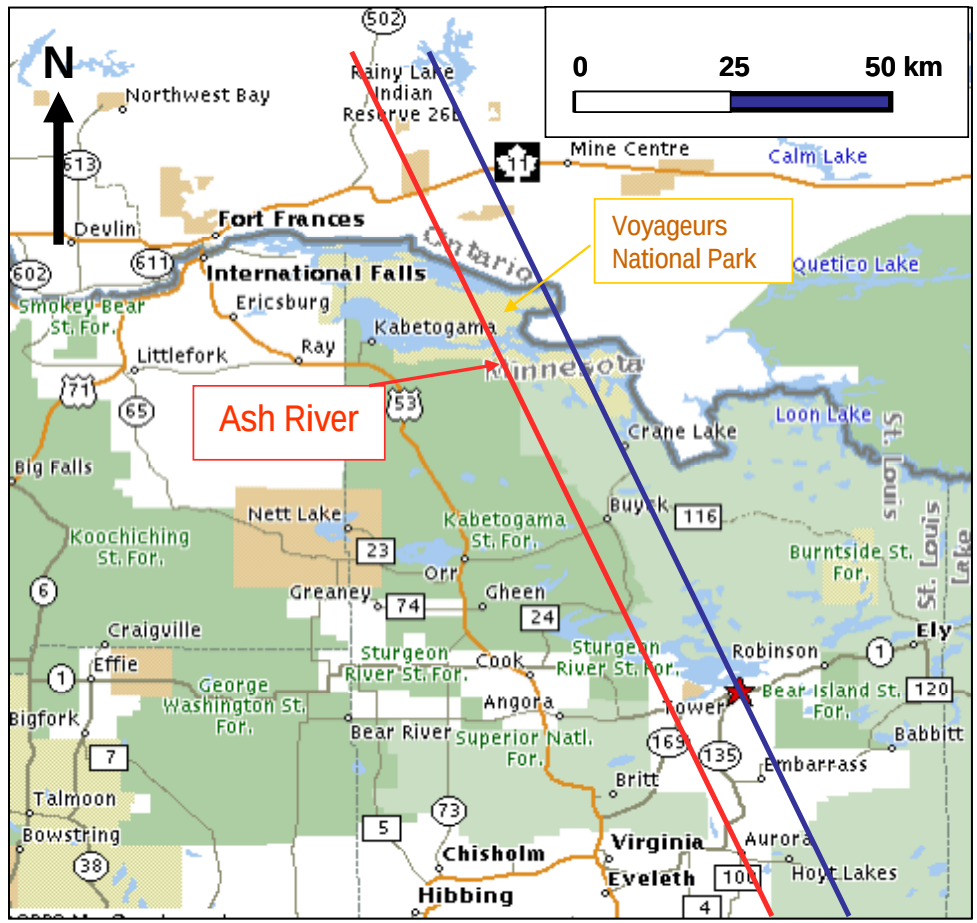
NOvA is off-axis at 14 mrad
For increased 2 GeV ν yield



Ash River Site

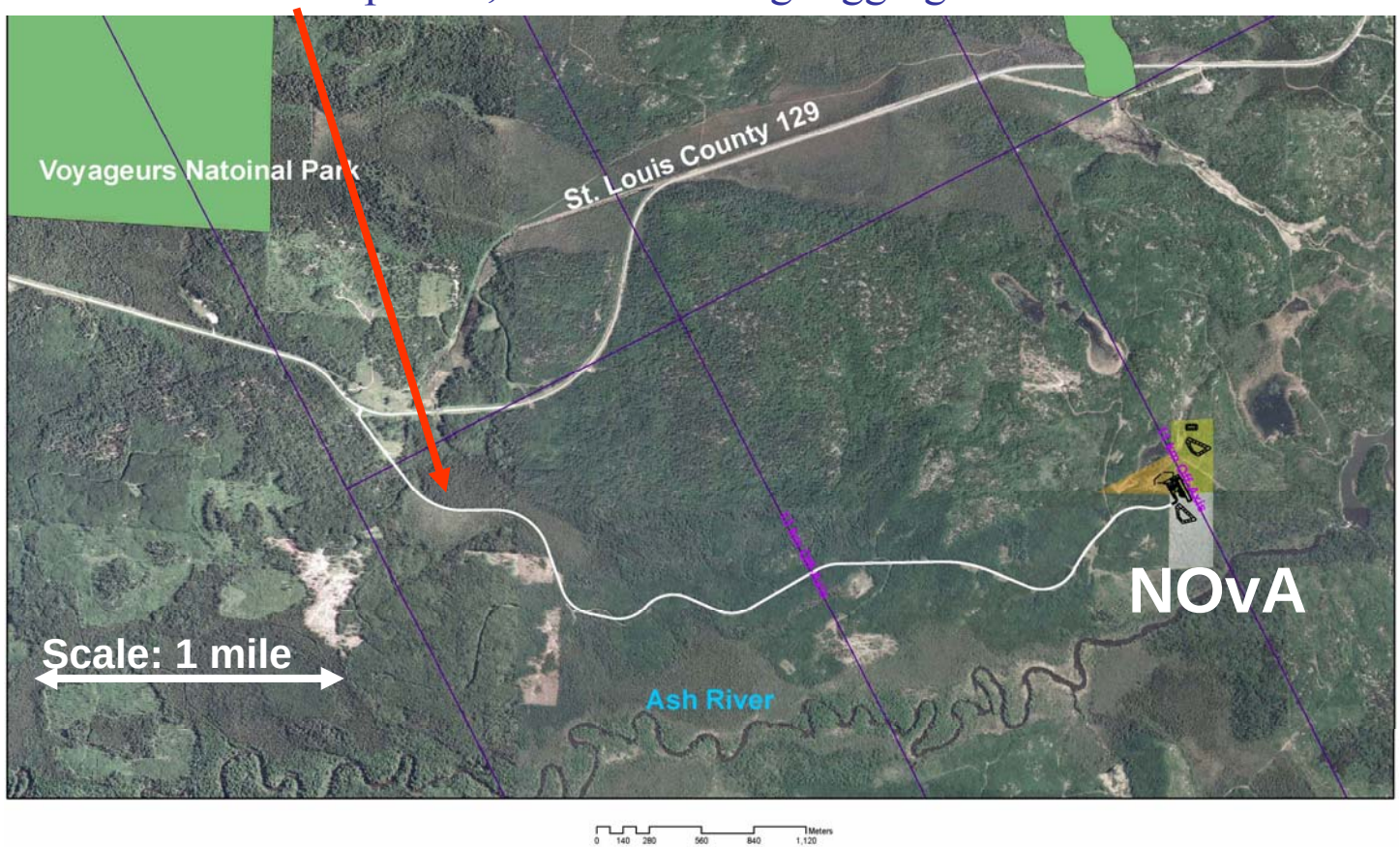
- Farthest site from Fermilab still inside the US and accessible by road
  - 810.5 km from Fermilab, just 1.5 miles south of Voyageurs National Park
  - 11. 8 km west of the NuMI beam (14.6 mrad off-axis)





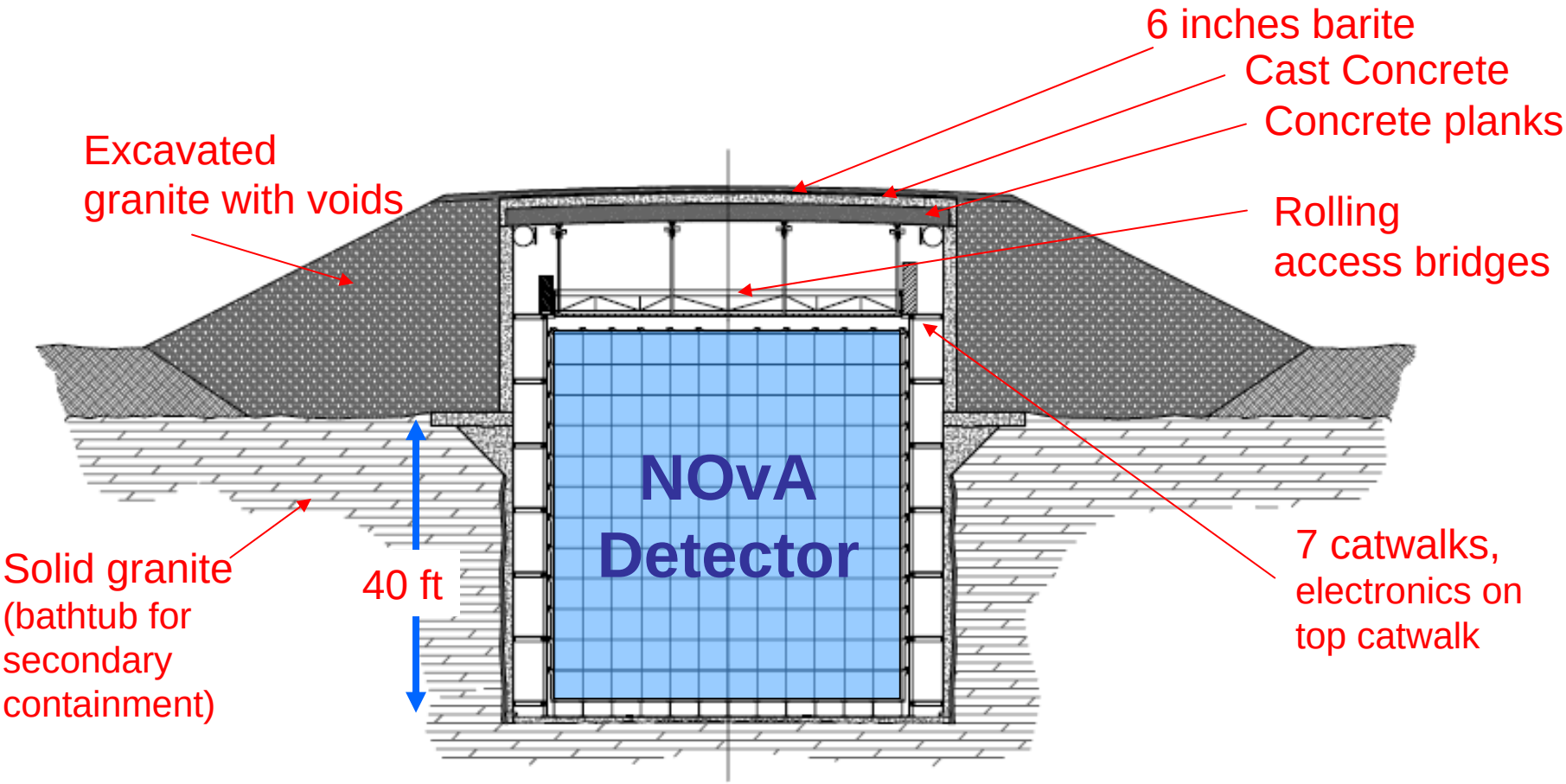
Ash River Site

- The 3.6 mile access road has an advanced technical design:
  - roadbed, utility corridor,
  - curves straightened, borings done all along the route
  - ~ 40 drawings
  - Will need wetlands permit, but for existing logging road



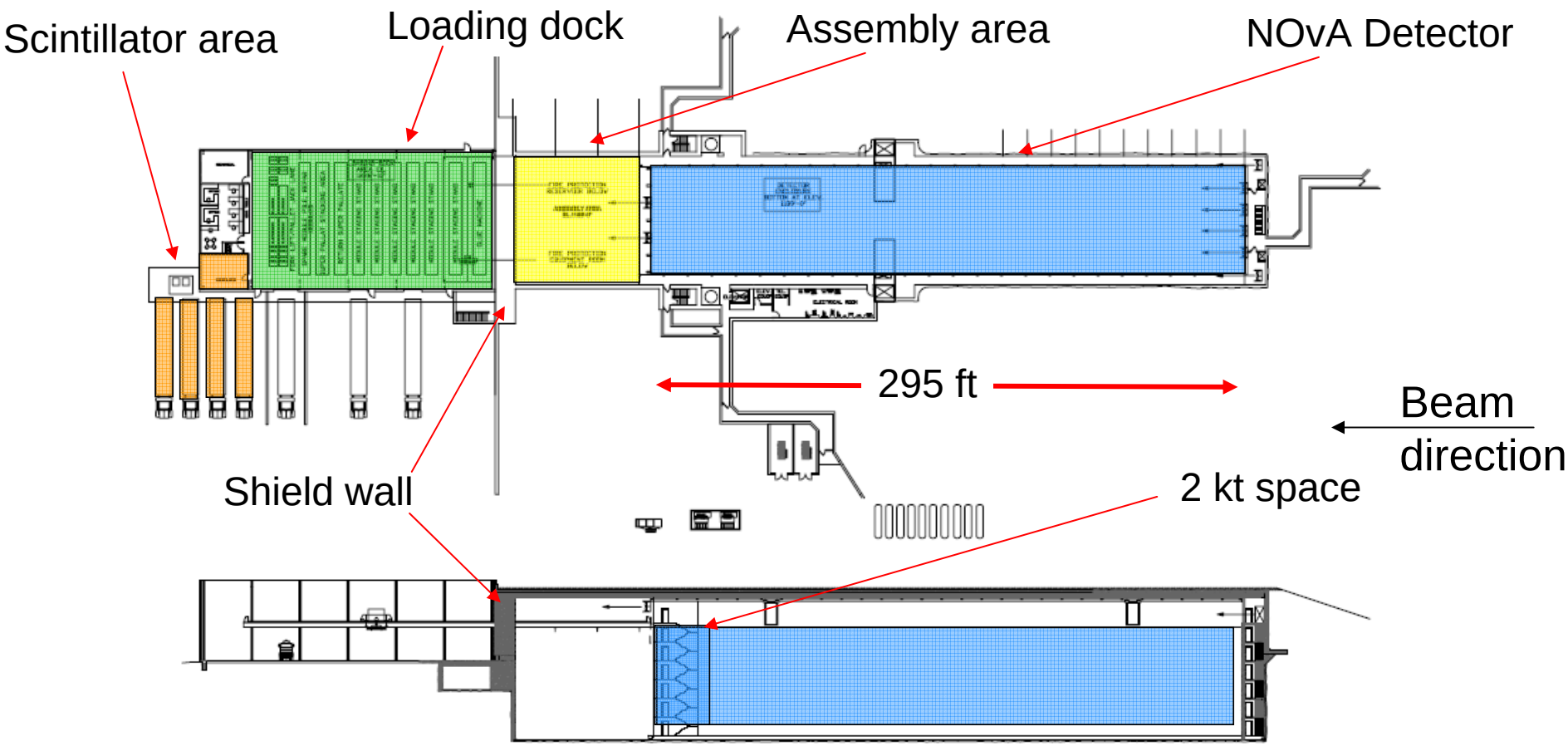
Site and Building

- Cross section as seen by the neutrino beam
  - 63 ft wide x 67 ft high
  - Secondary containment (detector is liquid scintillator)



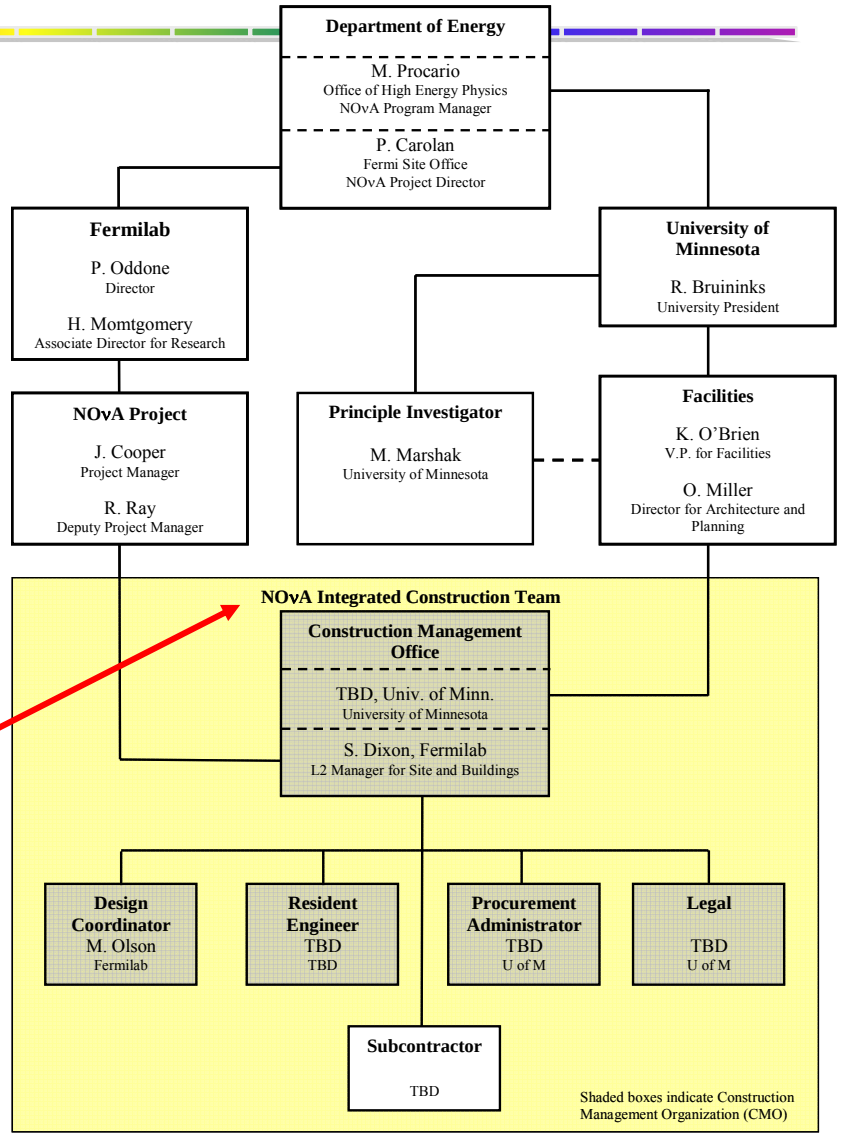
Site and Building

- Plan view & Longitudinal cross section
  - Building is sized for a 20 kt detector, allowing consideration of upscope if contingency can be earned

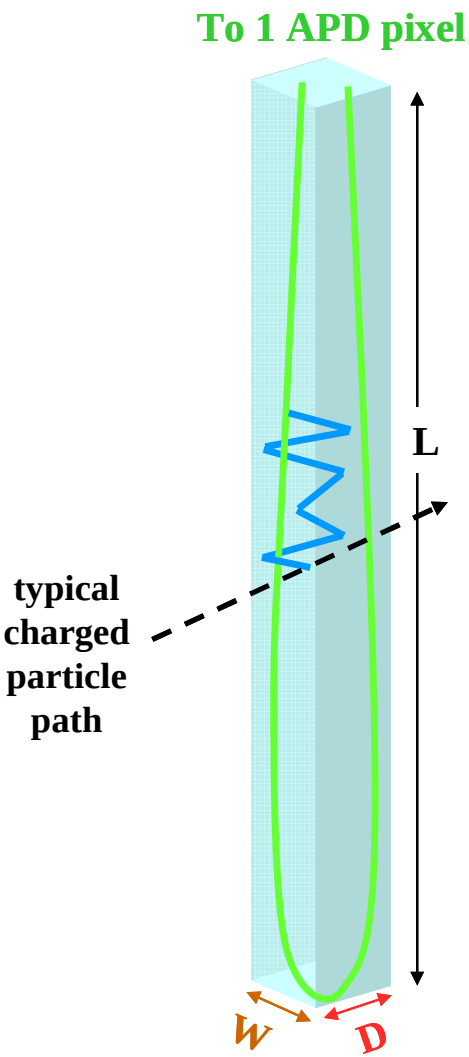


Ash River Organizational Wrinkle

- The University of Minnesota will receive a DOE Cooperative Agreement grant for the building
  - UM will acquire the land and an easement for the access road
  - UM will own and operate the building
- Officially part of the Acquisition Strategy adopted as part of the CD-1 approval on May 11, 2007
  - Negotiations now begin via DOE Chicago Office
  - An MOU between UM and the Fermilab Project are part of the scope of work
- Draft MOU "exists"
  - Integrated Construction Team
  - Use UM procurement rules, but consensus with Project on larger questions, e.g. AE design firm, major contractors
    - Succeeded on "project management" firm
  - UM will report monthly to Project Office
  - Earned Value computation can be done



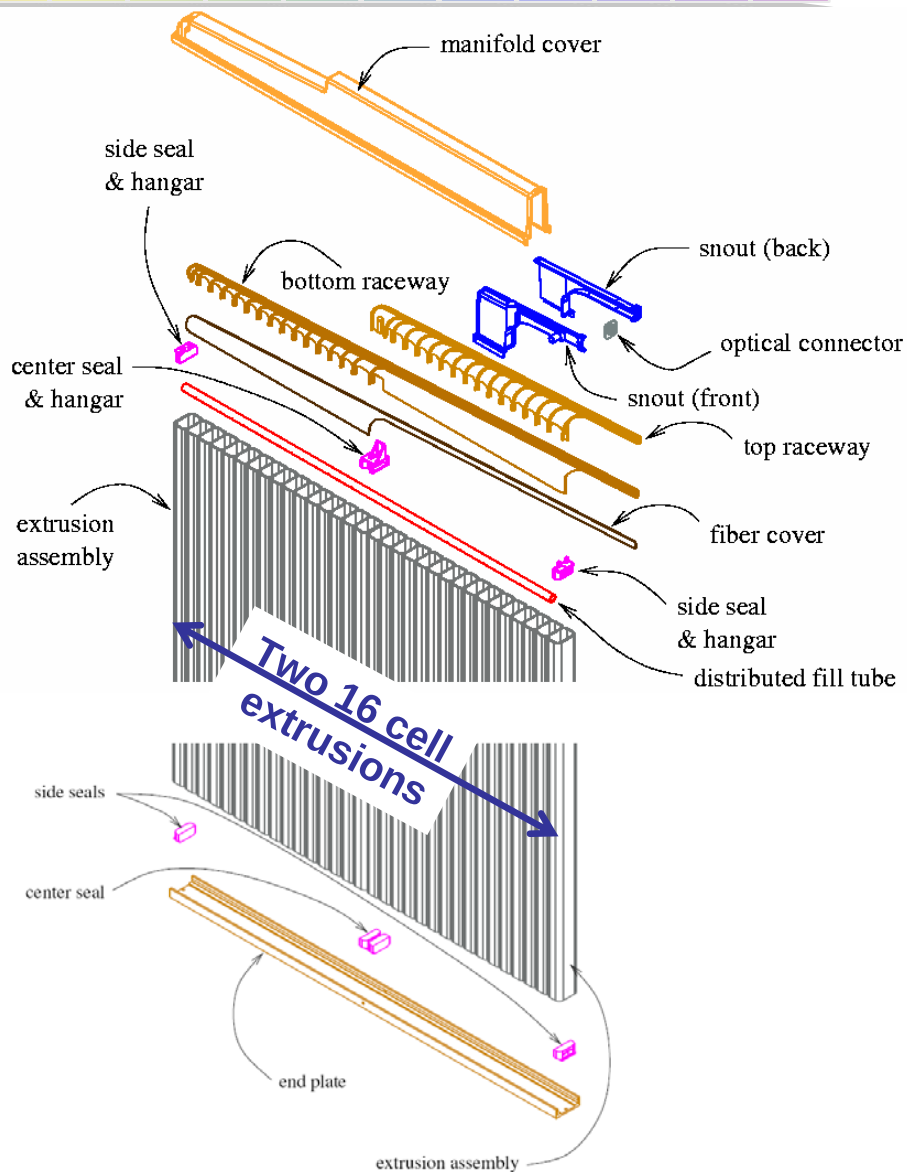
NOvA Detector design



- **Liquid scintillator** (3.9 million gallons)
  - Contained in 3.9cm x 6.6 cm cells of length 15.5 meters
  - 3.9 cm as seen by the beam
- Cell walls are **rigid PVC** (5.4 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 (18,000 km)
  - Fiber diameter 0.7 mm
  - Fiber shifts wavelength to ~ 520-550 nm along the fiber
- Avalanche photodiode (APD) converts light to electrical signal (14,136 devices, each with 32 pixels)
  - 85% quantum efficiency

Assembled into Extrusion Modules

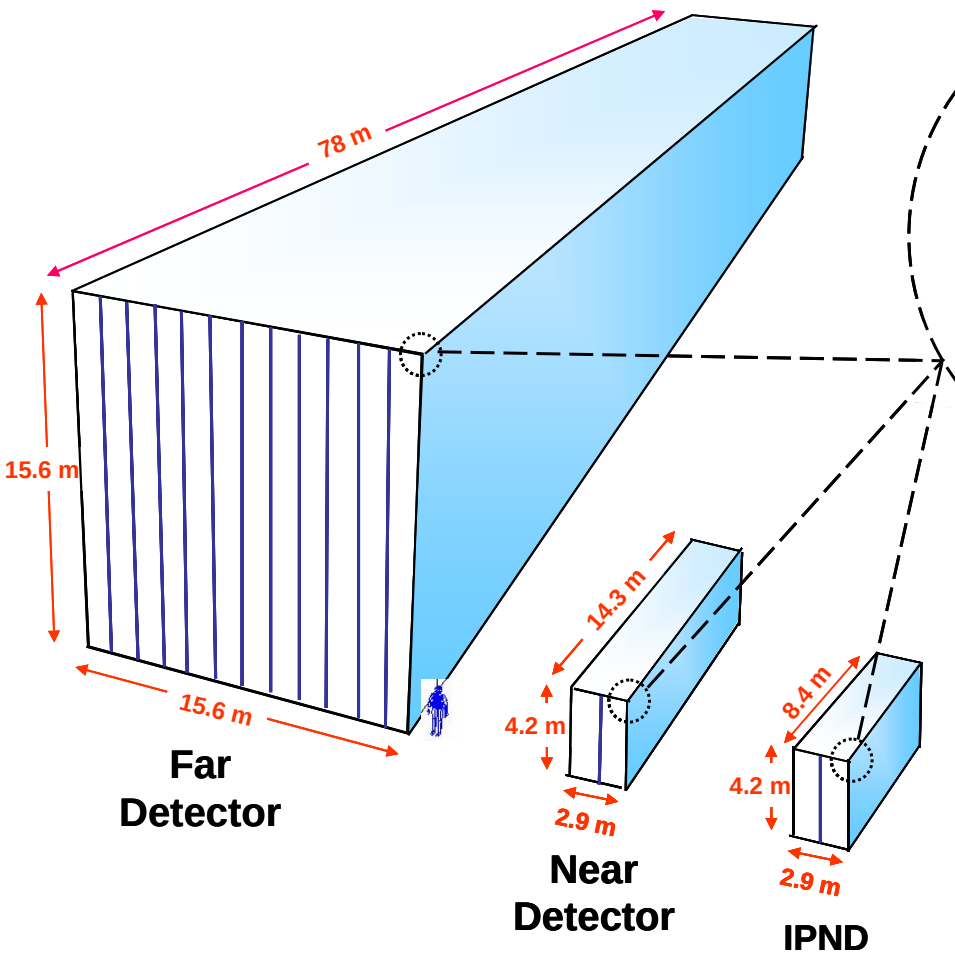
- **14,136 Modules to build**
- Construct from two 16 cell wide extrusions
  - Commercial extrusions with NOvA specific die and NOvA specific resin formulation
  - Sort for thickness, banana effects, test structurally and glue together at Factory #1 (Fermilab)
- Add fiber, manifold parts, and endplate parts
  - Fiber tested at Michigan State
  - Assembly at Factory #2, Univ. of Minnesota
  - Test for leaks when assembled
    - 32 cell modules are the primary containment for the liquid scintillator
- Shipped empty to Ash River
  - Modules fit in 53 ft semi trailer trucks

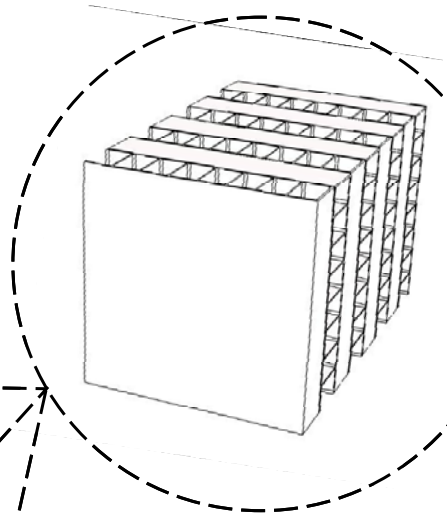


Electronics and Data Acquisition

- APD carrier board
  - Thermoelectric cooler holds APDs at -15 ^{o}C
- Front End Board (FEB)
  - ASIC: low noise pre-amp
    - Prototype chips in hand
    - One more design iteration underway
  - Digitize in quad 40 MHz ADCs (from CMS)
    - 8:1 multiplexing of 32 pixel APD
  - Un-triggered, continuously digitized, time-stamped, pedestal subtracted, zero-suppressed
- Data Concentrator Module (DCM)
  - 64 FEBs connect to one DCM
  - DCM interfaces to standard Gigabit Ethernet network
  - 152 commercial PCs process data
    - Buffer data waiting for spill time message, record all hits in 30 μs around spill
  - Random data off-spill can be collected for calibration (muon cosmics)
- Low Voltage Power system, Water Cooling system

NOvA assembles 3 Detectors



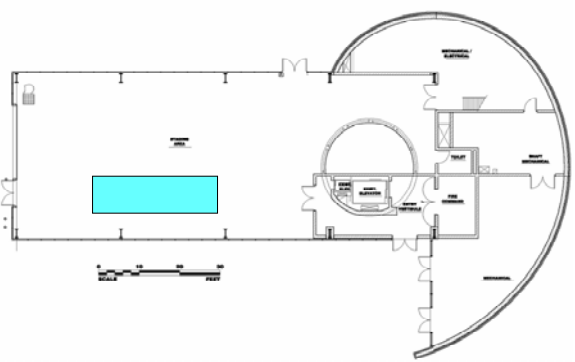


All have successive Layers of vertical and horizontal cells bonded together with adhesive

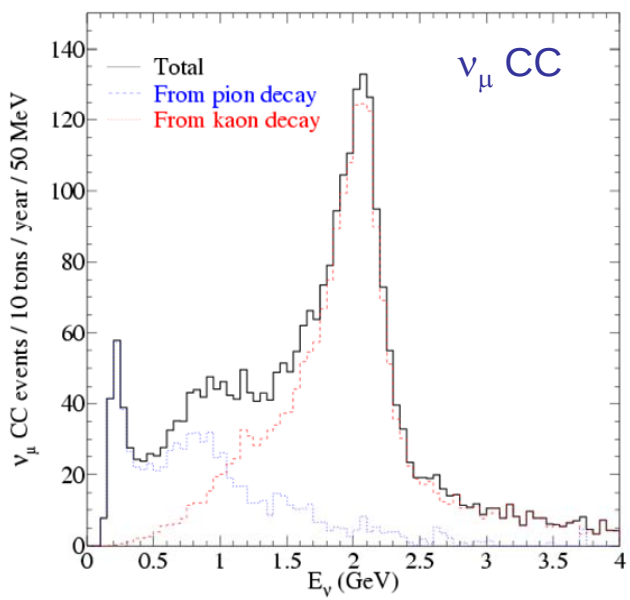
- 18,000 ton Far Detector
  - 12 by 12 extrusion modules
  - 1178 layers
- 218 ton Near Detector
  - 2 by 3 extrusion modules
  - 199 layers
- 88 ton Integration Prototype Near Detector (IPND), R&D goal in 2008
  - 2 by 3 extrusion modules
  - 124 layers, reuse 93 in Near Detector

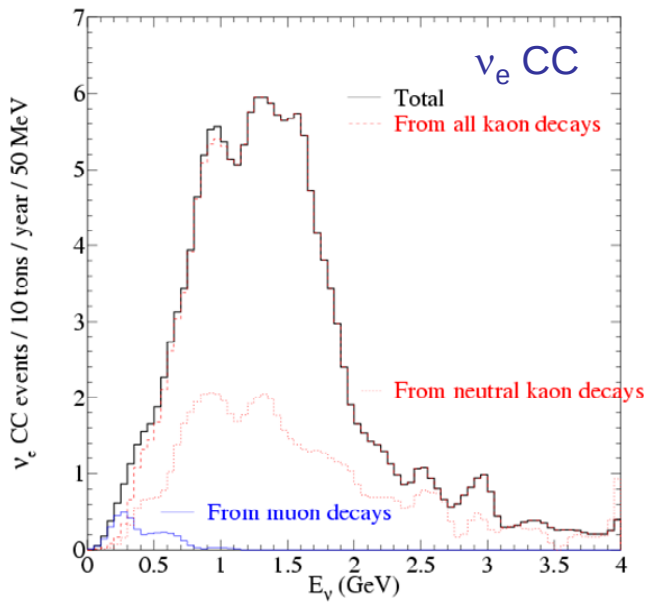
IPND – Integration Prototype

- Current schedule shows: Assembly done October 10, 2008
- IPND serves to force integration on a real device
- Then we see an off-axis beam at 108 mrad in the MINOS Service Building
- In one year of running,
  - ~ 10 tons fiducial mass (1/9 of total mass), see about
    - 2840 ν_μ CC events in the energy range 1.6 – 2.4 GeV, IPND too short for 2 GeV μ
    - 170 ν_e CC events in the energy range 0.5 -2.0 GeV
    - 1100 Neutral Current events in the range 1.6 – 2.4 GeV
- Useful for NOvA simulation effort



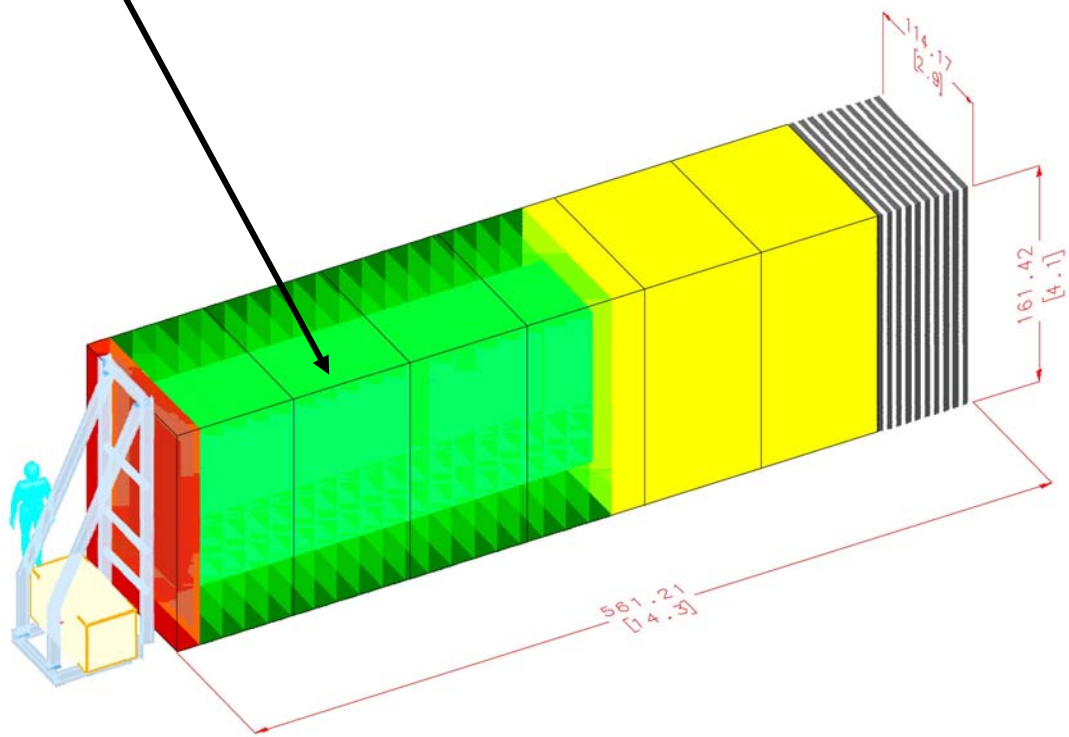
Plan view of
MINOS Service building





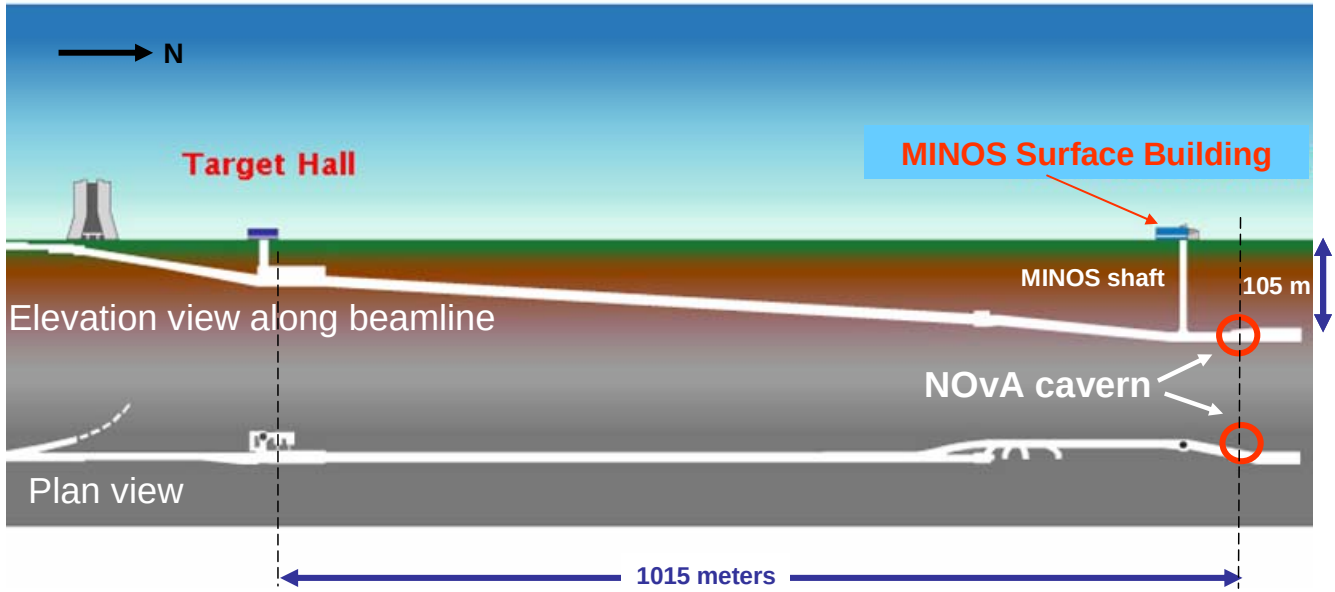
Near Detector

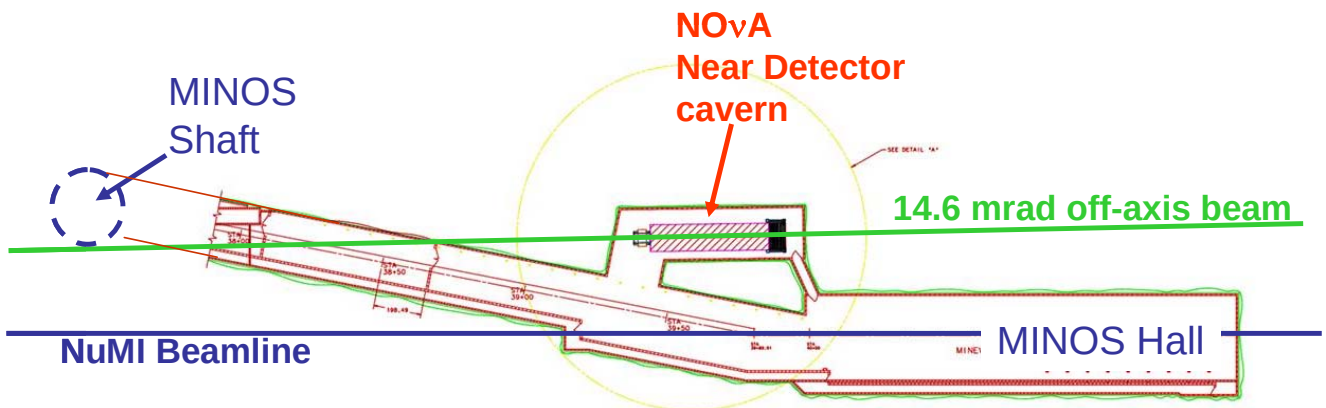
- Needs to be at 14.6 mrad to beam
- Needs to contain 2 GeV neutrino events
- Fiducial volume of 20 tons for event rate
- Event containment
- Muon Catcher
- 6 detector blocks
  - 3 recycled from IPND
  - Each 31 planes of extrusions



Near Detector site at Fermilab

- The Near detector requires excavation of a small new cavern underground
  - ~ 750 cubic yards
  - ~ $ 4 M incl. contingency

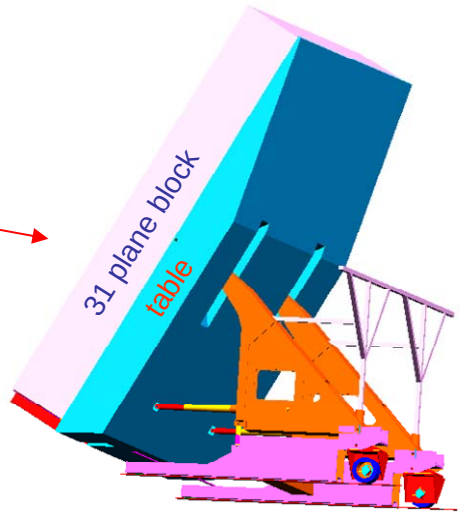


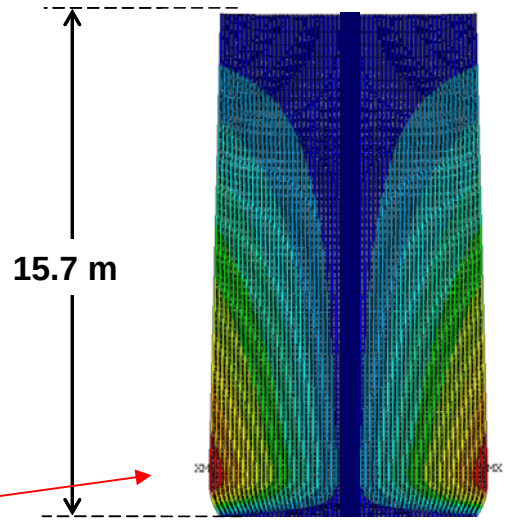


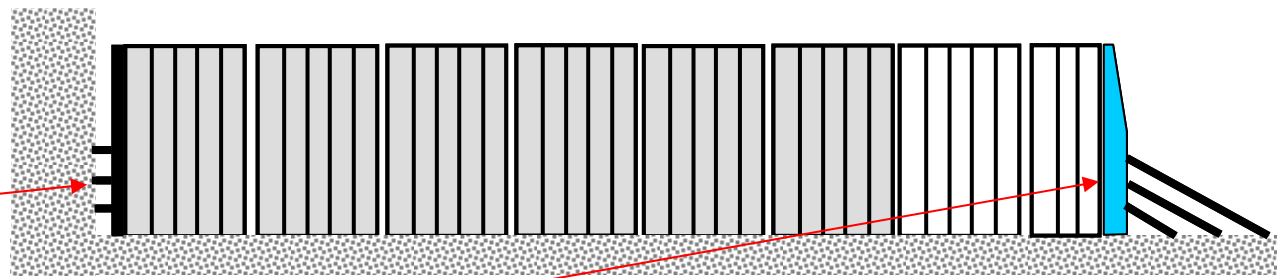
Far Detector Assembly

change to 2 slides?

- Build 31 plane blocks on a flat table
- Table pivots to stand block on edge
- Superblock consists of 5 blocks "touching" < 2-3 mm not observable
- Leave expansion gap of 20 mm between Superblocks
  - When filled with scintillator, a superblock swell by 20 mm near the bottom of the blocks
- Fill during construction
  - Filling follows by about a superblock
- Initial bookend is south granite wall
- Finally install strong bookend at end to resist further PVC deformation



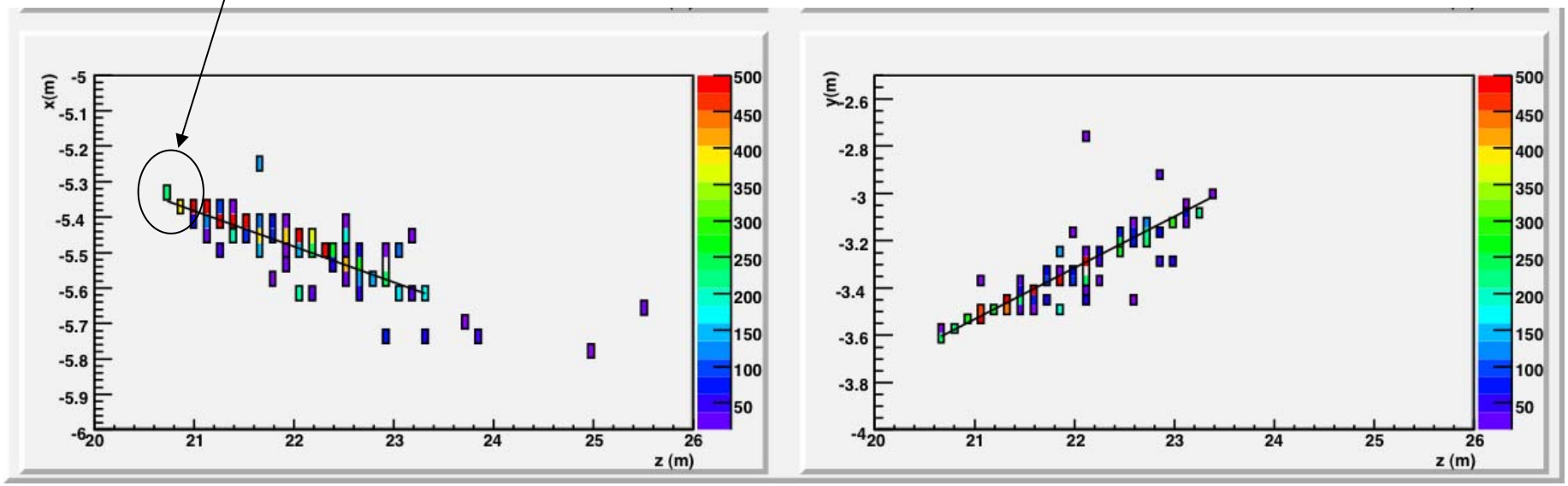




All superblocks up, 6 full

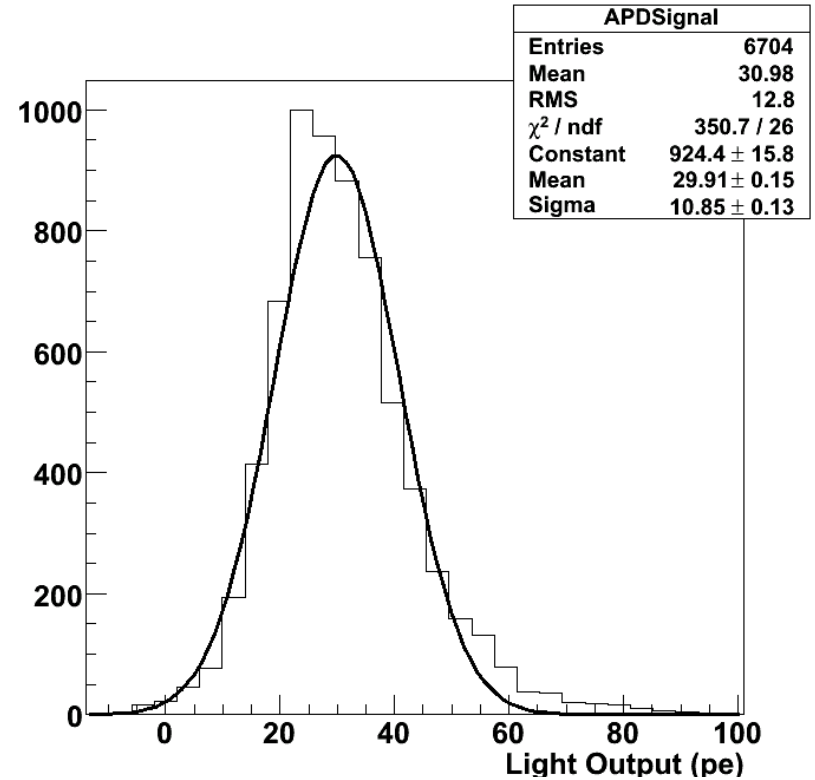
NOvA Detector Performance

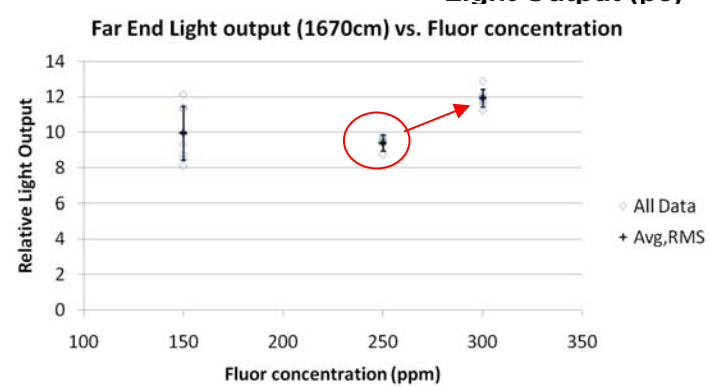
- NOvA is a Tracking Calorimeter
  - See track information in two views
  - See total energy via pulse height in hit cells
- Example 2.2 GeV electron neutrino quasi-elastic event
  - Vertex, see recoil
  - Outgoing track looks like an electron shower



NOvA Detector Performance

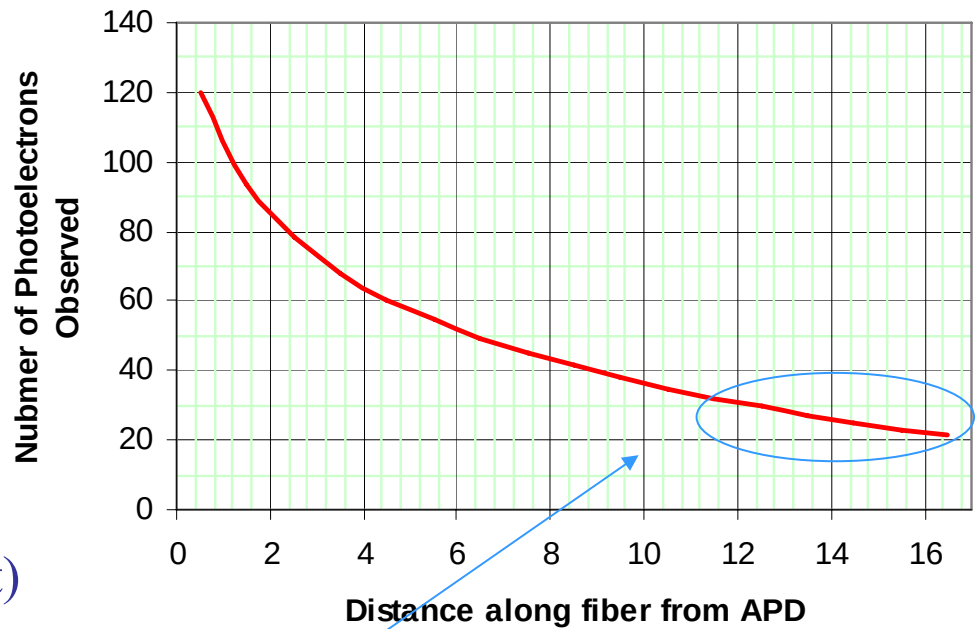
- CDR concluded we needed at least 20 p.e.with a threshold cut no higher than15 p.e.
- Threshold at 15 p.e. would yield 1 – 2 noise hits per event and a cosmic ray data rate of 1.8 GB/sec
- With improved PVC and 0.7 mm fiber we have observed 30 p.e. from the <u>far end</u> of a NOvA cell
- Fiber was flawed, so we actually expect 39 p.e.
  - Working to demonstrate this before the Lehman review
  - Working to demonstrate this in many cells, not just one.





NOvA Detector Performance

- Sounds like plenty of light, but we also expect statistical variations in construction for
  - PVC reflectivity
  - Scintillator mixing
  - Fiber batches
  - Fiber alignment to the APDs
  - Fiber position in the cell
  - And we would like to keep two mineral oil vendors as viable bidders (25% difference in light)



- It's not just the far end of the cell, since the far 3 - 4 meters has similar response
  - So, we have just enough to keep above 20 p.e. for all but ~ 8% of the cells (this is the low side tail beyond about a 2 sigma variation in construction)
  - Given a typical track length of 120 cells for a 2 GeV muon neutrino CC muon, only ~ 5 of the 60 vertical cells would fail the 20 p.e. performance requirement
  - Horizontal readouts switch sides every other layer and have 1/2 this effect.

Cost

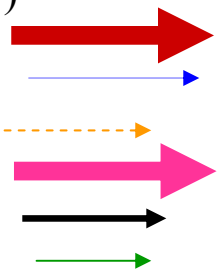
- We have a Procurement plan which talks about details of phased procurements for these large kt amounts

- We are dependent on the price of Crude oil
  - $ 333 K change in project cost
    for every $ 1 / barrel change in the price of crude
    - But lag times do occur, it doesn't change instantly

- Ron will talk next about costs in detail.
  - We believe we have an adequate contingency and conservative contingency in places where we have identified risk
    - Oil, cavern excavation

Transportation is another Cost

- **Line width proportional to mass** (in the style of Charles Joseph Minard, 1861)
  - Mineral oil comes from the LA / TX border
  - Pseudocumene comes from Corpus Christi, TX
  - Waveshifters come from Bensalem, PA
  - Scintillator gets mixed in Chicago
  - Extrusions come from Manitowoc, WI, but PVC resin comes from LA
  - Barite comes from Cartersville, GA



- **NOvA moves 18 kt from the Gulf to northern Minnesota**
  - **Deviations from N-S routes cost money in transportation**

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Cost

- Costs from Open Plan escalated using Cobra

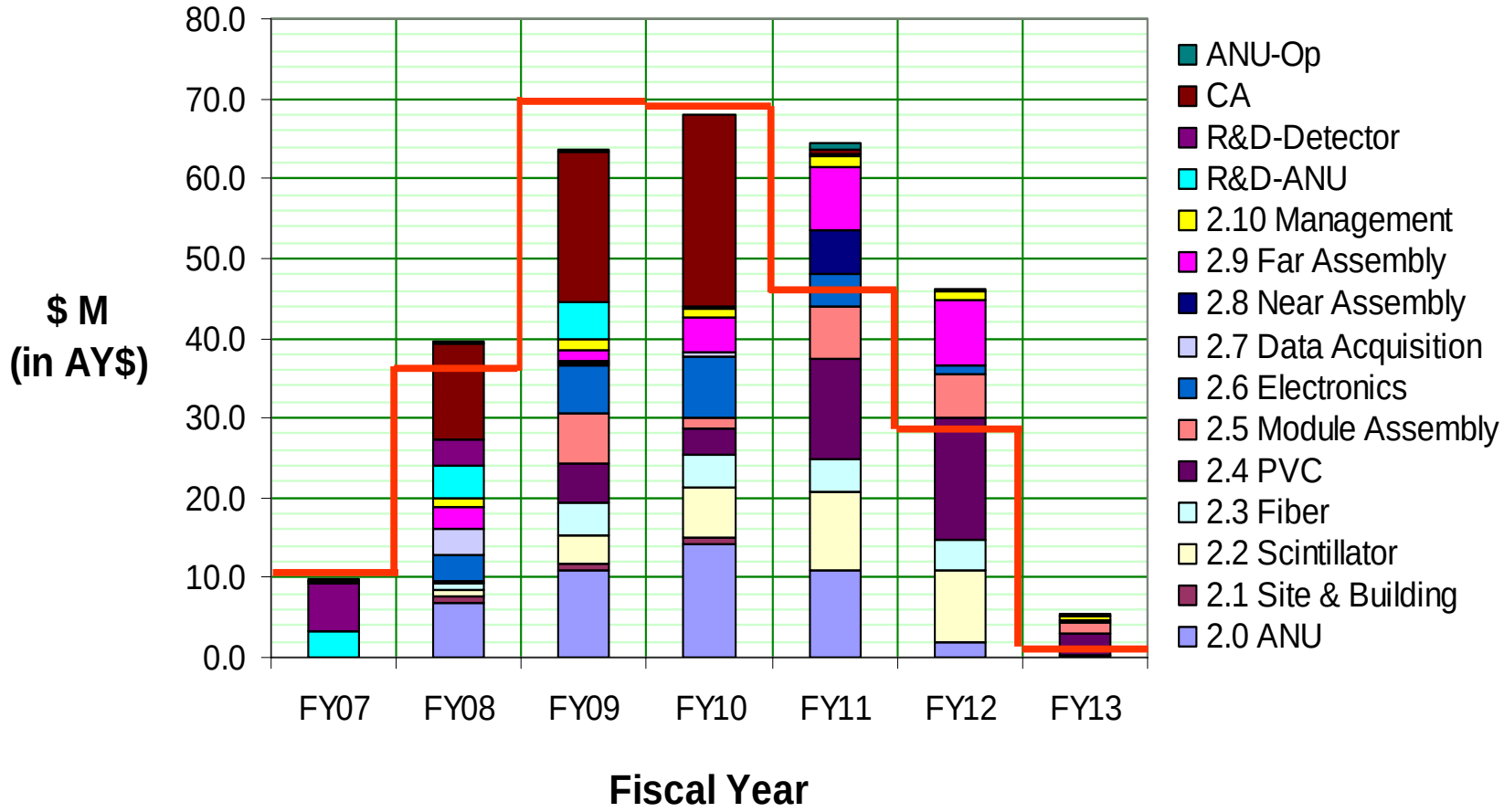
	WBS	Items	NOvA 's Cost Estimate AY $M									
			Estimated Cost (with indirects)			Contingency Estimate			Contingency %			Total Cost
			M&S	Labor[1]	Total	M&S	Labor[1]	Total	M&S	Labor[1]	Total	
TEC	2.0	Accelerator & NuMI Upgrades	$ 13.2	$ 20.5	$ 33.7	$ 4.4	$ 6.5	$ 11.0	34%	32%	33%	$ 44.7
	2.1	Far Detector Site and Building	$ -	$ 1.9	$ 1.9	$ -	$ 0.5	$ 0.5	0%	24%	24%	$ 2.4
	2.2	Liquid Scintillator	$ 23.0	$ 0.4	$ 23.4	$ 6.1	$ 0.3	$ 6.5	27%	87%	28%	$ 29.8
	2.3	Wave-Length-Shifting Fiber	$ 12.3	$ 1.2	$ 13.6	$ 3.4	$ 0.1	$ 3.6	28%	10%	26%	$ 17.1
	2.4	PVC Extrusions	$ 28.4	$ 1.7	$ 30.1	$ 8.0	$ 0.6	$ 8.6	28%	35%	28%	$ 38.7
	2.5	PVC Modules	$ 6.8	$ 8.6	$ 15.4	$ 2.0	$ 3.7	$ 5.7	29%	43%	37%	$ 21.1
	2.6	Electronics Production	$ 14.3	$ 1.1	$ 15.4	$ 6.2	$ 0.6	$ 6.8	43%	53%	44%	$ 22.2
	2.7	Data Acquisition System	$ 1.6	$ 1.8	$ 3.4	$ 0.4	$ 0.5	$ 0.9	25%	29%	27%	$ 4.3
	2.8	Near Detector Assembly	$ 3.6	$ 0.4	$ 4.1	$ 1.5	$ 0.2	$ 1.7	40%	50%	41%	$ 5.7
	2.9	Far Detector Assembly	$ 7.9	$ 6.0	$ 13.9	$ 4.8	$ 6.0	$ 10.8	61%	100%	78%	$ 24.8
	2.10	Project Management	$ 0.6	$ 5.7	$ 6.3	$ 0.1	$ -	$ 0.1	25%	0%	2%	$ 6.4
		Subtotal Construction	**$ 111.7**	**$ 49.5**	**$ 161.2**	**$ 36.9**	**$ 19.1**	**$ 56.0**	**33%**	**39%**	**35%**	**$ 217.2**
OPC		**R&D - Accelerator**	$ 1.4	$ 7.8	$ 9.3	$ 0.4	$ 3.0	$ 3.4	30%	38%	37%	$ 12.7
		R&D - Detector	$ 4.1	$ 5.0	$ 9.1	$ 0.2	$ 0.1	$ 0.3	5%	1%	3%	$ 9.3
		Cooperative Agreement	$ 46.9	$ -	$ 46.9	$ 9.3	$ -	$ 9.3	20%	0%	20%	$ 56.2
		Operating	$ 0.2	$ 1.2	$ 1.3	$ 0.1	$ 0.6	$ 0.7	36%	51%	49%	$ 2.0
		Total OPC:	**$ 52.6**	**$ 14.0**	**$ 66.6**	**$ 10.0**	**$ 3.6**	**$ 13.6**	**19%**	**26%**	**20%**	**$ 80.2**
		TPC:	**$ 164.3**	**$ 63.5**	**$ 227.8**	**$ 46.9**	**$ 22.7**	**$ 69.6**	**29%**	**36%**	**31%**	**$ 297.4**

Notes:

[1] Labor costs presented here include all project labor from Fermilab, other DOE facilities and Universities.

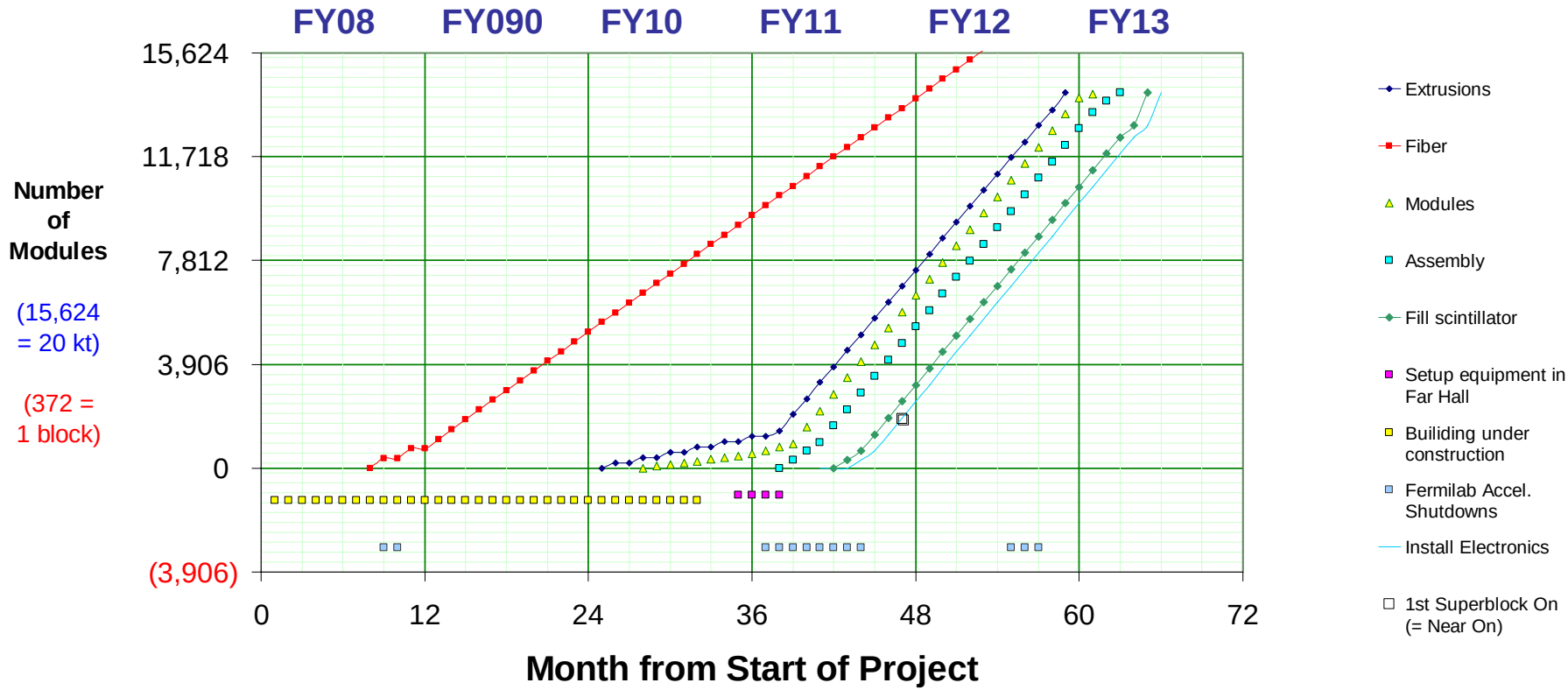
Cost Profile

- DOE funding profile in red,
  - costs in stacked histogram from Open Plan escalated using Cobra



Schedule

- Funding profile then lack of building at Ash River forces slow start on detector
  - Critical path is building, then assembly at Ash River



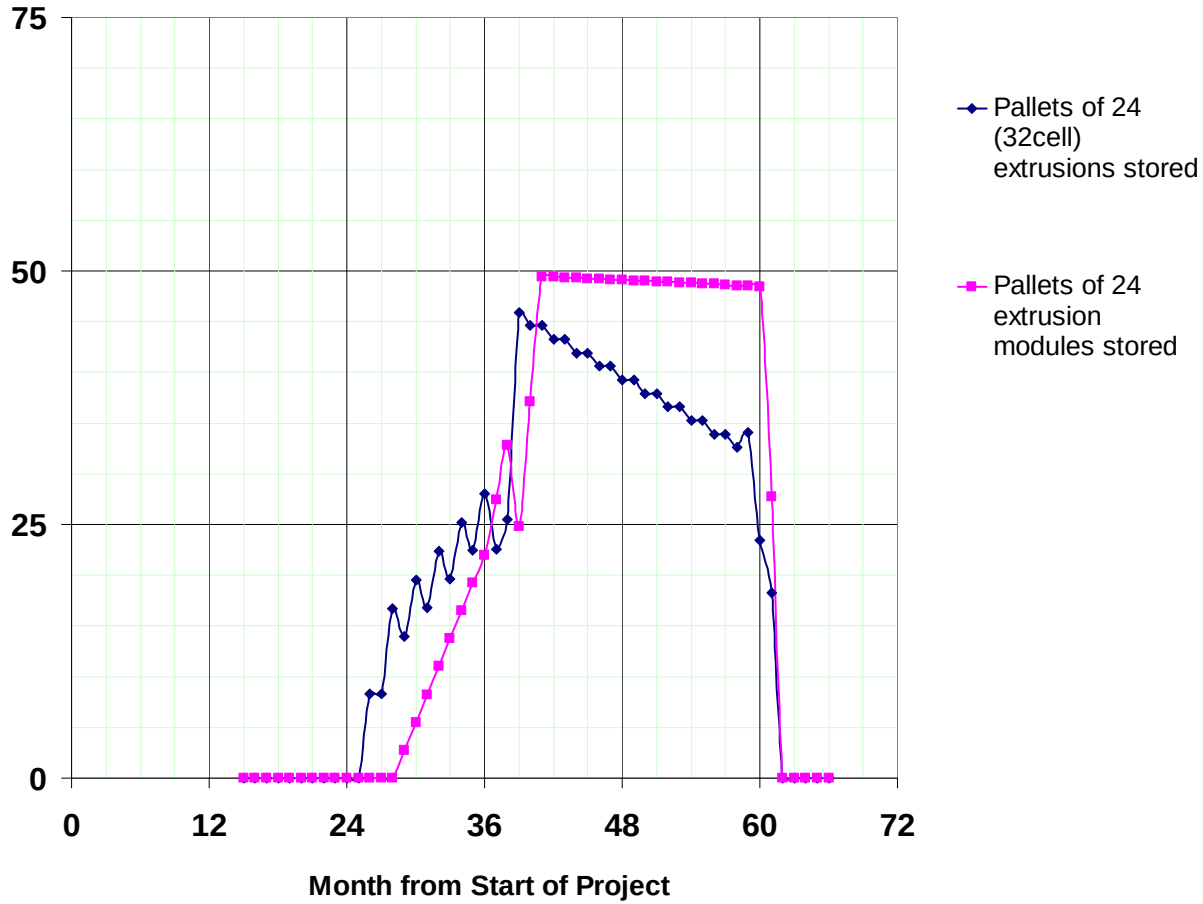
More graphics on Schedule

- Difference between
  - Extrusions, Extrusion Modules, Ash River assembly on previous slide imply storage costs, but also FLOAT

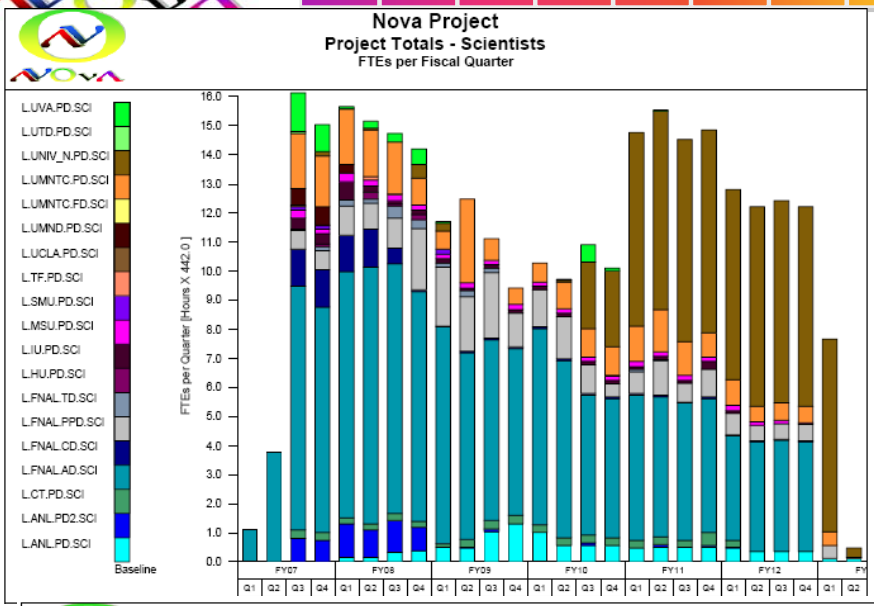
Number of PALLETS (24 modules per pallet) **stored**

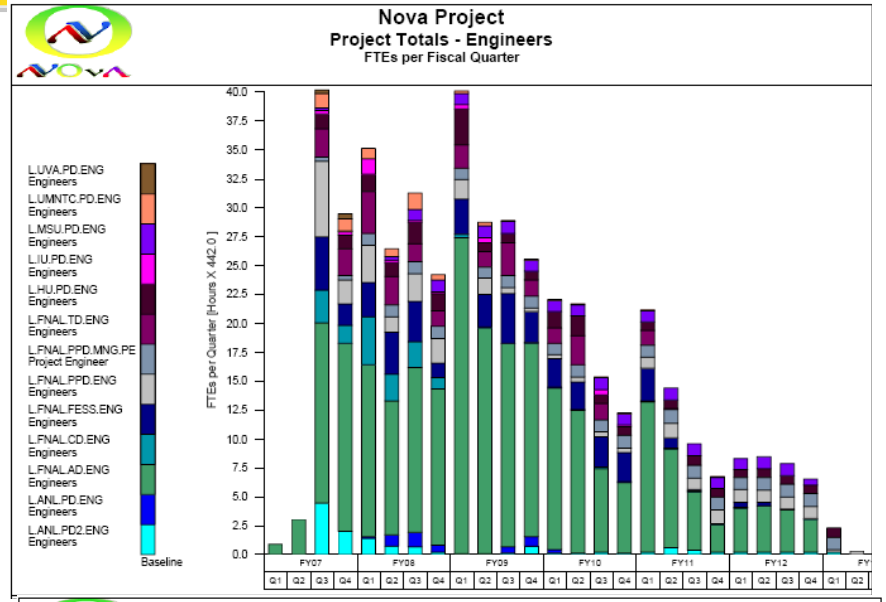
[50 pallets requires ~21,000 sq ft]

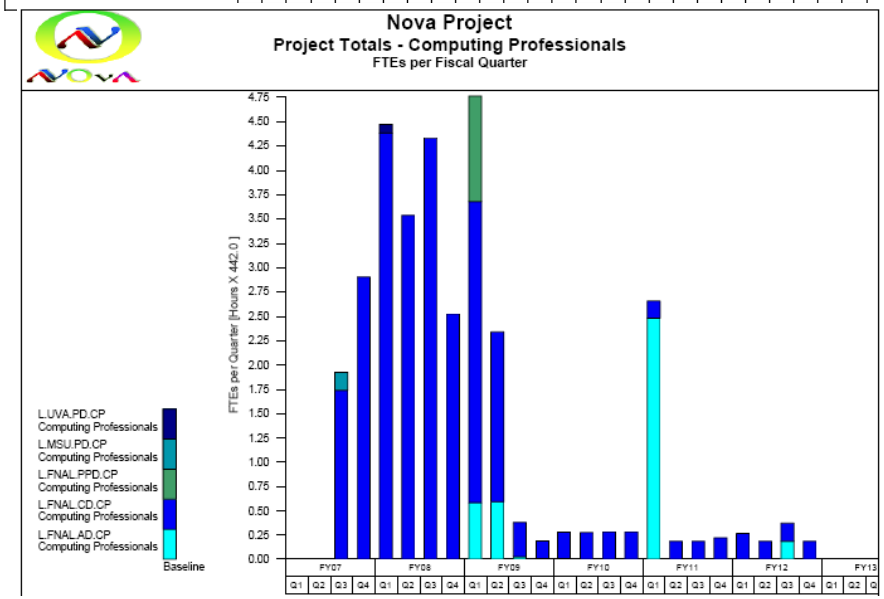
(25 pallets is ~ 1 month of production)

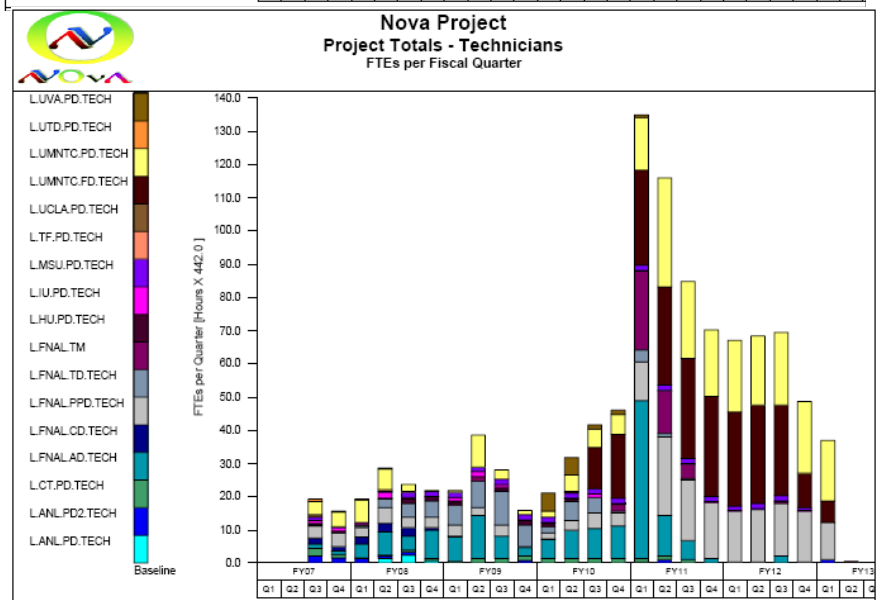


Human Resources









Other documents in hand

- Project Management Plan
- Configuration Management Plan
- Risk Management Plan
- Earned Value Management System
- Quality Assurance Plan
- Procurement Plan
- Preliminary Safety Analysis Document
- Security Vulnerability Assessment Report
- High Performance Sustainable Building considerations documented
- Monthly reporting in place since May, 2006
- Environmental Assessment (not done, in progress)
- Technical Design Report
- Full Cost & Schedule in Open Plan

Summary

- Still work to do to get the cost and schedule sufficiently in hand for a CD-2 approval
  - 2 weeks more effort should make a huge difference
  - Your input will help
  - If you validate the cost / part, we can scale the parts to match $ 260 M
- We also want to be ready for CD-3a on the following list
    - Access road, wish to break ground in April 2008
    - Site grubbing, building excavation, some concrete work
      - Wish to do this in mid summer 2008
      - Will have final building dimensions in hand no later than April 2008
    - Start phased procurement of long lead time single vendor items
      - APDs
      - Scintillator waveshifters
    - Plus a longer list from the Accelerator and NuMI Upgrades L2
  - Each L2 talk will point out their CD-3a items
  - Your comments on each will be useful