Updated NOνA Proposal

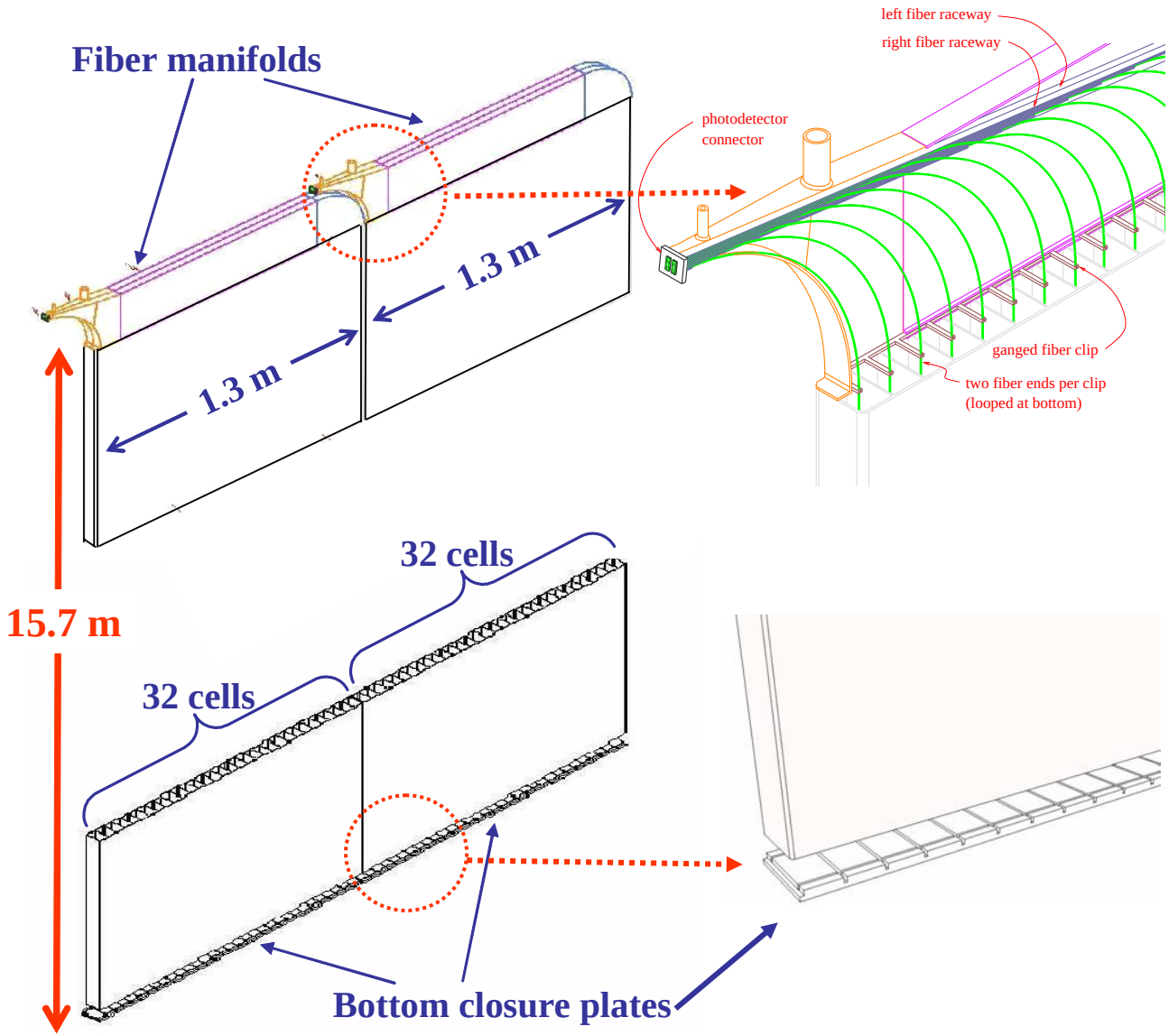
- **Following Aspen 2004, the PAC recommended that NOνA:**
  - **Finalize the choice of detector design, mass, and location.**
    - **We have**: Totally Active Liquid Scintillator, 30 kilotons,
      Ash River (810 km, 12 km off-axis)
      described briefly here, details in our March 21, 2005 proposal.
  - **Complete our proposed R&D program.**
    - **We have**: I will tell you where we stand on PVC structure engineering,
      on photoelectron yield, on cosmic ray backgrounds,
      and where we intend to go next.
  - **Update the proposal to reflect the complete science case.**
    - **We have**: The case is now much stronger with more protons (Gary's talk).
  - **Should report back as soon as the above items are addressed.**
    - **Here we are**
- **"This would be the time for consideration of Stage I approval."**

Updated NOνA Proposal

- **In addition the PAC asked that NOνA work with the Directorate and the larger neutrino community to:**
  - **Develop a coherent vision for a PD neutrino plan including NOνA as a first step.**
    - We participated in the APS Study and it calls for
      - » "a timely accelerator experiment with comparable (to reactor experiments) $\sin^2 2\theta_{13}$ sensitivity and sensitivity to the mass-hierarchy through matter effects."
      - » Sounds like NOνA to us
    - Gary will cover the reach of NOνA **before** and with a PD.
  - **Explore accelerated finding mechanisms.**
    - We (NOνA + Mont) did visit DOE last August, pitching for FY07 funds.
    - Feeling out people in Europe, we hear:
      - » "The major problem with NOνA, seen from here, is that whereas T2K is fully approved, it will be some time (2-3 years) before NOνA is approved and funded."
    - Yes, US approval schedules and future funding are always uncertain.
    - First things first: Can we convince the PAC and the laboratory?
      - » (Possible "second" thing, a funding hook: intermediate detector ?)

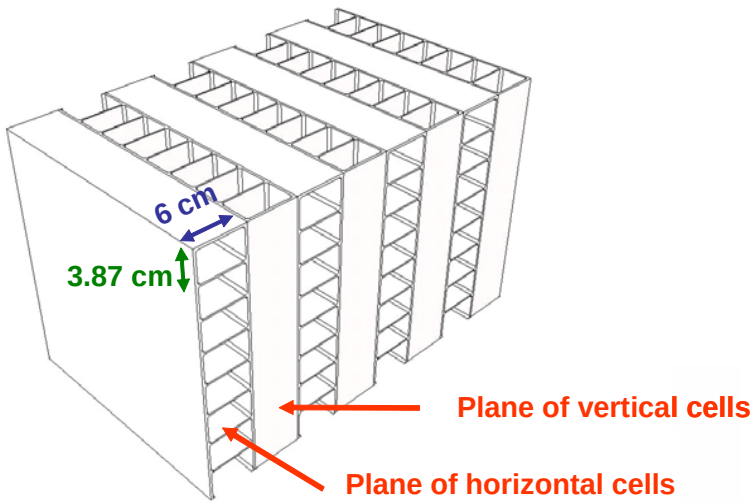
NOνA Structure

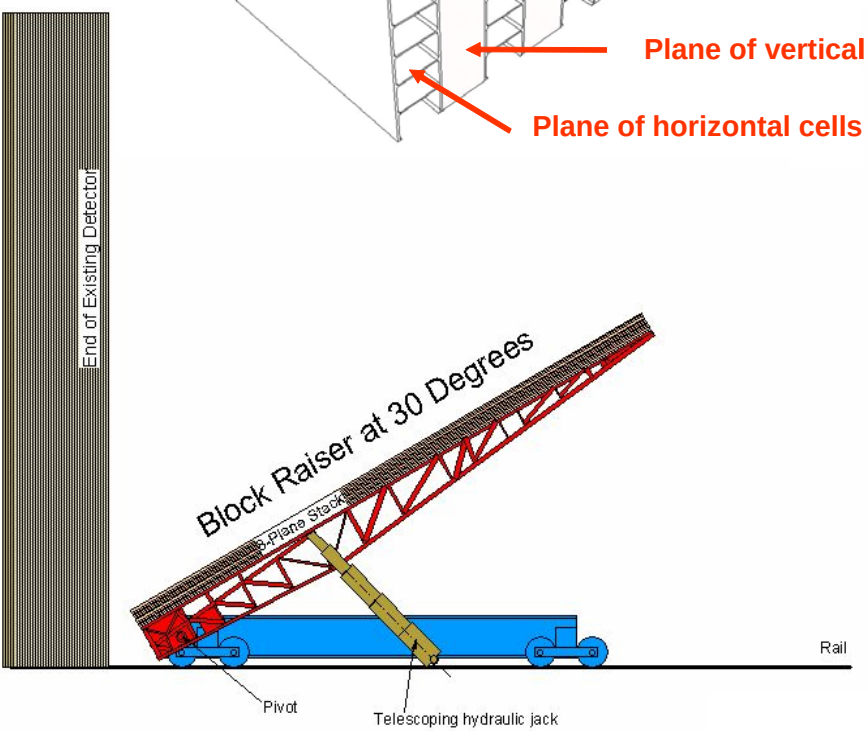
- **The basic component is a 32 cell rigid PVC extrusion**



- Cell walls are 3mm thick outside, 2mm thick webs inside
- Cells are
  - 15.7m long by ☆
  - 3.8 cm transverse to the beam by
  - 6.0 cm longitudinal☆
- PVC bottom closure ☆ plates & top fiber manifolds
  - Each cell has a looped wavelength shifting fiber, 0.8 mm in diameter
    - So two ends appear at the manifold
- There are ~24,000 such modules
  - each holds ~1000 kg of liquid scintillator
    - 307 gallons
  - each has ~250 kg of rigid PVC

NOνA Structure

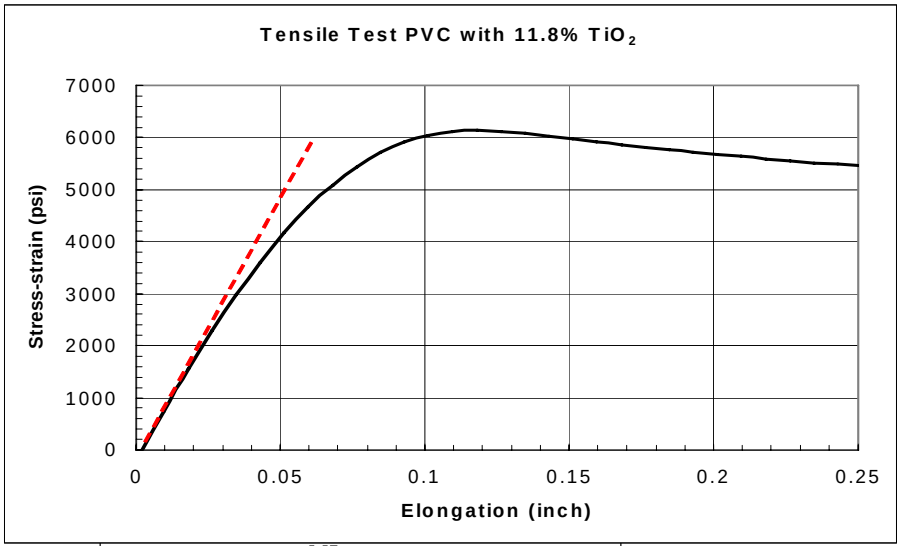


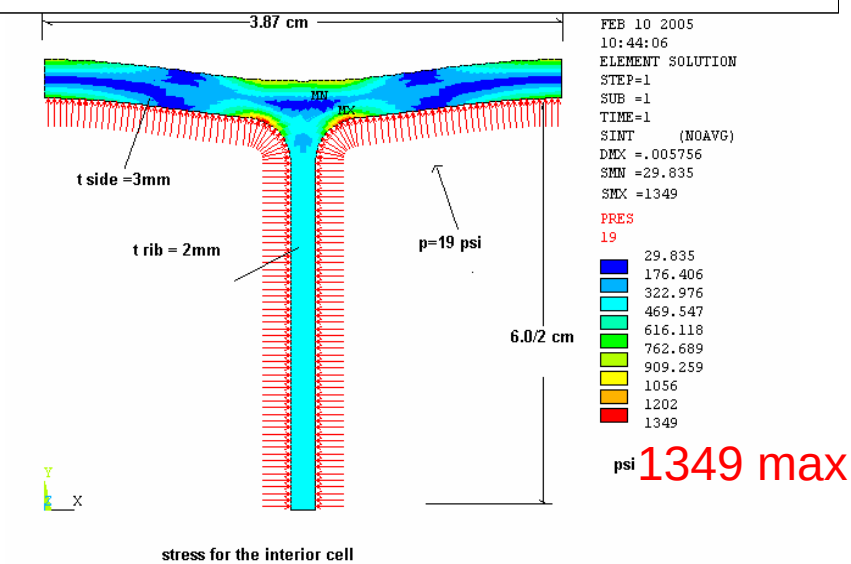


- These assembled extrusion modules get shipped to the Far Detector site
  - There we put 12 extrusion modules together on a flat table to make one plane of the detector
  - Successive planes have alternating vertical and horizontal cells
- 8 planes get expoxied together to make a strong honeycomb-like structure
  - 15.7 m by 15.7 m by 0.53 m thick
  - Empty mass is ~ 24 metric tons
  - Takes 900 kg of epoxy
- The assembled 8 plane block (still empty) gets raised to the vertical position by a "Block Raiser" and is epoxied to the 8 plane block installed the previous day

NOνA Structure: Engineering Studies

(one of our official R&D tasks)

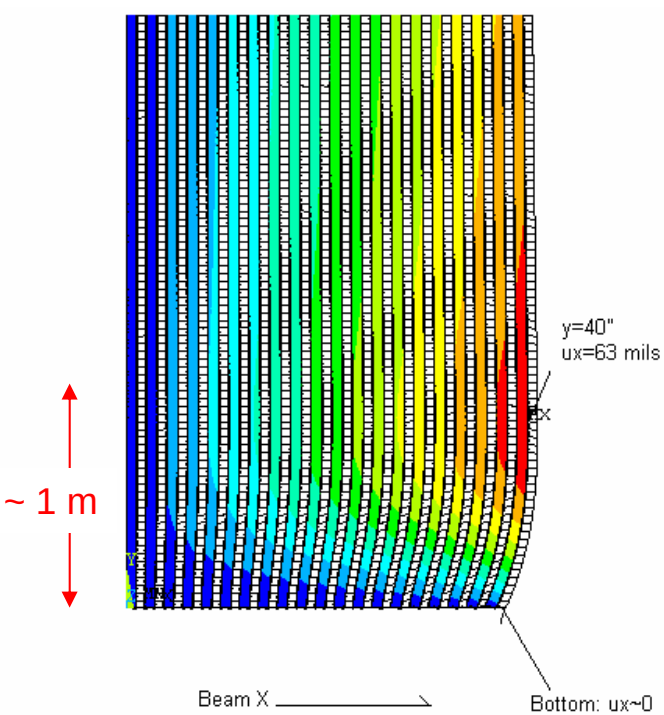


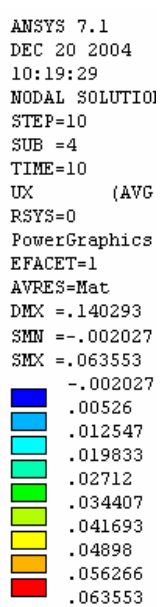


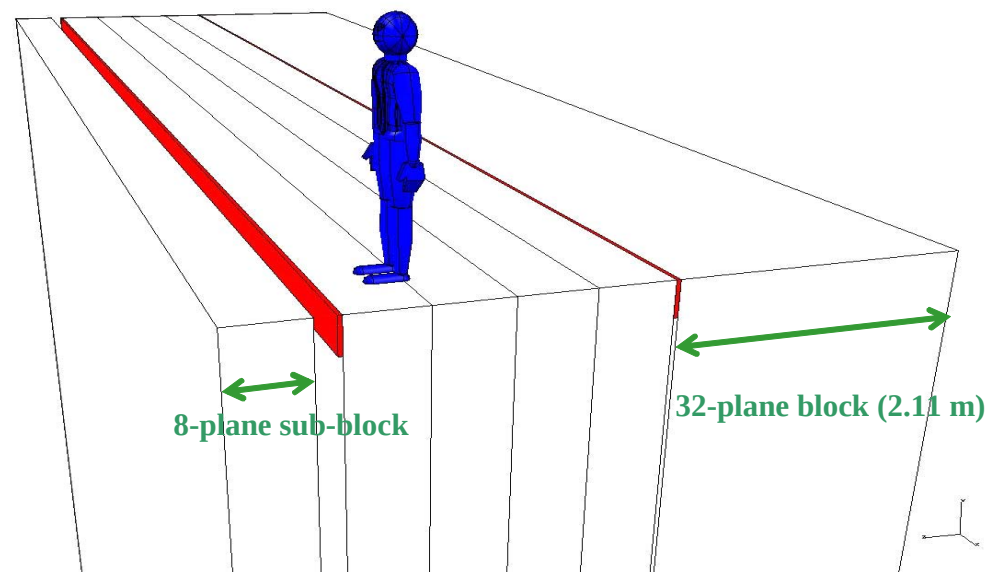
- A group of ~10 have looked at this structure over the last 6 months
- Our problem is that PVC is "plastic"
  - It gets billed as having a 6000 psi yield stress, but beyond ~2000 psi the material creeps and can creep to failure
    - We have measured this for ourselves with our PVC
- We have constrained our design to keep all stresses below 1500 psi.
  - took guidance from the Plastic Pipe industry which talks of a "design stress" level (& pipe lifetime) for hoop stress in buried pipes.
  - Our PVC would be a "2000 psi grade".
- Example: finite element of stress in a vertical cell filled with liquid at 19.2 psi (bottom)
  - Walls bow out, stretch web, but max stress is within our limit
    - Small areas which would probably only creep to distribute the stress locally, not like pipe
- Example: horizontal modules must be epoxied to vertical planes.
  - Horizontal cells see only 1.6 psi from the liquid but cannot support the load from horizontal cells above them, so transfer load to verticals
    - We checked that the shear on the epoxy is OK

NOνA Structure: Engineering Studies

- One surprising result is the build up of stress as we fill the construction with liquid
  - Finite element tells us that beyond ~80 planes the stress exceeds the 1500 psi limit
    - Friction pins the empty blocks to the floor
    - Liquid bows the walls to build up a displacement at ~ 1 m off the floor
    - Stress builds up right at the floor
  - So we plan a ~ 1cm expansion gap every 32 planes (every four 8-plane blocks)





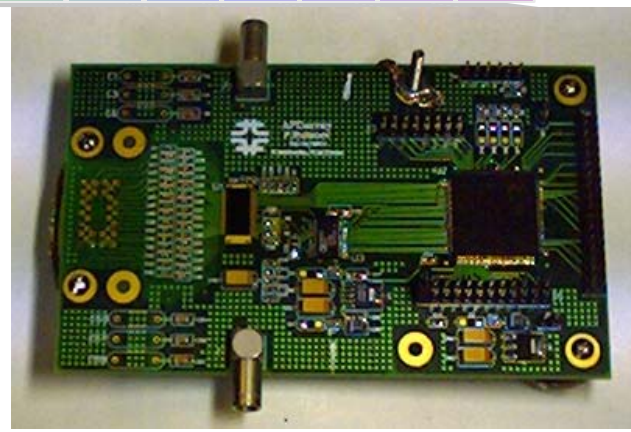


Displacement along X direction for the case of the 40 planes filled

NOνA Structure: Engineering Studies

- 10 internal NOνA notes on the structure
  - Buckling calculations for the 32-plane blocks, SF is OK
  - Cell size calculations
    - » Cells larger than 6 cm long by 3.8 cm wide would require thicker walls to keep below our design stress limit
  - Internal web failure from a poorly made section of extrusion?
    - » We propose to test all extrusions to several times max pressure.
    - » Built one that went to 100 psi
  - Thermal expansion checked.
  - Incomplete glue coverage evaluated.
- **We believe NOνA is structurally sound, safe, and constructible**
- It is still a unique structure
  - So a future R&D task is to contract with an outside engineering firm to check our conclusions and design.
  - Particularly to look for failure modes we may have missed.

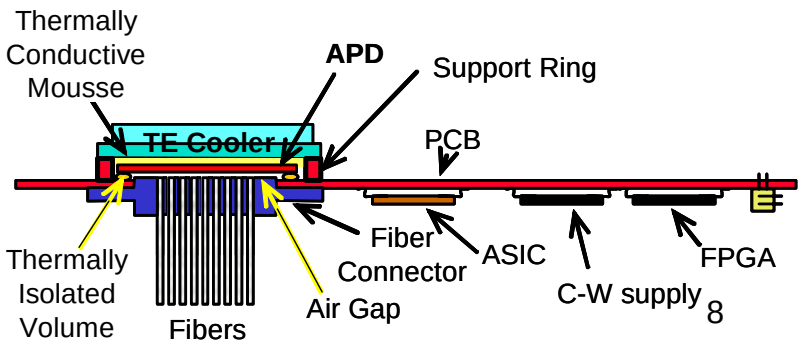
APD Update



- Recall that last June we had just put together a board combining the APD and the existing MASDA amplifier chip.
  - This is what we have used for our "demonstration of the photo-electron yield" – another official R&D task
  - It has a noise level of ~ 300 - 350 electrons, 3.5 pe equivalent
    - Cooled to -10 → -15 ^{o}C
    - Double correlated sampling, so low noise
- Meanwhile a redesign of MASDA for NOνA is well advanced.
  - match the APD input capacitance (matching 10 pF, not 70pF)
  - Expect ready for submission in August/September, but $
  - Expect production chip noise levels of ~ 200 electrons or ~ 2 pe
  - Thermal electrons in the APD are another 2 pe per μsec
  - Convolution is then expected to be ~ 250 electrons or **~2.5 pe**

Our spec is still a S / N of 10, or 25 pe from the far end of a cell

- Other R&D (see proposal Sections 7.3, 7.4)
  - Multiple correlated sampling, FPGA, reduce noise 25%
  - We are also working with Hamamatsu on a packaging scheme



Scintillator Photon Economics

- **Start with known MINOS parameters**
- .95 pe/mip @ 15 m with 1.2 mm fiber with photomultiplier and MINOS solid scintillator (1 cm thick)

- **Liquid Scintillator Changes**
- 10.6 pe @ 15 m with APD
  - (*1.4 from spectrum and *8 from QE at peak)
- 42.5 pe @ 15 m with fiber in a U loop
  - (*4 from 2 fibers each with perfect mirrors)
- 28 pe @ 15 m with 0.8 mm fiber
  - (*0.67, just ratio of diameters)
- 42 pe @ 15 m with liquid scintillator
  - (*1.5 since 2.56 cm thick x 4 cm wide cell gives more photons produced and more advantageous light collection geometry)

- **"Verifying this reasoning chain is a critical R&D test"**
  NOνA, June 2004 PAC Meeting

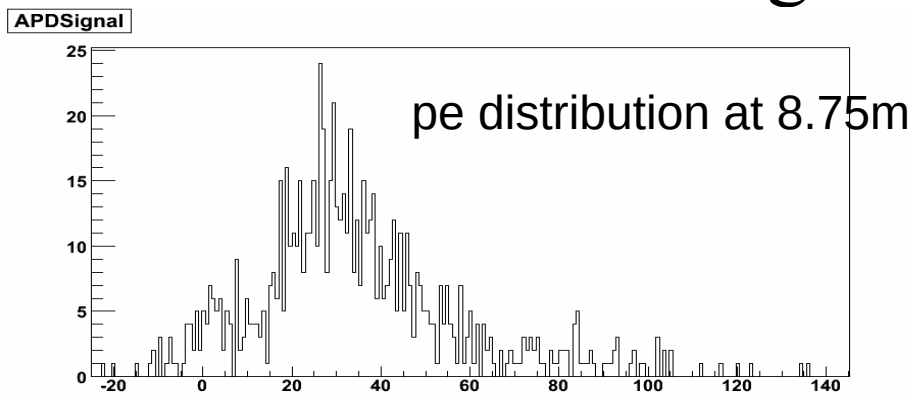
- **Verification:**
- Tested a 2.2 cm thick cell,
  so expect factor of ~ (2.2 / 2.56) ~**0.86**
- 2 fibers are not quite a factor of 2
  one can be "shadowed" by the other,
  measured correction factor is **0.86**
- We measured at 16.4 m, not 15 m.
  measured attenuation factor is (.8 / .94) = **0.85.**
- The liquid scintillator step involved modeling light bouncing around in the cell: geometry, reflectivity, fiber position.
  - Reflectivity of the PVC
    MINOS solid scintillator data is 90% at 425 nm,
    measured 87.5% reflectivity for our PVC
    another factor of **0.71** since many reflections.
  - Position of the Fiber (assumed in center)
    actually in corners, *** 0.76**, see Figure 6.9
- **Expect (42pe)**(.86)(.86)(.85)(.71)(.76)
  = 14.2 pe @ 16.4 m
- **We have measured 13 pe**
  (suspect fiber to pixel coupling not well controlled)

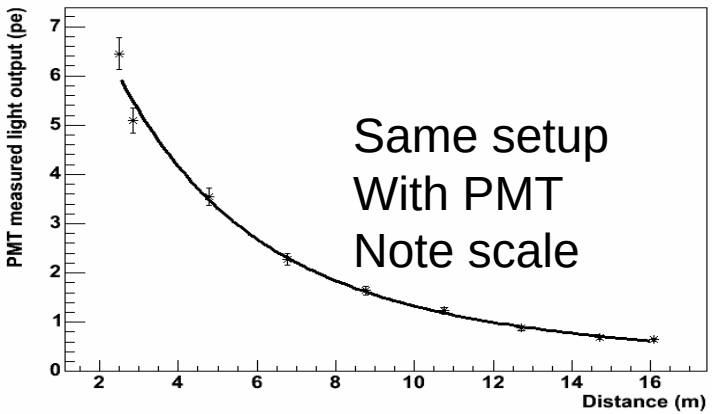
Scintillator Photon Economics

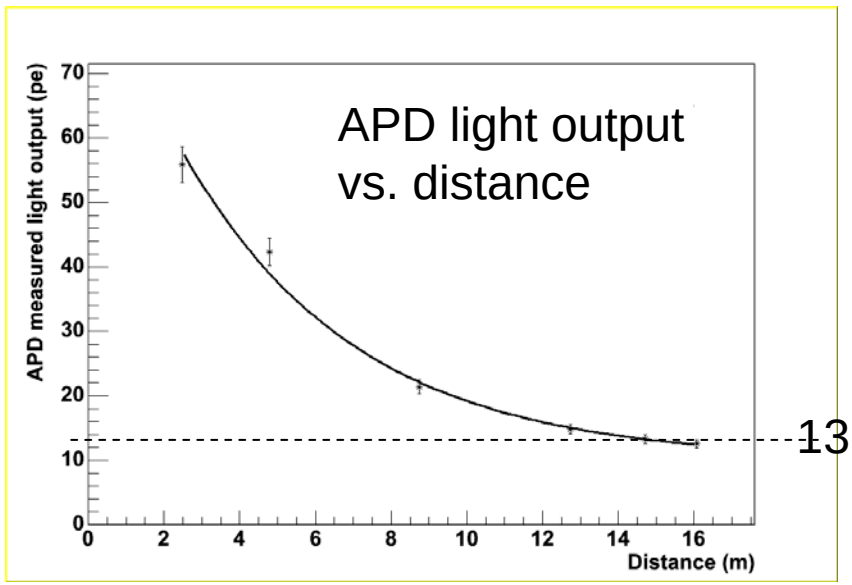
- **Do we have a problem?** **NO**
  - **FIRST, this proposal has one more factor due to the new cell size** (3.87 cm x **6.0** cm) vs. (4.2 cm x 2.2 cm)
    - Simulation says this should be a factor of 1.75
  - **So we expect 22.8 pe** =(13)(1.75)
    - With an APD gain of 100, 250 electrons noise in readout, this is close to our specification for a Signal to Noise ≥ 10 from the far end of a cell
- **Additional handles:**
  - **Can get ~ 10% more light per 1% increase in reflectivity.**
    - Now have 12% TiO_2, next batch is 15%.
      - » Also explore removing PVC additives, anatase vs. rutile TiO_2 , rutile particle size
  - **Can get 25% more light by controlling fiber position**
    - Requires R&D on spiders…
  - **Can change the fiber,** 0.8 → 0.9 mm diameter would give ~ 12.5% more; also 1 m shorter is 10% more
  - **Can get more light with more pseudocumene in the scintillator**
    - Light scales as ~ 2.2% more per 1% additional pseudocumene (we have 10% now).

Scintillator Photon Economics

- Just to show that we have done this full length:

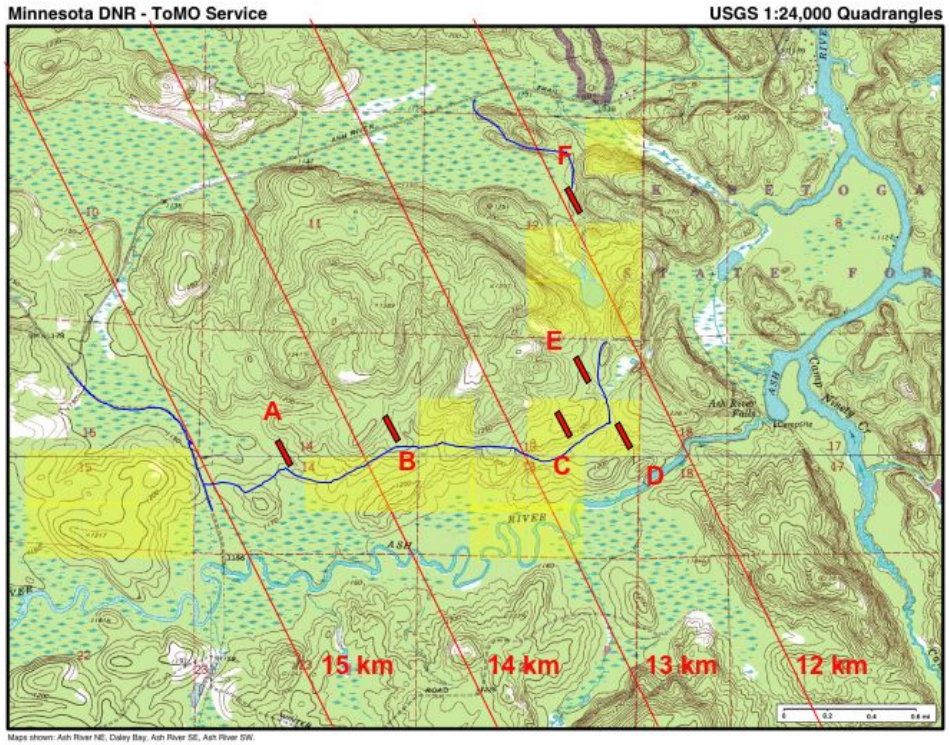






Far Detector Site, ES&H issues

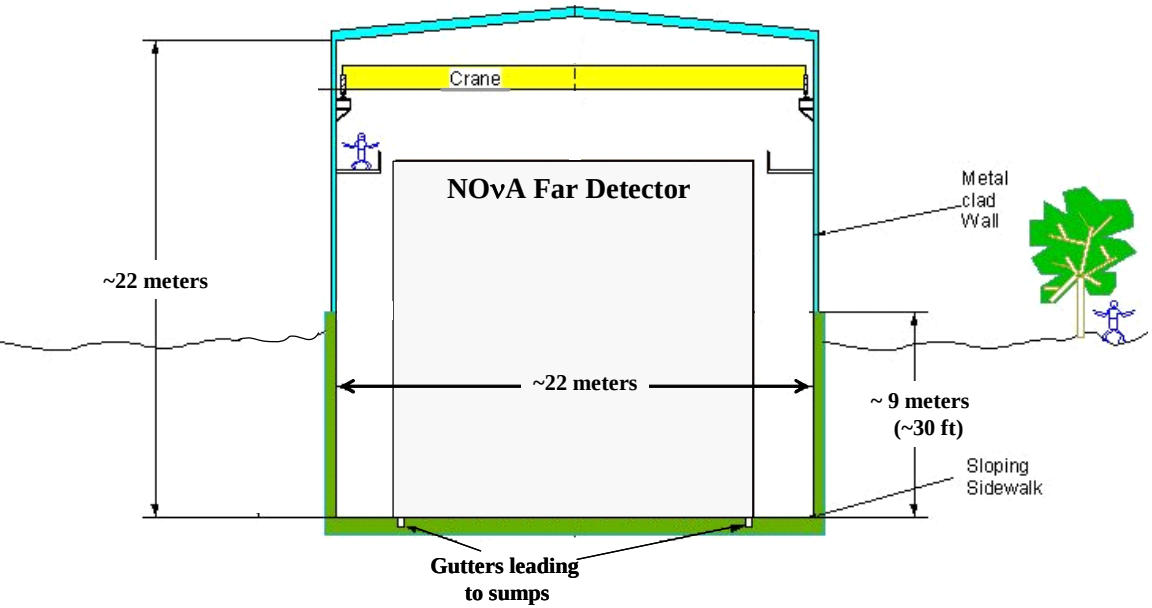
- Ash River near Voyageur's Nat'l Park
  - NuMI beam is 4.2 km in the air here
  - Thinking to visit sites in late April / early May?
    - Aerial photography in April "window"
    - Purchase?

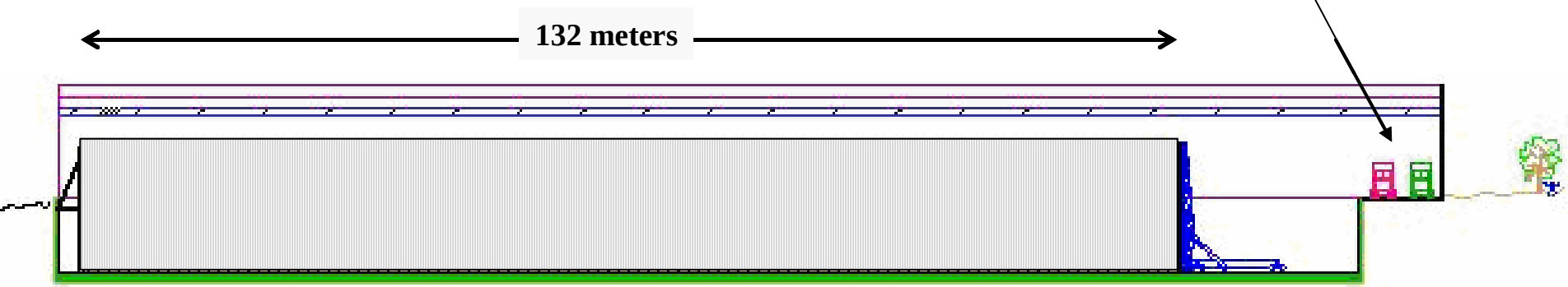


- Consulted with Fermilab ES&H Section experts
  - EA expected
- Three main NOνA-specific issues:
  - Secondary containment of the full scintillator inventory
  - Flammability of PVC
    - Fermilab Fire Protection Engineer (Jim Priest) found it very difficult to ignite
  - Flammability of Liquid Scintillator
    - Jim found it ignitable with a high energy (torch) flame
      - Still need to test if aerosol effect since PVC can form pinholes as it begins to melt, up to 19 psi inside
    - Advises dry chemical or non-alcohol foam fire protection
      - Scintillator floats
      - Toxic by-products in fire

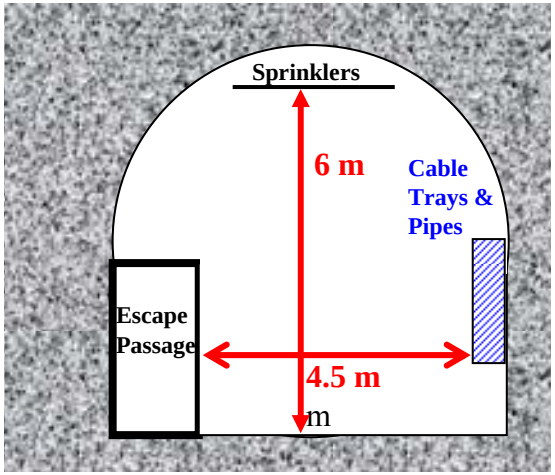
Far Site Building

- **Secondary containment with building below grade**
  - Epoxy paint coated bathtub (green) holds full inventory of scintillator
- Access
  - Catwalks for the top
  - Side aisles for scissor lifts
- "Lean-to" attachment (not shown) for liquid scintillator tanker storage
- HVAC 20 ± 10 ^{o}C
  - Scintillator damage below -20 ^{o}F, > +110 ^{o}F
- Truck staging area at grade level



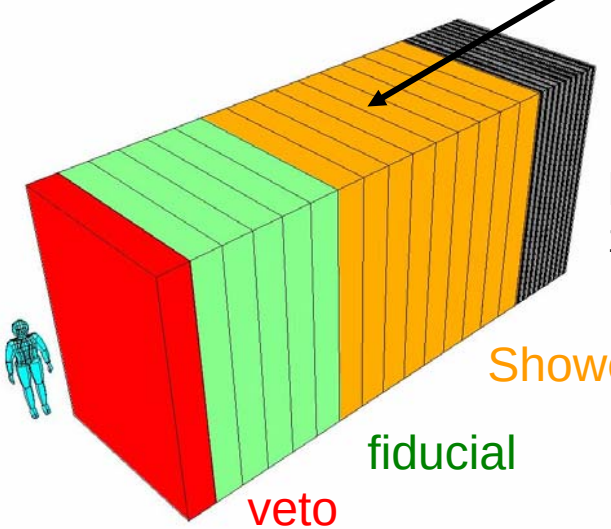


Near Detector structure



- 3.5 m by 4.8 m to fit in tunnels
- 15 sets of 8-plane blocks (each 1400 kg empty)
- Same cells, same fiber, same…..
- 262 tons
  - 145 tons active
  - 20 tons fiducial with surrounding "low energy" regions

Each section is an 8-plane block

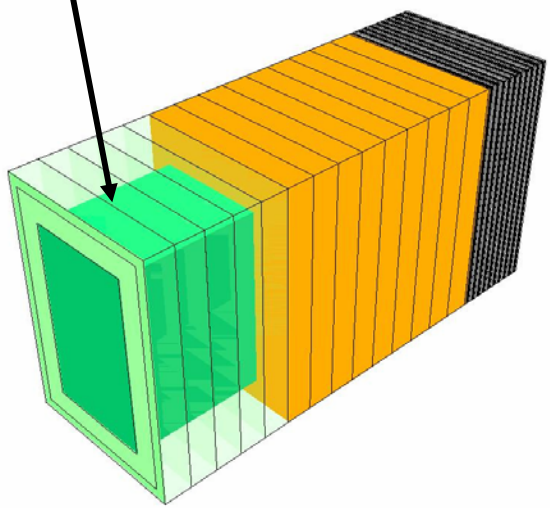


Muon catcher
1m steel + 10 planes

Shower containment

fiducial

veto

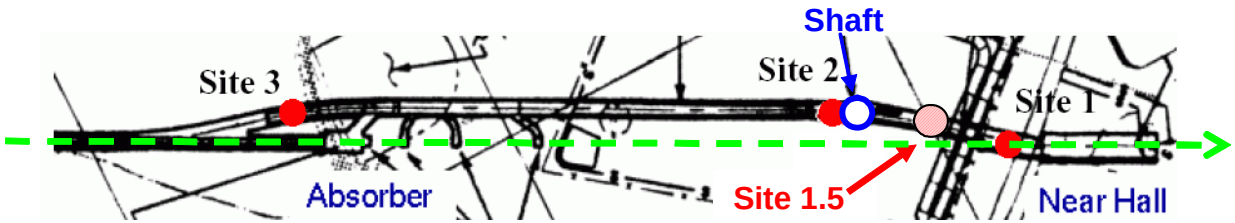


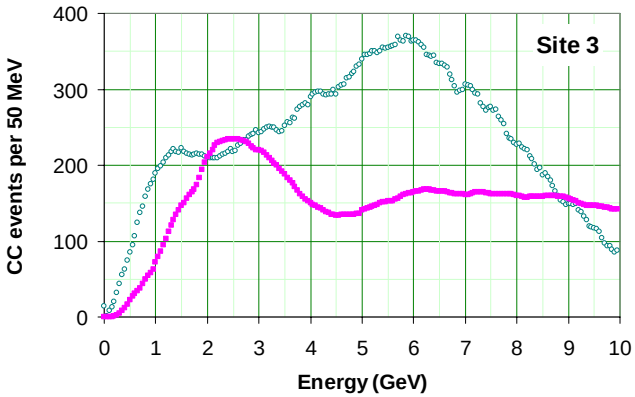
Near Detector **Purpose**

- **Understand detector response and energy calibration**
  - in a location where we can get lots of neutrino events in a short time
    - You want the Near Detector to be identical to the Far Detector.
    - Your understanding is helped by MINERνA cross section data since that tells you what you should have seen.
      - » Event energy effects, event type effects: QE, resonance, DIS about equal in NOνA
  - Testbeam running for calibration, track with cosmic muons

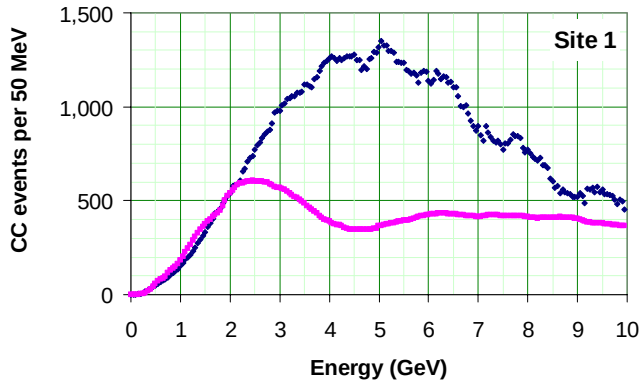
- **Understand backgrounds to a ν_e signal in the Far Detector**
  - Inherent beam ν_e , ν_μ CC, NC, short baseline ν_μ --> ν_e oscillations can all masquerade as ν_e signal events.
  - Philosophy
    - MC predicts Near to Far differences
      - » simple kinematics + horn magnetic field
      - » Line source effect, so Near to Far is not a simple ratio
      - » MIPP data needed, reducing MC prediction errors from ~20% to ~5%
    - Pick a Near location to best model each background
  - **Reality**
    - **All the backgrounds appear at every location, must untangle**
    - Moving the Near Detector around will let you figure this out, but requires careful work

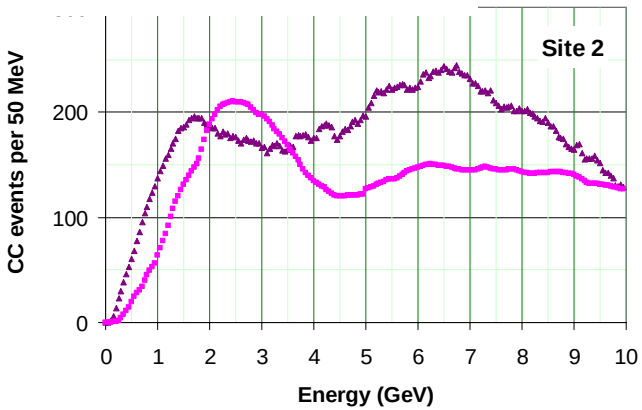
Beam ν_e background

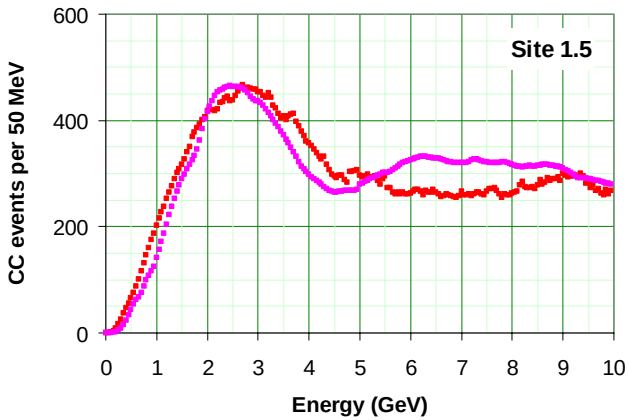




MC for Far Detector in pink normalized at 2 GeV



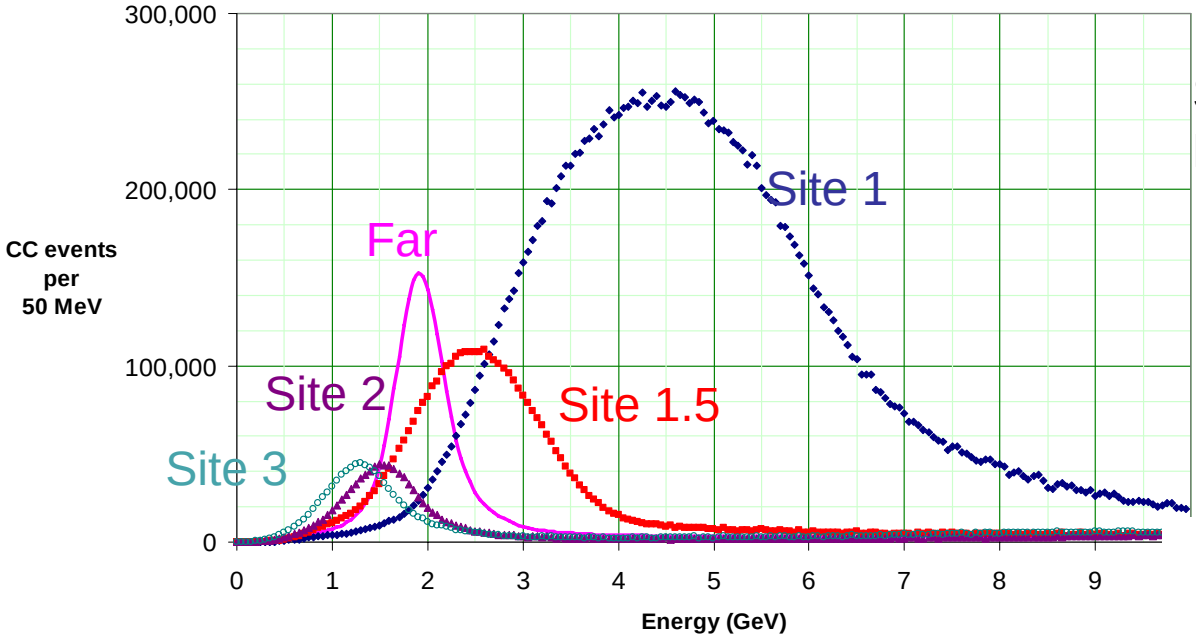




Site 1.5 is the best match

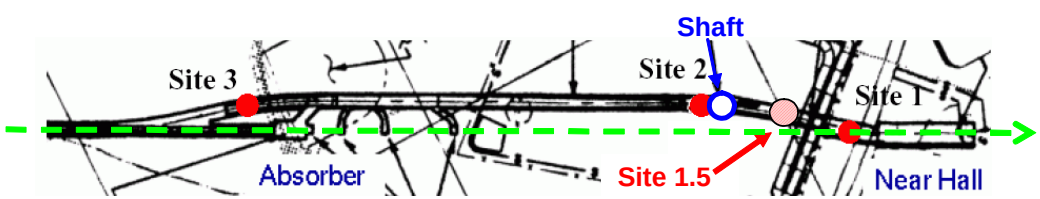
NC background

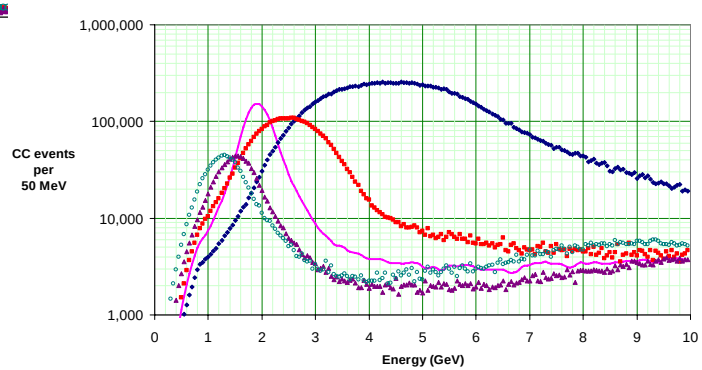
- Total ν flux in Near Detector models Far NC
  - Shape from ν_μ CC



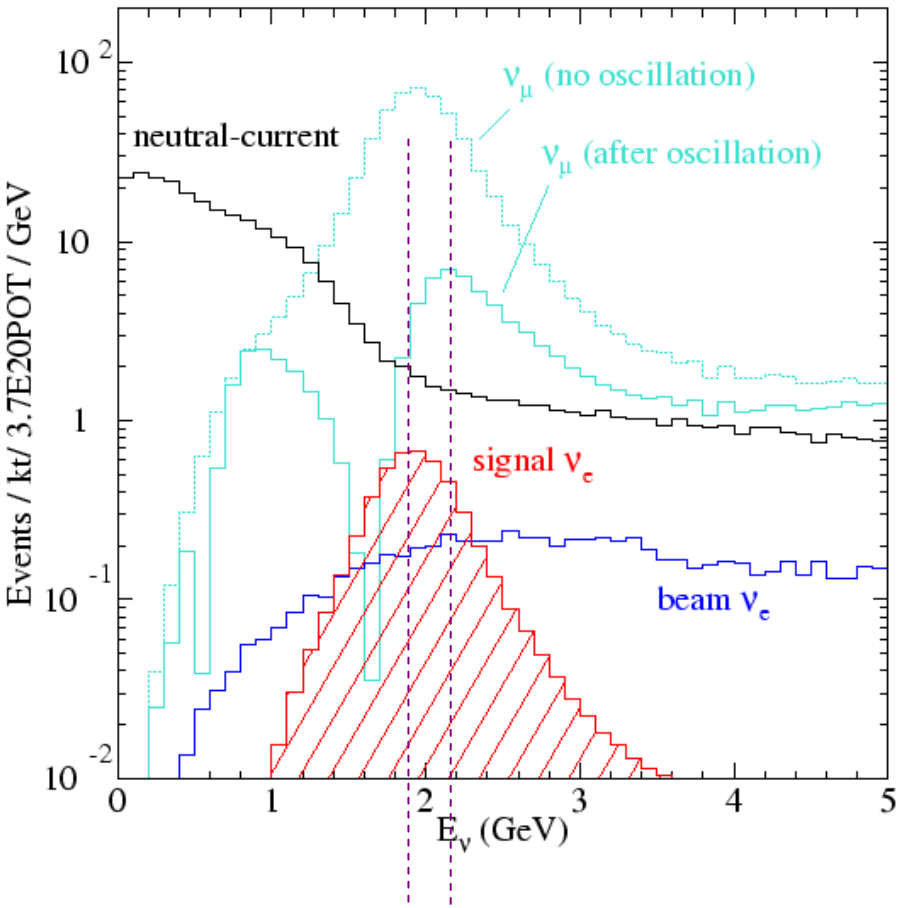
Site 1.5 not a great match,
Looks like we need a Site 1.75

For NC, feeddown to fake ν_e CC means tails are important





ν_μ CC background



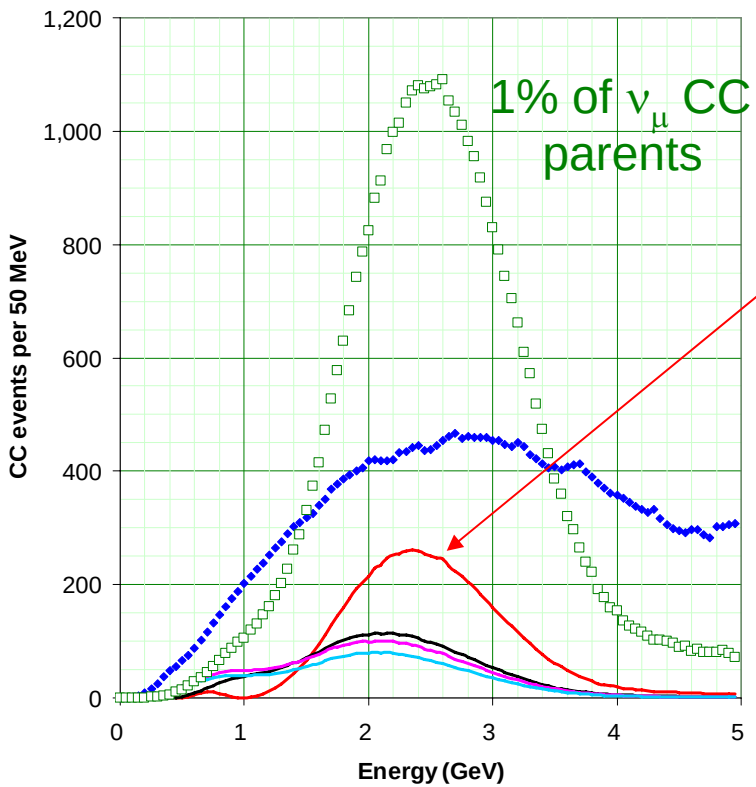
- Not the same energy distribution as for NC
  - Want slightly higher energy
- Also hard to extract
  - Scheme: look at ν_μ CC events, find the fake rate <u>with</u> a μ
  - Extrapolate *y*-distribution of clearly seen muons to low muon range (high *y*) where the muon is not seen and can really fake a ν_e.
  - Difficult, but our simulation shows this background is very small

Short baseline oscillations: LSND effect

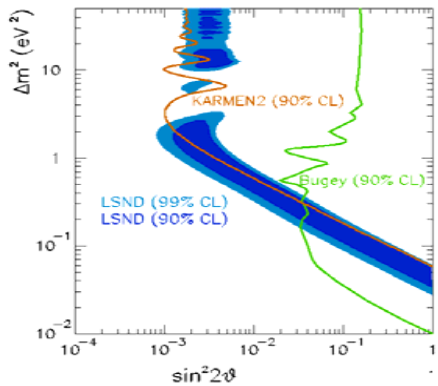
- MiniBooNE may tell us this fall that these exist, so we should understand this

$$P_{ab} = \sin^2(2\theta_{ab}) \sin^2[1.27\,(\Delta m^2)\,(L/E)]$$

$$= \sim 0.0026$$



LSND parameters		Near Detector excess at 2 GeV	Far Detector excess at 2 GeV
Δm^2 (eV^2)	$\sin^2(2\theta_{\mu e})$		
2.5	2.6×10^{-3}	52%	46%
1.0	4.0×10^{-3}	26%	70%
0.4	20.0×10^{-3}	24%	350%
0.25	40.0×10^{-3}	19%	700%



"beam ν_e" background summary

- The last few slides (Chapter 10 of the proposal) is an attempt to evaluate the background given data expected to be available in 2009
  - i.e. MiniBooNE, MIPP, MINERνA,
- Our simulation tells us the size of each background, nicely identified as to source (!)
  - 11.9 events from "real" beam ne events
    - Should know this to ~7% by matching to Site 1.5
  - 7.1 events from NC fakes
    - Should know this to ~ 5% from kinematics of flux prediction for the un-oscillated ν spectrum to the Far Detector
  - 0.5 events from nm CC fakes
    - Should know this to ~15% from our muon range extrapolation scheme
- Uncorrelated errors would imply 0.9 events uncertainty in a 19.5 event background or ~ 5%
  - This is an estimate and an outline of how to approach the problem
  - We do not pretend that we "know" this (yet)

Cosmic Ray Backgrounds

- Plan was to measure this with RPCs and absorber
  - Needed new electronics to be "live", $ 100 K not in budget
  - No appetite to look at RPCs anymore anyway
- Backup Plan was to measure using MINOS spare scintillator and electronics + absorber
  - Not enough spares exist to do a large scale test
  - Would require simulation to understand any result
  - Also not cheap ($ 75 K) and not in FY05 R&D budget
- AND, we really need to do this with a totally active device, not in a sampling calorimeter where one is more easily fooled by interactions in the absorber simulating a ν event in the active part
- So we have retreated to simulations to answer this one
  - Still want to measure this, see R&D slide coming

Cosmic Ray Backgrounds

- Muons, ~ 8 per 10 μsec spill
  - Fine for calibration monitoring, median energy is 4 GeV
  - Distributed, so not a problem for ν event recognition
  - Incoming charged track cannot fake ν_e
- Electrons and Photons, ~ 4 per 10 μsec spill
  - Most have energies below 100 MeV and shower in the top of the detector
  - Still worrying about high energy photons that may penetrate and fake a ν_e QE
  - Handles
    - angular distribution relative to Fermilab
    - Only 2% > 1 GeV, accompanied by other particles (but needs more simulation)
    - Most are e^+e^- conversions, so double pulse height at start may help
- Neutrons, ~ 1 every 100 spills with energy > 2 GeV
  - More vertical than muons, average angle ~20° from zenith
  - Median energy ~ 100-200 MeV
  - 1.5 GeV required to produce a single π @ 60° which might fake an electron
    - Angular distribution of neutrons and π products do not typically point to Fermilab
    - Apply our selection criteria for ν_e events and find 0.44 events pass in 5 years of data

Cost Estimate is $ 165 M (FY04 $)

WBS	Description	Base Cost (K$)	Overhead (K$)	Contingency (K$)	% Contingency	Sub-total (K$)
1.0	Far Detector					
1.1	Active Detector					
	1.1.1 PVC Modules + Assembly	19,513	2,184	7,085	33%	28,782
	1.1.2 Liquid Scintillator + handling	24,063	59	6,187	26%	30,309
	1.1.3 Waveshifting Fiber	13,400	8	4,022	30%	17,430
	1.1.4 EDIA	1,680	470	860	40%	3,011
1.2	Electronics, Trigger and DAQ	7,853	803	4,756	55%	13,412
1.3	Shipping & Customs Charges	4,799	960	1,200	21%	6,958
1.4	Installation	7,530	1,963	4,048	43%	13,541
	Far Detector Sub-total	78,837	6,446	28,159	33%	113,442
2.0	Near Detector	1,678	470	945	44%	3,092
3.0	Building and Outfitting					
3.1	Site Work	5,275	158	4,075	75%	9,509
3.2	Building	11,532	346	5,345	45%	17,223
3.3	Outfitting	1,262	38	1,300	100%	2,599
	Building & Outfitting Sub-total	18,070	542	10,720	58%	29,332
4.0	Project Management	2,985	805	948	25%	4,738
5.0	Additional Contingency	-	-	14,145		14,145
	due to the early stage of the cost estimate					
TPC	Total Project Cost	101,570	8,263	54,916	50%	164,749

- **INCLUDES $ 55 M contingency**
- Total is $ 6M more than TASD at Aspen
  - BUT also 5 kt more detector
  - 10% more overall contingency
- Main changes are
  - Larger cells, so fewer channels
  - Pre-mixed liquid scintillator
  - Cheaper Near Detector, same modules & electronics as Far

NOνA Schedule, Ch 14

Milestone	Date (in months relative to Project Start)	Proposed Calendar Dates	FY
Procure 32-cell test extrusions with final design	t_0 - 12	October-2005	
initiate R&D on APD packaging	t_0 - 12	October-2005	
start advanced conceptual design work: Far Site & Bldg	t_0 - 7	March-2006	06
Project Start	t_0	October-2006	
Order extrusions and fiber	t_0 + 1	November-2006	
Notice to Proceed on Far Site Work and Building *(linked to advanced conceptual designs above)*	t_0 + 1	November-2006	07
R&D prototype Near Detector complete	t_0 + 3	March-2007	
Site work complete	t_0 + 9	July-2007	
Begin receiving packaged APD modules *(linked to R&D start above)*	t_0 + 12	October-2007	
Start Extrusion Module Factories *(linked to available extrusions, manifolds, and electronics)*	t_0 + 12	October-2007	
Start construction of Near Detector	t_0 + 14	December-2007	08
Beneficial Occupancy of Far Building	t_0 + 19	May-2008	
Start Outfitting of Far Building	t_0 + 19	May-2008	
Start operation of Near Detector	t_0 + 21	July-2008	
Order scintillator oil for continuous delivery 6 months later	t_0 + 26	December-2008	
Far Building Outfitting complete	t_0 + 31	May-2009	09
Start construction of Far Detector	t_0 + 31	May-2009	
Start filling Far Detector planes with Scintillator	t_0 + 32	June-2009	
First kiloton (800 extrusion modules) operational	t_0 + 36	October-2009	
5 kilotons (4000 modules) operational	t_0 + 40	February-2010	10
10 kilotons (8000 modules) operational (5 kt / ~3 months)	t_0 + 43	May-2010	
Full 30 kilotons operational	t_0 + 57	July-2011	11

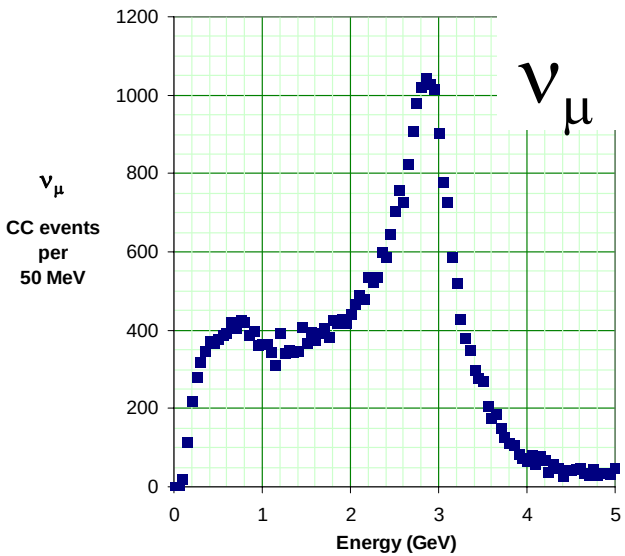
- Project Start = Oct,2006
  - Several critical R&D tasks must precede this
  - ~ "technically limited" but not too "high tech" since paced by
    - Far Site and Building work
    - Then Far Detector construction
    - Extrusion Module factories easily follow this schedule
- Partial Detector operational in Oct, 2009
  - First 5 kt operational in Feb, 2010
  - Full detector in July, 2011
  - Gary will show physics vs. time
- This is a VERY conservative schedule
  1. 18 months for site + building
  2. Then 12 months for outfitting
  3. Then Far Detector construction
  - **We believe the first two steps can be advanced by 7 to 9 months**
    - Easy for Extrusion factories to keep up

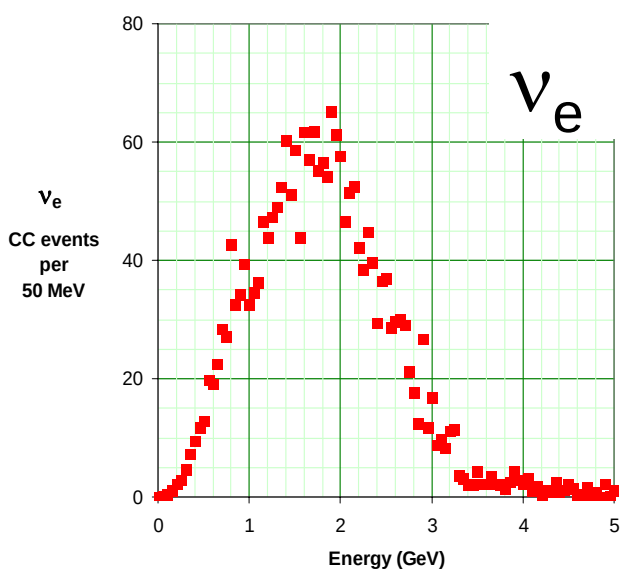
R&D, Ch 15

R&D Task	Approximate Materials & Services funding required (K$)	
Extrusions of Rigid PVC	325	250
Refectivity of Rigid PVC	50	
Bottom Closures and Top Manifolds	150	
Liquid Scintillator studies	50	
APD Packaging	275	200
ASIC Designs	135	2 passes on 2
Site and Building Designs	150	FESS
Structural Analysis and Prototypes	240	100
Prototype Near Detector	885	
Contingency @ ~ 33%	740	
Total	3,000	

- Straightforward list
- > half is a prototype Near Detector

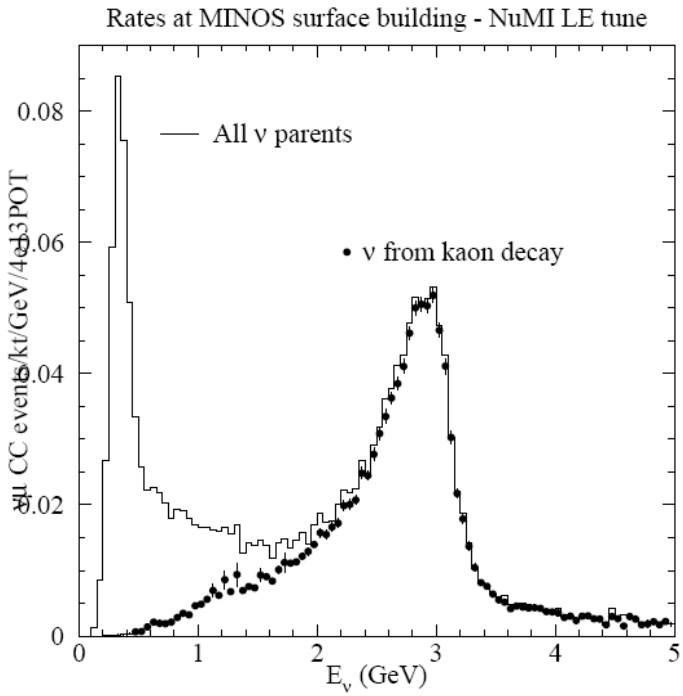
Why a prototype Near Detector?

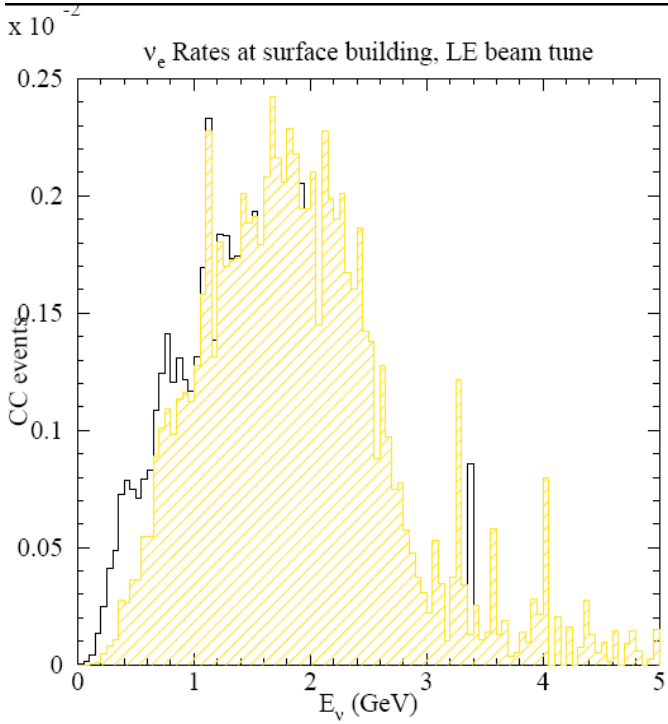




- Neutrinos in the MINOS surface building
  - 2200 CC ν_e / year
    - Less with low energy beam
  - ν_e Spectrum locked to ν_μ since K decays
  - Peak is at 2 GeV, what more could we want?
    - 10-15% of all events at 2 GeV are ν_e
- Advantages:
  - The building already exists.
  - We can initially avoid the complications of underground access.
  - The event rates are low enough that initially we would not need special fast electronics to reject multiple events in a single MI spill.
  - Large sample of ν_e CC events will aid in developing better pattern recognition algorithms.
  - We can gain experience with a fully active detector running on the surface.

prototype Near Detector in 2007





- LE spectrum similar, rates are lower
  - 1 year @ **3.4 e20**: 5,500 ν_μ CC in 3 GeV peak, 760 ν_e CC
    - (Proton Plan phase III in 3/2007)
  - (vs. ME @ 6.5 e20: 13,000 2,200)