Magnetic Tracking Calorimeters for Neutrino Factories

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NuFact05

Outline for Talk

- Orientation
  - > A few things from old workshops (NuMI off-axis & Nufact series)
- Magnetics from MINOS & thoughts
- Making a large device
  - > Ideas from MINOS, NOvA & MINERvA
- Plans for moving forward

Way back machine…

Neutrino Factories: Physics

S. Geer, arXiv:hep-ph/0008155

> v_e -> v_e oscillations might be observed at a high performance neutrino factory with L > 3000 km

> Requires background levels of *O*(10^{-5}) of the total CC rate

- But at what threshold?

Good Starting Places

S. Wojcicki (Nufact01)

- Review of many options – analytic calculations
- Final states with muons appear to offer the greatest physics potential
- Accessed with straight forward detector that are extensions of existing ones
- Need 4-5m of field to get 10^{-4} background
- ~2 GeV energy loss per meter of steel
- Might want to change focus in toroidal field
- No obvious reason why an iron/scintillator tracker not adequate

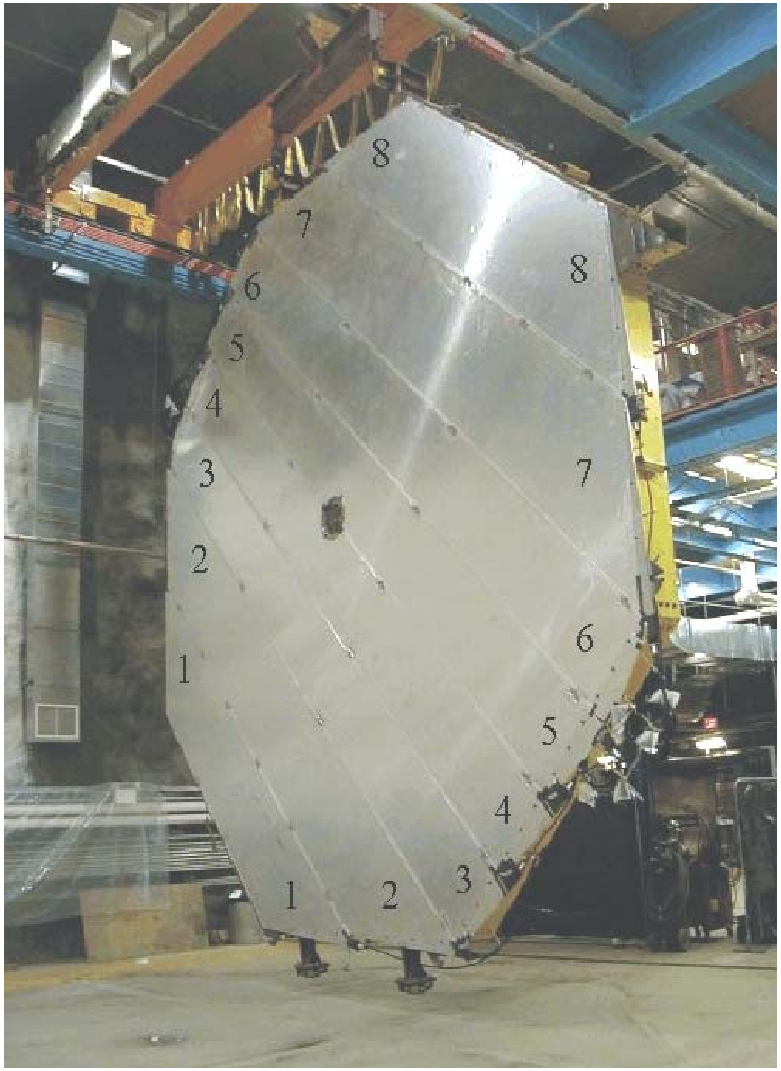
A. Cervera (Nufact04)

- Review of large magnetic detectors
- MONOLITH based
- Performance satisfactory for study of $\mu\pm$ at NuFact
- Electron identification… charge measurement

Making larger magnets

- Stan had was too pessimistic on the coil for a 10m toroid with 1T field
  - > Based extrapolation on MINOS ND
  - > MINOS ND design is saturated need much less current
  - > Had coil area is really 30x30 cm^2
- More on this later…

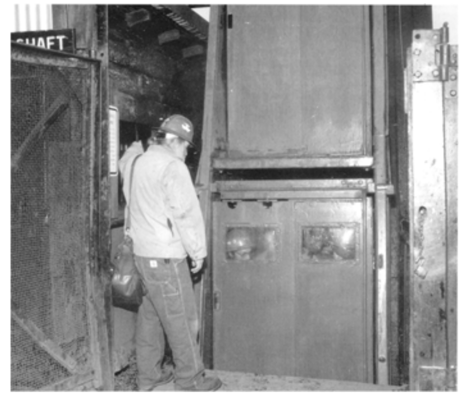
A MINOS Scintillator Plane



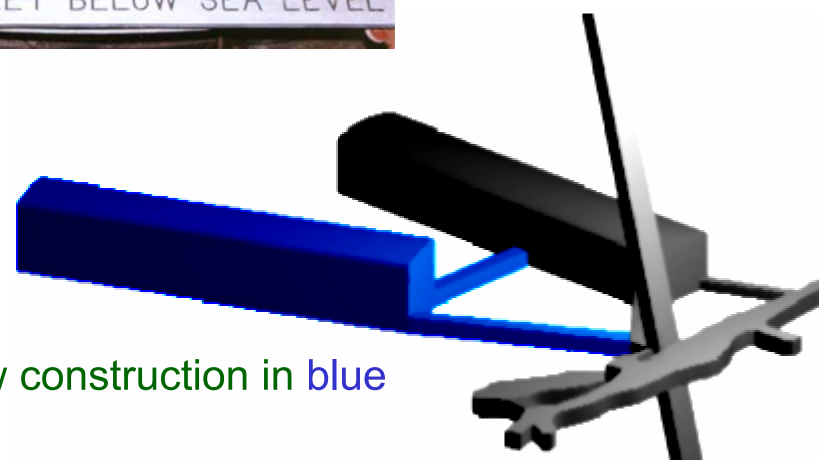
- Strips assembled into “modules”
- 8m diameter
- 192 strips per plane

Soudan Underground Laboratory

Soudan Underground Mine State Park

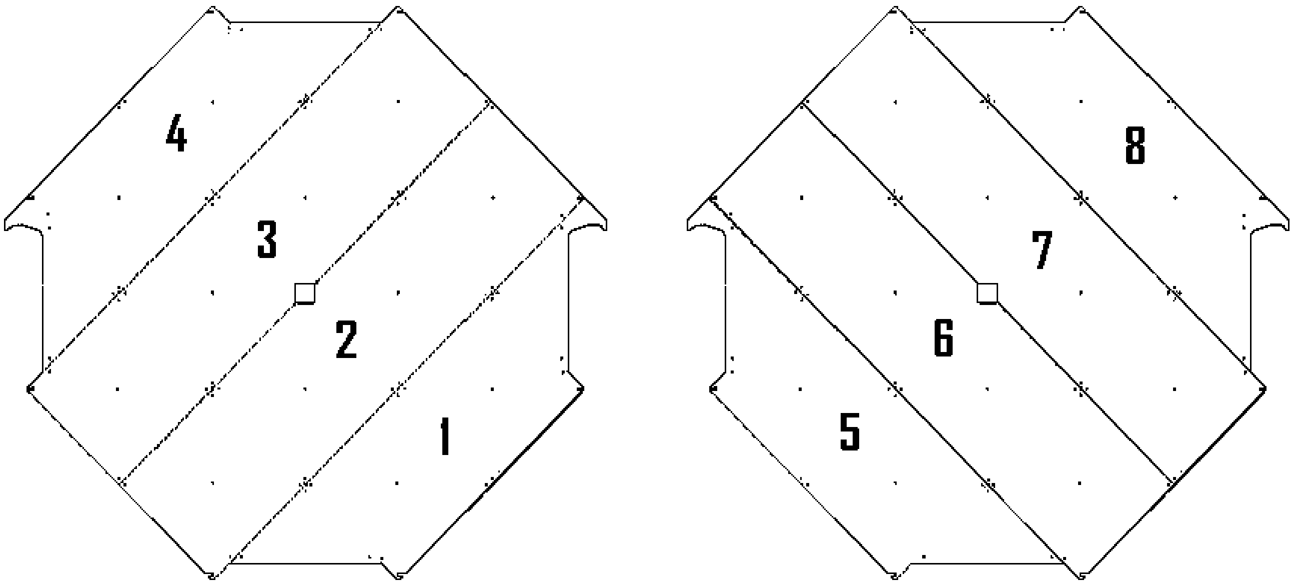


The Soudan shaft limits objects to a maximum size of 1m by 2m by 9m

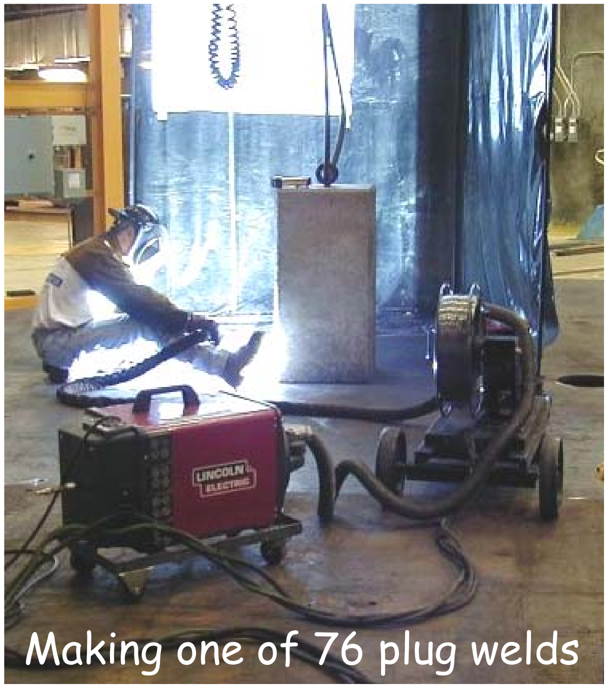


New construction in blue

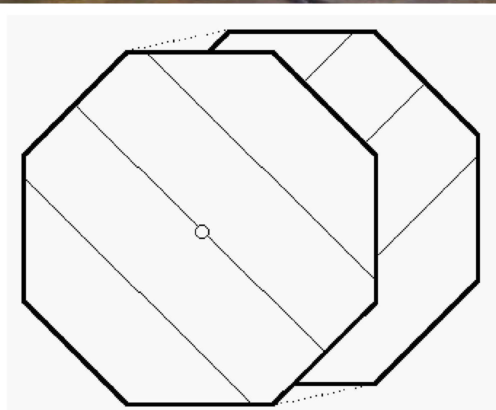
FD Steel Plane
Make from 2m-wide pieces



Making a MINOS Plane


Making one of 76 plug welds


Laying the steel into place

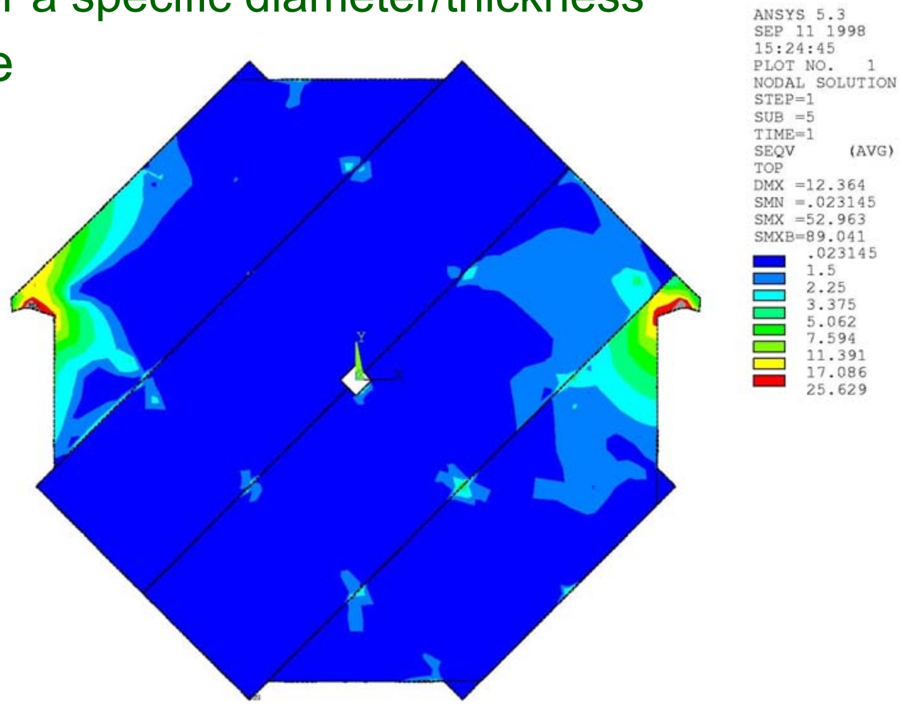


Plane Installation

Plane lifted to vertical

Steel Plate
& FEA Analysis for MINOS FD

- Plane thickness — Safety Margin
  - 2.00 cm — 1.7
  - 2.54 cm — 3.0
  - 4.00 cm — 4.4
  - Thicker makes easier structures
  - Will need to get engineering for a specific diameter/thickness
- Bigger device will be composite like MINOS FD
  - Widest single sheet of steel in US is 3.9m wide
  - ~15m longest length to cheaply ship (in US)
  - Therefore will have to be some kind of laminate like the MINOS FD

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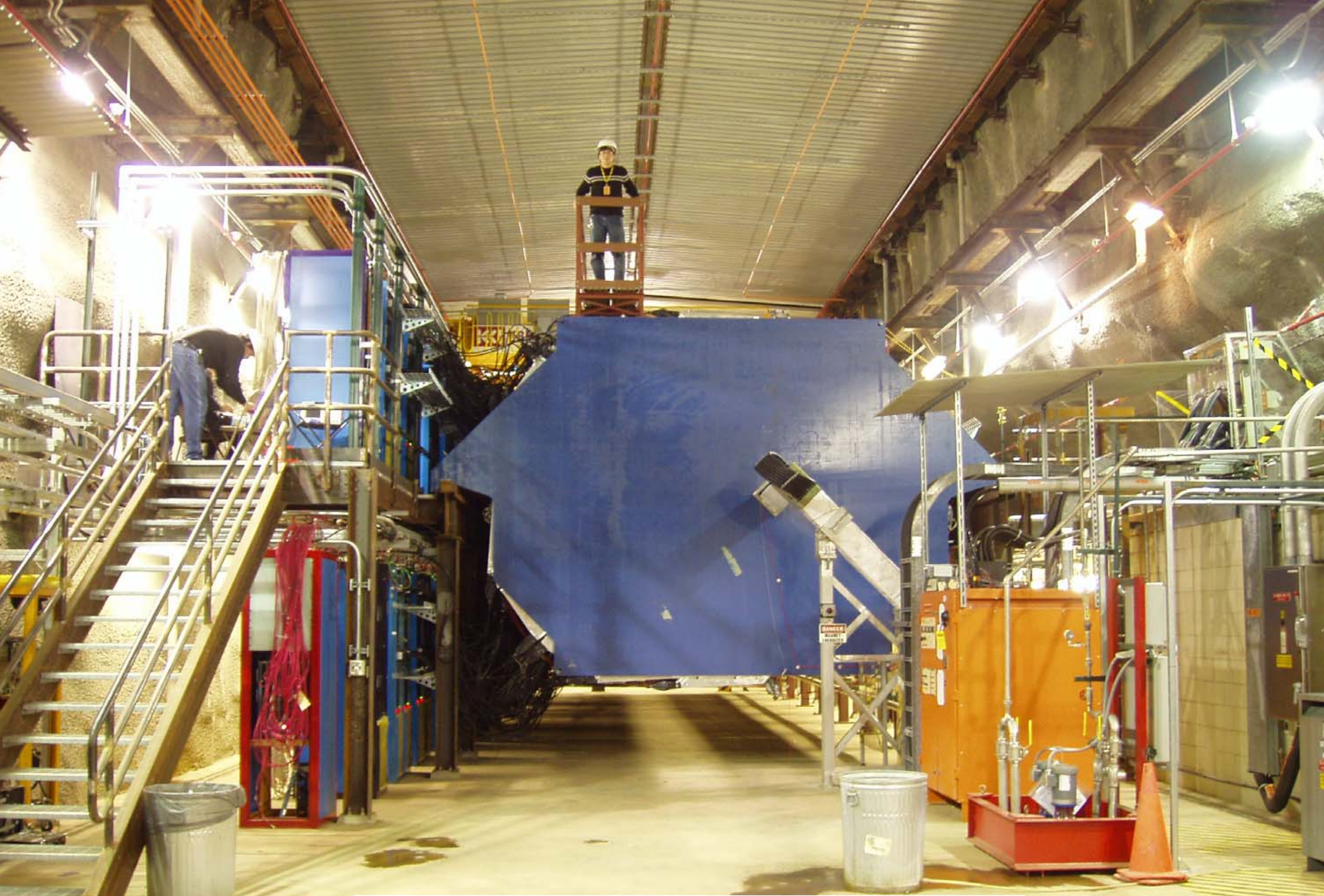
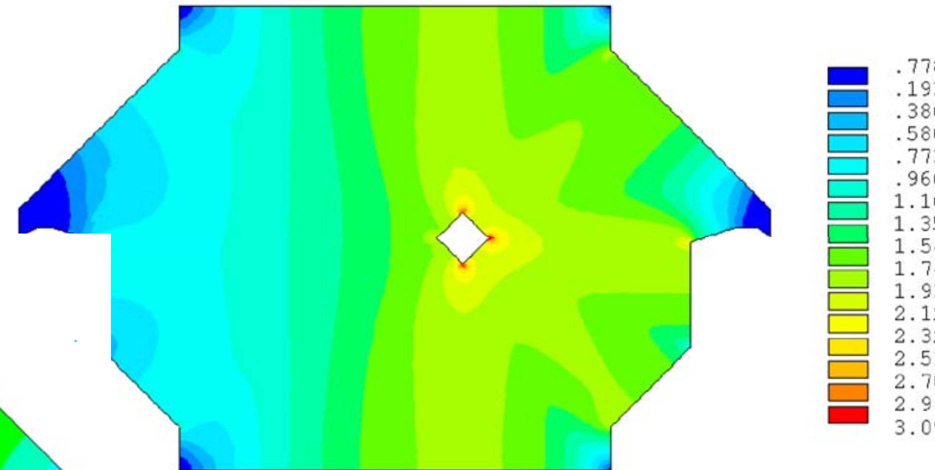


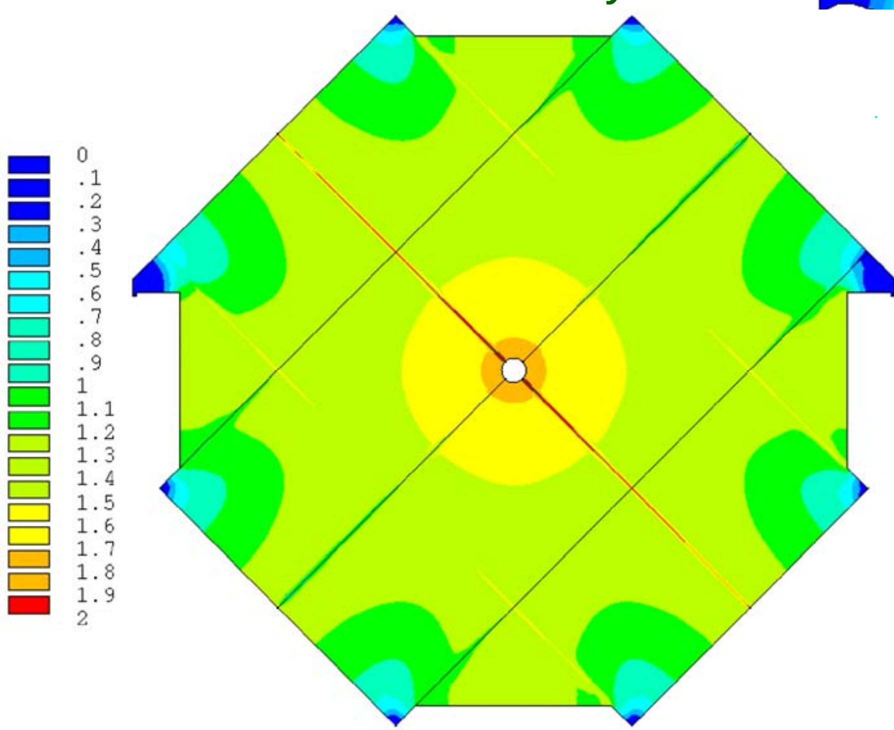
MINOS Near Detector
With 40 kA-turn coil

Magnetic Field Maps

- Full geometry FEA simulations including all gap structures
- Plots of |B| (T)
  - Different color keys

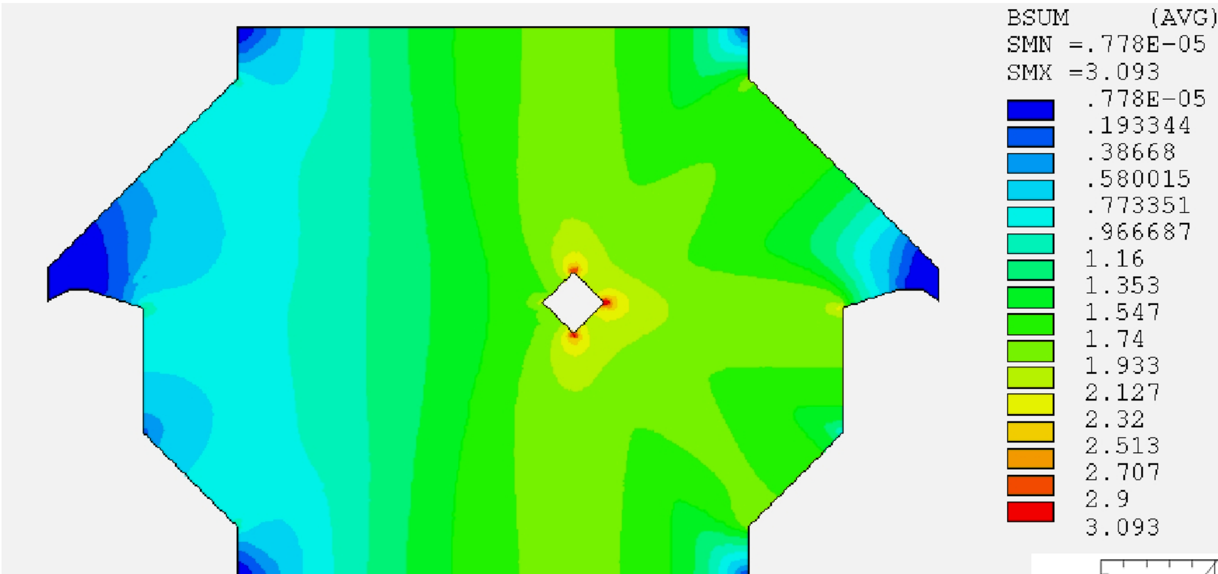


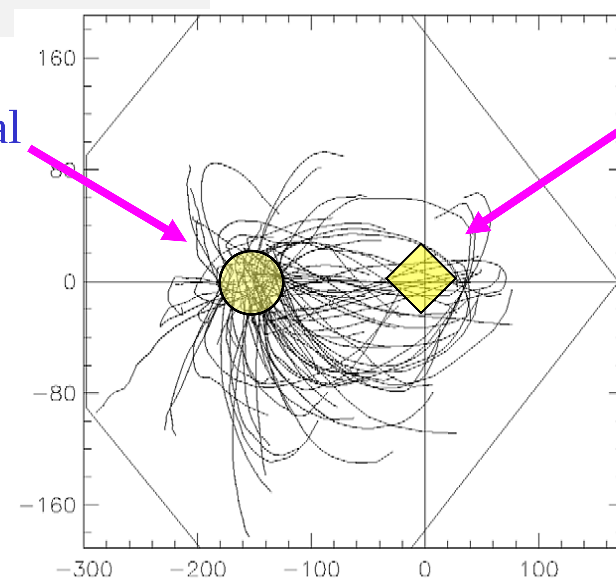
Field in an ND plane



Field in a slice through a FD plane – many slices could be averaged

Near Detector Magnetic Design

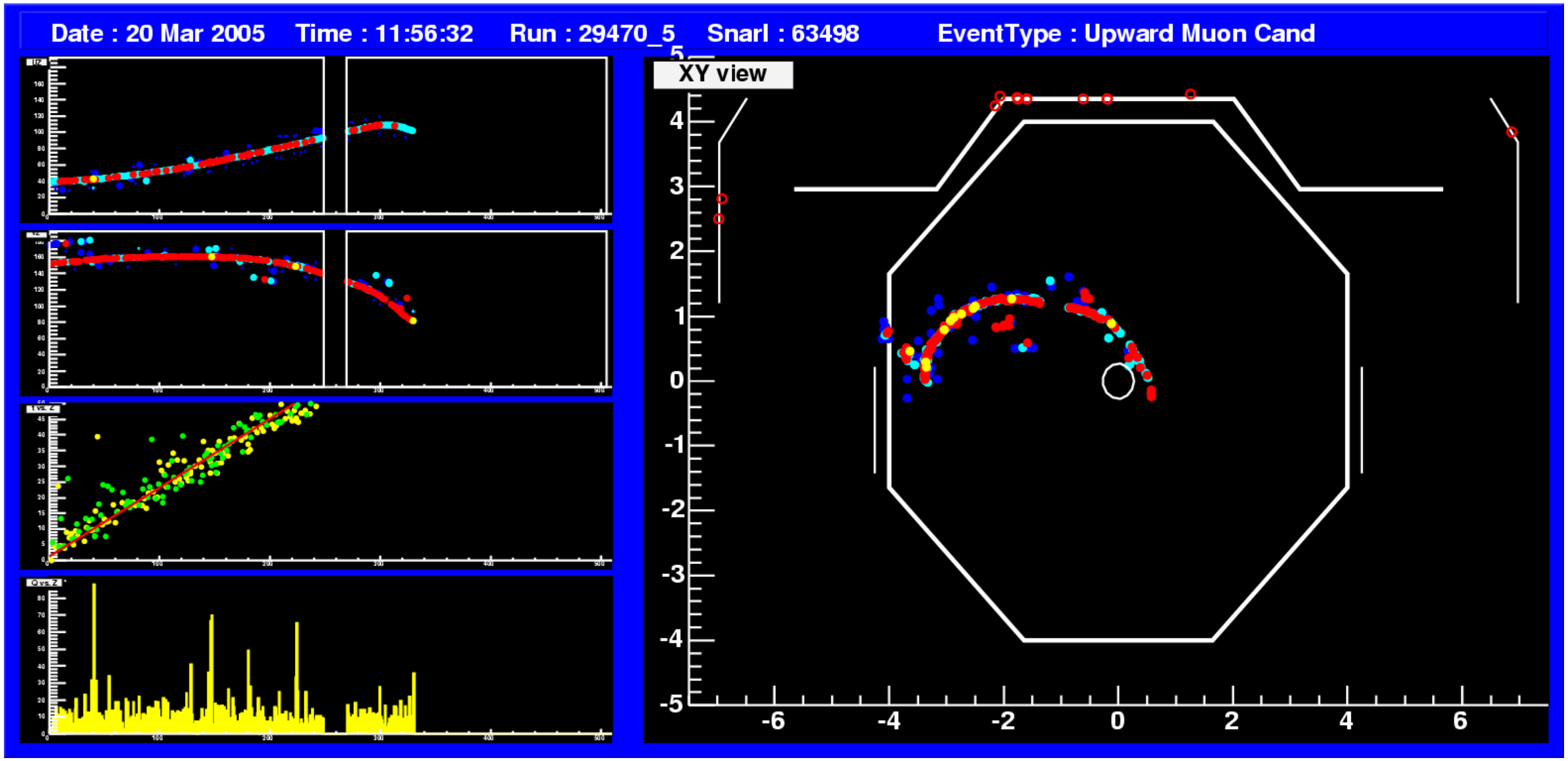




100 MINOS LE CC muon (MC) <p> ~ 2.5 GeV

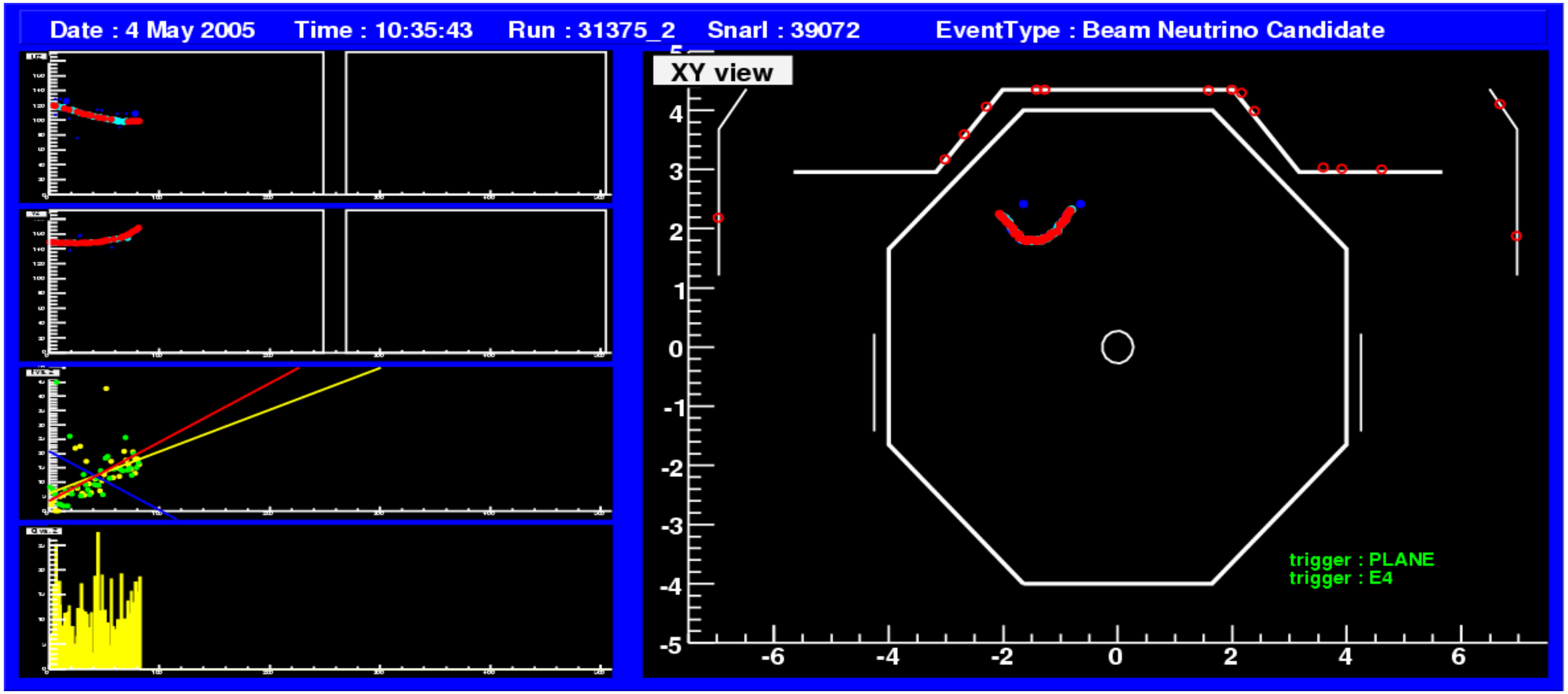
First MINOS FD beam event

A 13GeV stopping muon measured by range & curvature



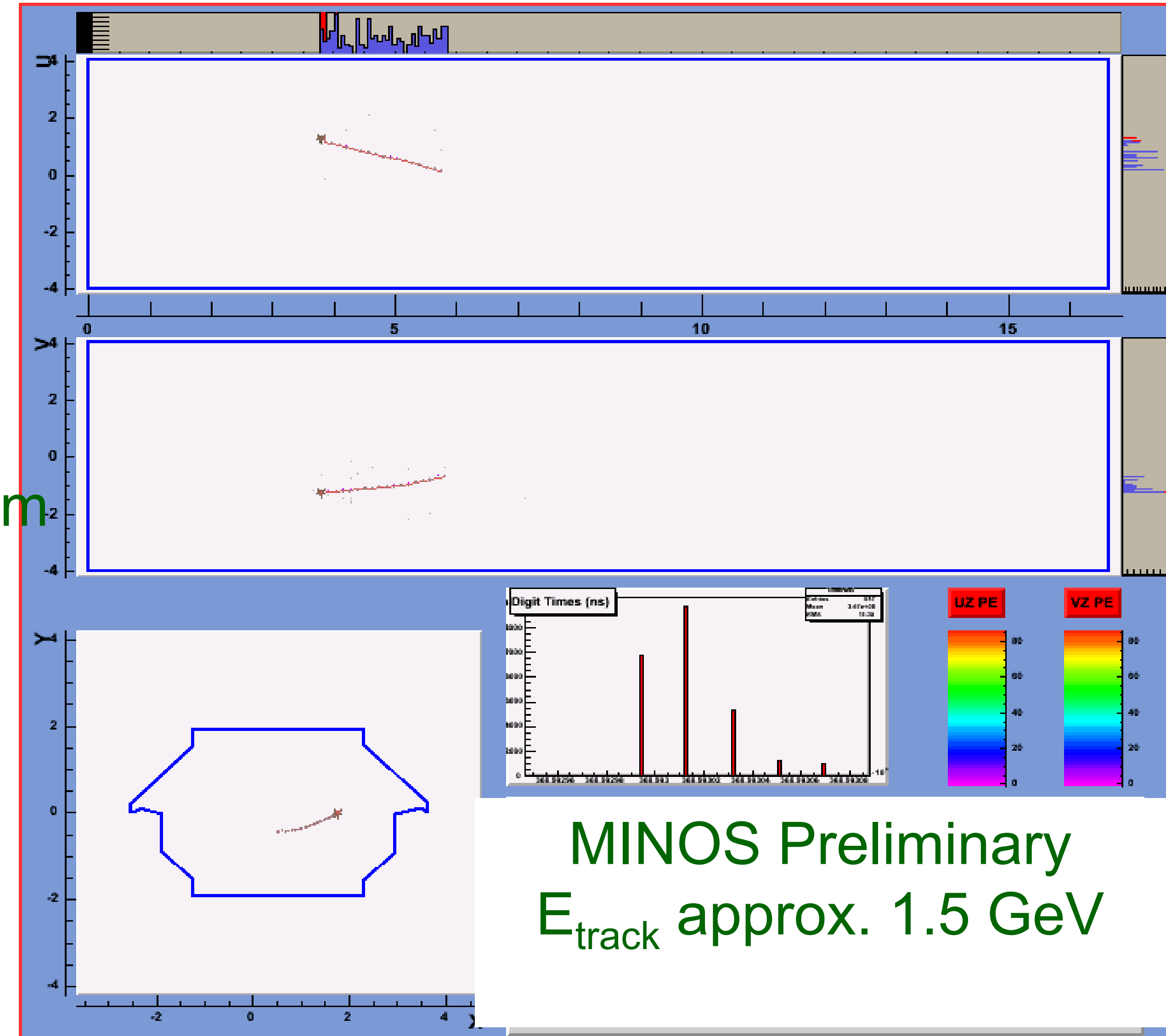
Defocused rock muon event

4 GeV stopping track (defocused)



Near Detector Event

Low-energy track from fiducial region

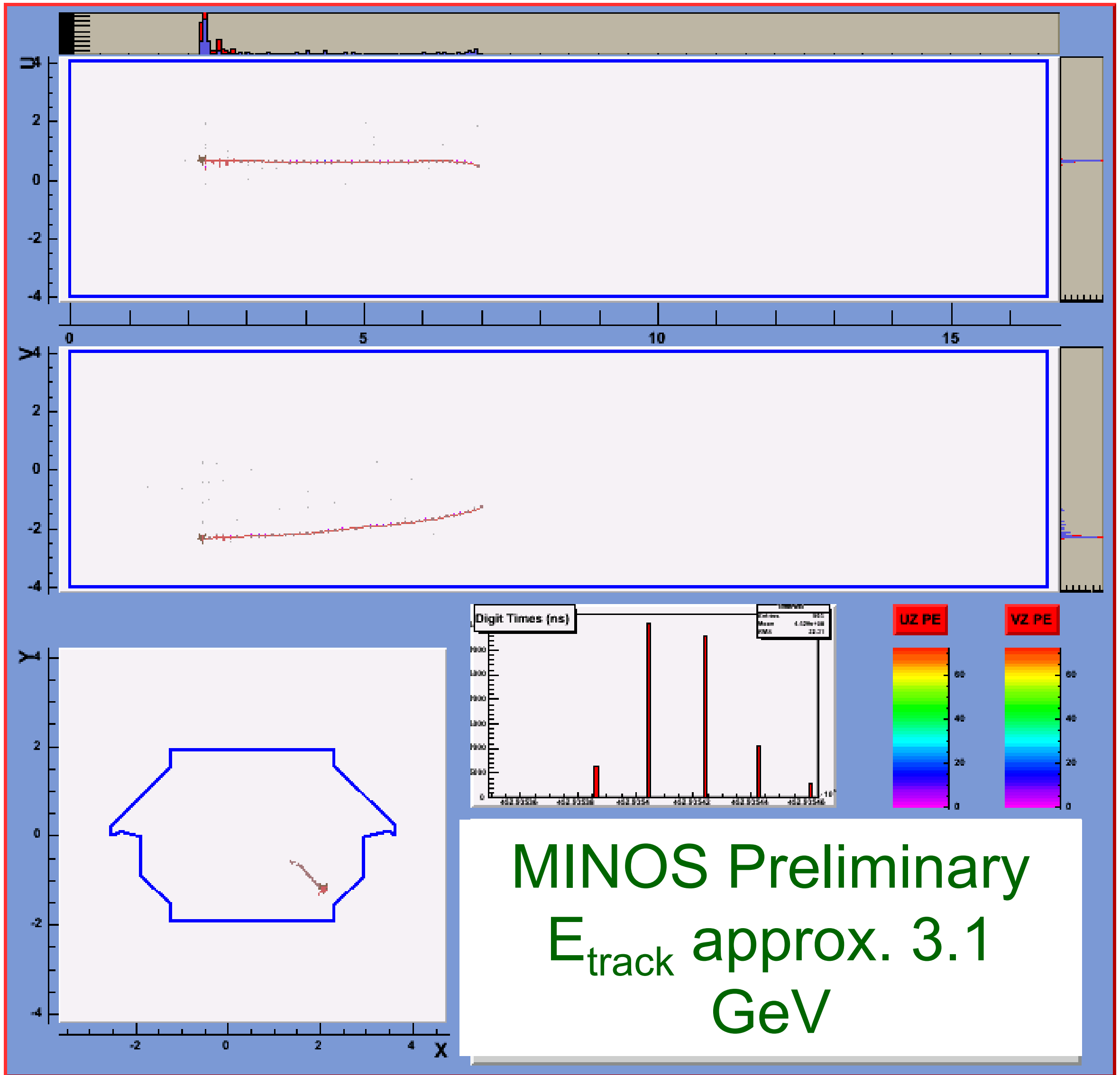


MINOS Preliminary

E_{track} approx. 1.5 GeV

Additional Near Detector Events

Medium energy track from near peak in "pseudo-medium" beam

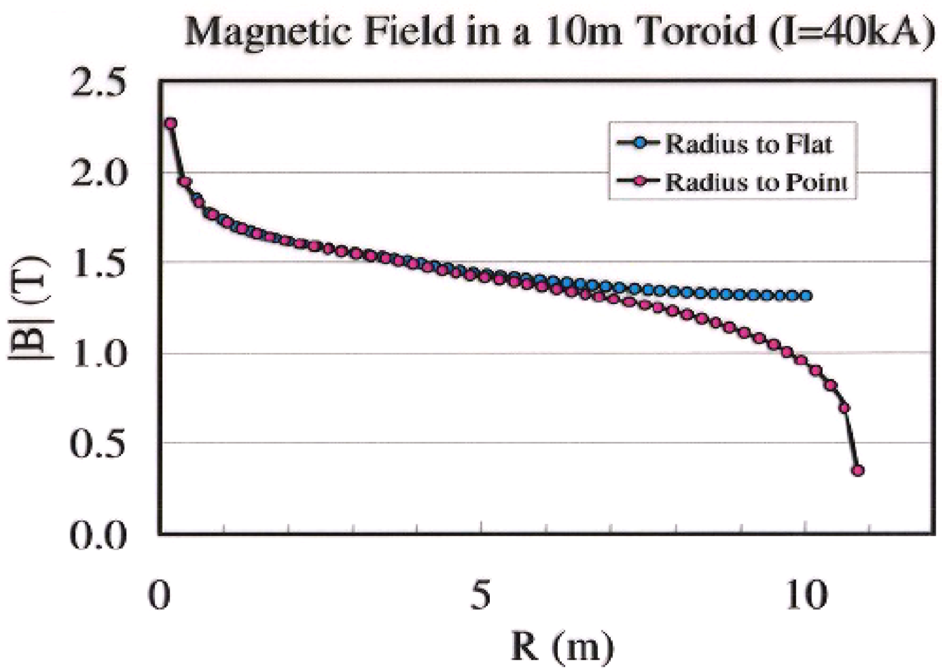


MINOS & Charge ID

- Still calibrating the MINOS fields
- Starting out with the hard problems (at least from the tracking point of view)
  - Cosmic ray charge ratio
  - Upward muon charge analysis
  - Contained vertex atmospheric muons
  - Much harder due to hard energy spectrum & steep angles
- To do list…
  - Make charge ID plots vs E for beam events in MC & compare with data
  - Show how well we can do it for the “easy” normally incident case

Making a Bigger Torus

- FEA model by R. Wands & J.K. Nelson (Fermilab) done for Stan’s talk 2002
- I = 40kA * r / 10m
  - > Recall MINOS ND is 40kA

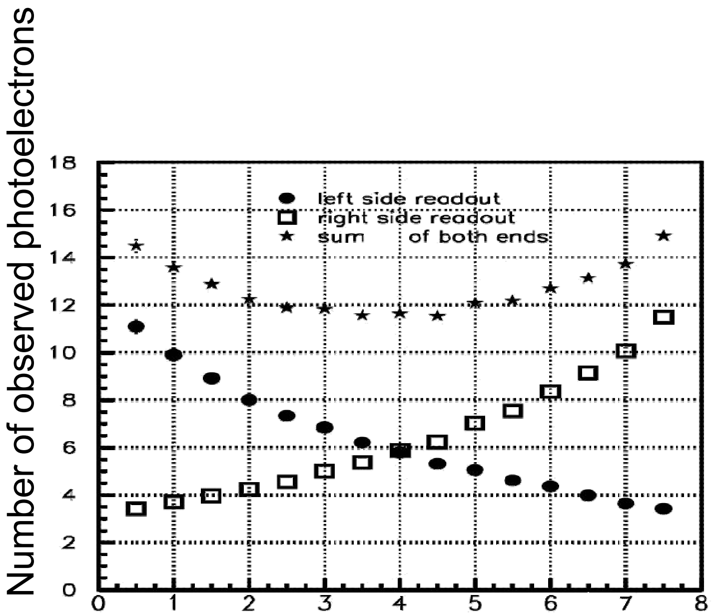


Readout Options

- RPC vs Solid Scintillator
  - >Costs are indiscernible (NOvA 11/03 proposal)
- Solid vs Liquid
  - >Active components 33% cheaper

MINOS has too much light (and works too hard to get it!)

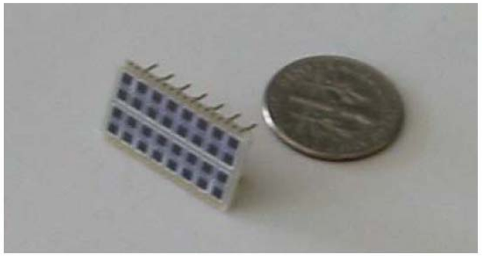
- Only needed 4pe for EM shower ID/measurement in 2.54 cm sampling
  - > Less for tracking and hadronic calorimetry
  - > Treated as contingency
  - > Can make longer cells
- APDs vs PMTs
  - > Cost dramatically lower
  - > 8× quantum efficiency of a MINOS PMT
  - > Also relaxes the light yield requirements
    - Allows longer cells

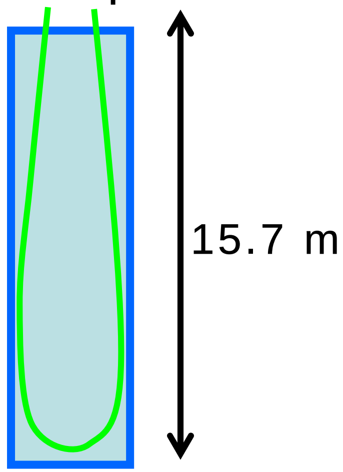


Distance along the scintillator (m)

NOνA Far Detector

- Liquid scintillator cells
  - > 1984 planes of cells
- Cell walls
  - > Extruded rigid PVC
  - > 3 mm outer; 2 mm inner
- Readout
  - > U-shaped 0.8 mm WLS fiber
  - > Acts like a prefect mirror
  - > APDs (80% QE)





50kt NOvA Sampling Detector
Solid Scintillator + PMT

~400m^2 and 1000 samples

Not fully loaded costs – only to show scaling

Use absolute costs from NOvA talk (next slide)

	Solid PMT		Solid APD	Liquid APD
Scintillator	22.3		27.3	14.2
optical fibers	12.0		12.0	12.0
Scintillator Assembly	25.7		21.4	13.5
Photodetector	7.5		1.7	1.7
Electronics (not DAQ)	15.3		8.4	8.4
Sum	82.8	$M	70.8	49.8

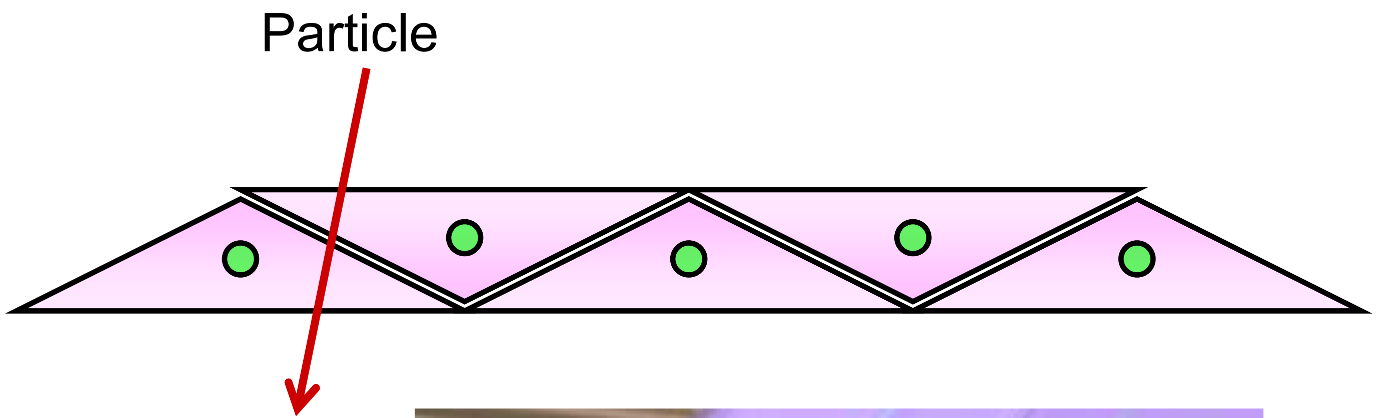
Full costs from NOvA TASD (3/05)

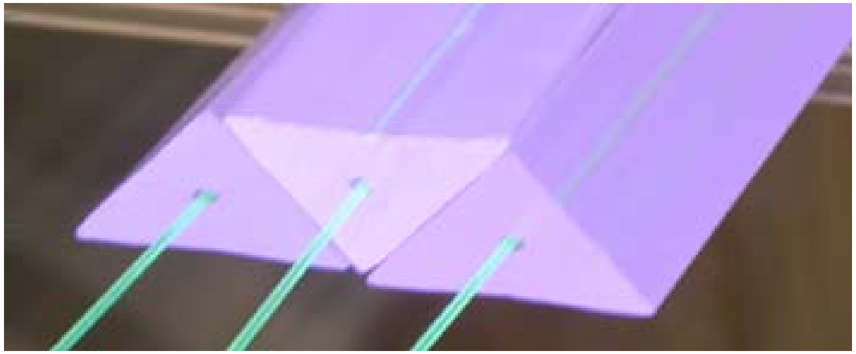
- NOvA instrumented area is huge
  - > 1984 planes of $246m^2$ -> $55k\$/250m^2$

	Total Cost M$
Far Detector	
Active detector	80
Electronics and DAQ	13
Shipping	7
Installation	14

  - > Would used significantly less instrumented for Fe/LS tracker (e.g. 20%?)
- Need to add in structure & iron (~2m$/kt)

MINER*ν*A Optics
(Pioneered by D0 preshower)





- Significantly enhance position resolution for wider strips
- Could make the same cell geometry for liquid cells too

Summary

- Detector is feasible
  - > Large area toroidal fields can by directly extrapolated from MINOS design
    - Thicker for large planes – some engineering needed to set the scale
  - > Can now make an affordable large are scintillator readout with NOvA technology
- Can optimize sampling to get lower tracking threshold
  - > Will try to MINOS-like design to see how charge ID for normally incident track compares to actual MINOS data
  - > Would also give good electron ID
  - > Could enhance position resolution with MINERvA-like triangles
- Come up with parameterization of resolutions, efficiency/fake rate, and costs for optimization