



Magnetized iron tracking detectors

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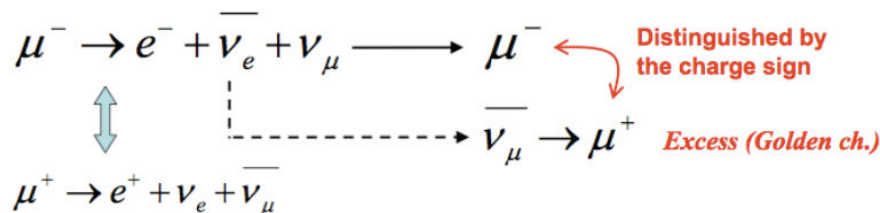
Workshop on European Strategy for
Future Neutrino Physics

October 3rd, 2009



Outline

- A current example: MINOS is the prototype
 - > Reminder of the primary purpose envisioned for this detector
 - Golden channel at the neutrino factory

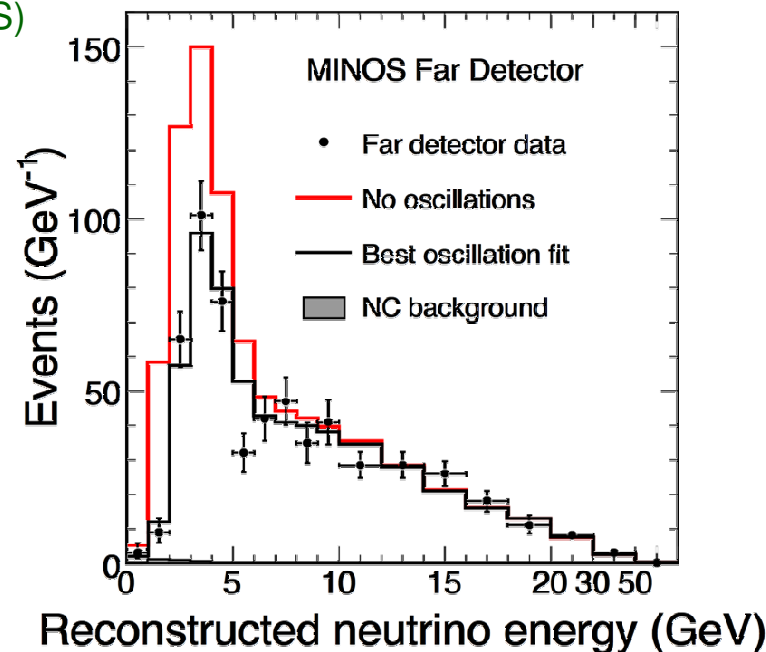


- Baseline detector of the ISS golden channel
 - > Detector overview
 - > Example of performance: the MINOS antineutrino analysis
- Scaling mass by a factor of 10 or more for neutrino factory
 - > “Super MINOS” – issues and nonissues
 - > Technologies advanced since MINOS design frozen
- Possible implementations
 - > R&D and related activities

The “MIND” a Magnetized Iron Neutrino Detector



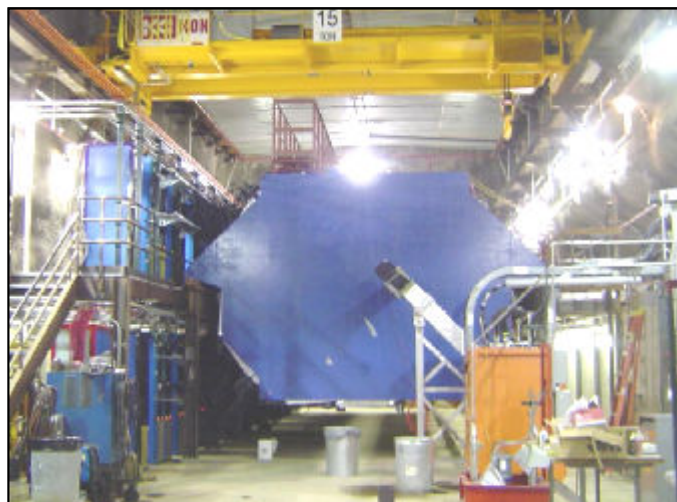
- The conceptual “super-MINOS” used for the ISS reference detector
 - > Sandwich of 4 cm thick iron plates (could be thinner)
 - > 4 cm thick detection layers (2 views)
 - Transverse resolution of 1 cm (as with MINOS)
 - Could be better (al a MINERvA)
 - > Fiducial mass of the order of 100 kt
 - $\sim 20\times$ MINOS
 - Much smaller instrumented mass than NOvA
- MINOS capabilities include
 - > Momentum by range or curvature
 - > Slower energy by calorimetry
 - > Muon charge sign analysis
 - > Electron spectrum
 - c.f. arXiv:0909.4996, Evans’ Poster
 - > Shower angle resolution too poor to study tau appearance like NOMAD
 - Some ability for tau appearance based on pion ID (MINOS TDR)



PRL **101** 131802 (2008)



Two MINOS Detectors



NIMA 596 190 (2008)



Iron and Scintillator tracking calorimeters

Near Detector

Monolithic planes

$3.8 \times 4.8 \text{ m}^2$

282 steel planes

Coil: 40 kA-turns (8 turns, 5kA)

2.54 cm thick steel plates

$1 \times 4.1 \text{ cm}^2$ scintillator strips

2.3 cm air gaps

Multi-anode PMT readout

Far Detector

Composite planes

$8 \times 8 \text{ m}^2$

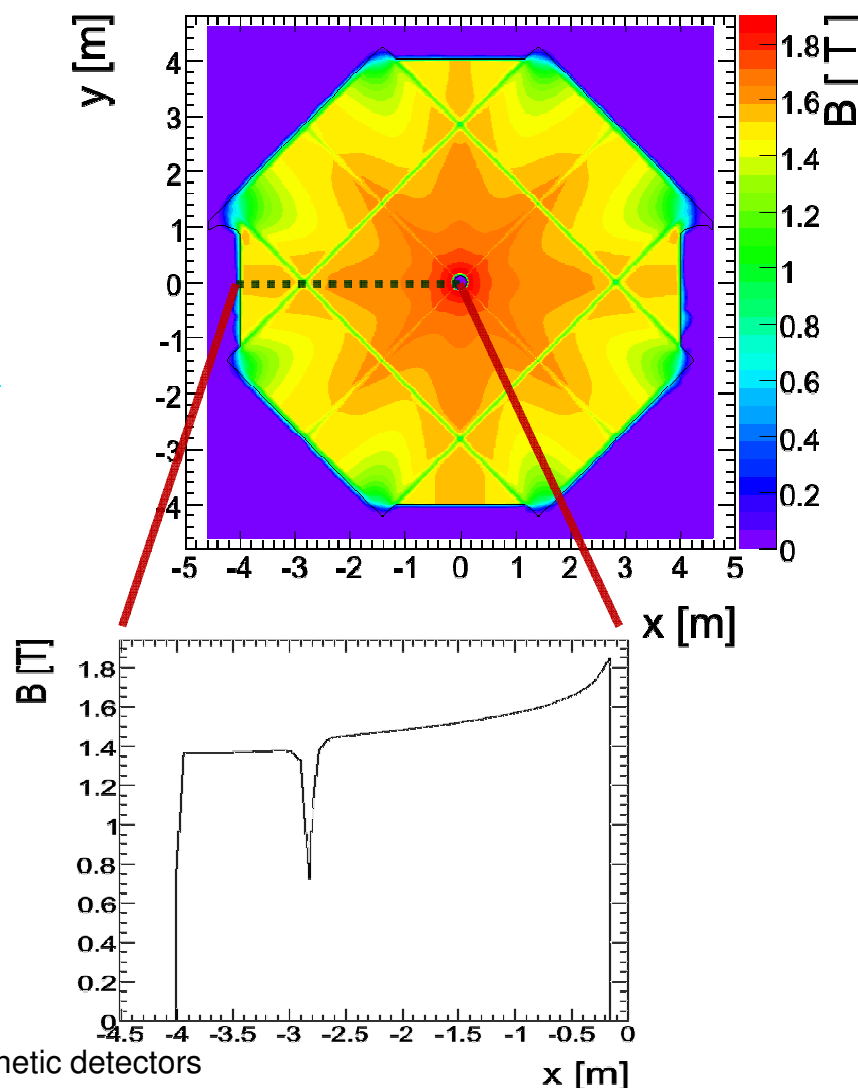
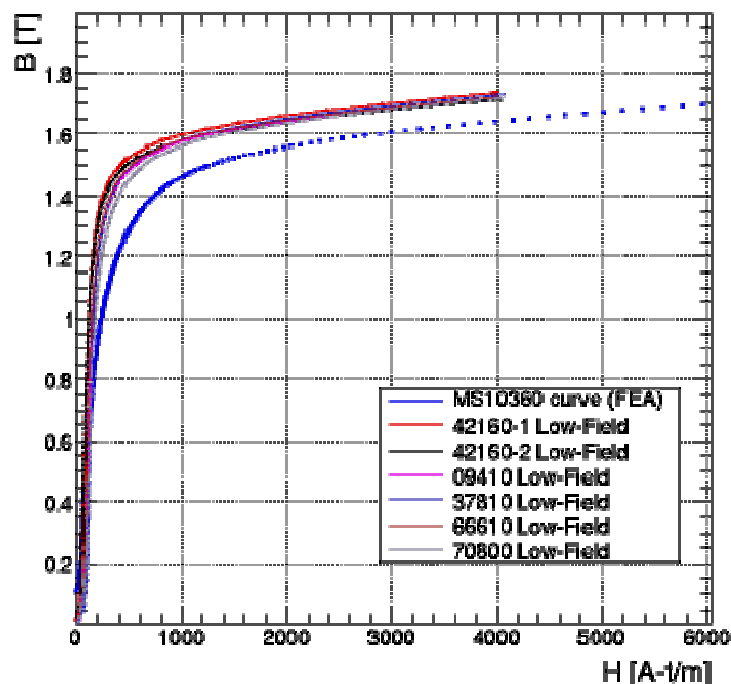
486 planes

Coil: 15.2 kA-turns (190 turns, 80A)



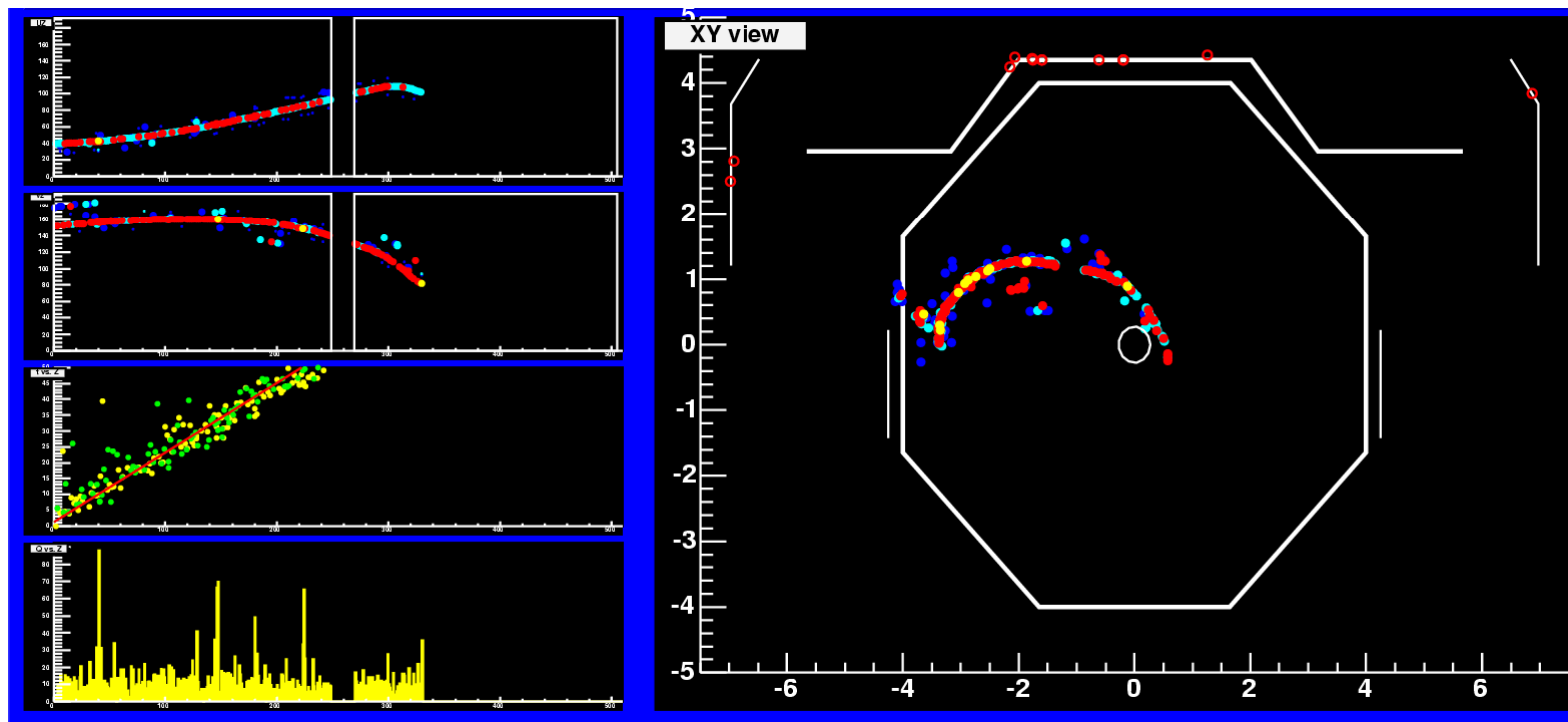
MINOS FD Magnetic Field Maps

- Full geometry FEA simulations including all gap structures
 - Measured “final” B-H curve
 - Note: red curve new since Golden07 (JKN) & ISS





13GeV muon



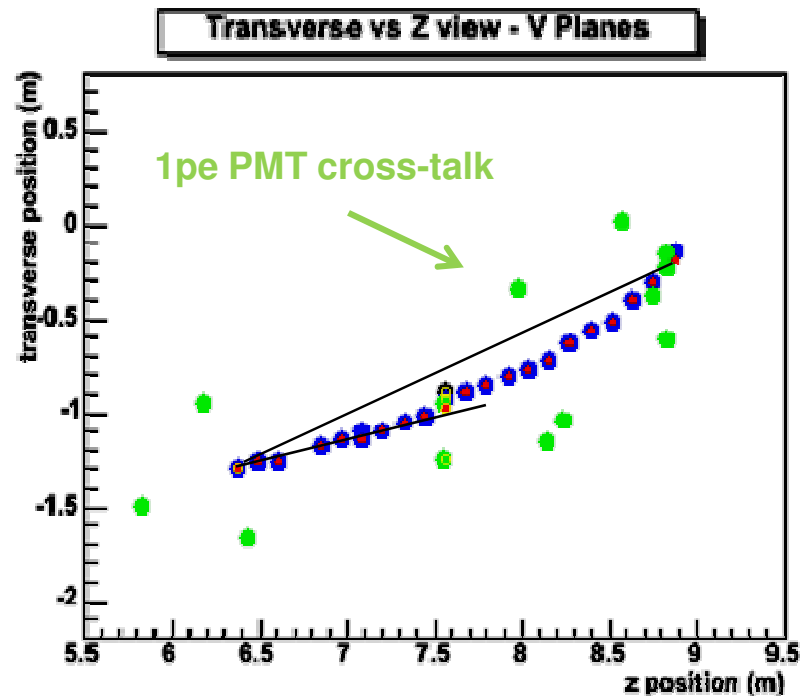
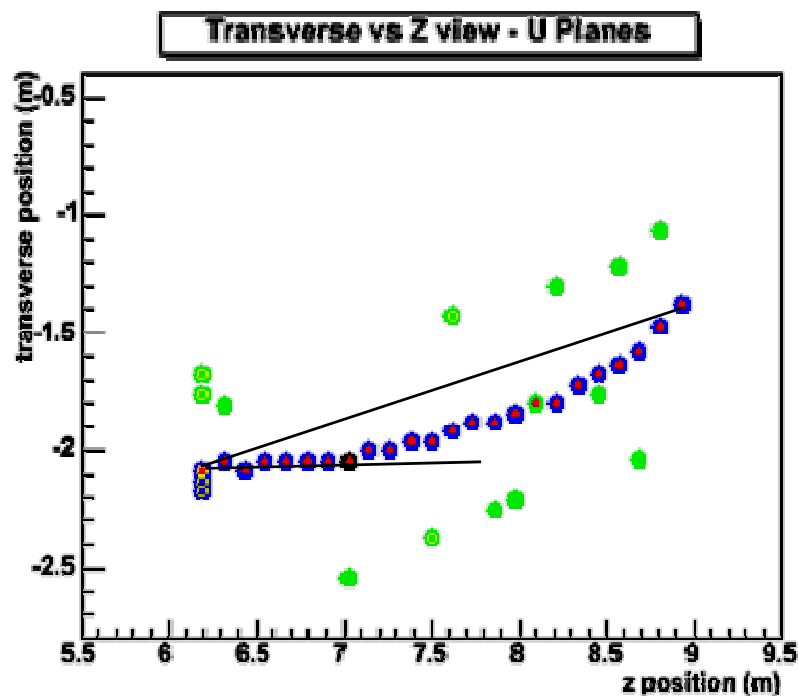


2 GeV muon

Track Energy 2.04 GeV
Shower energy 0.20 GeV

$q/p = -0.52 \pm 0.03$

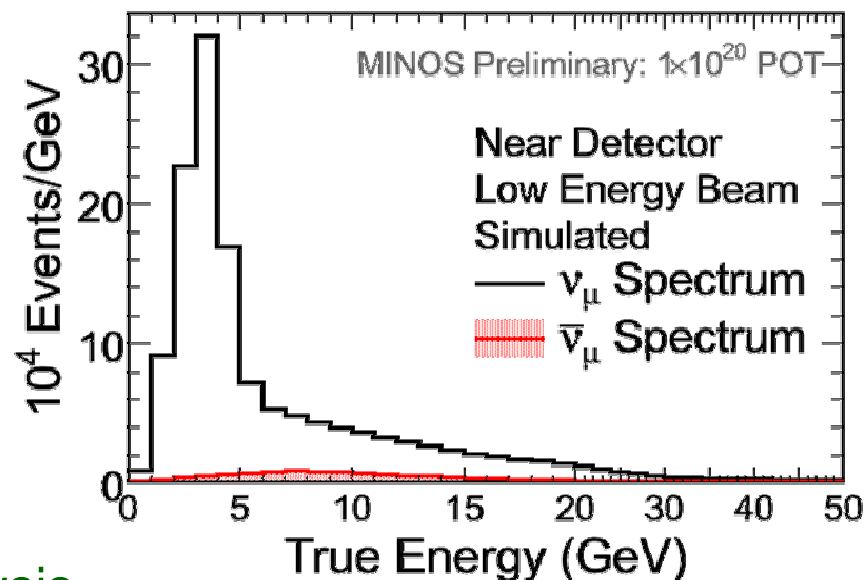
- < 2 PE
- $2 < \text{PE} < 20 \text{ PE}$
- > 20 PE Track hit





An example of charge-sign analysis

- MINOS antineutrino oscillation analysis
 - > 7% of the NuMI beam in neutrino mode is muon antineutrinos
 - Much smaller at 3 GeV
 - > Goal: select positive tracks for an antineutrino oscillation analysis
- A charge-sign cut alone removes 93% of the “wrong” sign muon neutrino CC events
 - > Beyond that additional cuts can further improve the purity



From: Fermilab Joint Experimental-Theoretical Seminar, May 15, 2009 & poster from Grant

Cutting out wrong sign & NC background

1. CC/NC separation parameter

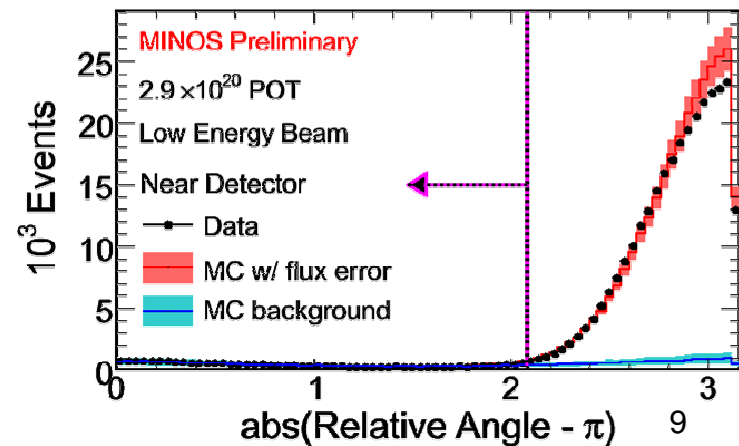
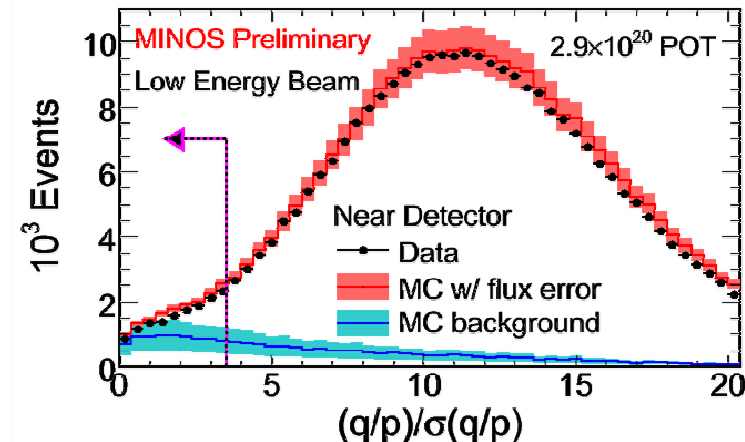
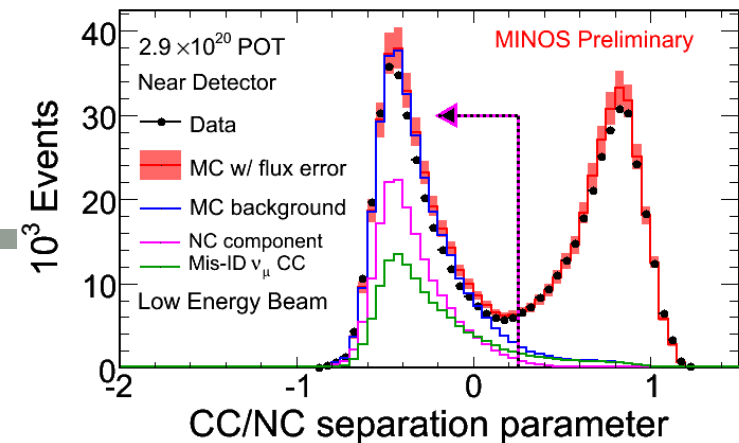
- > Developed for the 1st MINOS neutrino analysis (PRD 77, 072002, 2008)
- > Cut designed to remove NC events using low level quantities
- > Also removes mis-identified ν_μ CC high-y events where the muon is obscured by a large hadronic shower

2. Fitted charge-sign significance

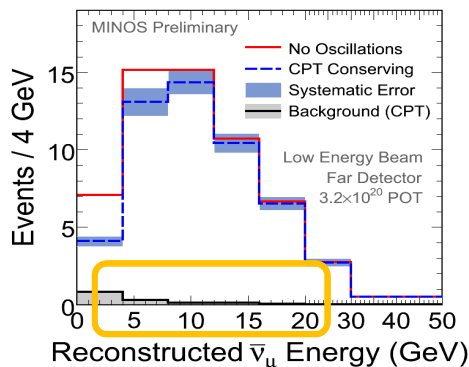
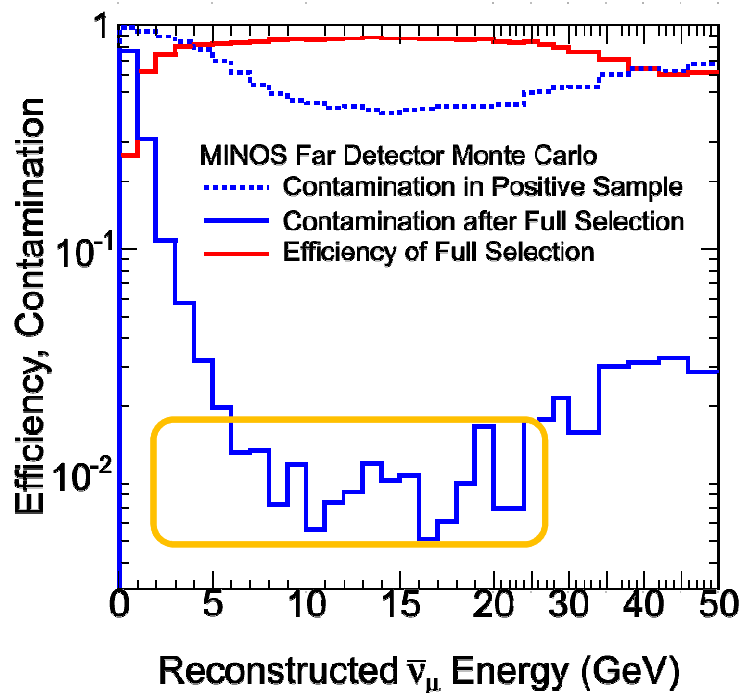
3. Relative angle

- > A measure of whether the track curves towards or away from the magnetic coil hole, relative to its initial direction

More aggressive cuts are available but were not optimal for this analysis



Charge sign selection for $\bar{\nu}_\mu$ analysis after simple charge cut



Overall results

- 10^3 rejection factor with good efficiency
 - True even in the b/g peak @ 3 GeV
- NC peaks at lowest energies
- 2:1 muon neutrino CC:NC b/g in sample
- Peaked at lowest energies

For E_ν from 5 - 25 GeV

- 500% background; $O(10^3)$ rejection factor

Did not **need** to cut harder for this analysis

- > Background ~1 wrong-sign event in sample
- > Harder NC/CC cut used in recent CC analysis
 - kNN gives μ/π ~99% separation; PRL08
- > Harder charge cuts used in cosmic ray the charge sign analysis
 - Particles were not normally incident
 - PRD 76, 052003, 2007

Do not see issues with achieving the $O(10^4)$ rejection needed for neutrino factory

- > Works well down to 2 GeV; below is harder
- > Needs a different detector optimization

Source of backgrounds for Golden Channel from *ISS summary*

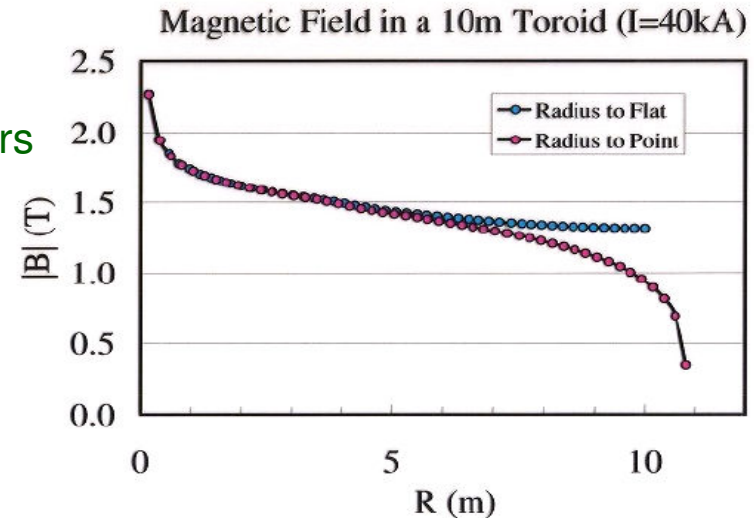


- The main backgrounds for a wrong-sign search are
 - > Right-charge muons whose charge has been misidentified, in ν_μ CC events
 - > Wrong-sign muons from hadron decays
 - > Wrong-sign hadrons misidentified as muons events
- How to address (pick one or more)
 - > Harder cuts (c.f. ISS)
 - > Higher field ($\rightarrow 1.7\text{T}$)
 - > Better resolution (e.g. triangles) or finer sampling can push these down
 - For ν_e MINOS is not optimal
 - $X_0 = 1.8\text{cm}$ in Fe vs 2.5cm plates in MINOS
 - $R_m = 3.2\text{cm}$ and 4cm scintillator in MINOS
 - > There are costs trade offs in these options, especially for electrons
- Note: current nufact simulations are behind the capabilities demonstrated by MINOS at equivalent cuts
 - > Systematic exploration of phase space of designs with these improvements and algorithms not yet in place yet

Possible issues (I): Magnetics and structure



- Can we make a larger magnet?
 - > Shown at nufact01 (Wojcicki) & nufact05 (JKN) based on work done with JKN & Bob Wands (Fermilab)
 - > Magnetization for a larger toroid
 - Octagonal plate with $r=10\text{m}$
 - Same current as MINOS ND
 - 1.7T at edges requires 9X more H
 - Can be achieved with normal conductors
 - > Yes, we can do it bigger & better
- Structural issues
 - > Nothing too difficult to address
 - MINOS could have had a thinner aspect ratio without significant redesign (e.g. 2cm)
 - > MINOS has no internal supports (other than coil)
 - This detector would need some
 - Fe a more structural material than the PVC-base NOvA
 - > I do not see this as a major issue but would need engineering



Possible issues (II)

Scaling the scintillator & readout

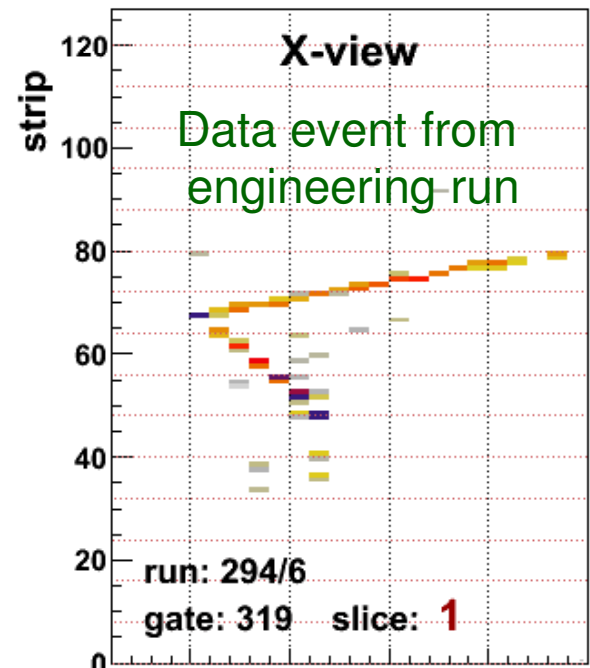


- MINOS is 5% solid scintillator
 - 5,400 kt total mass in instrumented regions
 - 0.25 kt of instrumented scintillator
 - Even 20X bigger is a fraction of the NOvA instrumented mass
 - Extrusion capacity is not unbearable
- MINOS had 95k scintillator strips/fibers
 - > Readout is only on the ends of strips – scales with surface area – larger diameter means less readout per unit mass
 - > MINOS is 8m across → NOvA is 15m across
- With care one can read out the longer device
 - > MINOS reads out with M16/M64 PMTs
 - Expensive and low QE – very “old school”
 - > NOvA is reading out 15m units with CMS-like APDs with much higher QE and some cooling required to reduce noise
 - High QE means very thin fibers
 - > T2K is using MPPCs intermediate QE; singles rates)
 - Lower QE than conventional APDs but other features make them very attractive
 - Might want MINOS-style 2-ended readout for light yield
- MIND has a factor of many less of whatever active detector is needed for a TASD
More on these topics during this session



Improving spatial resolution in MINERvA

- Use triangles with light sharing to get the position
- $\sigma = 2.5\text{mm}$ with 34mm wide cells in initial measurements
 - > MINOS is 10mm for 41mm strips
- Can apply this technique to NOvA style liquid cells too



R&D for segmented detectors from the ISS report and comments



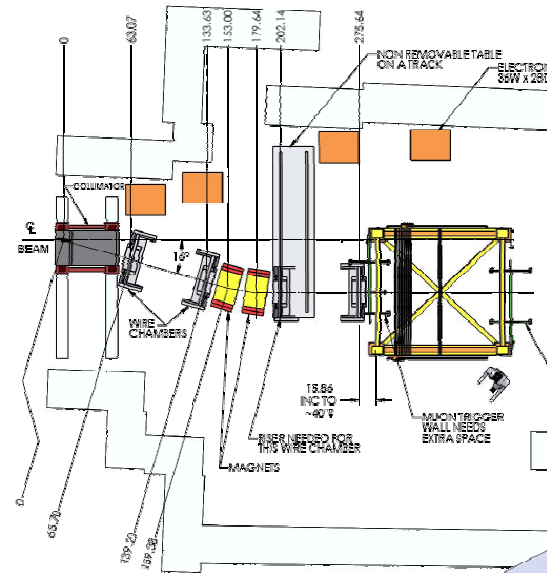
- Magnetized Iron Neutrino Detector (MIND) & Totally Active Scintillator Detector (TASD)
 - > Design, cost and engineering solutions for the magnet system for an iron calorimeter
straightforward to leverage MINOS
 - > R&D on magnetic field resistant photon detector technology, which could include testing of Multi-Pixel Photon Counters (MPPC), Silicon Photo-multiplier tubes (SiPM), Avalanche Photo Diodes (APD) or other similar technologies
T2K & NOvA have both made tremendous advances since the report – common with TASD
 - > Feasibility and cost of long strips of extruded scintillator with optic fiber readout
Would reduce labor significantly if a solid scintillator system is chosen (not a driver)
 - > Building prototype scintillator-fiber systems of varying lengths (5-20 m) and measurements of the attenuation of the signal as a function of the length of scintillator, measurement of the number of photoelectrons collected and studying the optimal geometry for the scintillator strips (for example, a comparison of the performance of square versus triangular cross-section of the scintillator strips)
Much of this ongoing on many systems for MINERvA, NOvA, T2K on the hardware side... this is largely for simulations now that we have benchmarked with data from detectors – more work with MINOS data would be useful demonstration too
 - > Study whether a different detector technology (such as Resistive Plate Chambers, RPC) would deliver the same performance at a reduced cost.
This is ongoing e.g. INO
 - > Build a prototype to put in a suitable test beam & test its performance inside a magnetic field
MINERvA test beam has all but the field but very useful for multiple/hard scattering studies
Possible to have a measurement in a field at CERN beam



Other miscellaneous notes

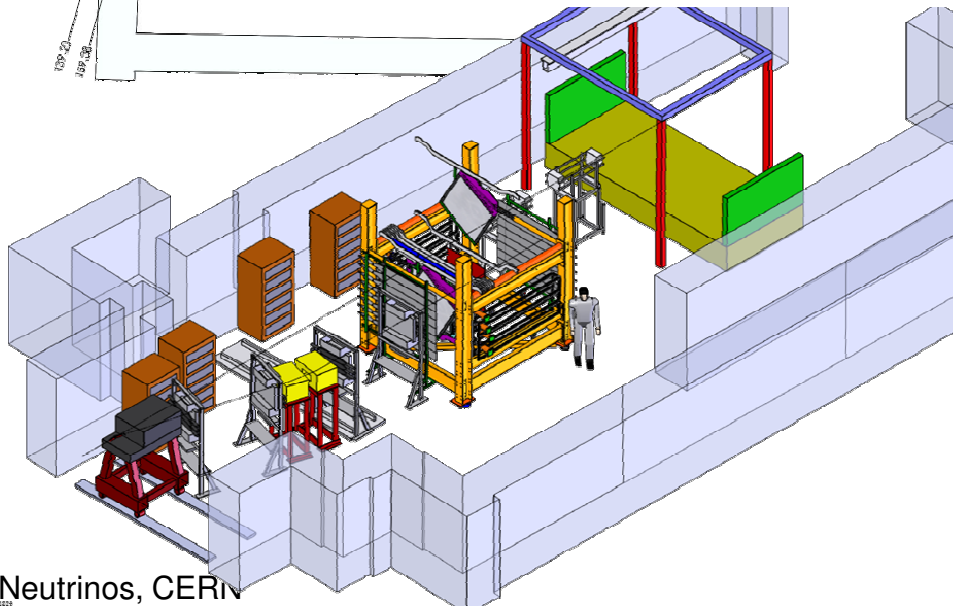
- Hadronic resolution $55\%E^{-1/2}$
- Electromagnetic resolution $17\%E^{-1/2}$
- Momentum by range is $\sim 7\%$ by curvature $\sim 16\%$ for the MINOS spectrum
- Have test beams for MINOS (done at CERN 02-04) and MINERvA (doing at FNAL; slide) addresses most needs – neither magnetized
 - > NOvA-type detector in FNAL beam would be interesting
 - > NOvA will deploy ND in off-axis on-surface location (narrow band beam – in 2010)
 - > NuMI near detector hall provides a nice test beam
- For the NOvA detector we did a number of studies of the costs for different readout options (2003/2004)
 - > For solid: steel, scintillator, assembly labor, fibers, and readout were all about the same costs – liquid much cheaper than solid
 - > Readout cost lower now
 - > Updated costs for Golden07 based on NOvA CDR costs – Mark to update today
- More dense than T ASD so should have smaller site costs & easier to site
- INO and MINOS addressing atmospheric neutrino capabilities

MINERvA's test beam program at new LE line at Fermilab's test beam facility



Running over next year

- 1.1m X 1.1m X 0.7m TASS
- Configurable
- No air-core magnet for TASS
- A. Bross has expressed interest





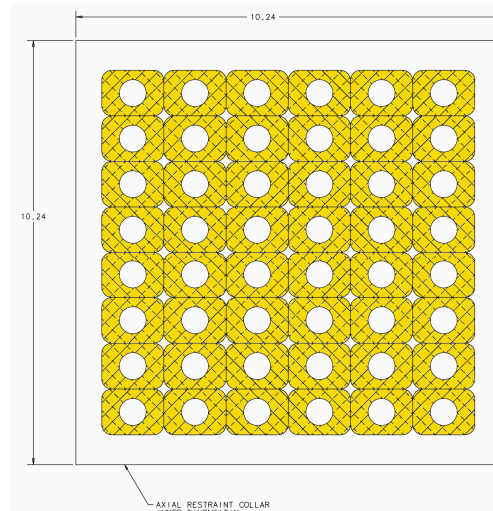
My summary from Nufact05 still holds

- A large MIND detector is feasible
 - > Large area toroidal fields can be directly extrapolated from MINOS design
 - Some structural engineering needed
 - > Can make an affordable large area scintillator readout with NOvA [or T2K] readout technology
- Can optimize sampling to get lower tracking threshold
 - > Try MINOS-like design
 - > Would also give good electron ID
 - > Could enhance position resolution with MINERvA-like triangles and/or thinner sampling
- 2009: We learned a great deal from MINOS, NOvA, T2K, and MINERvA over the last 4 years
 - > The nufact simulations are more advanced too (ISS work)



MINOS Near Detector Coil

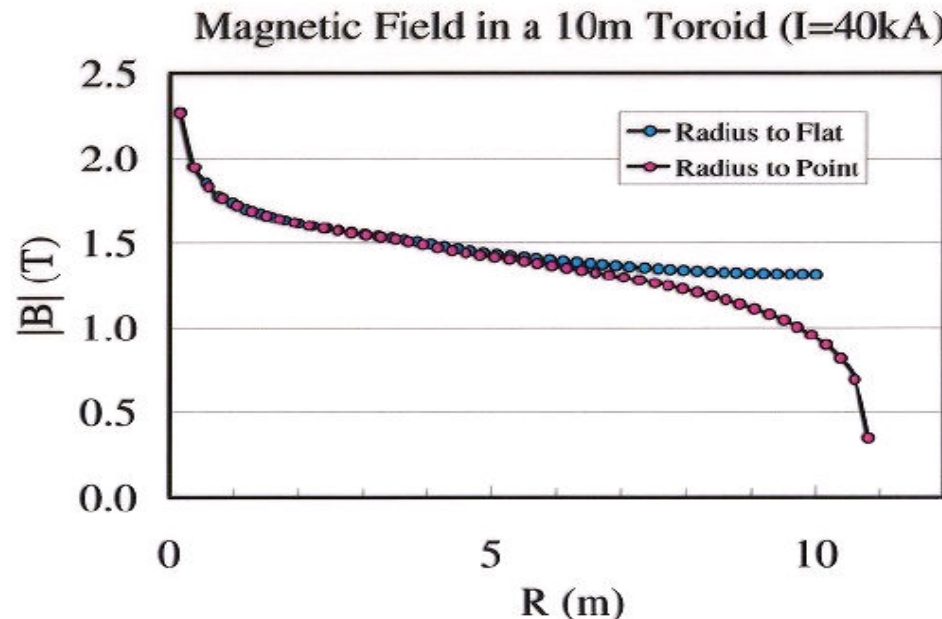
- The coil runs at 8 turns at 5kA
 - 25 x 25 cm² package
- Water cooled aluminum conductors
- 20m length





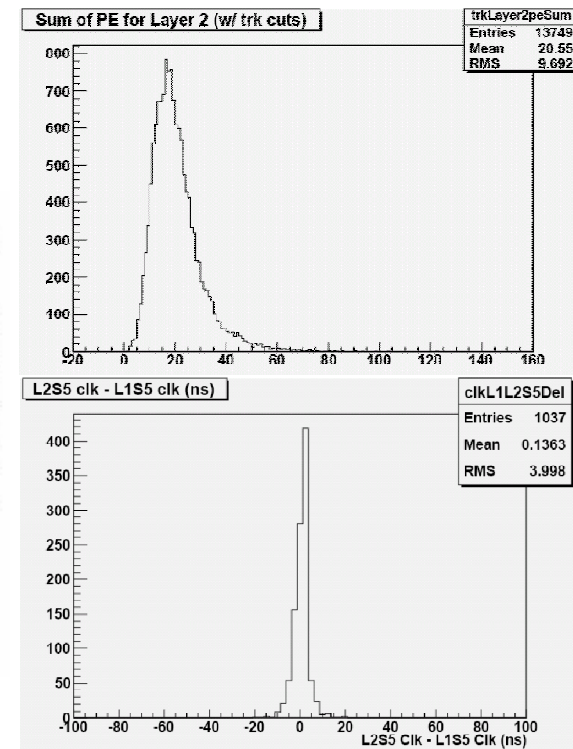
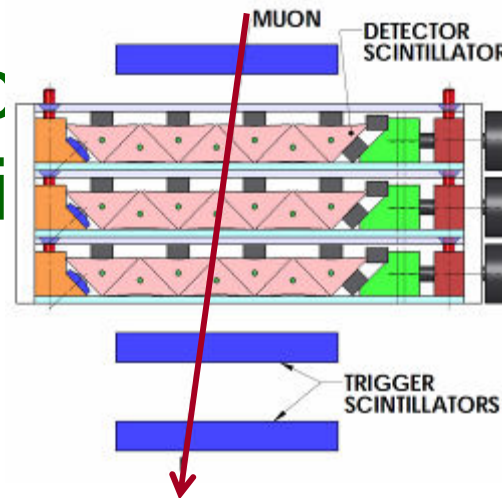
Making a Bigger Torus

- FEA model by R. Wands & J.K. Nelson (Fermilab) done for NuFact01
 - > MINOS ND is a 40kA coil
 - > Older B-H curve (prototype steel)
 - > Octagon with 8m radius (to flat)



Recent advances & plans Vertical Slice Test

- Small test detector tested using cosmic muons
- Light Yield: 6.5 pe/MeV
> Specification is > 4 pe/MeV
- Position Resolution: 2.5 mm



50kt NOvA Sampling Detector

Solid Scintillator + PMT



~400m² and 1000 samples

Not fully loaded costs – only to show scaling

Use absolute costs from NOvA workshop (ca. 2003)

	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

100kton MIND cost estimate (JKN - Golden07 – NOvA CDR basis)



Detector + installation	\$ 123
Iron	\$ 92
Coil	\$ 13
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100 kt MIND cost	\$ 228
Add'l contingency (25%)	\$ 57
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100 kt MIND cost	\$ 285