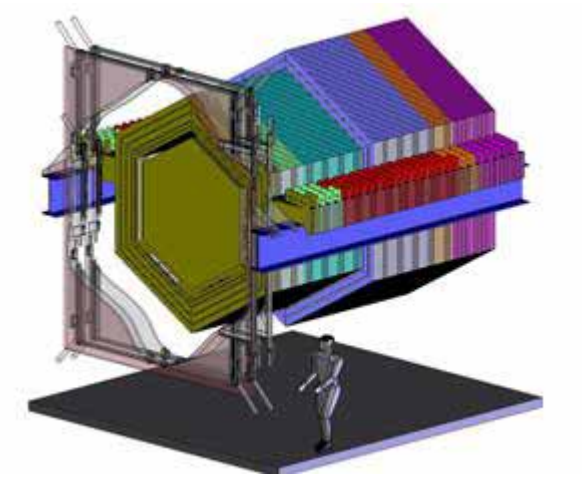
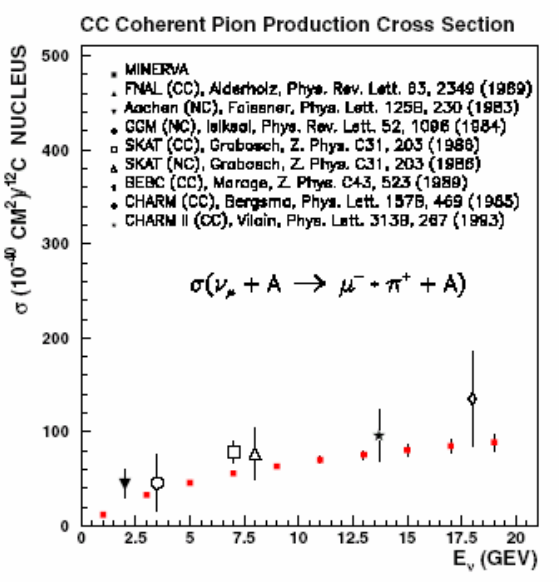


MINERνA (E-938)

Goals, Progress and Project

Kevin McFarland
University of Rochester
FNAL PAC Meeting
7 April 2005



MINERvA in a Nutshell

- MINERvA is a dedicated neutrino cross-section experiment operating in the NuMI near hall
  - in a unique position to provide critical input for world neutrino oscillation program
    - "neutrino engineering" for NuMI program *et al.*
  - provides an opportunity for studies of proton structure and nuclear effects in axial current
    - "Jefferson Lab west"
  - MINERvA has Stage One approval, and is poised to complete R&D and start construction

The MINERvA Collaboration

D. Drakoulakos, P. Stamoulis, G. Tzanakos, M. Zois
University of Athens, Greece

D. Casper#, J. Dunmore, C. Regis, B. Ziemer
University of California, Irvine

E. Paschos
University of Dortmund

D. Boehnlein, D. A. Harris#, M. Kostin, J.G. Morfin*, A. Pla-Dalmau, P. Rubinov, P. Shanahan, P. Spentzouris
Fermi National Accelerator Laboratory

M.E. Christy, W. Hinton, C.E. Keppel
Hampton University

R. Burnstein, O. Kamaev, N. Solomey
Illinois Institute of Technology

S. Kulagin
Institute for Nuclear Research, Russia

I. Niculescu. G. Niculescu
James Madison University

G. Blazey, M.A.C. Cummings, V. Rykalin
Northern Illinois University

W.K. Brooks, A. Bruell, R. Ent, D. Gaskell, W. Melnitchouk, S. Wood
Jefferson Lab

S. Boyd, D. Naples, V. Paolone
University of Pittsburgh

A. Bodek, R. Bradford, H. Budd, J. Chvojka, P. de Barbaro, S. Manly, K. McFarland*, J. Park, W. Sakumoto, J. Steinman
University of Rochester

R. Gilman, C. Glasshausser, X. Jiang, G. Kumbartzki, K. McCormick, R. Ransome#, E. Schulte
Rutgers University

A. Chakravorty
Saint Xavier University

D. Cherdack, H. Gallagher, T. Kafka, W.A. Mann, W. Oliver
Tufts University

J.K. Nelson#, F.X. Yumiceva
The College of William and Mary

* Co-Spokespersons
# Members of the MINERvA Executive Committee

HEP/NP Partnership

- This effort has sparked effort in NP community beyond our collaborators…
- JLab approved experiment (JUPITER)
  - data for neutrino cross-section modeling
- Now it's our turn!!

Neutrino Physics Comes to JLab

The inner workings of the sun, the mysteries of dark matter and dark energy and the structure of the early universe all may be unlocked by one cosmic key: neutrinos. Now, new research carried out in Jefferson Lab's experimental Hall C may help provide insight into neutrinos, the force that governs their behavior and, surprisingly, the structure of the nucleus of the atom.

from the JLab homepage today…

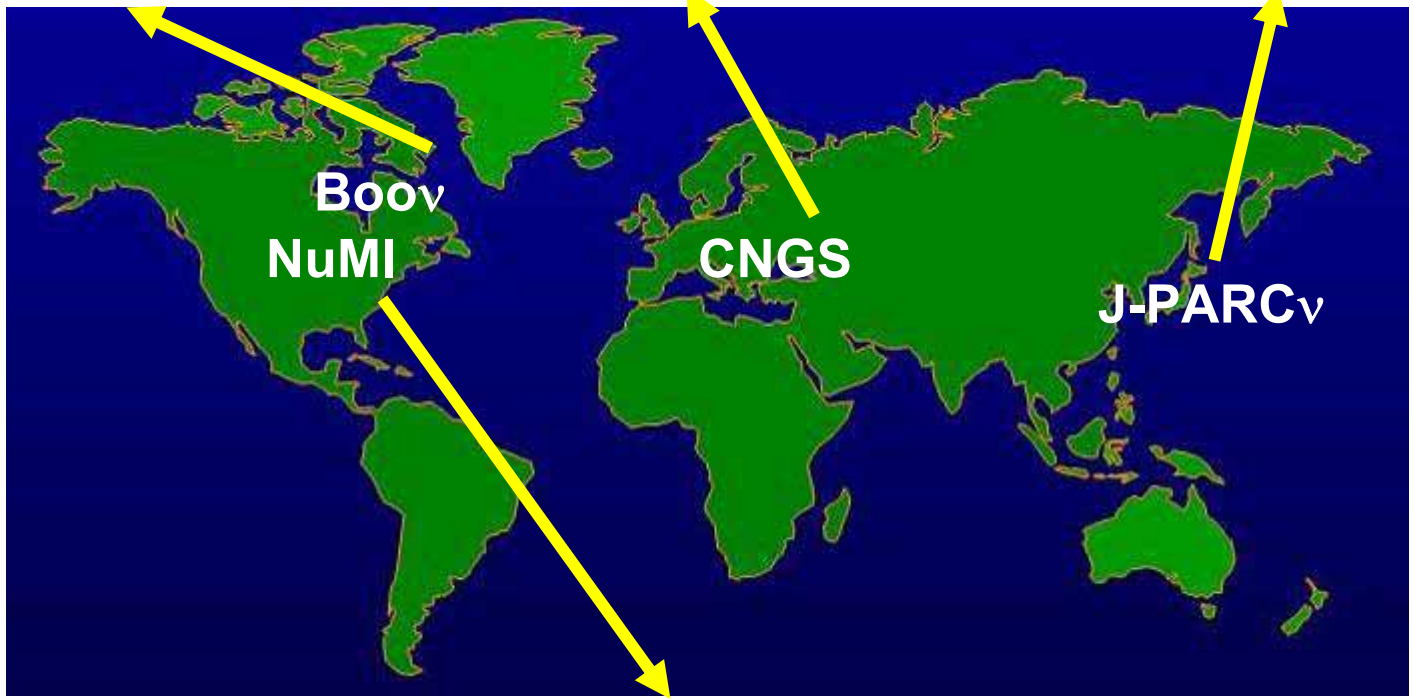
uniqueness…

NuMI: Unique in the World

no near hall, limited energy range

no near hall

near detectors off-axis in E~700 MeV beam



tunable, broadband beam energy from resonance to deep inelastic regime, spacious near hall, poised for a long run…

relevance…

MINERvA and Oscillations

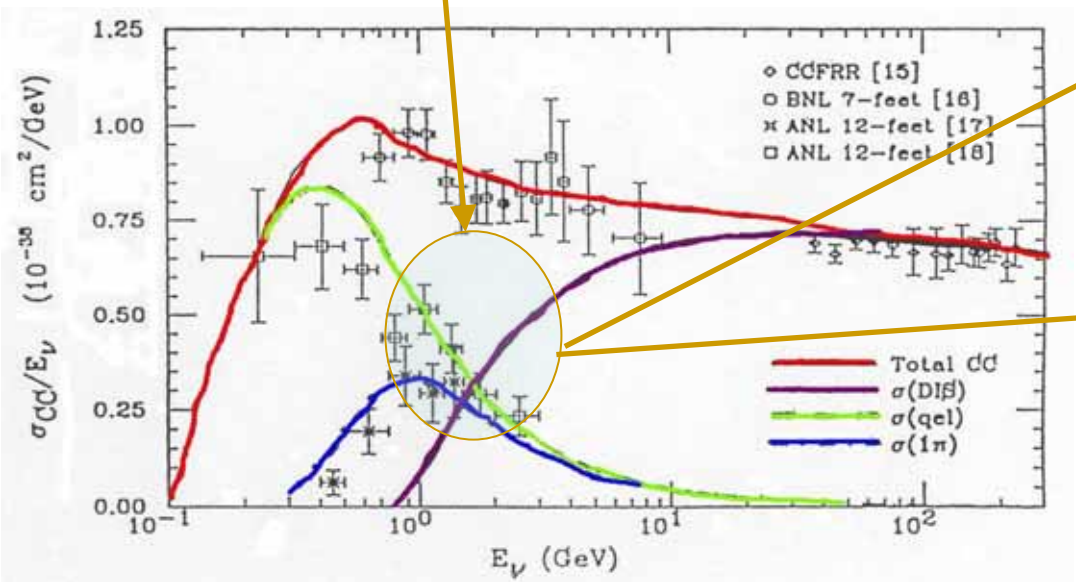
The recent ***APS Multidivisional Neutrino Study Report*** predicated its recommendations on a set of assumptions about current and future programs including:

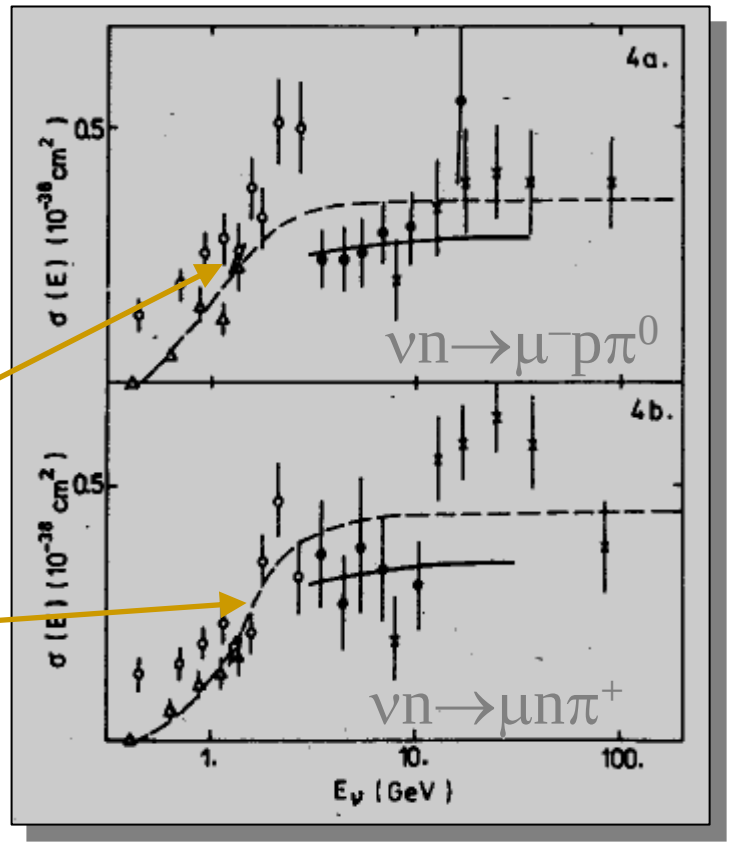
support for current experiments, international cooperation, underground facilities, R&D on detectors and accelerators, and

"determination of the neutrino reaction and production cross sections required for a precise understanding of neutrino-oscillation physics and the neutrino astronomy of astrophysical and cosmological sources. Our broad and exacting program of neutrino physics is built upon precise knowledge of how neutrinos interact with matter."

Why do we need to know more about neutrino cross-sections?

- At 1-few GeV neutrino energy (of interest for osc. expt's)
  - Experimental errors on total cross-sections are large
    - almost no data on A-dependence
  - Understanding of backgrounds needs *differential* cross-sections on target
  - Theoretically, this region is a mess... transition from elastic to DIS

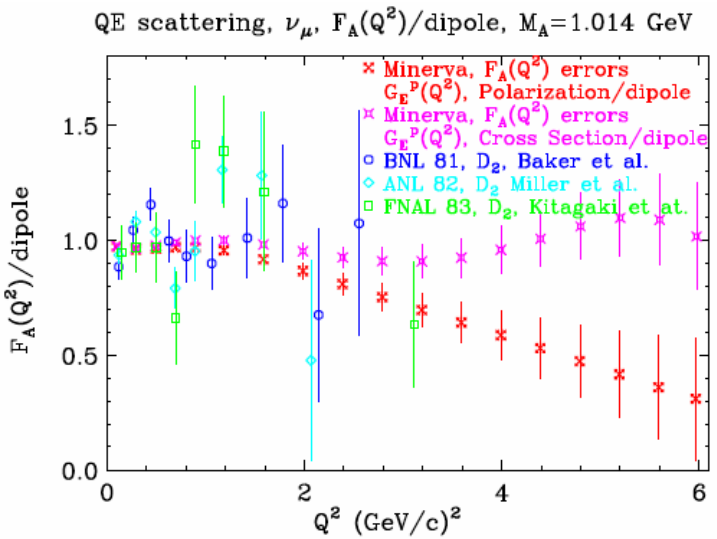




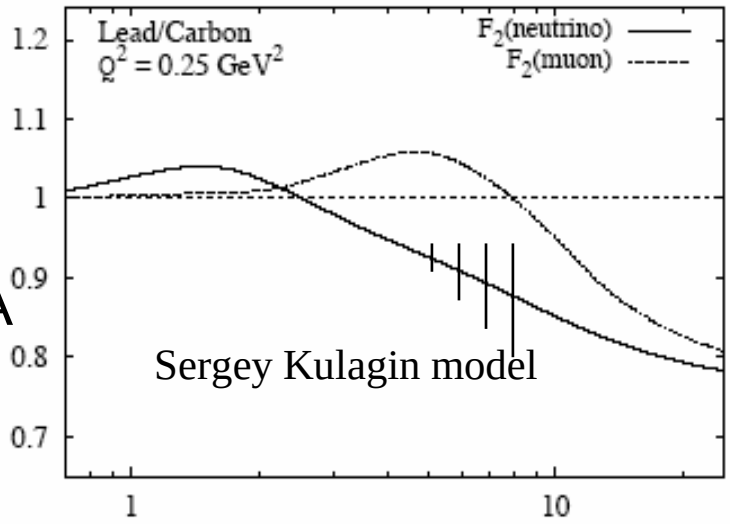
MINERvA and Cross-Sections

- Measurements unique to MINERvA
  - high Q^2 axial form factor of nucleon
    (complementary to high Q^2 vector FF, hot at JLab)
  - coherent cross-sections vs. energy
    (exploit resolution, fully active containing detector)
  - differential dists. for exclusive final states
    (multi-purpose containing detector, high statistics)
  - A-dependence of:
    - low Q^2 elastic (K2K/MiniBooNE "low Q^2 problem"?)
    - exclusive final states (nuclear re-interactions)
    - deep inelastic scattering (F_2^{ν}, xF_3^{ν})

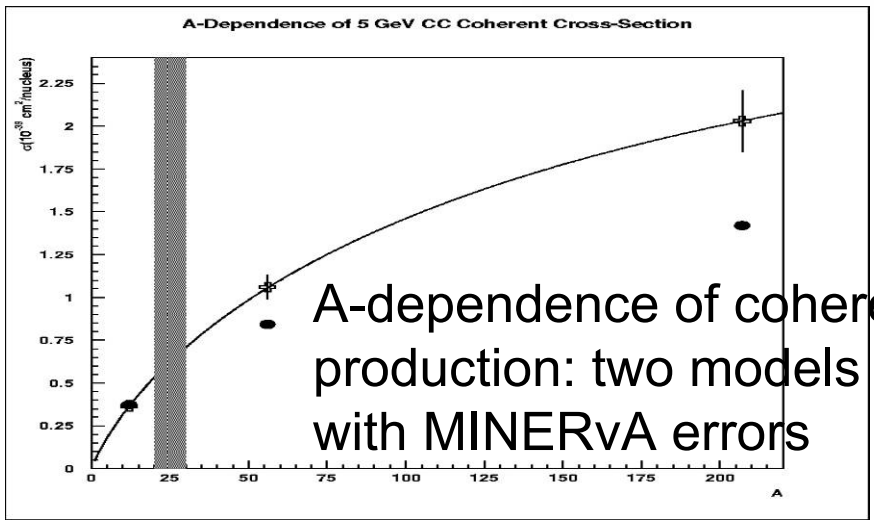
Sample Expected Results



Axial Form Factor at high Q^2: two models with MINERvA errors



F2, Pb/C, with MINERvA errors



A-dependence of coherent pion production: two models with MINERvA errors

how does this apply to oscillations?

Oscillation Measurements and Neutrino Interaction Uncertainties

- Current Generation's Primary Goal:
  - Precise Δm^2 measurement from ν_μ disappearance measurements vs. neutrino energy
  - Biggest systematic concern: how do you know you're really measuring the energy correctly?

MINOS

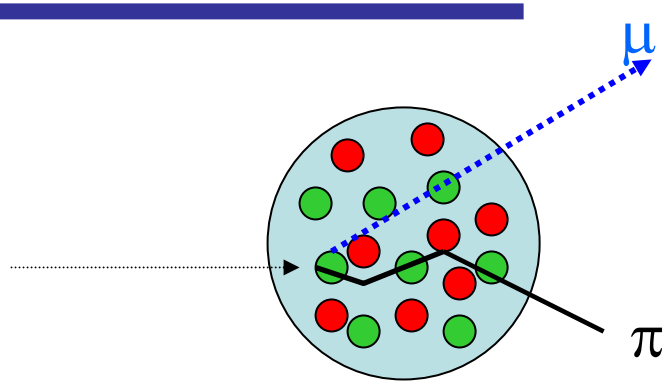
- Next Generation's Primary Goal:
  - Search for $\nu_\mu \rightarrow \nu_e$ transitions at one neutrino energy
  - Biggest systematic concern:
    - Predicting Background accurately
    - At first, claiming discovery based on an excess above background!
    - Later, precision measurements with neutrinos and anti-neutrinos

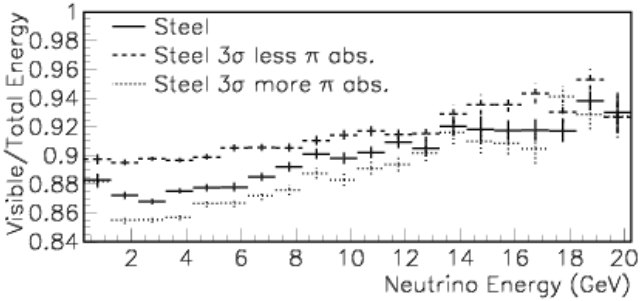
NOvA, T2K

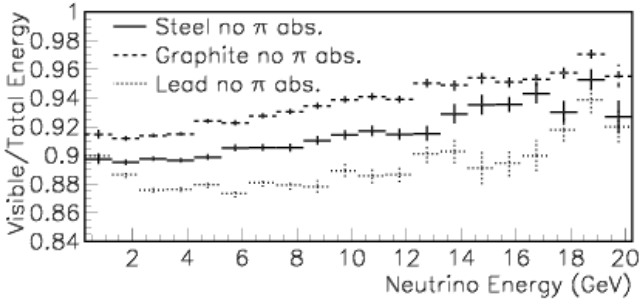
- Next Generation's "guaranteed" measurement
  - More precise Δm^2 measurement, if you can understand the backgrounds in narrow band beam

How MINOS will use MINERνA

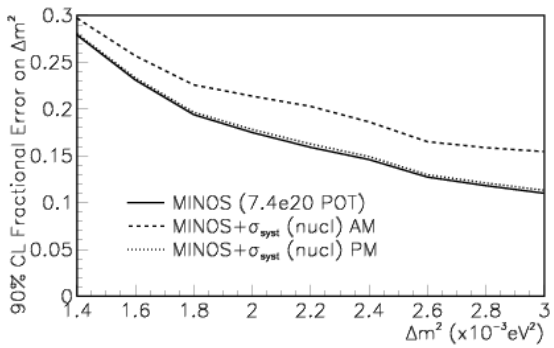
- Visible Energy in Calorimeter is NOT ν energy!
  - π absorption, rescattering
  - final state rest mass

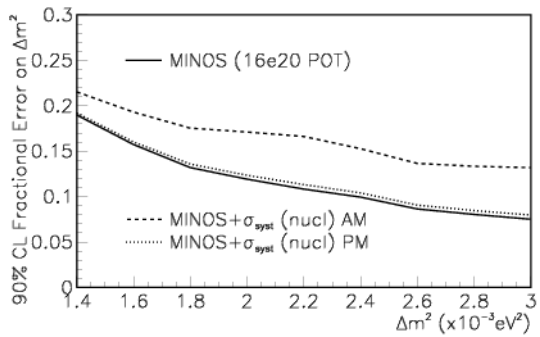




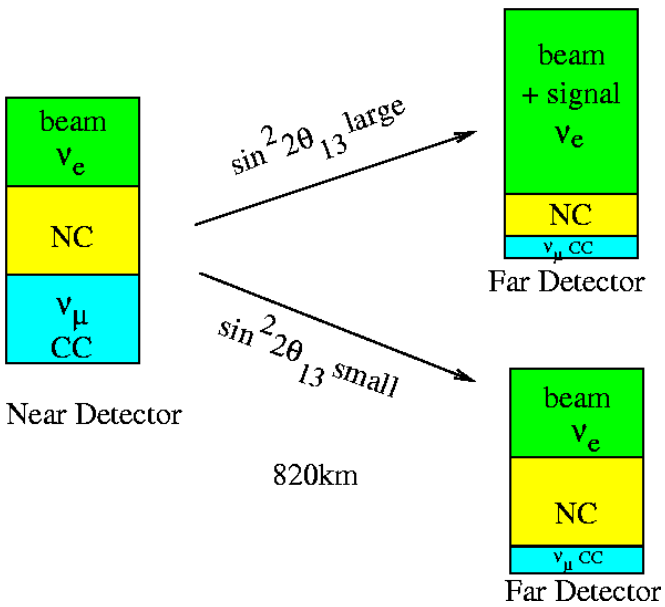


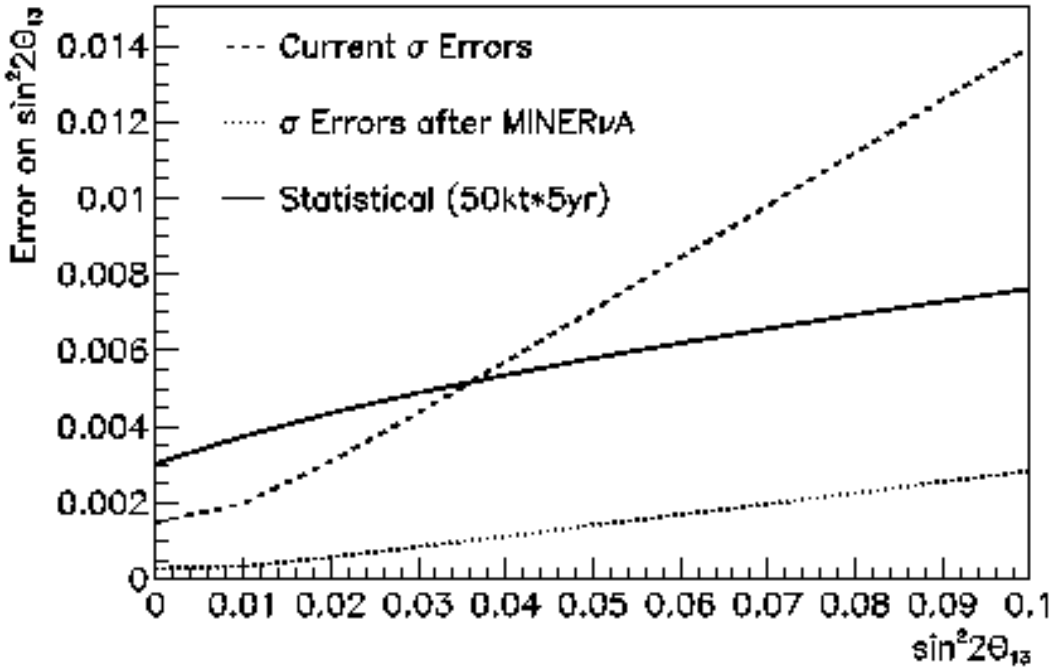
Nuclear Effects Studied in Charged Lepton Scattering, from Deuterium to Lead, at High energies, but nuclear corrections may be different between e/μ and ν scattering





How NOνA will use MINERνA Measurements

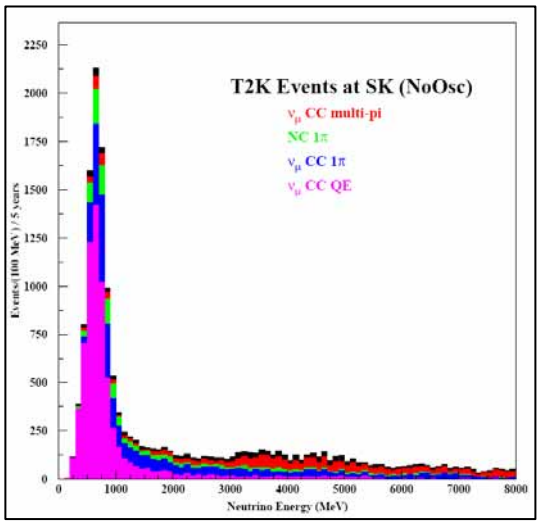


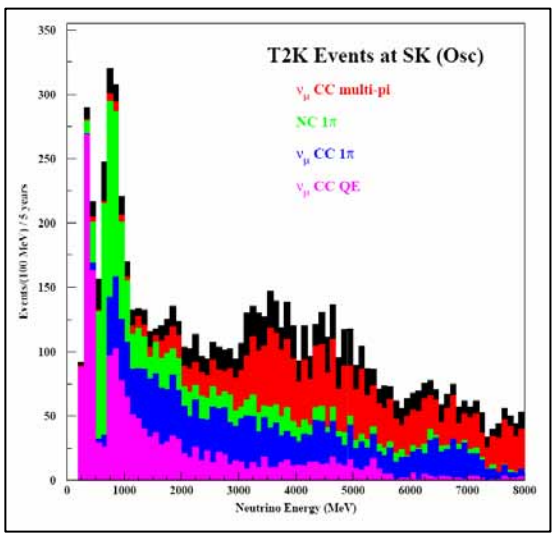


Process	QE	RES	COH	DIS
δσ/σ NOW (CC,NC)	20%	40%	100%	20%
δσ/σ after MINERνA (CC/NC)	5%/na	5%/10%	5%/20%	5%/10%

Without MINERνA, NOνA risks being limited by cross section uncertainties

How will T2K use MINERvA measurements





Note that as in NOvA, T2K's near detector will be a very different mix of events than the far detector.

To make accurate prediction, need

- 1 - 4 GeV neutrino cross sections
- Energy Dependence of cross sections

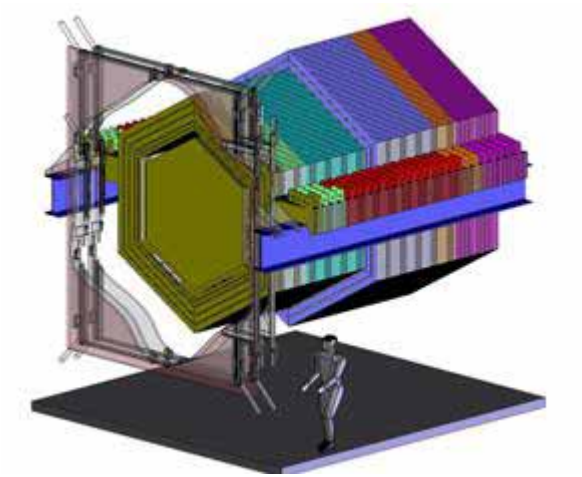
MINERvA can provide these with NuMI beamline Low Energy running!

What about Near Detectors?

- MINOS Near Detector:
  - Can't test nuclear effect models with only one nucleus!
- NOvA and T2K Near Detectors:
  - Can't measure energy dependence with only one energy
  - If near design is same as far, can't separate backgrounds any better near than far

MINERvA design solves all three of these problems

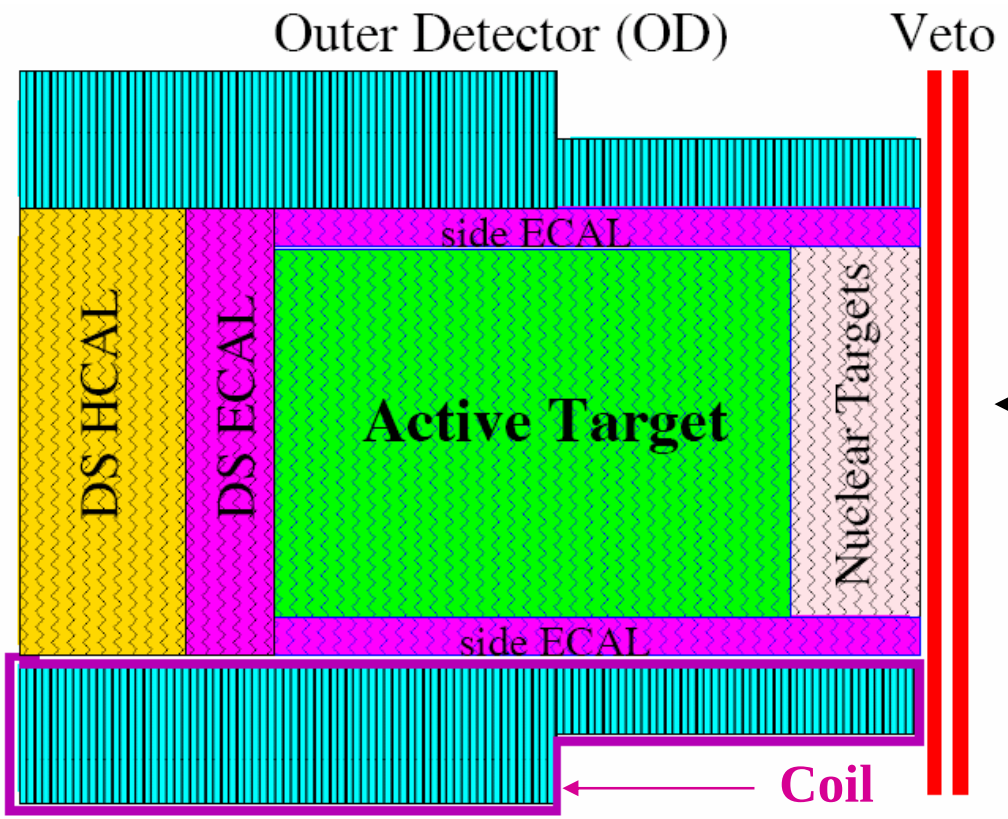
the MINERvA detector



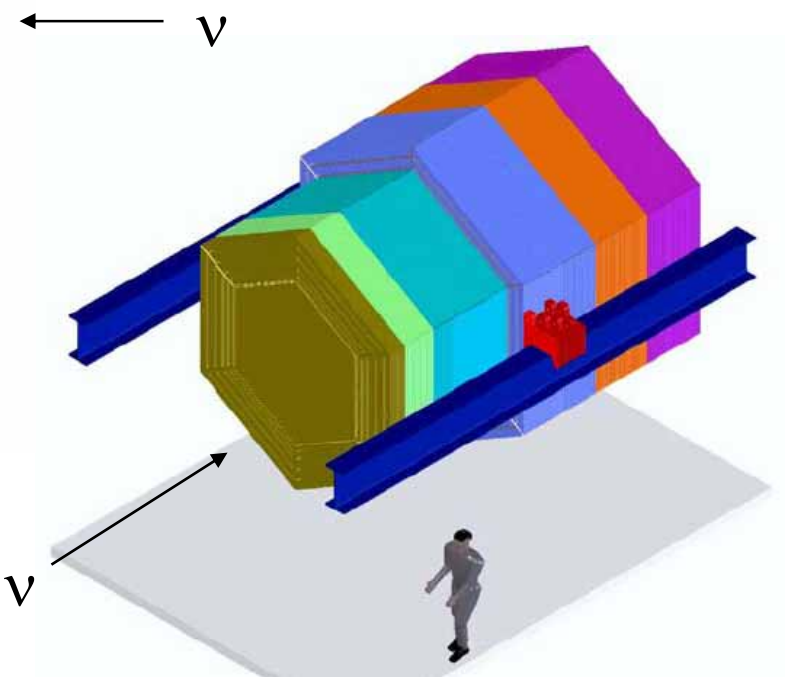
To Accomplish its Goals…

- MINERvA proposes to build a low-risk detector with simple, well-understood technology
- Active core is segmented solid scintillator (K2K SciBar)
  - tracking (including low momentum recoil protons)
  - particle identification
  - few ns timing (track direction, identify stopped $K^{\pm}$)
- Surrounded by electromagnetic and then hadronic calorimeters
  - photon (π^0) and hadron ($\pi^{\pm}$) energy measurement
  - magnetized for charge, momentum measurement of escaping muons at wide angles

Basic Detector Geometry

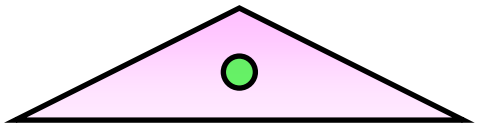


- Active segmented scint. detector 5.87 tons
- ~1 ton of US nuclear target planes (C, Fe, Pb)



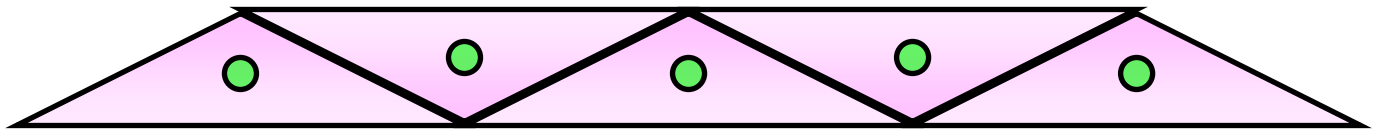
- DS Cals, Nucl. Targets just add absorber to scintillator planes
- Magnetized OD (HCAL) frames

Extruded Scintillator and Optics

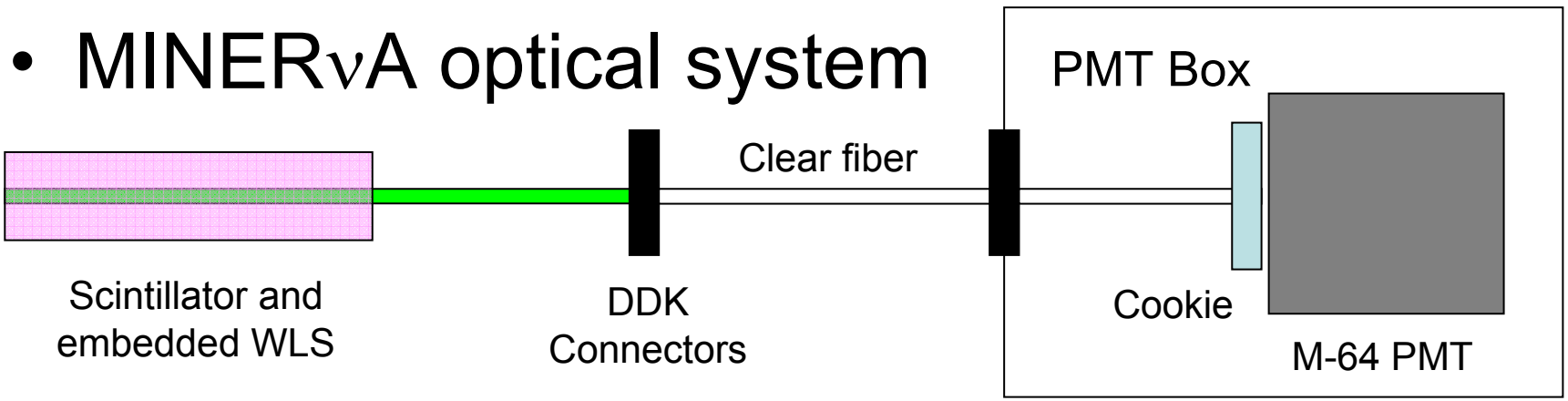


Basic element: 1.7x3.3cm triangular strips.
1.2mm WLS fiber readout in center hole

Assemble into planes



- MINERνA optical system



can one build it?

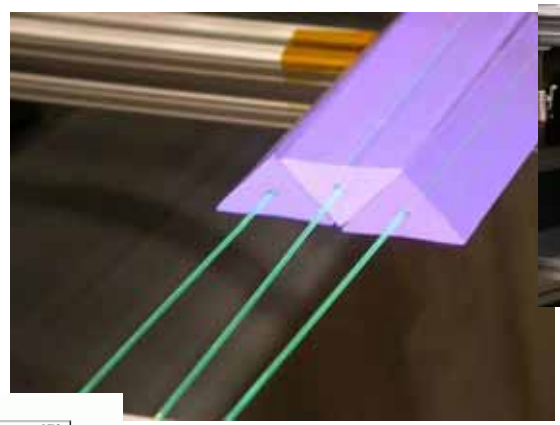
MINERvA R&D Progress

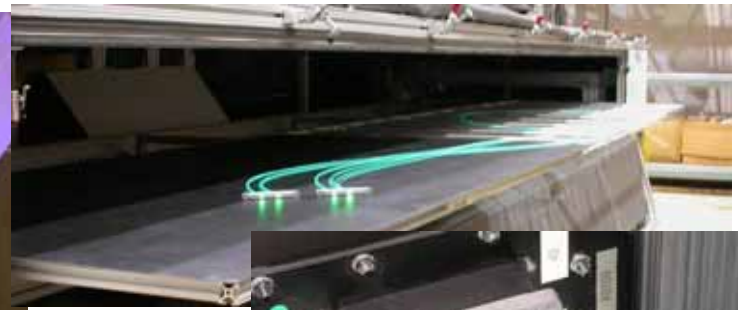
- Completed a vertical slice test (VST1)
  - Inner detector scintillator extrusions
    - FNAL, NIU
  - WLS fibers to PMT Box (MINOS) and similar PMT
    - Rochester, Tufts, FNAL (MINOS)
  - Prototype MINERvA Front-End electronics
    - FNAL, Irvine, Pittsburgh, Rochester
- Mechanical Design "complete" at concept level
    - Rochester, FNAL, Tufts
  - Prototyping cables, steel, PMT box: Tufts, Rutgers, Rochester
- Hit-Level Simulation
    - Irvine, Pittsburgh

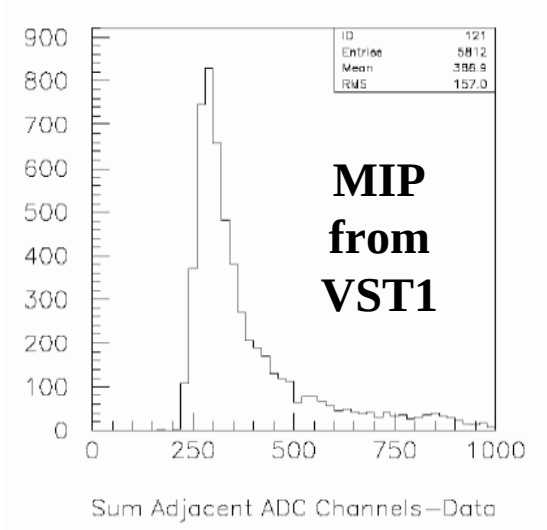
support for this work from FNAL-PPD, DOE HEP university funds, and funds from collaborating universities

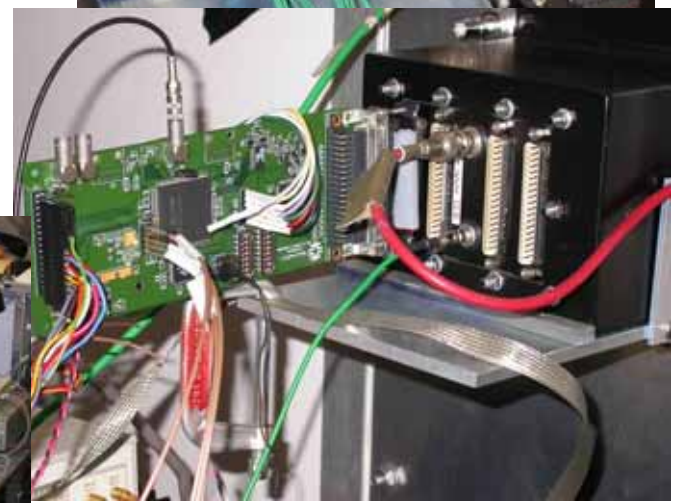
Vertical Slice Test (VST1)

VST1 array, electronics and DAQ





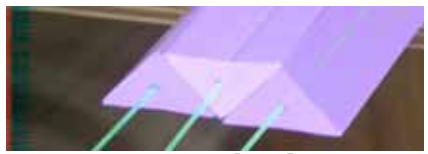


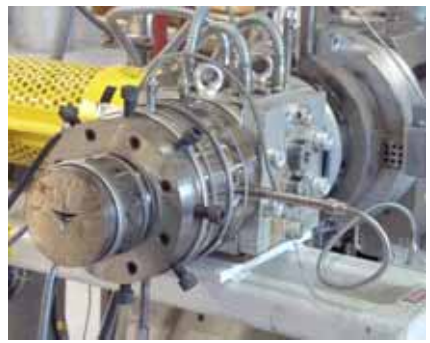


8 PE/MIP per doublet

Current Prototyping

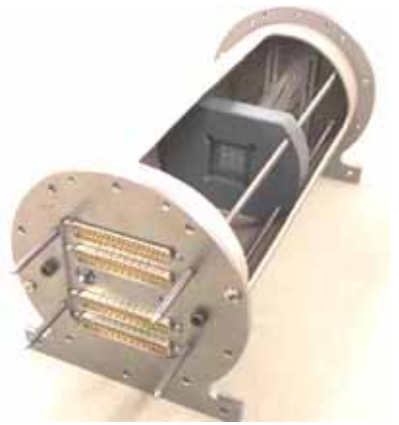
- Refining scint. extrusion





- First “trapezoid” of OD steel

- Prototype PMT box



- Prototype clear fiber cables in progress

- 2nd Prototype front-end and prototype readout electronics

the MINERvA project

Status of MINERvA Project

- We have developed a detailed costing and schedule model
  - basis for our design report and DOE/NSF proposals
  - costs down to Level-3 at worst, usually Level-4 or -5
- First FNAL director's ("Temple") review 1/05
  - generally positive report… they were impressed with our level of detail in design, cost, safety, etc.
  - recommended: formal project management plan, cost vs. physics optimization studies, development of more detailed resource-loaded cost and schedule model

MINERvA Costs

Project	WBS Code	Materials and Supplies	Salaries, Wages, Fringe	Engineering and Design	Total
Scintillator Extrusion / plane assembly	1.1	$1,322,089	$1,338,359	$45,074	$2,705,521
Clear Fibers and connectors	1.2	$445,864	$369,740	$68,960	$884,564
PMTs, boxes, testing	1.3	$1,263,124	$417,112	$0	$1,680,236
Electronics, DAQ and Controls	1.4	$574,730	$19,714	$459,359	$1,053,803
Frame and absorbers	1.5	$882,105	$0	$0	$882,105
Module assembly	1.6	$154,666	$512,932	$157,964	$825,562
Coil	1.7	$208,600	$0	$91,000	$299,600
Installation Preparation	2.1	$57,000	$184,400	$199,400	$440,800
NuMI Hall Infrastructure	2.2	$142,800	$150,100	$50,000	$342,900
Detector Installation	2.3	$0	$405,900	$0	$405,900
Total		$5,050,978	$3,398,257	$1,071,757	$9,520,991

legend for FNAL costs: FNAL $ > 2/3; FNAL $ > 1/4

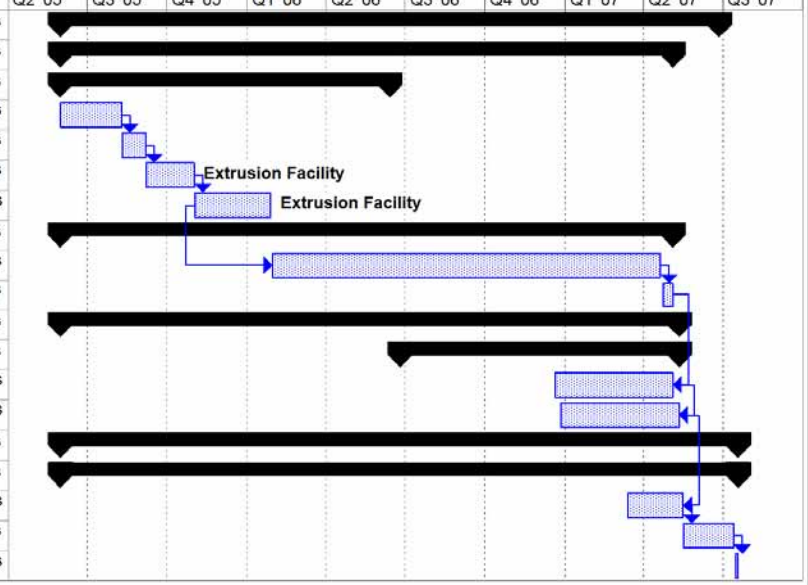
as presented to Temple review, Jan '05

- These costs include contingency (~40%), all University G&A
  - there is significant missing FNAL G&A. ~$0.5M in model where costs all flow through FNAL
- Assumes specific task distributions by institution and funds FY05-07

MINERvA Schedule

- Have identified critical paths, spending profile
- Time to complete:
  - roughly 24 months from start of “R&D” phase
  - roughly 18 months from start of “construction funding”

ID	WBS	Task Name	Duration
1	**1**	**Detector Construction**	**540 days**
2	**1.1**	**Scintillator Planes**	**503 days**
3	**1.1.1**	**Scintillator Extrusion**	**270 days**
7	1.1.1.4	Procurement of Co-Extruder	10 wks
8	1.1.1.5	Installation of Co-Extruder	4 wks
9	1.1.1.6	ID Die Tuning	2 mons
11	1.1.1.8	ID Scintillator Production	63 days
19	**1.1.3**	**Scintillator Plane Assembly**	**503 days**
22	1.1.3.3	Plane Production	16 mons
23	1.1.3.4	Plane Shipping	2 wks
94	**1.6**	**Module Assembly**	**508 days**
98	**1.6.2**	**Assembly and Mapping**	**230 days**
99	1.6.2.1	Module Assembly	98 days
101	1.6.2.3	Map Modules	98 days
108	**2**	**Detector Installation**	**556 days**
124	**2.3**	**Detector Module Installation**	**556 days**
126	2.3.2	Install Modules (excl. veto)	46 days
130	2.3.6	Install Coil	8.4 wks
131	2.3.7	Install Veto Wall	3 days



extrusion-plane-module construction path

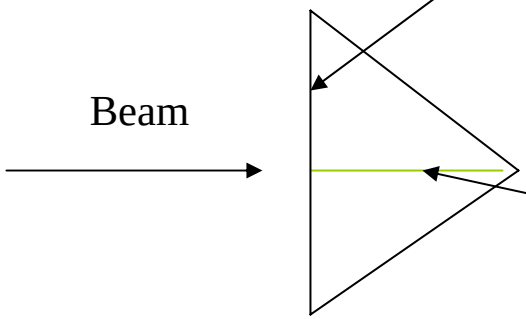
Project Management

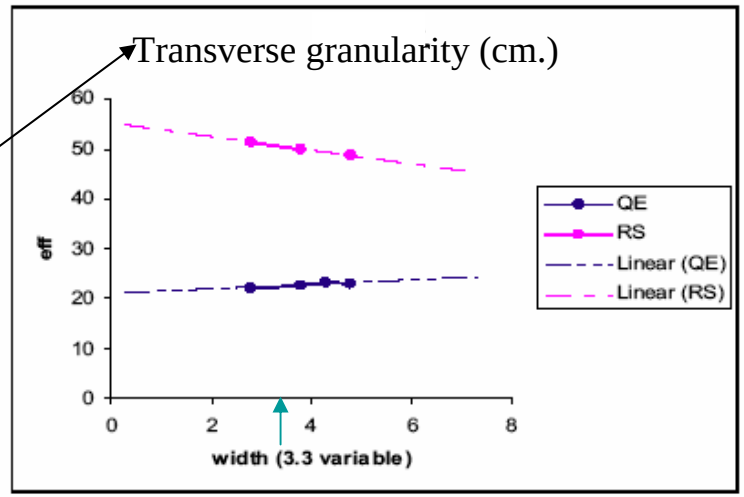
- Experiment has proposed and Fermilab directorate approved
  - Project Manager: Deborah Harris
  - Two co-Deputy Project Managers
    - KSM overseeing University efforts
    - Jorge Morfin overseeing Fermilab efforts
- Project Management Plan has been drafted by the executive committee
- Plan has had first reading by Ed Temple and Dean Hoffer, iterating with Project Manager and co-Deputy Project Managers
- WBS has been refined since Temple Review:

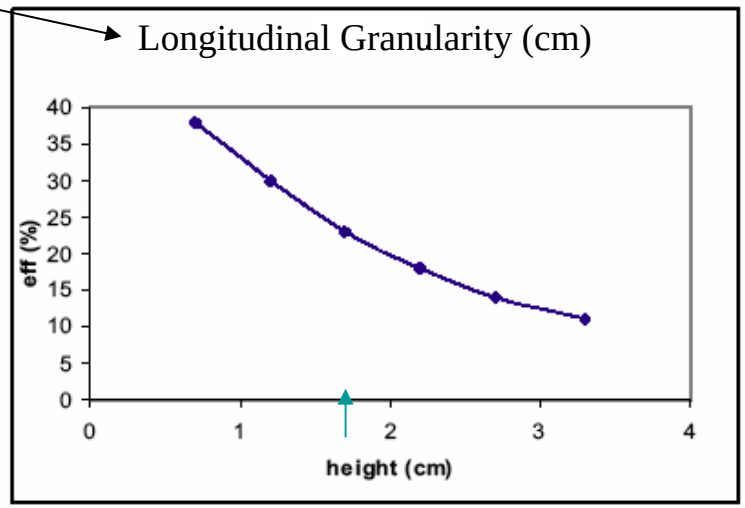
revisiting cost vs. physics optimization

Importance of Longitudinal Granularity
Proton Detection Efficiency

- Proton candidates from quasi-elastic and 1-pi production defined as hits in 3x, 1u and 1 v planes. Triangular extrusions, with light sharing, already considerably more efficient than rectangular extrusions

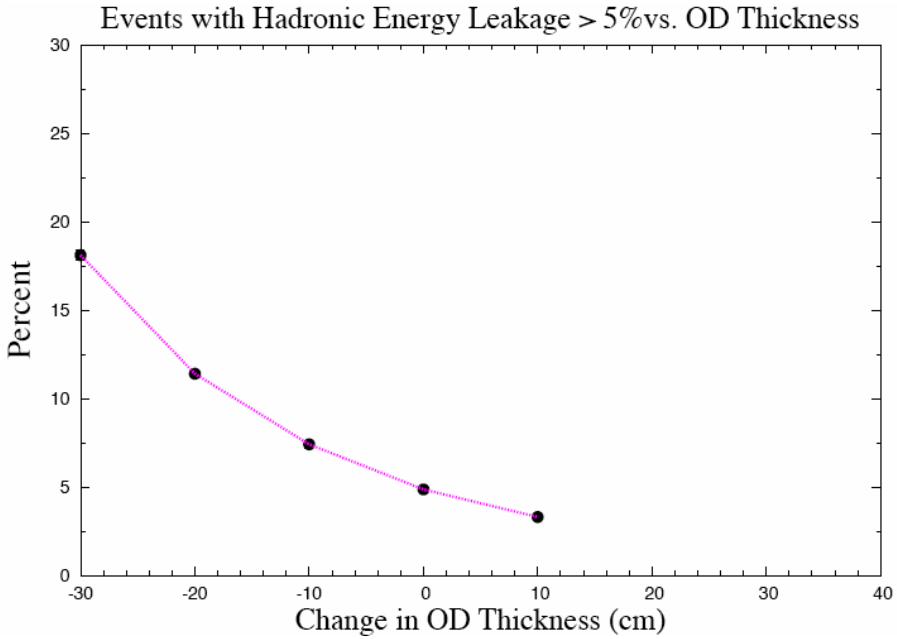






- Proton detection efficiency shows minimal dependence to transverse granularity but significant dependence to longitudinal granularity

The Importance of Barrel Calorimetry
Transverse Energy Containment



D. Naples
U. Pittsburgh

- Varying the nominal MINERνA outer detector thickness from 30 cm thinner to 10 cm thicker results in a factor of five change in the percentage of DIS events with greater than 5% of the hadronic energy leaking out of the outer detector. For the nominal MINERνA design, only 5% of DIS events lose more than 5% of their hadronic energy.

conclusions

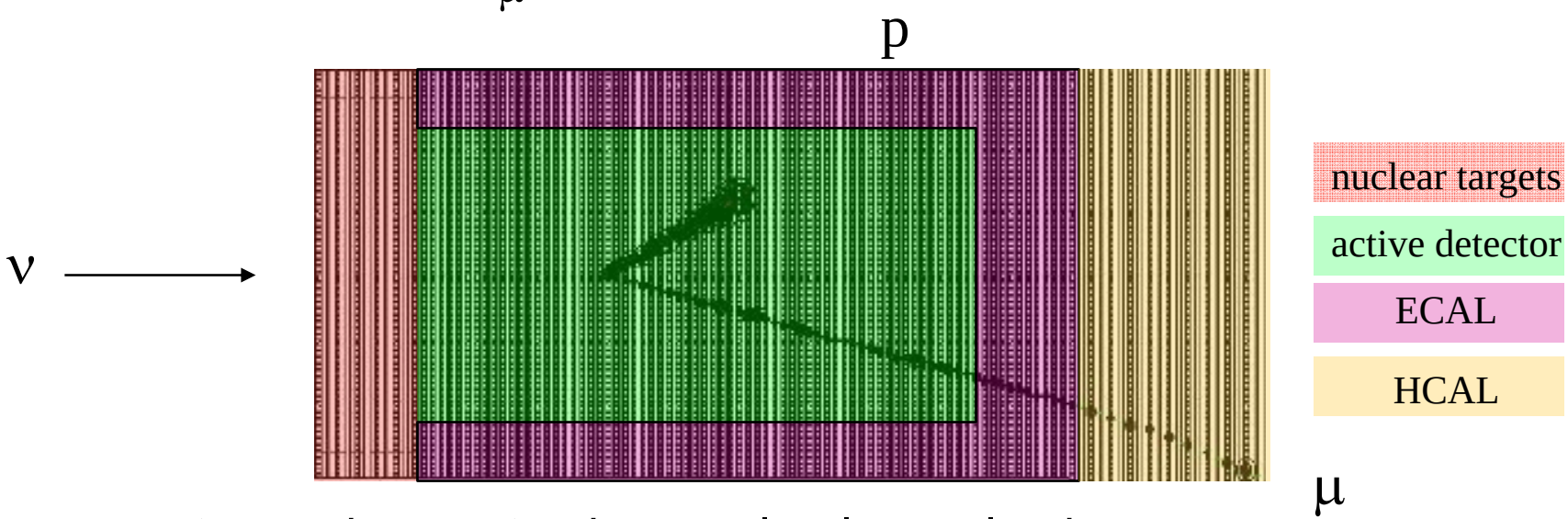
MINERvA…

- Opportunity for unique and critical FNAL role in world neutrino efforts in a modest-scale project
  - construction funds in FY07 means running in FY09
  - only possible because of investment in NuMI
- On track technically to build and use detector
  - R&D and prototyping progressing
- We are doing what projects do…
  … including waiting for funding

backup slides

Example Events

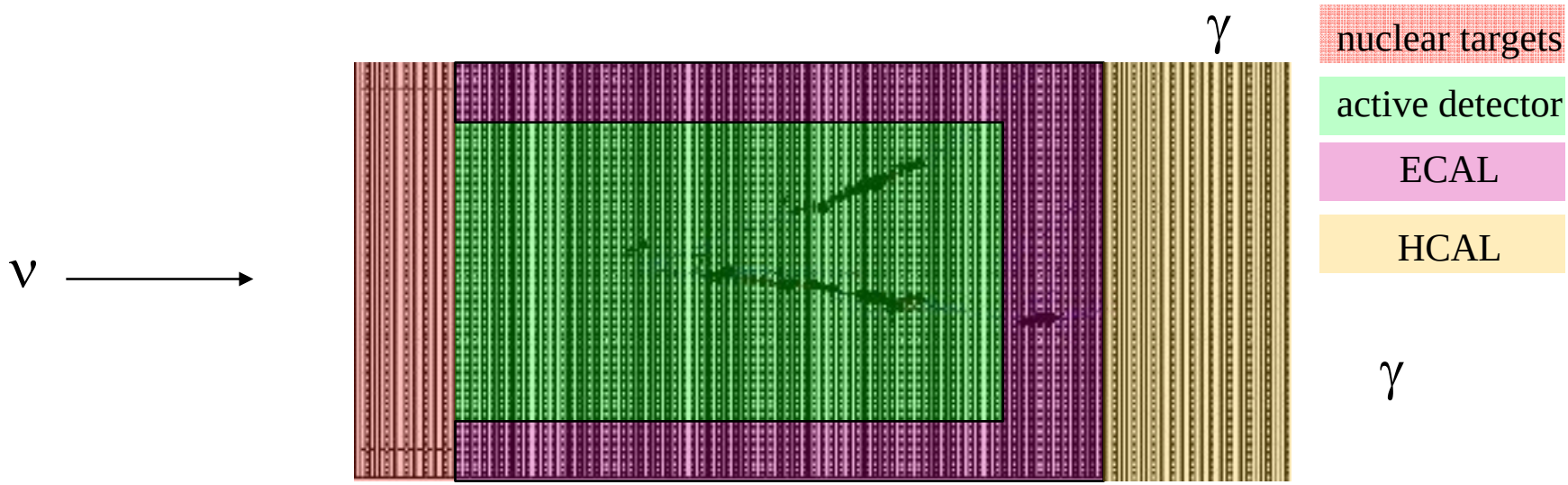
- Quasi-elastic $\nu_\mu n \rightarrow \mu^- p$



  - proton and muon tracks are clearly resolved
  - observed energy deposit is shown as size of hit; can clearly see larger proton dE/dx
  - precise determination of vertex and measurement of Q^2 from tracking

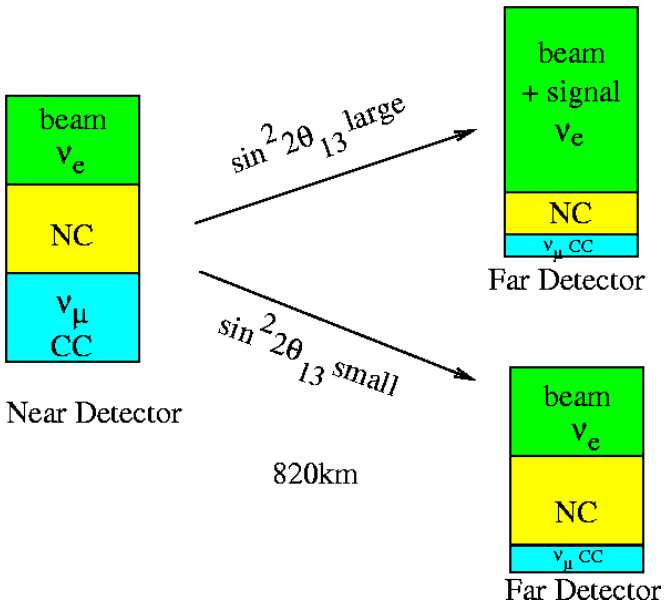
Example Events (cont'd)

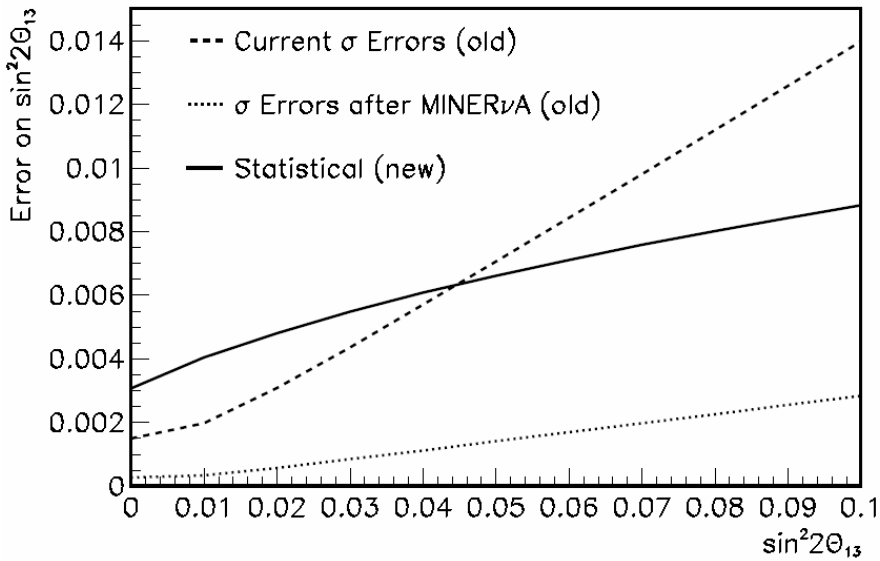
- π^0 Production



  - two photons clearly resolved (tracked). can find vertex.
  - some photons shower in ID,
    some in side ECAL (Pb absorber) region
  - photon energy resolution is ~6%/sqrt(E) (average)

Old NOvA vs New (TASD) NOvA





What about the change from old NOvA design to new design?

Old: FD background was ½ beam ν_e, ½ other

New: FD background is 2/3 beam ν_e, 1/3 other

New: Signal has more resonance contributions, more poorly known process

Extrapolating near to far will be easier, but probably by ~30%...

Statistical error is about the same (same FOM)

MINERνA statistics and running

Assume 9×10^{20} POT: **7.0×10^{20} in LE ν beam, 1.2×10^{20} in sME ν beam and 0.8×10^{20} in sHE ν beam**

ν_μ Event Rates per fiducial ton

Process	CC	NC
Quasi-elastic	103 K	42 K
Resonance	196 K	70 K
Transition	210 K	65 K
DIS	420 K	125 K
Coherent	8.4 K	4.2 K
TOTAL	**940 K**	**305 K**

Typical Fiducial Volume =
3-5 tons CH, 0.6 ton C, ≈ 1 ton Fe and ≈ 1 ton Pb

3 - 4.5 M events in CH
0.5 M events in C
1 M events in Fe
1 M events in Pb

Main Physics Topics with Expected Produced Statistics

- **Quasi-elastic** - $\nu + n \rightarrow \mu^- + p$ - 300 K events off 3 tons CH
- **Resonance Production** - e.g. $\nu + N \rightarrow \nu / \mu^- + \Delta$ 600 K total, 450K 1π
- **Coherent Pion Production** - $\nu + A \rightarrow \nu / \mu^- + A + \pi$, 25 K CC / 12.5 K NC
- **Nuclear Effects** - C: 0.6M events, Fe: 1M and Pb: 1 M
- **σ_T and Structure Functions** - 2.8 M total /1.2 M DIS events
- **Strange and Charm Particle Production** - (> 60 K **fully** reconstructed)

MINERvA Costs (Alternate Roll-up)

WBS	Items	Project Estimate (2005-2007) $ Base (always w/G&A included) $ M&S	SWF	Total	Base + Cont. $ M&S Total	M&S Cont %	Base + Cont. $ SWF Total	SWF Cont %	Total Cont %	Subproject Totals
1	MINERvA Detector Construction	3,578,786	2,519,437	6,098,224	4,871,760	36%	3,459,604	37%	37%	8,331,363
1.1	Scintillator Planes	932,686	1,015,362	1,948,048	1,322,089	42%	1,383,402	36%	39%	2,705,491
1.2	Clear Fiber Cables	298,017	289,113	587,130	445,864	50%	438,700	52%	51%	884,564
1.3	Photo Sensors	968,445	334,458	1,302,902	1,263,125	30%	417,112	25%	29%	1,680,237
1.4	Electonics and DAQ	409,029	347,249	756,278	574,730	41%	479,073	38%	39%	1,053,803
1.5	Frame and Absorbers	693,984	0	693,984	882,105	27%	-		27%	882,105
1.6	Module Assembly	127,626	468,255	595,881	175,246	37%	650,317	39%	39%	825,563
1.7	Coil	149,000	65,000	214,000	208,600	40%	91,000	40%	40%	299,600
2	MINERvA Installation	142,714	707,000	849,714	199,800	40%	989,800	40%	40%	1,189,600
2.1	Installation Preparation	40,714	274,143	314,857	57,000	40%	383,800	40%	40%	440,800
2.2	Hall Infrastructure	102,000	142,929	244,929	142,800	40%	200,100	40%	40%	342,900
2.3	Installation	0	289,929	289,929	-		405,900	40%	40%	405,900
	Project Totals	3,721,501	3,226,437	6,947,938	5,071,560		4,449,404			9,520,963

as presented to Temple review, Jan '05

- These costs include contingency (~40%), all University G&A
  - there is significant missing FNAL G&A. ~$0.5M in model where costs all flow through FNAL
- Assumes specific task distributions by institution and funds FY05-07

Vital Statistics of MINERvA

Number of Channels	30992
Channels in ID+CALS	25088
Channels in OD	5904
Volume of Scintillator (m^3)	22.5
WLS Fiber (km)	90.7
Clear Fiber (km)	41.6
Number of M-64 PMTs	503
Mass of ID (metric tons)	10.8
Mass of OD in ID region (metric tons)	98.0
Mass of CALS, Nuclear Targets (metric tons)	27.2
Mass of OD in CAL region (metric tons)	62.9
Total MINERvA Mass (metric tons)	199
Plastic Region Mass (metric tons)	5.87
Data Rate (bits/spill)	7.9E+6

A Brief History of MINERνA

- December 2002 - Two EOIs for neutrino scattering experiments using the NuMI beam and similar detector concepts presented to the PAC. PAC suggests uniting efforts and preparing proposal.
- December 2003 - MINERνA proposal presented to PAC. PAC requests more quantitative physics studies and details of MINERνA's impact on Fermilab.
- January 2004 -Submit proposal for MRI funding support (maximum $2M) of partial detector to NSF. Rejected due to no guarantee for funding rest of detector.
- March 2004 - MINERνA Impact Statement submitted to Directorate and presented to an Impact Review Committee.
- April 2004 - Proposal addendum containing additional physics studies and report from the Impact Review Committee presented to PAC. Receive Stage I approval.
- Summer 2004 - R&D Program concentrating on front-end electronics, scintillator extrusions and a "vertical slice test"
- October 2004 - Proposal to NP and EPP of NSF to fund bulk of MINERνA.
- December 2004 - Proposal to NP and HEP of DOE to fund bulk of MINERνA.
- January 2005 - First Director's Review of MINERνA
- February 2005 – With release of FY06 budget, DOE of budget process crystallizes; decision that MINERνA must be primarily funded by FNAL budget.

Fiber Testing and Qualification (pre-VST1)

- Fiber testing and qualification (Rochester)
  - attenuation and light yield of WLS fiber for different dopant concentrations
  - fiber flexibility and light loss tests