MINERνA (Main INjector ExpeRiment ν-A)

A High-Statistics Neutrino Scattering Experiment Using an On-Axis, Fine-grained Detector in the NuMI Beam

Quantitative Study of Low-energy ν - Nucleus Interactions

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Fermilab

Neutrinos Are Everywhere!

Neutrinos outnumber ordinary matter particles in the Universe (electrons, protons, neutrons) by a huge factor.

- Depending on their masses they may account for a fraction (few % ?) of the "dark matter"
- Neutrinos are important for stellar dynamics: $\sim 6.6\times10^{10}$ cm^{-2}s^{-1} stream through the Earth from the sun. Neutrinos also govern Supernovae dynamics, and hence heavy element production.
- If there is CP Violation in the neutrino sector, then neutrino physics might ultimately be responsible for Baryogenesis.
- **To understand the nature of the Universe in which we live we must understand the properties of the neutrino.**

What are the Open Questions in Neutrino Physics

From the APS Multi-Divisional Study on the Physics of Neutrinos

- What are the masses of the neutrinos?
- What is the pattern of mixing among the different types of neutrinos?
- Are neutrinos their own antiparticles?
- Do neutrinos violate the symmetry CP?
- Are there “sterile” neutrinos?
- Do neutrinos have unexpected or exotic properties?
- What can neutrinos tell us about the models of new physics beyond the Standard Model?

The answer to almost every one of these questions involves understanding how neutrinos interact with matter!

Among the APS study assumptions about the current and future program:

“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.**”

The MINERνA Experiment

Objectives of the Experiment

Bring together the experts from two communities

To use a uniquely intense and well-understood ν beam

And a fine-grained, fully-active neutrino detector

To collect a large sample of ν and $\overline{\nu}$ scattering events

To perform a wide variety of ν physics studies

1) The MINERνA Collaboration
2) Beam and Statistics
3) Survey of Physics Topics
4) Description and Performance of the Detector
5) Cost and Schedule
6) Summary

Bringing together experts from two communities to study low-energy ν - Nucleus Physics

Red = HEP, Blue = NP, Black = Theorist

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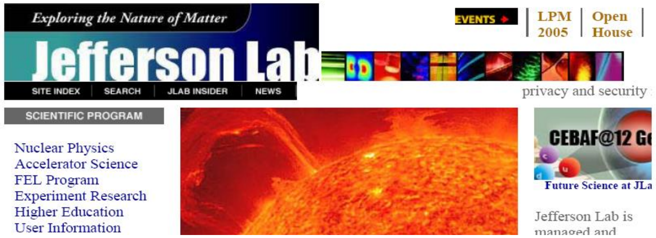
HEP/NP Partnership

- This partnership is truly a two-way street
  - significant NP participation in MINERvA because of overlap of physics with Jefferson Lab community



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.

Fermilab *Today*

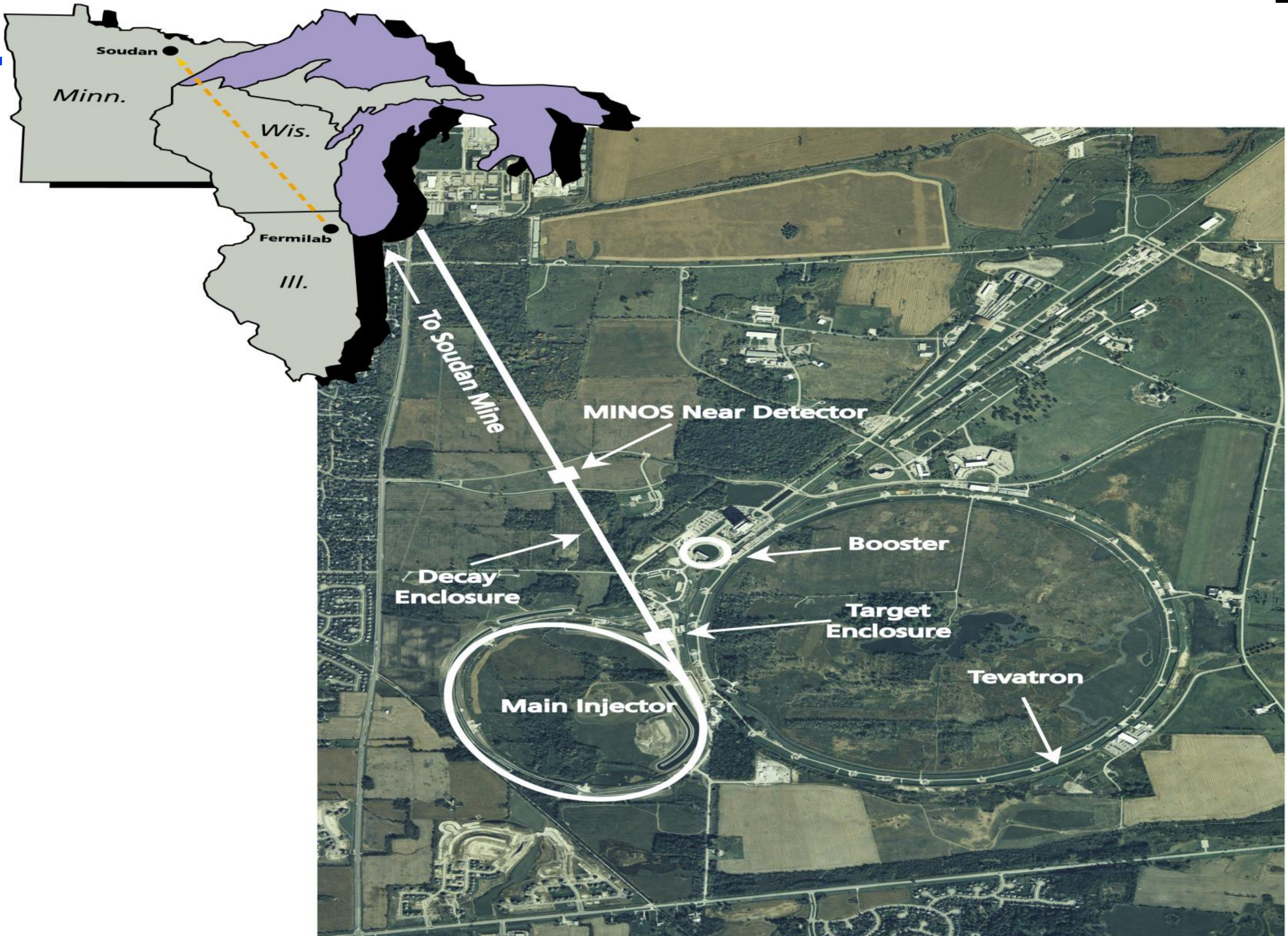
Nuclear Option: MINERvA Attracts Nuclear Physicists

This is the fourth article in a series on the MINERvA neutrino experiment.

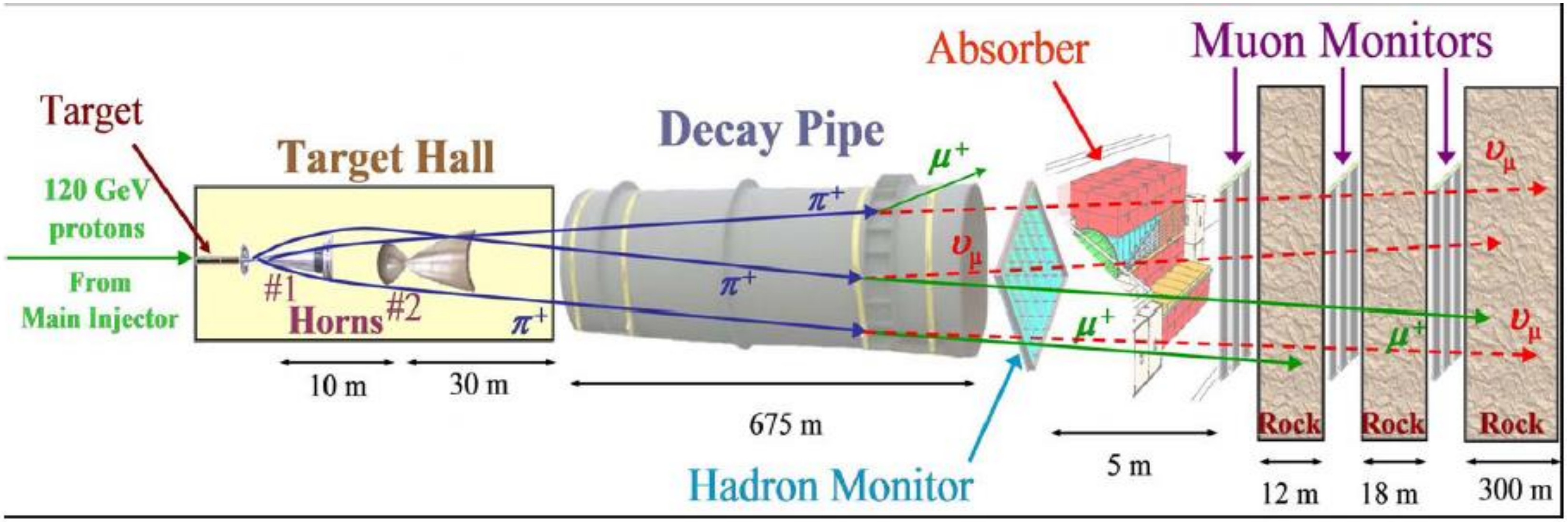
"MINERvA offers us the possibility of making a bridge in our understanding between the longer distance-scale properties of the nuclear force--responsible for the properties of nuclei--and the very short-distance scales explored in particle physics," says Ransome. "And this intermediate distance scale is of great interest to both communities."

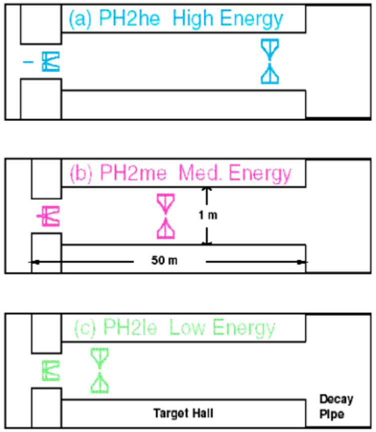
- JLab program (JUPITER)
  - data for neutrino cross-section modeling
  - already one dedicated experiment

To use a uniquely intense and well-understood ν beam. The NuMI Beam.



The NuMI Beam Configurations.





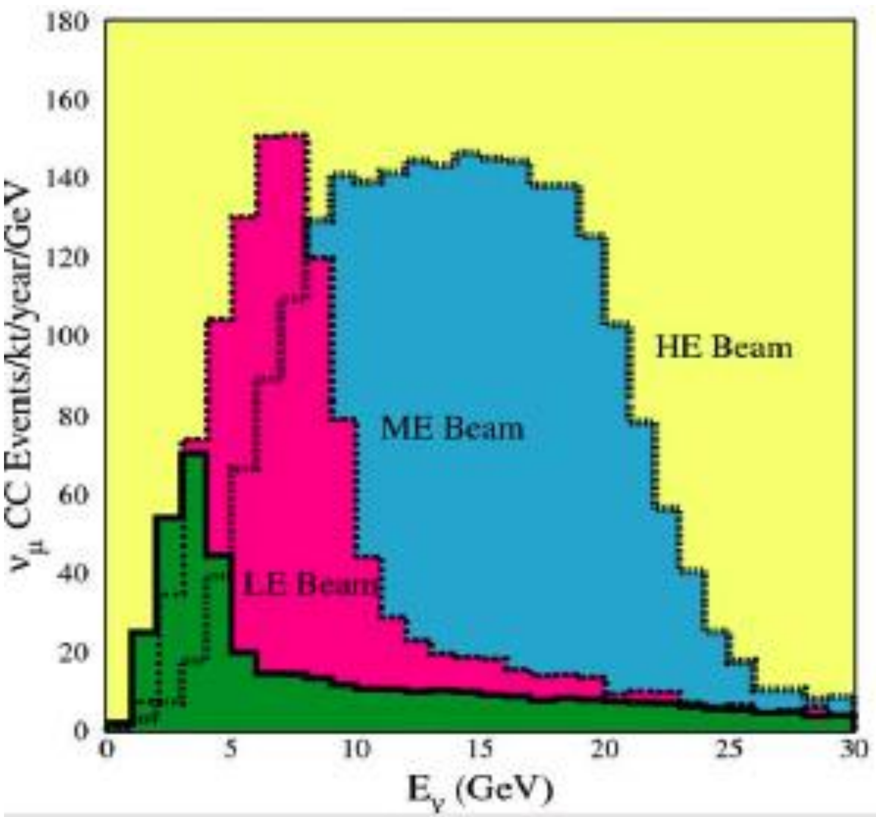
For MINOS, the majority of the running will be in the "low-energy" (LE) configuration.

Post-MINOS: NOνA would use the ME beam,

MINERνA would prefer the ME and HME beam

To collect a **large** sample of ν and $\bar{\nu}$ scattering events…

- LE-configuration: **Events-** (E_μ >0.35 GeV)
  E_{peak} = 3.0 GeV, $<E_\nu>$ = 10.2 GeV, rate = **60 K events/ton - 10^{20} pot**
- ME-configuration: **Events-**
  E_{peak} = 7.0 GeV, $<E_\nu>$ = 8.0 GeV, rate = **230 K events/ton - 10^{20} pot**
- HE-configuration: **Events-**
  E_{peak} = 12.0 GeV, $<E_\nu>$ = 14.0 GeV, rate = **525 K events/ton - 10^{20} pot**



With E-907 at Fermilab to measure particle spectra from the NuMI target, expect to know neutrino flux to ≈ ± 4 - 5%.

Why study low-energy ν scattering physics?

Motivation: NP - Compliment Jlab study of the nucleon and nucleus

Significant overlap with JLab physics kinematic region and introduces the axial-vector current

Four major topics:

Nucleon Form Factors - particularly the axial vector FF

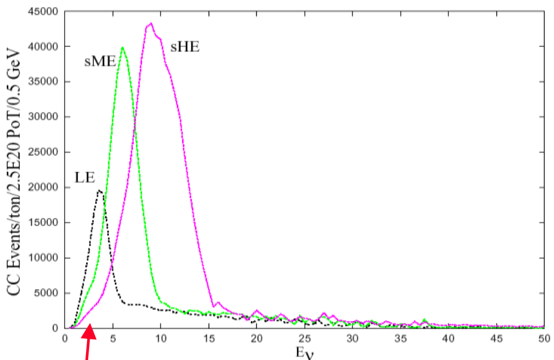
Duality - transition from resonance to DIS (non-perturbative to perturbative QCD)

Parton Distribution Functions - particularly high-x_{BJ}

Generalized Parton Distributions - multi-dimensional description of partons within the nucleon

Why study low-energy ν scattering physics?

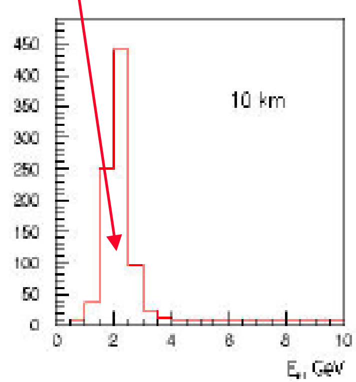
Motivation: EPP - Neutrino Oscillation Experiment Systematics

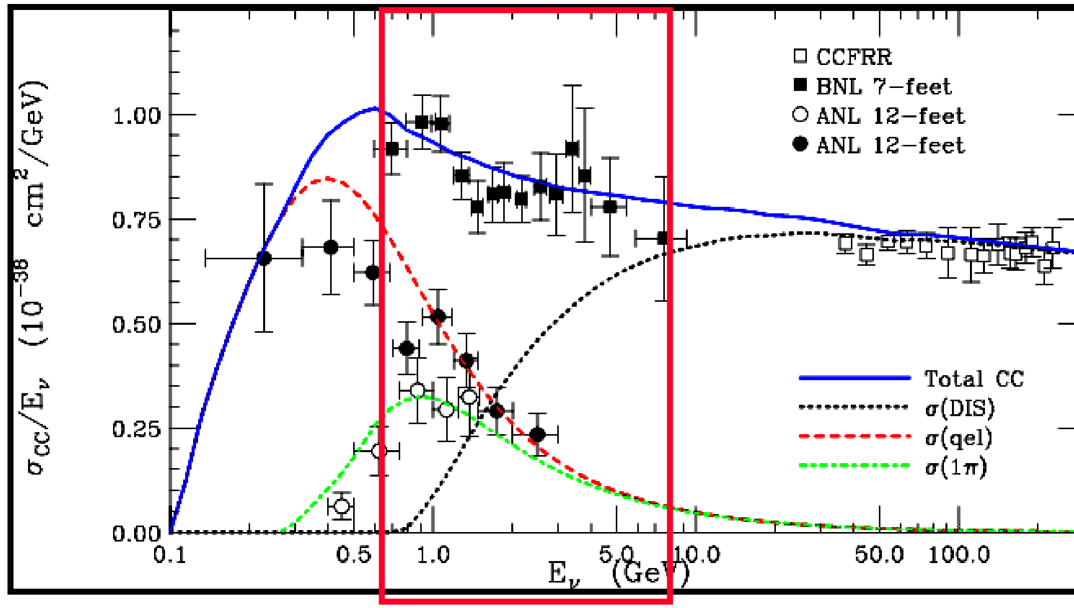


MINOS: Neutrino Beam

We need to improve our understanding of **low energy ν-Nucleus** interactions for oscillation experiments!

NuMI Off-axis Neutrino Beam





MINOS, MINERνA

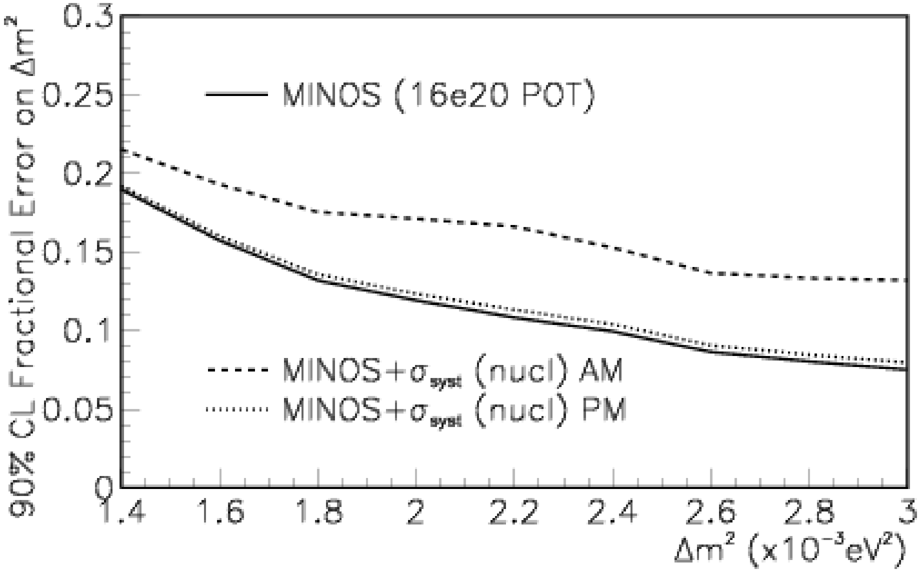
NOνA, MINERνA

T2K, SciBooNE

How MINERνA Would Help MINOS - How Nuclear Effects enter Δm^2 Measurement

Measurement of Δm^2 with MINOS

- Need to understand the relationship between the incoming neutrino energy and the visible energy in the detector

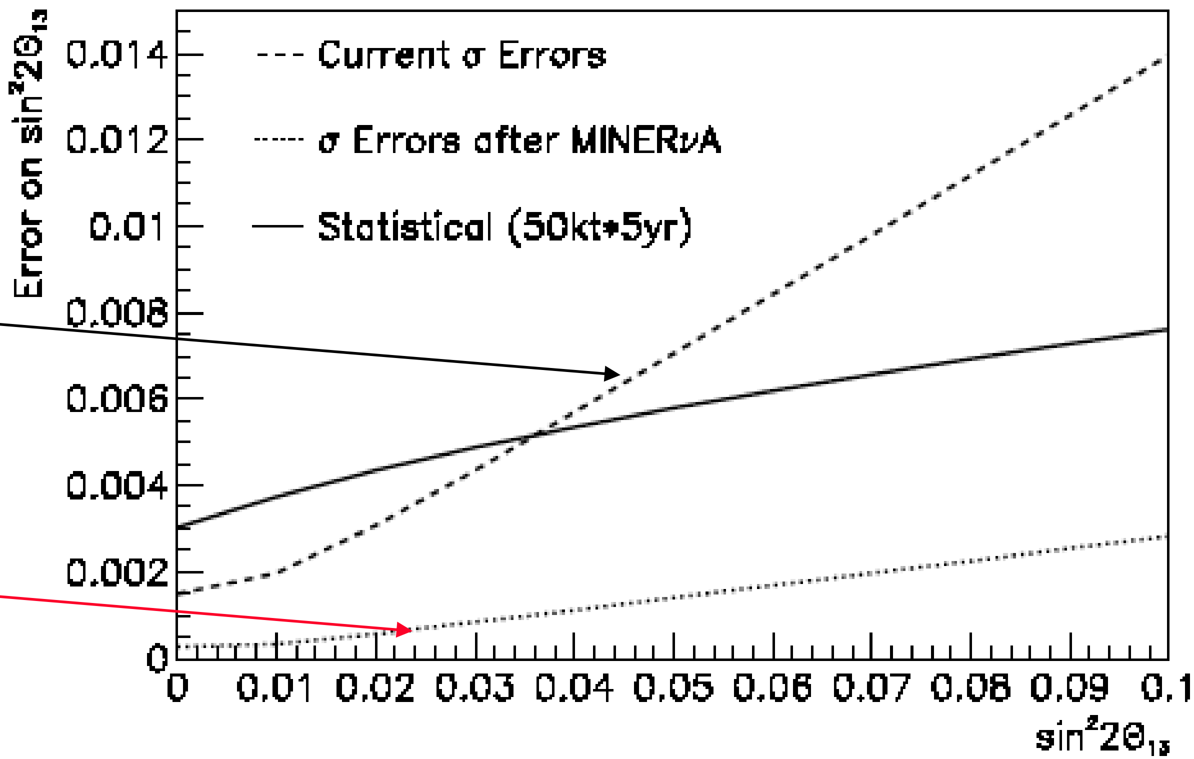


- Expected from MINERνA
  - Improve understanding of pion and nucleon absorption
  - Understand intra-nuclear scattering effects
  - Understand how to extrapolate these effects from one A to another
  - Improve measurement of pion production cross-sections
  - Understand low-ν shadowing with neutrinos

How MINERνA Would Help NOνA/T2K

Total fractional error in the predictions as a function of Near Detector off-axis Angle

Current Accuracy of
Low-energy Cross-sections
ΔQE = 20%
ΔRES = 40%
ΔDIS = 20%
ΔCOH_{Fe} = 100%

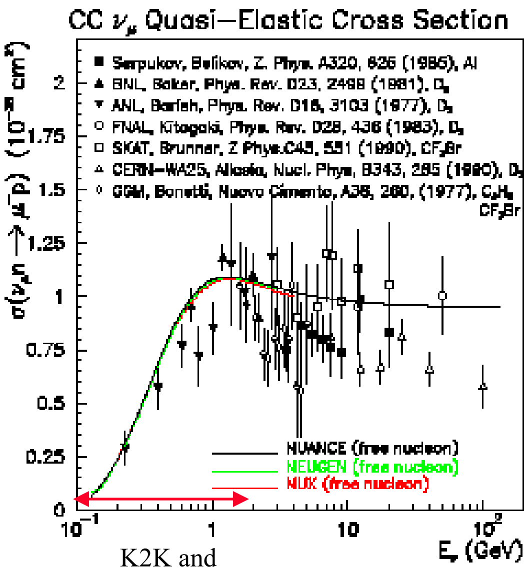


With MINERνA
Measurements of σ
ΔQE = 5%
ΔRES = 5, 10% (CC, NC)
ΔDIS = 5%
ΔCOH_{Fe} = 20%

Further Motivation - Current Data Sample

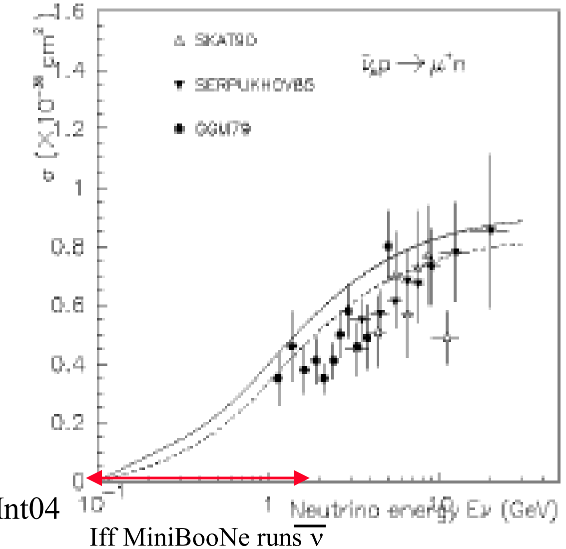
Exclusive Cross-sections at Low E_ν: Quasi-elastic - DISMAL

ν



K2K and MiniBooNe

S. Zeller - NuInt04

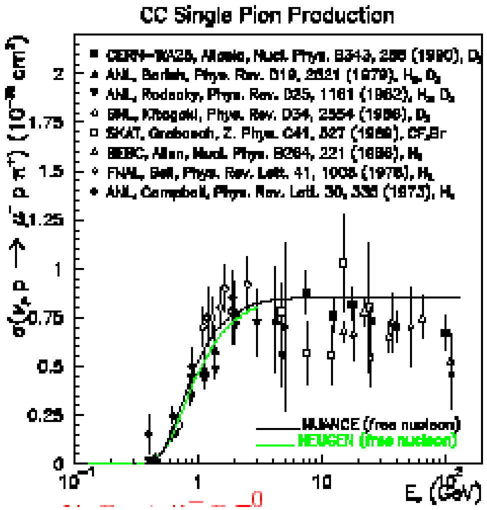


Iff MiniBooNe runs $\bar{\nu}$

$\bar{\nu}$

- World sample statistics is still fairly miserable!
- Cross-section important for understanding low-energy atmospheric neutrino oscillation results.
- Needed for all low energy neutrino monte carlos.
- Best way to accurately measure the axial-vector form factors

Exclusive Cross-sections at Low E_ν :
1-Pion and Strange Particle- DISMAL



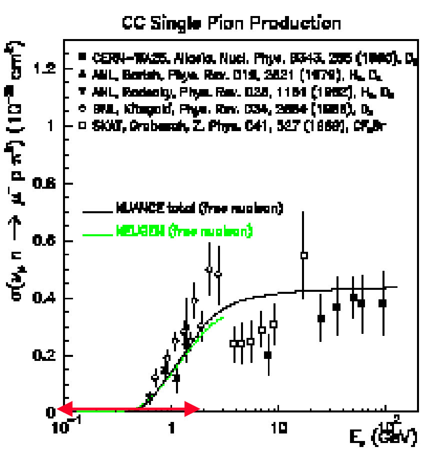
CC

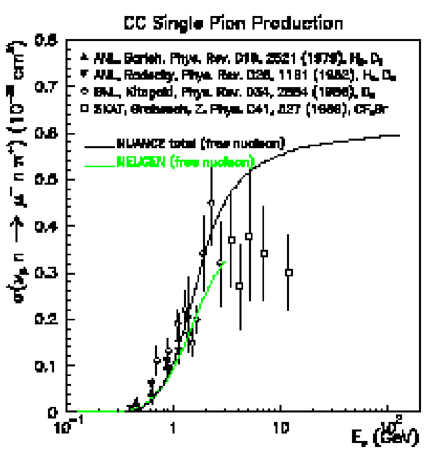
$\nu p \rightarrow \mu^- p \pi^+$

S. Zeller - NuInt04

$\nu n \rightarrow \mu^- p \pi^0$

$\nu n \rightarrow \mu^- n \pi^+$





Typical samples of NC 1-π

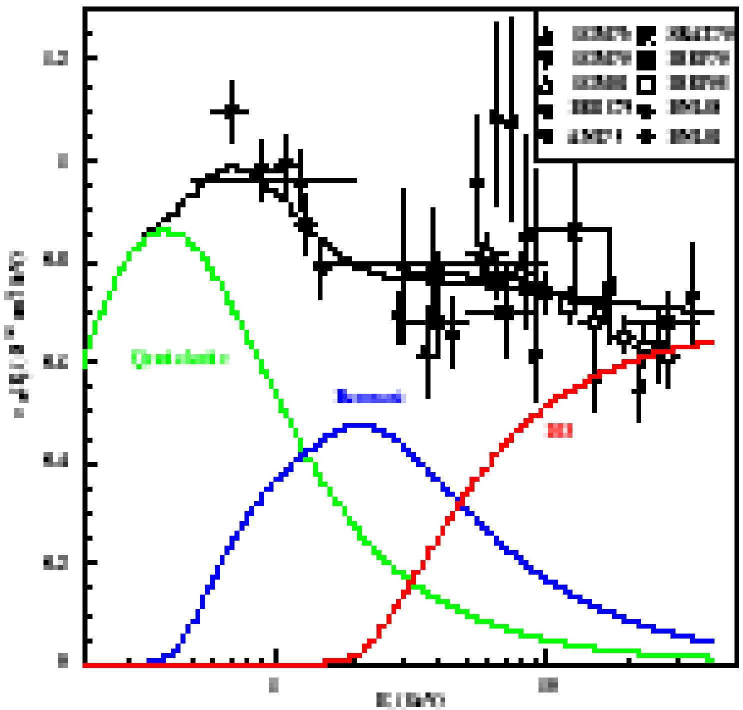
- ANL
  - $\nu\ p \rightarrow \nu\ n\ \pi^+$ (7 events)
  - $\nu\ n \rightarrow \nu\ n\ \pi^0$ (7 events)
- Gargamelle
  - $\nu\ p \rightarrow \nu\ p\ \pi^0$ (240 evts)
  - $\nu\ n \rightarrow \nu\ n\ \pi^0$ (31 evts)
- **K2K and MiniBooNe**
  - **Should produce interesting analysis of single π^0 production.**

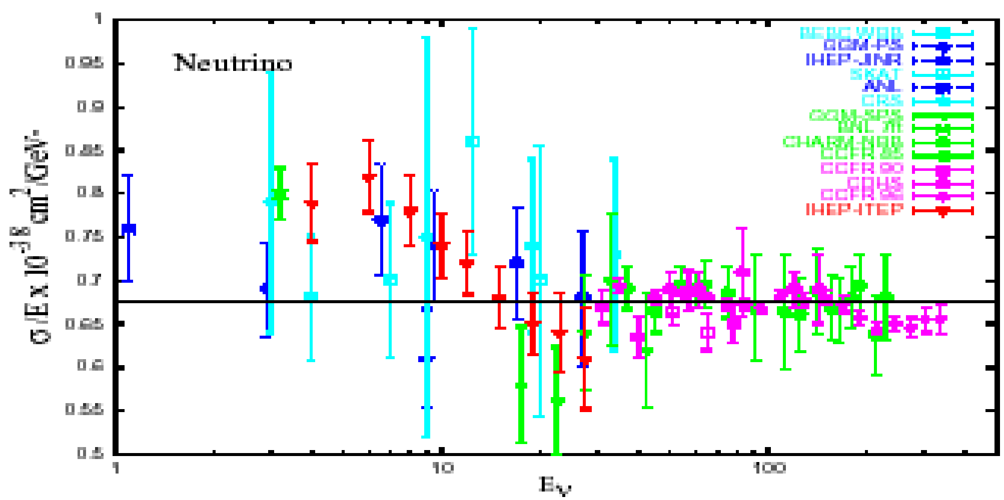
Strange Particle Production

- Gargamelle-PS - **15** Λ events.
- FNAL - ≈ 100 events
- ZGS - 30 events
- BNL - 8 events
- Larger NOMAD sample expected

How about σ_{Tot}?

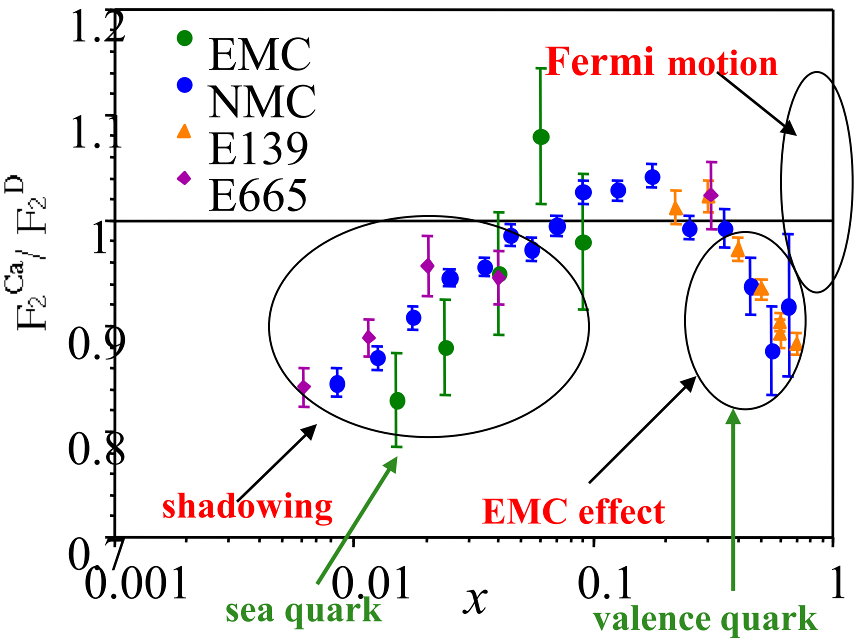
- Low energy (< 10 GeV) primarily from the 70's and 80's suffering from low statistics and large systematics (mainly from ν flux measurements).
- Mainly bubble chamber results --> larger correction for missing neutrals.
- How well do we model σ_{Tot}?

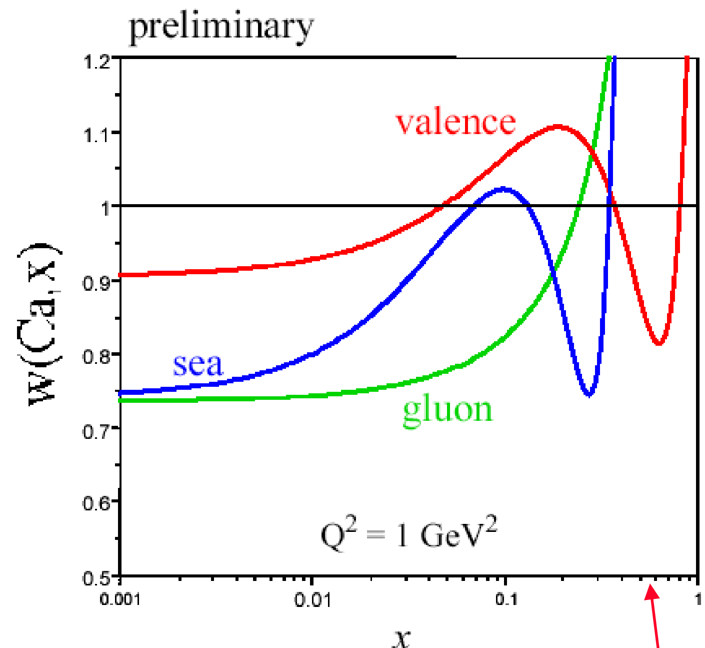




D. Naples - NuInt02

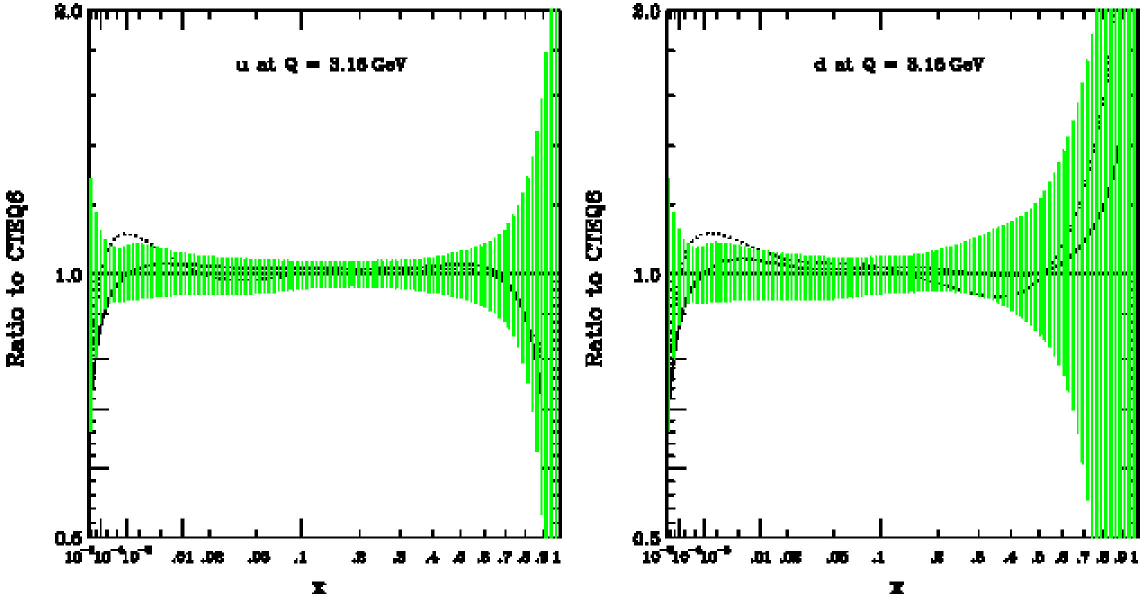
Knowledge of Nuclear Effects with Neutrinos: essentially NON-EXISTENT





- F_2 / nucleon changes as a function of A. Measured in μ/e - A **not in ν – A**
- **Good reason to consider nuclear effects are DIFFERENT in ν - A.**
  - **Presence of axial-vector current.**
  - **SPECULATION: Much stronger shadowing for ν -A but somewhat weaker "EMC" effect.**
  - **Different nuclear effects for valance and sea --> different shadowing for xF_3 compared to F_2.**
  - **Different nuclear effects for d and u quarks.**

High x_{Bj} parton distributions
How well do we know quarks at high-x?



- Ratio of CTEQ5M (solid) and MRST2001 (dotted) to CTEQ6 for the u and d quarks at $Q^2 = 10\ GeV^2$. The shaded green envelopes demonstrate the range of possible distributions from the CTEQ6 error analysis.
- Recent high-x measurements indicate conflicting deviations from CTEQ: E-866 u_V too **high,** NuTeV u_V & d_V too **low**
- CTEQ / MINERνA working group to investigate high-x_{Bj} region.

MINERνA ν Scattering Physics Program

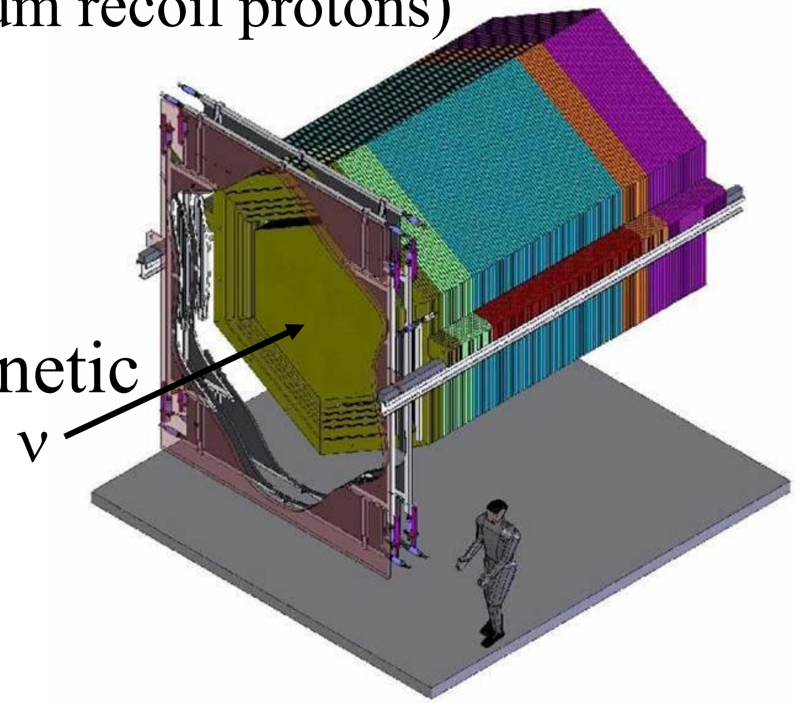
- Quasi-elastic
- Resonance Production - 1pi
- Resonance/transition Region - npi resonance to DIS
- Deep-Inelastic Scattering
- Coherent Pion Production
- Strange and Charm Particle Production
- σ_T , Structure Functions and PDFs
  - s(x) and c(x)
  - High-x parton distribution functions
- Nuclear Effects
- Generalized Parton Distributions

What detector properties do we need to do this physics?

- Must reconstruct exclusive final states
  - high granularity for charged particle tracking and ID, low momentum thresholds for particle detection such as $\nu_\mu n \rightarrow \mu^- p$
- But also must contain
  - electromagnetic showers (π^0, $e^\pm$)
  - high momentum hadrons ($\pi^\pm$, p, etc.)
  - from CC need $\mu^\pm$ (enough to measure momentum)
- Nuclear targets for the study of neutrino induced nuclear effects

Basic Detector

- MINERνA proposes to build a low-risk detector with simple, well-understood technology
- Active core is segmented solid scintillator
  - Tracking (including low momentum recoil protons)
  - Particle identification
  - 3 ns (RMS) per hit timing (track direction, stopped $K\pm$)
- Core surrounded by electromagnetic and hadronic calorimeters
  - Photon (π^0) & hadron energy measurement
- MINOS Near Detector as muon catcher



MINERνA Detector

Side HCAL: 116 tons

Side ECAL Pb: 0.6 tons

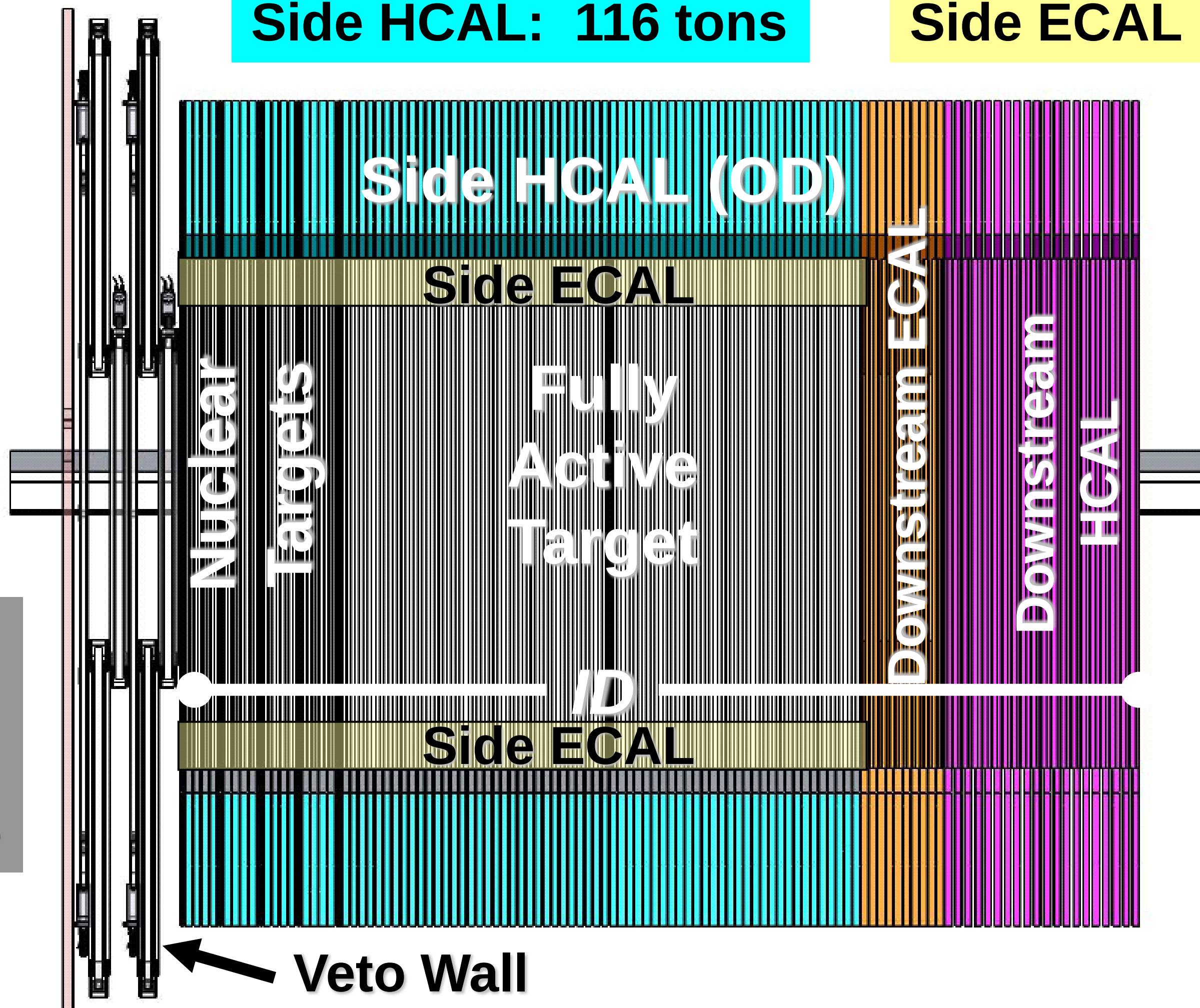
Fully Active Target: 8.3 tons

Nuclear Targets: 6.2 tons (40% scint.)

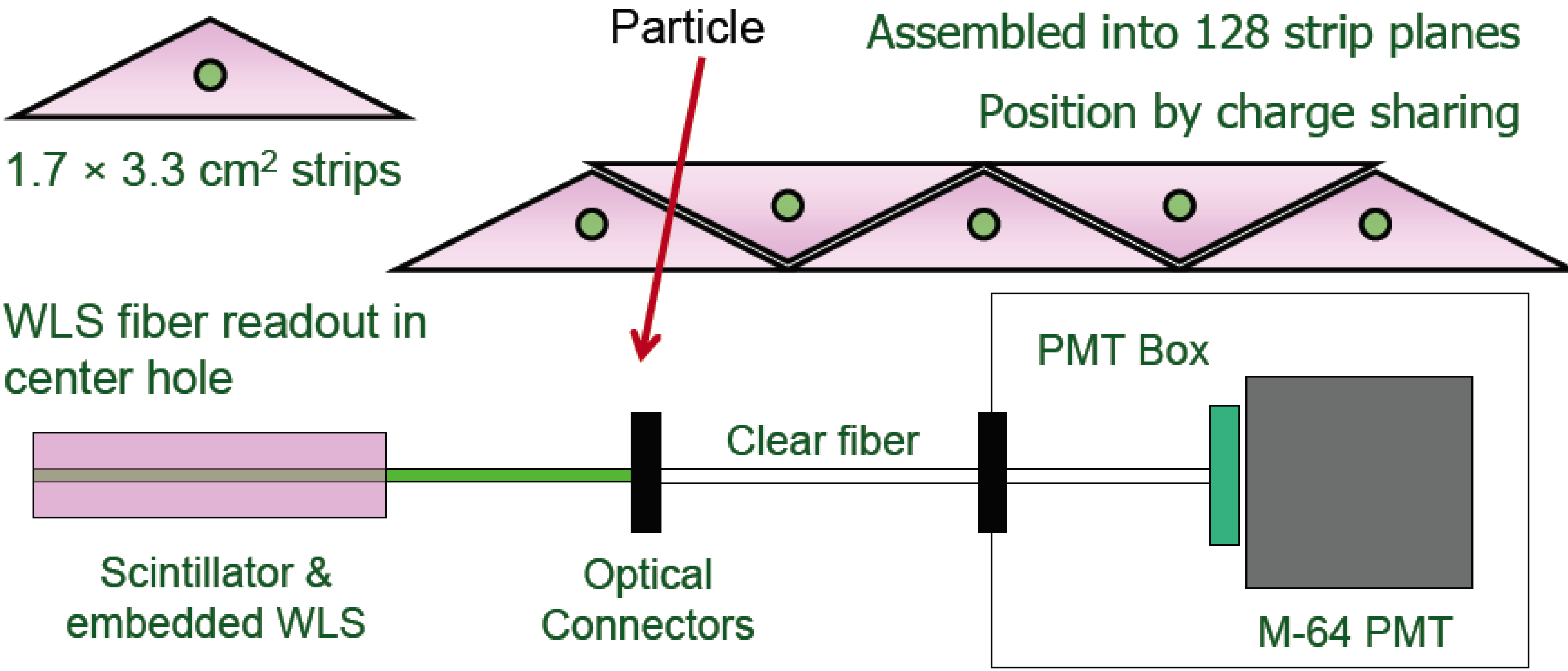
DS ECAL: 15 tons

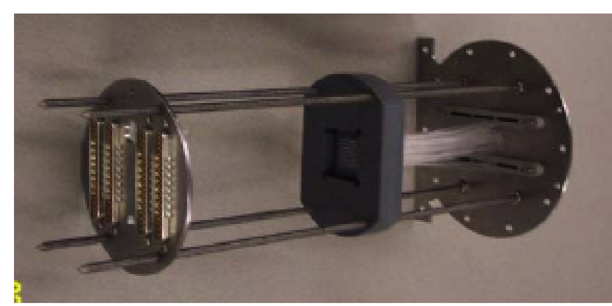
DS HCAL: 30 tons

ν

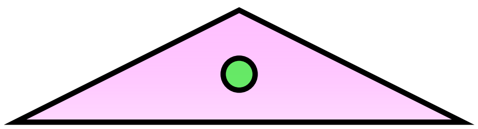


MINERνA Optics

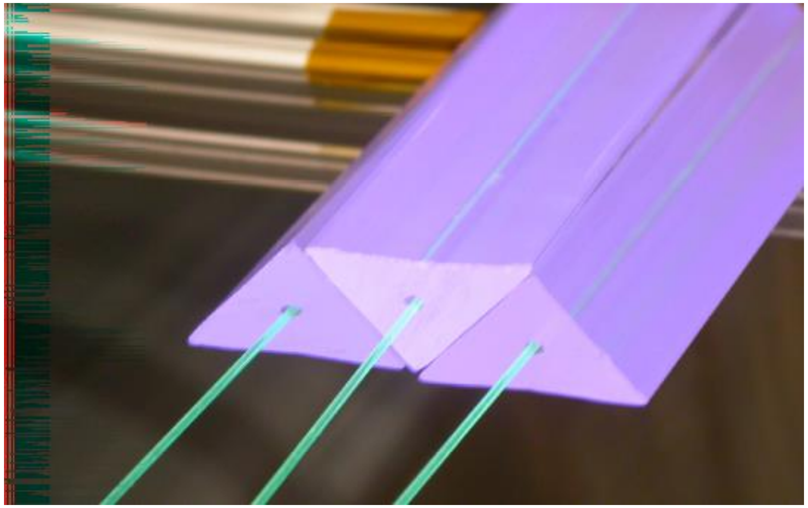




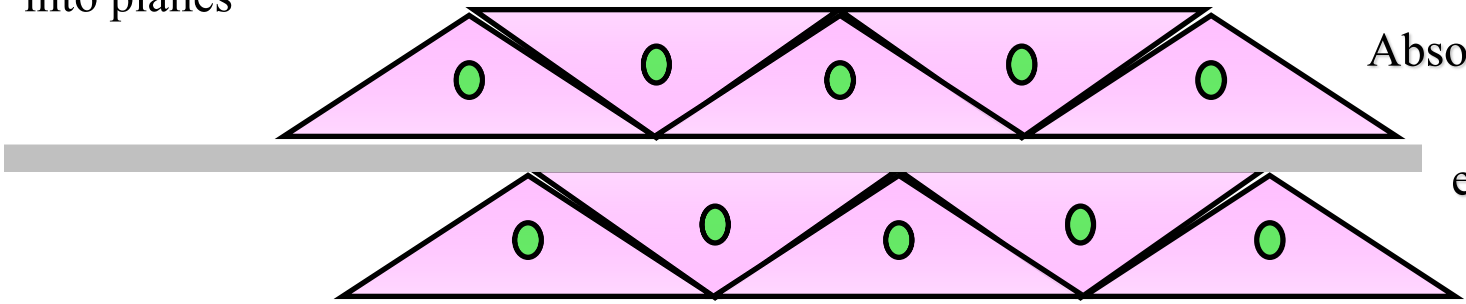
Extruded Scintillator and Optics



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



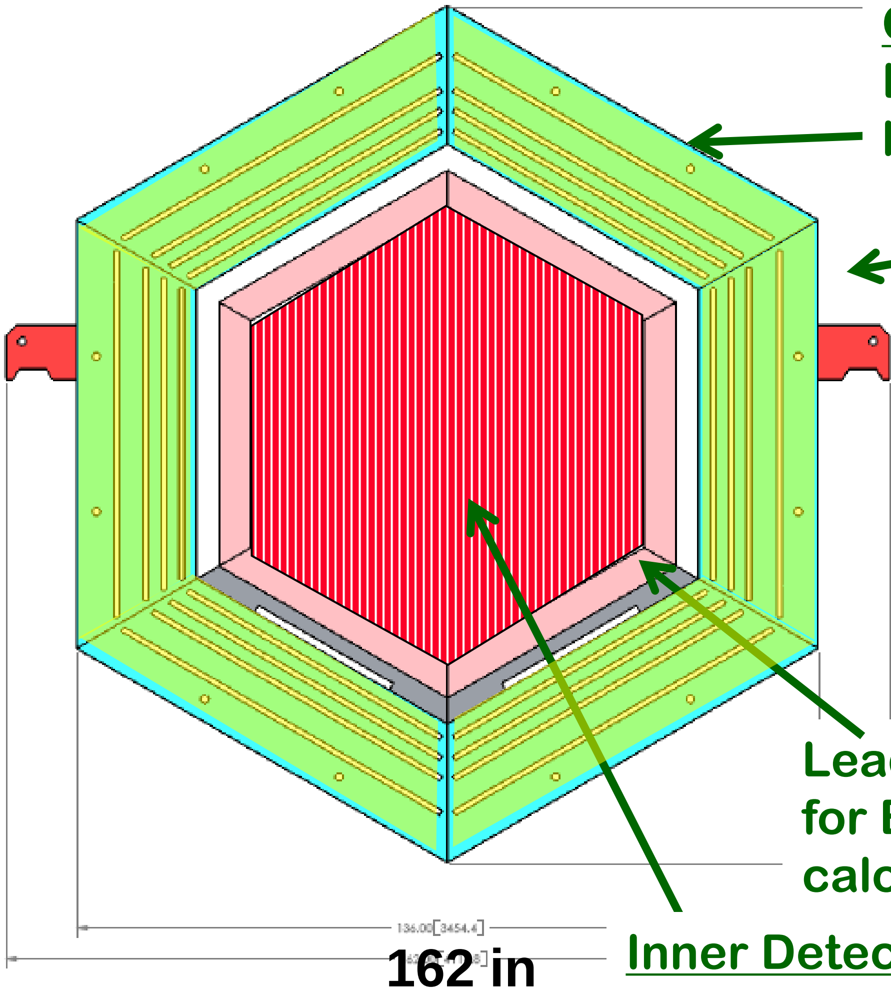
Assemble into planes



Absorbers between planes

e.g., E- or H-CAL, nuclear targets

MINERνA Detector Module



<u>Outer Detector</u> (OD)
Layers of iron/scintillator for hadron calorimetry. 6 "Towers"

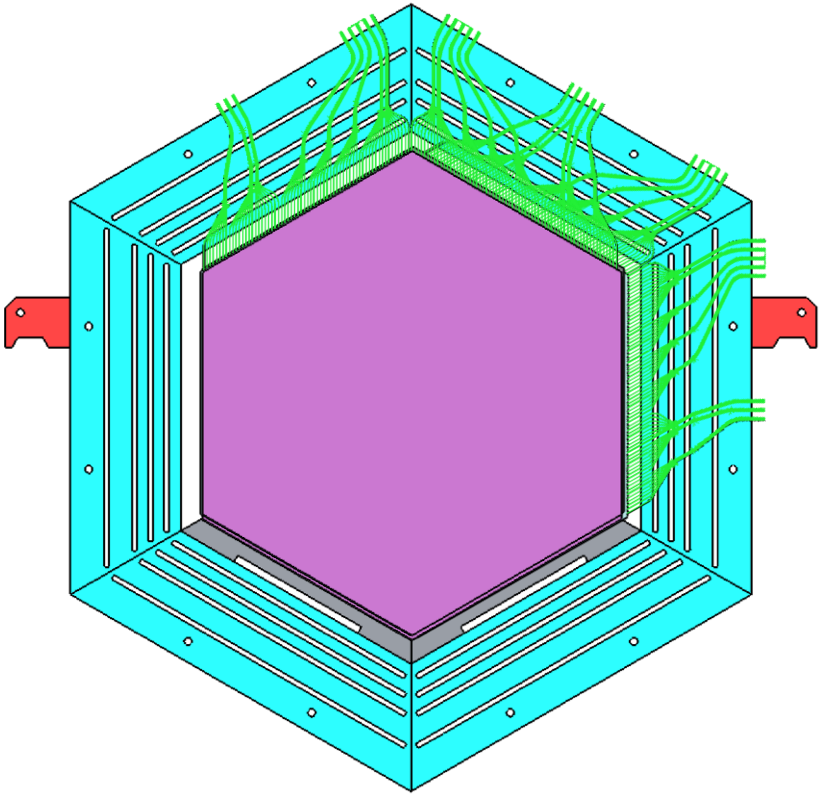
Lead Sheets for EM calorimetry

<u>Inner Detector</u> (ID)
Hexagonal X, U, V planes for 3D tracking

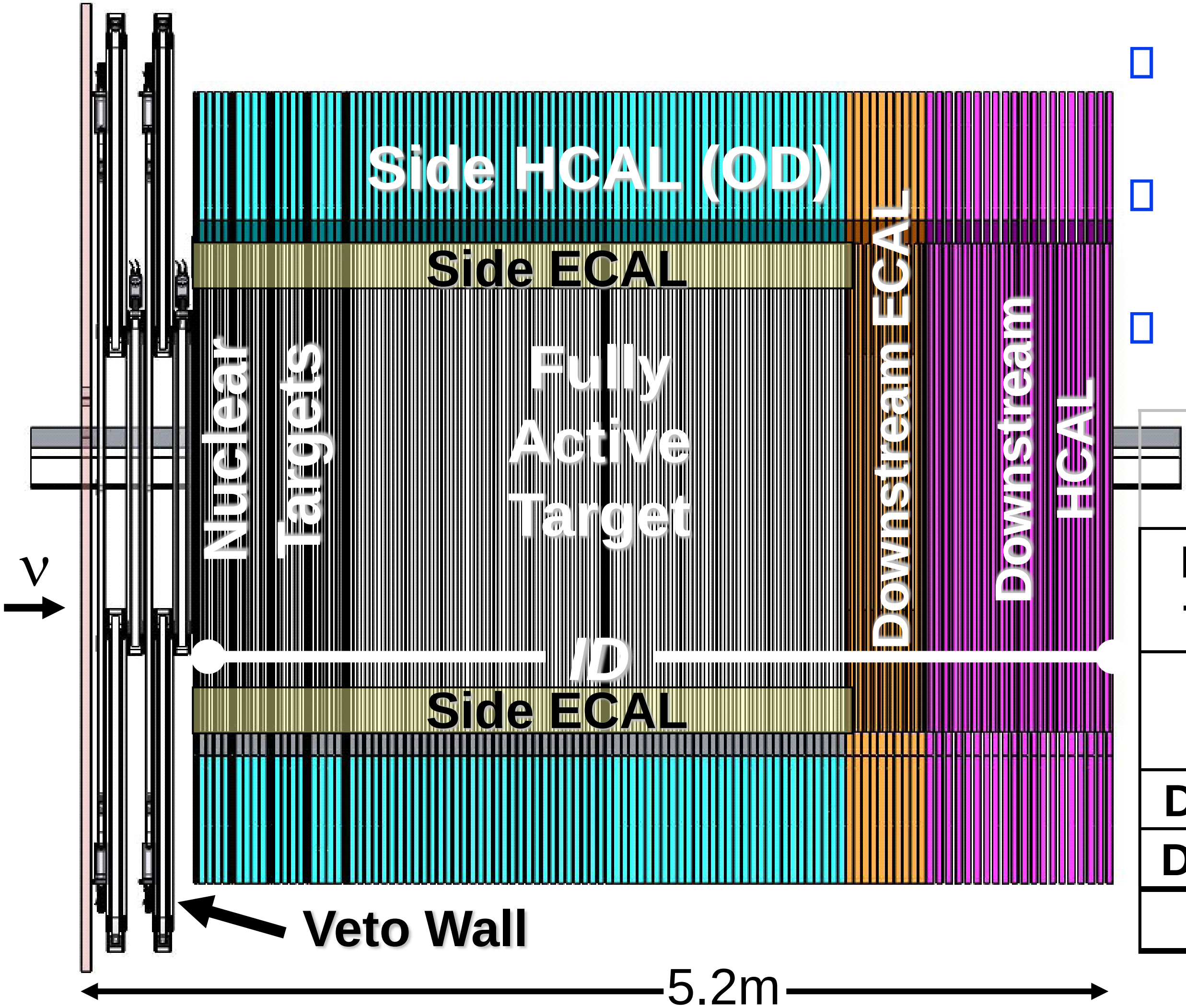
- A frame with two planes has 304 channels
  - 256 in inner detector
  - 48 in outer detector (two per slot)
- 4¾ M-64 PMTs per module
  - OD readout ganged in groups of four planes

Parts of MINERνA Modules (cont'd)

- Calorimeter modules are built by adding absorbers
  - one 1" steel absorber and one scintillator plane in DS HCAL
  - two 5/64" Pb absorbers and two scintillators in DS ECAL



Complete Detector

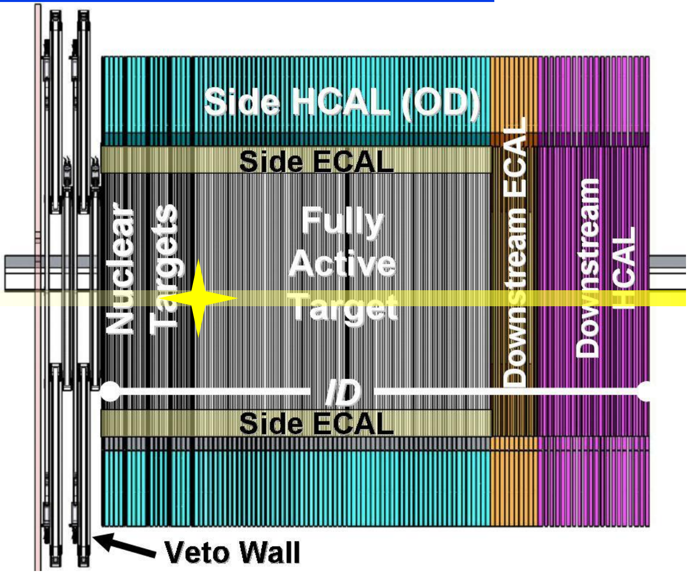


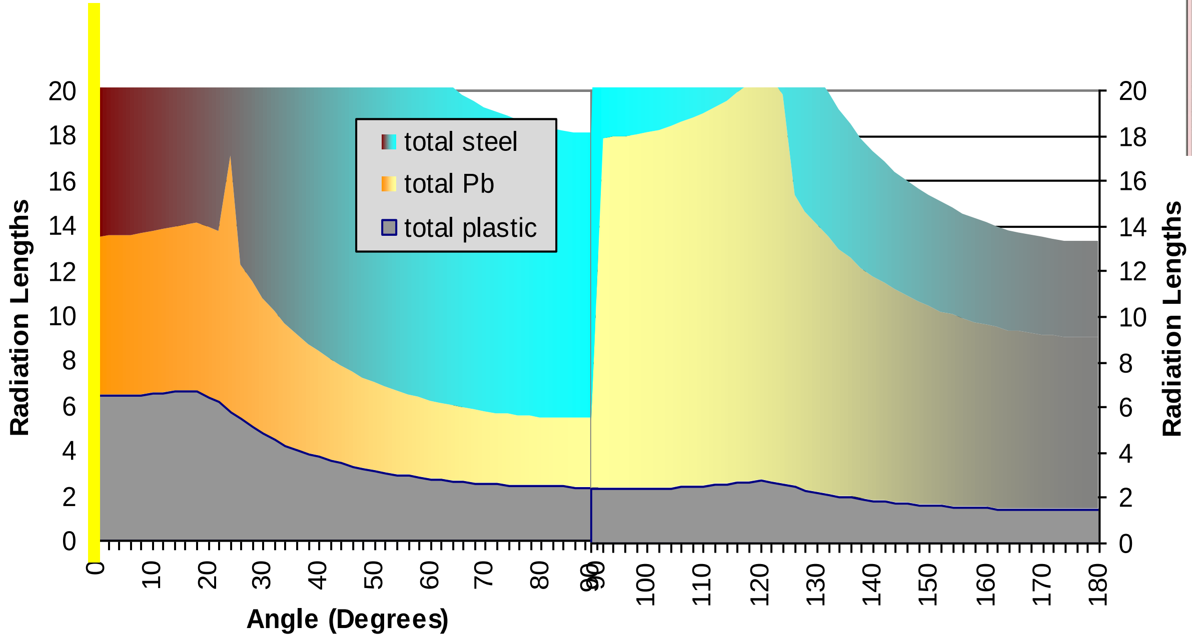
- Thin modules hang like file folders on a stand
- Attached together to form completed detector
- Different absorbers for different detector regions

	Frames	Scintillator Planes
Nuclear Targets	18	36
Active Target	60	120
DS ECAL	10	20
DS HCAL	20	20
Totals	108	196

MINERνA as Calorimeter

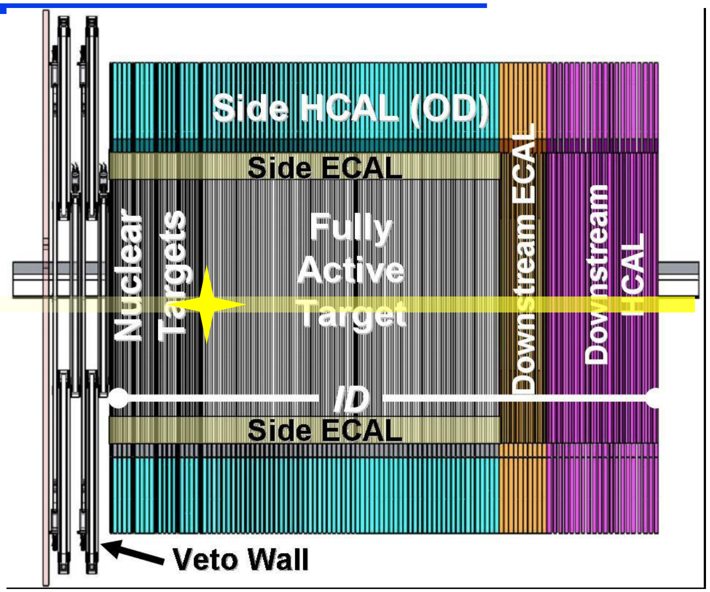
- Material in Radiation lengths
  - Relevant for photon and electron analysis
  - Side & DS Pb has 2mm plates

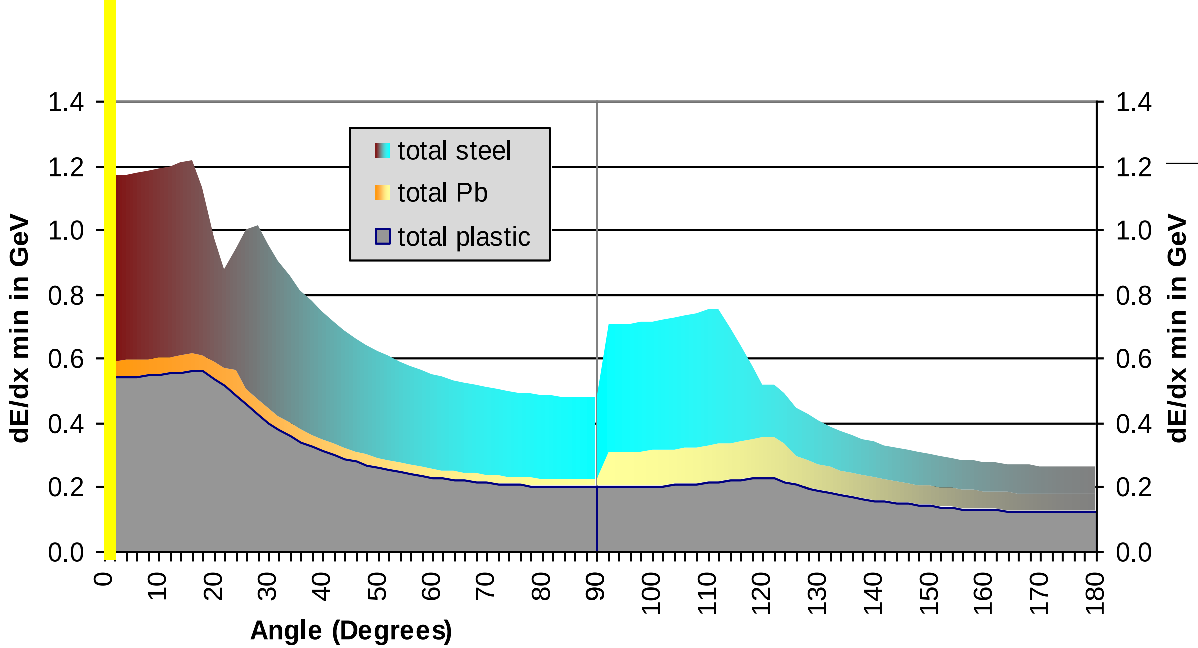




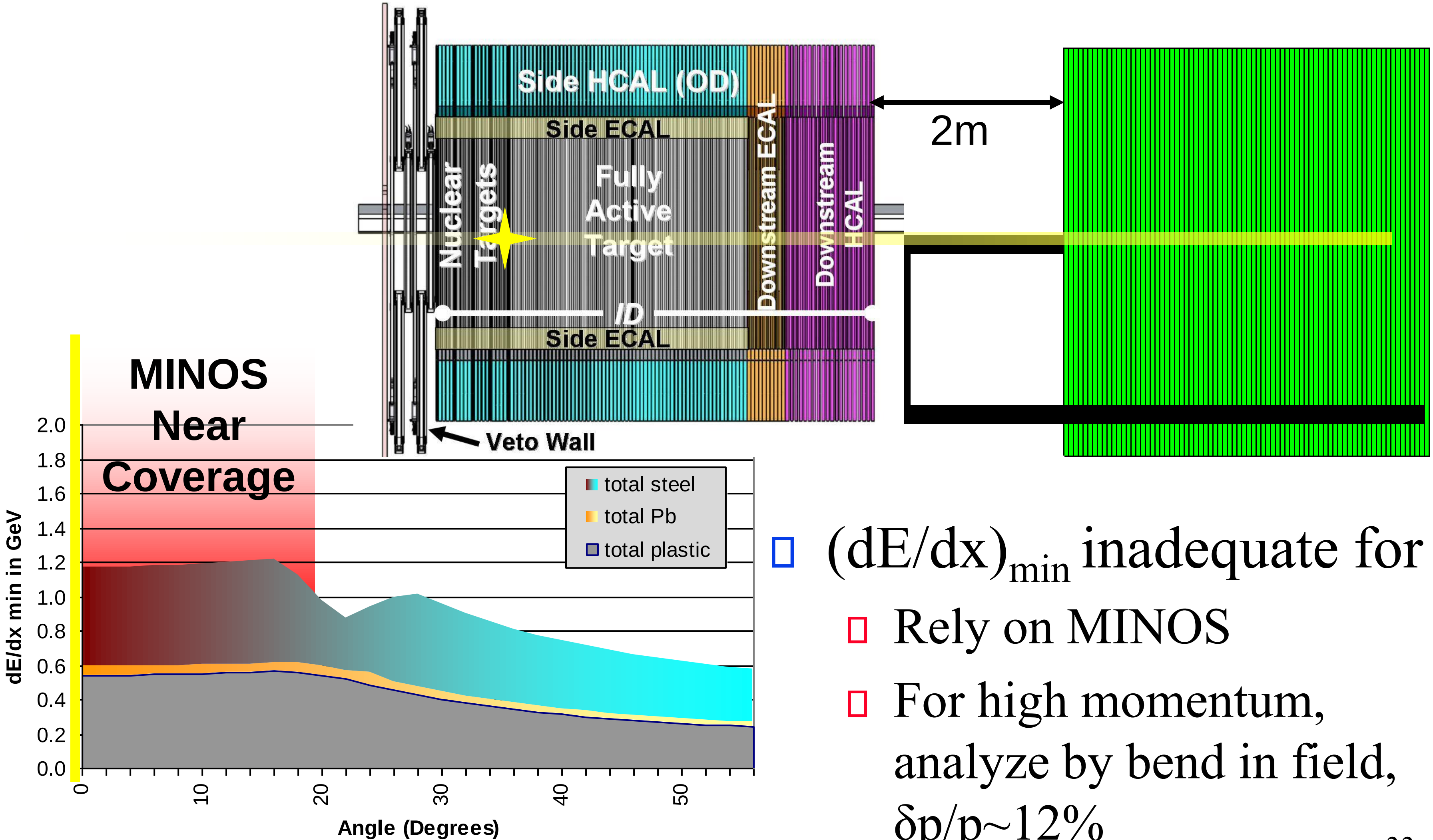
MINERνA as Range Tracker

- Material Thickness in $(dE/dx)_{min}$
  - Relevant for ranging out low energy particles





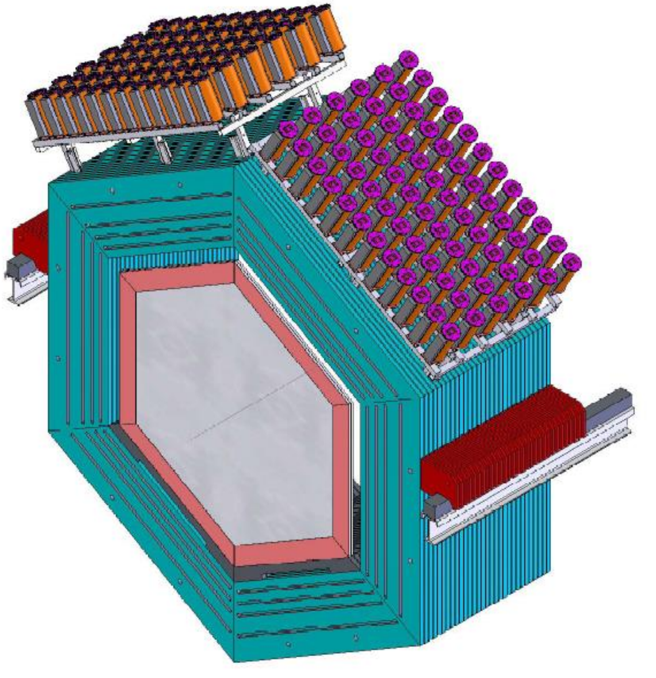
MINERνA with MINOS Near



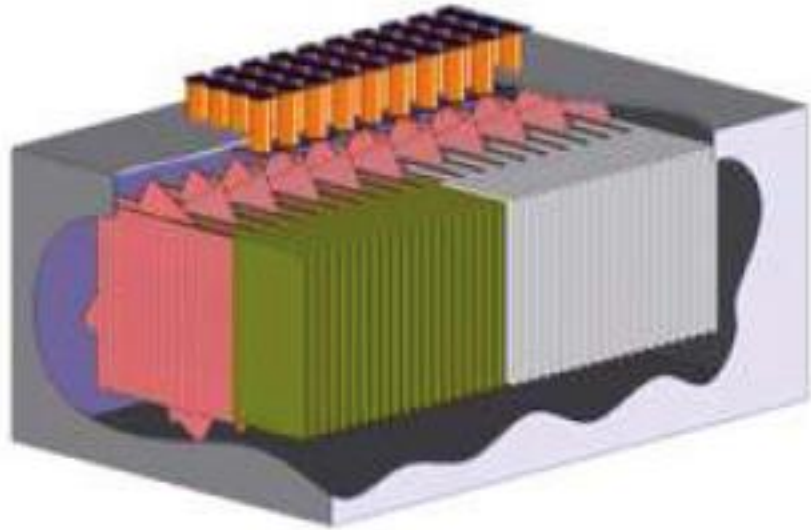
- $(dE/dx)_{min}$ inadequate for μ
  - Rely on MINOS
  - For high momentum, analyze by bend in field, δp/p~12%

Tracking Prototype

- Multi-plane Tracking Prototype to be built in 2007/2008
  - Roughly 20% of the full detector
  - Full EM Pb Calorimeter, no hadron Calorimeter
  - Tests to be performed
    - » Scintillator spacing uniformity
    - » Plane uniformity across many planes
    - » Planes stacked as close as physics dictates?
    - » How to replace PMT Boxes and front end boards



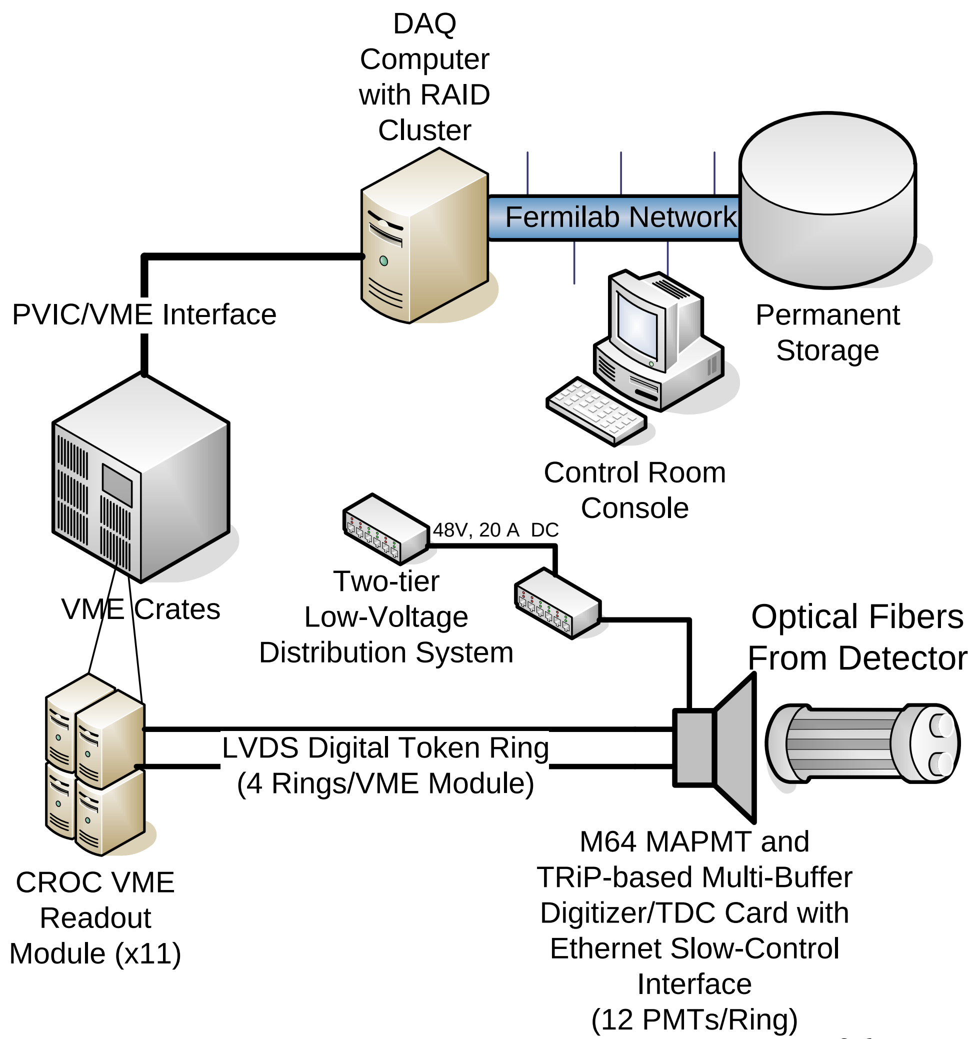
MINERvA Test Beam Detector



- 40 planes, XUXV orientation as in full MINERvA
- Removable lead and iron absorbers.
- In light-proof box
- Size will be smaller: ~1.2 x 1.2 m2
- Requesting Fermilab Test Beam Facility Upgrade to reach lower π/K/p momenta of order 250 MeV

Electronics/DAQ System

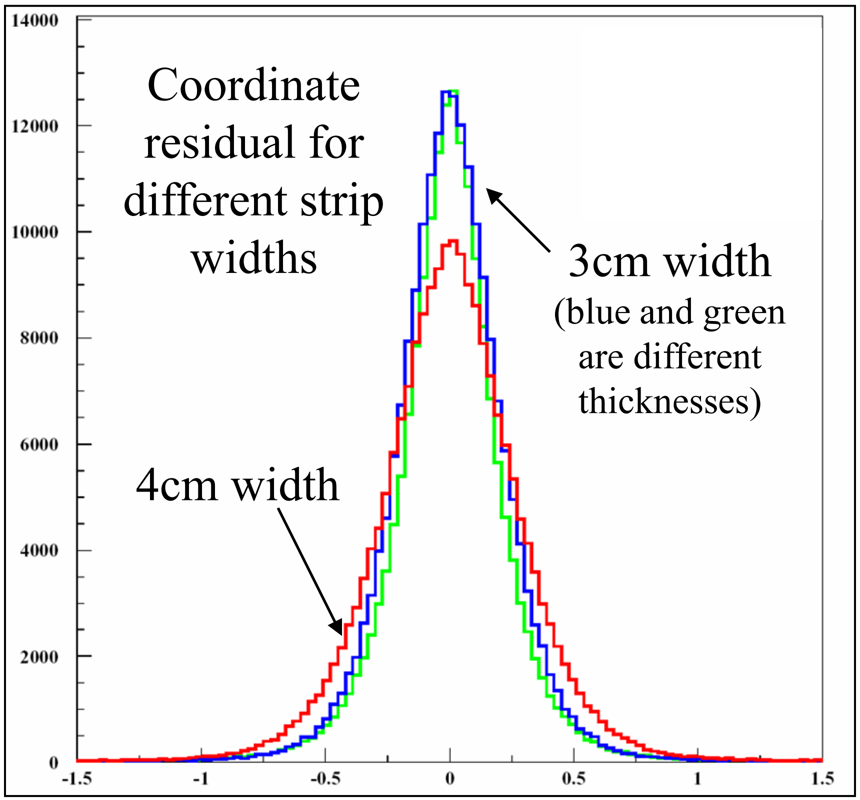
- Data rate is modest
  - ~1 MByte/spill
  - but many sources! (~31000 channels)
- Front-end board based on existing TriP-t ASIC
  - sample and hold in up to four time slices
  - few ns TDC, 2 range ADC
  - C-W HV. One board/PMT
- DAQ and Slow Control
  - Front-end/computer interface
  - Distribute trigger and synchronization
  - Three VME crates + server



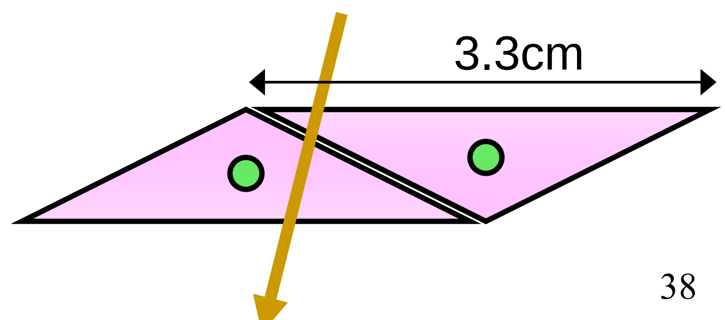
MINERνA Software

- **Off-line - NEUGEN/NUANCE-GEANT4 MC within GAUDI framework**
  - » **detector simulation**
  - » **pattern recognition**
  - » **reconstruction**
- **On-line - Prepare for data taking with tracking prototype and test-beam detector**
  - » **DAQ**
  - » **Data loggers**
  - » **Event monitoring**
  - » **Run controls**
  - » **Slow controls**
- **Upcoming second week-long software workshop in December.**

Performance: Optimization of Tracking in Active Target

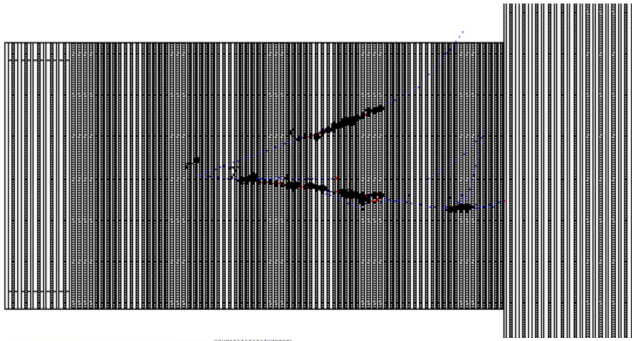


- Excellent tracking resolution w/ triangular extrusion
  - σ~3 mm in transverse direction from light sharing
  - More effective than rectangles (resolution/segmentation)
  - Key resolution parameters:
    - transverse segmentation and light yield
    - longitudinal segmentation for z vertex determination

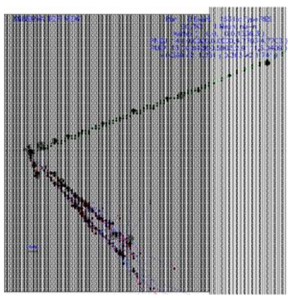


- technique pioneered by D0 upgrade pre-shower detector

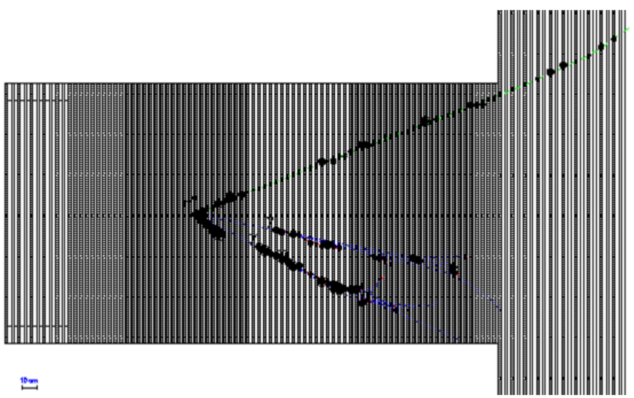
Performance: π^0 Energy and Angle Reconstruction

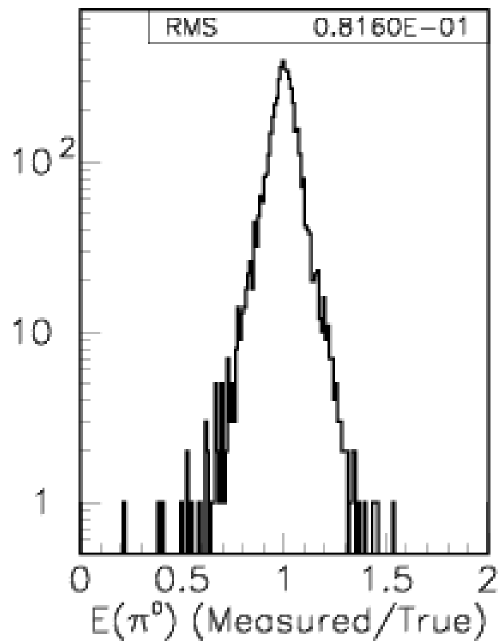


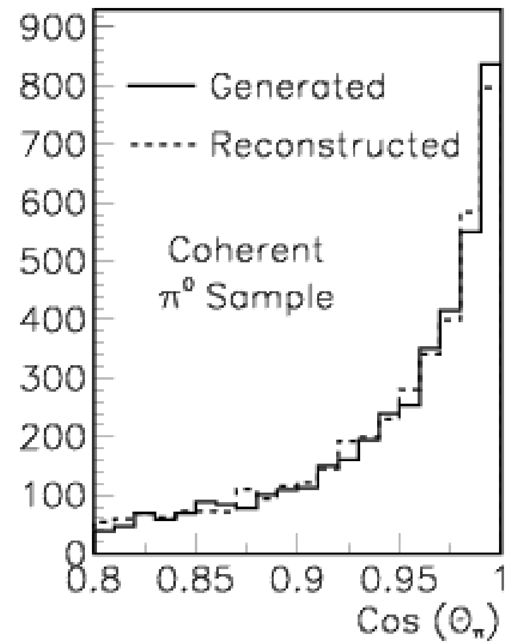
- π^0's cleanly identified
- π^0 energy resolution: 6%/sqrt(E)
- π^0 angular resolution better than smearing from physics



Coherent, resonance events with π^0

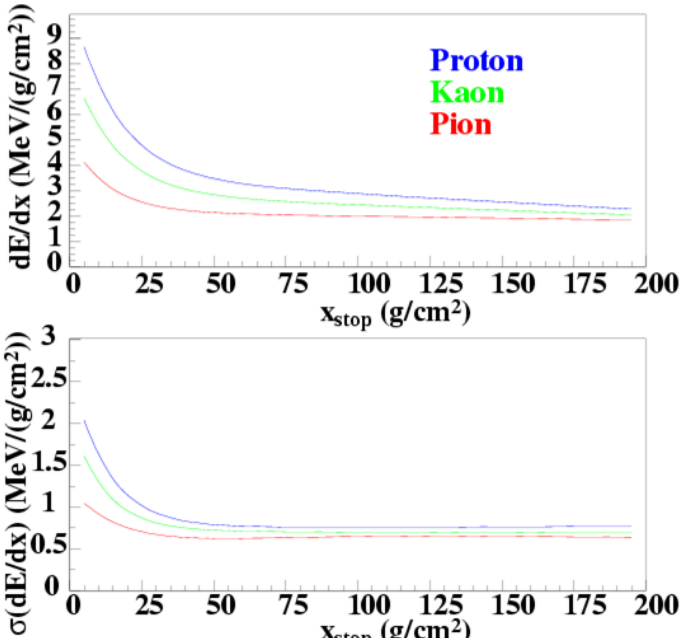






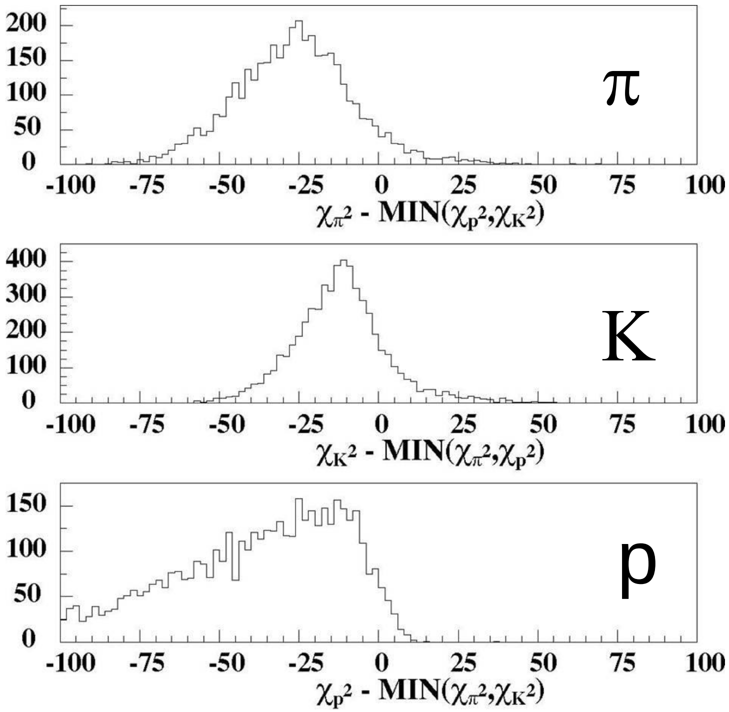
Performance: Particle Identification

- Particle ID by dE/dx in strips and endpoint activity



- Many dE/dx samples for good discrimination

Chi2 differences between right and best wrong hypothesis

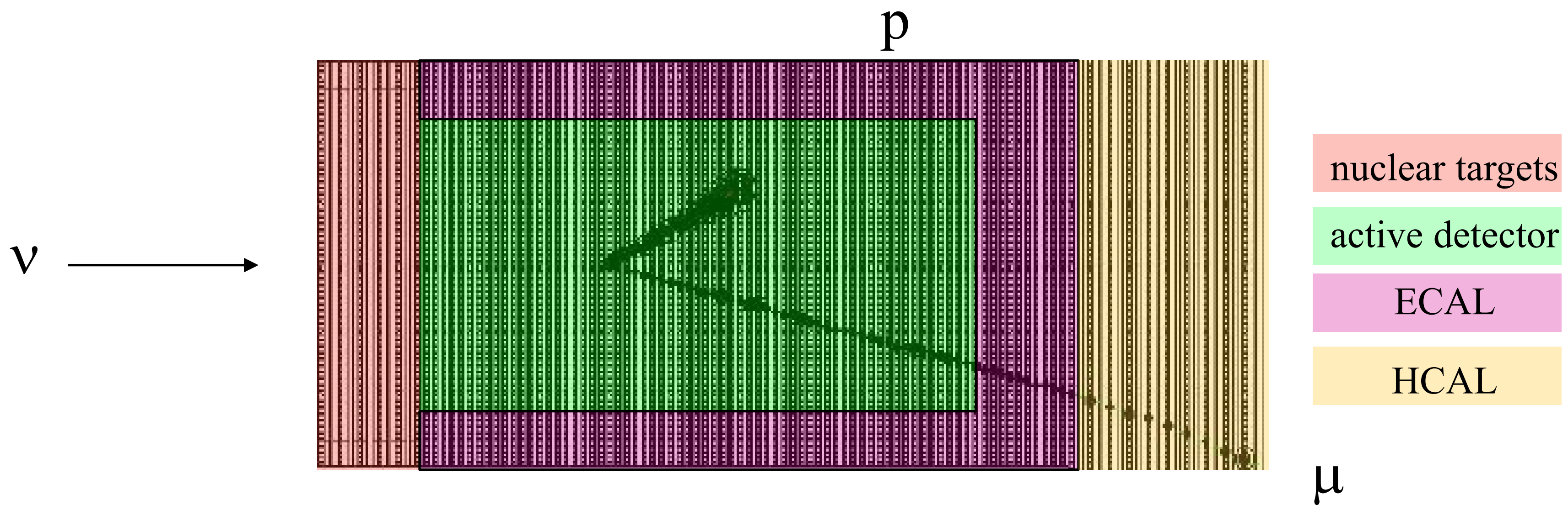


R = 1.5 m - p: μ =.45 GeV/c, π = .51, K = .86, P = 1.2

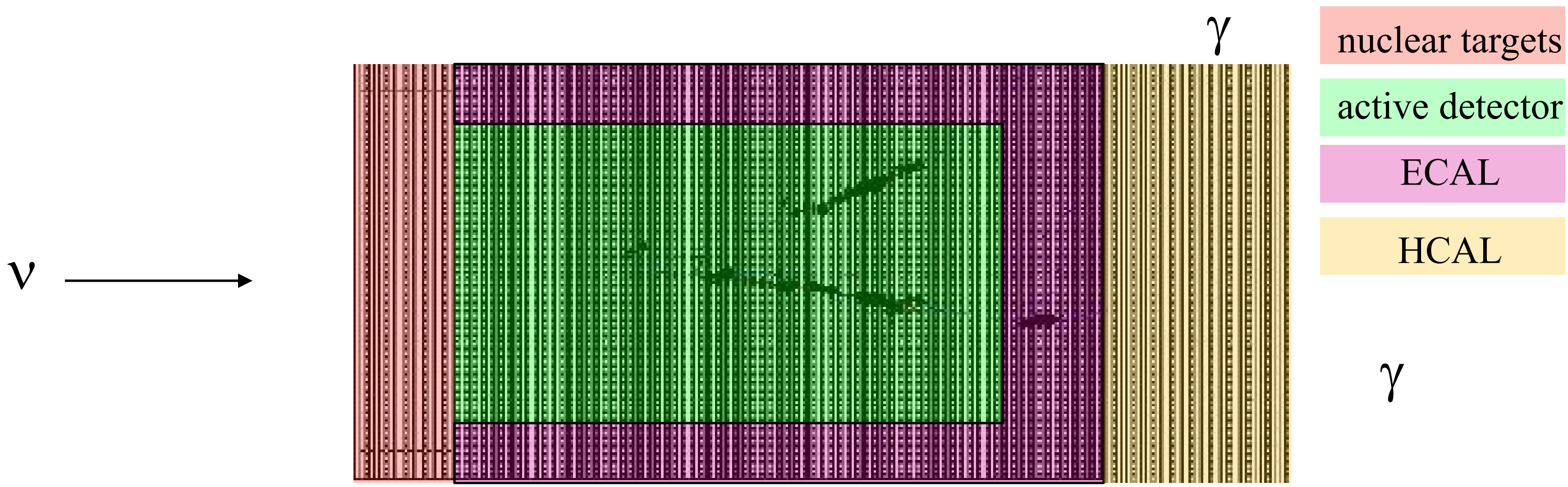
R = .75 m - p: μ =.29 GeV/c, π = .32, K = .62, P = .93

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

- Reminder: proton tracks from quasi-elastic events are typically short. Want sensitivity to $p_p \sim$ 300 - 500 MeV
- "Thickness" of track proportional to dE/dx in figure below
- proton and muon tracks are clearly resolved
- precise determination of vertex and measurement of Q^2 from tracking



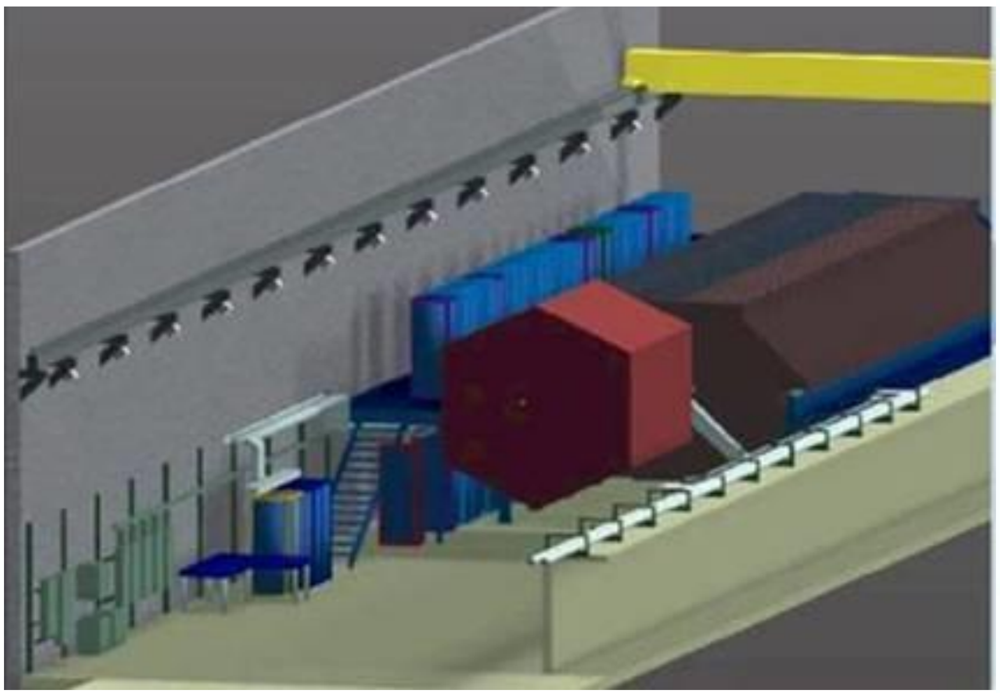
Performance: π^0 Production

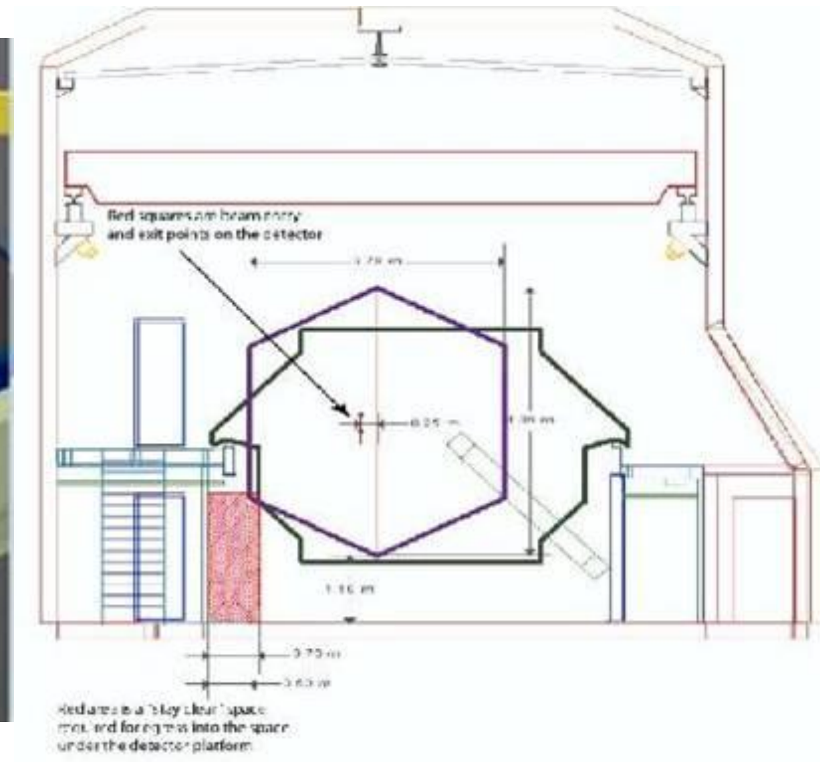


- two photons clearly resolved (tracked). can find vertex.
- some photons shower in ID,
  some in side ECAL (Pb absorber) region
- photon energy resolution is ~6%/sqrt(E) (average)

Location in NuMI Near Hall

- MINERνA preferred running position is as close as possible to MINOS, using MINOS as high energy muon spectrometer





Event Rates

14.5 Million total CC events in a 4 - year run

Assume 16**.0x**10^{20} **in LE and ME NuMI beam configurations in 4 years**

Fiducial Volume = 3 tons CH, 0.2t He, 0.15t C, 0.7t Fe and 0.85t Pb
Expected CC event samples:
9.0 M ν events in 3 tons of CH
0.6 M ν events in He
0.4 M ν events in C
2.0 M ν events in Fe
2.5 M ν events in Pb

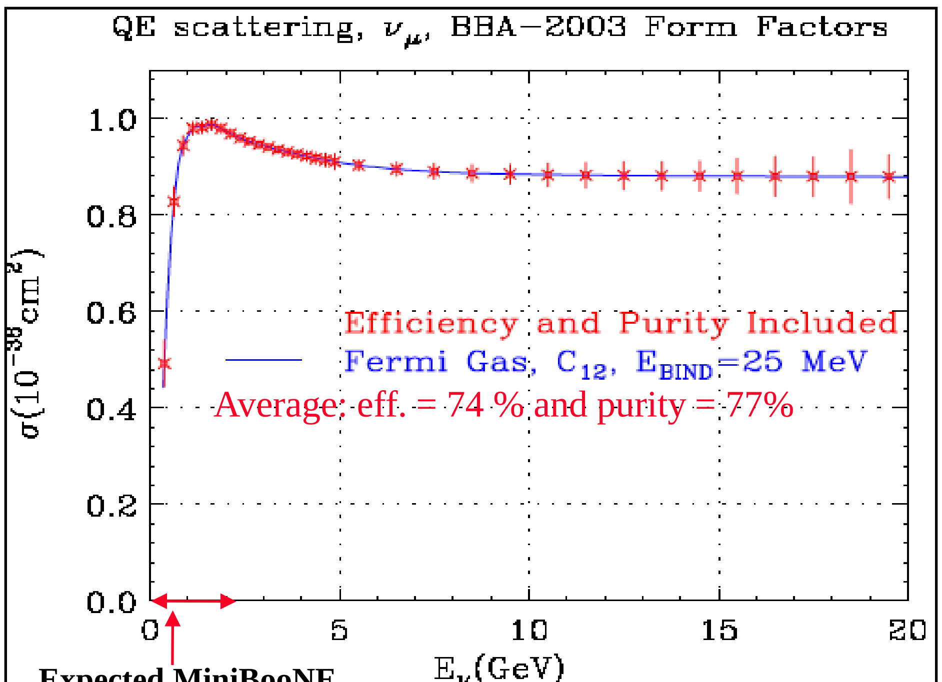
Main CC Physics Topics (Statistics in CH)

Quasi-elastic	**0.8 M events**
Resonance Production	**1.7 M total**
Transition: Resonance to DIS	**2.1 M events**
DIS, Structure Funcs. and high-x PDFs	**4.3 M DIS events**
Coherent Pion Production	**89 K CC / 44 K NC**
Strange and Charm Particle Production	**> 240 K fully reconstructed events**
Generalized Parton Distributions	**order 10 K events**
Nuclear Effects	**He: 0.6 M, C: 0.4 M, Fe: 2.0 M and Pb: 2.5 M**

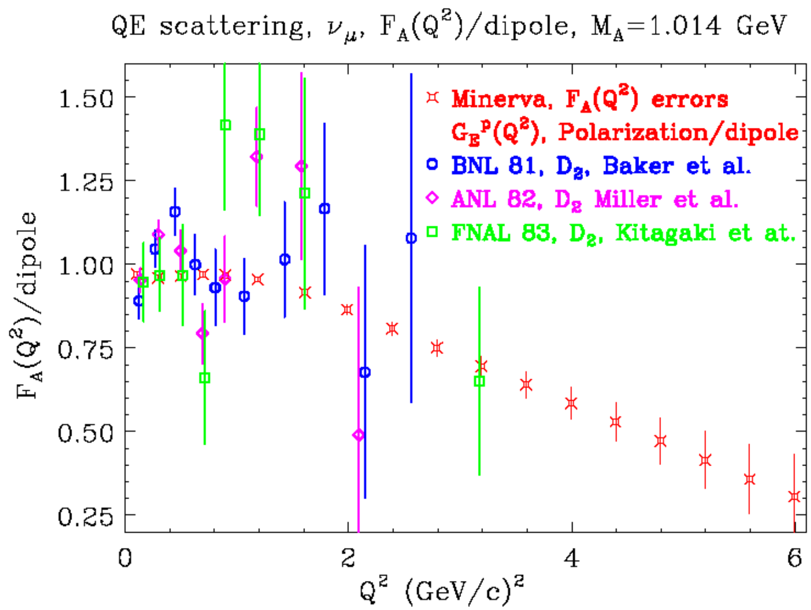
MINERνA CC Quasi-Elastic Measurements

Fully simulated analysis, - realistic detector simulation and reconstruction

- Quasi-elastic ($\nu + n \rightarrow \mu^- + p$, around **800 K events**)
  - Precision measurement of $\sigma(E_\nu)$ and $d\sigma/dQ$ important for neutrino oscillation studies.
  - Precision determination of axial vector form factor (F_A), particularly at high Q^2
  - Study of proton intra-nuclear scattering and their A-dependence (C, Fe and Pb targets)



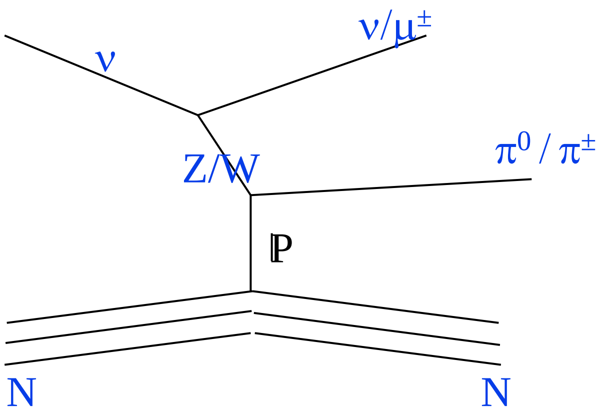
Expected MiniBooNE and K2K measurements

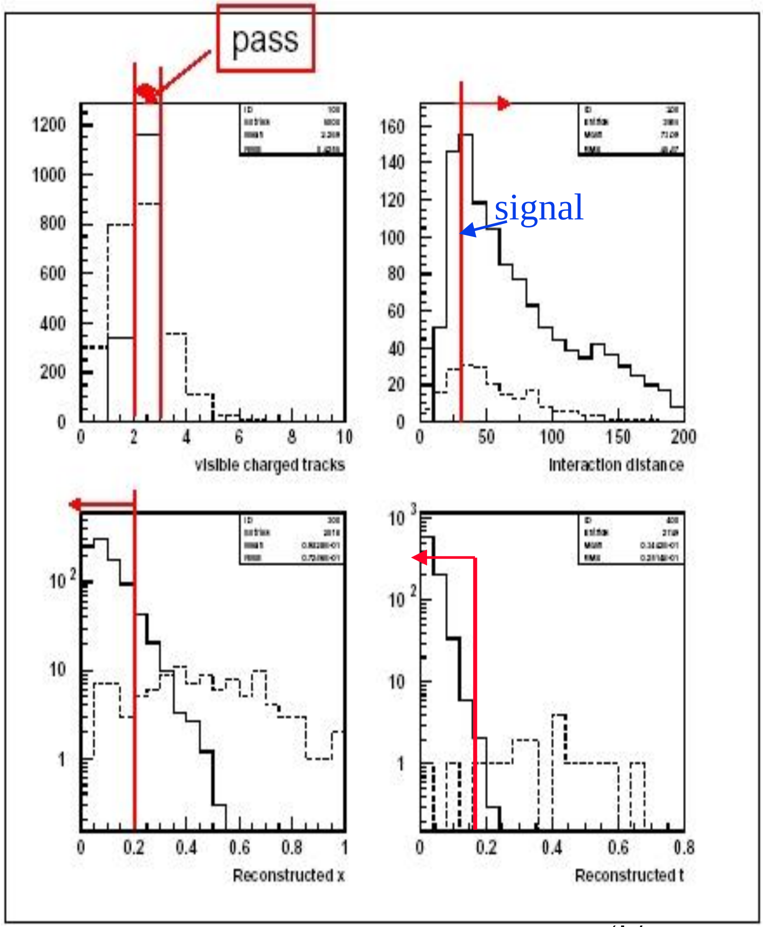


Coherent Pion Production

Fully simulated analysis, - realistic detector simulation and reconstruction

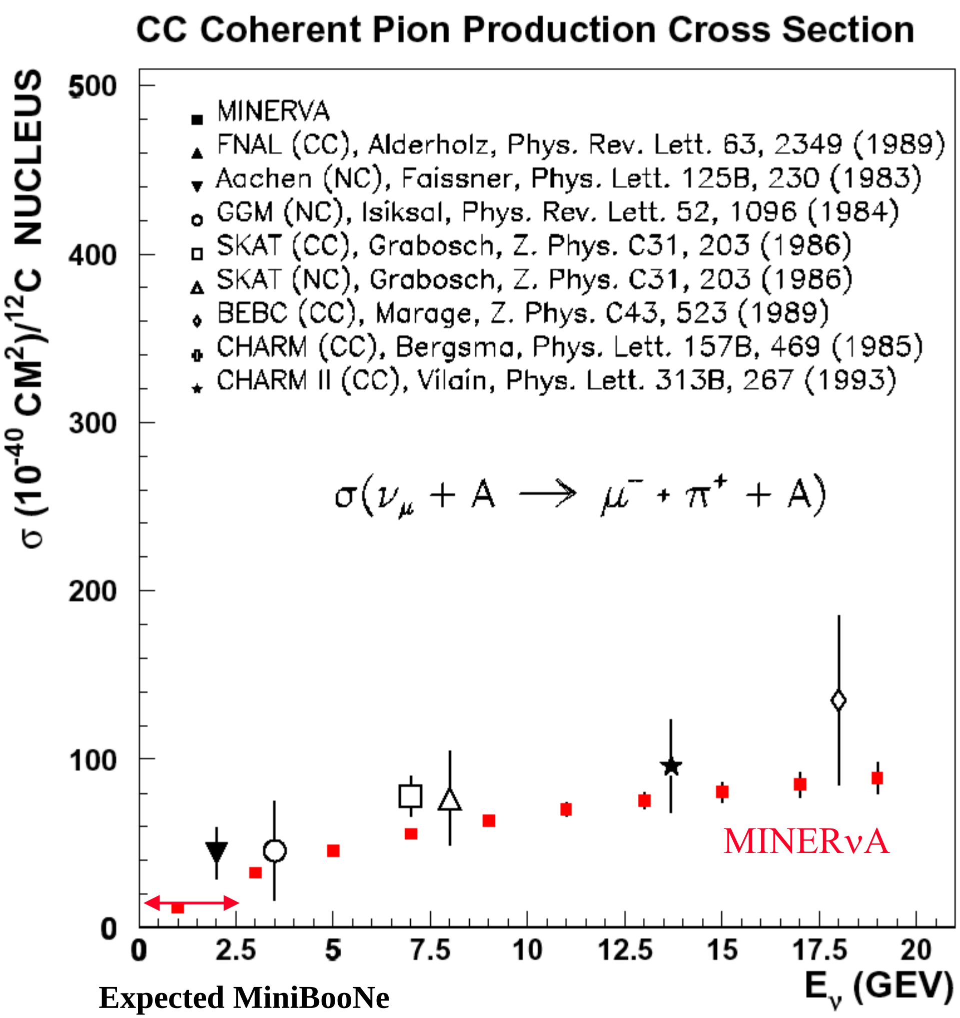
- Coherent Pion Production ($\nu + A \dashrightarrow \nu / \mu^- + A + \pi$, **85 K CC / 37 K NC**)
  - Precision measurement of $\sigma(E)$ for NC and CC channels
  - Measurement of A-dependence
  - Comparison with theoretical models



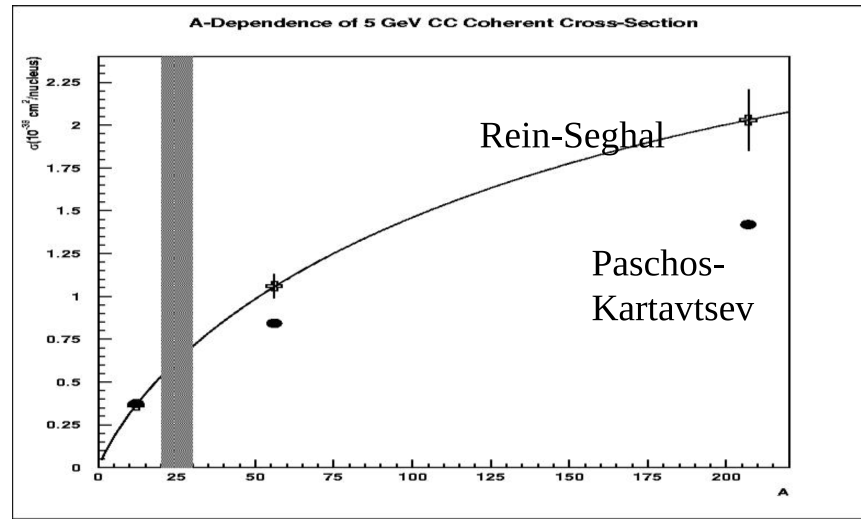


Selection criteria reduce the signal by a factor of three - while reducing the background by a factor of $\approx$ 1000.

Coherent Pion Production



Expected MiniBooNe and K2K measurements



MINERνA's nuclear targets allow the first measurement of the A-dependence of σ_{coh} across a wide A range

Recent K2K SciBar Result

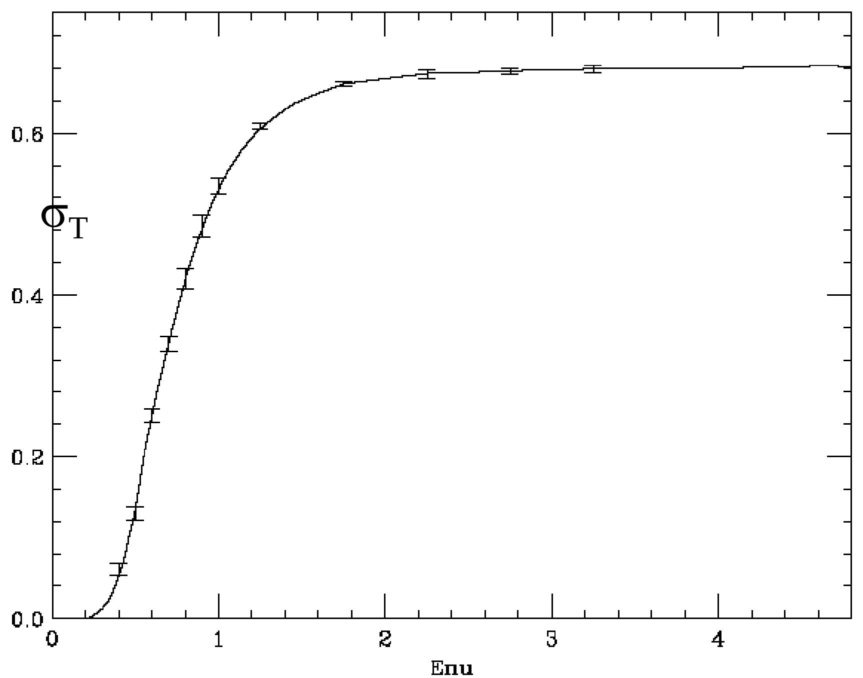
M. Hasegawa et al. - hep - ex/0506008

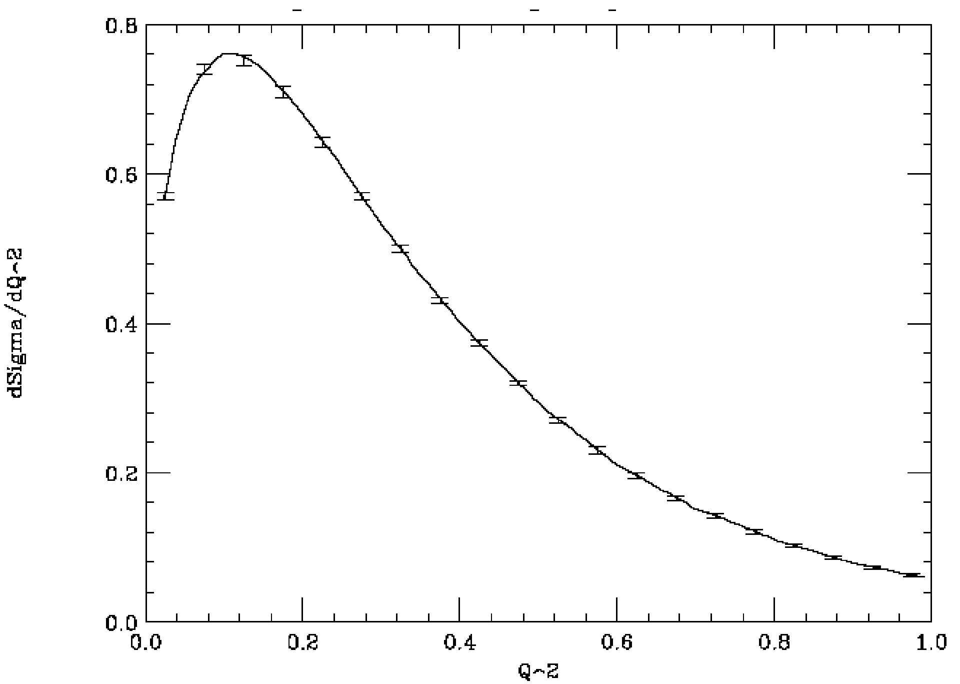
- Expect 470 CC coherent events according to Rein-Sehgal
- Find 7.6 ± 50.4

Resonance Production - Δ

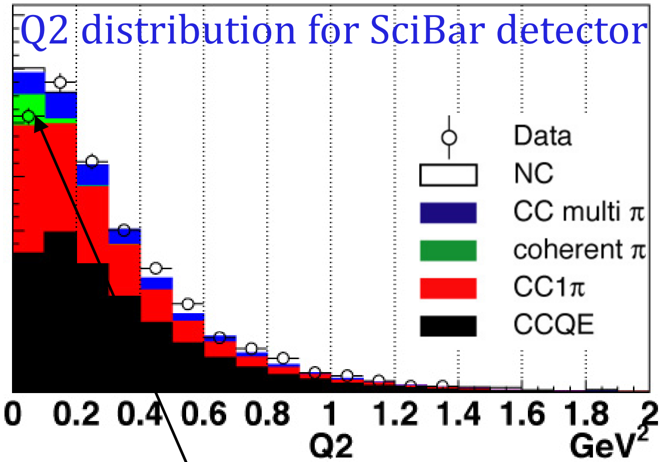
- Resonance Production (e.g. $\nu + N \dashrightarrow \nu / \mu^- + \Delta$, **1600 K total, 1200K 1π**)
  - Precision measurement of σ and dσ/dQ for individual channels
  - Detailed comparison with dynamic models, comparison of electro- & photo production, the resonance-DIS transition region -- duality
  - Study of nuclear effects and their A-dependence e.g. 1 π <–– > 2 π <––> 3 π final states

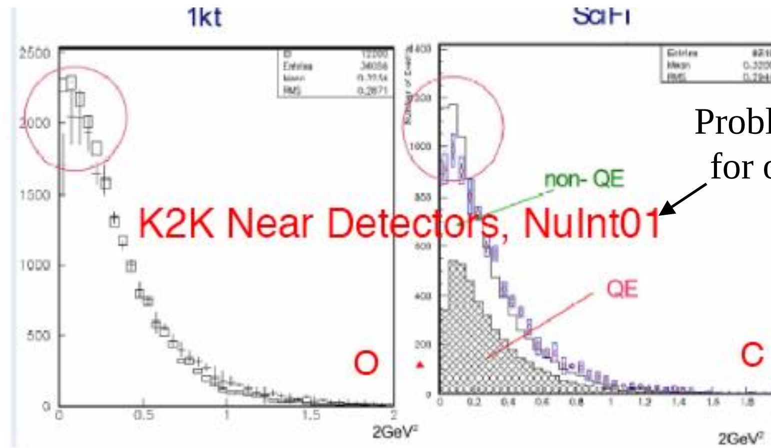
Total Cross-section and $d\sigma/dQ^2$ for the Δ^{++} - **Errors are statistical only**





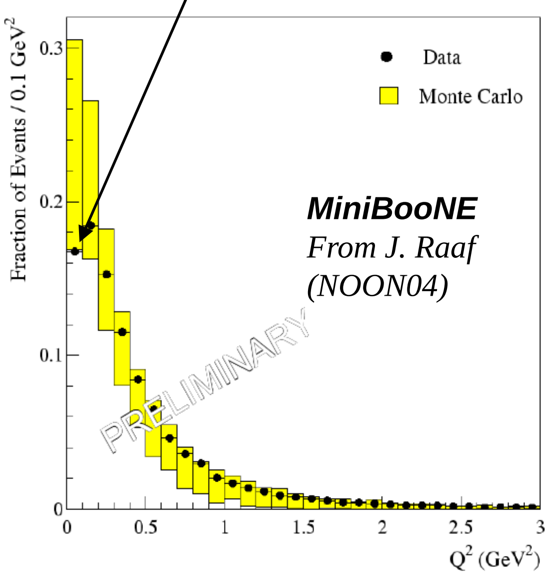
Nuclear Effects





Problem has existed for over four years

Larger than expected rollover at low Q^2



All "known" nuclear effects taken into account:
Pauli suppression, Fermi Motion, Final State Interactions

They have **not included** low-ν shadowing that is only allowed with axial-vector (Boris Kopeliovich at NuInt04)

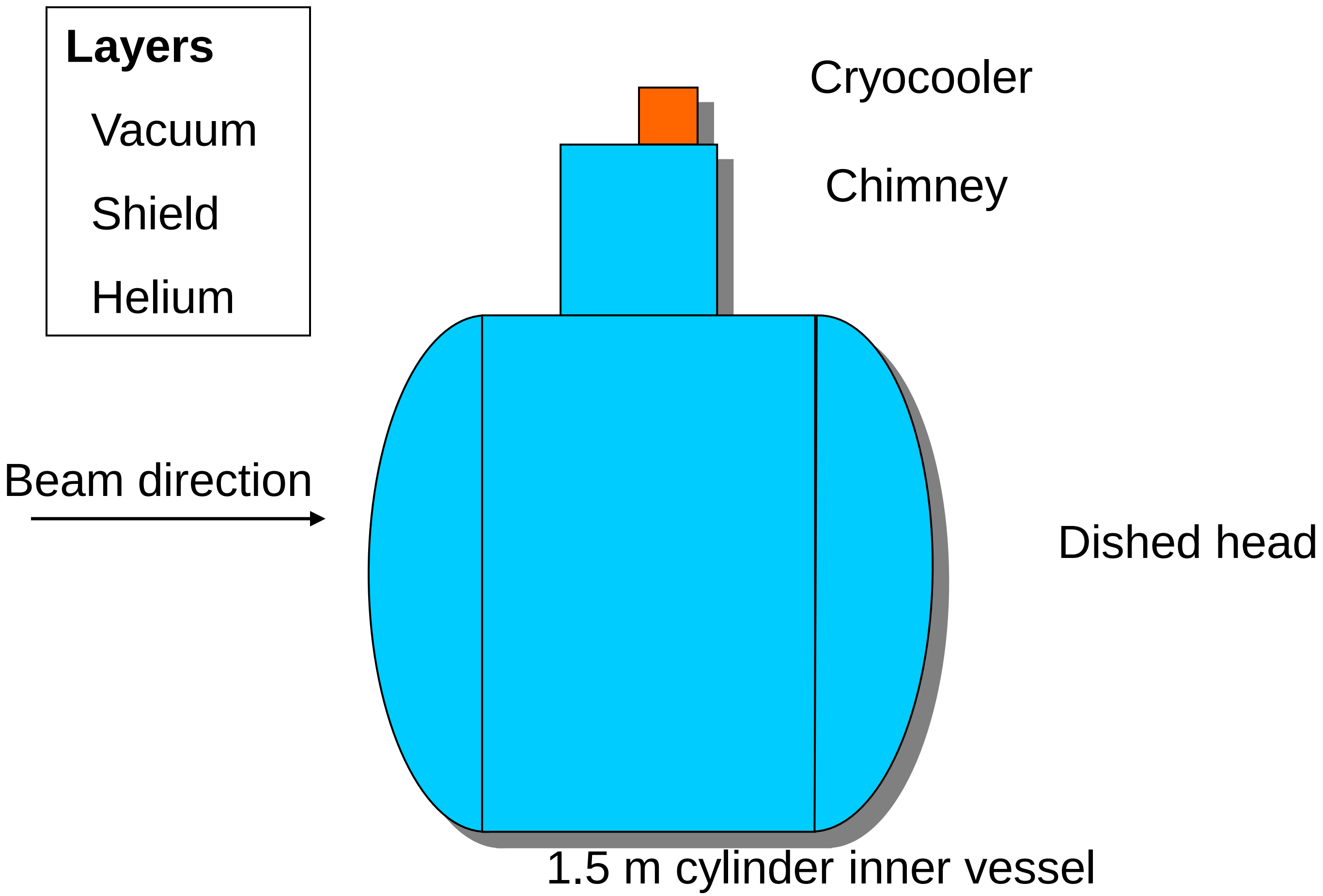
$L_c = 2\nu / (m_\pi^2 + Q^2) \geq R_A$ **(not m_A^2)**

L_c **100 times shorter with** m_π **allowing low ν-low Q^2 shadowing**

ONLY MEASURABLE VIA NEUTRINO - NUCLEUS INTERACTIONS! **MINERνA WILL MEASURE THIS ACROSS A WIDE ν AND Q^2 RANGE WITH C : Fe : Pb**

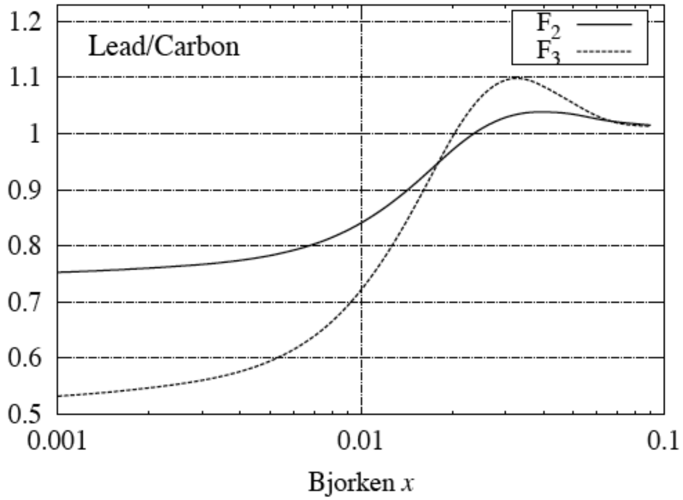
LATEST NEWS: He Target for MINERνA

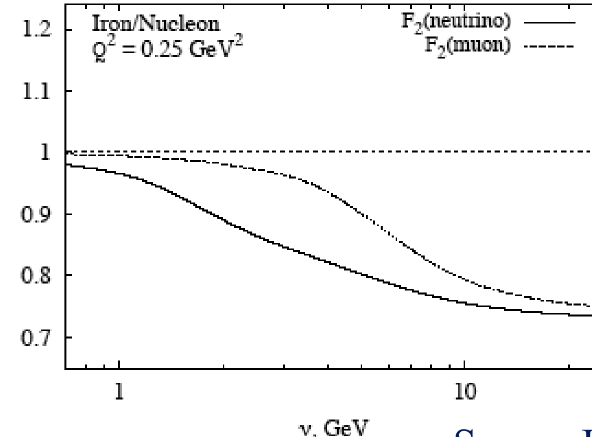
in addition to C, Fe and Pb targets



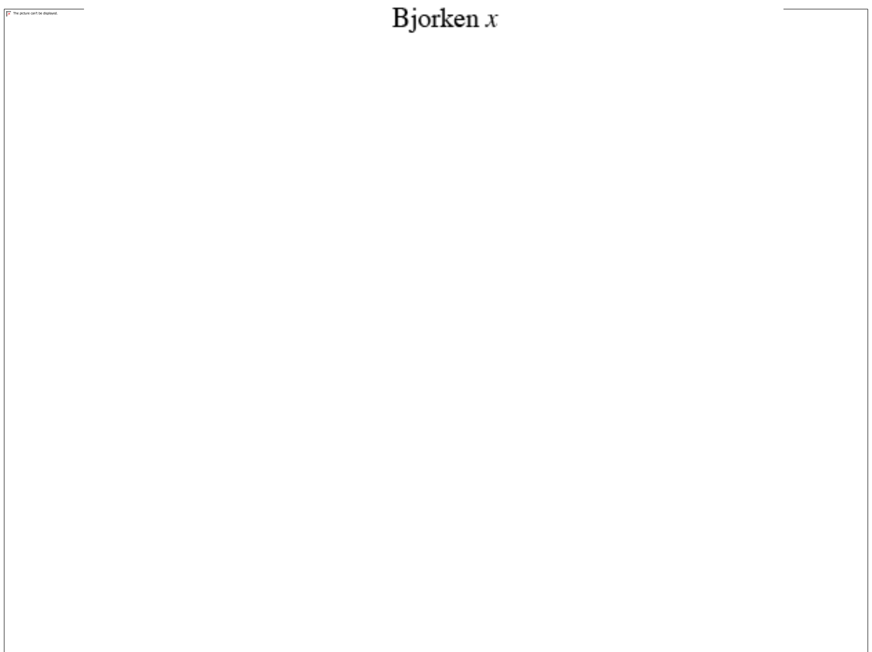
Nuclear Effects

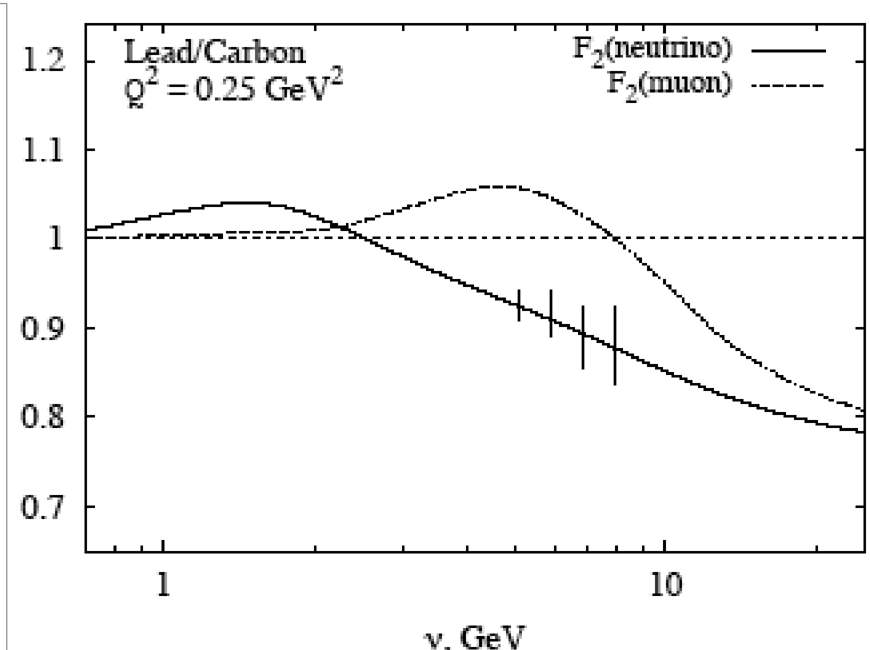
Difference between ν–A and μ–A nuclear effects





Sergey Kulagin





Strange and Charm Particle Production

- Theory: Initial attempts at a predictive phenomenology stalled in the 70's due to lack of constraining data.
- MINERνA will focus on exclusive channel strange particle production - **fully reconstructed events** (small fraction of total events) but still
  .
- **Important for background calculations of nucleon decay experiments**
- With extended $\overline{\nu}$ running could study single hyperon production to greatly extend form factor analyses
- New measurements of charm production near threshold which will improve the determination of the charm-quark effective mass.

Existing Strange Particle Production

Gargamelle-PS - **15** Λ events. FNAL - ≈ 100 events

ZGS -30 events BNL - 8 events

Larger NOMAD **inclusive** sample expected

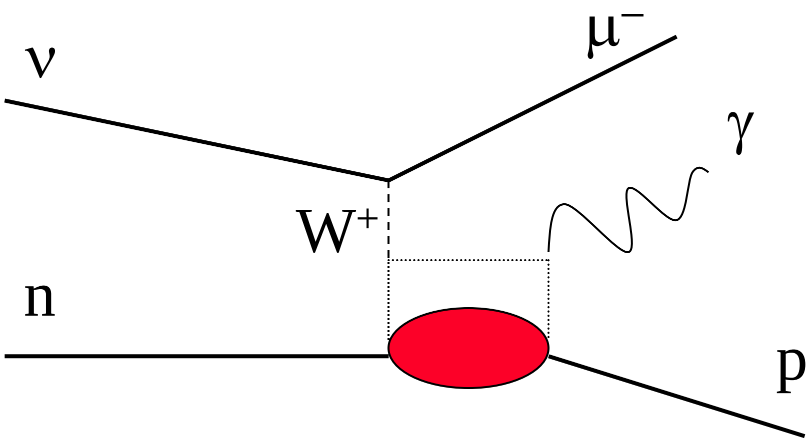
MINERνA Exclusive States

400 x earlier samples

3 tons and 4 years

$\Delta S = 0$	
$\mu^- K^+ \Lambda^0$	42 K
$\mu^- \pi^0 K^+ \Lambda^0$	38 K
$\mu^- \pi^+ K^0 \Lambda^0$	26 K
$\mu^- K^- K^+ p$	20 K
$\mu^- K^0 K^+ \pi^0 p$	6 K
$\Delta S = 1$	
$\mu^- K^+ p$	65 K
$\mu^- K^0 p$	10 K
$\mu^- \pi^+ K^{0n}$	8 K
$\Delta S = 0$ - Neutral Current	
$\nu K^+ \Lambda^0$	14 K
$\nu K^0 \Lambda^0$	4 K
$\nu K^0 \Lambda^0$	12 K

Generalized Parton Distribution Functions
Weak Deeply Virtual Compton Scattering



W> 2 GeV, t small, E_γ large -
Exclusive reaction

- First measurement of GPDs with neutrinos
- Weak DVCS would allow flavor separation of GPDs
- According to calculation by A. Psaker (ODU), MINERνA would accumulate 10,000 weak DVCS events in a 4-year run

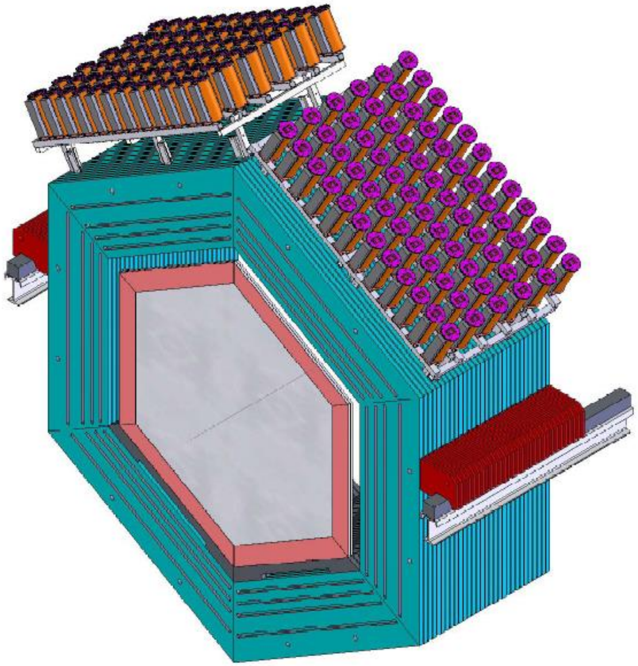
MINERνA Costs

- Costs (in k$) - including contingency, escalation and burdened
- We are revisiting all costs in detail for baselining
- R&D only in FY06-07, Mostly Construction Funds in FY08-10

	FY'06	FY'07	FY'08	FY'09	FY'10	TOTAL
MIE	0	0	5860	3420	390	9700
R&D	2855	4420	340	0	0	7600
Total	**2855**	**4420**	**6200**	**3420**	**390**	**17300**

MINERνA Schedule

- 2006 Continue R&D with Vertical Slice Test
- 2007 Multi-plane Tracking Prototype:
  - Roughly 20% of the full detector
  - Full EM Pb Calorimeter, no hadron Calorimeter
  - Tests to be performed
    - » Scintillator spacing uniformity
    - » Plane uniformity across many planes
    - » Planes stacked as close as physics dictates?
    - » How to replace PMT Boxes /front end boards



- 2007 Test Beam Detector Constructed
- 2008 Test Beam run and TP run
- 2008 Construction Begins
- 2009 Cosmic Ray Data and hopefully some neutrino data

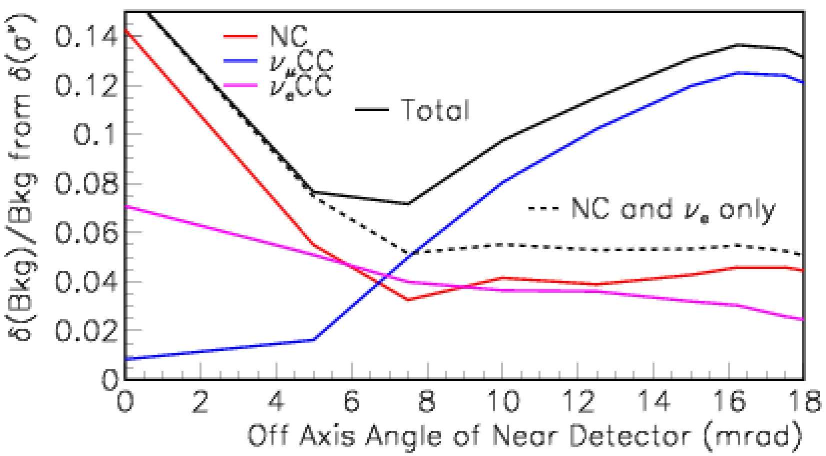
BACKUP SLIDES

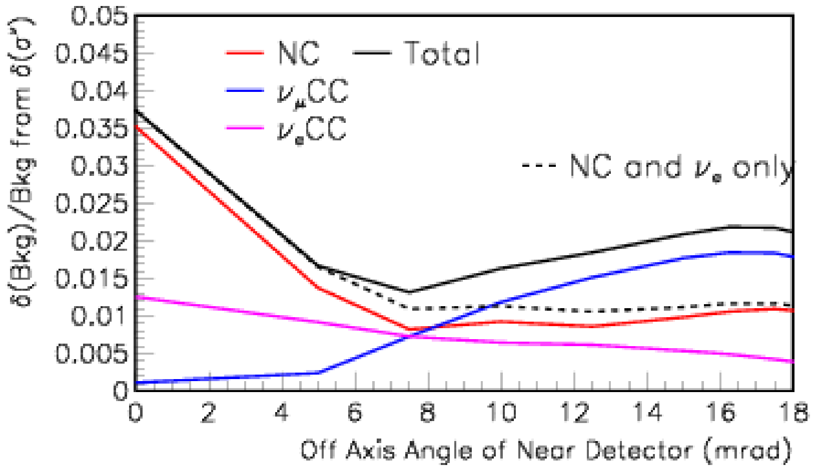
How MINERνA Helps NovA/T2K: Background Predictions

Total fractional error in the background predictions as a function of Near Detector off-axis Angle

Current Accuracy of Cross-sections
ΔQE = 20%
ΔRES = 40%
ΔDIS = 20%
ΔCOH_{Fe} = 100%

With MINERνA Measurements of σ
ΔQE = 5%
ΔRES = 5, 10% (CC, NC)
ΔDIS = 5%
ΔCOH_{Fe} = 20%





With MINERνA measurements of cross sections, decrease fractional error on background prediction by a factor of FOUR

R&D Goals for this summer - Electronics / Vertical Slice Test

Phase 1: Testing the TriP Chip

Test board being designed by P. Rubinov (PPD/EE); piggy back on D0 work

Reads out 16 channels of a MINOS M64 in a spare MINOS PMT box (coming from MINOS CalDet)

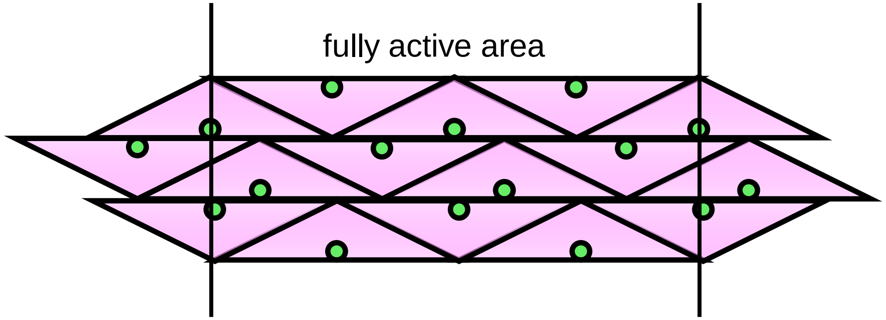
Questions:

1. Noise and signal when integrating over 10 μs.
2. Test self-triggering and external triggering mode for storing charge.
3. Test the dynamic range (2 TriP Channels / PMT channel)
4. Procedure to get timing from the TriP chip.

Early summer

Phase 2: Test our full system

Build a small tracking array in the new muon lab using strips and fibers of the proposed design and the readout system from Phase 1.
Use CR and β sources.



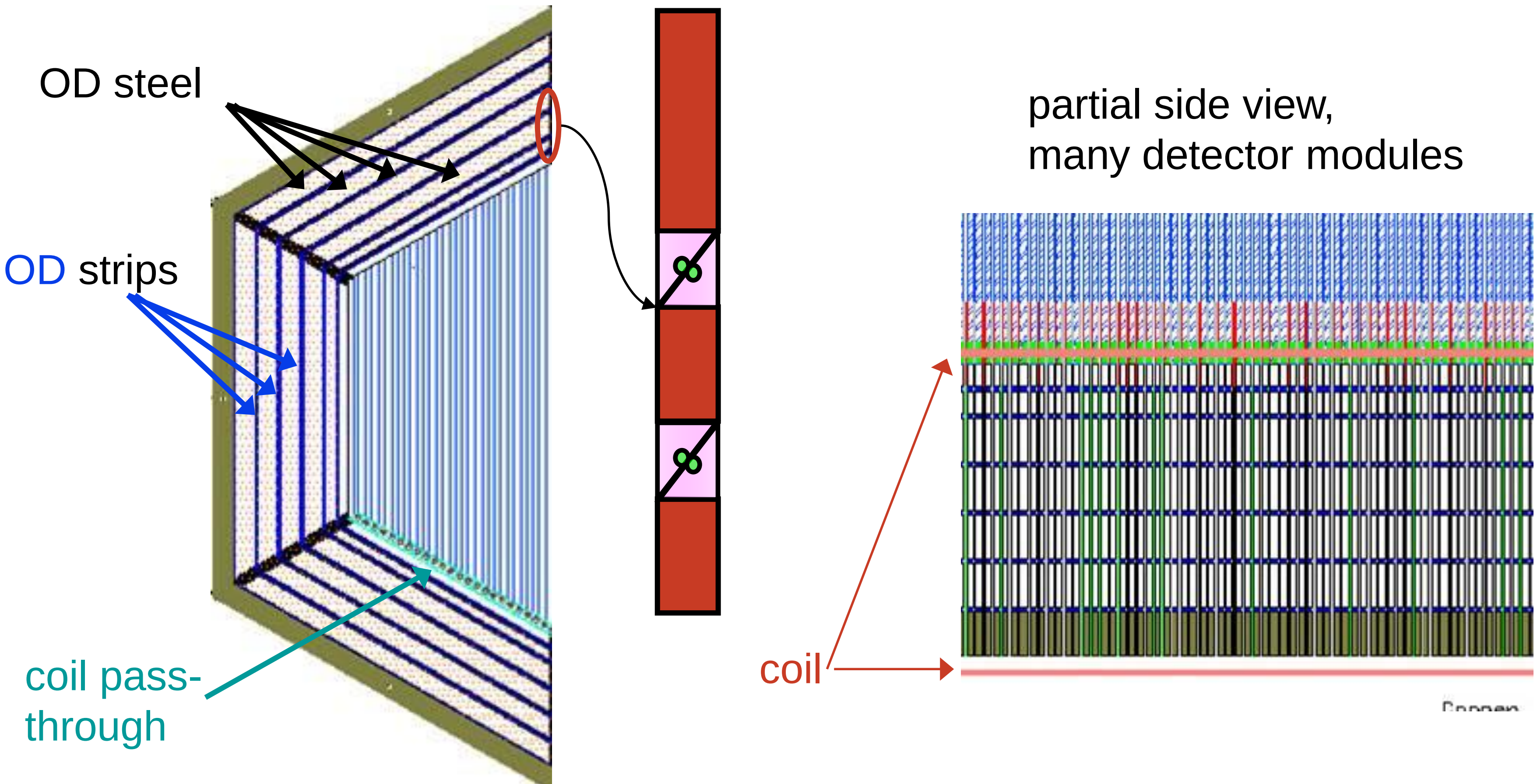
Questions:

1. Light yield – does it match our expectations?
2. Spatial resolution via light sharing in a plane
3. Timing
4. Uniformity

Late summer

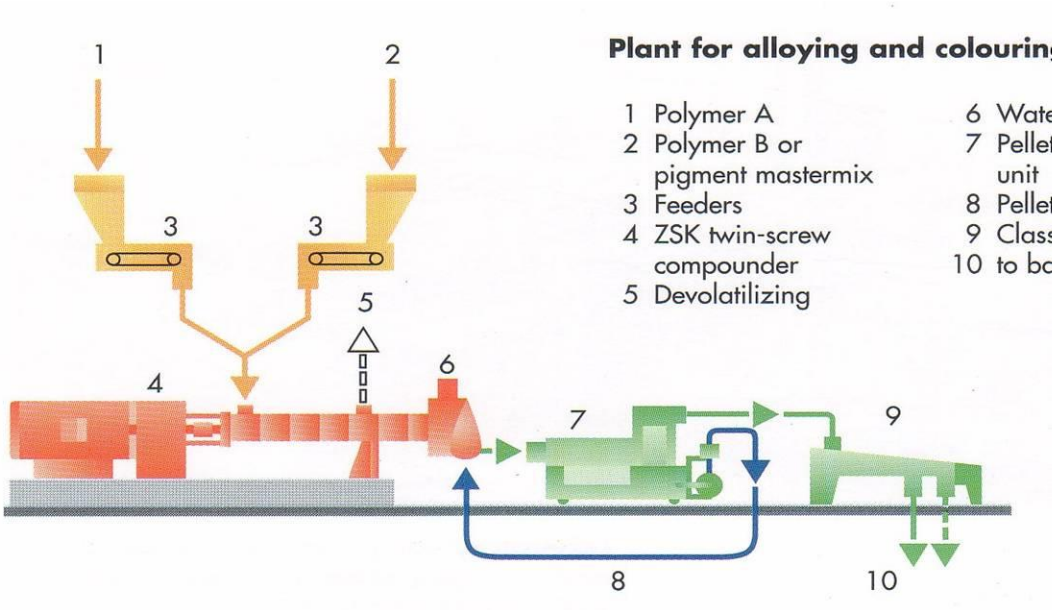
Calorimeters (cont'd)

- OD: 4" and 2" steel between radial sampling layers
  - coil at bottom of the detector provides field in steel



Extruding Scintillator

- Process is inline continuous extrusion
  - improvement over batch processing (MINOS)



- Tremendous capacity at Lab 5
  - the 18 tons of MINERνA in < 2 months, including startup and shutdown time

Extruding Scintillator (cont’d)

- Design of the die in order to achieve the desired scintillator profile
  - collaboration with NIU Mech. E. department (Kostic and Kim)

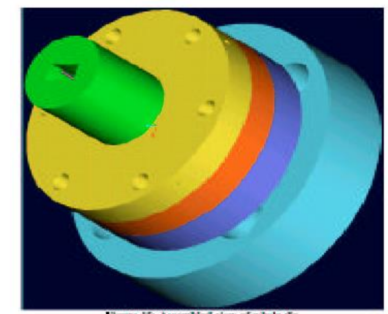
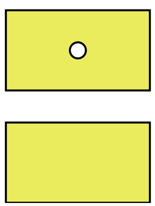
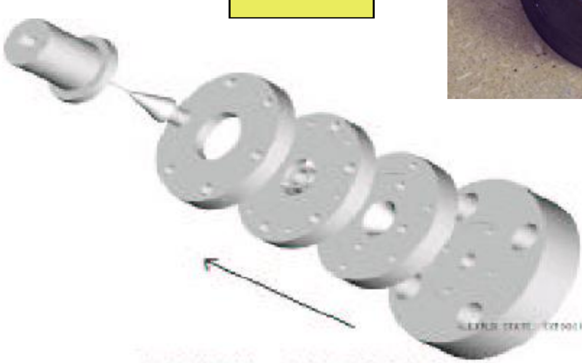


Figure 15: Assembled view of whole die

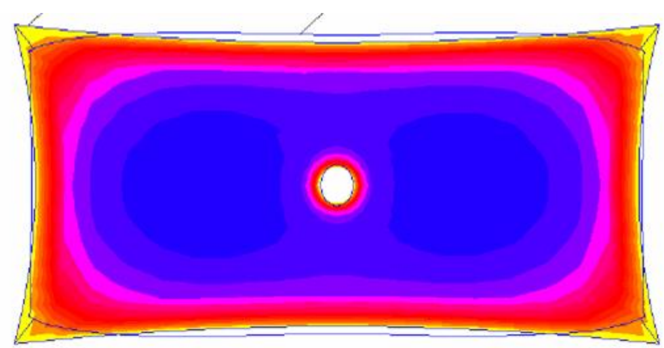
simulation of performance (design tool)





e 16: Exploded view of whole die (Full shade model)

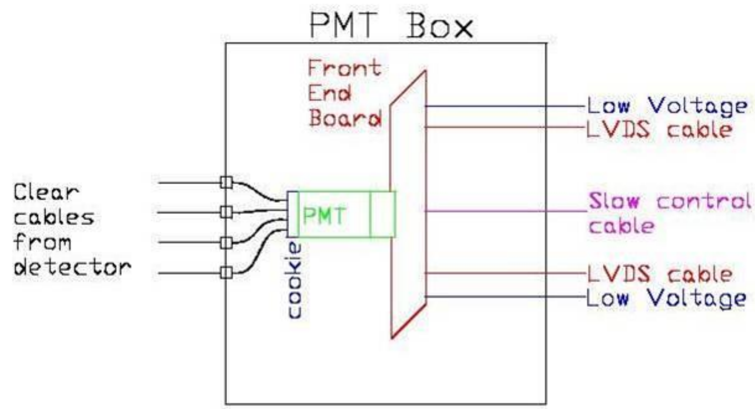
2x1cm rect. die developed at NIU for Lab 5

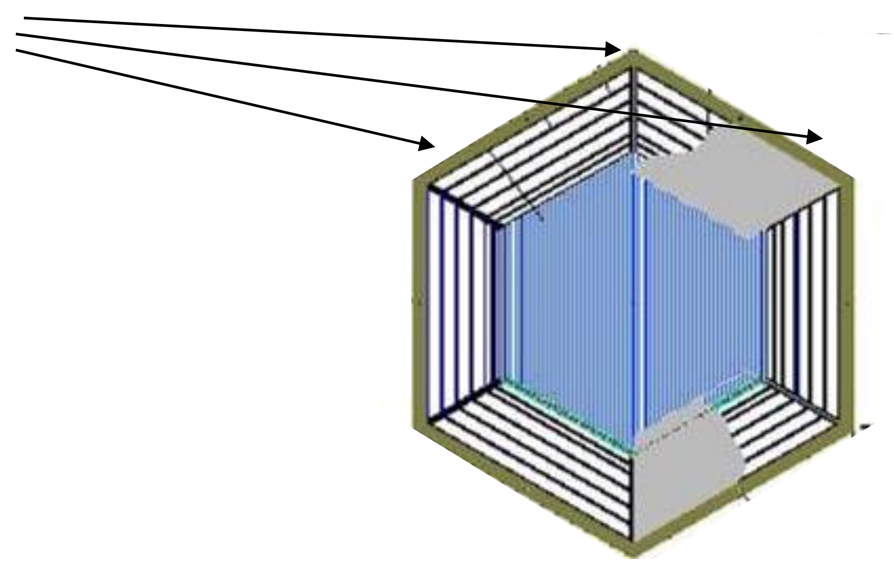


Die cross section and Extrudate Profile

PMT Boxes

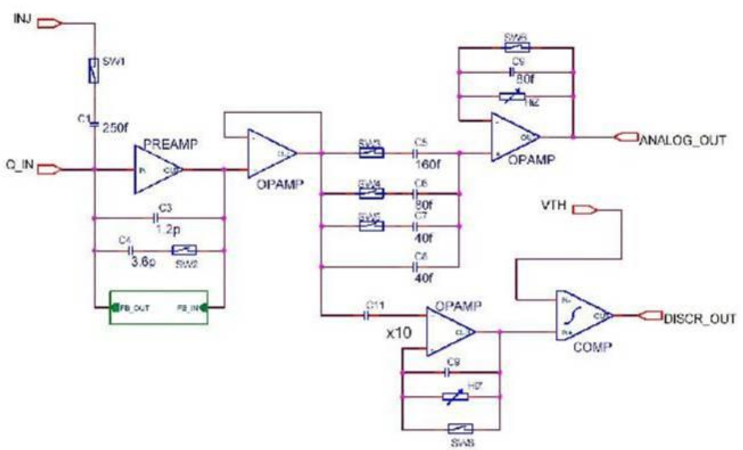
- Design is similar to MINOS MUX boxes
  - but no MUX!
- Mount on detector
  - minimizes clear fiber length

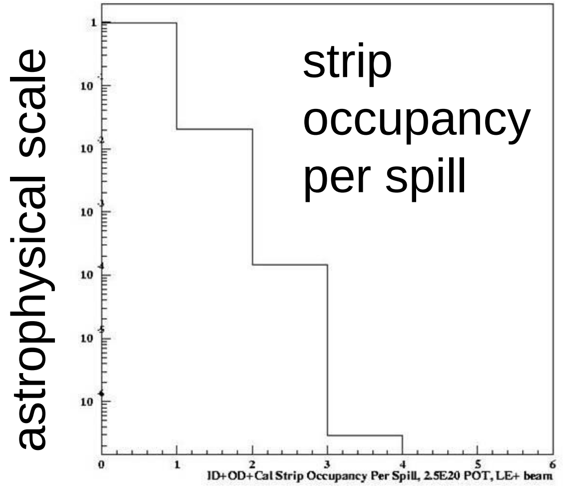




Front-End Electronics

- FE Readout Based on existing TriP ASIC
  - builds on FNAL work. existing submission “free”.
  - ADC (dual range) plus few ns resolution timing
- TriP ASIC provides sample and hold slices

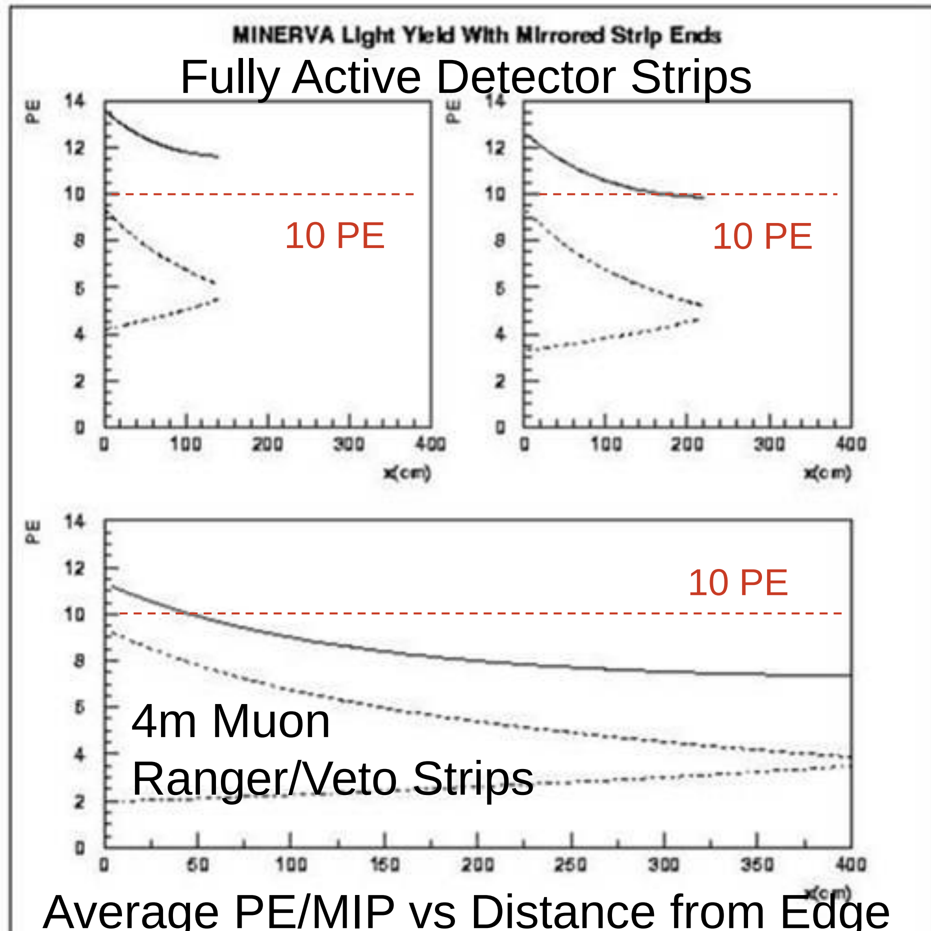




  - four-sample mode works on bench; this is our default
  - each time over threshold also recorded in spill

Light Yield

- **Critical question:** does light yield allow for low quantum efficiency photosensor?
- Study: use MINOS light MC, *normalized to MINOS results*, MINERνA strips
- Need roughly 5-7 PEs for reconstruction
- Must mirror fibers!



Fiber Processing

- Mirrors are clearly necessary
  - Lab 7 vacuum deposition facility (E. Hahn)
- Fibers (WLS, clear) bundled in connectors
  - working with DDK to develop an analog to MCP-10x series used in CDF plug upgrade
  - polishing also most effectively done at FNAL

- MRI proposal included costs for contracting FNAL effort through Universities