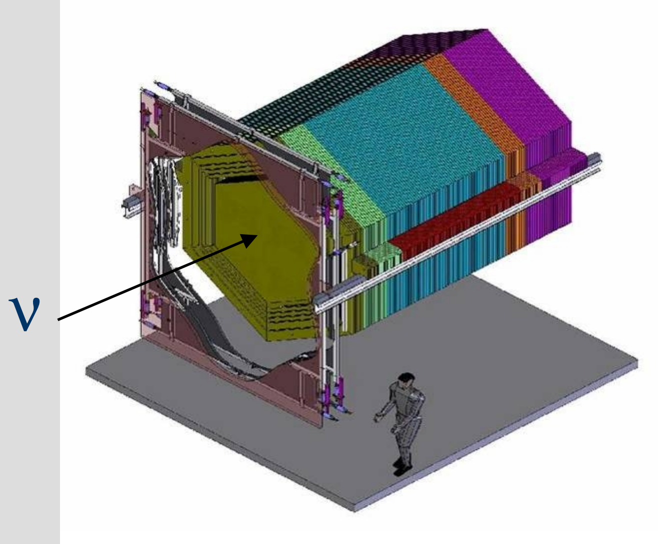
SOS Detector Tests for the MINERνA Experiment at FNAL



Eric Christy

Hampton University

HallC Collaboration Meeting – January 18, 2008

What is MINERνA and what do we hope to learn from it?

- MINERνA is a compact, fully active neutrino detector designed to study neutrino-nucleus interactions utilizing the NuMI neutrino beam at Fermilab

- Some of the physics that MINERνA will address are:

  1) quark/gluon structure of protons/neutrons via weak interaction scattering.

  2) nuclear dependence of structure functions, eg. EMC in neutrino scattering

  3) Axial form factor Q^2 dependence (an nuclear dependence)

  4) crucial input for neutrino flavor oscillation experiments
  => neutrino mass differences and mixing probabilities

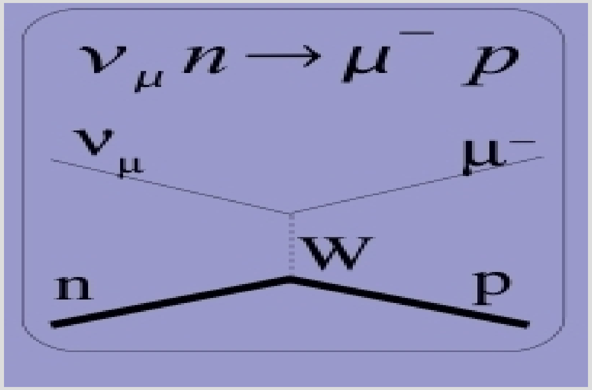
  5) quark-hadron duality studies in neutrino interactions

- MINERvA is unique in the worldwide program
  - The NuMI beam intensity will allow for the study of precision neutrino interaction measurements over a wide range of incident neutrino energies
  - The detector, with several nuclear targets, allows a first study of nuclear effects in neutrino interactions

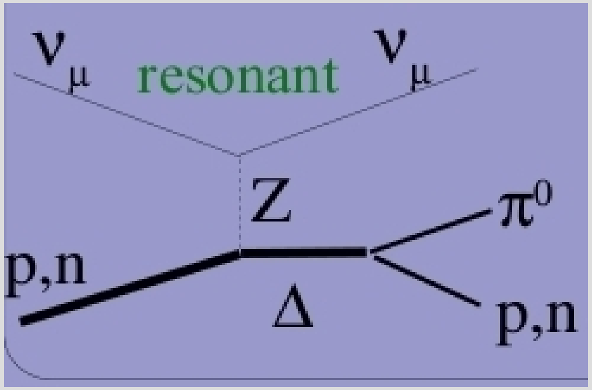
Neutrino – nucleon Scattering

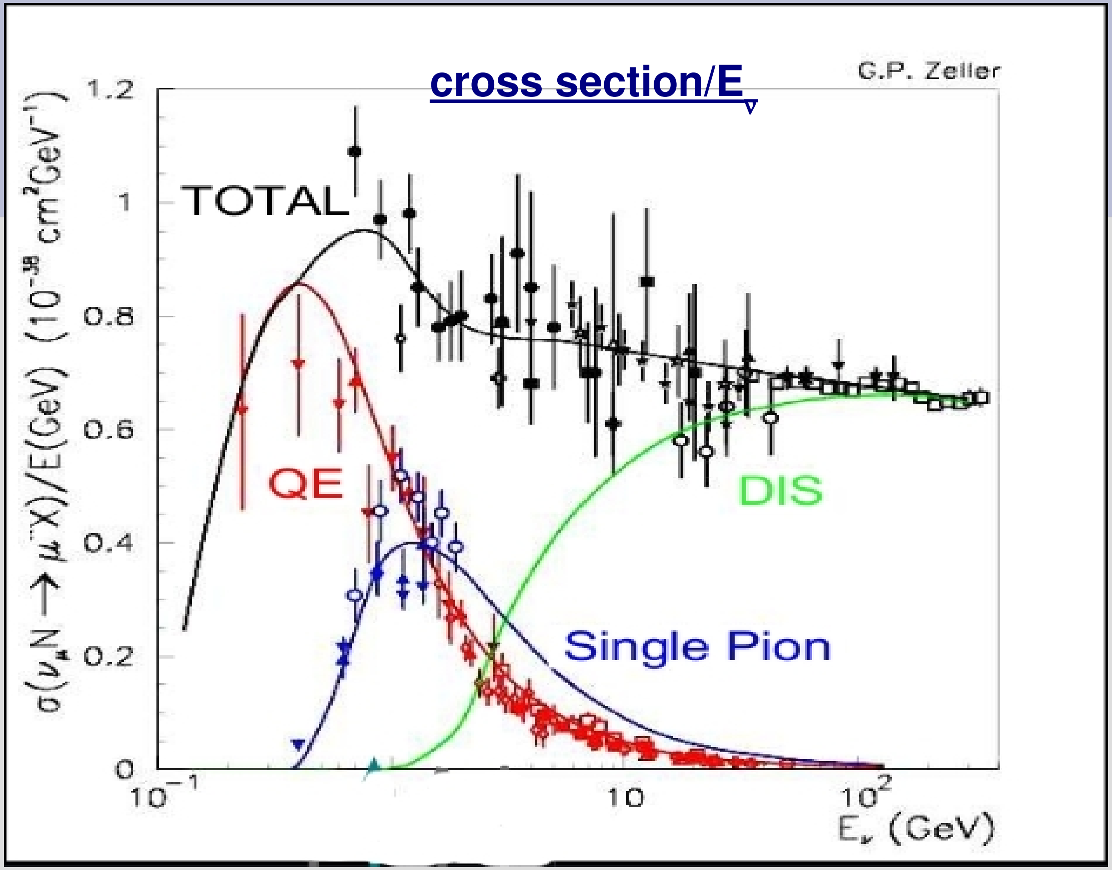
Exchange W or Z couples to *weak* charge.

Quasi-elastic



Resonance production





Current World data has large uncertainties

MINERvA will plans to reduce uncertainties to:

~5% for QE *and* ***5-10% for DIS***

Neutrino DIS SFs

$$F_2^{eN} = 5/18x\,(\,u + \bar{u} + d + \bar{d} + 2/5s + 2/5\,\bar{s}\,)$$

$$F_2^{\nu N} = x\,(\,u + \bar{u} + d + \bar{d} + s + \bar{s}\,)$$

Same PDFs!

For Proton

$$F_2^{\nu p} = 2x\,(\,\bar{u} + d + s\,)$$

$$F_2^{\bar{\nu} p} = 2x\,(\,u + \bar{d} + \bar{s}\,)$$

For x -> 1

$$F_2^{\bar{\nu} p} / F_2^{\nu p} \rightarrow u/d$$

$$xF_3^{\nu p} = 2x\,(\,d - \bar{u} + s\,)$$

$$xF_3^{\bar{\nu} p} = 2x\,(\,u - \bar{d} - \bar{s}\,)$$

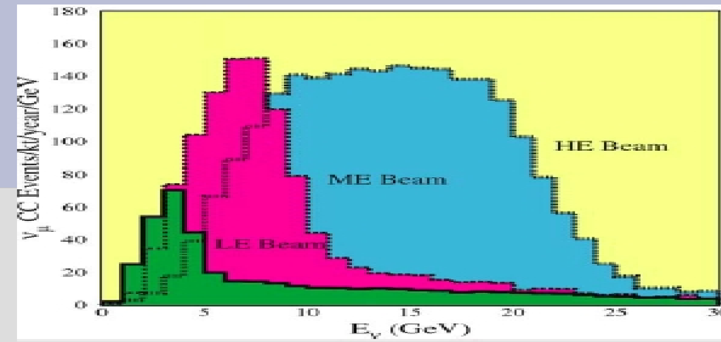
$$F_2^{\nu p} - xF_3^{\nu p} = 4x\,\bar{u}$$

$$F_2^{\bar{\nu} p} - xF_3^{\bar{\nu} p} = 4x\,u$$

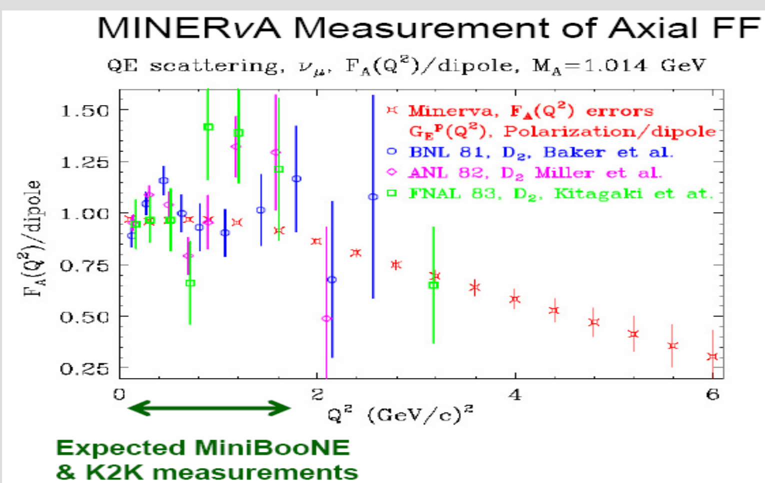
Sensitivity for **flavor** *and* **valence/sea** separations

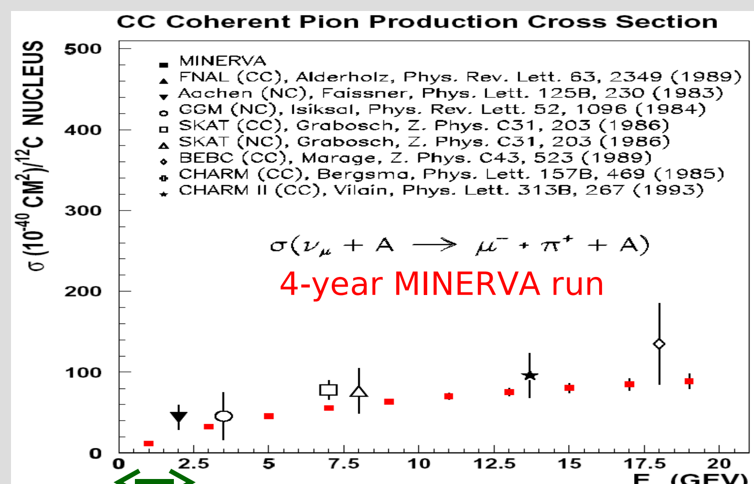
Statistics for Charge Current Physics

(for 1 year each of Low and Medium Energy running)



- **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**





Various groups working on models for $\nu -$ N scattering such as:

E. Paschos, O. Lalukulich

Models of weak vector and axial vector Resonance TFFs based on isospin symmetry, PCAC, and data on e-N TFFs and cross sections.

M. Sakuda, E. Paschos

Models of single π production resonance cross sections.

A. Bodek, U. Yang

Model of e-N and ν-N SFs in DIS (and resonance region using duality).

S. Kulagin, Petti

Nuclear modifications to ν-A DIS SFs.

O. Lalukulich, E. Paschos W. Melnitchuck

Phenomenological Models of duality in F_1, F_2, and F_3.

Neutrino oscillations from disappearance measurements

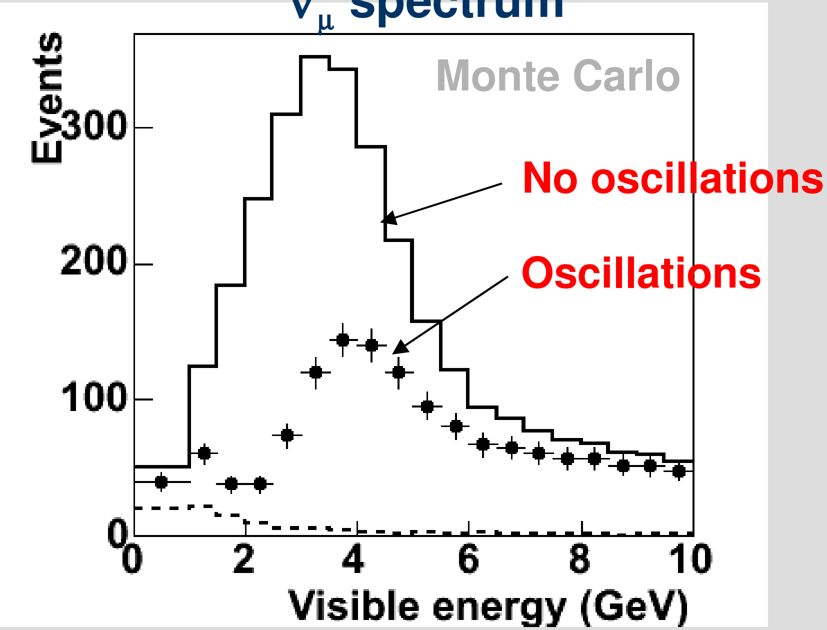
$$P(\nu_\mu \rightarrow \nu_\mu) = 1 - \boxed{\sin^2 2\theta} \sin^2(1.267 \boxed{\Delta m^2} L/E)$$

1 2

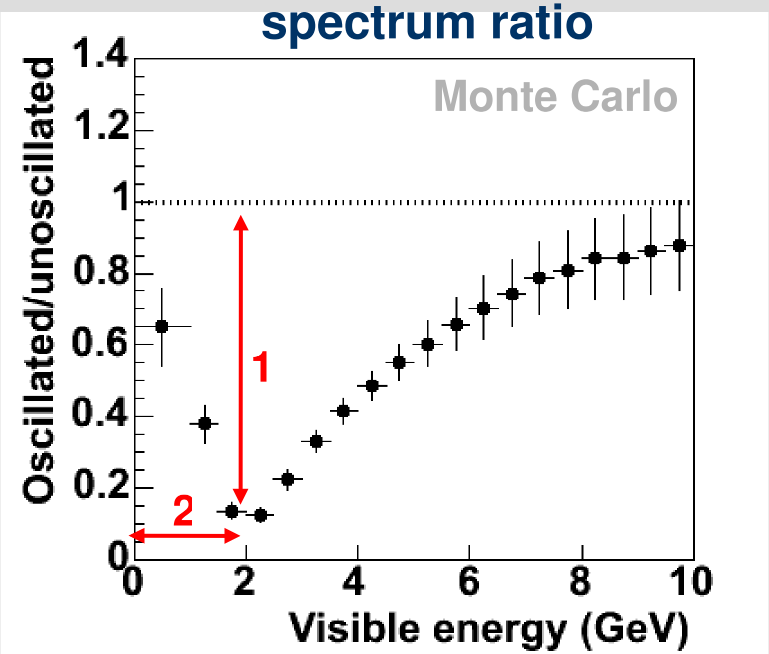
$$\sin^2 2\theta = 4U_{\mu 3}^2 (1 - U_{\mu 3}^2)$$

$$\Delta m_{23}^2 >> \Delta m_{12}^2$$

ν_μ spectrum



spectrum ratio



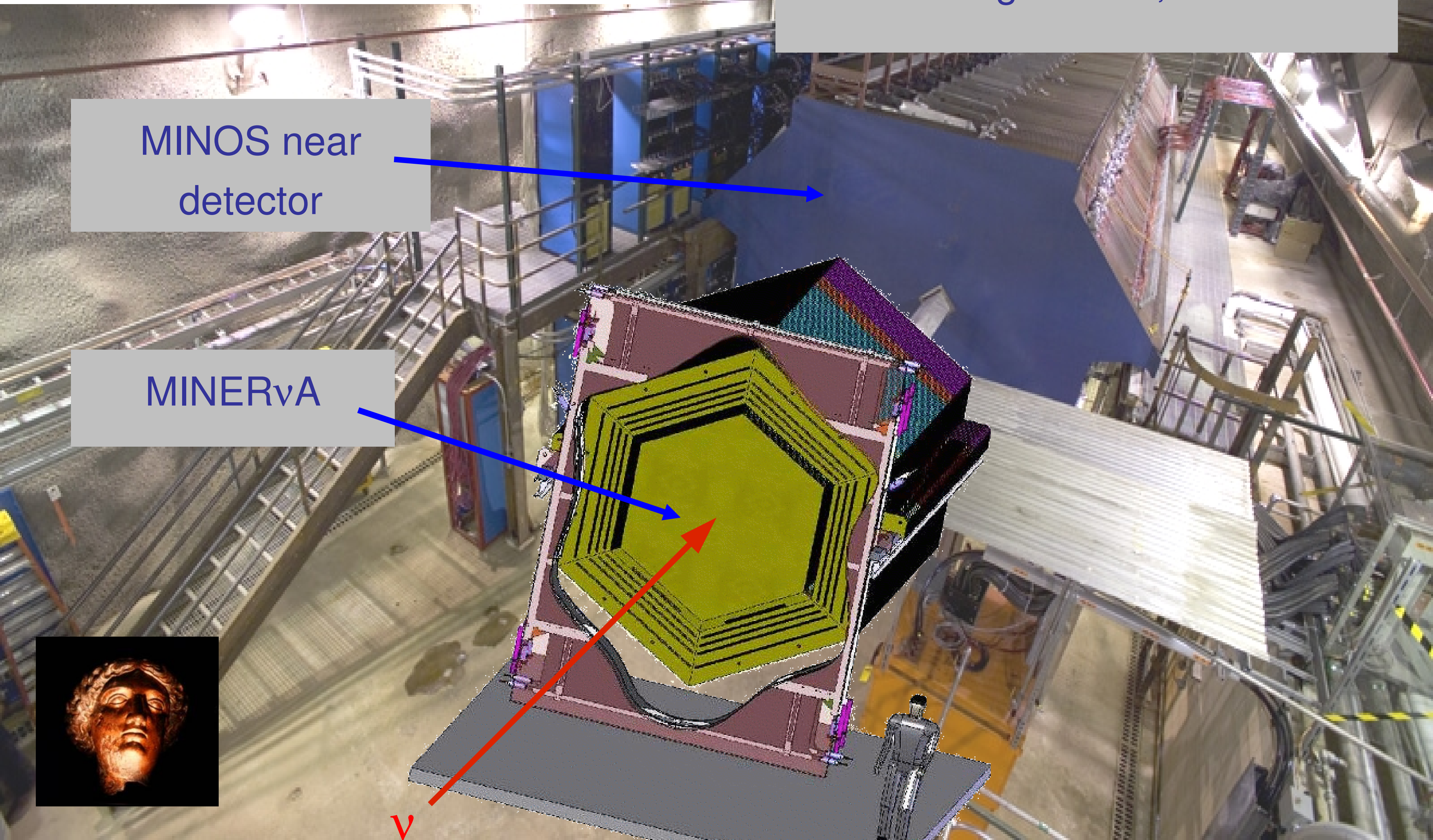
The simulation (Monte Carlo) depends on the physics that MINERνA will measure!

MINERνA

Main INjector ExpeRiment for ν-A

Active segmented scintillator detector: 5.87 tons

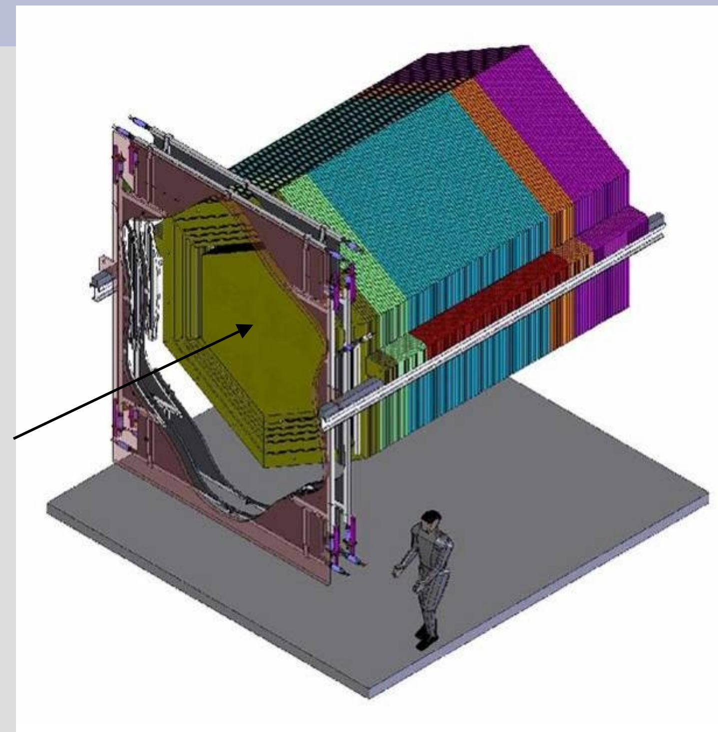
Nuclear targets of C, Fe and Pb

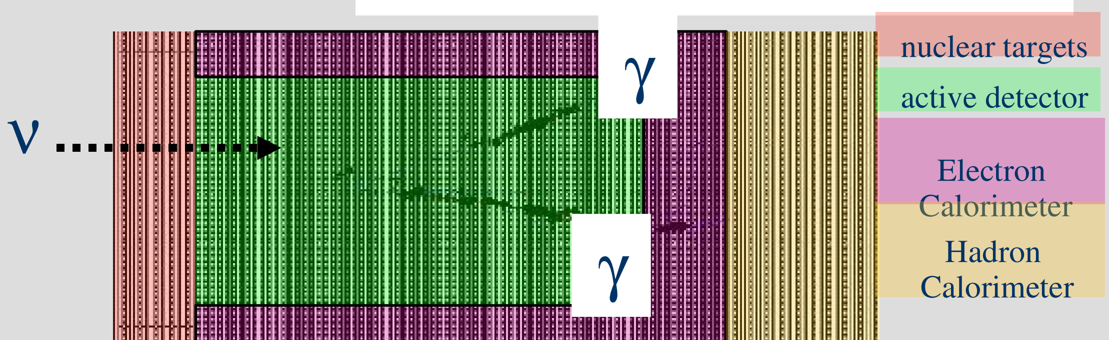


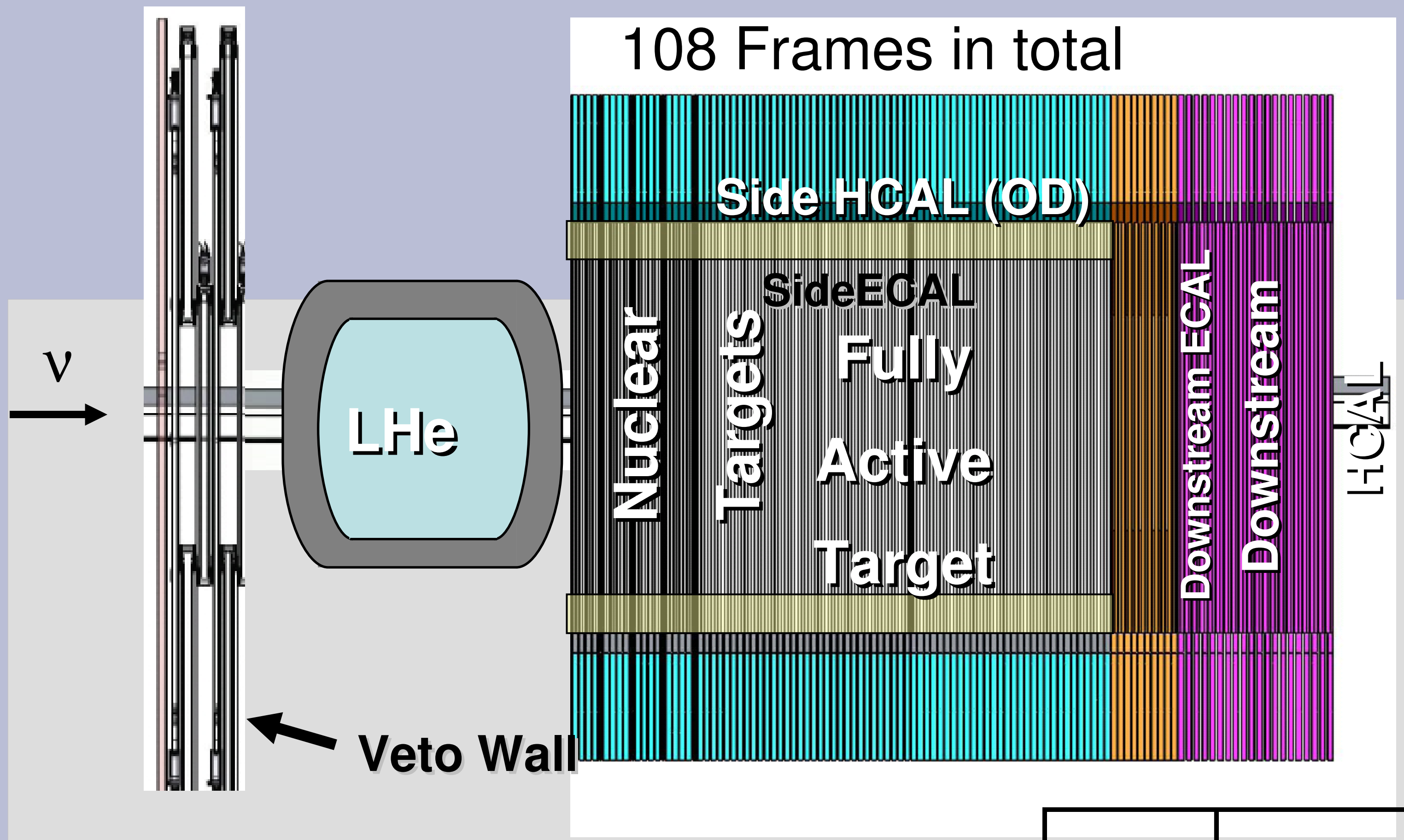
MINERvA's Detector

- Active core is segmented solid scintillator
  - Tracking (including low momentum recoil protons)
  - Particle identification
  - 3 ns (RMS) per hit timing (track direction, identify stopped *K*±)
  - Passive nuclear targets interspersed
- Core surrounded by electromagnetic and hadronic calorimeters
  - Photon (π^0) & hadron energy measurement
- MINOS Near Detector as muon catcher

ν







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

Fully Active

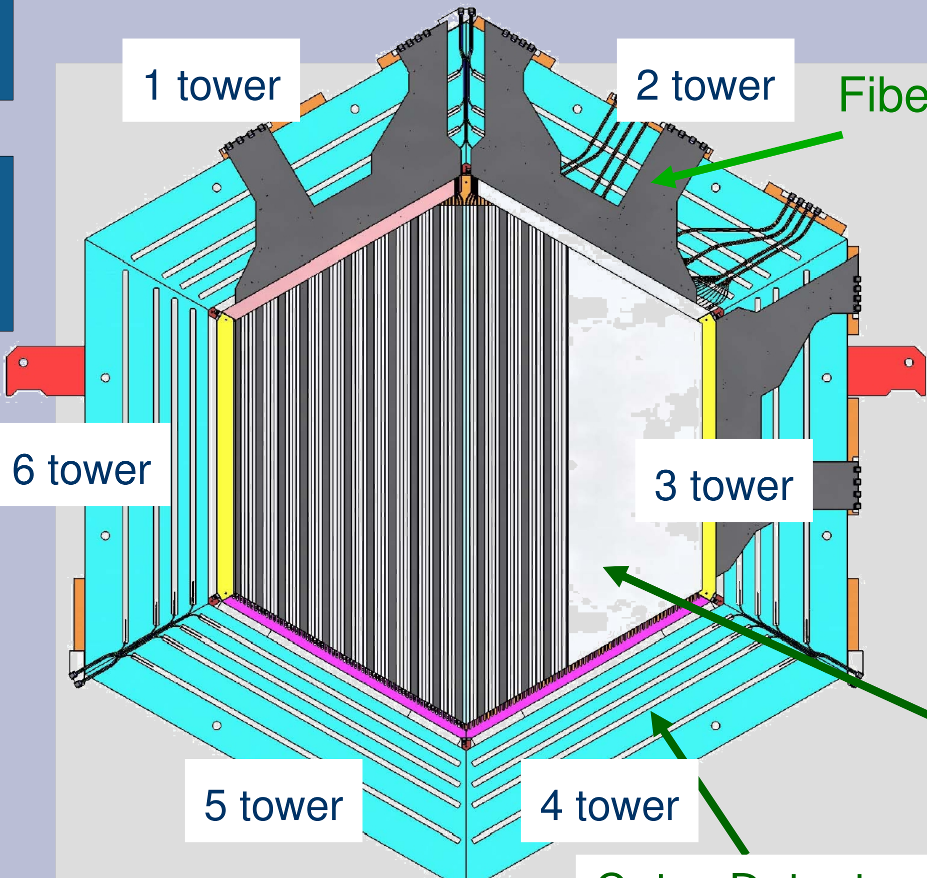
Target: 8.3 tons

Nuclear Targets:

6.2 tons (40% scint.)

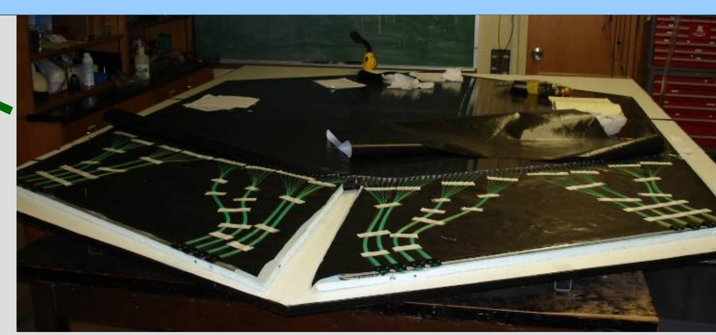
MINERvA Detector Module

Inner Detector Sextagon – X, U, V planes for stereo view



- **30,272 channels**
  - 80% in inner hexagon
  - 20% in Outer detector
- **473 M-64 PMTs** (64 channels)

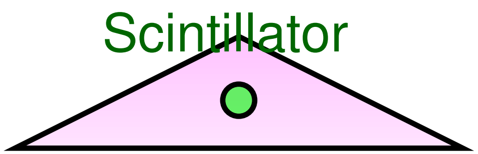
- **1 wave length shifting fiber per scintillator**, which transitions to a clear fiber and then to the PMT
- **128 pieces of scintillator per Inner Detector plane**
- **8 pieces of scintillator per Outer Detector tower, 6 OD detector towers per plane**



Outer Detector (OD) Layers of iron/scintillator for hadron calorimetry: 6 Towers / module

MINERvA Optics

(Inner detector scintillator and optics shown, Outer Detector has similar optics but rectangular scintillator)

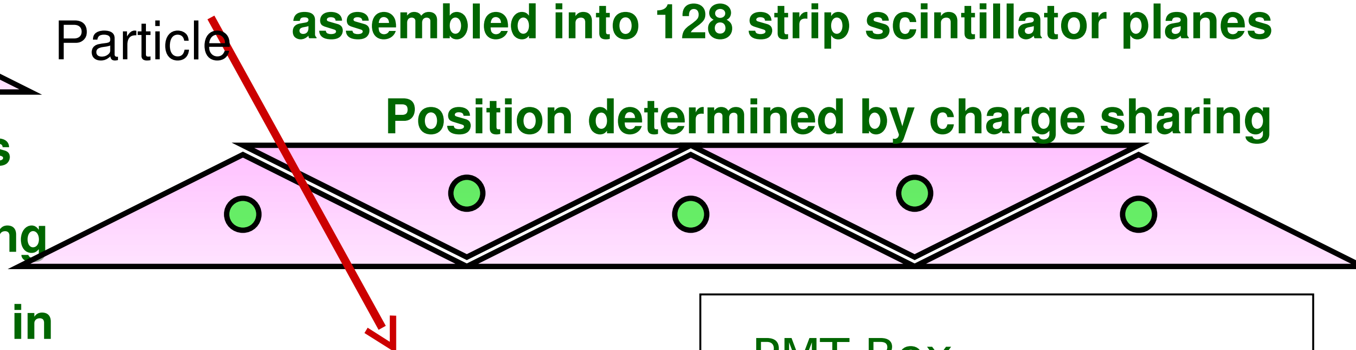


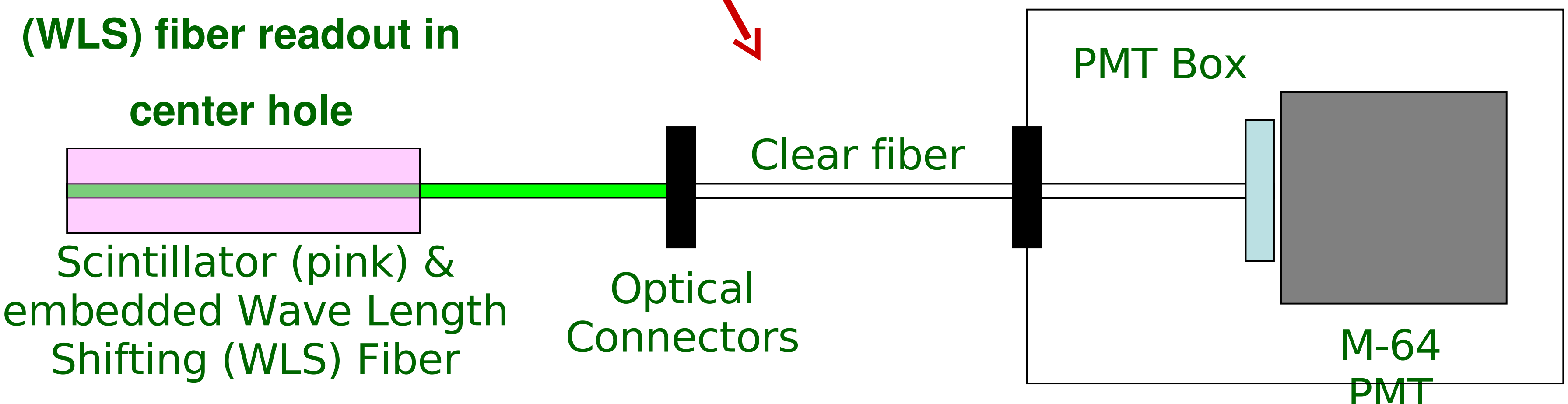
1.7 × 3.3 cm^2 strips

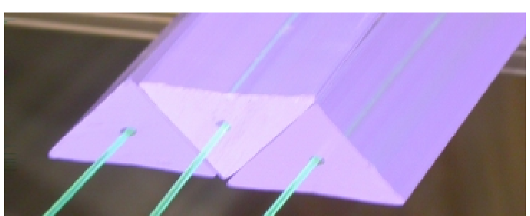
Wave Length Shifting (WLS) fiber readout in center hole

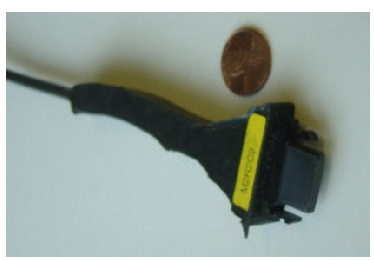
For the Inner Detector, scintillator is assembled into 128 strip scintillator planes

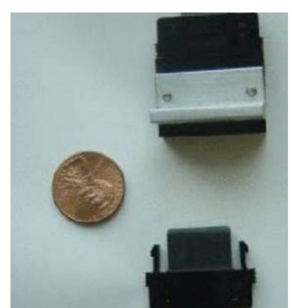
Position determined by charge sharing

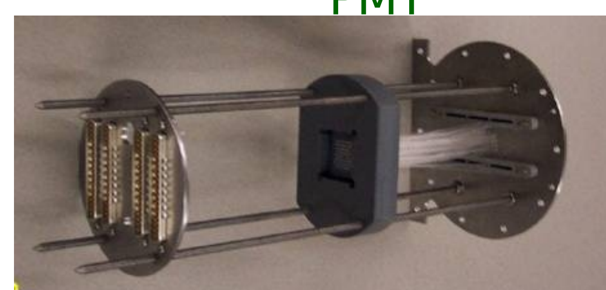












Main Contributers to SOS Test

Faculty:

M. Eric Christy (Hampton)

Jeff Nelson (W&M)

Gabriel Niculescu (James Madison)

Steve Wood (JLab)

Undergraduates:

Daniel Damiani (William & Mary)

Ian Howley (William & Mary)

Lyndsey Allison-Russel (Hampton)

Jamil Taylor (Hampton)

Graduate Students:

Stephen Coleman (William & Mary)

Tammy Walton (Hampton)

Anusha Liyanage (Hampton)

Ibrahim Albayrak (Hampton)

Status

Data taking completed *successfully* in early July with 10's of millions of pion events recorded and including:

- ***Momentum scan with P_{SOS} = 250, 325, 400, 450, 480, 510, 550 MeV/c***

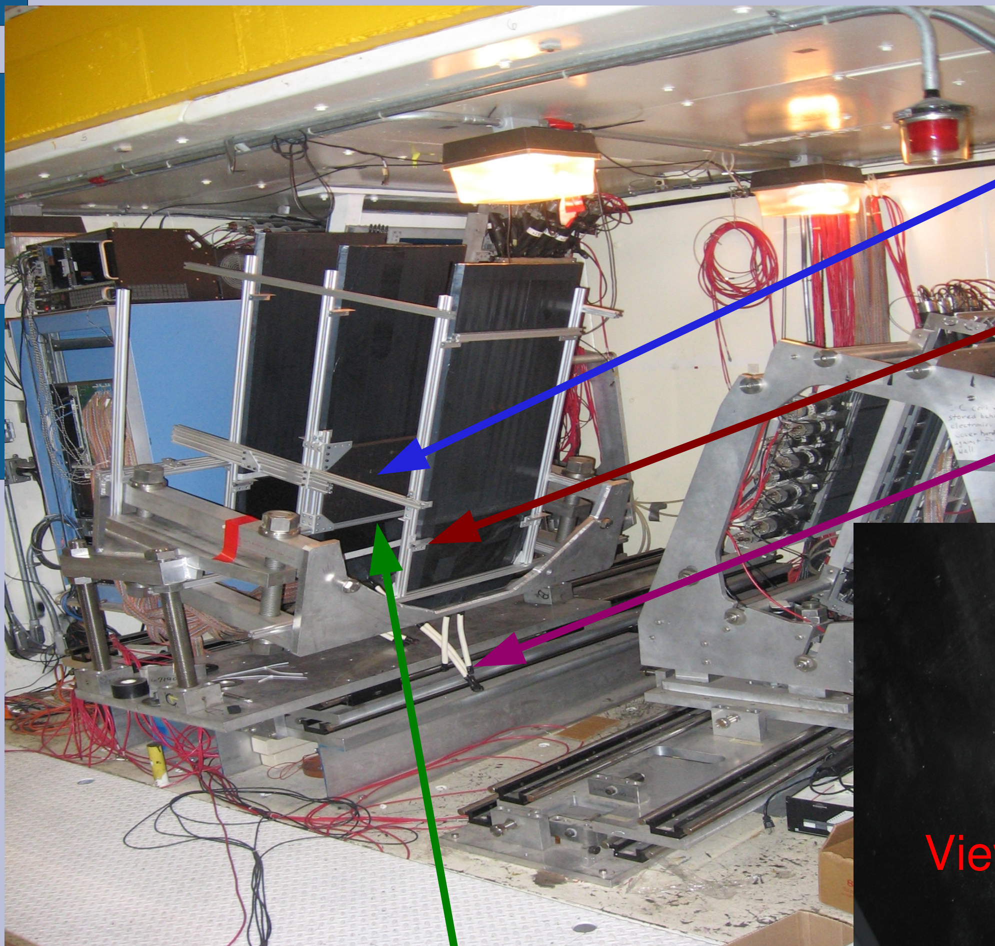
** ***Significant multiple scattering at these momenta => limits position resolution of planes***

- ***PMT HV scan from 650V – 925 V in 25V steps***

Allow us to study detector response to low energy hadrons, tracking, and techniques for calibration relative gain+response per channel

Difficult given geometry. Want to understand for MINERvA calibration with cosmics!

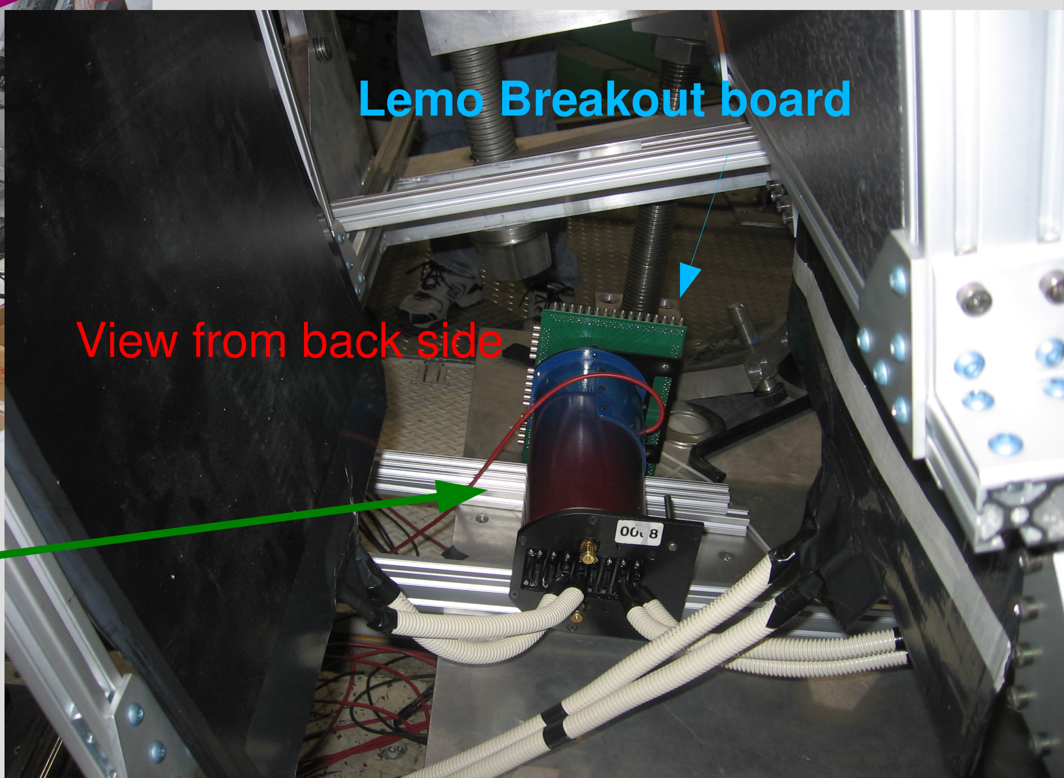
Configuration



1” Steel plate.

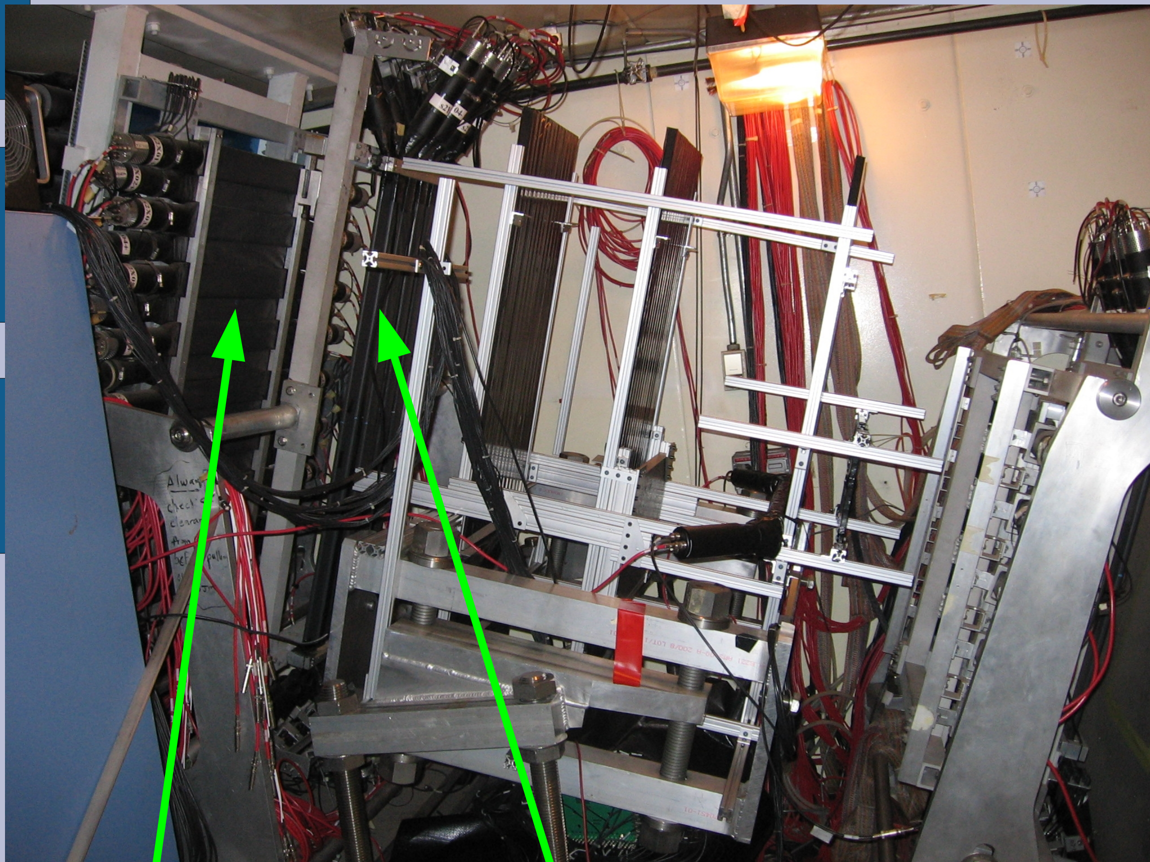
Shelves supporting bottom of planes.

Fiber bundles.



Mount PMT here.

(before final installation!)



Front horizontal (Y) segmented trigger scints

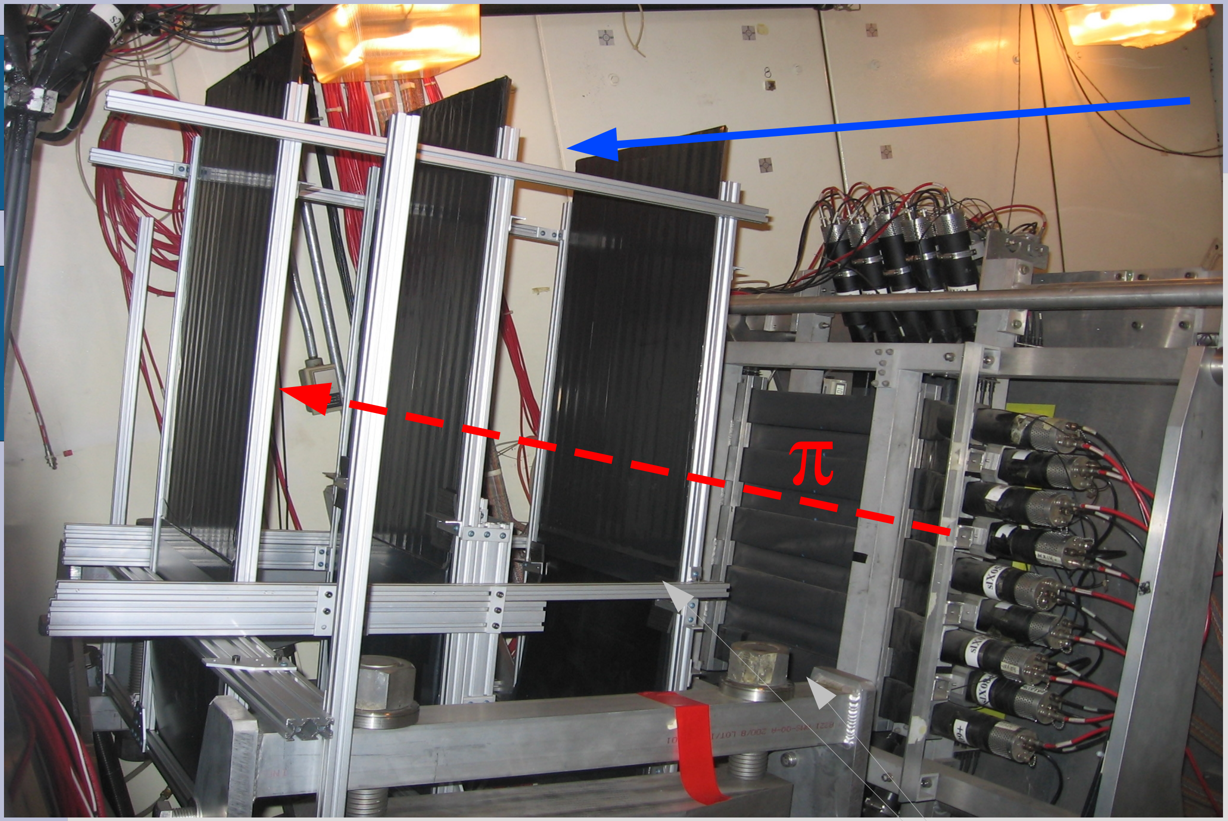
Drift Chambers

Back vertical (X) segmented trigger scints.

Back horizontal (Y) segmented trigger scints

Due to Inefficient X scintillators the Standard Trigger was

1Y & 2Y



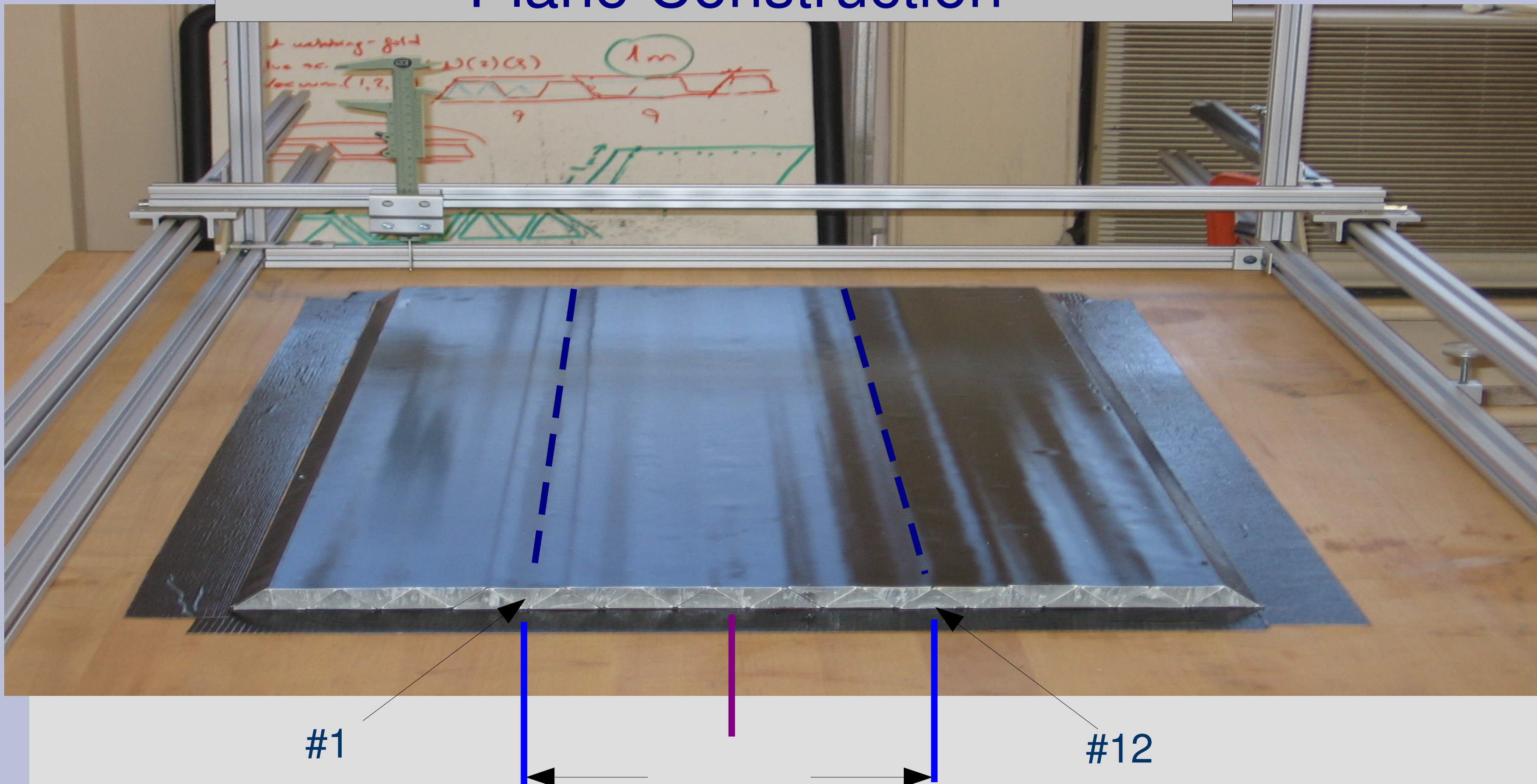
3 planes of 27 triangular strips each

- central 16 are fibered.

- only central 12 are readout in planes 1 & 2

Planes do **not** cover lowest ~10cm of vertical acceptance **but** do cover most of horizontal acceptance.

Plane Construction

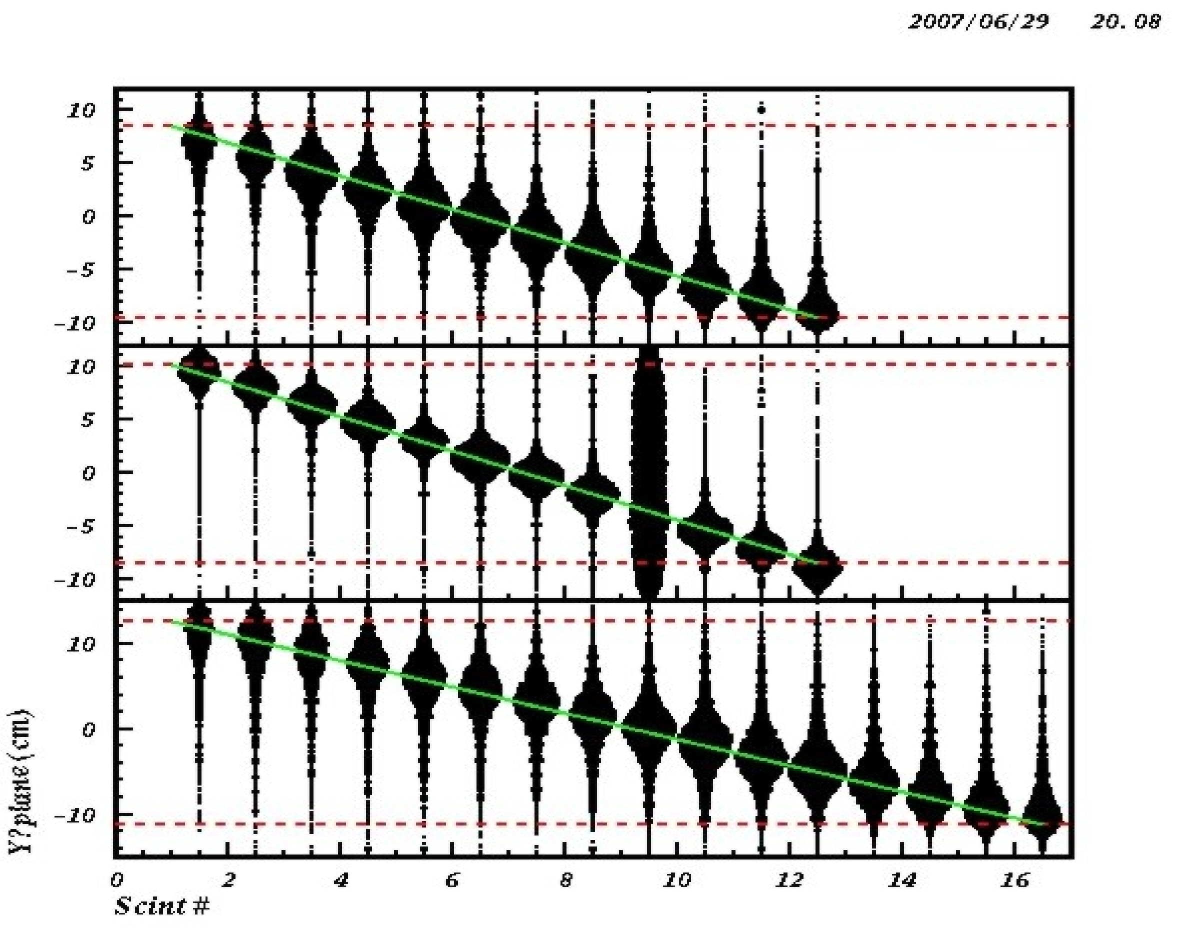


~1.65cm x 11 = 18.15 cm

- **Fiber-to-fiber distance ~ scintillator width/2 (+glue&web) ~ 3.3 cm / 2 = 1.65 cm.**
- **Planes 1&2, expect** **fiber #1 @ Y_plane = +9.08 cm** **and**
  fiber #12 @ Y_plane = -9.08 cm
- **Plane 3, expect** **fiber #1 @ Y_plane = -12.38 cm**
  fiber #12 @ Y_plane = +12.38 cm

Basic detector diagnostics:

Histogram Y position of track projected to each plane versus fiber # with ADC signal



Conclusions:

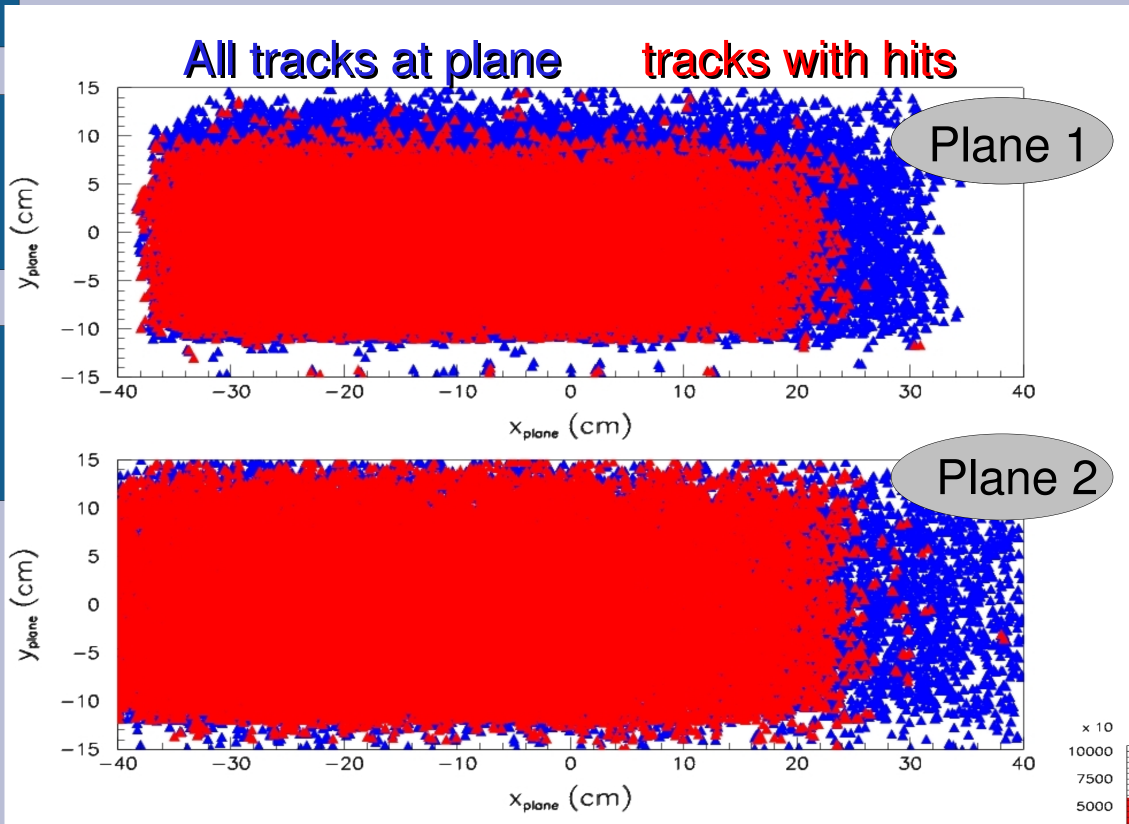
1) All strips have signals!

2) 1 strip (for most runs 2 strips) in plane 2 has noisy electronics.

3) Mapping looks good!

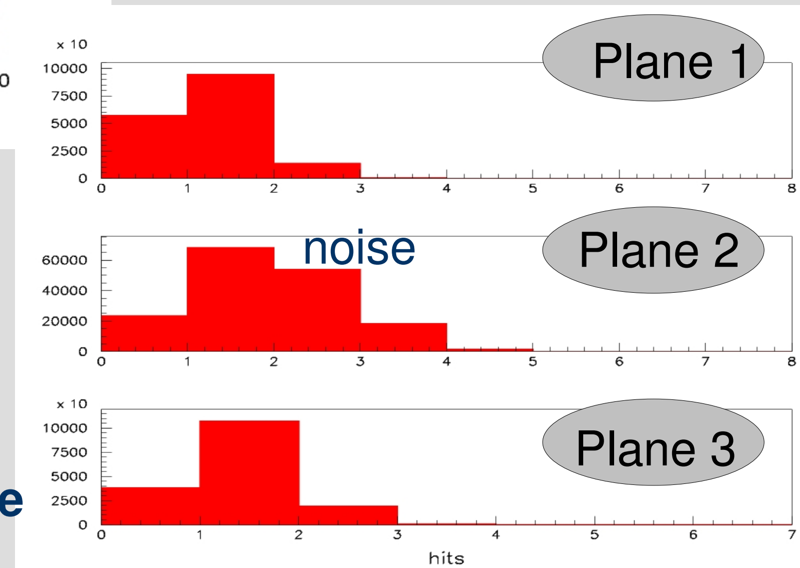
4) Pitch of strips is close to that expected (green line).

Acceptance Coverage of planes



> Edge detectors are at very edge of acceptance

> Plane 1 shifted left

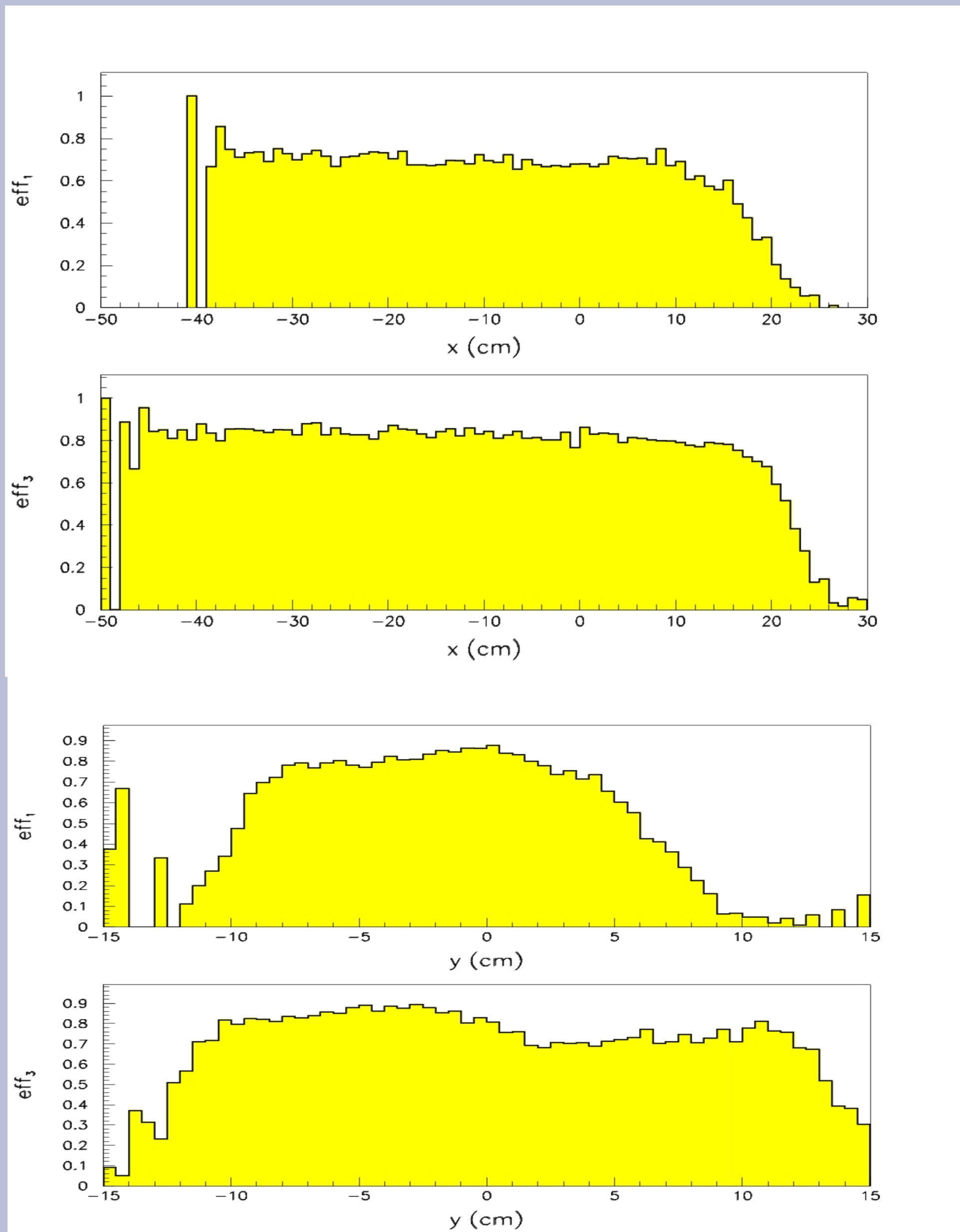


Hit multiplicity per plane @ 925V:

> Lower than expected multiplicity:

- large cable length => signal attenuation
- pedestal suppression + AC pedestal noise

Efficiency of planes at 925 V



Efficiency

Nhit_plane (ADC > 5 channels) / Ntracks

1) **Efficiency for all tracks is 75-85% for planes 1 & 3.**

2) **Plane 1 looks slightly less efficient.**

3) **Plane 2 includes noise hits and is an overestimation of the efficiency.**

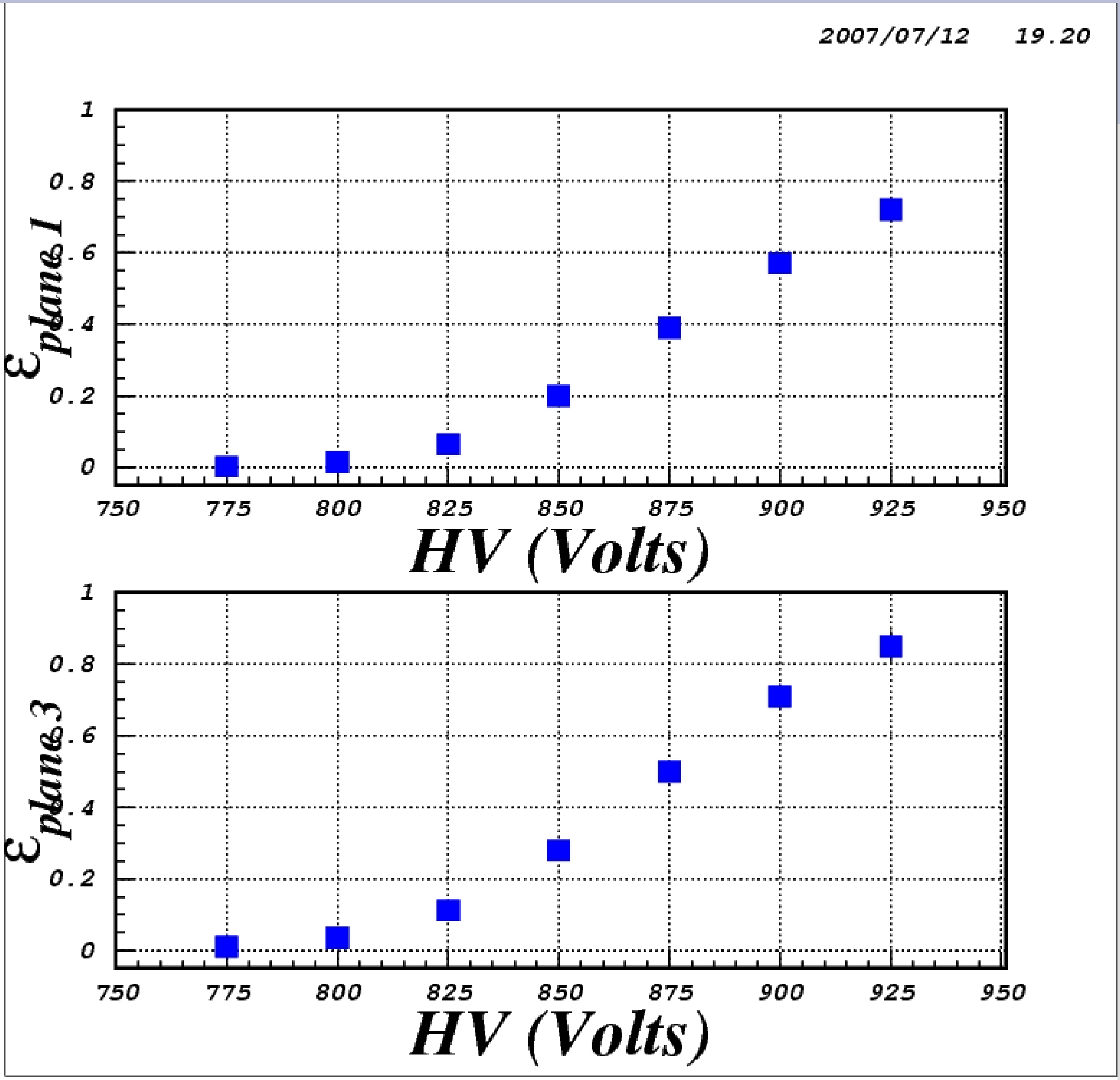
Efficiency vs. PMT HV

Still < 85% at 925 V, 2 possible reasons:

1) Need to check if there is an ADC cut being applied to 'hits'

2) Possibly partially due to pedestal suppression** when reading the ADC coupled with some AC noise.

** In any future run pedestal suppression would be disabled for the MINERvA channels

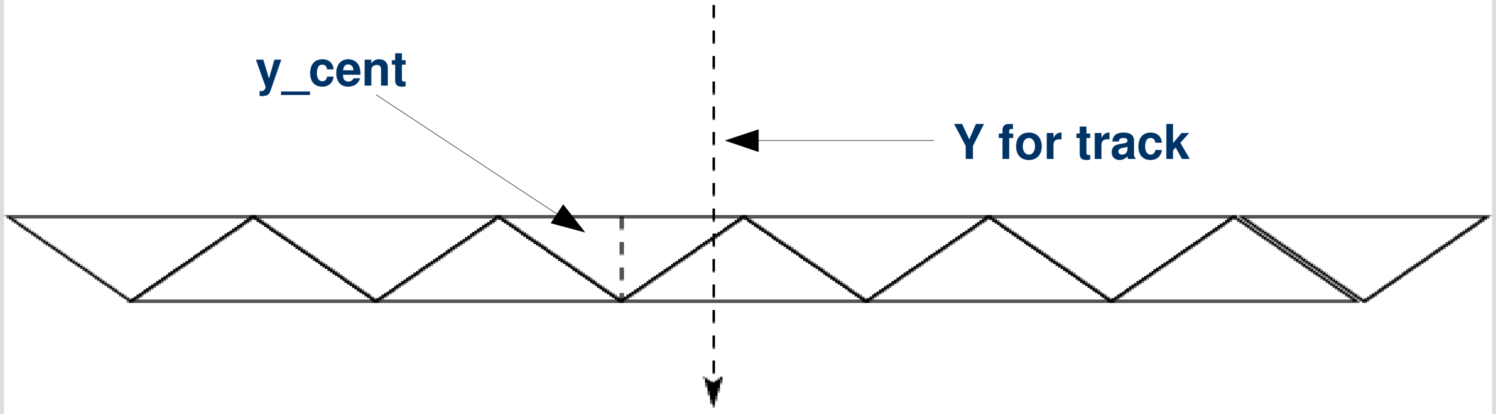


Determining relative gains

- Relative strip gain/response must be corrected for position from energy sharing .

- Try to determine Gain/response differences between strips by normalizing to dE/dx (dQ/dx) for (nearly) mono-energetic πs.

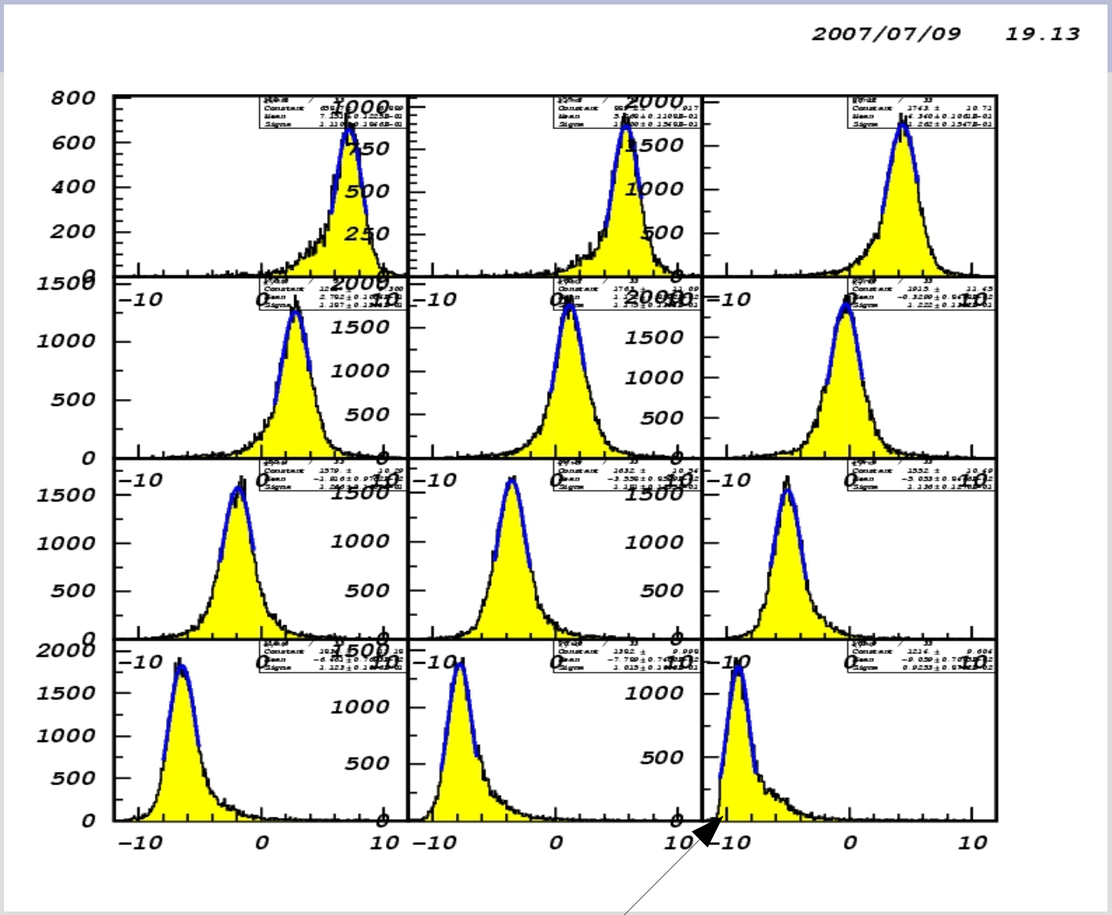
  => Must first determine dx by using track Y at plane and Y of strip center (Y_cent).



$$dz = [(y - y\_cent) - width/2] * height/width$$

Determining Y_cent positions

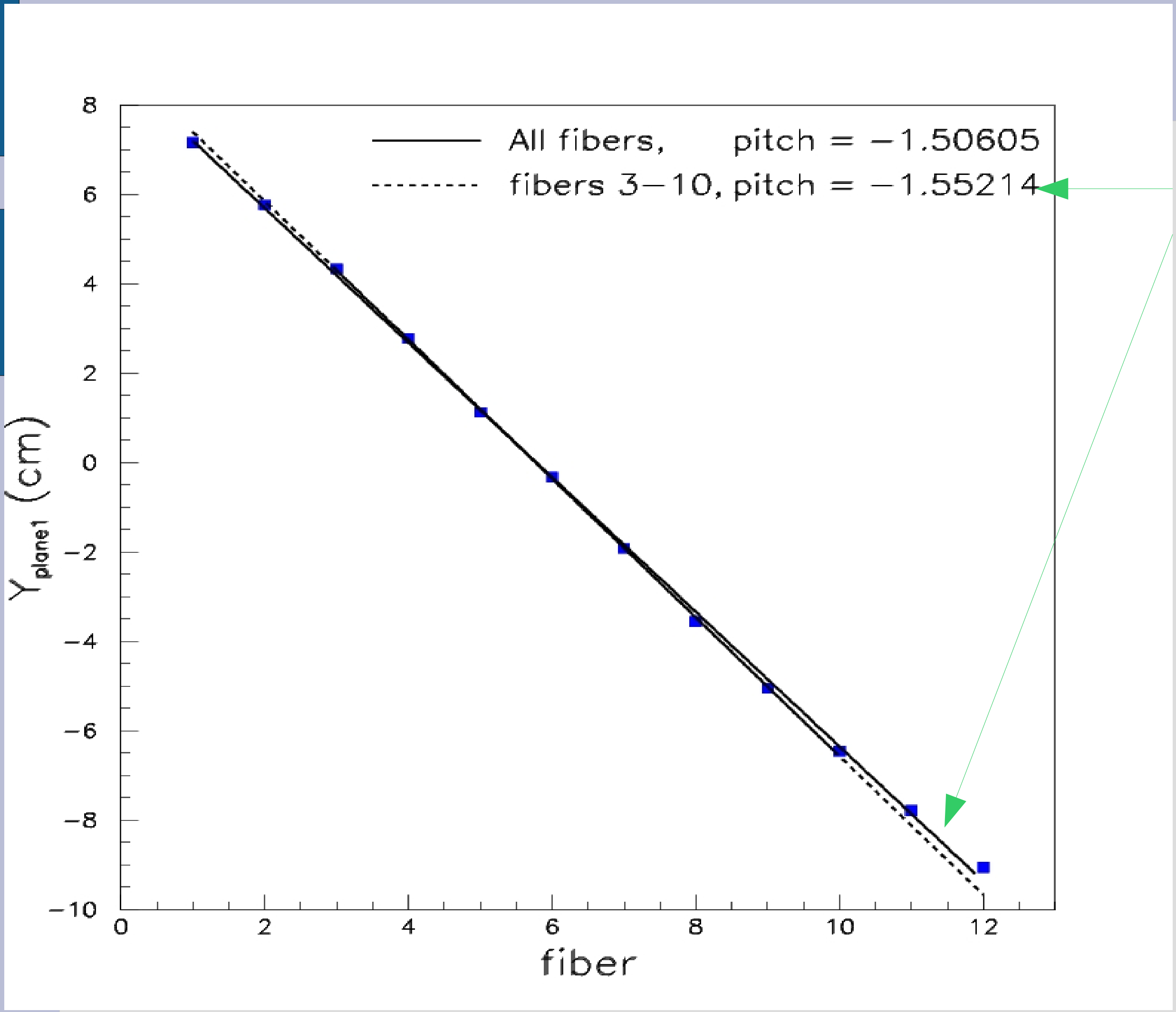
Histogram Y position of track projected to plane: fit with Gaussian.



Fiber #	Y_{plane1} (cm)
1	7.15
2	5.77
3	4.34
4	2.78
5	1.12
6	-0.33
7	-1.92
8	-3.56
9	-5.05
10	-6.46
11	-7.79
12	-9.06

Y position determined for edge detectors in plane 1 are biased by edge of SOS acceptance => *extracted Y is smaller than true value.*

Pitch Determination



Excluding edge strips gives more accurate result.

Pitch is still smaller than expected.

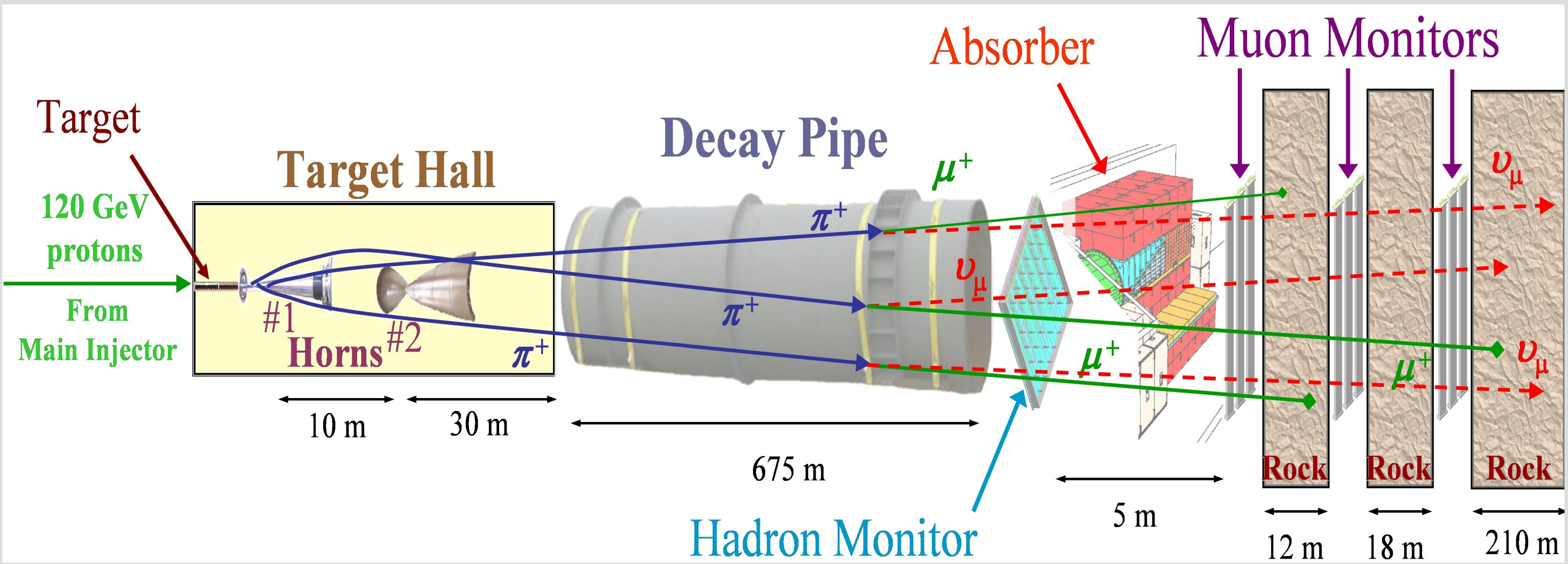
Position of outer strips more accurately determined from fitted pitch.

Future plans

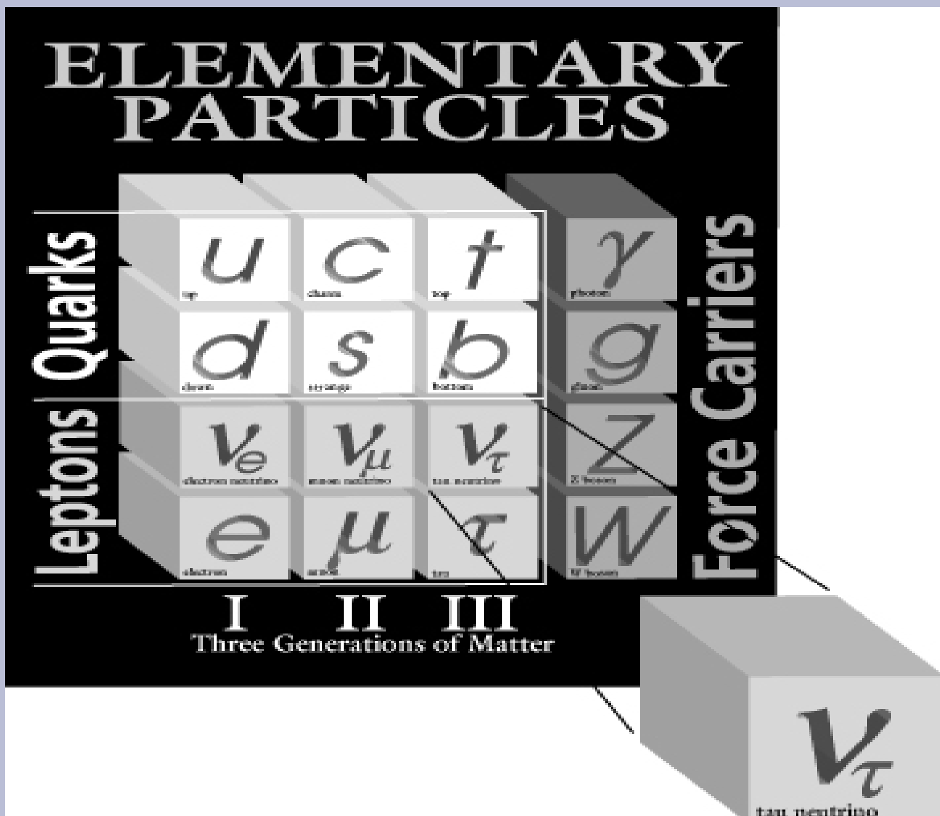
1. Finalize Y_cent positions for strips.
2. Develop procedure to calculate relative gains.
3. Calculate dE/dx for each plane for each event.
4. Energy sharing algorithm to deterine Y position at strip.
5. dE/dx versus P using momentum scan data.
6. Look at dE/dx in 2nd & 3rd plane with/without steel.
7. See if we have any 'loose' trigger (hodos before planes only) data to examine pion absorption in steel.
8. ???

Additional Slides

Fermilab NuMI Beamline

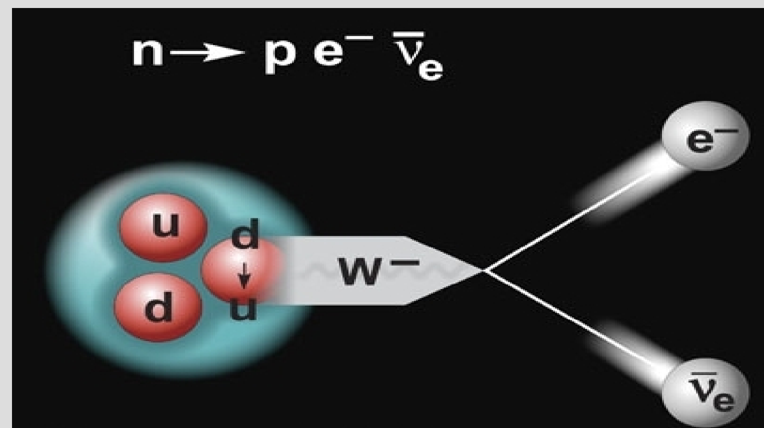


Neutrinos: Standard Model and Beyond



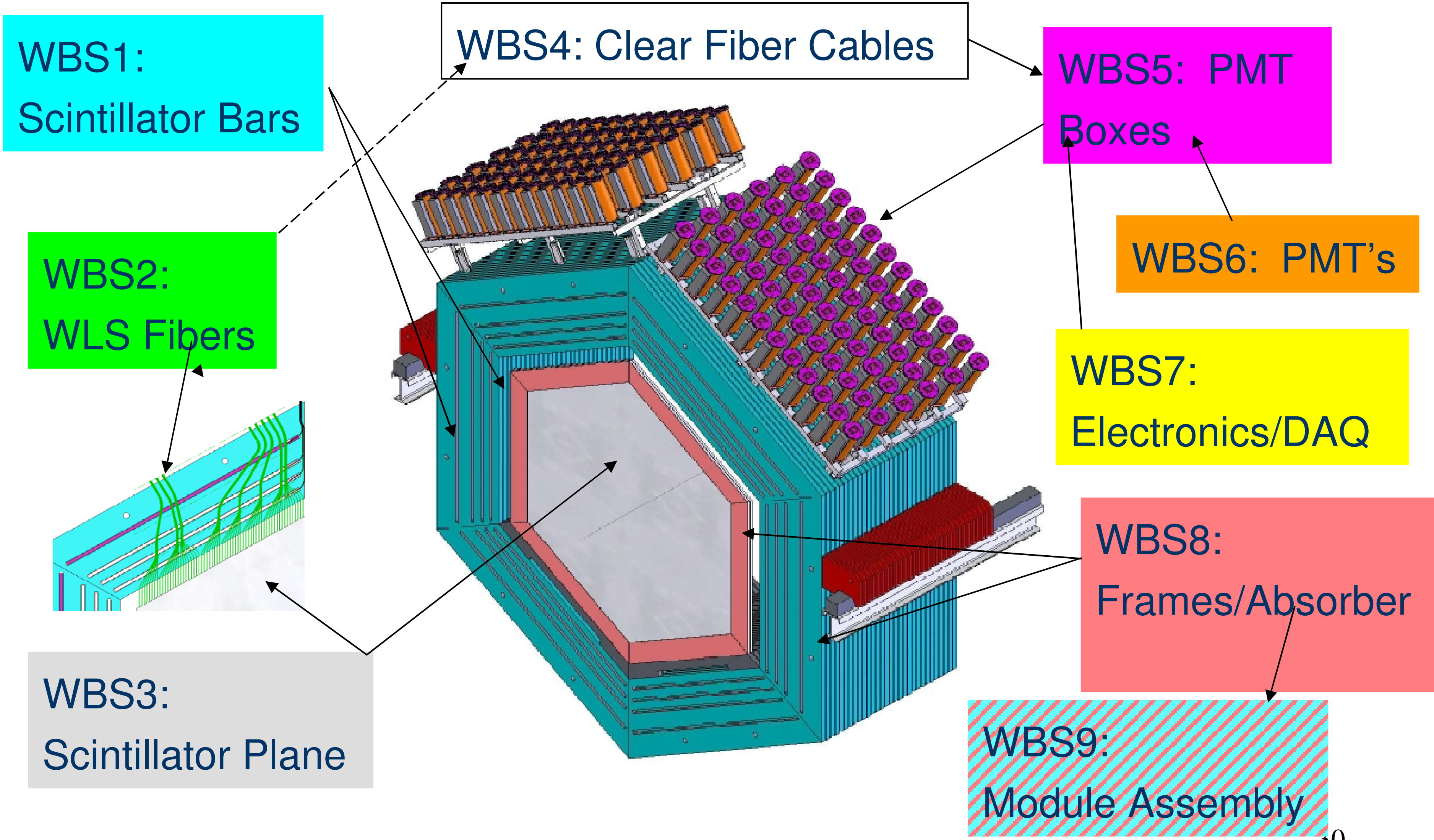
Different quarks flavors are known to mix, eg. **u -> d**

n beta decay is a weak interaction process



A free neutron (udd) decays to a proton (uud), an electron, and an antineutrino via a virtual (mediating) W boson. This is neutron β (beta) decay.

Standard model neutrinos do not mix


WBS1:
Scintillator Bars
WBS4: Clear Fiber Cables
WBS5: PMT
Boxes
WBS6: PMT's
WBS2:
WLS Fibers
WBS7:
Electronics/DAQ
WBS8:
Frames/Absorber
WBS3:
Scintillator Plane
WBS9:
Module Assembly

Charged Lepton to neutrino DIS SFs

$$F_2^{eN} = 5/18x\,(u + \bar{u} + d + \bar{d} + 2/5 s + 2/5\, \bar{s})$$

Same PDFs!

$$F_2^{\nu N} = x\,(u + \bar{u} + d + \bar{d} + s + \bar{s})$$

If Duality works well in Nuclei then even the RR prescription for

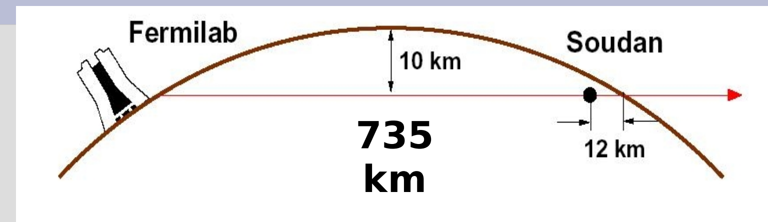
$$\sigma^{e}_{res} \;\text{->}\; \sigma^{\nu}_{res}$$

requires only PDFs and DIS nuclear corrections!

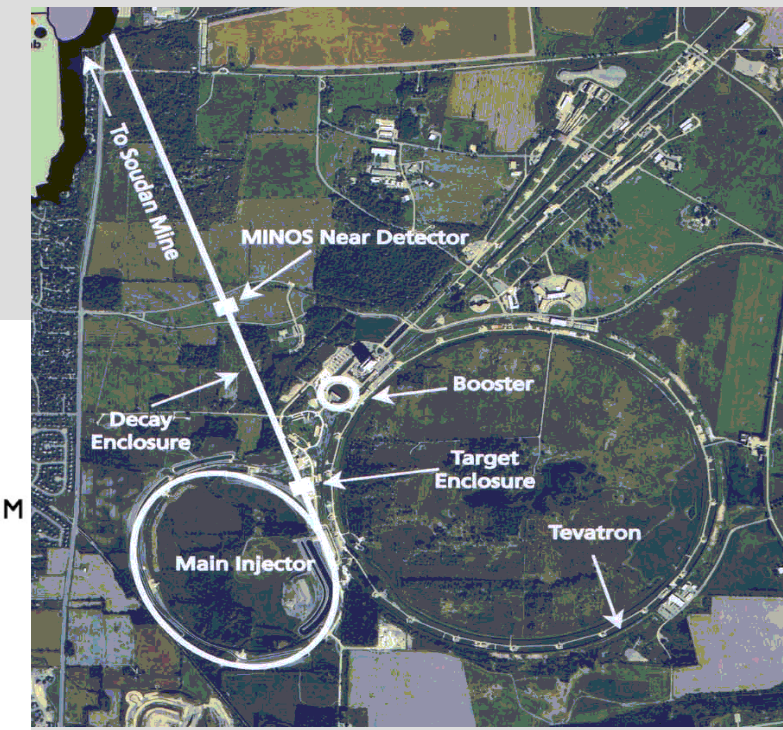
Do not need to know individual resonance couplings for inclusive cross sections!

MINOS (Main Injector Neutrino Oscillation Search)

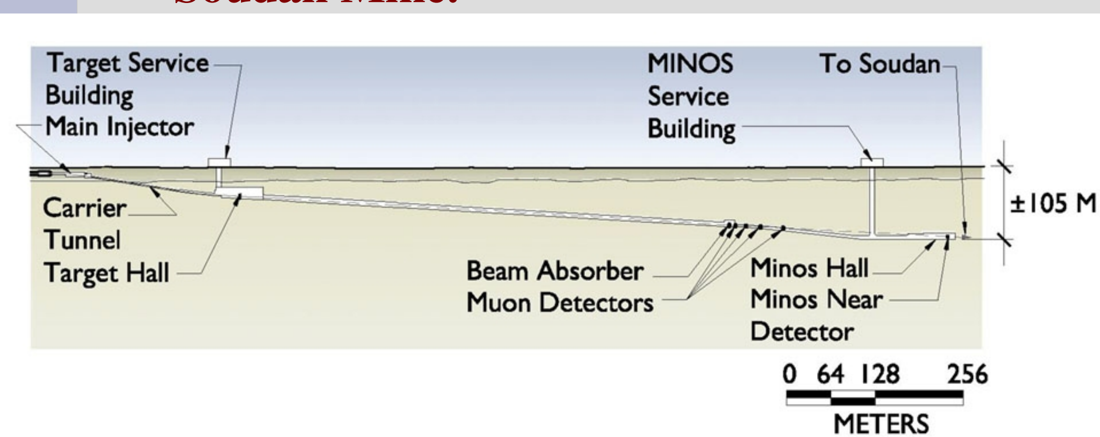
- Look for ν_μ disappearance in travel from near to far detector => oscillations into other flavors



- Near detector at Fermilab to (measures beam composition and energy spectrum of ν beam)



- Far detector in the Minnesota at Soudan Mine.



ν Oscillations (mass mixing)

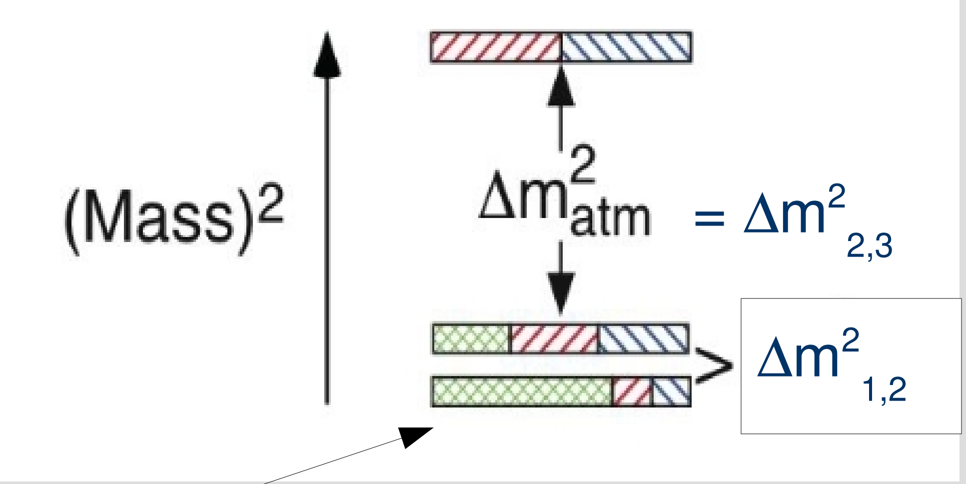
$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Mass eigenstates

Flavor states

Mixing Matrix

Mass hierarchy



Flavor states are linear combinations of mass states (and visa versa)