Neutrino Interactions in the MINOS Near Detector

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(for the MINOS Collaboration)

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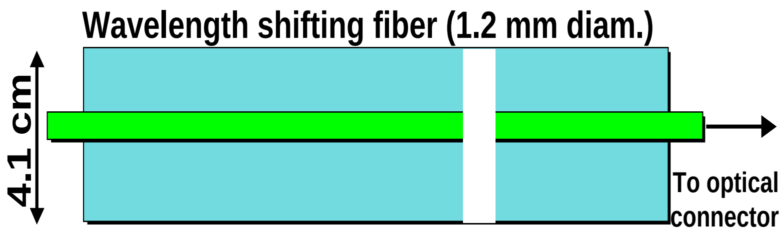
Outline

- Introduction
- Near Detector readout.
- Calibration system and resolution.
- Data taking.
- Event Topologies.
- Charged Current Sample.
- Ongoing analysis
- Summary

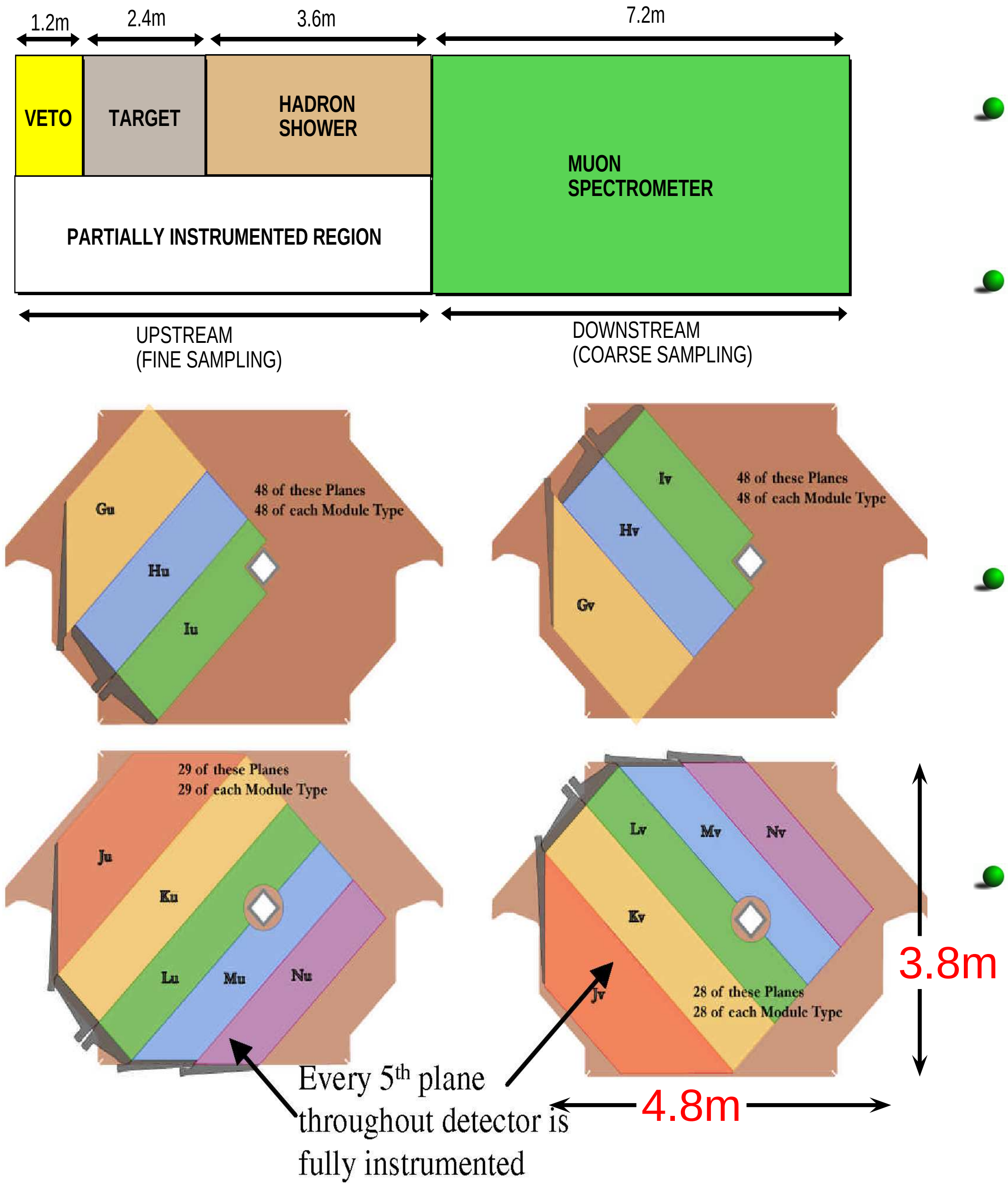
Near Detector

- 1 km from target.
- 0.98 kTon.
- 3.8m $\times$ 4.8m $\times$ 16.6m.
- Magnetic Field $\rightarrow$ 1.2 T.



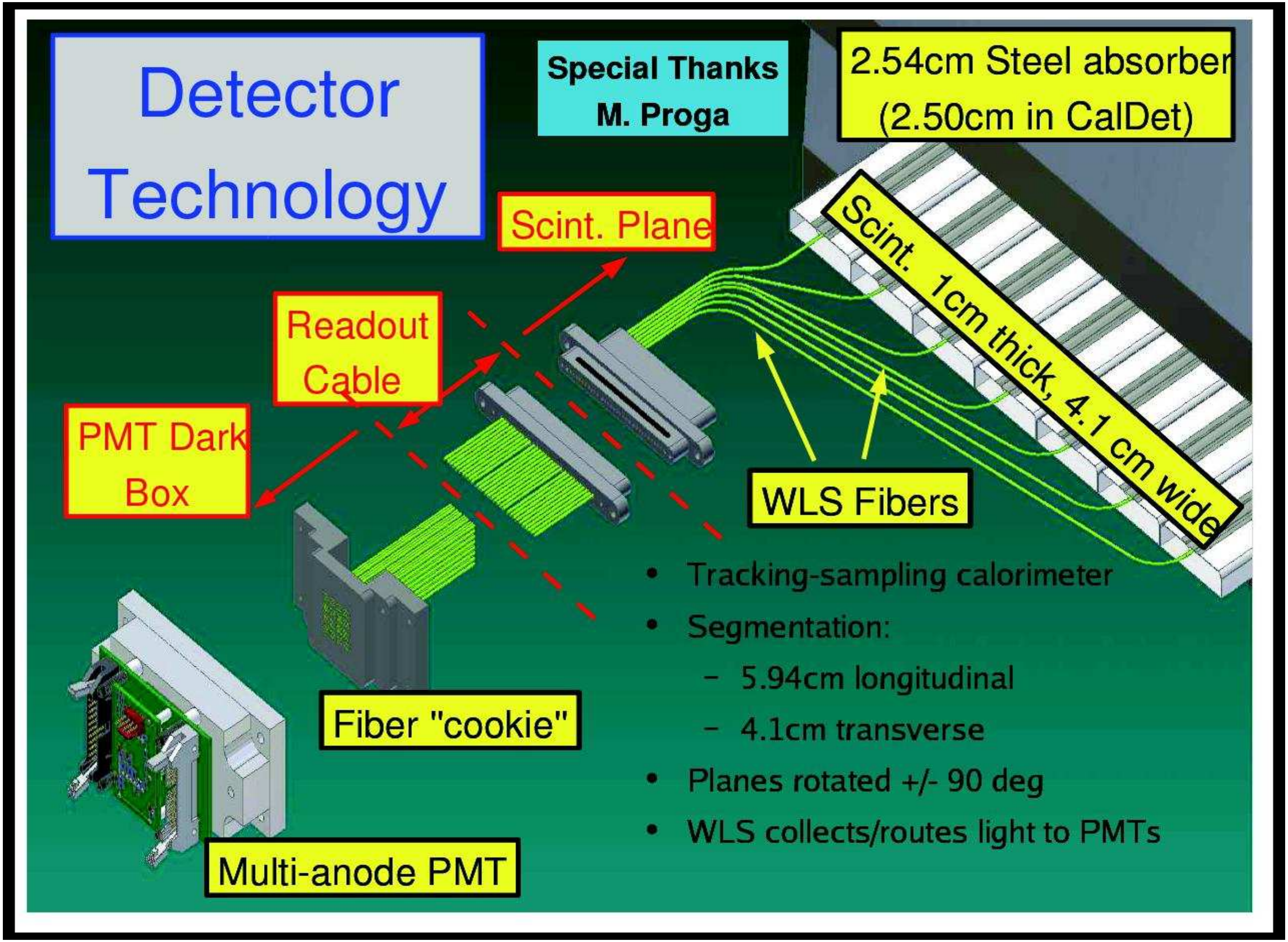
- Steel and scintillator tracking calorimeter.
- 1”Fe/1 cm scintillator.

Near Detector



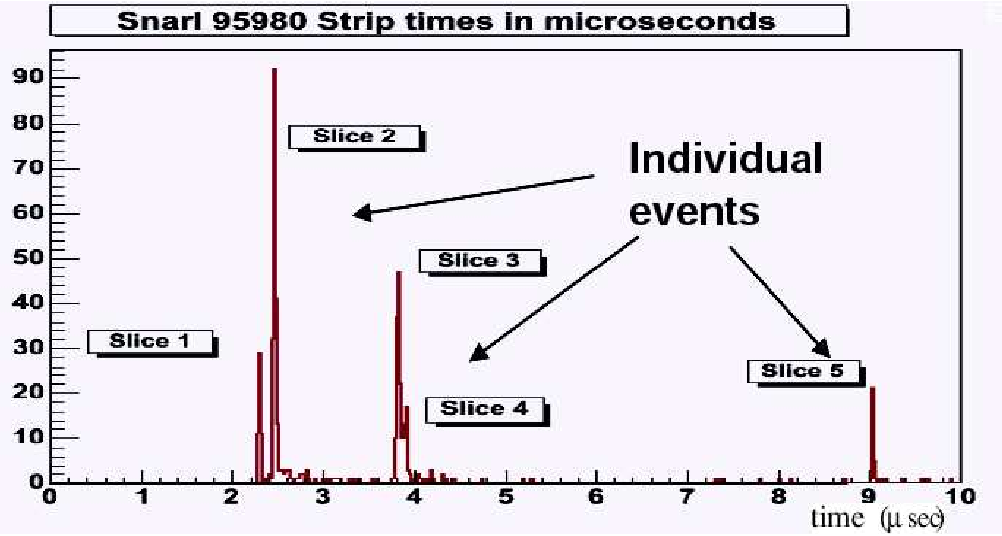
- 282 steel planes, 153 scintillator planes.
- Calorimeter region
  - Planes 0-120.
  - Partial instrumentation every alternate plane.
- Spectrometer region
  - Planes 121-282.
  - Only full instrumentation every 5th plane.
- Every 5th plane throughout the detector is fully instrumented.

Near Detector Readout

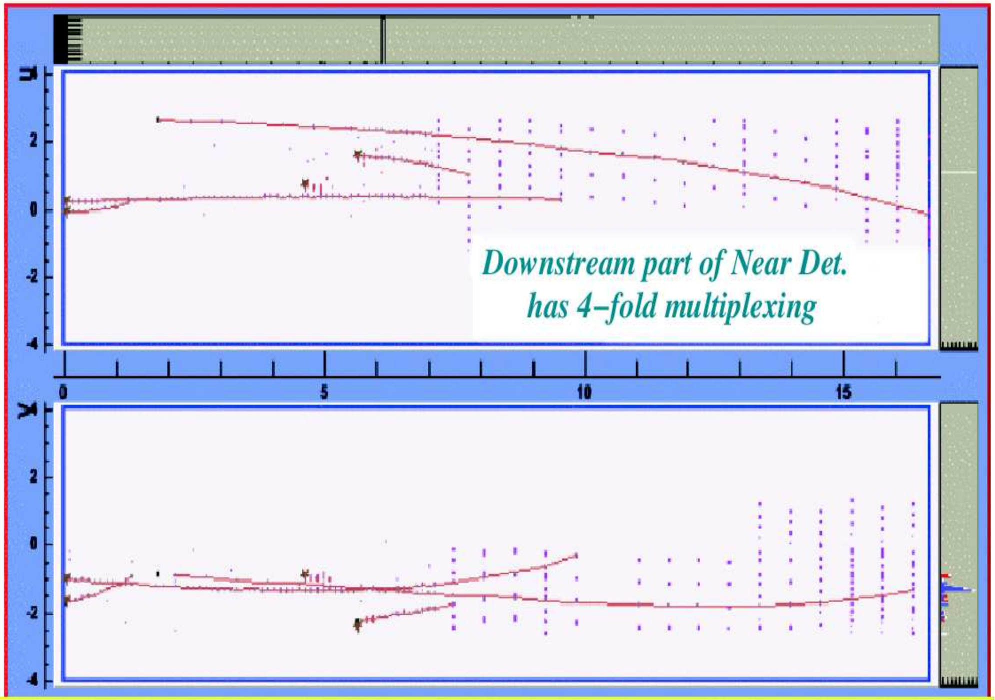


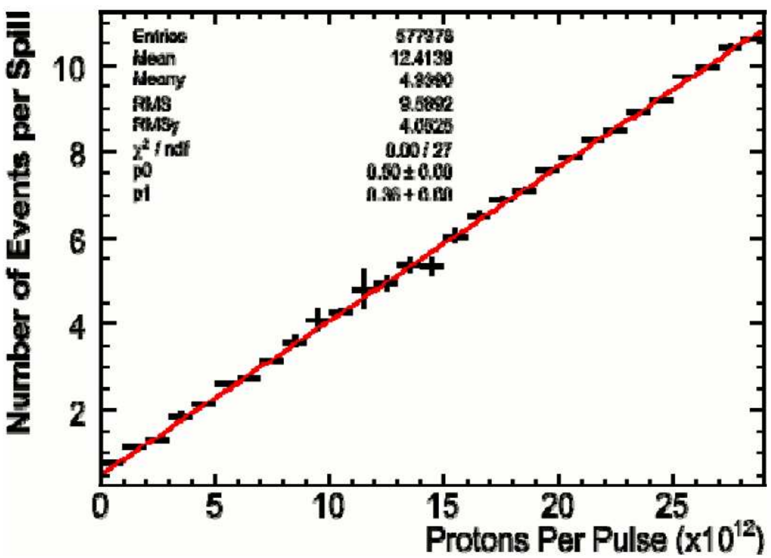
Near Detector Data

- ND sees large event rates in each 10 μs spill.
  - 19 ns, deadtimeless sampling used to readout PMTs.
  - Events are separated using timing and topology.
  - No rate dependent reconstruction effects observed.



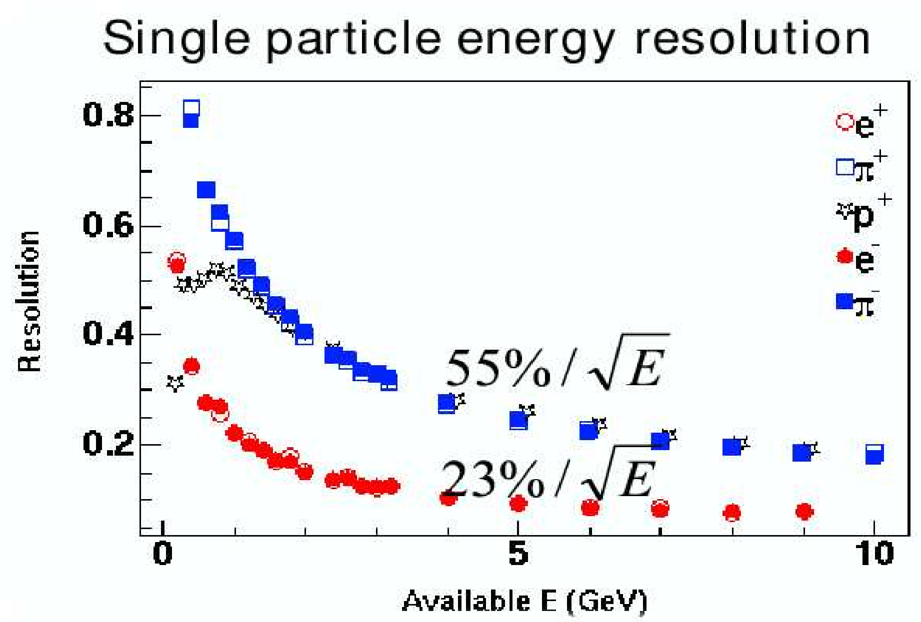
One near detector spill





MINOS Calibration System

- LED based light injection system
  - Calibrate PMTs.
- Cosmic Ray muons
  - Remove variations along and between strips.
- Stopping muons
  - Detector-to-detector relative energy calibration.
- Test beam with mini-MINOS detector (CALDET)
  - Measure absolute energy scales. (e,μ, π,p).



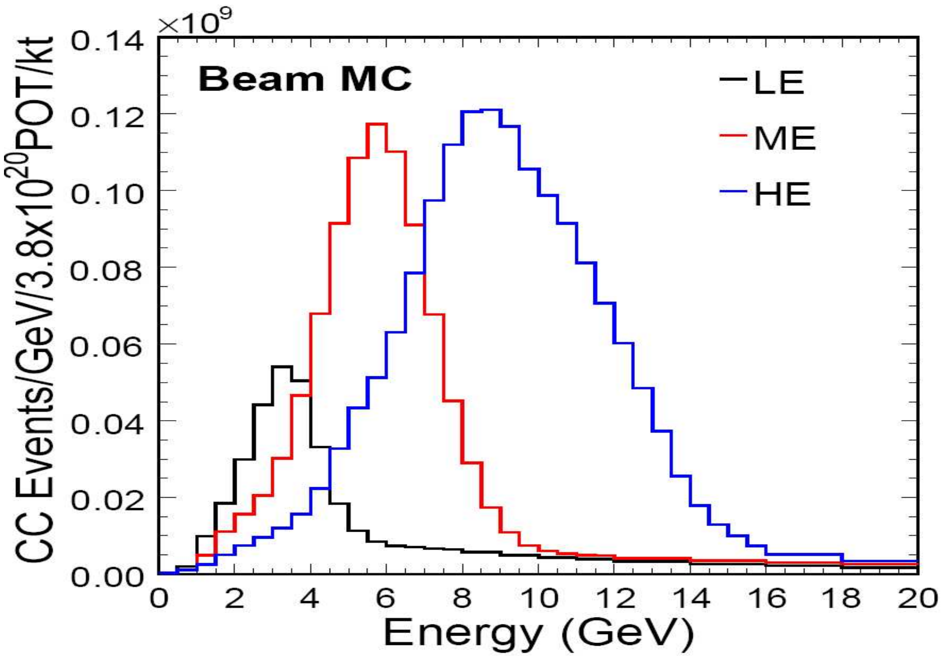
Shower energy resolution

$55\%/\sqrt{E}$ (single pion)

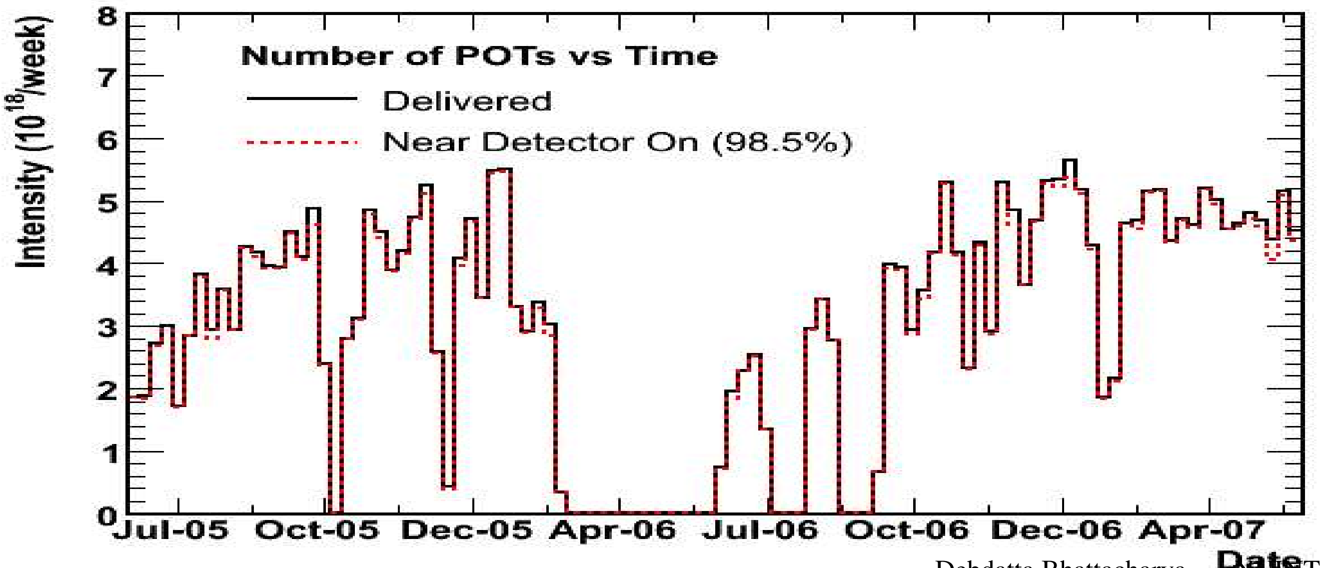
Muon momentum resolution

6% range, 13% curvature

Data Taking

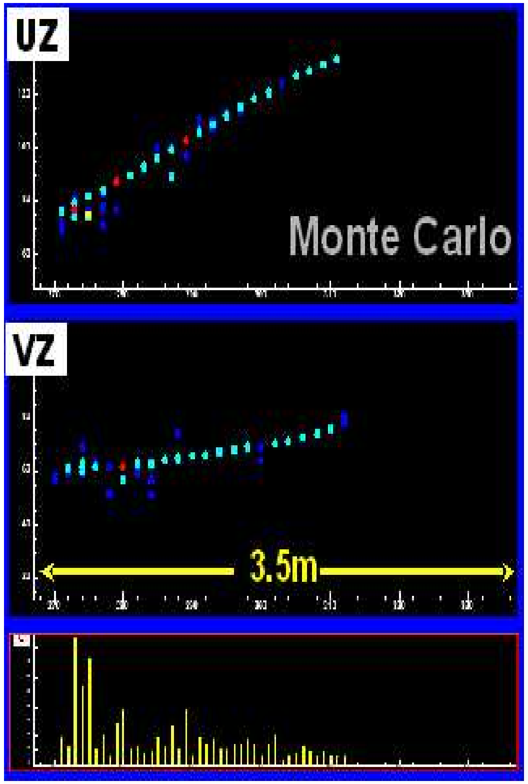


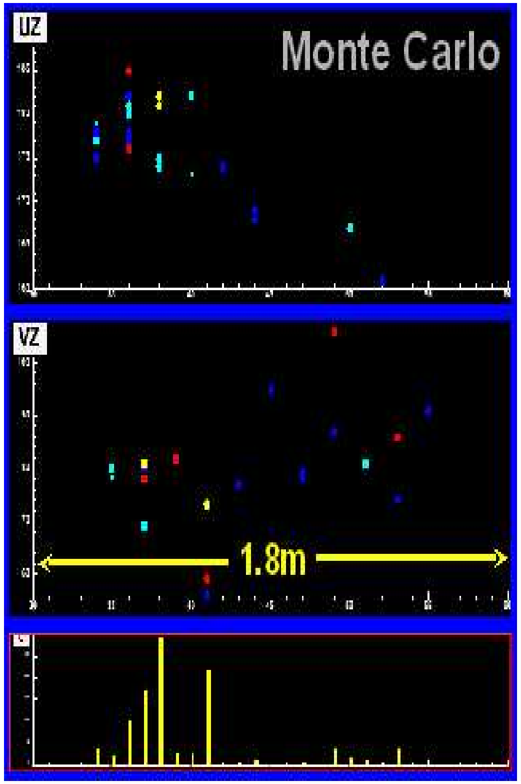
- Three beam configurations are LE, ME, and HE.
- Beam Composition :
  - 98.5% ν_μ + $\bar{\nu}_\mu$
    - 6.5% $\bar{\nu}_\mu$
  - 1.5% ν_e + $\bar{\nu}_e$

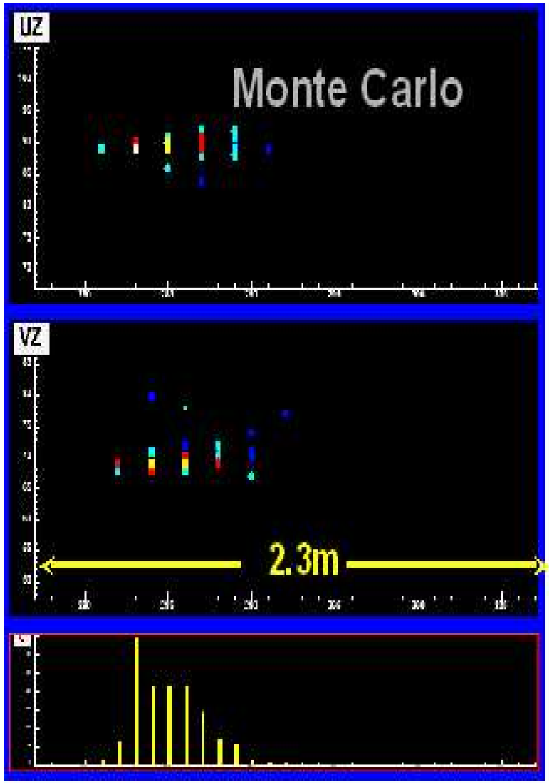


Event topologies

ν_μ charged-current	neutral-current	ν_e charged-current







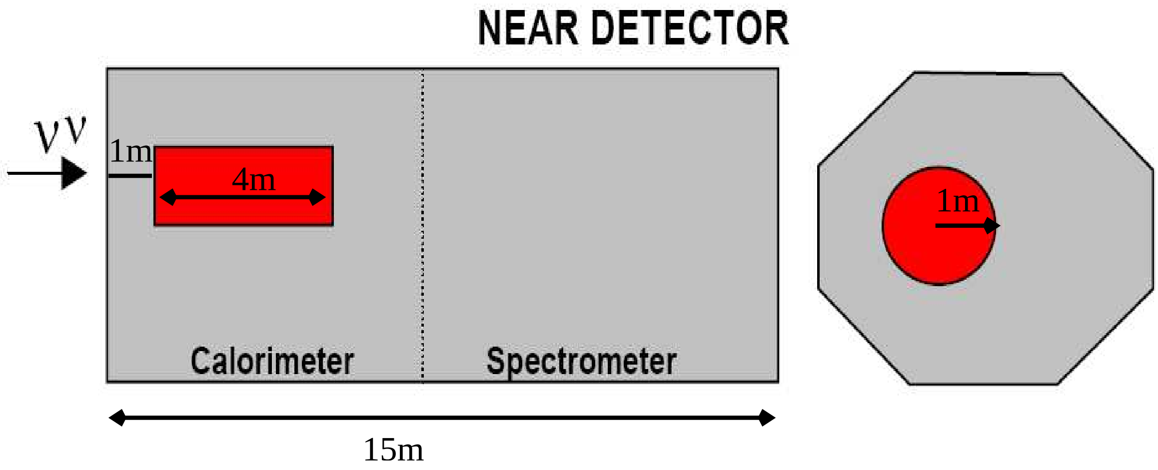
- long muon track
- diffuse shower, (no μ)
- EM-like shower, (no μ)

Reconstructed Energy

$$E_{VIS} = p_\mu + E_{shw}$$

Sample Selection

- One good track
  - stopping = P_{range}
  - exiting = $P_{\text{curvature}}$
- Vertex in fiducial volume
  - Centered on beam spot.
- Sign of muon track (for selecting ν_μ CC and $\bar{\nu}_\mu$ CC)



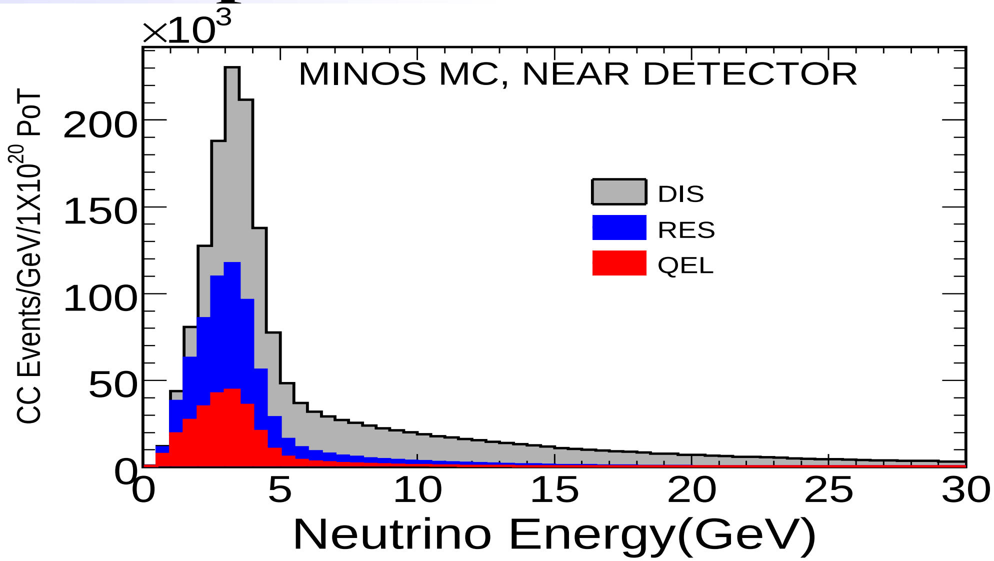
- CC/NC discrimination(analysis dependent)
  - PID cut - use variables like event length, fraction of event PH in track, track PH per plane.
  - Muon momentum Cut - minimum muon energy requirement to discriminate Neutral Current.

Near Detector Samples

CC sample for 3 $\times 10^{20}$ protons on target (May 05-Apr 07)

5.5e+06

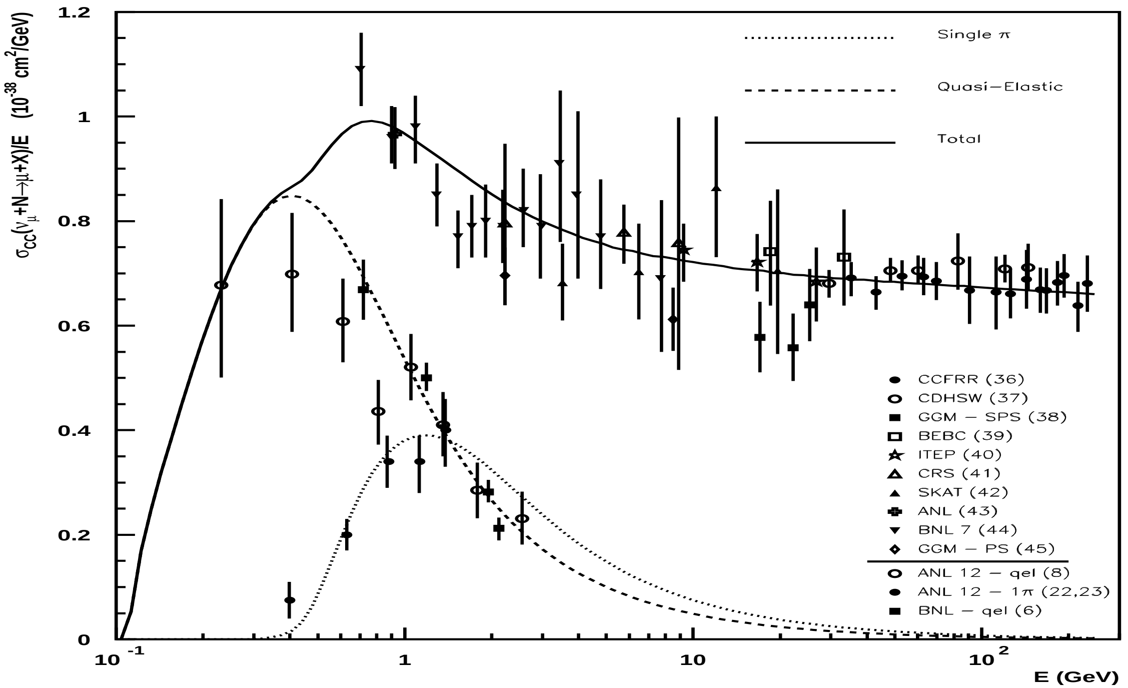
(fiducial mass 33 ton)



Ongoing Physics analysis

- Quasi Elastic νN scattering.
- Lowν flux extraction.
- Inclusive CC cross-section shape.
- DIS and structure function.
- Coherent Pion production.

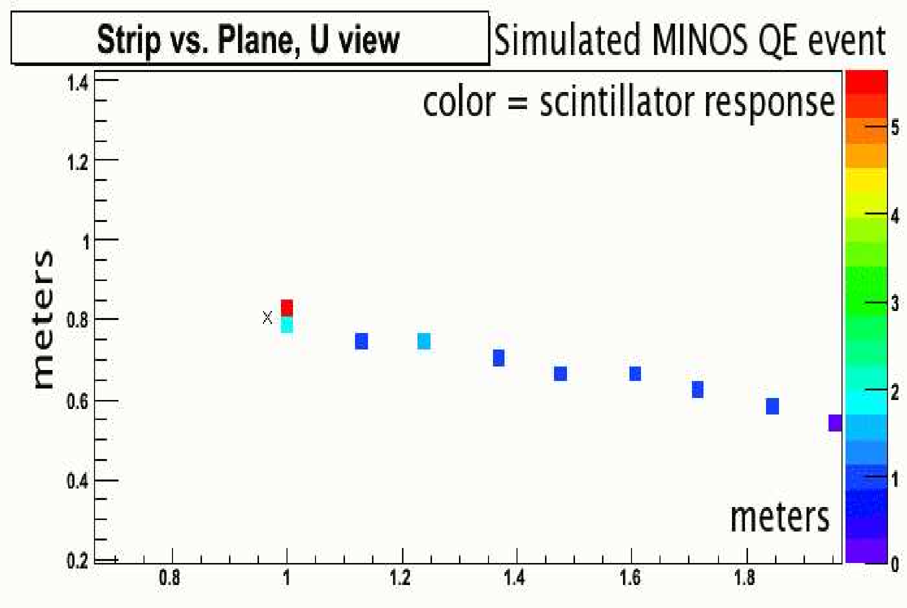
*Some of the topics will be covered in more detail in other talks.

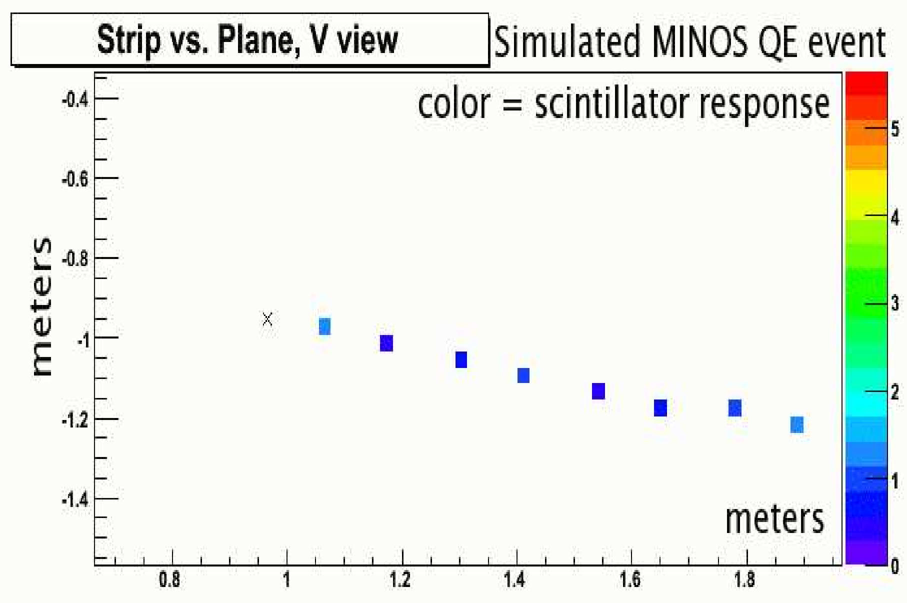


Quasi-Elastic Scattering

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

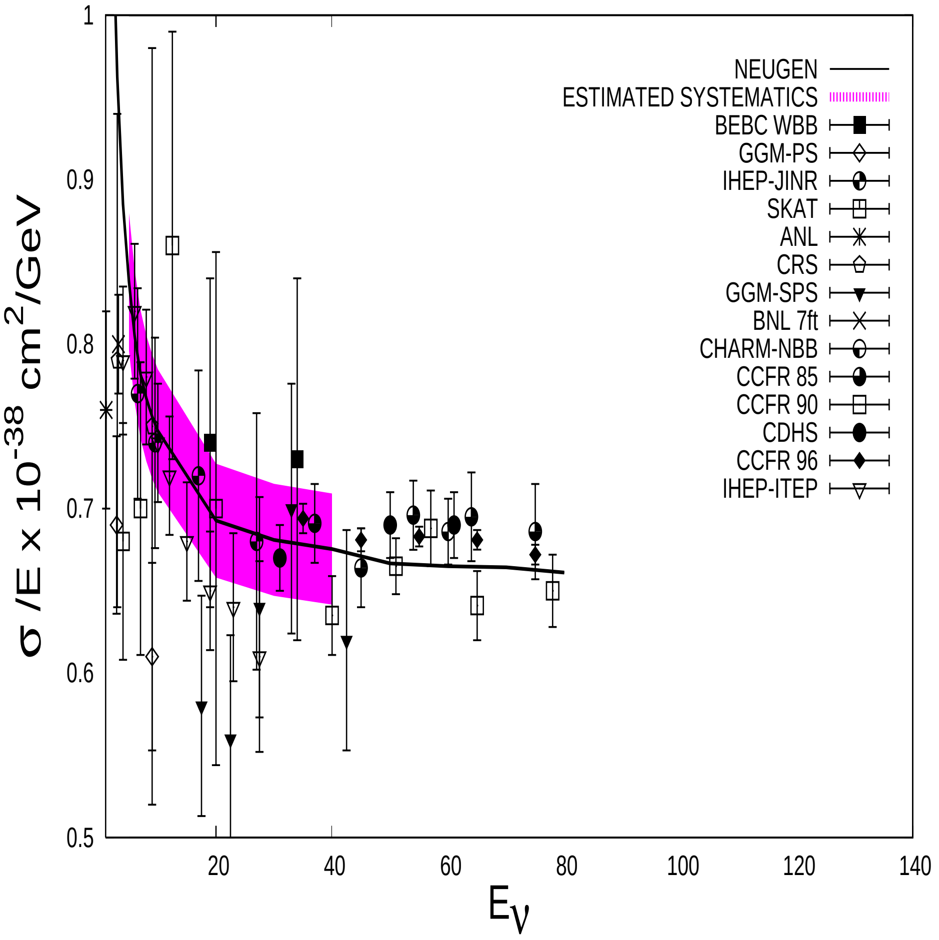
- Estimated sample size for 3×10^{20} protons on target **800,000** (fiducial mass 33 ton).
- The QEL-enhanced sample can be used
  - to extract the flux.
  - for M_A fitting.
- Look for a "well-defined" muon track with low E_{shw}/low W.
- Main background
  - Single pion interactions.
  - Difficult to isolate because of segmentation.





Total Cross-Section Shape

- Cross-section: $\sigma_{CC}(E) = \Phi(E)^{-1}(E)N_{CC}(E)f_{\mathrm{ACC}(E)}$
  - Energy dependence only: norm. to world average at high energy.
- Measurements of σ/E in the low energy region have limited precision ($\geq$ 10%).
- We expect to have lower systematics($\sim$ 5%). Main contribution
  - Muon and hadron energy scale.



Deep Inelastic Scattering

$$\frac{d^2\sigma^{\nu(\overline{\nu})}}{dxdy} = \frac{G_F^2 ME}{\pi}\left(\left[1 - y(1 + \frac{Mx}{2E}) + \frac{y^2}{2}\frac{1+(\frac{2Mx}{Q})^2}{1+R_L}\right]F_2(x,Q^2) \pm \left[y - \frac{y^2}{2}\right]xF_3(x,Q^2)\right)$$

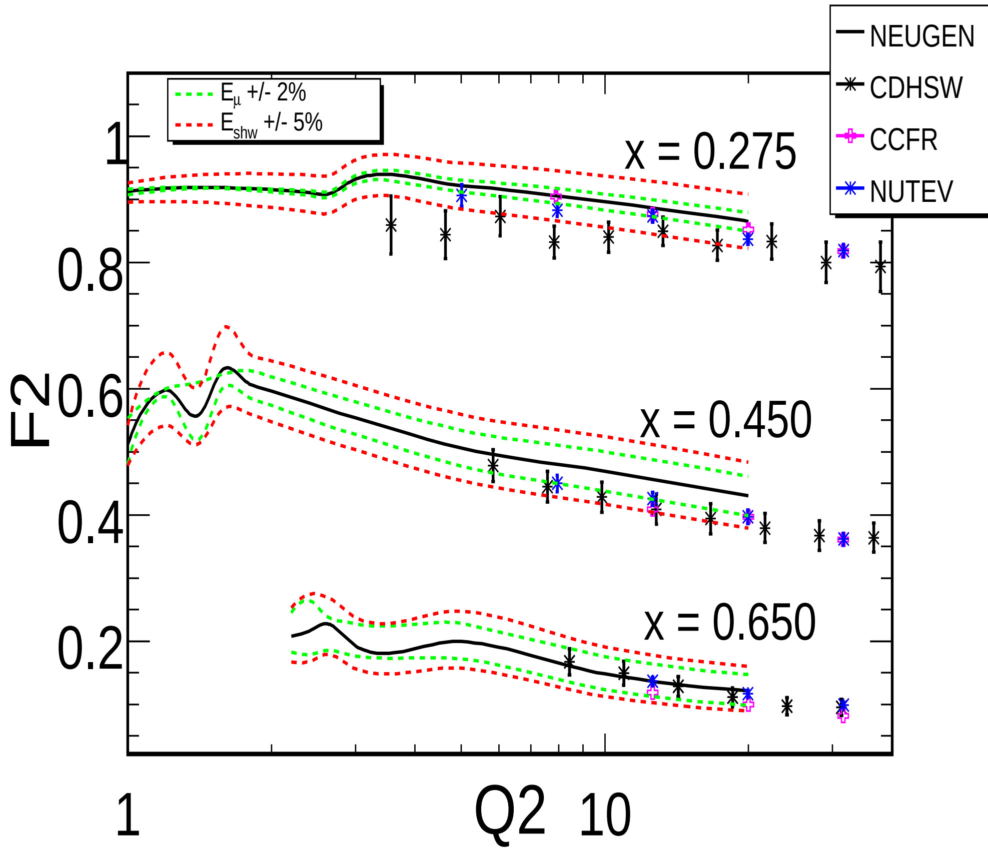
DIS is the largest contribution to the MINOS event sample.

DIS sample

$E_\nu > 5$ GeV, $E_{shw} > 1$ GeV

$Q^2 > 1\text{GeV}^2$, $W > 2$ GeV

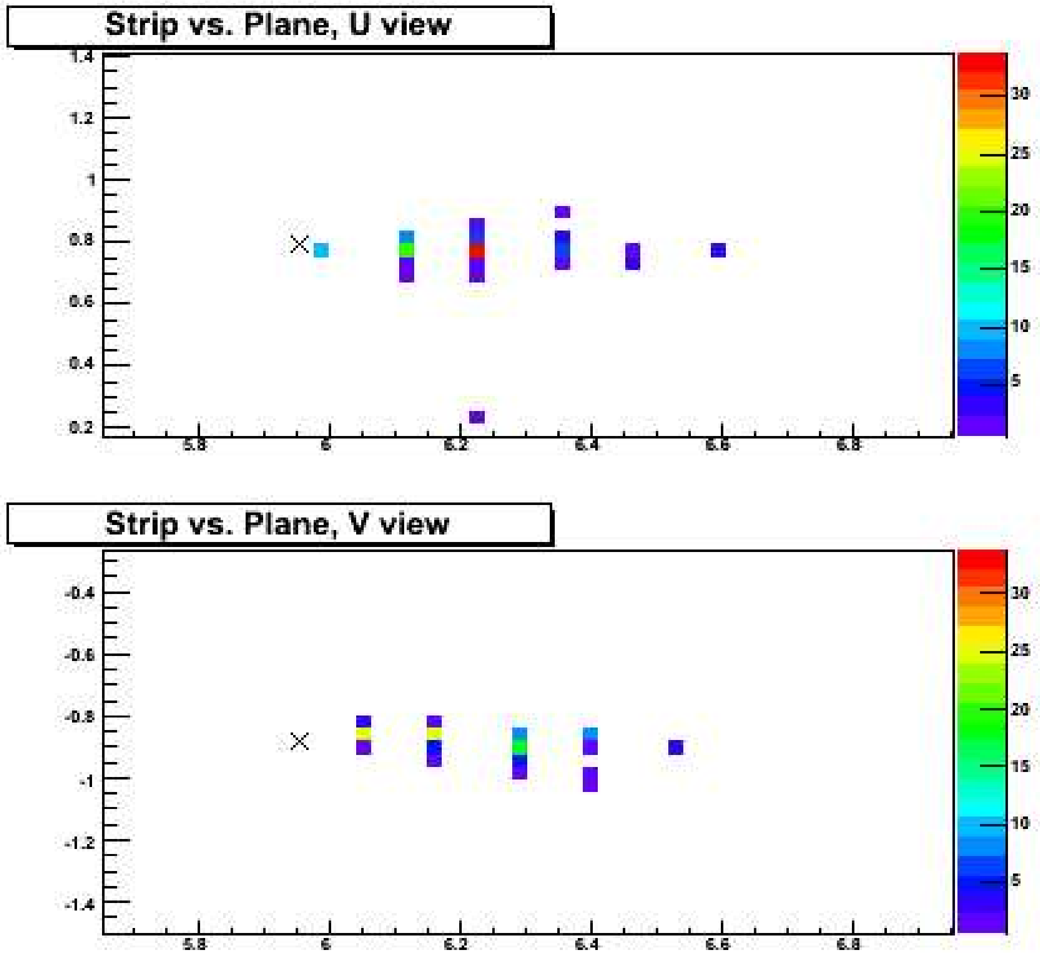
- The statistics for the CC DIS sample (for a total of $7.4 * 10^{20}$ protons on target)
  - ν sample - $2.6 * 10^6$ (NUTEV/CCFR - $1.0 * 10^6$)
  - $\bar{\nu}$ sample - $0.3 * 10^6$ (NUTEV- $0.3 * 10^6$,CCFR - $0.8 * 10^6$)
- The measurement will be systematics limited.

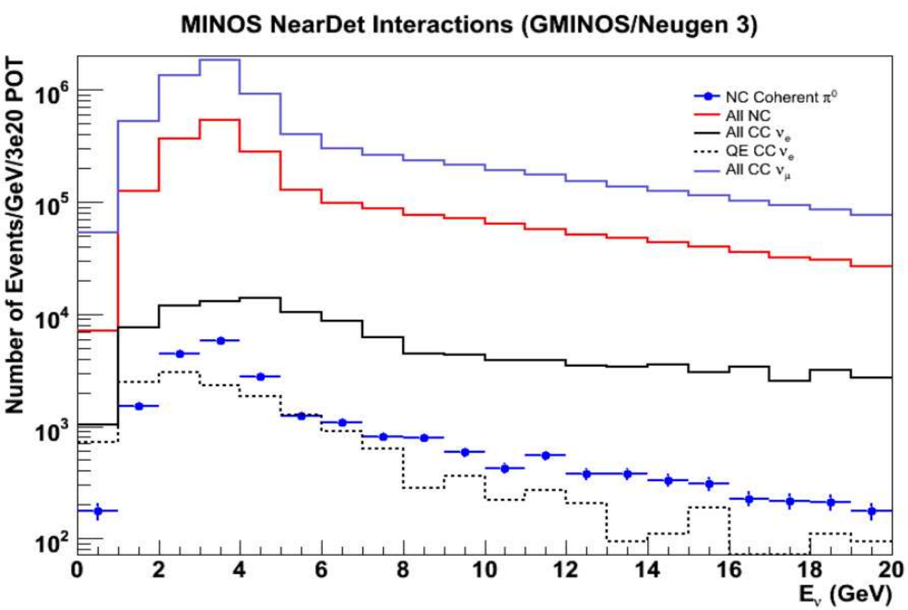


NC Coherent π^0 Production

- Neugen3 predicts 17,000 events for 3×10^{20} protons on target (fiducial mass 33 ton).
- ν_μ + A $\rightarrow$ ν_μ + A + π^0 (First NC measurement on a heavy target).
- Main backgrounds
  - other NC events.
  - CC ν_e
- Analysis also important for understanding ν_e appearance background.

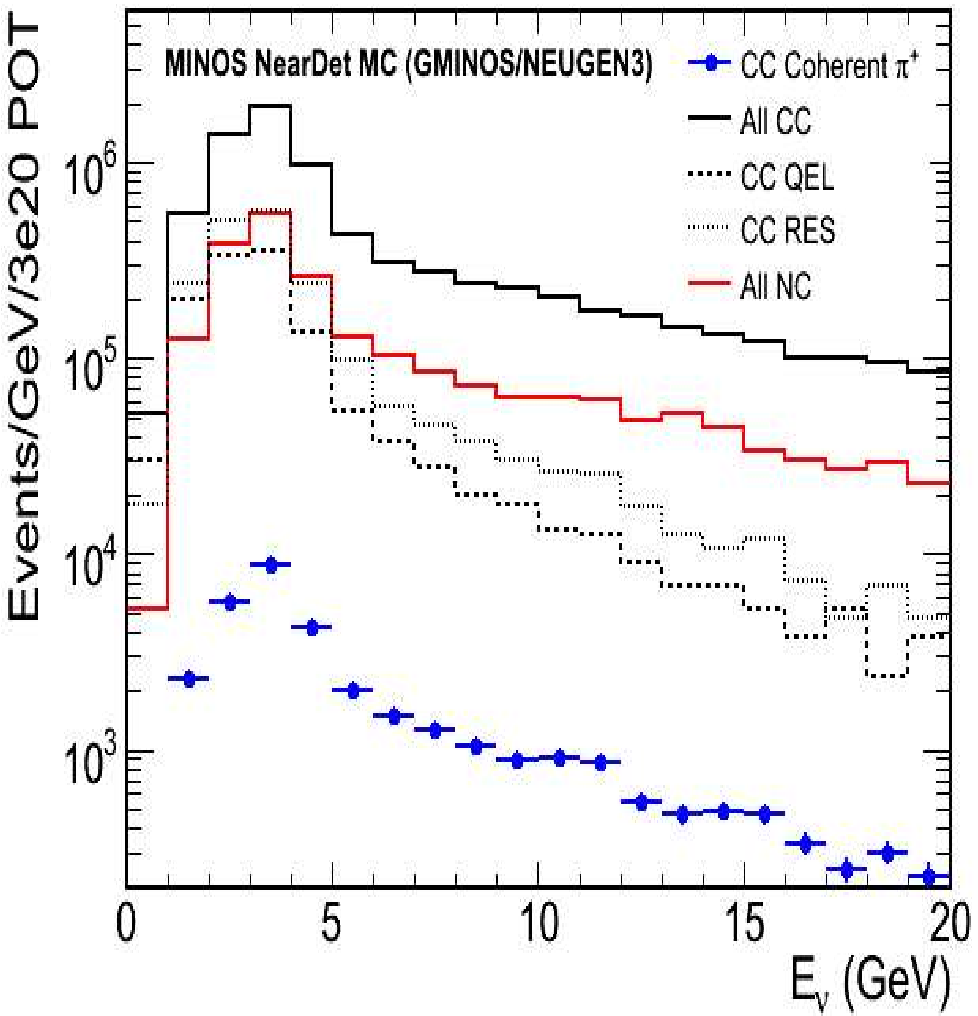
MINOS MC NC Coherent Event





Prospects of CC Coherent Analysis

- Neugen3 predicts 27,000 events for 3×10^{20} protons on target (fiducial mass 33 ton).
- ν_μ + A $\rightarrow \mu^-$ + A + π^+.
- Main background
  - Other CC events with low shower energy.
- High statistics
  - But reconstruction and selection will be a challenge because of segmentation
- Dominant uncertainty will be most likely from background contamination subtraction.



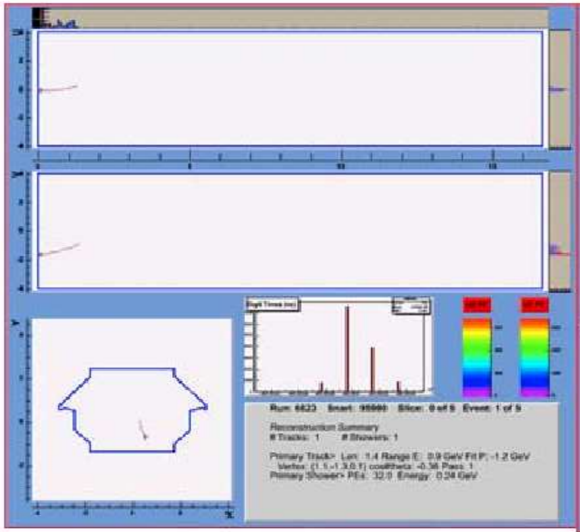
Summary

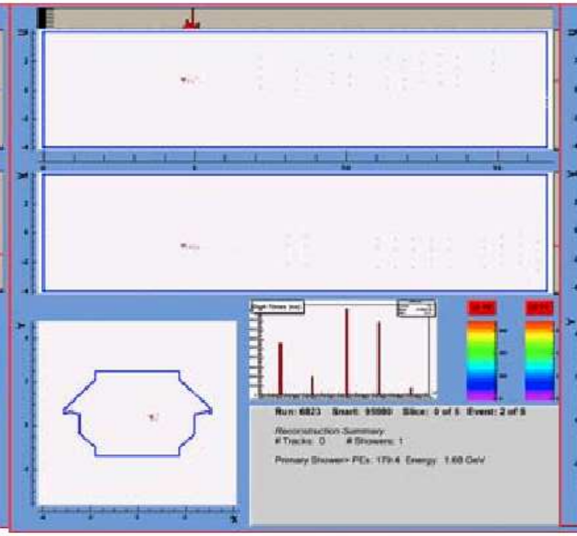
- Intense NUMI beam and high interaction rate offer oppurtunities for exploring cross-sections at low energy and rare channels.
- Some analyses underway
  - Flux extraction.
  - Total ν_μ CC and $\bar{\nu}_\mu$ CC cross-section shape extraction.
  - QEL parameters.
  - Stay tuned for results.
- Also ongoing
  - DIS differential cross-section extraction.
  - Structure Function extraction.
  - Coherent production cross-section.

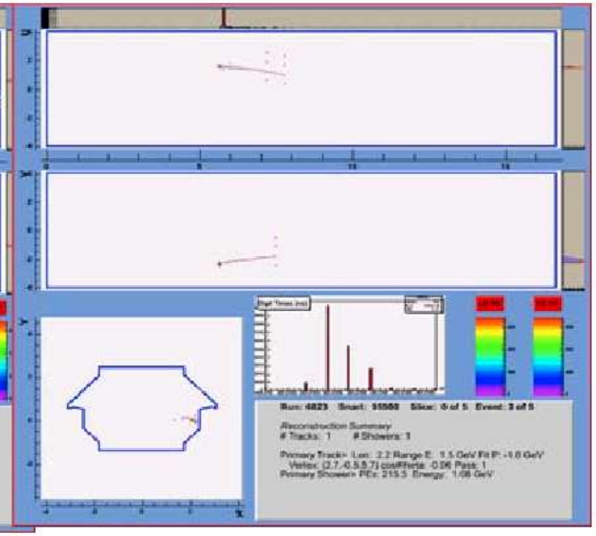
BACKUP SLIDES

Near Detector Data

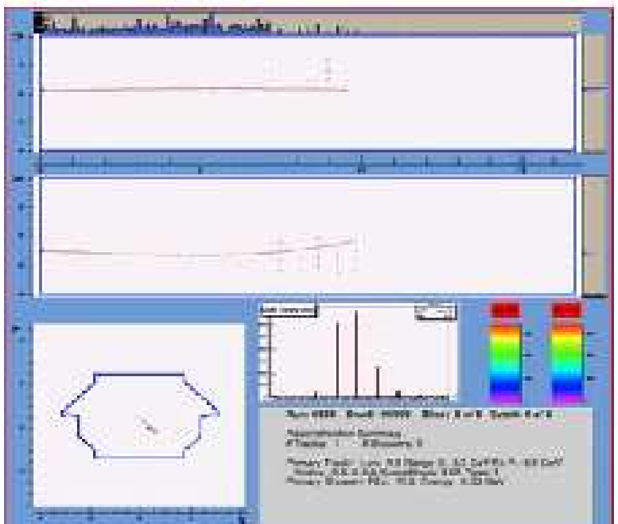
slice 1 , slice 4 , slice 5

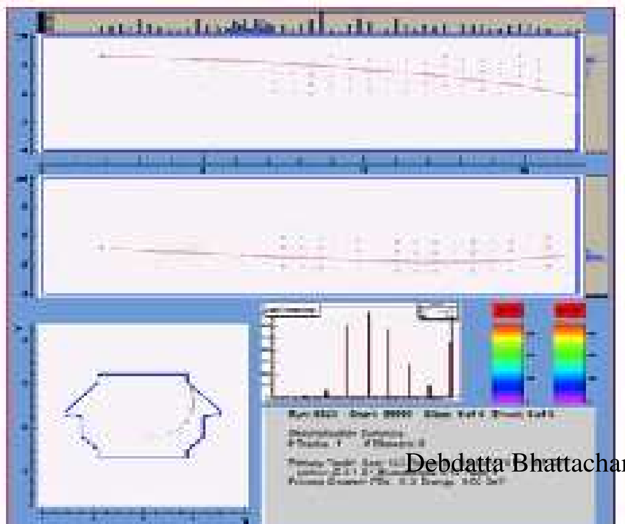






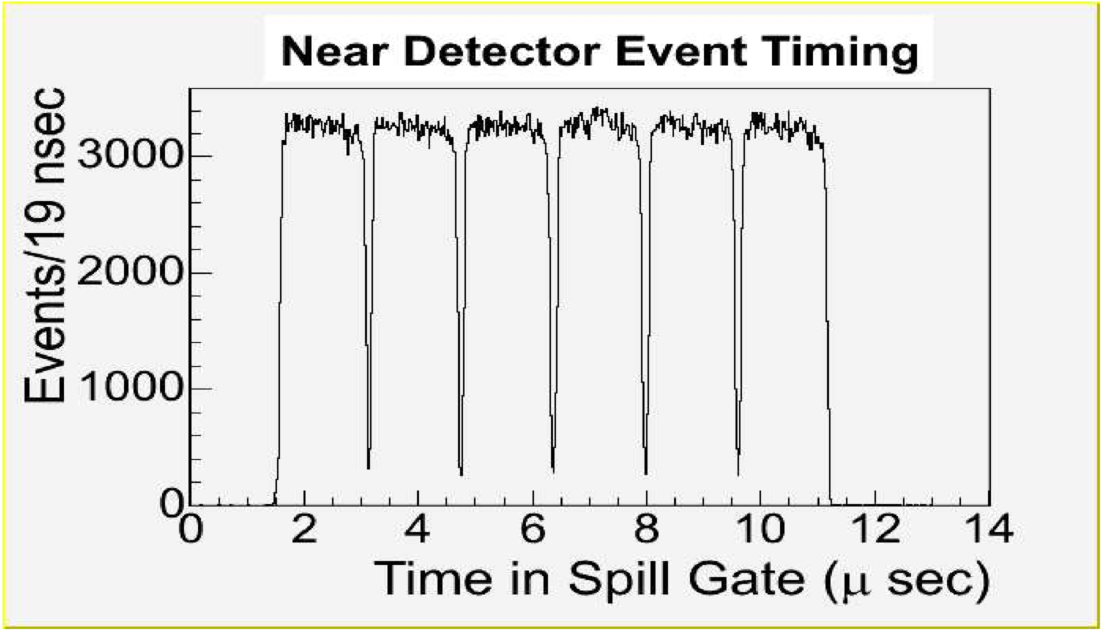
slice 2 , slice3



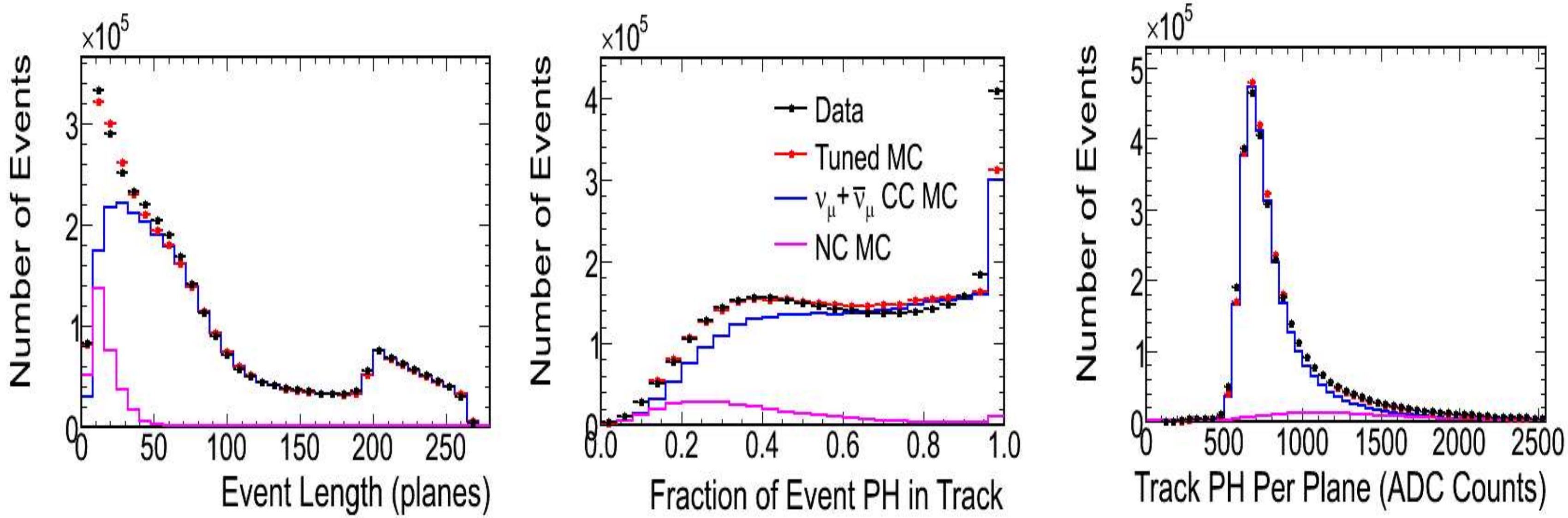


Special Runs

- ND reversed field runs, taking reversed field for 1 week, followed by a week of normal field, etc, up to a month of accumulated reverse ND field data. Weeks are alternated so as to keep tabs on detector stability using standard configuration data.
- High Energy Runs - These Runs were recorded between Jun 11, 2006 and Aug 13, 2006. In that run period, NuMI recorded 15.97 x E18 POT.
- Medium-High Energy Runs - These Runs were recorded between Jun 1, 2006 and Jun 11, 2006. In that run period, NuMI recorded 1.86 x E18 POT.



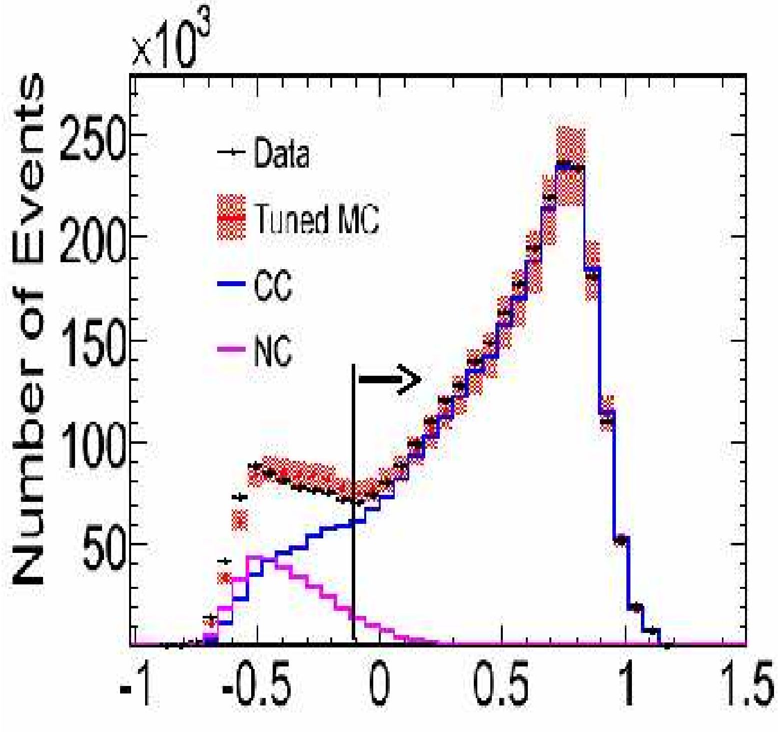
CC/NC Classification



CC-like and NC-like probability variables(P_{CC} and P_{NC}) are constructed from the product of the 3 PDFs for each event.

Event Classification Parameter

$$-(\sqrt{-log P_{CC}} - \sqrt{-log P_{NC}})$$



Quasi-Elastic Flux Extraction

Details of the qel display	effi ciency 90%
true P_μ = 2.1 GeV/c,proton = 0.7 GeV/c	high purity 70%(Ehad=0)
muon travels another 3 m and	moderate purity 60%(low Ehad)
bends to the centre of the detector.	modest purity 45%(two tracks)

- σ_{QEL} reasonably well constrained and flat with energy.
  - Select QEL enriched sample between 0.5 and 30 GeV $\rightarrow$ flux shape.
- Inclusive σ_{CC} is well known above 30 GeV on iron
  - Inclusive CC sample 10-30 GeV - flux normalization.

Selected Events

NC Background

$$\Phi(E) = \frac{\text{n(E)} - \text{n\_NC(E)}}{\sigma_{QEL}(E)\epsilon_{QEL}(E) + \sigma_{RES}(E)\epsilon_{RES}(E) + \sigma_{DIS}(E)\epsilon_{DIS}(E)}$$

Cross-Sections MC

Selection Efficiencies

Low ν Flux Measurement

- Start with the differential cross section equation , integrate over x for fixed ν

$$A = \frac{G_F^2 M}{\pi} \int F_2(x)dx$$
$$B = -\frac{G_F^2 M}{\pi} \int (F_2(x) \mp xF_3(x))dx$$
$$C = B - \frac{G_F^2 M}{\pi} \int F_2(x)(\frac{1+2Mx/\nu}{1+R} - \frac{Mx}{\nu} - 1)dx$$

$$\frac{d\sigma}{d\nu} = A(1 + \frac{B}{A}\frac{\nu}{E} - \frac{C}{A}\frac{\nu^2}{2E^2})$$

- At small $\nu/E \rightarrow \frac{d\sigma^{\nu}}{d\nu} = \frac{d\sigma^{\overline{\nu}}}{d\nu} = A$ relative flux is given by: $\Phi(E_\nu) \propto N(E_\nu)_{(\nu\rightarrow 0)}$

- Use the total cross-section to get the flux normalization.

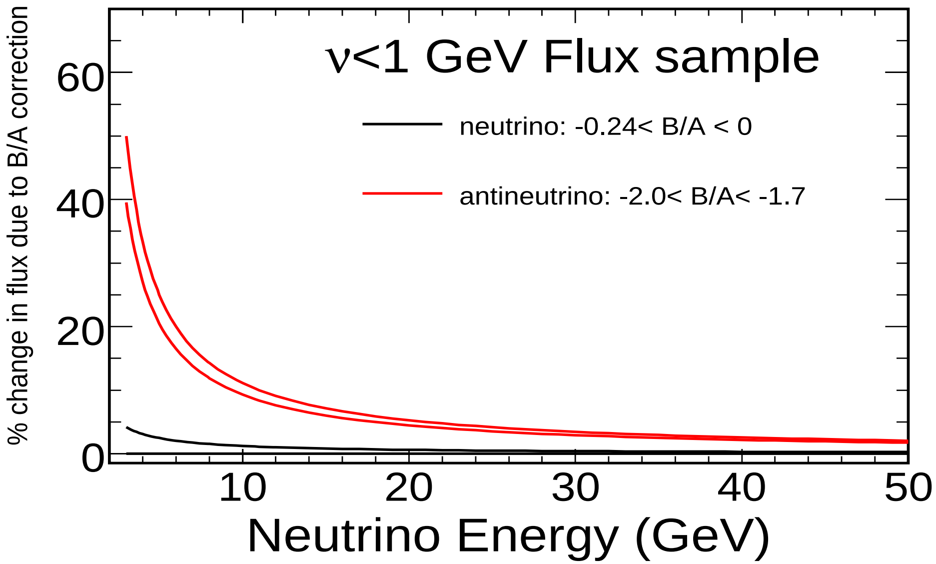
Event Selection	Flux will be used for
$p_\mu > 2$ GeV	tuning MC
$E_{\text{shw}} < 1$ GeV for $E_\nu < 10$ GeV	extracting the total cross-section shape
$E_{\text{shw}} < 2$ GeV for $10 < E_\nu < 50$ GeV	DIS analysis

Flux Measurement

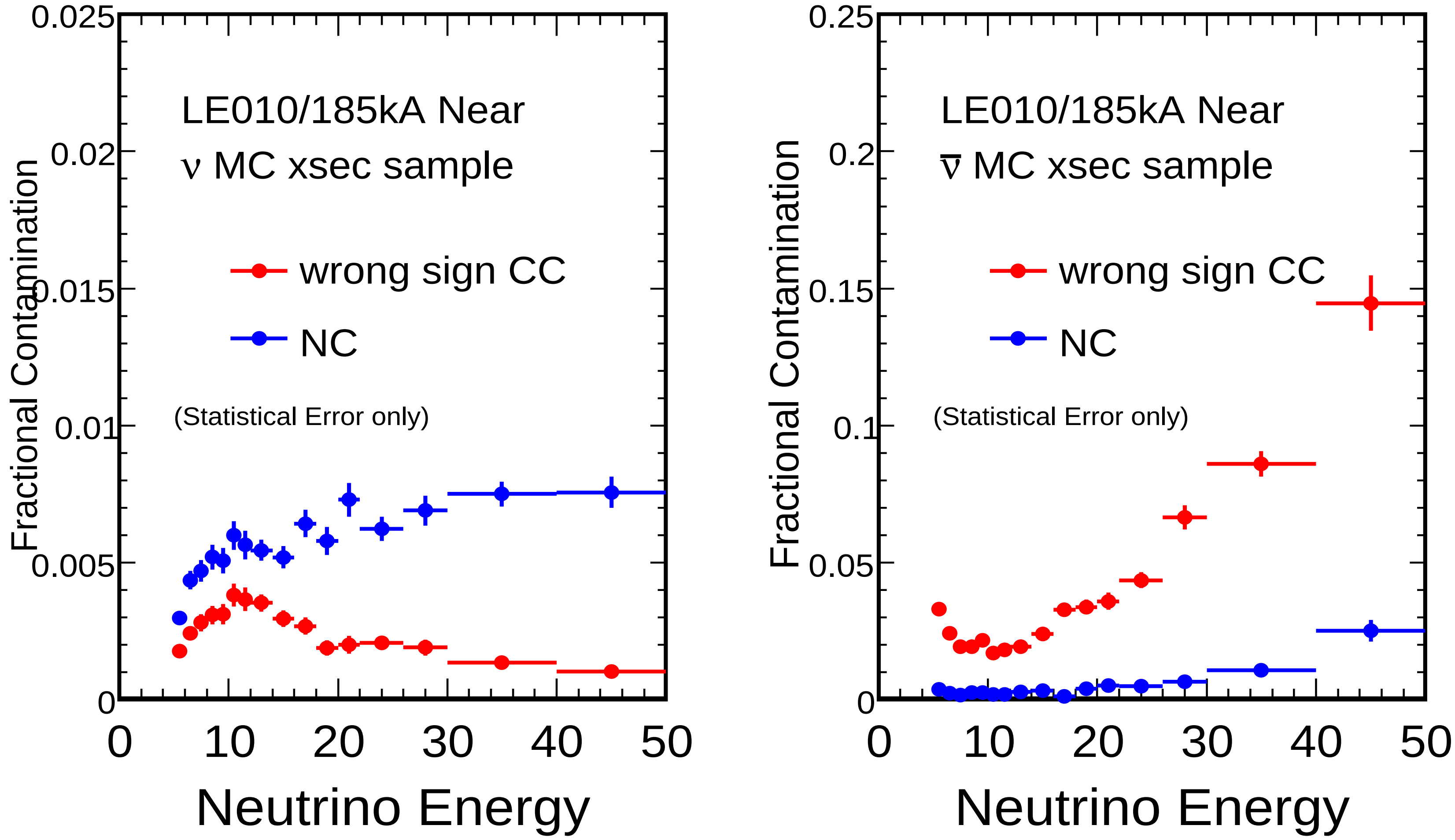
- Event Selection $p_\mu > 2$ GeV. Flux sample is selected by
  - $E_{\text{shw}} < 1$ GeV for $E_\nu < 10$ Gev.
  - $E_{\text{shw}} < 2$ GeV for $10 < E_\nu < 50$ Gev.
- Acceptance correction applied from Monte Carlo.
- Cross-section model used to apply corrections to the low ν sample.

Systematics from the B/A correction

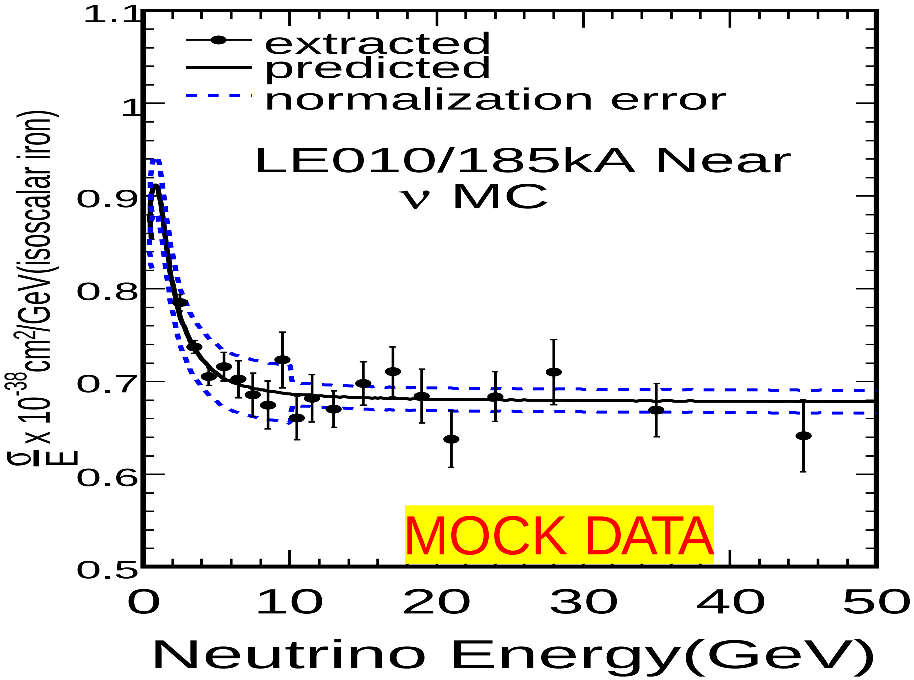
- Bands computed from physical limits
  - Neutrino: -0.24<B/A<0
  - Antineutrino: -2.0<B/A<-1.7

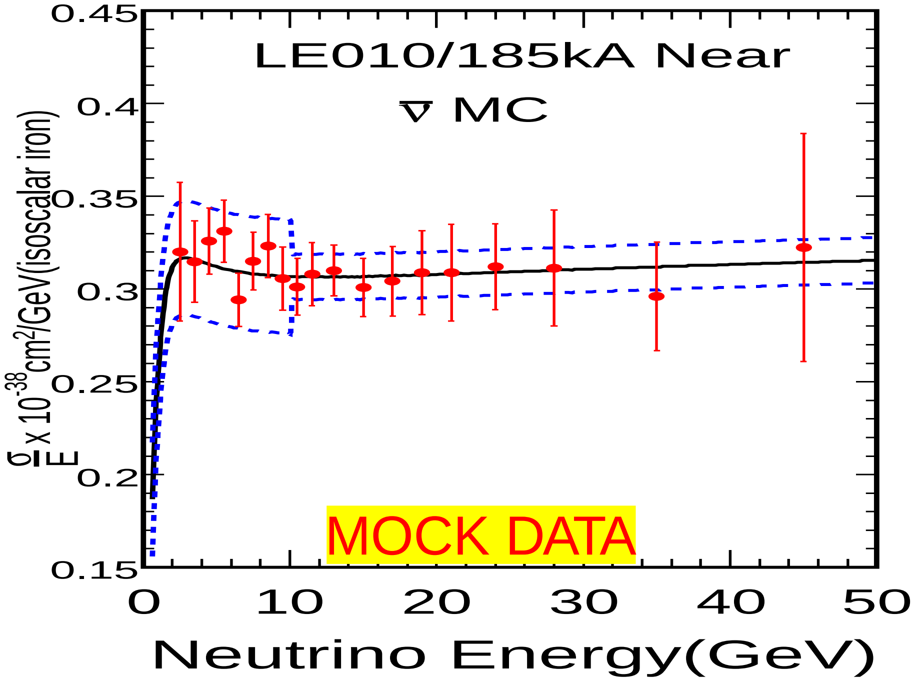


Fractional Contamination



Total Cross-Section Shape





- Cross-section: $\sigma_{CC}(E) = \Phi(E)^{-1}(E)N_{CC}(E)f_{\text{ACC}(E)}$
  - Energy dependence only: norm. to world average at high energy.
- Event Selection : $p_\mu > 2$ GeV, separate by muon charge.
- Purity: $\nu_\mu > 99.4\%$, $\bar{\nu}_\mu > 92\%$.