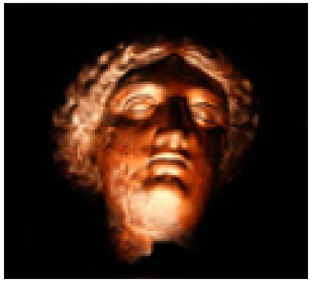
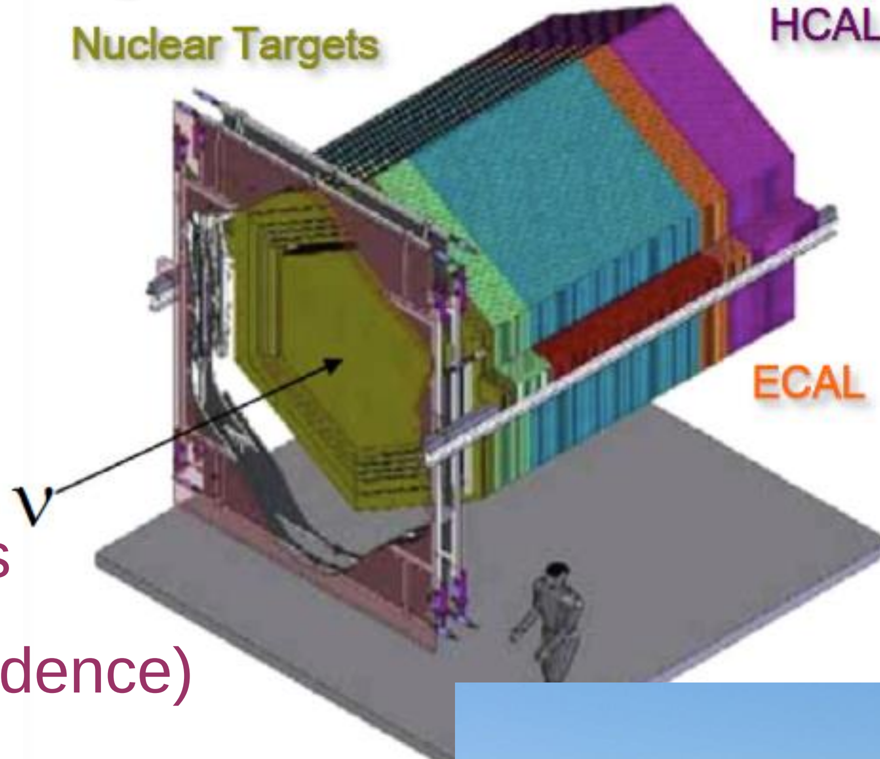


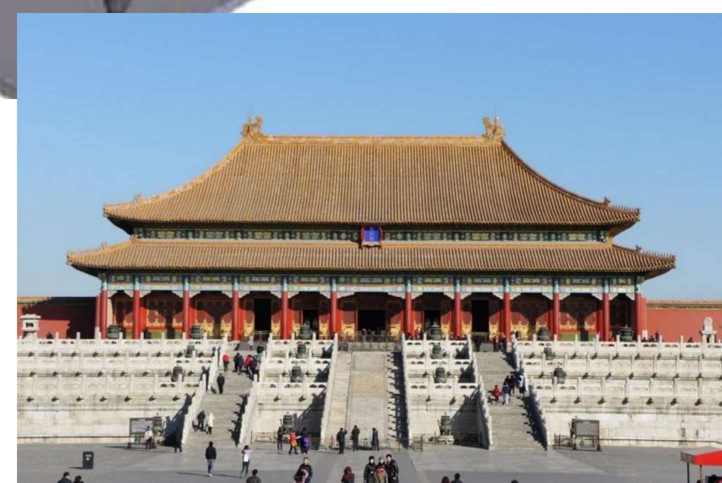
Charged Current Inclusive Scattering in MINERνA



- What is Minerνa ?
- Why Minerνa ?
- ν beam and ν flux
- $\bar{\nu}$ / ν inclusive x-sections
- x-section ratios (A-depndence)
- Outlook

Alessandro Bravar
for the Minerνa Collaboration

NUFACT 2013
August 21st '13

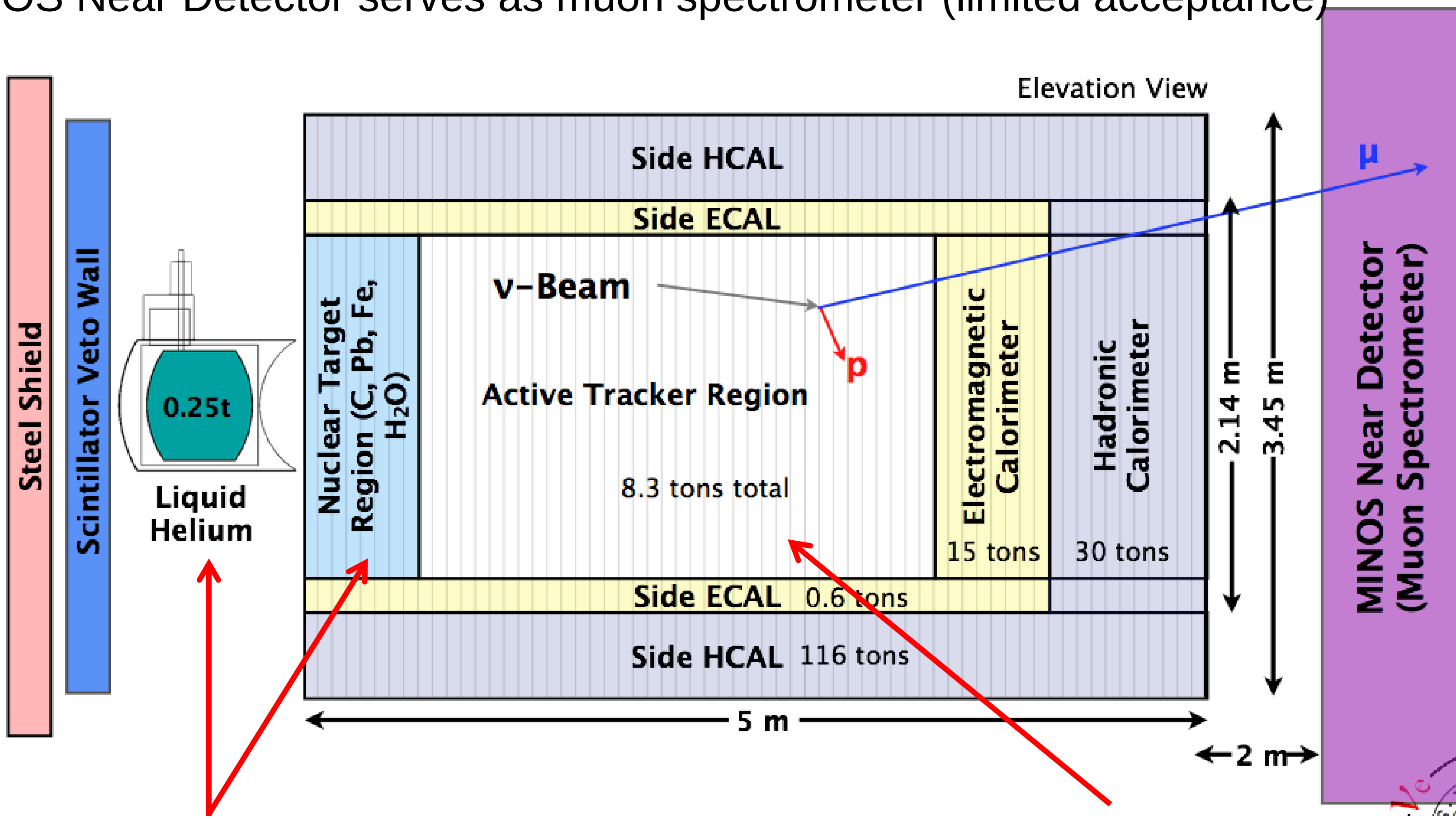


The MINERνA Detector

120 plastic scintillator modules for tracking and calorimetry (~32k readout channels)

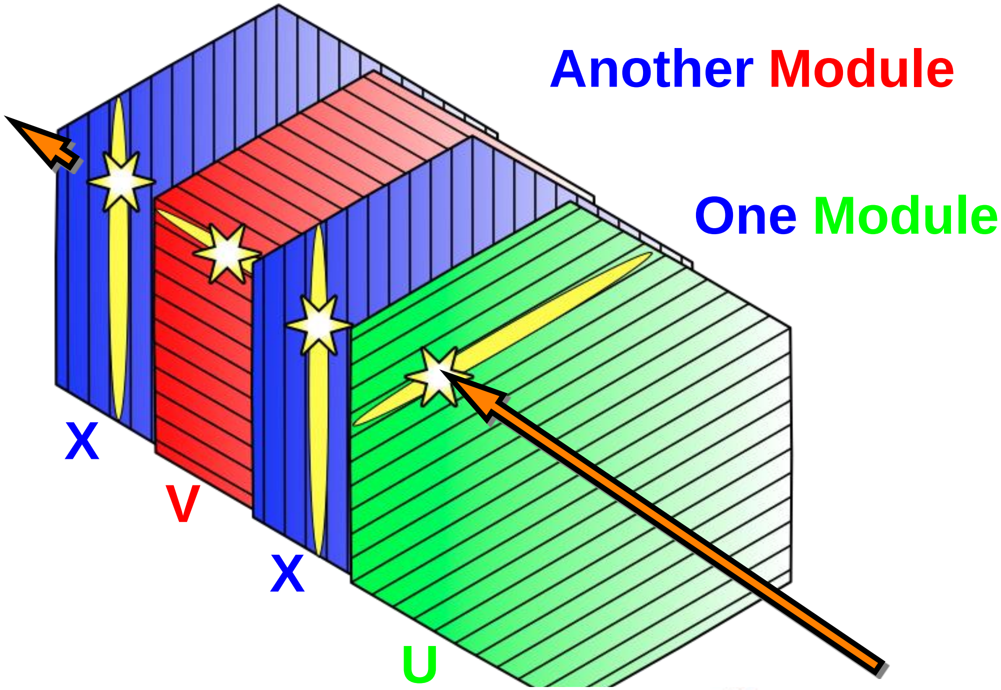
Construction completed in Spring 2010. He and H_20 targets added in 2011

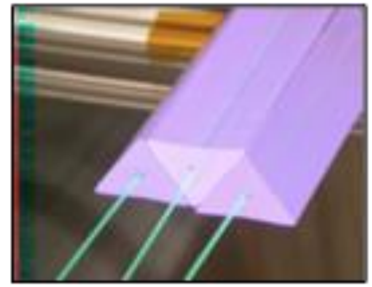
MINOS Near Detector serves as muon spectrometer (limited acceptance)



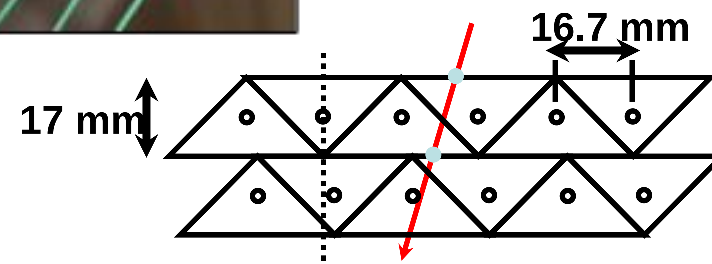
nuclear targets: He, C, H_20, Fe, Pb

fully active scintillator tracker

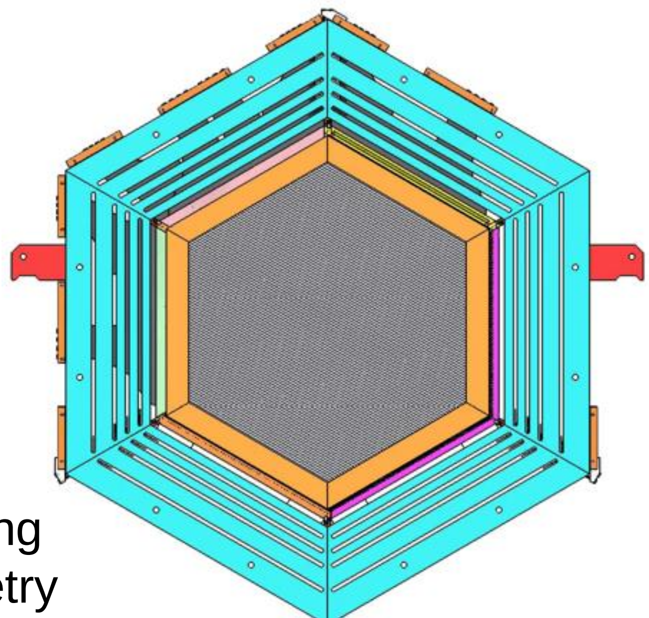




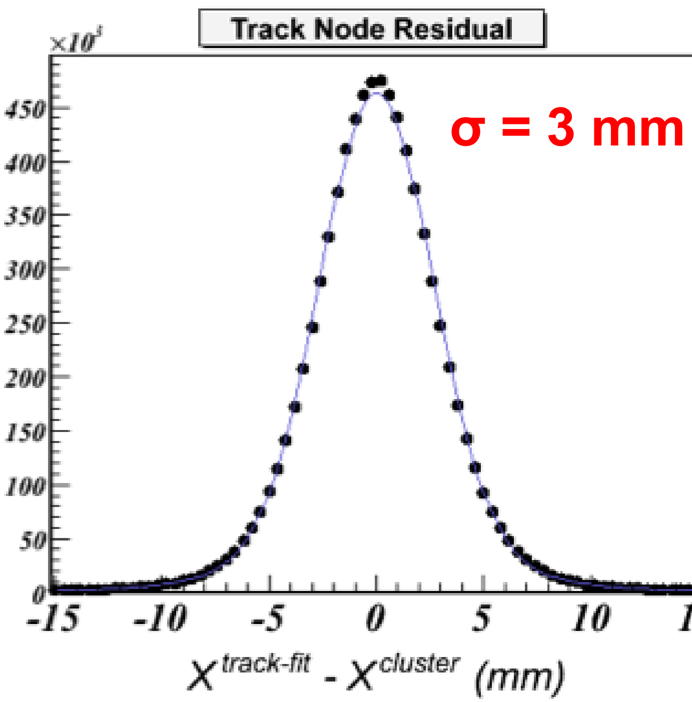
triangular scint. bars
with WLS fiber readout



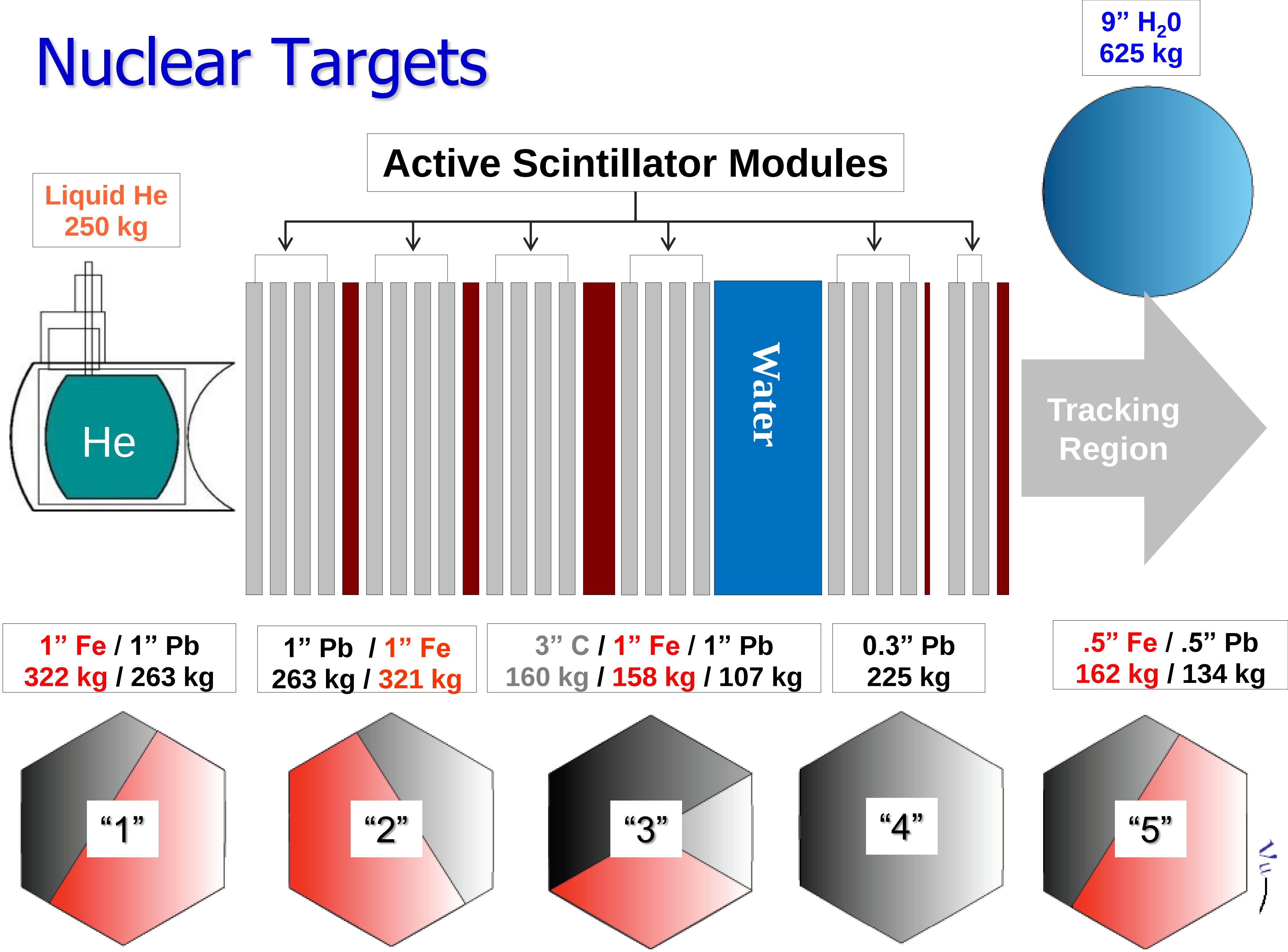
Charge sharing for improved position resolution (~3 mm) and alignment



Scintillator - tracking
Lead - EM calorimetry
Steel - hadronic calorimetry



Nuclear Targets



Why MINERνA ?

existing ν scattering data (~1 – 20 GeV) poorly understood
- mainly (old) bubble chamber data
- low statistics samples
- large uncertainties on ν flux

need detailed understanding of ν_μ and anti-ν_μ cross sections

ν oscillation
- precision neutrino oscillation measurements
- all experiments use nuclear targets (C, $H_2$0, Ar, Fe)
  - → additional complications whose impact needs to be understood

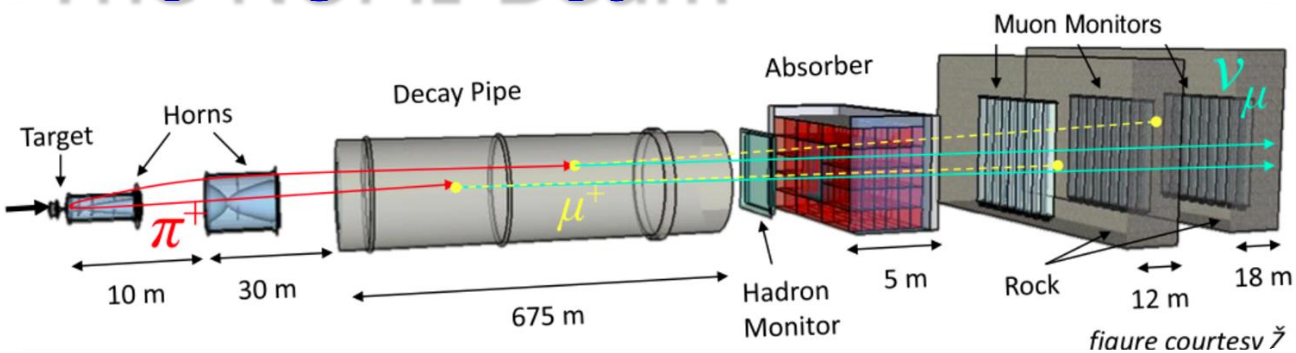
neutrinos – weak probe of nuclear (LE) and hadronic (ME) structure

elastic : axial form factors of the nucleon

inclusive : measure absolute cross section off the scintillator tracker (HC target) and cross section ratios off nuclear targets
- quark structure of the nucleon (parton distribution functions)
- nucleons are confined in nuclei and are not free
  - → expect deviations from ν – *free* nucleon (p or n) interactions
  - → quark densities modifications in nuclei (EMC effect)

MINERνA : transition region from exclusive states to DIS

The NUMI Beam



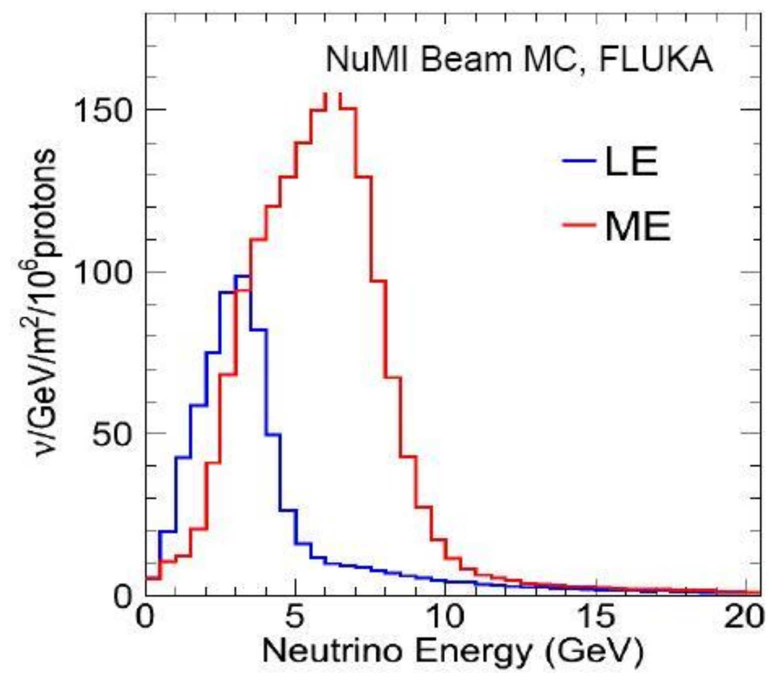
NuMI (Neutrinos at the Main Injector)

- 120 GeV protons from Main Injector, ~ 300 - 350 kW
- 90 cm graphite target
- 675 m decay tunnel

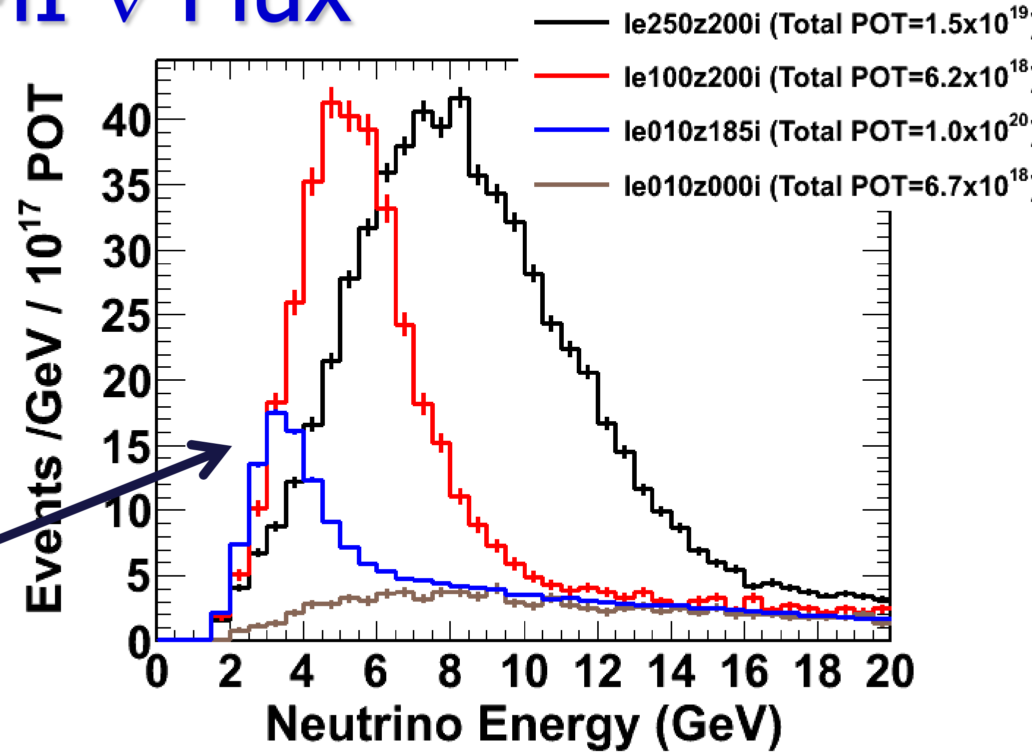
By moving the production target w.r.t. 1st horn one can modify the ν spectrum:
LE (peak ~3 GeV) $\rightarrow$ ME (peak ~6 GeV)

Flux determination

- muon monitor data
- special runs (vary beam parameters)
- ν_μ – electron scattering
- low–ν method
- external hadron production data

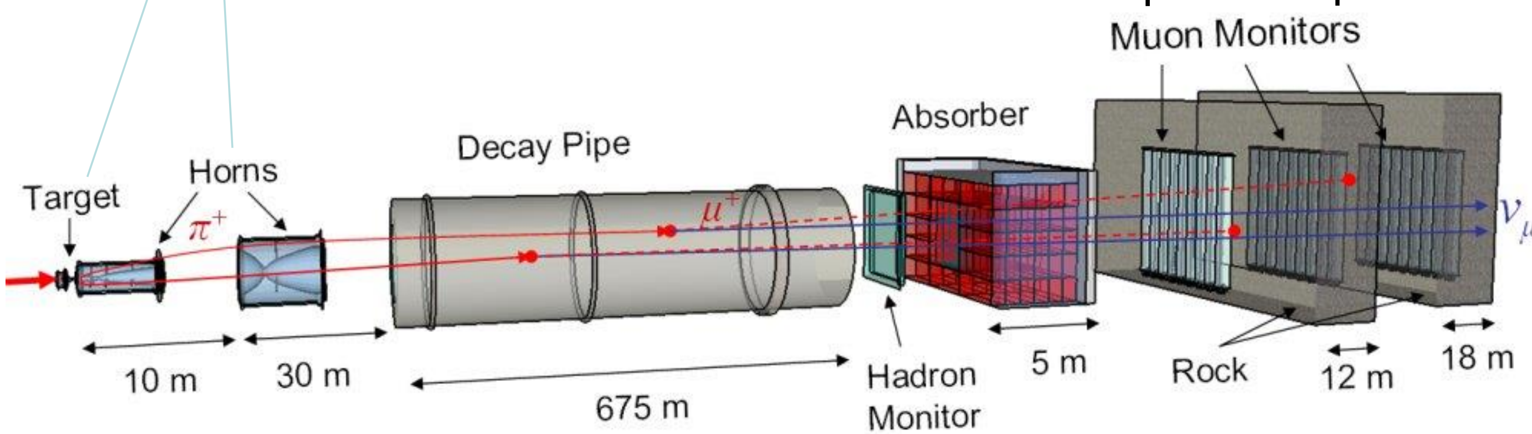


Understanding NuMI ν Flux



Vary the target position and the horn current to change the flux spectrum.

Monitor spread of μ± from π± decay

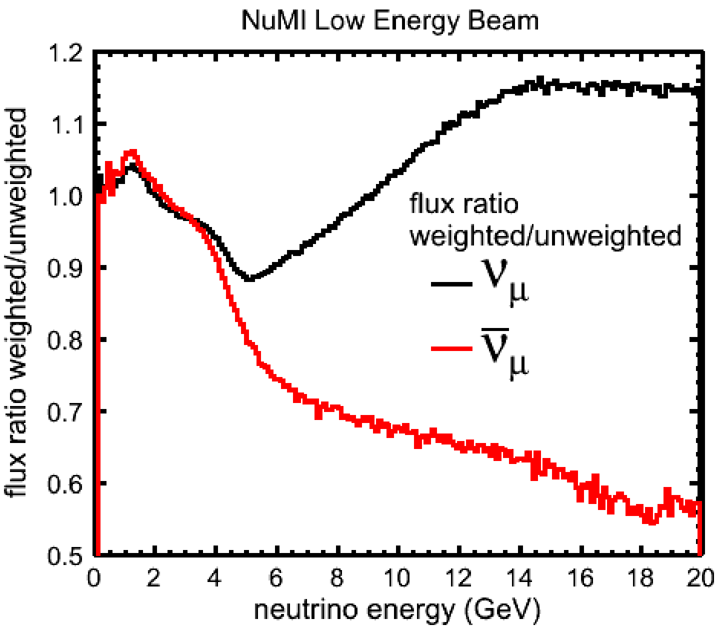


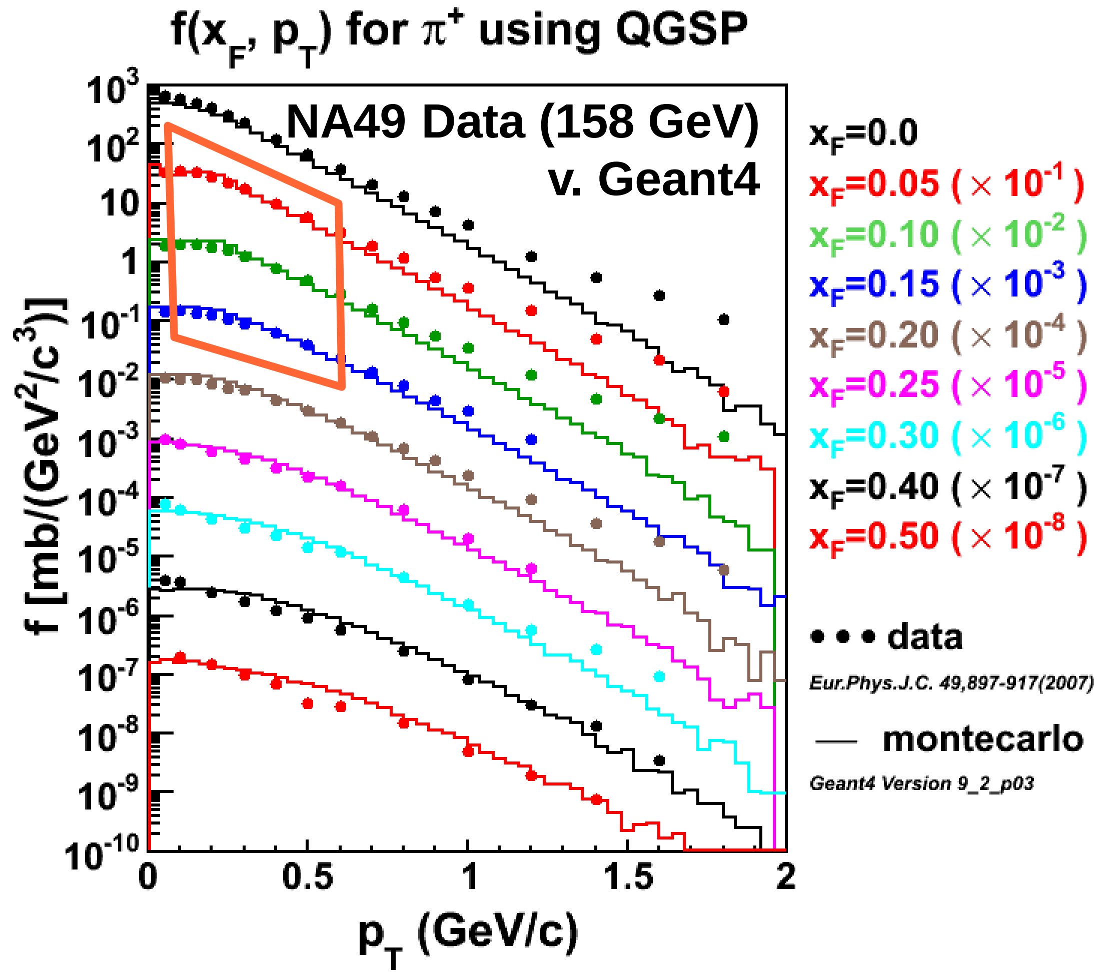
MINERνA

Tuning to Hadron Production Data

Hadron production simulated with Geant4 to predict flux.

Flux is reweighted based on hadron production data compared to Geant4.

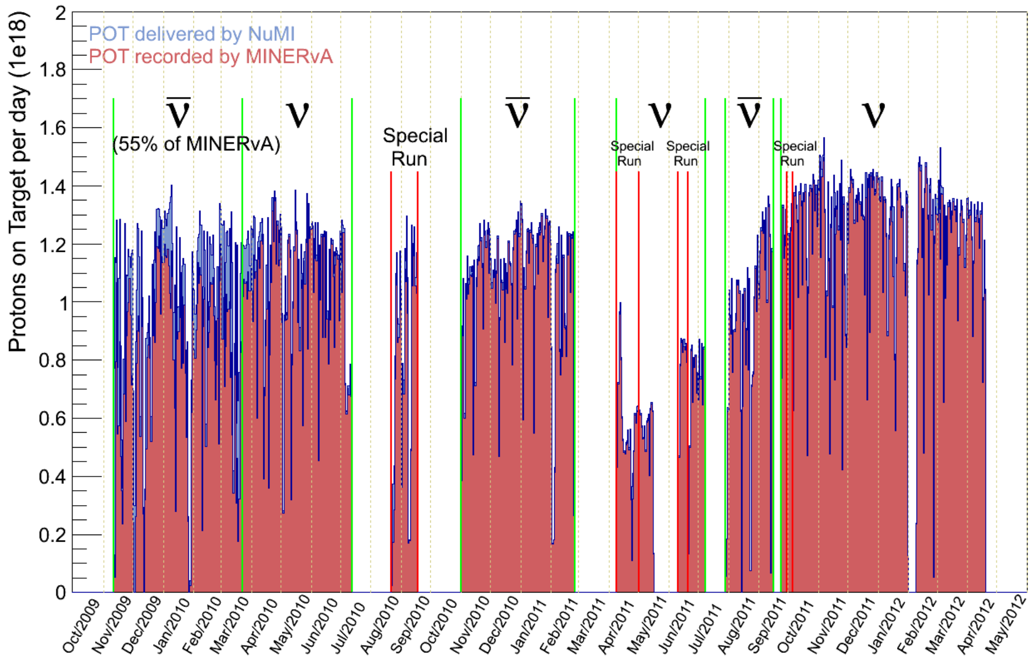


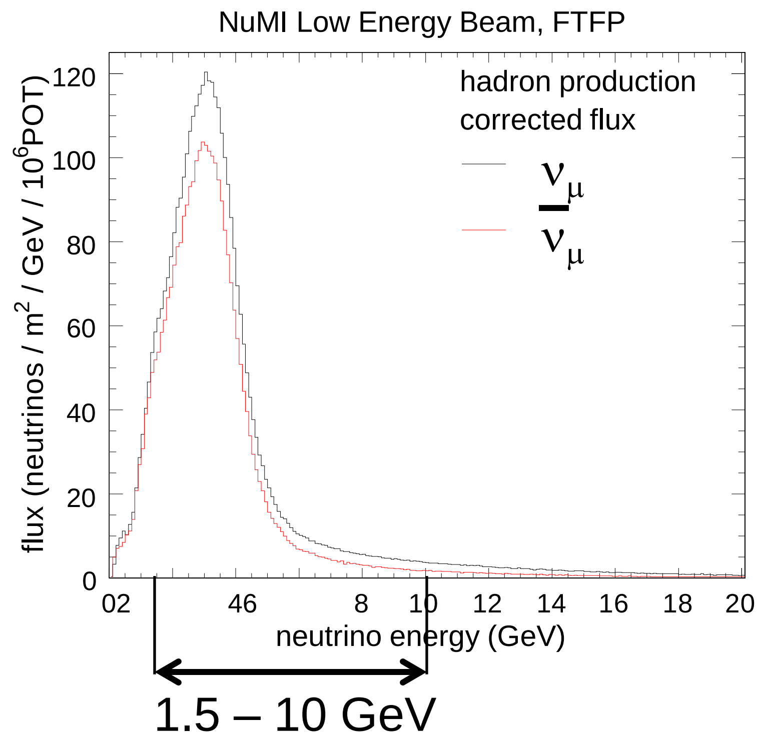


New hadron production data at 120 GeV

NA61 : p + C at 120 GeV using NuMI replica target in 2015 ?

Collected Data





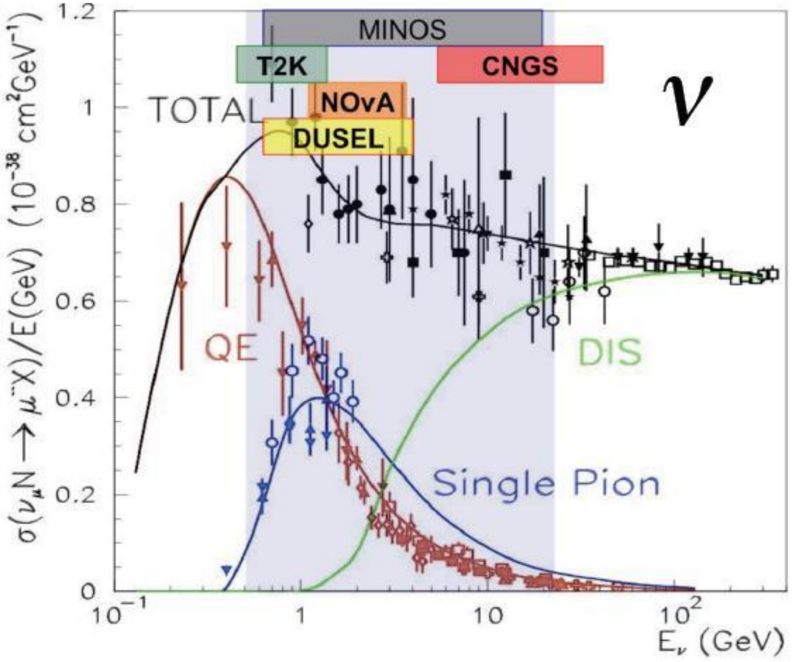
Low Energy (LE, peak ~3 GeV) run
2010 – 2012

LE ν mode 3.9 x 10^{20} POT
LE anti-ν mode 1.7 x 10^{20} POT
flux-calibration 4.9 x 10^{20} POT

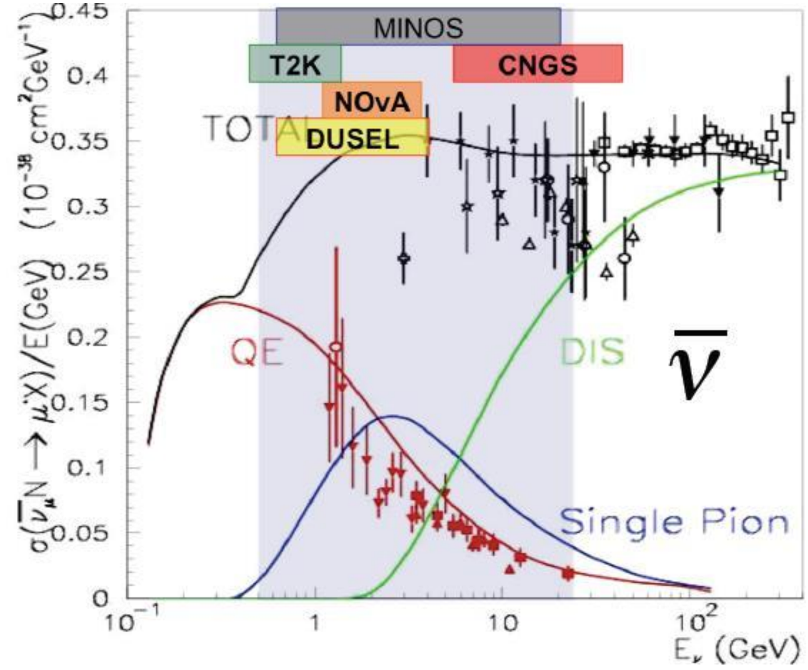
Medium Energy (ME, peak ~6 GeV) run
about to start → 2018 (NOνA era)
ν and anti-ν running

Target	Fiducial Mass	ν_μ CC Events in 4×10^{20} POT
Plastic	6.43 tons	1363k
Helium	0.25 tons	56k
Carbon	0.17 tons	36k
Water	0.39 tons	81k
Iron	0.97 tons	215k
Lead	0.98 tons	228k

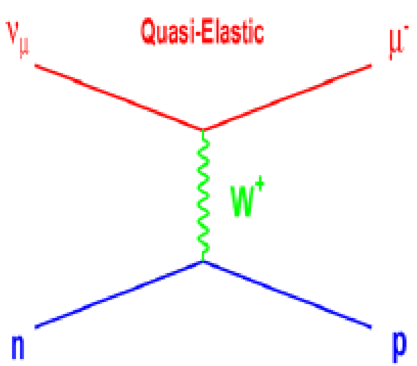
ν ×-sections



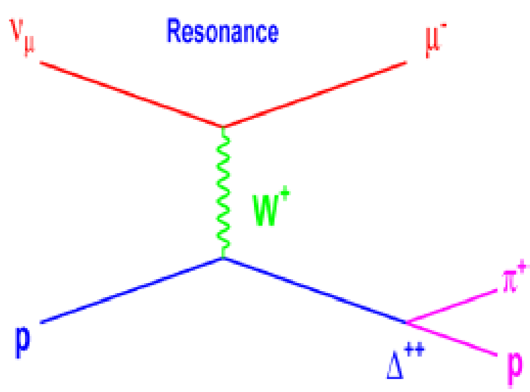
MINOS
T2K
CNGS
NOvA
DUSEL
TOTAL
QE
DIS
Single Pion
ν
$\sigma(\nu_\mu N \rightarrow \mu^- X)/E(GeV)$ $(10^{-38}$ cm^{2}GeV$^{-1})$
E_ν (GeV)



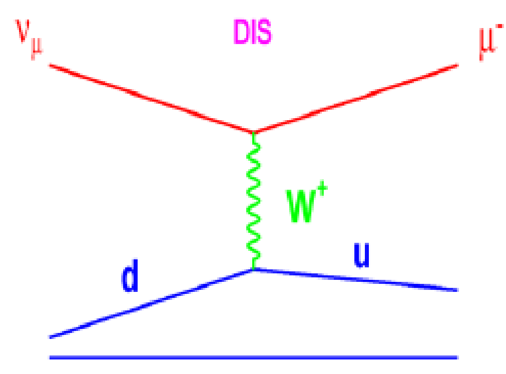
MINOS
T2K
CNGS
NOvA
DUSEL
TOTAL
QE
DIS
Single Pion
$\overline{\nu}$
$\sigma(\overline{\nu}_\mu N \rightarrow \mu^+ X)/E(GeV)$ $(10^{-38}$ cm^{2}GeV$^{-1})$
E_ν (GeV)



ν_μ
Quasi-Elastic
μ^-
W^+
n
p



ν_μ
Resonance
μ^-
W^+
p
π^+
Δ^{++}
p



ν_μ
DIS
μ^-
W^+
d
u

Probing Nucleon Structure

Charged lepton data show that quark distributions are modified when nucleon is confined (bound) in a nucleus:
PDFs of a nucleon within a nucleus are different a free nucleon.

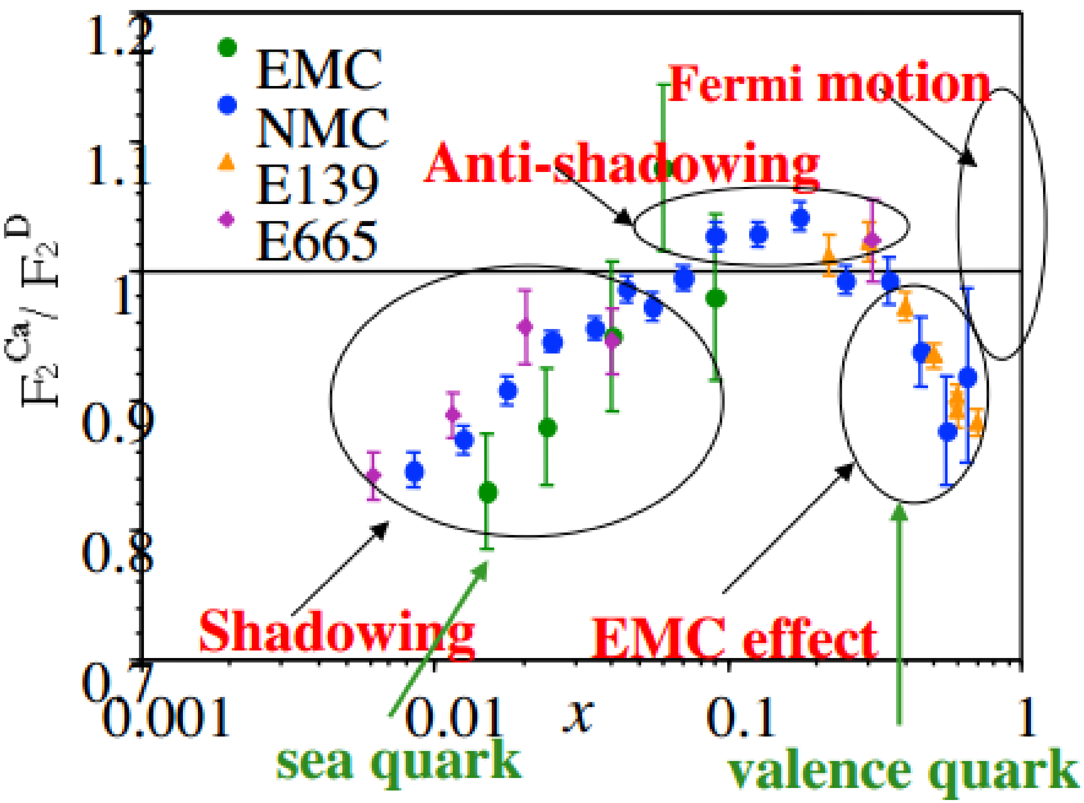
Nuclear effect in neutrino scattering are not well established.

ν probes same quark flavors
but with different "weights"
$\rightarrow$ expect different behavior

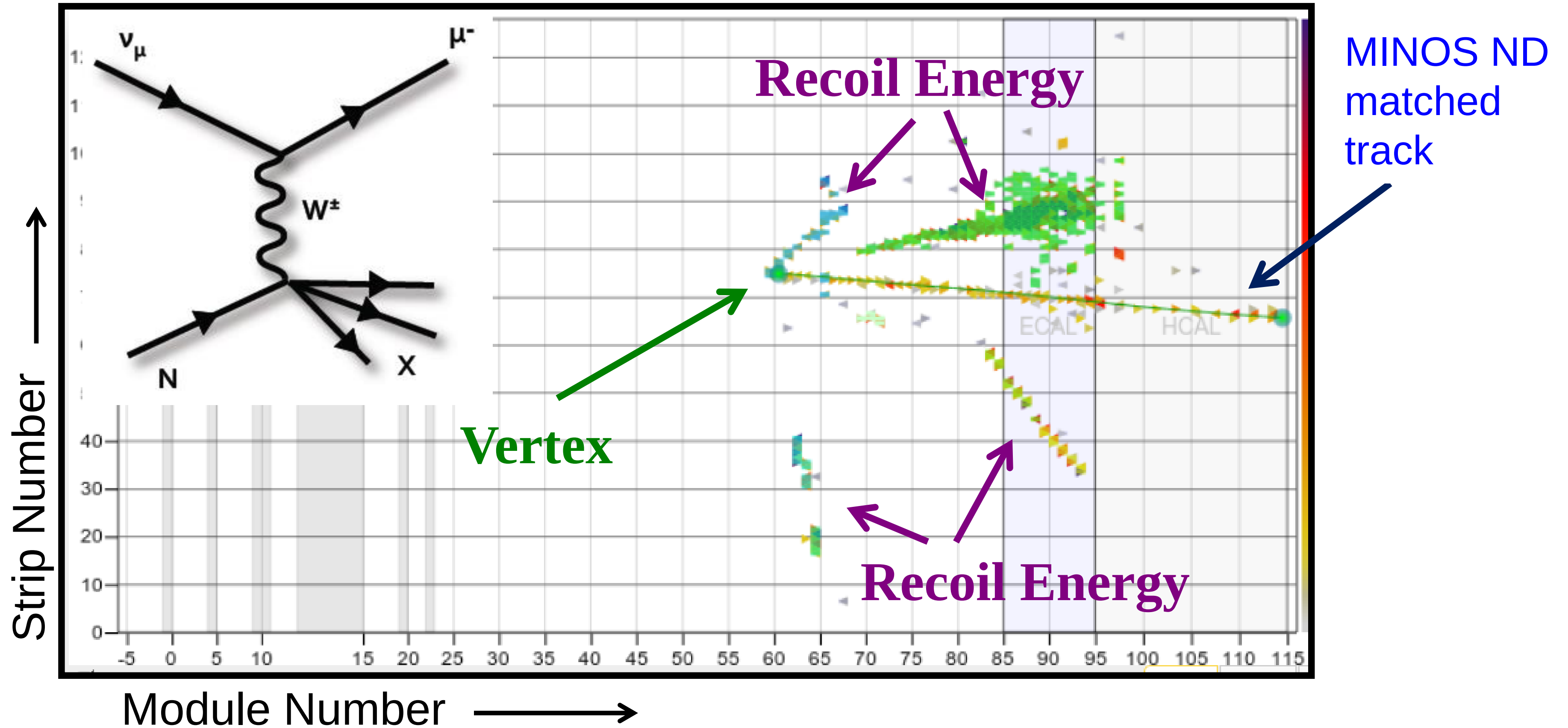
A-dependence has not been measured in ν scattering directly: experimental results to date have all involved one target material per experiment.

Should be studied over a wider range of A.

Ca / D Ratio (e / μ DIS)



Inclusive ν ×–sections



Event selection criteria :

- single muon track in MINERνA, well reconstructed and matched into MINOS ND
- reconstructed vertex inside fiducial tracker region or z position near nuclear target
- recoil energy E_{REC} reconstructed calorimetrically:
- incoming neutrino energy E_ν:

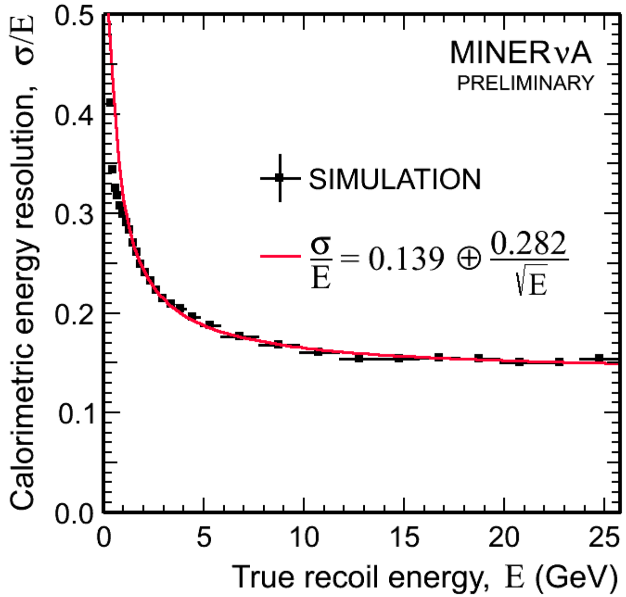
$$E_\nu = E_\mu + E_{REC}$$

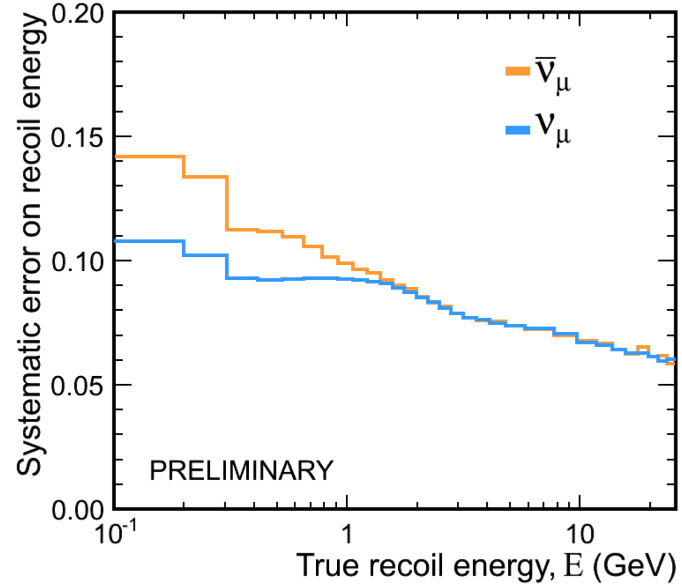
Recoil Energy

recoil energy E_{REC} reconstructed calorimetrically:

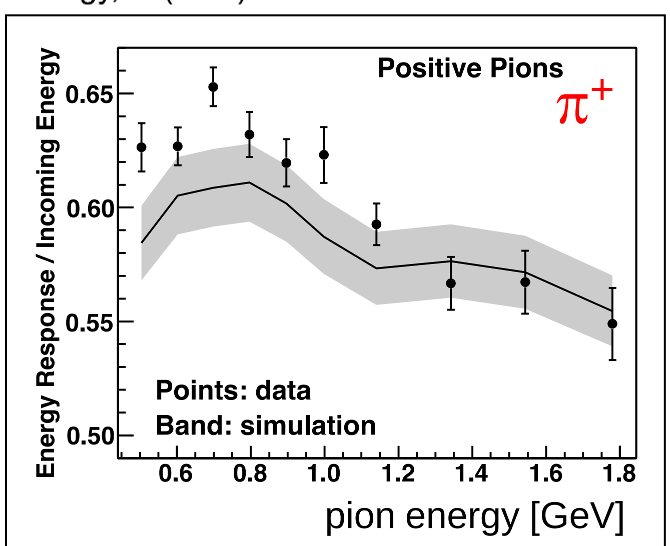
sum of visible energy, weighted by amount of passive material

calorimetric $E_{recoil} = \alpha \times \sum_i c_i E_i$





high-energy π^+ response measured in a test beam uncertainty ≈ 5%



convolution of single particle uncertainties

$\pi, K = 5\%$

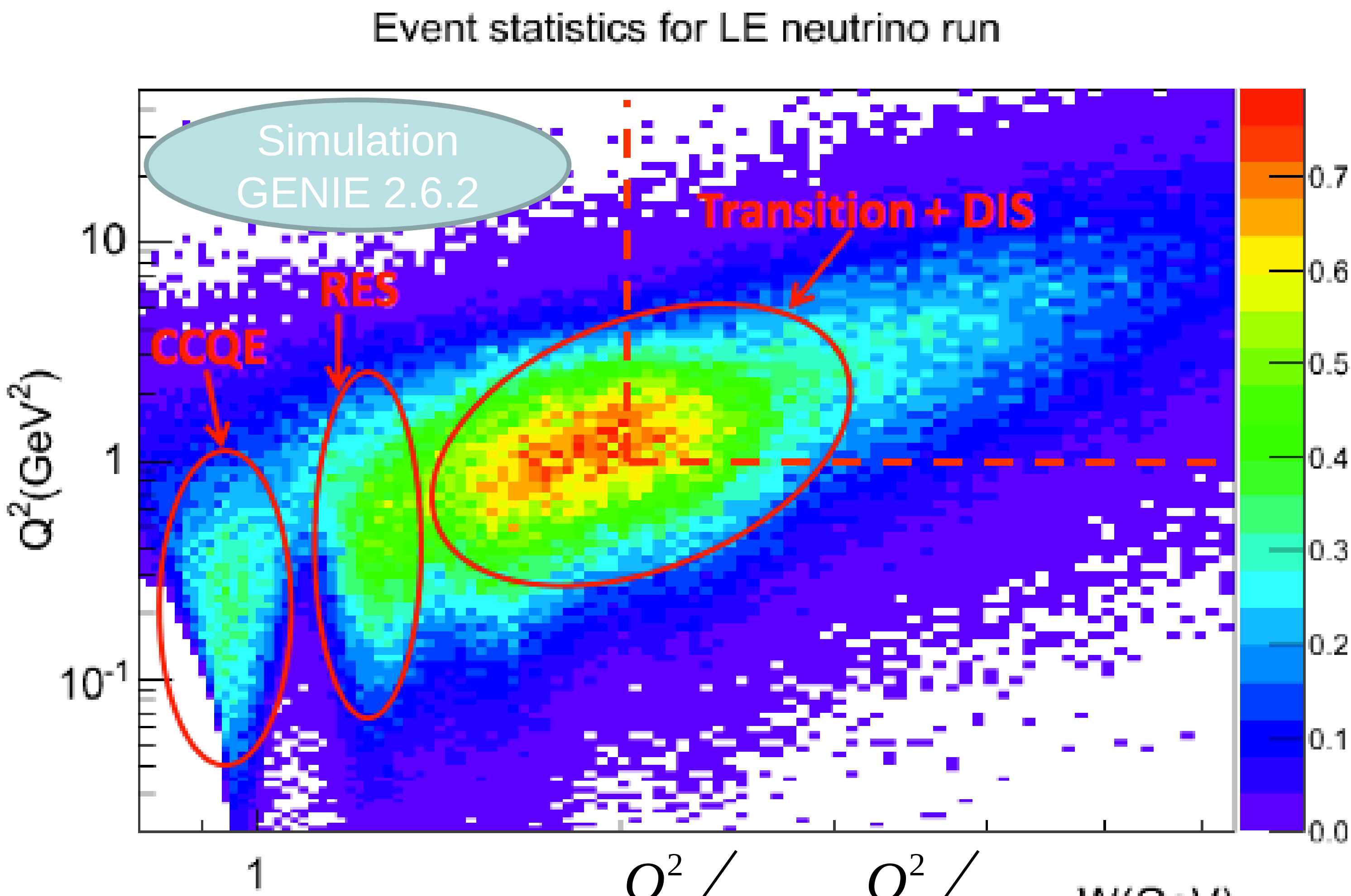
$e, \gamma = 3\%$

$p = 10\%$

$n = 20\%$

MINERνA W–Q² "Acceptance" LE (2010–12)

z axis : 10^3 events / 3 x 10^3 kg of C / 5e20POT

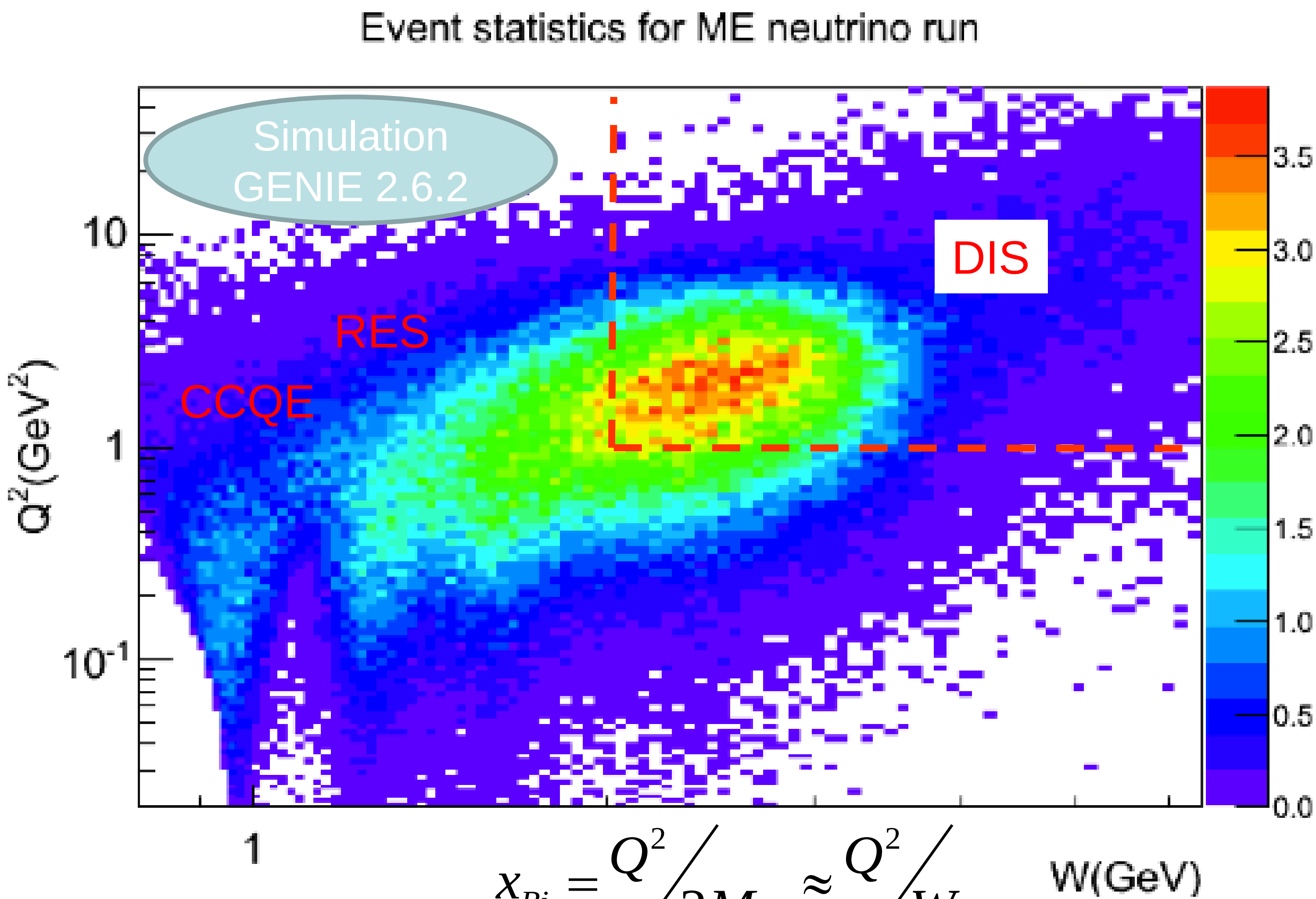


$$x_{Bj} = Q^2 / 2M\nu \approx Q^2 / W$$

kinematical distribution from GENIE 2.6.2 event generator: no cuts applied

MINERνA W–Q² "Acceptance" ME (2013–18?)

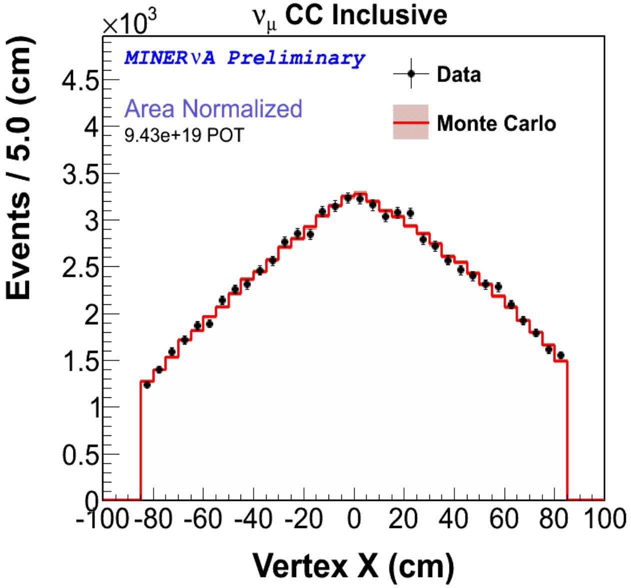
z axis : 10^3 events / 3 x 10^3 kg of C / 6e20POT

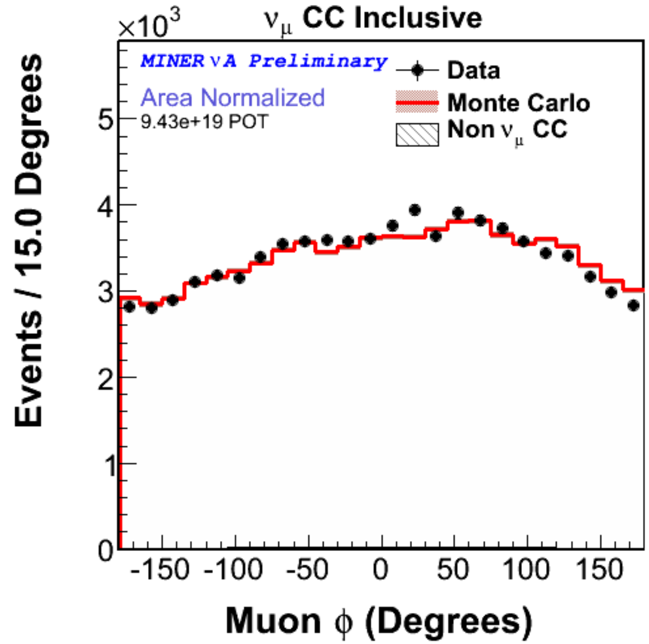


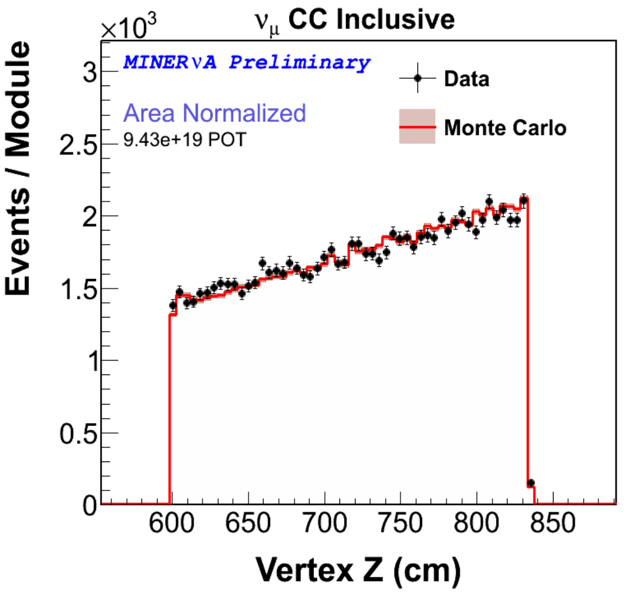
$$x_{Bj} = {Q^2}/{2M\nu} \approx {Q^2}/{W}$$

kinematical distribution from GENIE 2.6.2 event generator: no cuts applied

Vertex Distributions – Acceptance







"MINOS-matched" muons for CC ν_μ inclusive sample

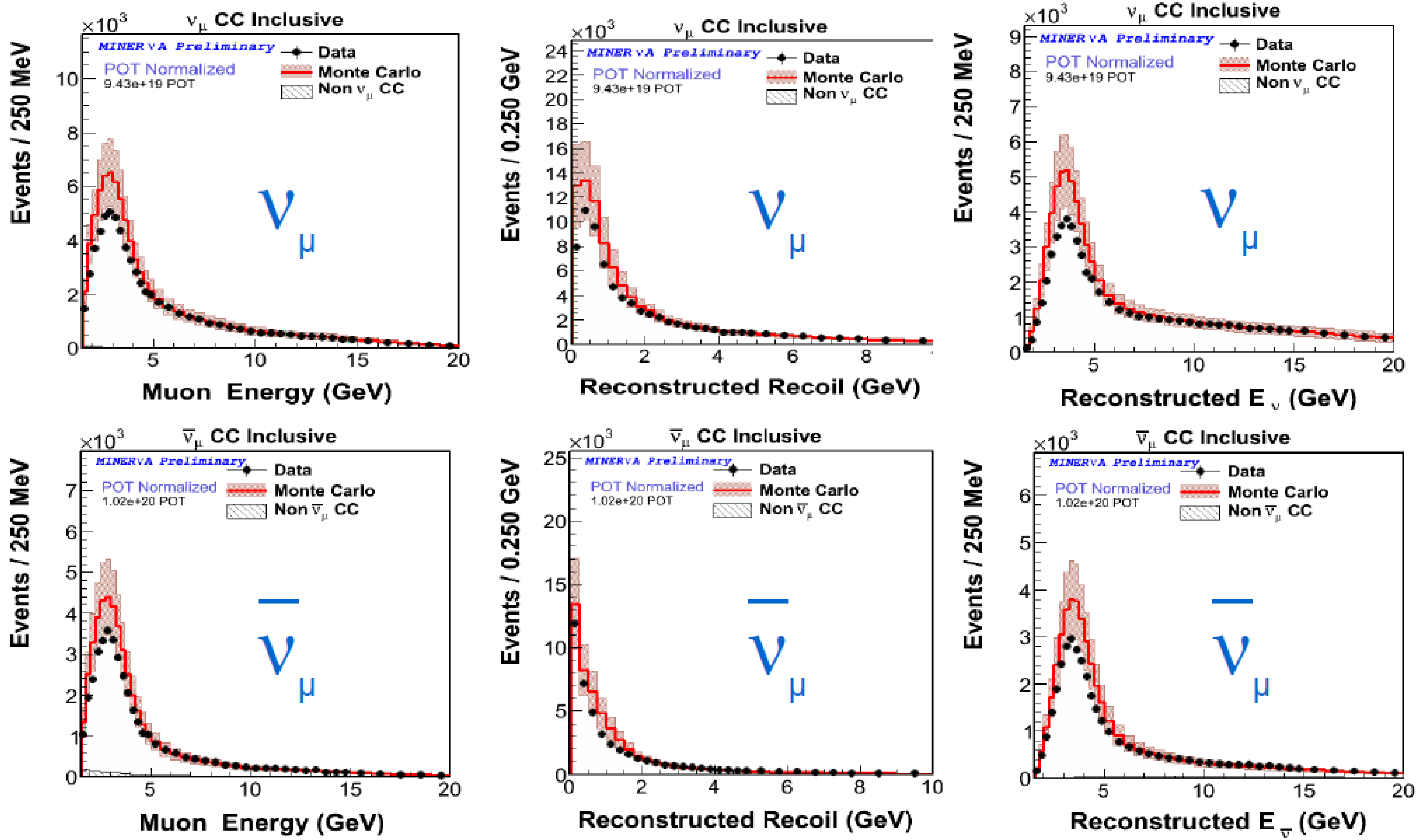
Energy threshold ~2 GeV

Good angular acceptance up to scattering
Angles of about 10 degrees,
with limit of about 20 degrees

Bias is complex but well understood

Very active effort to increase acceptance!

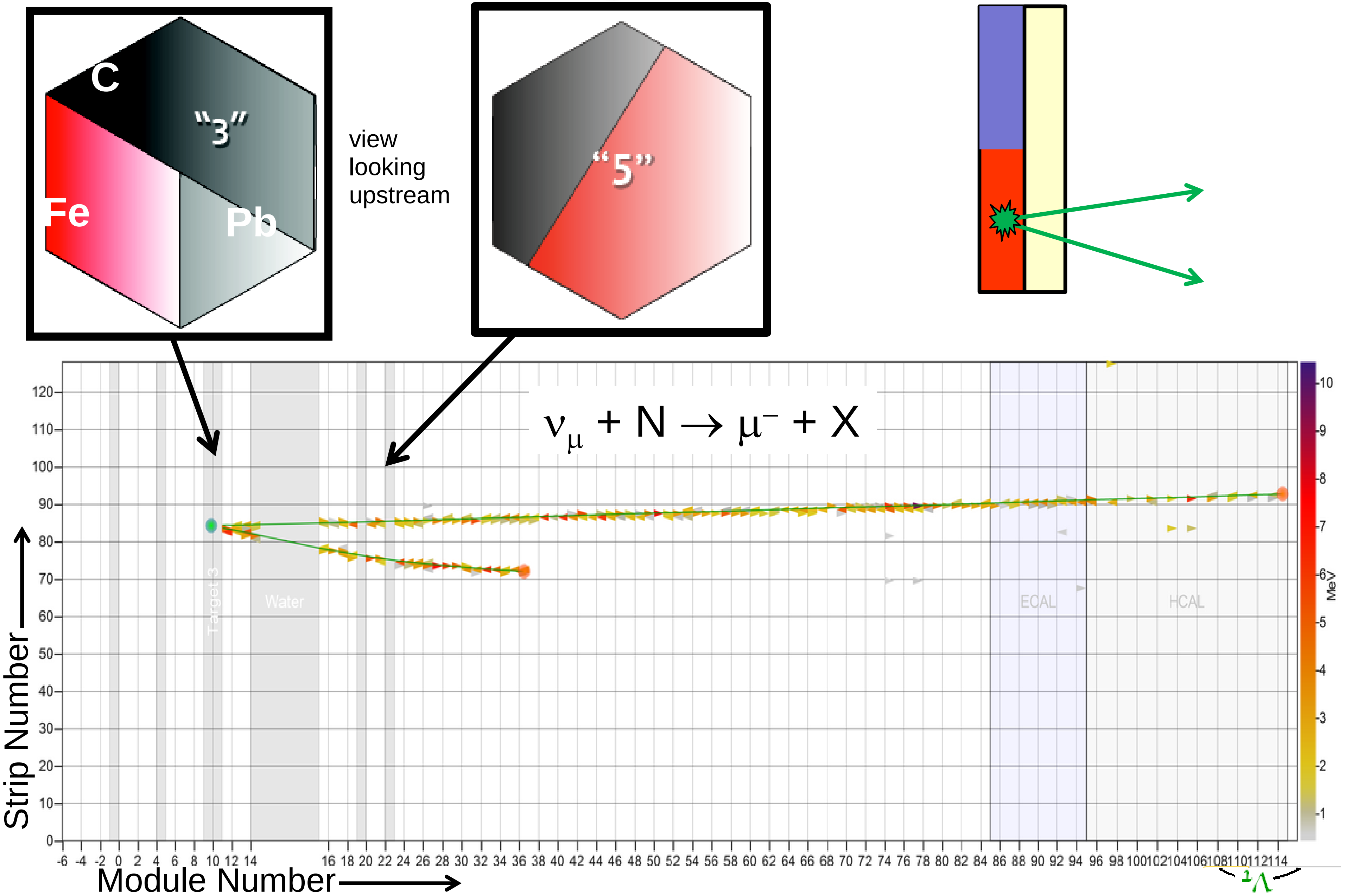
Reconstructed ν / $\bar{\nu}$ Inclusive Kinematics



Muon Energy (GeV) Recoil Energy (GeV) Neutrino Energy (GeV)

all distributions are absolutely normalized

An Event from Target 3

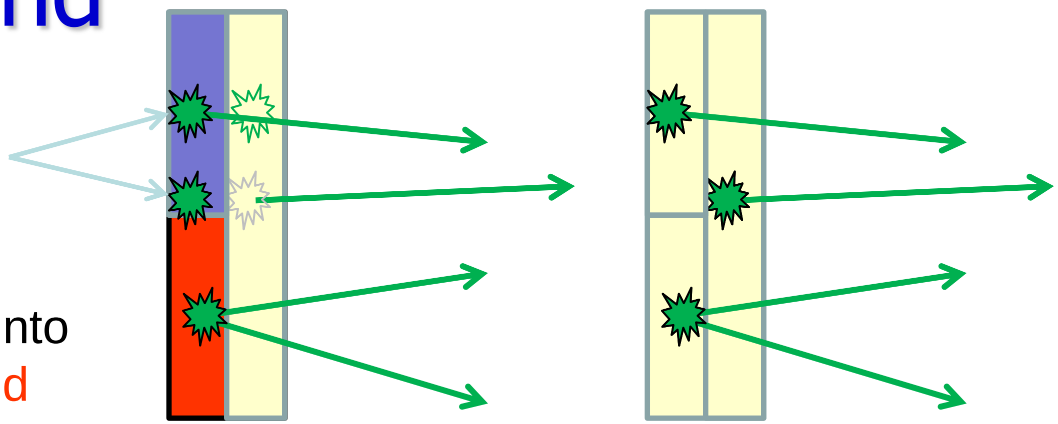


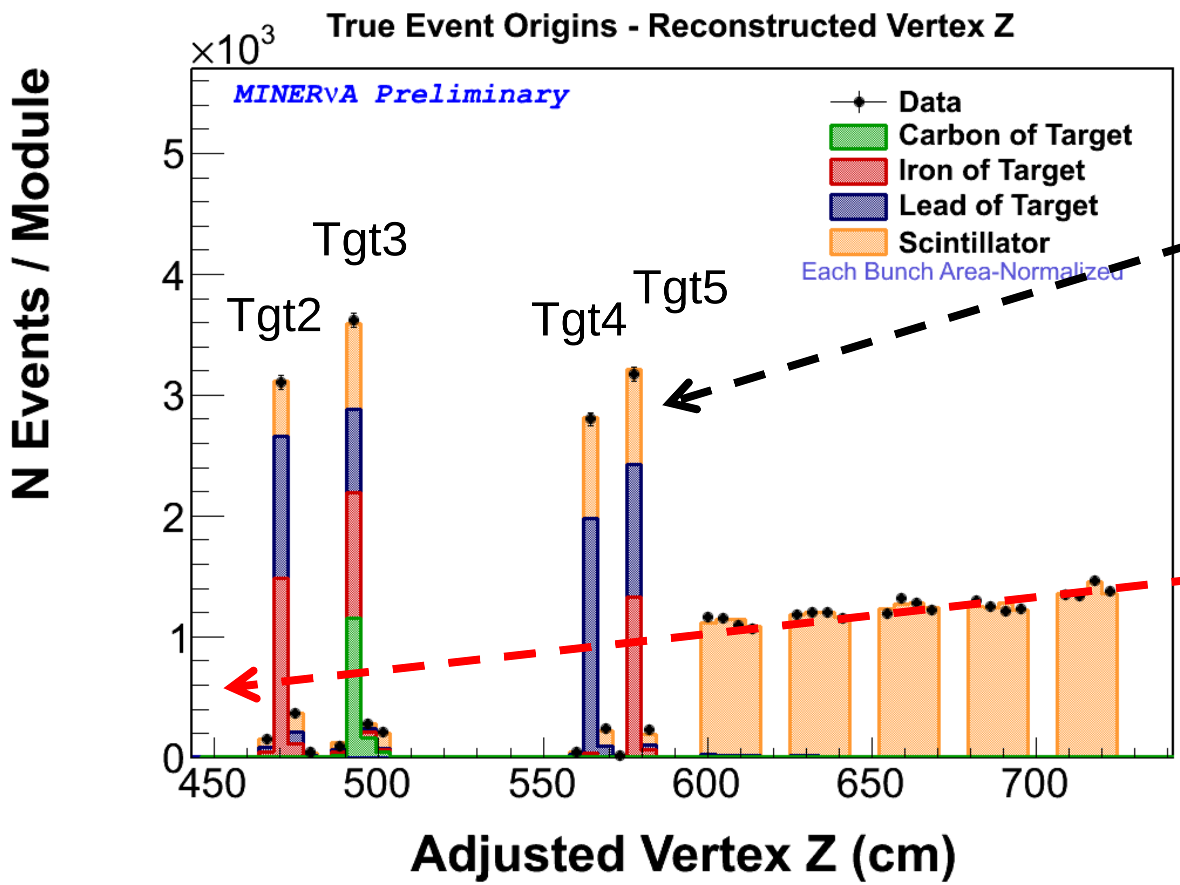
“Plastic” Background

Project the one track events to the passive target’s center in *z*

This is the best guess of the vertex

Scintillator events wrongly accepted into passive target sample are background



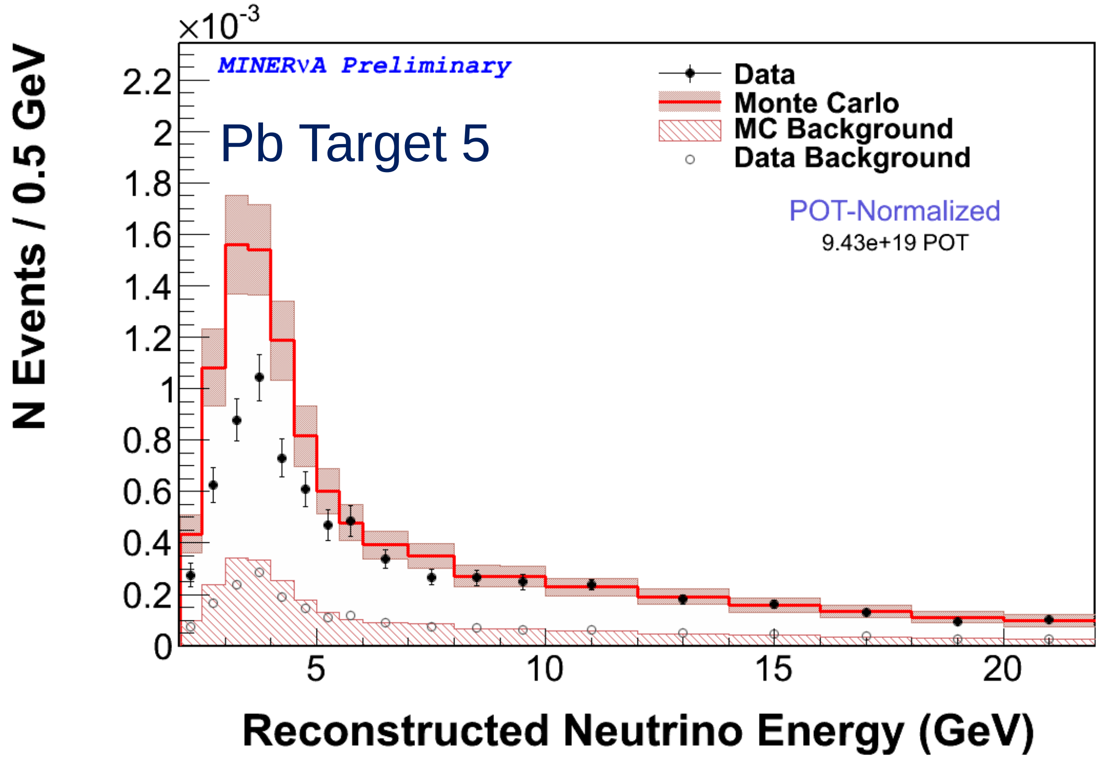


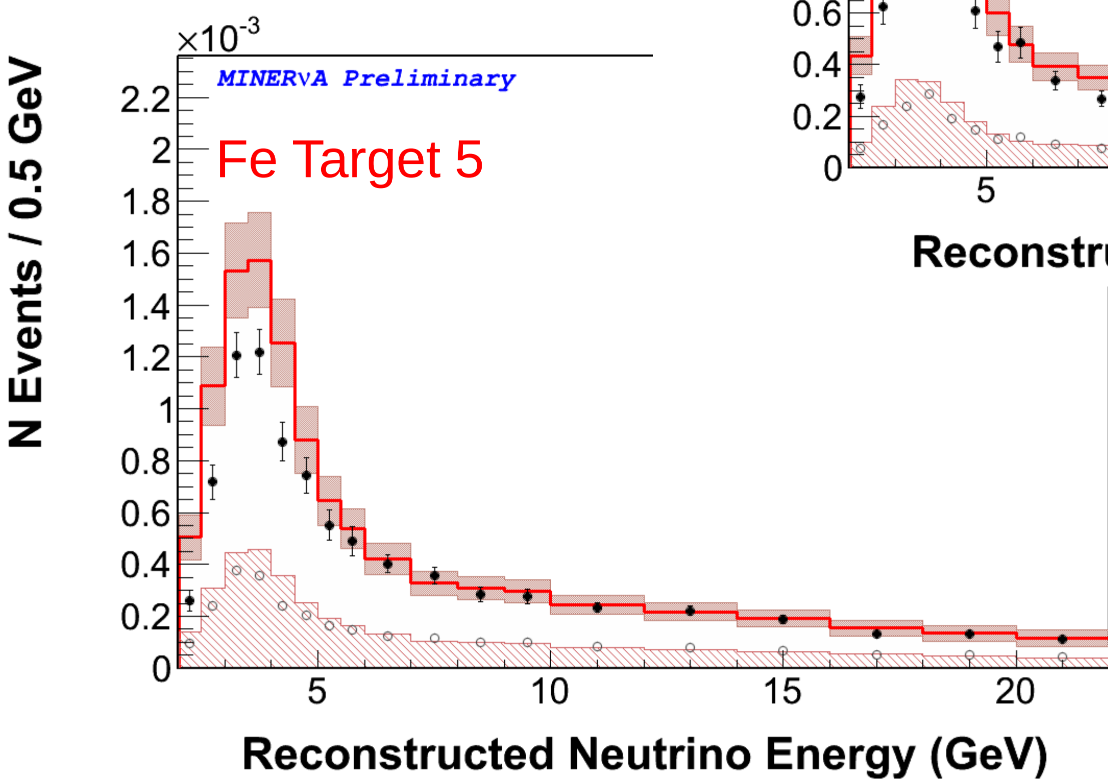
background : these peaks are at the location of the first module downstream of the passive targets

use downstream tracker modules to predict and subtract the “plastic background”

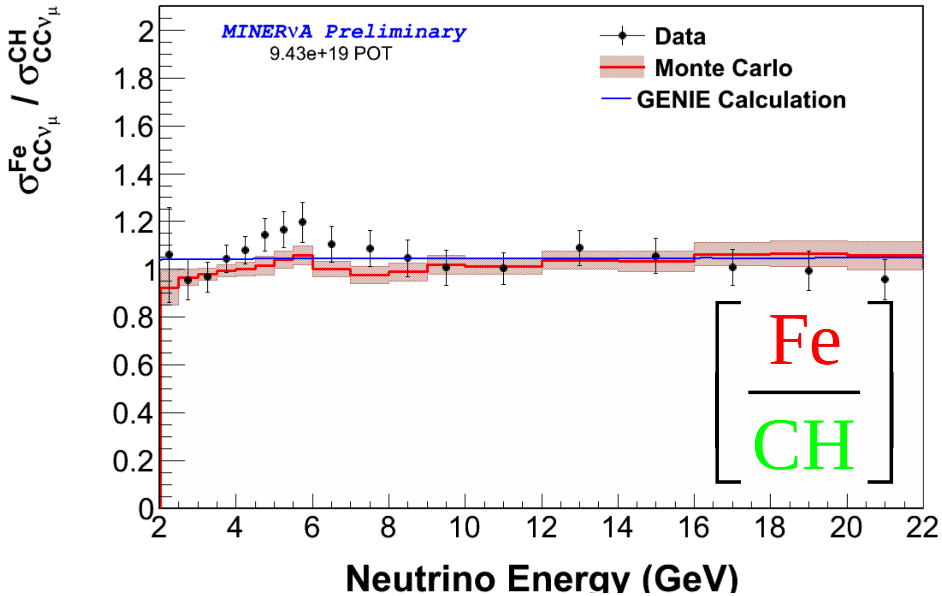
Accepted Events and Background (Target 5)

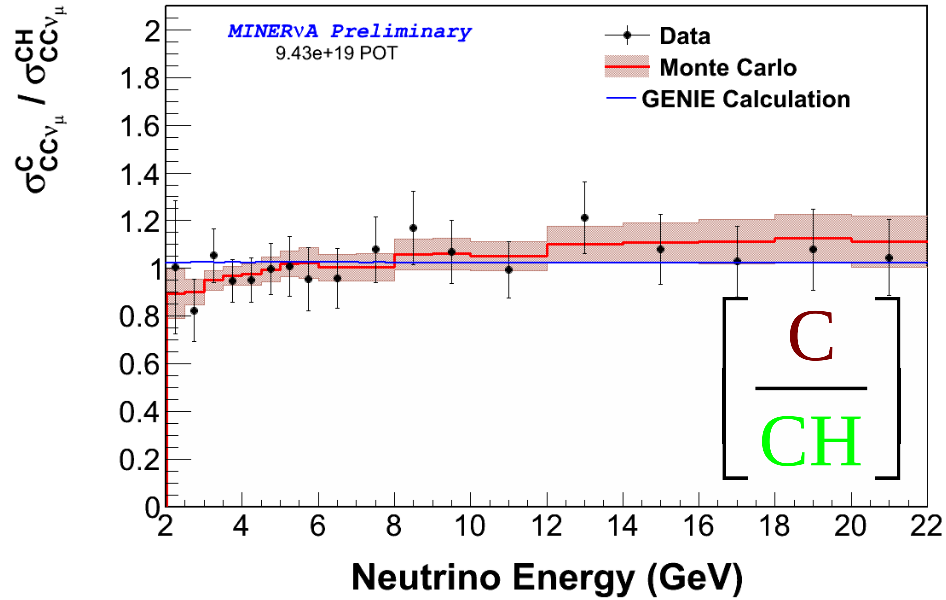
uses ~25% recorded neutrino data
and ~20% of target mass

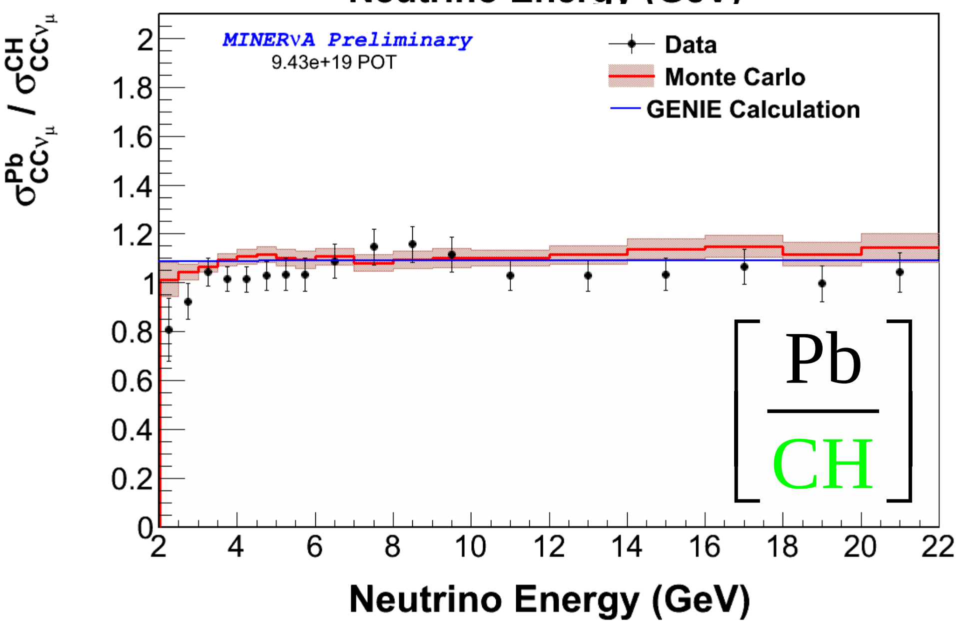




Ratio (E_ν) of Fe, C, Pb to CH Cross Sections





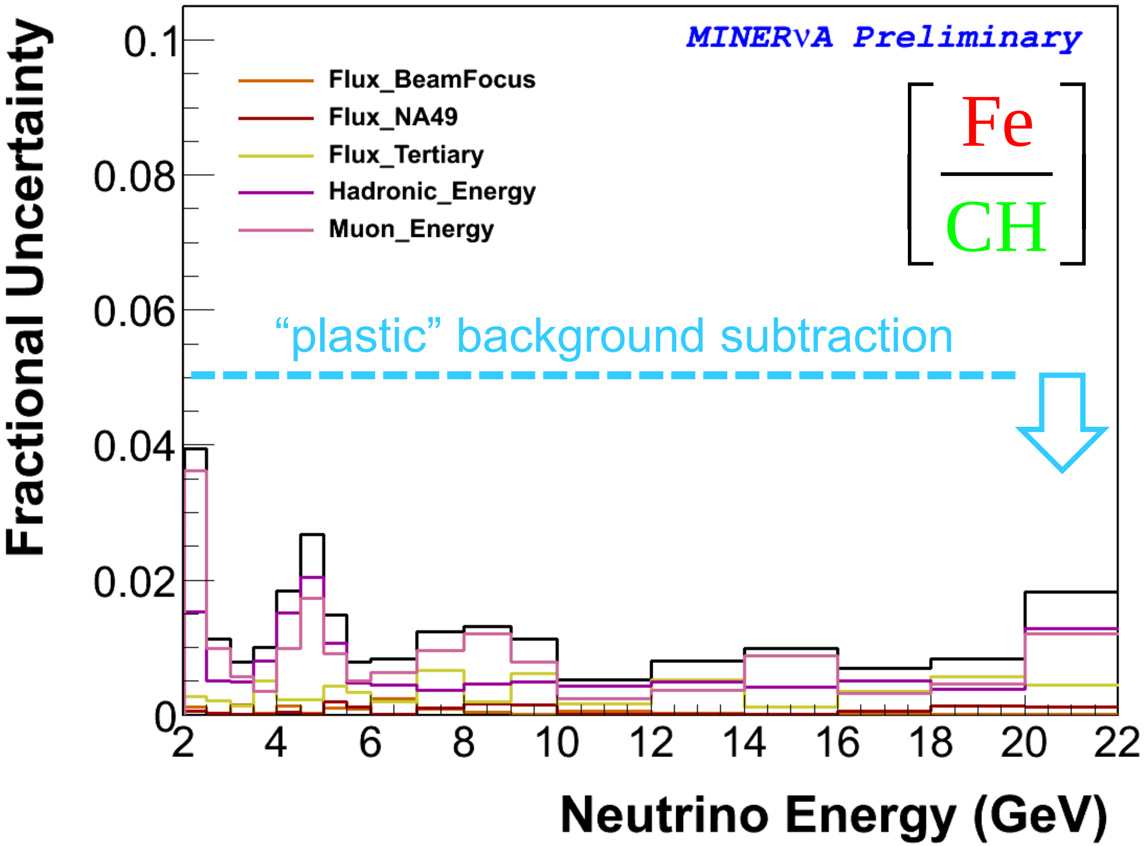


higher statistics
→ x, Q^2 in bins of ν energy

all targets in same beam
→ flux largely cancels

all targets in same detector
→ similar reconstruction

Systematic Errors - $\left[\frac{Fe}{CH}\right]$ Cross Section Ratio



absolute cross section ~ 15%
(ν flux uncertainty dominates)

all targets in same beam
→ flux largely cancels

all targets in same detector
→ similar reconstruction

largest uncertainty:
"plastic" background subtraction
(depends also on event topology)
~ 4 – 5%
work in progress to reduce this effect

Outlook

MINERνA studies neutrino interactions in the 1 – 20 GeV region
over the transition region from exclusive states to DIS
with high precision
- using a variety of nuclear targets (He, C, $H_2$0, Fe, Pb)
- using a fine-grained, high resolution fully active scintillator detector
- ⇒ study of nuclear and hadronic structure with neutrino interactions

MINERνA is producing results both in exclusive and inclusive channels

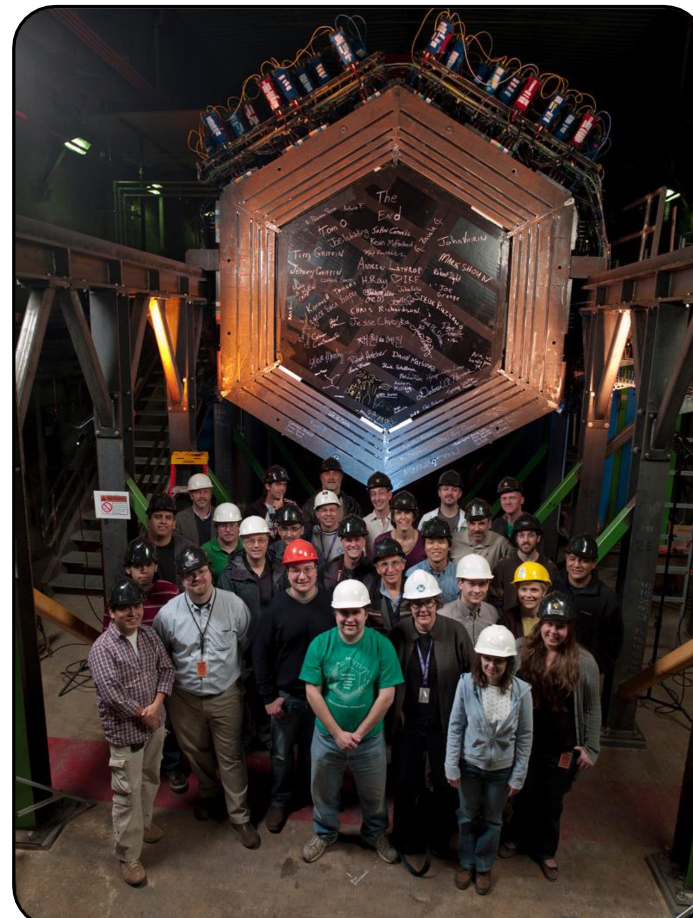
Inclusive analyses in progress …
- Cross sections on scintillator, carbon, iron, lead
- Nuclear target ratios

Data taking with a “medium energy” ν beam about to start,
E_ν peak ~6 GeV (1 – 20 GeV region).
The higher neutrino beam energy will allow us to access the DIS region
and study quark distributions at high x_{Bj}, $x_{Bj} > 0.1$

The MINERνA Collaboration

~80 collaborators
~20 institutions

University of Athens, Athens, Greece
Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil
UC Irvine, Irvine, CA
University of Chicago, Chicago, IL
Fermi National Accelerator Laboratory, Batavia, IL
University of Florida, Gainsville, IL
Université de Genève, Genève, Switzerland
Universidad de Guanajuato, Ganajuato, Mexico
Hampton University, Hampton, VA
Inst. Nucl. Reas. Moscow, Russia
Mass. Col. Lib. Arts, North Adams, MA
University of Minnesota-Duluth, Duluth, MN
Northwestern University, Evanston, IL
Otterbein College, Westerville, OH
University of Pittsburgh, Pittsburgh, PA
Pontificia Universidad Católica del Perú, Lima, Peru
University of Rochester, Rochester, NY
Rutgers University, Piscataway, NJ
Universidad Técnica Federico Santa María, Valparaiso, Chile
University of Texas, Austin, TX
Tufts University; Medford, MA
Universidad Nacional de Ingeniería, Lima, Peru
College of William & Mary, Williamsburg, VA



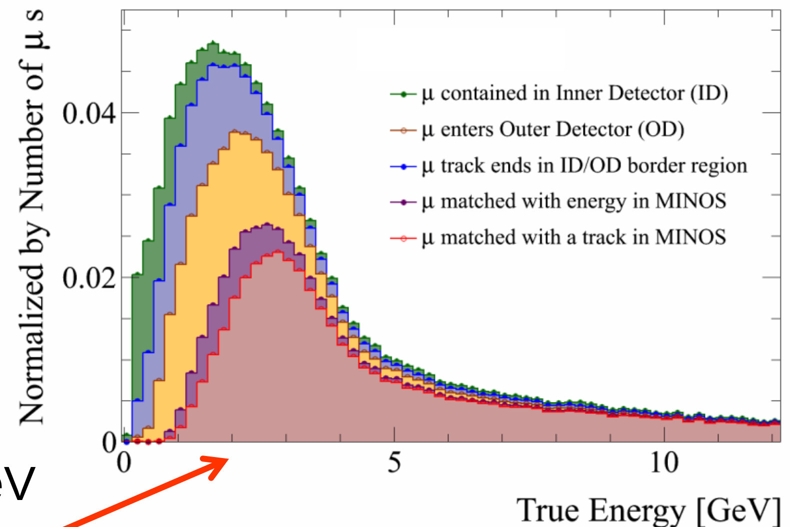
Detector Performance

Events visualized using with a fully active target with high granularity

Good tracking resolution (~3 mm)

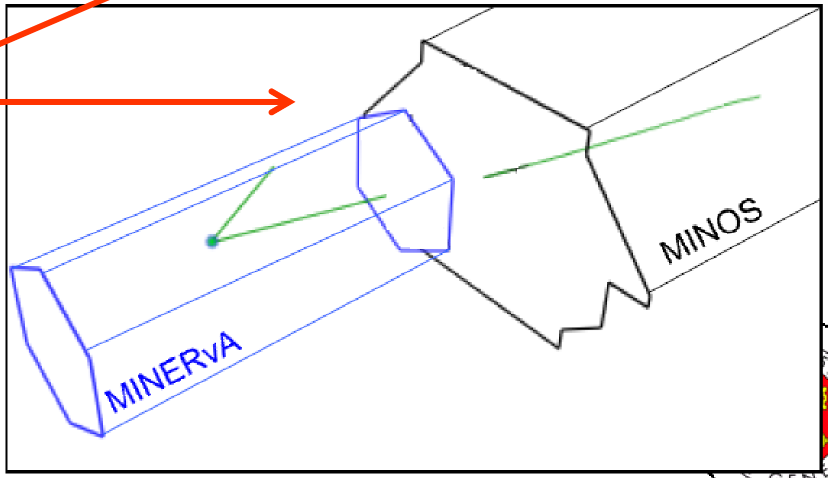
Calorimetry for charged hadrons and EM showers

Timing information (few ns)
pileup: several “rock” muons
more than one ν interactions per spill



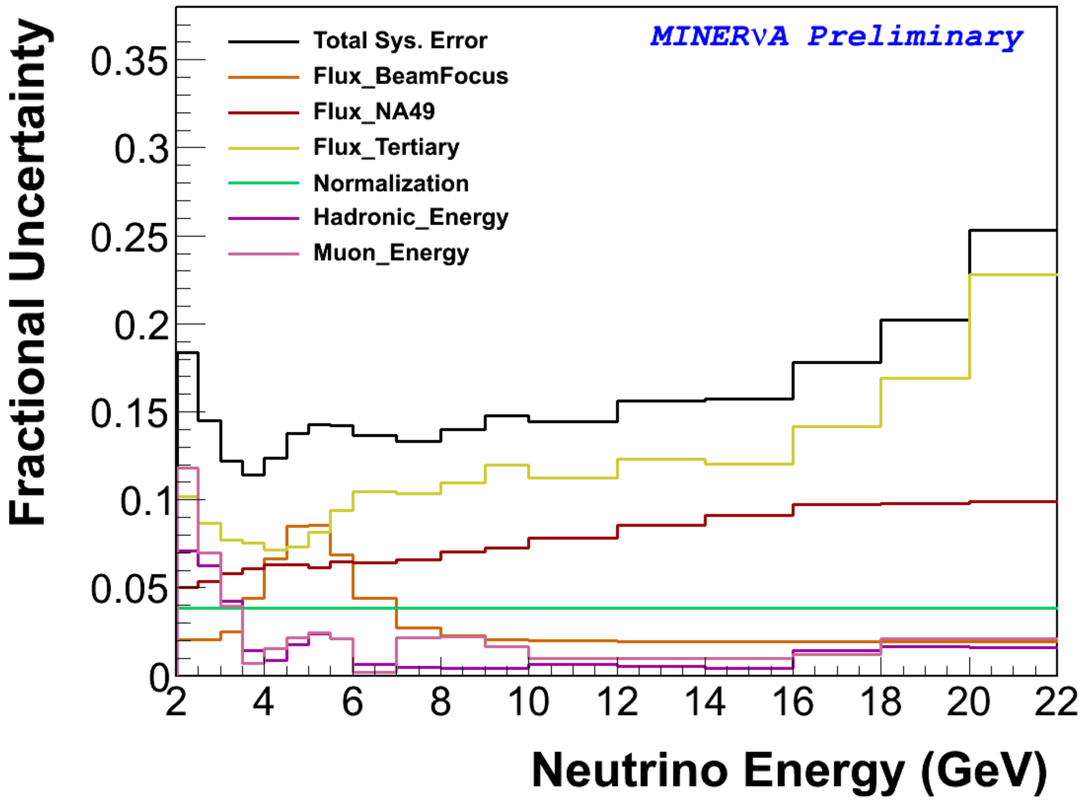
Containment of ν-induced events up to several GeV except for muons

Muon energy and charge measurement in MINOS ND
(acceptance is complex well understood)



Particle ID from dE/dx and energy + range
no charge determination
except for muons entering MINOS ND

Inclusive Cross Section Uncertainties



Beam Focus – Magnetic horns focusing the charged mesons that decay to neutrino beam

NA49 – A CERN hadron production experiment that constrains flux simulation (pC → X)

Tertiary – Neutrinos produced by decay of products other than pC in the NuMI target

Normalization – Uncertainty on flat normalization corrections applied to Monte Carlo

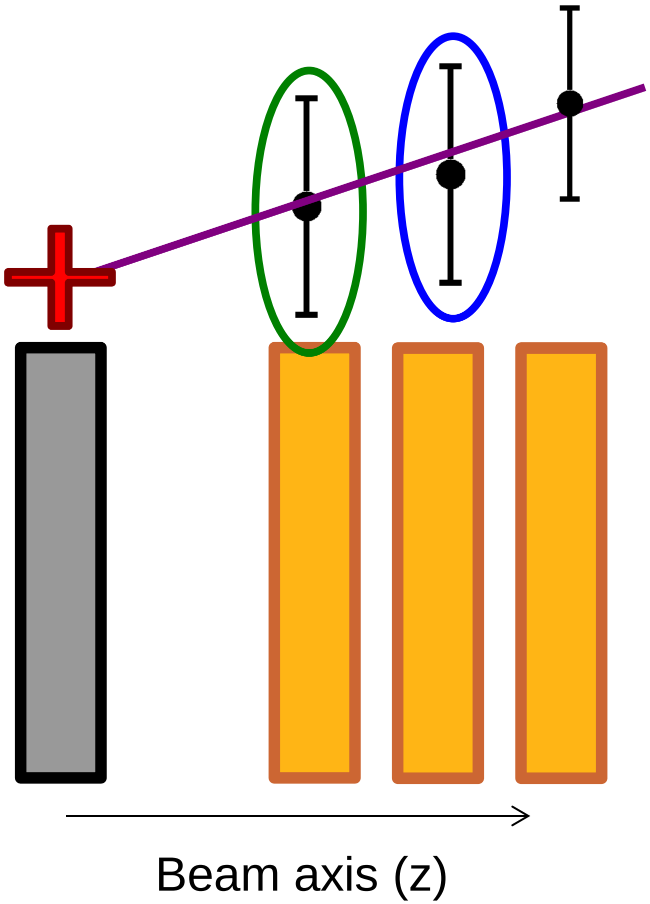
Hadronic Energy – Uncertainty on calorimetric recoil energy reconstruction

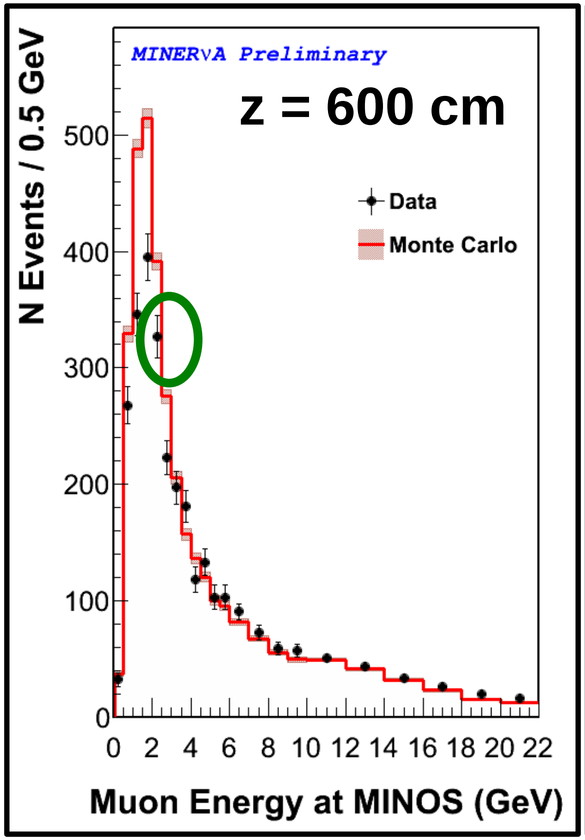
Muon Energy – Uncertainty on MINOS's momentum reconstruction + energy loss in MINERνA

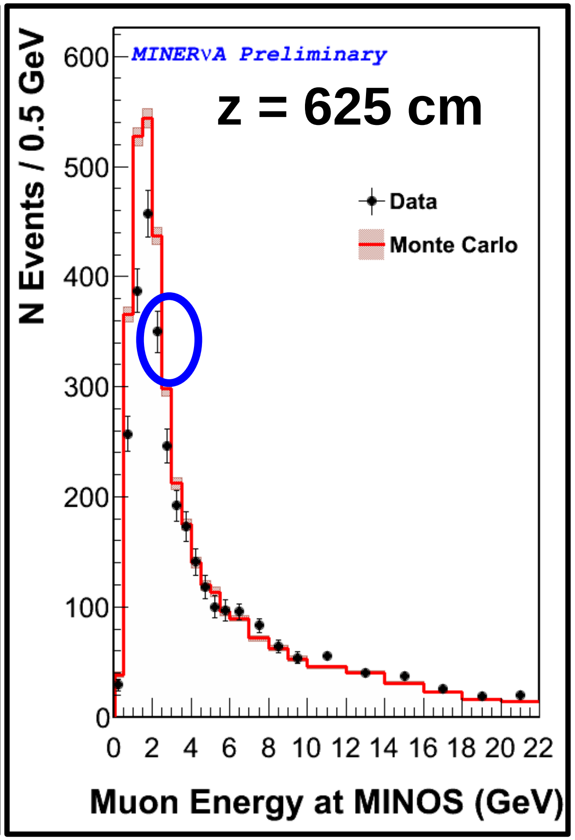
GENIE– Neutrino event generator Uncertainties for cross section, final state interaction models. Not an uncertainty on our measurement.

Background Subtraction

use plastic reference targets
to predict rate at the plastic background







prediction done in bins of muon momentum