Nuclear Physics with MINERνA

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Dehradun, India

Outline

- Motivation for nuclear physics with MINERνA
  - What do we want to accomplish?
- The nuclear program of MINERνA
  - Plastic (CH), Iron, Lead, Carbon, Water and liquid Helium
  - What can we do with these targets?
- Reconstruction and event selection
  - How do we get to results?
- Getting to Results
  - First steps towards charged current inclusive ratios of:

Iron:**Lead**:**Plastic**

Measure ν-A Cross Sections

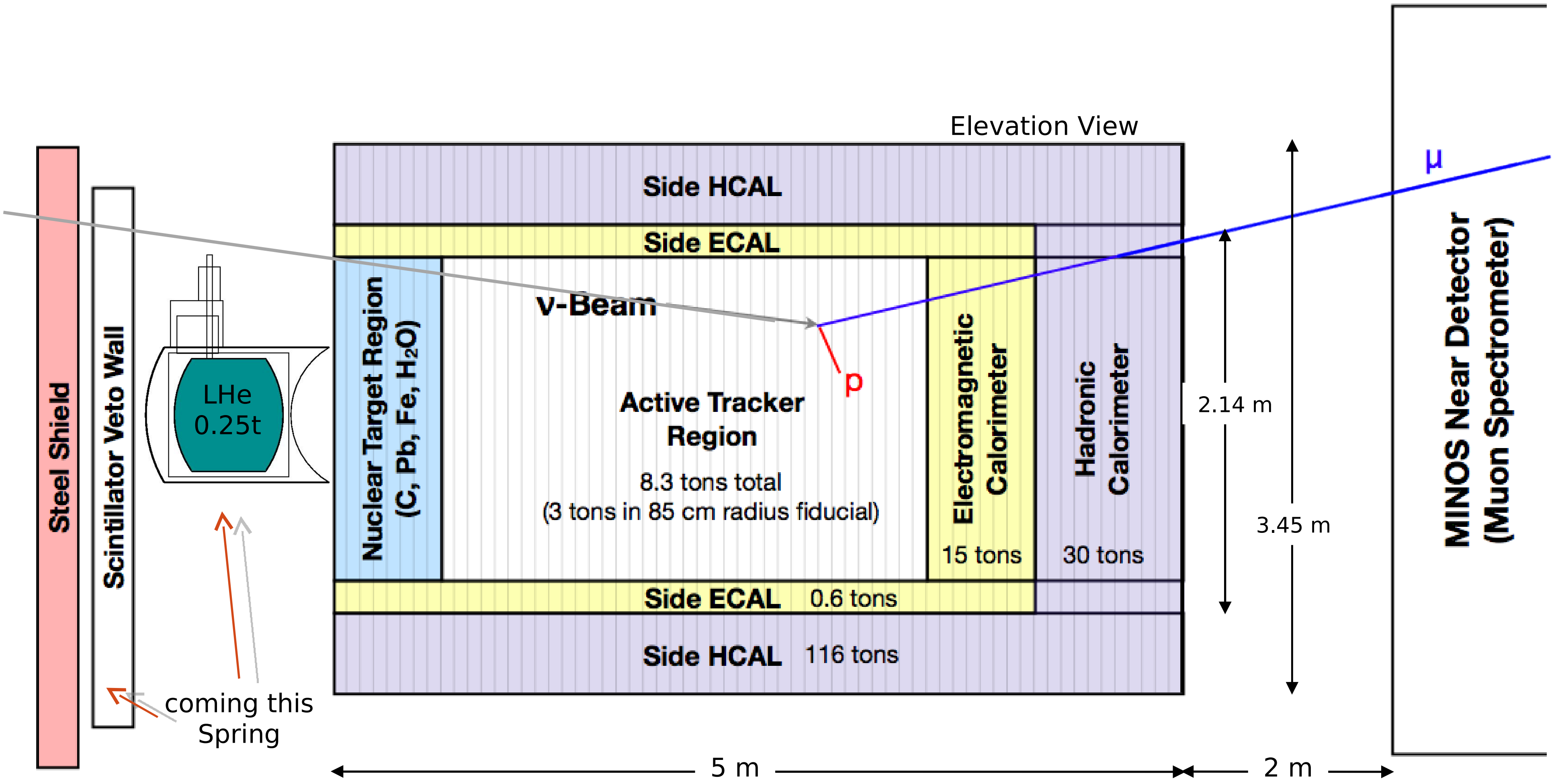
➡ Compare charged current (CC) inclusive cross sections among nuclear targets as a function of muon momentum

- Provide more precise charged current quasi-elastic cross sections to oscillation experiments
- Measure *x*-dependence of nuclear effects
    - e.g. F_2 and xF_3
        - Are sea and valence quarks affected differently?
- Contribute to community efforts to extract the dependence of nuclear parton distribution functions on A, *x* and Q^2

More MINERνA Objectives

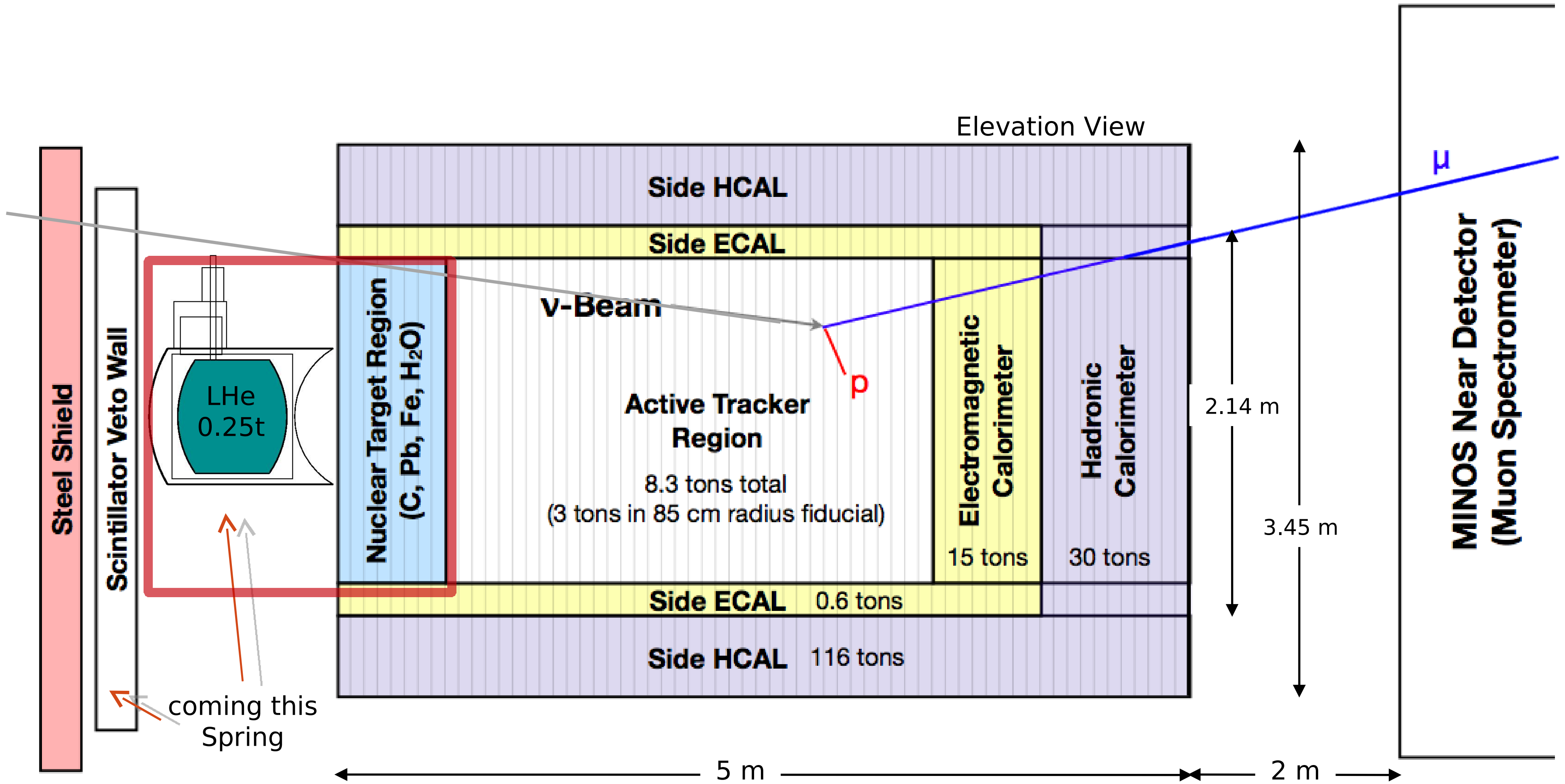
- Measure final state multiplicities as a function of A
  - Investigate pion absorption in the interaction nucleus
  - Observe final state interactions (FSI)
    - Improve models of ν-A interaction
- Measure hadronic energy as a function of A
  - What is the A dependence of observed energy?
  - Also measure unobserved energy emission via neutrons
    - Improves neutrino energy resolution

MINERνA Detector
a reminder

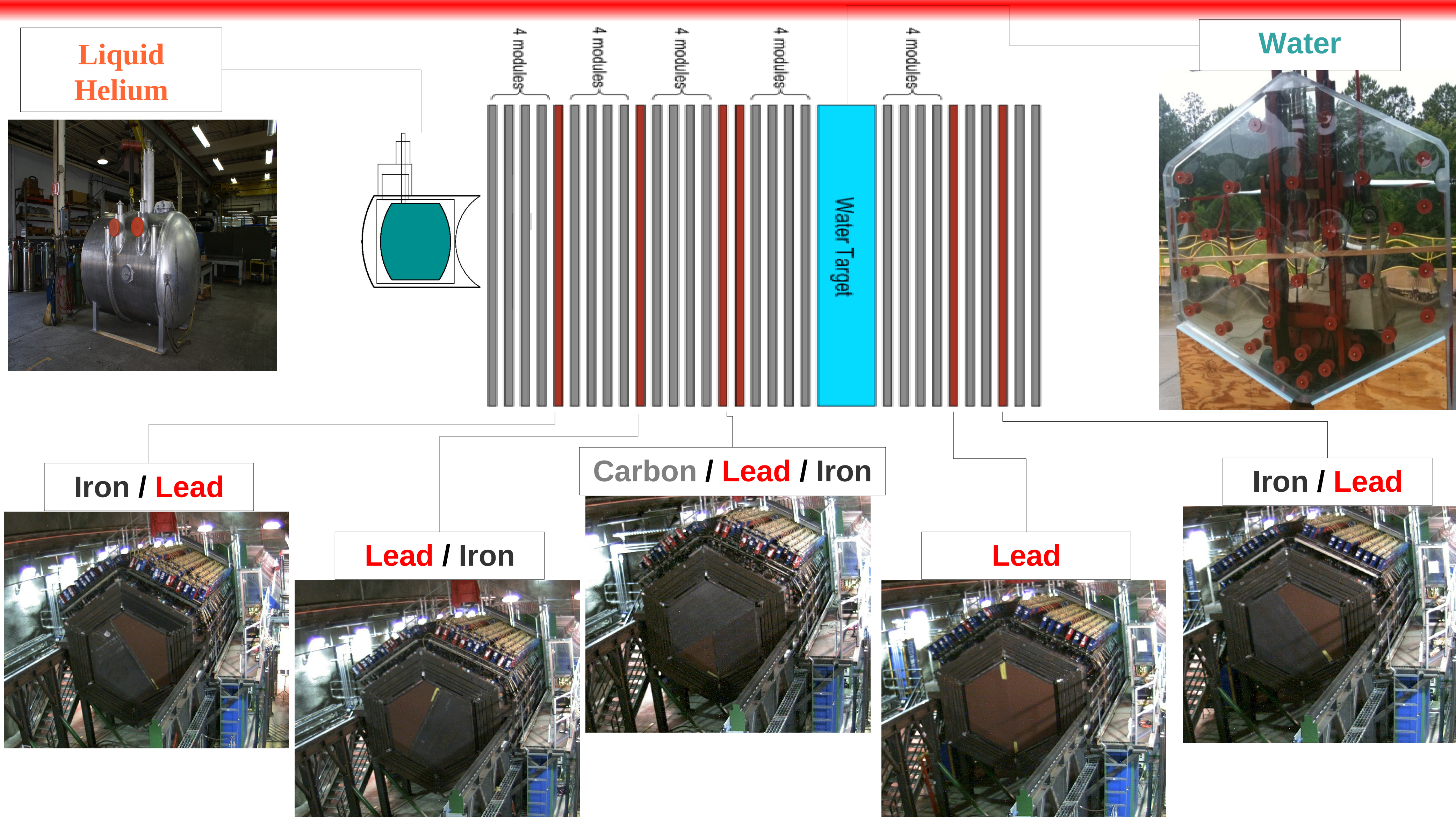


MINERνA Detector

a reminder



MINERνA Detector
Passive Targets



Event Rates

MC

MC generator is Genie 2.6.2
MC detector is Geant4

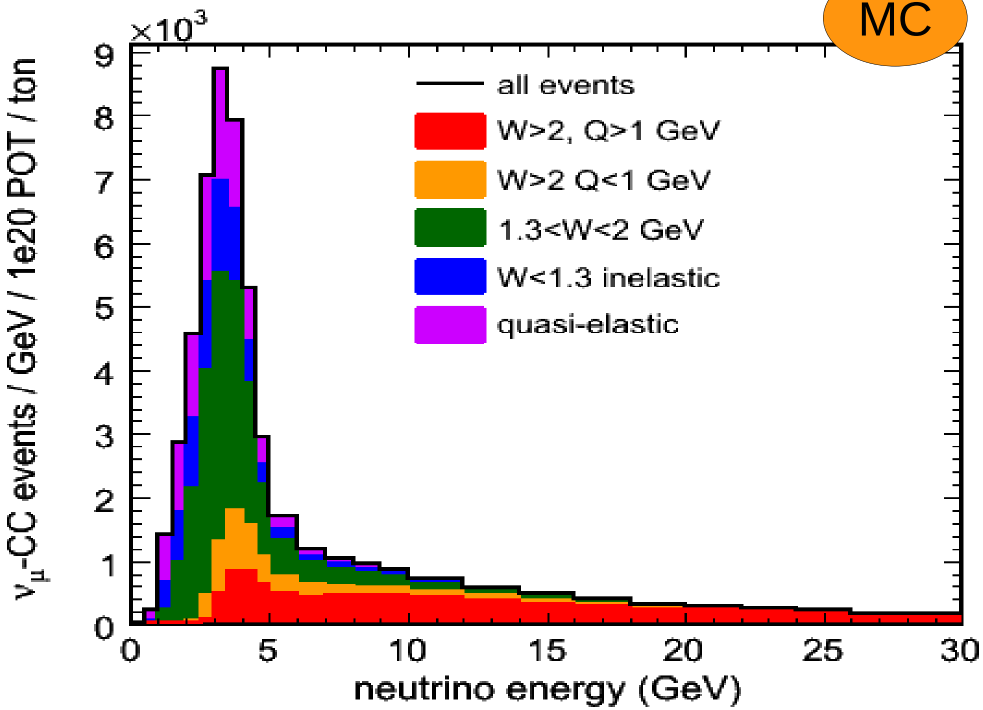
- MINERνA has been approved for 4.9e20 P.O.T. in the low energy neutrino beam
  - So far, we have received 1.2e20 P.O.T. (24% of total)

MC

Expected Event Rates for Low Energy Neutrino-tuned beam

Target	Fiducial Mass	ν_μ CC Events in 1.2e20 P.O.T.
Plastic	6.43 tons	409k
Helium	0.25 tons	16.8k
Carbon	0.17 tons	10.8k
Water	0.39 tons	24.4k
Iron	0.97 tons	64.5k
Lead	0.98 tons	68.4k

MC



- MINERνA has also been approved for 12e20 P.O.T. of **medium energy** beam

After both beam modes, MINERνA will have seen ~19M CC events in Plastic

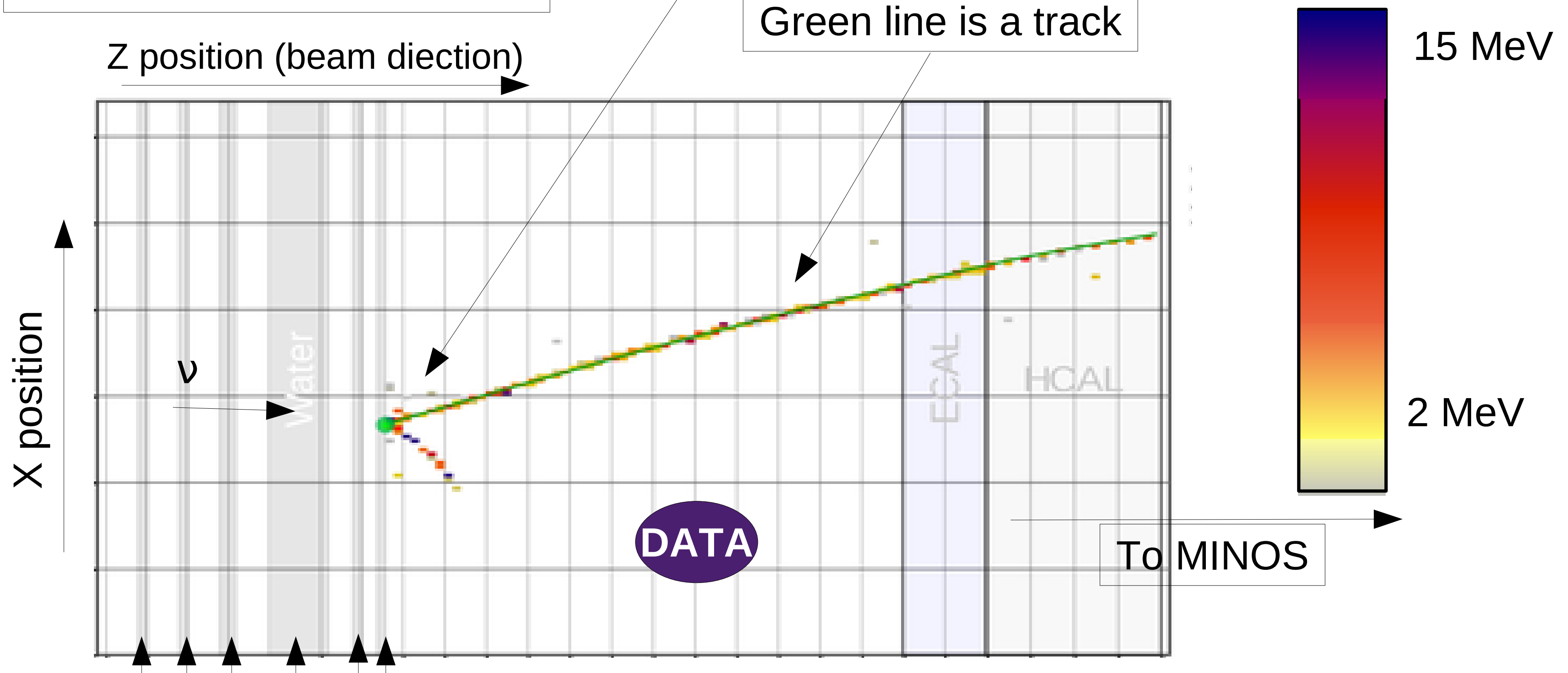
Nuclear Targets in Event Display

One view gives an overhead 2D view of MINERνA

Green dot is a vertex

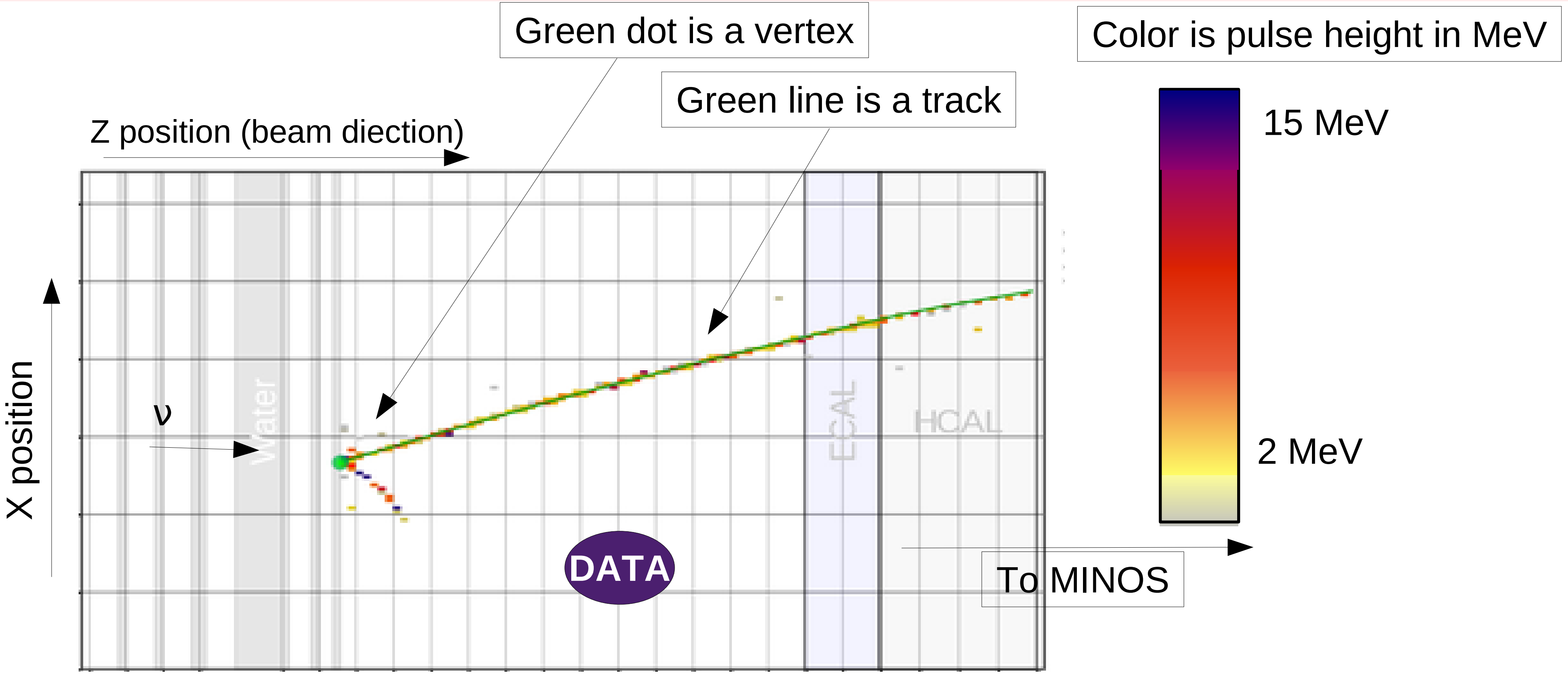
Green line is a track

Color is pulse height in MeV



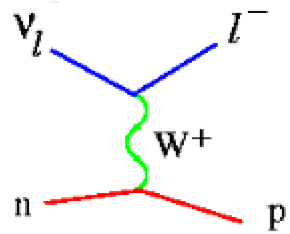
Shaded areas for passive targets

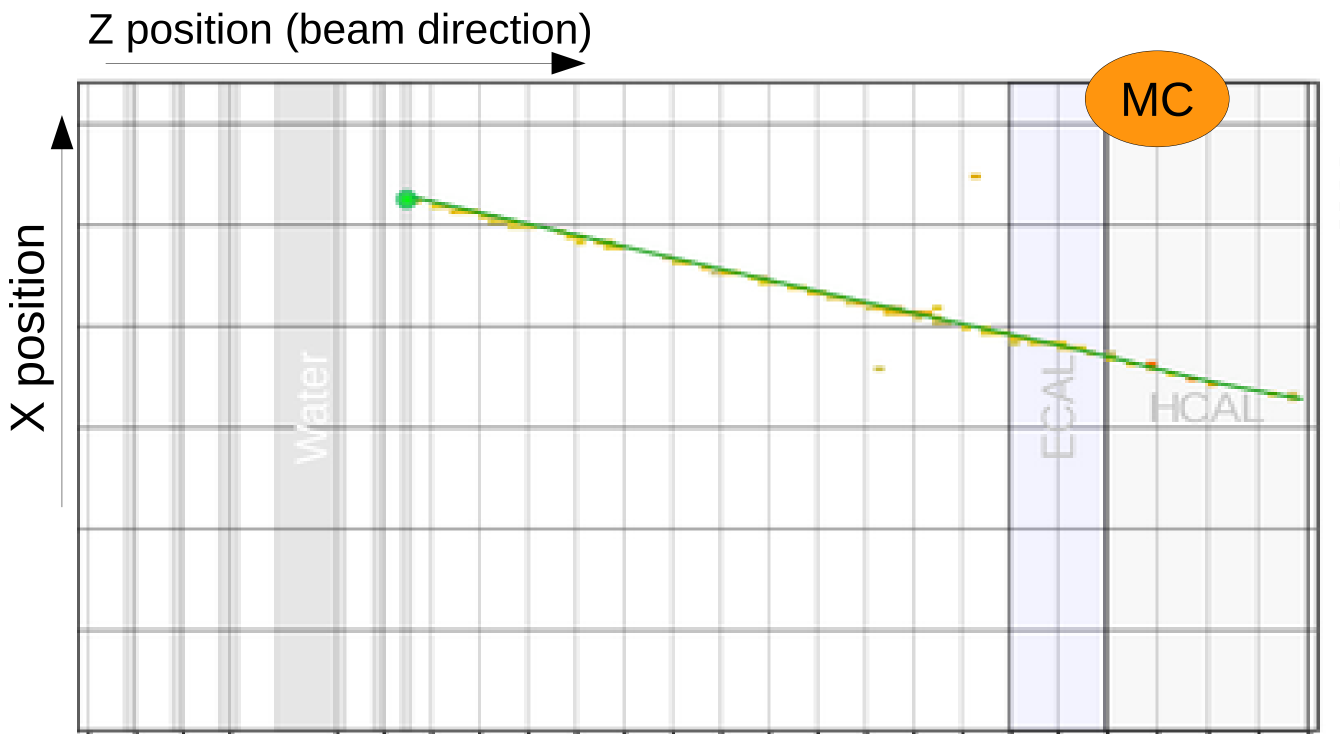
Muon-Centric Vertex Definition

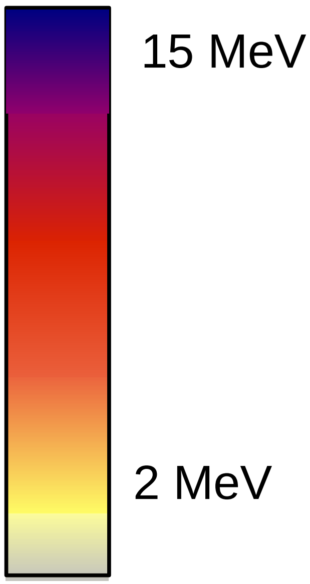


- Event Vertex = Origin of Muon
  - In the future, other tracks will be used to form a vertex

Quasi Elastic

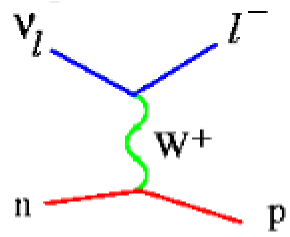


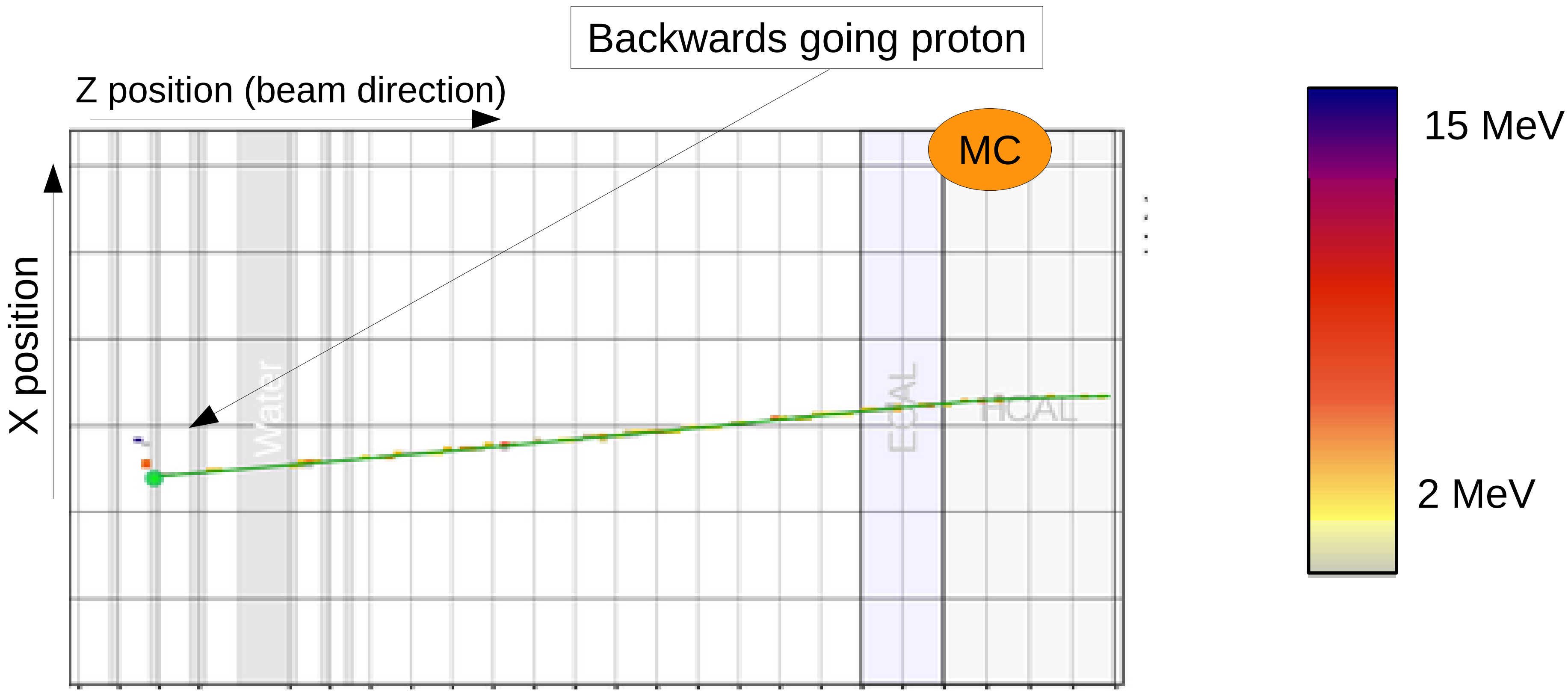




- 1 track QE event in **Lead**

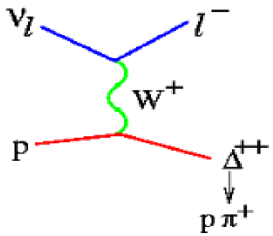
Quasi Elastic

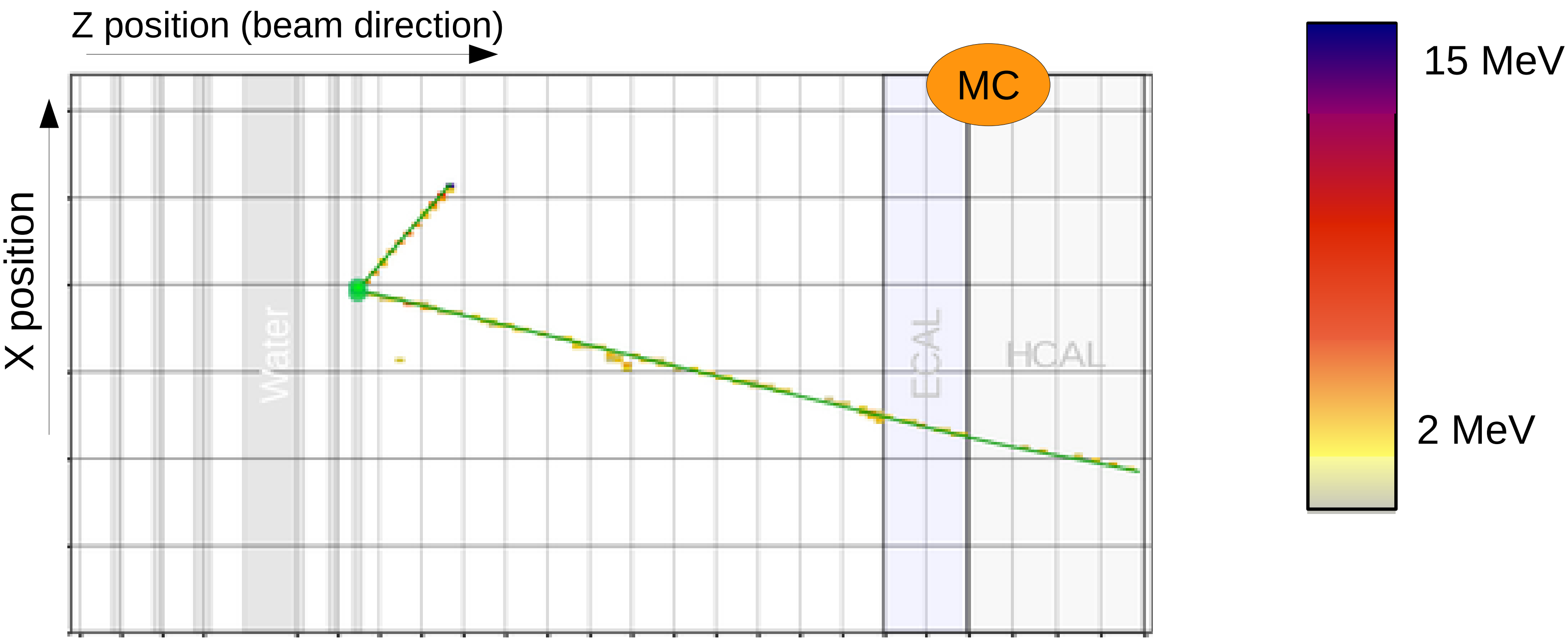




- A 2 track QE event in **Iron**
  - Measure the A dependence of the production of backwards going protons and pions

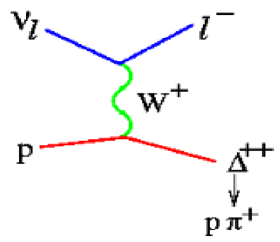
Resonance

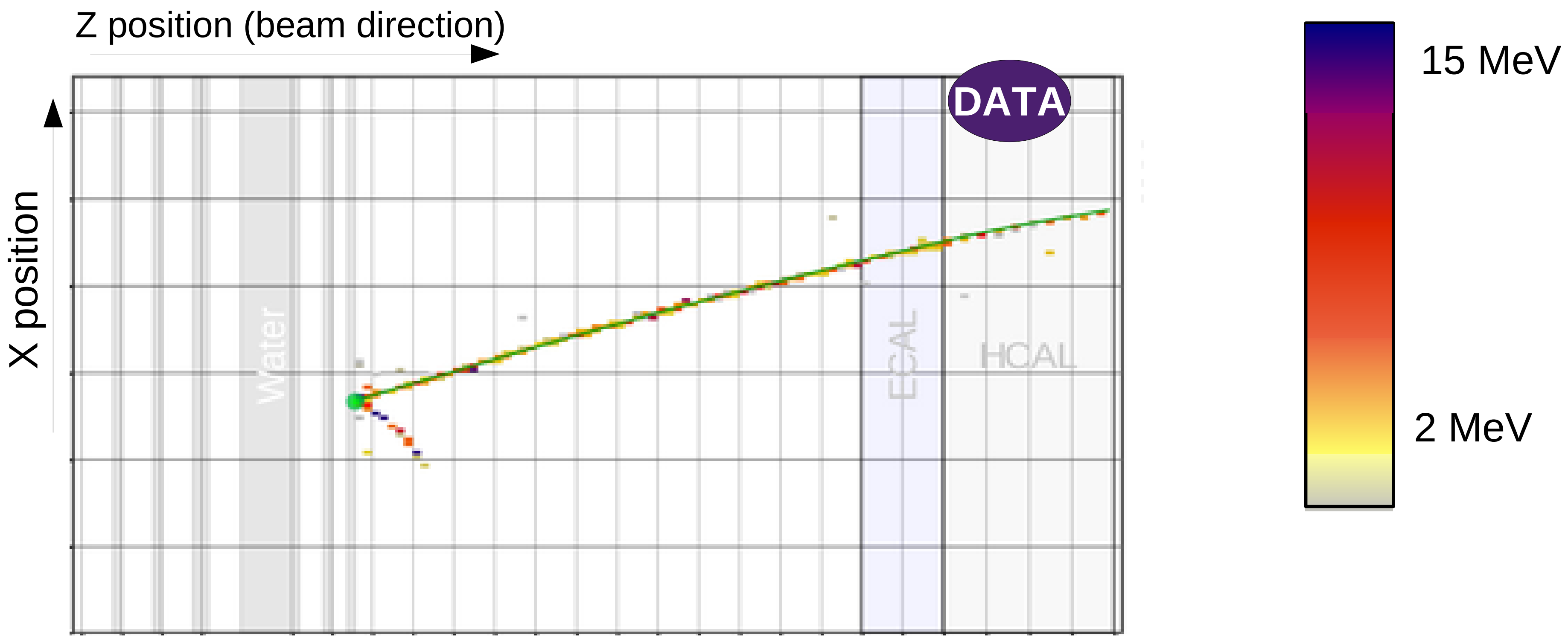




- Resonance production event clearly reconstructed in **Iron**

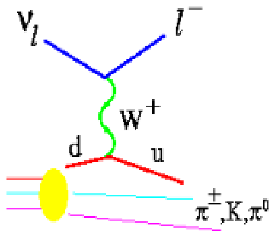
Resonance

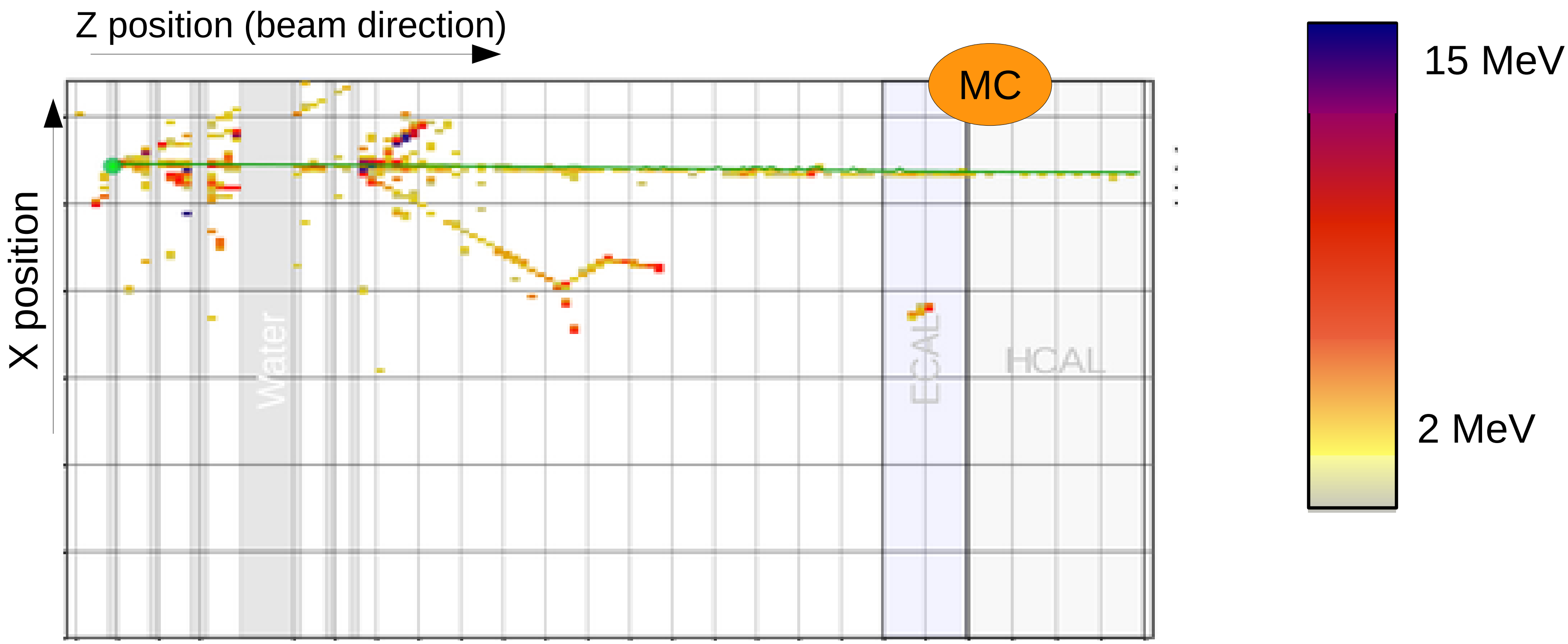




- Resonance production event candidate reconstructed in **Iron**

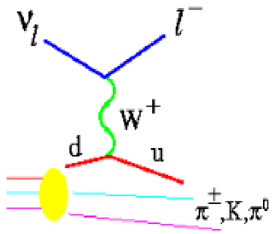
DIS



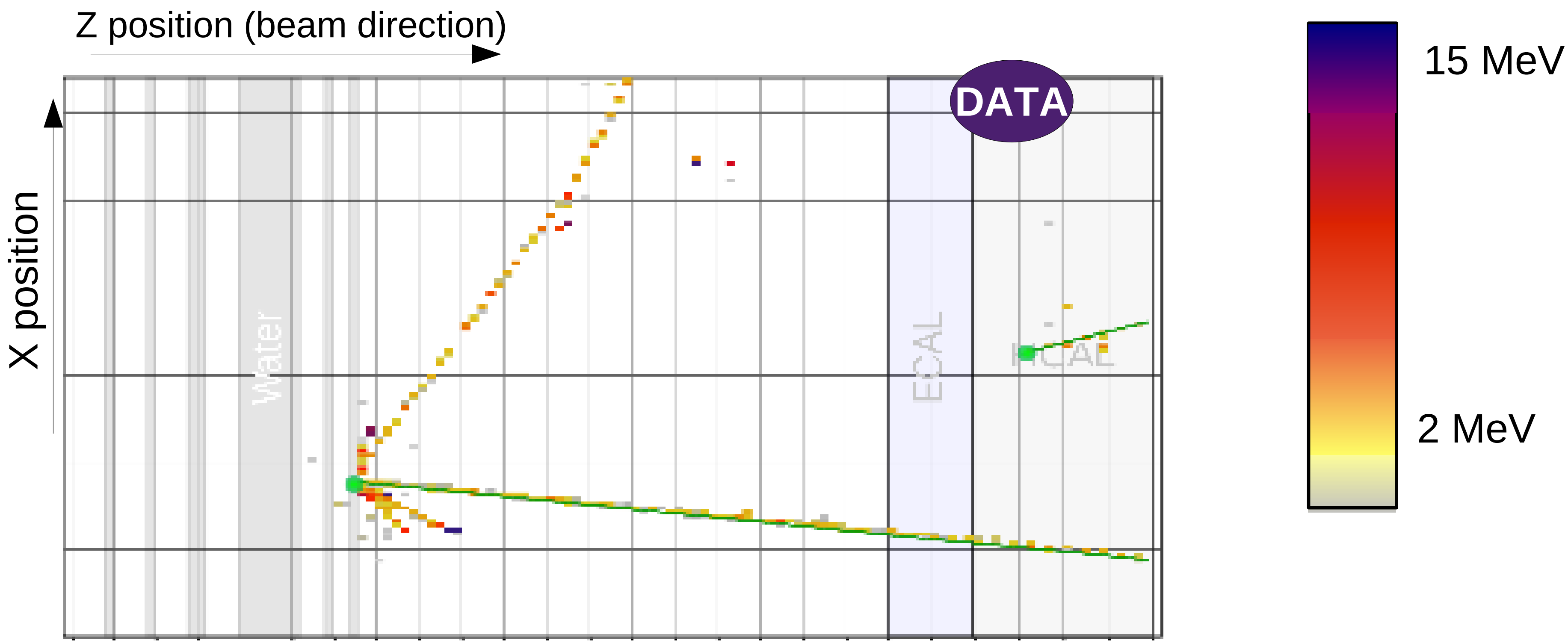


- A potentially difficult DIS event in **Lead**
    - The muon tracker figured it out, but let's start off easy...

DIS



- ...start off easy by focusing on the most downstream passive target



- A DIS event reconstructed in **Iron**

- How do we define a sample of events from this **Lead**/**Iron** target?

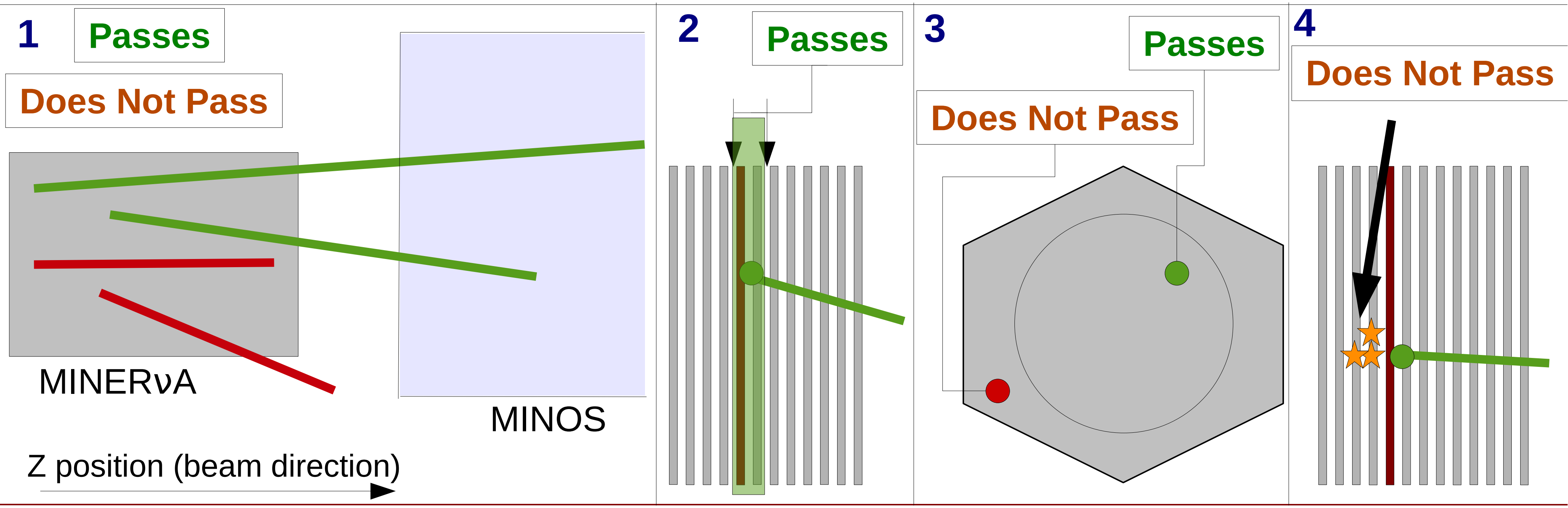
Nuclear Targets Event Selection

(1)Require that the muon is reconstructed in MINOS

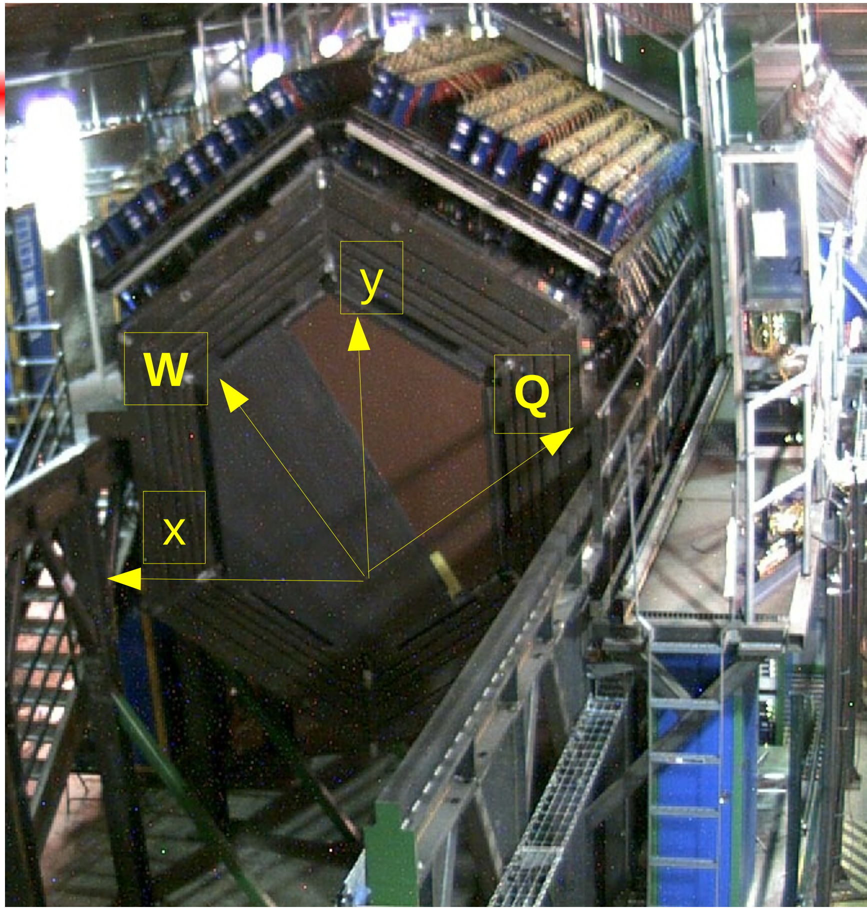
(2)Require that the muon vertex is in the target or in the first module downstream of the target

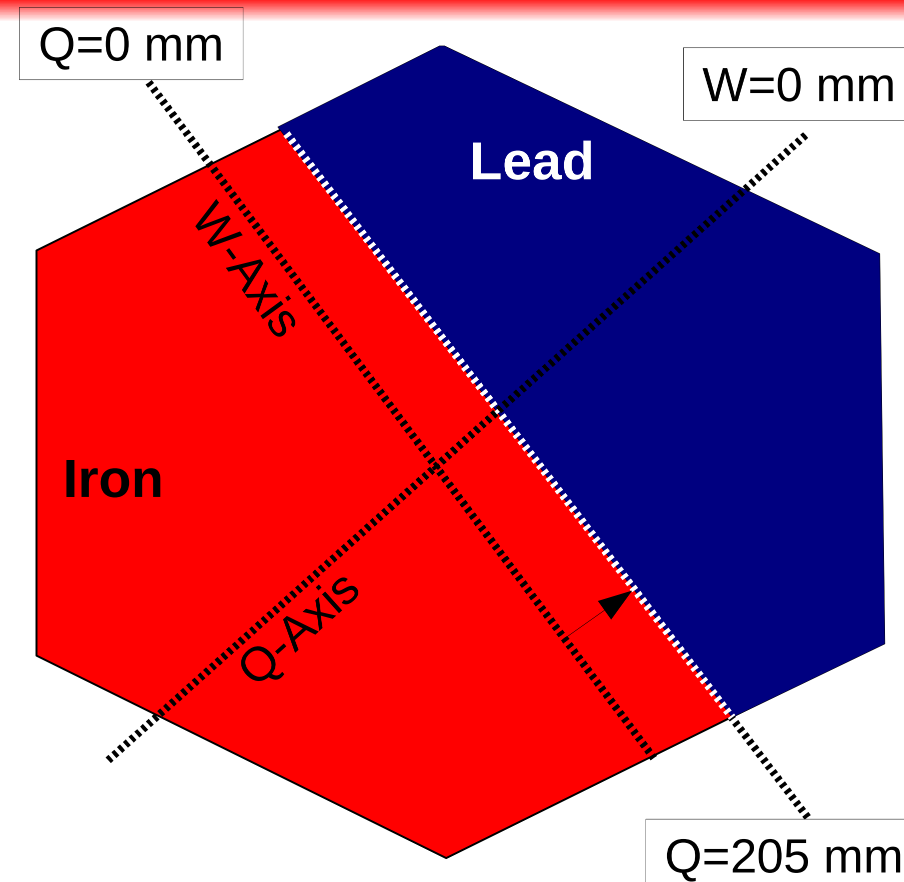
(3)Require that the muon vertex is inside the 85cm fiducial radius

(4)Require that there is no muon-like activity upstream of the target



Identification of Nucleus





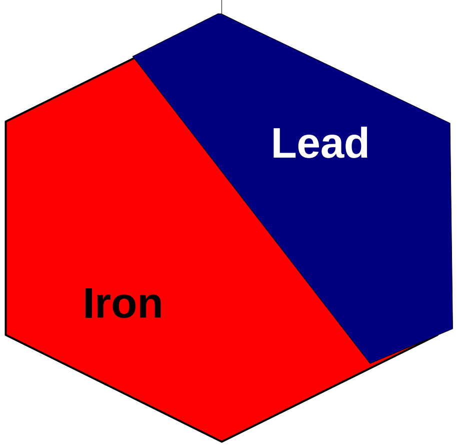
- Q_μ = where the muon track intersects the Z-center of the target

- **Lead** is Q_μ > 205 mm
- **Iron** is Q_μ < 205mm

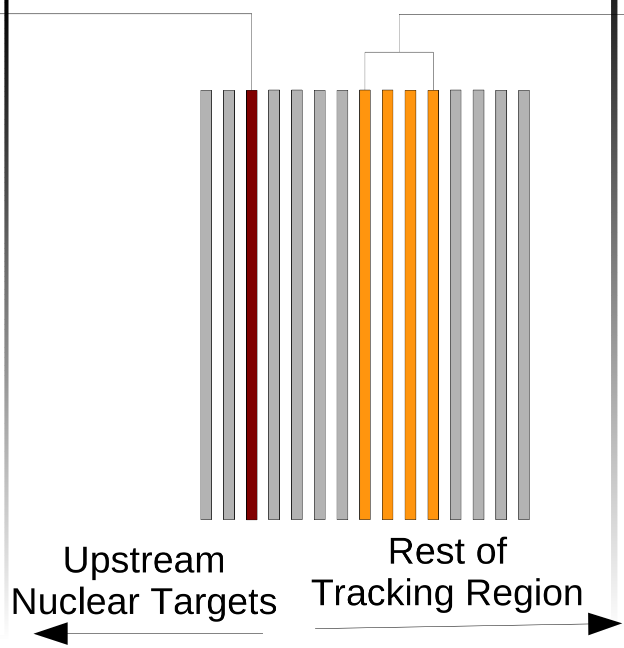
Nuclear Targets Considered

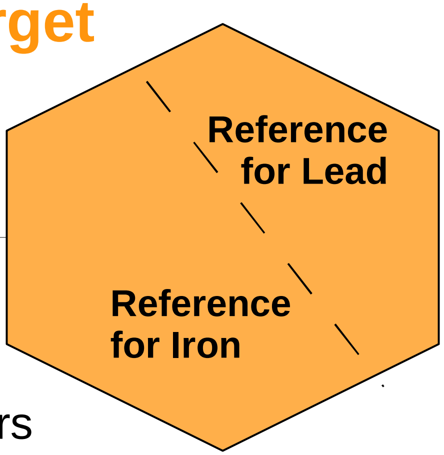
- Require that the muon be reconstructed in Minos
- Require that the muon vertex is in target and within 85cm radius
- Require that there is no muon-like activity upstream of the target

- Do this for a **passive target** and a **plastic reference target**



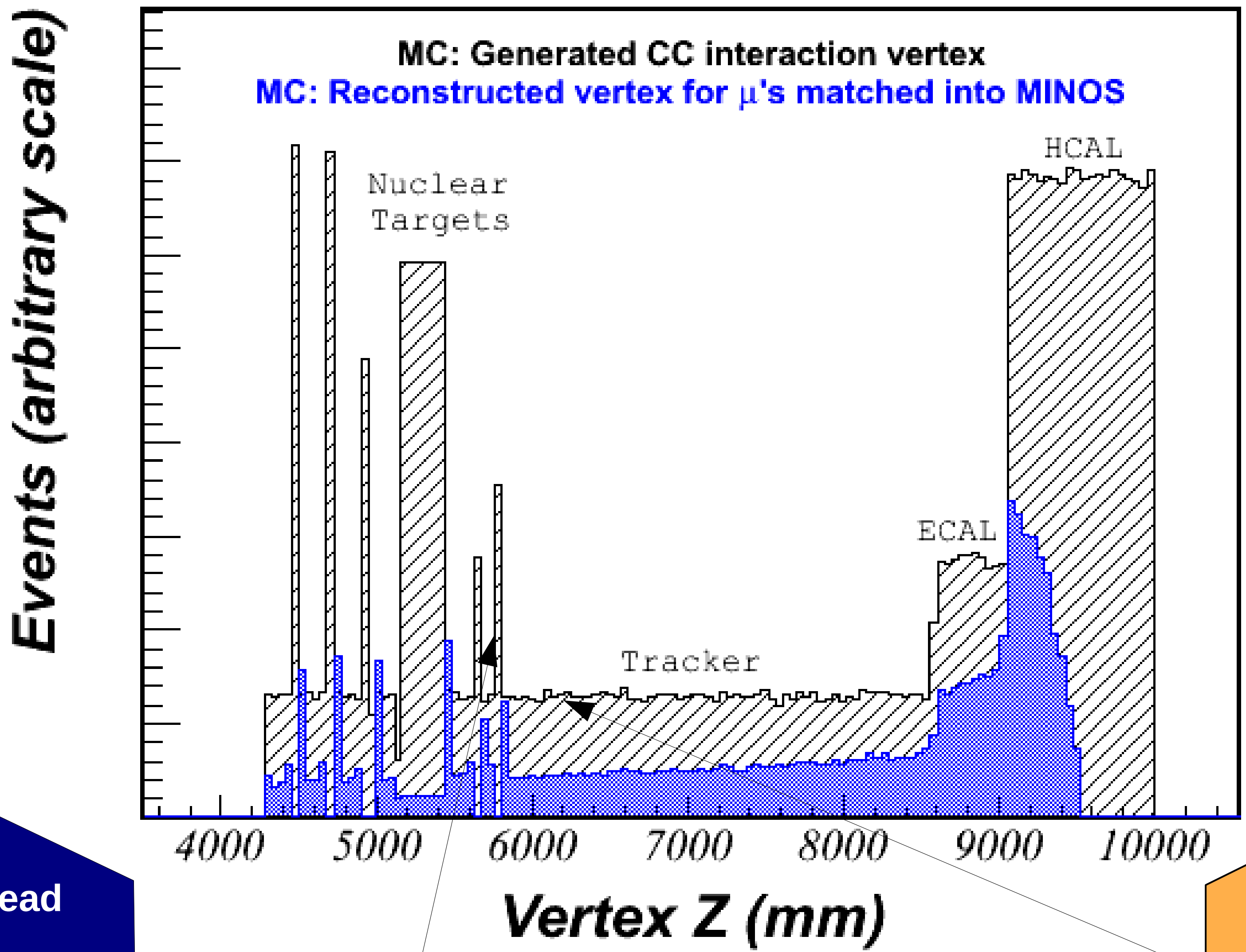
•Thickness = 1.3cm

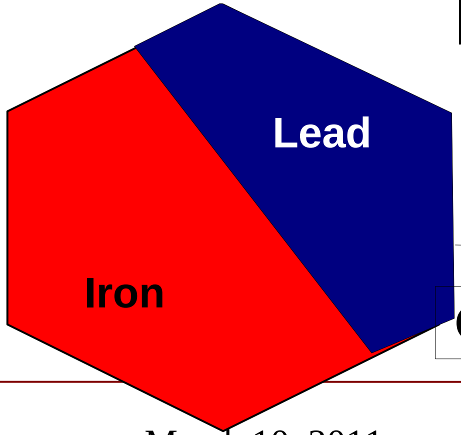




- Compare CH to Pb,Fe
- Minimize systematic errors
  - Efficiency, area, acceptance
- Group of 4 active scintillator modules
  - Thickness = 15cm of plastic
- Pretend it has same Fe/Pb divide as passive

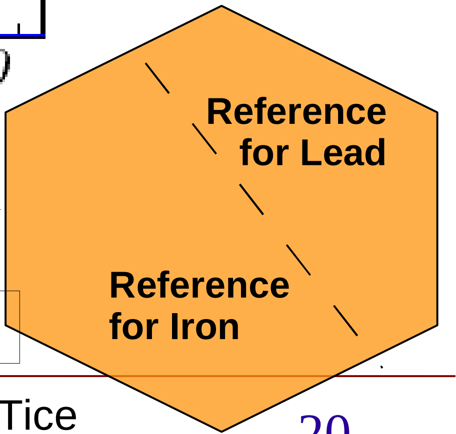
Location in the Detector





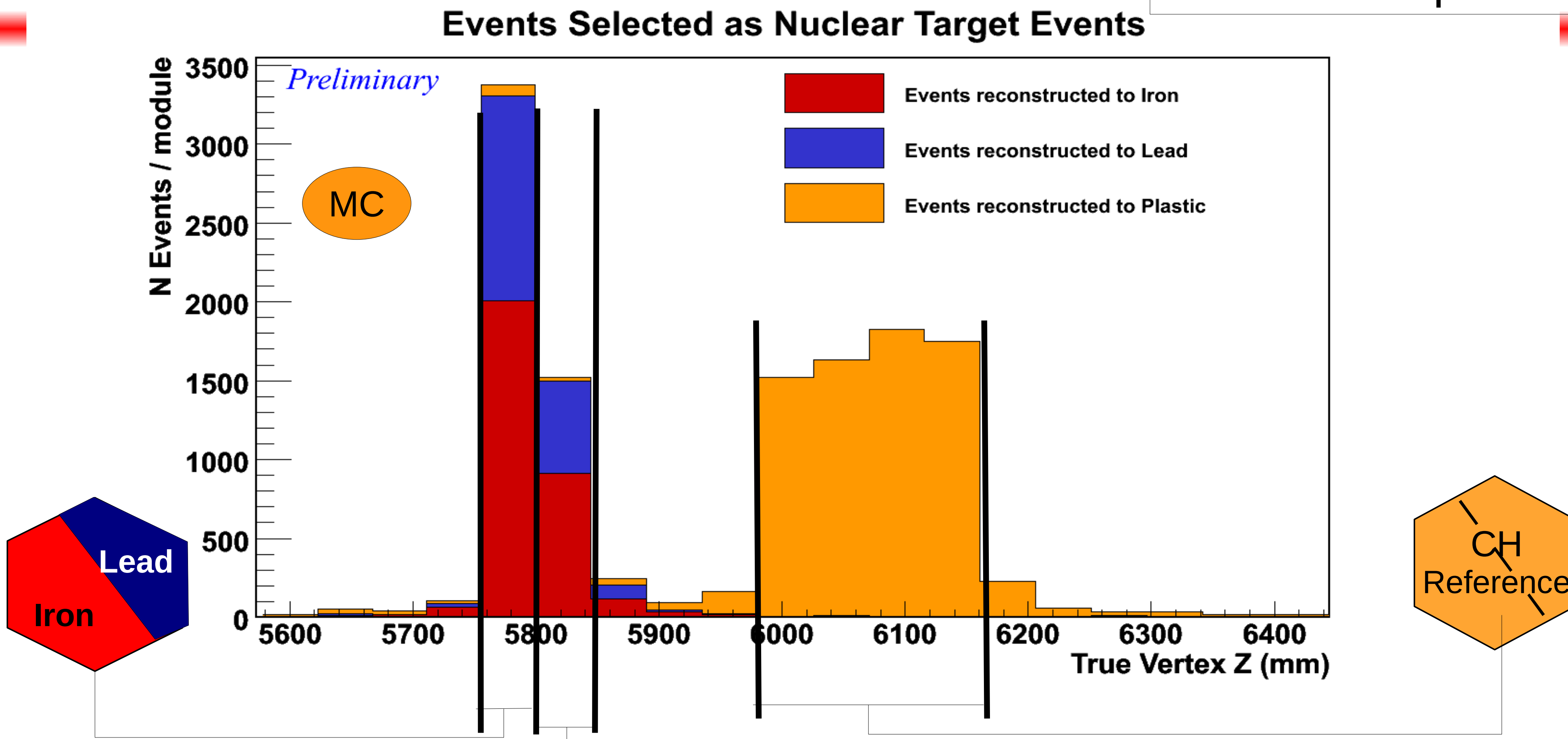
Centered at Z = 5778 mm

Centered at Z = 6069 mm



Vertex-Z Distribution

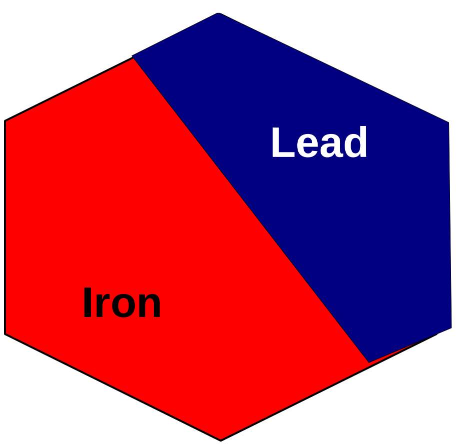
Iron-Rich Sample
Lead-Rich Sample
Plastic Sample

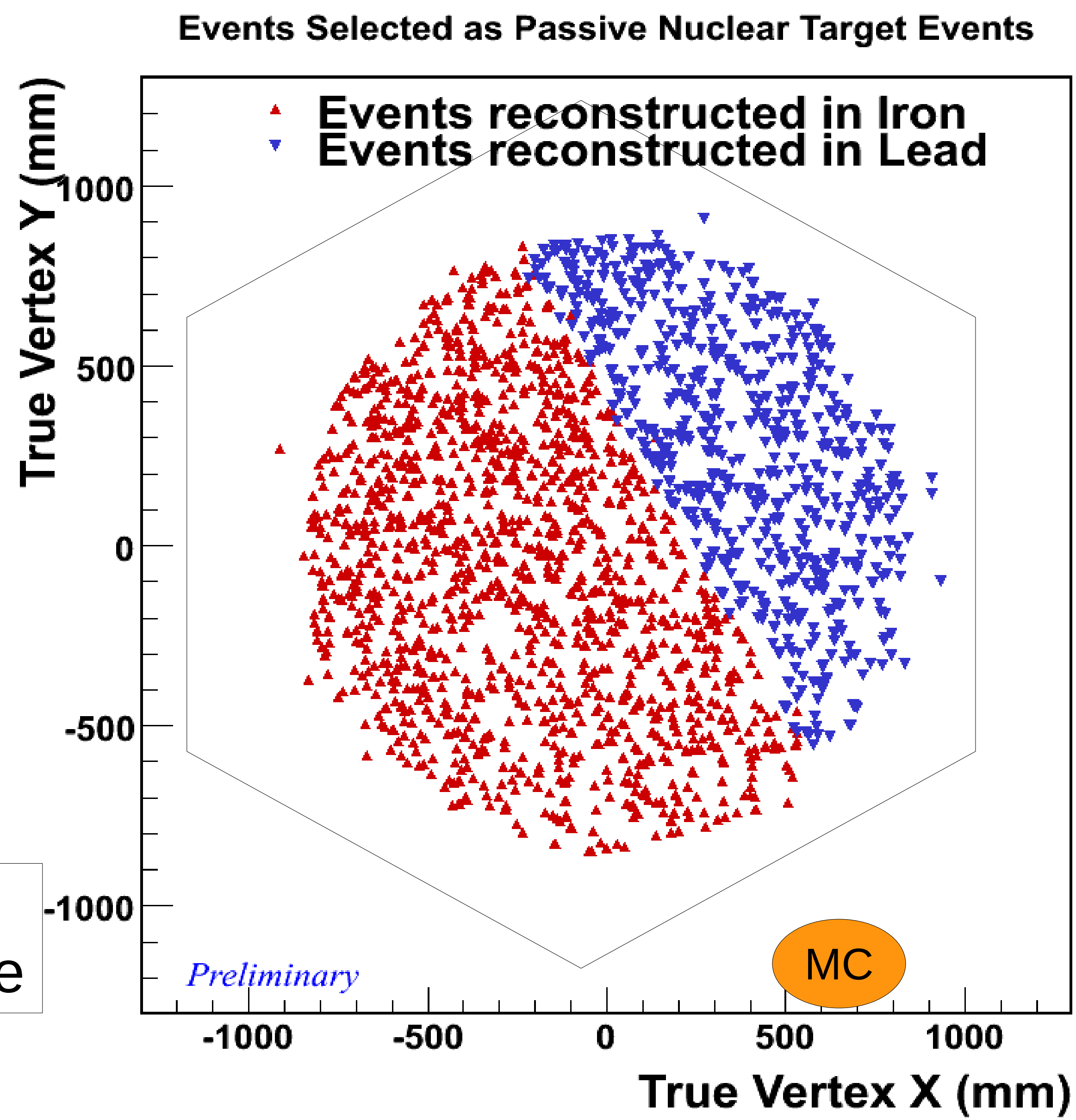


- Main contamination is first active module downstream of passive material
  - ALL events in passive target sample have a reconstructed vertex in this module

Misidentification of Nucleus

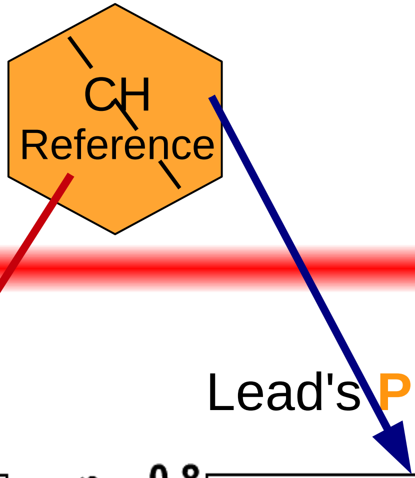
- **Blue** triangles in **Red** area are selected as events from **Iron** but are truly events from **Lead**





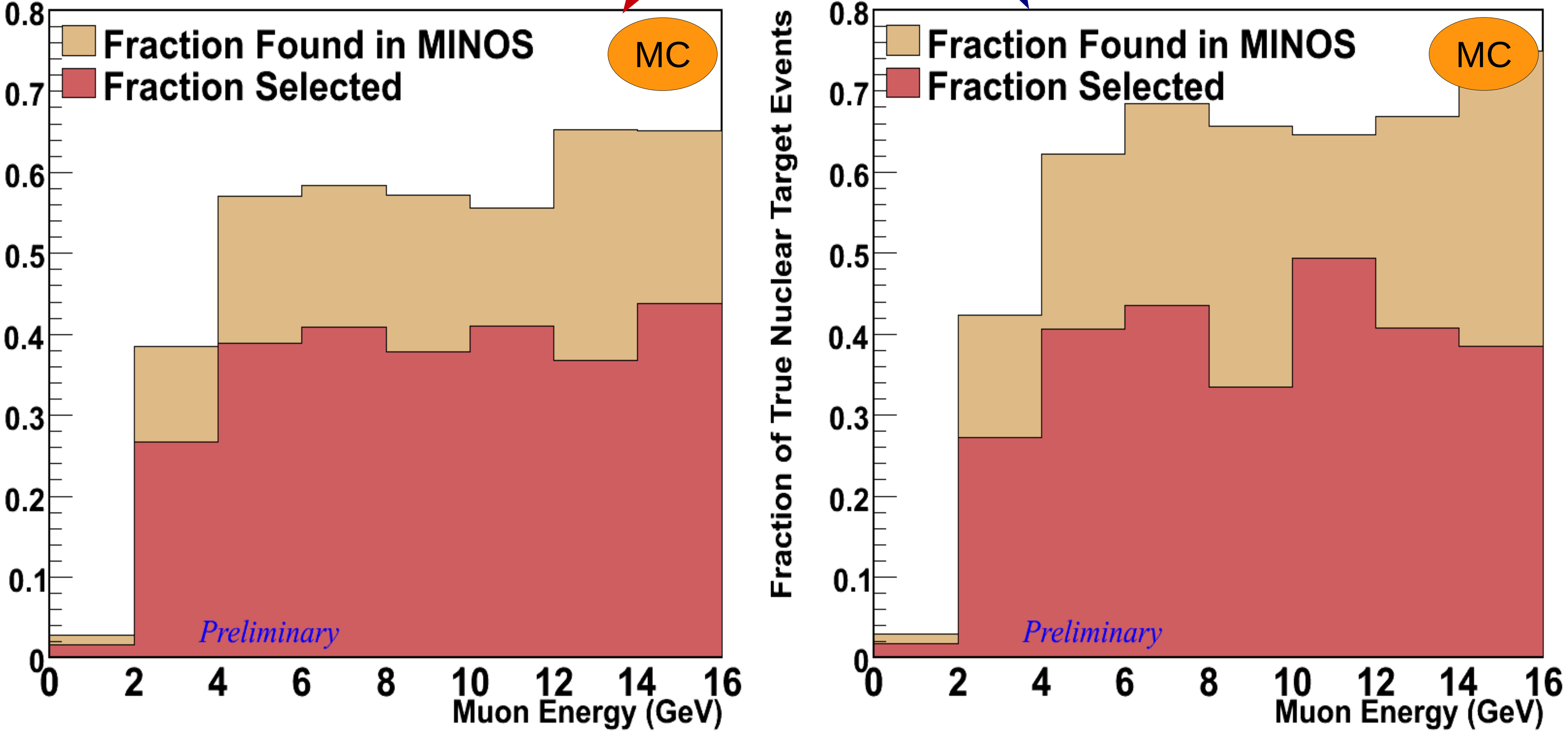
Iron-Rich Sample
Lead-Rich Sample

Efficiency



Iron's **Plastic Reference** Target

Lead's **Plastic Reference** Target

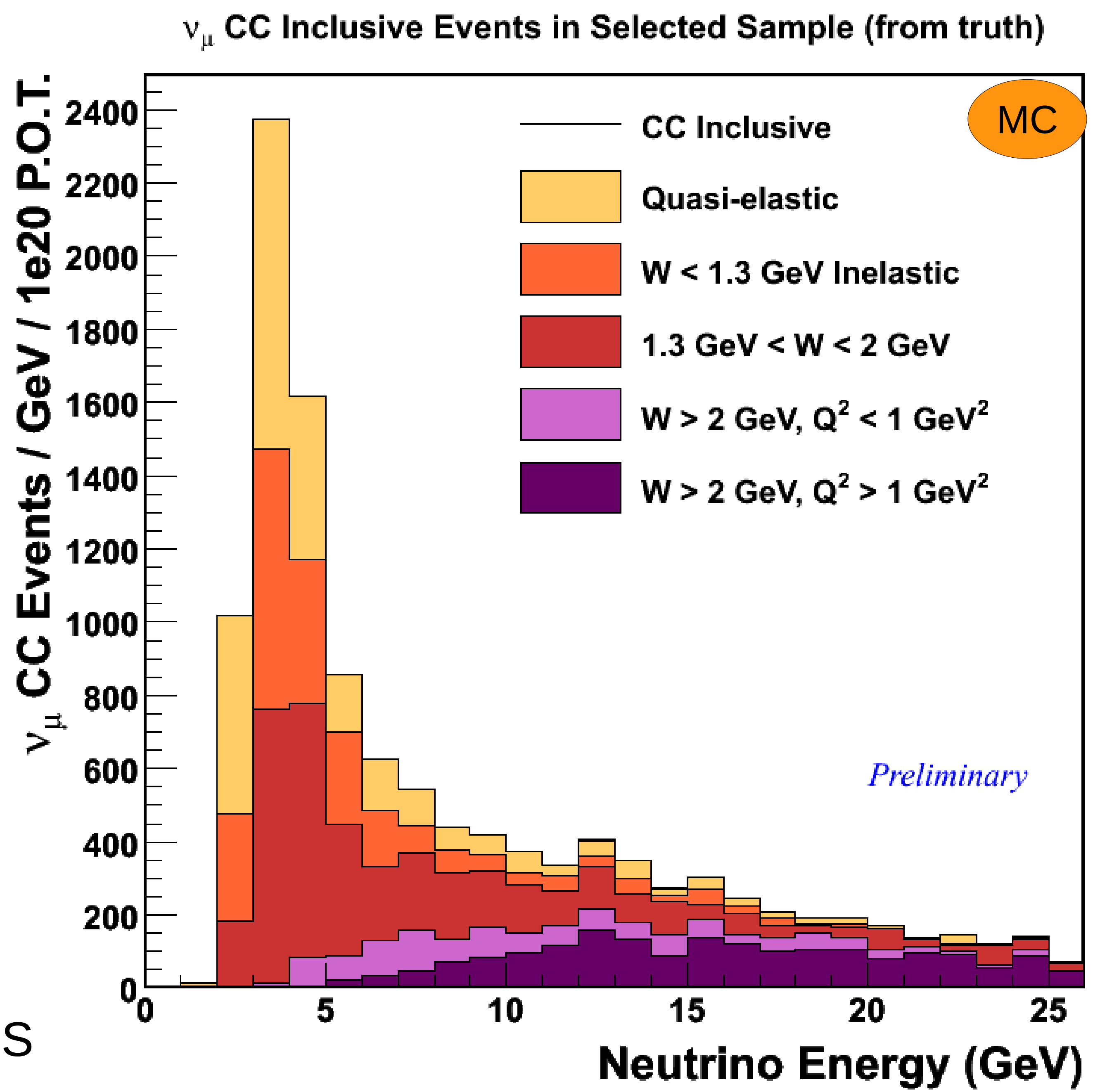


CC Channels

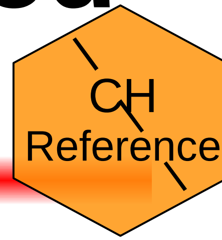
- Kinematic breakdown of events that make it into all 3 event samples

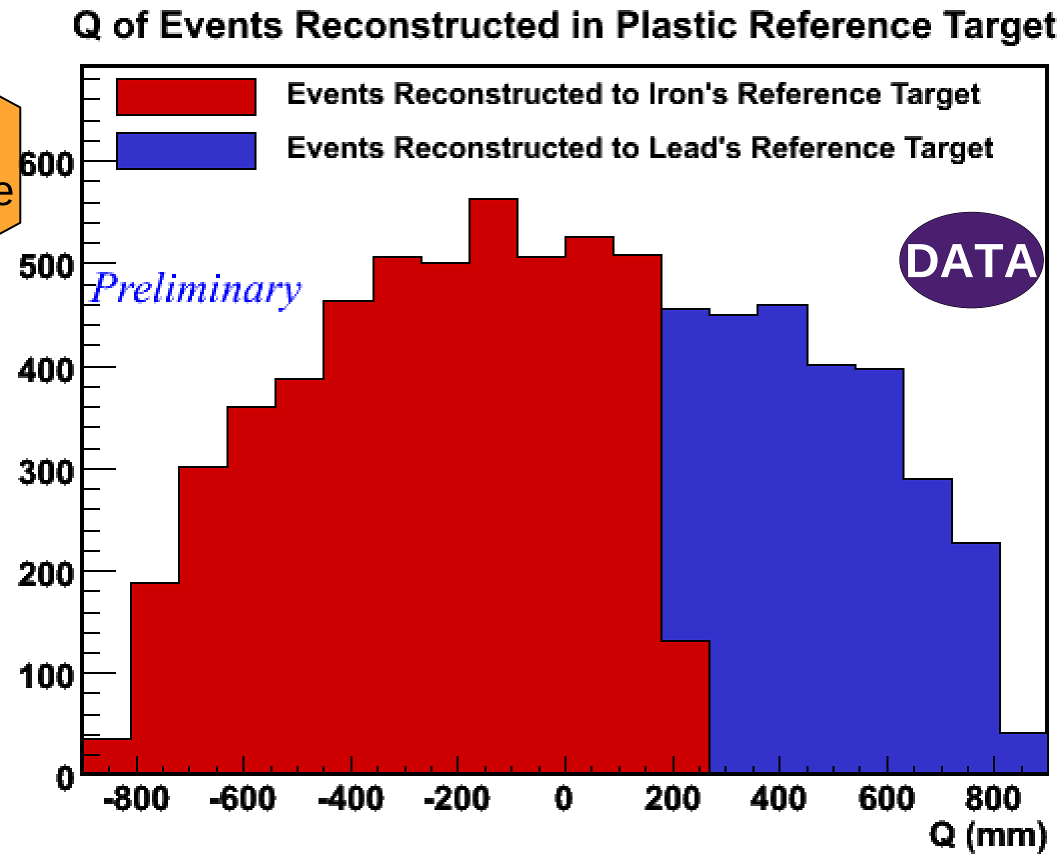
Iron-Rich Sample
Lead-Rich Sample
Plastic Sample

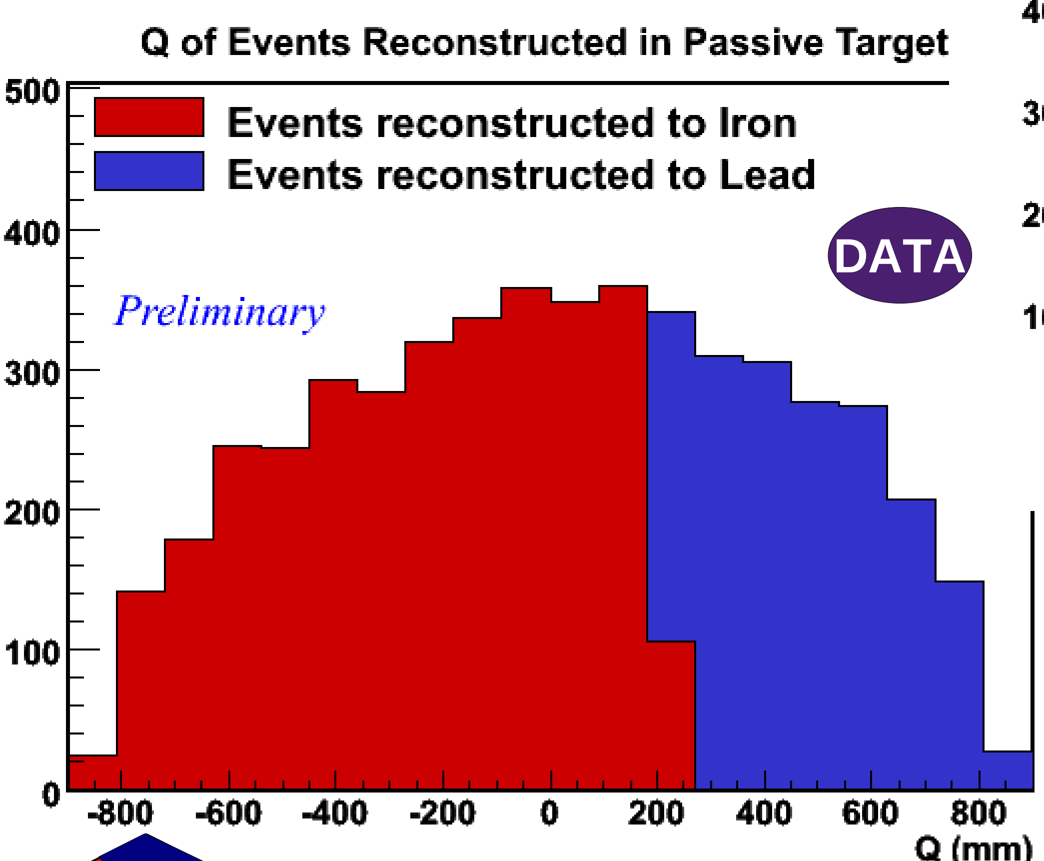
- Cutoff at low energies is from the requirement that the track is reconstructed in MINOS

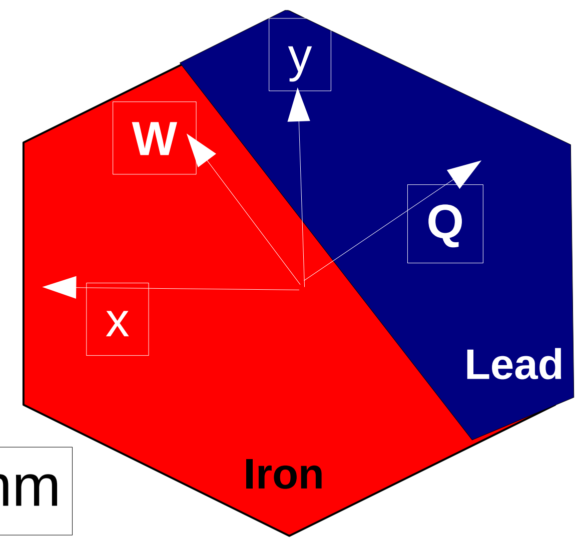


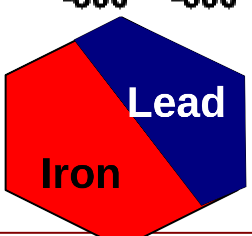
Events Selected





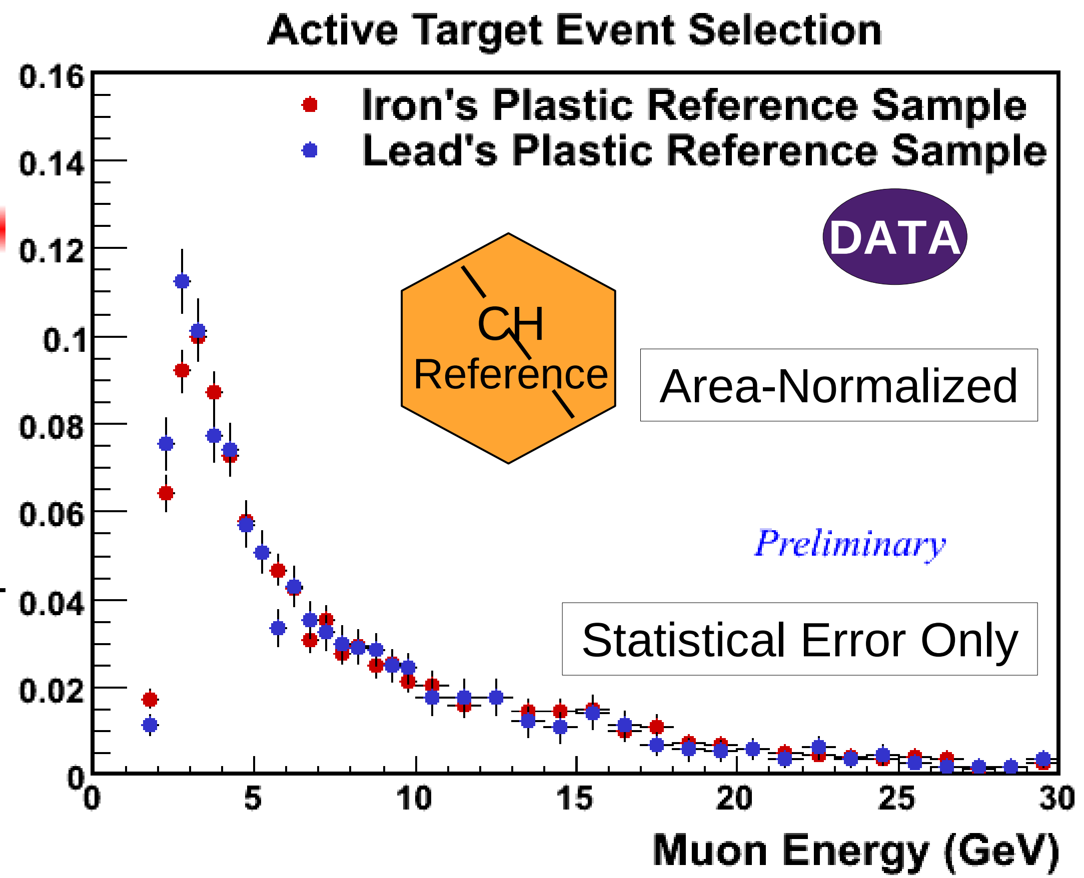


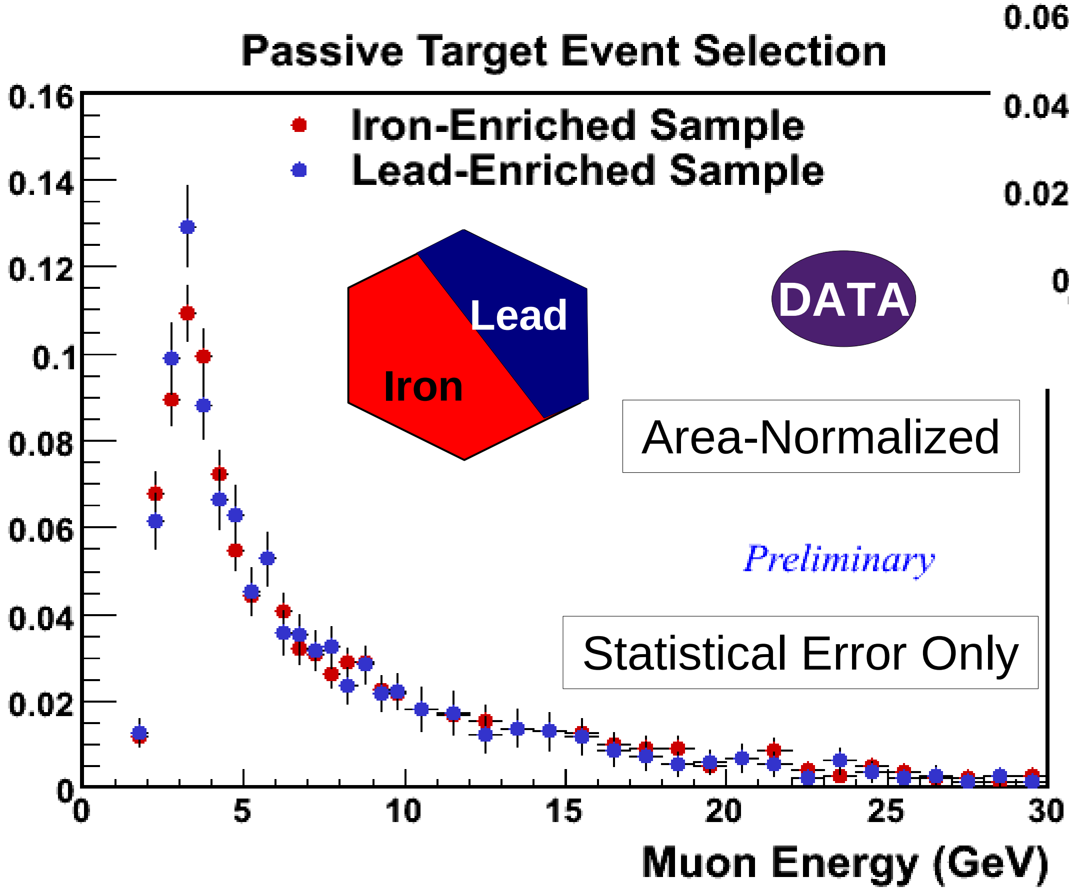




- **Iron** is Q_{μ} < 205mm
- **Lead** is Q_{μ} > 205 mm

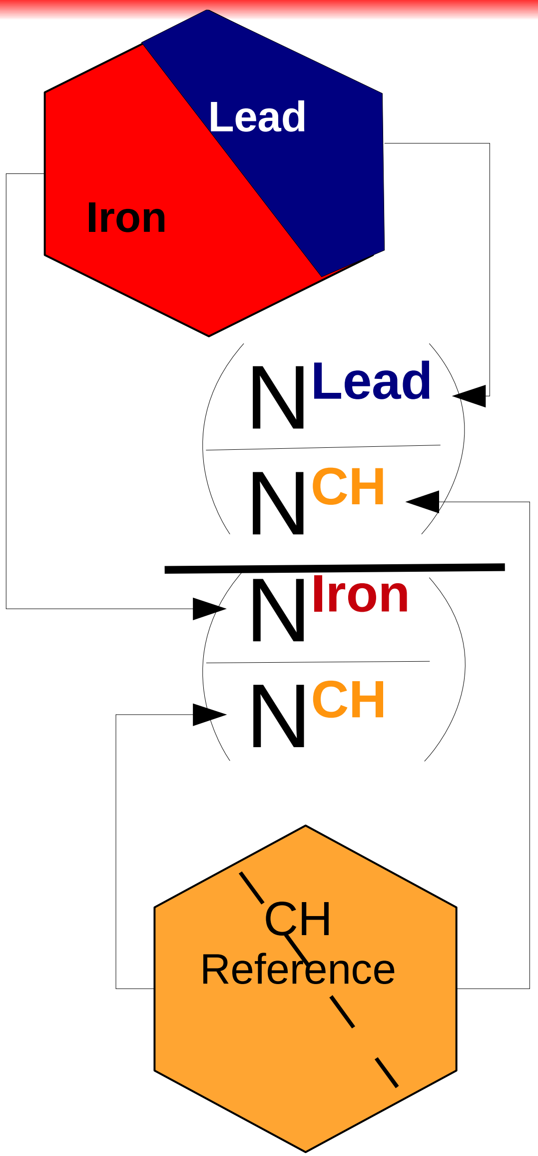
Muon Energy


Active Target Event Selection
Iron's Plastic Reference Sample
Lead's Plastic Reference Sample
DATA
CH Reference
Area-Normalized
Preliminary
Statistical Error Only
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
5
10
15
20
25
30
Muon Energy (GeV)


Passive Target Event Selection
Iron-Enriched Sample
Lead-Enriched Sample
Lead
Iron
DATA
Area-Normalized
Preliminary
Statistical Error Only
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
5
10
15
20
25
30
Muon Energy (GeV)

The Goal: Lead to Iron Ratio

- Ratio removes dependence on neutrino flux
  - **Lead** and **Iron** see the same beam



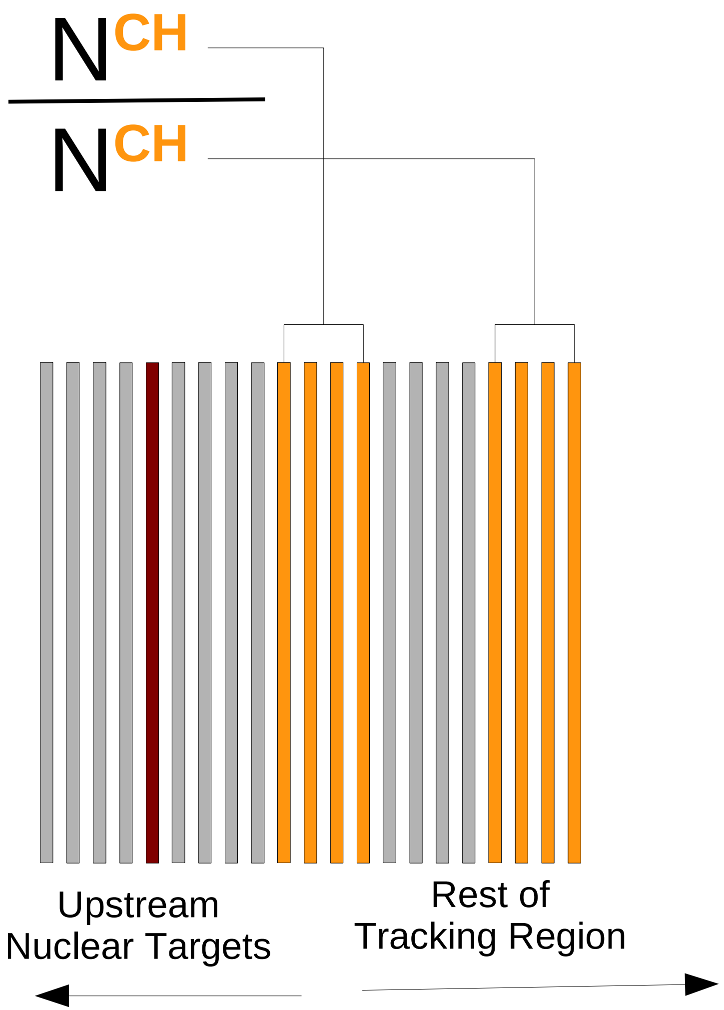
$$\frac{N^{Lead} / N^{CH}}{N^{Iron} / N^{CH}} = \frac{N^{Lead}}{N^{Iron}} =$$

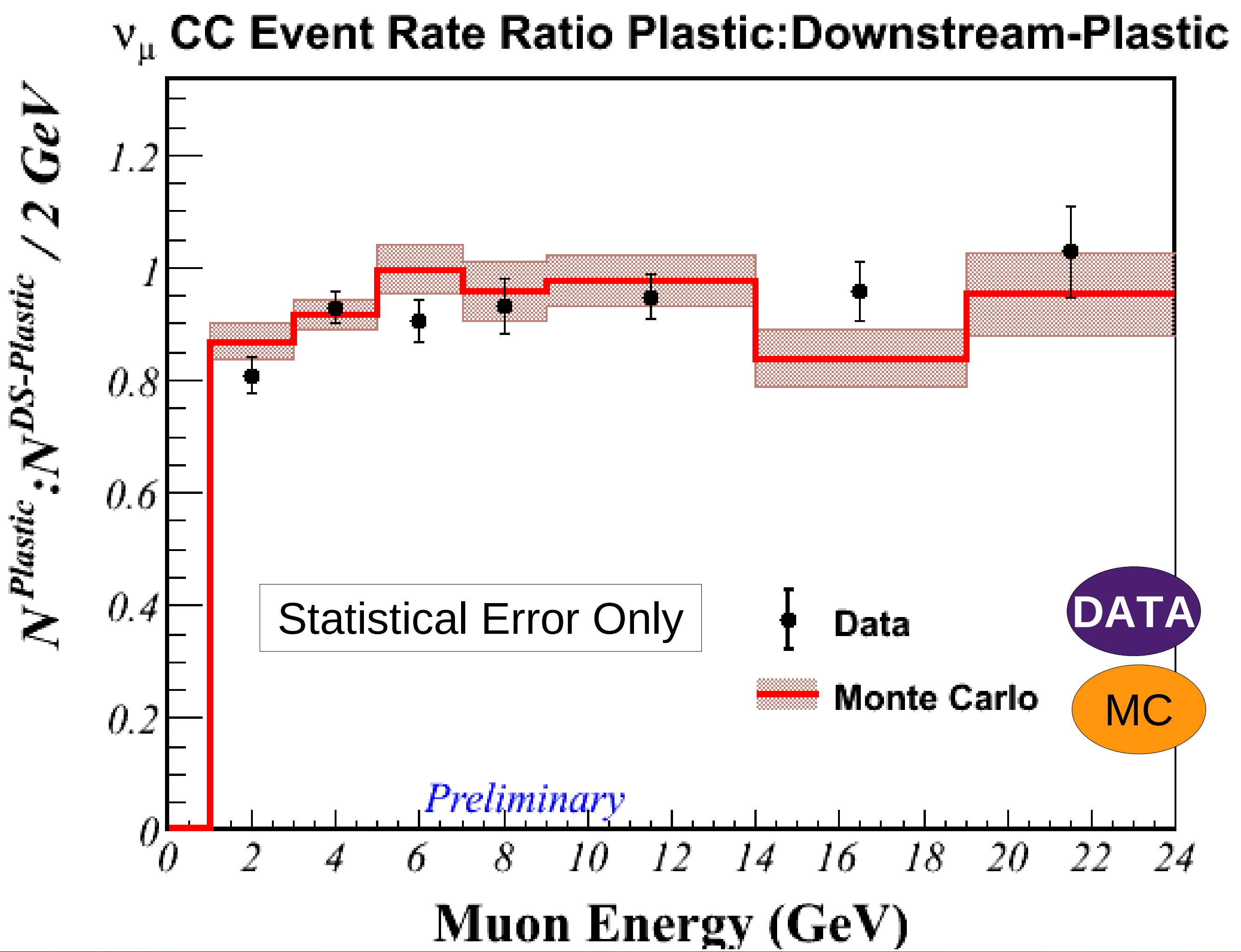
Coming Soon

- Using plastic reference targets minimizes systematic error from different X:Y regions

A Start: Plastic to Plastic Ratio
Targets differ only in Z-Position

- What if the **Plastic Reference** Target had a **Plastic Reference** Target?





Conclusion

- MINERνA will measure *x*-dependent cross sections on:

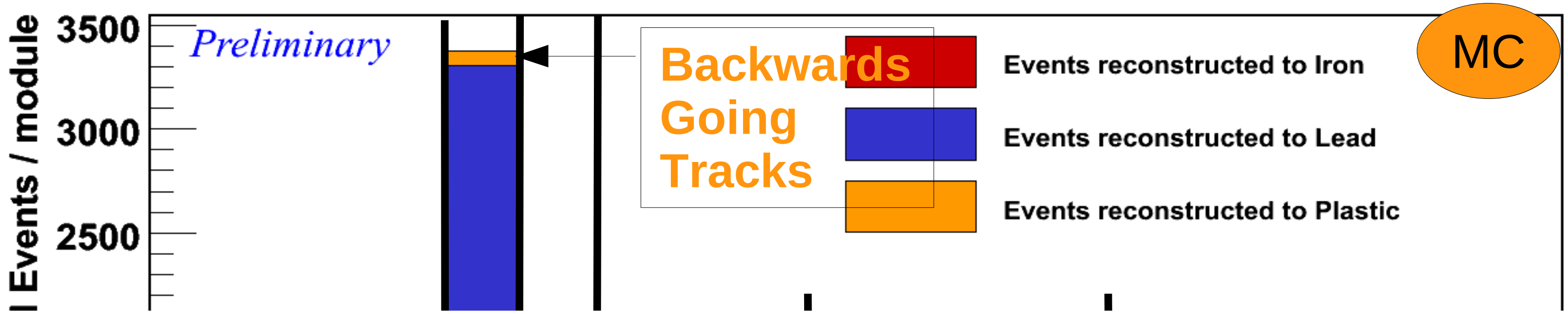
  CH, Fe, Pb, C, H20 and liquid He

- The nuclear program is designed to
  - Measure *x*-dependent nuclear effects
    - nuclear effects on F2 and *x*F3
  - Aid in the extraction A, *x*, Q^2 dependence of nuclear parton distribution functions
  - Measure final state interactions as a function of A
- Working to produce ratios of CC inclusive cross sections of ν_μ and $\bar{\nu}_\mu$ on **Plastic**, **Lead** and **Iron**

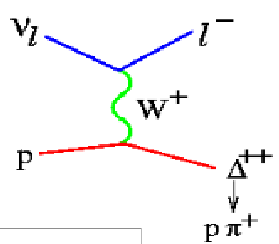
Backups

Vertex-Z Distribution

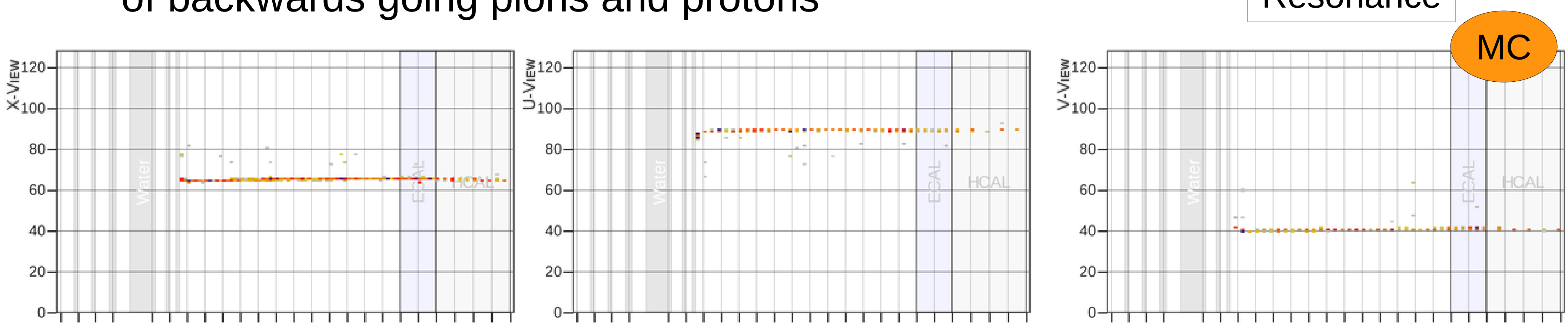
Events Selected as Nuclear Target Events



- Difficult to find the correct vertex with backwards going track when using only the muon to form a vertex
- MINERνA will study the A dependence of the production of backwards going pions and protons

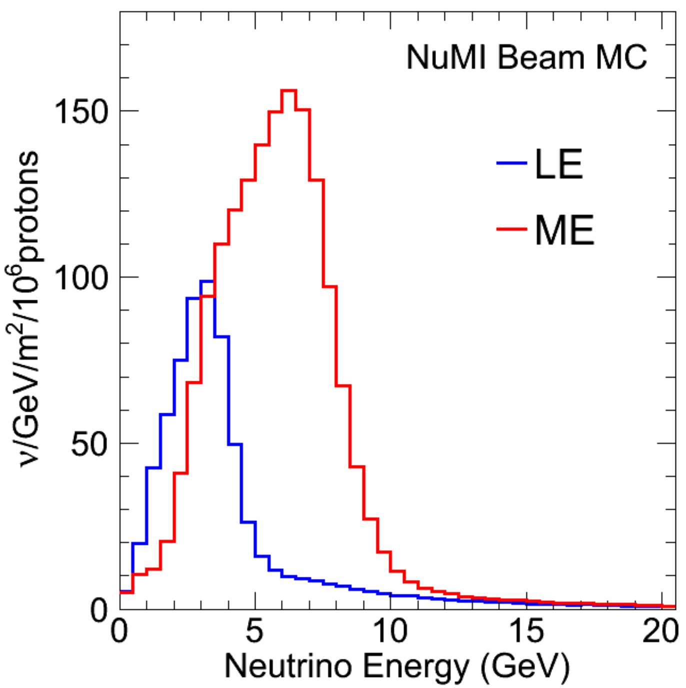


Resonance

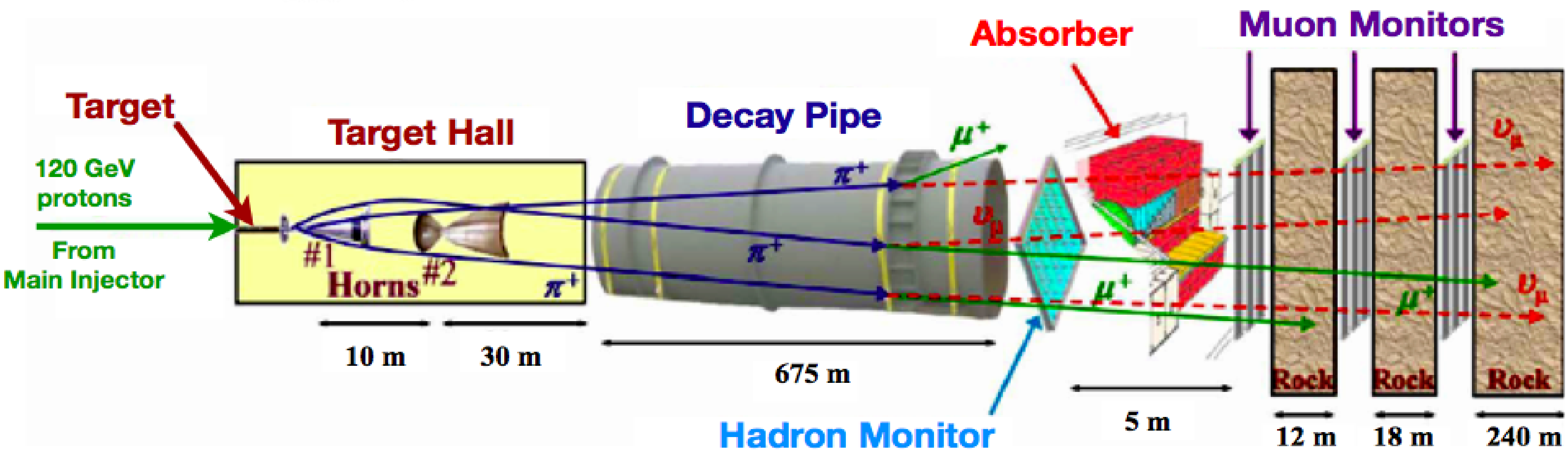


NuMI Beam Facility

Slide from D. Schmitz (Monday)



- Intensity: ~35e12 P.O.T per spill
  - about 1 ν event and a few rock muons in MINERνA per spill
- Spill length/frequency: 10μs / ~0.5 Hz.
- Beam power: 300 – 350 kW
- Mean energy of NuMI ν beam can be tuned by changing longitudinal positions of the target and horns
- Reversing current in focusing horns changes beam from mostly neutrinos to mostly antineutrinos
- Please see talk from M. Jerkins on Friday afternoon



Expected Event Rates

Slide from D. Schmitz (Monday)

Generator Level CC Event Numbers in Current Neutrino Data Set

	1.2e20 POT LE ν mode	1.2e20 POT LE anti-ν mode
Coherent pion production	**4k**	**3k**
Quasi-elastic	**84k**	**46k**
Resonance production	**146k**	**62k**
DIS, structure functions, high-x PDFs	**167k**	**19k**
C target	**11k**	**5k**
Fe target	**65k**	**20k**
Pb target	**68k**	**17k**
Scintillator Tracker	**409k**	**134k**

- Total MINERνA run plan in neutrino mode:
  - 4.9e20 P.O.T. in low-energy (LE) mode (March, 2010 – mid 2012)
  - 12e20 P.O.T. in medium-energy (ME) mode (beginning in 2013)