Inclusive Neutrino Cross Section Measurements at MINERvA

-**Brian G Tice**-

Rutgers, The State University of New Jersey

On behalf of the MINERvA collaboration

2012 Fall Meeting of APS Division of Nuclear Physics

Newport Beach, California

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Outline

- ν_μ / $\bar{\nu}_\mu$ inclusive charged current scattering

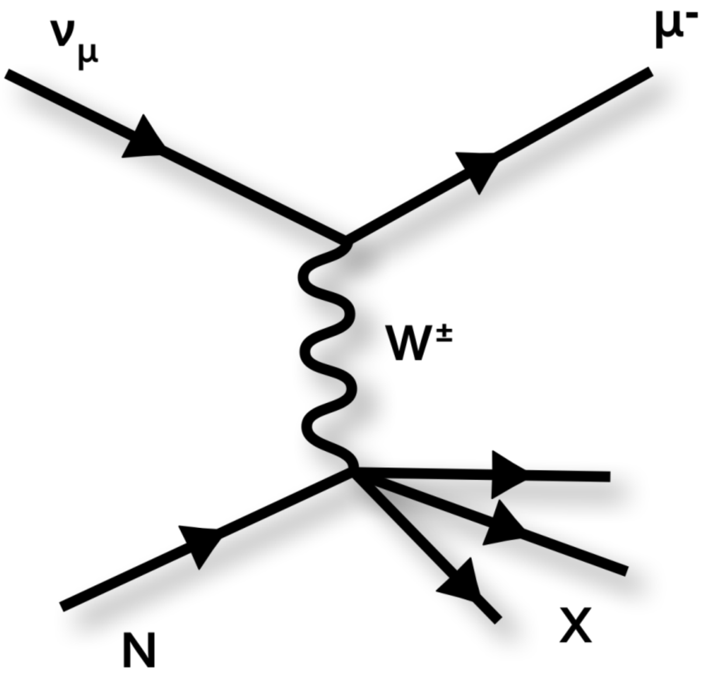
$CC\nu_\mu$ $CC\bar{\nu}_\mu$

- ν_μ inclusive charged current ratios of nuclear targets
  - **C, Fe, Pb, Scintillator**

$CC\nu_\mu$

Inclusive Charged Current Scattering

$CC\nu_\mu$ $CC\bar{\nu}_\mu$

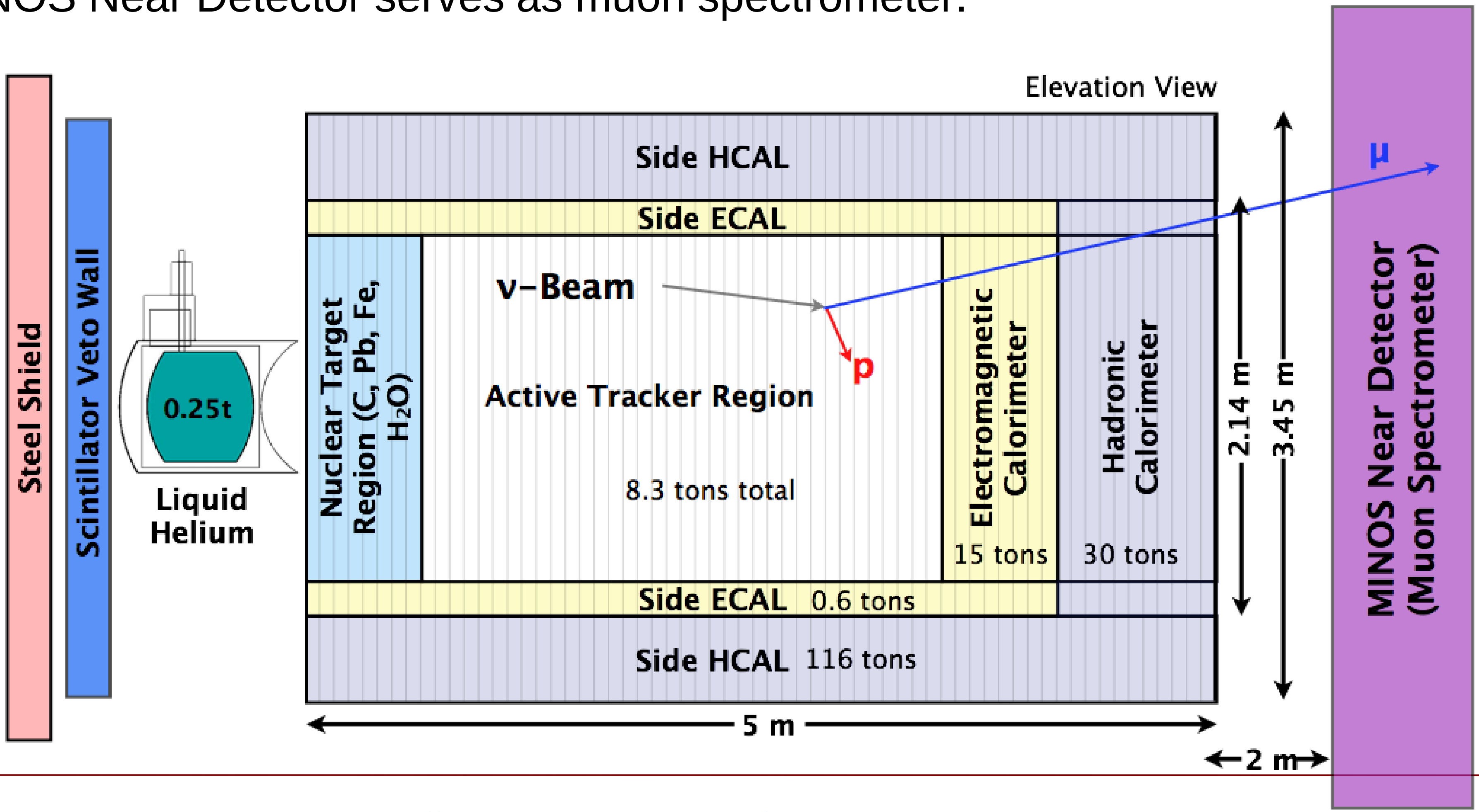


MINERvA Detector (again)

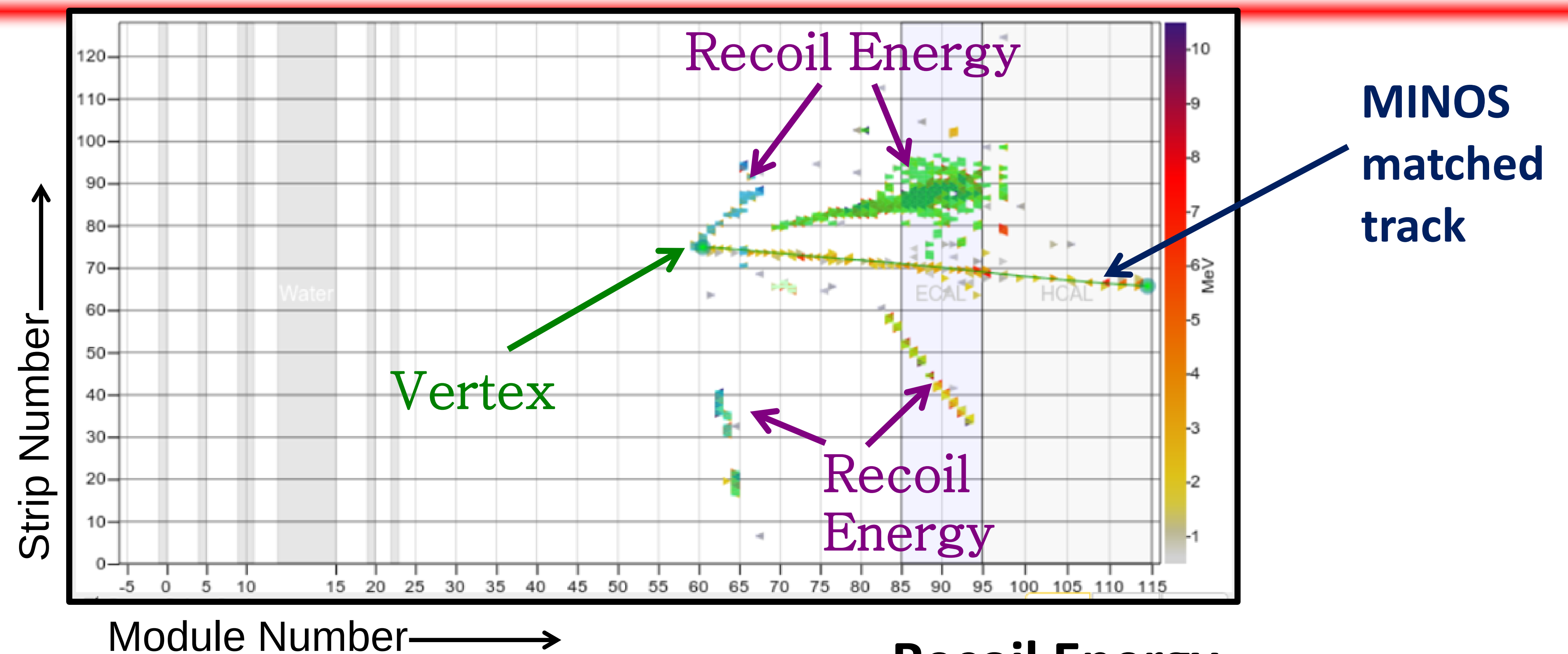
120 scintillator modules for tracking and calorimetry (~32k readout channels).

Construction completed Spring 2010. He and Water added in 2011.

MINOS Near Detector serves as muon spectrometer.



Event Reconstruction



Reconstructed objects

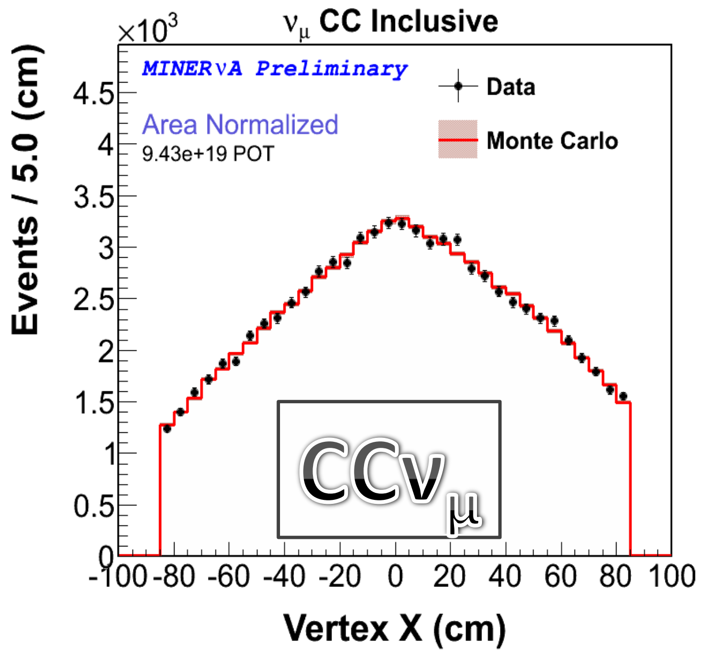
MINOS tracks, other tracks, vertices, endpoints, blobs

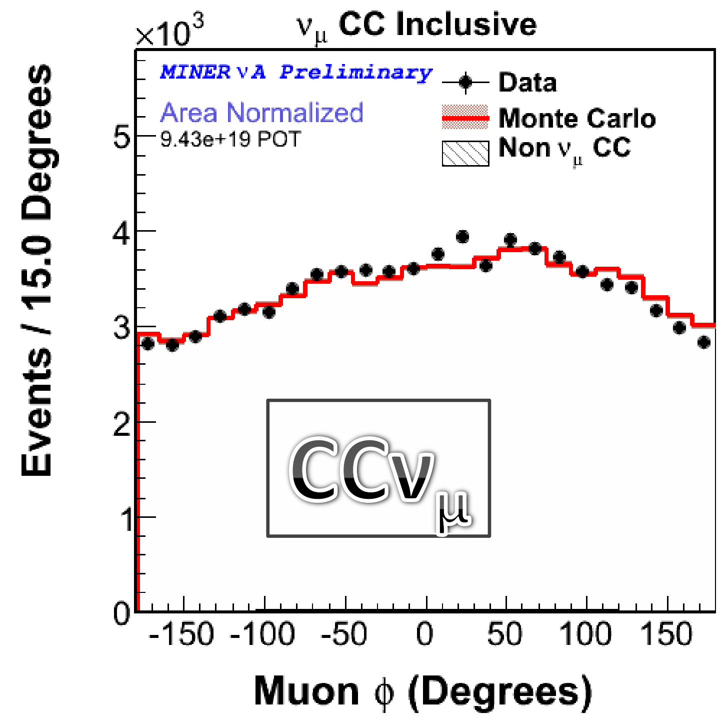
Recoil Energy

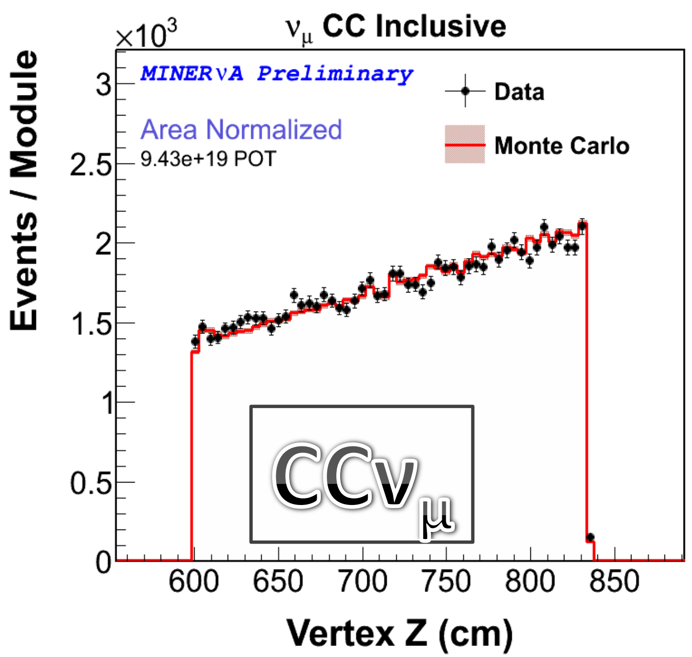
Sum of visible energy, weighted by amount of passive material

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

Vertex Distributions – Acceptance



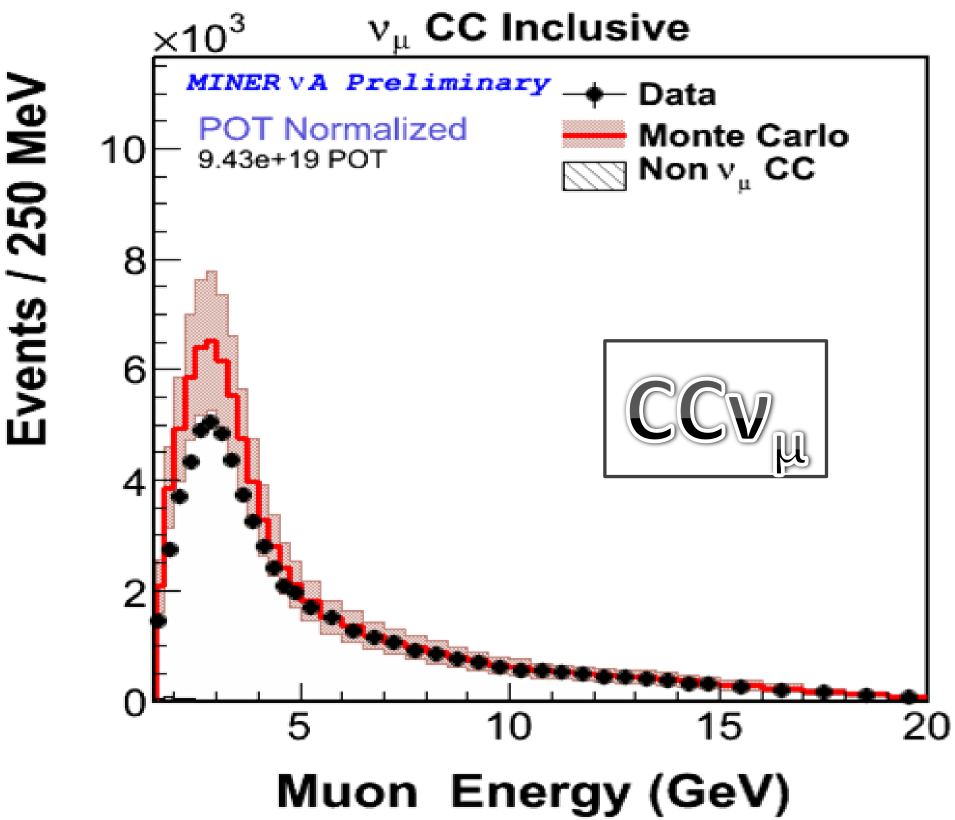


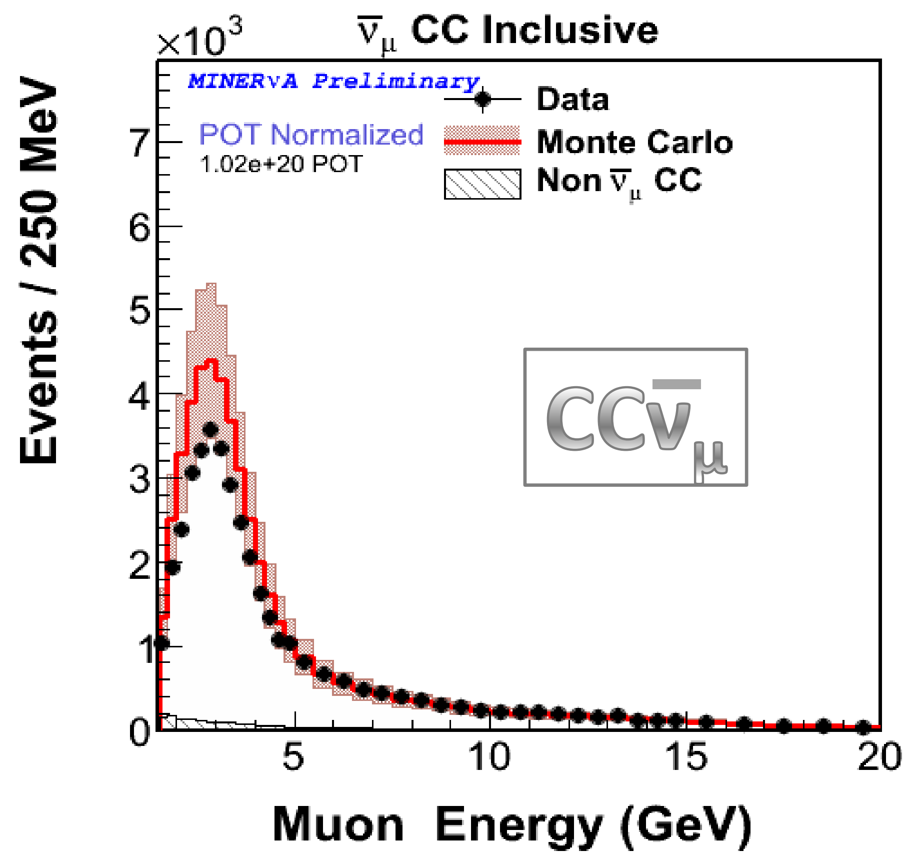


"MINOS-matched" muons (for CC ν_μ inclusives sample)

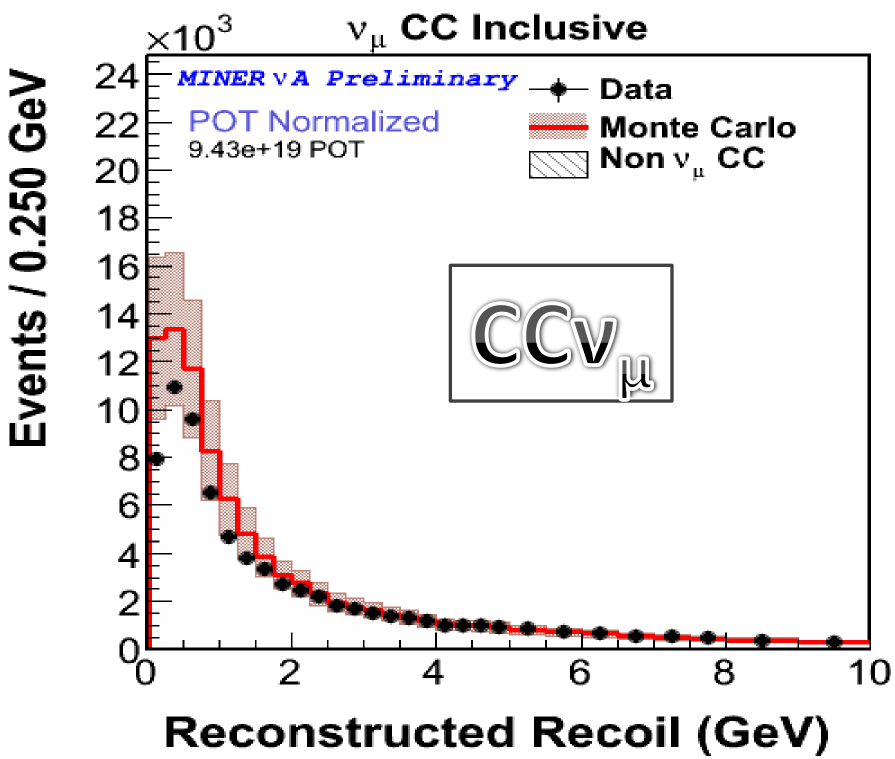
- Energy threshold ~2 GeV.
- Good angular acceptance up to scattering angles of about 10 degrees, with limit of about 20 degrees.
- Bias is complex but well understood.

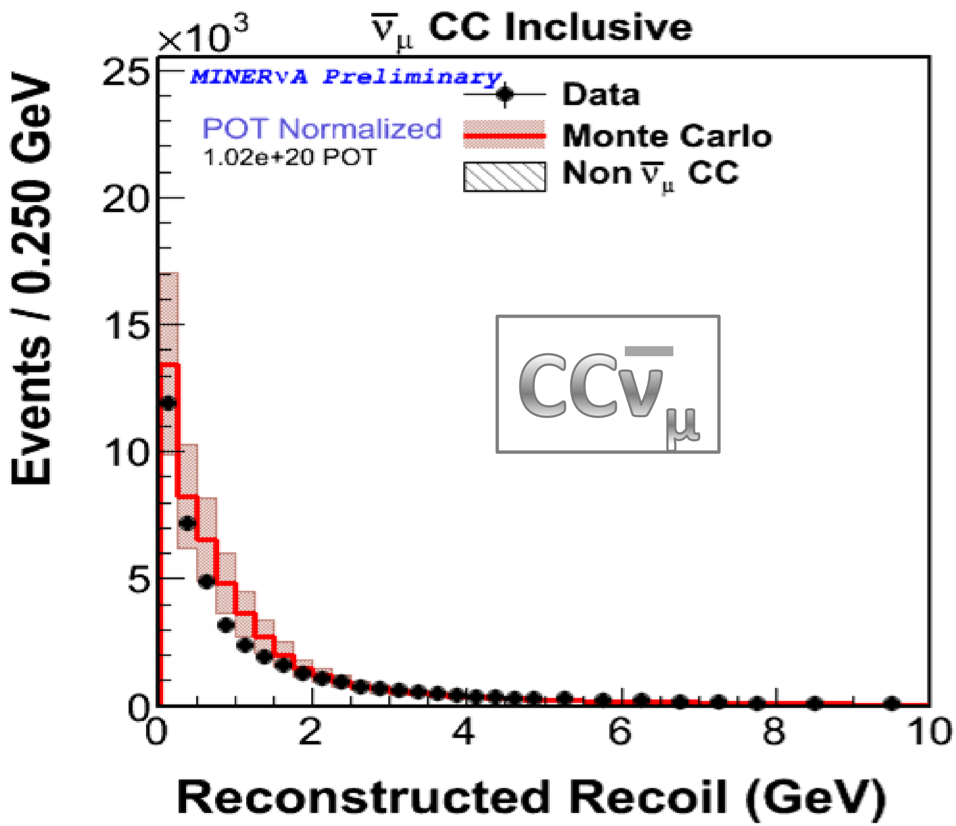
Muon Energy Distribution



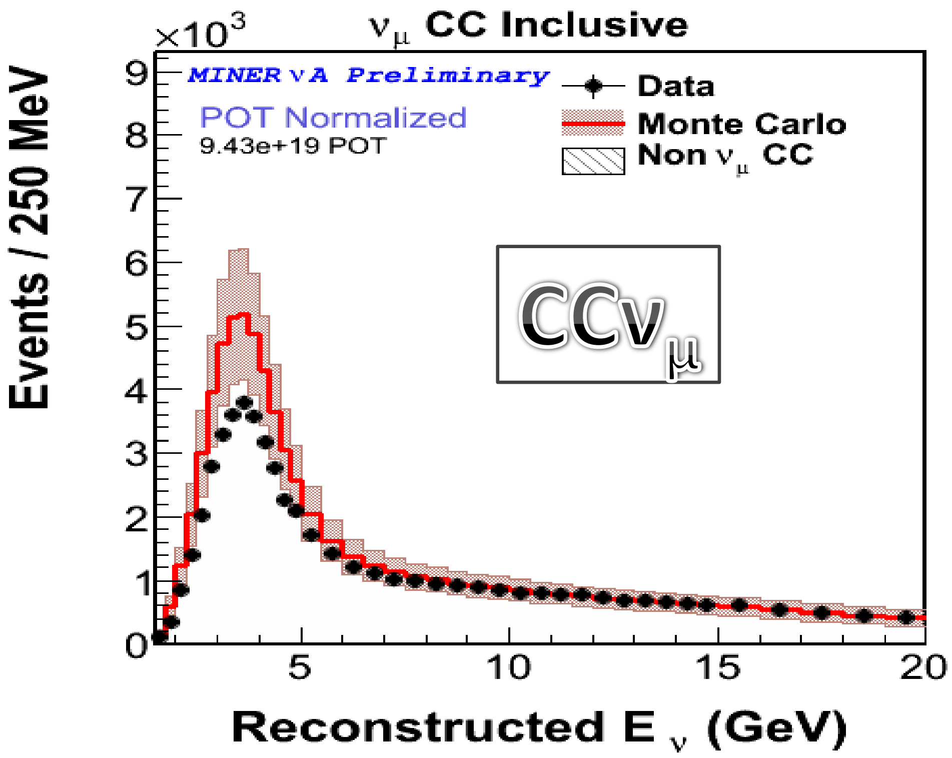


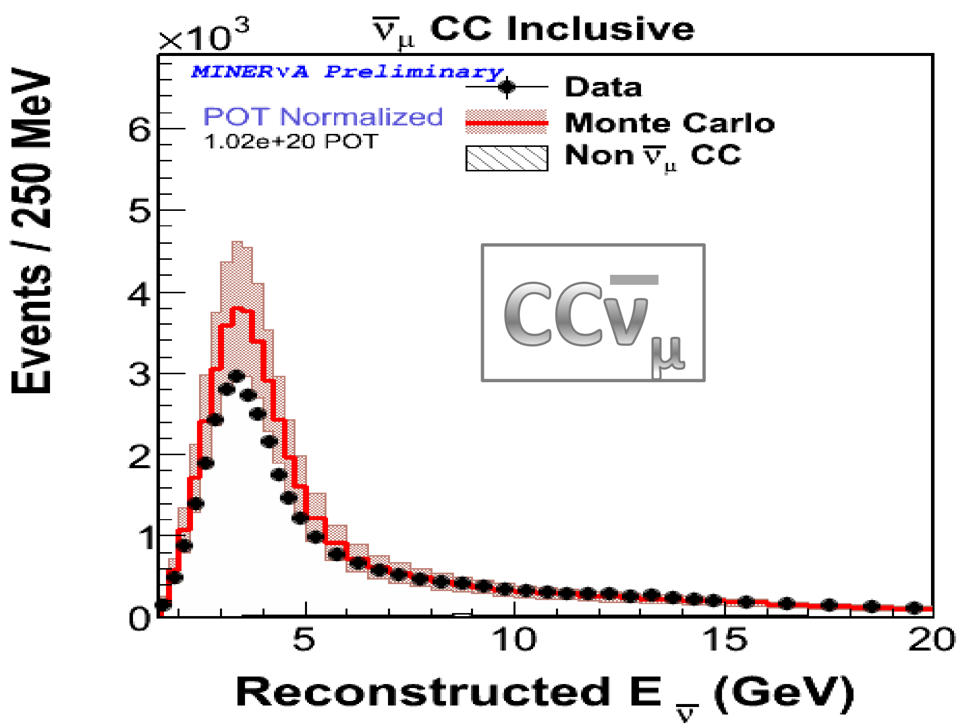
Recoil Energy Distribution



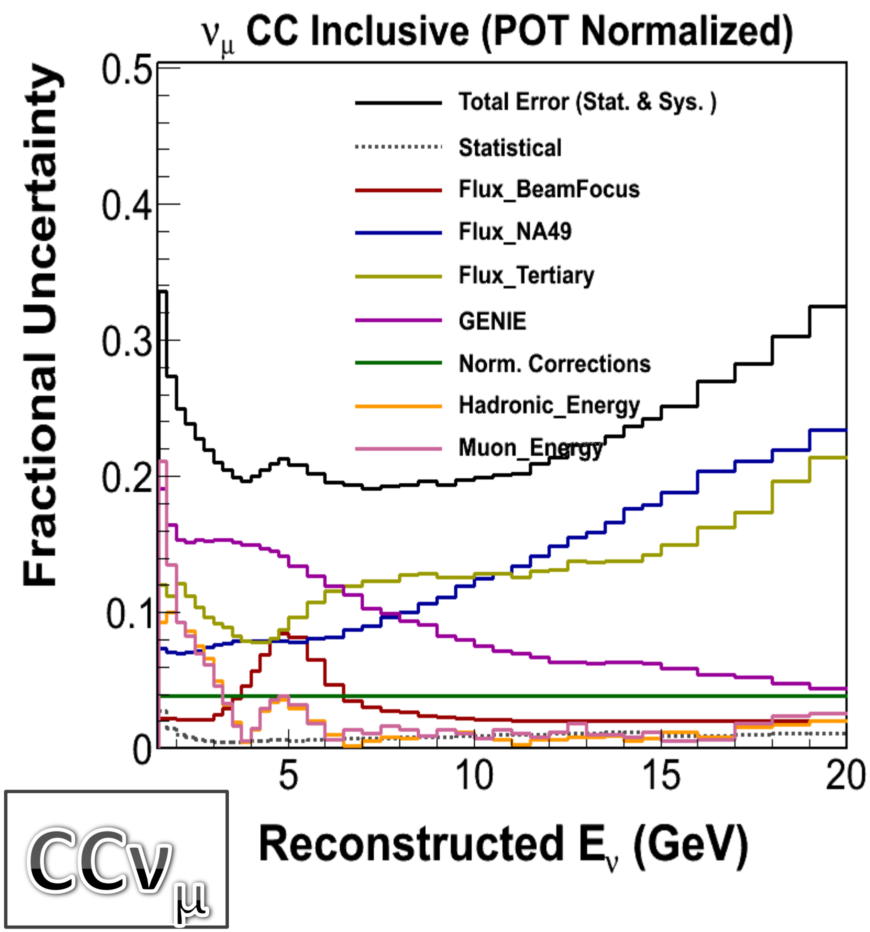


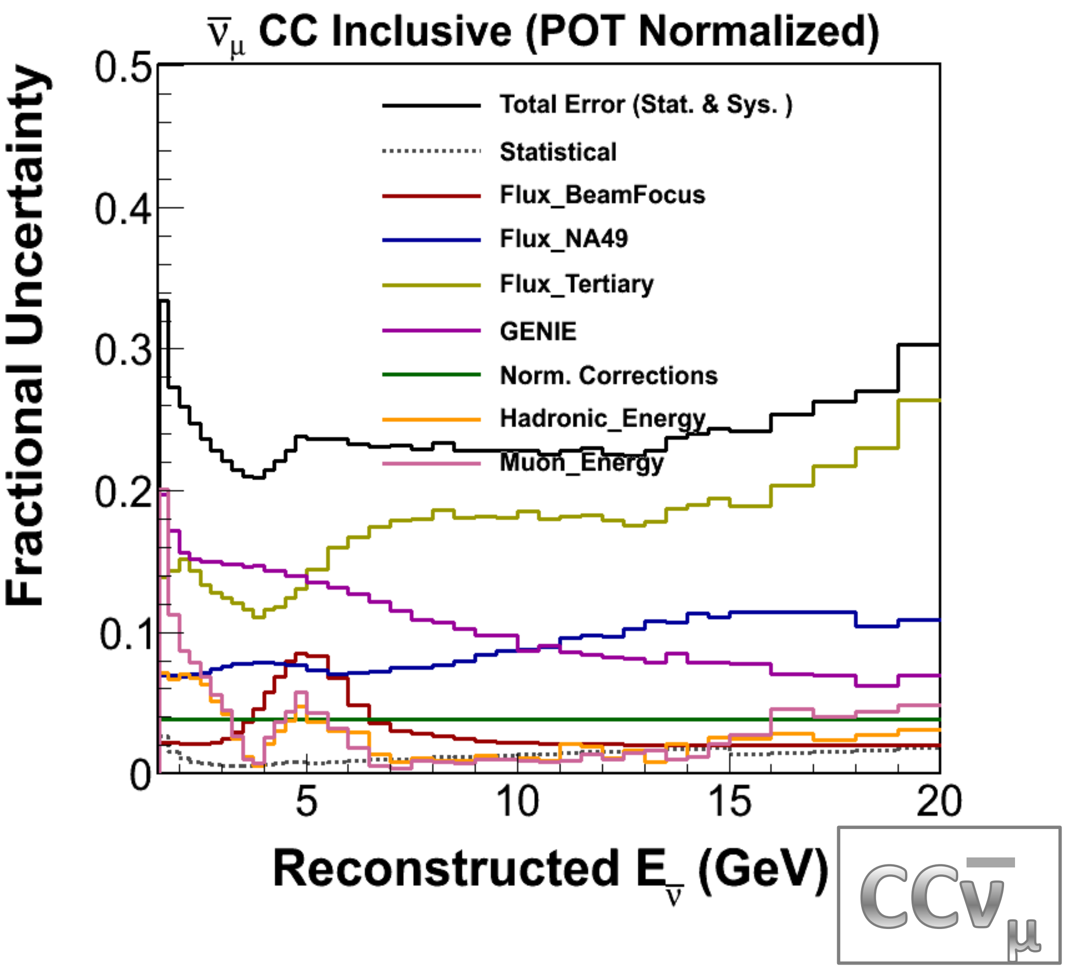
Neutrino Energy Distribution



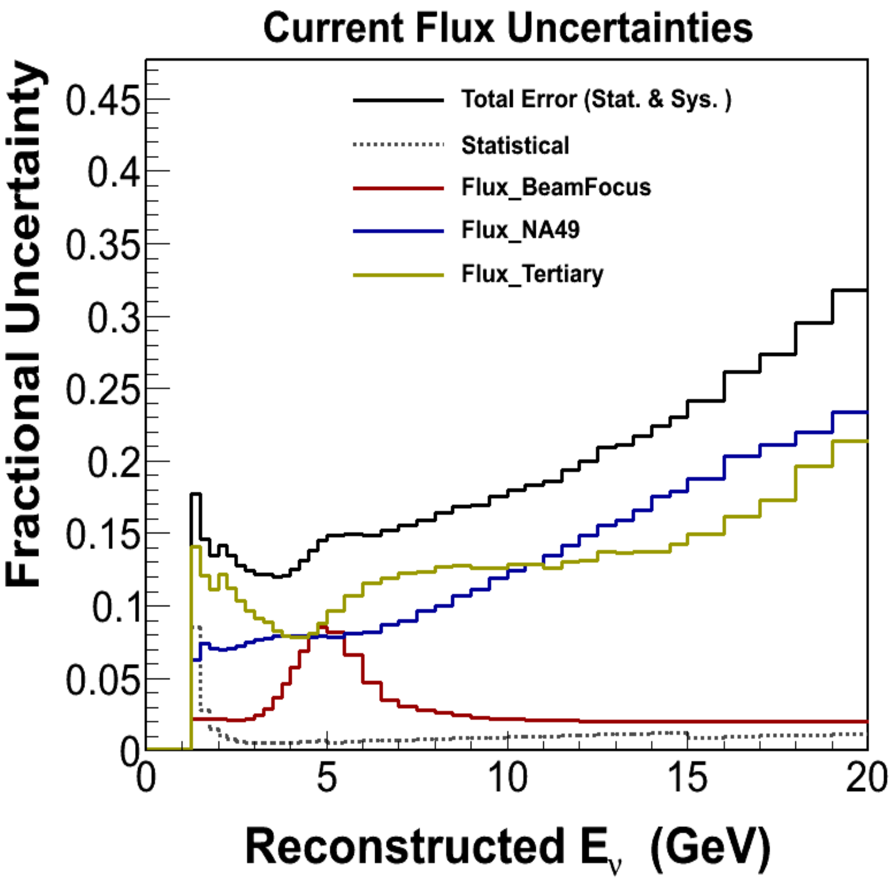


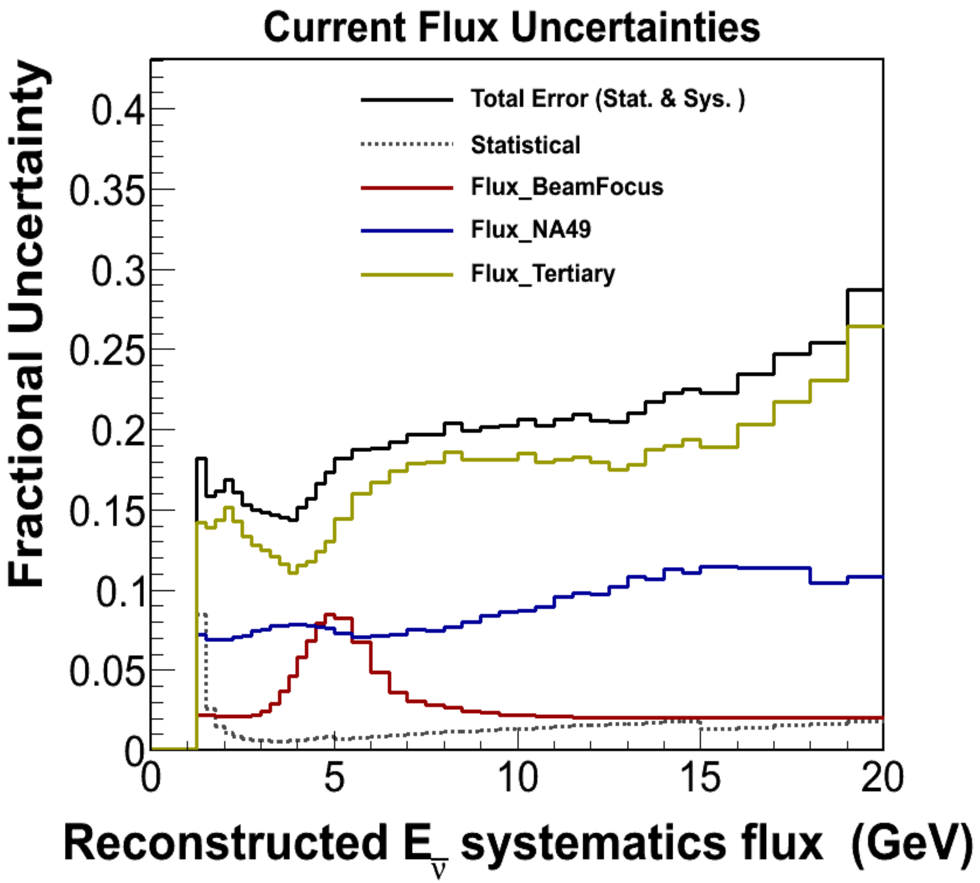
Errors on Neutrino Energy





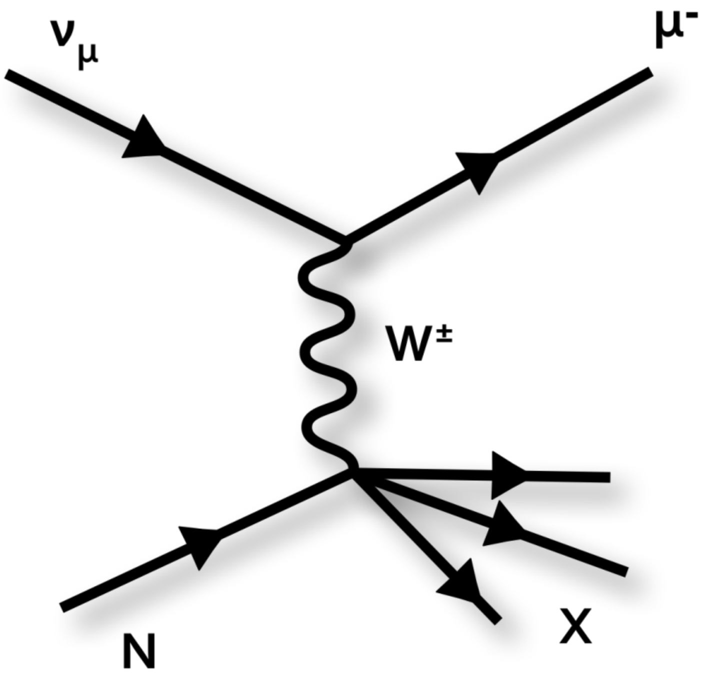
We have an aggressive plan to reduce these errors from the flux

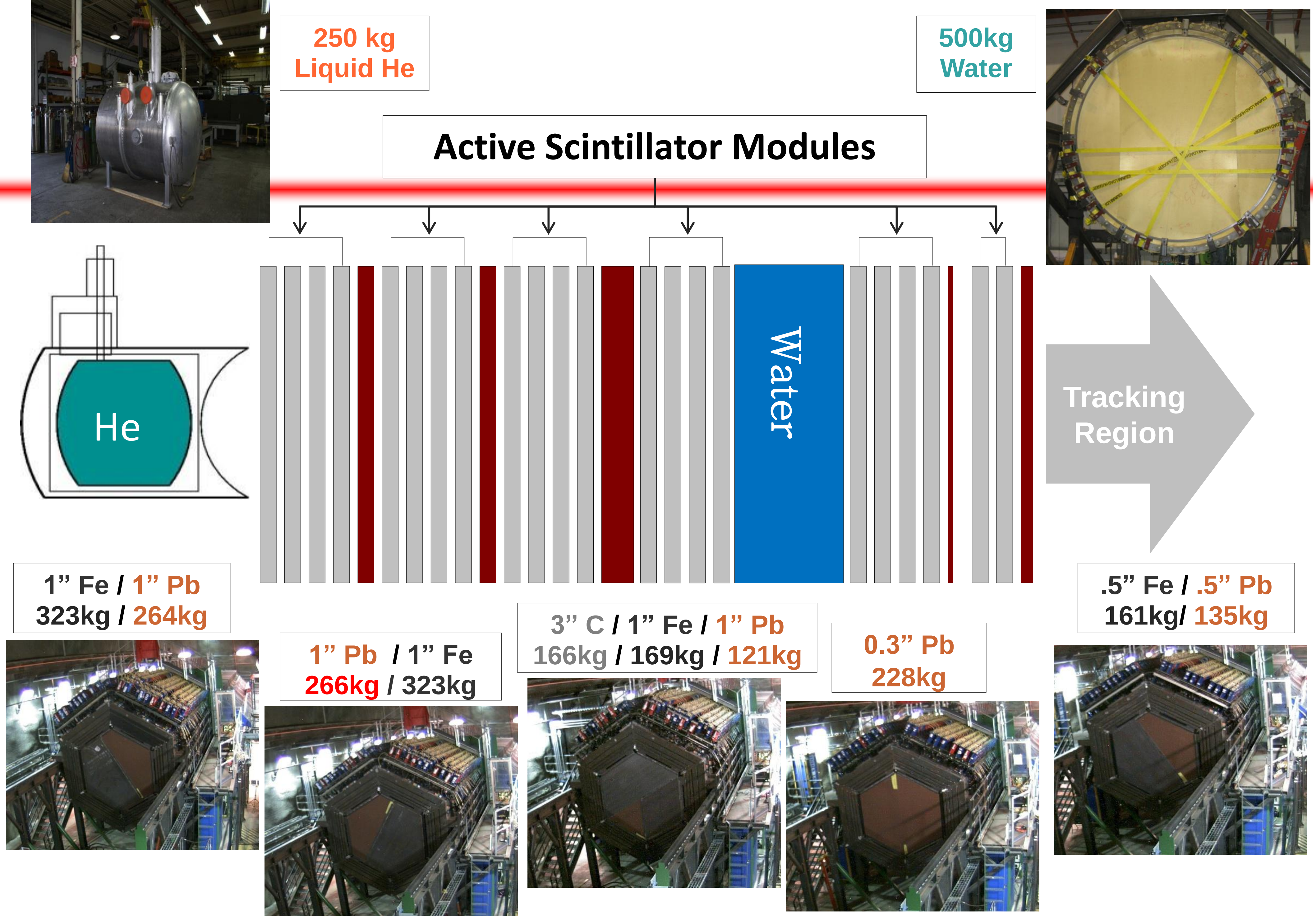


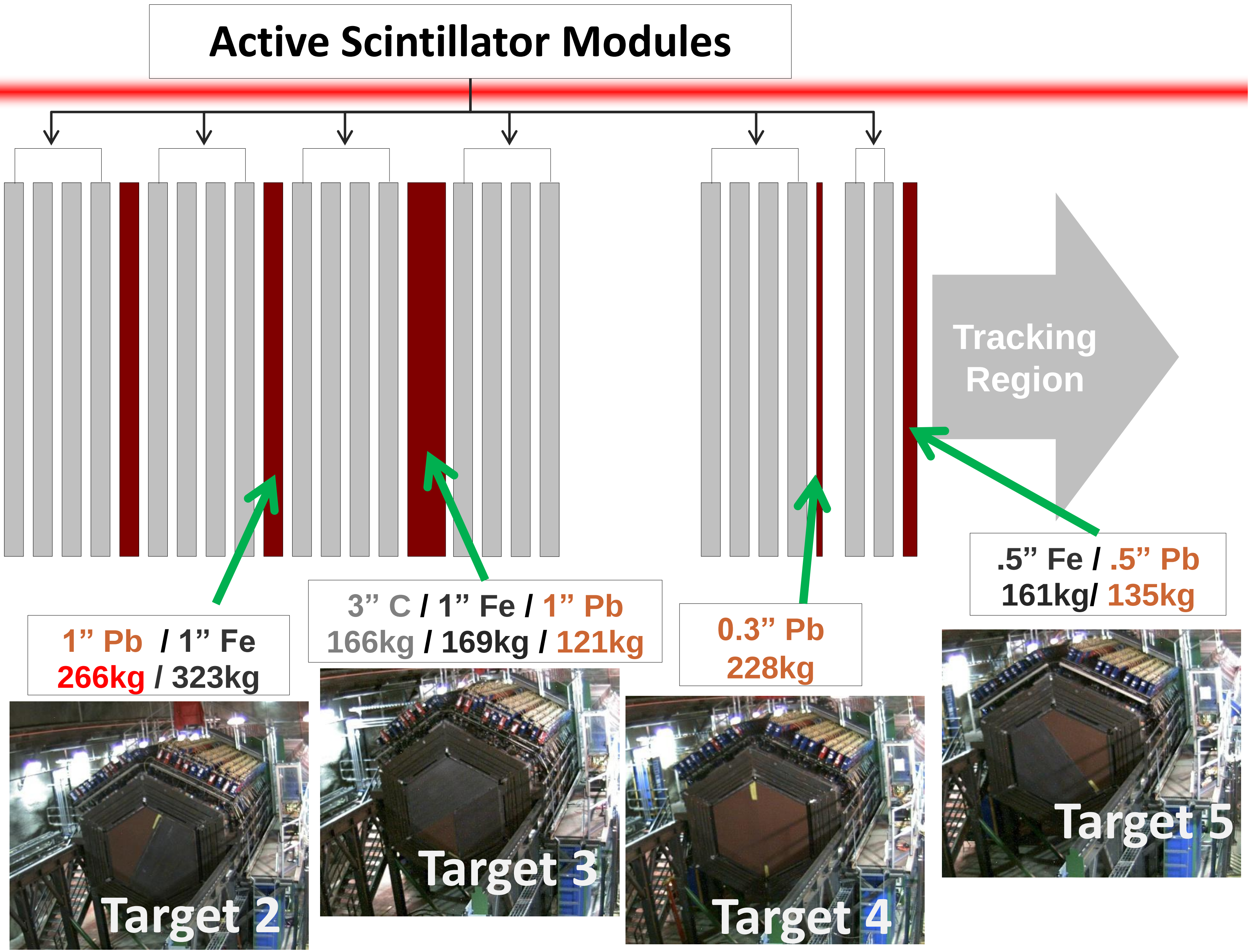


Nuclear Target Ratios Analysis

$CC\nu_{\mu}$




250 kg Liquid He
500kg Water
Active Scintillator Modules
He
Water
Tracking Region
1” Fe / 1” Pb
323kg / 264kg
1” Pb / 1” Fe
266kg / 323kg
3” C / 1” Fe / 1” Pb
166kg / 169kg / 121kg
0.3” Pb
228kg
.5” Fe / .5” Pb
161kg/ 135kg


Active Scintillator Modules
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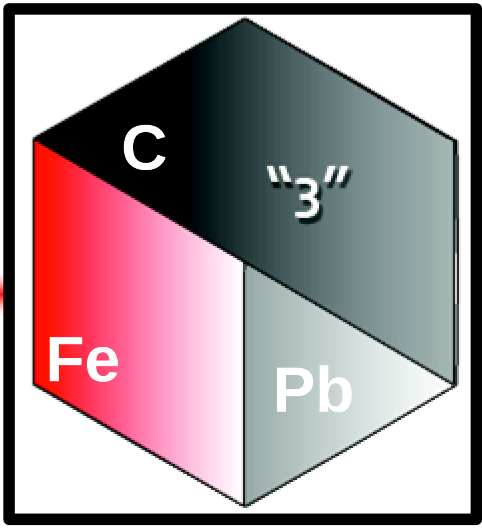
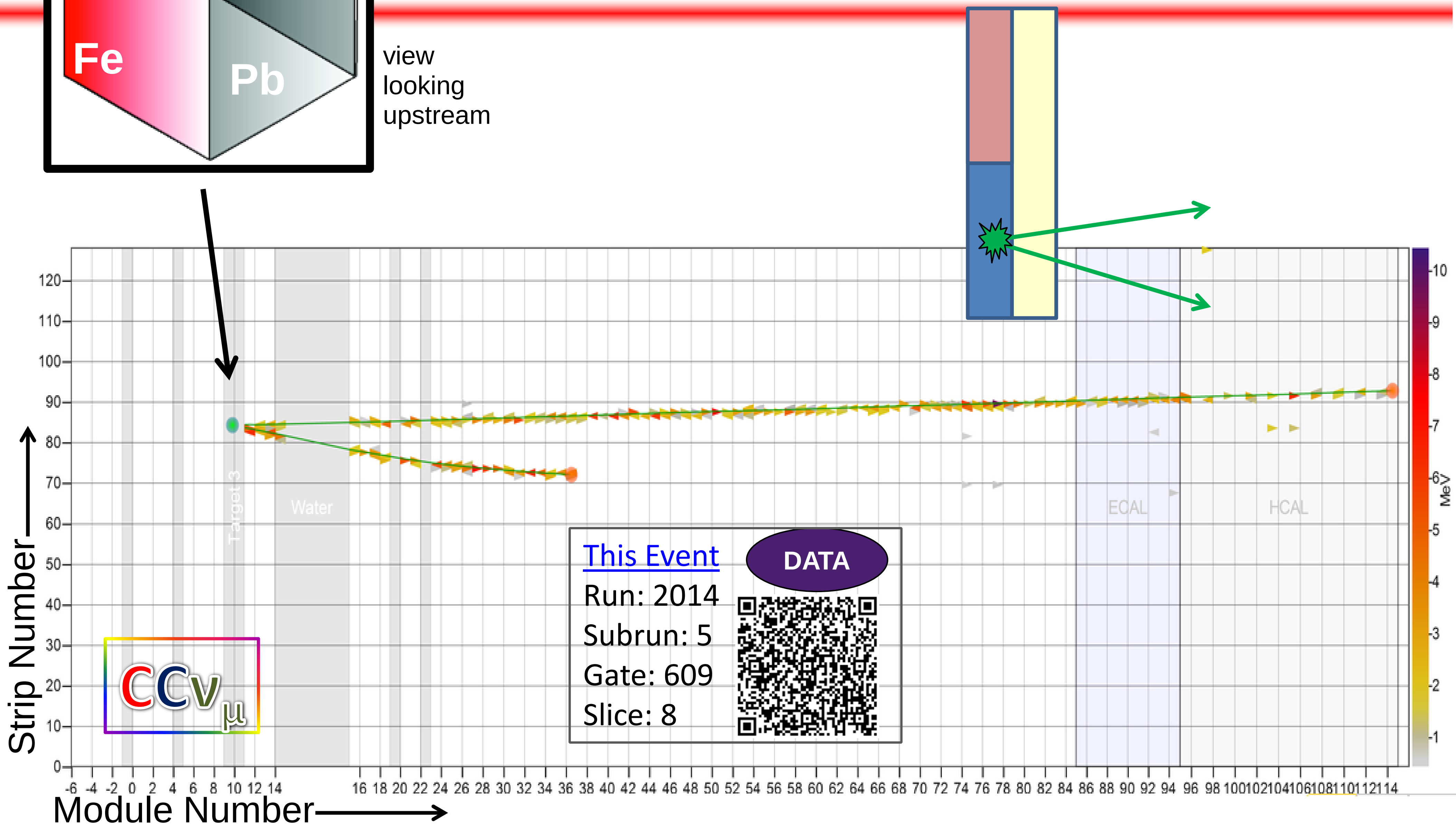
1" Pb / 1" Fe
266kg / 323kg
3" C / 1" Fe / 1" Pb
166kg / 169kg / 121kg
0.3" Pb
228kg
.5" Fe / .5" Pb
161kg/ 135kg
Target 2
Target 3
Target 4
Target 5

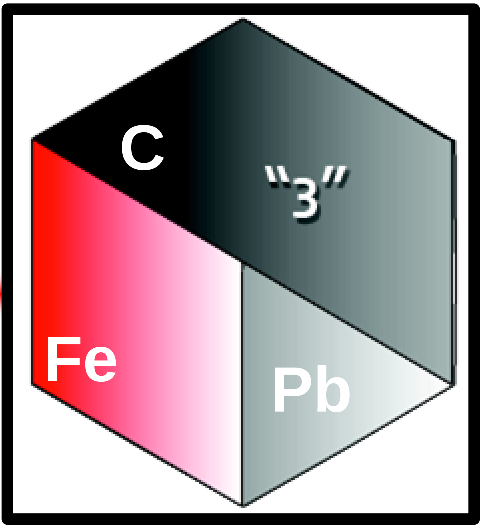
An event from target 3
Carbon candidate



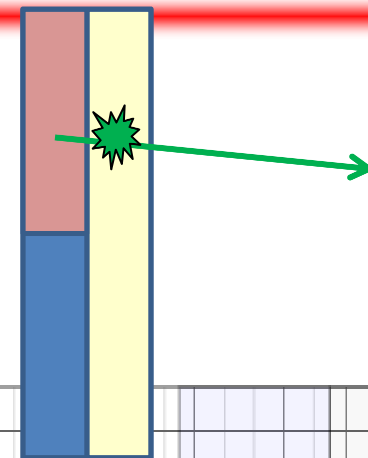
view looking upstream

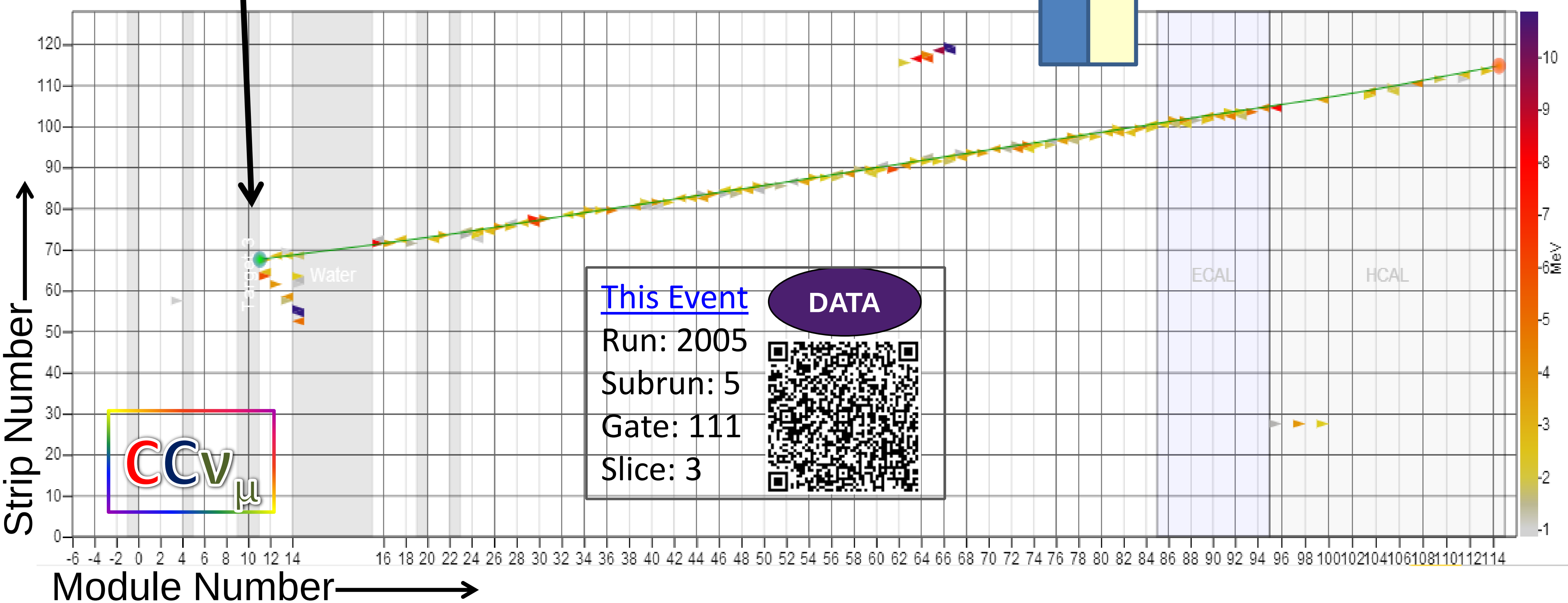


An event from target 3
Carbon candidate

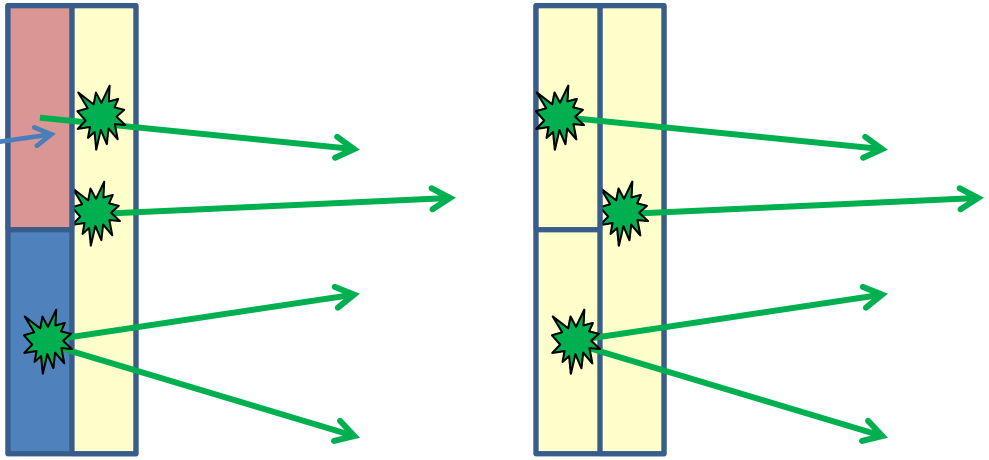


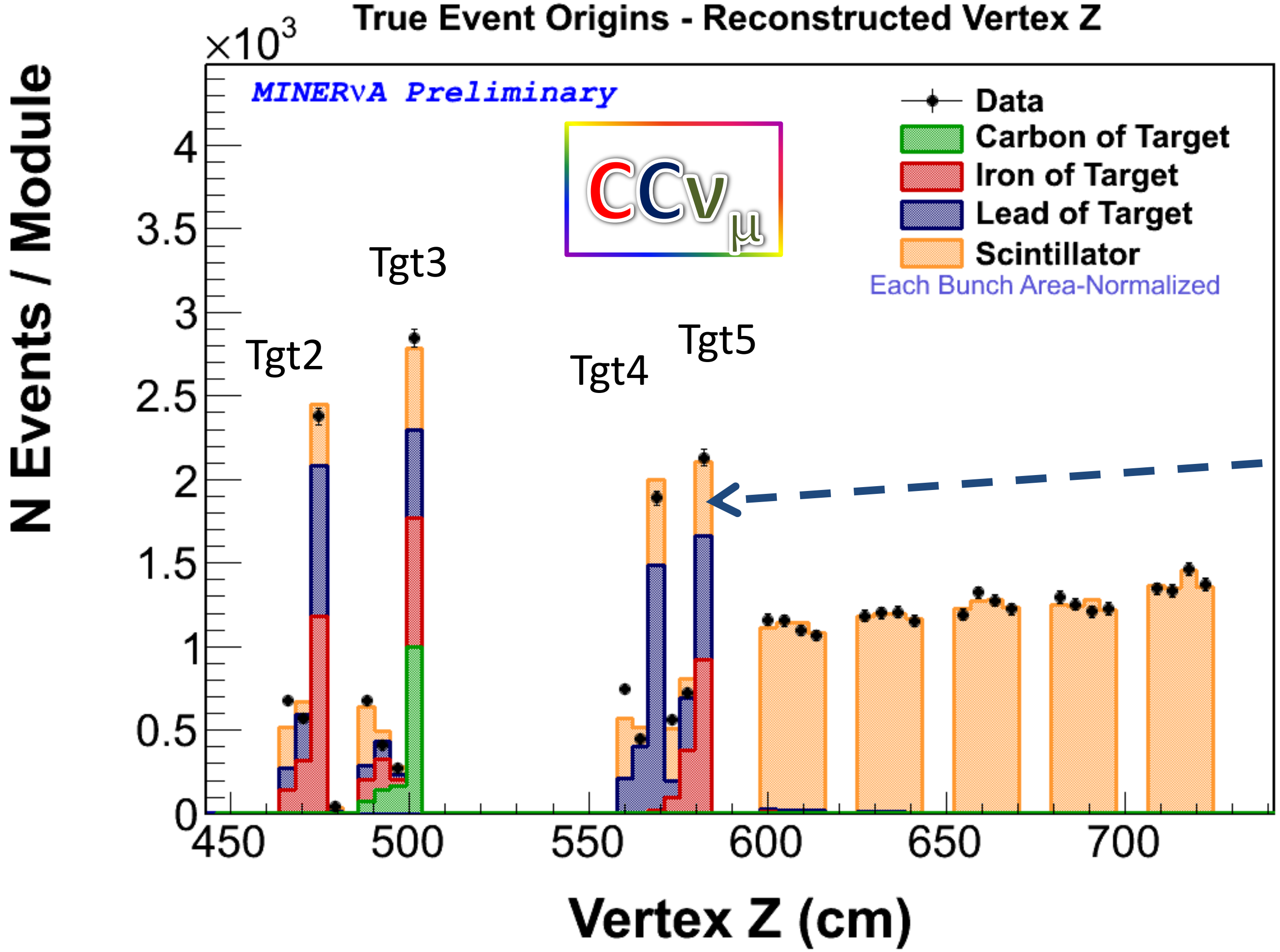
view
looking
upstream





One track events from passive target have a vertex in the first plane downstream of the target.

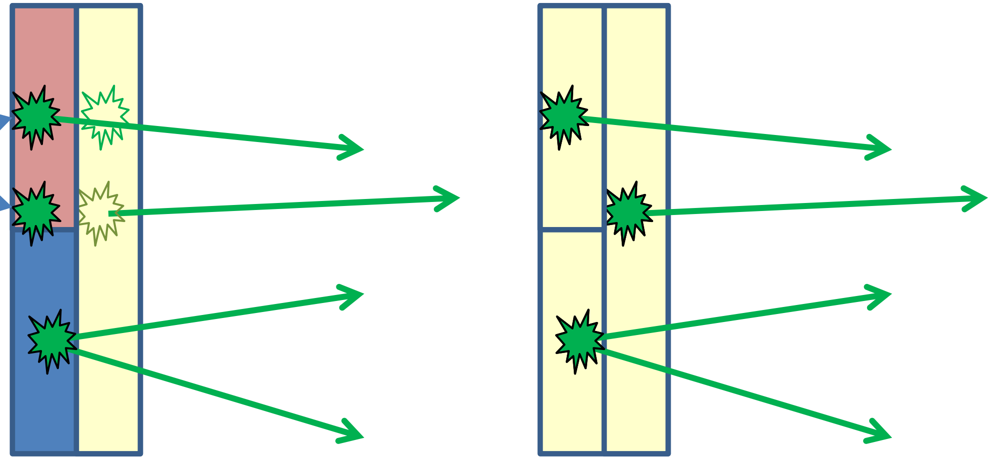


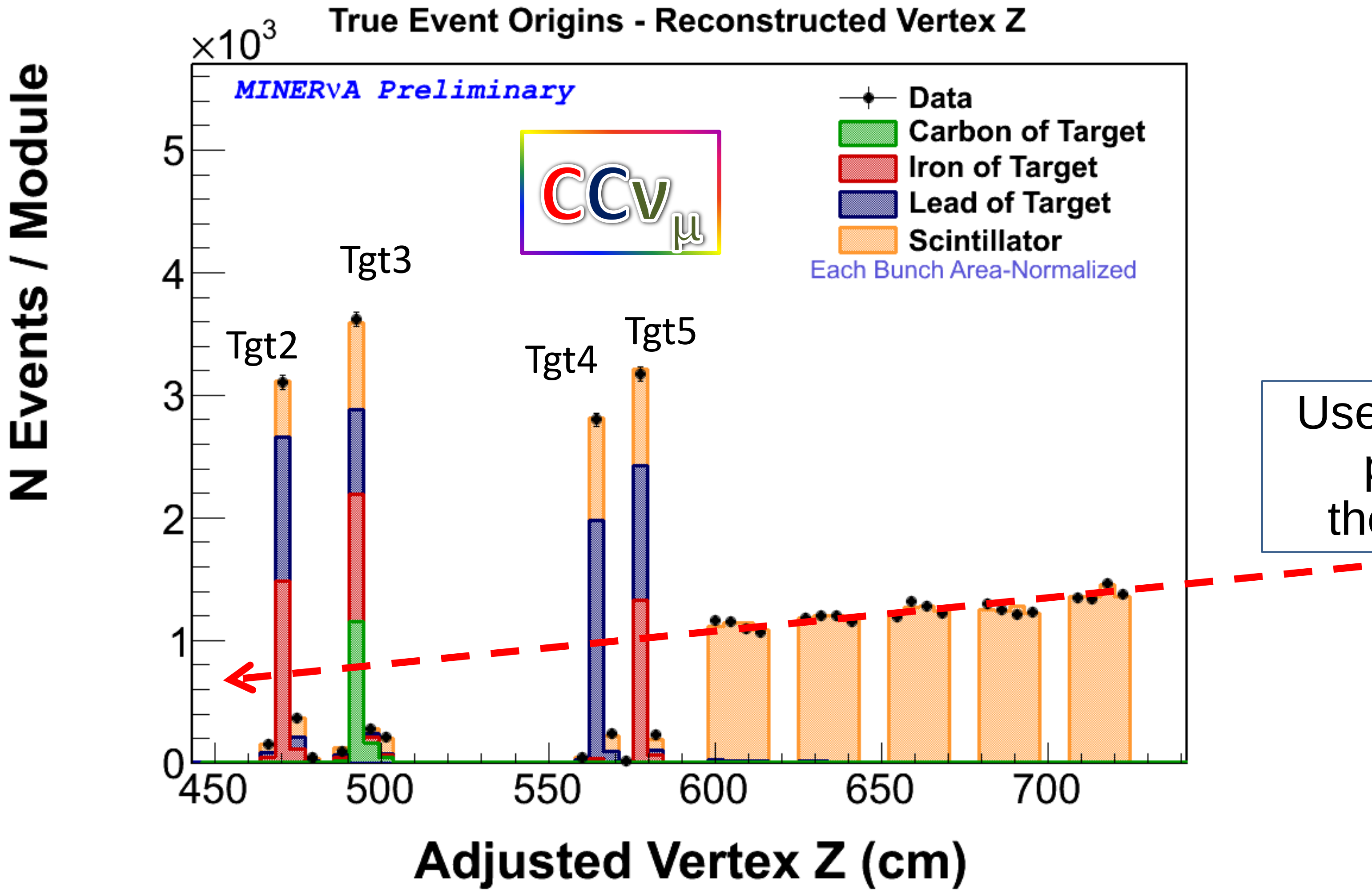


These peaks at the location of the first module after the passive targets.

Project the one track events to the passive target's center in Z.

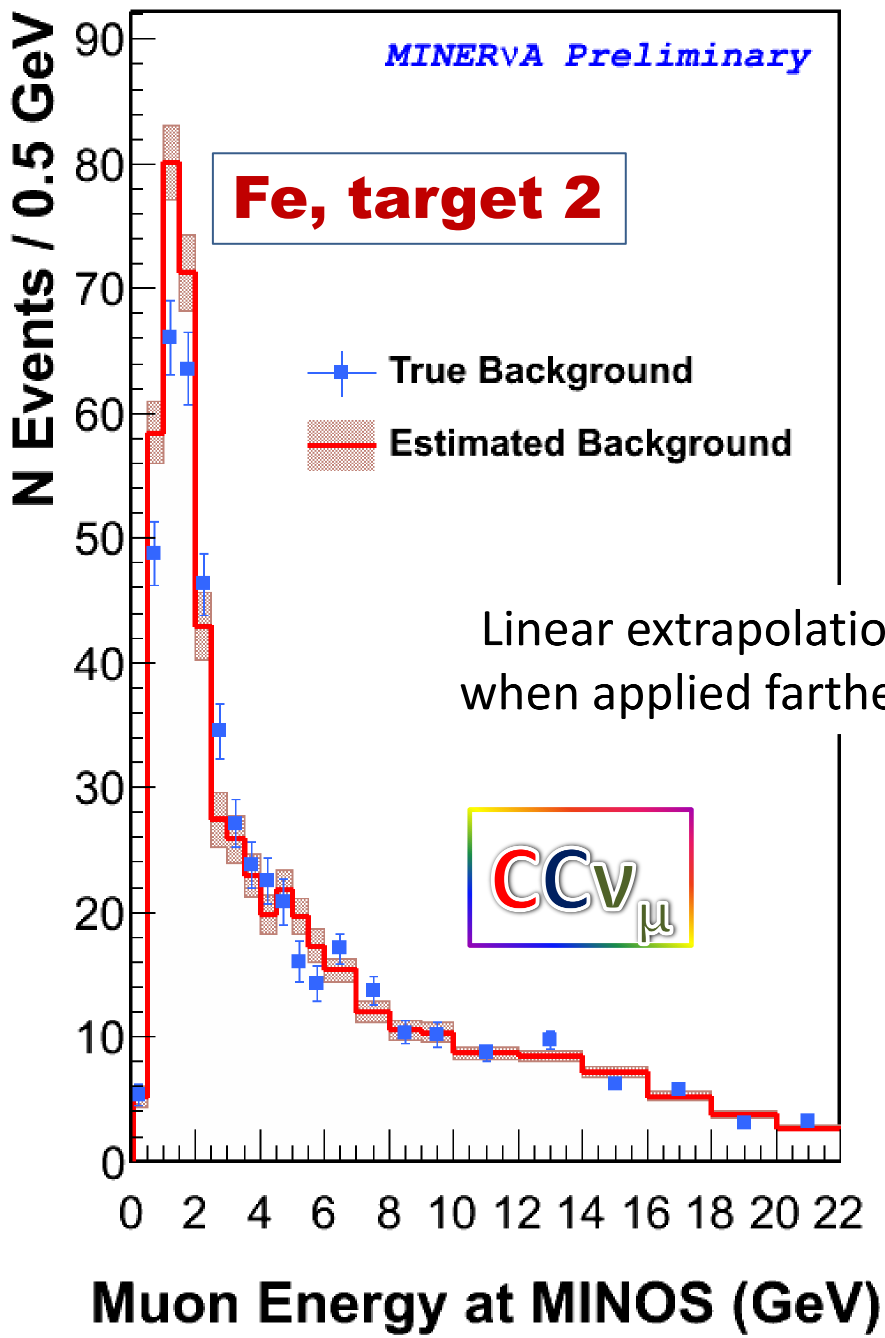
This is the best guess of the vertex.



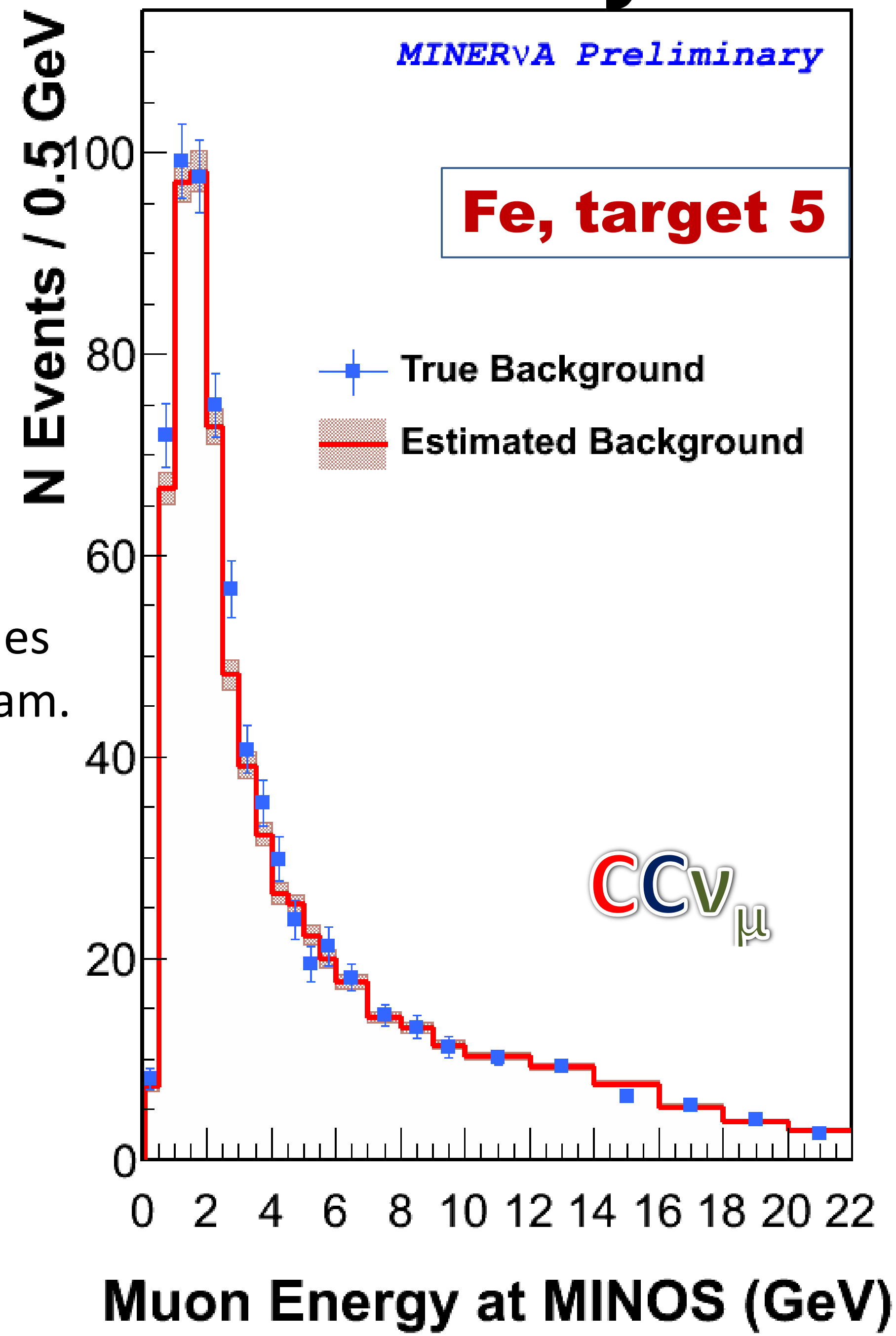


Use tracker modules to predict and subtract the plastic background.

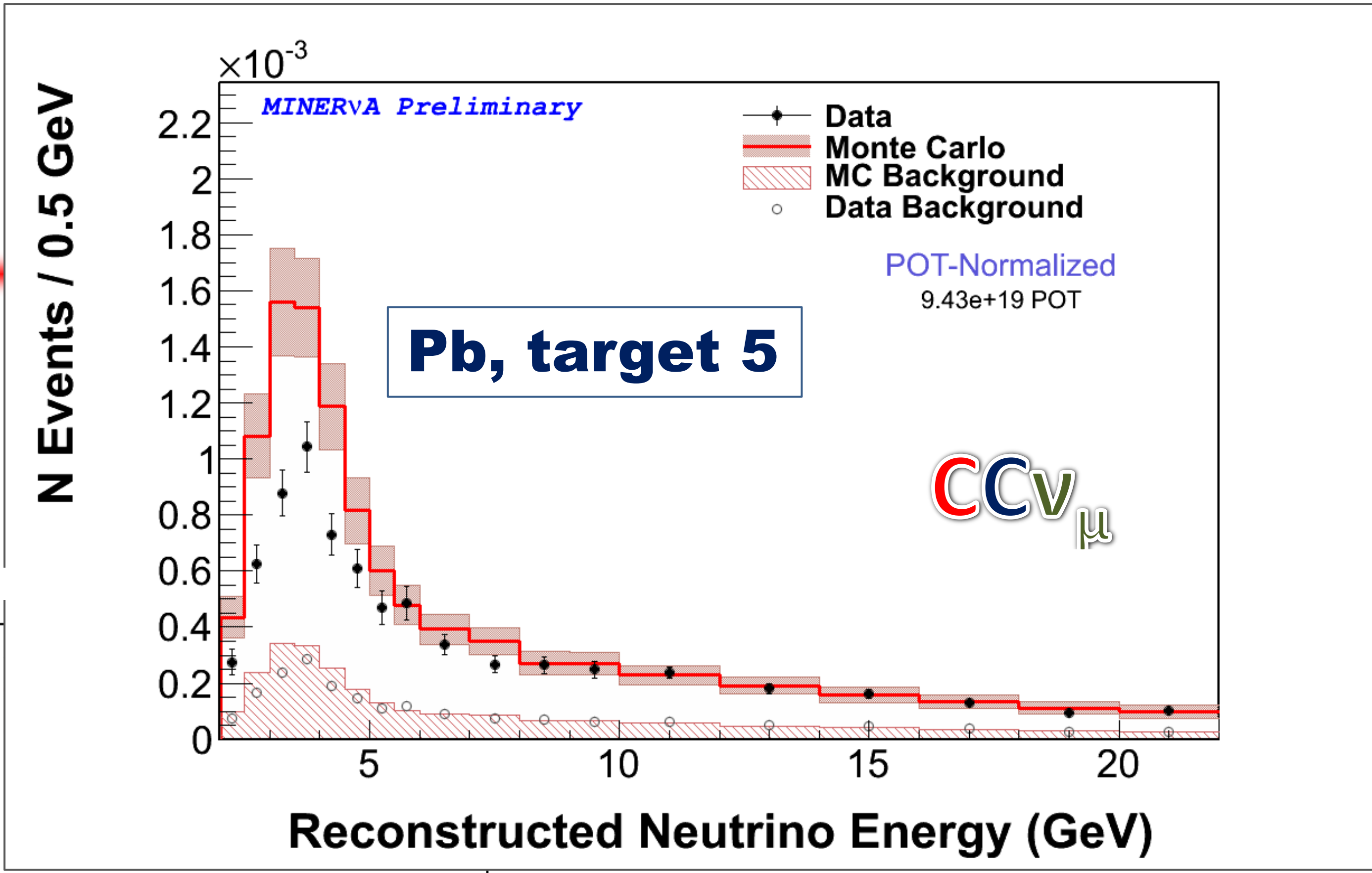
Background Subtraction Accuracy

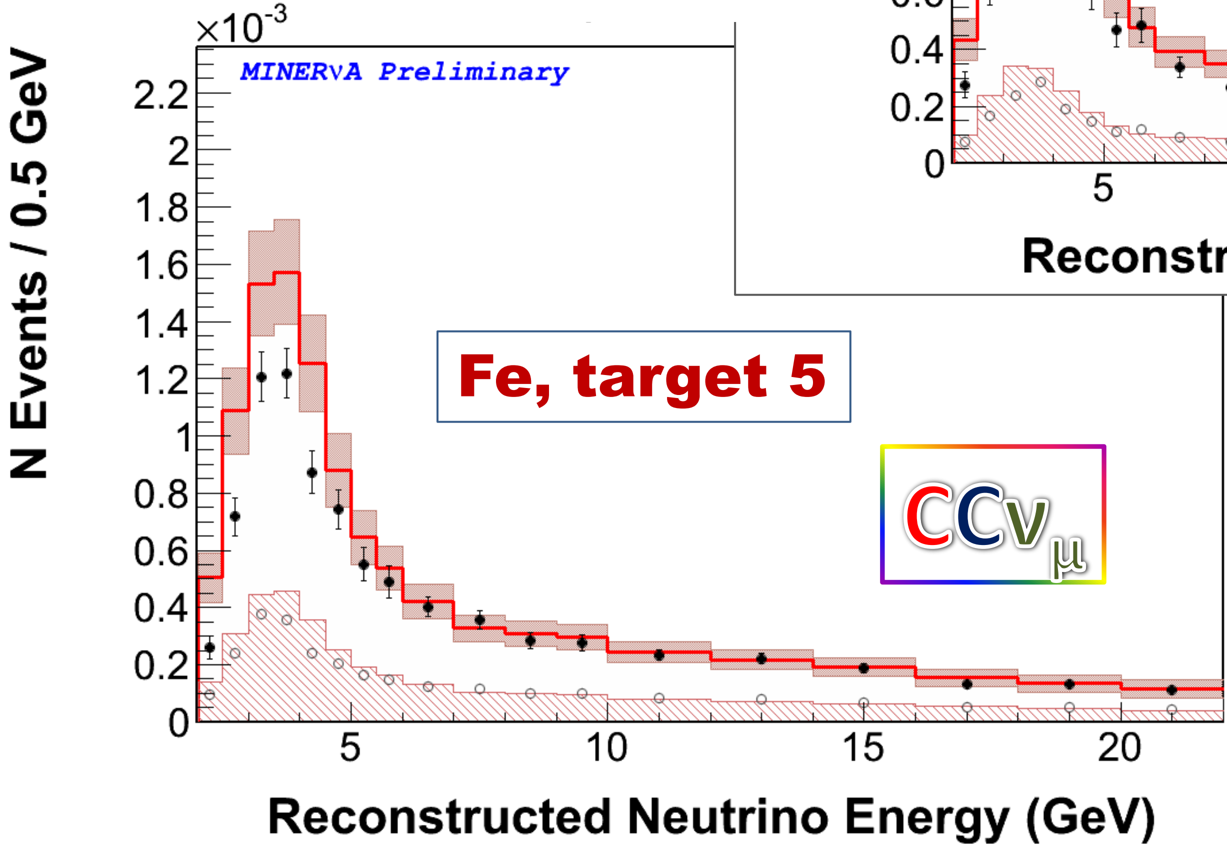


Linear extrapolation degrades when applied farther upstream.



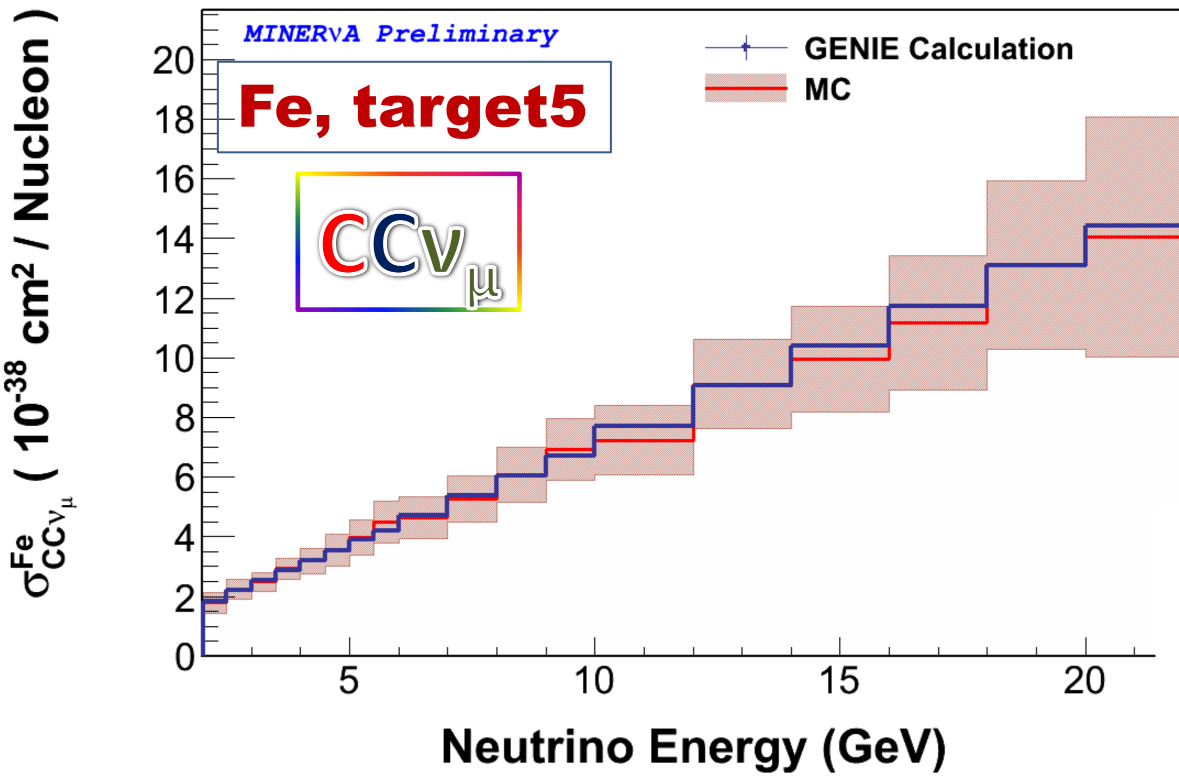
Accepted Events and Background

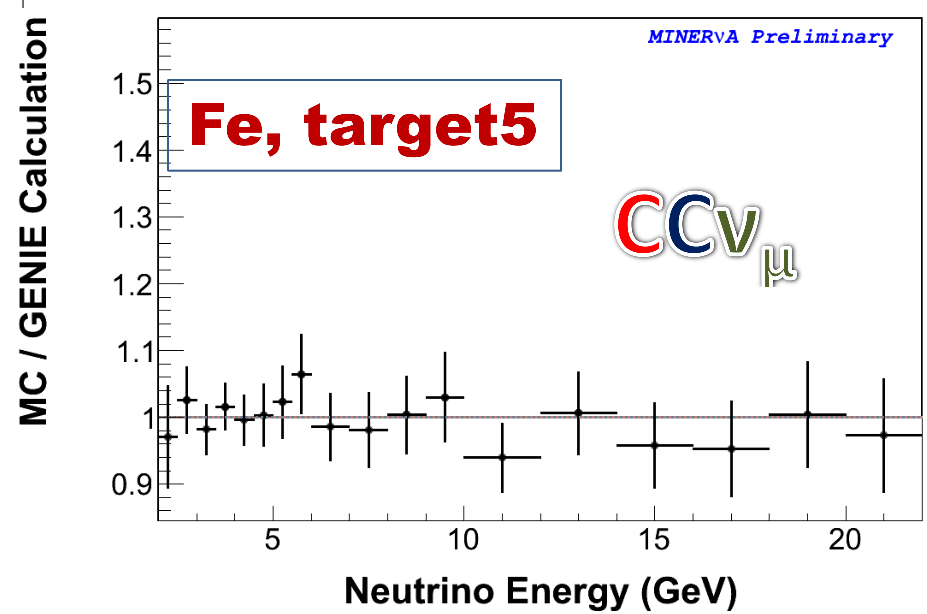




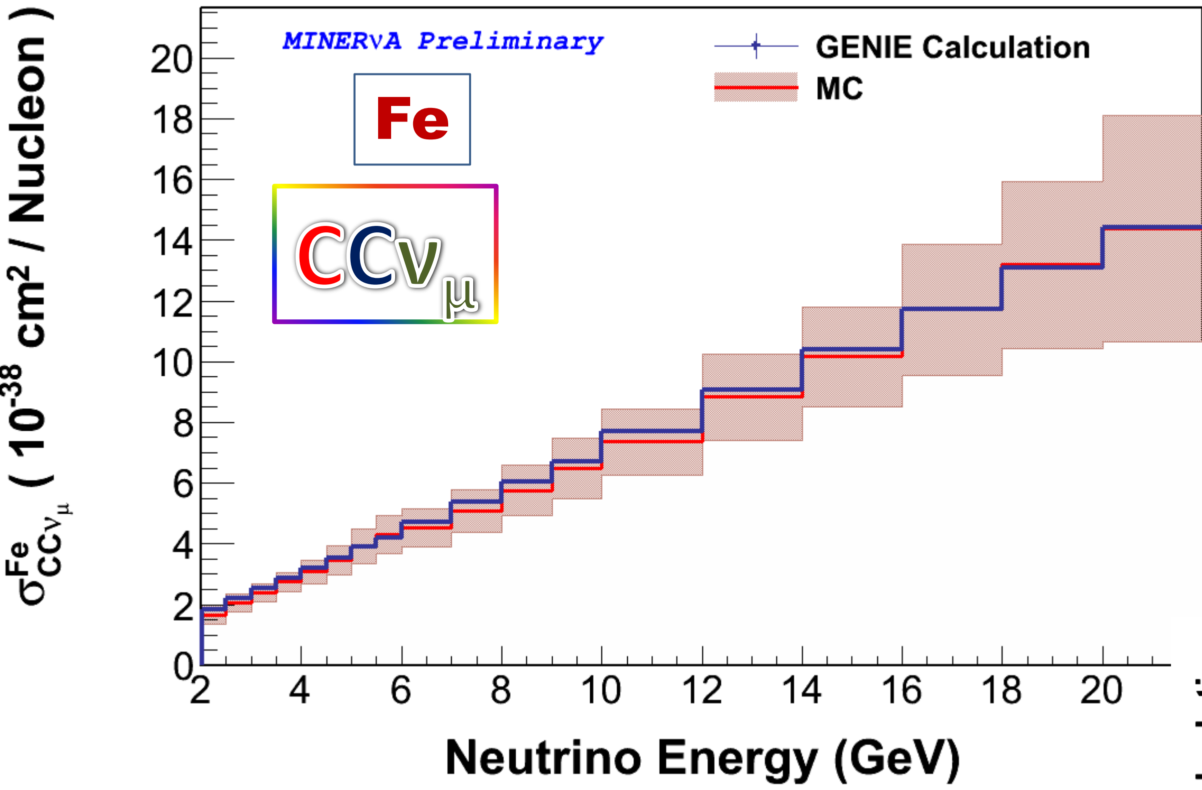
Uses ~25% neutrino data recorded and~20% of target mass.

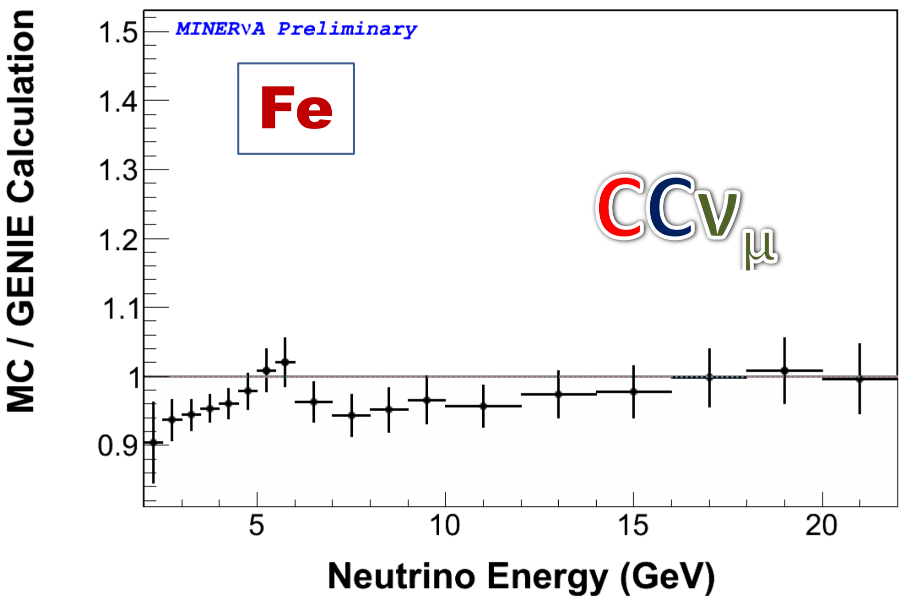
Form a Cross Section
Unfold, Acceptance Correction, Divide by Flux





Repeat For All Iron Targets, Add

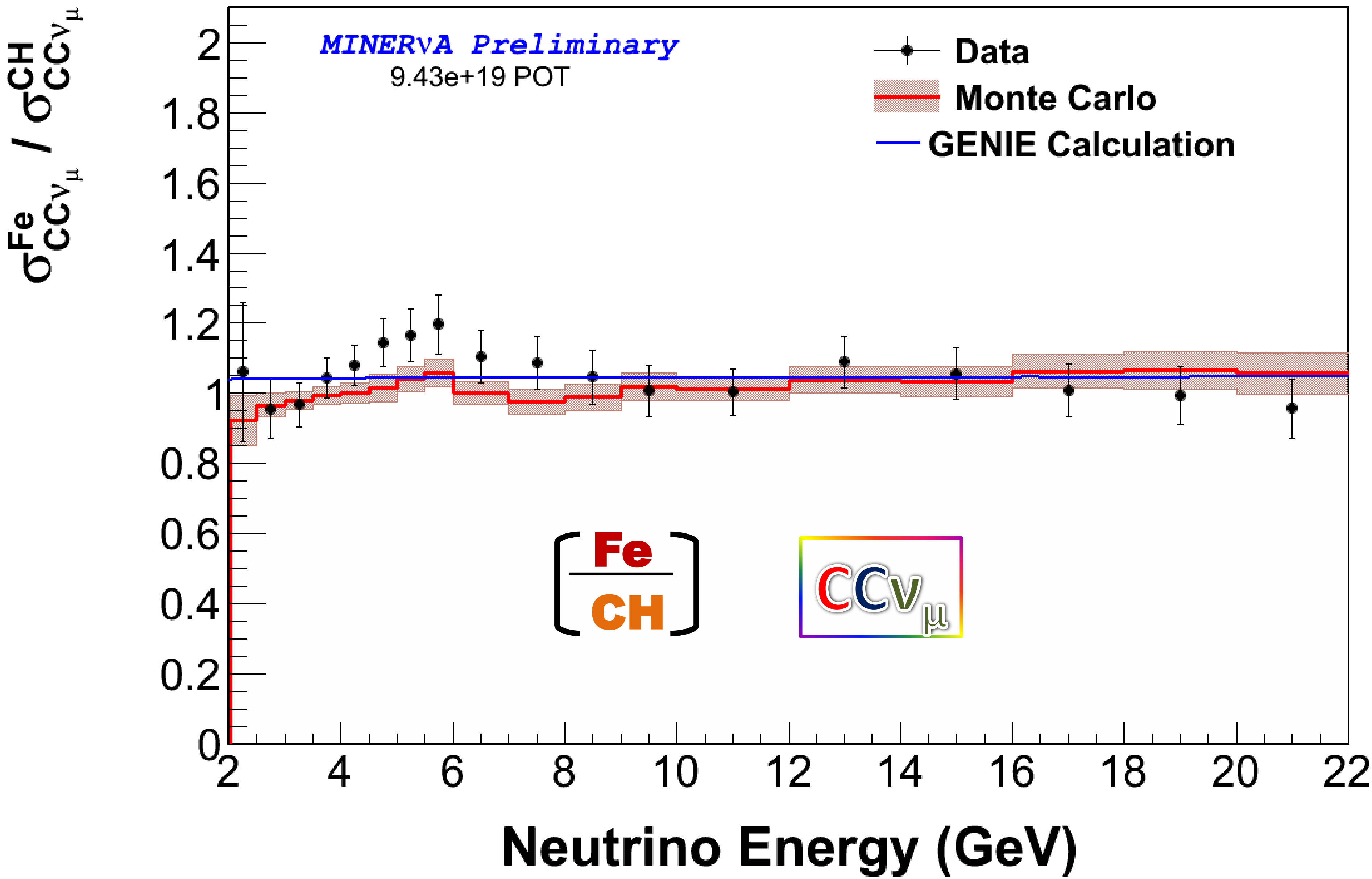




Discrepancy in 2-4GeV is due to inaccuracy of background subtraction in the upstream targets.

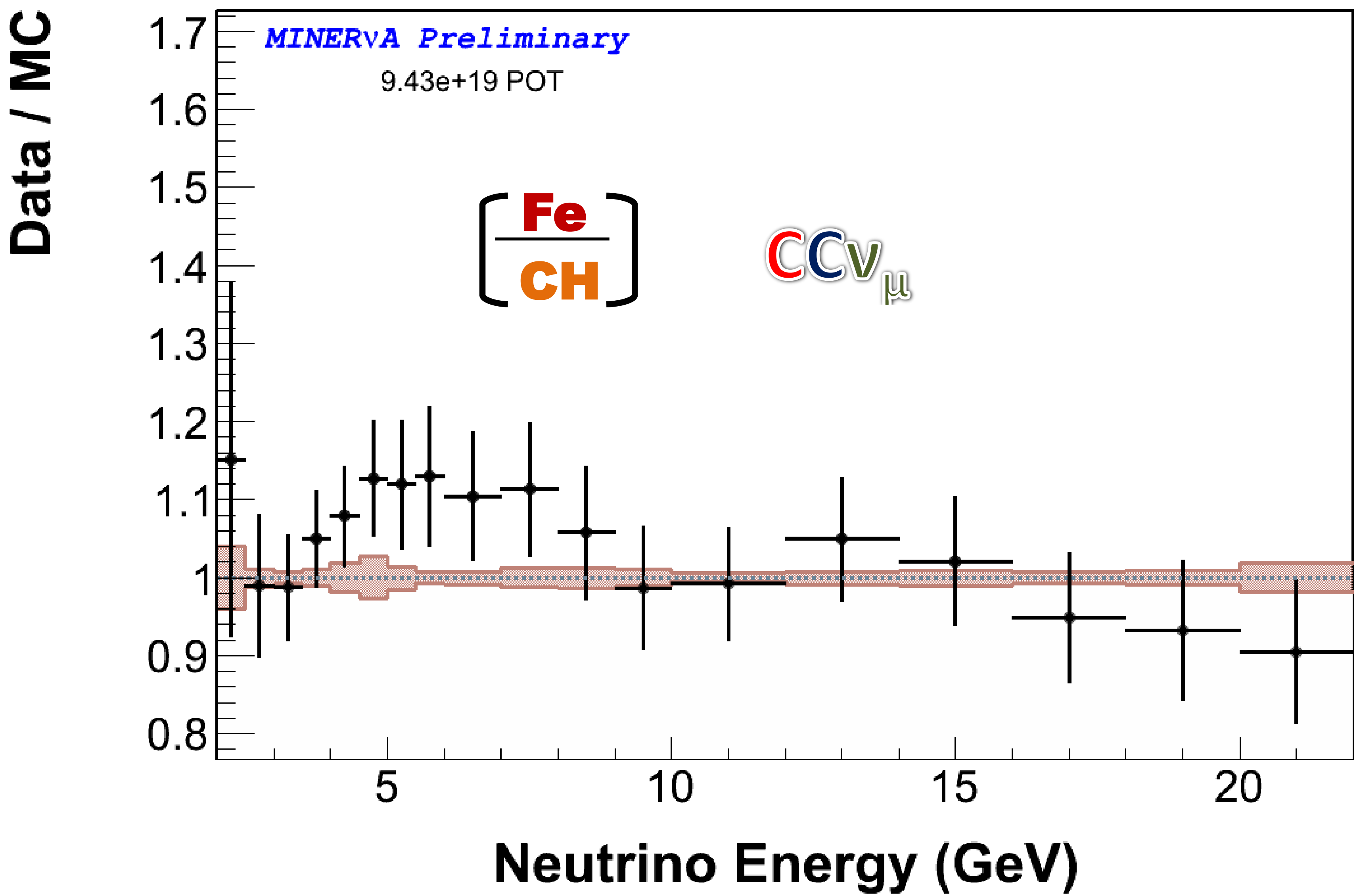
The event rate changes rapidly here.

Ratio of Iron to Scintillator Cross Section

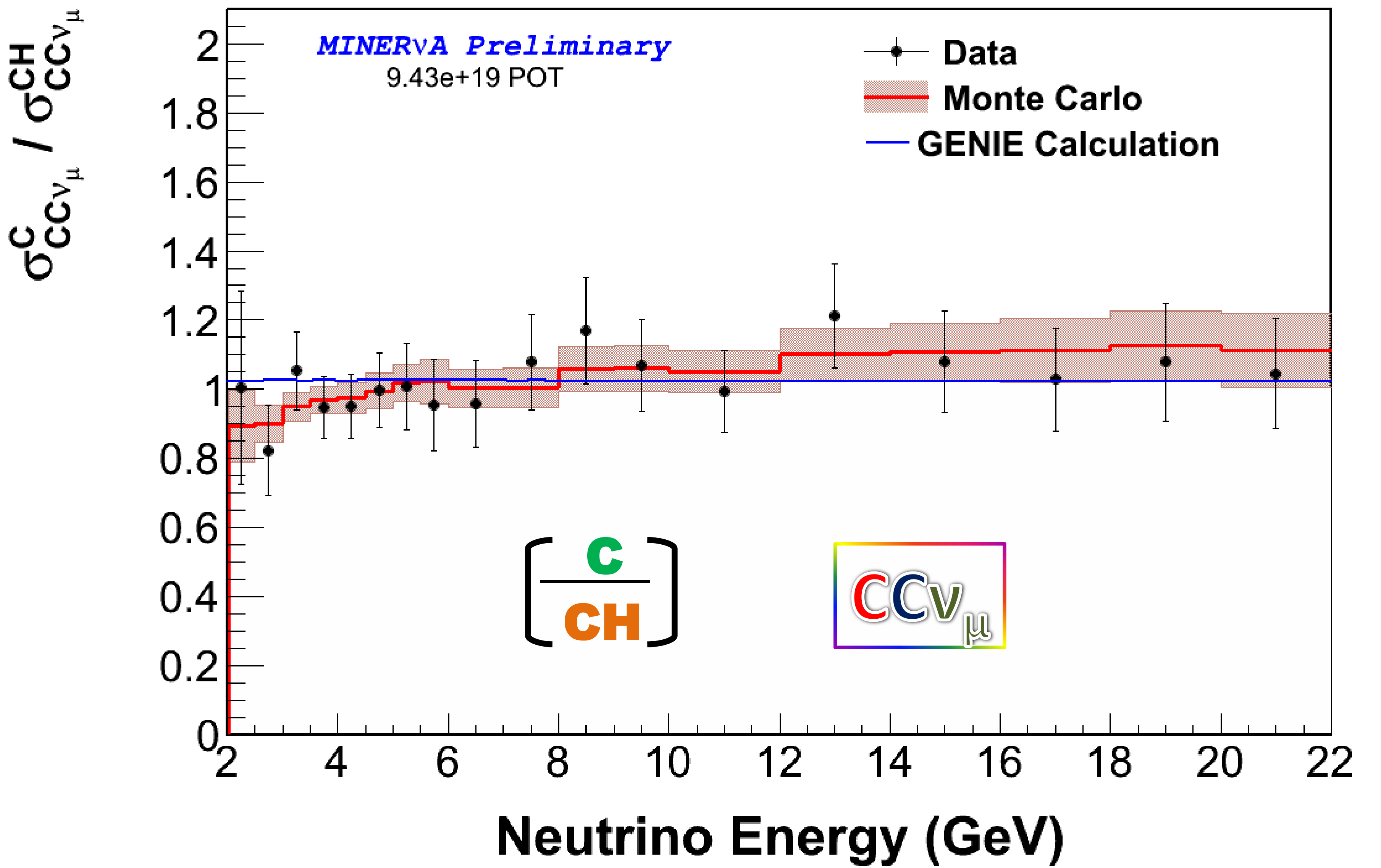


Ratio of Iron to Scintillator Cross Section

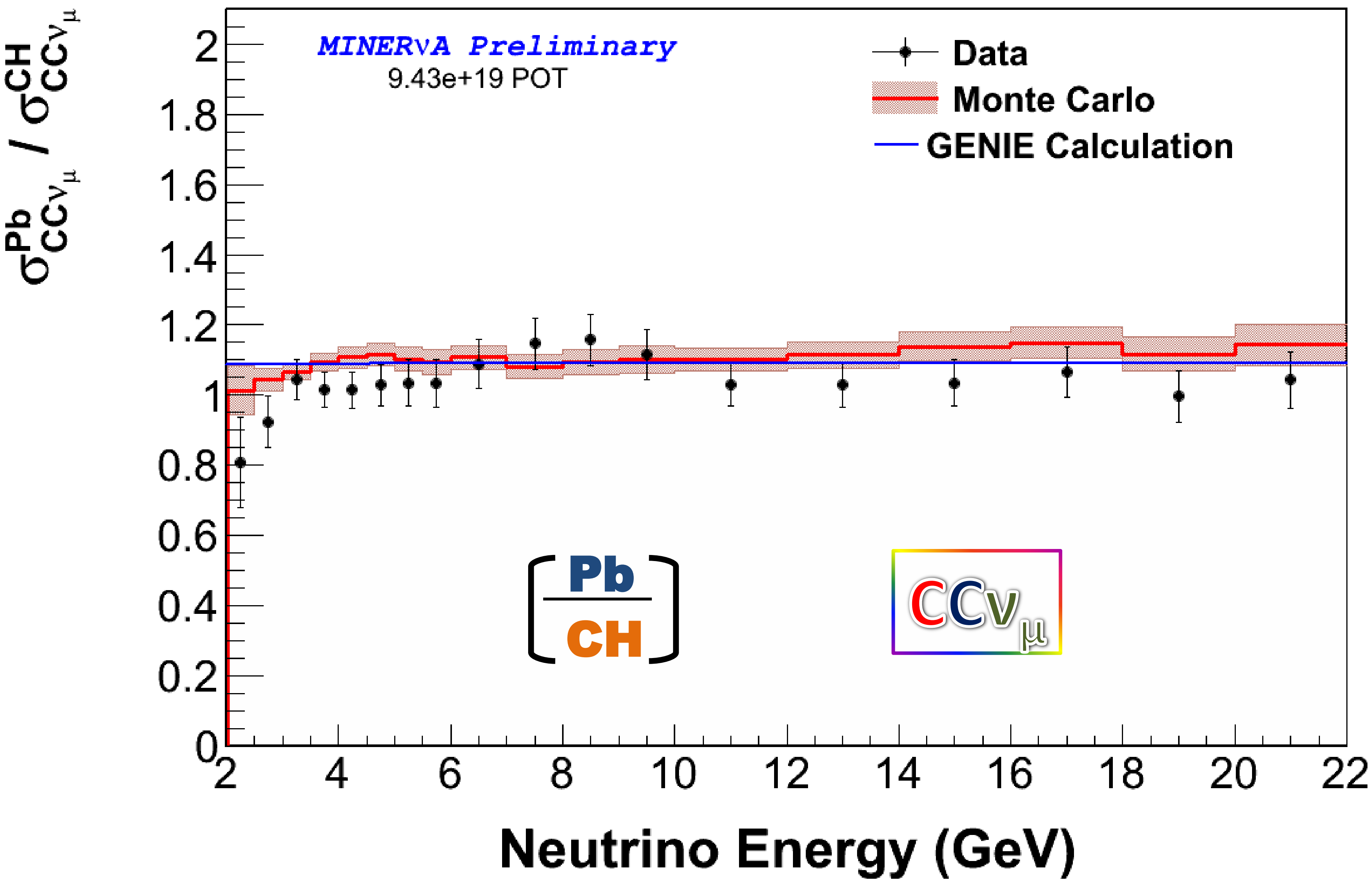
Compare Data to MC prediction



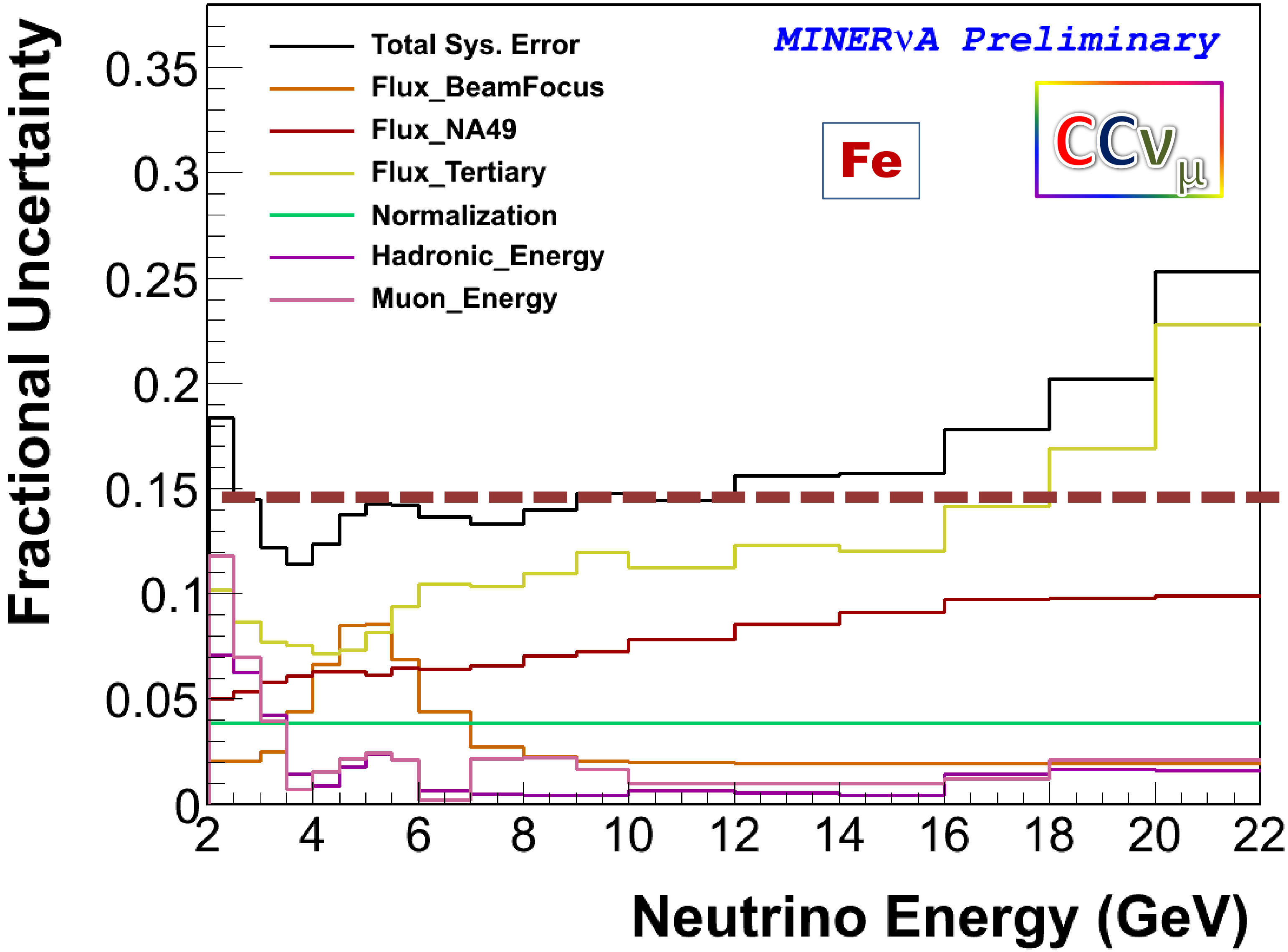
Ratio of Carbon to Scintillator Cross Section



Ratio of Lead to Scintillator Cross Section

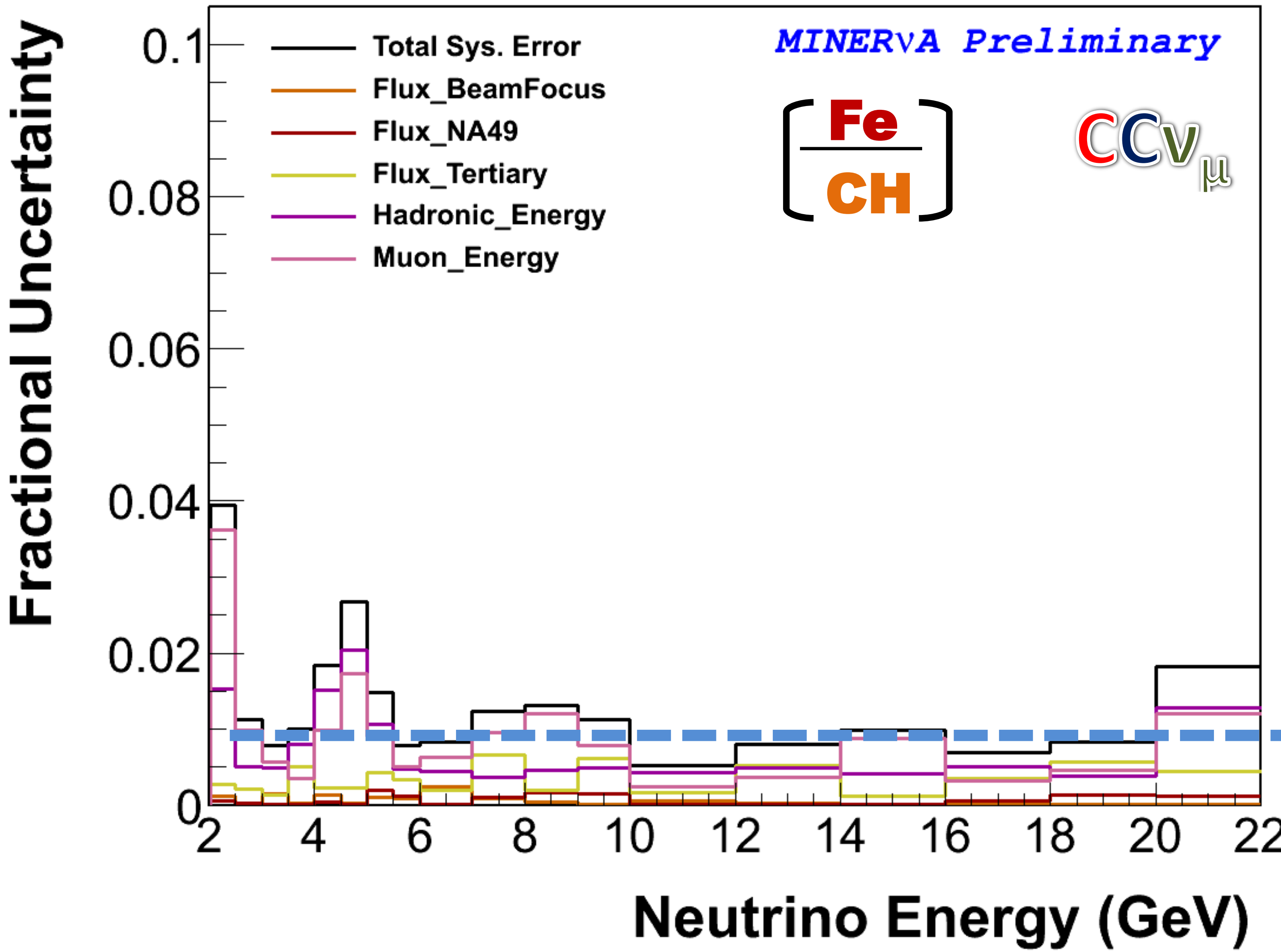


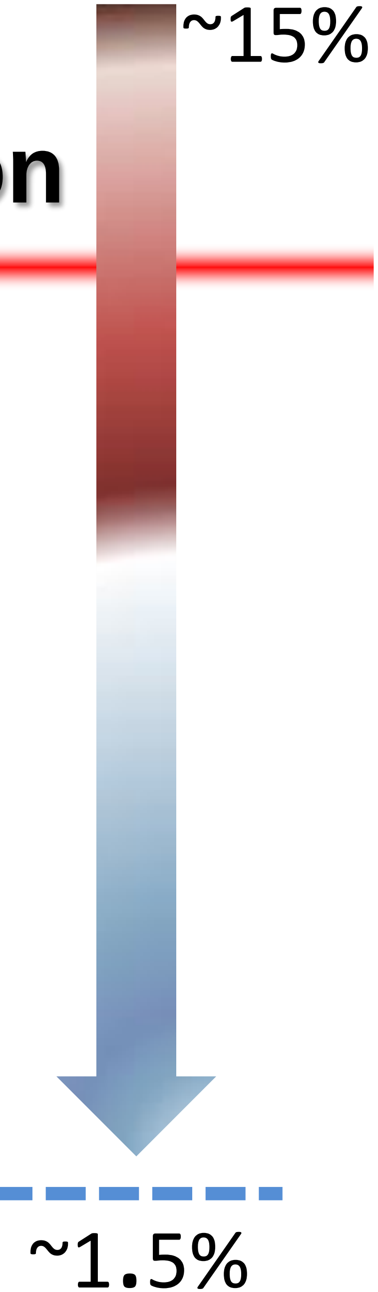
Systematic Errors – Fe Cross Section



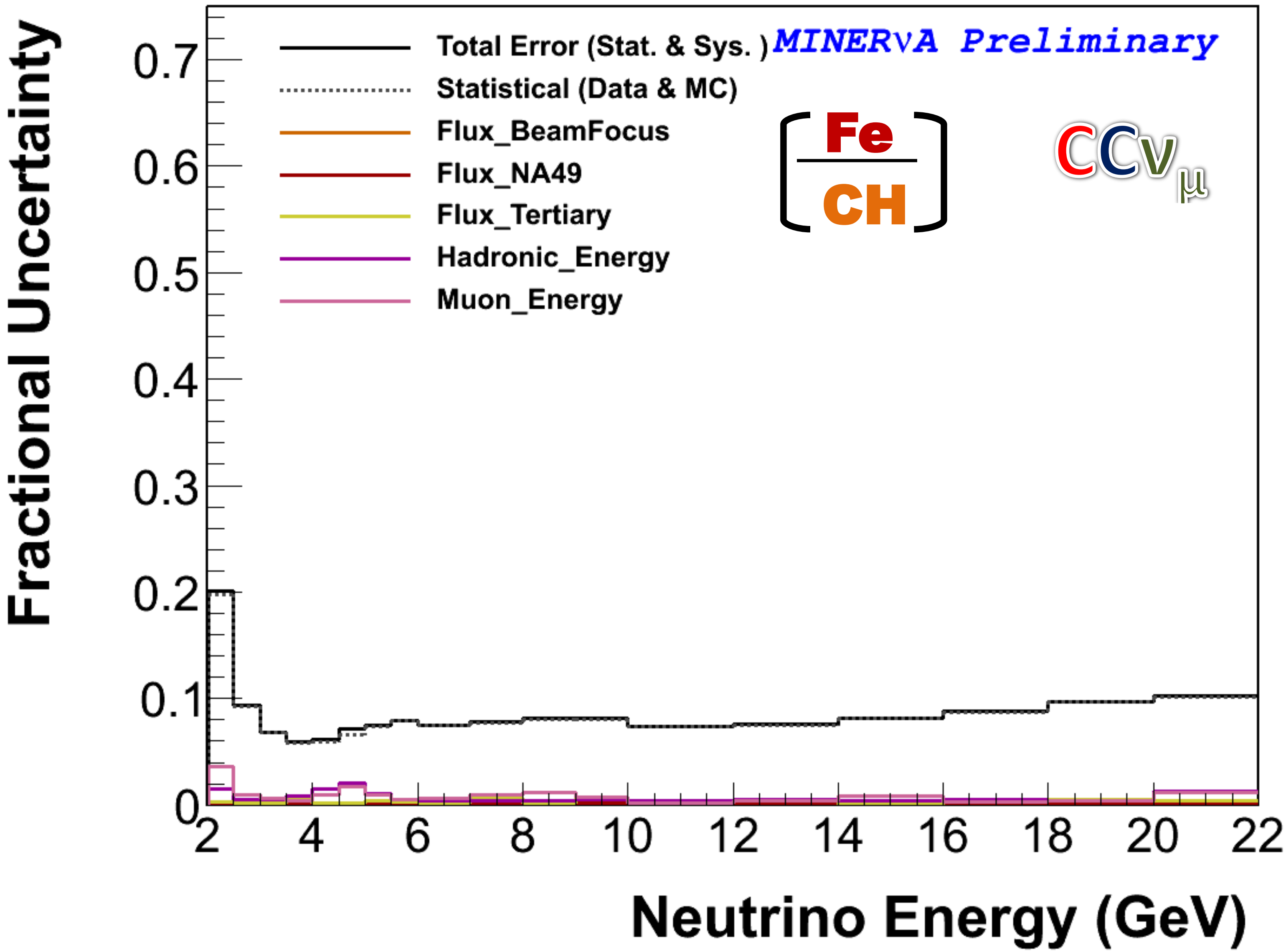
~15%

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





Total Errors - [Fe/CH] Cross Section

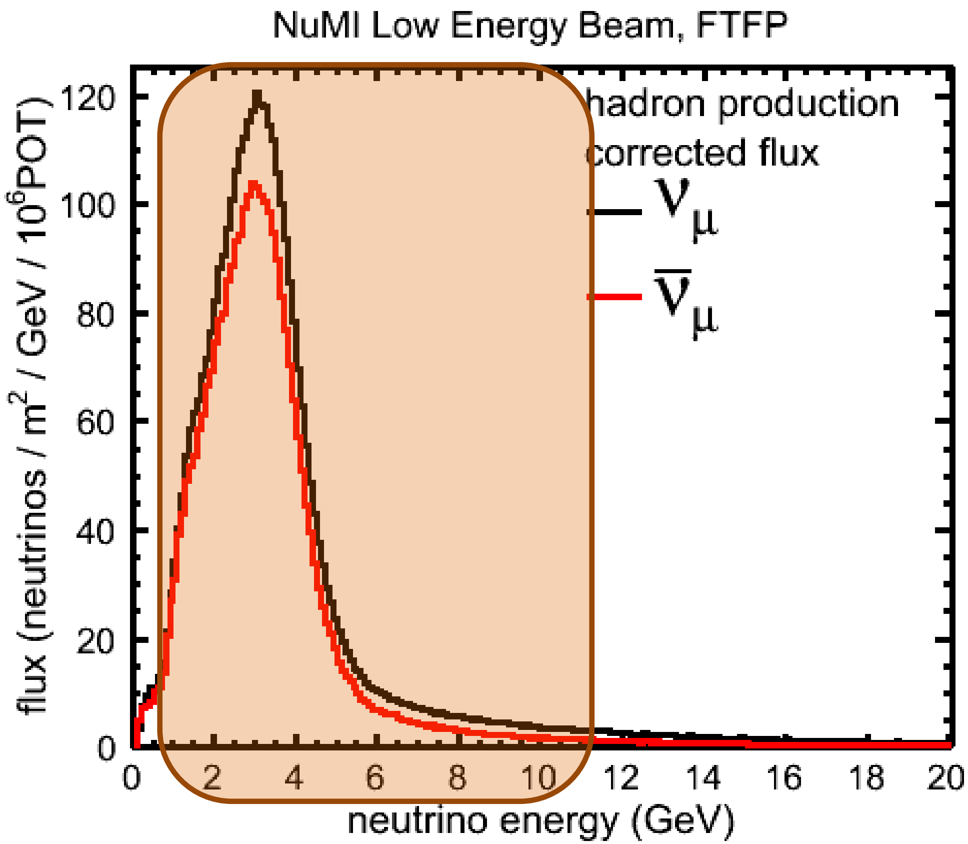


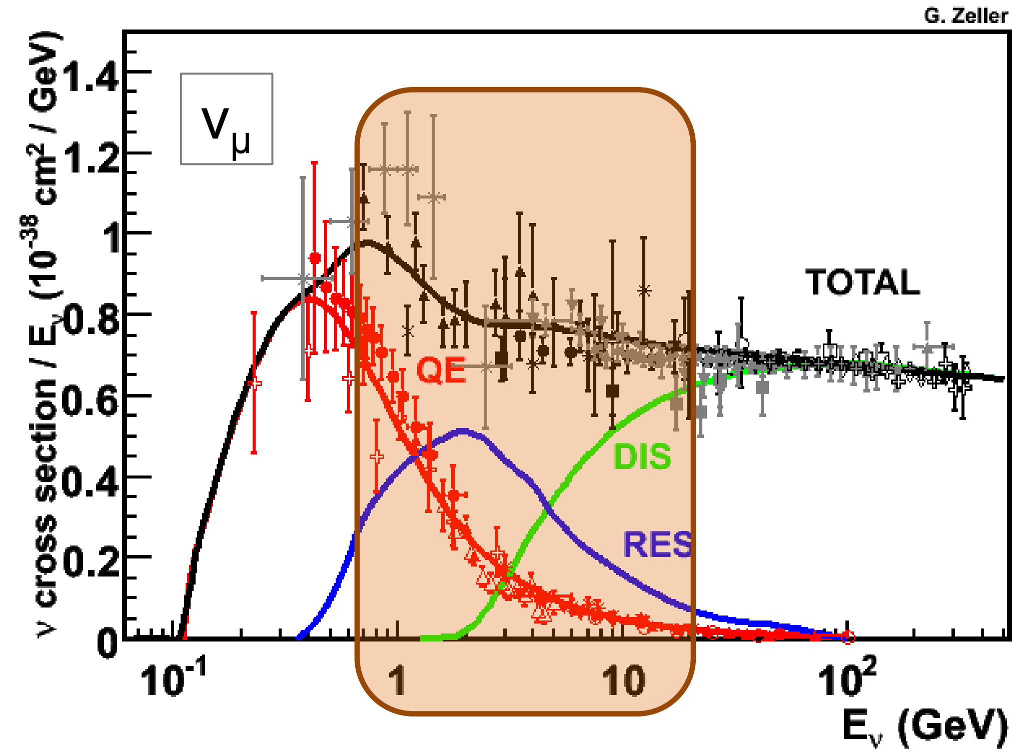
Conclusions

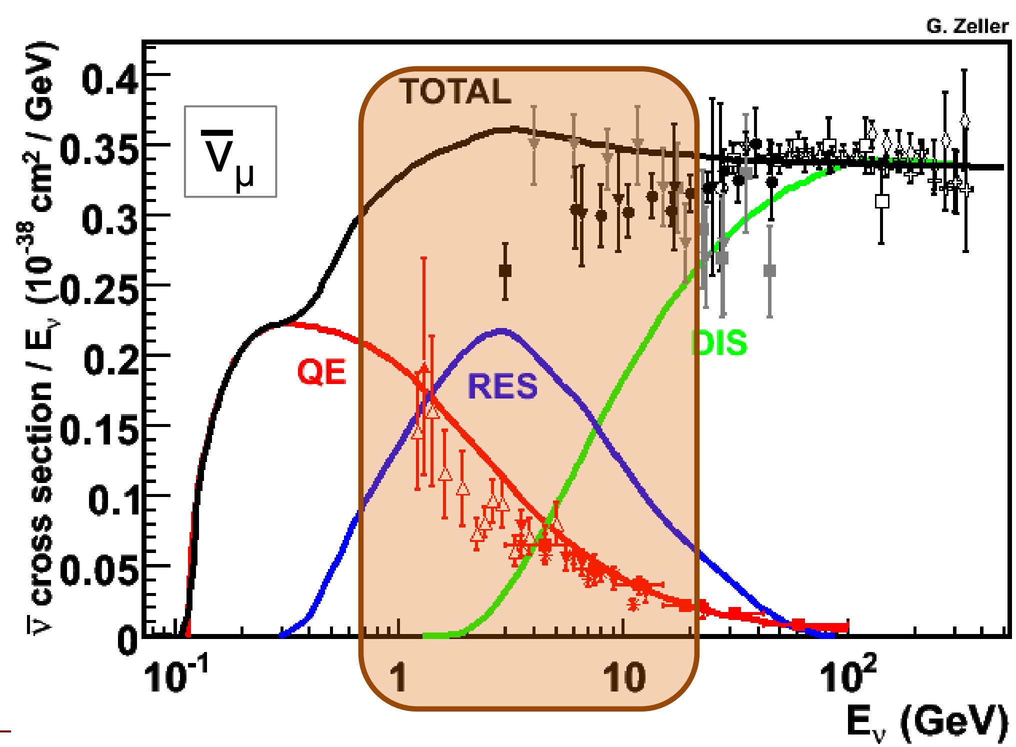
- MINERvA is performing well and is producing results.
  - Systematic errors have been explored. Improvements possible.
- Nuclear target ratios analysis method works well.
  - Subtraction of plastic contamination is improving.
  - Needs to use full statistics in hand. Processing imminent!

Backup

Neutrinos Seen





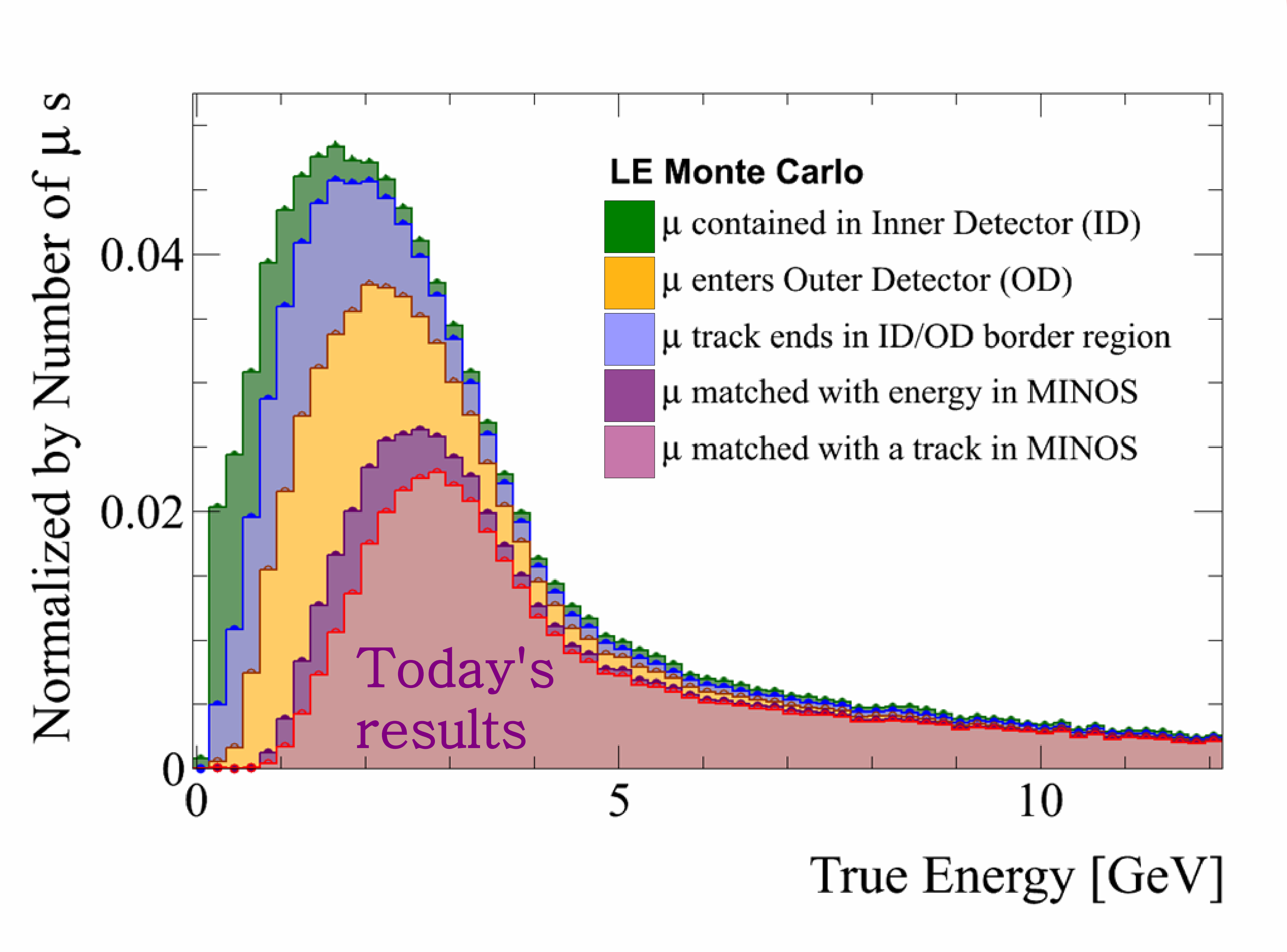


Data collected:

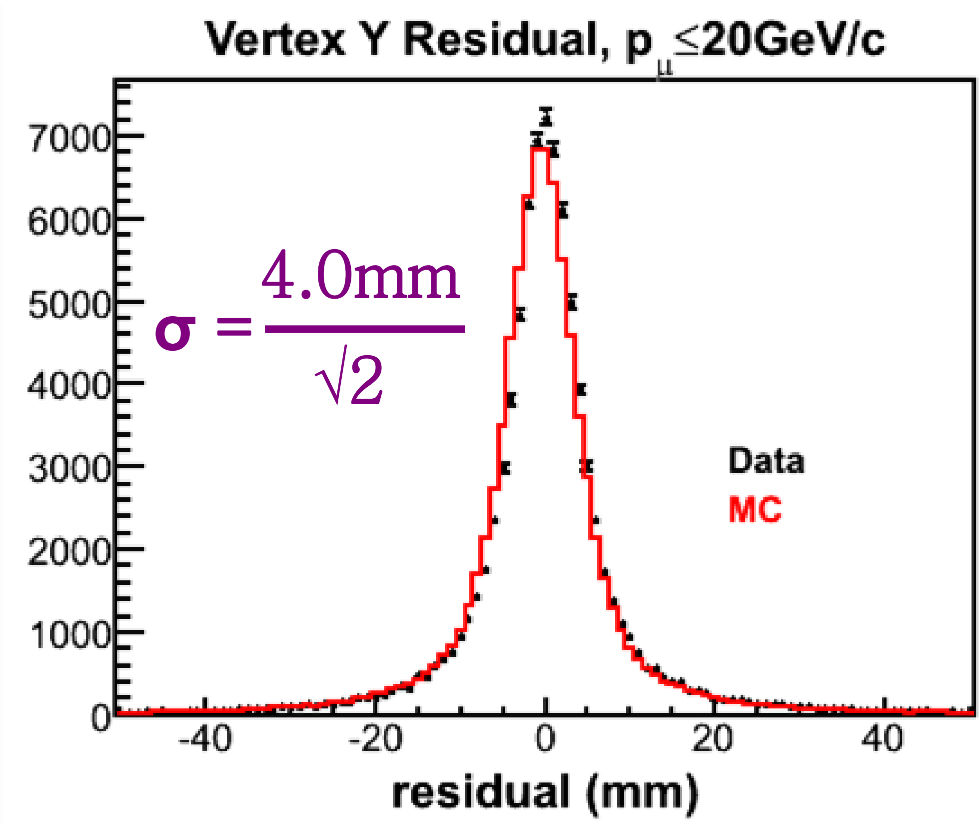
ν_μ **LE** 3.98×10^{20} POT

$\bar{\nu}_\mu$ **LE** 1.7×10^{20} POT

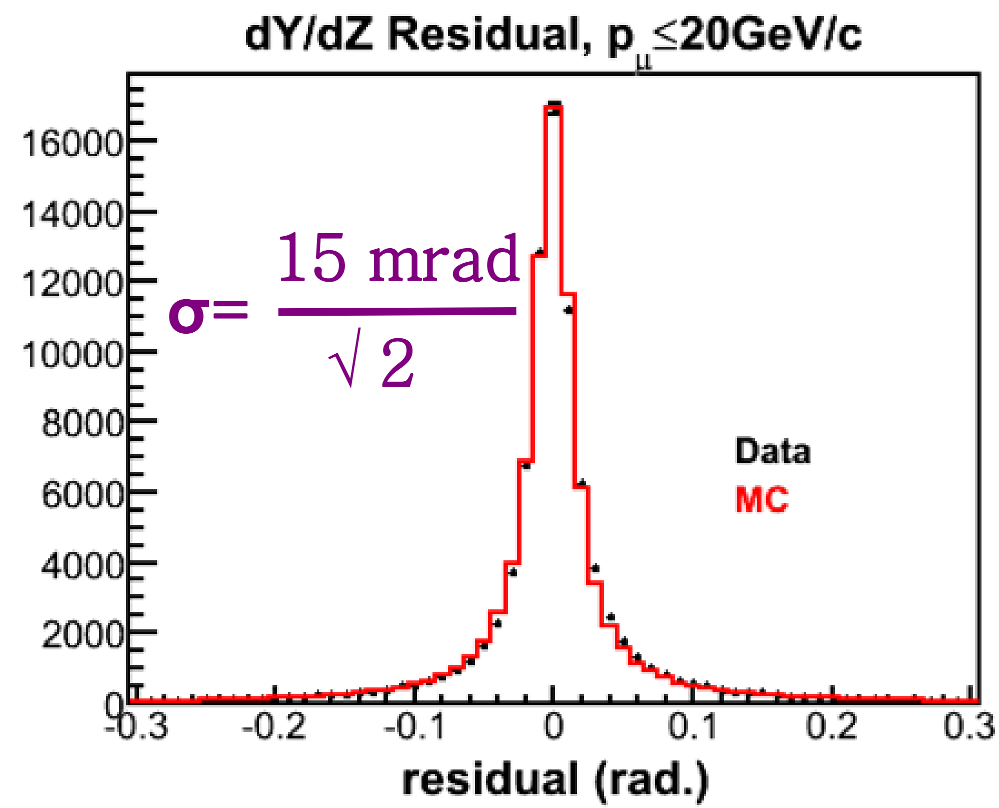
Where do the muons go?



Tracking Resolutions

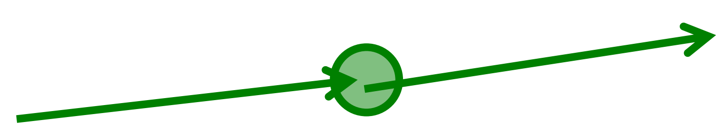


$$\sigma = \frac{4.0\text{mm}}{\sqrt{2}}$$

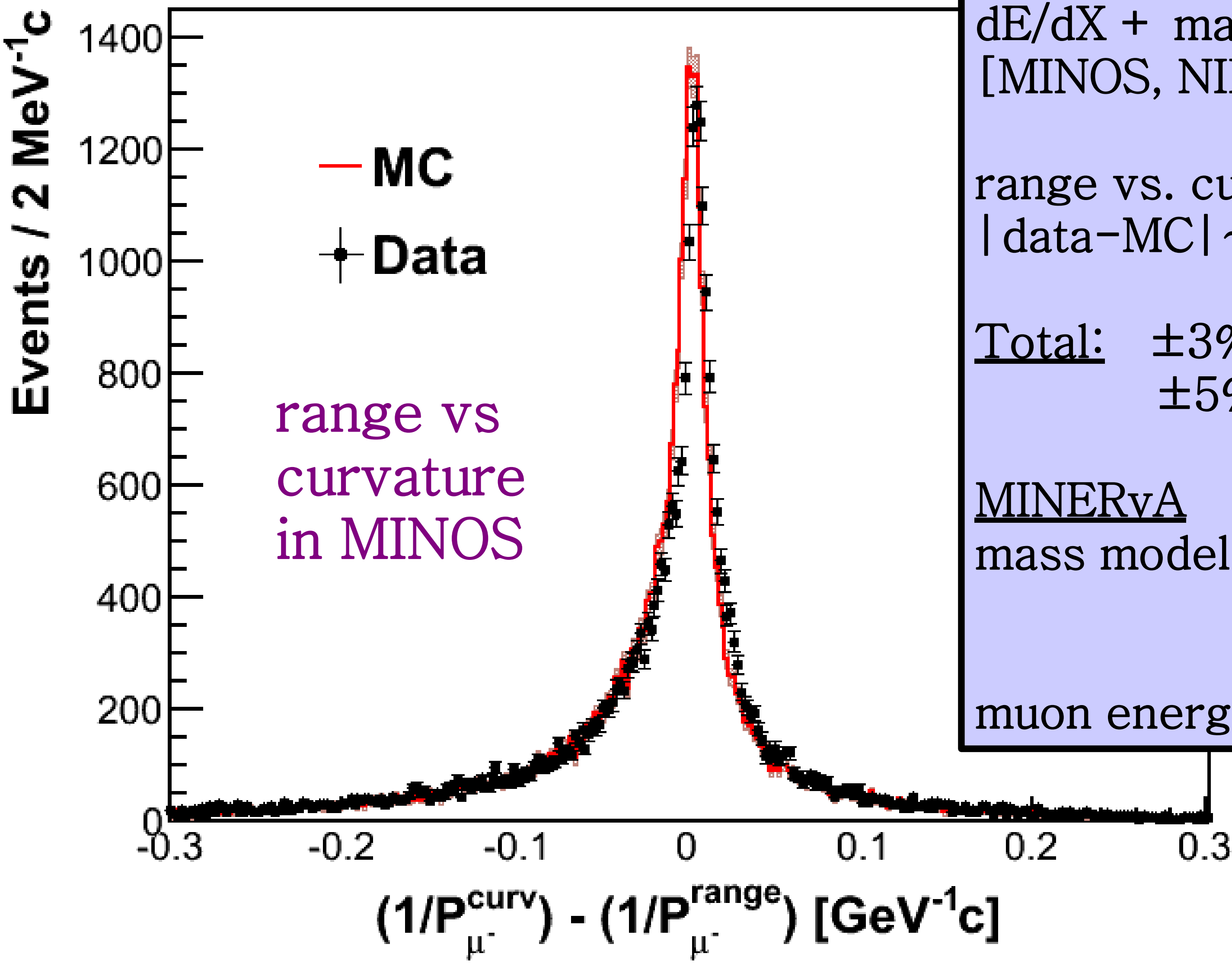


$$\sigma = \frac{15\ \text{mrad}}{\sqrt{2}}$$

Split-track study of rock m
in tracker region



Muon Energy Uncertainty



<u>MINOS</u>
dE/dX + mass model = 2%
[MINOS, NIM A 596, 190 (2008)]

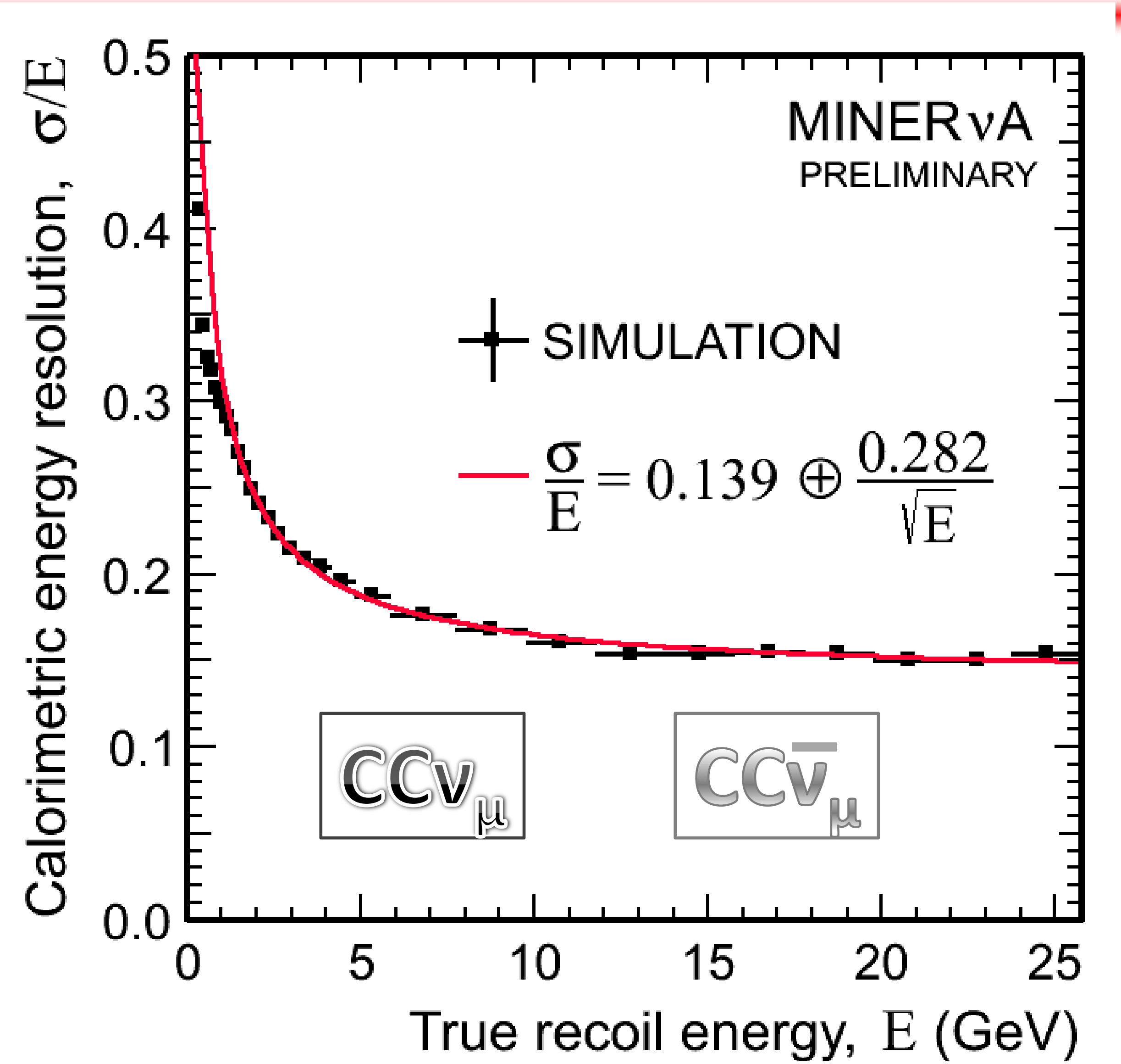
range vs. curvature
|data−MC| ~25 MeV

<u>Total:</u> ±3% p> 1.5 GeV
±5% p< 1.5 GeV

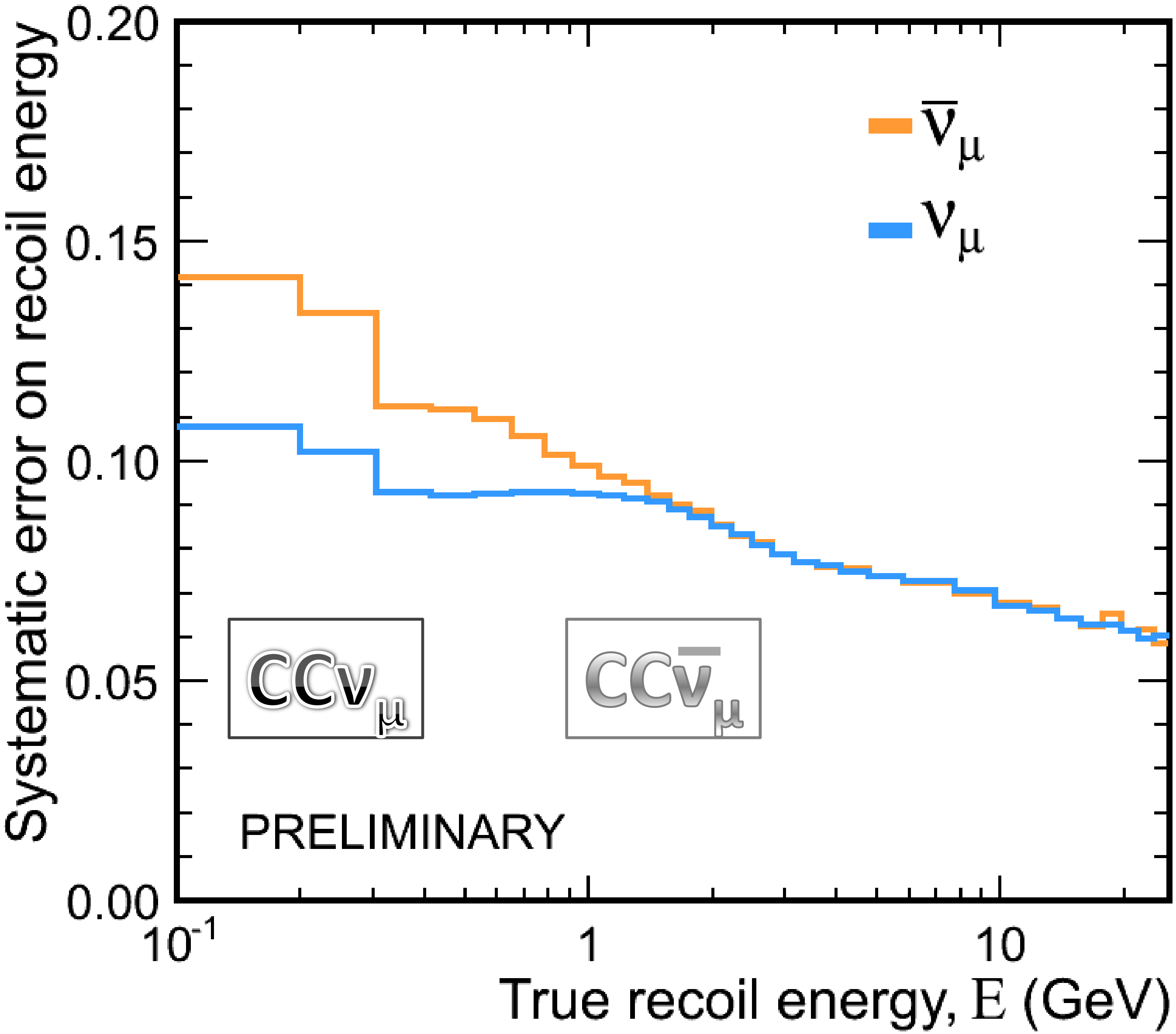
<u>MINERvA</u>
mass model = 11 MeV tracker
= 17 MeV Nucl.Tgts.

muon energy loss = 30 MeV

Recoil Energy Resolution

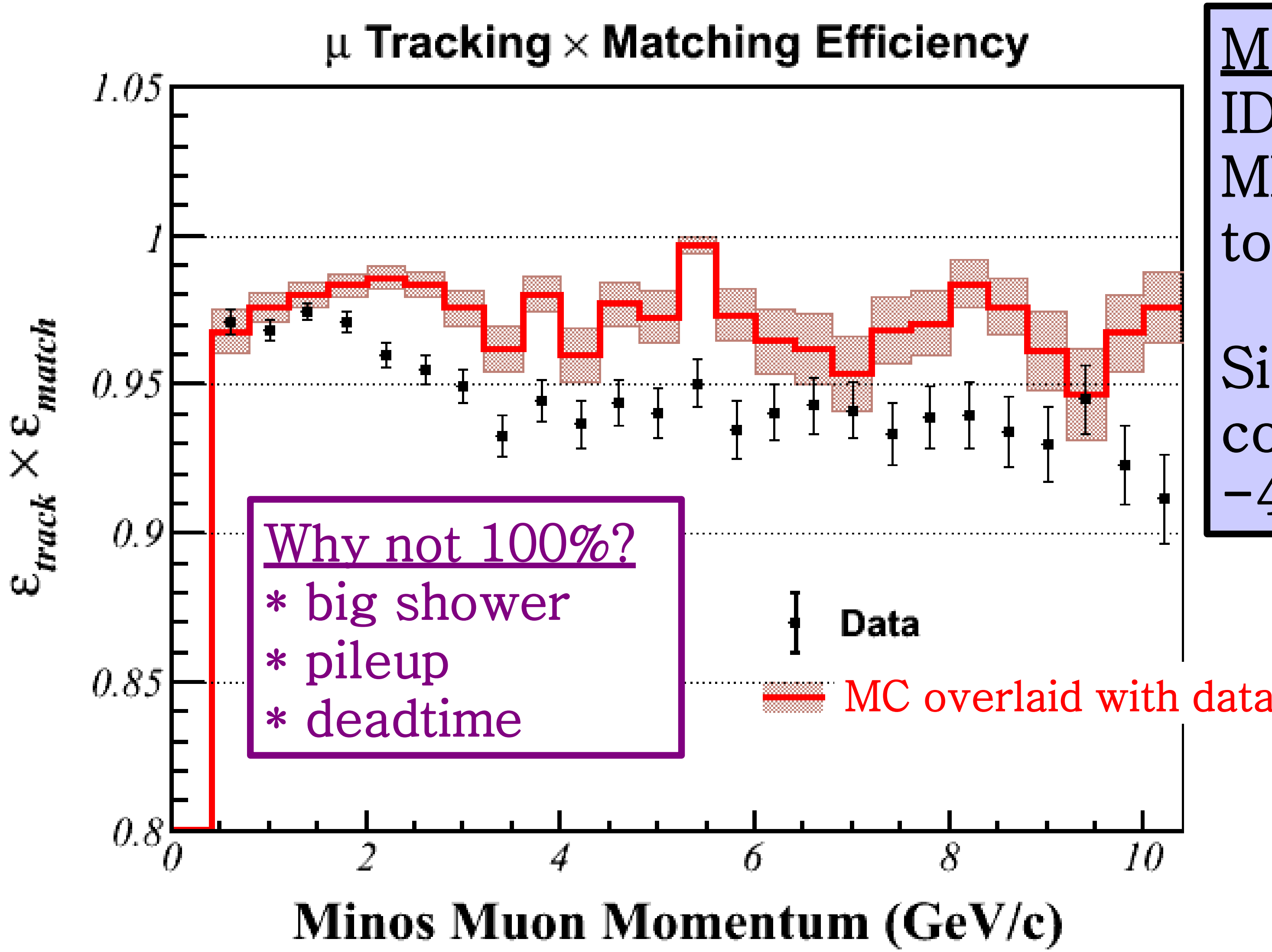


Recoil Energy Error



Convolution of single particle uncertainties
π,K = 5%
e,ɣ = 3%
p = 10%
n = 20%

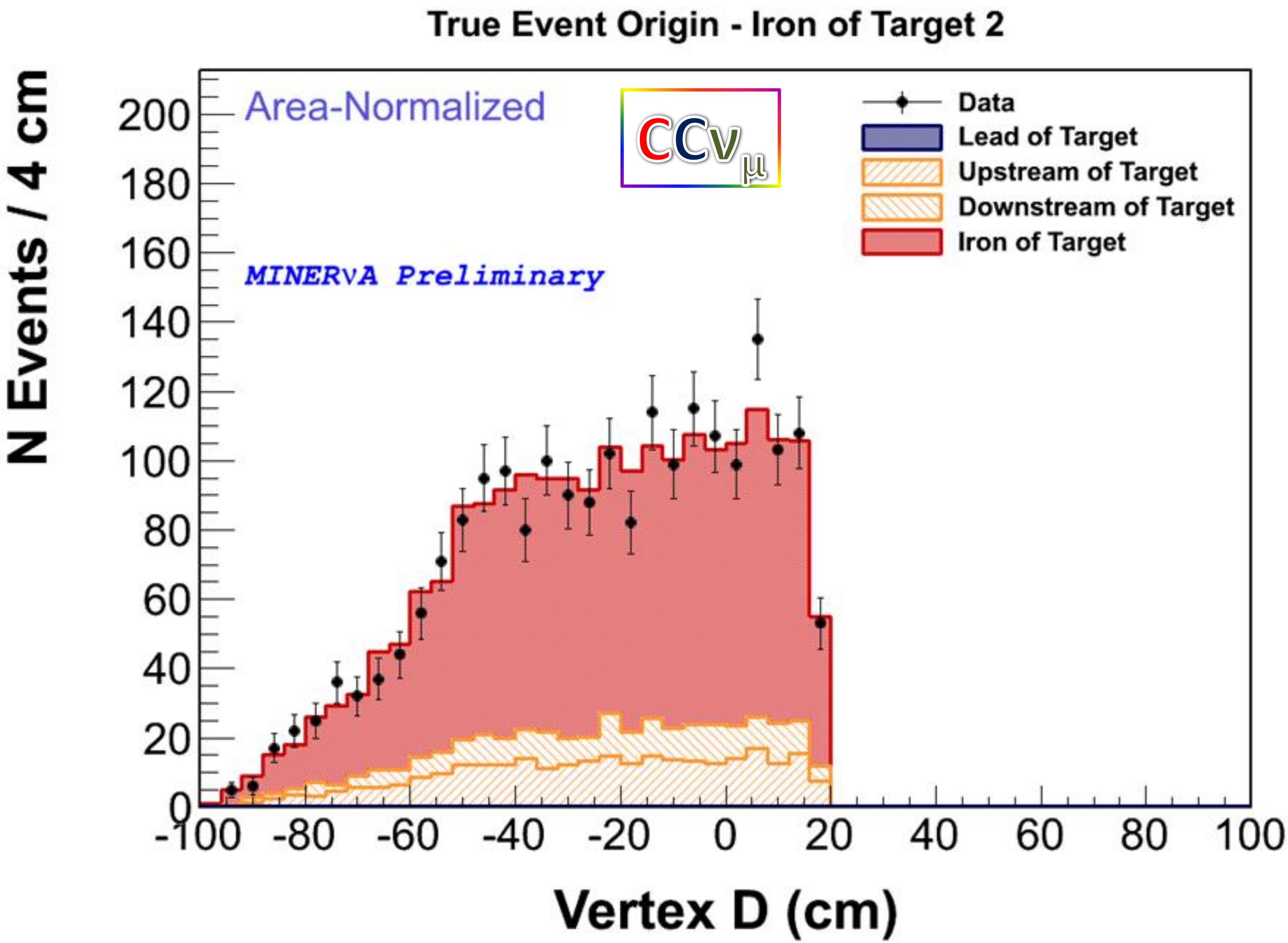
Tracking x Matching Efficiency

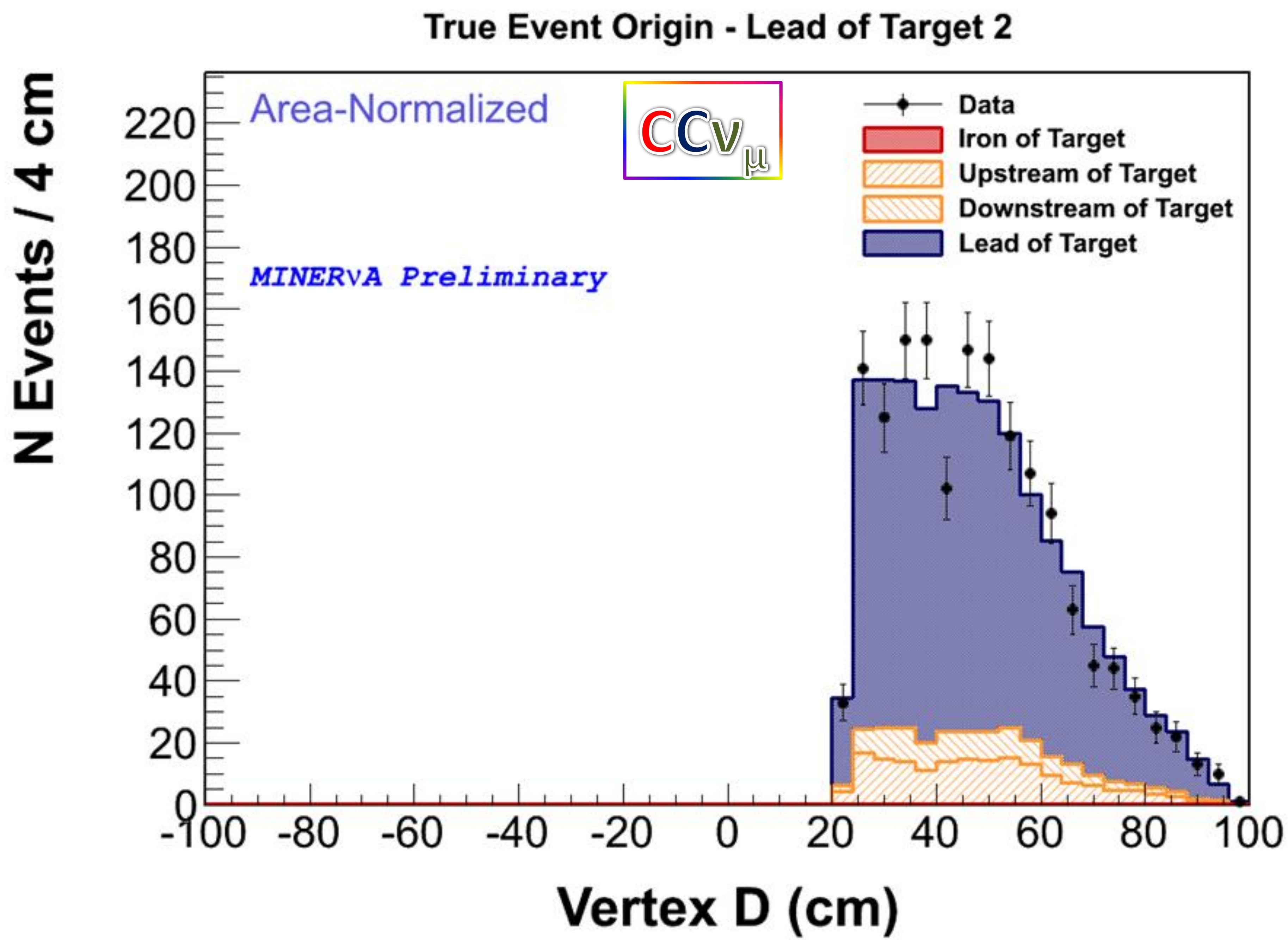


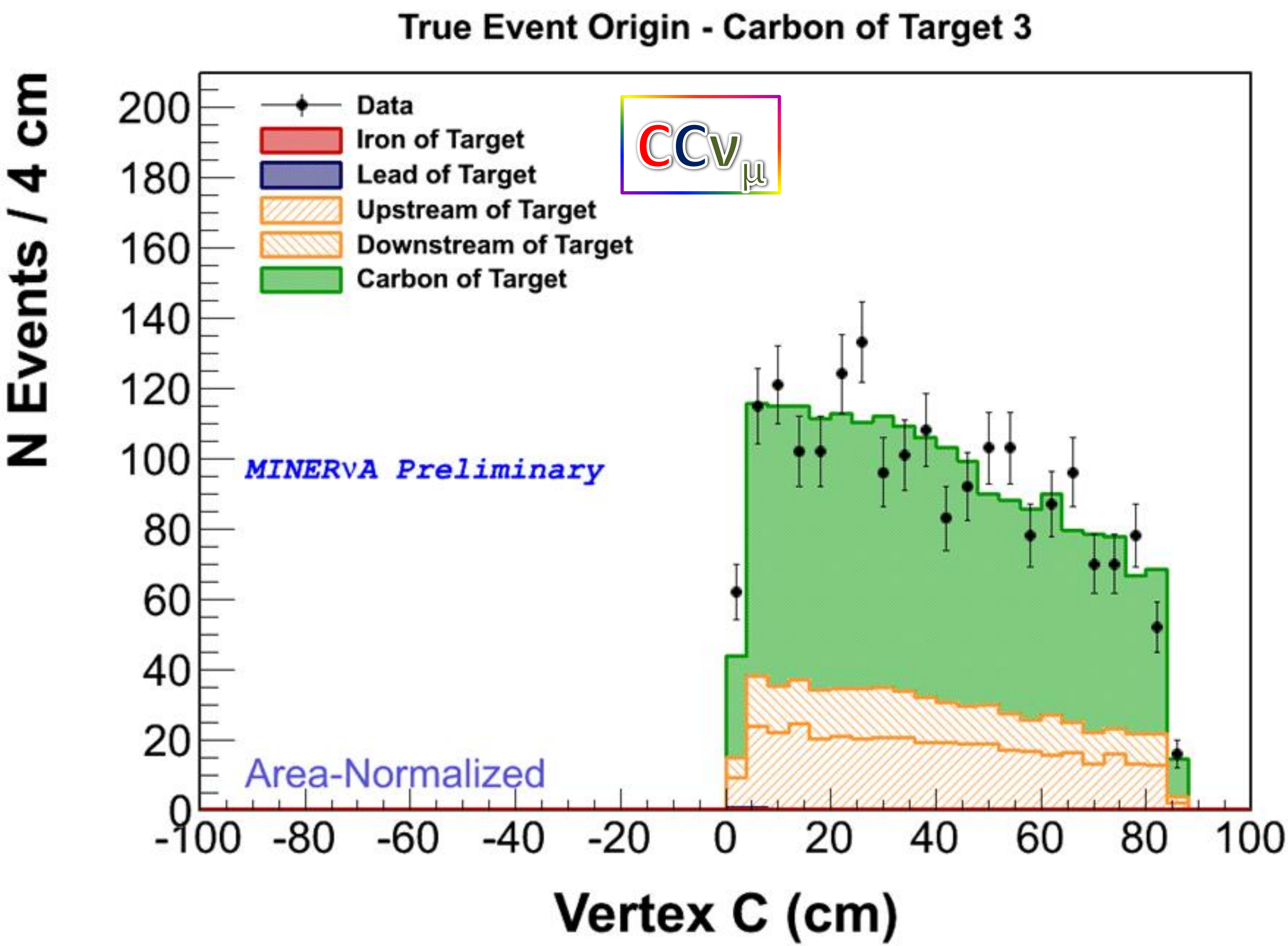
Why not 100%?
* big shower
* pileup
* deadtime

<u>Method</u>
ID clean μ in MINOS, point back to MINERvA

Single event MC correction $-4.6\pm2.5\%$


True Event Origin - Iron of Target 2
N Events / 4 cm
Vertex D (cm)
Area-Normalized
MINERνA Preliminary
CCν
μ
Data
Lead of Target
Upstream of Target
Downstream of Target
Iron of Target
200
180
160
140
120
100
80
60
40
20
0
-100
-80
-60
-40
-20
0
20
40
60
80
100


True Event Origin - Lead of Target 2
Area-Normalized
CCν$_\mu$
MINERνA Preliminary
Data
Iron of Target
Upstream of Target
Downstream of Target
Lead of Target
N Events / 4 cm
Vertex D (cm)
0
20
40
60
80
100
120
140
160
180
200
220
-100
-80
-60
-40
-20
0
20
40
60
80
100


True Event Origin - Carbon of Target 3
N Events / 4 cm
Vertex C (cm)
Data
Iron of Target
Lead of Target
Upstream of Target
Downstream of Target
Carbon of Target
CCν μ
MINERνA Preliminary
Area-Normalized
200
180
160
140
120
100
80
60
40
20
0
-100
-80
-60
-40
-20
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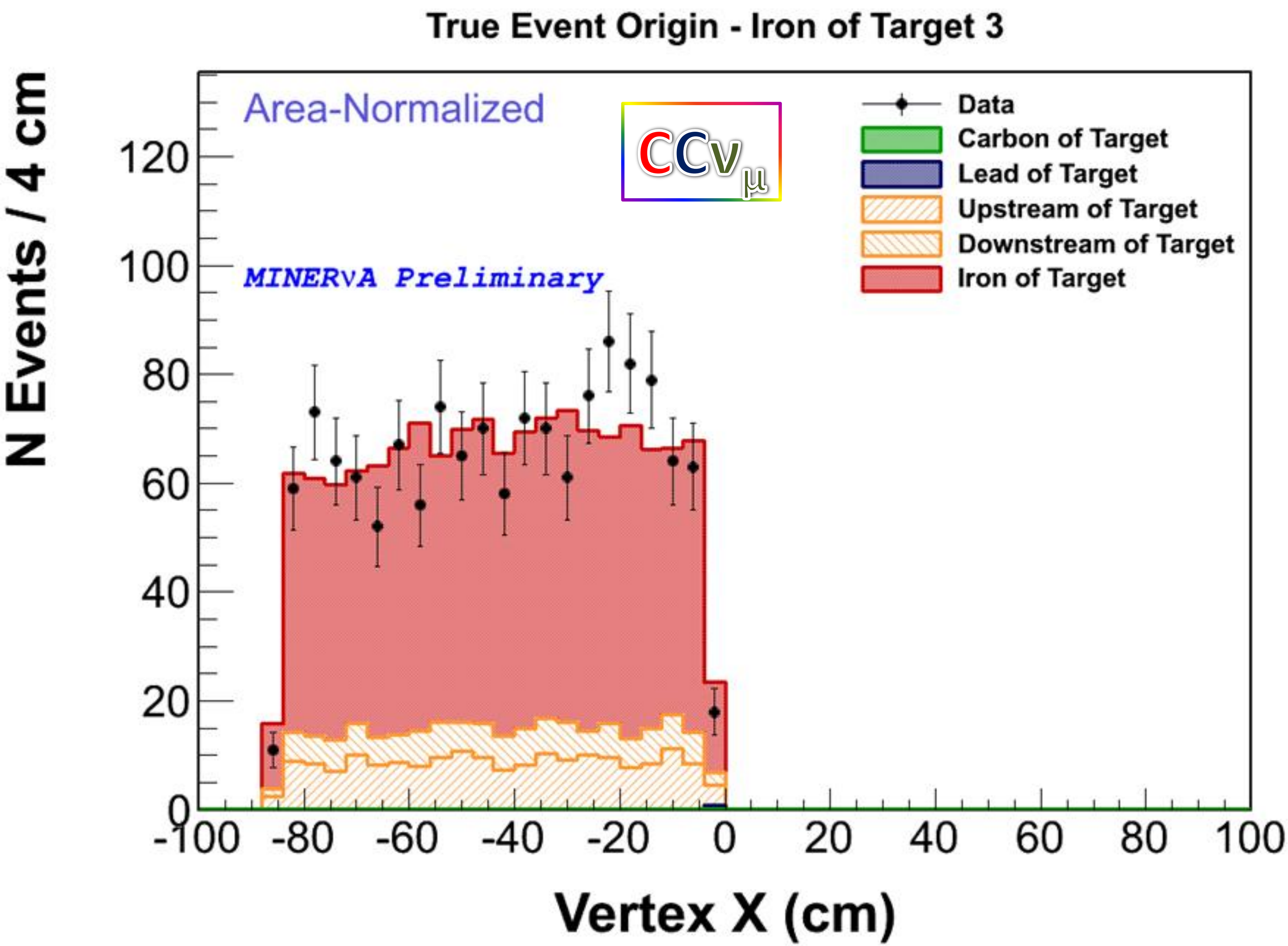
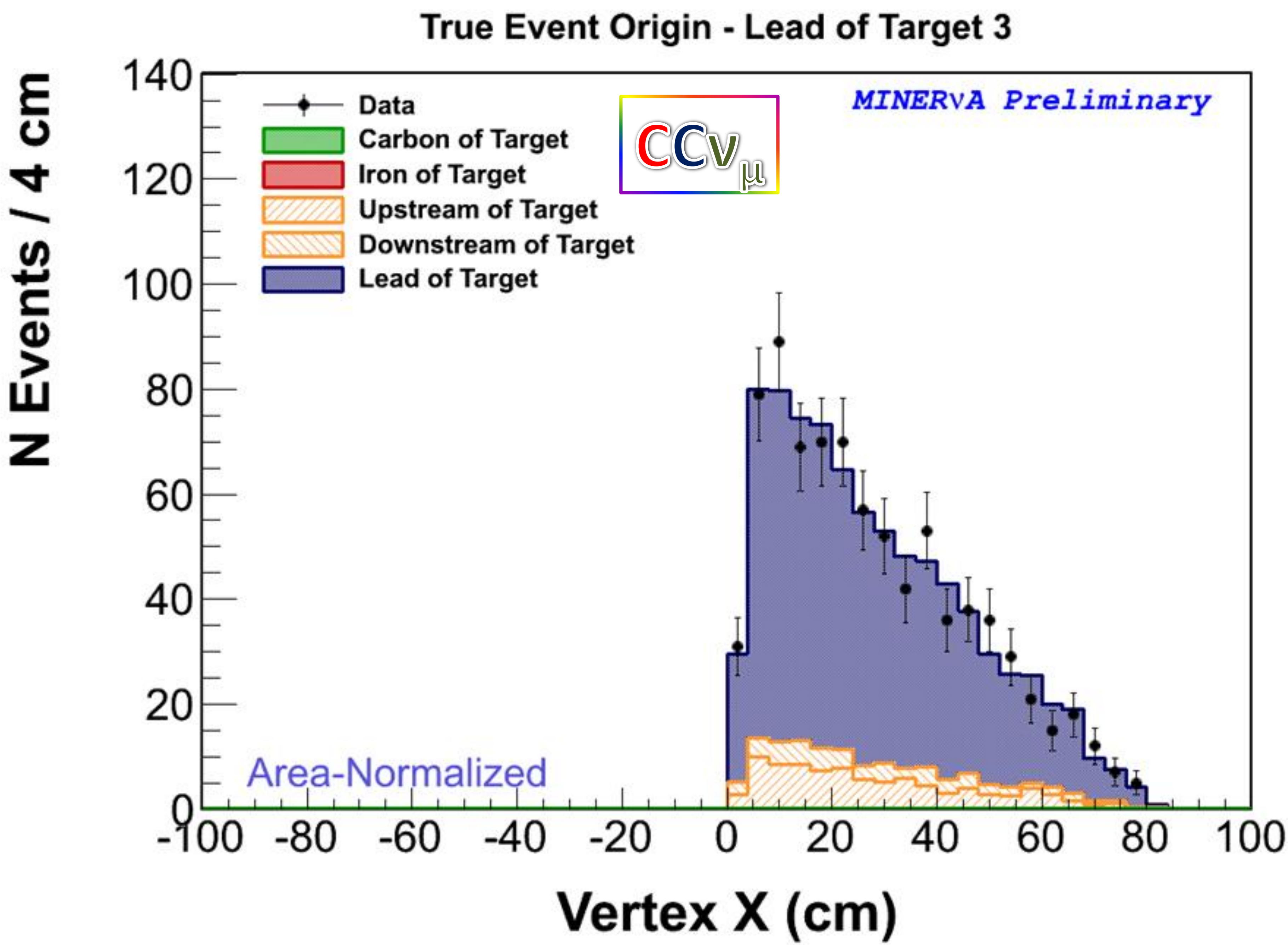
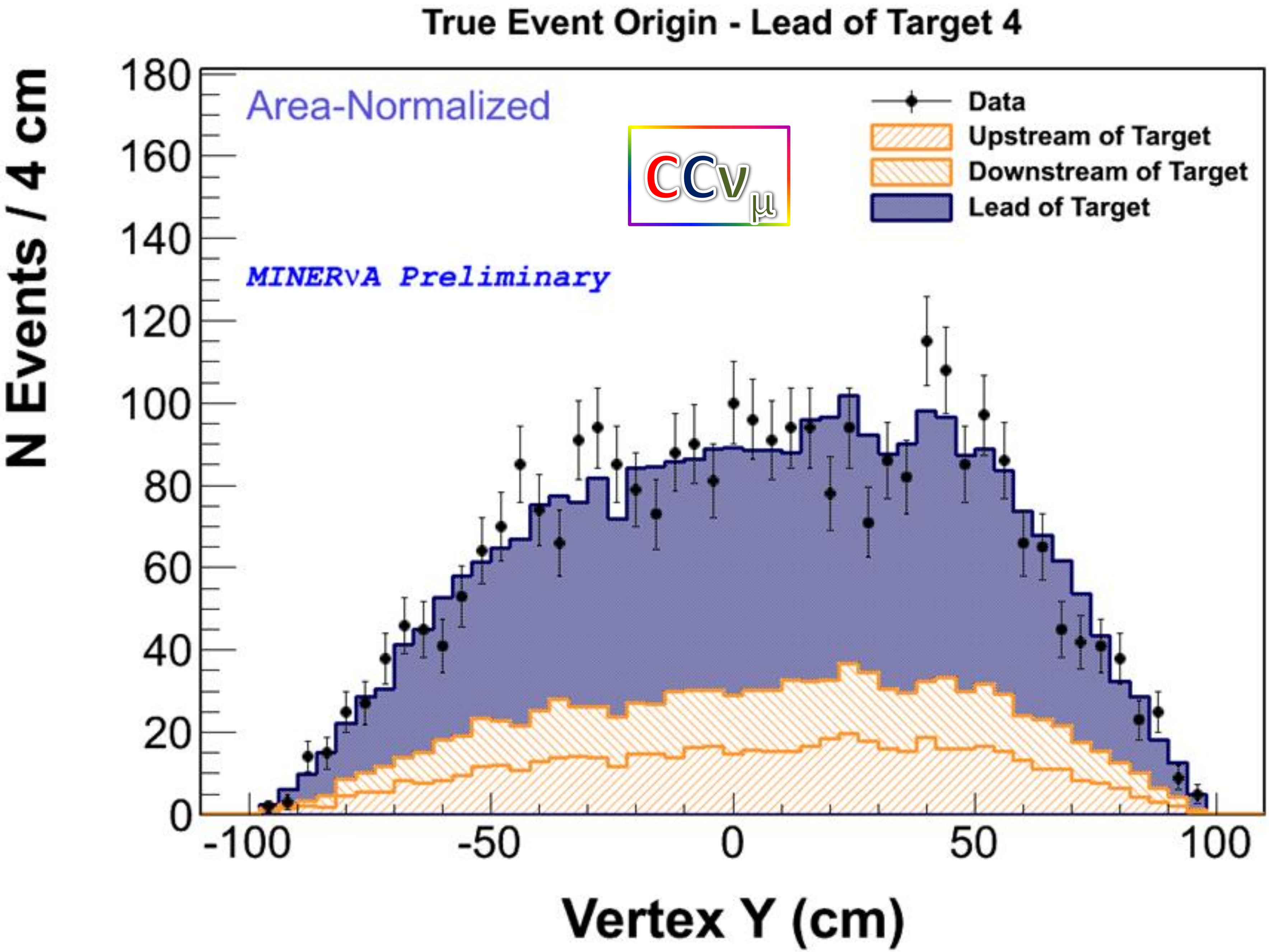
80
100

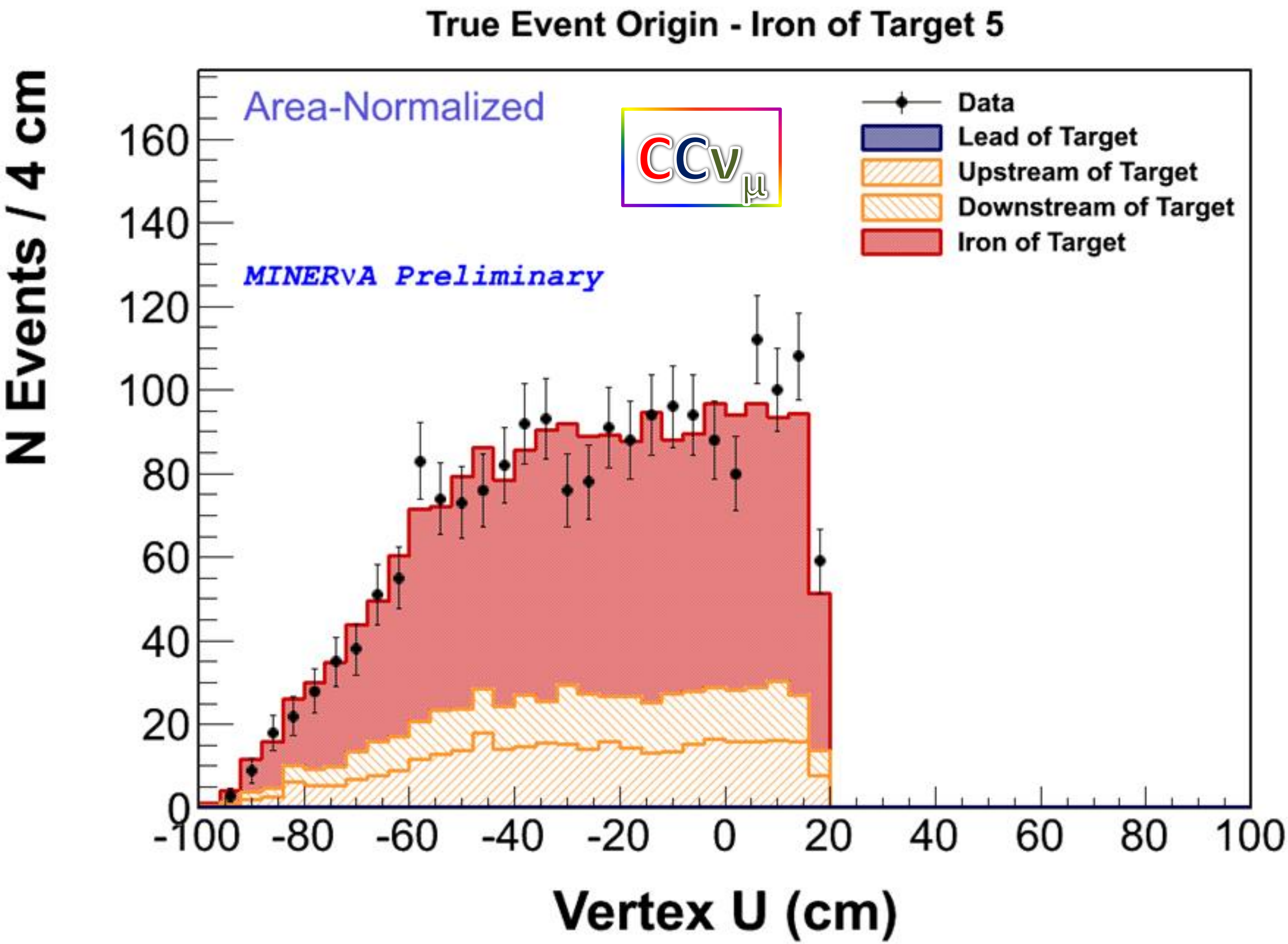

True Event Origin - Iron of Target 3
Area-Normalized
CCνμ
MINERνA Preliminary
Data
Carbon of Target
Lead of Target
Upstream of Target
Downstream of Target
Iron of Target
N Events / 4 cm
120
100
80
60
40
20
0
-100
-80
-60
-40
-20
0
20
40
60
80
100
Vertex X (cm)



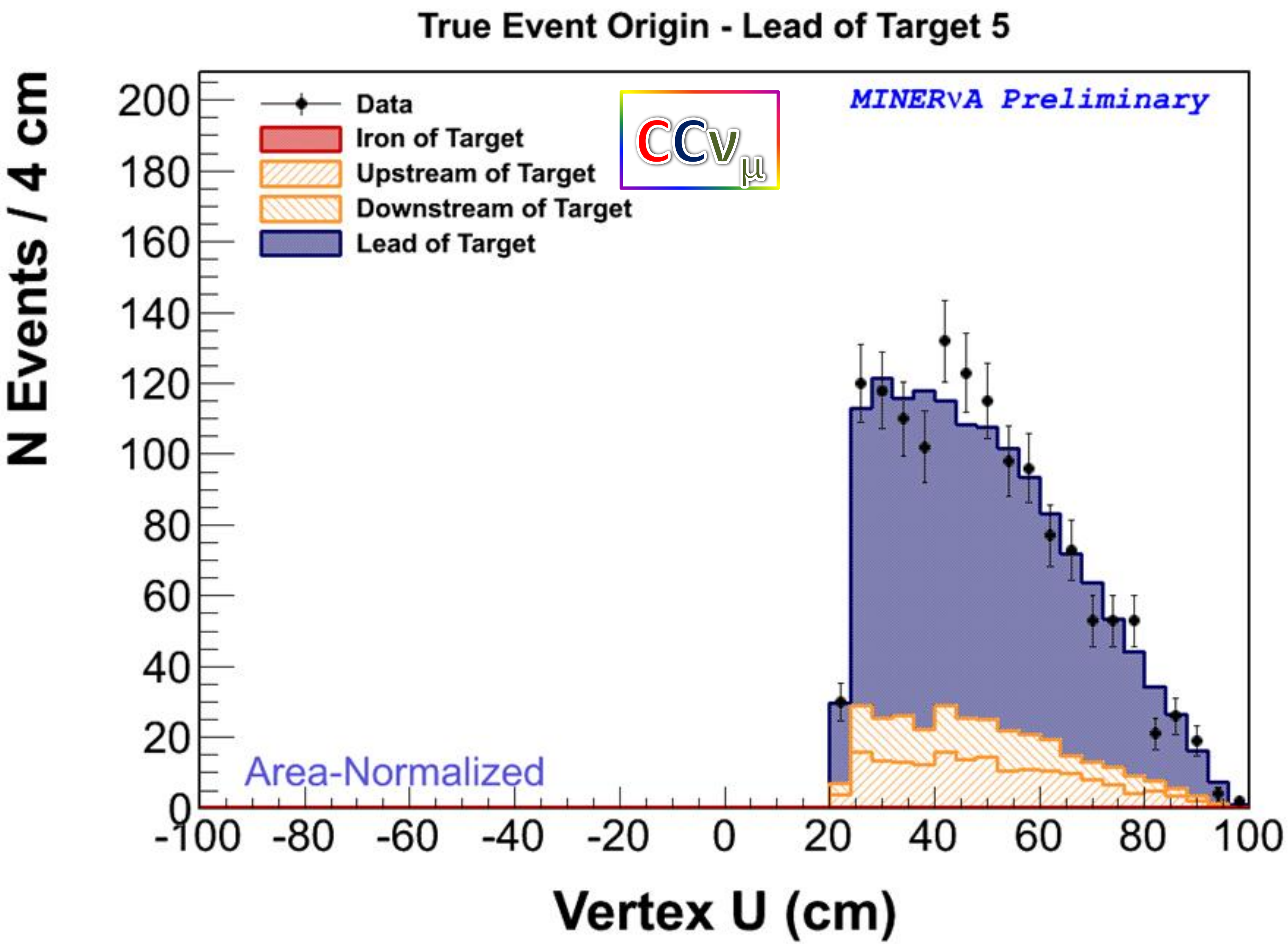
True Event Origin - Lead of Target 3
N Events / 4 cm
Vertex X (cm)
Data
Carbon of Target
Iron of Target
Upstream of Target
Downstream of Target
Lead of Target
MINERνA Preliminary
Area-Normalized



True Event Origin - Lead of Target 4
Area-Normalized
CCνμ
MINERνA Preliminary
Data
Upstream of Target
Downstream of Target
Lead of Target
N Events / 4 cm
Vertex Y (cm)
180
160
140
120
100
80
60
40
20
0
-100
-50
0
50
100

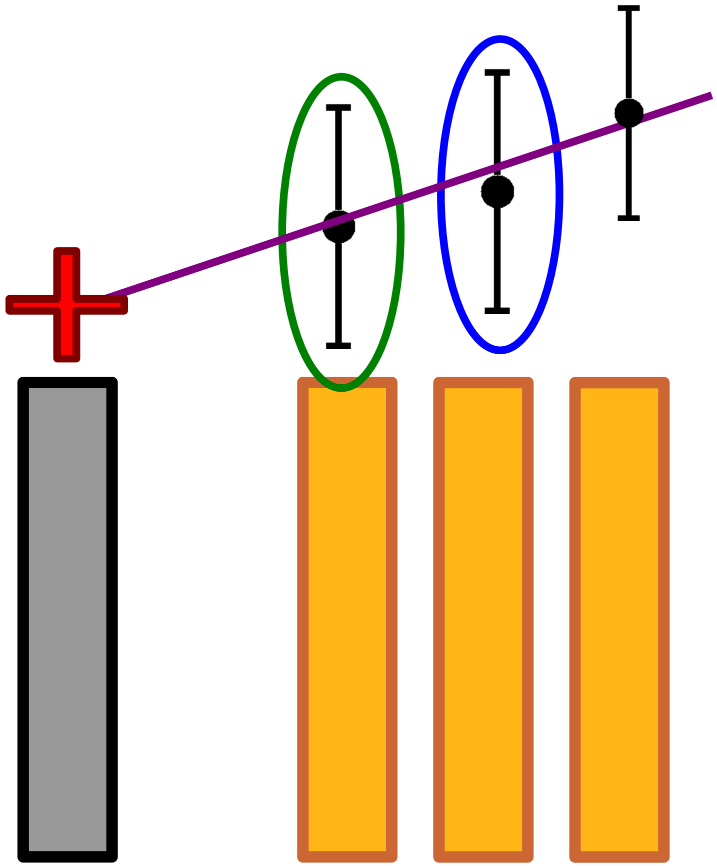


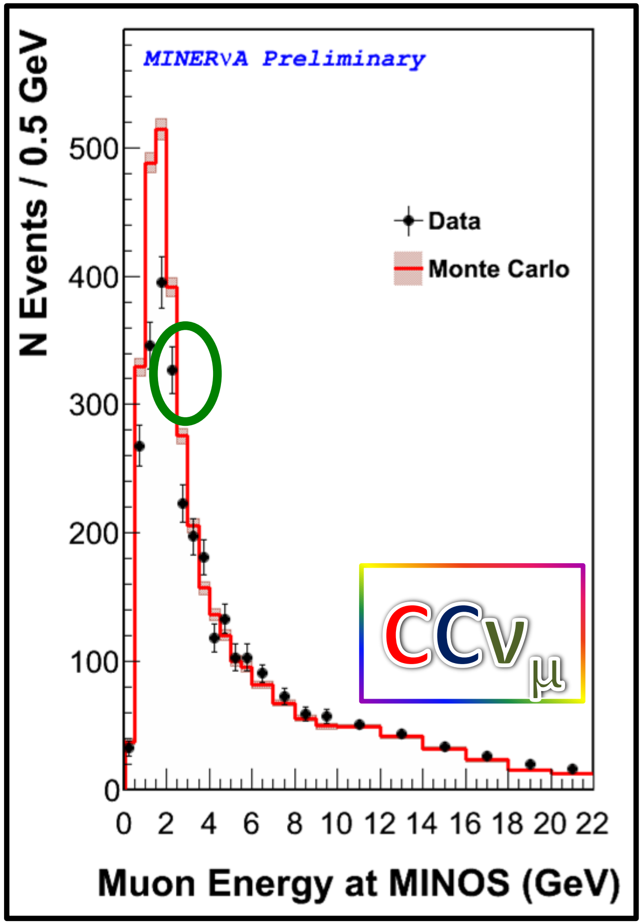
True Event Origin - Iron of Target 5
Area-Normalized
MINERνA Preliminary
$CC\nu_\mu$
Data
Lead of Target
Upstream of Target
Downstream of Target
Iron of Target
N Events / 4 cm
Vertex U (cm)
0
20
40
60
80
100
120
140
160
-100
-80
-60
-40
-20
0
20
40
60
80
100

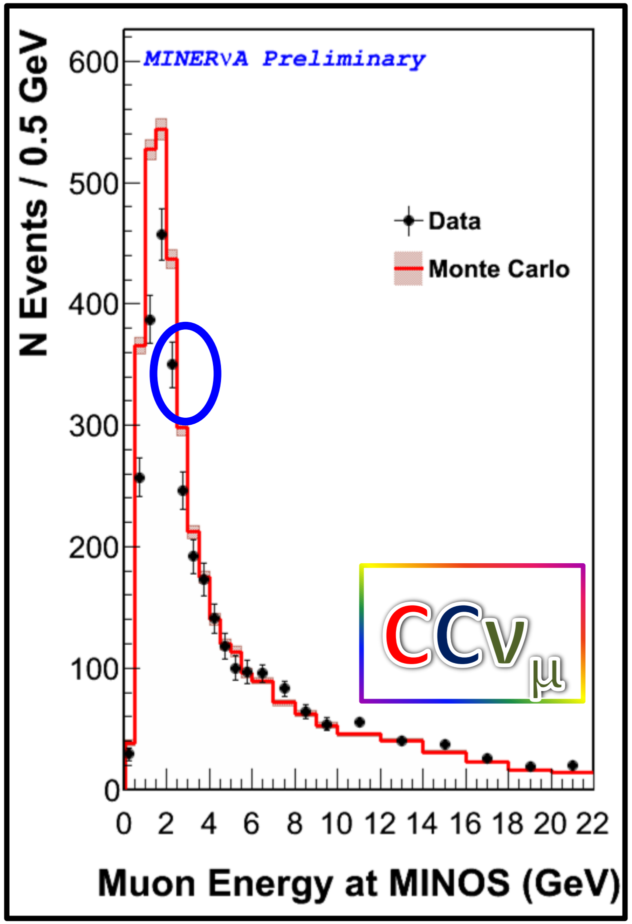

True Event Origin - Lead of Target 5
Data
Iron of Target
Upstream of Target
Downstream of Target
Lead of Target
CCν
μ
MINERνA Preliminary
Area-Normalized
N Events / 4 cm
Vertex U (cm)
200
180
160
140
120
100
80
60
40
20
0
-100
-80
-60
-40
-20
0
20
40
60
80
100

Background Subtraction

Use plastic reference targets to predict rate at the plastic background.



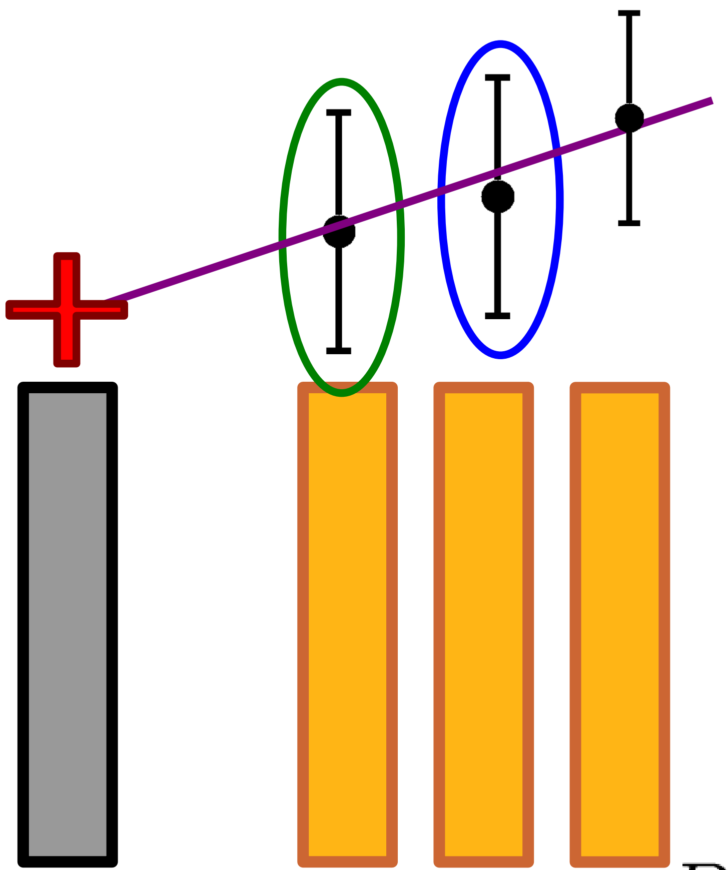


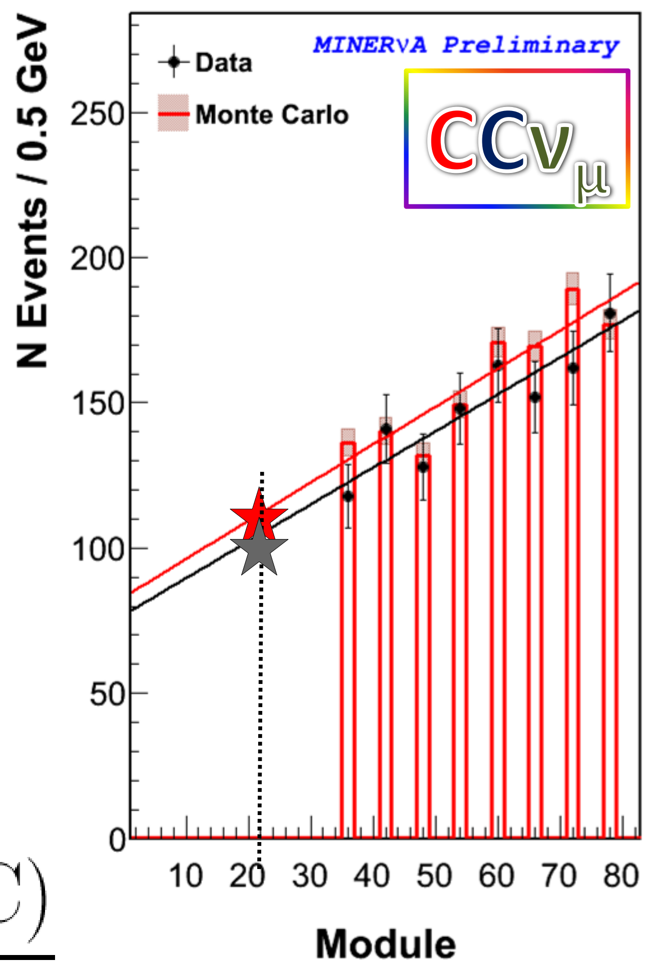


Prediction done in bins of muon momentum.

Background Subtraction

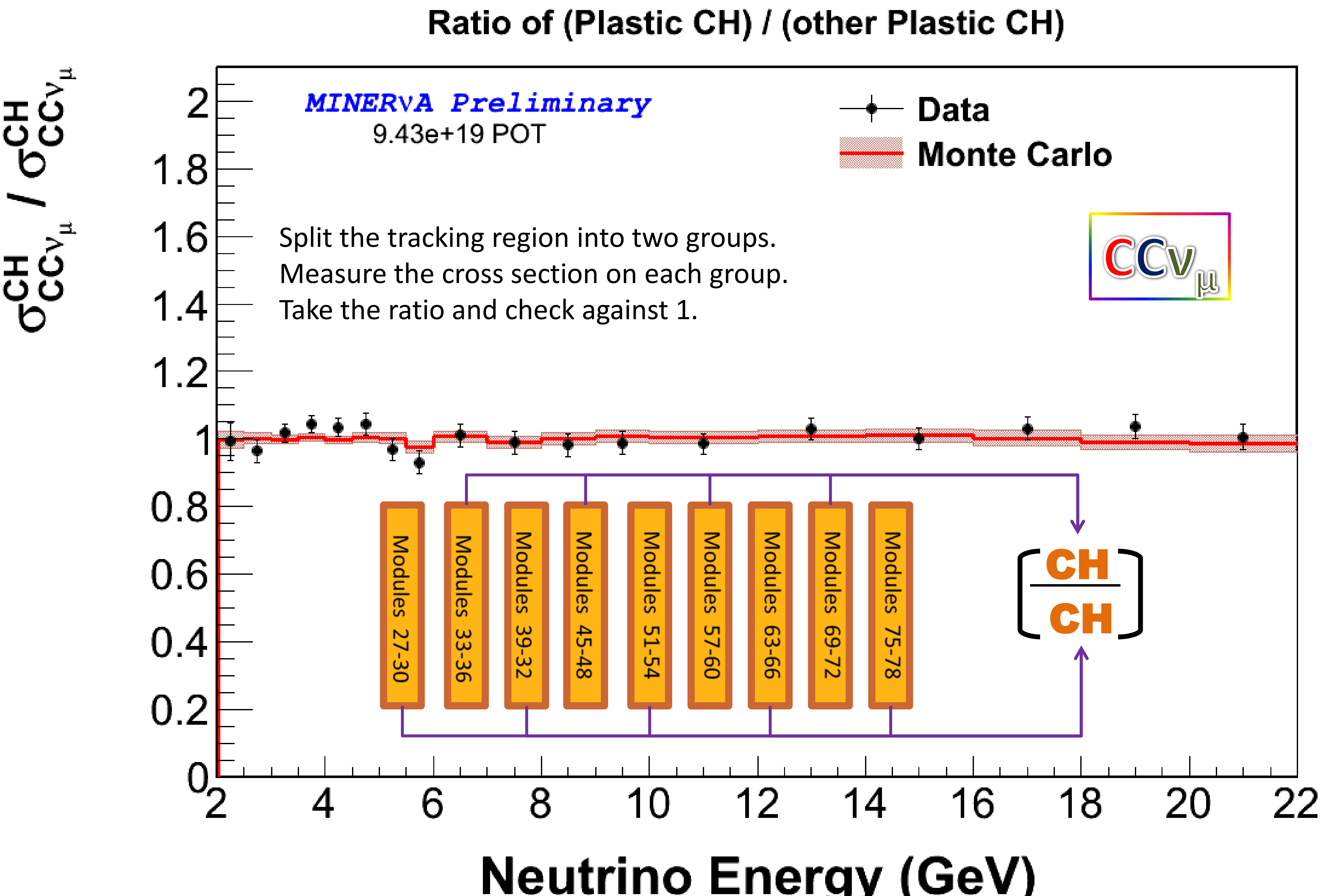
Use plastic reference targets to predict rate at the plastic background.





$$B(\mathrm{data}) = P(\mathrm{data})\frac{B(\mathrm{MC})}{P(\mathrm{MC})}$$

Background subtracted in both MC and data ~without using MC cross section model.



Ratio of (Plastic CH) / (other Plastic CH)
$\sigma^{CH}_{CC\nu_\mu} / \sigma^{CH}_{CC\nu_\mu}$
MINERvA Preliminary
9.43e+19 POT
Data
Monte Carlo
$CC\nu_\mu$
Split the tracking region into two groups.
Measure the cross section on each group.
Take the ratio and check against 1.
Modules 27-30
Modules 33-36
Modules 39-32
Modules 45-48
Modules 51-54
Modules 57-60
Modules 63-66
Modules 69-72
Modules 75-78
$\left[\frac{CH}{CH}\right]$
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2
4
6
8
10
12
14
16
18
20
22
Neutrino Energy (GeV)