NOvA Prong CVN Hand-Scan Study

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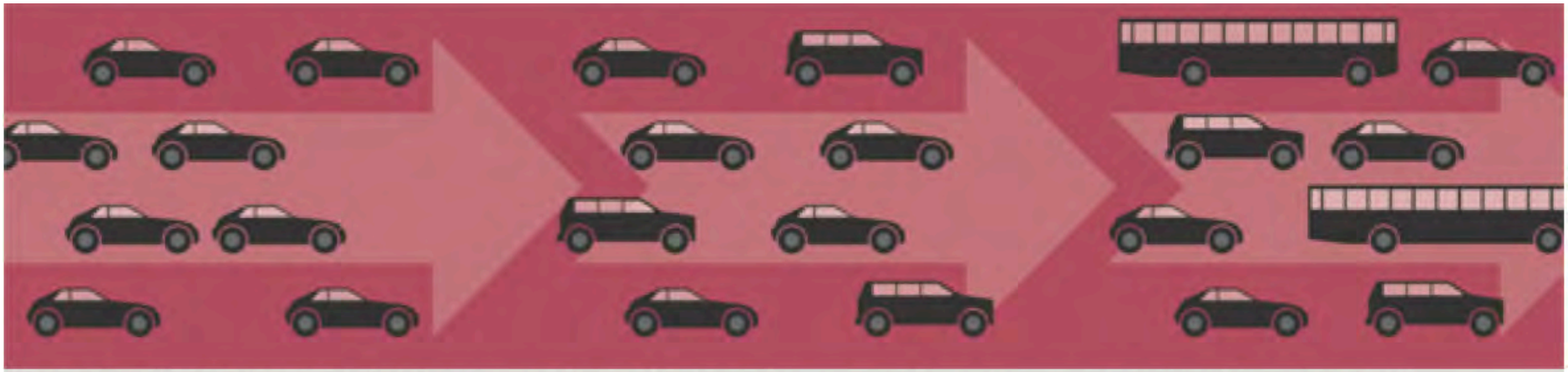
Research Goals of the NOvA experiment

- **Can we observe the oscillation of muon neutrinos to electron neutrinos?**



Completely unknown in the macroscopic world, neutrino oscillations are a quantum effect. They are equivalent to a sports car changing into a minivan or a bus, and then, many miles farther down the road, reappearing as a sports car.

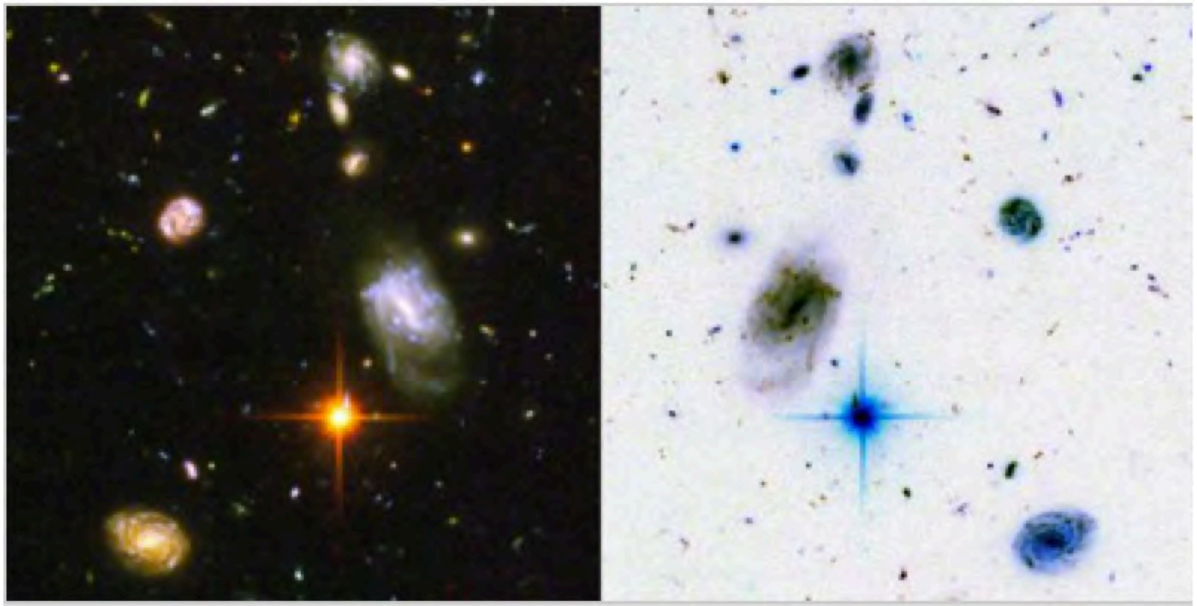
Research Goals of the NOvA experiment

- **What is the ordering of the neutrino masses?**

Physicists think the origins of neutrino masses are closely tied to subatomic processes that took place right after the big bang. Determining which neutrino types are heaviest and lightest—the neutrino mass ordering—is a first step toward revealing these processes.

Research Goals of the NOvA experiment

- **What is the symmetry between matter and antimatter?**



Physicists theorize that the big bang created equal amounts of matter and antimatter.

How does NOvA work?

- **The Intensity Frontier**
- **The NuMI beam**
- **The Detectors**

Near Detector

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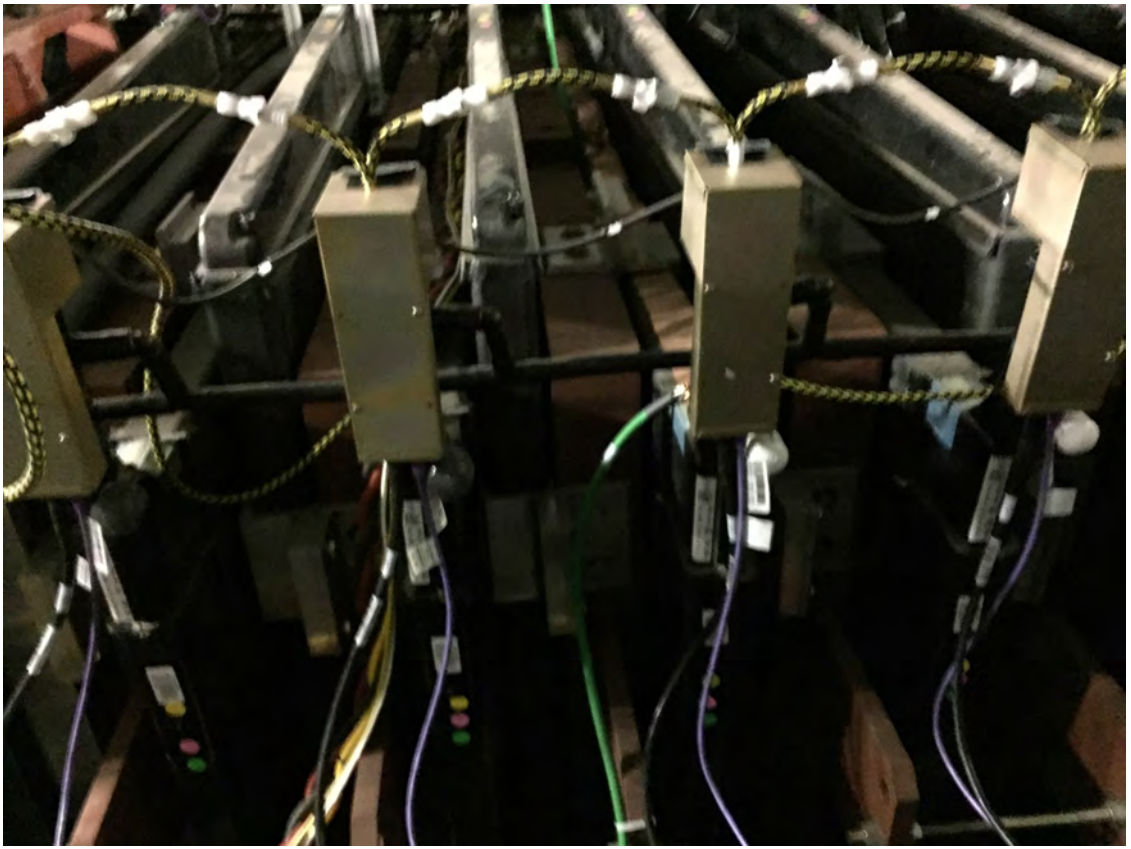
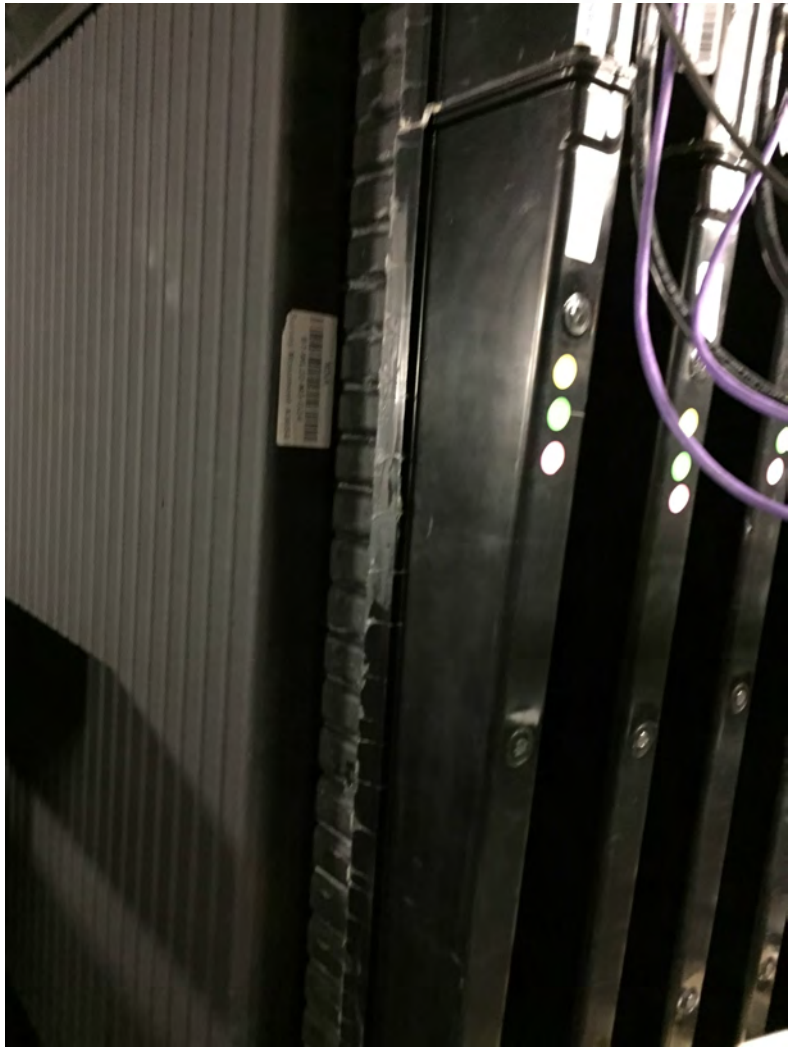
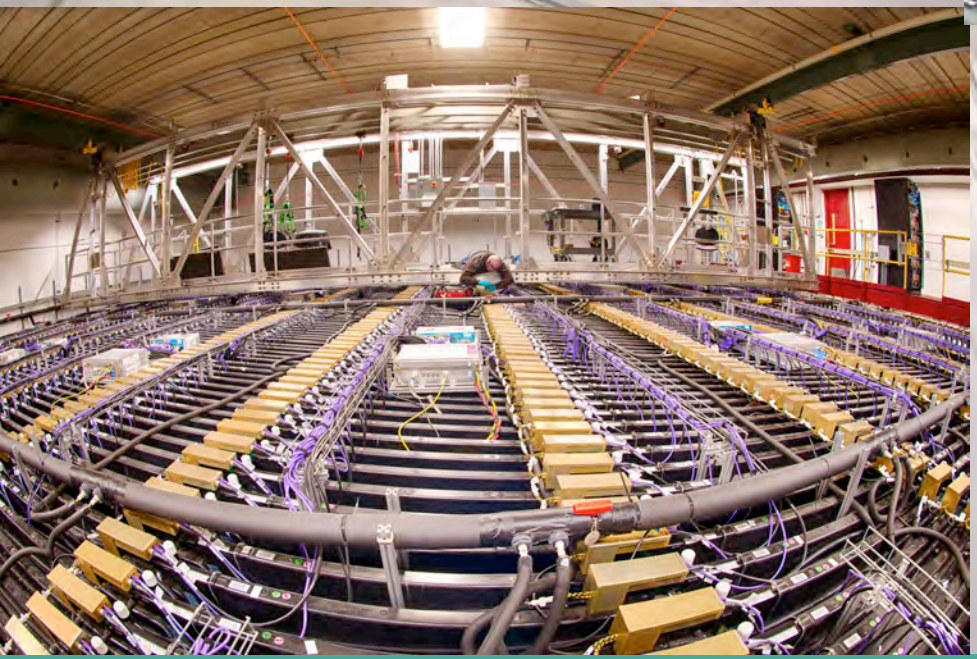




Far Detector



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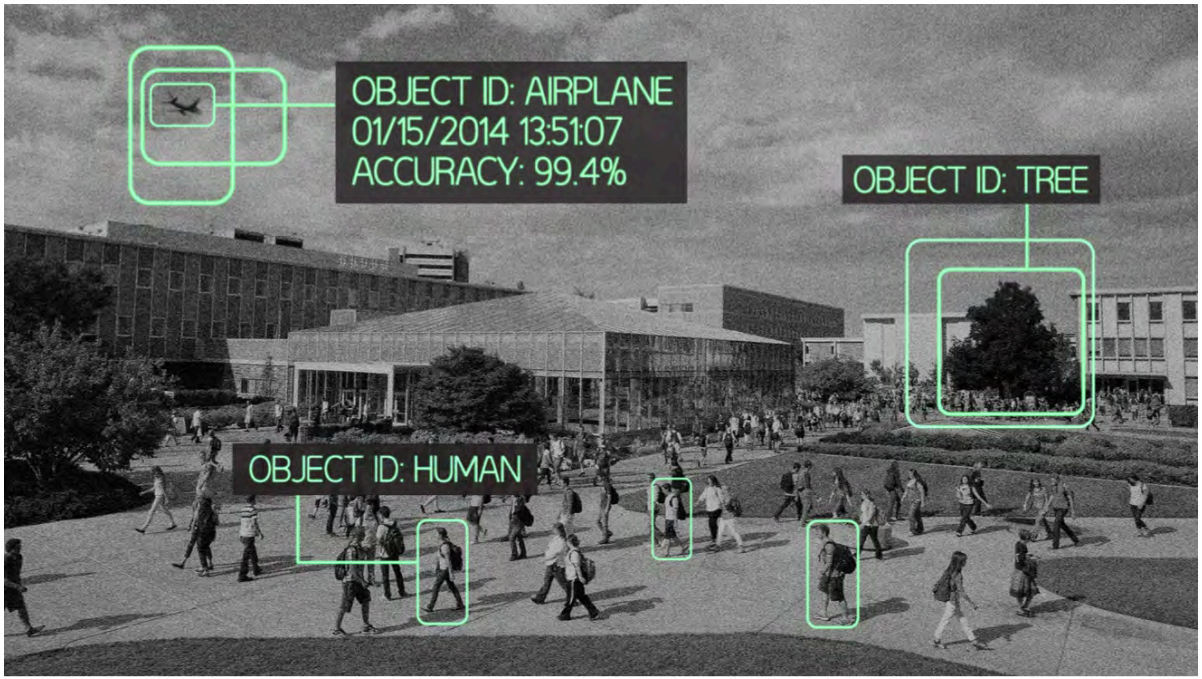
Convolutional Neural Network

- Computer vision is a field that includes methods for acquiring, processing, analyzing, and understanding images and, in general, high-dimensional data from the real world in order to produce numerical or symbolic information
- Recent advances in machine learning/computer vision have achieved near-human performance on image classification tasks

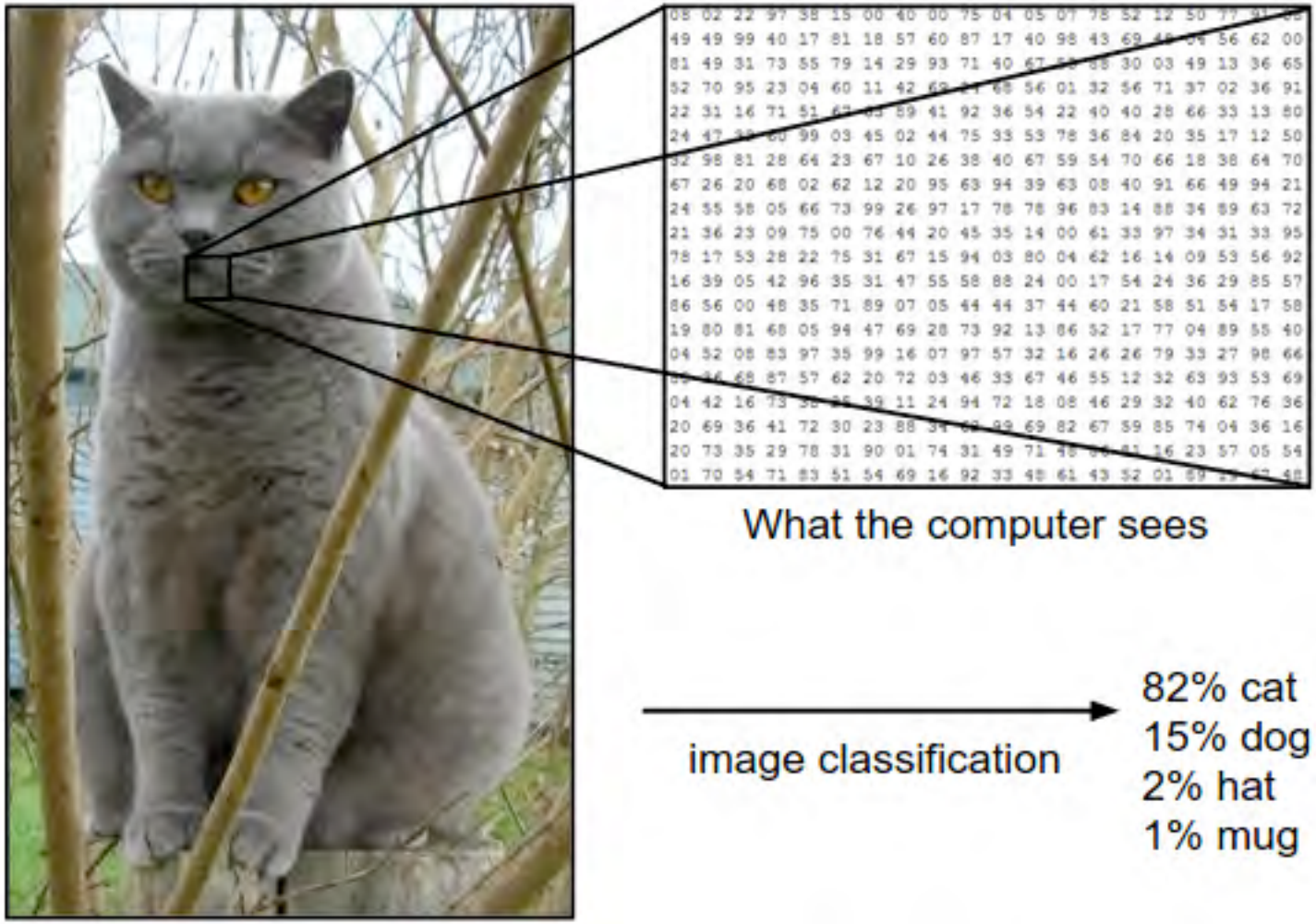


Convolutional Neural Network

- Computers are given an image and then different filters or kernals are applied to the image pixels or data to get the desired results… for example – this is an edge detection kernal

$$\frac{1}{8}\begin{bmatrix} -1 & -1 & -1 \\ -1 & +8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

Edge-detection kernel



What the computer sees

image classification

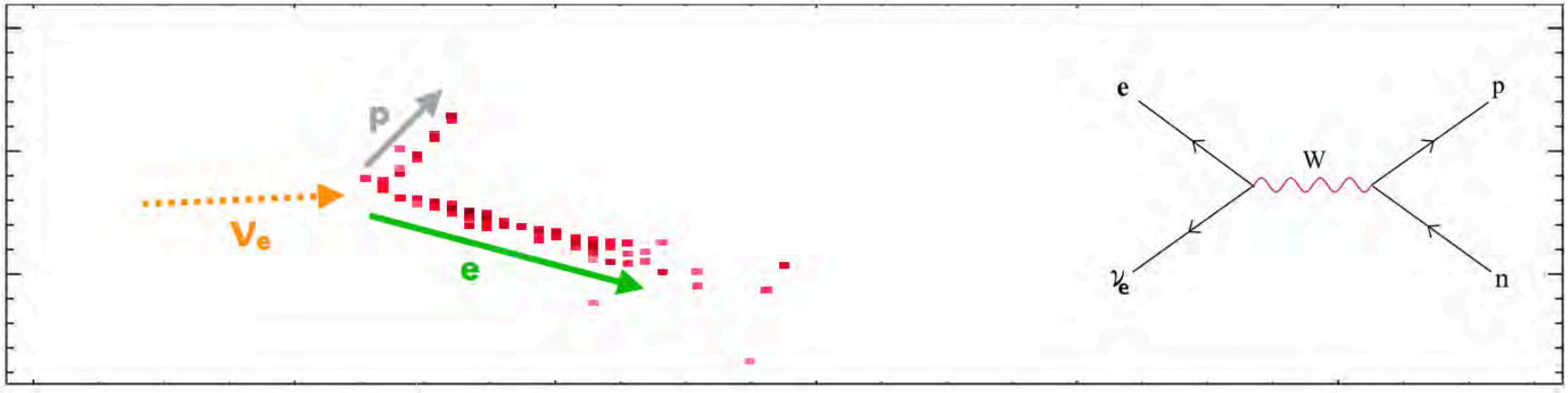
82% cat
15% dog
2% hat
1% mug

CVN and NOvA

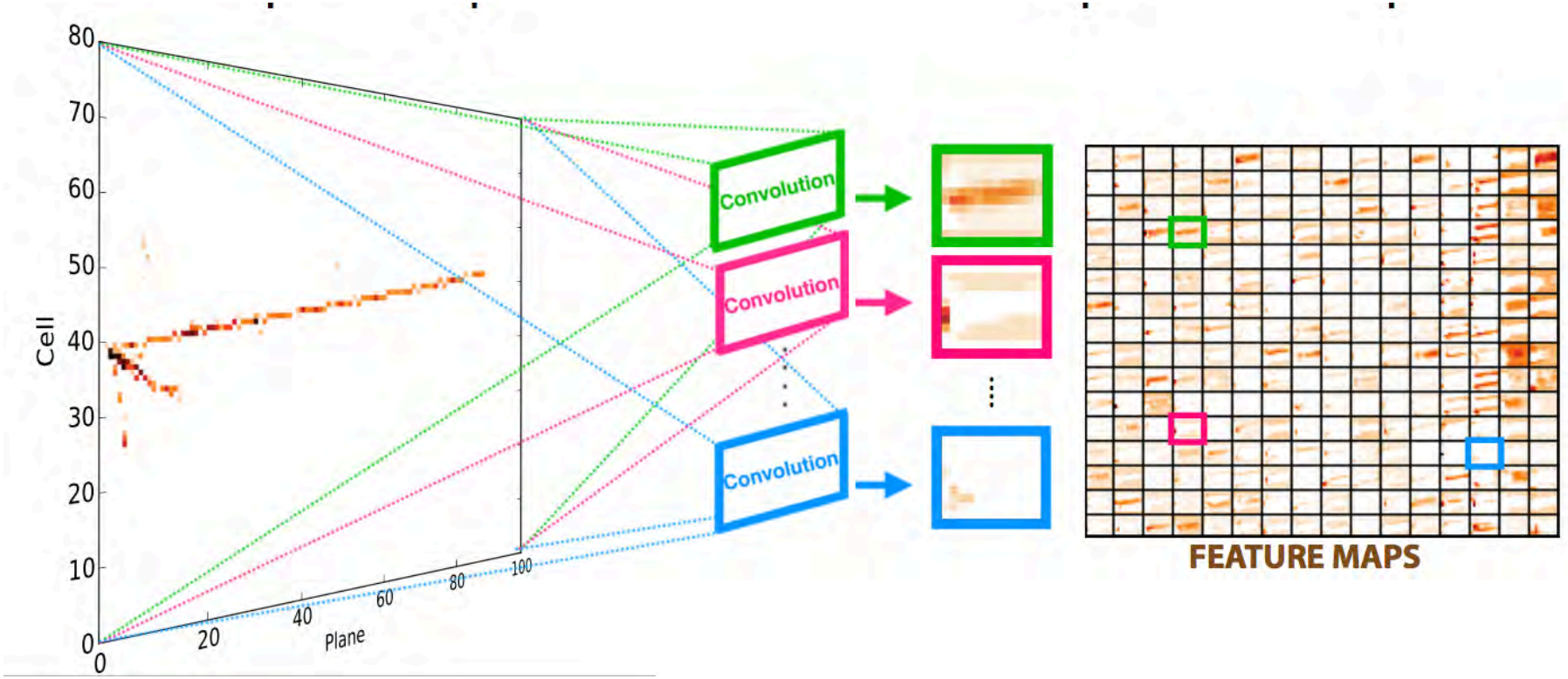
- Traditional particle detection uses multiple variable reconstruction techniques where there are more uncertainties and errors acquired at every step
- Using a CVN, an unreconstructed image or “raw data” can be used to determine each individual particle within an event as opposed to classifying the entire event.
- We have a first draft of a network that identifies each particle, but now we need to try to understand how it performs and how to proceed from here to understand its behavior

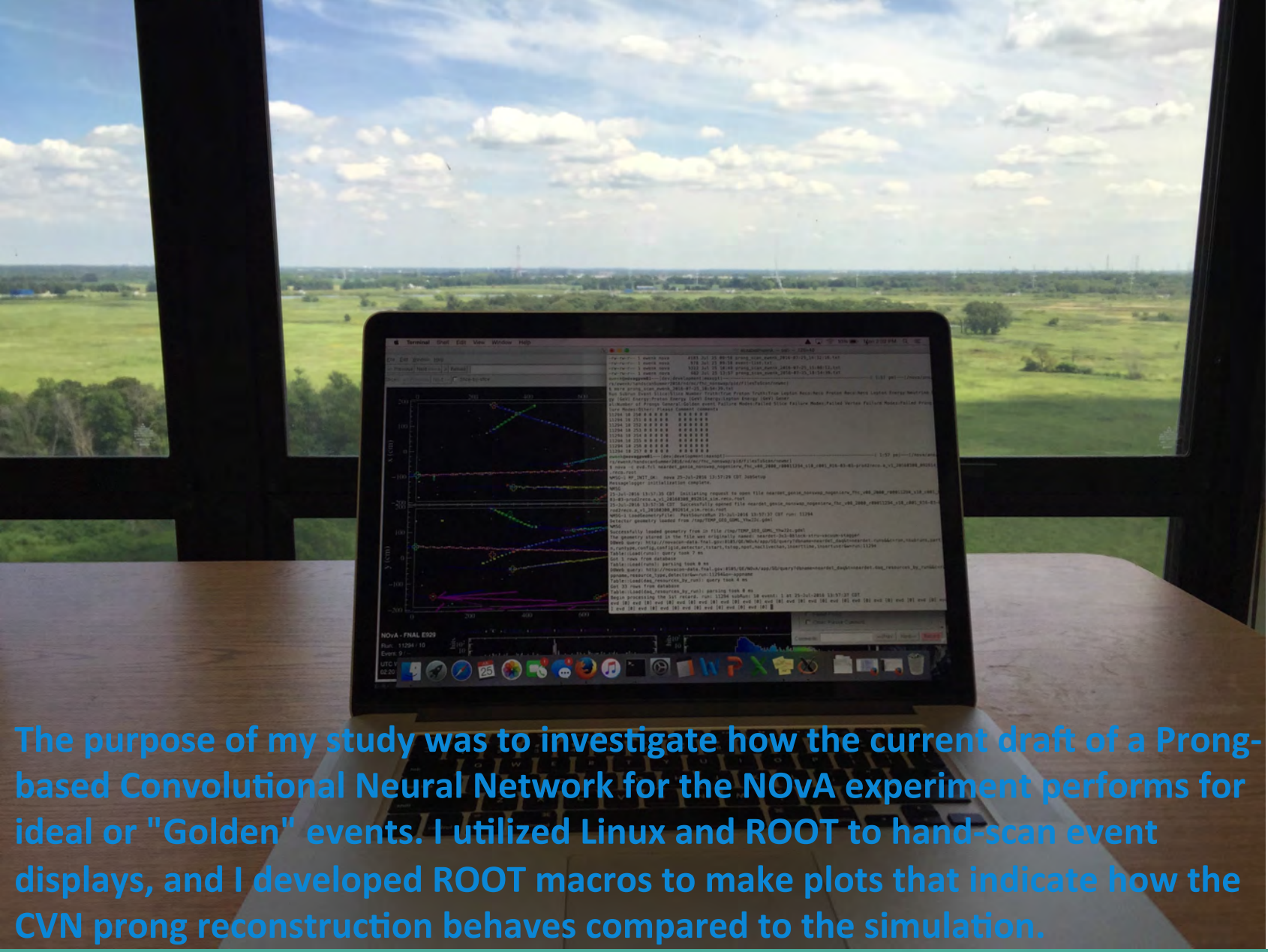
CVN and NOvA

- Some events are easier to identify than others (specifically a proton – lepton pair).
- It is important to get a sample of “golden events” via hand-scanning (a technique that dates back to over 50 years ago) that should be good candidates for the individual particle (prong) detection technique – meaning events that should behave well with CVN program
- Once we have identified these golden events, we can then compare the performance of the CVN program to the truth



CVN and NOvA


Cell
Plane
Convolution
Convolution
Convolution
FEATURE MAPS



The purpose of my study was to investigate how the current draft of a Prong-based Convolutional Neural Network for the NOvA experiment performs for ideal or "Golden" events. I utilized Linux and ROOT to hand-scan event displays, and I developed ROOT macros to make plots that indicate how the CVN prong reconstruction behaves compared to the simulation.

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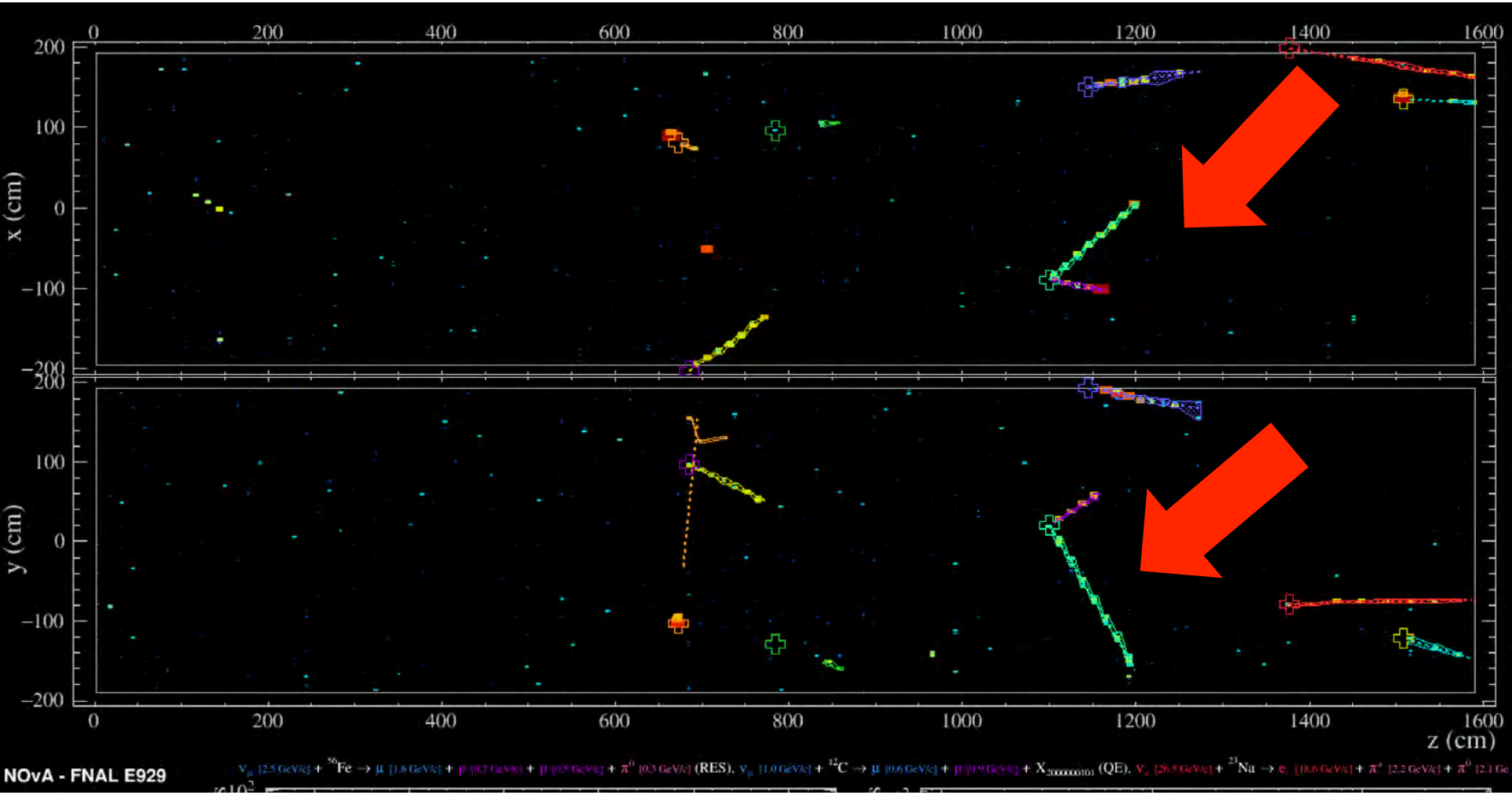
Hand-Scan Prong CVN Study

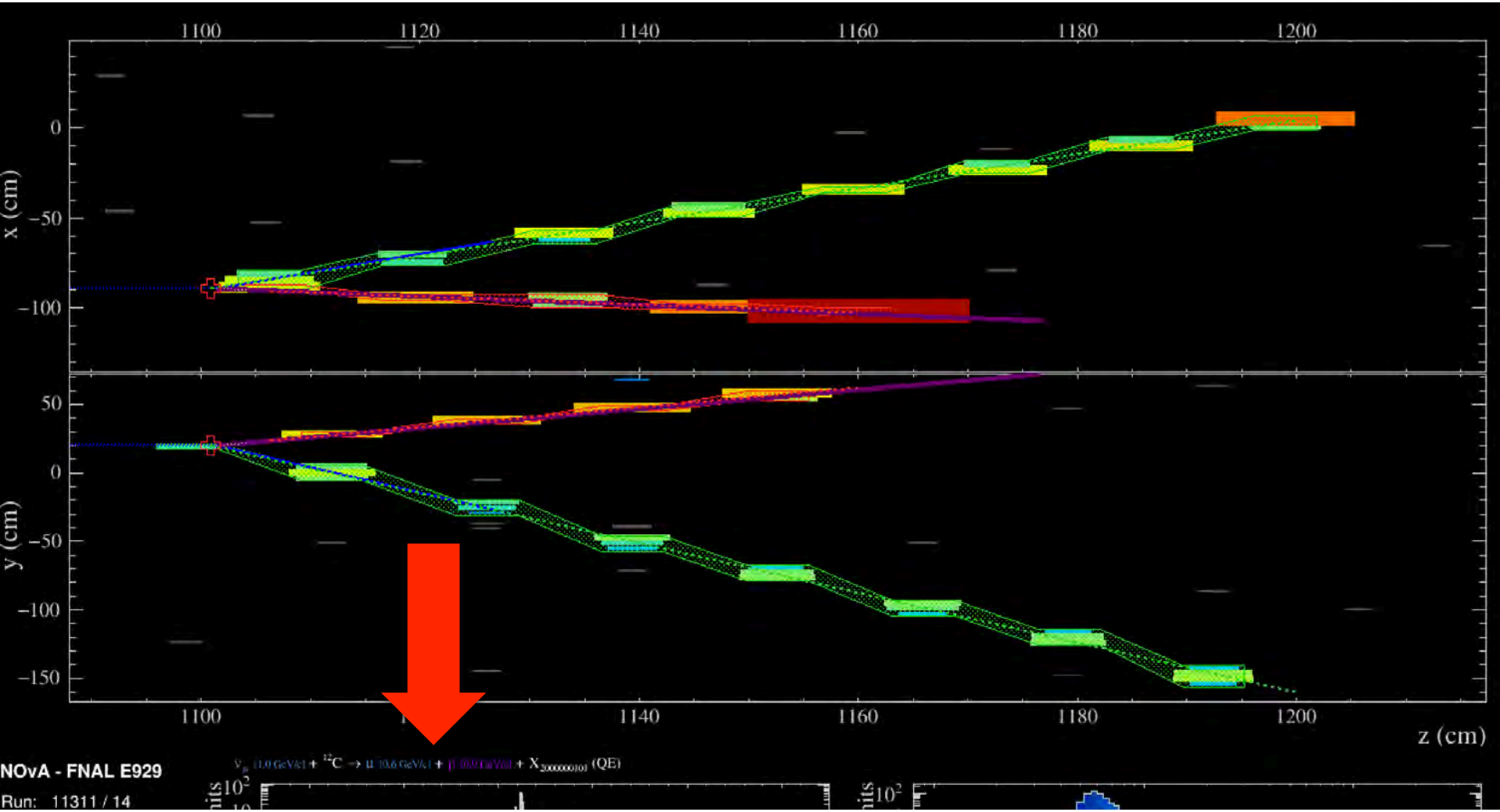
- Hand-Scanned Event Displays to select “Golden Events” to be run through prong-based CVN to analyze its behavior
- 6000 Events Scanned and 610 “Golden Events” Selected
- Investigations included:
  - True ID vs. Reco ID by particle
  - Confidence Factor (CVN ID) of Correctly Reconstructed Particles
  - Purity of True Particles
  - Efficiency of Reconstructions with respect to: Initial Neutrino Energy and Number of Hits within Prong
  - “Golden Events” compared to all simulated events
- Near Detector Monte Carlo Simulated Files
  - neardet_genie_nonswap_nogenierw_fhc_v08_2000_r00011311_s14_c000_R16-03-03-prod2reco.a_v1_20160308_092614_sim.pidpart.root
  - neardet_genie_nonswap_nogenierw_fhc_v08_2000_r00011294_s10_c001_R16-03-03-prod2reco.a_v1_20160308_092614_sim.reco.root
  - neardet_genie_nonswap_nogenierw_fhc_v08_2000_r00011302_s22_c002_R16-03-03-prod2reco.a_v1_20160308_082112_sim.reco.root

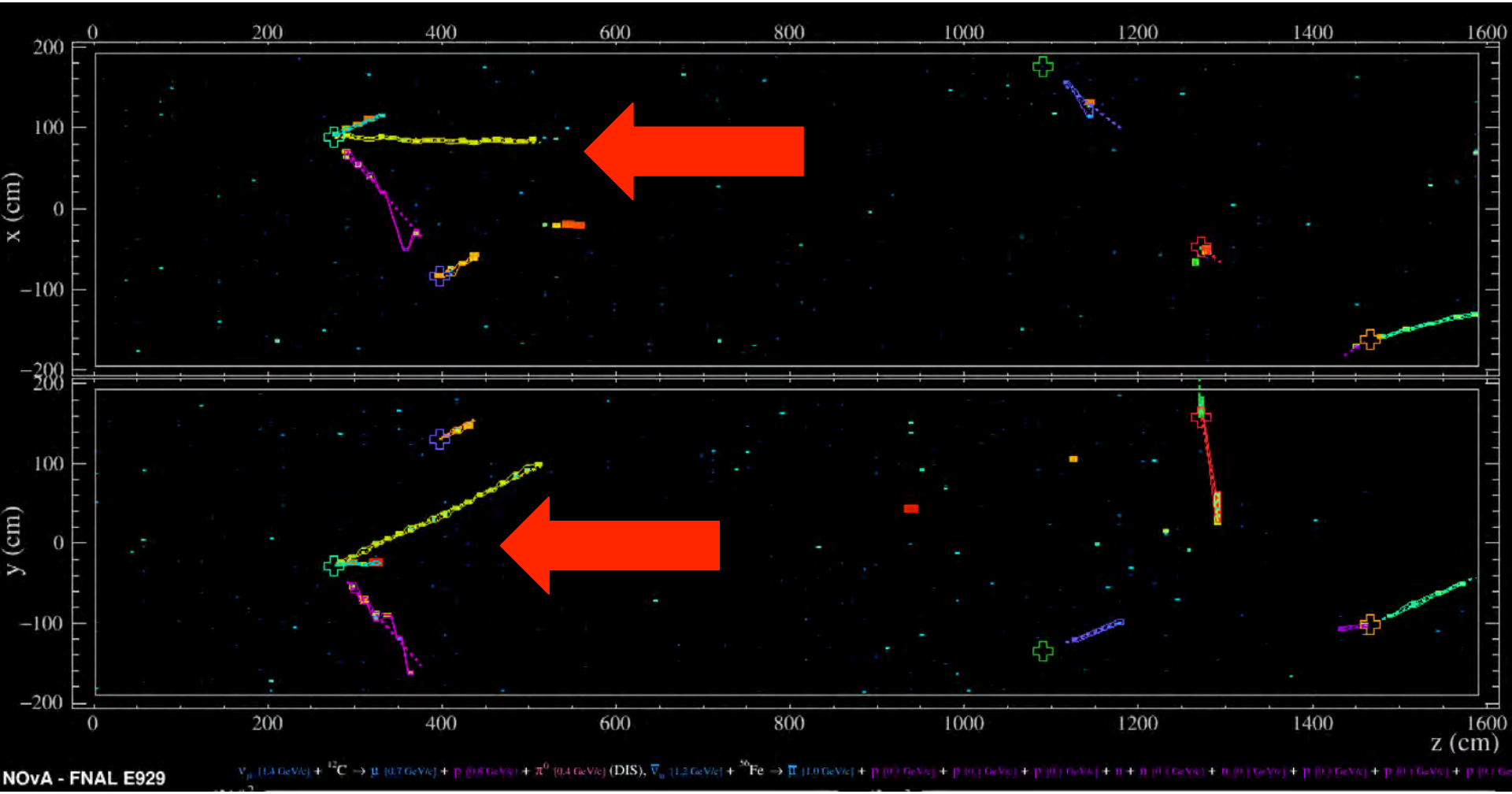
CVN: docdb 14692 and 14670

Hand-Scan Prong CVN Study

- Criteria for Classifying "Golden Events"
  - Energy of neutrino must be < 4.0 GeV
  - Hits and Prongs must be completely confined within the detector
  - Reconstruction must have distinct Proton / Lepton Prongs
  - Reconstructed Vertex must align with the Simulated Vectors
  - Reconstructed Prongs must match Simulated Vectors and Text
- Slices that were made for the Plots include
  - Slice Energy must be between 0.5 – 5.0 GeV
  - Prong Energy must be greater than 0.1 GeV


0
200
400
600
800
1000
1200
1400
1600
200
100
0
−100
−200
x (cm)
y (cm)
z (cm)
NOvA - FNAL E929


1100
1120
1140
1160
1180
1200
x (cm)
0
−50
−100
y (cm)
50
0
−50
−100
−150
z (cm)
NOvA - FNAL E929
Run: 11311 / 14


0
200
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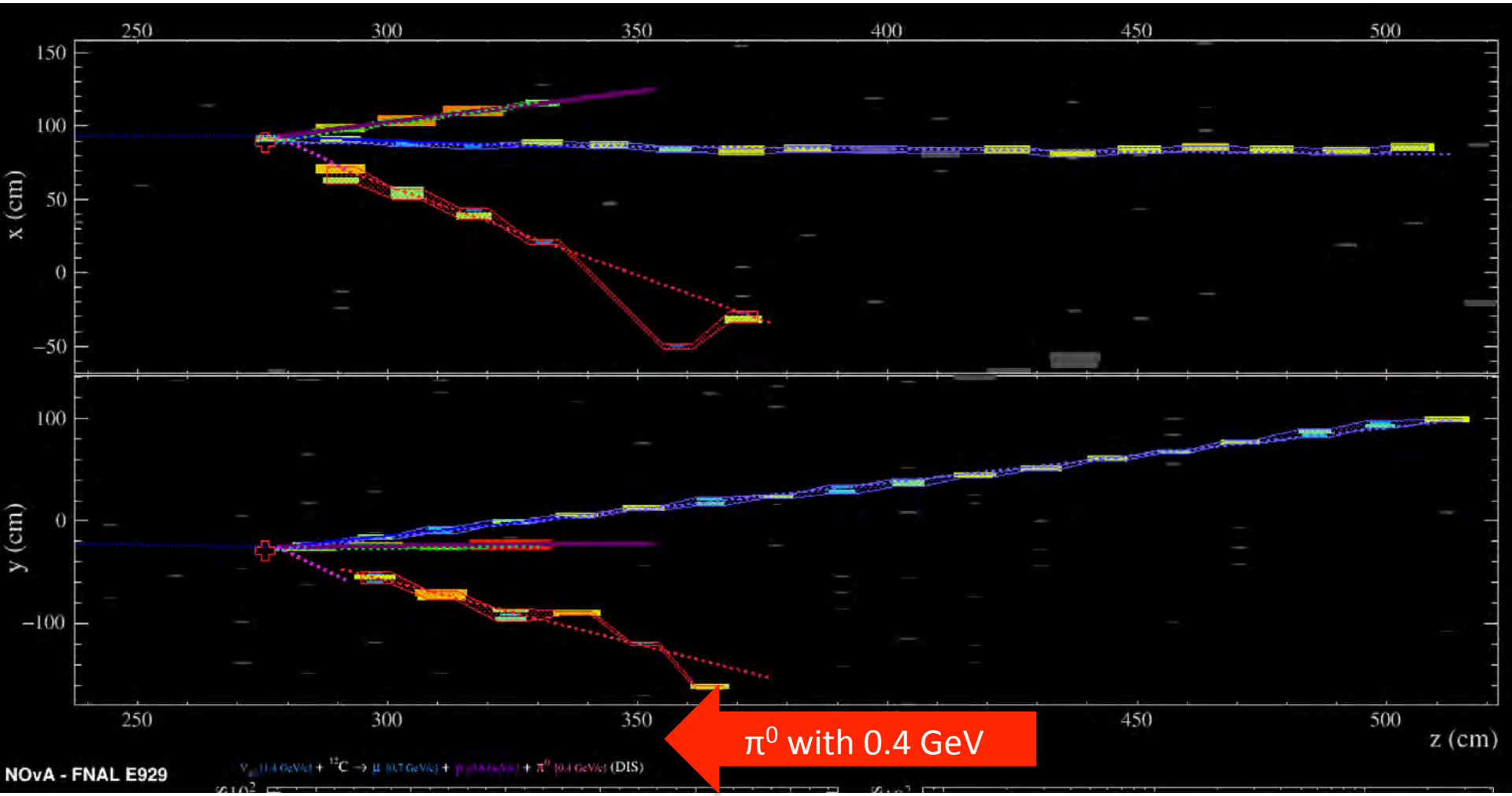
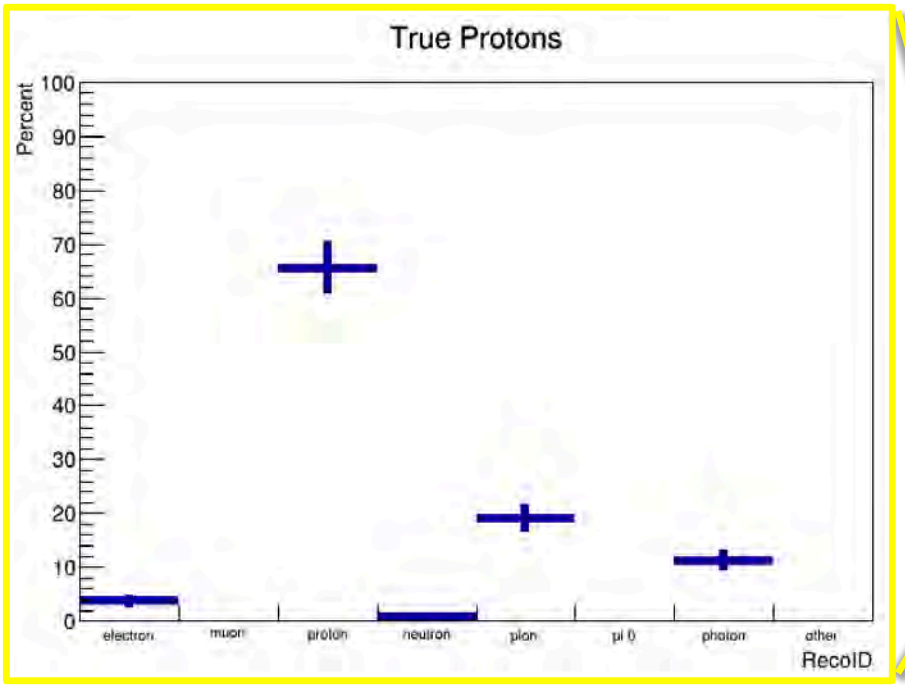
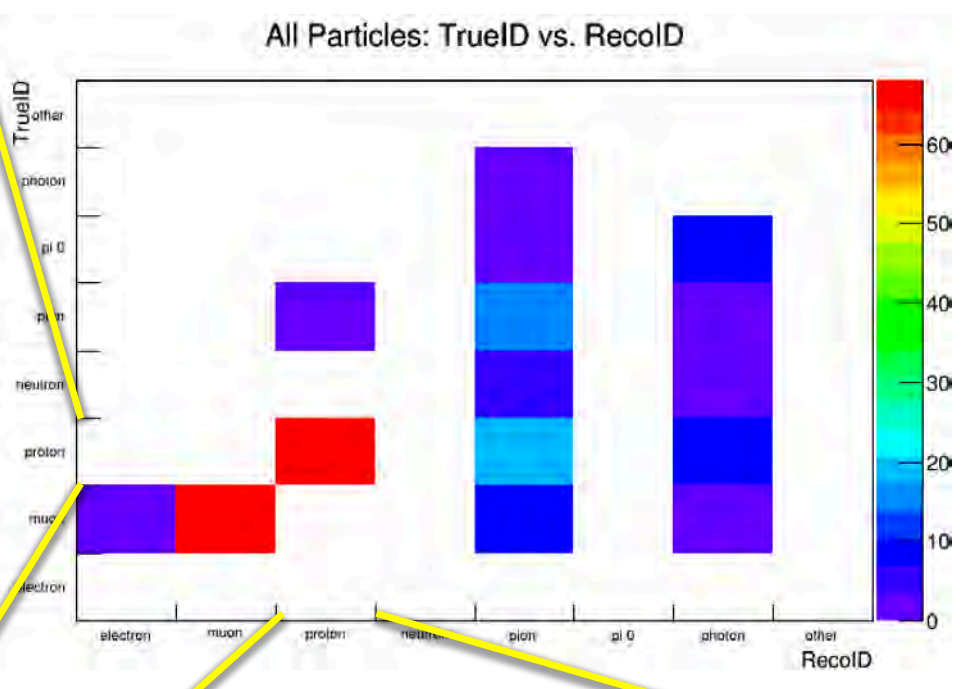
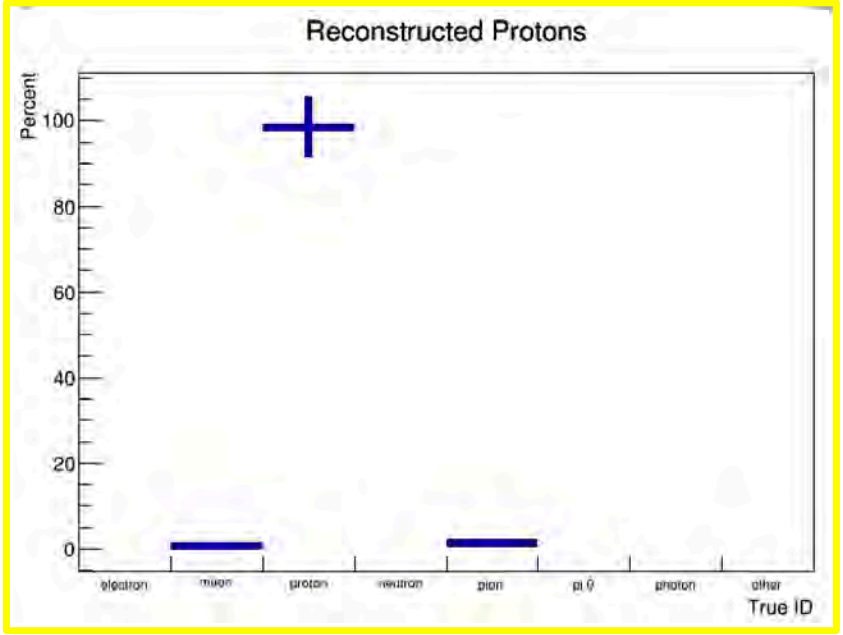
600
800
1000
1200
1400
1600
200
100
0
−100
−200
x (cm)
y (cm)
z (cm)
NOvA - FNAL E929

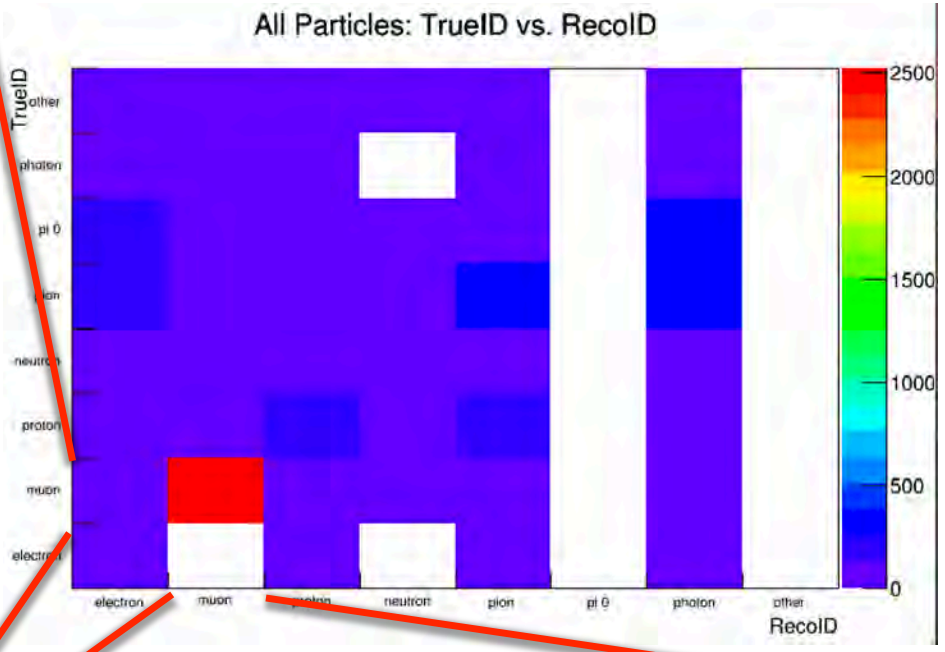

250
300
350
400
450
500
150
100
50
0
−50
x (cm)
100
0
−100
y (cm)
z (cm)
NOvA - FNAL E929
π^0 with 0.4 GeV



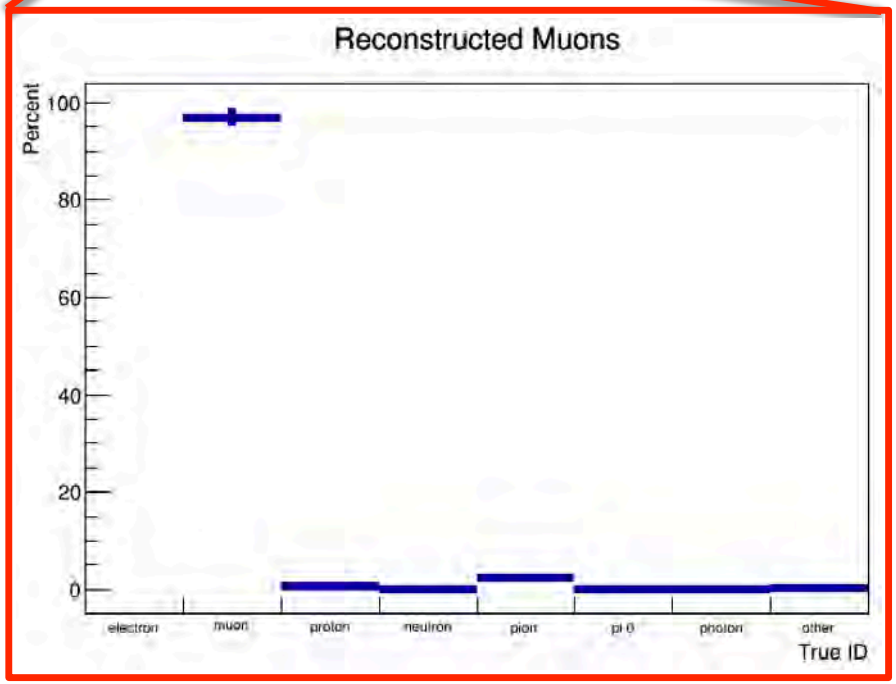


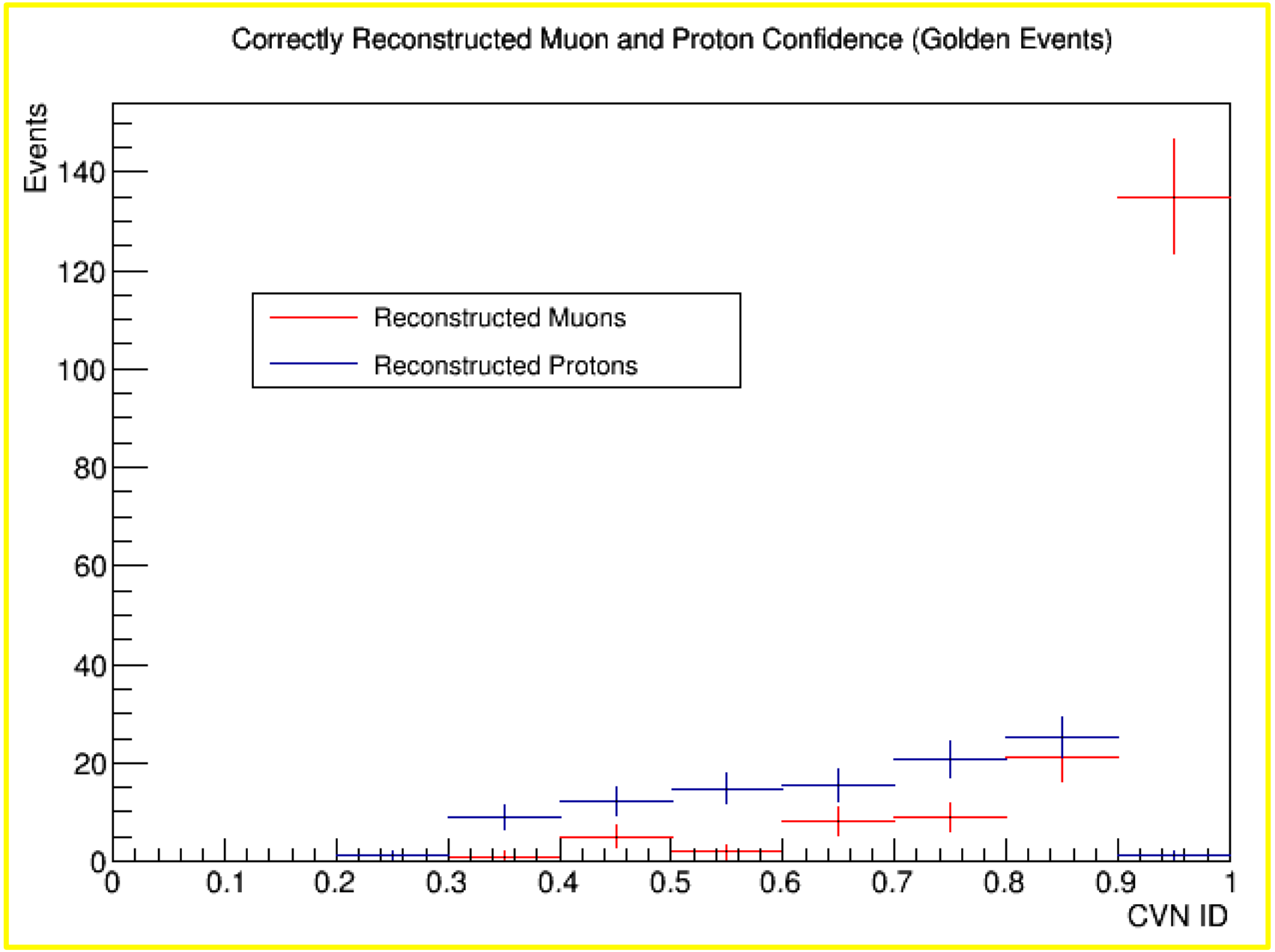
GOLDEN EVENTS PROTONS

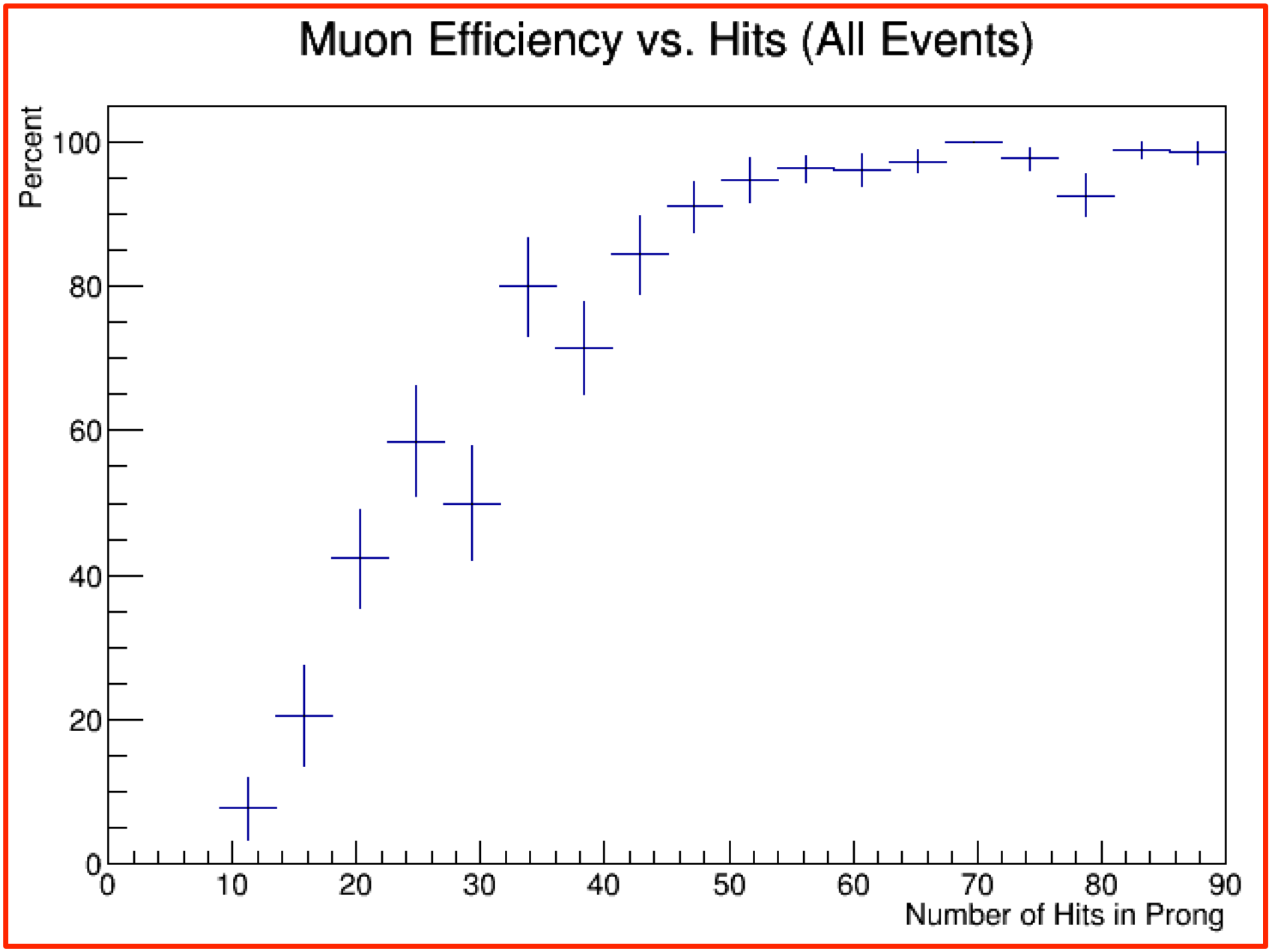


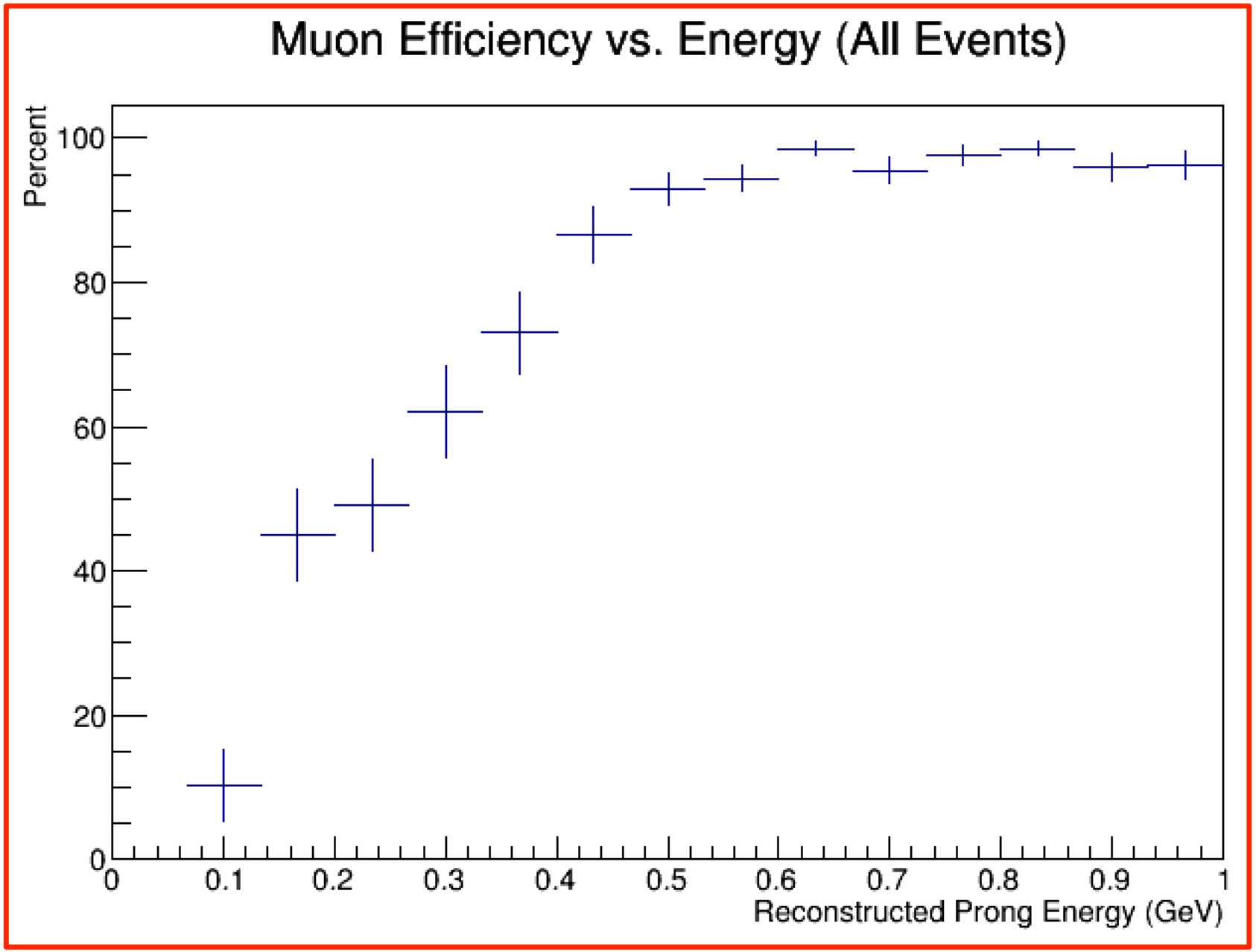


ALL EVENTS MUONS




Correctly Reconstructed Muon and Proton Confidence (Golden Events)
Events
140
120
100
80
60
40
20
0
Reconstructed Muons
Reconstructed Protons
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
CVN ID


Muon Efficiency vs. Hits (All Events)
Percent
100
80
60
40
20
0
0
10
20
30
40
50
60
70
80
90
Number of Hits in Prong


Muon Efficiency vs. Energy (All Events)
Percent
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Reconstructed Prong Energy (GeV)

How my experiences this Summer will impact my teaching…

- Science research requires collaboration – Physicists at Fermilab are CONSTANTLY meeting to discuss their findings and how to proceed from there
- Physics is not just about doing labs – scientists must have effective communication skills both in speaking and writing
- Research must be unbiased – results are not “good” or “bad,” but they can be compared to what was expected
- New ideas and content are best received when they are explained patiently, with multiple teaching approaches, from different angles, and in terms that make sense to learner

Acknowledgments:

- Thank you to Alex Himmel, for sharing his office with me (and just about everyone else on the NOvA experiment when they have questions). I sincerely appreciate his willingness to use his very limited time teaching me about neutrinos and making sure that I really understand. I very grateful with his unparalleled patience for my confusion with histograms and how they are loaded!
- Thank you to Evan Niner for putting up with me slacking him all day, everyday, about ROOT, Linux, Ttrees, and histograms. I cannot begin to explain how much it meant to me that he not only gave me answers to my questions, but that he also took the time to explain why and how things work the way they do – even if I didn't really need to know to complete the task!
- Both Alex and Evan truly epitomize the ideal educator!
- Thank you to Harry and Pratima for dedicating their time and efforts into making the TRAC program so successful. I wholeheartedly believe that my unprecedented experiences this summer will carry over into my classroom which will, in turn, influence my students to pursue their education in STEM.

Sources:

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