Data Acquisition and Reconstruction Efficiency with the SBND Photon Detection System (PDS)

Lynn Tung

New Perspectives 2022

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FERMILAB-SLIDES-22-048-V

Introduction

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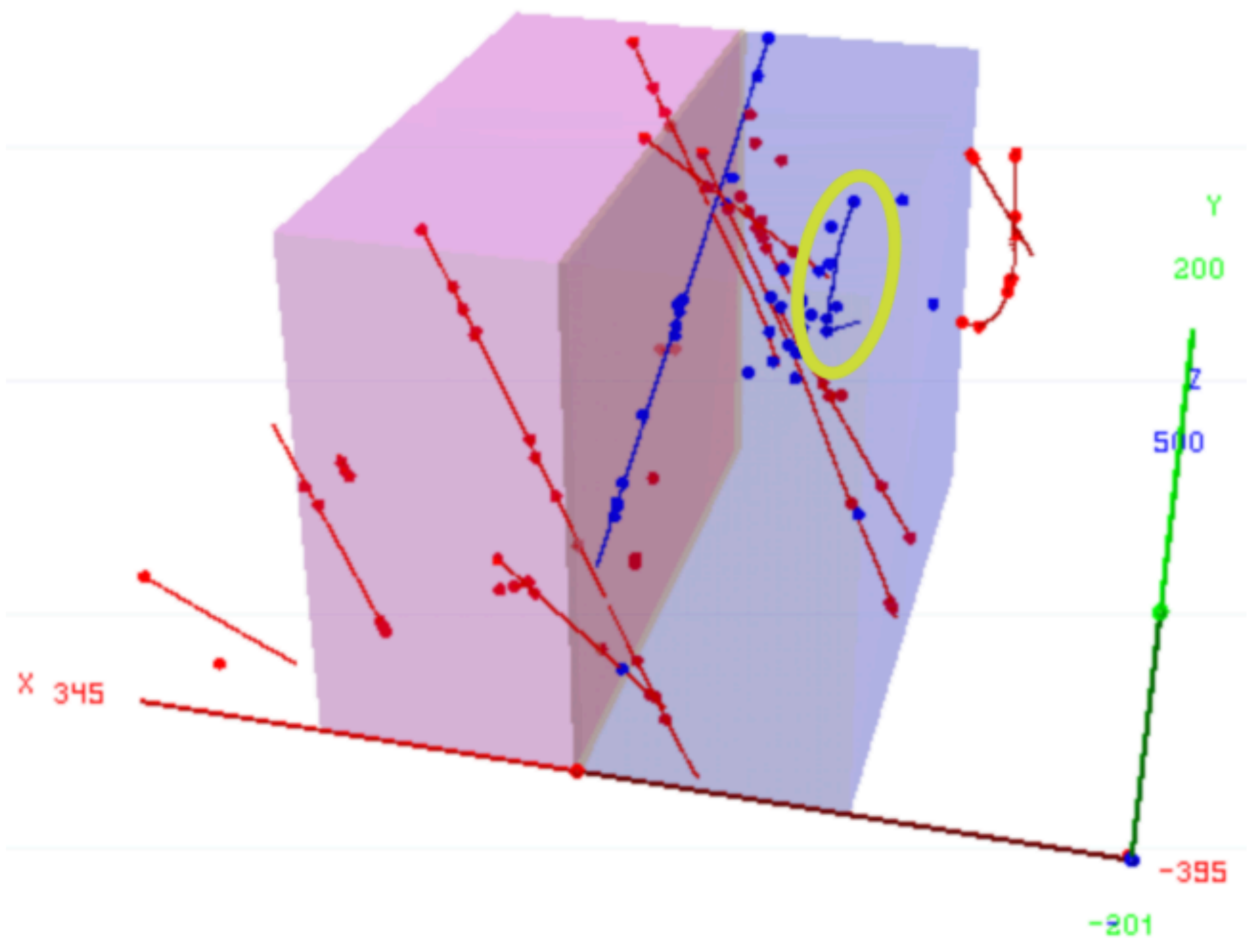
- **Challenge: How to find, identify, and analyze neutrino events? How to separate these from background?**



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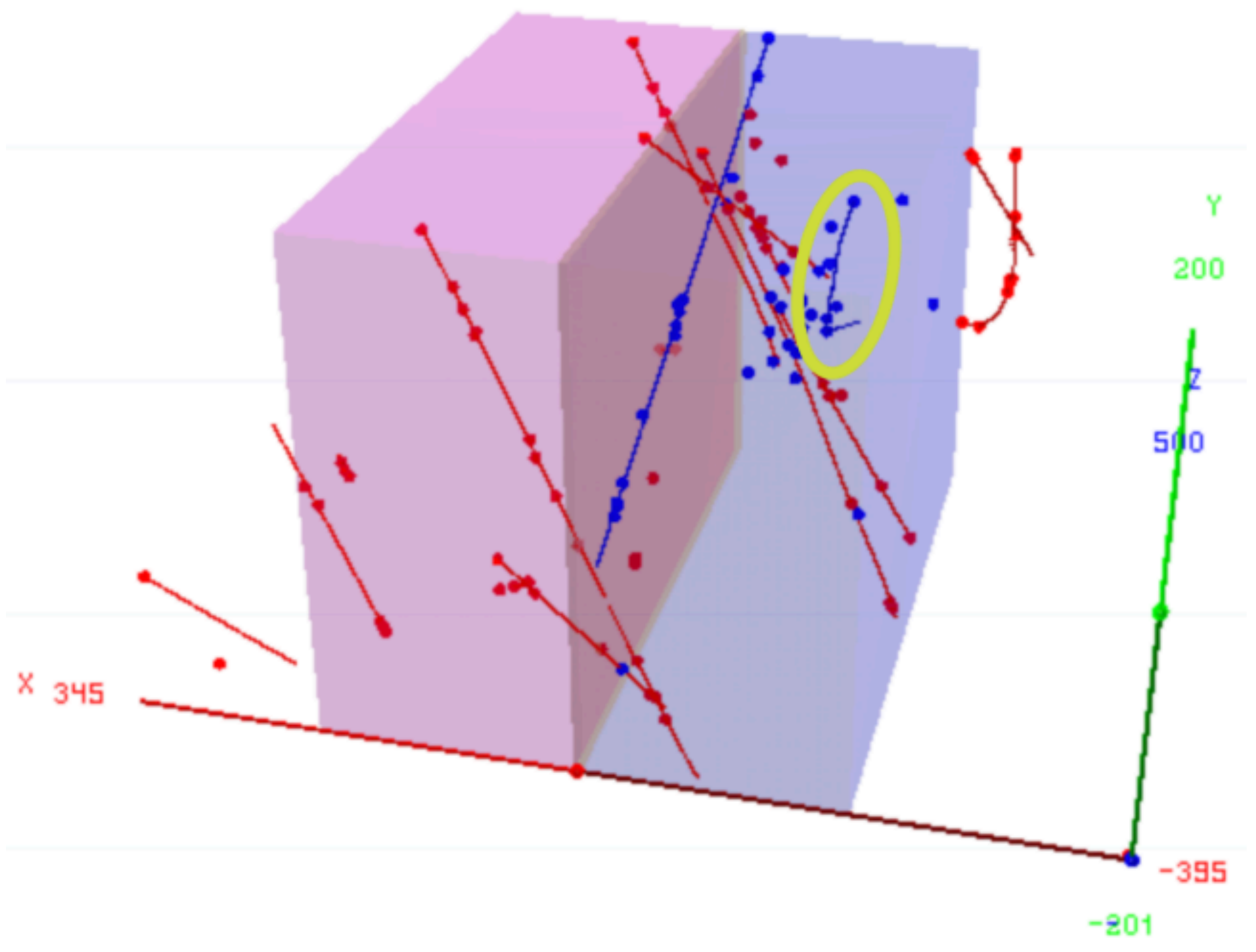
  - TPC readout: 3 ms



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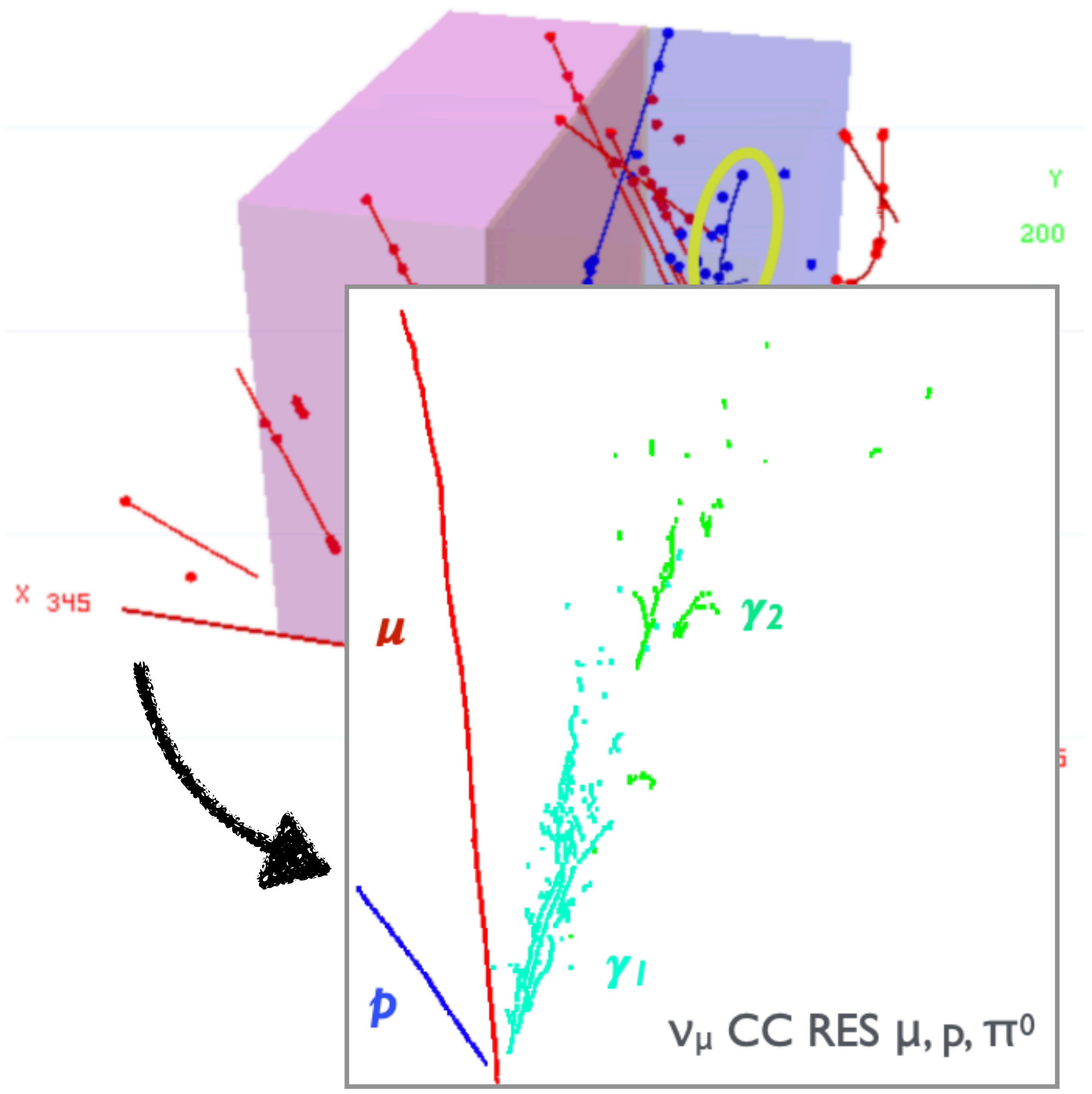

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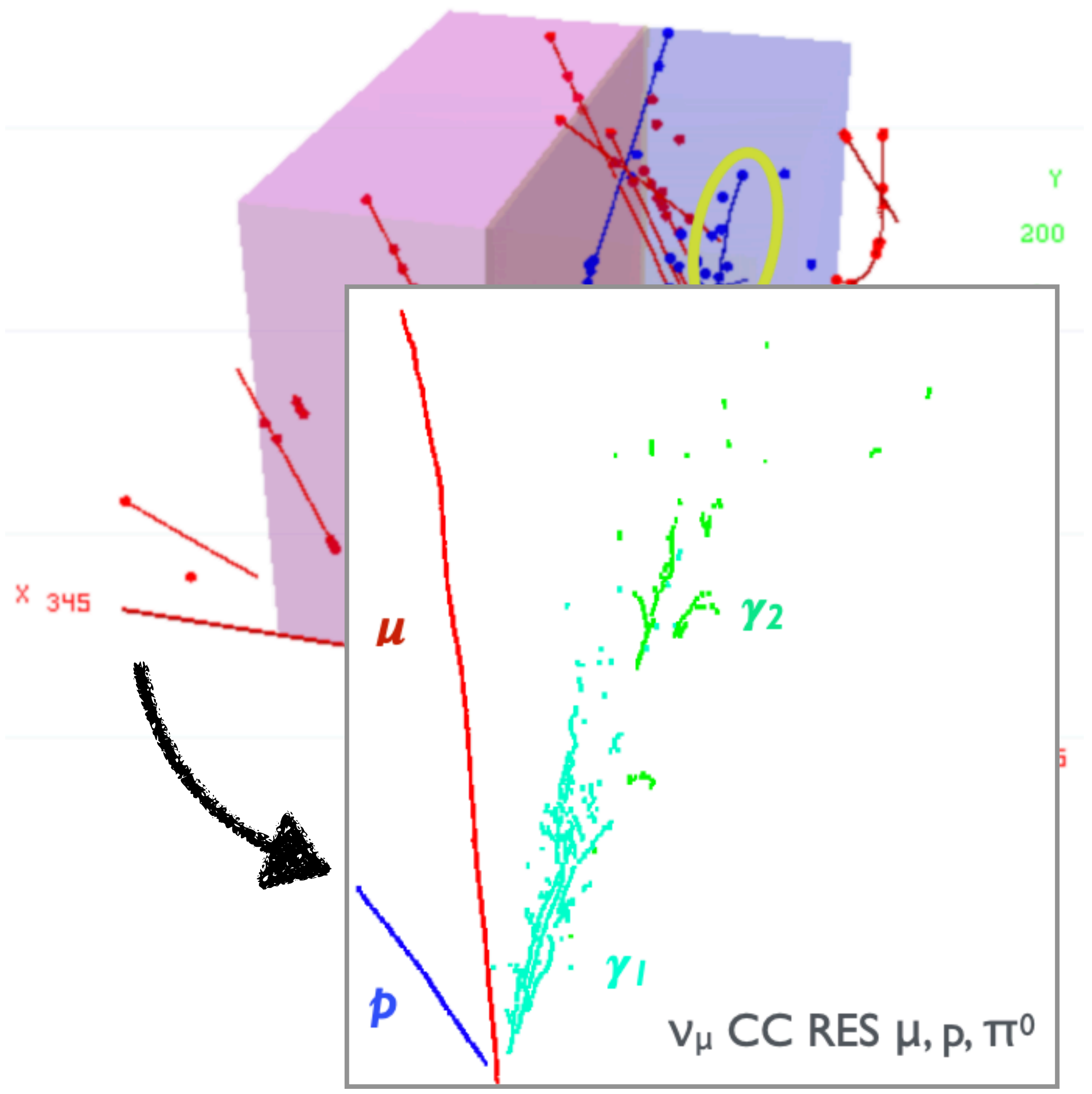

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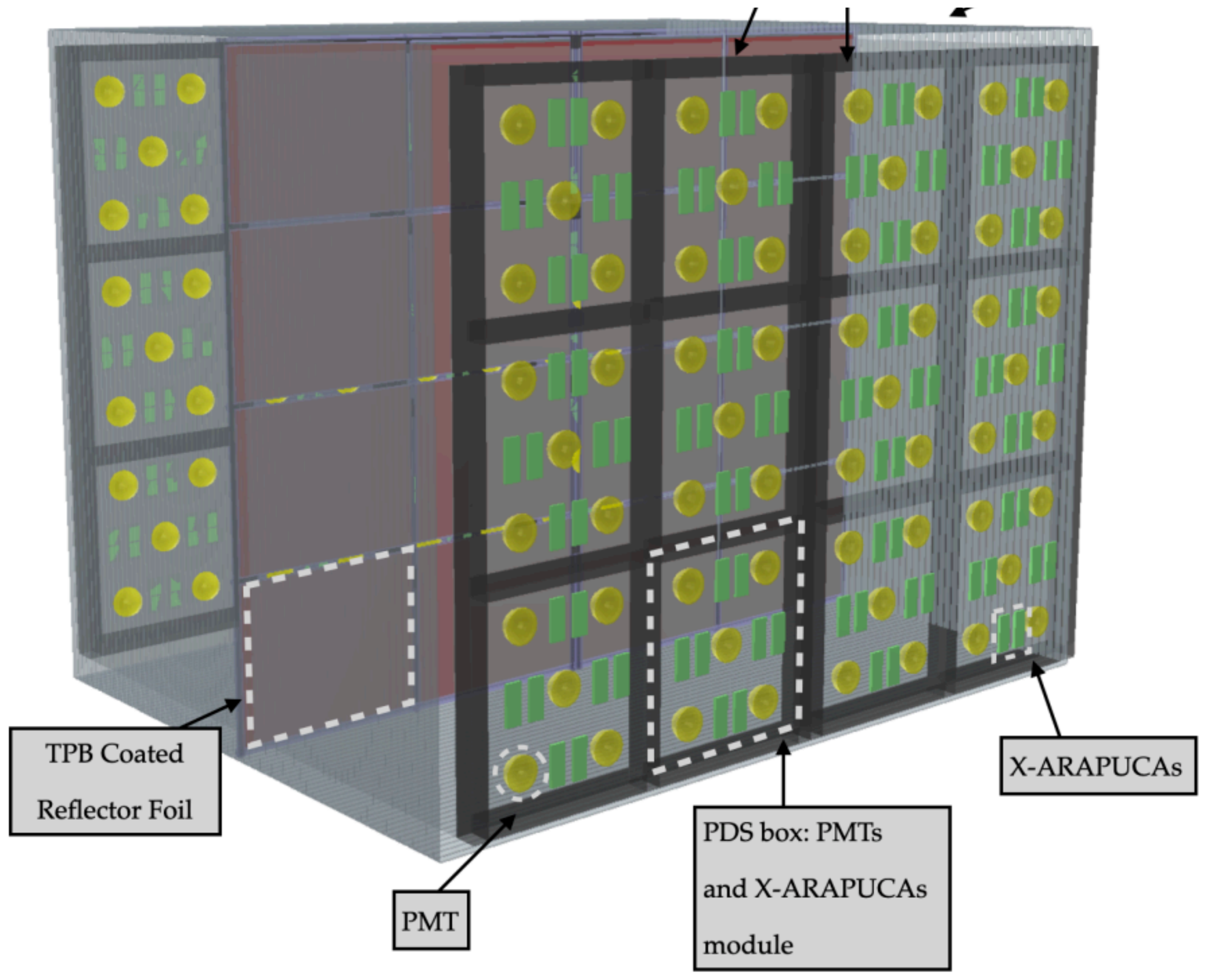

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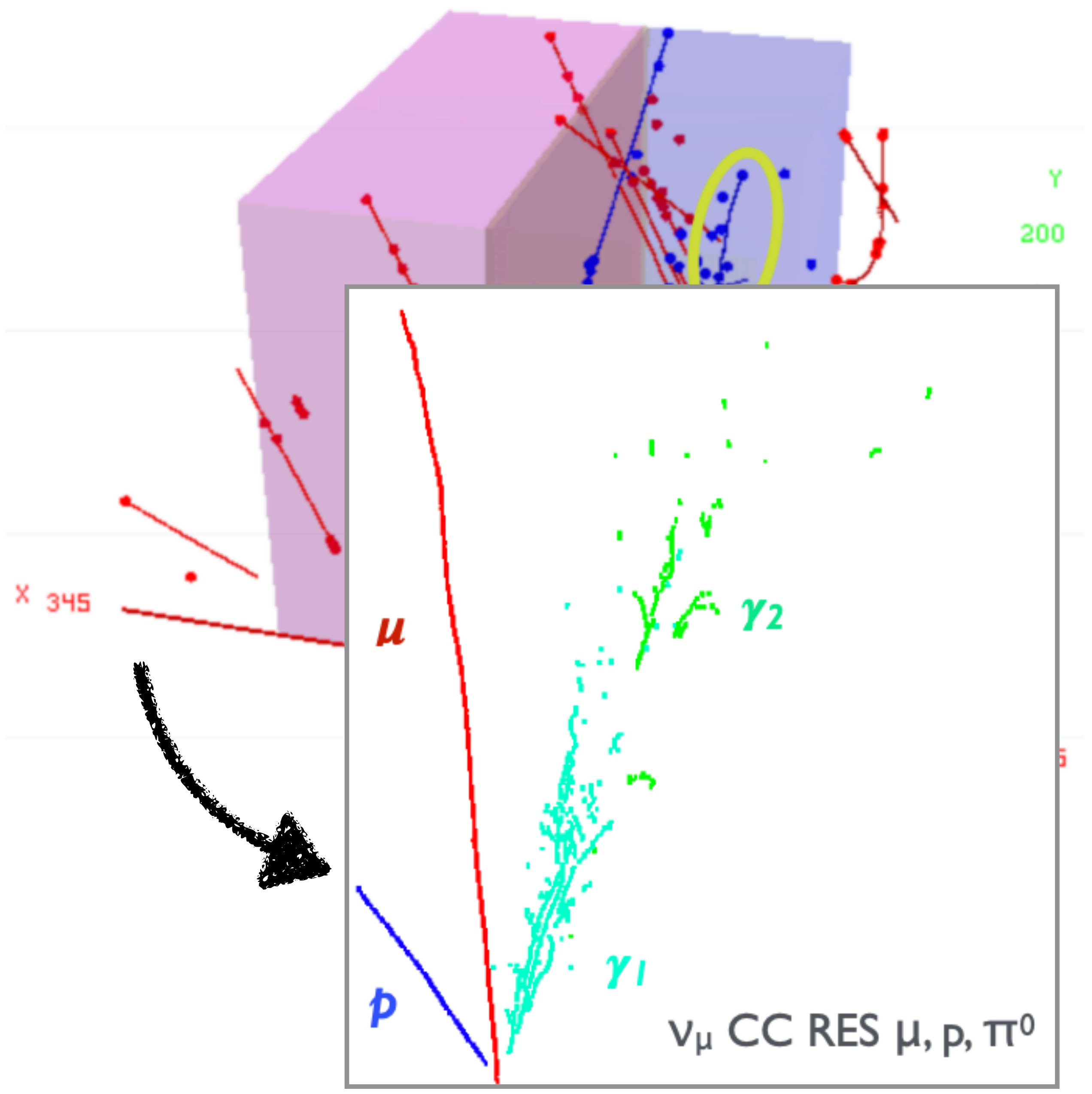

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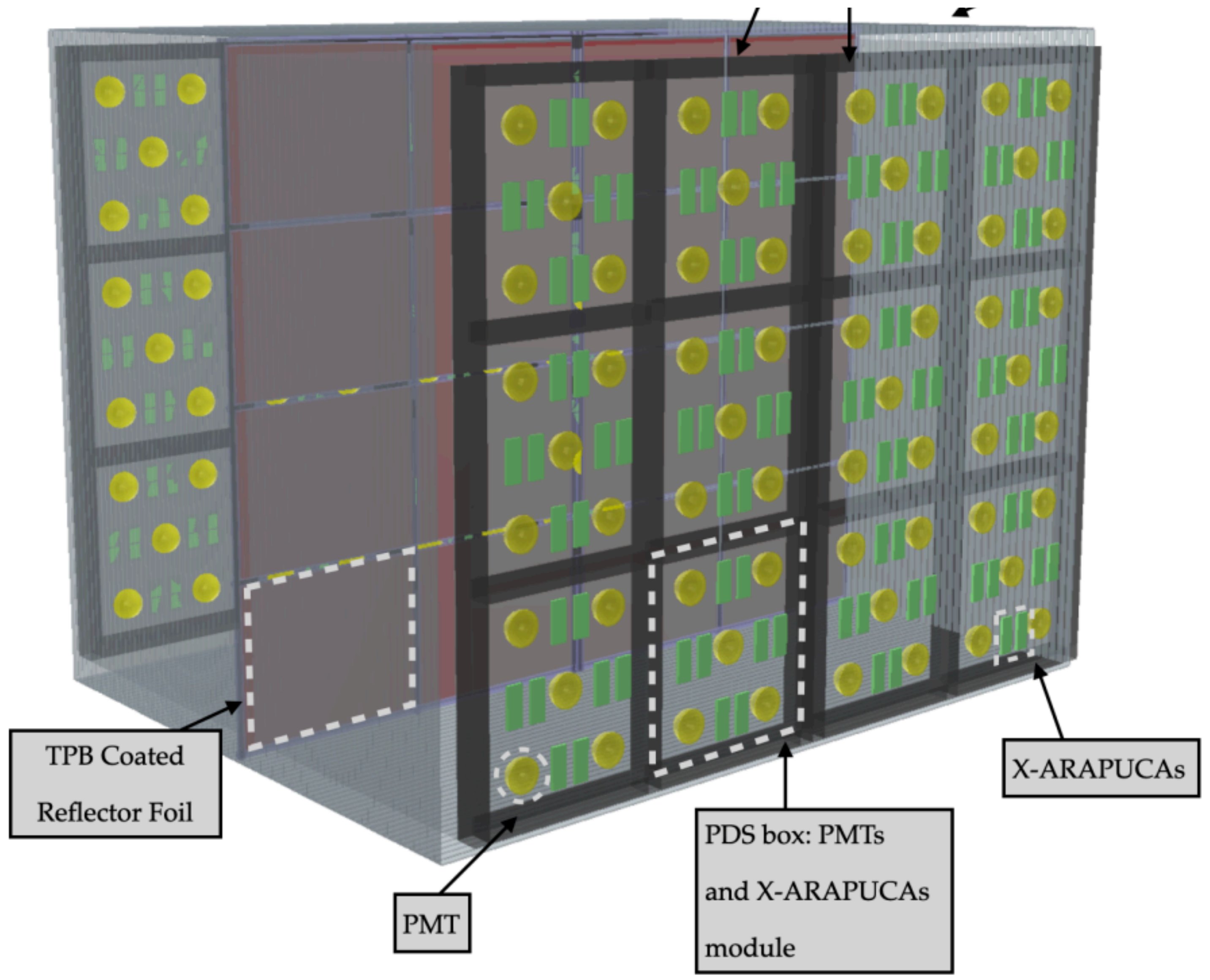

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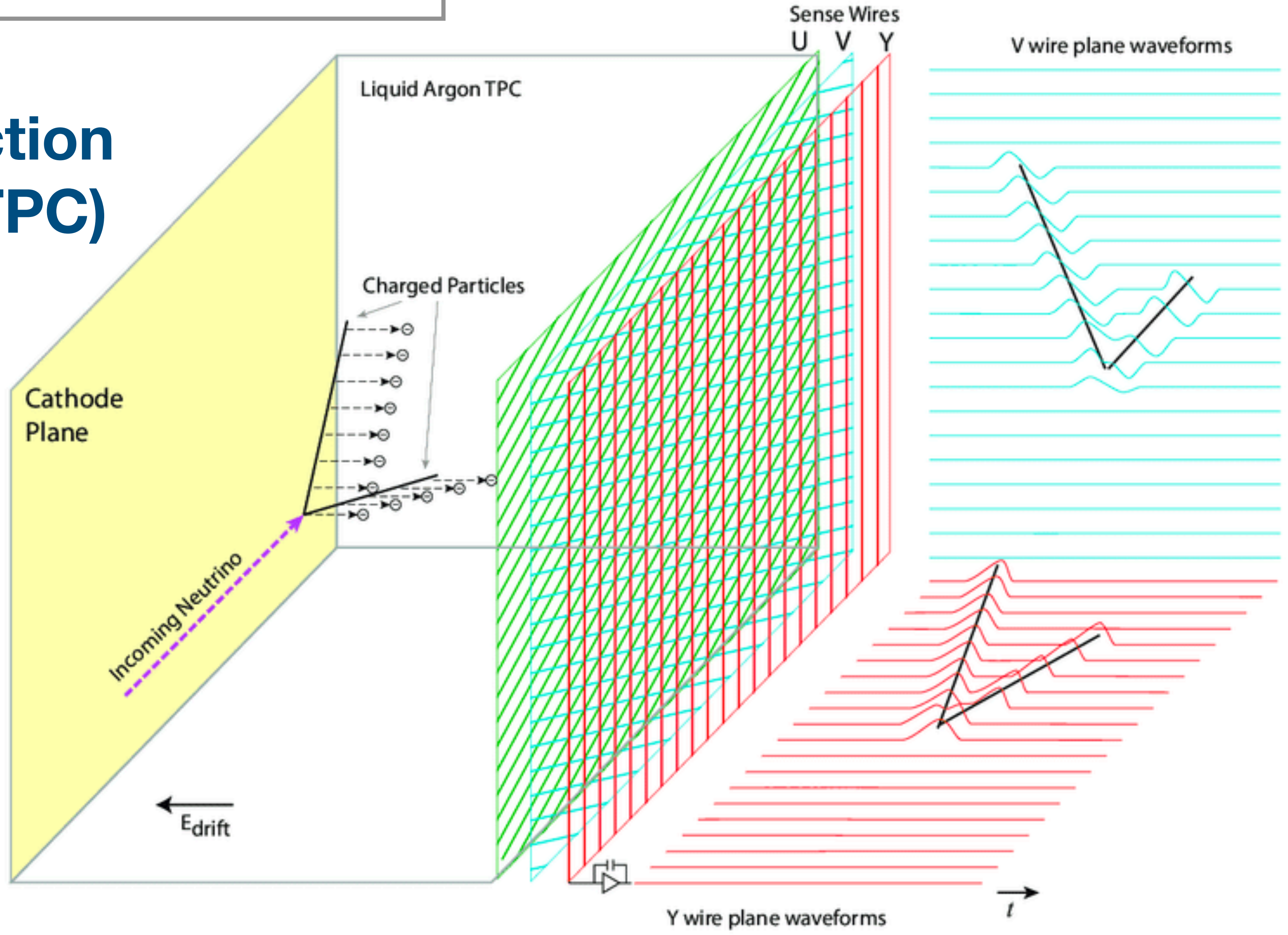

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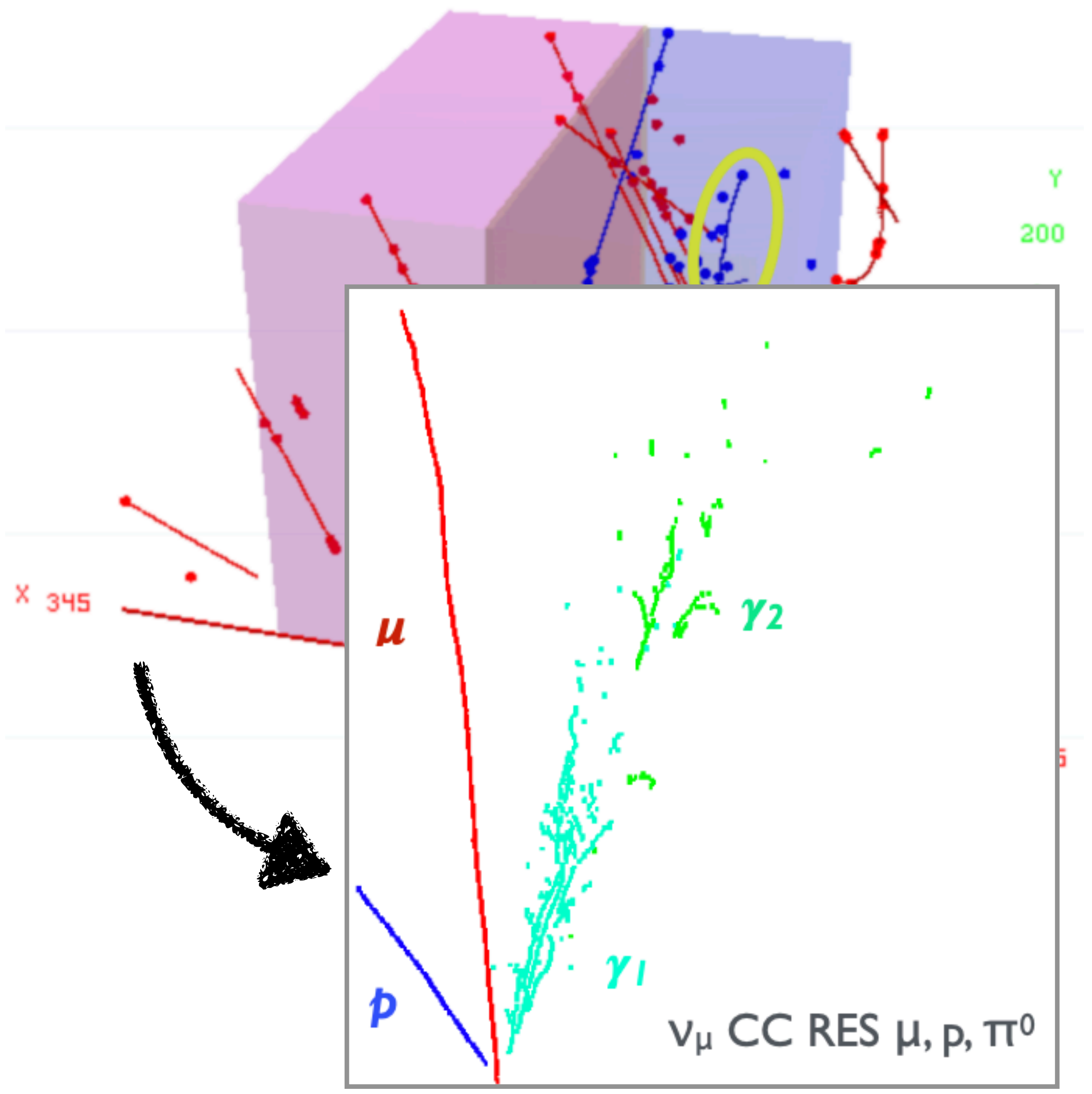

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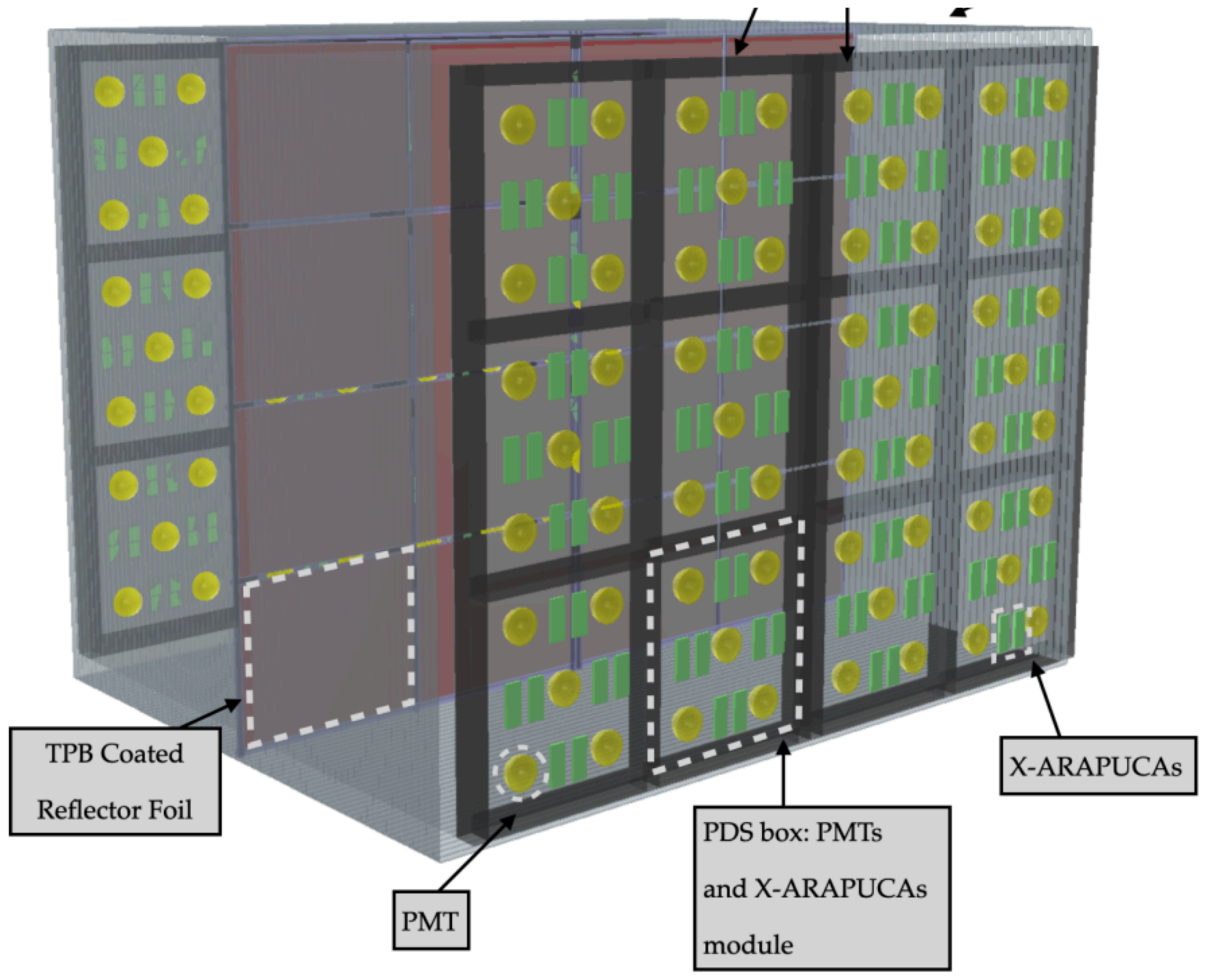

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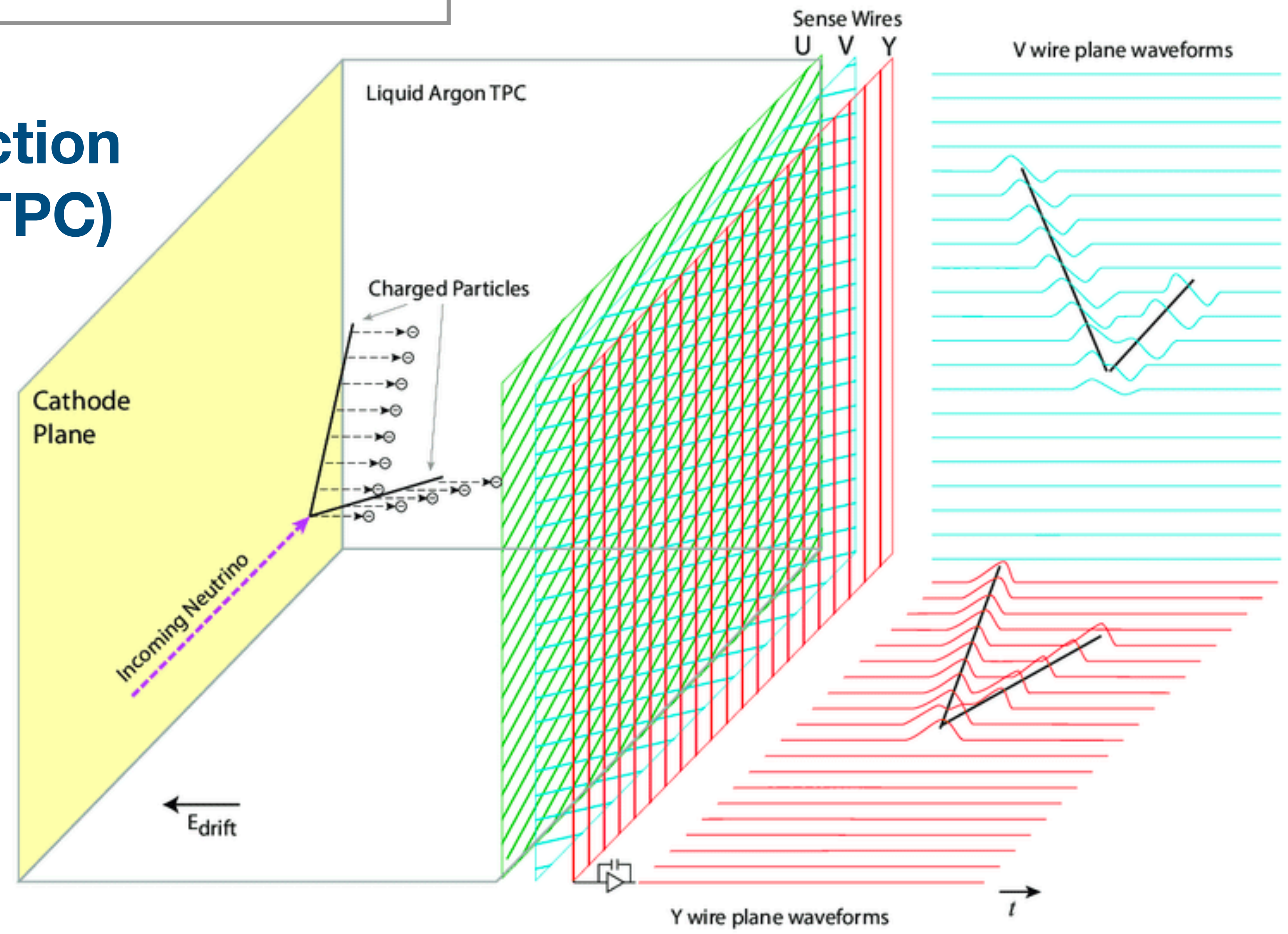

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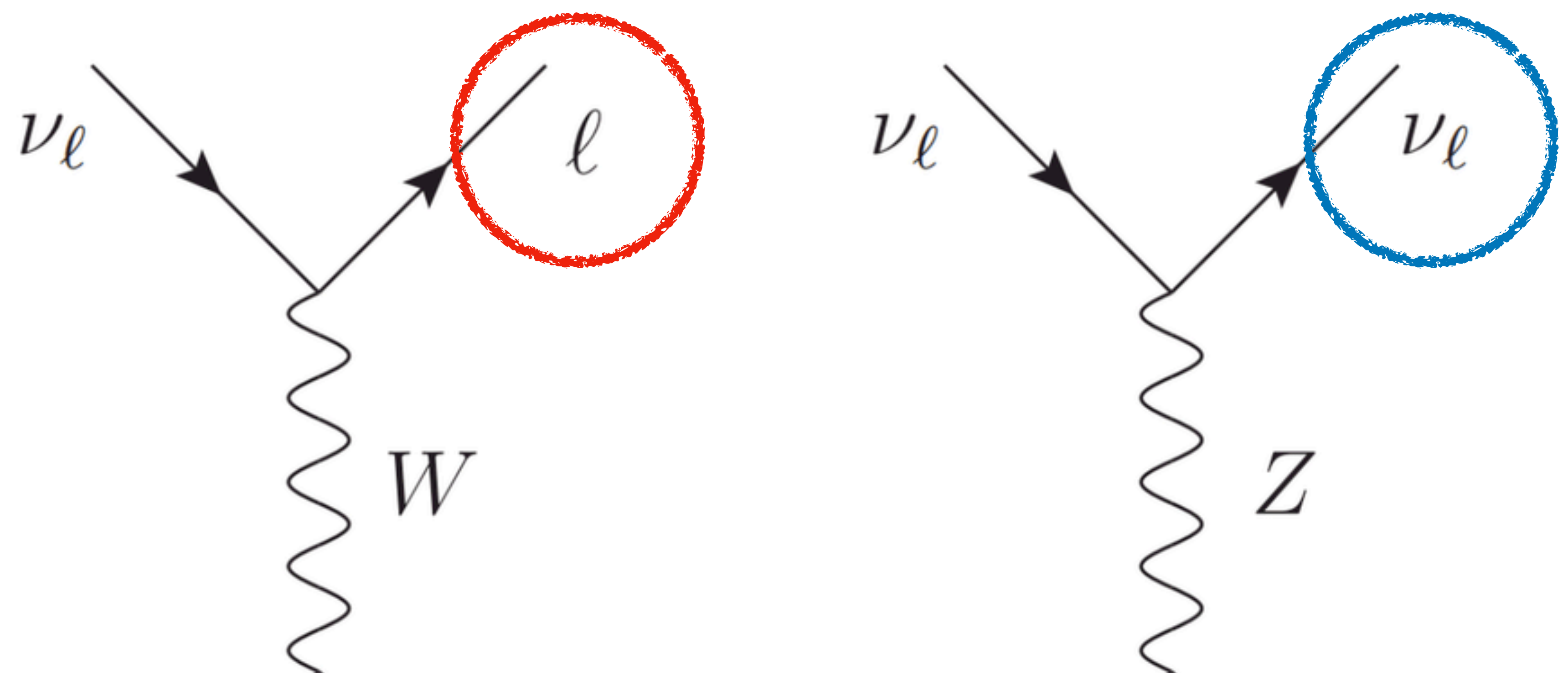
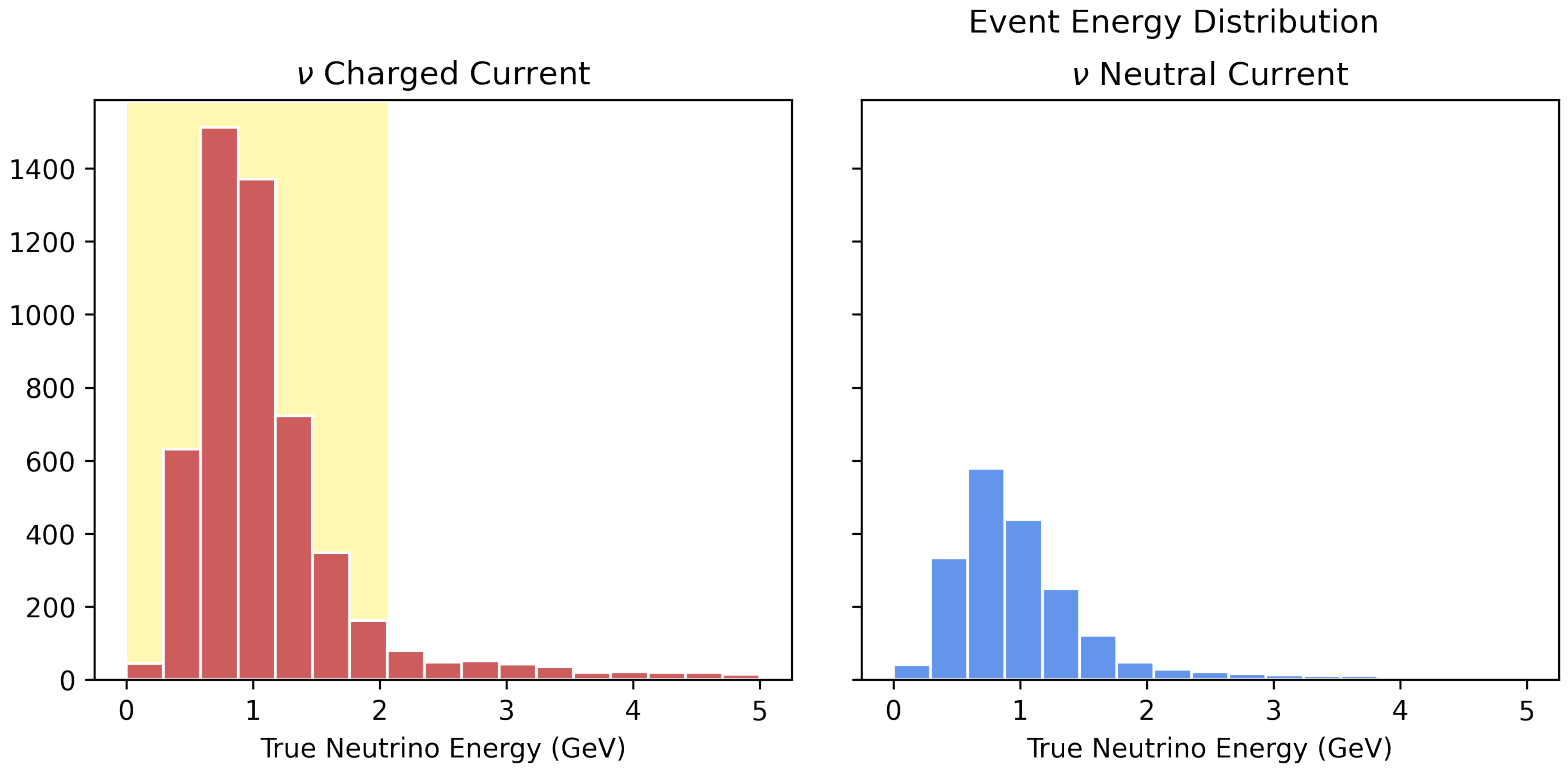


Charged Current (CC) **Neutral Current (NC)**



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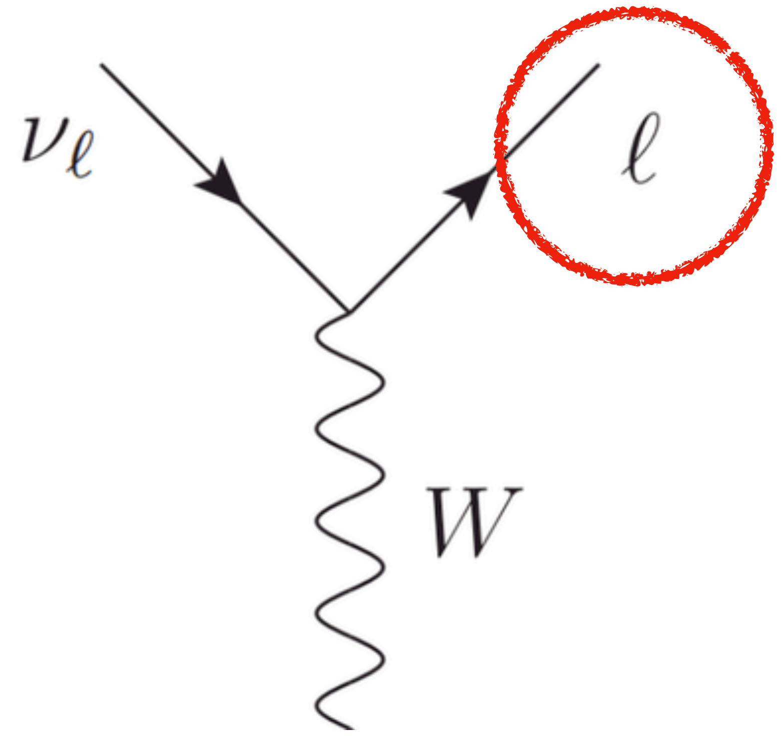
- **Cosmic Muons:** main background → can look like ν_μ CC event!

energy range discussed in this presentation

NC plots available in backup slides



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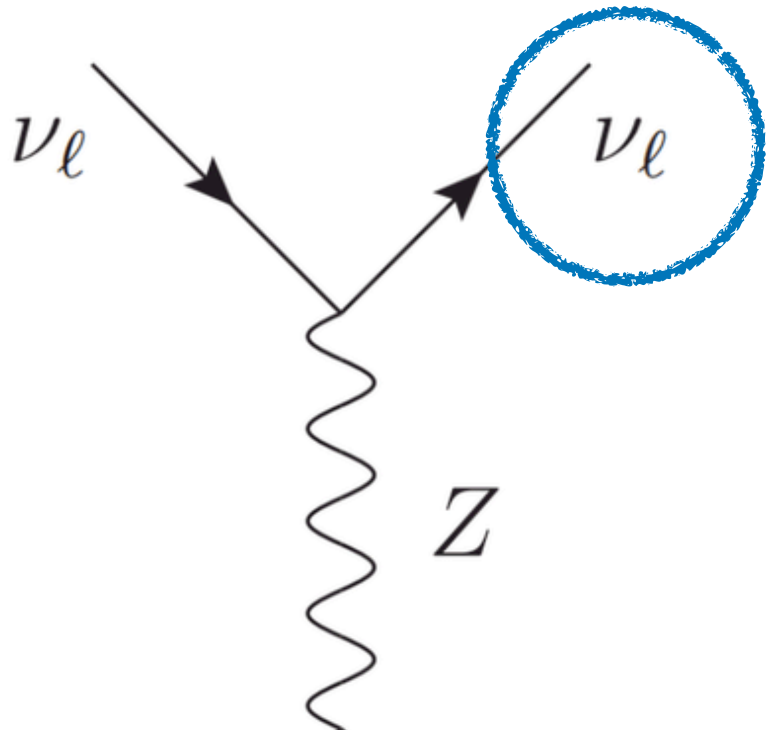

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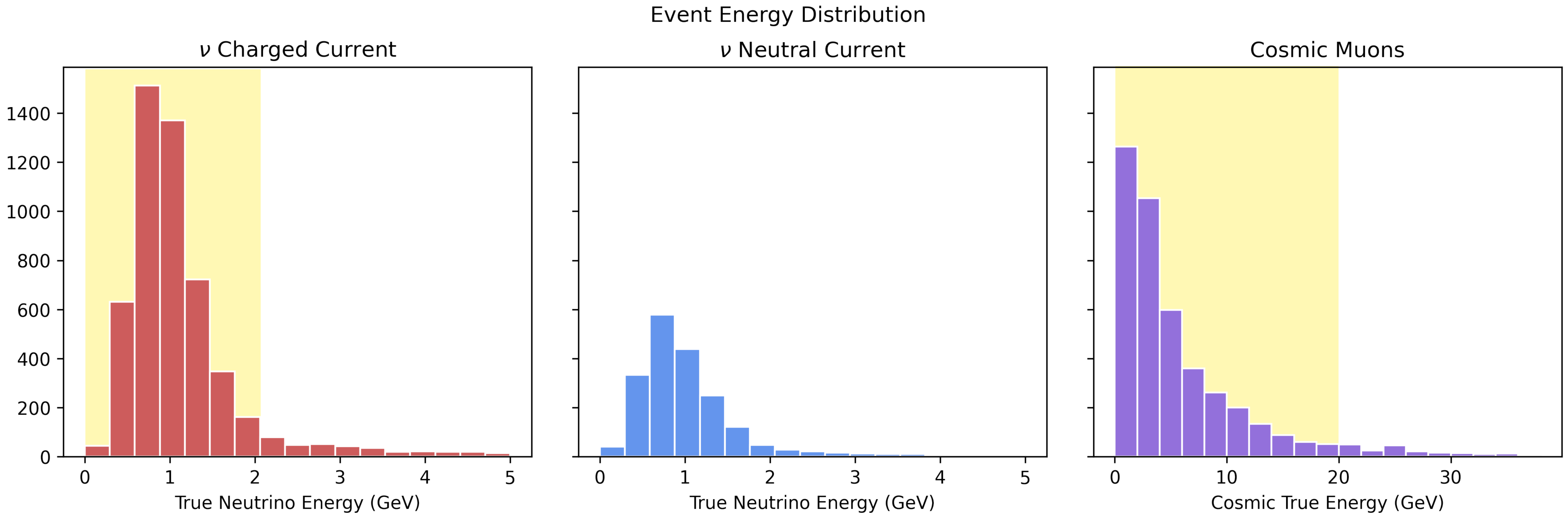

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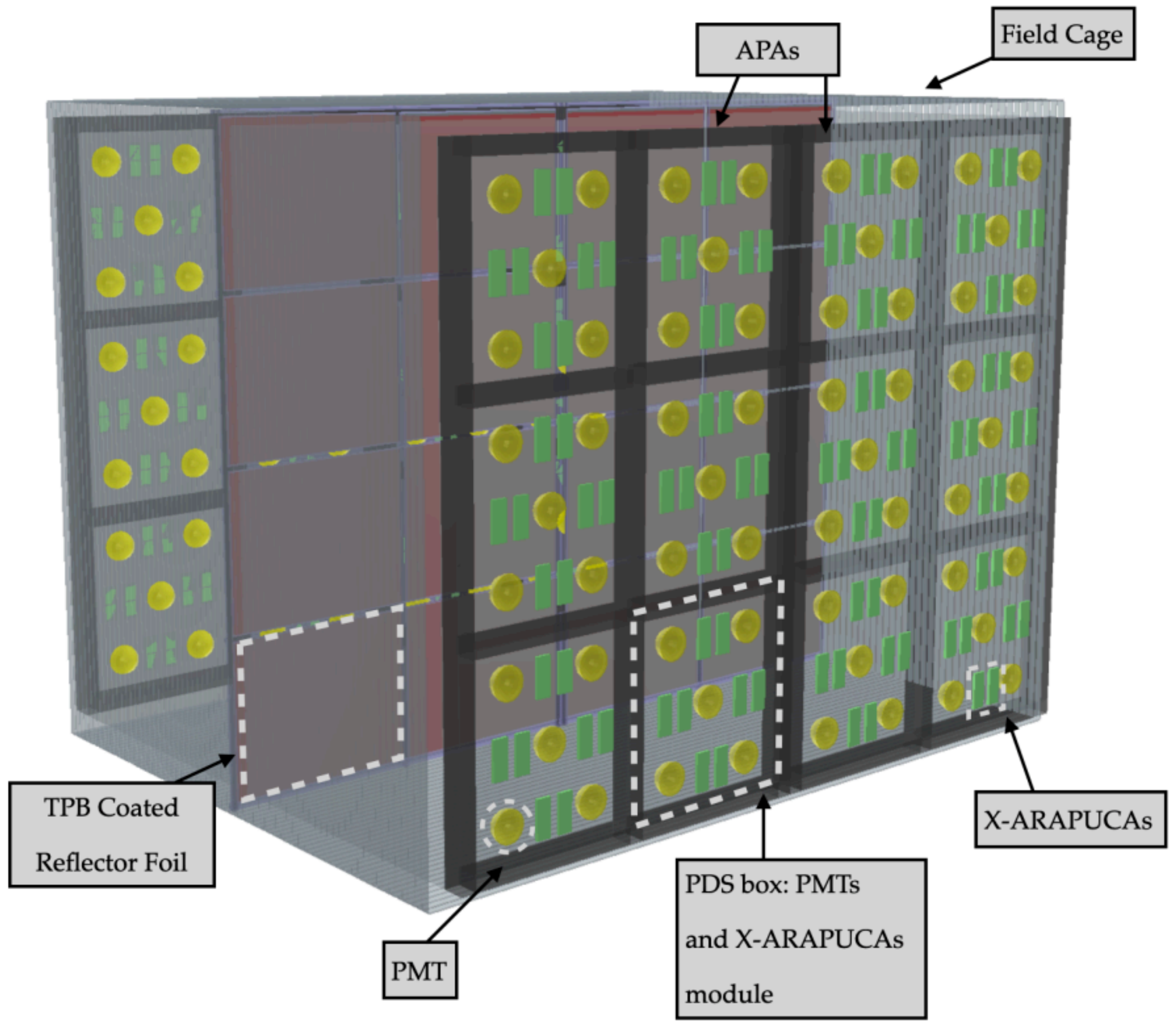
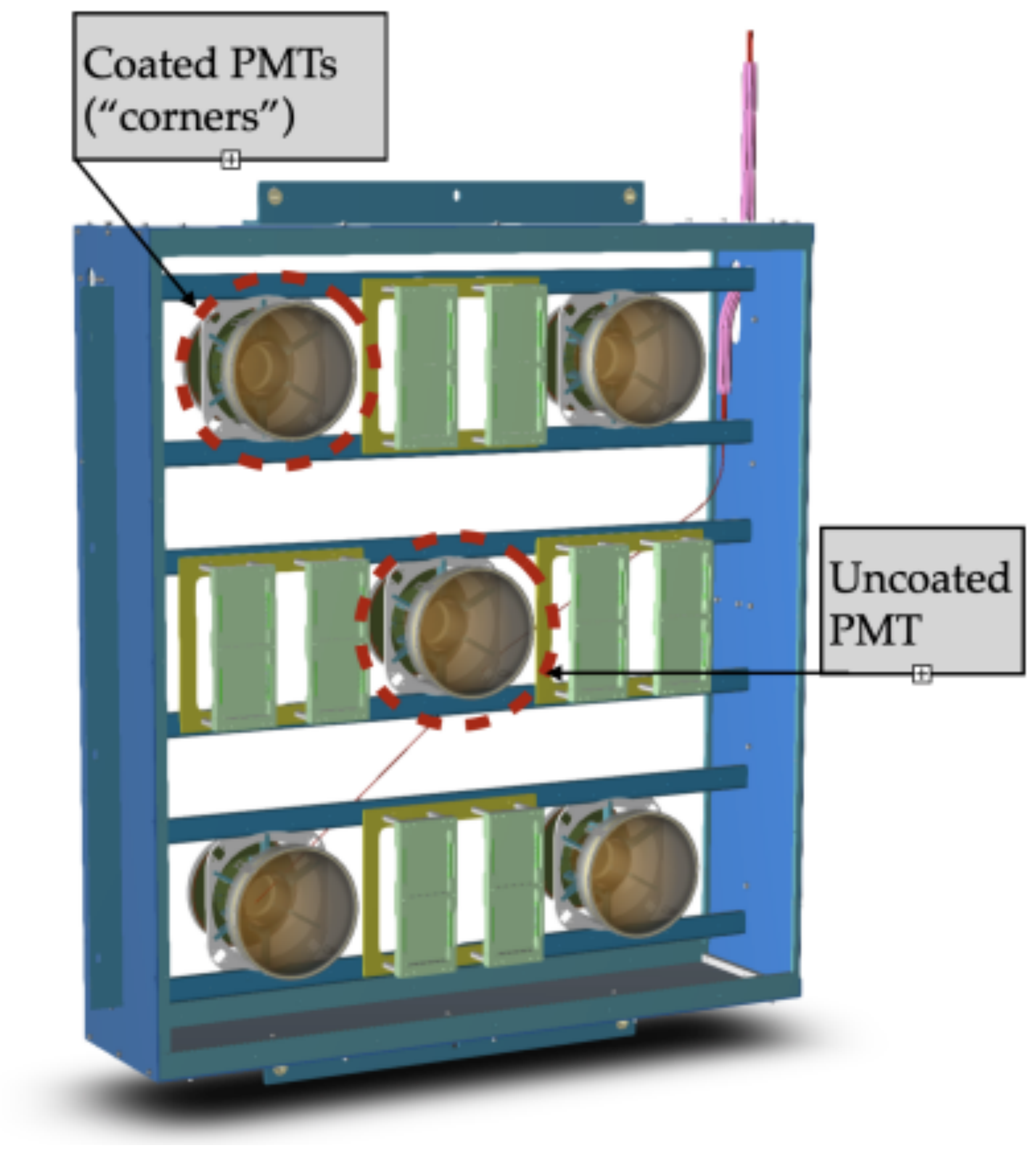


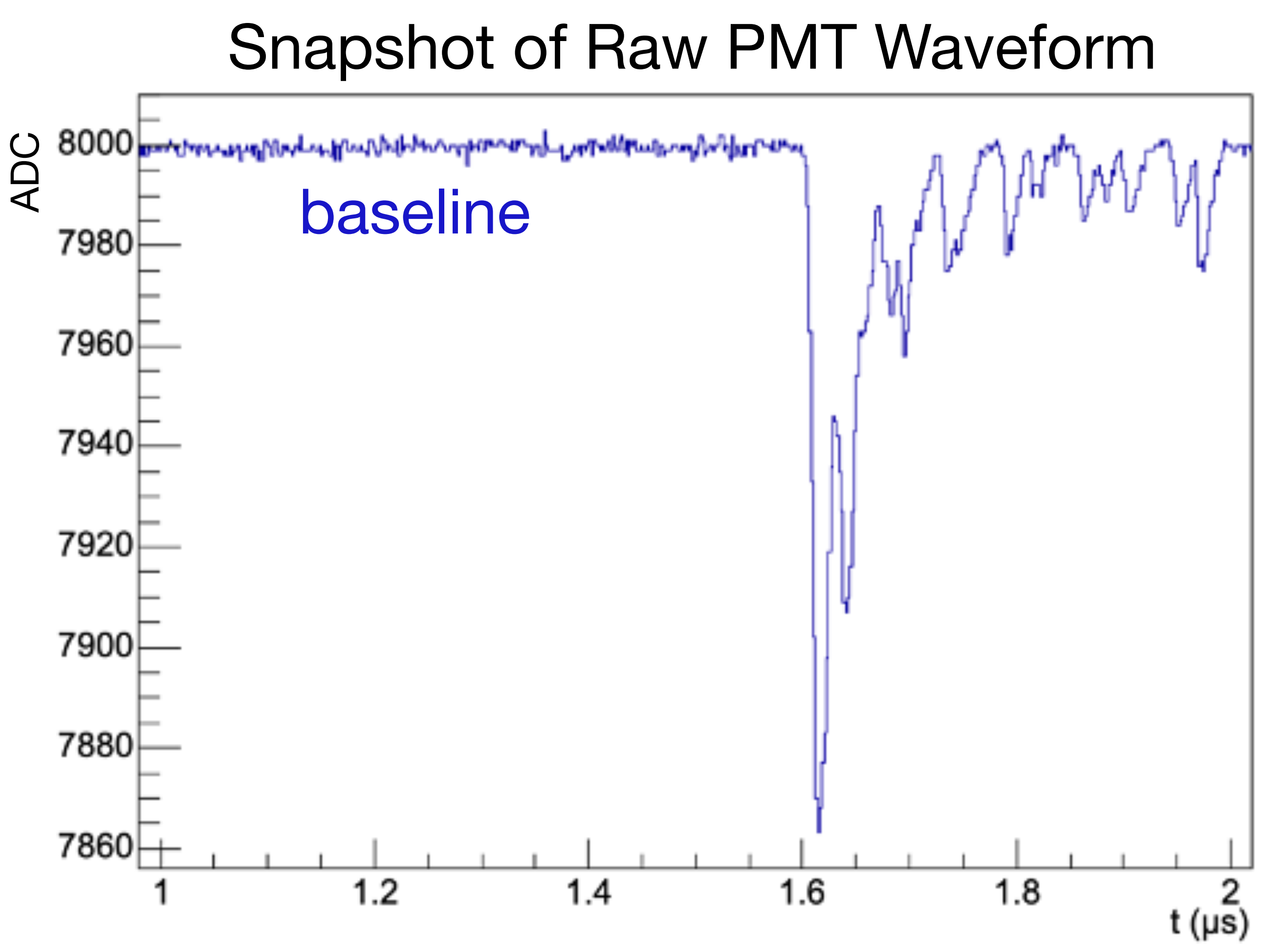


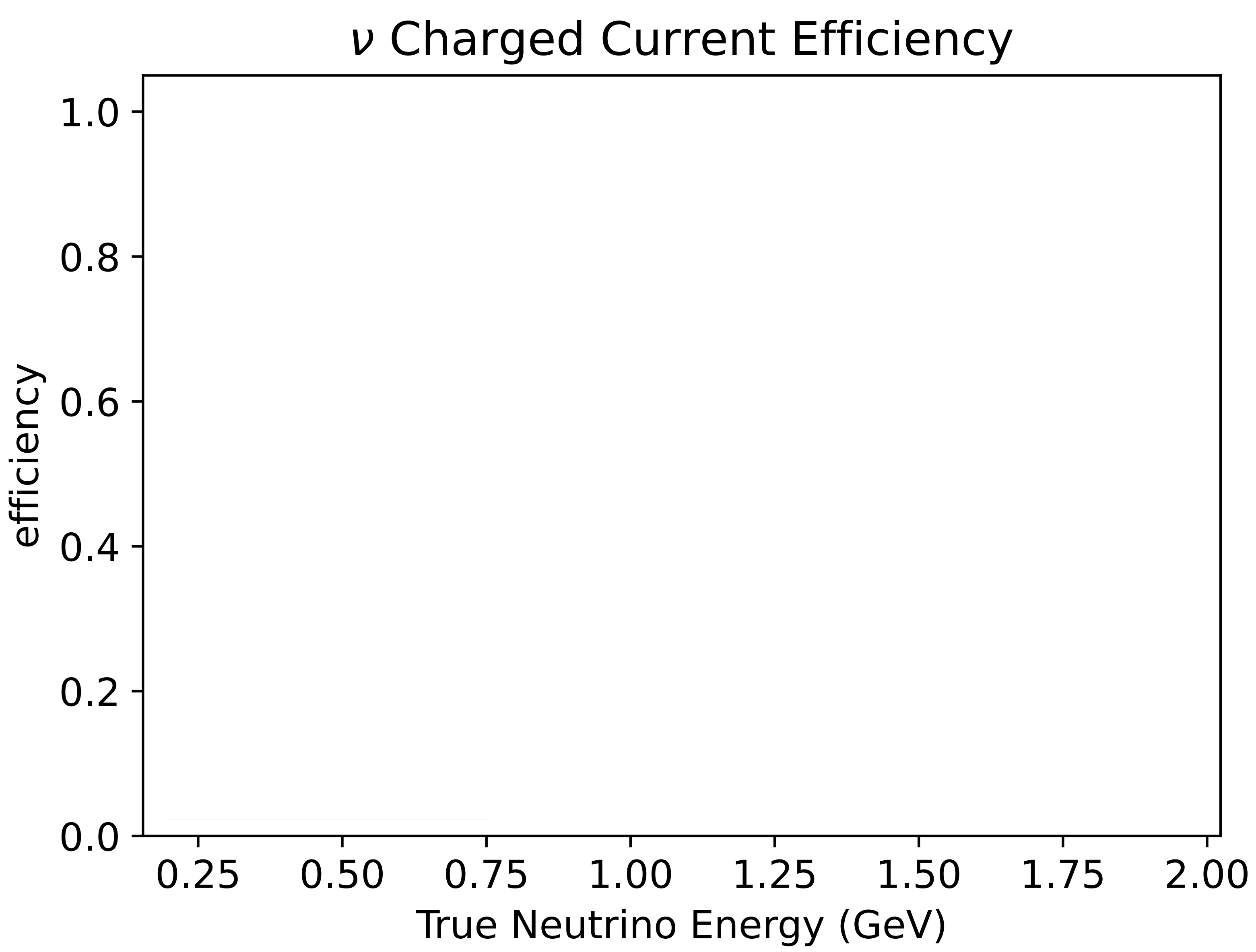
SBND PDS system:

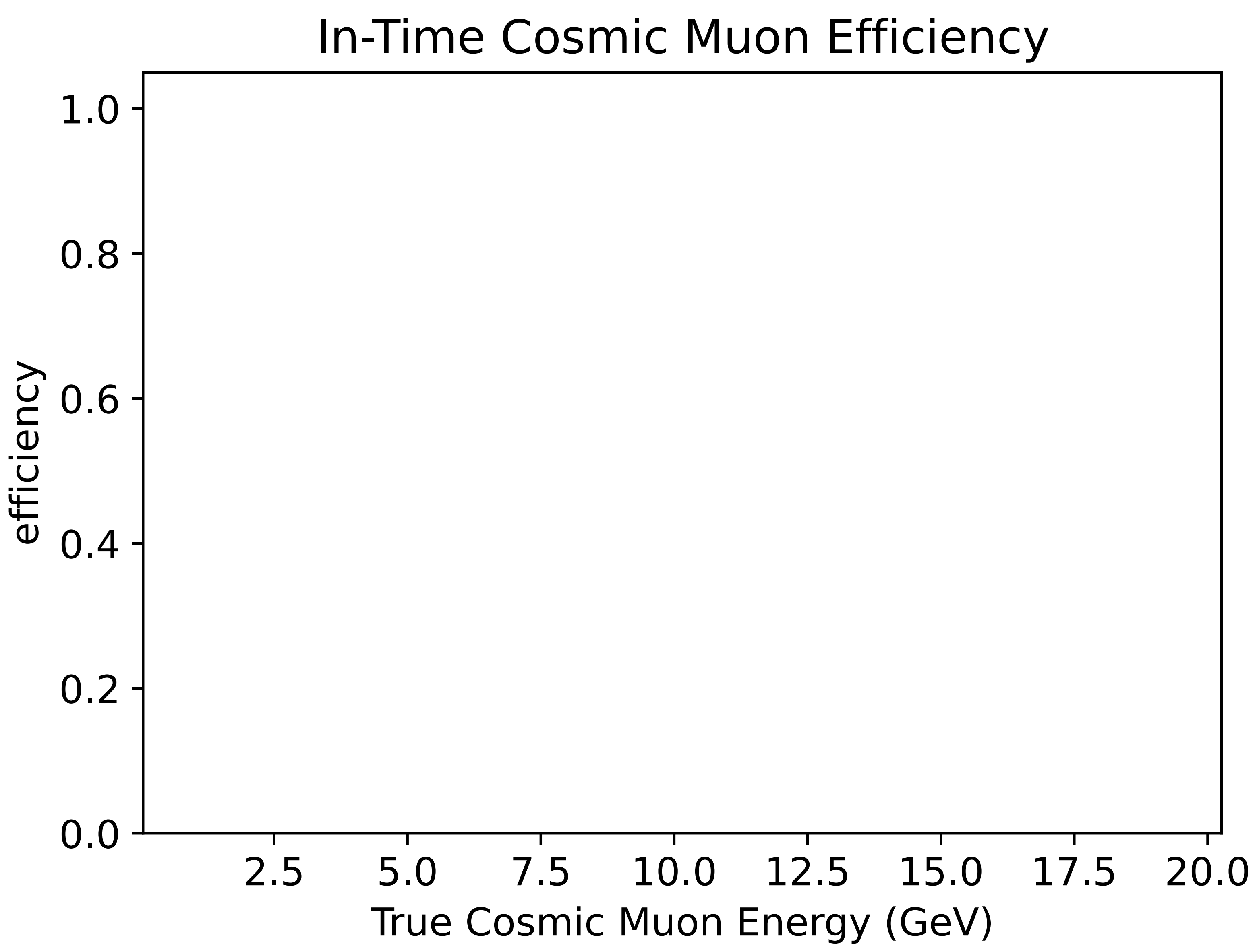
- 120 8-inch Hamamatsu **photo-multiplier tubes (PMTs)** and 192 **ARAPUCAs**
- Reflective cathode plane increases light yield
- PDS records both visible and VUV light

PMT Hardware Trigger

- During beam spill: does a PMT measure light?







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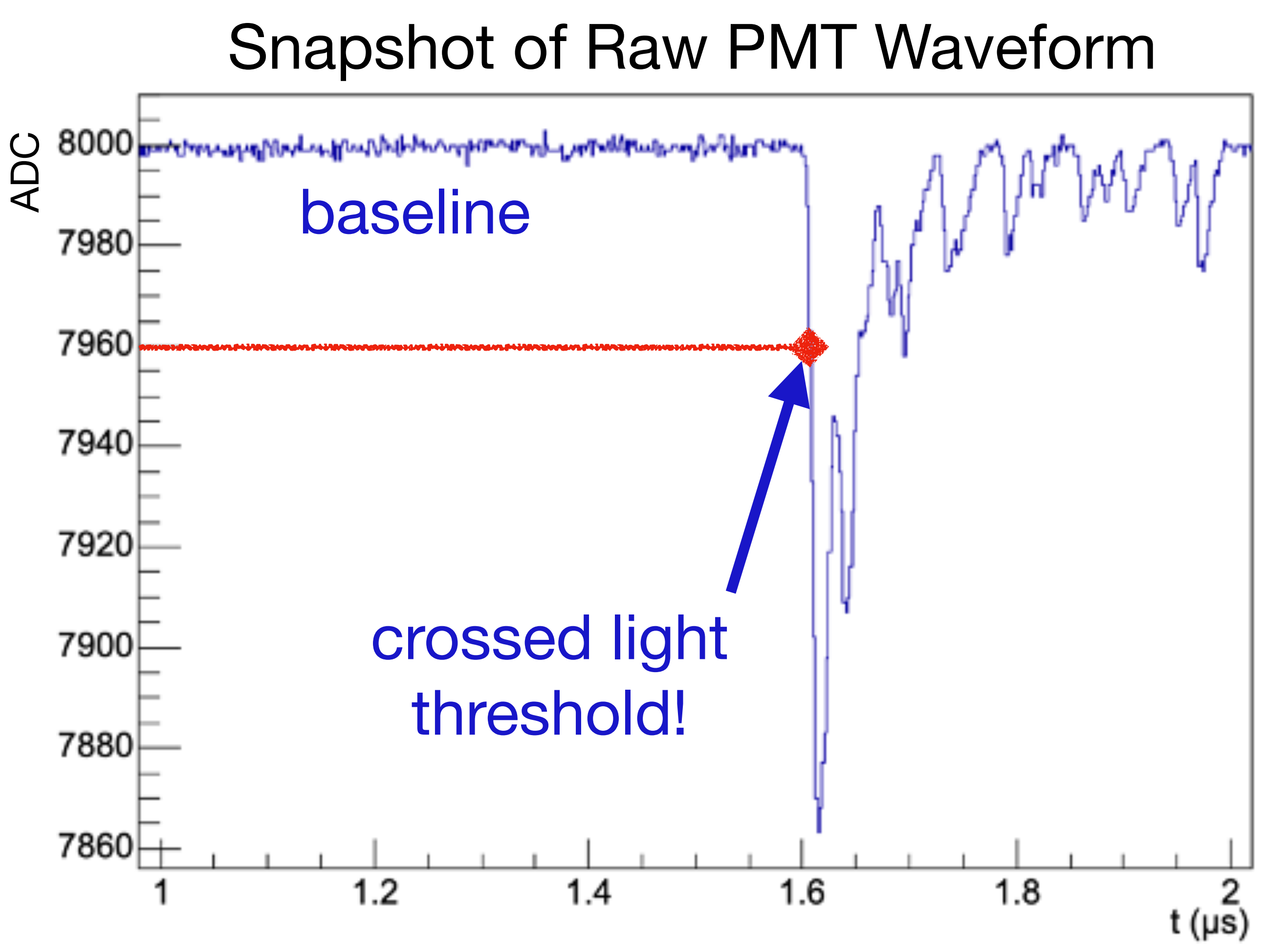

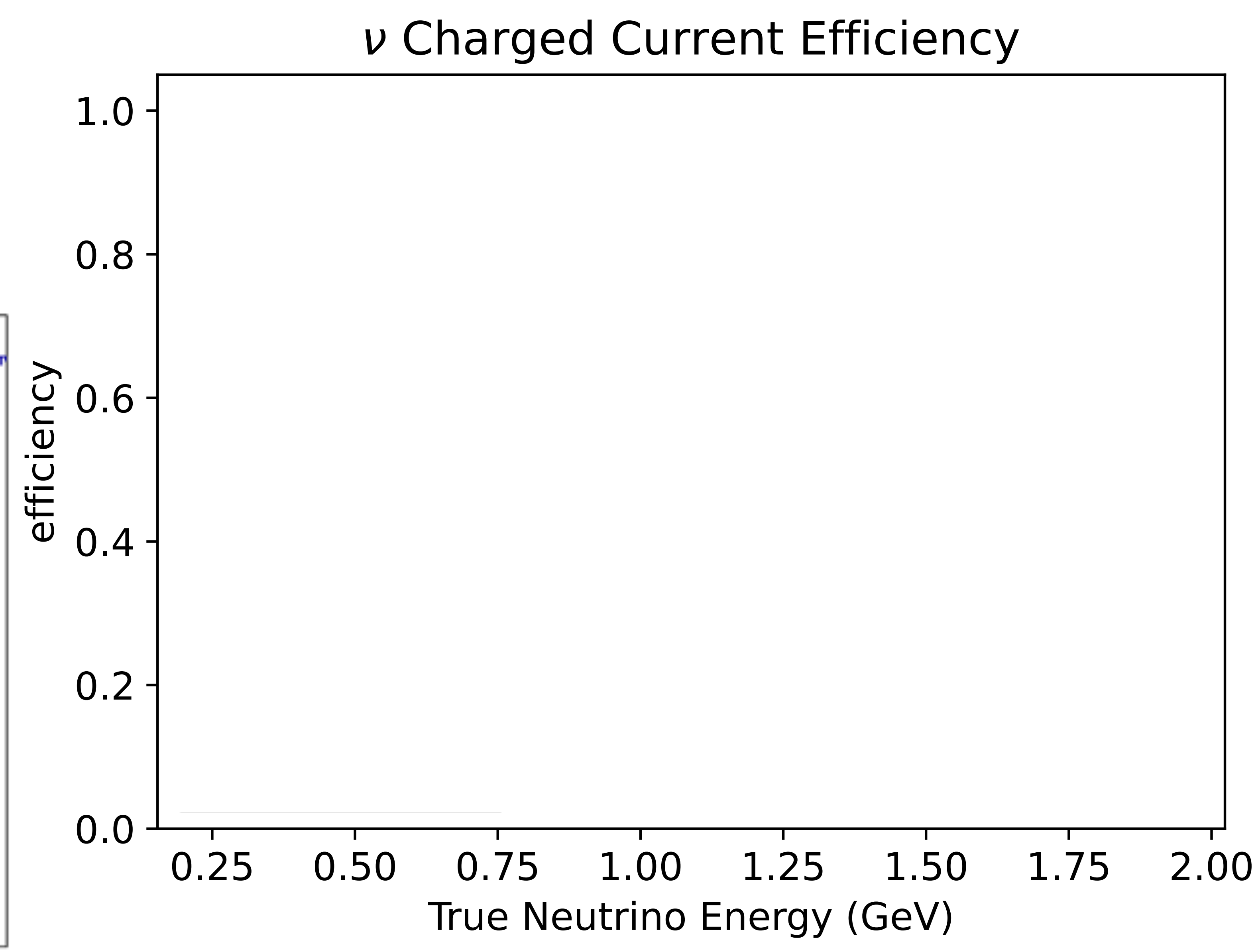

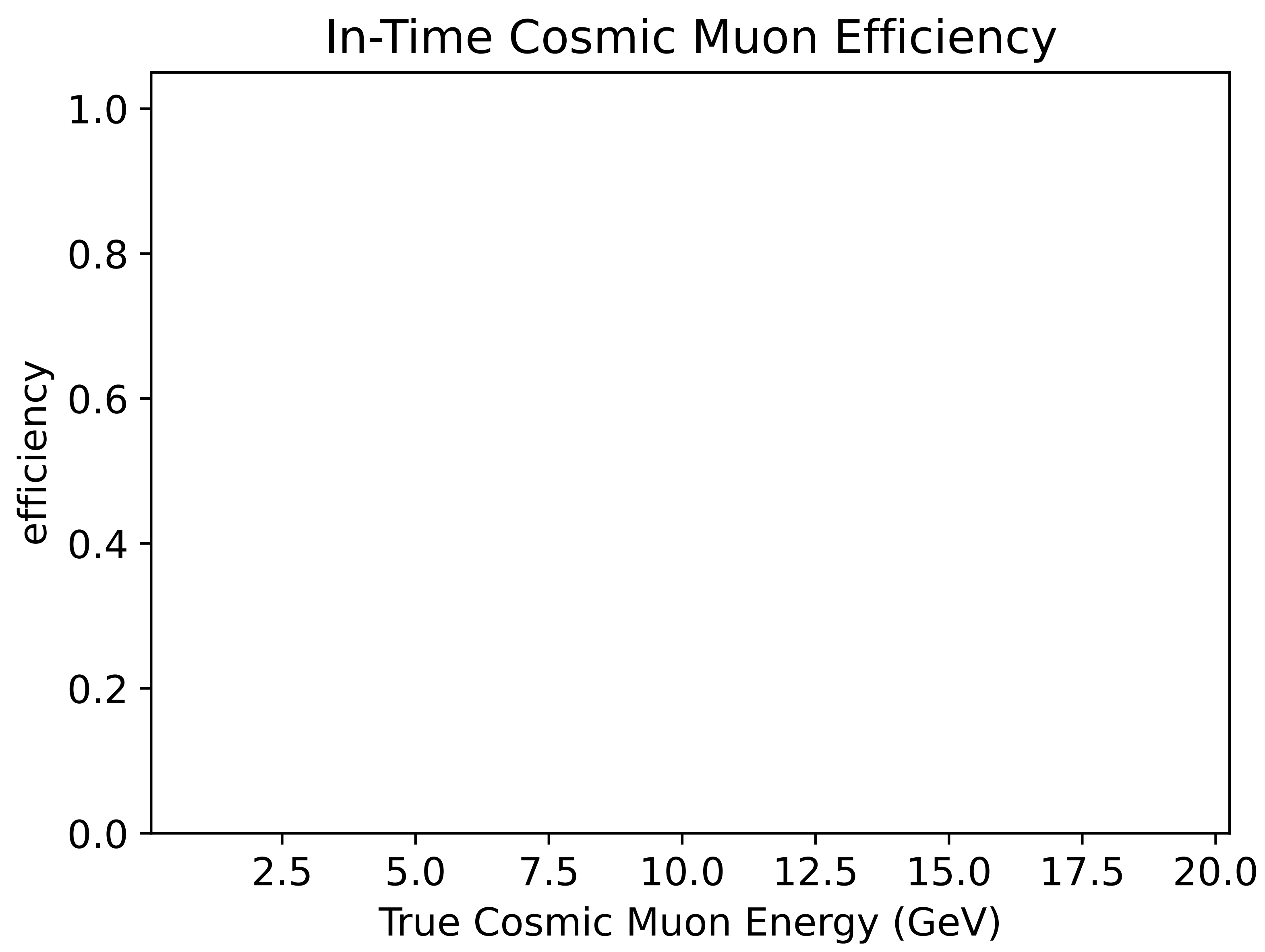

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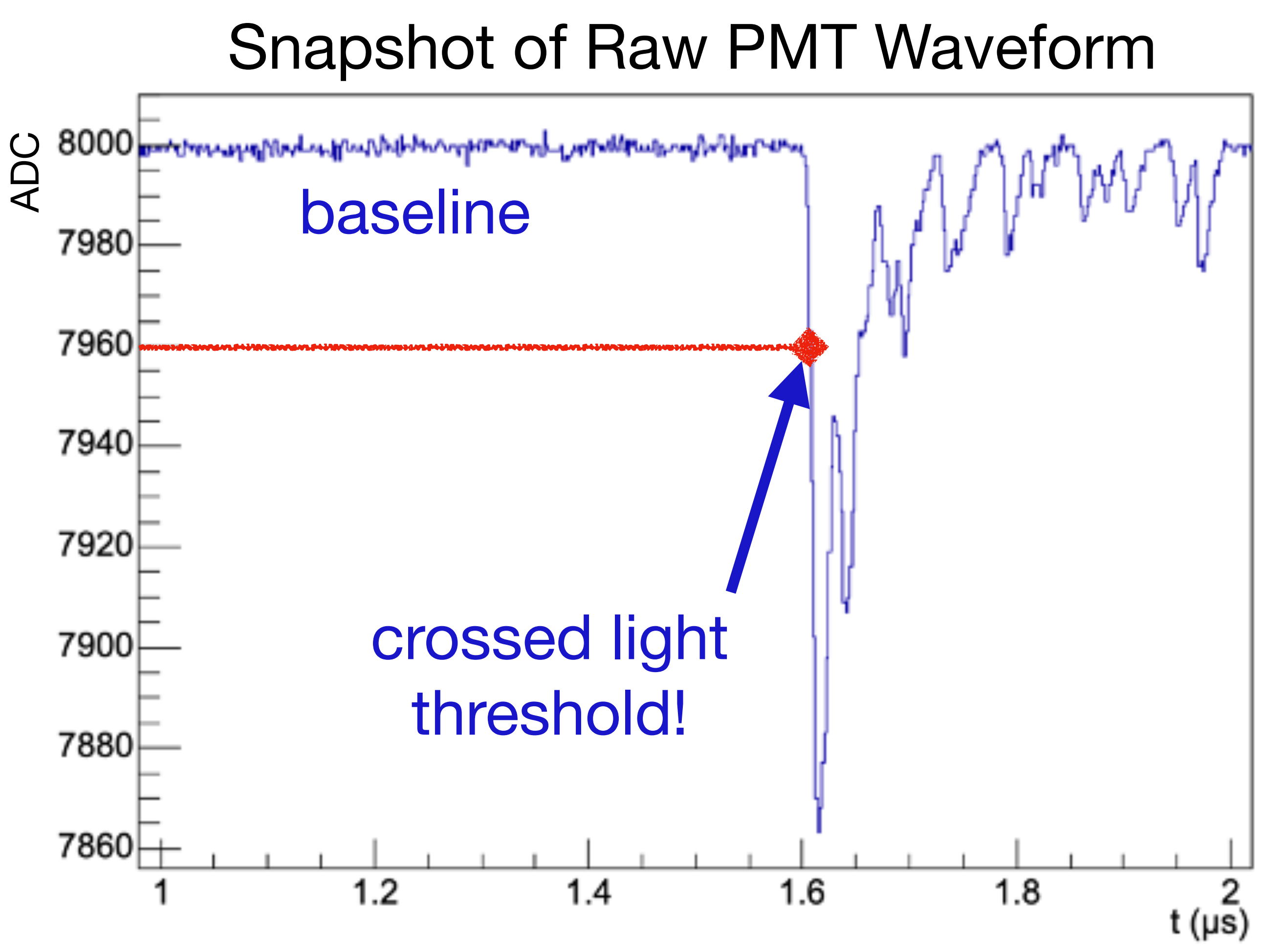

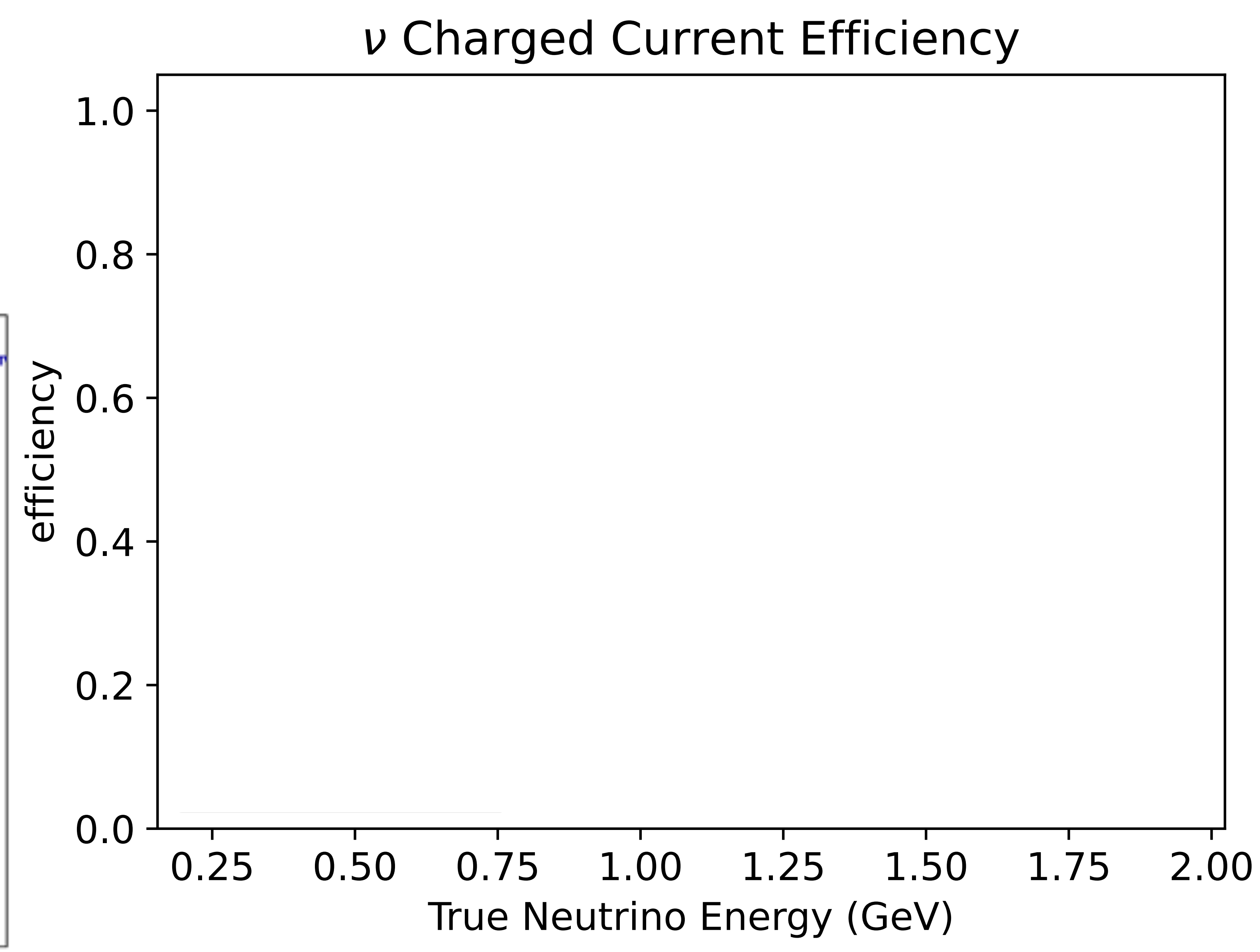

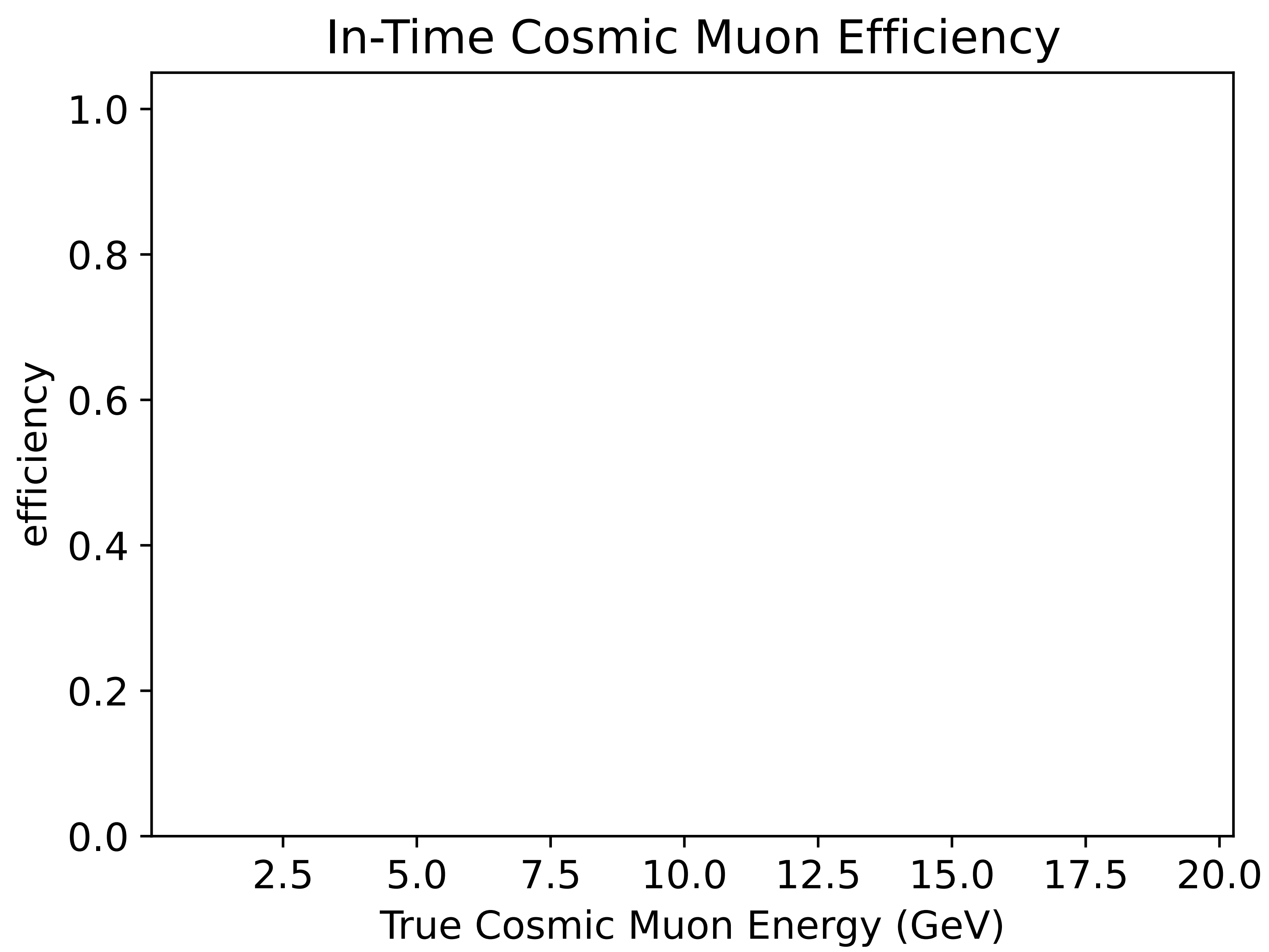

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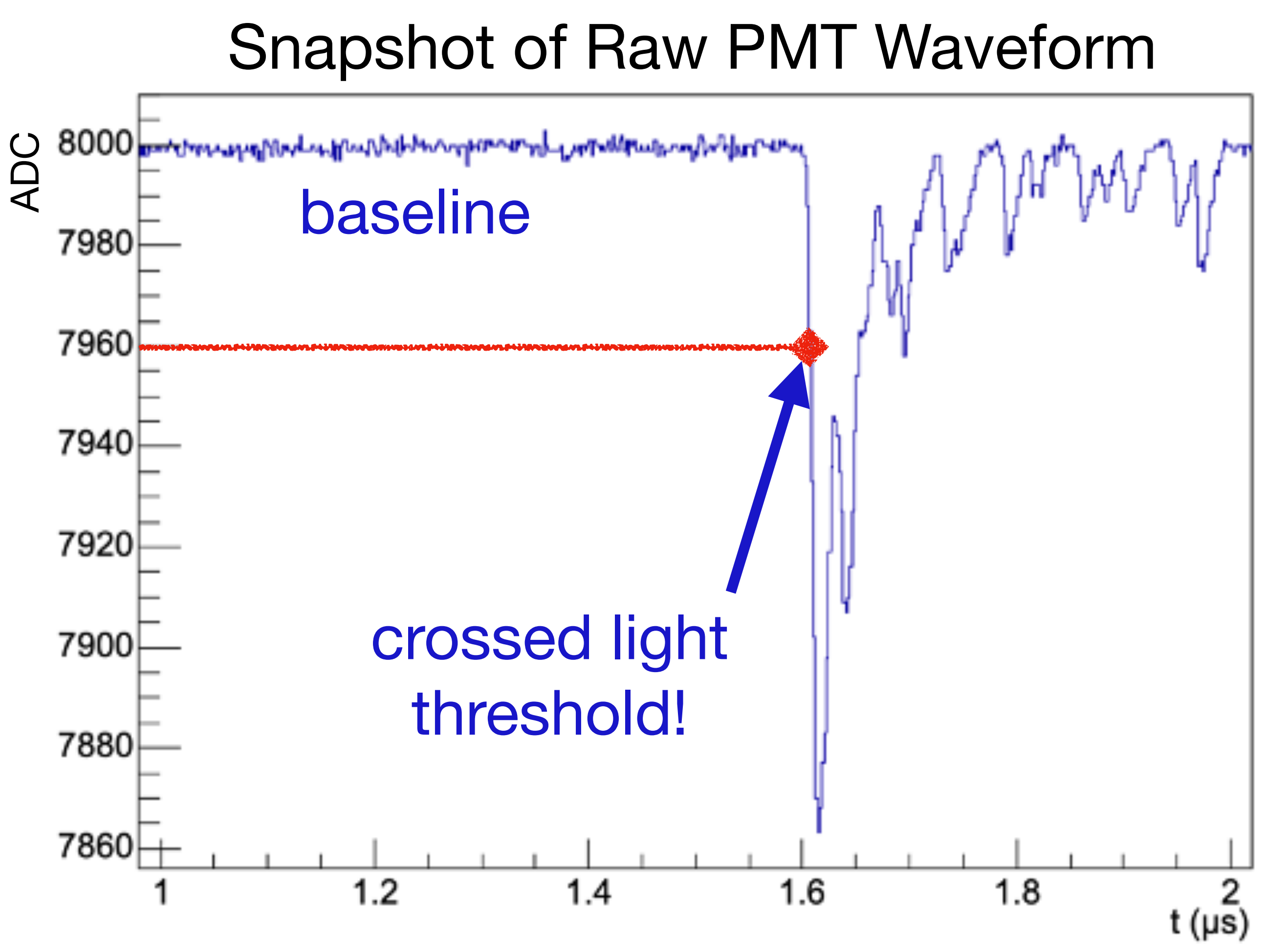

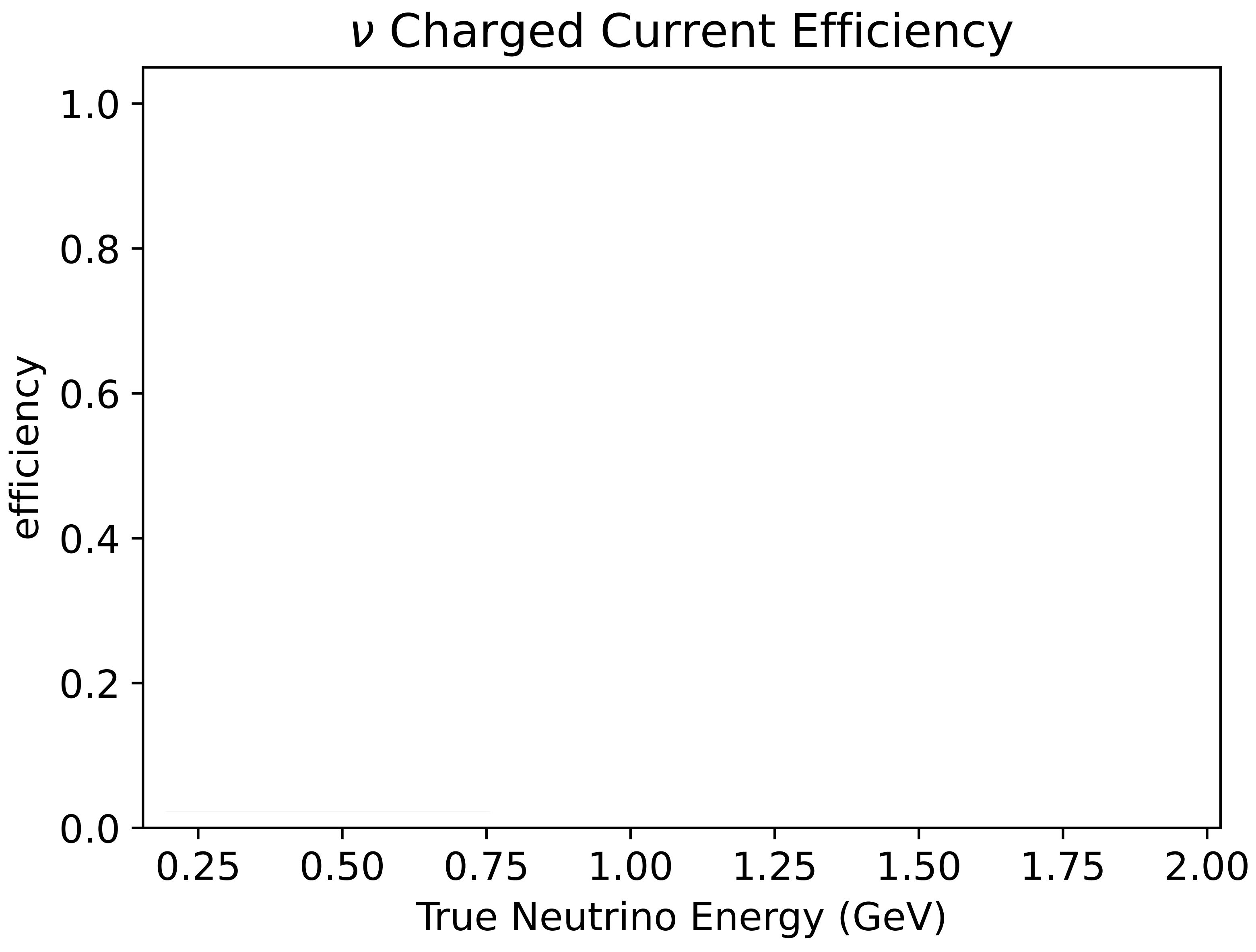

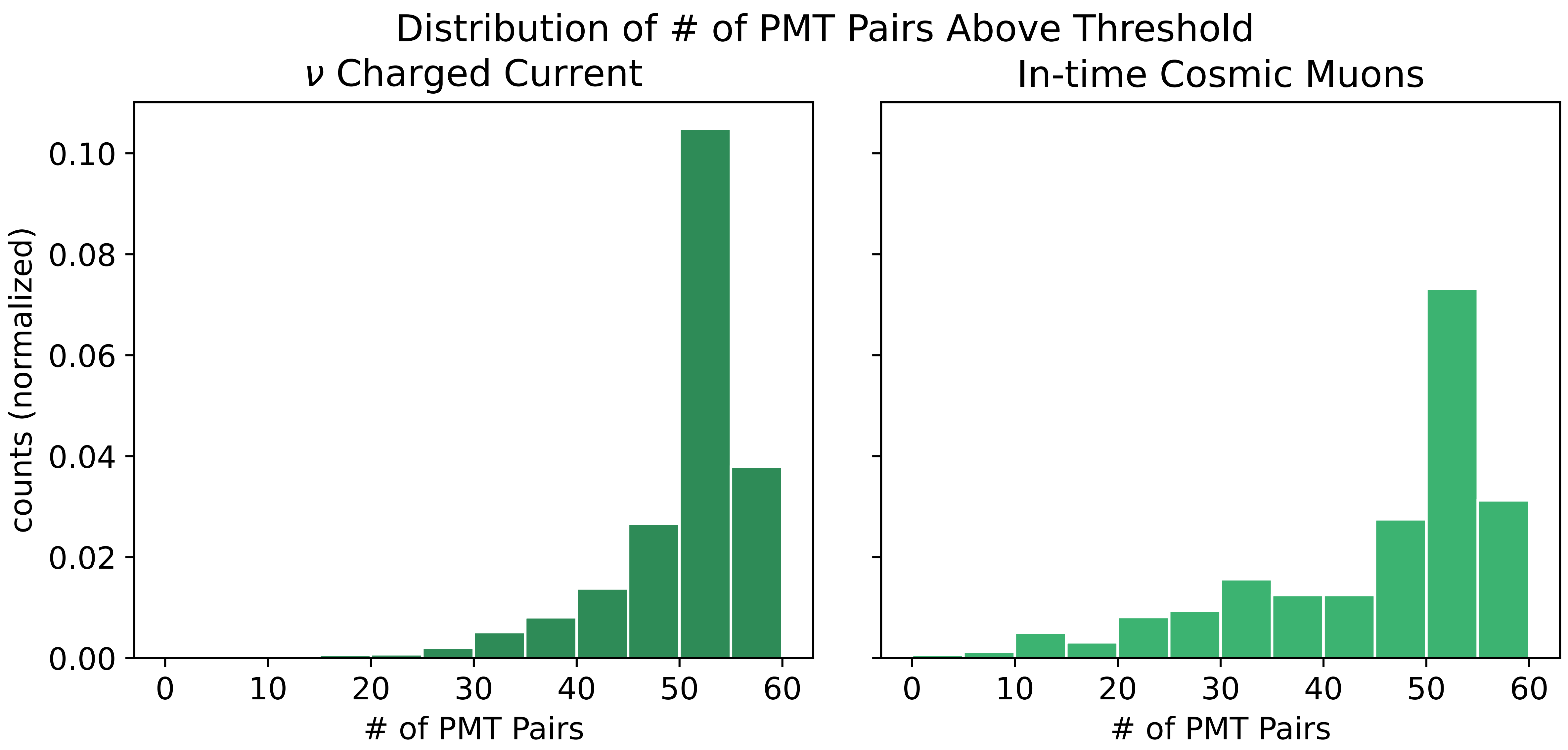

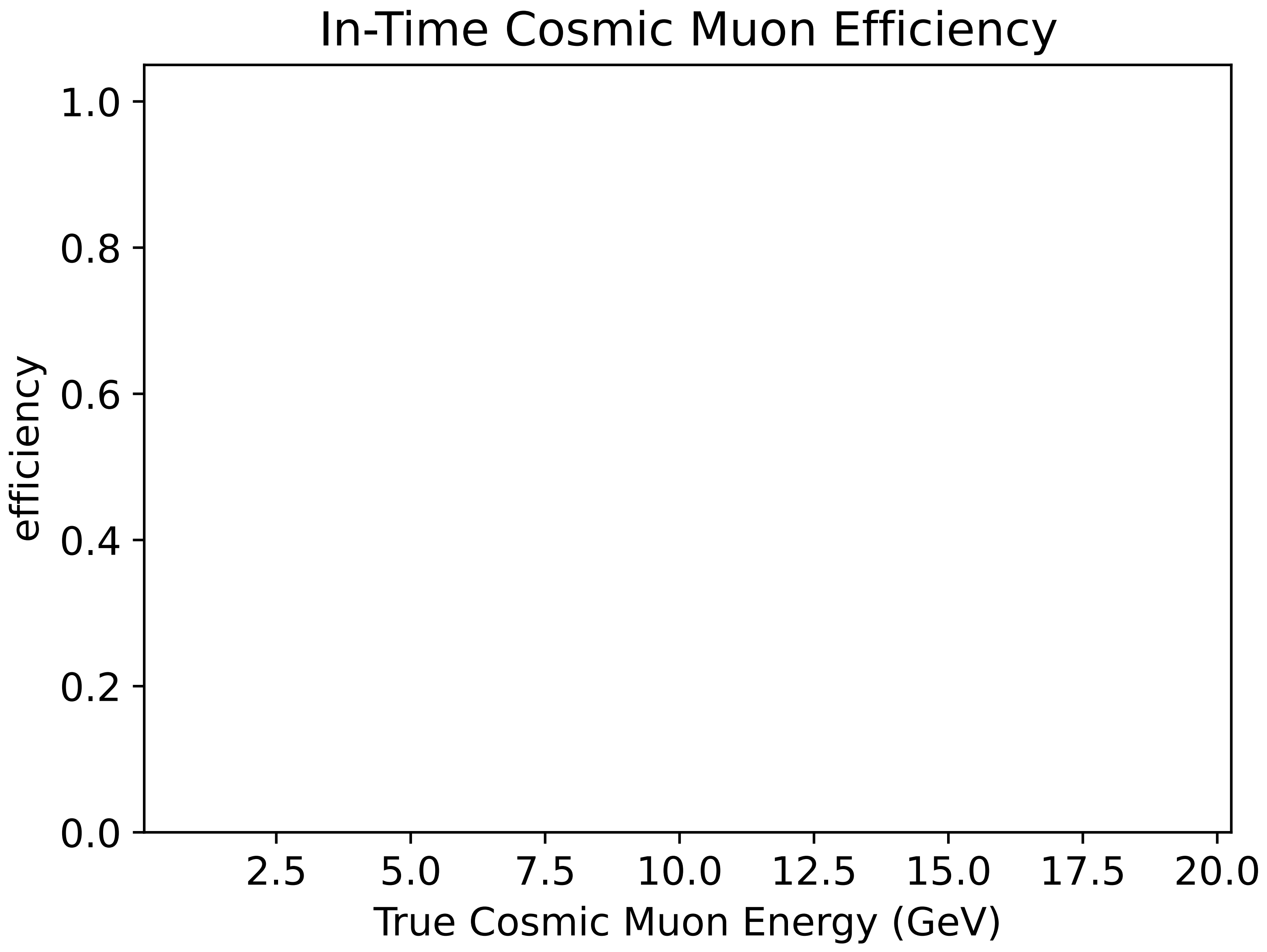

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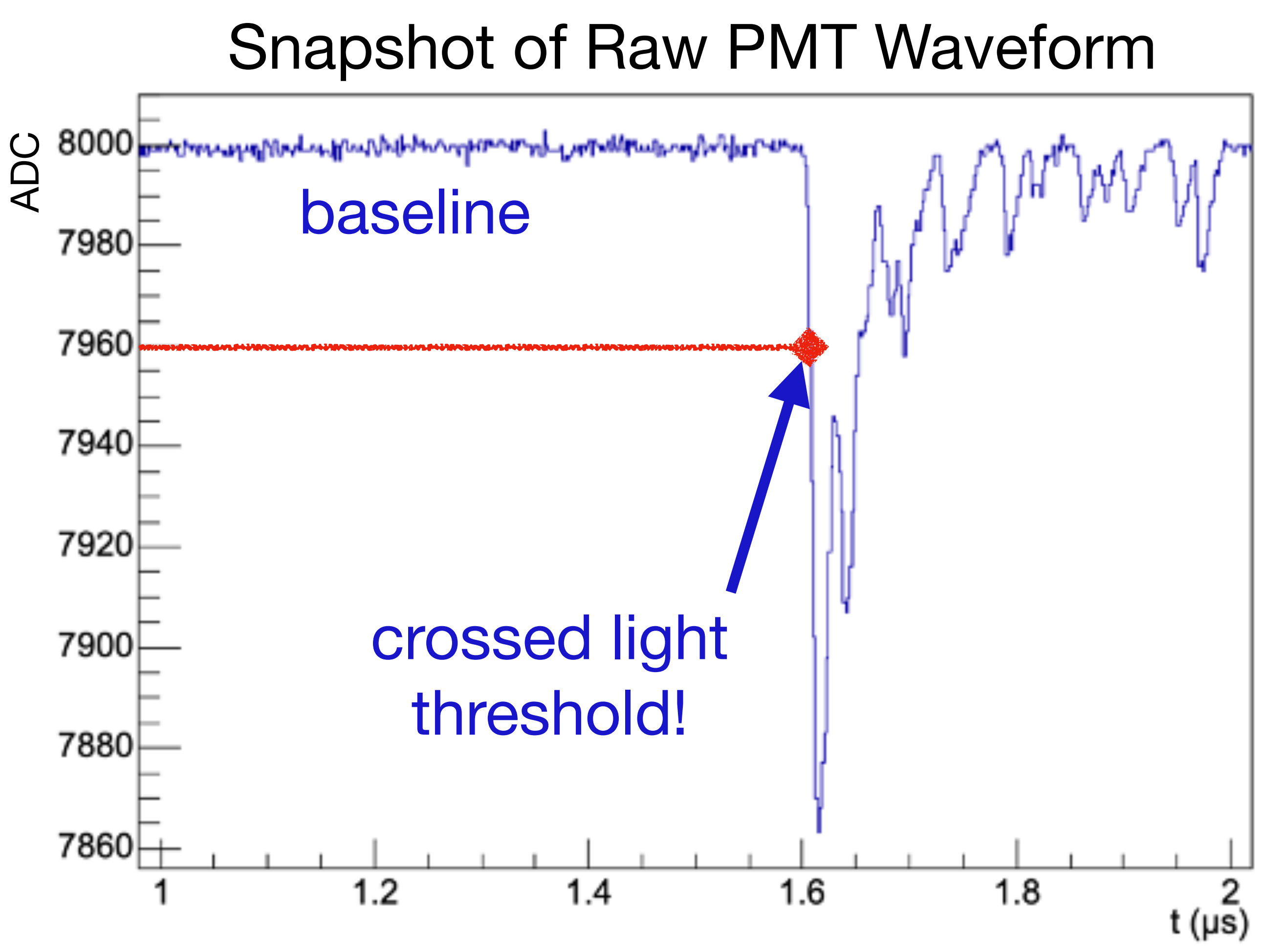

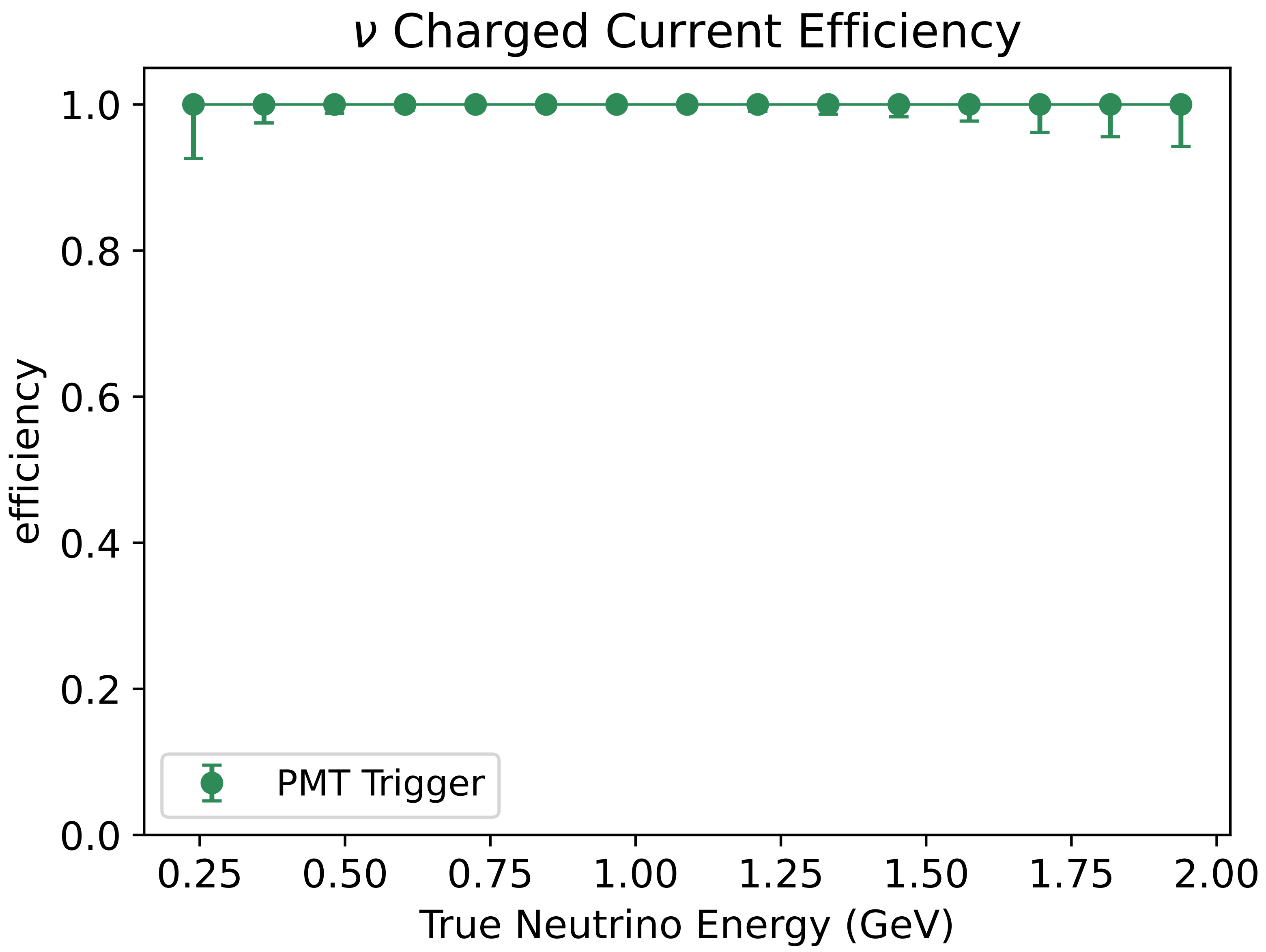

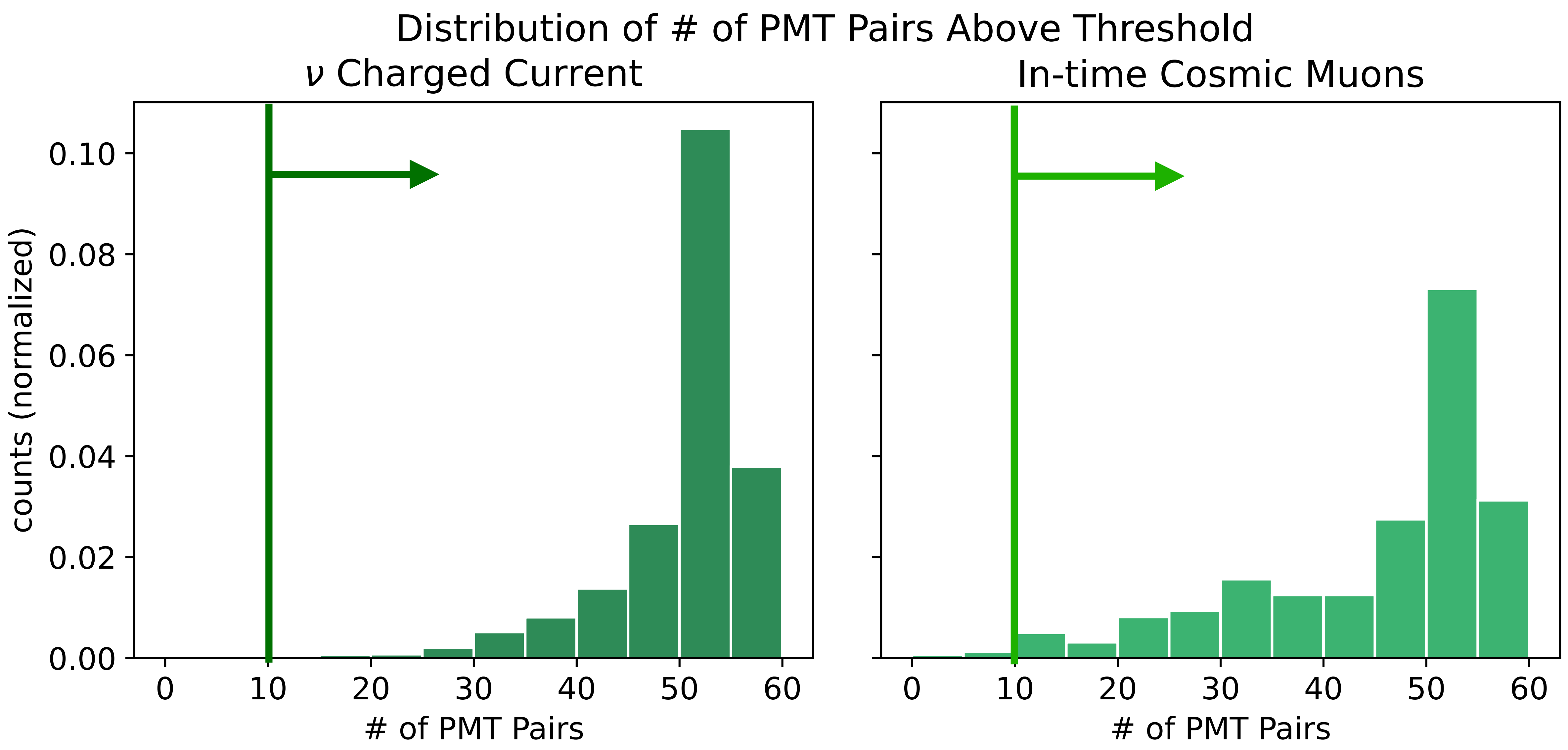

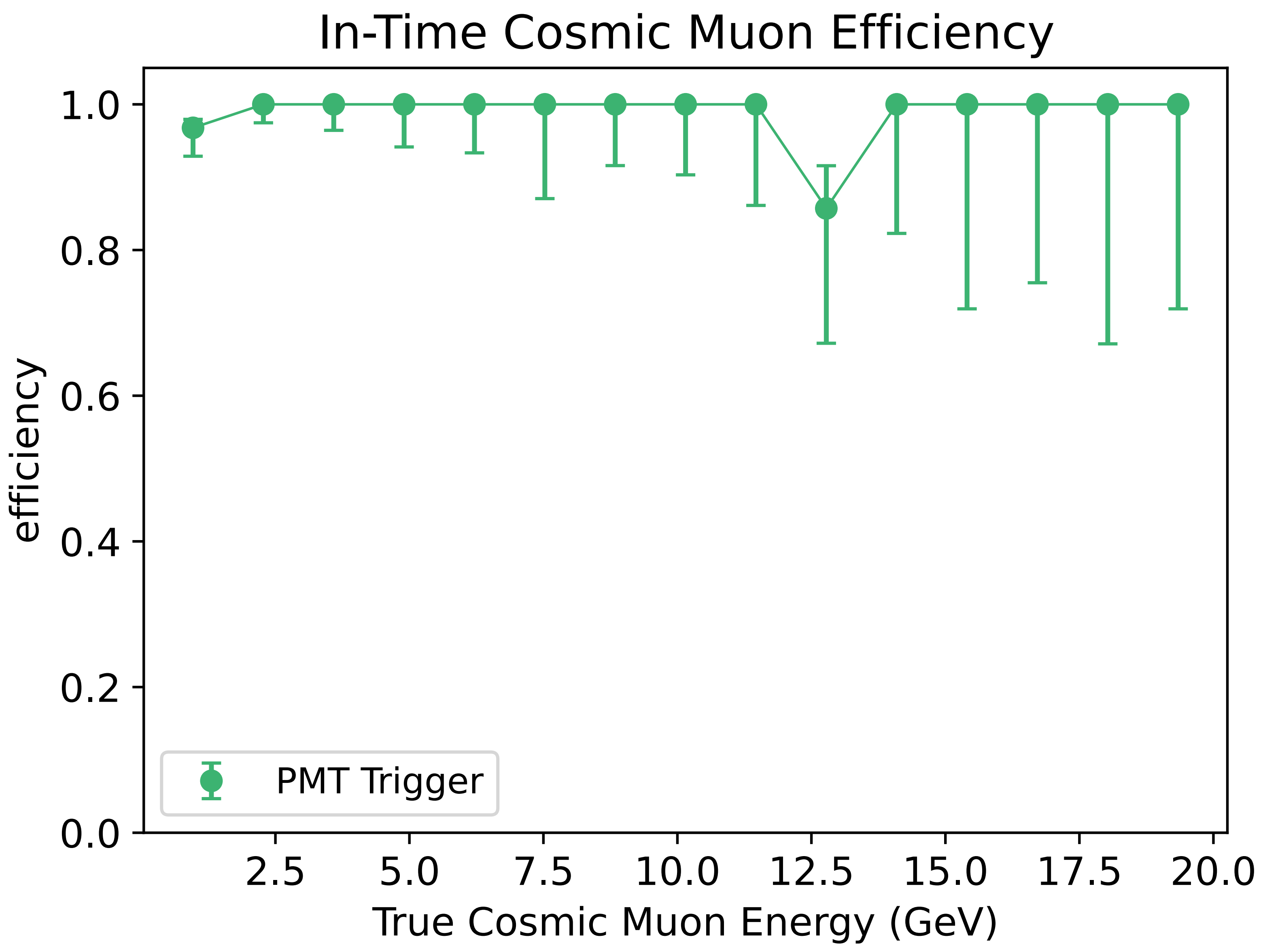

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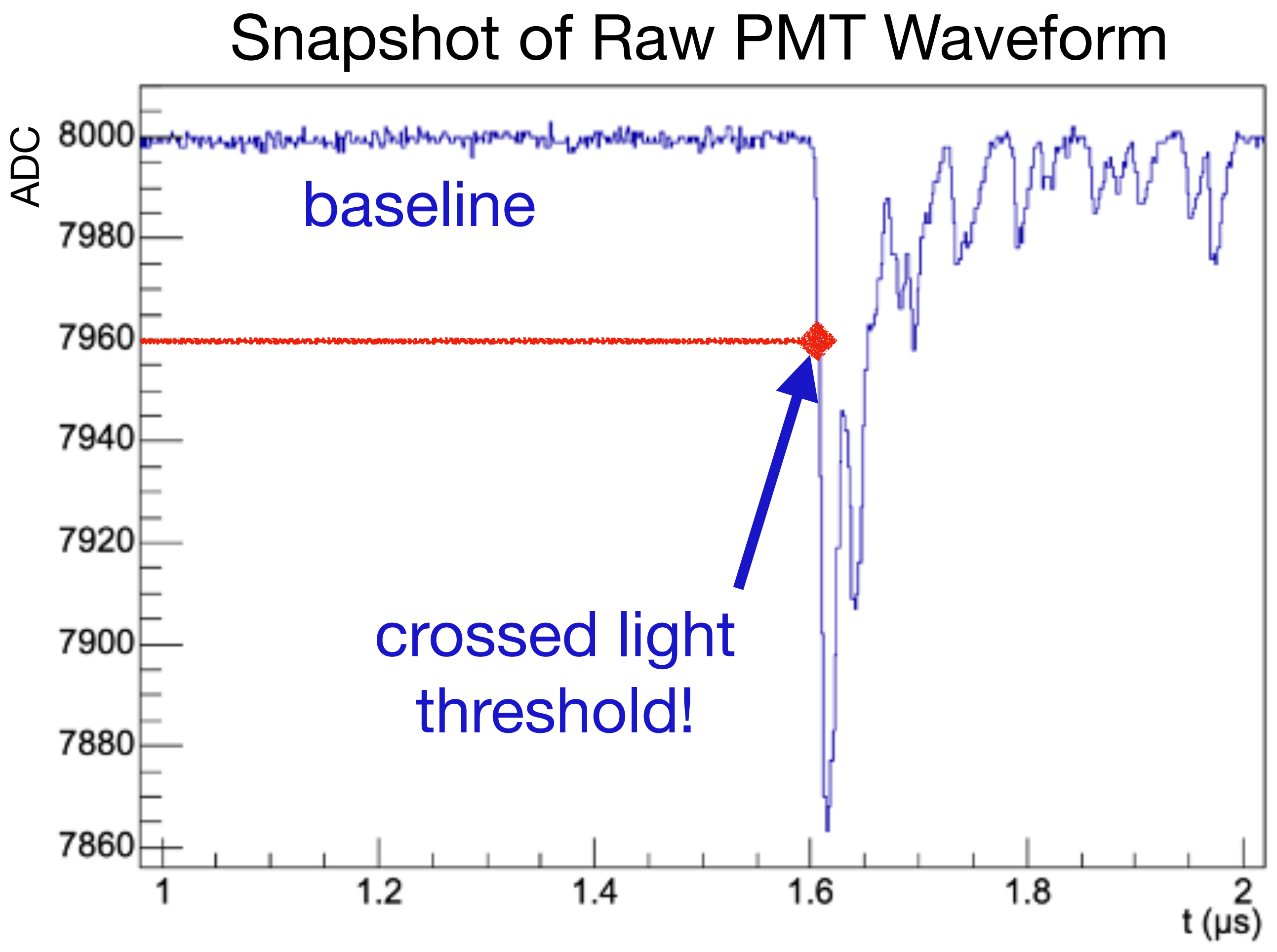
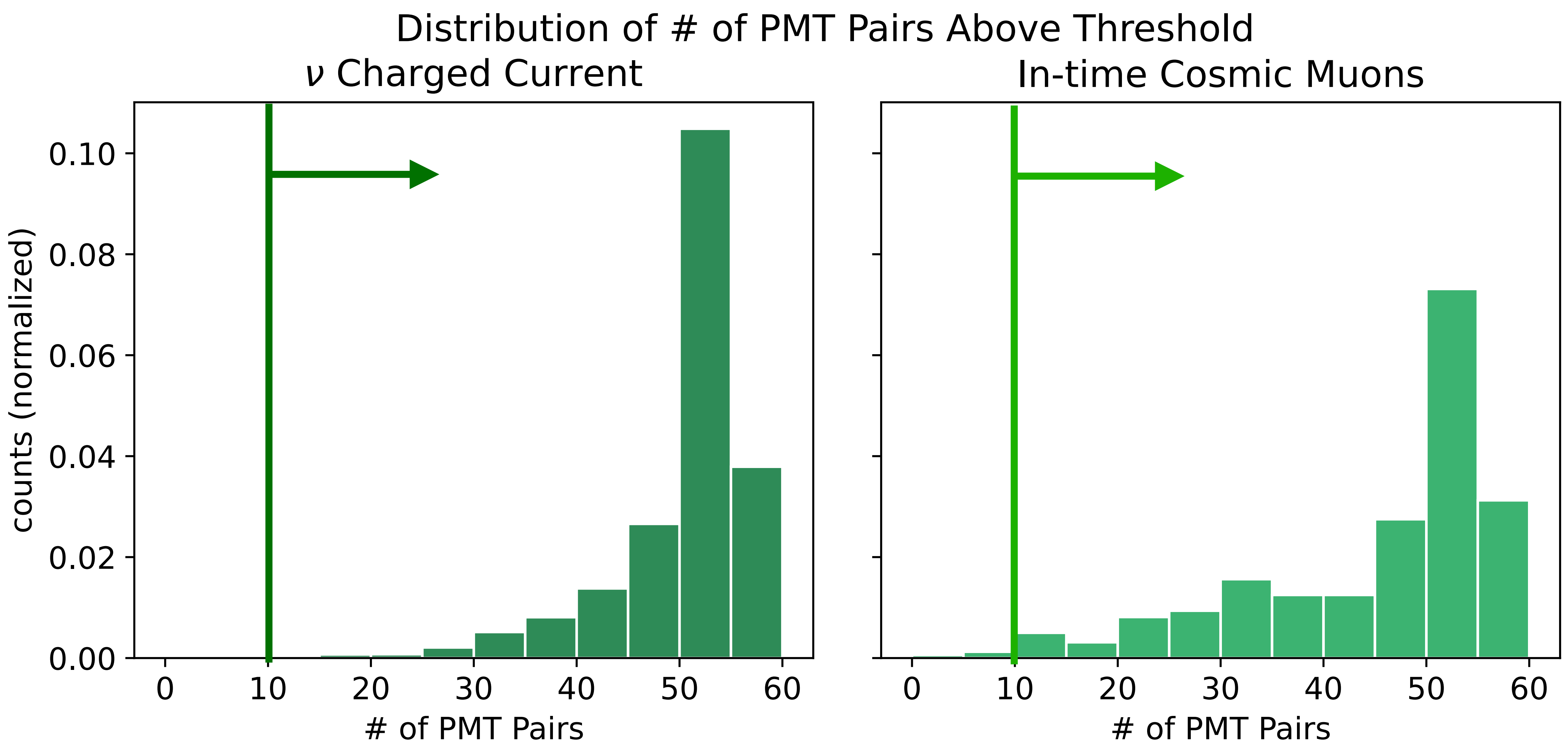
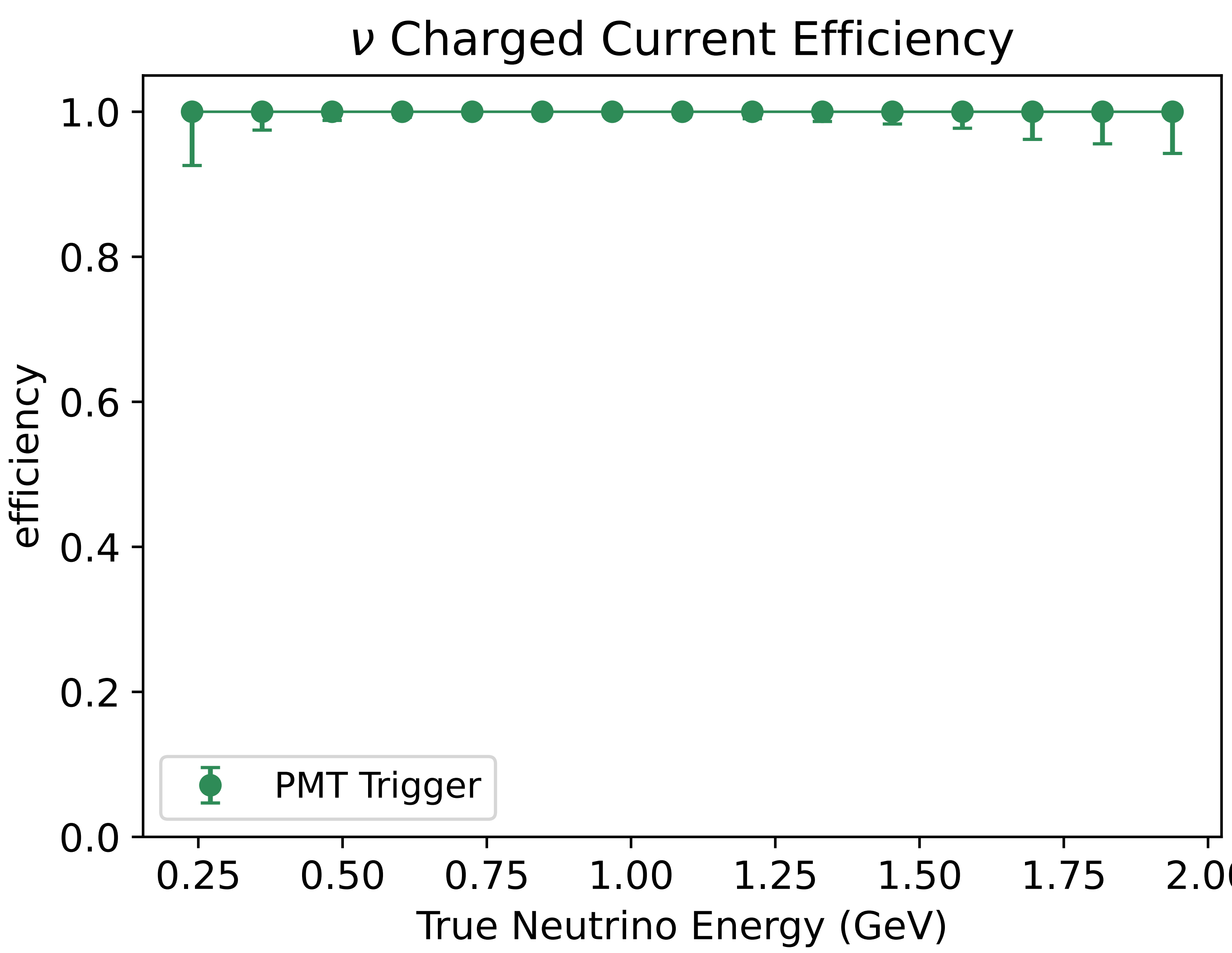
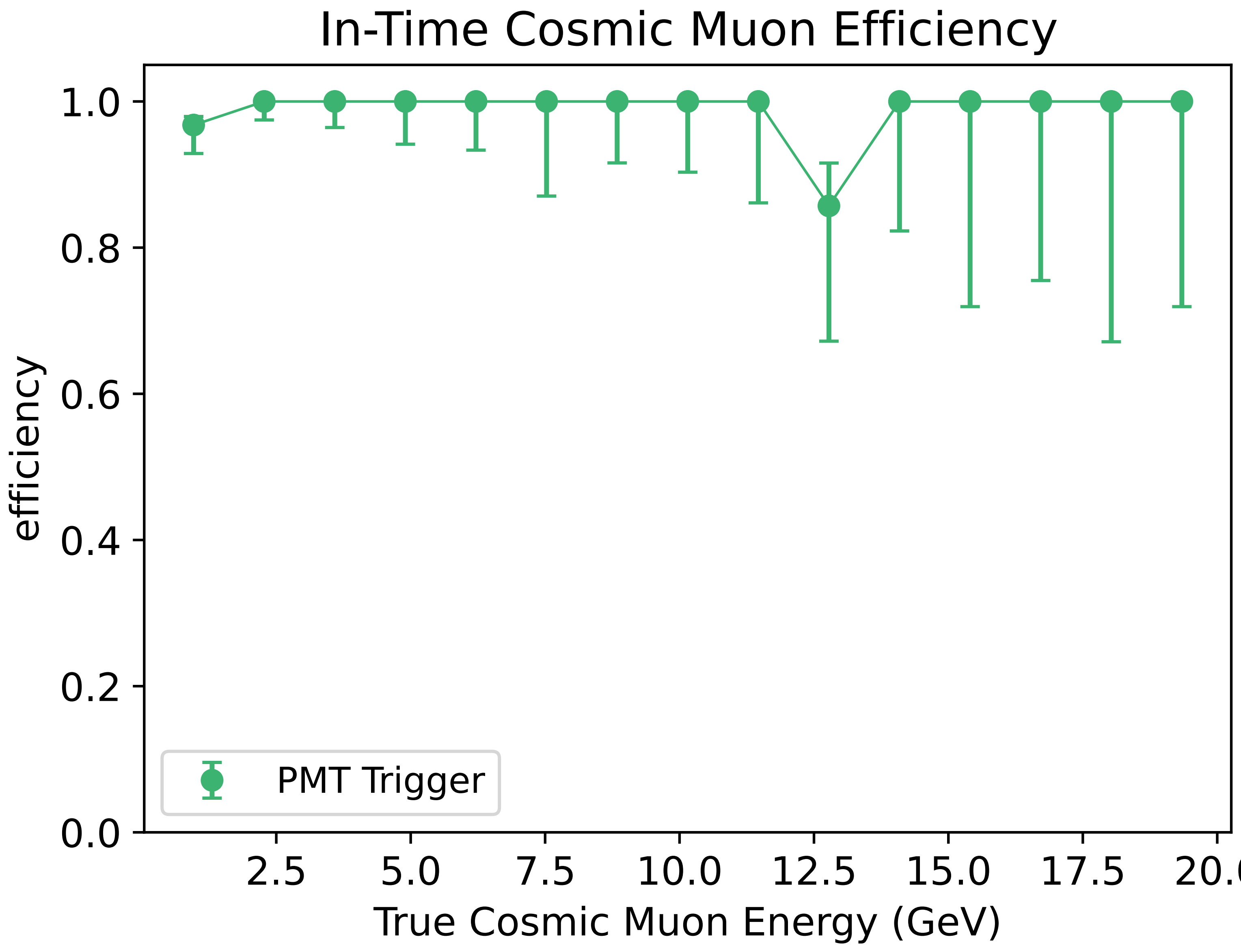


CC neutrino events: ~100%

cosmic muon efficiency: ~95-100%







TPC Reconstruction & Pandora

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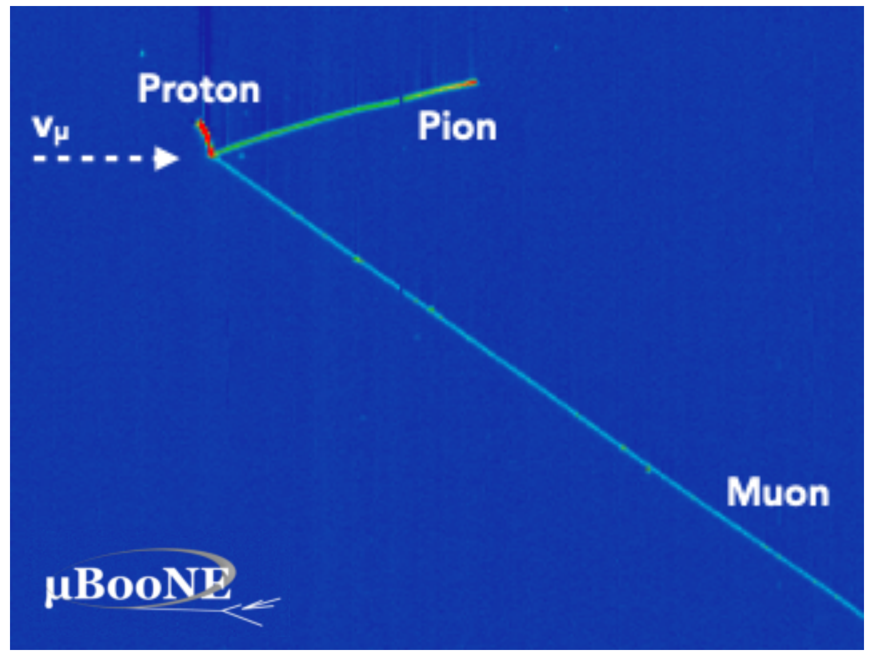
LArTPC Event Display



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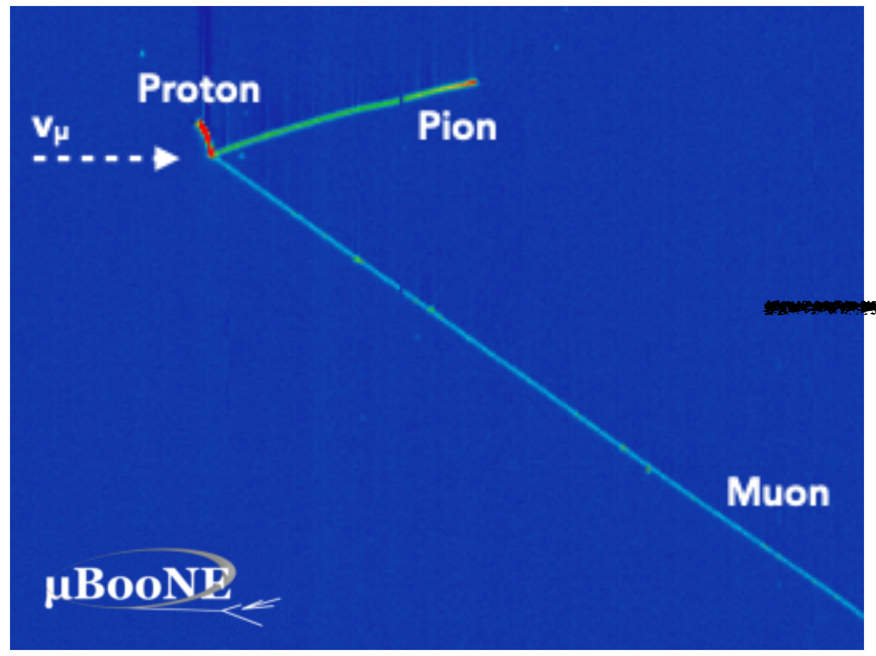

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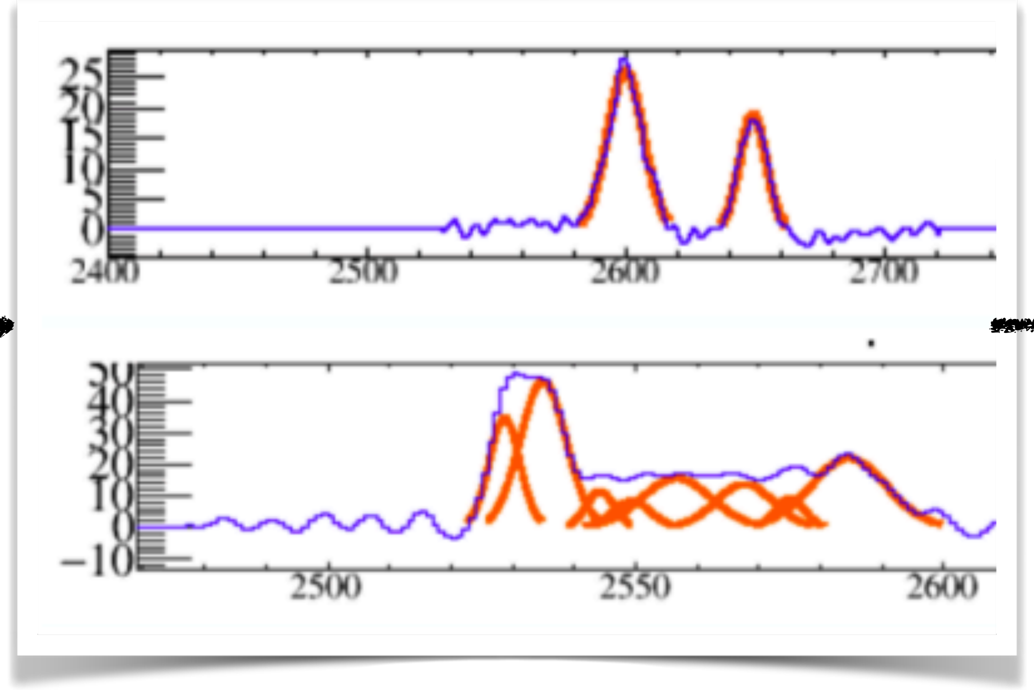

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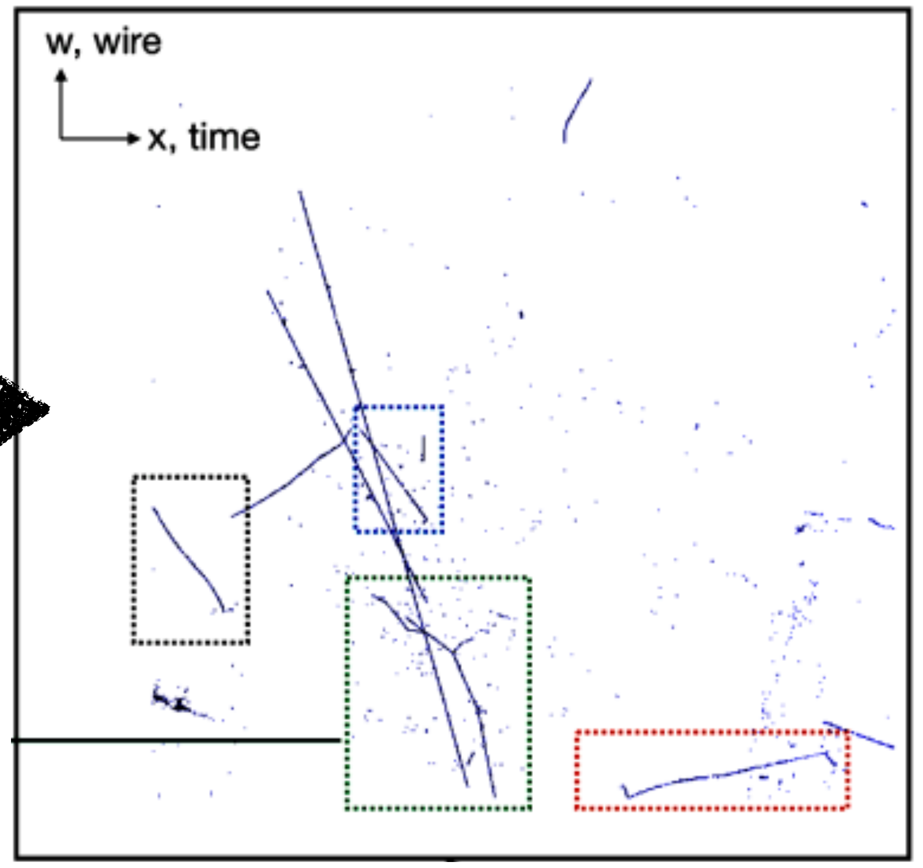
Track Finding: "Slicing"



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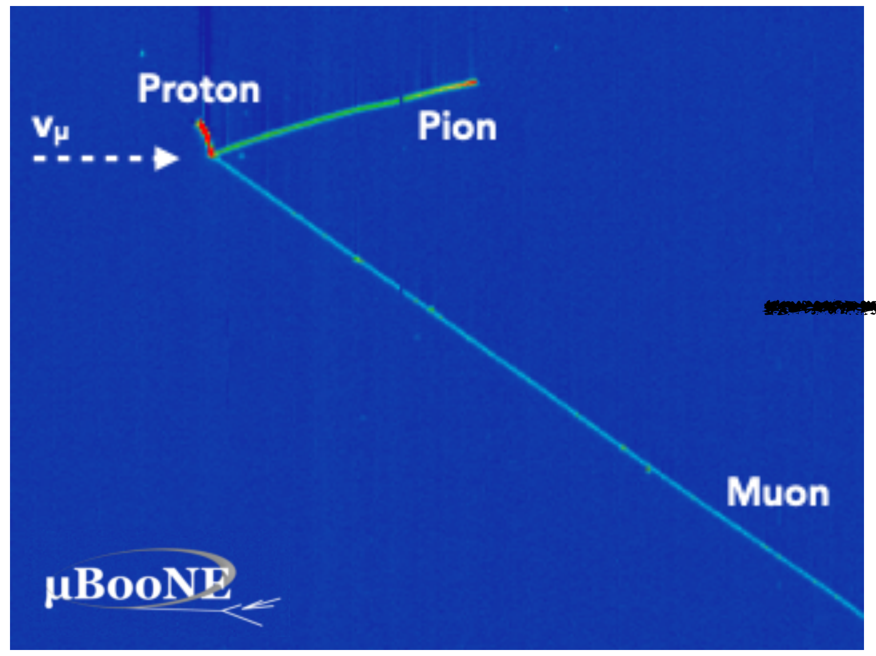

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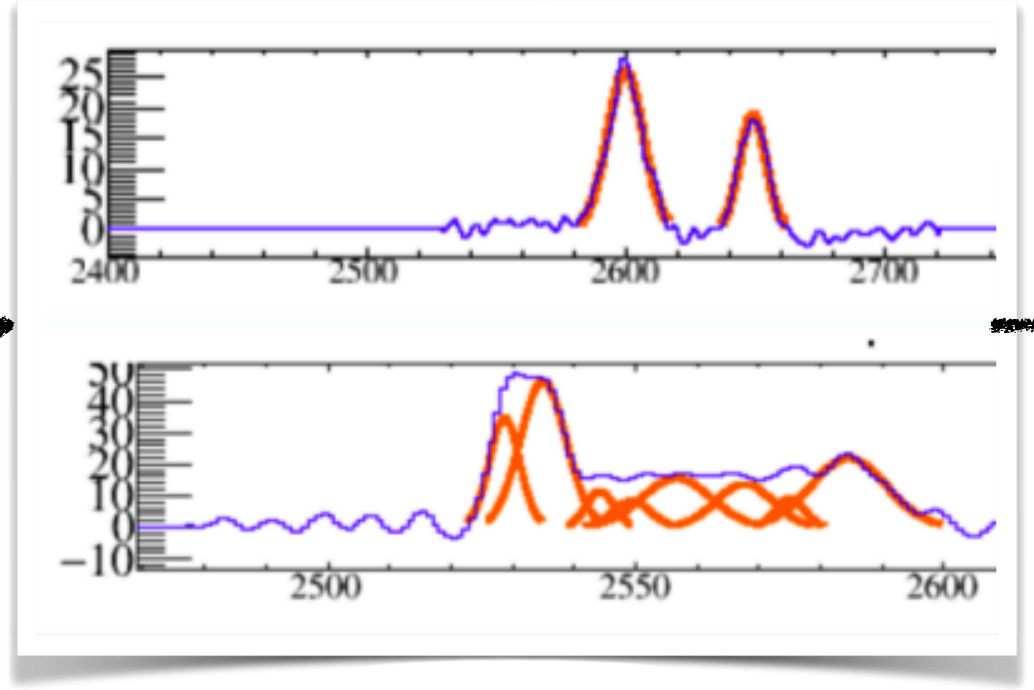

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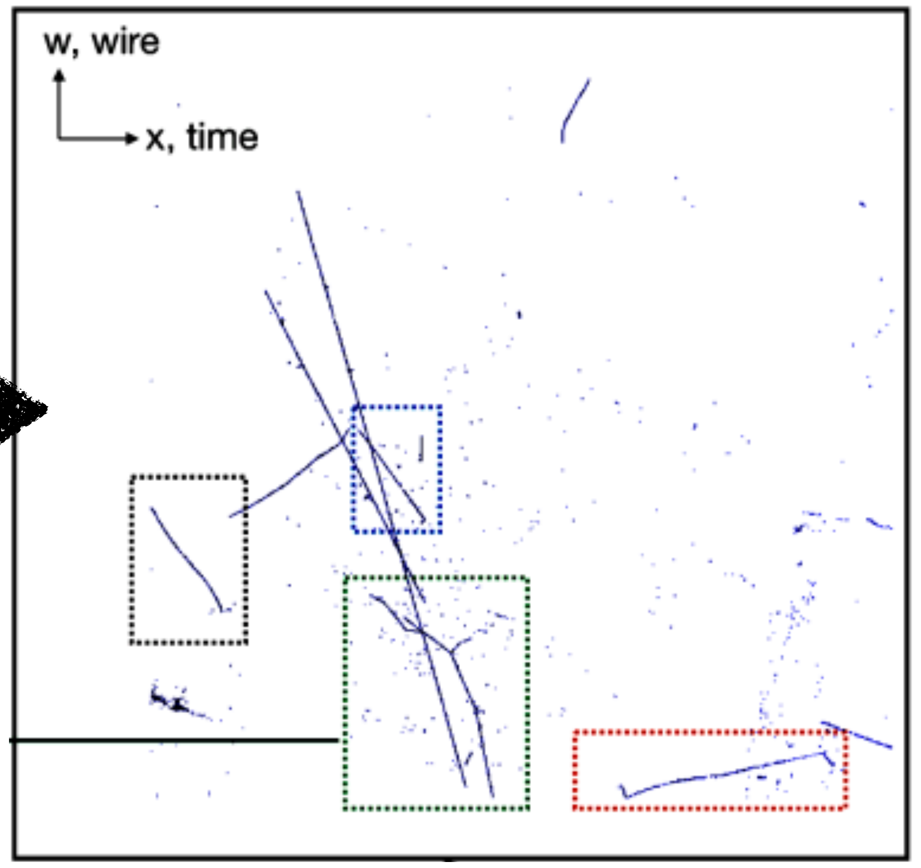

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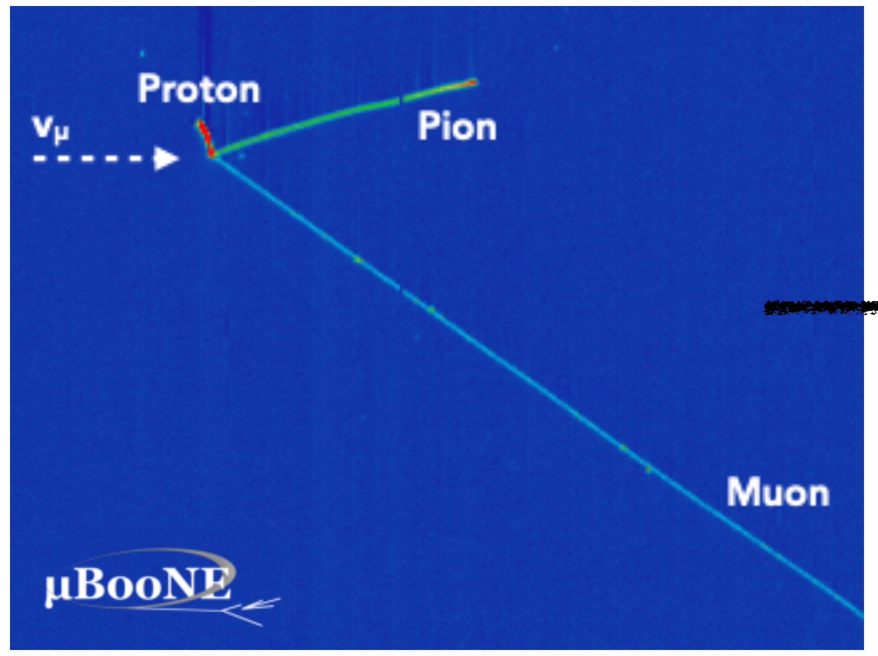

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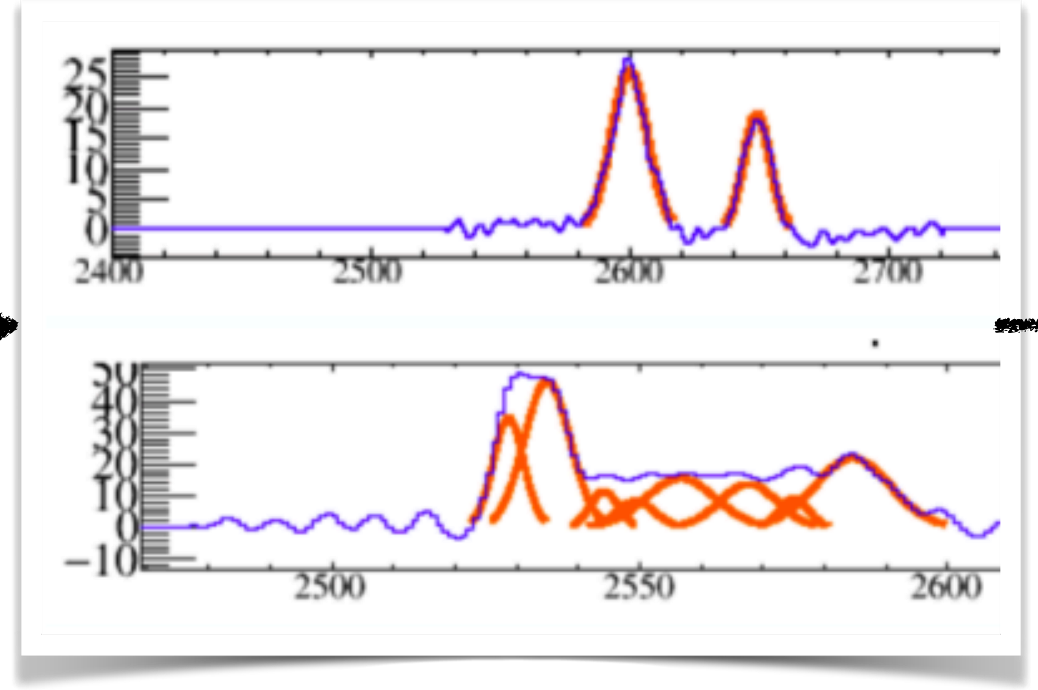

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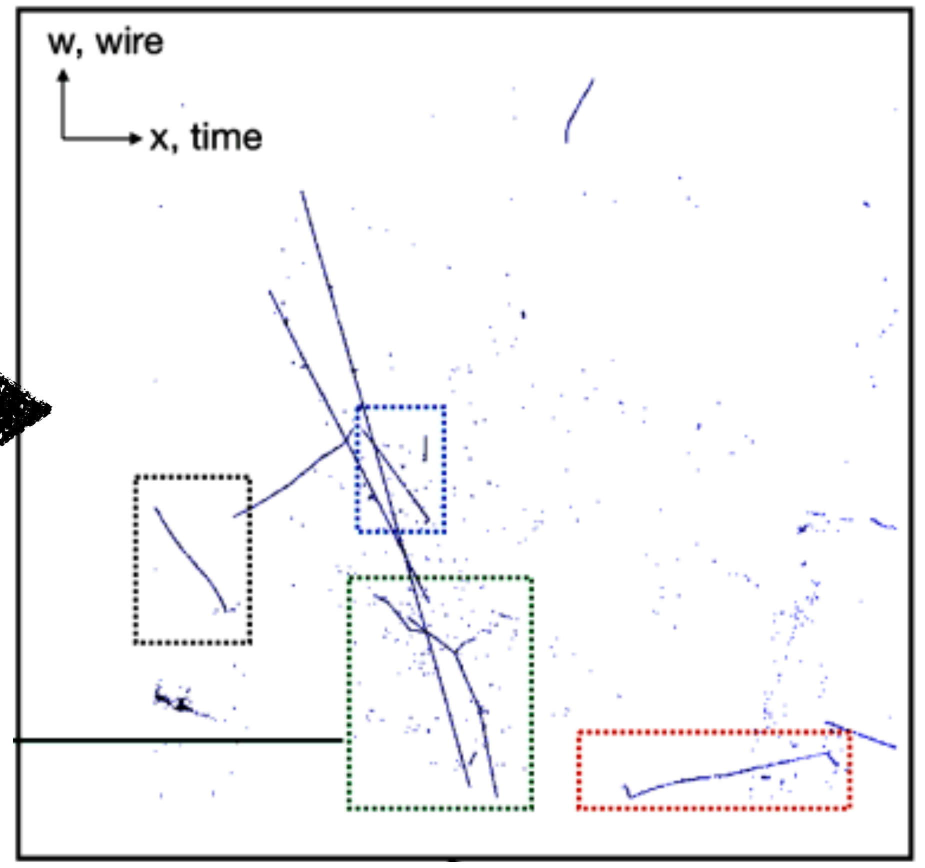

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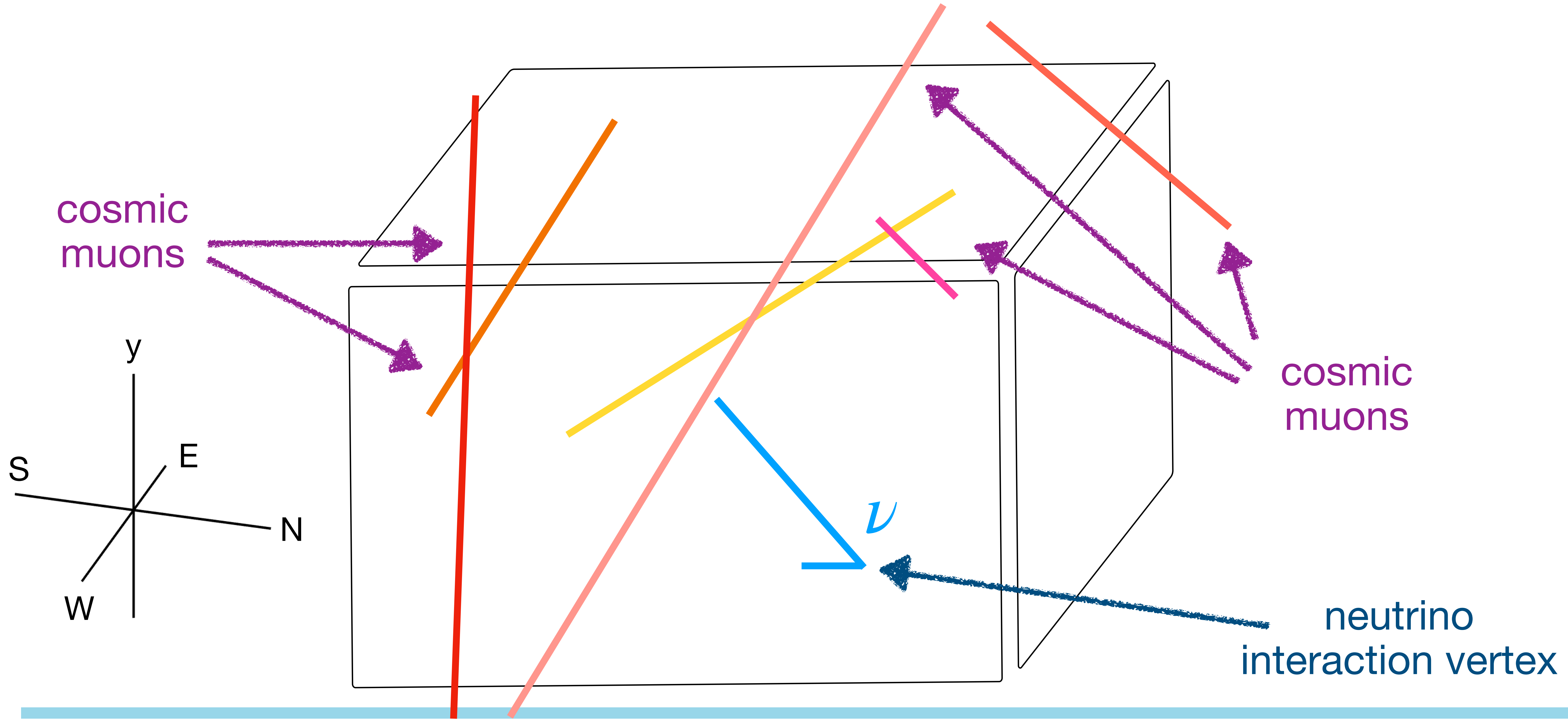
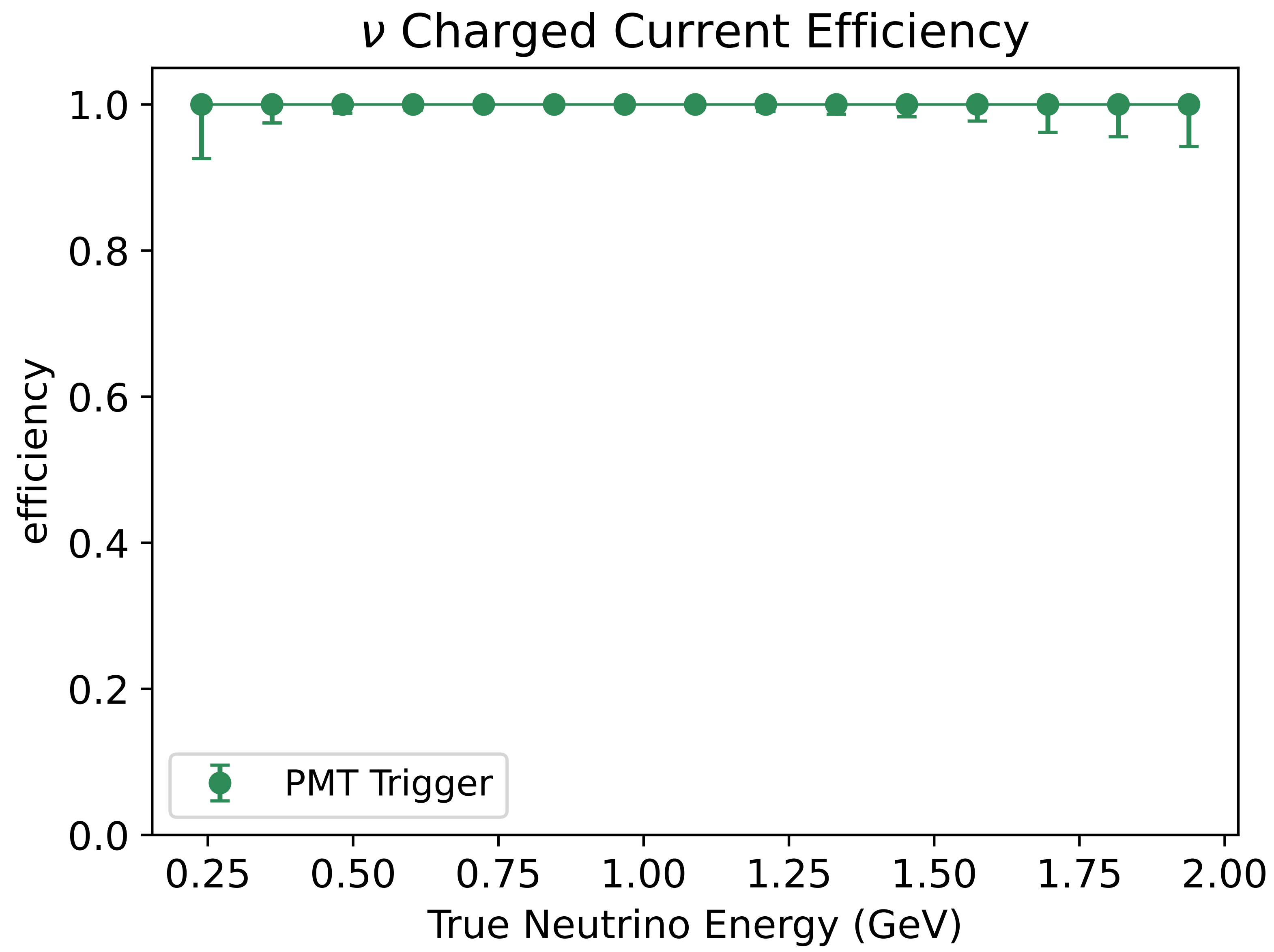
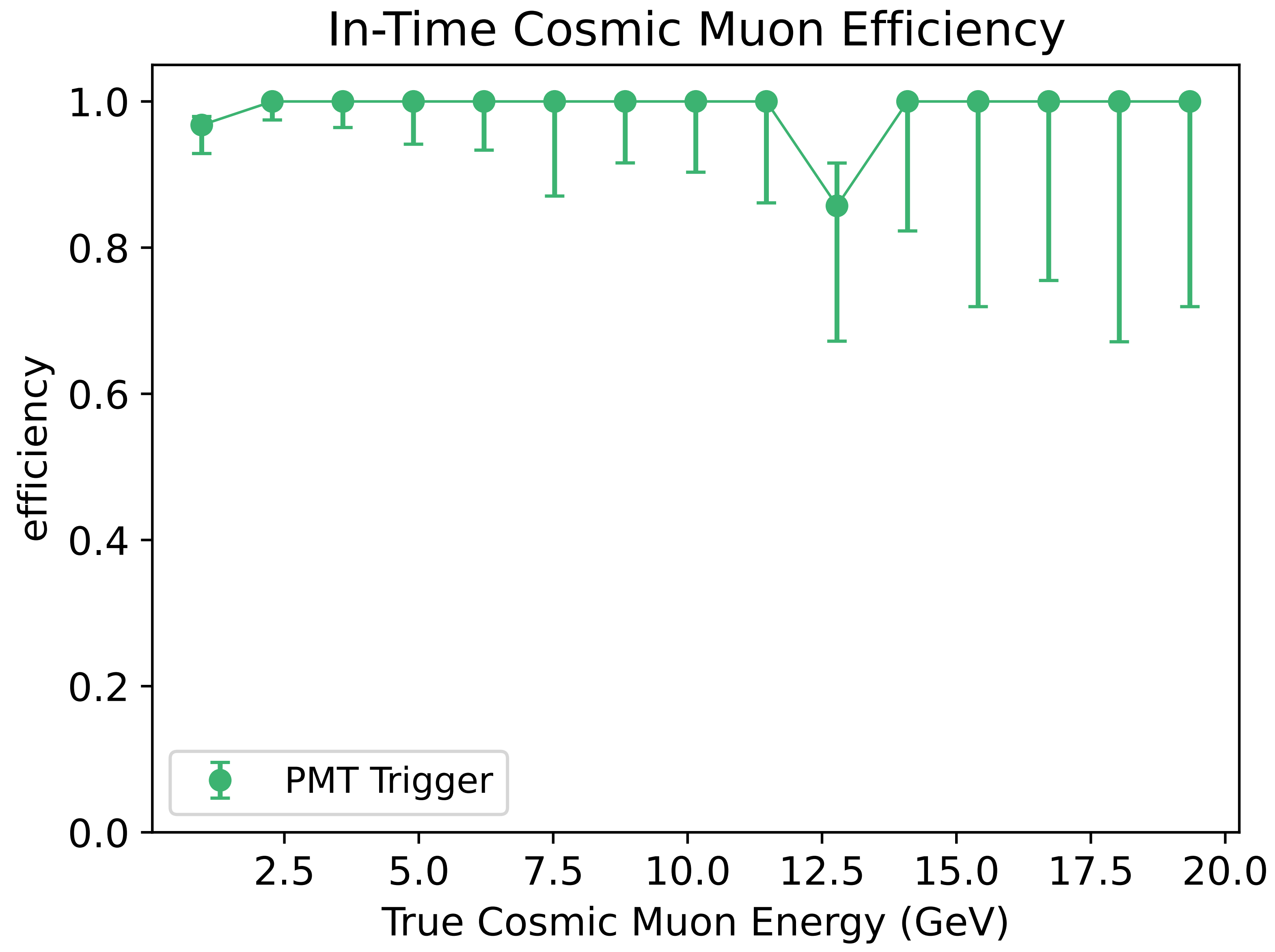
2. Neutrino Candidate Scoring







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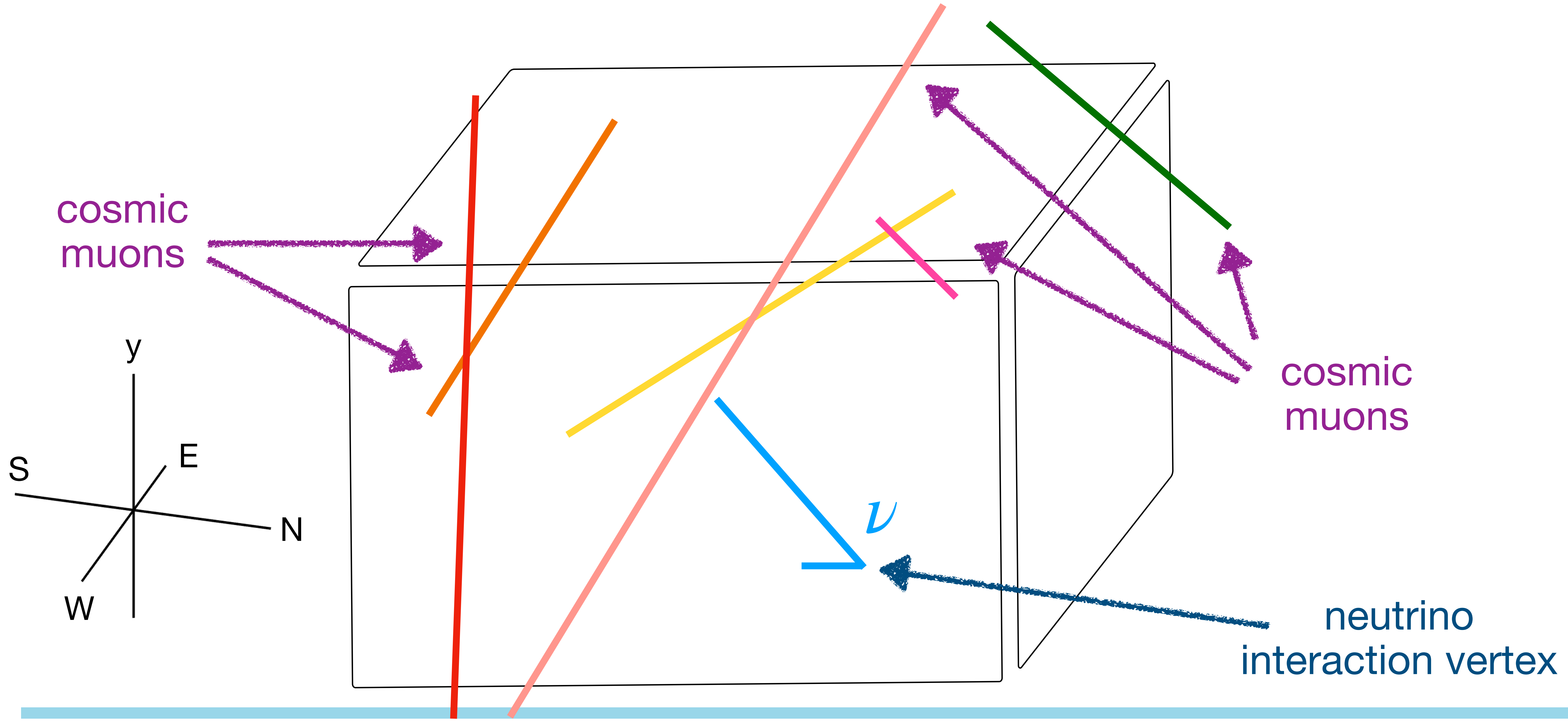

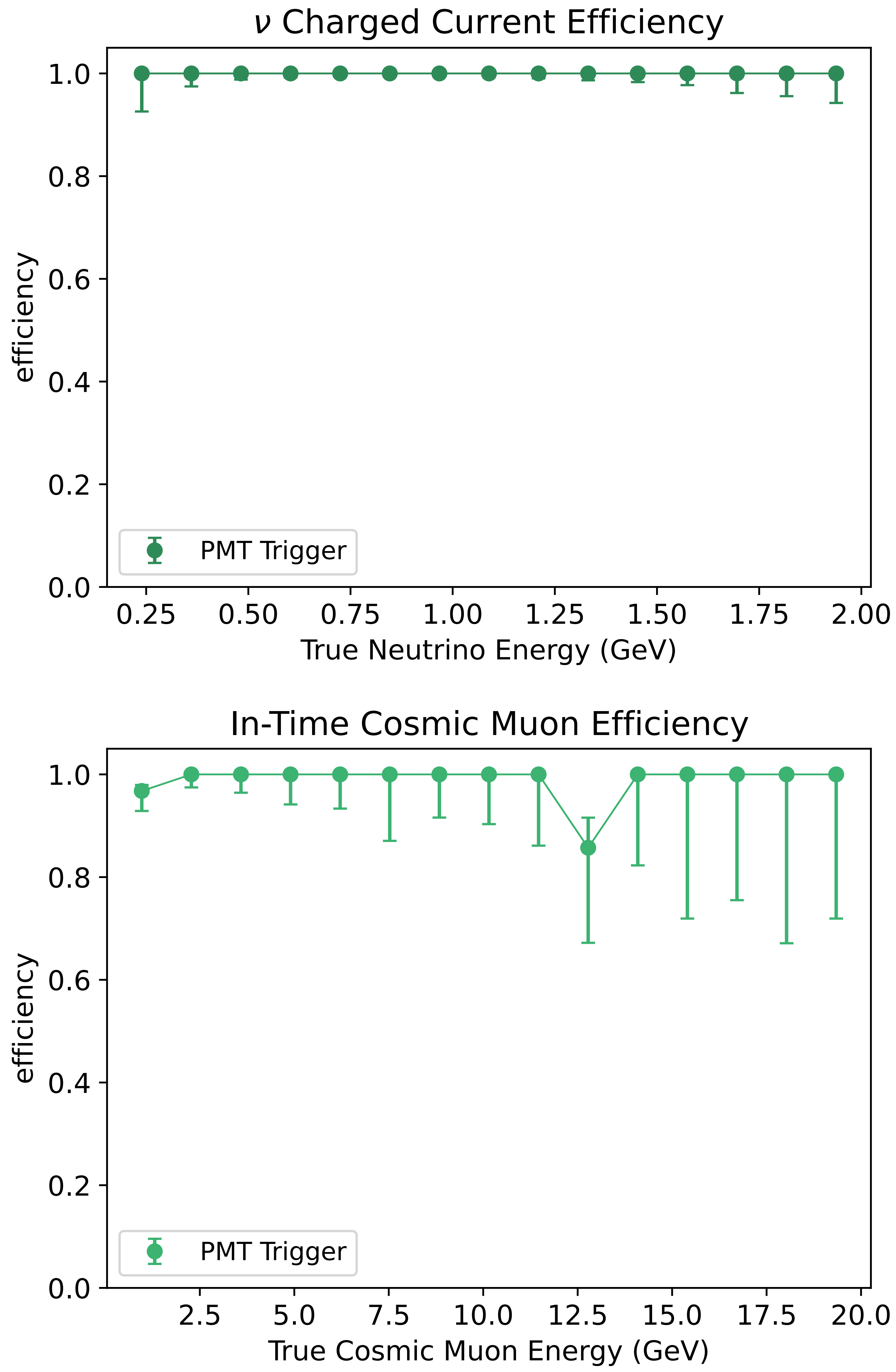

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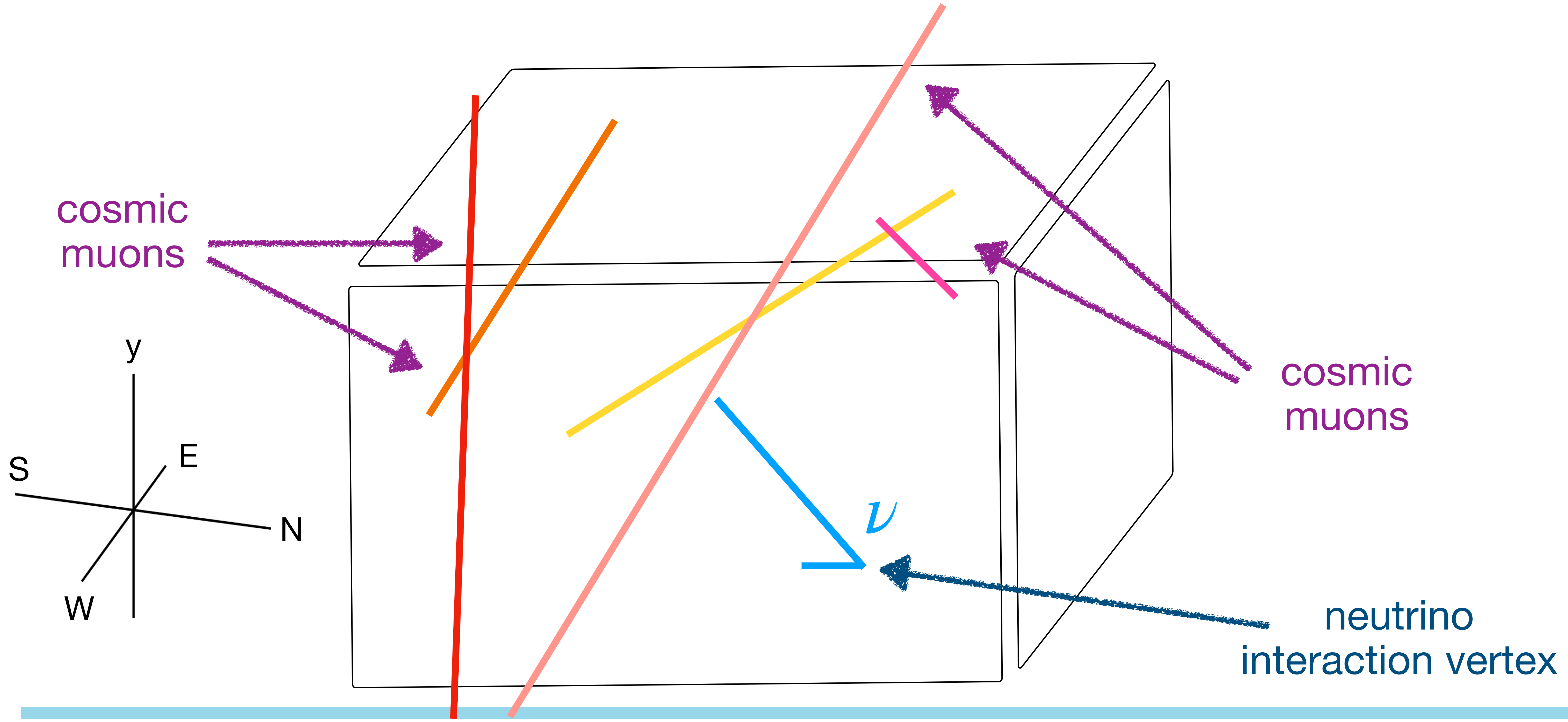
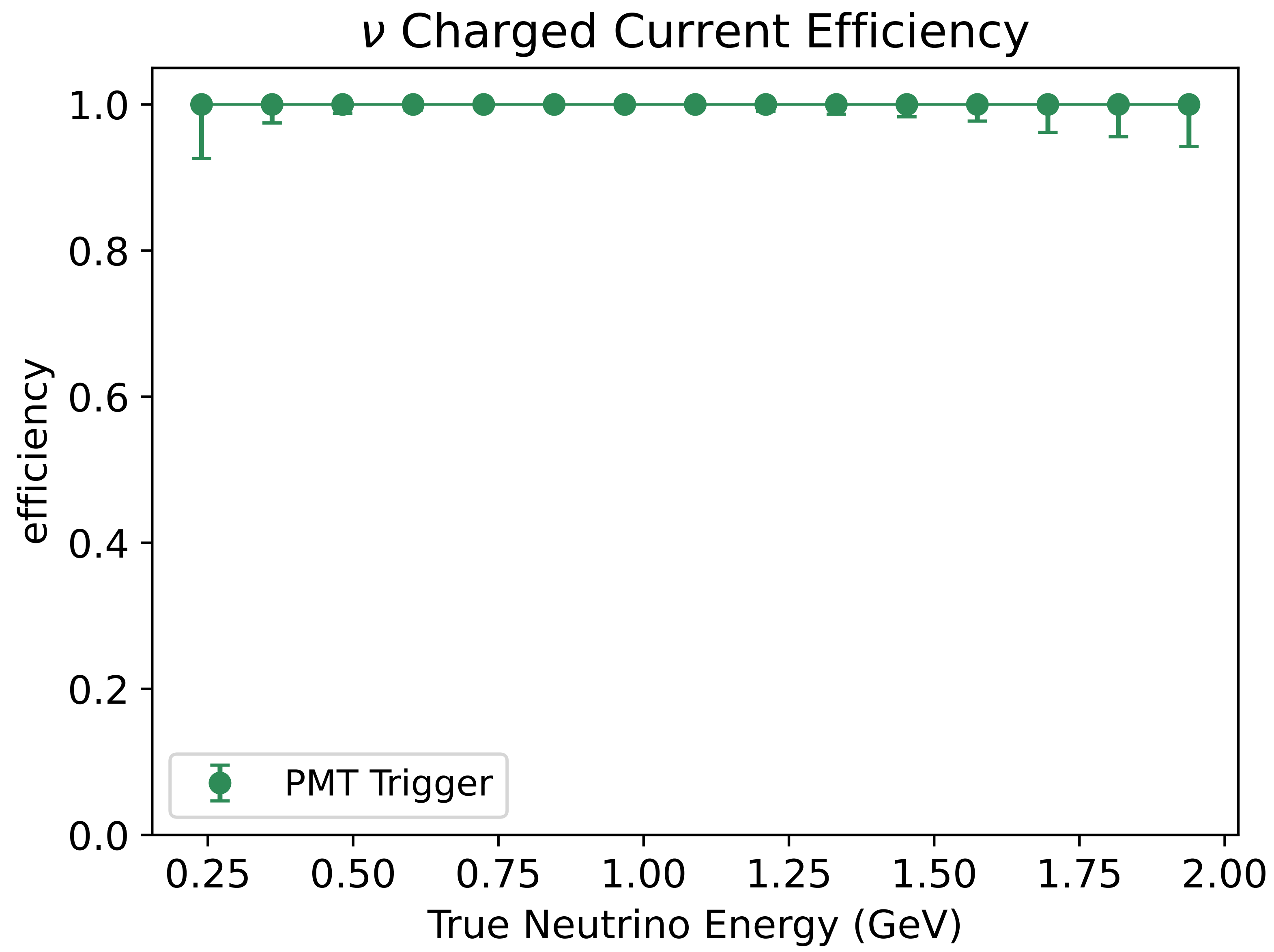
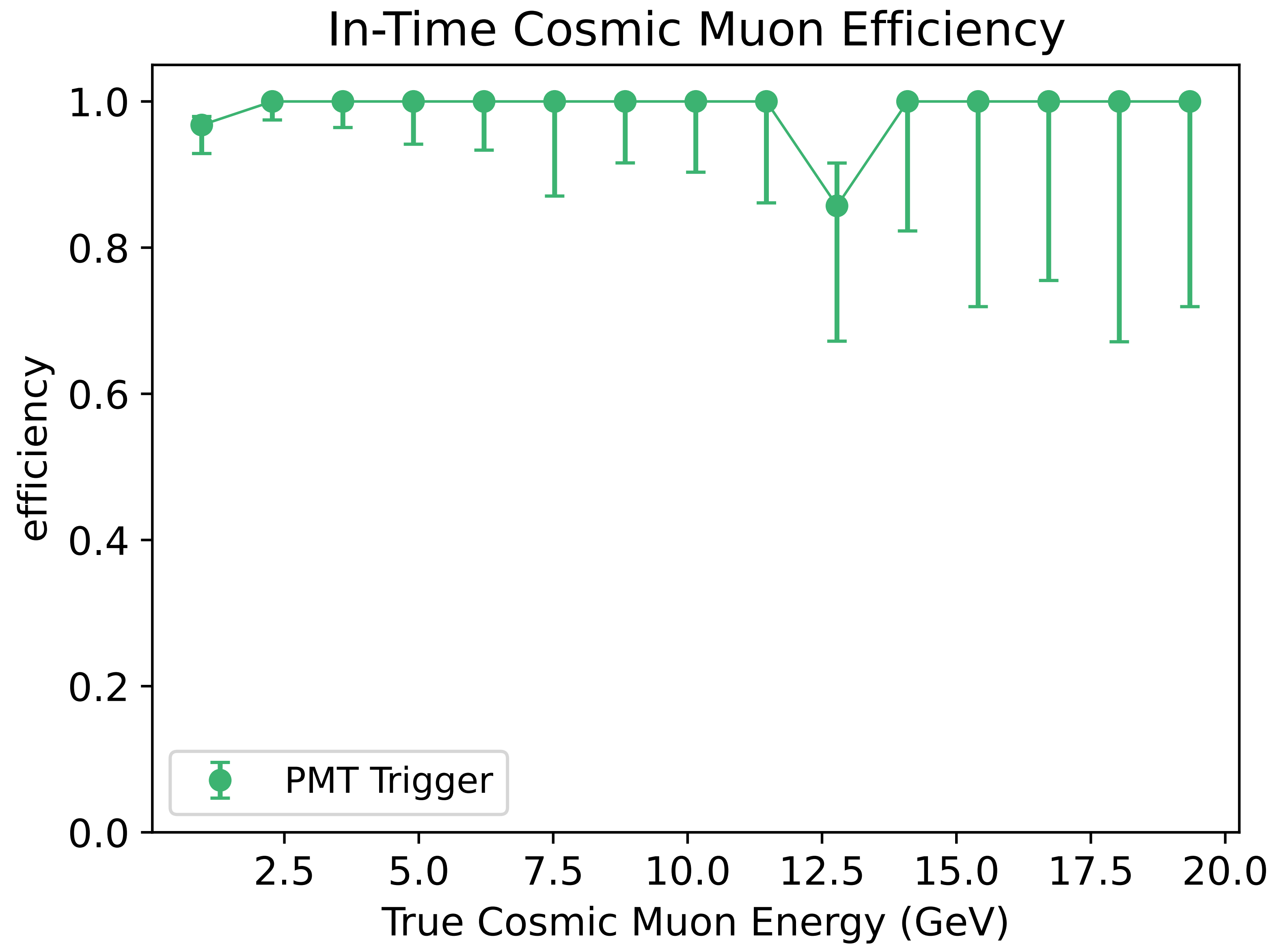


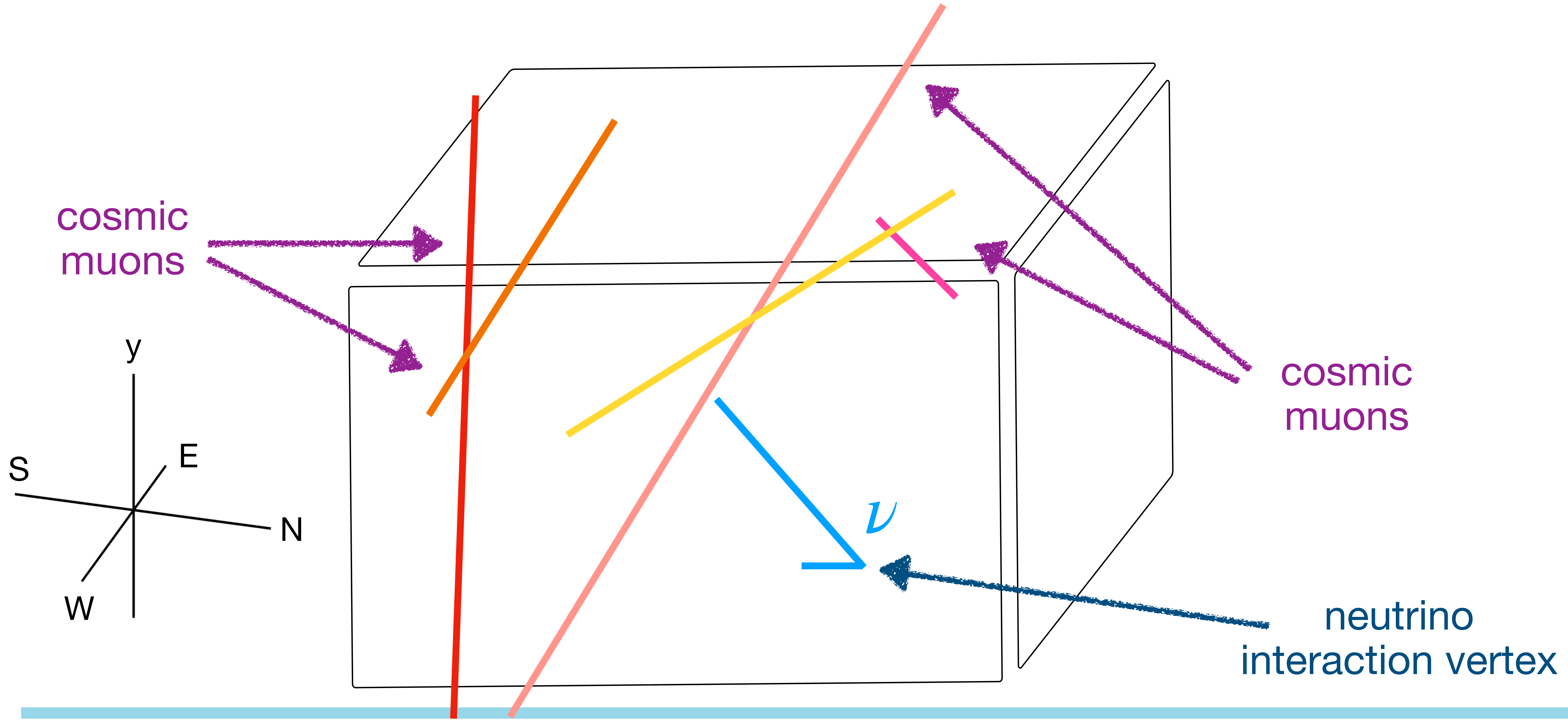


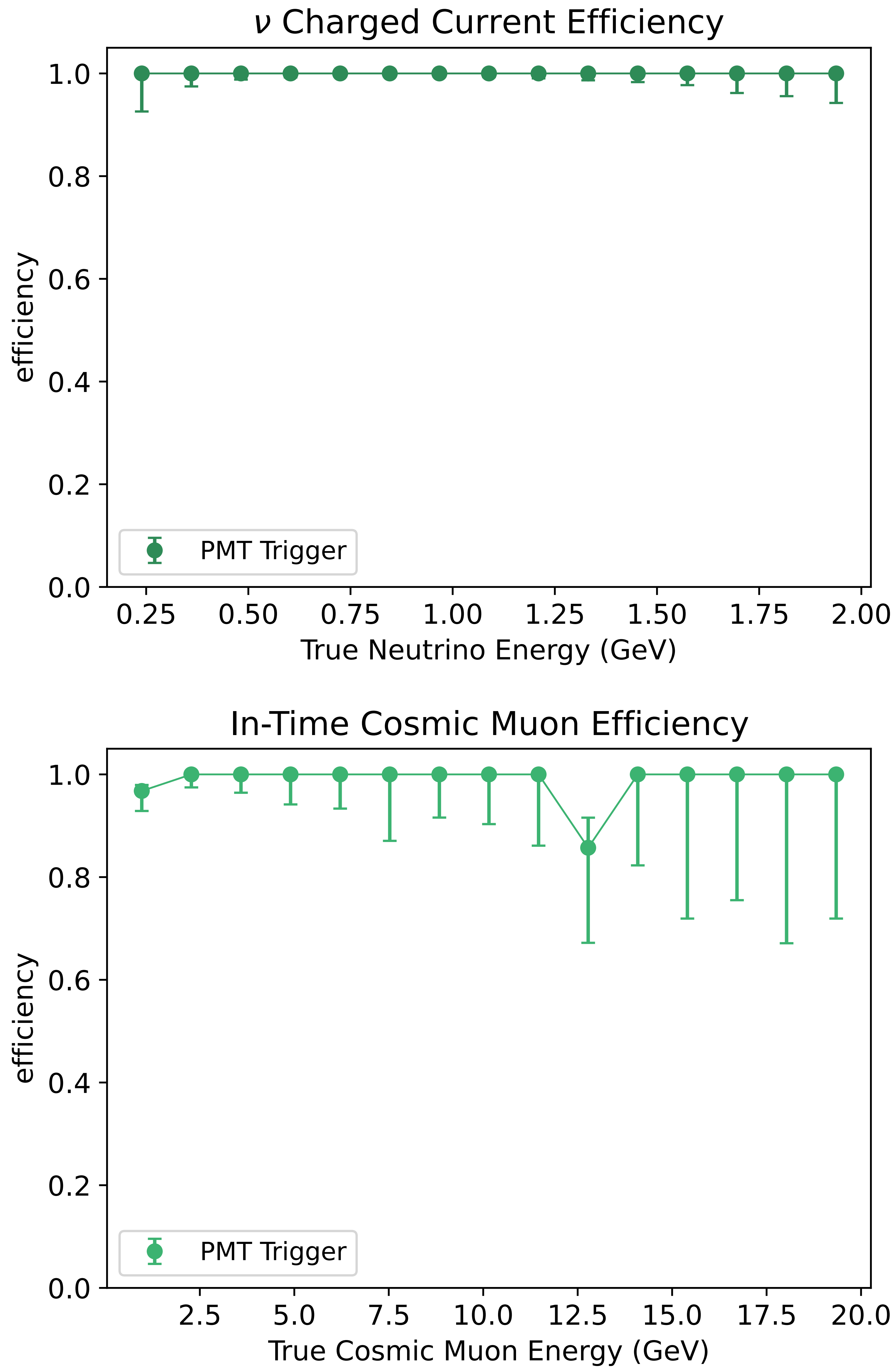


Pandora: ν (Nu) Candidate

1. **Unambiguous Cosmic Removal**
2. Neutrino Candidate Scoring

- Un-contained (clear enter and exit) Muons
  - anode-cathode crossers (EW, out-of-time)





Pandora: ν (Nu) Candidate

1. **Unambiguous Cosmic Removal**
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- Un-contained (clear enter and exit) Muons
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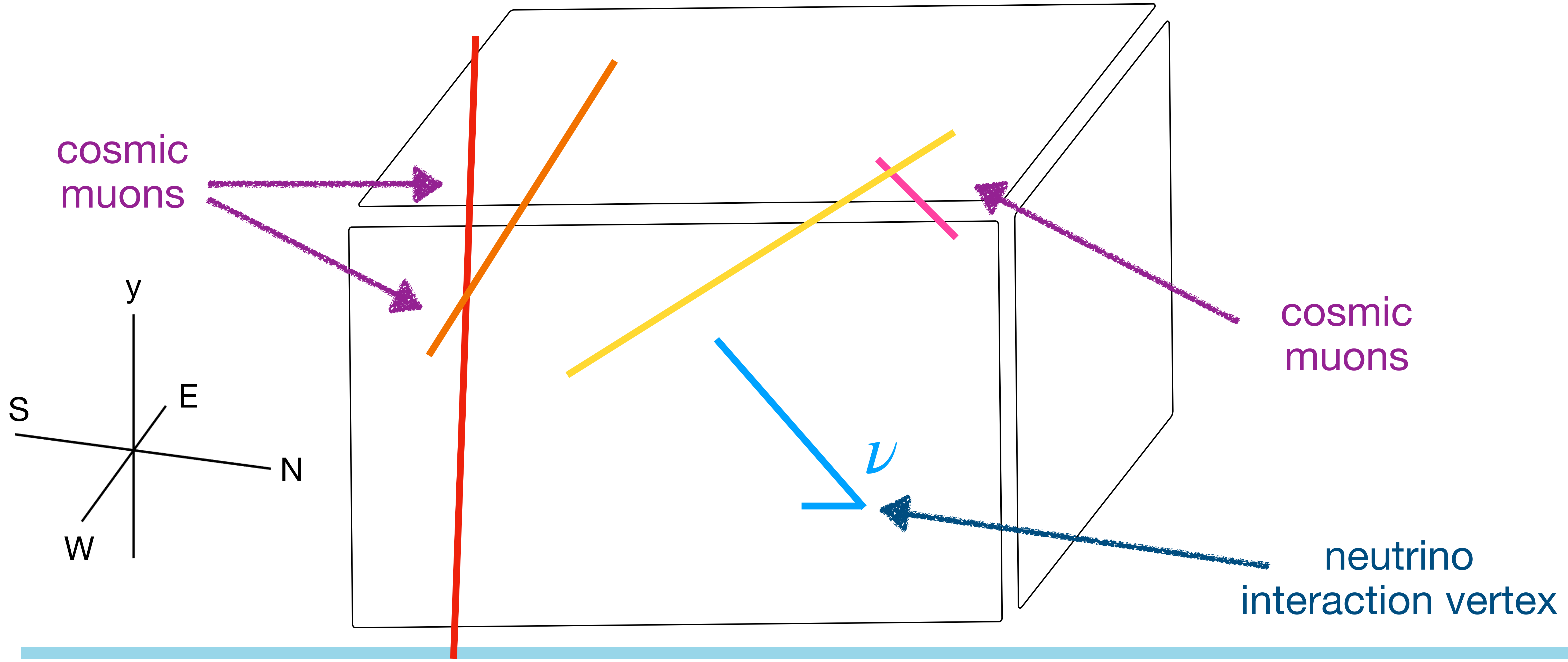
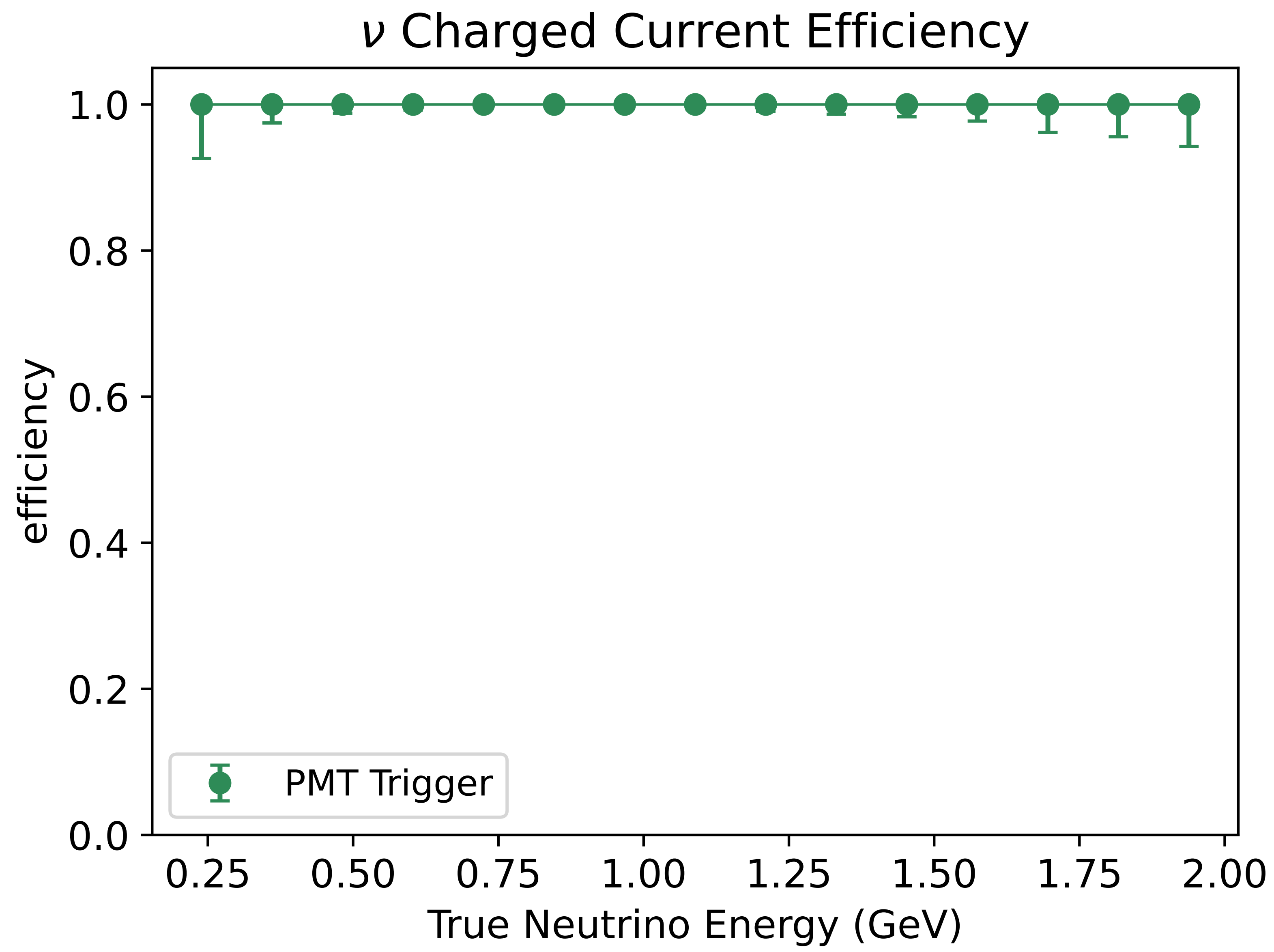
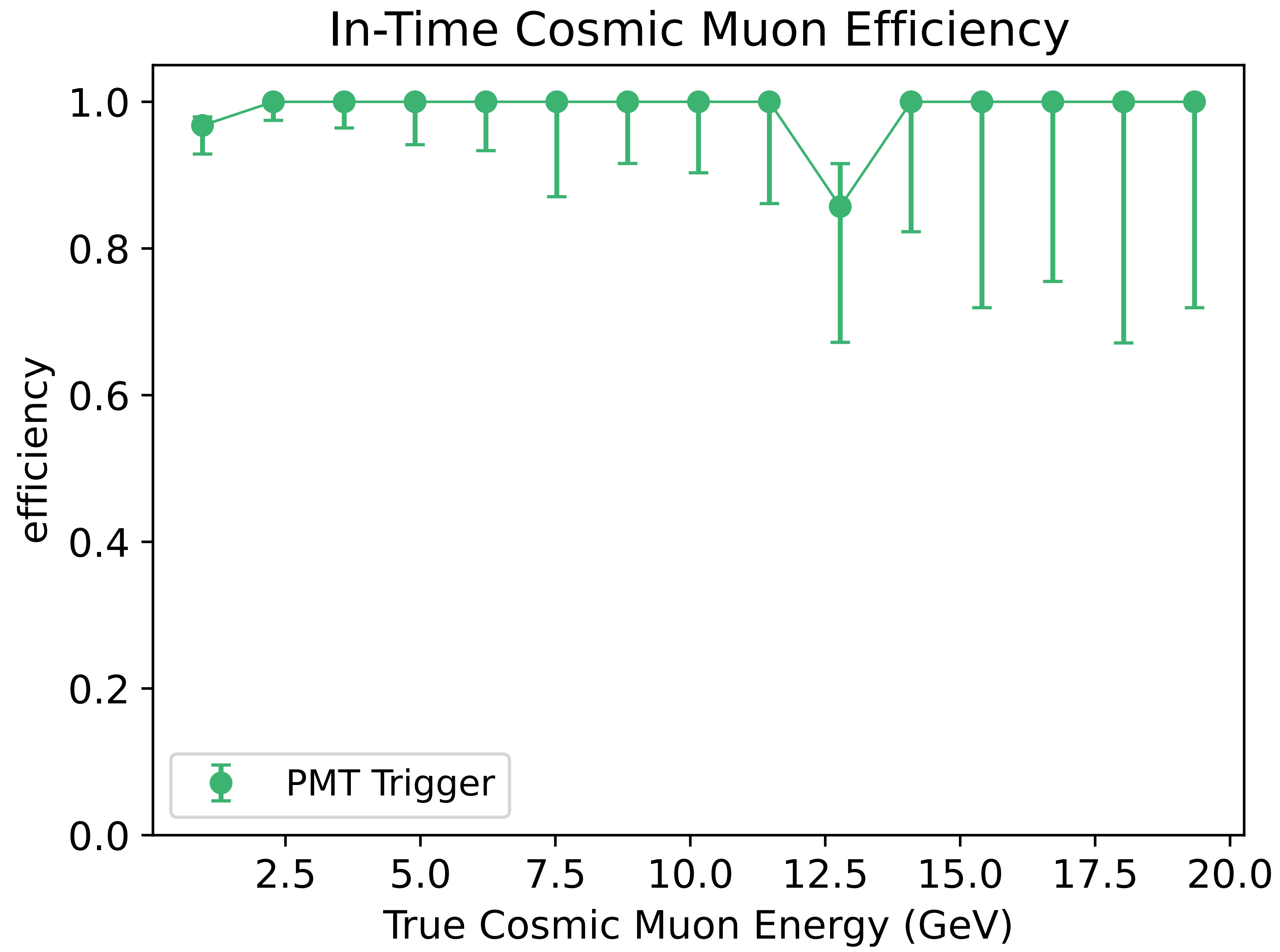
  - top-bottom crossers (same y-coordinates)







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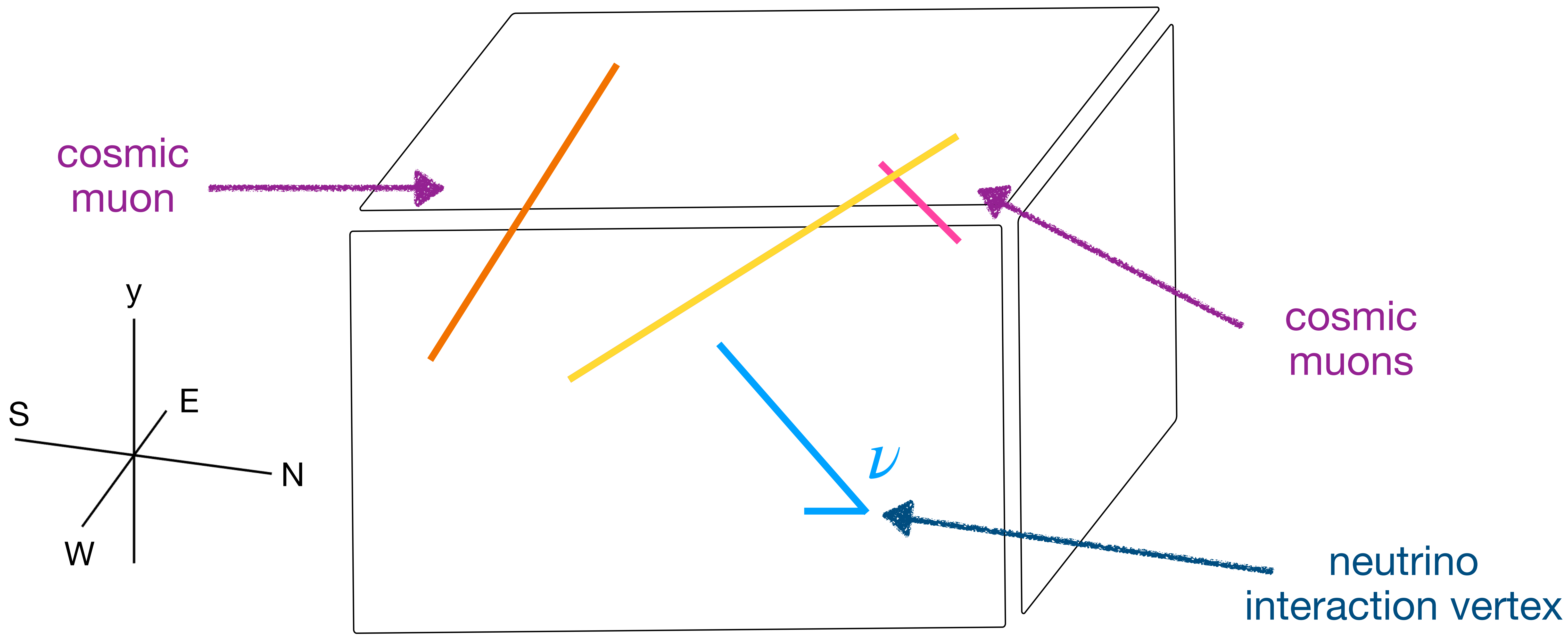
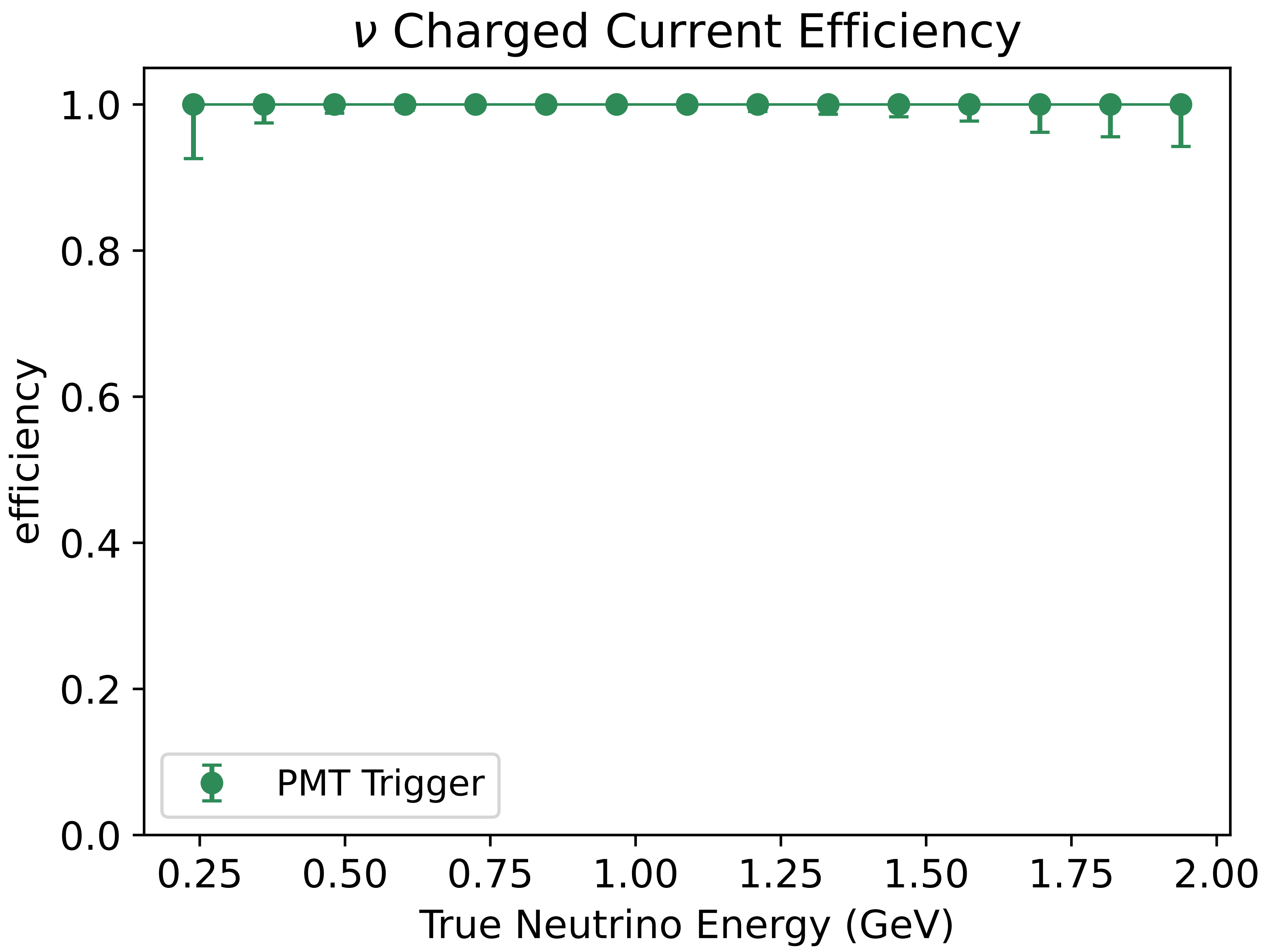
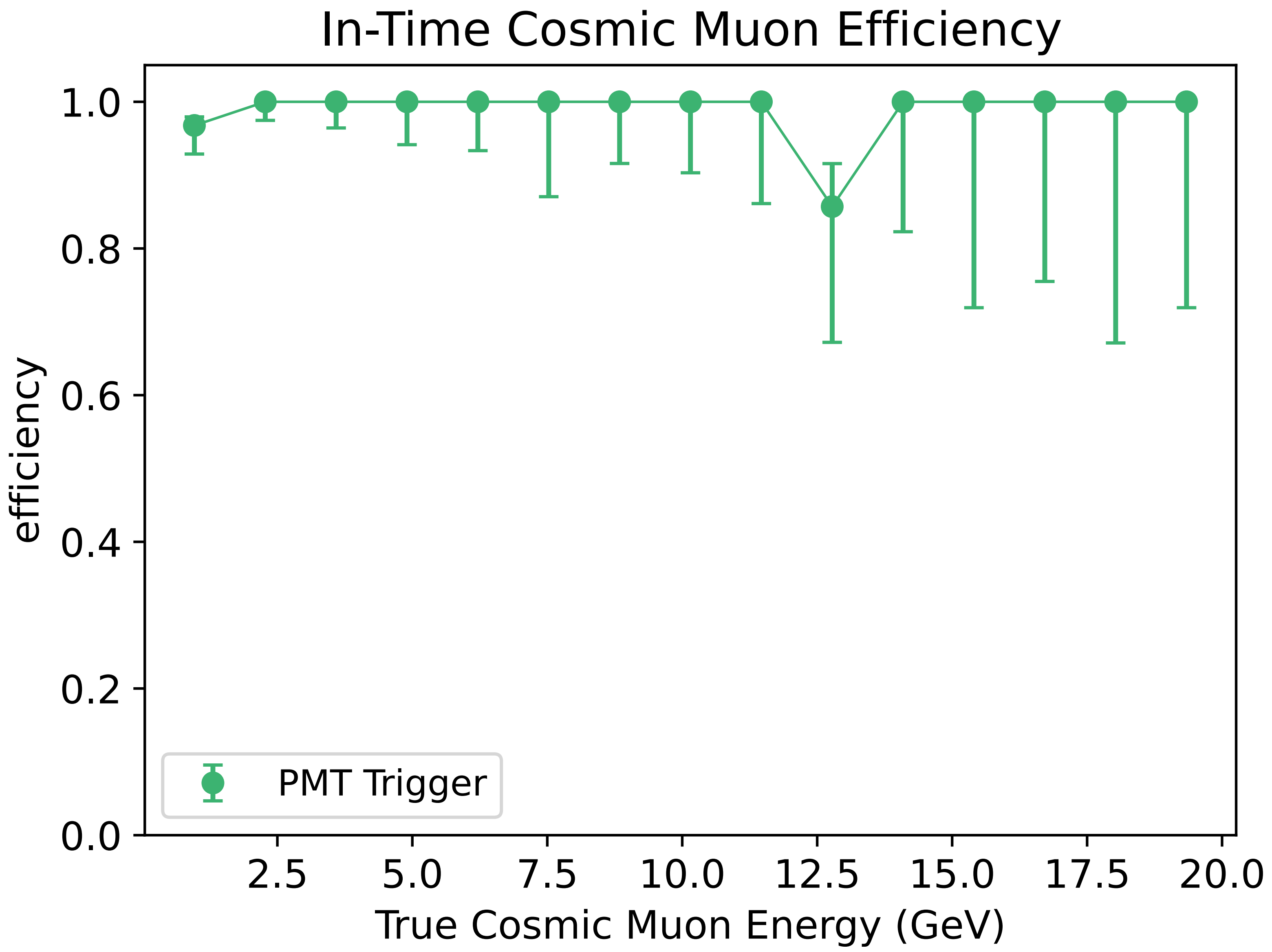




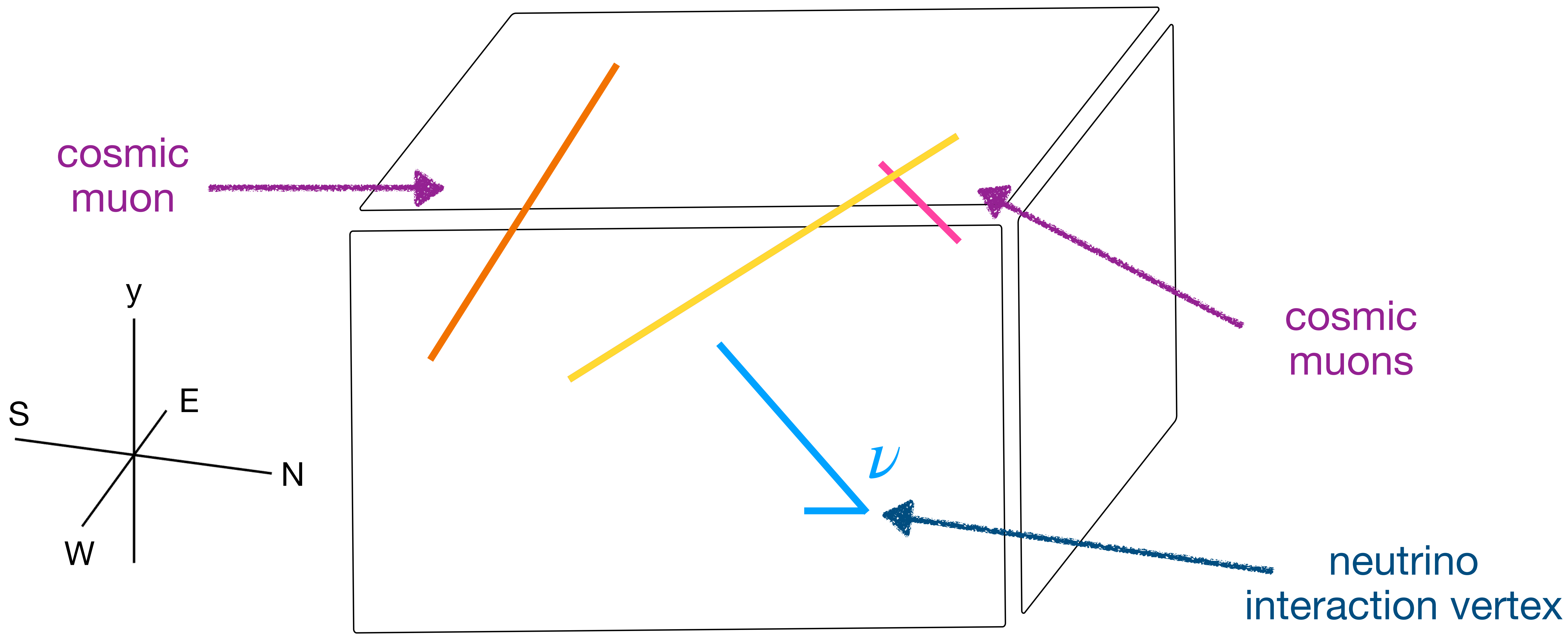


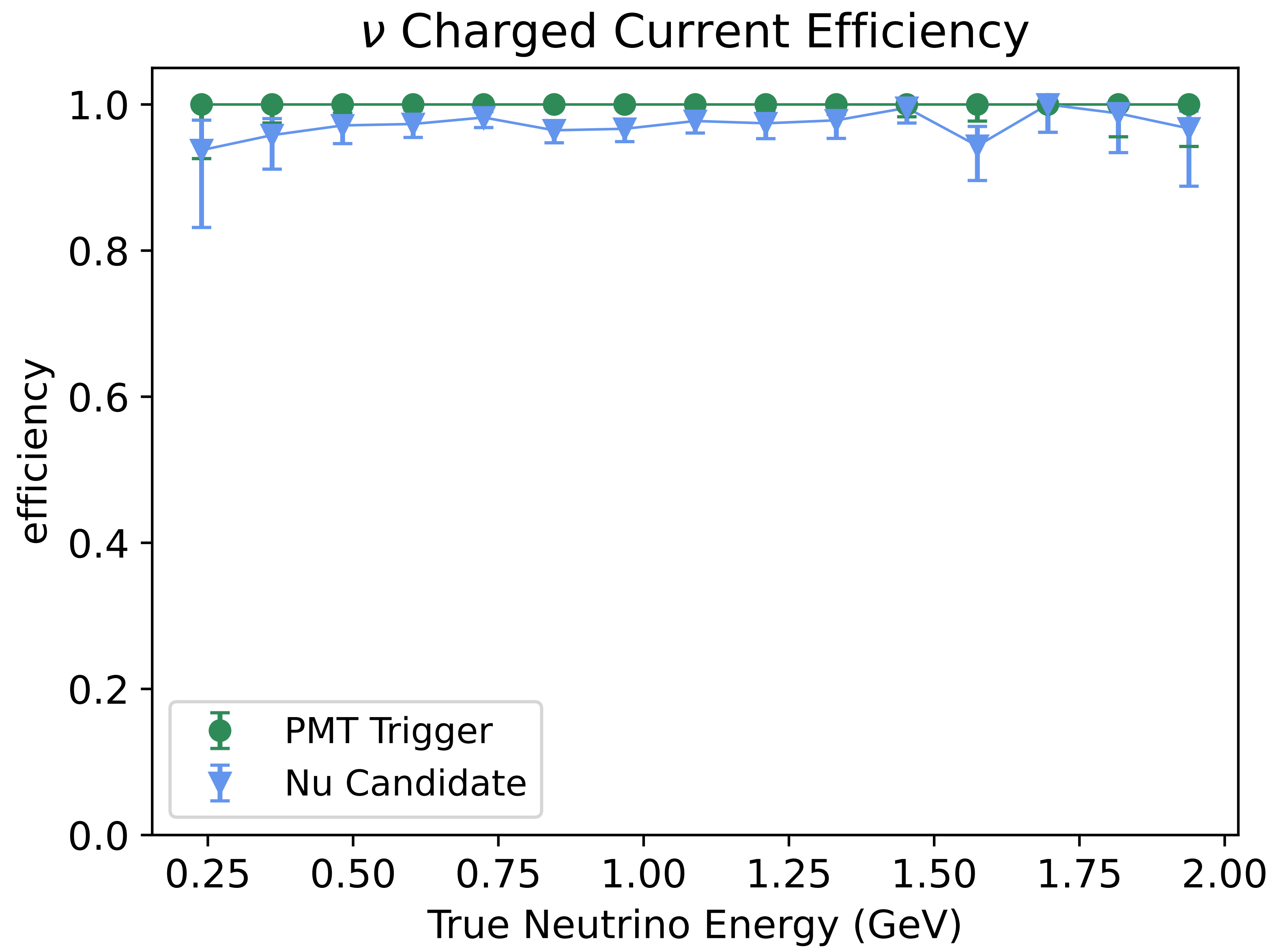
Pandora: ν (Nu) Candidate

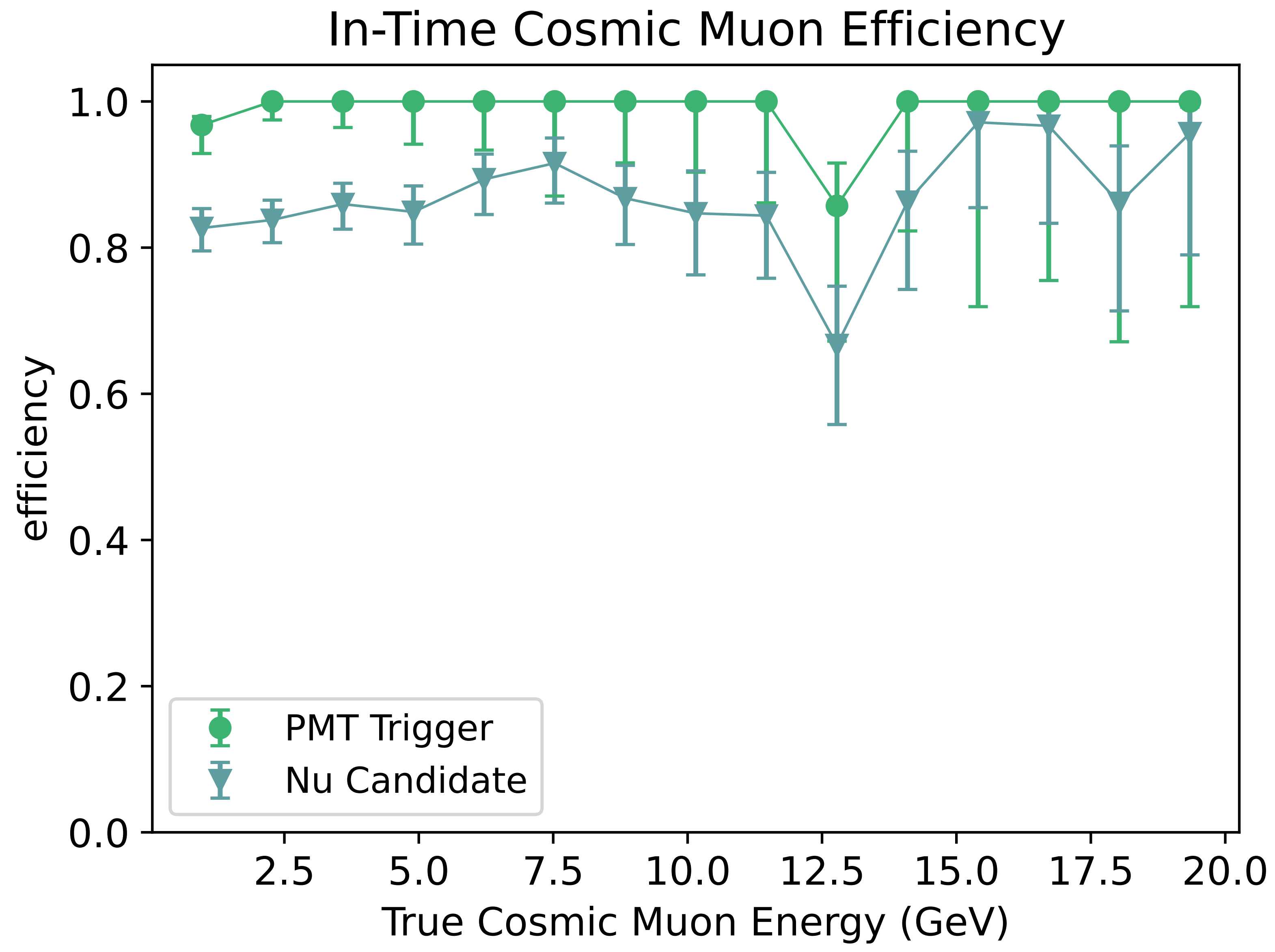
1. **Unambiguous Cosmic Removal**
2. Neutrino Candidate Scoring

CC neutrino events: ~95-100%

cosmic muon efficiency: ~80-95%



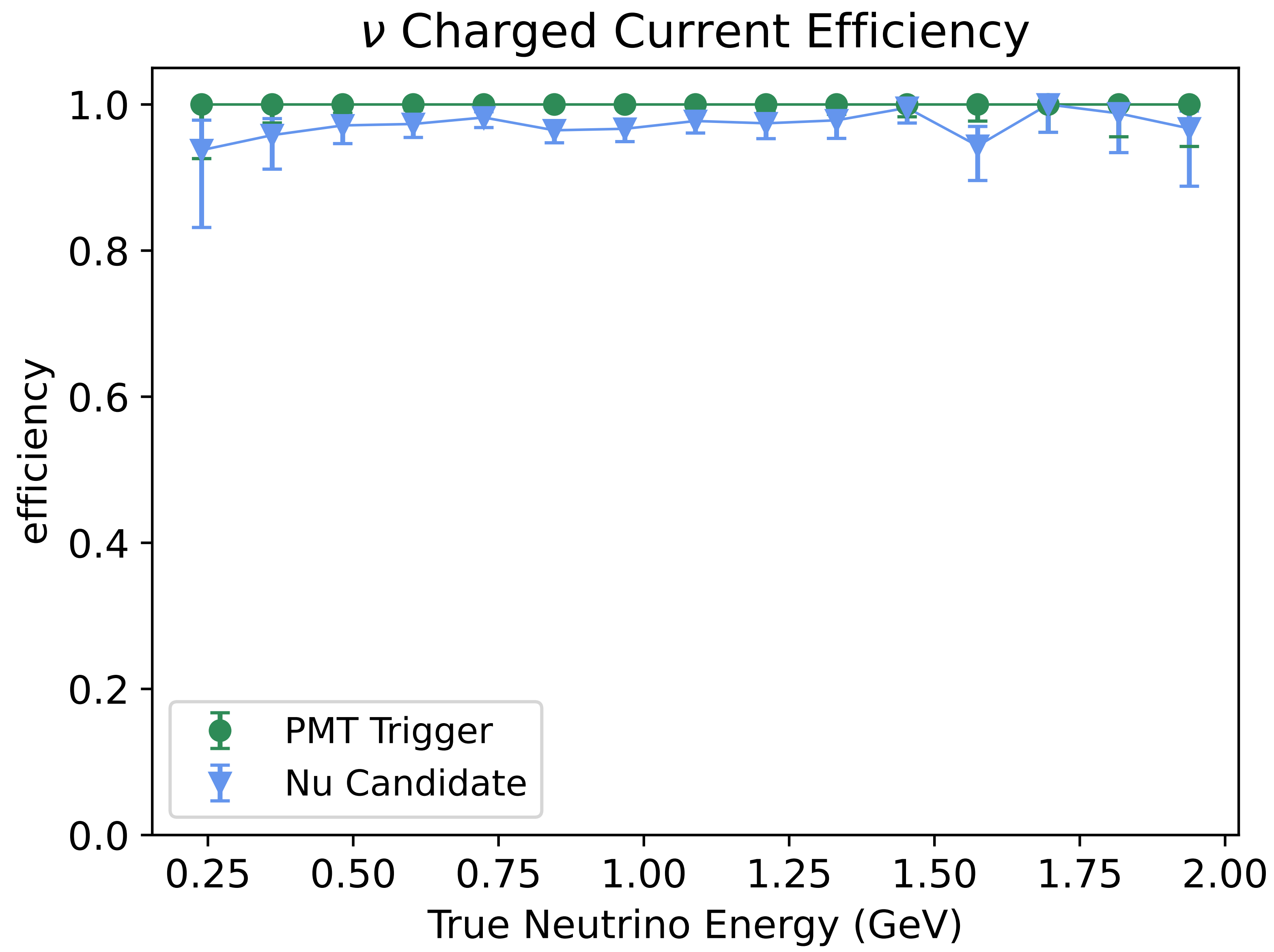


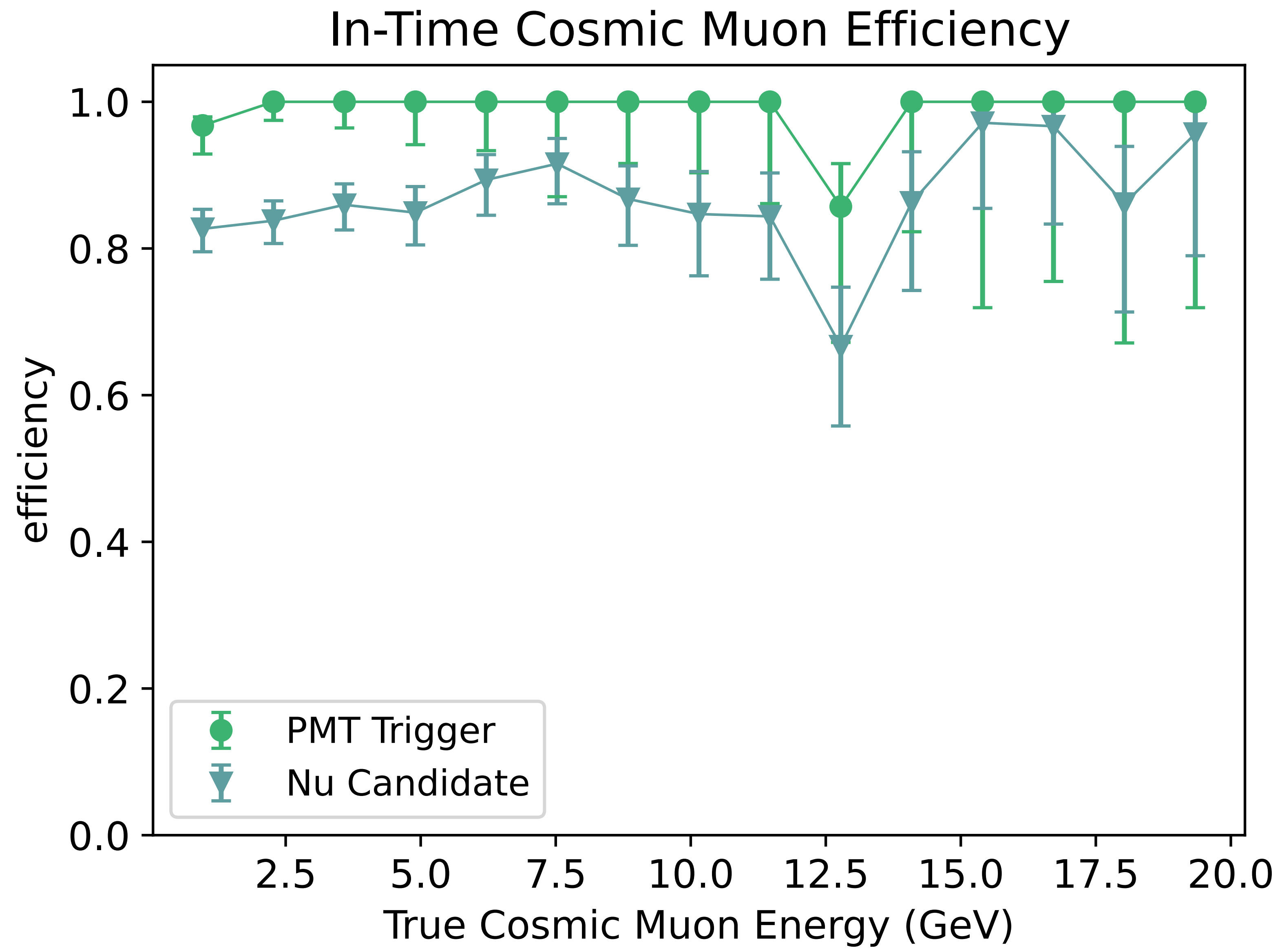


Pandora: ν (Nu) Score

1. Unambiguous Cosmic Removal
2. **Neutrino Candidate Scoring**

- Multivariate analysis with boosted decision trees





Pandora: ν (Nu) Score

1. Unambiguous Cosmic Removal
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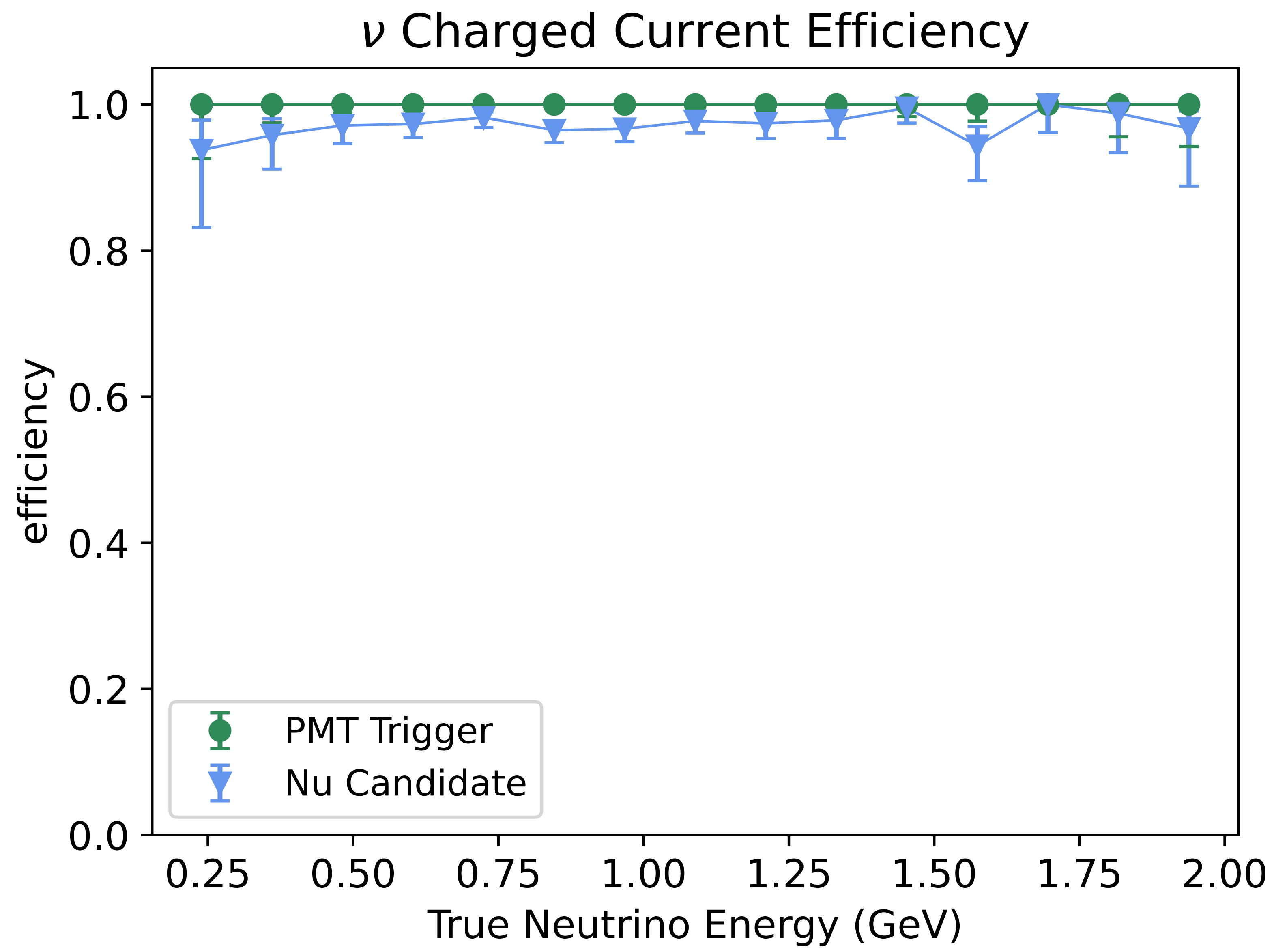
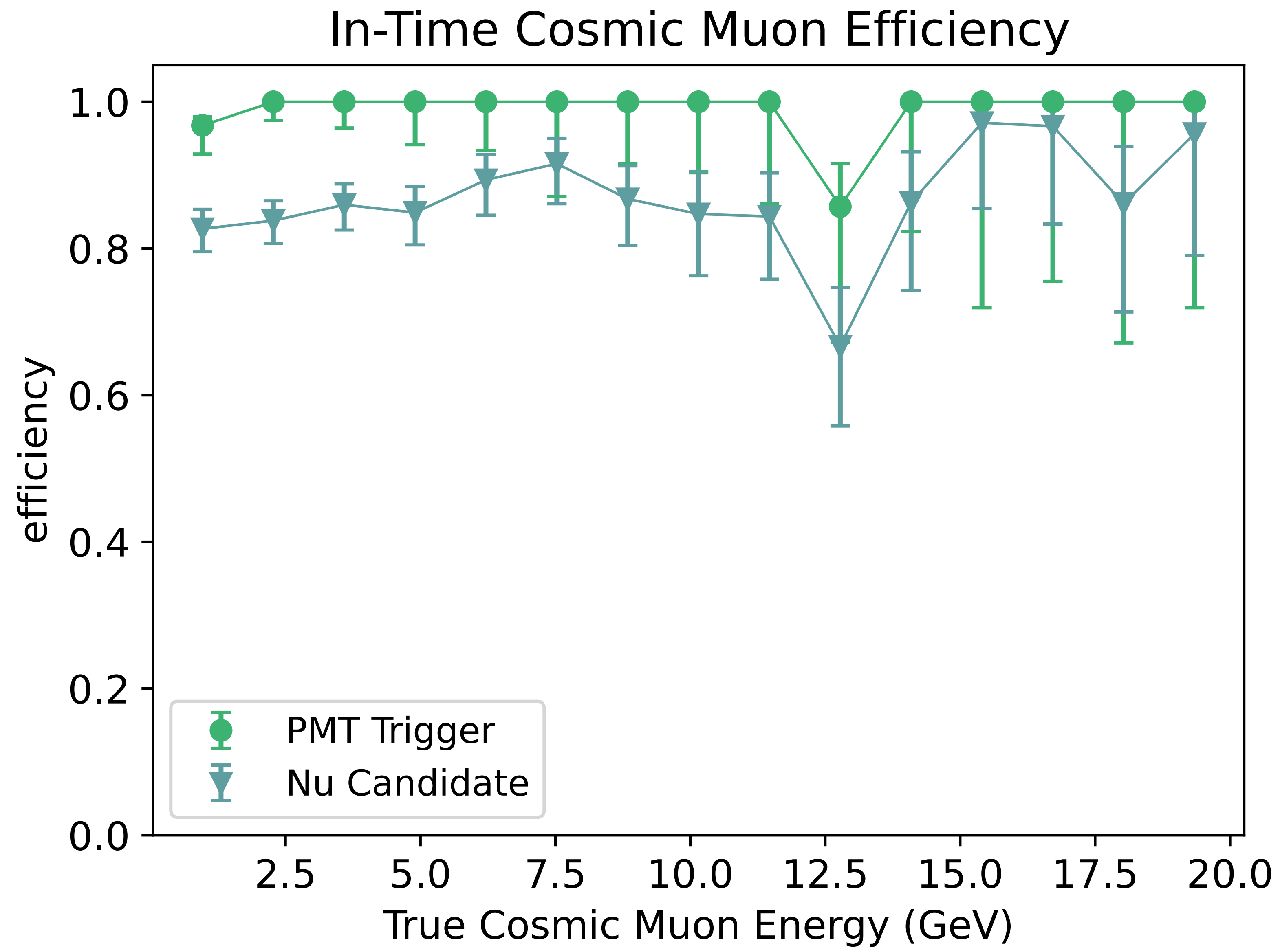
  - variables include: # of daughter particles, number of hits collected on wires, length and direction of tracks, etc.





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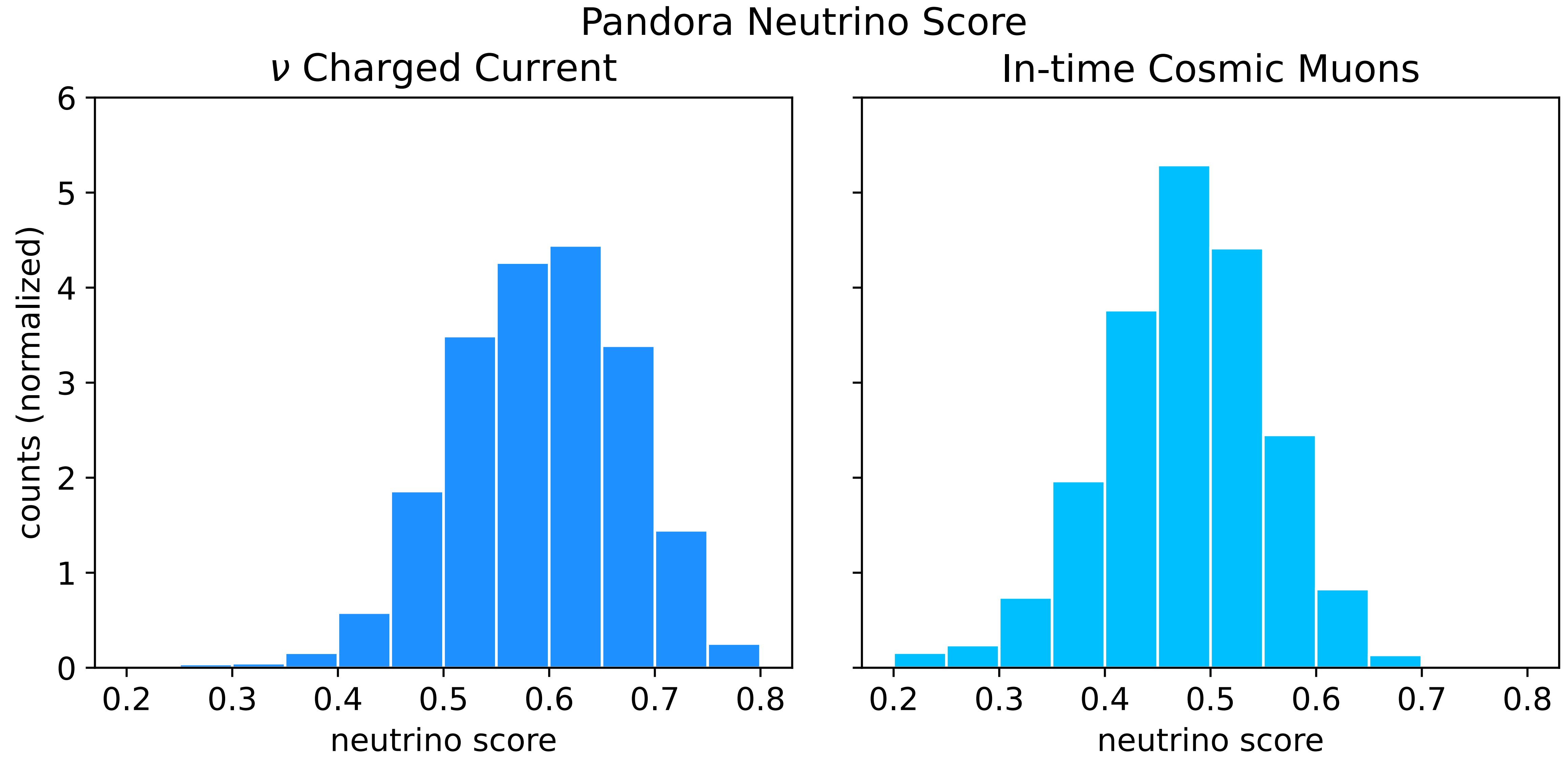
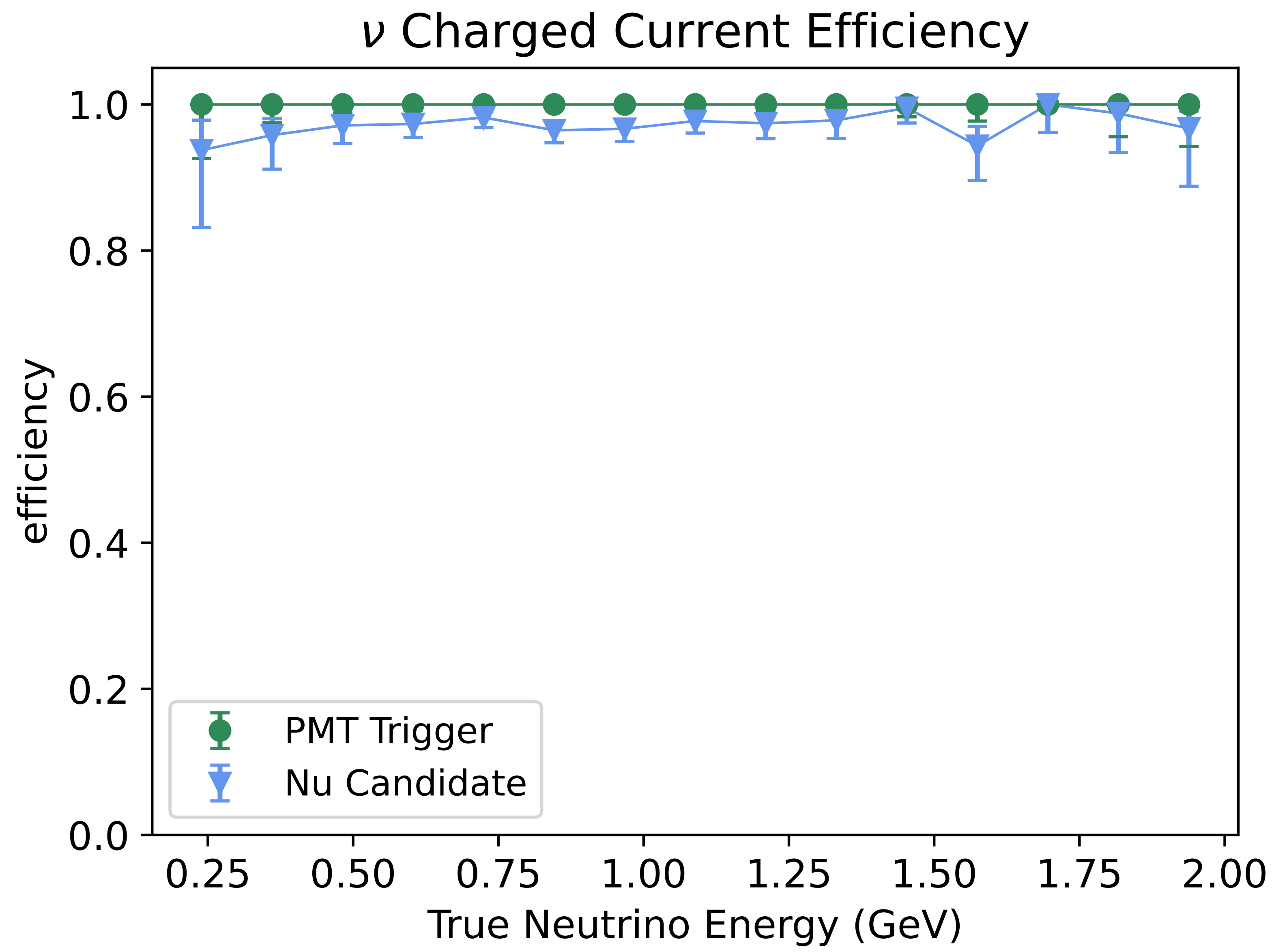
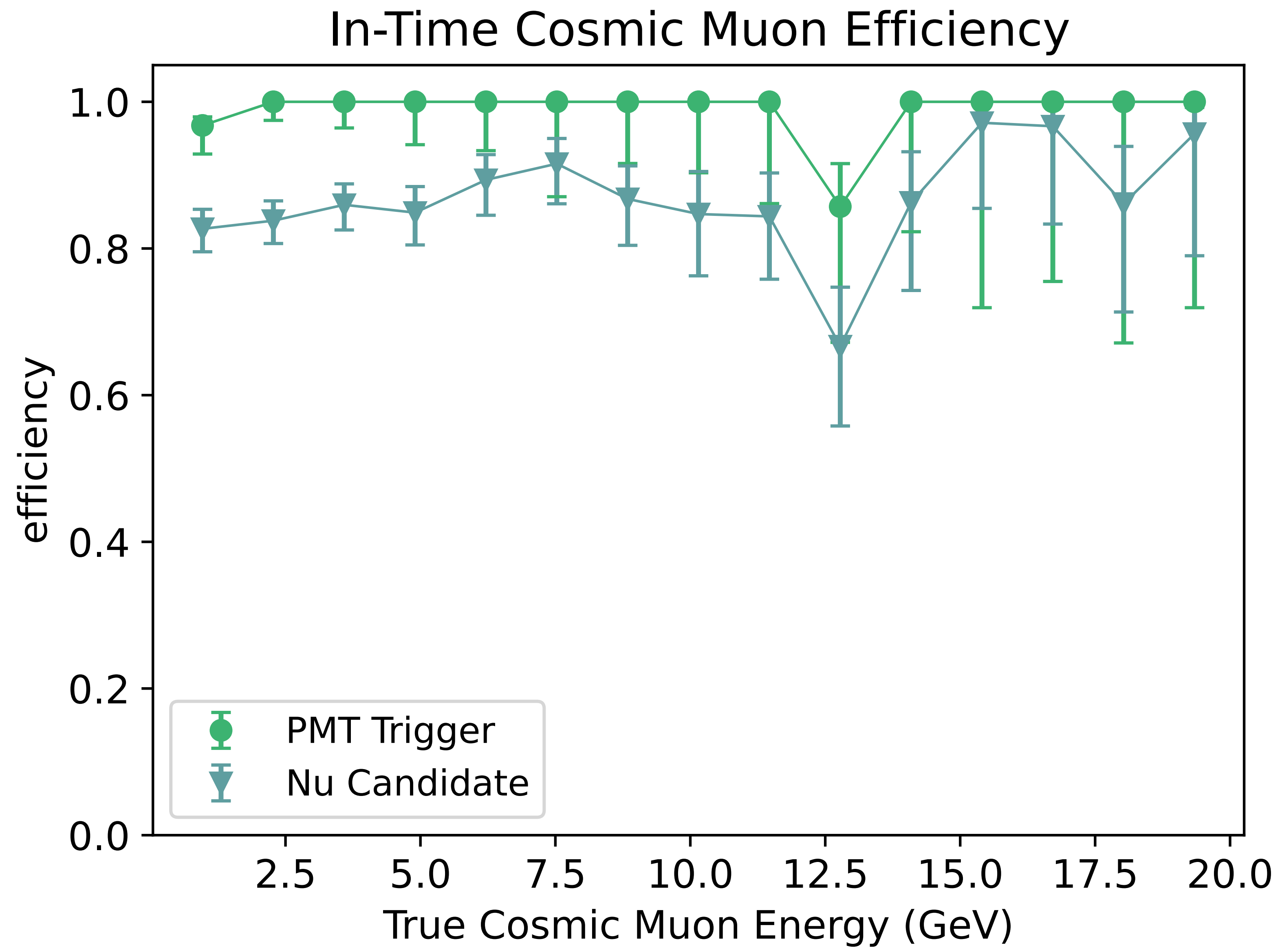


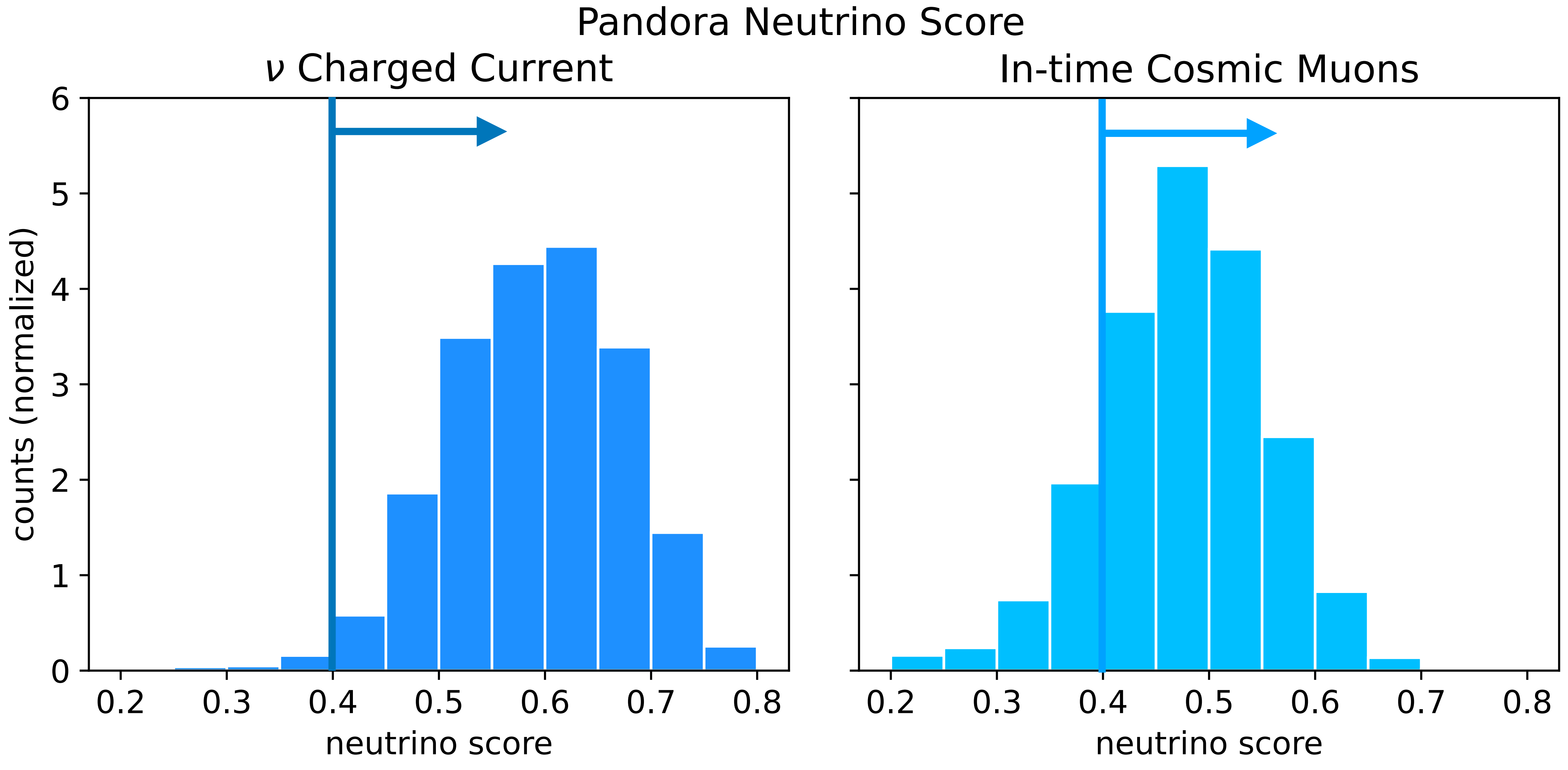


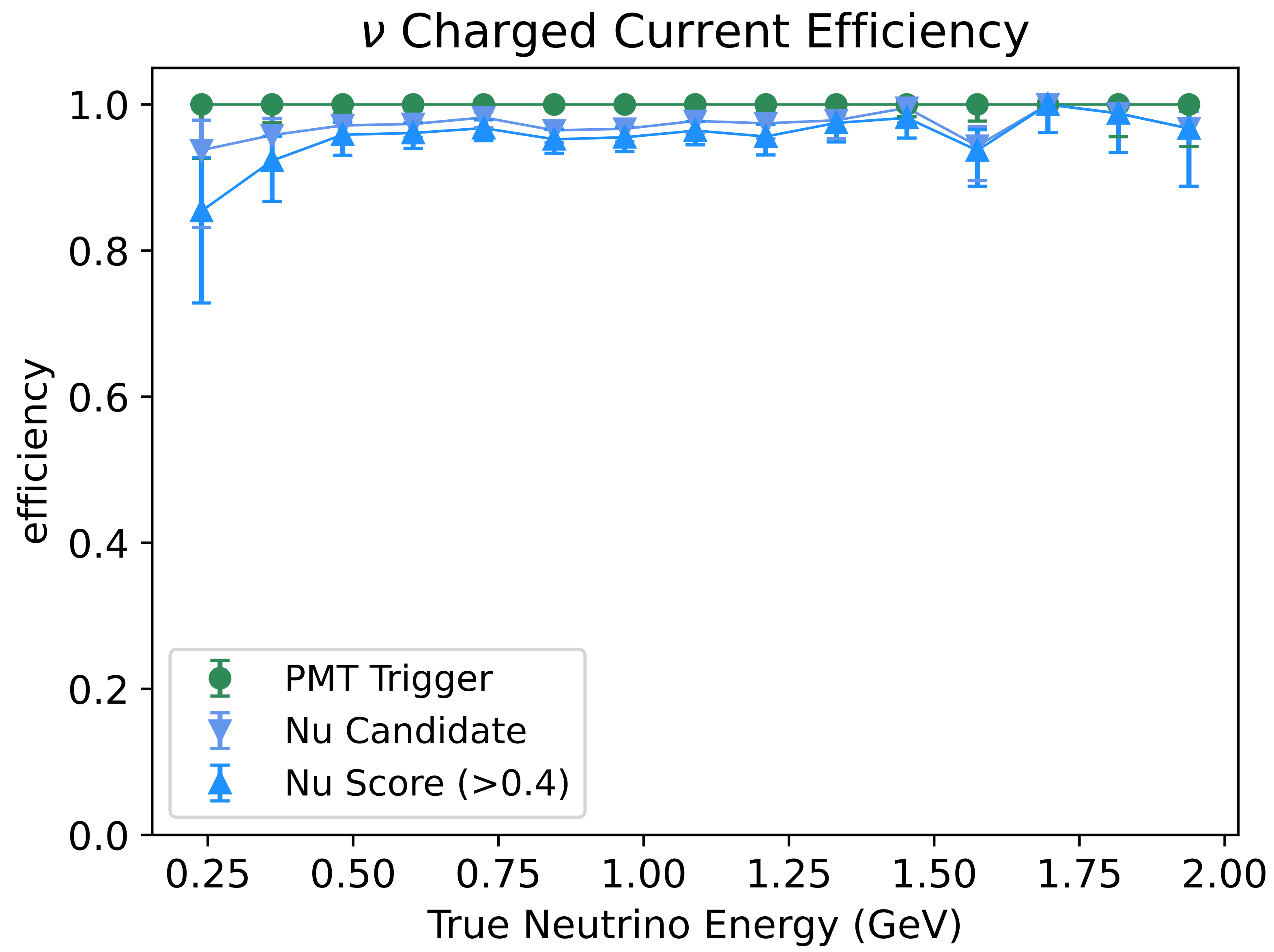


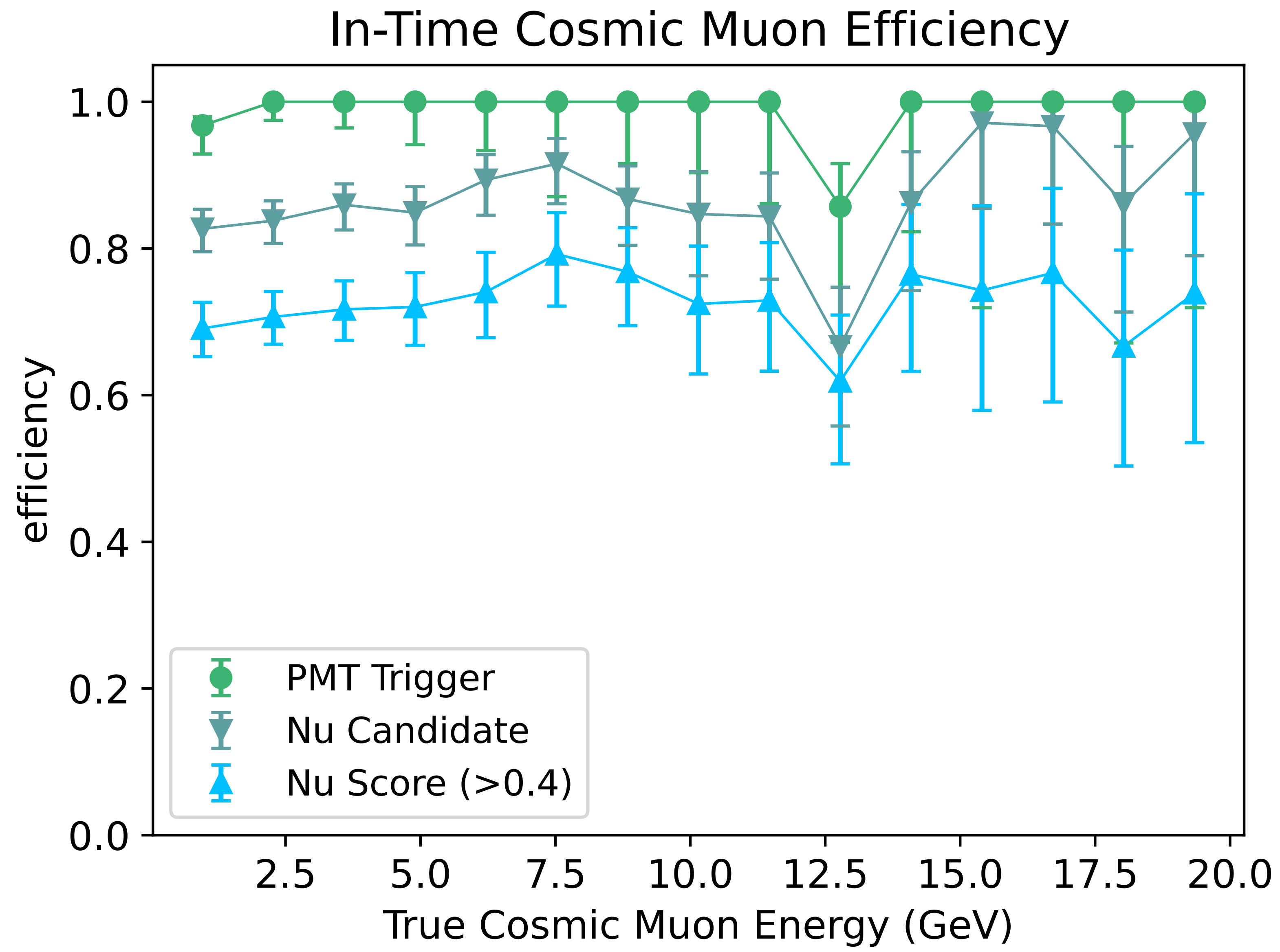
Pandora: ν (Nu) Score

1. Unambiguous Cosmic Removal
2. **Neutrino Candidate Scoring**

- apply cut at ν-score > 0.4







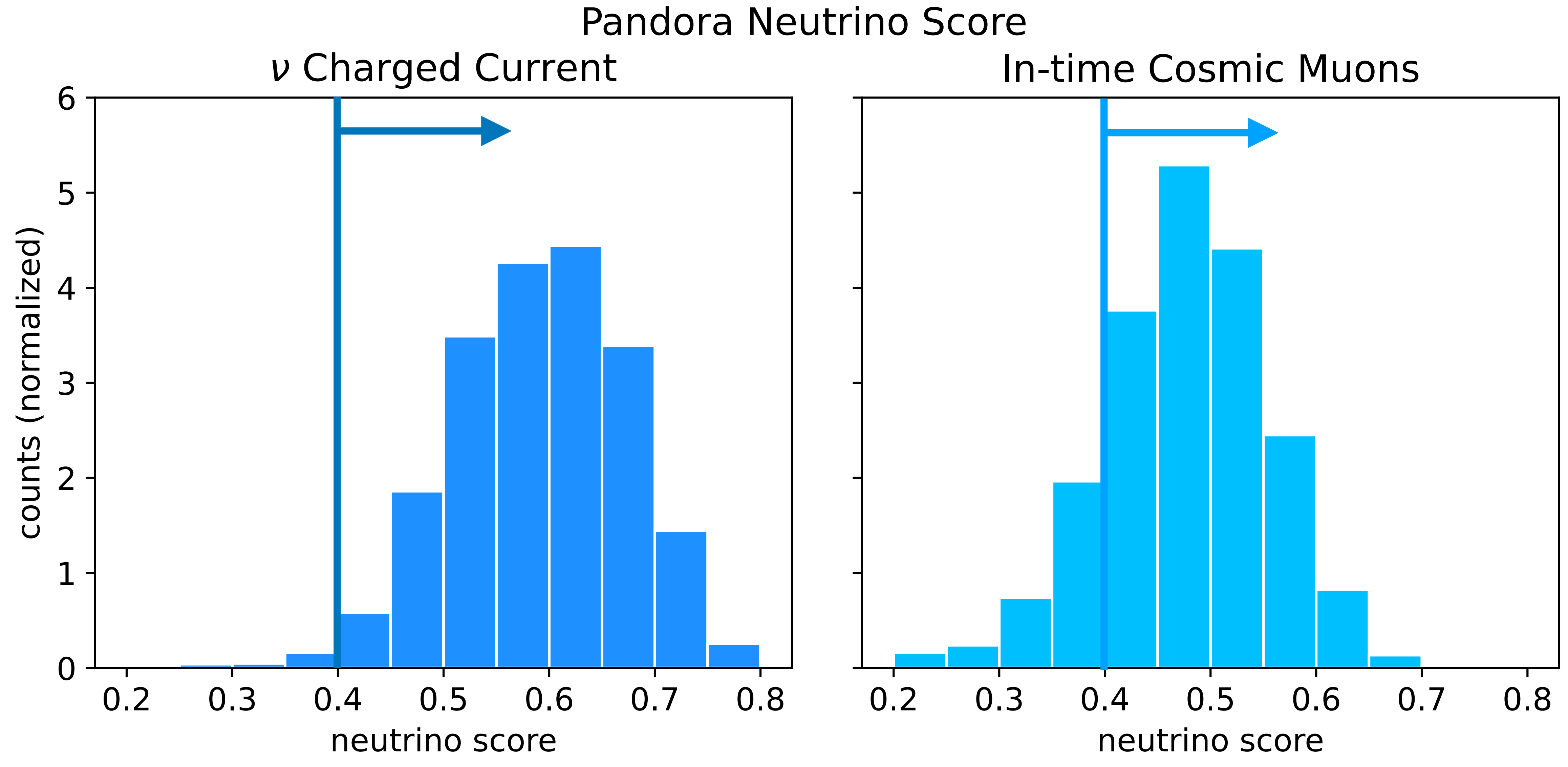
Pandora: ν (Nu) Score

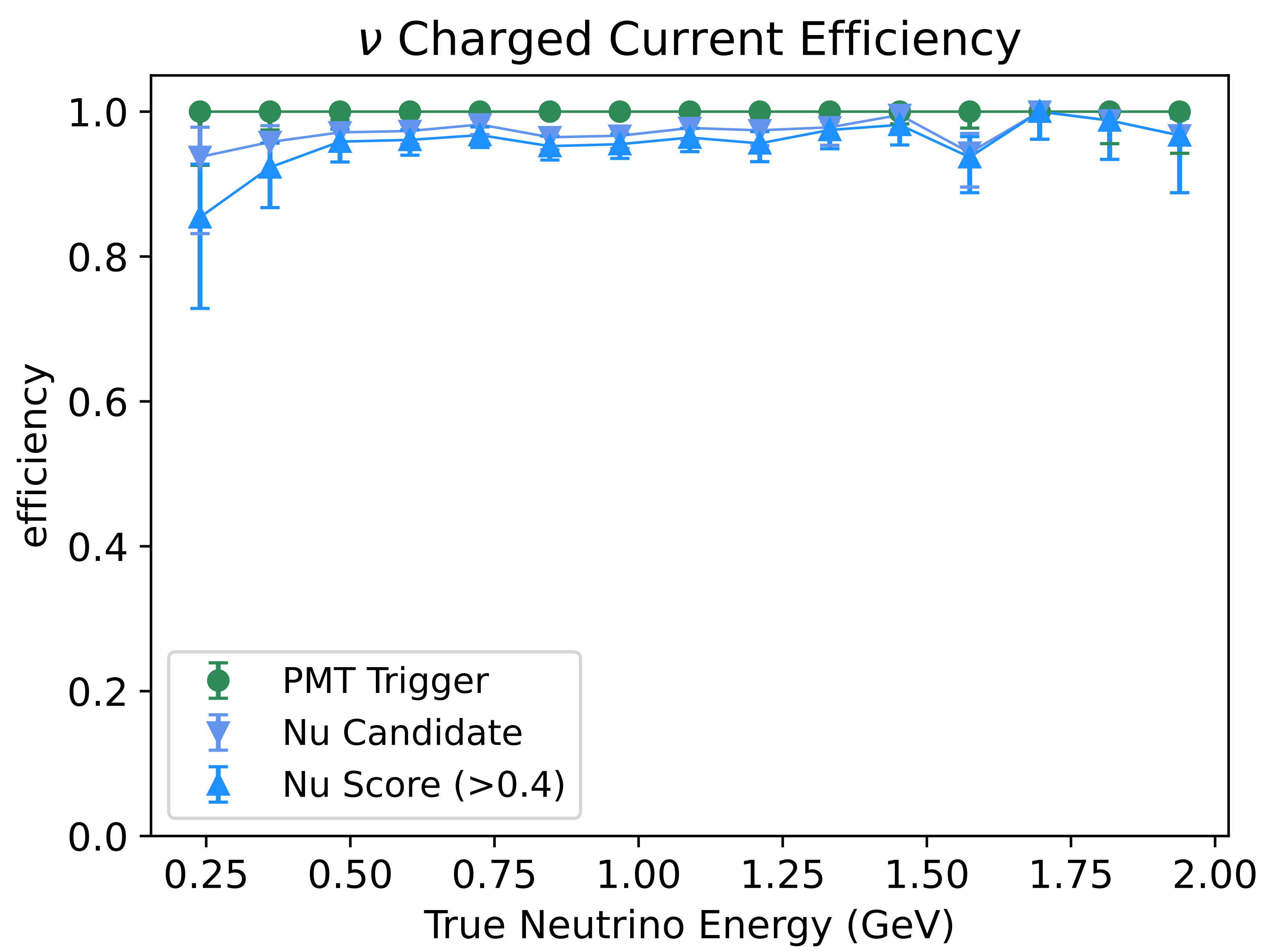
1. Unambiguous Cosmic Removal
2. **Neutrino Candidate Scoring**

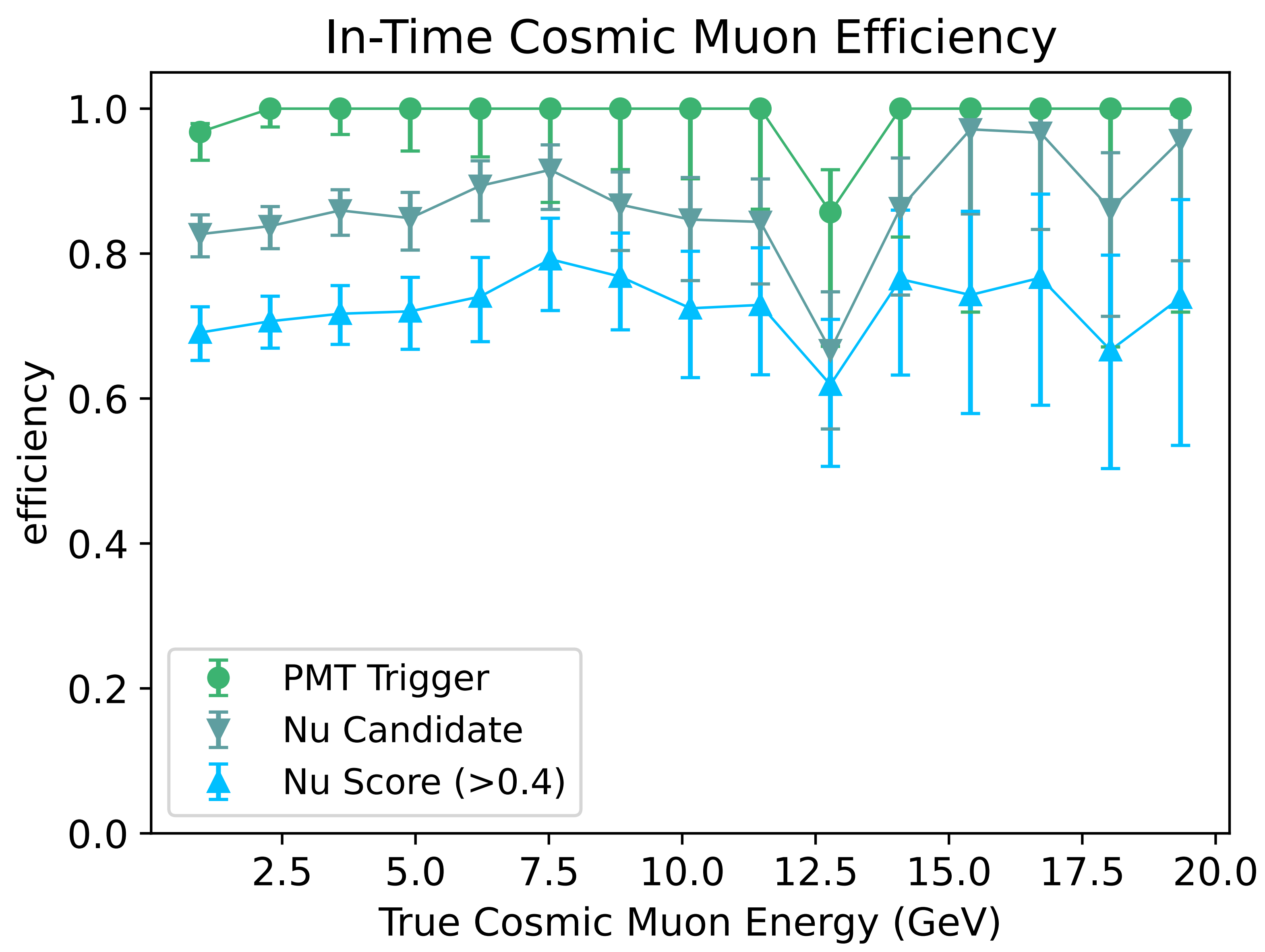
- apply cut at ν-score > 0.4

CC neutrino events: ~90-95%

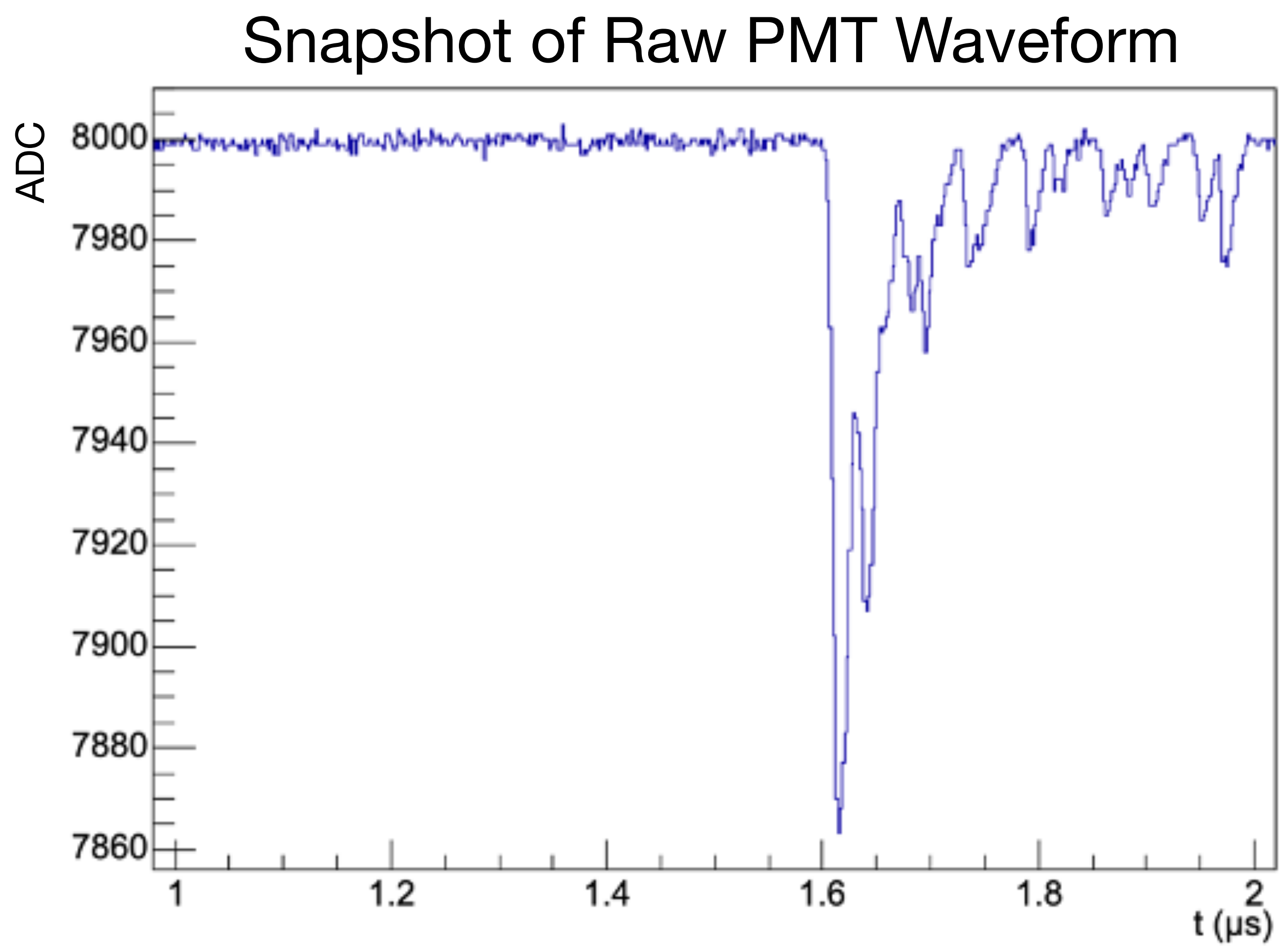
cosmic muon efficiency: ~70%







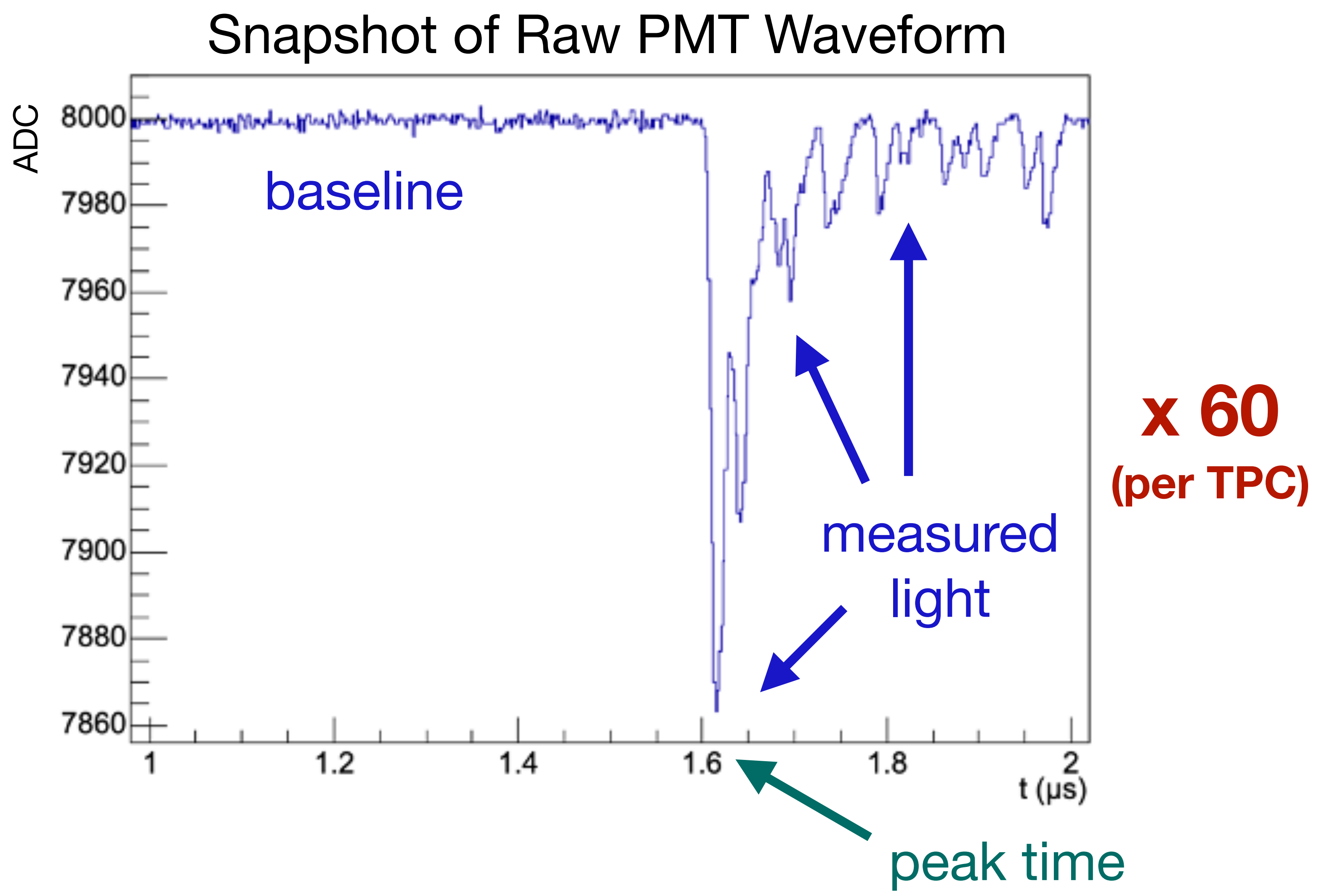
Light Reconstruction



x 60
(per TPC)

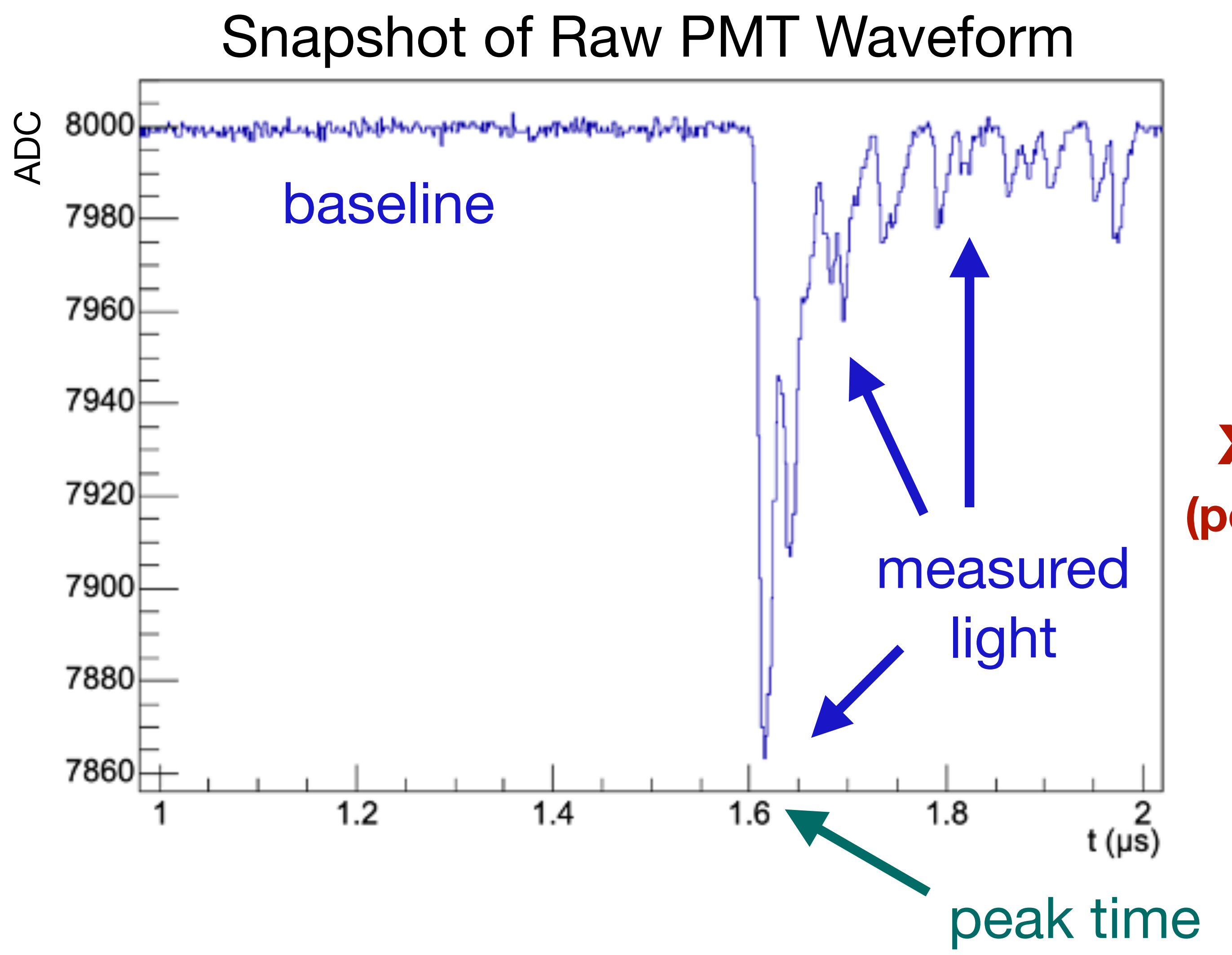
- After PMT data acquisition and triggering:
  - light waveforms

Light Reconstruction



- After PMT data acquisition and triggering:
  - light waveforms → optical hits
    - various hit times, # of photoelectrons, PMT spatial coordinates

Light Reconstruction

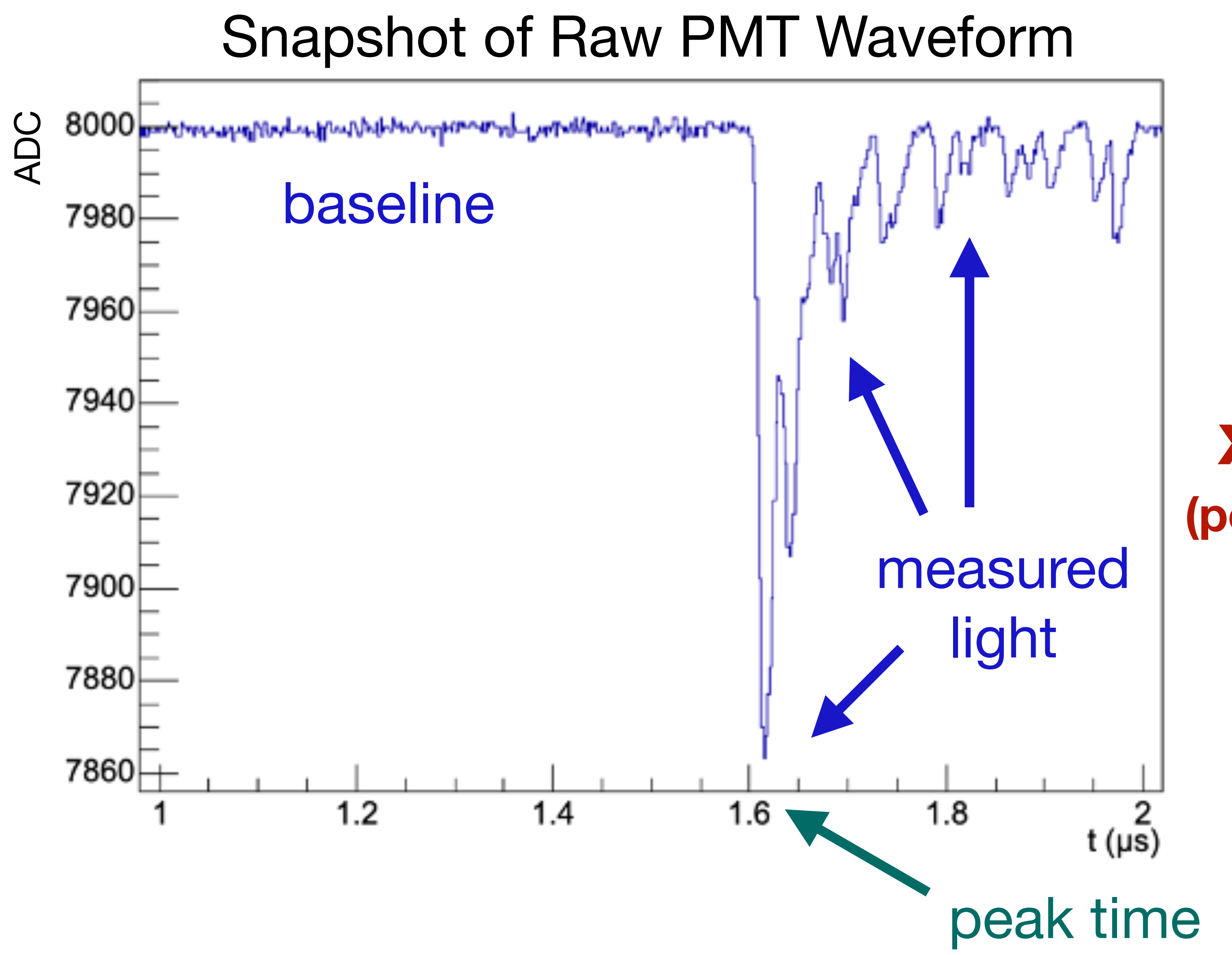


x 60
(per TPC)

Flash Creation

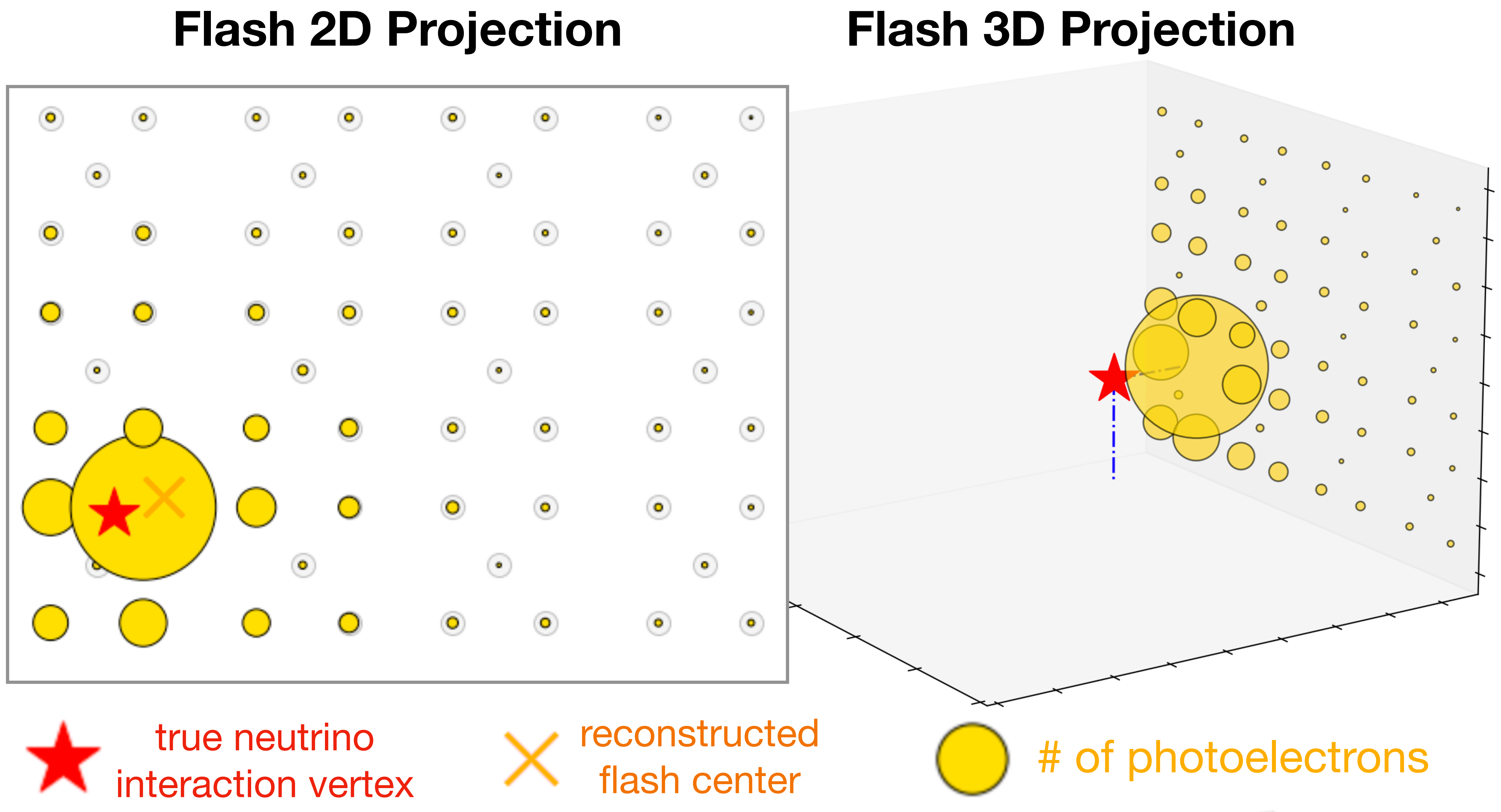
- After PMT data acquisition and triggering:
  - light waveforms → optical hits
    - various hit times, # of photoelectrons, PMT spatial coordinates
  - combine time-coincident optical hits

Light Reconstruction



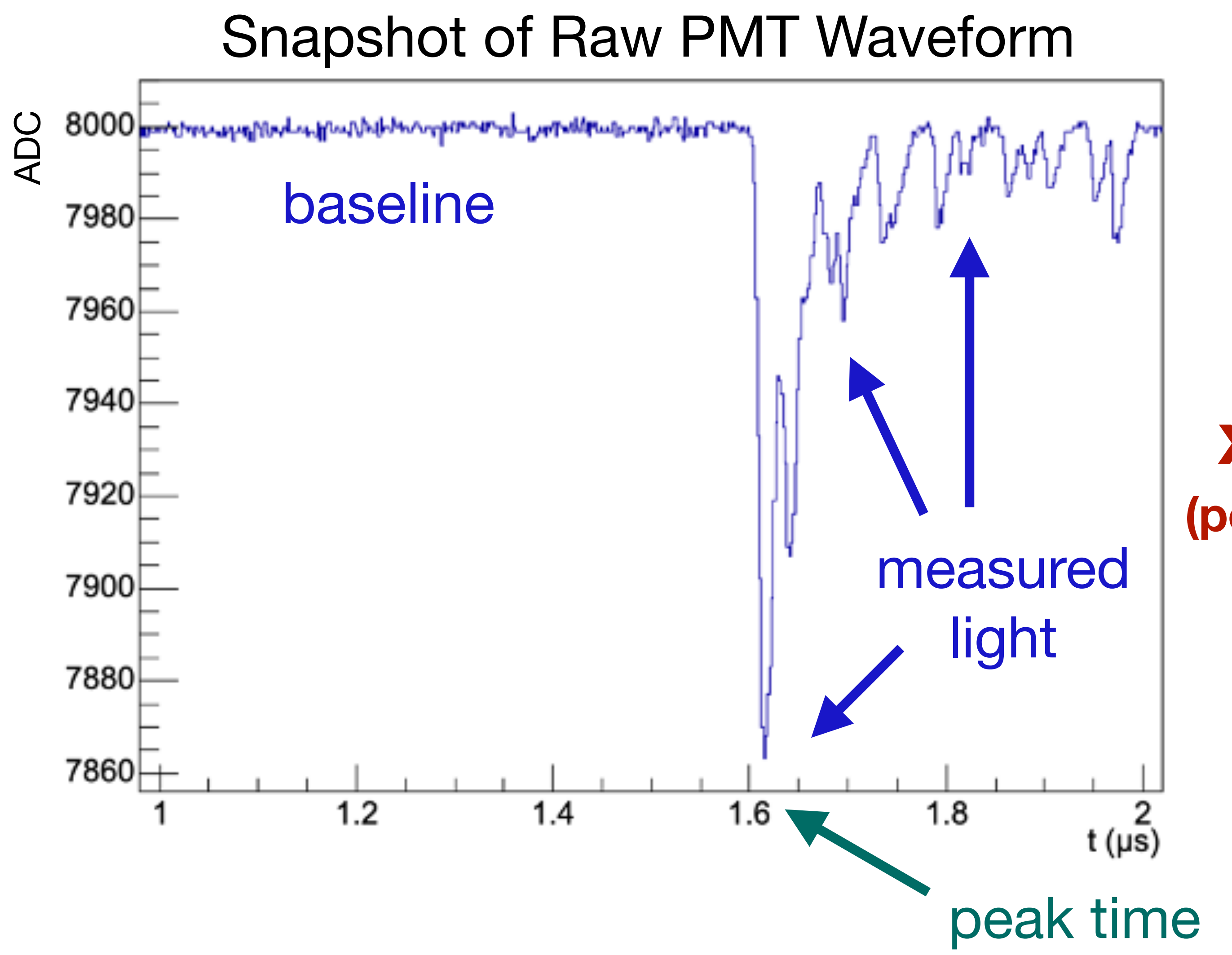
x 60 (per TPC)

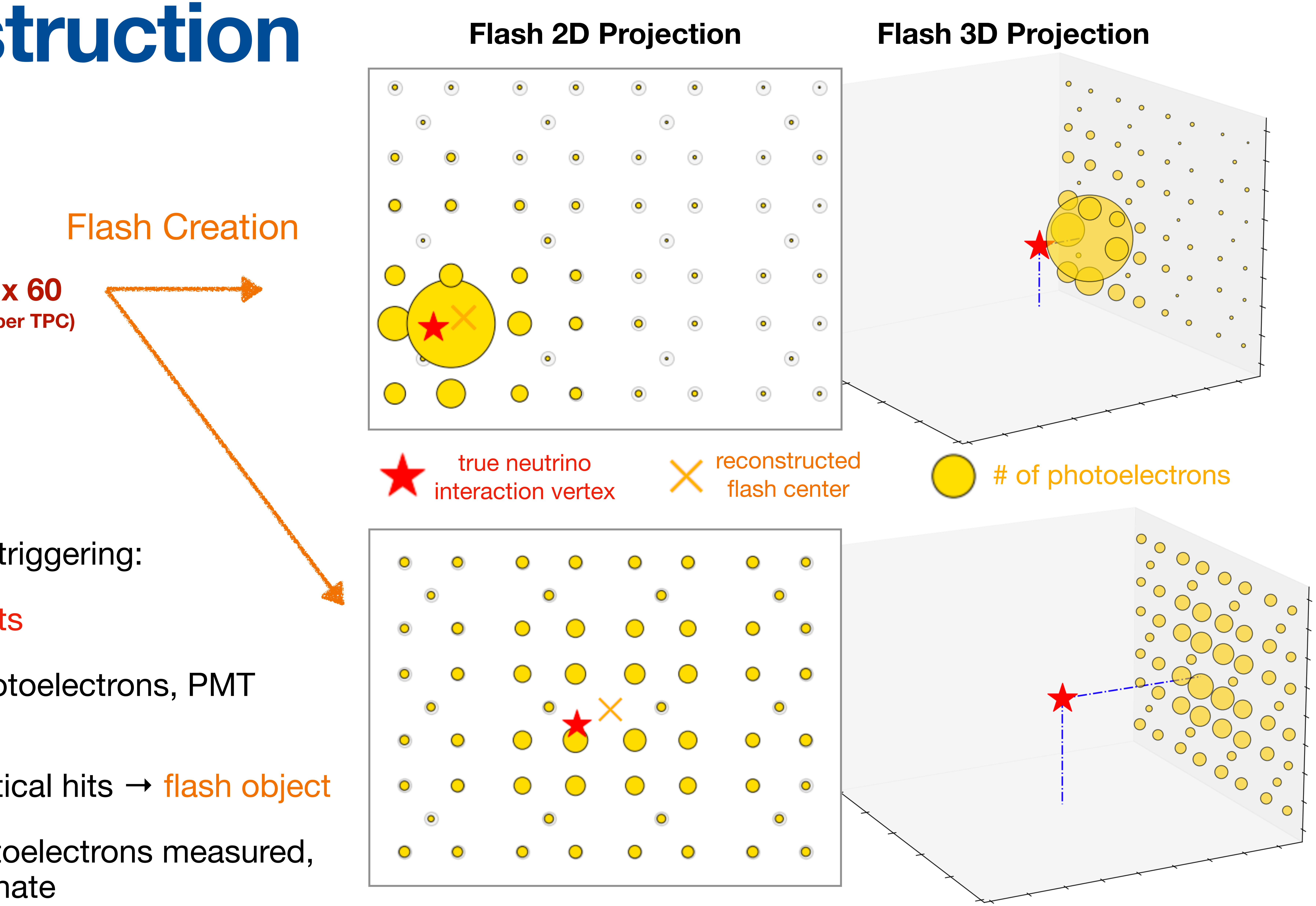
Flash Creation



- After PMT data acquisition and triggering:
  - light waveforms → optical hits
    - various hit times, # of photoelectrons, PMT spatial coordinates
  - combine time-coincident optical hits → flash object
    - one flash time, total photoelectrons measured, one "flash center" coordinate

Light Reconstruction





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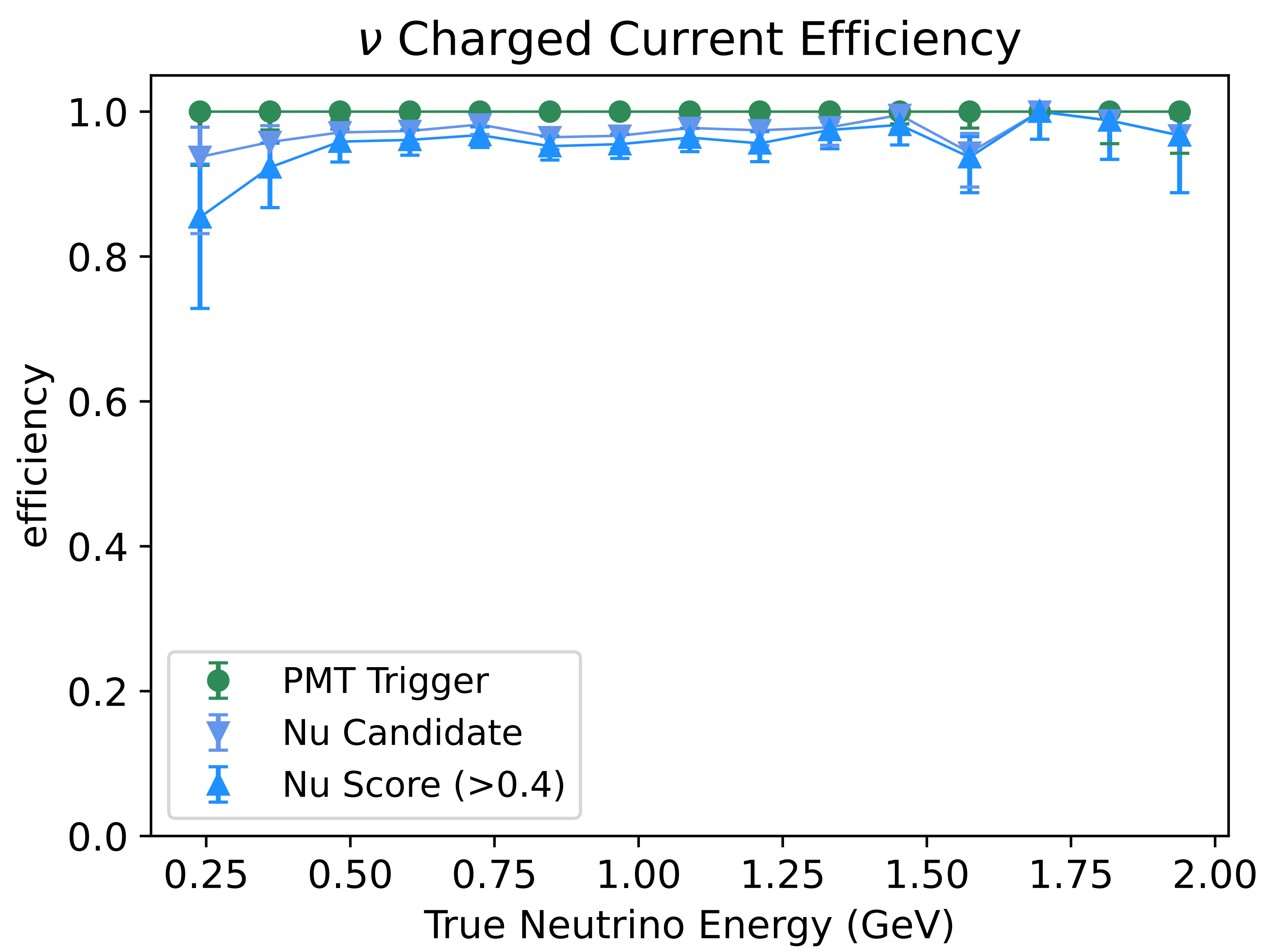
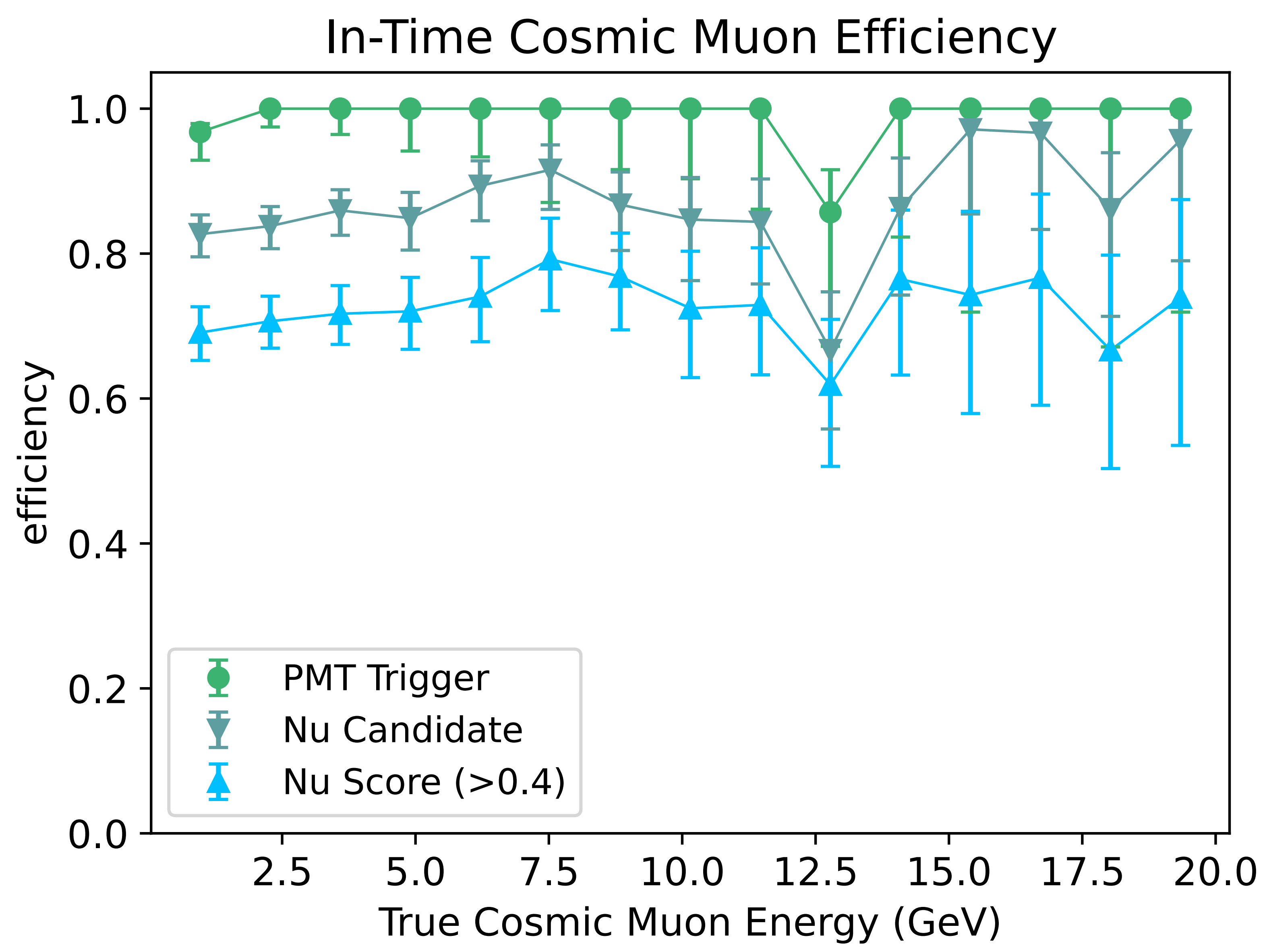
Flash Reconstruction

- How many flashes are created? When do the flashes happen?





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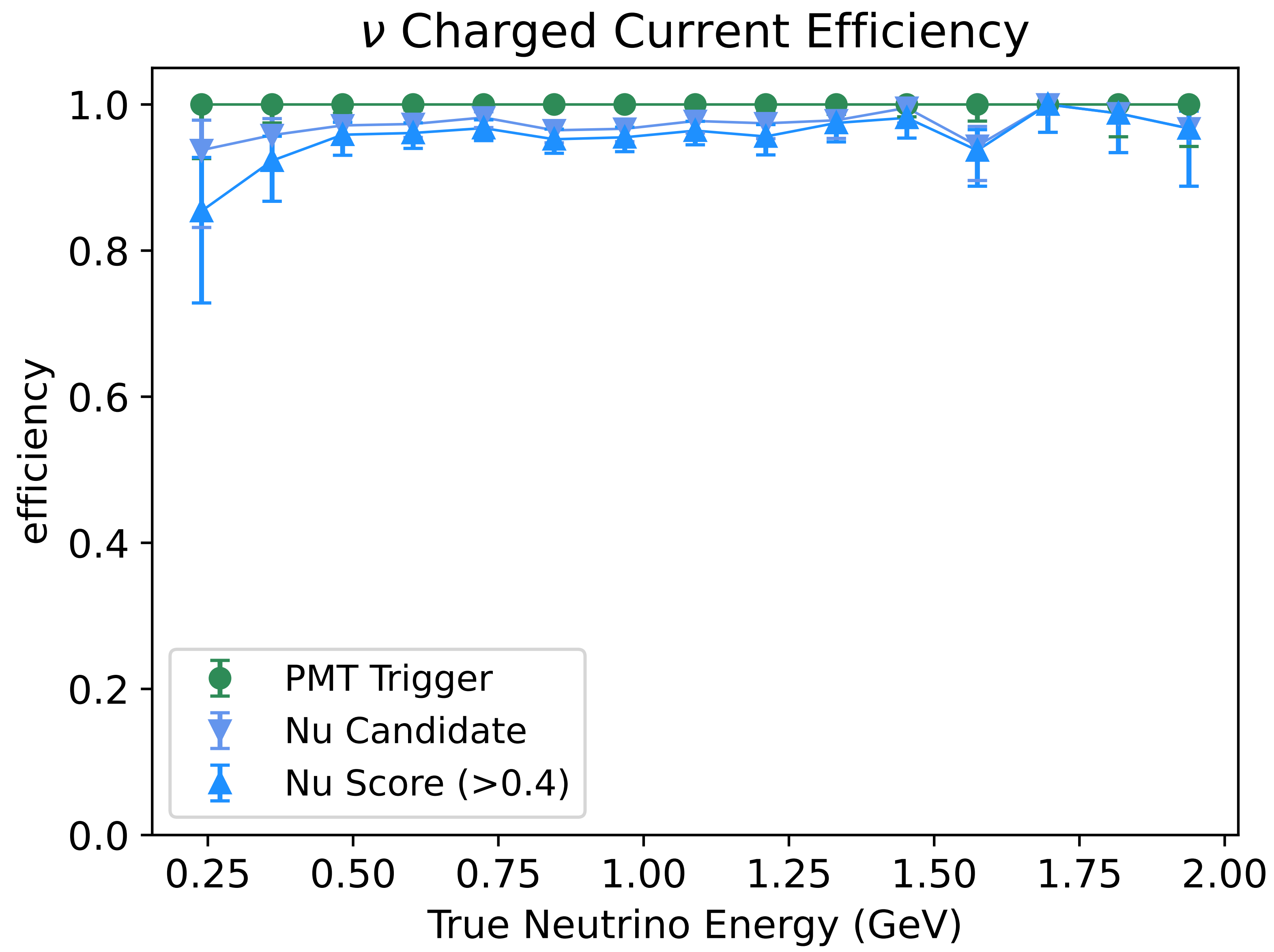

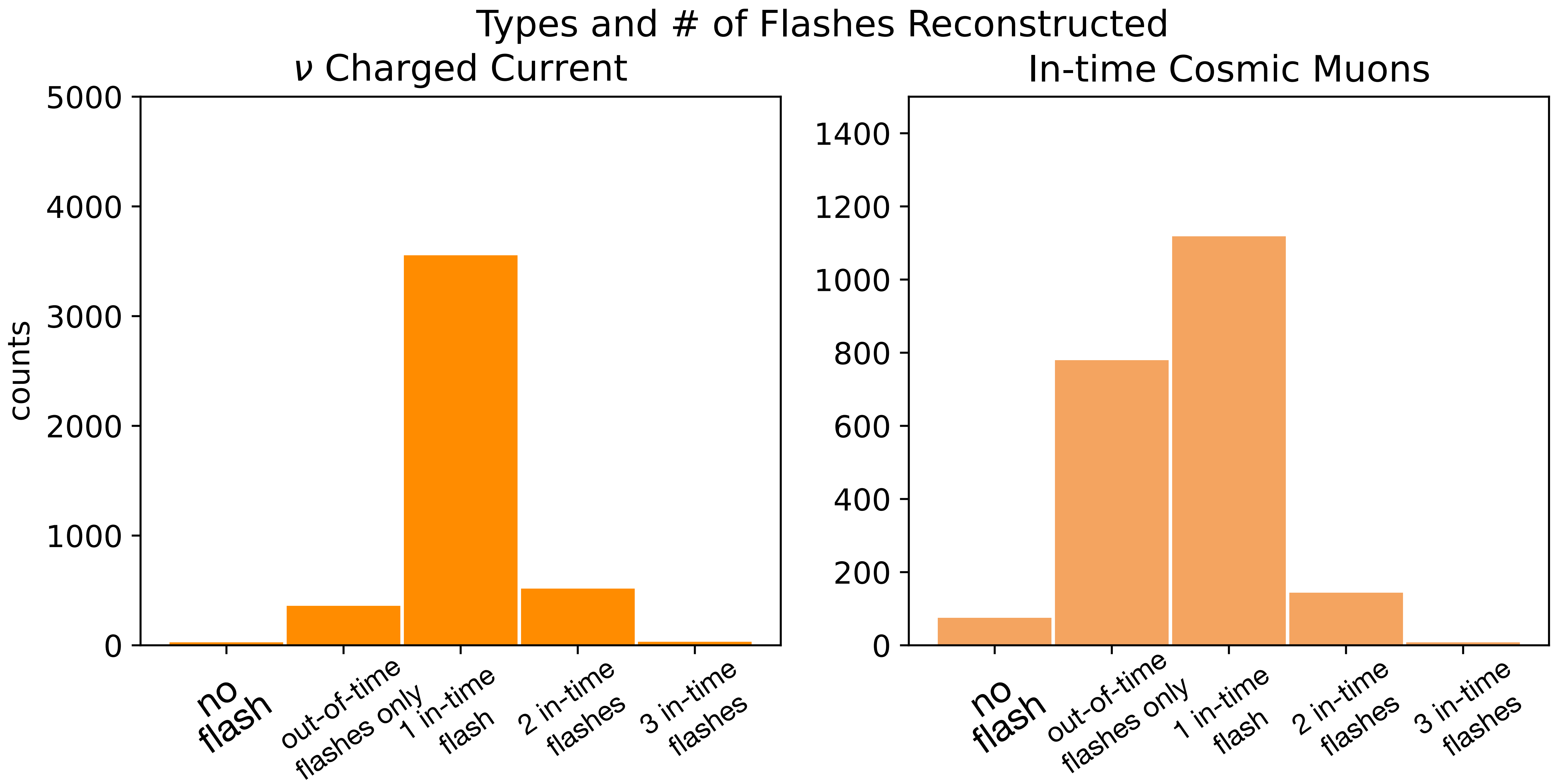

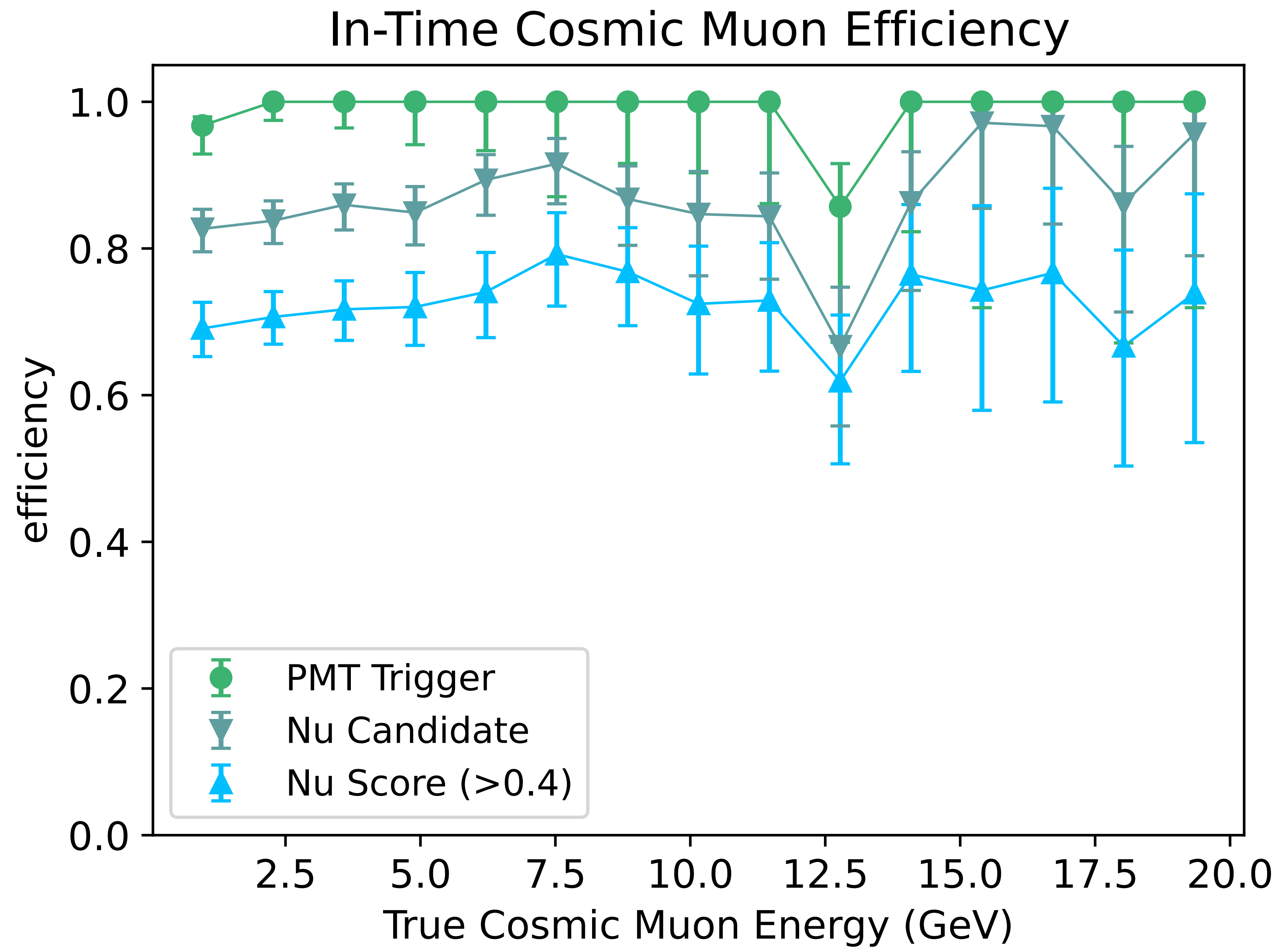

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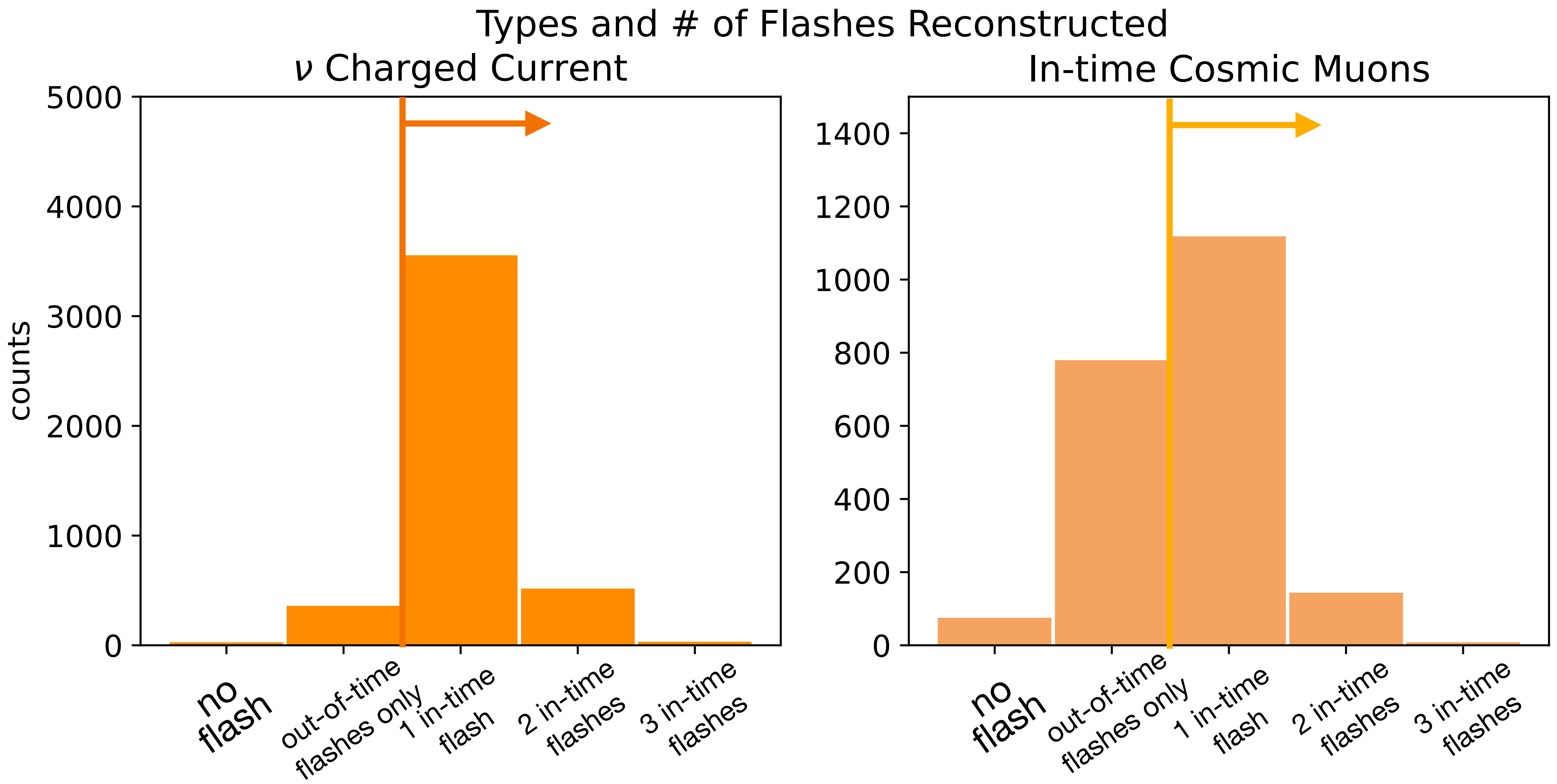
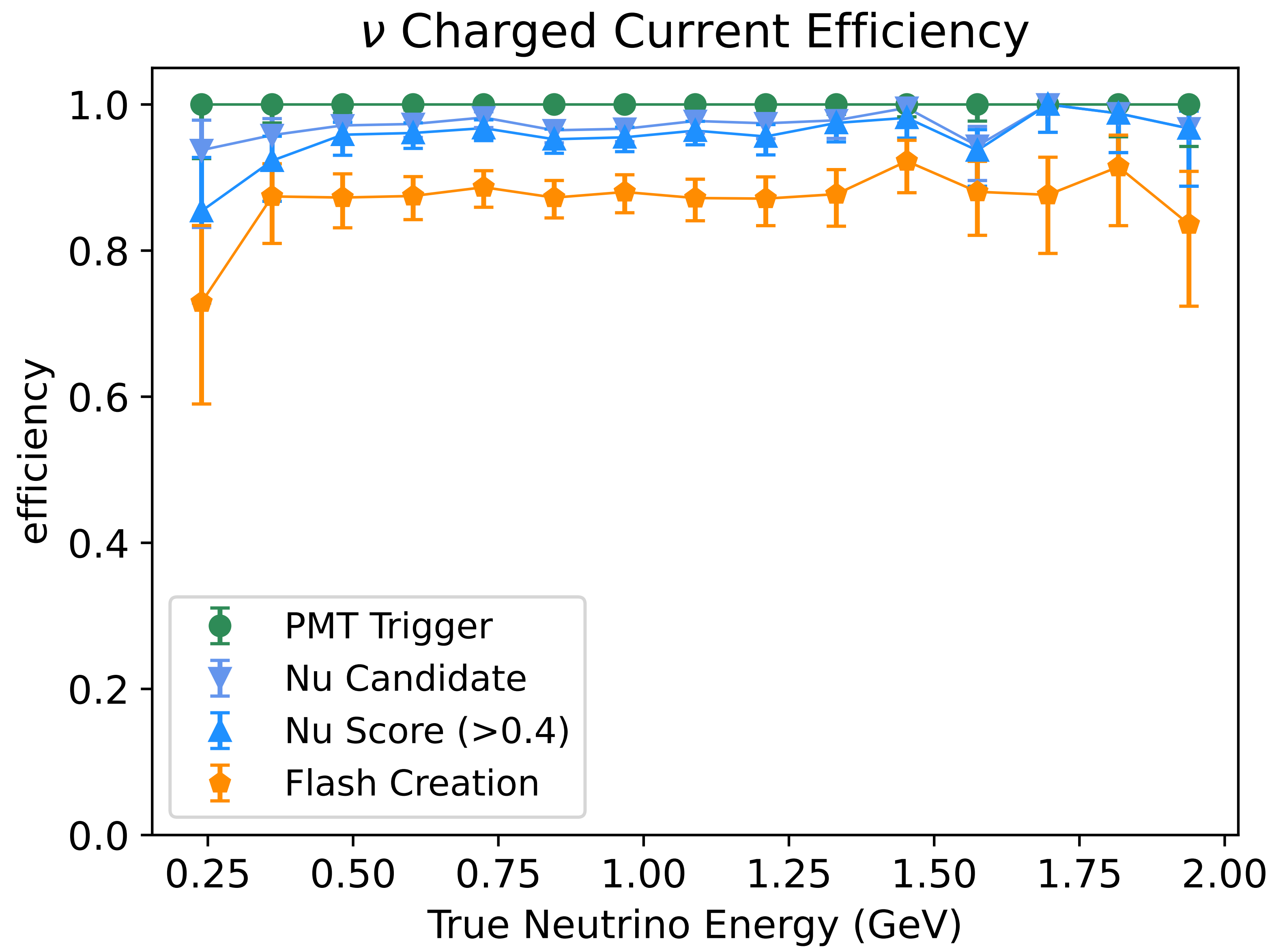
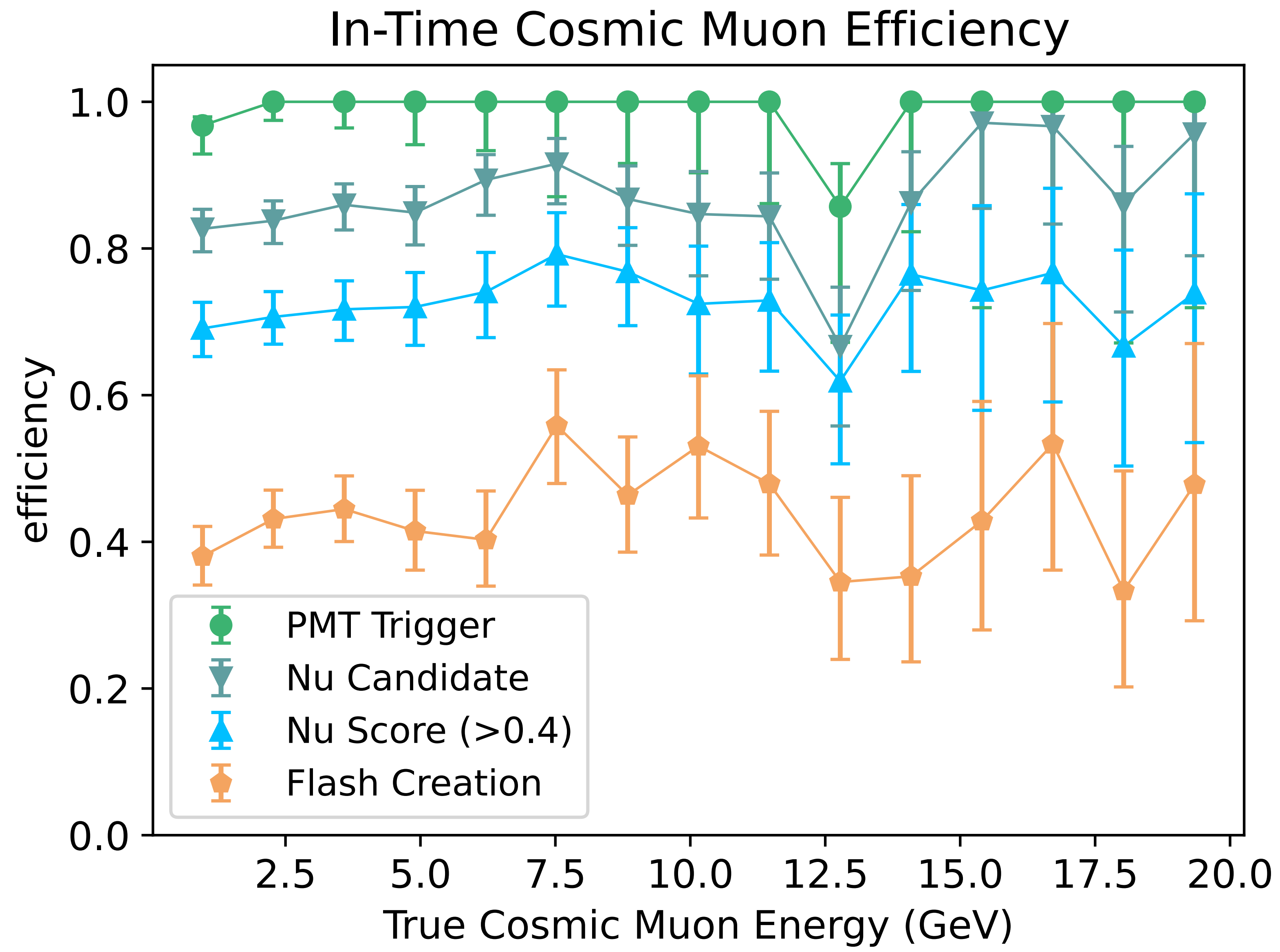
Flash Reconstruction

- How many flashes are created? When do the flashes happen?
- select events with in-time flashes





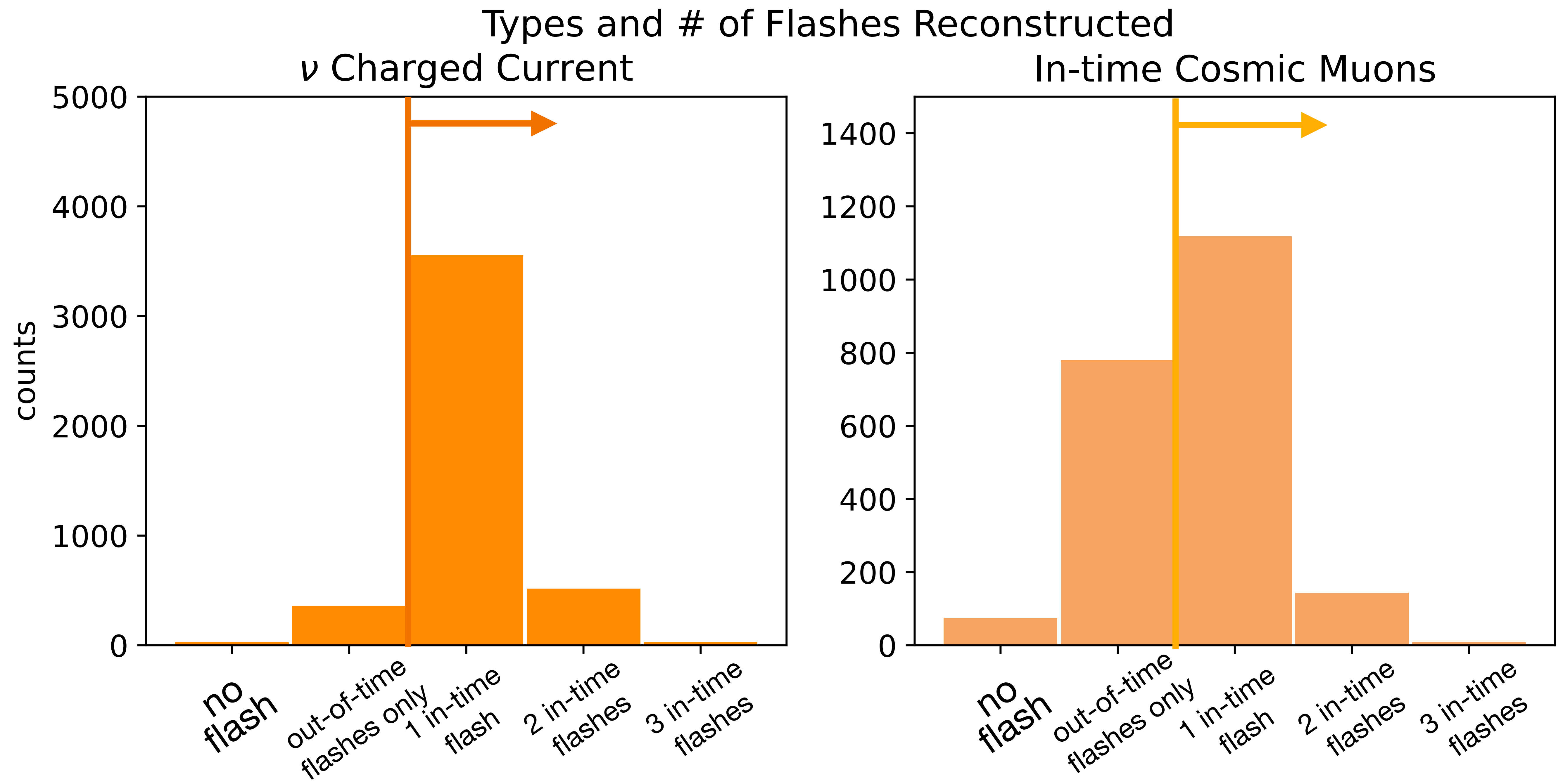


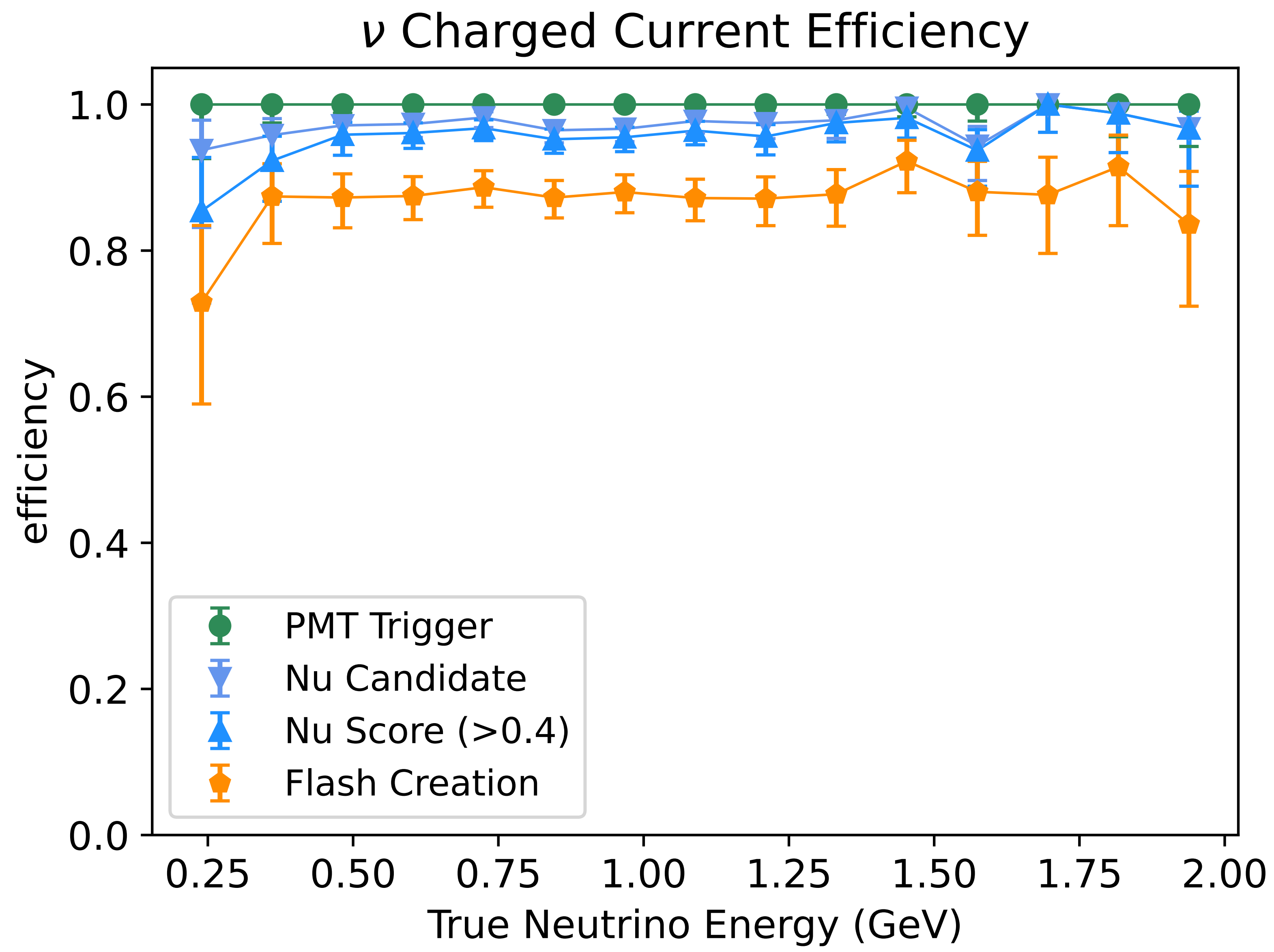
Flash Reconstruction

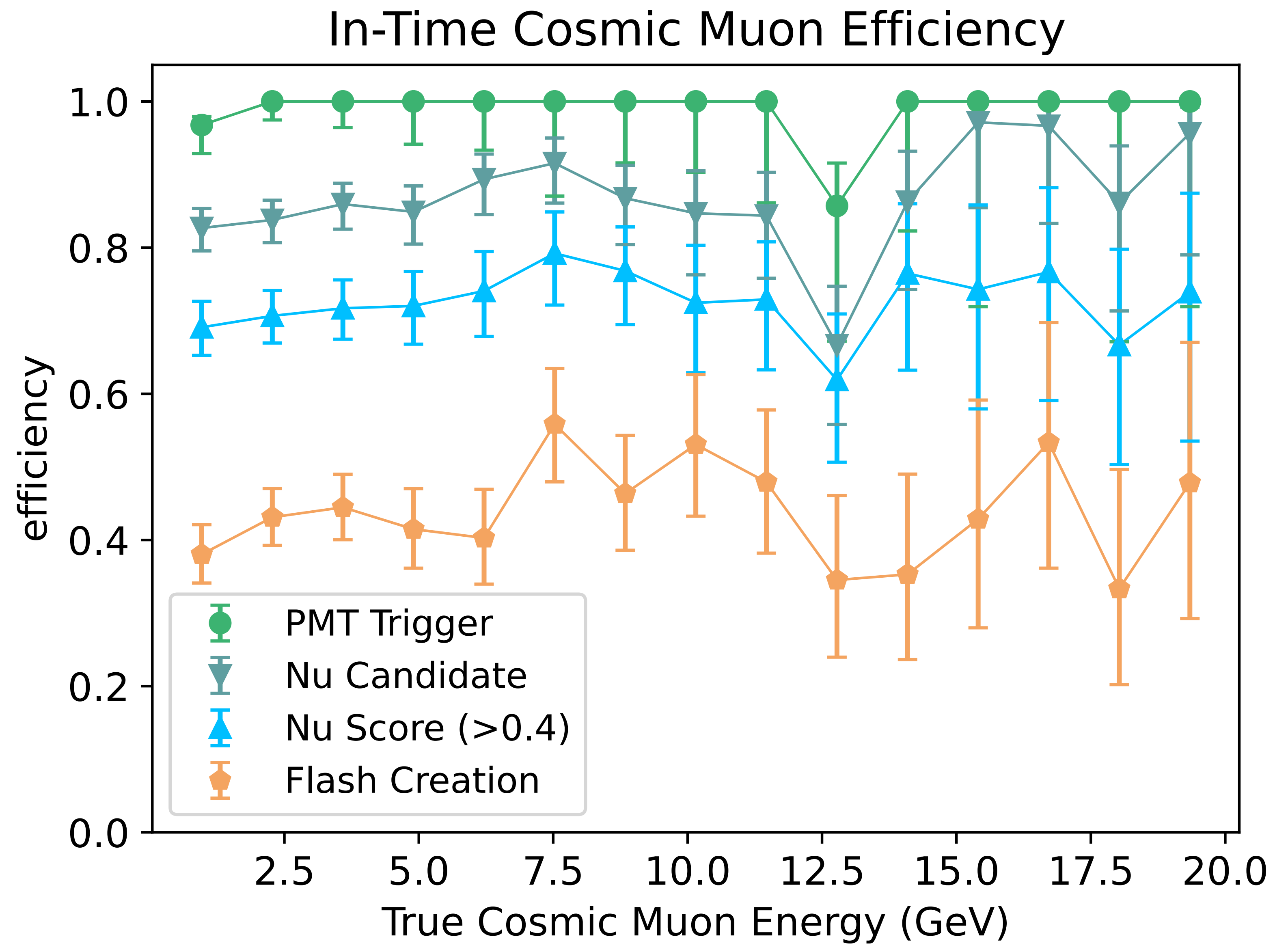
- How many flashes are created? When do the flashes happen?
- select events with in-time flashes

CC neutrino efficiency: ~85-90%

cosmic muon efficiency: ~40-50%

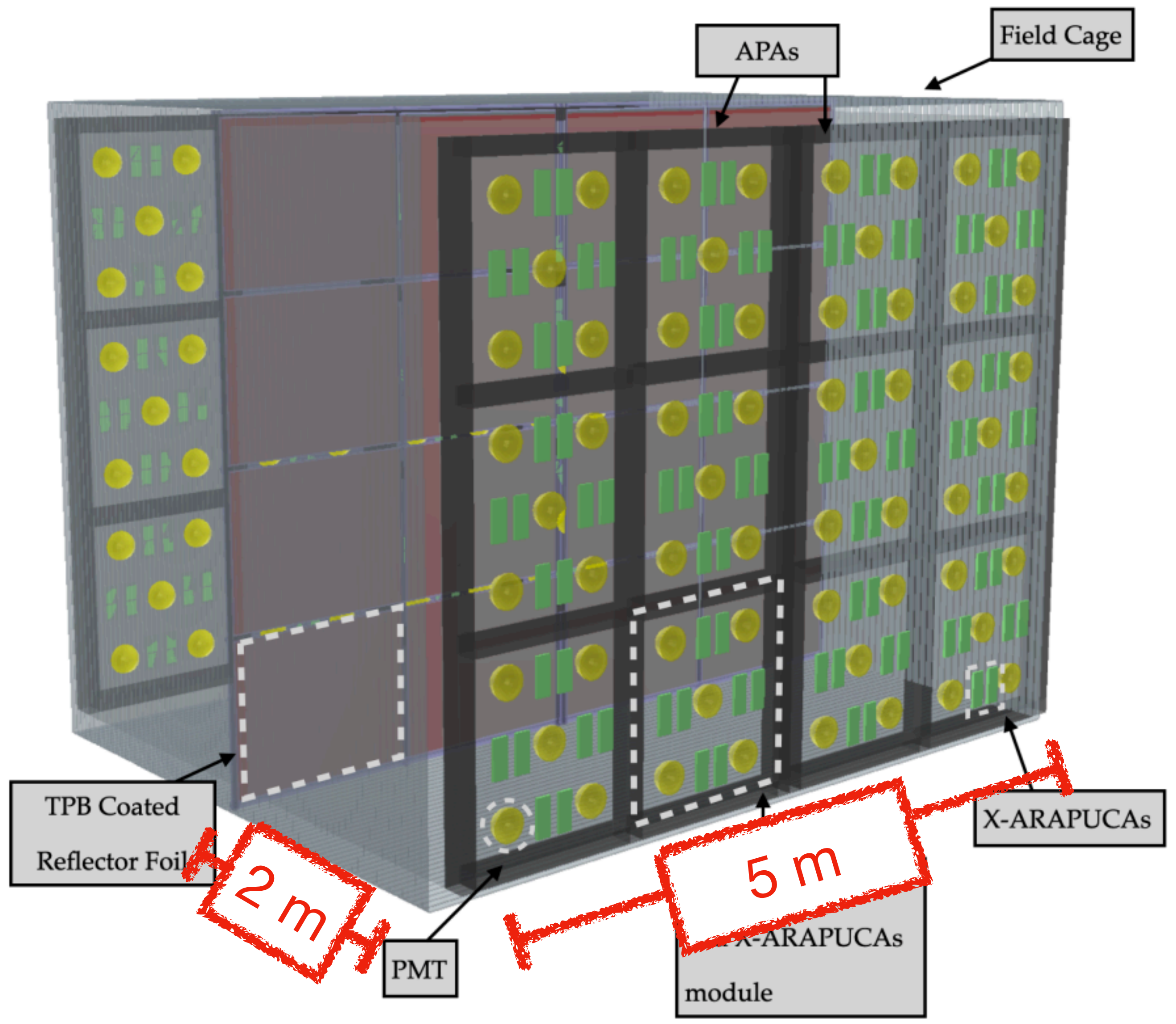






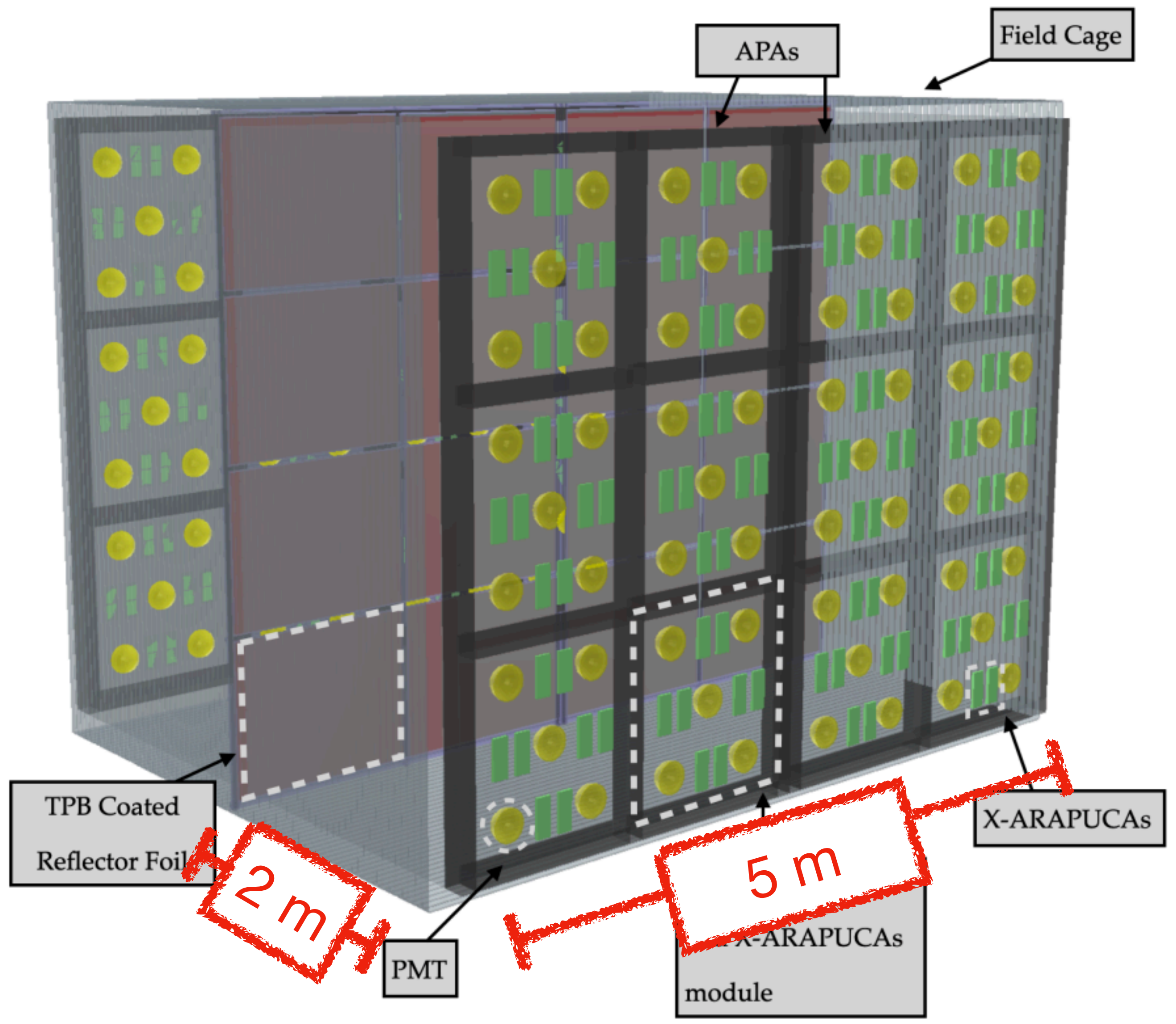
Flash Matching

- TPC: reconstructing tracks of ionization electrons
  - electrons *drift* to wire planes at 0.16 cm/us



Flash Matching

- TPC: reconstructing tracks of ionization electrons
  - electrons *drift* to wire planes at 0.16 cm/us
  - **1.3 *ms* of readout** for 1 drift volume → unknown time
  - wires separated by 3mm → **high spatial resolution**



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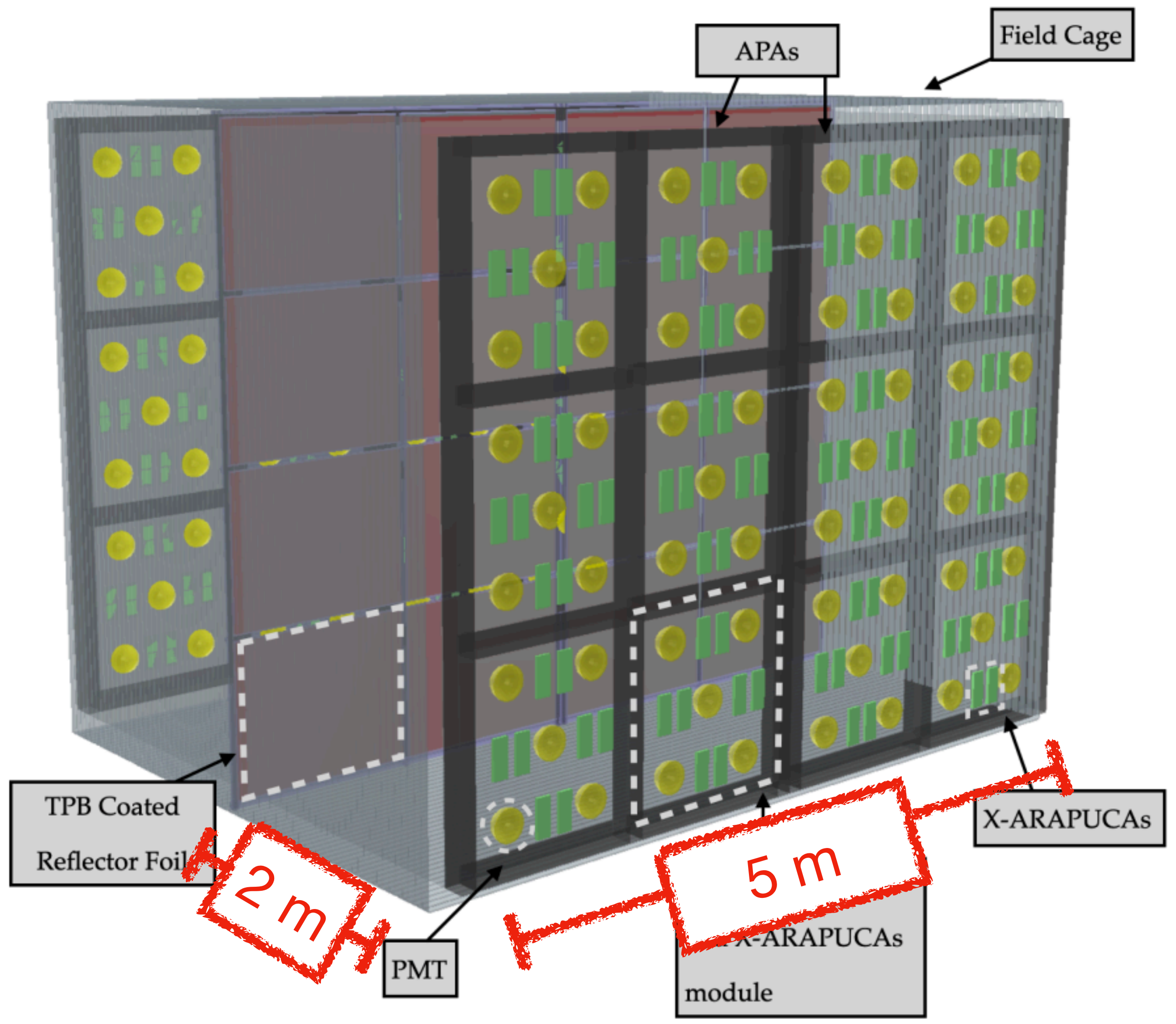
  - wires separated by 3mm → **high spatial resolution**
- PDS: reconstructing scintillation light signals



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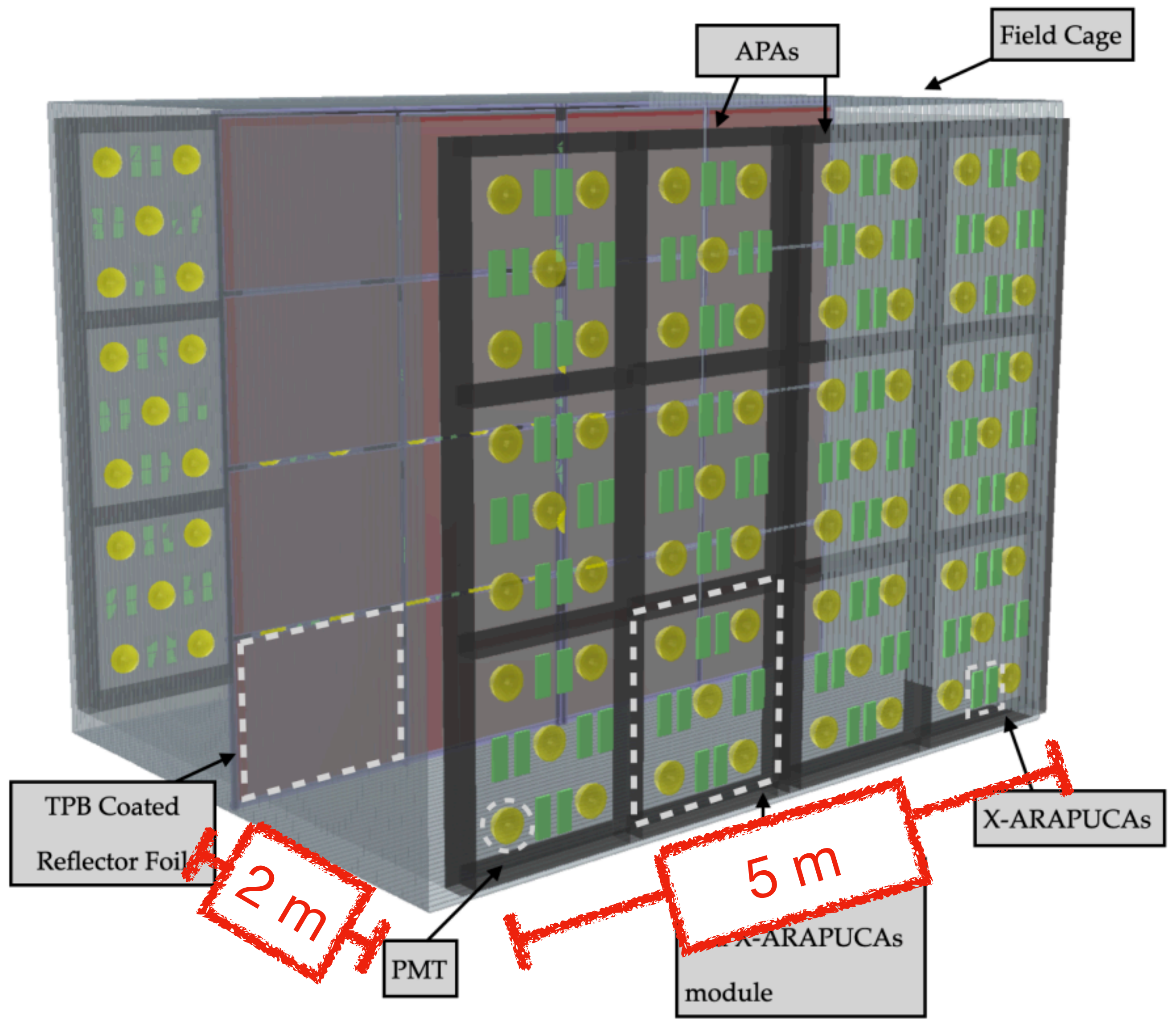
- PDS: reconstructing scintillation light signals
  - PMTs separated ~0.5 meter → poor spatial resolution
  - light travels in nanoseconds → **high timing resolution**



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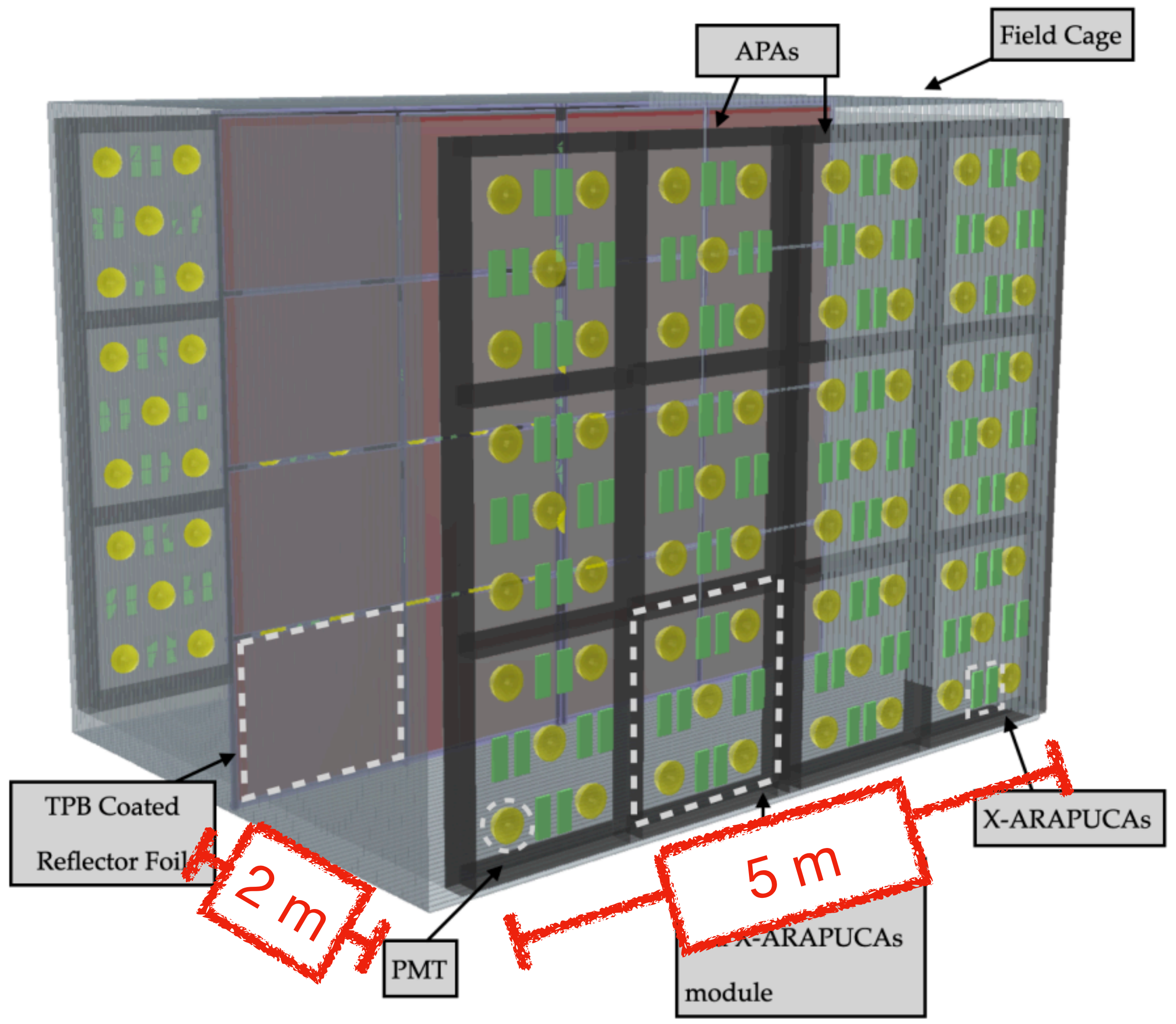
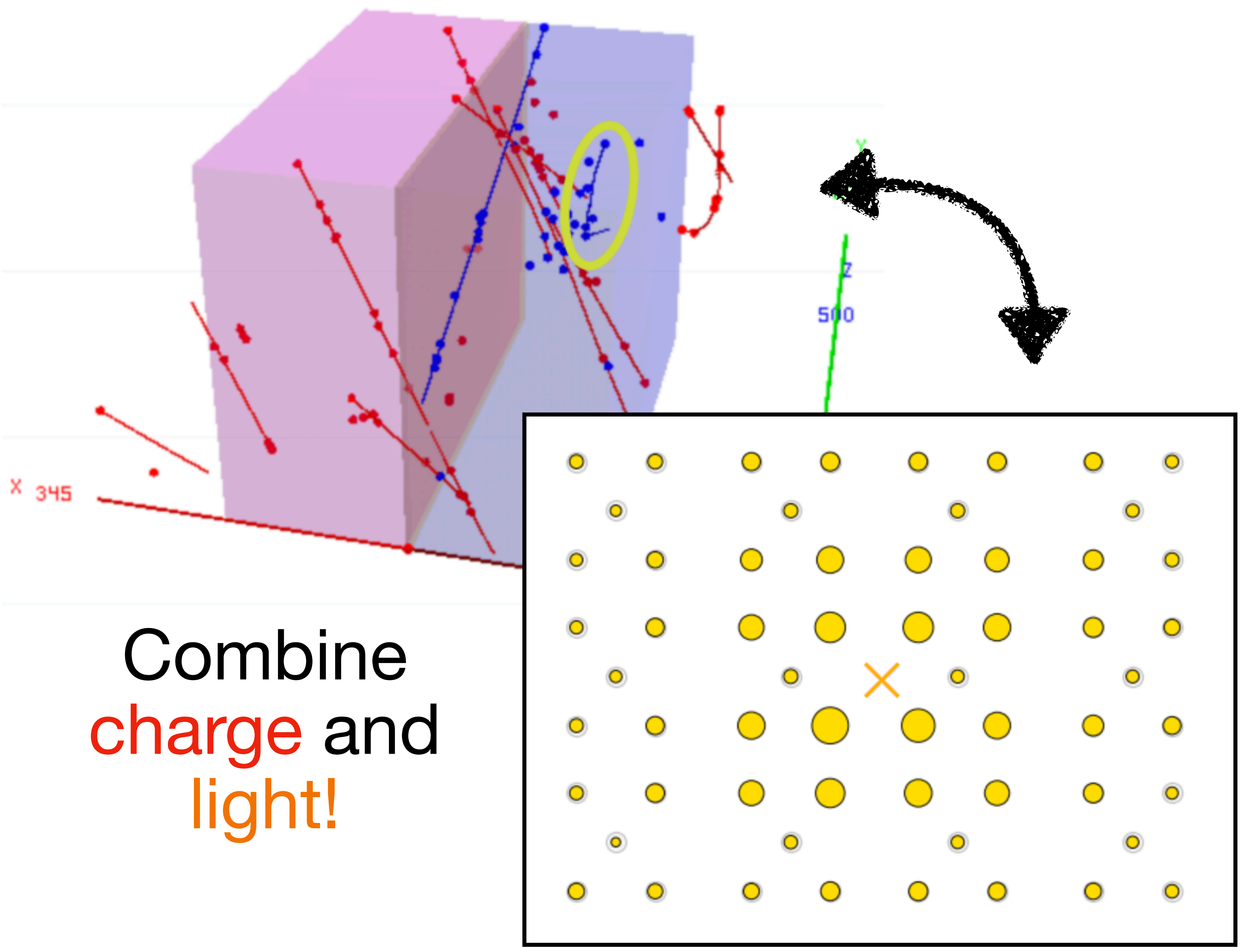


- **Flash Matching: Combine TPC info and PDS flashes for good timing and good spatial reconstruction!**



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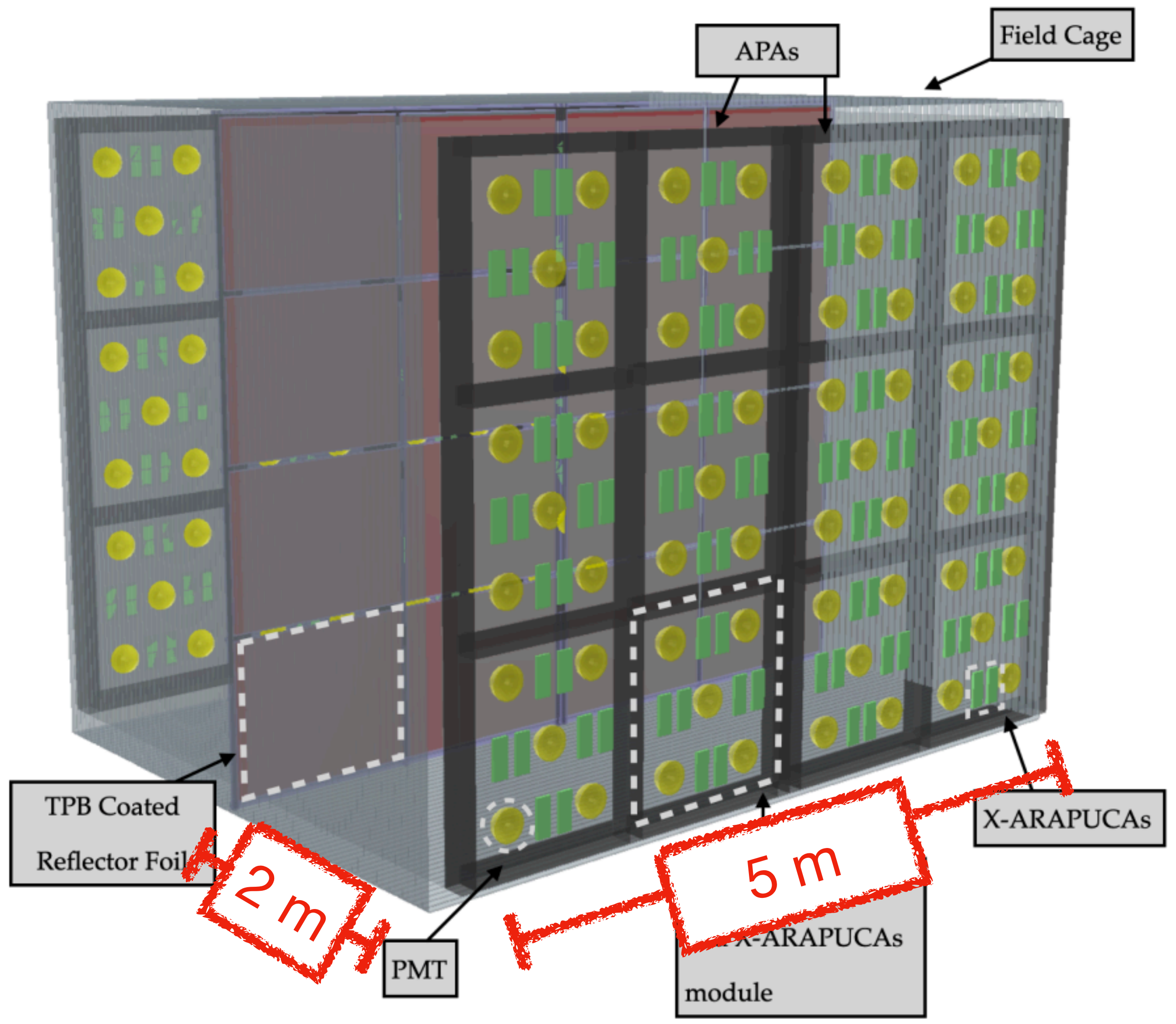
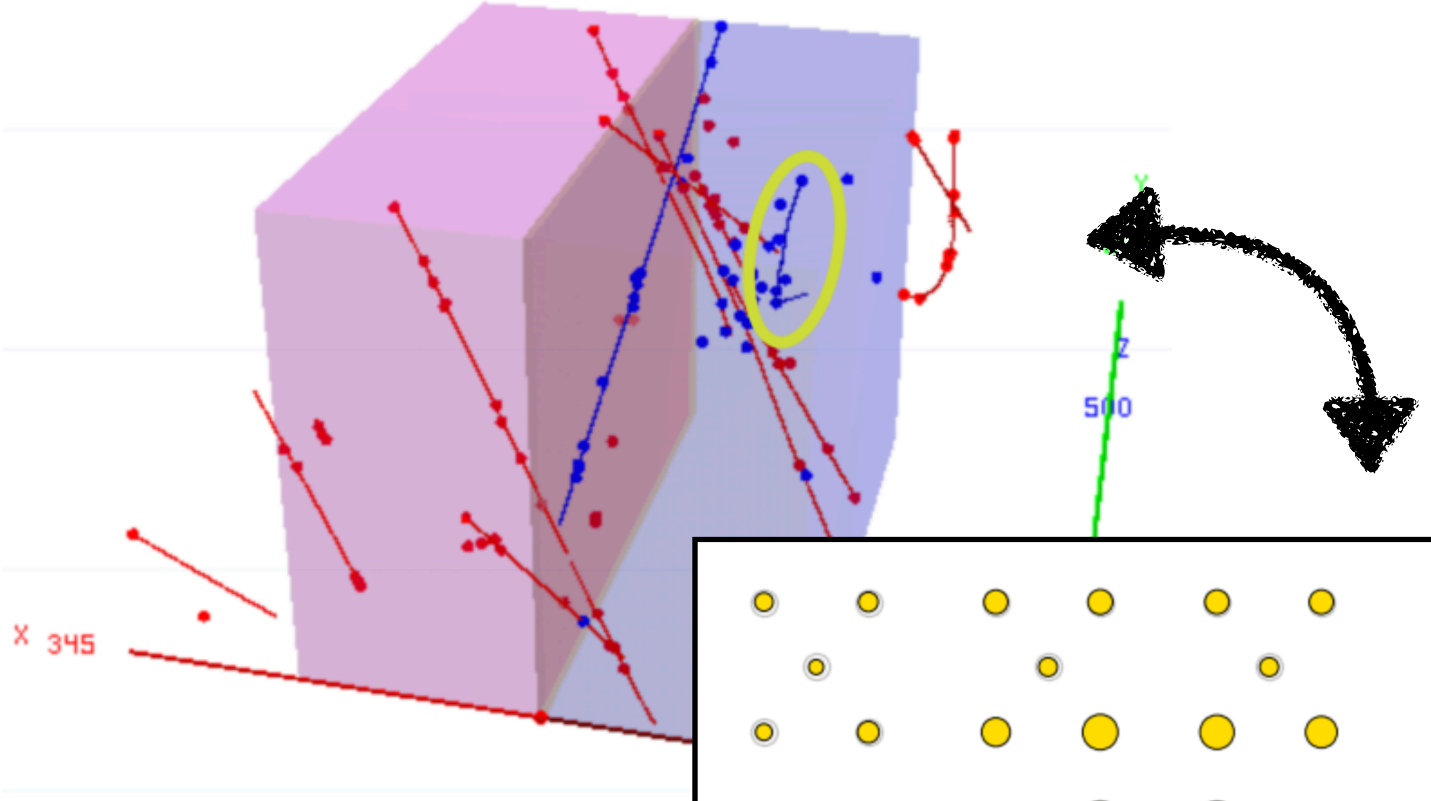
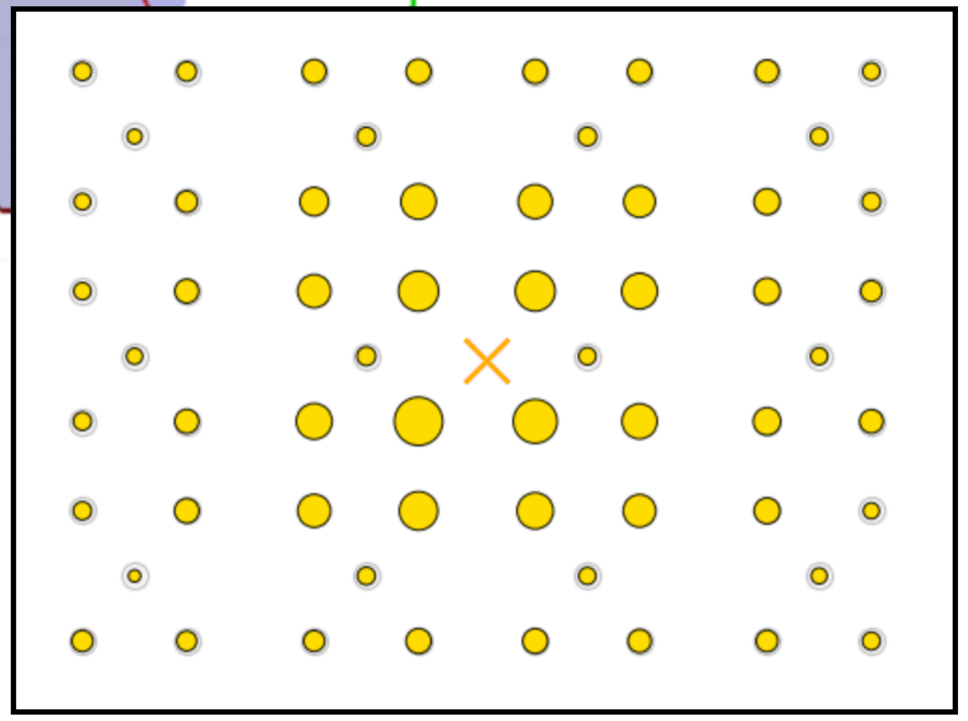


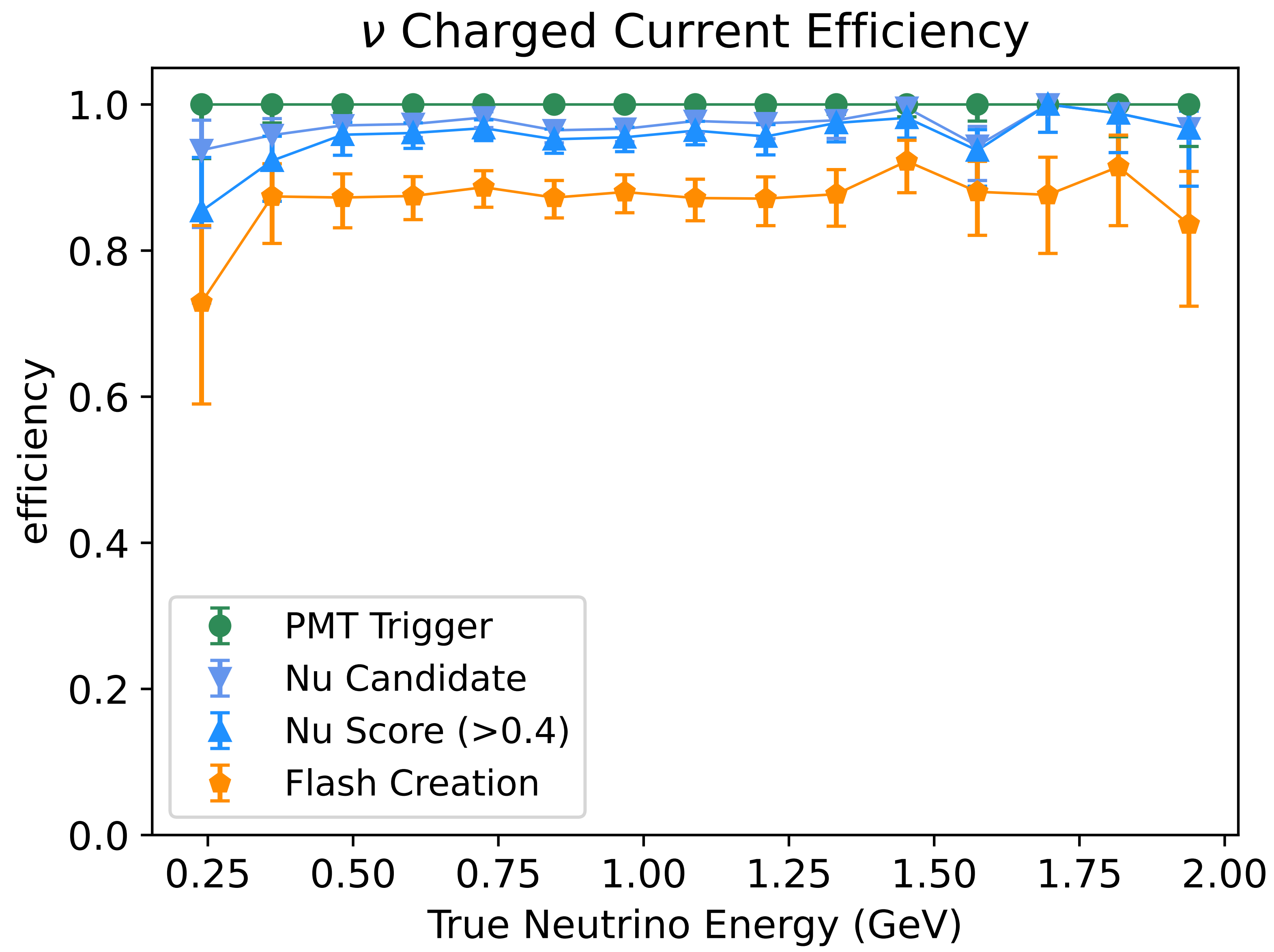
- **Flash Matching: Combine TPC info and PDS flashes for good timing and good spatial reconstruction!**
- Inputs to SBND Flash Matching score:
  - spatial centers of charge vs. spatial centers of light
    - e.g. Pandora reconstructed vertex vs. flash center
  - ratios of visible and VUV light
  - footprint of light

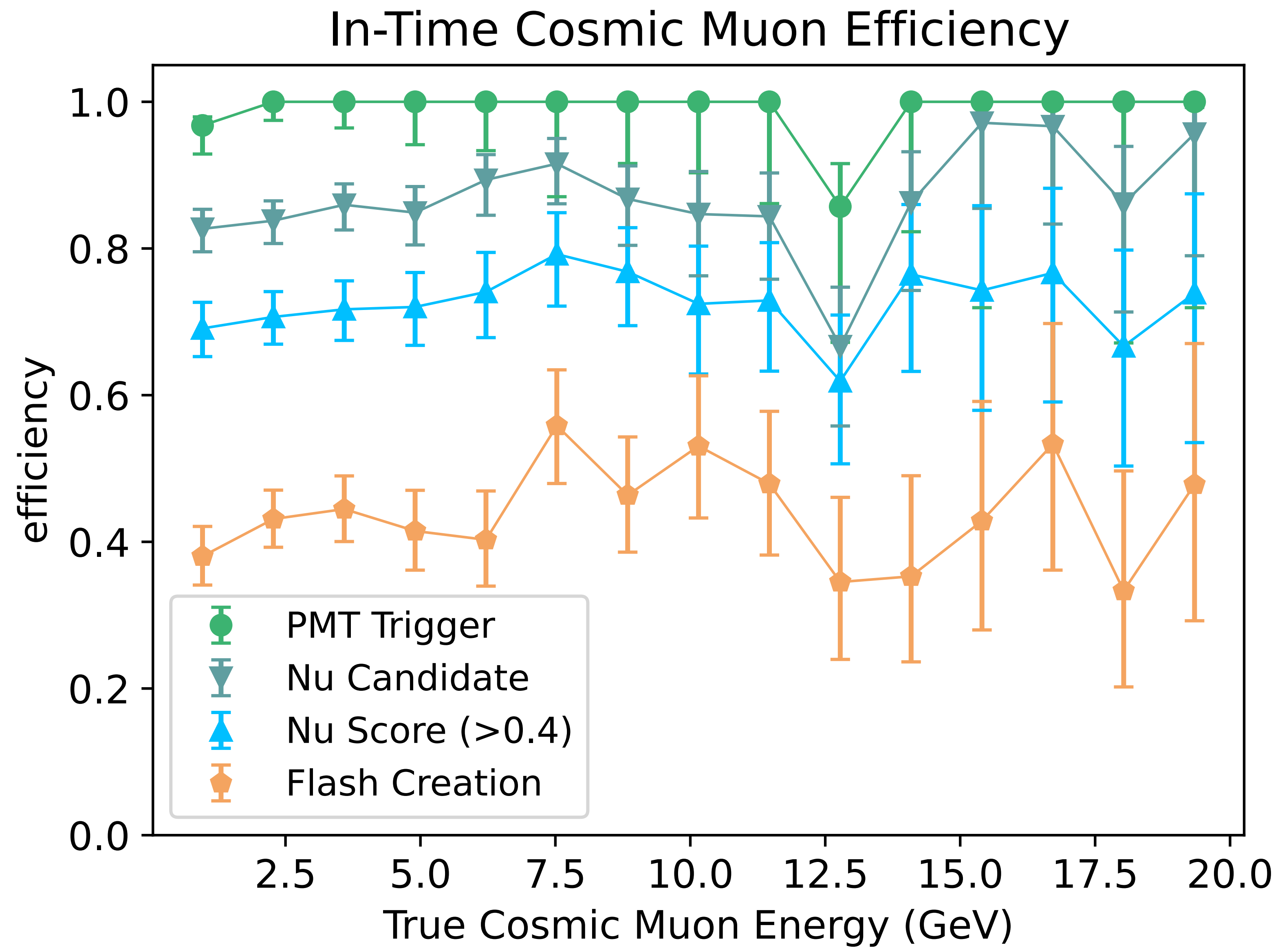


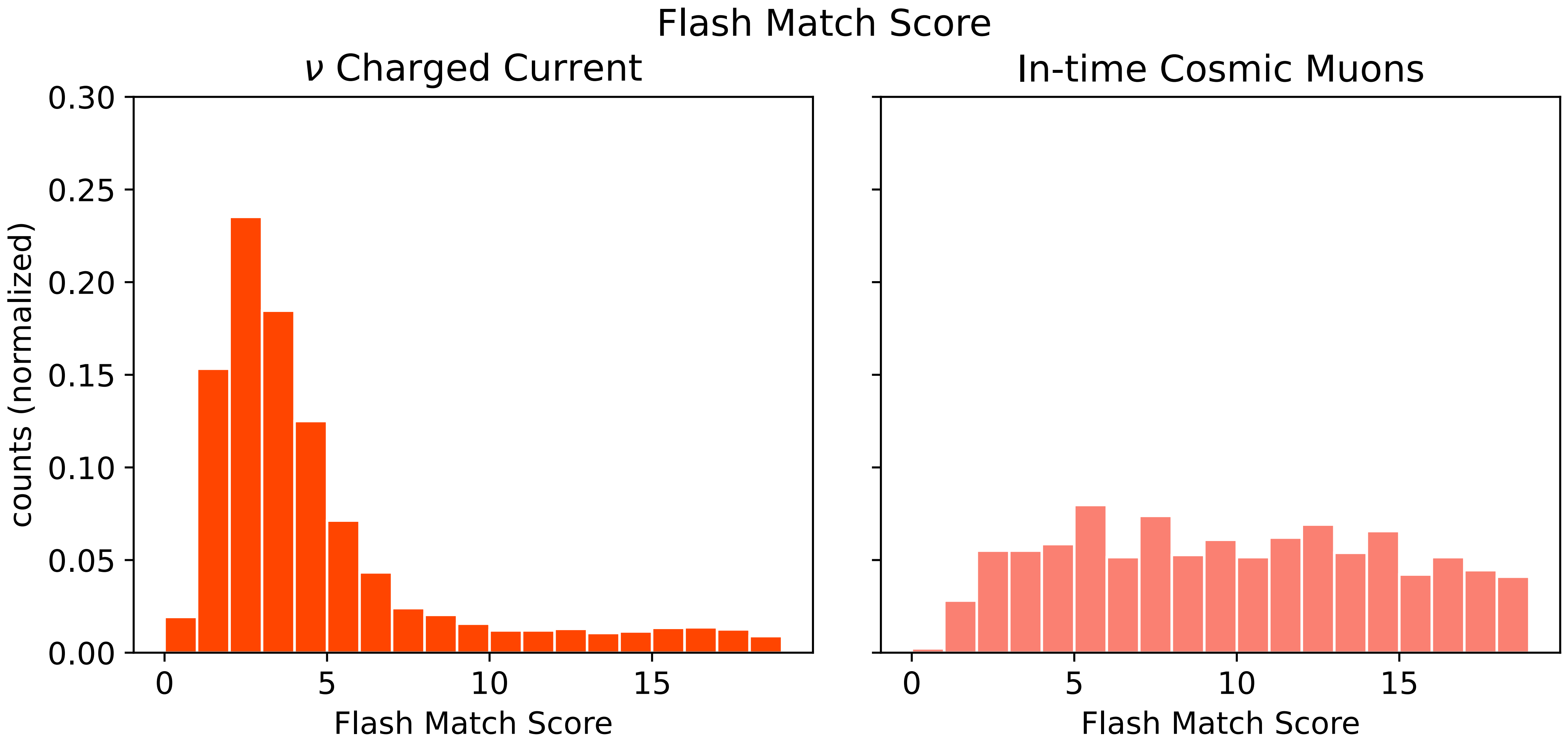
Combine charge and light!



Flash Matching







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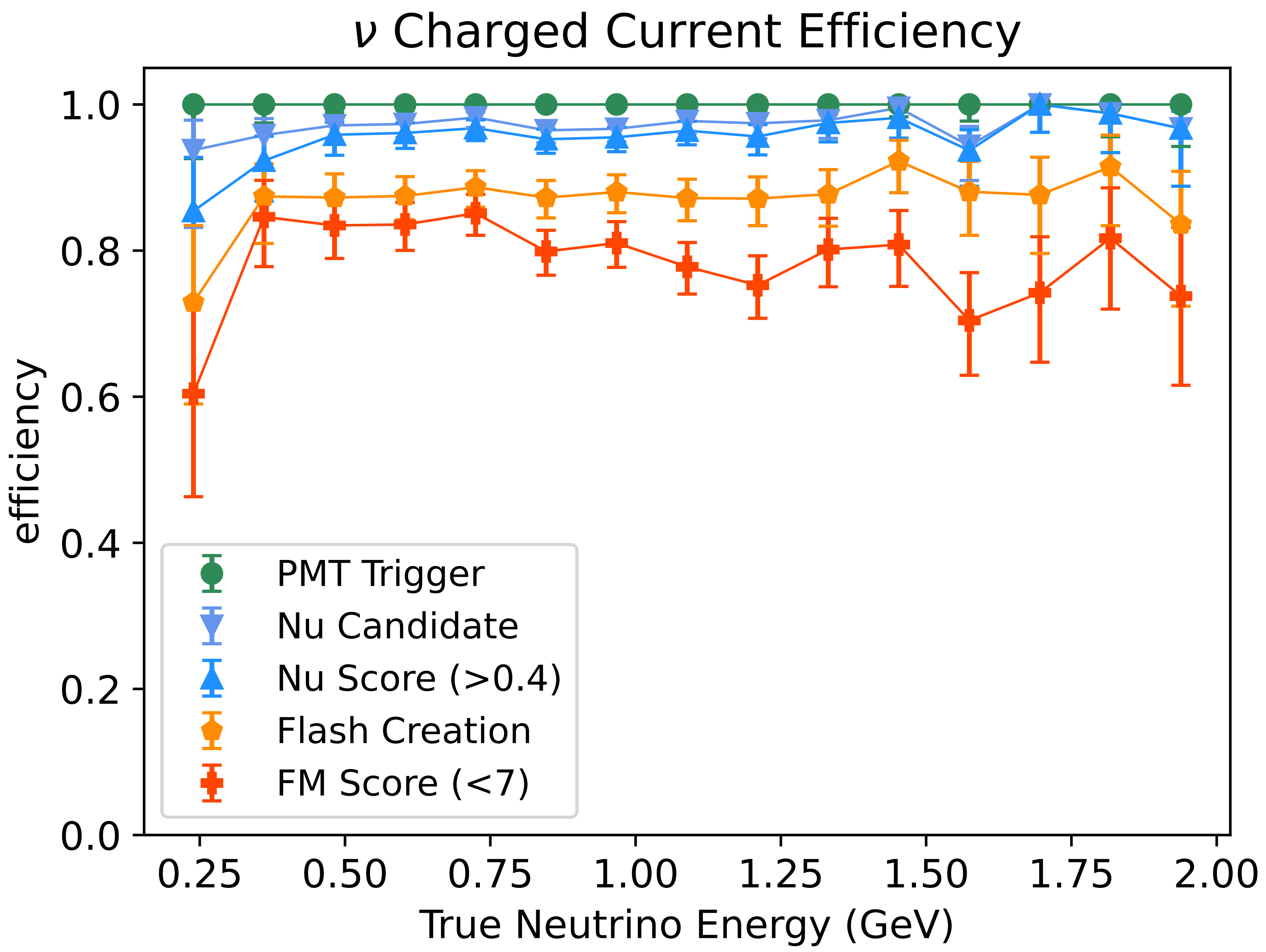
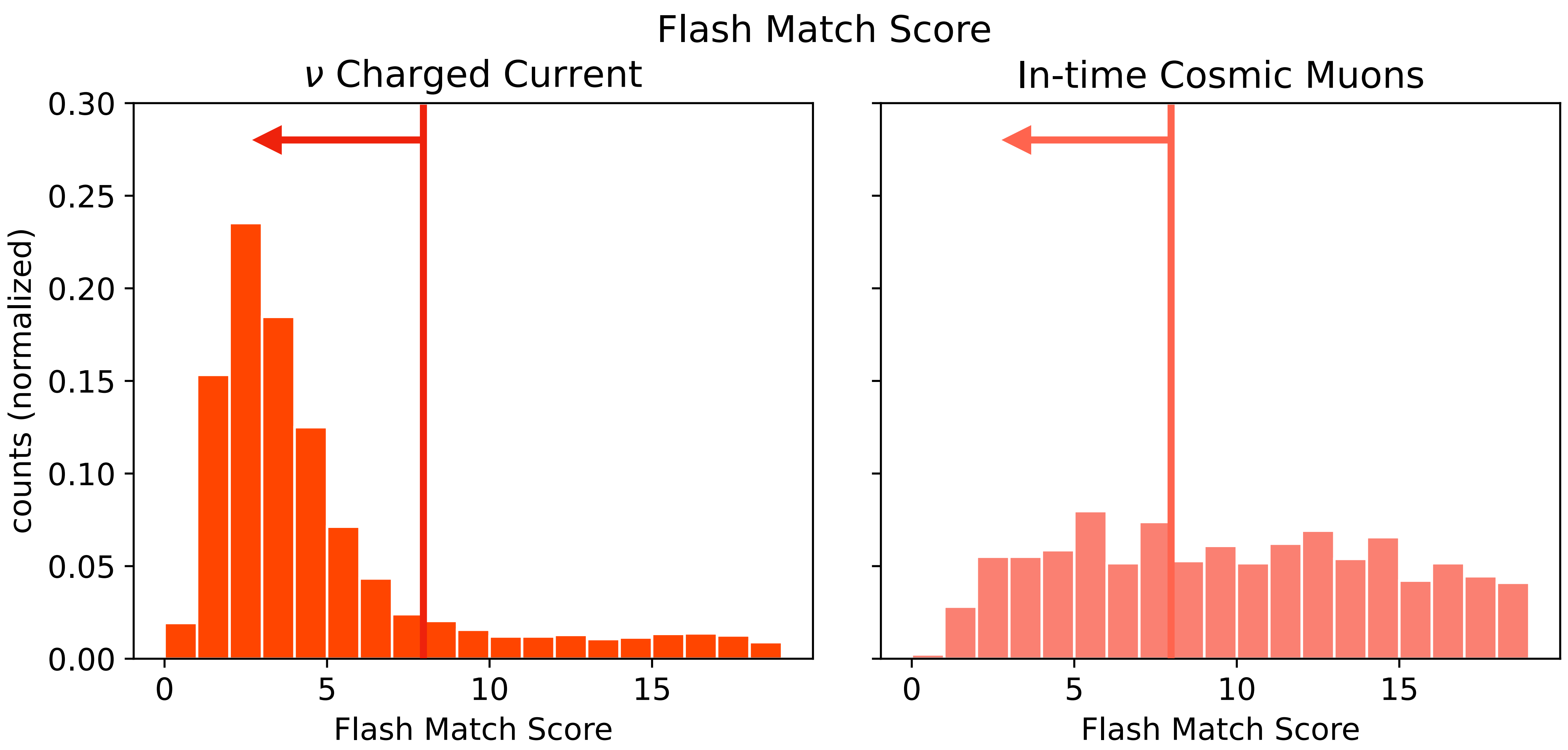
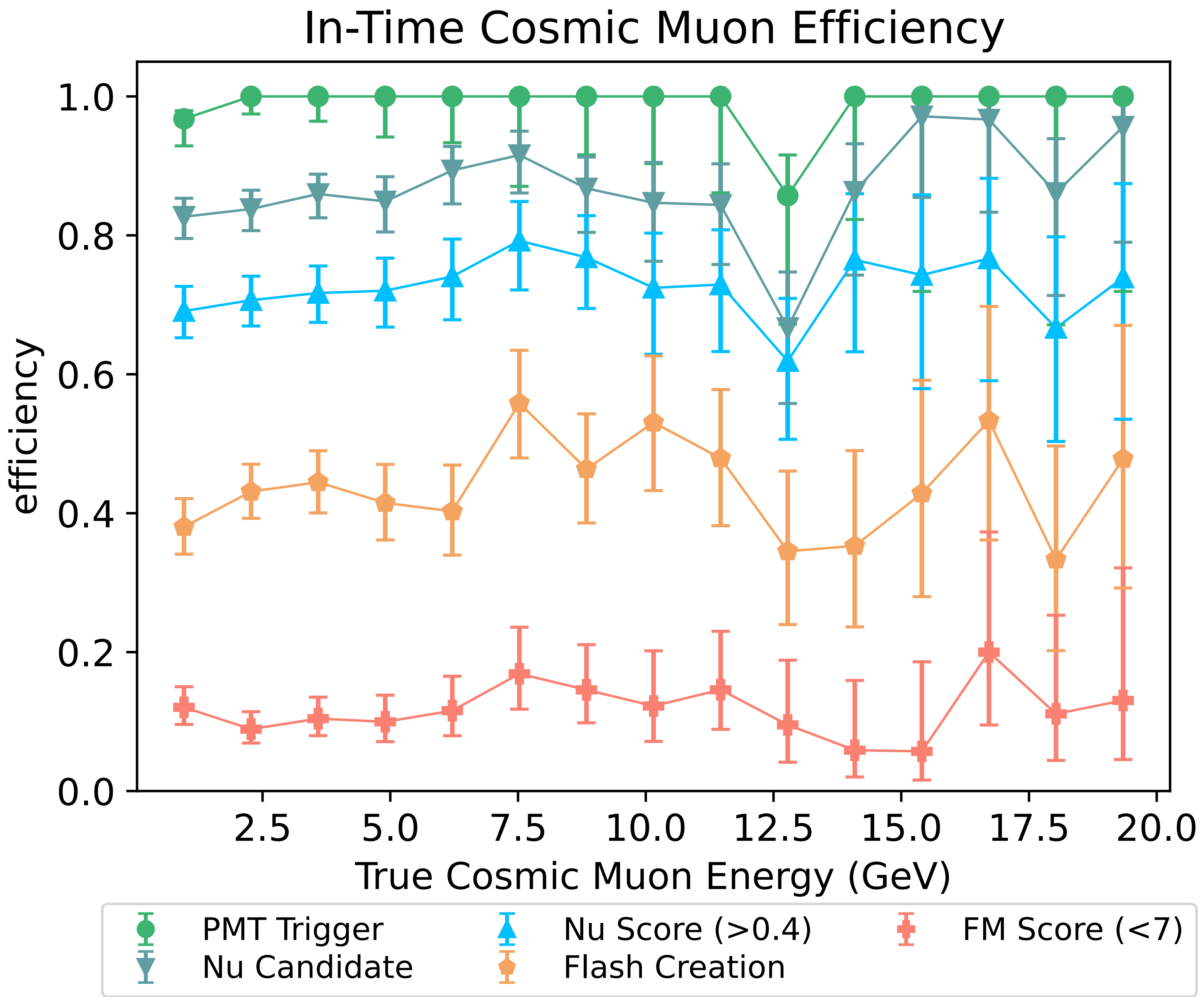
Flash Matching

- select events with flash score <= 7





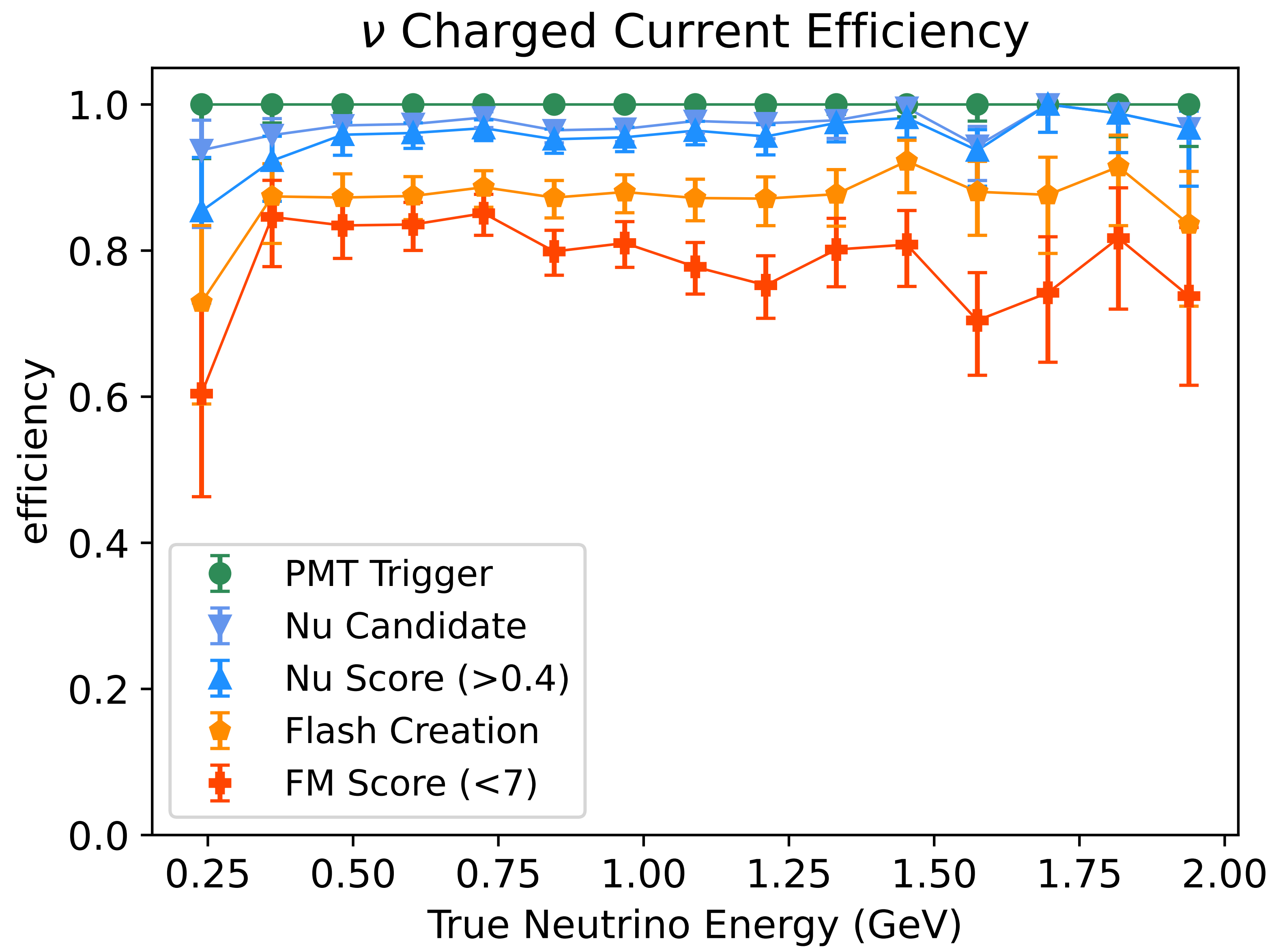


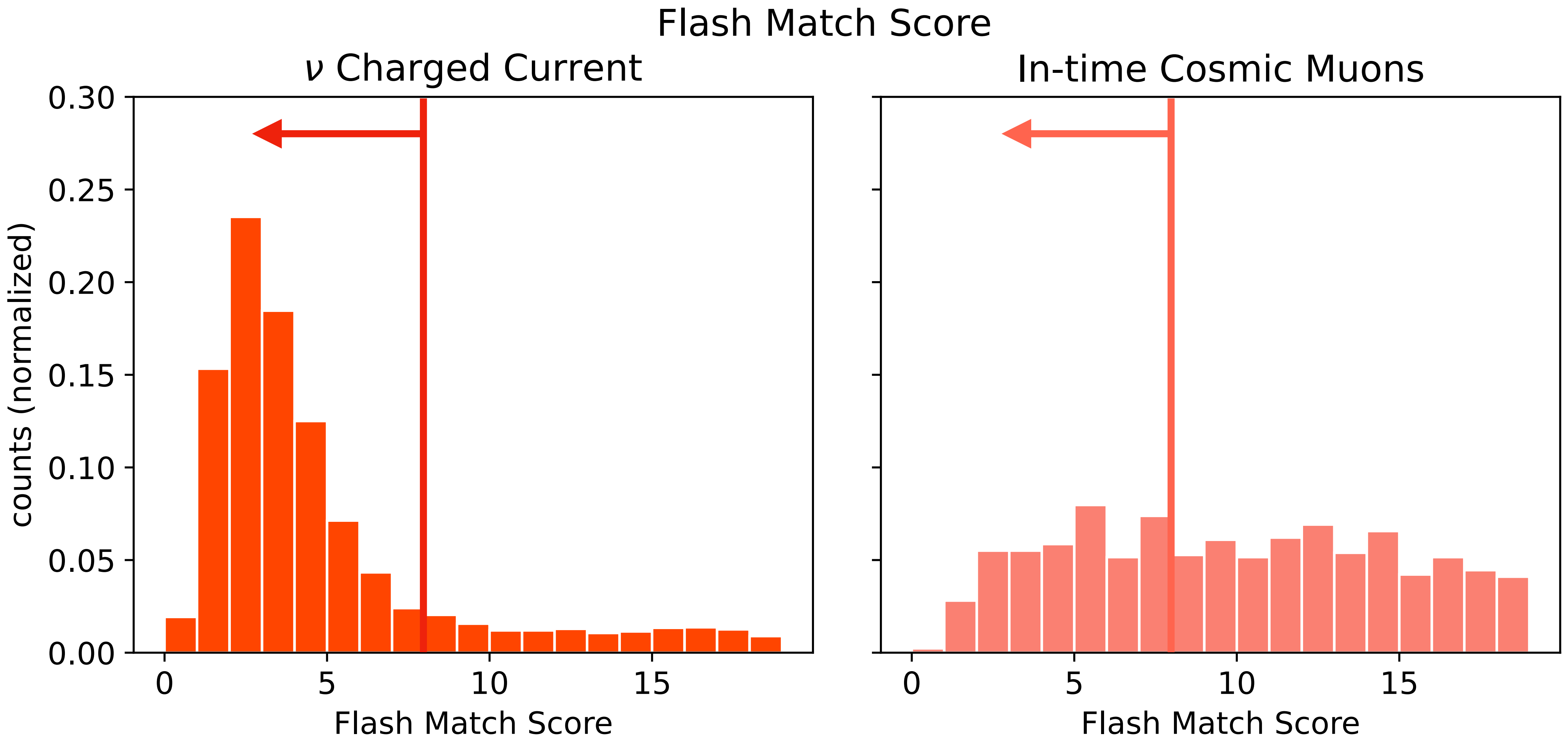
Flash Matching

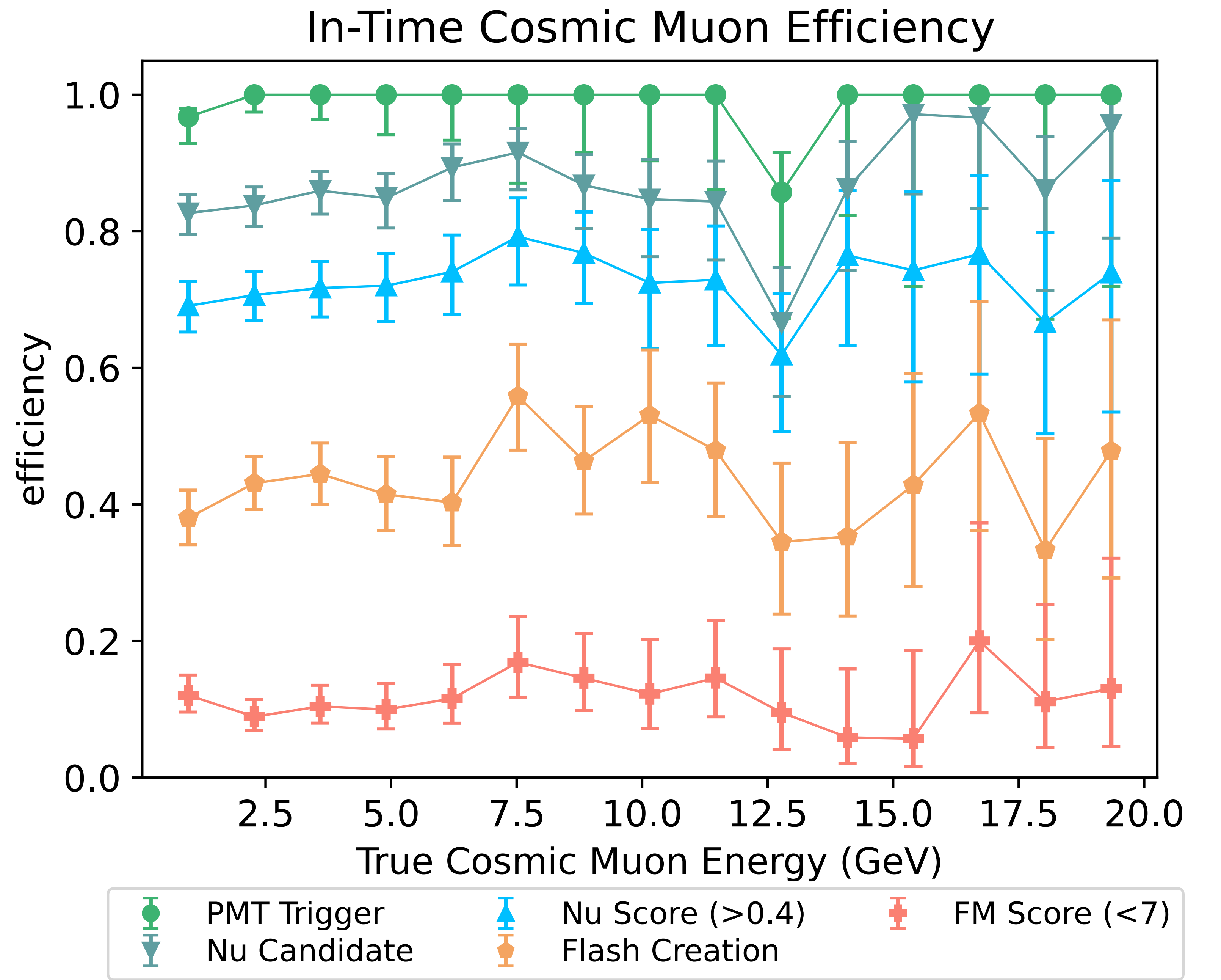
- select events with flash score <= 7

CC neutrino efficiency: ~70-80%

cosmic muon efficiency: < 20%







Flash Matching

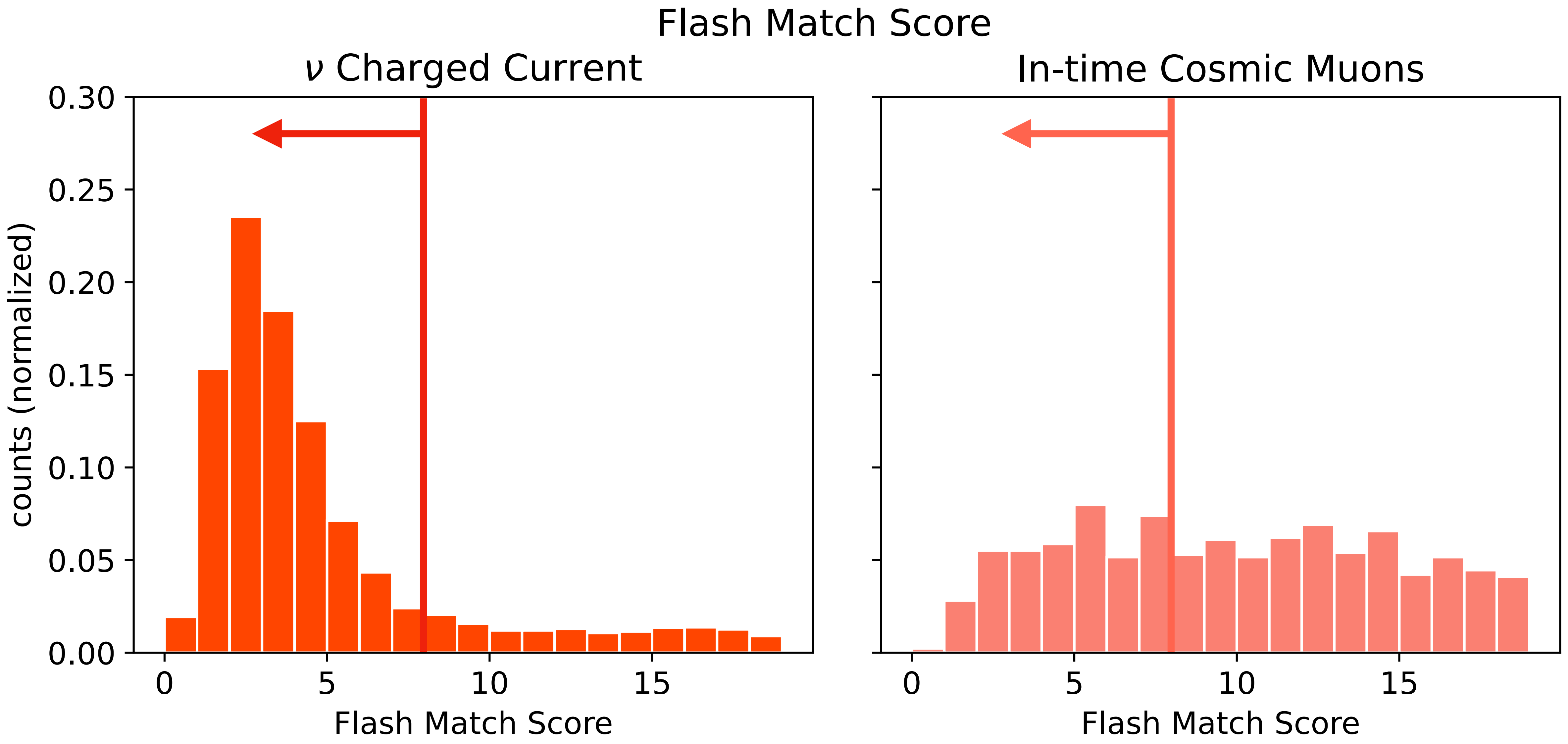
- select events with flash score <= 7

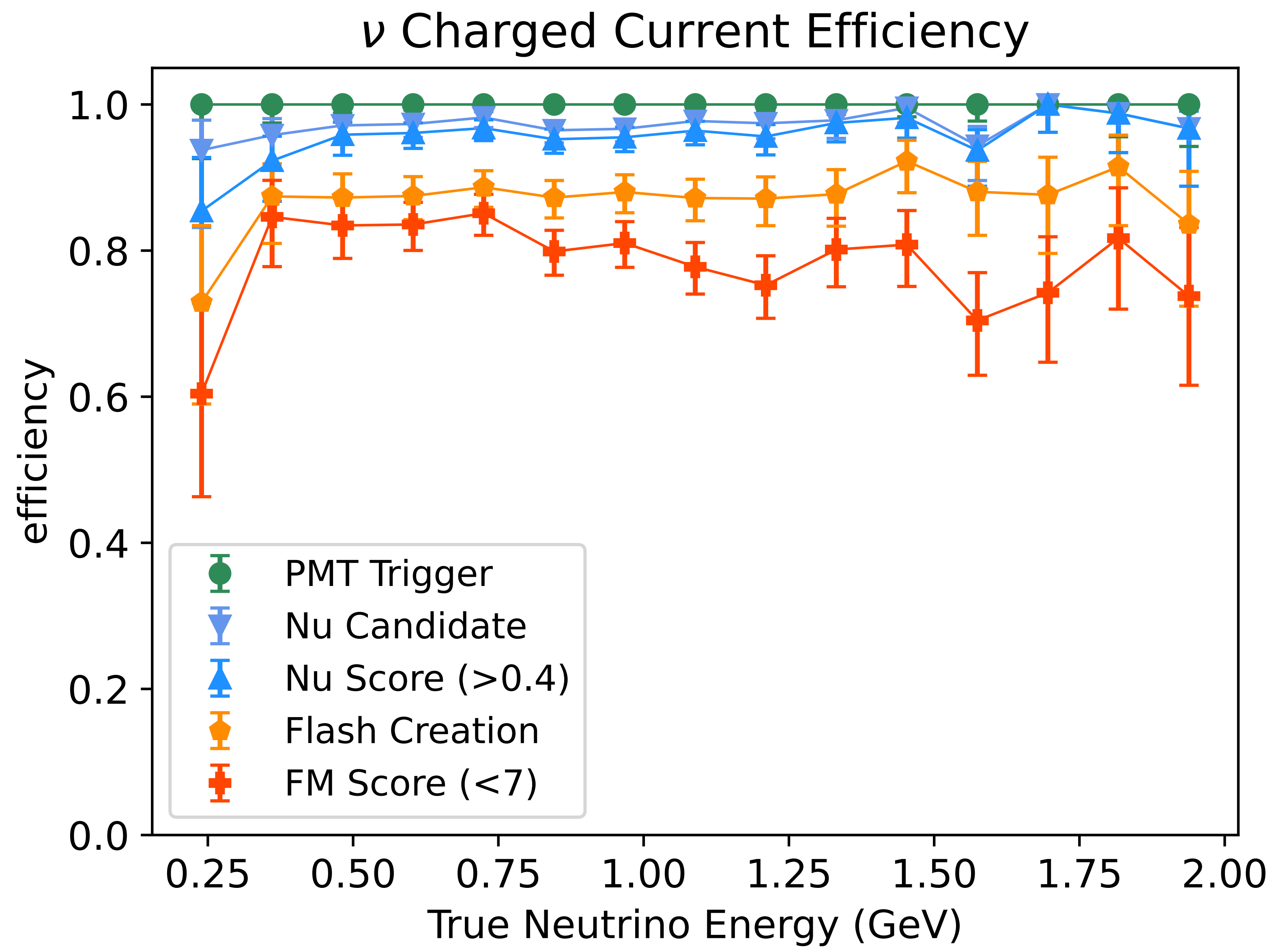
CC neutrino efficiency: ~70-80%

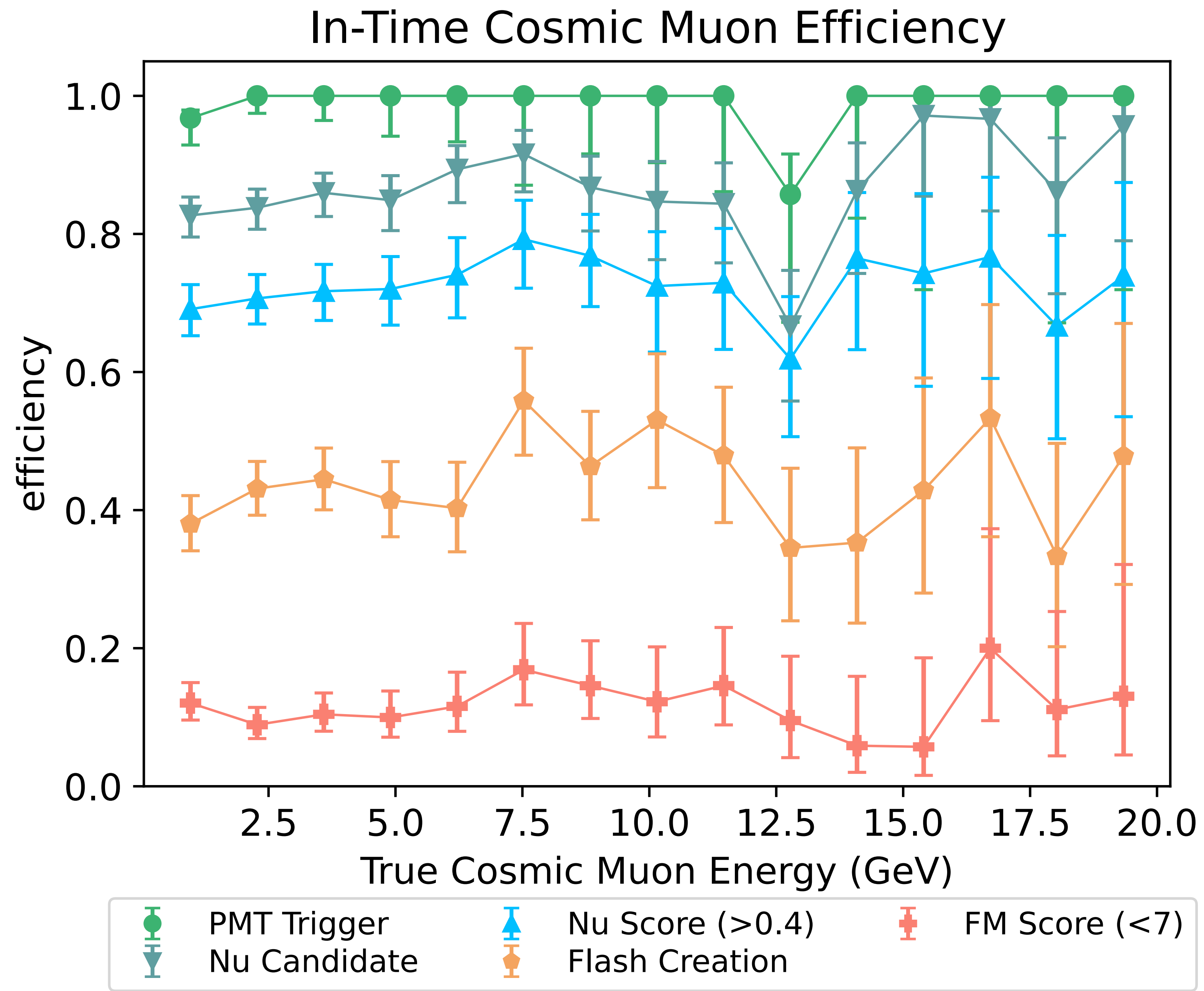
cosmic muon efficiency: < 20%

- removes an additional 60% of cosmics!

Combining sub-system info is **very powerful!**

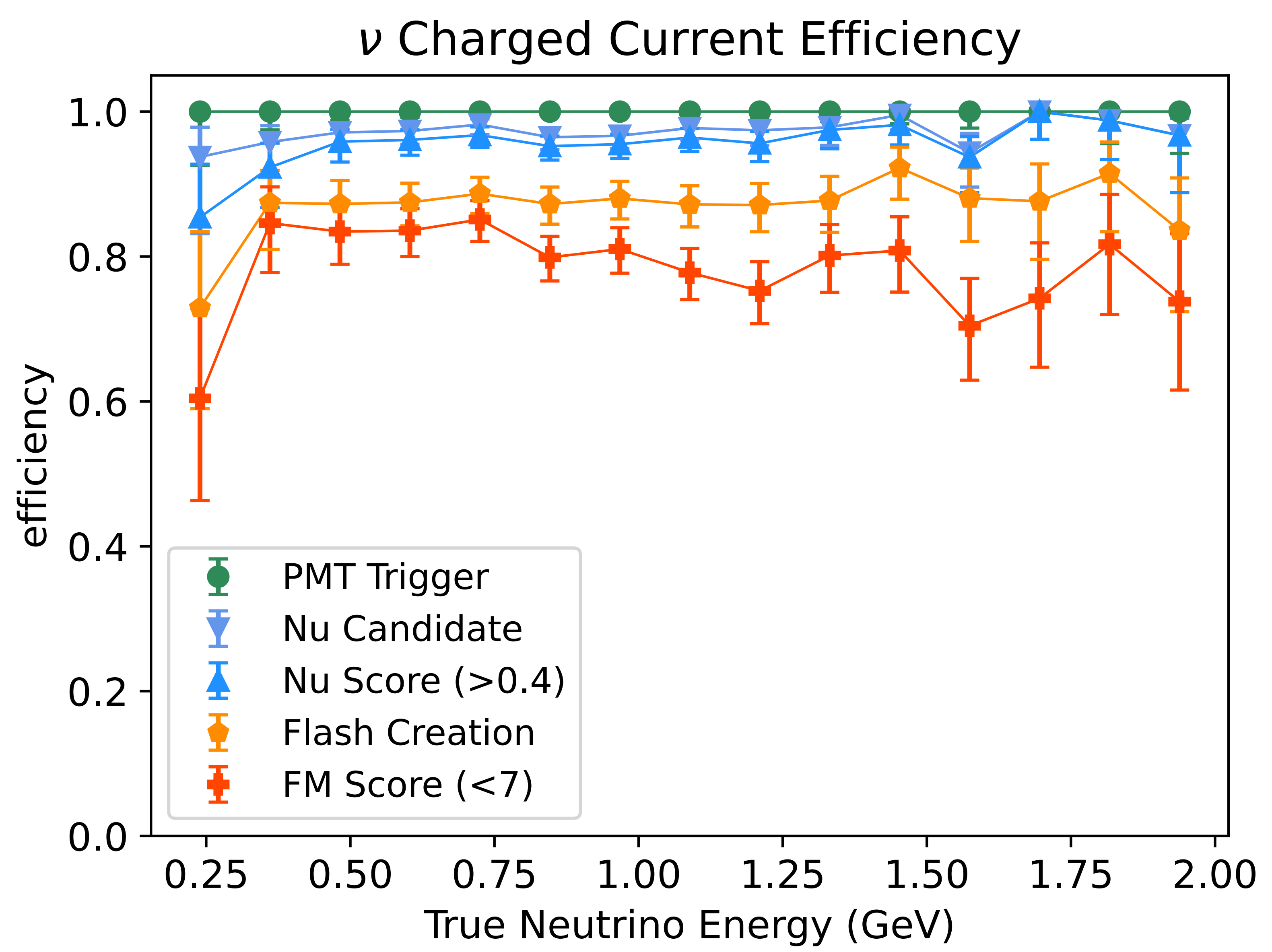


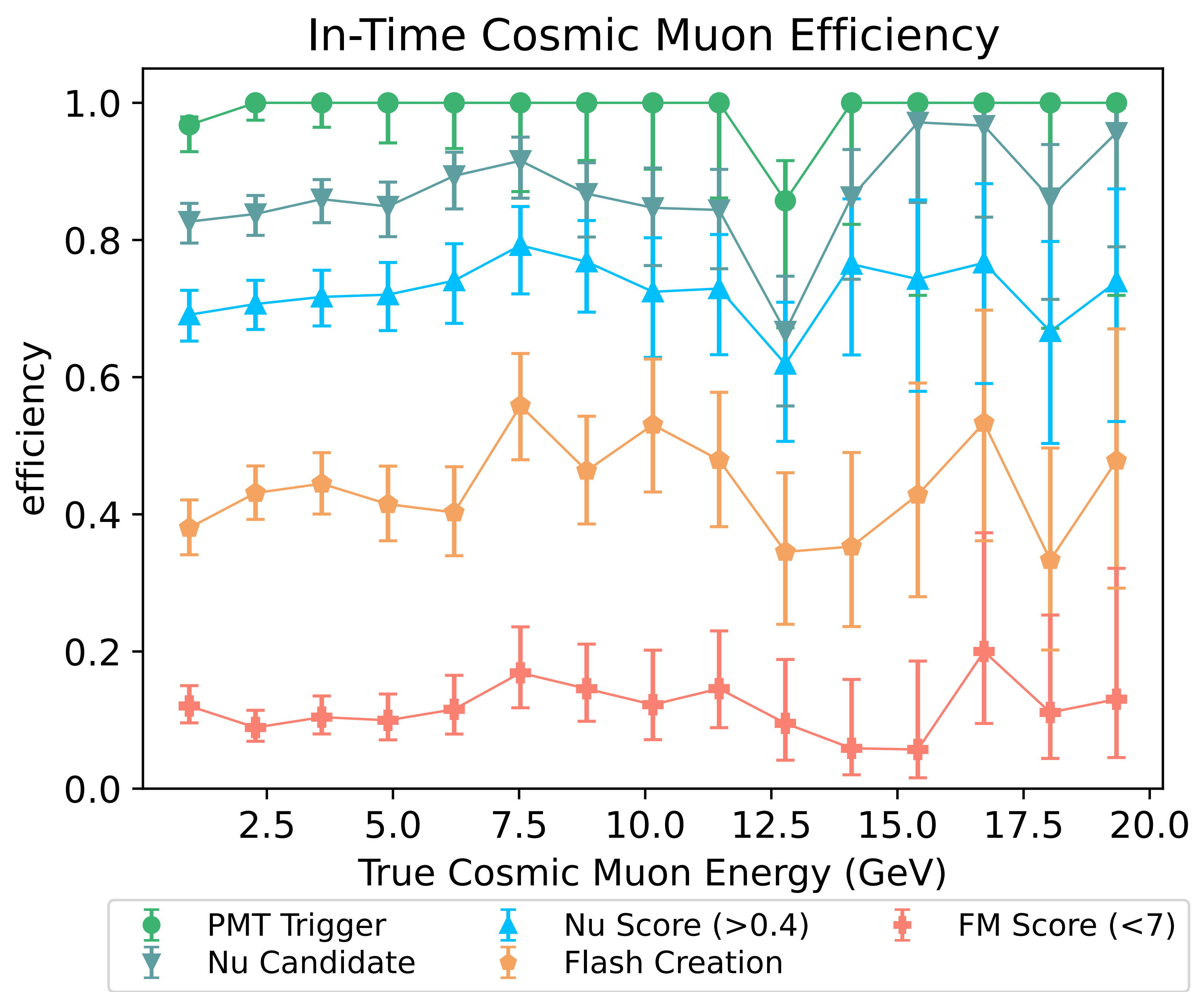




Conclusions and Outlook

- At the end of the standard reconstruction chain:
  - **CC neutrinos: >~70% efficiency**
    - low-energy events: ~60% efficiency
  - **less than 20% of cosmic muons remain**





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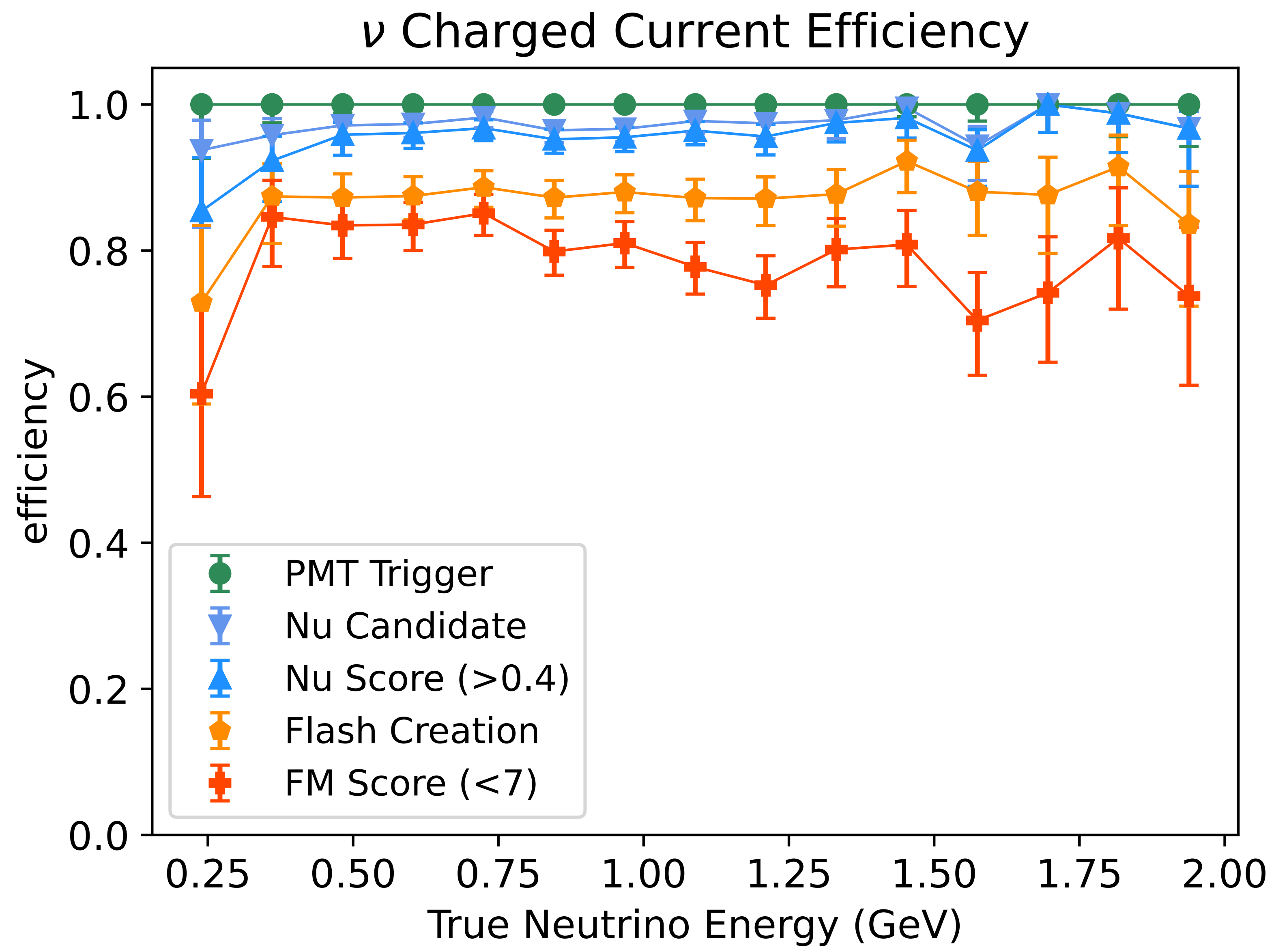
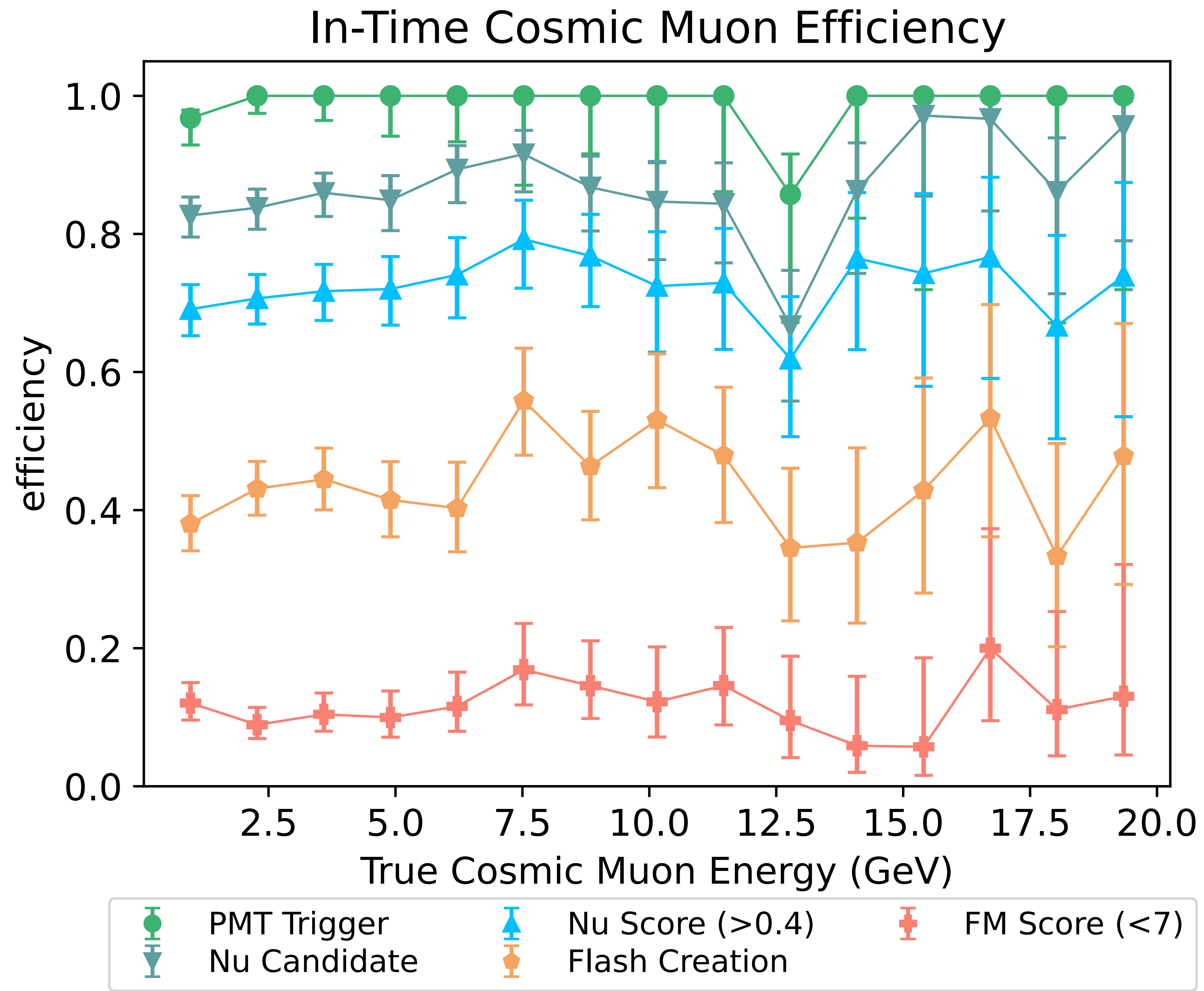
Future Improvements





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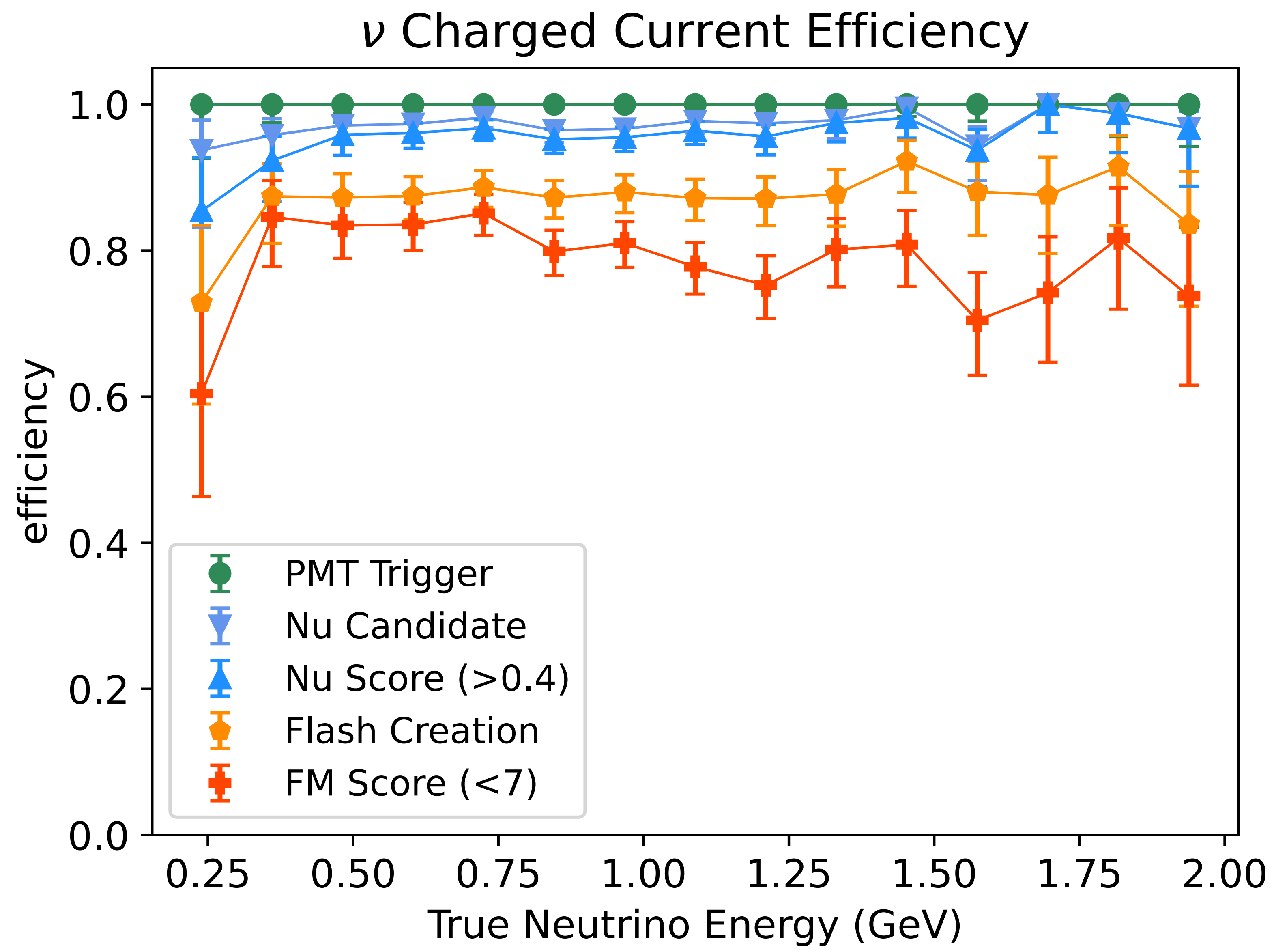
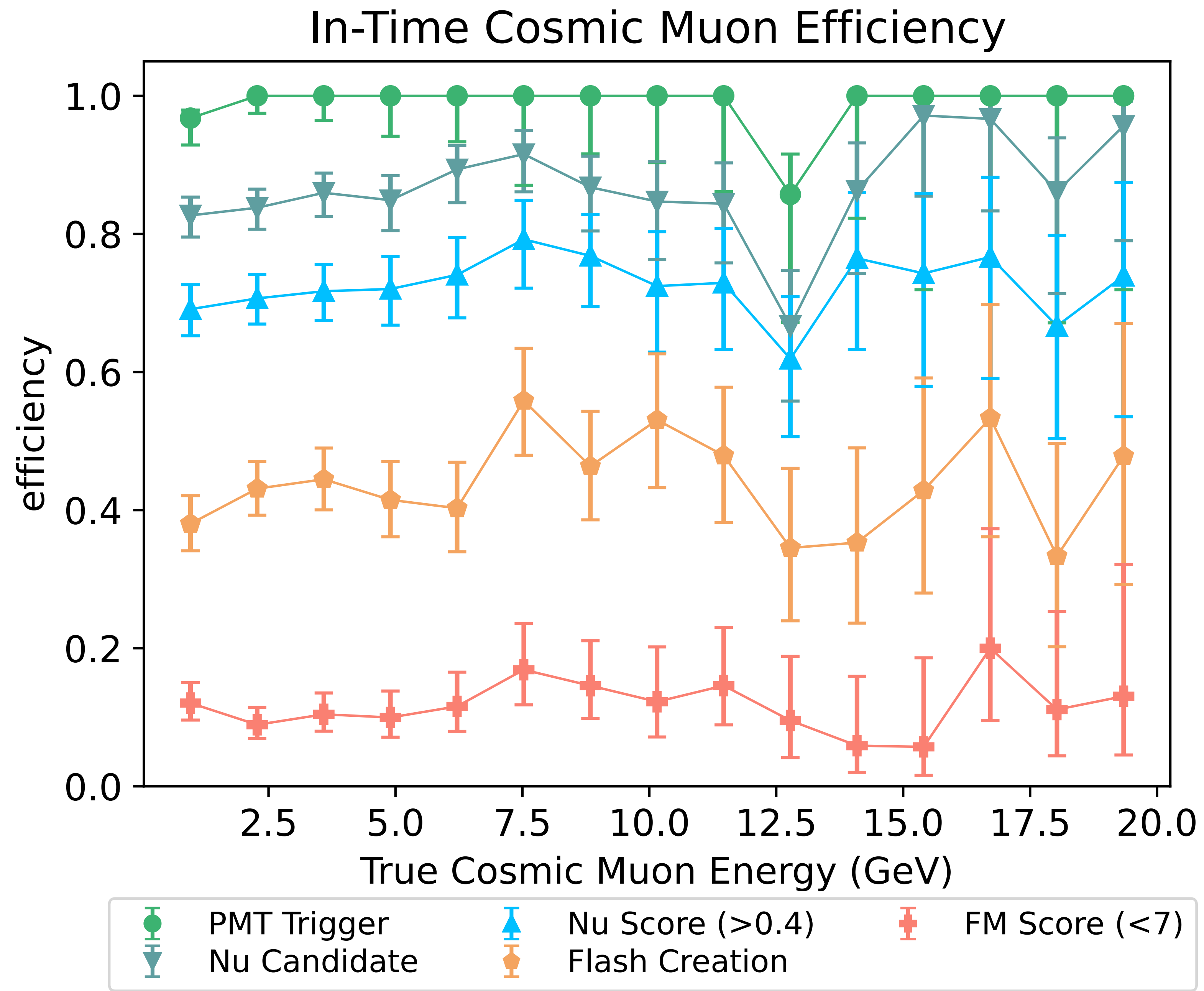
Future Improvements

- **Flash Creation + Matching** stage has largest decreases in efficiency for neutrino events:
  - currently implementing improvements to flash





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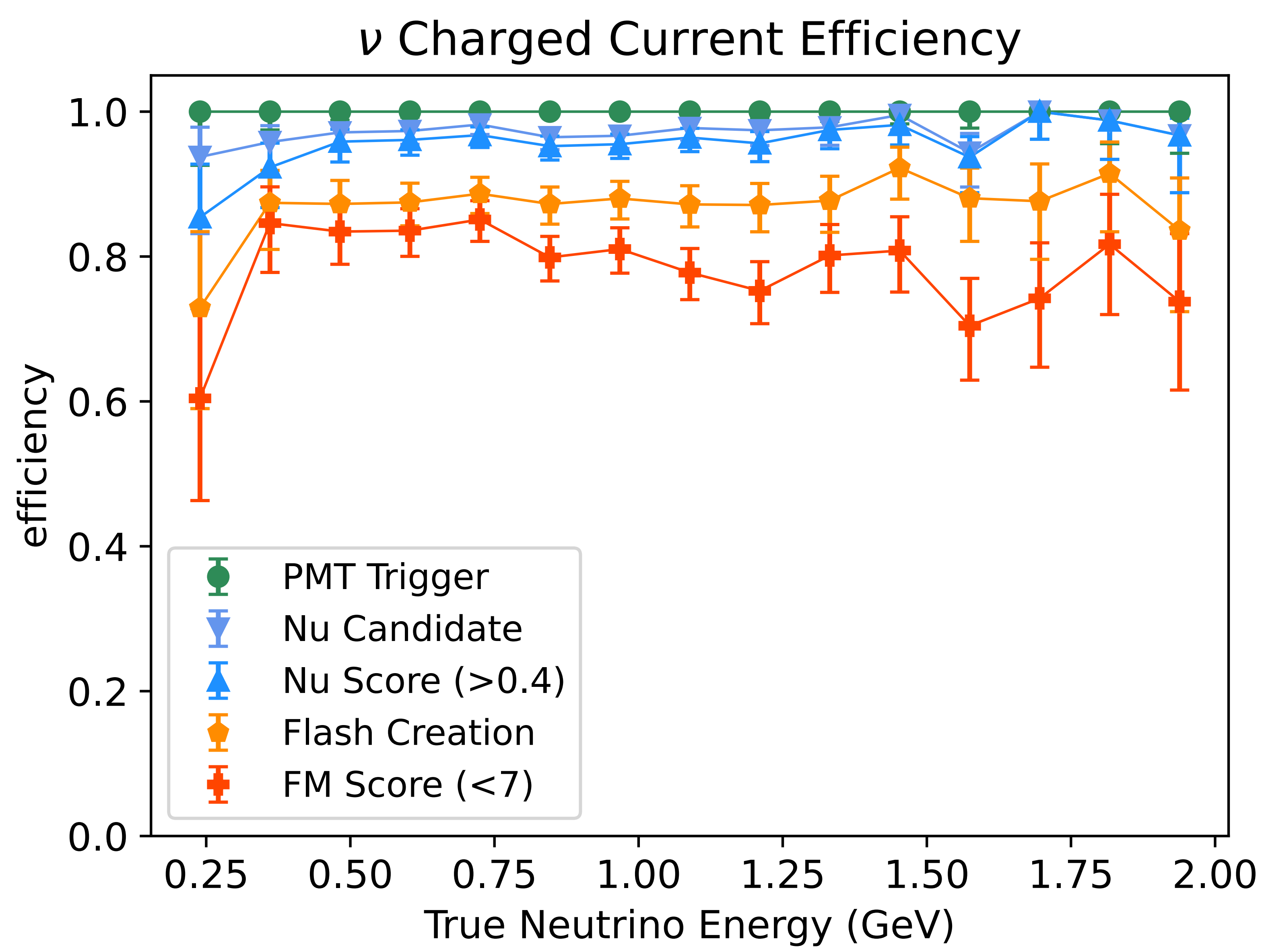
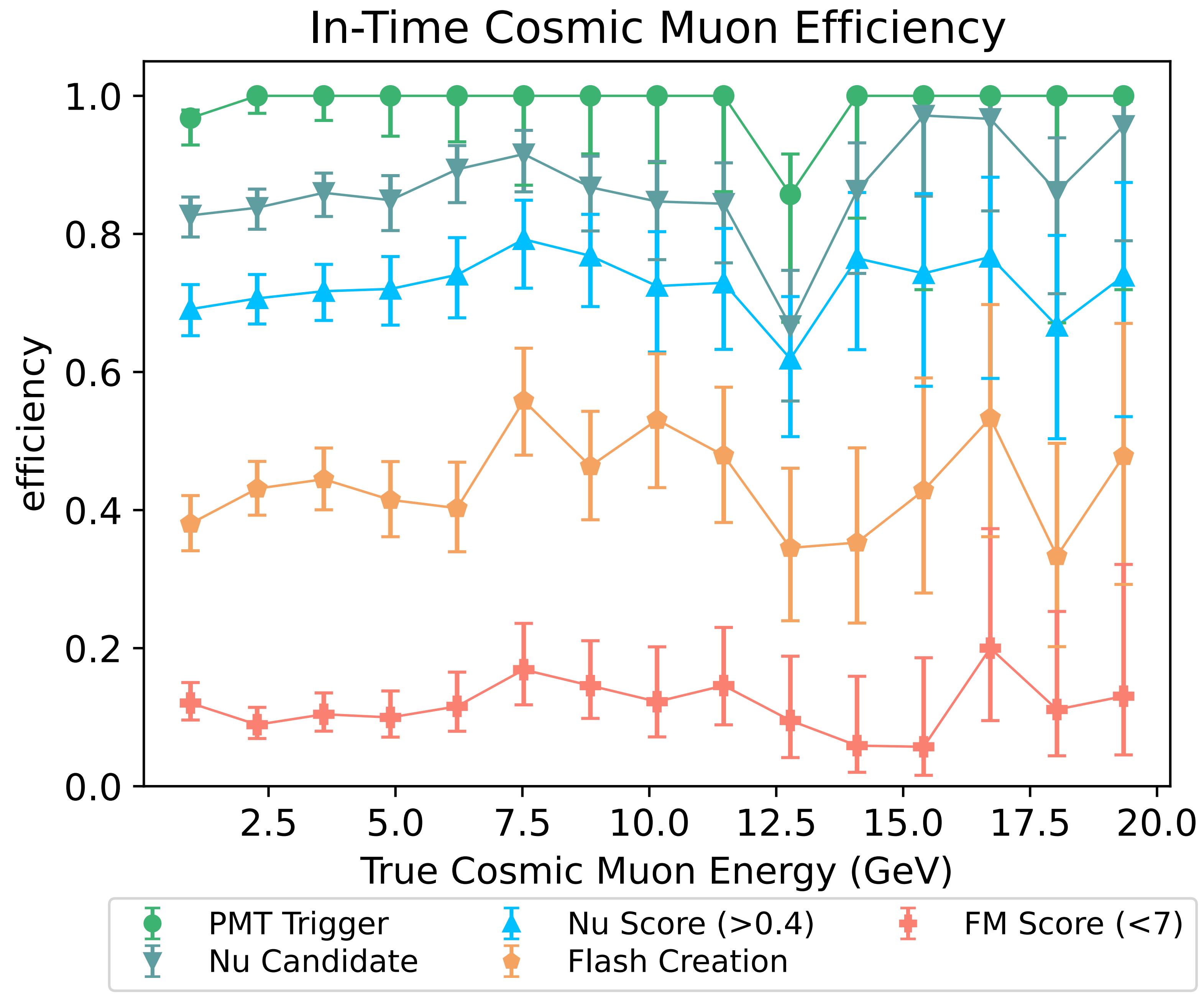
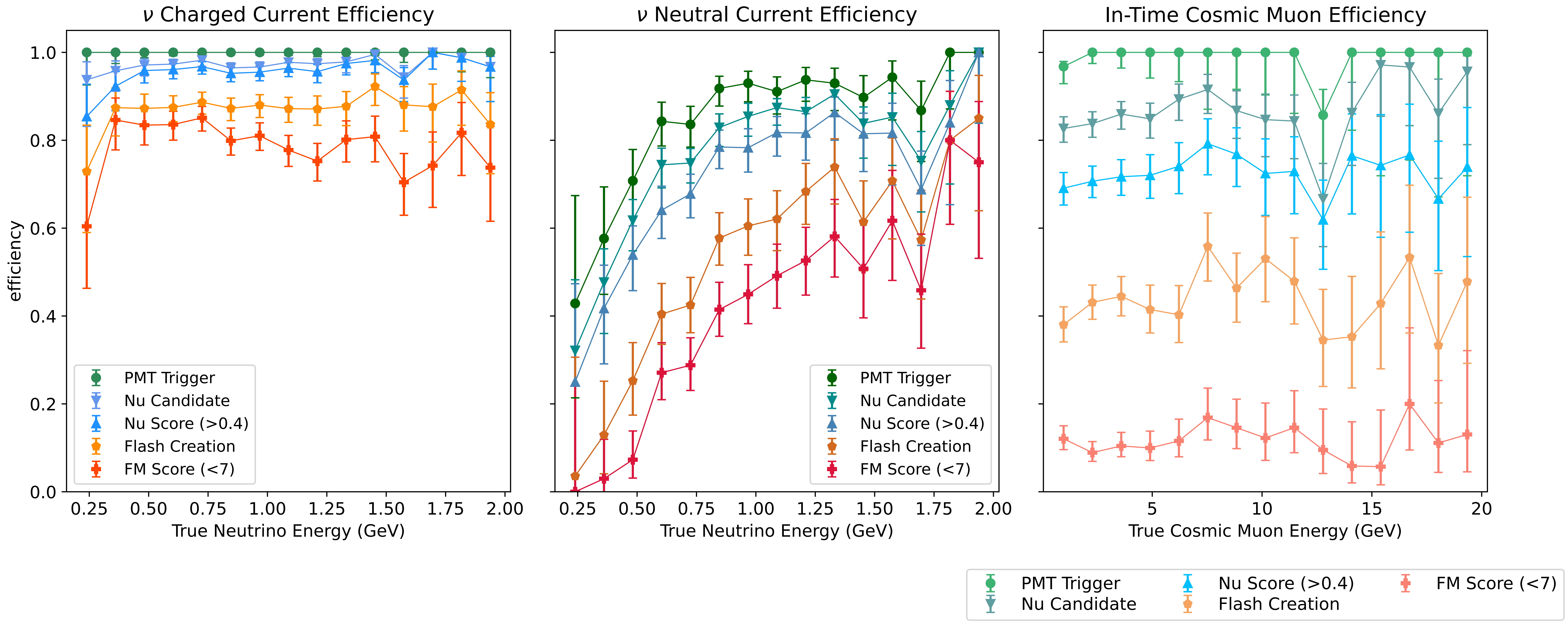
Future Improvements

- **Flash Creation + Matching** stage has largest decreases in efficiency for neutrino events:
  - currently implementing improvements to flash creation and matching algorithms in SBND
- Improved reconstruction chain:
  - combining sub-system info with boosted decision trees for a single cosmic rejection score

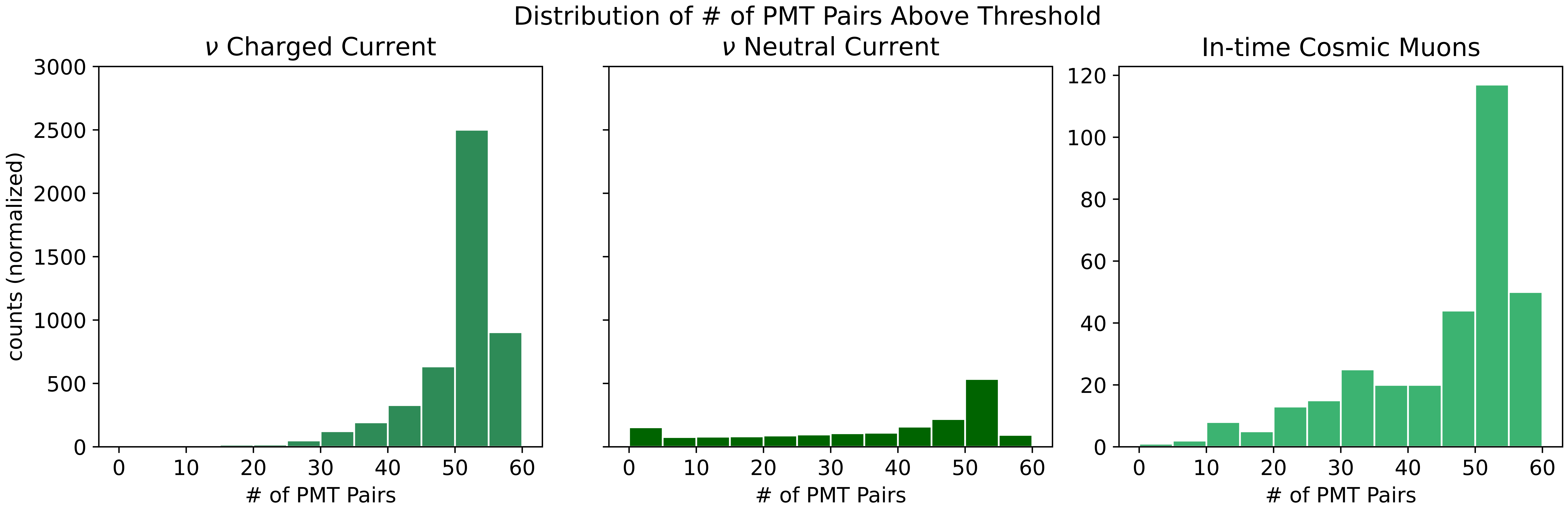


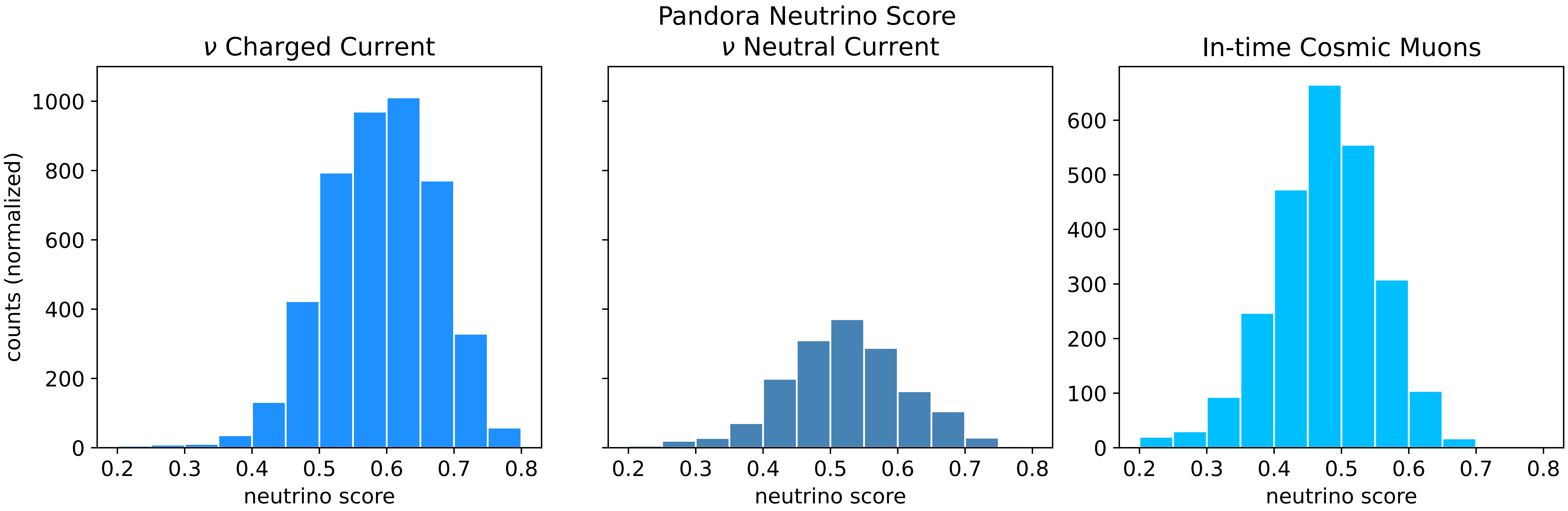


Backup

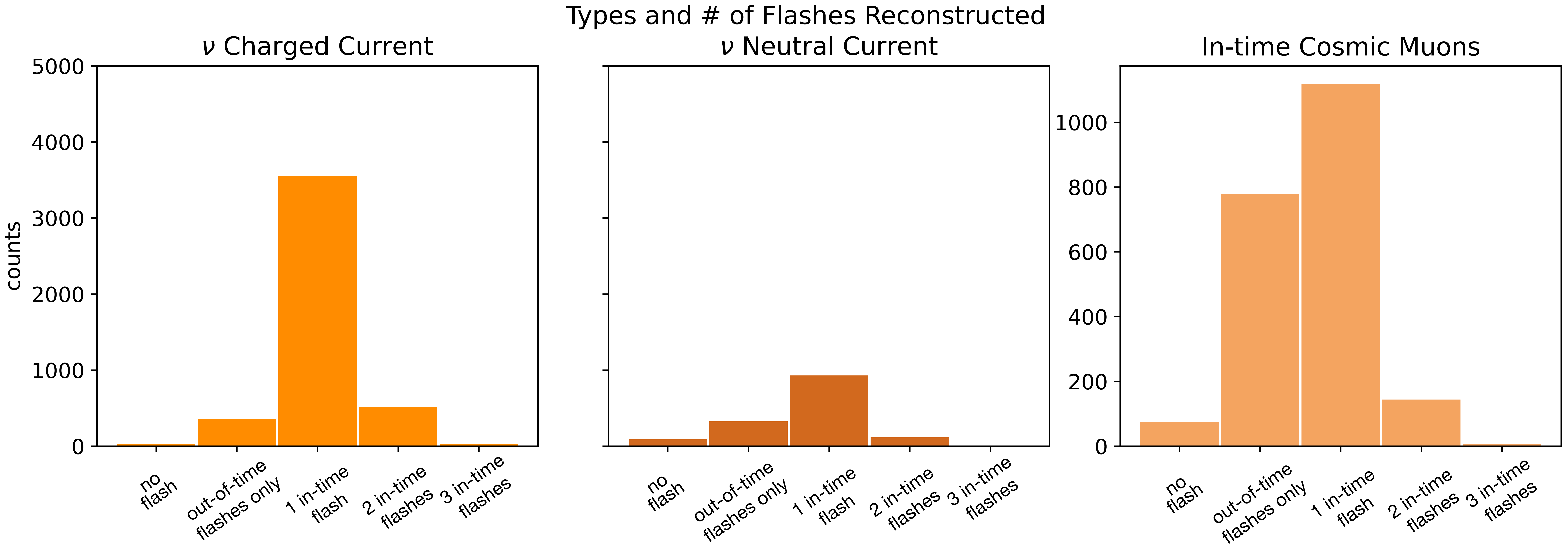


ν Charged Current Efficiency
ν Neutral Current Efficiency
In-Time Cosmic Muon Efficiency
efficiency
1.0
0.8
0.6
0.4
0.2
0.0
0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00
True Neutrino Energy (GeV)
5 10 15 20
True Cosmic Muon Energy (GeV)
PMT Trigger
Nu Candidate
Nu Score (>0.4)
Flash Creation
FM Score (<7)

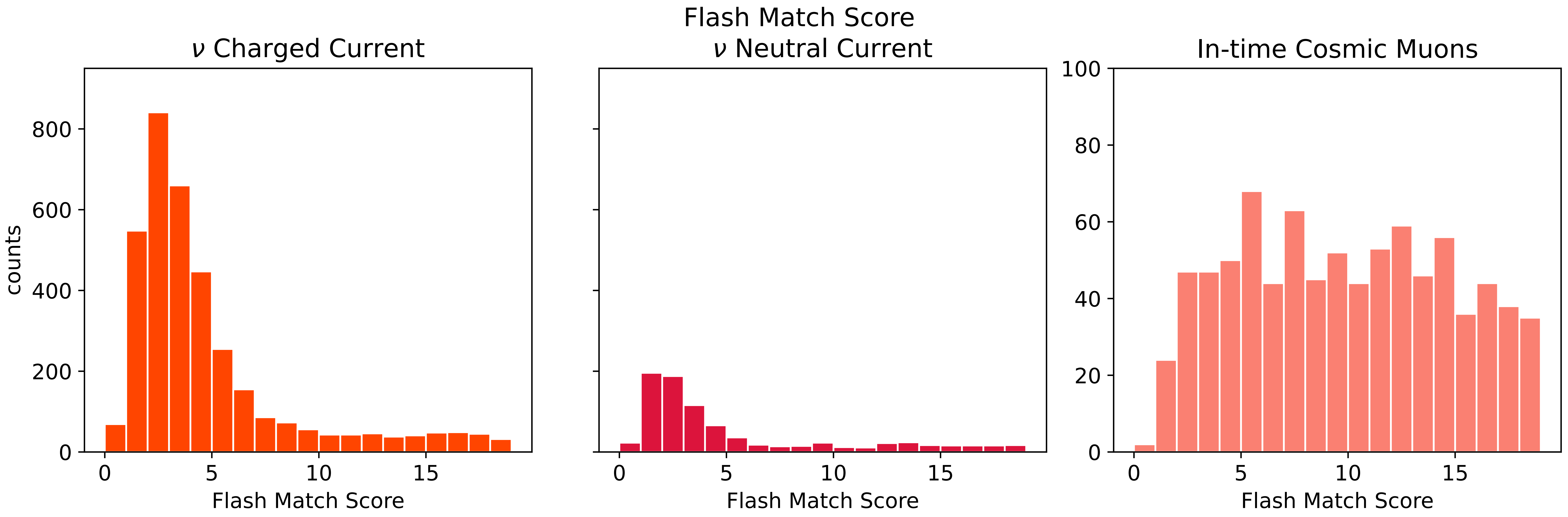

Distribution of # of PMT Pairs Above Threshold
ν Charged Current
ν Neutral Current
In-time Cosmic Muons
counts (normalized)
3000
2500
2000
1500
1000
500
0
120
100
80
60
40
20
0 10 20 30 40 50 60
# of PMT Pairs



Pandora Neutrino Score
ν Charged Current
ν Neutral Current
In-time Cosmic Muons
counts (normalized)
1000
800
600
400
200
0
500
300
100
0.2
0.3
0.4
0.5
0.6
0.7
0.8
neutrino score



Types and # of Flashes Reconstructed
ν Charged Current
ν Neutral Current
In-time Cosmic Muons
counts
5000
4000
3000
2000
1000
0
1000
800
600
400
200
0
no flash
out-of-time flashes only
1 in-time flash
2 in-time flashes
3 in-time flashes


Flash Match Score
ν Charged Current
ν Neutral Current
In-time Cosmic Muons
counts
0
200
400
600
800
20
40
60
80
100
0
5
10
15
Flash Match Score
Flash Match Score
Flash Match Score