Dichroicon Occupancy and Shadowing Effects from Michel Electrons In EOS

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Workshop on Hybrid Scintillation/Cherenkov Detection Technologies
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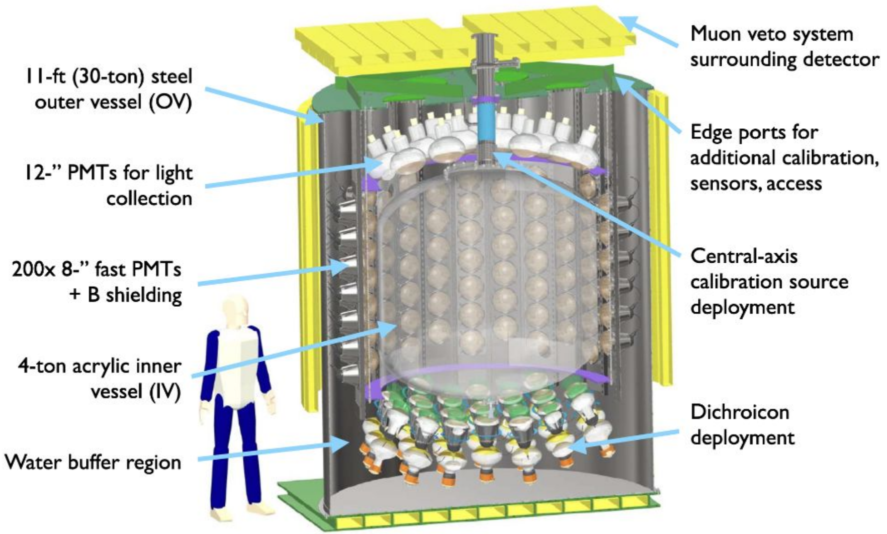
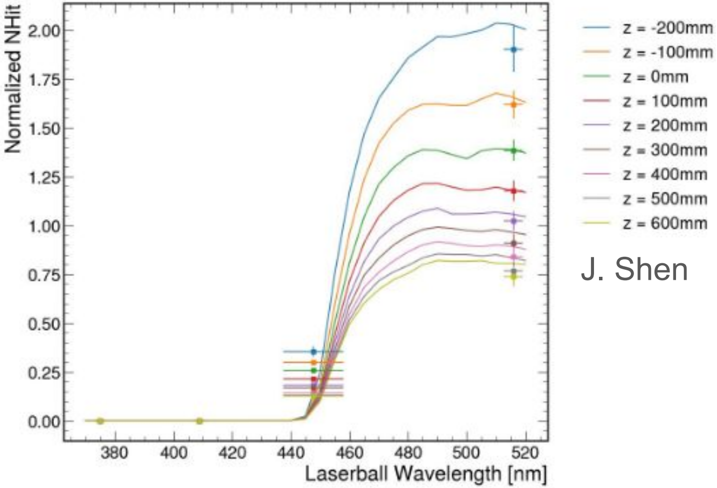
EOS Detector Overview

- Novel technology demonstrator currently deployed at the University of California, Berkeley
- Uses water-based liquid scintillator, fast PMTs, and dichroicons to explore the capabilities of hybrid event detection, leveraging both Cherenkov and scintillation light simultaneously
- Results will improve simulation models used to predict the performance of future kton-scale hybrid detectors such as THEIA
- Potential redeployment at the Spallation Neutron Source at Oak Ridge National Lab to reconstruct neutrinos at supernova energies



Probing EOS Dichroicons

- Twelve dichroicons with a cut-on wavelength of 450 nm are mounted on 8" PMTs at the bottom of EOS to detect long wavelength (Cherenkov) light
- Twenty-four 8" PMTs sit around them to detect transmitted short wavelength (scintillation) light
- Thirteen 10" PMTs are positioned behind them to detect transmitted short wavelength (scintillation) light
- Laserball scans across a range of wavelengths and heights in water have demonstrated good agreement between data and simulation for dichroicon occupancy.



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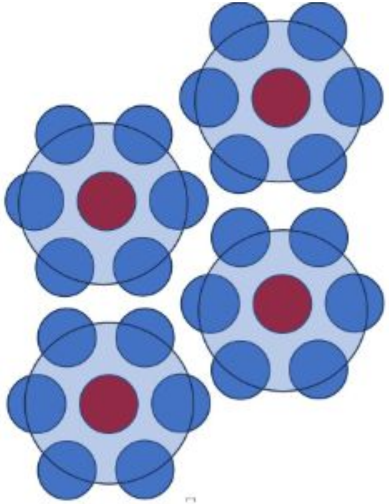
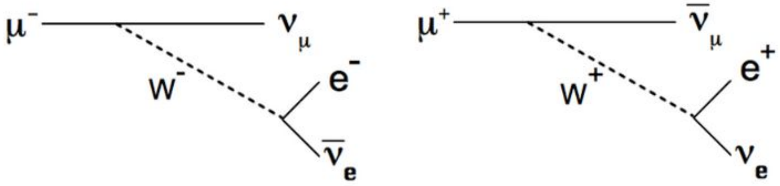
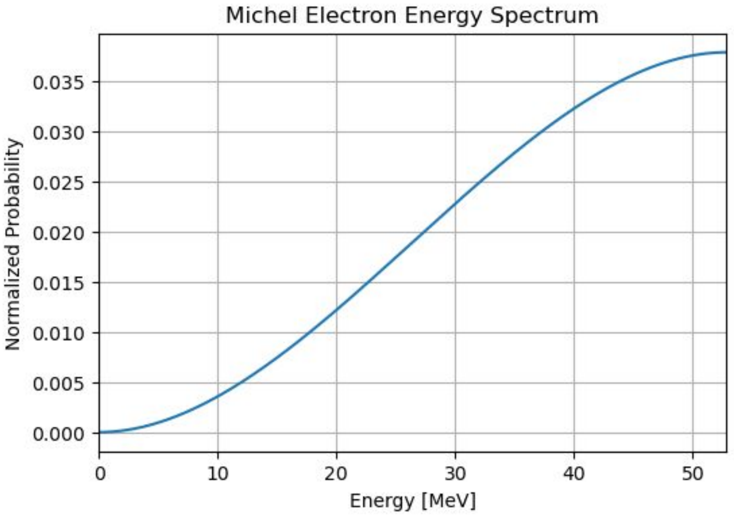


Probing EOS Dichroicons with Michel Electrons

- Surface level detectors such as EOS observe the large flux of muons produced in cosmic ray showers
- Muons that stop in EOS decay with a half life of 2.197 μs and produce low-energy (Michel) electrons
- Michel electrons have a well understood energy spectrum, making them a reliable (and easy to simulate), isotropic, single electron calibration source
- Creating a Michel electron trigger is straightforward
    - First trigger on a high energy event (stopping muon candidate)
    - Then open a several μs long window and trigger on all low energy events (Michel electron candidates)
- **<u>Goal:</u>** Assess the accuracy of our dichroicon model using a new source. Integrate over wavelength and compare the number of Cherenkov hits from Michel electrons in water between data and simulation





Analysis Procedure

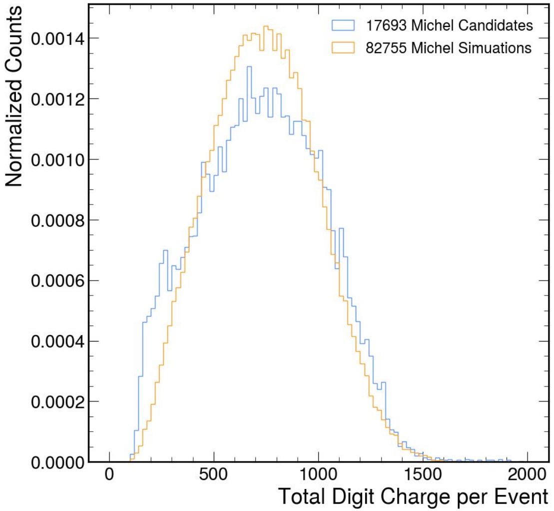
- Define hits as waveforms that cross 4 mV threshold

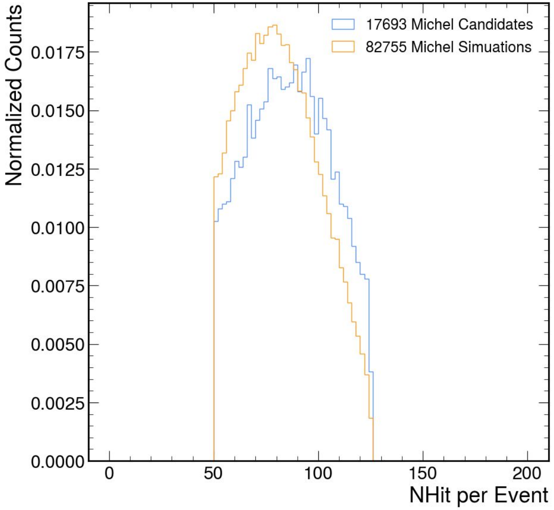
- Apply hit cleaning cuts to remove:
  - Cross-talk
  - Digitizer noise
  - PMT dark noise

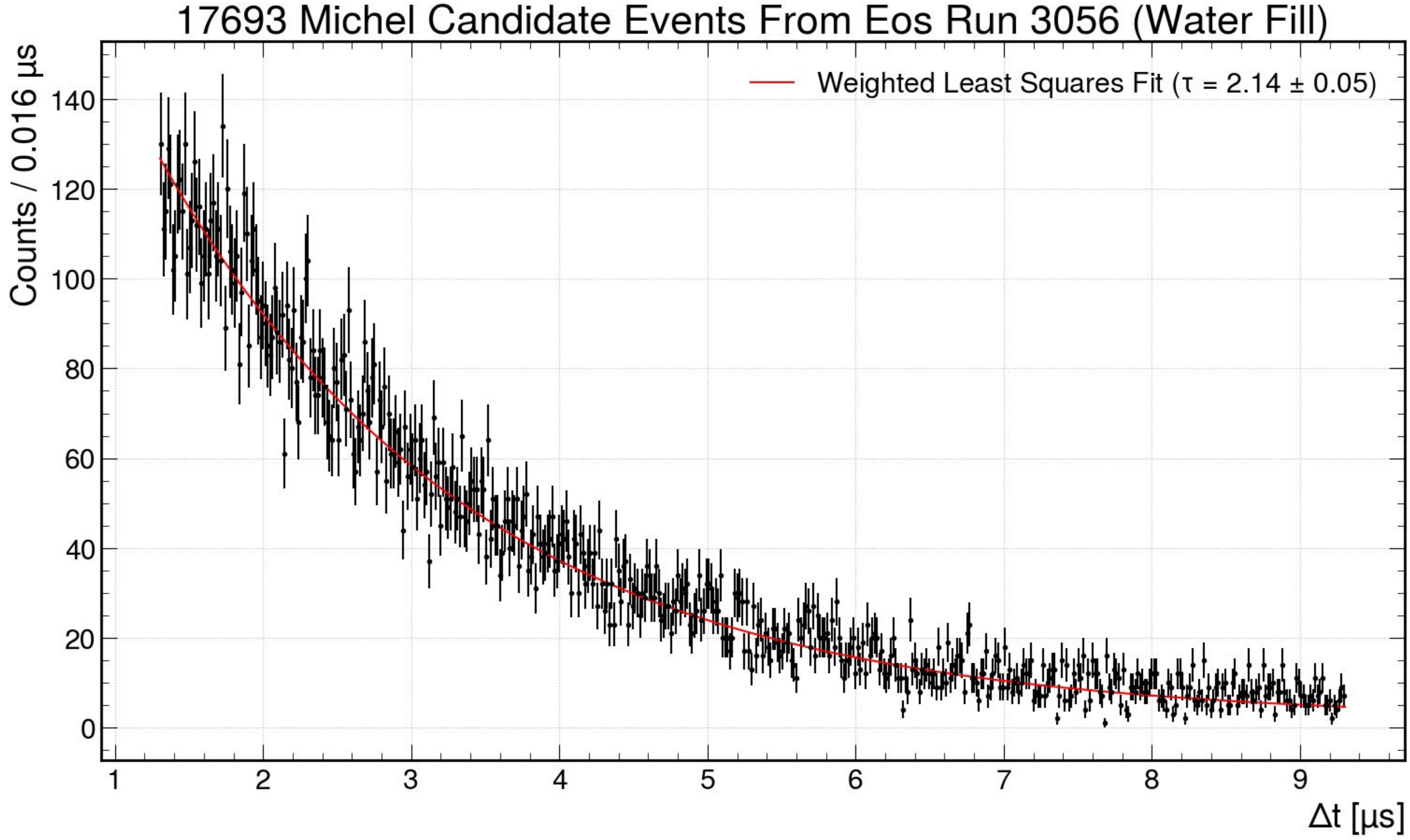
- Apply fiducial volume cut using reconstructed event vertex

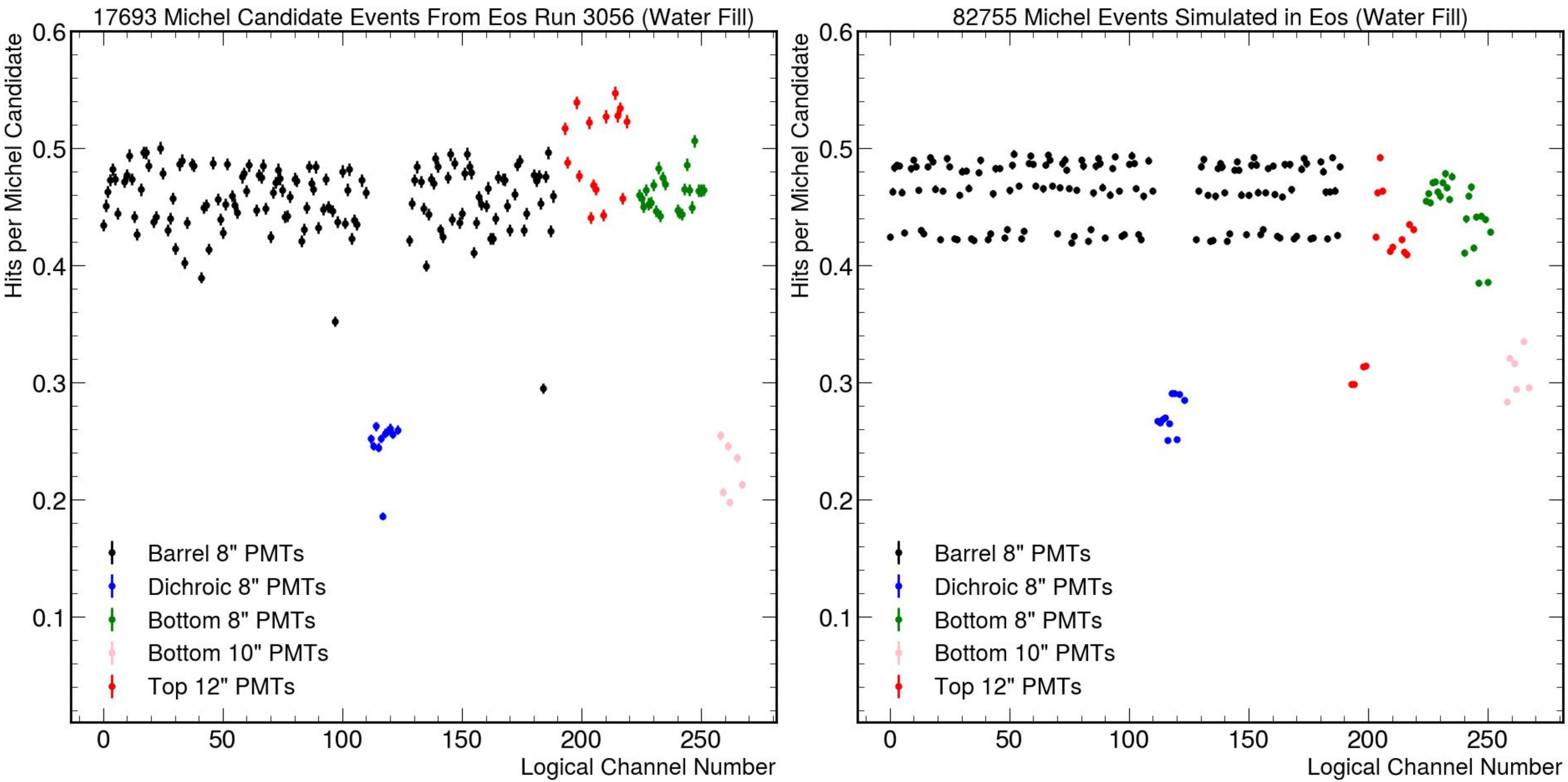
- Classify events as stopping muon candidates (prompt + high energy) or Michel electron candidates (delayed + low energy) using NHit

- Apply purity cut on michel candidates using, Δt, the time since the last stopping muon candidate

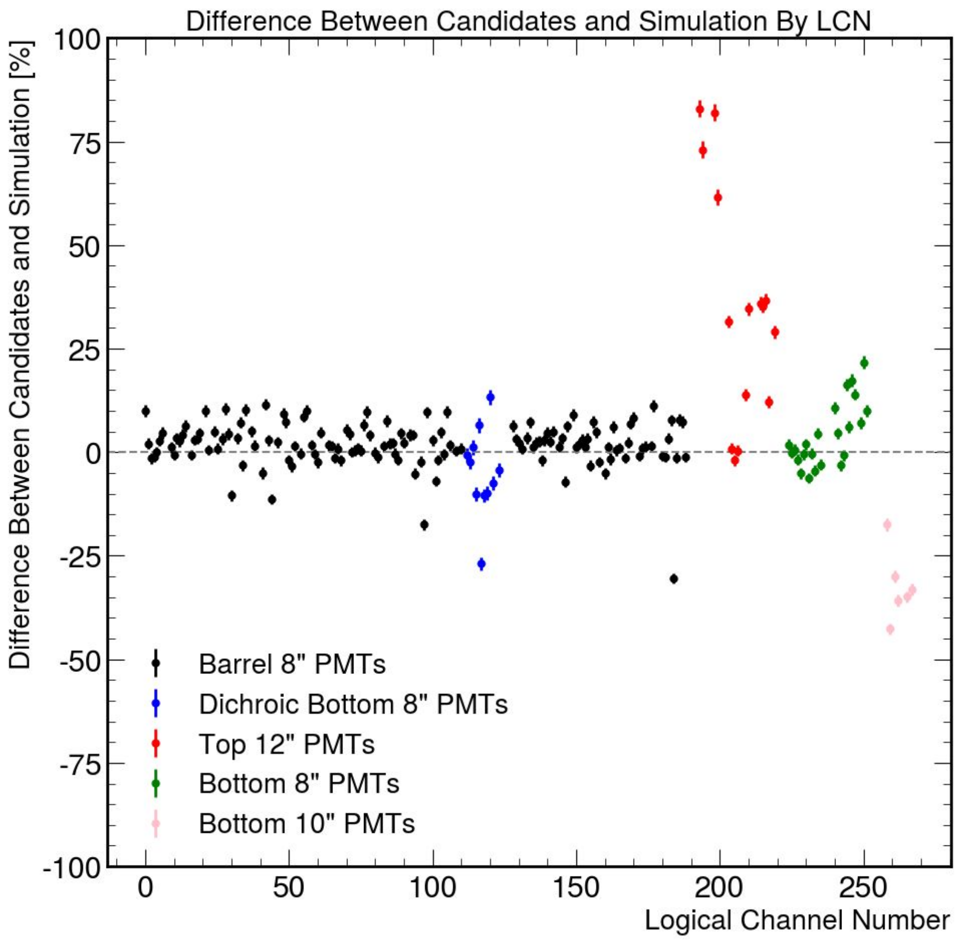


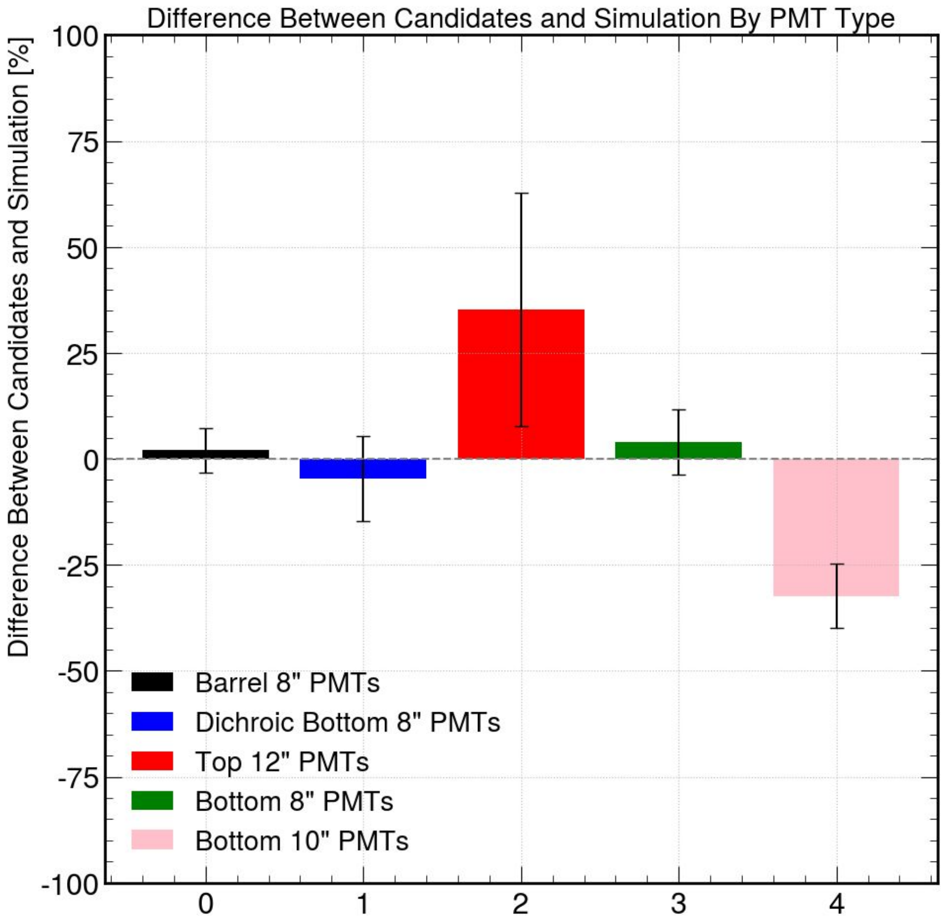


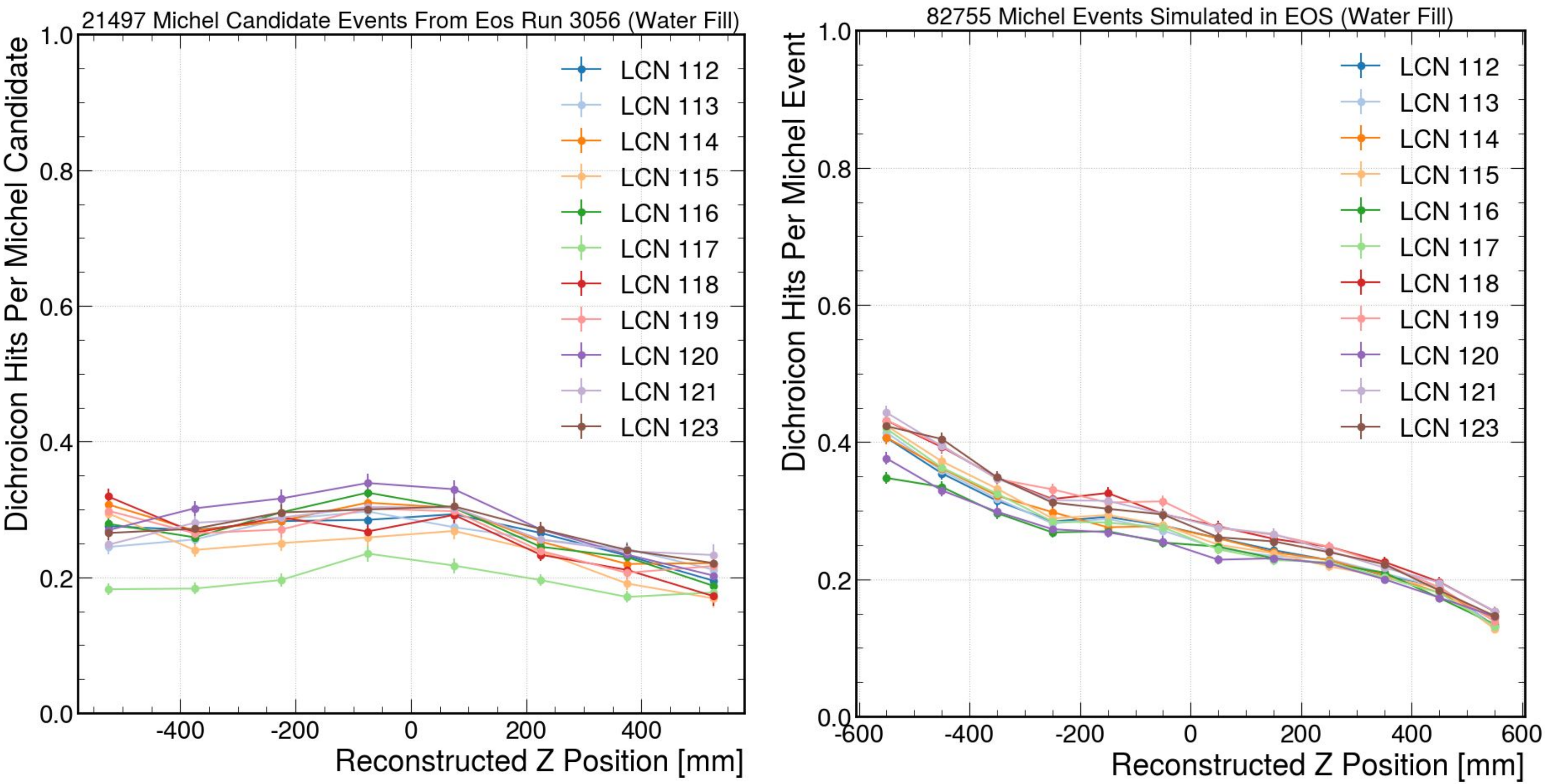

17693 Michel Candidate Events From Eos Run 3056 (Water Fill)
Weighted Least Squares Fit (τ = 2.14 ± 0.05)
Counts / 0.016 μs
0
20
40
60
80
100
120
140
1
2
3
4
5
6
7
8
9
Δt [μs]



17693 Michel Candidate Events From Eos Run 3056 (Water Fill)
Hits per Michel Candidate
Logical Channel Number
Barrel 8" PMTs
Dichroic 8" PMTs
Bottom 8" PMTs
Bottom 10" PMTs
Top 12" PMTs
82755 Michel Events Simulated in Eos (Water Fill)
Hits per Michel Candidate
Logical Channel Number
Barrel 8" PMTs
Dichroic 8" PMTs
Bottom 8" PMTs
Bottom 10" PMTs
Top 12" PMTs

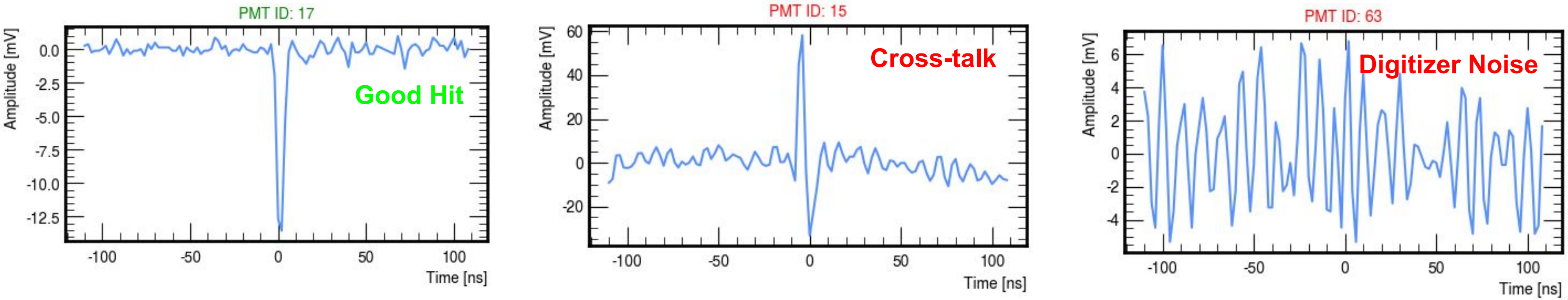

Difference Between Candidates and Simulation By LCN
Difference Between Candidates and Simulation [%]
Logical Channel Number
Barrel 8" PMTs
Dichroic Bottom 8" PMTs
Top 12" PMTs
Bottom 8" PMTs
Bottom 10" PMTs

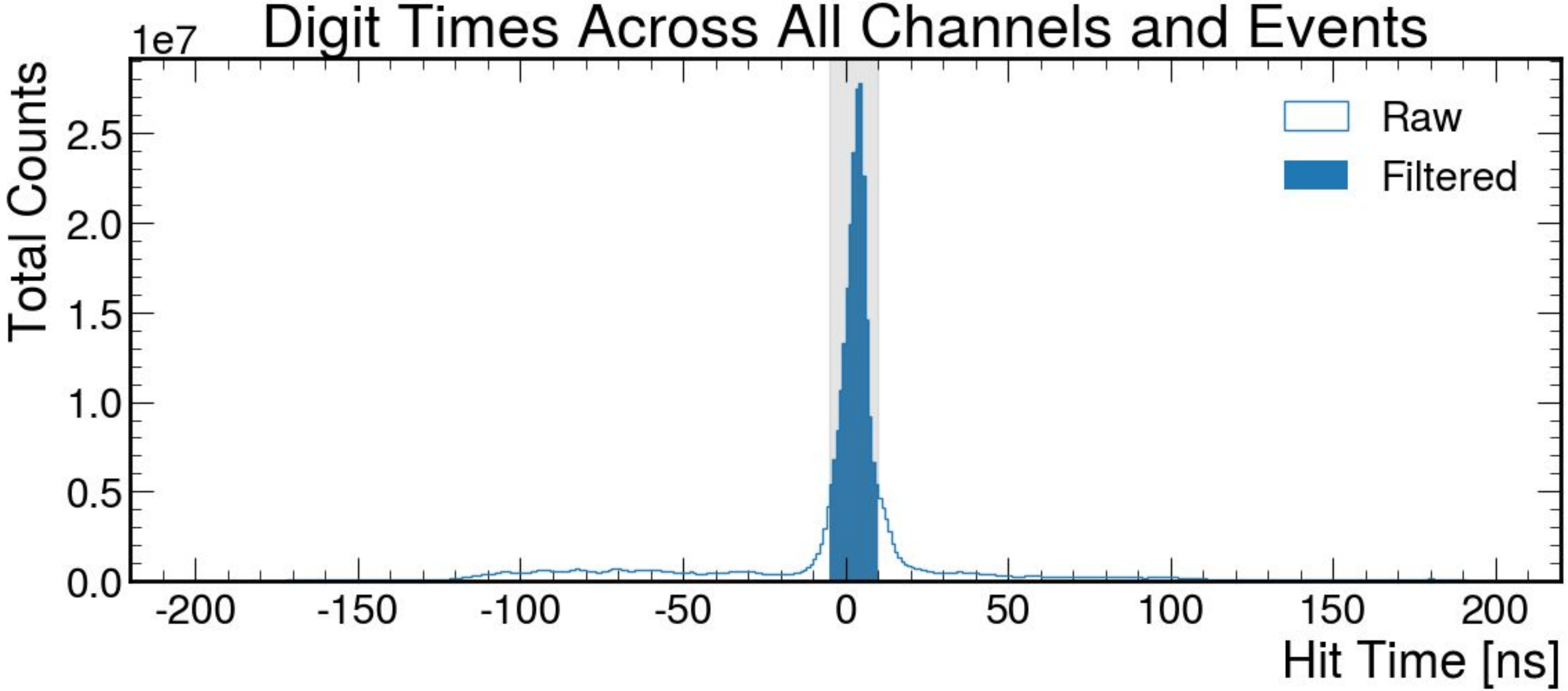

Difference Between Candidates and Simulation By PMT Type
Difference Between Candidates and Simulation [%]
Barrel 8" PMTs
Dichroic Bottom 8" PMTs
Top 12" PMTs
Bottom 8" PMTs
Bottom 10" PMTs


21497 Michel Candidate Events From Eos Run 3056 (Water Fill)
Dichroicon Hits Per Michel Candidate
Reconstructed Z Position [mm]
1.0
0.8
0.6
0.4
0.2
0.0
-400
-200
0
200
400
LCN 112
LCN 113
LCN 114
LCN 115
LCN 116
LCN 117
LCN 118
LCN 119
LCN 120
LCN 121
LCN 123
82755 Michel Events Simulated in EOS (Water Fill)
Dichroicon Hits Per Michel Event
Reconstructed Z Position [mm]
-600
600

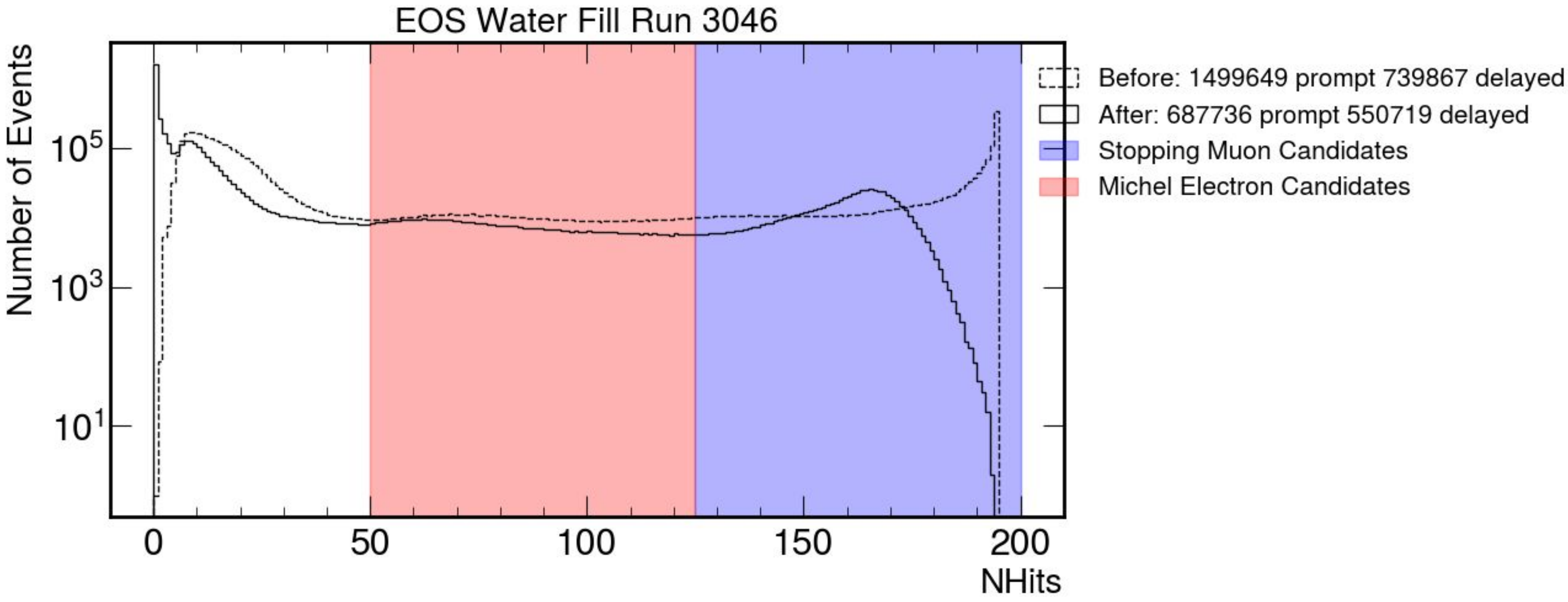
THANK YOU FOR LISTENING!

Extra Slides

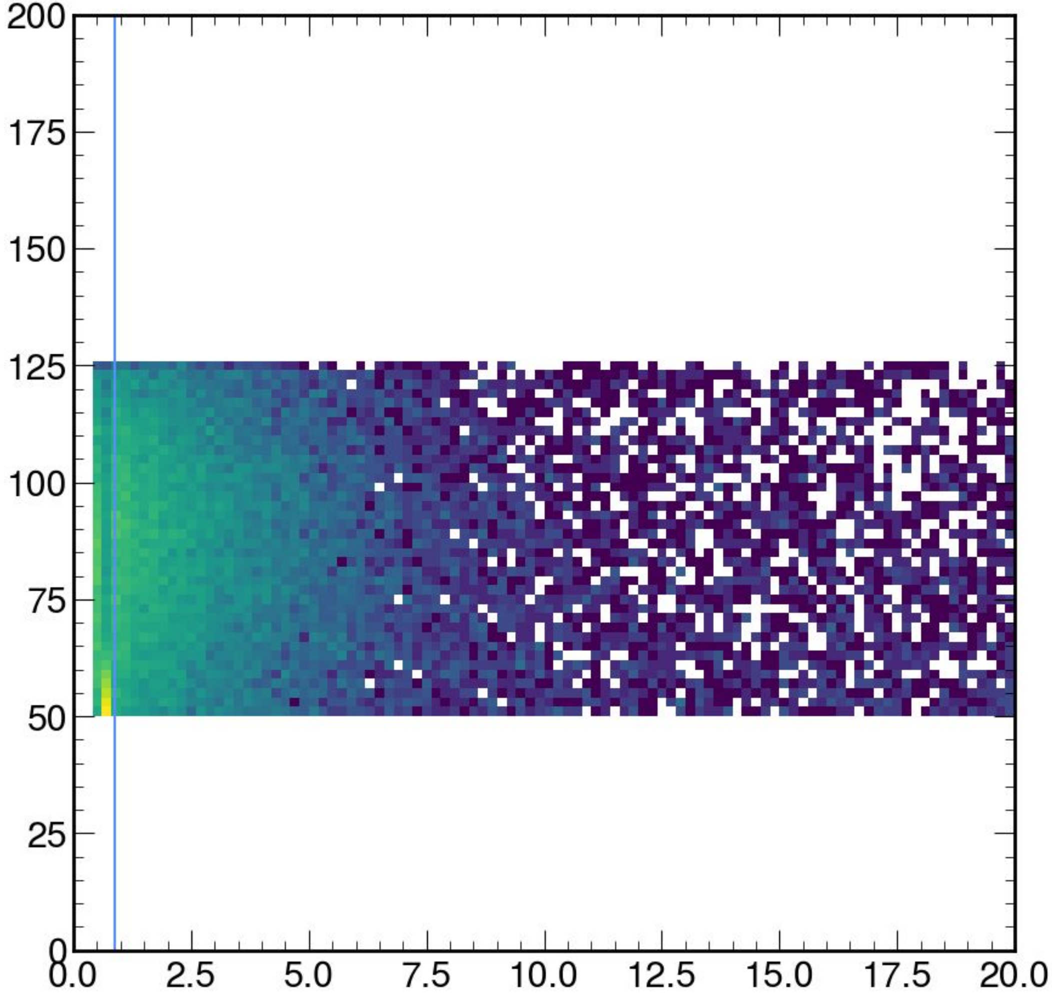

PMT ID: 17
Good Hit
Amplitude [mV]
0.0
-2.5
-5.0
-7.5
-10.0
-12.5
-100
-50
0
50
100
Time [ns]
PMT ID: 15
Cross-talk
Amplitude [mV]
60
40
20
0
-20
-100
-50
0
50
100
Time [ns]
PMT ID: 63
Digitizer Noise
Amplitude [mV]
6
4
2
0
-2
-4
-100
-50
0
50
100
Time [ns]

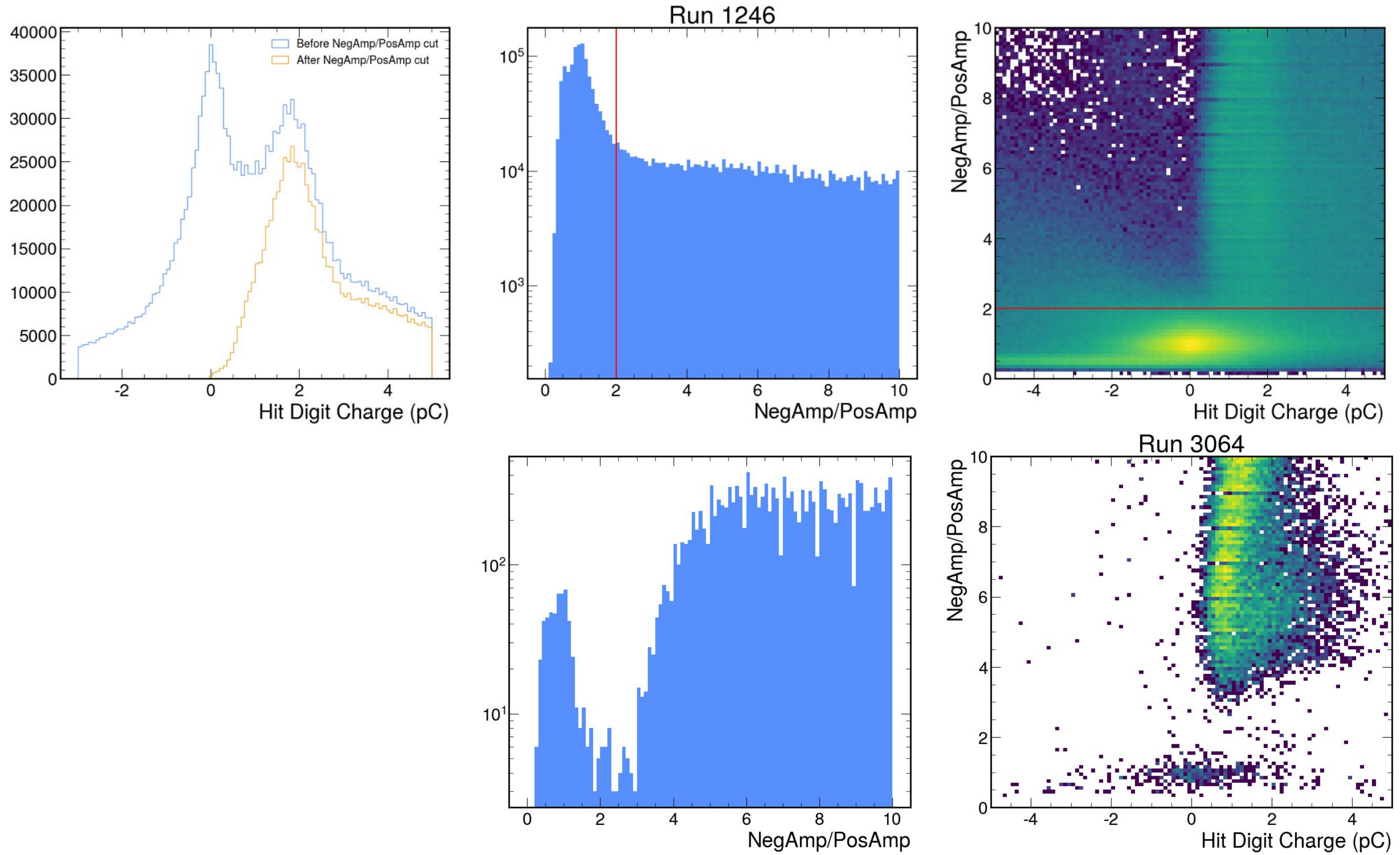


Digit Times Across All Channels and Events
1e7
Total Counts
2.5
2.0
1.5
1.0
0.5
0.0
Raw
Filtered
-200
-150
-100
-50
0
50
100
150
200
Hit Time [ns]



EOS Water Fill Run 3046
Number of Events
10^5
10^3
10^1
0
50
100
150
200
NHits
Before: 1499649 prompt 739867 delayed
After: 687736 prompt 550719 delayed
Stopping Muon Candidates
Michel Electron Candidates


200
175
150
125
100
75
50
25
0
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0



Before NegAmp/PosAmp cut
After NegAmp/PosAmp cut
Hit Digit Charge (pC)
Run 1246
NegAmp/PosAmp
NegAmp/PosAmp
Hit Digit Charge (pC)
NegAmp/PosAmp
Run 3064
NegAmp/PosAmp
Hit Digit Charge (pC)