MicroBooNE Trigger System

Operation Readiness Review
Nov. 23, 2015

B. Eberly (SLAC)
T. Wongjirad (MIT)

the MicroBooNE PMTs
mounted inside
the cryostat (on the left)

Outline

- In this talk, I'll discuss the MicroBooNE trigger system

- In particular, I'll describe the PMT Trigger and the light collection system (LCS)

- Report on the the effort to commission the PMT trigger using the first three months of data

MicroBooNE Trigger

- MicroBooNE has several triggers designed for various situations/event types
  - **BNB**: booster neutrino beam trigger
  - **NuMI**: NuMI beam trigger
  - **EXT**: constant 0.1 Hz trigger
  - **LASER**: in time with the laser calibration system
  - **CALIB**: in time with the ASIC calibration pulses
  - **MuCS:** Muon counter system triggers readout
  - **Paddle:** triggers when paddles saturated (to study any break down events)
  - **PMT:** triggers when light seen by PMTs

MicroBooNE Trigger

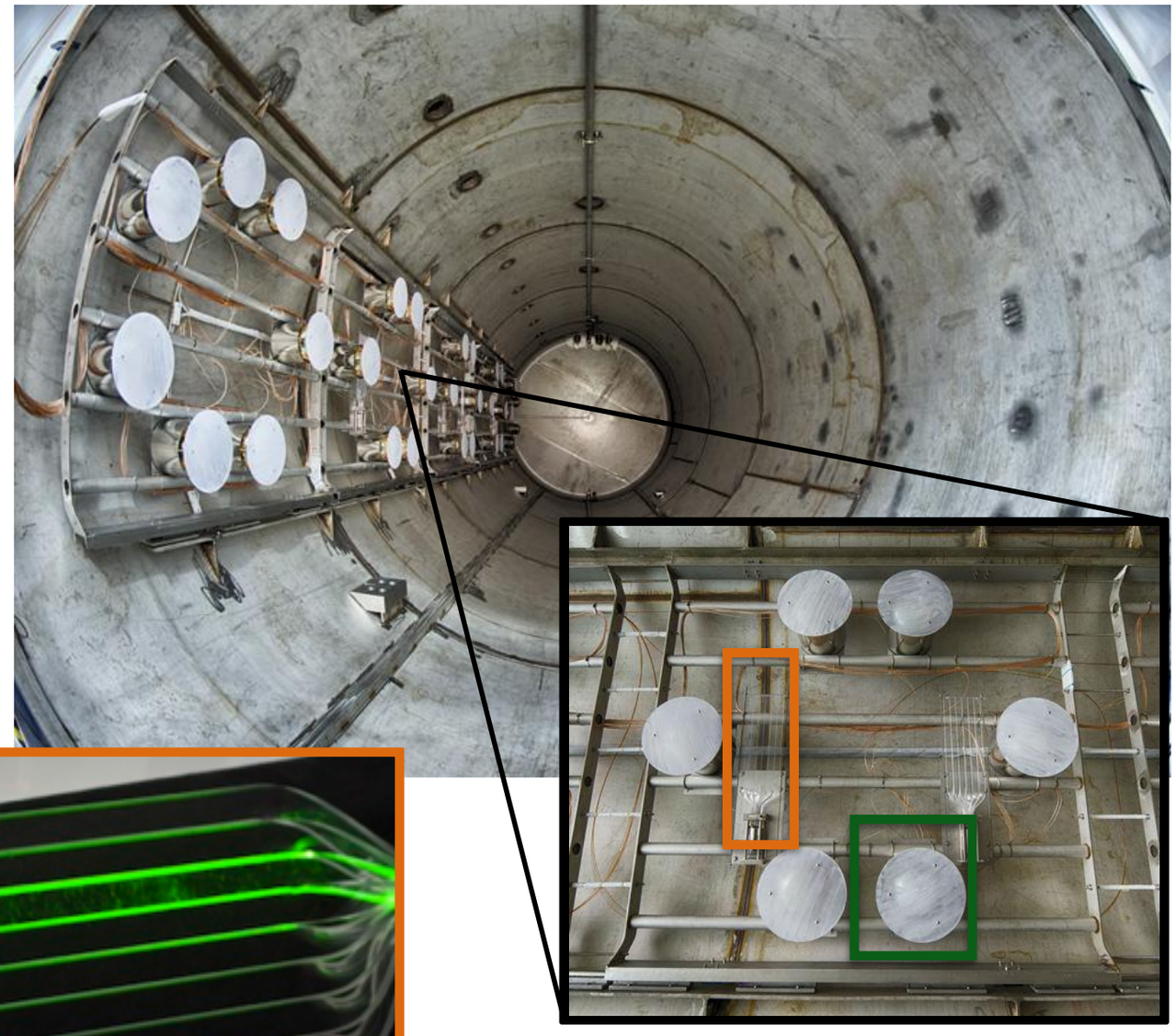
- Beam triggers always take priority
  - These come early and veto other triggers
- BNB efficiency is above 99.8%
- EXT efficiency is ~85%, as expected, as it is vetoed by the beam triggers

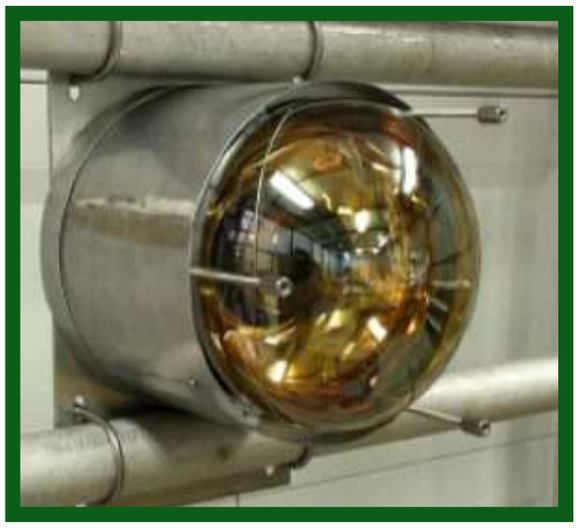
PMT Trigger

- Saving every spill is too costly in terms of disk storage and processing
- Will reduce the data rate using a PMT trigger
  - Save only those events where a certain number of photoelectrons are seen in coincident with the beam triggers
- Studying what threshold to set — given background rate of photons — and what a given threshold means for our efficiency in accepting events
  - First a quick review of the light collection system

LCS System Overview

- Two types of photodetectors installed:
  - 32 8” PMTs with tetra-phenyl butadiene (TPB)-coated acrylic plate
  - 4 TPB-coated acrylic light guide paddles



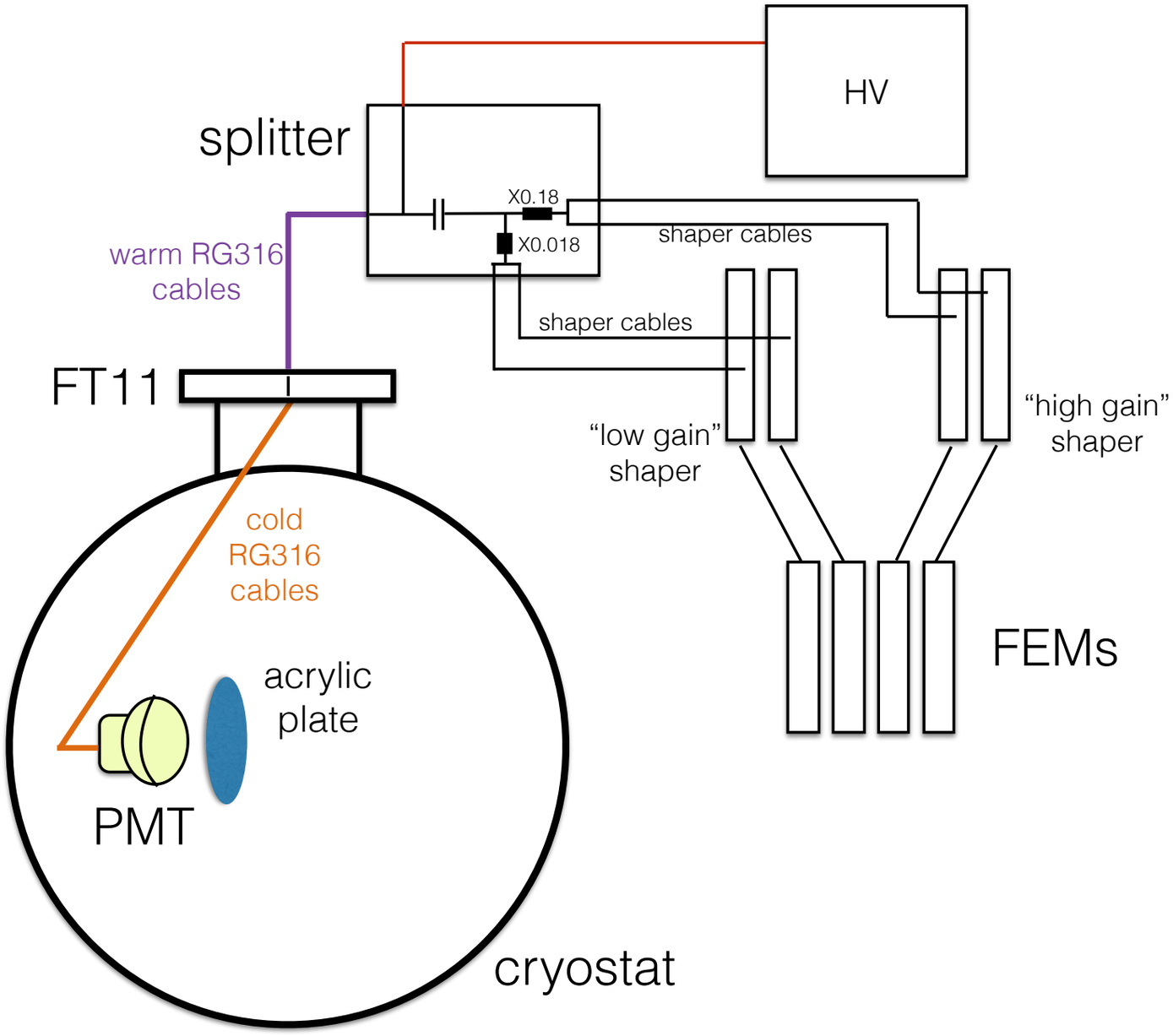


(photographed w/o TPB-coated plate)

(illuminated by green LED)

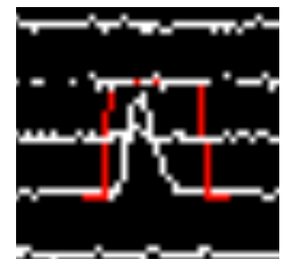
PMT Readout Overview

- Schematic of LCS connections
- Note: not a SLED
- 4 copies of waveforms can be saved for each PMT
  - 2 “high gain”: 0.18x
  - 2 “low gain”: 0.018x
- Currently using only 1 copy of high and low gains
- FEMs (front-end modules) digitize waveforms and perform trigger logic

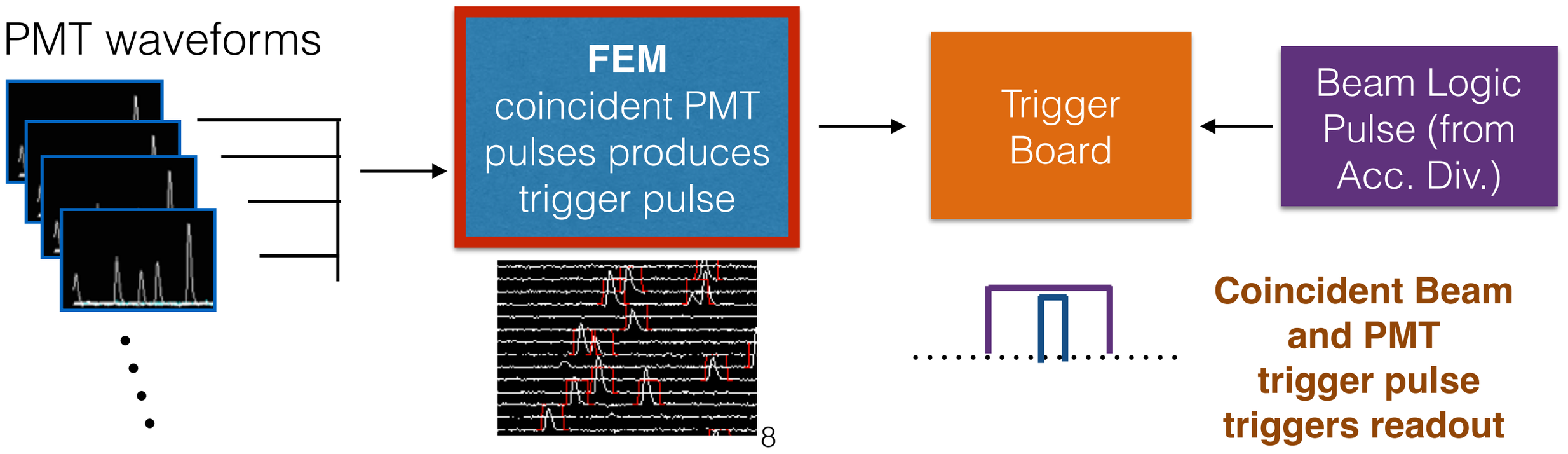


Forming a PMT Trigger

- The component which forms PMT trigger is PMT Readout FEM (front end module)
  - **Digitizes the (shaped) PMT waveforms**
  - **Looks for pulses on the digitized waveforms from each PMT**



- The FEM assembles identified pulses and determines if a PMT trigger forms
- PMT Trigger goes to the logic board. If coincident with beam logic pulse, then entire readout system (PMT+TPC) is triggered to record the event



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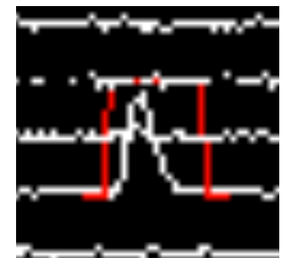

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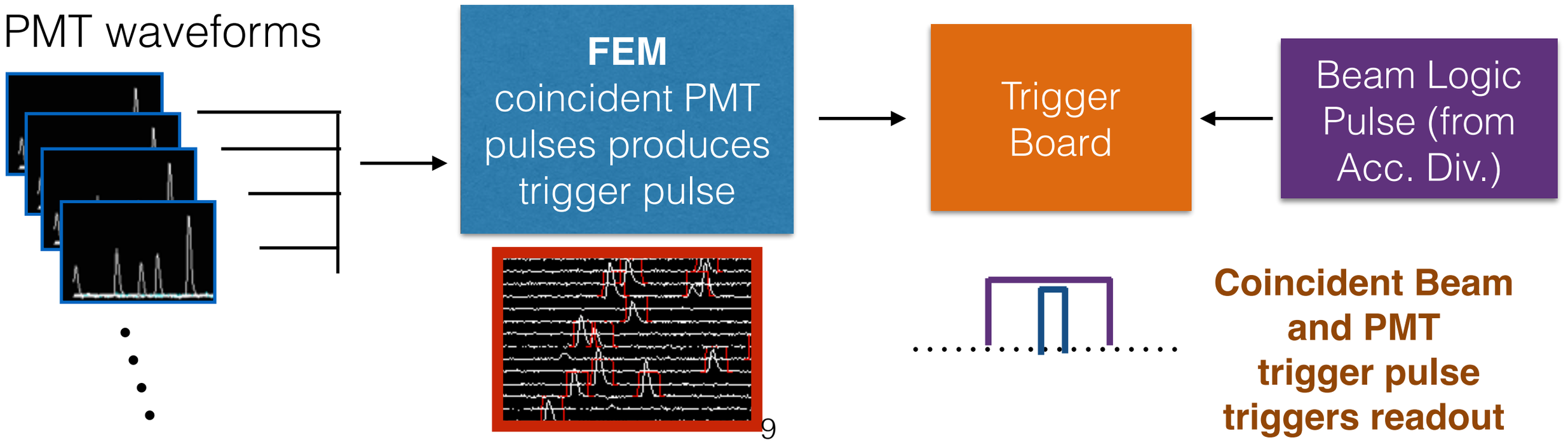

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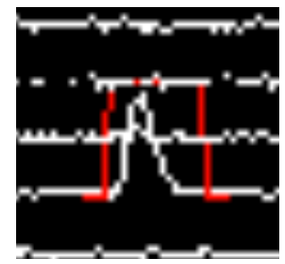

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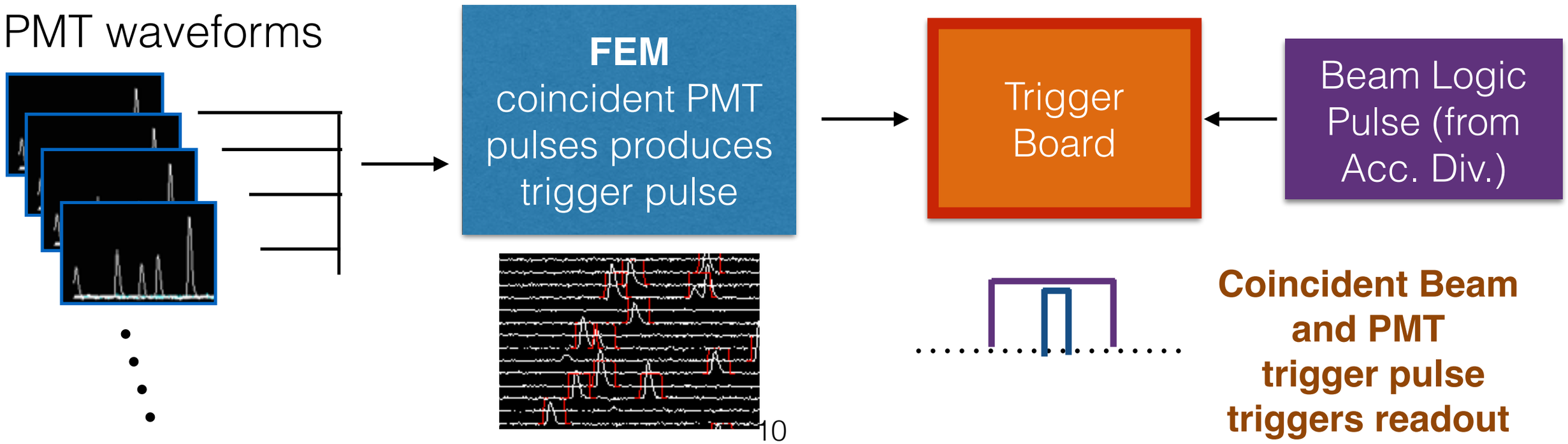


Commissioning the Trigger

- The initial MicroBooNE run plan has been to save every spill in the first three months of data taking
- Use this to commission the trigger system
- Formed a task force composed of several institutions

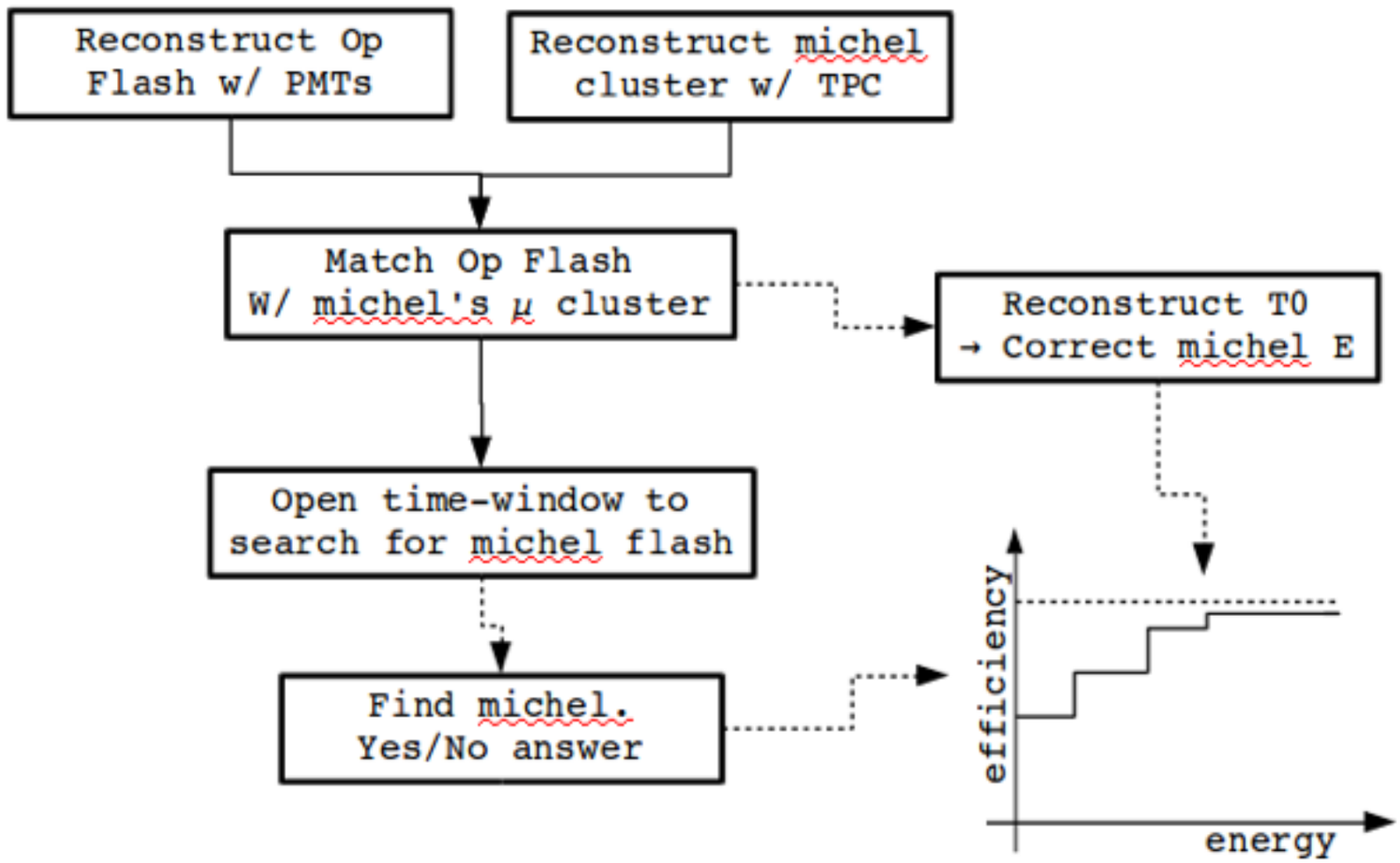
- MIT: T. Wongjirad, J. Moon
- Fermilab: M. Toups
- Columbia: K. Terao, D. Caratelli
- NMSU: K. Woodruff
- Yale: X. Luo
- IIT: R. An
- Manchester: A. Furmanski, G. Karagiorgi
- SLAC: B. Eberly

Commissioning the PMT Trigger

- For a certain threshold, what is the efficiency of the PMT trigger as a function of energy deposited and position
  - Using Michel electron sample
- What is the expected efficiency for beam events (using MC)
- To trust the above, need to compare (and then tune) the MC optical simulation to data
- Finally, what is background rate of light in the detector? Determines the lowest threshold that can be set

Michel Analysis

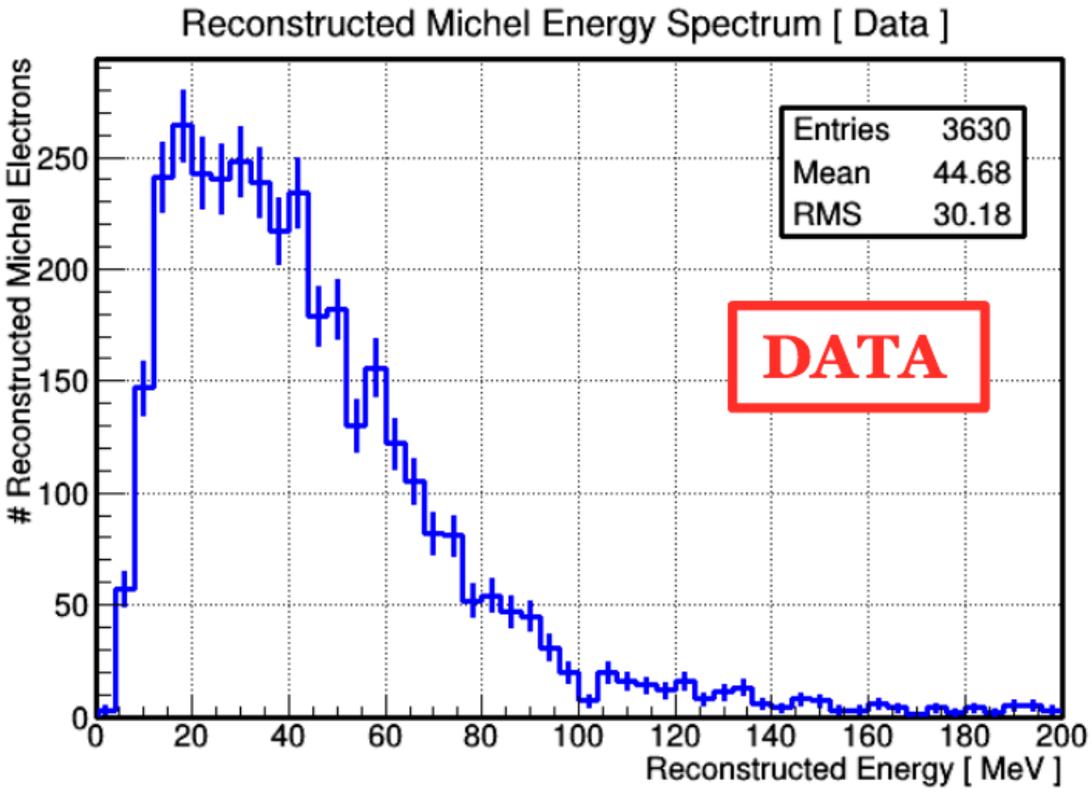
- Isolate sample of Michel Electrons identified in the TPC, which provides position and energy deposited
- Determine efficiency of triggering on event with PMTs as a function of energy and position

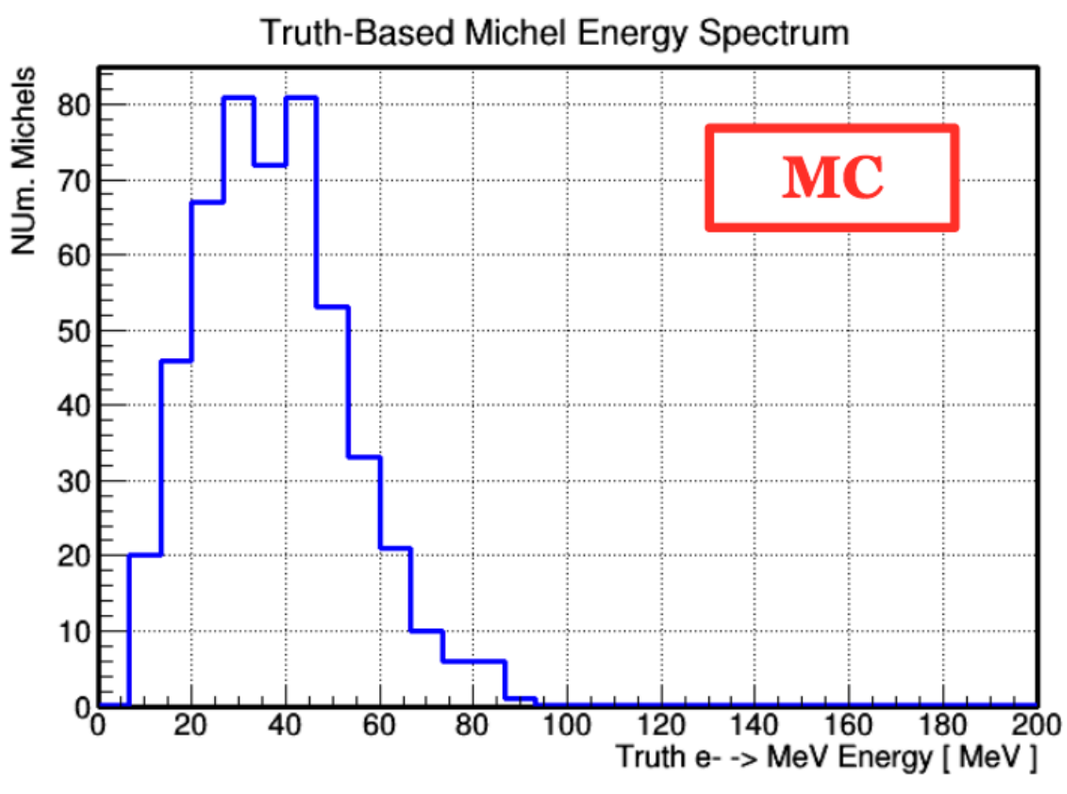


D. Caratelli (Columbia)

Michel Analysis

- Status: Developed automated algorithm for selecting Michel tracks in the TPC data

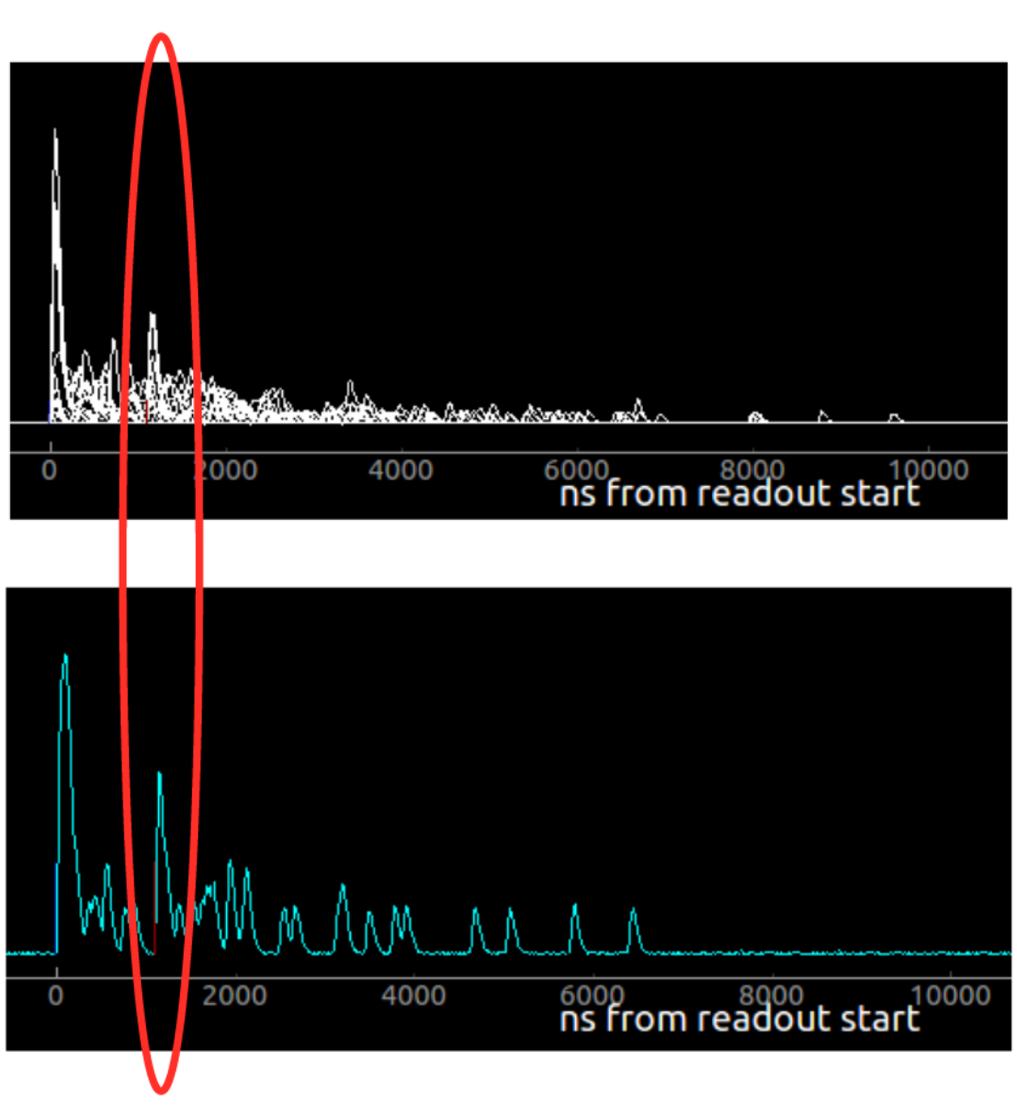


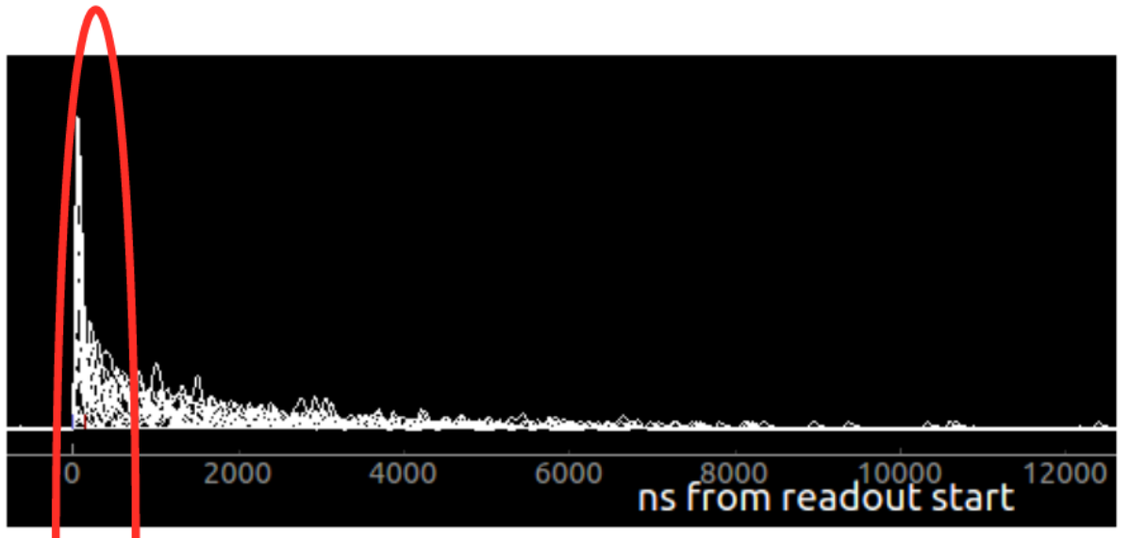


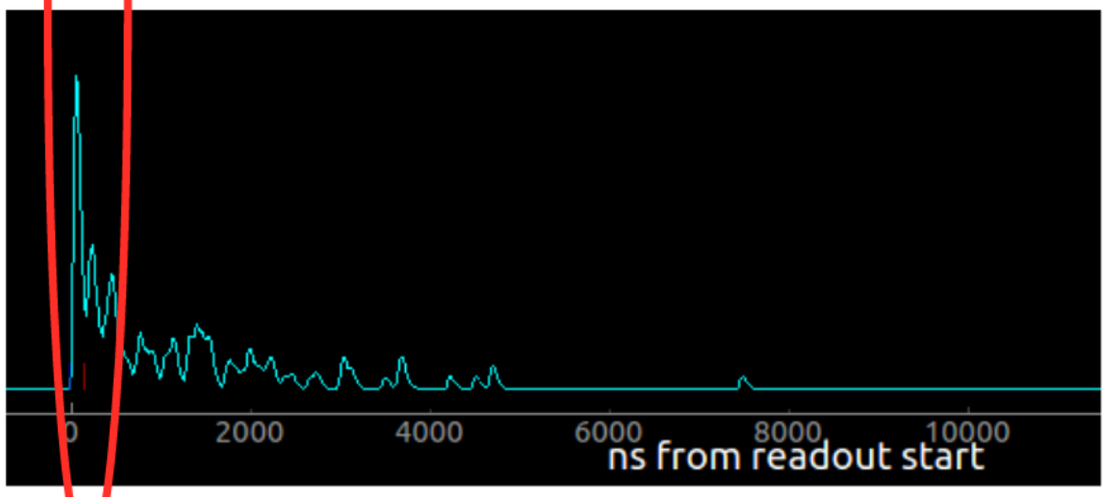
D. Caratelli (Columbia)

Michel Flash ID

- Status: working on identifying Michel in the optical waveforms

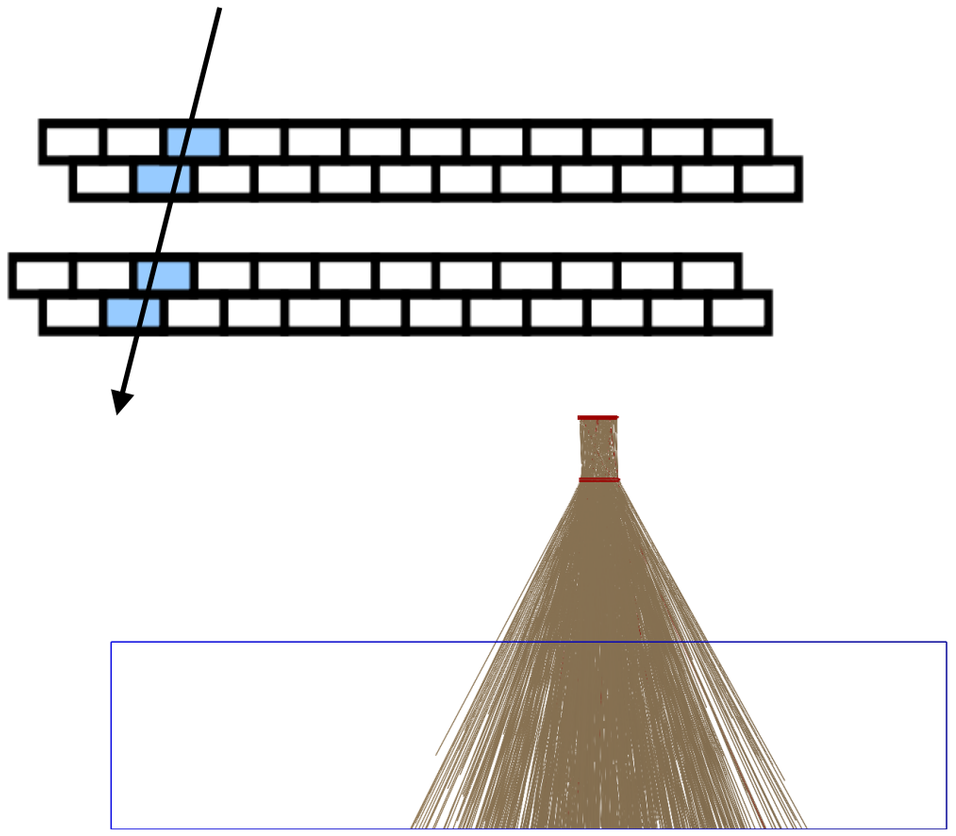






Light Yield Studies

- Check the data/MC agreement
- Using events trigger by the Muon Counter System — x-y arrays of scintillator strips that provide a trigger when a muon passes through — also provides direction

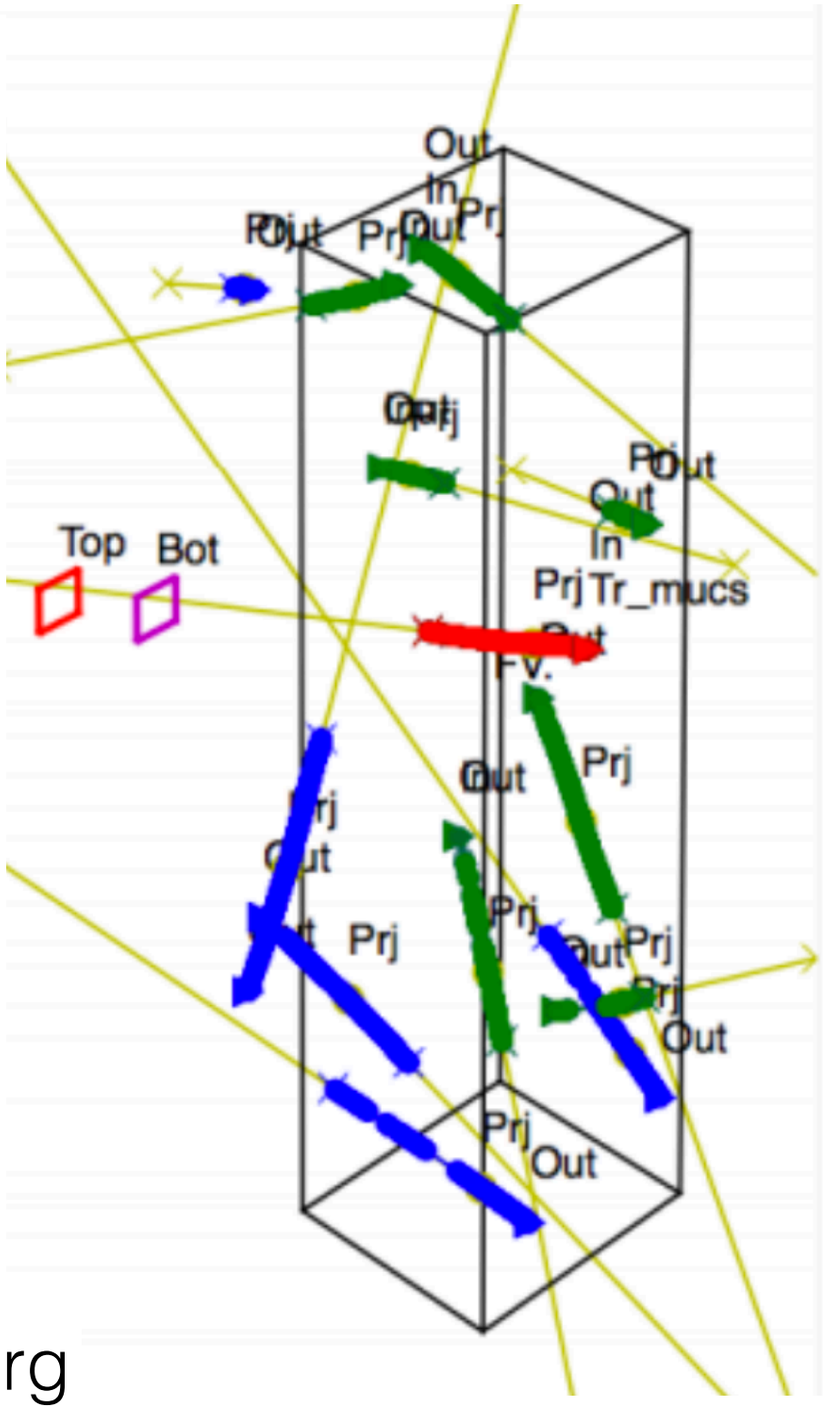


Light Yield Studies

Using the MuCS to trigger readout.

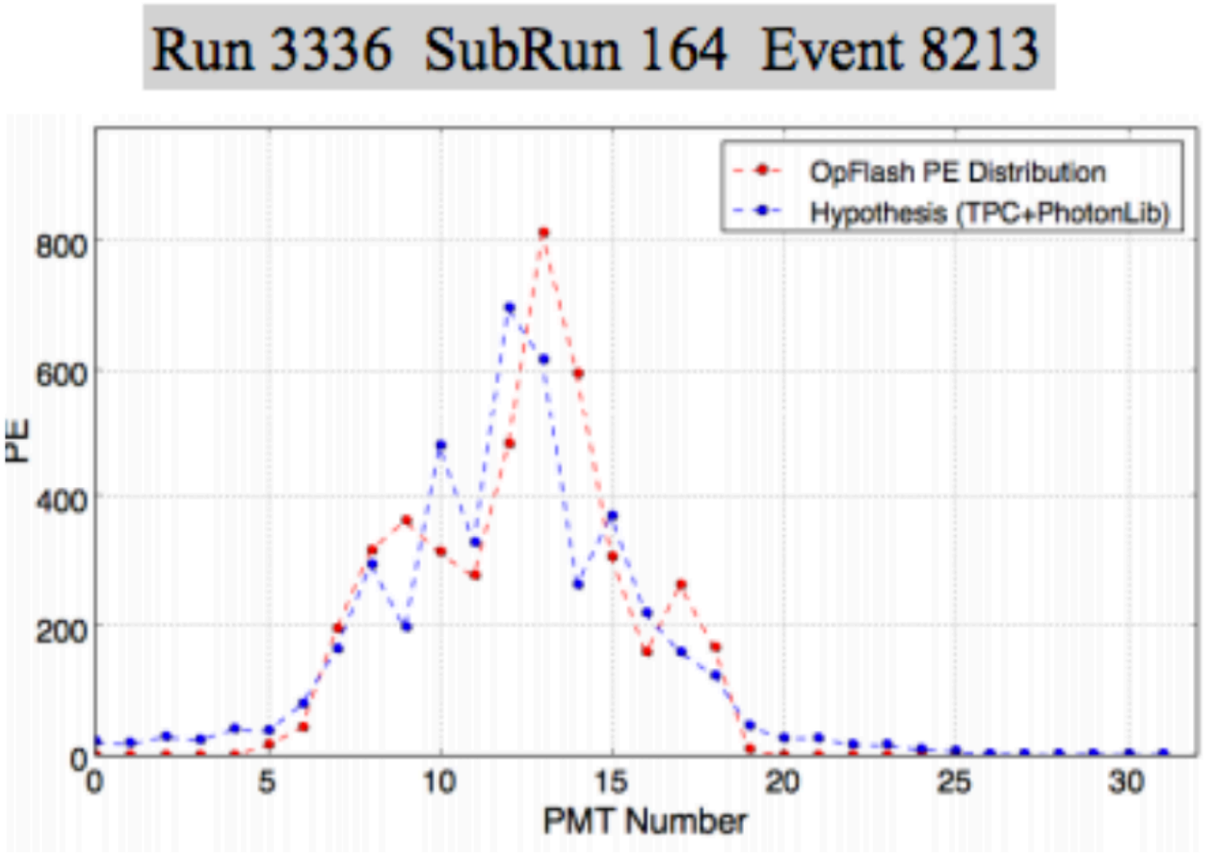
We can then identify, in the TPC data, the muon track passing through the detector

For each track we can compare the amount of scintillation light seen in the data to amount predicted by the optical simulation for the track



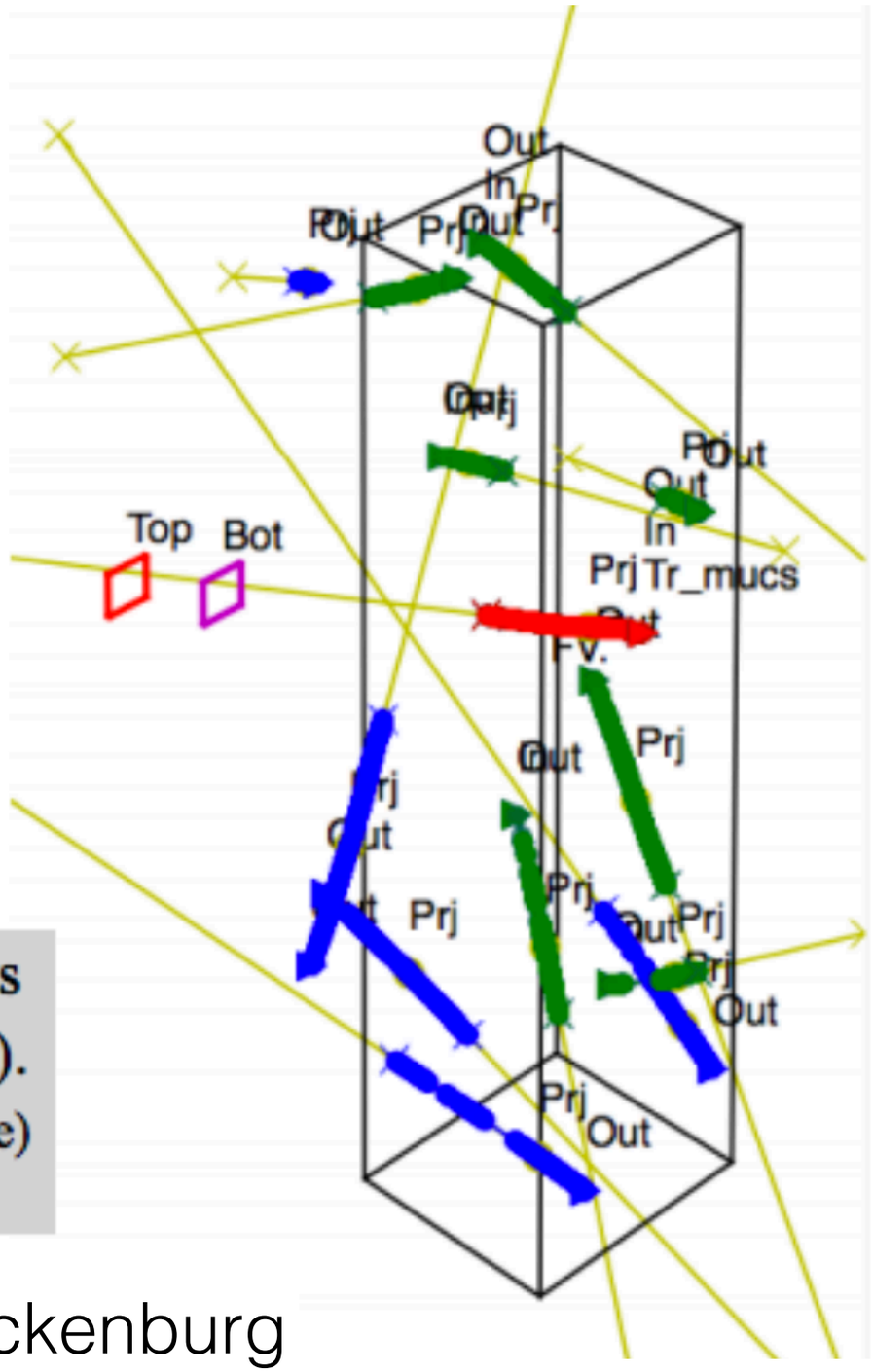
Work by R. An, K. Terao, A. Hackenburg

Light Yield Studies



Hypothesis derived based on trajectory points along the reconstructed track (trackkalmanhit).

- Assumes same light level at each point (VERY naive)
- No TPC charge information used YET



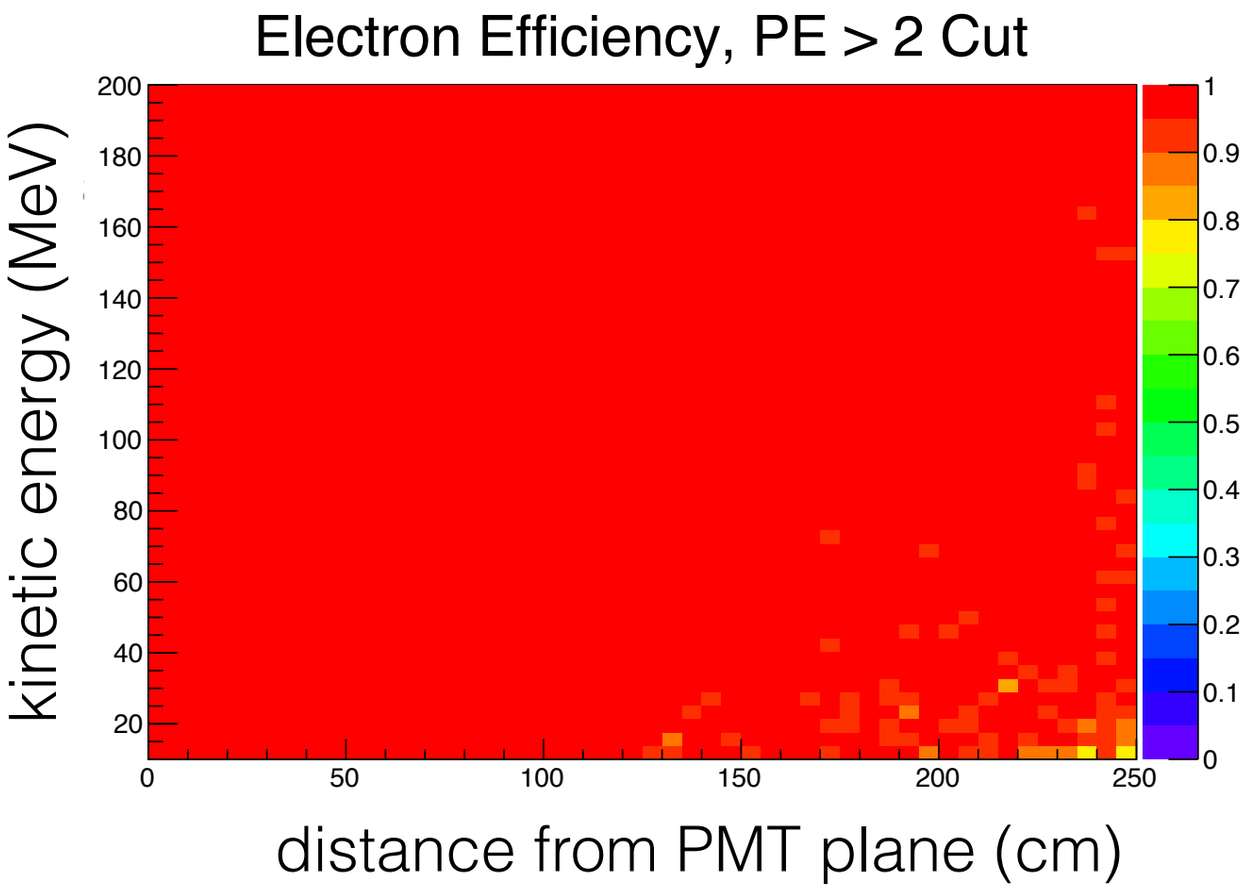
Work in progress: R. An, K. Terao, A. Hackenburg

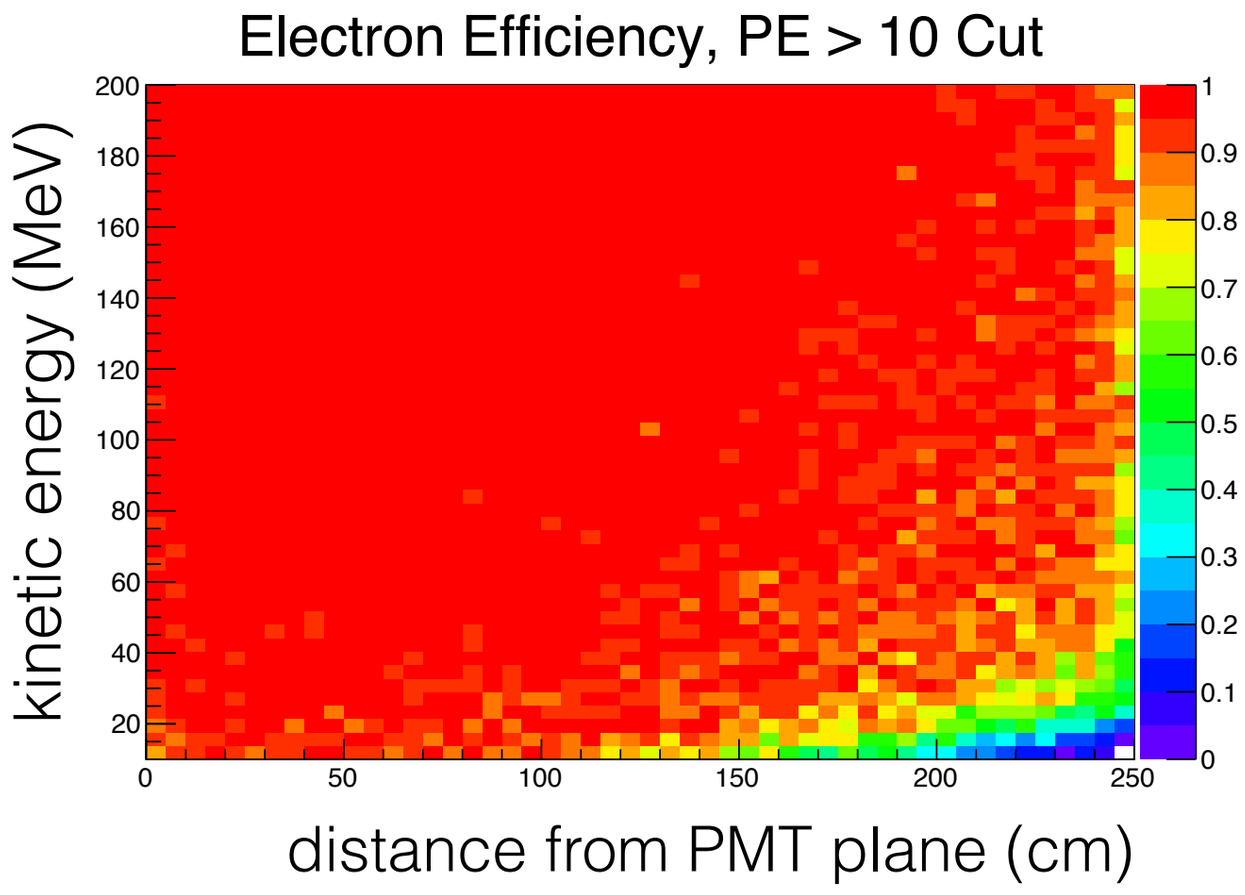
MC Efficiency Studies

- Using MC to estimate what type of events we might lose with a certain threshold
- Plan is to single particle and neutrino events
- Note: will have to incorporate result of MC/data of comparisons of light yield, but good to (1) have a current estimate and (2) have the machinery in place
- Show single particle efficiencies
- Beam MC events to be generated soon

Single Electron Efficiencies

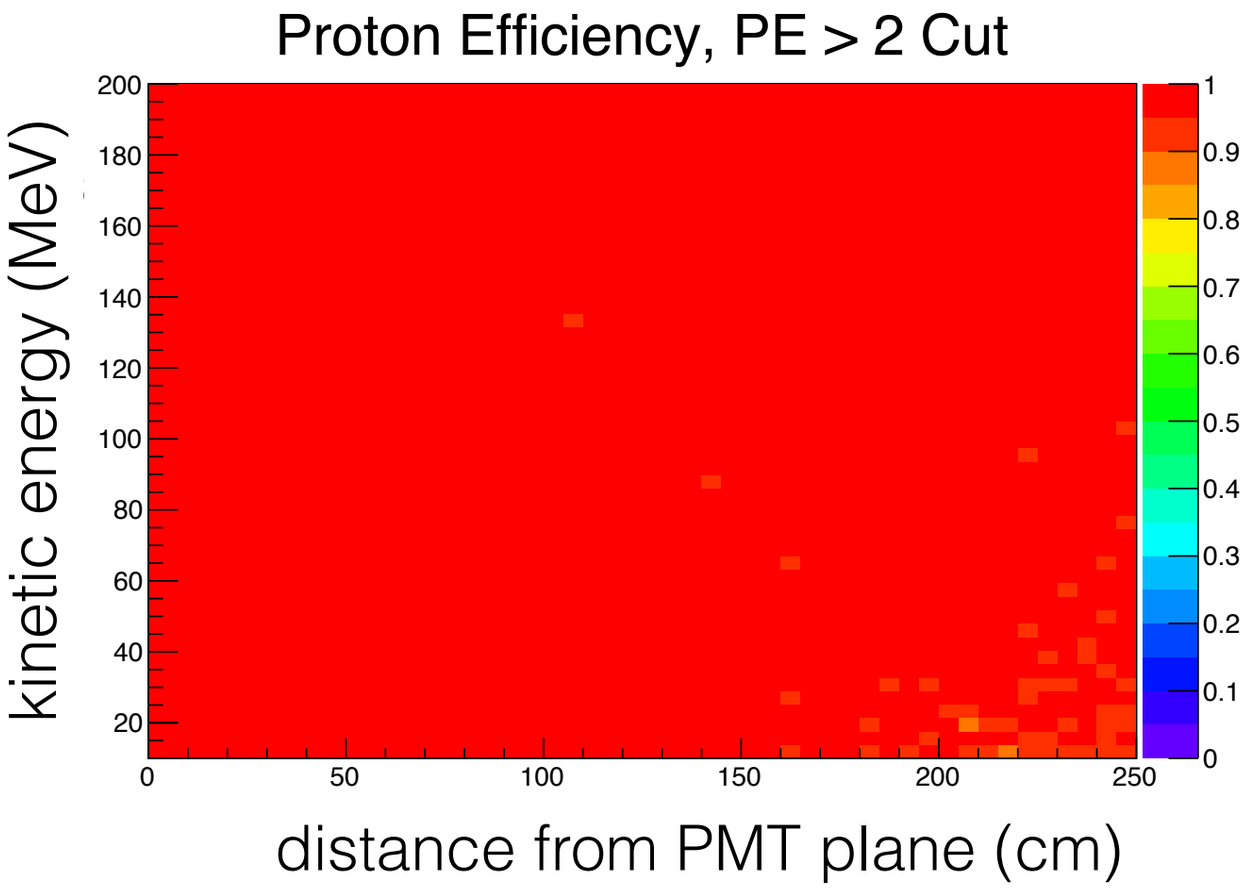
- Single electron sample, generated uniformly over the detector, isotropic direction, with KE between [10,203] MeV

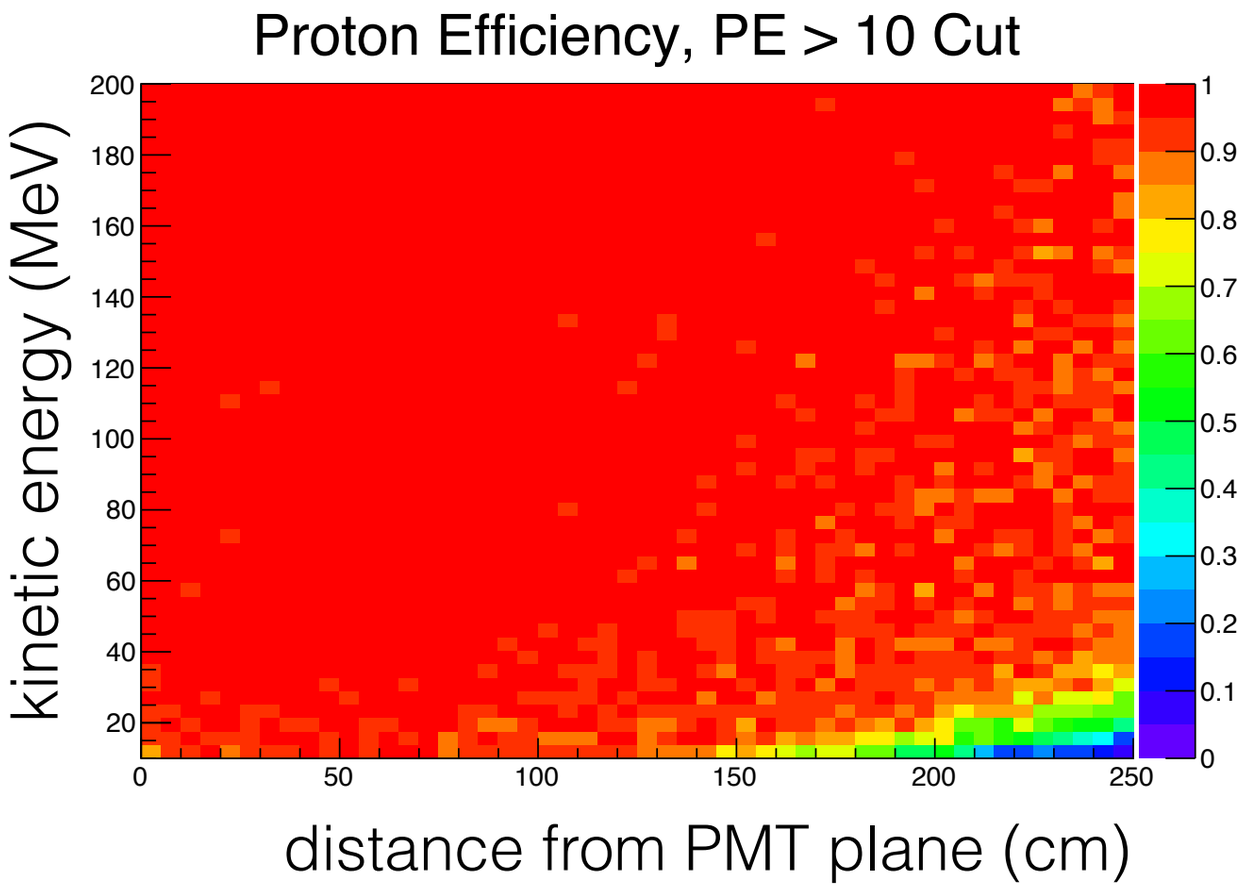




Single Proton Efficiencies

- Single proton sample, generated uniformly over the detector, isotropic direction, with KE between [10,203] MeV



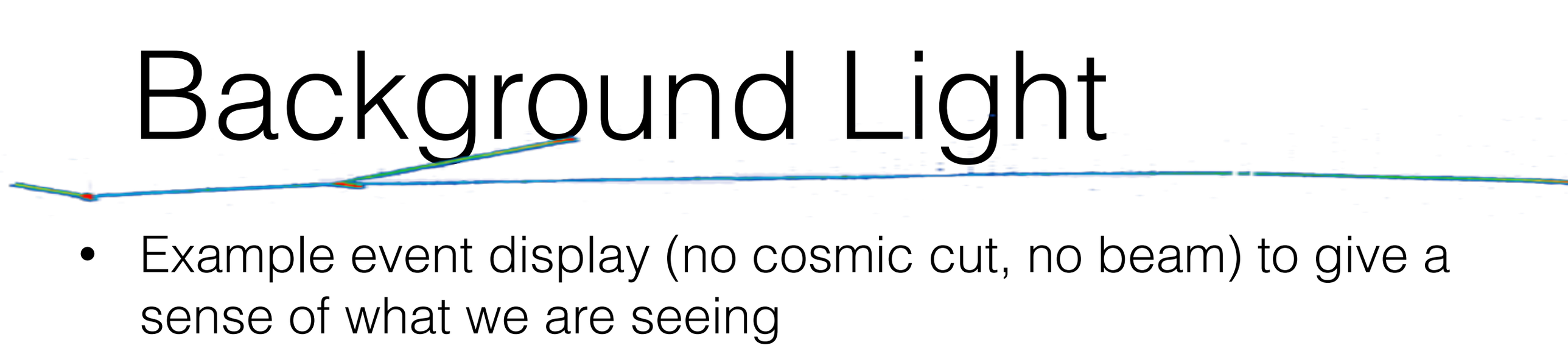


Trigger Rate

- What's the current rate of background light?
  - Determines accidental PMT trigger rate
  - Limits how low the threshold can be set
- Expect tens of kHz per tube from dark noise
- Expect about ~5.5 kHz of cosmic ray muons

Background Light

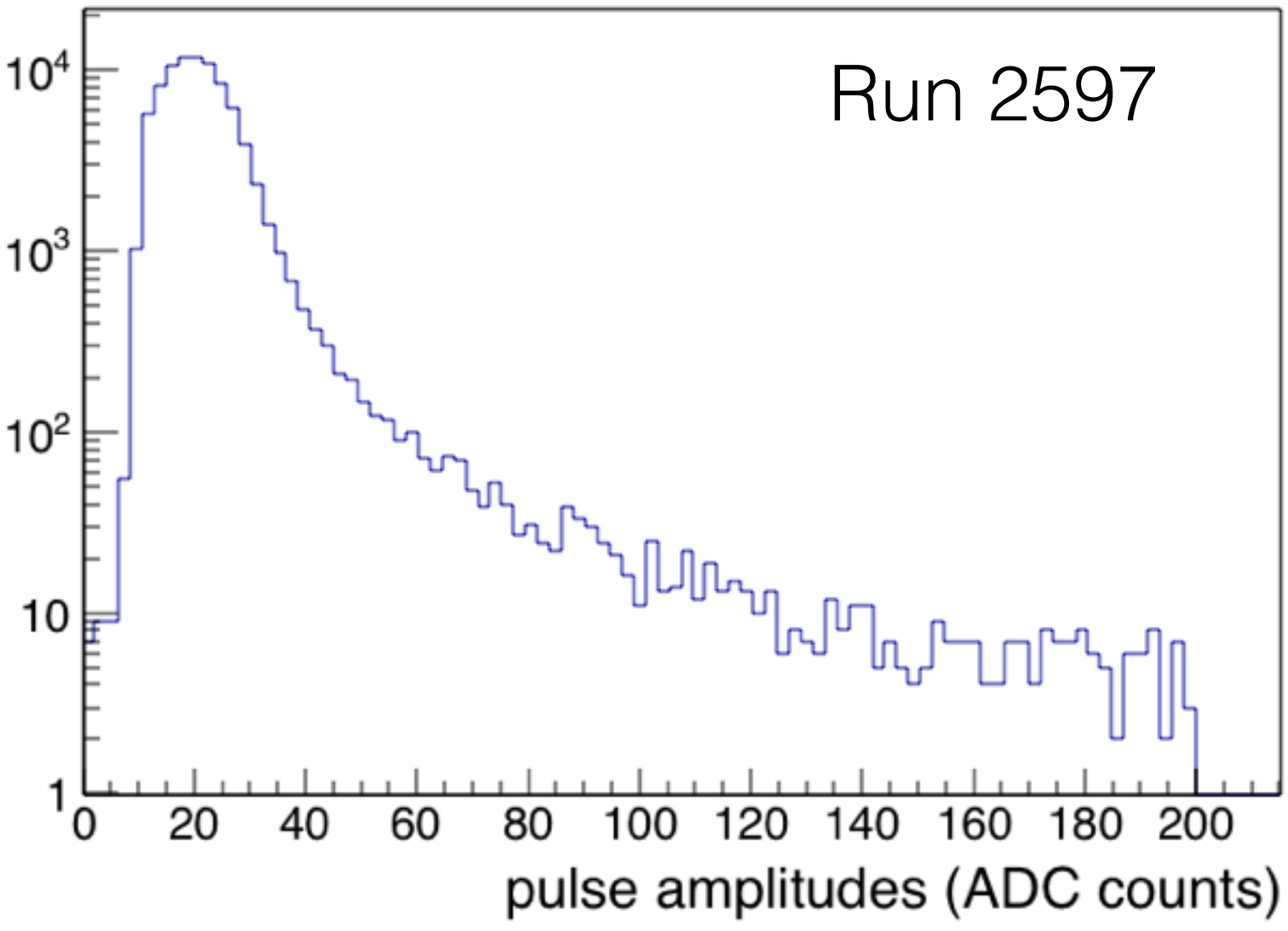
- Example event display (no cosmic cut, no beam) to give a sense of what we are seeing
- Red boxes identify pulses found by a constant fraction discriminator (with threshold of 10 ADC counts/0.5 pe)



- Rate is higher than expected — about 200-300 kHz per tube
  - What is it from? How does it affect our threshold?

Background Light

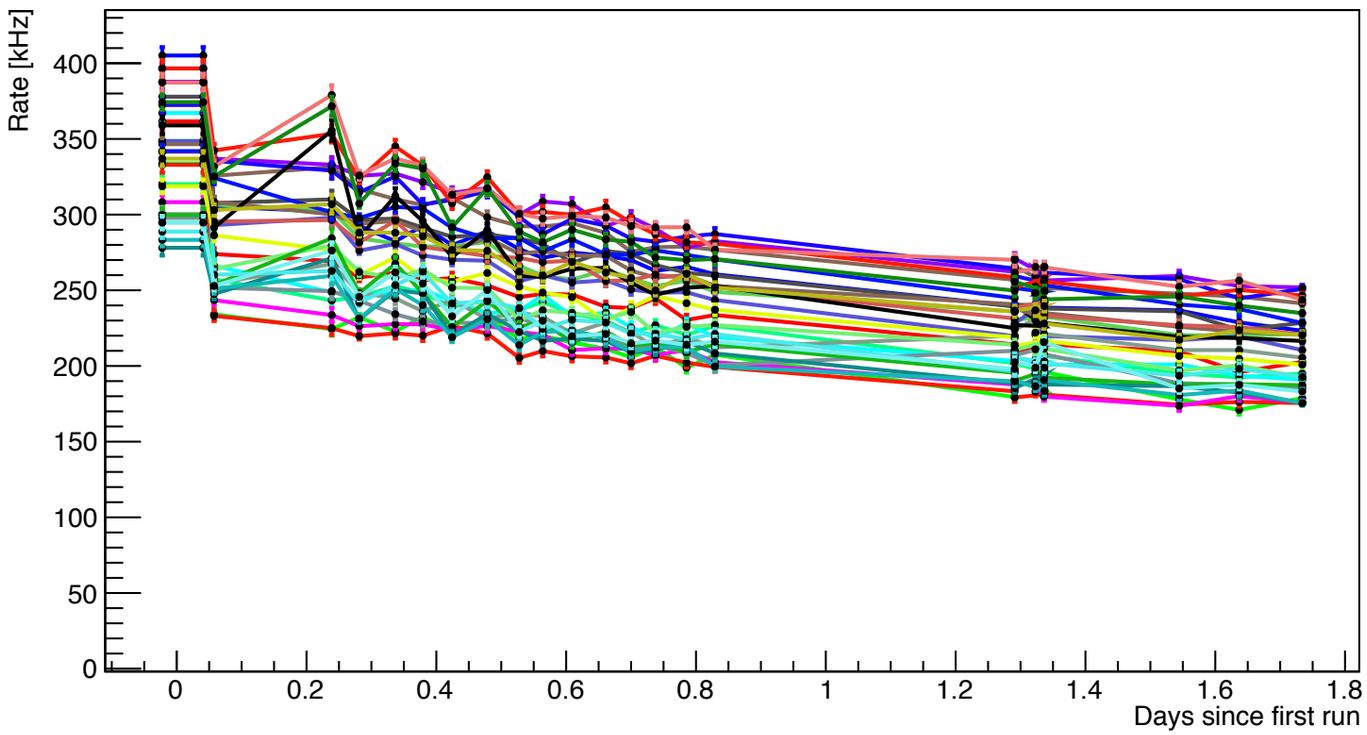
- Example distribution of pulse amplitudes
- Single PE pulses are 20 ADC counts (PMT responses have been tuned to be uniform)
- Majority of pulses seen are single PE

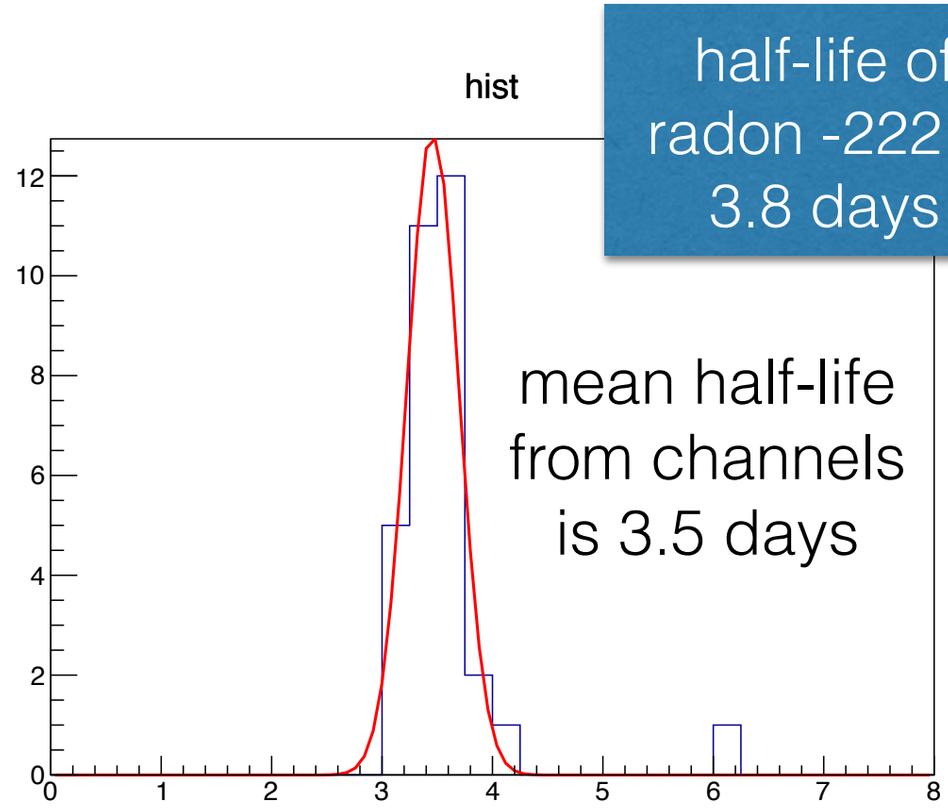


Still working to understand this source of light — evidence that some of it is due to radioactivity associated with the Liquid argon purity filters

Filters and Rate

- saw that background light correlates with if time after we bypassed the liquid argon filters,
  - saw a decrease in the pulse rate in all channels
- Saw a sudden drop in rate, and the a slower one lasting 1.5 days
- If one assumes a constant PMT dark rate of the expected 10 kHz, then the mean fitted half-life to the long decrease from all the channels is 3.5 days +/- 0.2 days





half-life of radon -222 is 3.8 days

mean half-life from channels is 3.5 days

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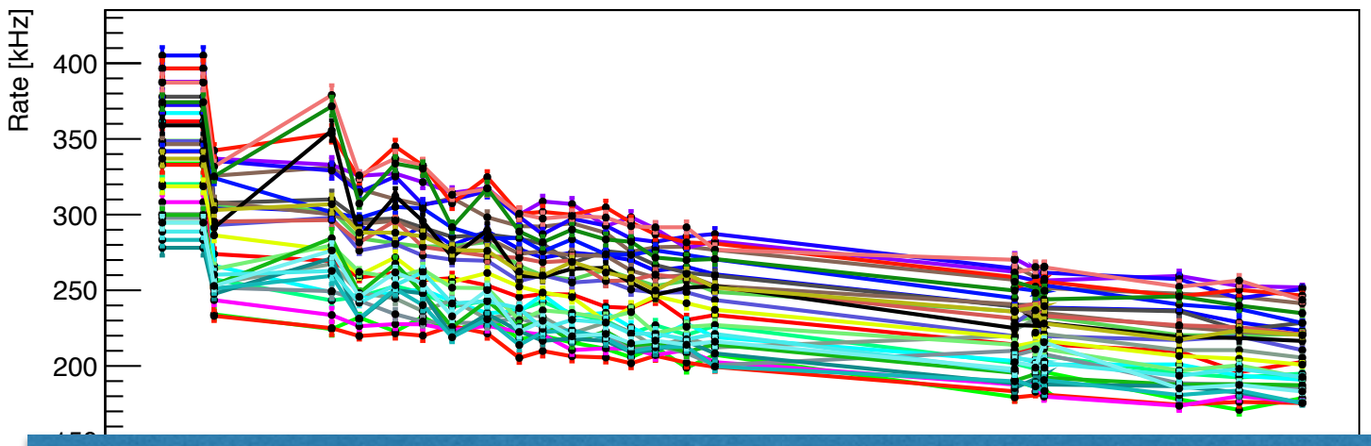
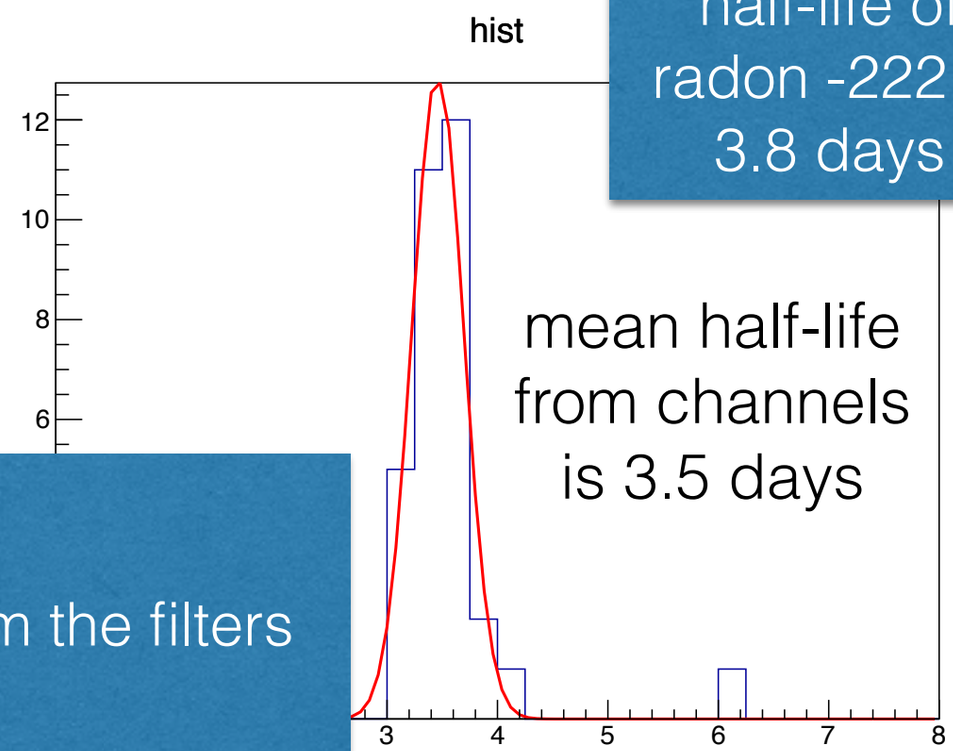




half-life of radon -222 is 3.8 days

mean half-life from channels is 3.5 days

Formed a Radon Task Force to
(1) confirm the rate is from emanation of radon from the filters
(2) mitigate it

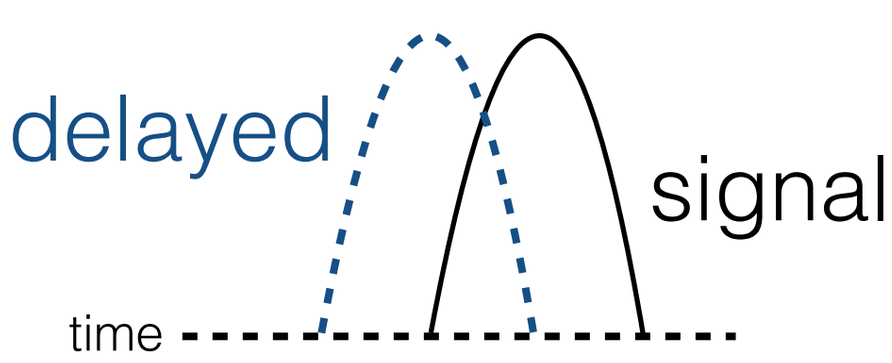
Trigger Rate

- What does the current rate mean for our trigger threshold?
- First, short review of how the PMT trigger is formed

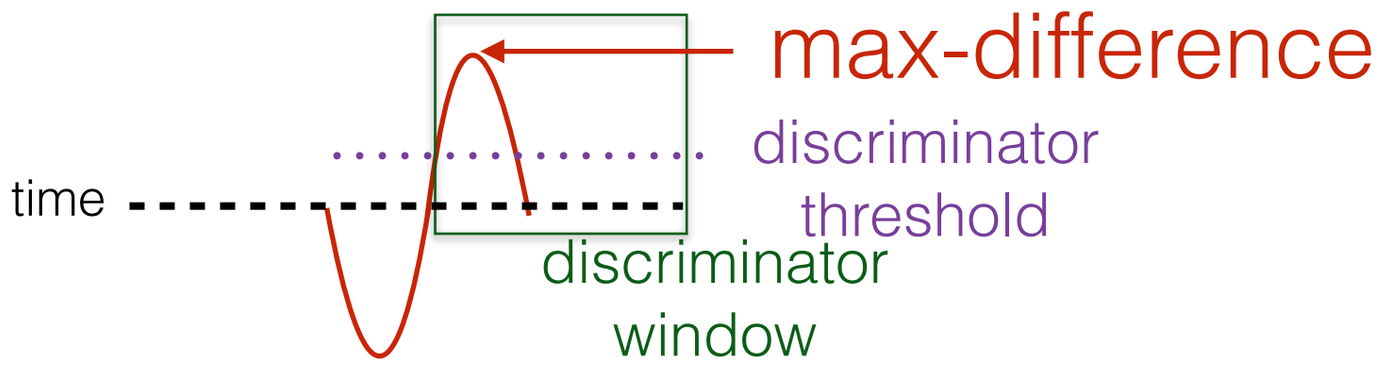
Forming a PMT Trigger

- Two measures are used by the FEM to form PMT triggers
  - Number of coincidence PMT pulses
  - Summed max(difference) of coincident discriminator fires
- FEM uses constant-fraction discriminator to find pulses

waveform (one PMT)



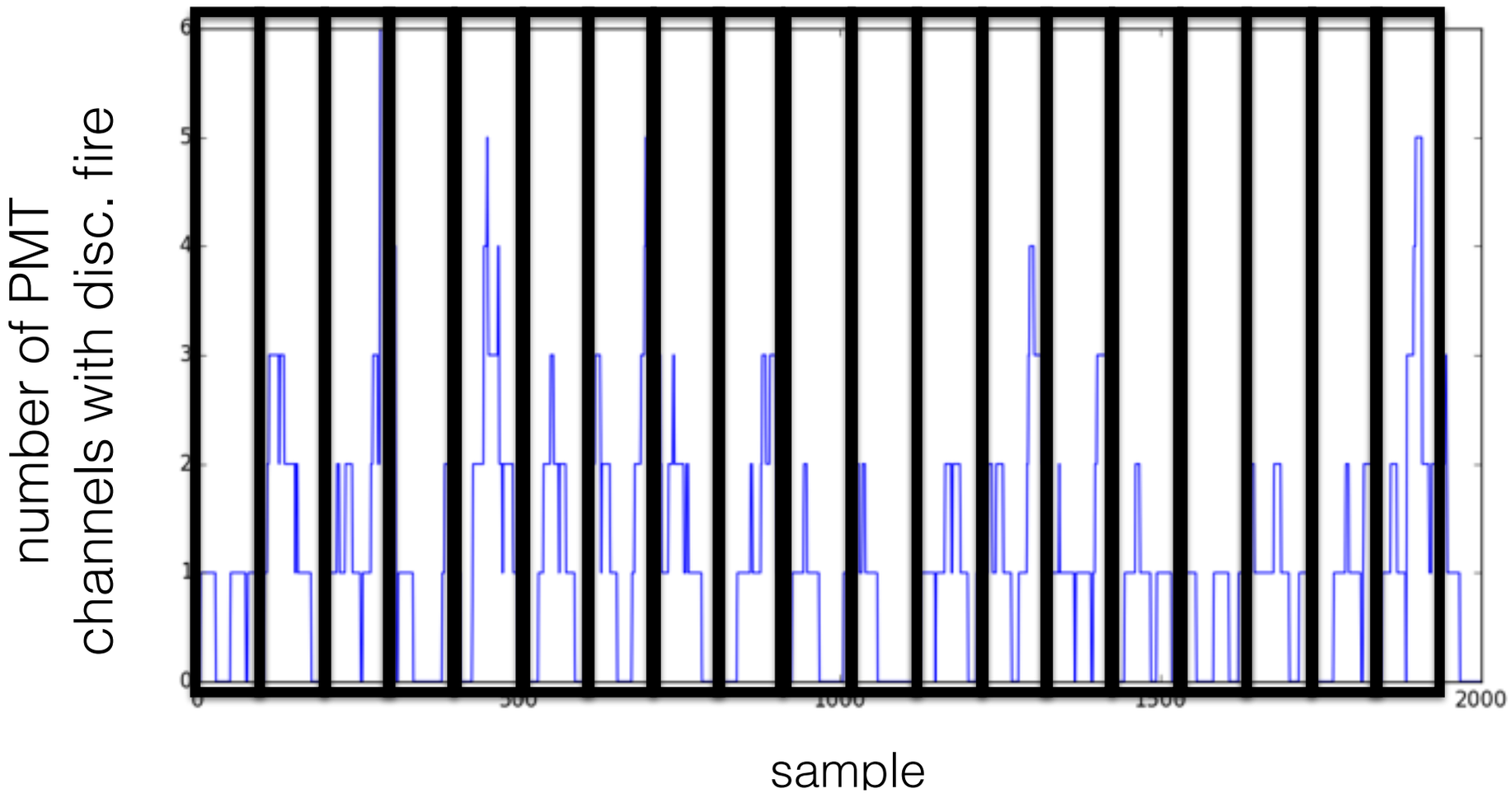
subtracted signal



Discriminator

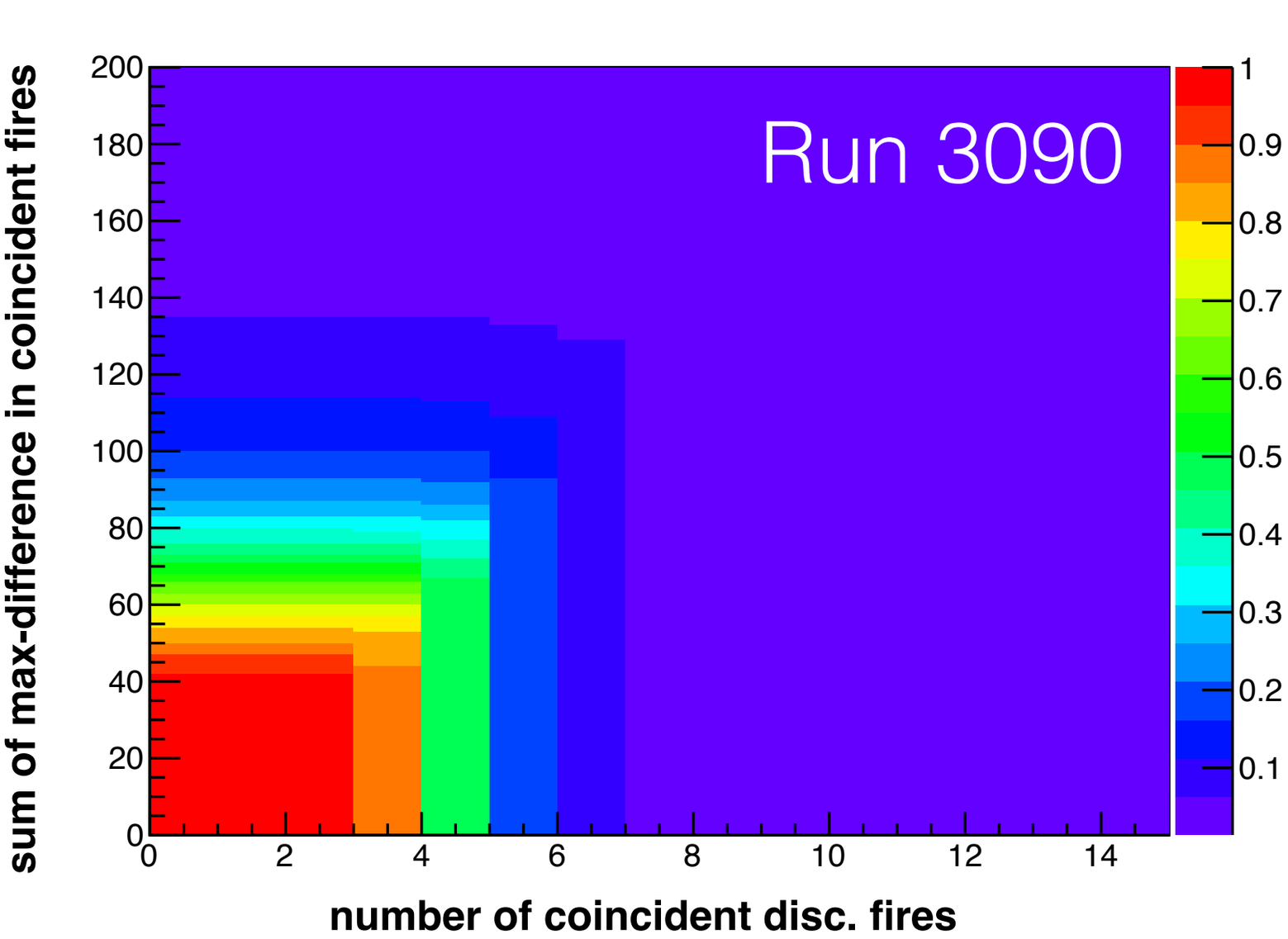
- To study fraction of 1.6 microsecond beam windows will form a trigger from the background light, used beam readout windows (23 usec) and chopped them up into 1.6 sec windows

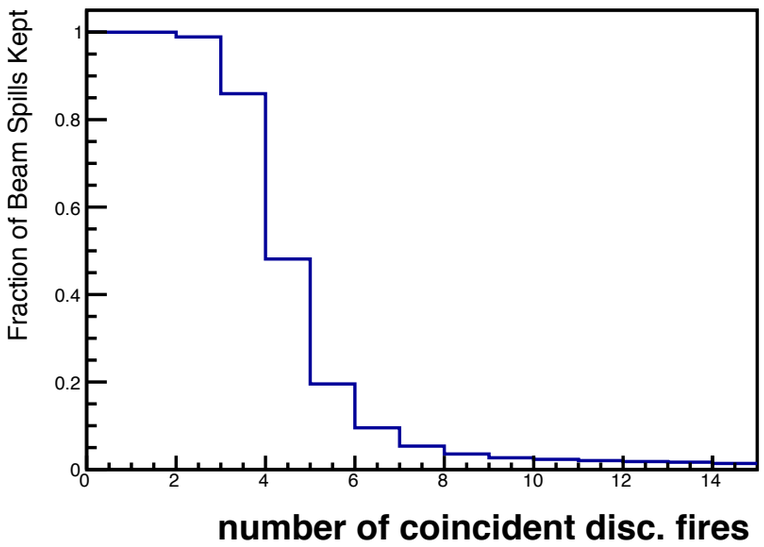
- Applied software emulator of trigger to determine trigger variables and, thus, if trigger forms for given threshold values

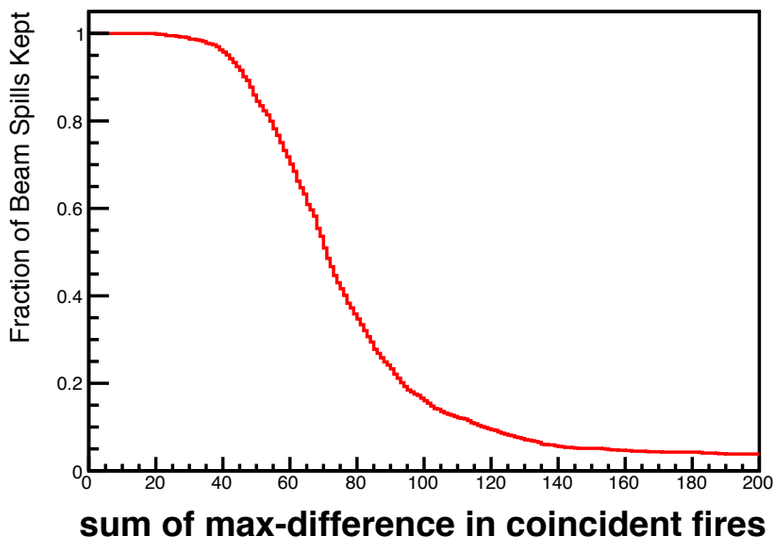


Measuring Rate vs. Trigger Variables

- Studied the PMT trigger rate as a function of logic variables for BNB sized windows (1.6 microseconds)



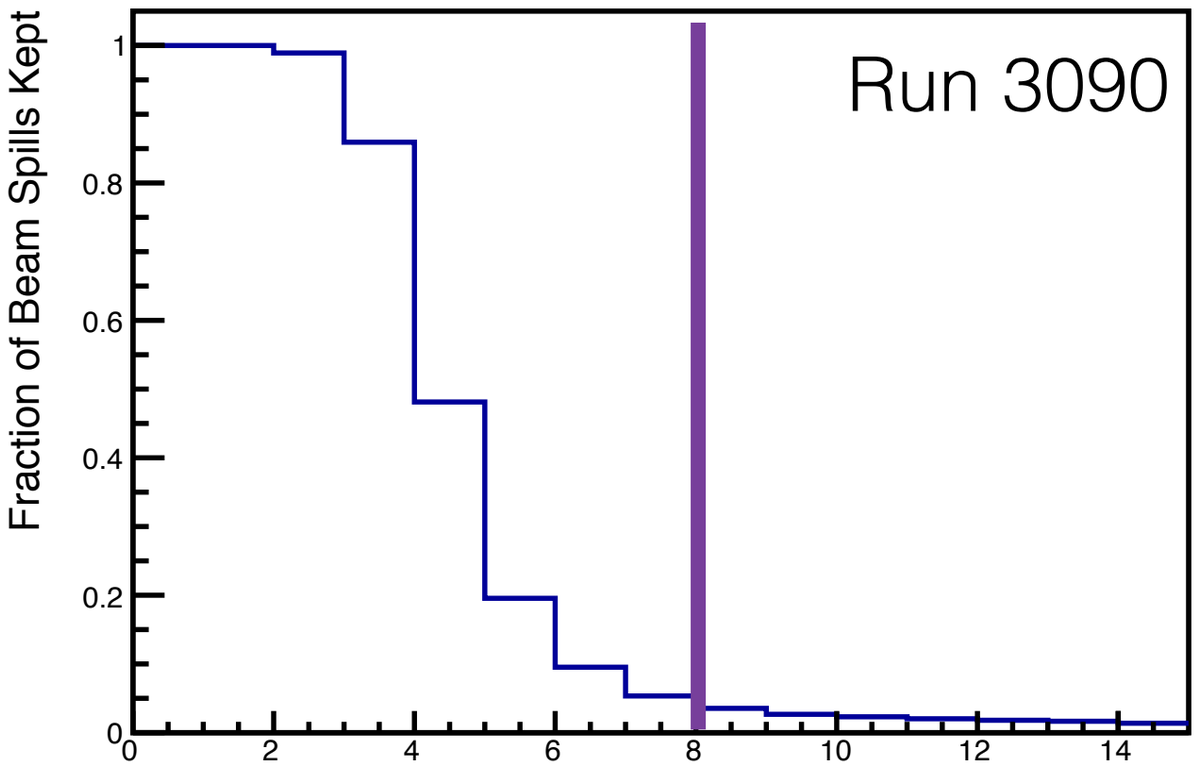


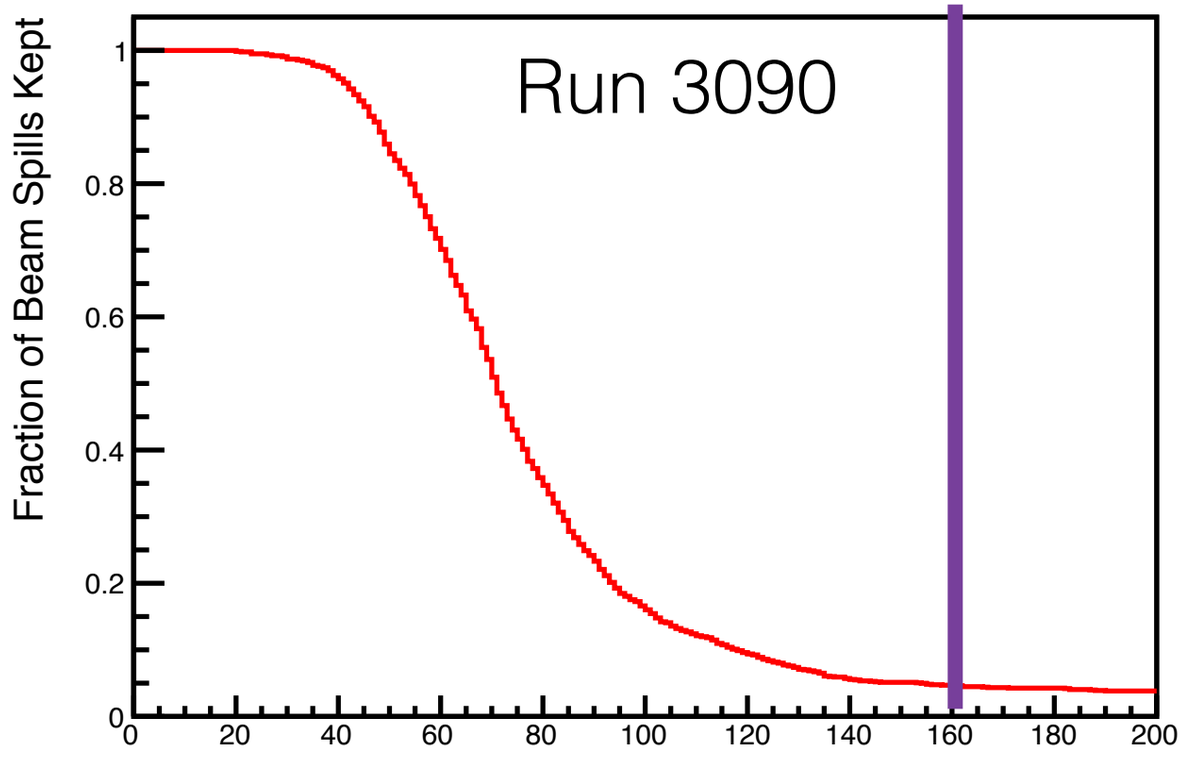


Measuring Rate vs. Trigger Variables

- Studied the PMT trigger rate as a function of logic variables for BNB-sized windows (1.6 microseconds)

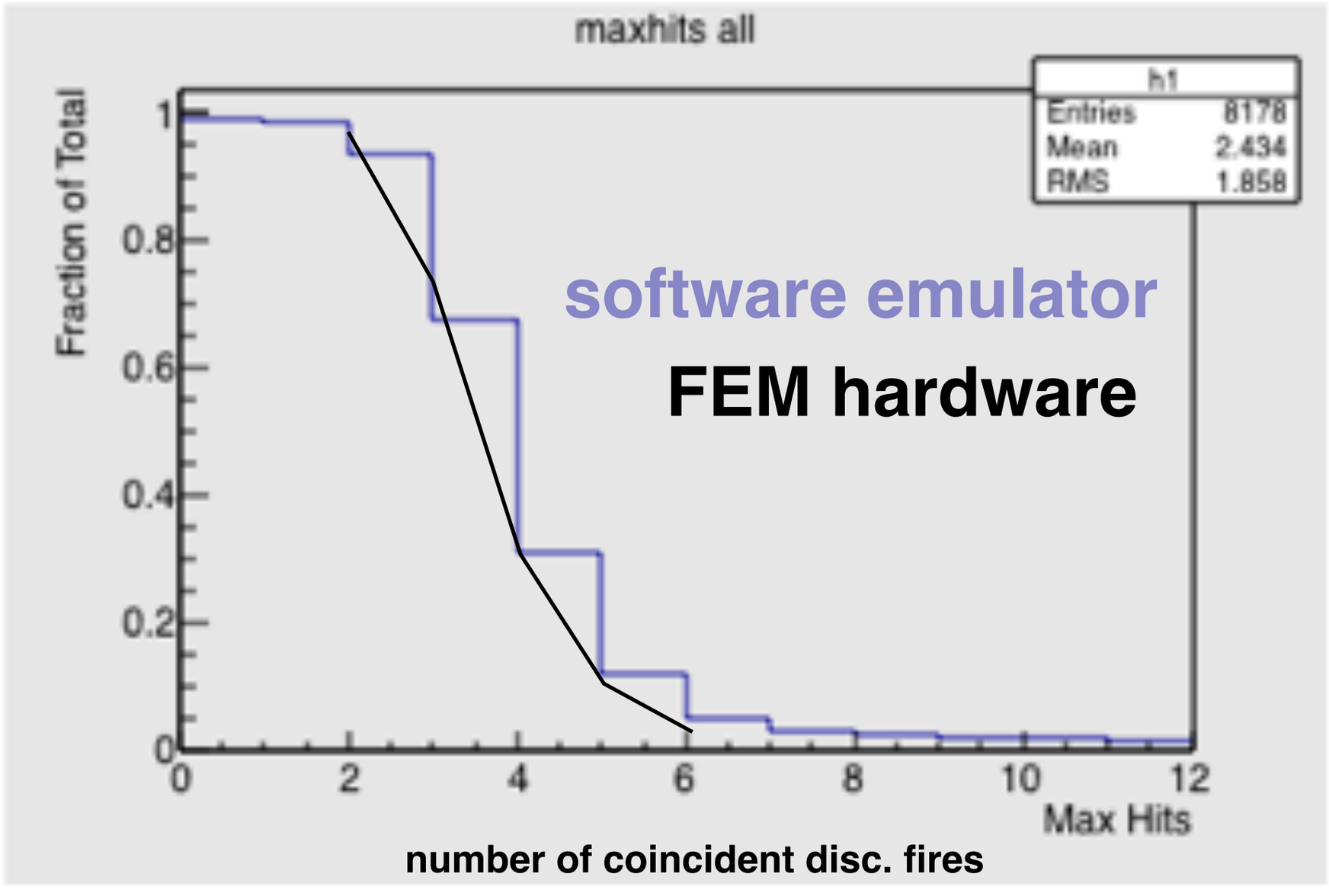
8 PE cut brings trigger rate to ~5%





Measuring Rate vs. Trigger Variables

Confirmed with hardware (with older run with lower single-pe rate)



Trigger Commissioning Status

- Status
  - Trigger Efficiency Study with Michel Electrons
    - TPC selection algorithm defined and demonstrated to work on MC and data samples. Working on refinements
    - Developing reconstruction tools for Optical flash selection of Michels
  - Optical MC tuning
    - Can extract muons using MuCS to provide sample to tune LY
    - Machinery to study MC samples (single particle and beam events)
    - Need to tune MC
- Trigger emulation
  - Studied on data
  - More detailed emulation verification
  - High stats. analyses on MC samples
- Defined method using in-time neutrino events (in backups)

Trigger Commissioning: Next Steps

- Schedule
  - Next month: Finish analyses
    - MuCS data vs. comparison
    - Michel analysis
    - MC efficiency studies using trigger emulation
  - Beginning of next year, present results of studies to collaboration. Together we approve the trigger threshold to run at

Backup Slides

Safety

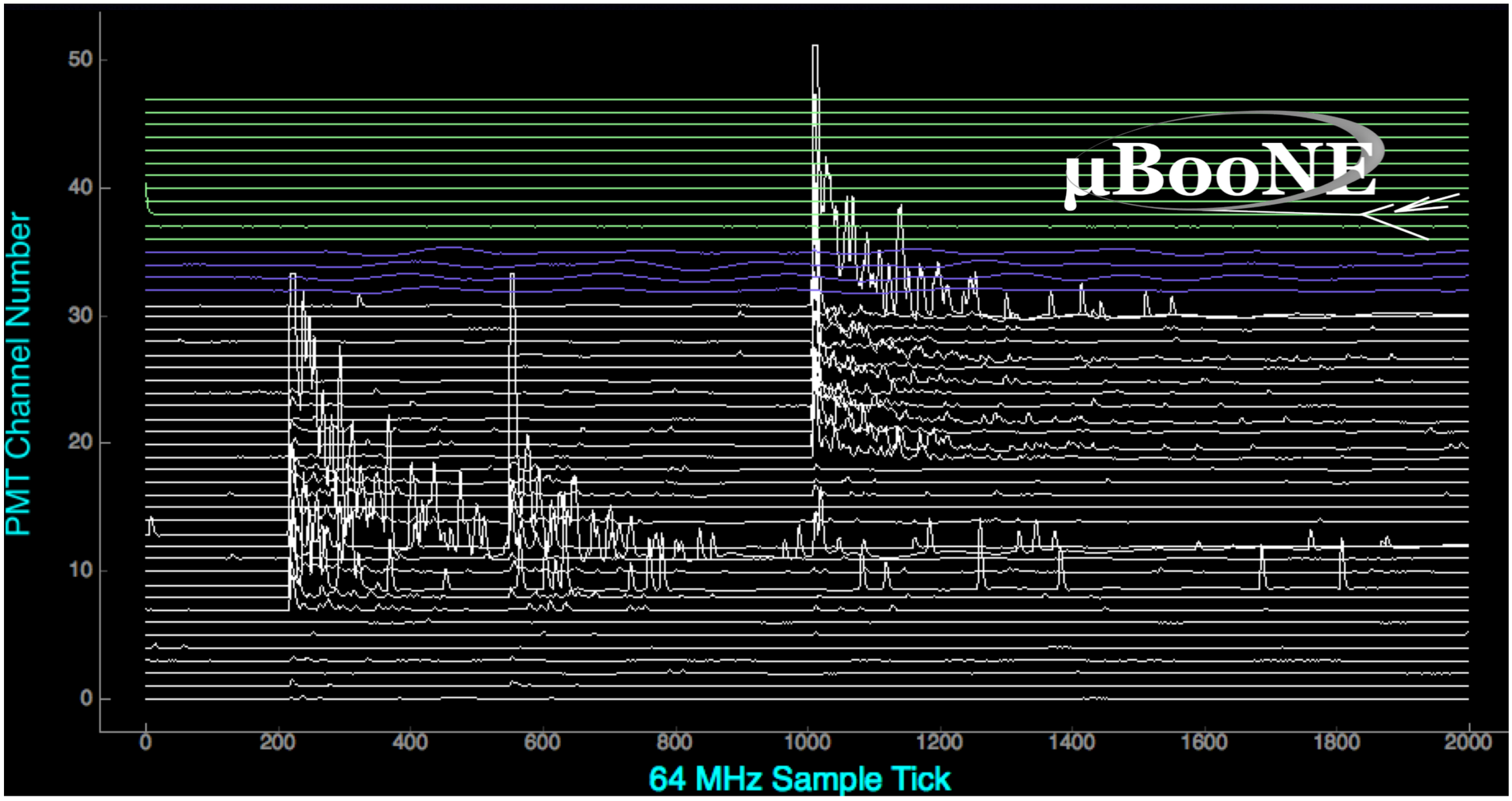
- The safety risk is the HV power supply that biases the PMTs
- Only PMT experts are allowed to work with this object
- We only connect and disconnect cables to this unit when the power is off
- There are Lexan covers and shields in the back of the rack that protect users from HV components

Outline

- In this talk, I'll describe the PMT trigger system
  - including necessary background information on the light collection system (LCS) and readout
- The light collection system is currently operation and stably taking data in conjunction with the TPC
- As planned, we are in the process of commissioning the PMT trigger using the first three months of data

LCS Operational

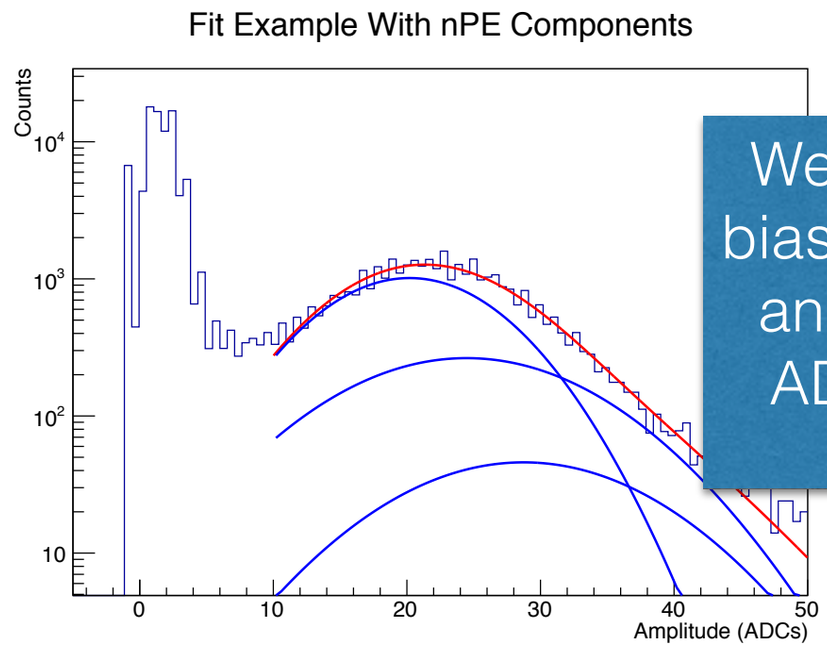
System is operational



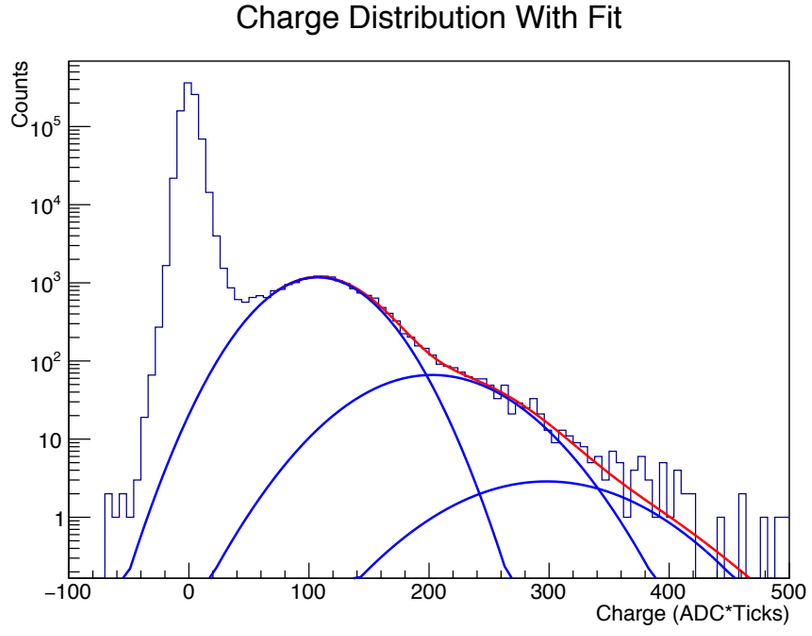
white traces are from PMTs
blue are from acrylic light guides
green is logic channels

PMT calibration

- single photoelectron (spe) response has been measured



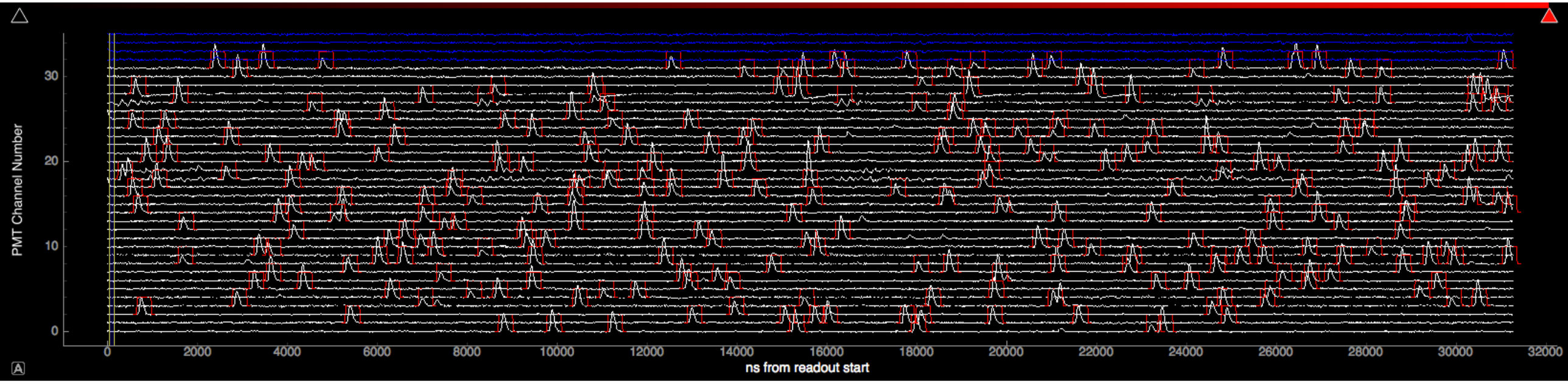
We've set the PMT bias voltages so that an SPE has a ~20 ADC count pulse heiaht



FEM CH	SPE (ADCs)	SPE (ADC*ticks)
0	18	101
1	19	105
2	20	112
3	20	110
4	20	117
5	19	109
6	18	103
7	18	99
8	17	97
9	20	108
10	20	109
11	19	105
12	21	118
13	20	109
14	20	111
15	19	106
16	18	102
17	18	104
18	19	107
19	20	112
20	20	108
21	21	114
22	19	104
23	18	100
24	19	100
25	19	106
26	20	107
27	21	109
28	20	108
29	20	111
30	20	109
31	19	105

Forming a PMT Trigger

- Example event display to give a sense of what we are seeing
- Red boxes identify pulses that pass the threshold (10 ADC counts)



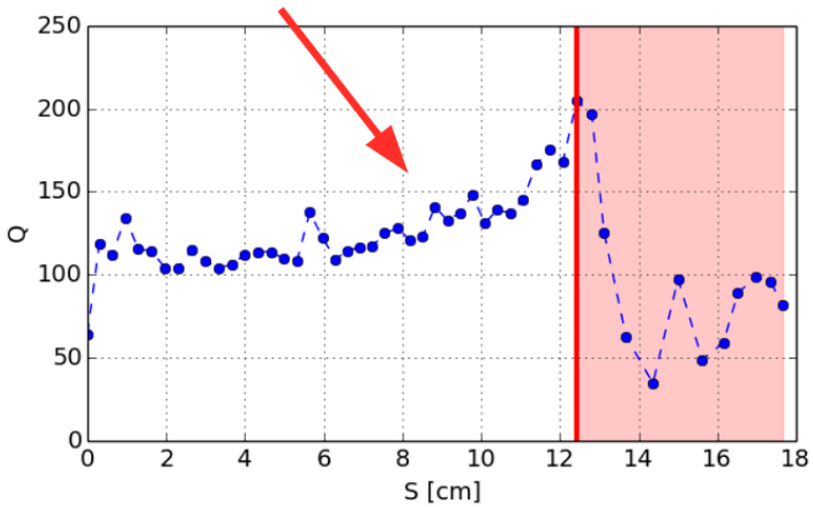
Michel Analysis

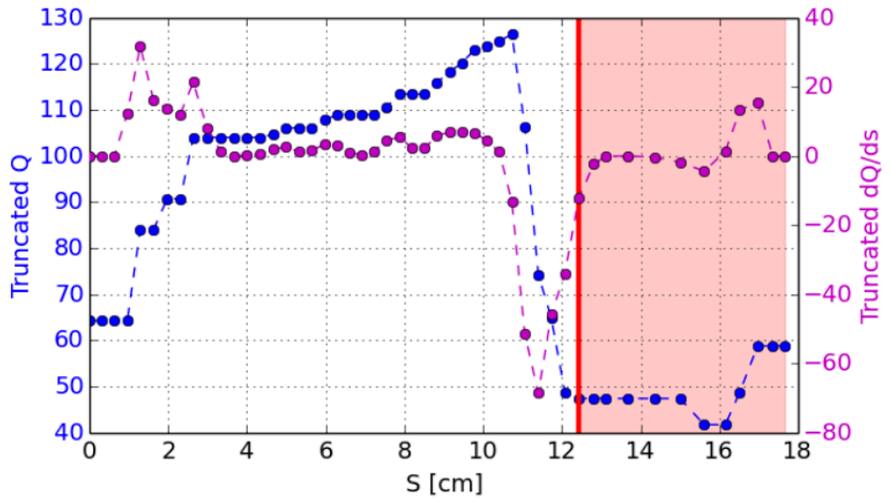
•Original work by Vic and Kathryn, updates by David C. and David K.

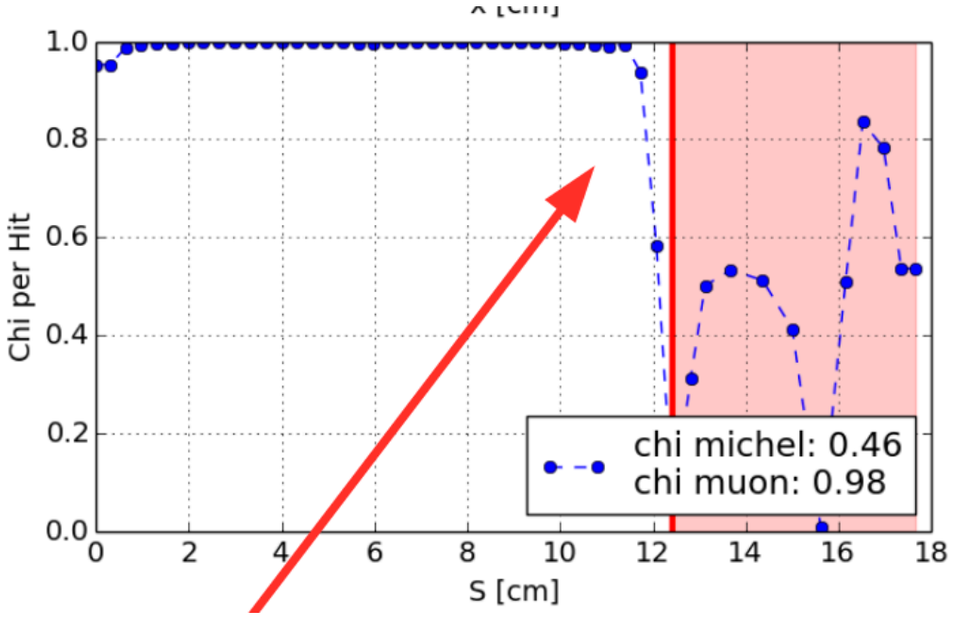
•Start with 2D cluster reconstruction in collection plane

•Find Michel using the cluster charge profile and linearity profile

•Good purity (80-90%, can be much higher with tighter cuts) but low efficiency (~10%)

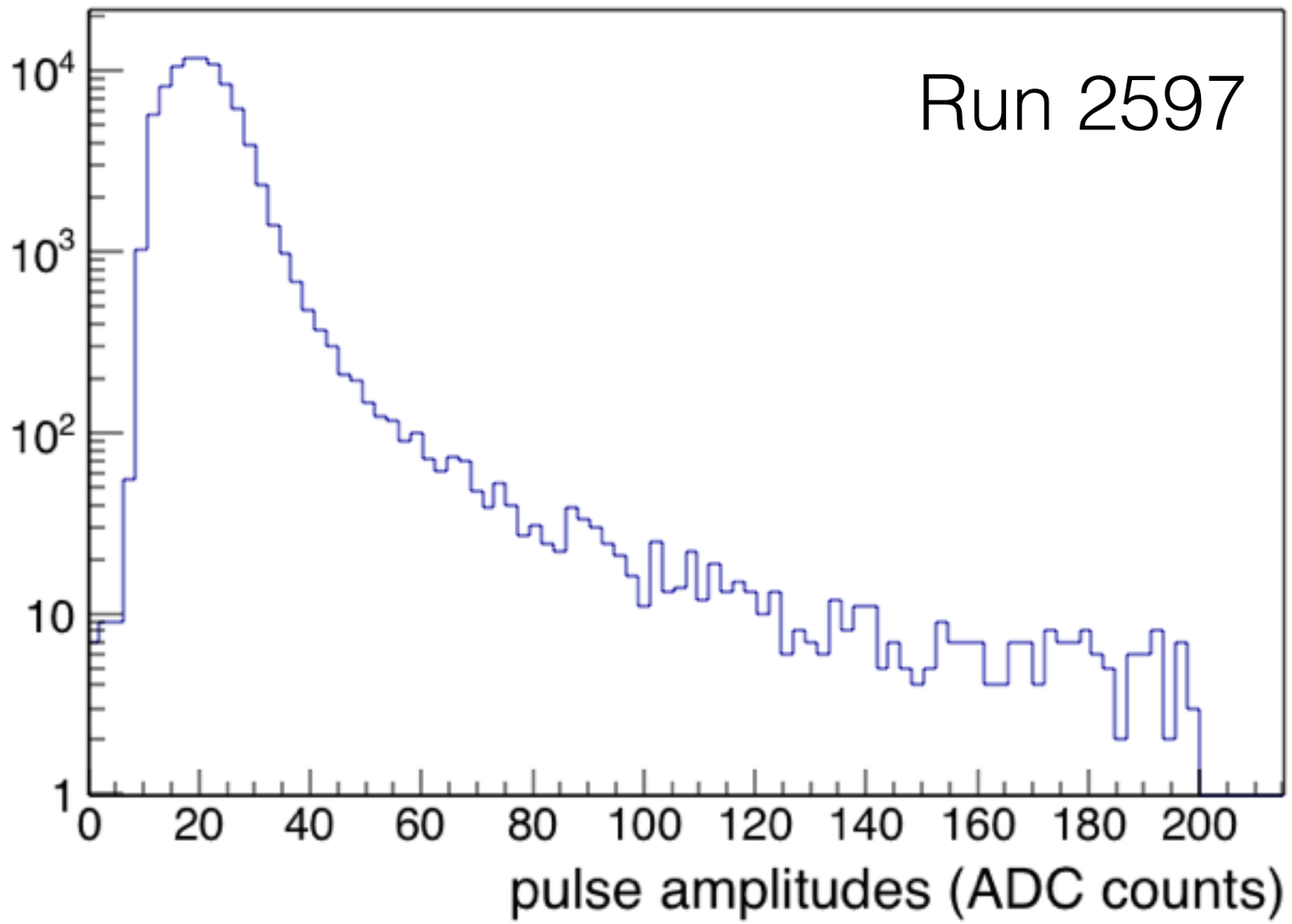






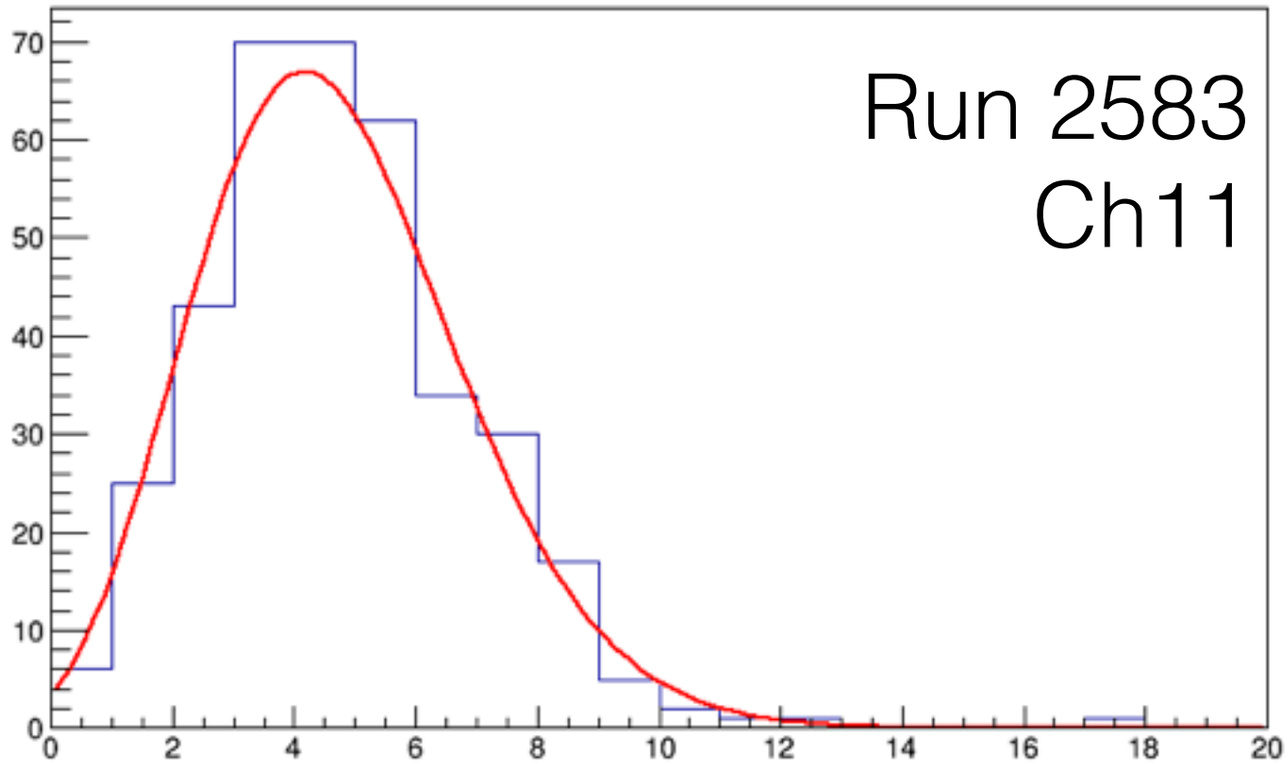
Studying Background Light Rate

- Example distribution of pulse amplitudes
- Single PE pulses are 20 ADC counts (PMT responses have been tuned to be uniform)
- Majority of pulses seen are single PE



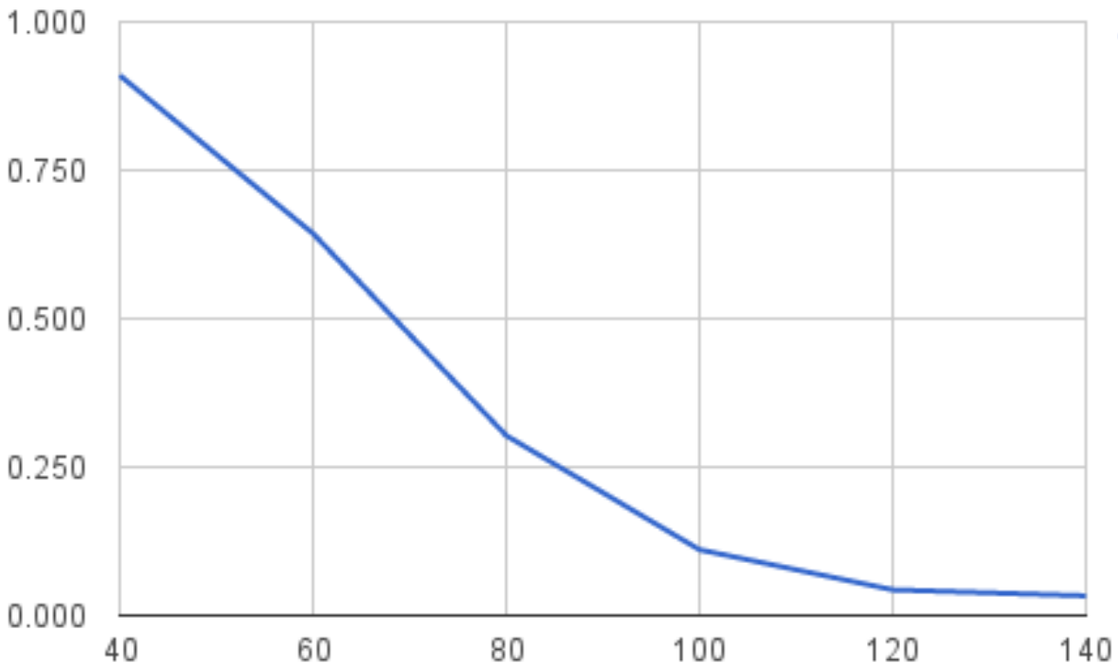
Studying Background Light Rate

- Example distribution of pulses per event window
- Using only events without large pulses in order to not be influenced by cosmics and late-light
- Red curve is fitted Poisson distribution

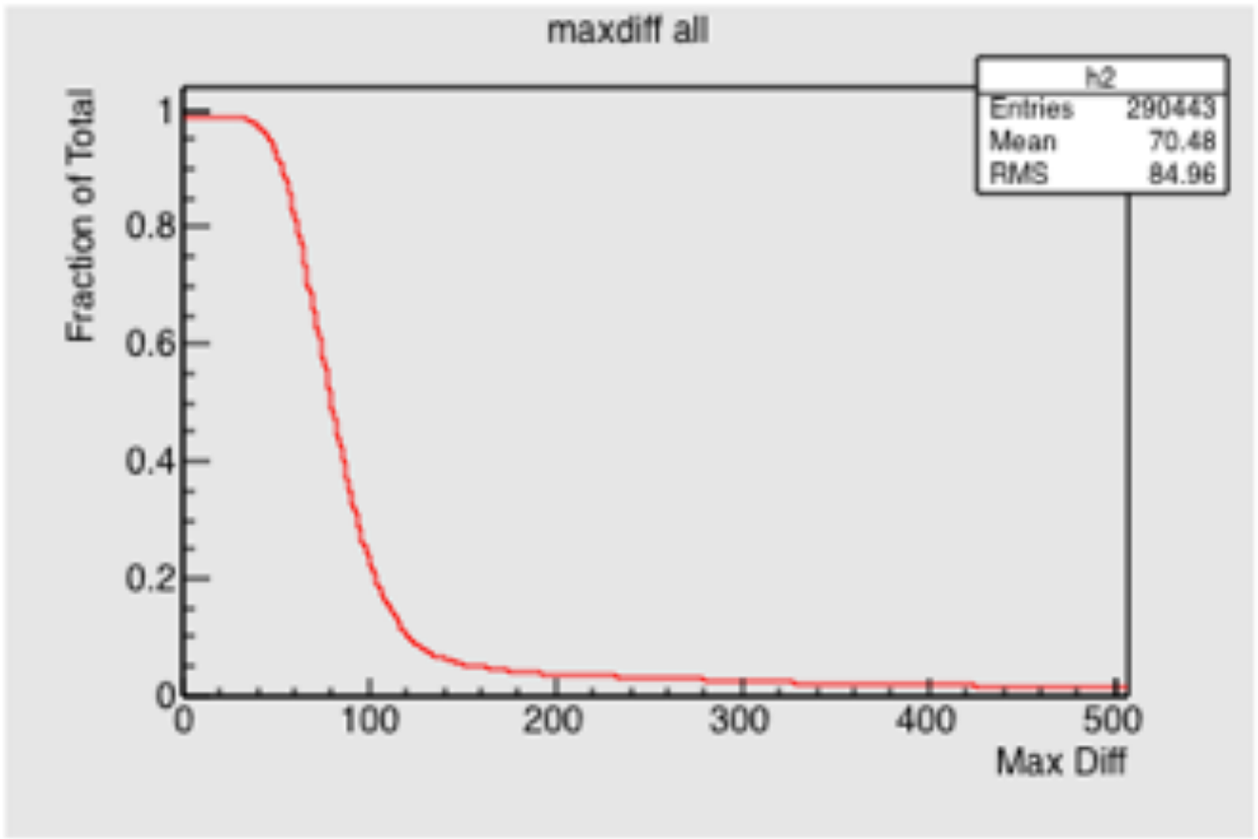


Studying Background Light Rate

Confirmed with hardware (with older run with lower single-pe rate)



summed ADC difference seen by coincident discs.



Using FEM

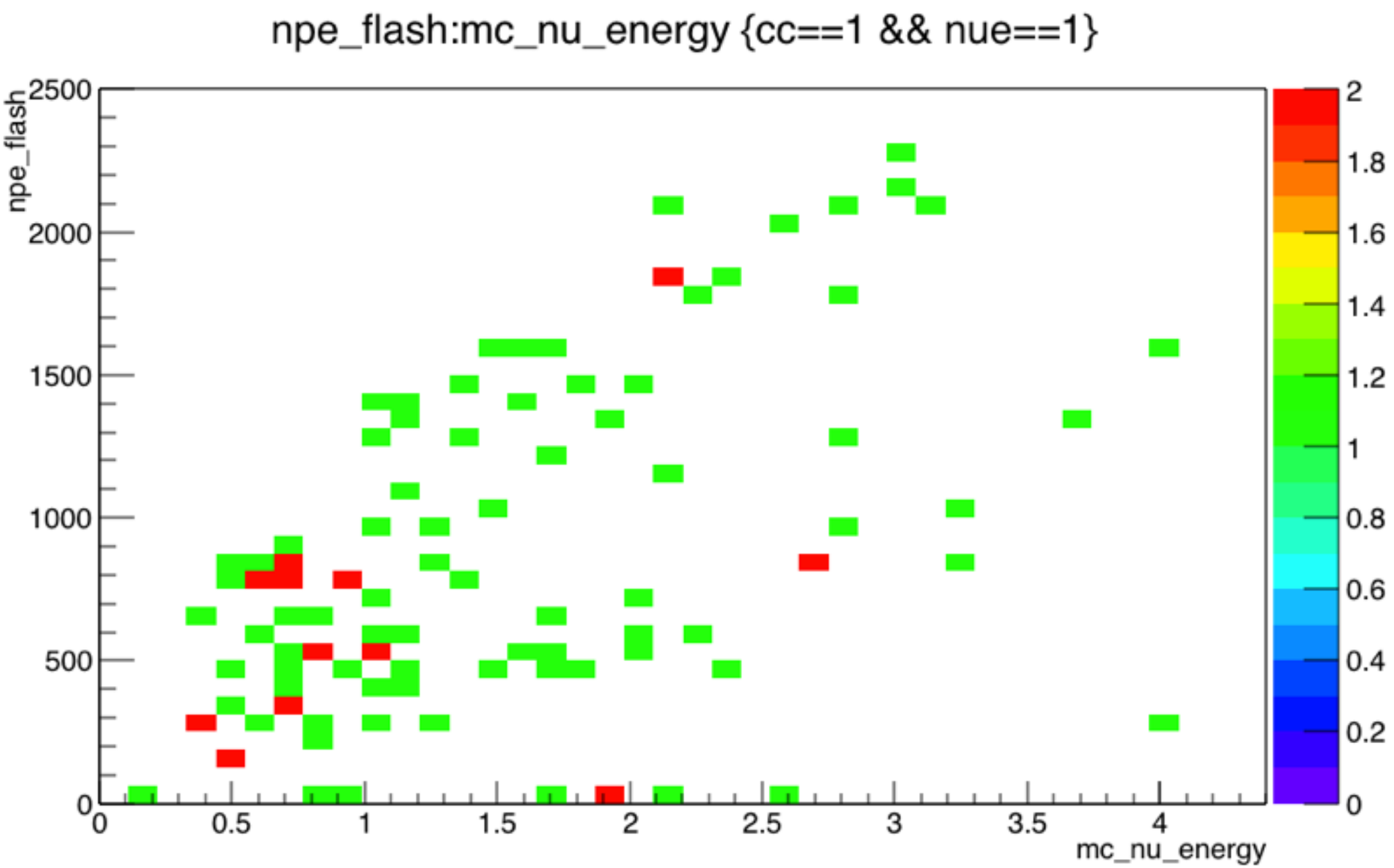
Soft. emulation of FEM

Simplistic Nu MC Check

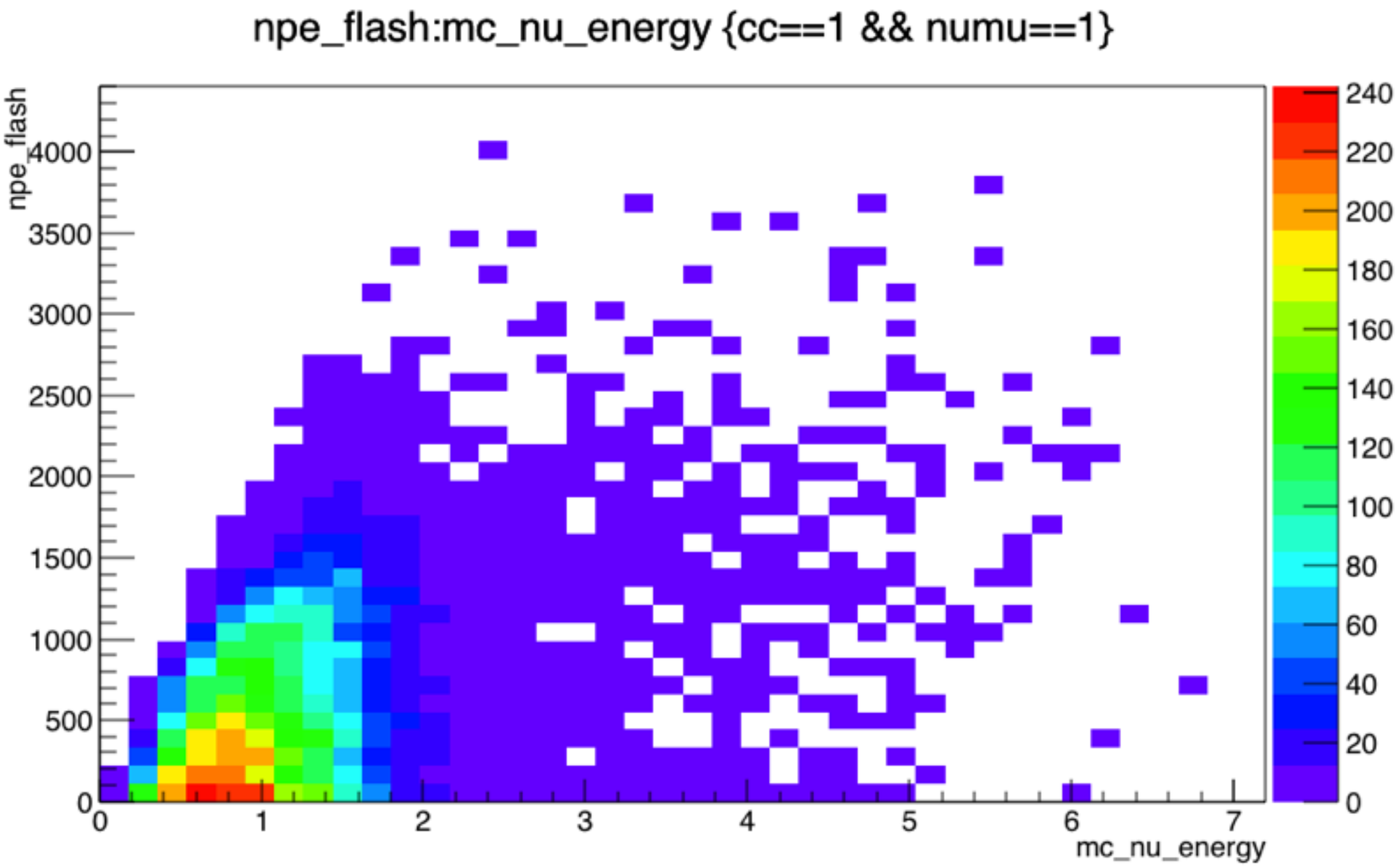
Note: old MC
Regenerating Events soon

Cut	cc nue	cc numu	NC proton
>0	97	11188	2918
>1	97	11188	2918
>4	96 (98%)	11136 (99%)	2839 (97%)

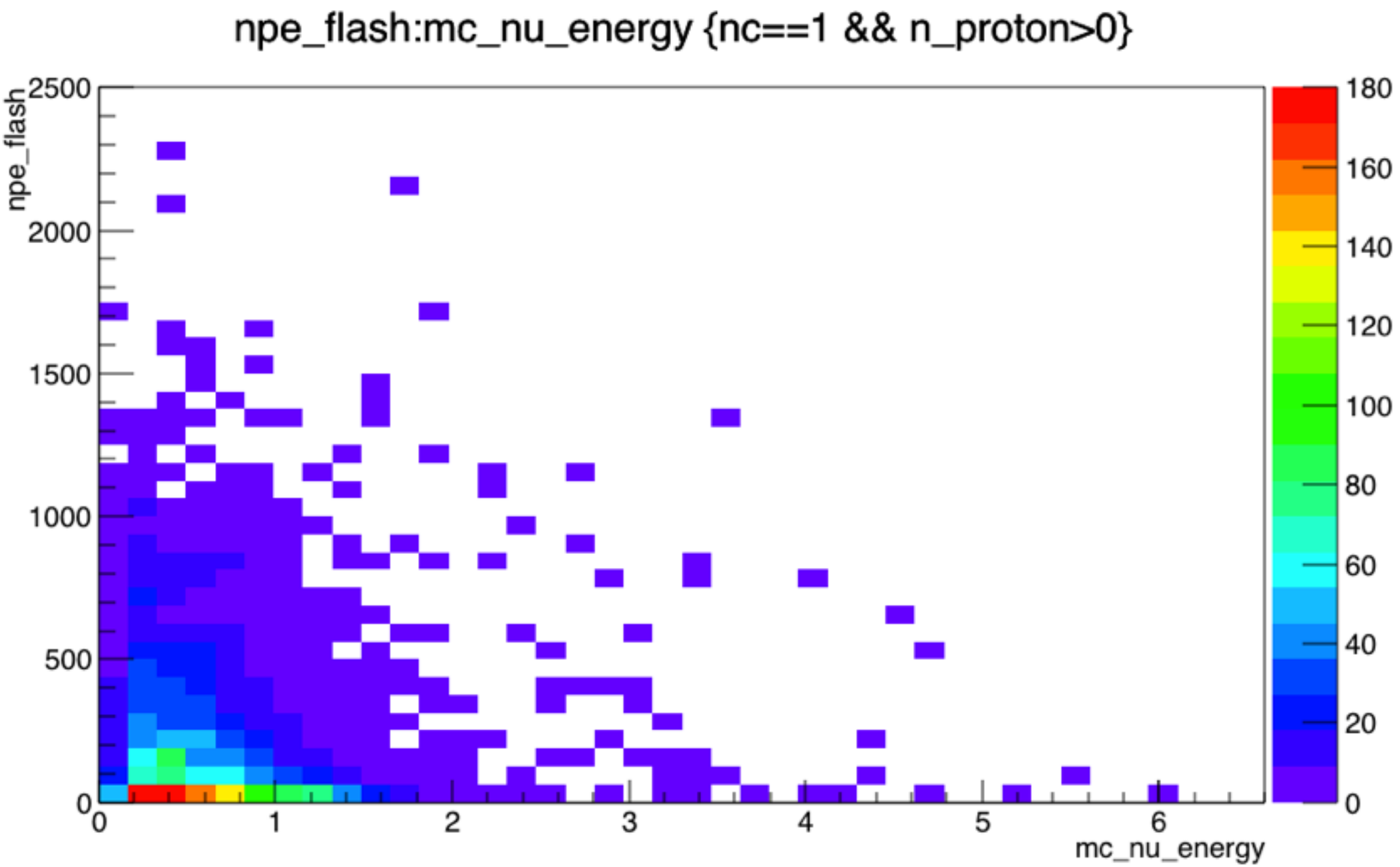
PMT Trigger


npe_flash:mc_nu_energy {cc==1 && nue==1}
npe_flash
2500
2000
1500
1000
500
0
0
0.5
1
1.5
2
2.5
3
3.5
4
mc_nu_energy
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0

PMT Trigger

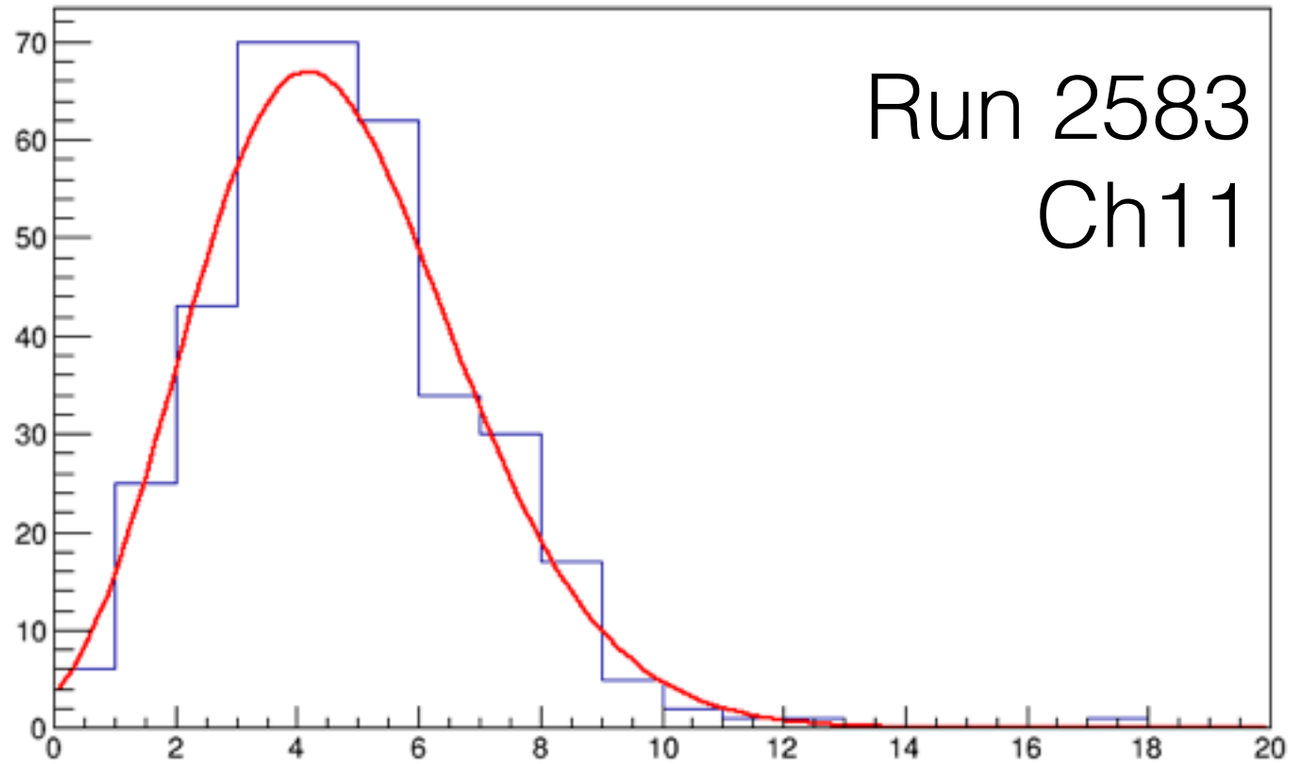

npe_flash:mc_nu_energy {cc==1 && numu==1}
npe_flash
4000
3500
3000
2500
2000
1500
1000
500
0
0
1
2
3
4
5
6
7
mc_nu_energy
240
220
200
180
160
140
120
100
80
60
40
20
0

PMT Trigger


npe_flash:mc_nu_energy {nc==1 && n_proton>0}
npe_flash
2500
2000
1500
1000
500
0
0
1
2
3
4
5
6
mc_nu_energy
180
160
140
120
100
80
60
40
20
0

Background Light

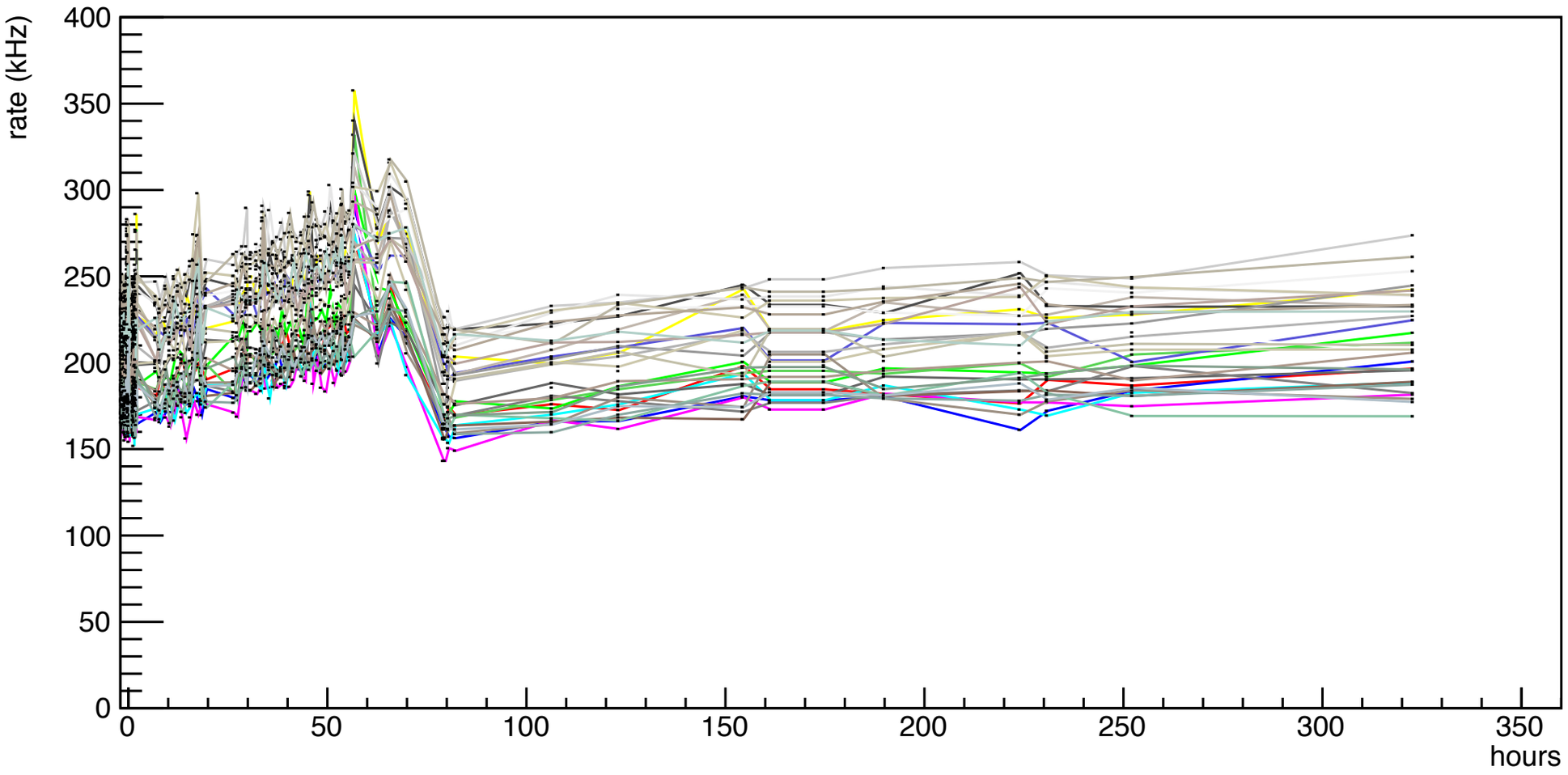
- Example distribution of pulses per event window
- Using only events without large pulses in order to not be influenced by cosmics and late-light
- Red curve is fitted Poisson distribution



Still working to understand this source of light — evidence that some of it is due to radioactivity associated with the Liquid argon purity filters

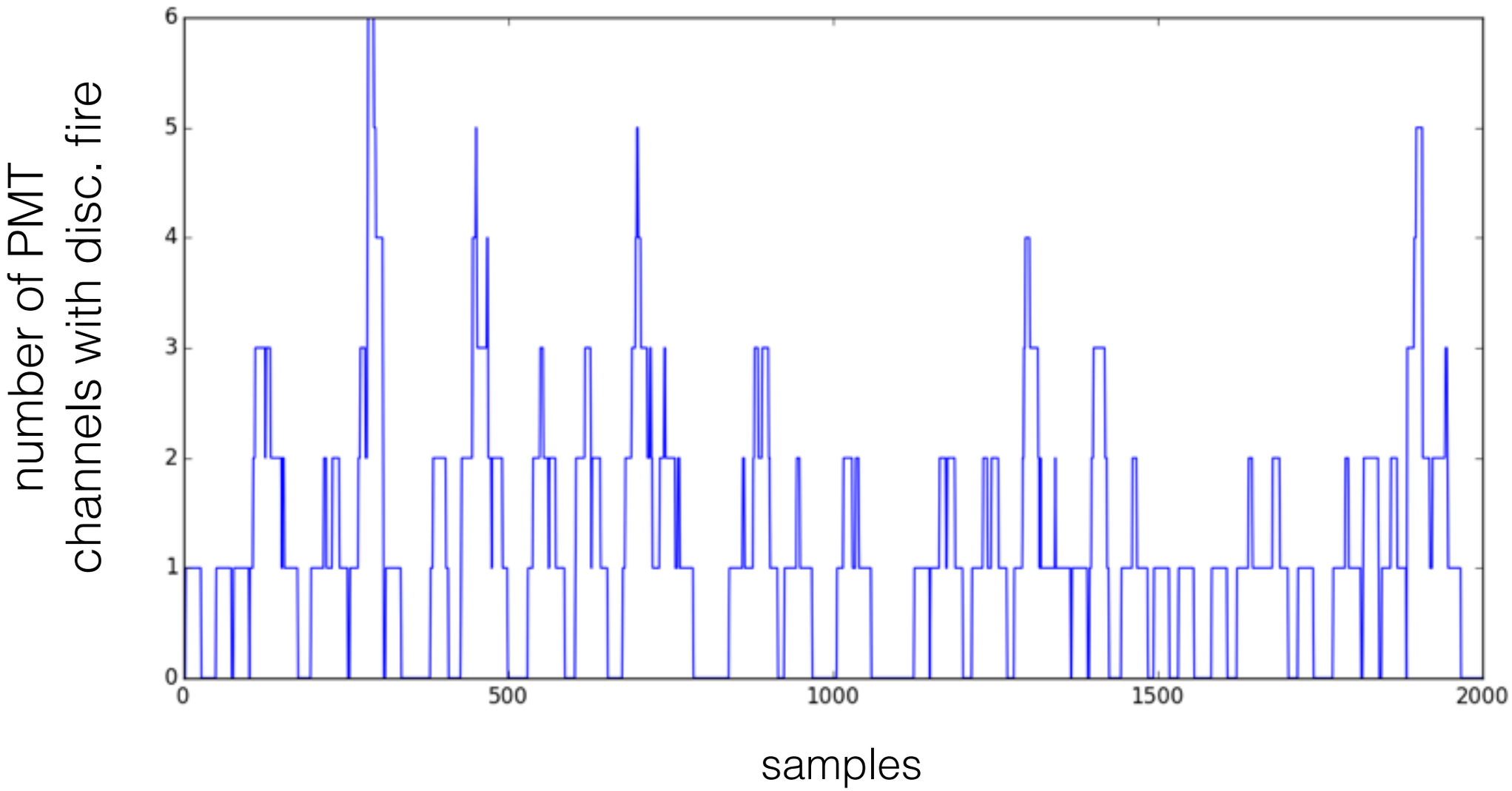
Filters and Rate

- When we reconnect the filters, we see the rate of pulses increase
- Note that the sudden drop coincides with the turn on with the drift HV



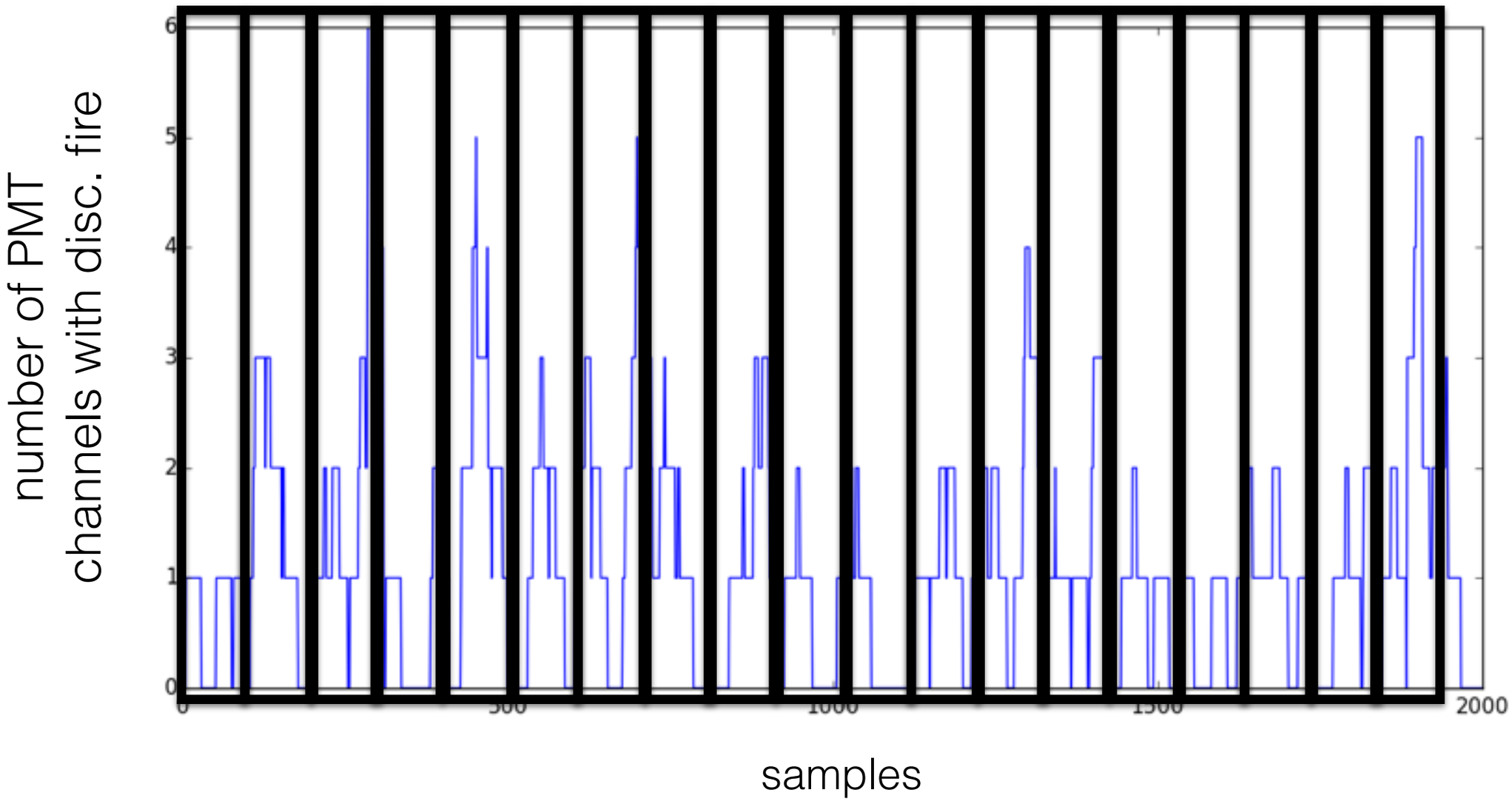
Discriminator

- Multiplicity of hits



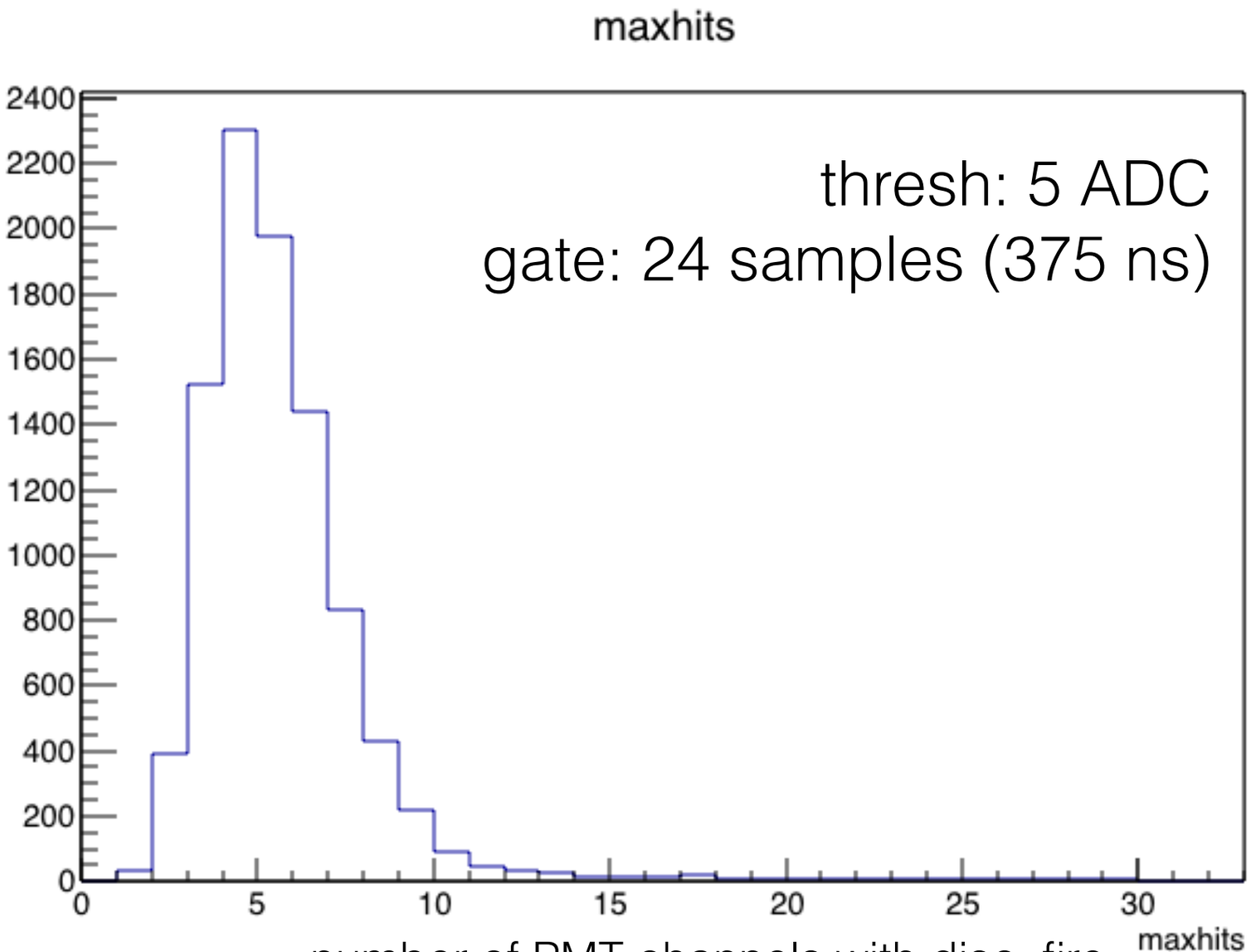
Discriminator

- To mimic 1.6 microsecond gates, just chopped up into 102 sample windows
- Then checked number of PMT disc. fires in each window



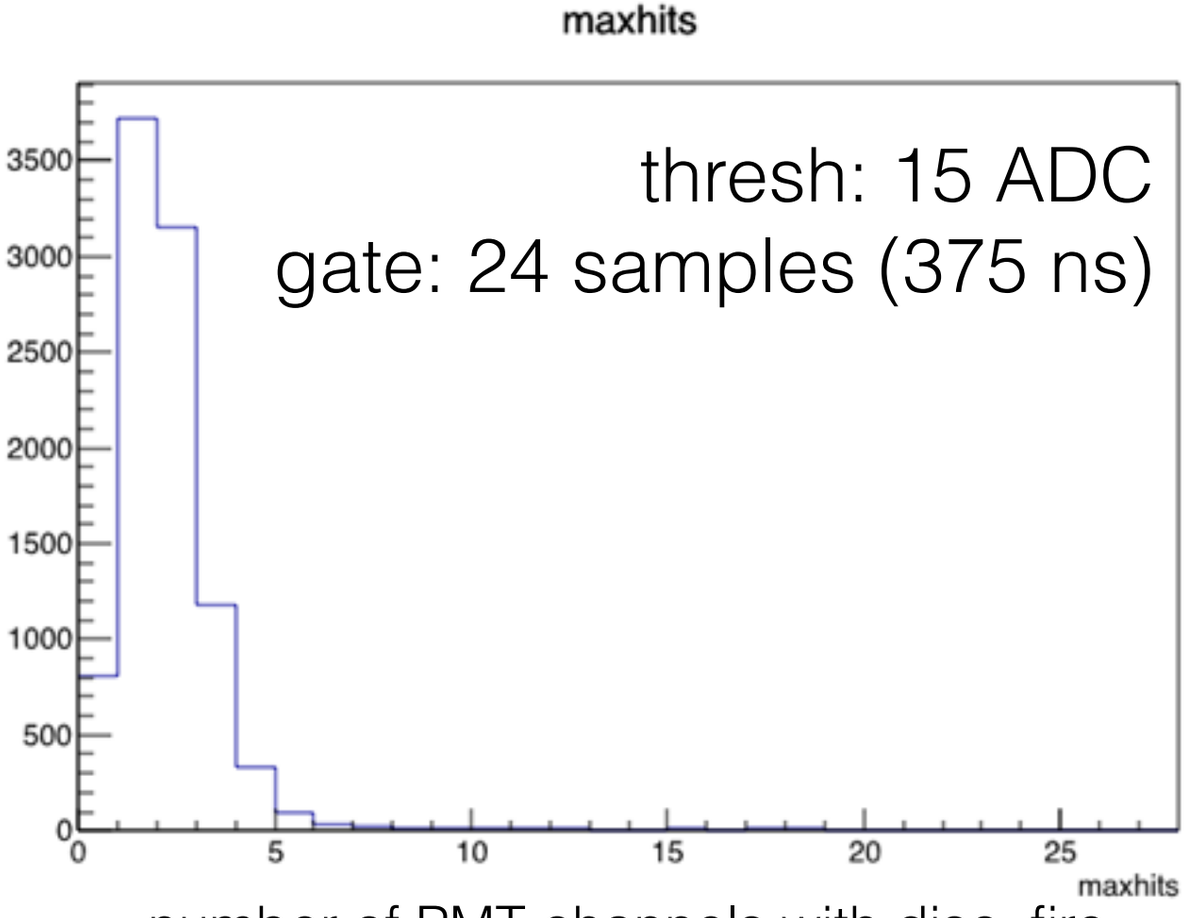
Triggers

- Set threshold to roughly 25% of 1 pe for each PMT
- All windows have at least one disc. fire. On average 5!

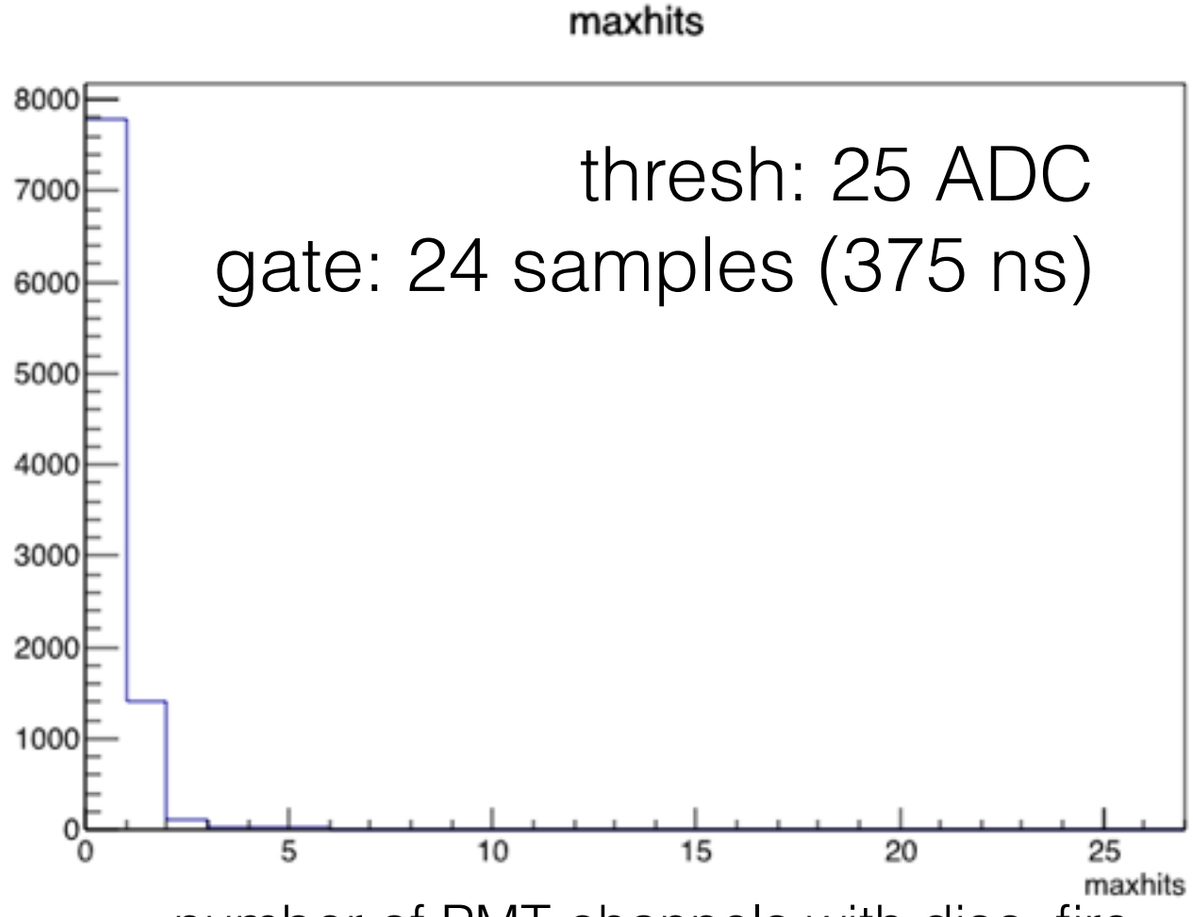


Triggers

- Have to set a threshold to keep disc. firing on every beam window



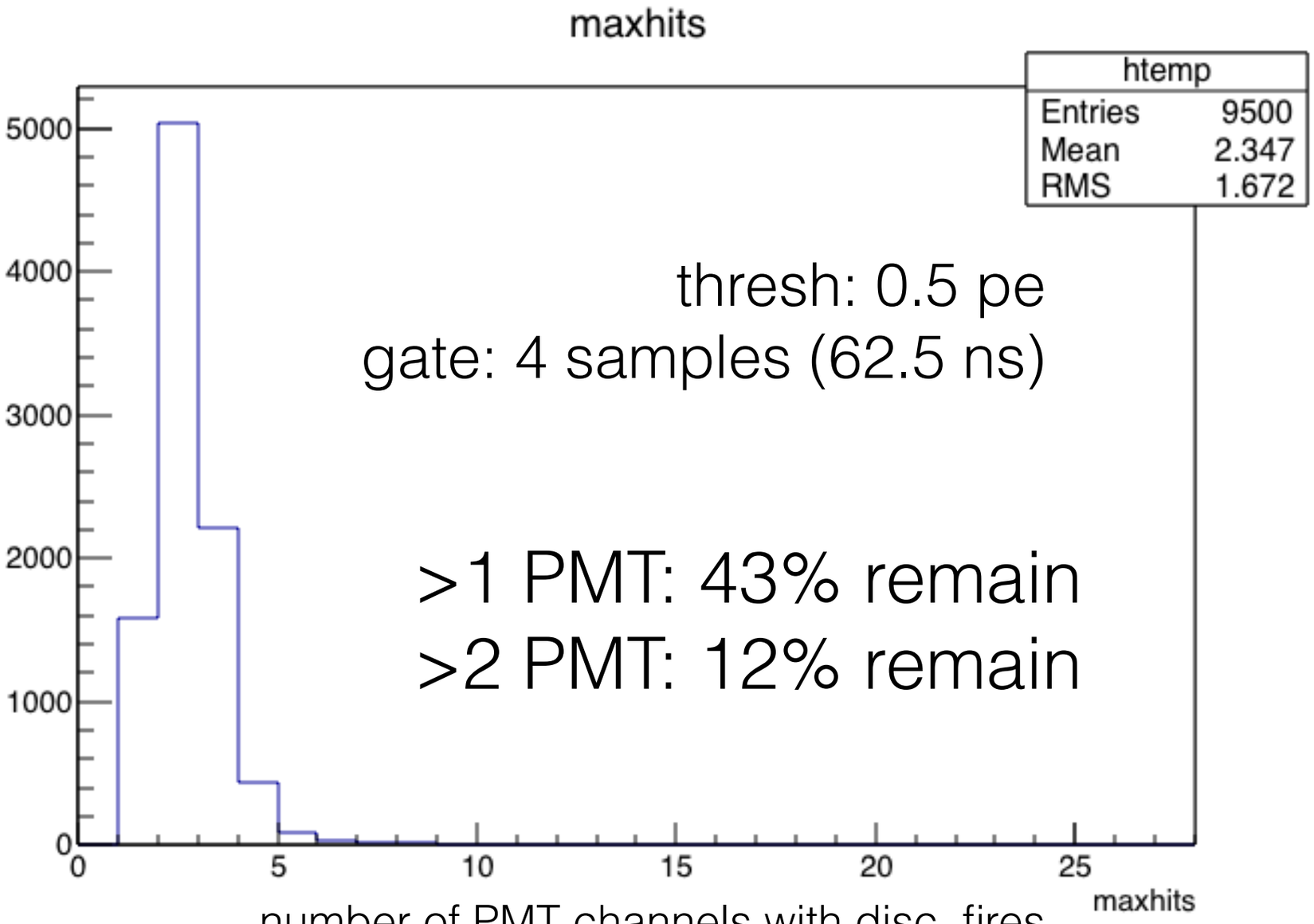
number of PMT channels with disc. fire



number of PMT channels with disc. fire

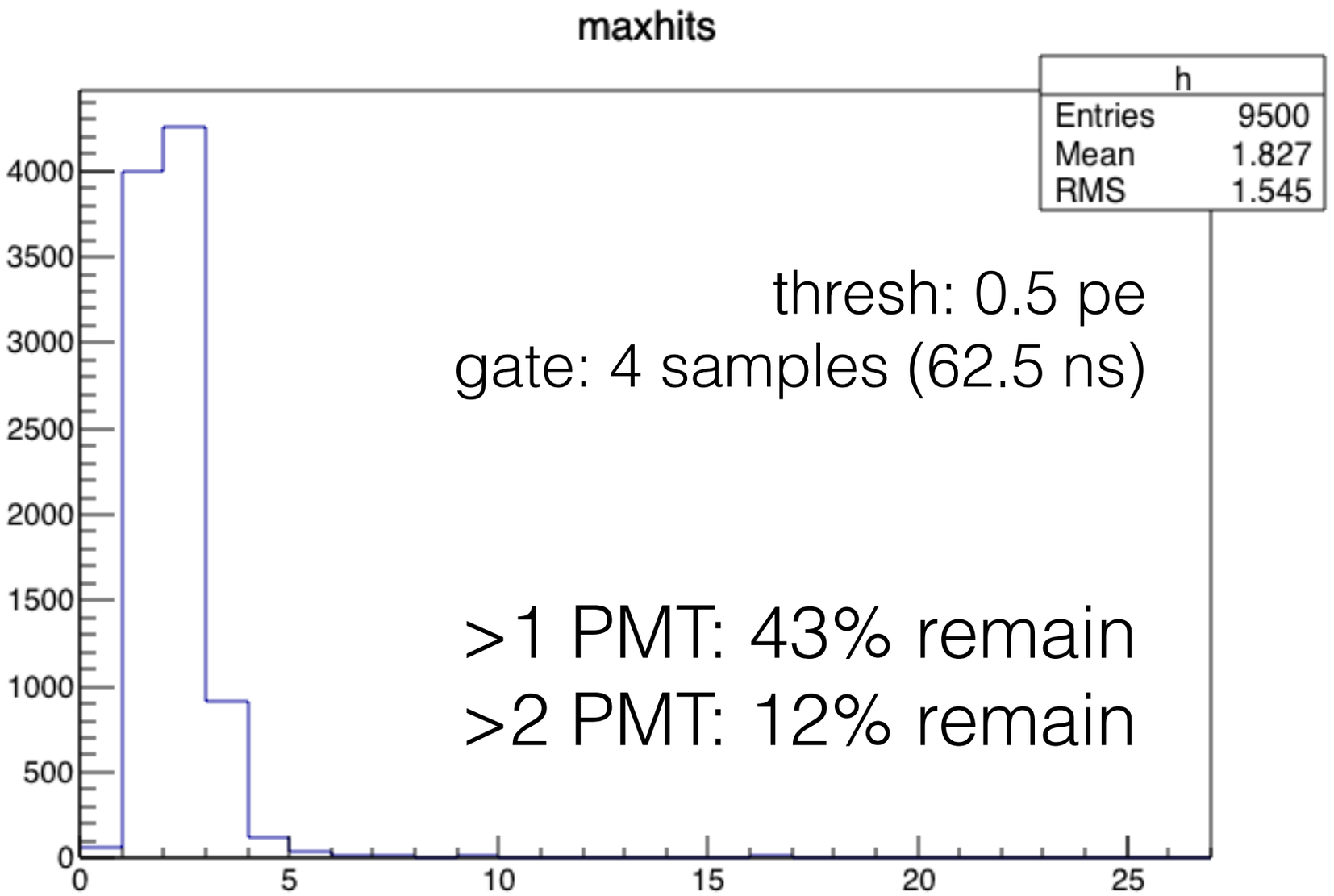
Triggers

- Fiddling with parameters: 4 sample coincidence gate (based on 50 ns coincidence spec in docdb 2470)



Triggers

- Accounting for varied PMT gains



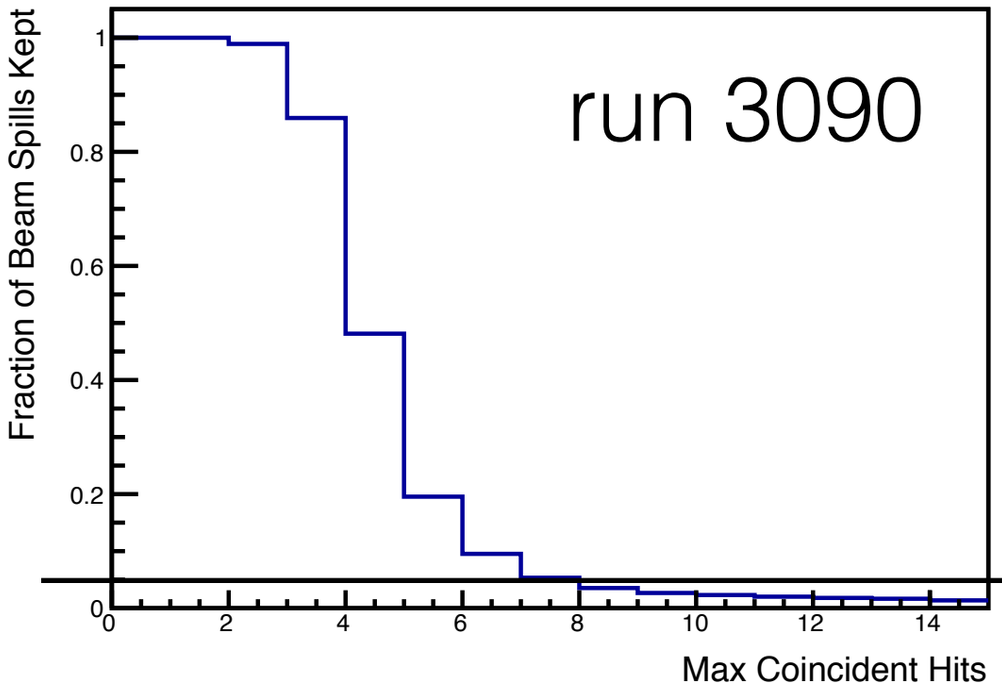
PMT Trigger

Implementing Clustering in Trigger will help a little

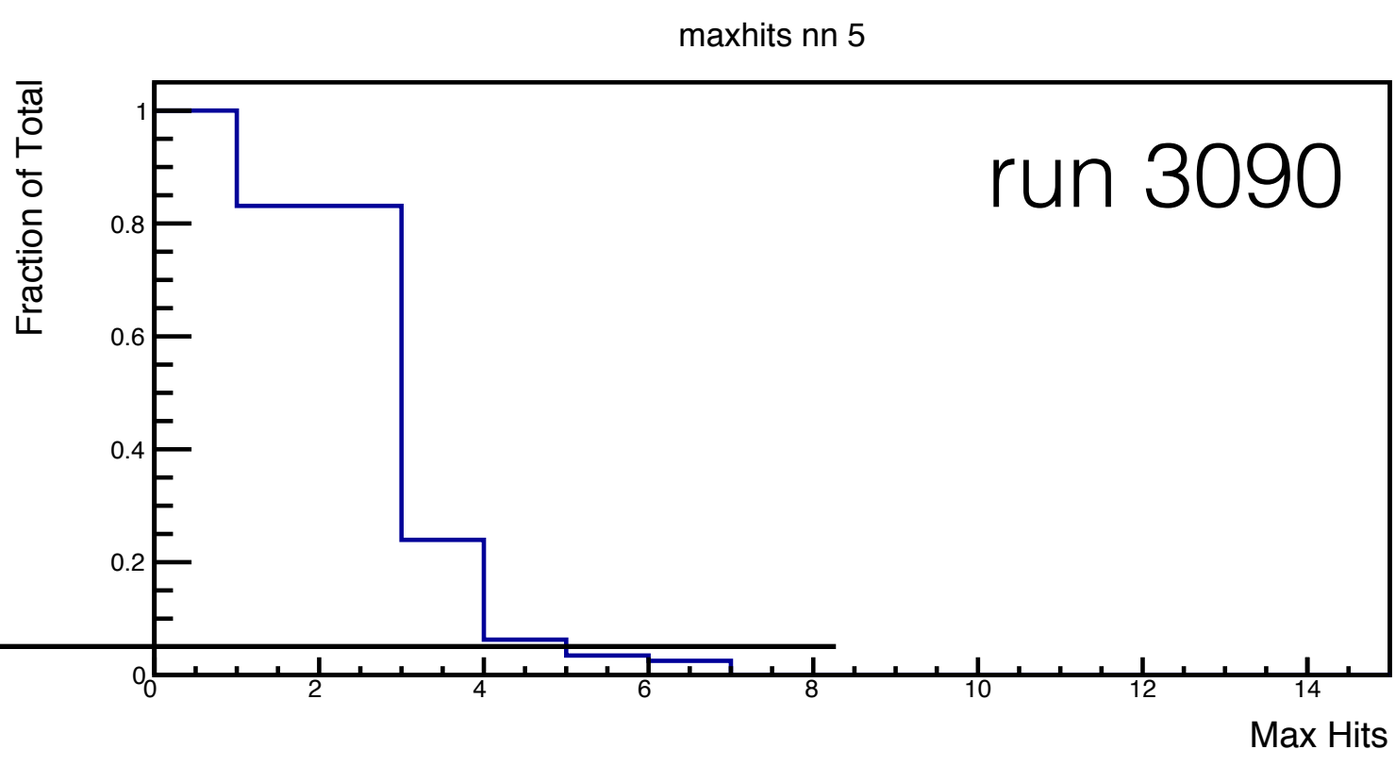
Moves pe threshold from 8 to 5 pe (for 5% accidental fraction)

requires firmware update.

Current trigger

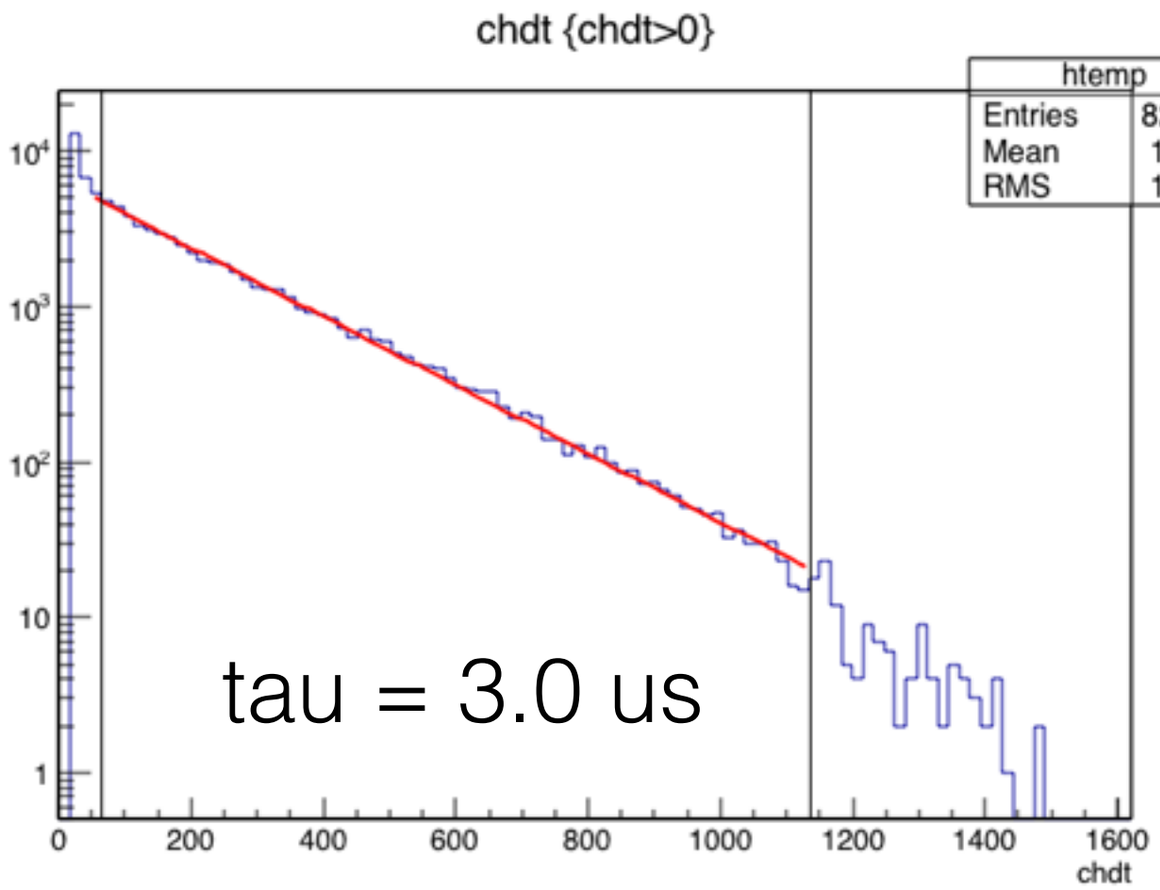


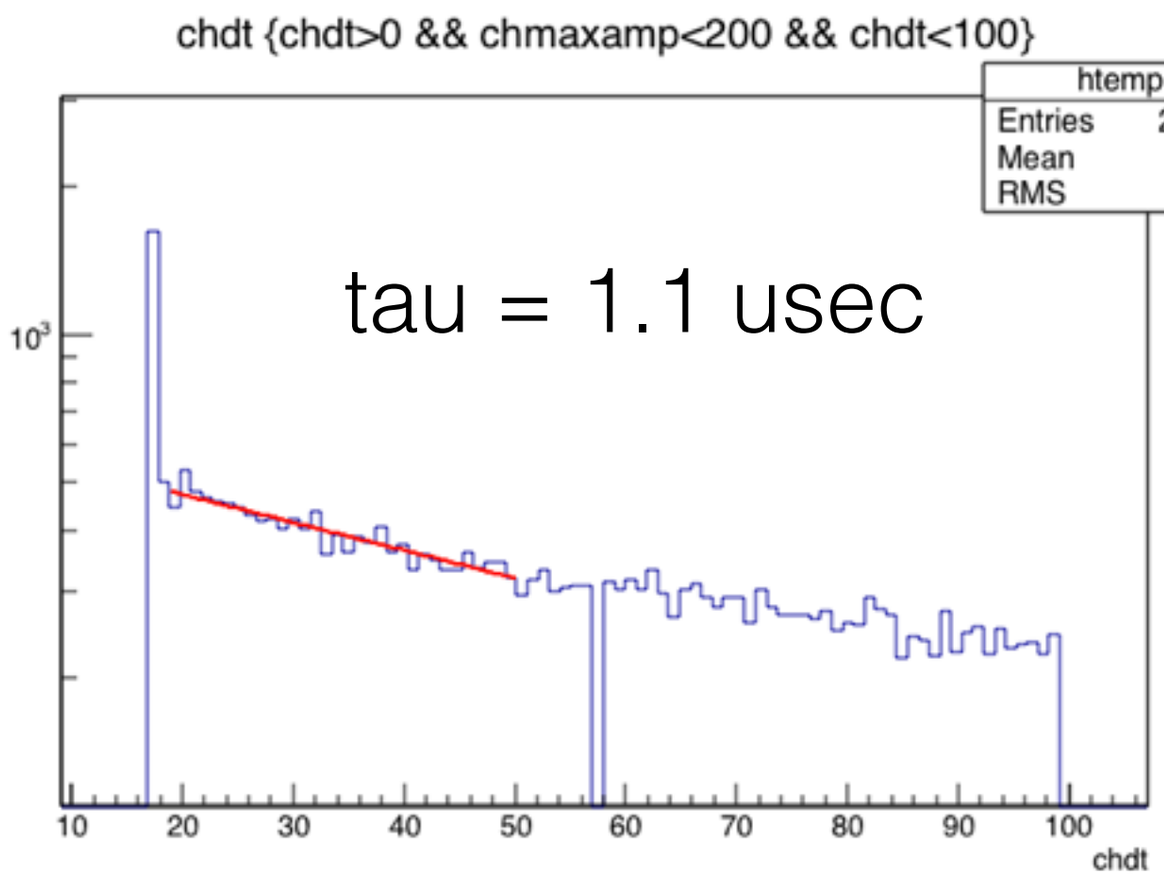
5 Nearest-Neighbors trigger



Background Light Timing

time between pulses on one channel
(not on the system as a whole)





cfd setting: threshold 7, delay 4, width 15, deadtime 15
select only events where all pulses <200 ADC counts — to remove cosmics