Monte Carlo Study and Data Analysis of the Neutron Multiplicity Meter

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The Neutron Multiplicity Meter (NMM) Collaboration

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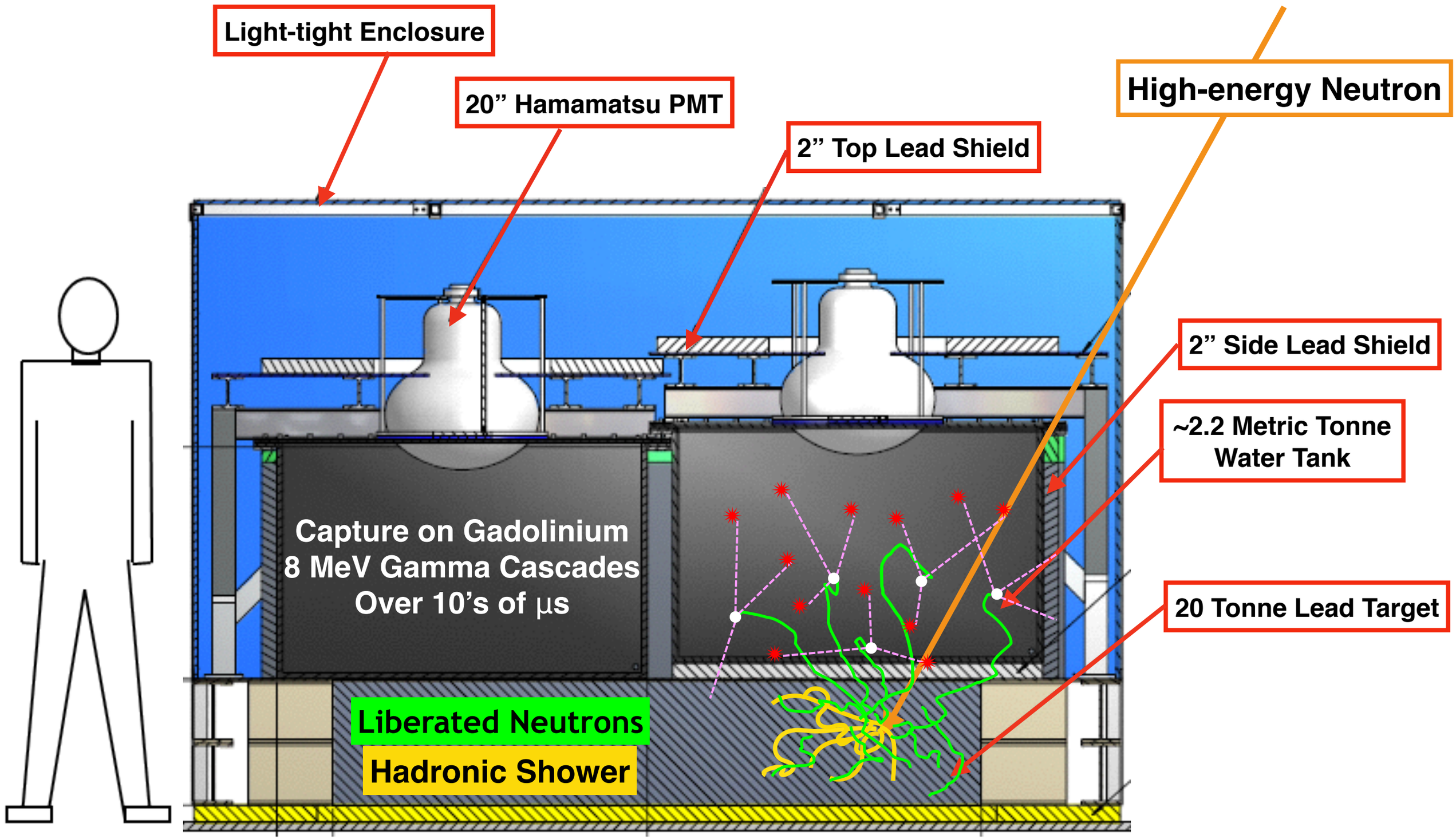
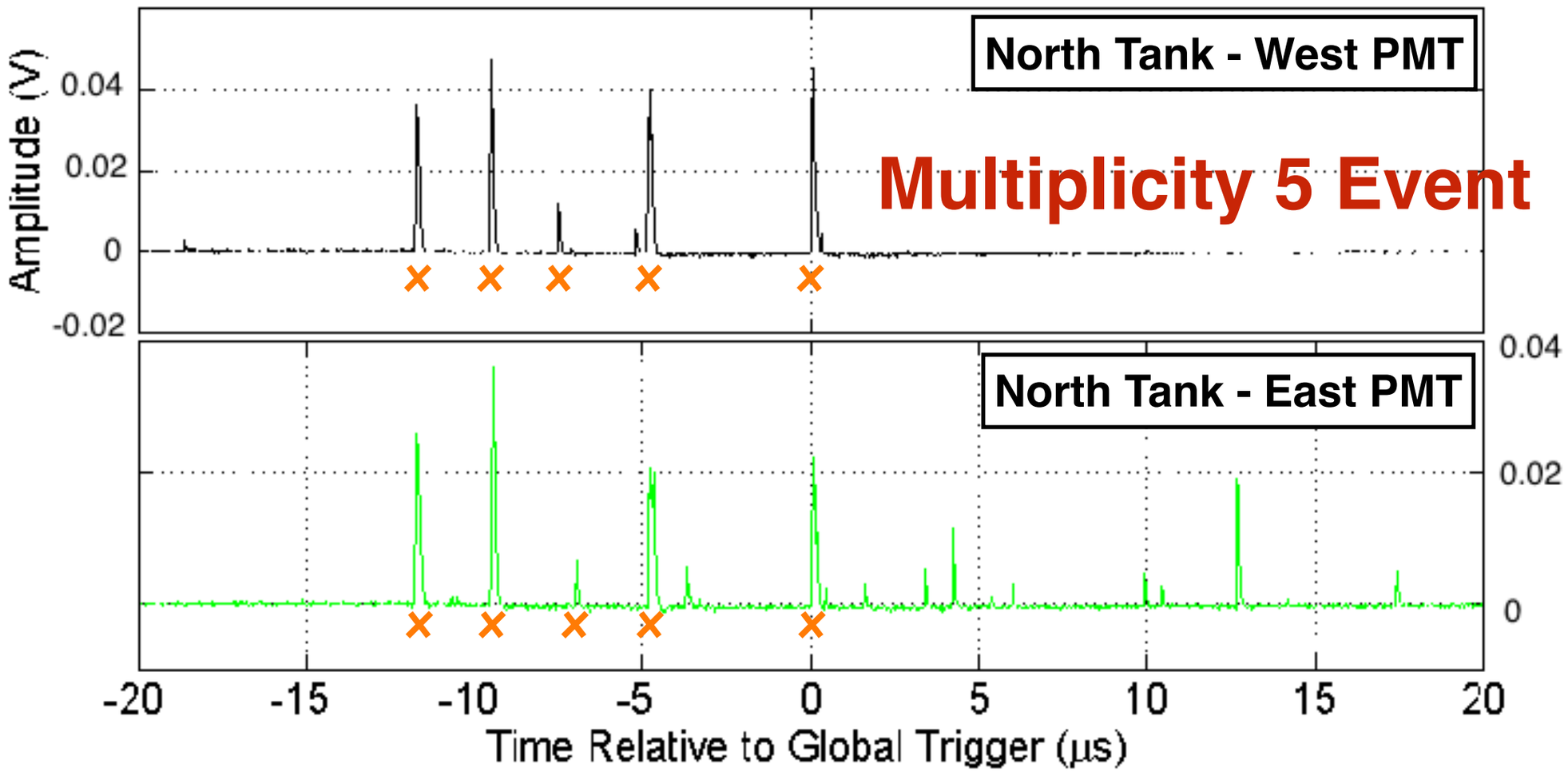
The Neutron Multiplicity Meter (NMM)



The aim of the experiment is to measure the flux of high energy neutrons (> ~50 MeV) deep underground (Soudan at 2090 m.w.e).

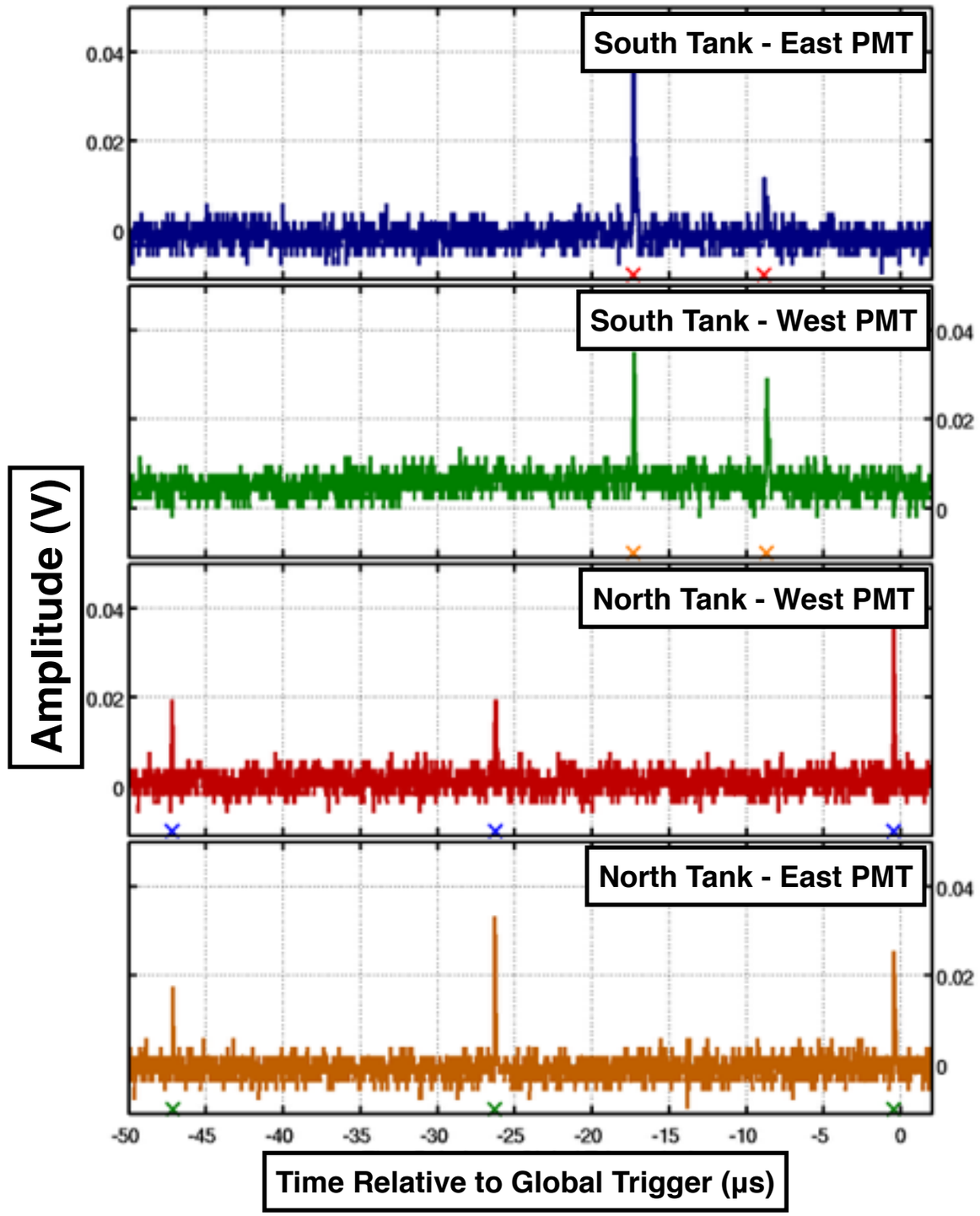
Candidate High-energy Neutron Event

- Relatively large coincident pulse heights from captured secondary neutrons created by high energy neutron
- Clustered pulse train due to ~10 μs Gd capture time
- The experiment triggers if there are at least 5 coincident pulses within 60 μs.

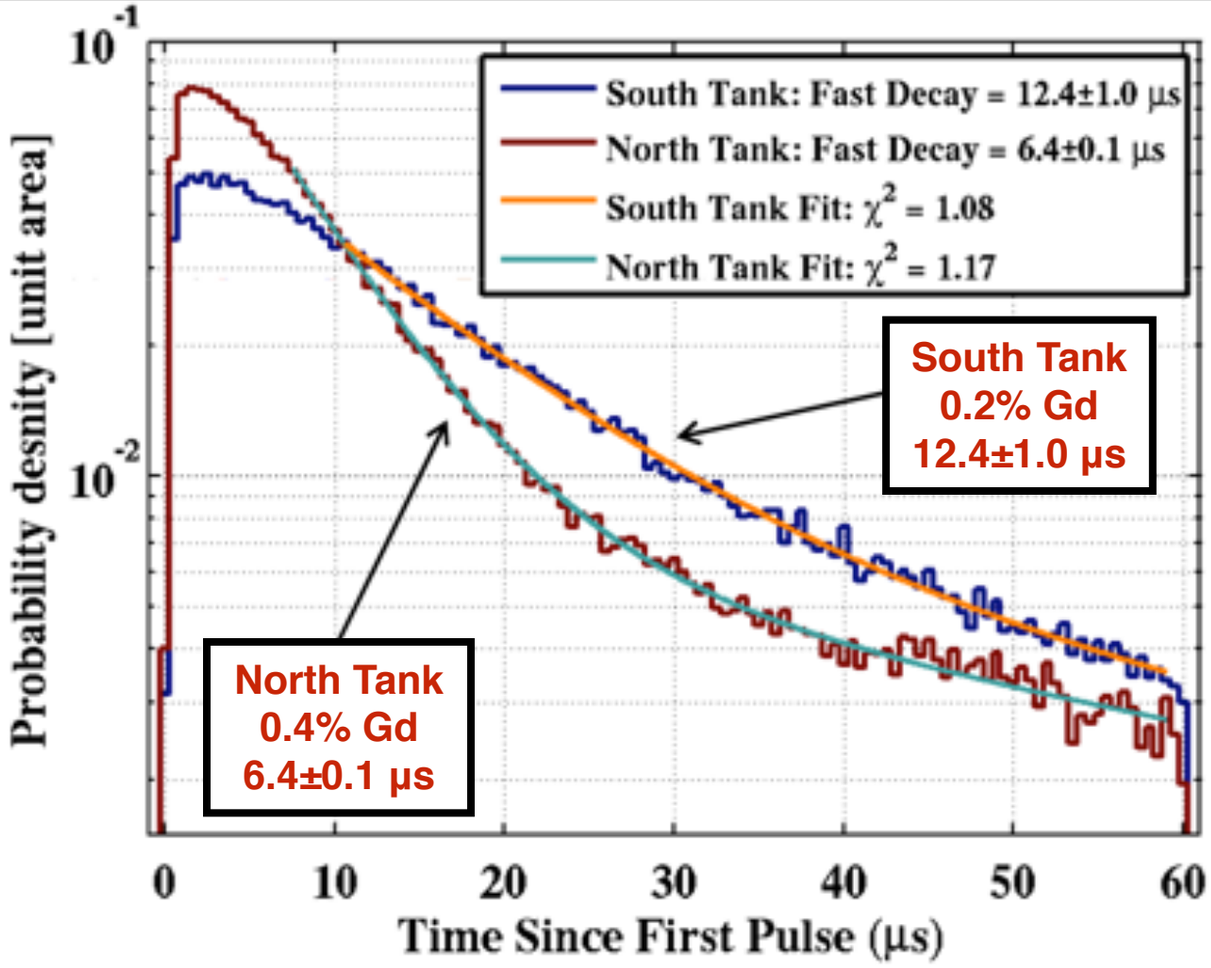


Gamma Background

- Relatively small coincident pulse heights
- Truly random timing
- Usually spread between tanks



Gamma Background Rejection

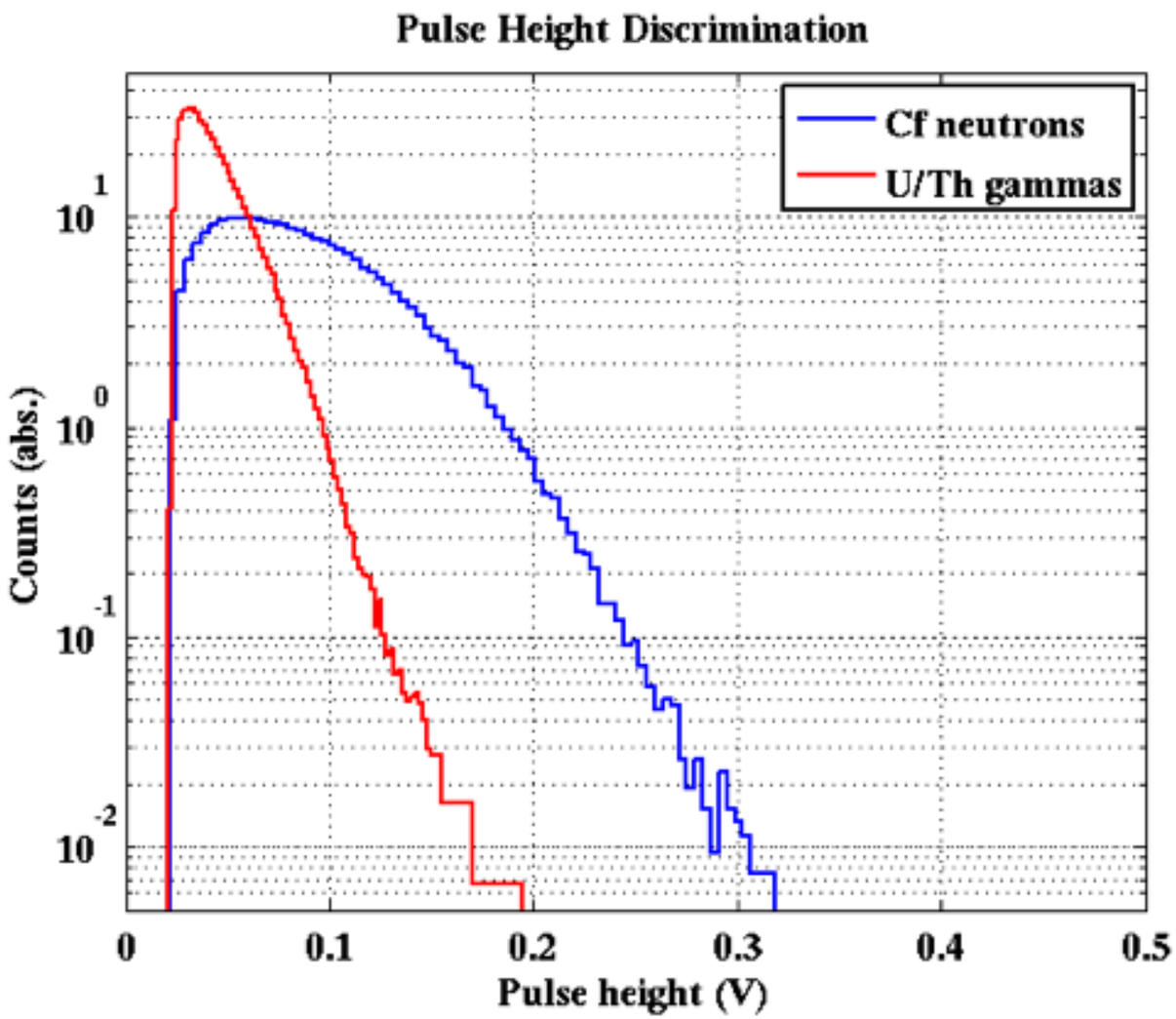


Discrimination based on pulse timing

- **U/Th gammas ~ 1 per 2 ms**
- **neutron captures cluster in characteristic time**
- **Mostly achieved by the event trigger which requires 5 coincident pulses in 60 μs**

Discrimination based on pulse height

- **Use neutron pulse-height likelihood**



Pulse-height Discrimination

- Pulse height PDFs for neutron and photon, $P_n(A)$, $P_g(A)$

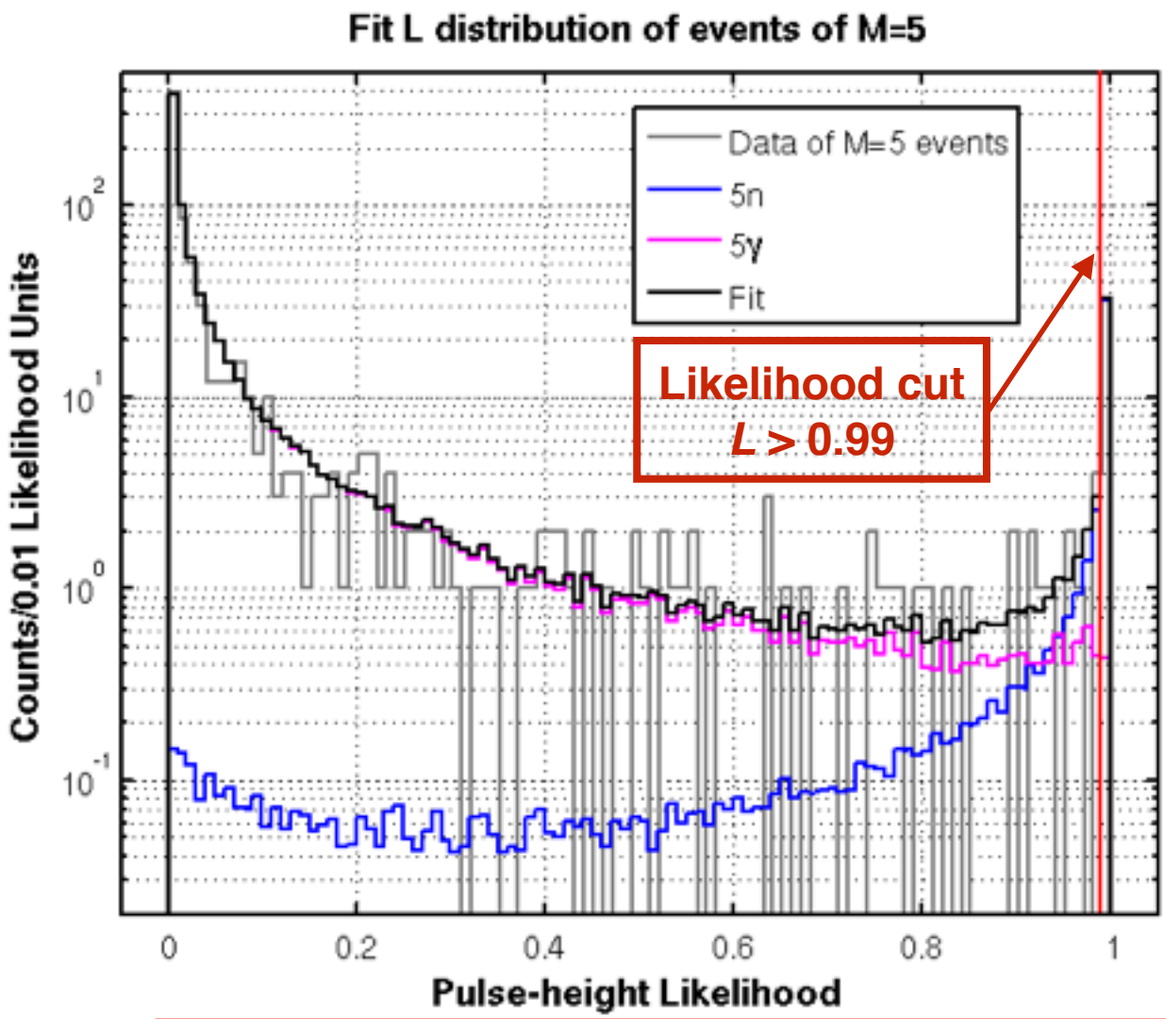
- Likelihood for all-neutron and all-gamma events,

$$n \equiv \prod_i P_n(A_i),$$

$$g \equiv \prod_i P_g(A_i).$$

- Define a pulse-height likelihood function

$$L \equiv \frac{n}{n+g}.$$



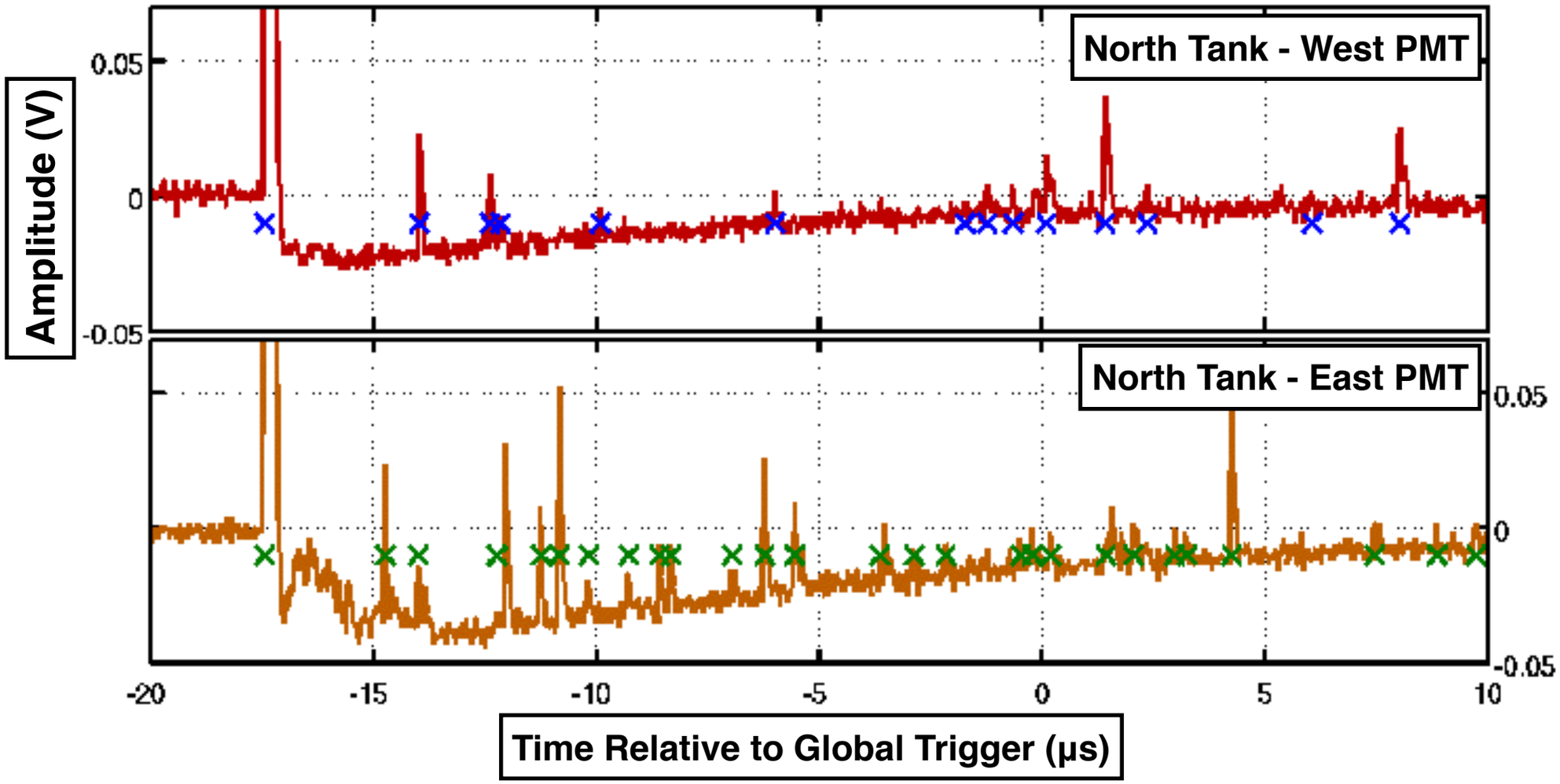
Multiplicity-5 events from ~6 month data.

- Signal and background components from MCs based on individual neutron and gamma pulse-height PDFs from calibration data
- $\chi^2 = 82.8/94$;
- Indicating the efficiency ~ 68% and the expected background leakage ~ 0.4 events for a cut at L > 0.99

Muon Background

Large dE/dx events (> 80% of all recorded events)

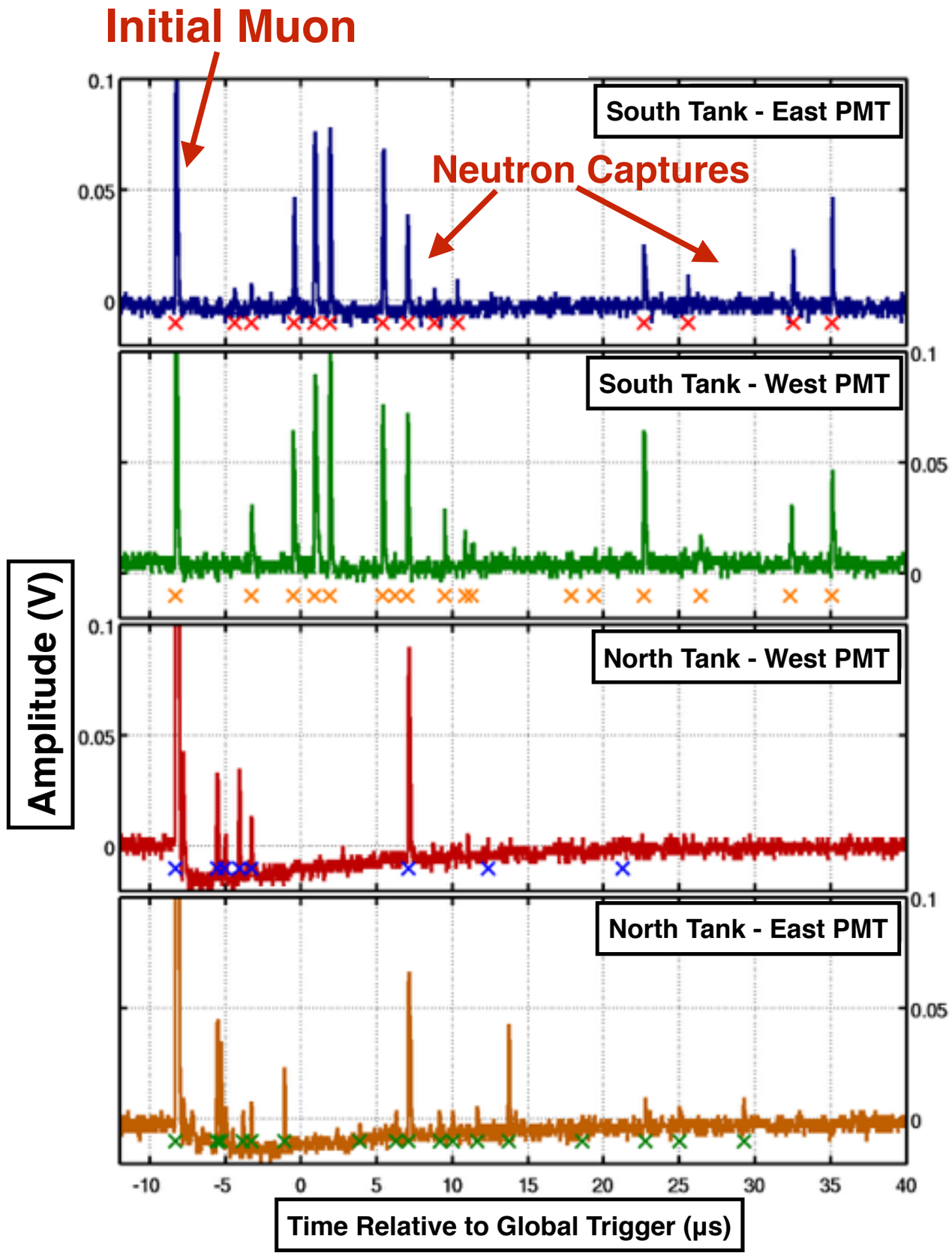
- Large initial pulse (from muon passing through tank) with after pulsing
- Large individual channel multiplicities, with some coincidences
- We currently remove muons by cutting events with any coincident pulse > 300 mV



Muon Background

Clipping muons

- May or may not be accompanied by a large pulse
- Some will initiate hadronic showers in Pb and in water
- Low rate of a true indistinguishable background



Full muon simulation

- Geant4-9.5 based package with Shielding physics list, and fully modeled detector in the Soudan cavern with 4 m Rock surrounded.

- Propagate 3.382 x 10^7 muons (~217.36 live days) in the rock at 4 m above the cavern ceiling, sampled from the production of MC via MUSIC/MUSUN (Courtesy Angie Reisetter).

- This MC incorporates:

  - production of H.E. neutrons and hadronic showers

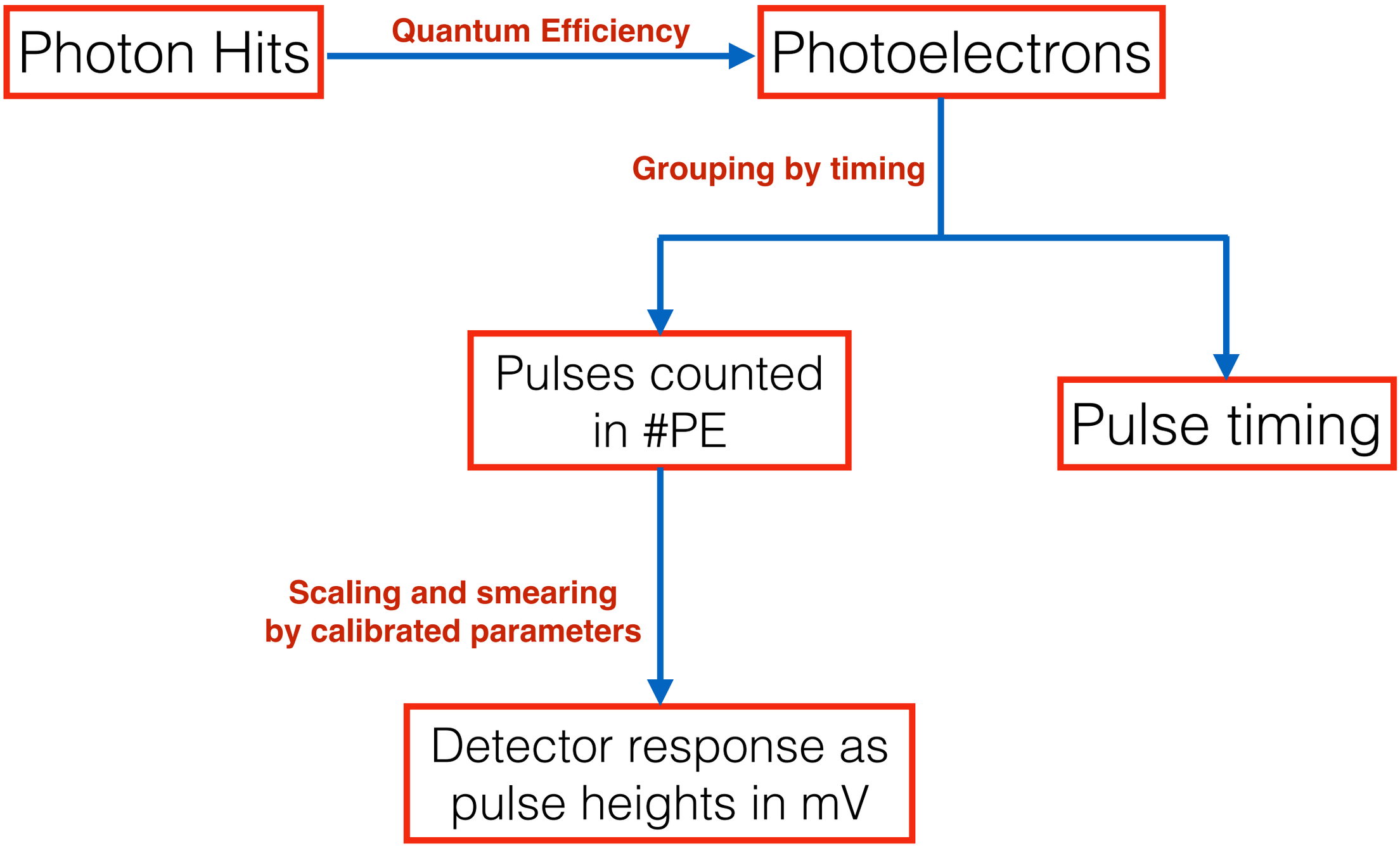
  - detector responses of H.E. neutrons, muon hits and secondary particles

Process and analysis of simulated data

Recorded Info:

- photon hits on PMT surfaces
- neutron captures
- particles crossing boundaries of water tanks, lead stack, and cavern

Process and analysis of simulated data: Pulse Generation



Process and analysis of simulated data: Event Classification

- **High-Energy Neutron Events:** all pulses are neutron captures
- **Contaminated Events:** both neutron captures & other pulses
  - with muon induced pulse (e.g. clipping muons)
  - without muon induced pulse

- Use simulation to understand the content of multiplicity in the data from the detector

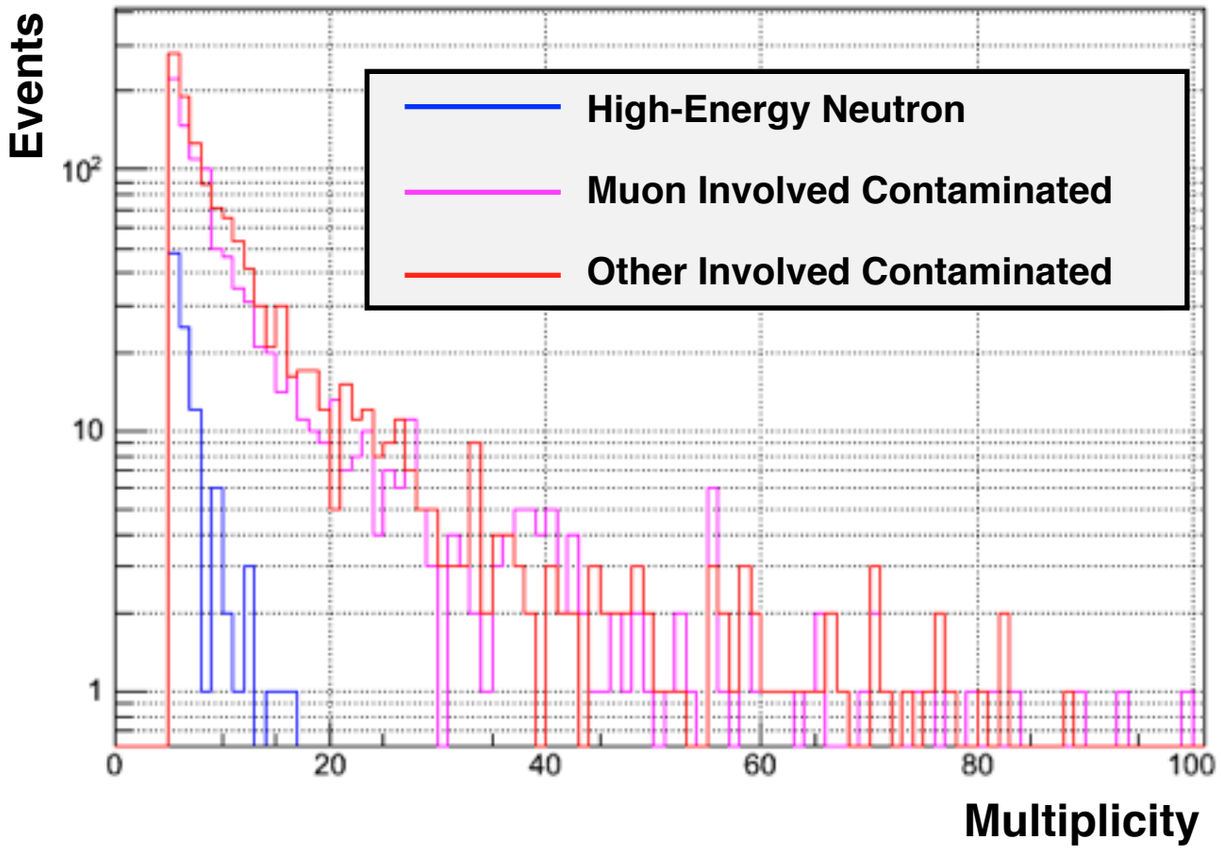
Process and analysis of simulated data: Event Selection Cuts

Use the same selection cuts as in real data analysis

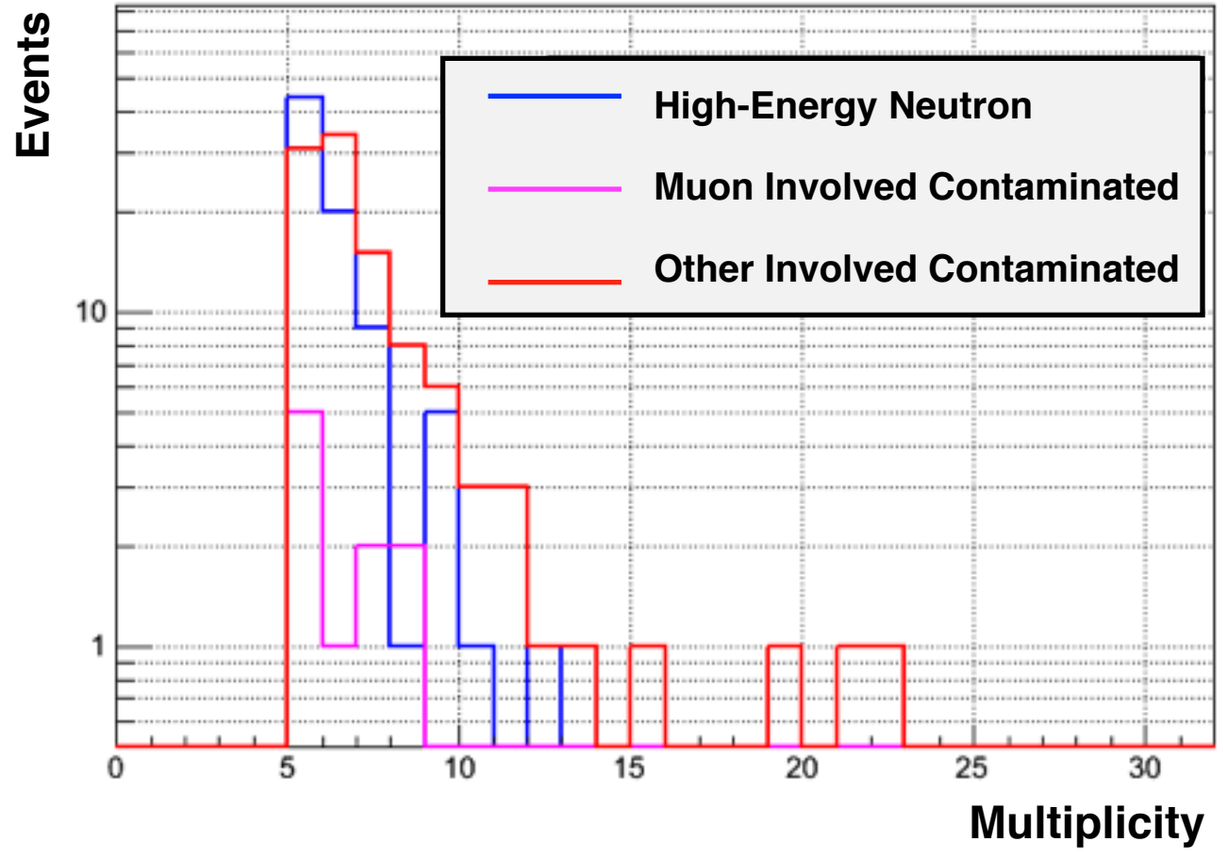
- Multiplicity >= 5 (Multiplicity 5 in 60 μs trigger in the real data being used for comparison)
- Muon rejection cut: pulse height < 300 mV
- Neutron pulse-height likelihood cut: L > 0.99
  - with efficiencies:
    - ~ 77% for H.E. neutron events
    - ~ 90% for muon involved contaminated events
    - ~ 82% for other particle involved contaminated events

Muon Rejection Cut

Before Muon Cut

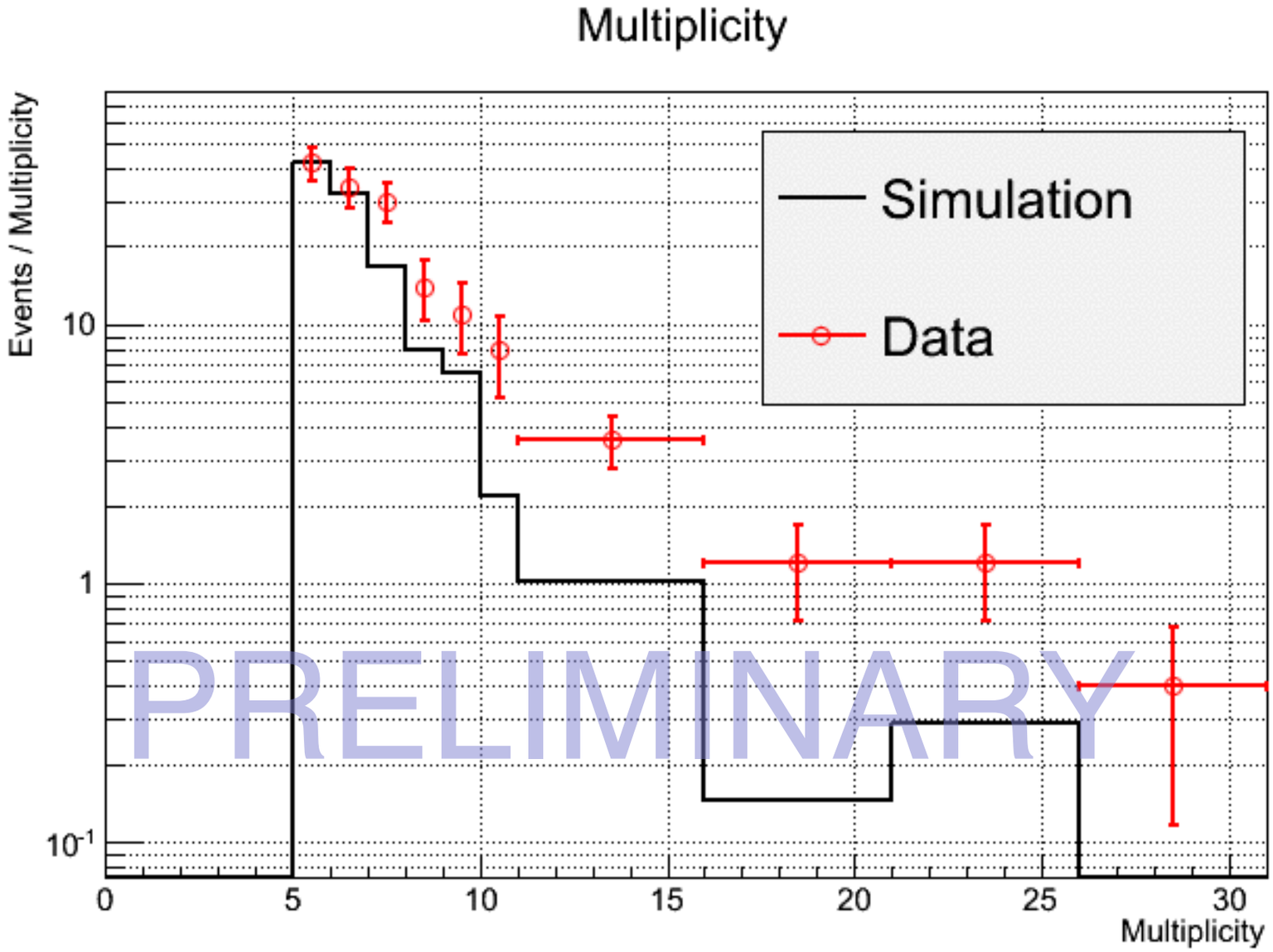


After Muon Cut



- Efficiencies or Leakage:
  - ~ 80% for H.E. neutron events
  - 1.0% for muon involved contaminated events
  - 8.5% for other particle involved contaminated events

Comparison with Real Data



- ~217.36 live days of simulation
- Normalized to158.23 days

- ~158.23 live days of high-energy neutron search data
- Trigger with multiplicity 5 in 60 μs

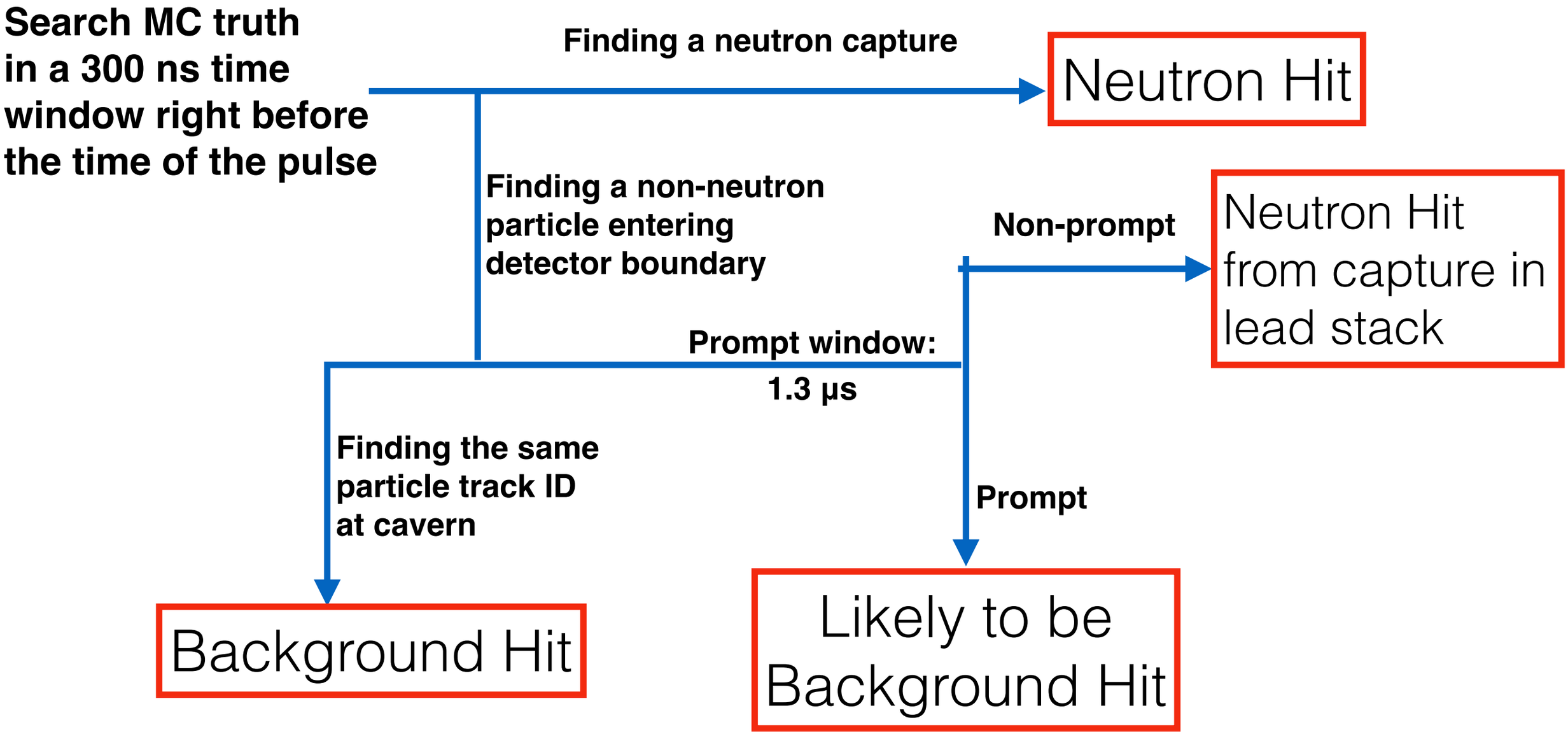
- **Good agreement for multiplicity 5-6**
- **Excess in data compared to MC for higher multiplicities**

Conclusions

- Very recent result shows excess in measured neutron flux over MC for high neutron multiplicities.
- Suggests neutron spectrum is harder than predicted by MC
- Or, muon rejection cut removes more events in MC than in data.
  - More careful checks to take.
- More and better data will clarify this discrepancy.
- ~ 158 live days of NMM-only data analyzed in this work, out of ~630 live days collected in total
- ~ 1 year (and ongoing) of data taken with the NMM correlated with Soudan all-cavern veto (See Anthony Villano's poster).

Backup Slides

Process and analysis of simulated data: Pulse Tagging/Classification

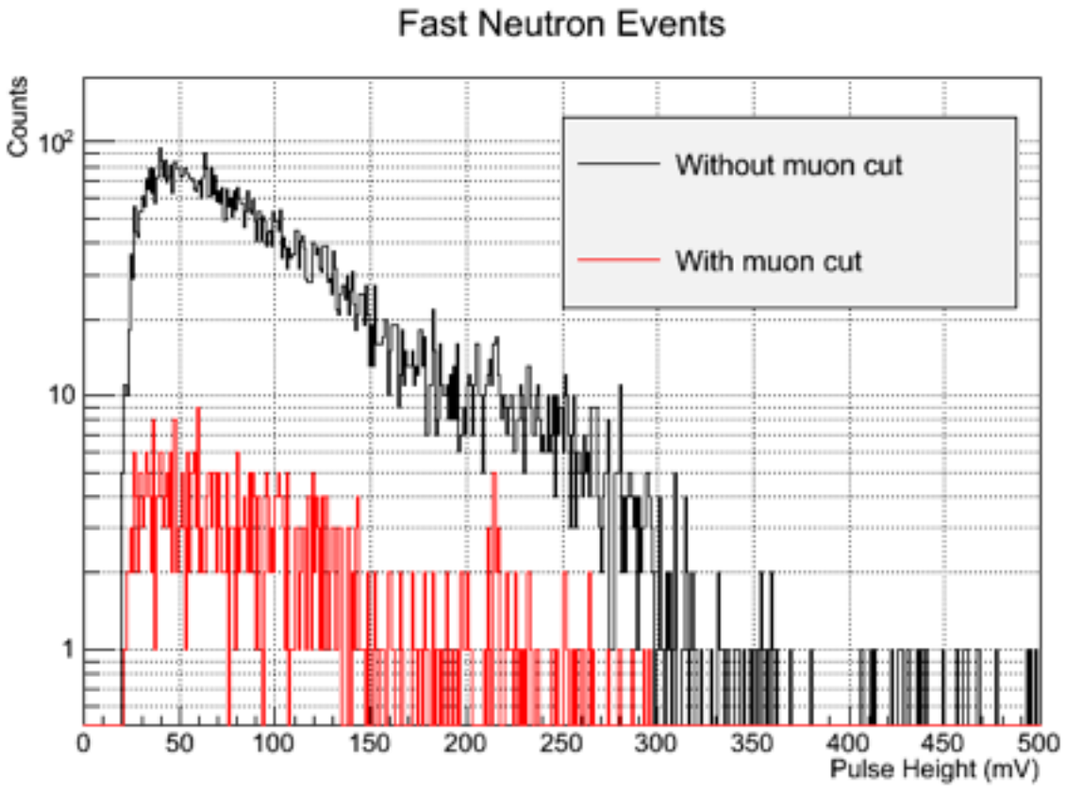


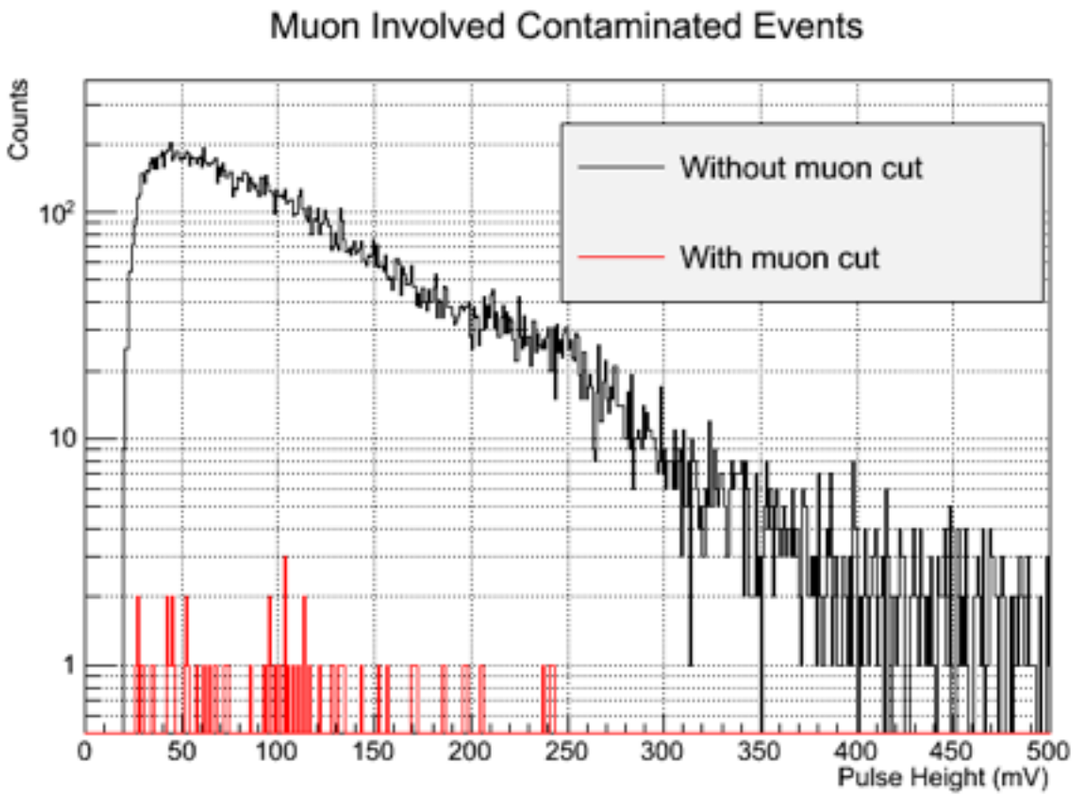
Stats of muon simulation

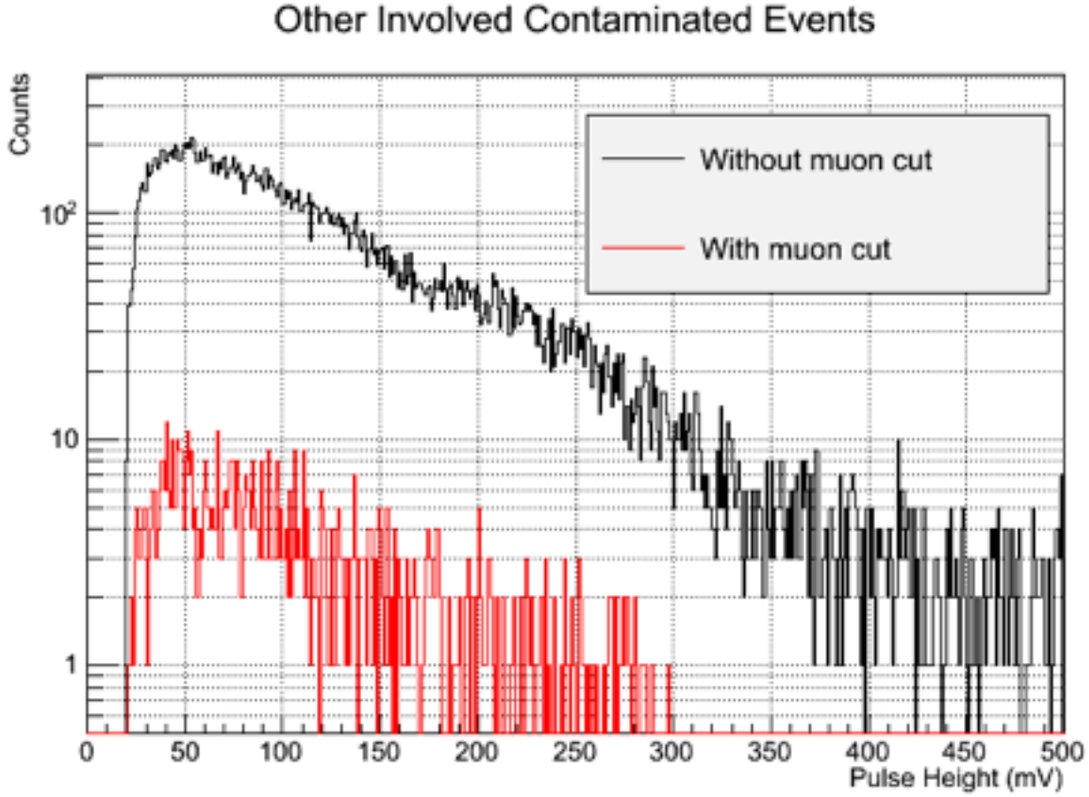
	All detected	N >= 5	Muon rej. cut PH < 300 mV	L > 0.99
H.E. Neutron Events	6204	101	81	62
Muon Involved Contaminated Events	7755	1013	10	9
Other Involved Contaminated Events	6341	1251	106	87
Muon Involved Backgrounds	123730	0	0	0
Other Involved Backgrounds	76353	0	0	0
Total	220383	2365	197	158

Muon Rejection Cut

- Efficiencies or Leakage:
  - ~ 80% for H.E. neutron events
  - 1.0% for muon involved contaminated events
  - 8.5% for other particle involved contaminated events







Likelihood distribution