Designing and executing a cosmic ray experiment

Phys150 Special topics

David Stuart, UC Santa Barbara

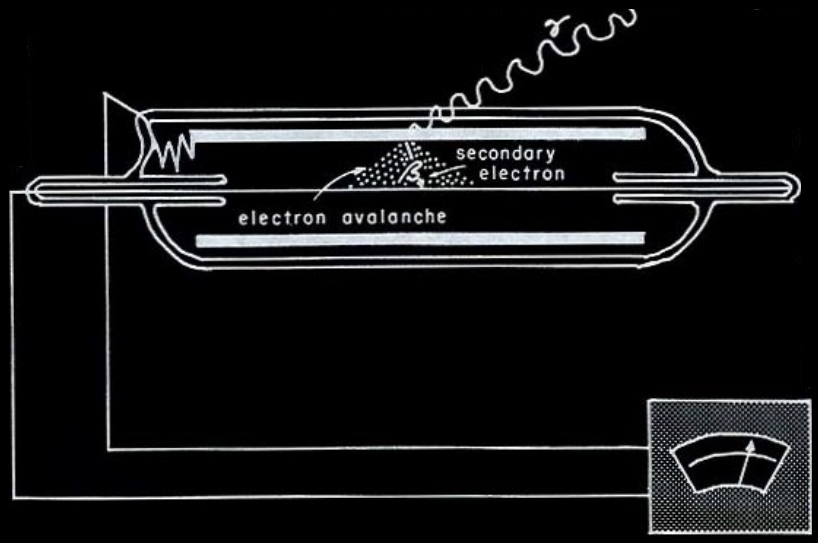
Review

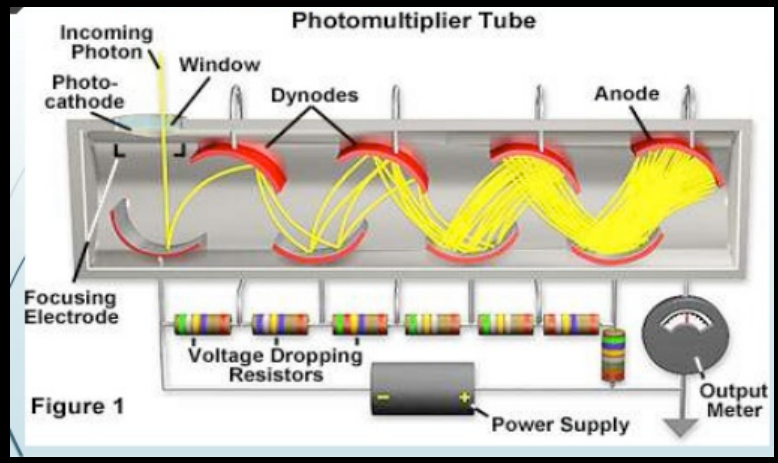
Discussed radiation detection:

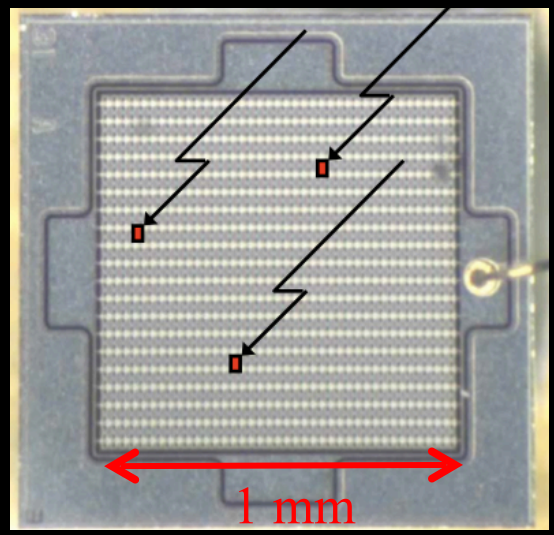
Energy deposited into ionizing and/or exciting atoms

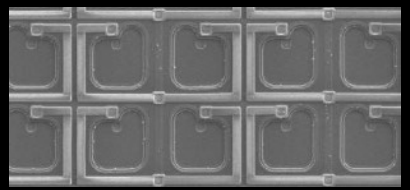
Amplify a small number of released electrons into a detectable current pulse

- Geiger counter does this with electron drift through a gas in high electric field, with impact ionization causing an avalanche of electrons.
- Photomultiplier (PMT) converts photon to electron then drifts through high electric field in vacuum, and avalanche of electrons at a series of dynodes.
- Silicon photomultiplier (SiPM) does this with e-h pair creation and drift of electron through silicon crystal with avalanche from impact ionization.







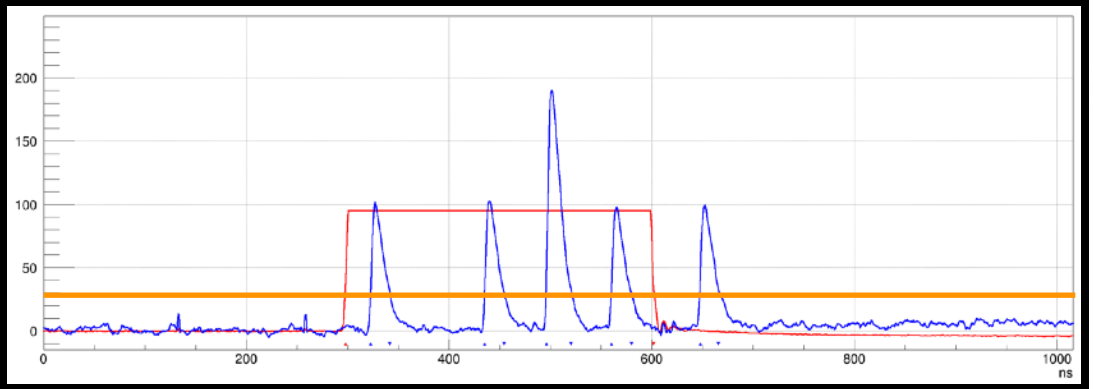


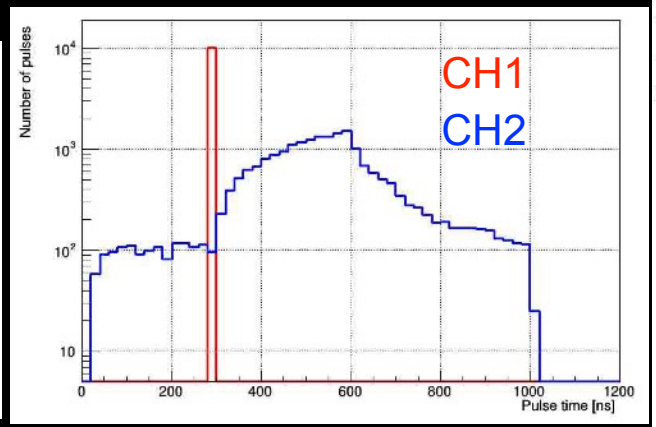
Review

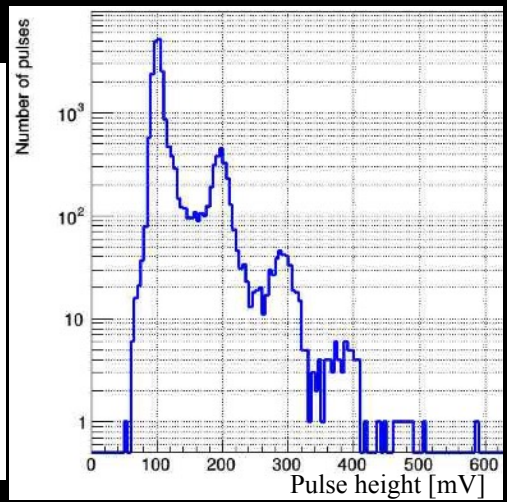
Played with photon detection with a SiPM using an LED

- A quick look on the scope showed most of the effects
- A more detailed look came from recording and analyzing data
- Recorded waveforms, processed with pulse finding, recorded distilled pulse data.

  [event, tEvt, dtEvt, …, channel, pulseNum, pulseTime, pulseHeight, pulseArea, pulseWidth]
- Plotting observables from nTuple allows measurement and hypothesis testing.







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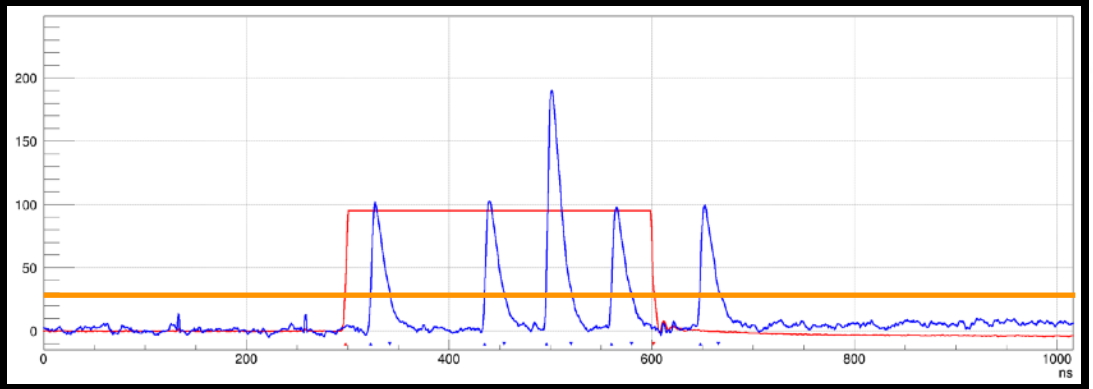
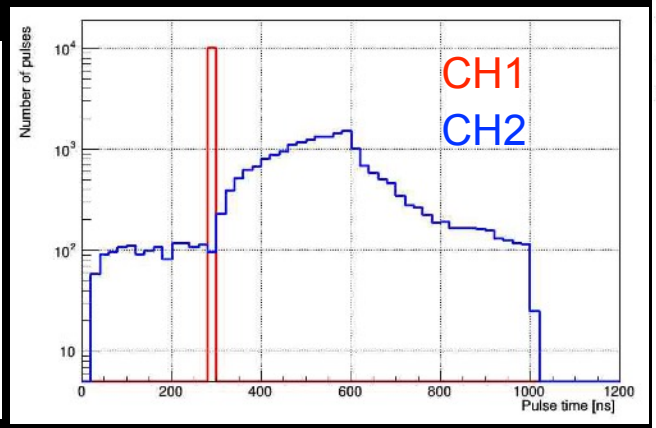
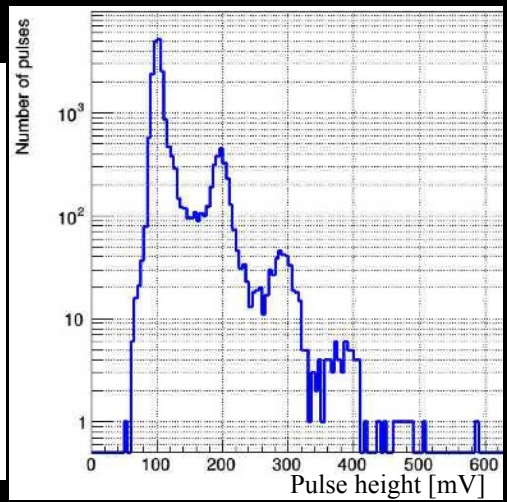
- We could study this data quite a bit more, both in depth and breadth, eg:
  - Scaling of pulse height not exactly linear?
  - Is the pulse height distribution different for the "ambient photons" vs the LED photons?
  - Does the pulse time distribution decay back to the same value as ambient photons?
  - Is there anything interesting in the time difference between photons?







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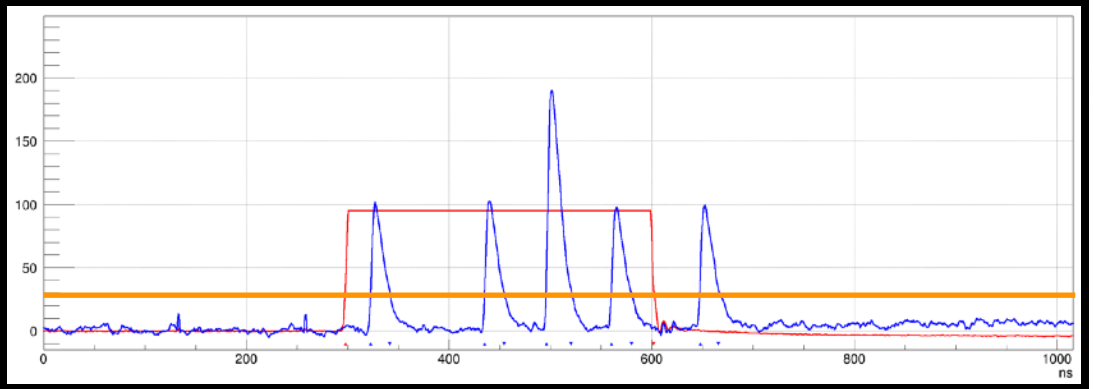
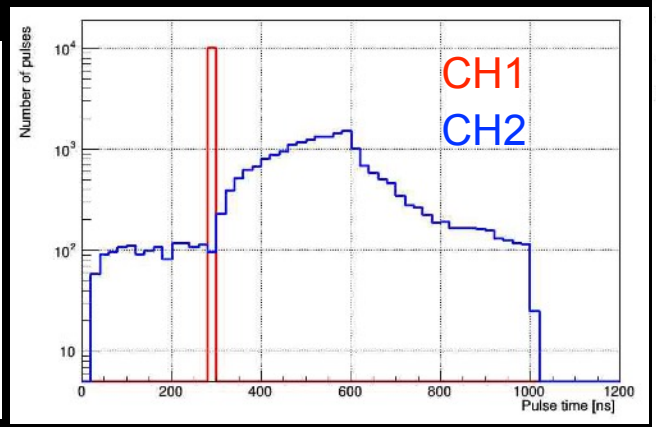
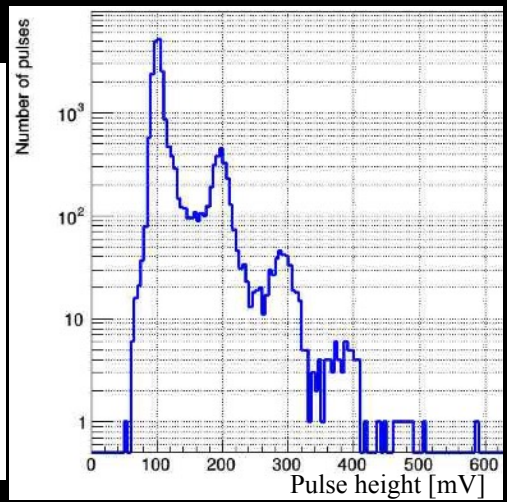
Select nTuple elements

Correlation between nTuple elements

Collect different data (see here)







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Even if we understood all the biases, we would want to do (1) as a *calibration* of the instrument we use for (2). In fact, we would want to do it repeatedly.

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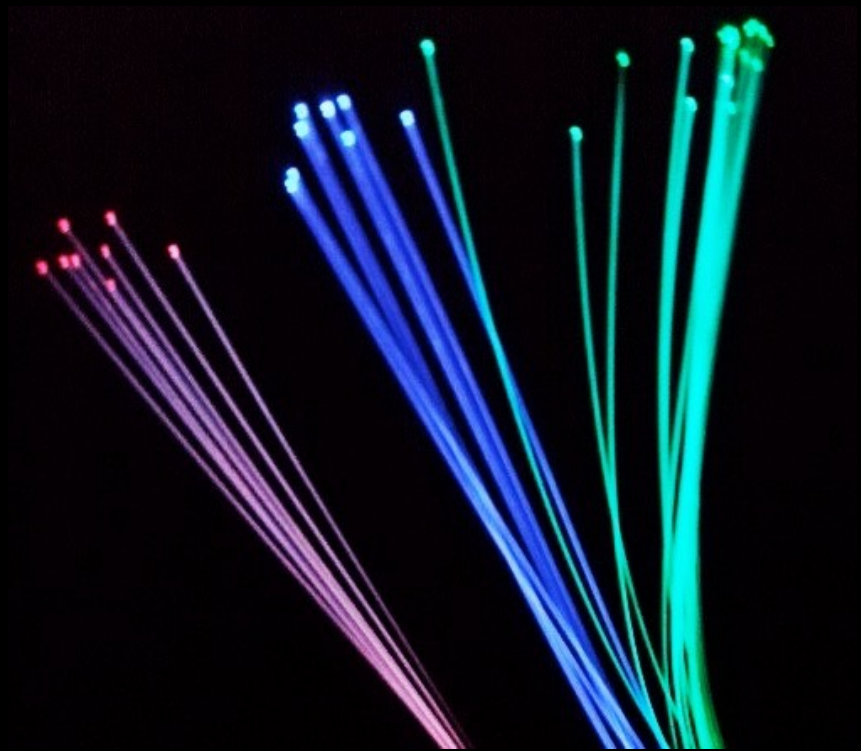
We'll proceed on to (2) but bring *validation* and *calibration* in as we go.

Detecting radiation with light

With the ability to detect single photons, we should be able to detect radiation based on photons emitted during atomic de-excitation after ionization.
This is called “scintillation light”.
It can be optimized by choosing a detector material with complex organic molecules that have many energy states to produce near-UV photons as they de-excite.

Several companies make these,
mostly for medical imaging and
for the oil exploration market.



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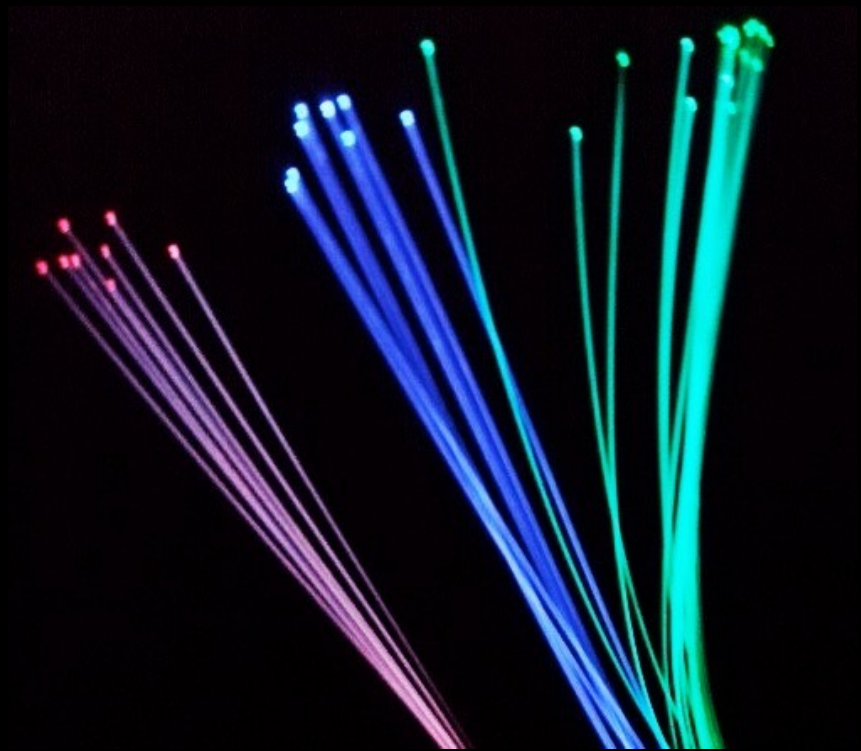
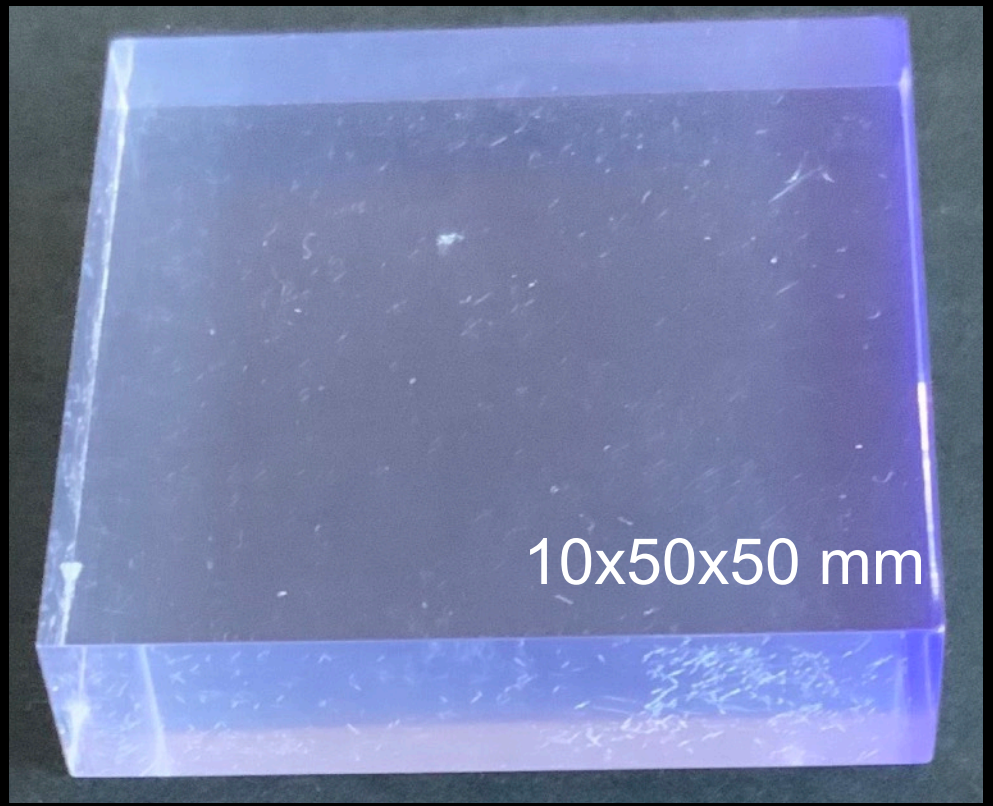
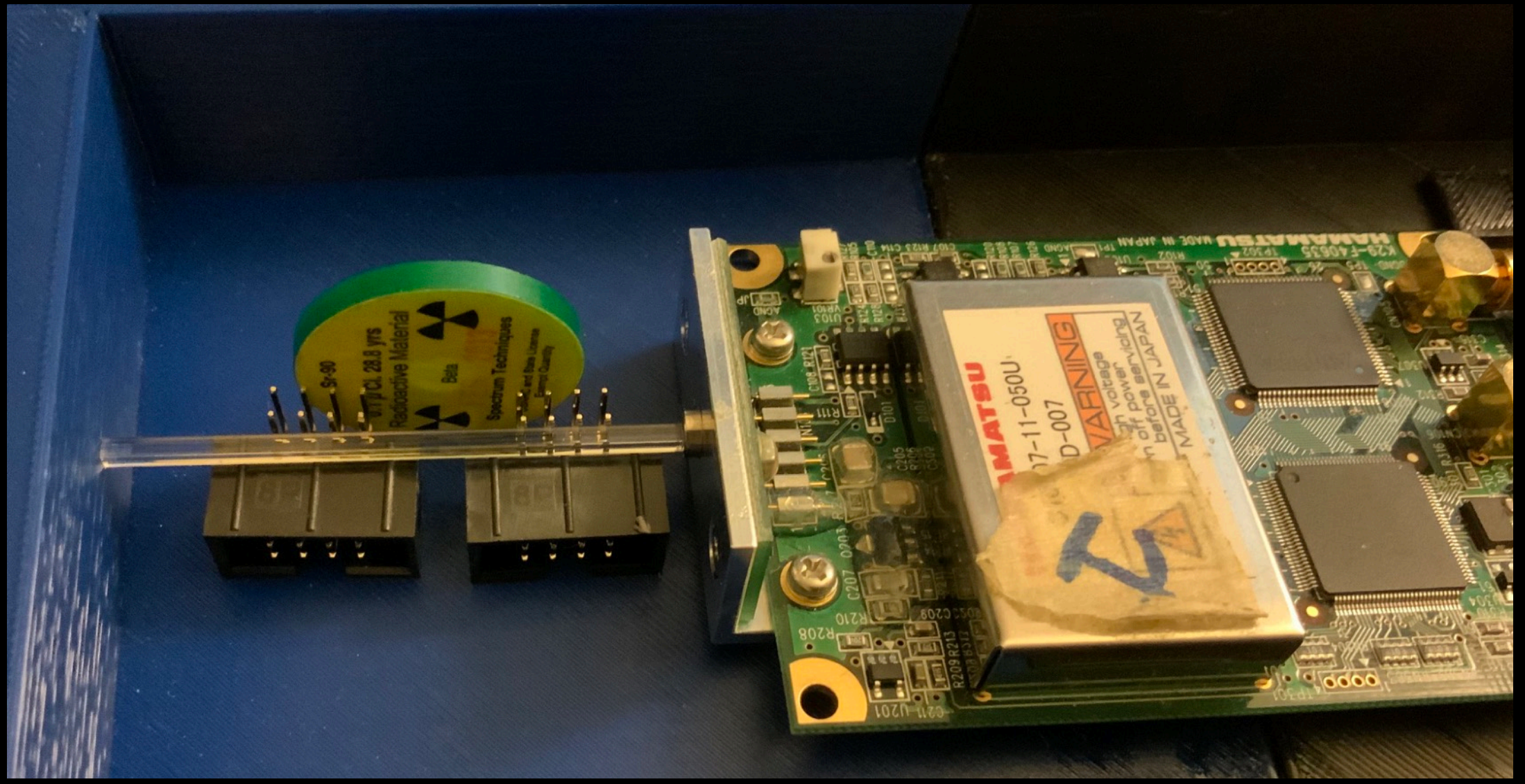




Detecting radiation with light

Let’s try to measure scintillation photons from a beta source on this little scintillator bar, placed in the “dark box”.



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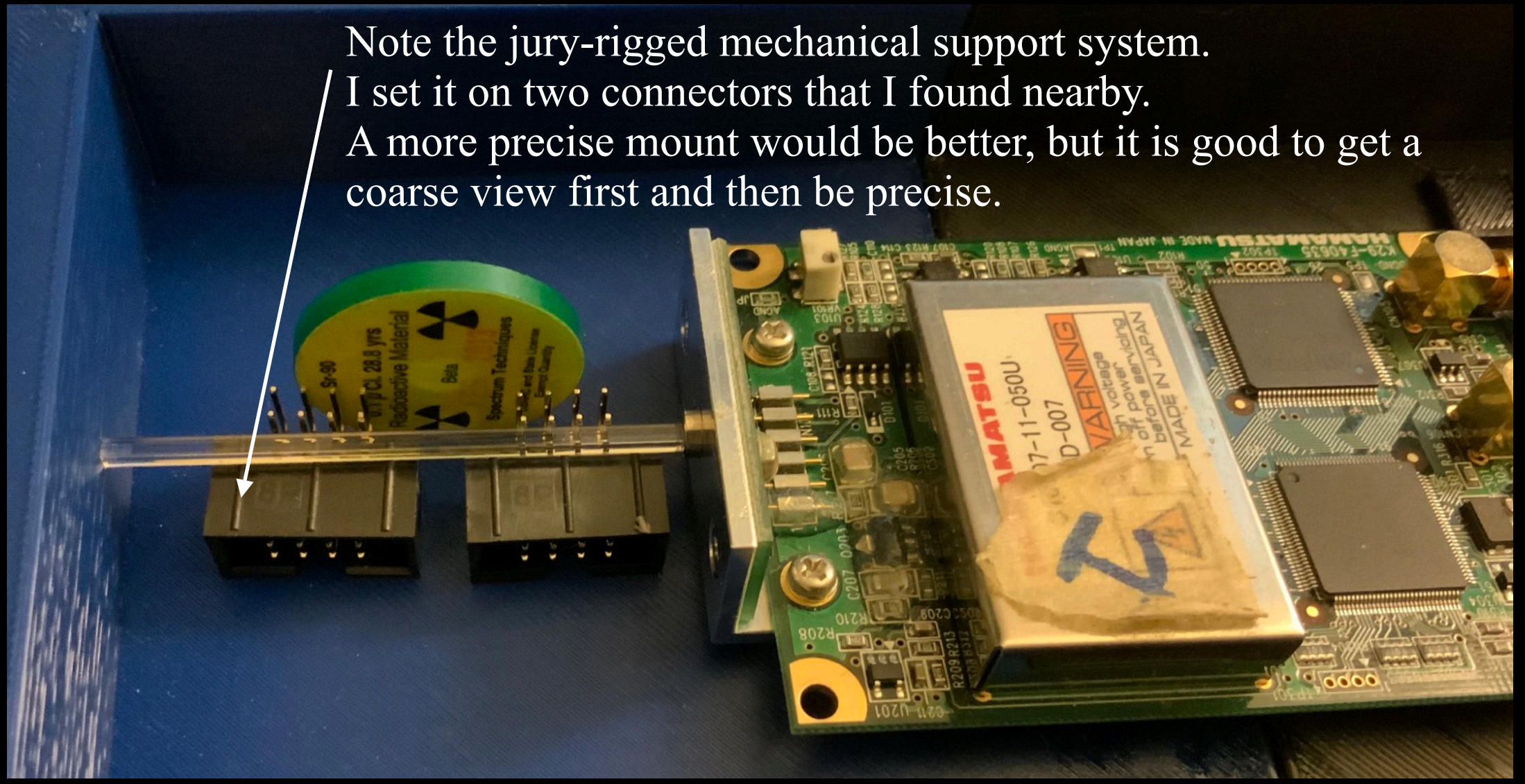

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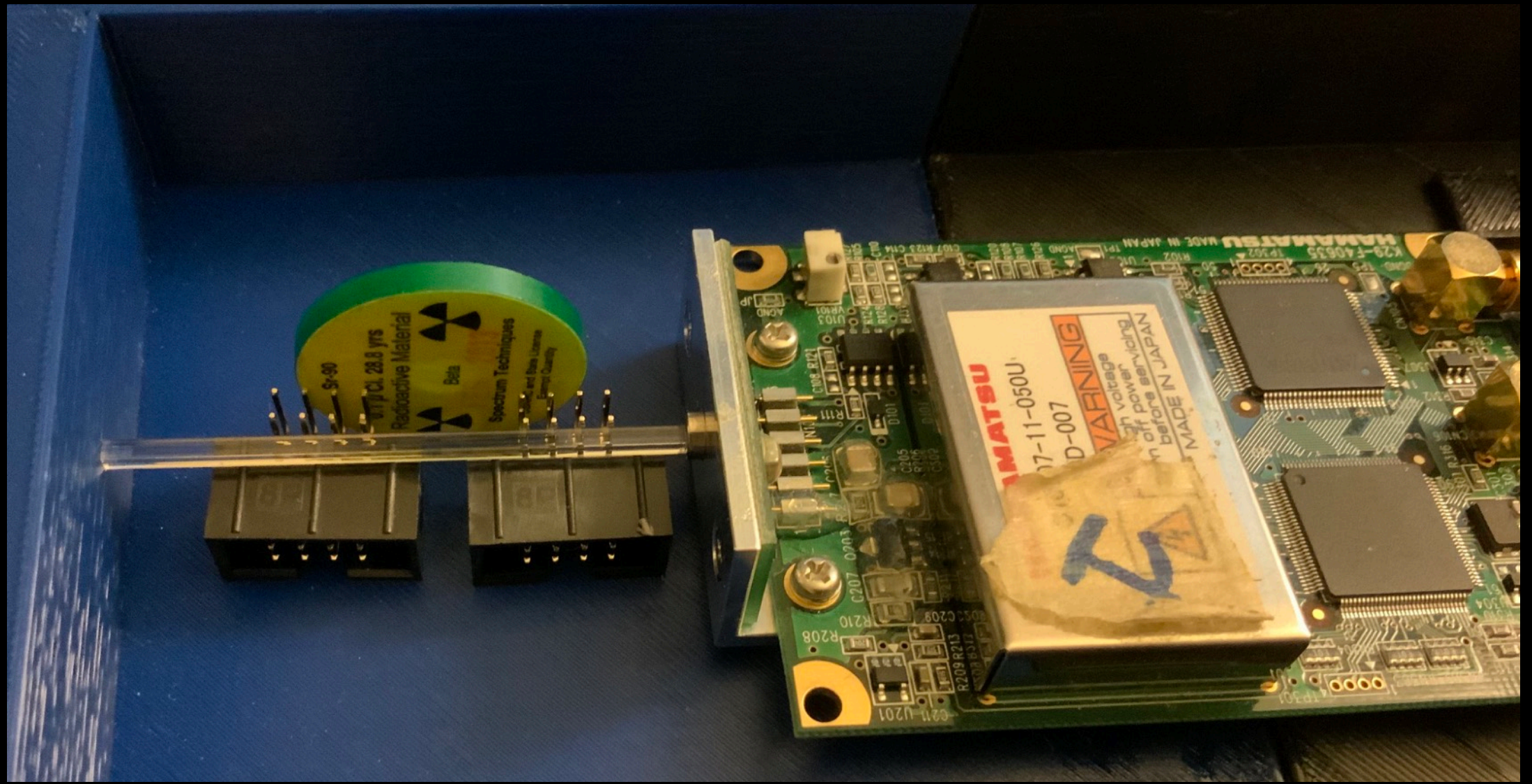
With the LED test, we used the LED driving pulse to know *when* to look for photons.
We need a *trigger* for our measurement.



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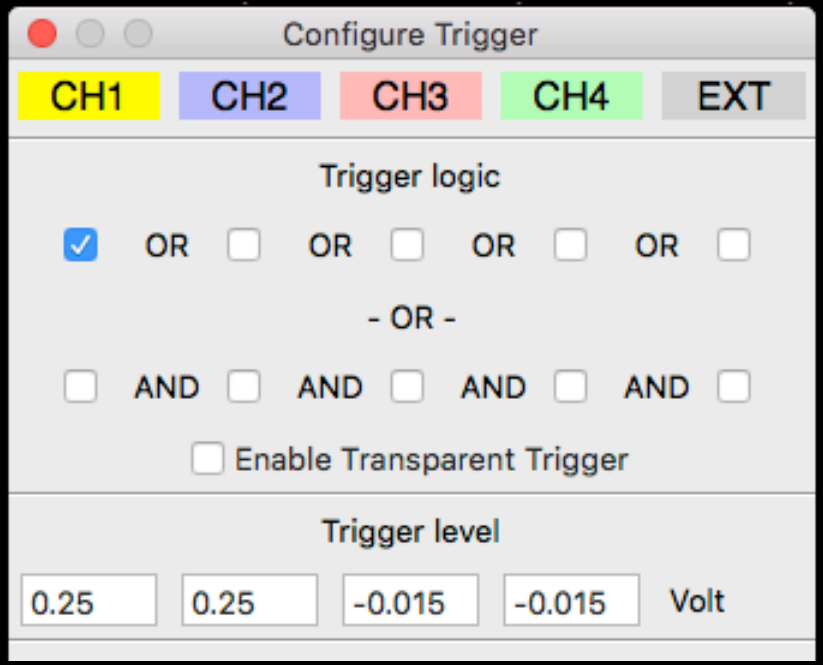

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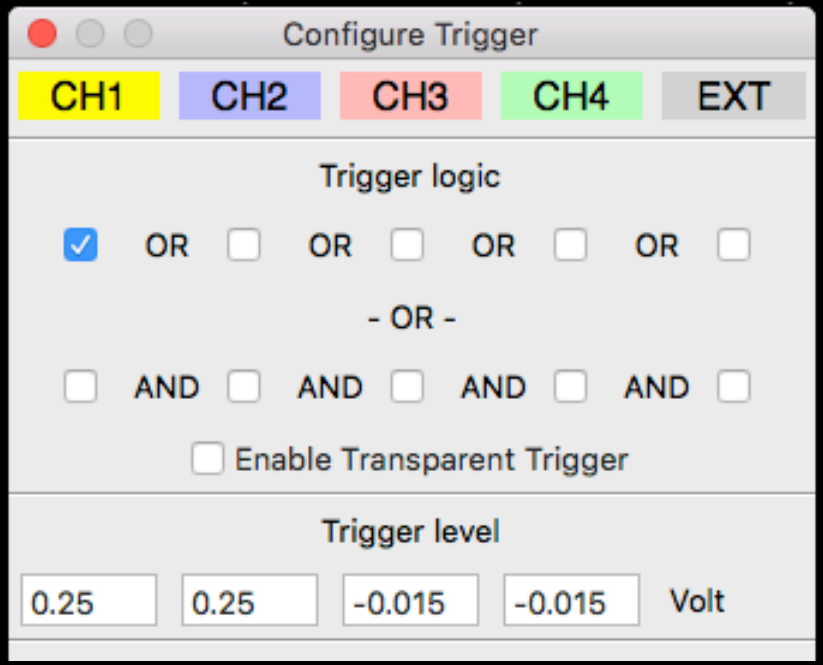
So let's collect data with this setup. But there is a problem…
With the LED test, we used the LED driving pulse to know *when* to look for photons.
We need a *trigger* for our measurement, ie record which time window.
This is the same idea as triggering an oscilloscope.
We can self-trigger, ie record a waveform whenever the signal is above some value.
Triggering at ≥ 1 photon?
    That would trigger so often that we would only be "live" for a small time.
Triggering at ≥ 10 photons?
    That would bias the sample, like polling selects people who talk to random callers.

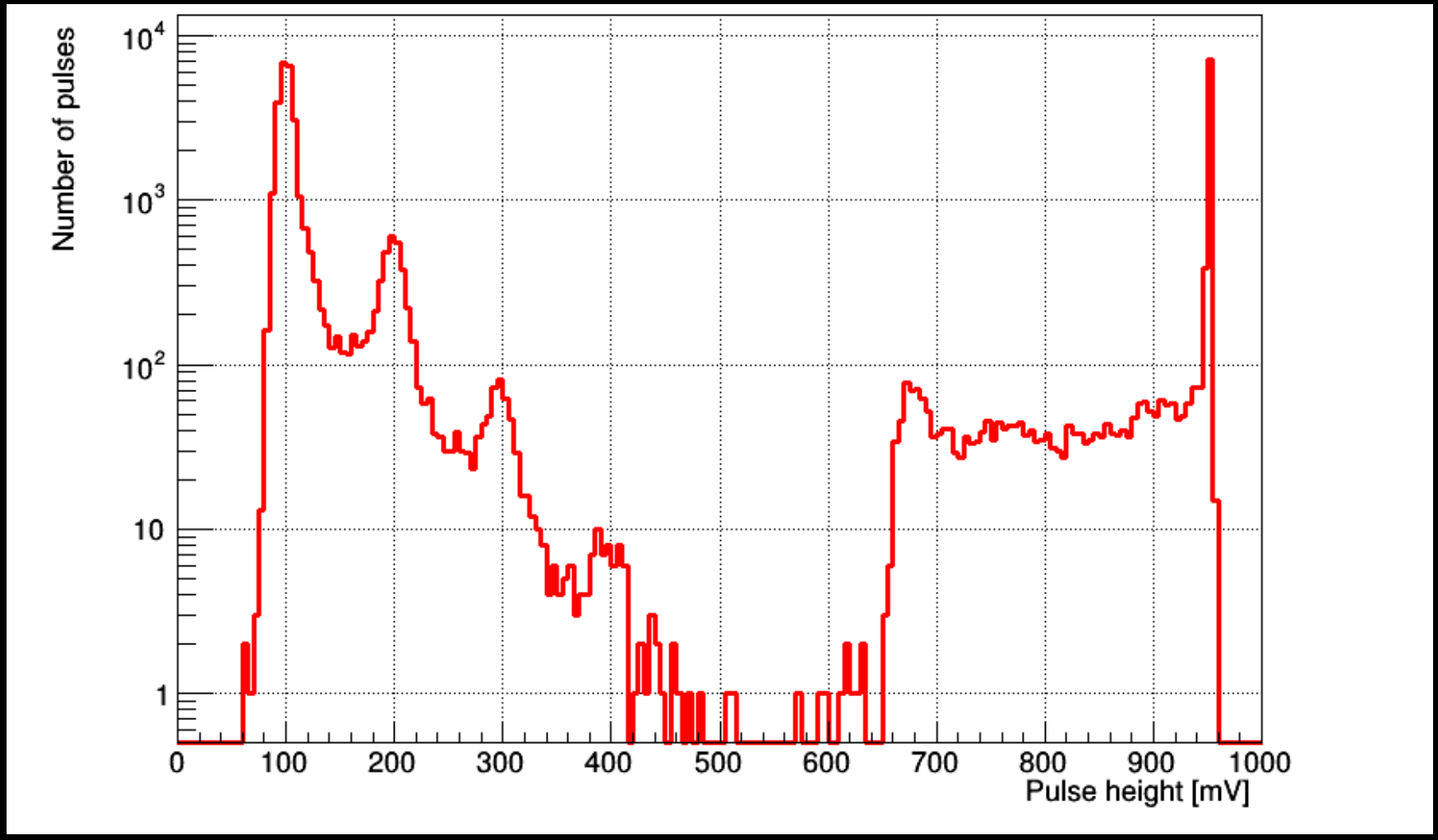


Detecting radiation with light

We can think about dealing with the bias later, let's first just get a coarse look.
Trigger at $\geq$ 650 mV, which is how many photons?
What do you expect the pulse height distribution to look like?

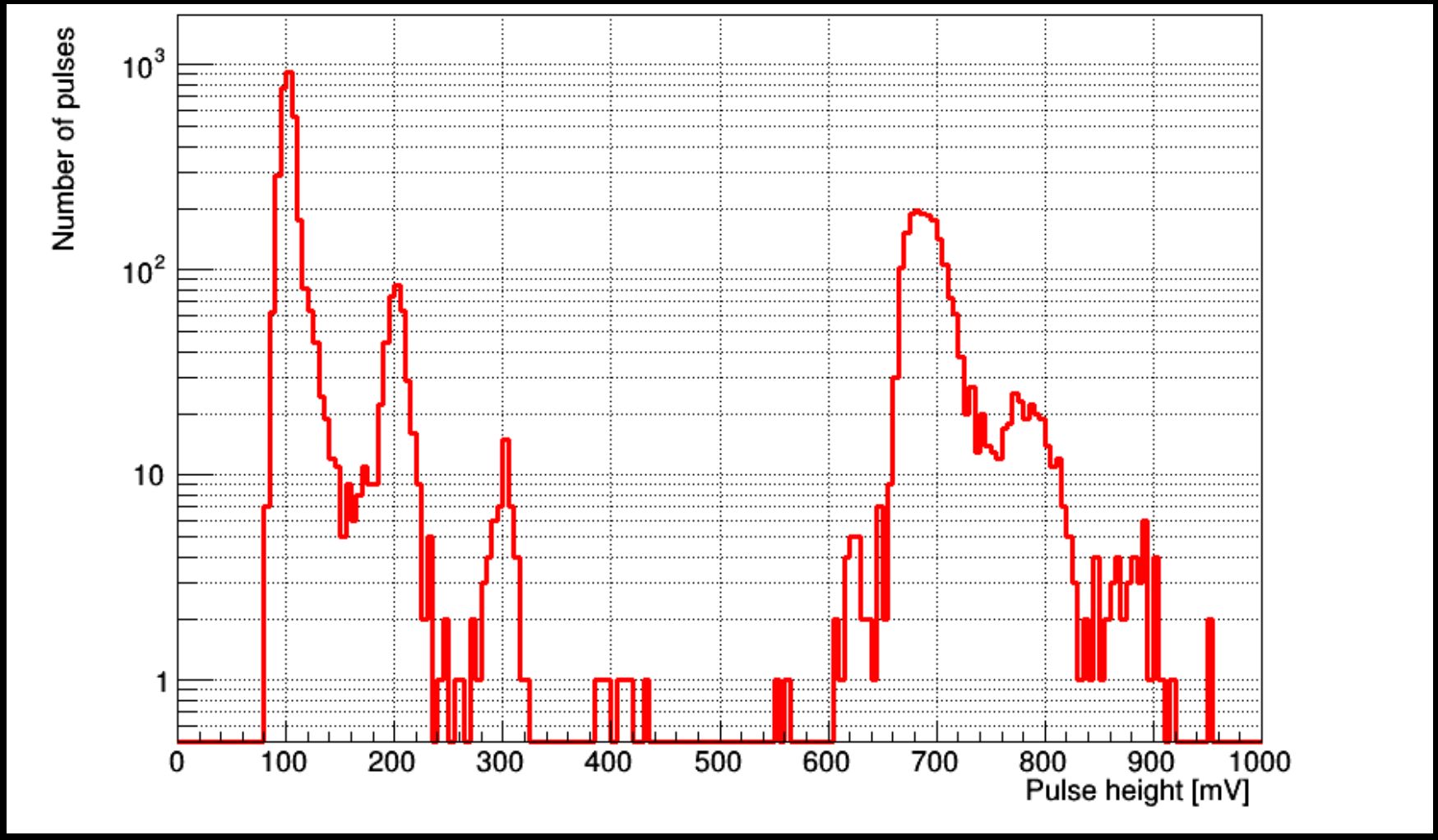
Detecting radiation with light

We can think about dealing with the bias later, let's first just get a coarse look.
Trigger at ≥ 650 mV, which is ~ 7 photons
Note trigger bias and digitizer's input saturation.
Origin of pulses below trigger threshold?
Are all the large pulses just due to trigger bias?



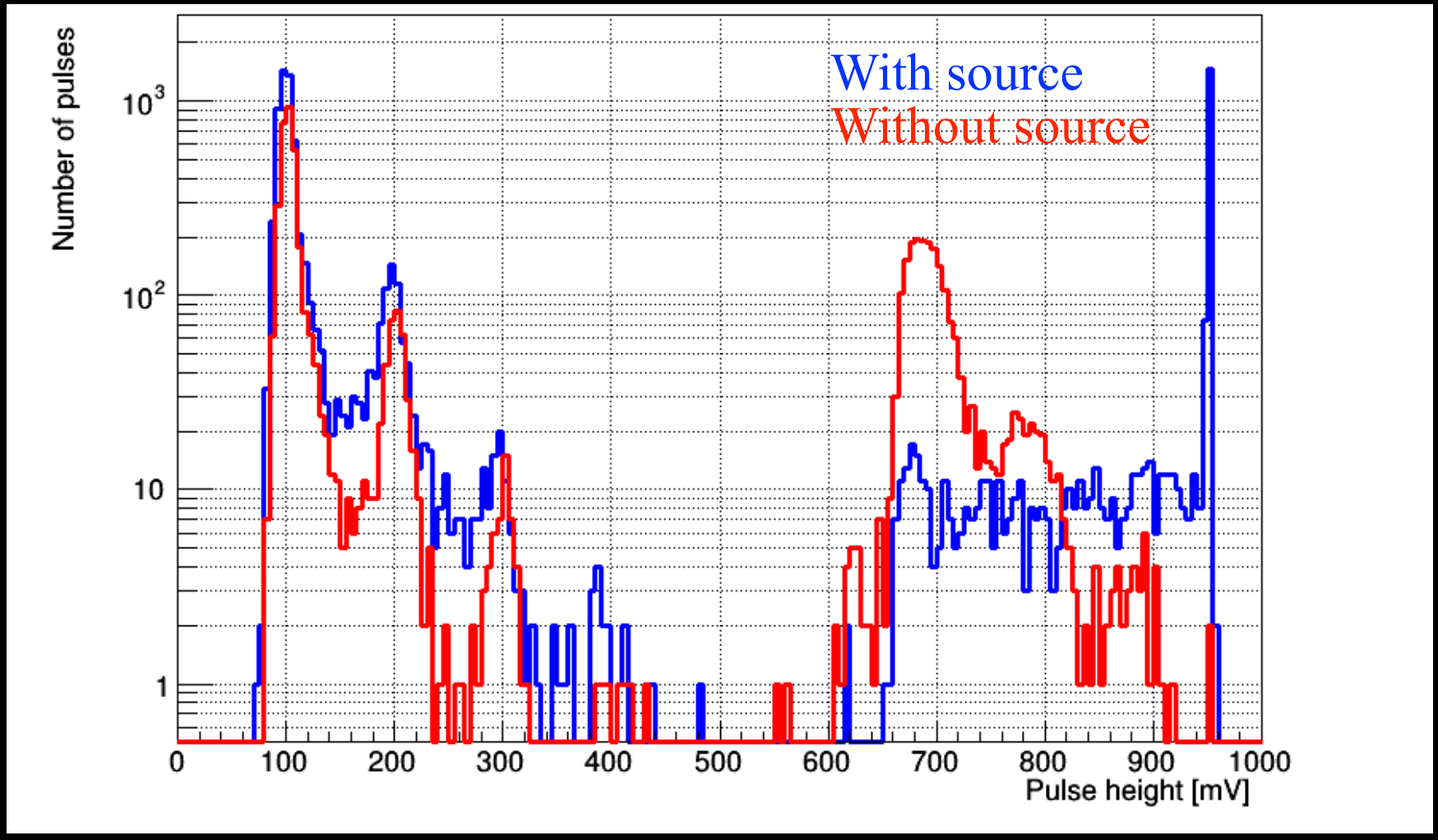
Detecting radiation with light

We can think about dealing with the bias later, let's first just get a coarse look.
Trigger at ≥ 650 mV, which is ~ 7 photons
Compare to data with no source.
See fewer big pulses, though this run is shorter, 2061 events vs 10,000 events.



Detecting radiation with light

We can think about dealing with the bias later, let's first just get a coarse look.
Trigger at ≥ 650 mV, which is ~ 7 photons
Compare to data with no source, *using the same number of events*.
See more large pulses with the source present, but also more small pulses.
And the shape at the trigger changes.
Ideas for why?

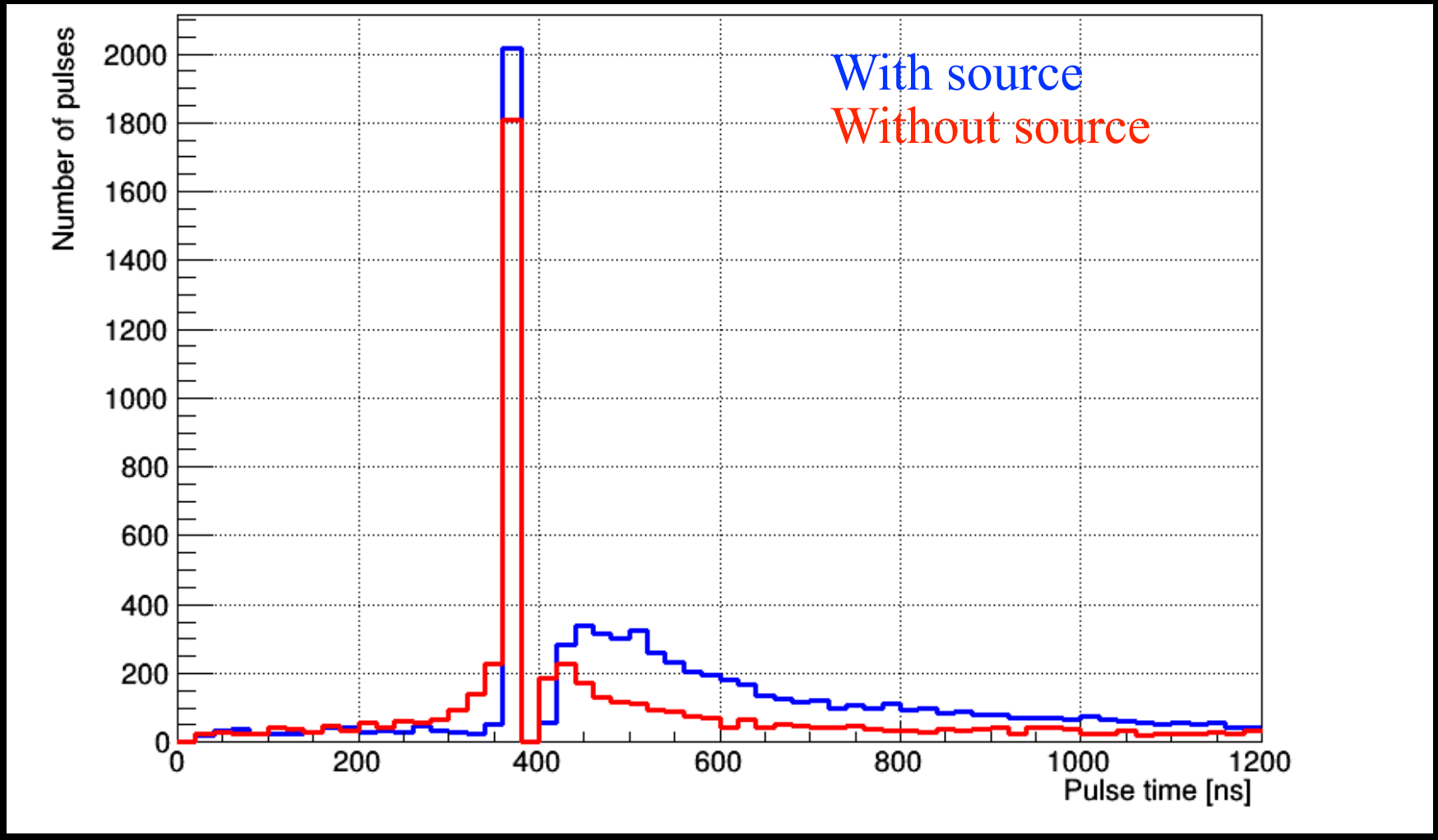


Detecting radiation with light

We can also learn from the distribution of the time of the pulse…

Detecting radiation with light

Big spike at 380 ns. Why?
Excess blue after main pulse. Why?
Distributions are the same before 200 ns. Why?



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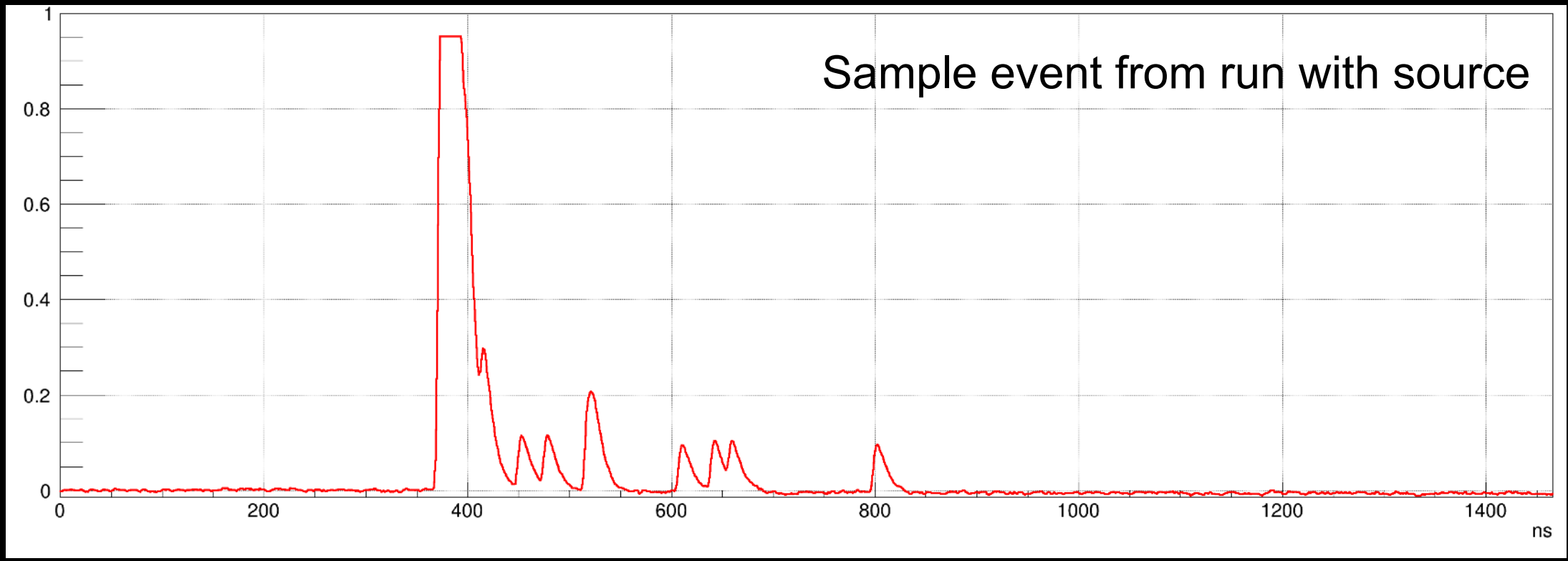

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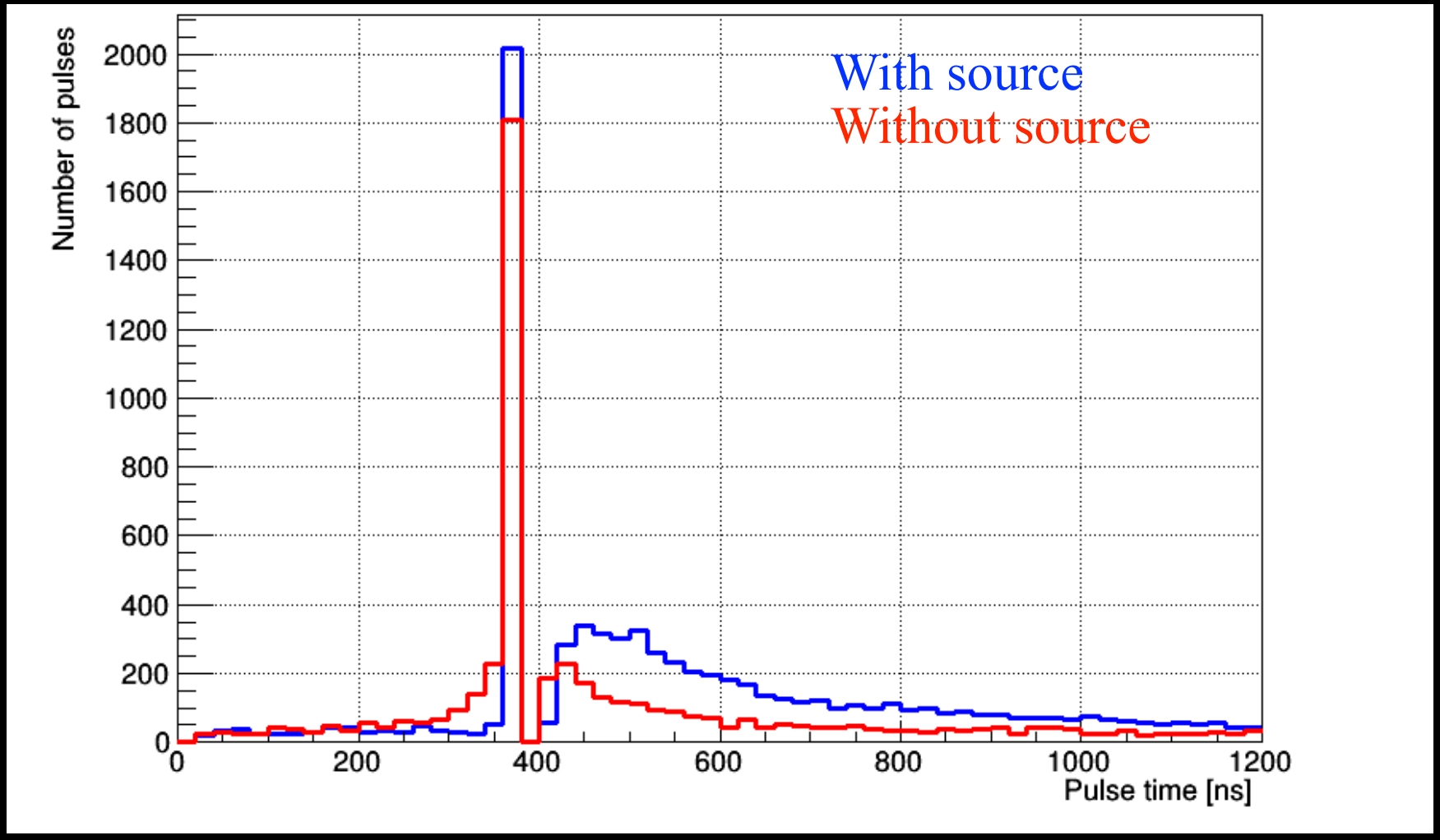
Other observations?



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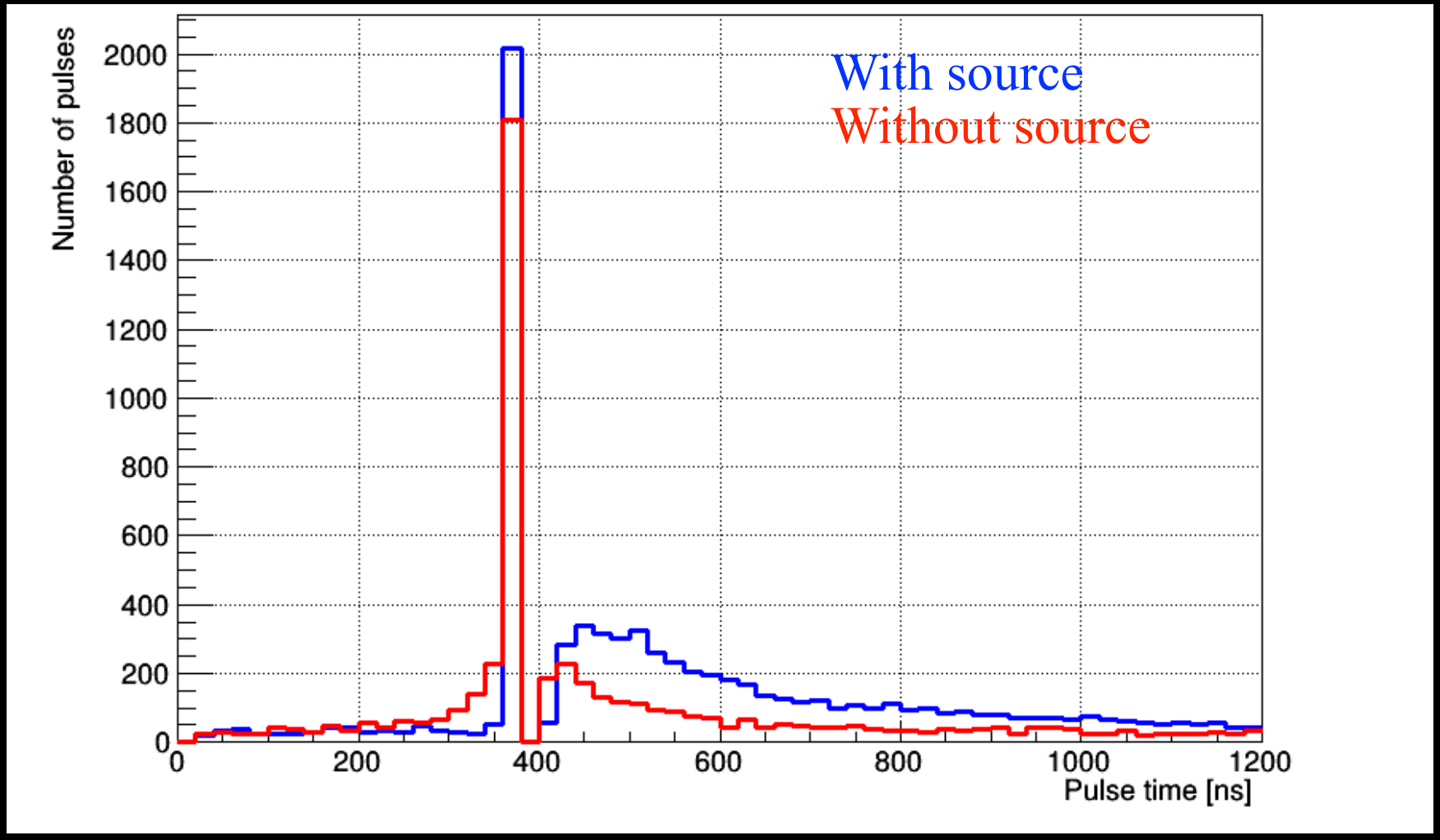
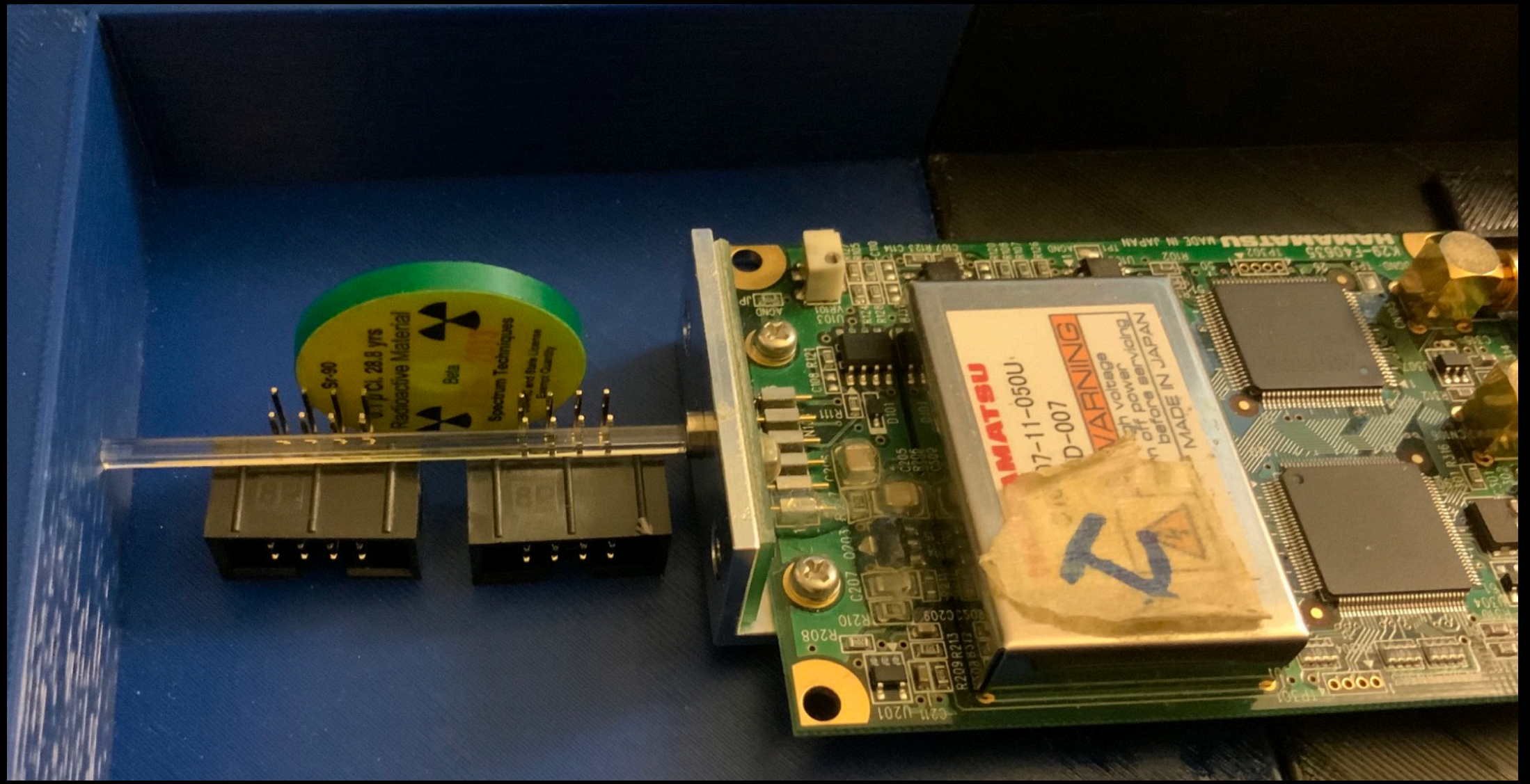
Excess red before main pulse. Why?



Detecting radiation with light

We can conclude that we see excess light generated in the scintillator from the source.
But, it was a difficult measurement because we had a lot of background to overcome.
How to do better?



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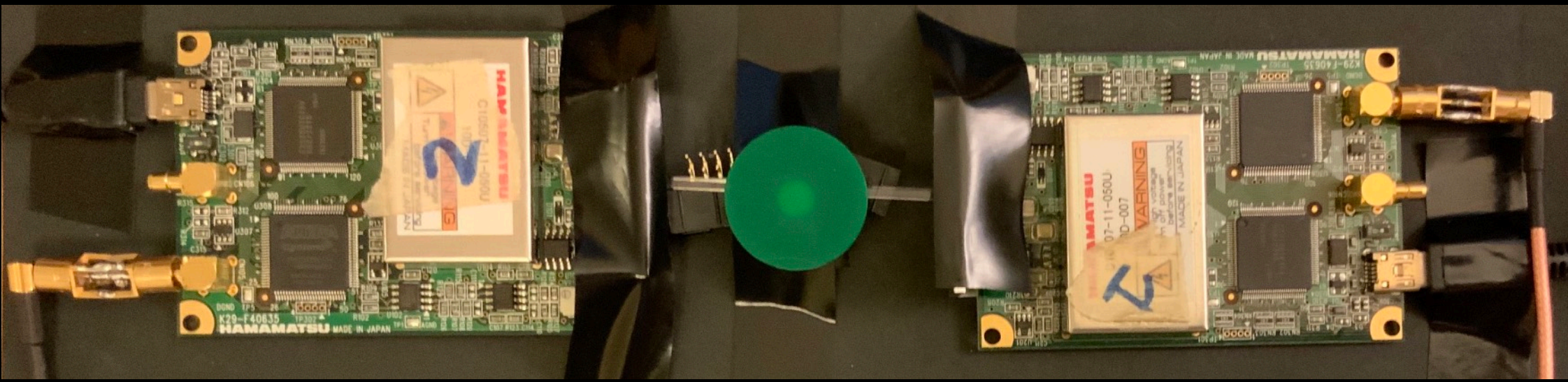
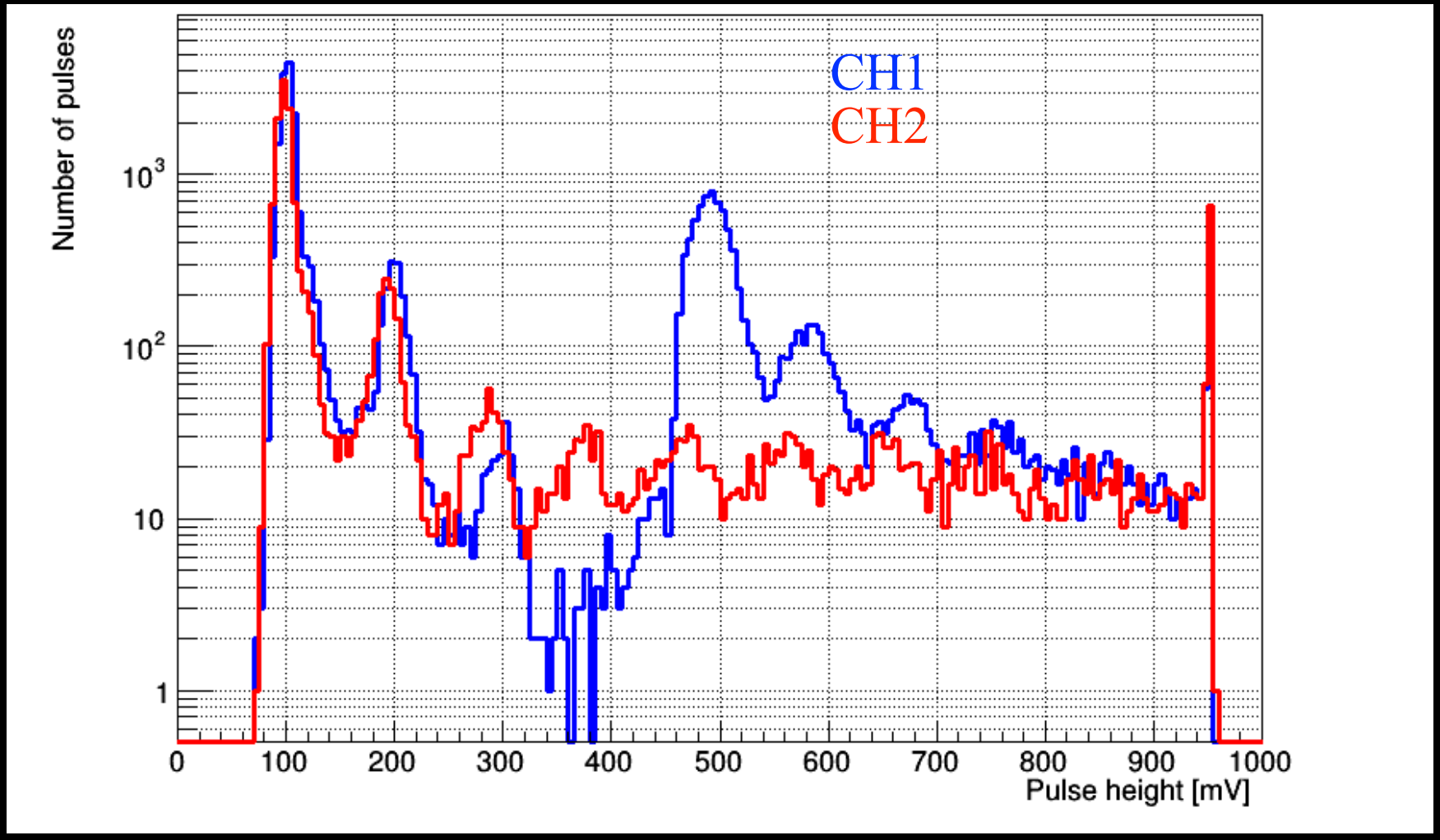


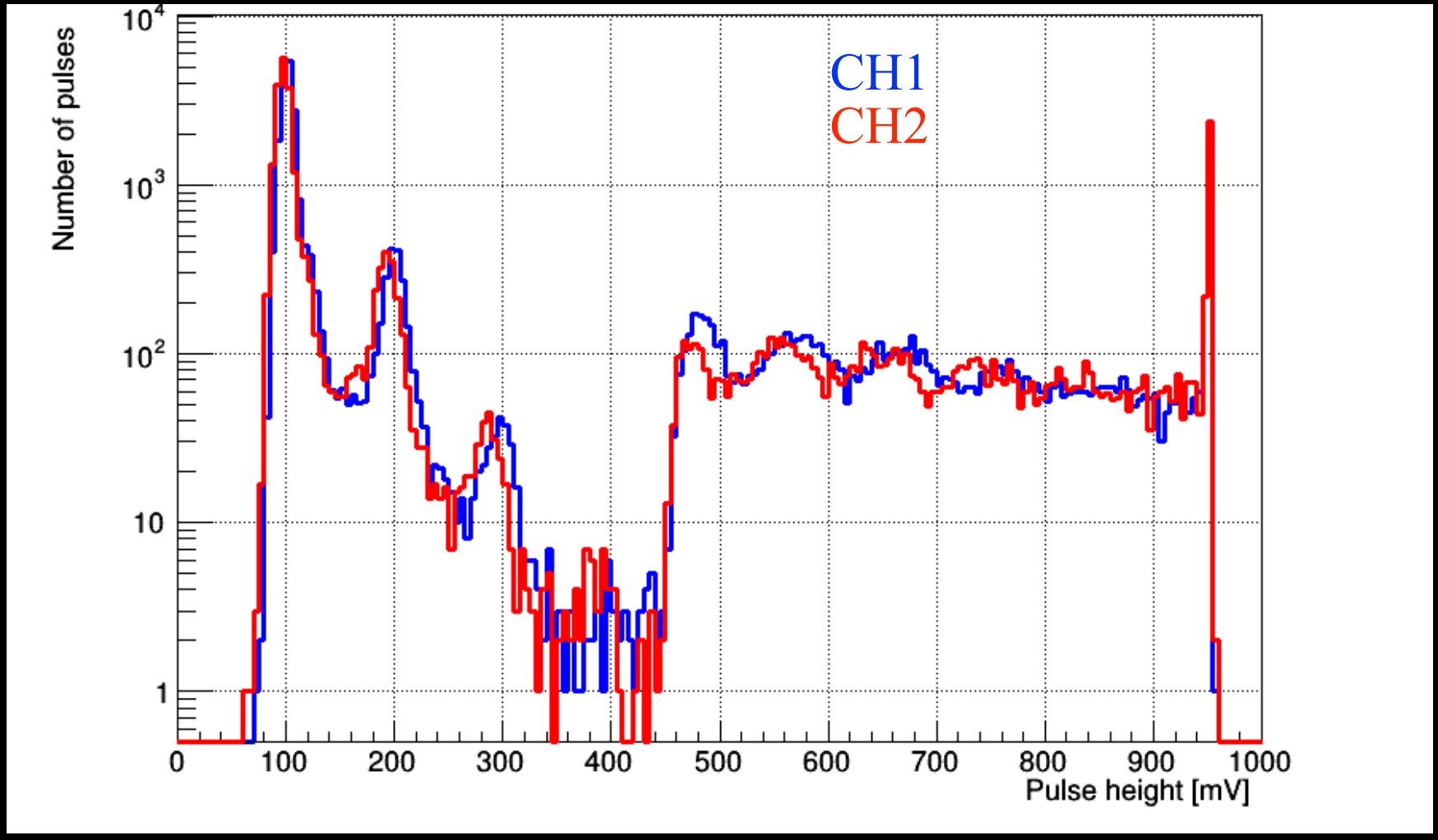
Detecting radiation with light

Trigger on CH1 at 450 mV, which is ~ 5 photons and look at both CH1 and CH2.



Detecting radiation with light

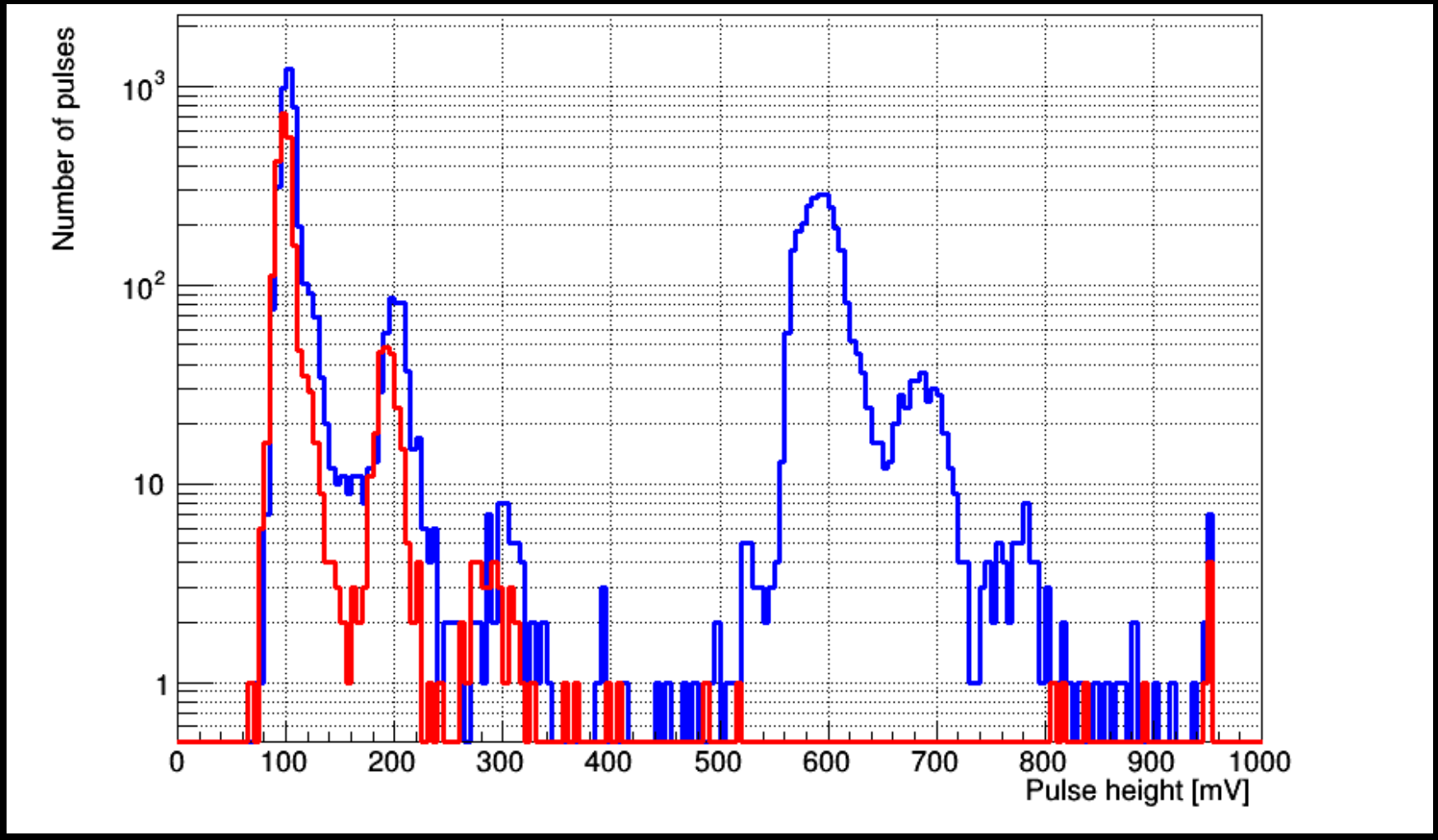
Trigger on CH1 AND CH2 at 450 mV.



Detecting radiation with light

Trigger on CH1 at 550 mV, without a source.

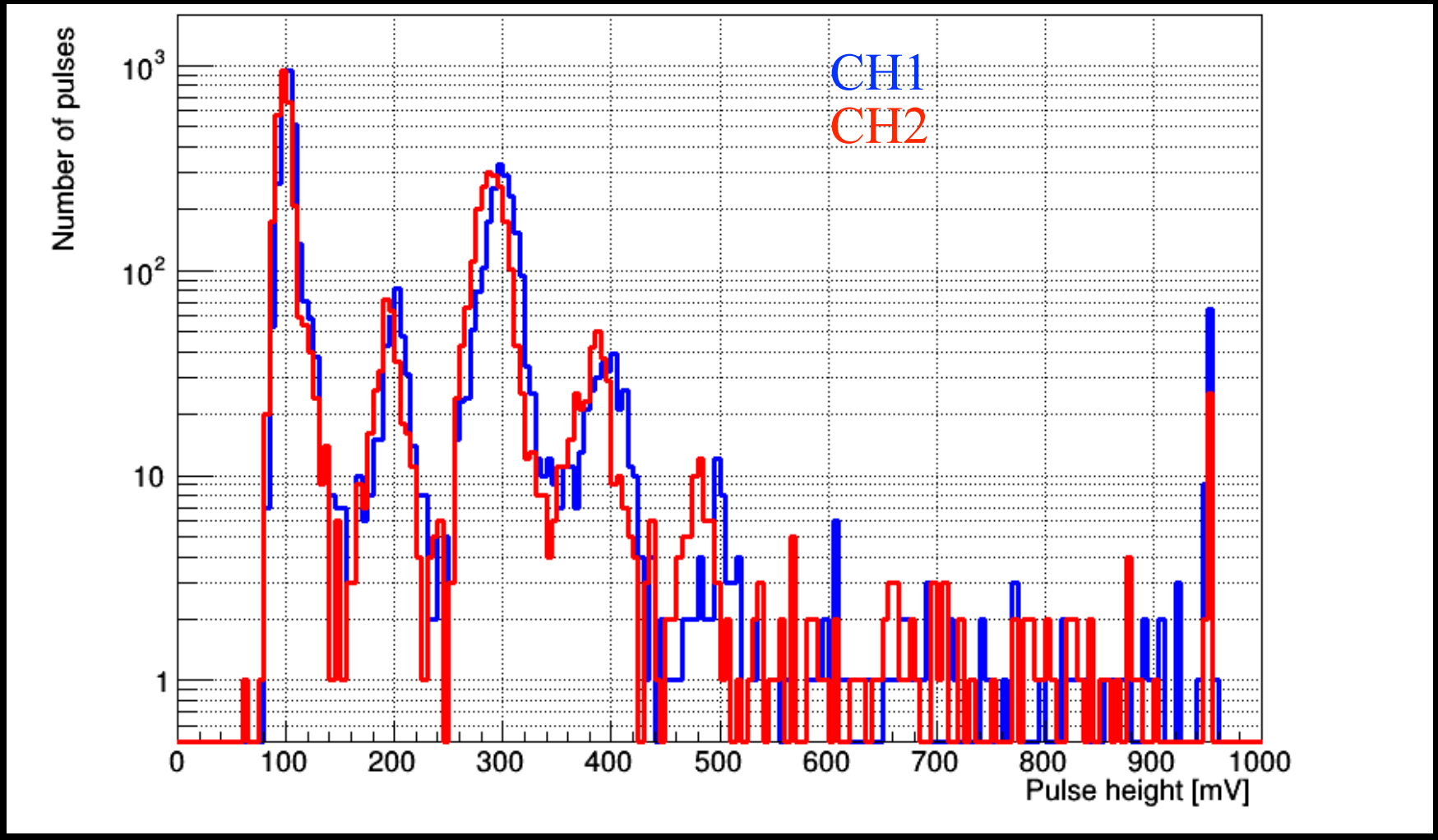
Conclusions?



Detecting radiation with light

Trigger on CH1 AND CH2 at 250 mV, without a source.

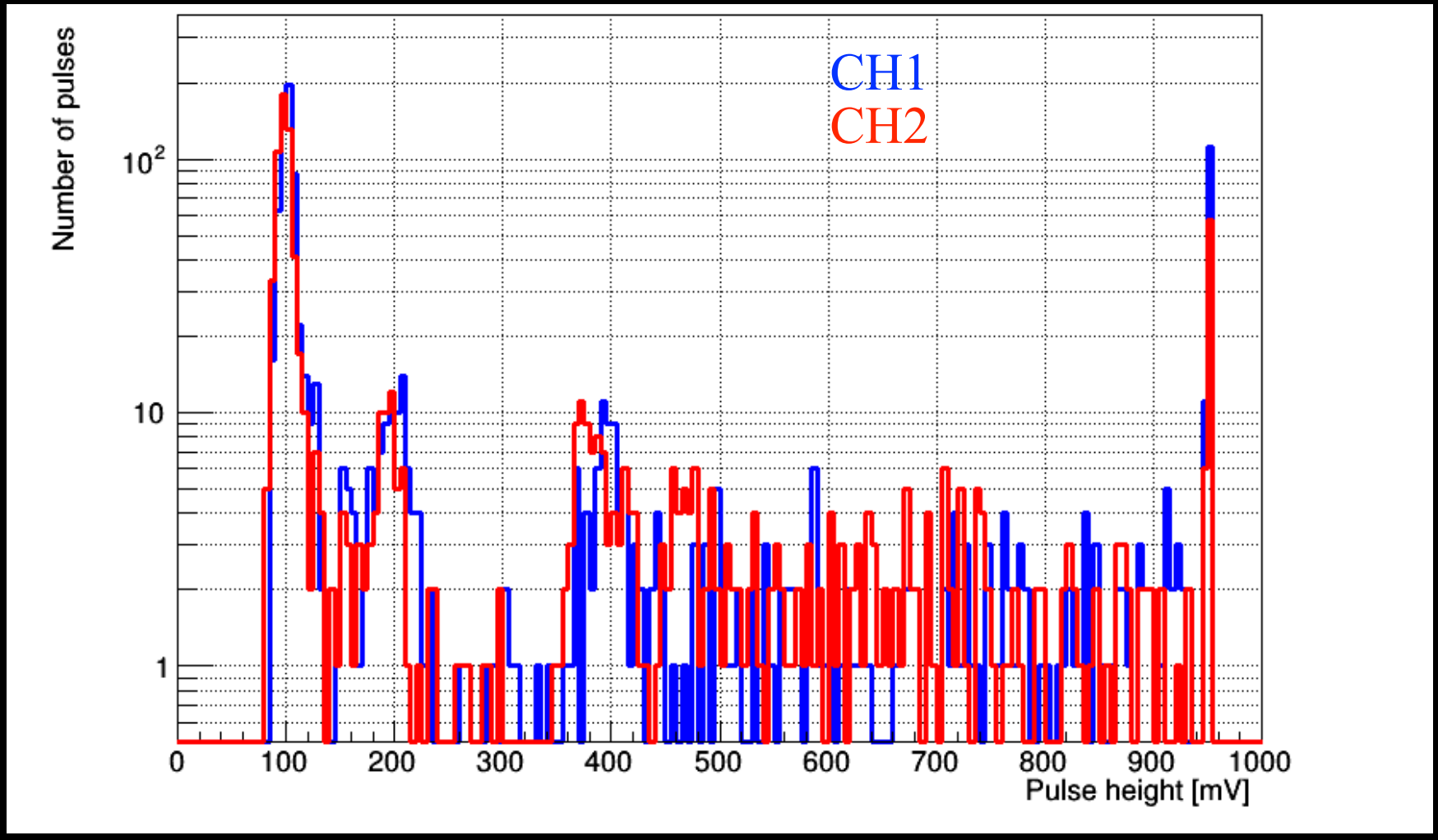
Conclusions?



Detecting radiation with light

Trigger on CH1 AND CH2 at 350 mV, without a source.

Conclusions?



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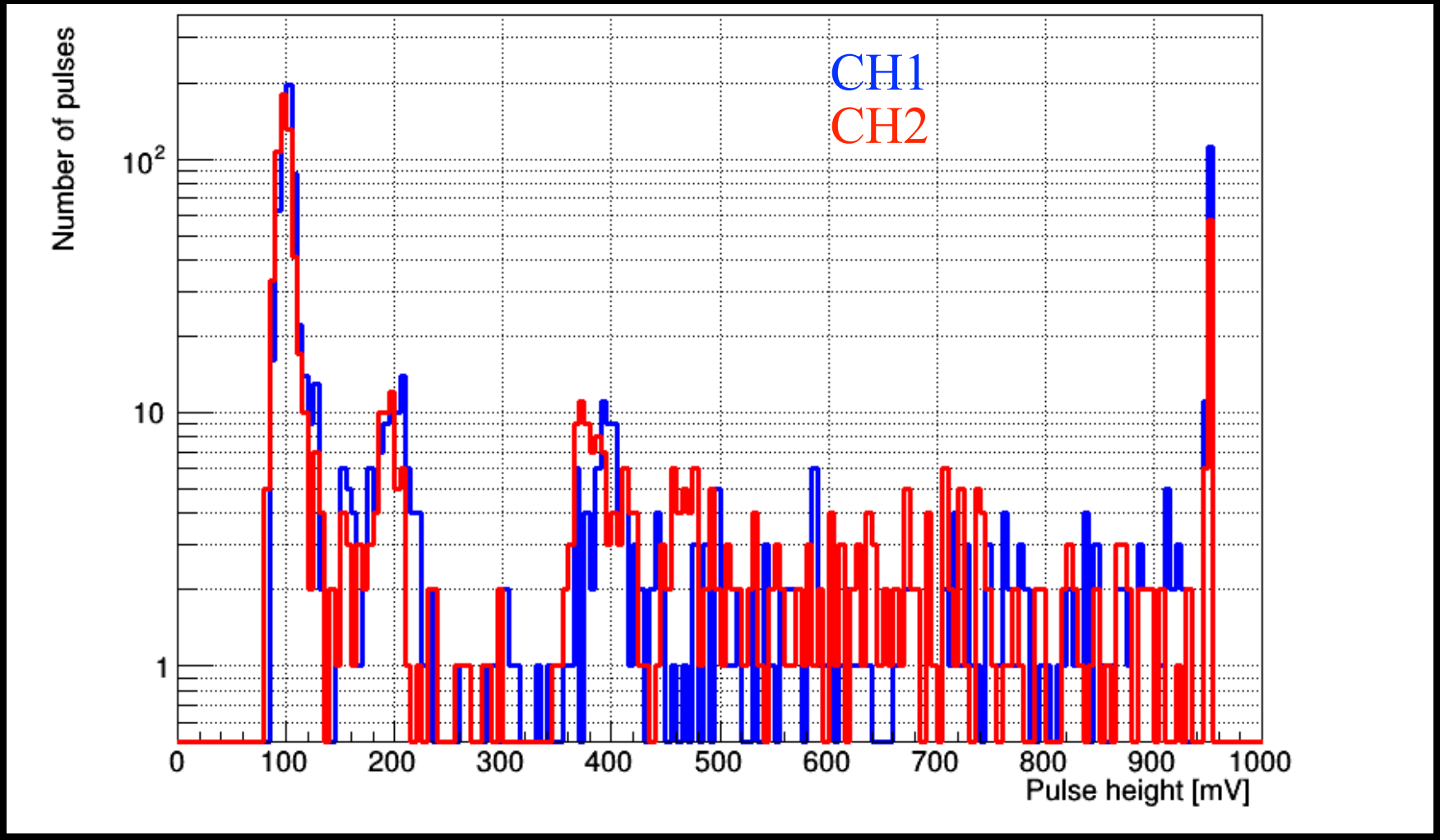
Trigger on CH1 AND CH2 at 350 mV, without a source.

There is evidence of large, coincident pulses even without a source.
⇒There is another source of radiation, ie a background radiation.



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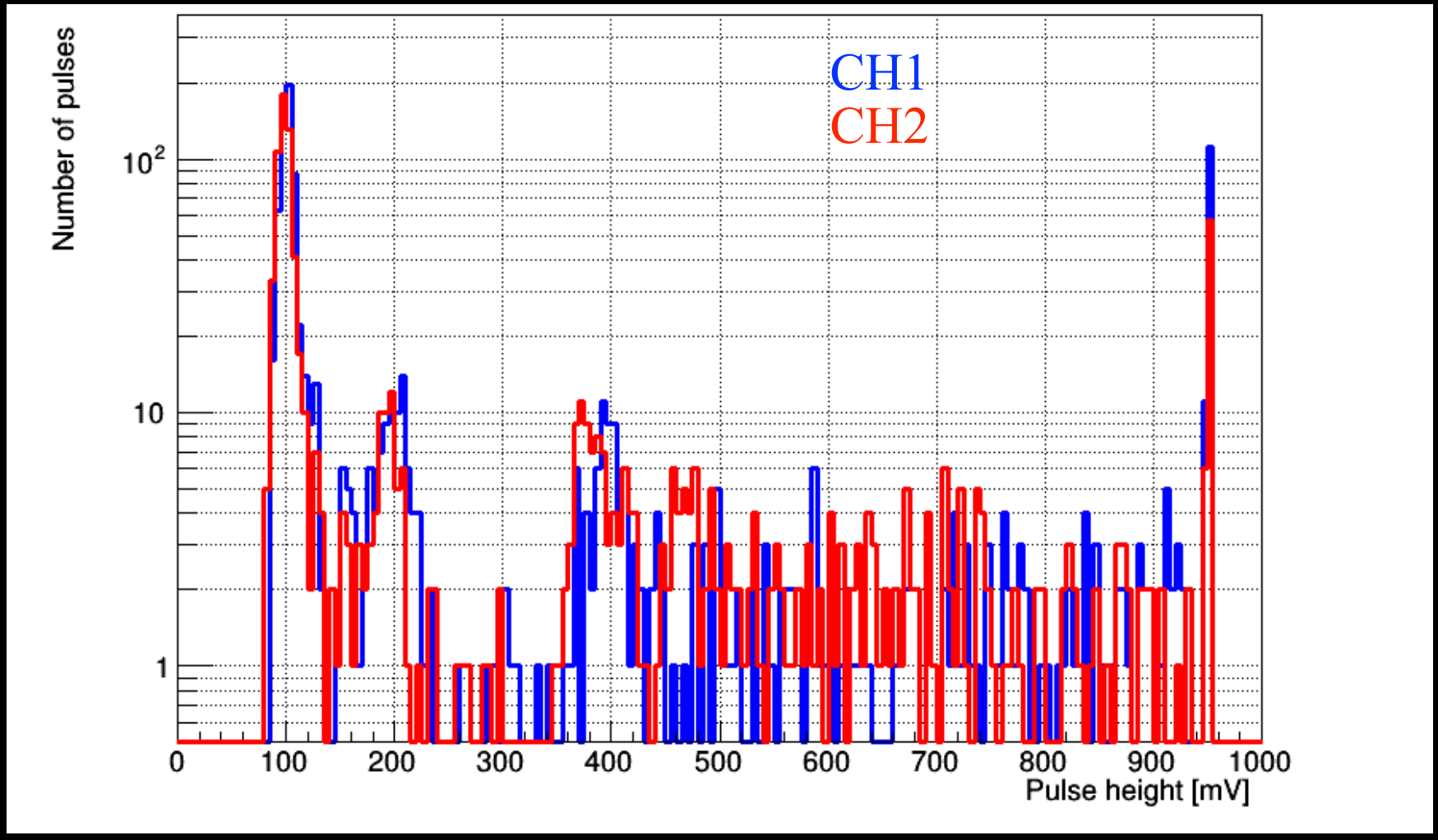
Ideas for additional studies of this data in order to understand this excess?



Lab this week

For this week's lab work

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Plot histograms of the key observables.
  First reproduce some of the ones I've shown.
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And we will be on Zoom to answer questions at times TBD.
Will start with Friday 2-3 PM when I will be available.

Post (and answer) questions in the ELog's "Questions" tab.
Use discord: PHYS150-Stuart in https://discord.gg/invite/PzPbSUm