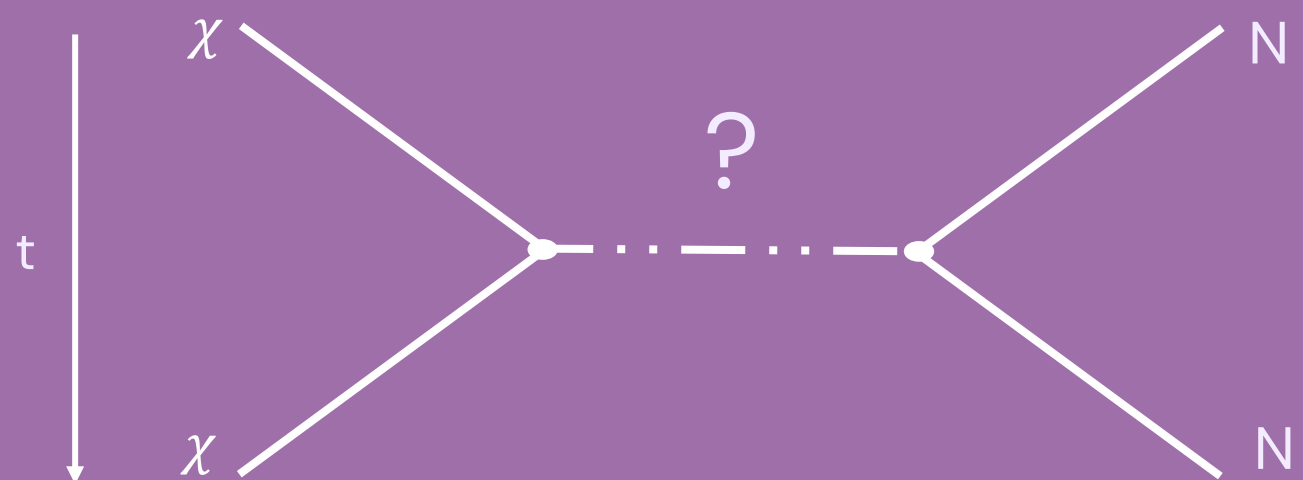


A Highly Segmented Backing Array for Nuclear Recoil Calibration

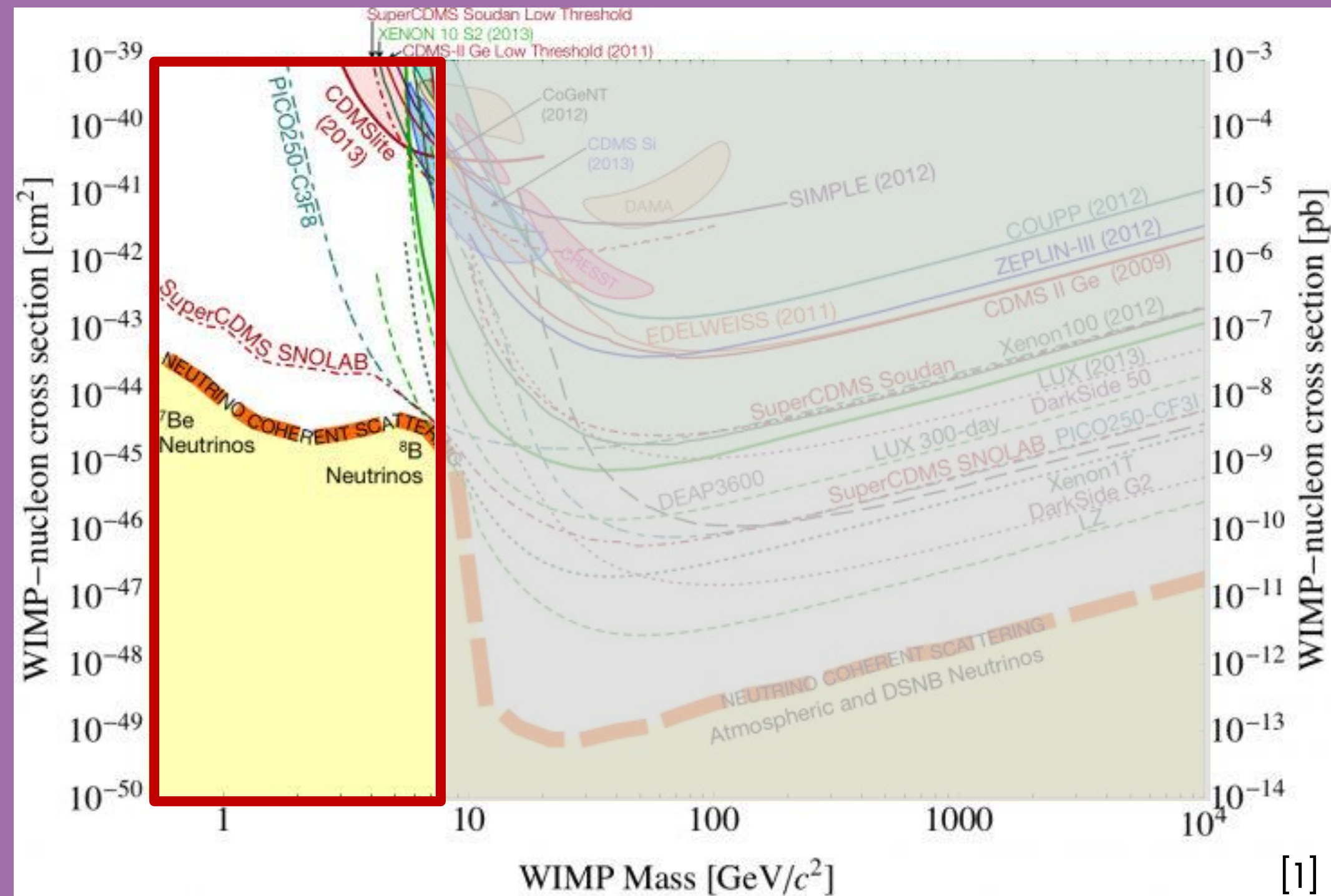
ISABELLA FOTI

Dark Matter ROI

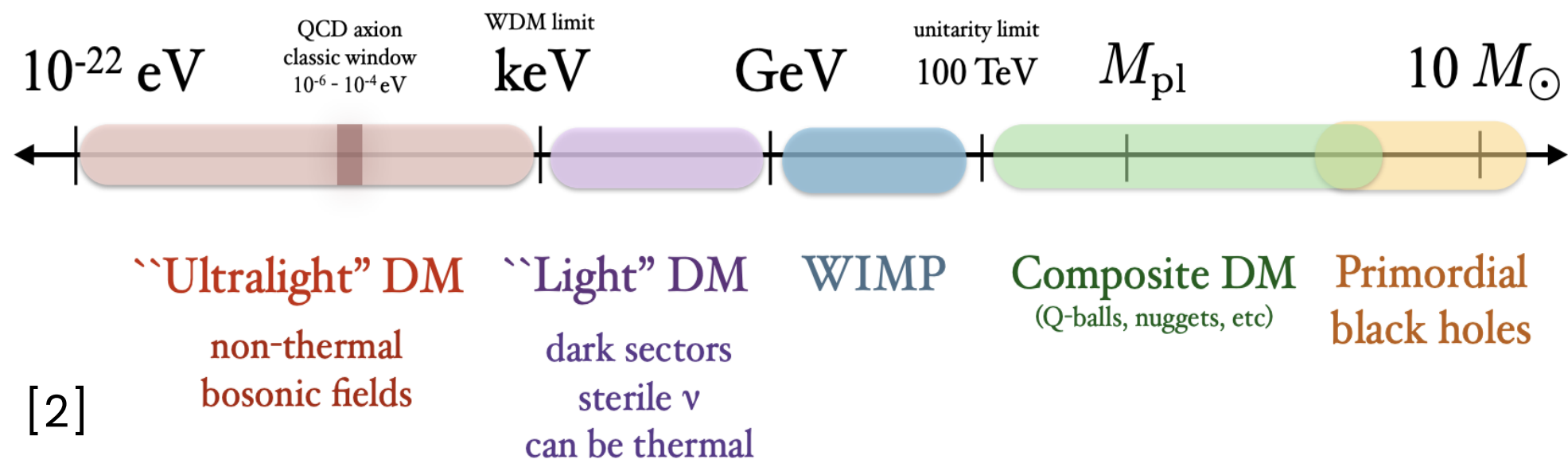
Mass in range $0.5 - 5 \text{ GeV}/c^2$



- Overlap with Standard Model
- Insight into mediator
- Signal strength of $10^{-2} - 10^2 \text{ keV}$ [4]

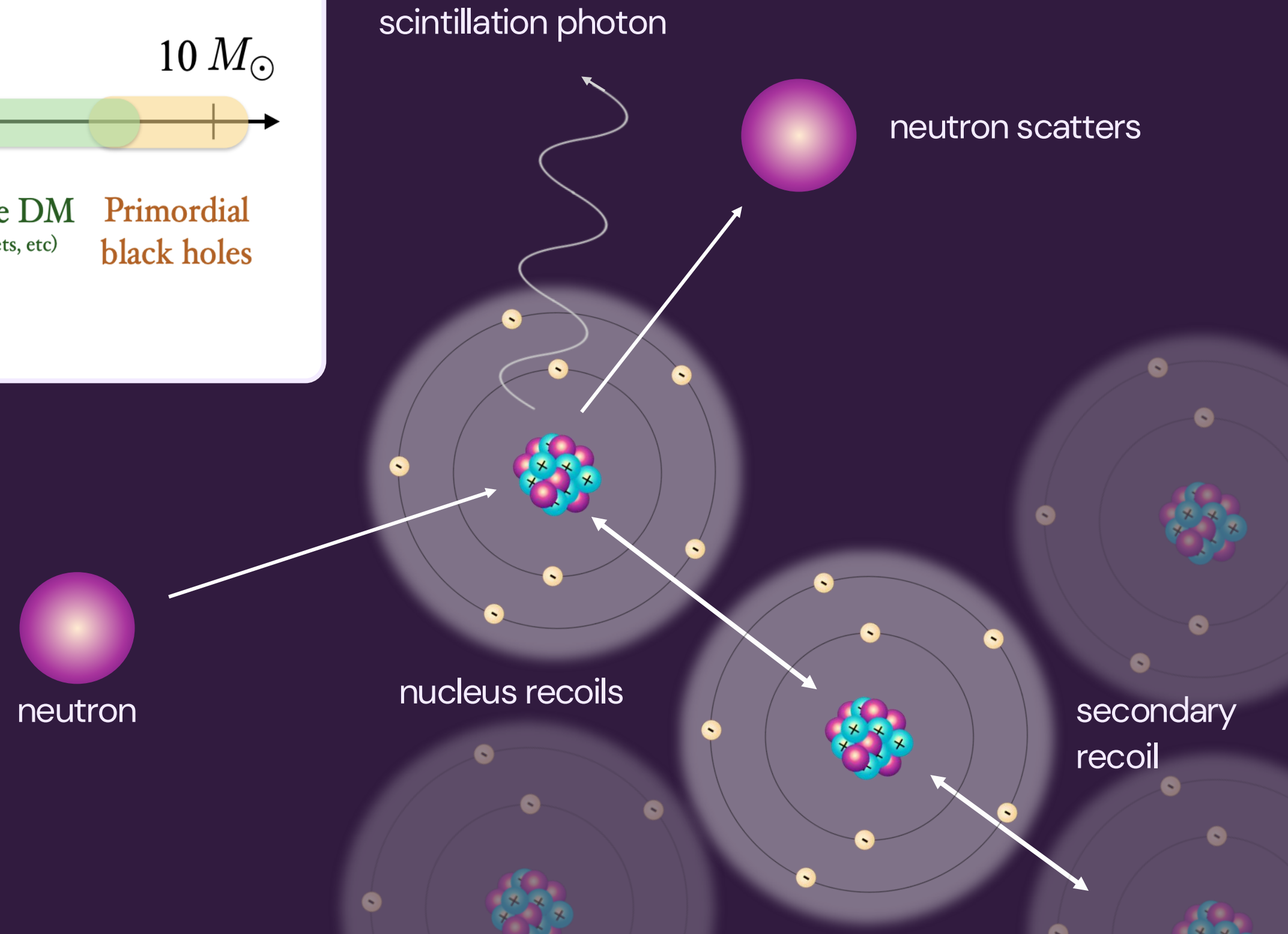


Nuclear Recoil



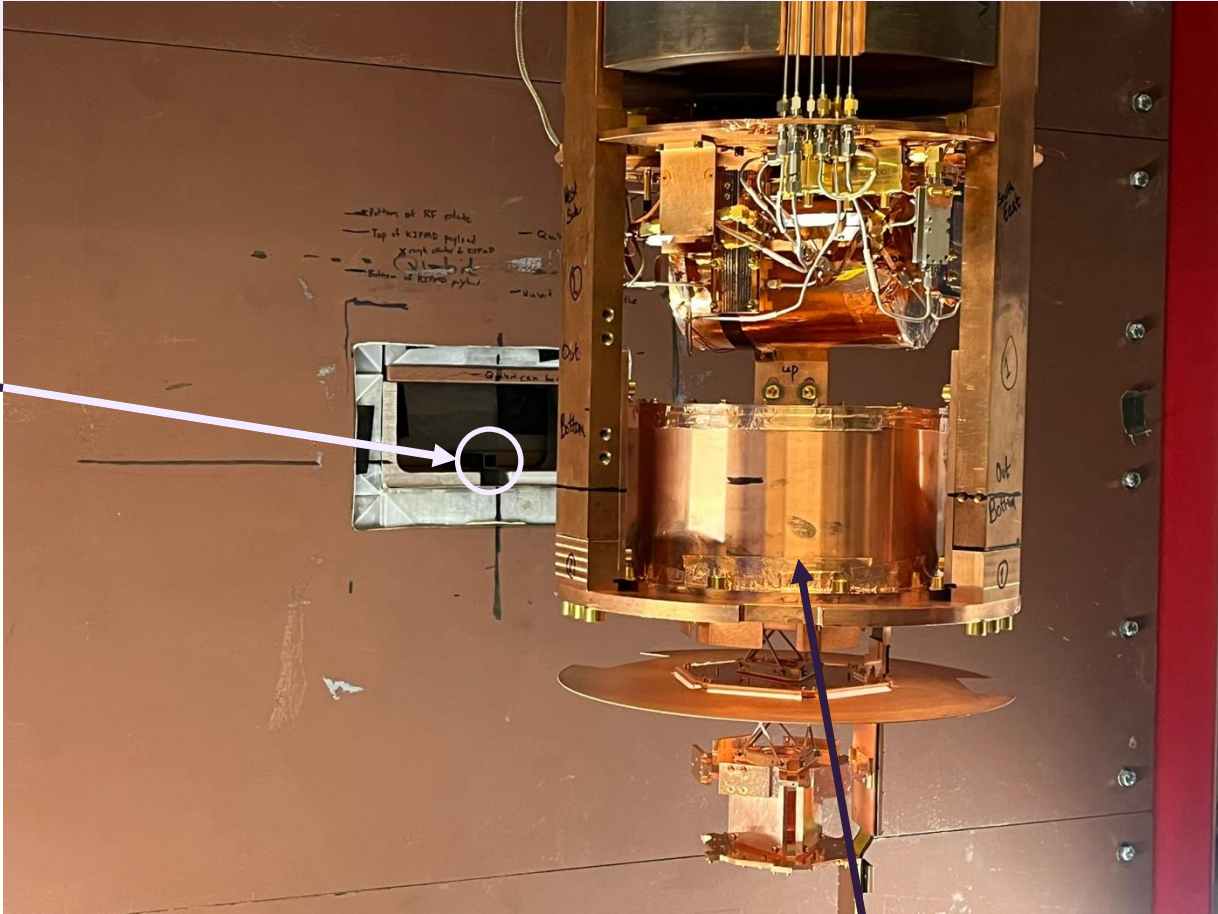
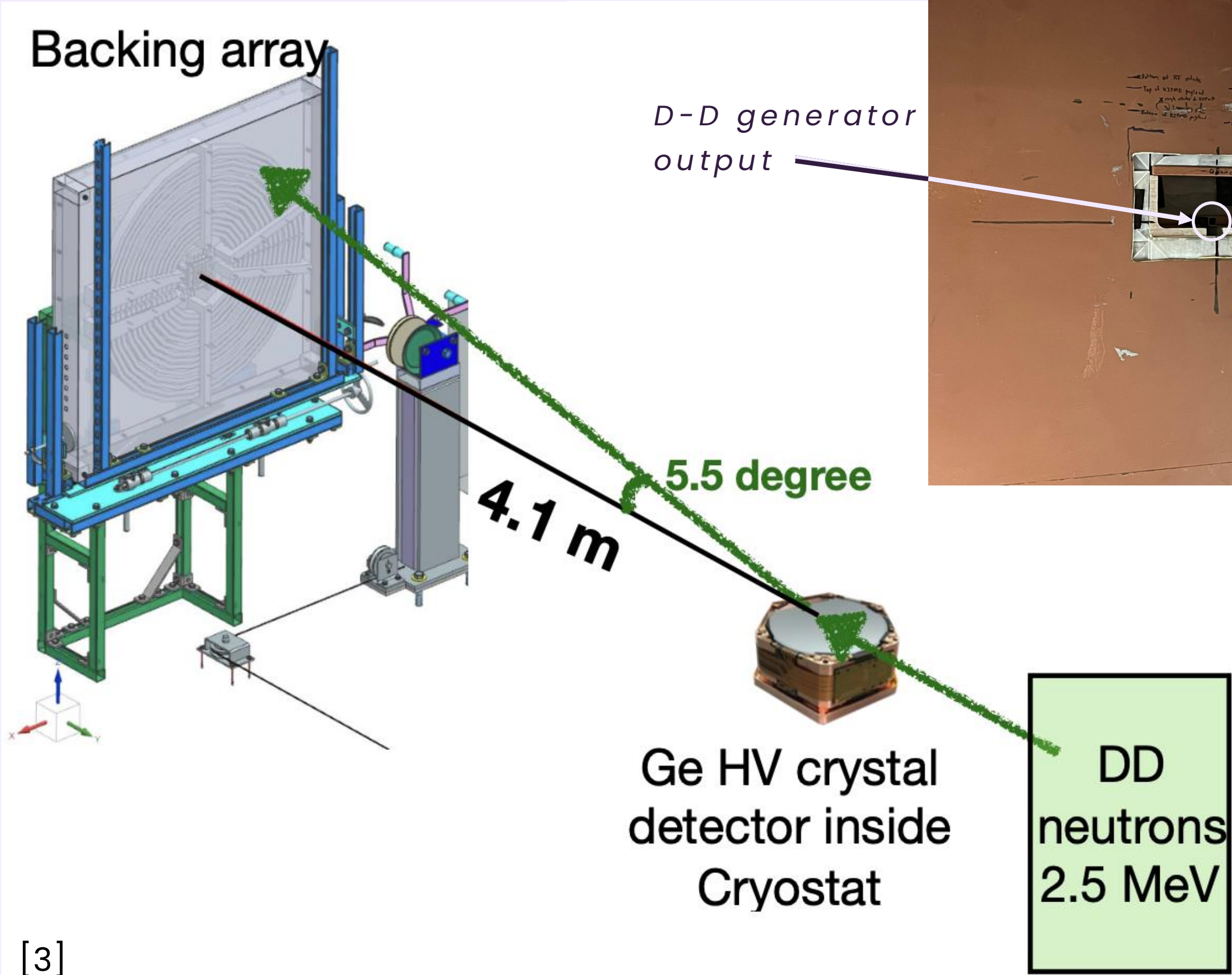
Neutron-Nucleus Scattering

In a scintillation or ionization detector, the nuclear and electron recoil (NR and ER) will cause a collision cascade within the medium



Our Experiment

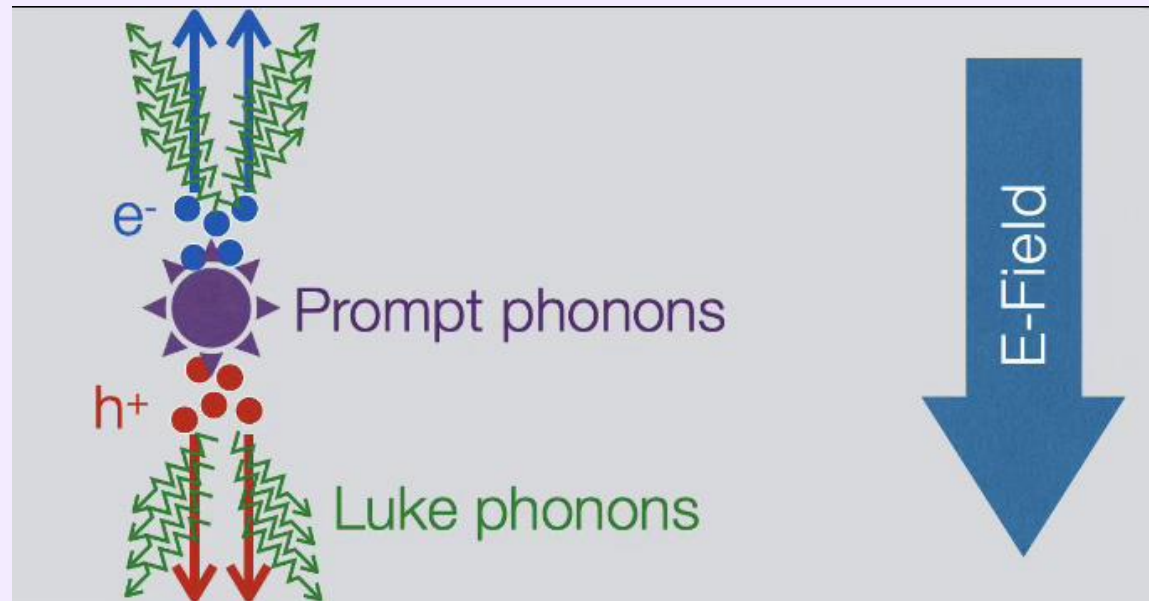
/03



SNOBOX Ge detector

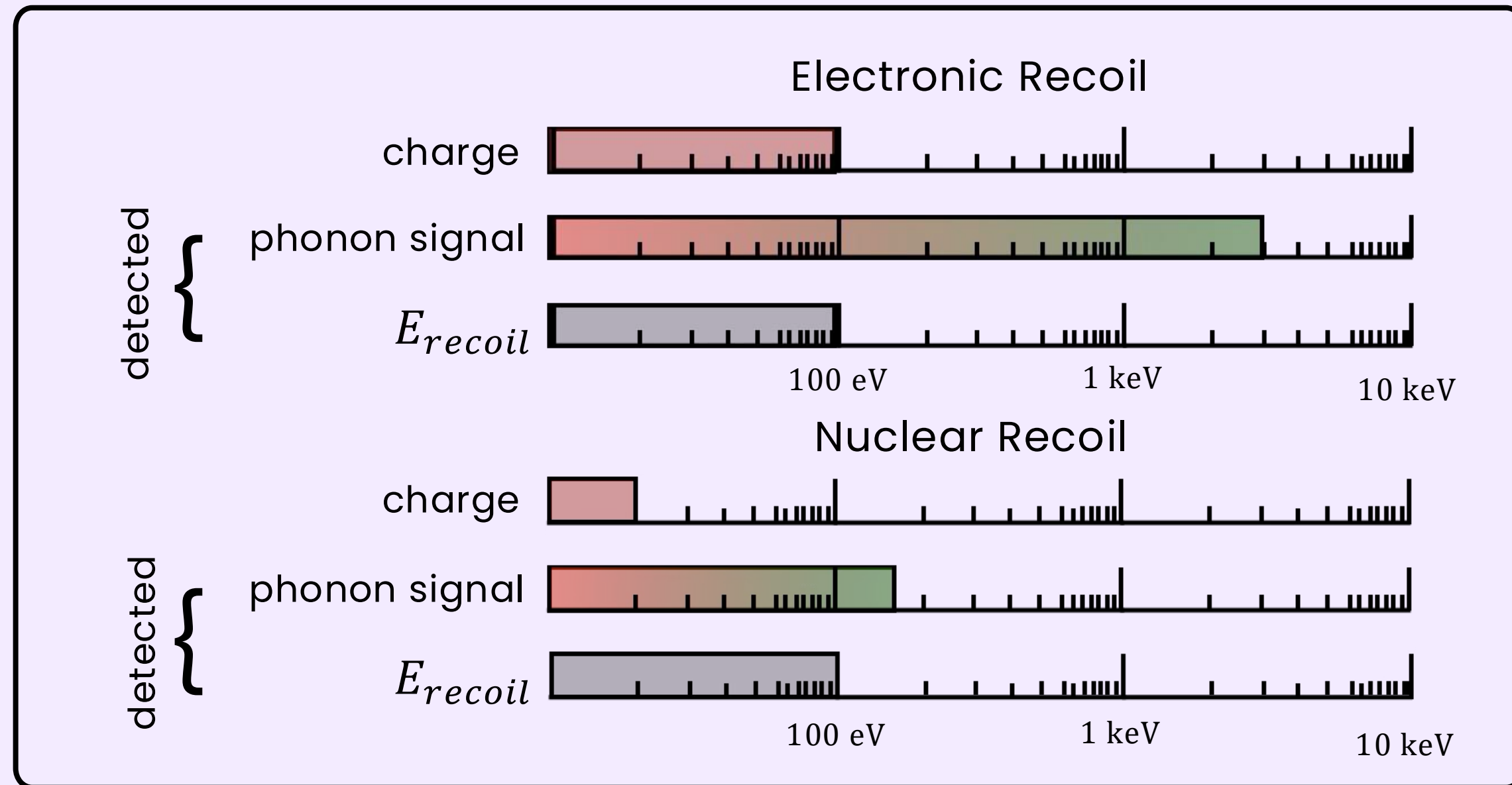
Ionization yield

/04



$$E_{\text{phonon}} = E_{\text{recoil}} + n_{\text{eh}} \cdot e \cdot V_b$$

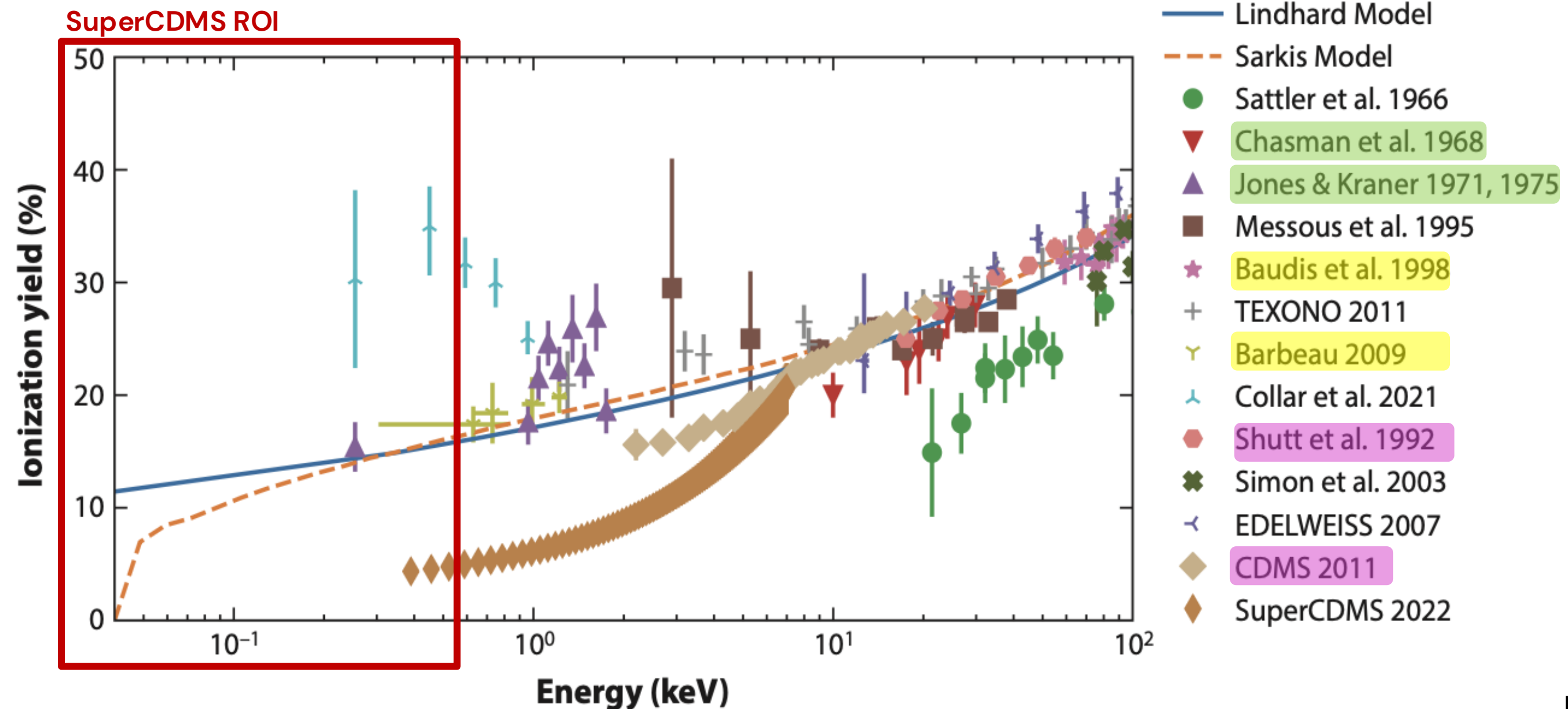
$$E_{\text{recoil}} = \text{prompt phonon} + \text{surface recombination phonon}$$



$$\text{Quenching Factor (QF)} = \frac{\text{Detected signal from nuclear recoil}}{\text{Detected signal from electron recoil of same energy}}$$

Determining the Quenching Factor (QF)

/05



[4]

Linhard Model: $f = \frac{kg(\epsilon)}{1 + kg(\epsilon)}$

The fraction of nuclear recoil energy transferred to electronic states [8]

The Backing Array

14 Rings.

28 Scintillator bars.

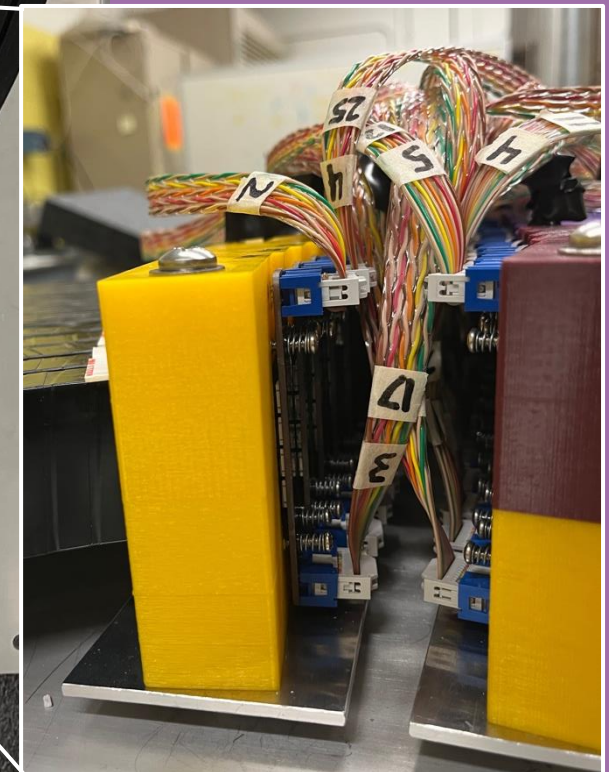
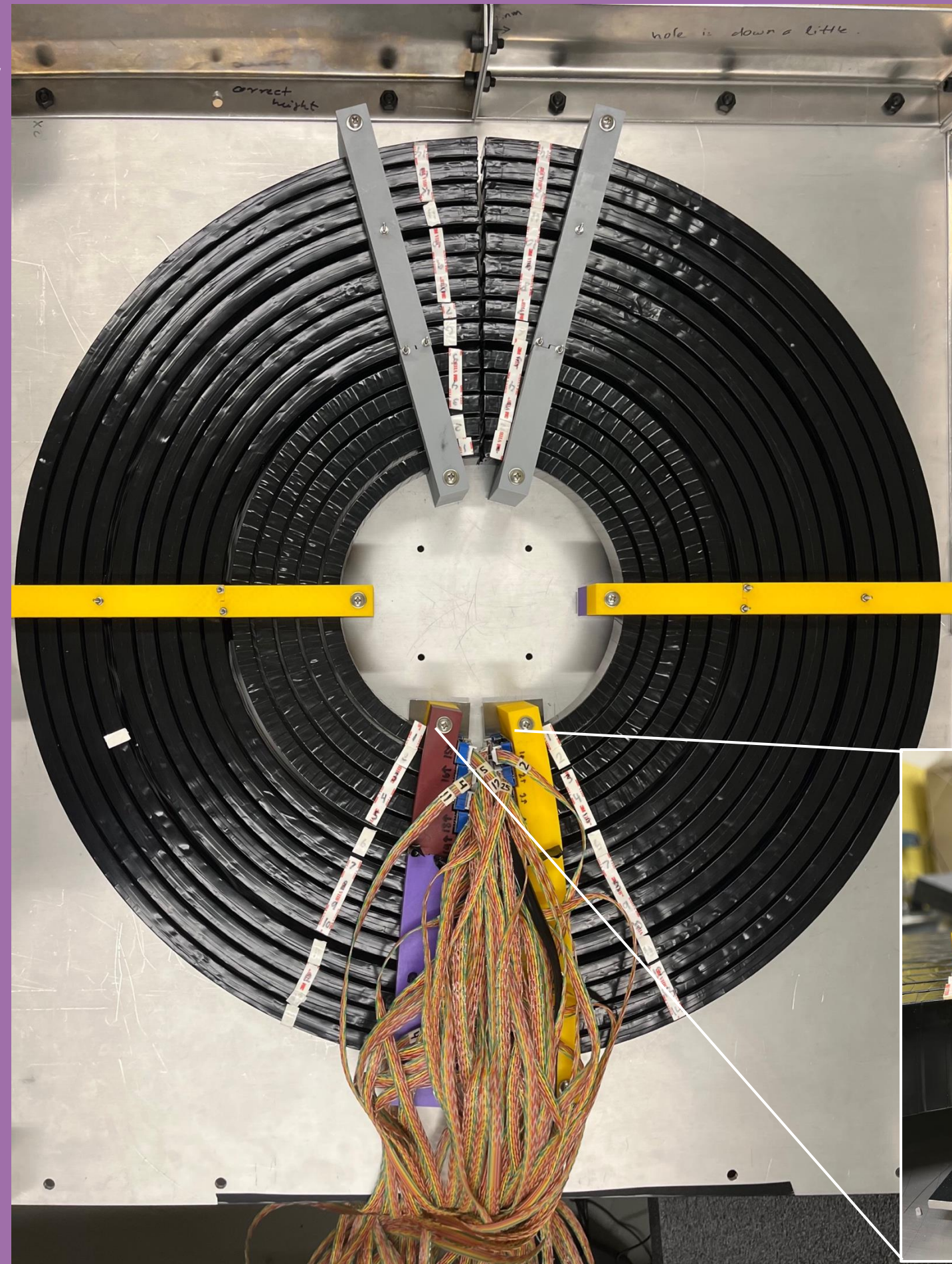
224 Silicon Photomultipliers.

Plastic EJ-200 Scintillator bars [5]:

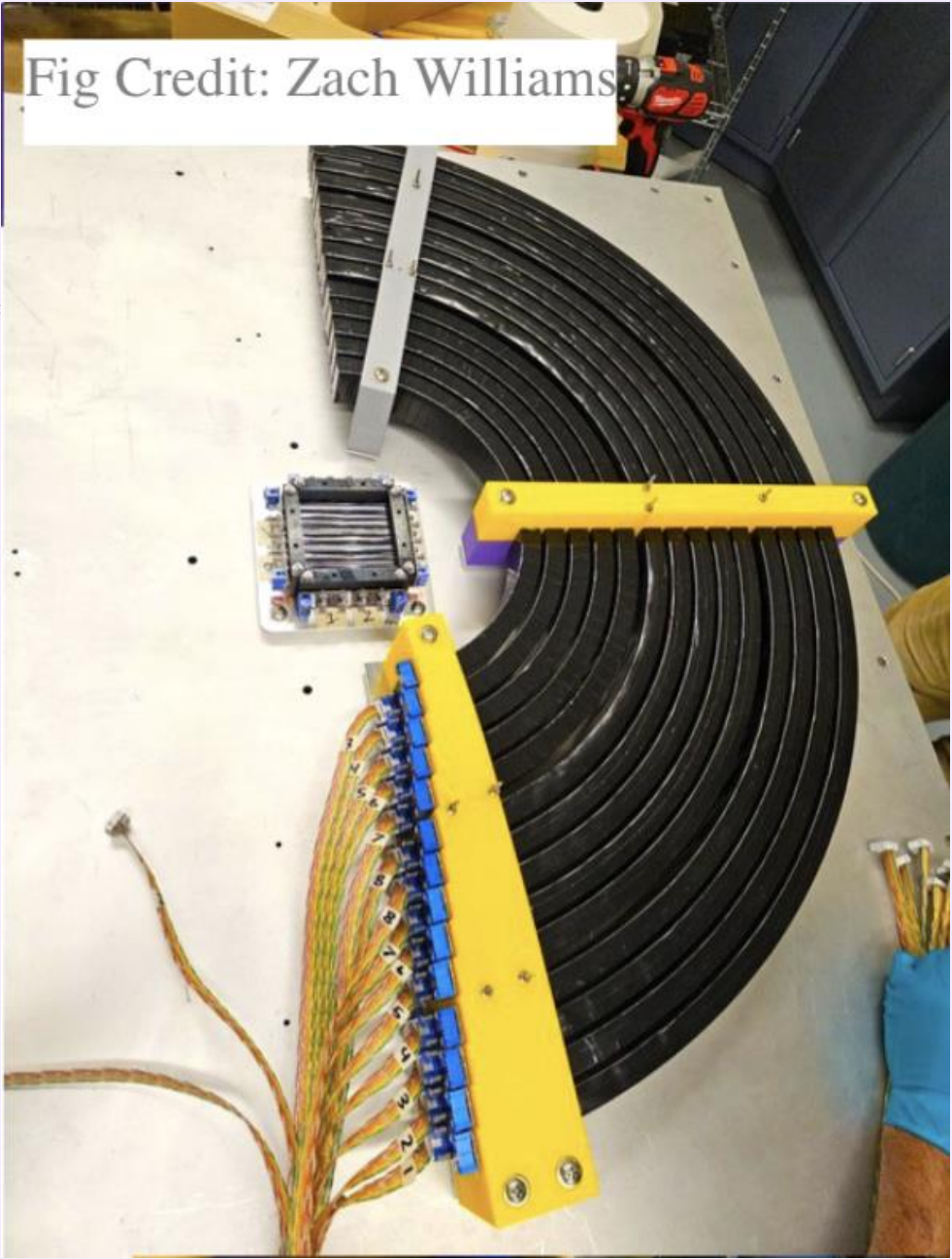
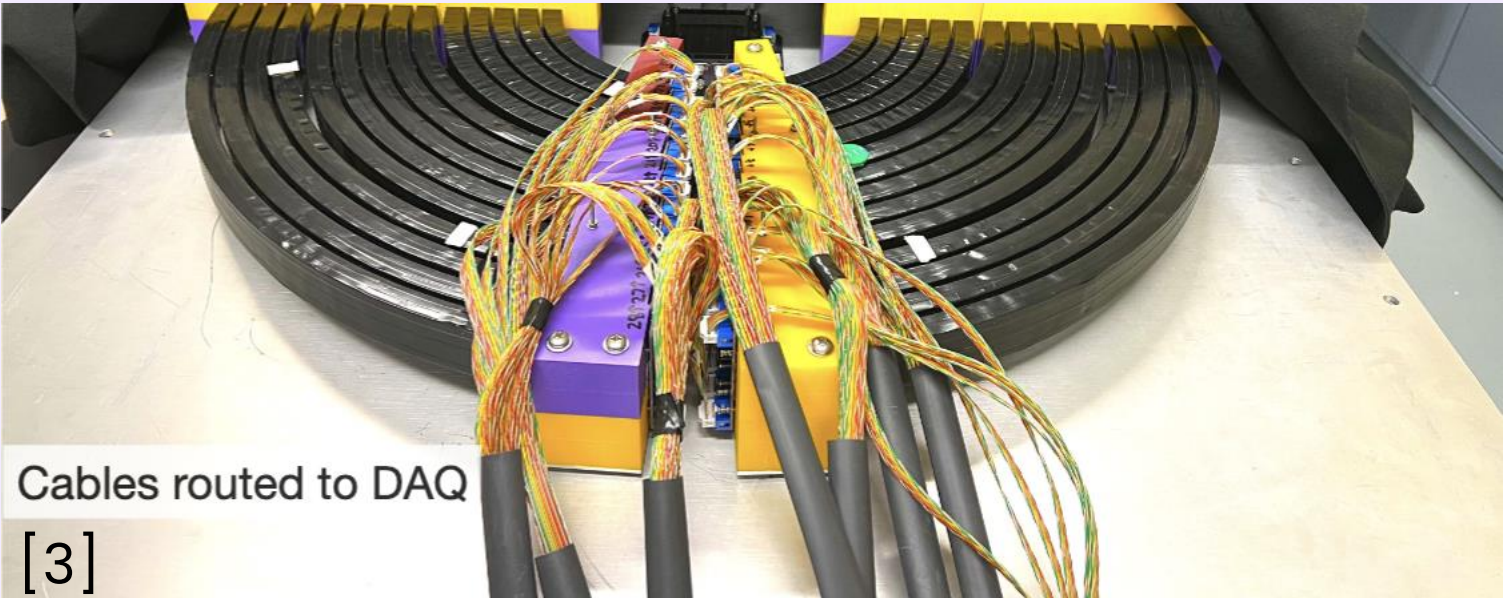
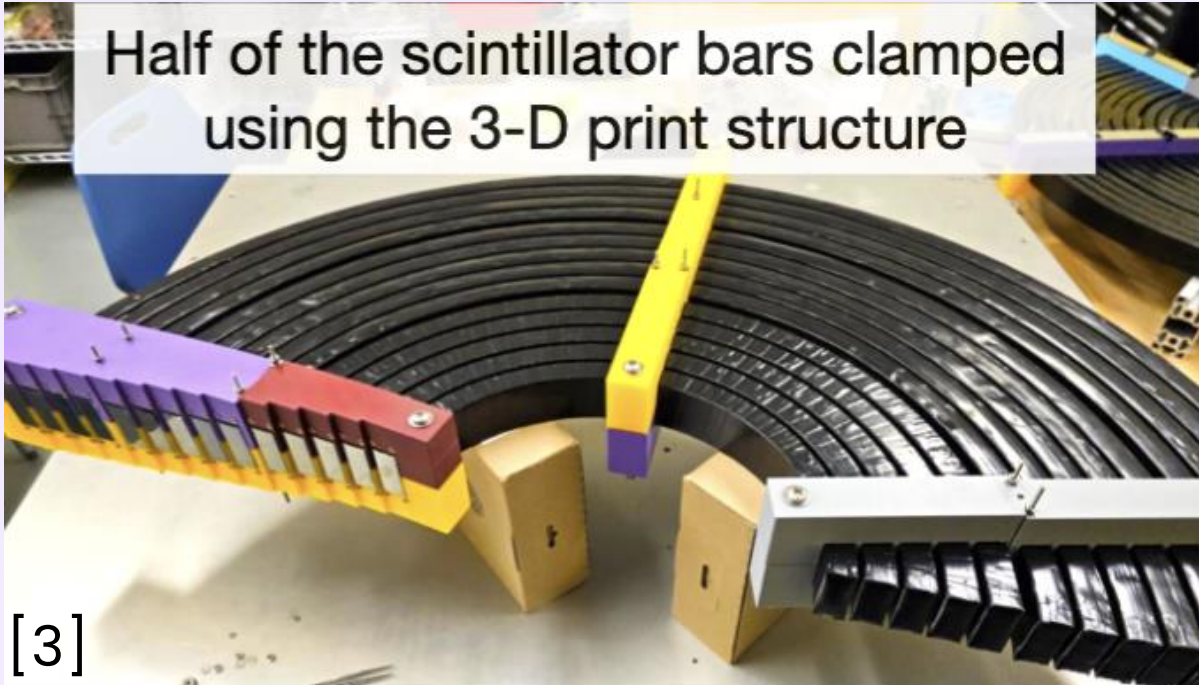
- Long optical attenuation length
- Fast timing
- Emission spectra of most commercial photomultipliers (SiPMs)

Lone Wolves:

Lone scintillator bars will be sporadically placed inside the lead shielding around the fridge/detector.



Construction



Construction cont.

/08

A replica of the existing stand was built at NU. We can now do a trial run of construction and attachment of the highlighted blue backing array stand.

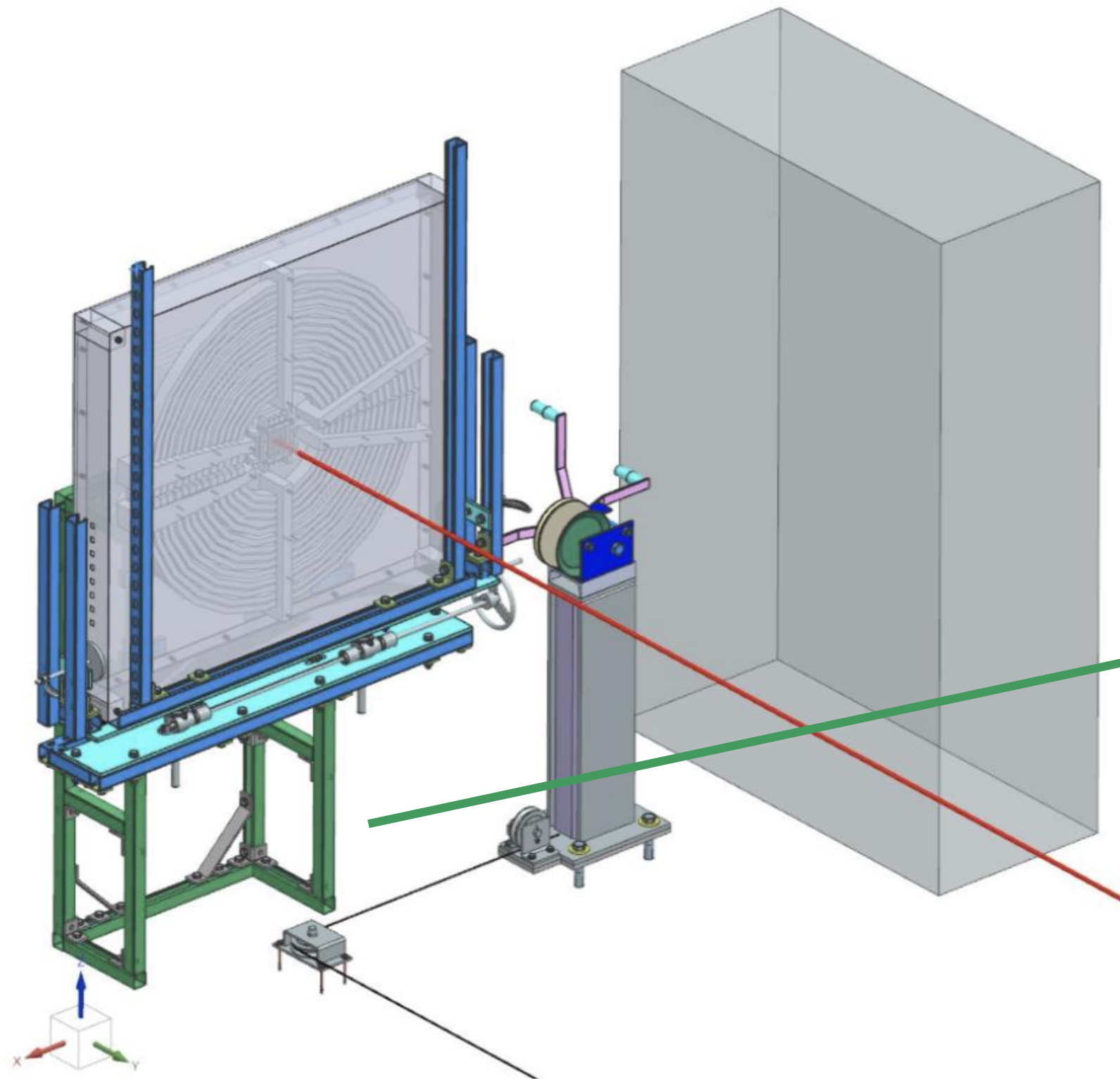
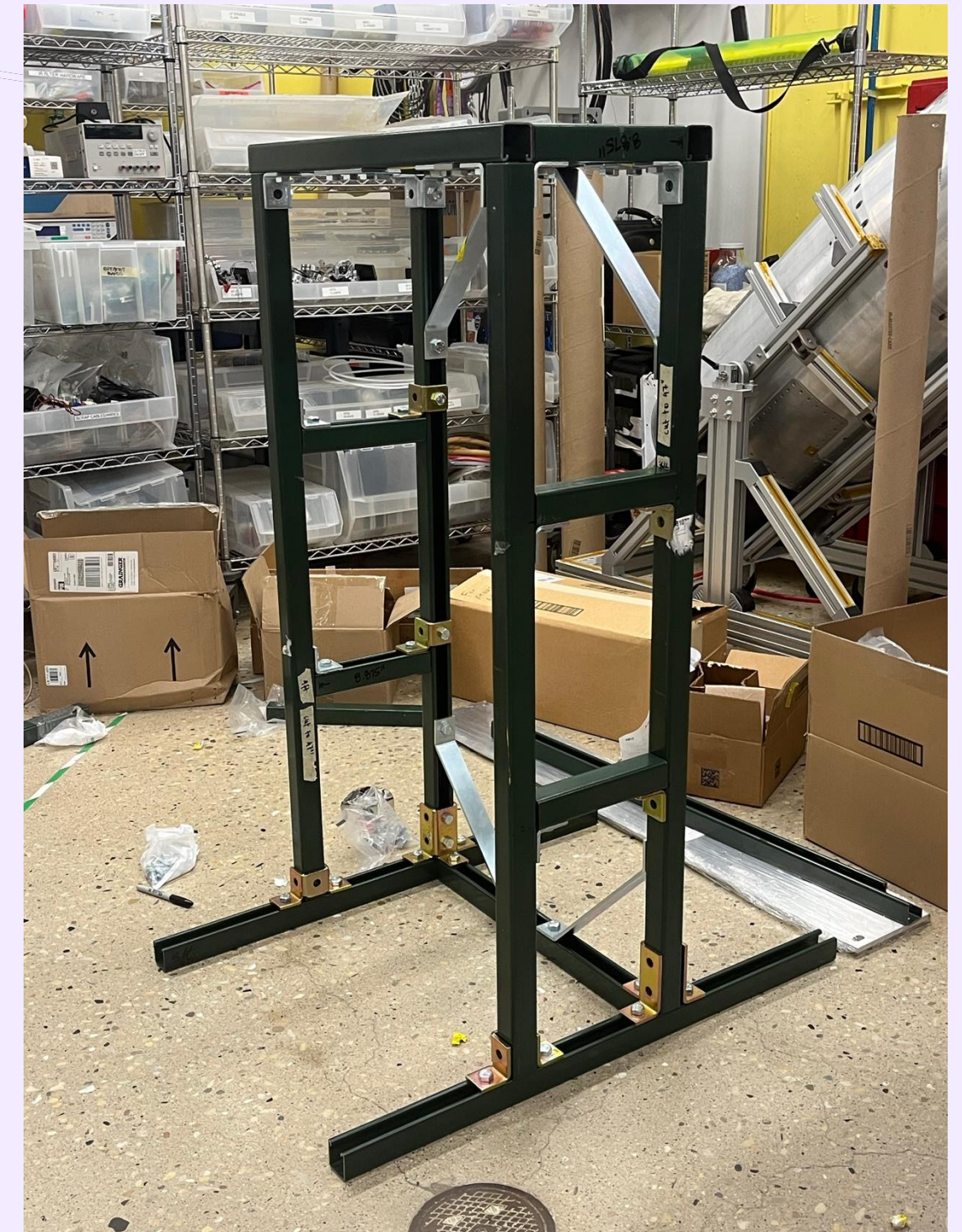


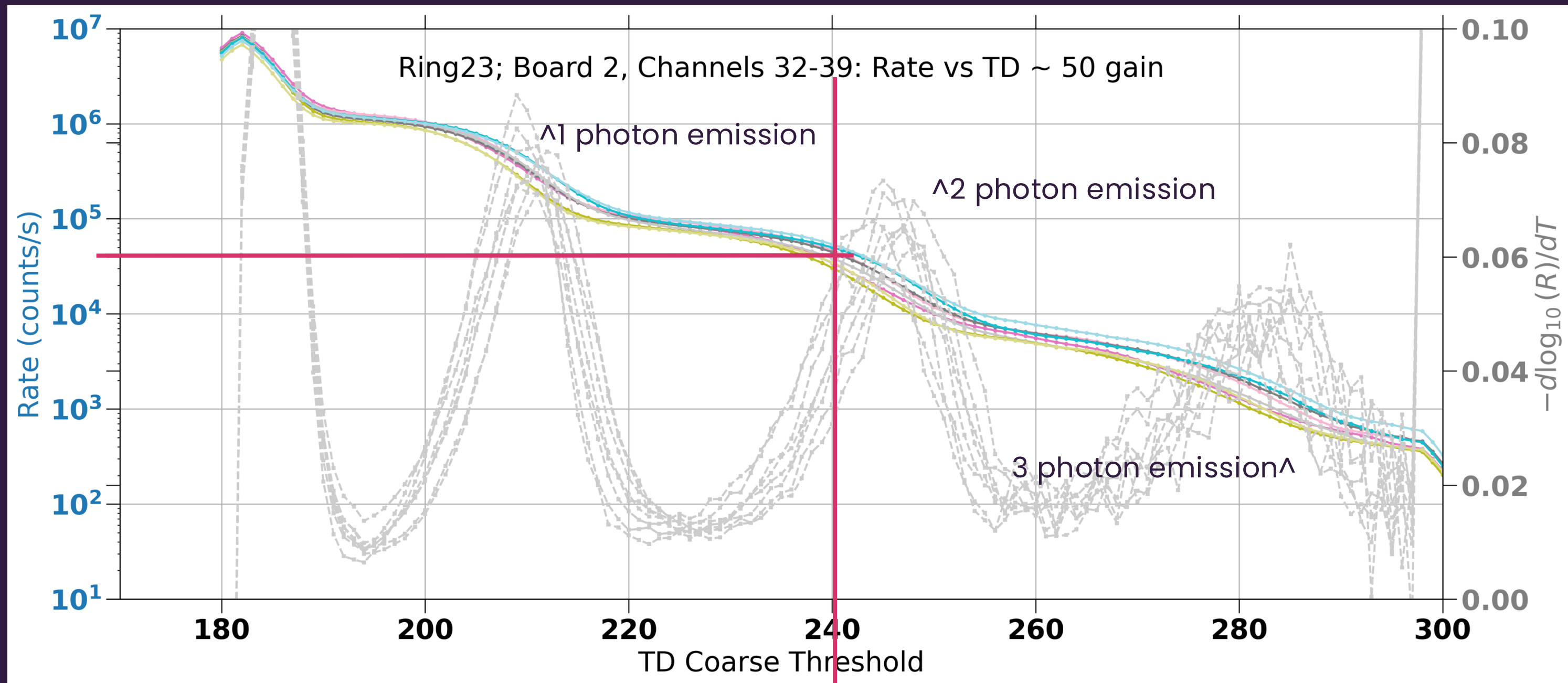
Fig Credit: Parth Gandhi

Using the design of the existing stand, extra support was added via additional unistrut.



Voltage Tuning

/09

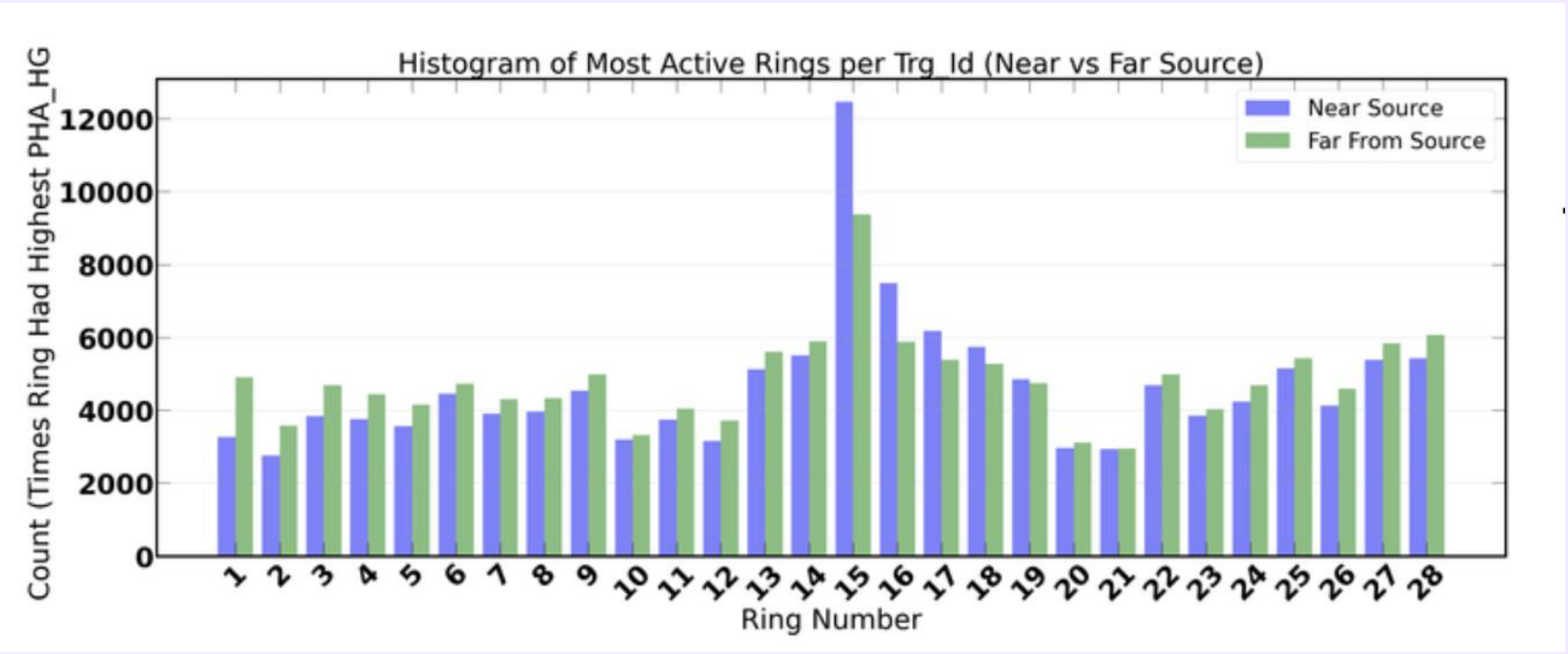
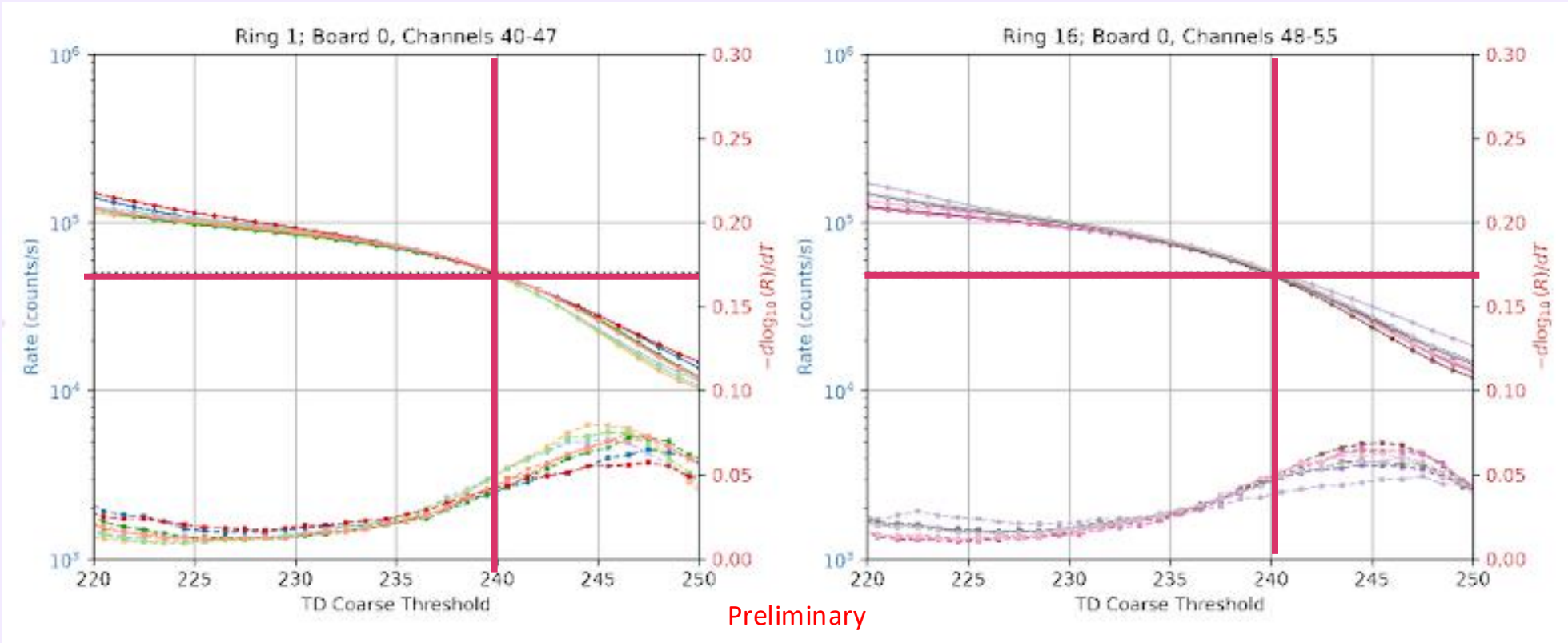
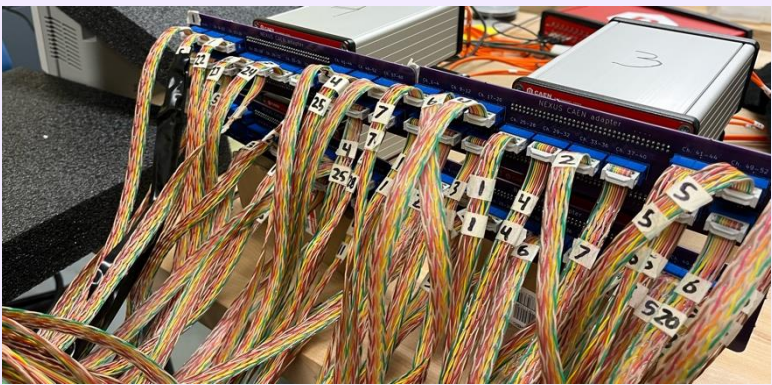
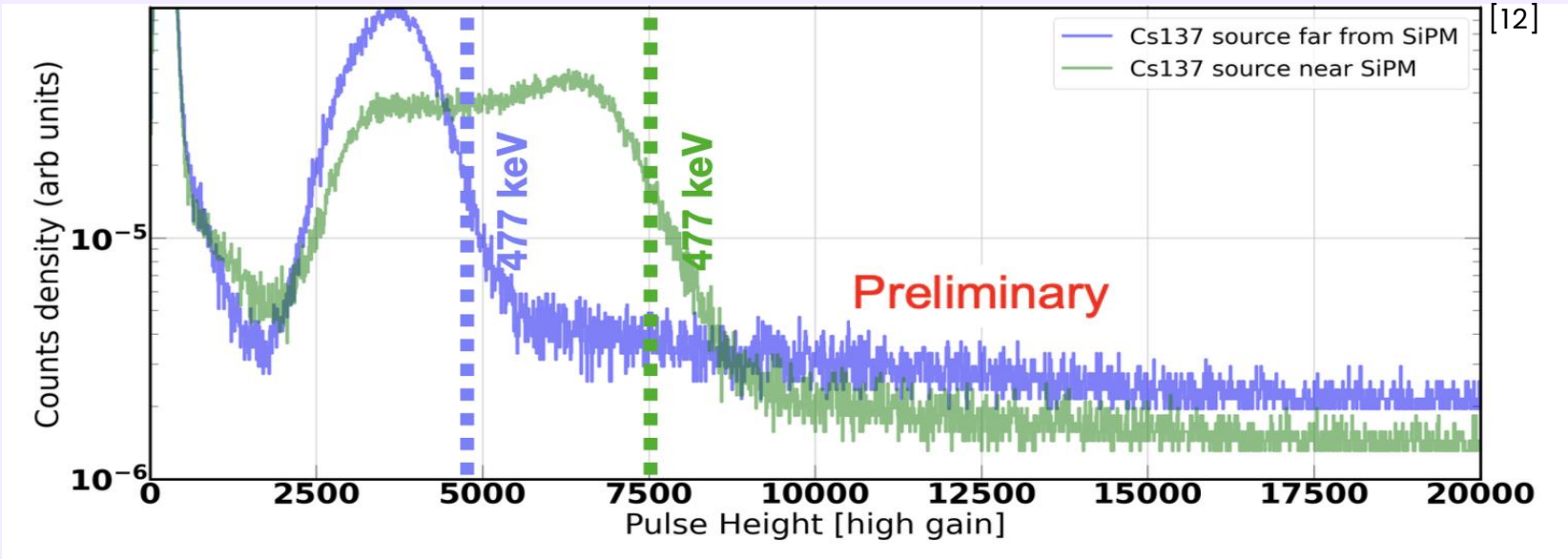


Goal:
Lower threshold and ensure all (~90%) channels cross voltage threshold at the same rate (y-axis position) of $5 \cdot 10^4 \text{ counts} \cdot \text{s}^{-1}$ corresponding to the onset of the 2-photon peak

Goal voltage threshold set for 240

working towards installation

10

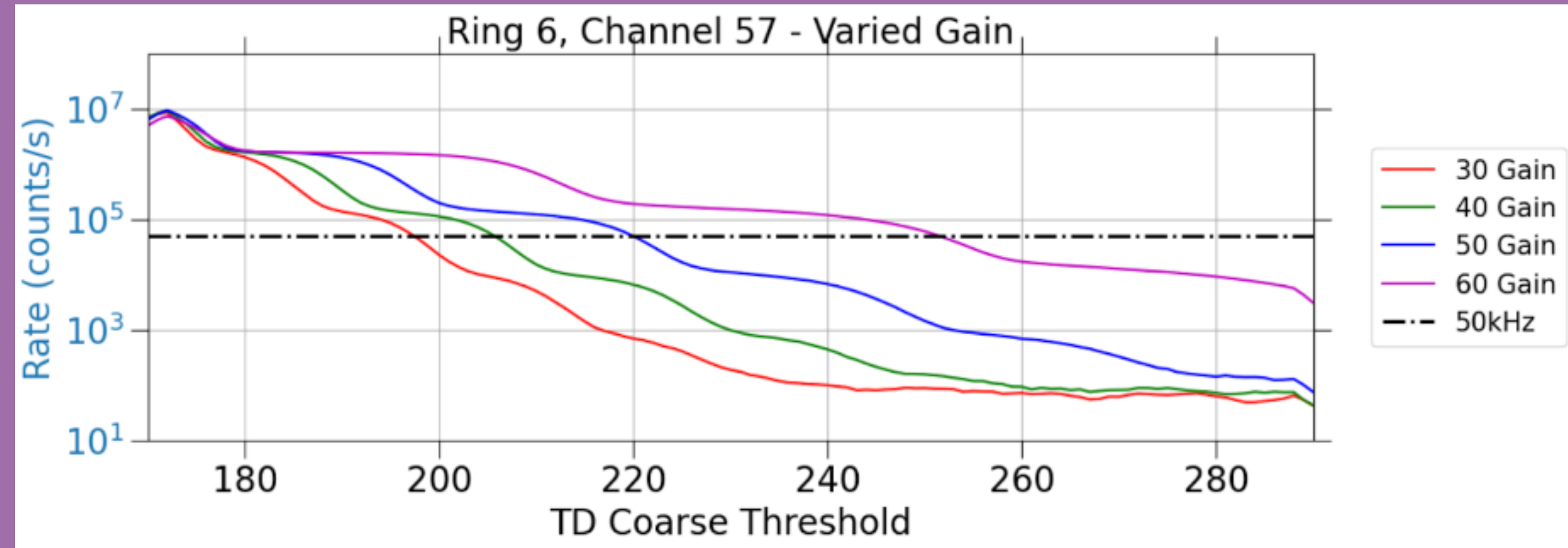


Setting and Gain Optimization

/11

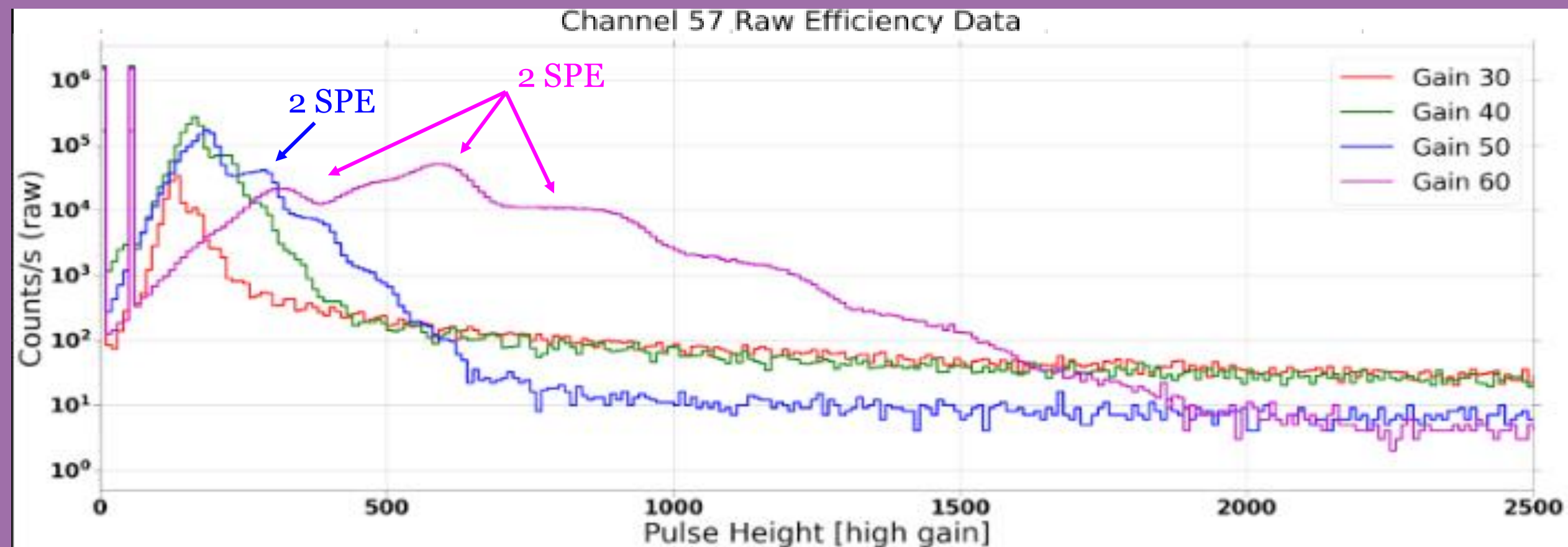
Staircase Sweep →

Goal is to take the TD Course Threshold values where the staircase of each gain crosses 50kHz



Spectroscopy Mode →

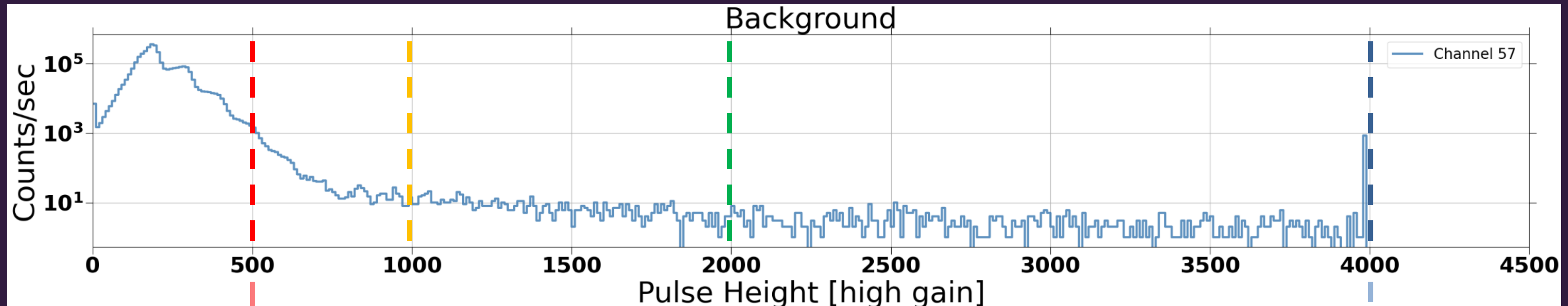
How does the gain affect the resulting spectrum?
50 gain gives us the most resolution without saturating most of the PHA values.



SPE == Single Photon Emission

Picking Source for Collection Eff.

12



$$\frac{\text{photon emission}}{\text{PHA}} = \frac{4 \text{ SPE}}{500 \text{ PHA}} = 0.008 \text{ photons/PHA}$$

**Detector saturation
@ 4096 PHA
== 262 keV**

Assume collection efficiency of ~10%

Then we can directly calculate the energy spectrum that is output as PHA.

Looking for a peak/Compton edge around
1000 PHA or 64 keV

Photon Collection Efficiency

/13



Americium-241 has a peak at 59.4 keV

The source is set beside the SiPM (bottom) and far from the SiPM (top).

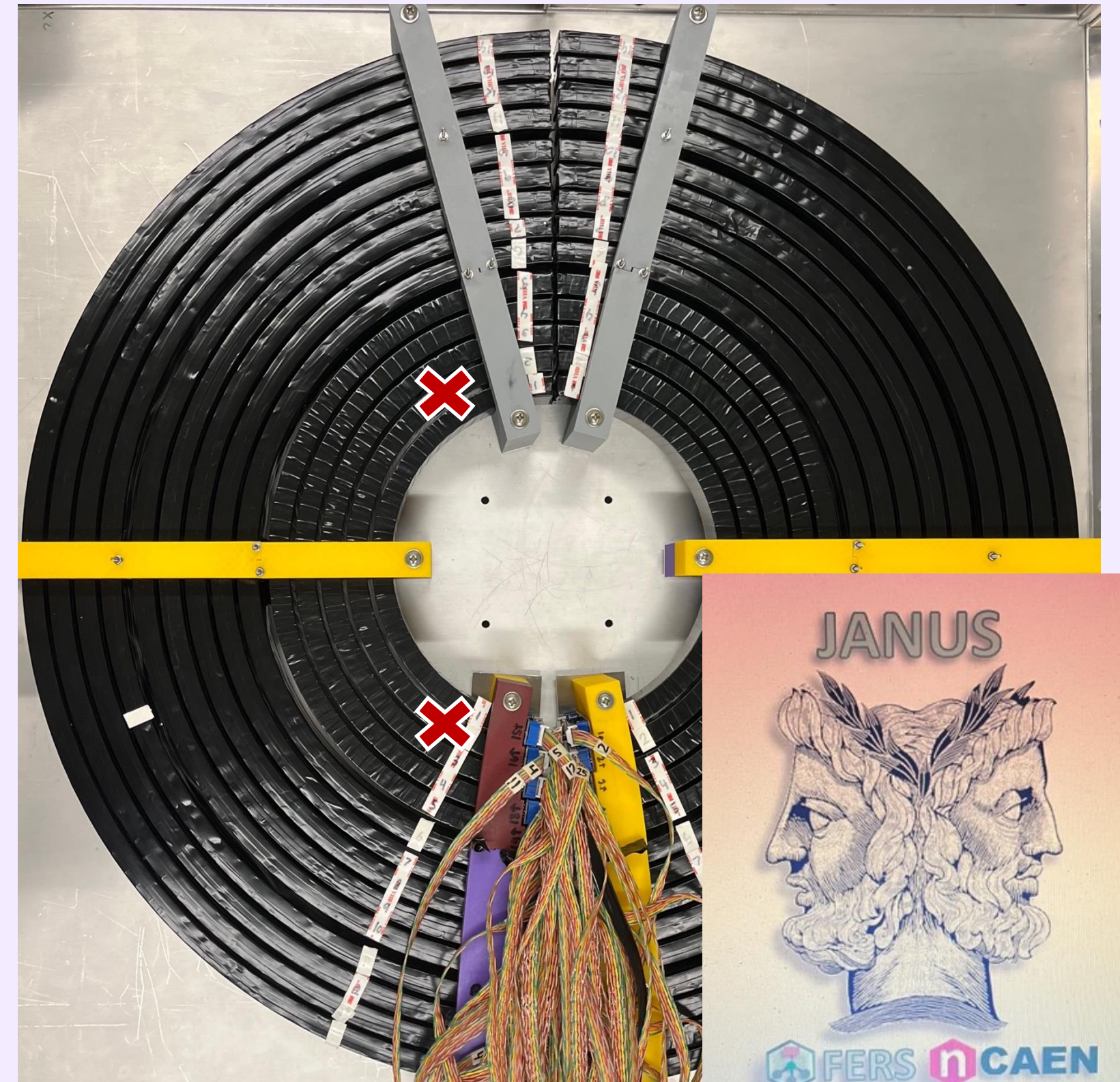
Majority Level 8:

An event will only be catalogued if all 8 channels fire simultaneously

Trigger OR64:

Detector triggers when any single channel receives a count over the set threshold value.

Data taken at gain-50 and gain-10 in Spectroscopy mode via JANUS CAEN software.



future calibration

14

Next steps:

(1) Photon Collection Efficiency

Using spectroscopy mode to identify Americium-241 peak in a single ring spectrum

(2) Timing Mode

Rerun the detector in Timing Mode with oscilloscope trigger to confirm location ID capability

(3) Build Stand Procedure

Construct Backing Array stand on replica and write concrete procedure for installation

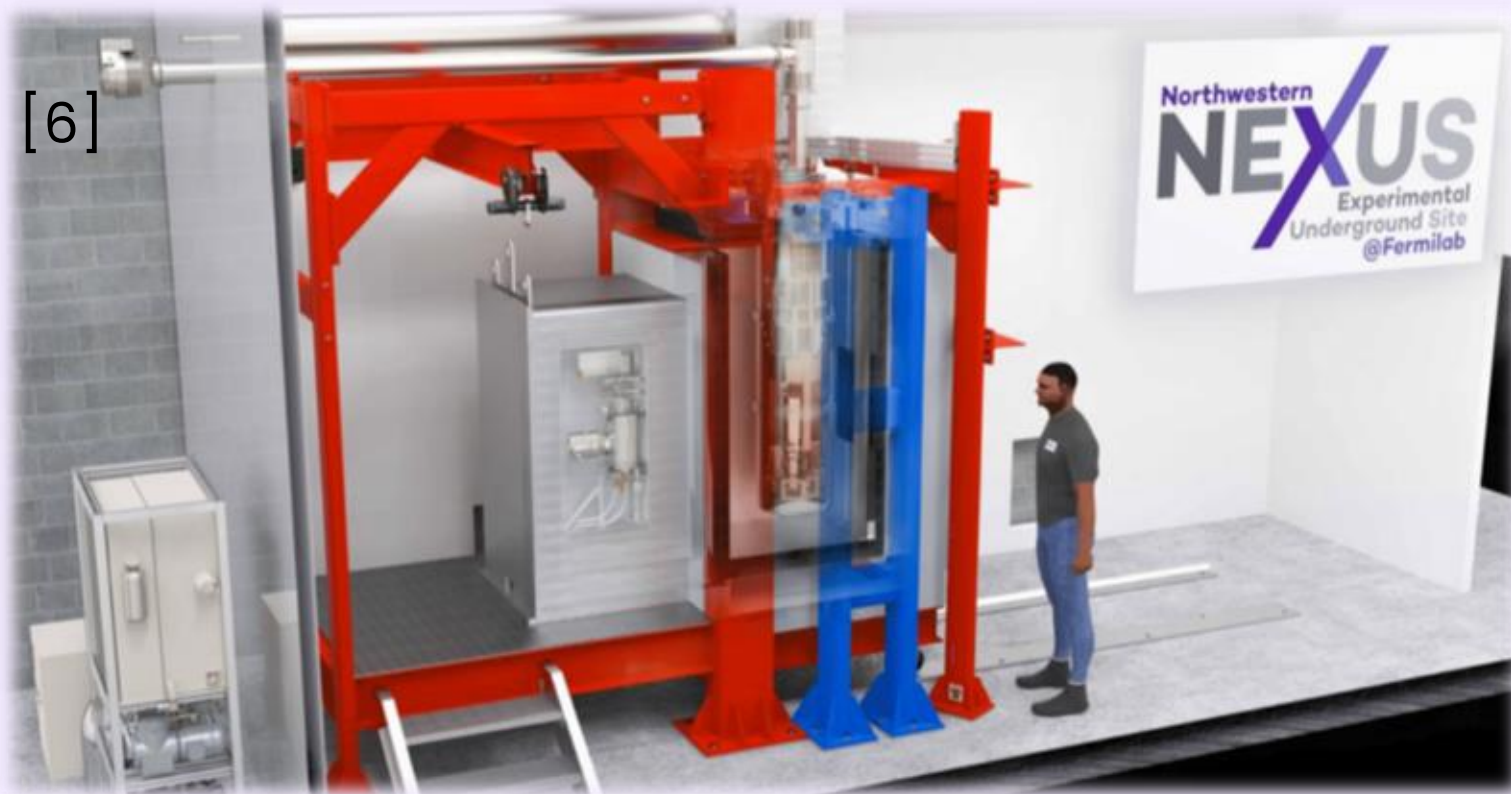
(4) Commission at Fermilab

Transport parts and detector to the underground Batavia site

NEXUS

Northwestern EXperimental Underground Site

Located 100m underground in the MINOS Hall, NEXUS is a custom dilution fridge for calibration of dark matter measurements and retro-fitted for RF payloads [6,7].



SuperCDMS

Gratefully acknowledges support from:



U.S. DEPARTMENT
of **ENERGY**



U.S. National Science Foundation
WHERE DISCOVERIES BEGIN



Arthur B. McDonald
Canadian Astroparticle Physics Research Institute



NSERC
CRSNG

INNOVATION

Canada Foundation
for Innovation

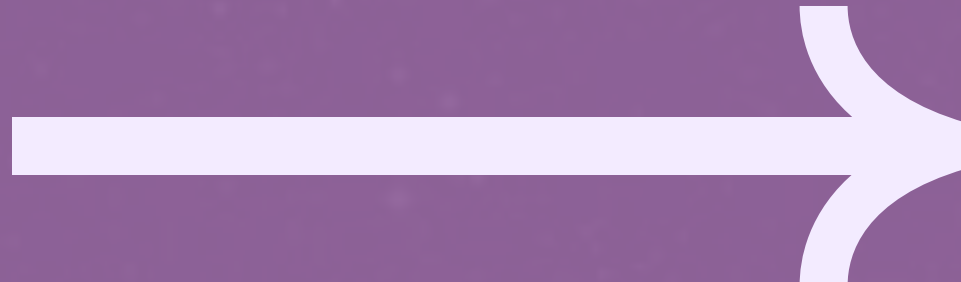
Fondation canadienne
pour l'innovation



Emmy
Noether-
Programm

DFG Deutsche
Forschungsgemeinschaft



Thank 
you! **Any**
questions?

ISABELLA FOTI

References

Dark Frontiers/2026

- [1] Mahapatra Group. CDMS: World Best Sensitivity to WIMPs [Online]. https://people.tamu.edu/~mahapatra/cdms_research.html [07/12/2026].
- [2] T. Lin, in Proceedings of TASI Lectures: Theory in an Era of Data, Boulder, Colorado, 2018.
- [3] C. Hayes, *Progress Towards Measuring the Ionization Yield of Germanium Using a SuperCDMS-Style HV Detector at NEXUS* in Proceedings of the APS March Meeting, Batavia, Illinois, 2026.
- [4] J. Xu, P.S. Barbeau, and Z. Hong, Annu. Rev. Nucl. Part. Sci. **73**: 95–121 (2023). [published]
- [5] ELJEN Technology. General Purpose: EJ-200, EJ-204, EJ-208, EJ-212 [Online]. 2021. <https://eljentechnology.com/products/plastic-scintillators/ej-200-ej-204-ej-208-ej-212> [07/12/2026].
- [6] D. Baxter, *Development of new techniques for low-mass dark matter detection* in Proceedings of GUINEAPIG Workshop on Light Dark Matter, Vancouver, British Columbia, 2022.
- [7] Hollister, H. *et al.* (SQMS Collaboration), *A Review of Ultralow Temperature and Low Background Facilities at Fermilab* in Proceedings of SQMS Quantum Science March Meeting, London, England, 2024.
- [8] S. Fallows, Ph.D. thesis, Univ. of Minnesota, 2014.
- [9] C.H. Fang, S.T. Lin, S.K. Liu, H.T.K. Wong, H.Y. Xing, L.T. Yang, Q. Yue, and J.J. Zhu, Phys. Rev. D **112** (2025). [published].

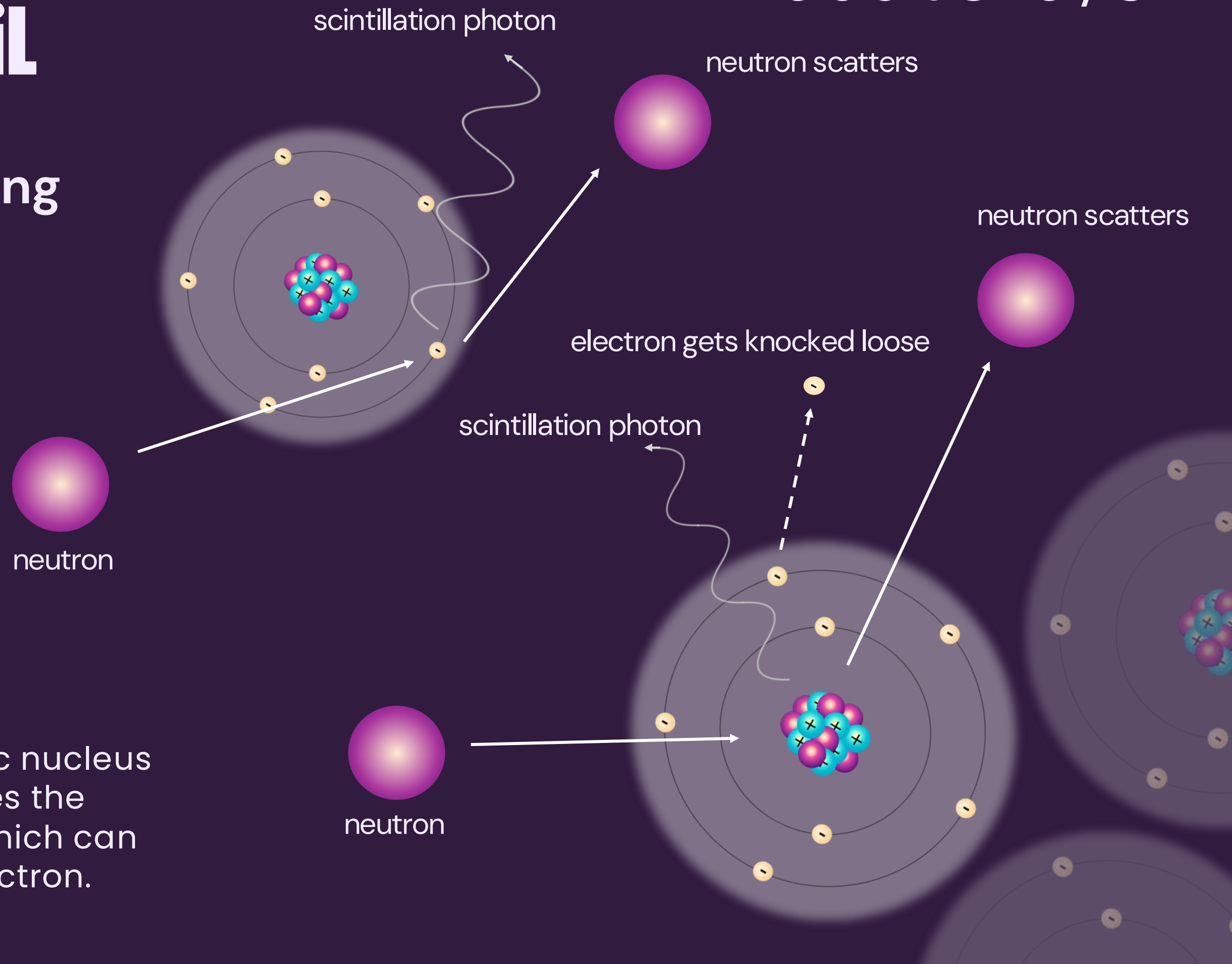
Electron Recoil

Neutron-Electron Scattering

Happens due to magnetic dipole interaction ~ also called magnetic scattering.

Migdal Scattering

IA sudden collision and recoil of atomic nucleus by a fast-moving neutron which causes the electron cloud to become disturbed which can cause the ejection/excitation of an electron.



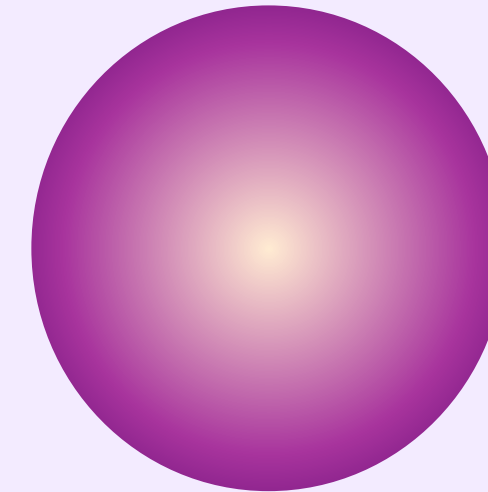
Calibrating for something we can't detect, with something we can

additional/02

Neutron

Characteristics:

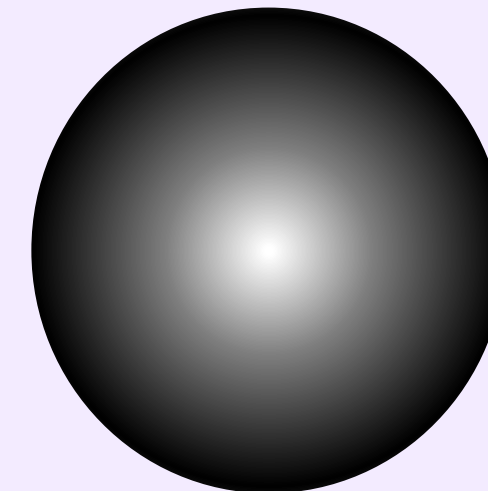
- Chargeless
- Interacts via gravity and the weak nuclear force



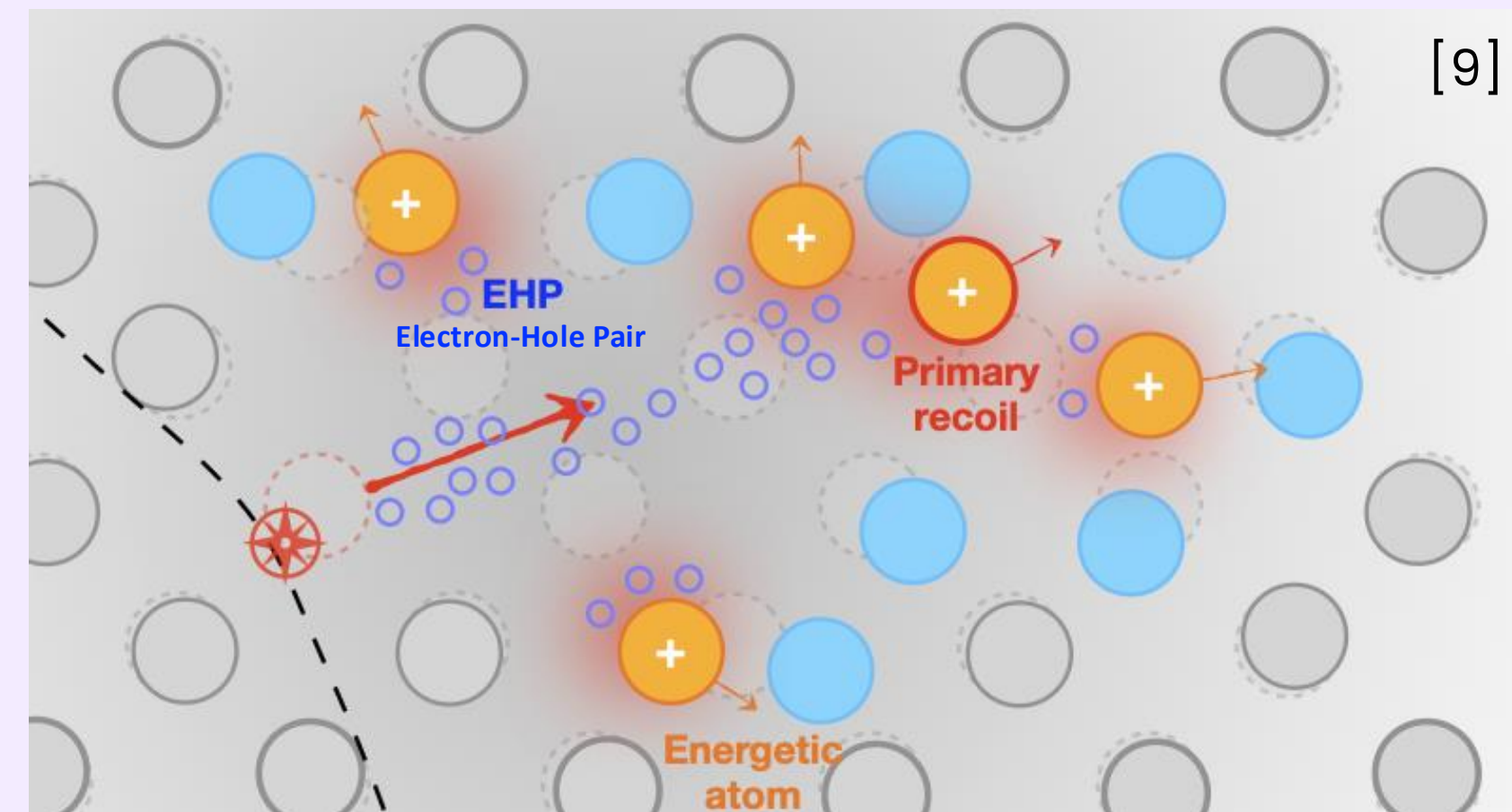
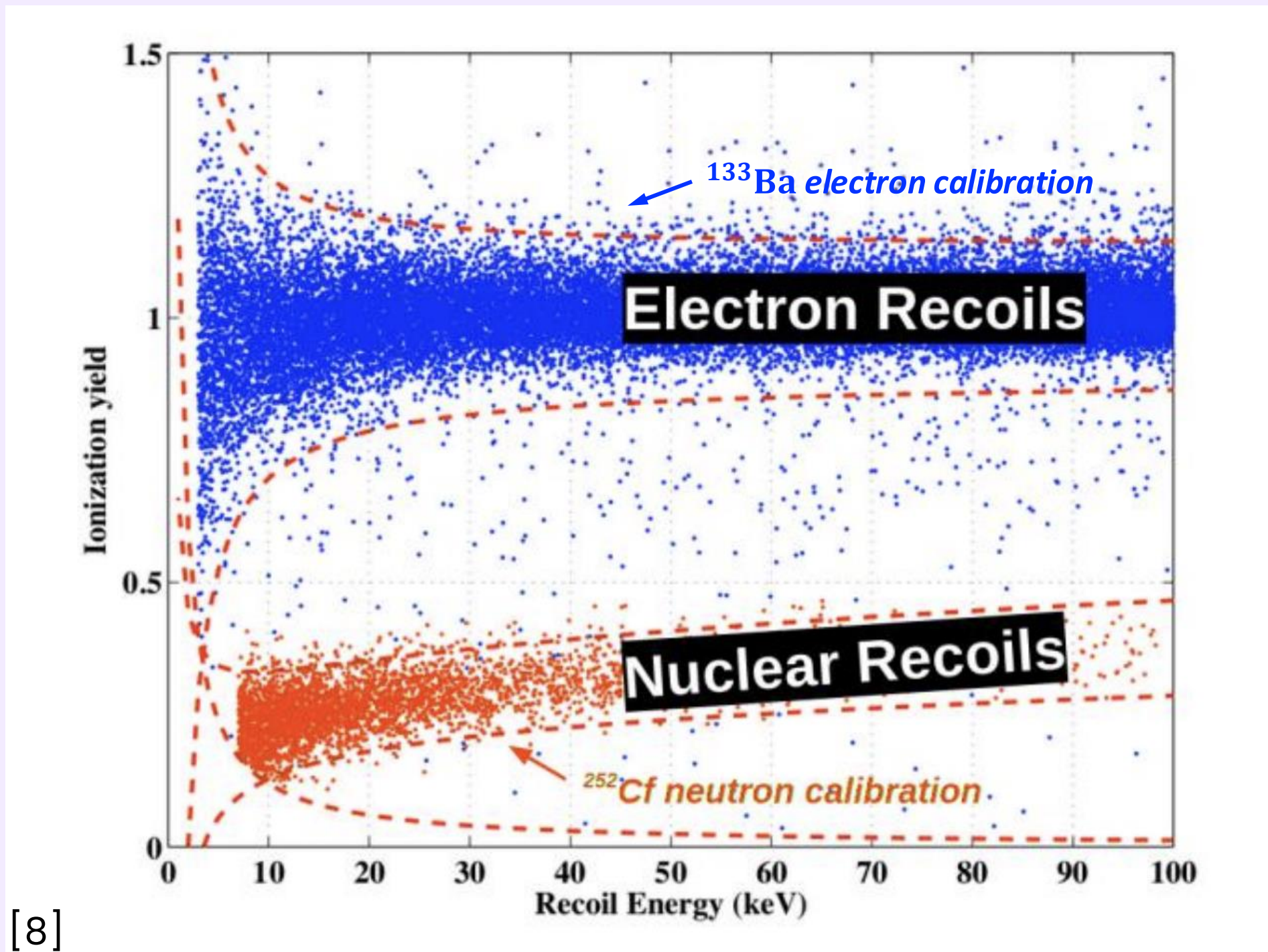
Weakly Interacting Massive Particle

Theoretical characteristics:

- Chargeless
- Interacts with SM particles via gravity and/or weak-scale forces

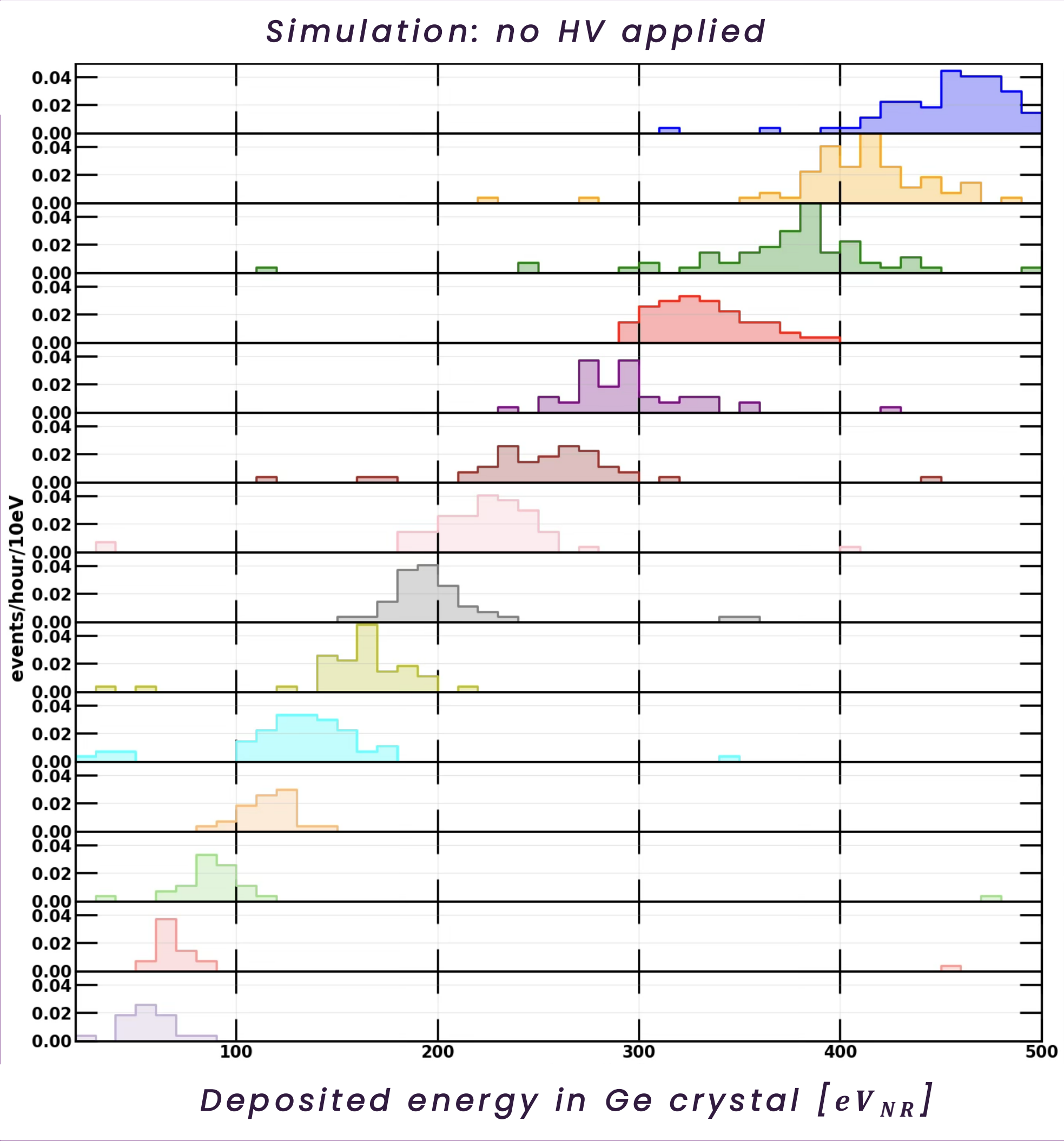


We've cascaded our energy away... additional/03



...and our NR signal is drowned in electrons!

Ionization yield
preliminary
simulation



additional/04

6.2°

5.9°

5.5°

5.2°

4.9°

4.6°

4.3°

4.0°

3.7°

3.3°

3.0°

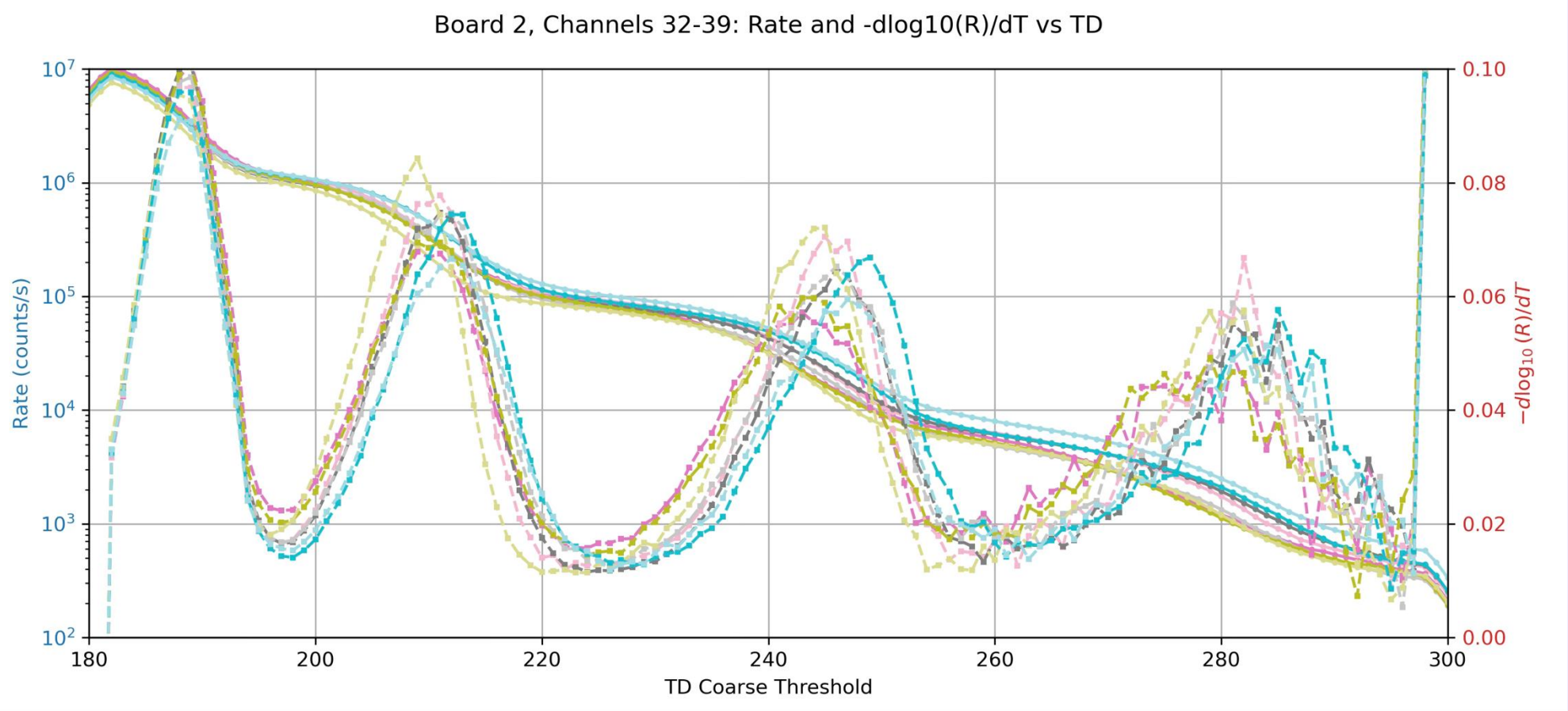
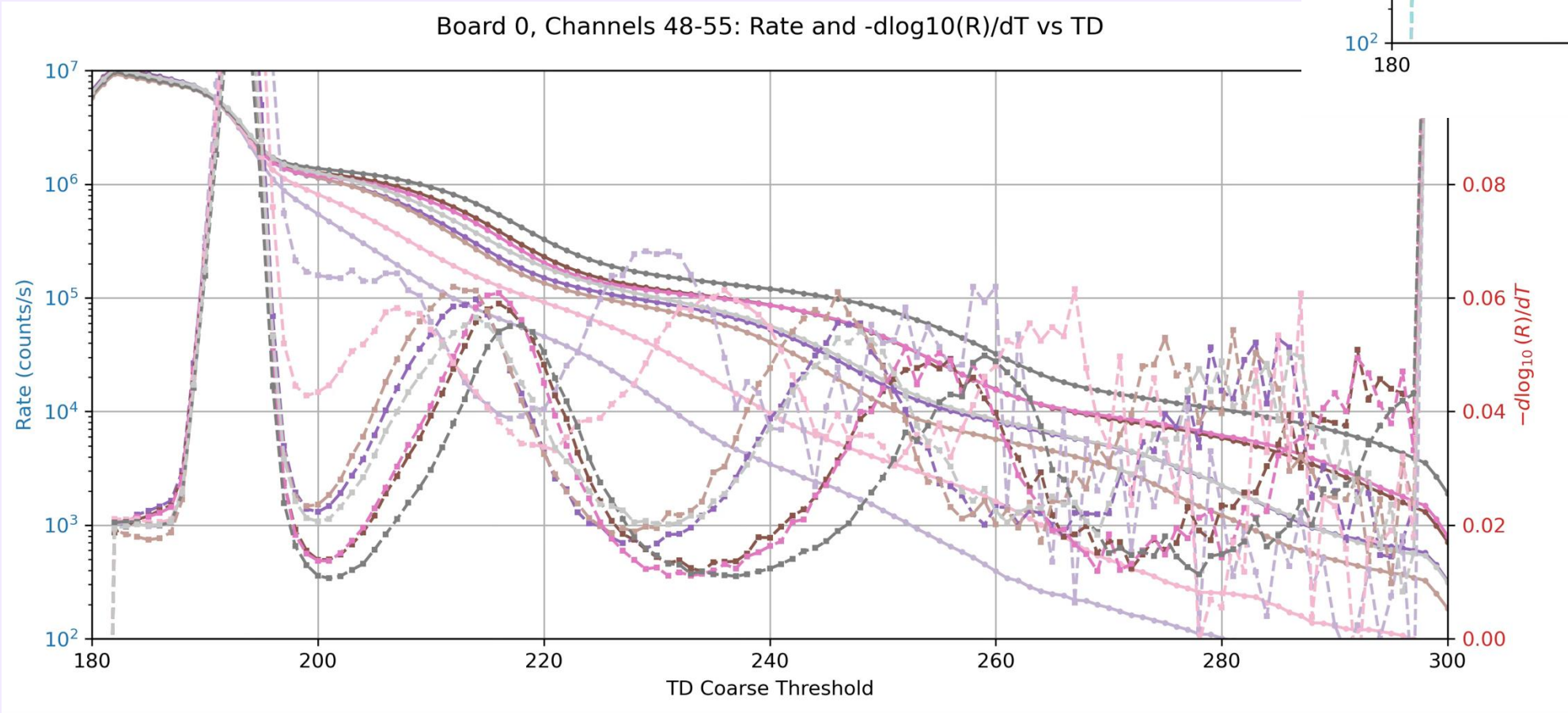
2.7°

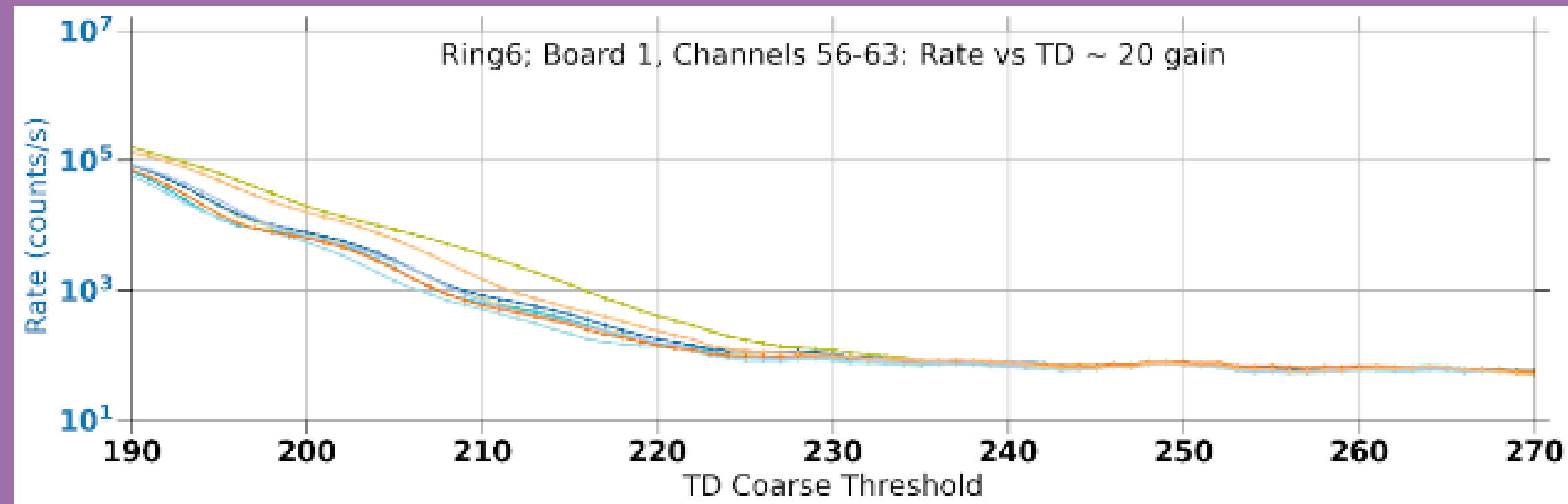
2.4°

2.0°

Very much needed voltage tuning

additional/05

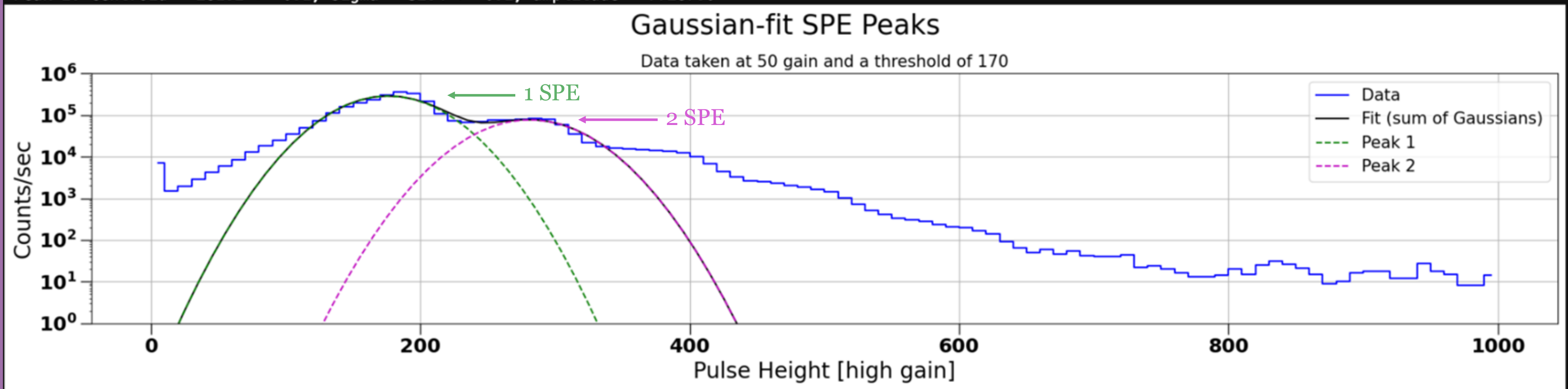




Gaussian fitting

additional/07

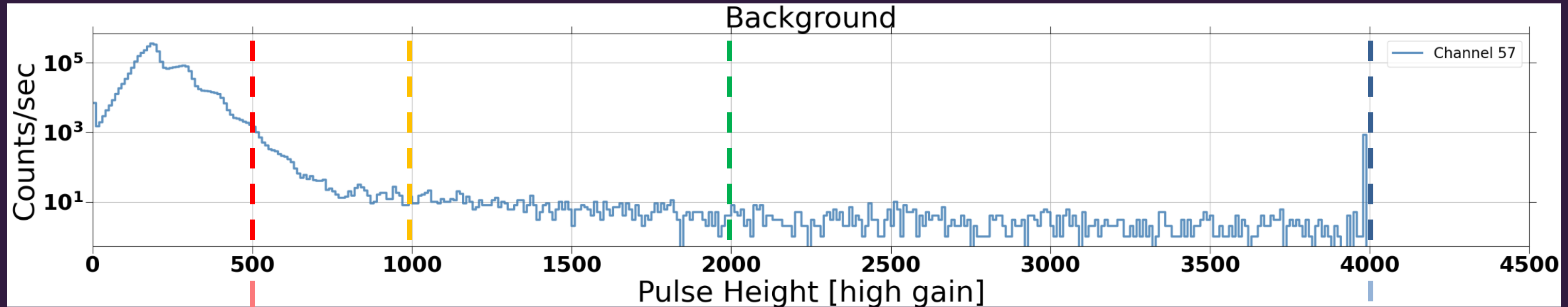
Candidate peak locations: [185. 285.]
Candidate peak heights: [365606. 84345.]
Peak 1: centroid = 176.0 $\pm$ 0.0, sigma = 31.0 $\pm$ 0.0, amplitude = 288530.3
Peak 2: centroid = 281.2 $\pm$ 0.1, sigma = 32.4 $\pm$ 0.1, amplitude = 77287.0



Threshold set @ 170 keV_{NR}

Americium-241 Calculations

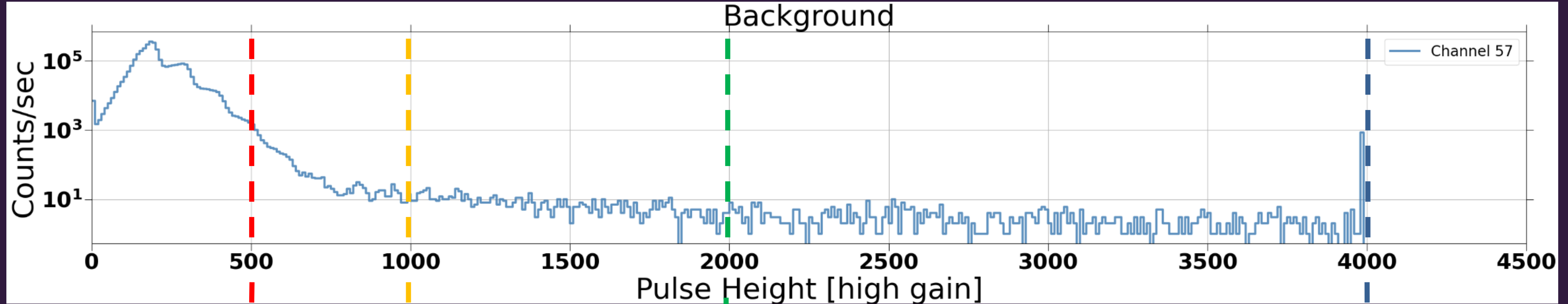
additional/08



$$\frac{\text{photon emission}}{\text{PHA}} = \frac{4 \text{ SPE}}{500 \text{ PHA}} = 0.008 \text{ photons/PHA}$$

Detector saturates @ 4096 PHA, with this value, our assumed collection efficiency of ~10%, and the conversion factor of 10 *photons/keV* we can find the energy of this saturation point.

$$\begin{aligned} & \frac{\text{photons read}}{\text{counts/s}} \cdot \text{counts} \cdot \frac{\text{actual photons}}{\text{photons read}} \cdot \frac{\text{keV}}{\text{actual photons}} \\ &= \frac{4 \text{ SPE}}{500 \text{ PHA}} \cdot 4096 \text{ counts} \cdot \frac{10 \text{ actual photons}}{1 \text{ read photon}} \cdot \frac{1 \text{ keV}}{10 \text{ actual photons}} = 262.144 \text{ keV} \end{aligned}$$



$$\frac{\text{energy}}{500 \text{ counts}} = \frac{262.144 \text{ keV}}{4096 \text{ counts}}$$

$$\text{energy} = 32 \text{ keV}$$

$$\frac{\text{energy}}{1000 \text{ counts}} = \frac{262.144 \text{ keV}}{4096 \text{ counts}}$$

$$\text{energy} = 64 \text{ keV}$$

$$\frac{\text{energy}}{2000 \text{ counts}} = \frac{262.144 \text{ keV}}{4096 \text{ counts}}$$

$$\text{energy} = 128 \text{ keV}$$

$$\text{energy} = 262.144 \text{ keV}$$

If we want to see a photo-peak or Compton edge around 1000 (a semi-arbitrary choice), we need a source with a peak ~ 64 keV which matches with an Americium-241 source, having a peak at 59.4 keV. With a gamma branching ratio of $\sim 36\%$ we can find the ideal energy output/size of the source.

Am-241 Calculations cont.