Improvements to the Technique for Measuring Low-Temperature Scintillation Properties

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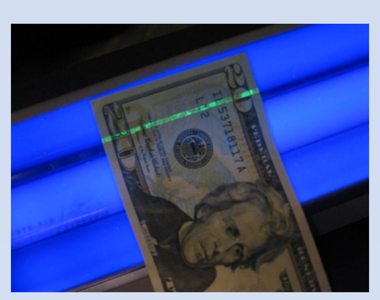
Background & Goal

I re-designed an experimental setup for measuring the scintillation properties of Bismuth Germanate (BGO) **and Cerium-doped Gadolinium Aluminum Gallium Garnet** (GAGG:Ce) **at temperatures approaching absolute zero**, following the failure of our past methodology. This new design allows us to more accurately measure the exact number of photoelectrons measured, with the added benefit of being able to also measure decay time.

The prior state of the art is that BGO has been measured using a method like ours, but only to 4 Kelvin; while GAGG:Ce has only been measured to -10 degrees Celsius. Eventually, this work will be used in ASCENT, a proposed γ-ray observatory to look at supernova remnants thousands of light-years away, and hopefully other high-energy astrophysics missions too.



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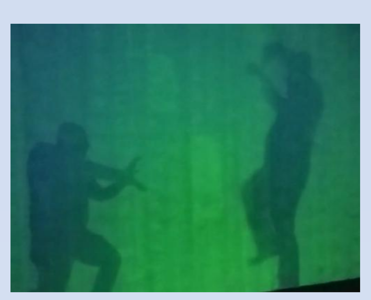

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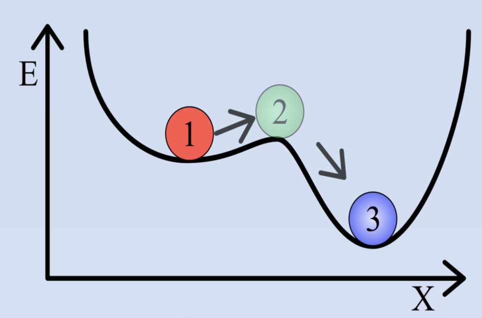

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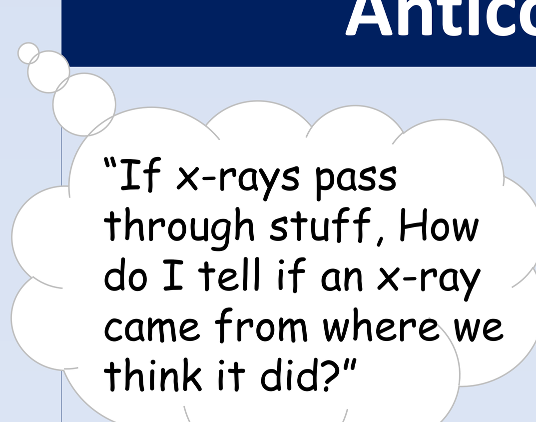
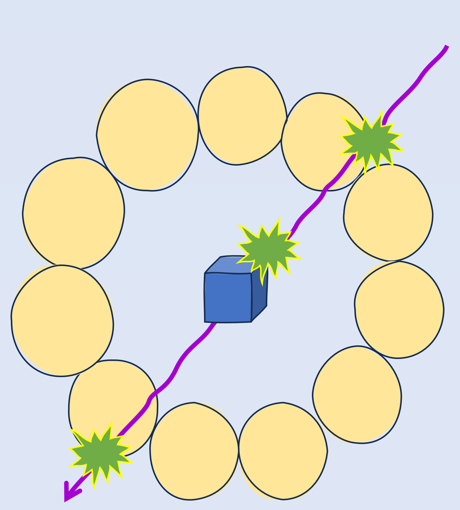
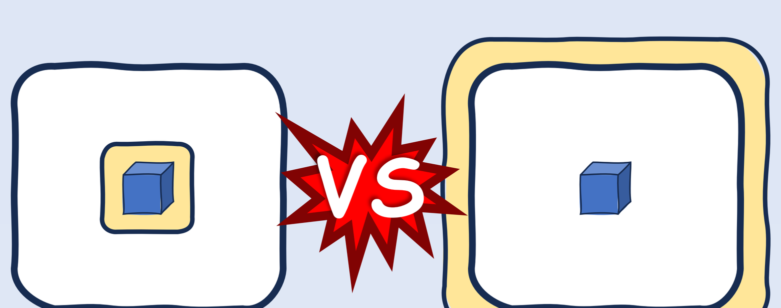
Scintillation is almost the same process as fluorescence and phosphorescence (the difference between the two being the meta-stability of phosphorescence), except with radiation instead of UV light.

Anticoincidence Shielding



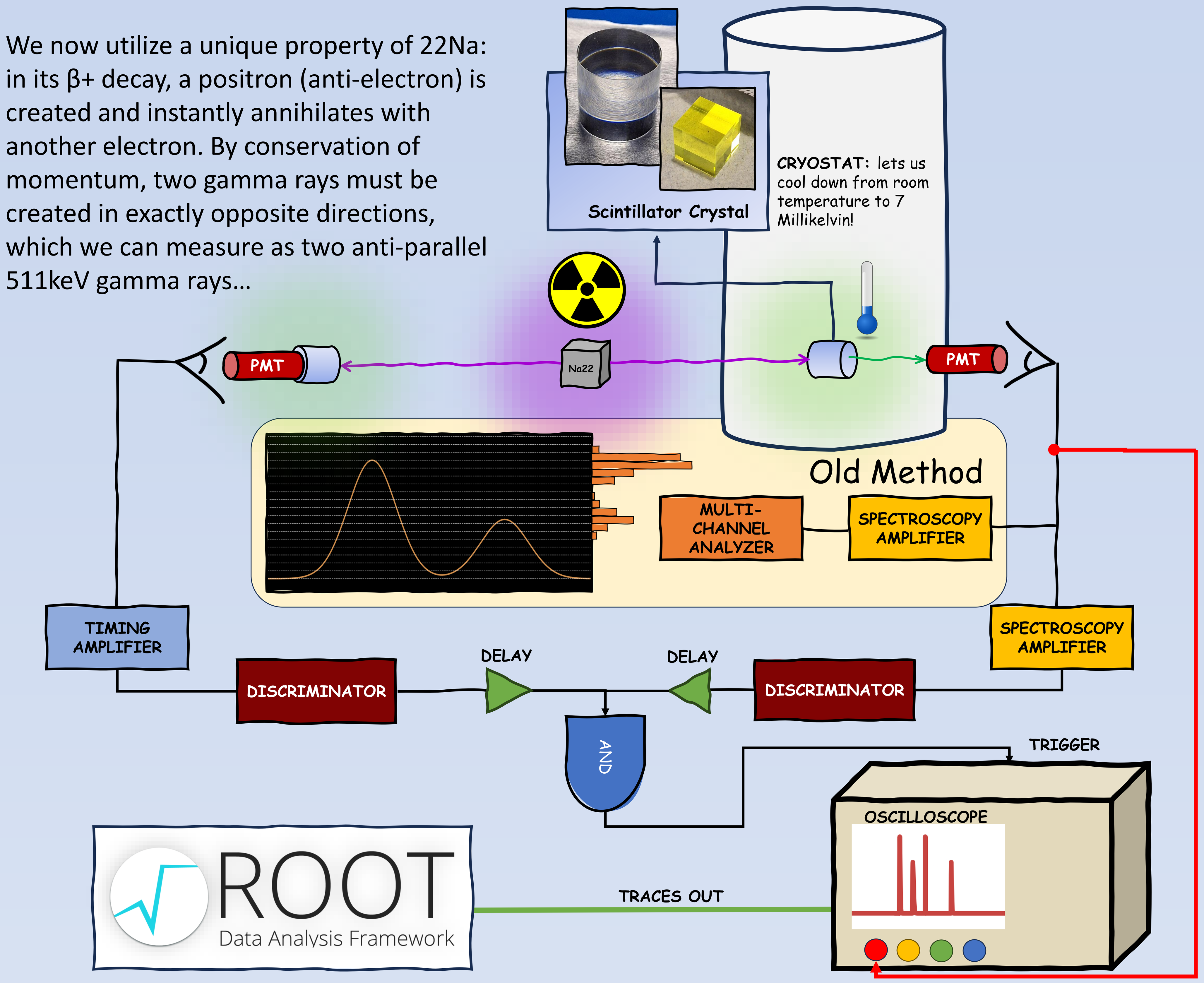
We just need to notice them! Scintillators light up when struck by high-energy radiation. If we detect this light, then we can mark a possible event as "background". If we note all the times when a "hit" was likely just a stray x-ray, we can reduce this residual background! However, scintillators are heavy, and our sensitive Transition Edge Sensors (TESs) must be in a cryostat to work. Can we also put scintillators in there? Will they still be effective? This is the question we try to answer.



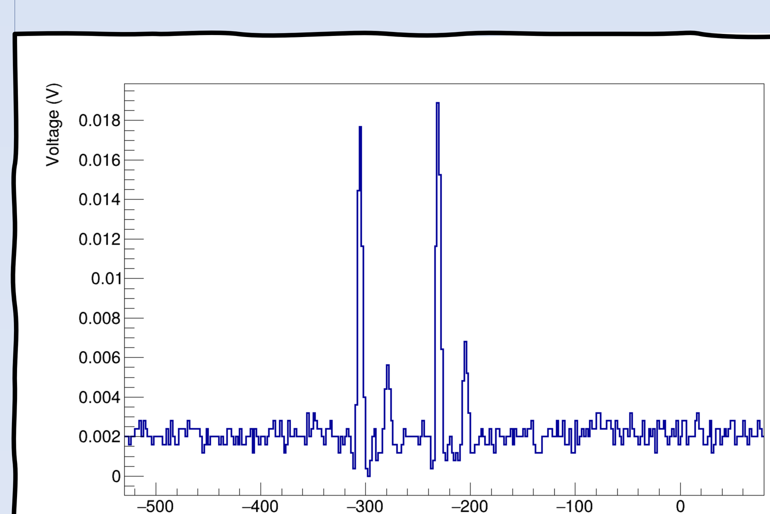


Old vs. New Experimental Setup

We now utilize a unique property of 22Na: in its β+ decay, a positron (anti-electron) is created and instantly annihilates with another electron. By conservation of momentum, two gamma rays must be created in exactly opposite directions, which we can measure as two anti-parallel 511keV gamma rays…

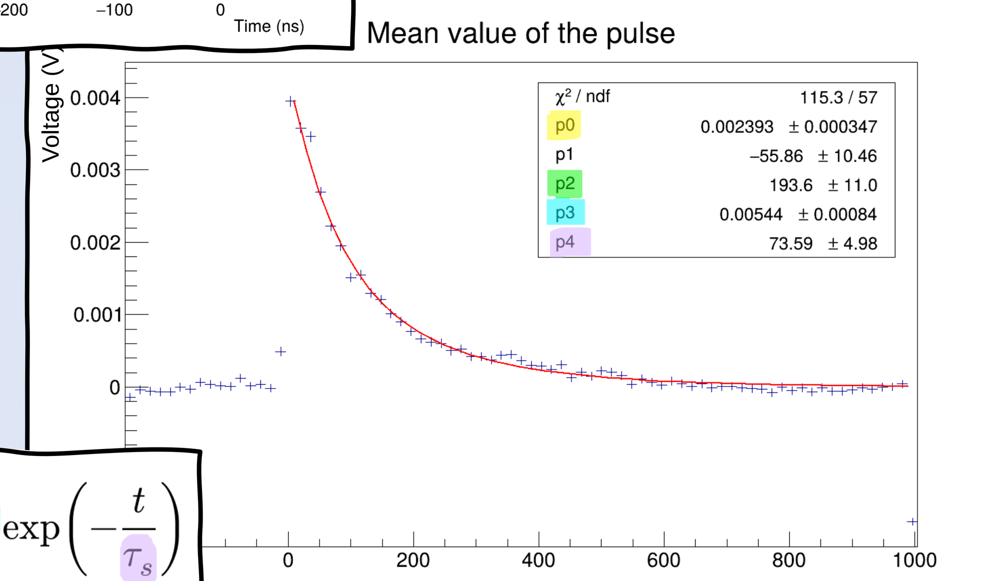


Preliminary Results

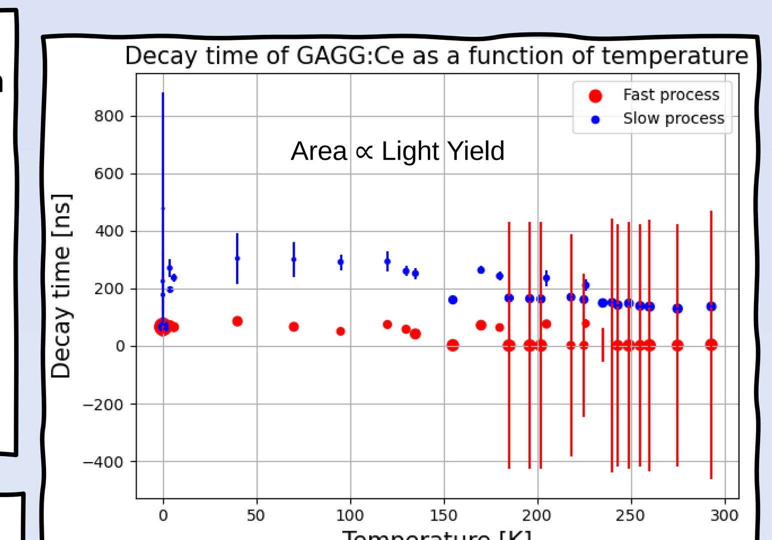


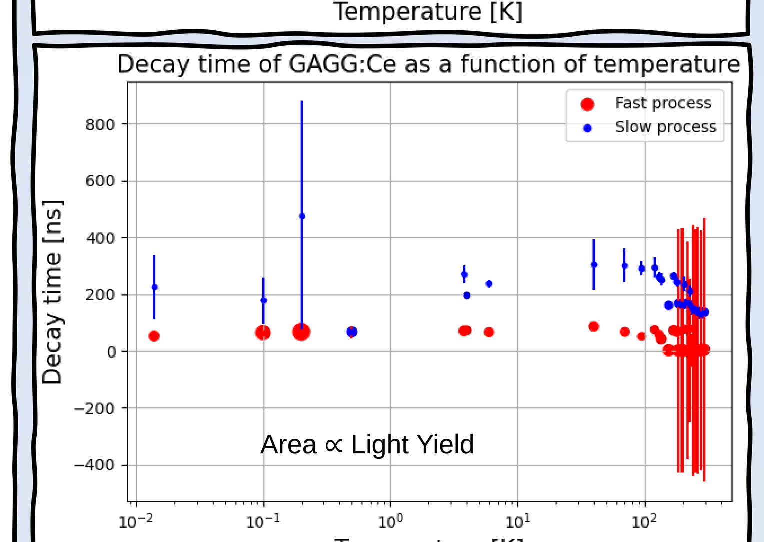
Gracious credit to Merlin Kole for running the experiment and getting me started with the data analysis.
Each oscilloscope trace (such as this one to the left) doesn't mean much on its own. Each peak represents only a single photon! However, when we time-sync these photon pulses to the other PMT, catching the other 511keV photon, we can reconstruct the full picture (below).

Mean value of the pulse



$$N = A\exp\left(-\frac{t}{\tau_f}\right) + B\exp\left(-\frac{t}{\tau_s}\right)$$





Interpretation

- GAGG:Ce's decay time remains stable (same order of magnitude) over broad temperature ranges, making it a viable material for anticoincidence shielding at superconducting temperatures.
- Between 150 Kelvin and 125 Kelvin, there is an increase in decay time for both the slow and fast components of GAGG:Ce. The measurement of this phenomenon is new, so the interpretation of this is yet unknown.

Future work

- We also collected enough data to reconstruct the light yield of GAGG:Ce, but we have not done the formal analysis of that yet. (It seems to be consistent enough to call GAGG:Ce a very promising candidate for ASCENT anyways.)
- We had trouble measuring BGO with the old method before due to its long decay time
  - We likely need to adjust the new method to make the BGO measurement – only so many photons will fit in a single scope trace
  - Measurement will also take more time due to slower event rate
- Getting scintillators to work inside of the cryostat is step one. Getting light detectors inside the cryostat without creating too much heat is the next step.
  - We have been investigating the silicon photomultiplier NUV-HD-Cryo SiPM, and we know that it works. Another undergraduate, Zach Greenberg, is working on the combined GAGG:Ce and SiPM together in the same system.

References

Kislat, Fabian, et al. *ASCENT - A Balloon-Borne Hard X-Ray Imaging Spectroscopy Telescope Using Transition Edge Sensor Microcalorimeter Detectors*. 2023. *DOI.org (Datacite)*, https://doi.org/10.48550/ARXIV.2301.01525.

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Acknowledgements: I would like to offer my most sincere gratitude to Dana Hamel (as this project was funded by the Undergraduate Research Award, possible due to his donations), Kasun Wimalasena and Adrika Dasgupta for their help handling the radioisotope sources, Jason Legere for offering his expertise in PMT spectroscopy, Fabian Kislat for the guidance and opportunity to do this work, and Merlin Kole for doing the measurements over the course of last semester.