Low-Temperature Luminescence of Plastic Scintillators for use in Particle Detectors

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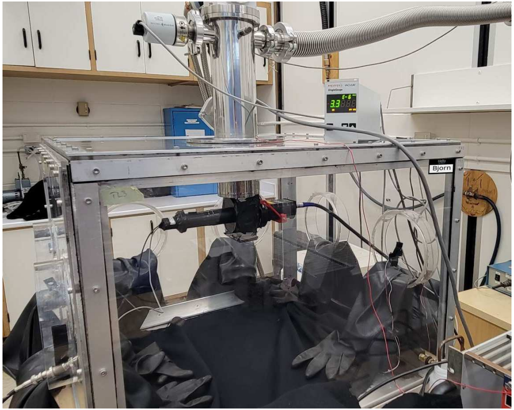
Introduction To Cryogenic Tests of Scintillators

- Scintillation is a temperature dependent property, as such the temperature-dependent scintillation of scintillators should be quantified.
- Many inorganic scintillators have an temperature dependent light yield, typically at cryogenic temperatures.
- Organic polymers, such as acrylic, have a temperature dependent fluorescence with peaks at cryogenic temperatures.
- The light yield of plastic scintillators has not been widely studied at cryogenic temperatures. Experiments such as NUCLEUS [1] use PSC at cryogenic temperatures.
- All plastic scintillators used are EJ-200 from Eljen Technologies.

Optical Cryostat



- **Cryostat used for:** PSC α
- **Temp Range:** 300 K $\rightarrow$ 4 K

- **Cryostat used for:** PSC γ
- **Temp Range:** 300 K $\rightarrow$ 10 K

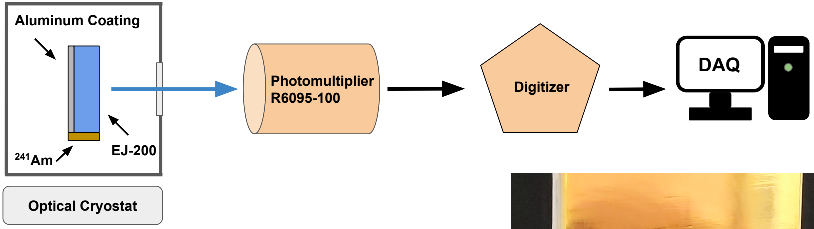
PSC - Samples

A **B** **C**

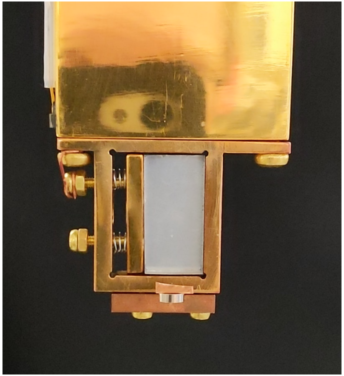
A: PSC with aluminium for α study. **B:** Small cylinder for table top γ. **C:** Large cylinder for cryostat γ.

α Measurements

PSC - α measurement Apparatus

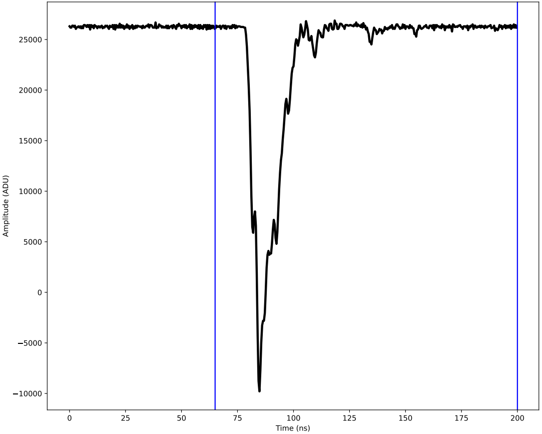


- **Top:** Schematic diagram of the apparatus used for the α particle measurements.
- **Right:** Plastic scintillator in a holder with an ^{241}Am source attached to the bottom of the source holder.



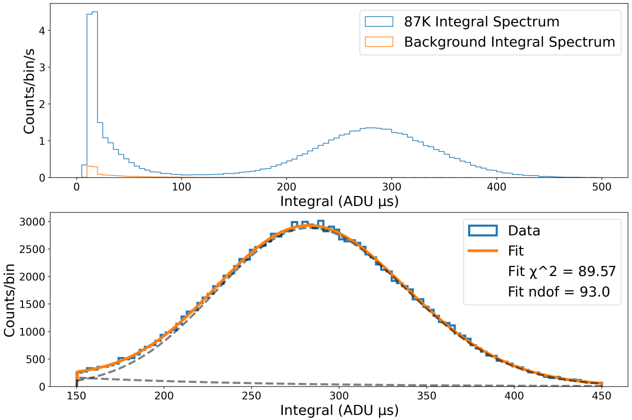
PSC - α Measurement Pulses

- Sample pulse for plastic scintillators under α excitation. Integration region is shown by the two vertical lines.



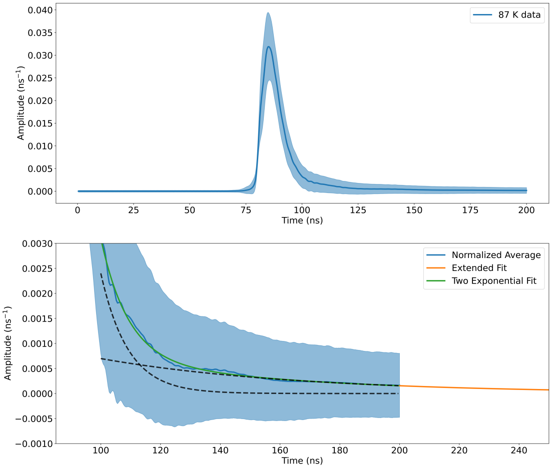
PSC - α Measurement Analysis

- Integral distribution of the EJ-200 with α excitation and background with no source.
- Main α peak is fit with a skew normal distribution plus an exponential background.
- Mean of the normal distribution is used for the light yield of the plastic scintillator at a given temperature.

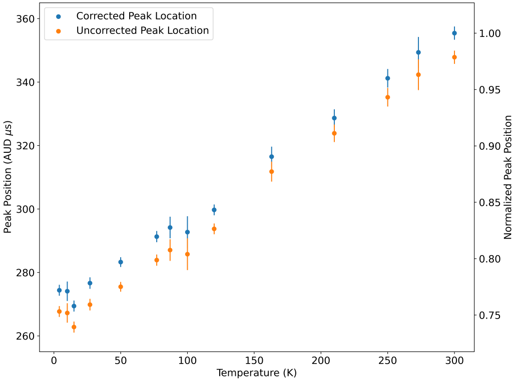


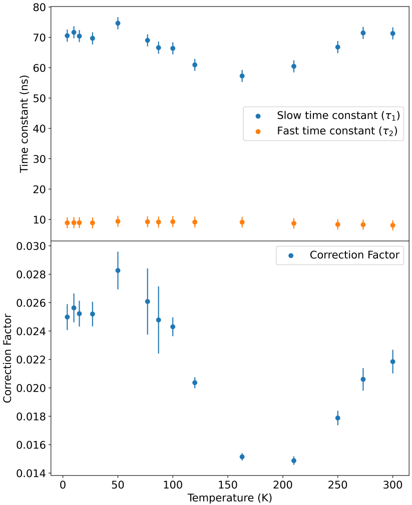
PSC - α Measurements Average Pulse

- Average pulse of α events.
- Due to short acquisition window (200 ns), the full event was not captured. A correction factor was determined by extrapolating a fit of the tail of the pulse.
- Tail was fit with a sum of two exponentials. One for the fast scintillation component, and one for the slow scintillation component.



PSC - α Analysis Results

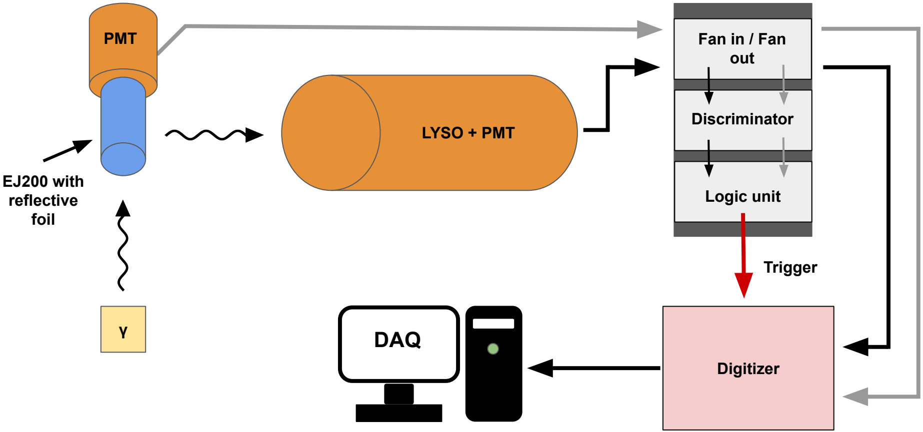




- Location of the mean with and without the correction factor.
- Time constants, and correction factors for each temperature.

γ Measurements

PSC - γ Measurement Table Top Apparatus

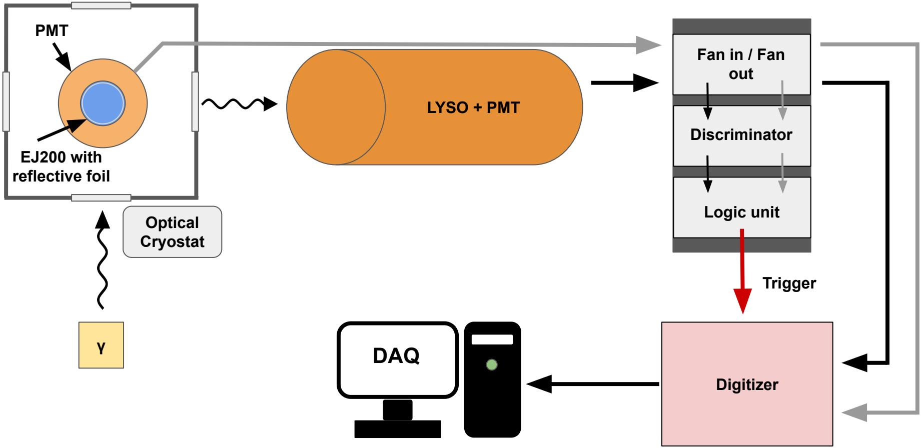


Schematic diagram of the apparatus used for the table top Compton Scattering.

PSC - γ Measurements Table Top Apparatus

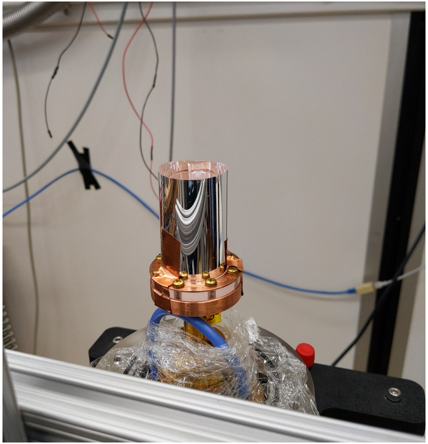
- Picture of the table top γ apparatus.

PSC - γ Measurements Cryostat Apparatus



Schematic diagram for the apparatus used for cryostat Compton scattering

PSC - γ Measurements Cryostat Appatatus

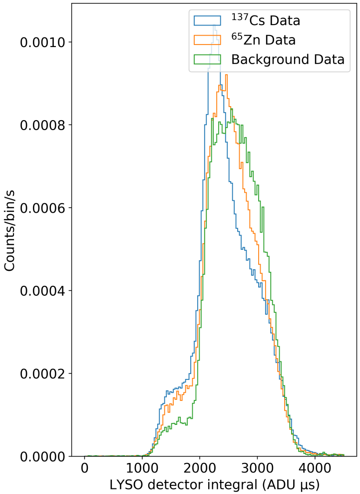


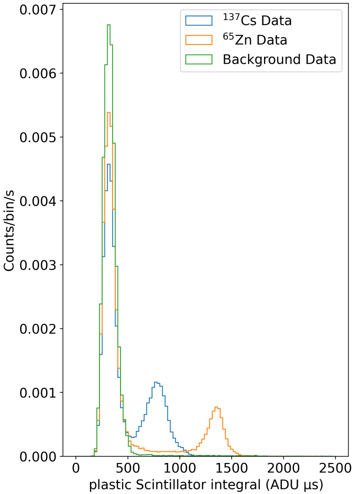
PSC in cryostat surrounded by teflon tape and reflective foil.

Cryostat fully assembled with LYSO outside the cryostat.

PSC - γ Compton Scattering Analysis Table top 1

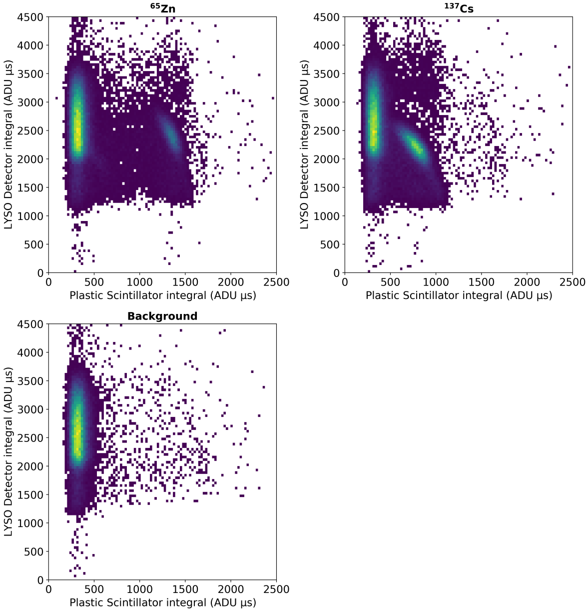
- Integral distribution of the table top Compton scatter experiment.





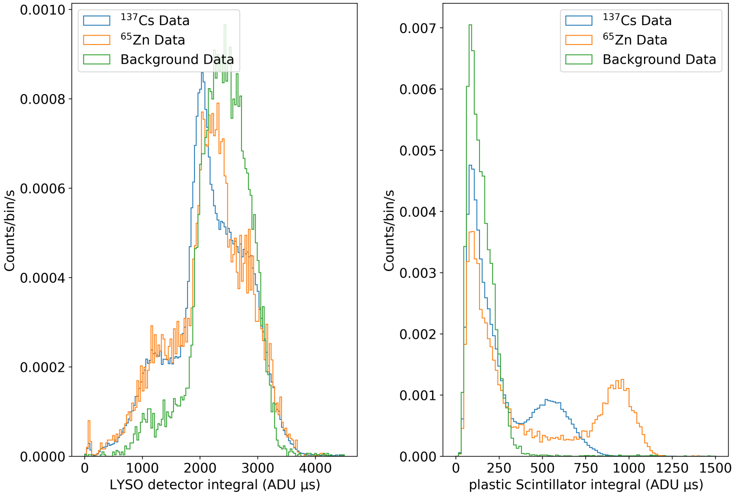
PSC - γ Compton Scattering Analysis Table top 2

- 2-dimensional integral distribution of the table top Compton scatter experiment.



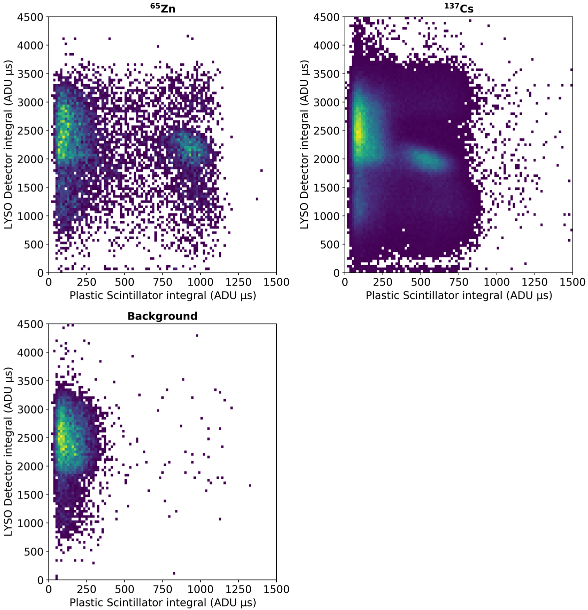
PSC - γ Compton Scattering Analysis Cryostat 1

- Integral distribution of the cryostat Compton scatter experiment.



PSC - γ Compton Scattering Analysis Cryostat 2

- 2-dimensional integral distribution of the cryostat Compton scatter experiment.



Summary and Conclusion

- Plastic scintillators under α excitation see a decrease in light yield when temperature decreases.
- Compton scattering experiments produce good results using table top method and the room temperature cryostat.
- A new inner shroud is being manufactured and once received, a full cryostat run will be completed.

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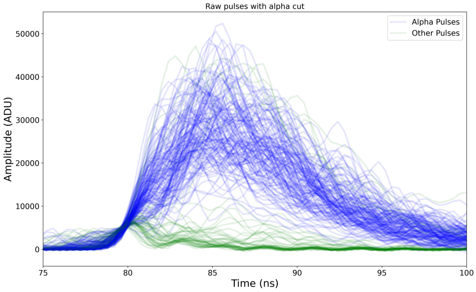
References I

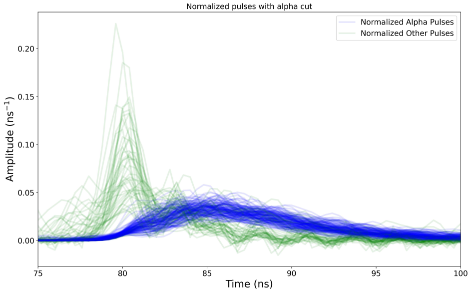
[1] A. Erhart et al. "Development of an Organic Plastic Scintillator-based Muon Veto Operating at Sub-Kelvin Temperatures for the NUCLEUS Experiment". In: *Journal of Low Temperature Physics* 209 (2022), pp. 346–354. DOI: https://doi.org/10.1007/s10909-022-02842-5.

Backup Slides

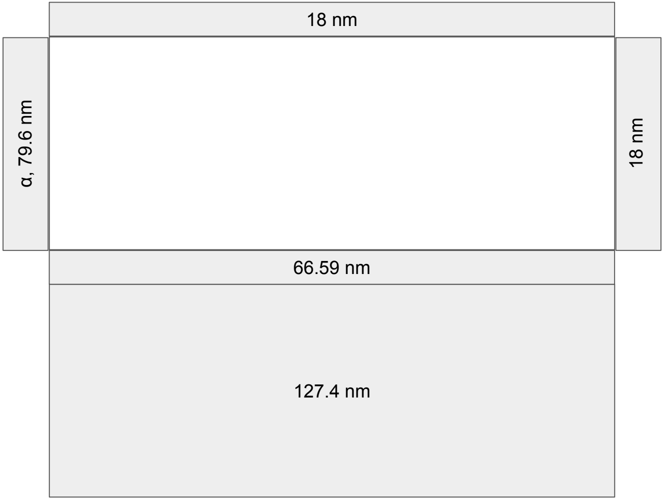
PSC - α Measurement Average Pulse

- Average pulses are created for α events.
- α events are determined by the mean of the skew normal distribution.
- Average pulses can be used to determine the decay constants for the scintillator.
- Blue: Random sampling of events that have an integral within 2σ of the mean. Green: Random sampling of events that fall outside this range.





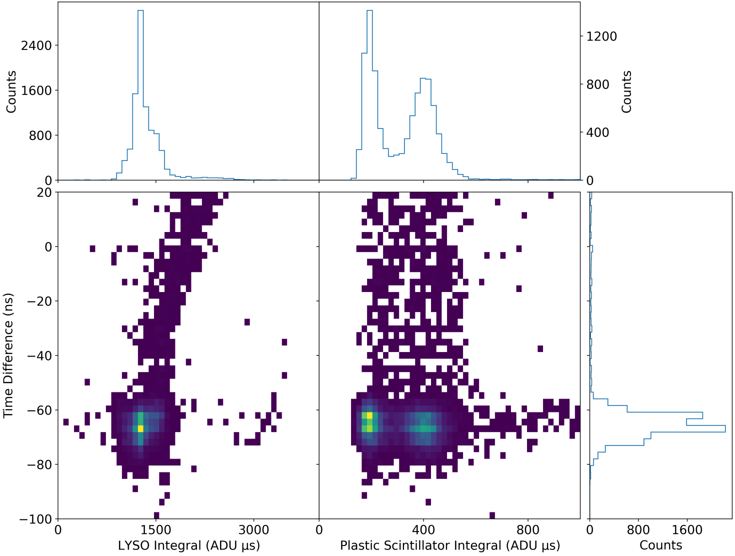
PSC - α Aluminium Deposition Thicknesses



Deconstructed rectangle showing the thicknesses of the aluminium coating on each surface.

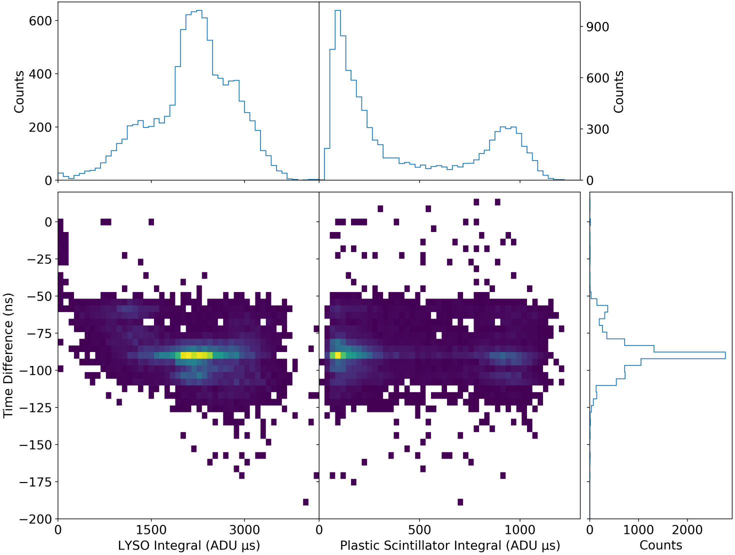
PSC - γ Table Top Timing

- Time difference between the event in the plastic scintillator and the LYSO detector.
- Distribution of background events is limited to lower time difference, due to a slower response time of the LYSO PMT.



PSC - γ Cryostat Timing

- Time difference between the event in the plastic scintillator and the LYSO detector.
- Distribution of background events is more evenly distributed due to a delay added to the discriminated signal from the plastic scintillator.



PSC - Temperature Dependence

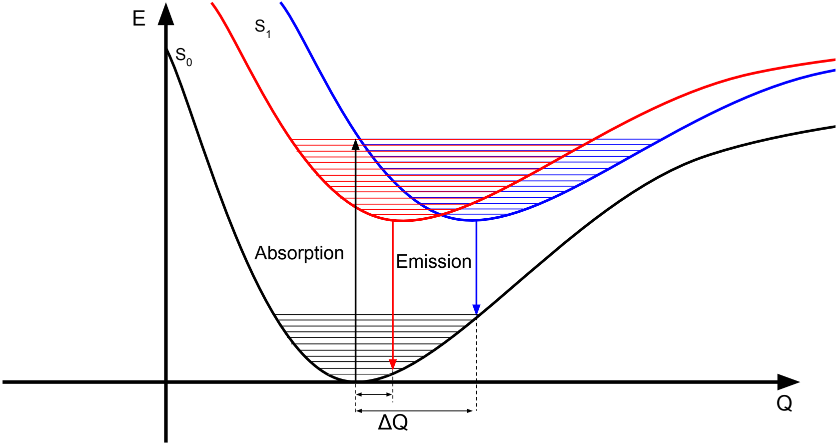


Illustration of the Franck-Condon principle which is a common explanation for the temperature dependence of scintillators.