FLUORESCENCE OF OPTICAL MATERIALS DOWN TO 4 K – ACRYLIC, TPB, PYRENE

Emma Ellingwood for the CAFE group*

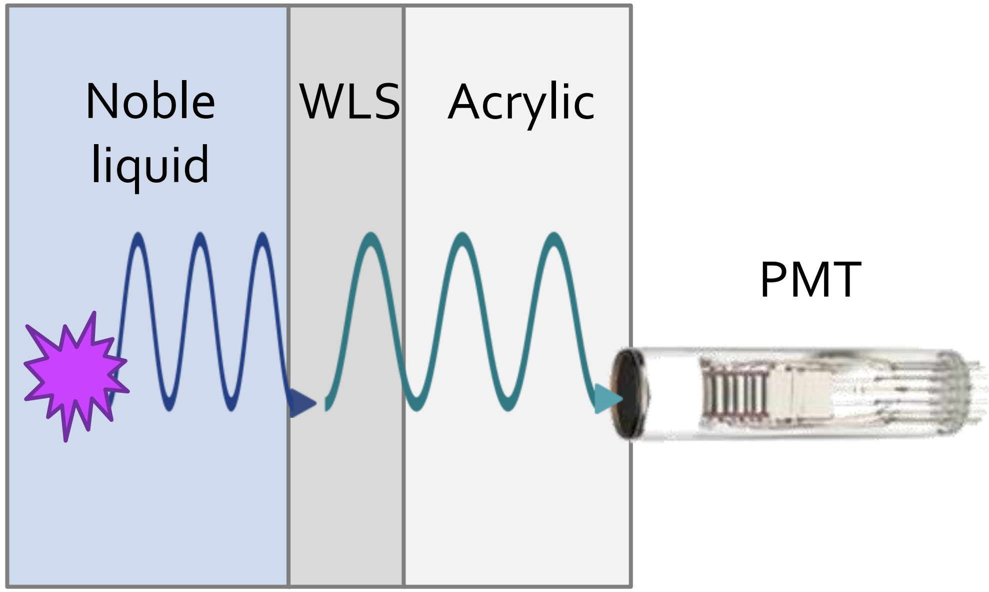
Queen's University

February 18, 2022

*Cryogenic Apparatus for Fluorescence Experiments:
H. Benmansour, P.C.F. Di Stefano, E. Ellingwood, P. Skensved, J. Hucker, Q. Hars

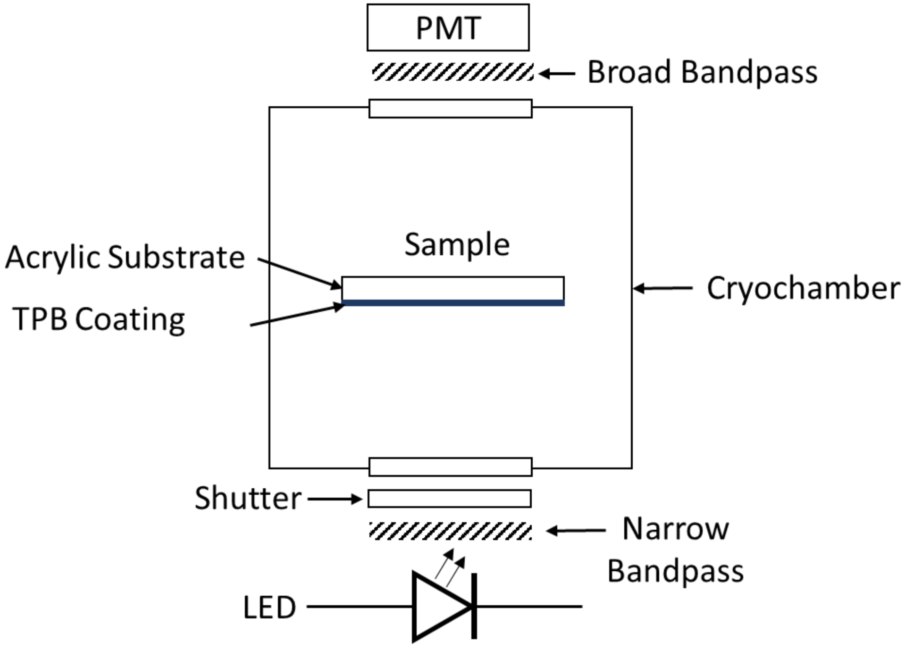
Motivation

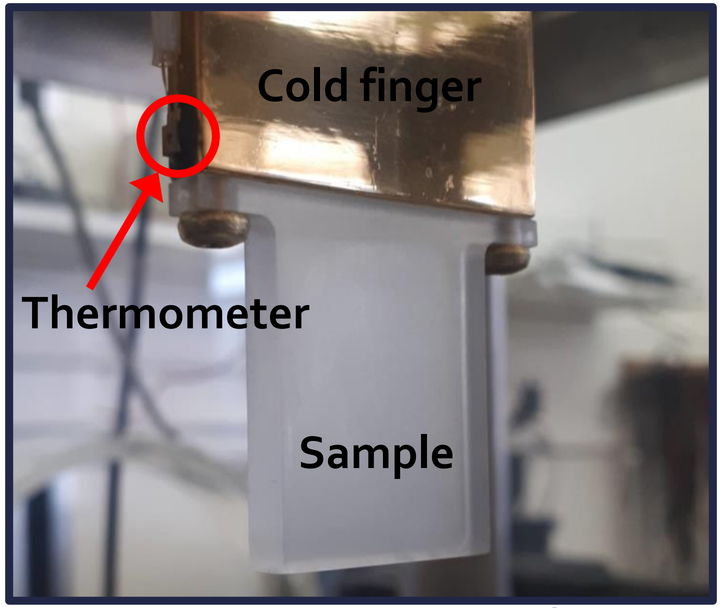
- Liquid noble element dark matter, such as DEAP-3600 and DarkSide-20k) and neutrino detectors must operate at cryogenic temperatures.
- Particle interactions in these detectors generally emit in the UV range. That light must pass through wavelength shifters (WLS) to convert the light to the visible range where conventional photodetectors like photomultiplier tubes (PMT) are more sensitive.
- The fluorescence of transparent materials used for these detectors and coatings applied to them, like wavelength shifters, can change with temperature.



Optical Cryostat

- System capable of measurements between 4 K and 300 K at $<10^{-6}$ mbar.
- Sample excited with a ~6 ns wide 285 nm LED pulse.
- R6095-100 PMT read out with a NI PXIe digitizer.
- Broad bandpass filter with a 375 nm lower limit to eliminate stray UV LED light from reaching the PMT.
- A function generator is used to trigger the LED pulsing circuit and the digitizer.
- A spectrometer can also be attached at the same position as the PMT.



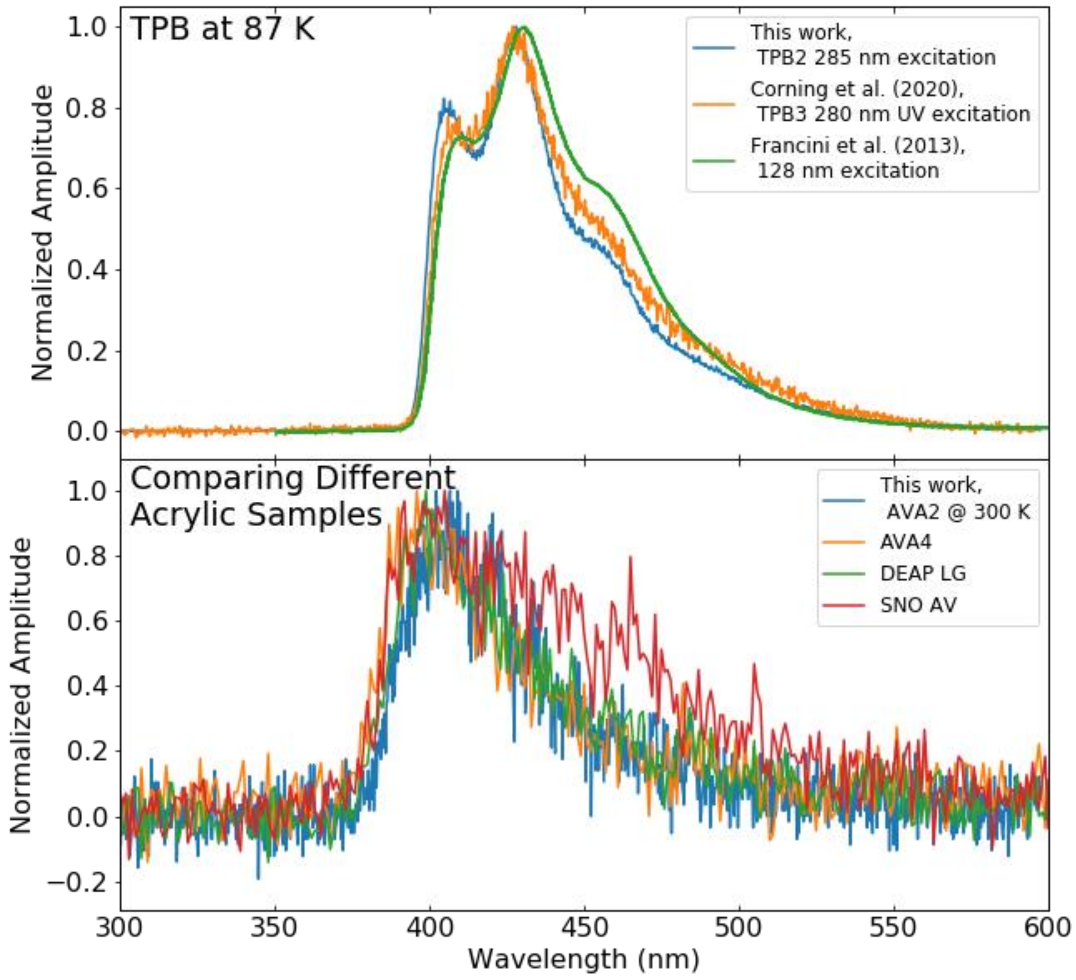


ACRYLIC AND TPB STUDY

E. Ellingwood, et al., **Ultraviolet-induced fluorescence of poly(methyl methacrylate) compared to 1,1,4,4-tetraphenyl-1,3-butadiene down to 4 K**, submitted to Nucl. Instrum. Methods. Phys. Res. A (2021). arXiv:2112.11581

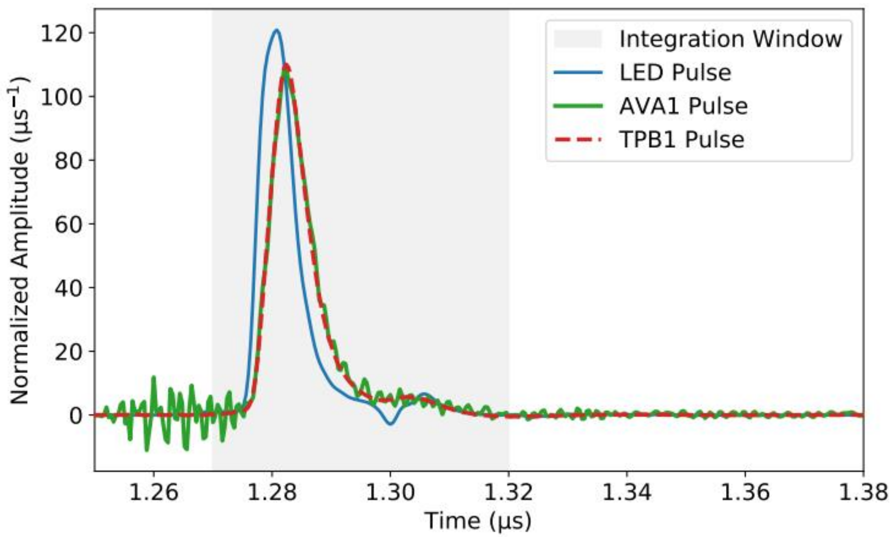
Comparison of TPB and acrylic spectra to literature

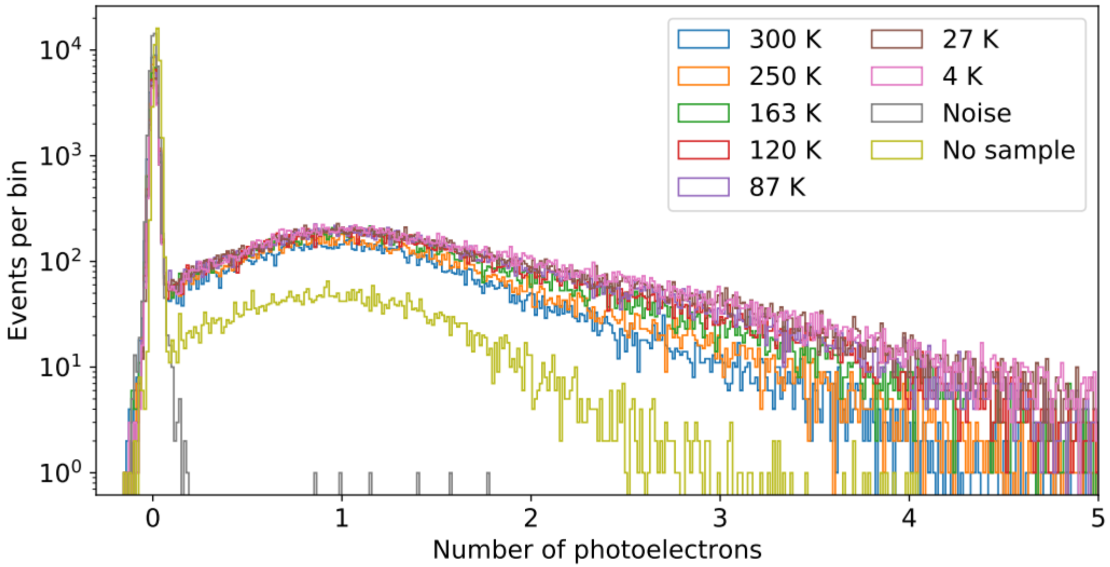
- TPB and acrylic samples presented in literature were not all prepared or measured in the same way.
- The acrylic and TPB spectra look similar to spectra from literature at the same temperatures.
- Different formulations and measurement technique can account for the slight differences in spectral features.
- Based on our research the luminescence in acrylic may partially be due to additives to PMMA included in commercial acrylics. This effect is only really visible at low temperatures when the light yield is higher.



Acrylic Light Yield Results

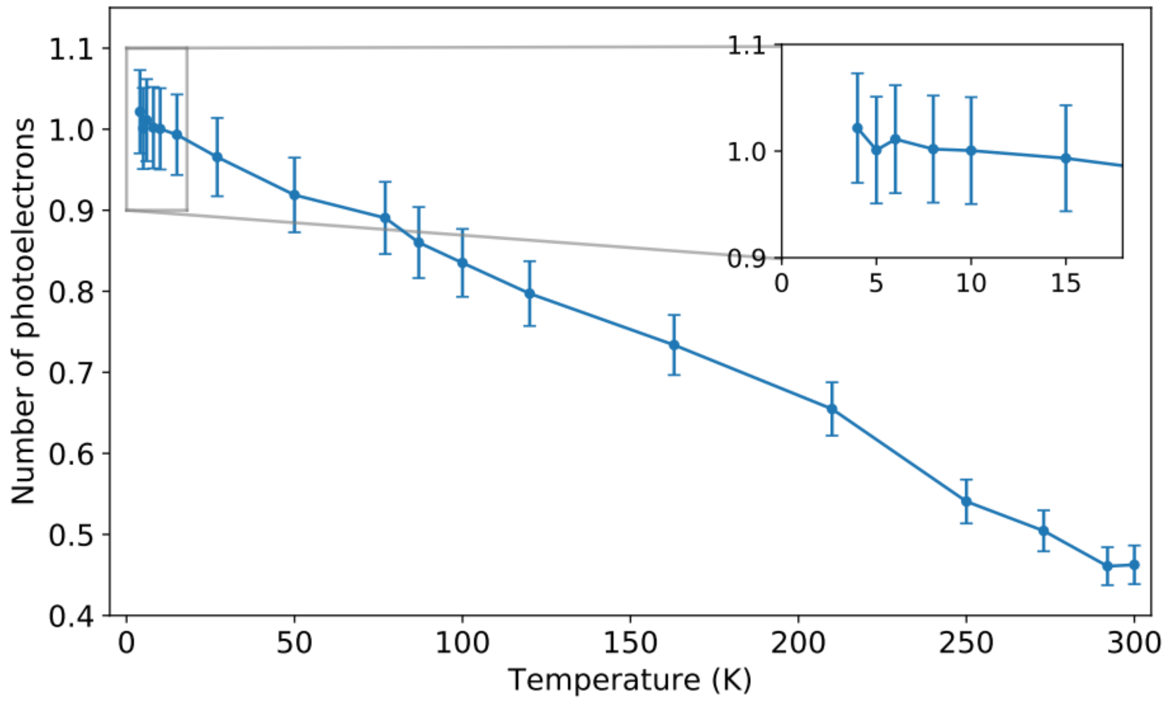
- Average fluorescence pulses of acrylic (labelled AVA1), TPB (TPB1) and the direct pulse from the UV LED.
- The integral of these pulses between the bounds for all events at a specified temperature produces a distribution of the number of photoelectrons.
- Based on the light yield distribution for noise only, no sample and acrylic data runs, there is a faint, but clear fluorescent light yield above the background (no sample data) of these acrylic measurements.





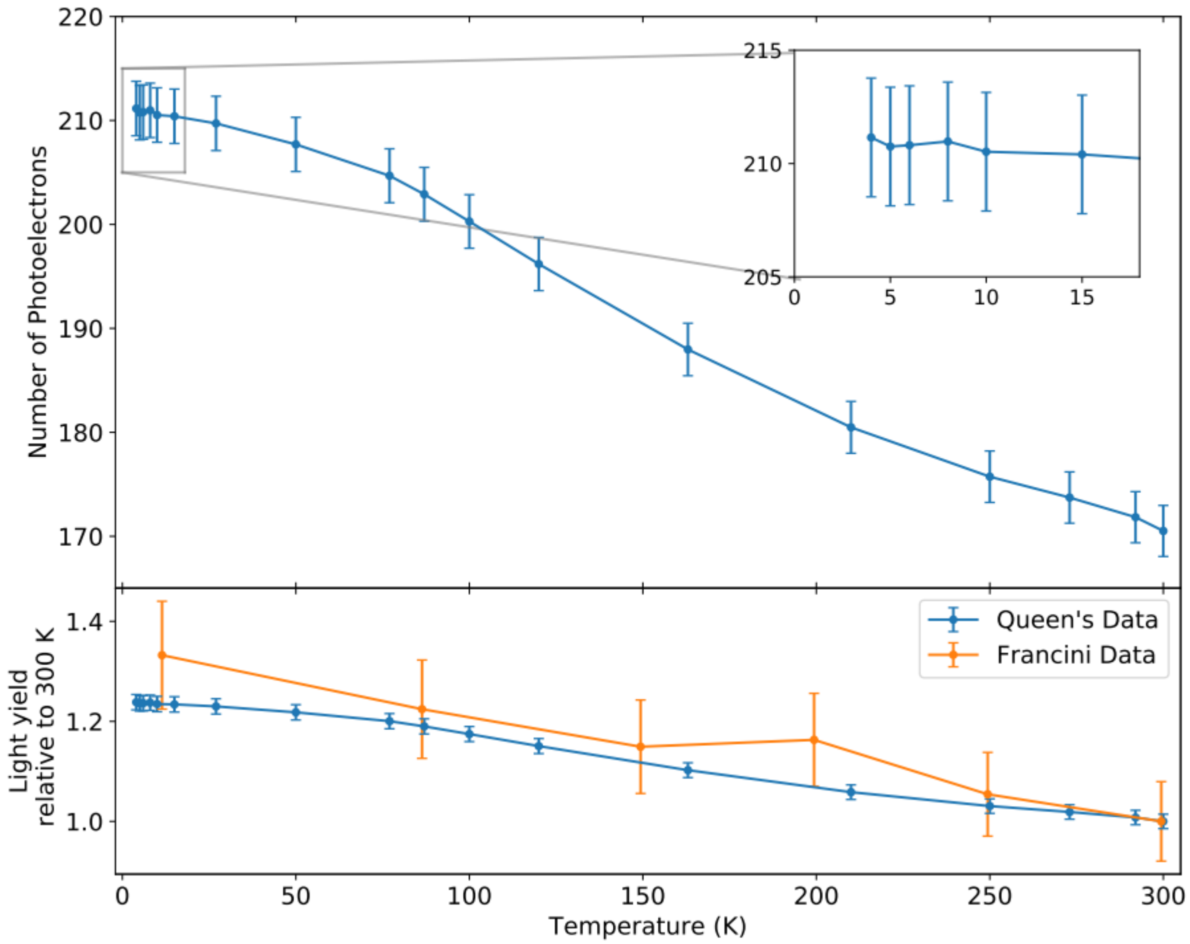
Acrylic Light Yield Results

- The overall average fluorescence light yield of the acrylic sample is quite low; at most temperatures less than 1 photoelectron was observed on average per event.
- Relative to the light yield at 300 K, at 87 K the light yield increased by ~85%
- At 4 K the light yield had increased by ~120% relative to 300 K.



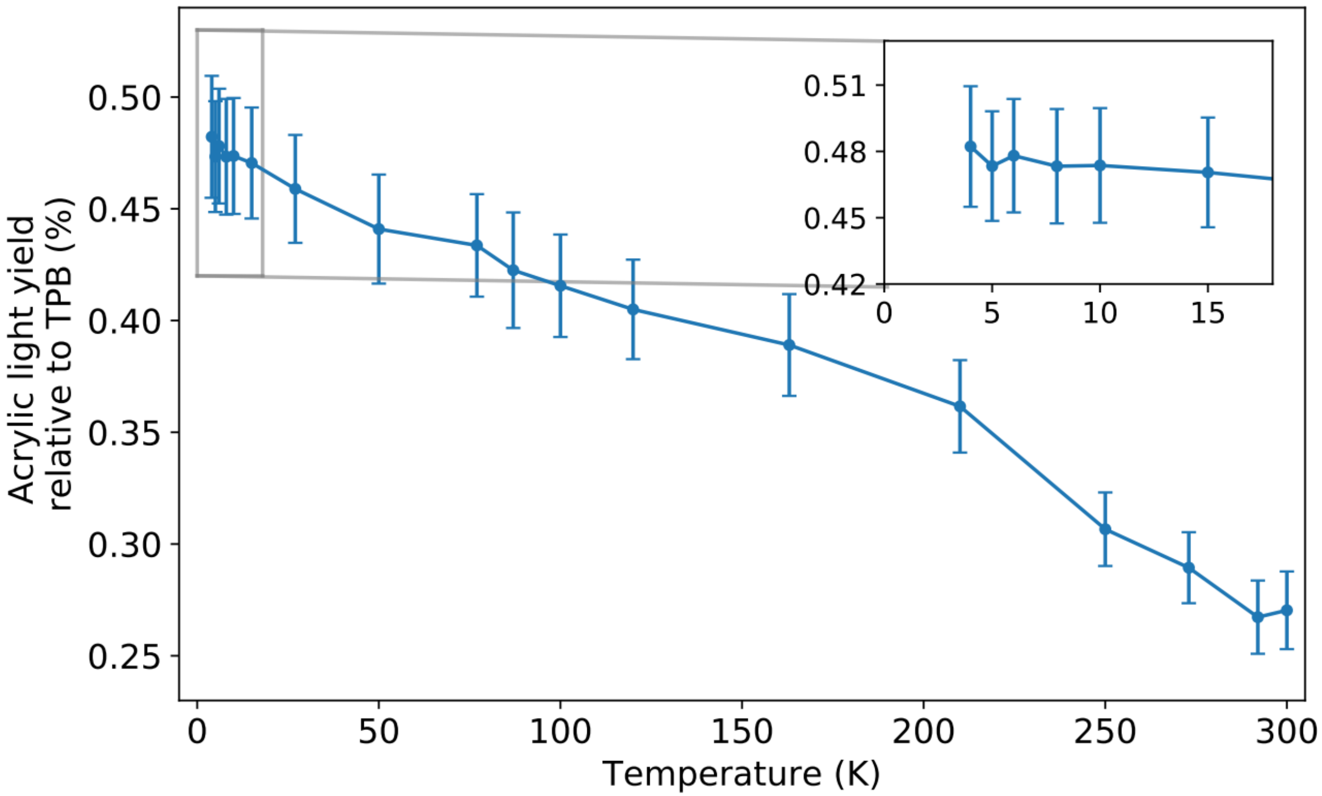
TPB Light Yield Results

- At 87 K there is a 19.0% increase in light yield compared to 300 K
- At 4 K, the light yield has increased by 23.8% relative to 300 K.
- These numbers are consistent within errors with previous characterizations of TPB down to low temperatures, and specifically at 87 K.
- Compared our result to results from (Francini, 2013) (https://doi.org/10.1088/1748-0221/8/09/P09006)



Acrylic-TPB Relative Light Yield

- The relative light yield varies from approximately 0.3% at 300 K to 0.5% at 4 K.
- A previously published work (Araujo et al. 2019), with similar samples, but different excitation wavelengths and methods, sets an upper limit of 0.2% at 300 K.



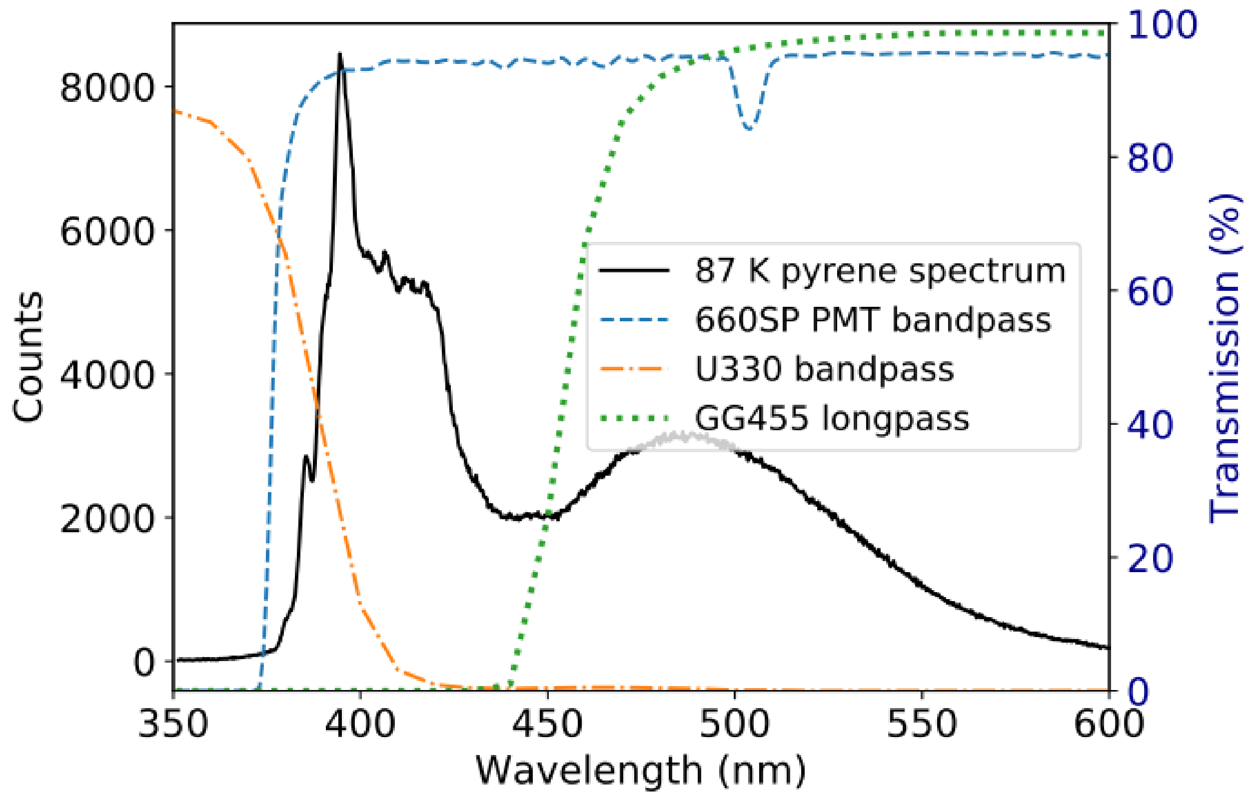
PYRENE STUDY

H. Benmansour, et al., **Fluorescence of pyrene-doped polystyrene films from room temperature down to 4 K for wavelength-shifting applications**, J. Instrum. 16 (12) (2021) P12029. doi:10.1088/1748-0221/16/12/p12029.

D. Gallacher, A., et al. **Development and characterization of a slow wavelength shifting coating for background rejection in liquid argon detectors**, Submitted to Nucl. Instrum. and Methods Res A, (2021) http://arxiv.org/abs/2109.06819

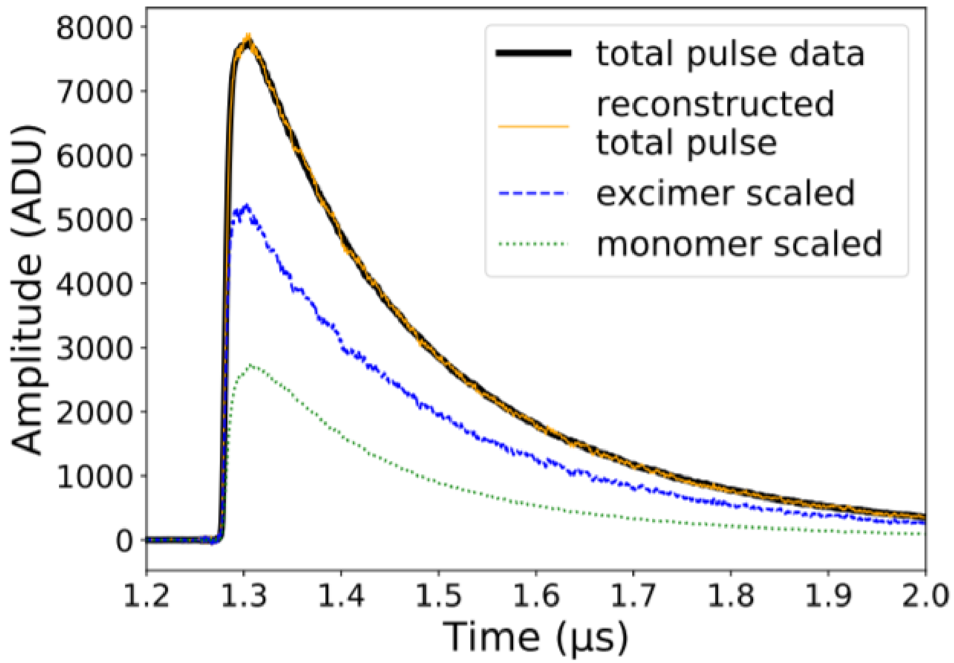
Pyrene Spectrum

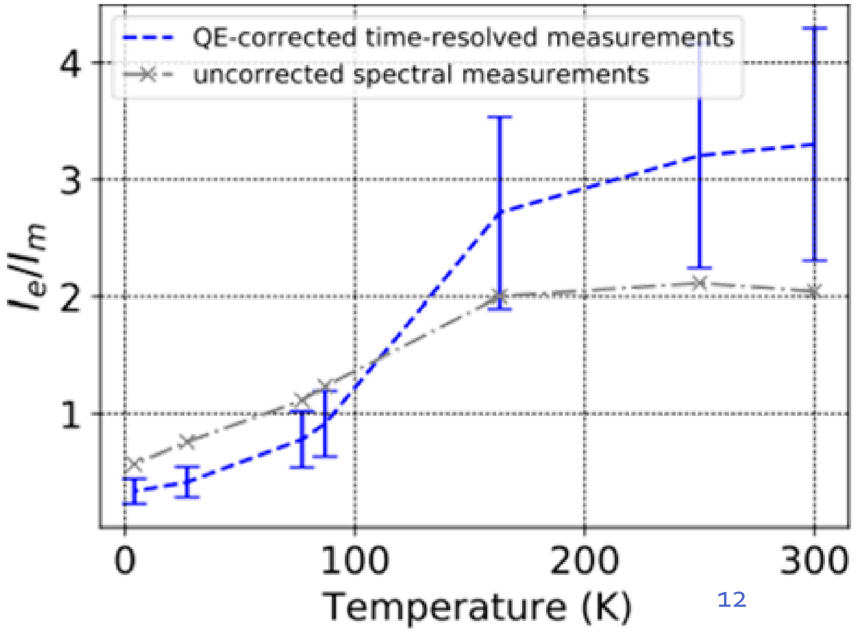
- Pyrene is used as a complementary WLS to TPB in DEAP-3600.
- The pyrene fluorescence mechanism consists of two components: monomer and excimer
- Filters are used in time resolved measurements to separately fit contributions from different emissions
- The U330 bandpass is intended to captures the shorter wavelength monomer part of the spectrum
- The GG455 longpass covers the longer wavelength excimer part of the spectrum



Monomer and Excimer Intensity

- At each temperature there are three data sets taken: one to study the excimer, one for the monomer, and one without those filters to study the total data pulse.
- We scale the monomer and excimer data such that their sum best reconstructs to the total pulse data.
- The integral of those scaled monomer and excimer pulses between specific bounds is then used to determine the proportion of the total light that comes from the monomer or excimer.





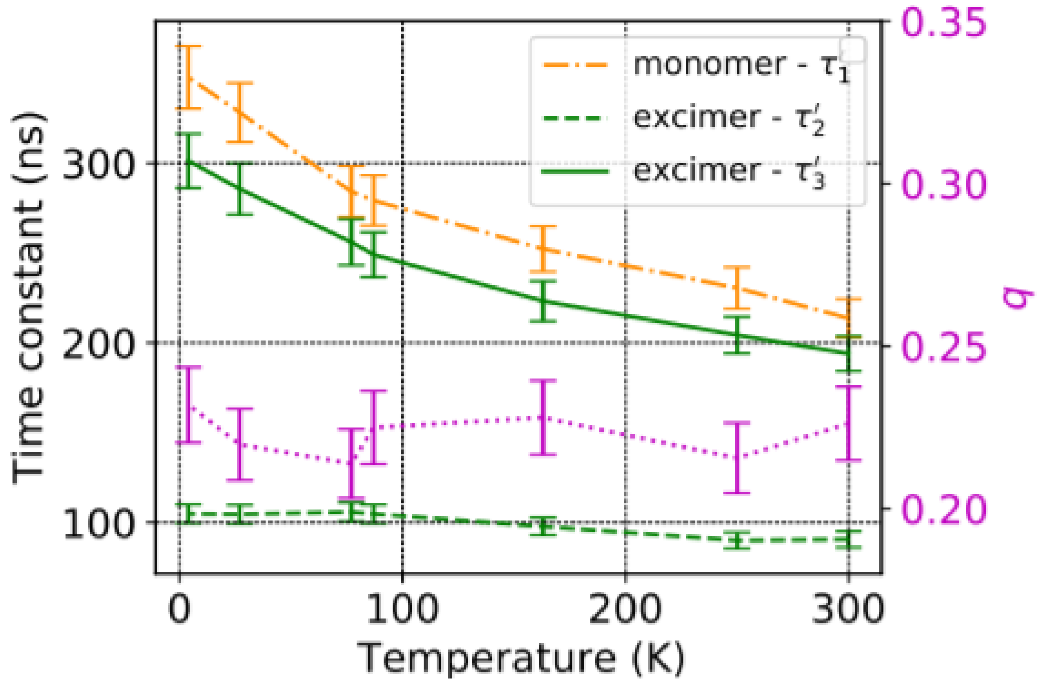
Pyrene Time Constants

- The monomer model used is based on (Johnson, 1979) which is an exponential fit with a parameter depending on a factor q that characterizes the non-exponential nature of the decay caused by excimer formation.

$$i_m(t) = \frac{N_1'}{\tau_1'} e^{-\frac{t}{\tau_1'} - 2q\sqrt{\frac{t}{\tau_1'}}}$$

- The excimer fit features a dual exponential decay for the dynamic and static excimer with a rise component which accounts for the formation time of the dynamic excimer

$$i_e(t) = -\frac{N_{\text{rise}}'}{\tau_{\text{rise}}'} e^{-\frac{t}{\tau_{\text{rise}}'}} + \frac{N_2'}{\tau_2'} e^{-\frac{t}{\tau_2'}} + \frac{N_3'}{\tau_3'} e^{-\frac{t}{\tau_3'}}$$



Conclusions

- The fluorescent light yield from acrylic, TPB and pyrene all increase with decreasing temperature.
- The faint fluorescence of acrylic is likely due to additives in commercial acrylics.
- The time constants and proportion of monomer to excimer depends on the temperature.
- In general, the overall light yield of pyrene increases with lower temperatures.