Fluorescence of optical materials down to 4 K – acrylic, TPB, pyrene

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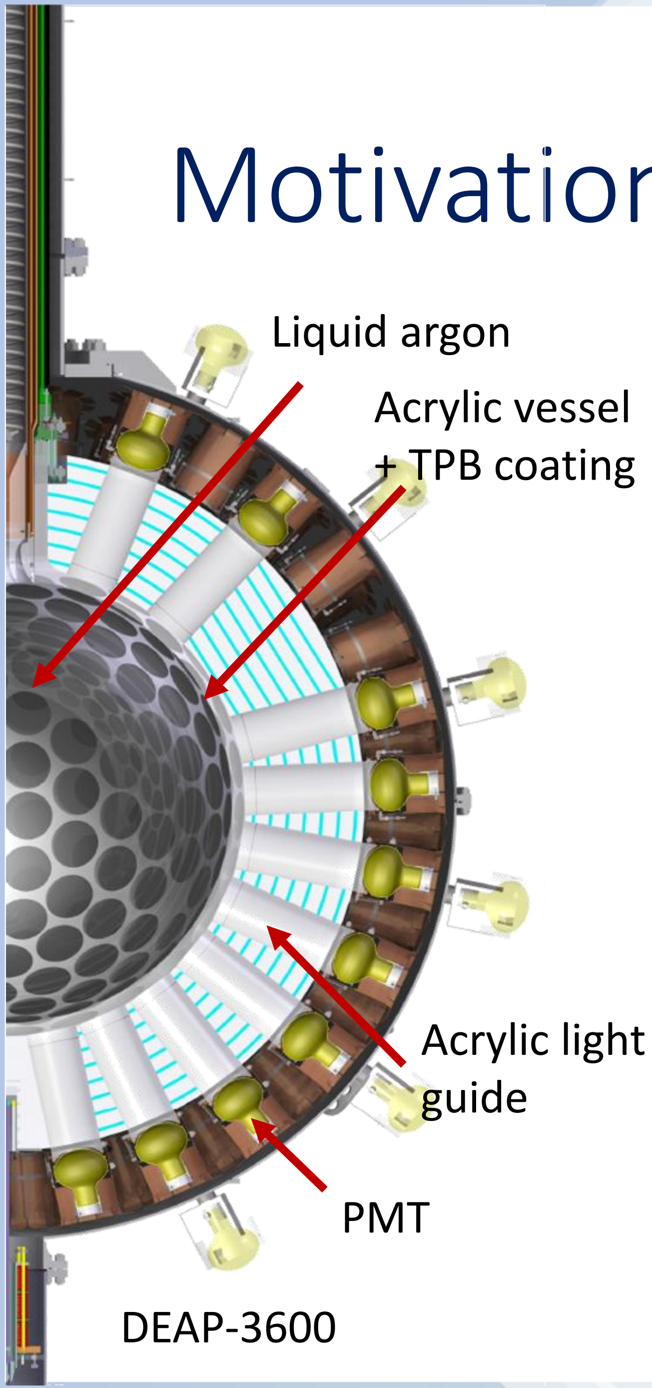
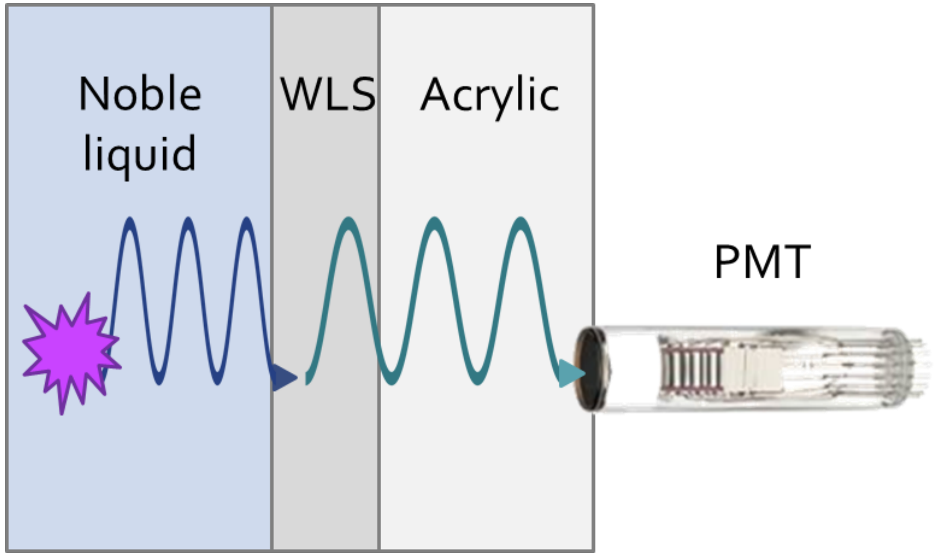
Motivation



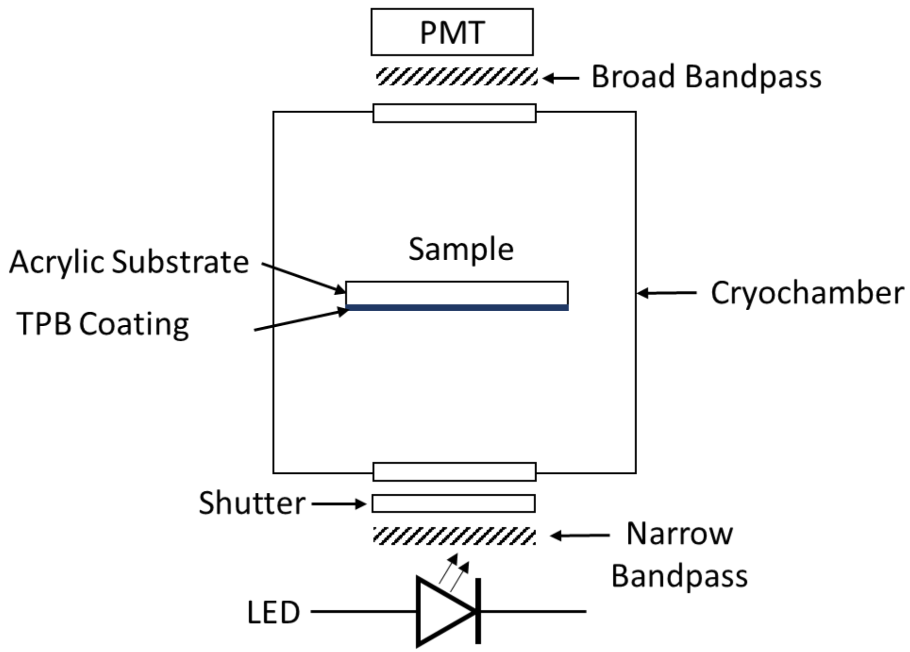
DEAP-3600

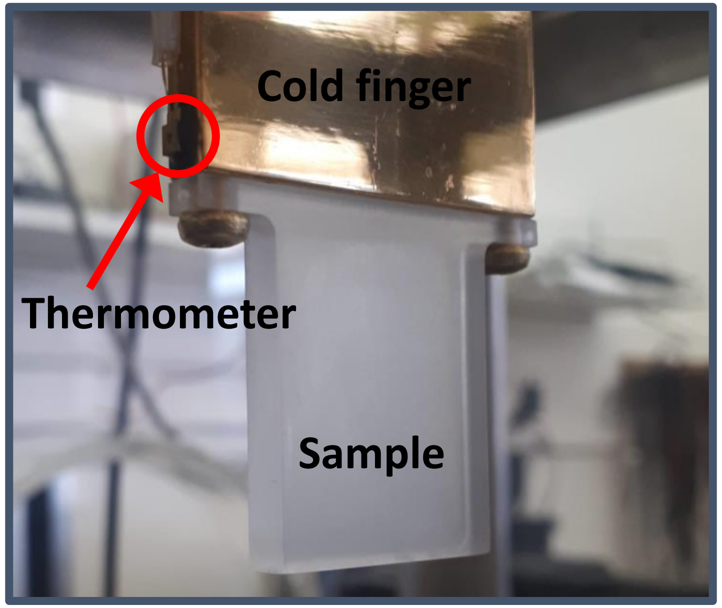


- Noble liquid dark matter (and neutrino) detectors must operate at cryogenic temperatures.
- Particle interactions emit UV scintillation light.
- That scintillation light is absorbed by a wavelength shifter (WLS) which emits fluorescent light in the visible range where conventional photodetectors like photomultipliers tubes (PMT) are more sensitive.
- Fluorescence properties 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.
- Time-resolved mode:
  - Excited with a ~6 ns wide 285 nm LED pulse.
  - Fluorescent light detected by a PMT read out by a digitizer.
  - Broad bandpass filter with a 375 nm lower limit to eliminate stray UV LED light from reaching the PMT.
- Spectral mode:
  - LED run continuously
  - Spectrometer can also be attached at the same position as the PMT to study wavelength dependent fluorescence features.





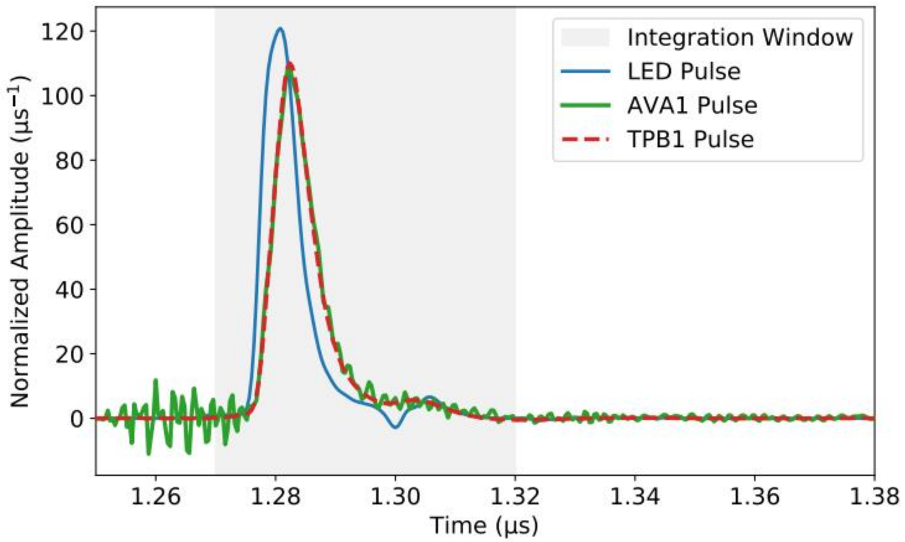
Acrylic and TPB Study

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

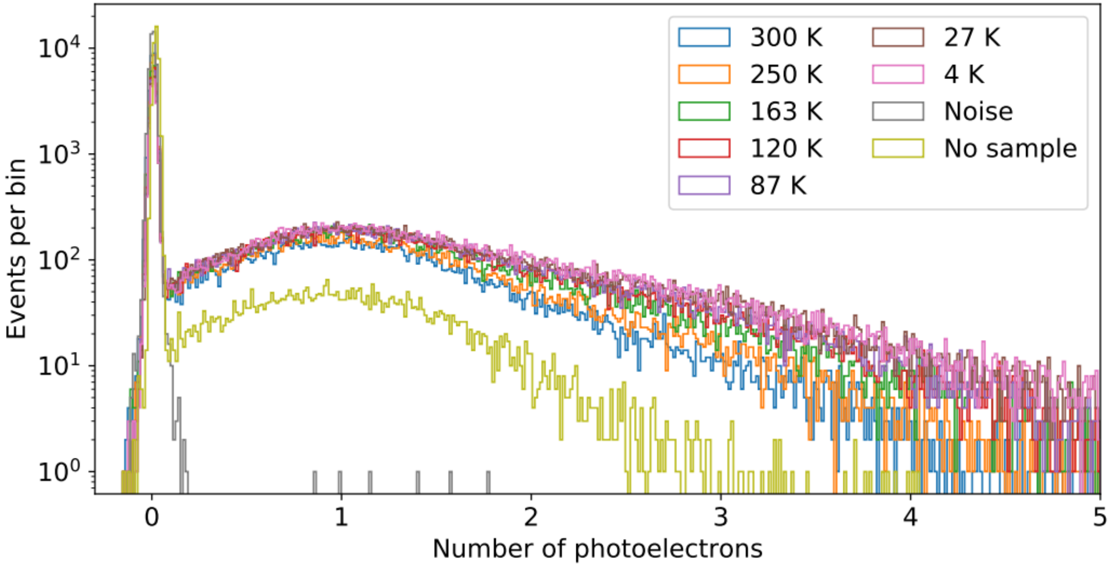
Calculating the Acrylic Light Yield

- At each temperature 45000 individual fluorescence pulses are recorded.
- The light yield is found by integrating each PMT pulse event in a 50 ns time window and building an integral distribution.
- The quoted light yield is the mean of this integral distribution expressed in terms of the number of photoelectrons.
- We also took data when no LED light was reaching the sample (noise) and a run with all the same settings as the acrylic data, but with no sample at room temperature.

Average Pulses

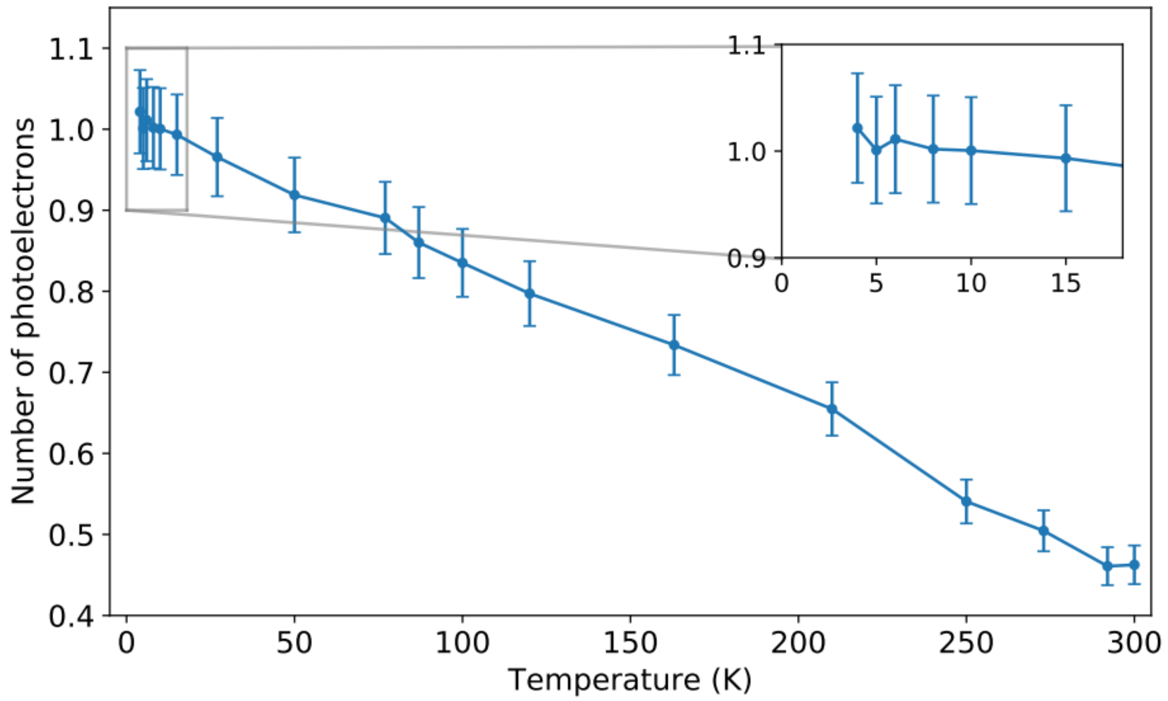


Integral Distribution



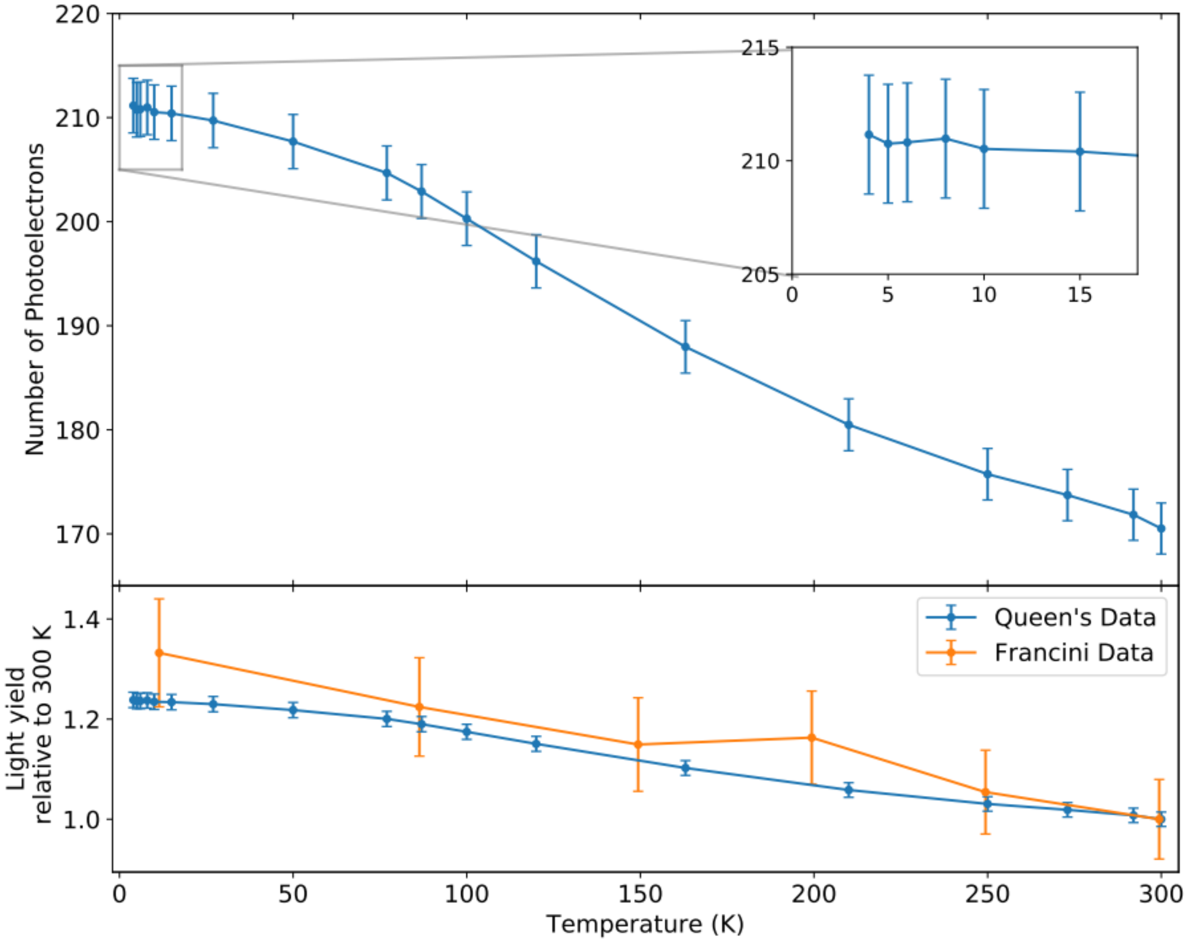
Acrylic Light Yield Results

- 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.



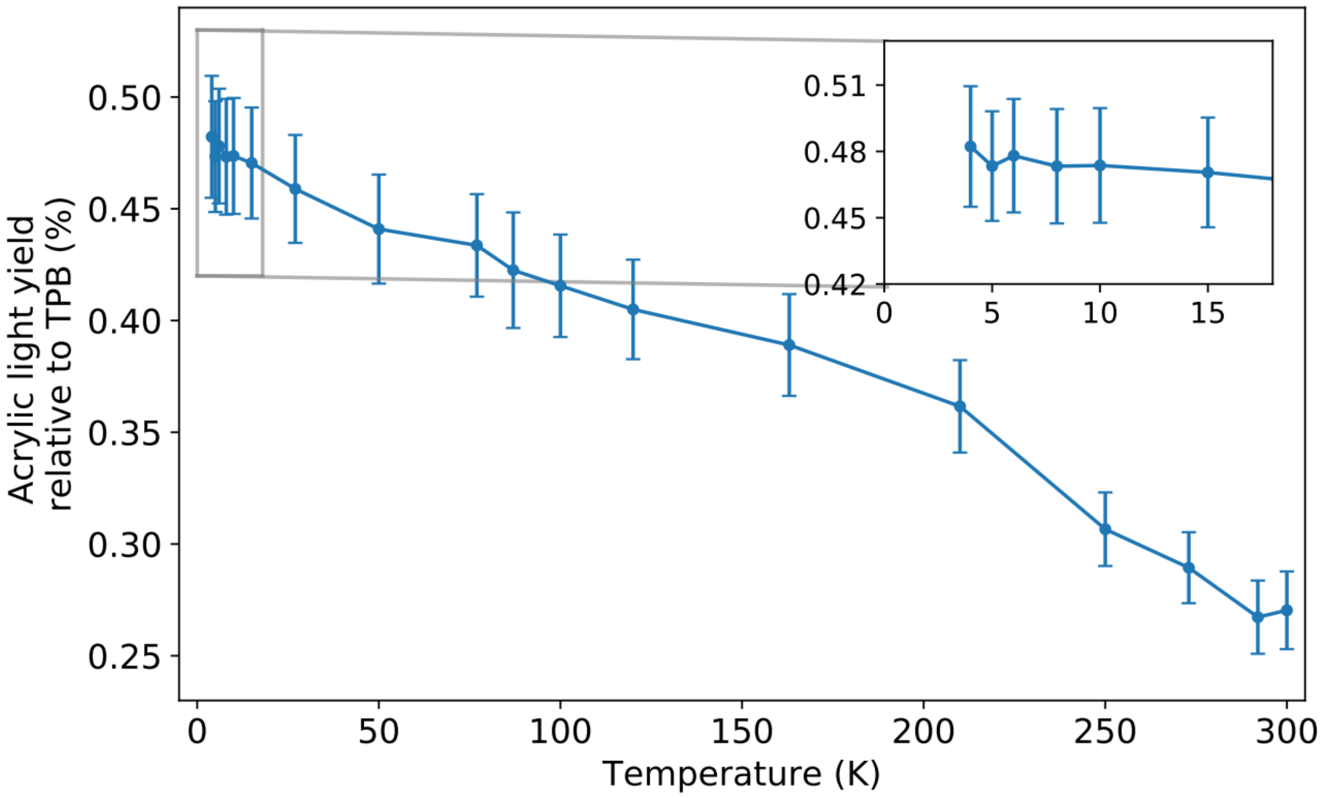
TPB Light Yield Results

- 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)



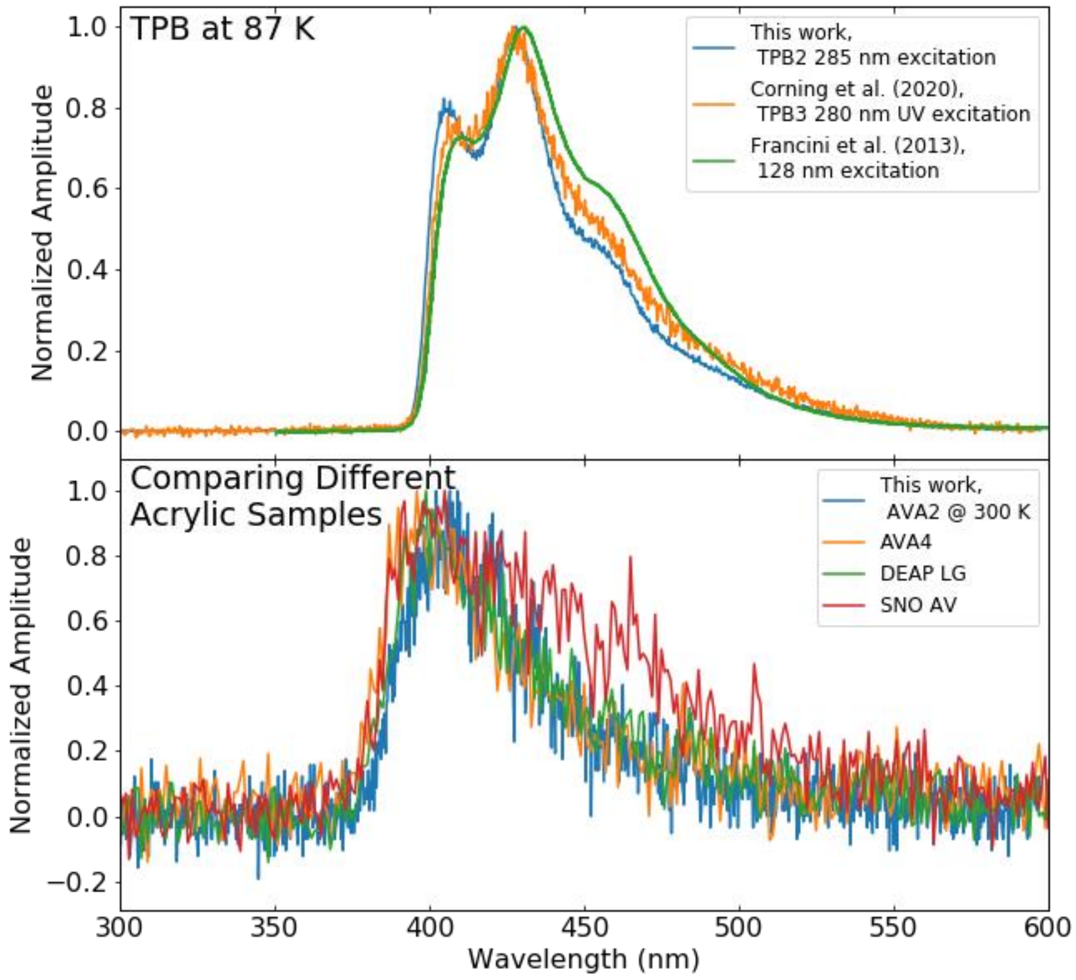
Acrylic-TPB Relative Light Yield

- Relative light yields are used to compare light yield results of different materials independent of the measurement method.
- The relative light yield varies from approximately 0.27% at 300 K to 0.48% at 4 K.



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 techniques can account for the slight differences in spectral features.



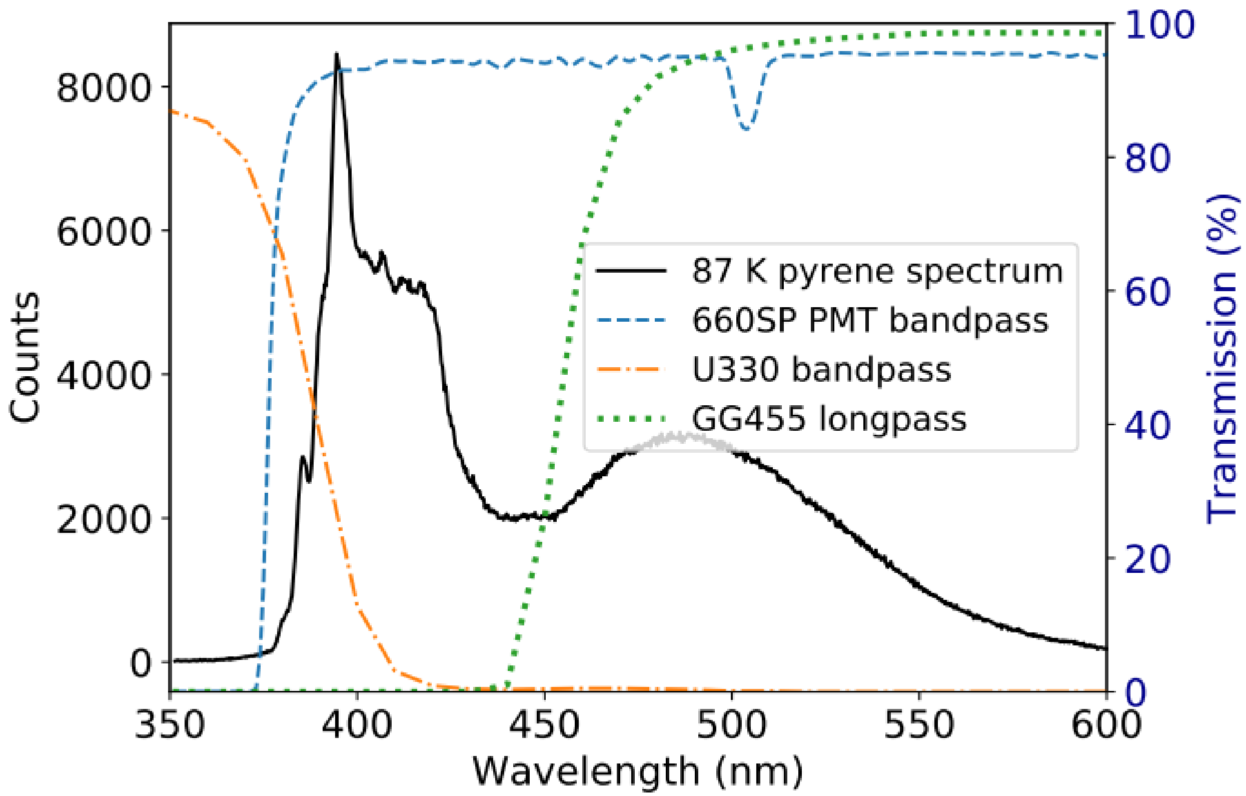
Pyrene Study

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 et al. **Development and characterization of a slow wavelength shifting coating for back-ground rejection in liquid argon detectors**. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 1034:166683, 2022.

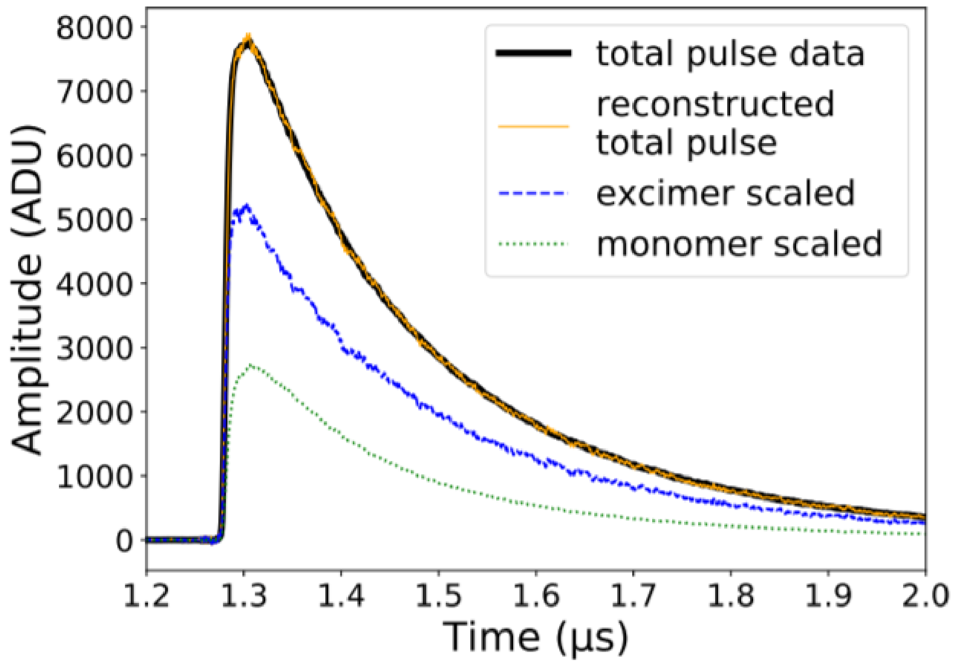
Pyrene Spectrum

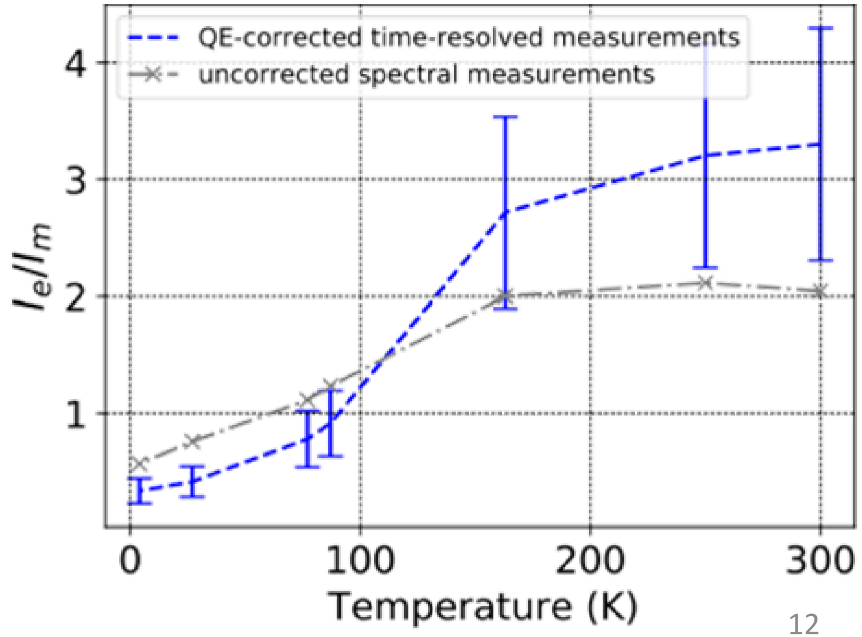
- Pyrene is used as a complementary WLS to TPB in DEAP-3600.
- The pyrene fluorescence mechanism consists of two components: monomer and excimer
- Filters are used in time-resolved measurements to separately fit contributions from different emissions.
- The U330 bandpass is intended to captures the shorter 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 time bounds is then used to determine the proportion of the total light that comes from the monomer or excimer.





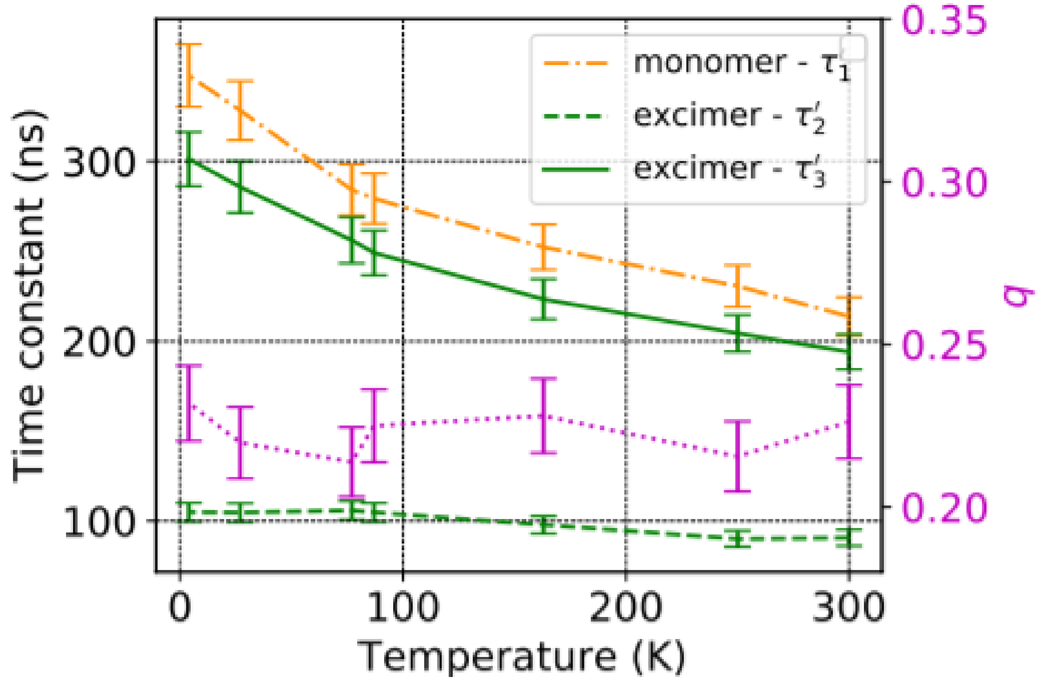
Pyrene Time Constants

- 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.

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

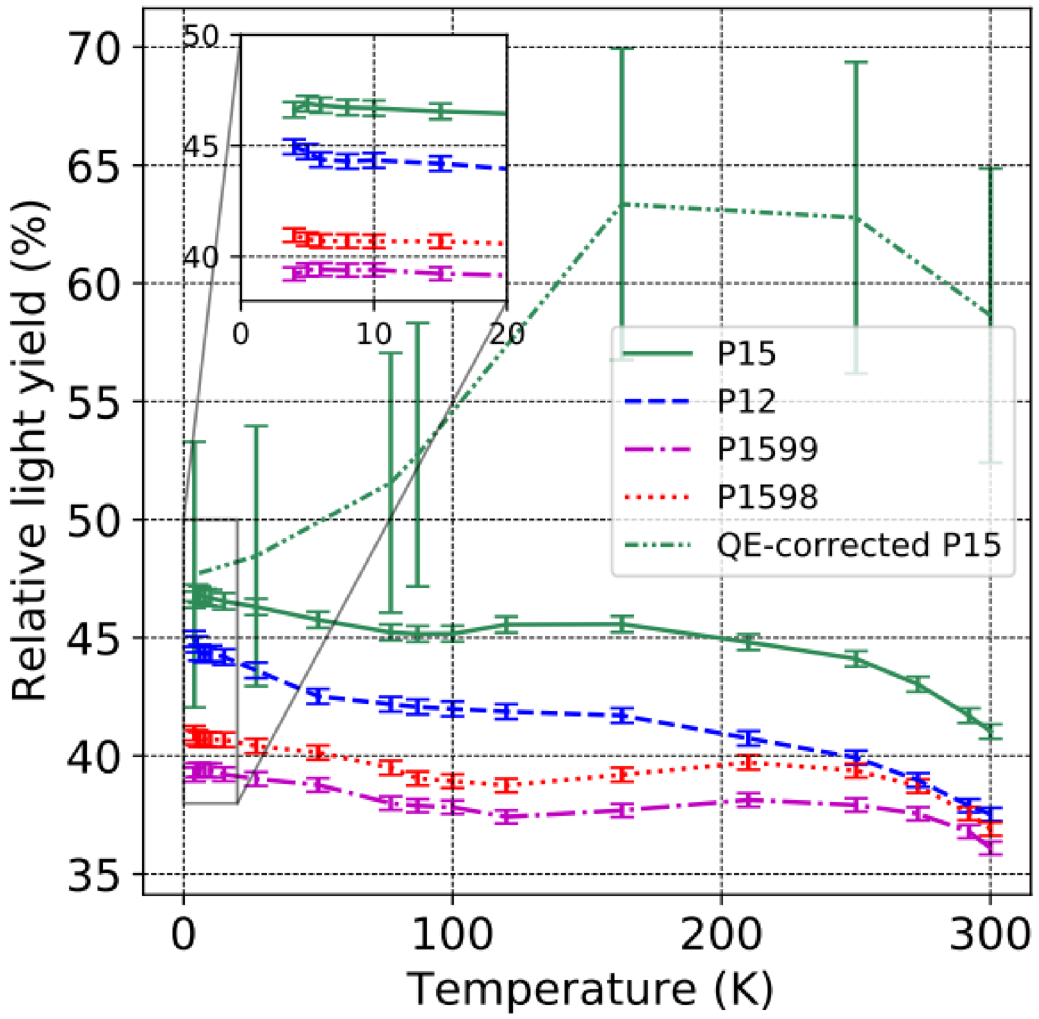
- The excimer fit features a dual exponential decay for the dynamic and static excimer with a rise component which accounts for the formation time of the dynamic excimer

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



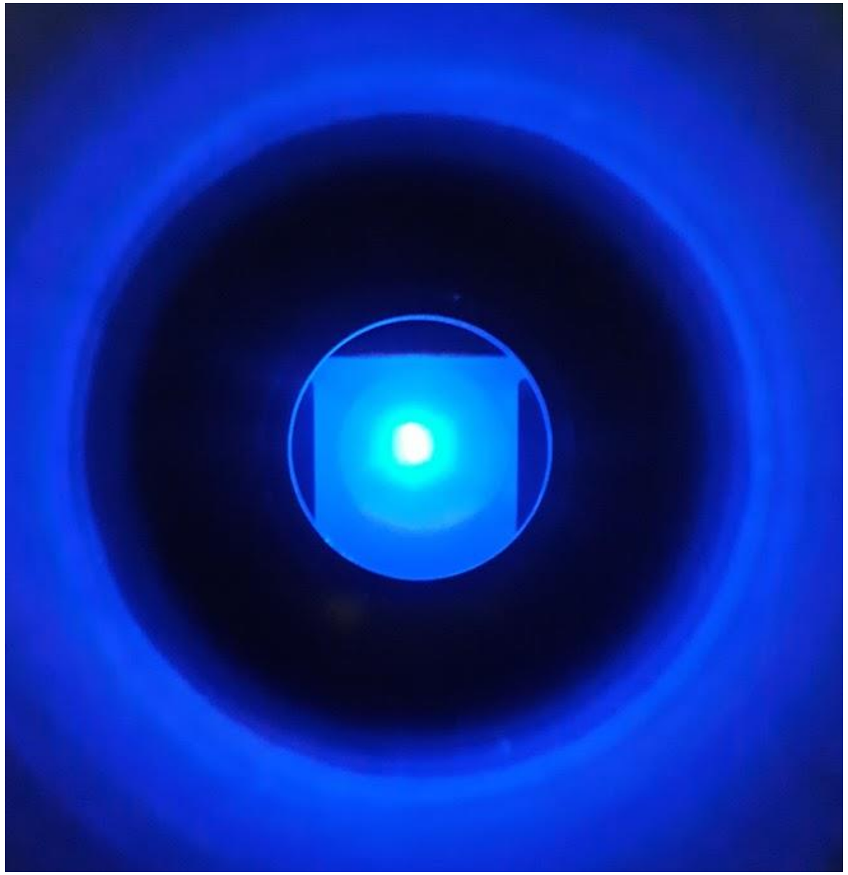
Pyrene Light Yields

- Like the previous study this is the light yield relative to TPB.
- We actually studied four different types of pyrene-polystyrene coatings which varied in their concentration and fluorescence grade.
- Regardless of the fluorescence grade or concentration of the pyrene-polystyrene coating, the light yield increases during cooling.



Conclusions

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



Fluorescence from a TPB coated acrylic sample