Characterization of pyrene films for background rejection in liquid argon dark matter experiments

LIDINE - September 16th 2021

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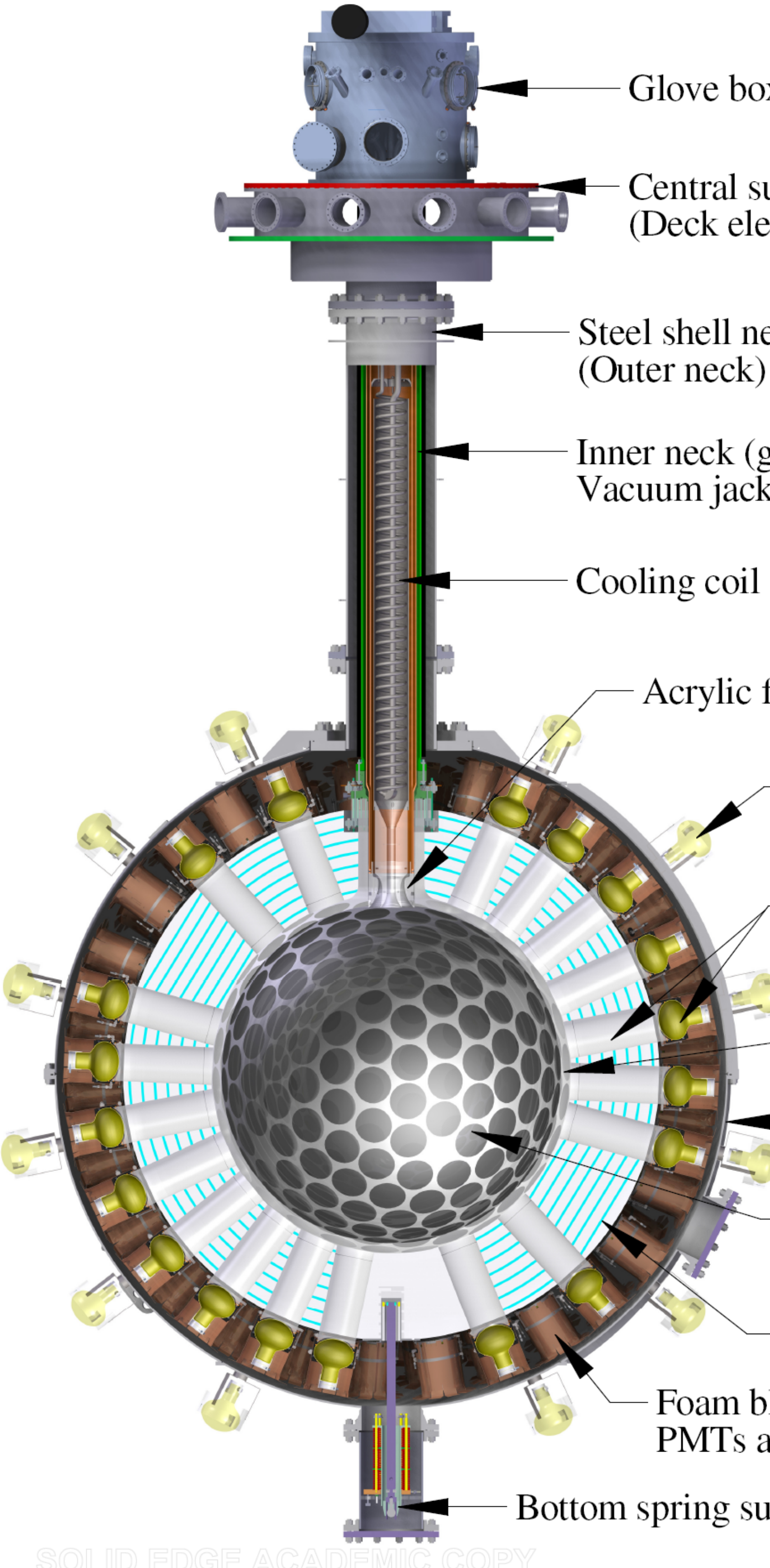
The DEAP-3600 experiment

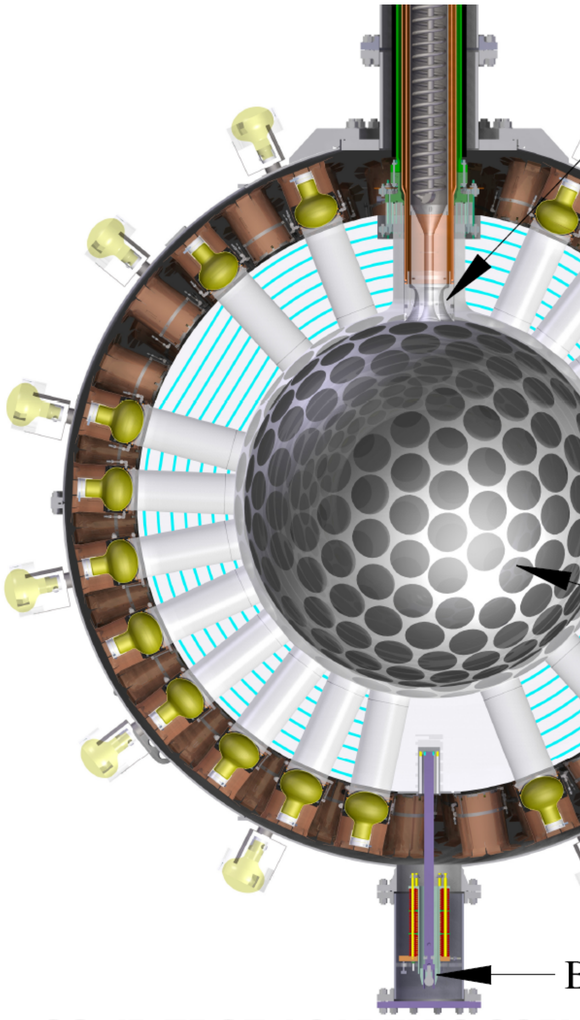
- Dark matter direct detection experiment
- Located at SNOLAB in Sudbury, Ontario
- 2km underground to greatly reduce cosmic and atmospheric backgrounds
- Acrylic vessel filled with liquid argon LAr at 87K and coated with a wavelength shifter (TPB)
- WIMP-argon nucleus interaction



Various types of backgrounds

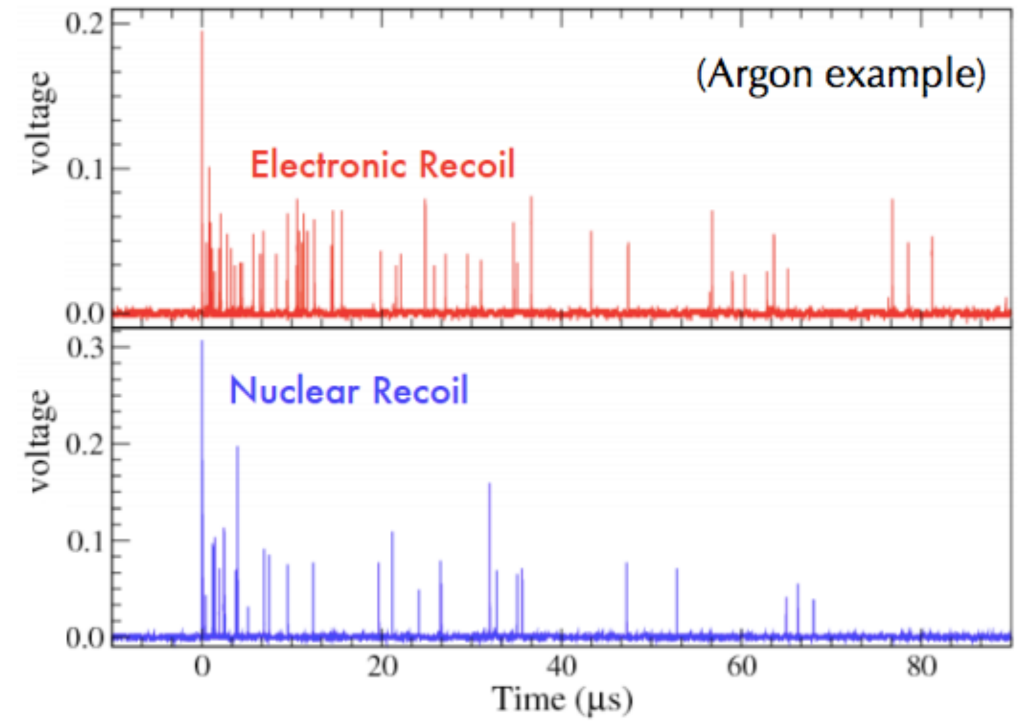
DEAP very sensitive but many sources of background:

- Alpha decays from radon progeny
- Beta decays from 39Ar
- Gamma rays and neutrons mainly from PMT glass

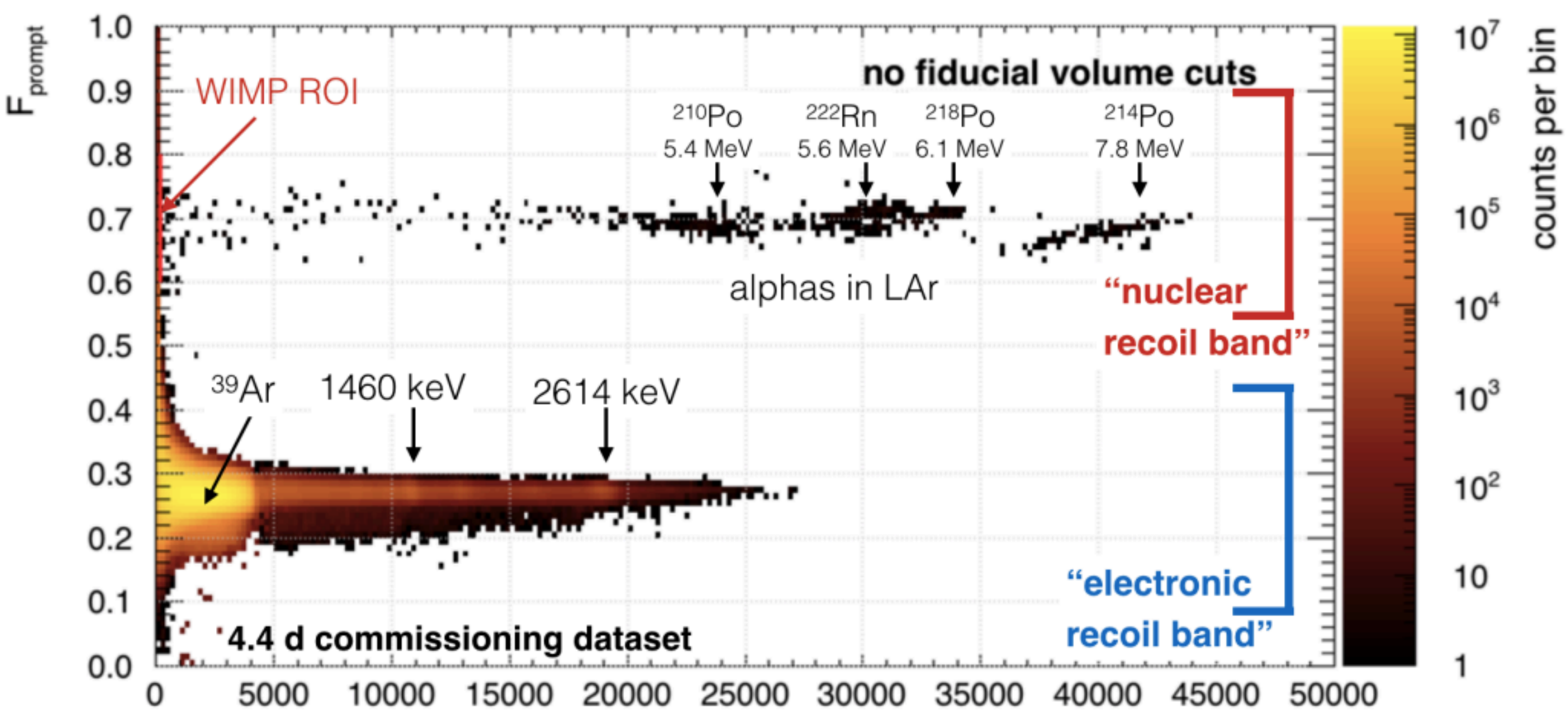


Pulse shape discrimination in DEAP

$$F_{prompt} = \frac{\sum_{t=-28ns}^{60ns} PE(t)}{\sum_{t=-28ns}^{10\mu s} PE(t)}$$



Amaudruz et al. - Astropart.Phys. 85 (2016) 1-23



B. Lehnert et al. 2018

—> PSD separates Ar39 background from Ar40 NR with an efficiency >10^9

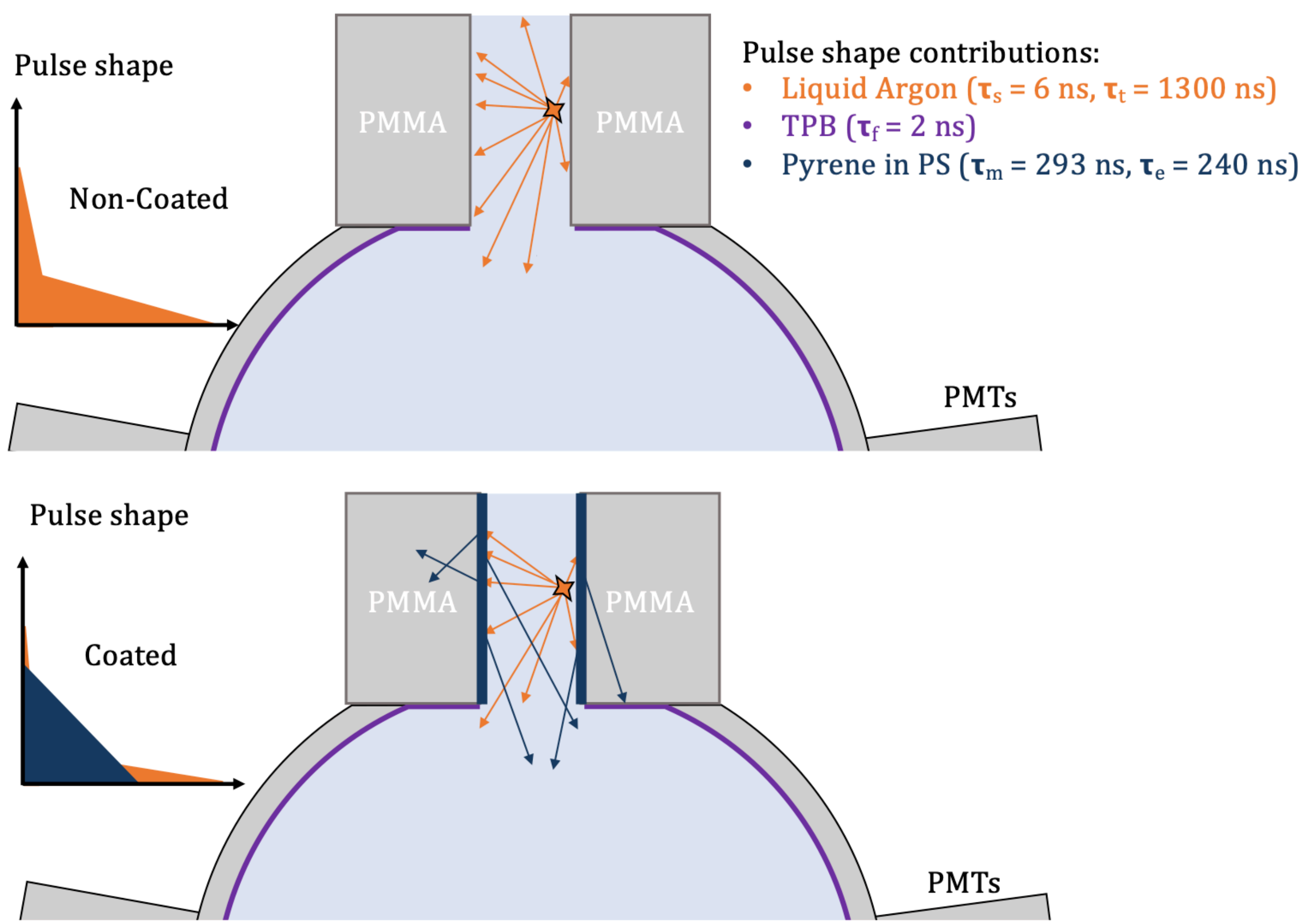
—> most alphas have energy high enough to be discriminated from WIMP signal

Slow wavelength shifter coating

—> alphas on the neck produce scintillation light that is shadowed by the acrylic, creating an artificial “low energy” event that **<u>mimics a WIMP-like signal</u>**

	Source	N^{CR}	N^{ROI}
β/γ's	ERs	2.44×10^9	0.03 ± 0.01
	Cherenkov	$< 3.3 \times 10^5$	< 0.14
n's	Radiogenic	6 ± 4	$0.10^{+0.10}_{-0.09}$
	Cosmogenic	<0.2	<0.11
α's	AV surface	<3600	< 0.08
	Neck FG	28^{+13}_{-10}	$0.49^{+0.27}_{-0.26}$
	Total	N/A	$0.62^{+0.31}_{-0.28}$

DEAP collaboration 2019



Gallacher et al. 2021

—> to mitigate this problem:
add a coating of long time constant scintillator on the neck

Pyrene good candidate?

Queen's University

Study of pyrene

—> pyrene has low vapour pressure, **pure pyrene not suitable**

—> **pyrene embedded in polystyrene matrix** is cryogenically stable

Our objective at Queen's

—> understanding **pyrene+polystyrene fluorescence at liquid argon temperature**

1) Wavelength spectra
2) Fluorescence yield
3) Fluorescence decay times

Our main asset

—> a cryogenic facility which boasts **good optical efficiency** and **a base temperature of 4K**

Pyrene luminescence study

4 samples :

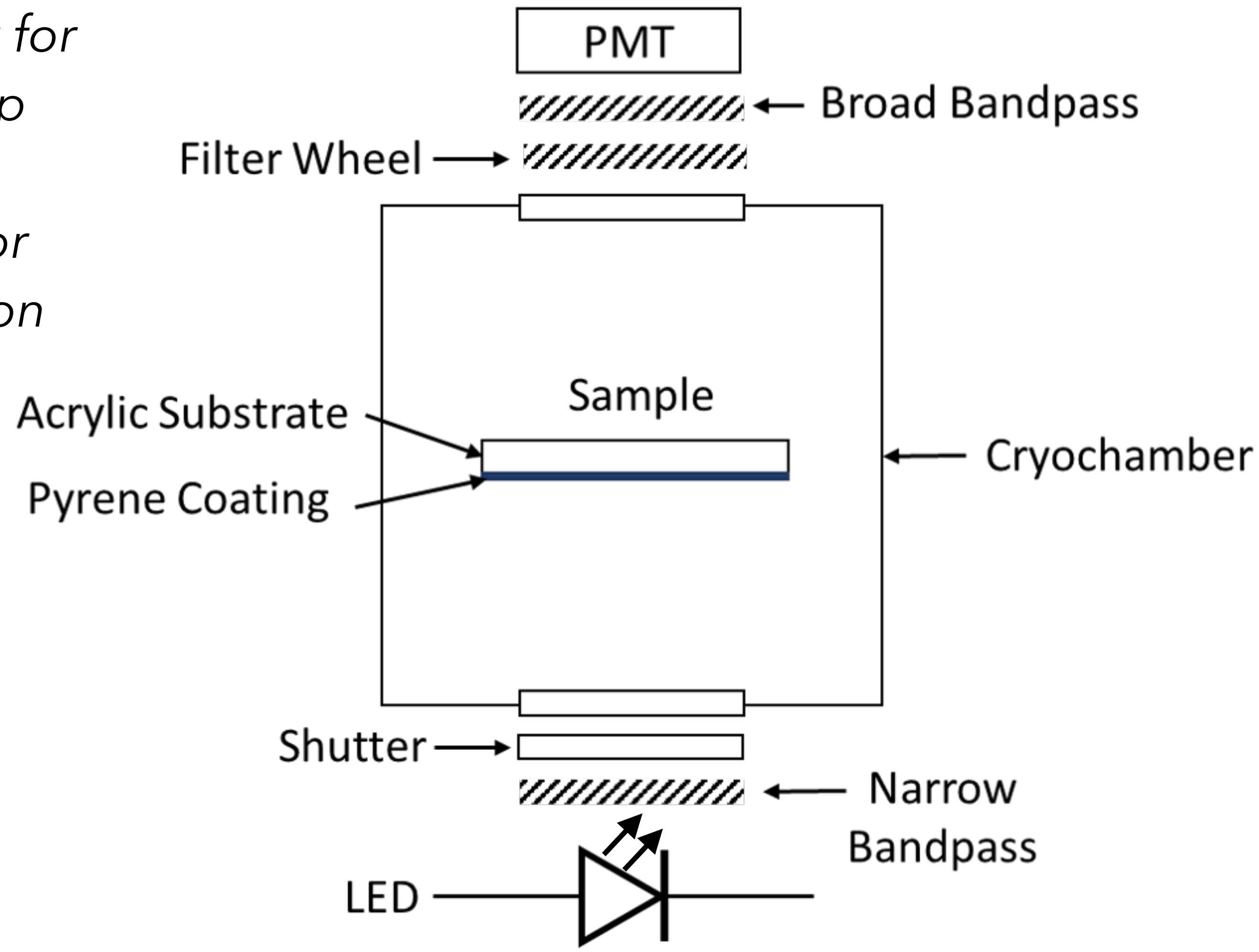
–> **P12**: pyrene **12%,** polystyrene 88% - Fluorescence Grade > **99.9%**
–> **P15**: pyrene **15%,** PS 85% - FG > **99.9%**
–> **P1599**: pyrene **15%**, PS 85% - FG **99%**
–> **P1598**: pyrene **15%**, PS 85% - FG **98%**

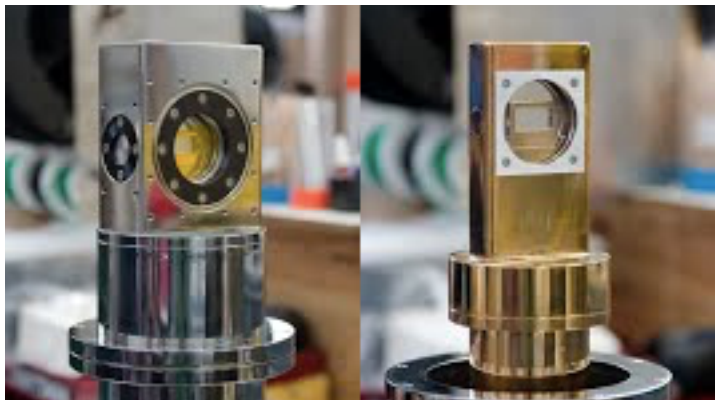
- coating **facing the LED** - transmitting geometry
- **pulsing LED** - 50 Hz - UV LED **285 nm**

Samples manufactured at Carleton University

Temperature (K)
300
292
273
250
210
163
120
100
87
77
50
27
15
10
8
6
5
4

- *See Emma Ellingwood's talk for details of experimental setup*
- *See David Gallacher's talk for details on sample preparation*

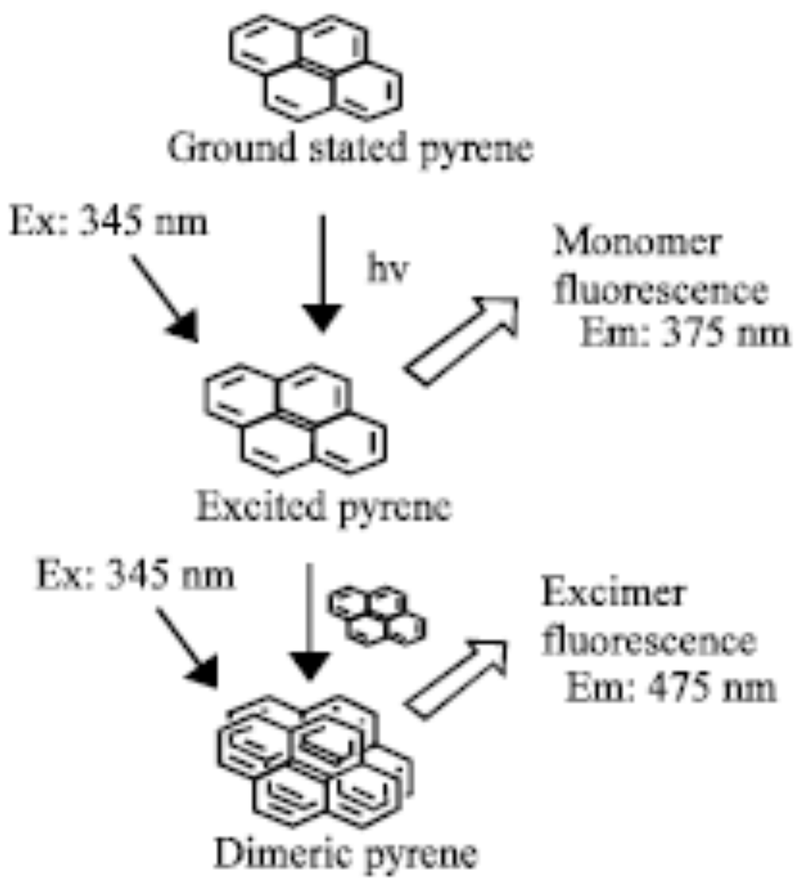


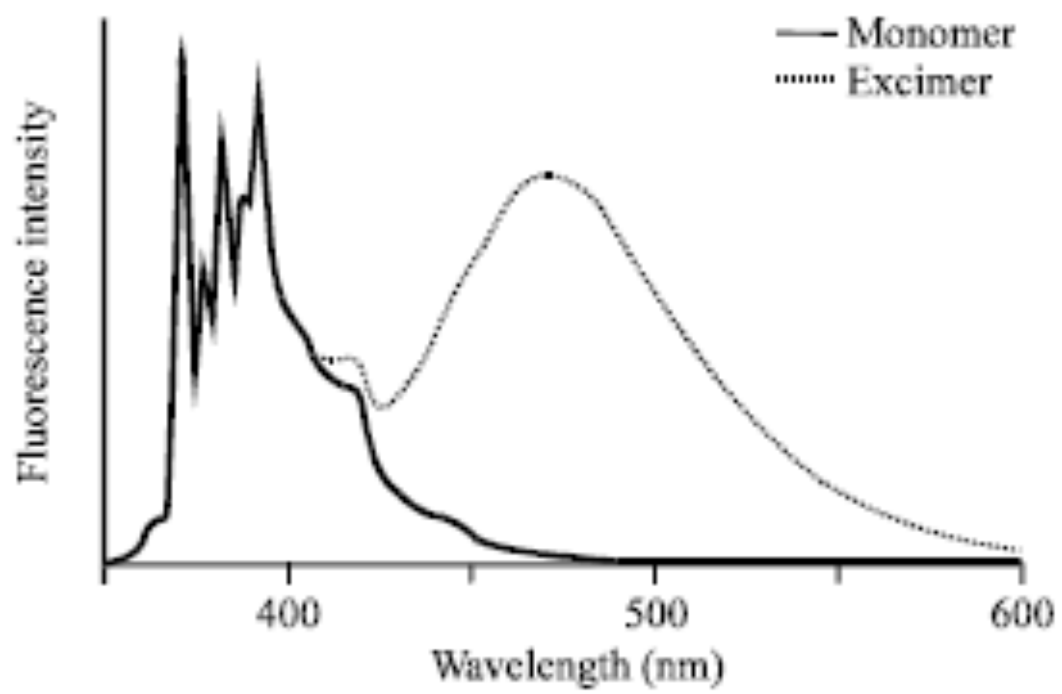


1) Pyrene fluorescence spectra

Problem: Understanding the spectra evolution of pyrene

Birks et al. 1966, Proc. R. Soc. Lond.





Monomer emission ~390nm
1 excited pyrene molecule

Excimer emission ~490nm
1 pyrene excited dimer

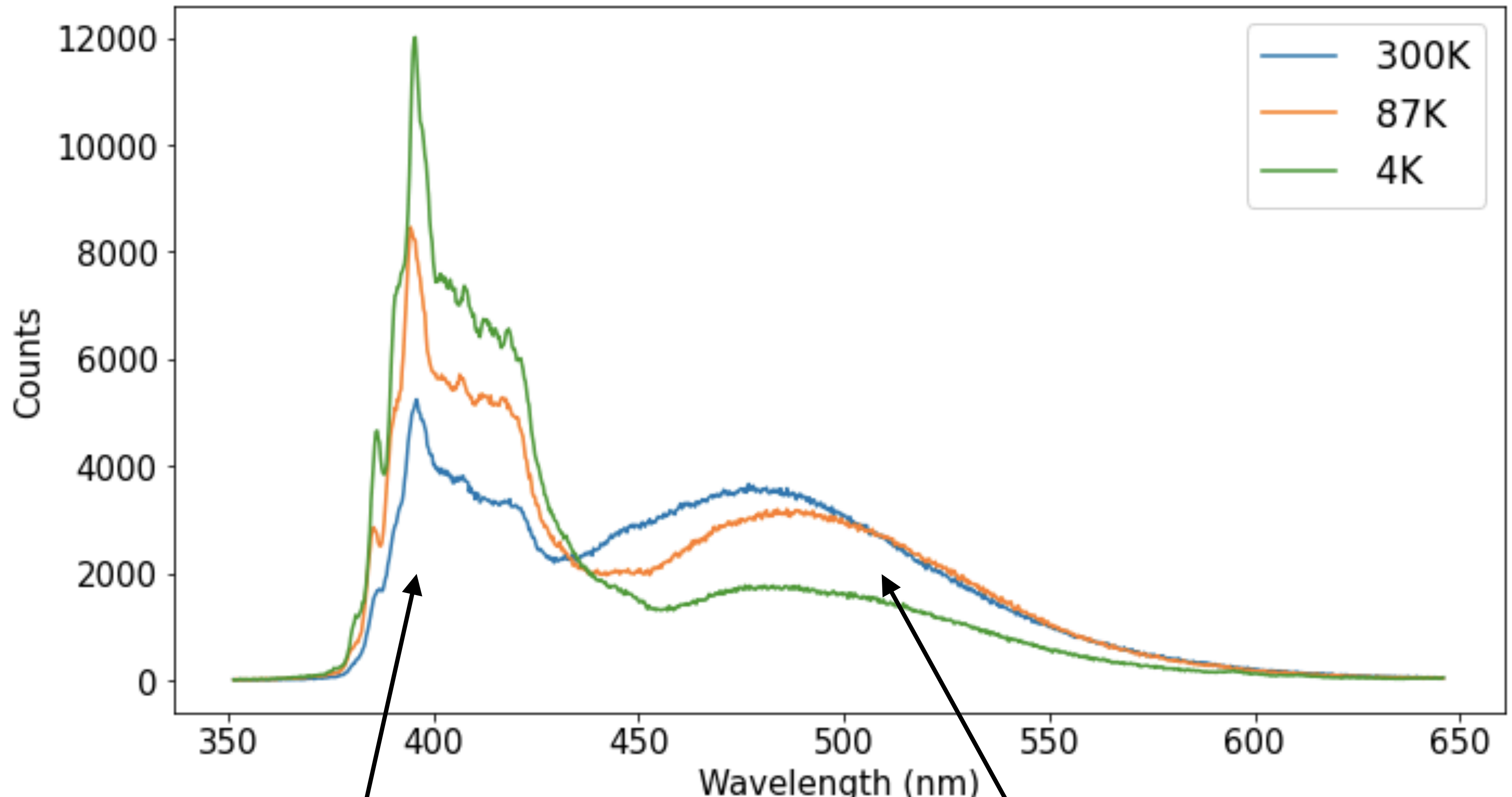
How does the pyrene spectrum evolve when temperature decreases?

1) Pyrene fluorescence spectra

Problem: Understanding the spectra evolution of pyrene

Spectra obtained with PMT replaced with a spectrometer and LED in DC mode —> constant UV intensity

15% Pyrene + PS



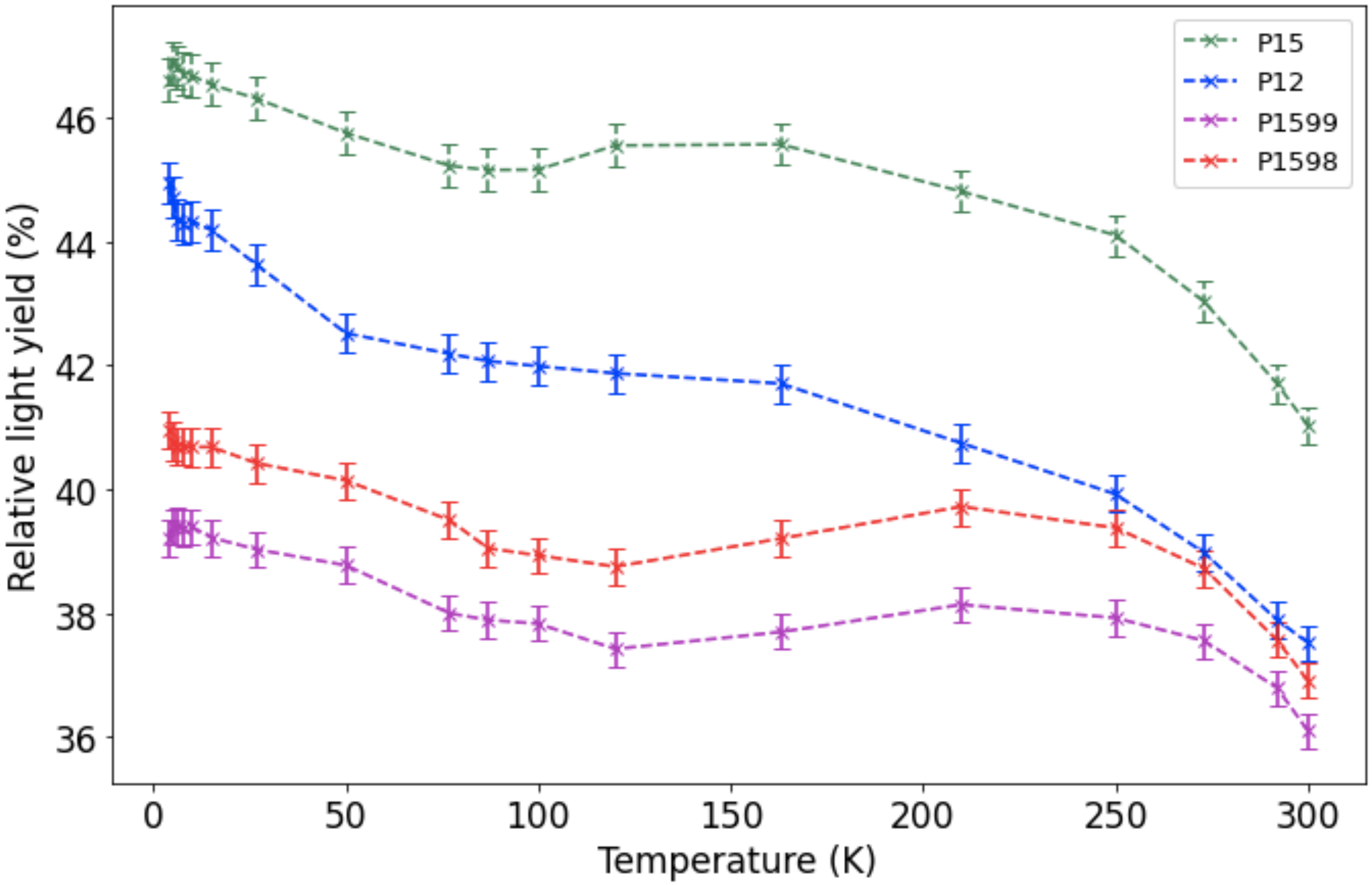
Monomer intensity ↗ when T ↘

Excimer intensity ↘ when T ↘

2) Fluorescence yield, purity and concentration

Problem: Understand the influence of purity and concentration on light yield

Light yield relatively to TPB



15 and 12
—> pyrene concentration

P1599 and P1598
—> low pyrene purity

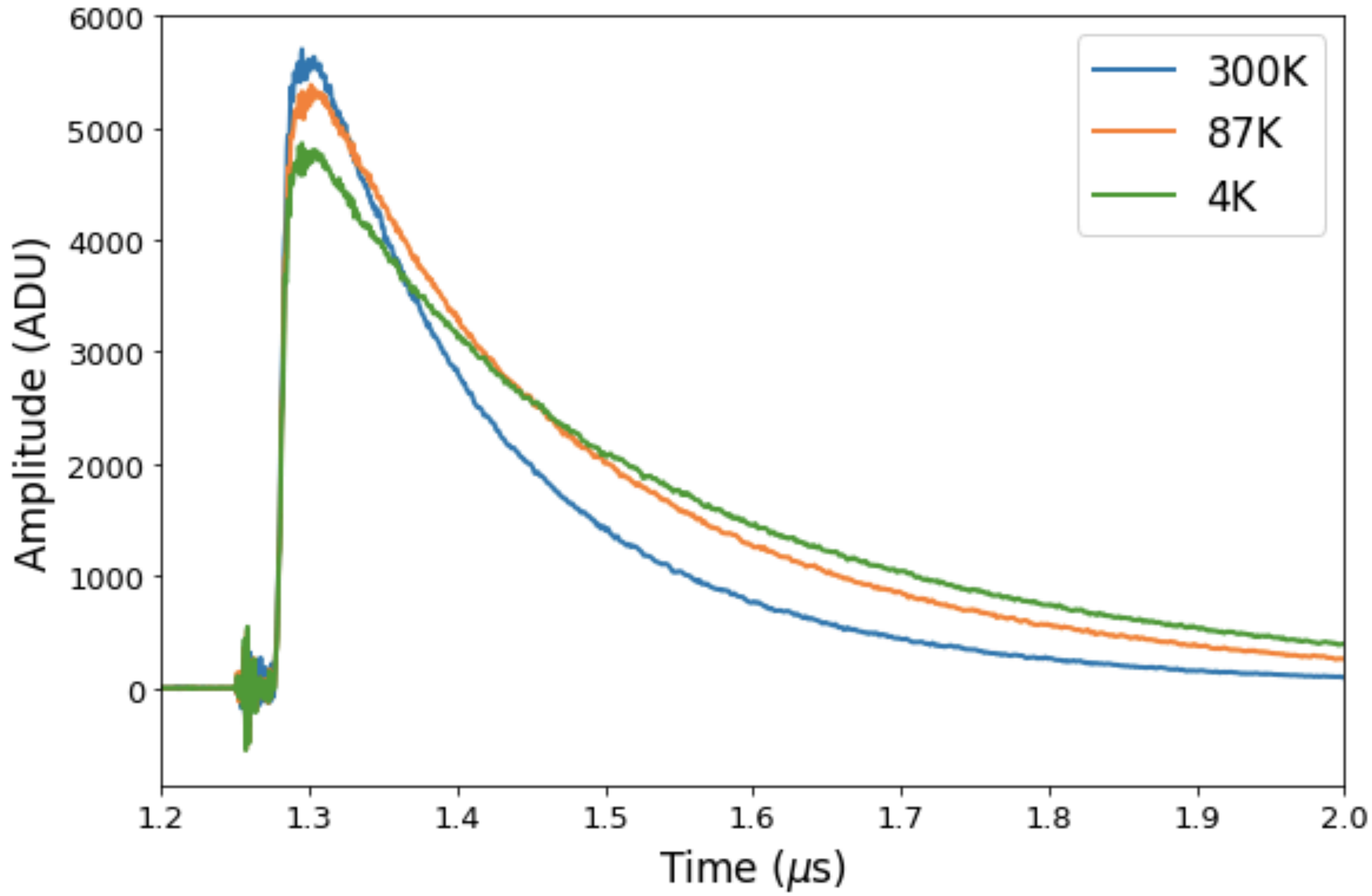
—> higher concentration, higher yield
—> purest pyrene, higher yield

3) Model for pyrene fluorescence

Problem: Understanding the fluorescence of pyrene

Time-resolved measurements:

ADU = voltage unit

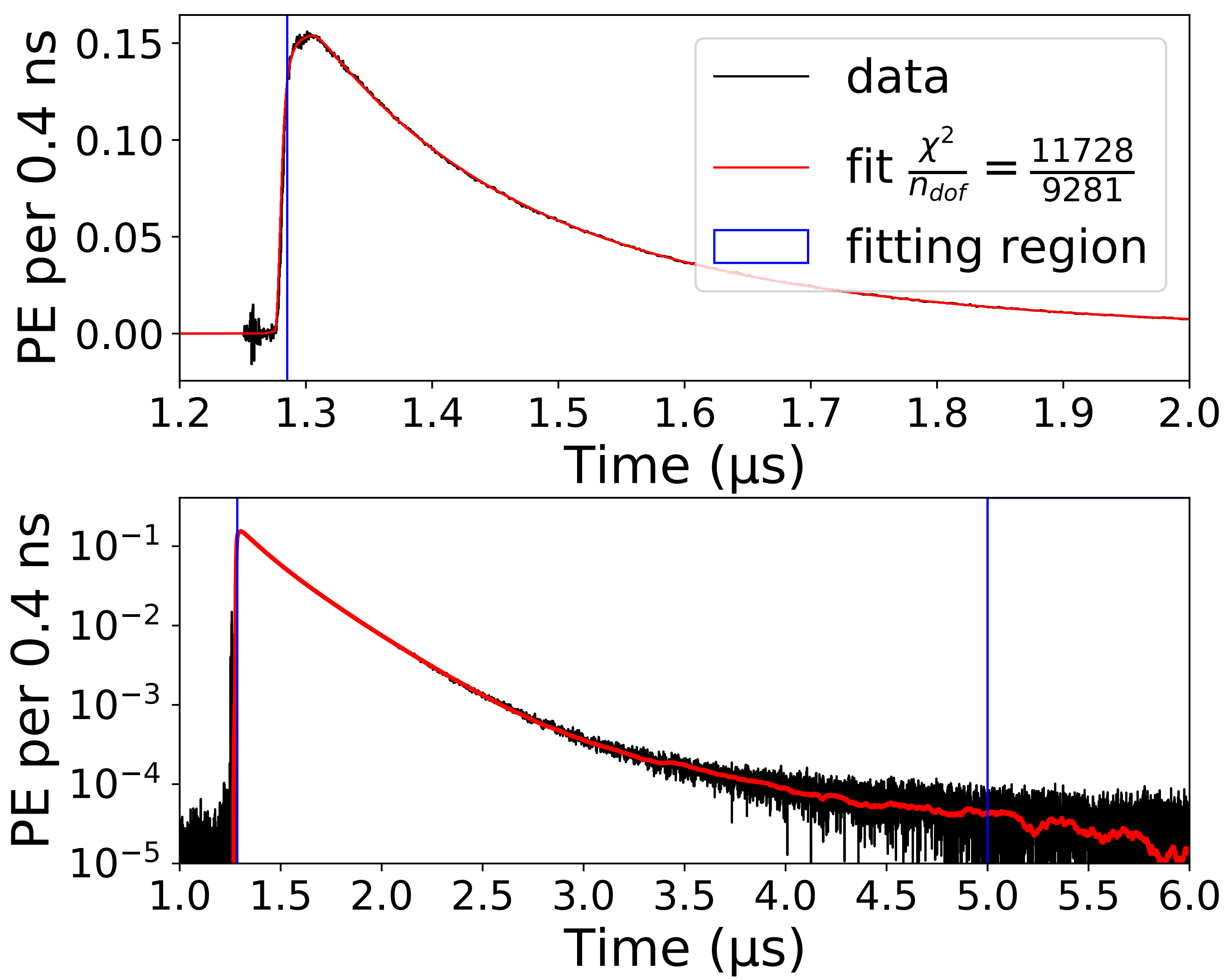


—> Profiles include both excimer and monomer emissions

3) Model for pyrene fluorescence

Problem: Understanding the fluorescence of the pyrene

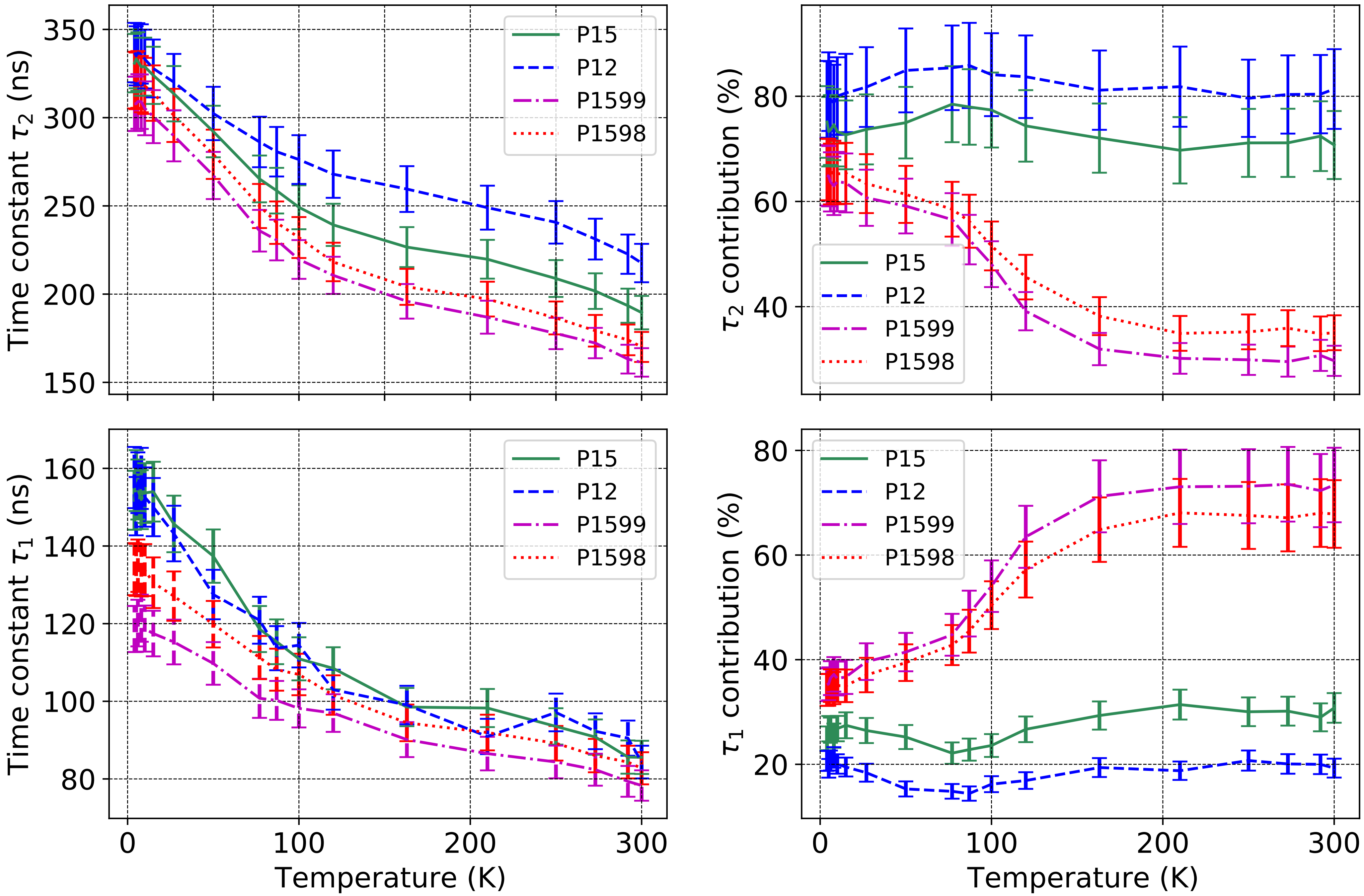
$$i(t) = -\frac{N_{rise}}{\tau_{rise}} e^{-\frac{t}{\tau_{rise}}} + \frac{N_1}{\tau_1} e^{-\frac{t}{\tau_1}} + \frac{N_2}{\tau_2} e^{-\frac{t}{\tau_2}}$$



—> 1 rise time, 2 decay time

3) Model for pyrene fluorescence

Two decay times



—> purity reinforces the contribution of the long time constant

—> At 87K, decay of P15 dominated by a 250 ns component

Conclusion: pyrene from 300 K to 4 K

- fluorescence yield increases as the sample is cooled and represent **between 35% and 50%** of TPB

- decay **slows down when sample is cooled** and remains **much slower than TPB**: O(100 ns) vs O(ns)

- fluorescence yield **higher** with **high concentration** and **high purity** of pyrene
—> **15% Pyrene + PS (FG 99.9%)** will be used for neck coating in DEAP

- **monomer** and **excimer (static and dynamic)** observed

- **15% Pyrene + PS (FG 99.9%)** dominated by a 250 ns component at LAr temperature
—> high potential for alpha discrimination in the neck of the DEAP detector
—> pyrene coating will be applied in next DEAP upgrade

- *See David Gallacher's talk for details on background discrimination*

Queen's University

Thank you, any question?

Backup

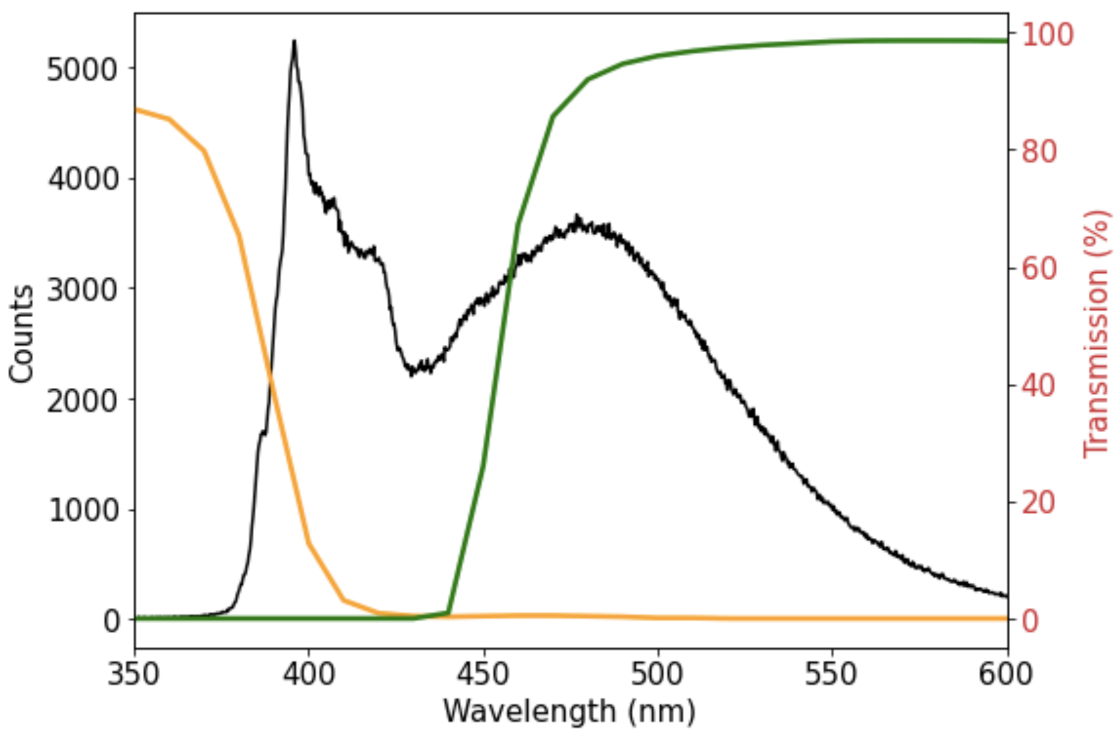
Model for pyrene fluorescence

Using optical filters...

…we can separate excimer and monomer emissions

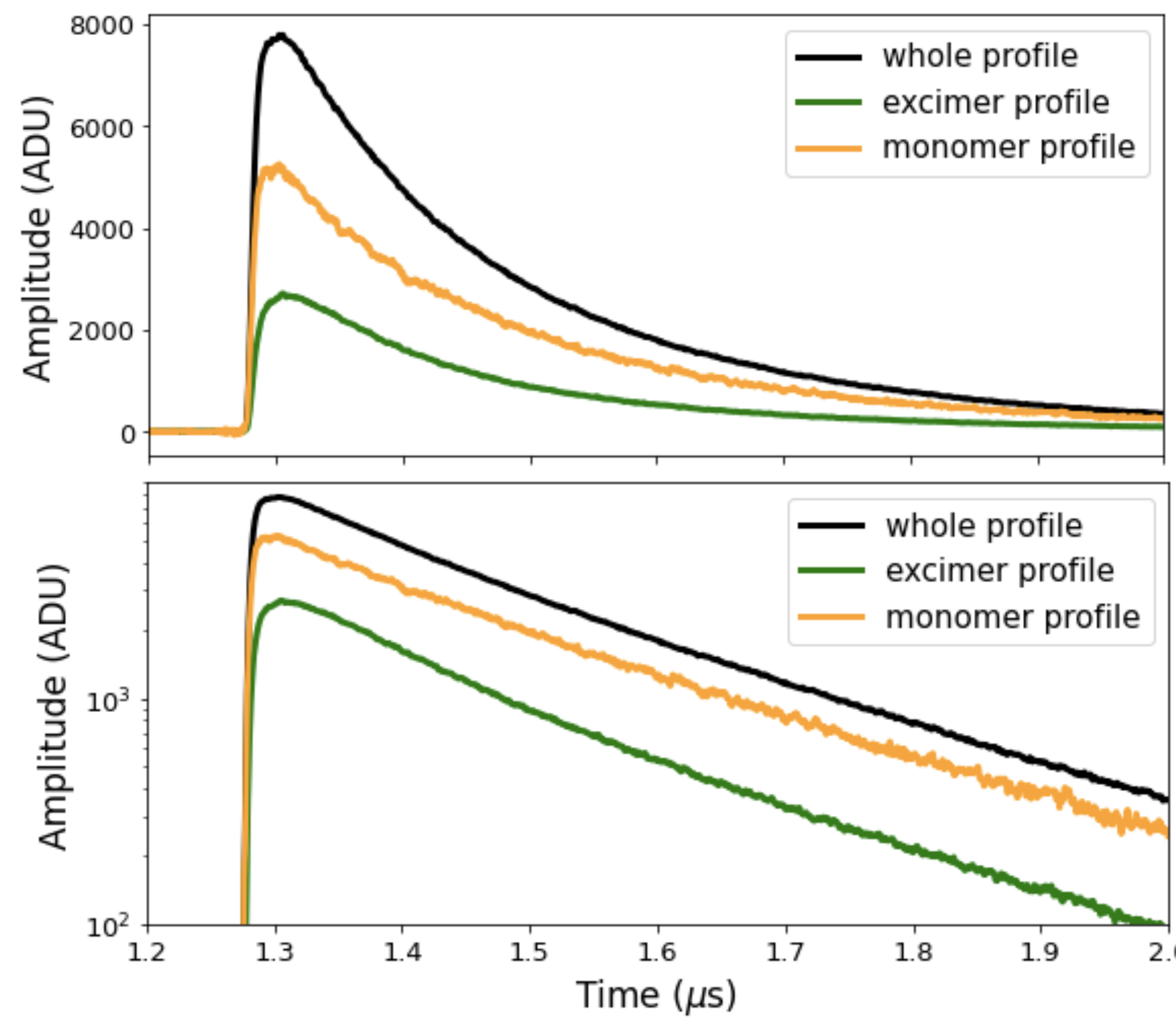
Bandpass 330nm

Monomer emission ~390nm



Longpass 455nm

Excimer emission ~490nm



—> Monomer and excimer profiles modeled separately

Model for pyrene fluorescence

Excimer

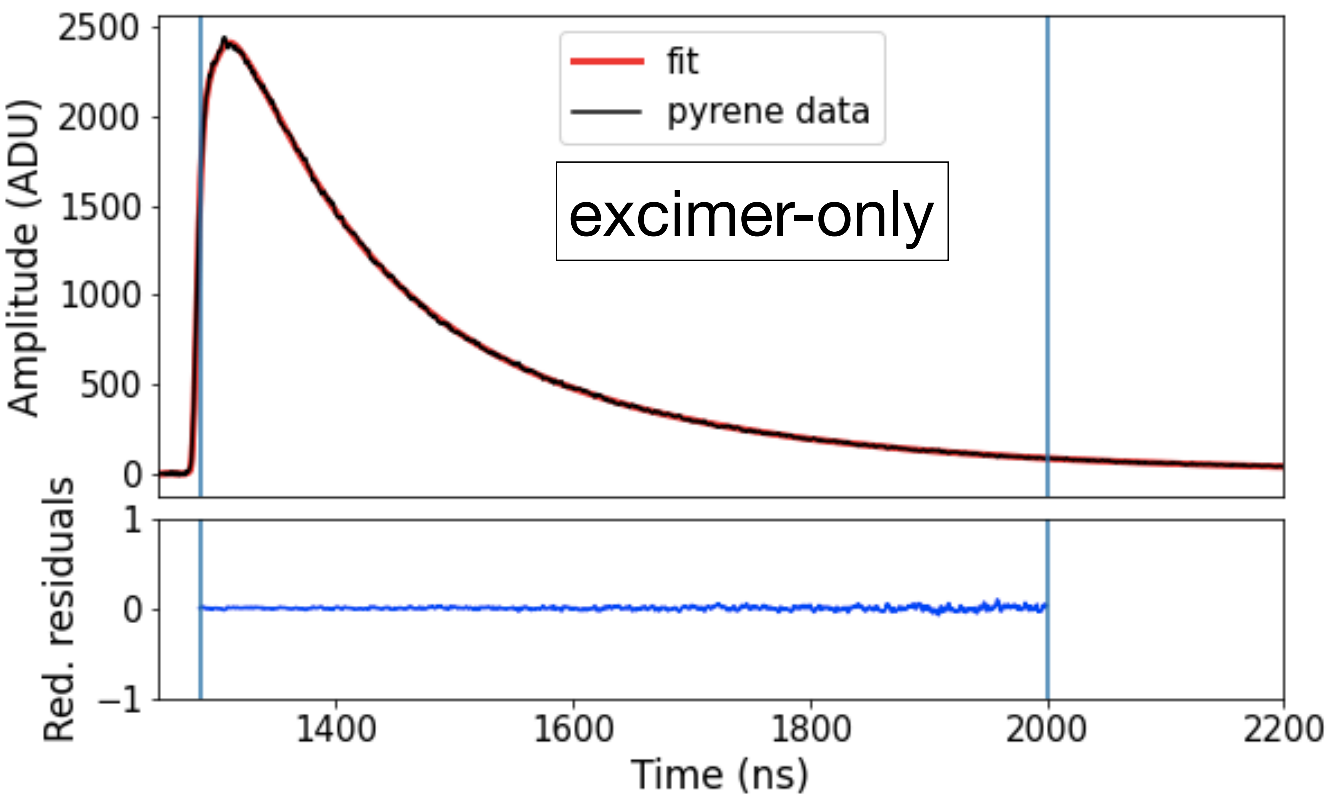
Adapted from Winnik 1993

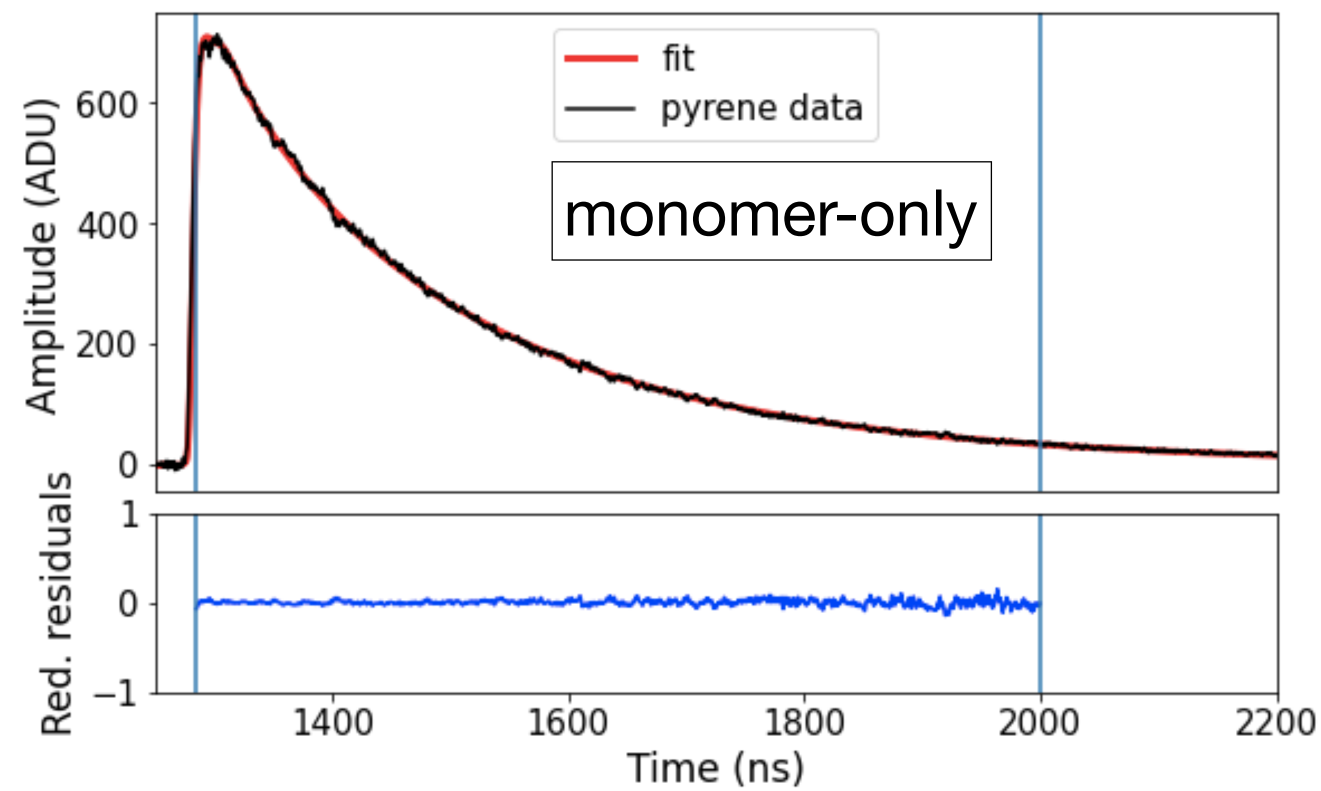
$$i_e(t) = -\frac{N_{rise}}{\tau_{rise}} e^{-\frac{t}{\tau_{rise}}} + \frac{N_2}{\tau_2} e^{-\frac{t}{\tau_2}} + \frac{N_3}{\tau_3} e^{-\frac{t}{\tau_3}}$$

Monomer

Adapted from Johnson 1980

$$i_m(t) = \frac{N_1}{\tau_1} e^{-\frac{t}{\tau_1} - 2q\sqrt{\frac{t}{\tau_1}}}$$





—> 1 rise time, 3 decay times