Pulse-Shape Discrimination in DEAP-3600

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for the DEAP-3600 Collaboration

https://arxiv.org/abs/2103.12202

https://doi.org/10.1140/epjc/s10052-020-7789-x

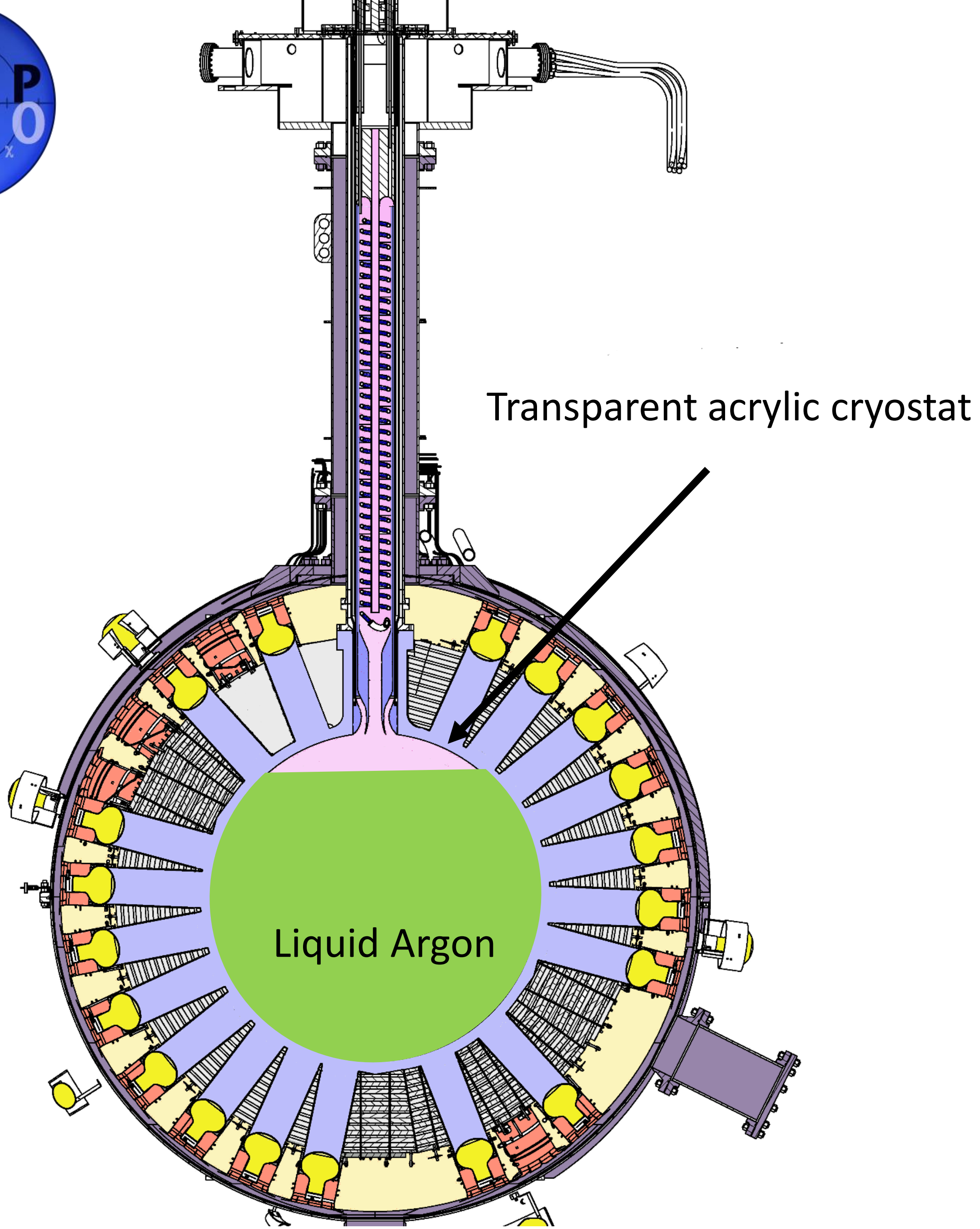
Dark matter

Experiment with

Argon

Pulse shape discrimination

The next 10 minutes



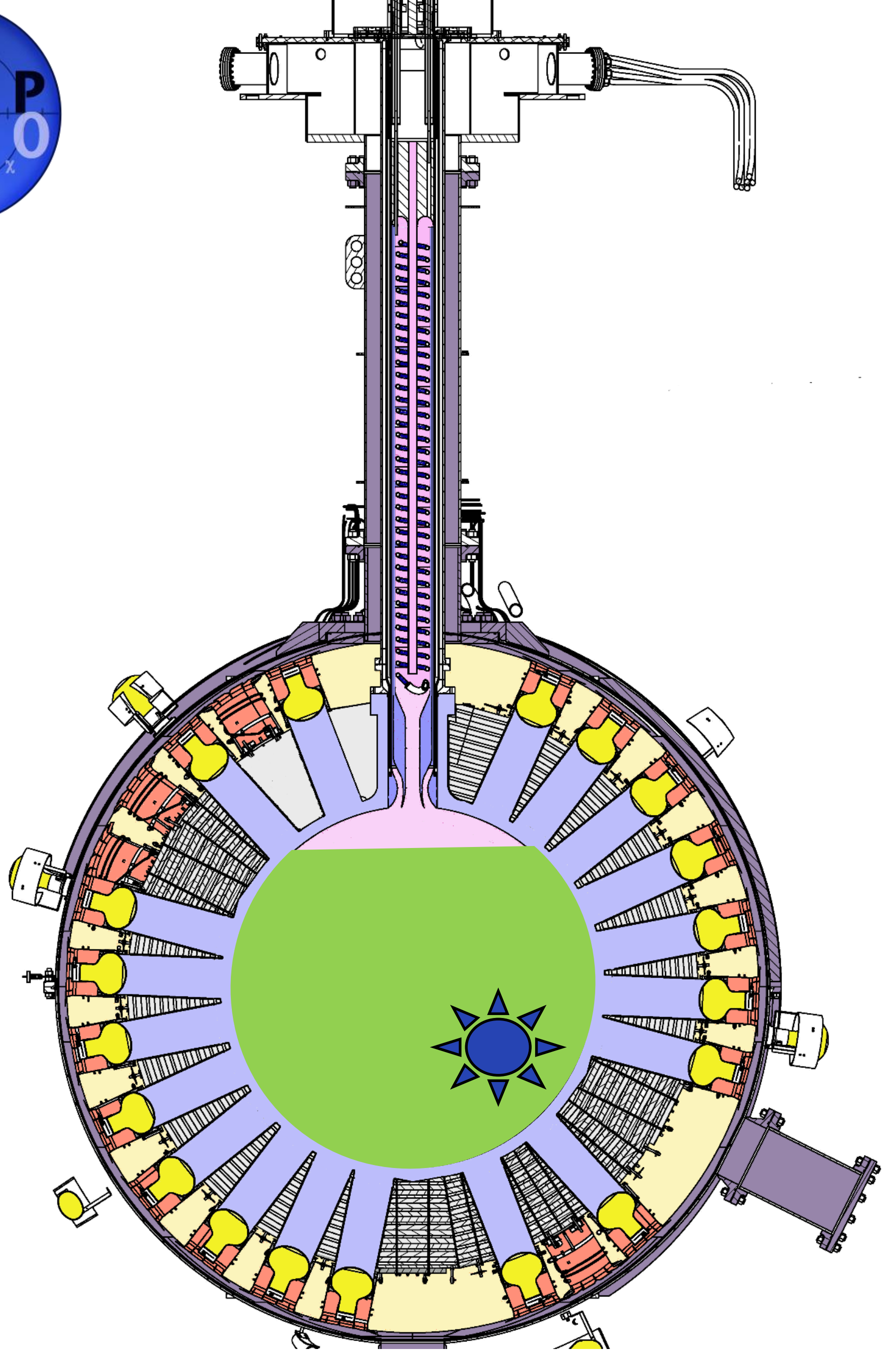
Scintillation occurs in 3300 kg of liquid argon

Radiation in LAr produces scintillation light at 128 nm

Light is wavelength shifted to ~420nm by TPB layer

Light is detected by 255 PMTs

https://doi.org/10.1016/j.astropartphys.2018.09.006



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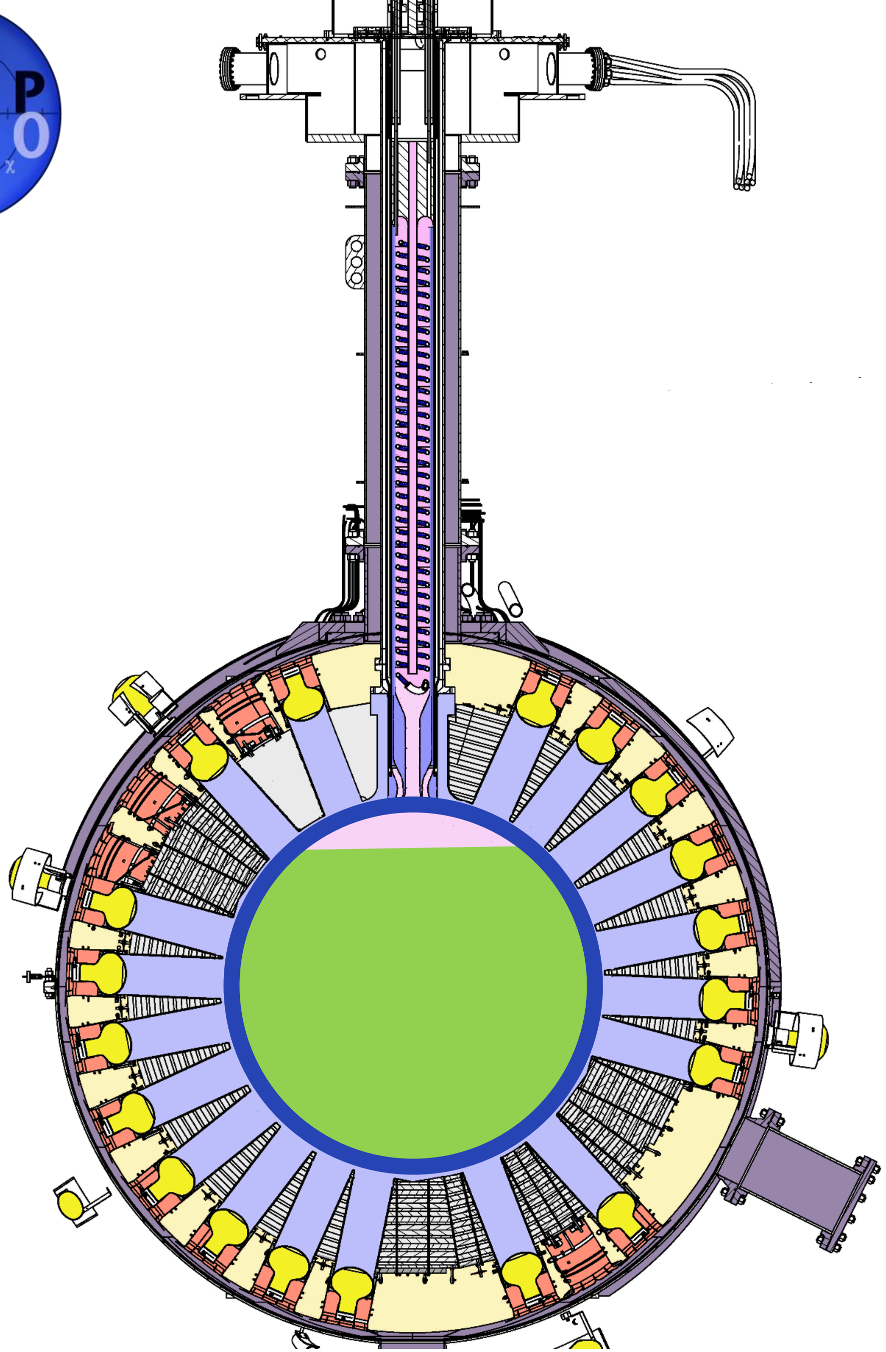

[Scintillation occurs in 3300 kg of liquid argon]()

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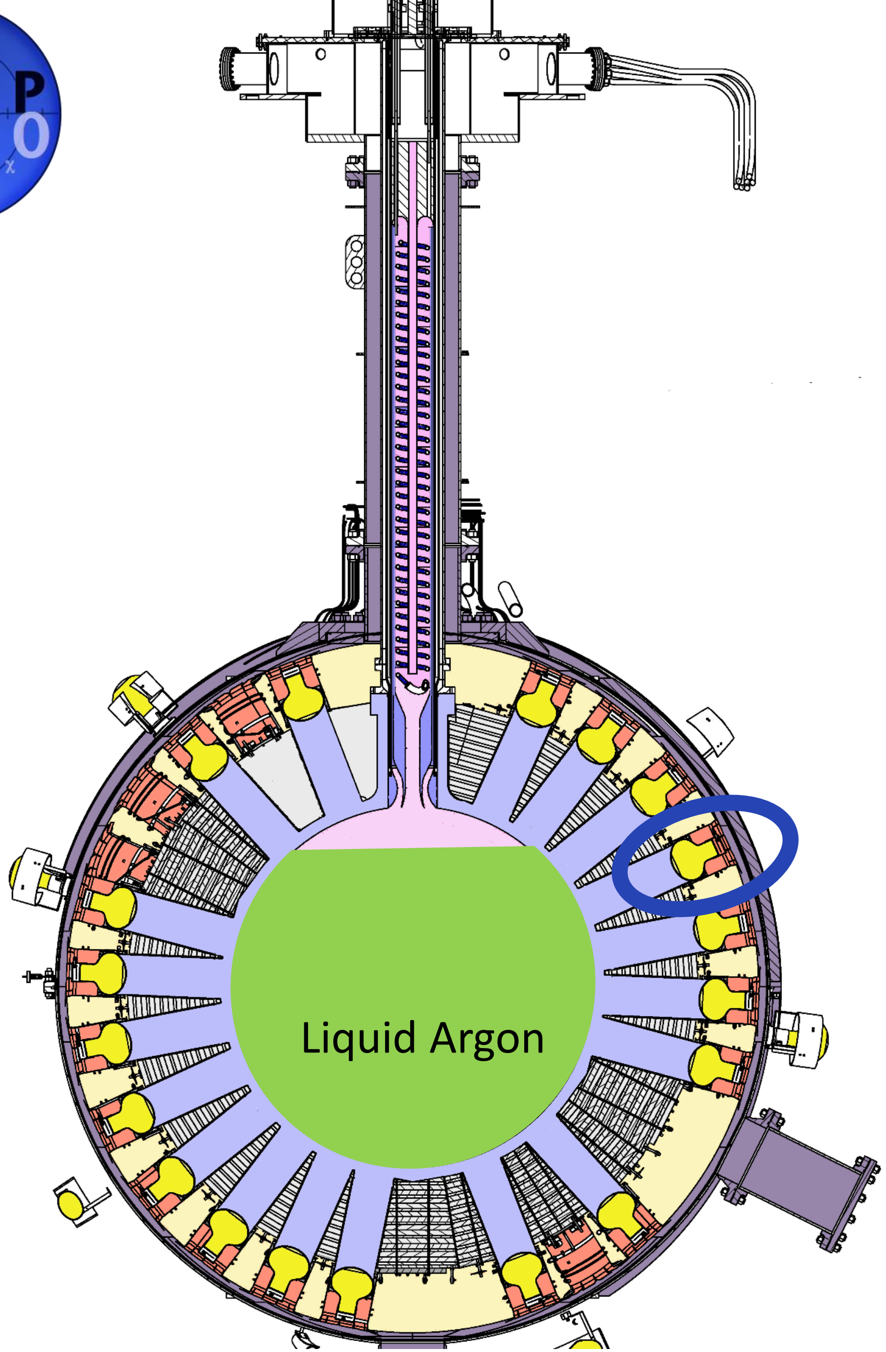

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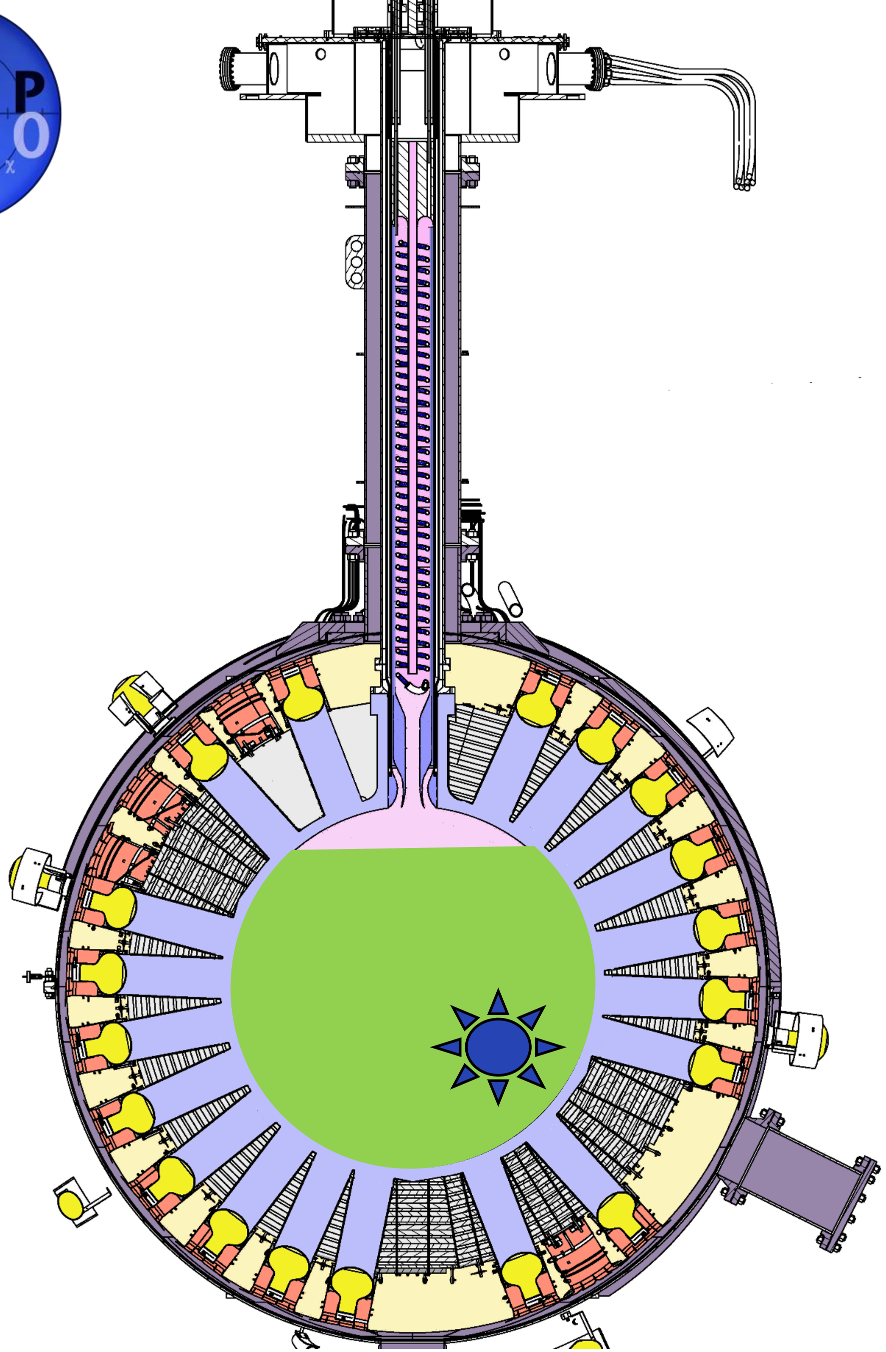


Particles that cause an argon nucleus (or an alpha particle) to recoil …

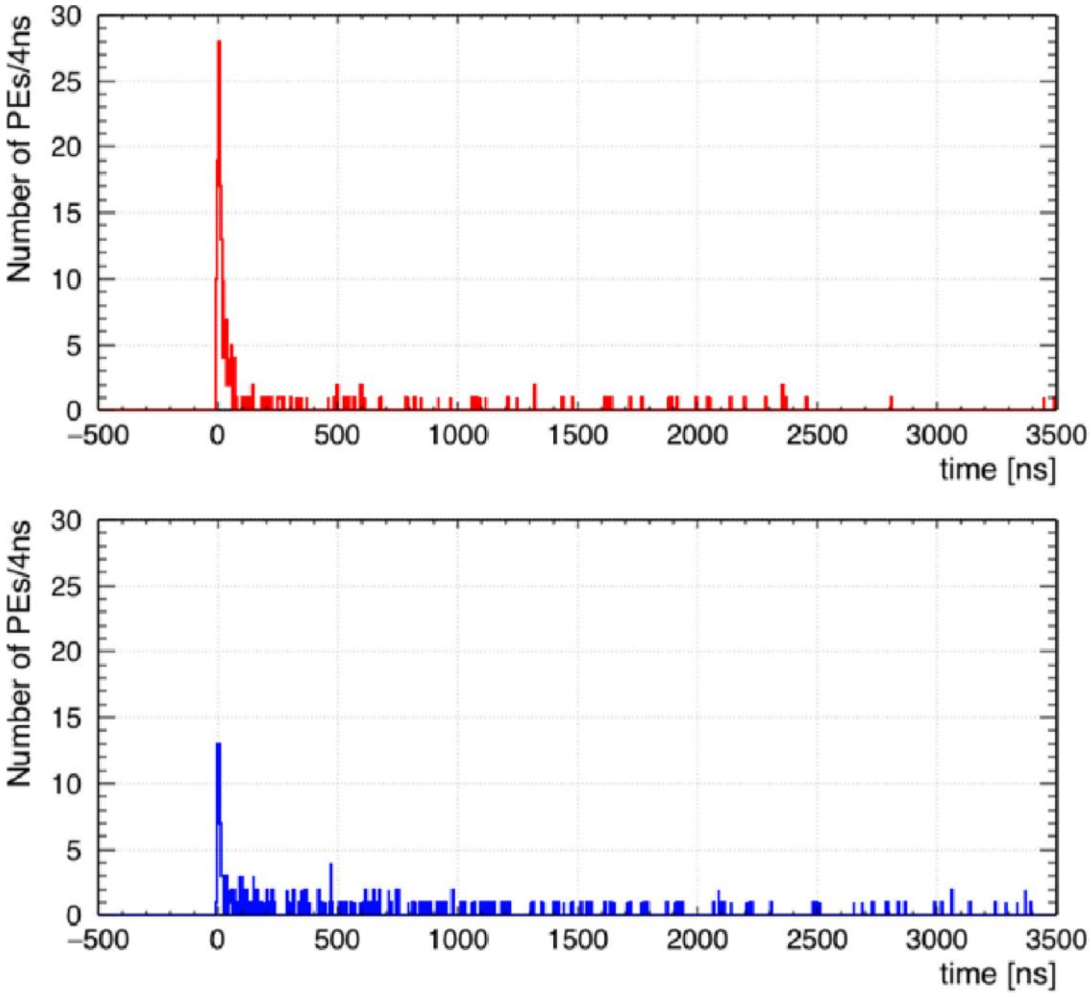
- neutrons
- dark matter
- radon …

excite the argon preferentially to a state that decays in <u>nanoseconds</u>.

Particles that interact with electrons

- electrons
- gamma rays …

Excite the argon preferentially in a state that decays in <u>microseconds</u>



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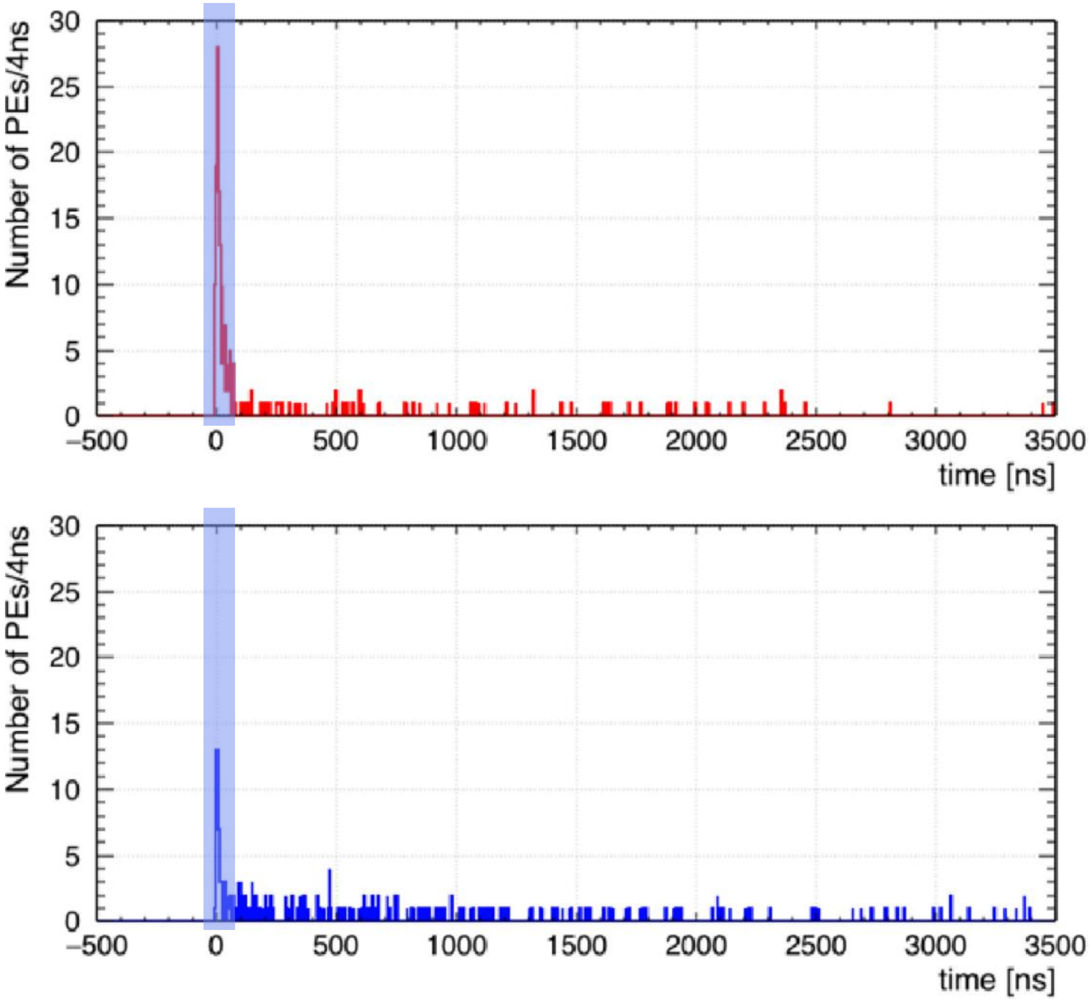
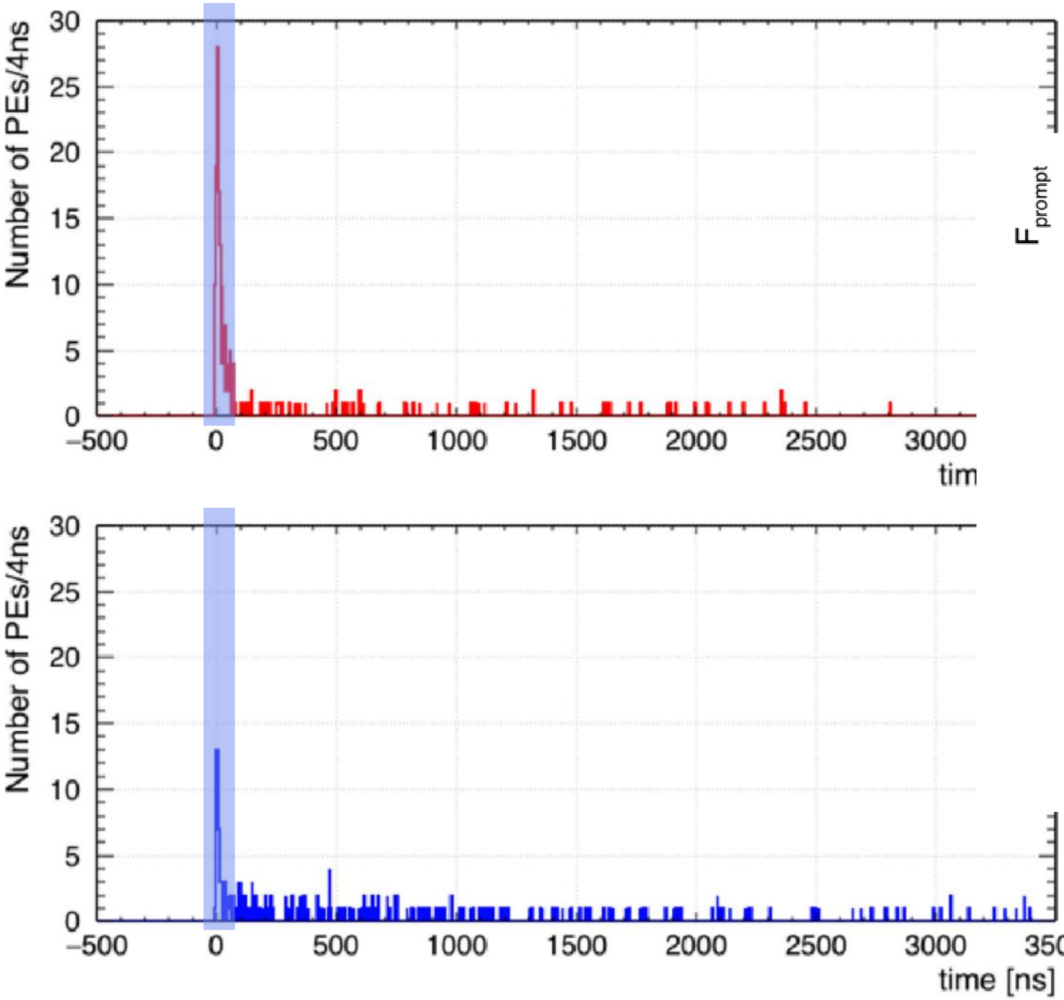
Method 1: Prompt Fraction Analysis

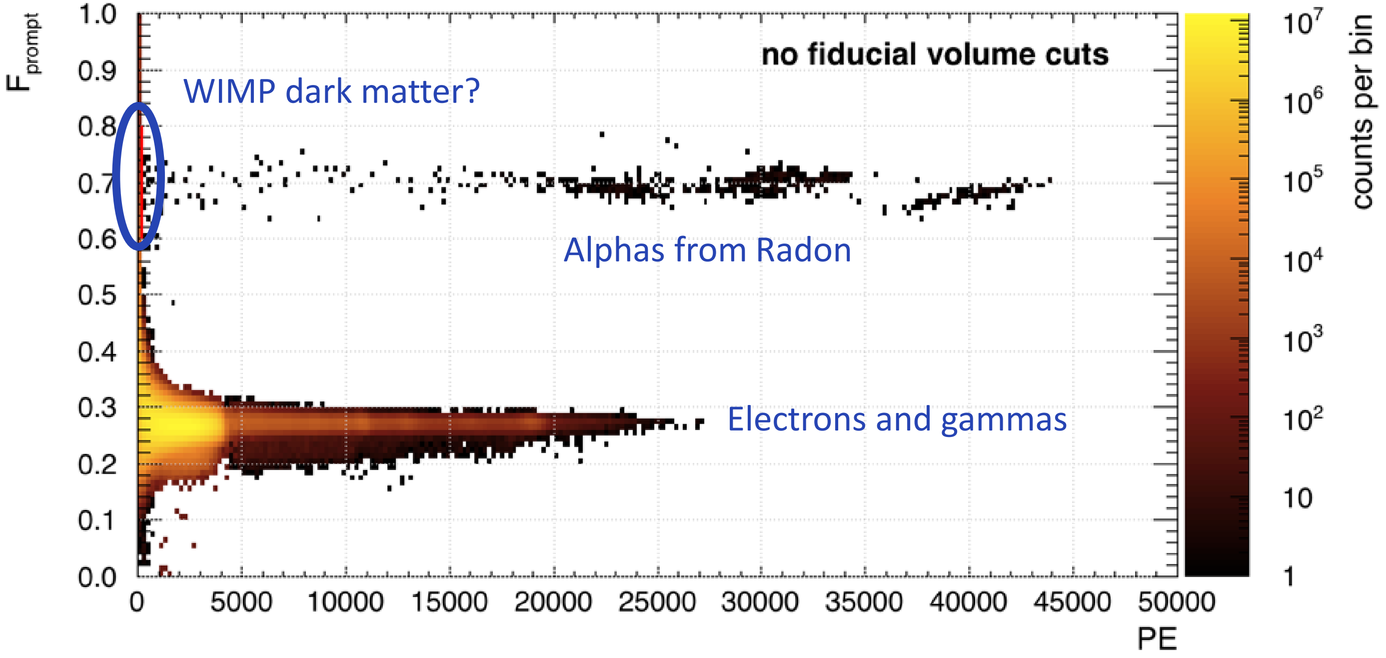


$$F_{prompt} = \frac{Number\ of\ photons\ in\ prompt\ window}{Total\ number\ of\ photons}$$

$$F_{\text{prompt}} = \frac{\sum_{t>t_{\text{start}}}^{t<t_{\text{prompt}}} n(t)}{\sum_{t>t_{\text{start}}}^{t<t_{\text{total}}} n(t)}$$

Method 1: Prompt Fraction Analysis

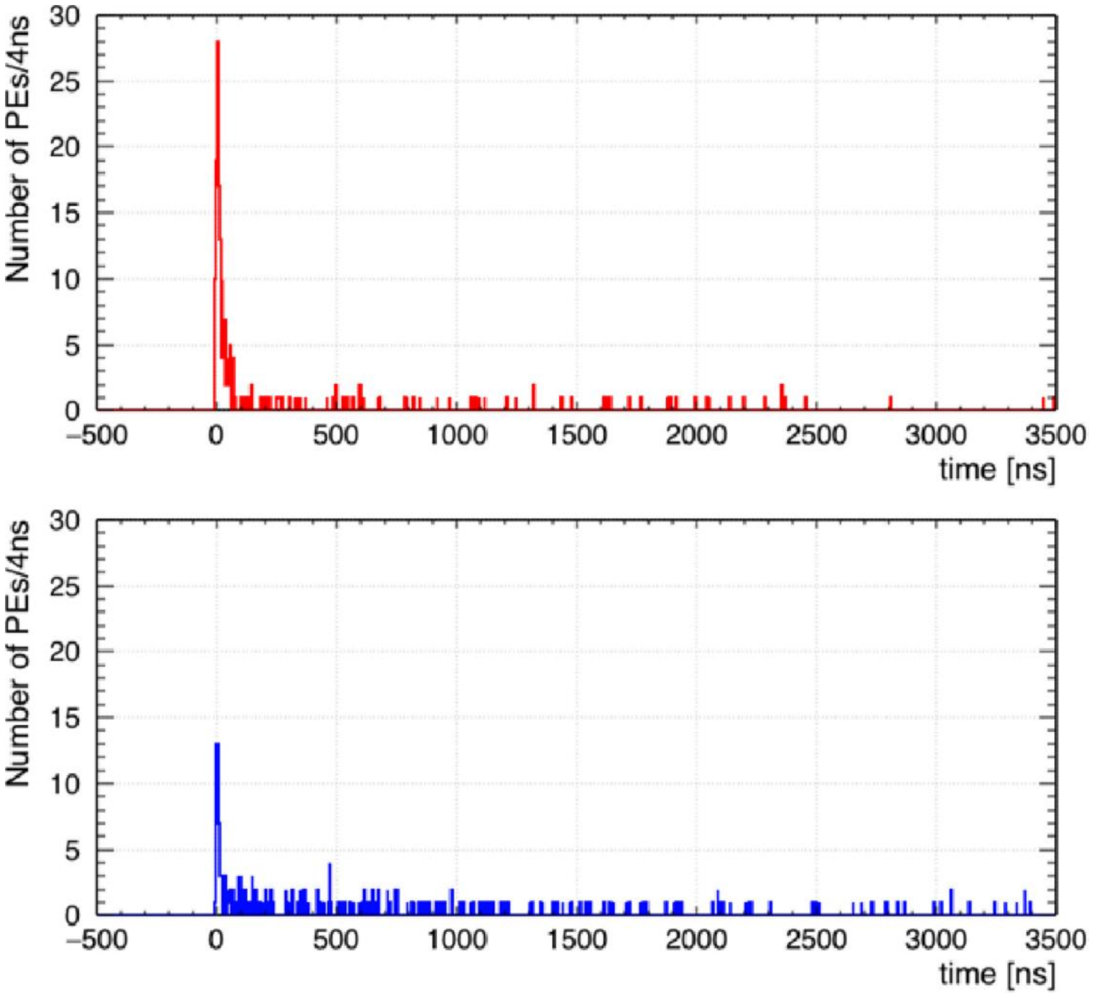




4 days data from 2016

https://doi.org/10.1103/PhysRevLett.121.071801

Method 2: Likelihood Ratio Based on Pulse Shape

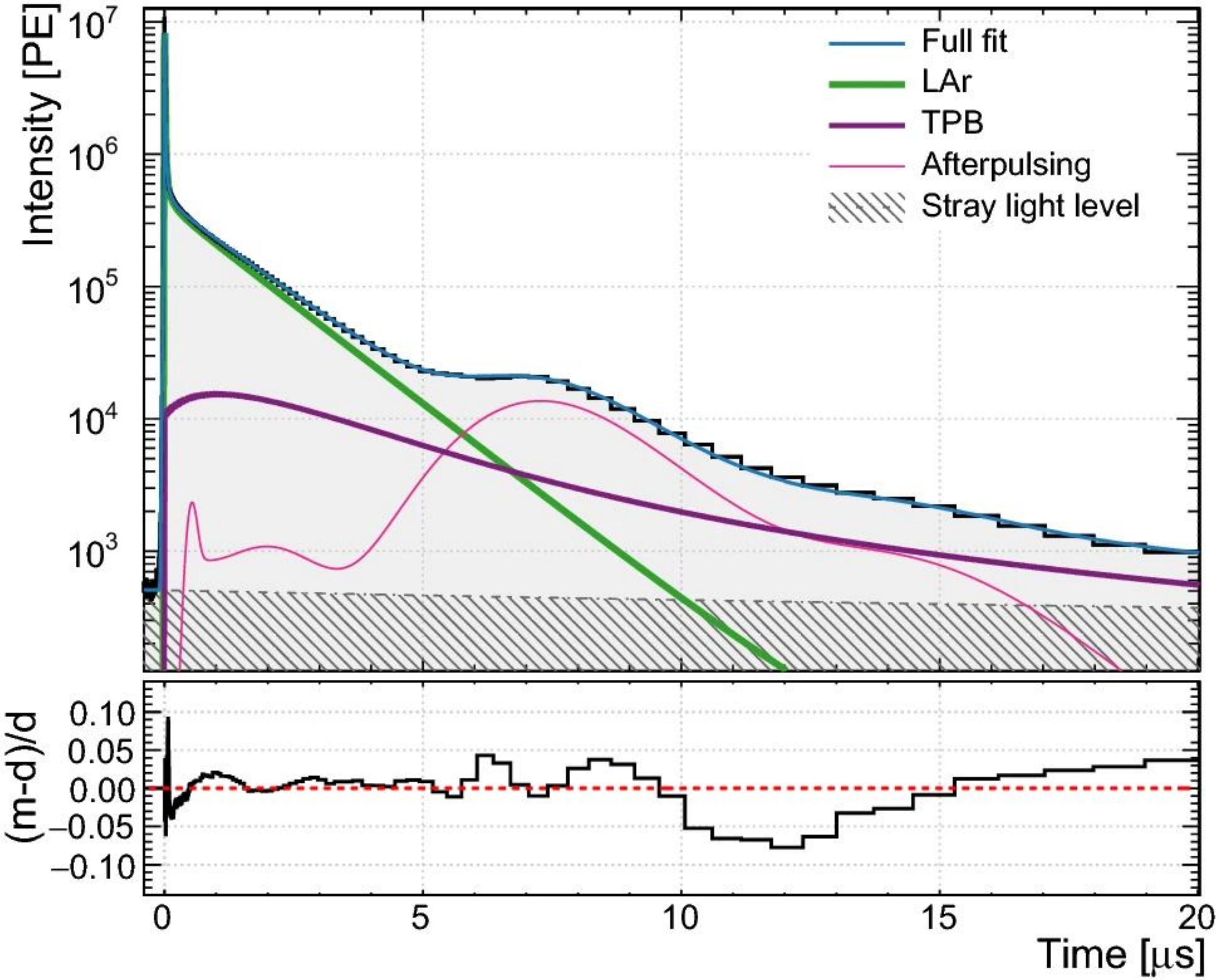


$$L_{\text{recoil}} = \frac{1}{2} + \frac{\sum_{t>t_{\text{start}}}^{t<t_{\text{total}}} w(t)n(t)}{\sum_{t>t_{\text{start}}}^{t<t_{\text{total}}} n(t)}$$

with the weights defined as

$$w(t) = \frac{1}{2} \cdot \log \frac{p(t)_{\text{nr}}}{p(t)_{\text{er}}}.$$

Pulse-Shape Model includes scintillation, TPB, and PMT effects



Electron-recoil pulse shape from
https://doi.org/10.1140/epjc/s10052-020-7789-x

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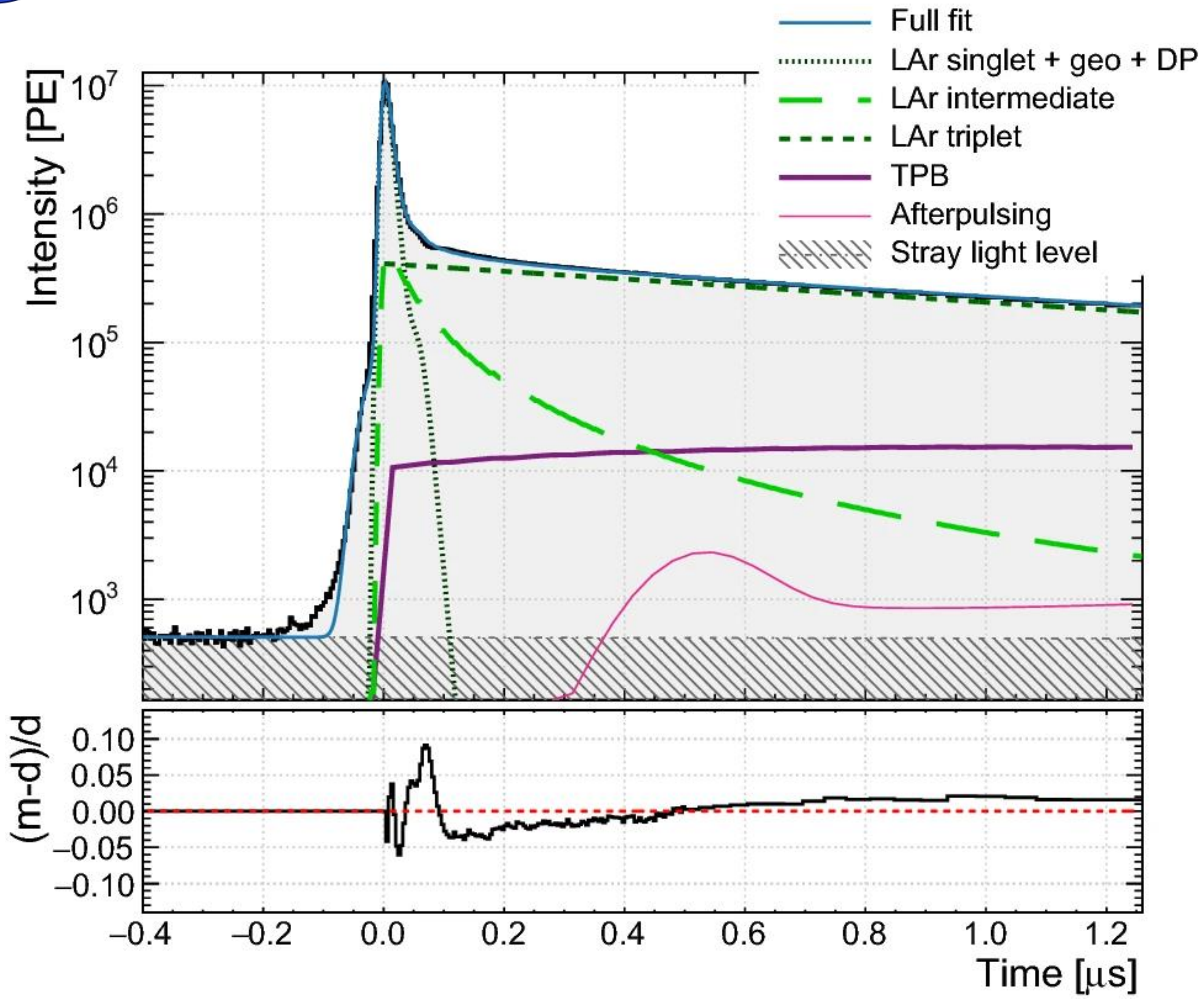
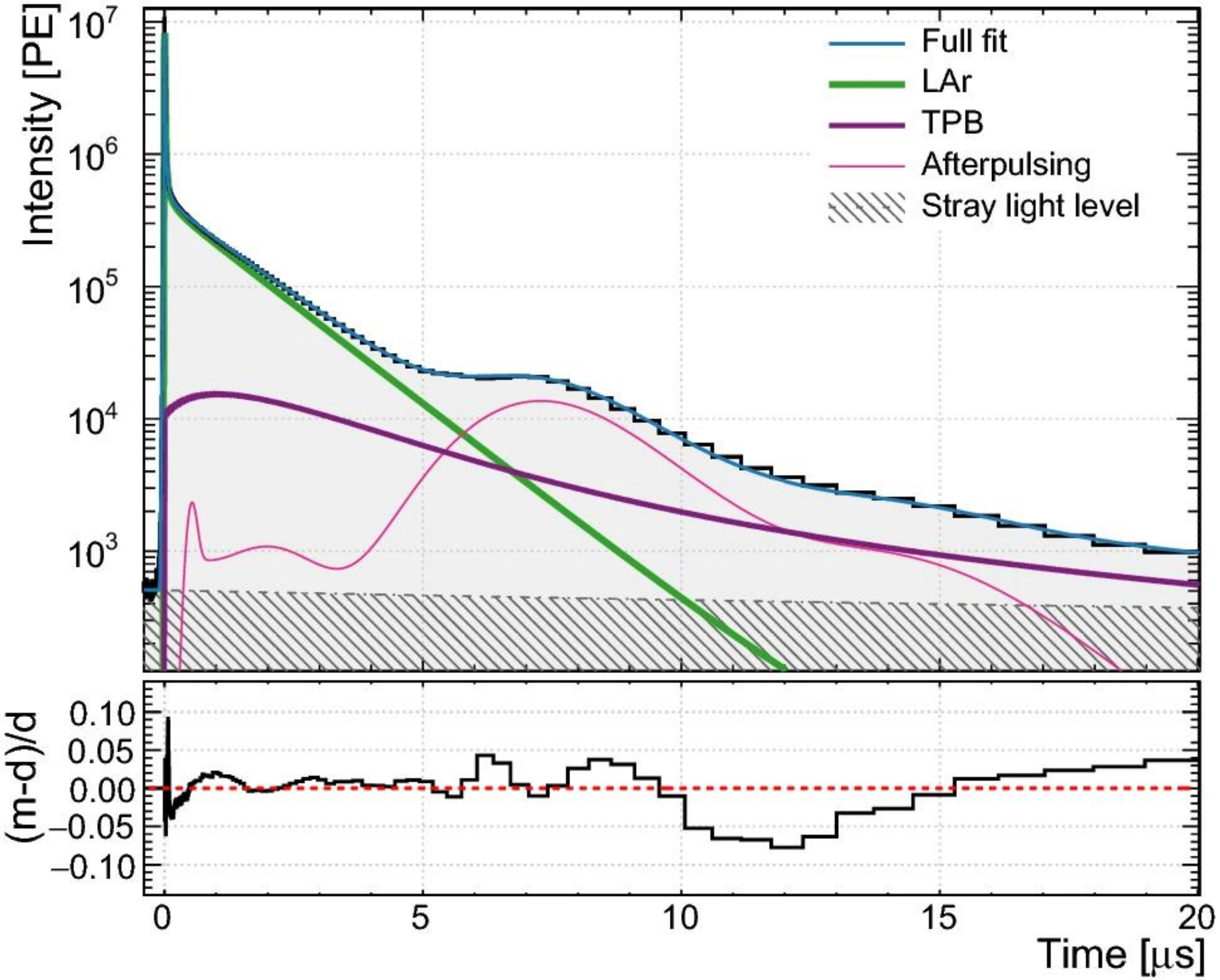


Electron-recoil pulse shape from https://doi.org/10.1140/epjc/s10052-020-7789-x

Best fit is with an intermediate scintillation component.

The intermediate component has been attributed to electrons ejected out of immediate reach of their ion's potential and recombine after a random walk. M. Hofmann, T. Dandl, T. Heindl et al., Ion-beam excitation of liquid argon. EPJ C 73(10), 2618 (2013)

PMT and TPB Effects can be removed

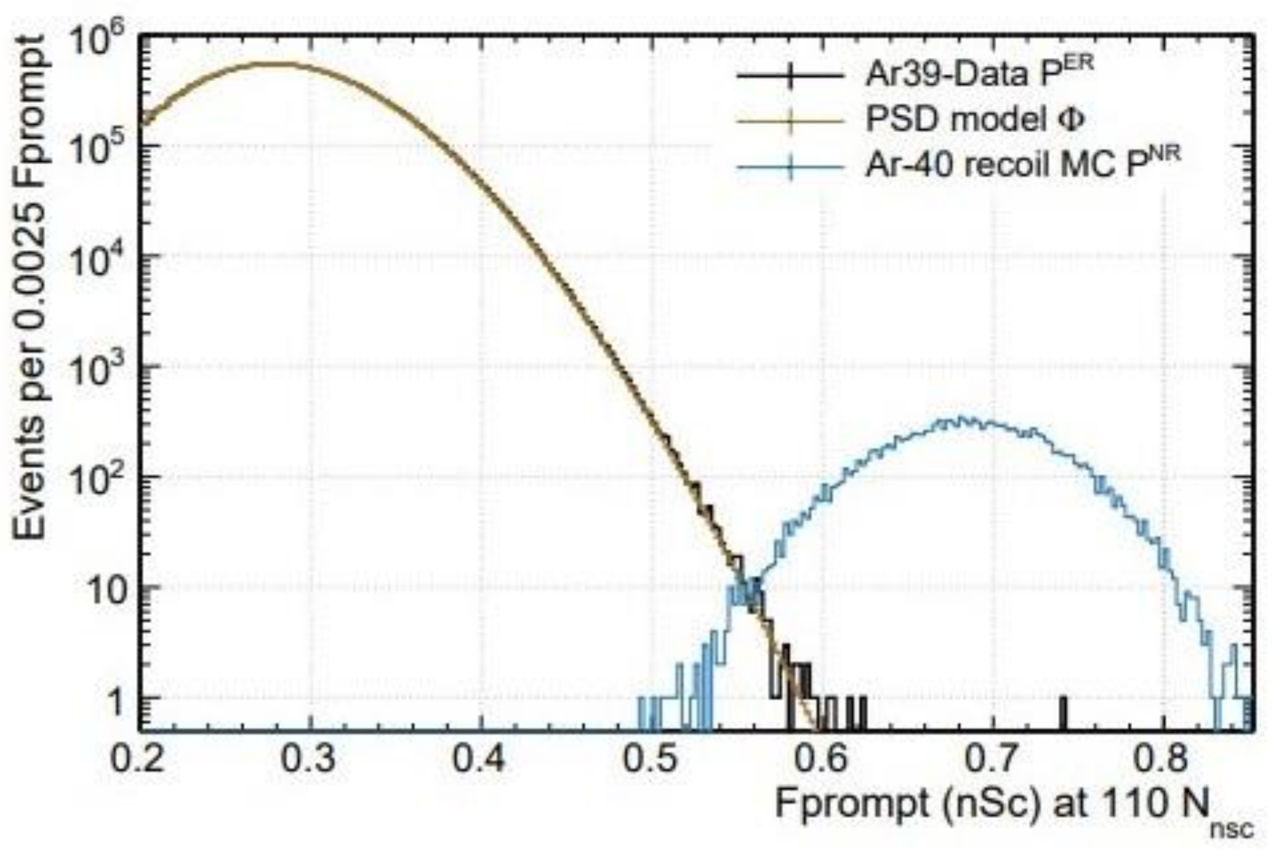


Two estimators of PMT signals:

1: Charge division by mean SPE charge.
Biased estimator – includes afterpulsing etc

2: Bayesian analysis of PMT hits is used to estimate the probability a given PMT signal is from scintillation, late TPB emission, or stray light/dark noise.

Data at ~18 keV_{ee}

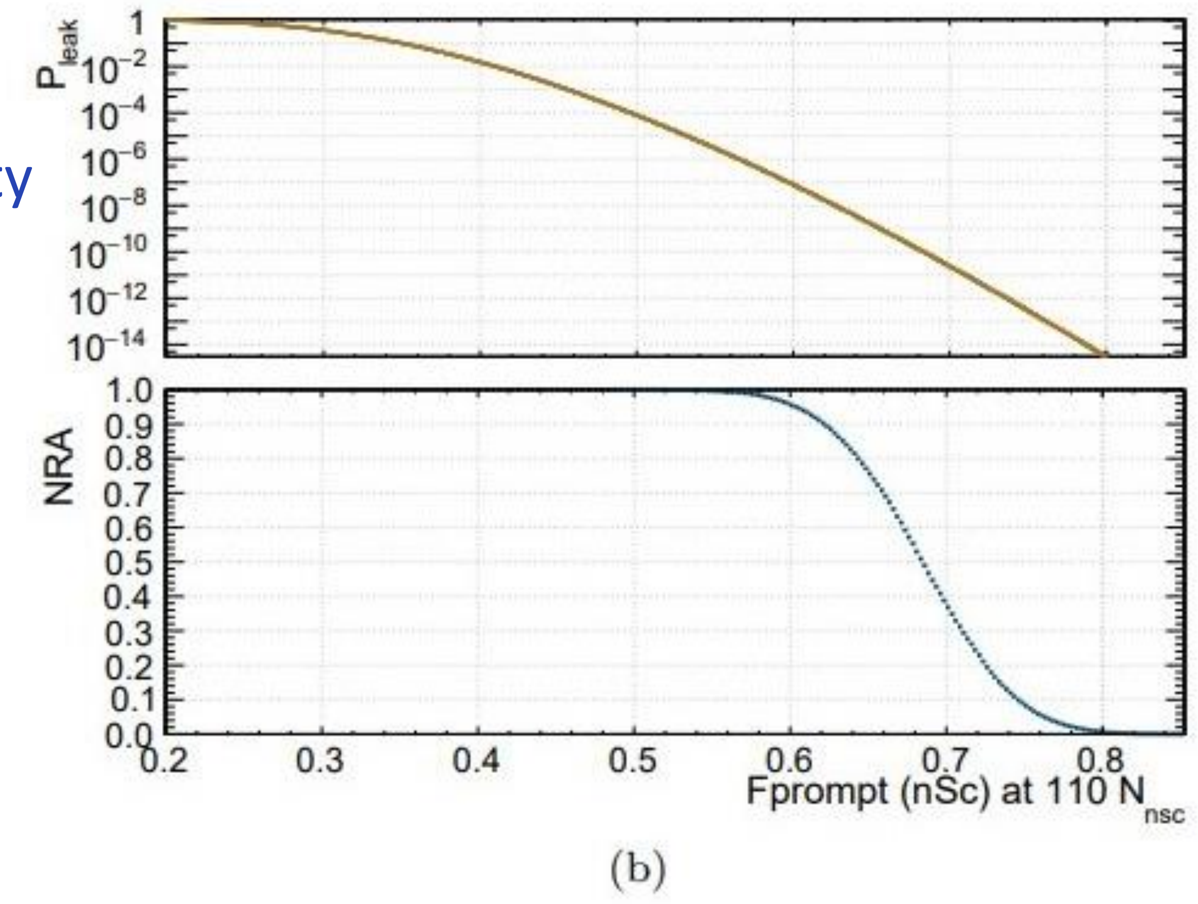


Prompt fraction after Bayesian removal of PMT effects

Data at ~18 keV_{ee}

Leakage probability of EM events

Nuclear recoil acceptance



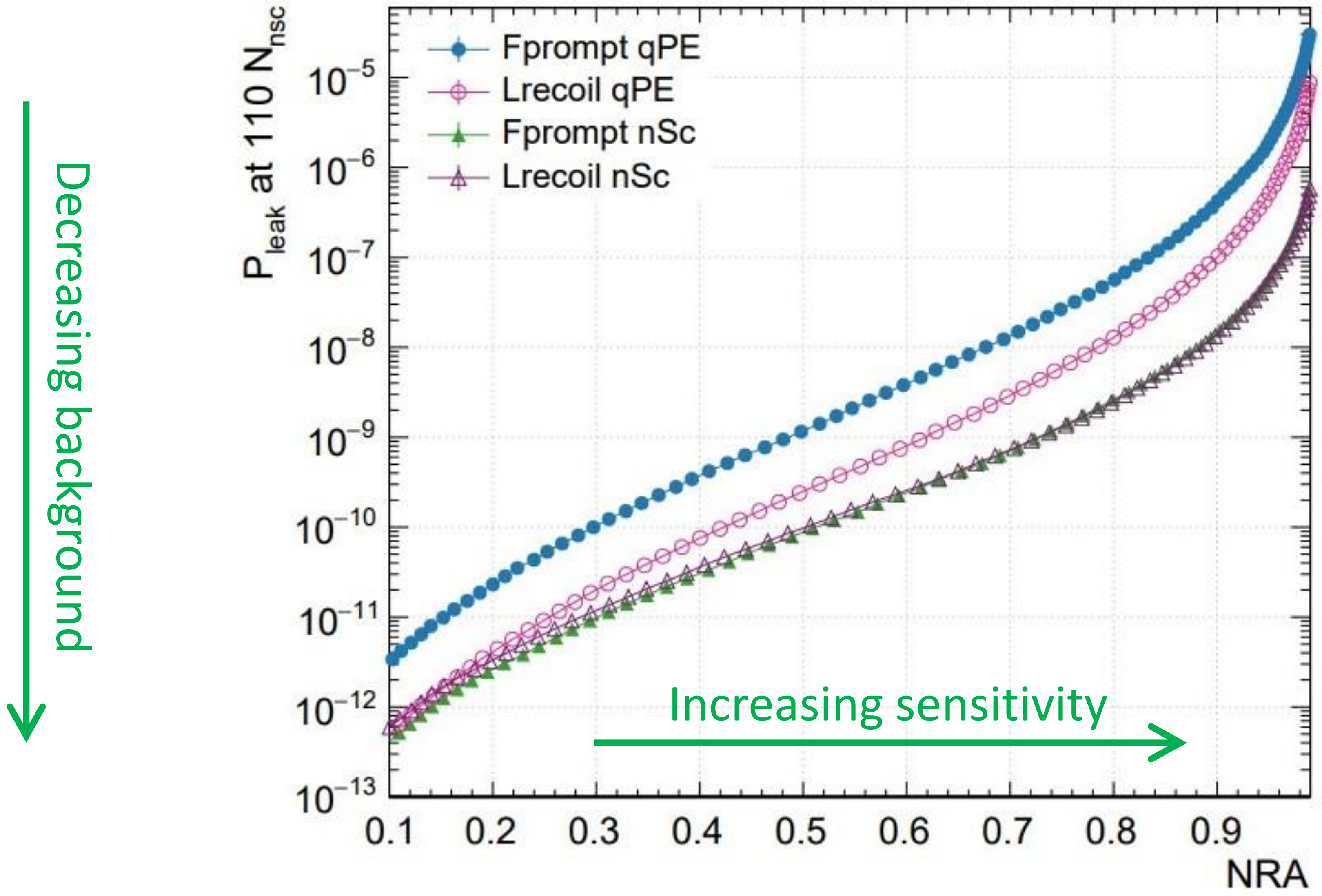
1

10^{-14}

1

0

Data at ~18 keV_{ee}



No PMT/TPB corrections

Prompt fraction method

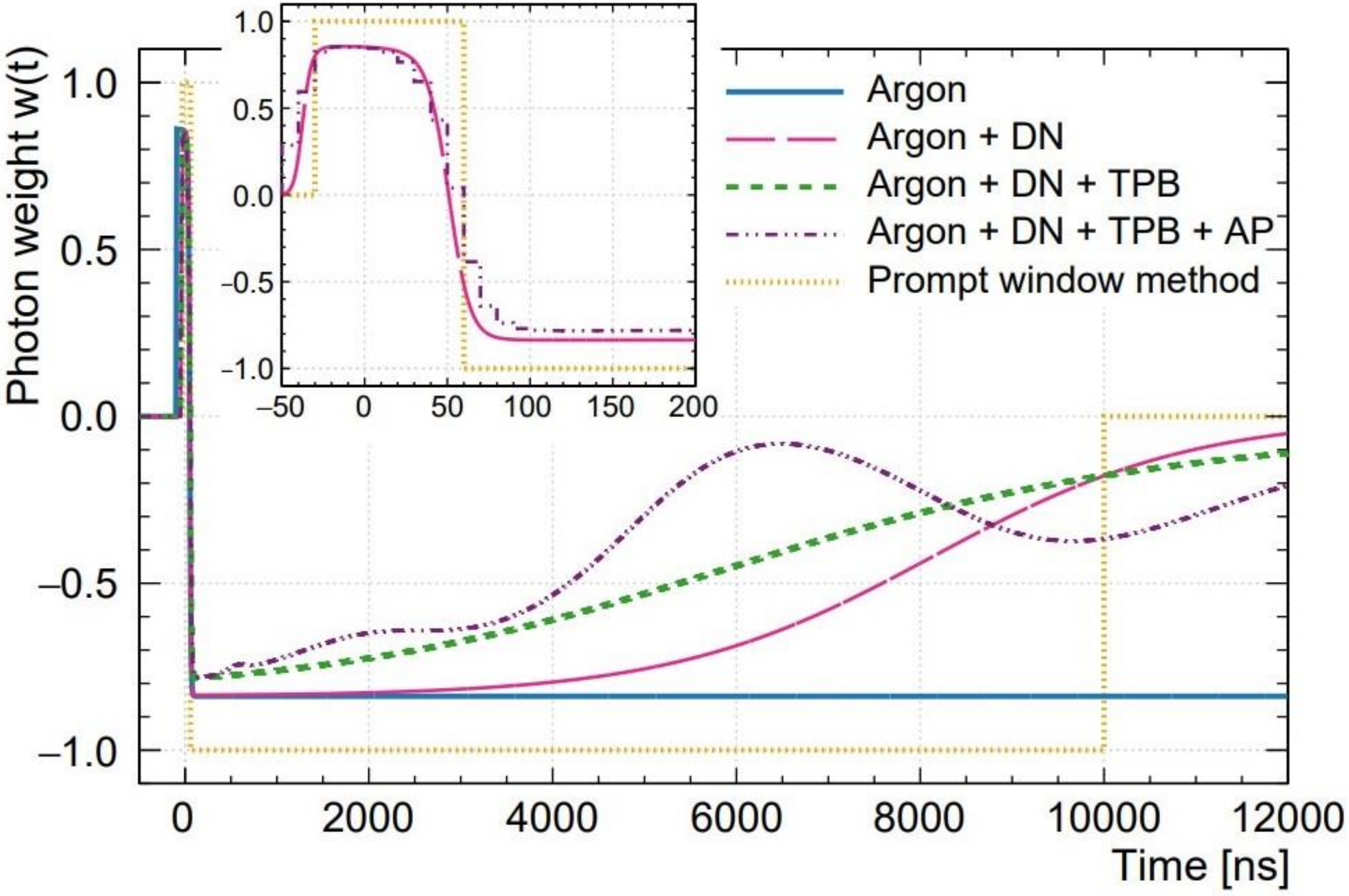
Likelihood ratio method

With PMT/TPB corrections

Prompt fraction

Likelihood ratio

After removing PMT effects, the weights in the likelihood ratio approximately give Fprompt.



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Fprompt can be written as w(t)=1 in the prompt region and w(t)=-1 in the late region.

Summary

- PSD in DEAP-3600 works as designed to separate EM and nuclear-recoil events.
- Do the information theory when coming up with PSD methods:
  - Extra bits on disk is not the same as extra usable information
- Spend time to understand your measurement artifacts. They matter!

DEAP 3600

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Canadian Nuclear Laboratories

Laboratoires Nucléaires Canadiens

Carleton UNIVERSITY

US University of Sussex

Particle Physics Rutherford Appleton Laboratory

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