In-Situ and Ex-Situ Observations of an Extremely Long-lived Tail in TPB Fluorescence Under Alpha Excitation in DEAP-3600

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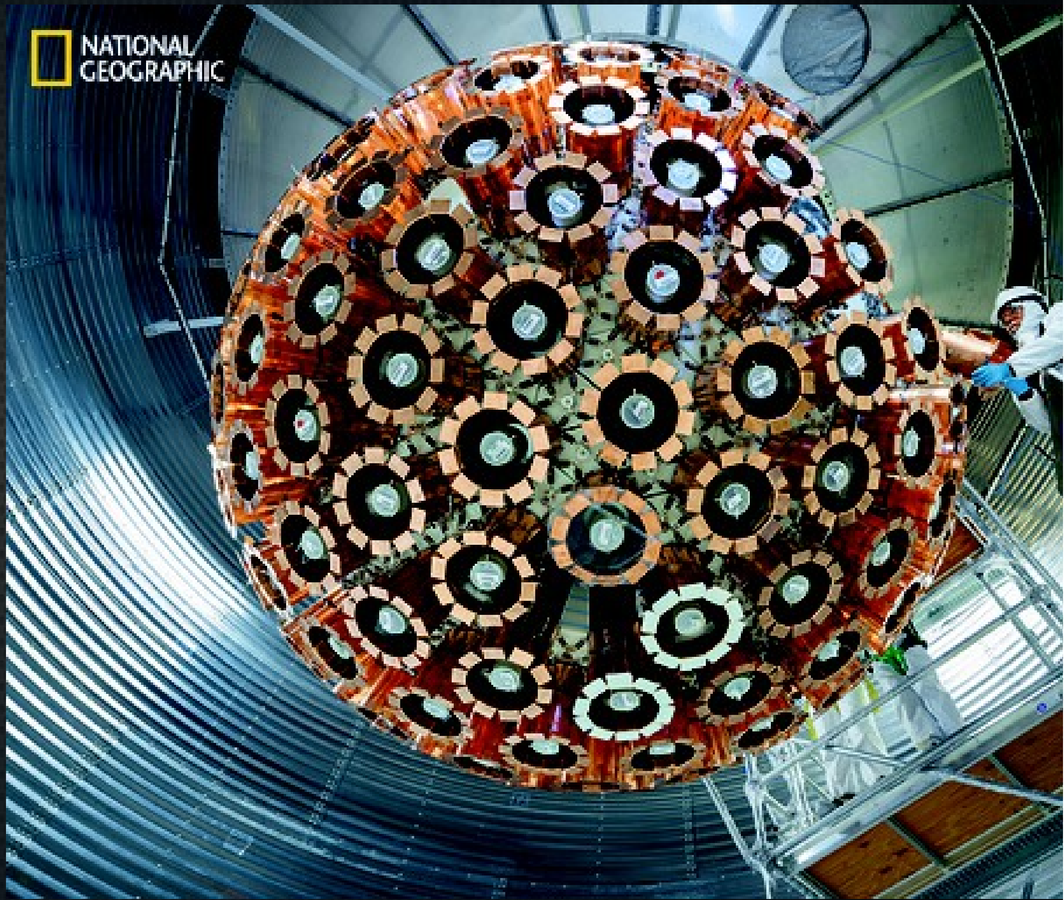
(Carleton University)
with C. Stanford, J. Xu, F. Calaprice
and the
DEAP-3600 Collaboration

CAP 2017
Kingston, Ontario

A Bit About DEAP

- Located at SNOlab
- Over 3 tonnes LAr
- TPB Wavelength Shifter
- Viewed by 255 PMTs
- 50 cm acrylic light guides between PMTs and LAr
- Inside water tank muon veto



Dark matter interactions are rare

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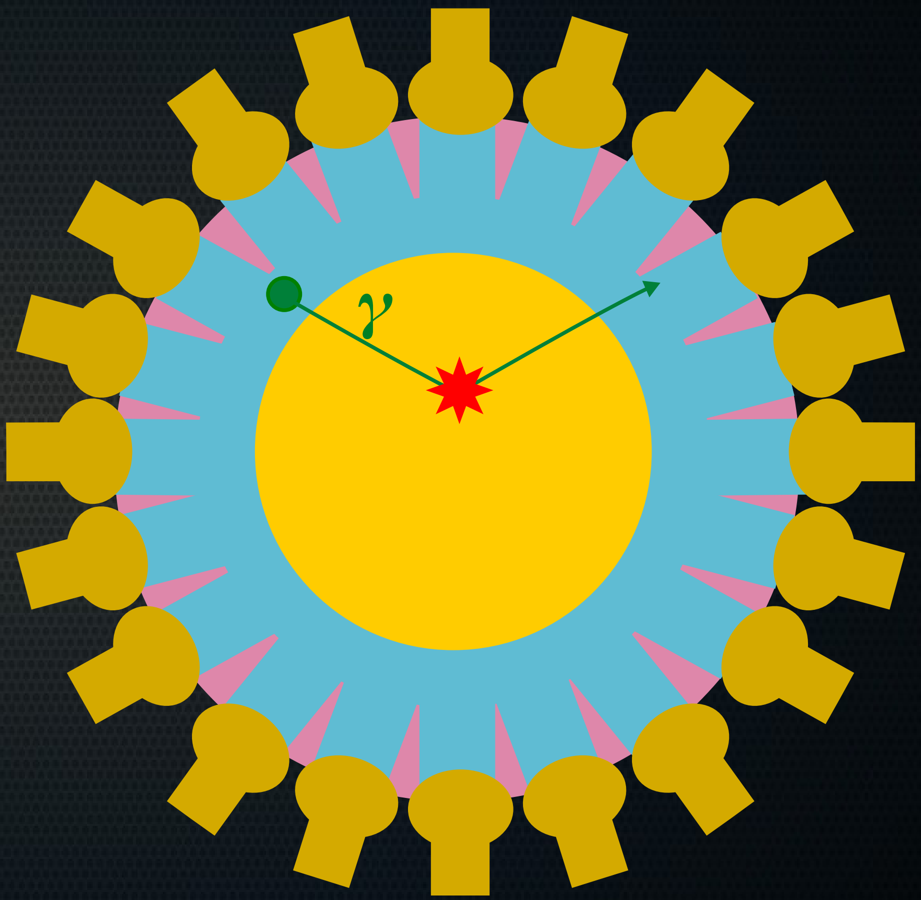
In order to detect dark matter, we must have as little background as possible

Scintillation

- Particle scatters in LAr
- Singlet and triplet dimers form
- 128 nm photos emitted
- TPB shifts photons to visible
- Photons are detected



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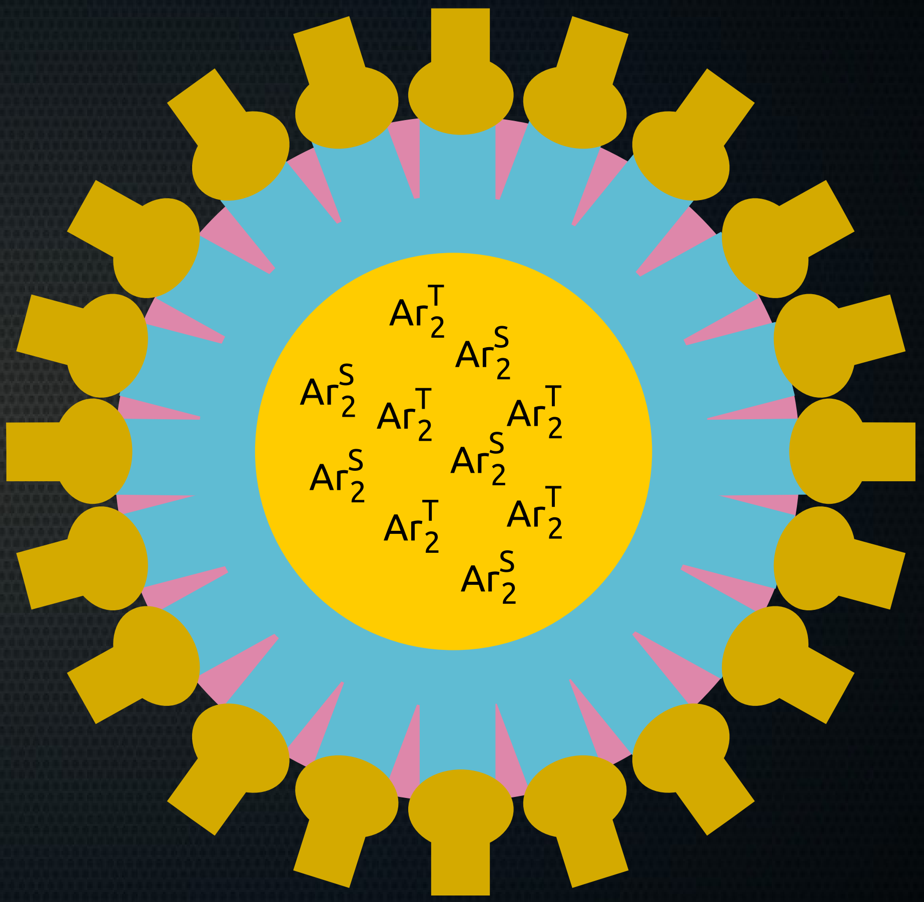

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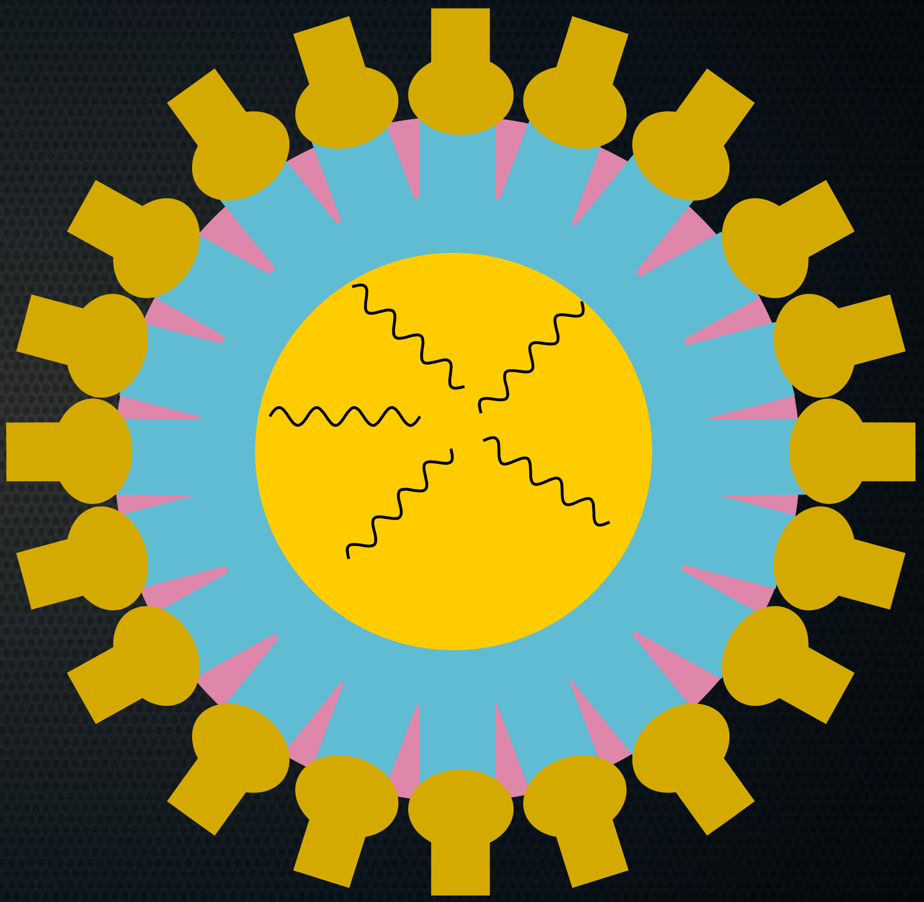

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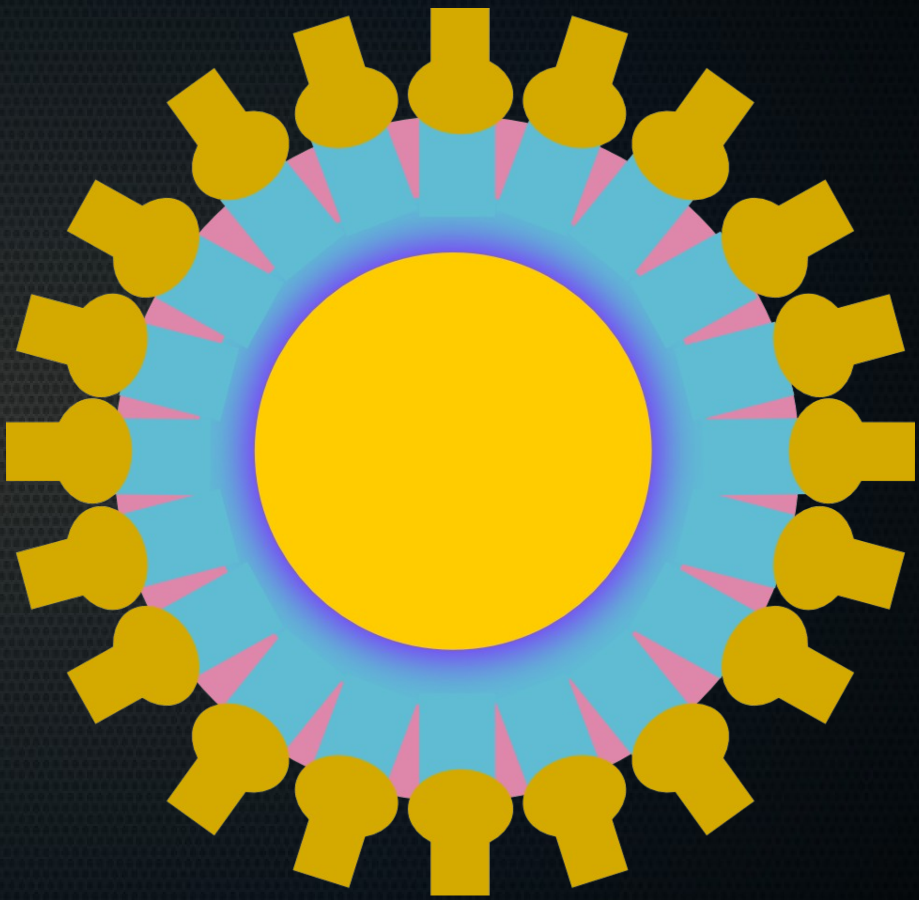

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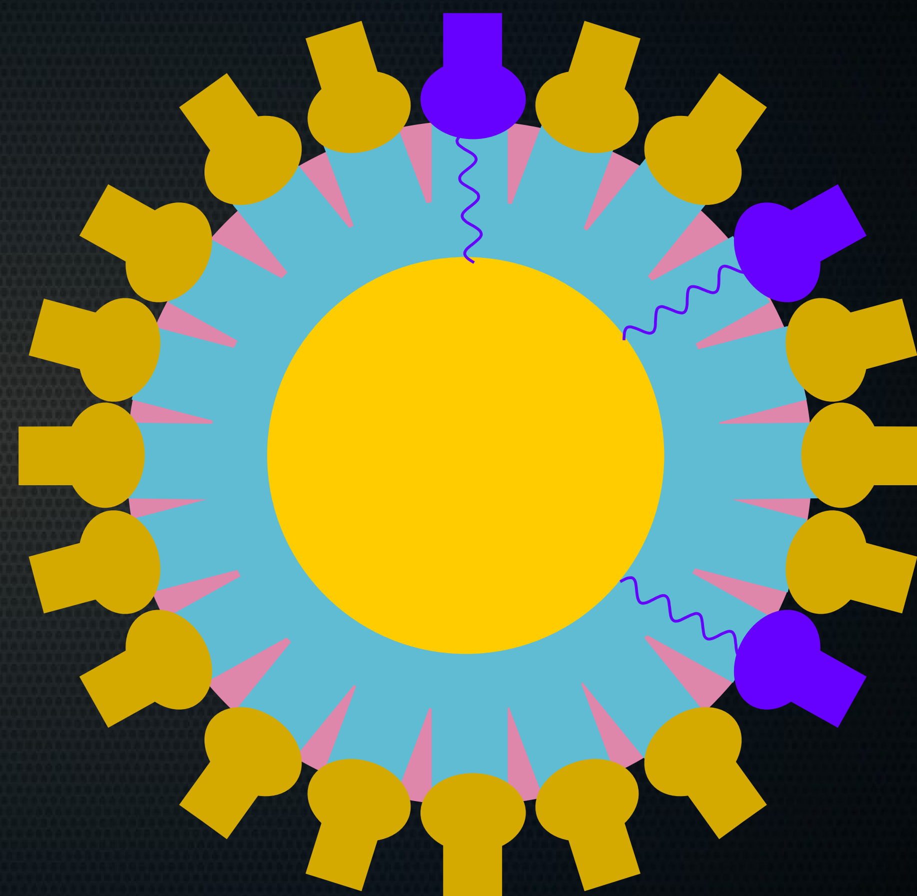
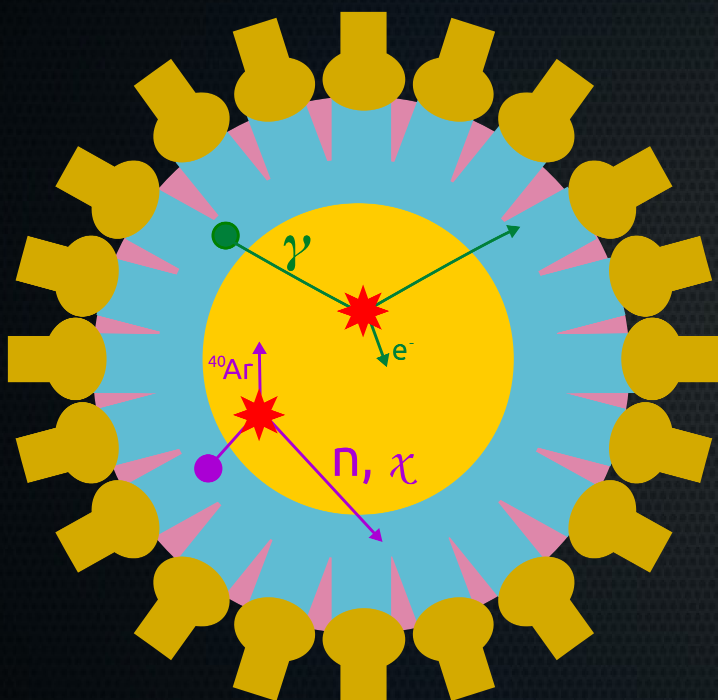
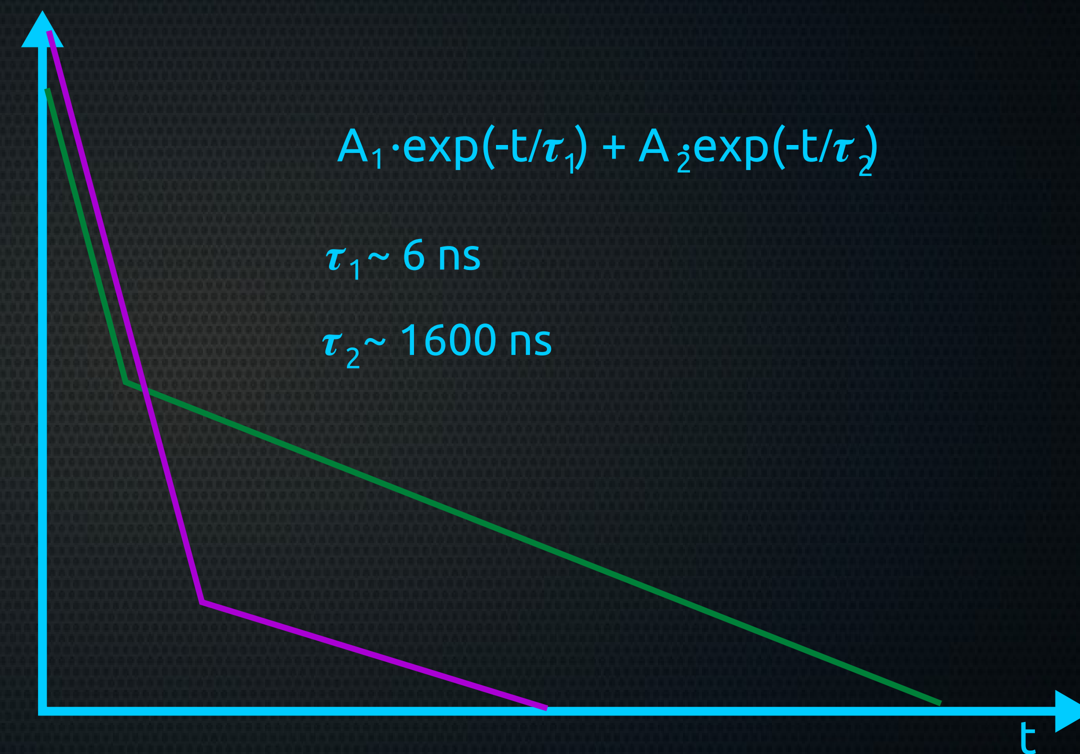


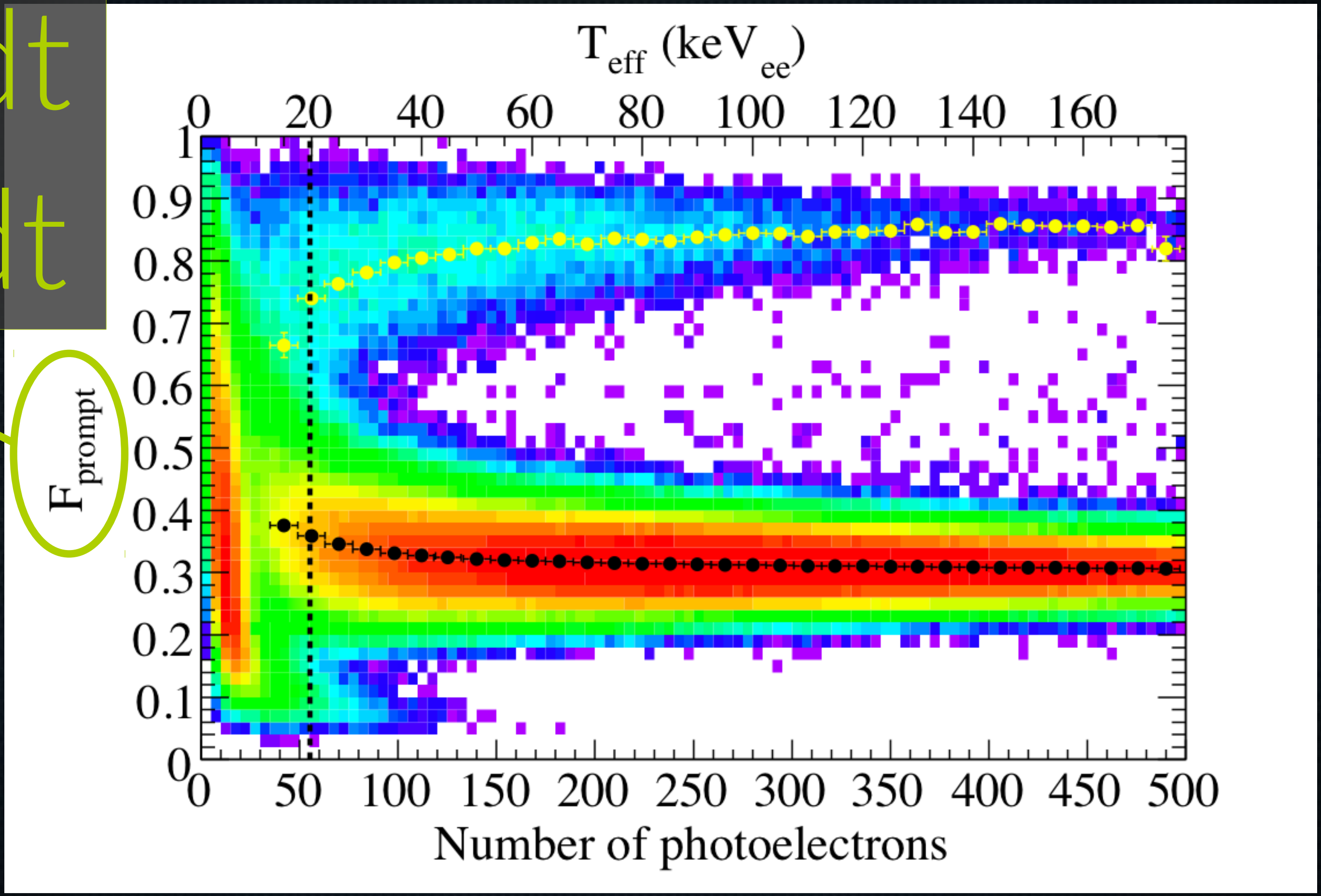
Pulse Shape Discrimination





Pulse Shape Discrimination

$$\frac{\int_{0\,\text{ns}}^{150\,\text{ns}} s(t)\,dt}{\int_{0\,\text{ns}}^{10\,\text{us}} s(t)\,dt}$$



From DEAP-1 [Astroparticle Physics 85 (2016) 1-23]

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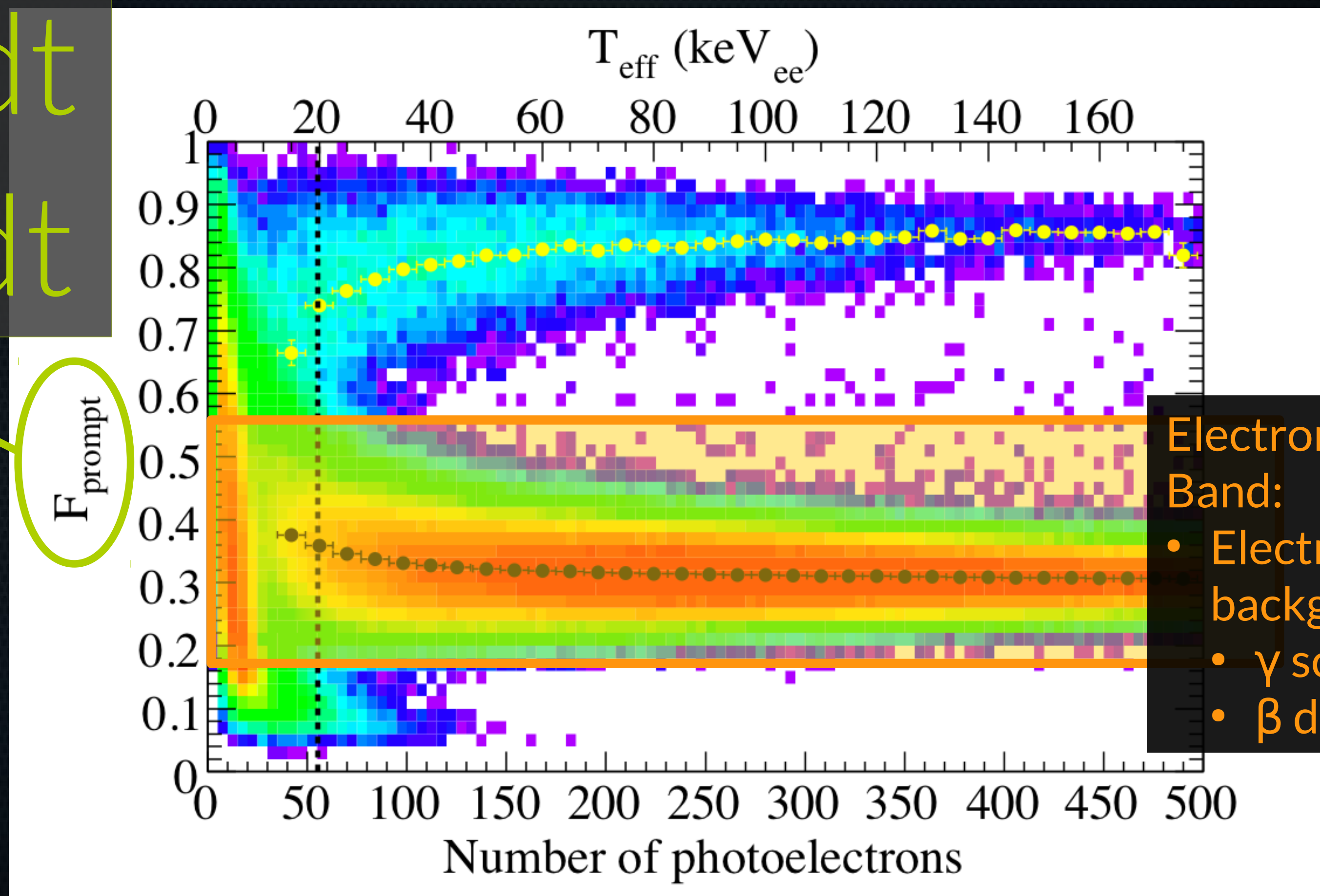

Electron Recoil Band:

- Electron scatter backgrounds
  - γ scatters
  - β decays

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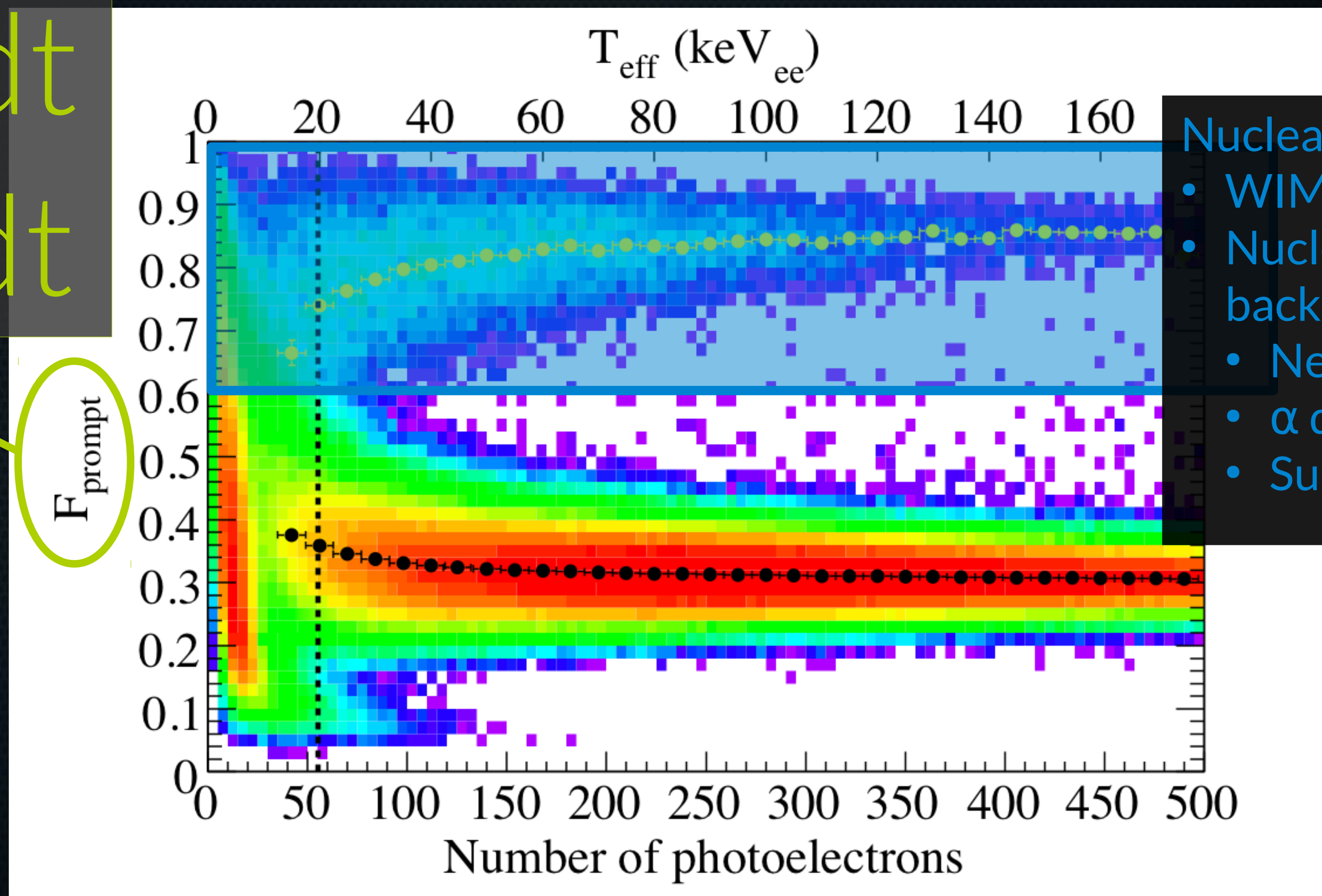

Nuclear Recoil Band:

- WIMPs
- Nuclear scatter backgrounds
  - Neutrons
  - α decays
  - Surface Bkgds

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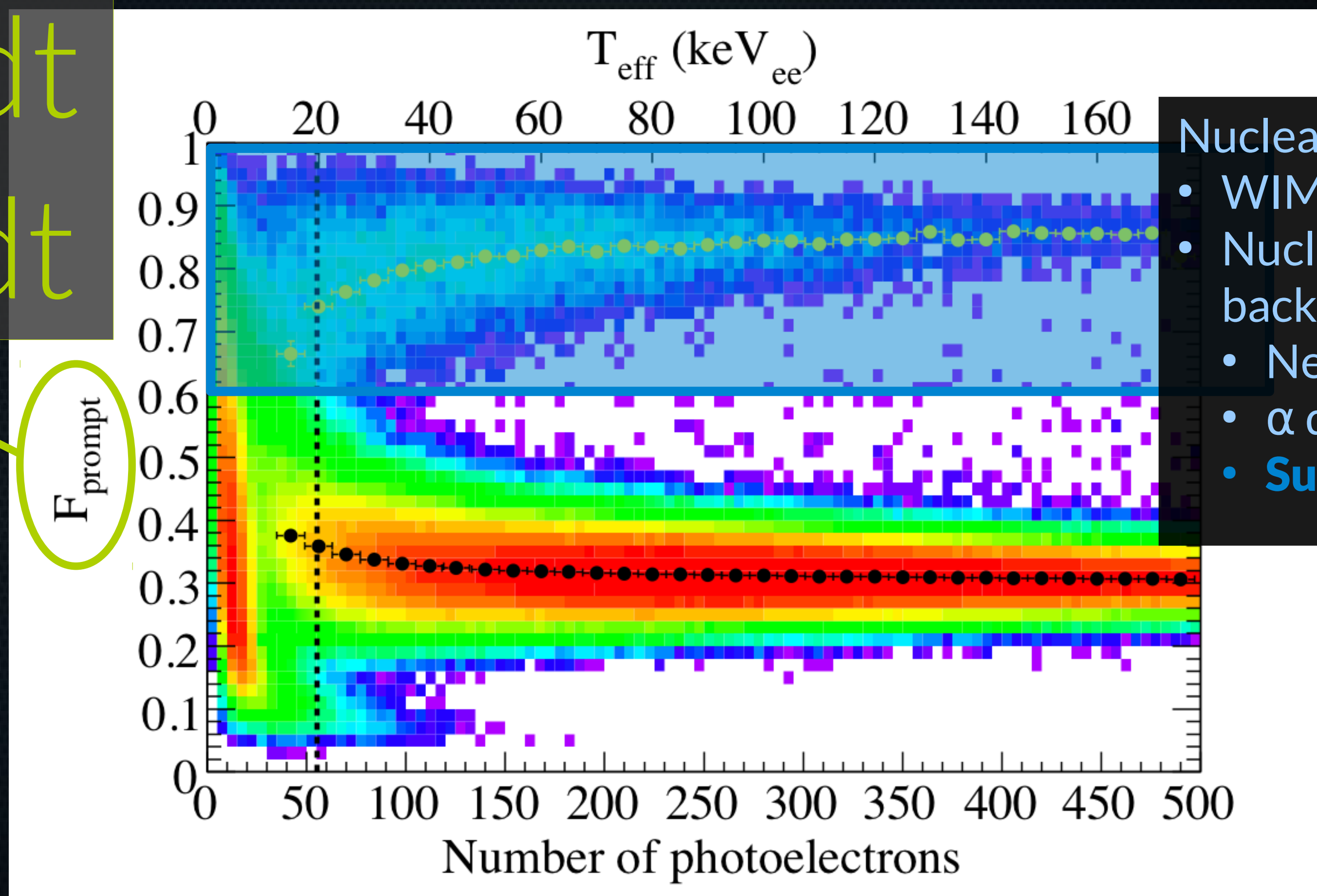

Nuclear Recoil Band:

- WIMPs
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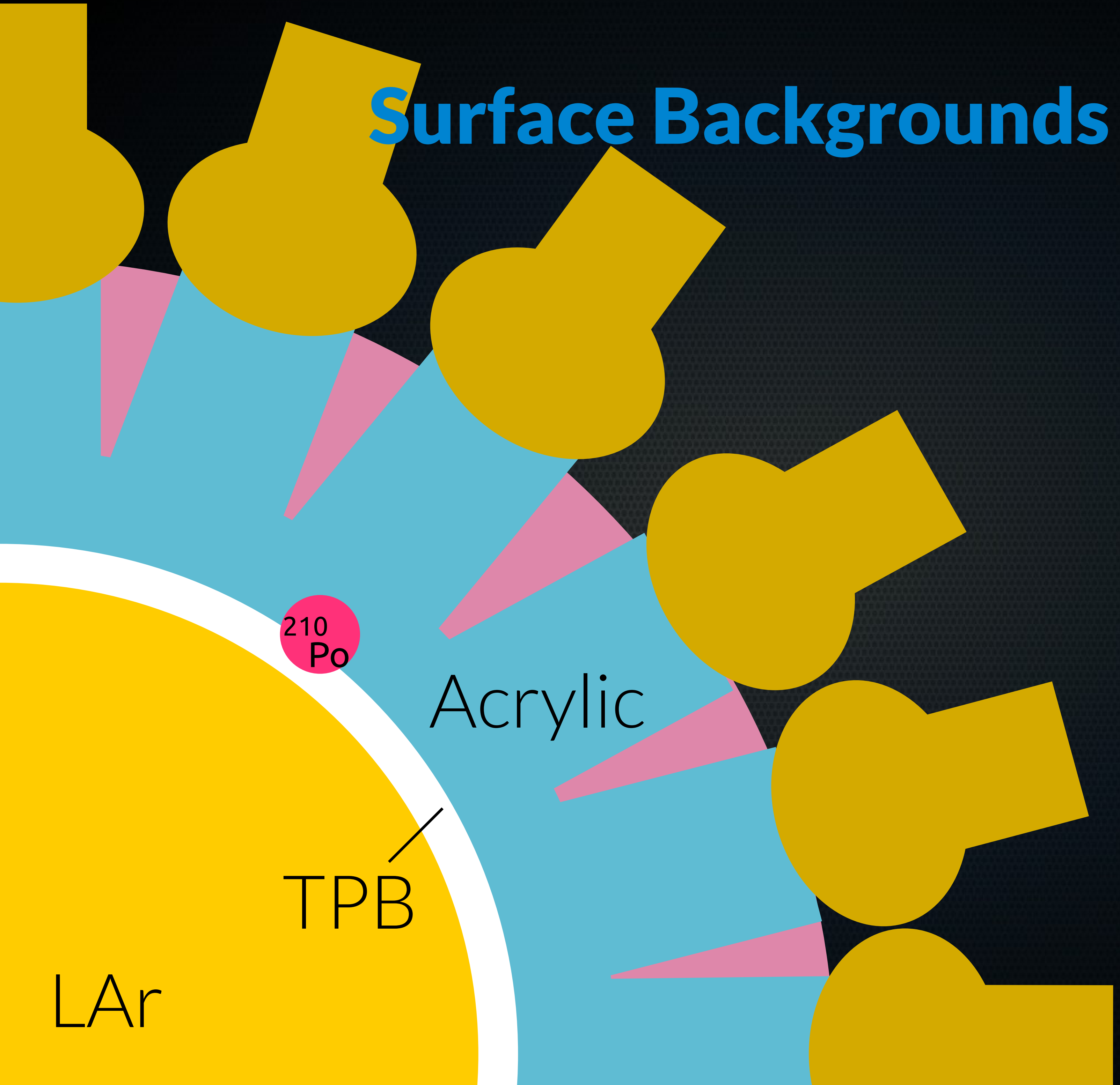
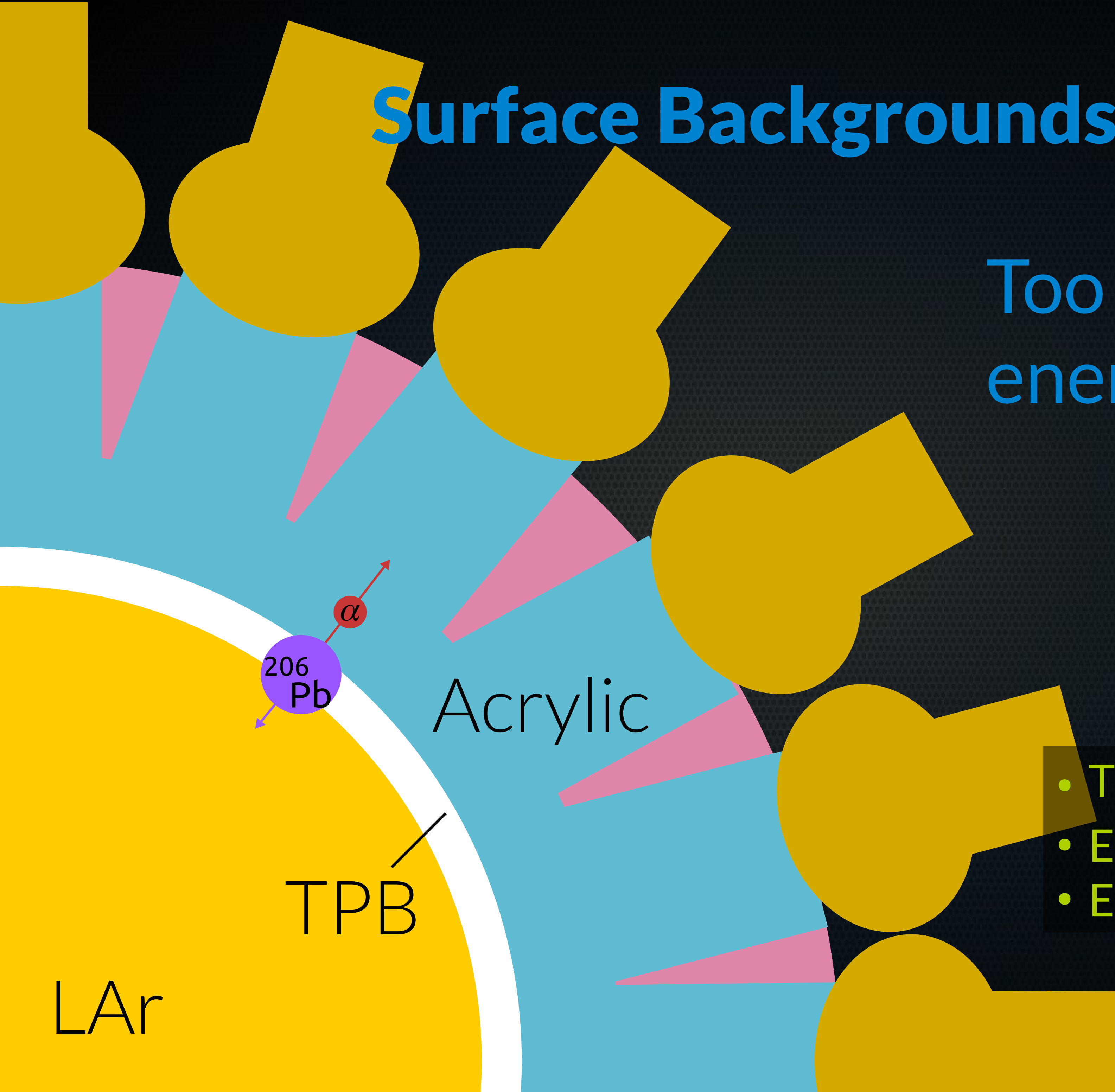
Surface Backgrounds



Surface Backgrounds

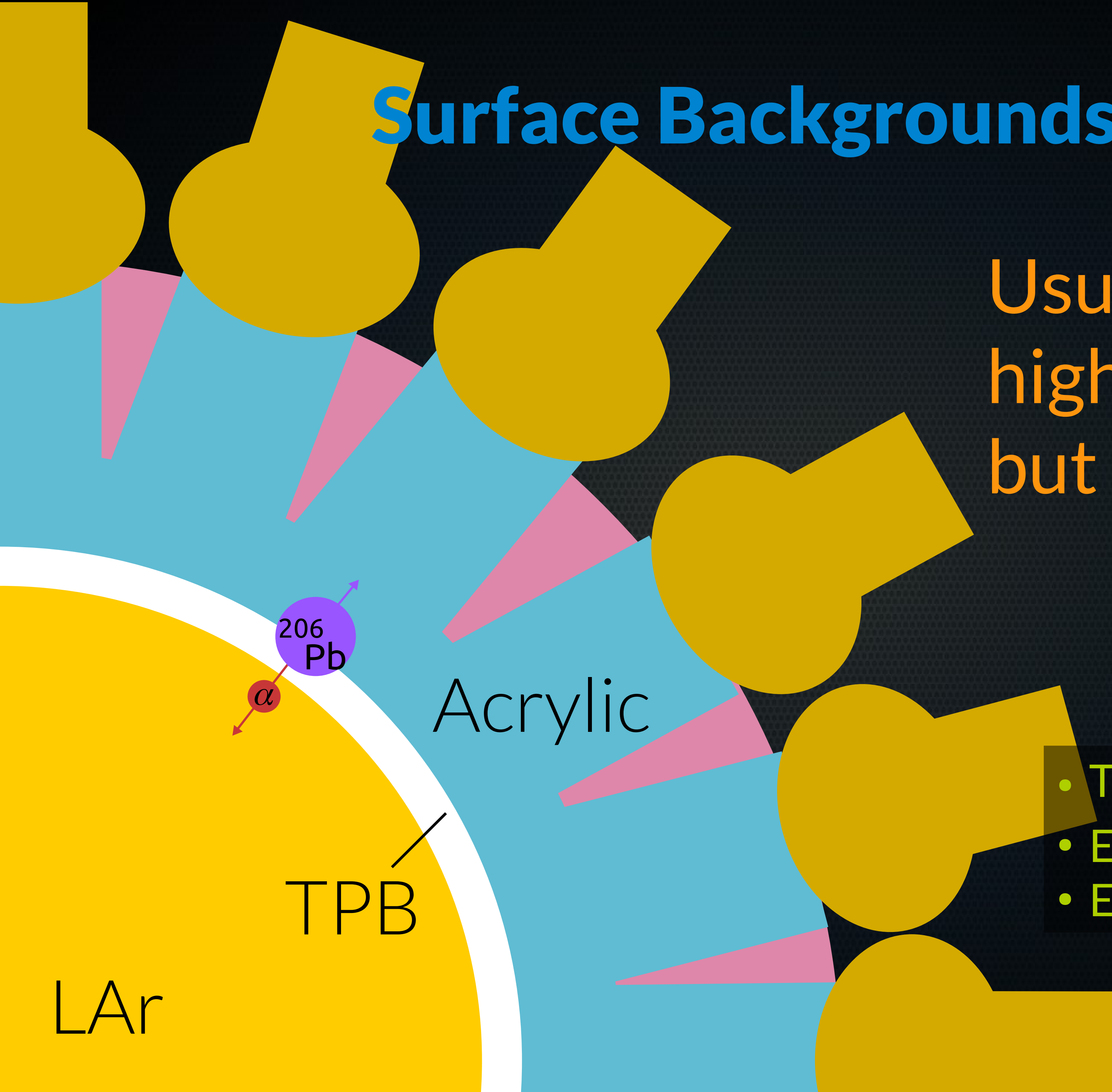


Too low energy

- $T^{1/2}_{Po\text{-}210}$ = 138 d
- E(α) = 5.304 MeV
- E(^{206}Pb) = 103 keV

Surface Backgrounds

Usually too high energy, but maybe...



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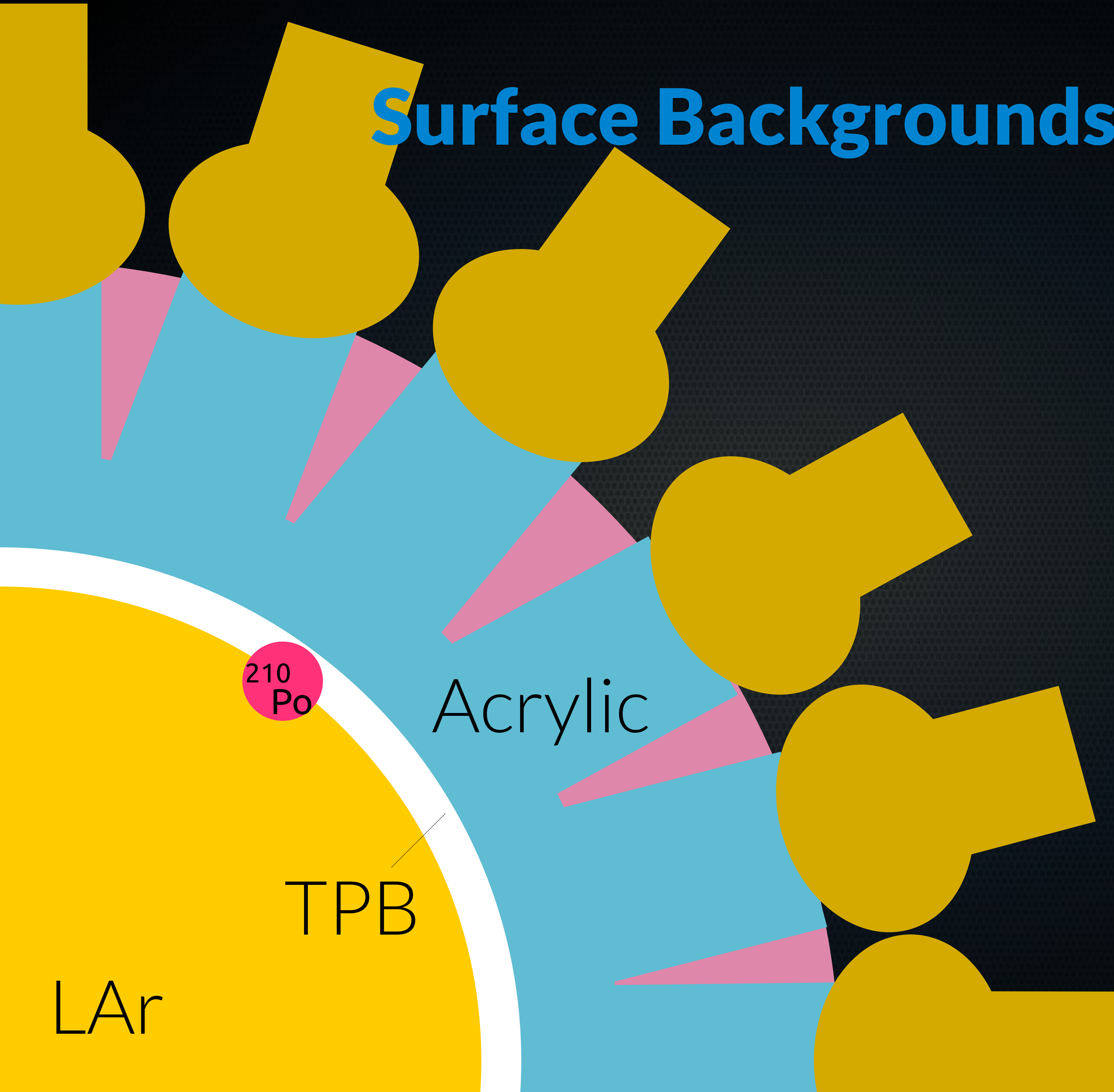

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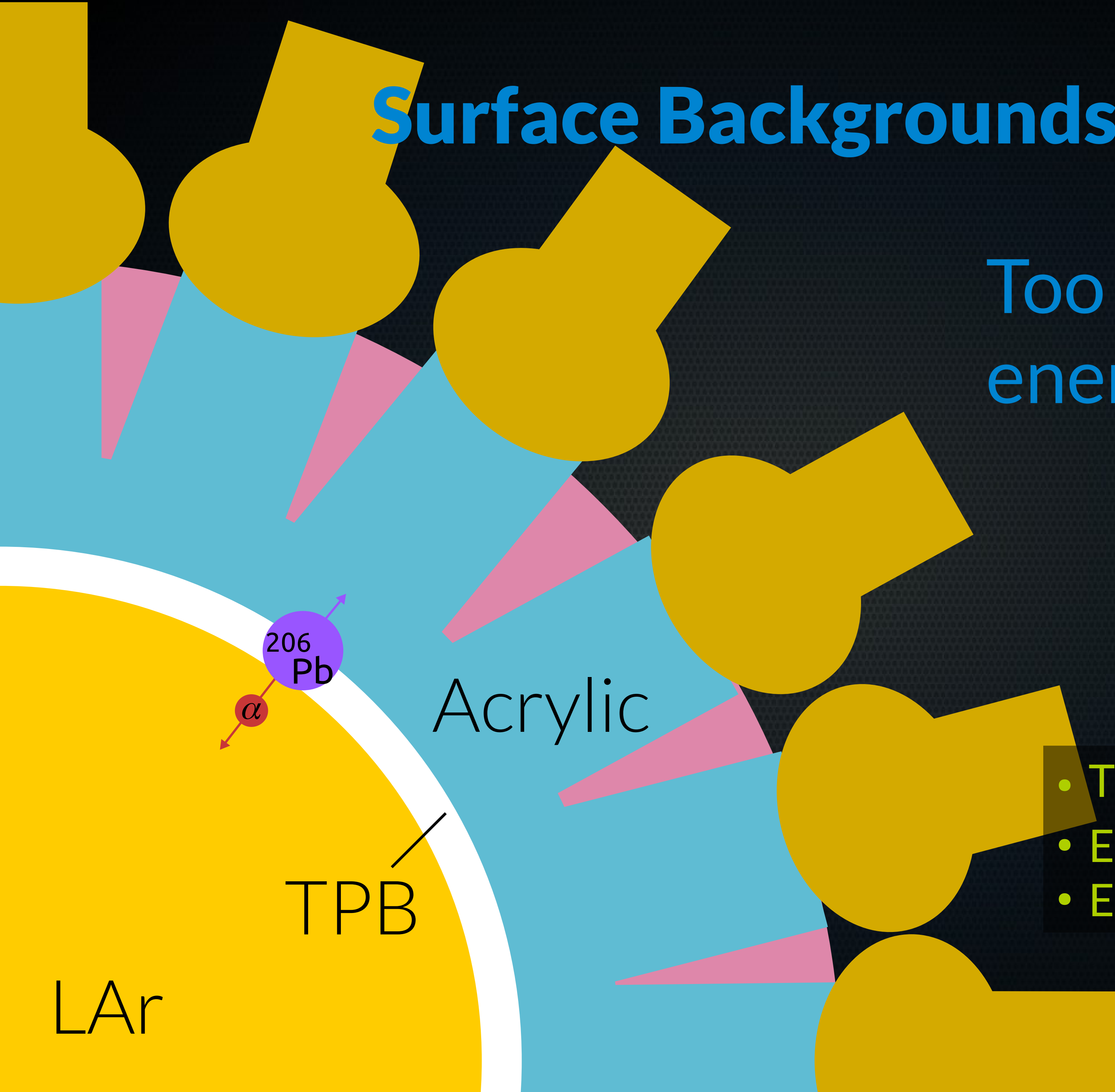

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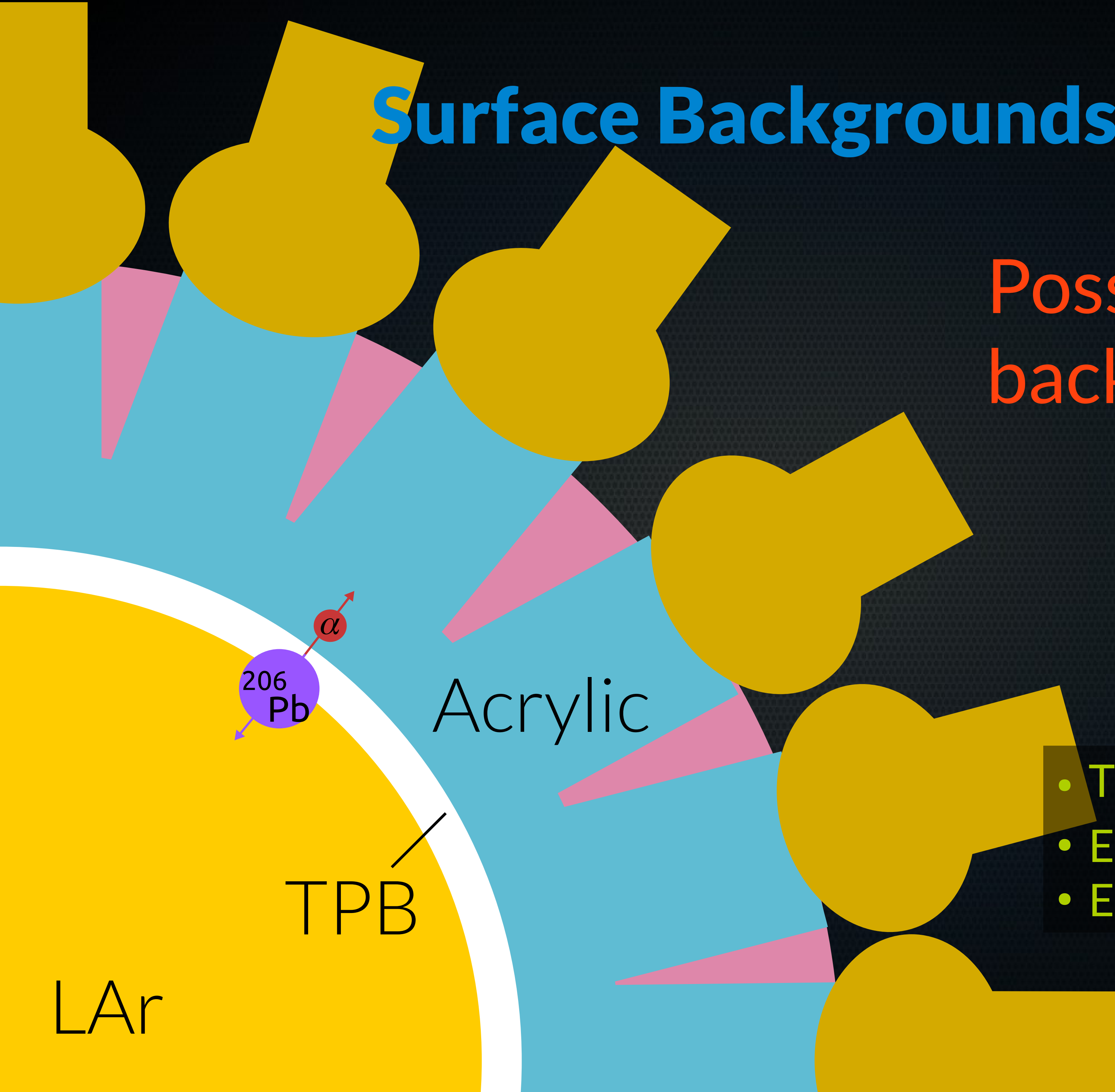

Possible background!

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Both of these dangerous cases involve the α scintillating in the TPB

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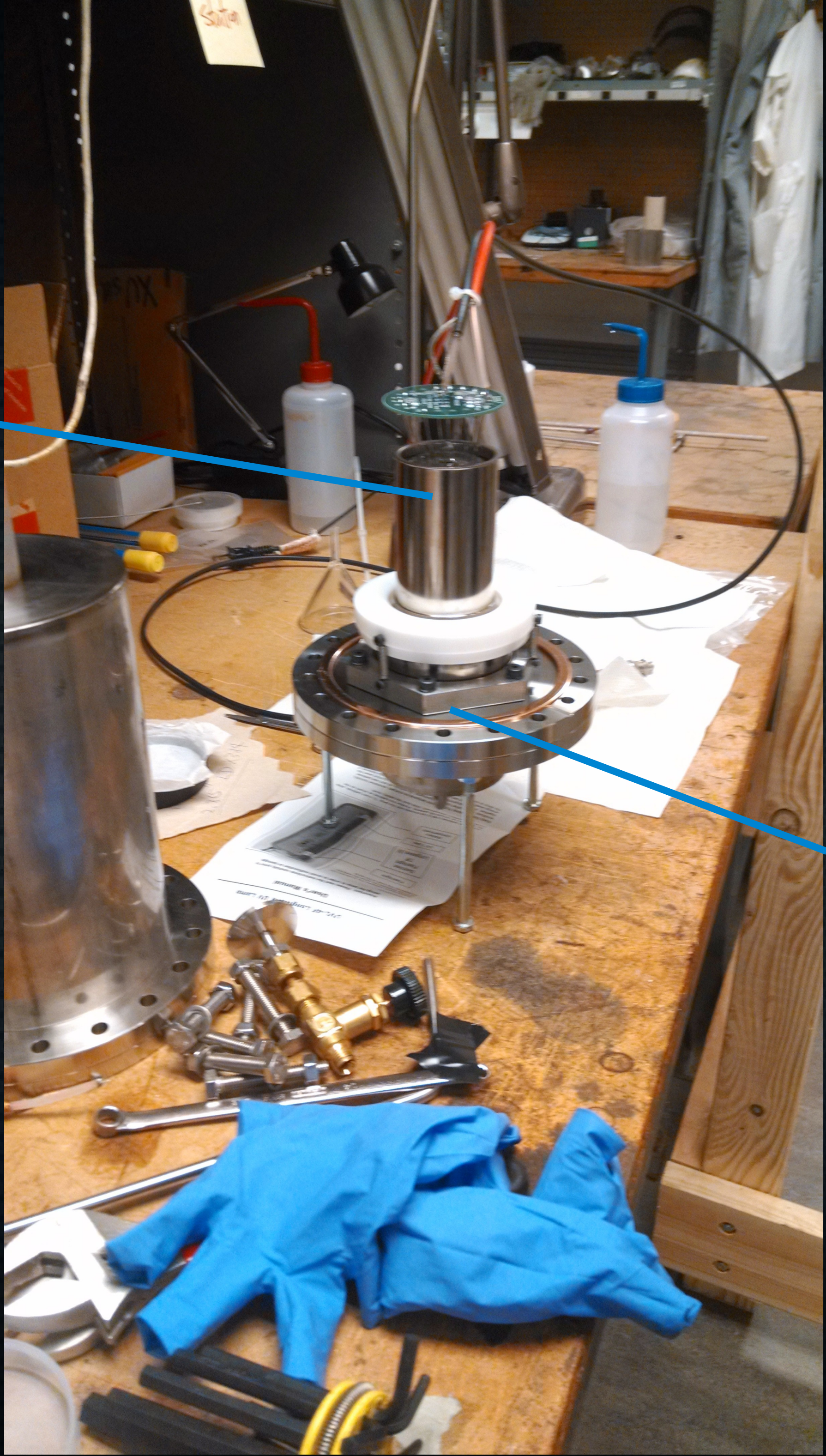
What does TPB scintillation look like under **α** excitation?


OMEGA


PMT
Contains Spectralon Cup
Filled with vacuum or LAr

~0.3 mg/cm^2 of Tetraphenyl Butadiene (TPB)

$$S(t) = \left(N_0 e^{-t/\tau_s} + f(t)\right) * \mathrm{Gaus}(t, \sigma_r)$$

Time resolution

$$S(t) = \left(N_0 e^{-t/\tau_s} + f(t)\right) * \mathrm{Gaus}(t, \sigma_r)$$

Singlet decays

$$S(t) = \left(N_0 e^{-t/\tau_s} + f(t)\right) \ast Gaus(t, \sigma_r)$$

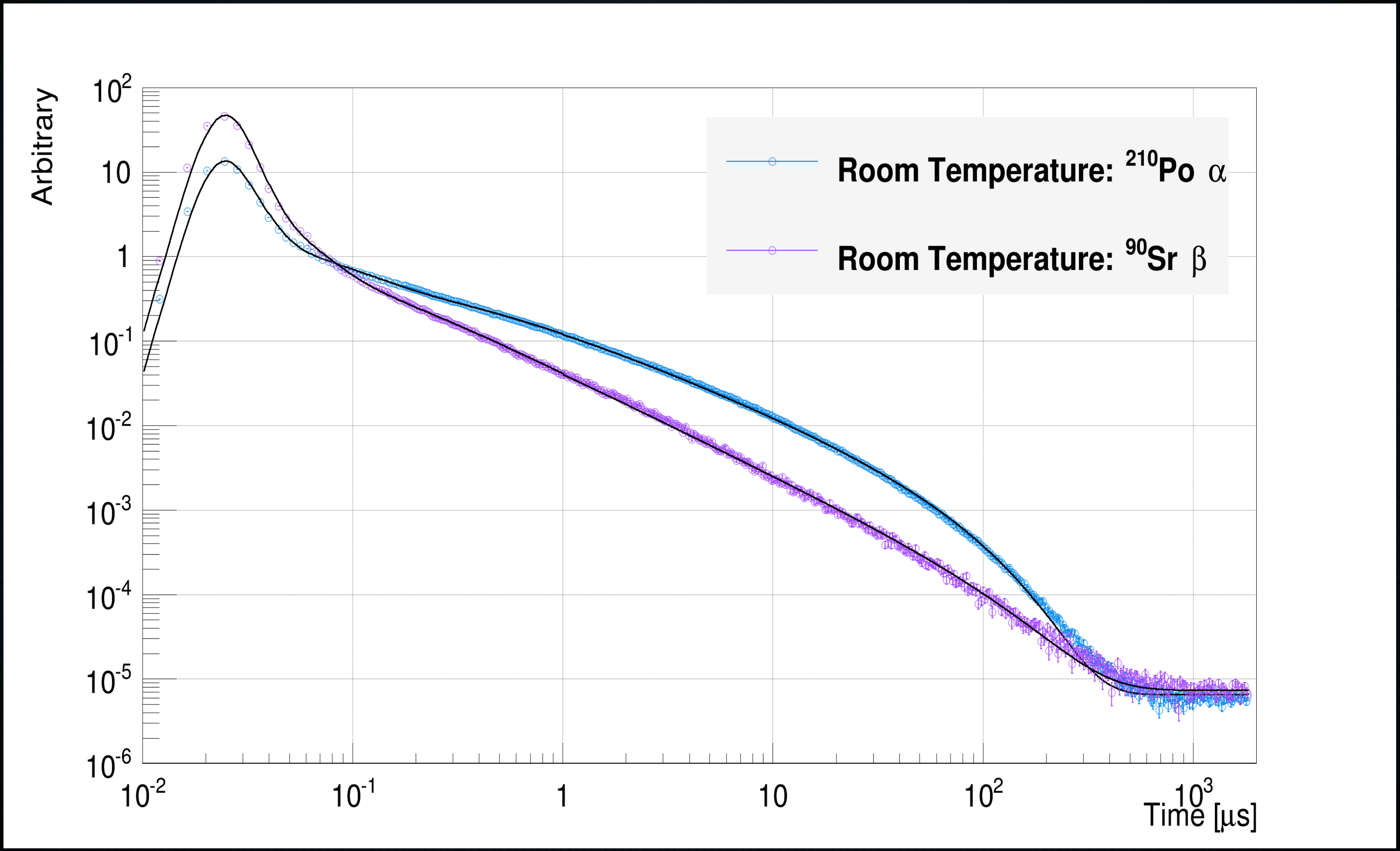
Triplet decays

$$S(t) = \left(N_0 e^{-t/\tau_s} + \overbrace{f(t)}^{\text{Triplet decays}}\right) * \mathrm{Gaus}(t, \sigma_r)$$

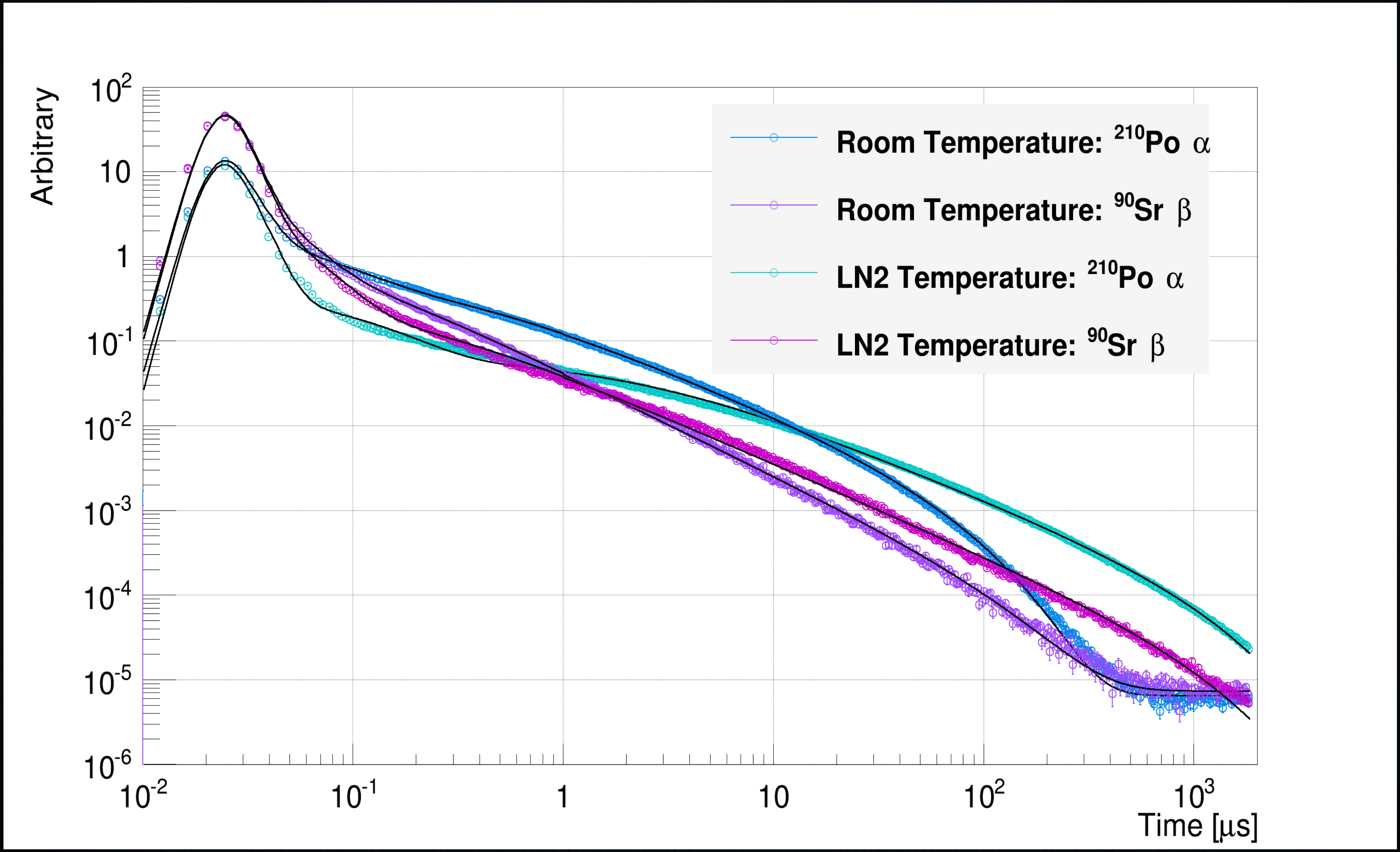
$$f(t) = \frac{k_s}{2t_b}\frac{k_{tt}}{\chi_{tt}} \frac{N_T(0)\exp(-2t/\tau_T)}{\left\{1 + \frac{t_a}{2t_b}\exp\left(\frac{t_a}{\tau_T}\right)\left[\mathrm{Ei}\left(-\frac{t+t_a}{\tau_T}\right) - \mathrm{Ei}\left(-\frac{t_a}{\tau_T}\right)\right]\right\}^2 (1 + t/t_a)} .$$

R. Volts and G. Laustriat, "Radioluminescence des Milieux Organiques I. Étude Cinétique." Le Journal de Physique (29). 1968

Different Waveforms for α and β Scintillation

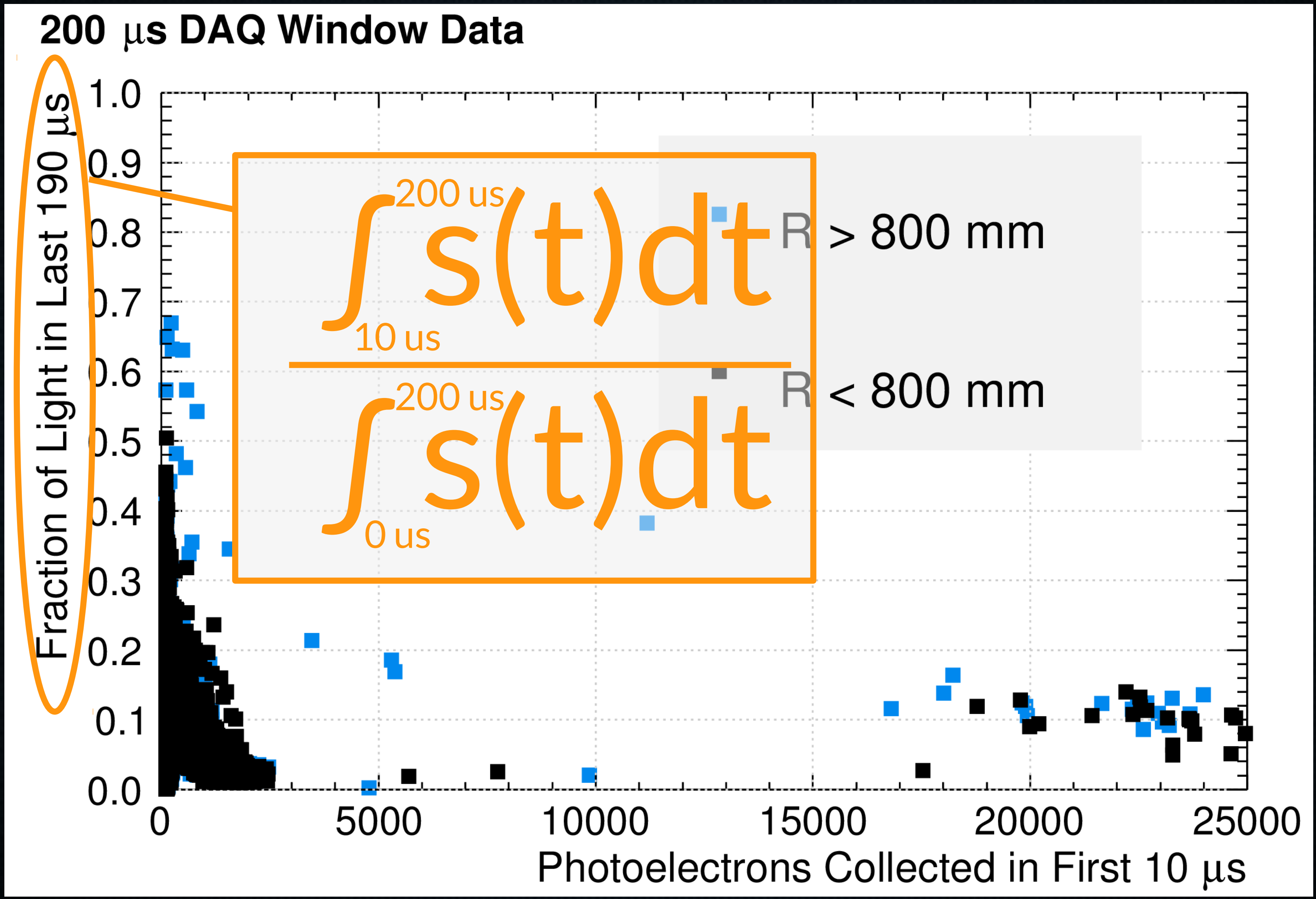


Longer Tails and More Extreme Difference at Cryogenic Temperature



Does this long tail appear in actual experiments?

Evidence for Tail in DEAP-3600



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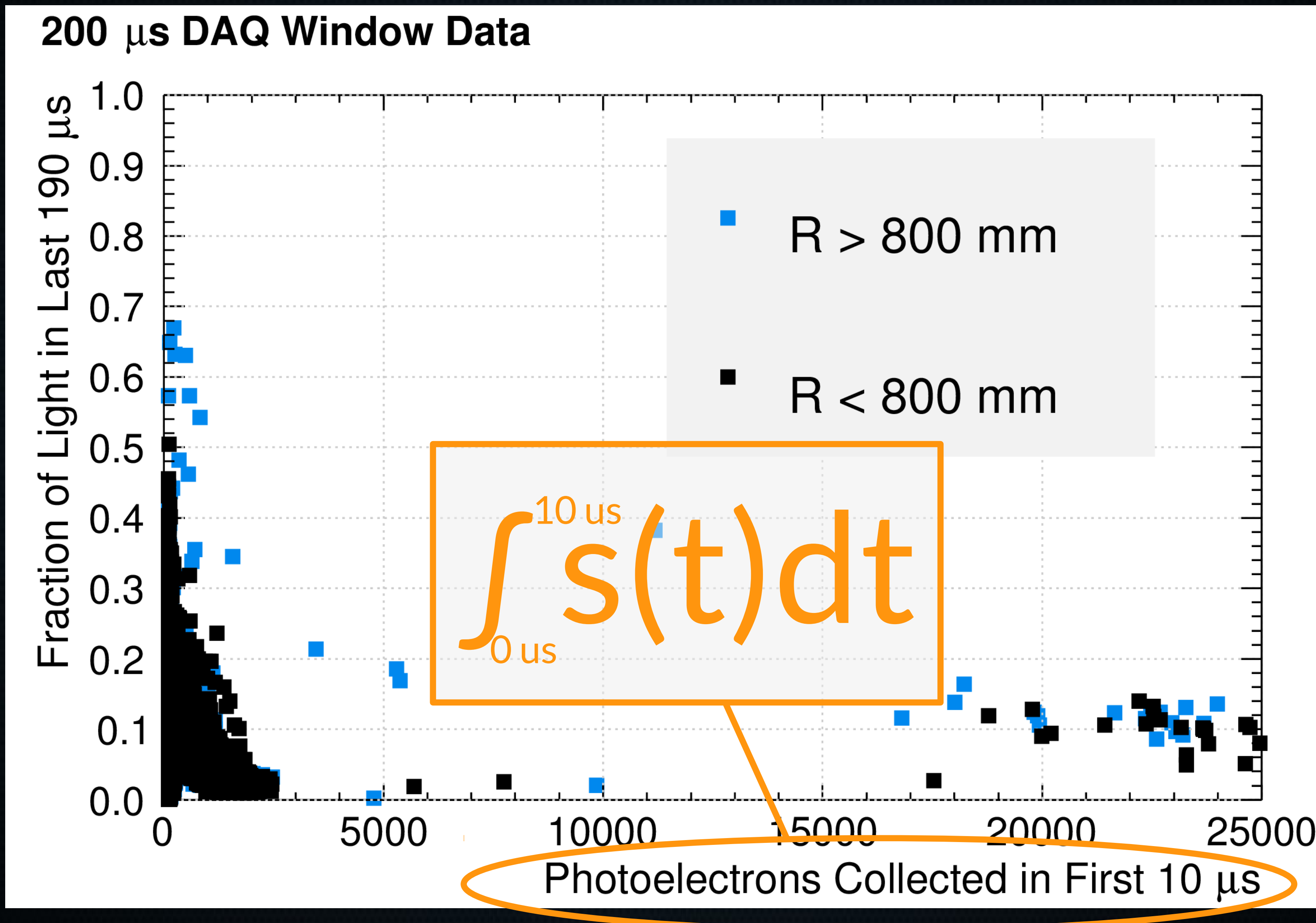

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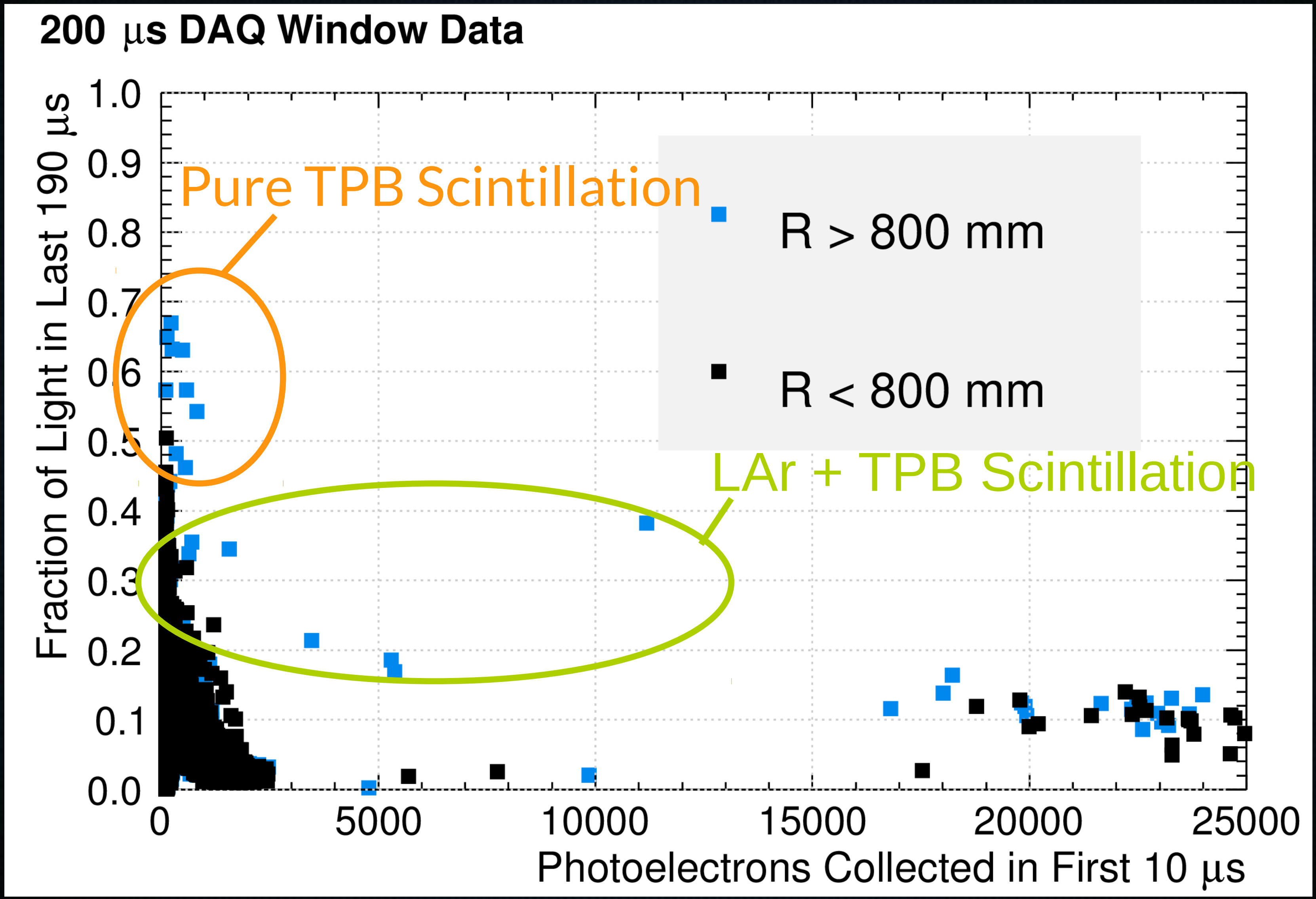

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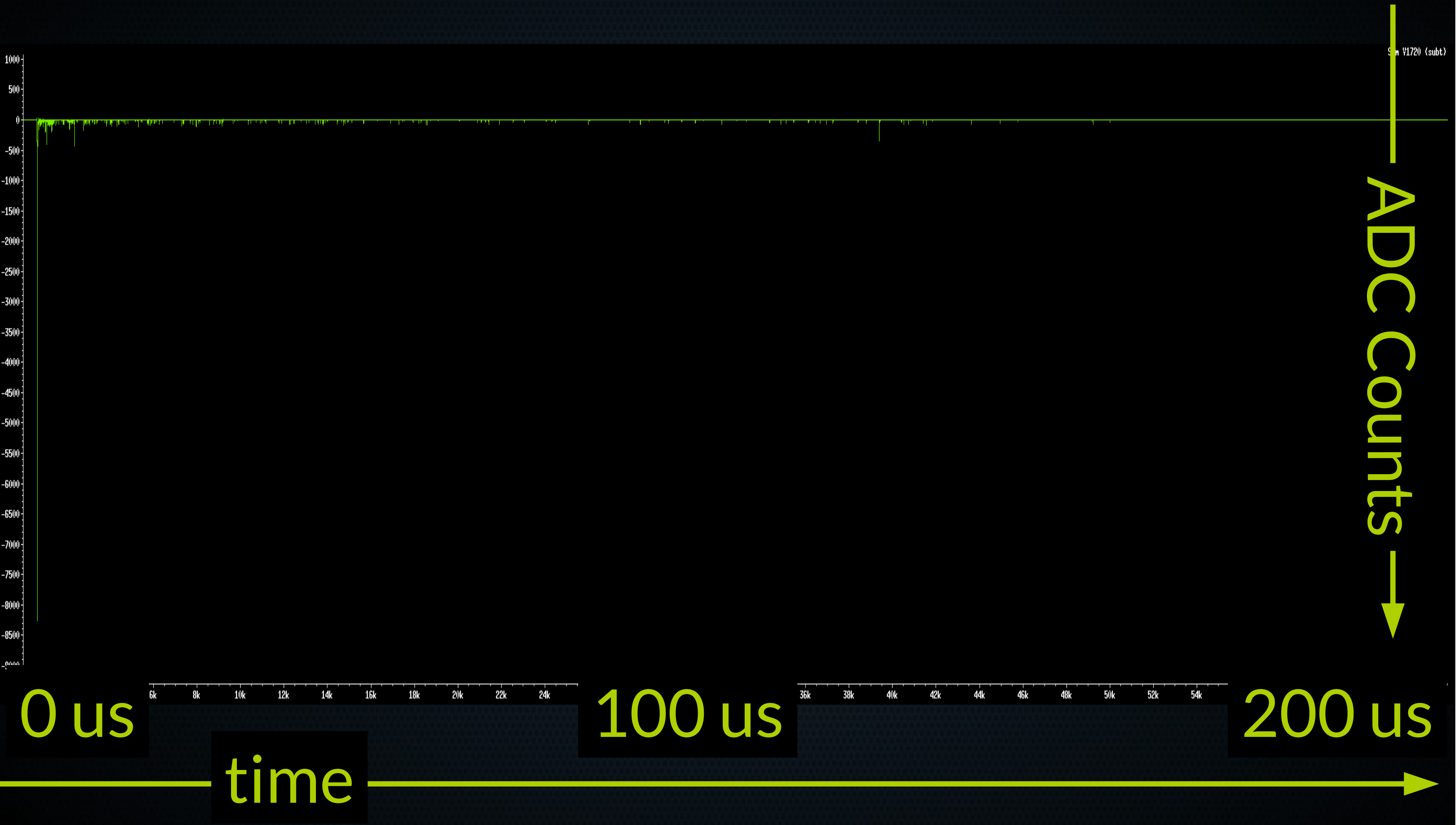

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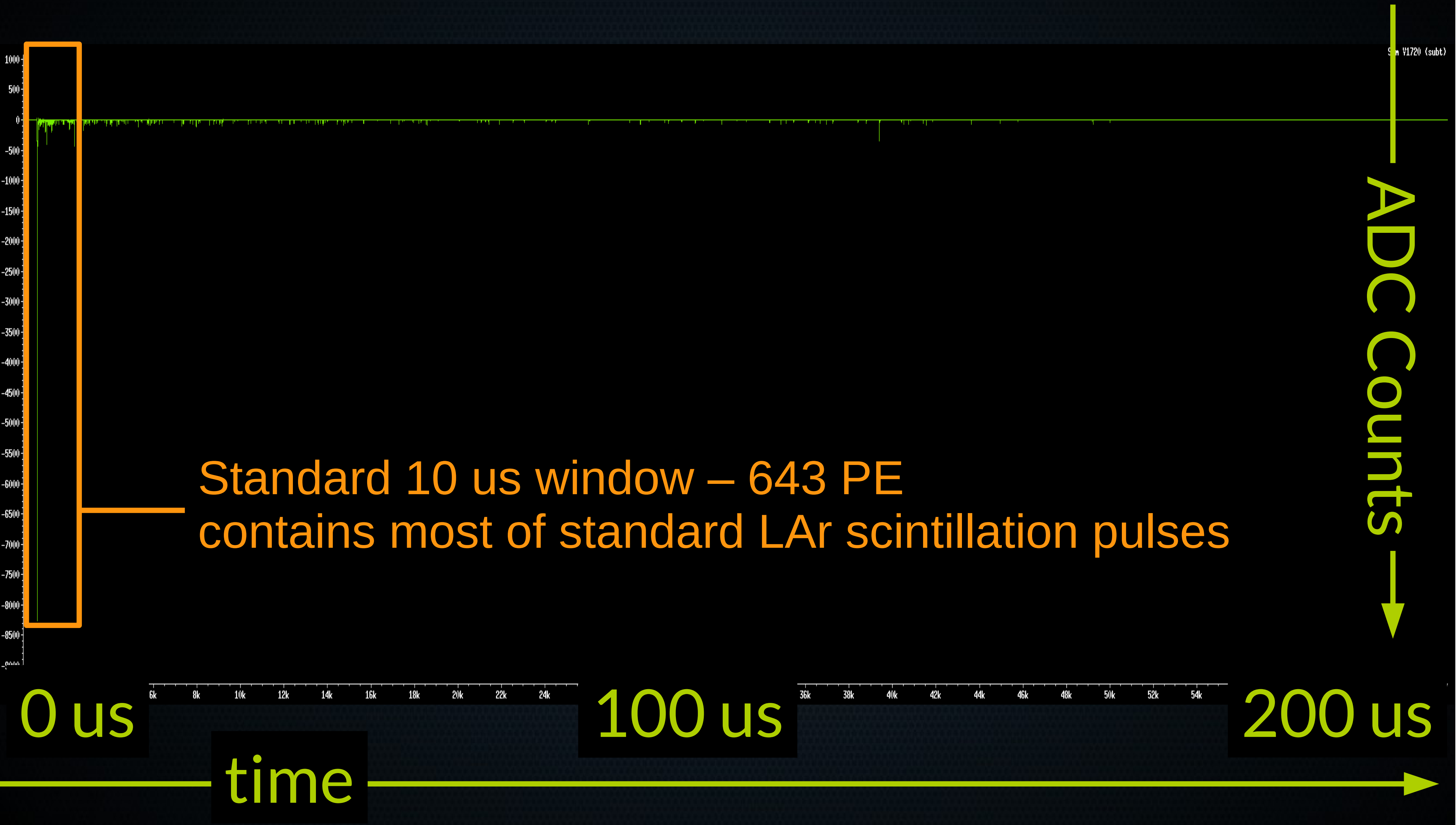

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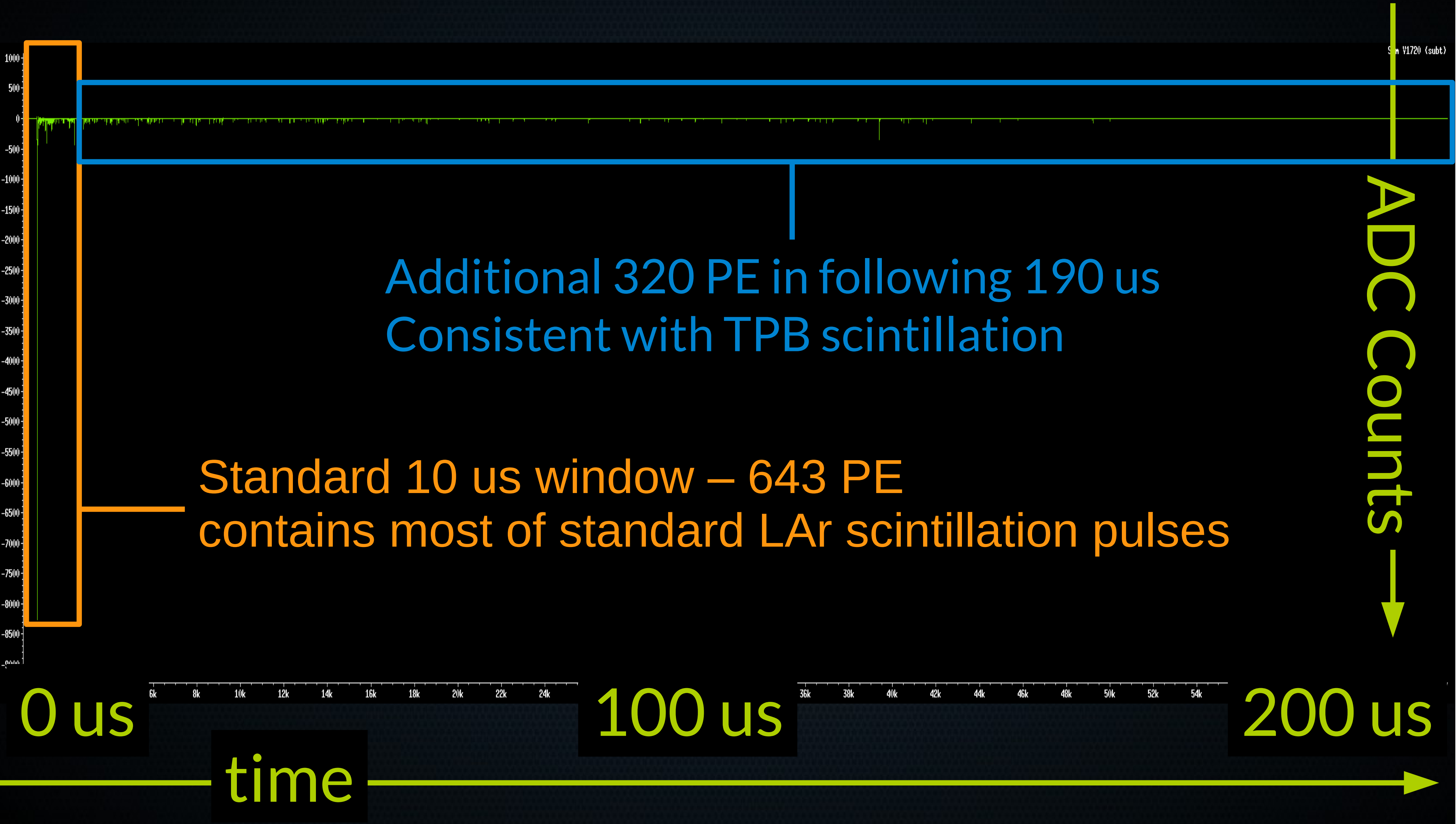
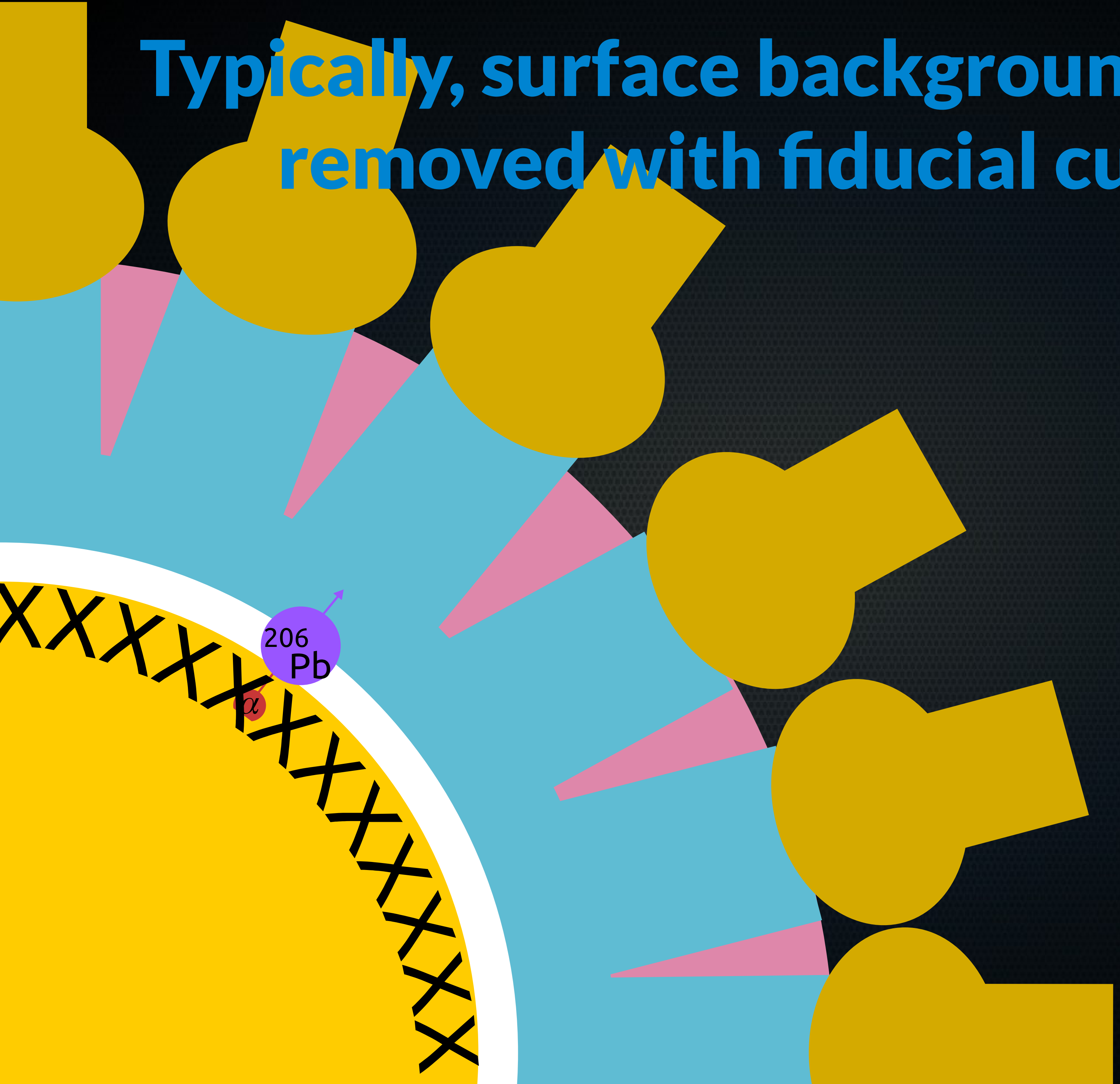


Typically, surface backgrounds are removed with fiducial cuts



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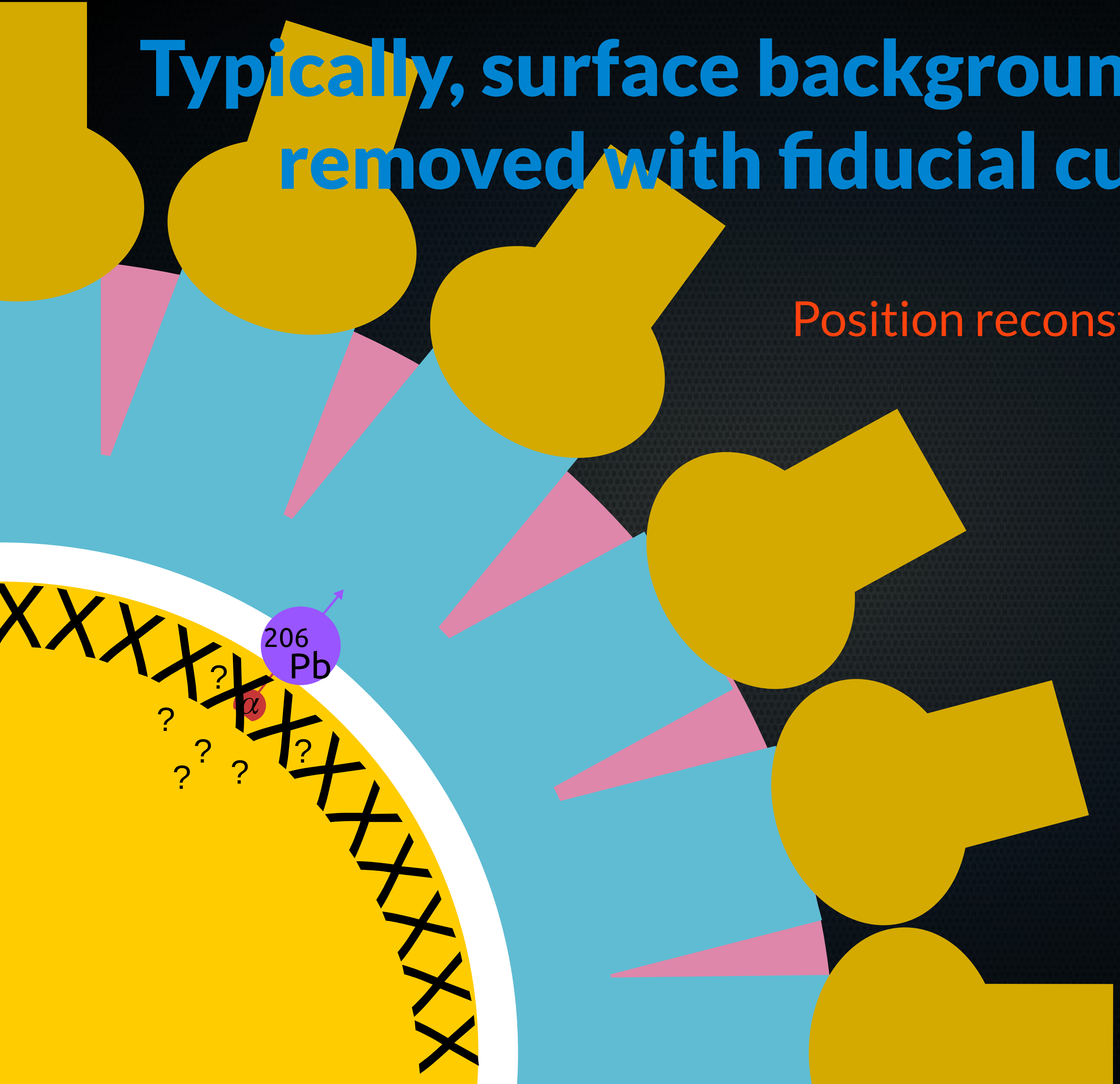
Position reconstruction is hard



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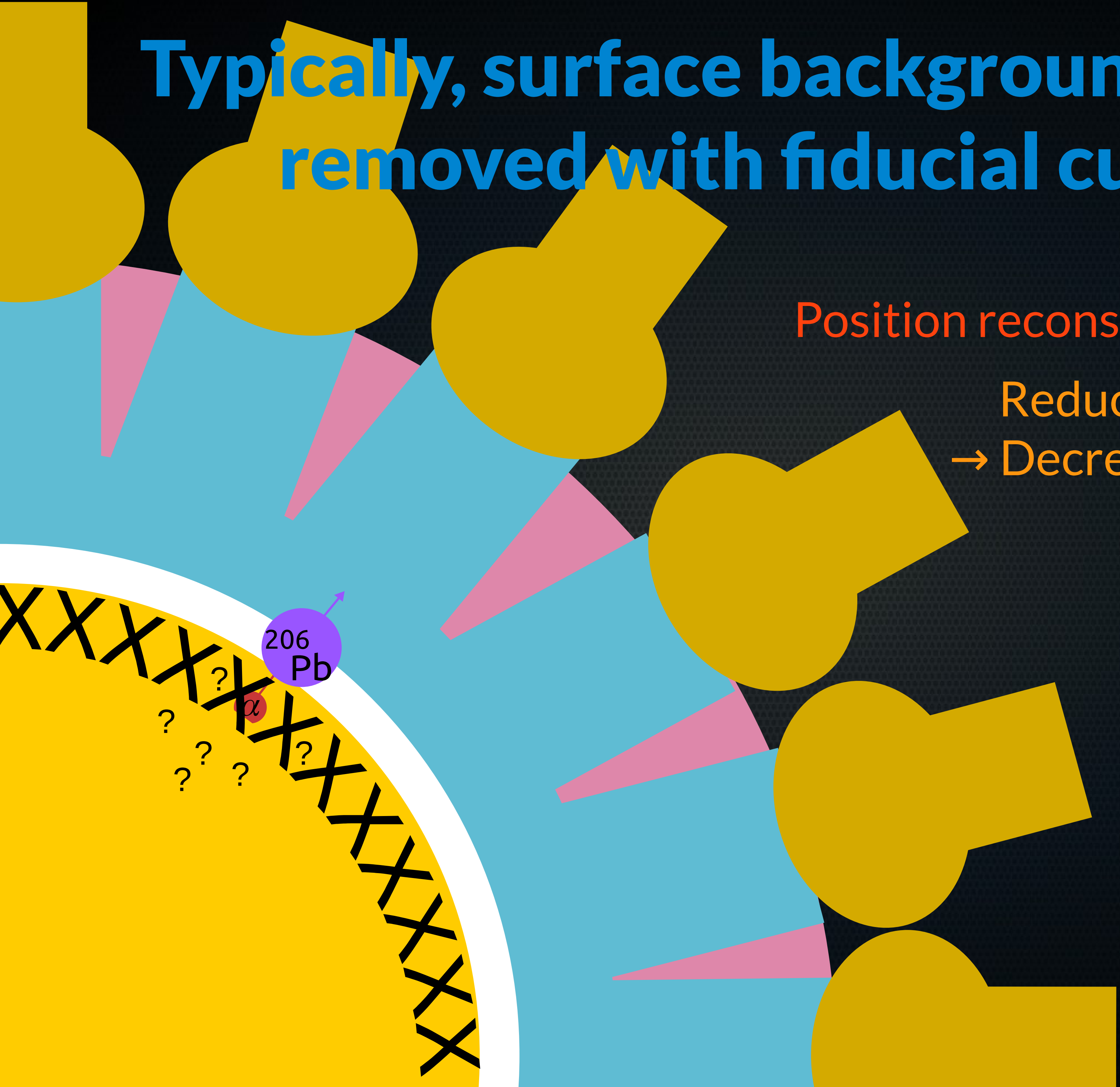

Position reconstruction is hard

Reduces fiducial mass
→ Decreases sensitivity

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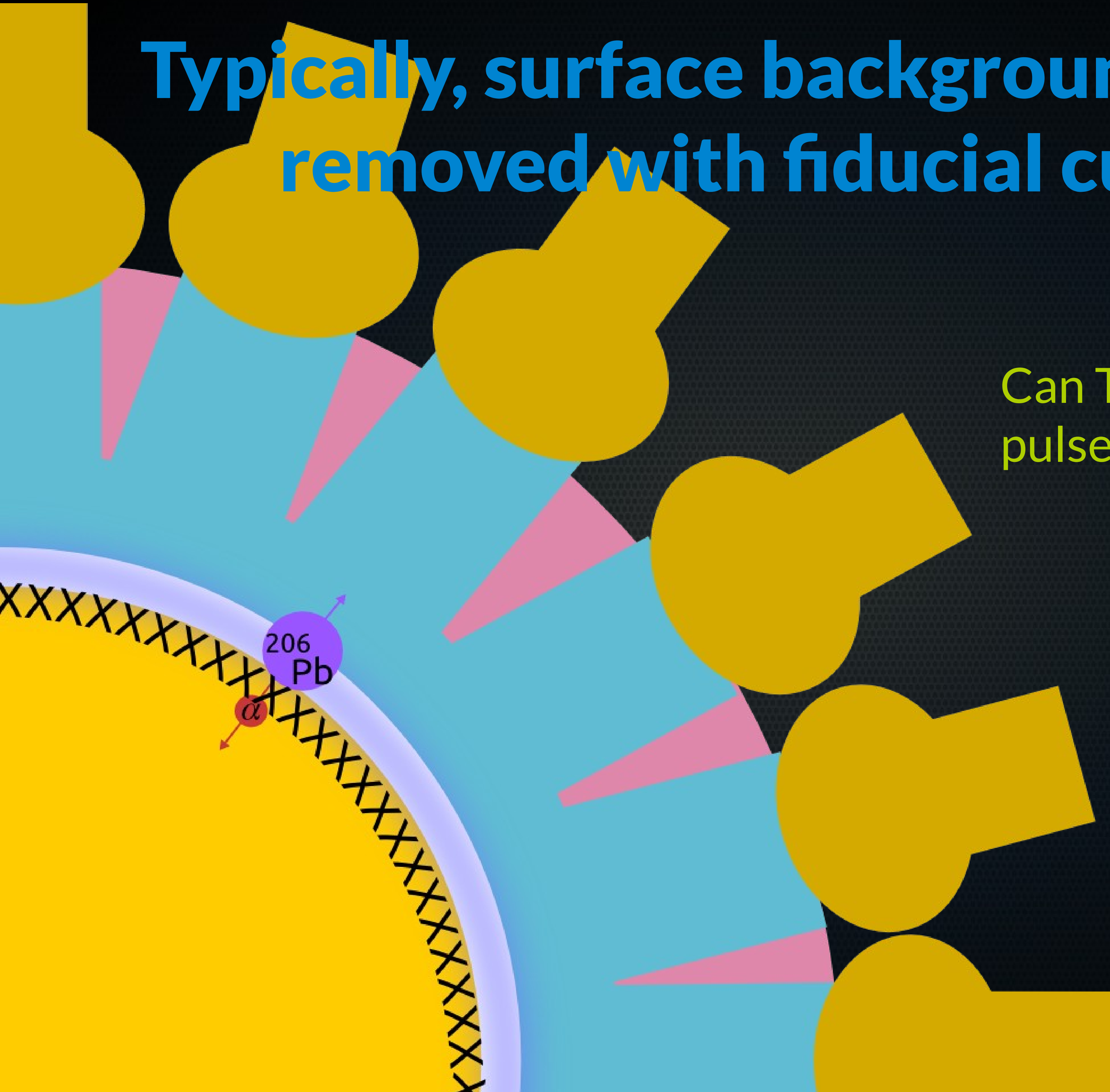


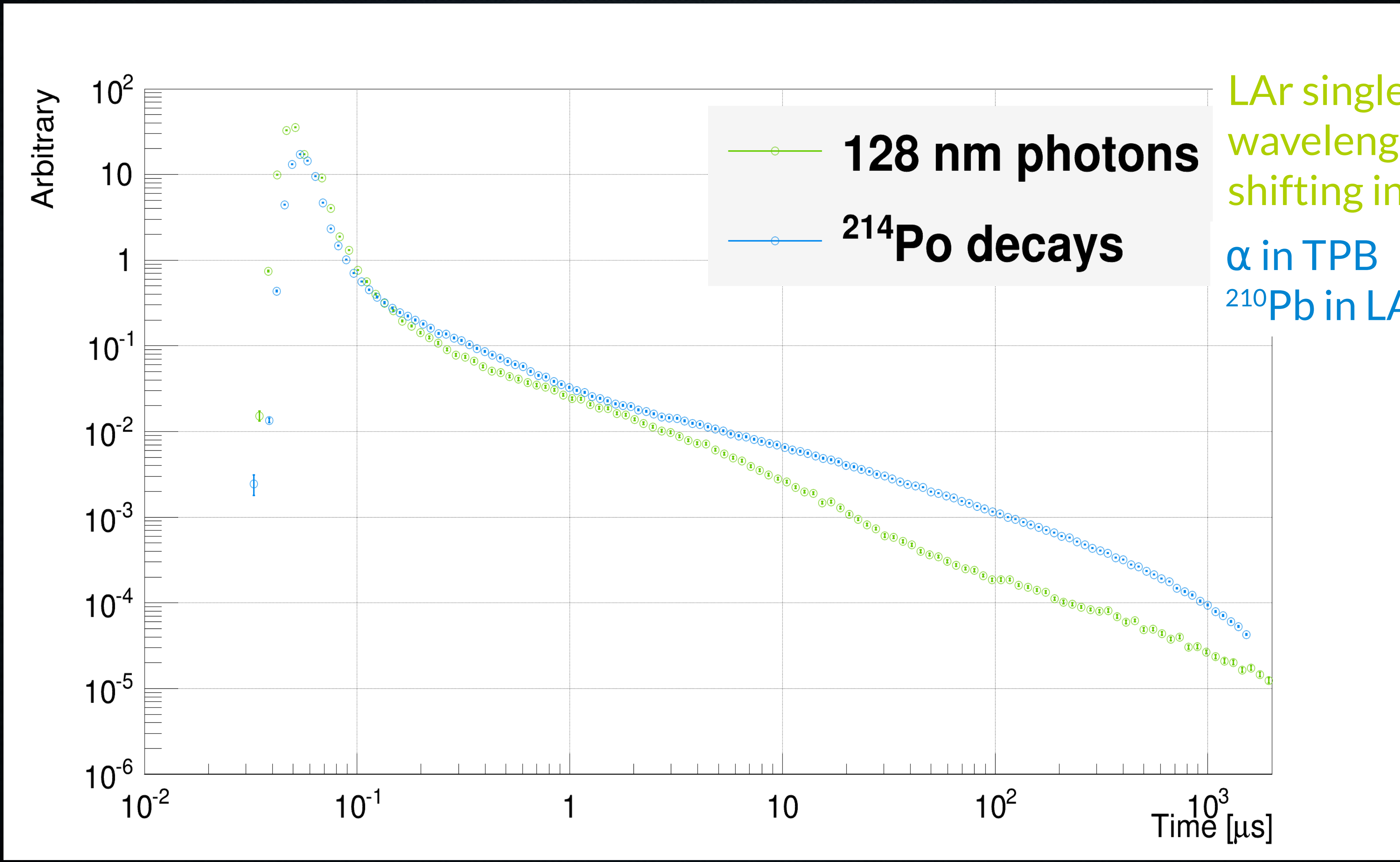
Can TPB scintillation pulse shape help?

Conclusion

- Surface α decays are an important background in low-background experiments
- We have seen an extremely long tail in TPB scintillation under α excitation, significantly different from its wavelength shifting and β scintillation time constants
- Evidence that this tail appears in DEAP-3600
- Could be used as a powerful tool for discriminating these backgrounds

End

Difference between Wavelength Shifting and Surface Backgrounds



LAr singlets wavelength-shifting in TPB

α in TPB
^{210}Pb in LAr