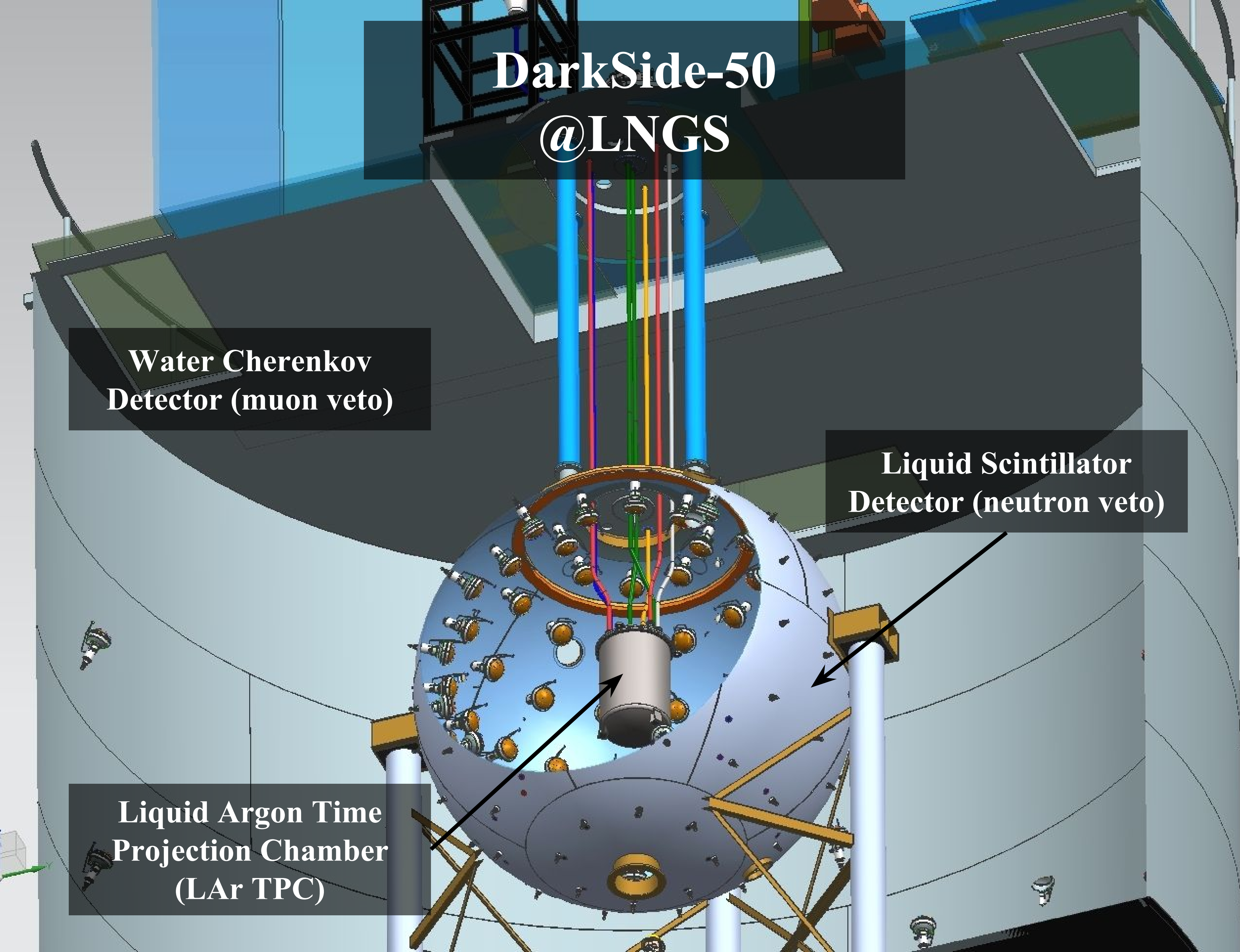
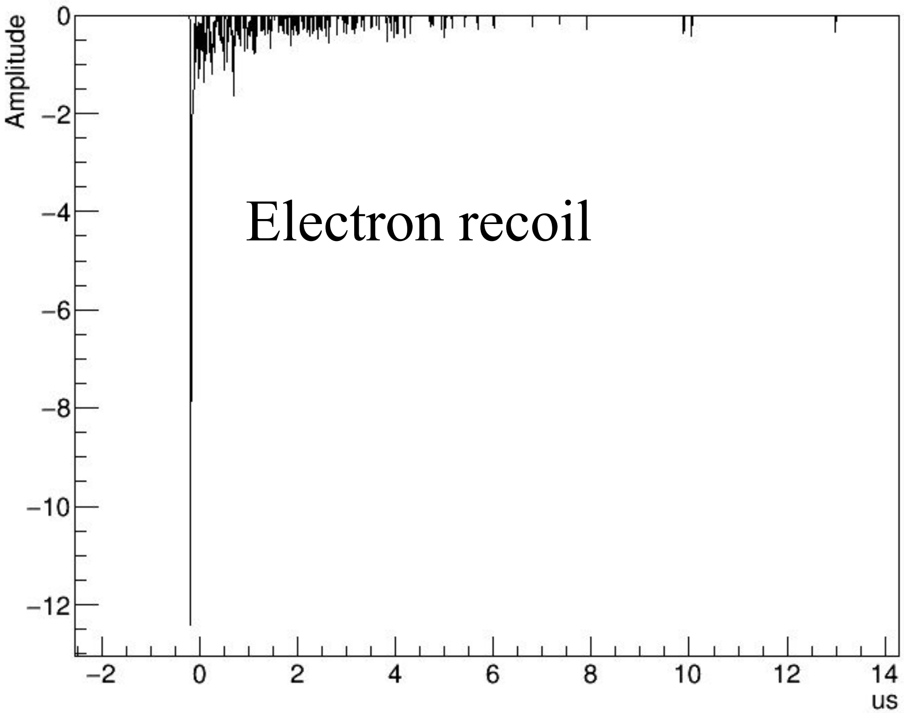
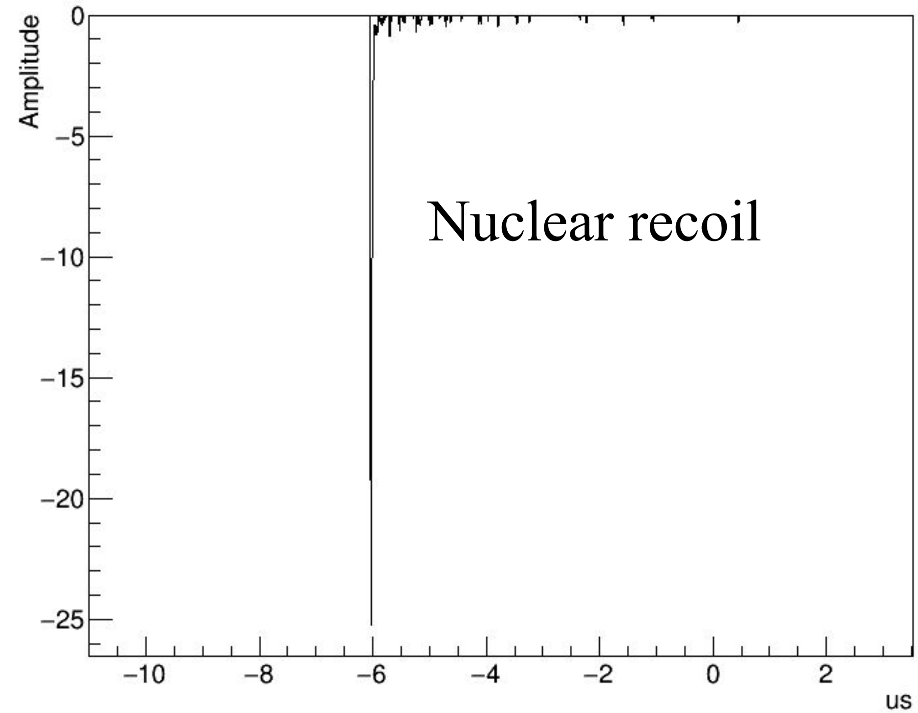
Surface Background Rejection Using Tetraphenyl-butadiene (TPB)

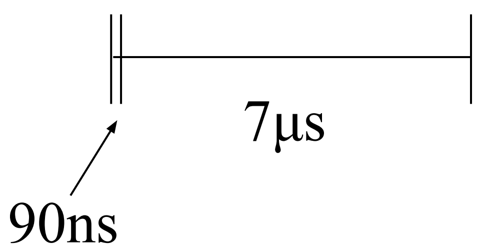
TAUP
July 2017
Chris Stanford


DarkSide-50
@LNGS
Water Cherenkov
Detector (muon veto)
Liquid Scintillator
Detector (neutron veto)
Liquid Argon Time
Projection Chamber
(LAr TPC)

Pulse Shape Discrimination (PSD)







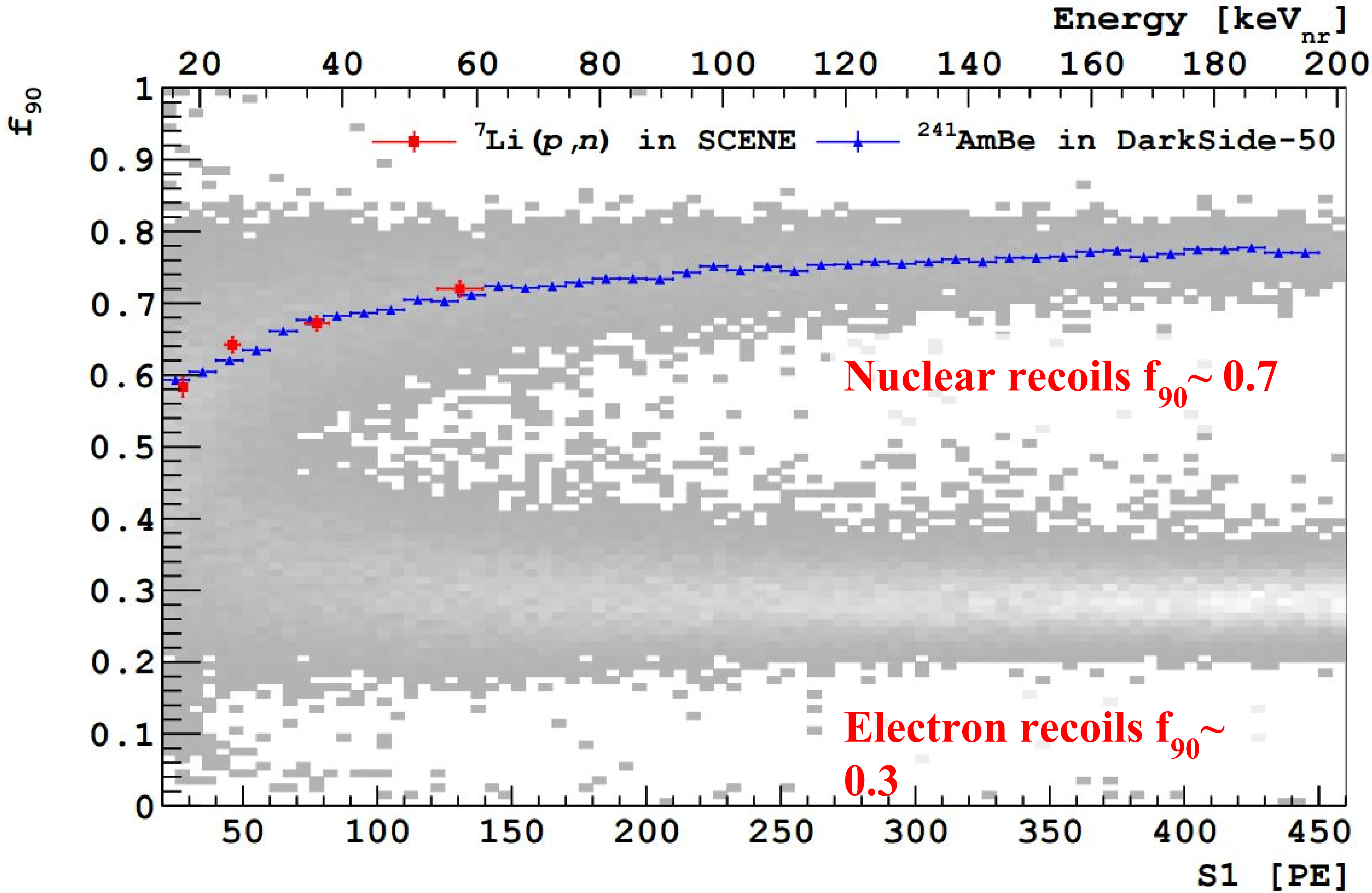
$$f_{90} \equiv \frac{\text{Integral of first 90ns}}{\text{Integral of first 7}\mu\text{s}}$$

LAr scintillation has 2 components:

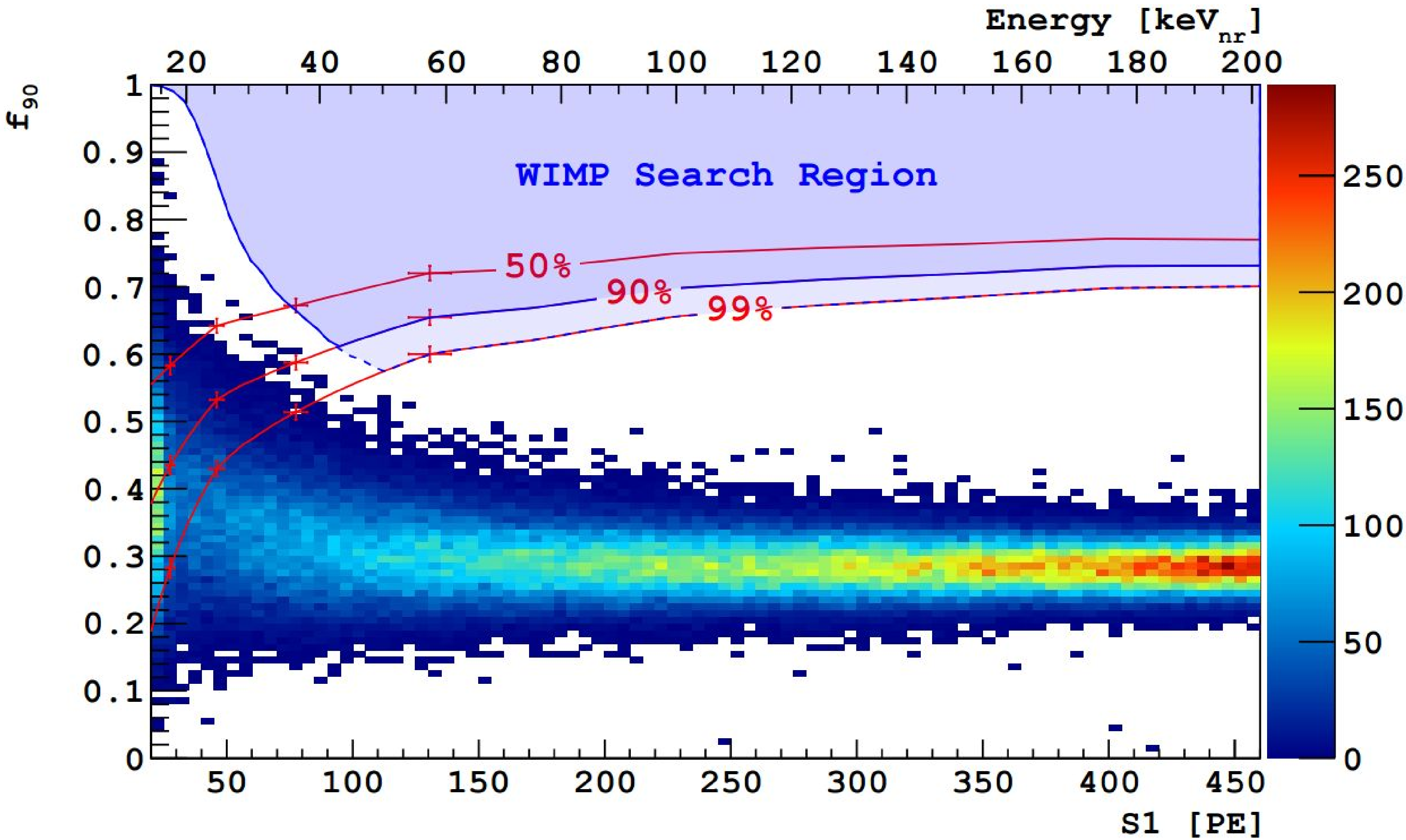
$\boldsymbol{\tau}_1$~7 ns, $\boldsymbol{\tau}_2$~1600 ns

Electron and nuclear recoils produce different ratios of the two components

Pulse Shape Discrimination (PSD)

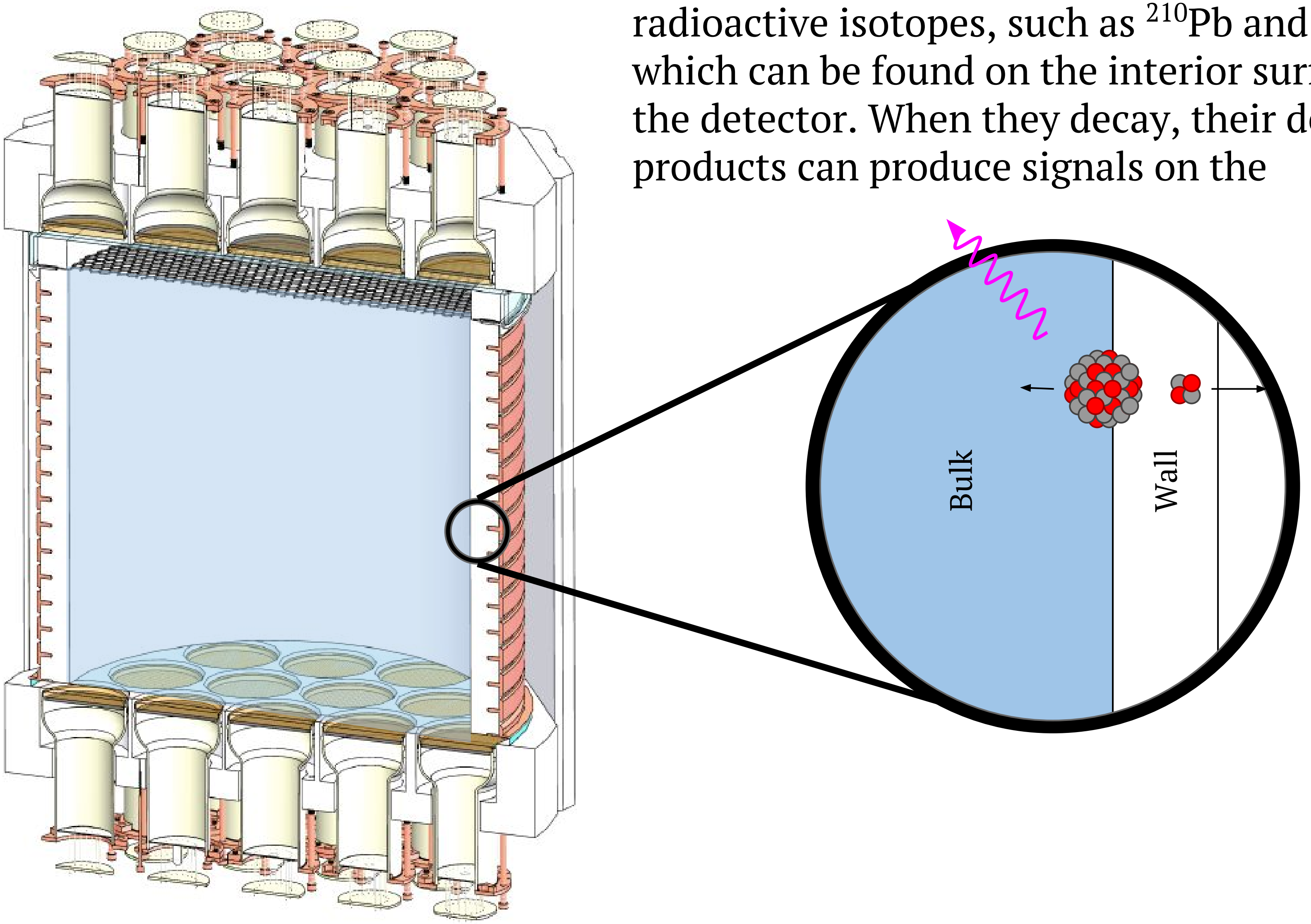


Dark Matter Search
Results: 2616 kg days



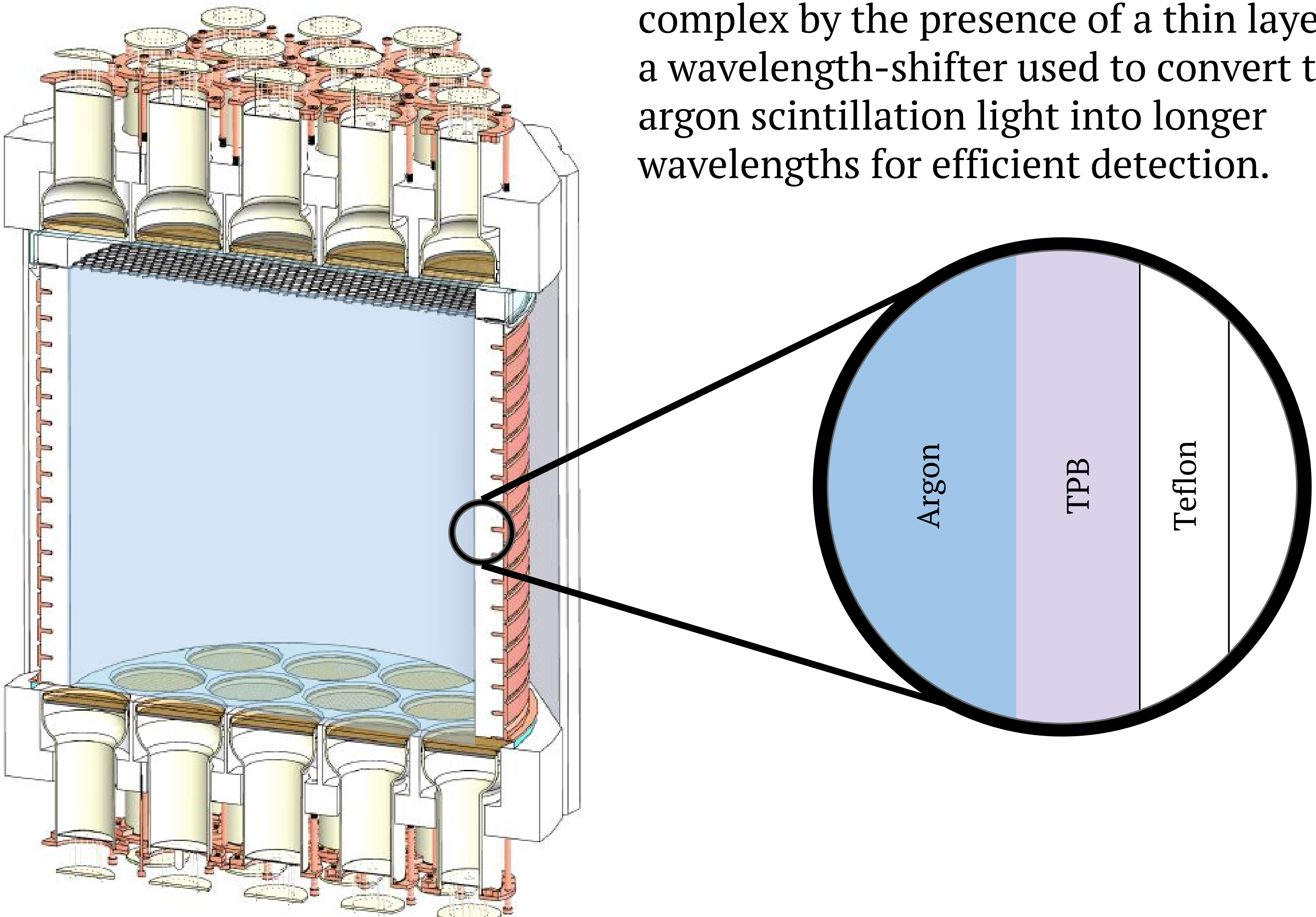
Surface Backgrounds

Surface backgrounds refer to long-lived radioactive isotopes, such as ^{210}Pb and ^{210}Po, which can be found on the interior surfaces of the detector. When they decay, their decay products can produce signals on the



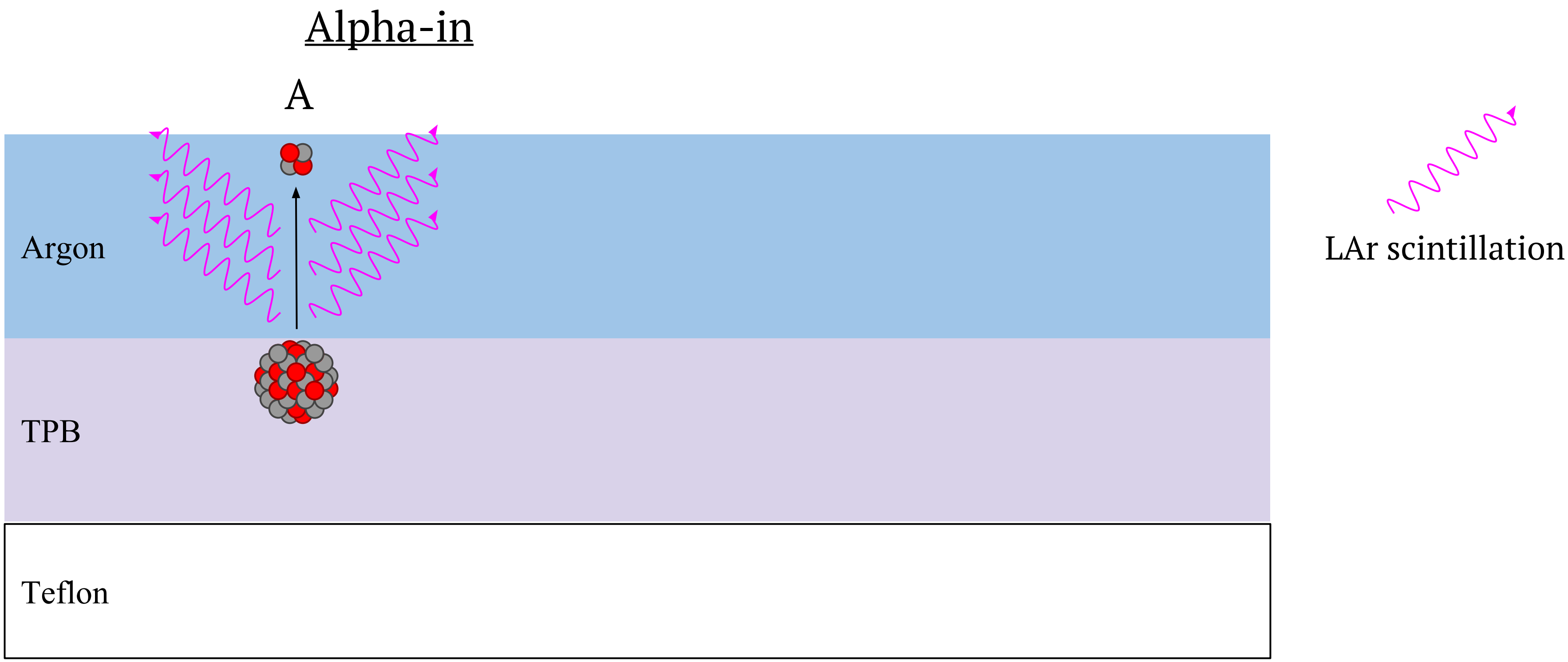
Surface Backgrounds

In liquid argon detectors, the surface is made complex by the presence of a thin layer of TPB, a wavelength-shifter used to convert the 128nm argon scintillation light into longer wavelengths for efficient detection.



Surface Backgrounds

Surface backgrounds encompass a large class of different signals that depend on the depth and kinematics of the decaying isotope.



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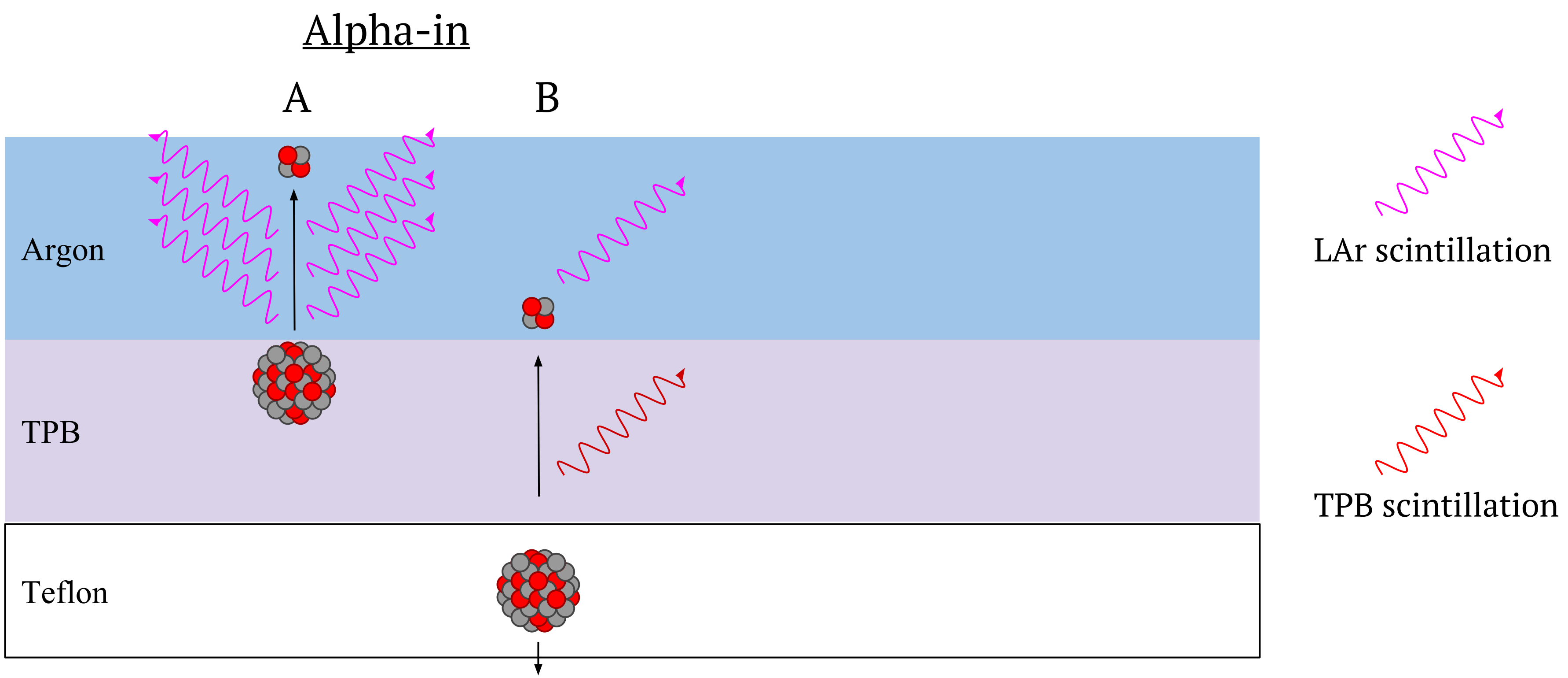

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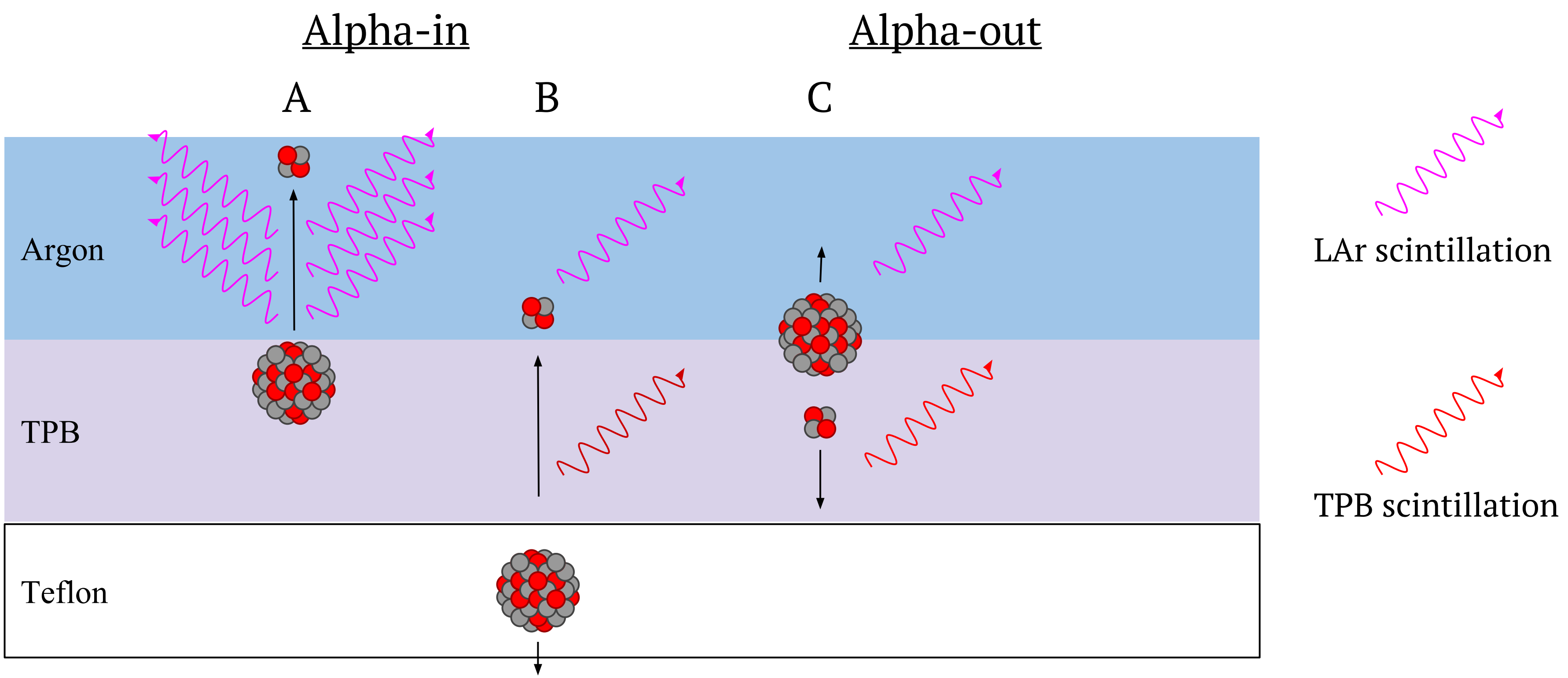

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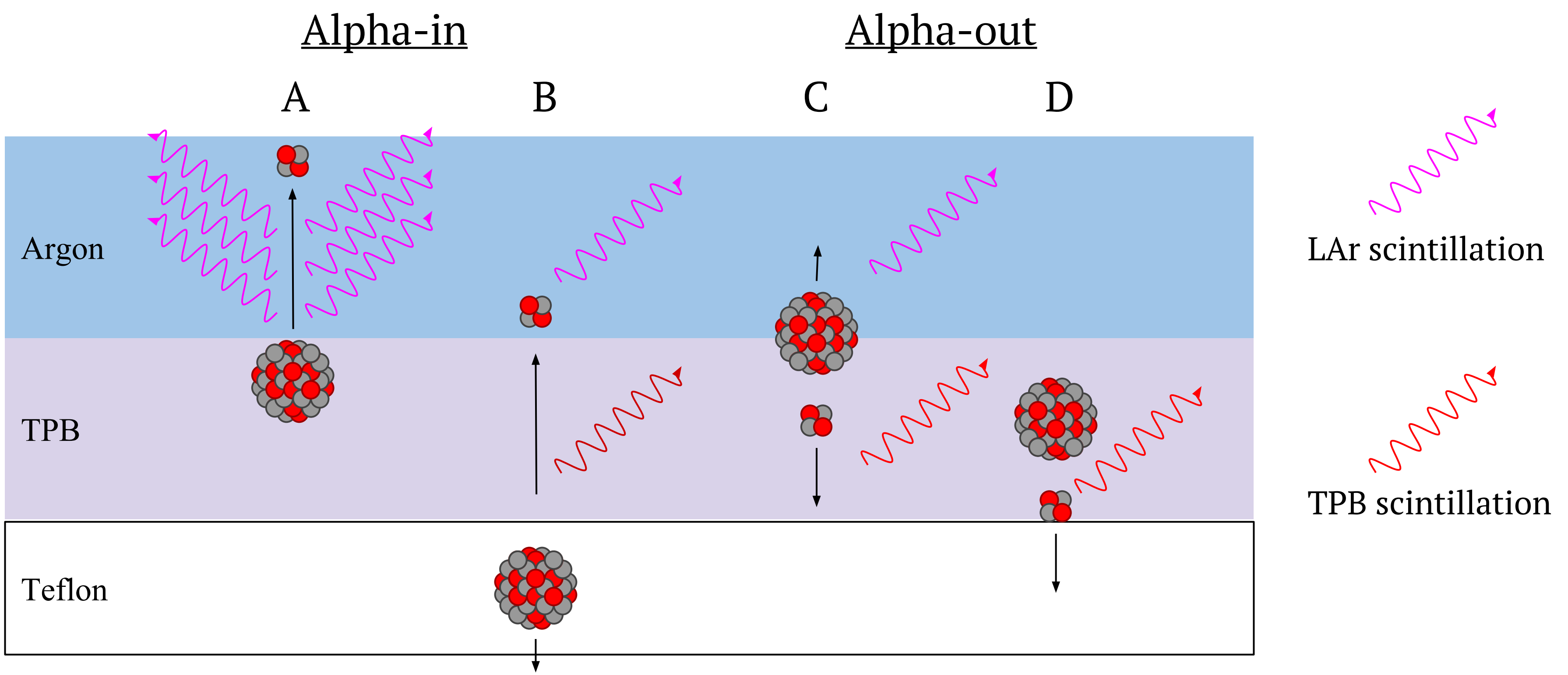

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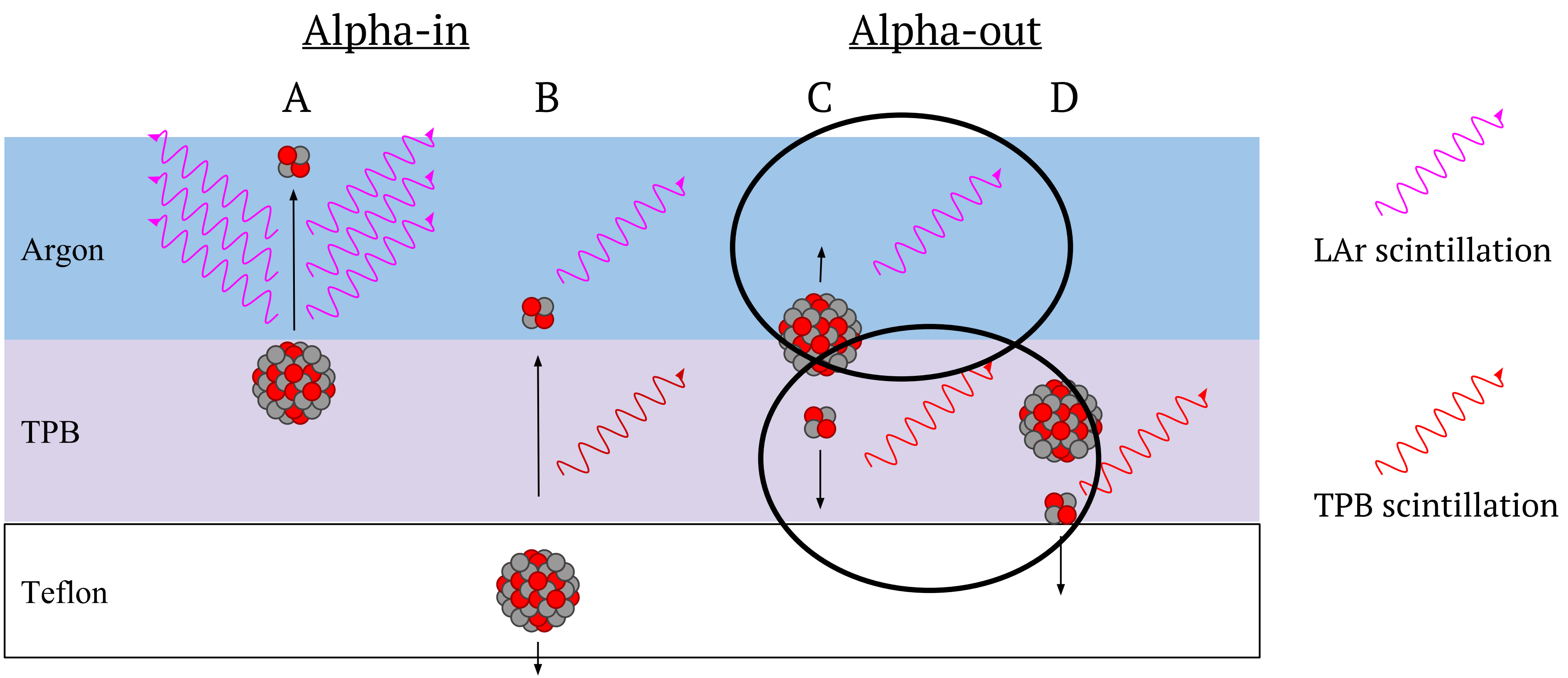
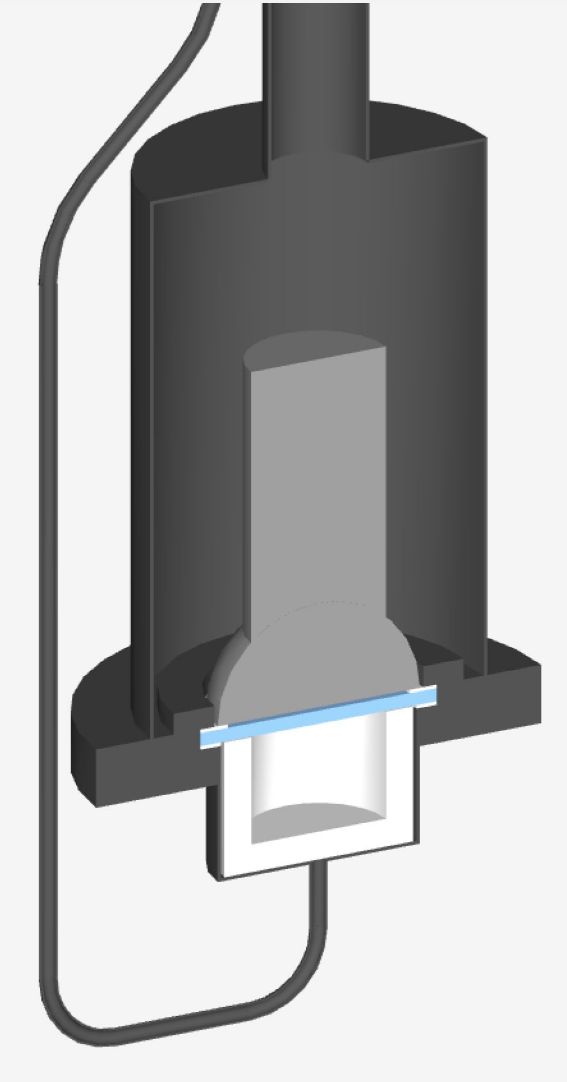


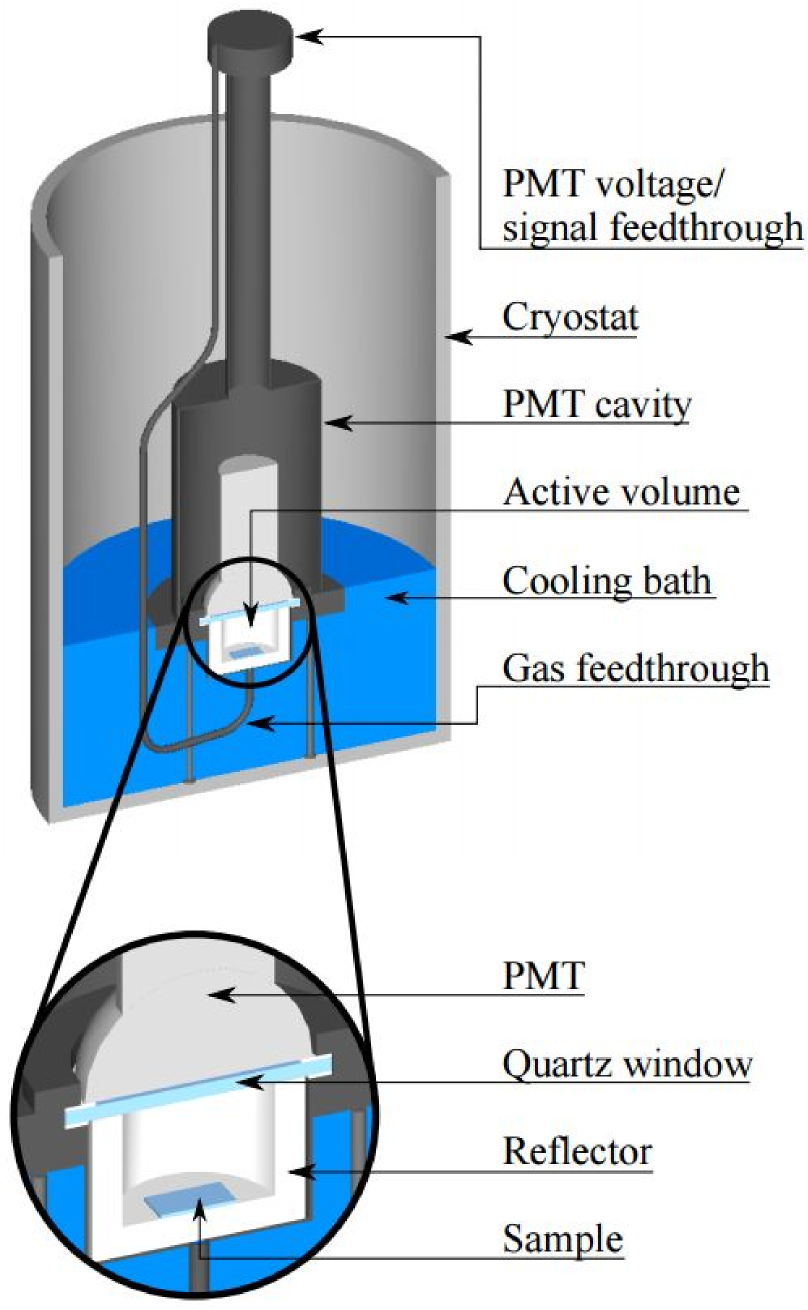
What do these signals look like?

RaDOSE

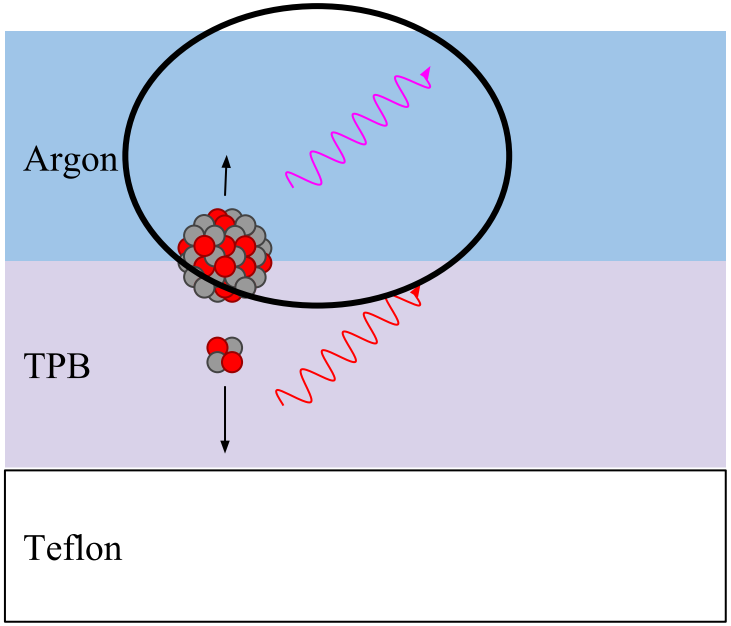
Radon **D**aughter and **O**rganic **S**cintillator **E**xperiment



RaDOSE


PMT voltage/
signal feedthrough
Cryostat
PMT cavity
Active volume
Cooling bath
Gas feedthrough
PMT
Quartz window
Reflector
Sample

Measurement #1
Nuclear Recoil in LAr



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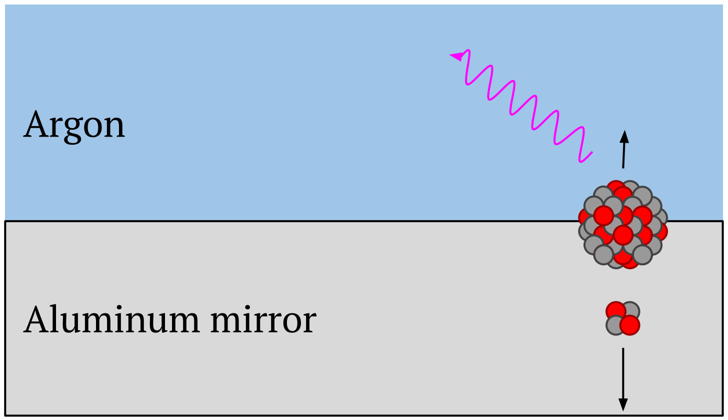

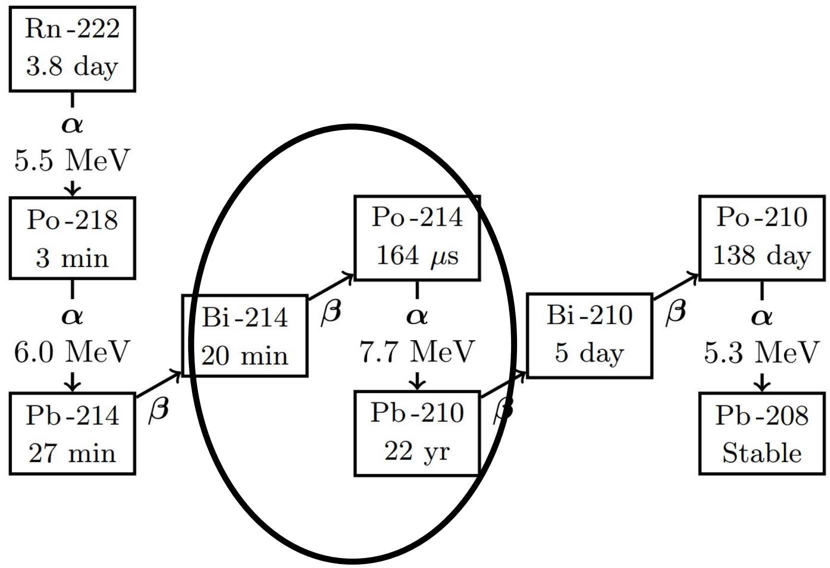

A Bi-Po coincidence search was performed to pick out the Pb^{210} nucleus (146 keV) scintillation in the argon.

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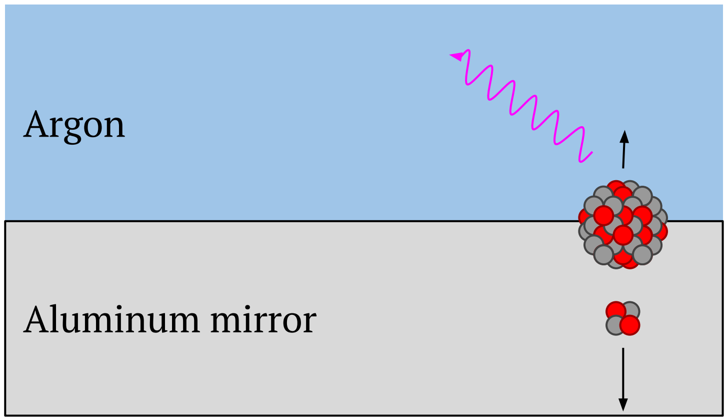
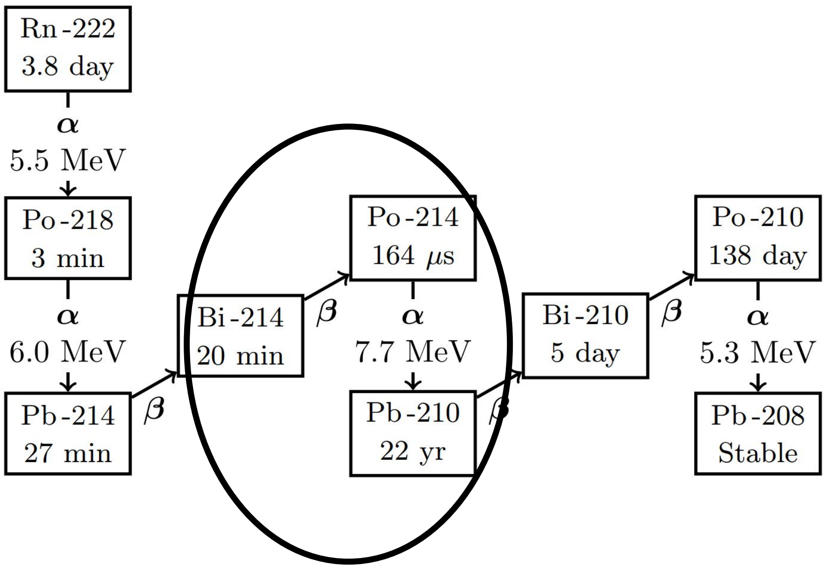
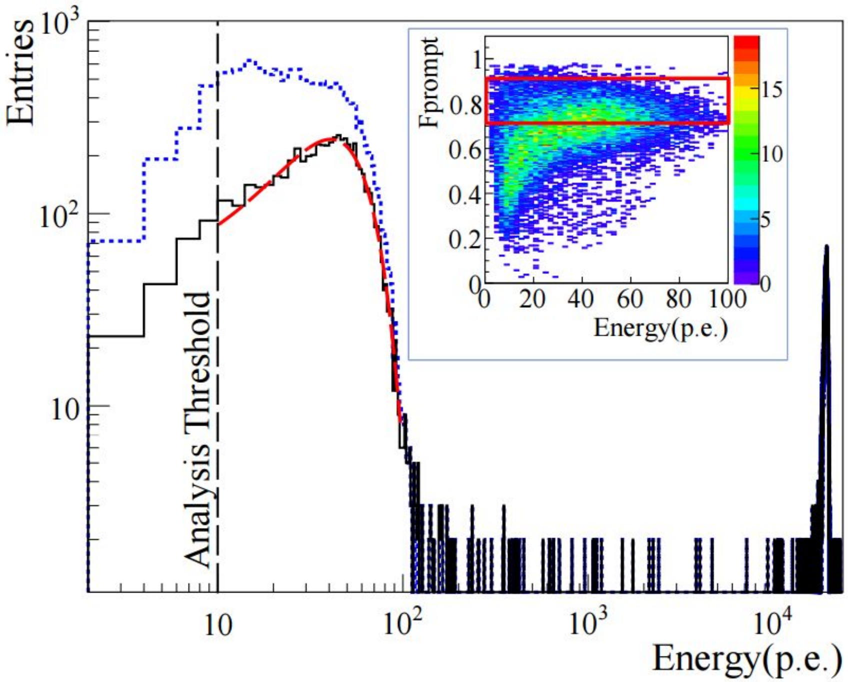




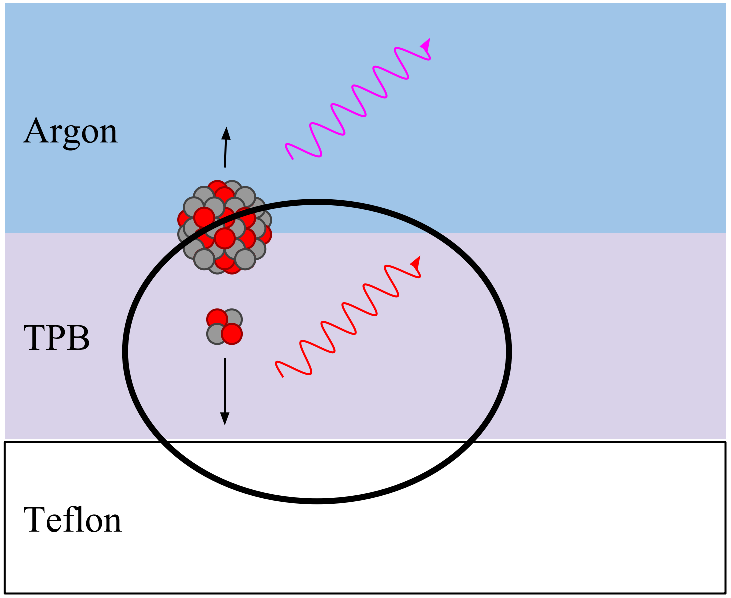


A Bi-Po coincidence search was performed to pick out the Pb^{210} nucleus (146 keV) scintillation in the argon.

Quenching factor ~ 1/20

Lower energy Pb^{206} nucleus (103 keV) would produce only a modest 5 keV_{ee} signal.

Measurement #2
Alpha in TPB



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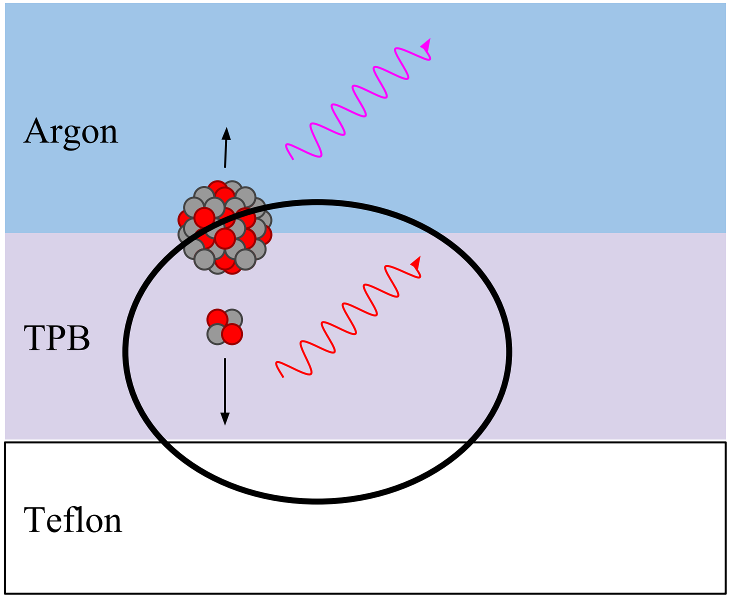
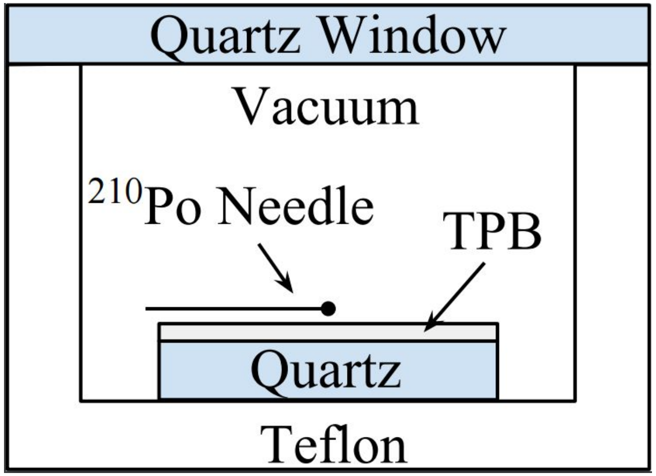
Alpha in TPB





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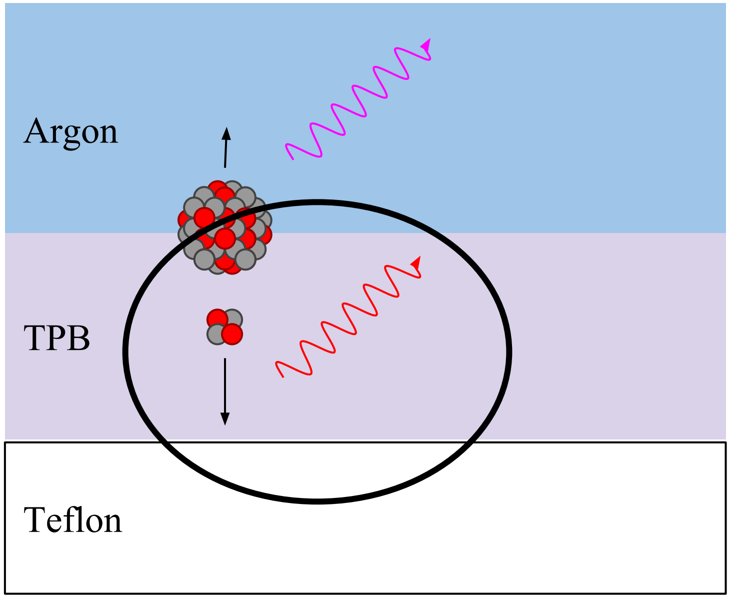
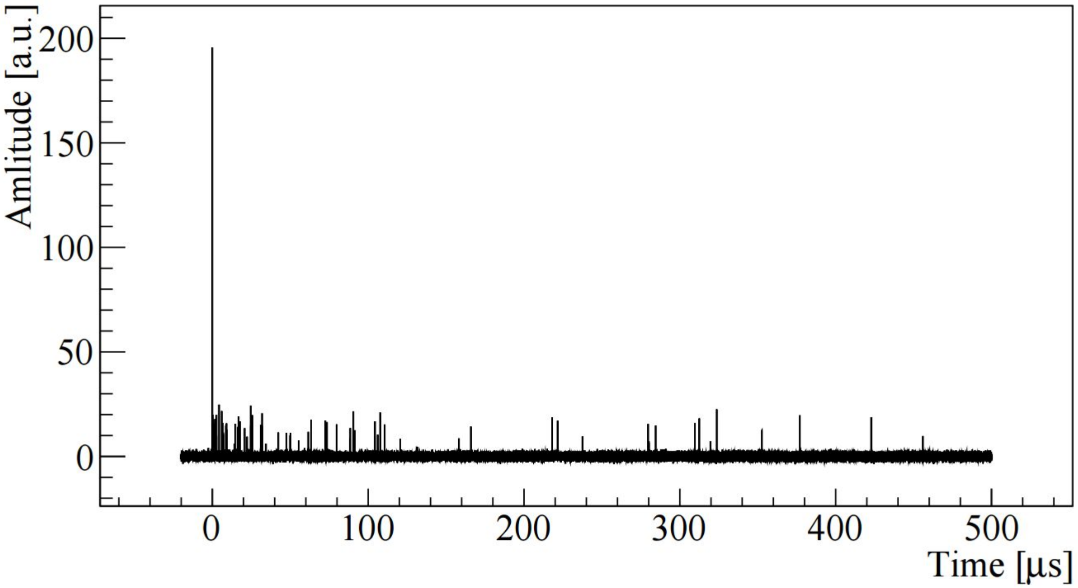
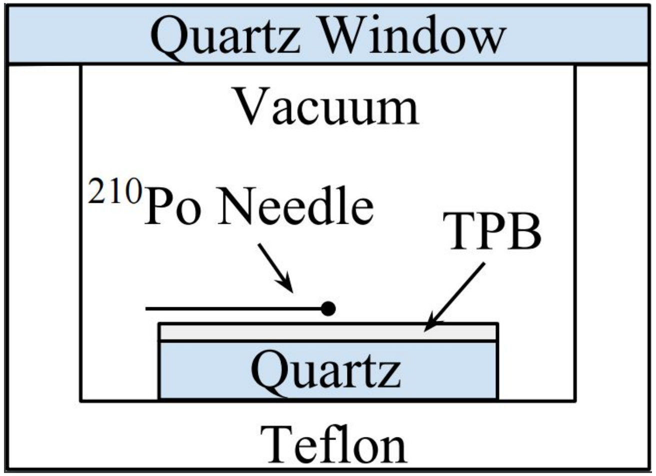
Alpha in TPB



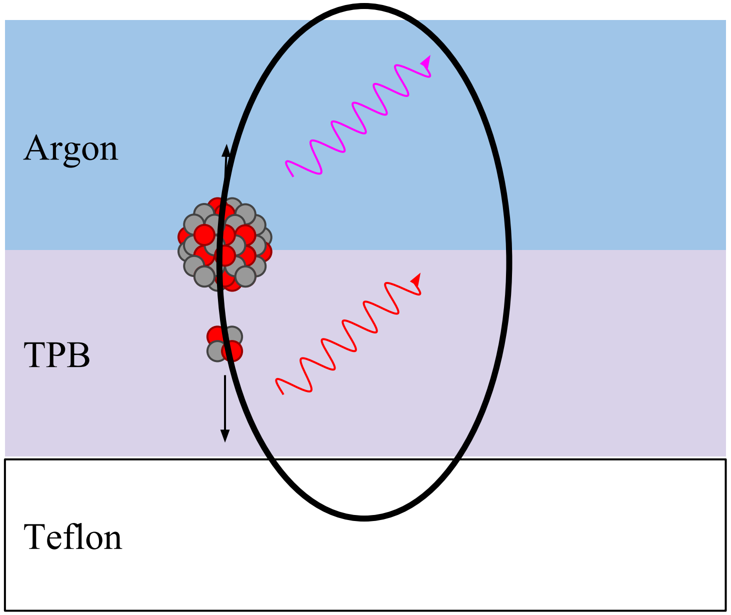


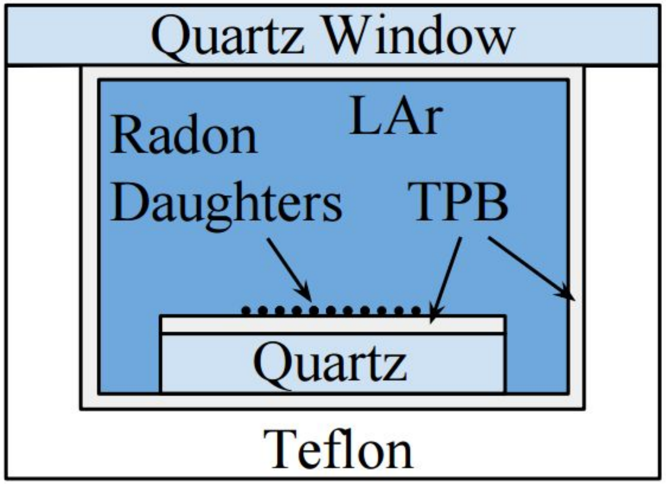


Millisecond-long scintillation lifetime, much longer than the LAr scintillation lifetimes.

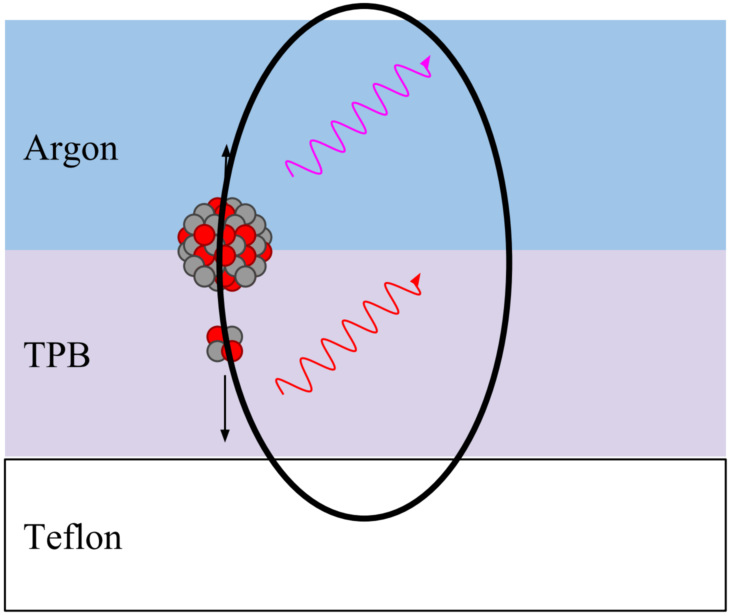
f_{90} (7µs window) ~ 0.7 (nuclear recoil-like, bad)
f_{90} (2ms window) ~ 0.2 (good)

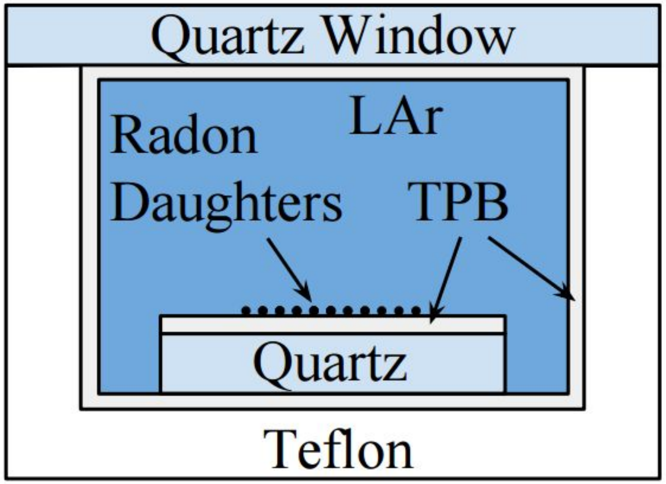
Measurement #3
Full Surface Background

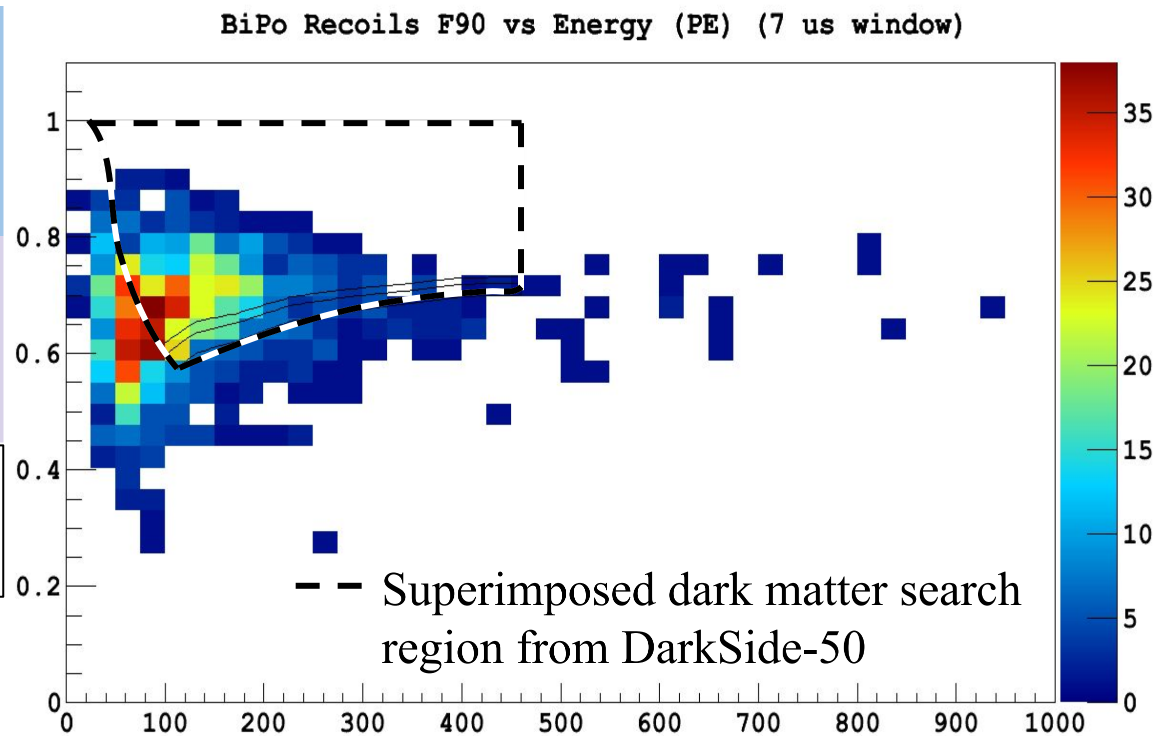




Measurement #3
Full Surface Background



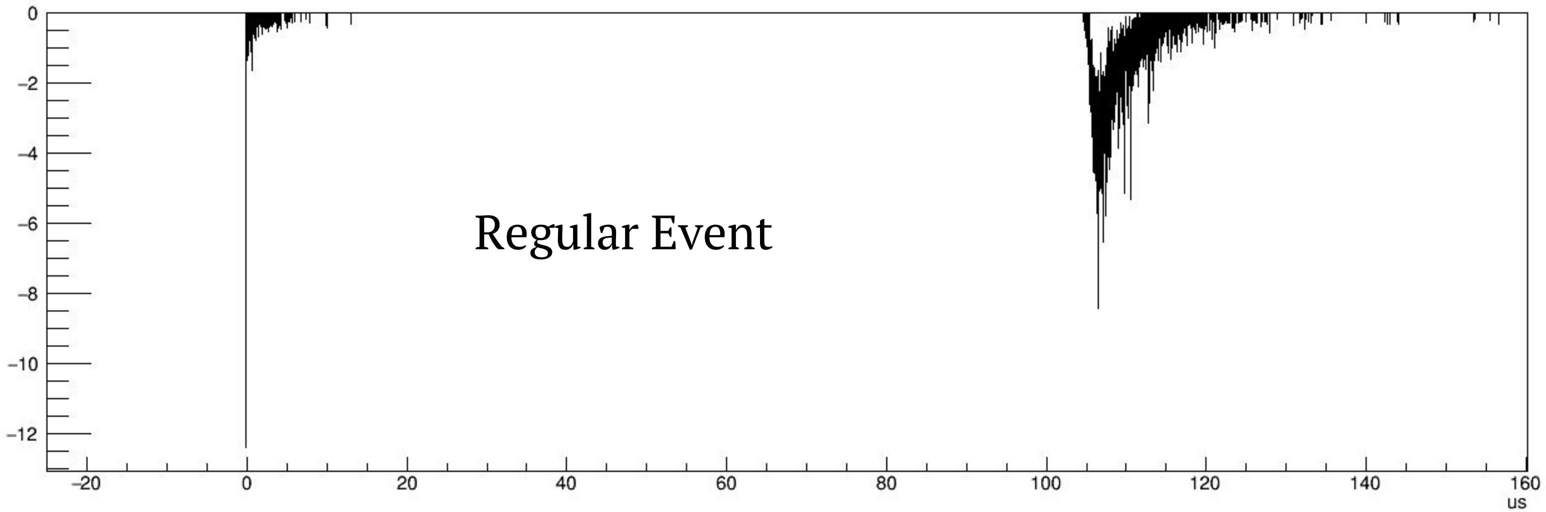


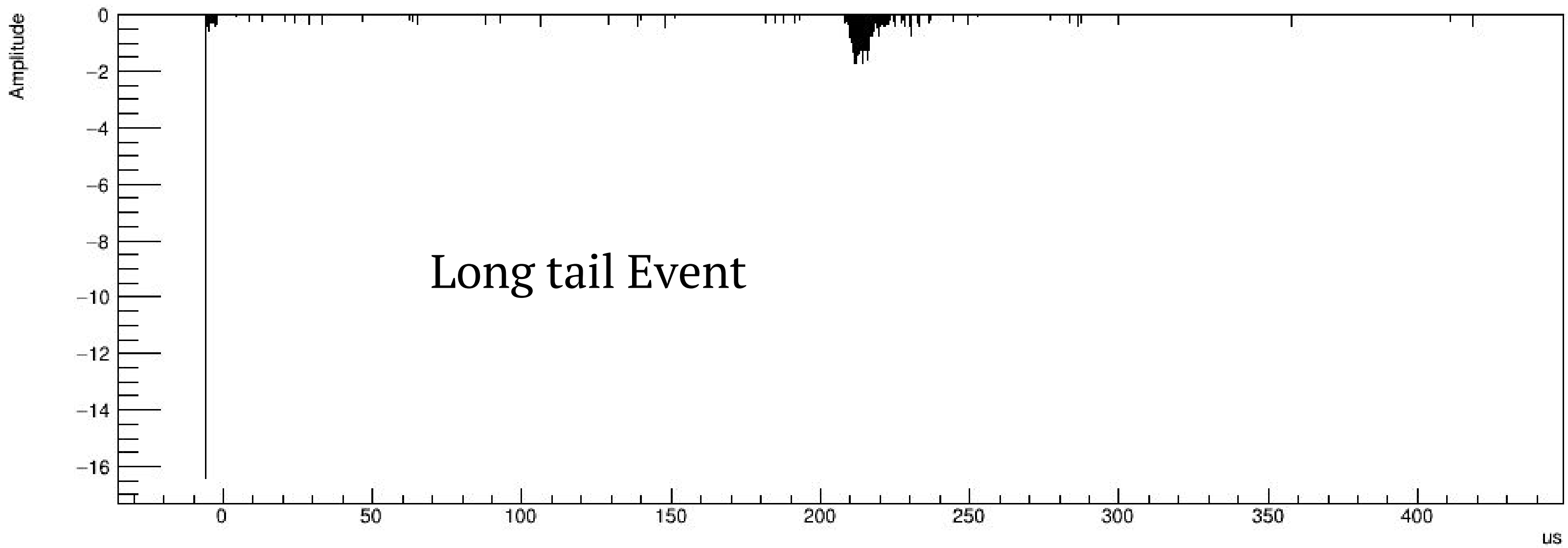


Using the standard definition of the S1 pulse (7μs), this type of event falls right within the dark matter search region of a liquid argon experiment.

Developing a Tail Cut

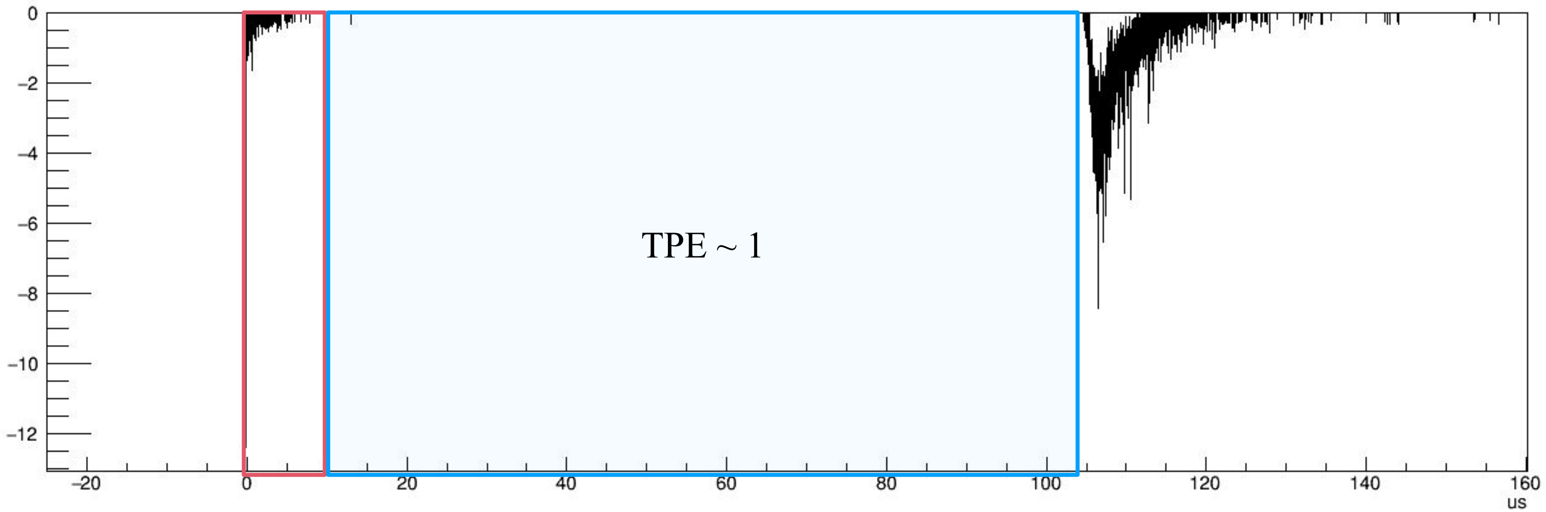
Developing a “long tail” cut in a two-phase detector is made more difficult by the presence of S2.

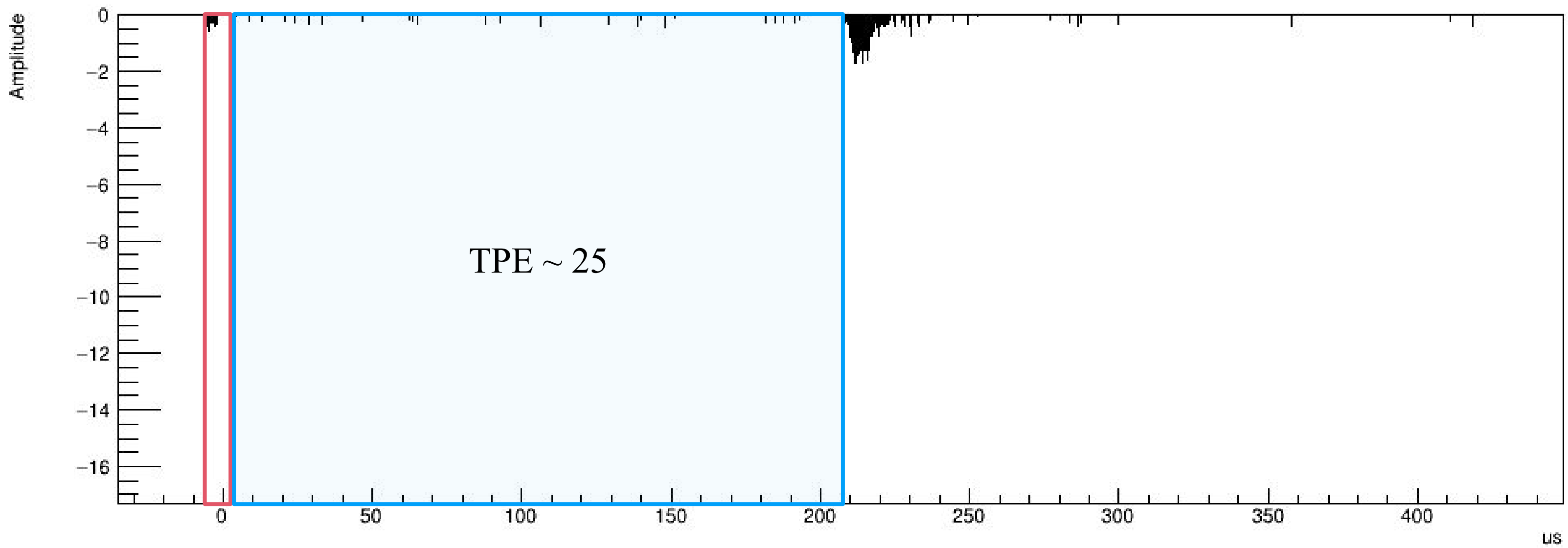




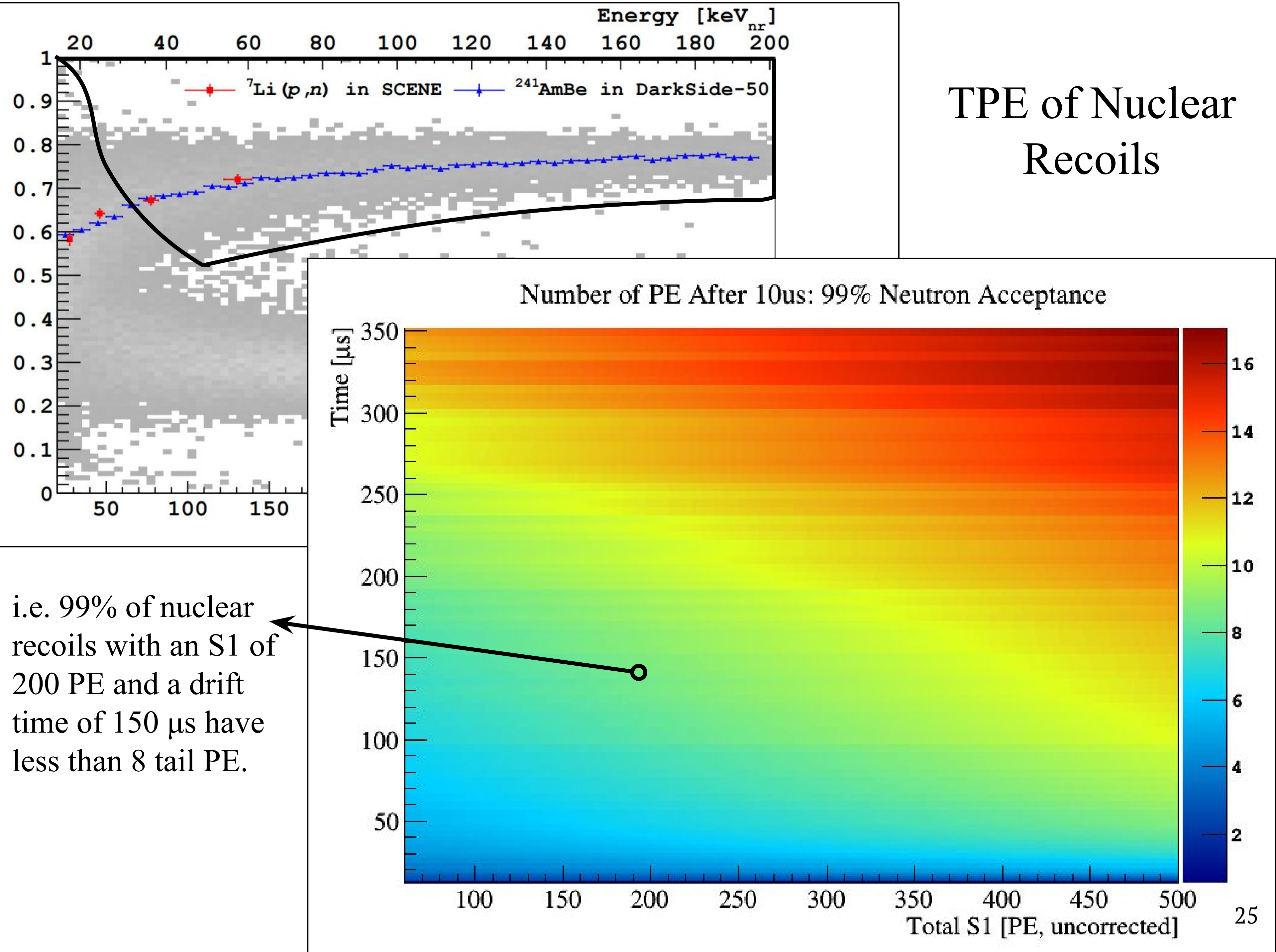
Tail PE (TPE) ≡ Number of PE starting 10μs after S1 up to the beginning of S2

TPE is dependant on both S1 and drift time.





TPE of Nuclear Recoils

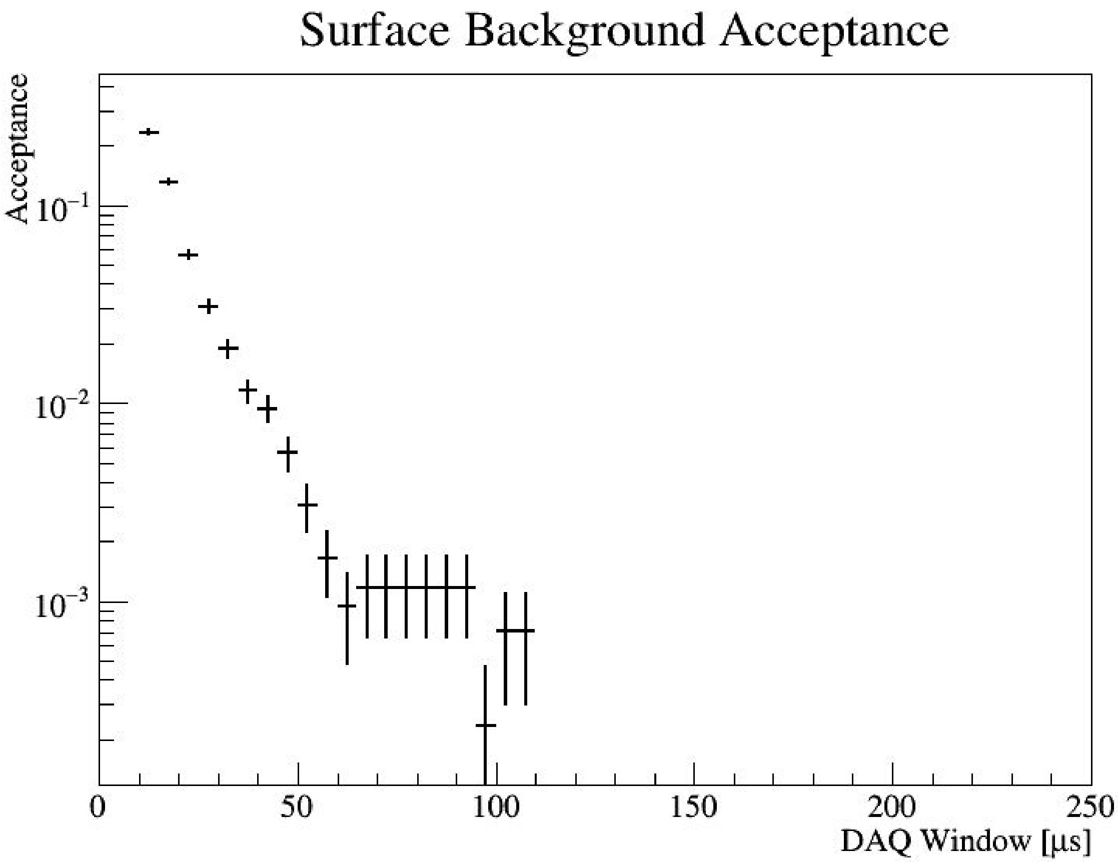


i.e. 99% of nuclear recoils with an S1 of 200 PE and a drift time of 150 μs have less than 8 tail PE.

Tail Cut Performance

We now apply the tail cut on the surface events measured in RaDOSE.

RaDOSE events do not have S2, so each event was sampled multiple times, placing an “artificial S2” at different points in the waveform and determining if it would pass the tail cut with the given drift time.



Integrated Acceptance
(40us to 336us):

1/2000

Other Applications

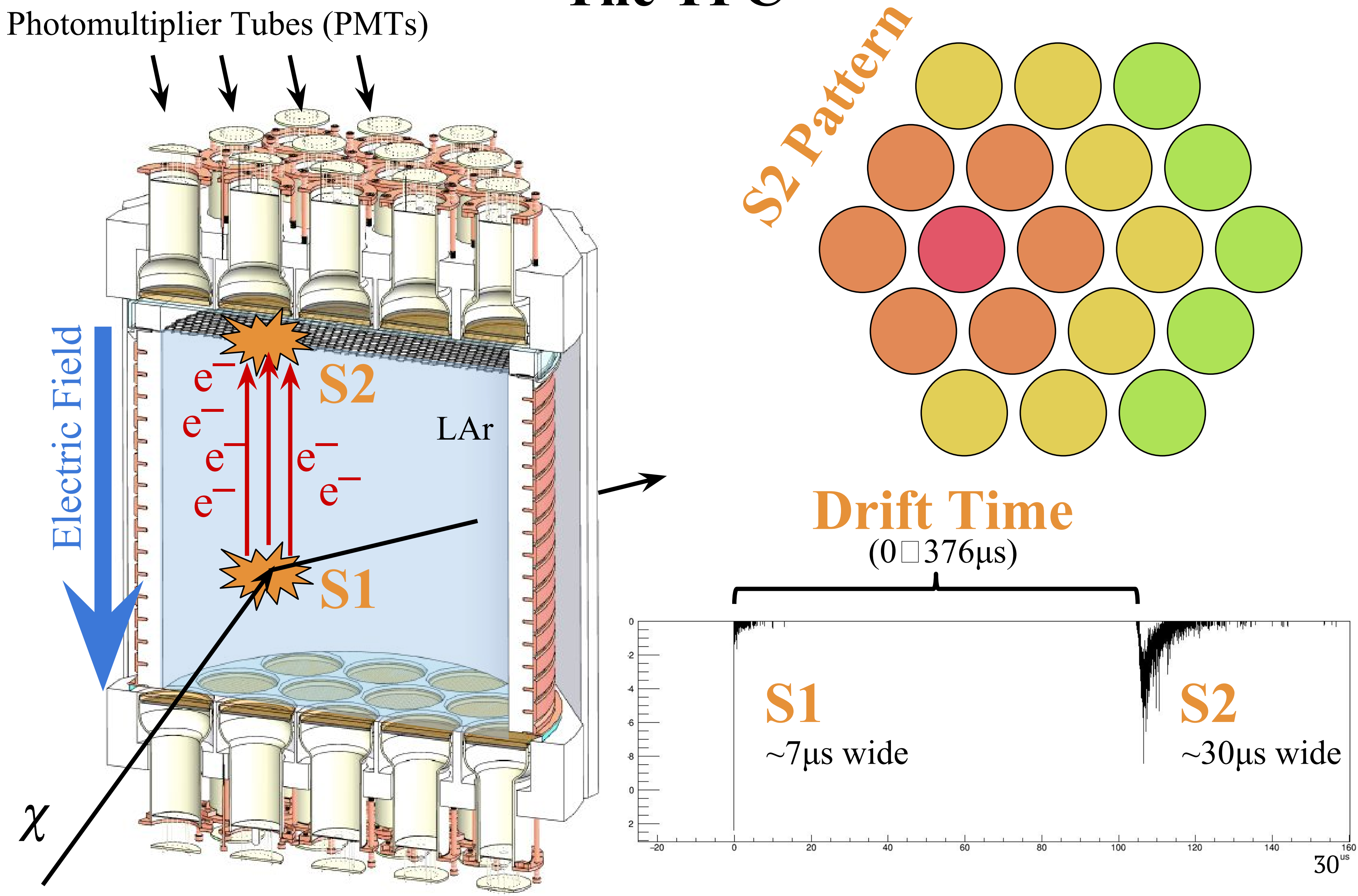
Long-tail scintillation

- Property of TPB, not argon
- May exist for other organic wavelengths shifters (confirmed for p-Terphenyl)
- Can be exploited in other experiments

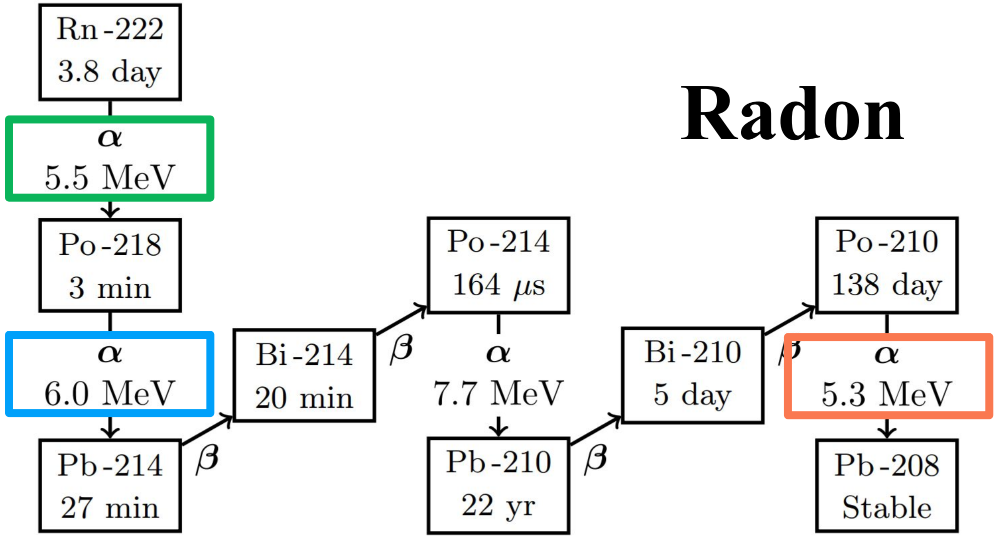
Thank You

Extra Slides

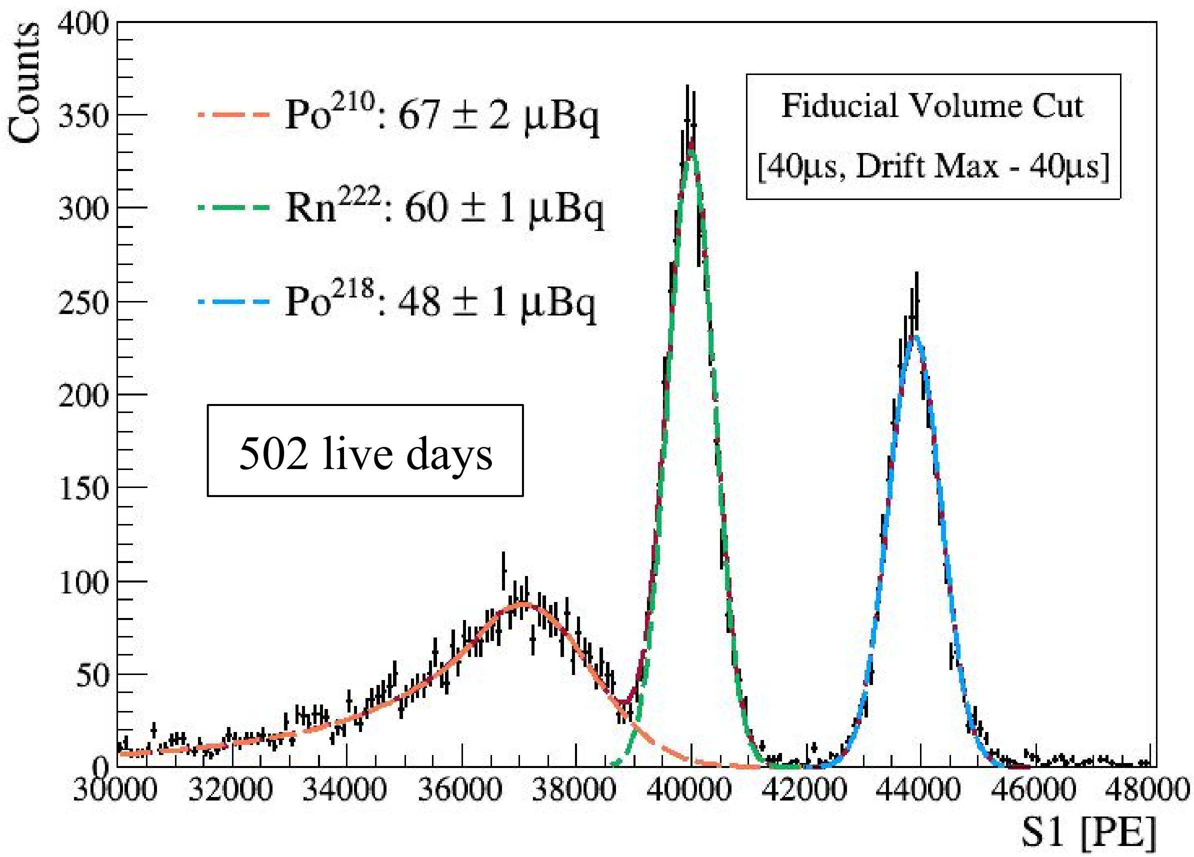
The TPC

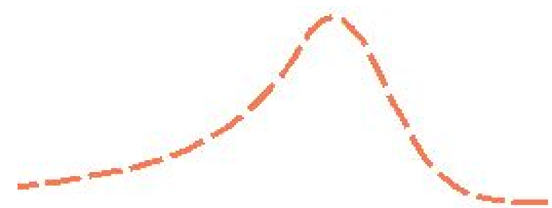

Photomultiplier Tubes (PMTs)
S2 Pattern
Electric Field
e⁻
S2
LAr
S1
χ
Drift Time
(0□376μs)
S1
~7μs wide
S2
~30μs wide

Radon

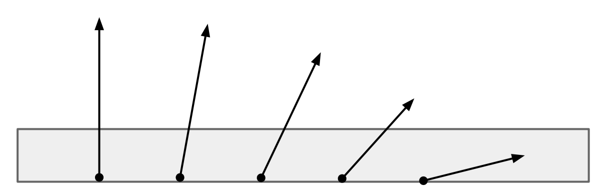


The Po-214 alpha has a close coincidence with the Bi-214 beta and falls within the same event, so its energy is not reconstructed here.

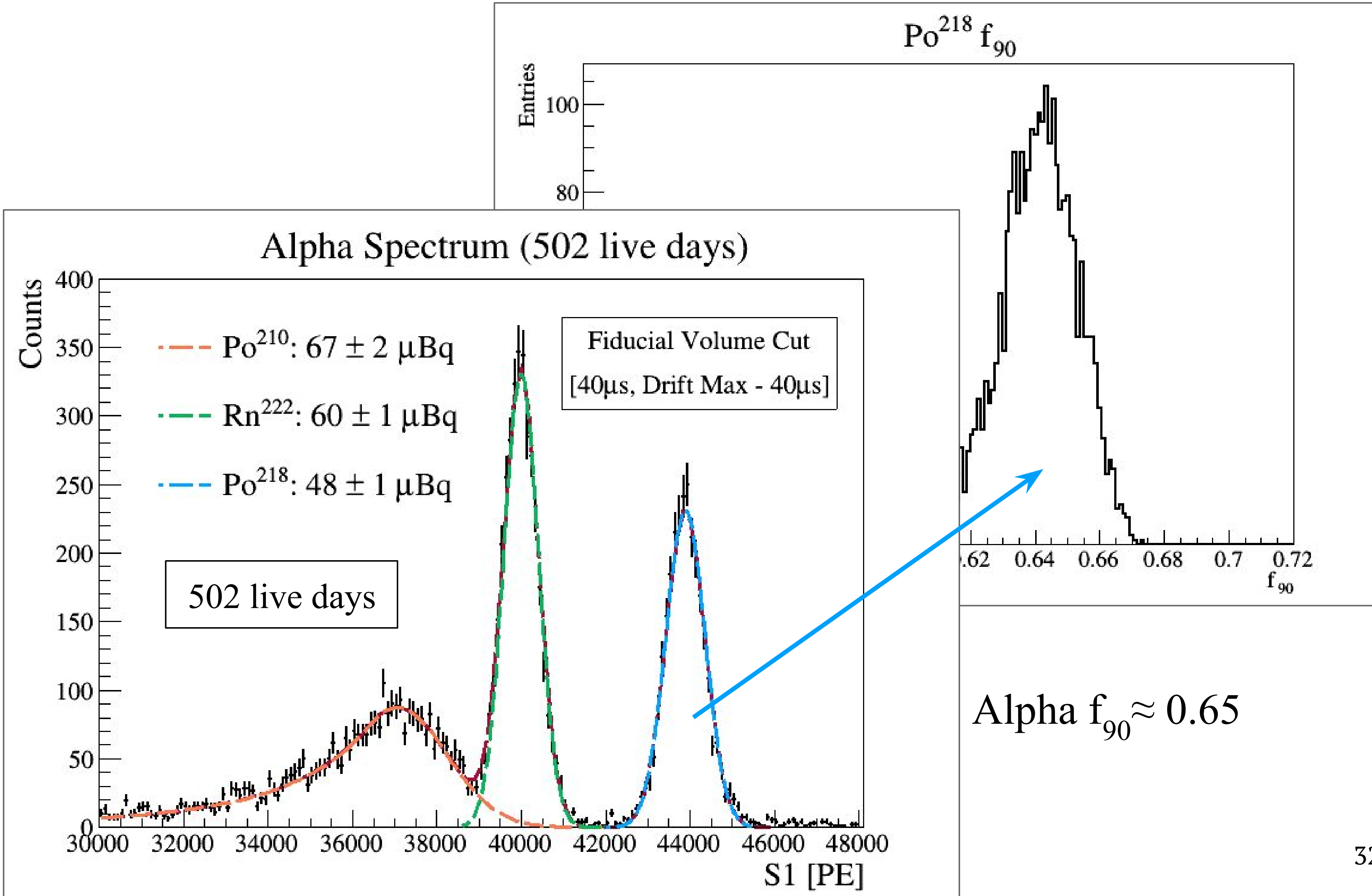




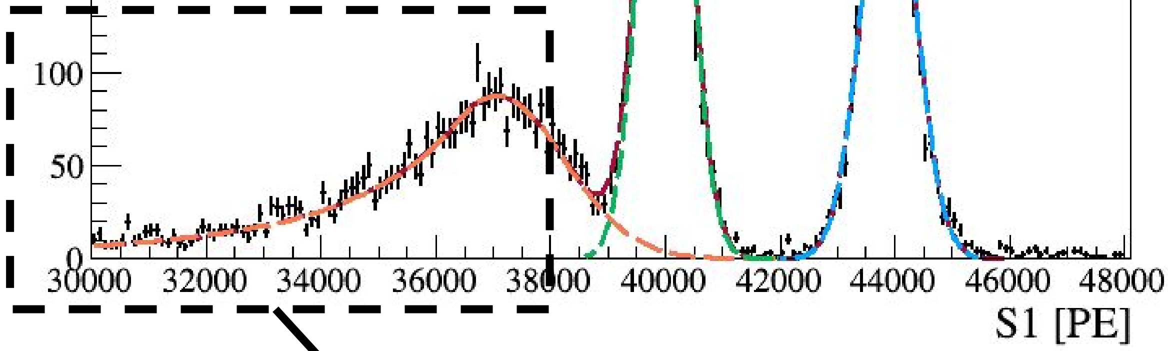
The “Crystal Ball” function is used to model particles going through a thin layer, where the energy loss depends on the angle:



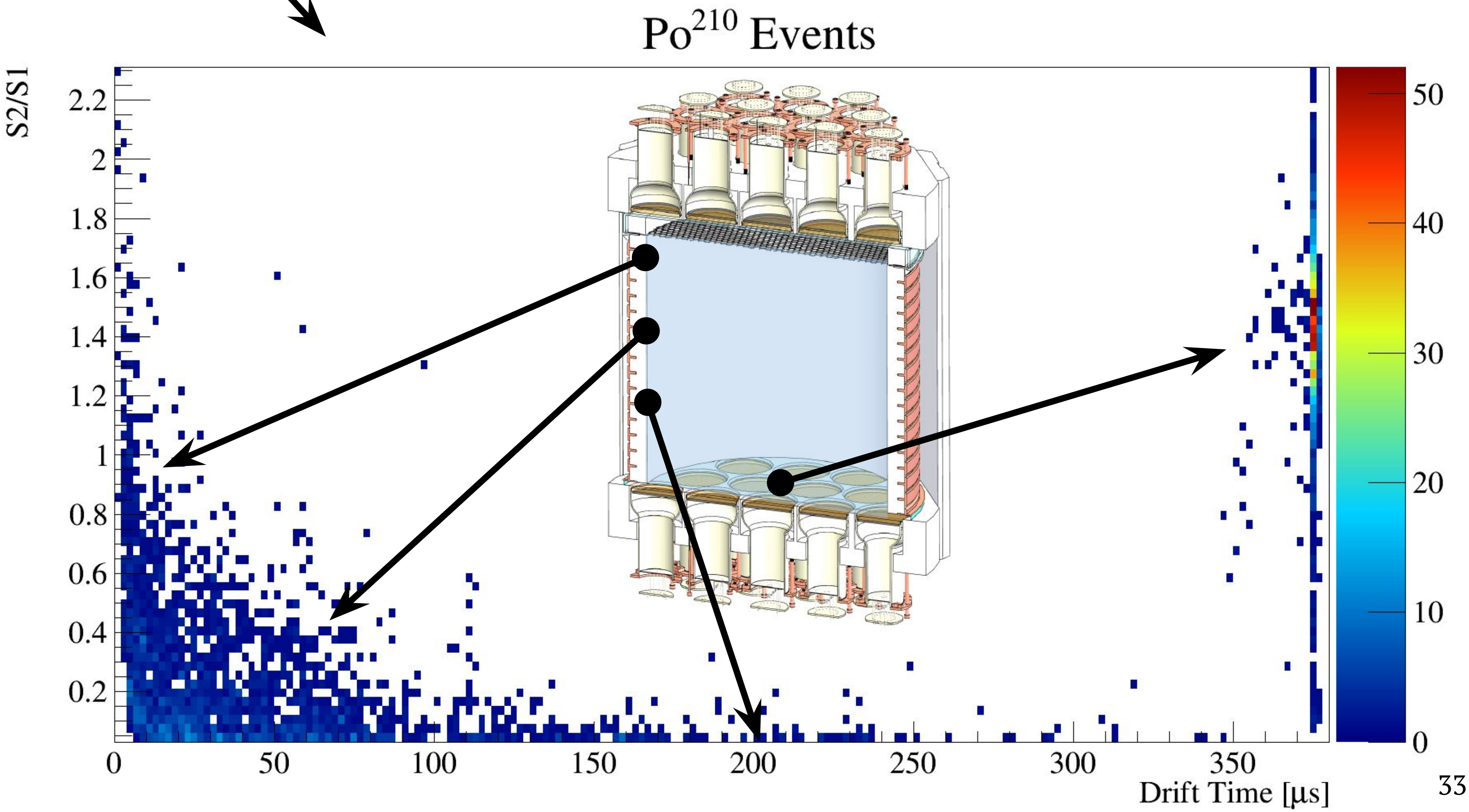
Radon



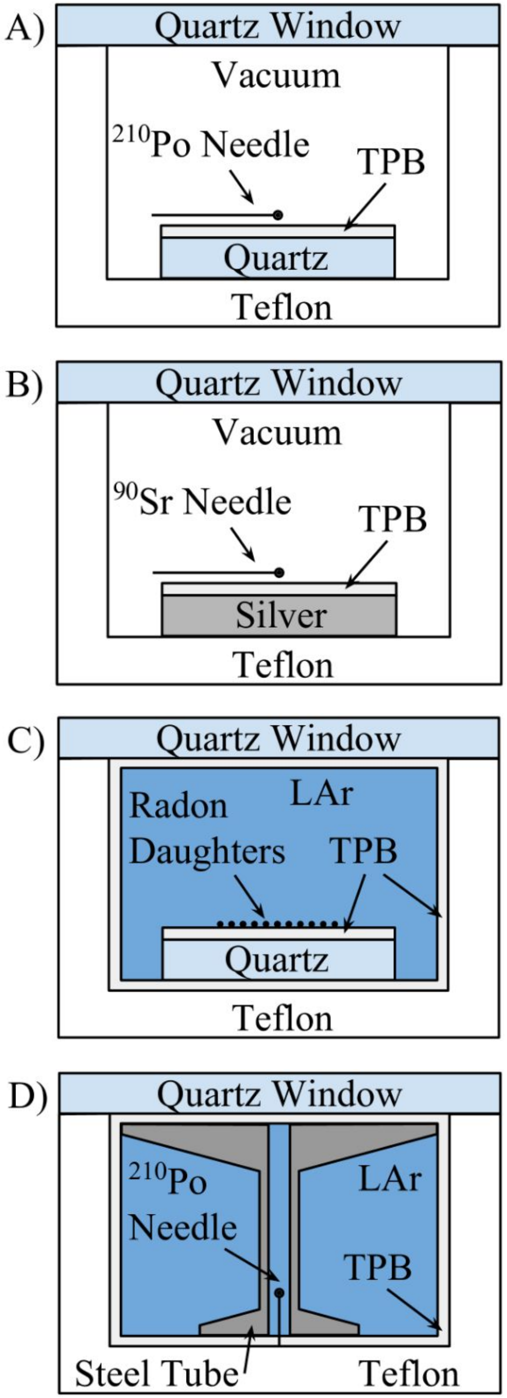
Alpha $f_{90} \approx 0.65$

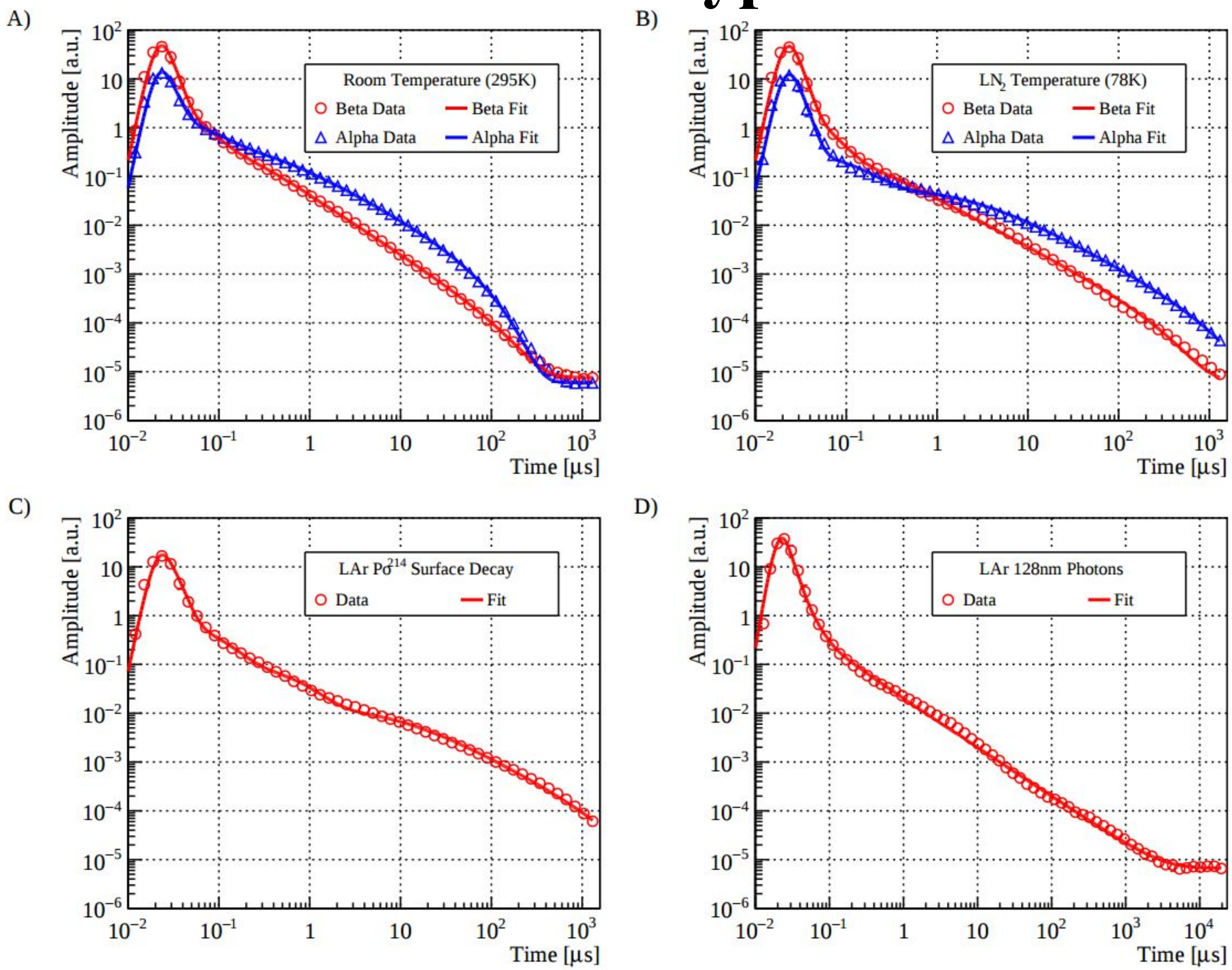


Po^{210}
"The Wall Effect"



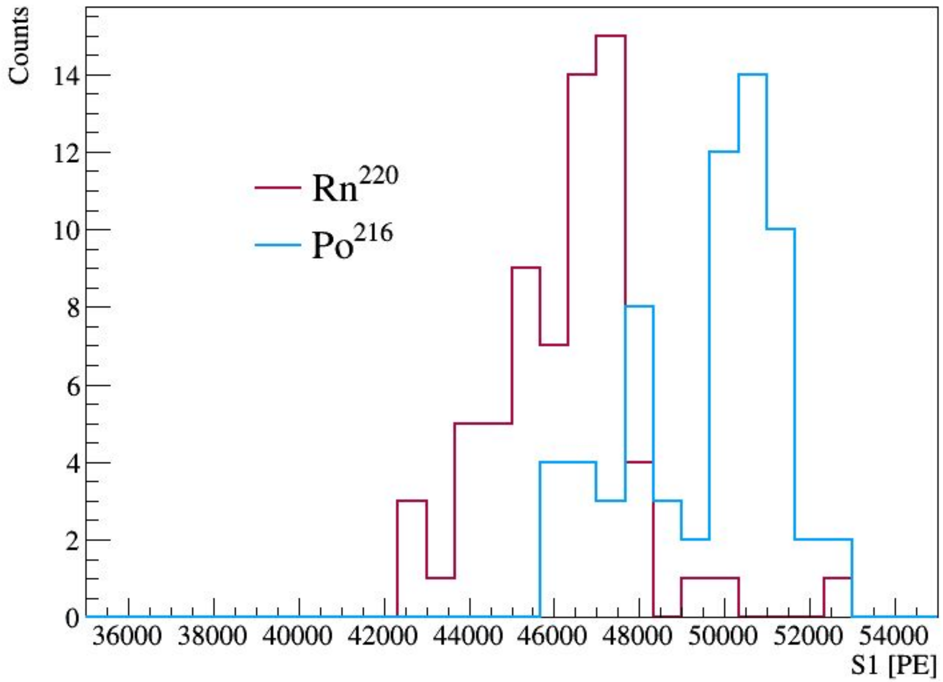
TPB Scintillation Under Different Radiation Types

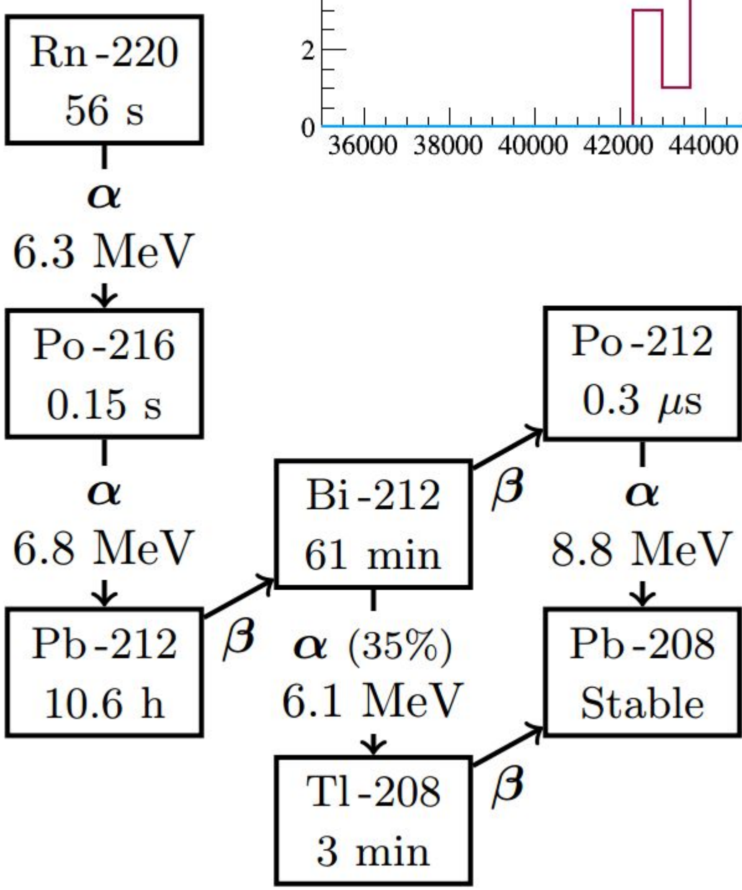


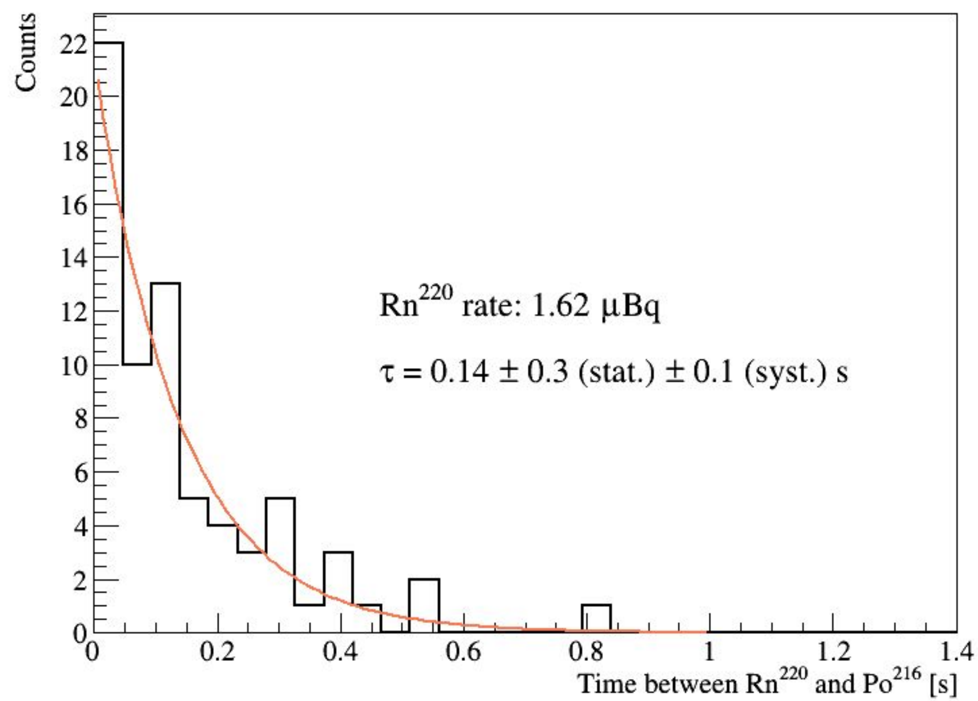


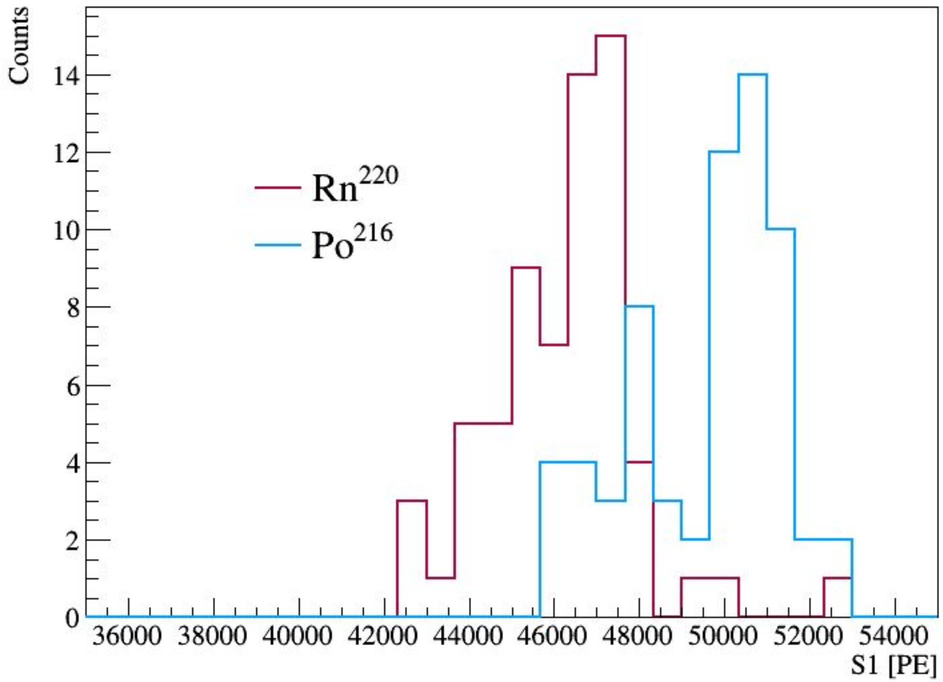
Tail Fit:

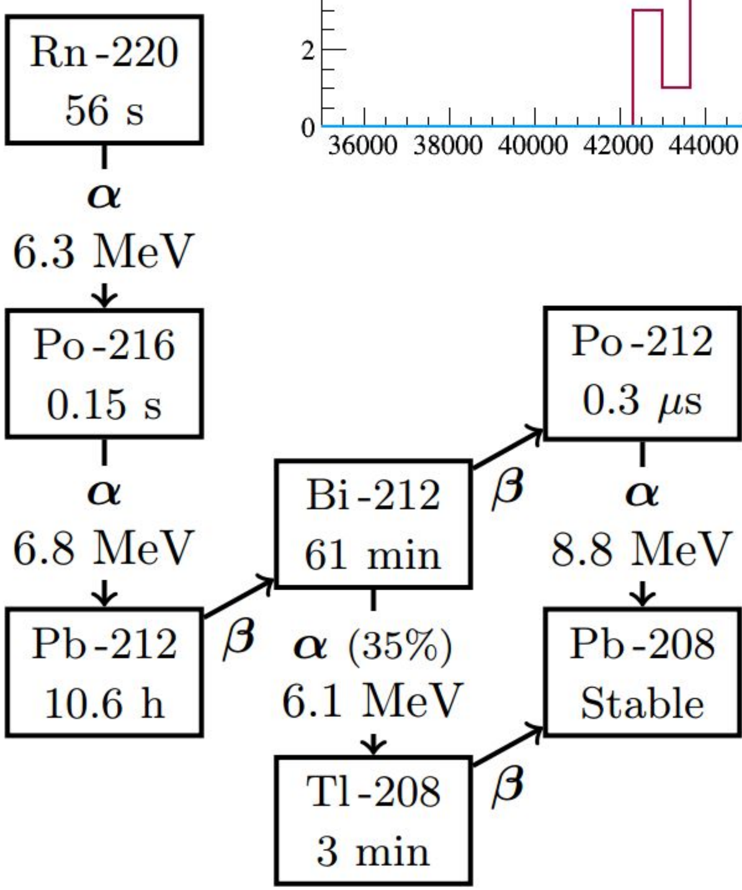
$$f(t) = \frac{k_s}{2t_b}\frac{k_{tt}}{\chi_{tt}}\frac{N_T(0)\exp(-2t/\tau_T)}{\left\{1+\frac{t_a}{2t_b}\exp(\frac{t_a}{\tau_T})\left[\mathrm{Ei}(-\frac{t+t_a}{\tau_T})-\mathrm{Ei}(-\frac{t_a}{\tau_T})\right]\right\}^2(1+t/t_a)}$$


Counts
Rn^{220}
Po^{216}
S1 [PE]


Rn-220
56 s
α
6.3 MeV
Po-216
0.15 s
α
6.8 MeV
Pb-212
10.6 h
β
Bi-212
61 min
β
α (35%)
6.1 MeV
Tl-208
3 min
β
Po-212
0.3 μs
α
8.8 MeV
Pb-208
Stable


Counts
Rn^{220} rate: 1.62 μBq
$\tau = 0.14 \pm 0.3$ (stat.) ± 0.1 (syst.) s
Time between Rn^{220} and Po^{216} [s]


Counts
14
12
10
8
6
4
2
0
Rn^{220}
Po^{216}
36000 38000 40000 42000 44000 46000 48000 50000 52000 54000
S1 [PE]


Rn-220
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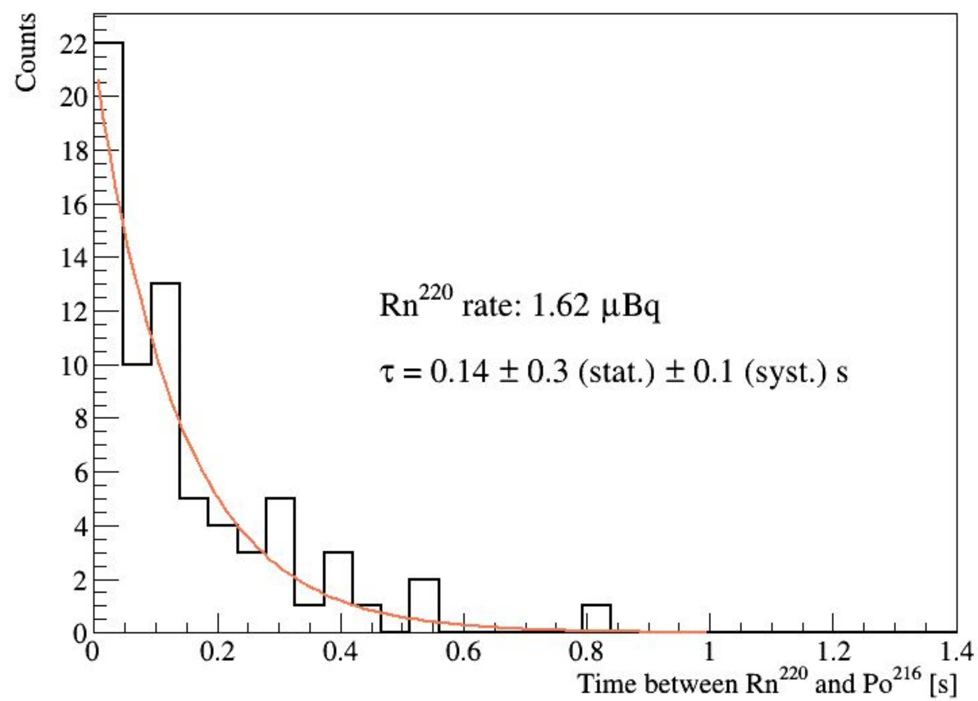
Tl-208
3 min
β
Po-212
0.3 μs
α
8.8 MeV
Pb-208
Stable


Counts
22
20
18
16
14
12
10
8
6
4
2
0
Rn^{220} rate: 1.62 μBq
τ = 0.14 ± 0.3 (stat.) ± 0.1 (syst.) s
0 0.2 0.4 0.6 0.8 1 1.2 1.4
Time between Rn^{220} and Po^{216} [s]