Ac-227 as a Calibration Source in PROSPECT

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on behalf of the PROSPECT collaboration

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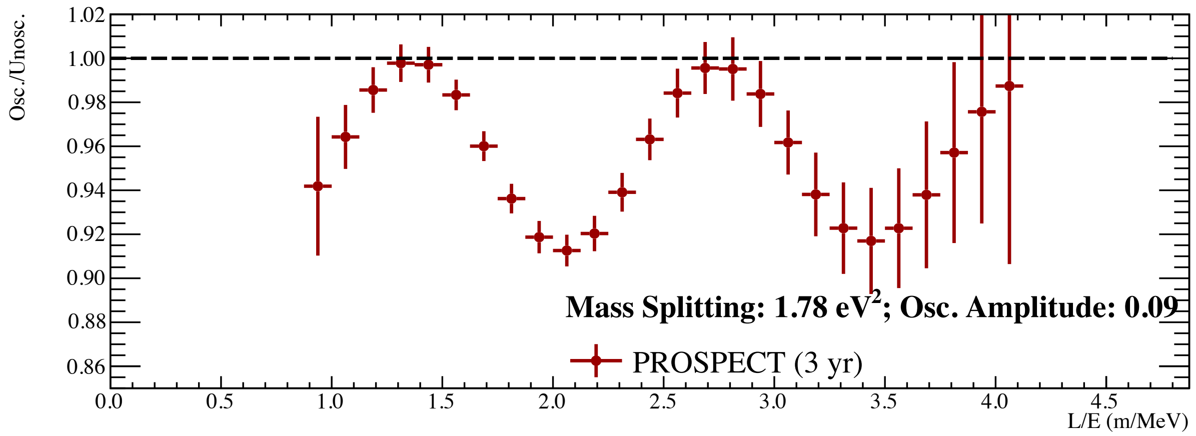
Introduction

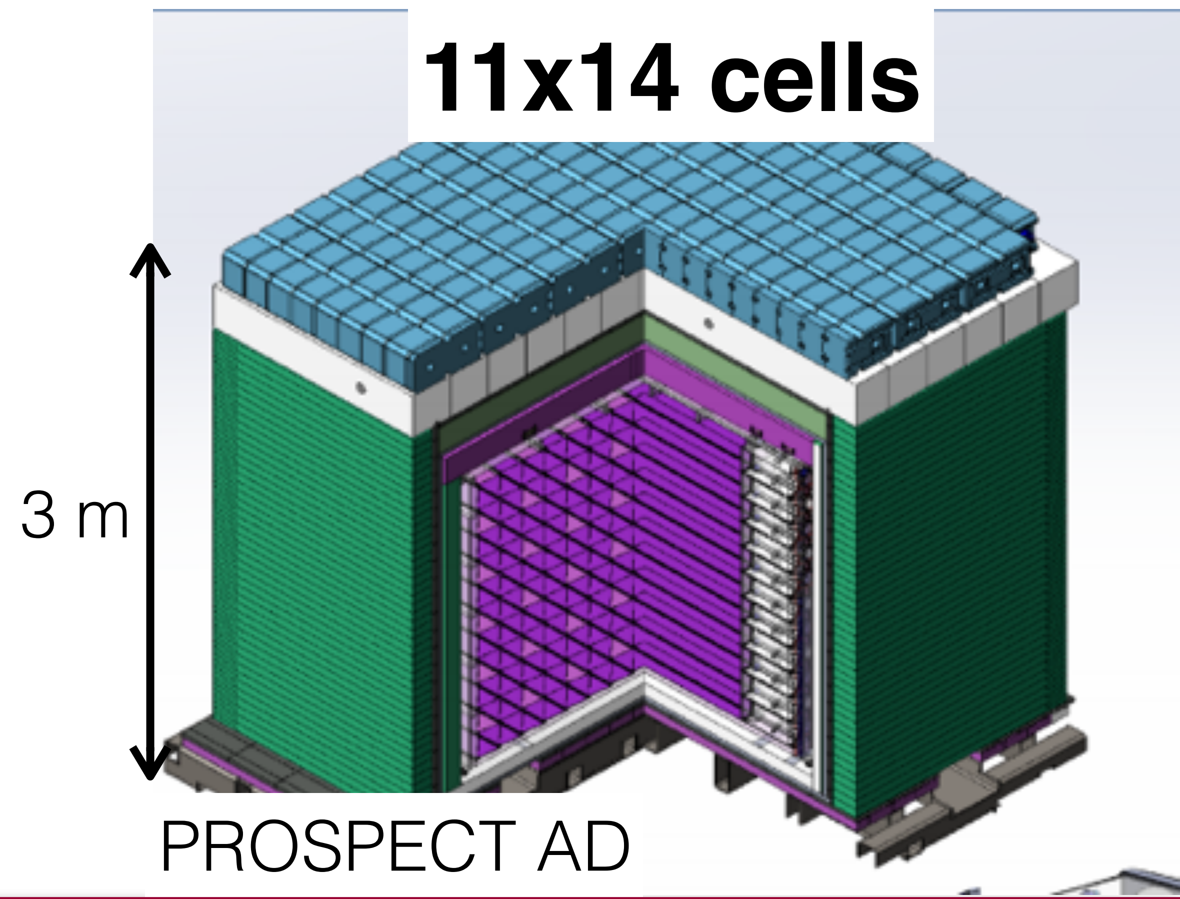
PROSPECT - The Precision Reactor Oscillation and Spectrum Experiment

See talk by P. Mumm

- Probe short baseline oscillations of antineutrinos in search of an eV-scale sterile neutrino
- Make a precise measurement of the U-235 spectrum from the High Flux Isotope Reactor at Oak Ridge National Lab



For greatest sensitivity to oscillation signature, must verify that segment-to-segment volume variation is understood to better than 1%



Measuring the Relative Volumes of 154 Cells

Want to

- Dissolve a source in the Li-6 loaded liquid scintillator (LiLS)
- Measure the rate of the source in each cell over the lifetime of the detector
- Using measured rates, define the relative cell-to-cell volume to 1% or better over a year

Need a source that

- Will be uniformly distributed - no adsorption or sinking
- Not degrade the scintillator
- Will not introduce significant background to our IBD (inverse beta decay) signal

Why Ac-227?

- α, α coincidence in the decay chain: ${}^{219}Rn \rightarrow {}^{215}Po \rightarrow {}^{211}Pb$
- Half-life of Po-215 is small - 1.78 ms -> low accidental rate
- Decay of Po-215 is mono-energetic with quenched energy, ~0.85 MeVee, distinct from neutron capture peak, 0.5 - 0.6 MeVee
- Alpha mean free path is a few microns, creating a highly localized signal contained in a single cell

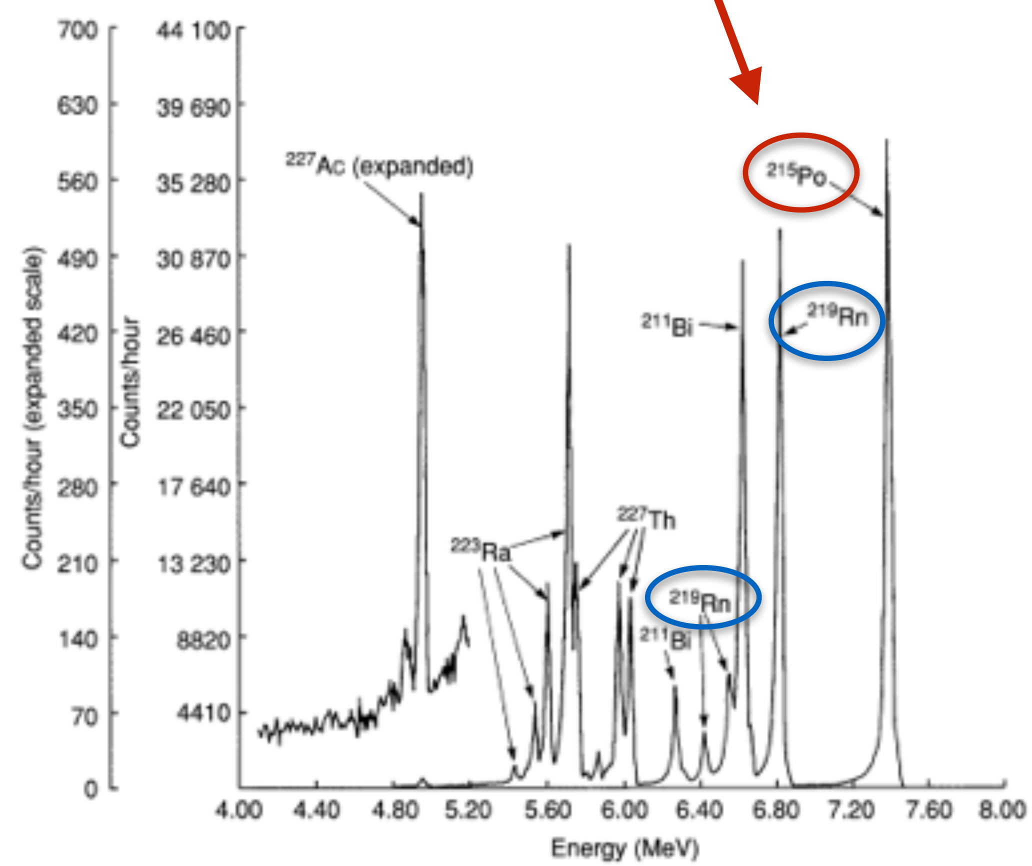
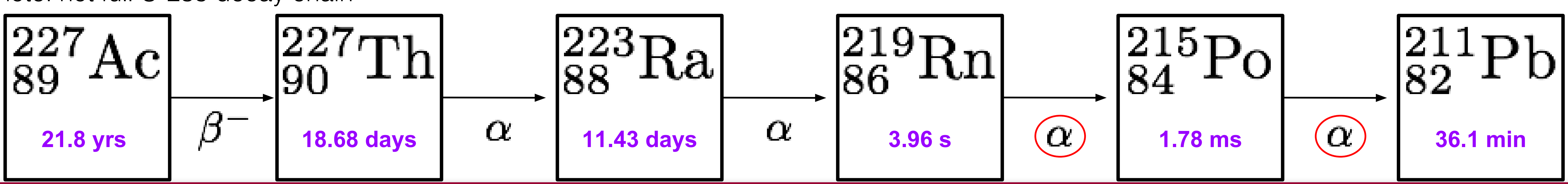


Fig. 2.4 *Alpha spectrum of ^{227}Ac in equilibrium with its decay products (Kirby, 1970).*

Therefore we can

- Use a low activity - 1.8 Bq in AD
- Use alpha coincidence (RnPo's) to calculate the rate per cell

note: not full U-235 decay chain



Testing for Adsorption

2/27/17: Dispensed Ac-227 into 12 mL vials of LiLS at BNL at ~94 Bq per vial

S2 - Reference

S3 - UVT acrylic

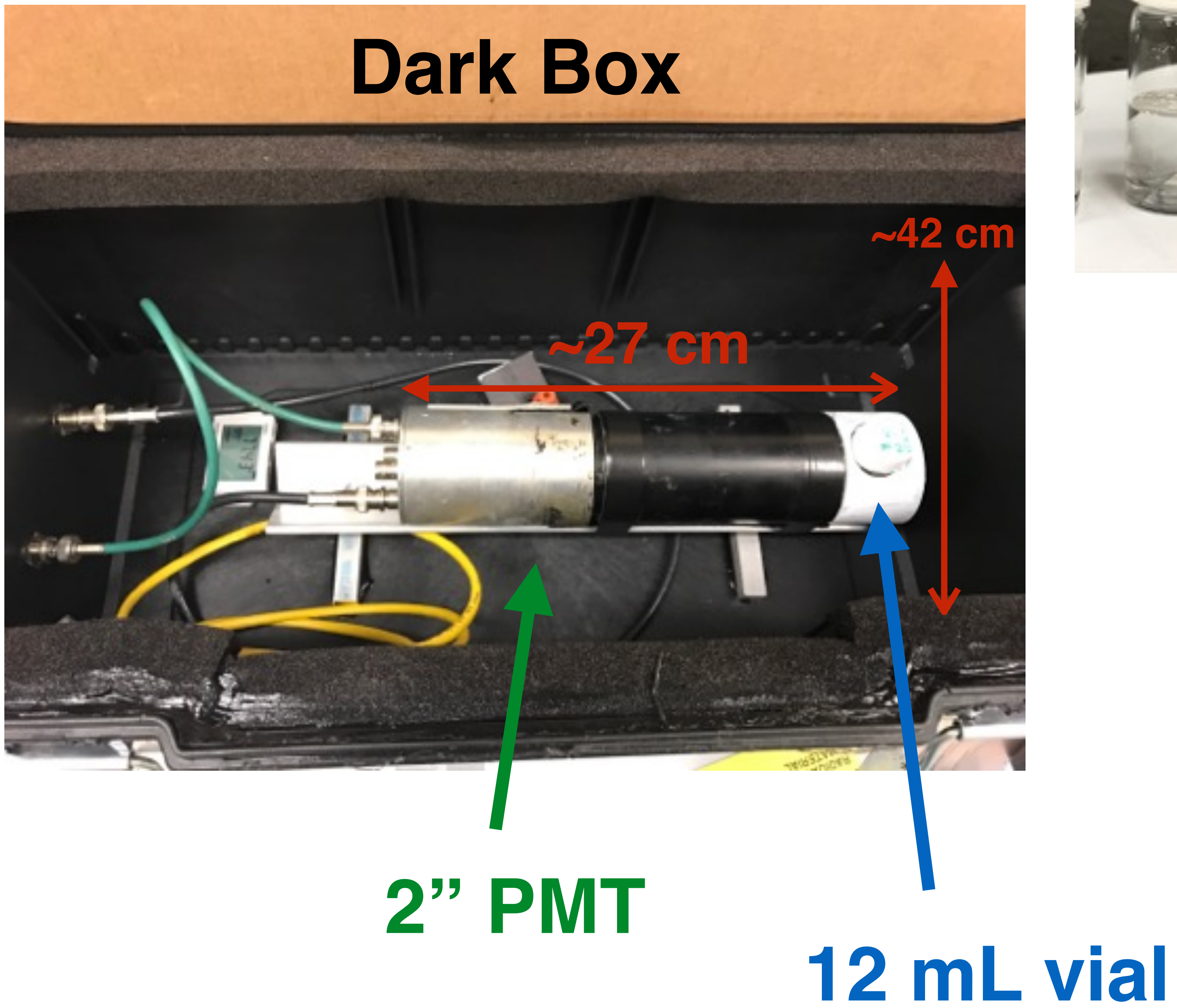
S4 - FEP (flourinated ethylene propylene)

S5 - PLA (polylactide)

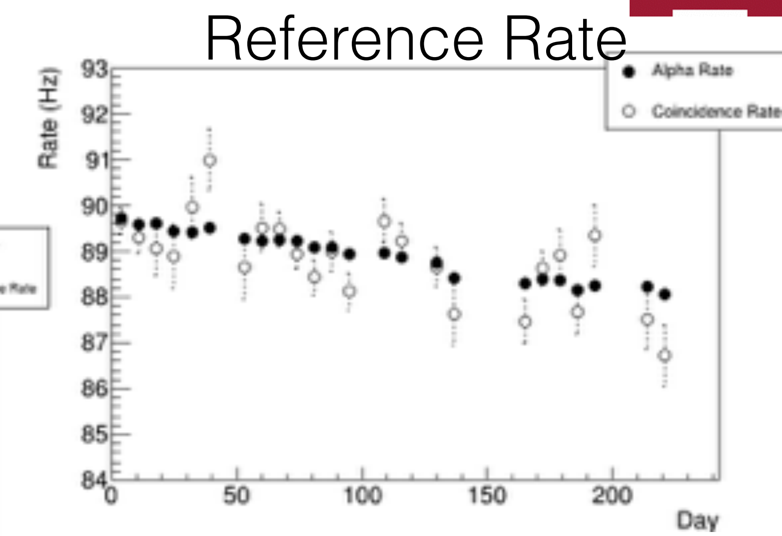
S6 - PEEK nut (polyether ether ketone)

S7 - RG188 cable

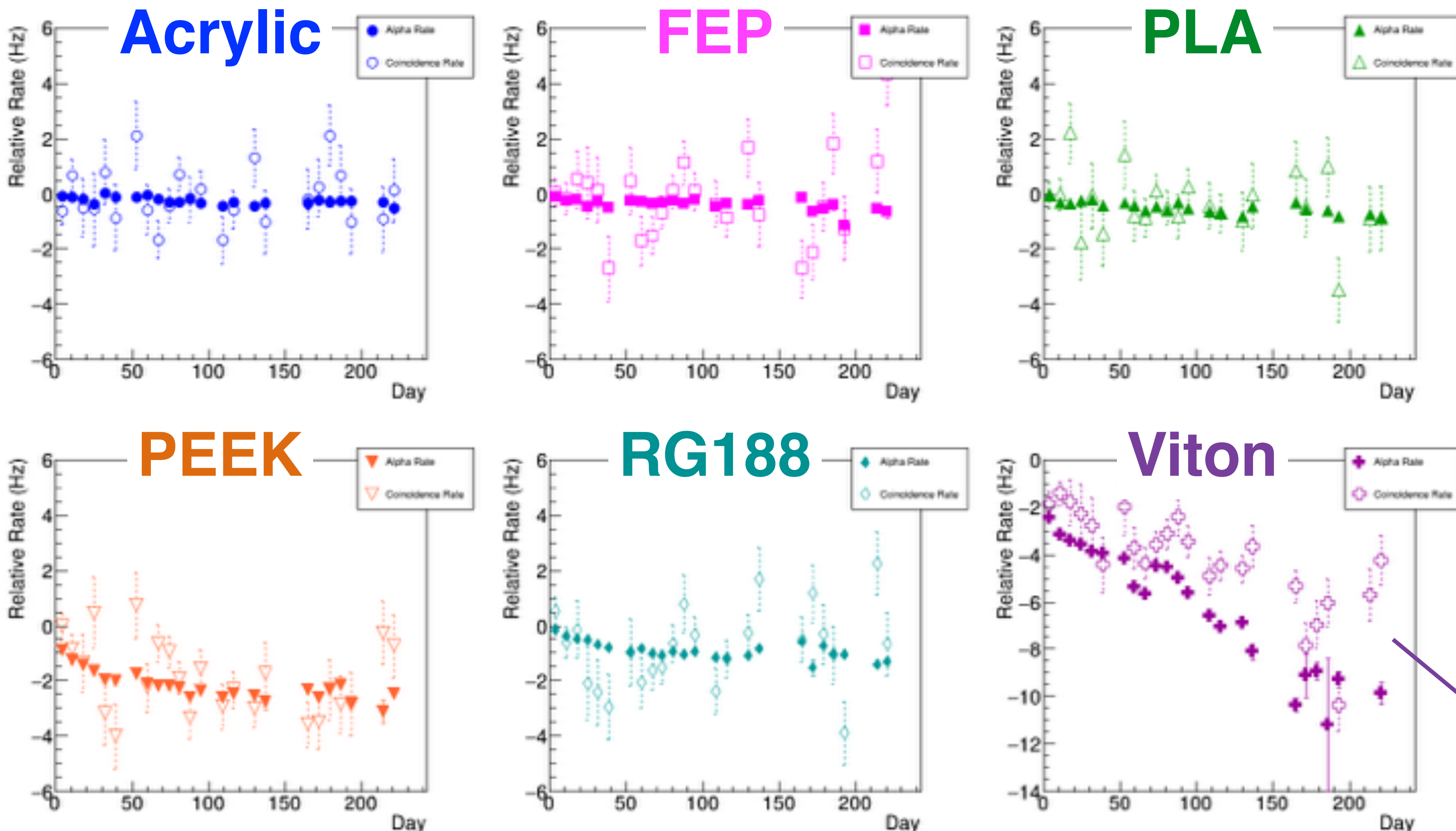
S8 - Viton o-ring



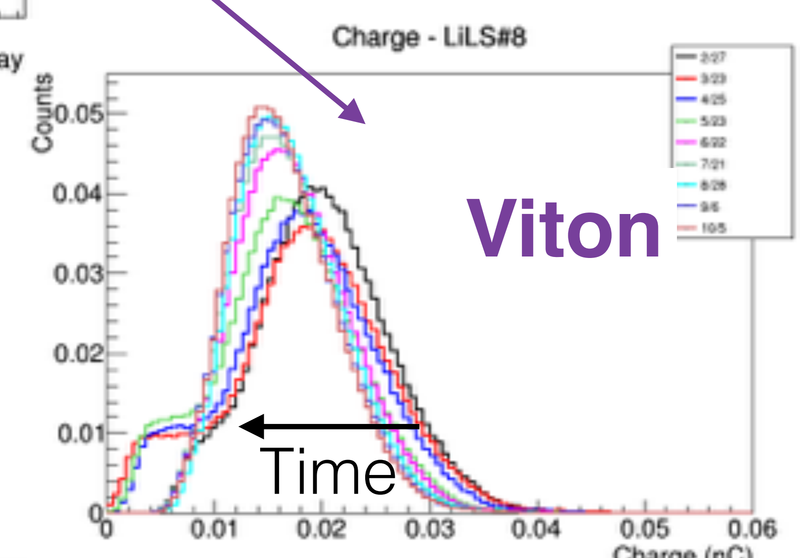
Results of Tests for Adsorption



Material - Reference Rate



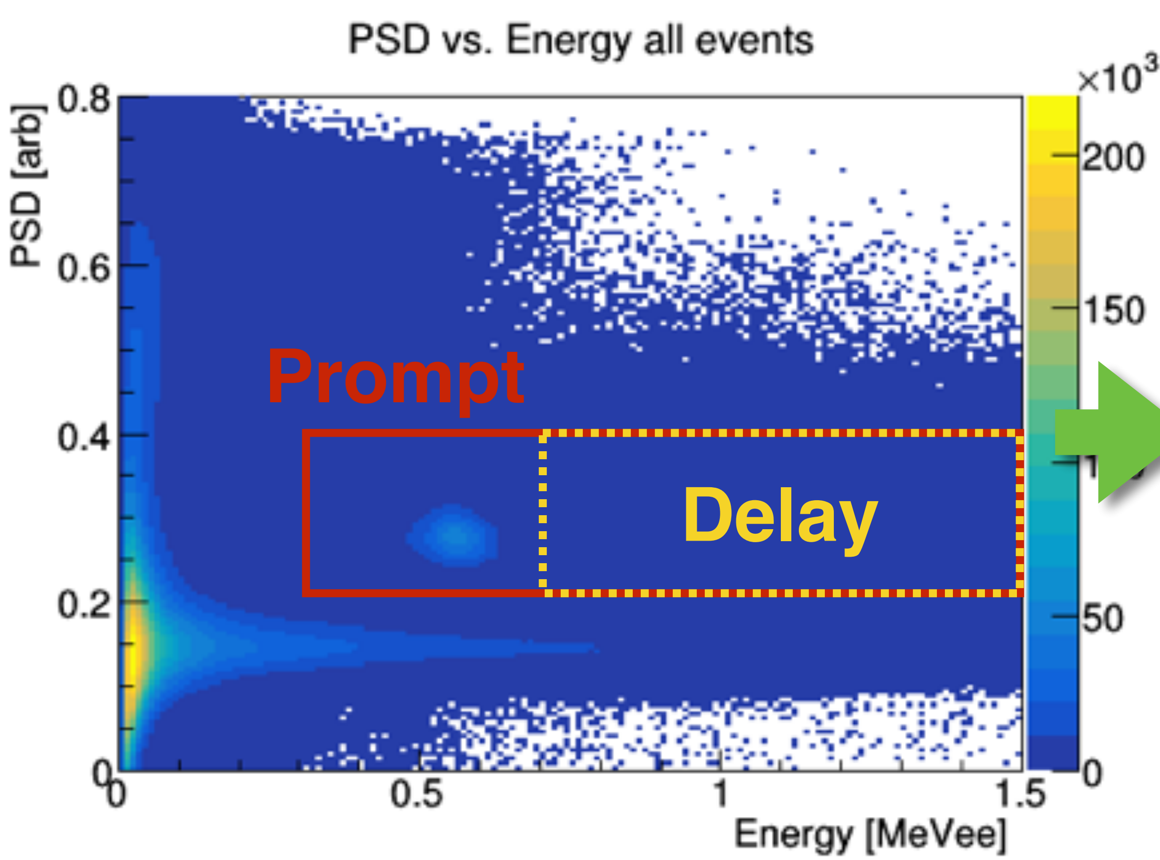
Shift in energy creating threshold effects - losing some alphas. At present not believed to be adsorption.



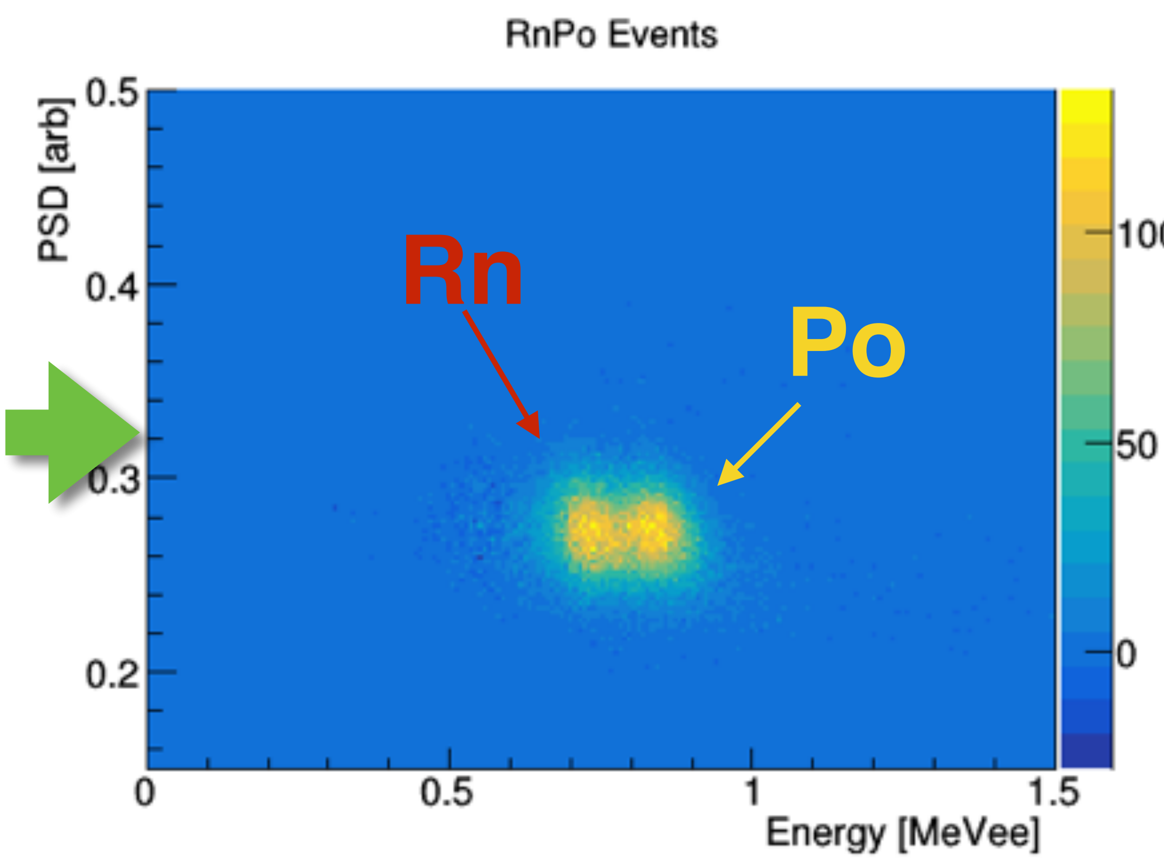
No significant signs of adsorption

Prototype Test

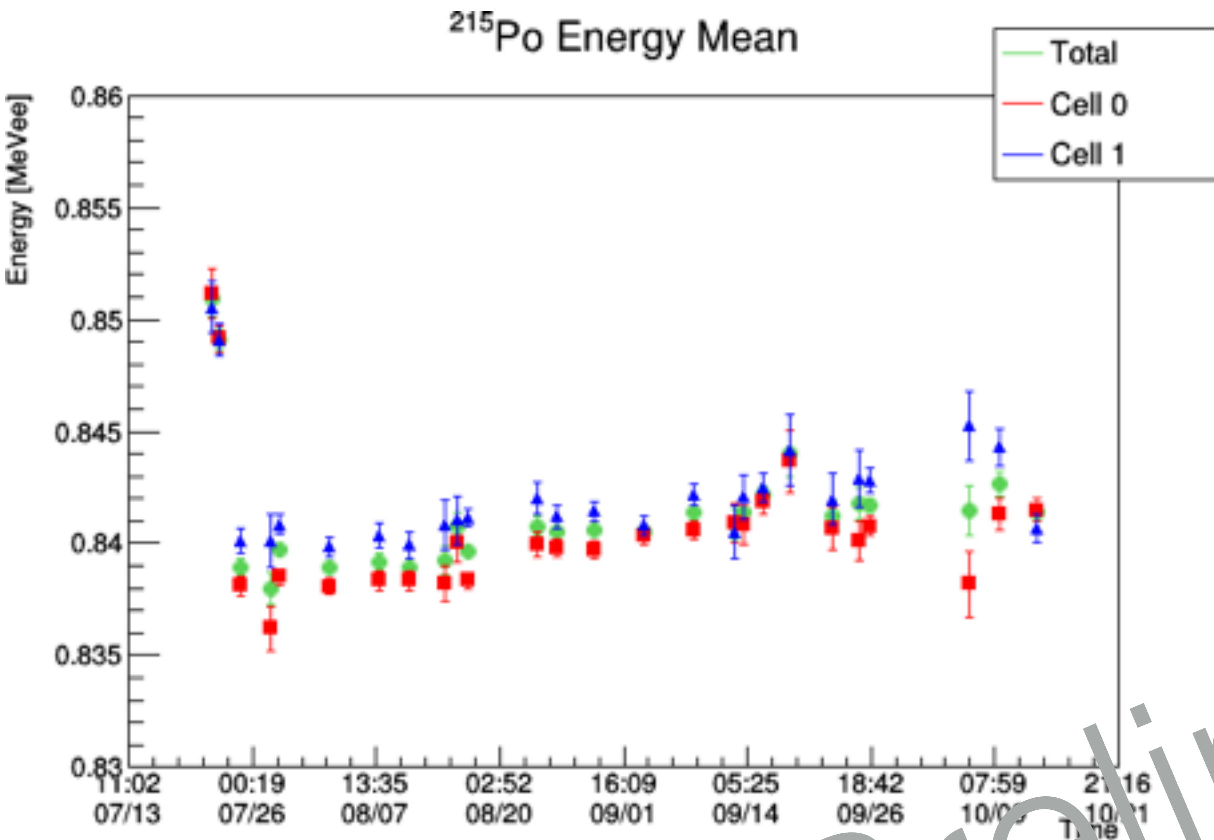
2 cell prototype detector at Yale University
Loaded the Li-6 scintillator with Ac-227

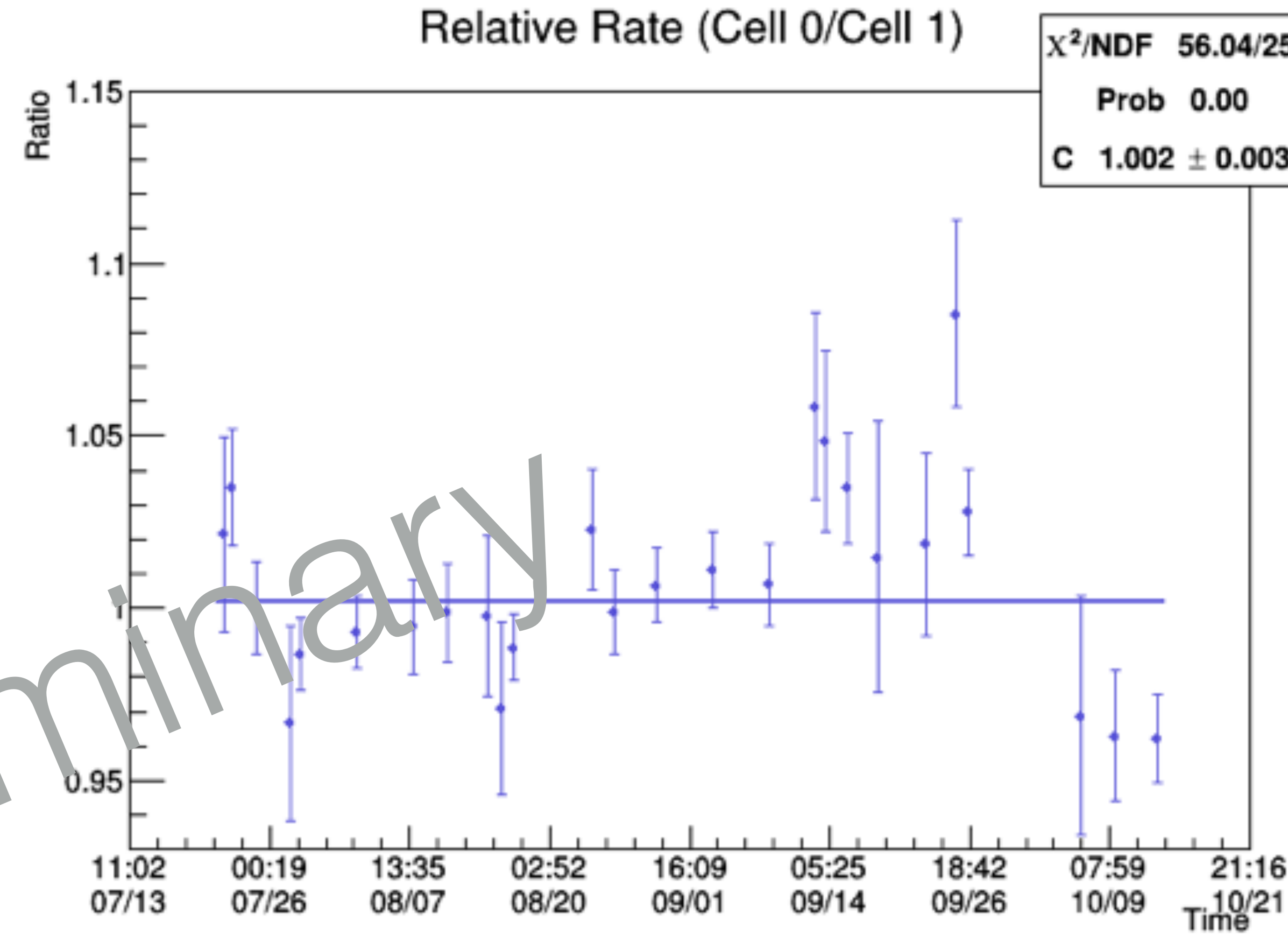


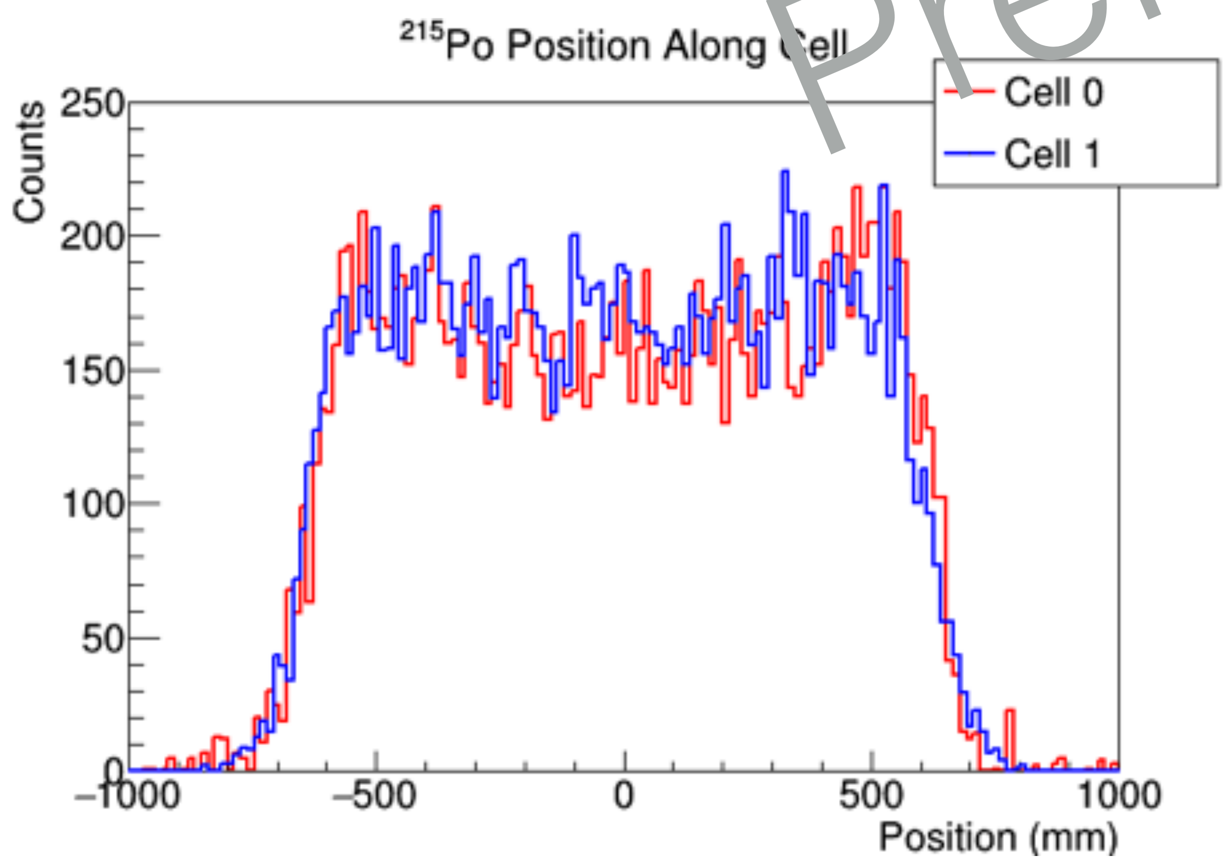
Cuts on:
Energy
PSD
Position
Time



Prototype Test







- Useful for energy and position calibration
- See no degradation of the LiLS from Ac-227 spiking
- See no significant increase in background near neutron capture signal
- Initial calculations for AD estimate background from (alpha, n) to be < 7.5/day compared to 900/day IBD events

Summary

- Placing Ac-227 in the PROSPECT detector will allow us to measure the relative cell-to-cell volume to 1% or better
- Can use Ac-227 to calibrate energy and position
- See no significant signs of adsorption
- Have mitigated risks to the liquid scintillator
- Proof of concept through adsorption and prototype tests
- Use of Ac-227 in AD still being evaluated

Placing Ac-227 in the PROSPECT AD is a low risk way to measure relative volume variation throughout the detector

PROSPECT Collaboration

BROOKHAVEN NATIONAL LABORATORY

NIST

Lawrence Livermore National Laboratory

OAK RIDGE National Laboratory

Drexel

W&M

Yale

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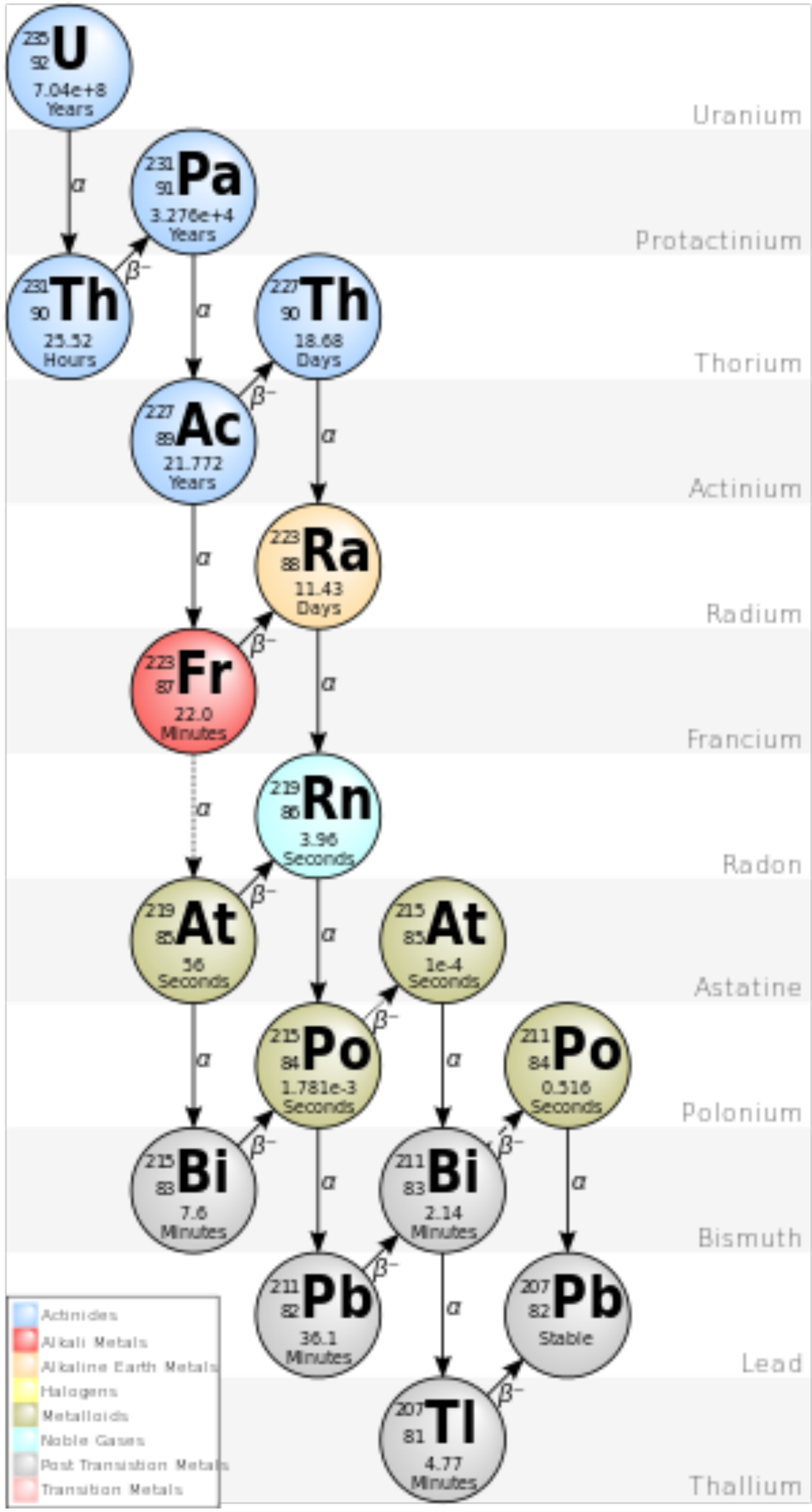
prospect.yale.edu

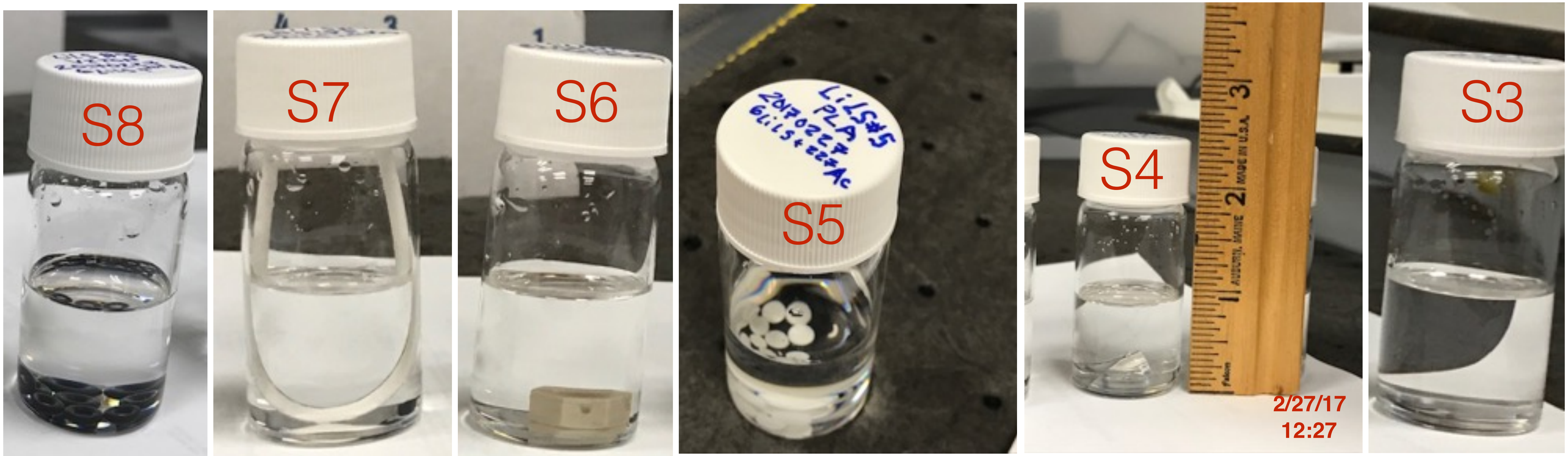
Publications:
arXiv:1309.7647,
NIM A806 (2016) 401,
JINST 10 (2015) P11004,
Journal of Phys. G 43 (2016) 11

Backup

U-235 Decay Chain



Materials Tested for Adsorption



S2 - Reference

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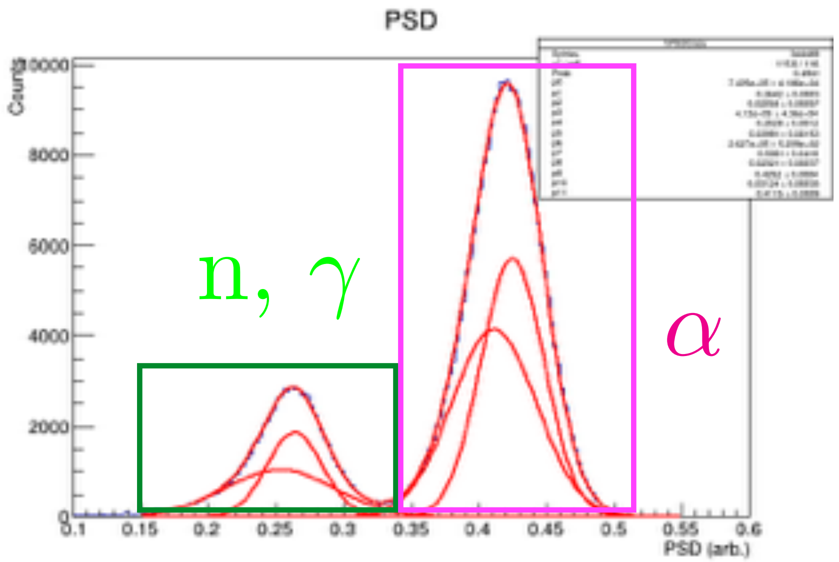
S8 - Viton o-ring

Adsorption Testing - Calculating Rate

- Alpha Rate
  - Fit PSD distribution with four gaussians

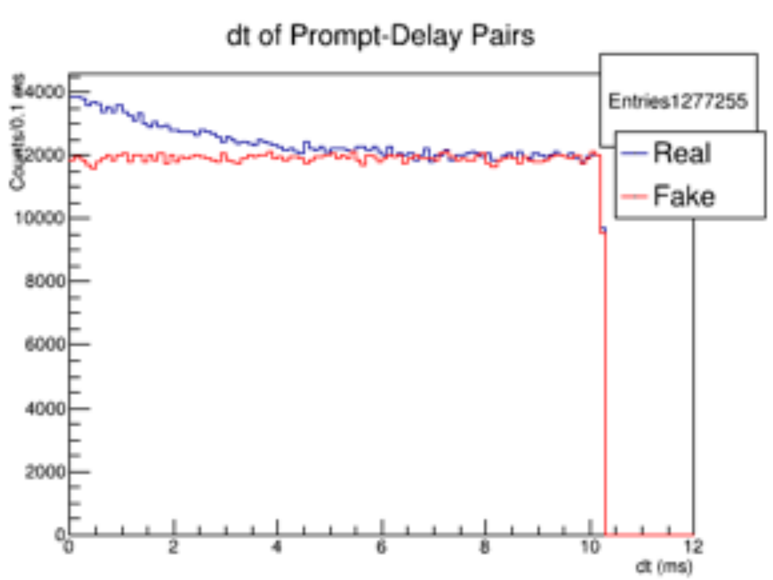


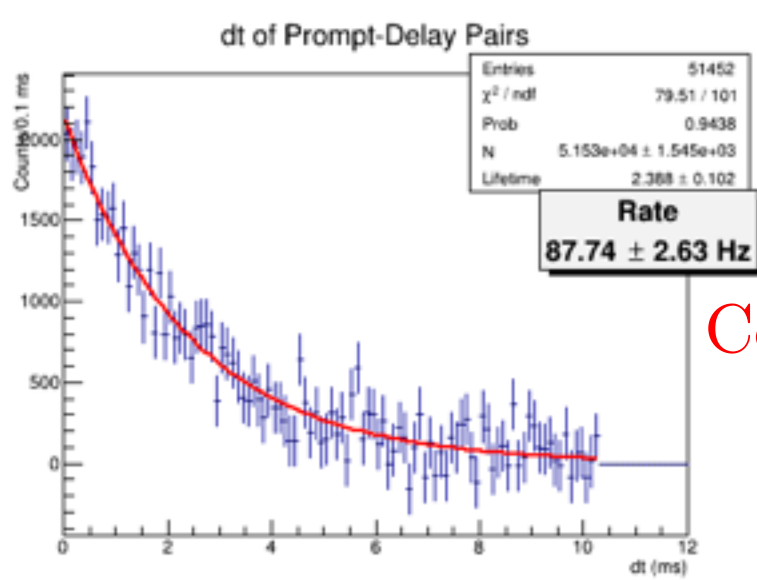
$$f(x) = \left\{ C_1 e^{-\frac{1}{2}\left(\frac{x-\mu_1}{\sigma_1}\right)^2} + C_2 e^{-\frac{1}{2}\left(\frac{x-\mu_2}{\sigma_2}\right)^2} + N\left[\frac{f}{\sqrt{2\pi\sigma_3^2}} e^{-\frac{1}{2}\left(\frac{x-\mu_3}{\sigma_3}\right)^2} + \frac{1-f}{\sqrt{2\pi\sigma_4^2}} e^{-\frac{1}{2}\left(\frac{x-\mu_4}{\sigma_4}\right)^2} \right] \right\} * bin-width$$

Number of alphas

$$\text{Alpha rate} = \frac{N}{livetime*5}$$

- Coincidence Rate
  - Find dt between prompt-delay and prompt-fake delay events
  - Subtract and fit with exponential $N(t) = Ne^{t/\tau}$

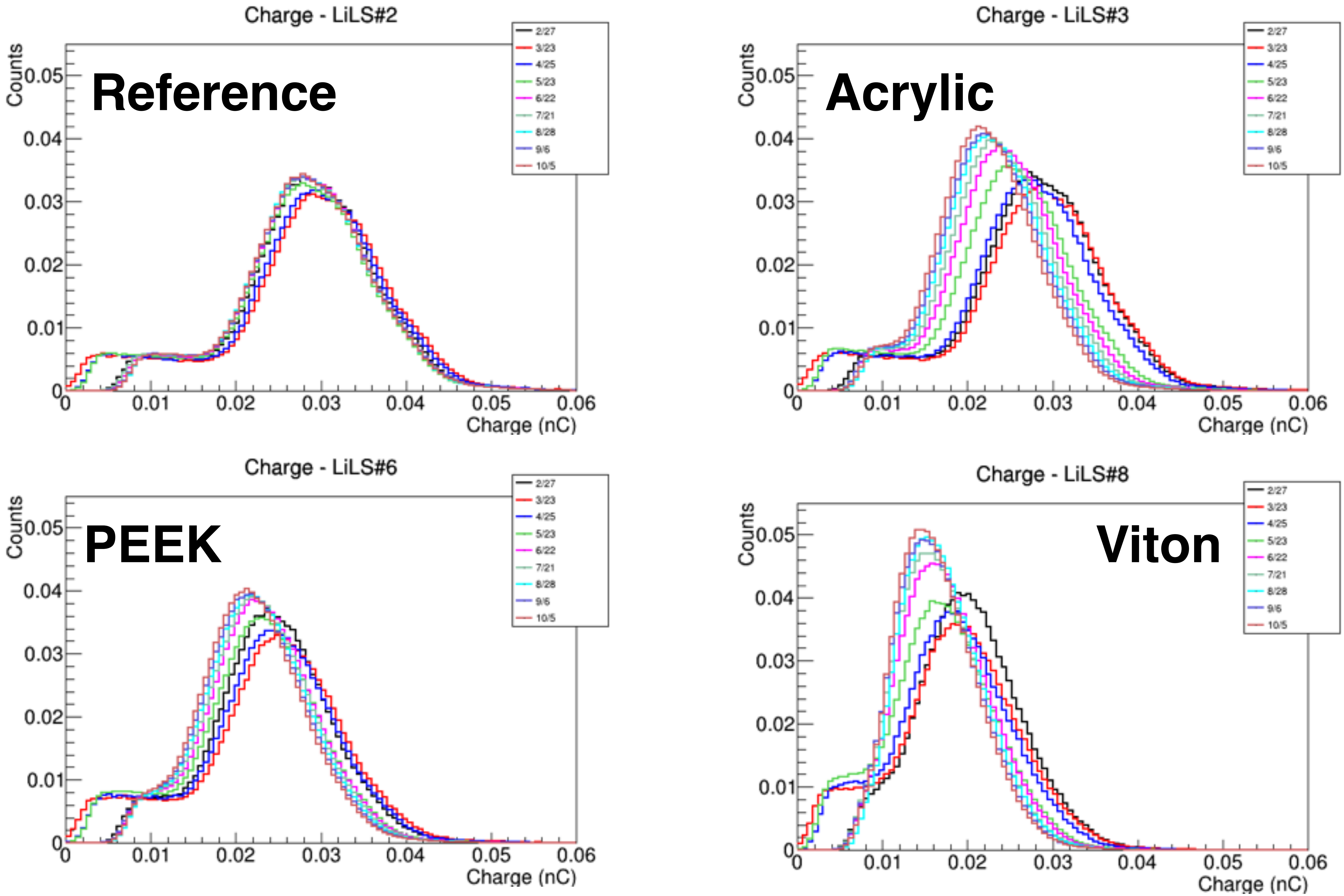




$$\text{Coincidence rate} = \frac{N}{livetime*efficiency}$$

from energy & PSD cuts

Adsorption Tests - Energy Shift



Ac-227 in P50X

- May 26, 2017 - spiked LiLS prepared for P50X at BNL
  - Concentration: **1.77 +/- 0.09 mBq/g**
  - Origin vial, LiLS#9, left at BNL for observation
    - Measured activity: **3.395 +/- 0.010 Bq**
- June 20, 2017 - spiked LiLS shipped to Yale
- July 21, 2017 - spiked LiLS added to barrel of LiLS and P50X filled
  - Expected activity per cell: **90.66 +/- 4.48 mBq**

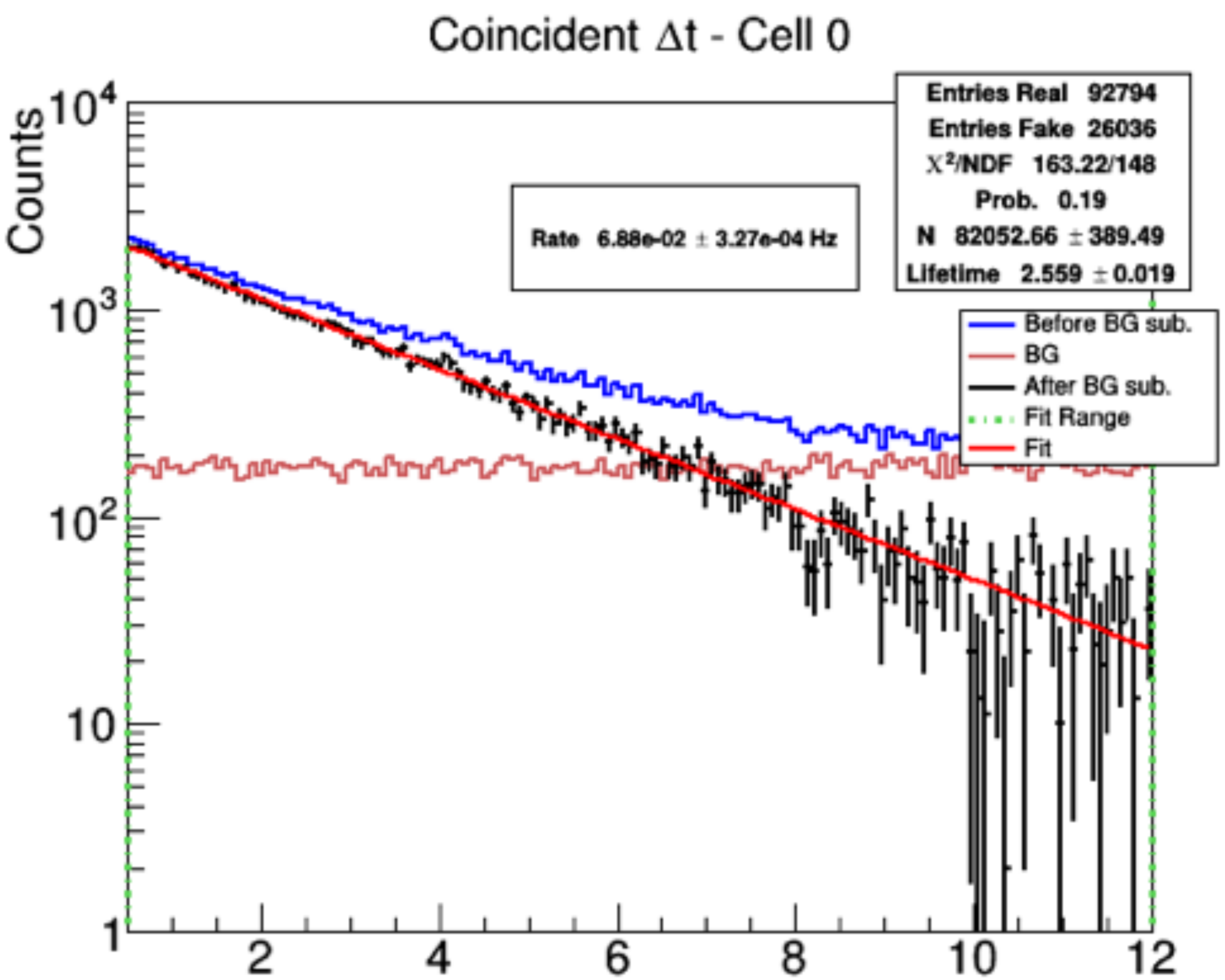
- See docdb-1897 for David's calculations

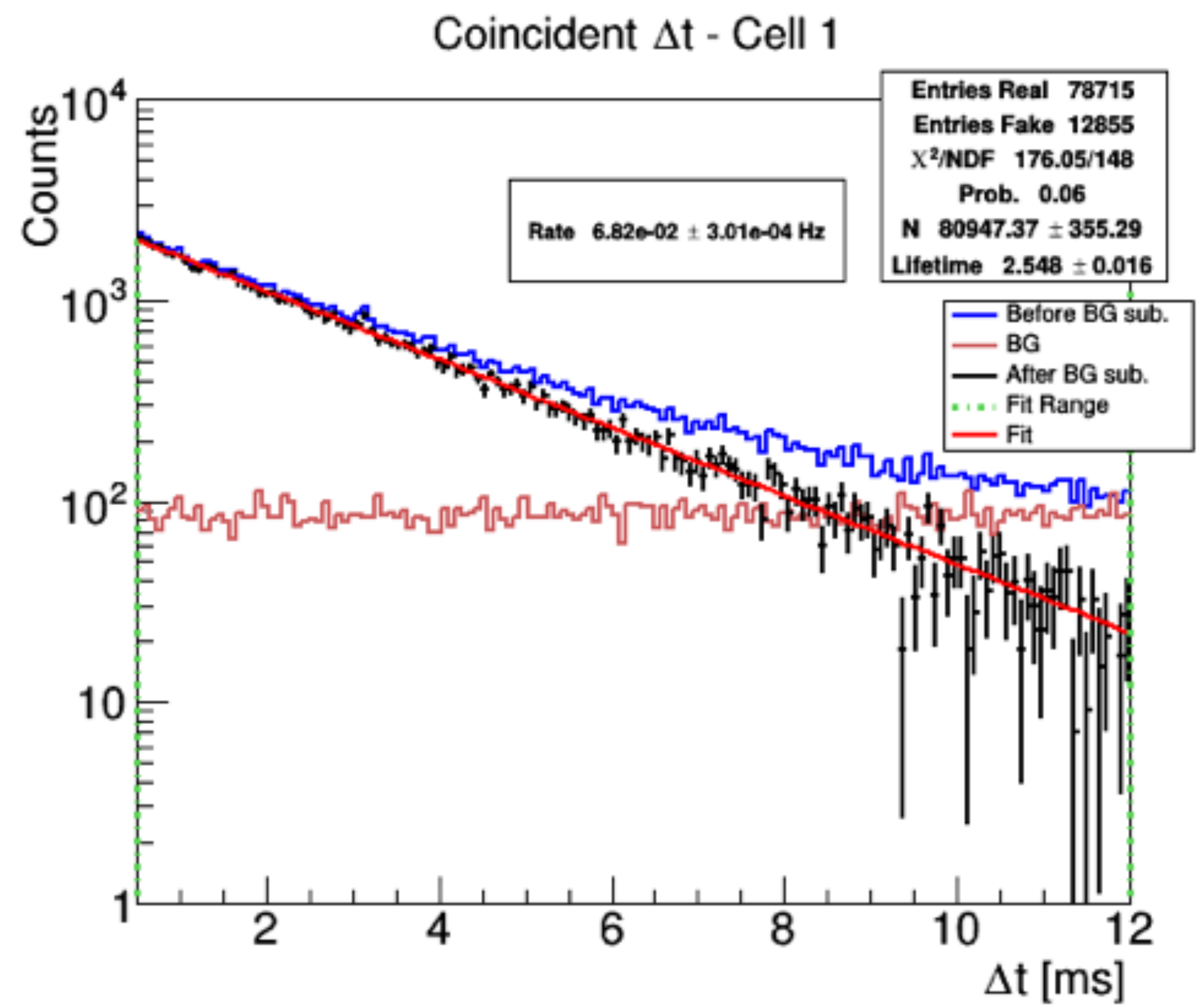
Ac-227 in P50X - Coincidence dt

$$f(t) = Ne^{-t/T}\frac{binwidth}{T}$$

T = 2.57 ms,
lifetime of Po-215

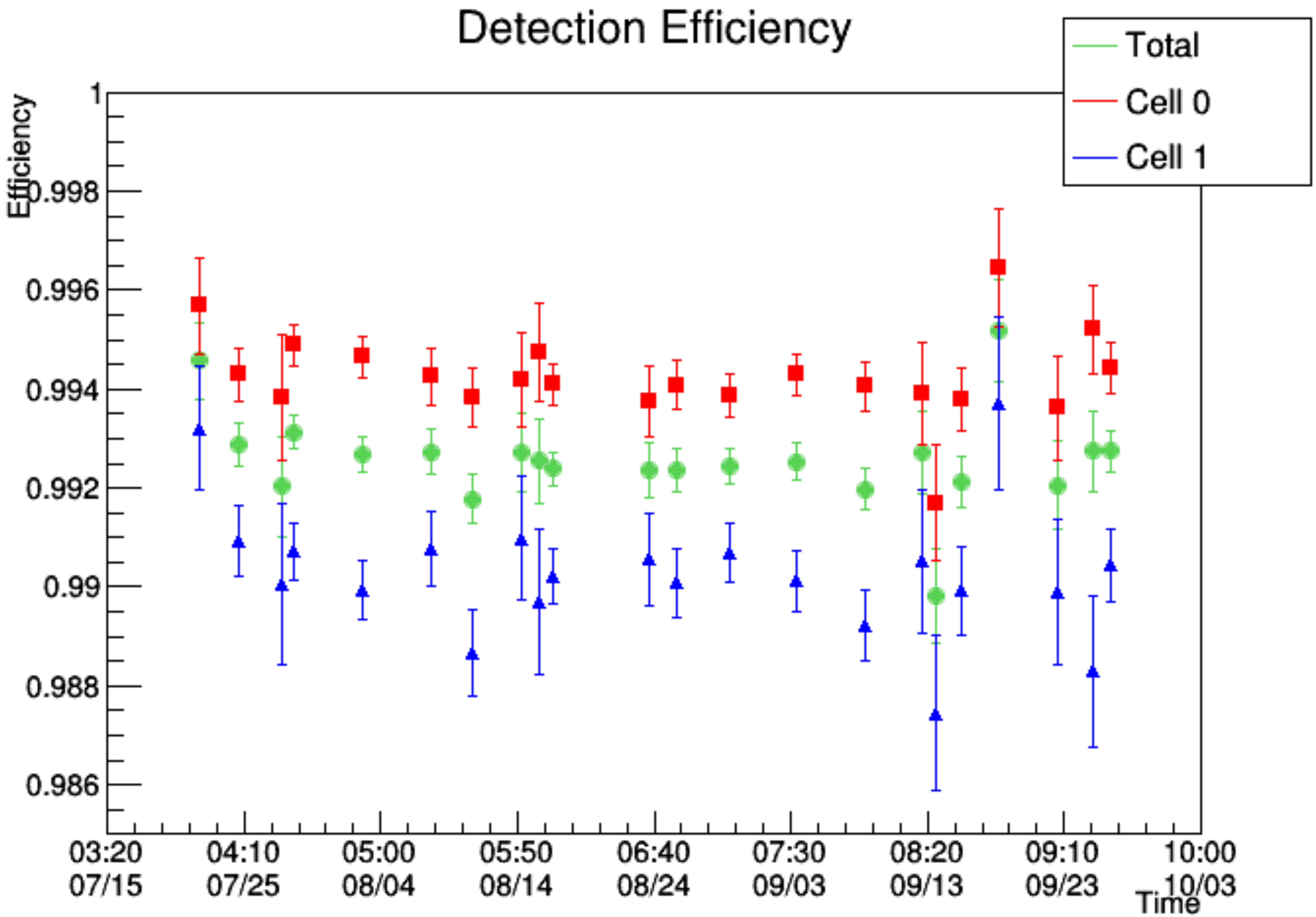
$$rate = \frac{N}{livetime*efficiency}$$





Series 030
339 hours

Ac-227 in P50X - Efficiency



- Efficiencies: PSD cut on prompt and delay, energy cut on delay, and position cut