Understanding Alpha Background in DEAP-3600

Carl Rethmeier

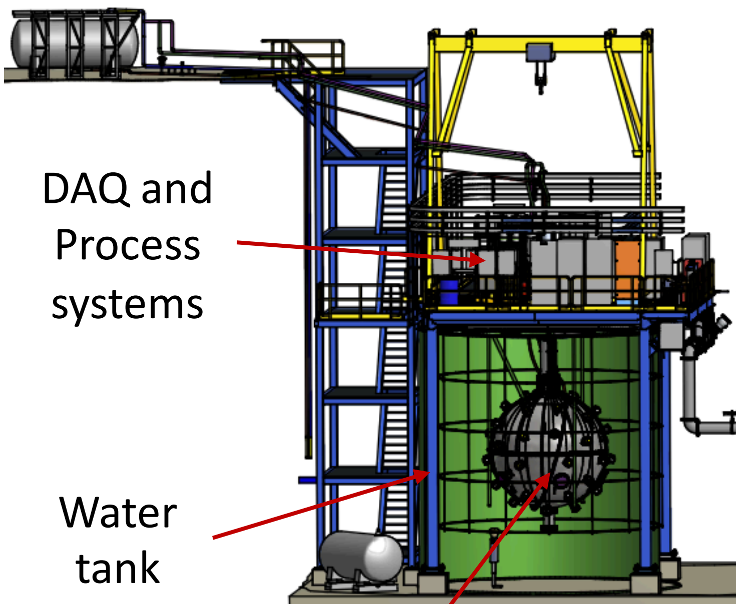
2019 CAP Congress

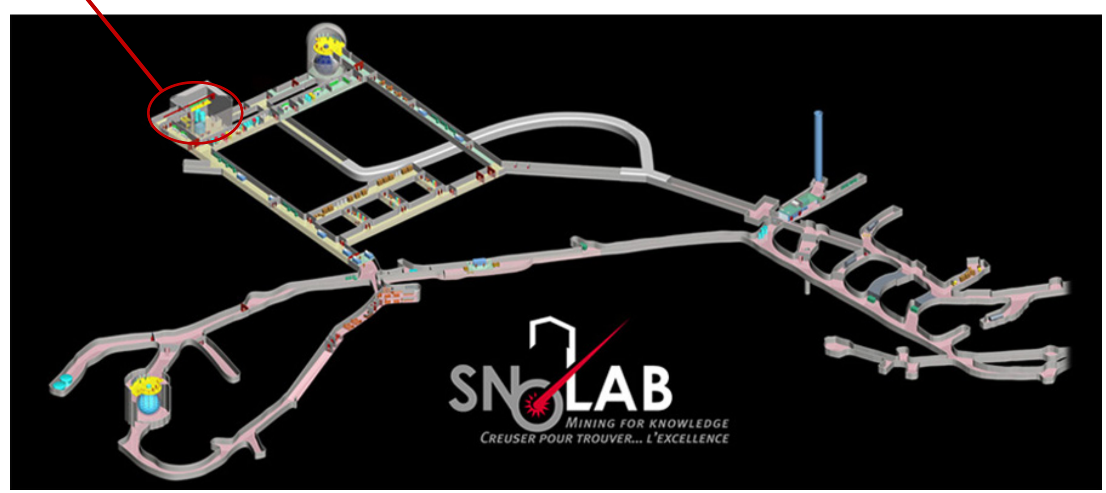
DEAP-3600 Collaboration

UNIVERSITY OF ALBERTA
Canadian Nuclear Laboratories
Laboratoires Nucléaires Canadiens
Carleton UNIVERSITY
GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
INFN
Istituto Nazionale di Fisica Nucleare
NATIONAL RESEARCH CENTER "KURCHATOV INSTITUTE"
LaurentianUniversity
UniversitéLaurentienne
Instituto de Física
PRINCETON UNIVERSITY
Queen's UNIVERSITY
ROYAL HOLLOWAY UNIVERSITY OF LONDON
Particle Physics
Rutherford Appleton Laboratory
SNOLAB
US University of Sussex
Technical University of Munich
TRIUMF

DEAP-3600

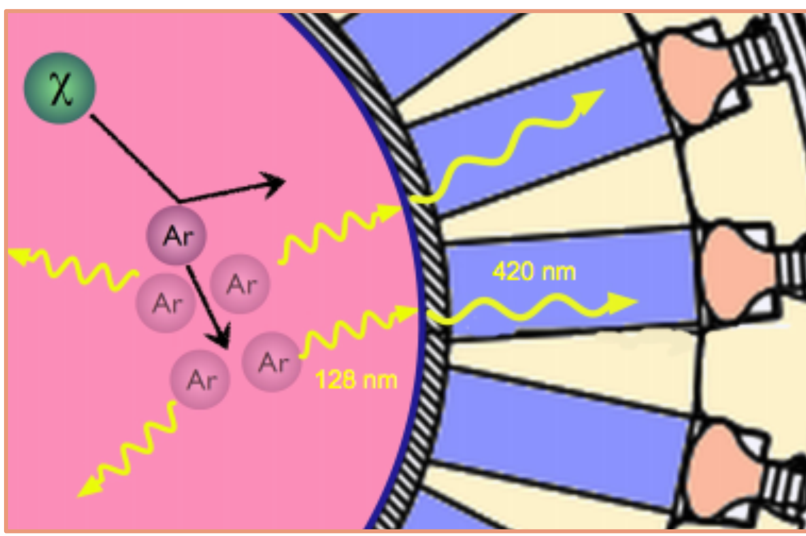
- Main goal is to search for WIMP (Weakly Interacting Massive Particle) dark matter
- Located 2 km underground at SNOLAB
    - Overhead rock blocks solar and cosmic backgrounds
- Detector is a spherical acrylic vessel filled with 3.3 tonnes of liquid argon (LAr)
- Acrylic vessel encased within steel shell and placed in a water tank

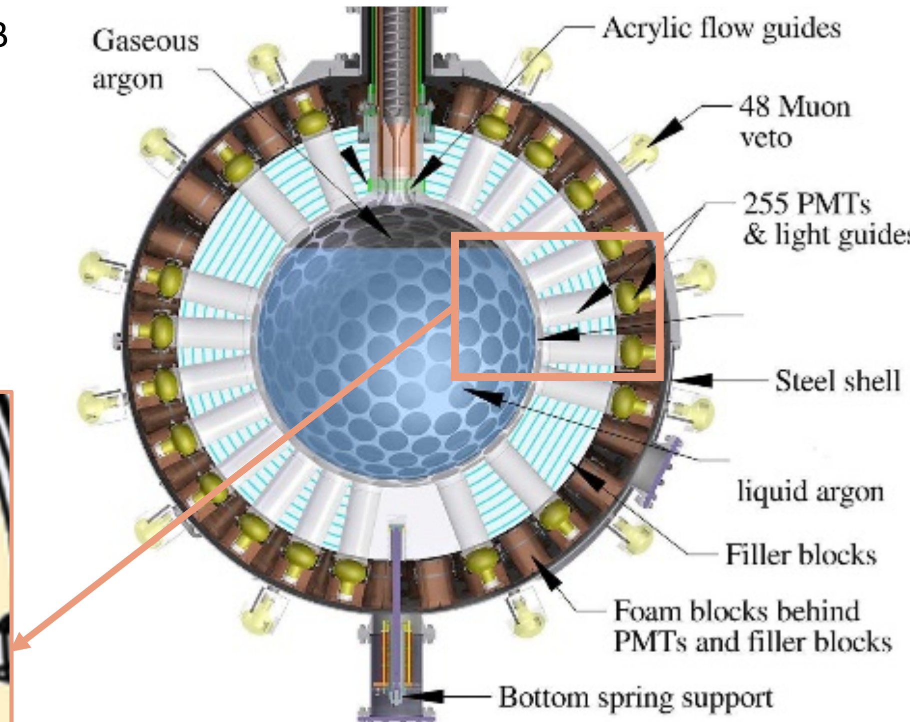




How We See the Signal

- WIMP scatters off argon atom
- Recoil produces UV scintillation light
- UV light is converted to visible when it hits TPB on detector surface
- Visible light can pass through acrylic and enter PMTs
- Light produces Photo-Electron (PE) in PMT
- PE triggers an avalanche of charge, which is proportional to total light entering PMT

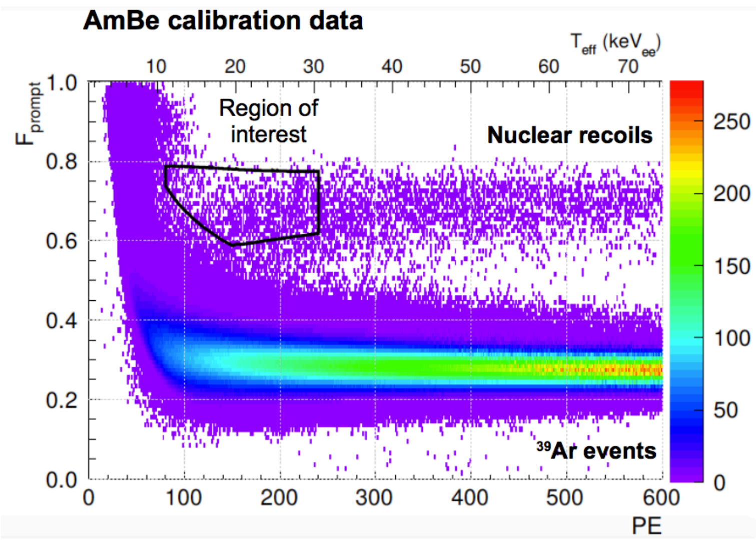




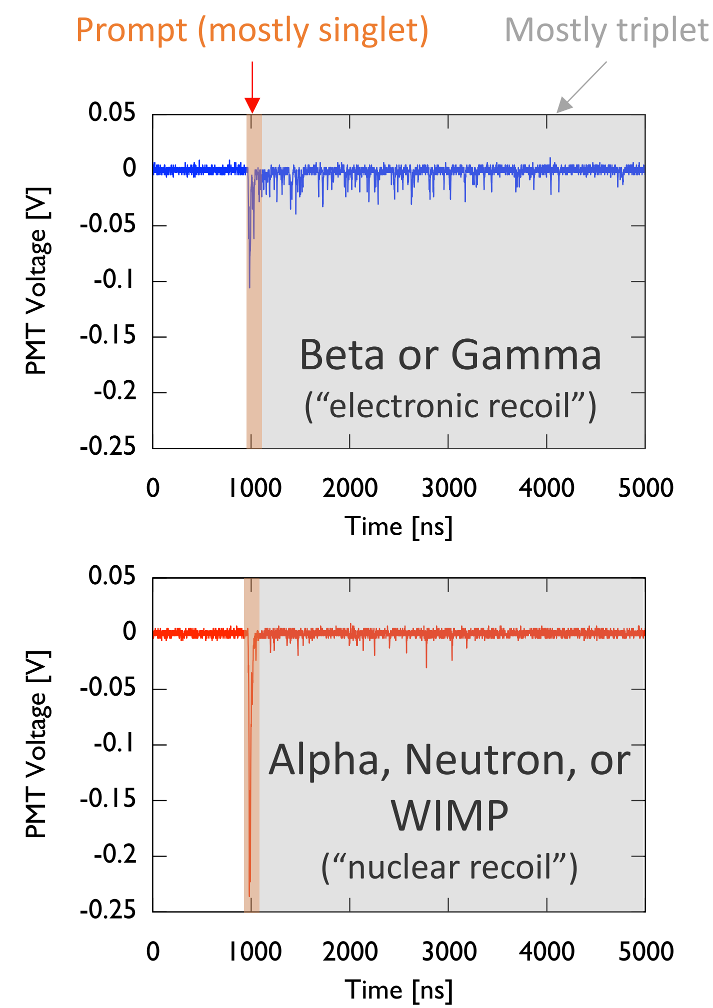
Pulse Shape Discrimination (PSD)

- Argon has long-lived triplet (1600 ns) and short-lived singlet (6.7 ns) excited states

- Electromagnetic interactions produce more triplets vs singlets than nuclear interactions

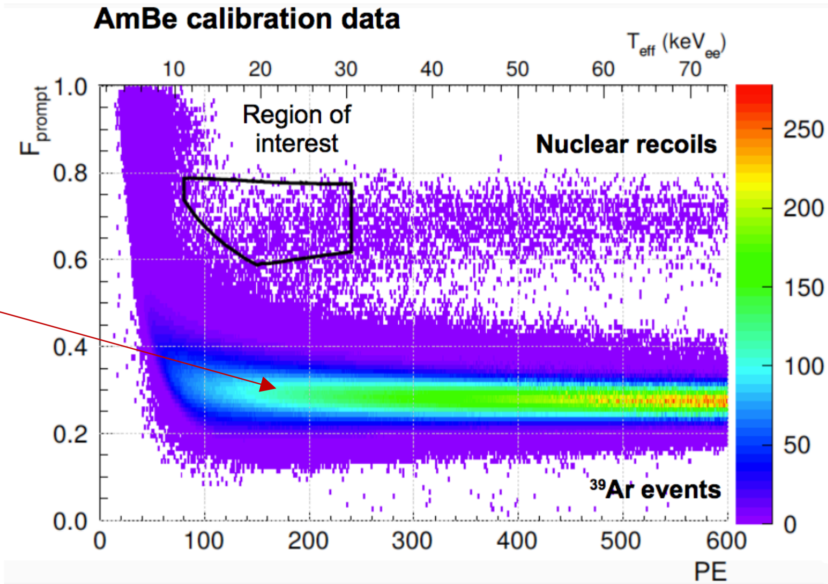


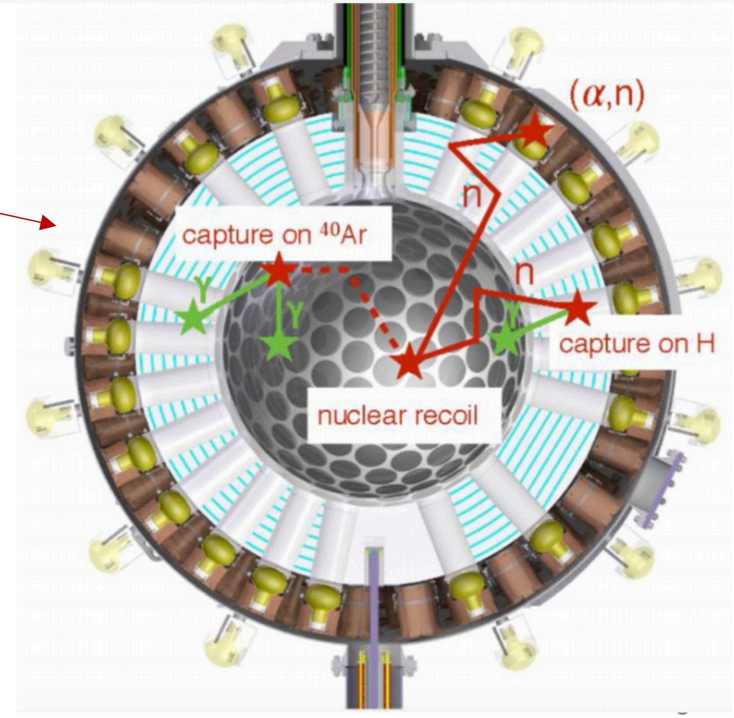
$$F_{prompt} = \frac{Prompt\ Light}{Total\ Light} = \frac{\int_0^{150\ ns} Q(t)dt}{\int_0^{13{,}500\ ns} Q(t)dt}$$



Backgrounds

- Betas and gammas
  - Ar39 is main source
  - Excluded with PSD
- Neutrons
  - Detector shielded against external neutrons
  - Neutrons produce gammas that allow us to count them
- Alpha decays
  - We'll talk about these

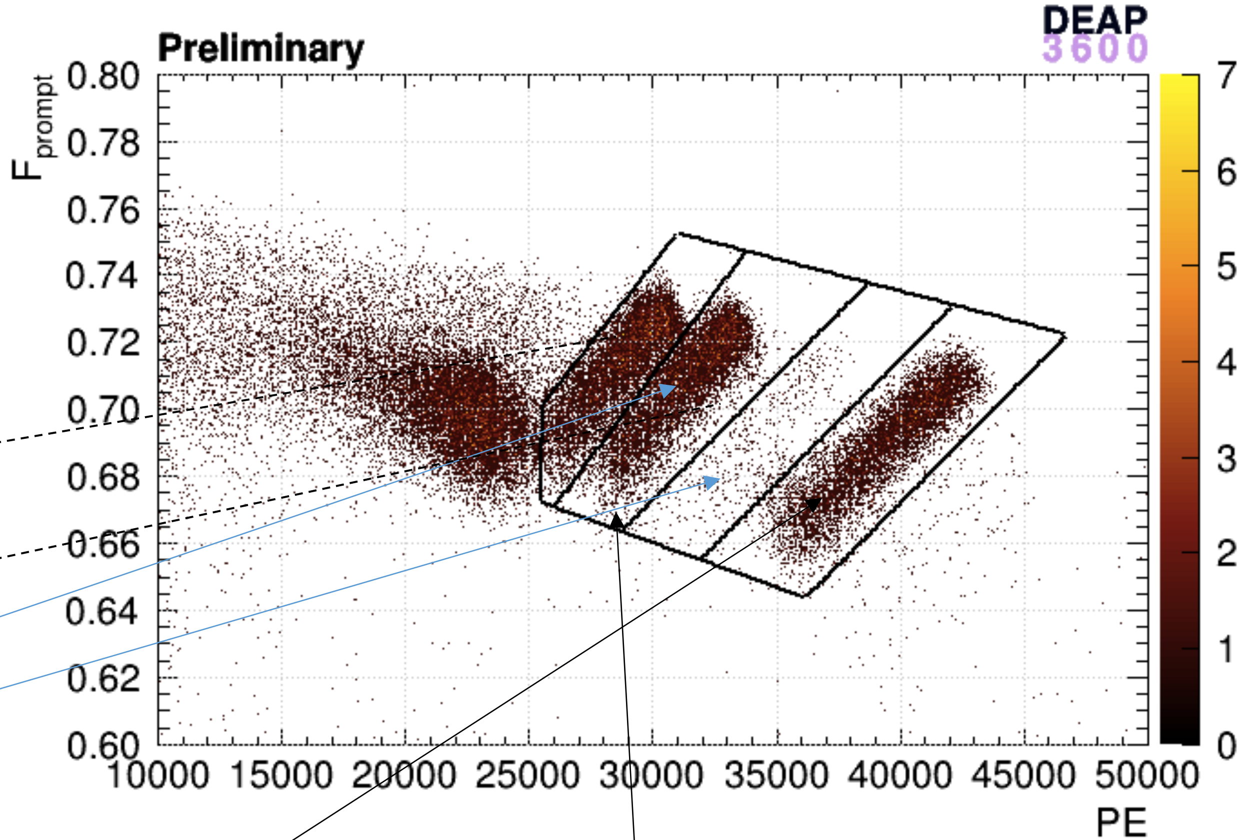


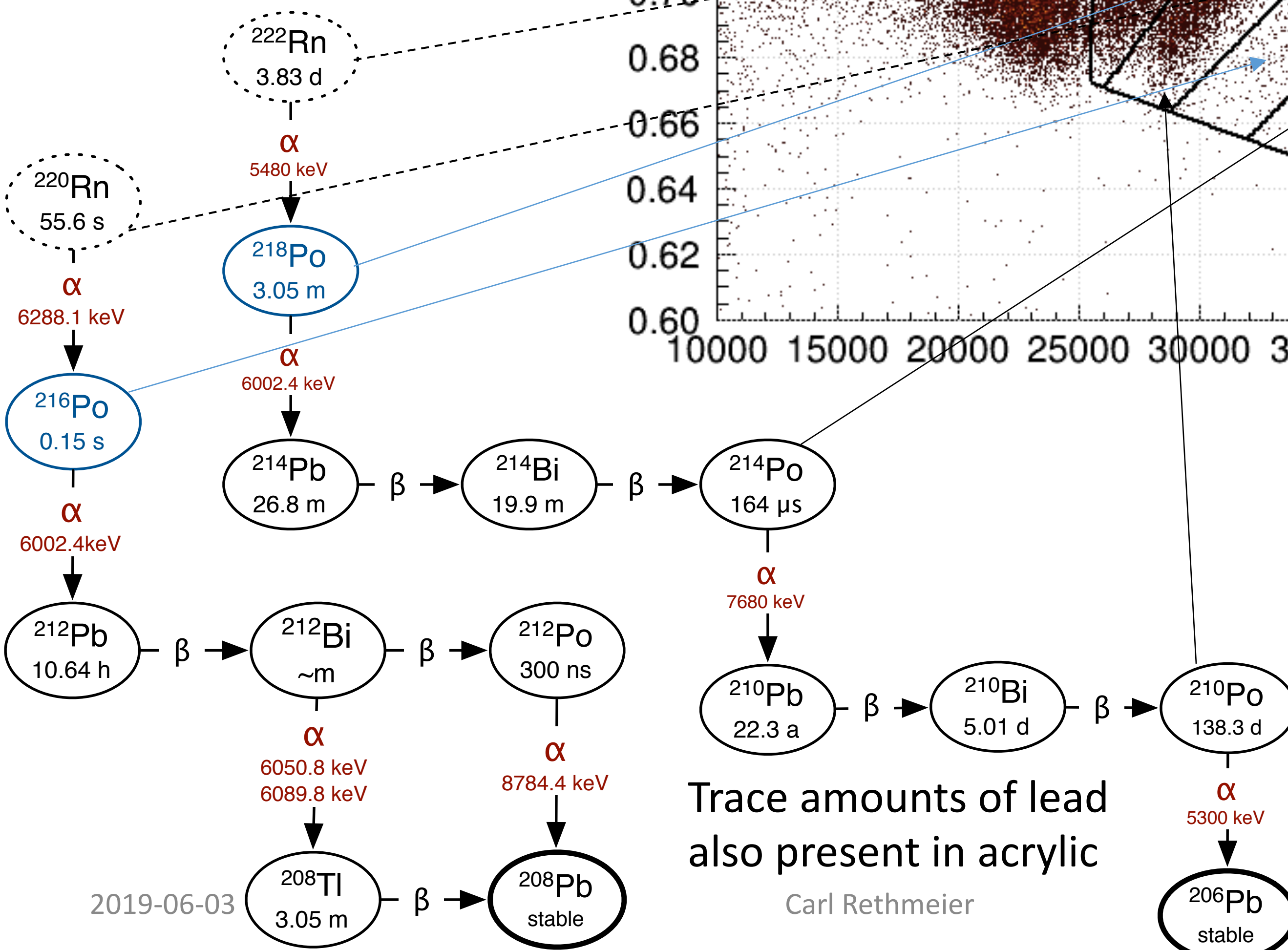


Alpha Decays

U238 and Th232 are present in detector components and process systems.

Radon is part of these decay chains, and enters liquid argon

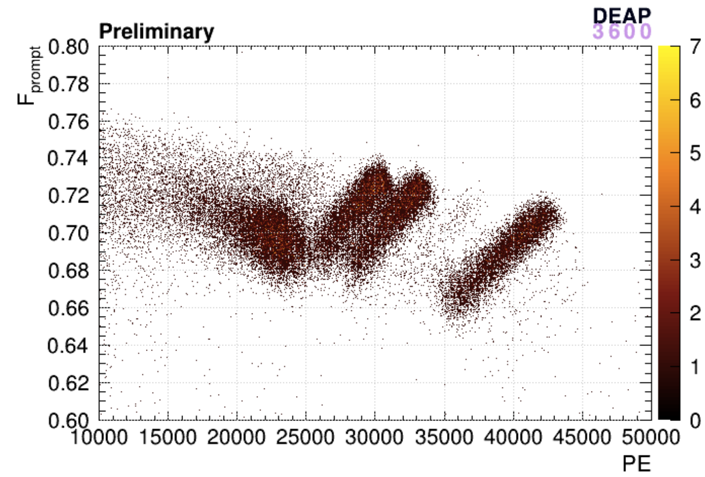


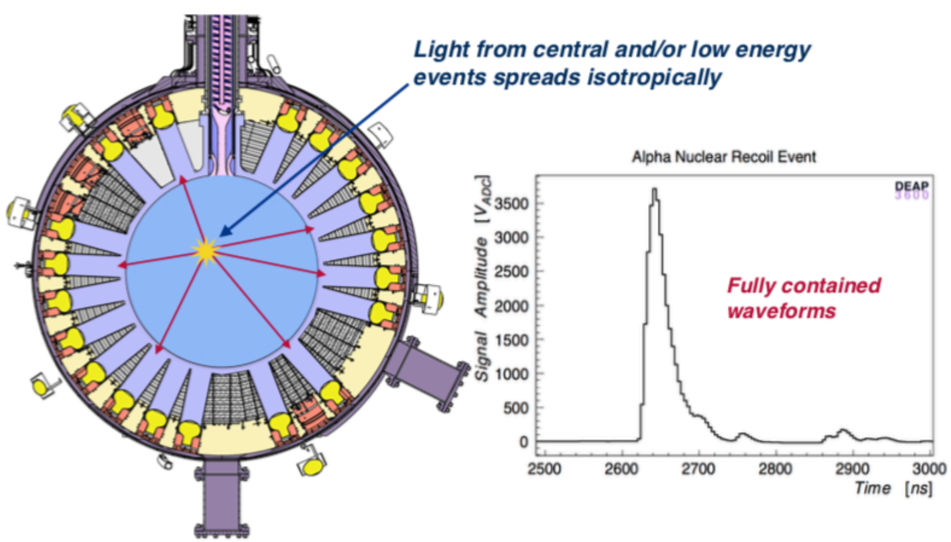


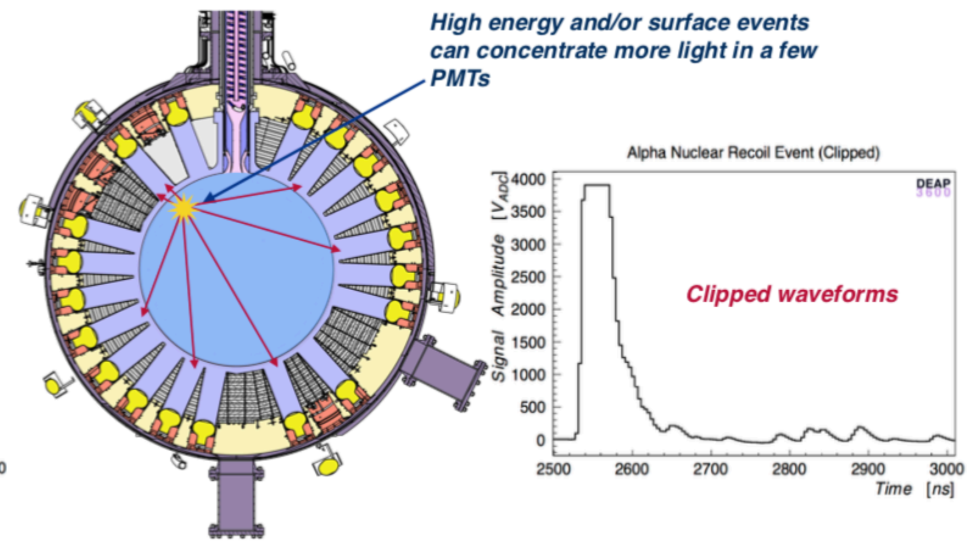
Trace amounts of lead also present in acrylic

PMT Saturation and Digitizer Clipping

- PMT pulses can get clipped and saturated
- This occurs when a high amount of light enters a PMT
- ”Clipping” refers to pulses that are cut off when digitizers reaches gain limit
- “Saturation” refers to a non-linear PMT response due to high total charge in PMT

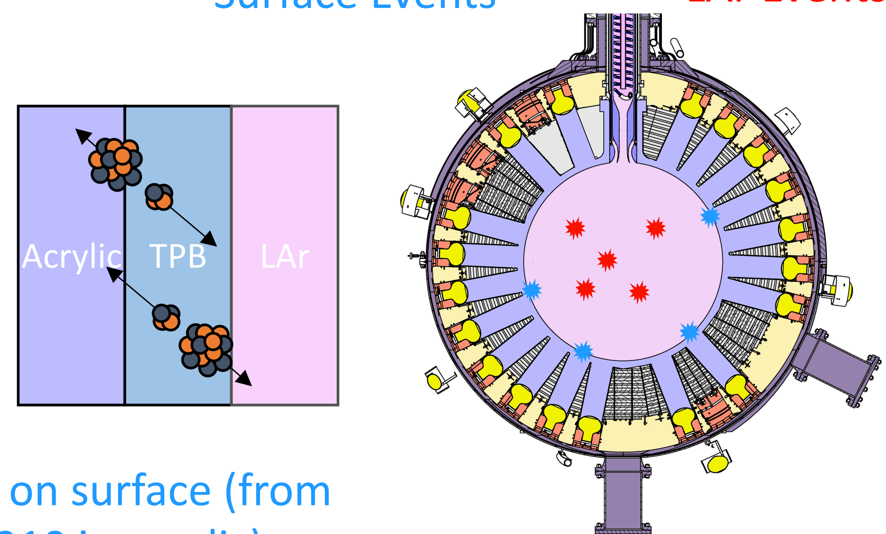


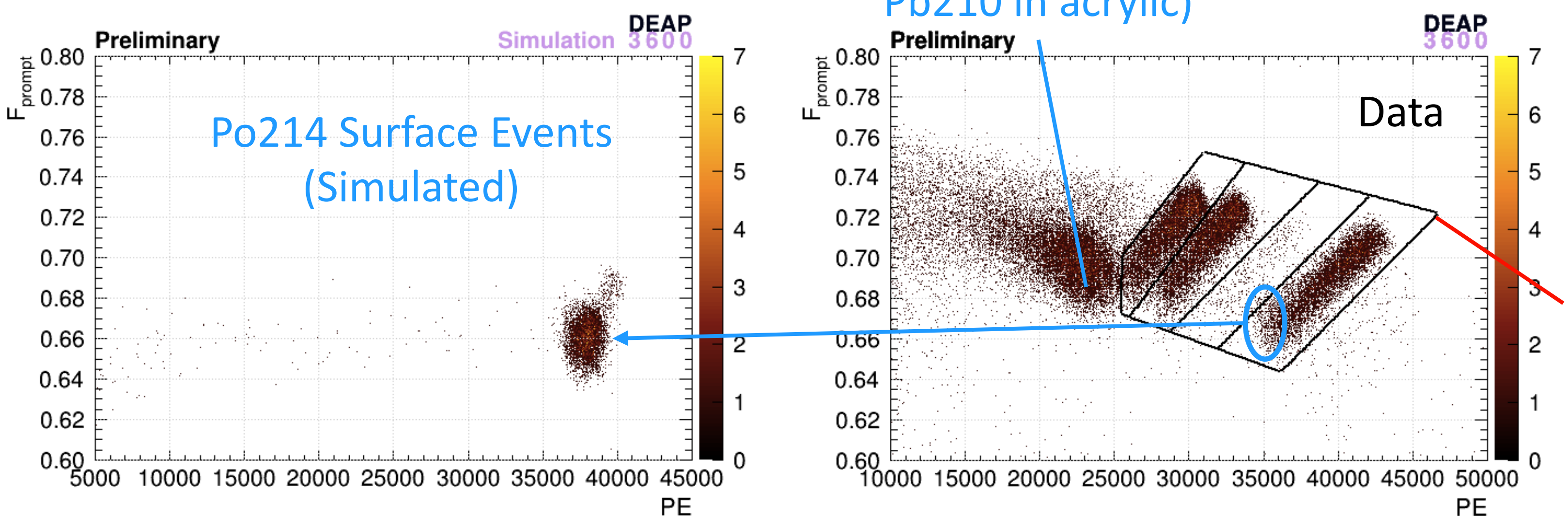




Why We Care about the Alpha Background

- If their energy gets partially absorbed, they could leak into the WIMP region of interest
- So we need to know how much of each isotope we have and where they are located



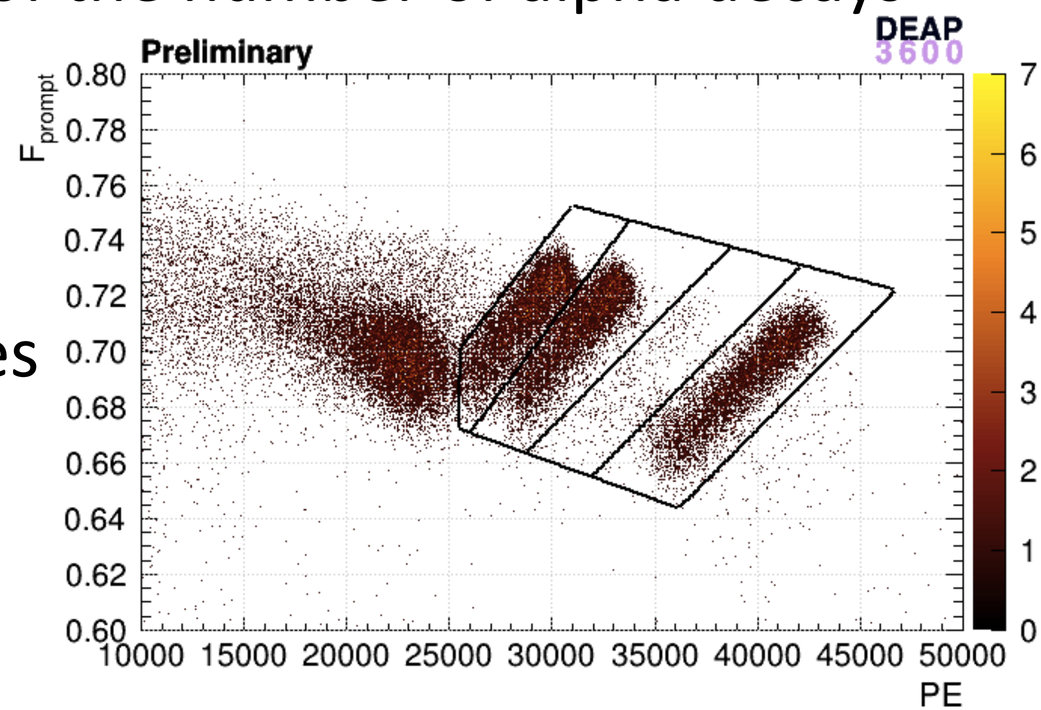


We have used 3 methods to determine the activity of radon-220 and radon-222 in the LAr

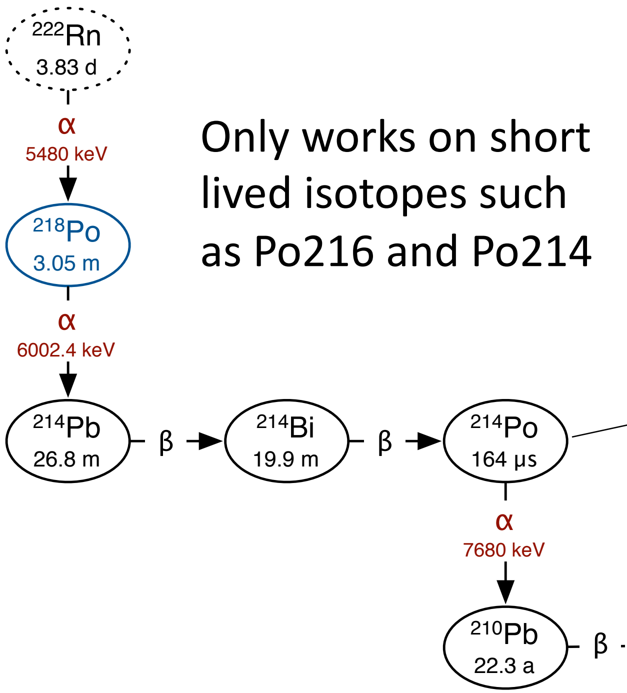
- The methods are based on counting the number of alpha decays the following ways:
  - Cut and count
  - Time-coincidence tagging
  - Multi-component spectrum fit

Cutting and Counting

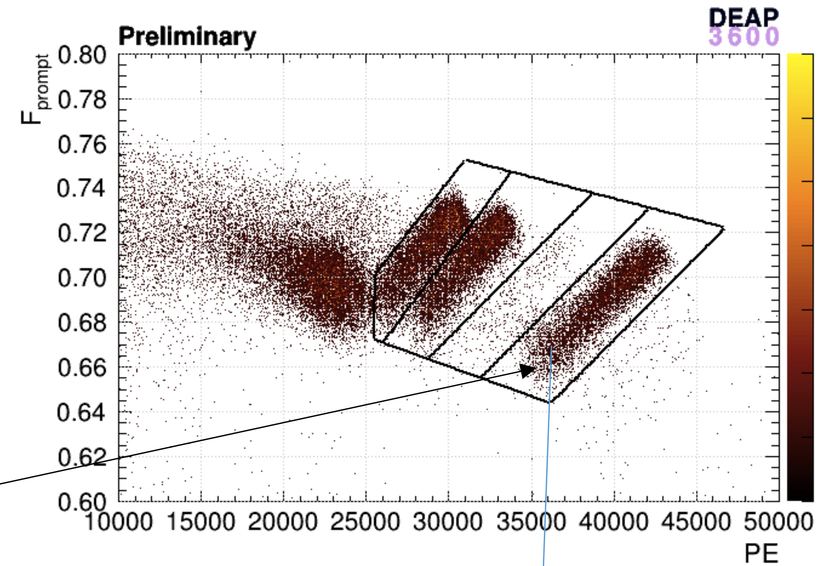
- Can locate populations of alpha decays with known energies
- Make cuts along the minima between them
- Get rough estimate of the number of alpha decays
- Very difficult to assign uncertainties
- Events can leak out of or into these boxes



Time Coincidence Tagging



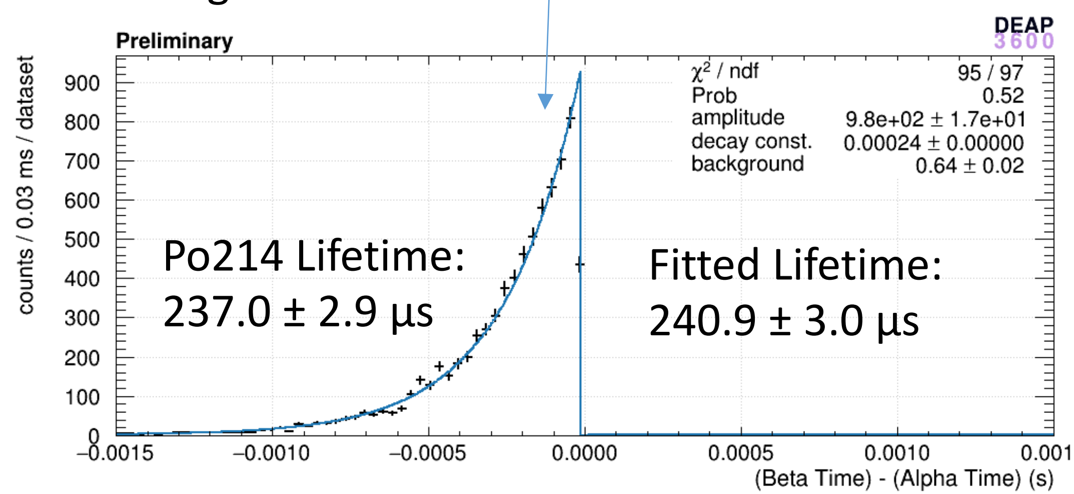
Only works on short lived isotopes such as Po216 and Po214



Select an event in an alpha "box"

Signal Window

Random Window

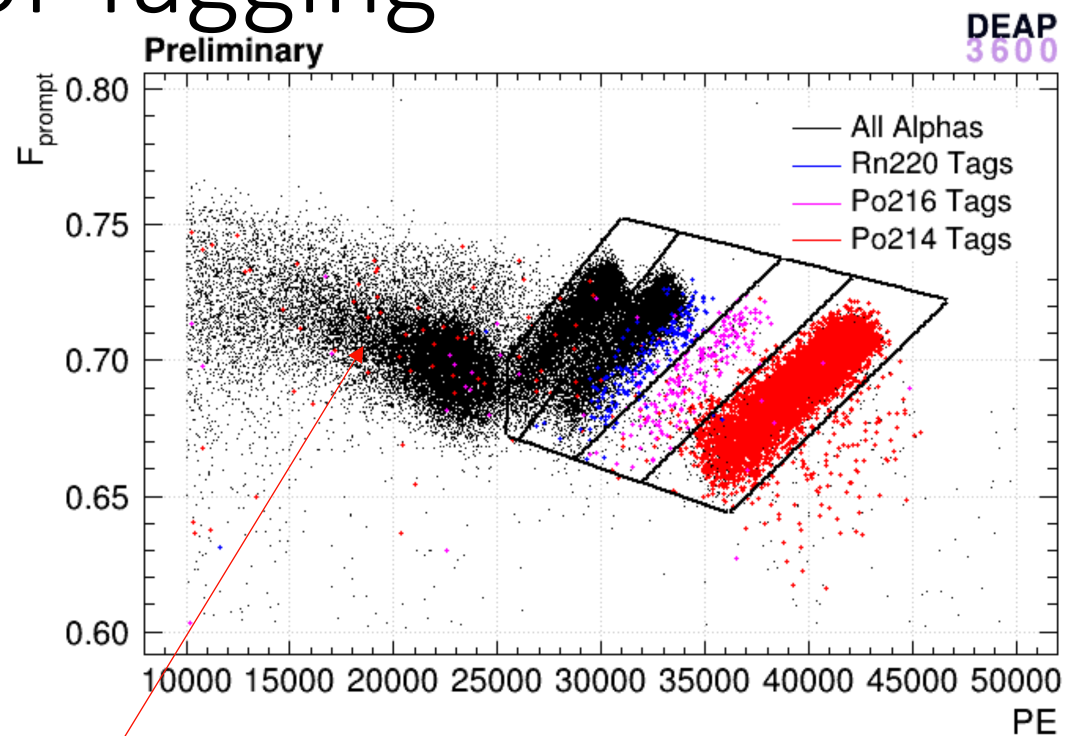


Look for event within a short time window before and after

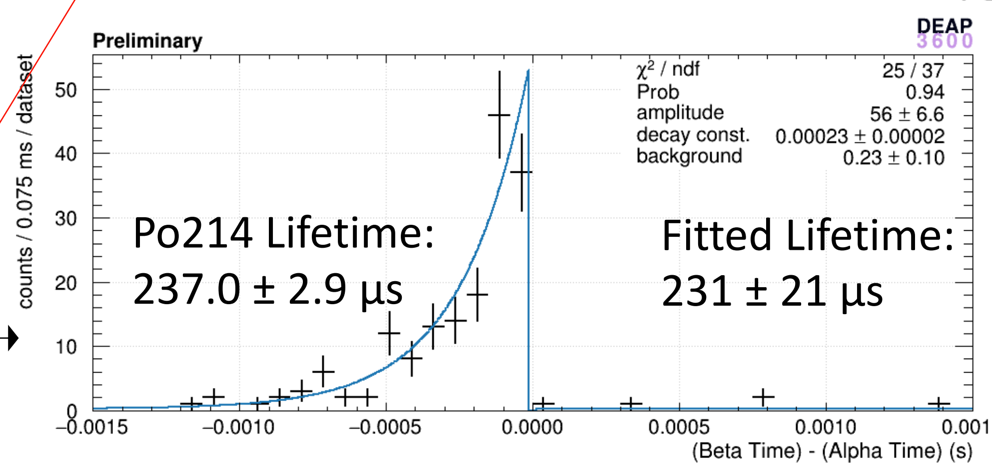
Advantages of Tagging

- 1.5 ms window for Po214 tagging captures 99.8% of decays
- Pileup of Po214 with its parent (Bi214) removes 5.5% of Po214 tags
- Other Po214 tag cuts are ~87% efficient

- Rn220 tagging with Po216 is 90.8% efficient based on 0.5 s window (0.209 ± 0.003 s lifetime)



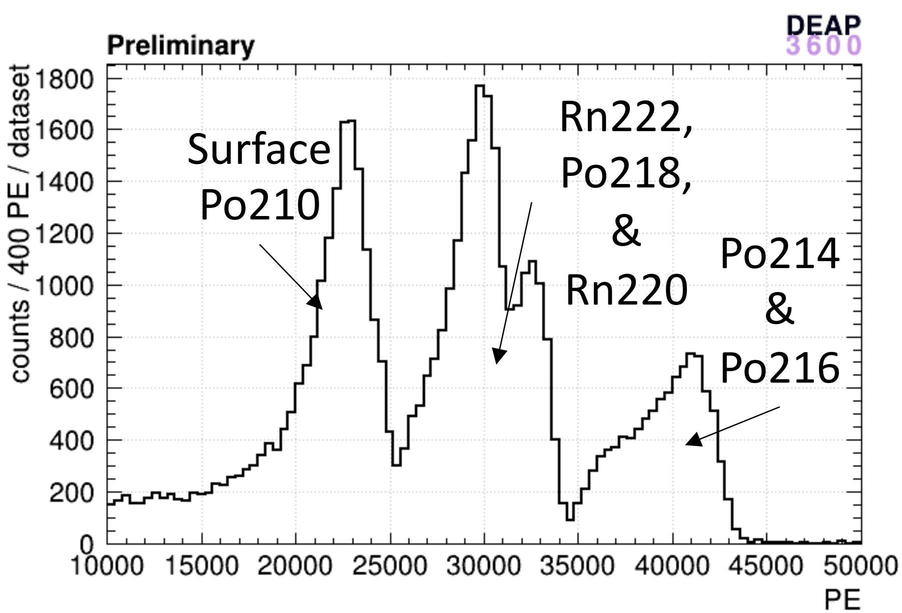
Selected Po214 events with degraded energy (red dots to the left of Po214 peak) and fitted decay time

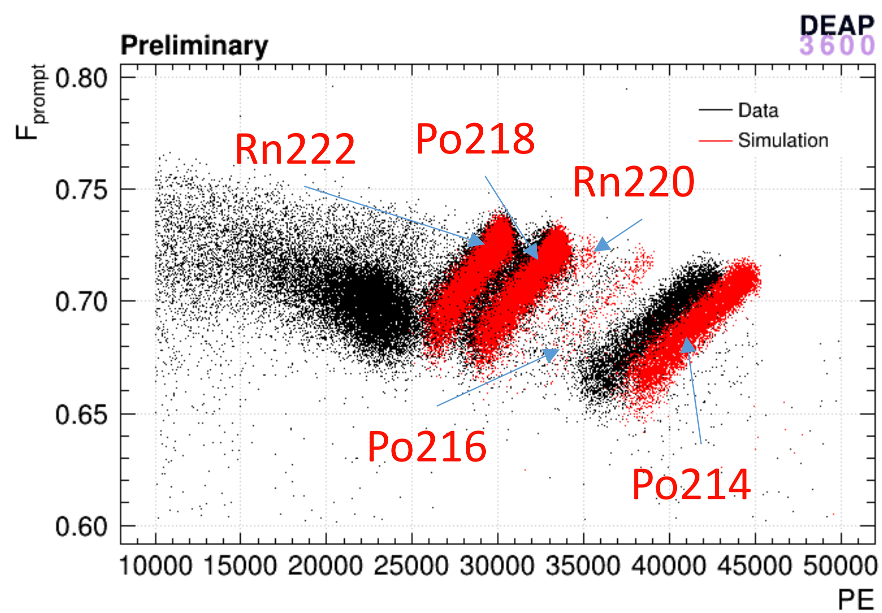


Multi-Component Fit

- Simulate alpha decays within the detector and fit the resulting model to the data
- MC is not perfect
  - But it's close enough to perform a fit

Po214 mismatch is due mostly to PMT saturation in data





Energy Correction

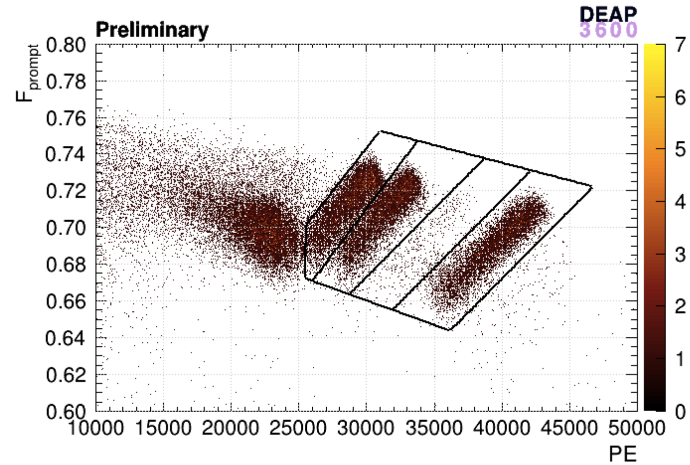
Select populations using box cuts

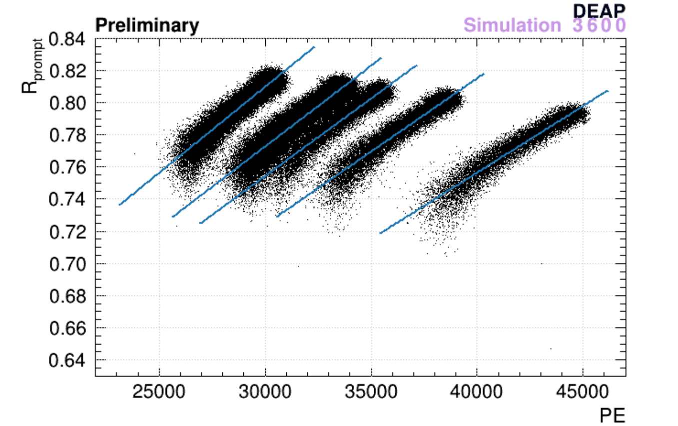
Fit line to each population

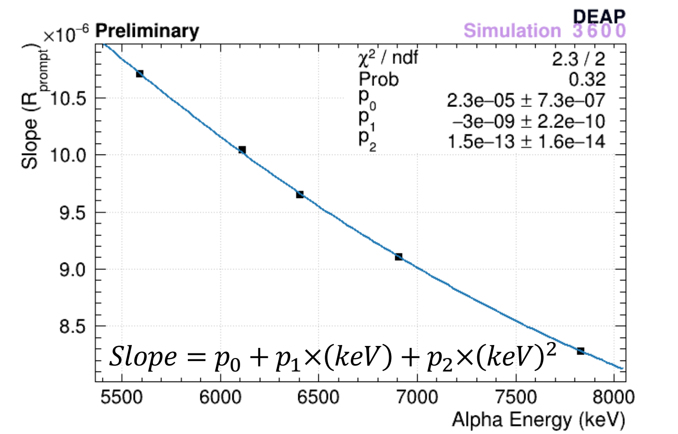
Plot the slopes and intercepts of the lines on a graph vs keV and fit a polynomial to the graph

Numerically solve calibration function for each event in dataset

$$F_{prompt} = PE \times slope(keV) + intercept(keV)$$



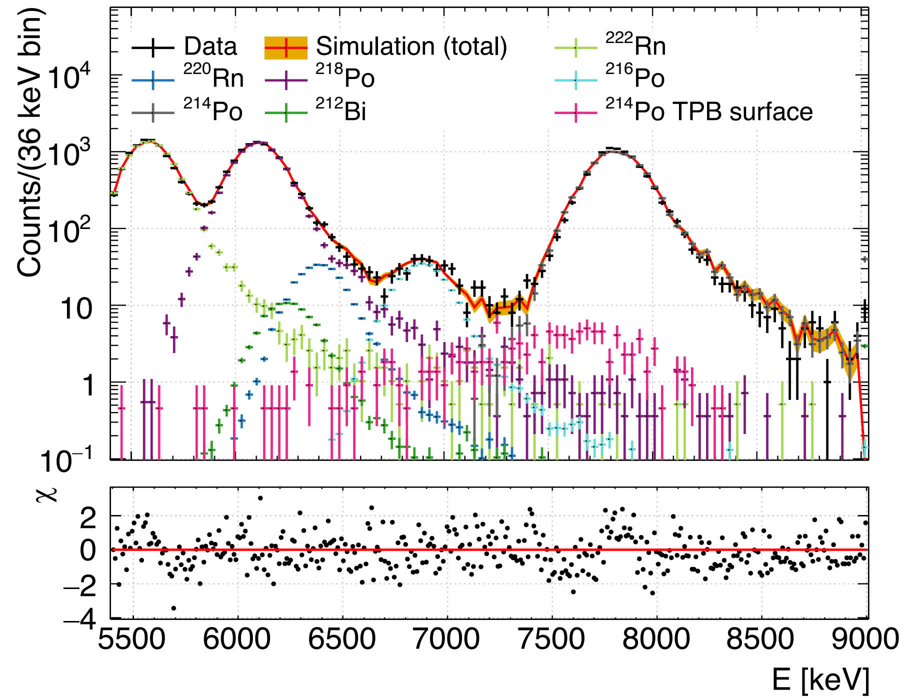


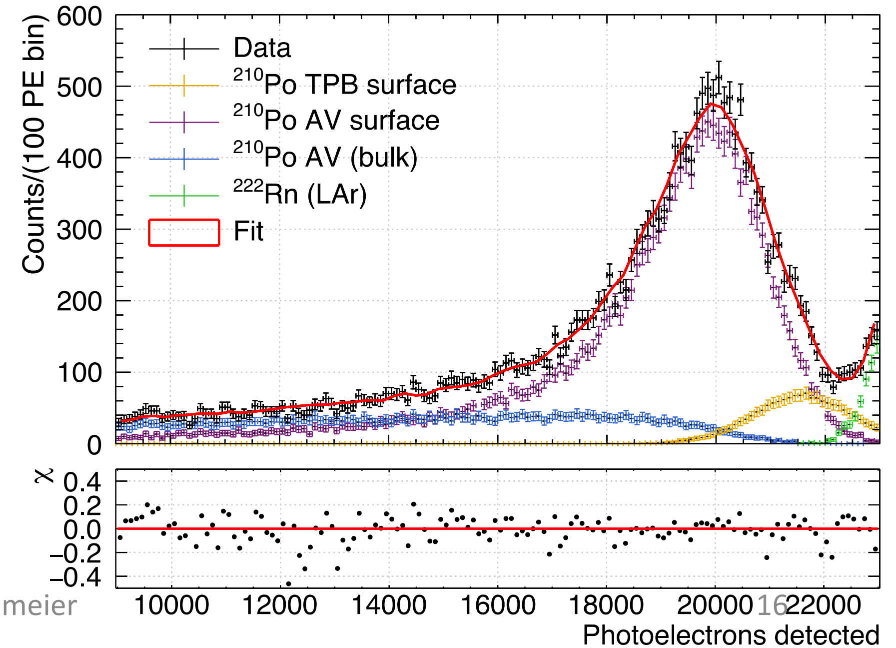


Results

- Able to fit out almost all alpha decays in liquid argon
- Also performed separate fit of Po210 components on detector surface

Component	Activity / Rate
^{222}Rn LAr	(0.153 ± 0.005) µBq/kg
^{218}Po LAr	(0.159 ± 0.005) µBq/kg
^{214}Po LAr	(0.153 ± 0.005) µBq/kg
^{214}Po TPB surface	< 5.0 µBq/m^2
^{220}Rn LAr	(4.3 ± 1.0) nBq/kg
^{216}Po LAr	(4.5 ± 0.4) nBq/kg
^{212}Bi LAr	< 5.6 nBq/kg
^{212}Po LAr	(3.4 ± 1.1) nBq/kg
^{210}Po TPB & AV surface	(0.26 ± 0.02) mBq/m^2
^{210}Po AV (bulk)	(2.82 ± 0.05) mBq

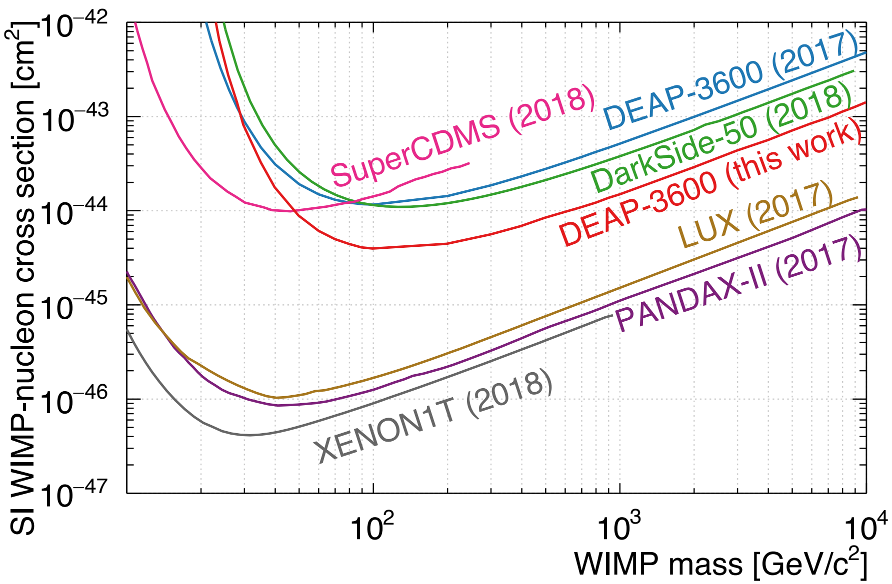




Summary

- Alpha backgrounds have been modelled and fit out
- Results show that DEAP LAr has the lowest specific radon activity of the noble liquid based dark matter detectors
- Overall DEAP result is the most sensitive of any liquid argon experiment to date

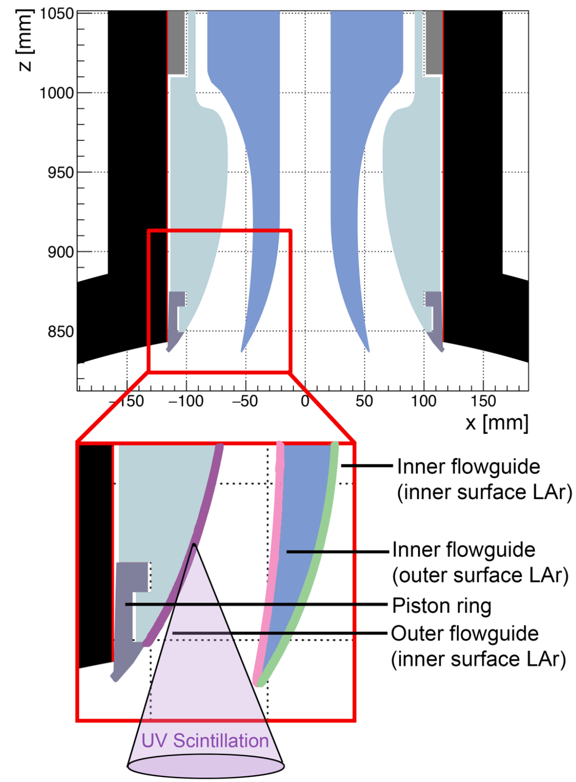
Experiment	Activity/Rate	Target	Reference
DEAP-3600	0.15 μBq/kg	LAr	
DarkSide-50	1.74 μBq/kg	LAr	C. J. Stanford, Ph.D. thesis, Princeton University (2017)
PandaX-II	6.6 μBq/kg	LXe	Phys. Rev. D 93, 122009 (2016)
LUX	66 μHz/kg	LXe	Physics Procedia 61 (2015) 658 – 665
XENON-1T	10 μBq/kg	LXe	XeSat2017 talk [link]



Backup

Neck Alpha Decays

- Alpha decays in the neck were a significant background
- We were able to cut out these events
- Made model-based prediction of expected number of events in ROI



Component	Activity / Rate
^{210}Po inner FG, IS	(14.1 ± 1.3) µHz
^{210}Po inner FG, OS	(16.8 ± 1.4) µHz
^{210}Po outer FG, IS	(22.7 ± 1.6) µHz