Australian National University

ARC CENTRE OF EXCELLENCE FOR DARK MATTER

SABRE South NaI BiPo characterisation

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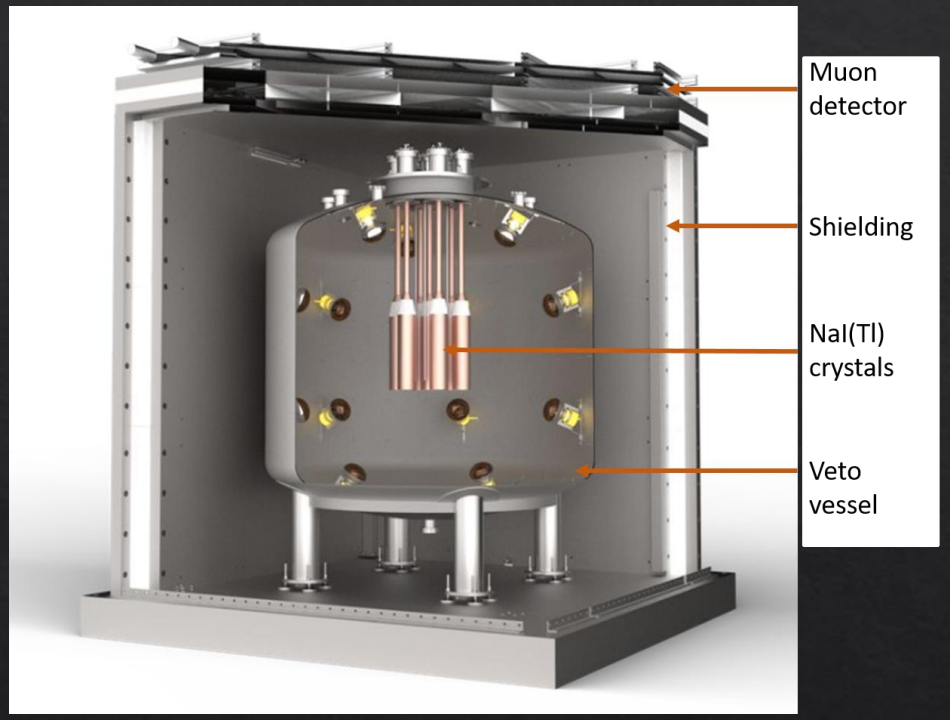
22 November 2022

SABRE

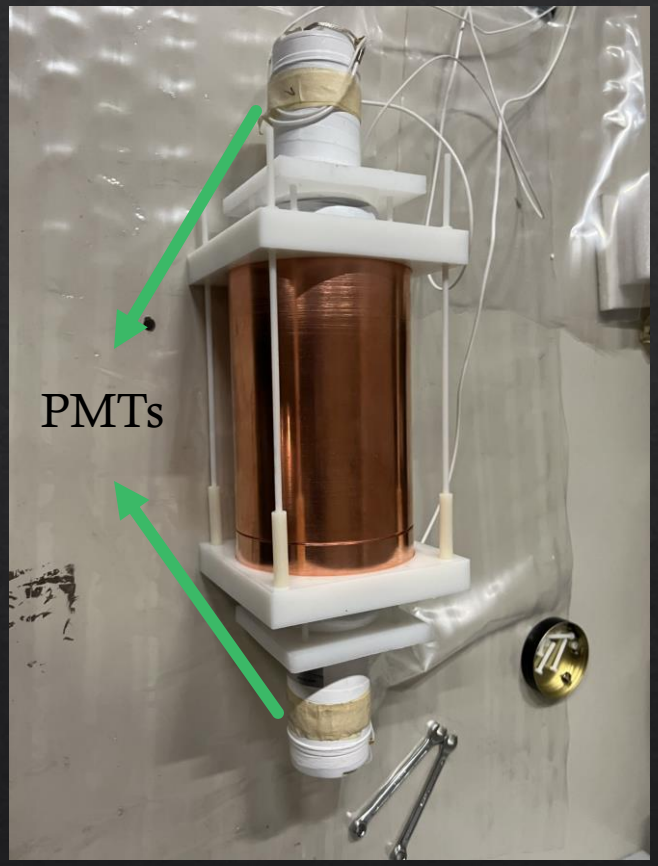
- SABRE South part of SABRE international collaboration NaI dark matter detector
- Aim is to confirm or refute annual modulation claims by DAMA/LIBRA at LNGS, Italy
- Annual modulation is approximately 0.01 cpd/kg/keV, whereas the background is expected to be 1 cpd/kg/keV in the 1-6 keV region of interest
- Characterisation of intrinsic backgrounds ^{238}U, ^{232}Th, ^{210}Pb important
- Expected in the ppb levels
- SABRE focusing on development of ultra-pure NaI.



Cut-out view of a 3D rendering of SABRE.
Credit: Michael Mews (The University of Melbourne)

NaI-035

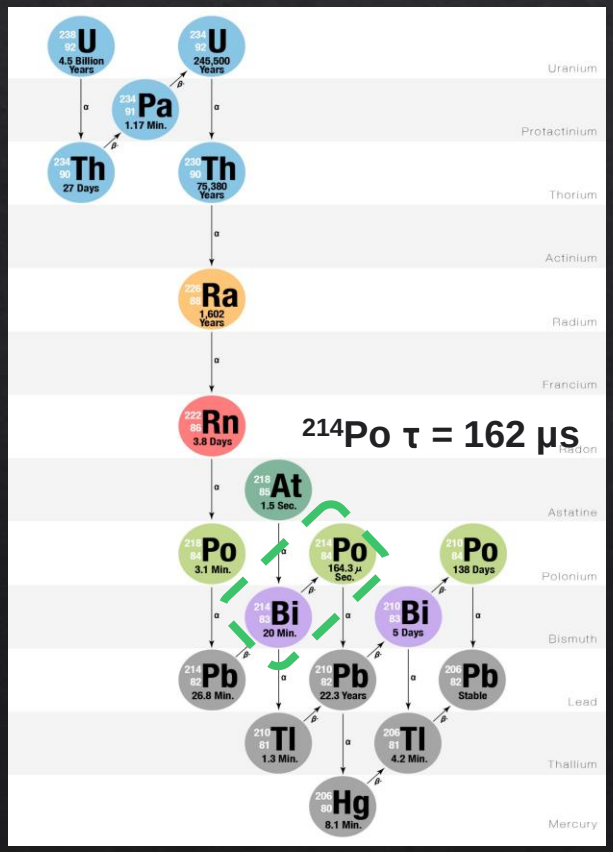
- Set-up to measure backgrounds in LNGS, Italy
- Crystal encapsulated and wrapped in reflective material
- 2 x Hamamtsu 3” 11065 PMTs
- Two sets of runs since May 2022:
  - Low Gain
  - High Gain
- This work: Characterisation of ^{238}U and ^{232}Th in NaI-035



BiPo Decay

"Slow BiPo"

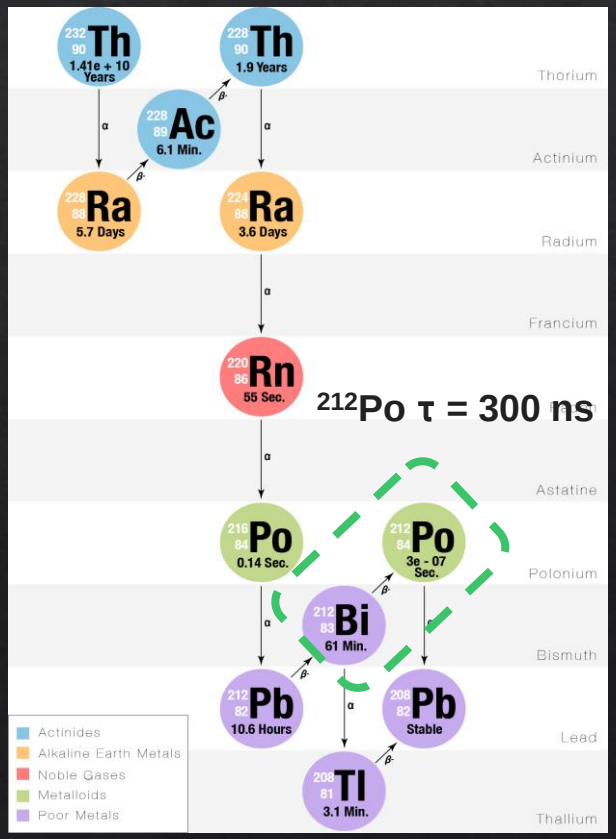
$^{214}Bi \xrightarrow{\beta} {}^{214}Po \xrightarrow{\alpha} {}^{210}Pb$



https://www.nachi.org/gallery/radon/uranium-238-decay-chain

"Fast BiPo"

$^{212}Bi \xrightarrow{\beta} {}^{212}Po \xrightarrow{\alpha} {}^{208}Pb$



https://www.nachi.org/gallery/radon/thoron-decay-chain

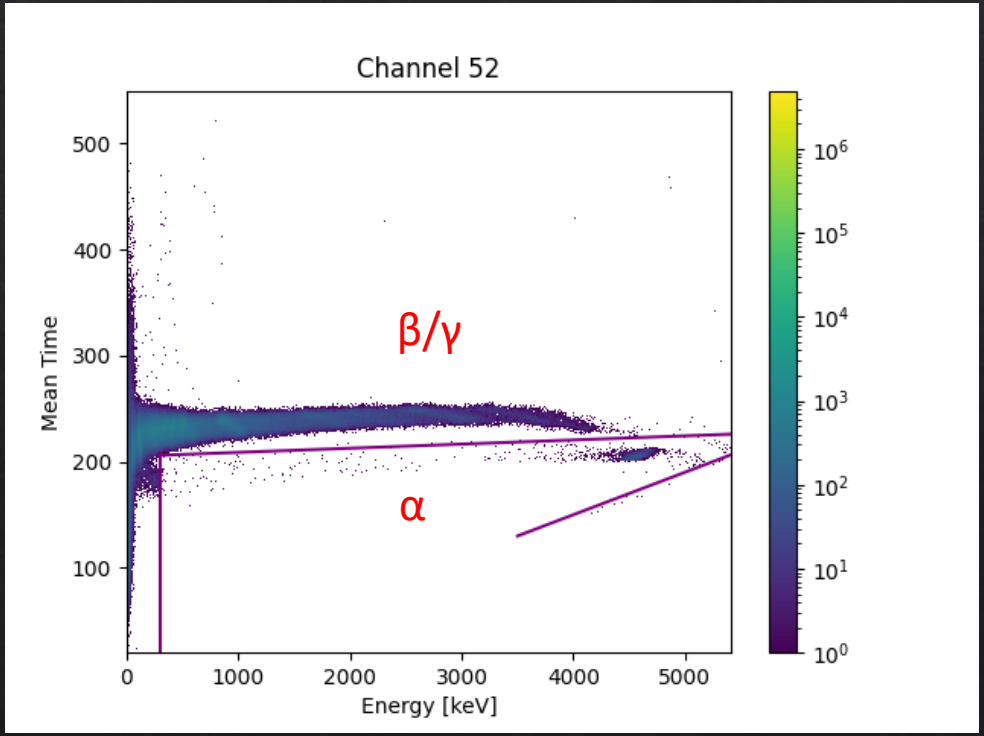
Slow BiPo

- Looking for β followed by an α with $t_{1/2}$ = 162 μs
  - Digitiser recording window = 5 μs
  - Two events in quick succession
- NaI has pulse shape discrimination:
  - Different integrated charge deposit – alphas more energy deposit
  - Different amplitude weighted mean times

$$\text{Amplitude weighted mean time } \langle t \rangle_{600} = \frac{\sum_{t_i < 600 \text{ ns}} h_i t_i}{\sum_{t_i < 600 \text{ ns}} h_i}$$

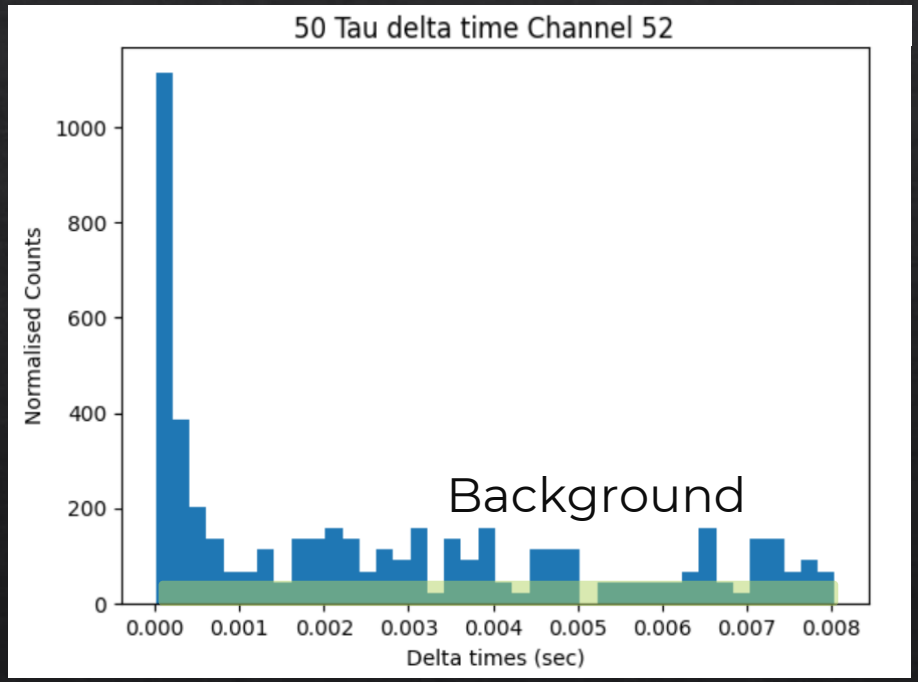
Separation of β/α using Mean Time and Charge

- Plot MT vs Energy for summed channels
- Prepare cuts and separate β/γ and α



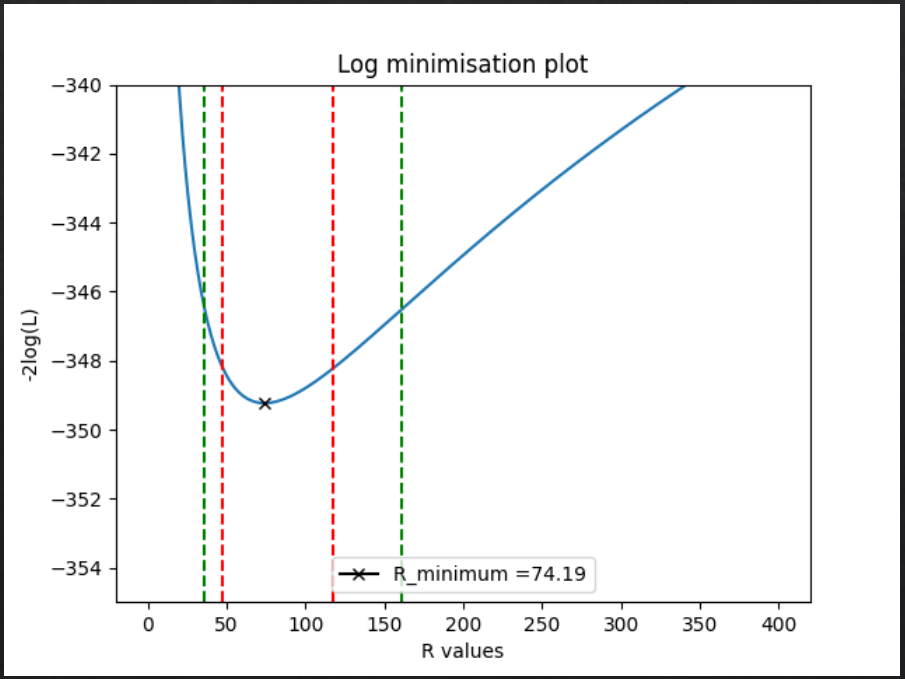
Calculate time difference

- Look out to events with $\Delta(t_\alpha - t_\beta) < \Delta n\tau$
- Fit data to exponential decay with background
- $PDF = N(1 + Re^{-\lambda t})$
  - N can be found by normalising the PDF
  - R – ratio of decay component to the background.



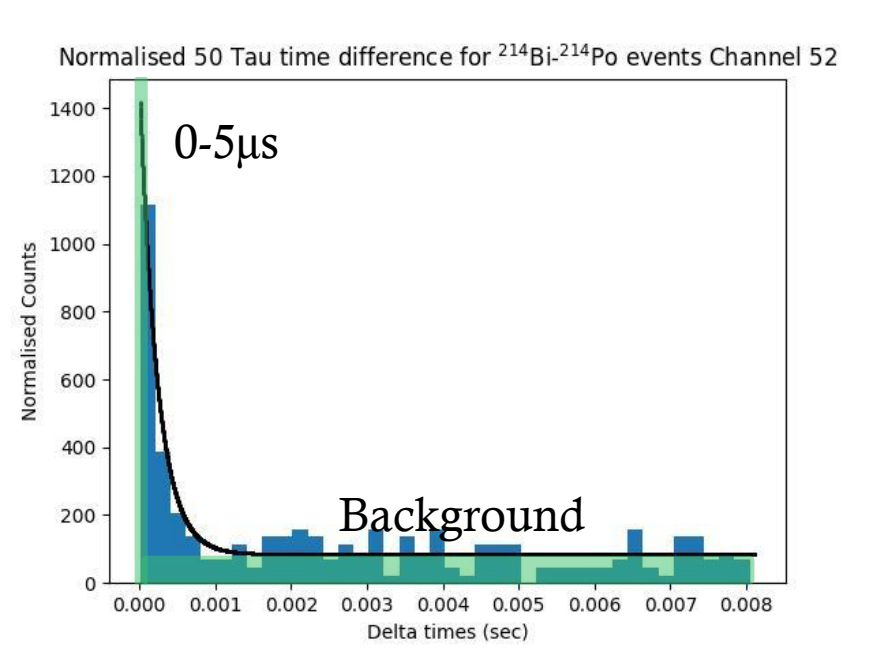
Find Background Rate

- Look out to events with $\Delta(t_\alpha - t_\beta) < \Delta n\tau$
- Fit data to exponential decay with background
- $PDF = N(1 + Re^{-\lambda t})$
- R found calculating using a likelihood analysis
  $L_{max} = \prod(PDF_i)$
  $L_{min} = -\sum\log(PDF_i)$
- Fit an exponential to the $\Delta n\tau$ data



Find Background Rate

- Digitiser collection window = 5μs
  - We could miss BiPo events in this window
  - Fraction of missed events = 1 - exp(-λ*5μs) ≈ 2%



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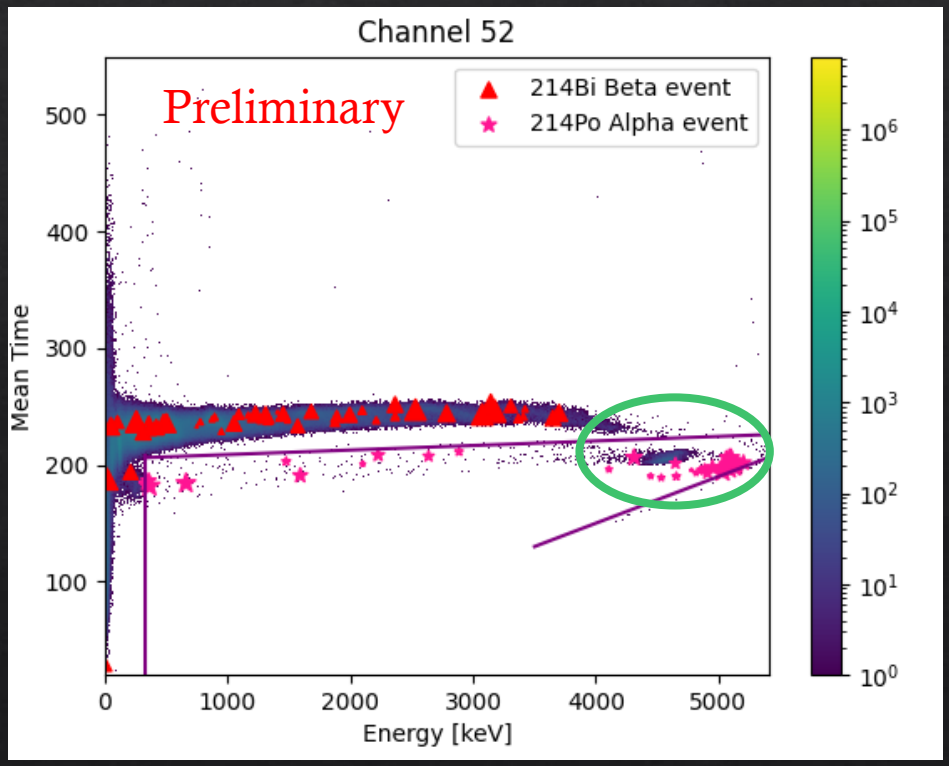
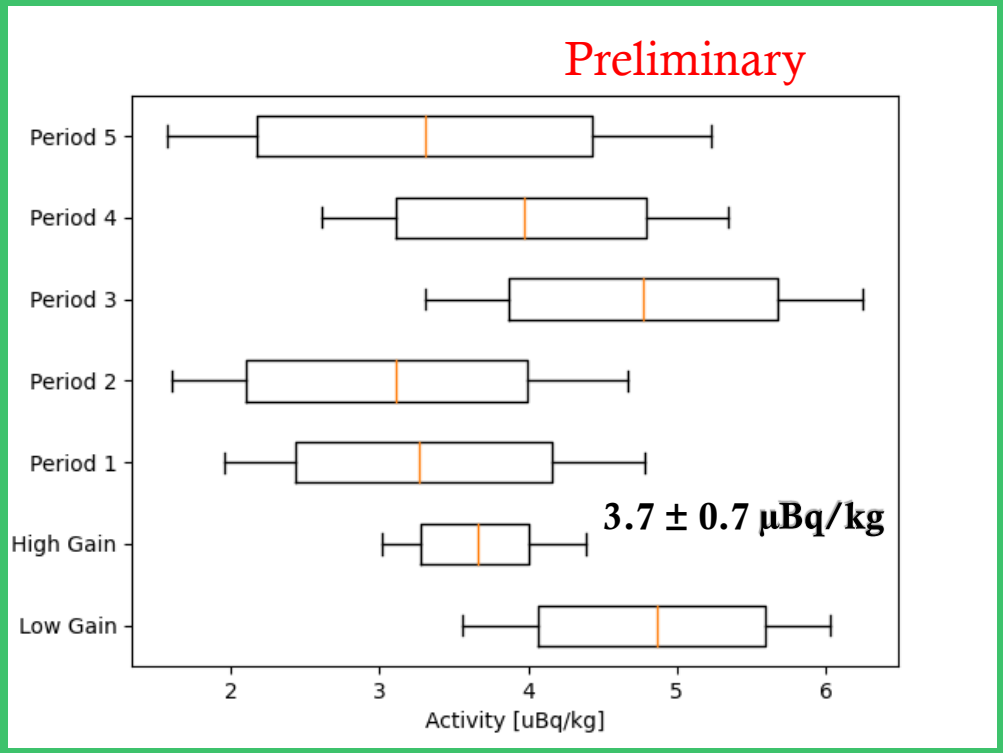


Results



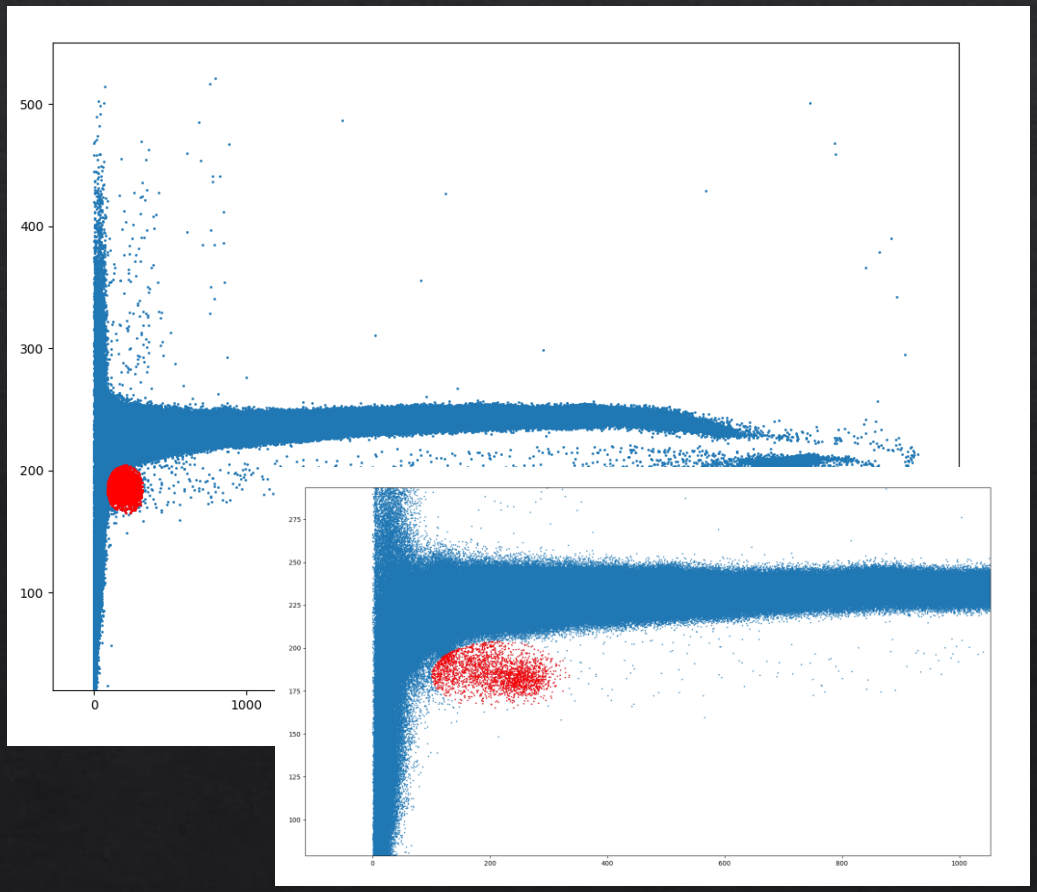
Data set	Duration (days)
Low Gain	~ 13
High Gain	~ 60
High Gain Period 1- 4	~ 12
High Gain Period 5	~ 9

NaI-033: 5.9 ± 0.6 μBq/kg

Mass NaI-035 - 3.7 kg

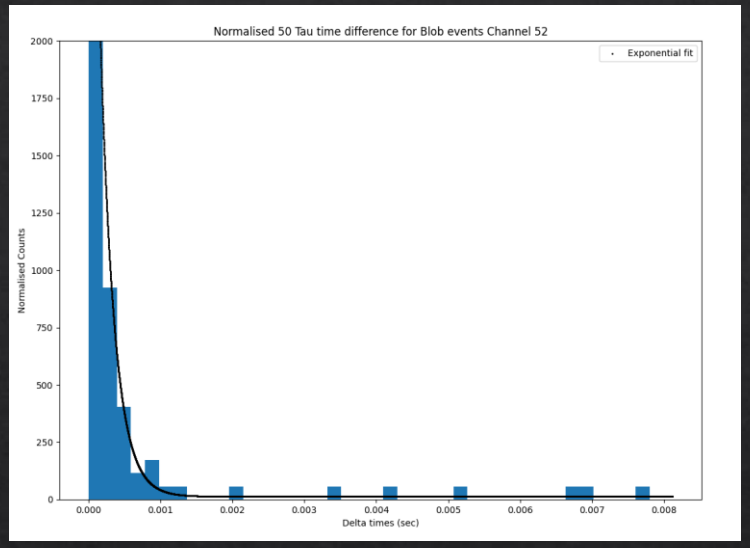
Blob

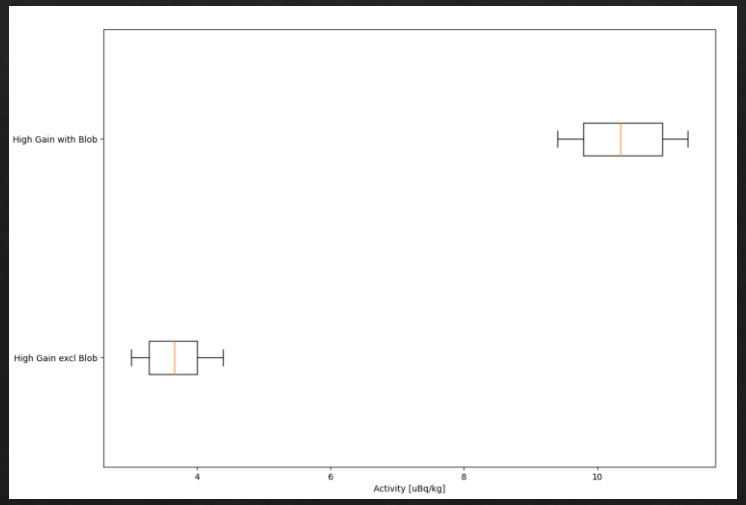
- Region should not normally be present
- Present in High and Low Gain data



Analysis on Blob

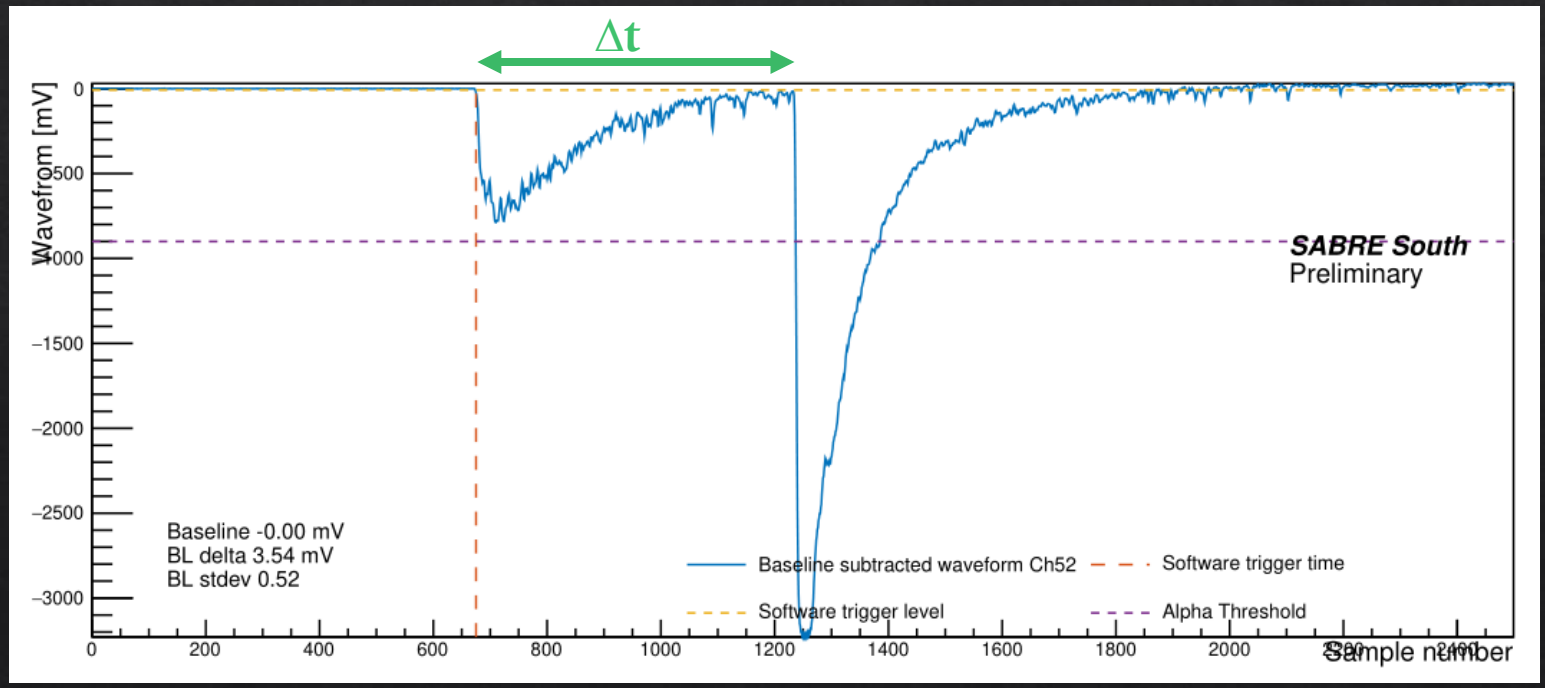
- Can fit an exponential
- Can calculate $t_{1/2}$ that fits to this:
  - 140 ± 25 μs
- Approximately 10.4 ± 0.9 μBq/kg
- Compared to 3.7 ± 0.7 μBq/kg
- Working toward determining if this needs to be included in α





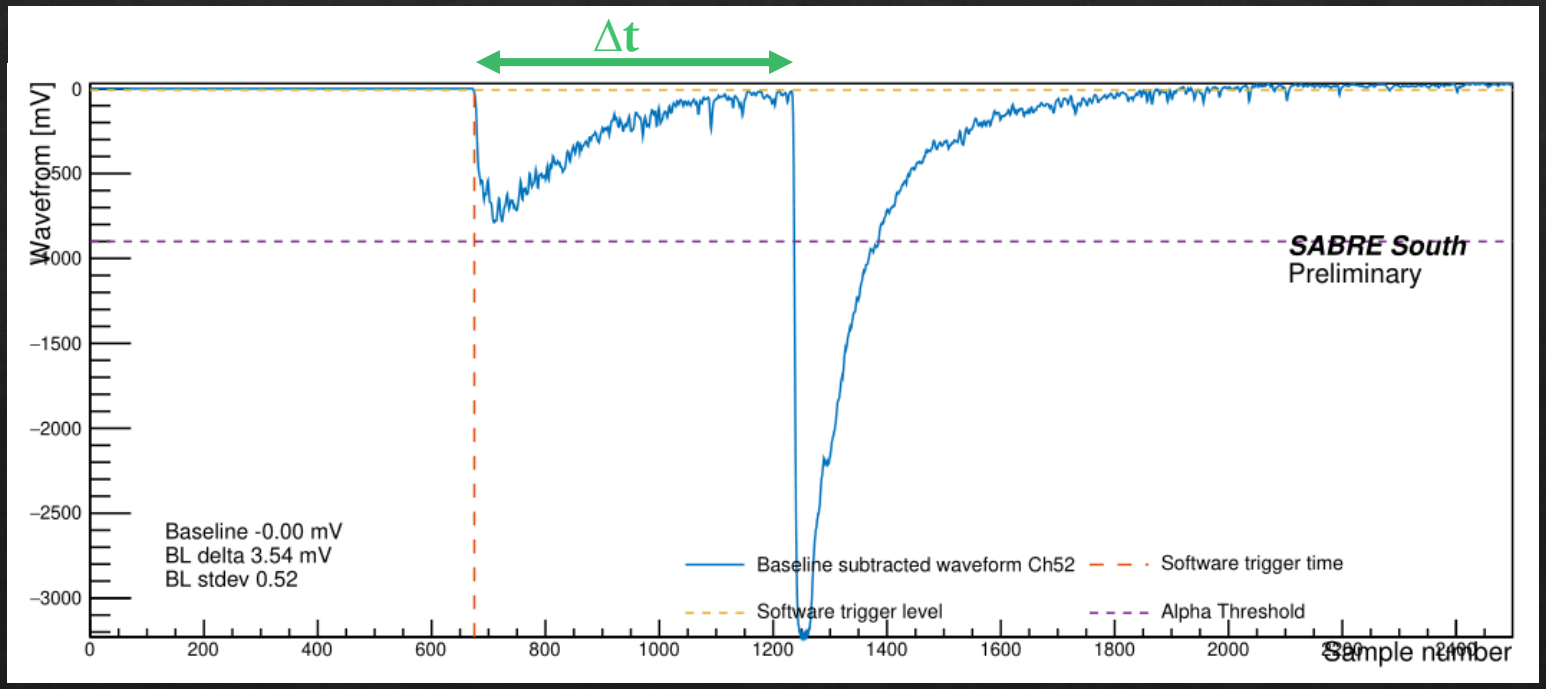
Fast BiPo

- Looking for β followed by an α with τ = 300 ns
  - Digitiser recording window = 5 μs
  - Look in one trigger



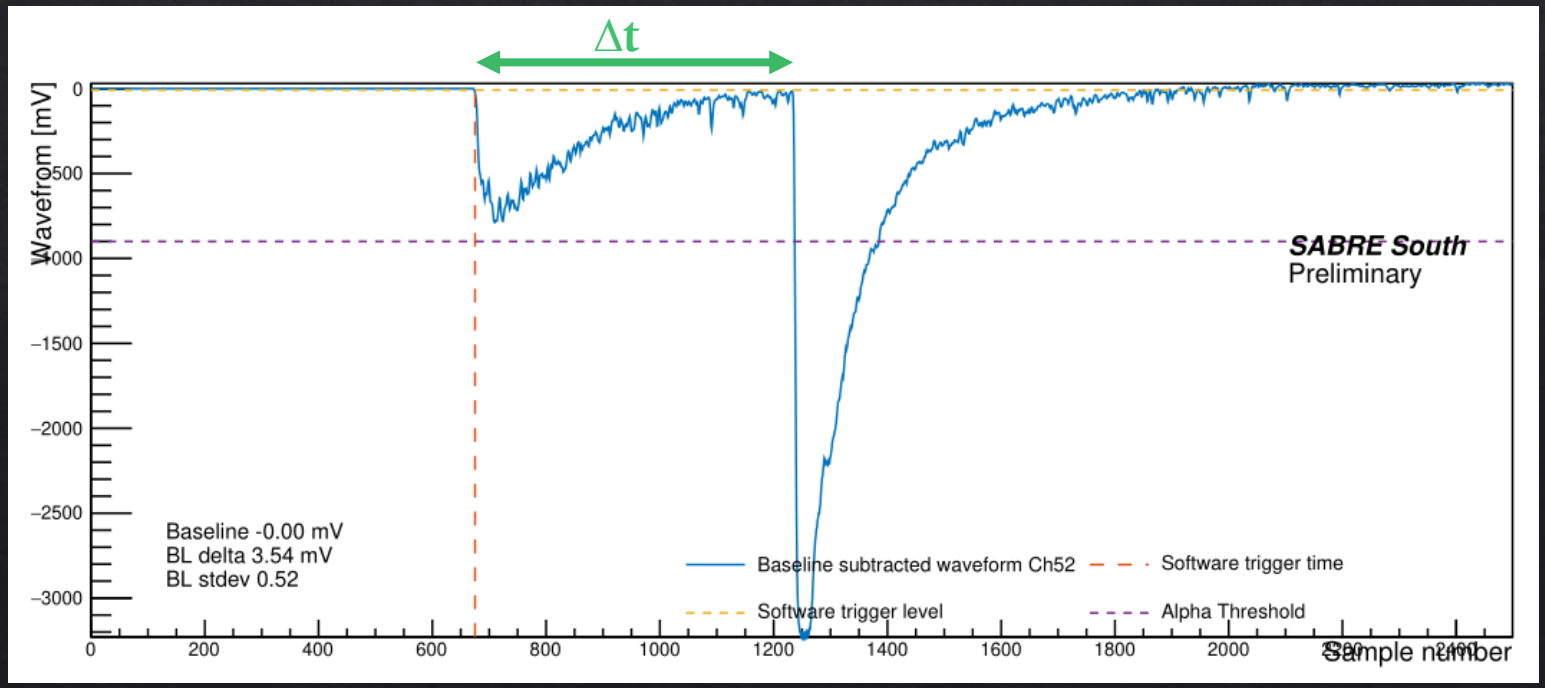
Fast BiPo

- Set Alpha trigger threshold
  - Set a minimum Δt
  - Requires some experimentation
- Identified 26 events – 1.4 ± 0.2 μBq/kg
- NaI-033: 1.6 ± 0.2 μBq/kg



Issues

- This leaves open to missing events, where the β peak is larger than the α threshold
- Δt currently set arbitrarily and could result in missed events
- Once we have good number, we can do a similar analysis to slow BiPo
- Must look through many waveforms.



Future Work

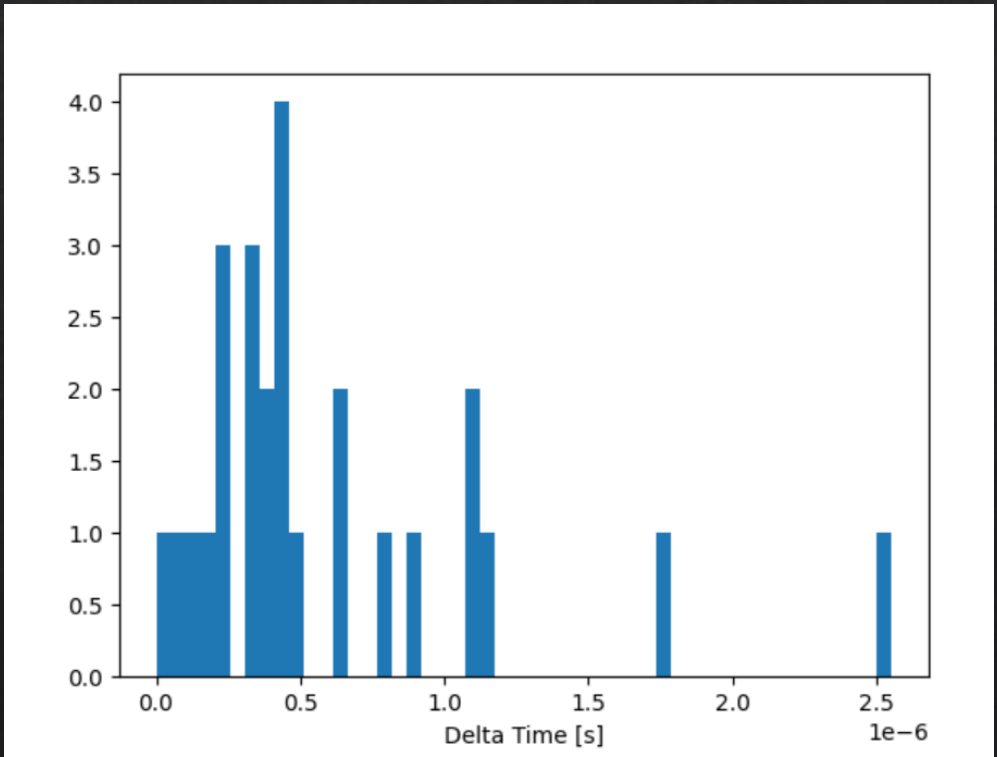
- Before getting custom algorithm, we can explore lowering (negative) the α threshold to the ^{212}Bi β energy
- Fit exponential to Δt and do analysis similar to slow BiPo
- Compare to Low Gain

Conclusion

- Developed a method to identify and analyse BiPo in the ^{238}U decay
- Determine if Blob should be included in α
- Developed the basic analysis and method to identify BiPo in the ^{232}Th decay
  - Needs algorithm improvements

Fast BiPo

- Set Alpha trigger threshold
  - Requires some experimentation
- Identified 26 events



Blob Included Analysis

- The following Δt distribution is for the blob included in the overall analysis.