Sensitivity Studies and Development of the Gas Supply System for the SuperNEMO Experiment

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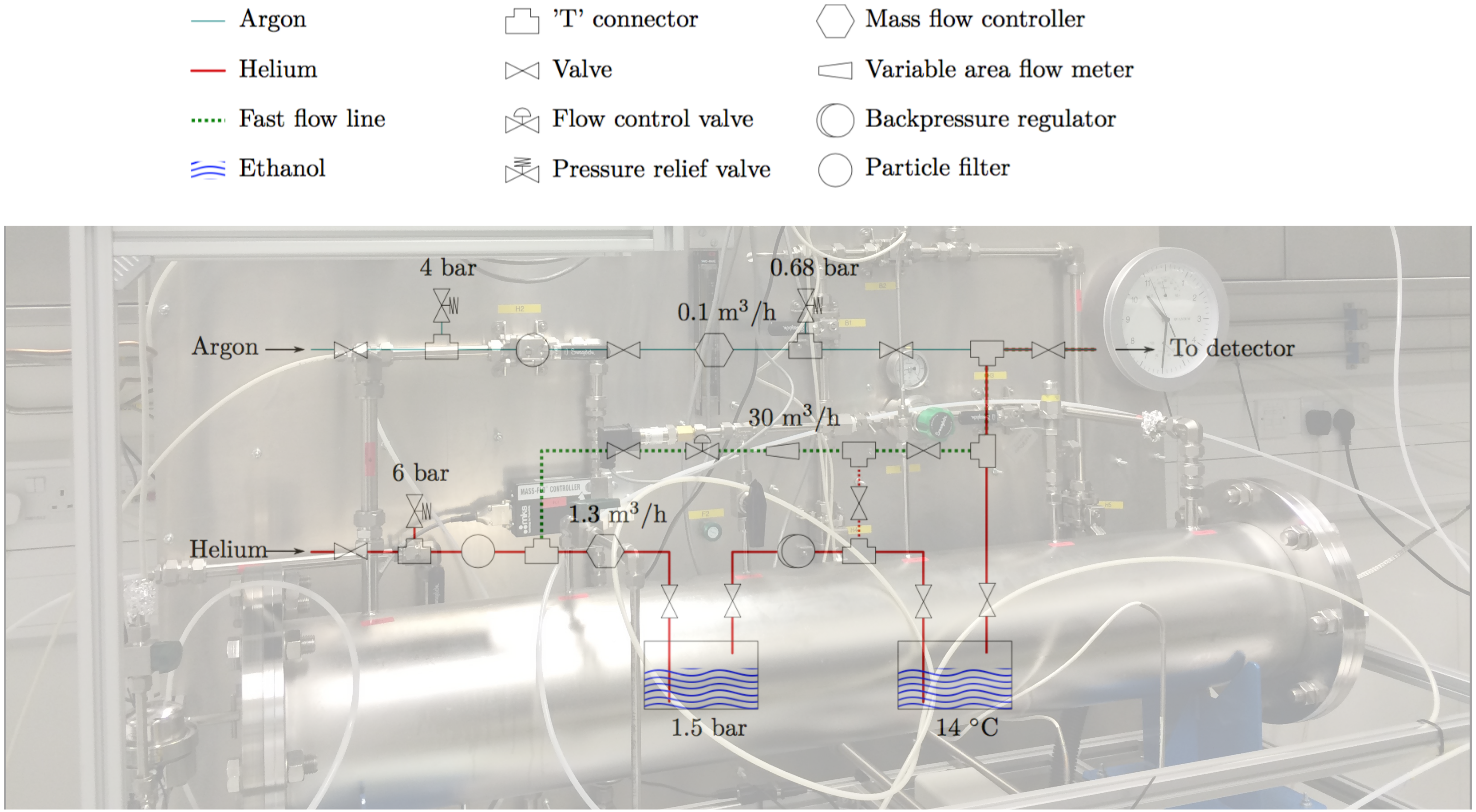
Gas System

- 95% Helium, 4% Ethanol, 1% Argon



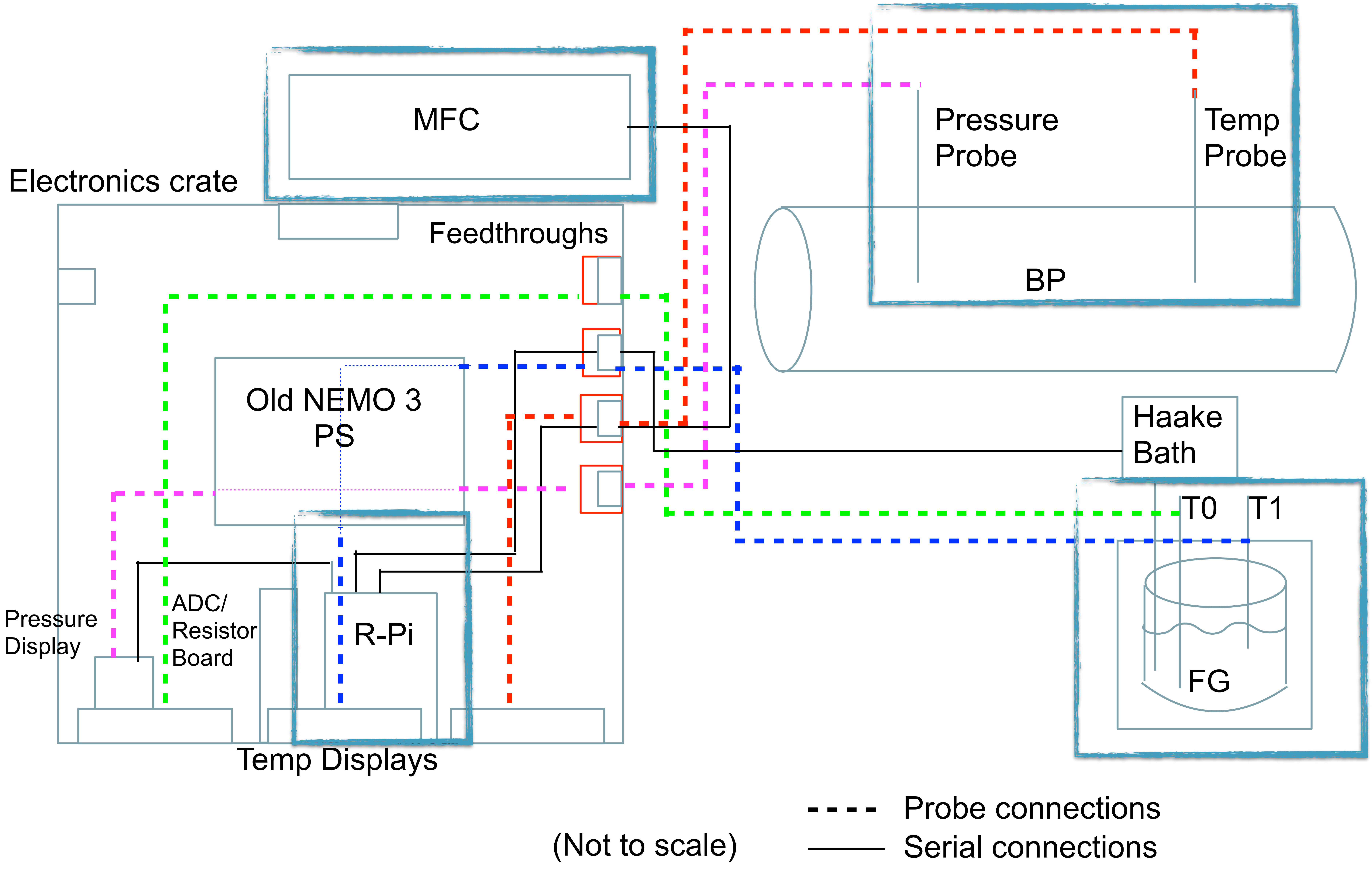
Helium - Minimises multiple scattering, reduces energy loss.

Ethanol - Quencher, prevent re-firing.

Temperature change of ~2°C, ~0.5% change in ethanol fraction. Affects hit efficiencies.

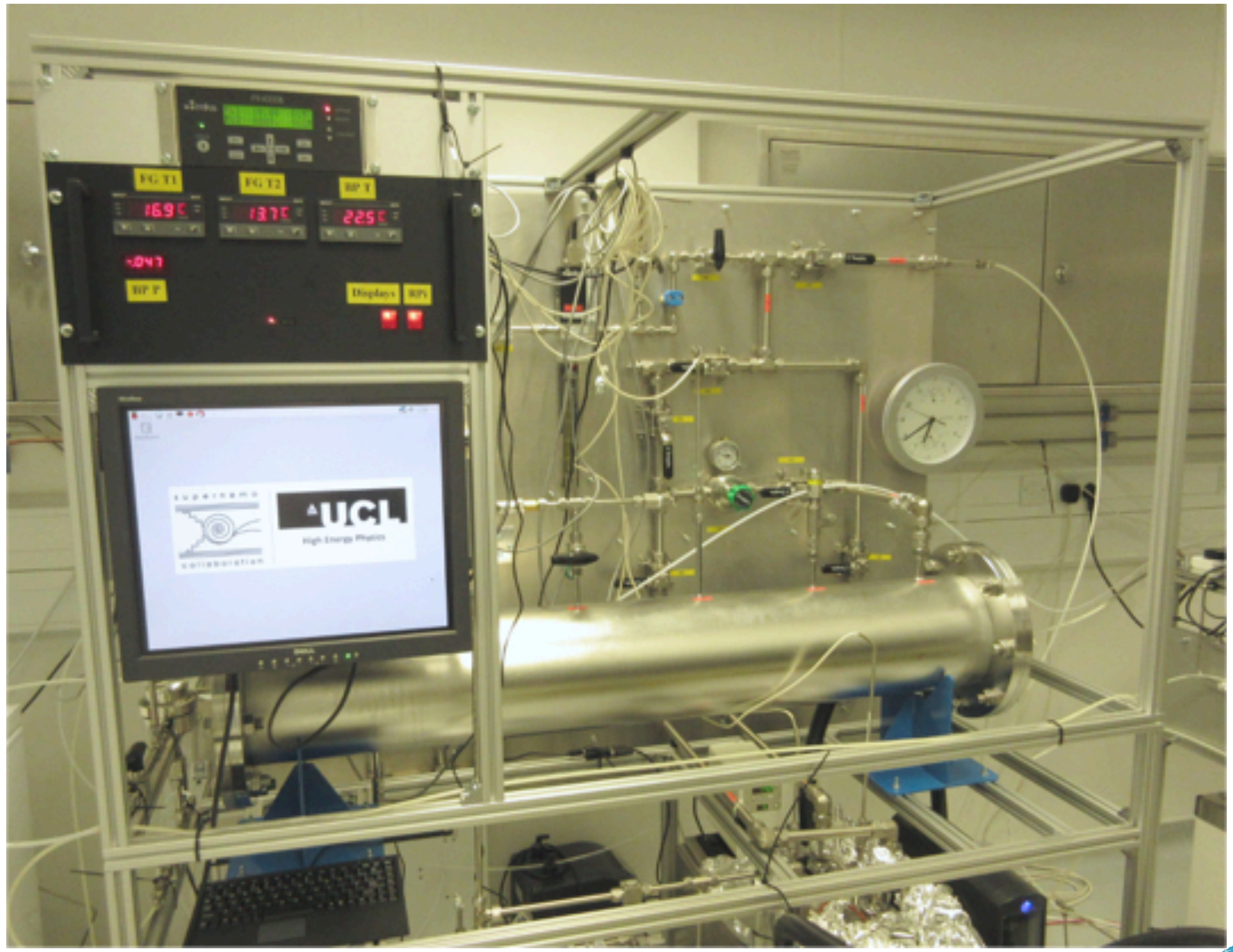
- Aim: control/monitor pressure, temperature, flow rates

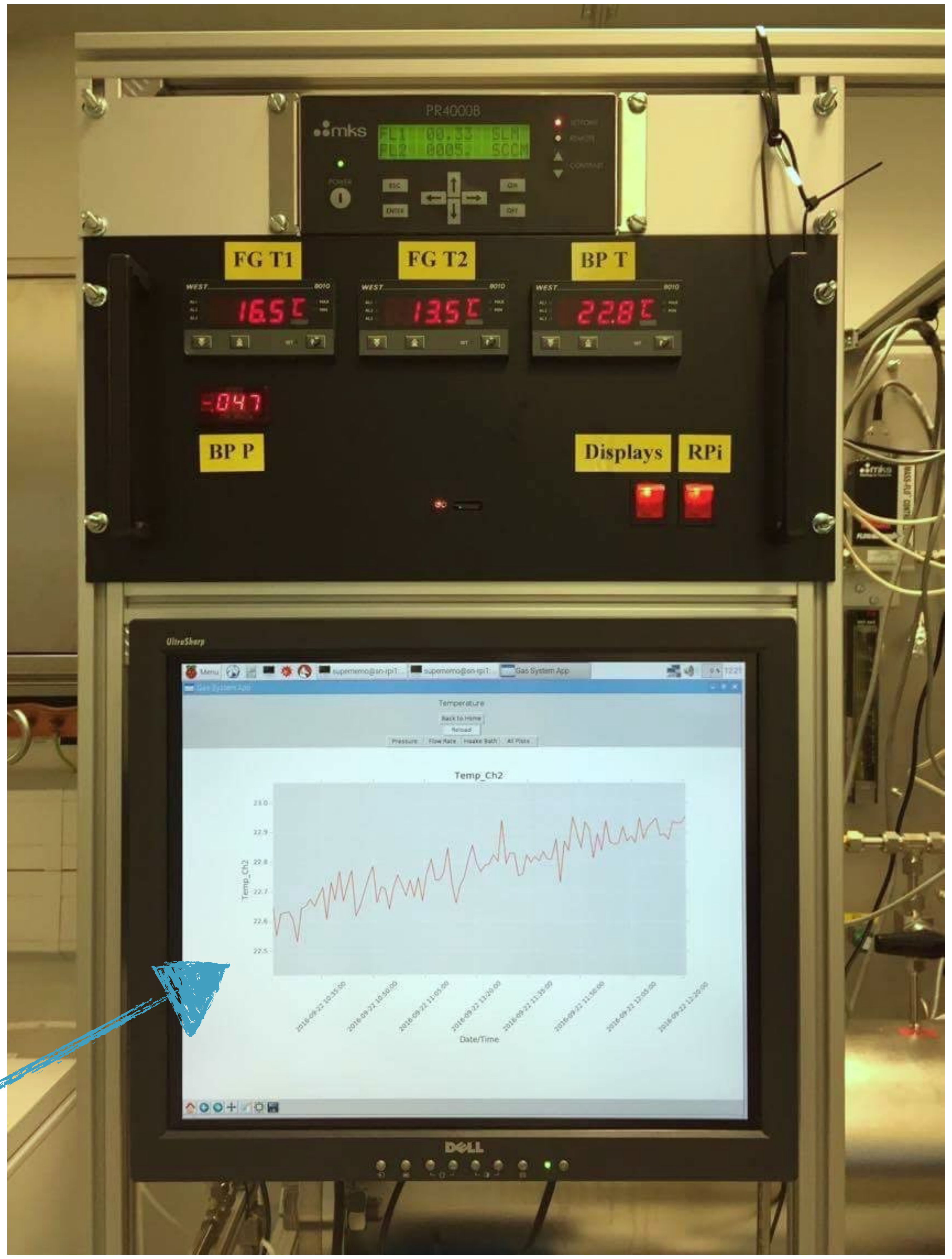
Gas System Electronics Crate



(Not to scale)

Further work on Gas System hardware





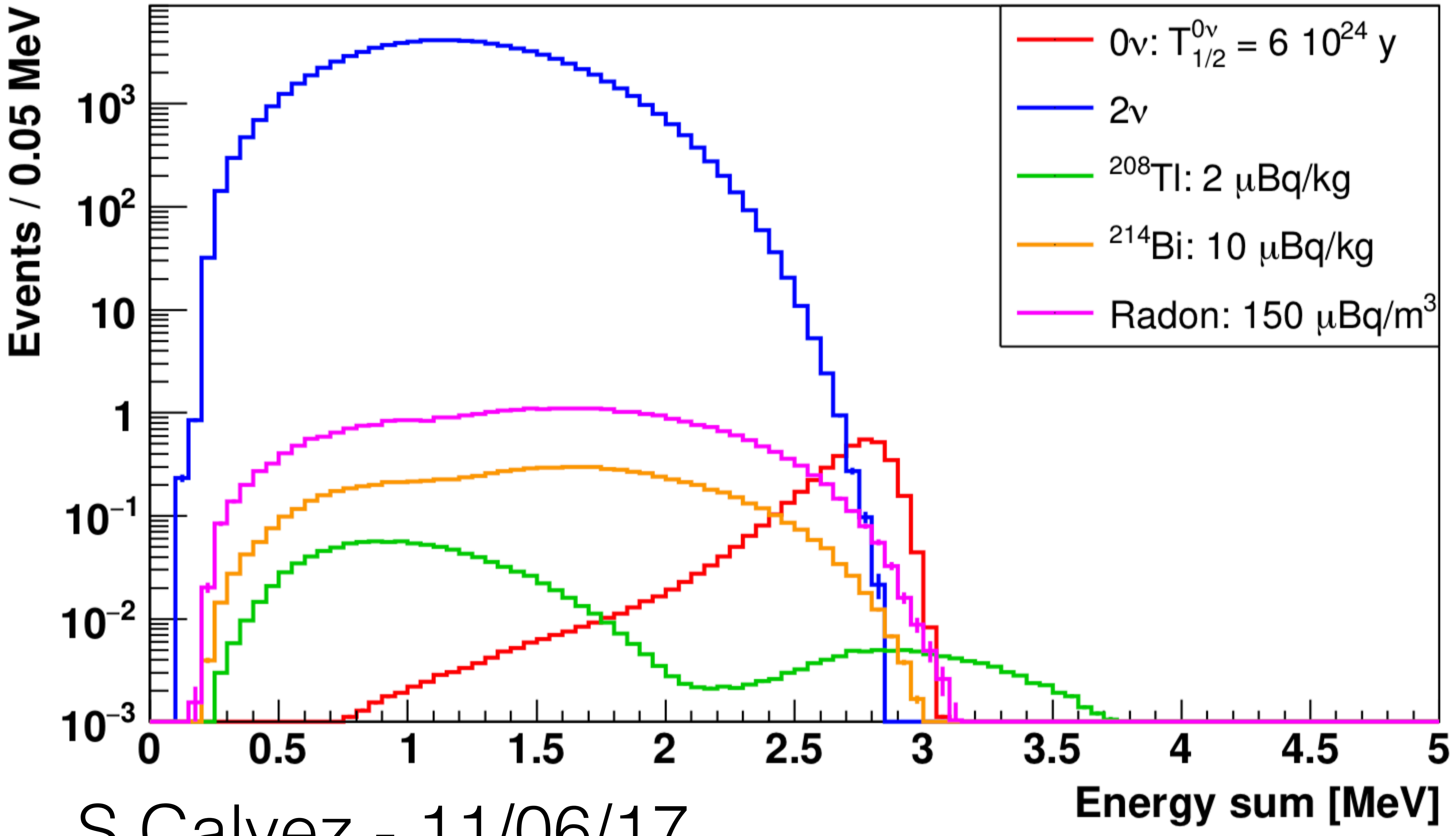
- Display installed for local monitoring

From Gas System to Backgrounds

- Reduce radon deposition in the tracker by flowing gas through the detector.
- ^{222}Rn eventually decays to ^{214}Bi which forms one of the key backgrounds to $0\nu\beta\beta$.
- Further details of radon reduction strategies in Fang Xie's talk "Radon Background Mitigation Strategy for the SuperNEMO Experiment".

What are our key backgrounds?

- ^{214}Bi, ^{208}Tl are both β decaying isotopes
- ^{214}Bi, ^{208}Tl in naturally occurring ^{238}U and ^{232}Th decay chains
- Bi - 3.27 MeV, Tl - 4.99 MeV
- Mimic 0νββ signal - Q - 2.998 MeV



S.Calvez - 11/06/17

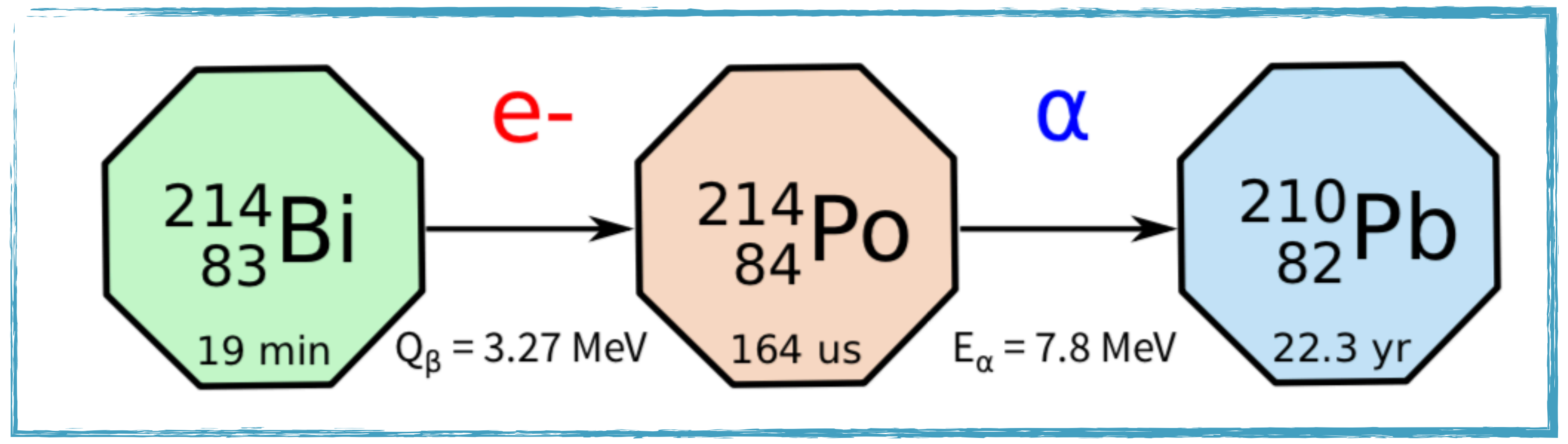
Target activities

- How much contamination from these backgrounds?
- Target activities in the foils: Bi - < 10µBq/kg, Tl - < 2 µBq/kg
- Radon - < 0.15 mBq/m³, 2mBq for demonstrator volume

Detector Property	NEMO-3	SuperNEMO
Isotope	^{100}Mo	^{82}Se
Source Mass	7 kg	100 kg
$0\nu\beta\beta$ Efficiency	18%	30%
Energy Resolution	8% @ 3 MeV	4% @ 3 MeV
^{214}Bi in foils	300 µBq/kg	10 µBq/kg
^{208}Tl in foils	100 µBq/kg	2 µBq/kg
^{222}Rn in tracker	5 mBq/m^3	0.15 mBq/m^3
$T^{0\nu}_{1/2}$ Sensitivity	10^{24} yr	10^{26} yr
$\langle m_{\beta\beta} \rangle$ Sensitivity	0.3 – 0.7 eV	40 – 100 meV

Measure ^{214}Bi activity

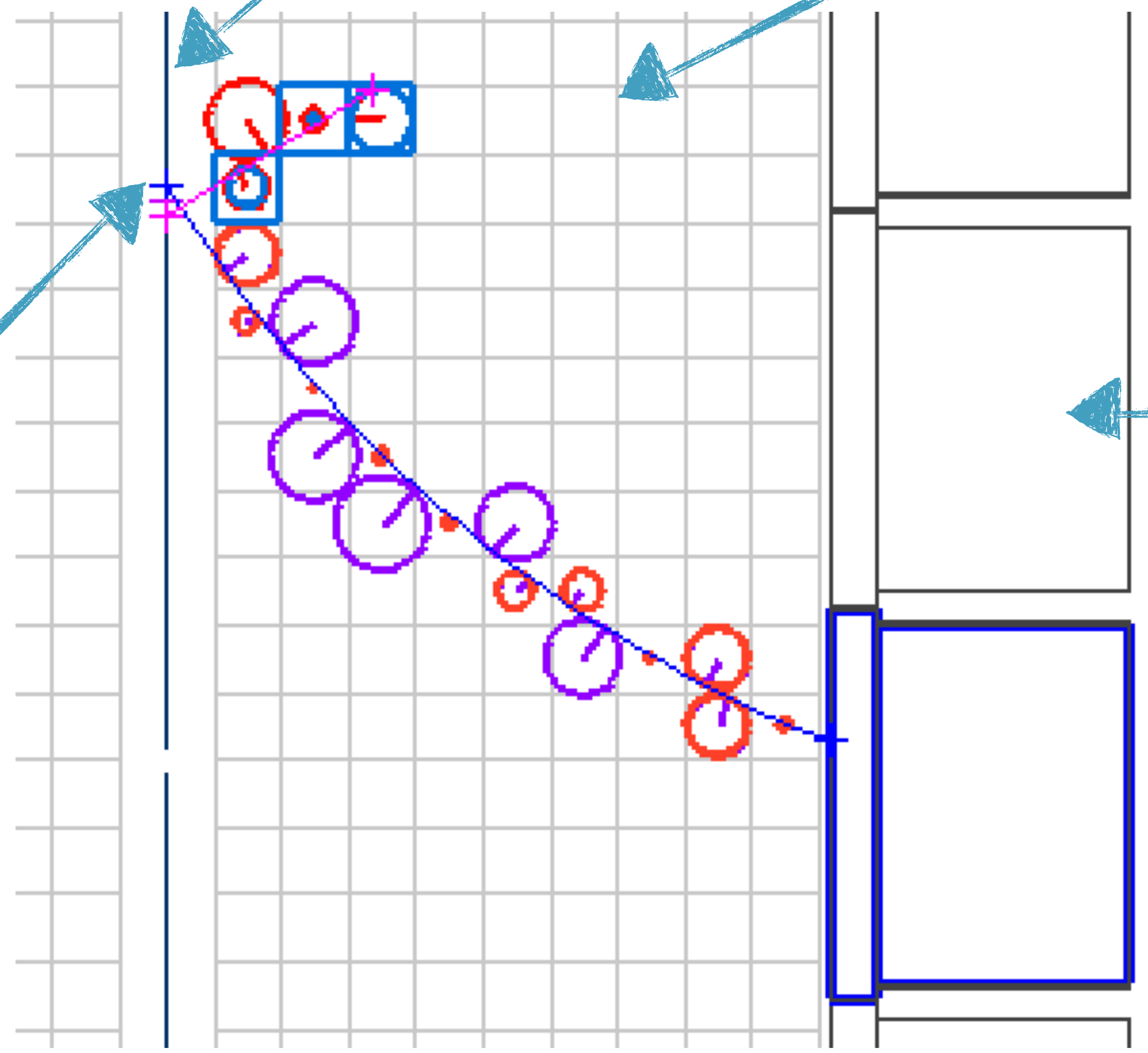
- Identify a topology that gives a clean ^{214}Bi sample - 1e1α topology



1e1α events 1 electron, 1 alpha and N gammas (N>=0)

Source foil

Tracker cells



Calorimeter optical module

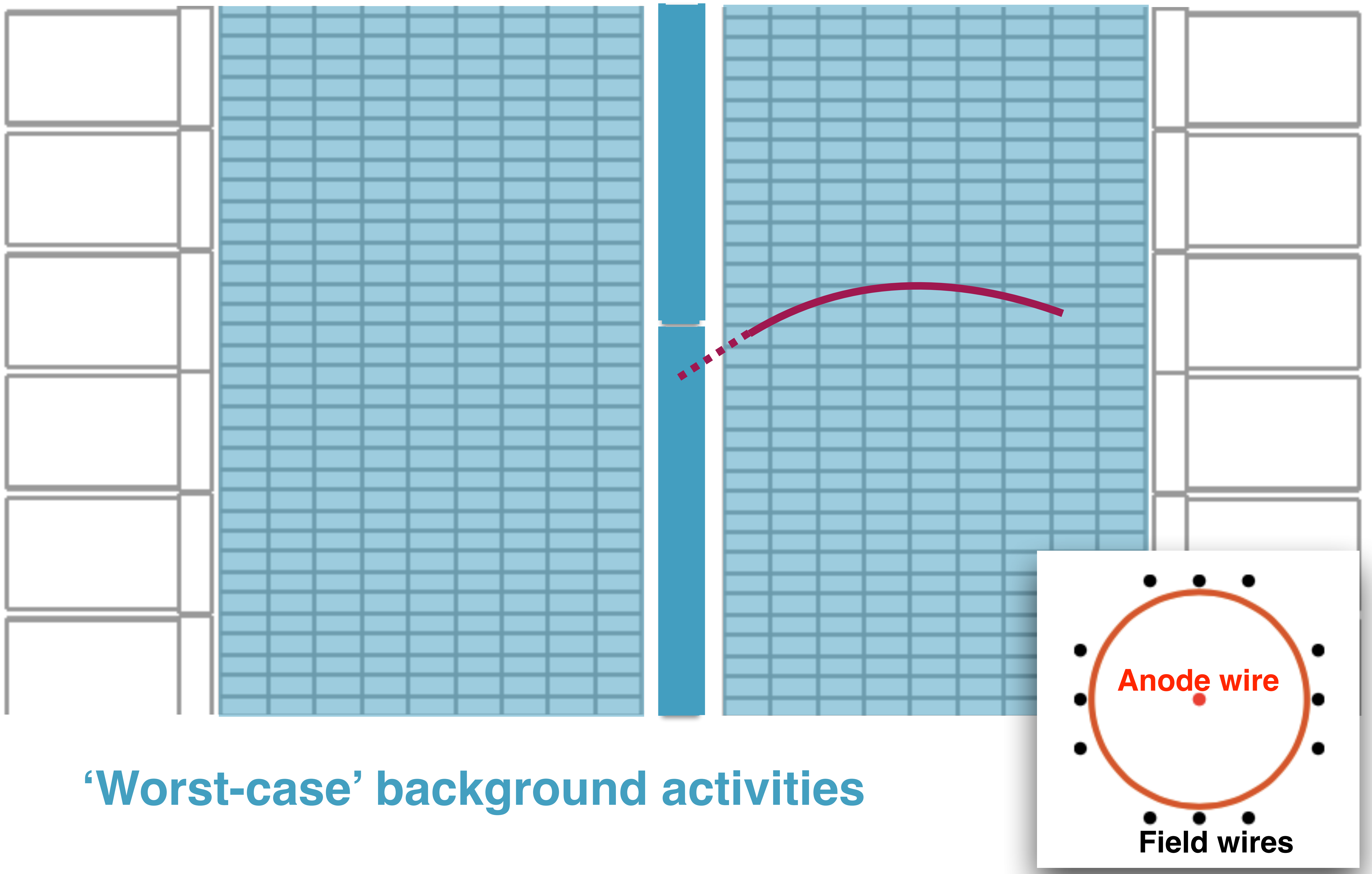
with a reconstructed vertex on the foil

UCL

Measure ^{214}Bi activity

- Identify a topology that gives a clean ^{214}Bi sample - 1e1α topology
- Identify detector regions that contribute to reconstructed sample

Assuming 7 kg isotope - Demonstrator



'Worst-case' background activities

Source foil bulk: estimated **15.4 mBq** from BiPo 'upper limit' (target 70 μBq).

- ^{214}Bi contamination of foils from natural ^{238}U decay chain

Source foil surface: estimated **0.18 mBq**

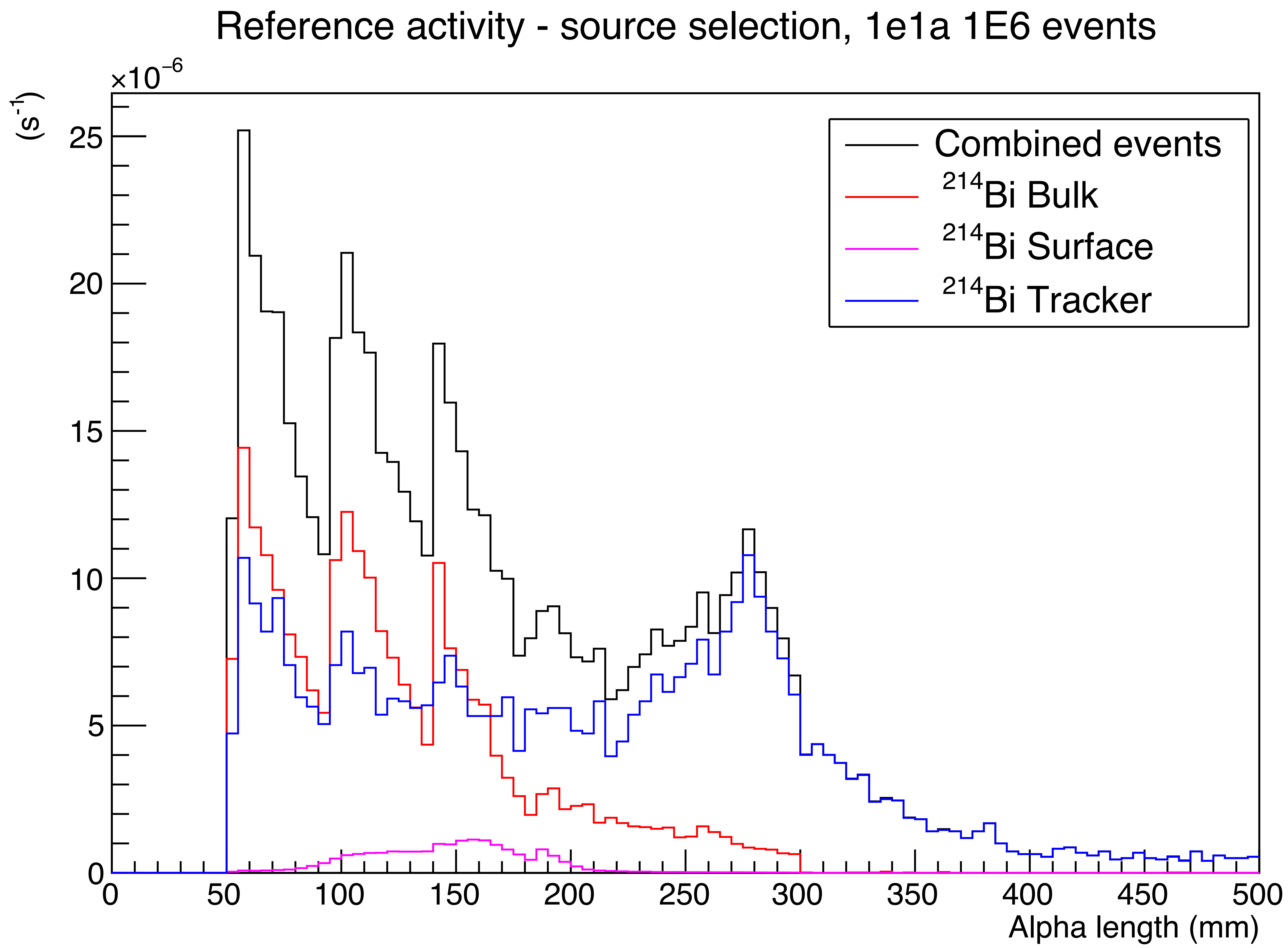
- ^{214}Bi contamination of mylar wrapper from natural ^{238}U and ^{232}Th decay chains
- Bi deposited from Rn in tracker

Radon in tracker: estimated **45.5 mBq** (before flow rate suppression, expected to meet target - 2.4 mBq for demonstrator.)

- Positive ^{214}Bi ions from Rn decay are deposited on field shaping wires
- Impossible to distinguish activity in first tracker layer from activity in foil

Measure ^{214}Bi activity

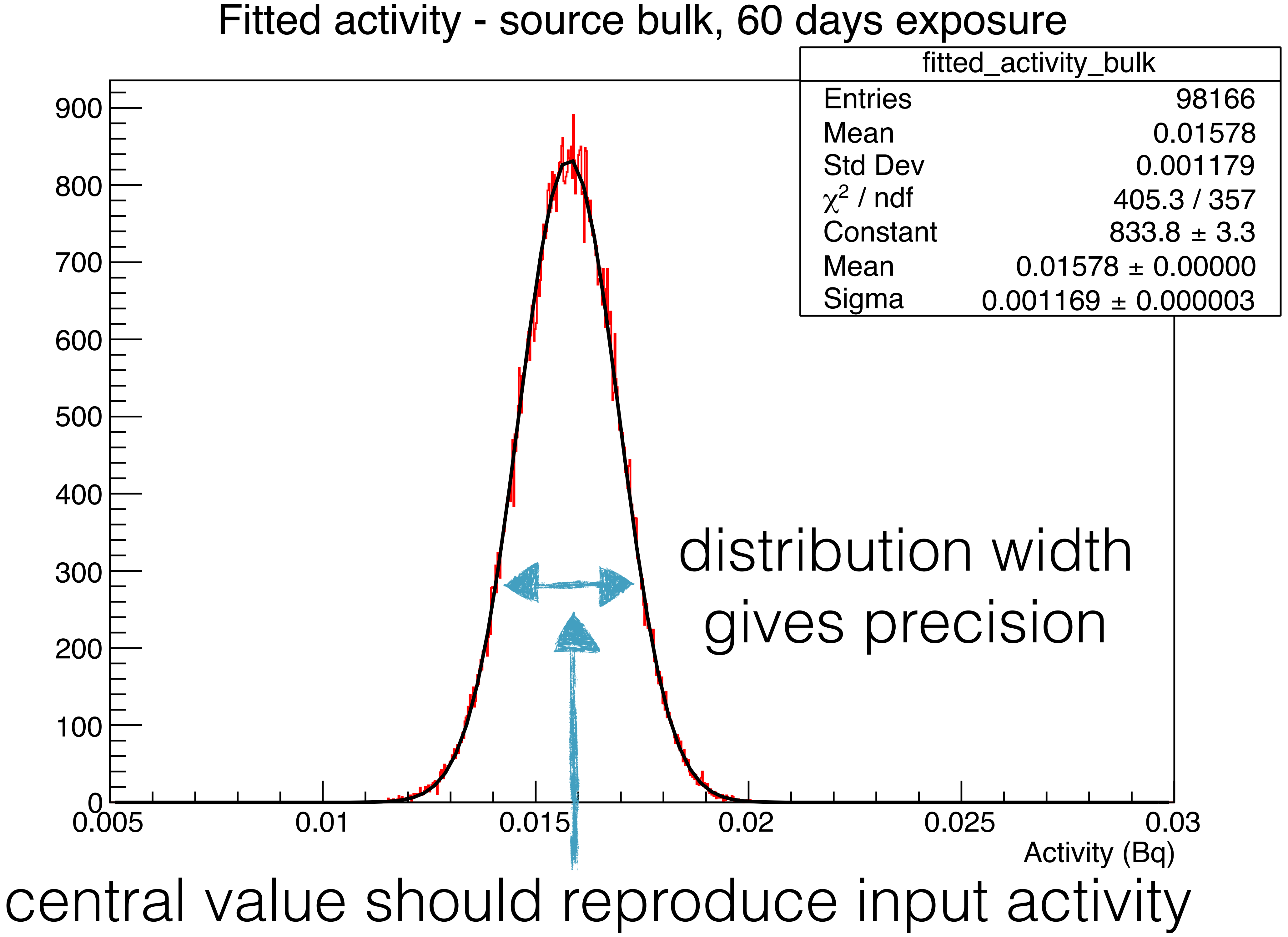
- Identify a topology that gives a clean ^{214}Bi sample - 1e1α topology
- Identify detector regions that contribute to reconstructed sample
- Find a variable in which each sample has a distinctive shape



alpha particle track lengths for foil bulk, surface, and tracker wires

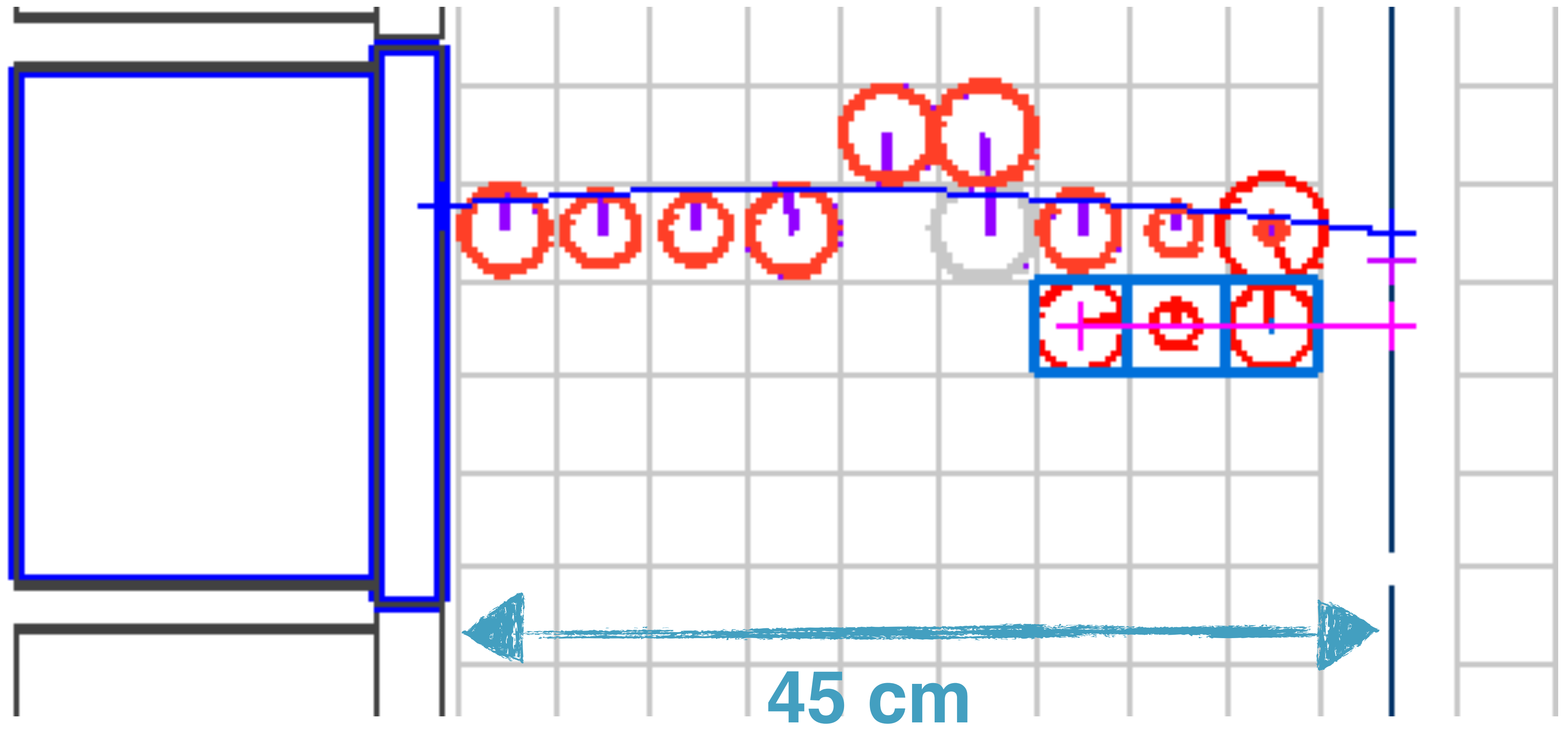
Measure ^{214}Bi activity

- Identify a topology that gives a clean ^{214}Bi sample - 1e1α topology
- Identify detector regions that contribute to reconstructed sample
- Find a variable in which each sample has a distinctive shape
- Generate pseudo data from a combination of each sample, fit for the fractional contributions of each, and check we can reproduce the activities
- How long must we run to achieve acceptable precision on our measured activity?



Measure ^{214}Bi activity

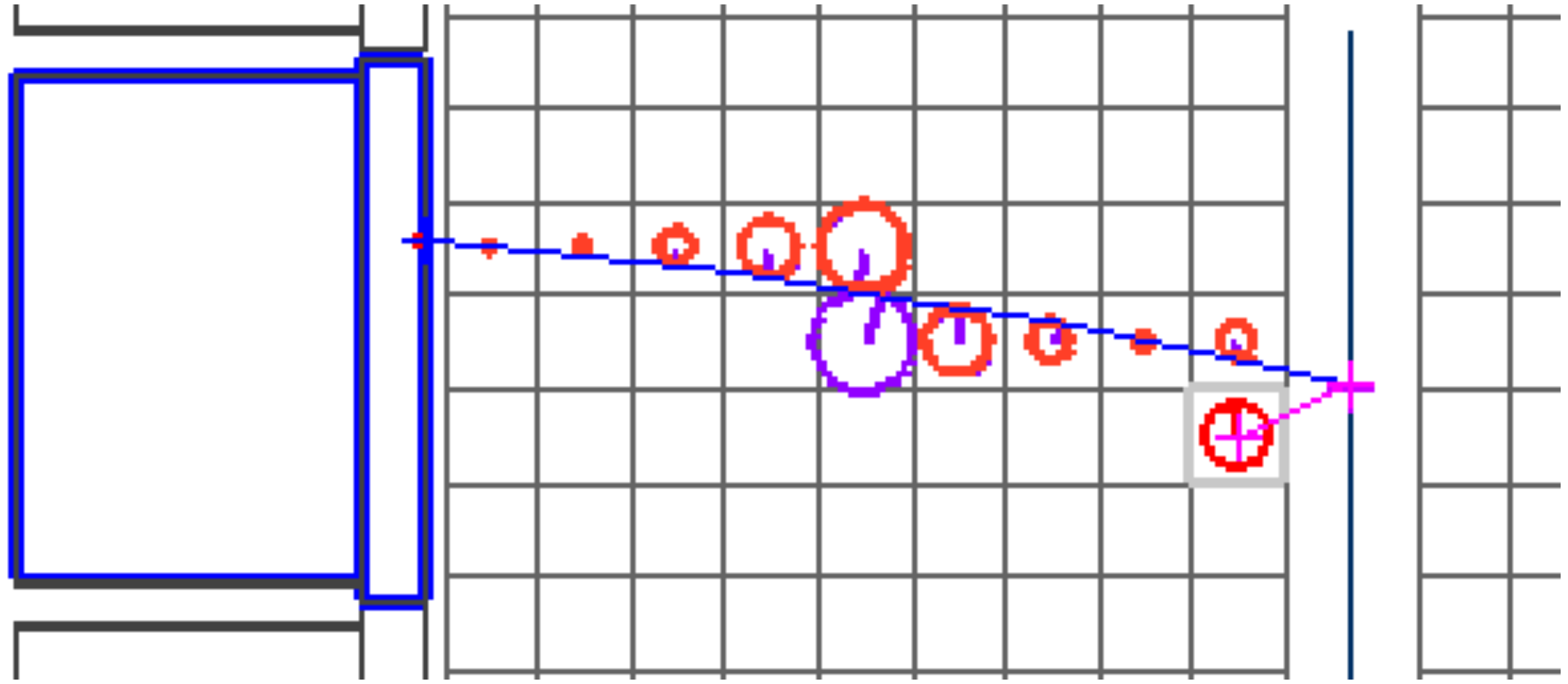
- Identify a topology that gives a clean ^{214}Bi sample
- Identify detector regions that contribute to reconstructed sample
- Find a variable in which each sample has a distinctive shape
- Generate pseudo data from a combination of each sample, fit for the fractional contributions of each, and check we can reproduce the activities
- How long must we run to achieve acceptable precision on our measured activity?
- Once we have a reliable ^{214}Bi activity measurement, we can use that to constrain the ^{208}Tl activity from a distribution where both contribute.



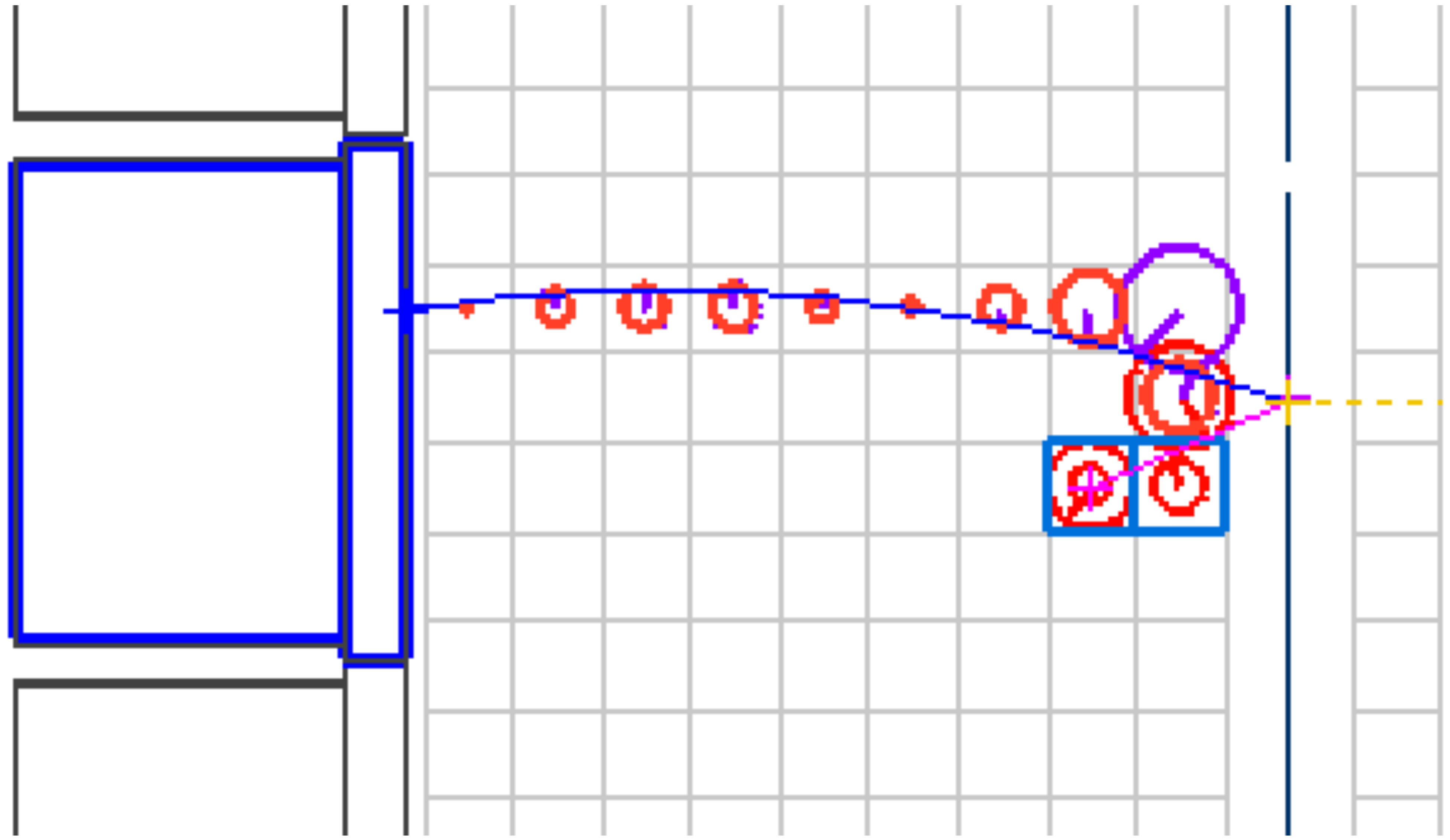
Alphas: short, straight, delayed tracks, not reaching the calorimeter wall.

'Long' alphas (>2 hits) are clustered and fitted by a standard module in the pipeline. Track fitted from the centre of the furthest delayed cell back to the foil (if there is a hit in the first layer).

Short alphas (1-2 hits) cannot be fitted so are dealt with by a custom module 'Alpha Finder'.



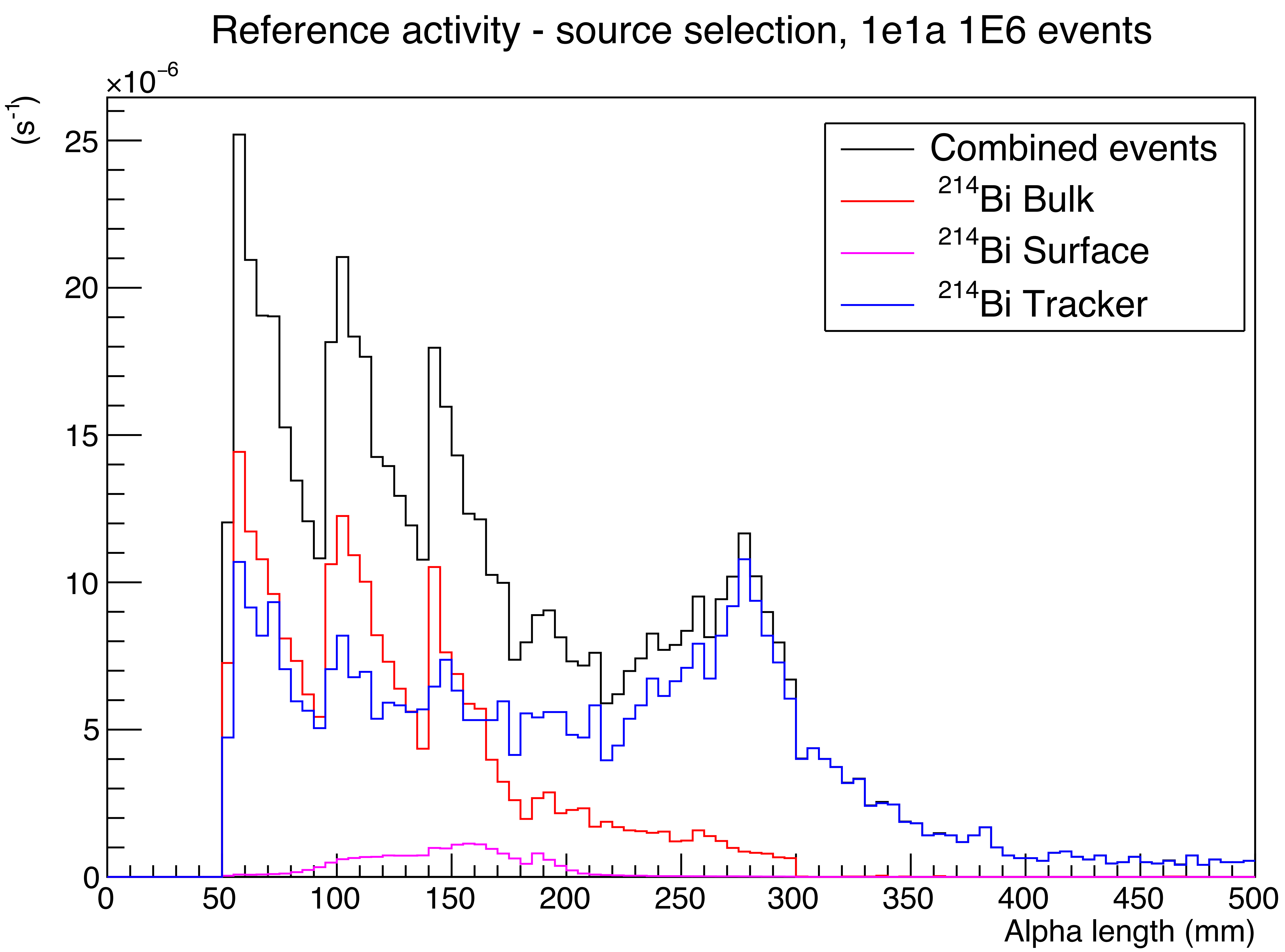
1 delayed hit: Track is fitted from centre of delayed cell to the vertex extrapolation of the prompt track



2 delayed hits: Track is fitted from centre of the furthest delayed cell to the vertex extrapolation of the prompt track

In both cases a prompt track is required.

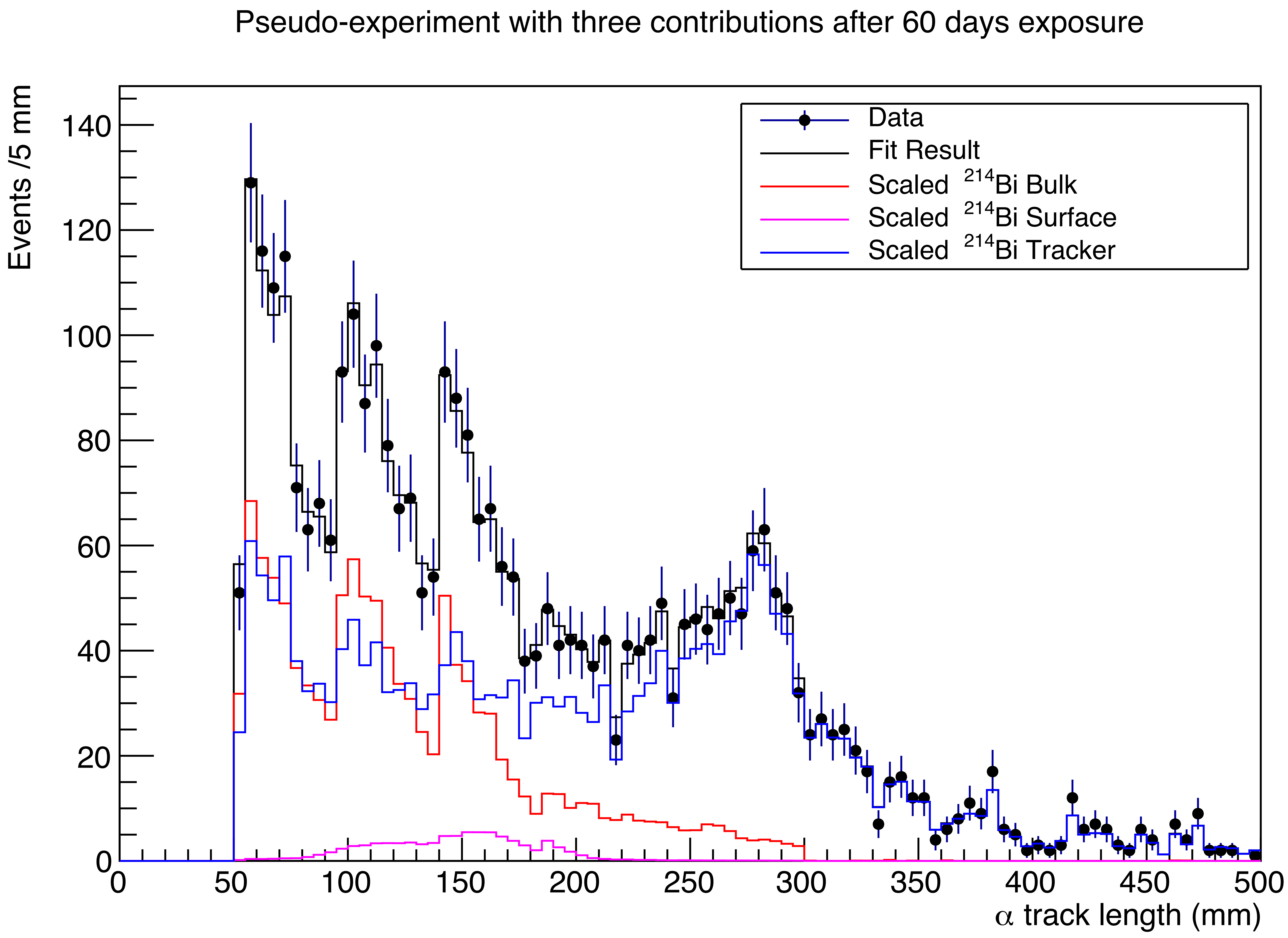
Individual contributions normalised by activity



A_{bulk} = 15.4 mBq, A_{surf} = 0.18 mBq, A_{track} = 45.5 mBq

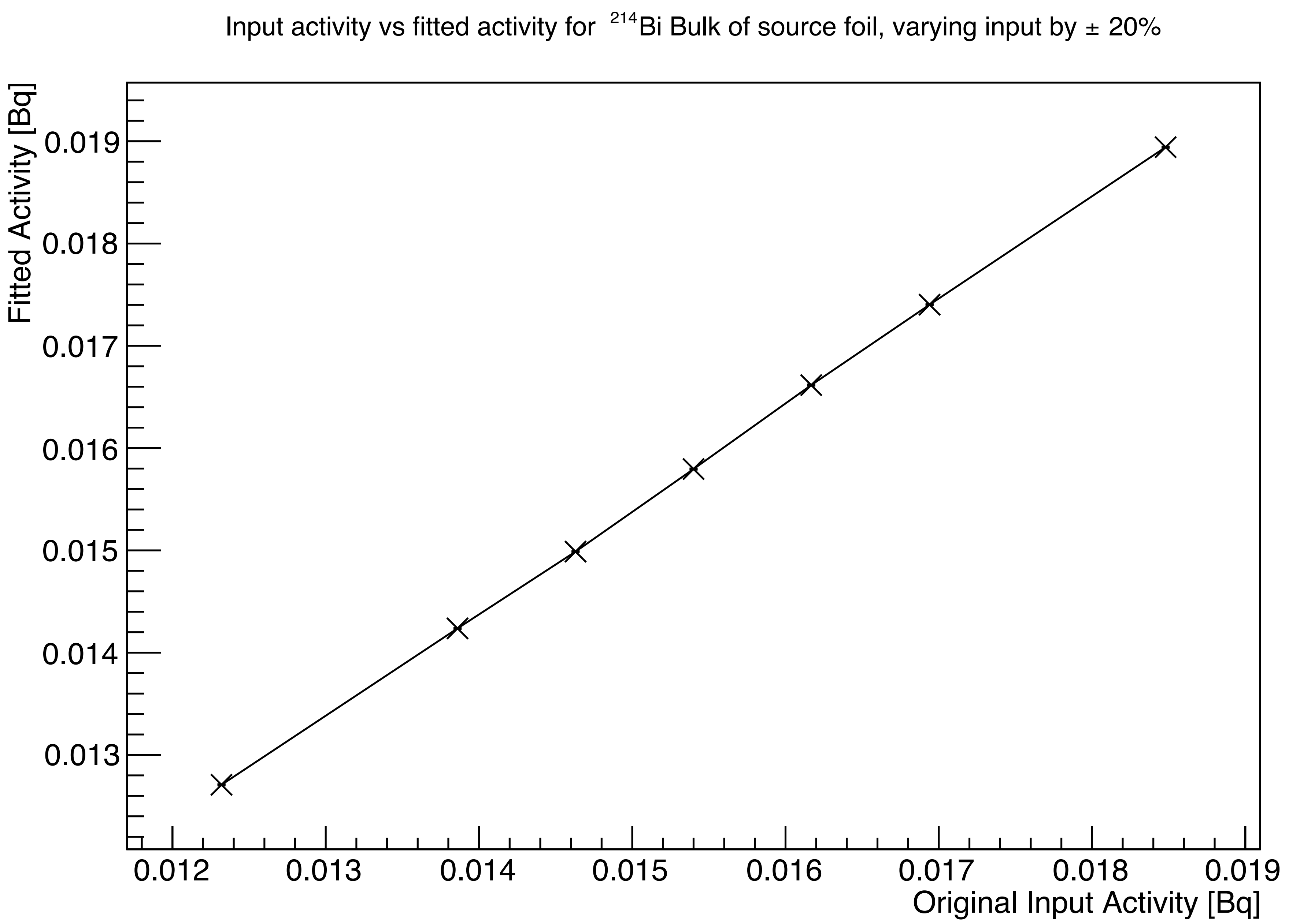
Showing individual contributions from bulk, surface and wires

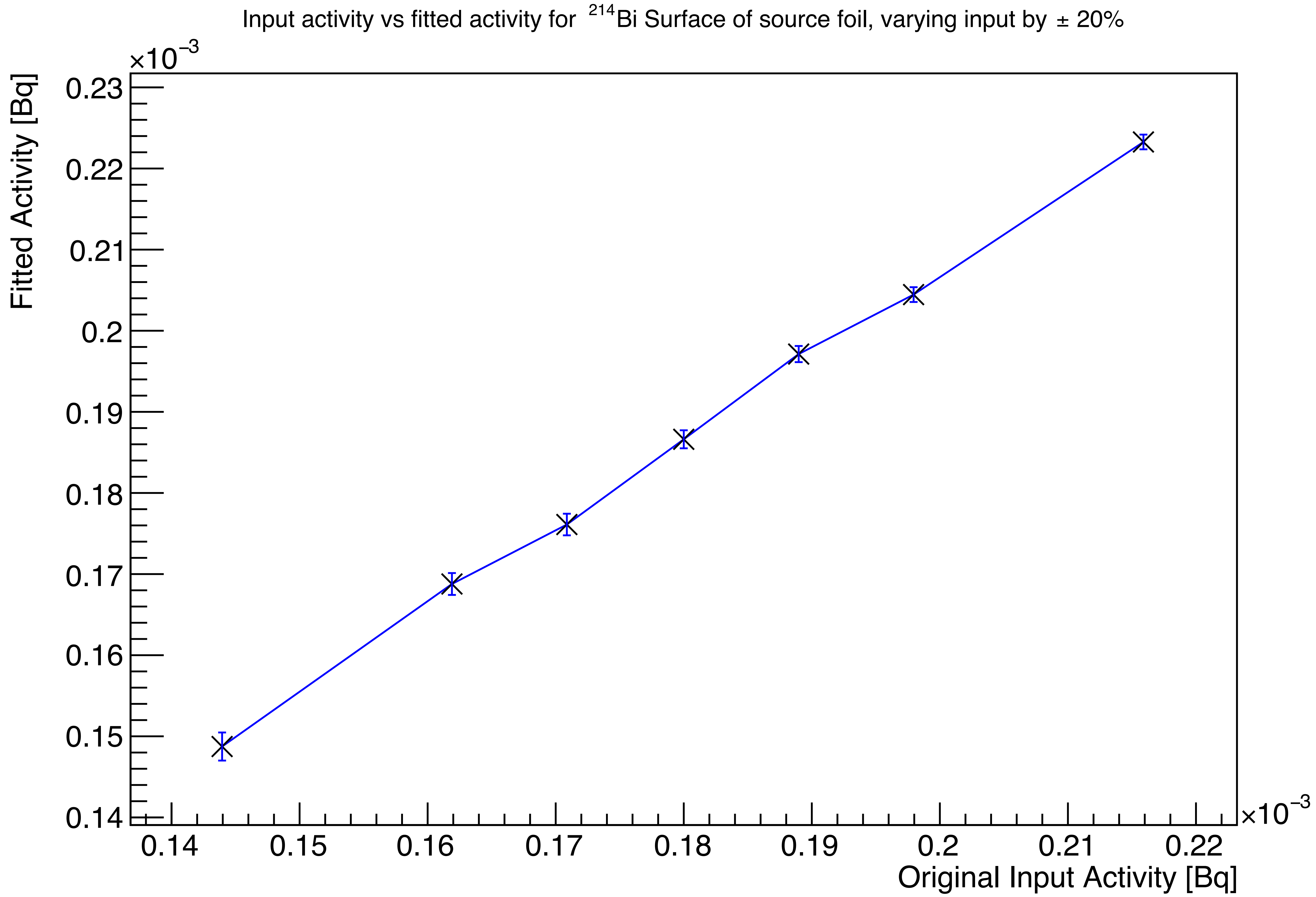
Pseudo Experiment

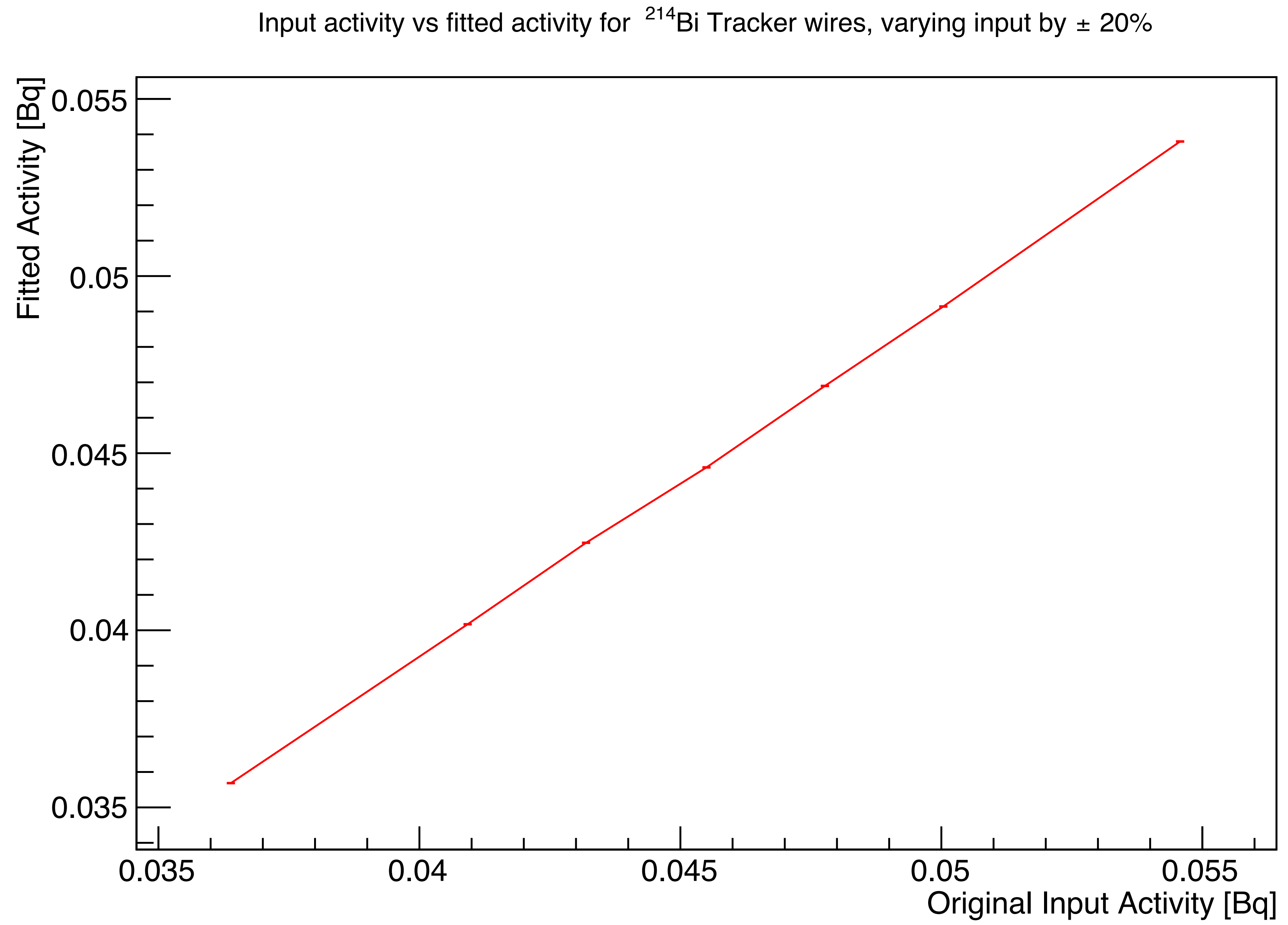


A_{bulk} = 15.4 mBq, A_{surf} = 0.18 mBq, A_{track} = 45.5 mBq

Input vs output activity



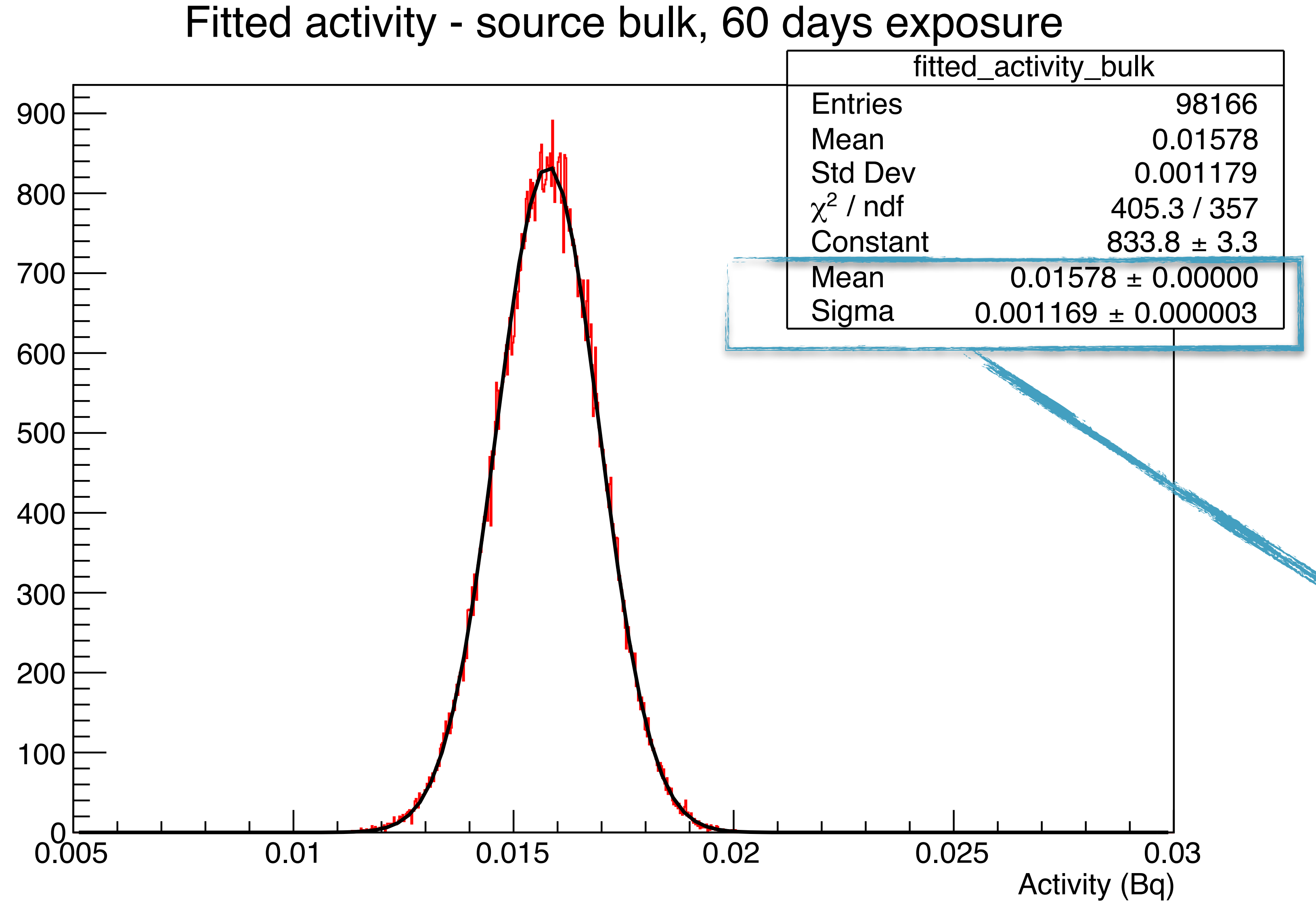


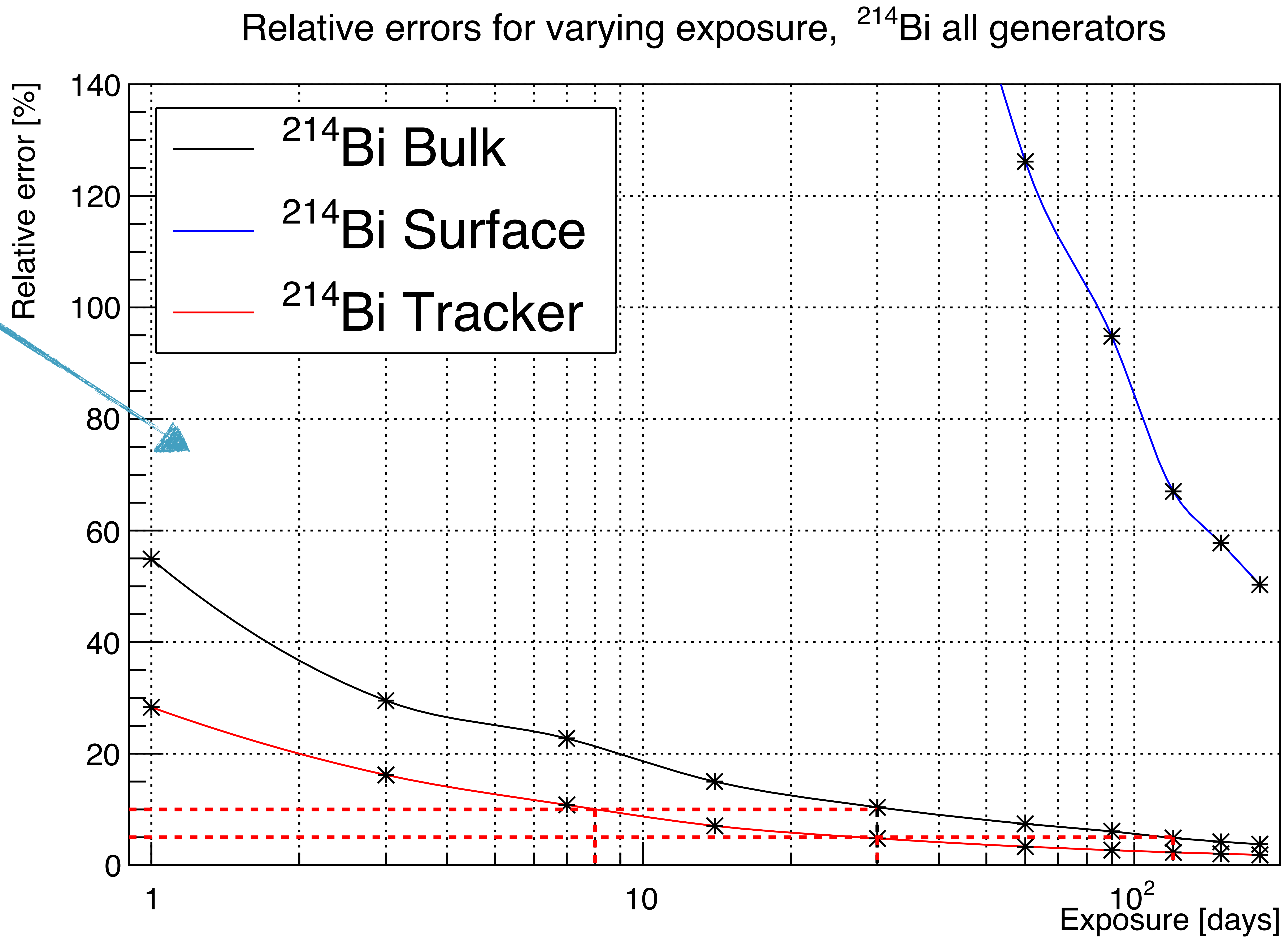


- Varied input activities by ± 20%, check quality of fit.
- Exposure 180 days.

Relative errors σ/μ

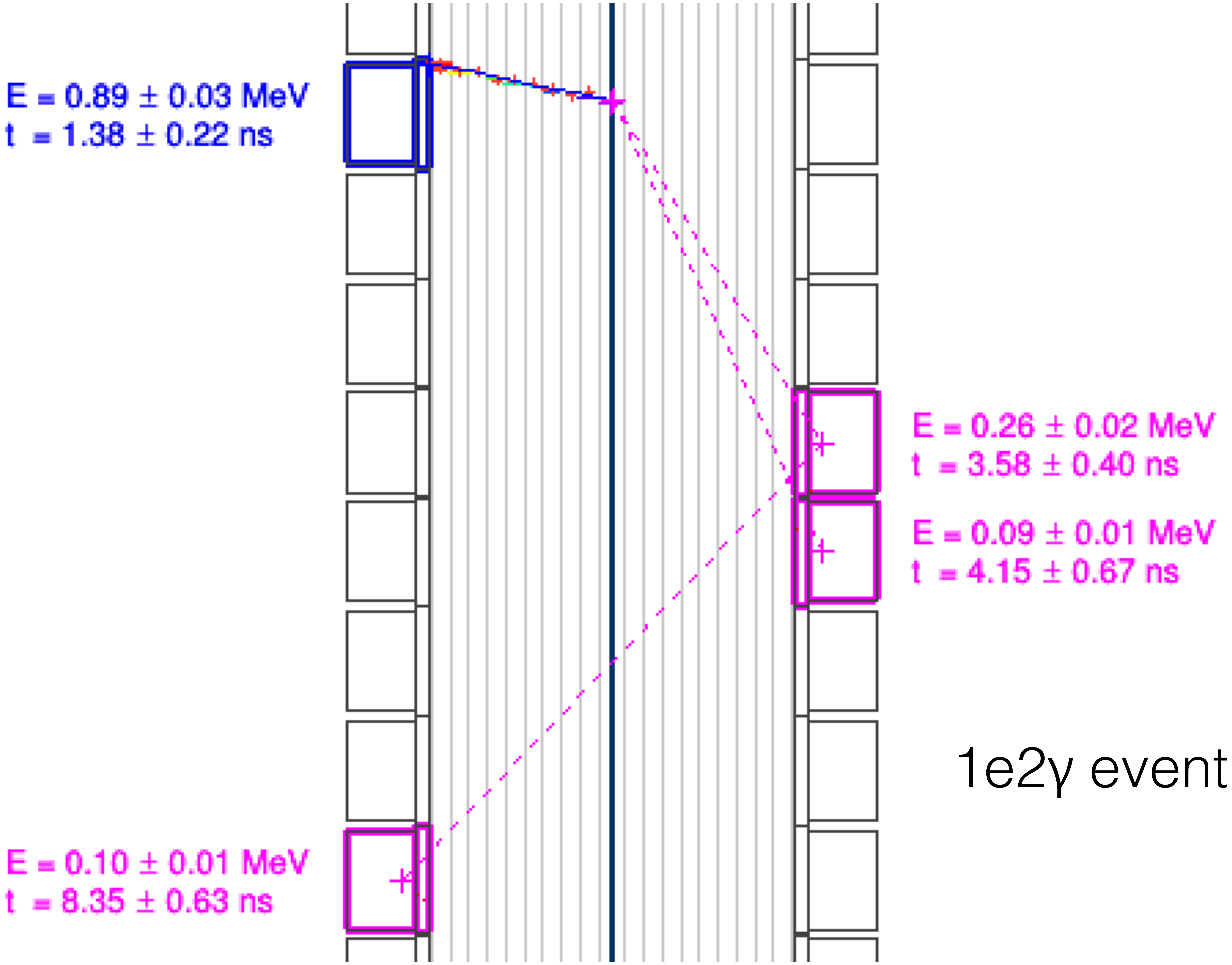
σ/μ from the distribution of the outputted activities.





10% :
8 days Tracker
30 days Bulk

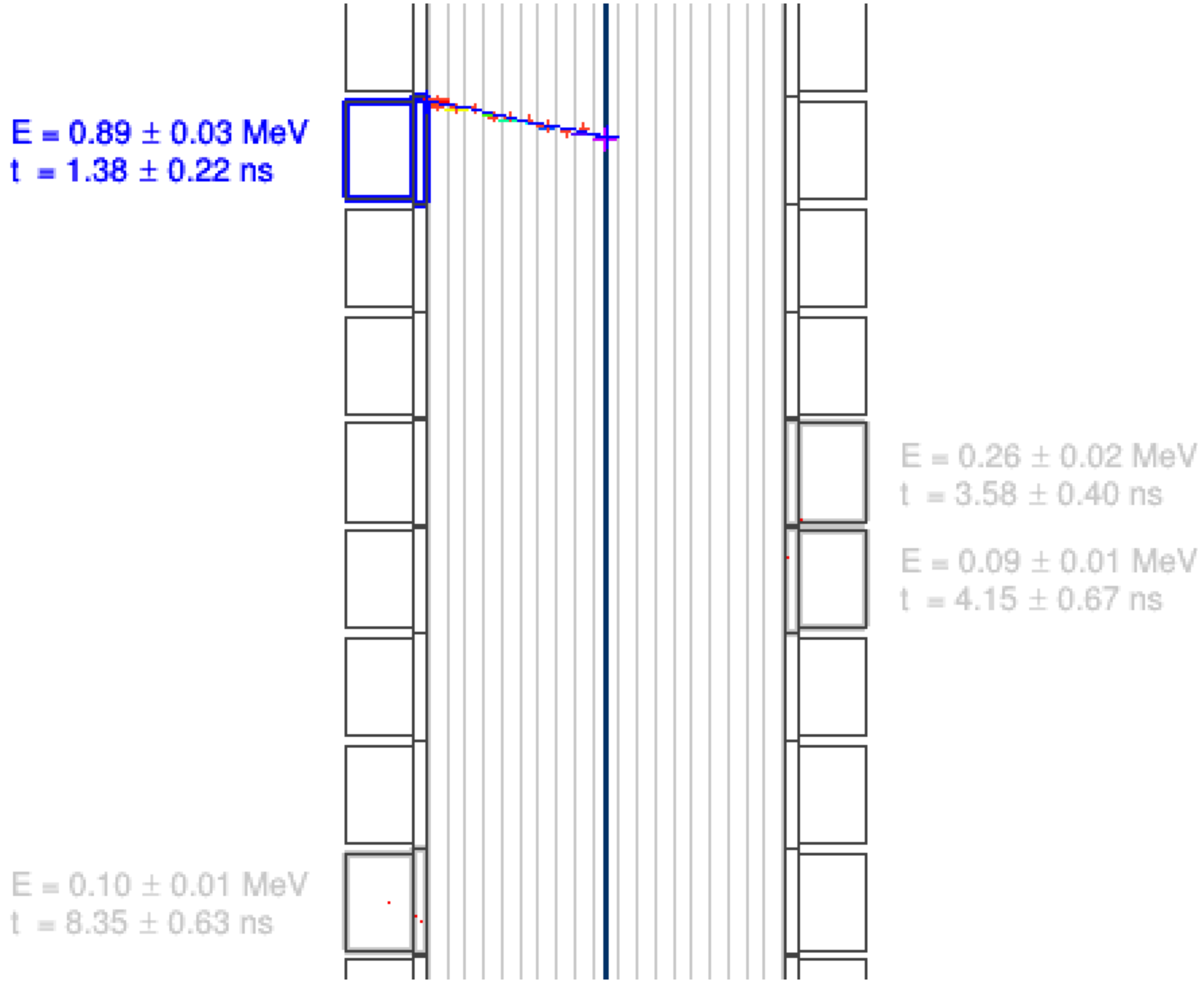
1eNγ topology - event has 1 electron, no alphas and N gammas (N>0)

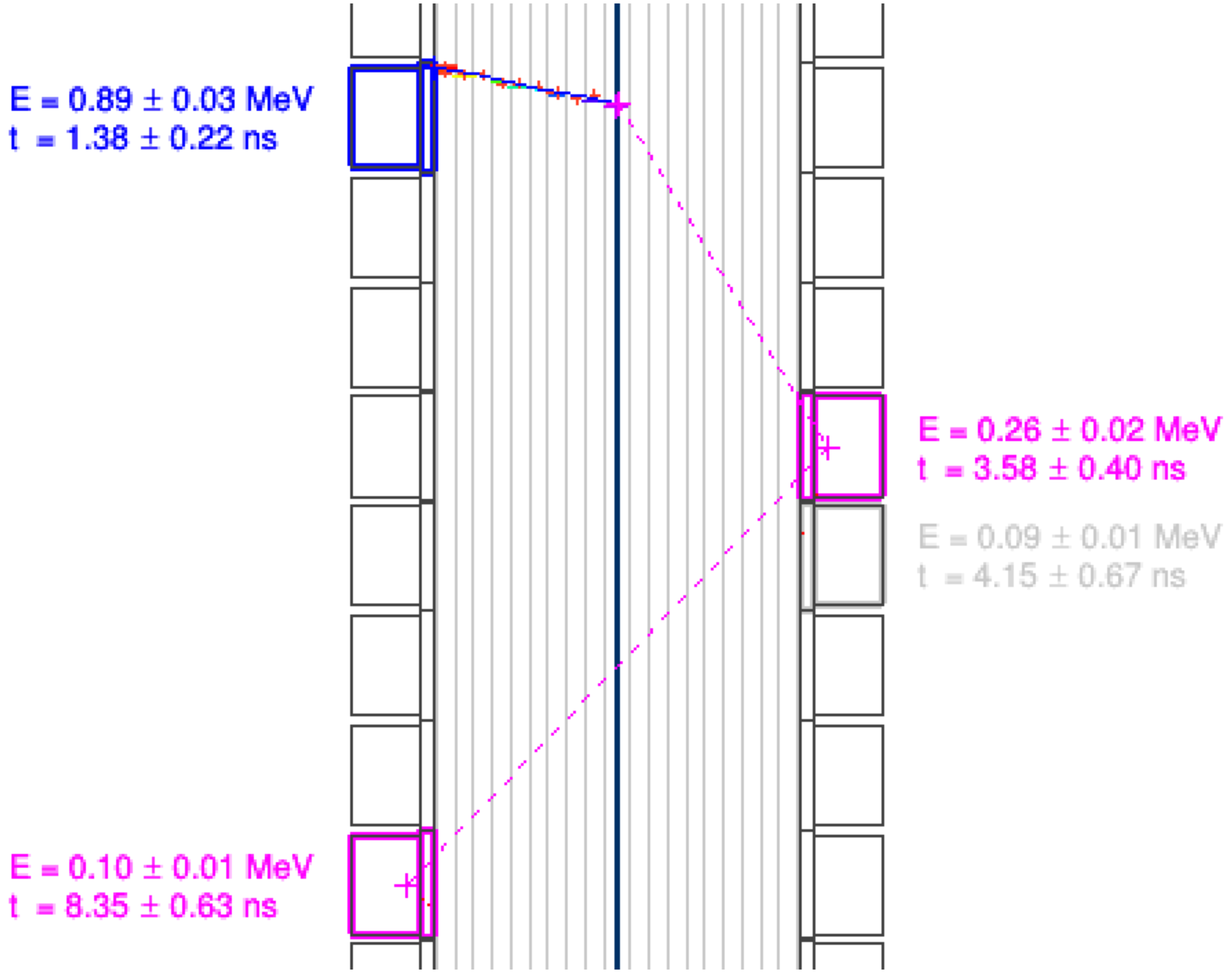


1e2γ event

Gamma Identification

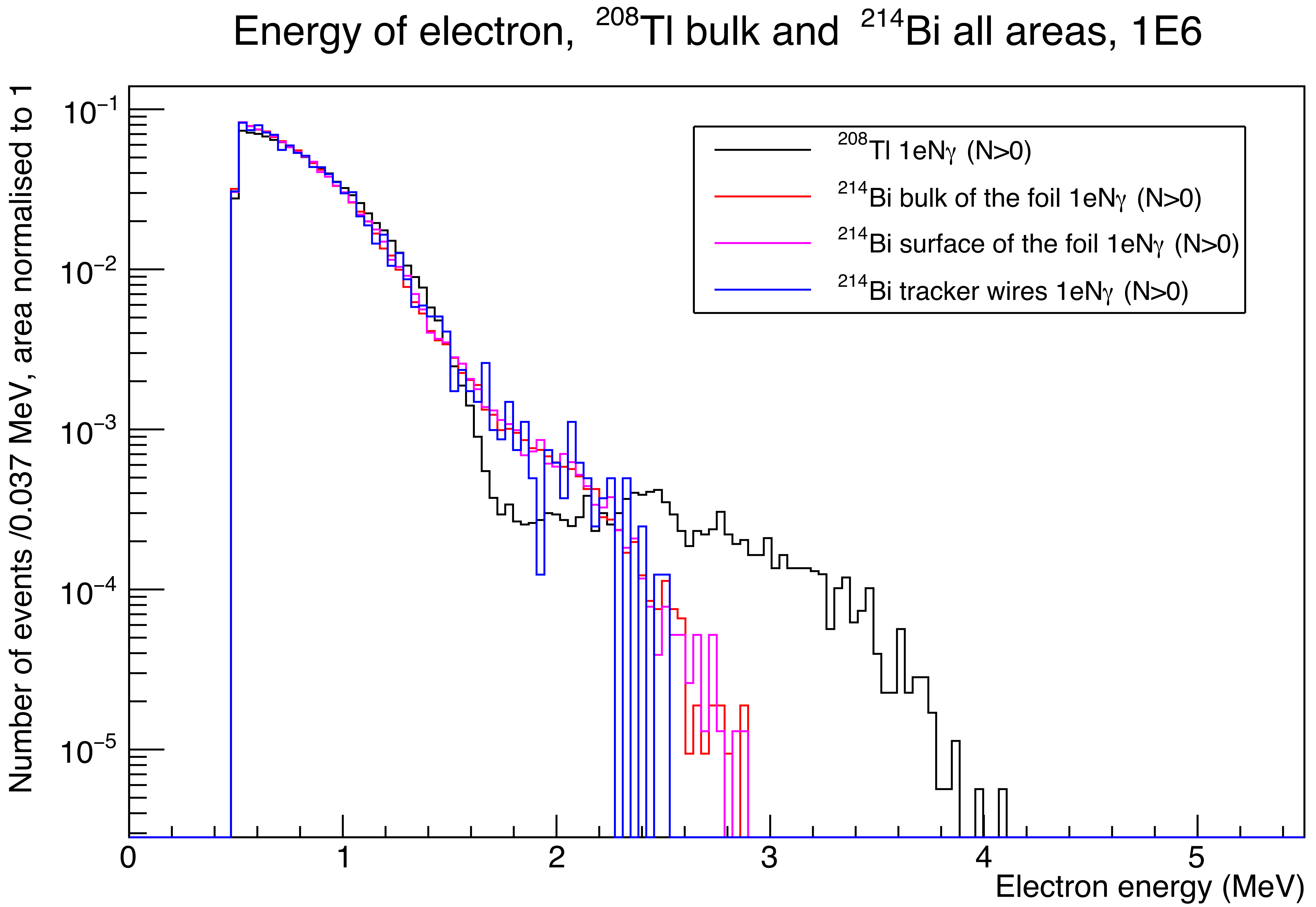
Isolated calorimeter hits



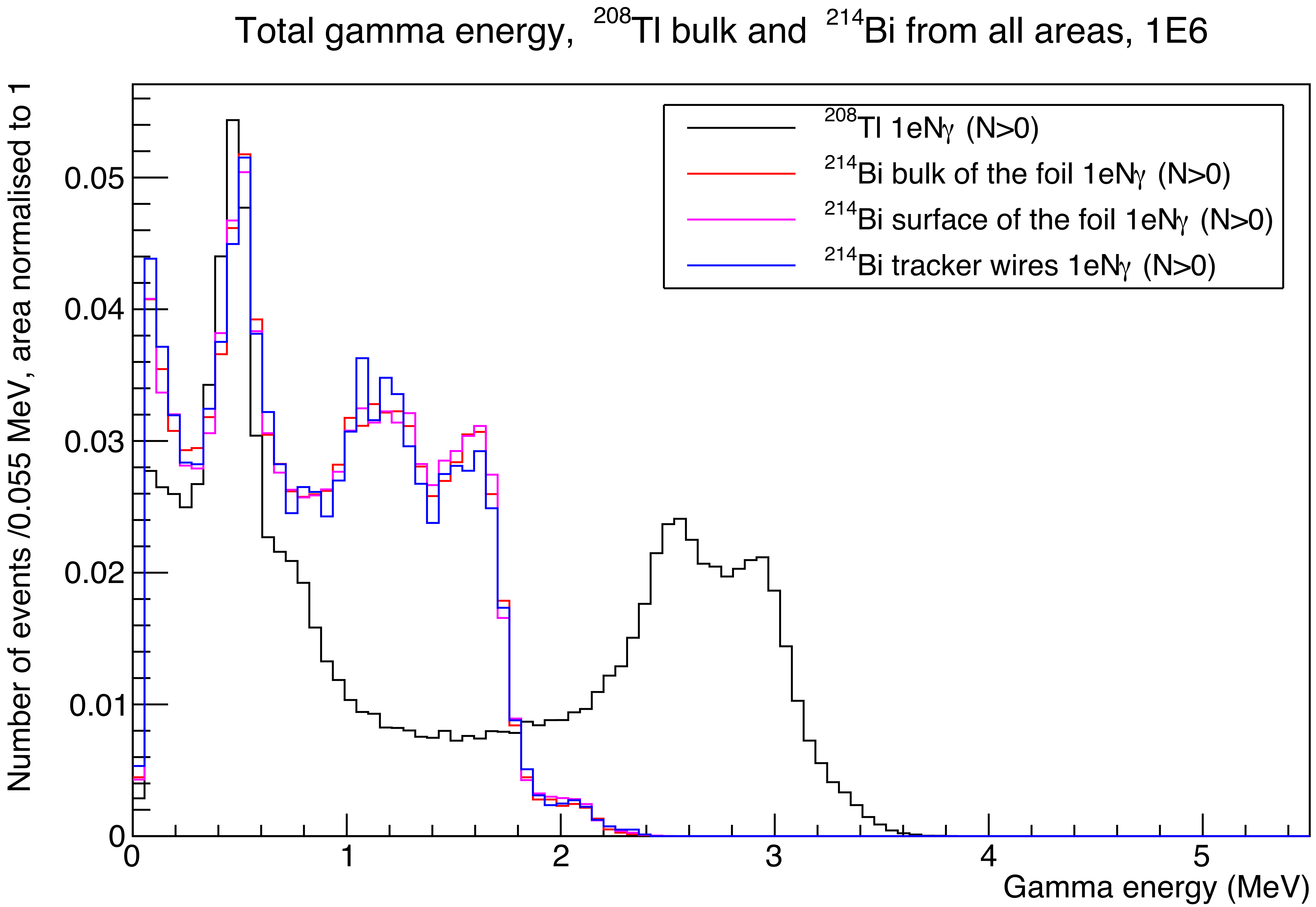


Hits chained if it is possible for a gamma to traverse this distance in the times found

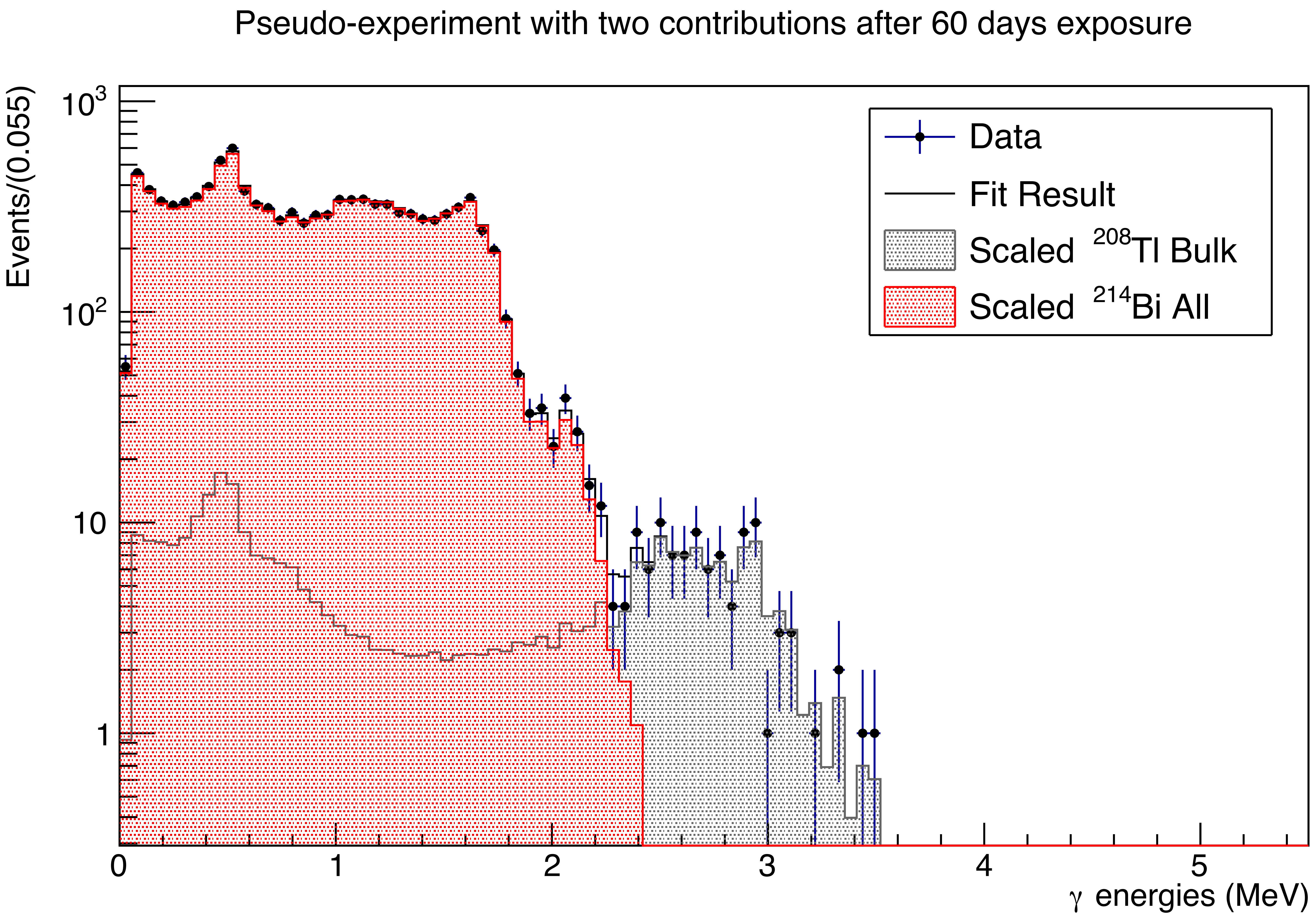
^{208}Tl Electron Energy



^{208}Tl Total Gamma Energy



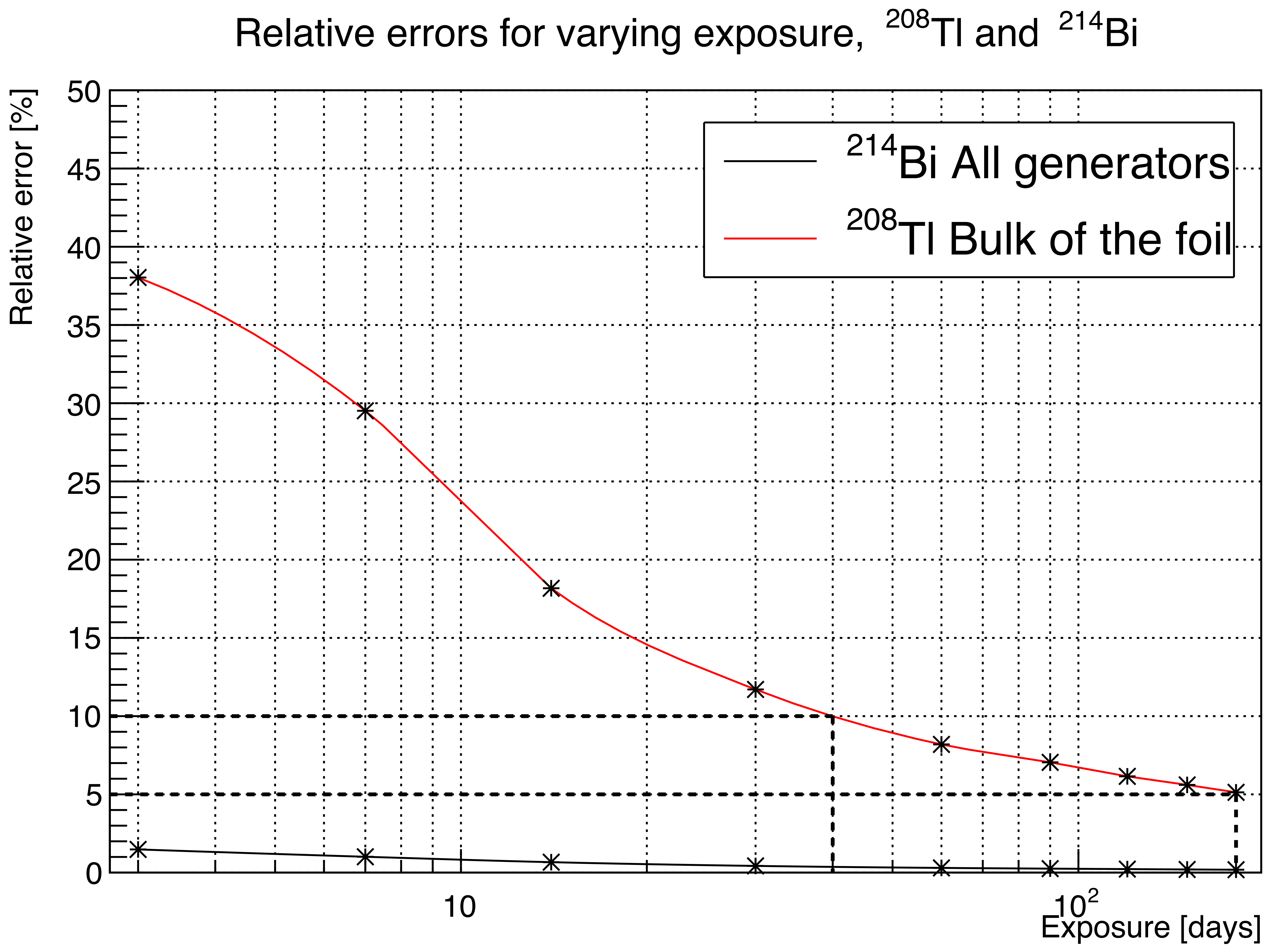
^{208}Tl - Pseudo experiment



Normalised activity and exposure of 60 days, log scale to show shape difference.

^{214}Bi - 61.08 mBq, ^{208}Tl - 370μBq

- Apply TFractionFitter
- Plot ^{208}Tl fitted activities and find the relative errors



^{208}Tl

10% : 40 days

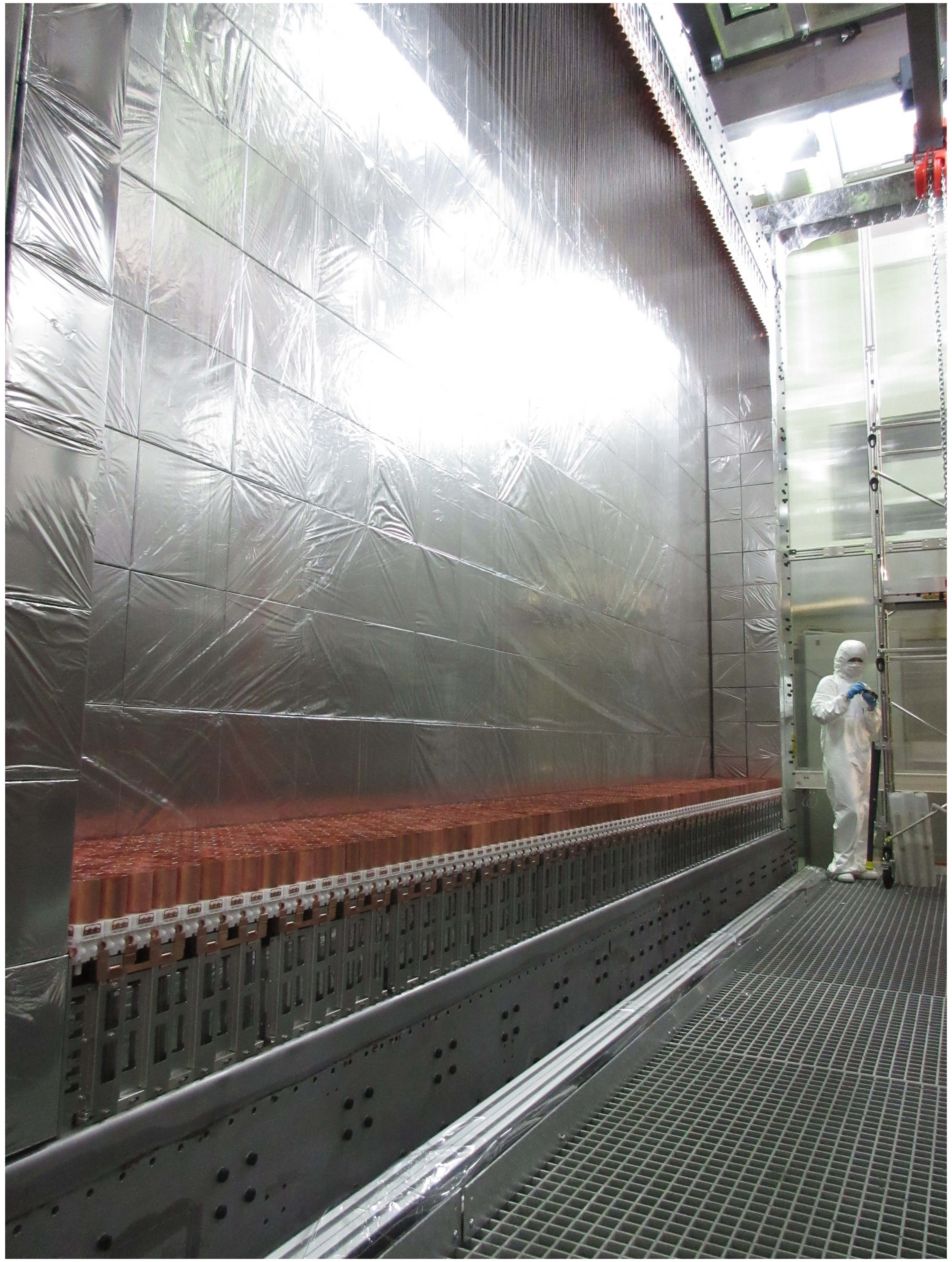
5% : 180 days

^{214}Bi

1.5%: 3 days

Summary

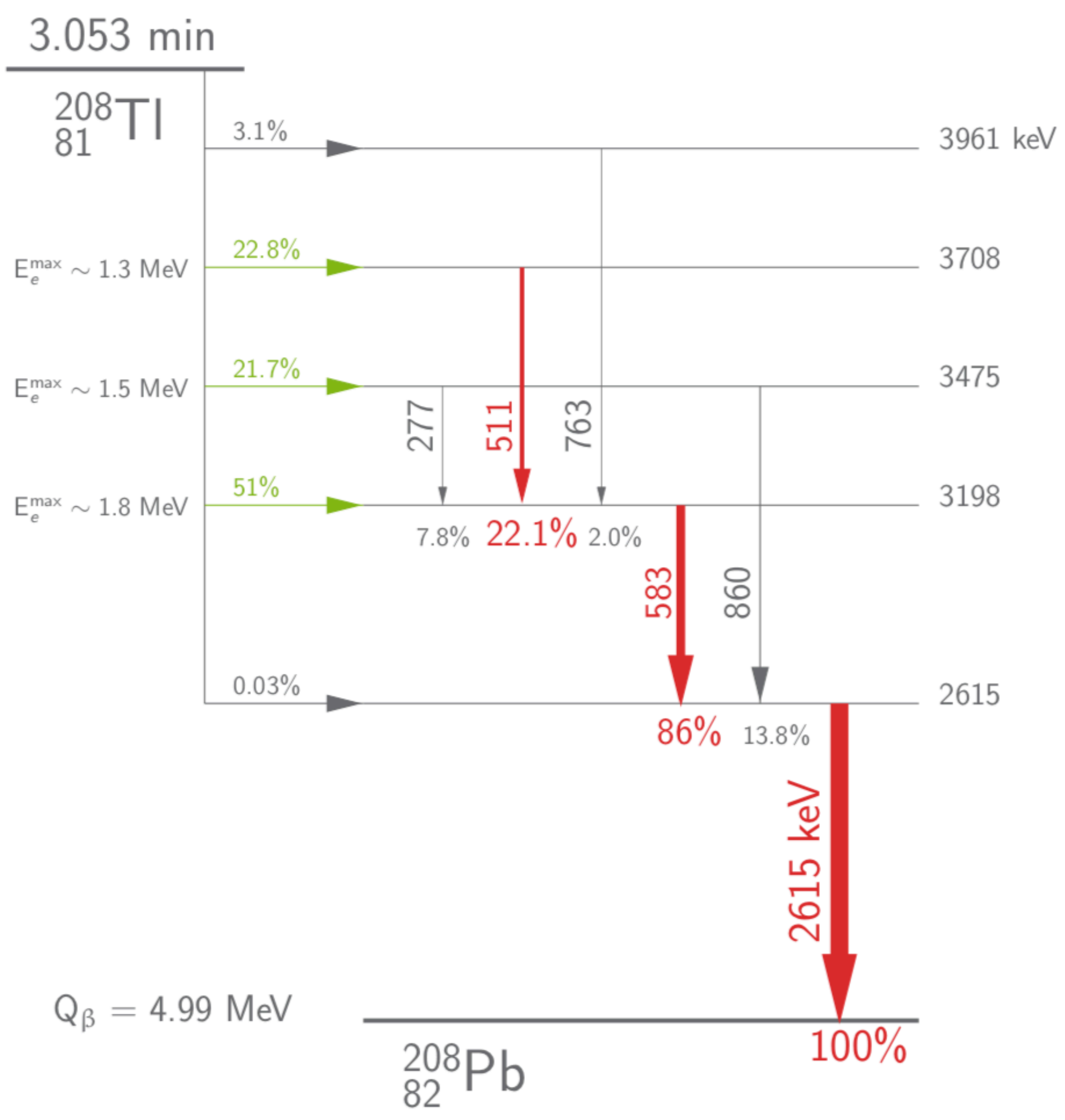
- Demonstrator commissioning to start this year (2018).
- Gas System integrated with SuperNEMO slow control & monitoring, and ready for running.
- Initial estimates calculated for how long it will take to measure the significant backgrounds to the $0\nu\beta\beta$ process.



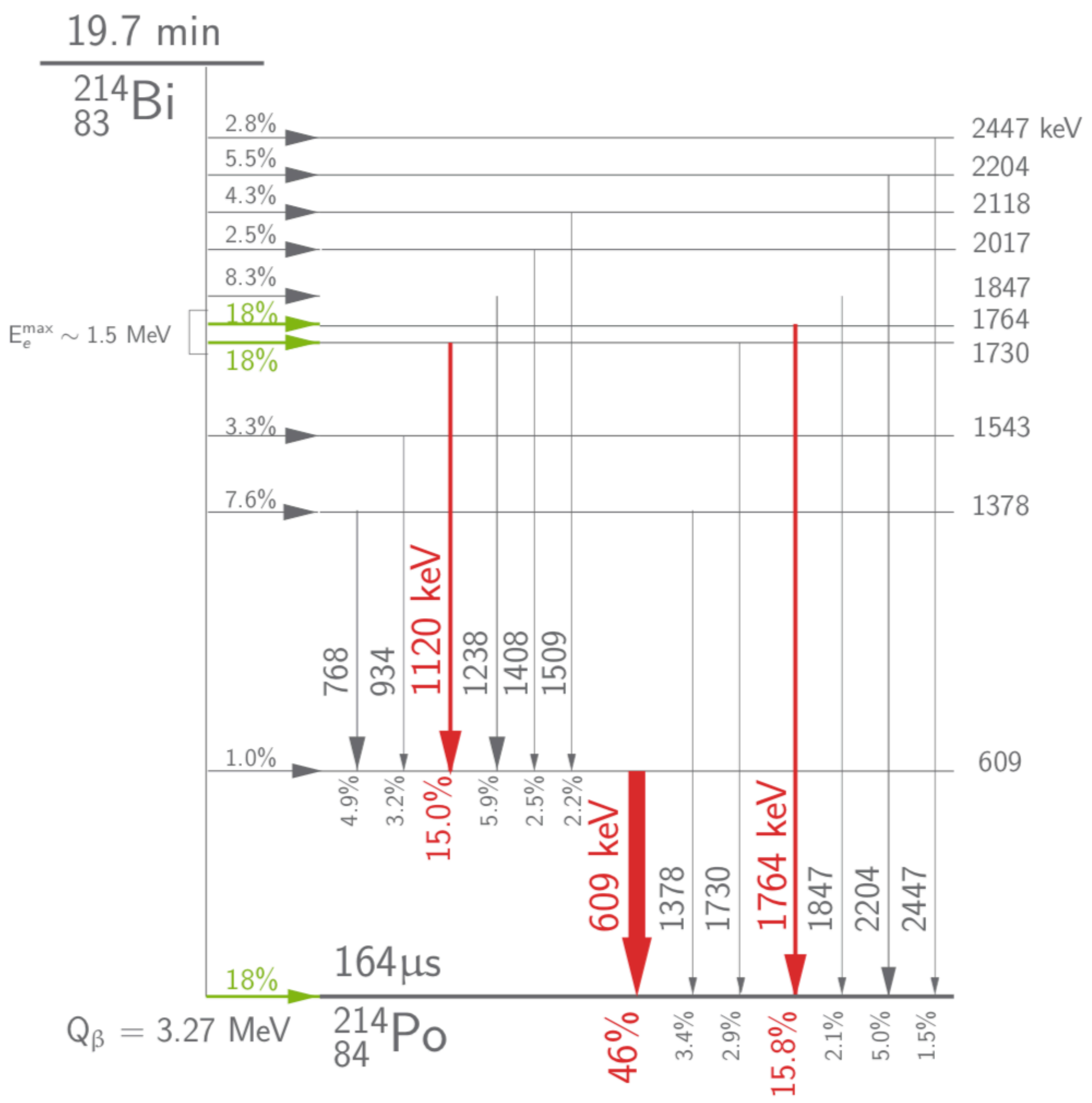
Thank you!

Back ups

Back ups



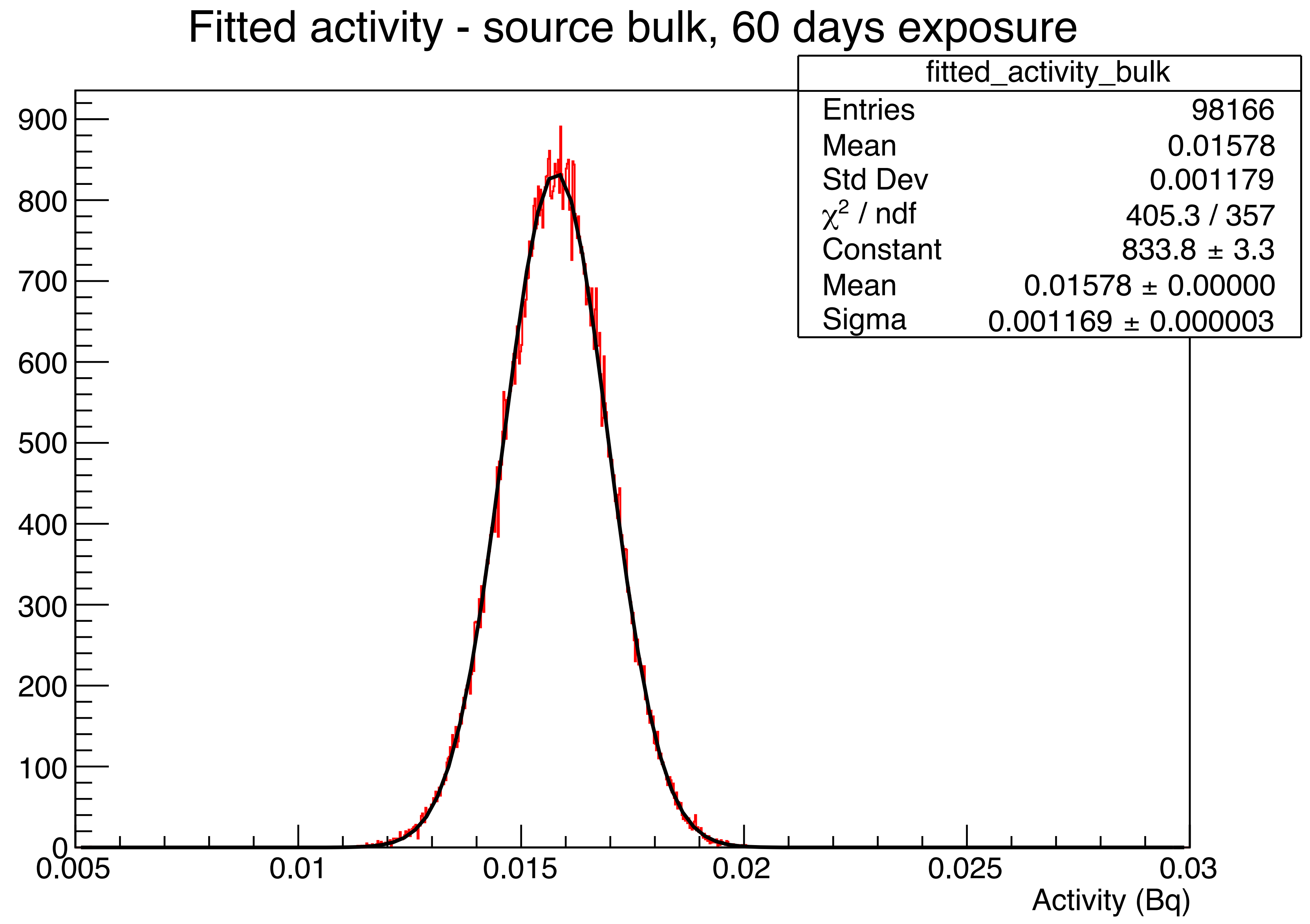
3.053 min
208 81 Tl
3.1%
3961 keV
22.8%
3708
21.7%
3475
51%
3198
0.03%
2615
277
511
763
7.8%
22.1%
2.0%
583
860
86%
13.8%
2615 keV
100%
Qβ = 4.99 MeV
208 82 Pb

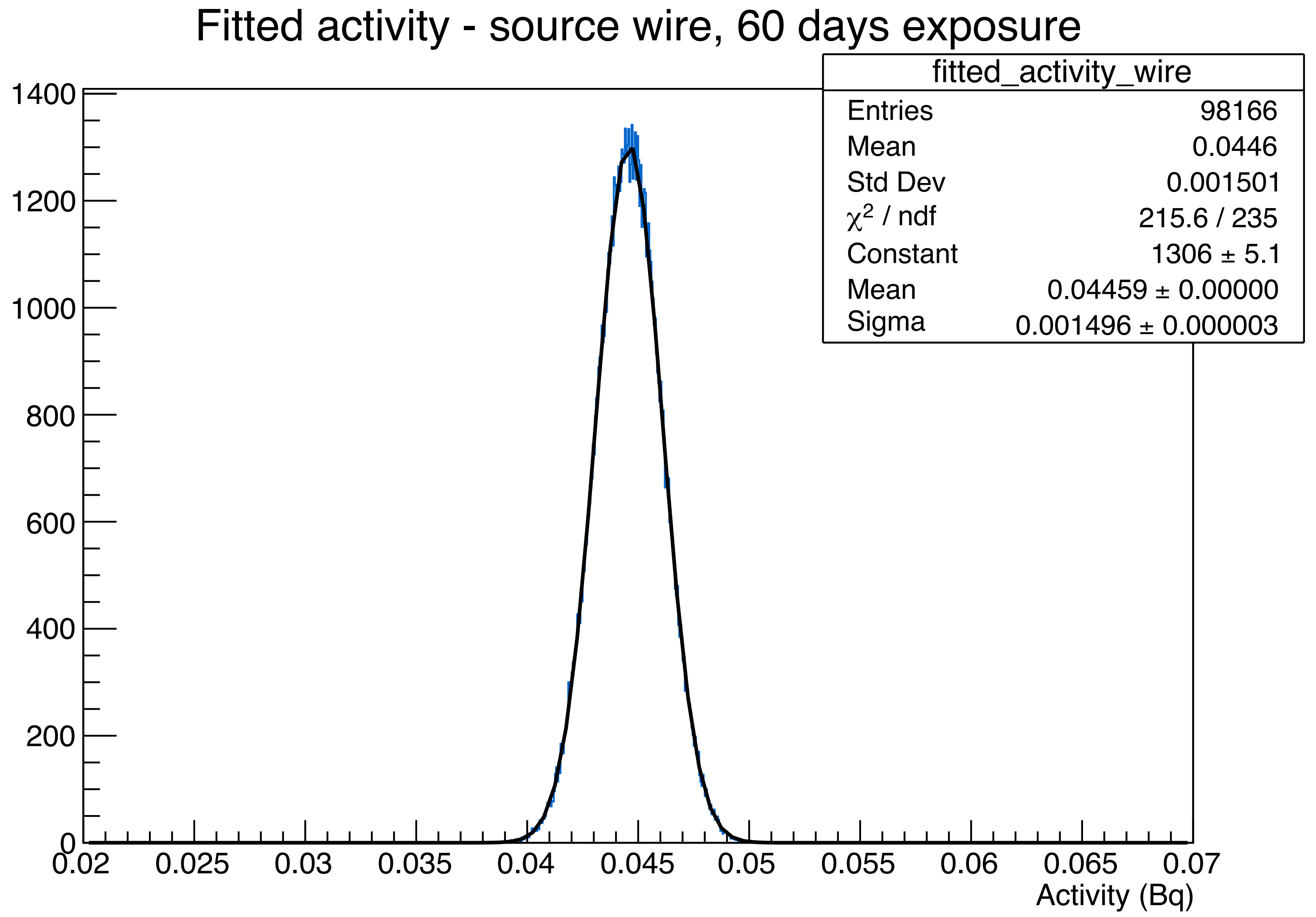


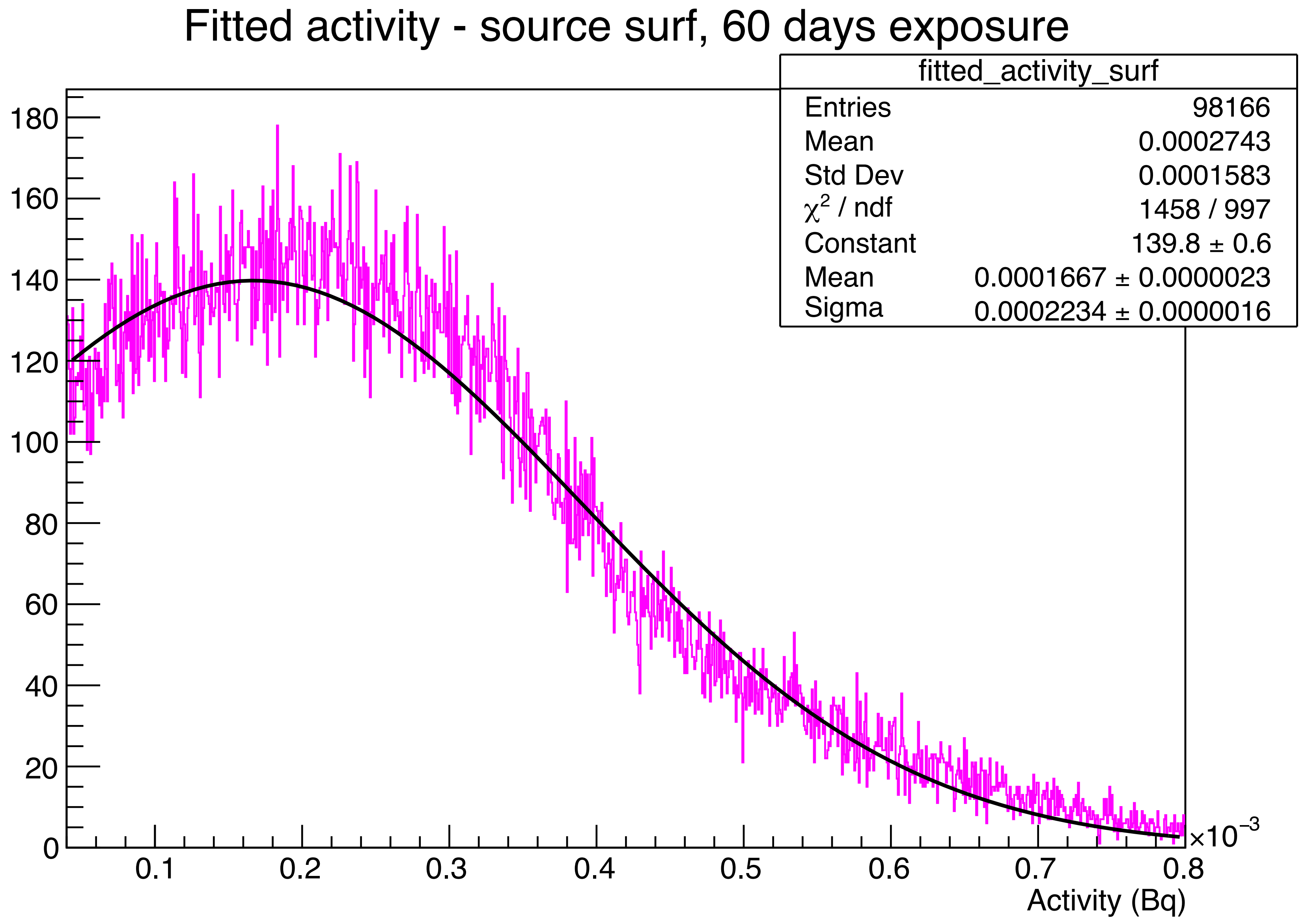
19.7 min
214 83 Bi
2.8%
5.5%
4.3%
2.5%
8.3%
18%
18%
3.3%
7.6%
1.0%
18%
2447 keV
2204
2118
2017
1847
1764
1730
1543
1378
609
768
934
1120 keV
1238
1408
1509
4.9%
3.2%
15.0%
5.9%
2.5%
2.2%
609 keV
1378
1730
1764 keV
1847
2204
2447
164µs
Qβ = 3.27 MeV
214 84 Po
46%
3.4%
2.9%
15.8%
2.1%
5.0%
1.5%

Fitted Activities - 60 days

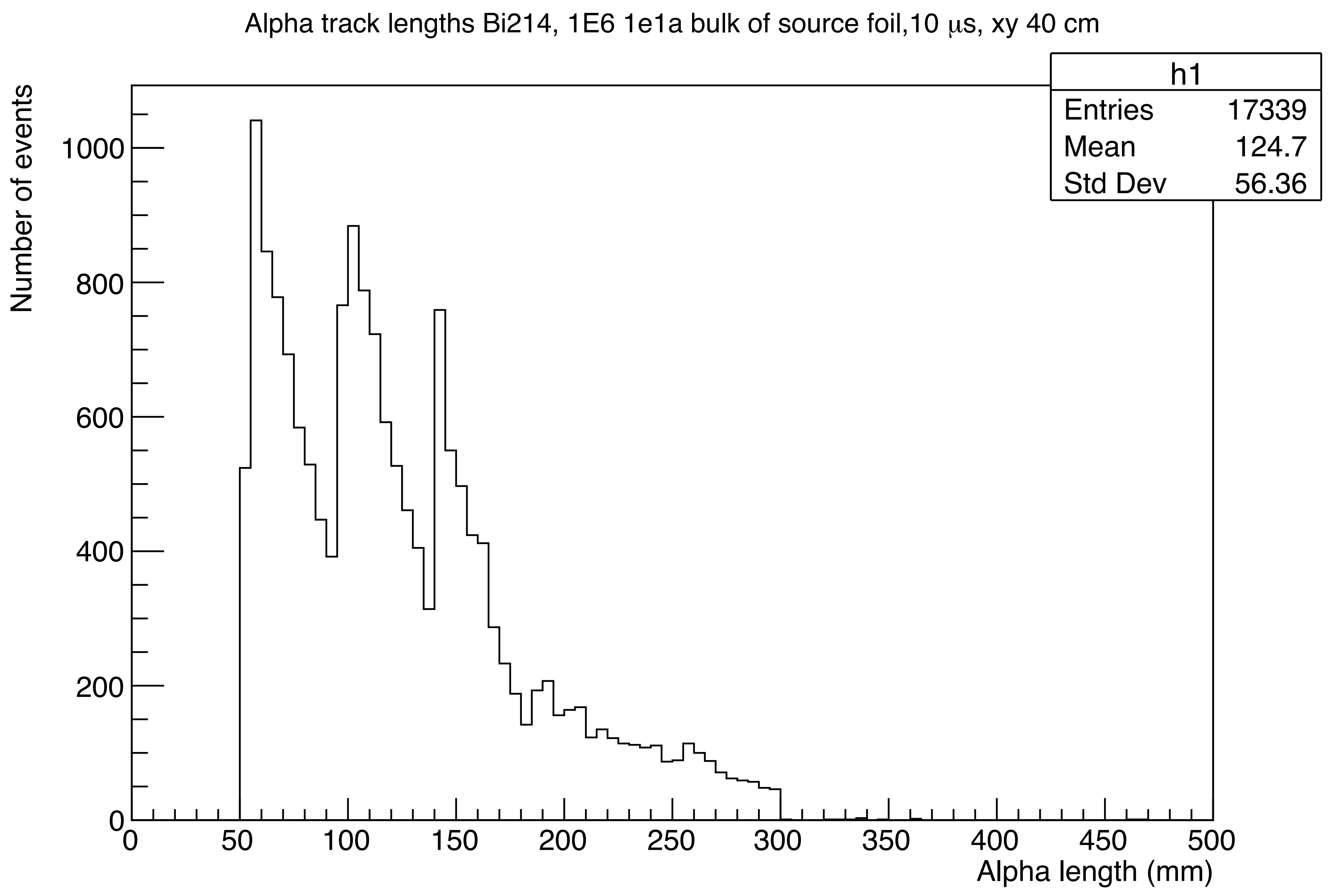
- Repeated mock data generation and fitting 10^5 times.
- Calculated new fitted activities, plotted and fitted gaussian:

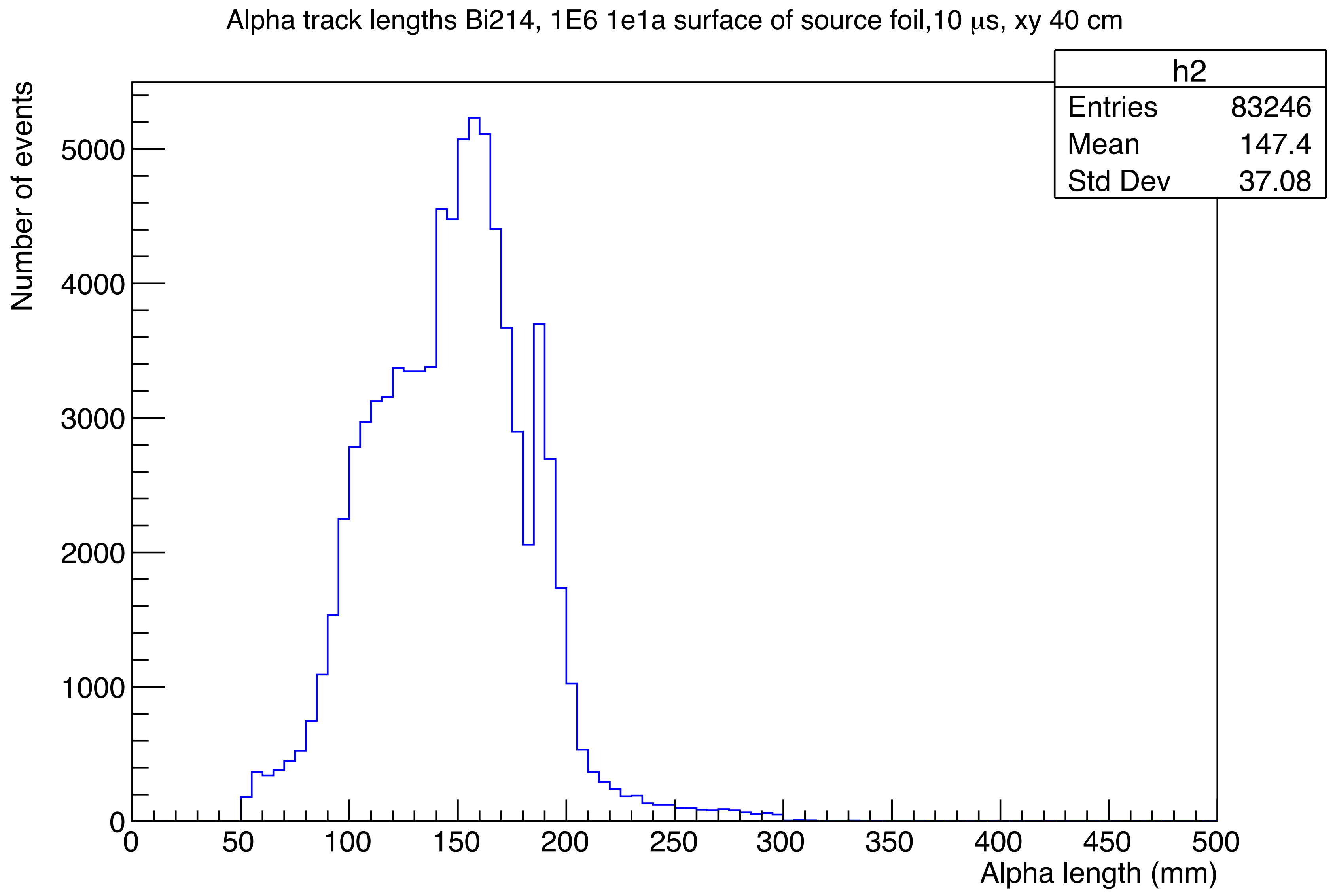


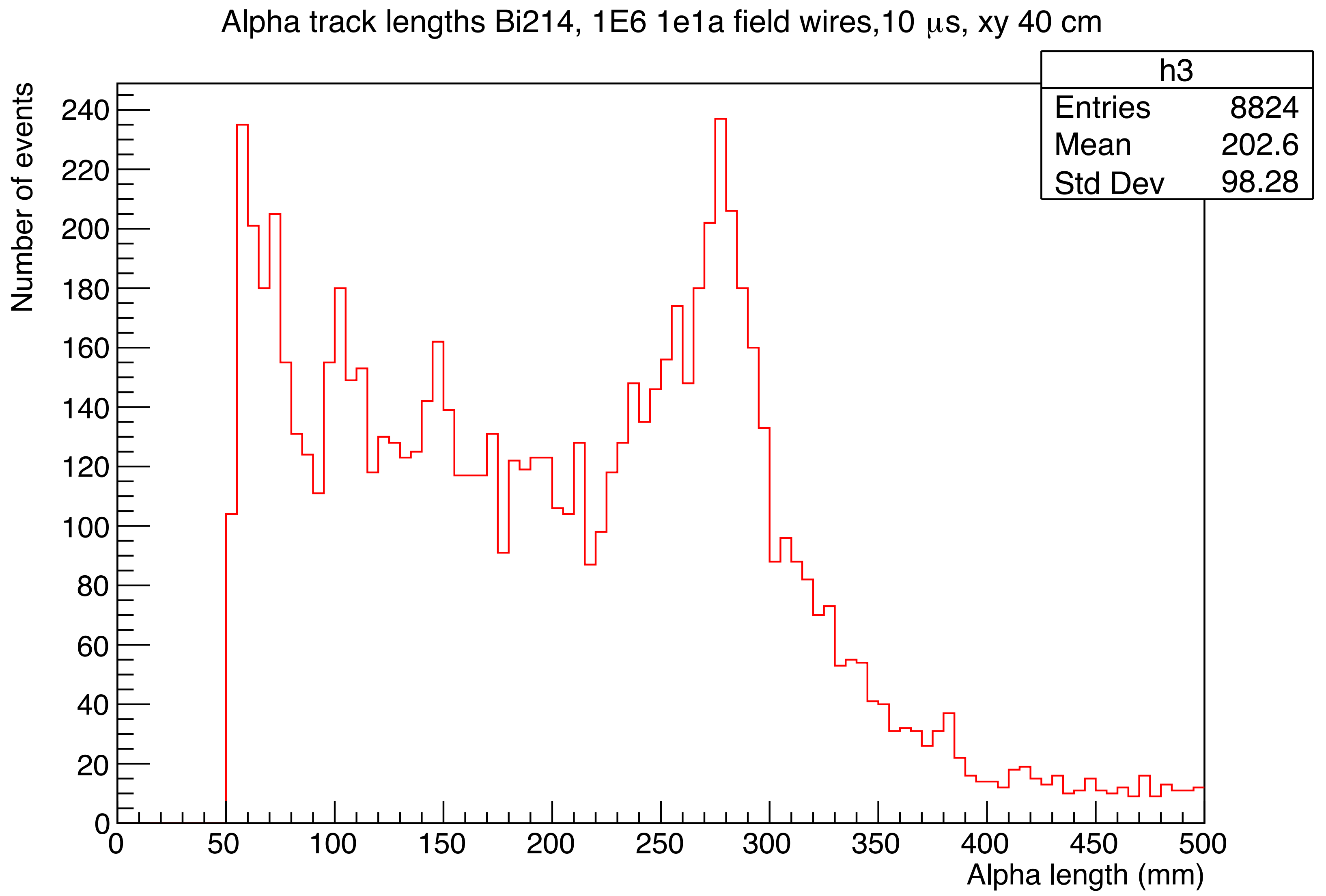




1E6 events generated in source foil bulk, on the surface of the foil, and on the tracker field wires.







Reconstruction efficiencies for different topologies