



CALIBRATION OF Ge DETECTORS WITH AUTOMATED ALGORITHM

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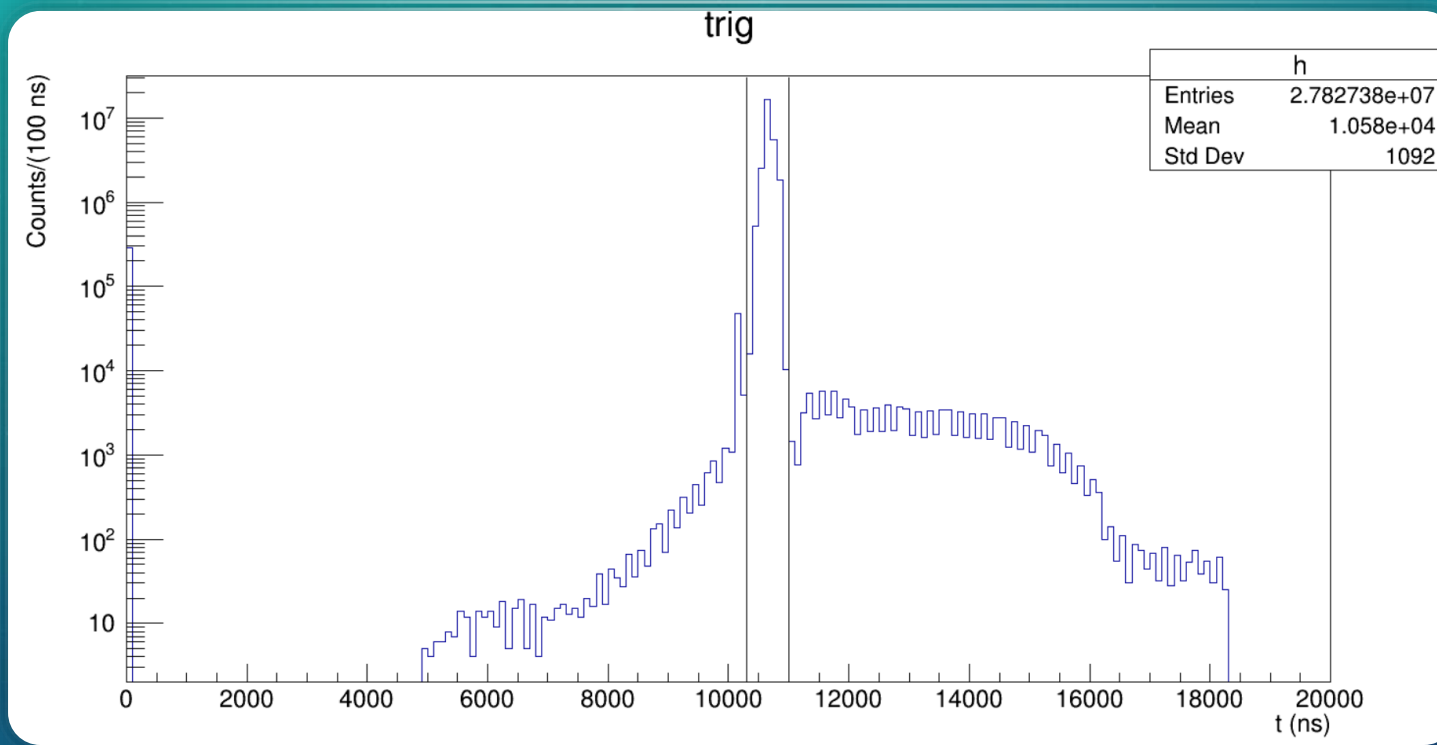
OUTLINE

- Discuss the updated fit function
 - This work was done during winter holidays and results were included in the progress report, but it was not discussed in the collaboration meeting
 - The results from previous fit function (Gaus + lin) were presented without applying any cuts
 - The new fit function was used after applying the cuts
- Discuss the algorithm for automatically fitting peaks from detectors 2-8
 - Focus is to reduce entering raw numbers by hand
 - Look at the energy resolution of all the detectors

UPDATING THE FIT FUNCTION

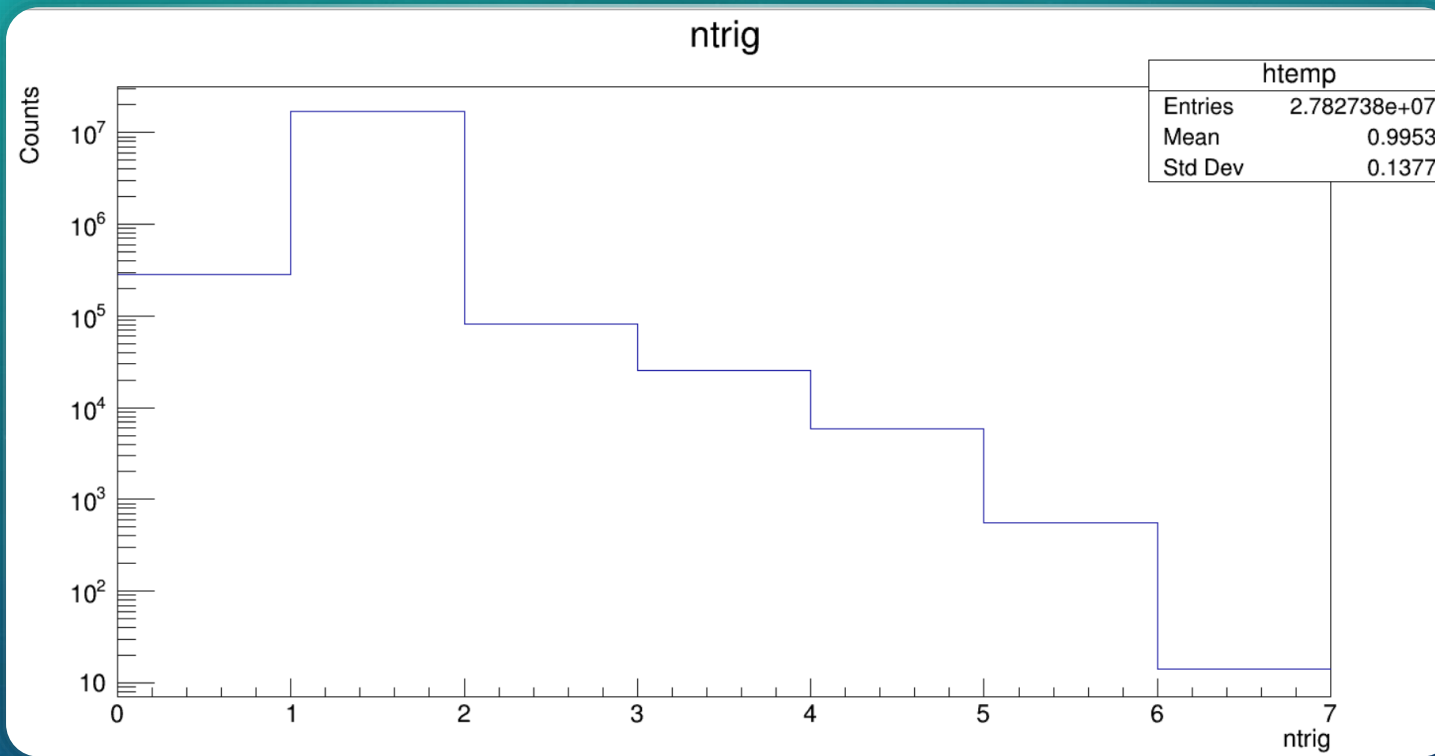
- We changed the fit function to include incomplete charge collection and Compton scattering
 - Total function = $\text{Gaus} + \text{Erfc} + \text{Lin} + \text{Gaus} * \text{Erfc}$
 - Gaus: to model the peak
 - Erfc+Lin: to model flat background with linear and Compton scattering with erfc
 - Gaus*Erfc: to model incomplete charge collection in Ge detector
- Before using the new fit function, we applied some quality cuts to our data

CUT ON TRIGGER TIME



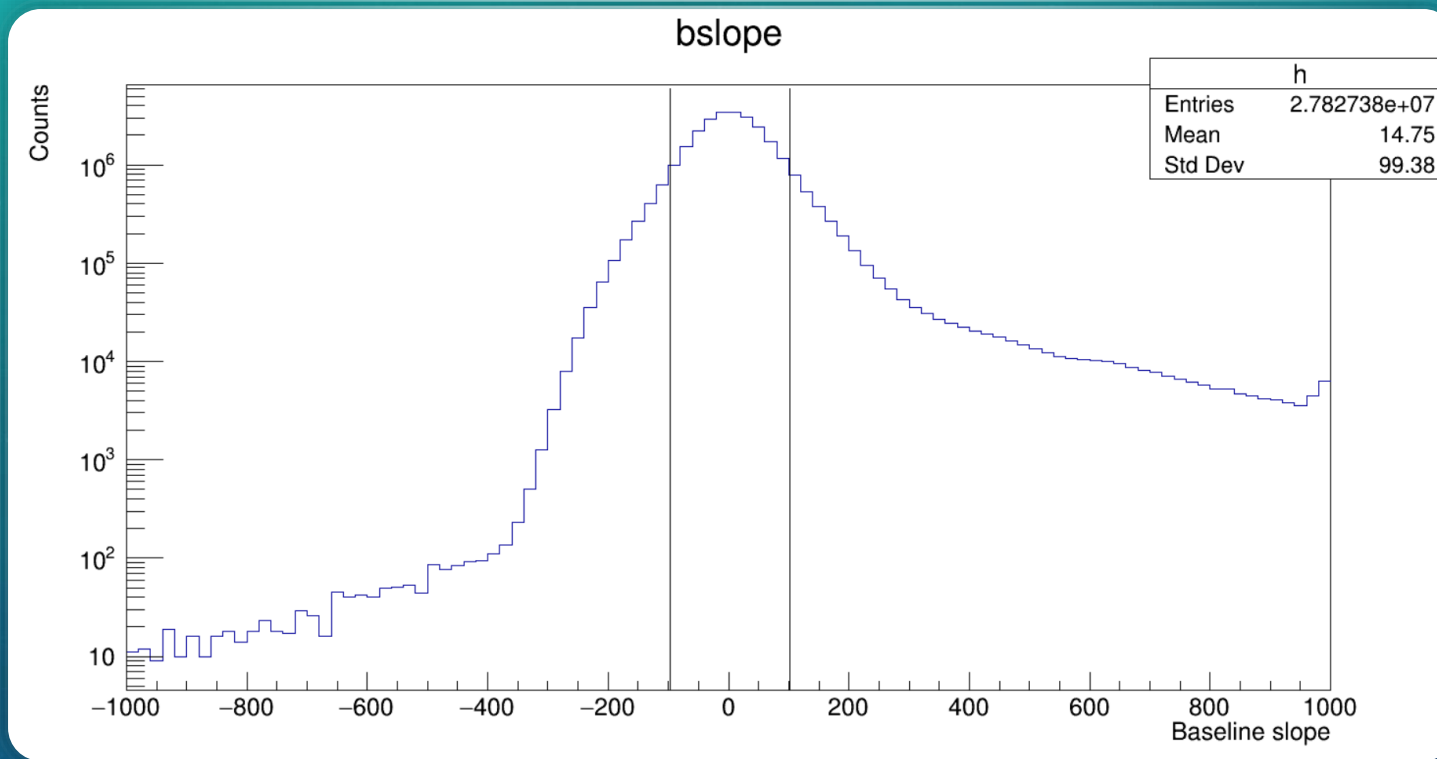
- In LLAMA, the position of reconstructed peak within the waveform is in “GEMDTrigger_trigger”
- If a pulse is reconstructed correctly, the trigger should be approximately in the middle of the waveform
- Trigger timing cut for detector #1 was applied between 10300 ns and 11000 ns
- The boundaries are chosen where first minima (approximately) on both sides of the peak is obtained

CUT ON TRIGGER NUMBER



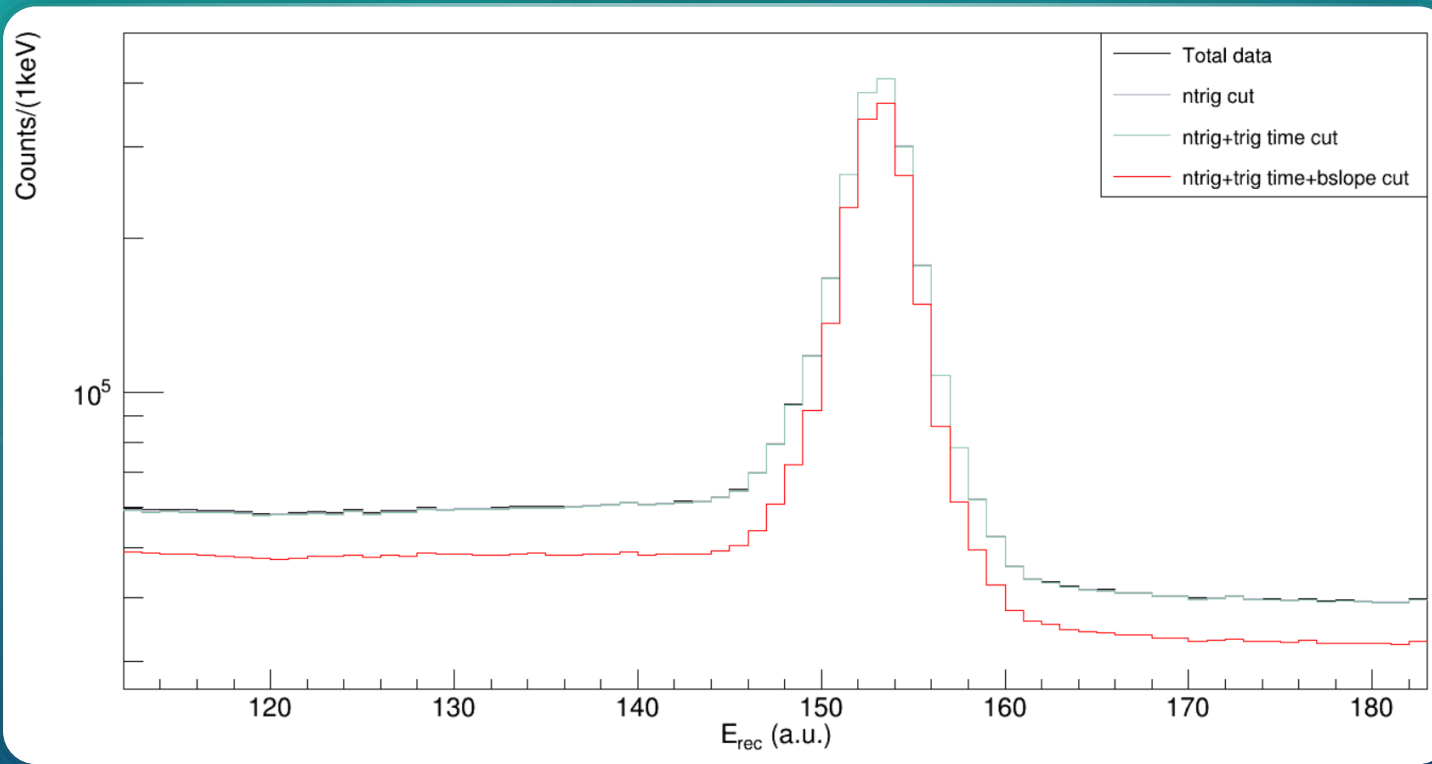
- When the digitizer gives V-t distribution within a time window, ideally, there should be only 1 voltage pulse reconstructed within the waveform
- Multiple pulses can be sometimes reconstructed within the waveform, as seen in plot
- LLAMA saves this information in “GEMDTrigger_triggerNumber”
- We applied a cut to confine the number of triggers to 1
- We noticed some discrepancy between total number of events and the integral of this histogram, still investigating the issue

CUT ON BASELINE SLOPE



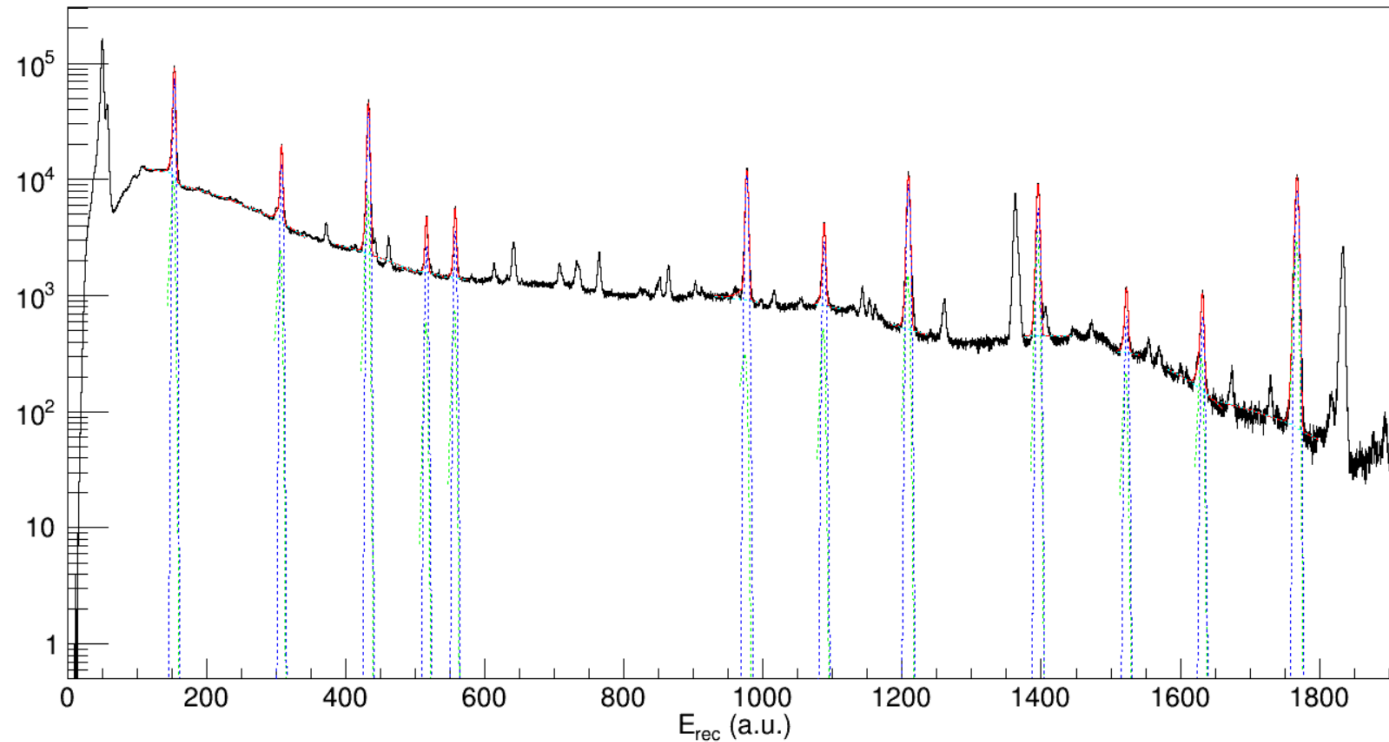
- Baseline slope cut within ± 100 for flat/regular events (det #1)
- Region chosen close to ± 2 sigma (sigma ~ 60) from the mean of baseline slope
- Need to discuss this in detail with TUM group for better understanding and selecting the range

EFFECT OF INDIVIDUAL CUTS ON DATA

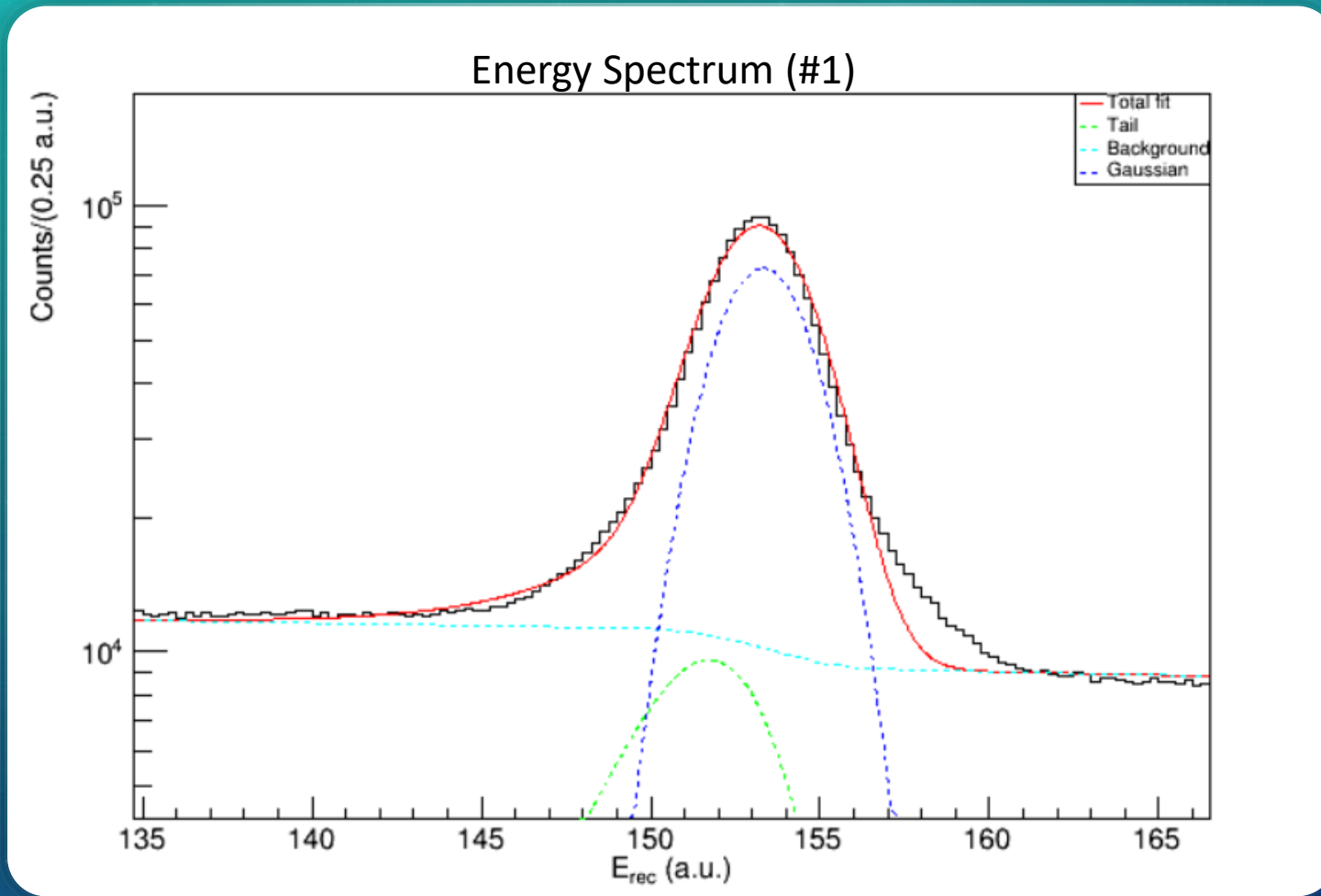


- Change in energy spectrum with each consecutive cut is shown
- Trigger number and trigger timing cuts do not have huge impact on the counts
- Baseline slope reduces the counts by some fraction
- Efficiency of all cuts = 82% accepted

DETECTOR #1- FIT OF ALL THE PEAKS



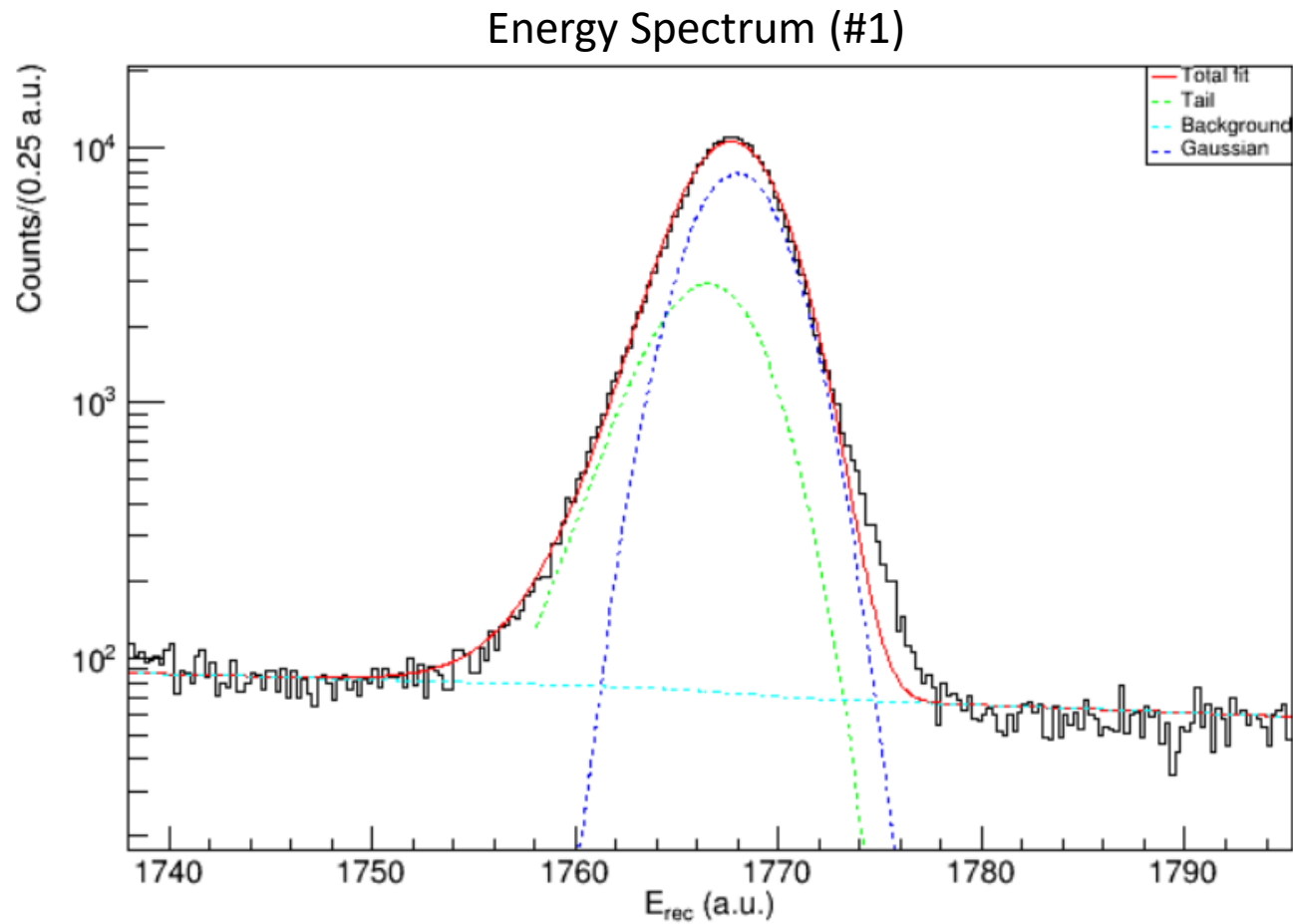
- All 12 peaks were fitted to the same function for detector #1
- Status “CONVERGED” and Error Matrix “ACCURATE” in all the peaks
- The range of fitting (left/right width) is a “hyperparameter” and needs to be tuned by hand to give a good fit.



FITTED PEAK (121 keV)

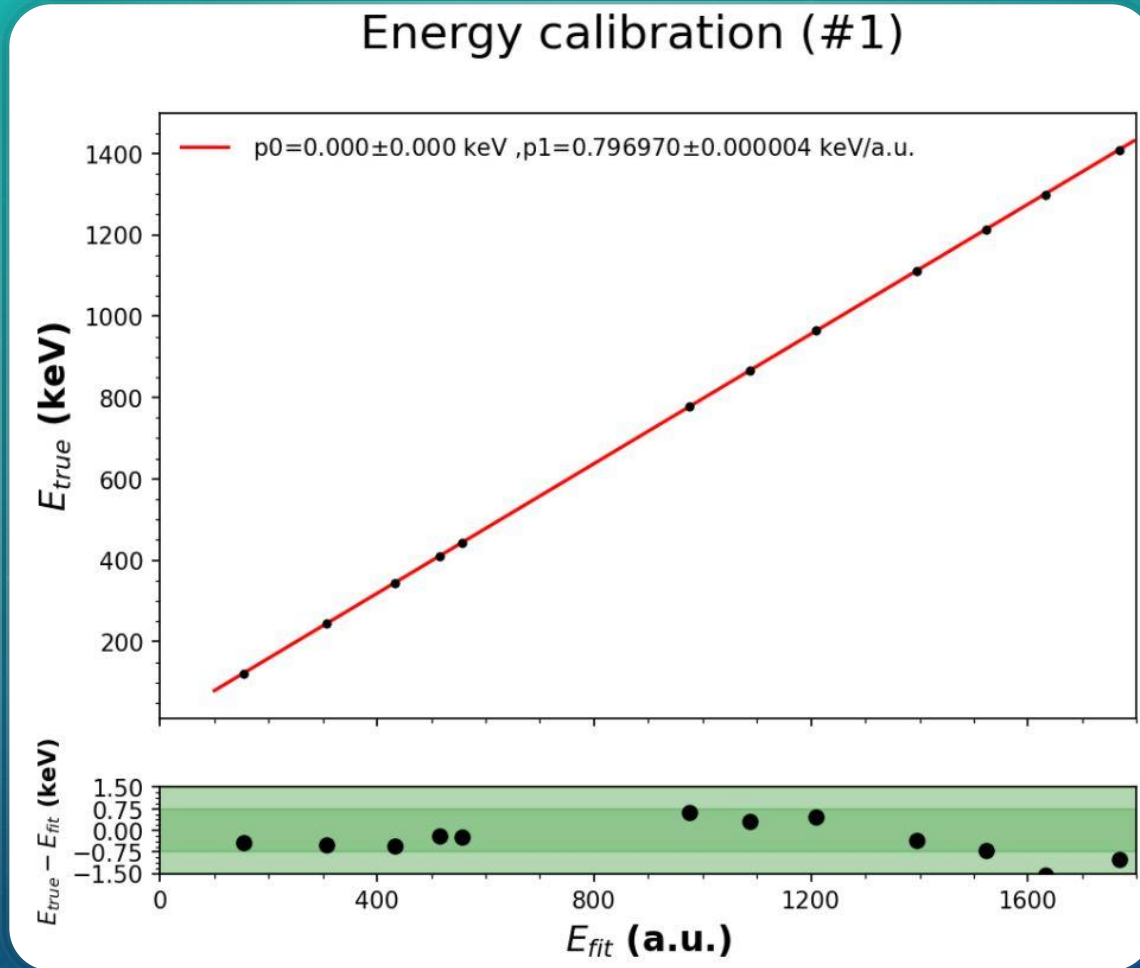
- Shows fit of highest intensity peak
- Individual functions such as Gaussian peak (blue), background (cyan) and tail portion (green) are shown along with complete fit (red)
- The more complicated fit functions still does not describe the peaks very well, as there are obvious right tails
- These right tails are seen with trapezoidal filter in Co-60 spectrum, so we should investigate it further

DETECTOR #1



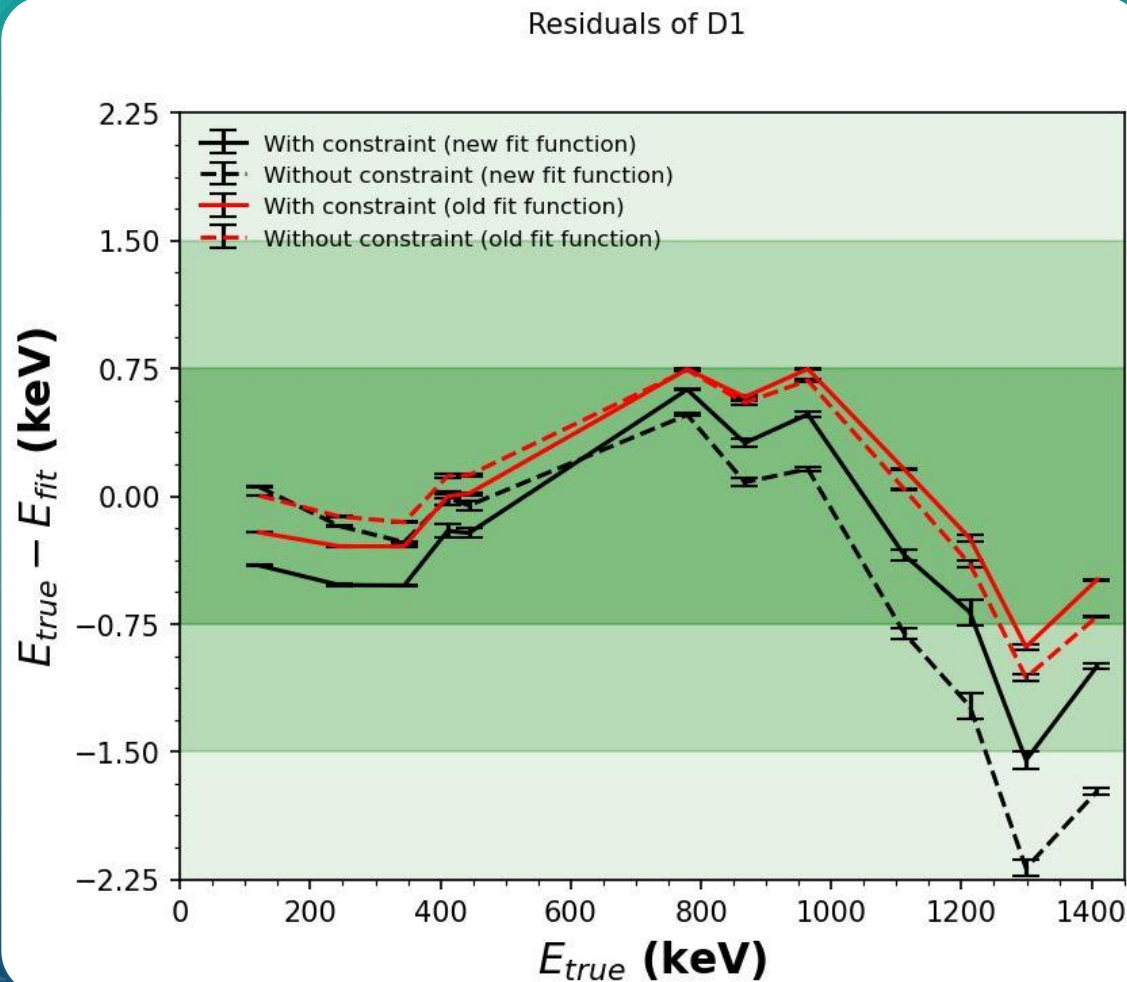
- Peak at 1408 keV

ENERGY CALIBRATION CURVE



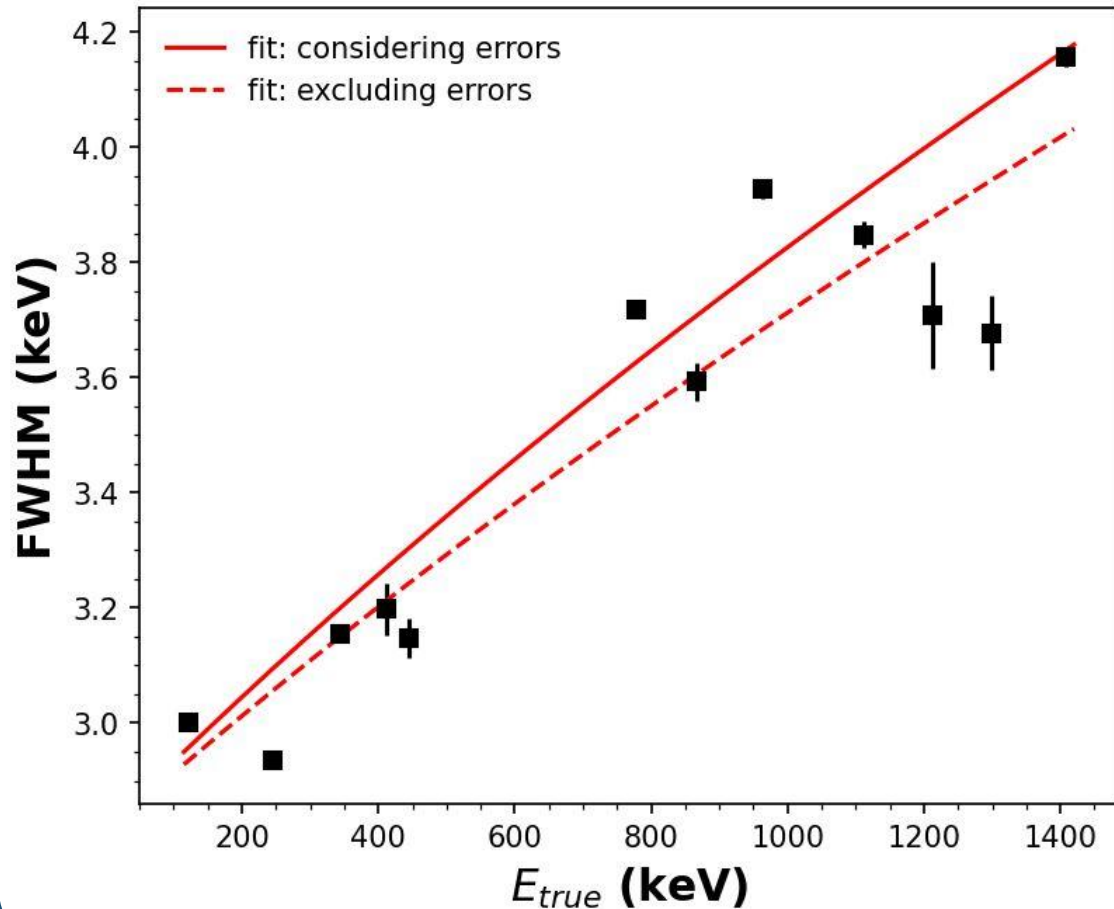
- Calibration constant has changed by a very small value (of the order of $\sim 1E-4$) compared to previous fit function
- In the previous fit, no limit was put on intercept value, but the parameter limit in this new fit was set between 0 and $1E5$
- Intercept is very small ($\sim 1E-11$) but positive (negative in earlier case, which makes no sense)

RESIDUALS



- With constraint on intercept, the residuals of the new peak fitting function are within -1.5 keV to +0.6 keV (black solid line)
- With same constraint, the residuals from previous peak fitting function are within -0.9 keV to +0.75 keV (red solid line)
- The residuals become worse with the new fit function
- Error bars show statistical errors only

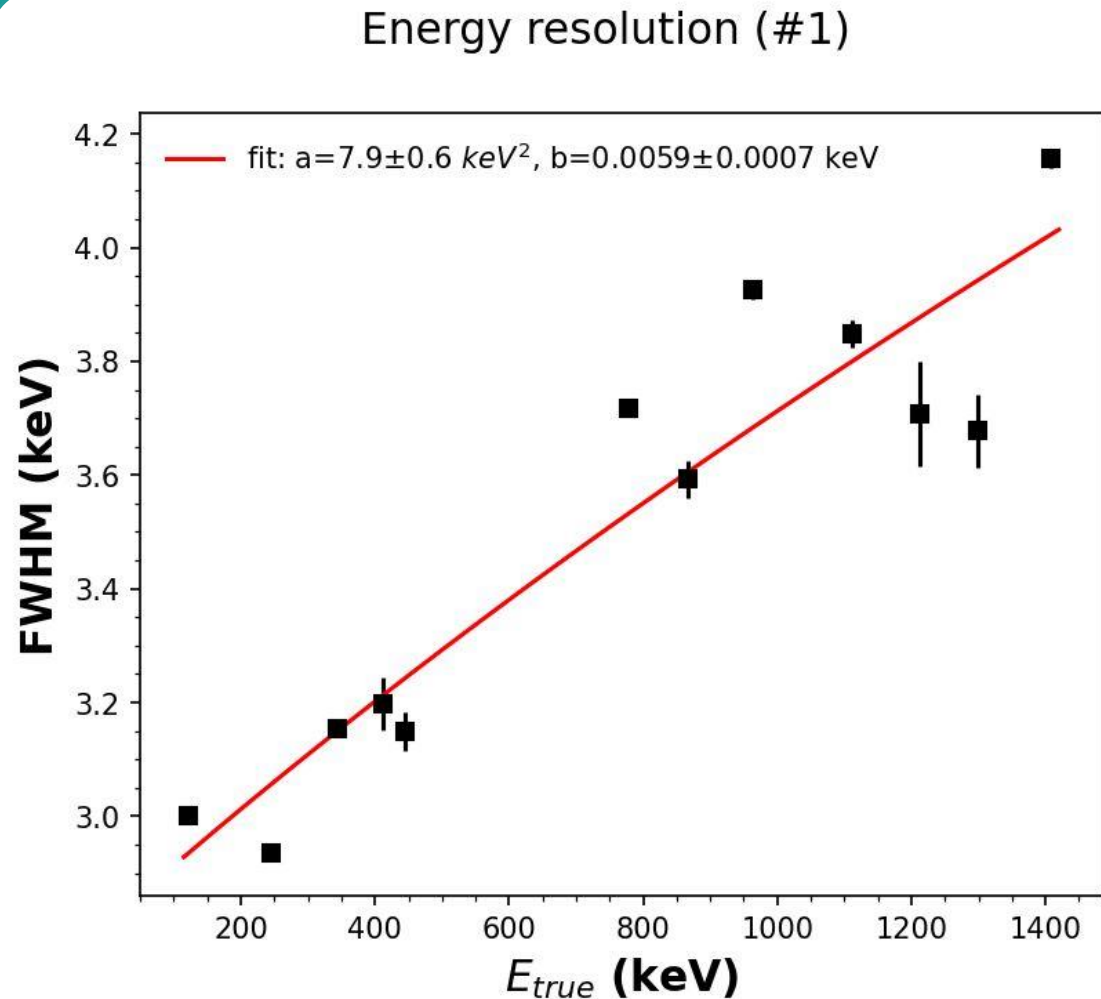
Energy resolution (#1)



ENERGY RESOLUTION

- When including errors, the fit ignores points at higher energies (solid line)
- This means that these points have much larger errors, but here we include only statistical error
- We should consider systematic errors in future
- For now, we fit the data without taking errors into account (dashed line)

ENERGY RESOLUTION



- The energy resolution obtained from the fit is 3.9 keV at 1.3 MeV
- Comparable to the value obtained from MIDAS (~ 5.7 keV Co-60 at 1.1 MeV)
- Fit function used is $FWHM = 2.355 \cdot \sqrt{a + bE}$
- Need to try a different fit function for resolution to include more physics

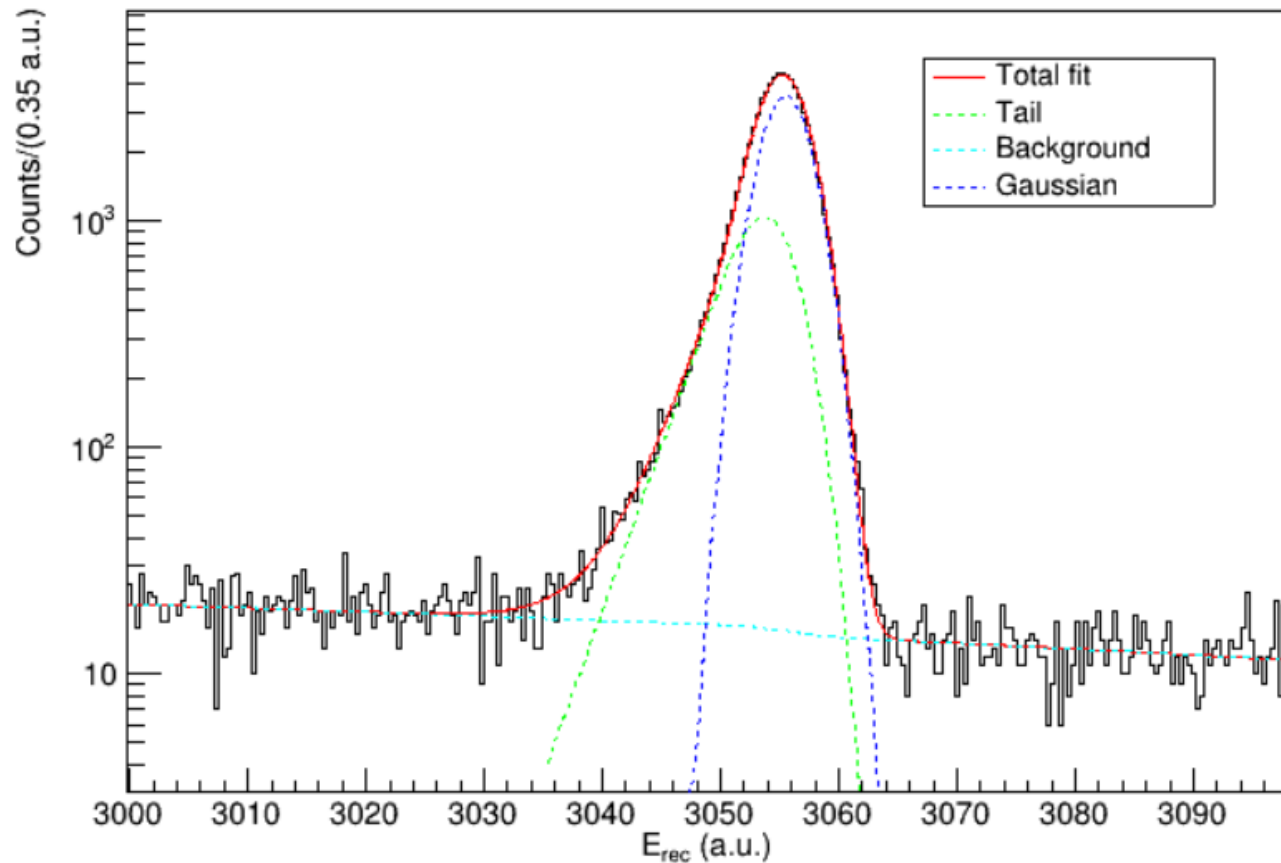
CALIBRATION OF OTHER DETECTORS

AUTOMATED ALGORITHM

- Determine 2 peaks corresponding to true energies 121 keV and 244 keV
- Determine an approximate width of the peaks, width0 (usually 1.5-2 keV)
- Calculate the preliminary slope of the spectrum
 - Prelim. Slope = difference in true energy of first two peaks / difference between location of first two peaks in a.u.
- Calculate the approximate location of other 10 peaks, we call it E_{try}
 - $E_{\text{try}} = E_{\text{true}} / \text{prelim. slope}$
- To find the exact location of peaks, find the left/right bins using $E_{\text{try}} - 10 * \text{width0}$ and $E_{\text{try}} + 10 * \text{width0}$, respectively
- Set the axis range within this region and get the maximum bin within this range
- Obtain E_{refined} using maximum bin and bin width, $E_{\text{refined}} = \text{maximum bin} * \text{bin width}$
- This E_{refined} becomes the energy parameter we set for our fit function

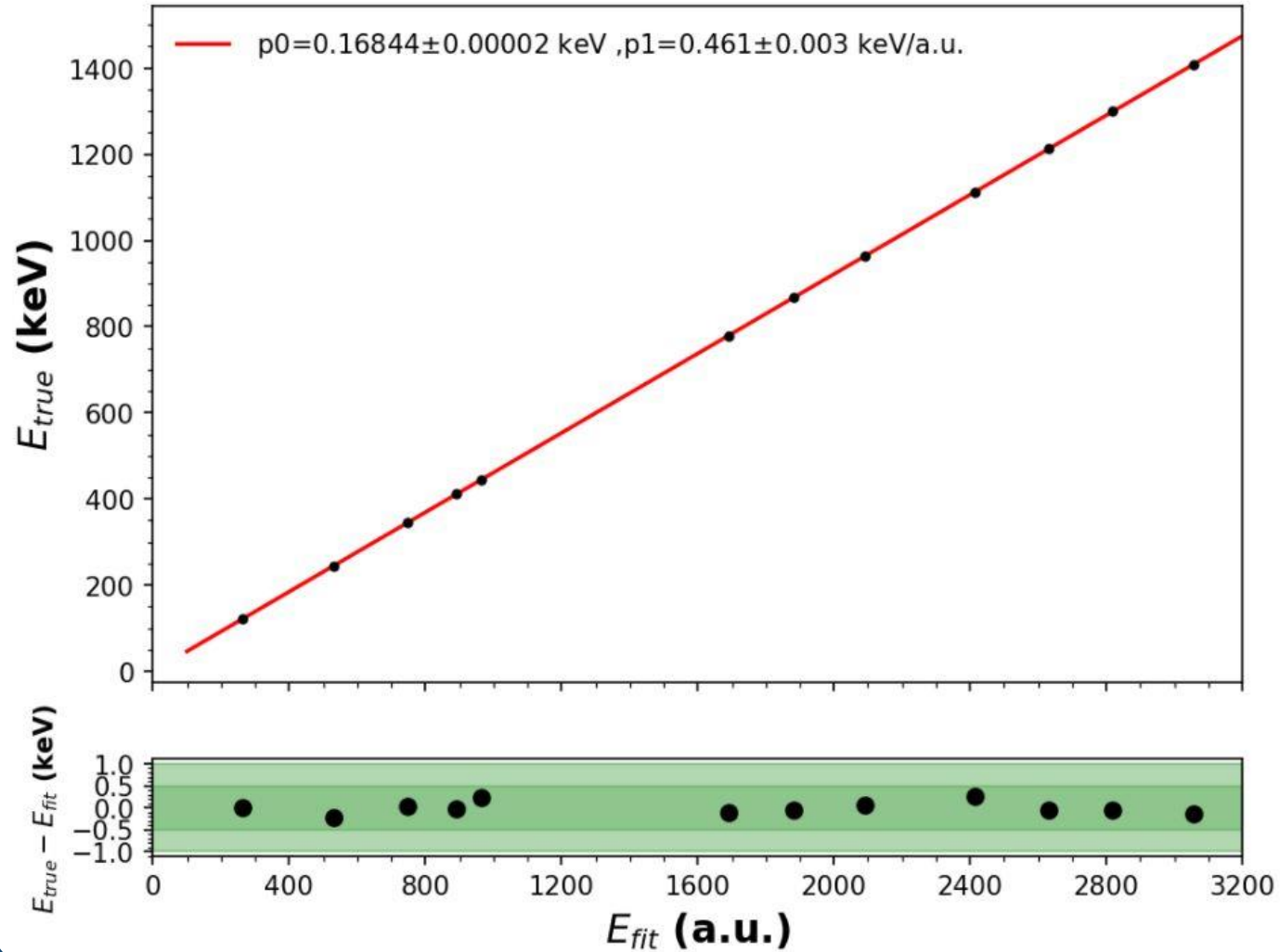
DETECTOR #2

Energy Spectrum (#2)



- Peak at 1408 keV

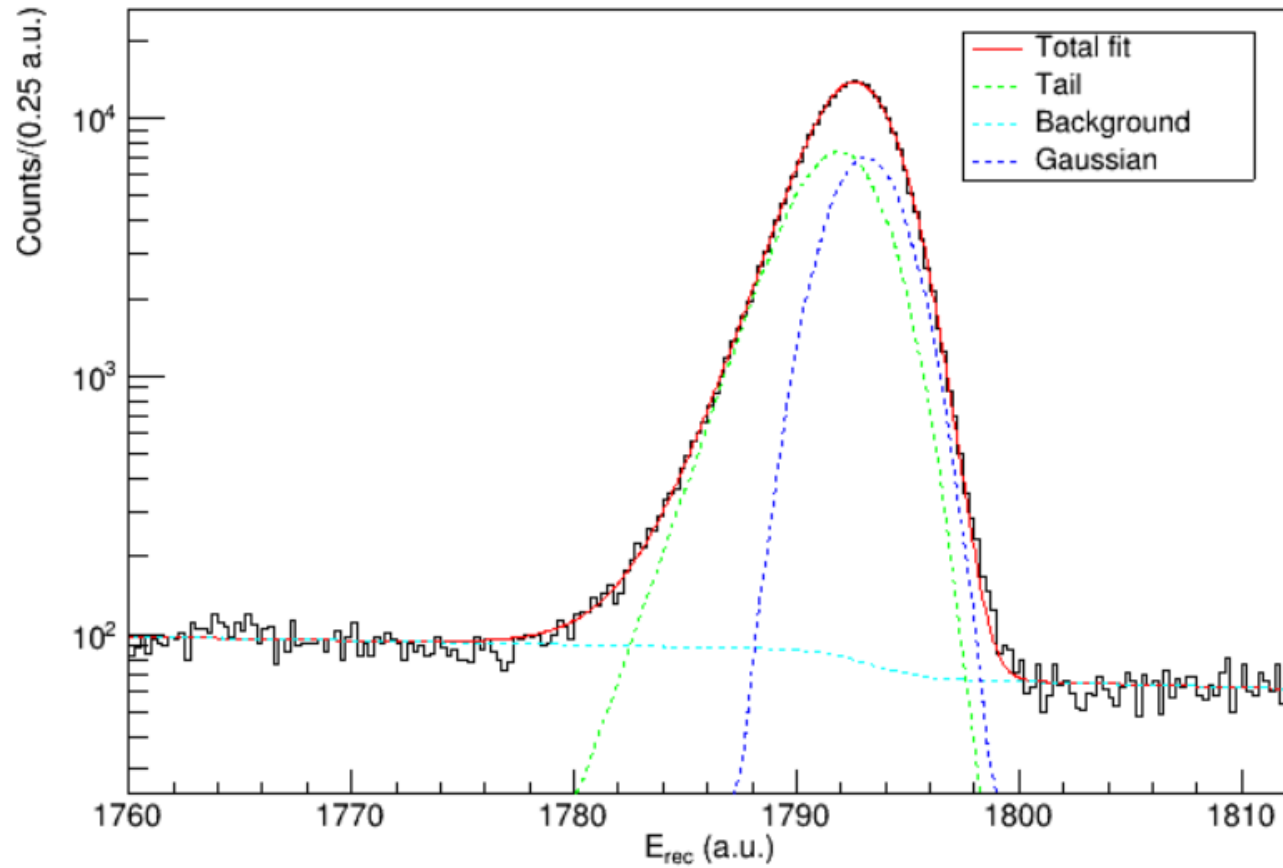
Energy calibration (#2)



DETECTOR #2

- Status “CONVERGED” and Error Matrix “ACCURATE” in all the peaks

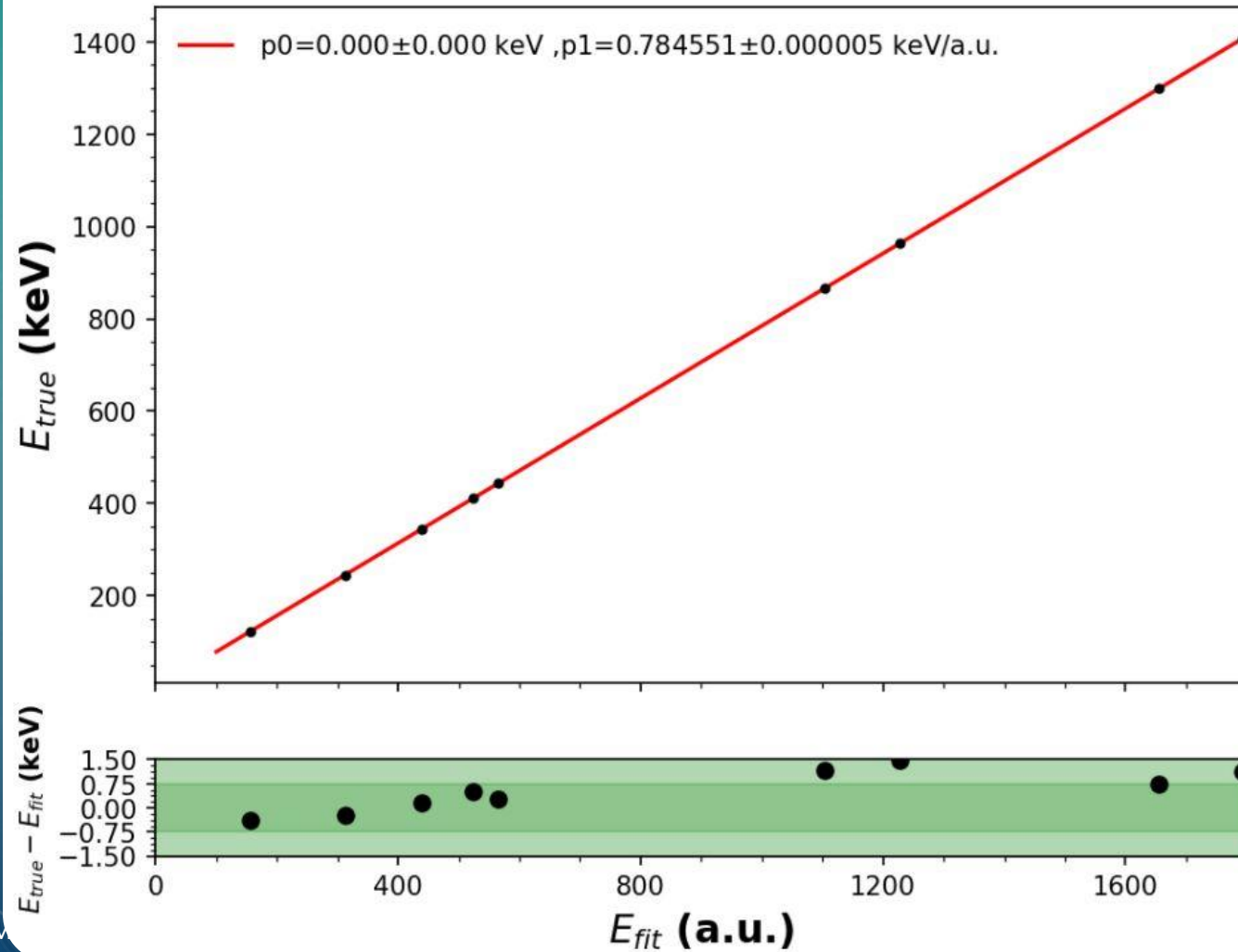
Energy Spectrum (#3)



DETECTOR #3

- Peak at 1408 keV

Energy calibration (#3)

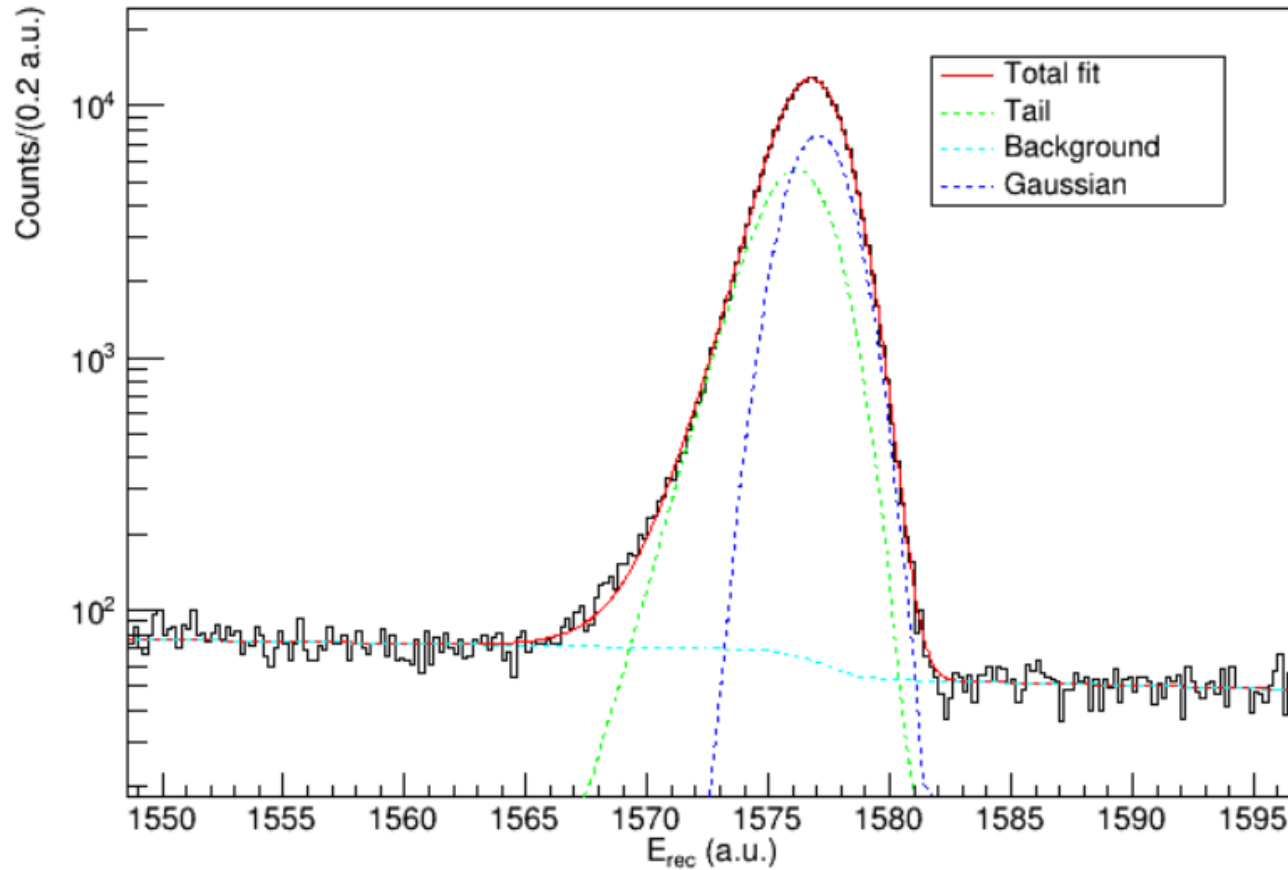


DETECTOR #3

- A few peaks do not give a good fit, Error Matrix has some uncertainty, or it is not positive-definite
- Look at every fit and exclude those lines
- Lines excluded: 778.904 keV, 1112.074 keV, 1212.948 keV
- Fit rest of the lines, status “CONVERGED” and Error Matrix “ACCURATE”
- Intercept is very small ($\sim 1E-11$)

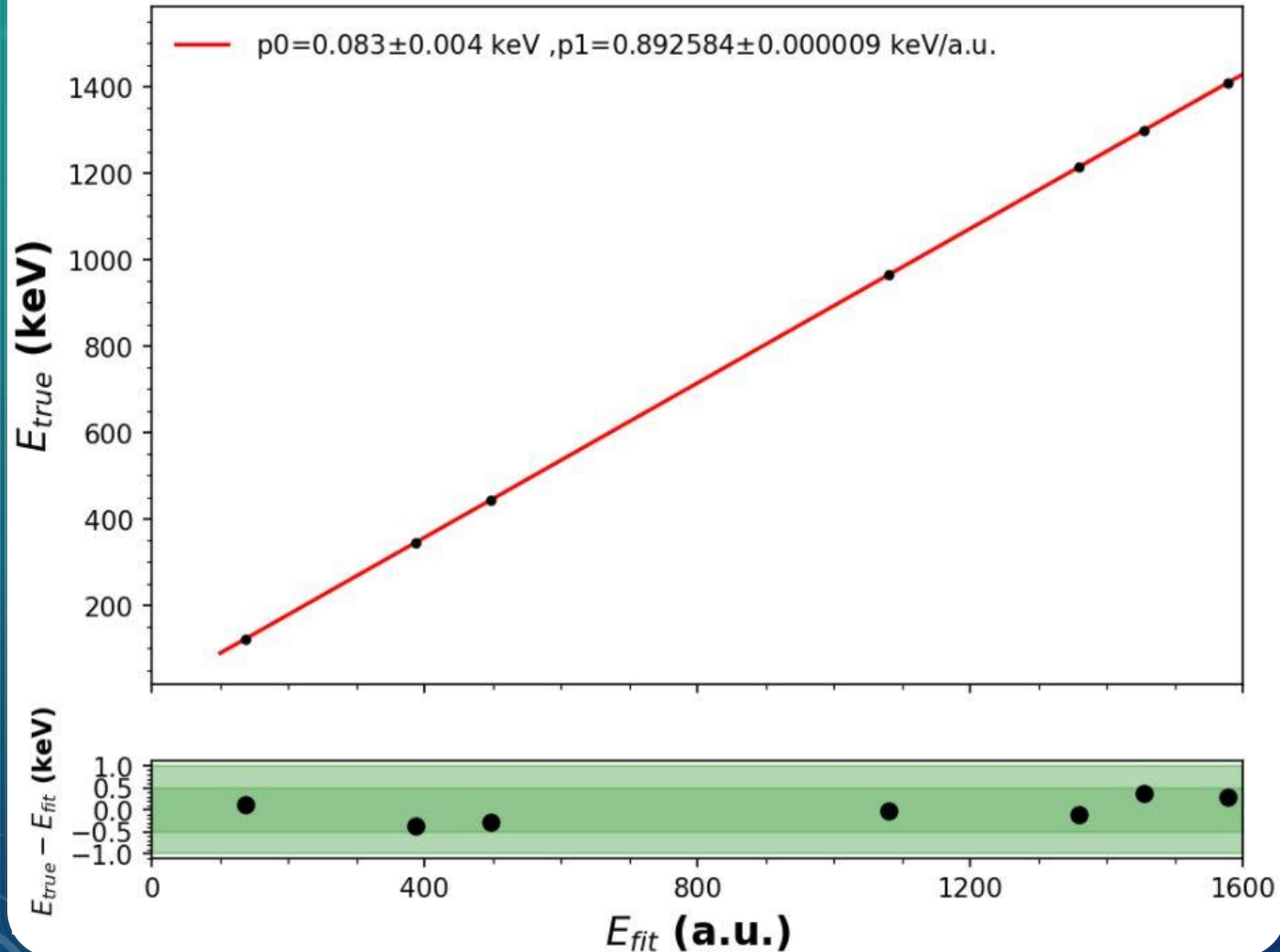
DETECTOR #4

Energy Spectrum (#4)



- Peak at 1408 keV

Energy calibration (#4)

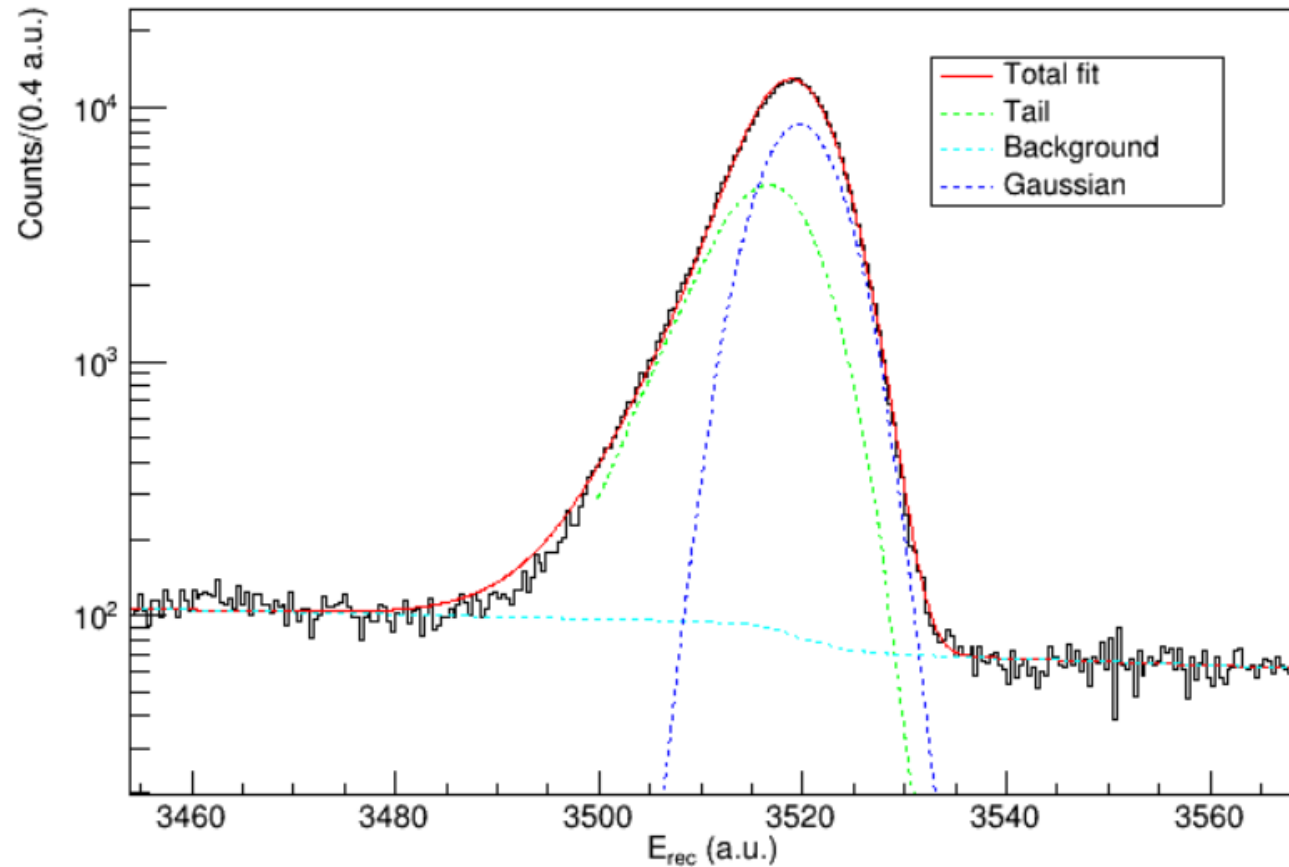


DETECTOR #4

- Among all the detectors, had to exclude 5 lines (maximum)
- Lines excluded: 244.6975 keV, 411.1163 keV, 778.904 keV, 867.378 keV, 1112.074 keV

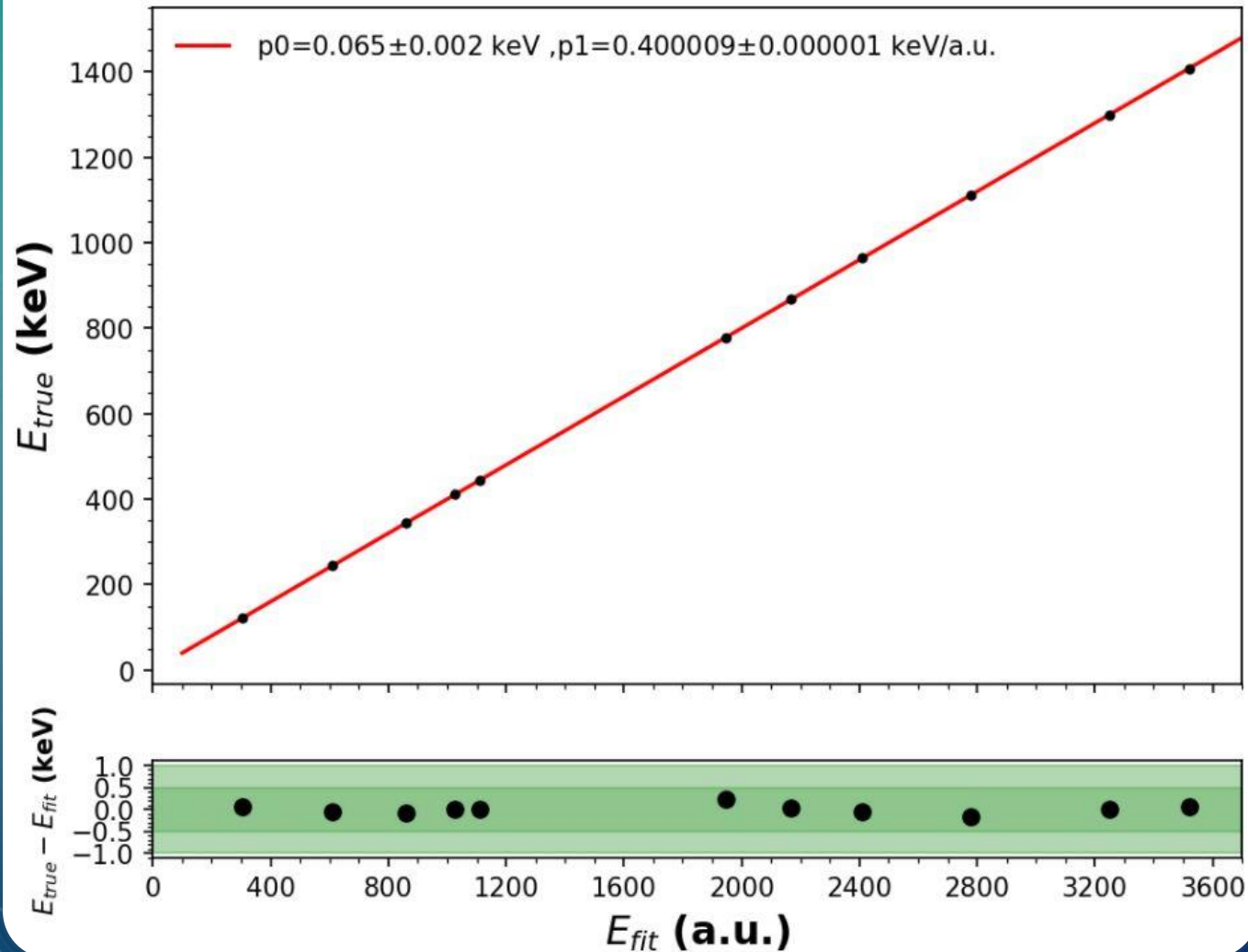
DETECTOR #5

Energy Spectrum (#5)



- Peak at 1408 keV

Energy calibration (det #5)

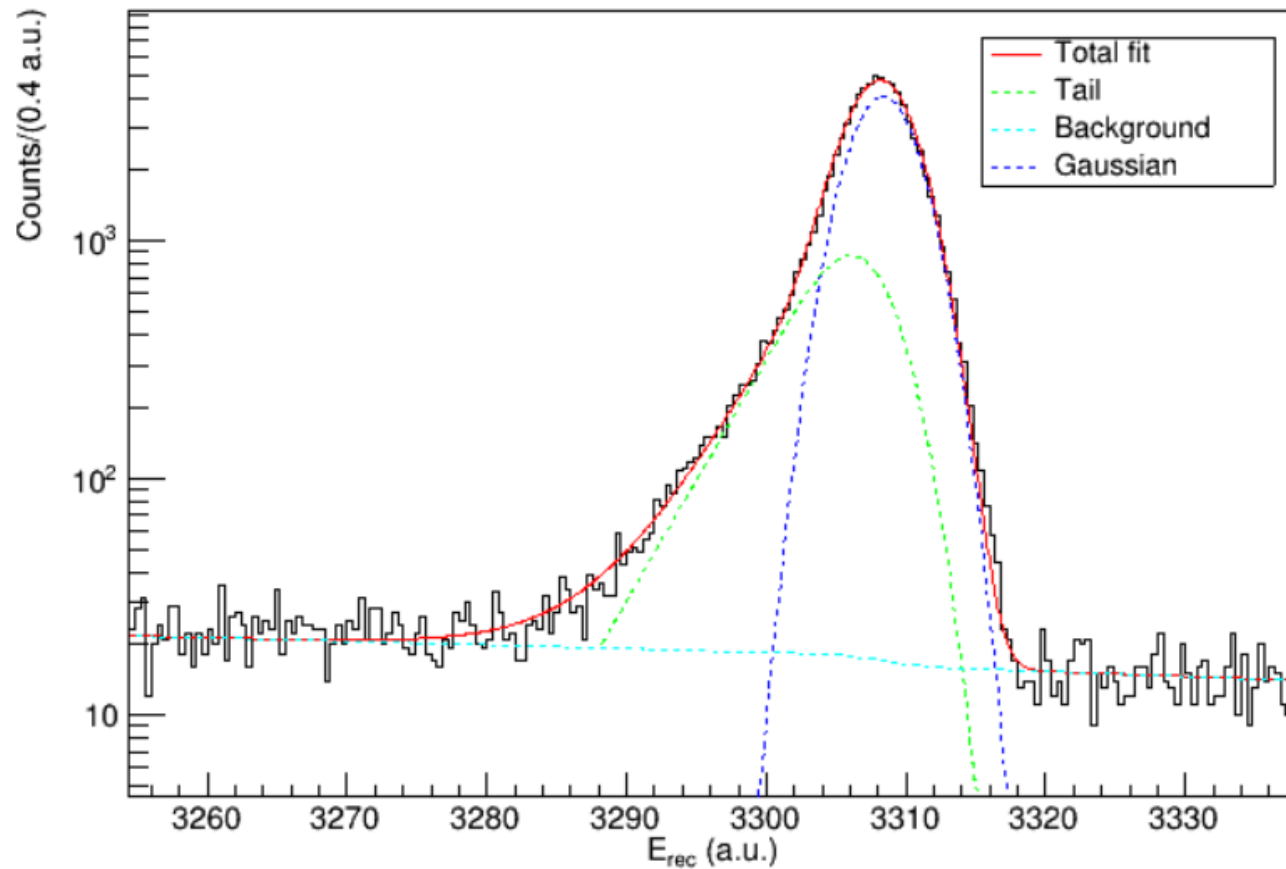


DETECTOR #5

- Lines excluded: 1212.948 keV

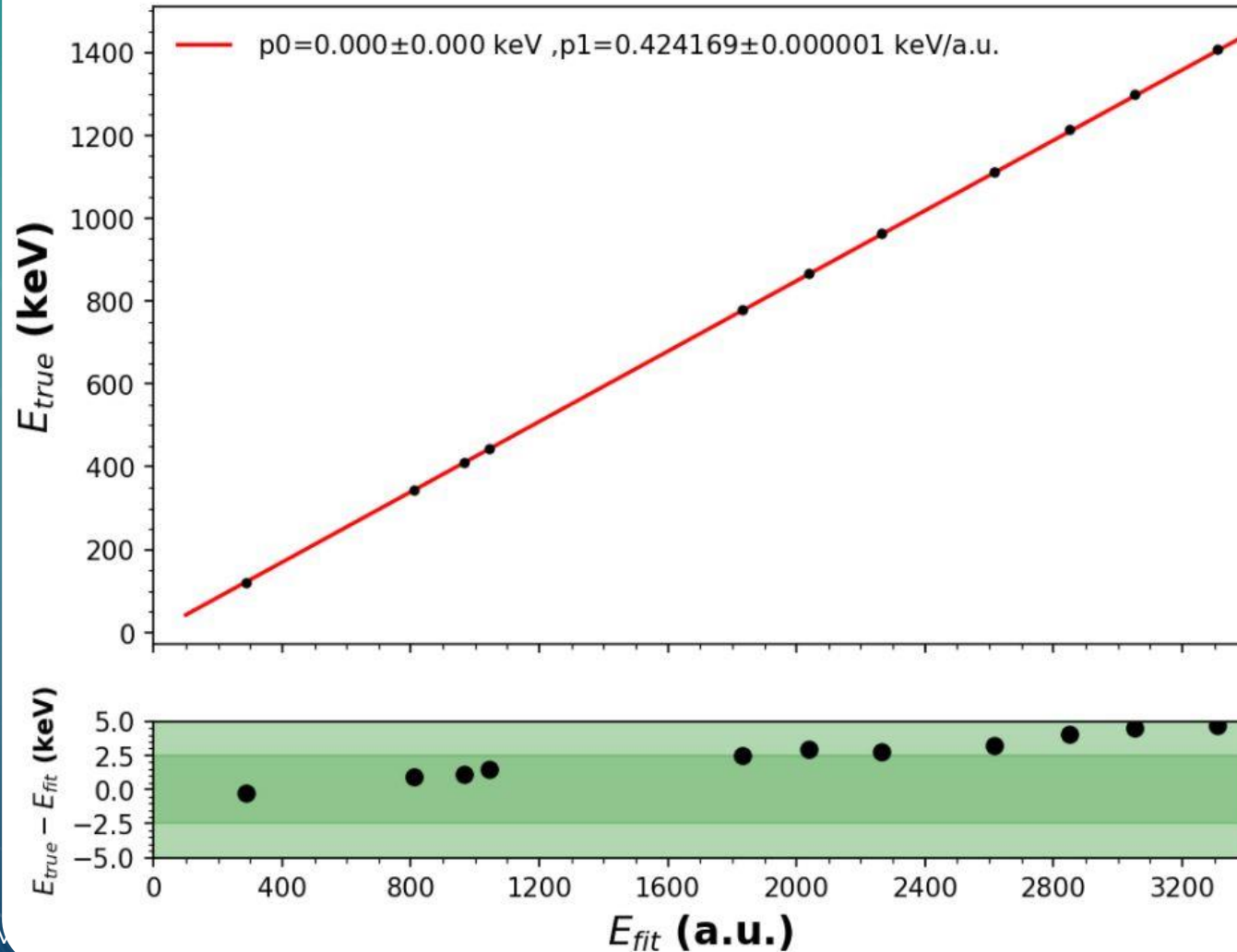
DETECTOR #6

Energy Spectrum (#6)



- Peak at 1408 keV

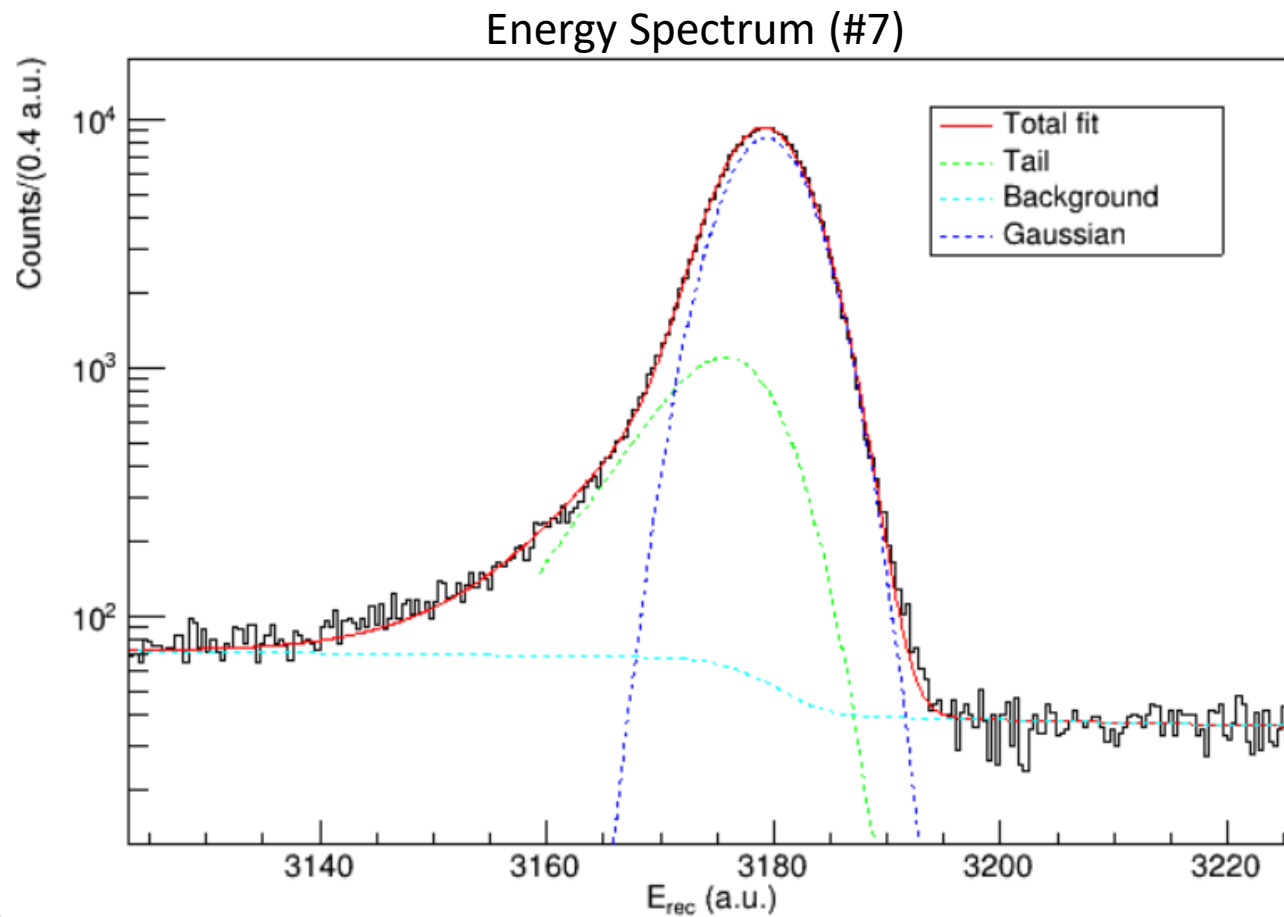
Energy calibration (det #6)



DETECTOR #6

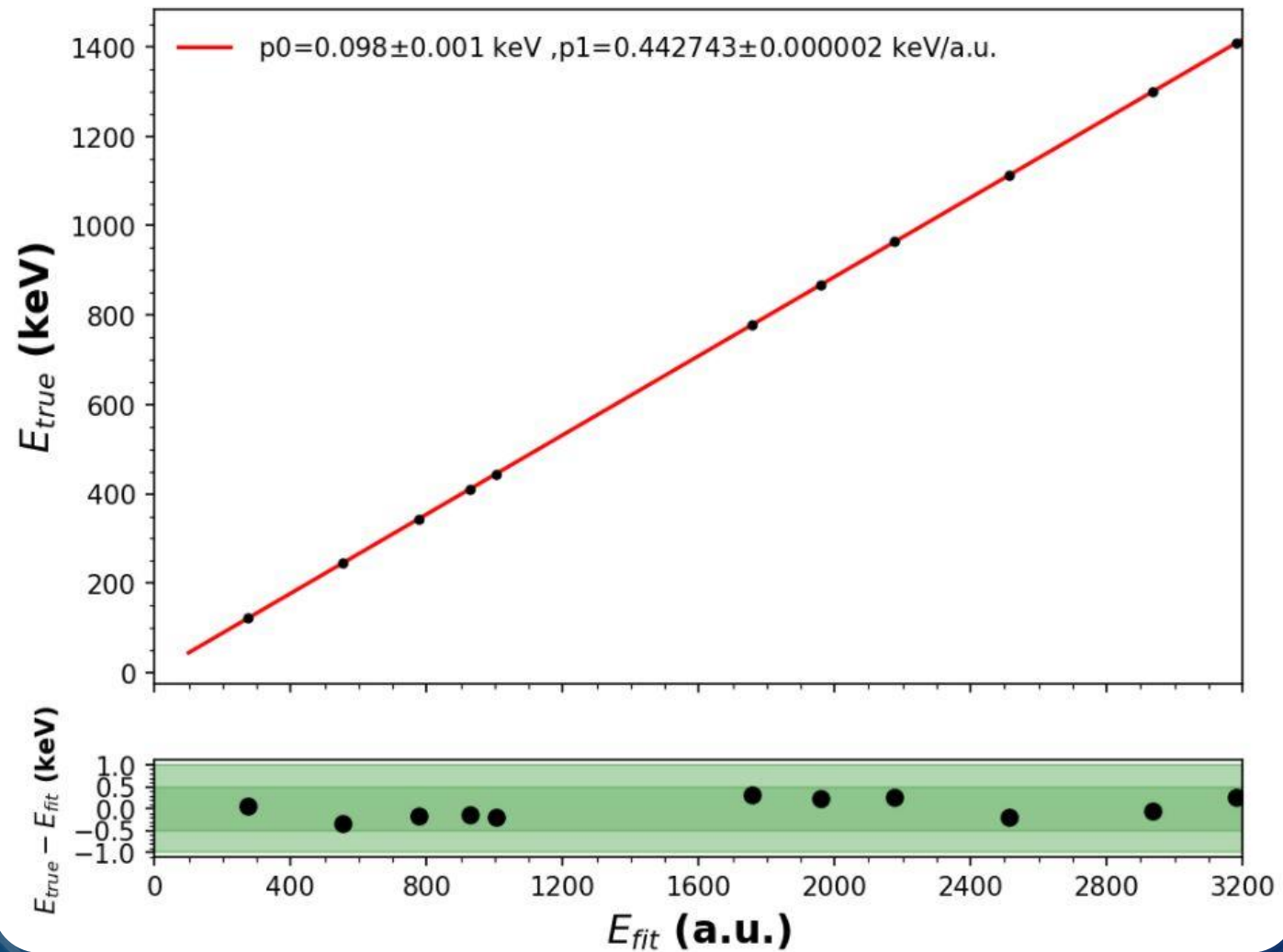
- Lines excluded: 244.6975 keV
- Intercept is very small ($\sim 1E-11$)

DETECTOR #7



- Peak at 1408 keV

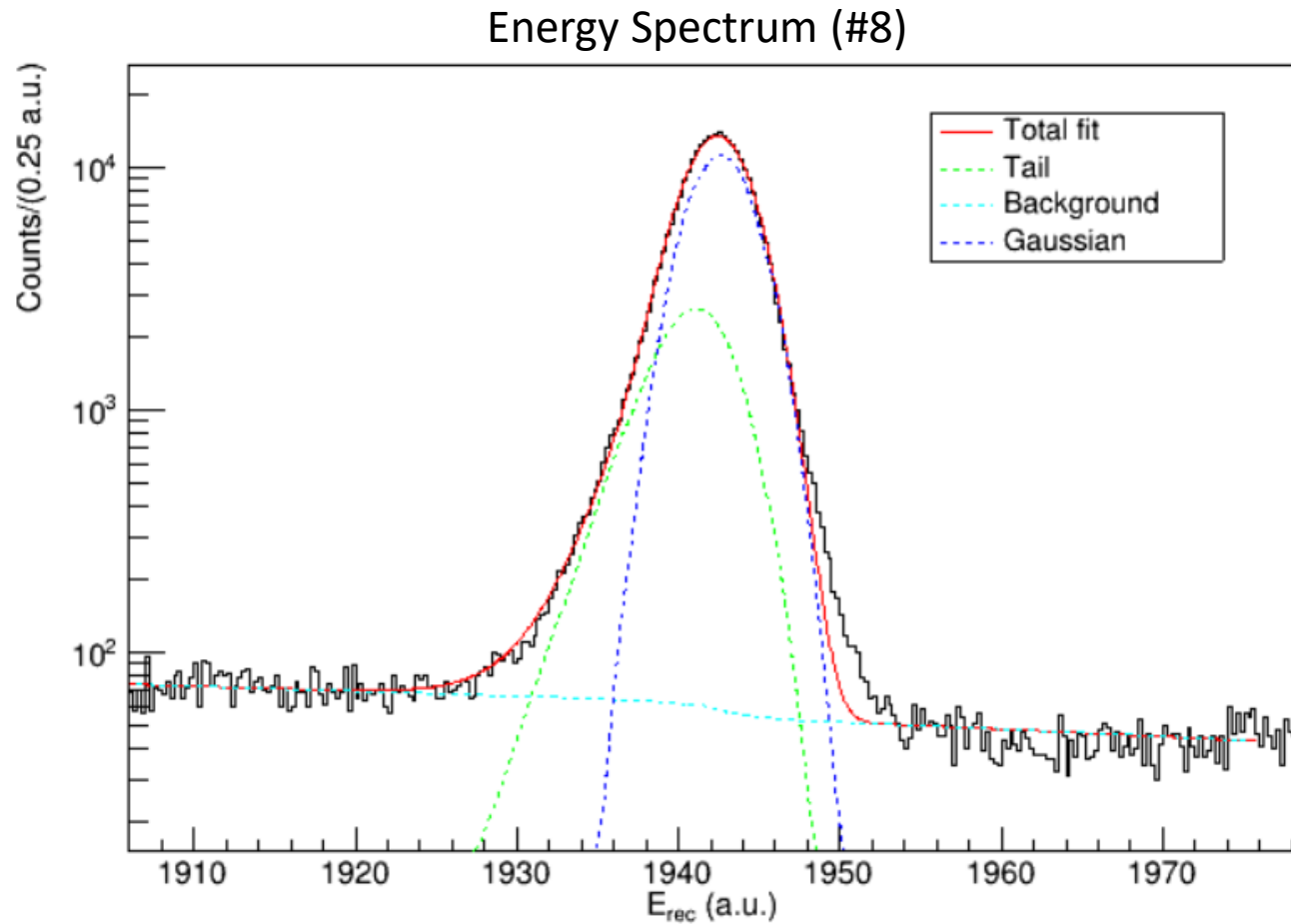
Energy calibration (#7)



DETECTOR #7

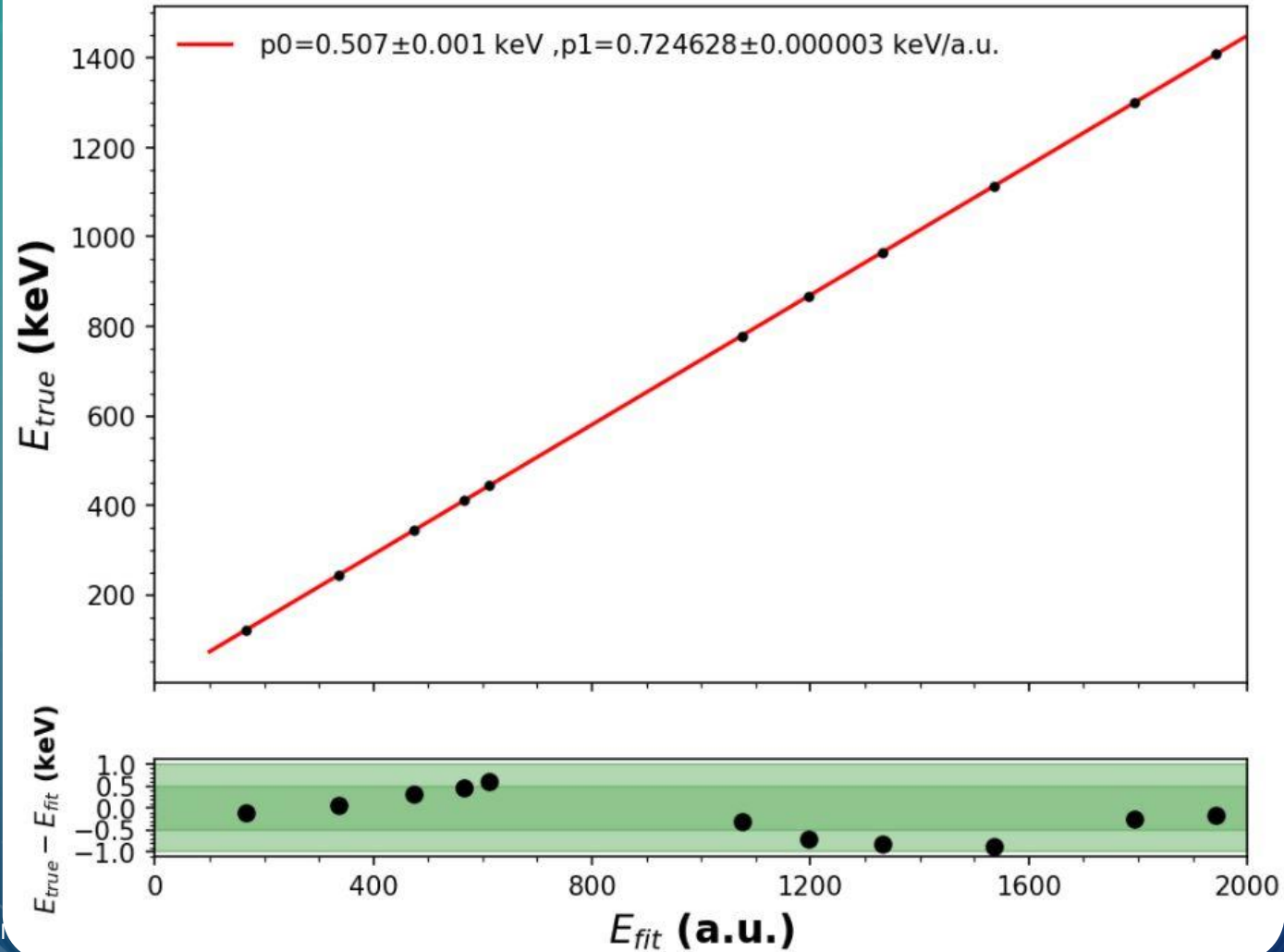
- Lines excluded: 1212.948 keV

DETECTOR #8



- Peak at 1408 keV

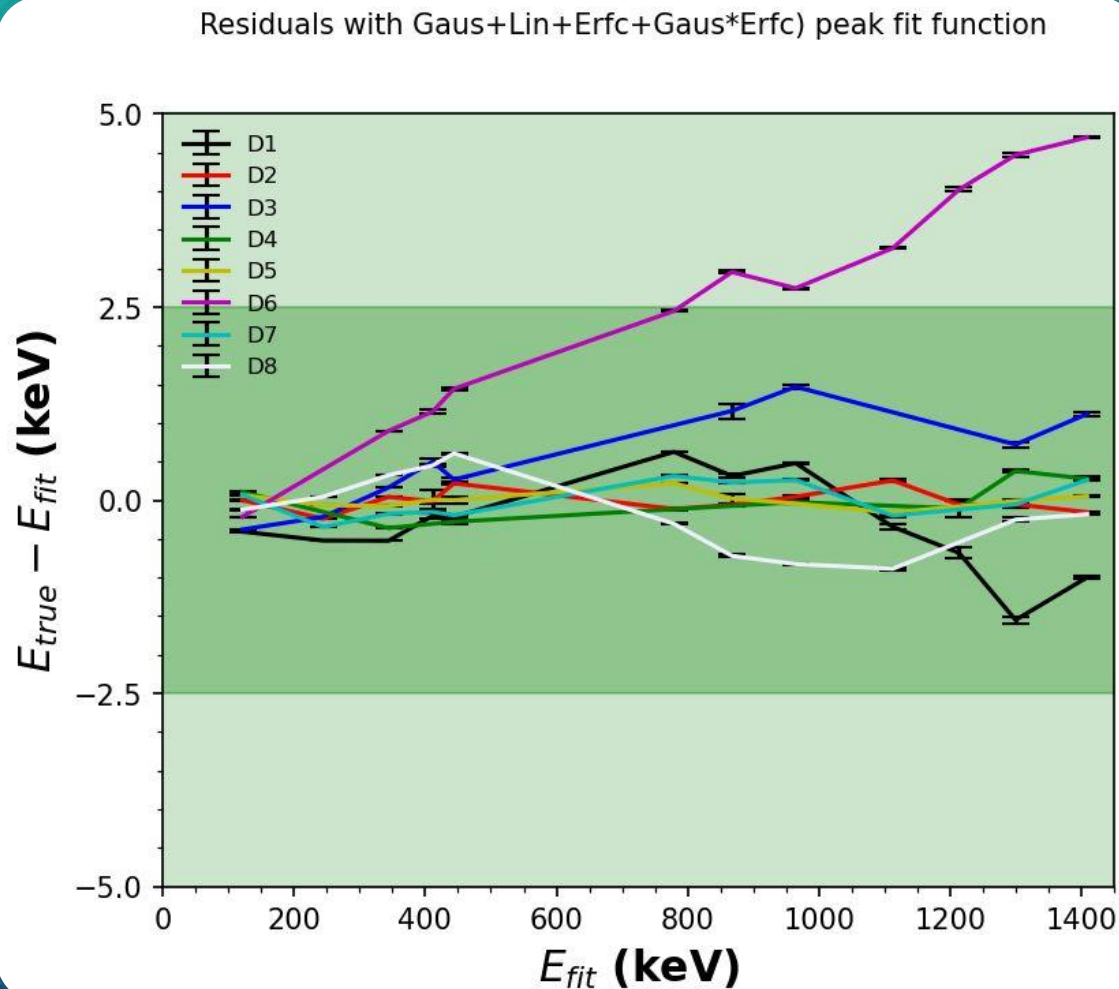
Energy calibration (#8)



DETECTOR #8

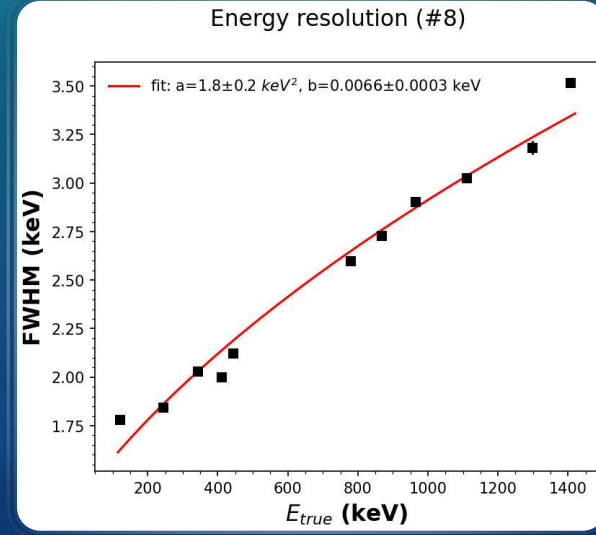
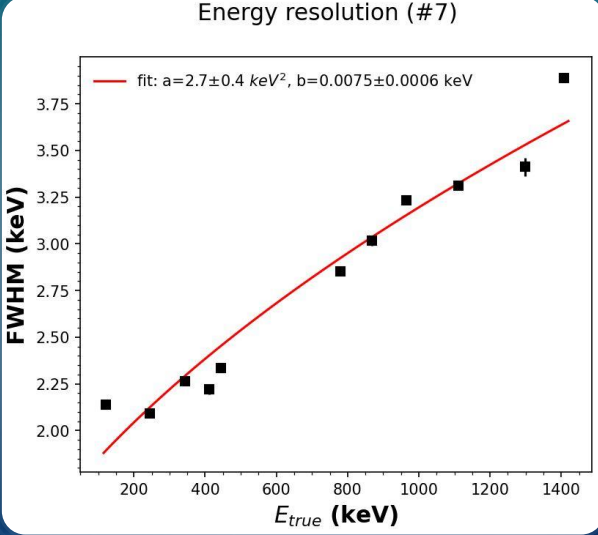
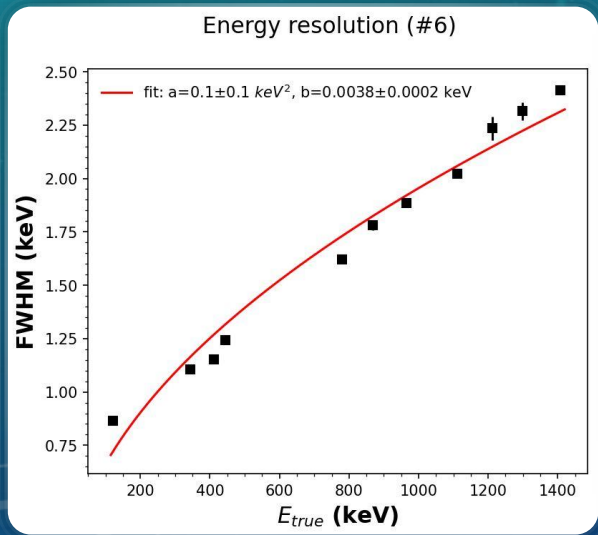
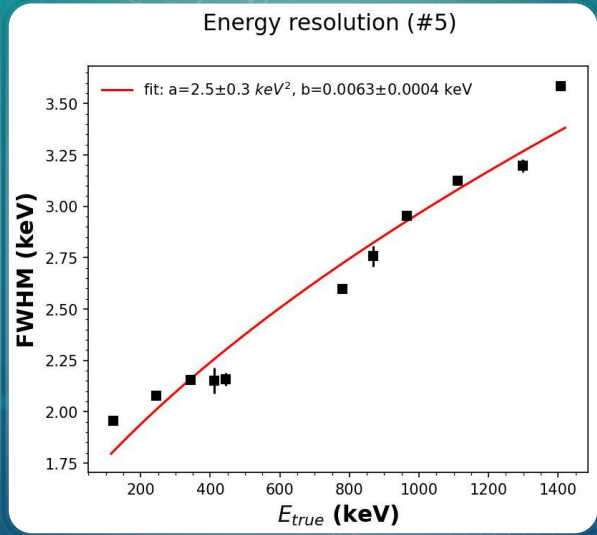
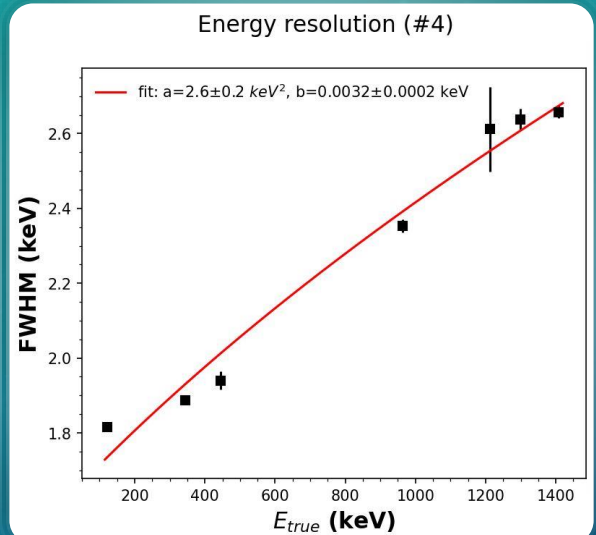
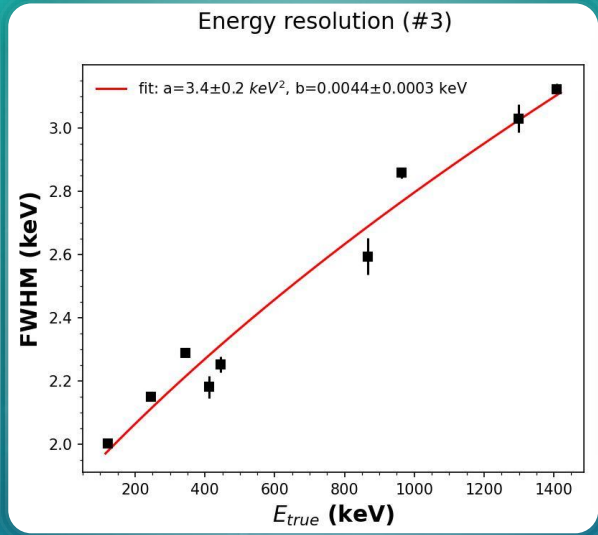
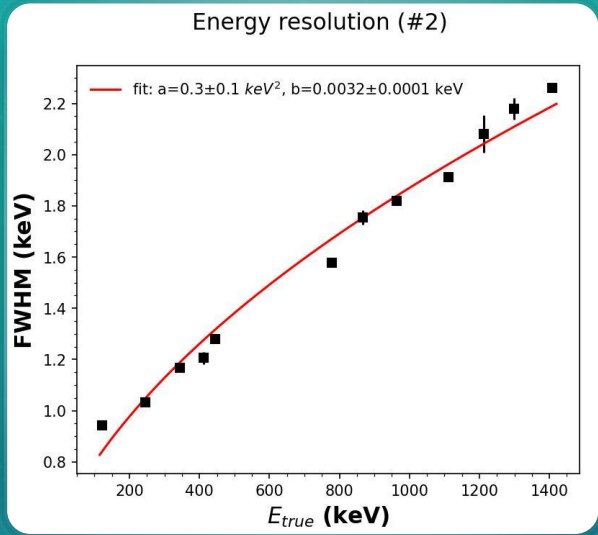
- Lines excluded: 1212.948 keV

RESIDUALS



- For different detectors, range of residuals varies in different ranges
- We need to look in detail at det #6 and understand why the residuals are worse than usual here

ENERGY RESOLUTION



• Fit function used is

$$FWHM = 2.355 \cdot \sqrt{a + bE}$$

ALL PARAMETERS IN TABLE

Detector #	Energy calibration		Residuals	Energy resolution		FWHM @1.3 MeV (keV)
	Fit func. $y = m*x+c$		$E_{true} - E_{fit}$	Fit func. $y = (a+b*x)^{0.5}$		
	Slope (m) (keV/a.u.)	Intercept (c) (keV)		a (keV) ²	b (keV)	
1	0.8	0	(-1.5)- (0.6)	7.93	0.007	3.9
2	0.46	0.17	(-0.24)- (0.26)	0.56	0.003	2.1
3	0.78	0	(-0.38)- (1.47)	3.45	0.005	3
4	0.89	0.08	(-0.36)- (0.38)	2.91	0.003	2.6
5	0.4	0.07	(-0.16)- (0.22)	2.91	0.006	3.3
6	0.42	0	(-0.21)- (4.69)	0.38	0.003	2.2
7	0.44	0.1	(-0.35)- (0.32)	3.49	0.007	3.5
8	0.72	0.51	(-0.89)- (0.61)	2.27	0.006	3.2

SUMMARY

- We updated the fit function and applied some quality cuts suggested by TUM
- Using the updated method, FWHM at 1.3 MeV is 3.9 keV for detector #1 and <4keV for other detectors
- A new algorithm to fit peaks in the energy spectrum was applied which seems to work very well to a first approximation
- Not all peaks were included for energy calibration
- In the final study, this technique could help us understand how the results change when we change our approach

NEXT STEP

- Analyze the change in calibration constants using data from calibration runs on different days
- Apply other cuts to data after further discussion in upcoming LLAMA analysis meetings
- Redo the entire process with trapezoidal filter