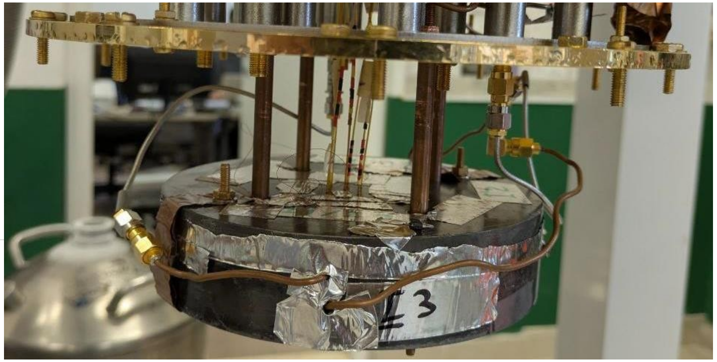
SAPIENZA
UNIVERSITÀ DI ROMA

Background with mild shield: high energy spectrum with multidimensional analysis

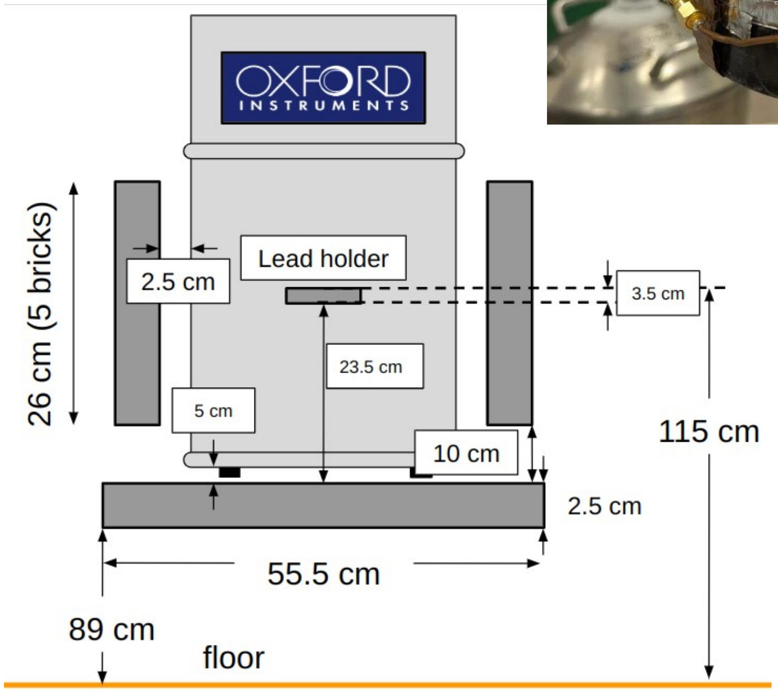
BULLKID Digest
12/11/2025
Matteo Cappelli

Background with mild shield

Data with internal and external lead shields.
290 hours for 2 clusters with 15 KIDs.
19 Apr 22:00 – 5 May 8:00.
Presentation by D. Delicato at the last collaboration meeting.

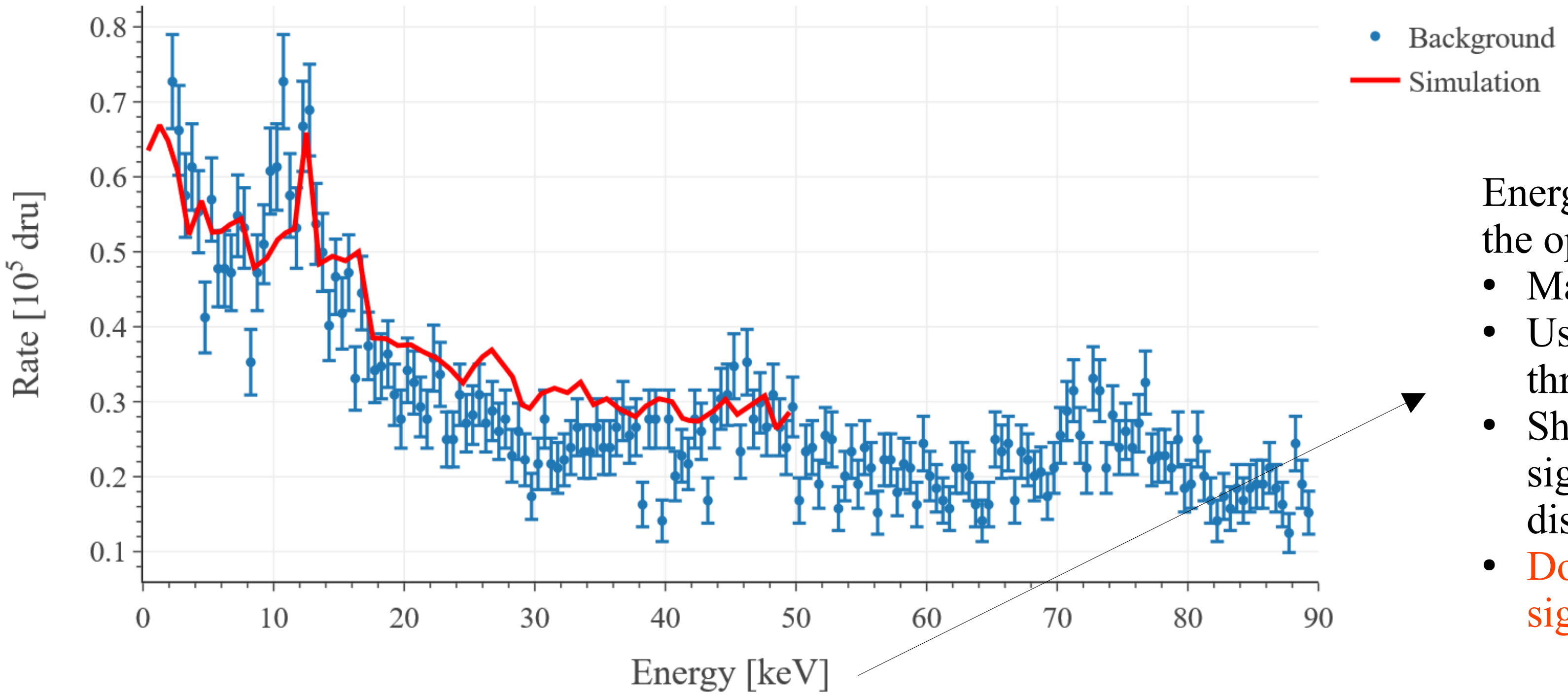


		1	2	3	4	5	
13	12	11	10	8	7	9	6
14	15		16	17	18		19
27	26	25	24	23	22	21	20
29	28	30	31	32	33	34	35
43	42	41	40	39	38	36	37
44	45	46	47	48	49	50	51
	57	56	55	54	53	52	



High energy spectrum previous results

Background in the range [2-90] keV is compatible with simulations with visible Pb X-ray peaks.
Presentation by D. Delicato at the last collaboration meeting.



Energy reconstructed with the optimum filter:

- Maximizes the SNR
- Used for lower the trigger threshold
- Shape parameters for signal/background discrimination
- Does not account for signals in neighbor pixels

Analysis with N-dimensional optimum filter (OFND)

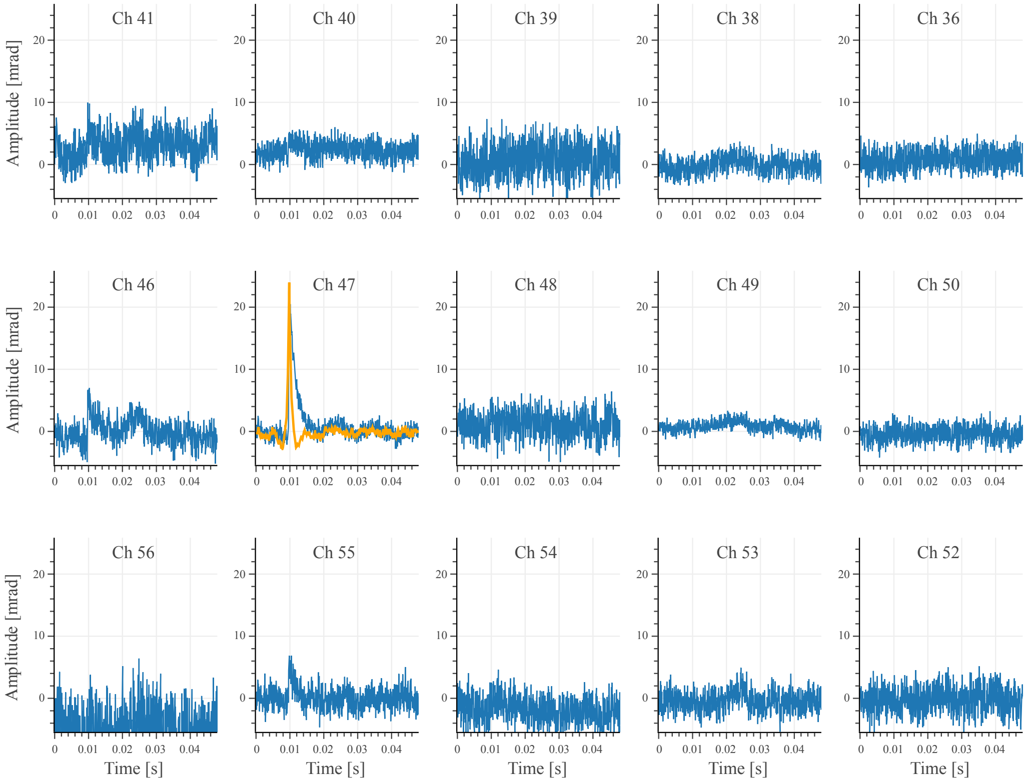
The multidimensional optimum filter combines the waveforms in different pixels to improve the resolution. Shape parameters can be used as a further cluster cut. Talk at collaboration meeting in Pisa.

The filtered signal is:

$$\tilde{v}_{\text{filt}}(f) = \frac{1}{K} \sum_{a,b=1}^{N} \underbrace{\tilde{s}_a^*(f)}_{\text{templates}} \underbrace{\hat{\sigma}_{ab}^{-1}}_{\text{noise covariance}} \underbrace{\tilde{v}_b(f)}_{\text{waveforms}}$$

$$K = \int_{-\infty}^{\infty} df \sum_{a,b=1}^{N} \tilde{s}_a^*(f)\hat{\sigma}_{ab}^{-1}\tilde{s}_b(f)$$

10 % baseline resolution improvement on pixel 47 (see talk at last BULLKID Digest).
Presented also the improvements on the low energy background near threshold.



Analysis with N-dimensional optimum filter (OFND)

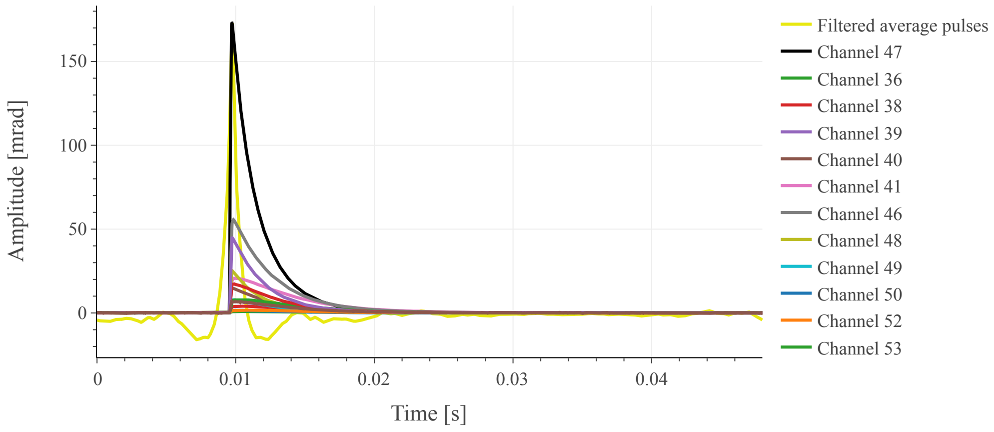
Here, I present an analysis of the high energy particle background with amplitude estimated with OFND.

Goals:
- Have a unique amplitude estimator both for the low energy and the high energy parts of the spectrum
- Calibrate using lead peaks
- Evaluate efficiencies with the pulse shape variables from OFND
- Check compatibility of the two amplitude estimators
- Check compatibility with the previous analysis

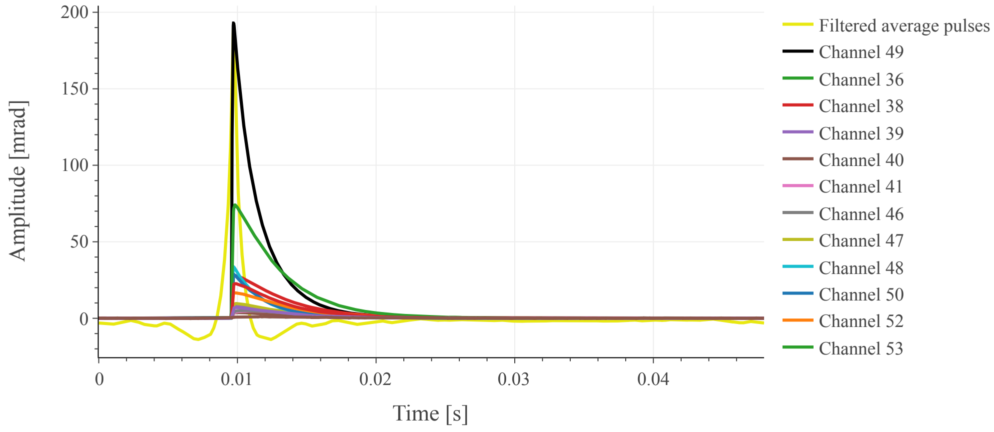
Template pulses

The template pulses for the two pixels are built with **LED fired on the main channels** and **signals in coincidence on neighbors dice**.
Amplitude range of ~ 50 - ~ 300 mrad to avoid pulse shape distortions at large phases.

Average pulses of main channel 47



Average pulses of main channel 49



Noise covariance

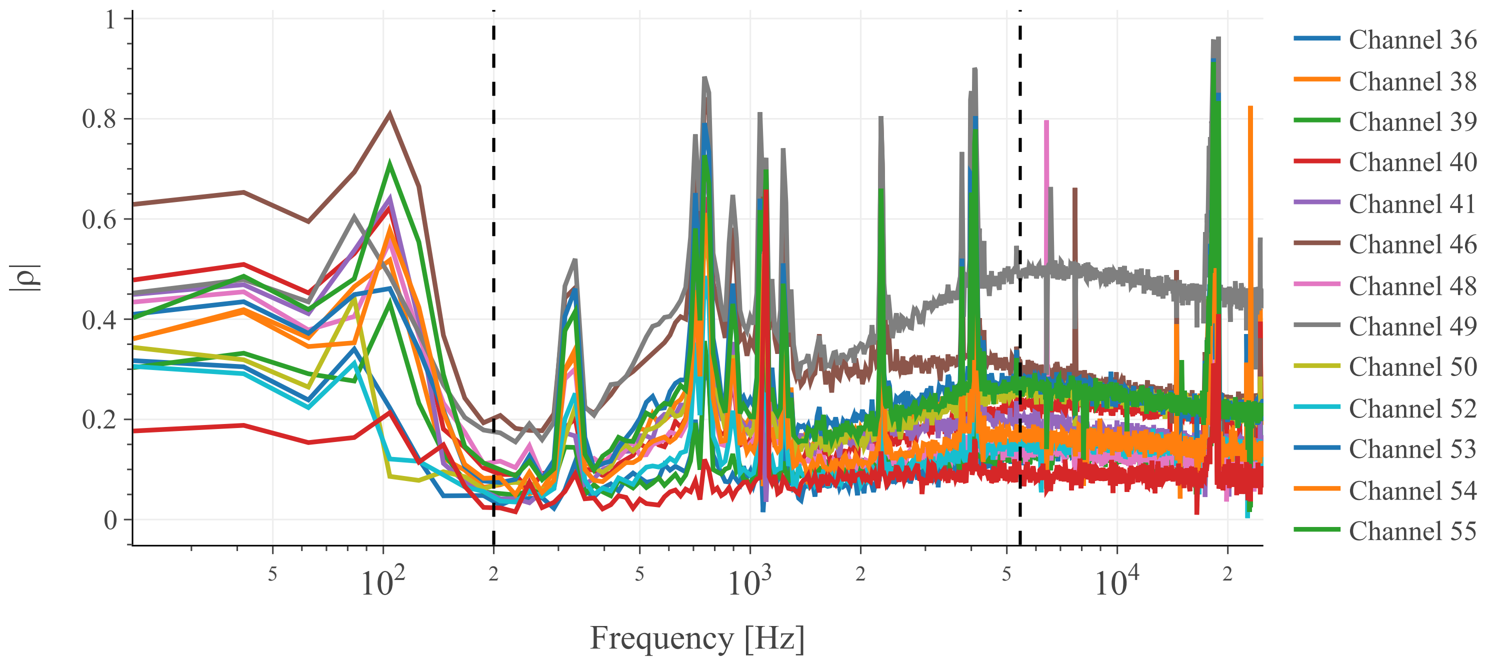
Defined as $\hat{\sigma}_{ab} =< \tilde{n}_a^*(f)\,\tilde{n}_b(f) >$

Diagonal elements contain the noise power spectra of the pixels.

Correlation is defined as:

$$\rho_{ab}(f) = \frac{\hat{\sigma}_{ab}(f)}{\sqrt{\hat{\sigma}_{aa}(f)\hat{\sigma}_{bb}(f)}}$$

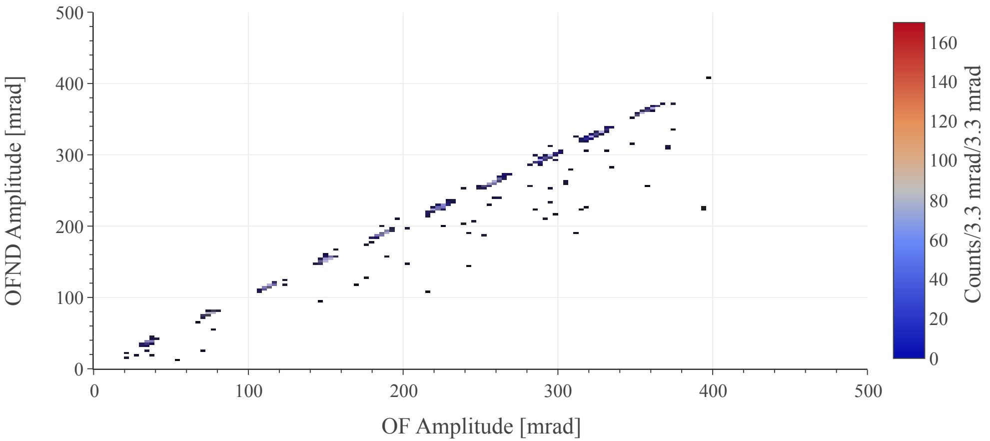
Noise correlation between channel 47 and neighbour channels



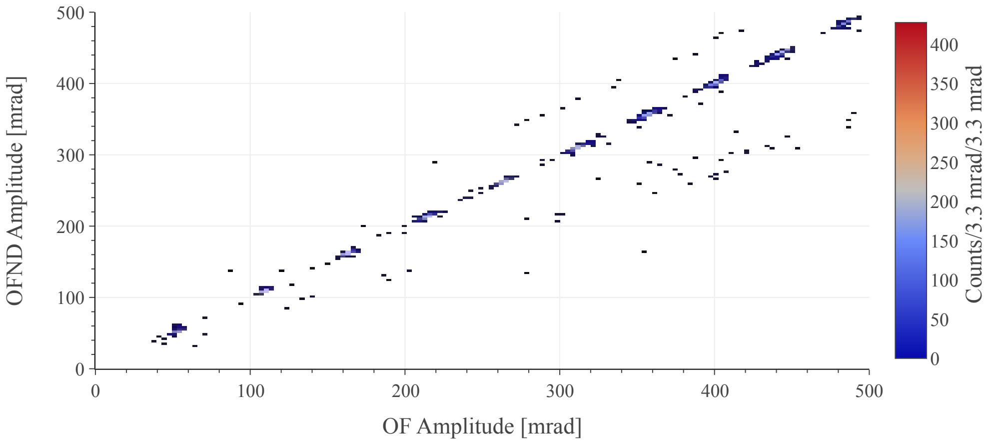
Amplitude comparison

On LED events, the two different amplitude are compatible.

Channel 47



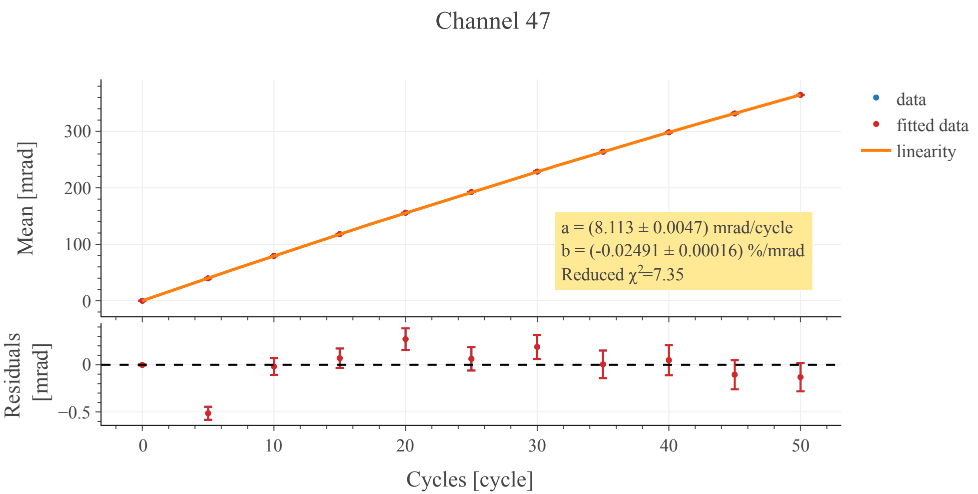
Channel 49

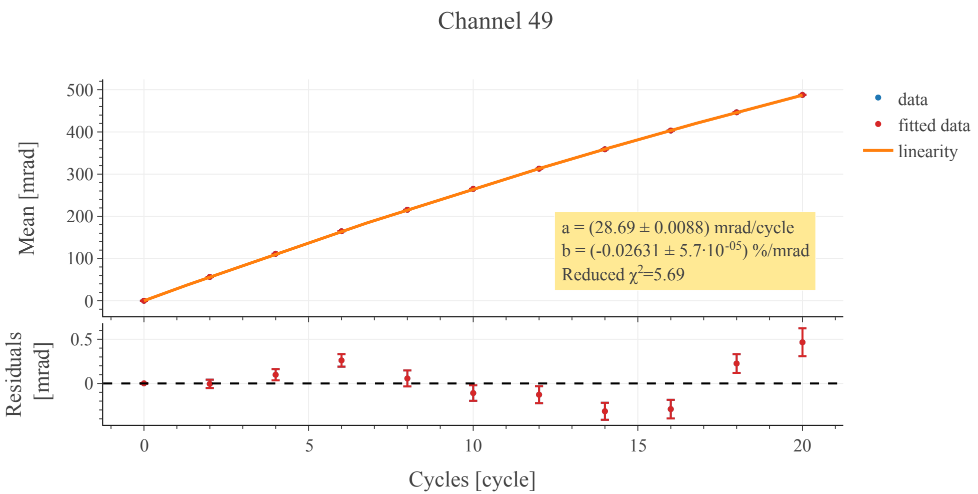


An analysis with this amplitude variable is feasible.

Amplitude linearization

OFND amplitude is linearized using the LED calibration data. Amplitude fitted against the number of LED bursts.





Non linearities up to 9 % on pixel 47 and 12 % on pixel 49

Fit function: $A = a \cdot n_c(1 + b \cdot a \cdot n_c)$ where n_c is the number of the led bursts

Amplitude linearized is defined as: $A_{\text{lin}} \equiv a \cdot n_c = \dfrac{-1 + \sqrt{1 + 4ba}}{2b}$

Cluster cuts: Ψ_i

We do our usual cluster cut to identify events in which the interaction took place in the main pixels 47 or 49.

Amplitude on main pixel

Amplitude on pixel i

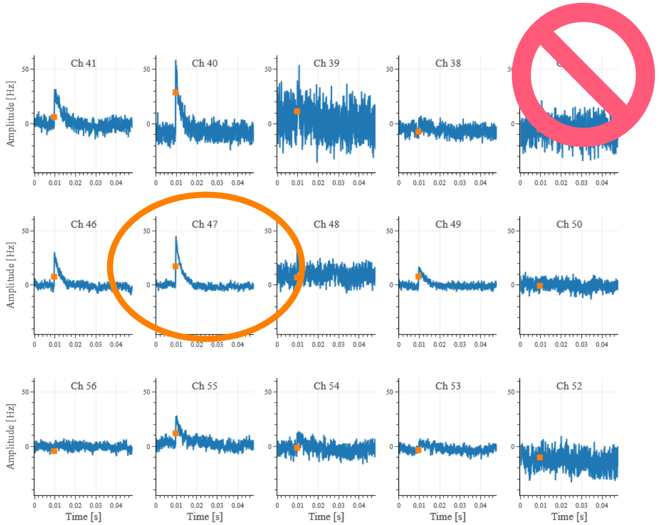
Mean amplitude ratio between pixel i and main pixel

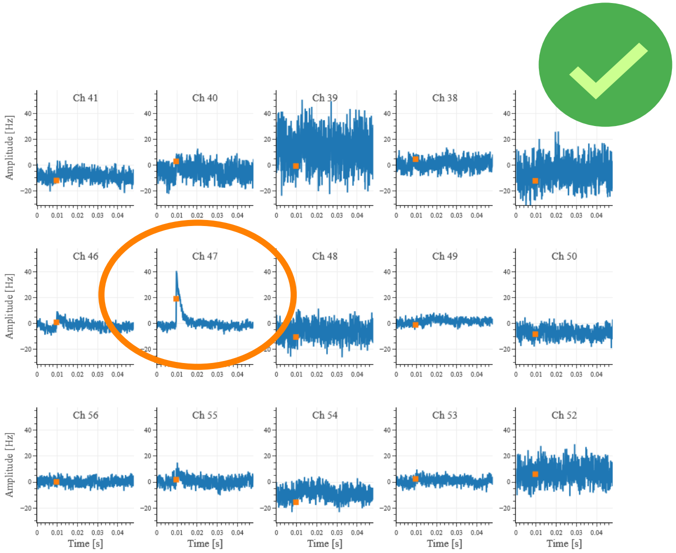
$$\psi_i = \frac{\delta\phi_i - (\delta\phi_c \cdot \mu_{ri})}{\sqrt{\sigma_{0,i}^2 + (\sigma_{0,c} \cdot \mu_{ri})^2}}$$

Noise on pixel i

Noise on main pixel

Signals in neighbor pixels





Only signal in the main pixel

Cluster cuts: Ψ_i

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Amplitude on pixel i

Amplitude on main pixel

Mean amplitude ratio between pixel i and main pixel

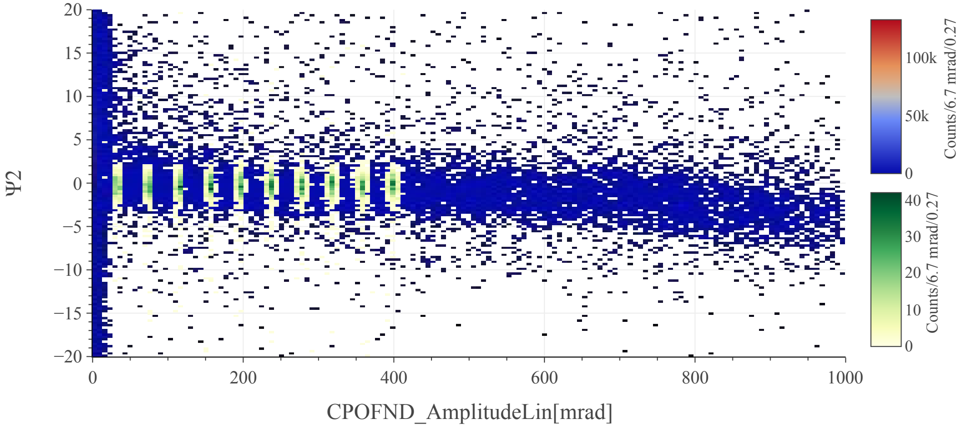
$$\psi_i = \frac{\delta\phi_i - (\delta\phi_c \cdot \mu_{ri})}{\sqrt{\sigma_{0,i}^2 + (\sigma_{0,c} \cdot \mu_{ri})^2}}$$

Noise on pixel i

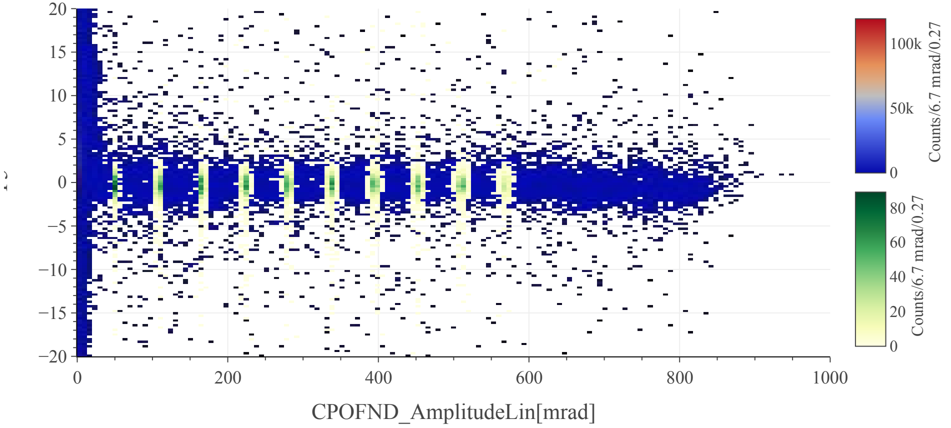
Noise on main pixel

LED and Background

Channel 47



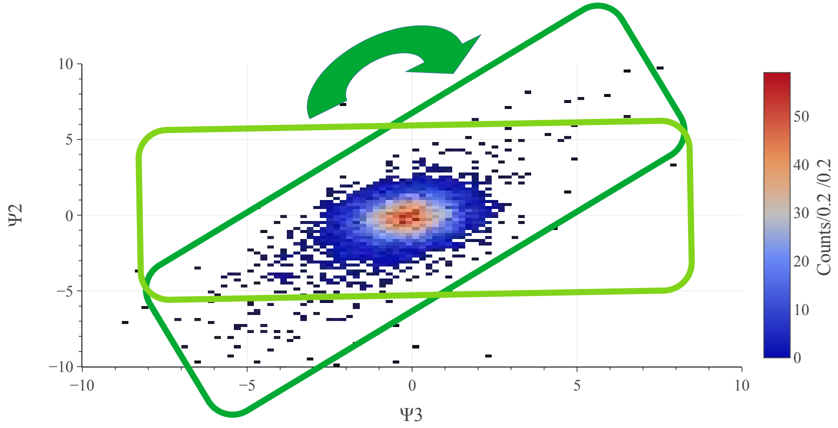
Channel 49



Cluster cuts: Ω

We can rotate the different Ψ_i and combine them to build a unique variable to cut events.

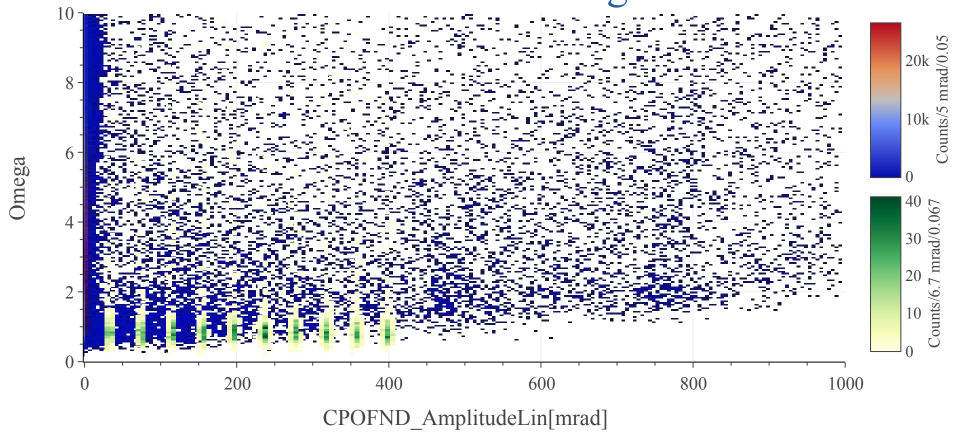
$$\Psi_i \rightarrow (\Psi_i)_R$$



Construct the Ω variable as:

$$\Omega = \sqrt{\sum_{i=1}^{14}[(\Psi_i)_R]^2}$$

LED and Background



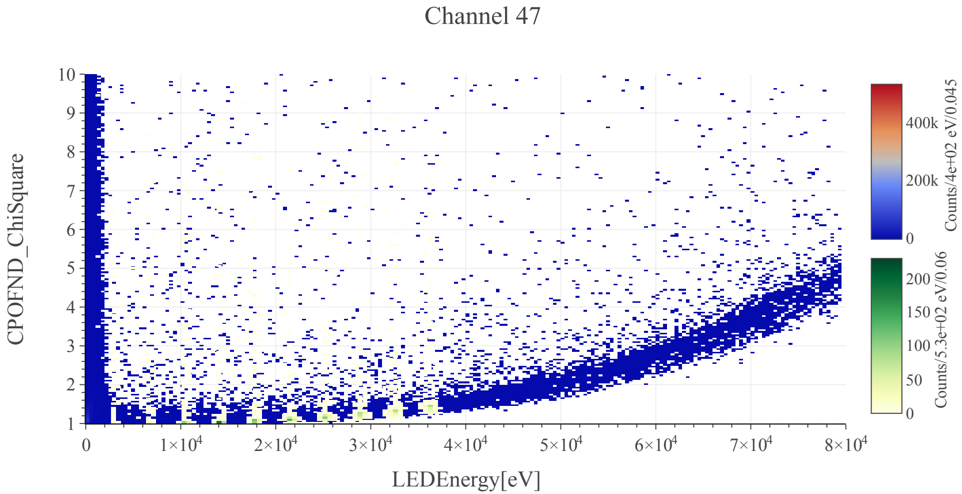
Shape cuts: χ^2_{OFND}

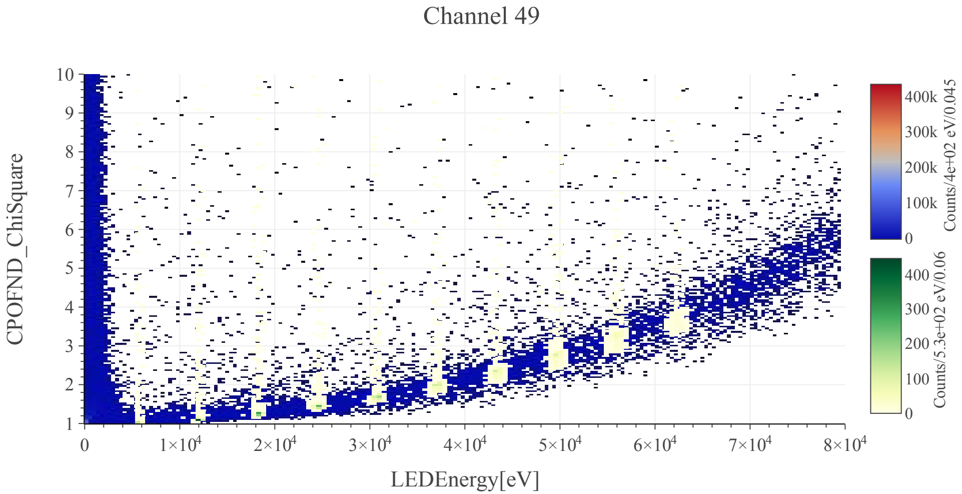
Generalization of the χ^2 of the matched filter defined as:

$$\chi^2_{\mathrm{OFND}} = \sum_{a,b=1}^{14} \int_{-\infty}^{\infty} df\, [\tilde{v}_a(f) - \hat{A}\tilde{s}_a(f)]^* \hat{\sigma}_{ab}^{-1} [\tilde{v}_b(f) - \hat{A}\tilde{s}_b(f)]$$

Needs a matching of all the waveforms with the average pulses.

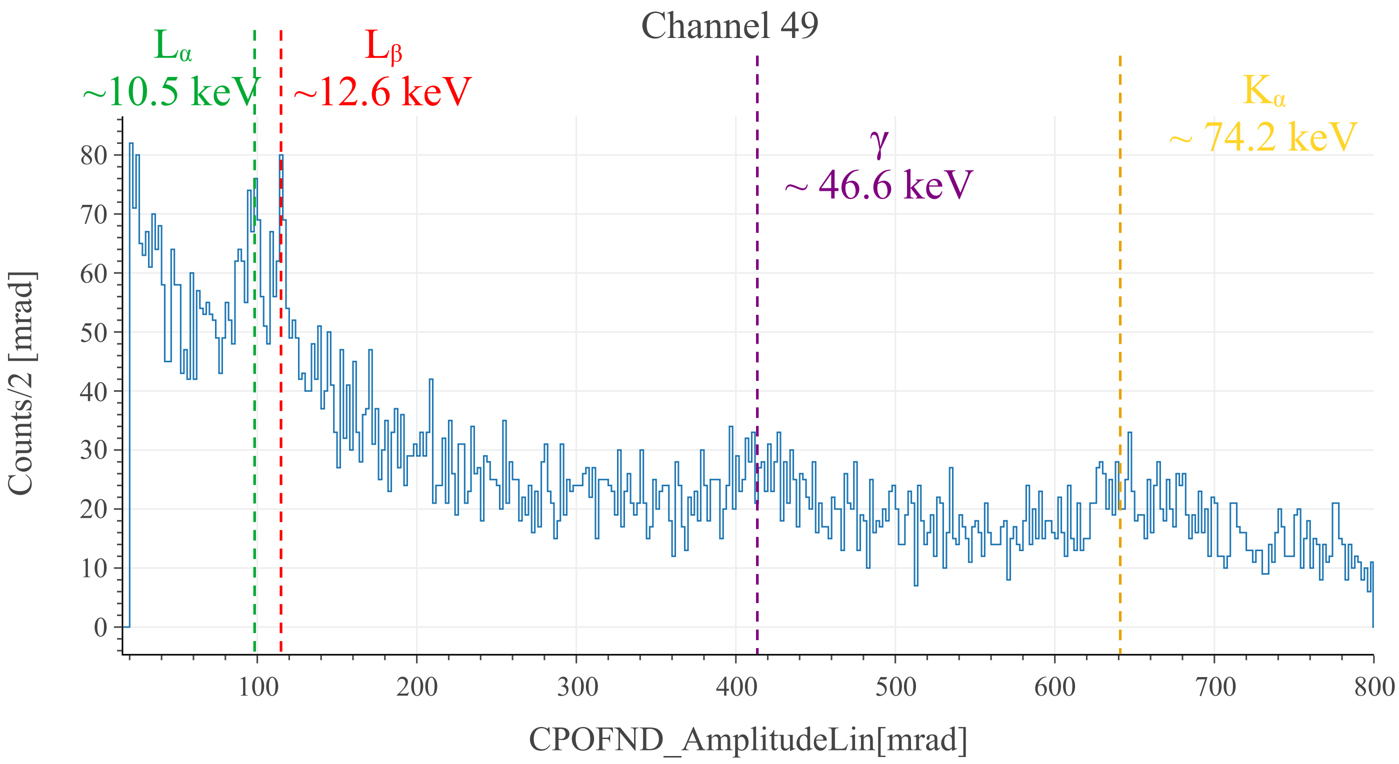
LED and Background





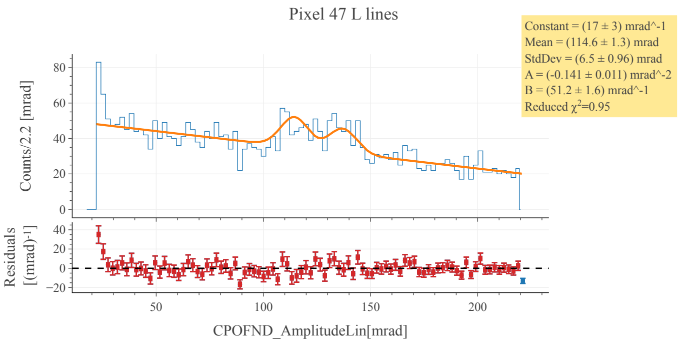
Lead peaks

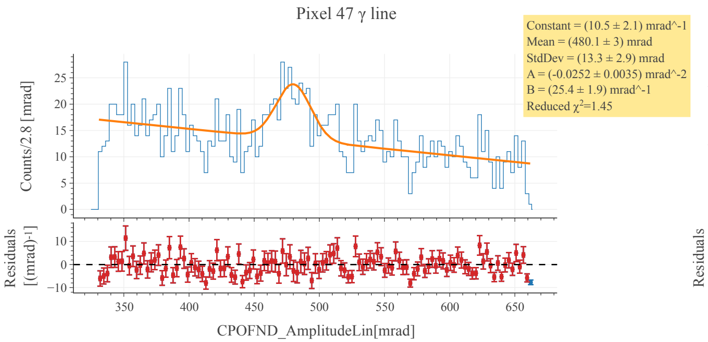
With some preliminary cuts, we can identify the lead peaks used for calibration.

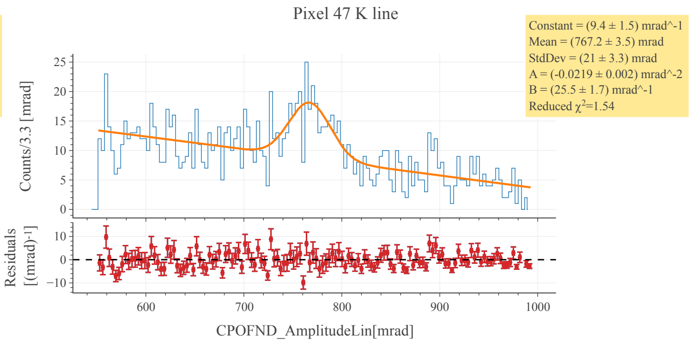


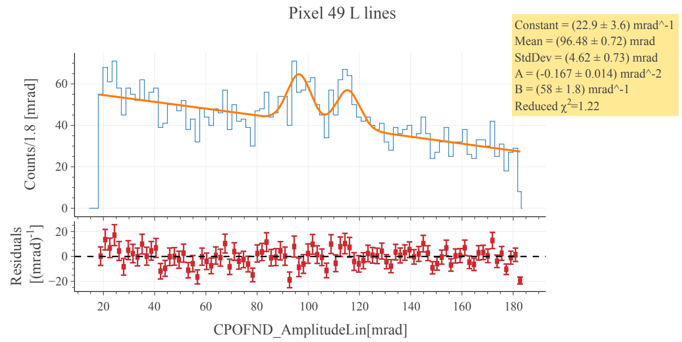
Fitting the lead peaks

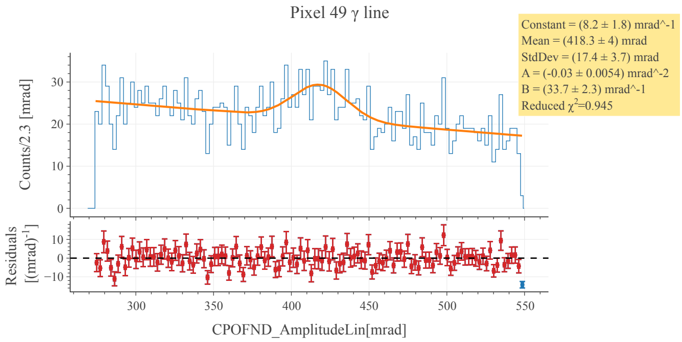
- The energy spectrum is divided in 3 ranges.
- Peaks are fitted with a gaussian plus a 1-degree polynomial
- In the case of the double peak, the intensity and the position of the second peak is fixed by theory

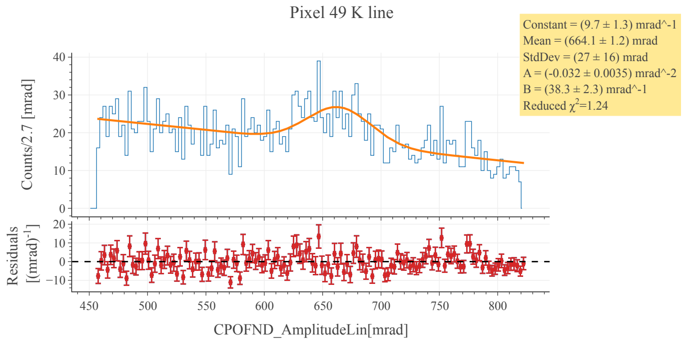






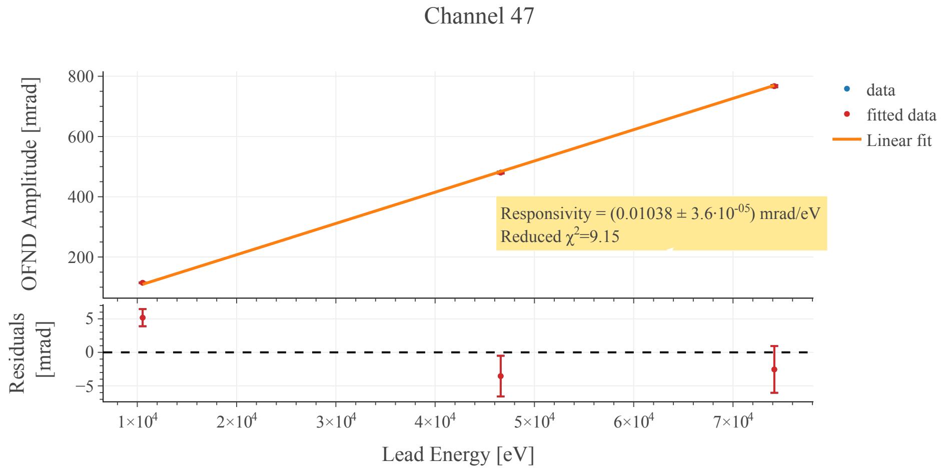


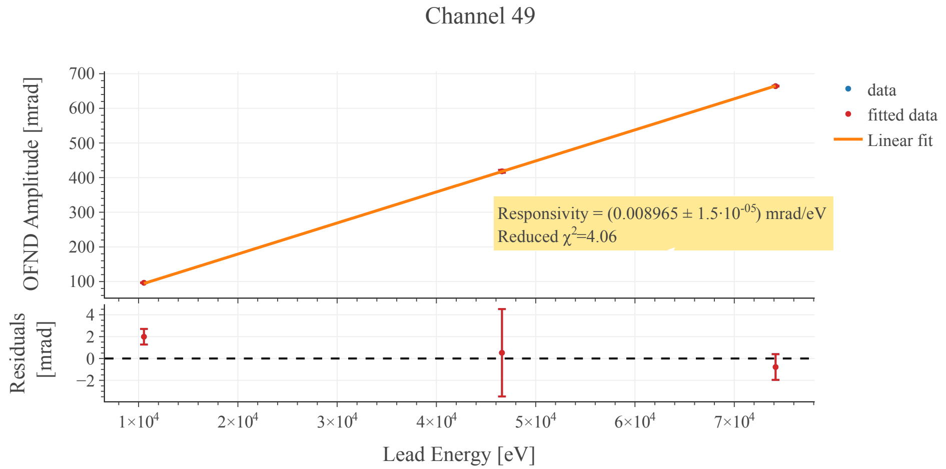




Lead calibration

- Since L_β parameters are fixed, we have three points to calibrate with lead peaks.





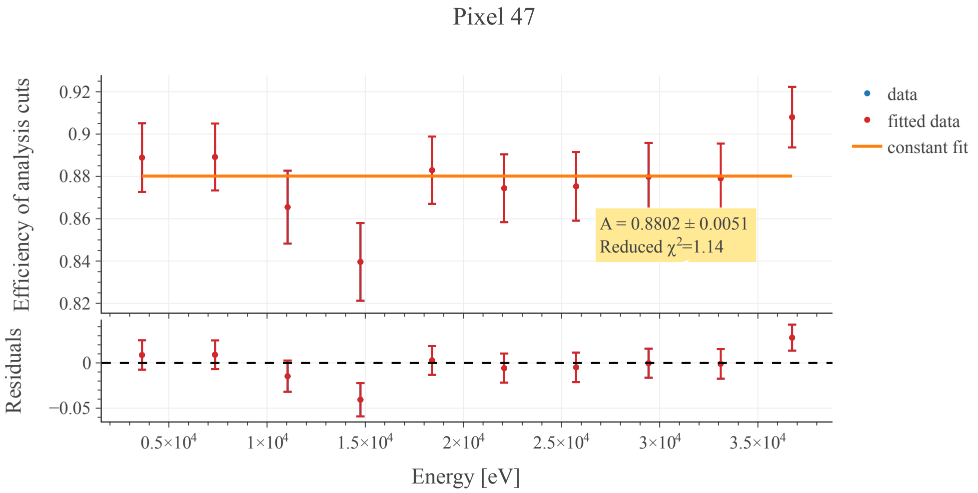
- Almost perfect matching between the LED and the lead calibration, valid up to 6 %

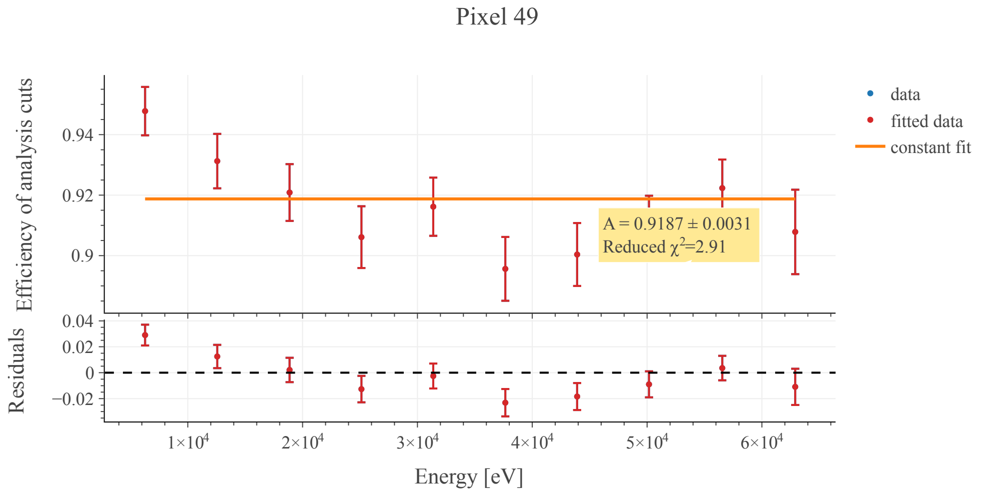
Analysis cuts and efficiencies

Analysis cuts:

- $\chi^2_{OFND} < 6$
- $\Omega < 4.5$
- Other basic and loose pulse shape cuts

Efficiencies evaluated on LED pulses, but soon will be done on lead peaks to avoid LED/background differences

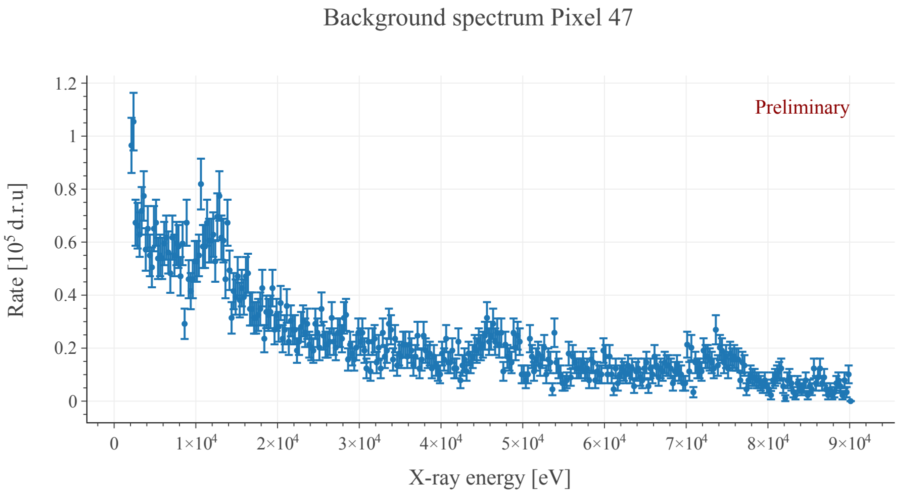


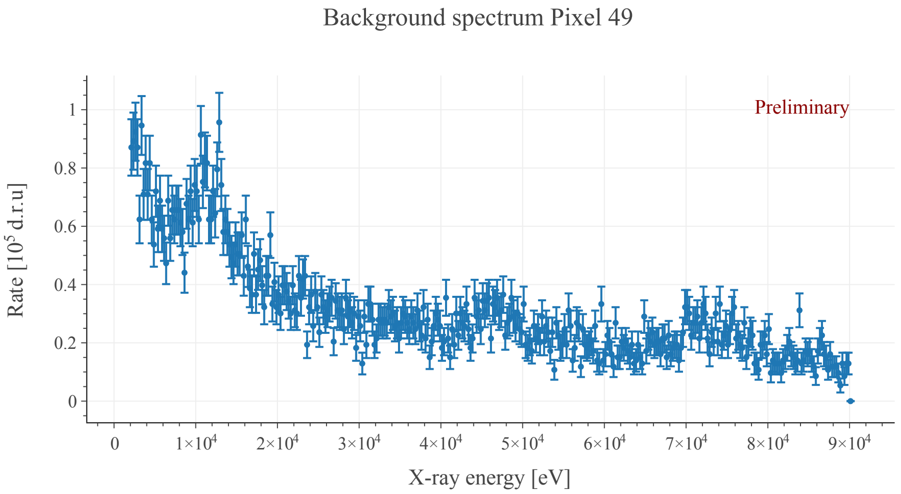


High efficiency of ~90 %

Preliminary energy spectra

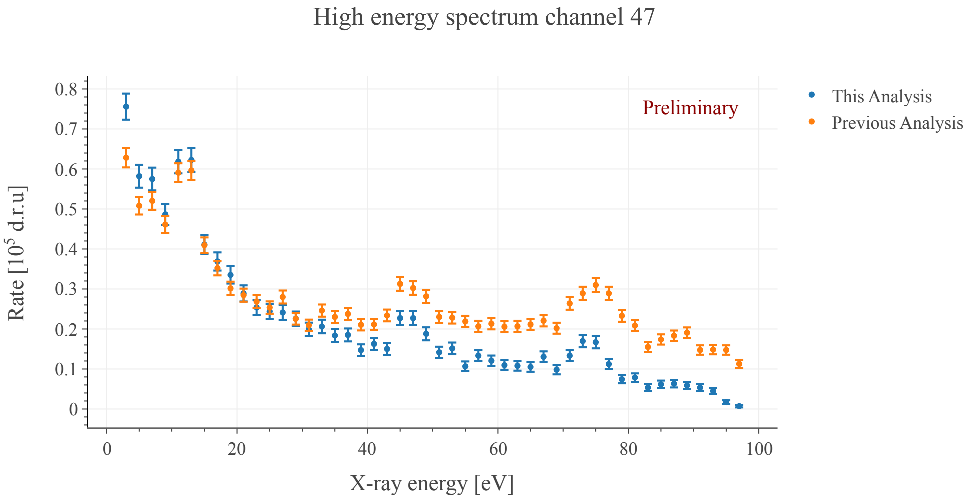
- Background of around ~10^4 d.r.u
- Slightly difference between the two pixels (efficiency mismatch)

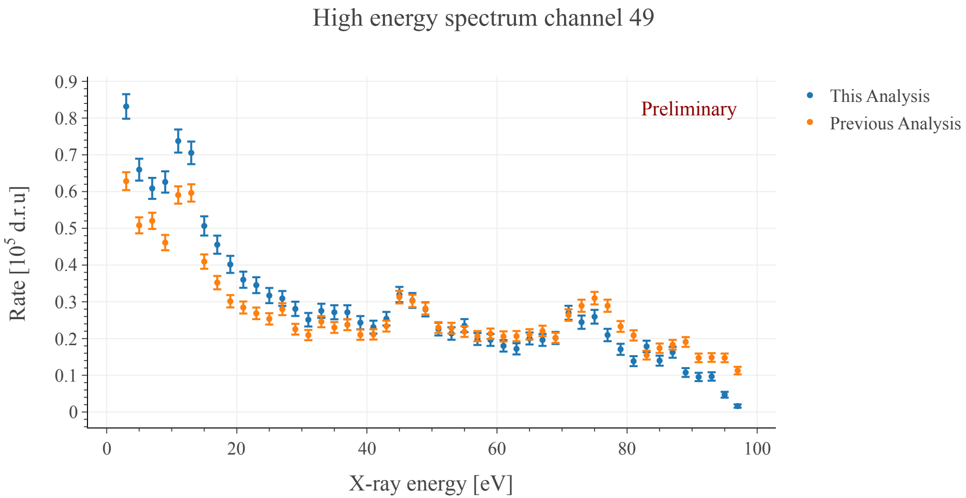




Comparison with previous analysis

Previous analysis done by Daniele and Matteo.

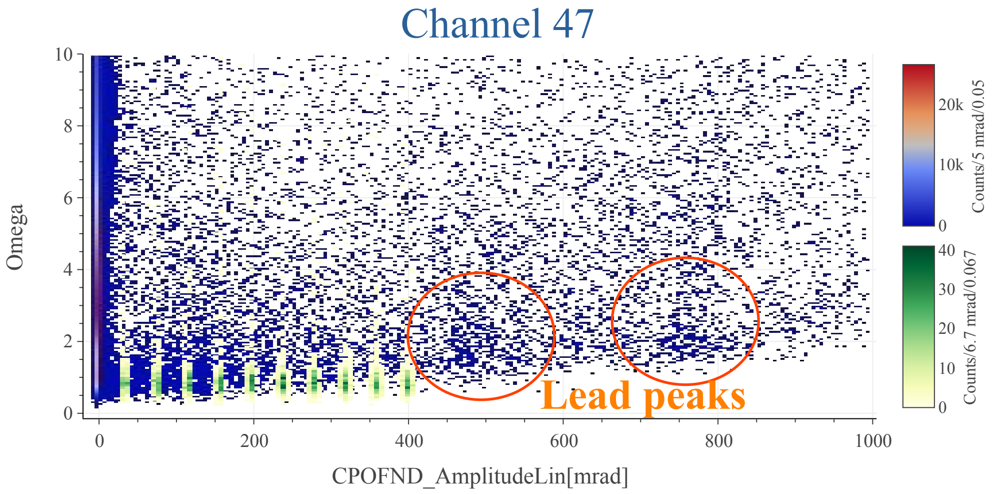


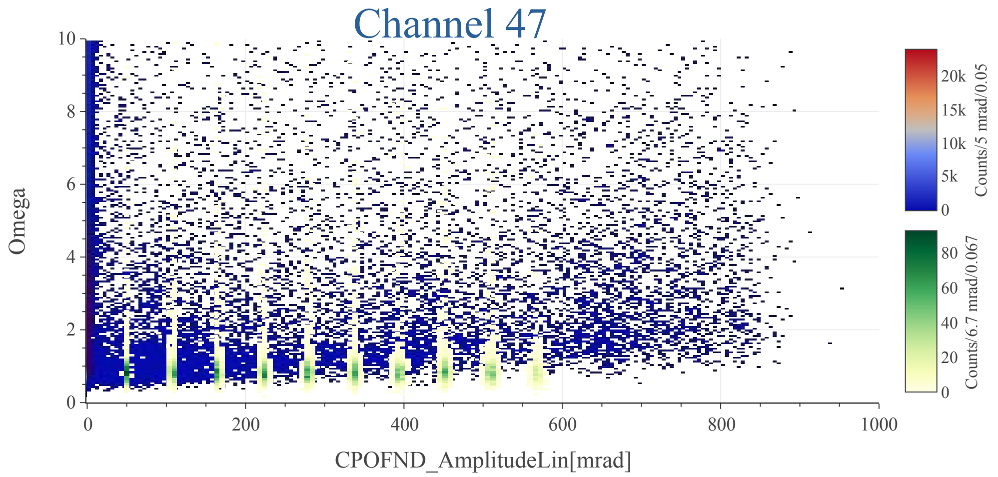


Mismatch due to differences in efficiencies: estimated **on lead peaks in previous analysis**, I evaluated **on LED pulses in this analysis**.
Particularly visible at high energies where **LED/background** differences arise.

Cluster cuts differences LED/Background

At high energies LED pulses are not matching the background in terms of phonon leakage.





TO-DO

- Re-do the analysis evaluating the cluster cuts variables and the efficiencies on lead peaks
- Check again compatibility
- Asses the efficiencies on other shape variables (χ_L, χ_R ...)

thanks for your attention!