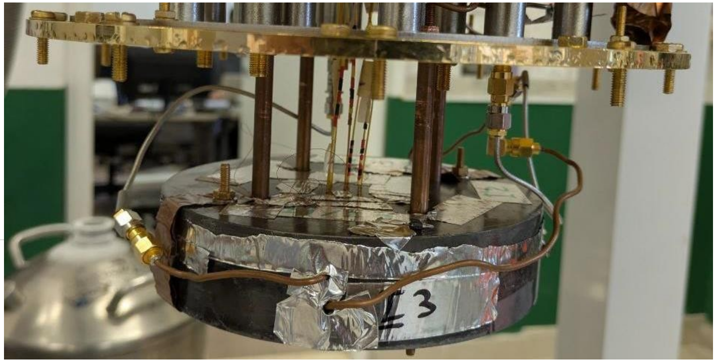
SAPIENZA
UNIVERSITÀ DI ROMA

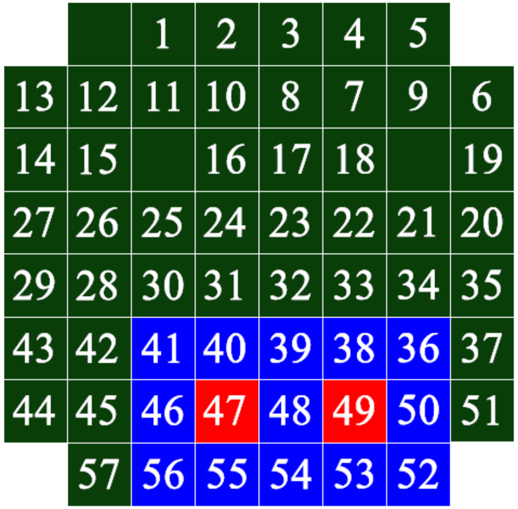
# Bakground with mild shield: high energy spectrum with multidimensional analysis

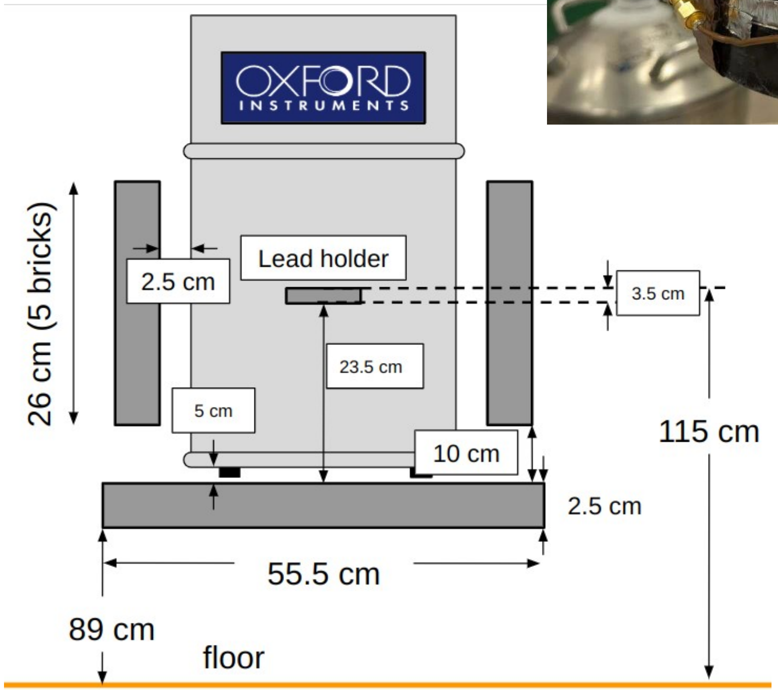
BULLKID Analysis meeting
5/11/2025
Matteo Cappelli

# Background with mild shield

Data with internal and external lead shield.
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.

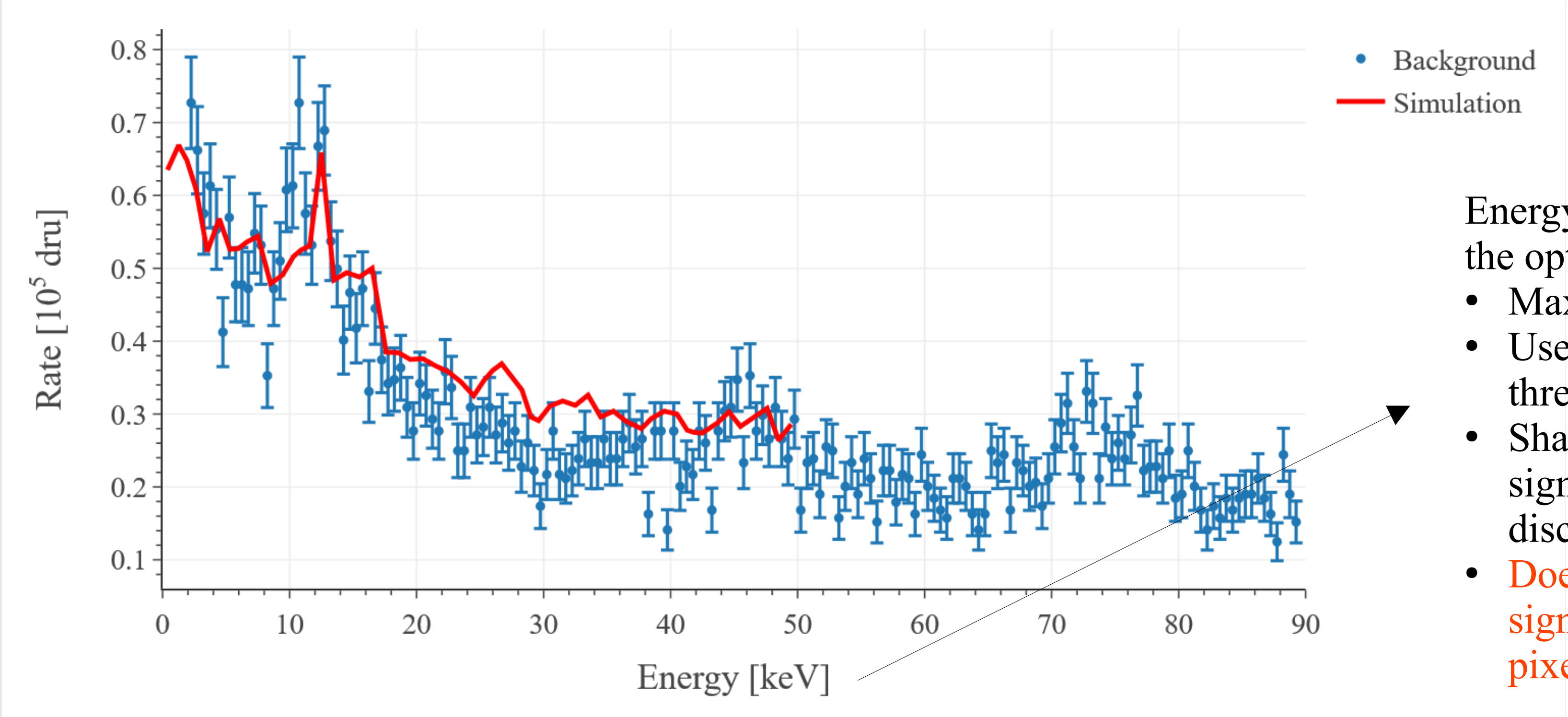





# High energy spectrum results

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 neighbour 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:

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

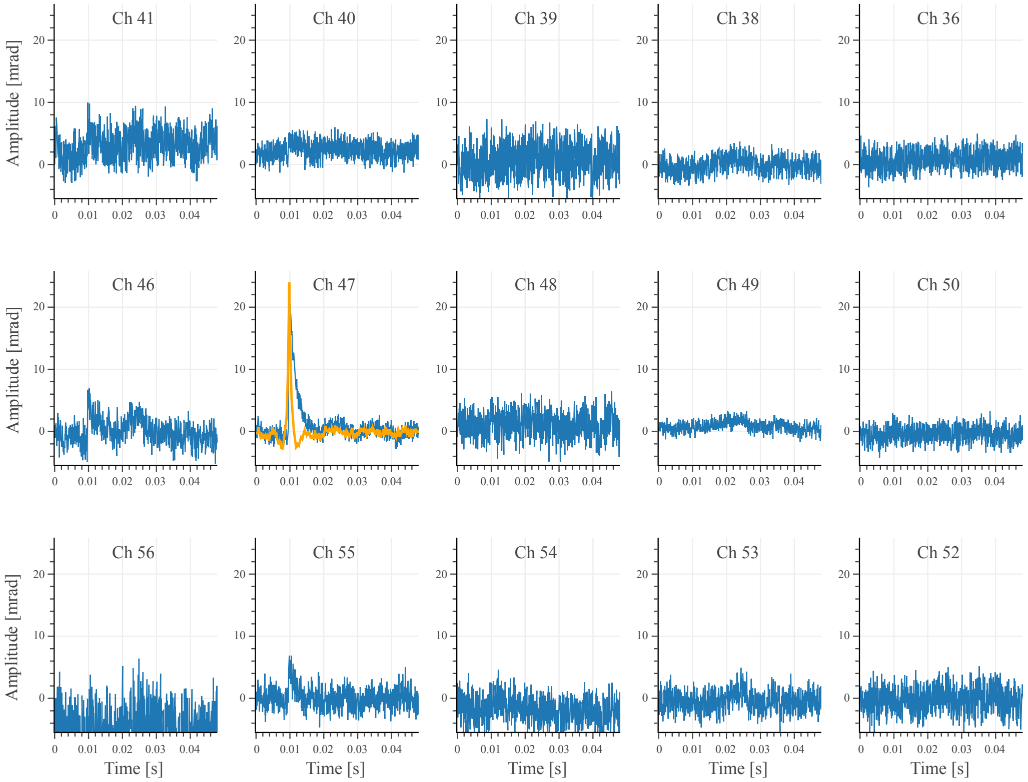
templates

noise covariance

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 improvements** 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)

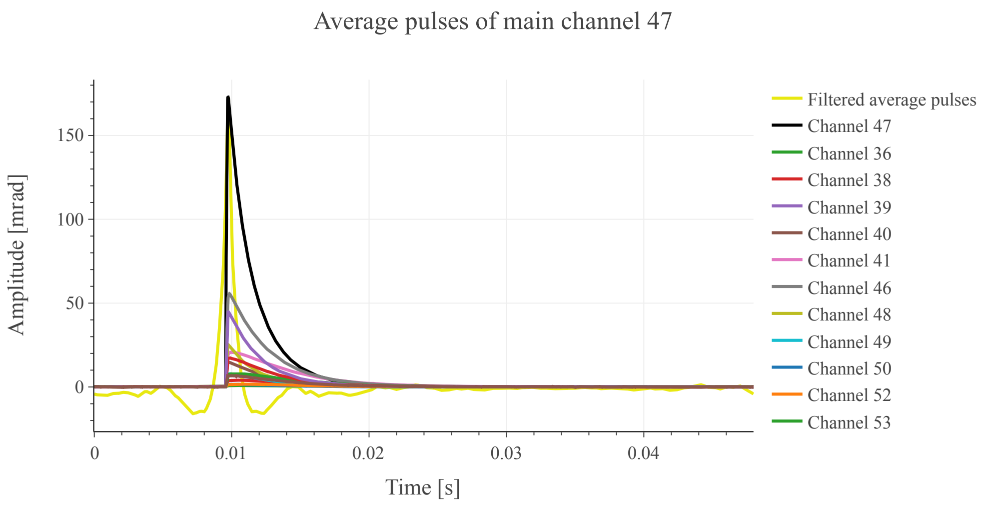
Here, I present an analysis of the high energy particle background with amplitude estimated with OFND.

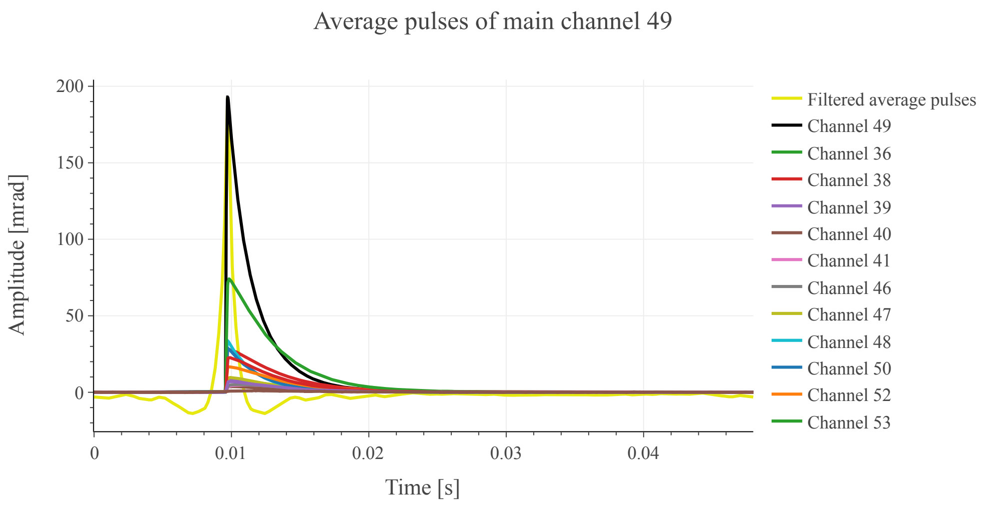
**Goals:**

- 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 with previous analysis

# Template pulses

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



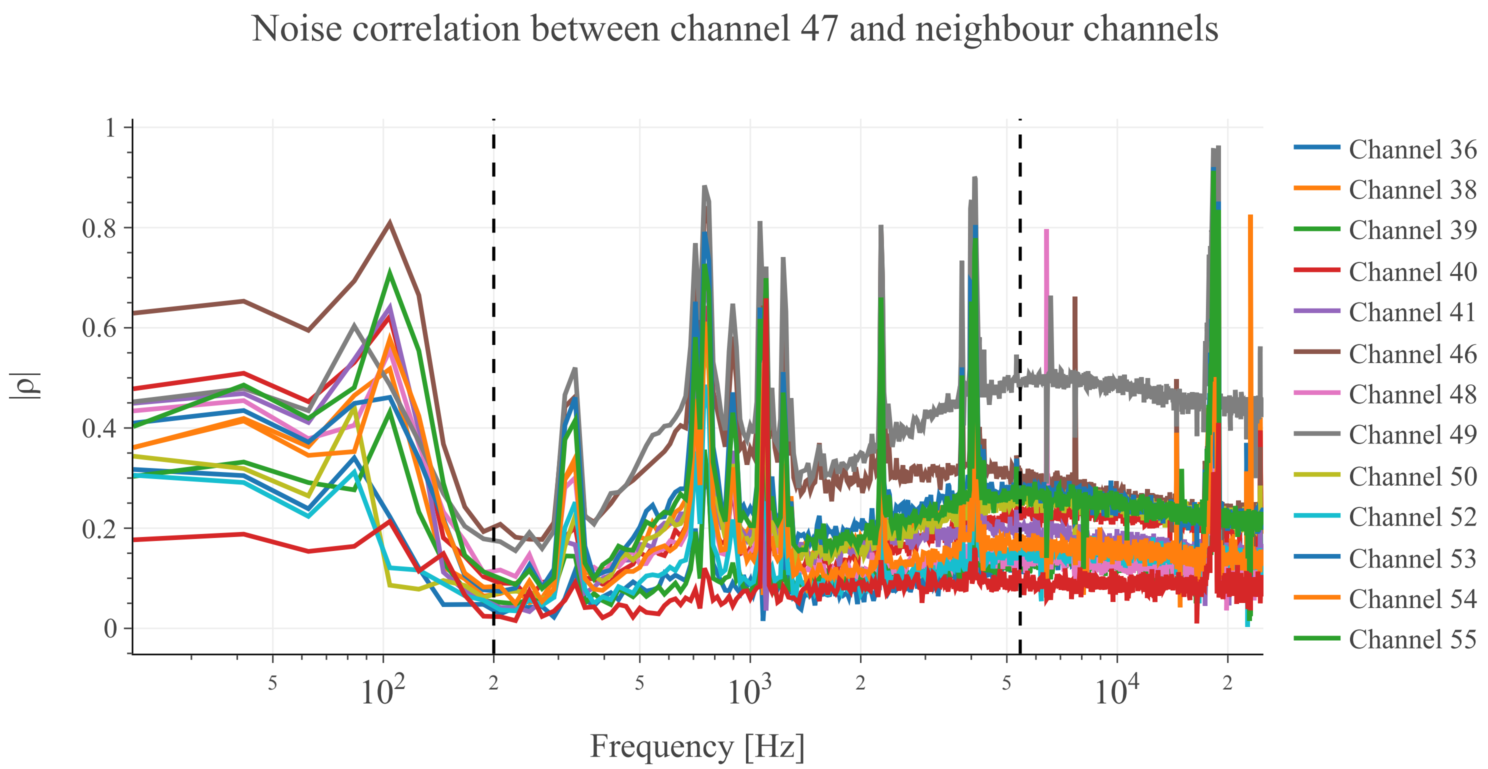



# Noise covariance

Defined as $\hat{\sigma}_{ab} =< \tilde{n}_a^*(f)\,\tilde{n}_b(f) >$ Diagonal elements contain the noise power spectra of the pixels

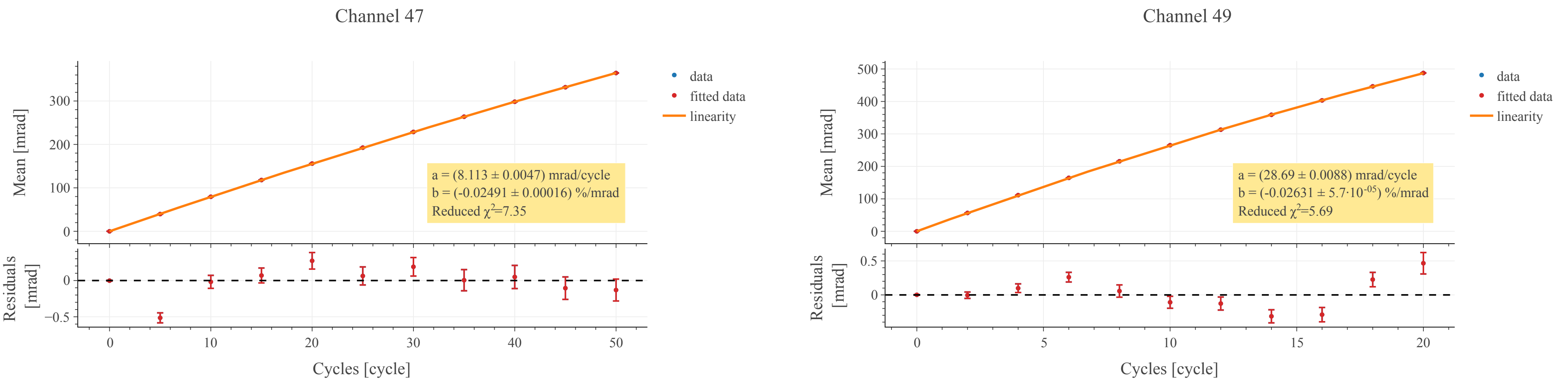
Correlation is defined as:

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



# 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: $\Psi_i$

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

Amplitude on pixel i

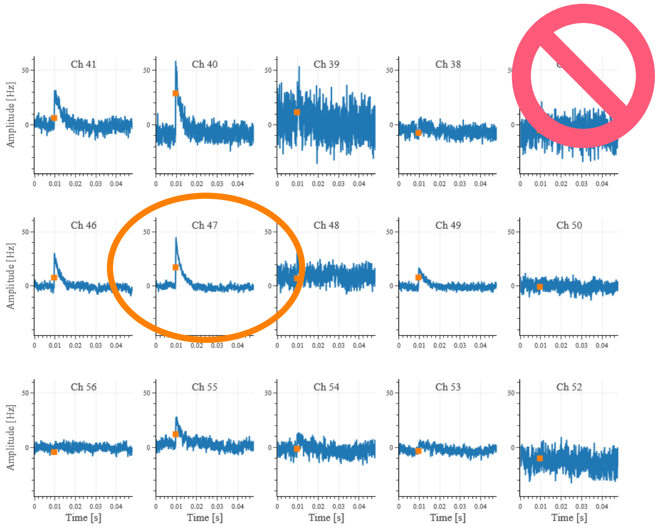
Amplitude on main pixel

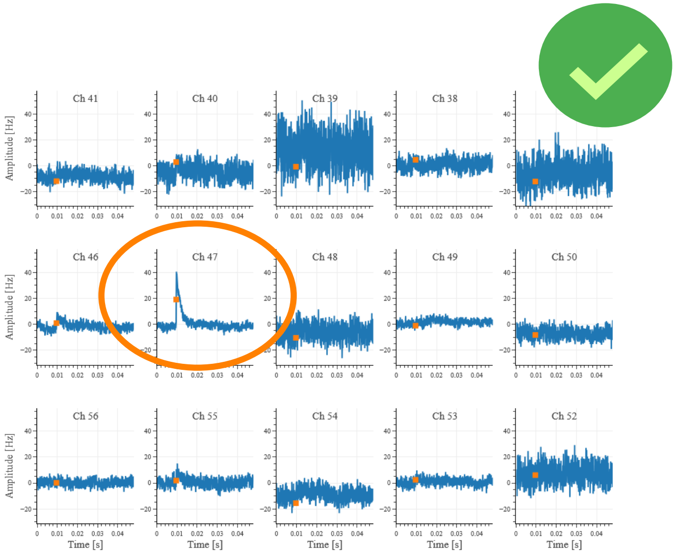
Mean amplitude ratio between pixel i and main pixel

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

Noise on pixel i

Noise on main pixel



# Cluster cuts: $\Psi_i$

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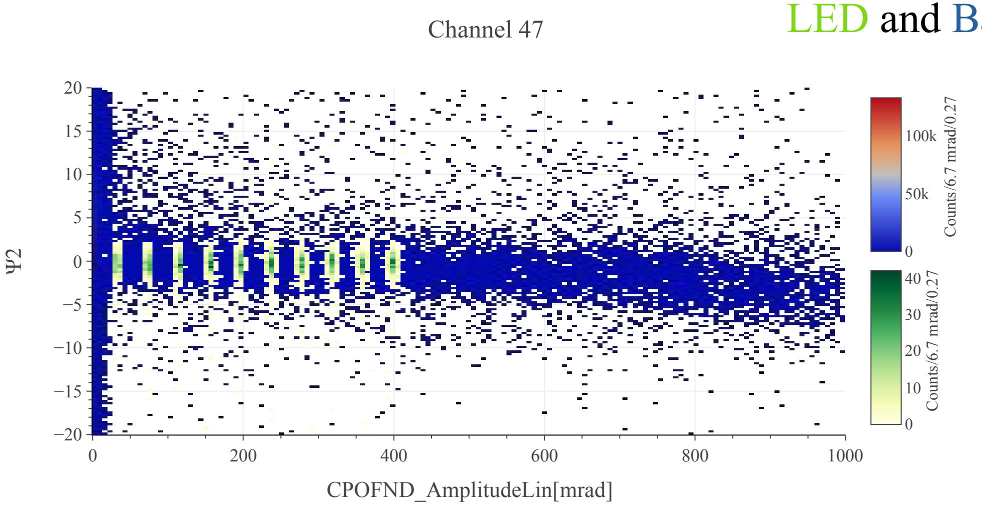
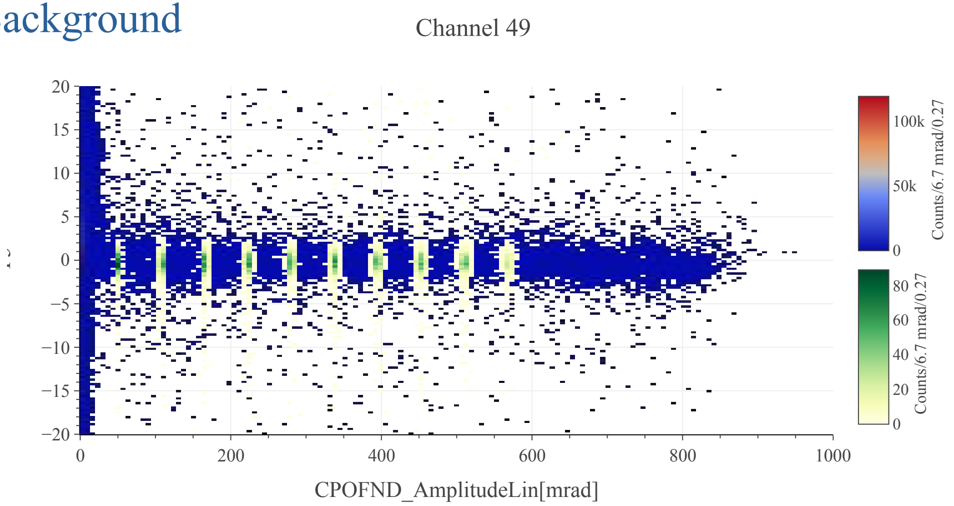
$$\psi_i = \frac{\delta\phi_i - (\delta\phi_c \cdot \mu_{ri})}{\sqrt{\sigma_{0,i}^2 + (\sigma_{0,c} \cdot \mu_{ri})^2}}$$

Noise on pixel i

Noise on main pixel

LED and Background

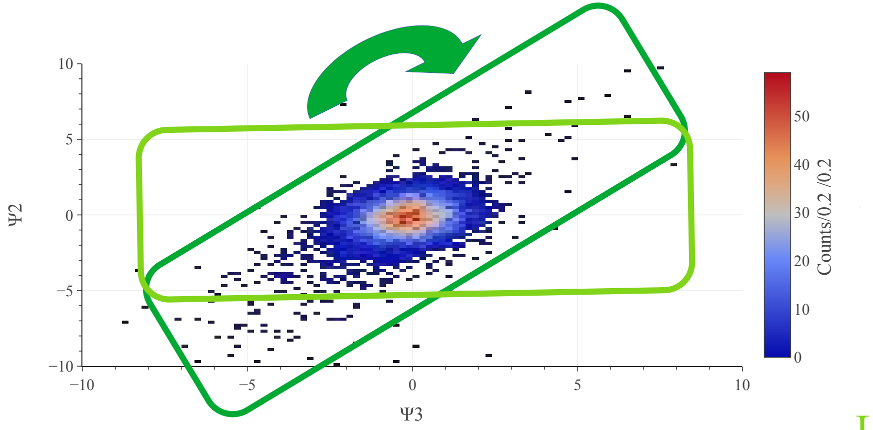


# Cluster cuts: $\Omega$

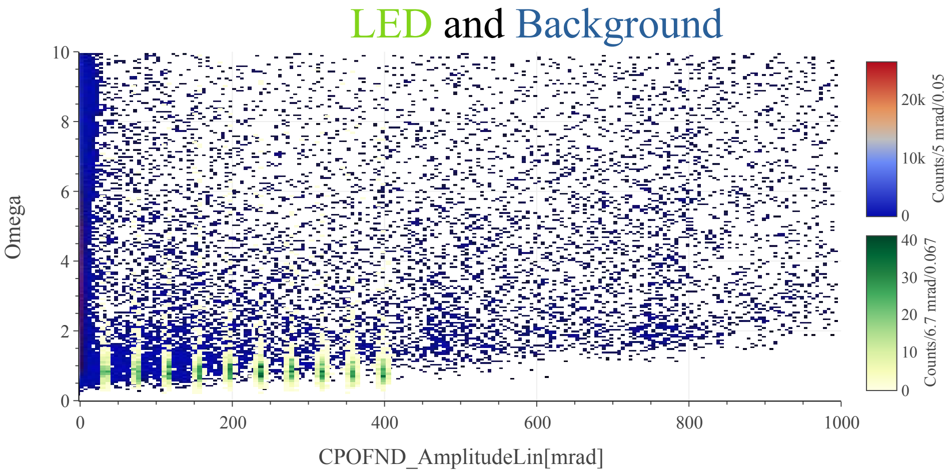
We can rotate the different $\Psi_i$ and combine them to build a unique variable to cut events.

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




Construct the $\Omega$ variable as:

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



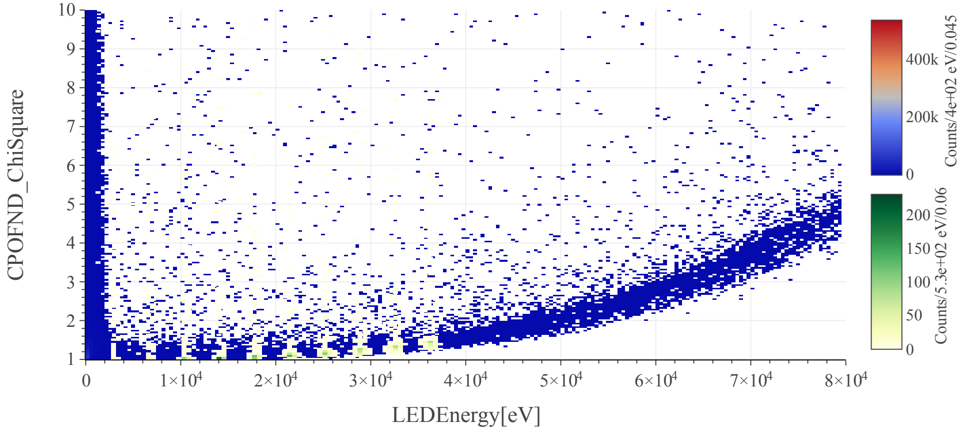
# Shape cuts: $\chi^2_{\mathrm{OFND}}$

Generalization of the $\chi^2$ of the matched filter defined as:

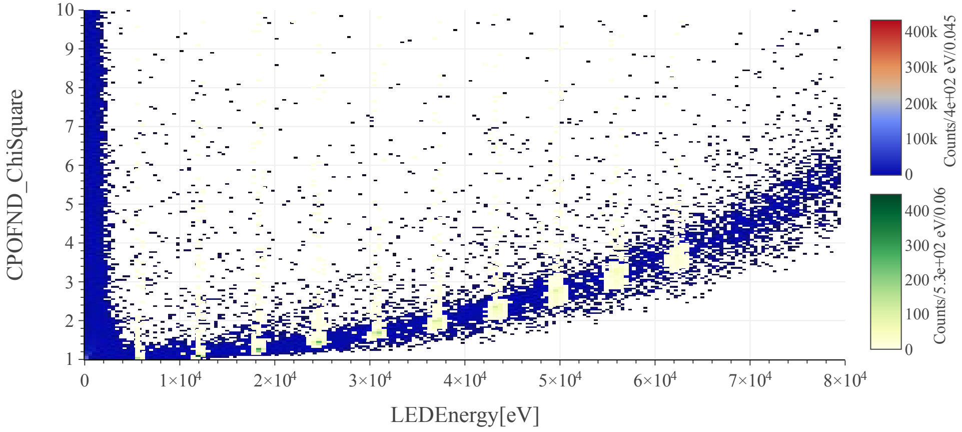
$$\chi^2_{\mathrm{OFND}} = \sum_{a,b=1}^{14} \int_{-\infty}^{\infty} df\, [\tilde{v}_a(f) - \hat{A}\tilde{s}_a(f)]^* \hat{\sigma}_{ab}^{-1} [\tilde{v}_b(f) - \hat{A}\tilde{s}_b(f)]$$

LED and Background

Channel 47

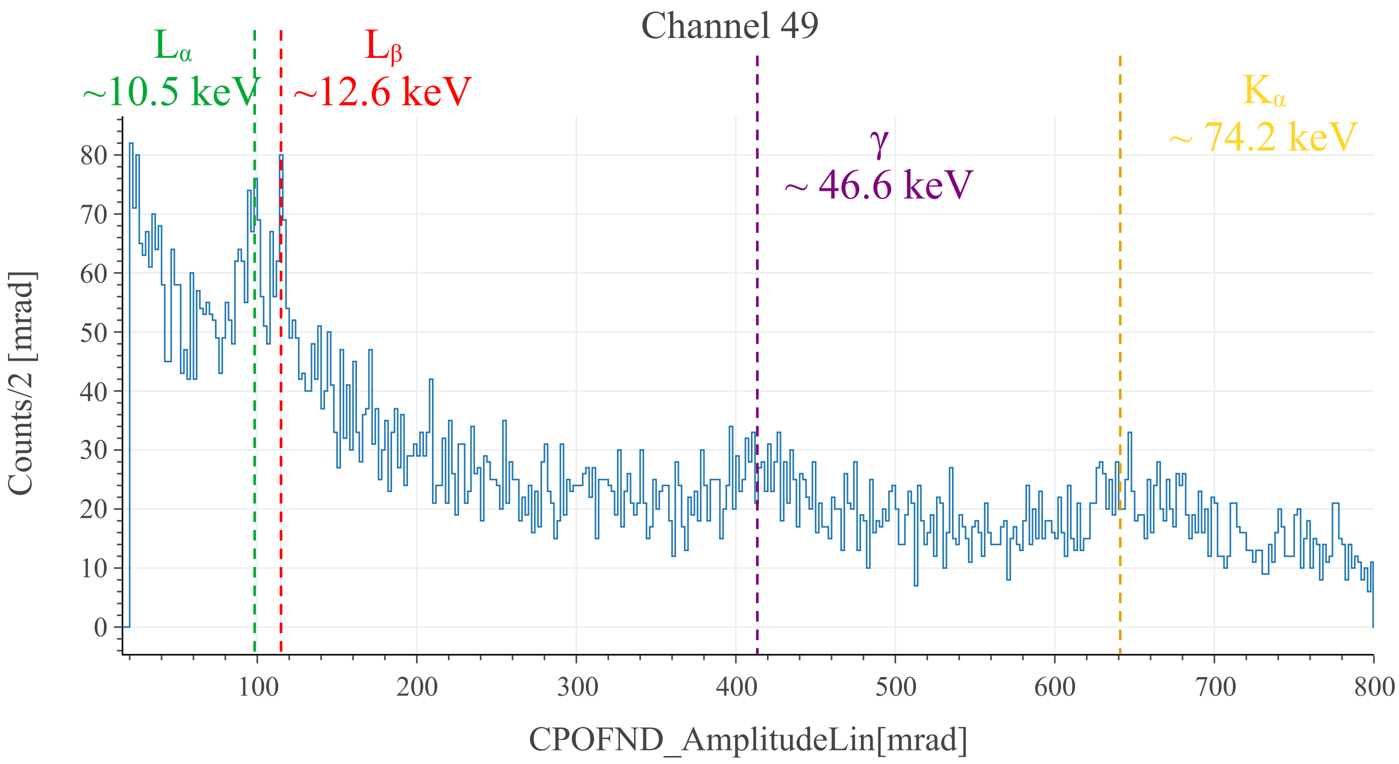



Channel 49



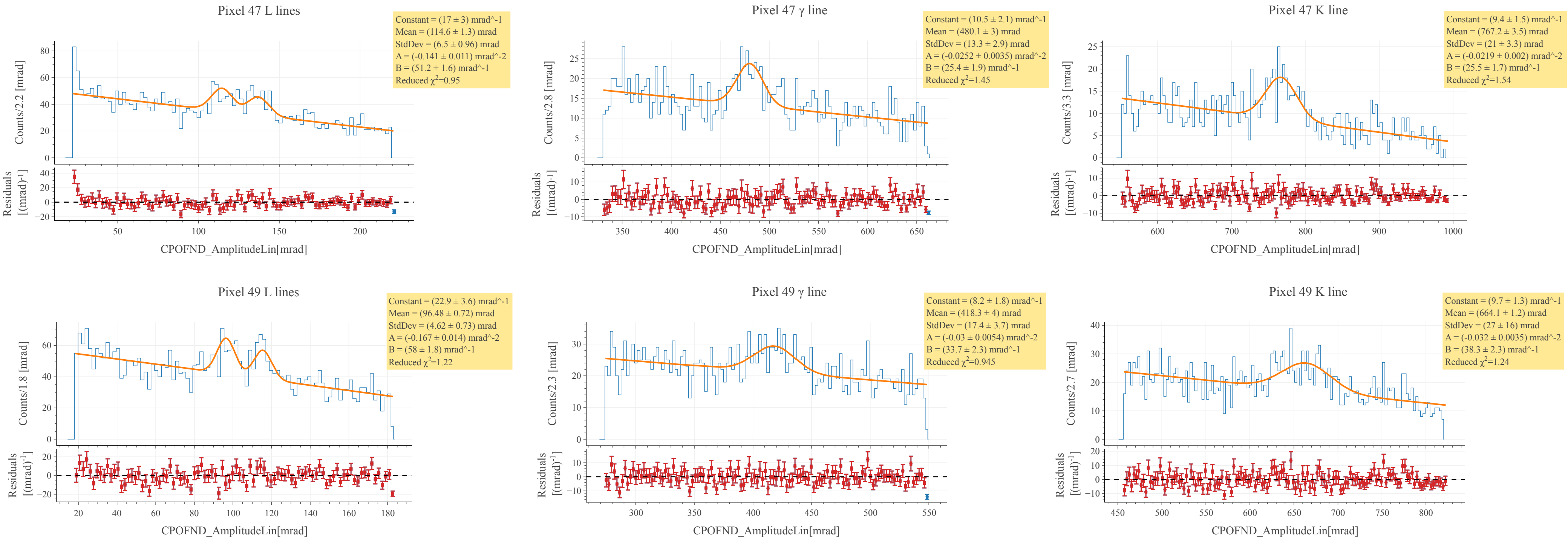
# Lead peaks

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



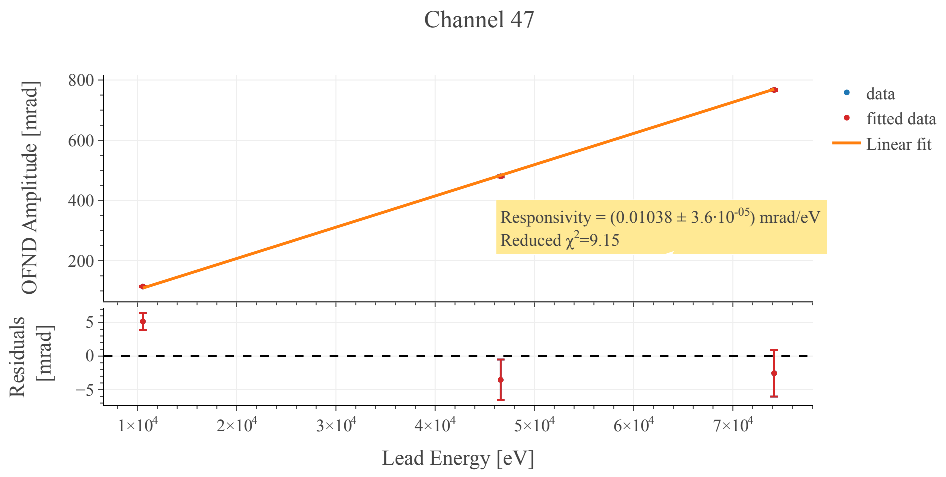
# Fitting the lead peaks

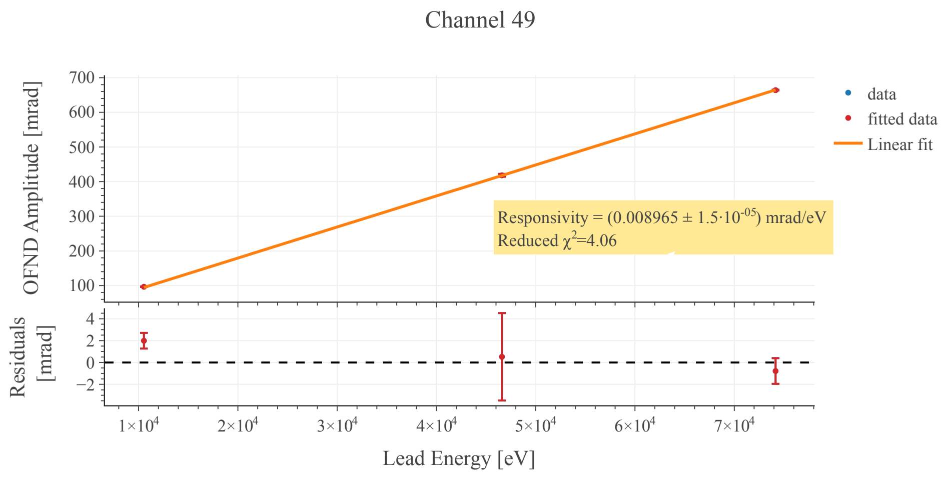
- The energy spectrum is divided in 3 ranges.
- Peaks are fitted with a gaussian plus a 1-degree polynomial
- In the case of the double peak, the intensity and the position of the second peak is fixed by theory



# Lead calibration

- Since $L_\beta$ parameters are fixed, we have three points to calibrate with lead peaks.



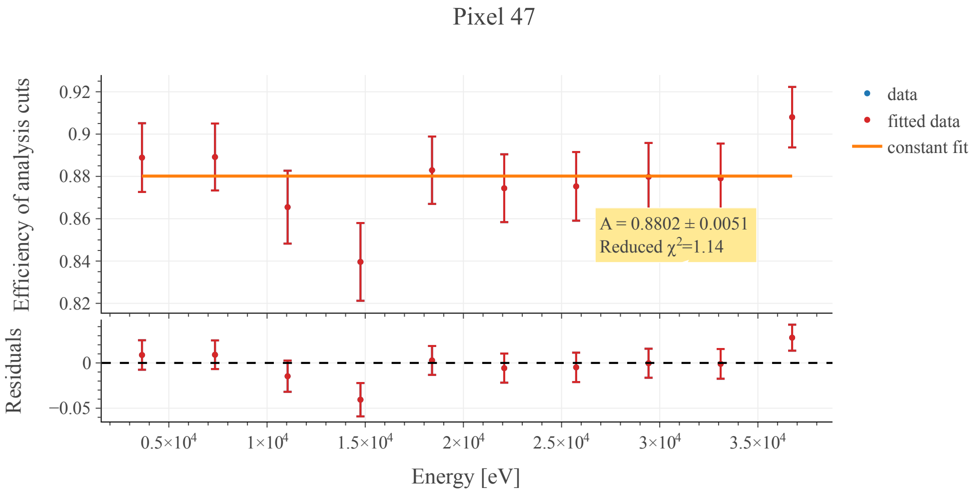



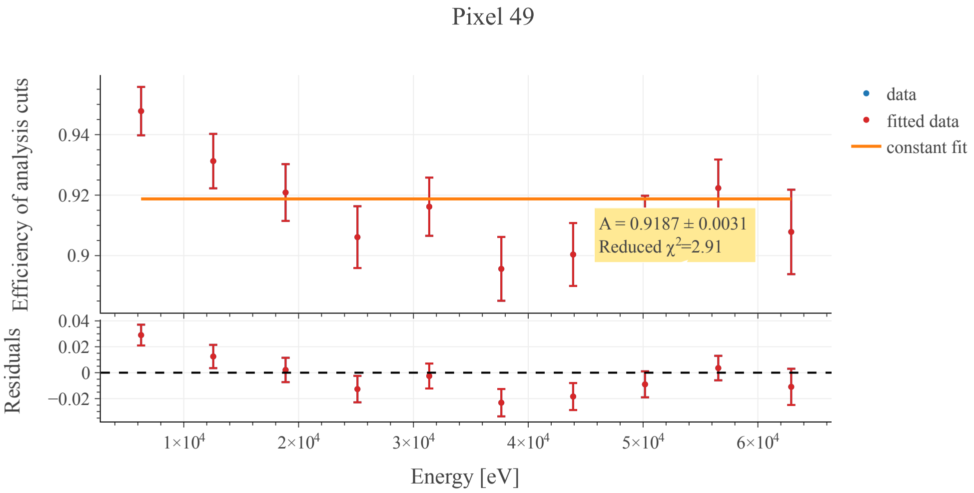

- Almost perfect matching between the LED and the Lead calibration, valid up to 6 %

# Analysis cuts and efficiencies

Analysis cuts:
- $X^2_{OFND} < 6$
- $\Omega < 4.5$
- 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

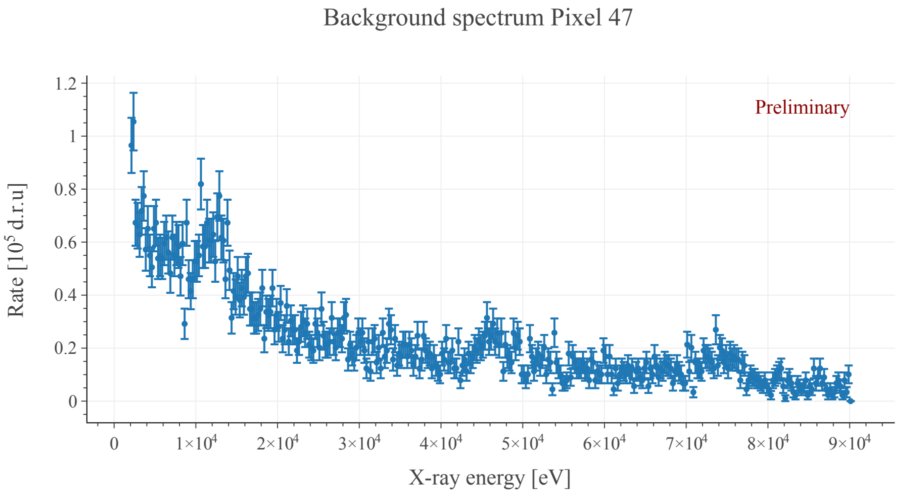


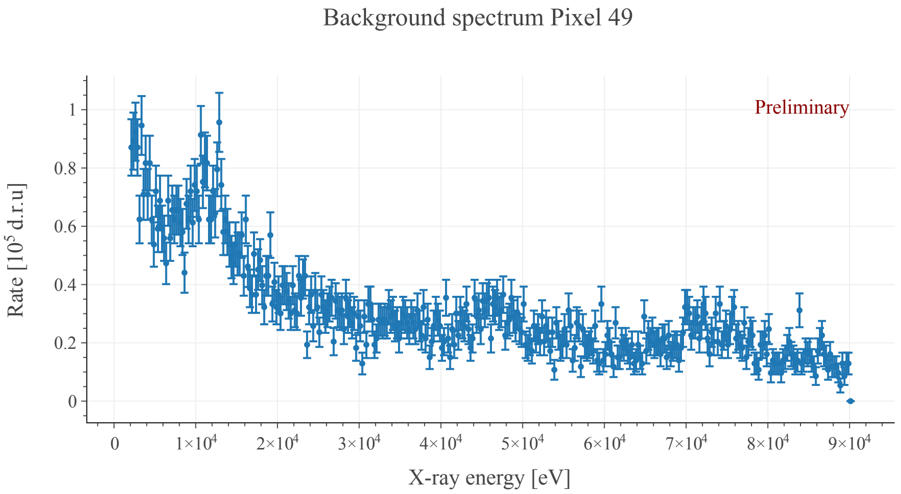




High efficiency of ~90 %

# Preliminary energy spectra

- Overall level compatible with previous result
- Slightly difference between the two pixels (efficiency mismatch)




TO DO:
- Refine cuts variables and cuts
- Evaluate efficiency on lead peaks
- Check consistency with low energy spectrum

# thanks for your attention!