



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

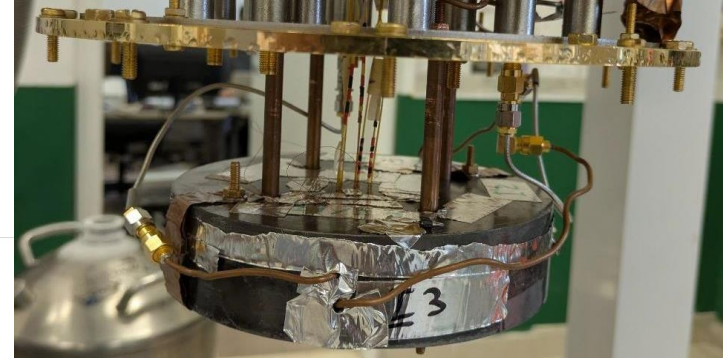
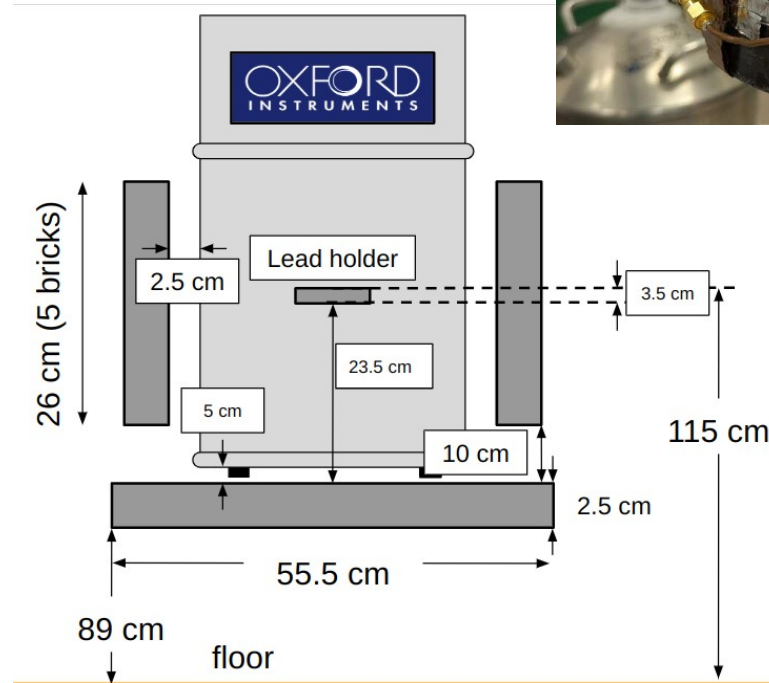
Data with internal and external lead shield.

290 hours for 2 clusters with 15 KIDs.

19 Apr 22:00 – 5 May 8:00.

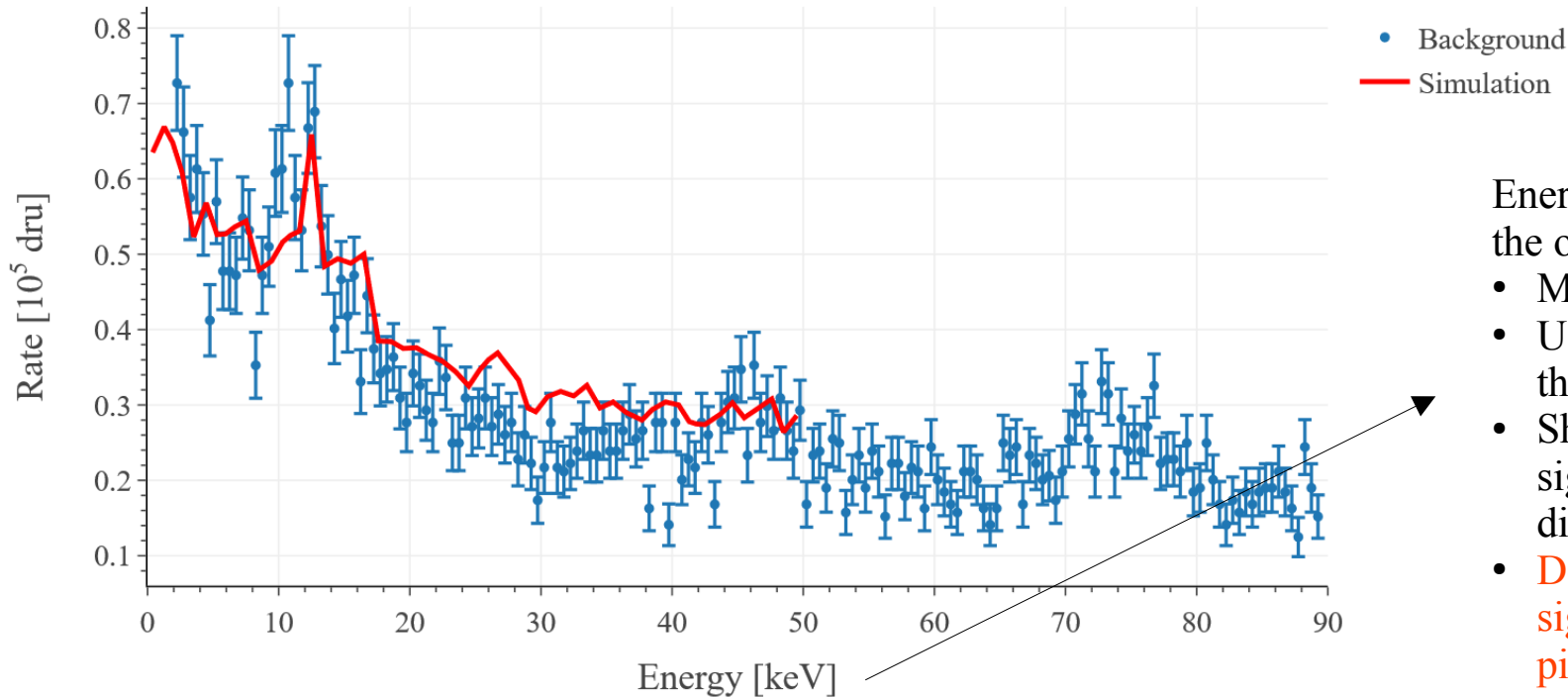
Presentation by D. Delicato at the last collaboration meeting.

		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 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)

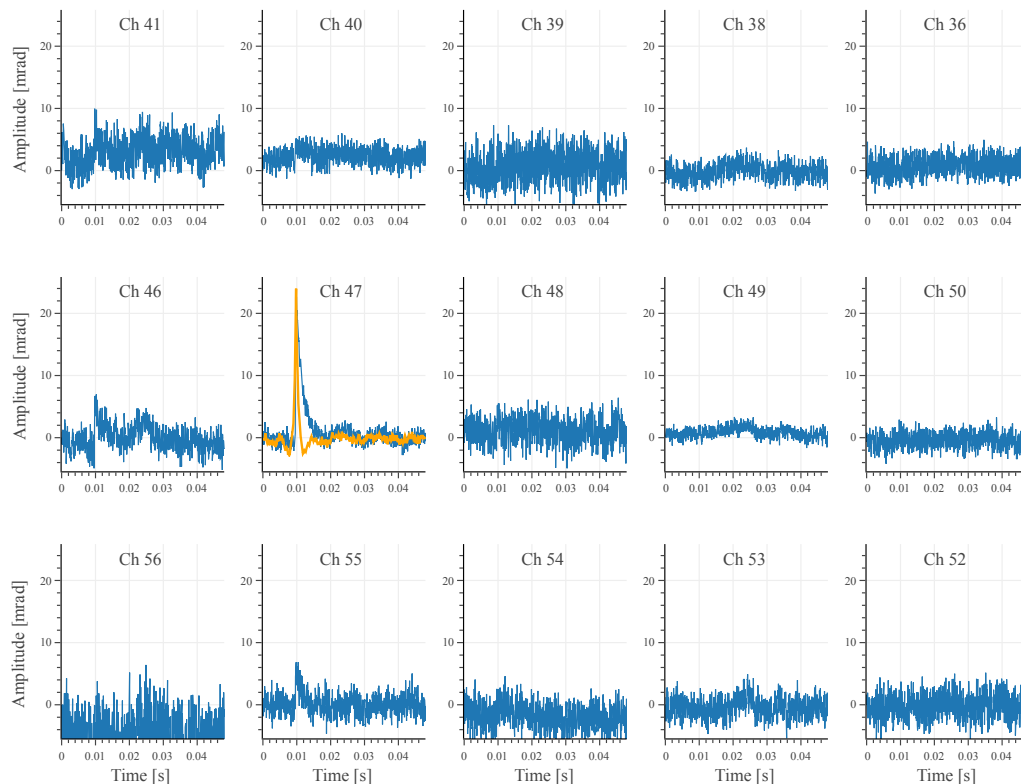
The multidimensional optimum filter combines the waveforms in different pixels to improve the resolution. Shape parameters can be used as a further cluster cut. **Talk at collaboration meeting in Pisa.**

The filtered signal is:

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

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:

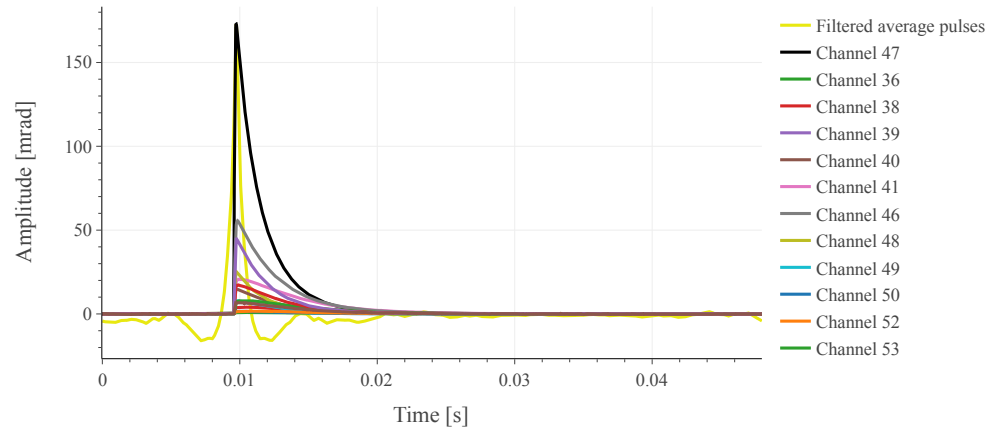
- Have a unique amplitude estimator both for the low energy and the high energy parts of the spectrum
- Calibrate using lead peaks
- Evaluate efficiencies with the pulse shape variables from OFND
- Check compatibility with previous analysis

Template pulses

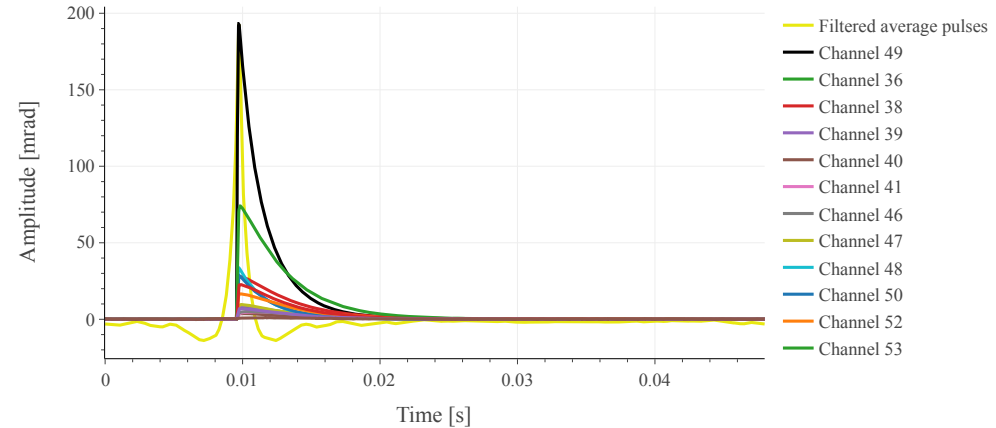
The template pulses for the two pixels are build with **LED fired on the main channels** and **signals in coincidence on neighbours dice**.

Amplitude range of ~ 50 - ~ 300 mrad to avoid pulse shape distortions at large phases.

Average pulses of main channel 47



Average pulses of main channel 49



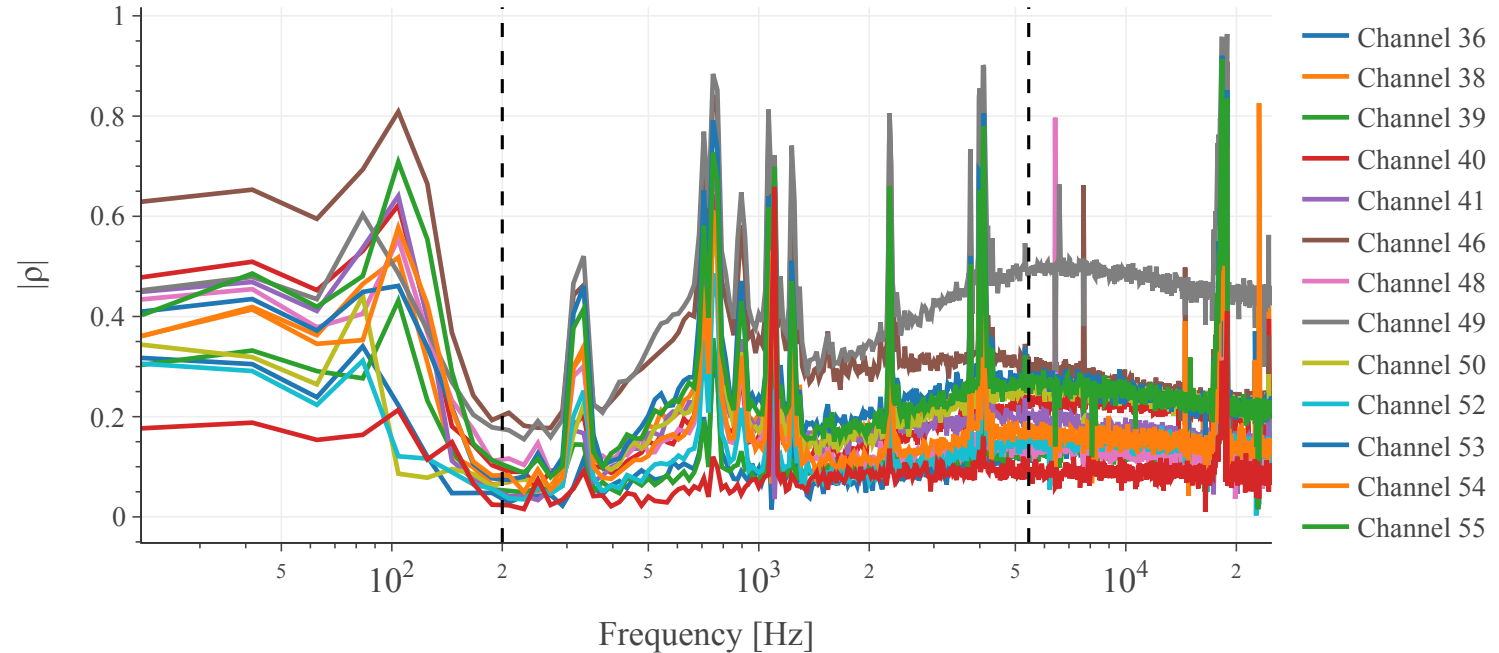
Noise covariance

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

Noise correlation between channel 47 and neighbour channels

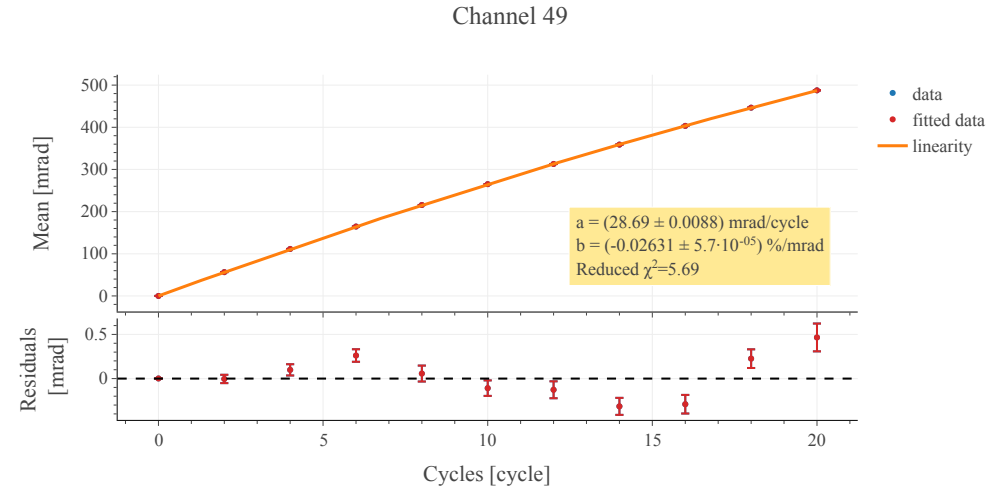
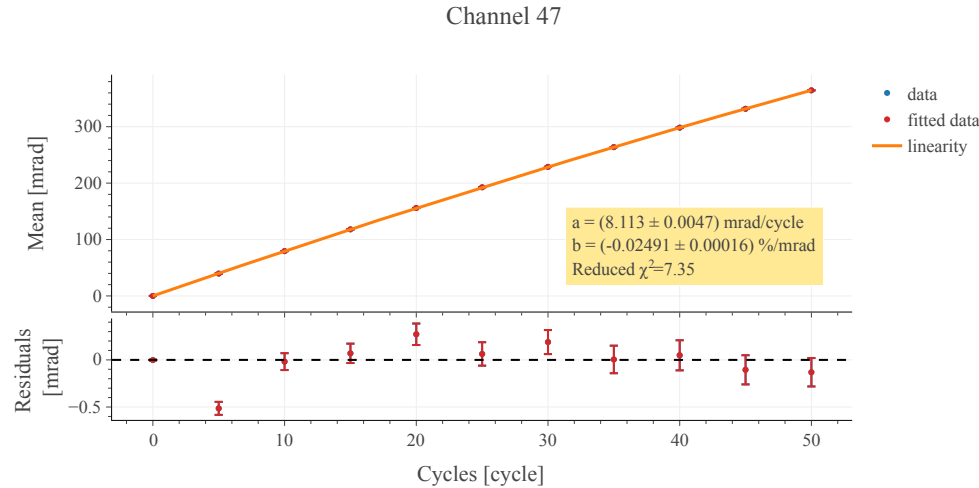
Correlation is defined as:

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



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: $A_{\text{lin}} \equiv a \cdot n_c = \frac{-1 + \sqrt{1 + 4ba}}{2b}$

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

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

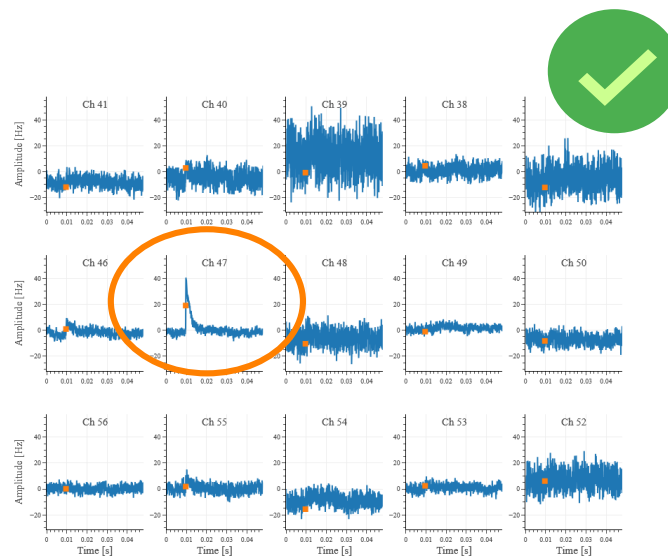
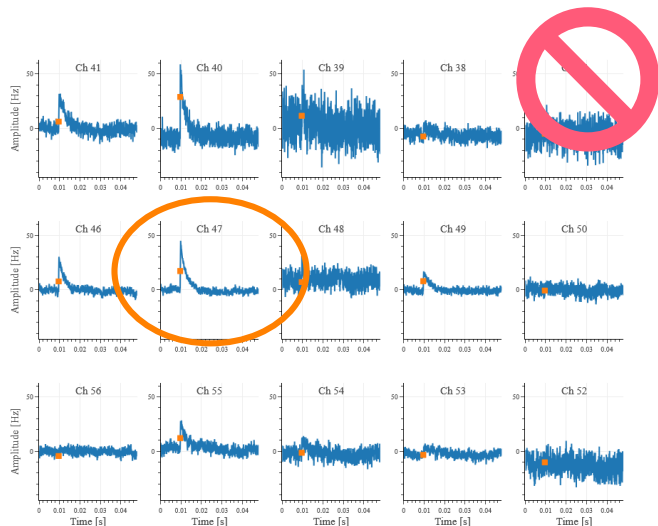
Amplitude on pixel i

Amplitude on main pixel

Mean amplitude ratio between pixel i and main pixel

Noise on pixel i

Noise on main pixel



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

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

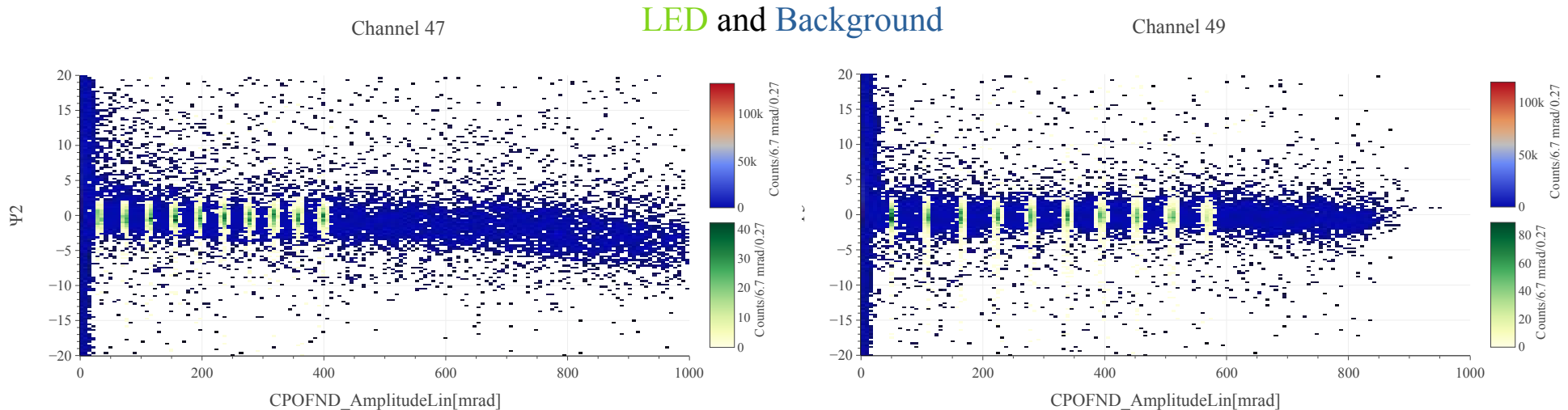
Amplitude on pixel i

Amplitude on main pixel

Mean amplitude ratio between pixel i and main pixel

Noise on pixel i

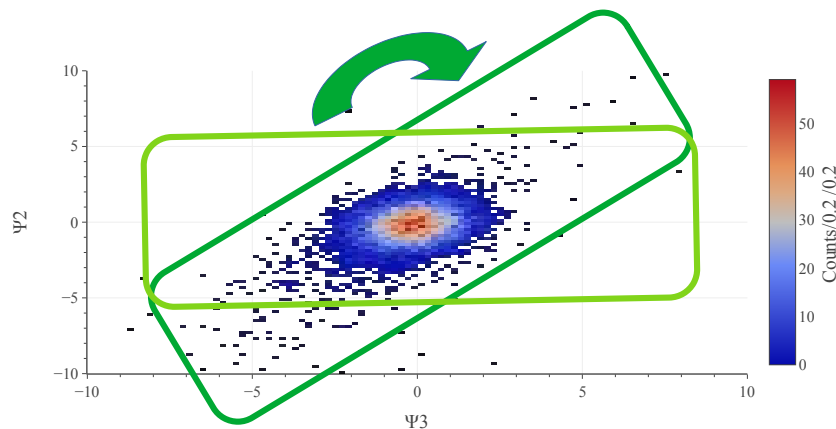
Noise on main pixel



Cluster cuts: Ω

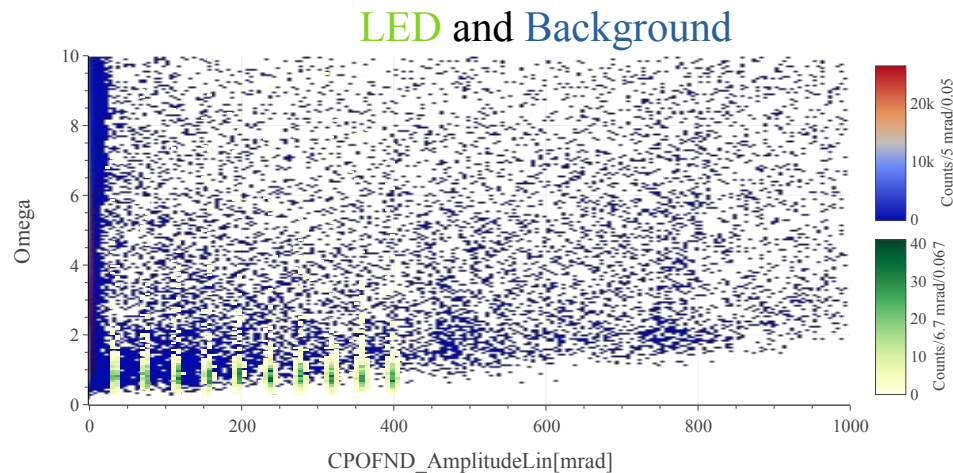
We can rotate the different Ψ_i and combine them to build a unique variable to cut events.

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



Construct the Ω variable as:

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



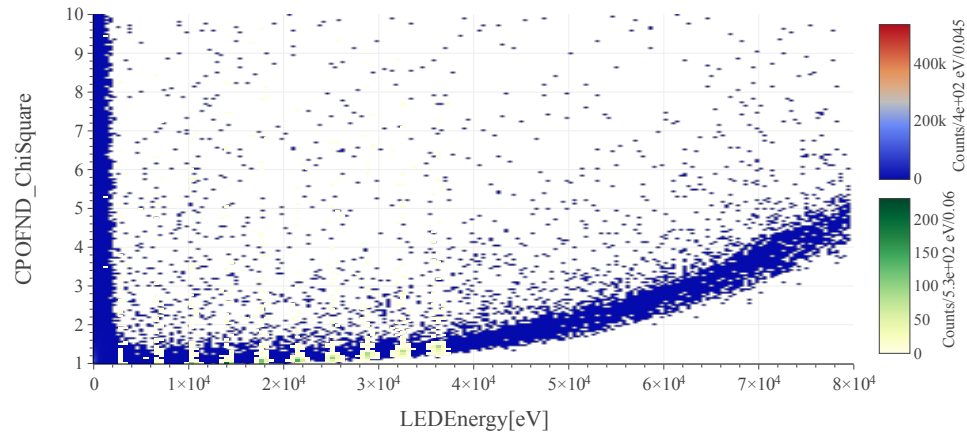
Shape cuts: χ^2_{OFND}

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

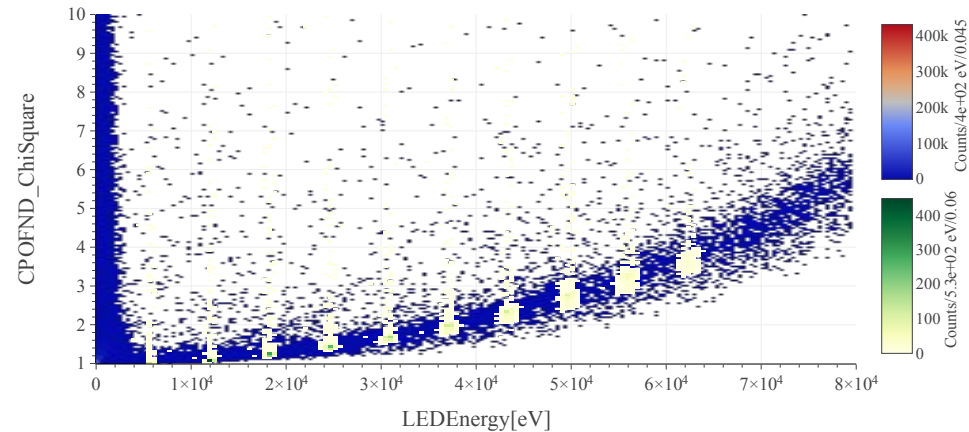
$$\chi^2_{\text{OFND}} = \sum_{a,b=1}^{14} \int_{-\infty}^{\infty} df [\tilde{v}_a(f) - \hat{A}\tilde{s}_a(f)]^* \hat{\sigma}_{ab}^{-1} [\tilde{v}_b(f) - \hat{A}\tilde{s}_b(f)]$$

LED and Background

Channel 47

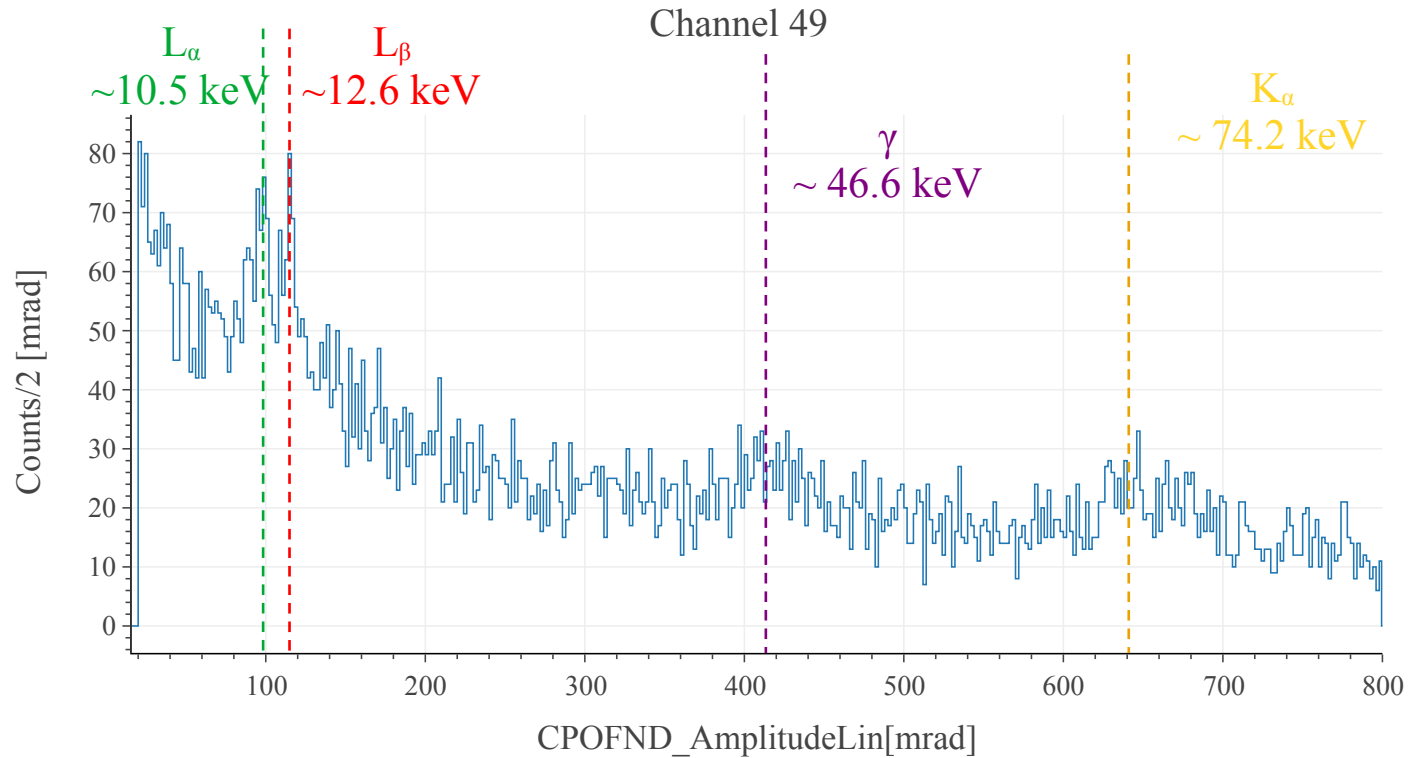


Channel 49



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

Pixel 47 L lines

Constant = $(17 \pm 3) \text{ mrad}^{-1}$
 Mean = $(114.6 \pm 1.3) \text{ mrad}$
 StdDev = $(6.5 \pm 0.96) \text{ mrad}$
 $A = (-0.141 \pm 0.011) \text{ mrad}^{-2}$
 $B = (51.2 \pm 1.6) \text{ mrad}^{-1}$
 Reduced $\chi^2 = 0.95$

Pixel 47 γ line

Constant = $(10.5 \pm 2.1) \text{ mrad}^{-1}$
 Mean = $(480.1 \pm 3) \text{ mrad}$
 StdDev = $(13.3 \pm 2.9) \text{ mrad}$
 $A = (-0.0252 \pm 0.0035) \text{ mrad}^{-2}$
 $B = (25.4 \pm 1.9) \text{ mrad}^{-1}$
 Reduced $\chi^2 = 1.45$

Pixel 47 K line

Constant = $(9.4 \pm 1.5) \text{ mrad}^{-1}$
 Mean = $(767.2 \pm 3.5) \text{ mrad}$
 StdDev = $(21 \pm 3.3) \text{ mrad}$
 $A = (-0.0219 \pm 0.002) \text{ mrad}^{-2}$
 $B = (25.5 \pm 1.7) \text{ mrad}^{-1}$
 Reduced $\chi^2 = 1.54$

Pixel 49 L lines

Constant = $(22.9 \pm 3.6) \text{ mrad}^{-1}$
 Mean = $(96.48 \pm 0.72) \text{ mrad}$
 StdDev = $(4.62 \pm 0.73) \text{ mrad}$
 $A = (-0.167 \pm 0.014) \text{ mrad}^{-2}$
 $B = (58 \pm 1.8) \text{ mrad}^{-1}$
 Reduced $\chi^2 = 1.22$

Pixel 49 γ line

Constant = $(8.2 \pm 1.8) \text{ mrad}^{-1}$
 Mean = $(418.3 \pm 4) \text{ mrad}$
 StdDev = $(17.4 \pm 3.7) \text{ mrad}$
 $A = (-0.03 \pm 0.0054) \text{ mrad}^{-2}$
 $B = (33.7 \pm 2.3) \text{ mrad}^{-1}$
 Reduced $\chi^2 = 0.945$

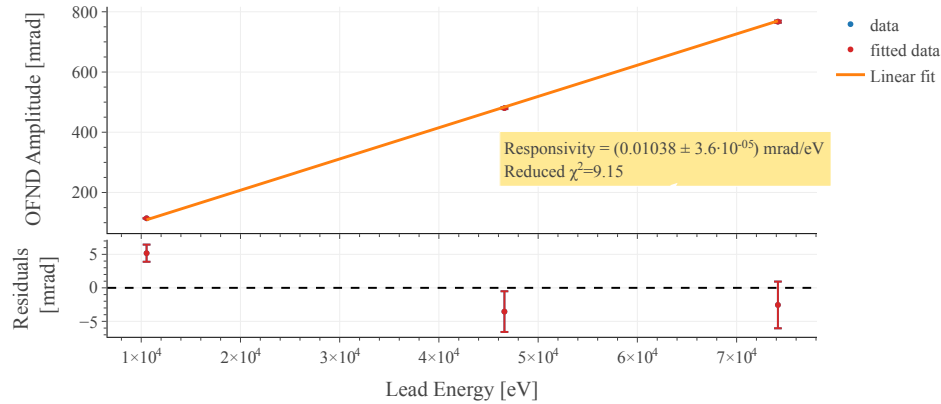
Pixel 49 K line

Constant = $(9.7 \pm 1.3) \text{ mrad}^{-1}$
 Mean = $(664.1 \pm 1.2) \text{ mrad}$
 StdDev = $(27 \pm 16) \text{ mrad}$
 $A = (-0.032 \pm 0.0035) \text{ mrad}^{-2}$
 $B = (38.3 \pm 2.3) \text{ mrad}^{-1}$
 Reduced $\chi^2 = 1.24$

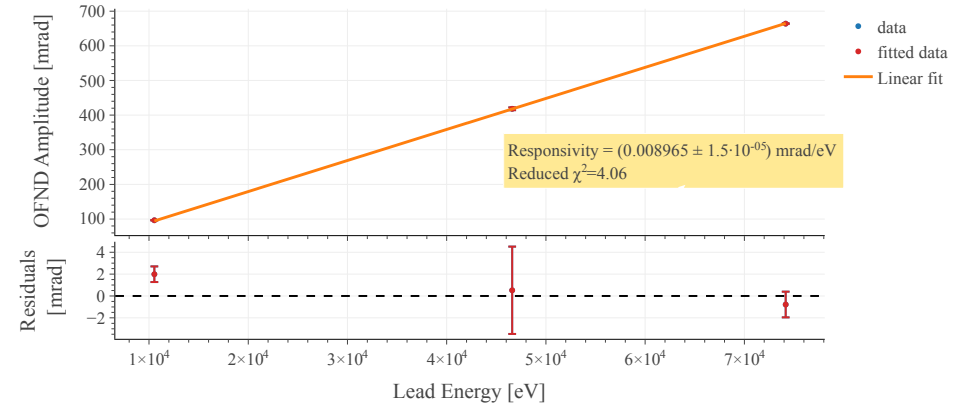
Lead calibration

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

Channel 47



Channel 49



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

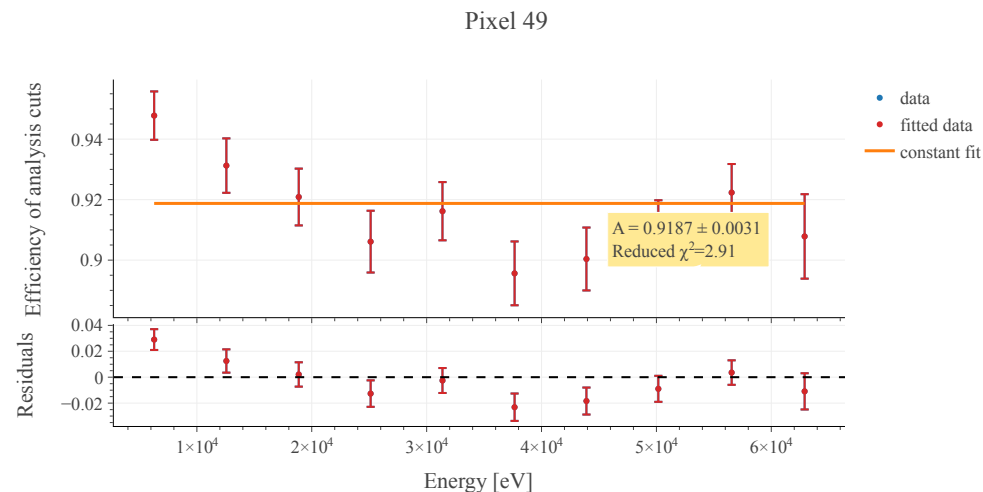
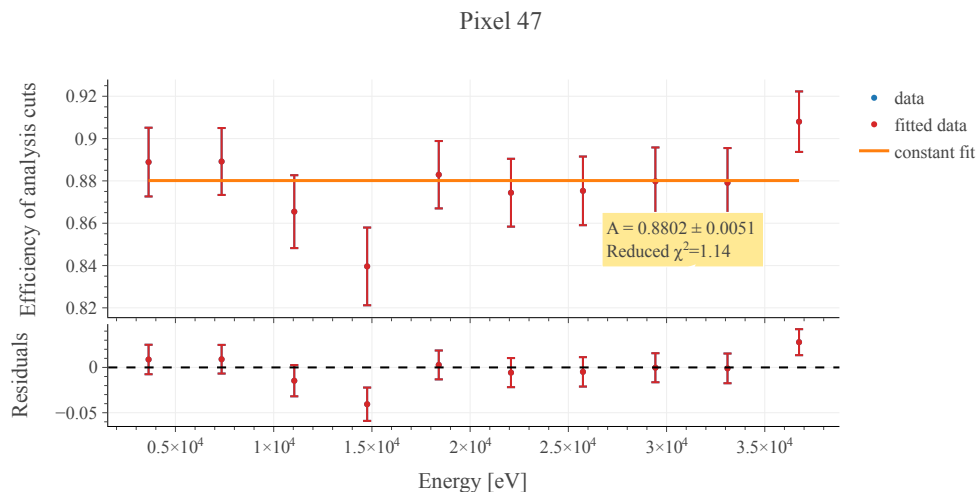


Analysis cuts and efficiencies

Analysis cuts:

- $\chi^2_{\text{OFND}} < 6$
- $\Omega < 4.5$
- 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

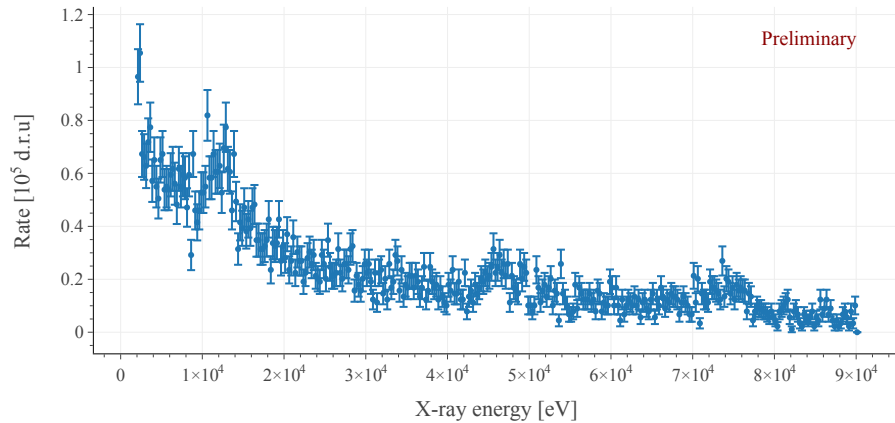


High efficiency of ~90 %

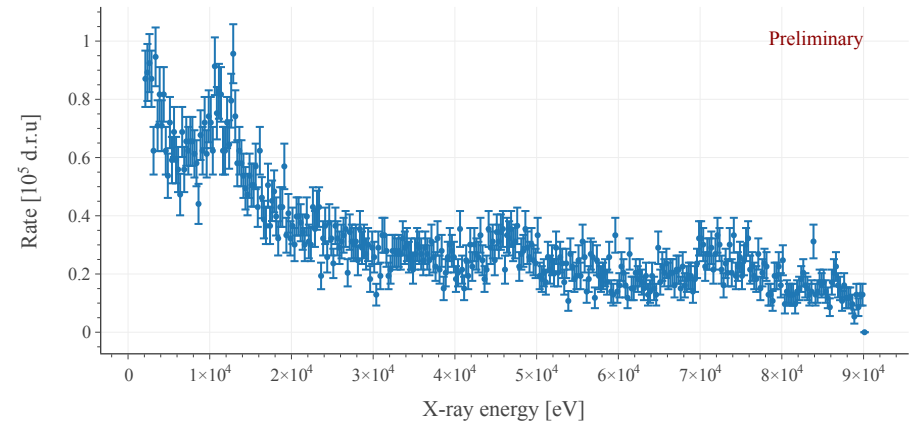
Preliminary energy spectra

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

Background spectrum Pixel 47



Background spectrum Pixel 49



TO DO:

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



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thanks for your attention!
