Below threshold events in BULLKID

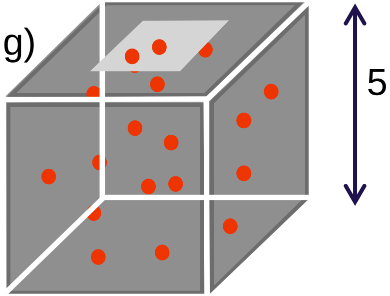
Matteo Folcarelli
EXCESS workshop, Sapienza, 06/07/2024

The BULLKID phonon-detector array

Phonon mediation:
detection of phonons created by the energy release of particles in a **silicon** die

KID (~ 2x2 mm^2 x 60 nm, 0.5 µg)

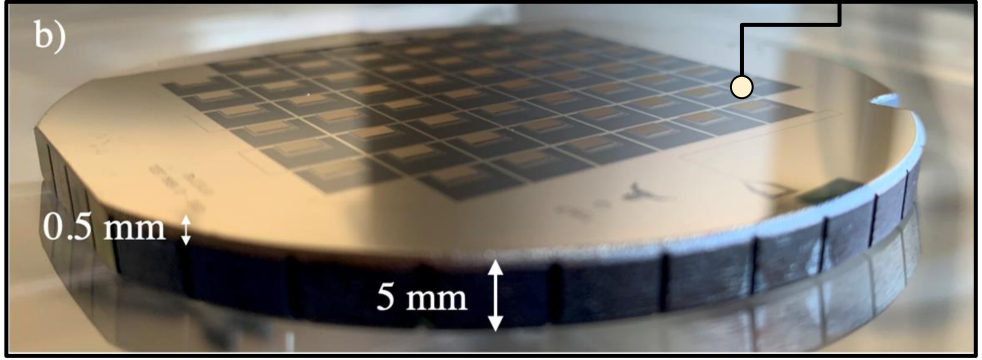
Silicon die (0.34 g)
at < 80 mK



Monolithic structure
with
60 detectors in 1
Fully multiplexed
(single readout line)

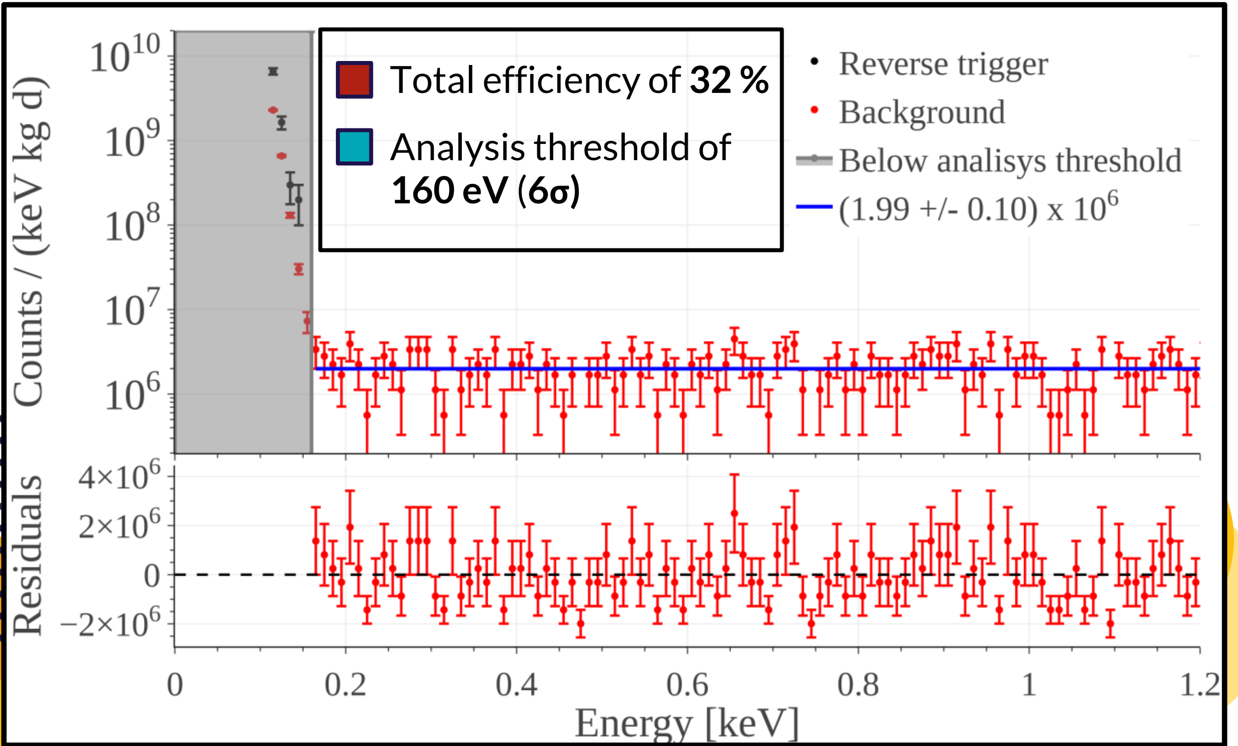
Carving of dice in a thick silicon wafer

Lithography of KID sensors



60 nm thick aluminum film

Last workshop: surface background



[Delicato et al. Low-energy spectrum of the BULLKID detector array operated on surface. Eur. Phys. J. C 84, 353 (2024).]

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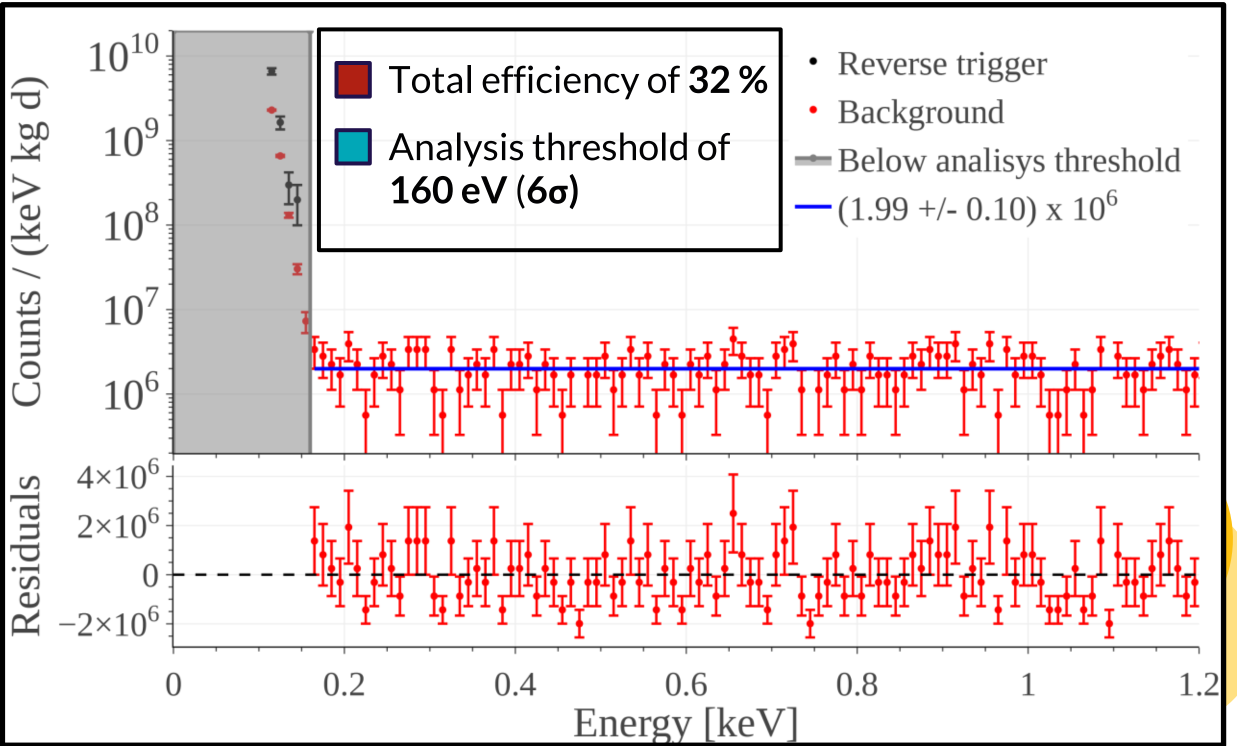


Delicato et al. Low-energy spectrum of the BULLKID detector array operated on surface. Eur. Phys. J. C 84, 353 (2024).

Strategy:

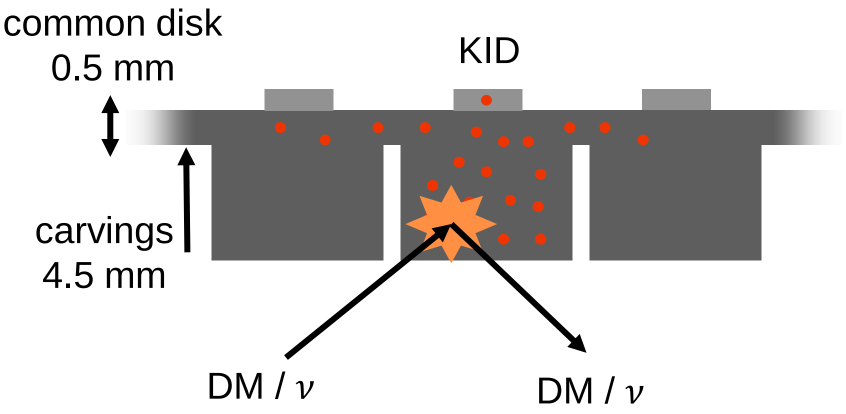
This talk:

- Understand **which events populate the spectrum** below analysis threshold

September/end of 2024:

- New data-taking on surface in a **lower background condition**

Phonon leakage and mapping



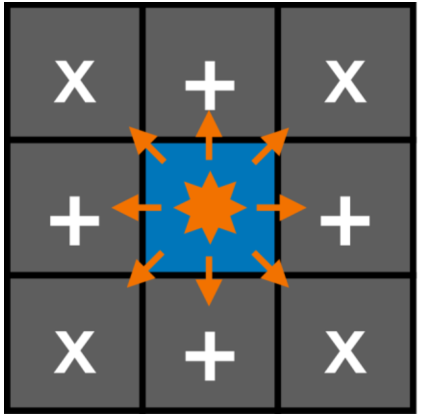
50 % of phonons is detected in the interaction die

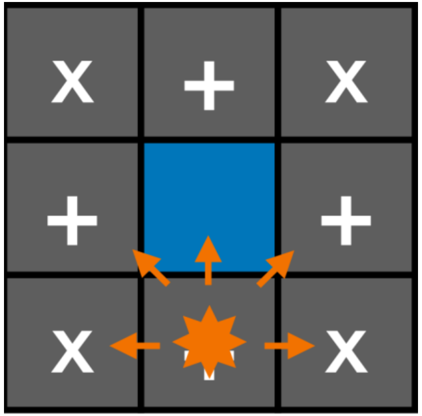
50 % of phonons leaks out and it is detected in nearby dice

This reduces the phonon collection on the KID

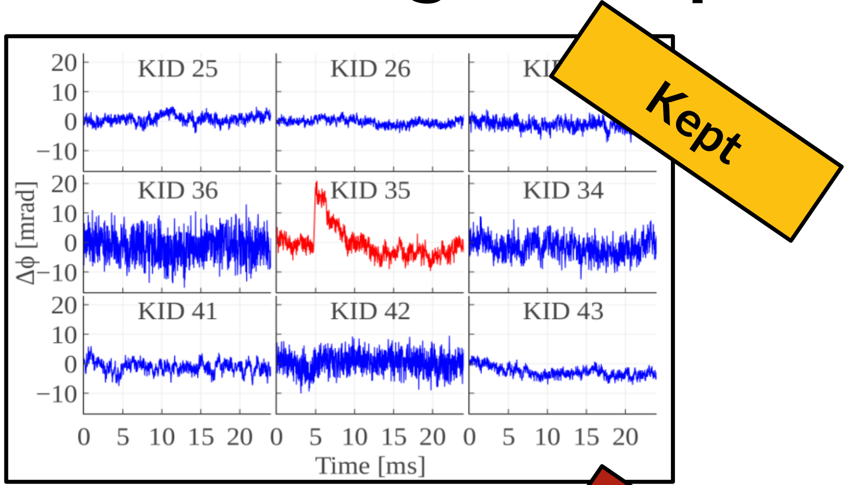
but

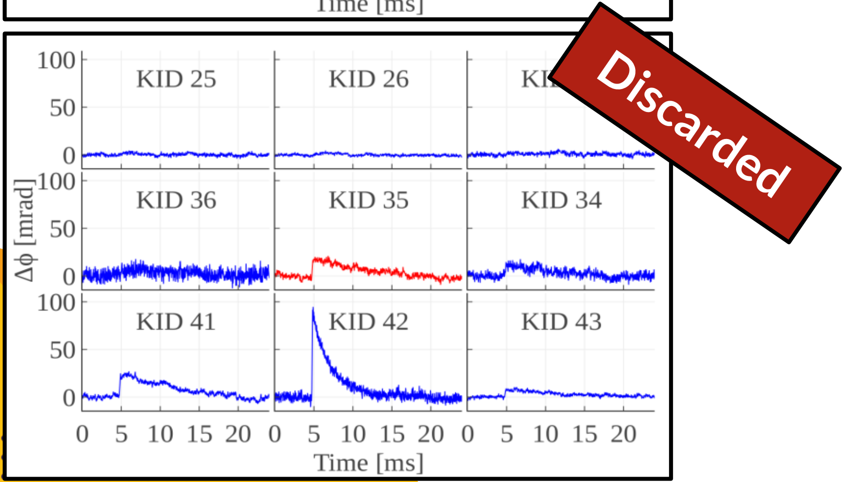
it allows the identification of the interaction voxel





Background: pulse shape + phonon cuts





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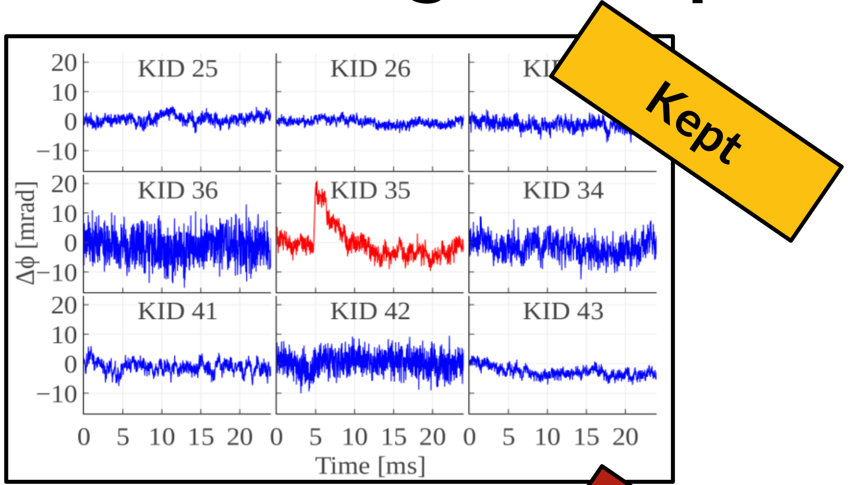
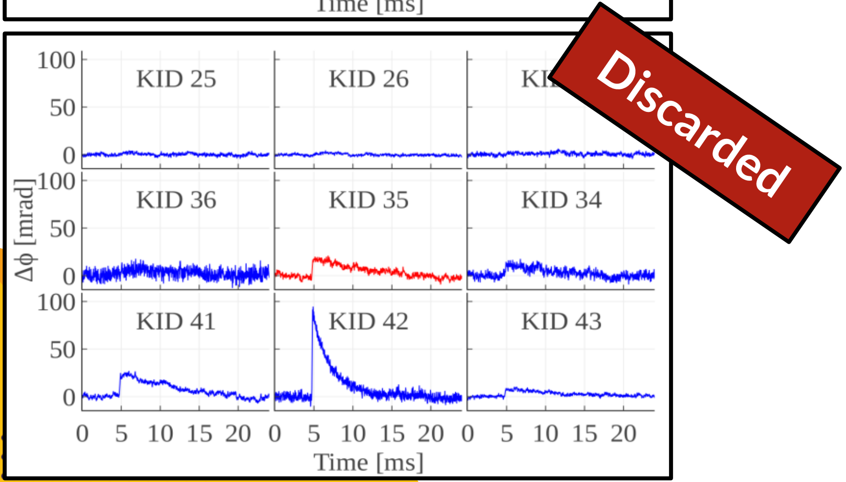
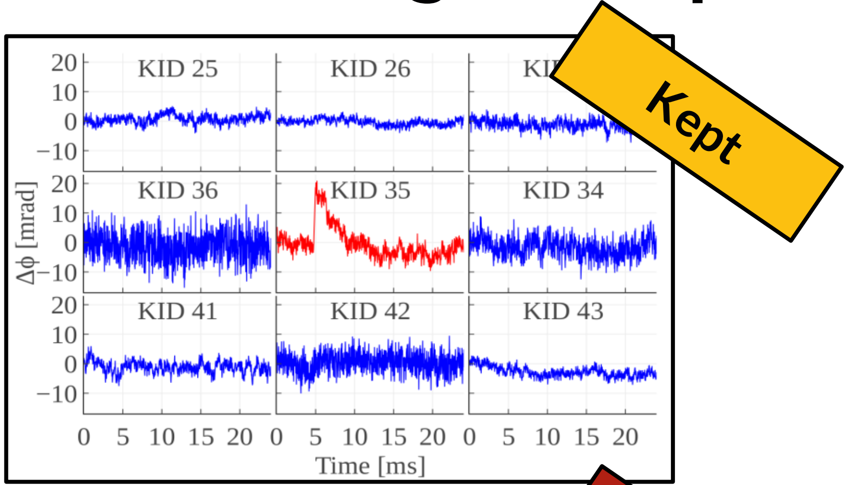
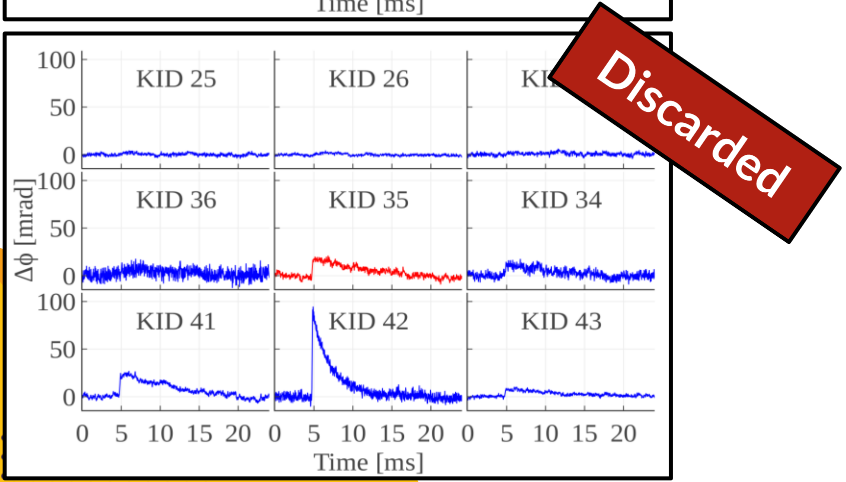




$$\psi_n = \frac{A_n - A_{35} \cdot \langle A_n / A_{35} \rangle}{\text{norm.}}$$

Background: pulse shape + phonon cuts





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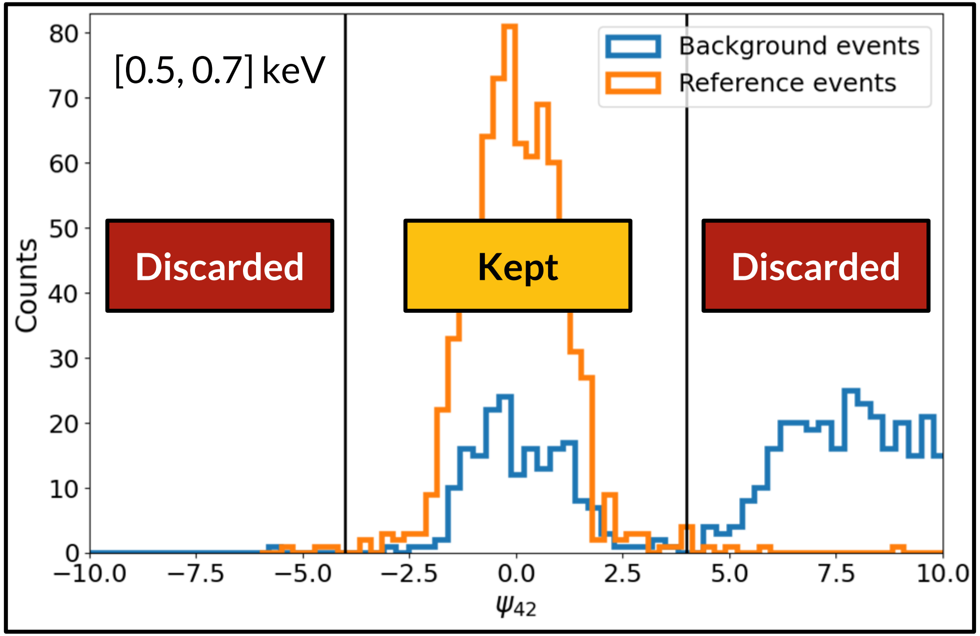
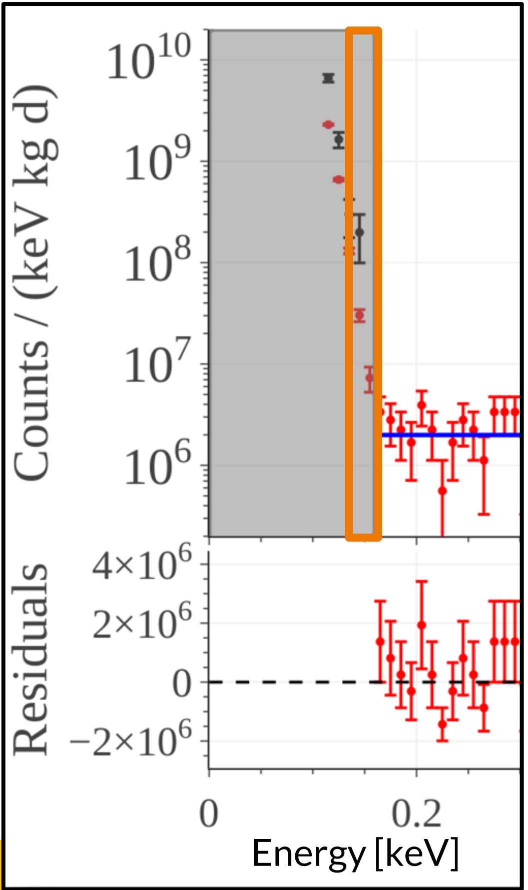
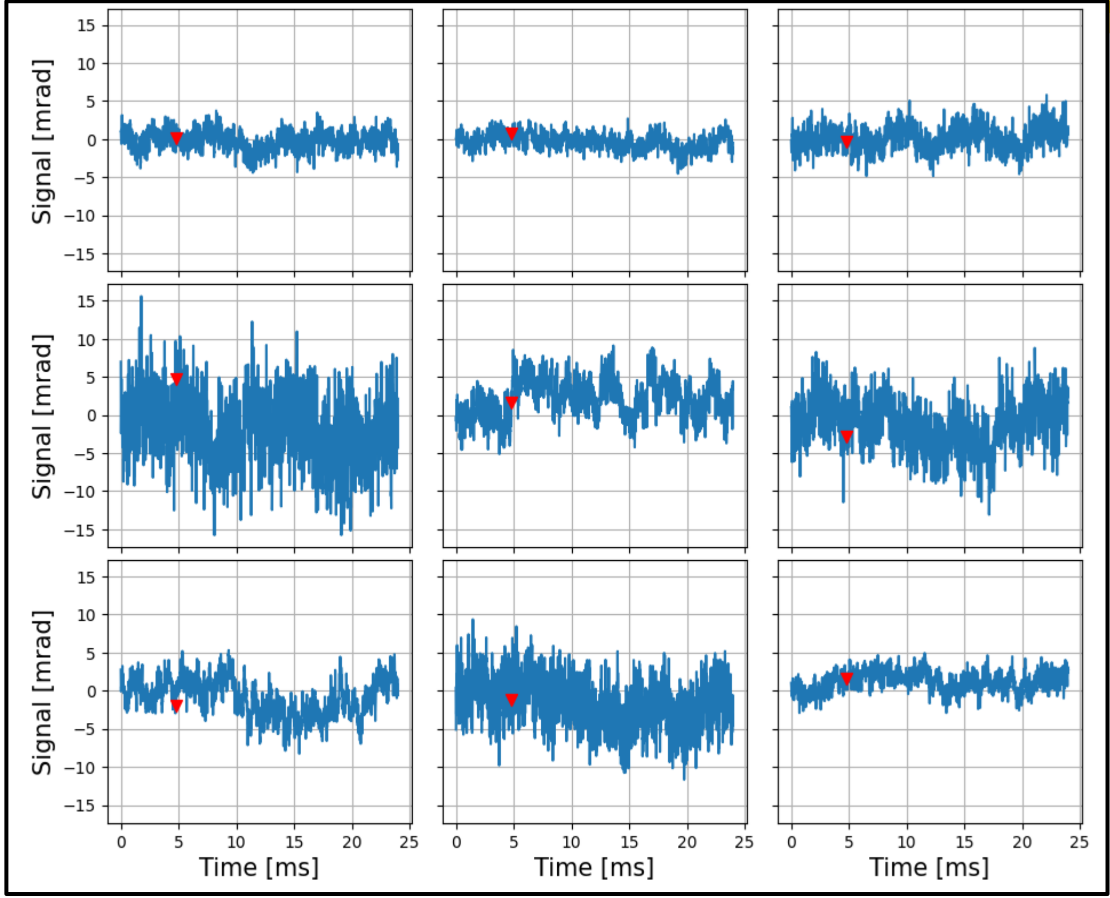


Background: pulses at threshold

Selected the pulses in this **one sigma-width region**





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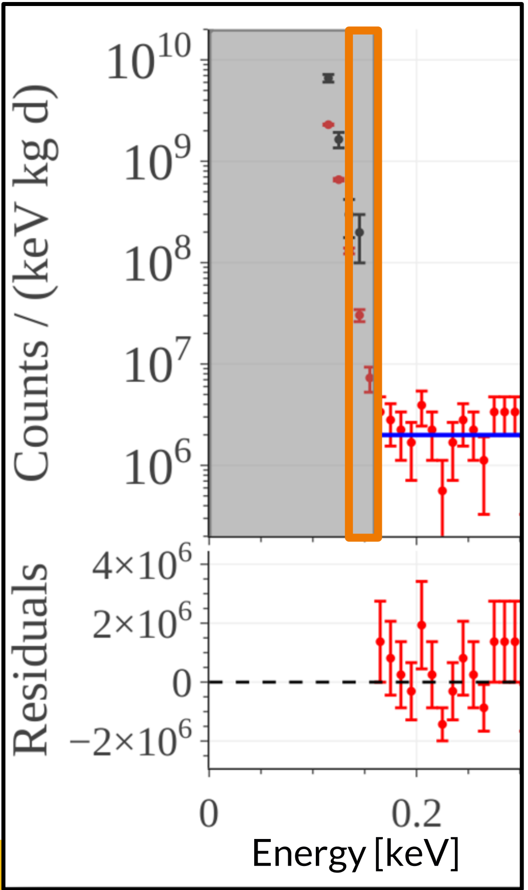

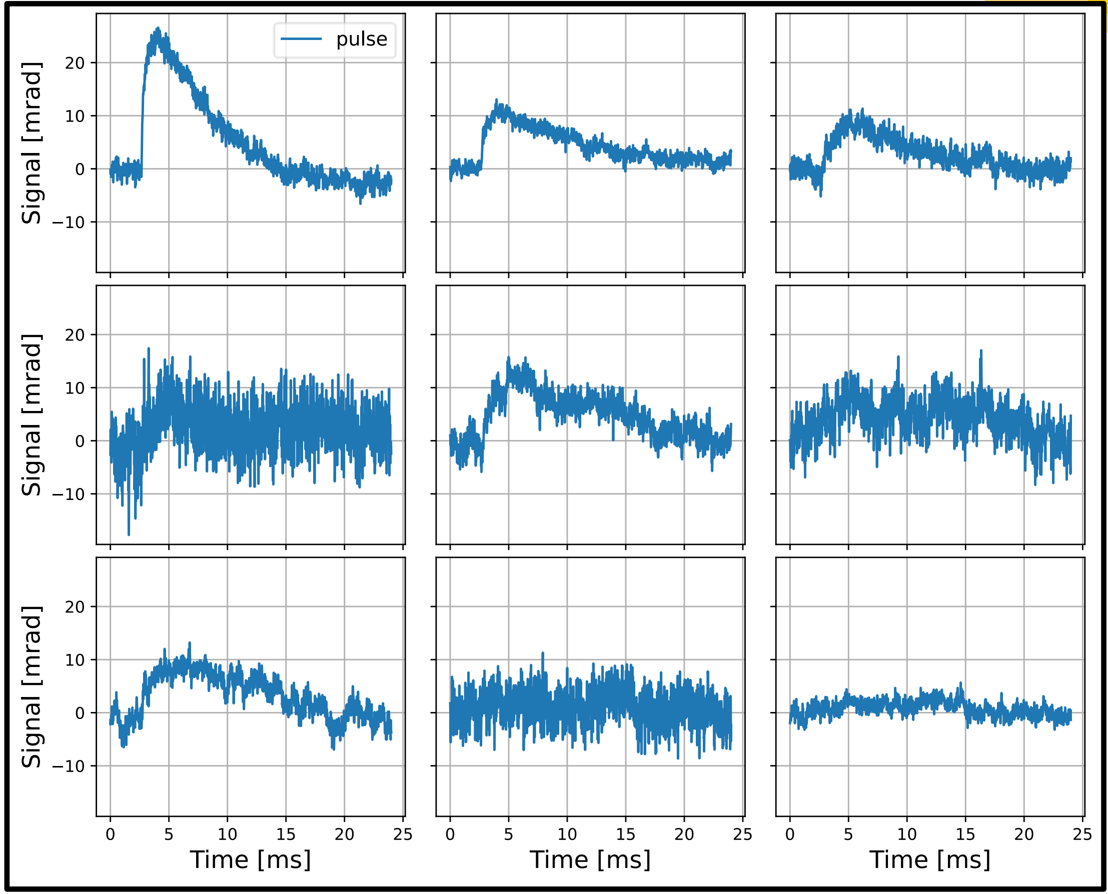

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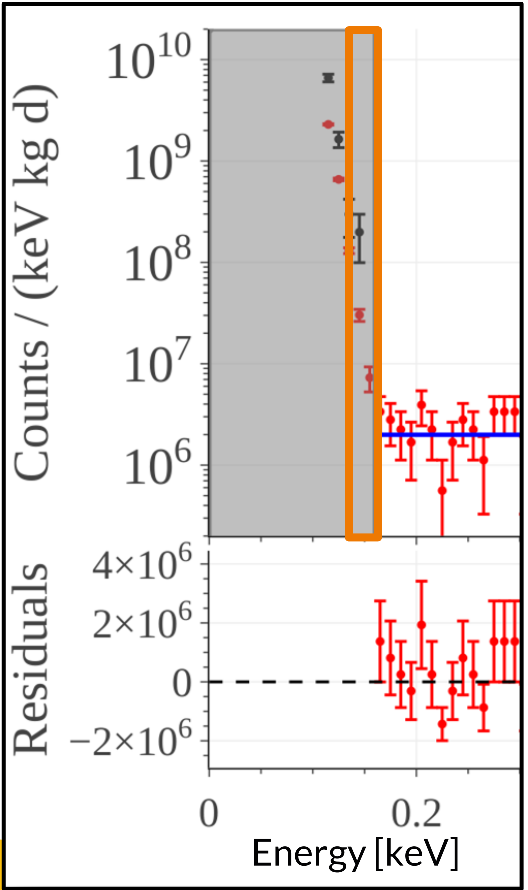
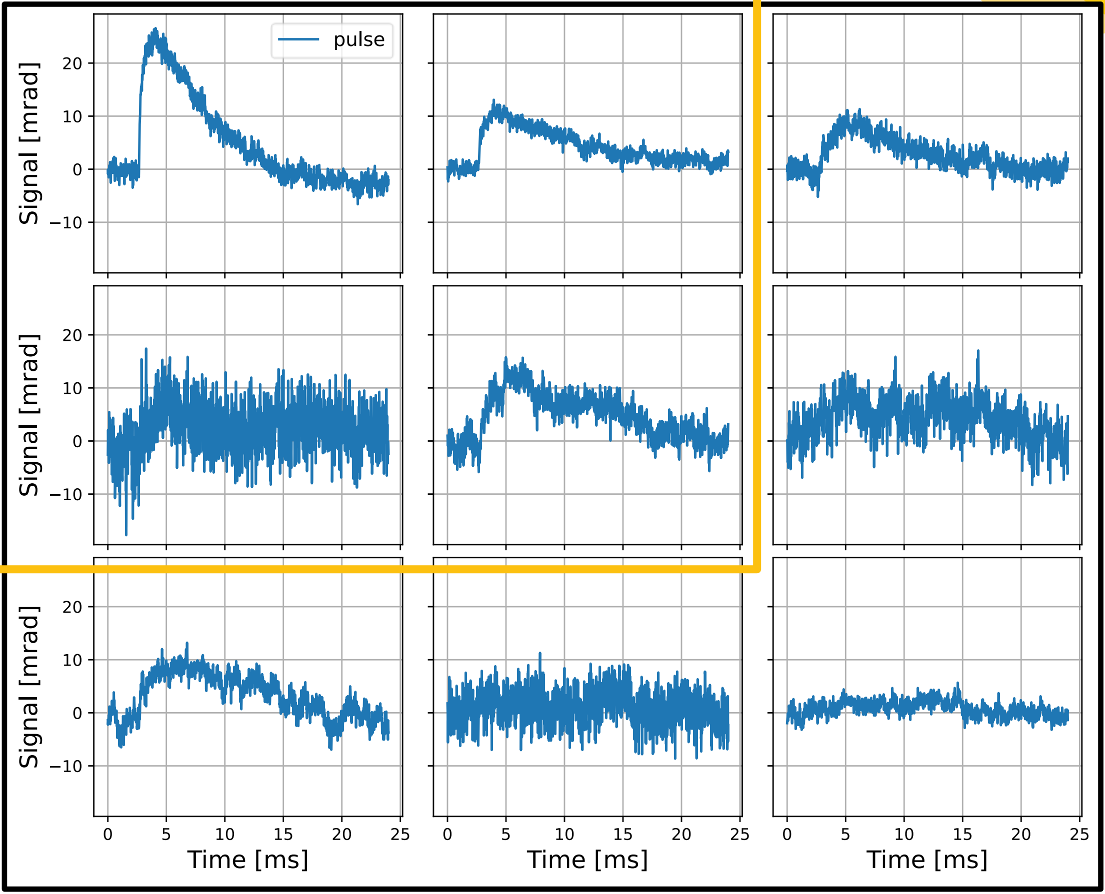
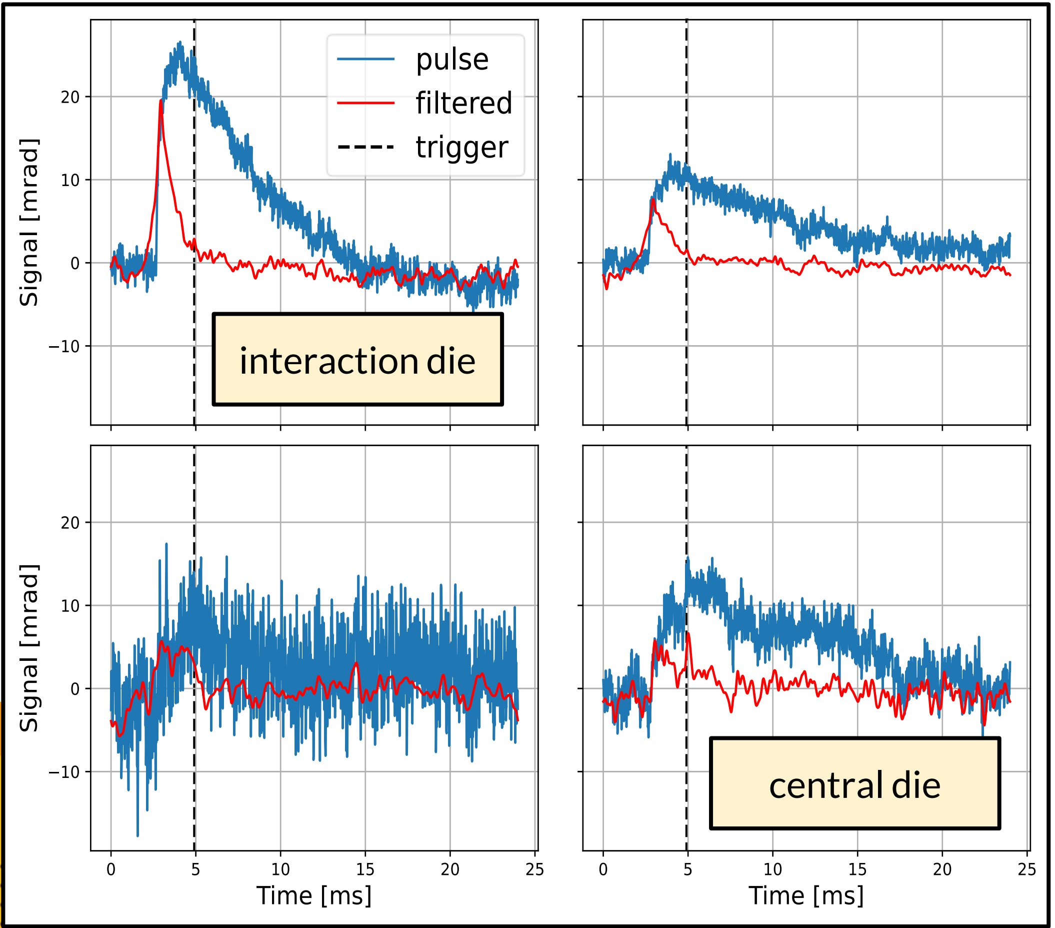




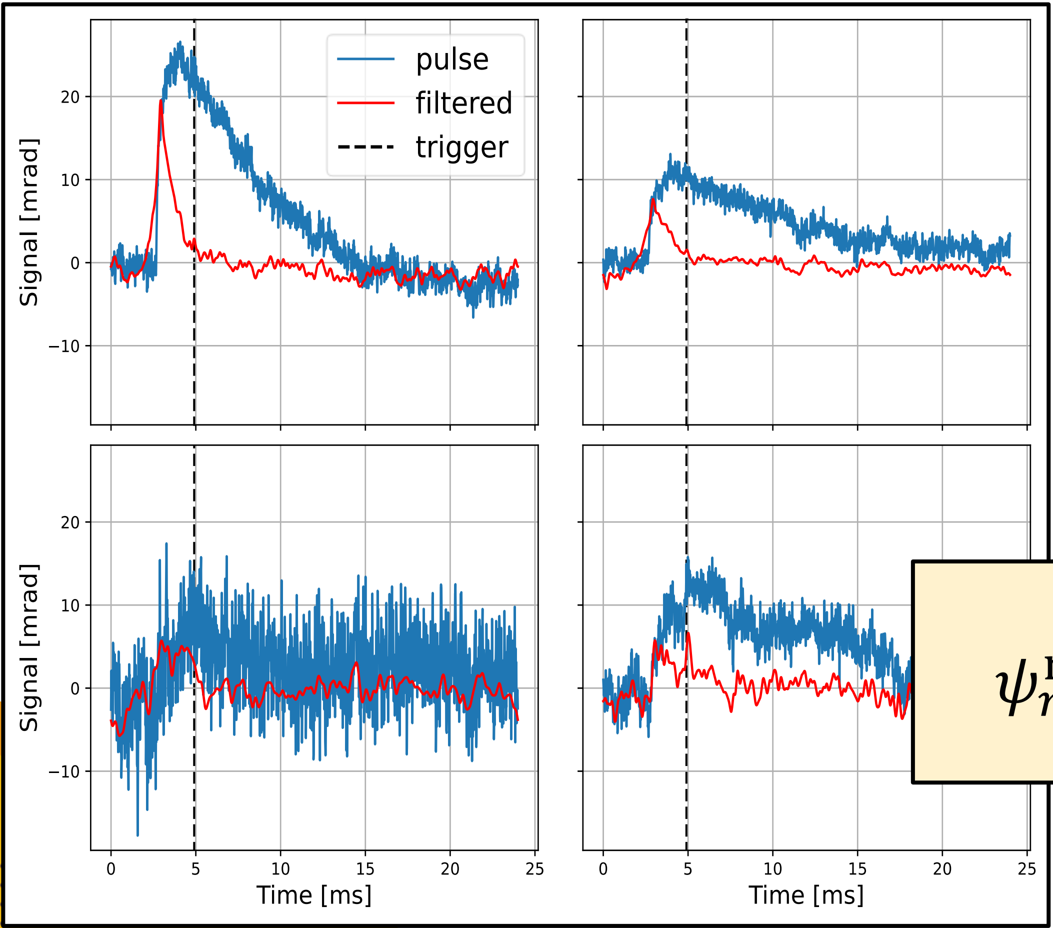
Background: pulses at threshold



Sometimes the coincident amplitude fails due to **retarded events**

The great difference between the beginning of the pulse and the trigger point causes **a failure in the evaluation of the amplitude**

Background: pulses at threshold



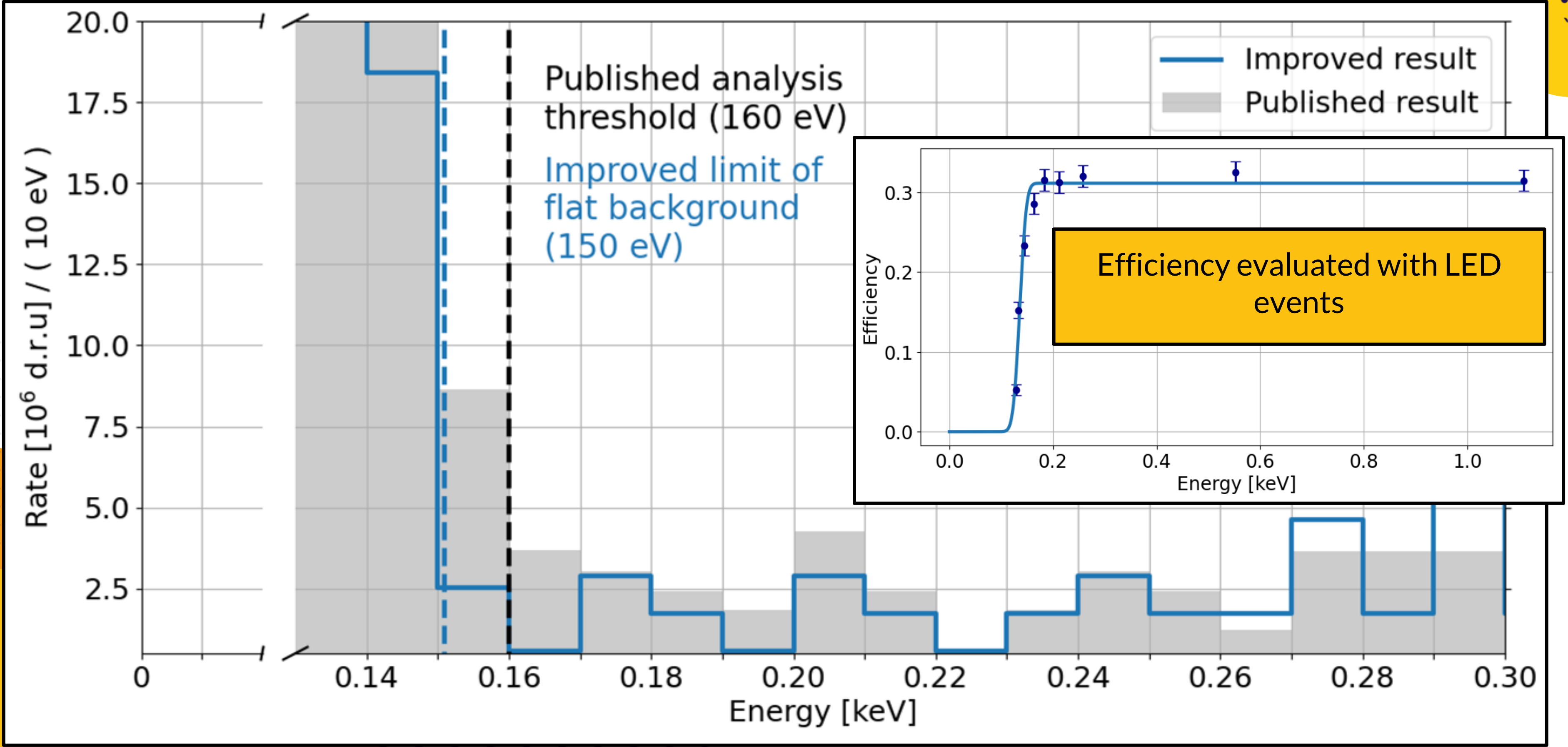
Sometimes the coincident amplitude fails due to **retarded events**

The great difference between the beginning of the pulse and the trigger point causes **a failure in the evaluation of the amplitude**

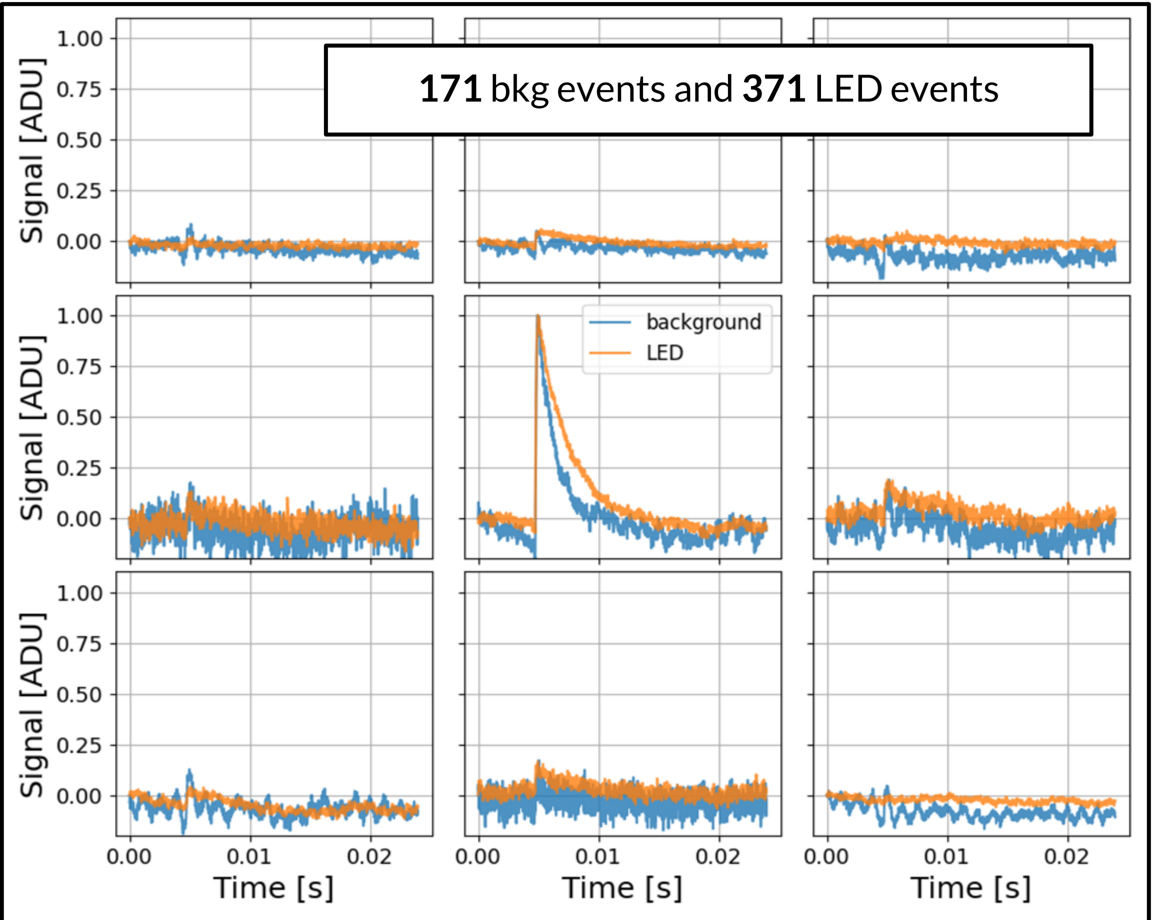
- A new variable:

$$\psi_n^{\max} = \frac{A_n^{max} - A_c \cdot \langle A_n / A_c \rangle}{\text{norm}}$$

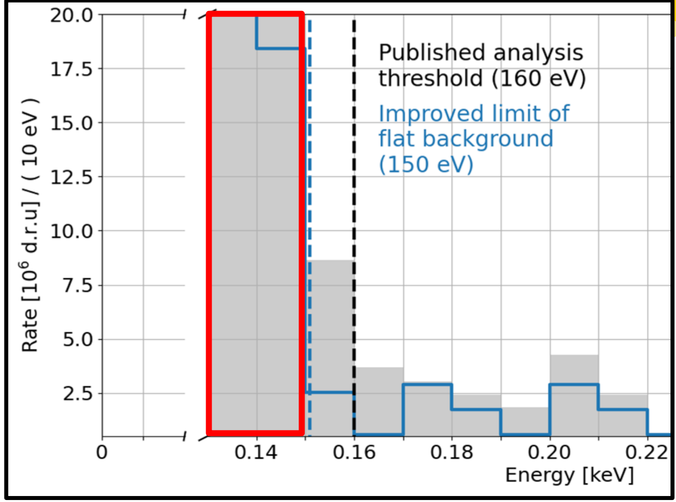
Background: updates on the surface result



Background: pulses at threshold



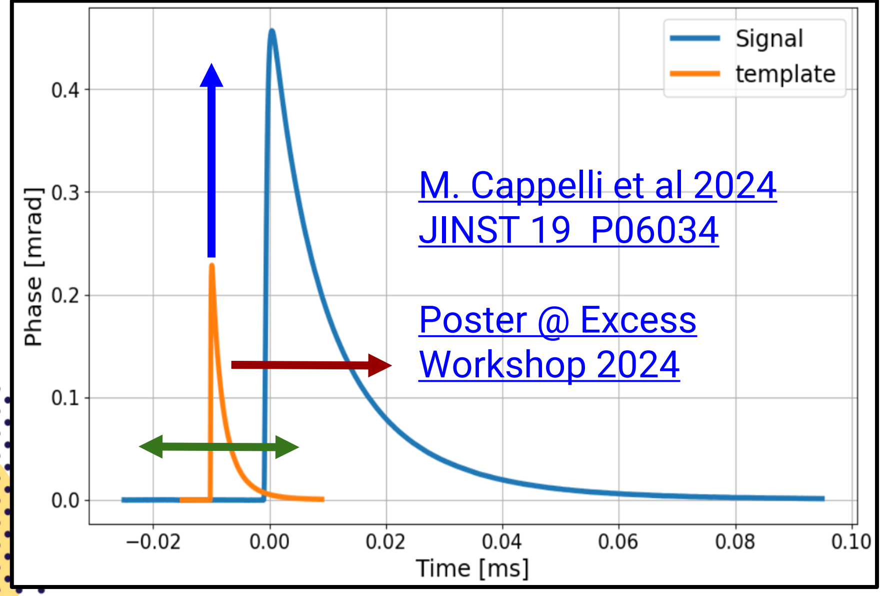
171 bkg events and **371** LED events



Apart from a **different decay time**, there does not seem to be an **appreciable difference** between reference events and threshold events

Background: pulses' deformation

New algorithm to spot the **amplitude**, **time shift** and **deformation**



[M. Cappelli et al 2024 JINST 19 P06034]

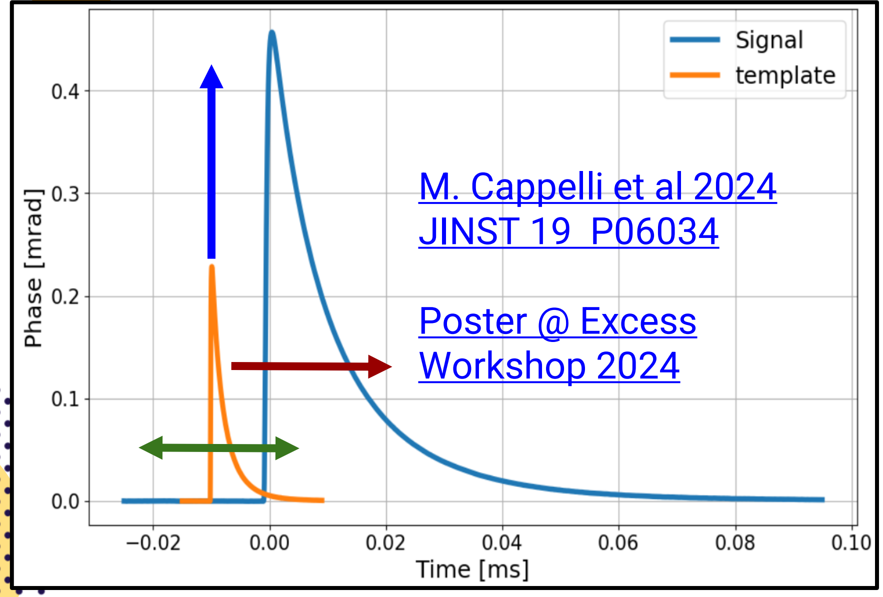
[Poster @ Excess Workshop 2024]

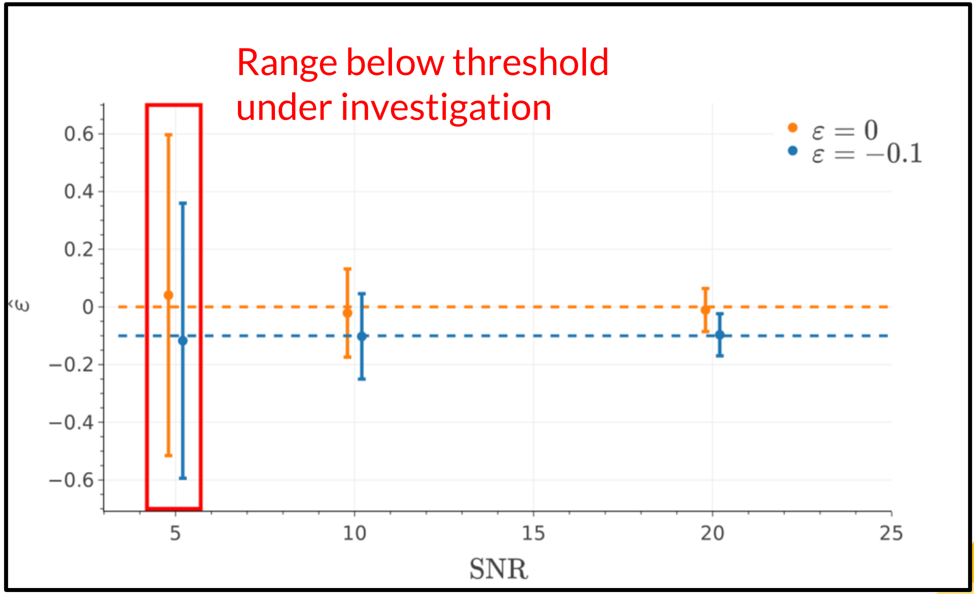
$\mathcal{E}$ is the deformation percentage reconstructed by the algorithm

Background: pulses' deformation

New algorithm to spot the **amplitude**, **time shift** and **deformation**

Simulated pulses with the deformation evaluated from the average pulses



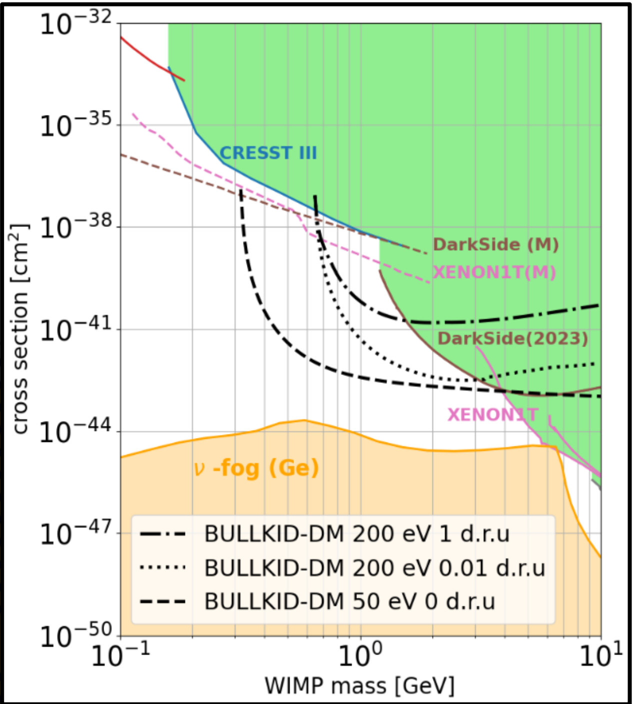


$\mathcal{E}$ is the deformation percentage reconstructed by the algorithm

The two families cannot be discriminated at this level of SNR

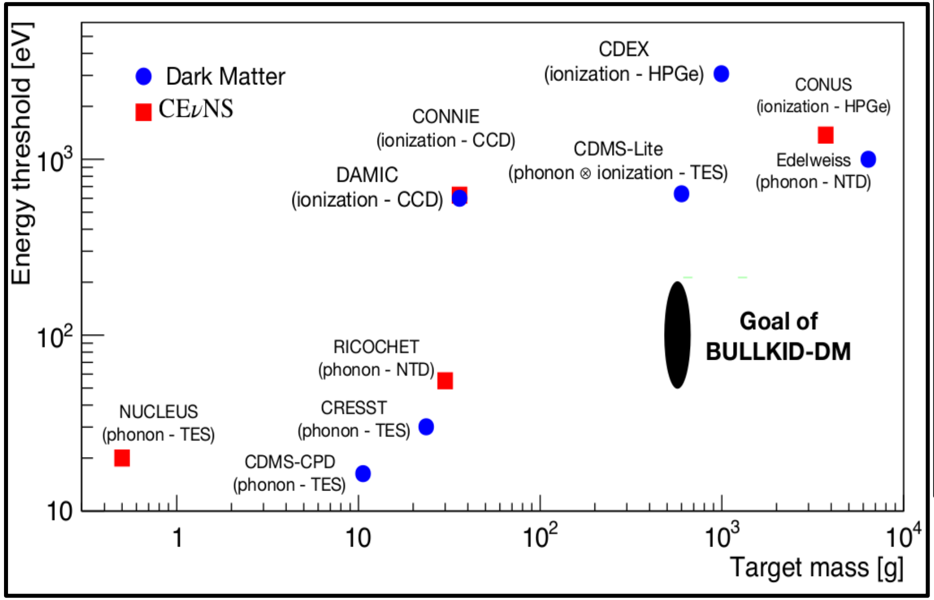
BULLKID: Impact on Dark Matter search

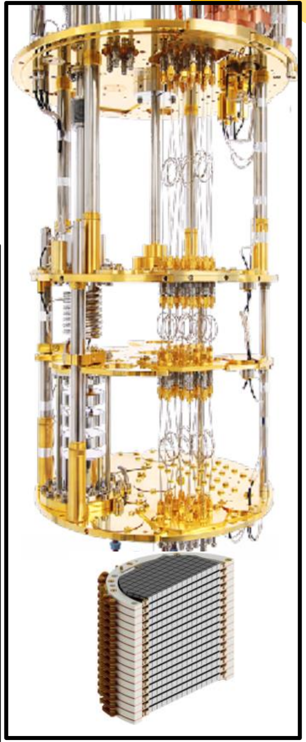
Sensitivity studies performed assuming 1 year of data acquisition at LNGS



Nuclear recoil detector with:

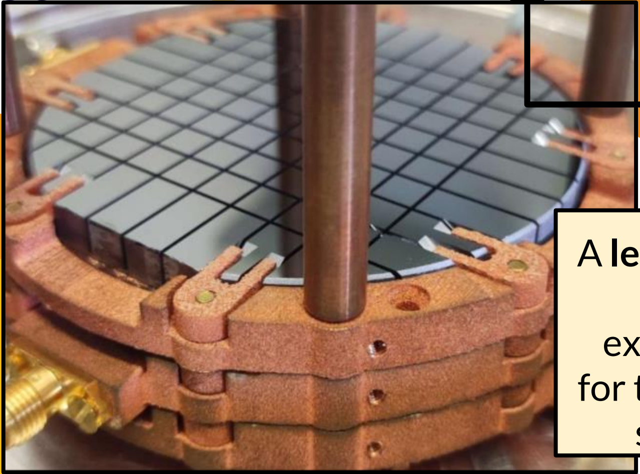
- 0.6 kg of silicon target (fiducialized)
- 200 ÷ 50 eV threshold
- background reduced to $1 \div 10^{-2}$ d.r.u





Towards the experiment

	BULLKID prototype	BULLKID-DM demonstrator		BULLKID-DM
mass	20 g	60 g		600 g
# of sensors	60	180		2300
threshold	160 eV	200 eV		200 eV or lower
bkg (d.r.u)	$2x10^6$	$< 10^5$		1 - 0.01
laboratory	Sapienza U.	Sapienza	LNGS?	LNGS
installation	2023	2024	2025	2027?



A **lead case around the stack** is expected in July for the background suppression

Towards the experiment

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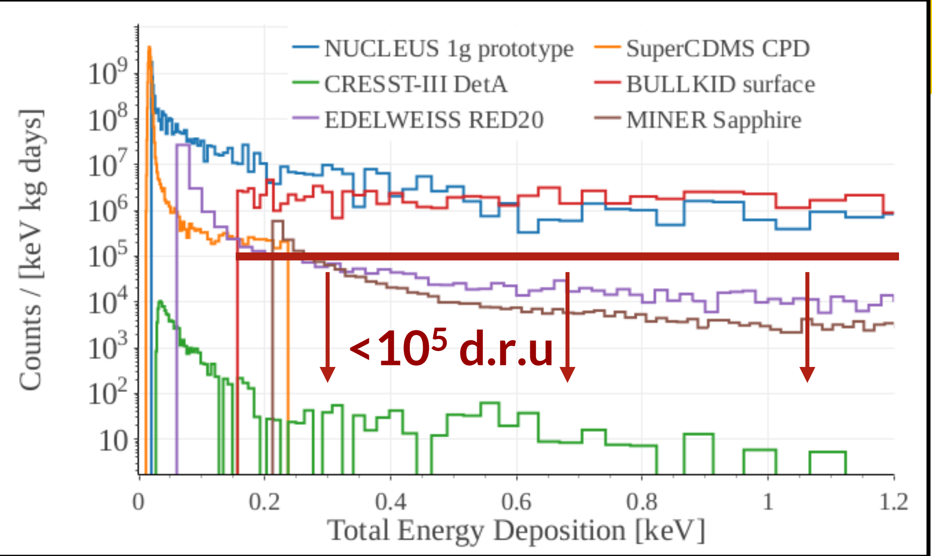
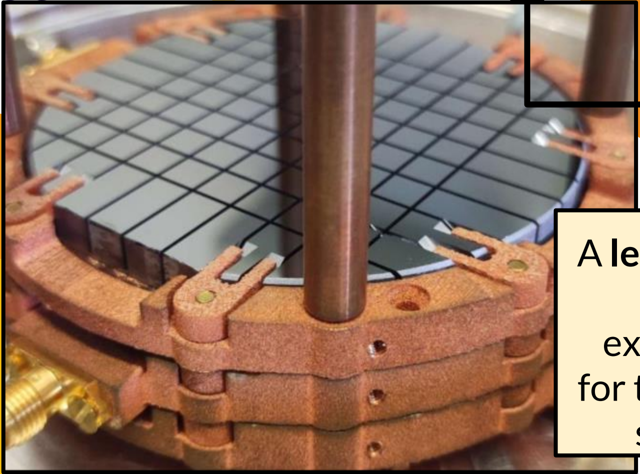




A **lead case around the stack** is expected in July for the background suppression

The necessary **transition to a demonstrator** will allow us to express **more stringent information about the low energy excess** under conditions of lower contamination and greater exposure

INFN Ferrara Roma LNGS Pisa

Karlsruher Institut für Technologie

Thank you for the attention

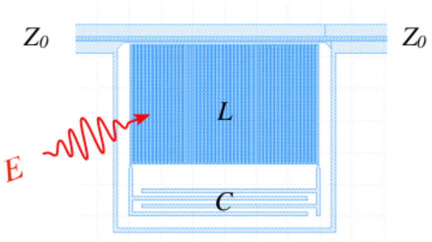
Matteo Folcarelli
EXCESS workshop, Sapienza, 06/07/2024

BACKUP

Kinetic Inductance Detectors (KIDs)

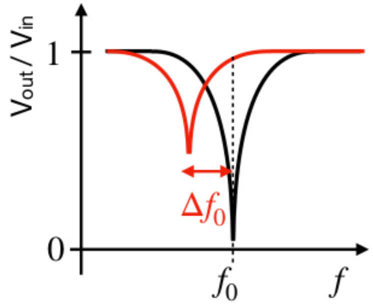
- LC resonator made of superconductive aluminum (T < 200 mK)
- The absorbed energy breaks Cooper pairs; hence the inductance changes
- A phase and magnitude signal is measured

resonator $f_0 = 1/\sqrt{LC}$

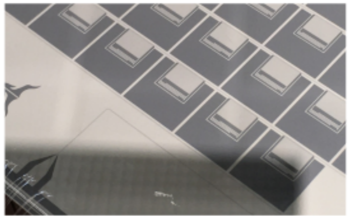


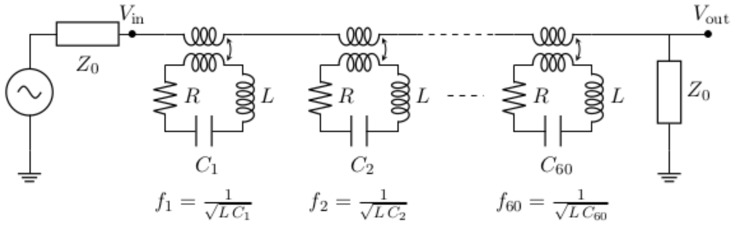
$E \rightarrow \Delta n_{pairs} \rightarrow \Delta L \rightarrow \Delta f_0$

frequency response

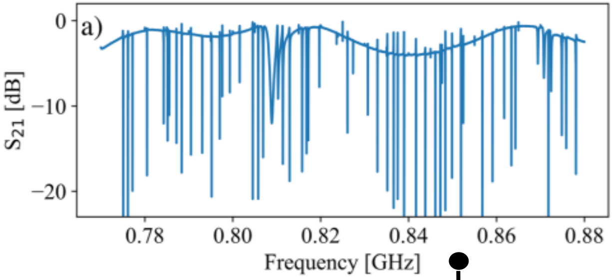


Readout: different KIDs coupled to a the same line





frequency scan of the 60 KIDs of BULLKID

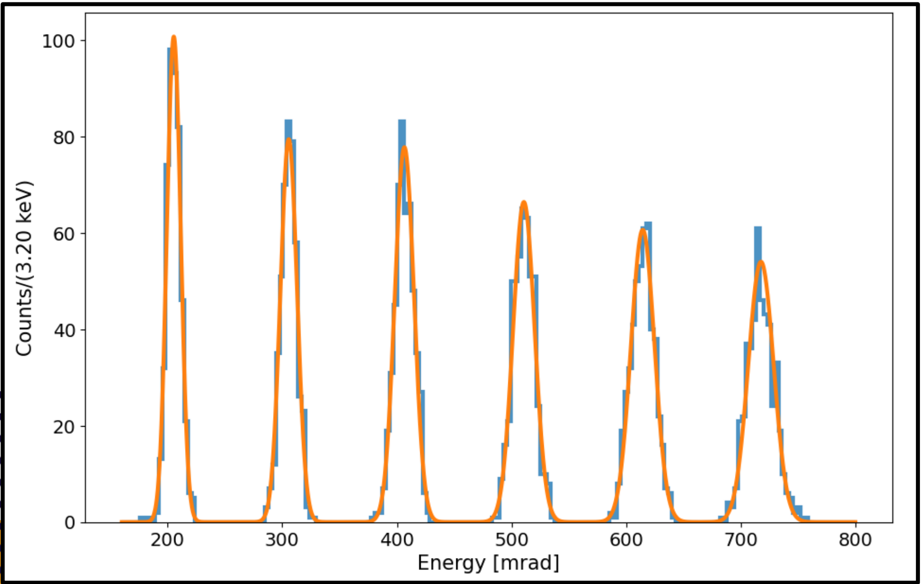


circuit

scheme

resonances

Calibrazione ottica

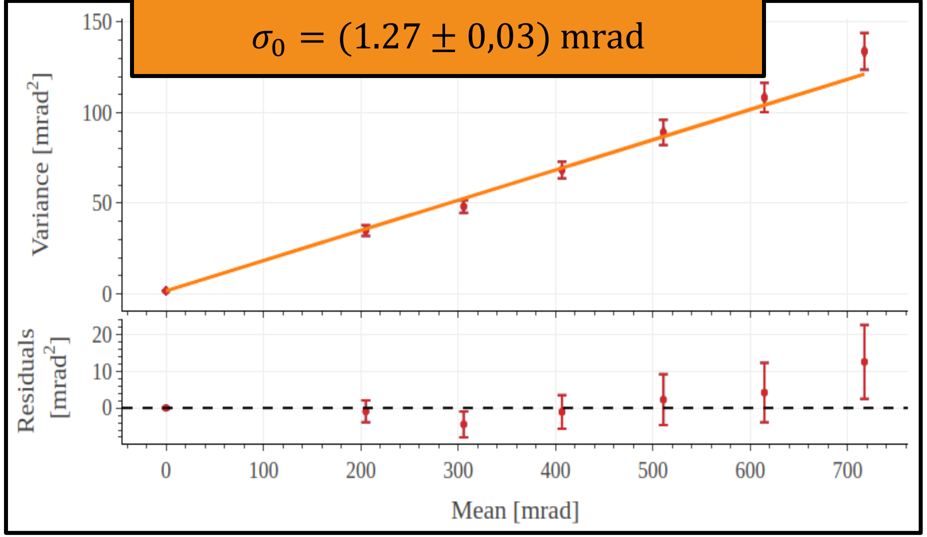


$$\sigma^2 = \sigma_0 + r \cdot \mu$$

poster @ EXCESS workshop 2024

$r = (167 \pm 5) \cdot 10^{-3}$ mrad/phonon

$\sigma_0 = (1.27 \pm 0{,}03)$ mrad

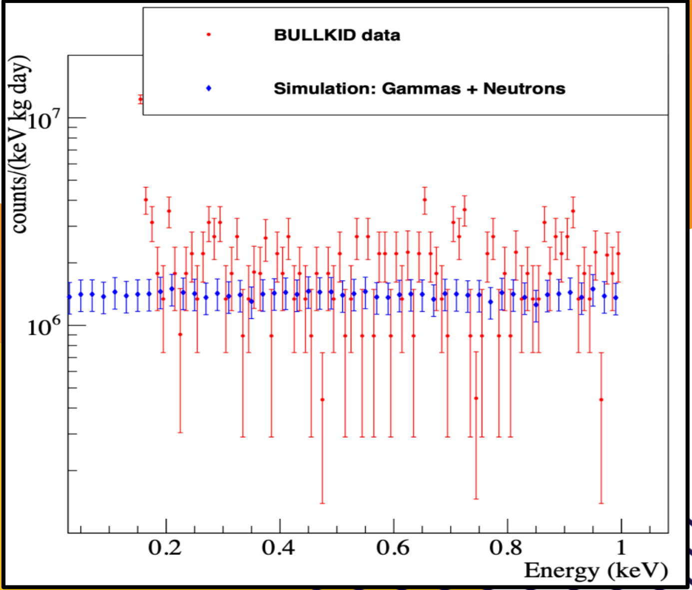


From **poissonian statistics** we can infer the number of phonons absorbed in the die. Then we know the **energy of the single photon.**

Simulations: validation on Sapienza's setup

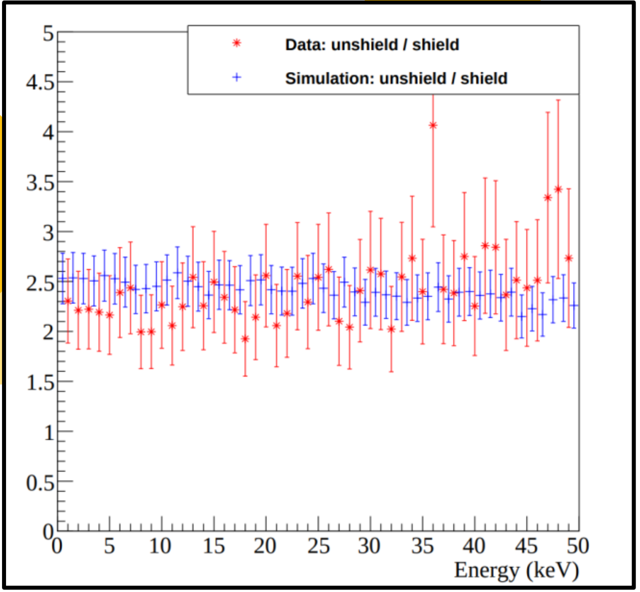
Background consists mainly of gammas (99%) and neutrons (1%)

Agreement observed over a wide energy range

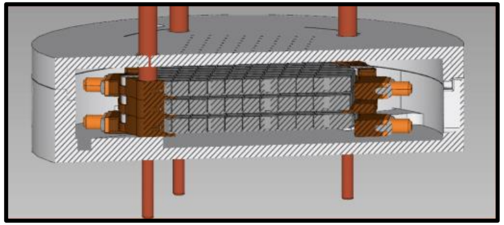


Lead castle @ Sapienza

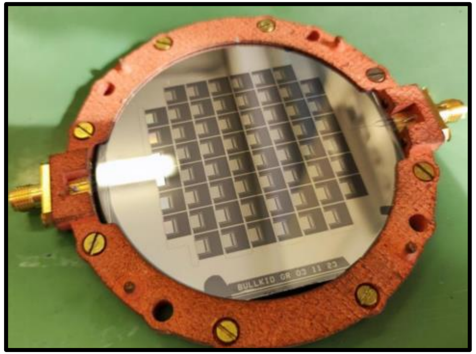
Reduction factor with respect to the unshielded background

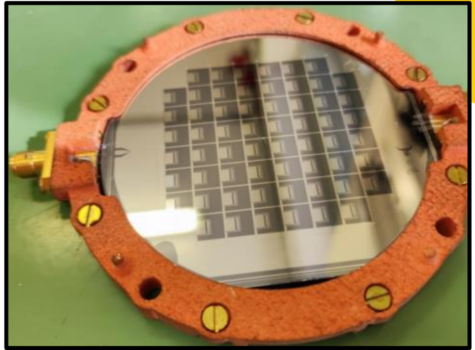


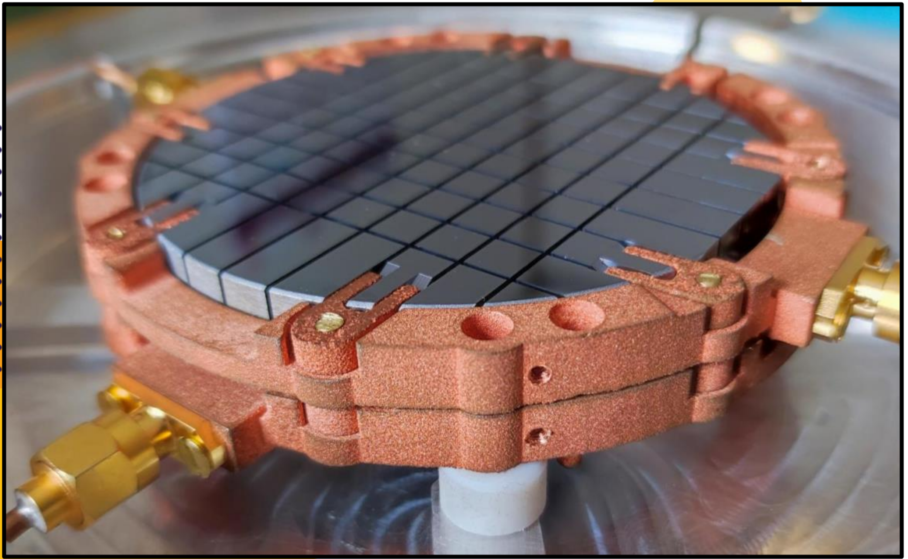
Status of the 3-wafer demonstrator

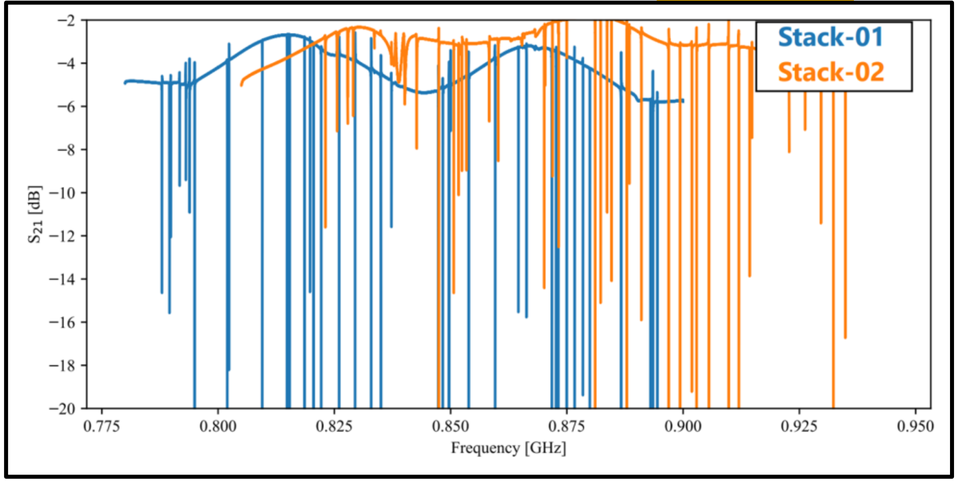


2-wafer stack operated. No issues observed

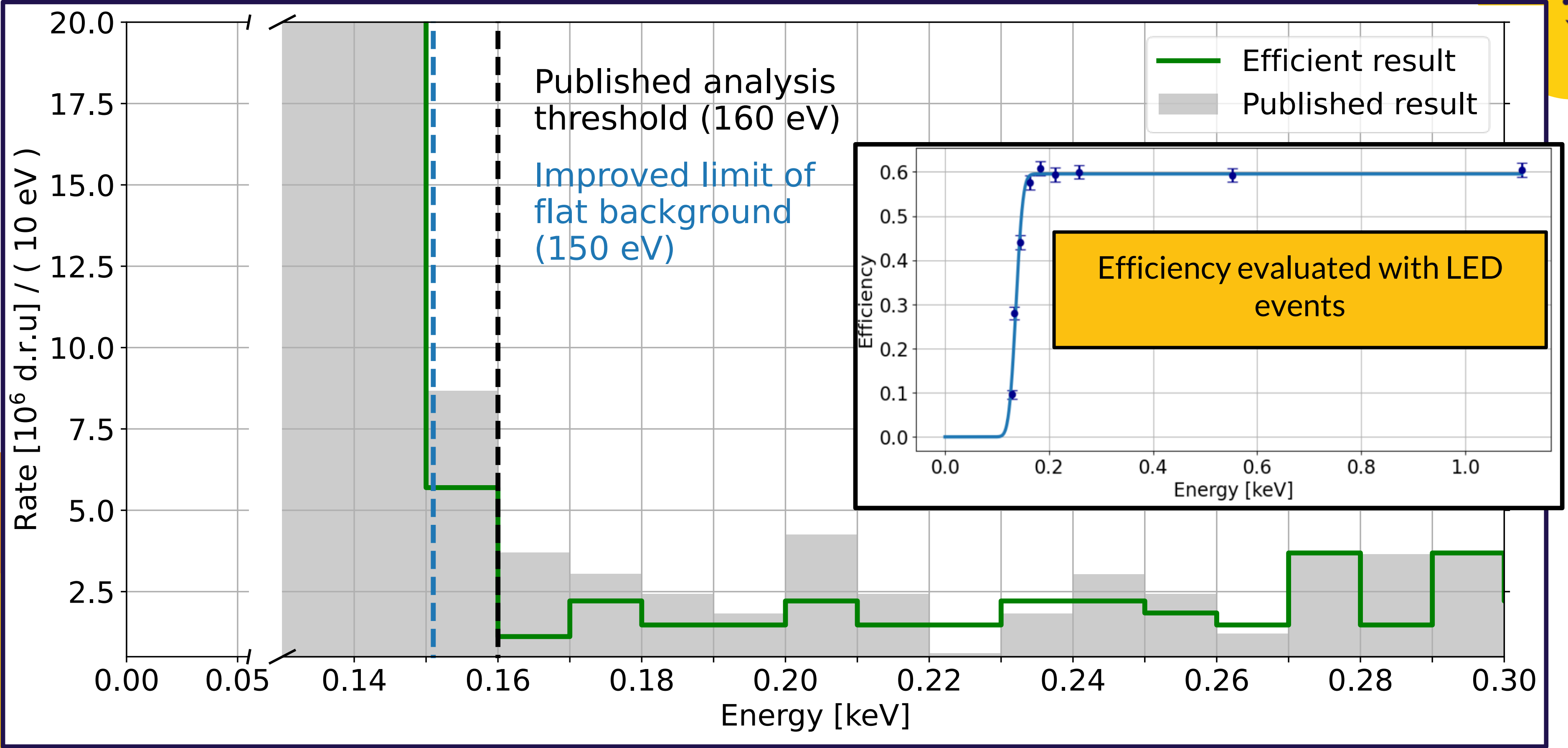




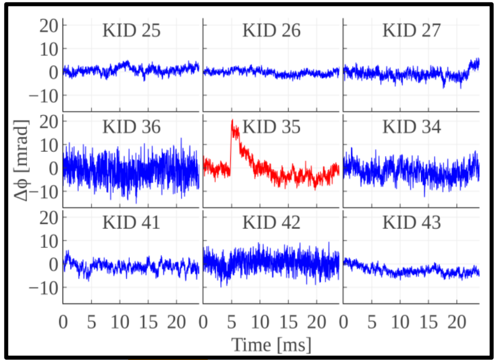




Background: efficient analysis



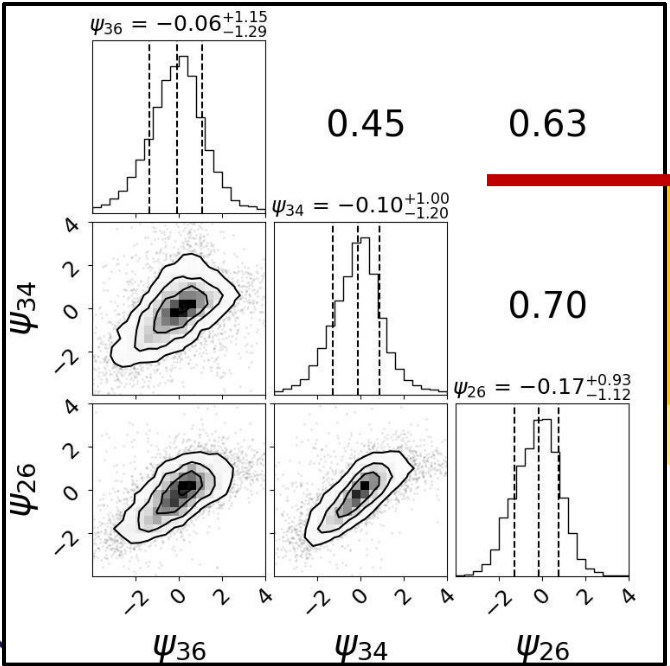
Efficient phonon leakage cut

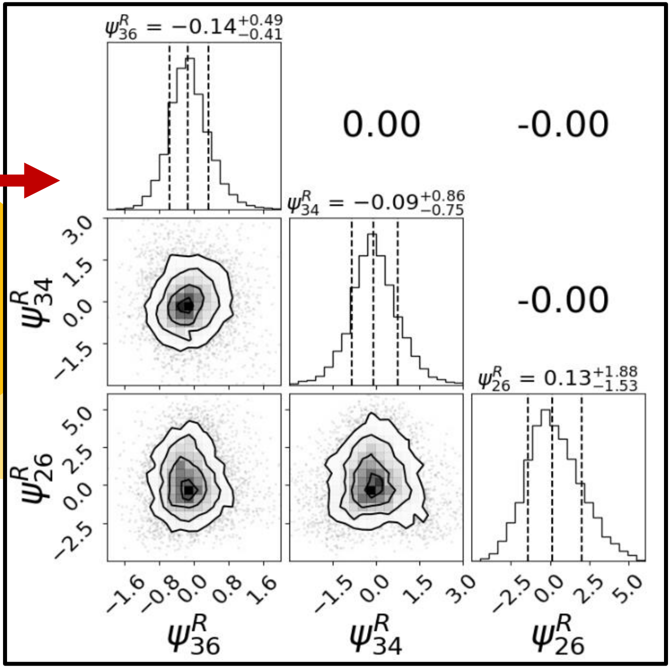


Correlation plot between some leakage variables. On the upper diagonal the correlation coefficients.

Leakage variables

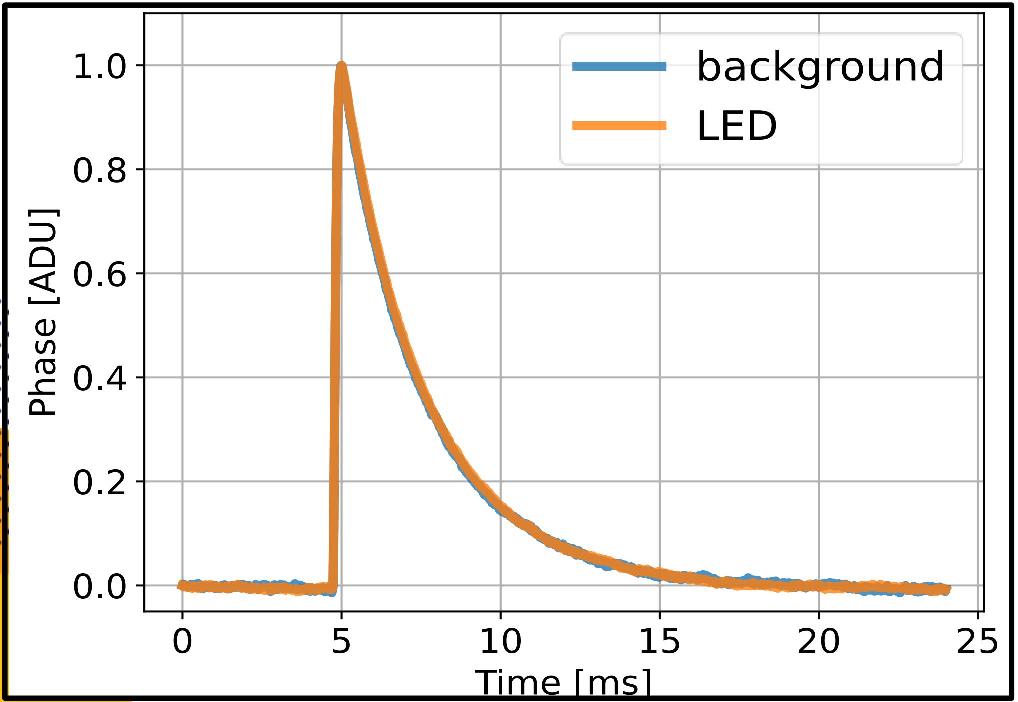
Rotated leakage variables





Cutting on the decorrelated (rotated) variables increases the cut's efficiency

LEDs and background events



At high SNR ([0.7,1.3] keV)

LED and Background events are identical