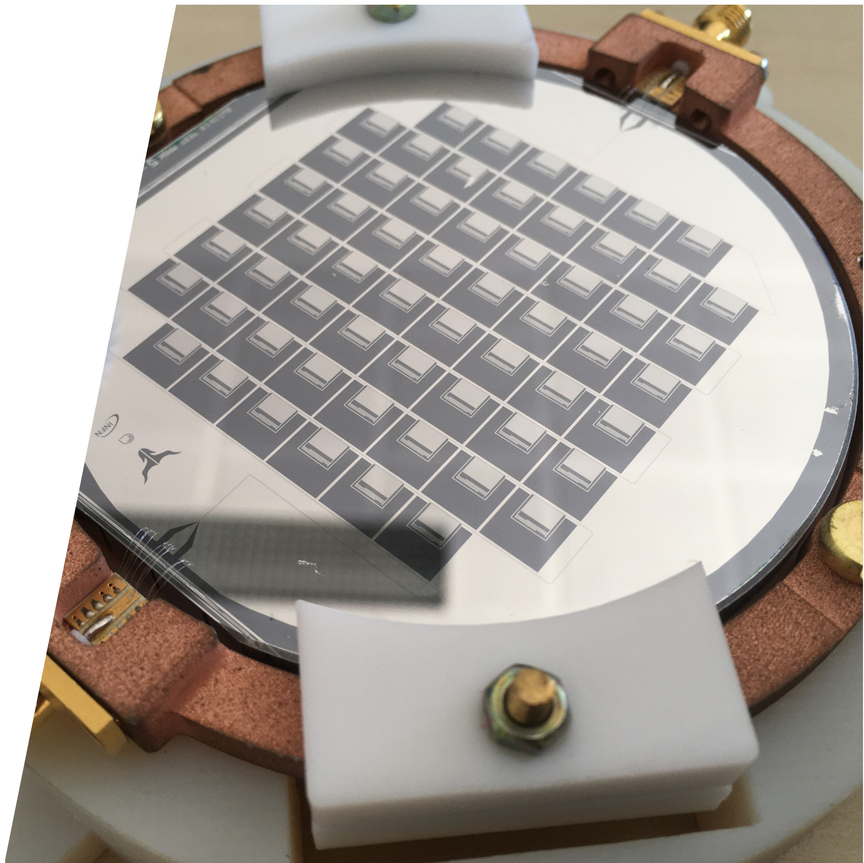
The low energy spectrum of BULLKID

29 Aug 2023 update:
results on arXiv:2308.14399
added comparison w NUCLEUS-1g bkg

Marco Vignati, on behalf of the BULLKID coll.
EXCESS@Taup, Vienna, 26 August 2023

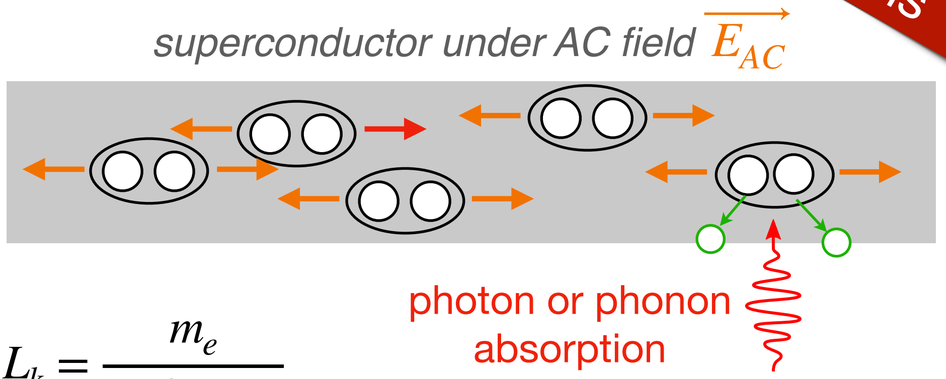


Kinetic Inductance Detectors

100% athermal phonons

AC superconductivity

- Electrons bound into Cooper pairs (no dissipation)
- High quality factors (Q ~ 10^4 - 10^6)
- Inertia from the mass of pairs (*kinetic inductance, L_k*)

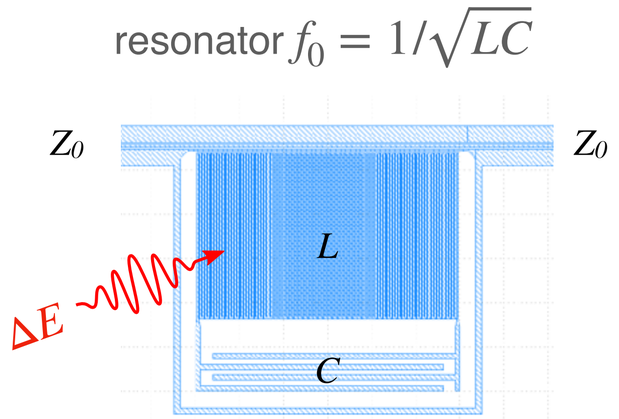


$$L_k = \frac{m_e}{2\, e^2\, n_{\text{pairs}}}$$

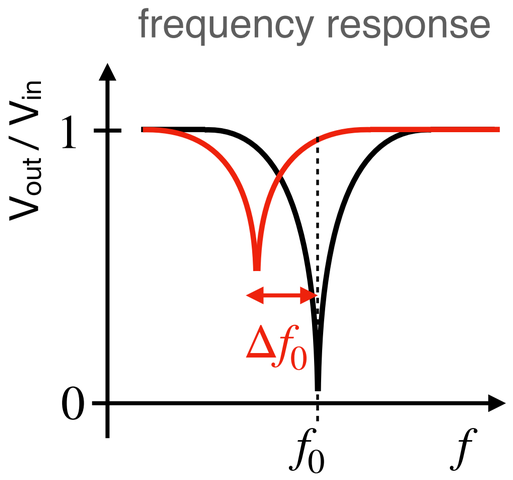
Kinetic Inductance Detector (KID)

- Superconductor at T < 200 mK (Al)
- LC resonator

Invented by J. Zmuidzinas and his group at Caltech in 2003 for astrophysical applications



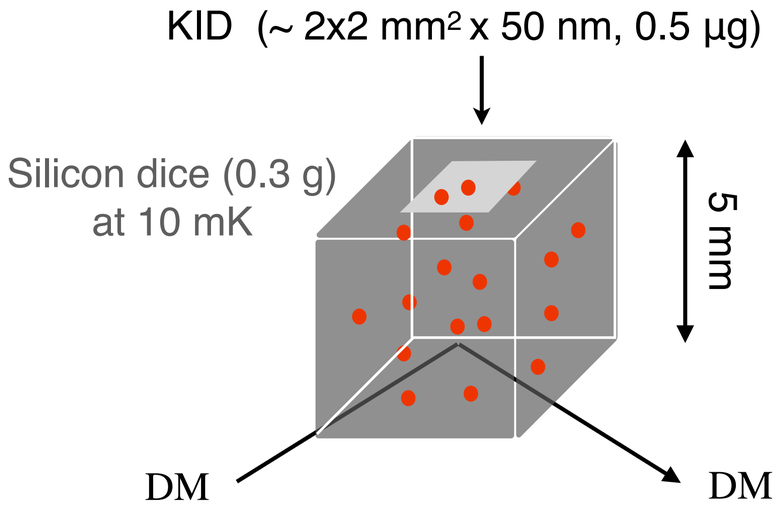
$$\Delta E \rightarrow \Delta n_{\text{pairs}} \rightarrow \Delta L_k \rightarrow \Delta f_0$$



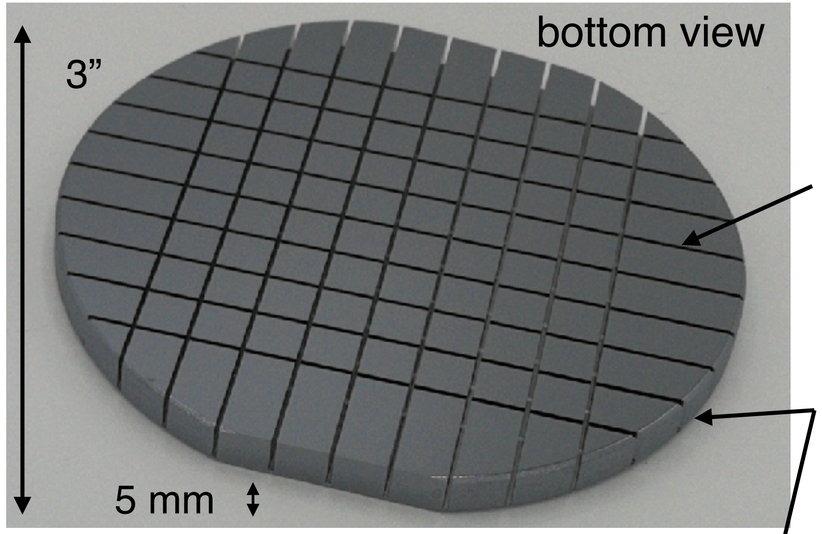
The BULLKID phonon detector array

Phonon mediation

detect phonons created by nuclear recoils in a silicon dice



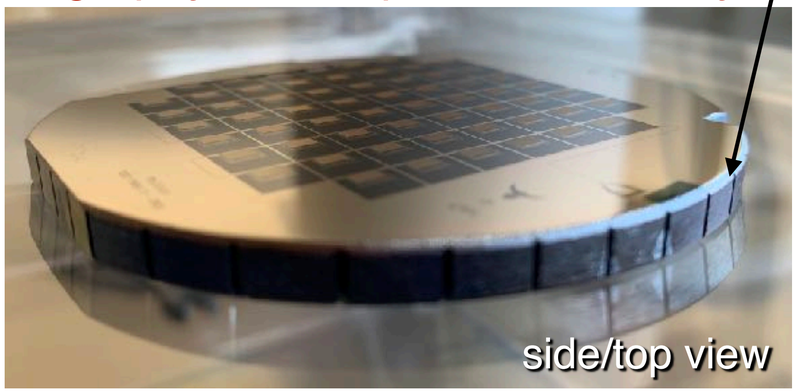
carving of dices in a thick silicon wafer



4.5 mm deep grooves
- 6 mm pitch
- chemical etching

0.5 mm thick common disk:
- holds the structure
- hosts the KIDs

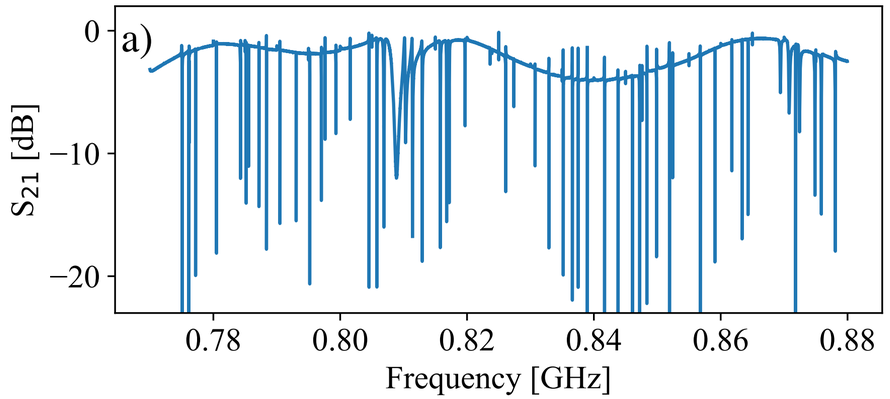
lithography of multiplexed KID array

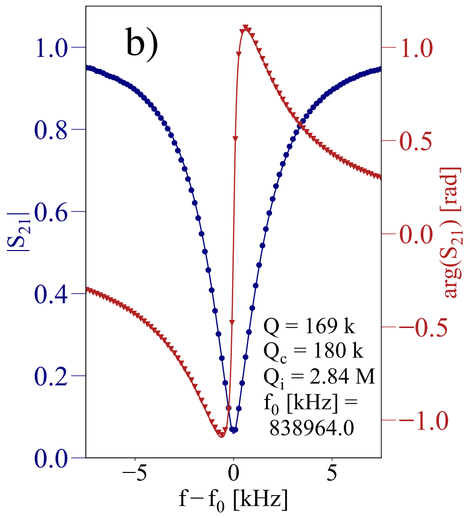


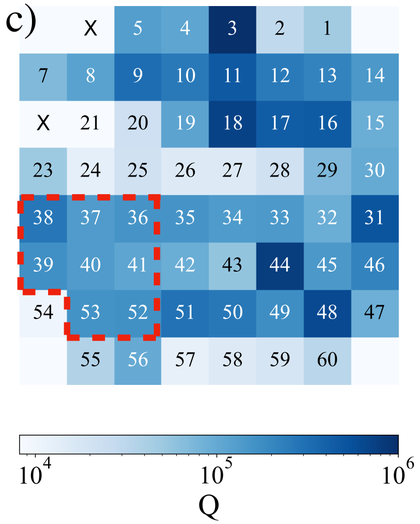
KID array
- 60 nm aluminum film
- 60 KIDs lithography

First results (Summer ’22)

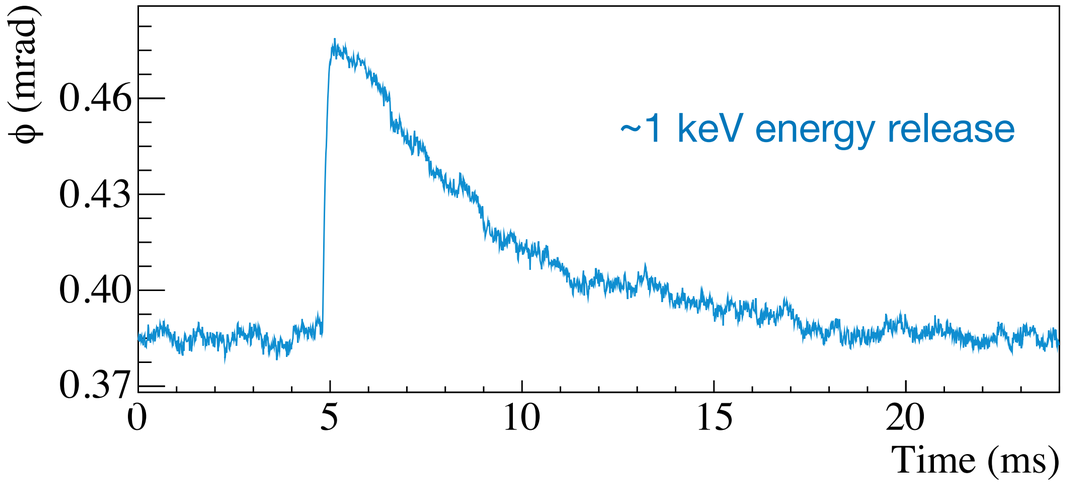
Frequency scan of the KID array

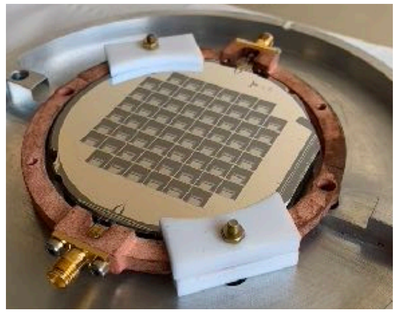






Particle interaction in a dice





+) 58/60 KIDs alive

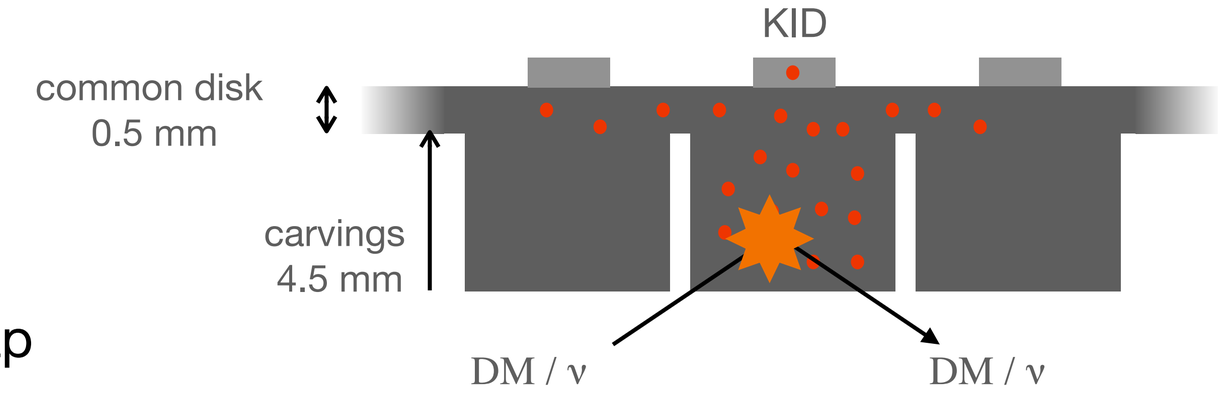
+) RMS@0 eV: **26 ± 7 eV**

–) Response not uniform

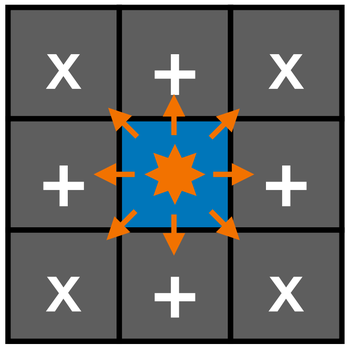
A. Cruciani, et al, Appl. Phys. Lett. 121, 213504 (2022)

Phonon leakage

- Phonons generated by interactions
  - 40% absorbed by the KID
  - the rest leaks in nearby voxels or decays below the KID aluminum gap



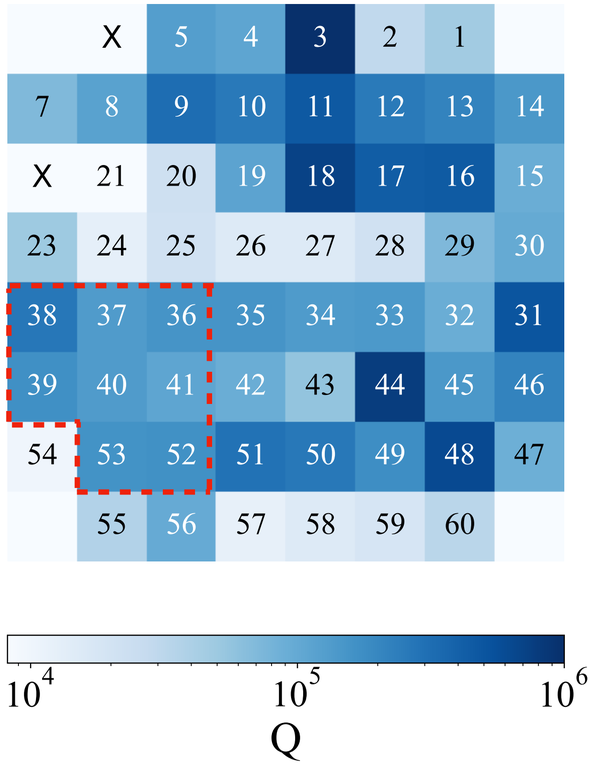
- Measured energy leakage relative to central voxel:
  - (14 ± 3) % in each “+” voxel
  - (5 ± 1) % in each “x” voxel



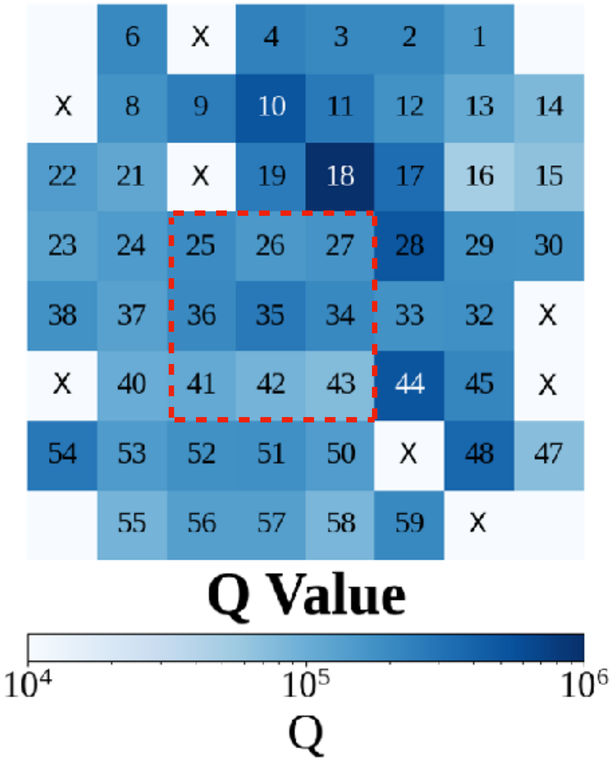
This effect reduces the phonon focusing on the KID but
it can be exploited to reconstruct the interaction voxel

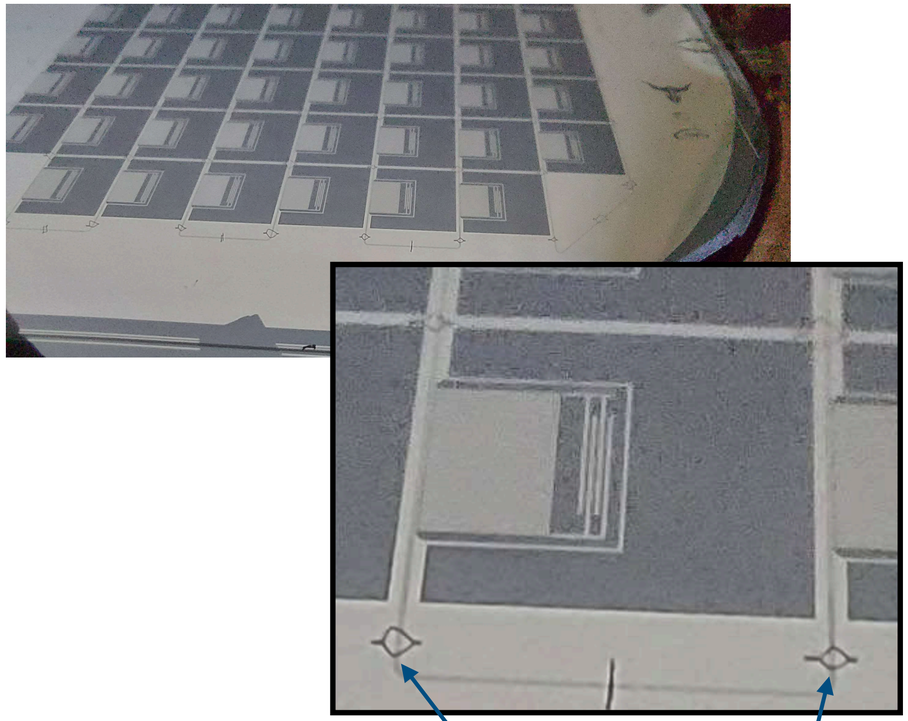
Improvement of uniformity

First version of the array



Same array with improved grounding





Airbridges connecting GND planes

+) 58/60 KIDs alive

–) Response not uniform

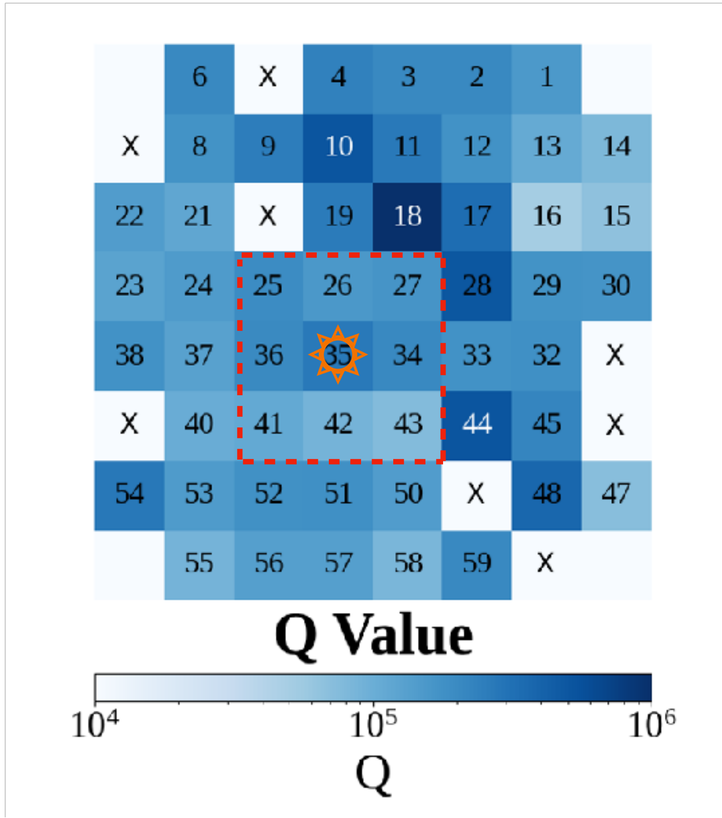
+) All KIDs with Q ~ 10^5 (optimal sensitivity)

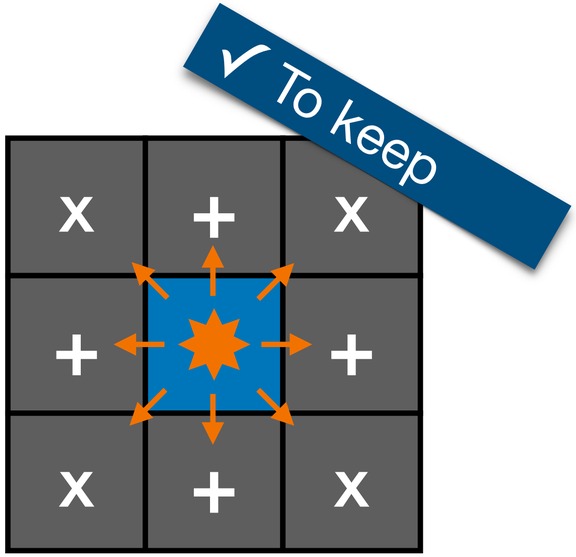
–) Some resonator lost during operations

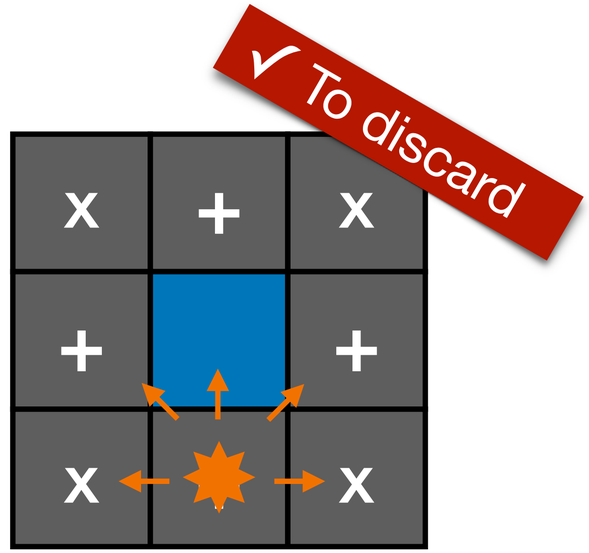
Combined analysis of a 9-voxel cluster

Measurement of the energy spectrum of the central voxel

Use the 8 external voxels as “veto” exploiting the phonon leakage



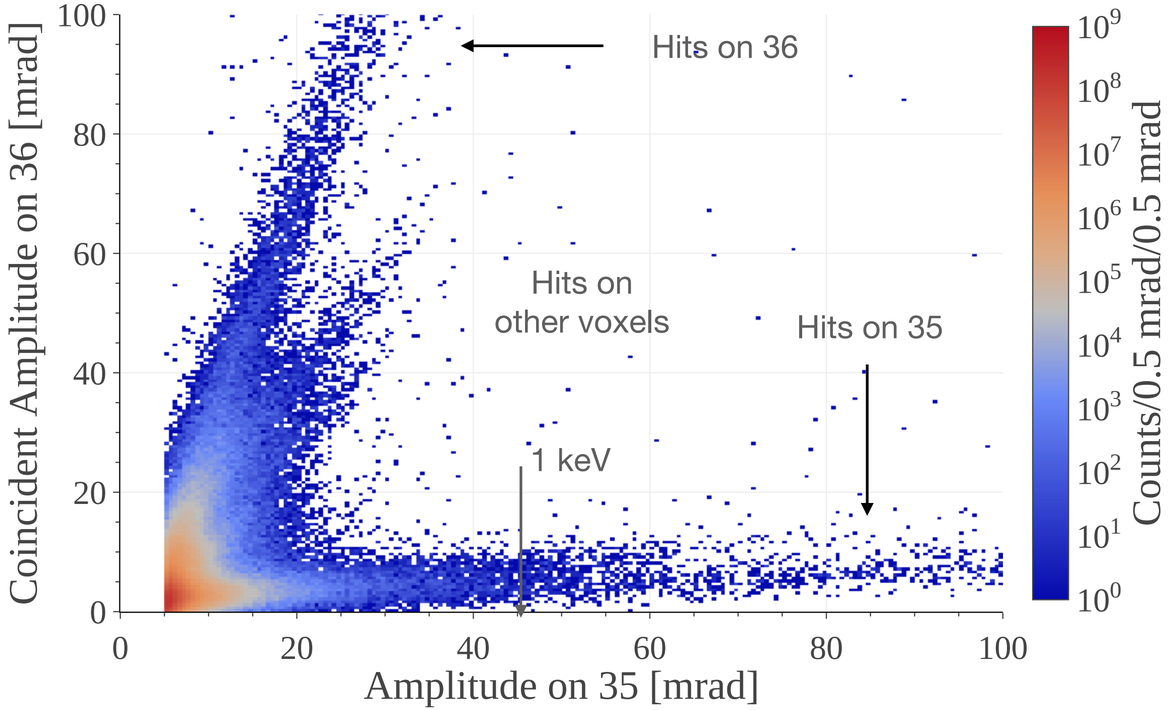




Phonon leakage, selection

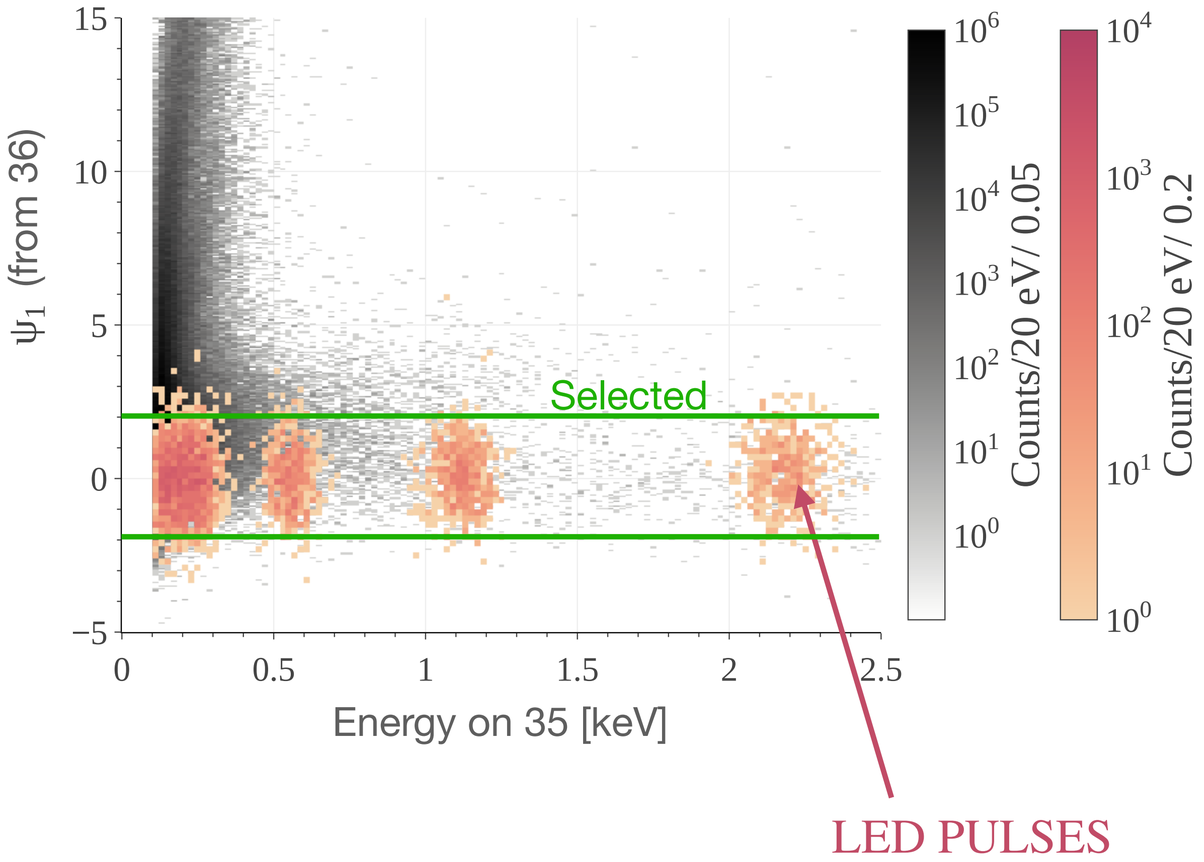
25	26	27
36	35	34
41	42	43

Pulse shape cuts only



$$\psi_n = \frac{A_n - A \cdot r_n}{\sqrt{\sigma_{0,n}^2 + r_n^2 \cdot \sigma_0^2}}$$

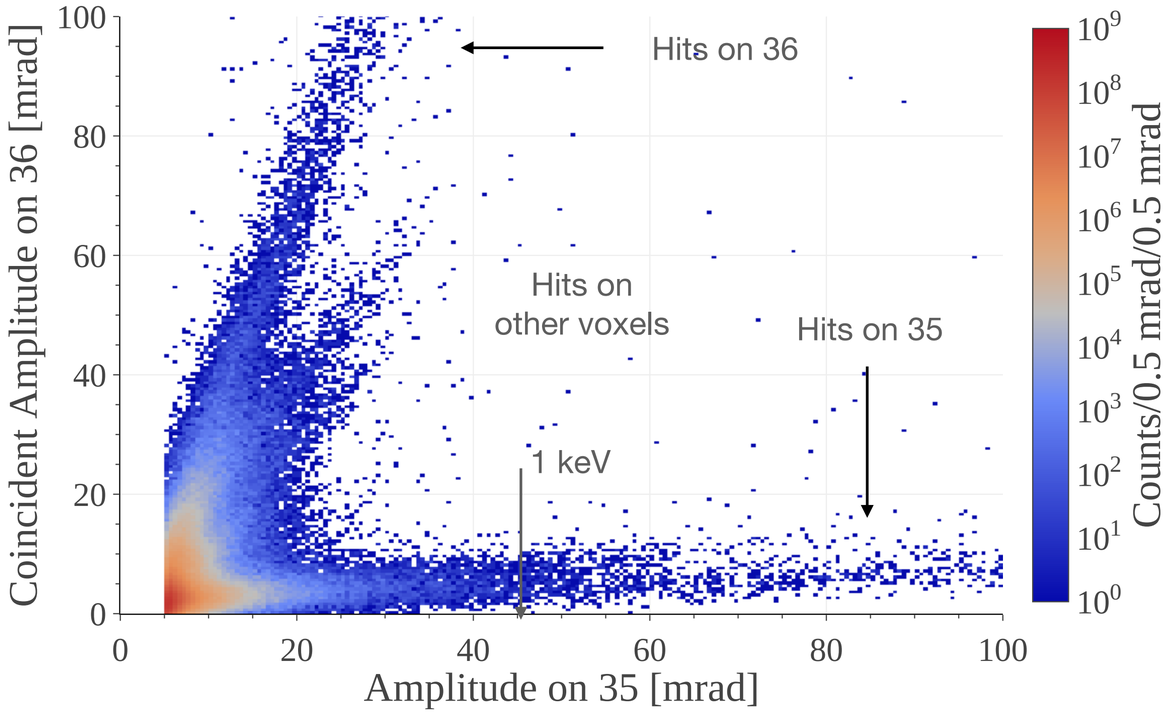
r_n: expected leakage



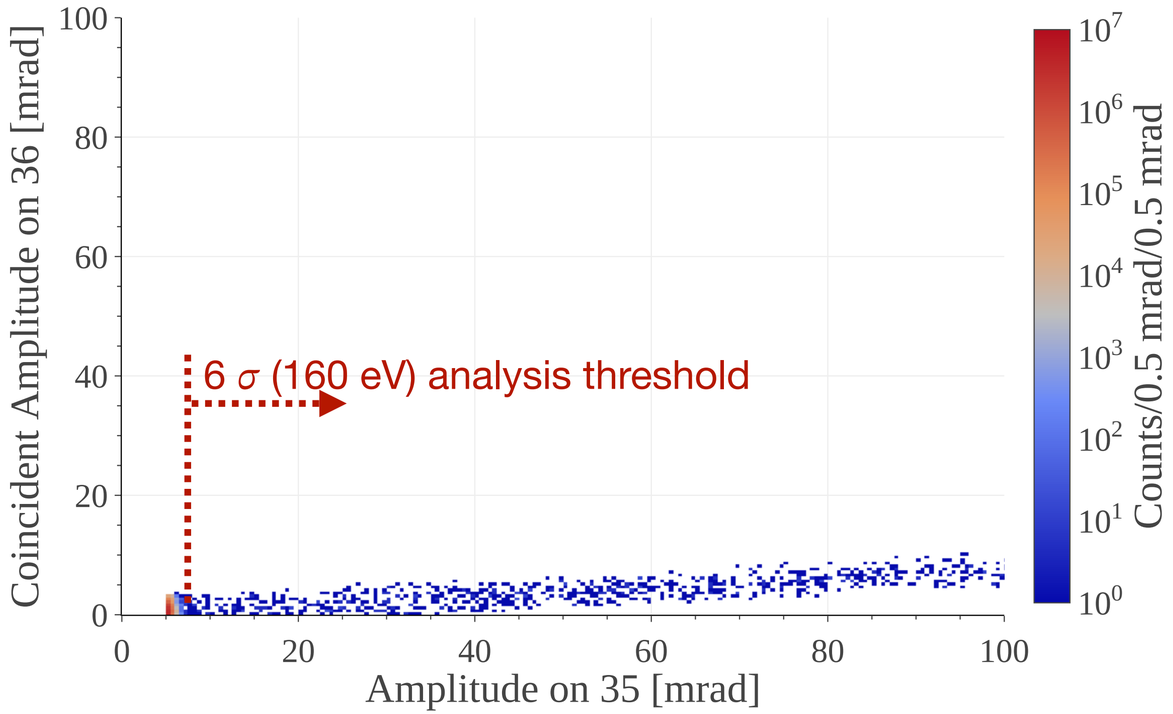
Phonon leakage, selection

25	26	27
36	35	34
41	42	43

Pulse shape cuts only



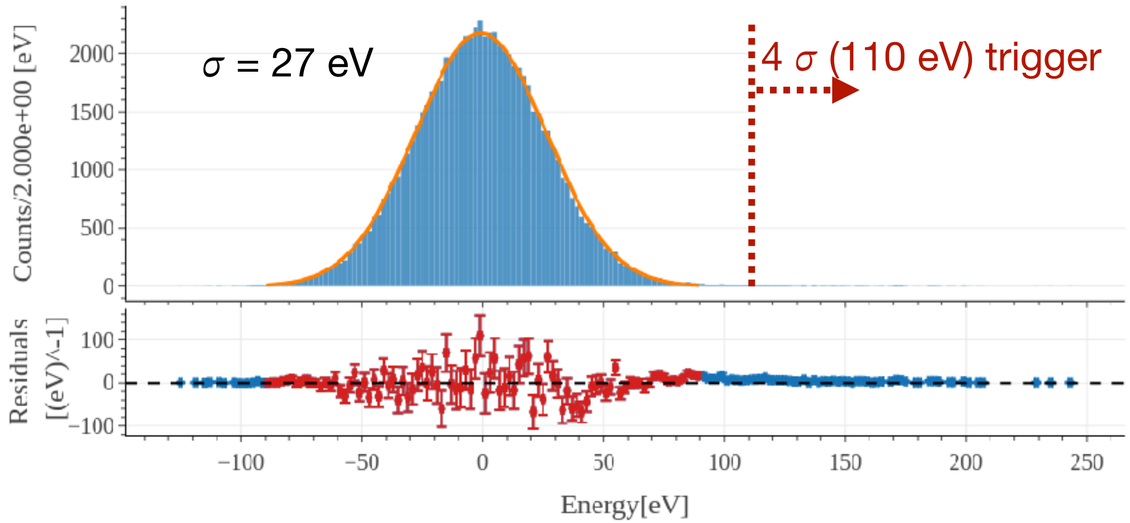
Pulse shape cuts
+ coincident amplitude cut on 8 neighbours



Study of the energy threshold

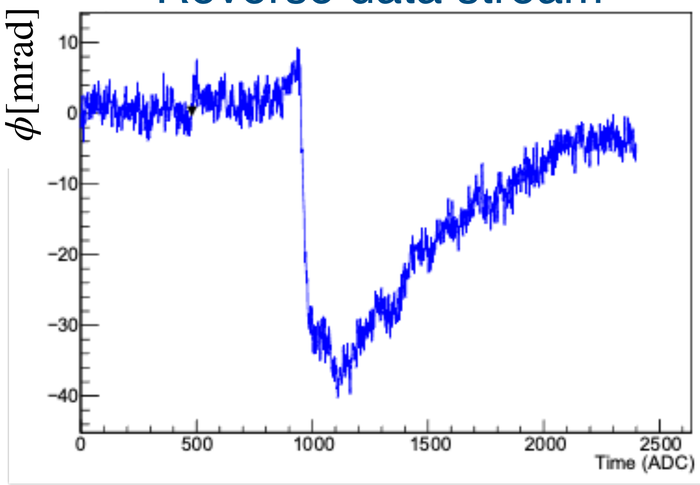
Energy threshold usually set at 5 noise σ

- Reduces the rate of of false triggers
- We choose 4σ for the trigger

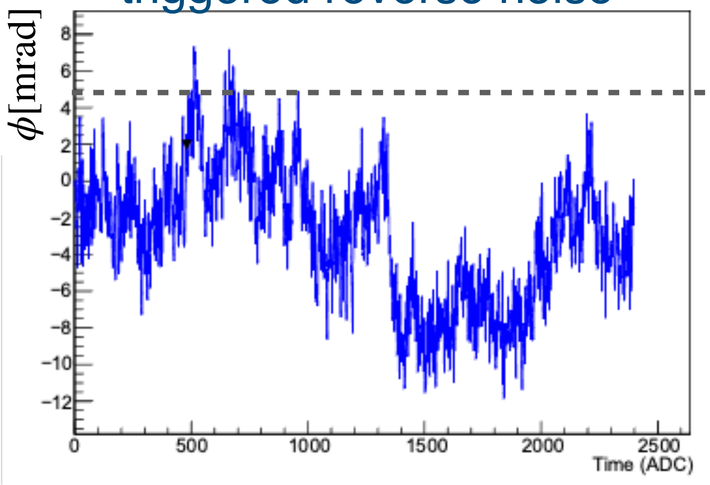


Statistics of false triggers from reverse data stream (minus sign on samples)

Reverse data stream

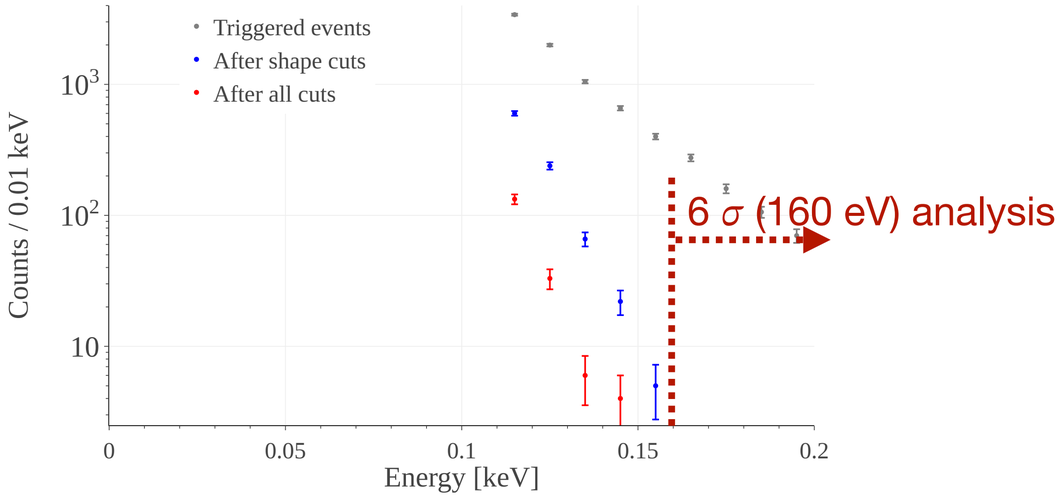


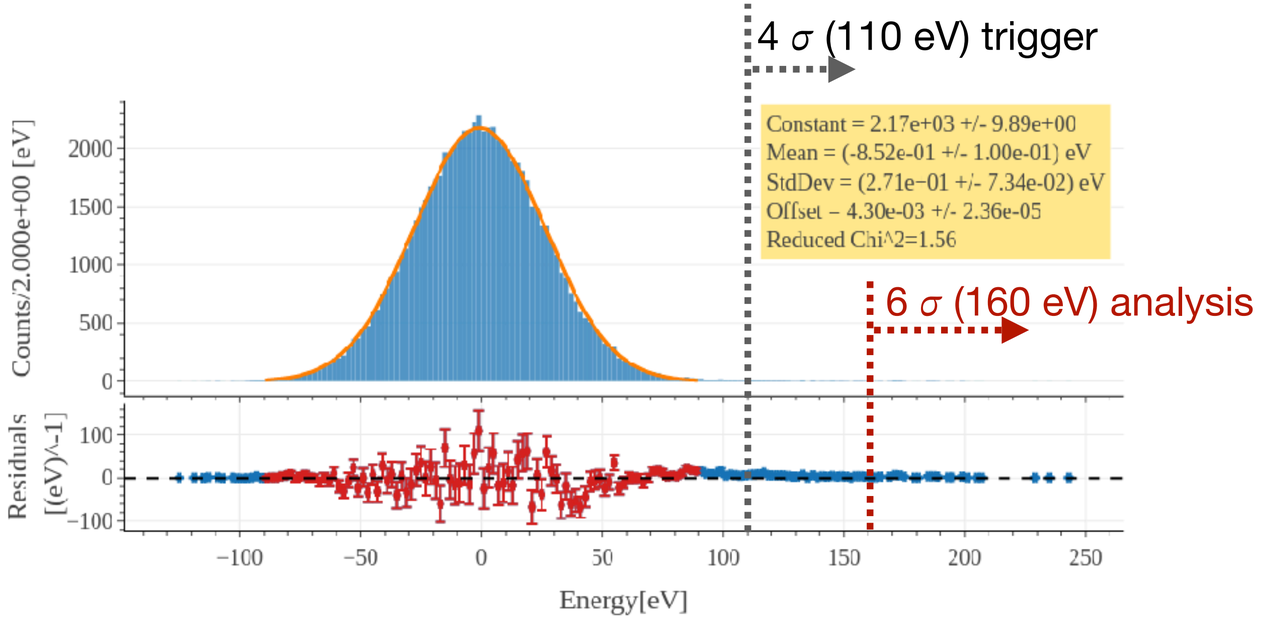
triggered reverse noise



trigger threshold

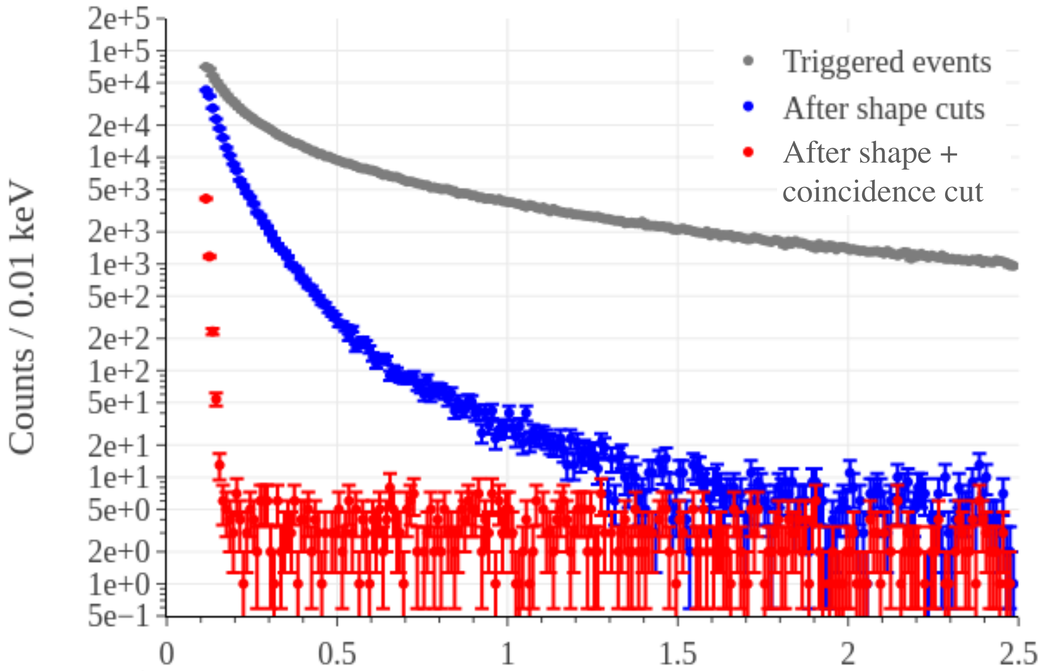
Reverse trigger spectrum (30 mins live time)

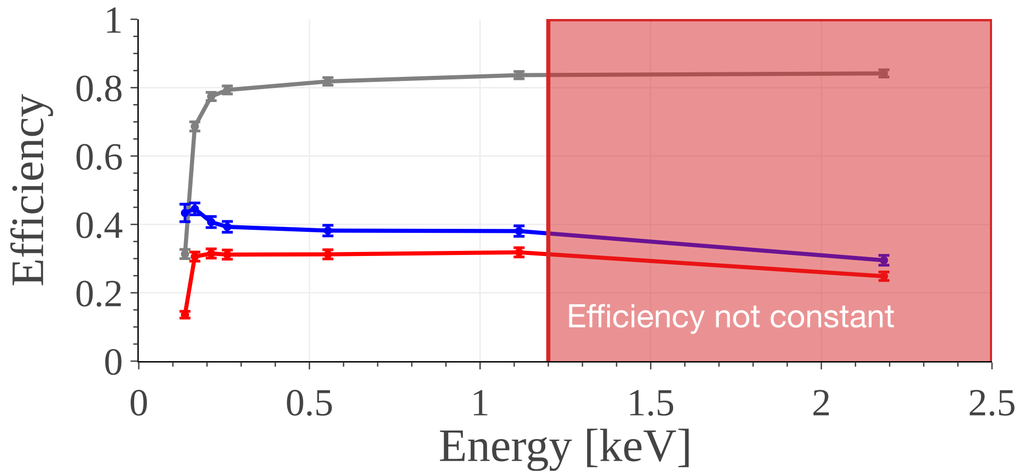




From the spectrum of false positive reverse triggers surviving the cuts
we set the analysis threshold to 6σ

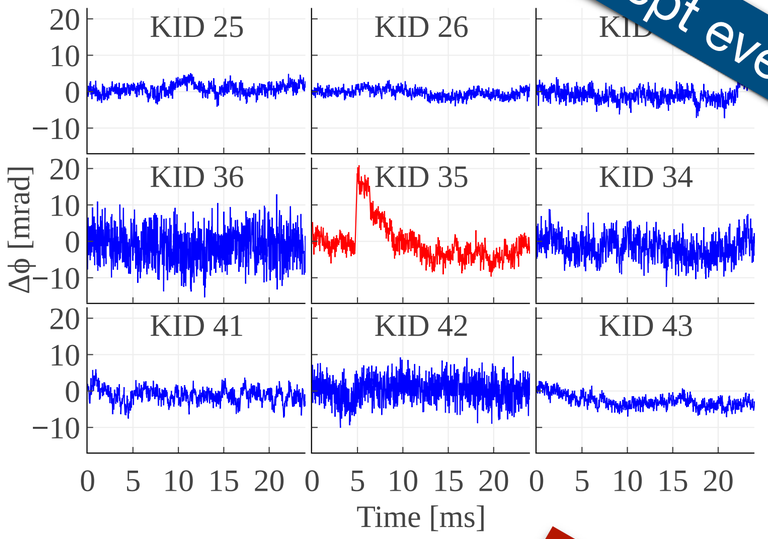
Background: shape + coincidence cut



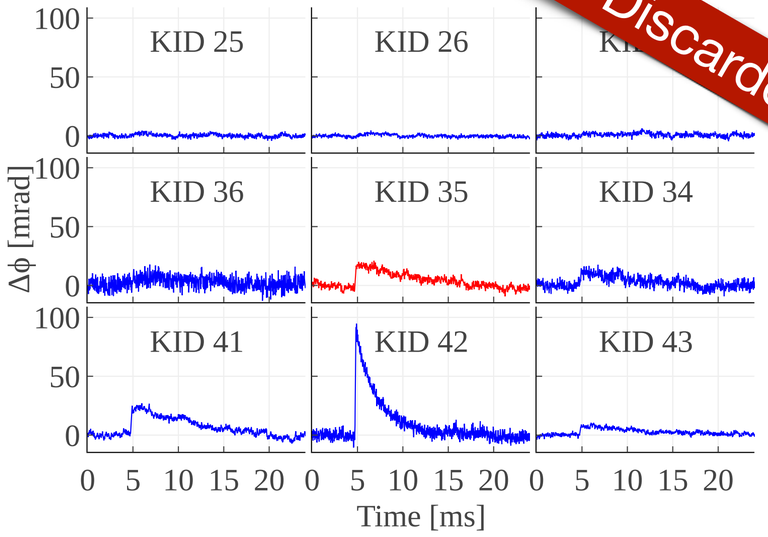


Trigger only
Cuts only
Cuts + trigger

✓ Kept event

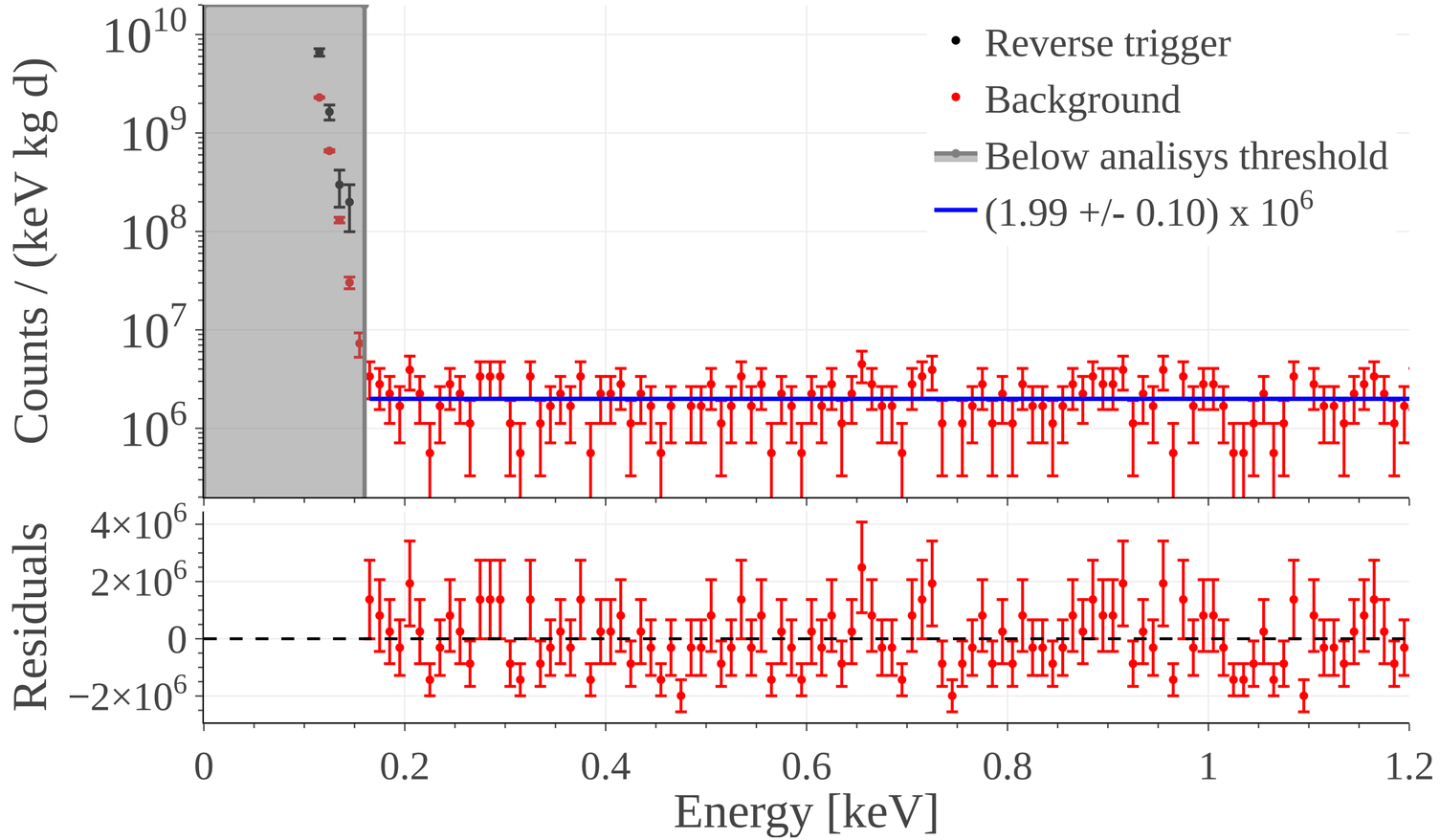


✓ Discarded



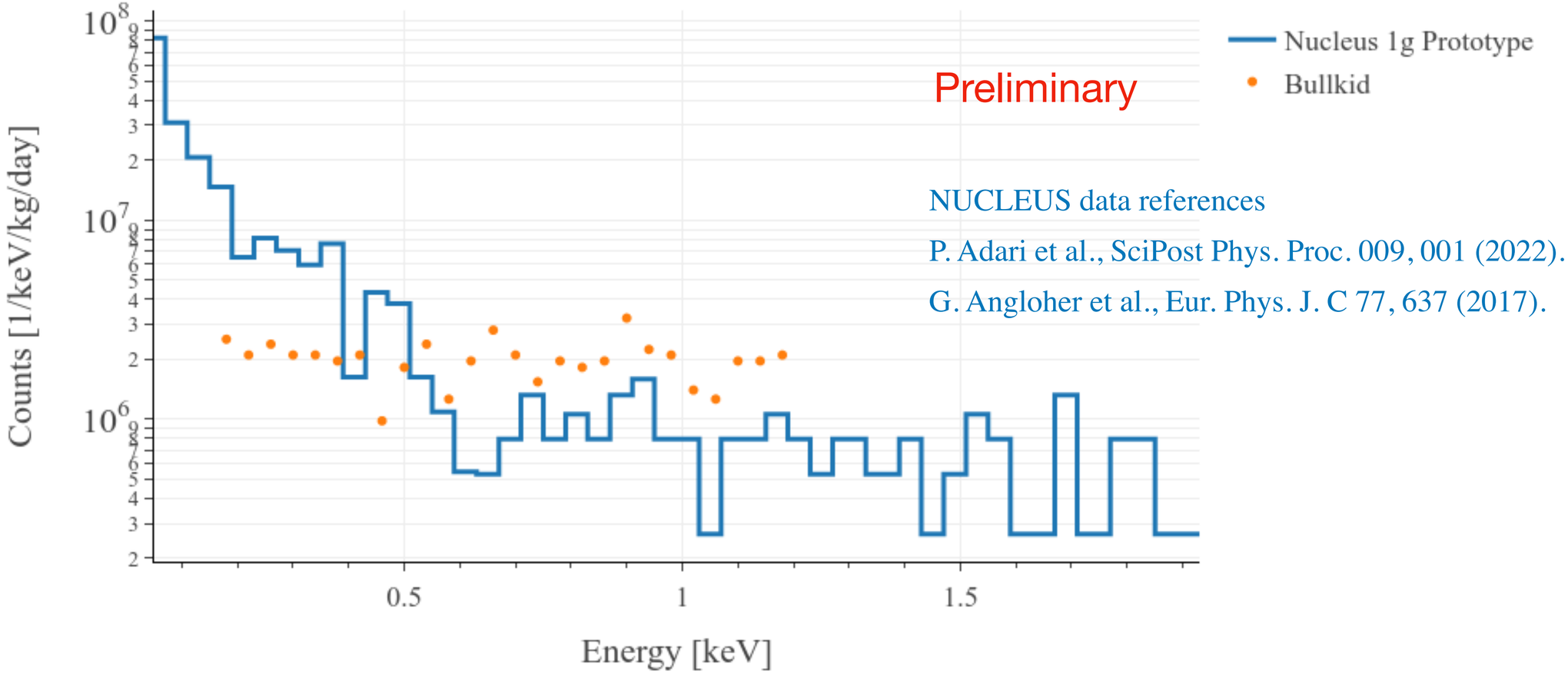
Background: result

Above ground lab, no shield, 39 live hours



The excess above trigger threshold is compatible with false positives (noise).
Background is flat above analysis threshold.

Comparison with NUCLEUS-1g



NUCLEUS data references

P. Adari et al., SciPost Phys. Proc. 009, 001 (2022).

G. Angloher et al., Eur. Phys. J. C 77, 637 (2017).

BULLKID: the team

Sapienza University & INFN Rome

A. Ahmad, ***A. Cruciani,*** *M. del Gallo Roccagiovine, D. Delicato, G. Del Castello, M. Giammei, D. Maiello, V. Pettinacci,* ***M. Vignati;***

University & INFN Ferrara

L. Bandiera, V. Guidi, ***A. Mazzolari,*** *M. Romagnoni, M. Tamisari;*

Institut Néel - CNRS

M. Calvo, D. Delicato, ***A. Monfardini;***

BULLKID

funded by the INFN and by Sapienza U.