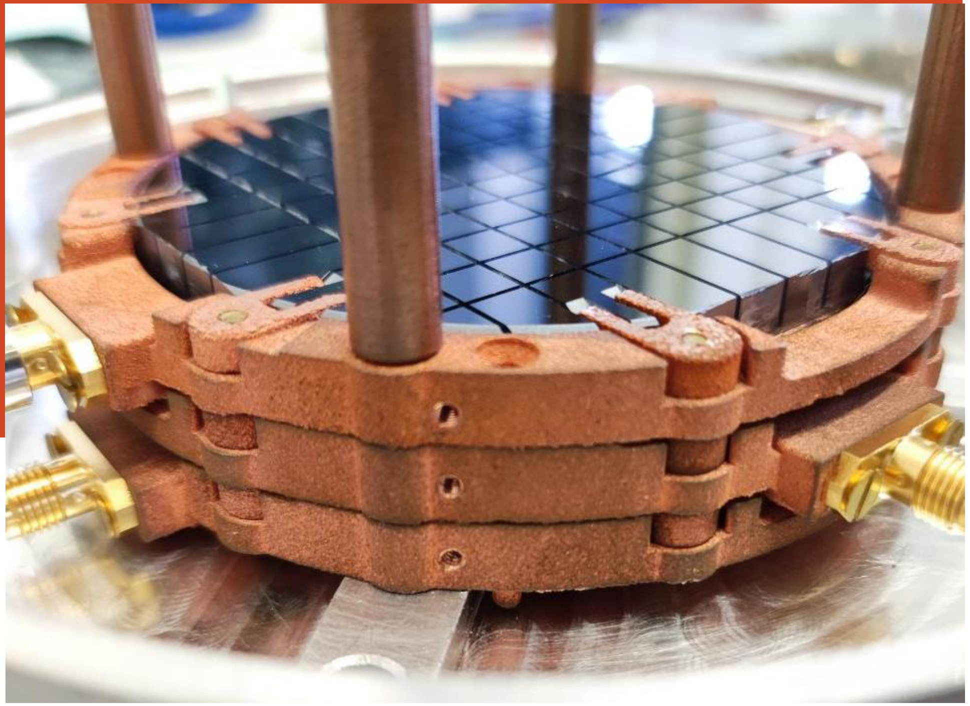
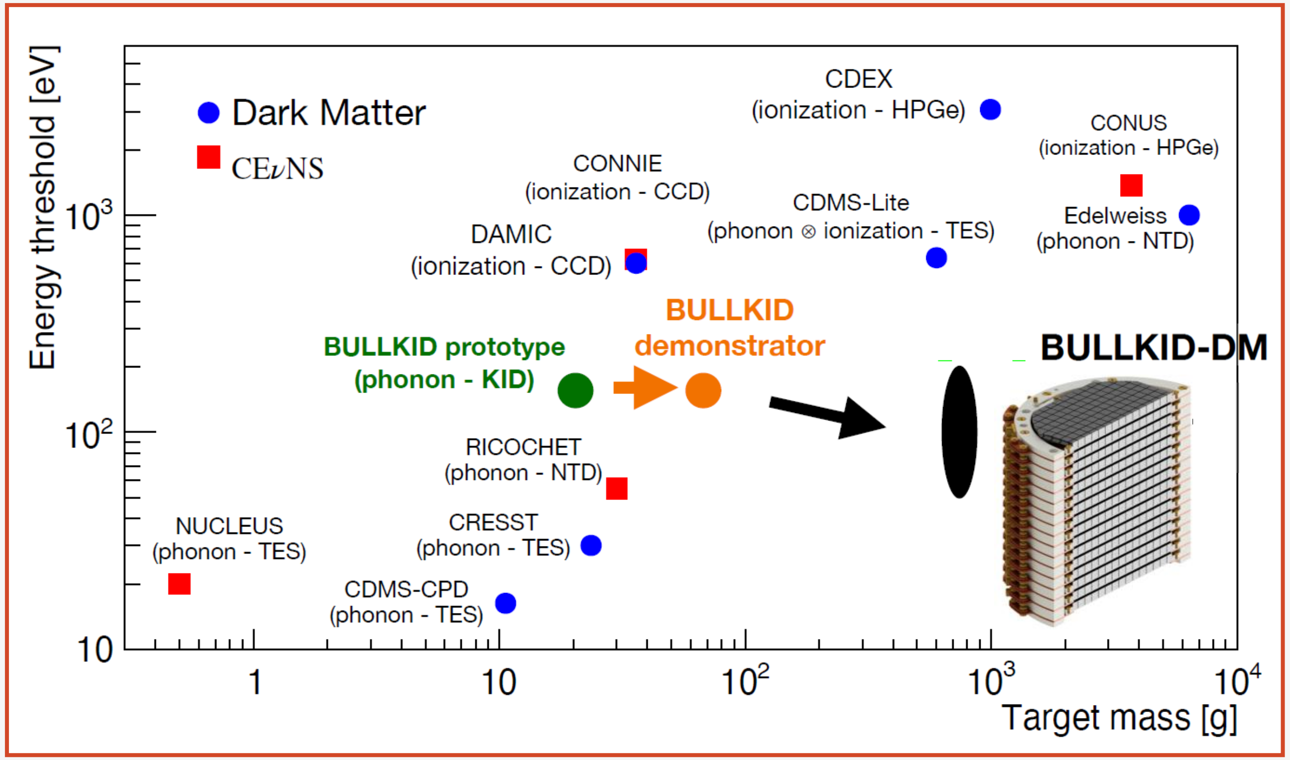
Surface background with mild shield: an update from the demonstrator

01/07/2025 – BULLKID-DM Meeting – Ferrara

Daniele Delicato on behalf of the collaboration

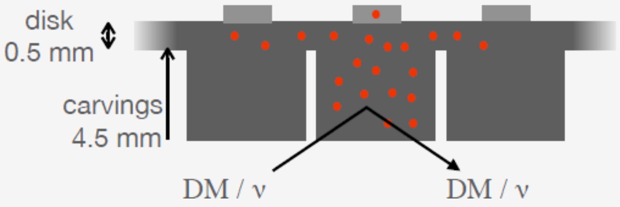


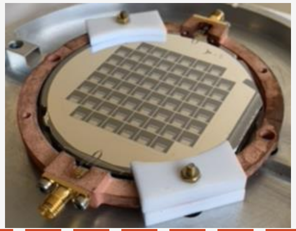
Status of the BULLKID 3″ demonstrator



Threshold (ongoing R&Ds):

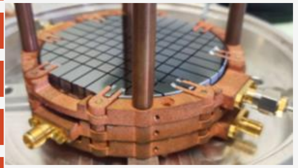
1. Replace Al with Al-Ti-Al KIDs: 5x inductance
2. Deeper carvings for higher phonon focussing





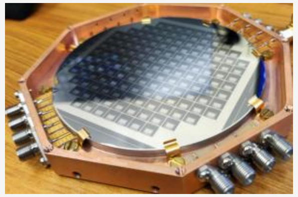
Prototype - 20 g / 60 dice

single 3″ wafer
concluded in 2023



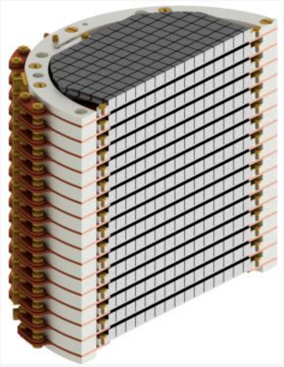
Demonstrator - 60 g / 180 dice

3-layer stack of 3″ wafers
operations ongoing



R&D on large wafer 50 g / 145 dice

single 100 mm wafer first operations fall 2024



BULLKID-DM - 800 g / 2300 dice

16-layer stack of 100 mm wafers
commissioning in 2026 at Sapienza U.
Fiducial mass: 600g

Status of the BULLKID 3″ demonstrator*

***as of, 16/01/25**

- **Thermalization** of the wafers via the copper structure
- **Electrical coupling** not compromised by proximity among wafers
- **Energy threshold** on par with earlier prototypes
- **Scale readout and analysis** to simultaneously measure multiple wafers
- **Background** in a shielded environment **flat and lower than 10^5 dru**

From the CDR:

For the time being we plan to repeat the measurement with a mild lead shield at Sapienza U. before the end of the year (the maximum amount of lead is limited to a few kg by the load that the current cryostat can sustain). This shield is expected to reduce the background by a factor close to 50, below 10^5 DRU.

Flat background $< 10^5$ dru demonstrated

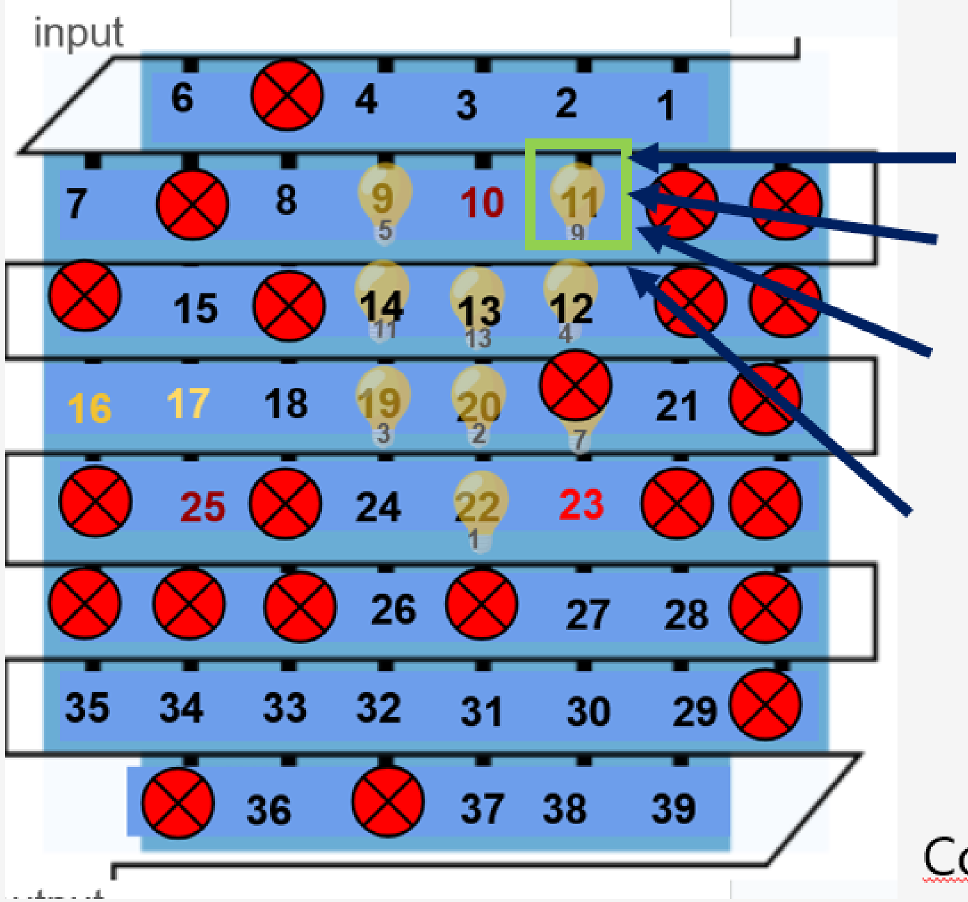
- Above ground
- Passive internal and external Pb shields

To probe background < 650 eV

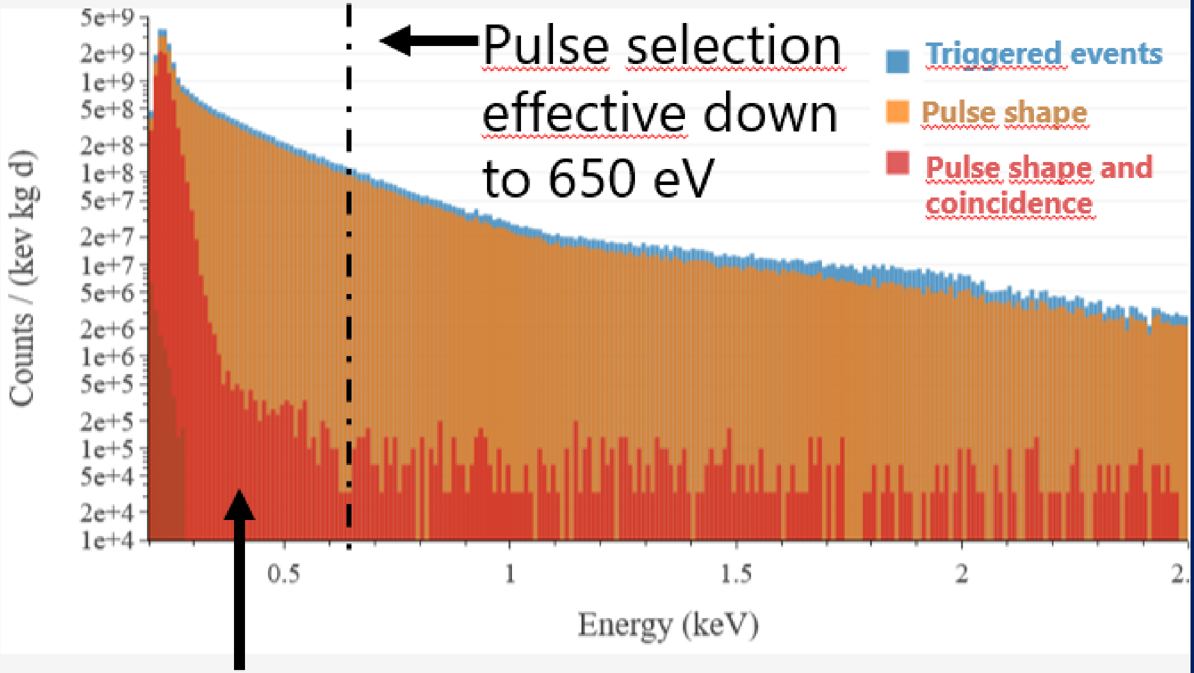
- Lower threshold
- More active pixels
- **Overall better samples are needed**

Status of the BULLKID 3″ demonstrato

STACK-01 RESULTS FROM 01/25



(Many!) missing pixels **do not allow vetoing from some directions**



Counts **not** compatible with noise false positives

20

factor

ted

elds

needed

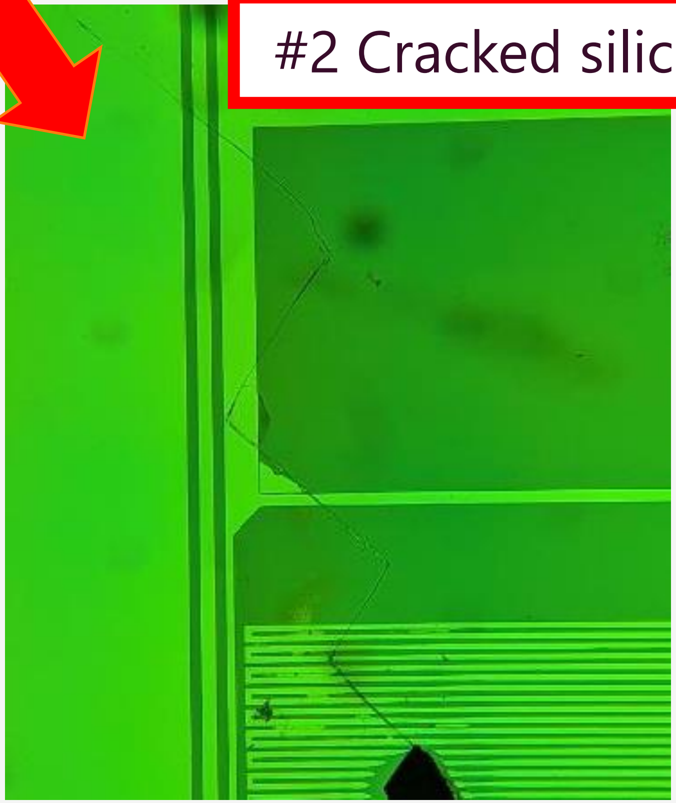
Conclusions last meeting: produce more uniform arrays

Fabrication in **Grenoble** 10/02 – 21/02

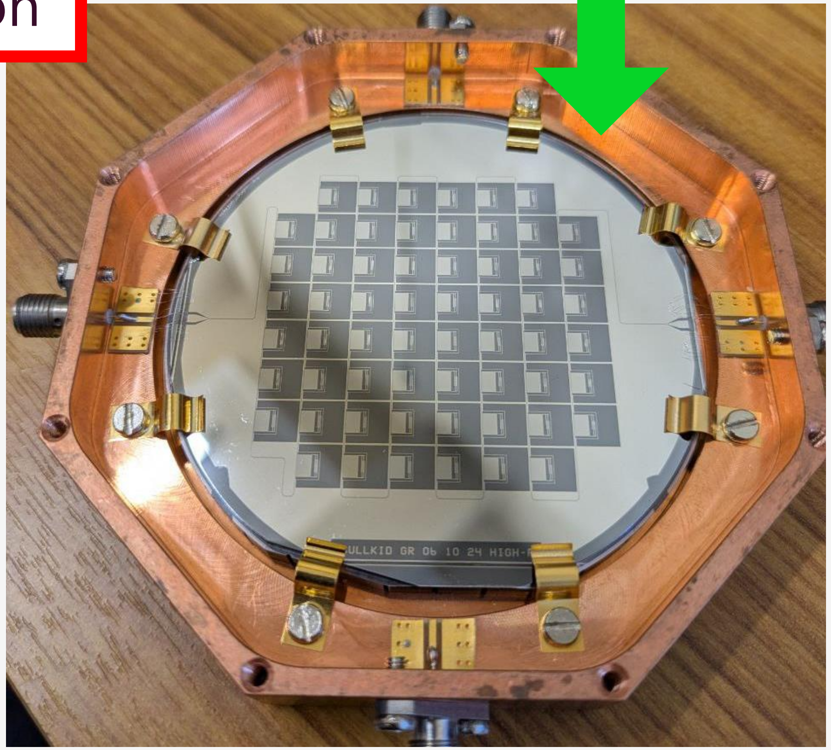
- **3 wafers delivered from Ferrara**

#1 Scratched surface

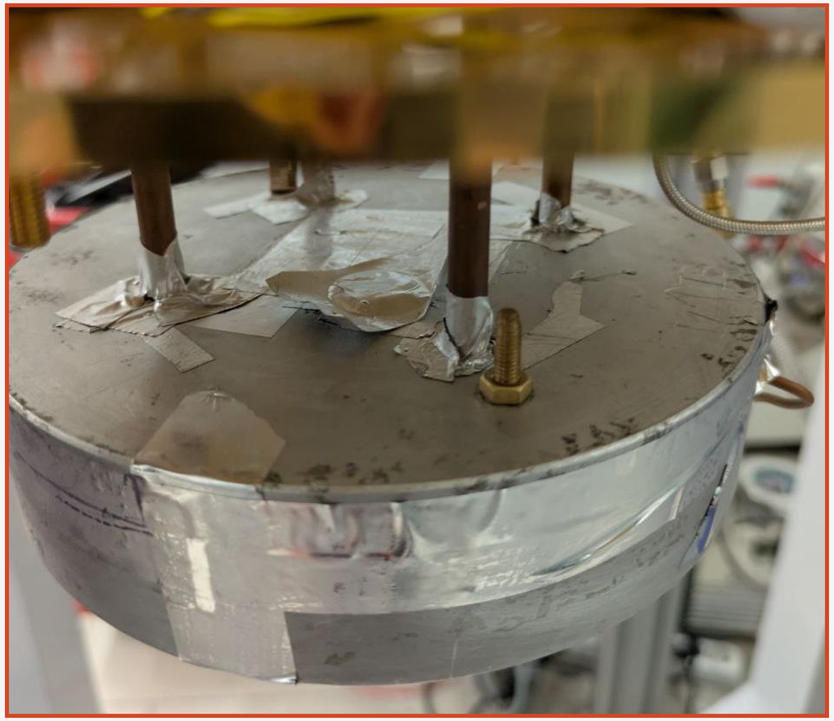
#2 Cracked silicon



#3 lithography successful



Fabrication status of additional stack elements: STACK-04



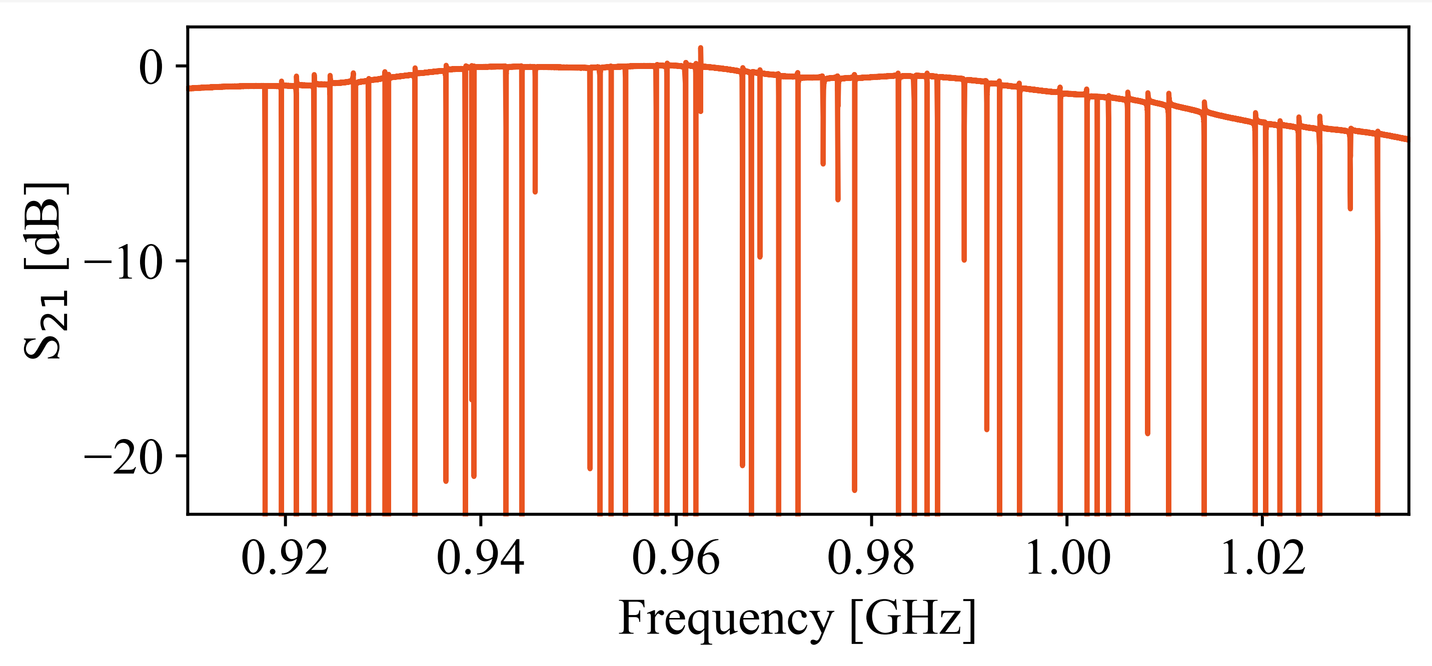
Stack-04: 60nm Al

57 working pixels out of 60

Quality factor (median): 120k

Coupling Q factor (median): 130k

Bonding across the line removed artifacts



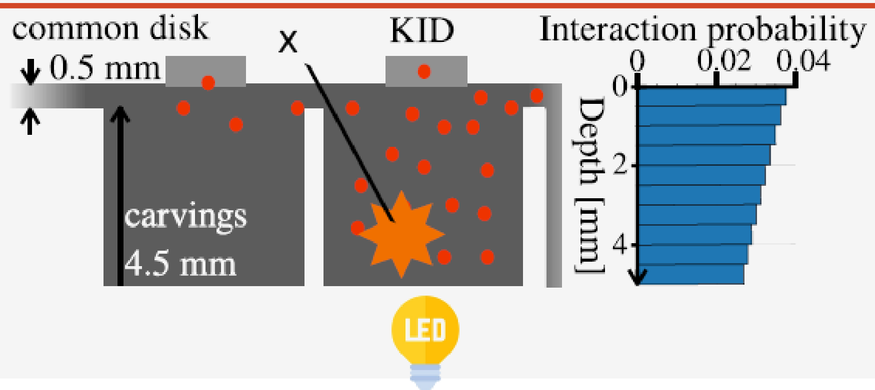
Preliminary test in ROME + bondings

P165 @ 30mK; Qi > 5M

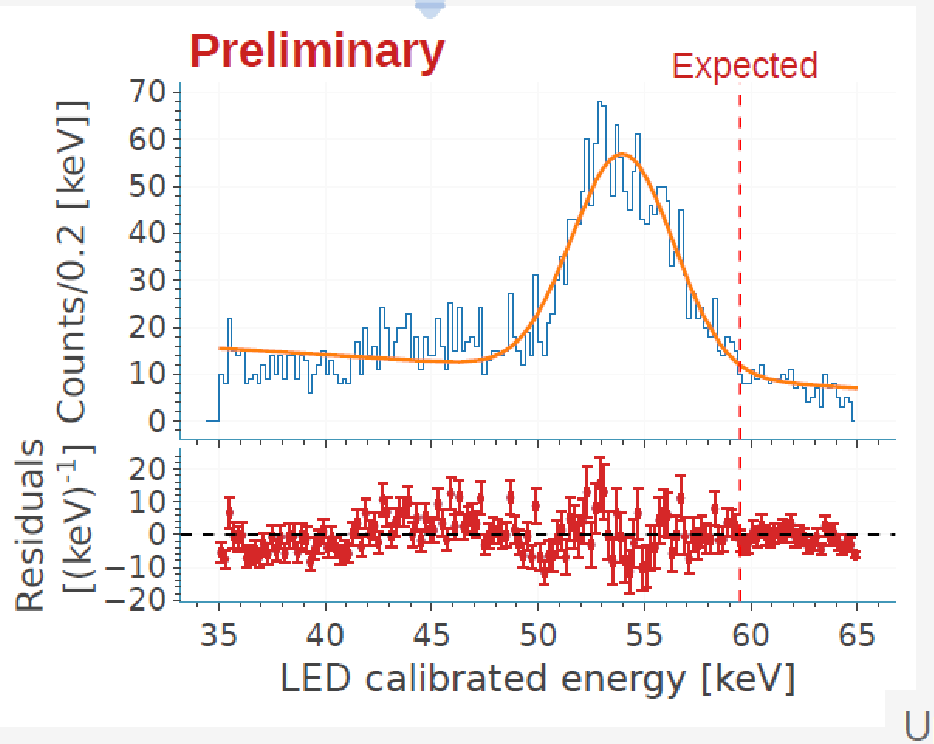
Single wafer configuration

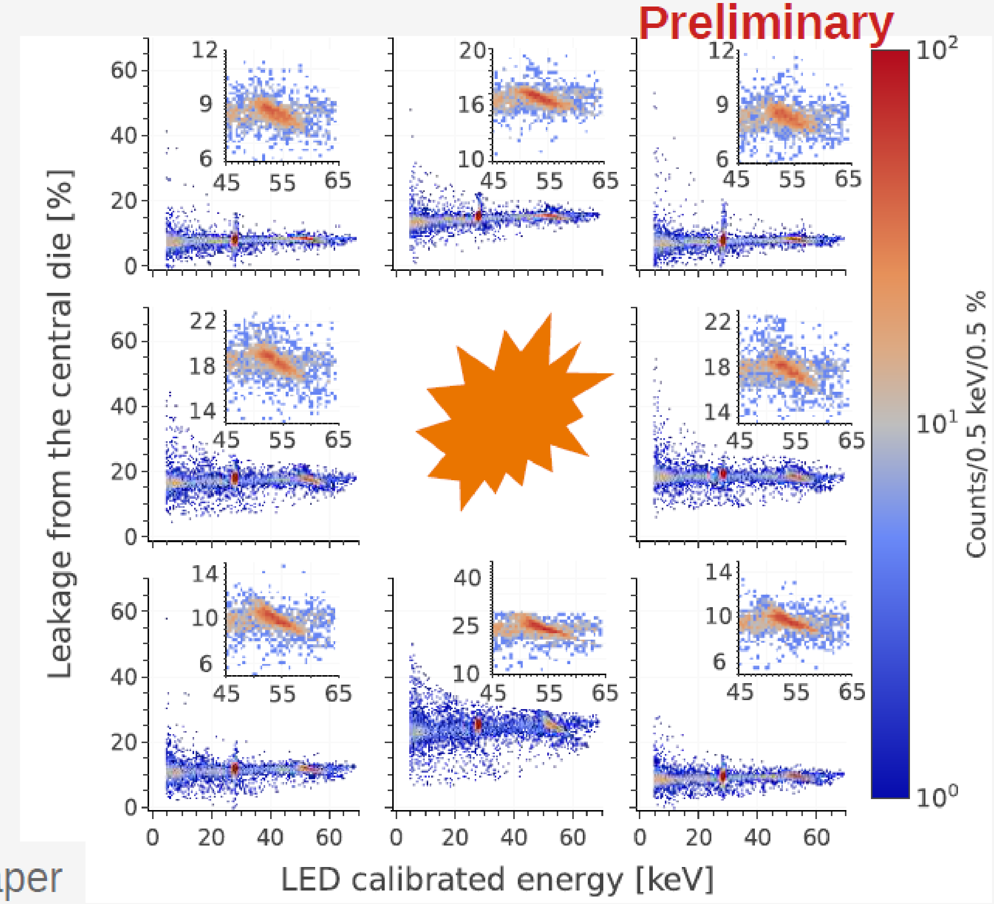
Bulk (Am) vs Surface (LED) events

See talk by M. Folcarelli



- Dedicated cooldown with Am source (59.5 keV X-Ray)
- -10% discrepancy between calibrations
- Same leakage between bulk and LED

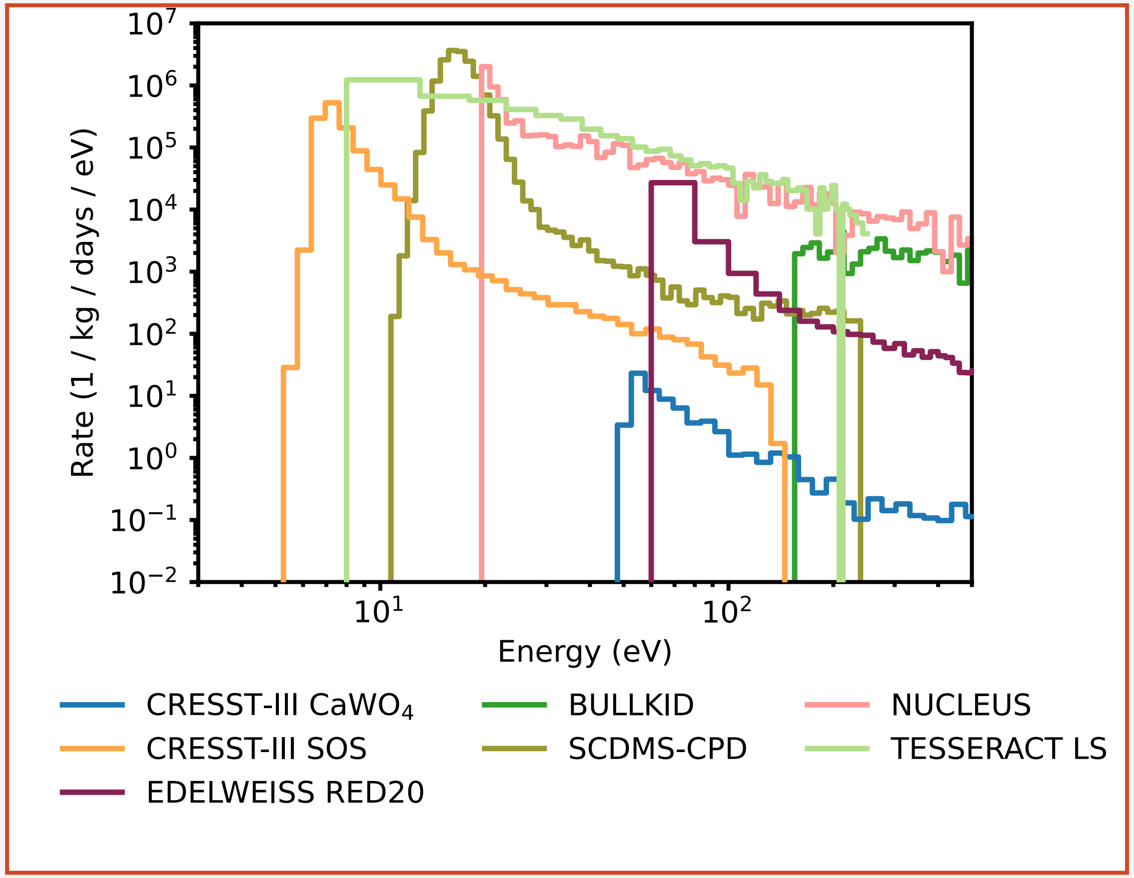




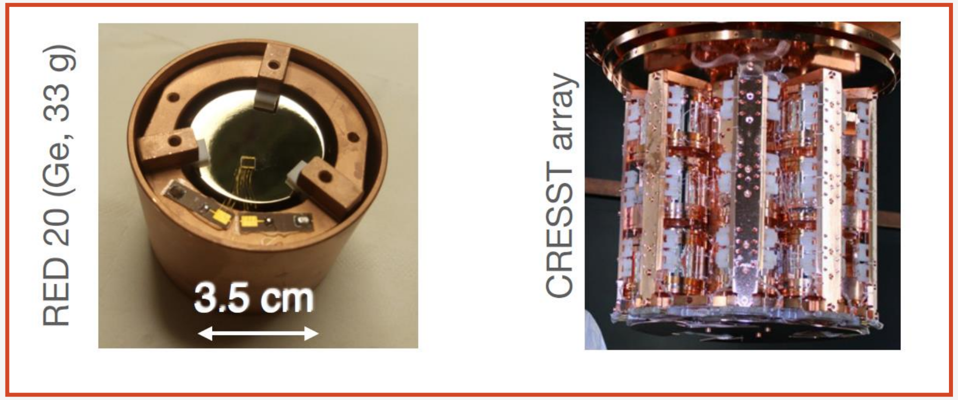
Upcoming Paper

Background issue in low-T experiments

Not understood excess background rising at low energies



- Phonon bursts (crystal-support friction) ?
- Lattice relaxations after cool down?
- Phonon leakage from interactions in the supports?

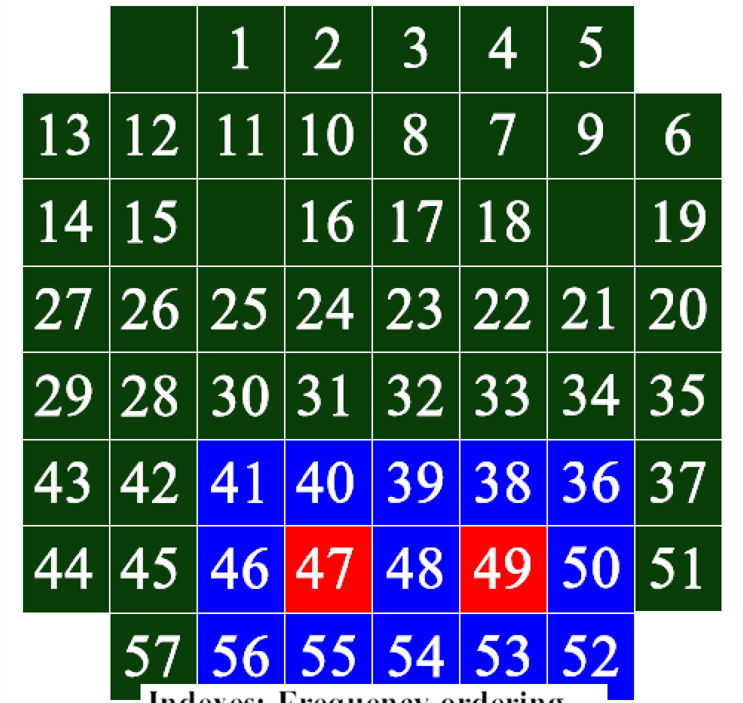


Excess workshop 2025
Santa Fe, 31 May
https://indico.cern.ch/event/1502420/

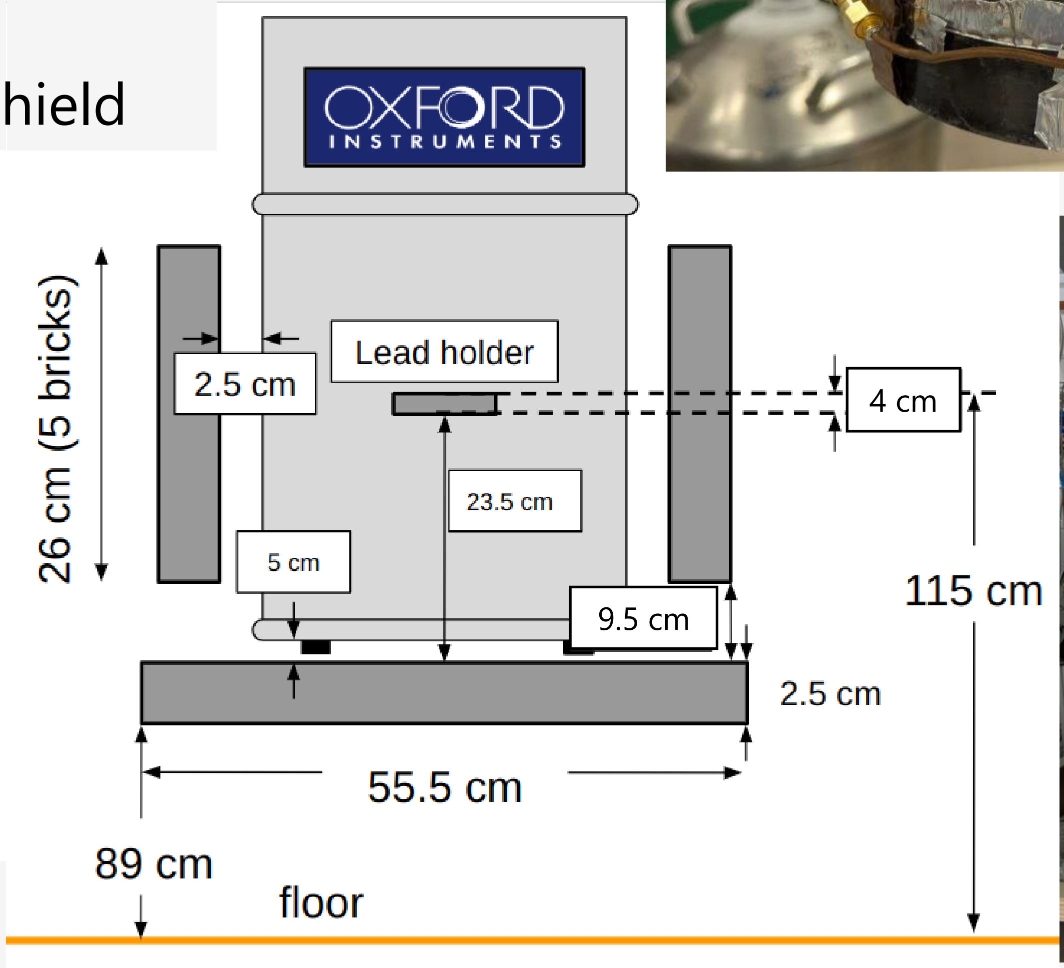
This background limits the sensitivity of present experiments

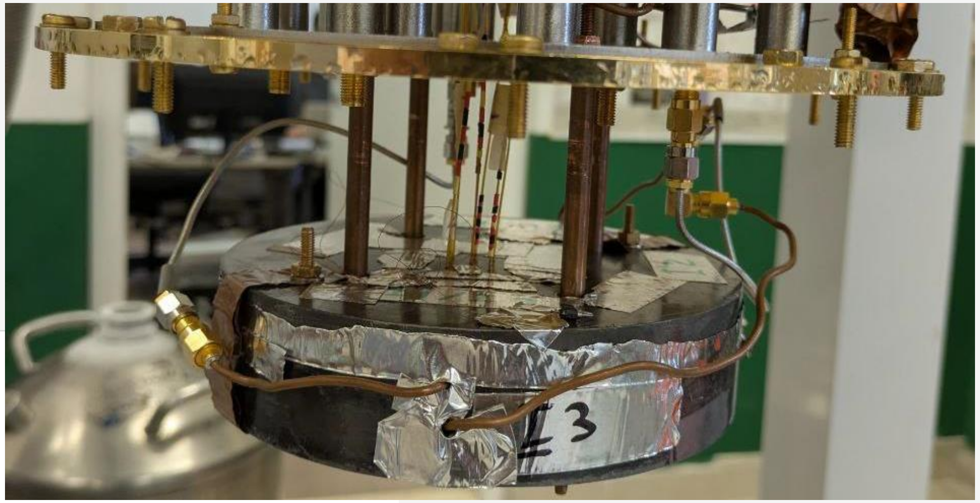
Background with mild shield

15 KIDs in **2 Clusters**
Run time: **19 Apr 22:00 -> 5 May 8:00**
Live hours per cluster: 290
Internal and external lead shield

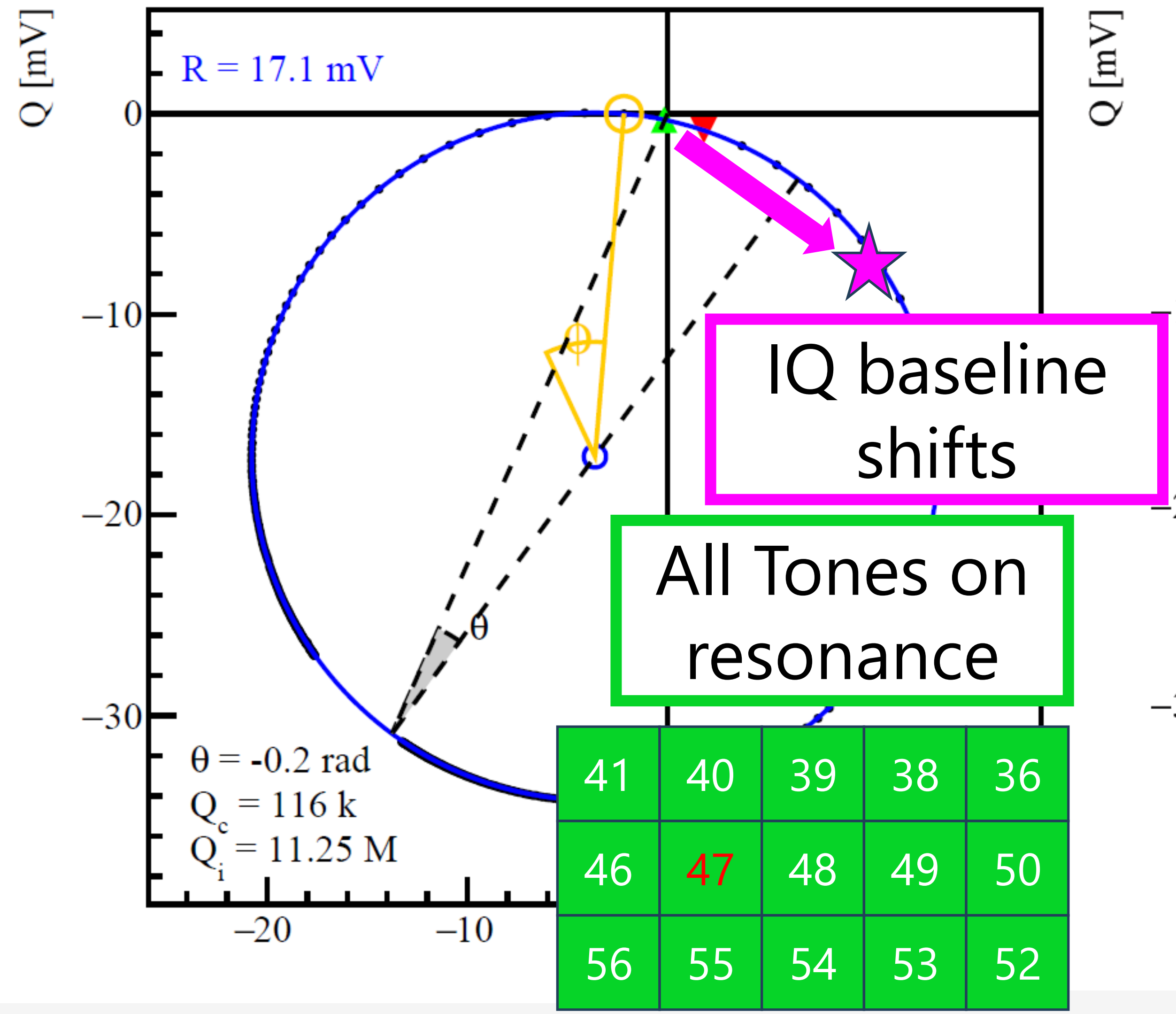


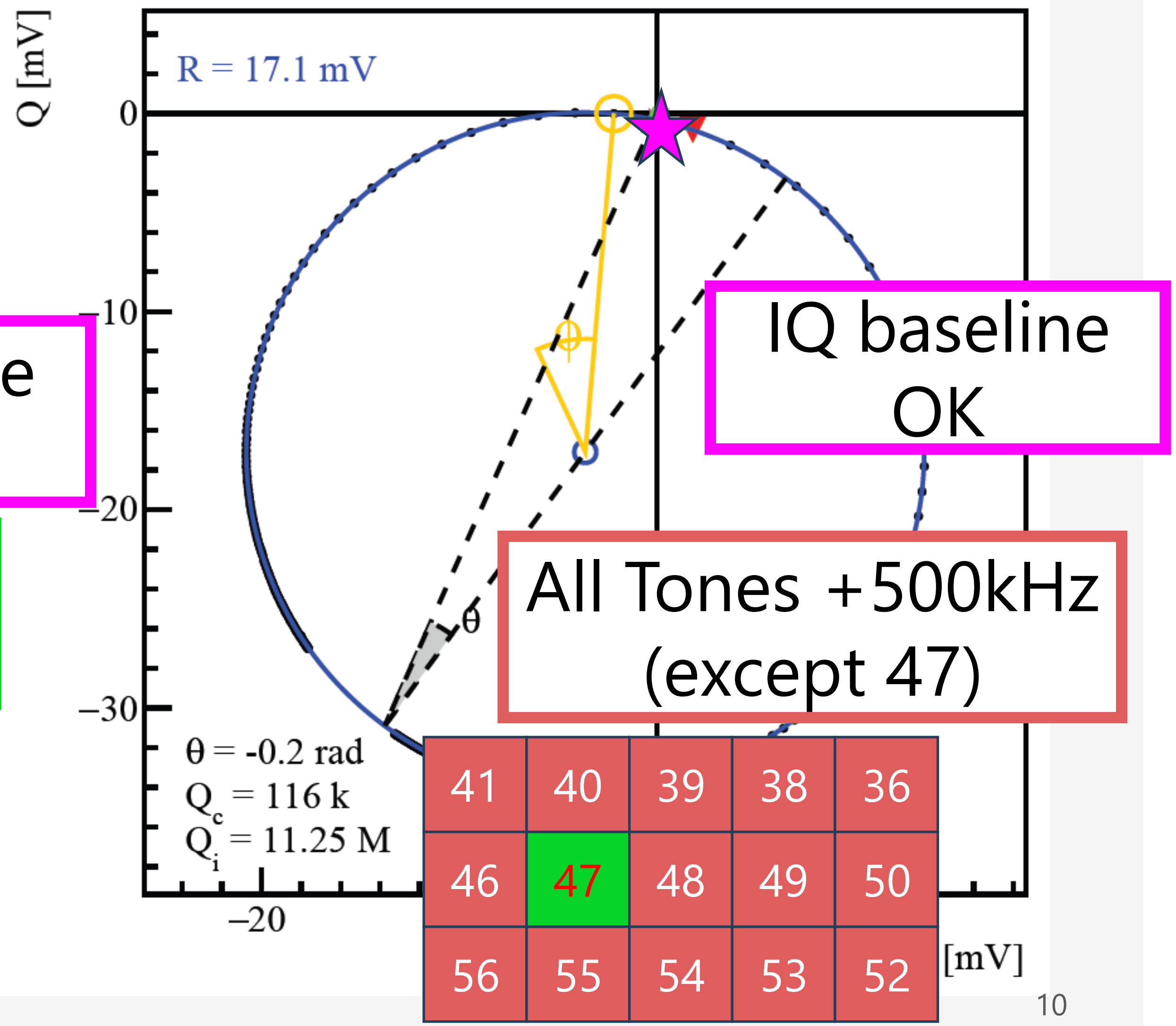
Indexes: Frequency ordering
Triggering
Acquired in coincidence as veto





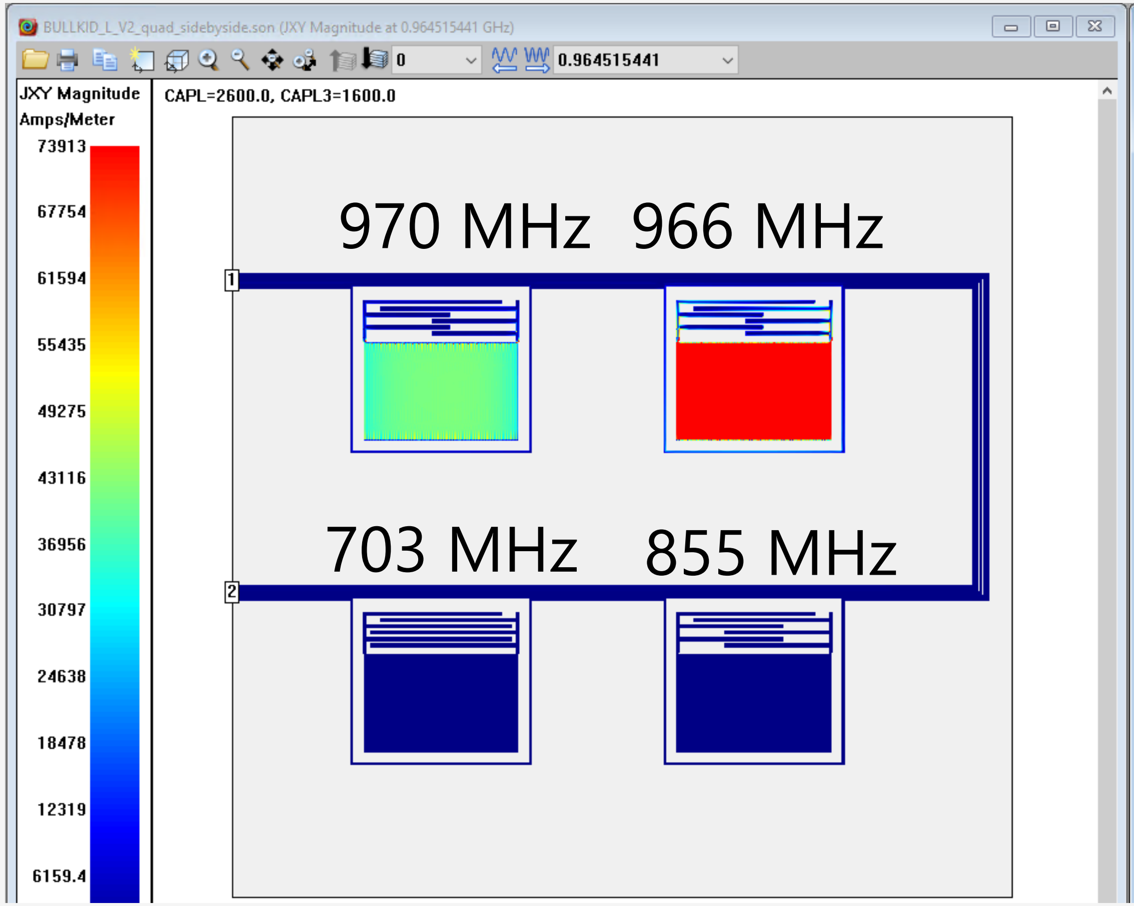
More pixels, more electronic x-talk

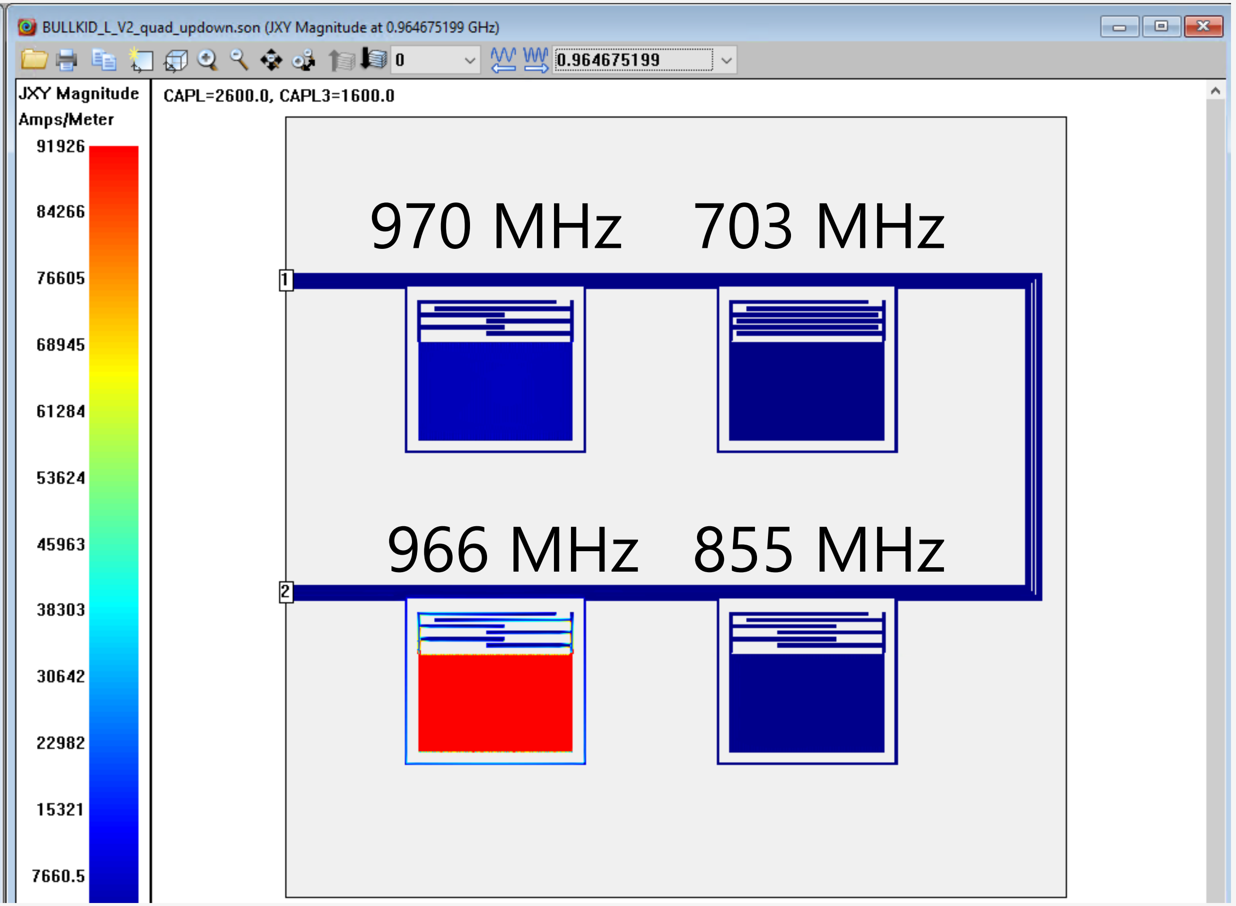




Sonnet simulations of x-talk induced by proximity

See talk by M. Cappelli

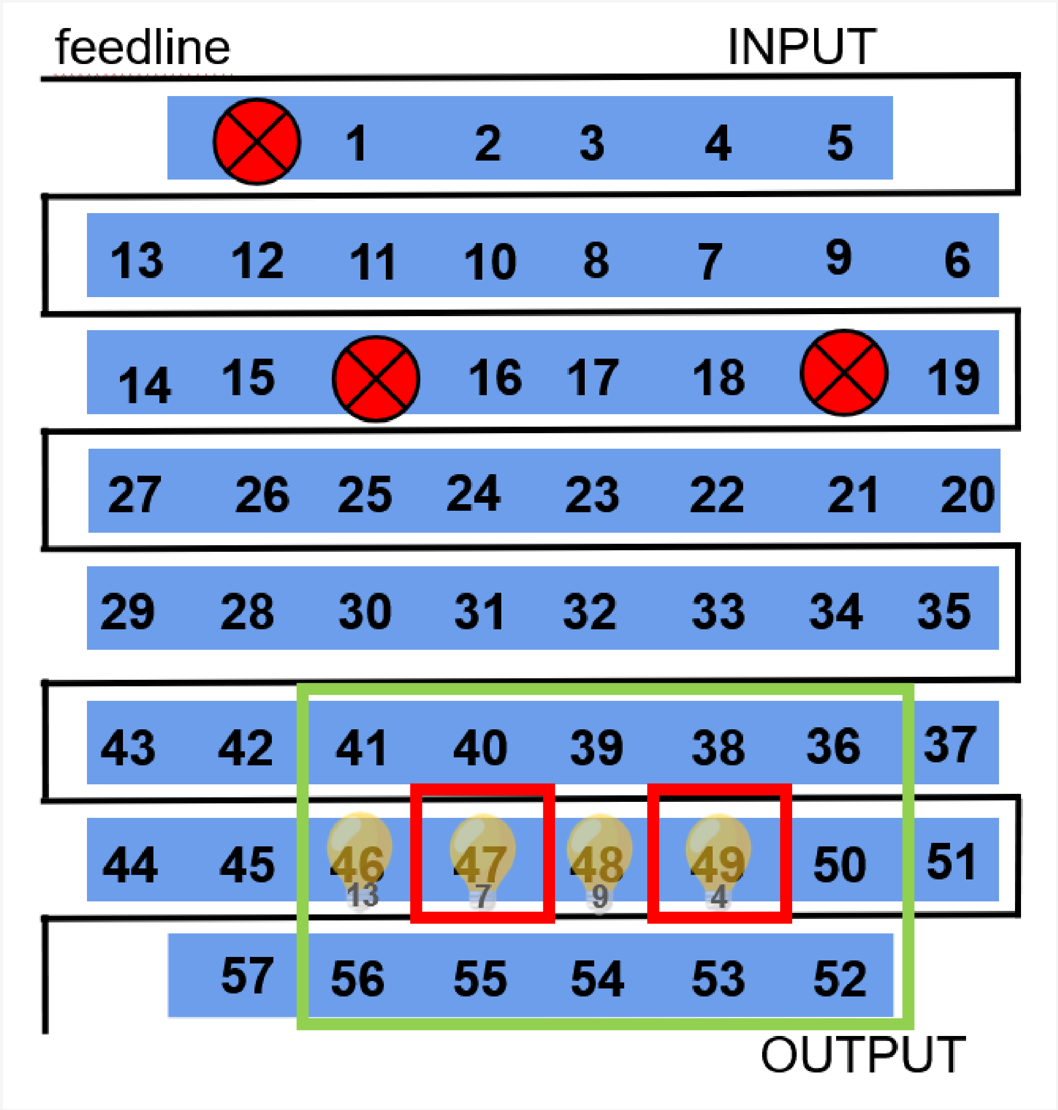




Induced current density: 30%

Induced current density: 3%

More pixels, more possible clusters



F7 --> KID-47 R 10.6 mrad / kev; σ_0 **35 eV**

F4 --> KID-49 R 9.3 mrad / keV; σ_0 **30 eV**

F9 --> KID-48 Distrupted by microwave x-talk

Power distibution:

47 and 49 @ opt power / asym 0.19

38, 40, 46, 50, 53, 55 @ -12 dBm TxPwr

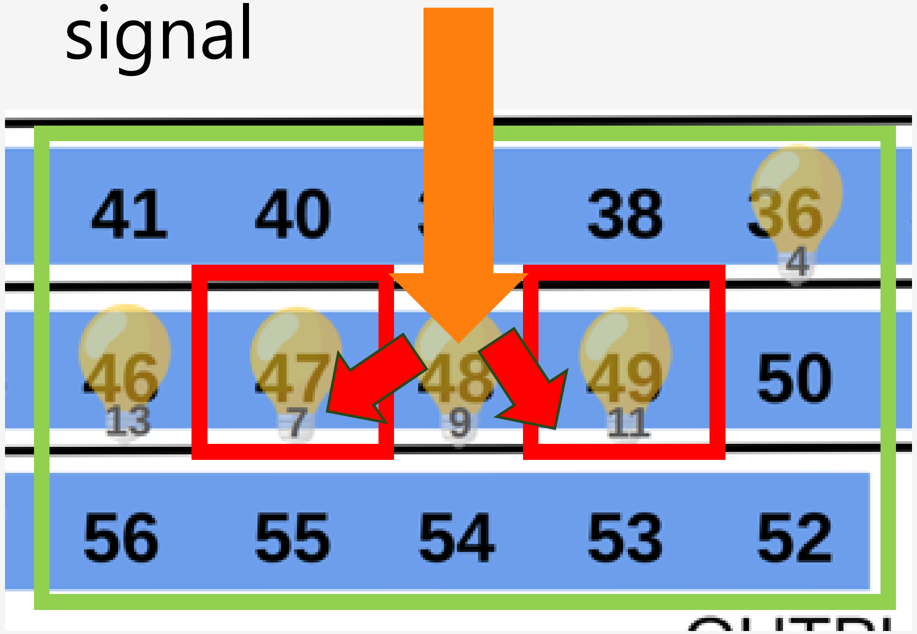
36, 49, 41, 48, 52, 54, 56 @ -16 TxPwr

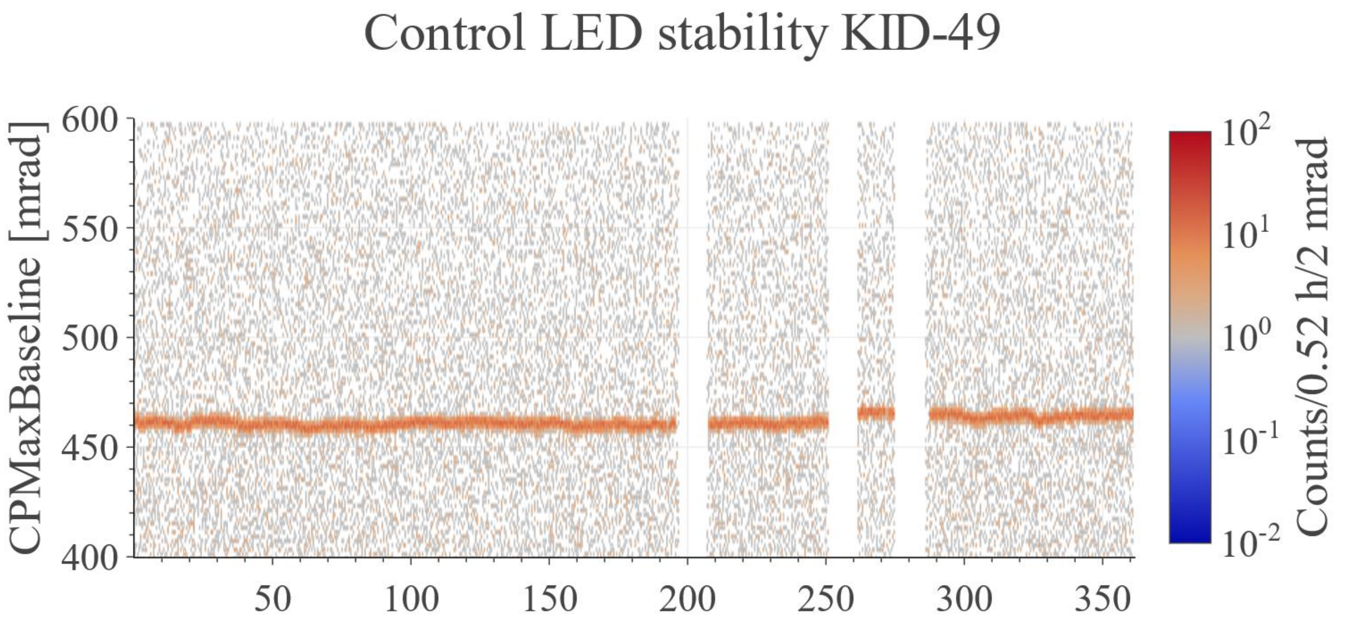
Power limited by amplifier -1dB compression and by KID EM X-talk

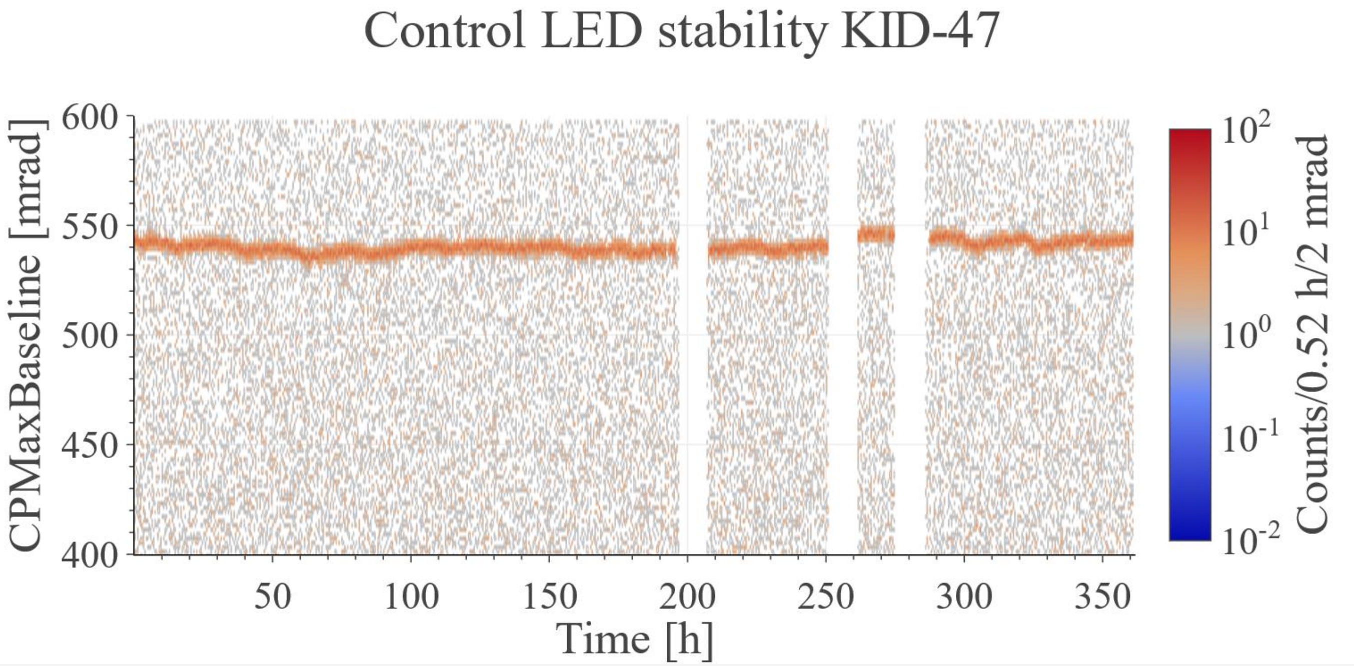
41	40	39	38	36
46	47	48	49	50
56	55	54	53	52

Stability evaluation

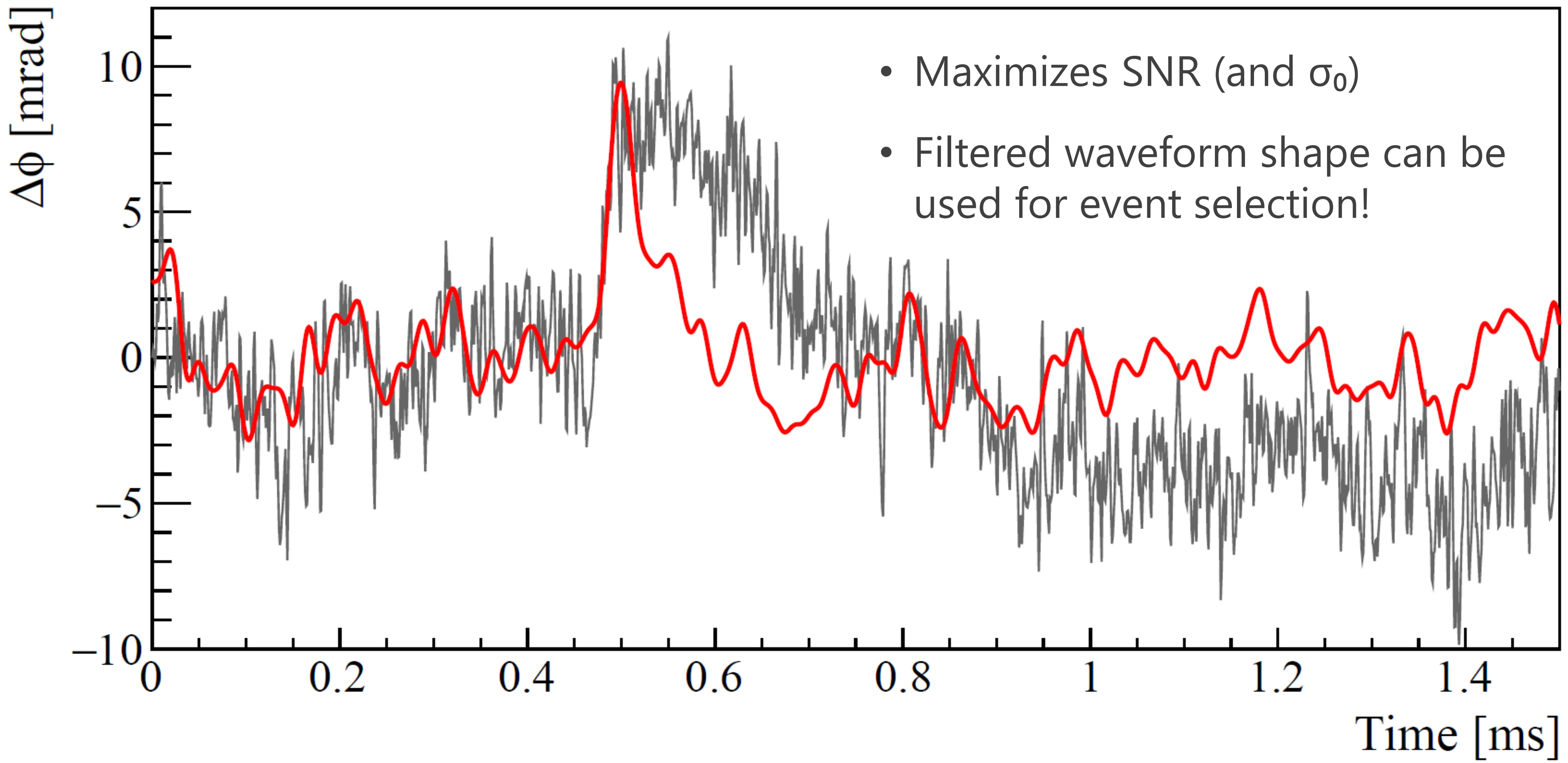
Fire LED on KID-48, evaluate stability of masters with leakage signal







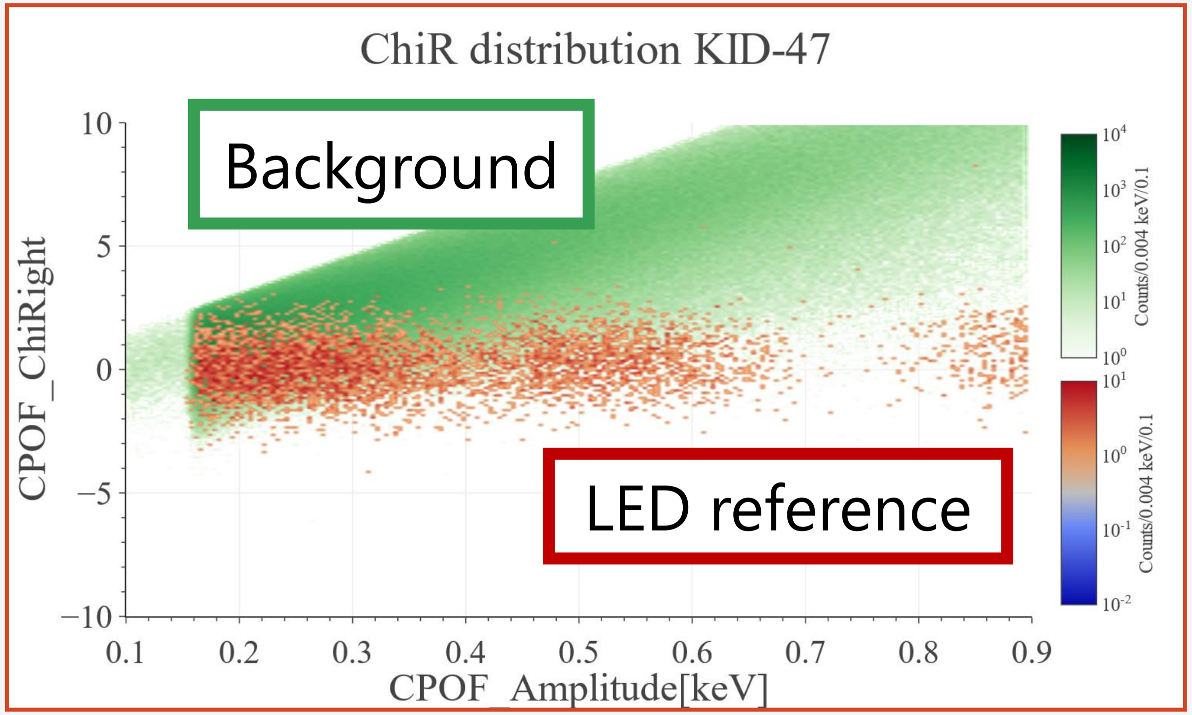
Optimum filter used for energy reconstruction

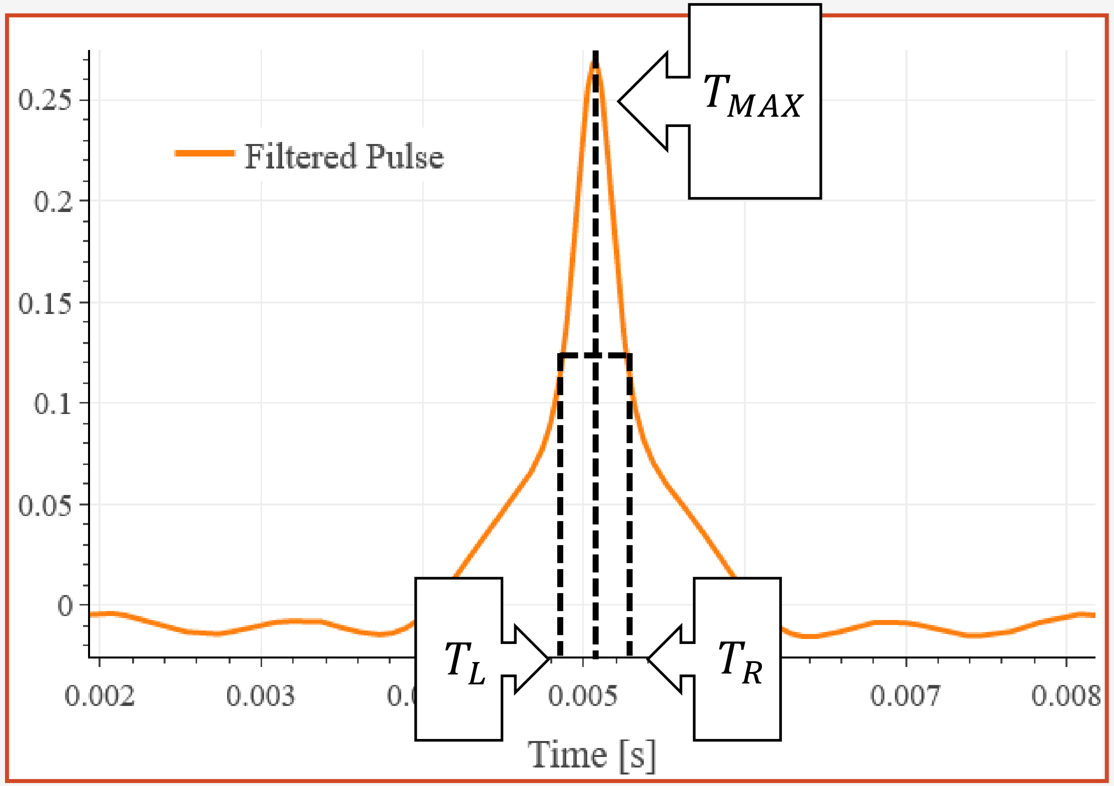


- Maximizes SNR (and σ_0)
- Filtered waveform shape can be used for event selection!

Pulse selection, shape cuts on OF parameters

- Cut **Chi2** (index of deviation from template in the whole window)
- Cut on **ChiLeft** (index of deviation at T_L)
- Cut on **ChiRight** (index of deviation at T_R)

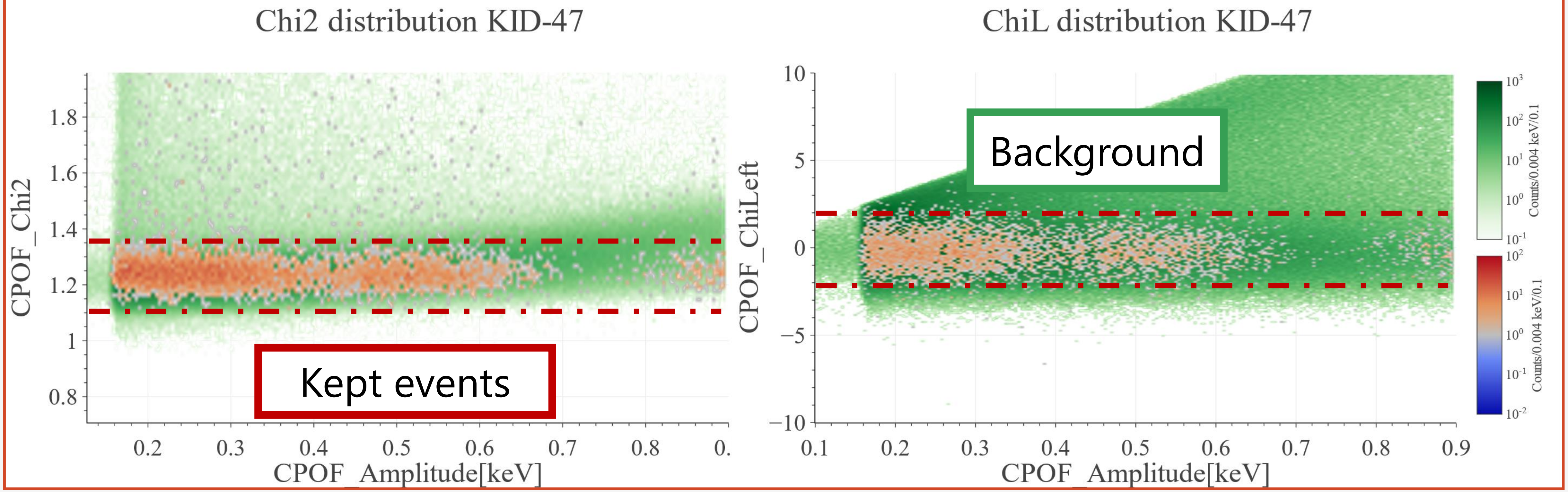




$$\chi^2(t_i) = \frac{\left[A(t_i) - \alpha_i A(t_{\max})\right]^2}{\sigma^2\left(1+\alpha_i^2\right) - 2\alpha_i R(t_i - t_{\max})}$$

Pulse selection, shape cuts

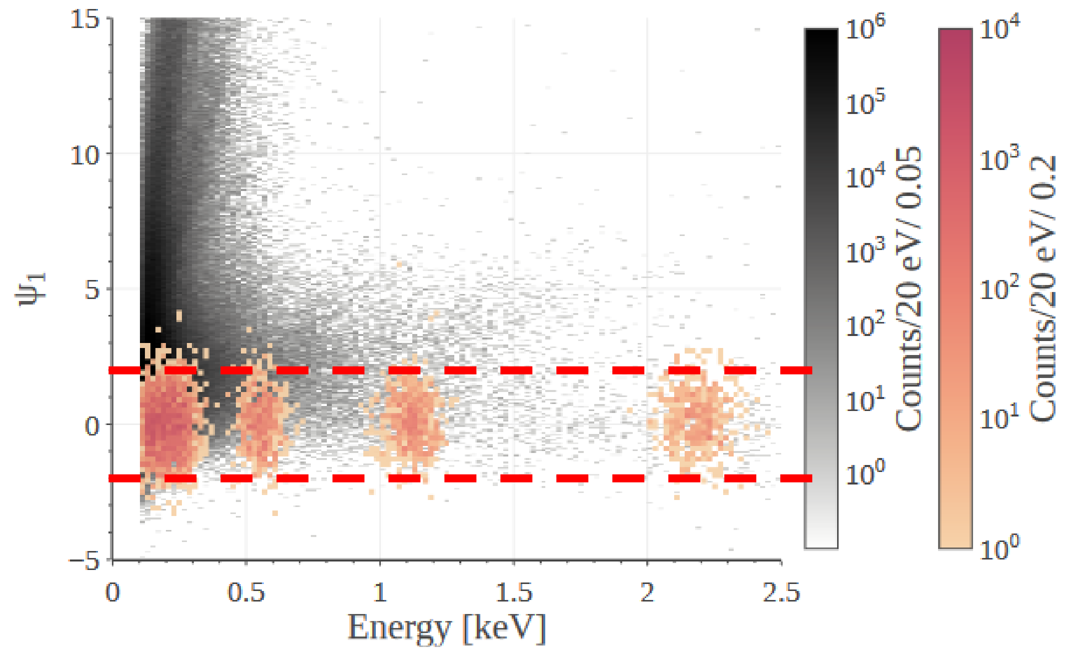
$$\chi^2(t_i) = \frac{\left[A(t_i) - \alpha_i A(t_{\max})\right]^2}{\sigma^2\left(1+\alpha_i^2\right) - 2\alpha_i R(t_i - t_{\max})}$$



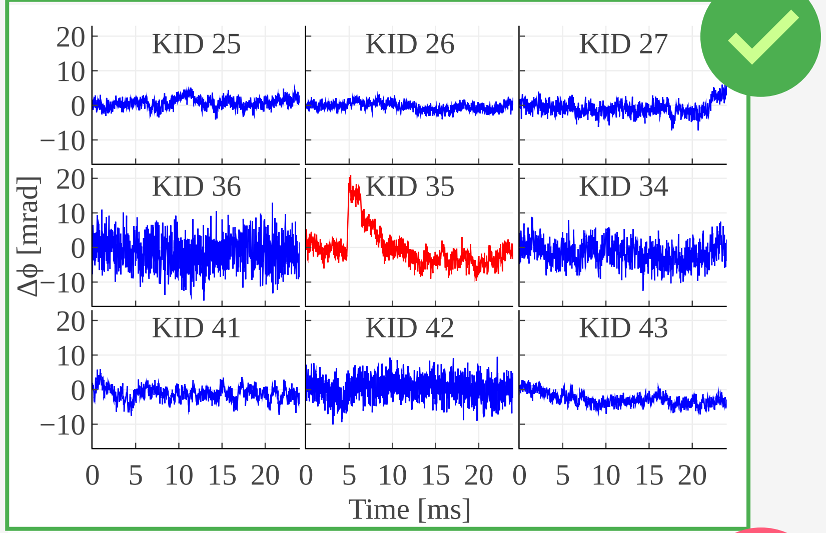
Chi2 ∈ [1.1 , 1.38]

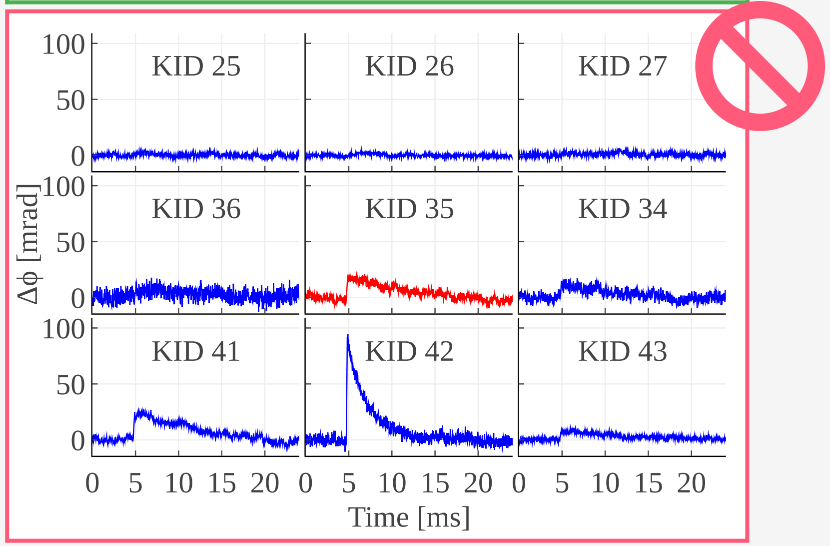
ChiL ∈ [−2 , 2]

Evaluation of cluster cuts

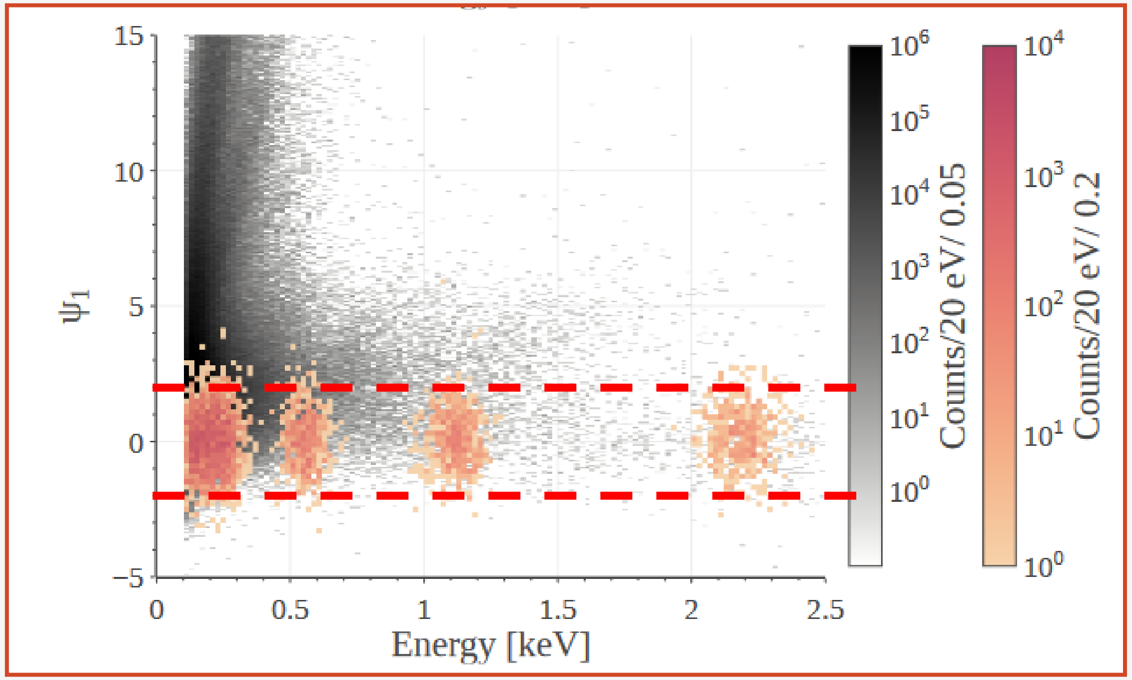


$$\psi_i = \frac{\delta\phi_i - (\delta\phi_c \cdot \mu_{r_i})}{\sqrt{\sigma_{0,i}^2 + (\sigma_{0,c} \cdot \mu_{r_i})^2}}.$$



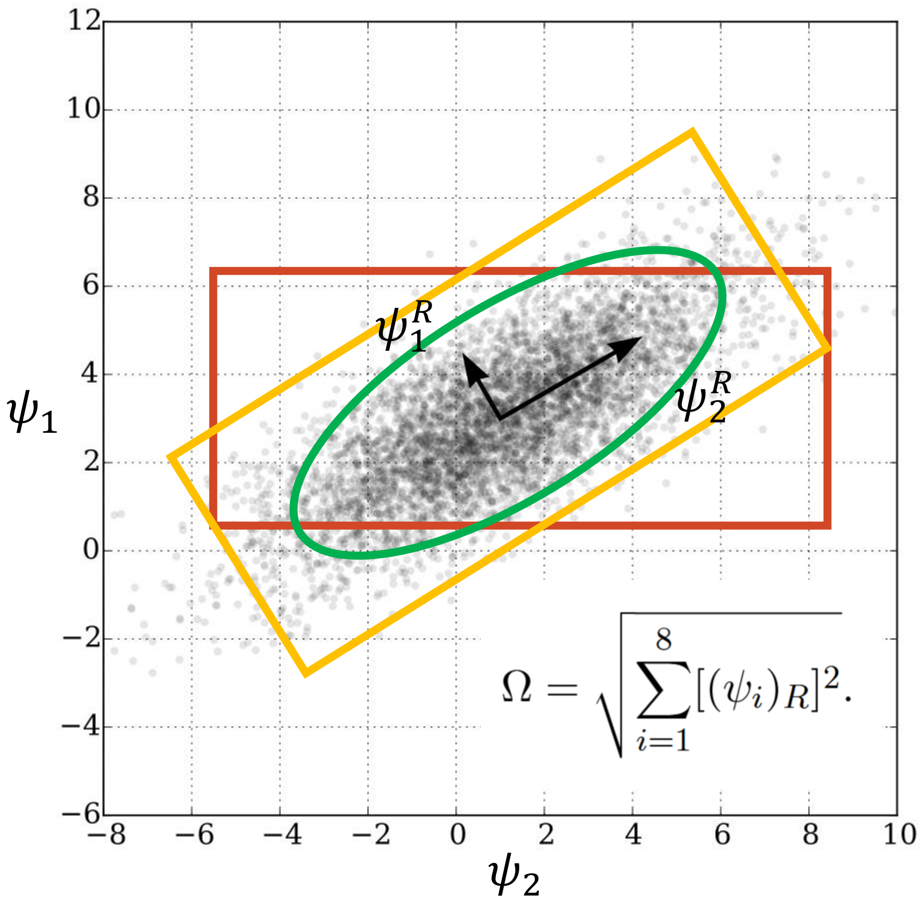


Evaluation of cluster cuts



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

2D example of PCA*



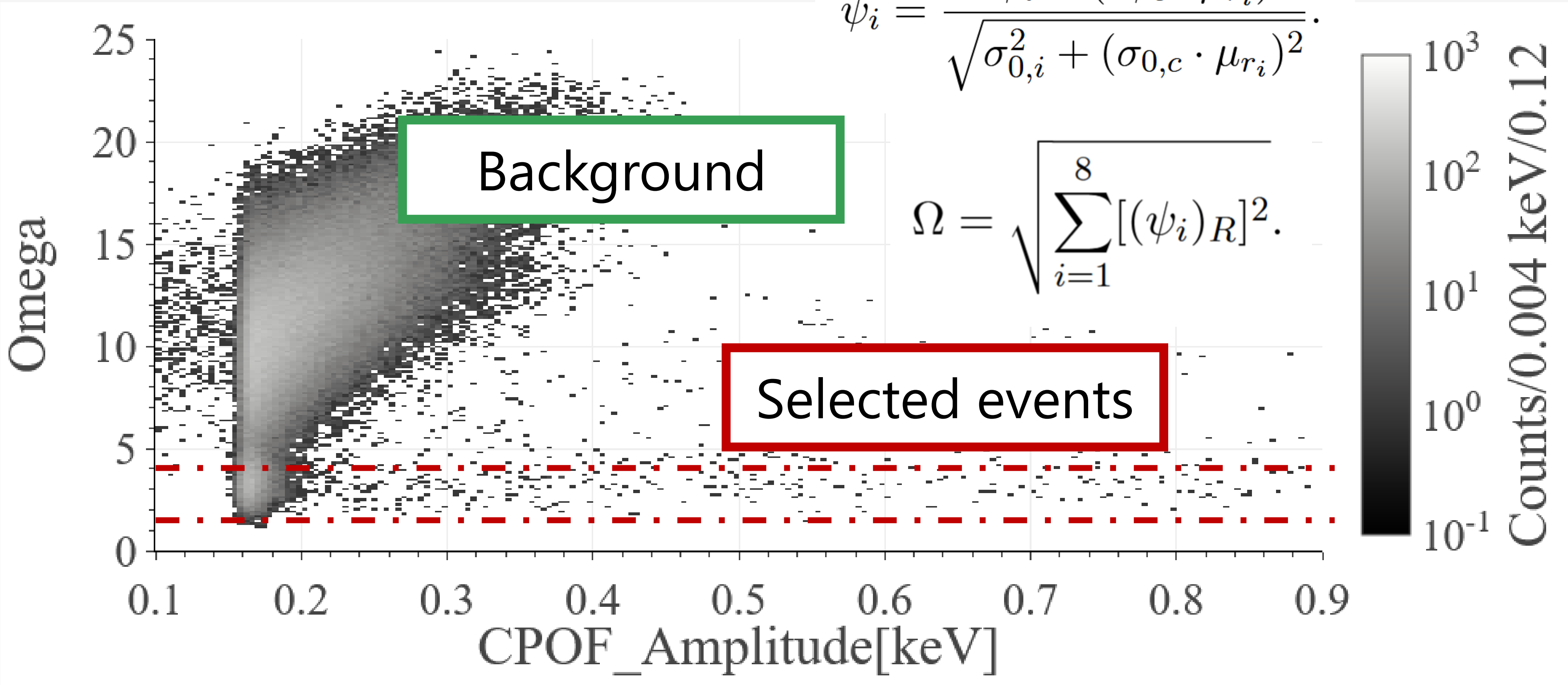
$$\Omega = \sqrt{\sum_{i=1}^{8} [(\psi_i)_R]^2}.$$

* Not actual data from BULLKID

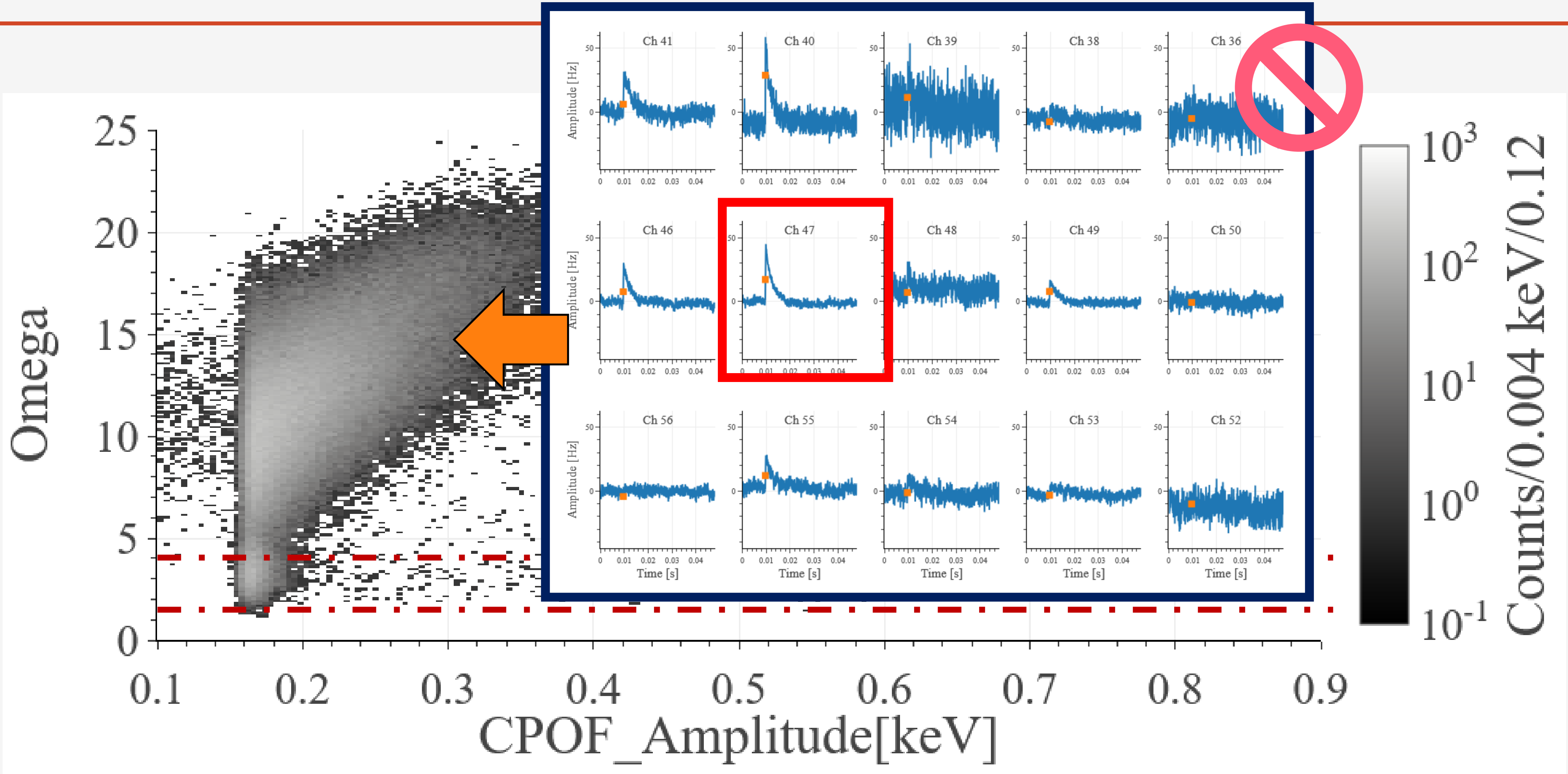
Pulse selection, coincidence cuts (KID-47)

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

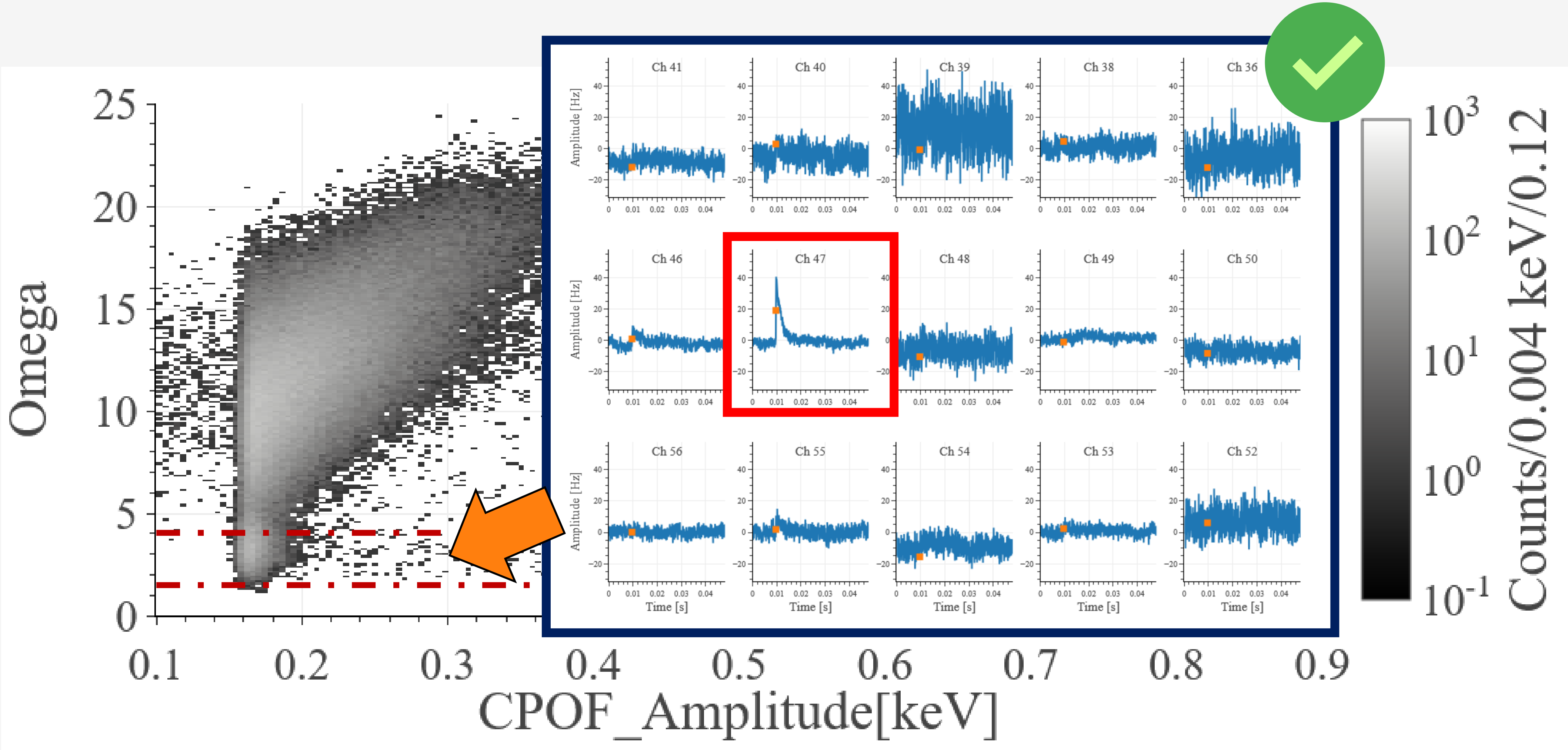
$$\Omega = \sqrt{\sum_{i=1}^{8} [(\psi_i)_R]^2}.$$



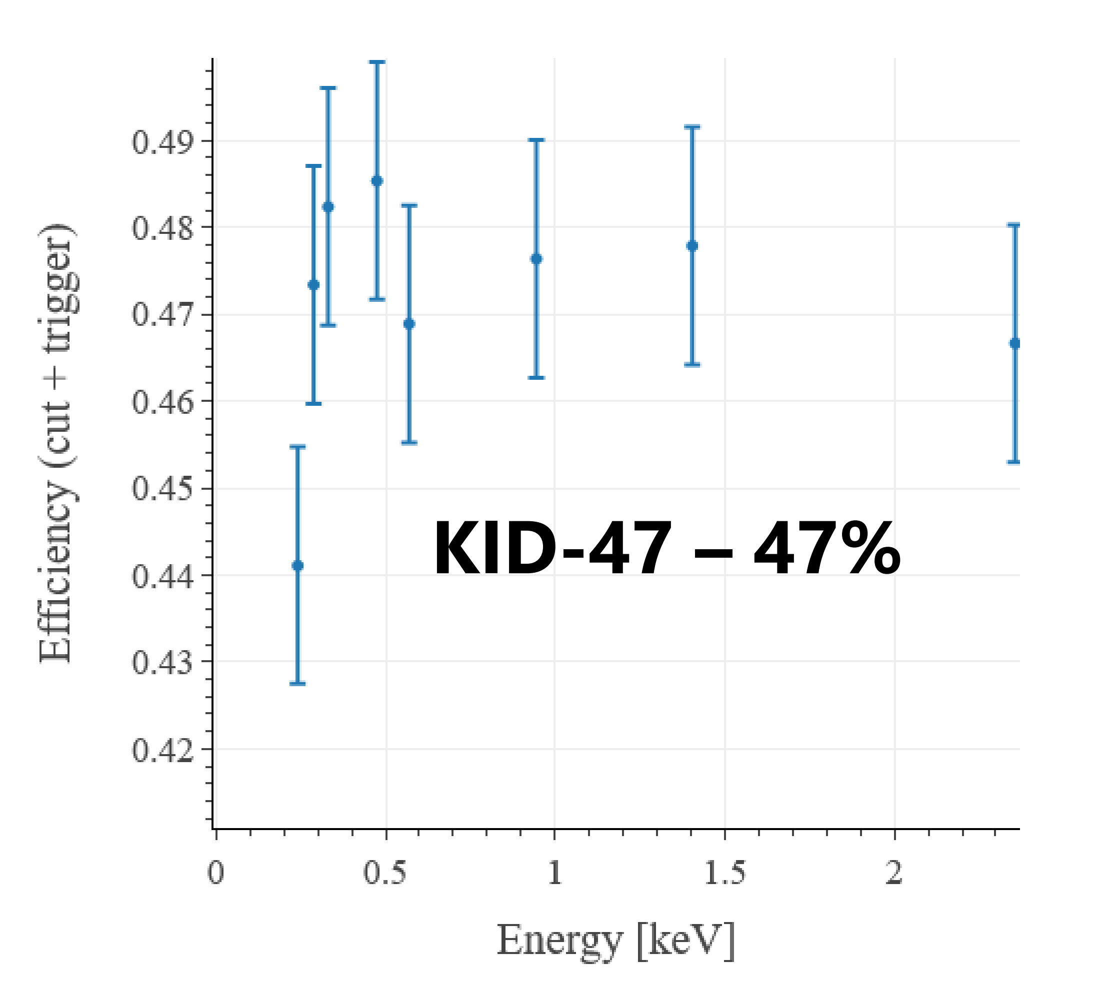
Pulse selection, coincidence cuts (KID-47)

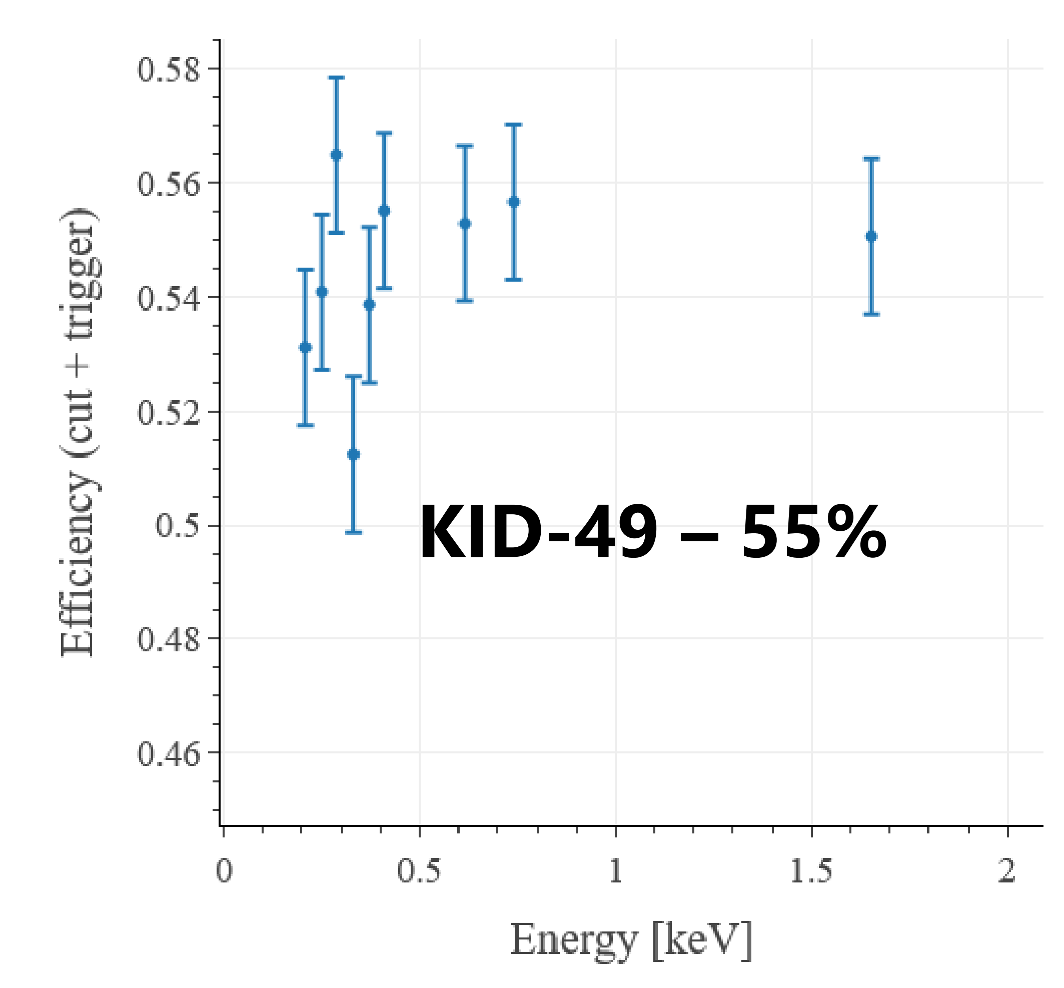


Pulse selection, coincidence cuts (KID-47)

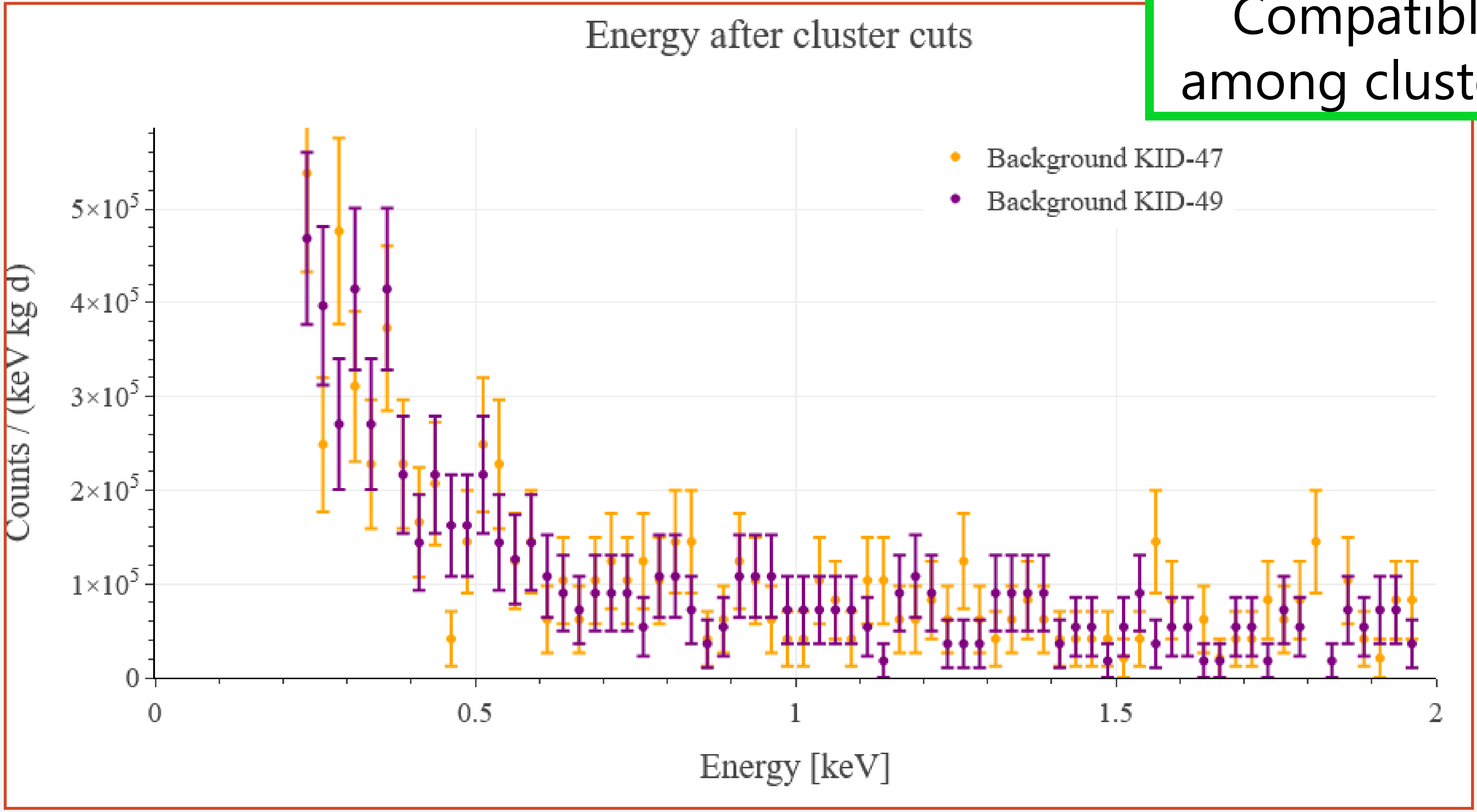


Efficiency evaluation on LED events



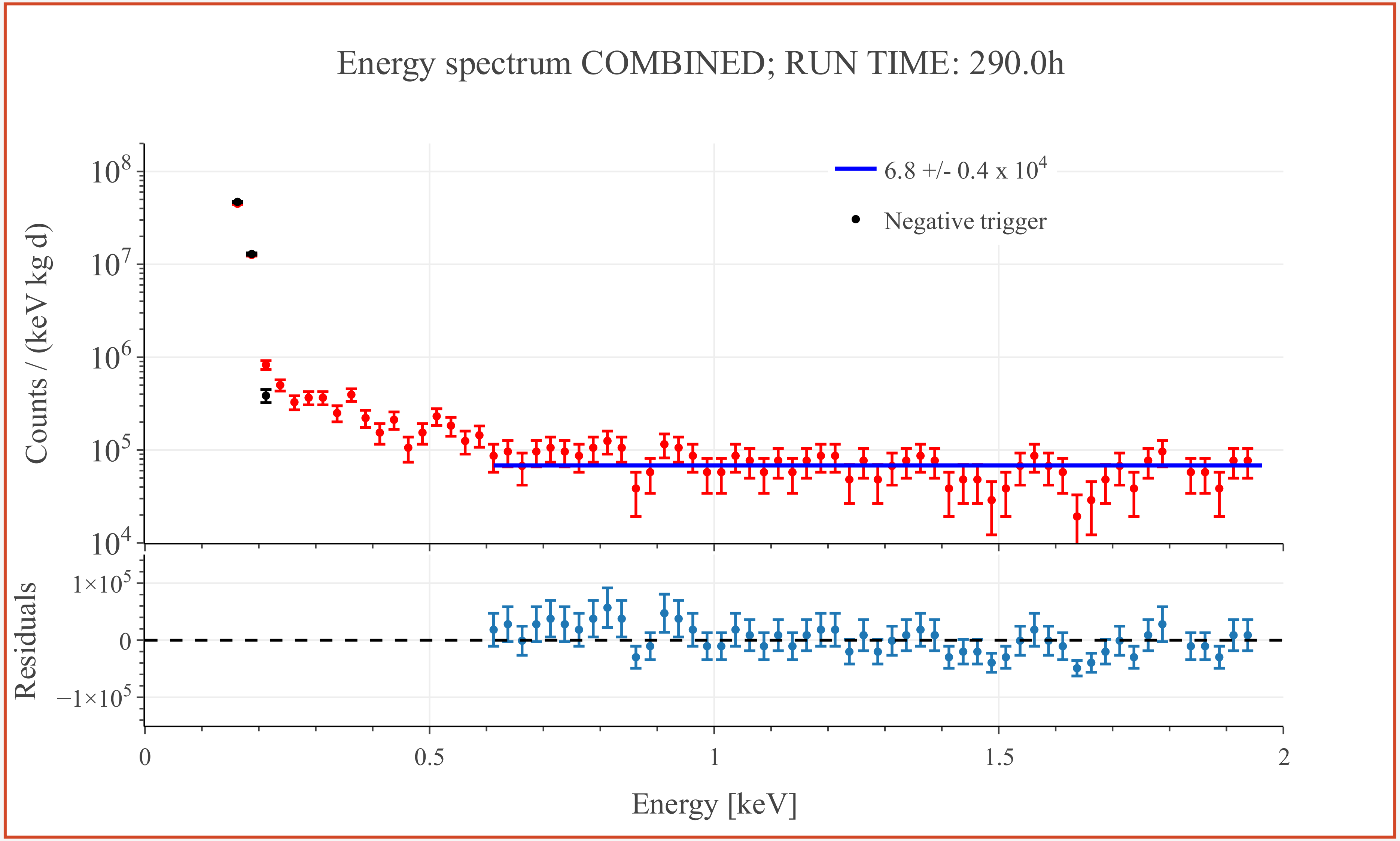


Background: result on surface @Sapienza U., Pb shield, 290 live hours

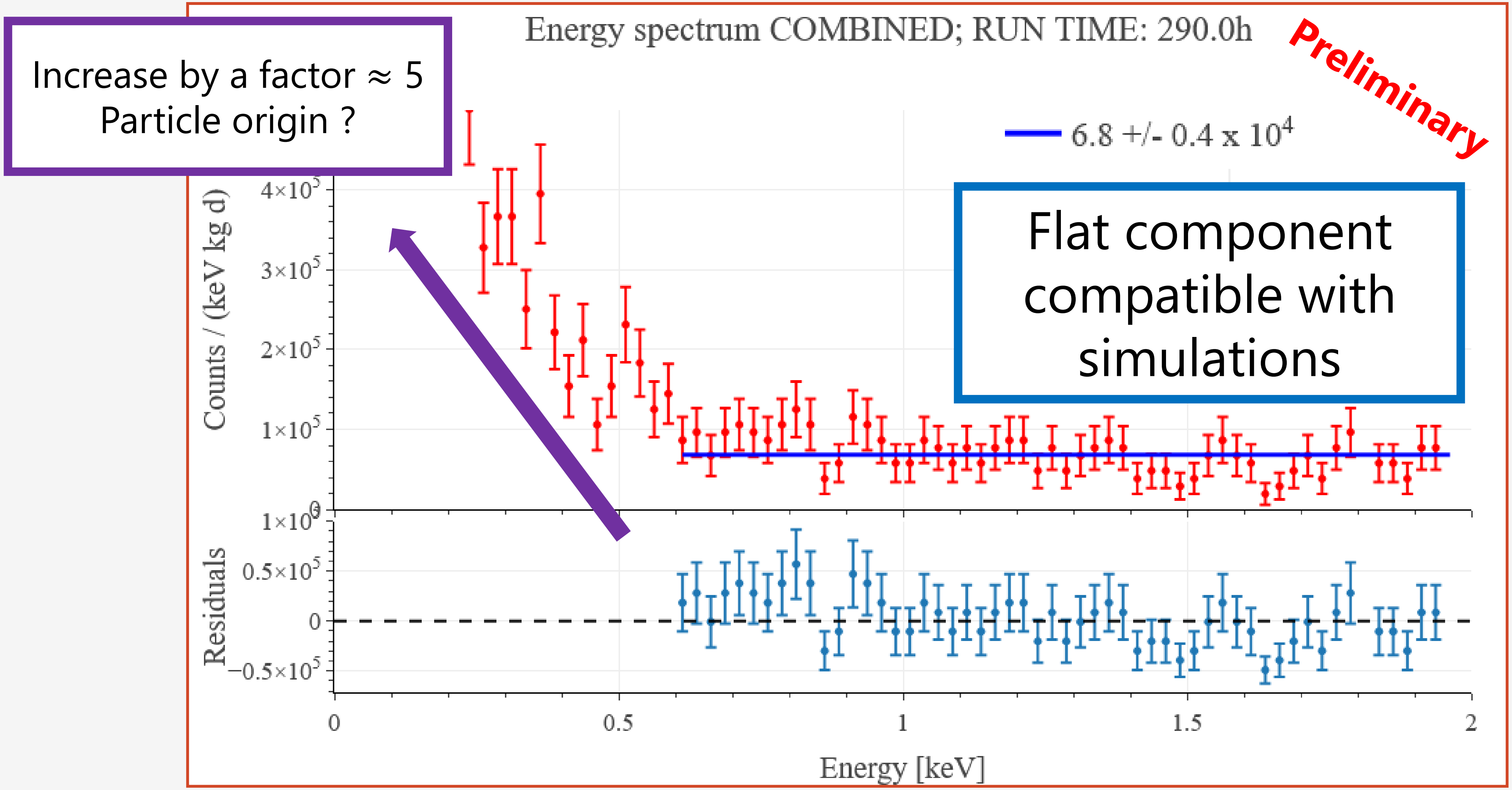


Compatible among clusters!

Background: result on surface @Sapienza U., Pb shield, 290 live hours

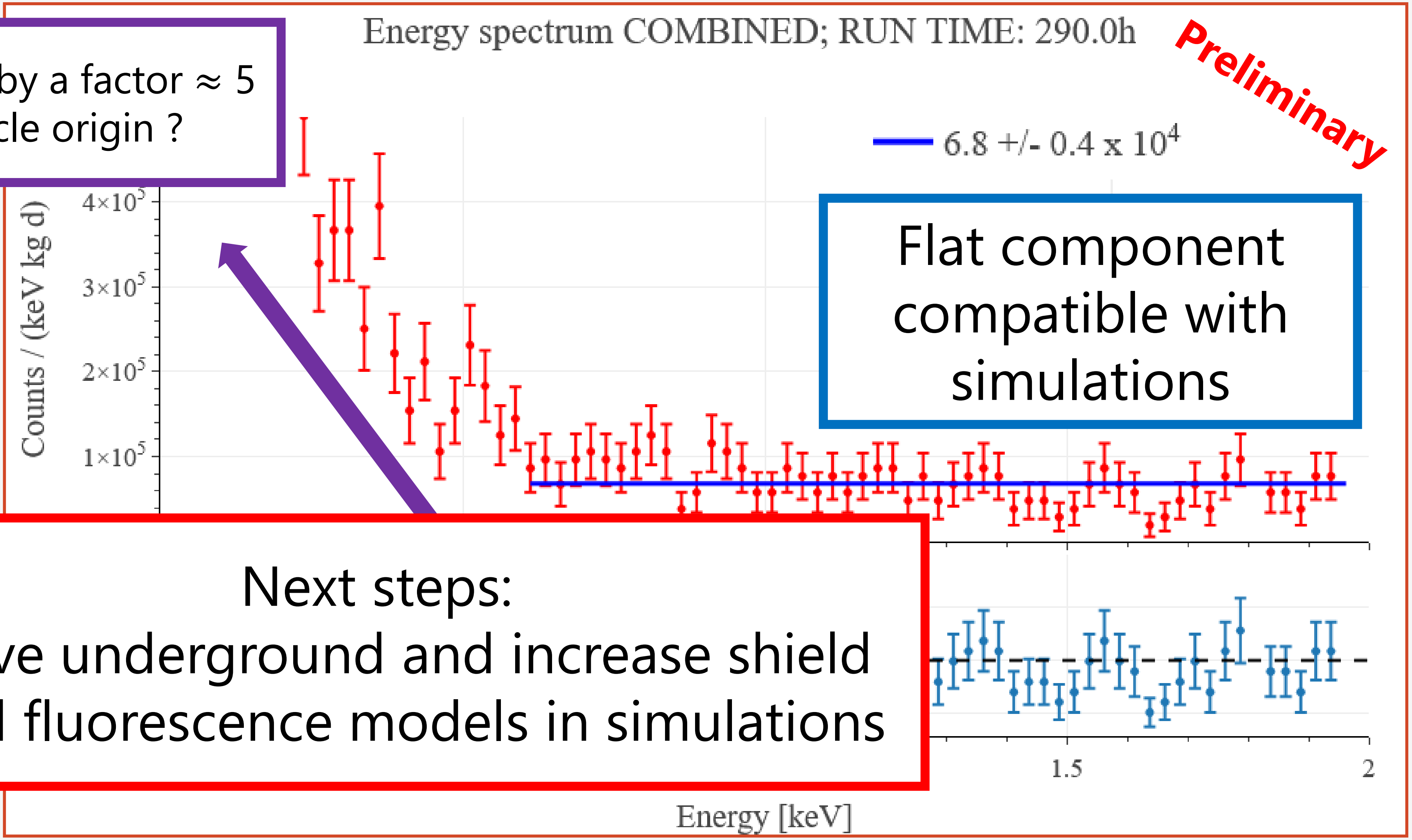


Background: result on surface @Sapienza U., Pb shield, 290 live hours



Background: result on surface @Sapienza U., Pb shield, 290 live hours

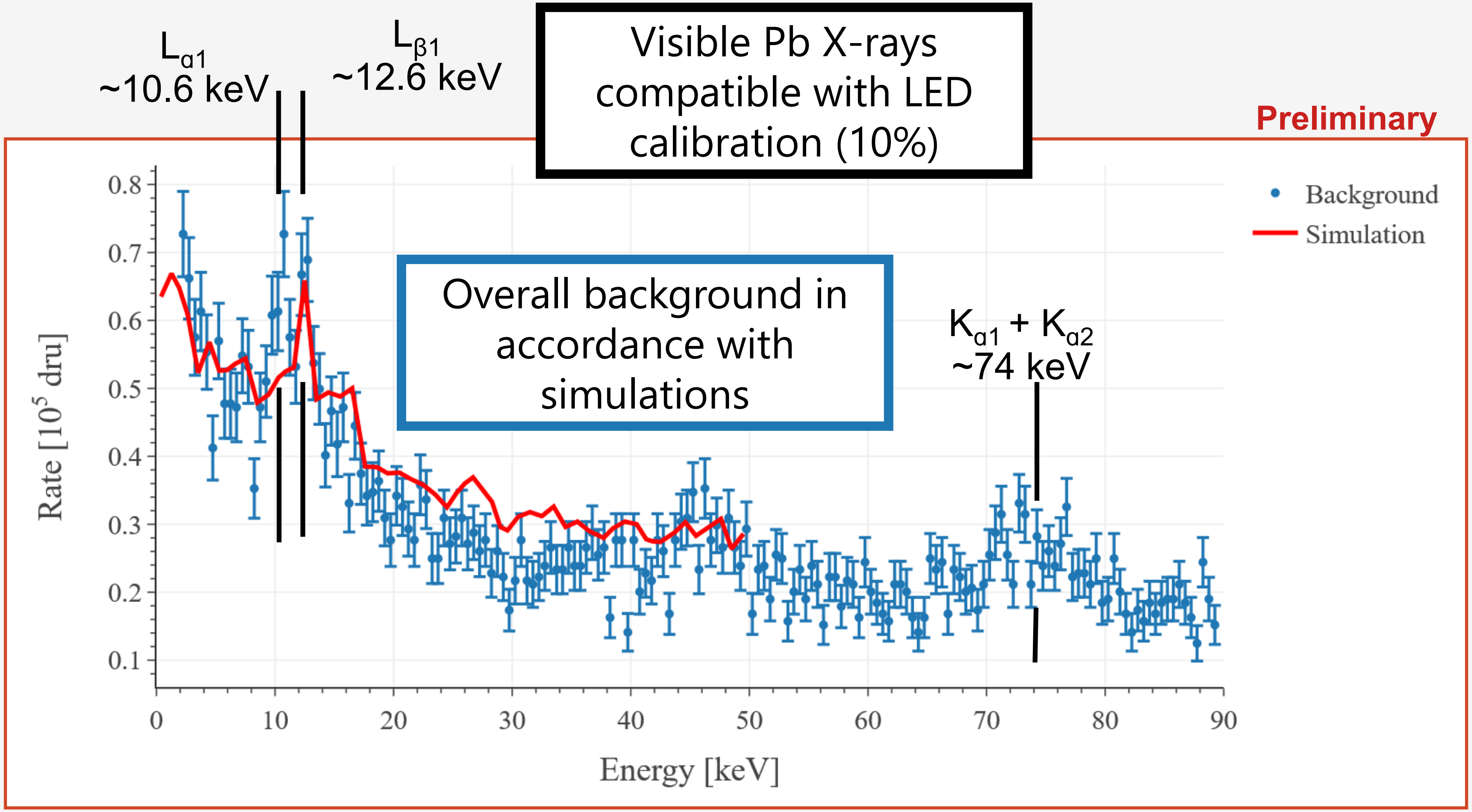
Increase by a factor ≈ 5
Particle origin ?



Flat component compatible with simulations

Next steps:
1) Move underground and increase shield
2) Add fluorescence models in simulations

High Energy Spectrum and Simulation Comparison



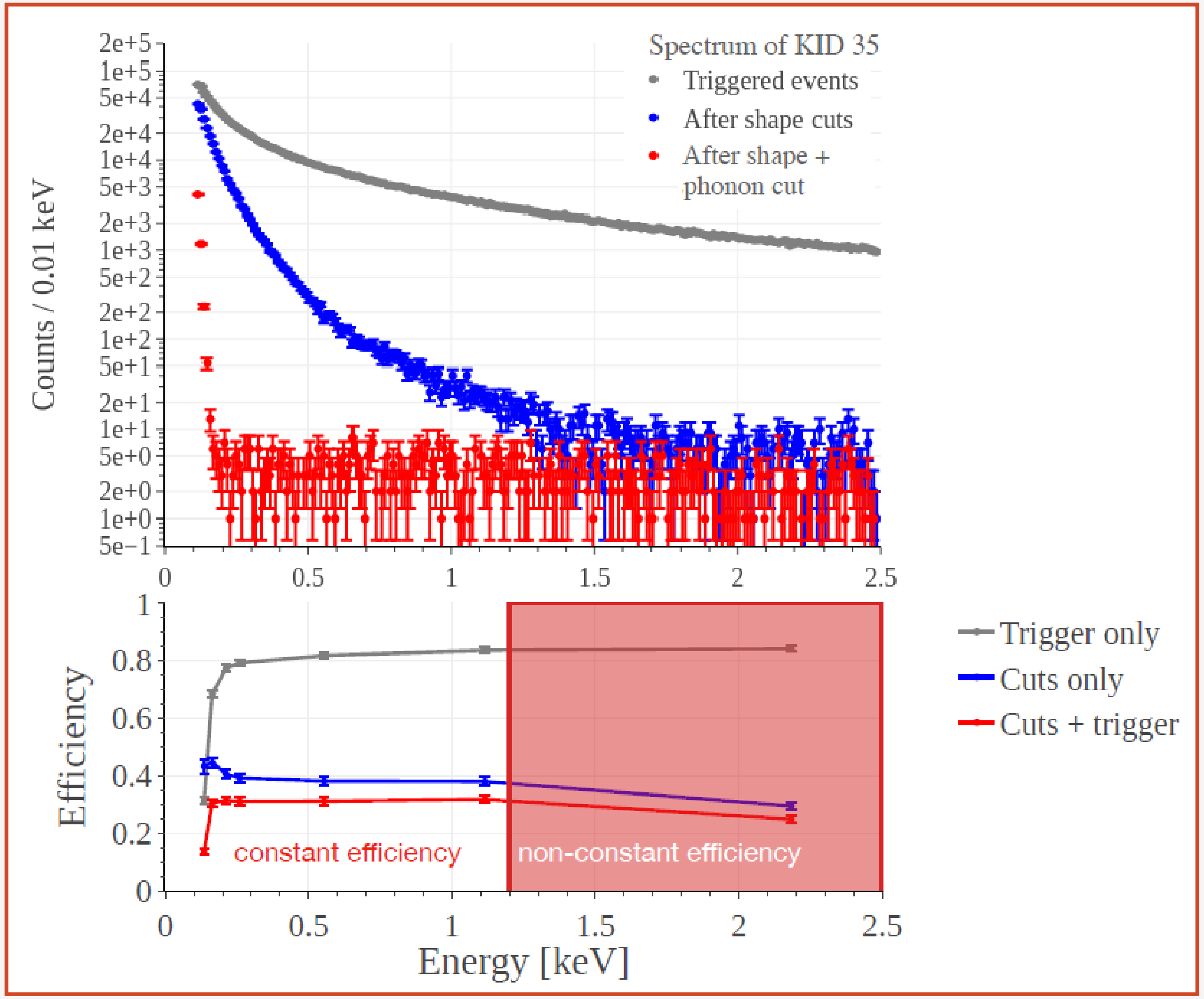
Conclusion and future prospects

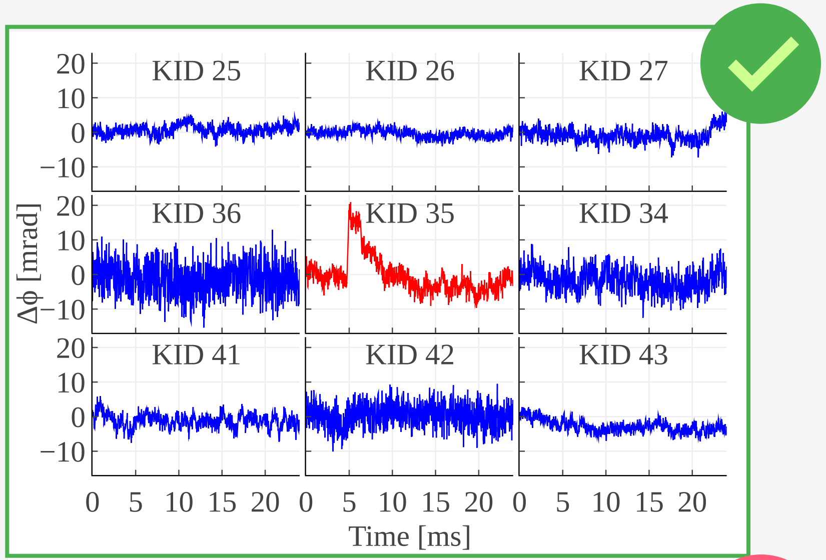
What do we need to investigate the spectrum further?

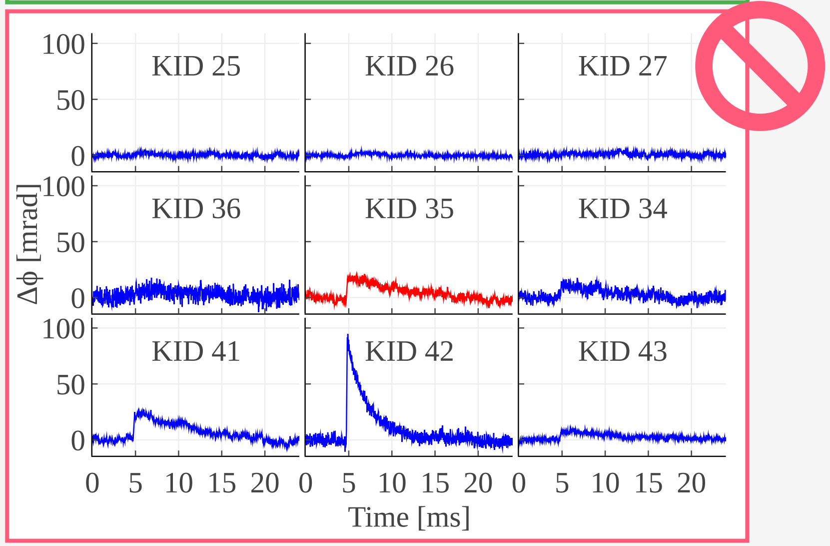
- **More simulations**
- More pixels per cluster?
- Better resolution of veto pixels
- Lower threshold (AlTiAl ready to test)
- More shielding

BACKUP SLIDES

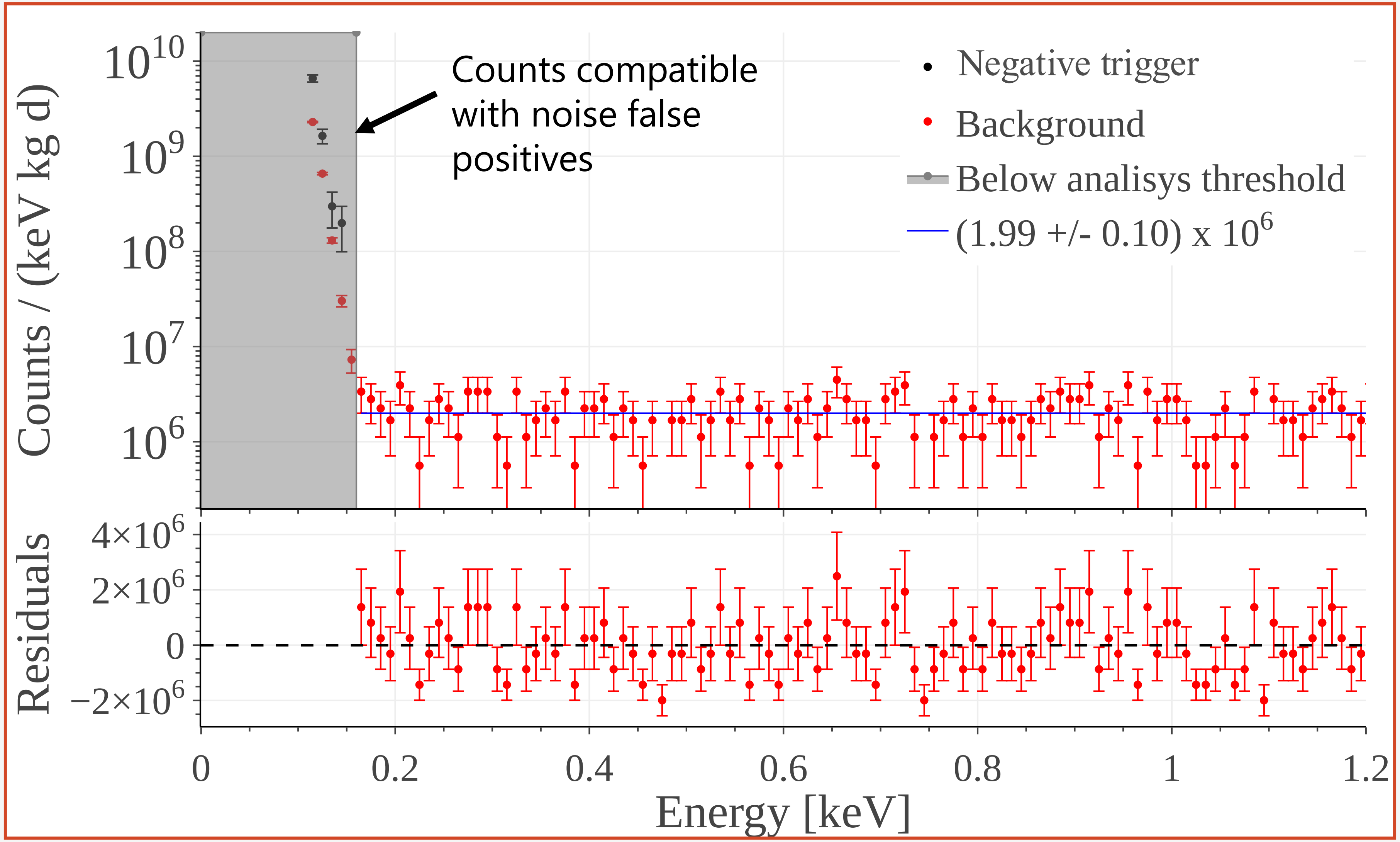
Background: pulse shape + phonon cuts





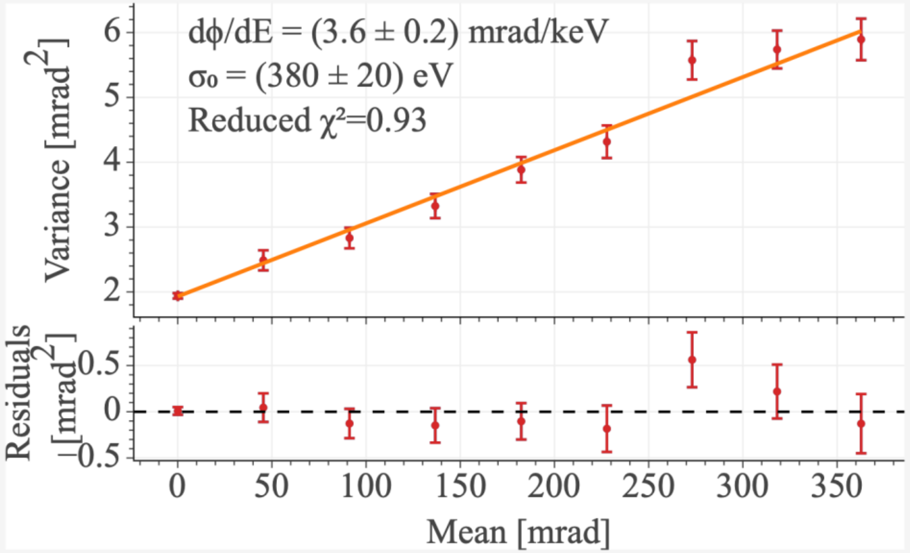


Background: result on surface @Sapienza U., no shield, 39 live hours

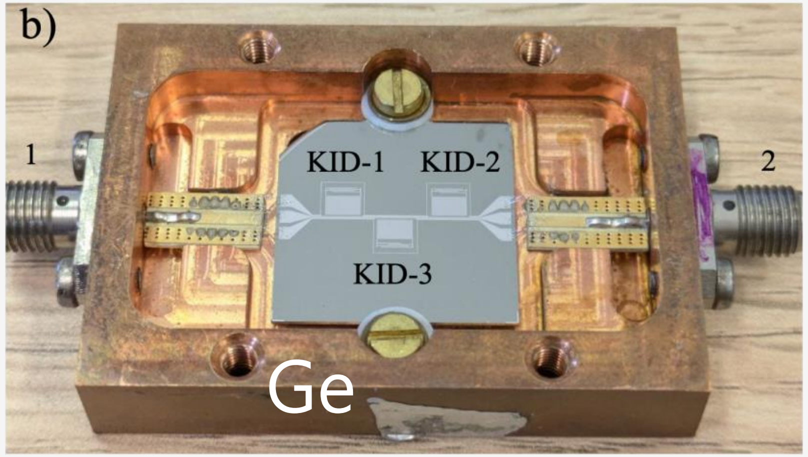


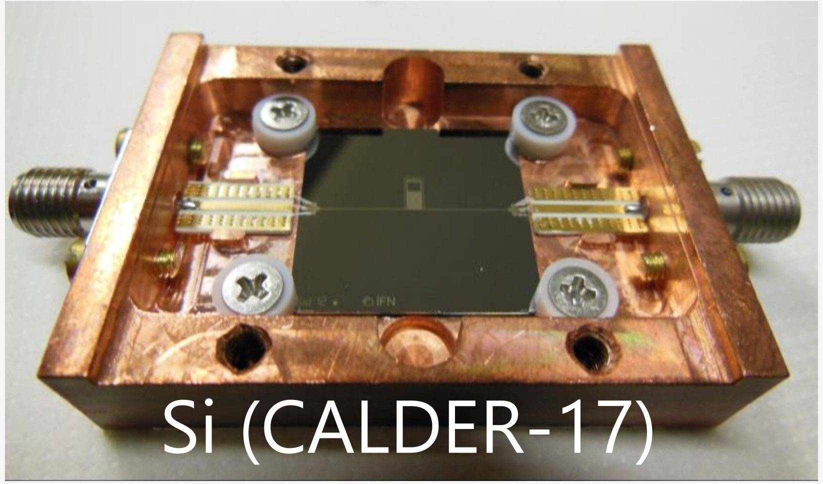
D. Delicato et al, Eur. Phys. J. C 84 (2024) 353

KIDs on Germanium for neutrino detection



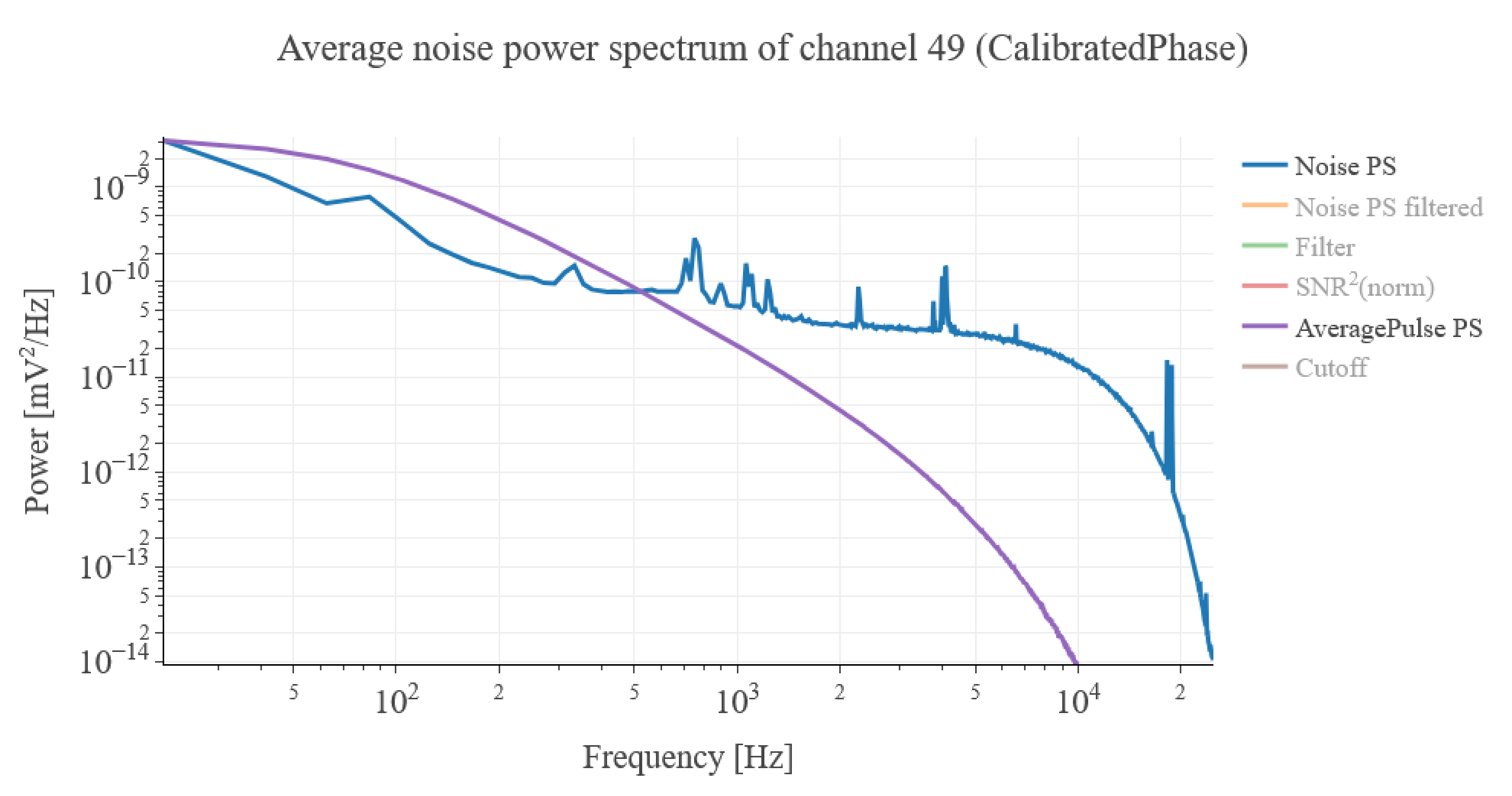
	$d\phi/dE$ [mrad/keV]	σ_0 [eV]	η [%]	$\frac{A_{KID}}{A_{TOT}}$
KID-1	3.6 ± 0.2	380 ± 20	2.0 ± 0.2	0.12
KID-2	2.5 ± 0.1	450 ± 22	2.0 ± 0.2	"
KID-3	2.2 ± 0.2	540 ± 31	1.6 ± 0.2	"
CALDER-17	5.8	115 ± 6	$7.4 - 9.4$	0.42





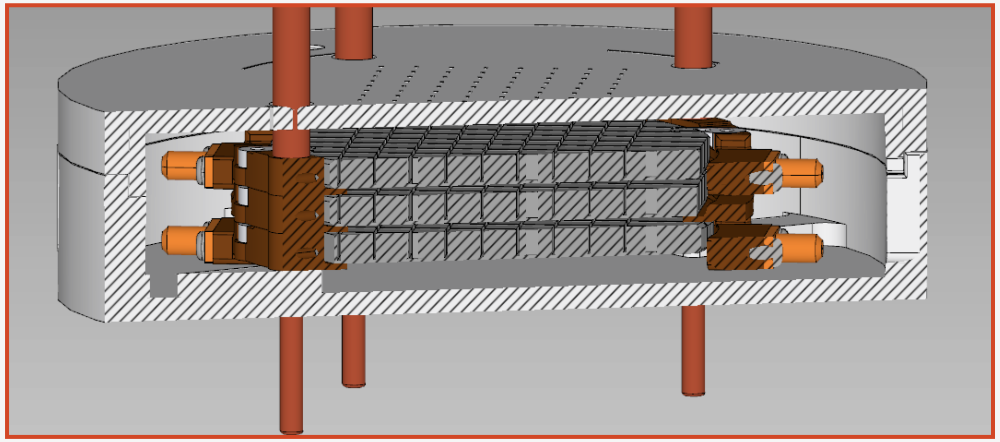
D. Delicato et al, Appl. Phys. Lett. 126, 153502 (2025)

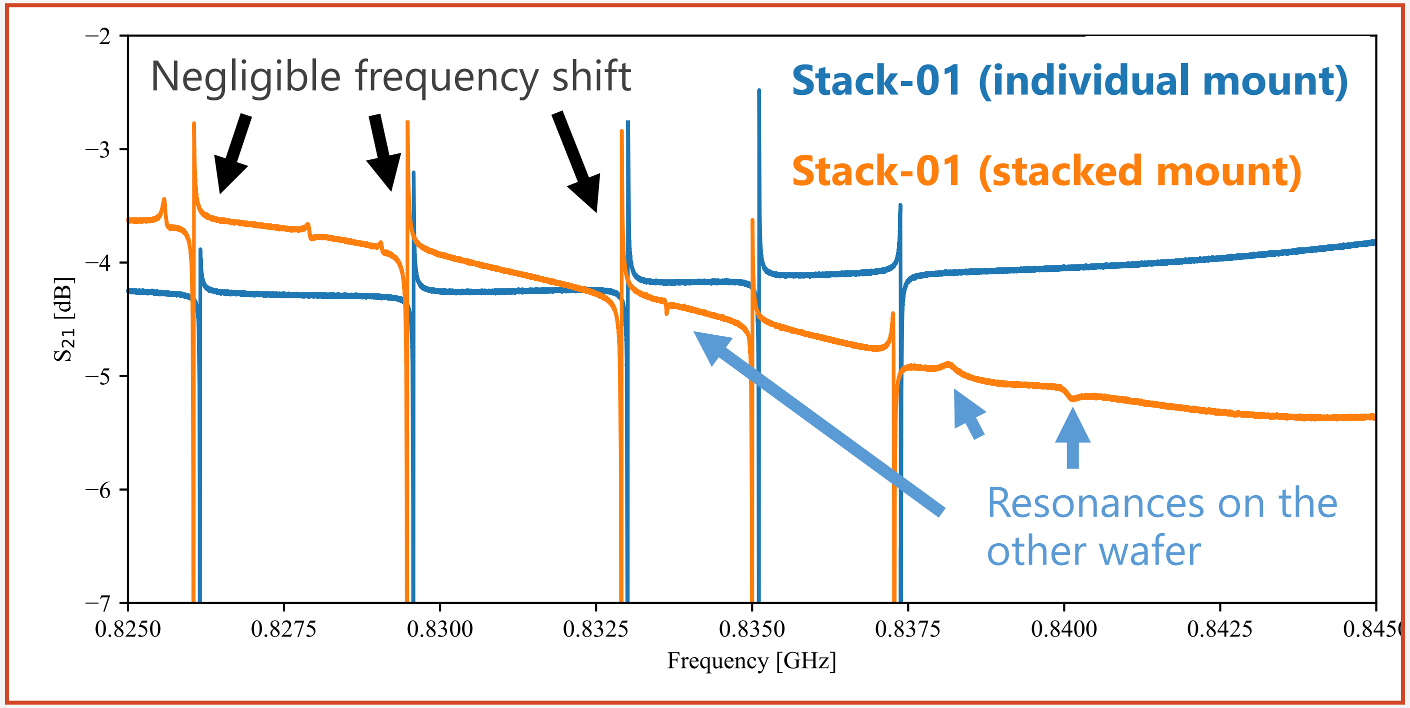
Pulse and noise power spectra

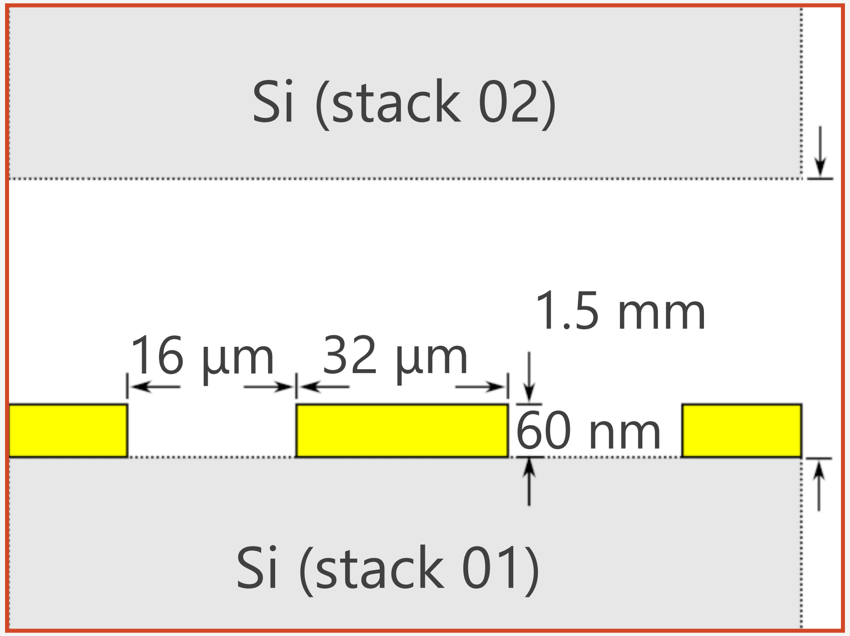


Status of the 3-wafer stack

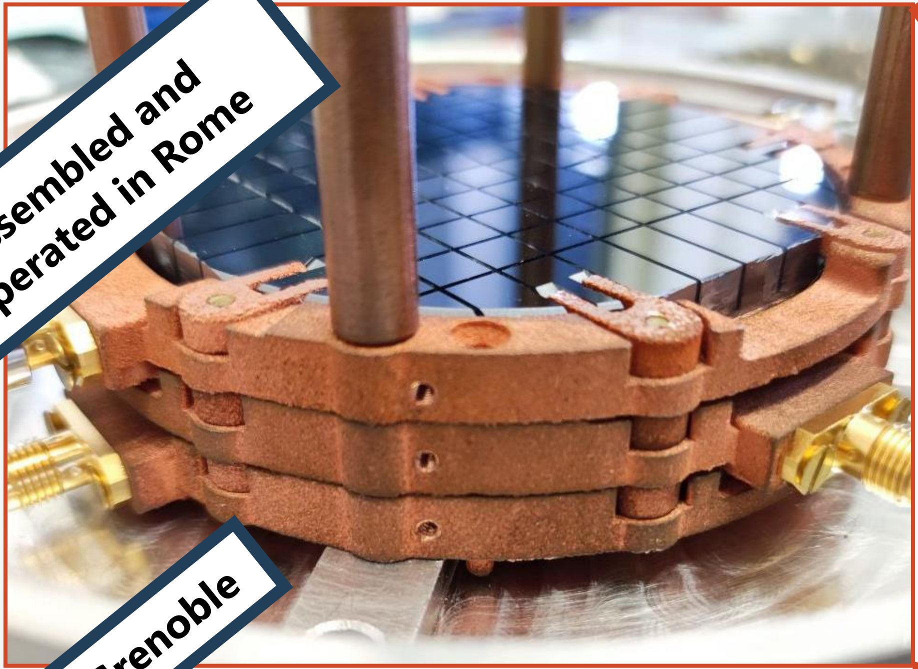
- Holding structure: **thermalization** and mounting
- Reproducibility of the **electrical coupling**
- Reproduce the results of the unstacked wafers

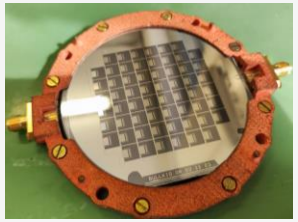
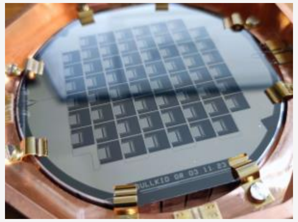






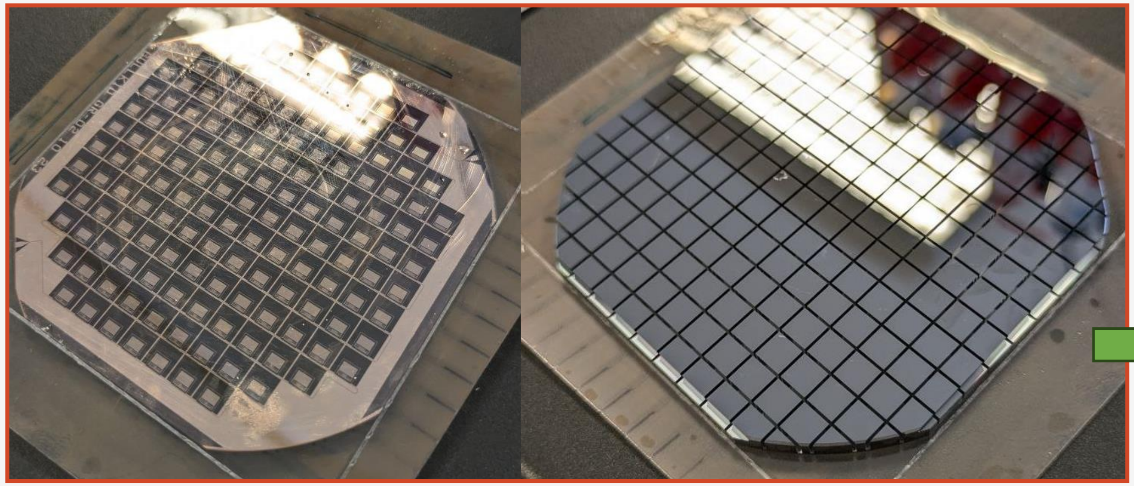
Status of the 3-wafer stack

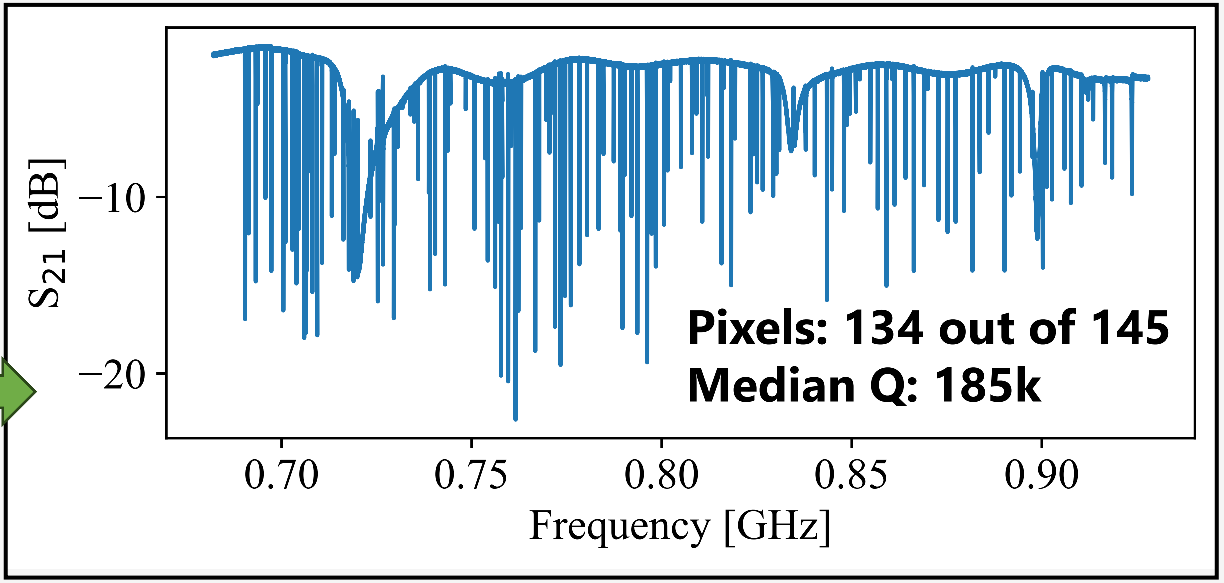


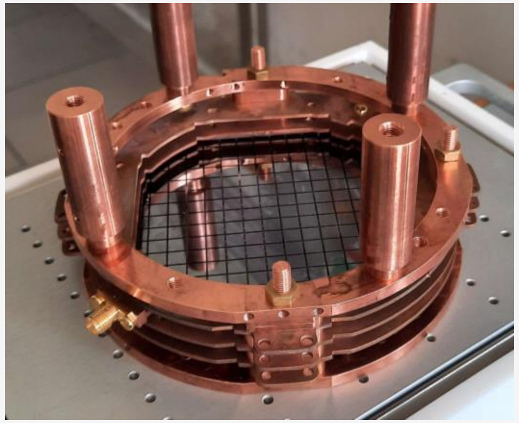
Stacked configuration with the **250 Kg lead castle shielding**

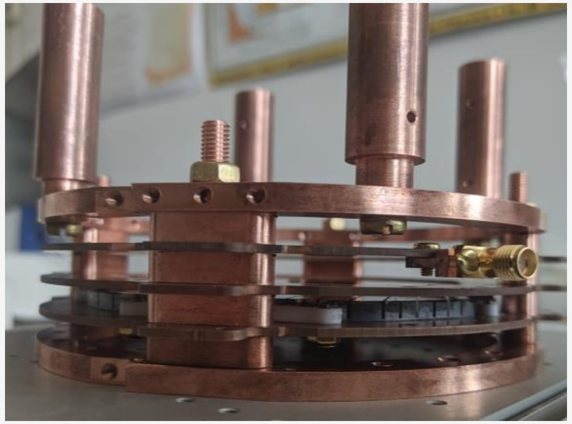
Scalability for the 100mm mask: thick wafer





Assembly produced

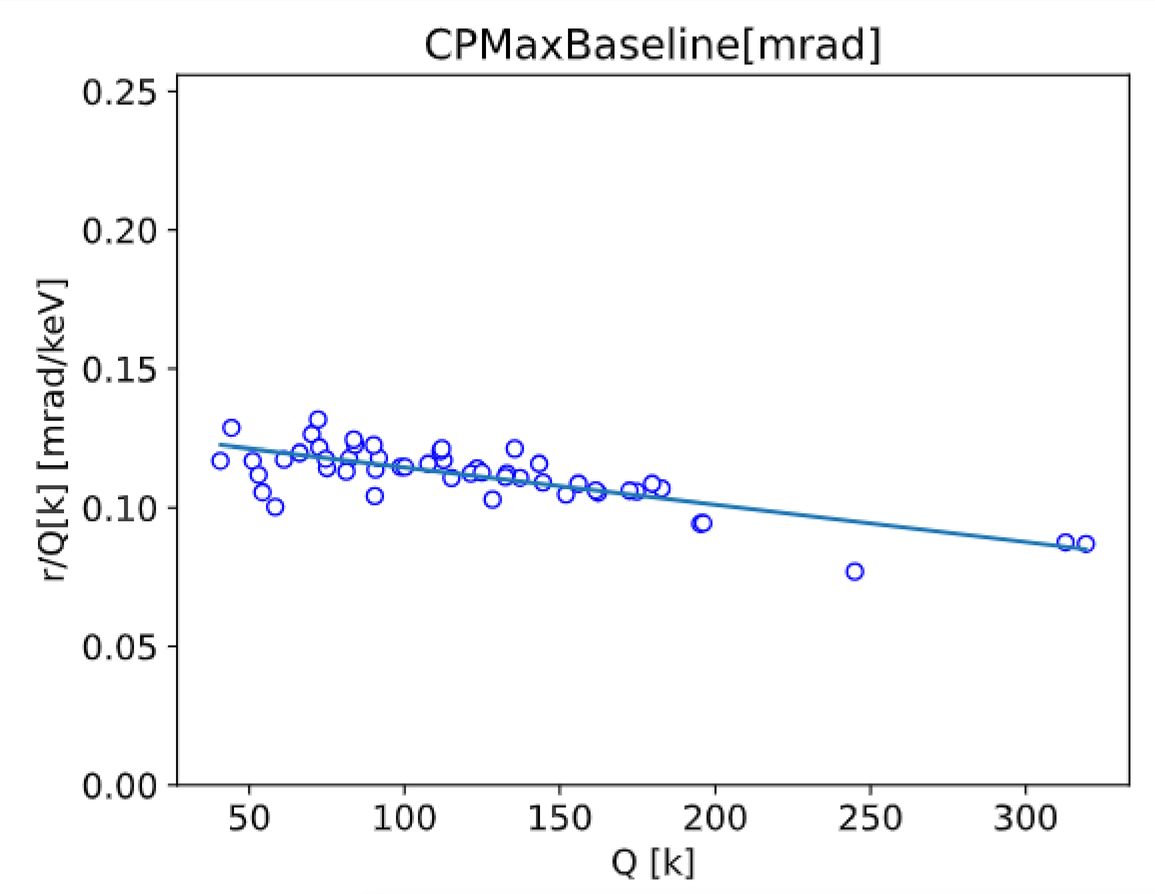


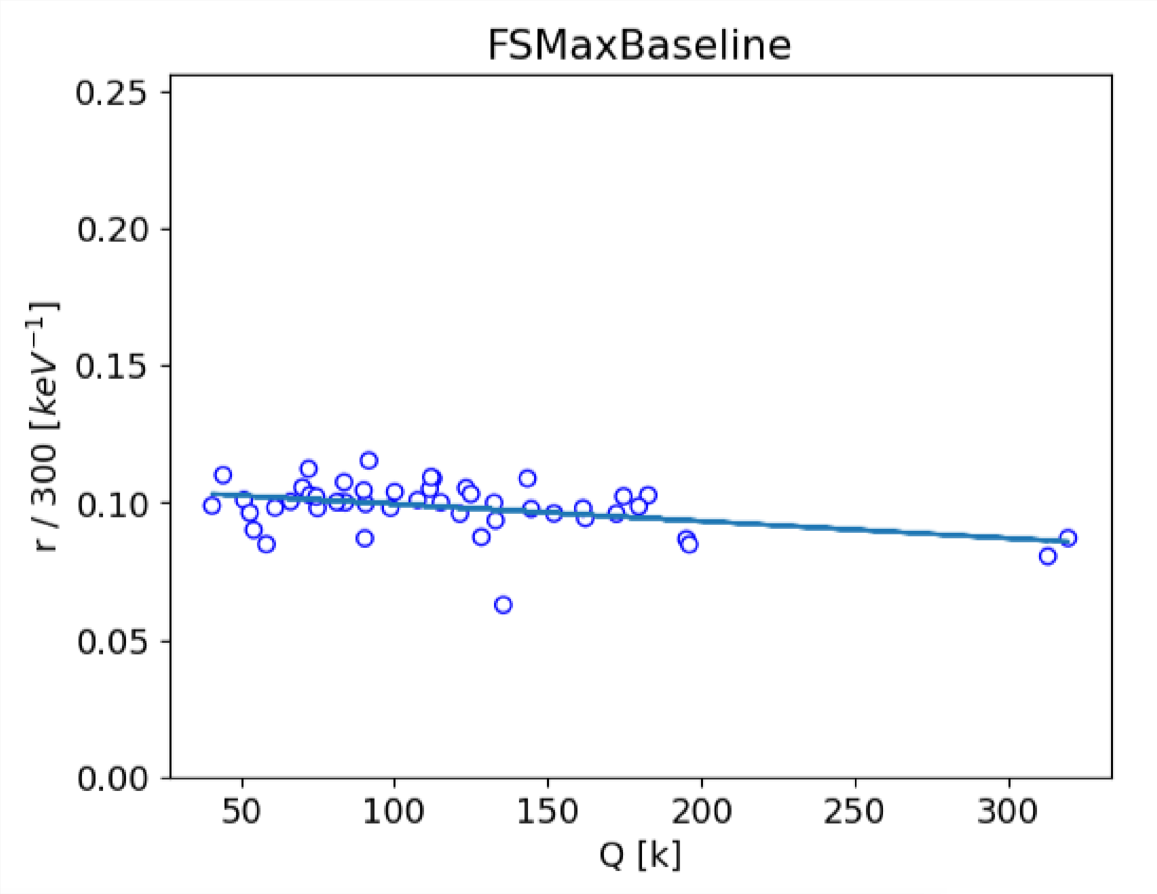


Next steps:

- **Series wafer production**
- **Lithography**

Uniformity of wafer response to Americium source





Essentially same response to Am across the array

Uniformity of wafer response to Americium source

Noise after calibration (FS) @ low bias power