BULLKID: 3" x3 Demonstrator

19/03/2024 – BULLKID-DM Meeting – LNGS

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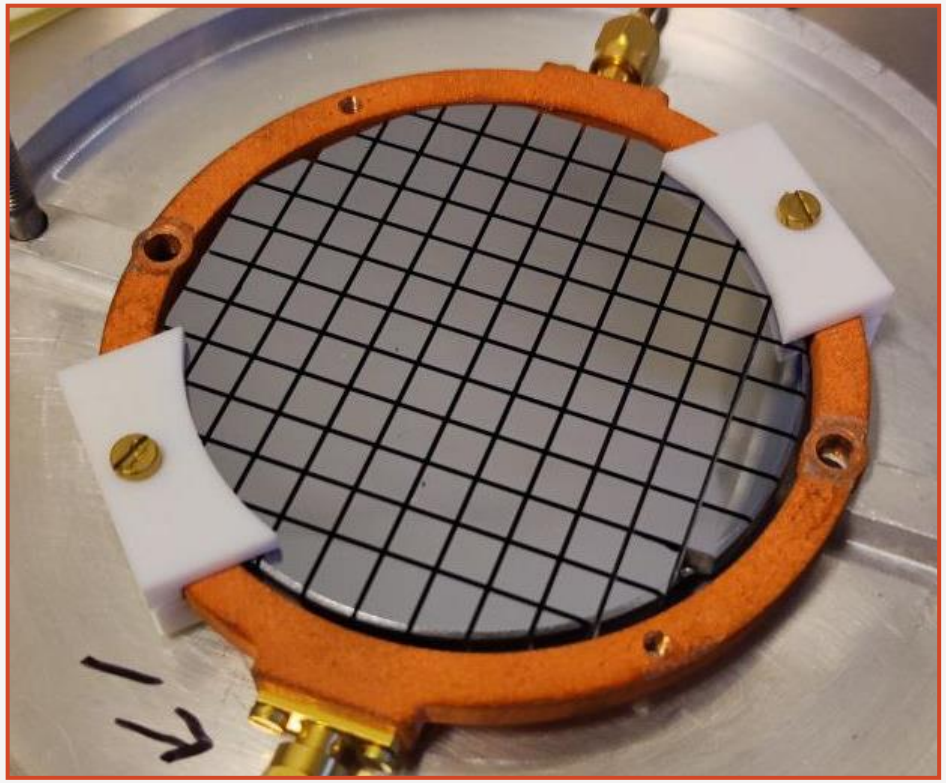
Project goal

Obtain a cryogenic, **low threshold nuclear recoil detector** for light dark matter ($0.1 \div 10$ GeV) searches and neutrino physics (CEvNS).

Detector specifications:

- Phonon sensors
- Background rejection
- Silicon target
- Target mass ≈ 1 kg
- Energy threshold ≈ 100 eV
- High segmentation (≈ 2000 detector units)



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- **Background rejection**
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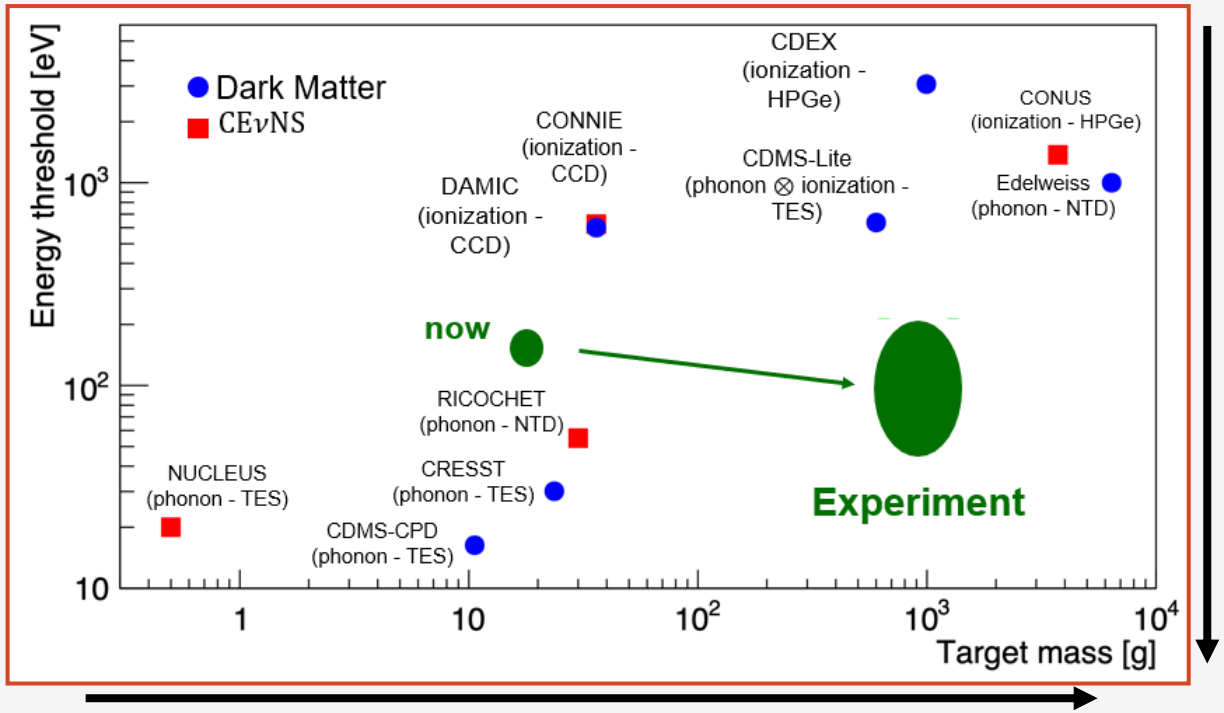
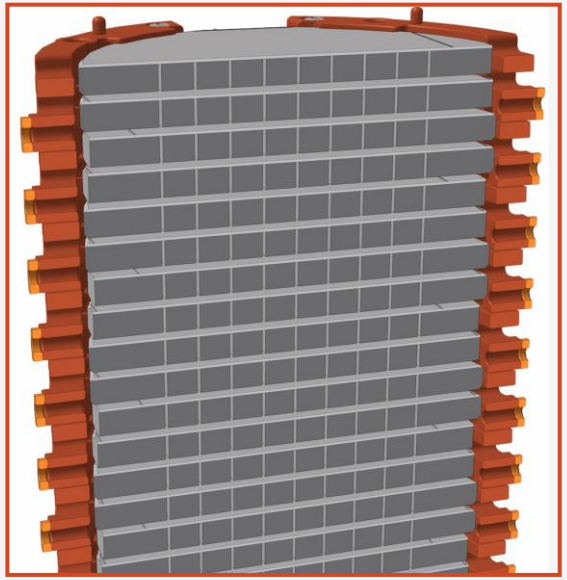
Achievable by stacking many wafers one on top of the other

Towards the experiment





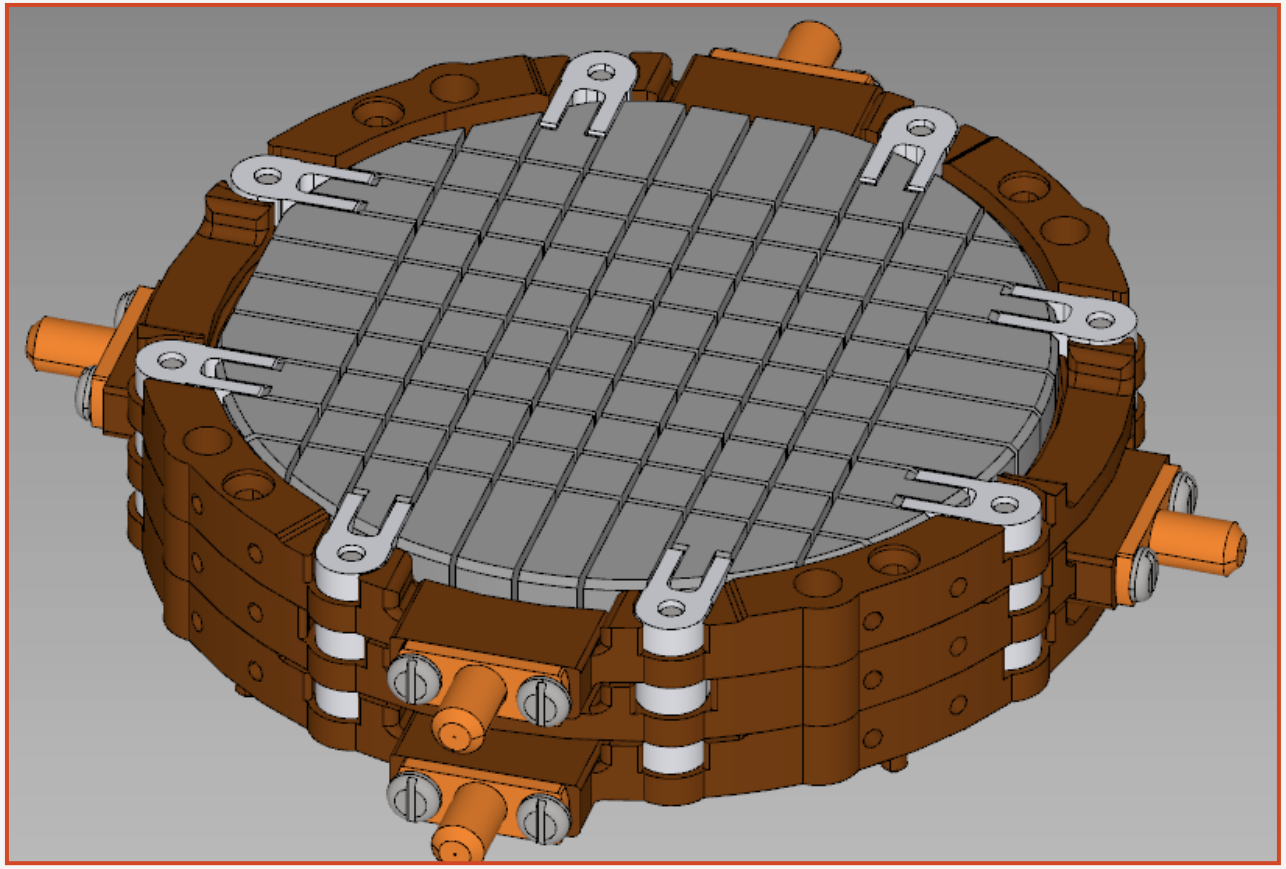
Produce a scalable nuclear recoil detector with:

- 15 (**4”**) or 30 (**3”**) BULLKIDs (2000 voxels)
- 200 ÷ 50 eV Threshold (**160 eV demonstrated**)
- 0.6 kg of silicon

Setup of a first 3 wafer demonstrator

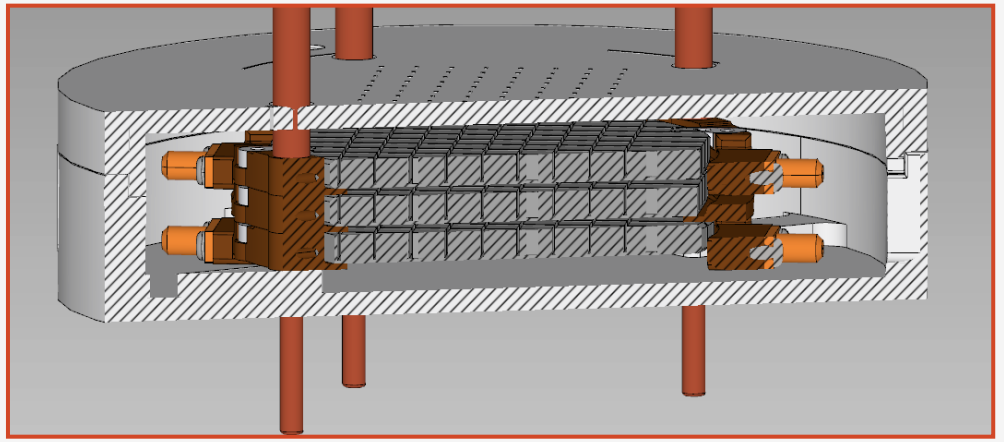
3 inch demonstrator:

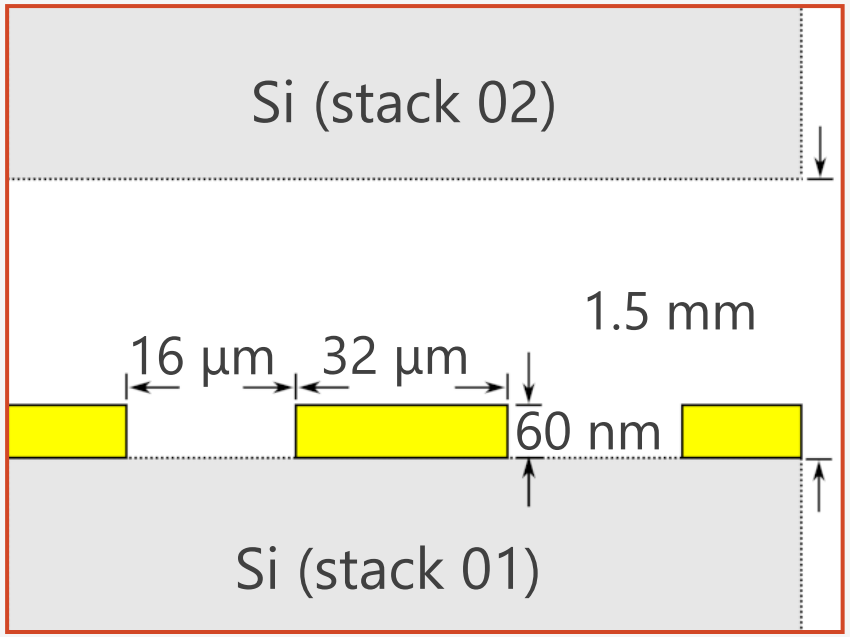
- 3x 3inch wafers
- Identical lithography (60nm Al) with 60 KIDs per unit
- Total instrumented mass of 61.2g
- Three independent readout lines
- Passive shielding (PB + ??)



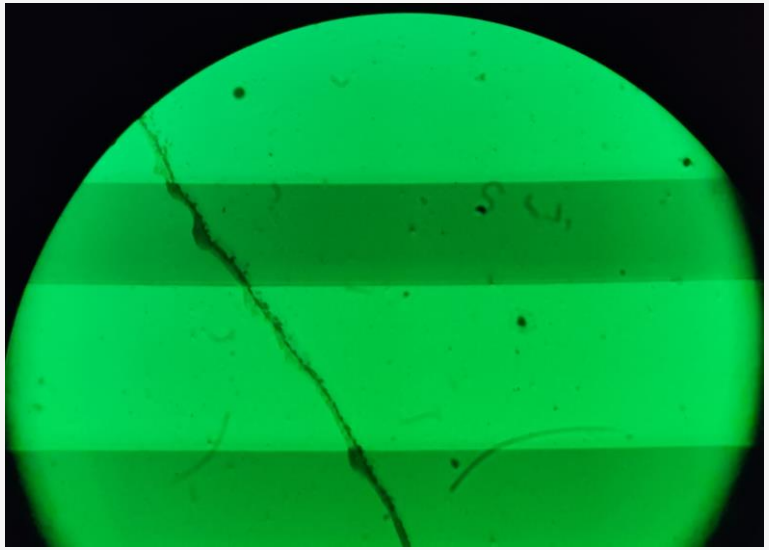
Goals of a first 3 wafer demonstrator

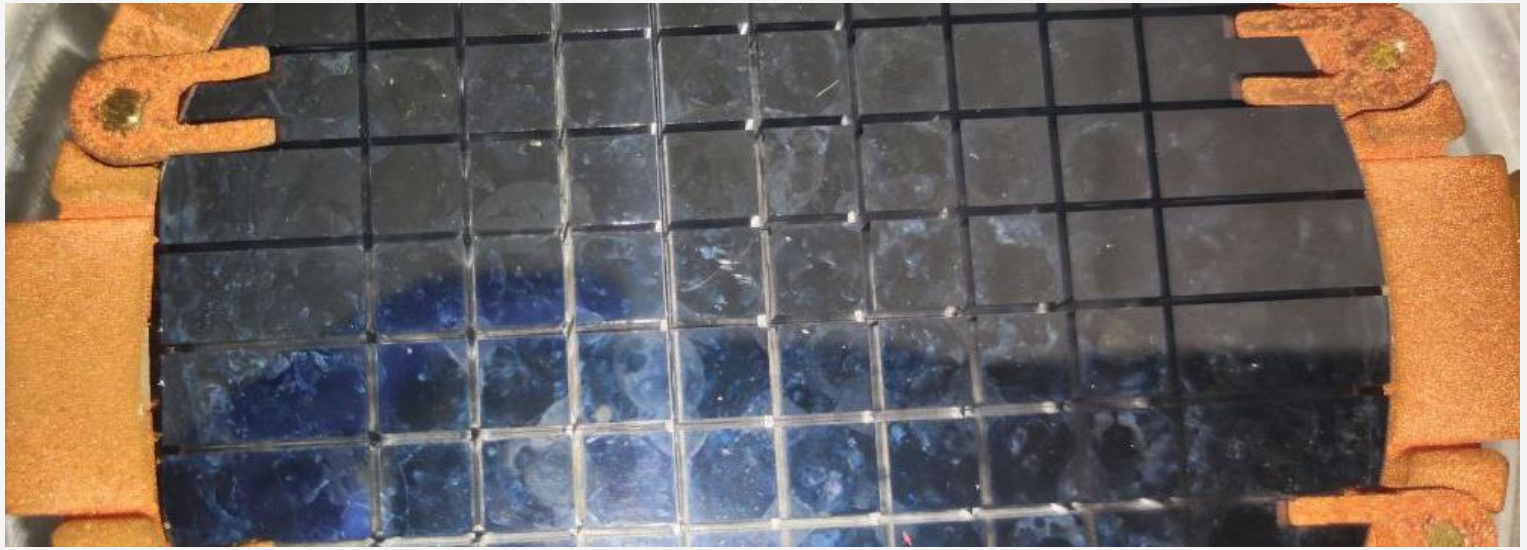
- Show the feasibility of mounting and thermalizing the holding structure
- Prove the reproducibility of the electrical coupling
- Reproduce the energy resolution of the unstacked wafers
- Scale readout and analysis to simultaneously measure multiple wafers

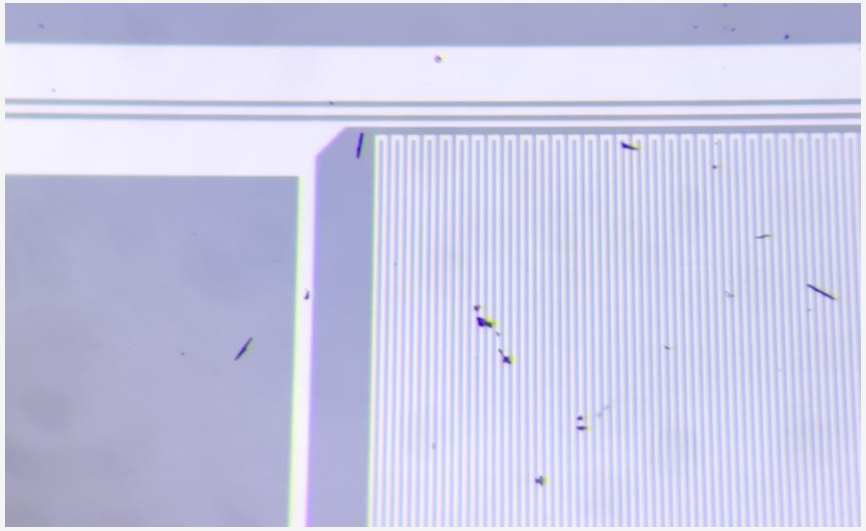


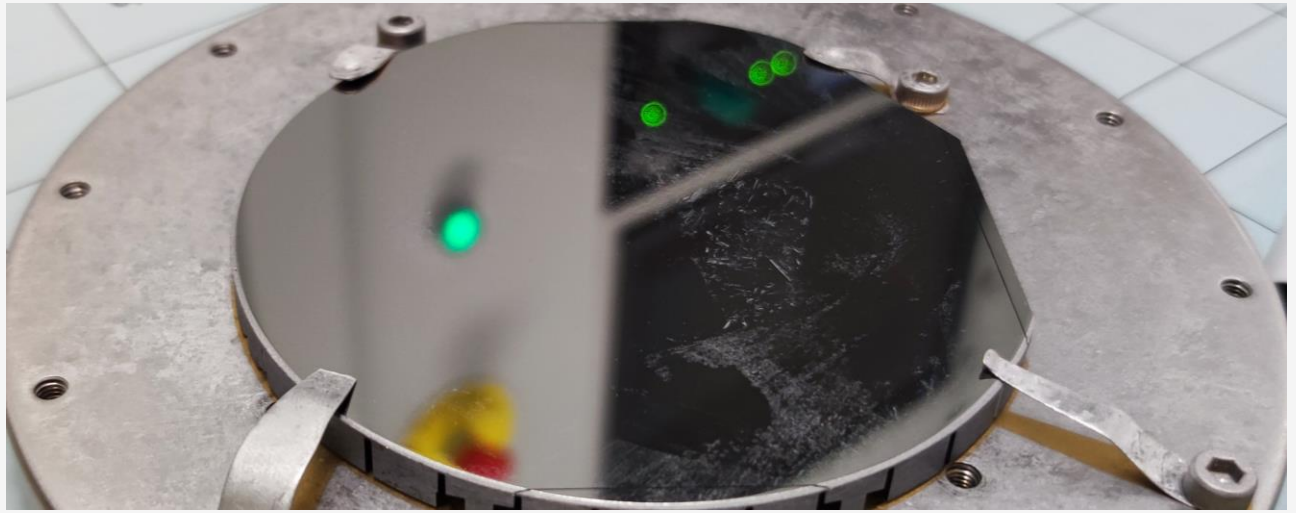


Current prototype: fabrication difficulties

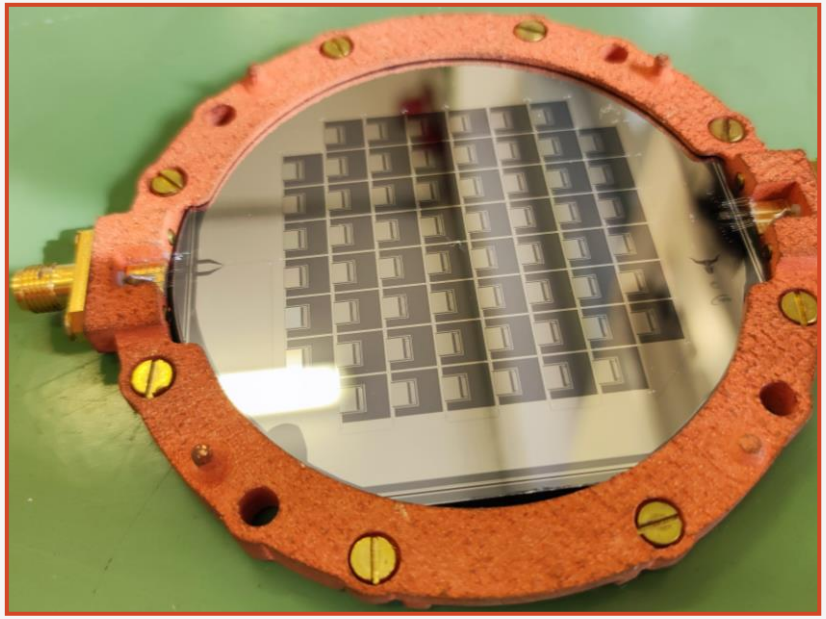








Current prototype of the 3 wafer demonstrator

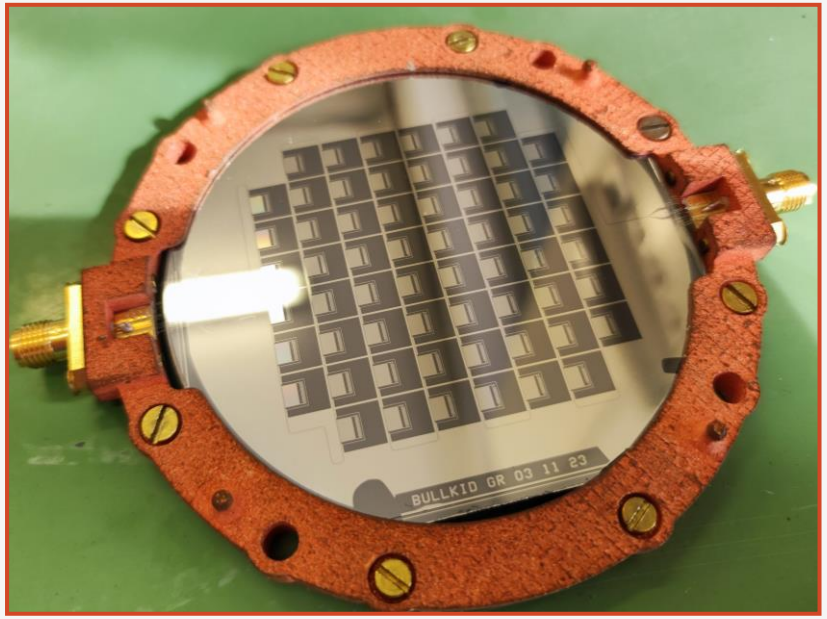


Stack-01: 60nm Al

40 working pixels out of 60

Quality factor (median): 185k

Coupling Q factor (median): 190k



Stack-02: 90nm Al

44 working pixels out of 60

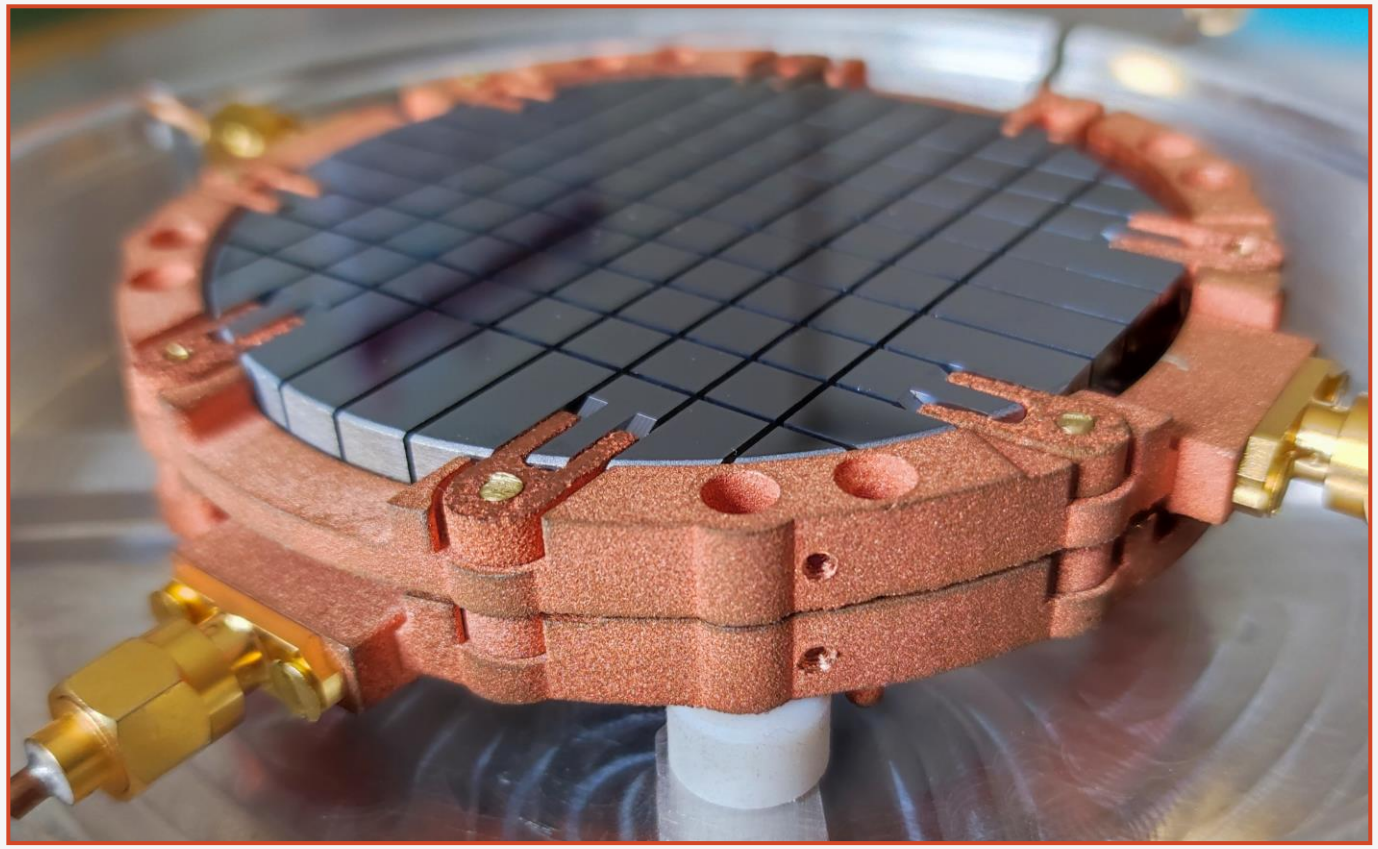
Quality factor (median): 80k

Coupling Q factor (median): 140k

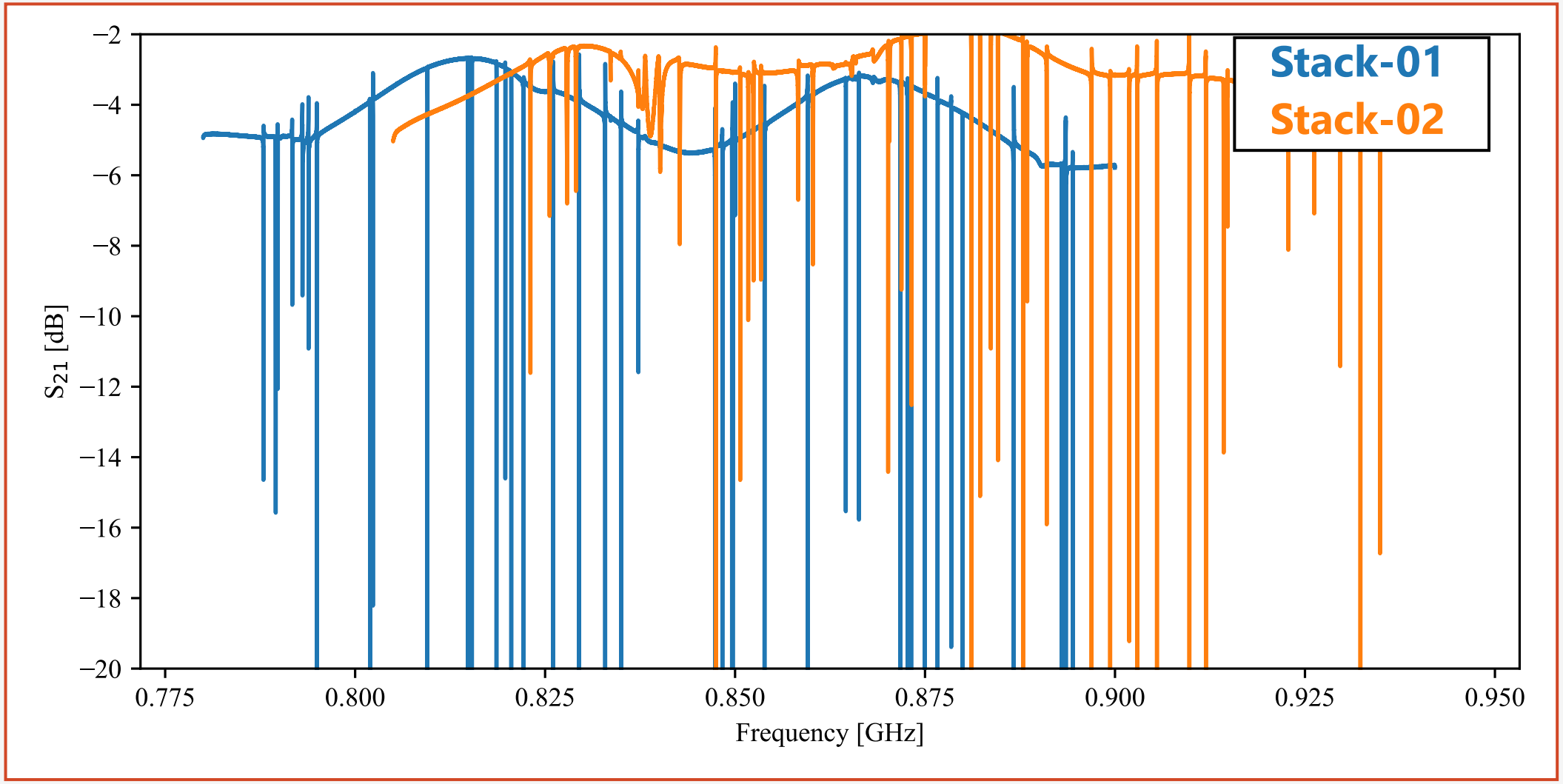
Current prototype of the 3 wafer demonstrator

First prototype:

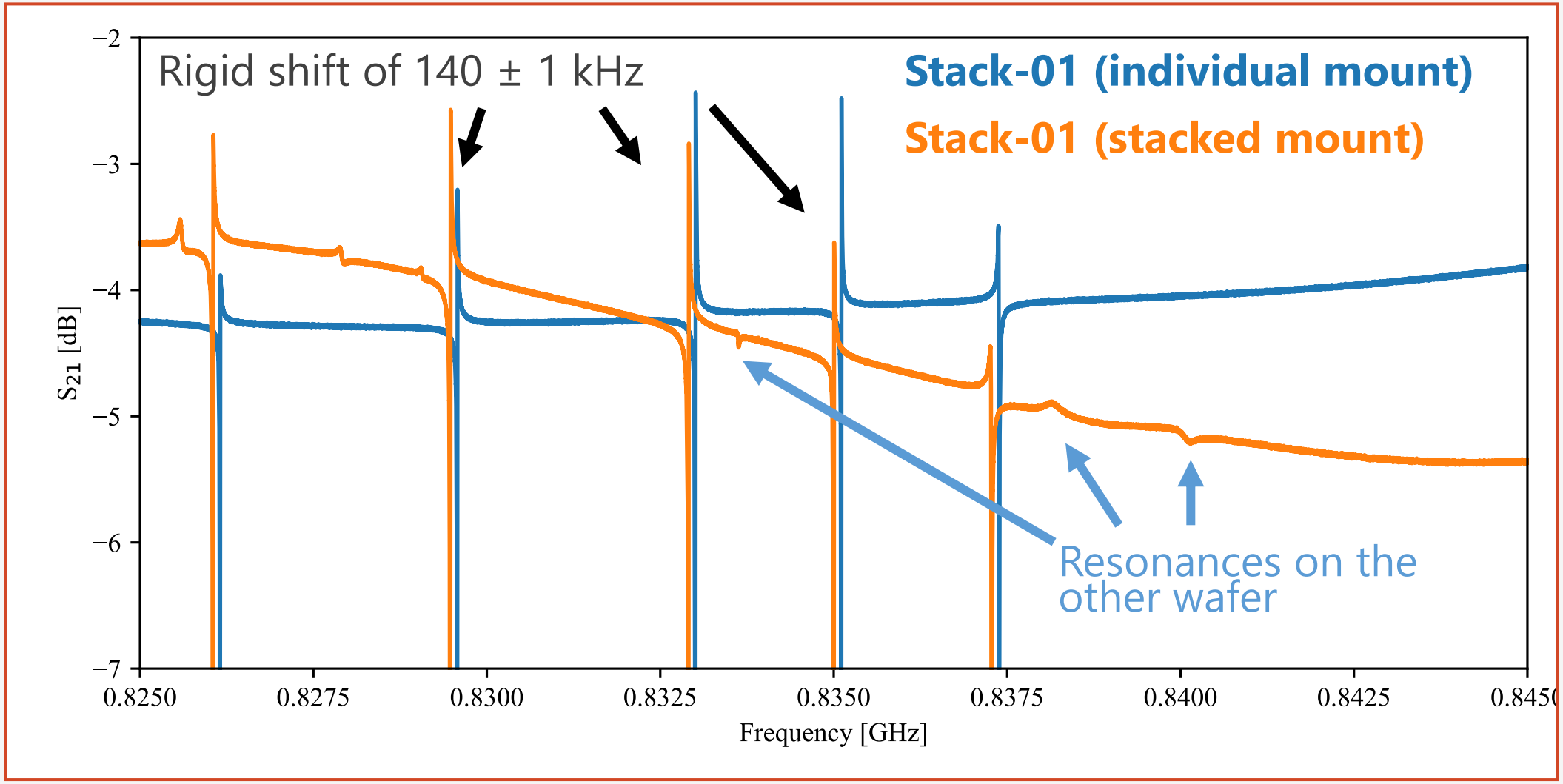
- 2x 3inch wafers
- Slightly different lithographic process to ease fabrication
- Two RF lines read sequentially
- Pixel uniformity is limited due to production difficulties
- Setup ready in our cryolab in Rome



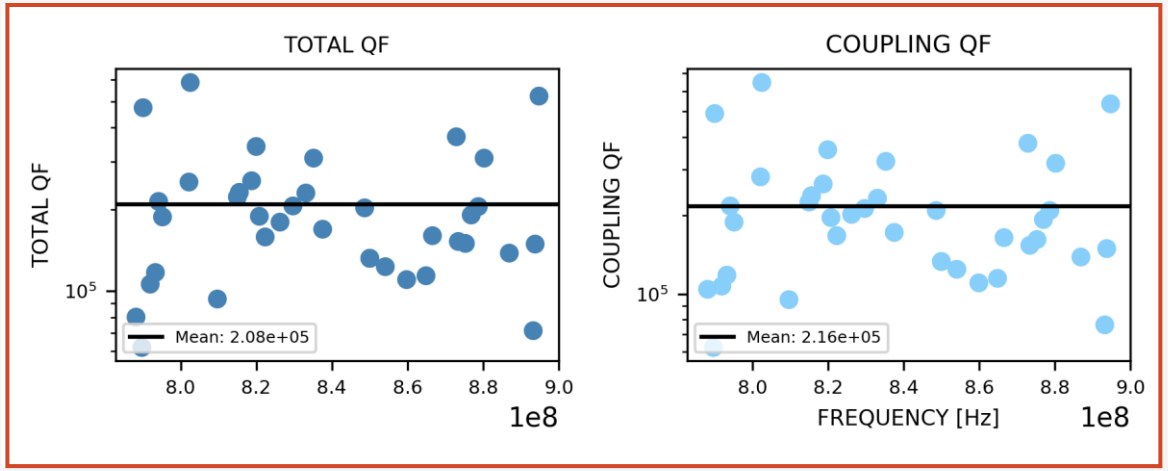
Independent scan on line 1 and 2

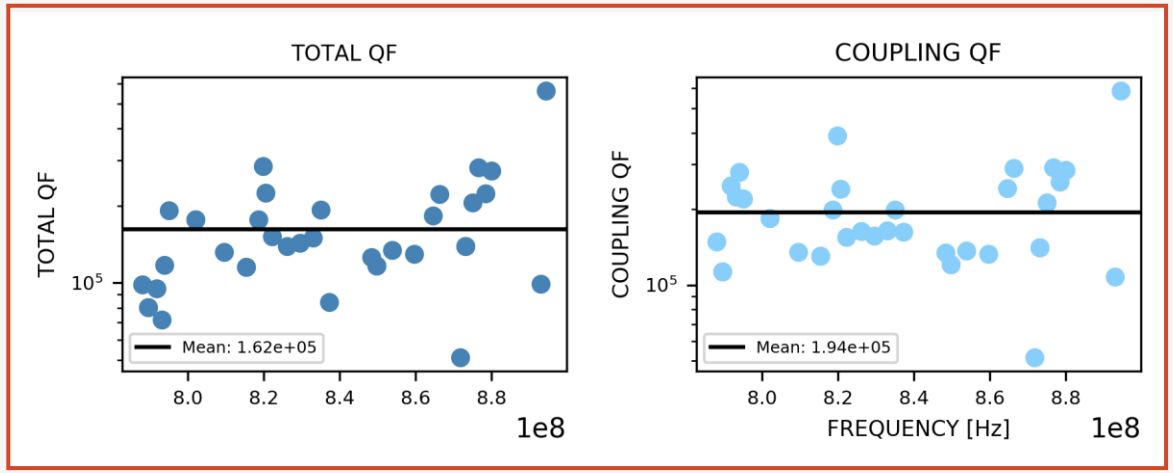


Preliminary results above ground



VNA scan on line 1: Q factor comparison





Stack-01: Individual mounting

Quality factor (median): 185k

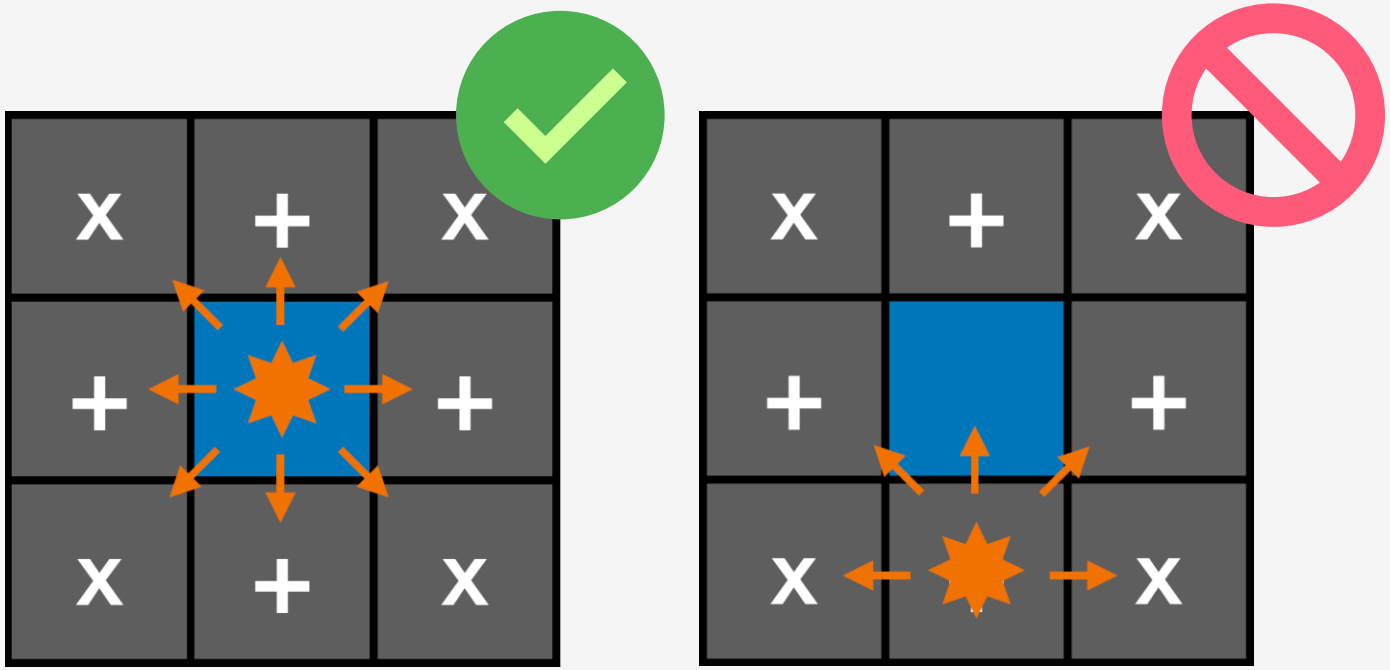
Coupling Q factor (median): 190k

Stack-01: Stacked mounting

Quality factor (median): 140k

Coupling Q factor (median): 160k

Preliminary results above ground: shielded background



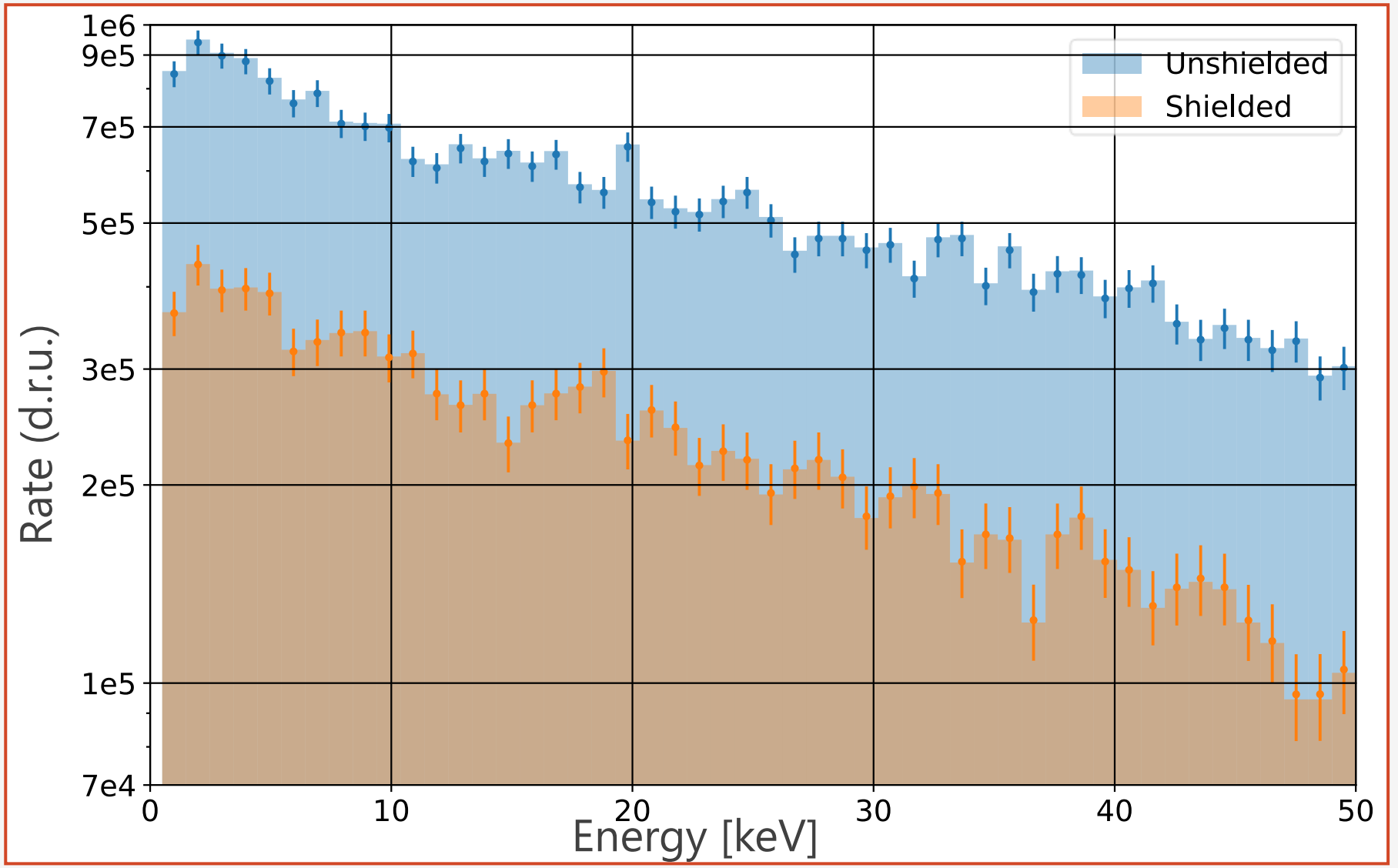
Resolution (KID-20): 50±2 eV @ 28±1 mrad/keV

Single 0.34g die vetoed by 8 neighbours

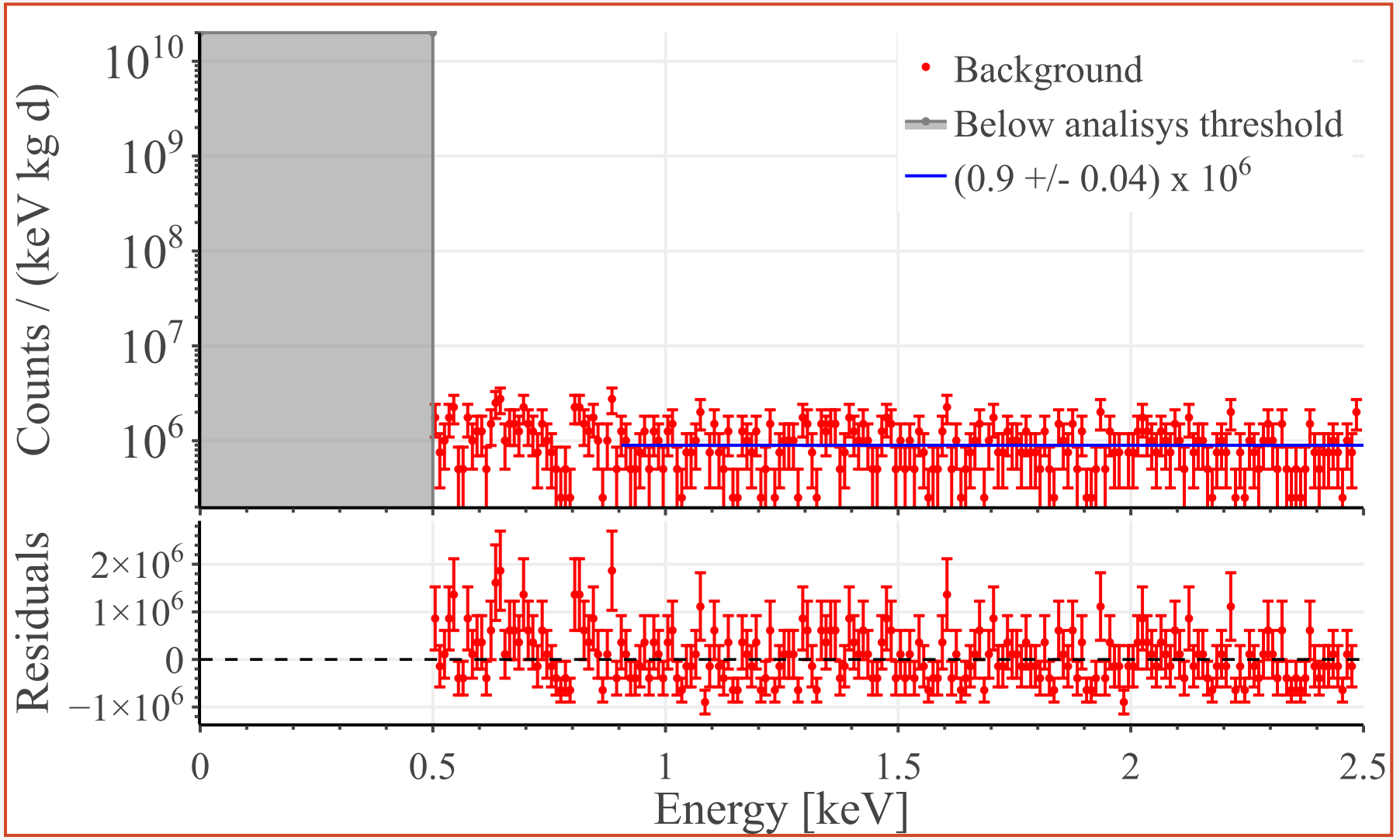
Total exposure of 40h

Acquisition above ground with passive lead shield

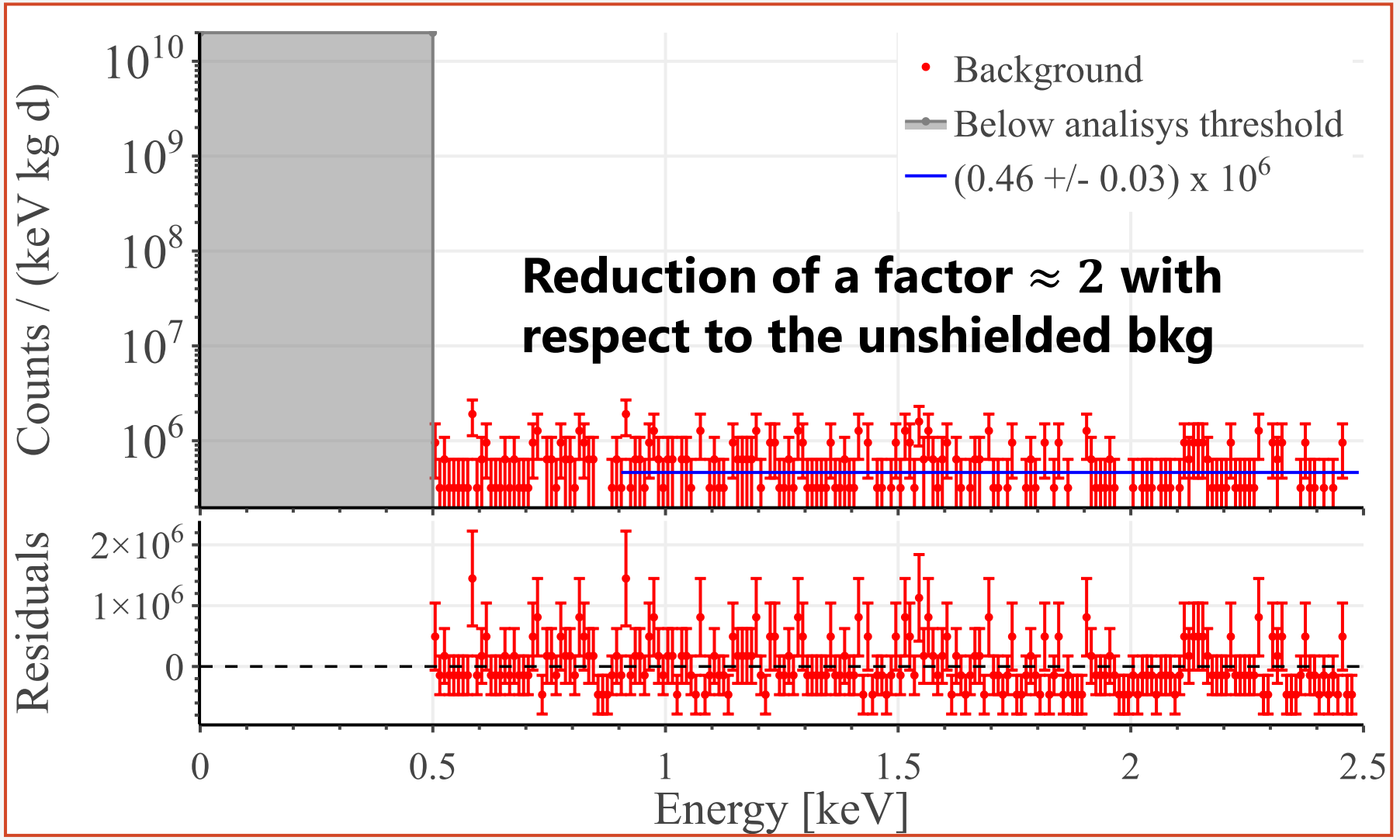
Above ground background analysis



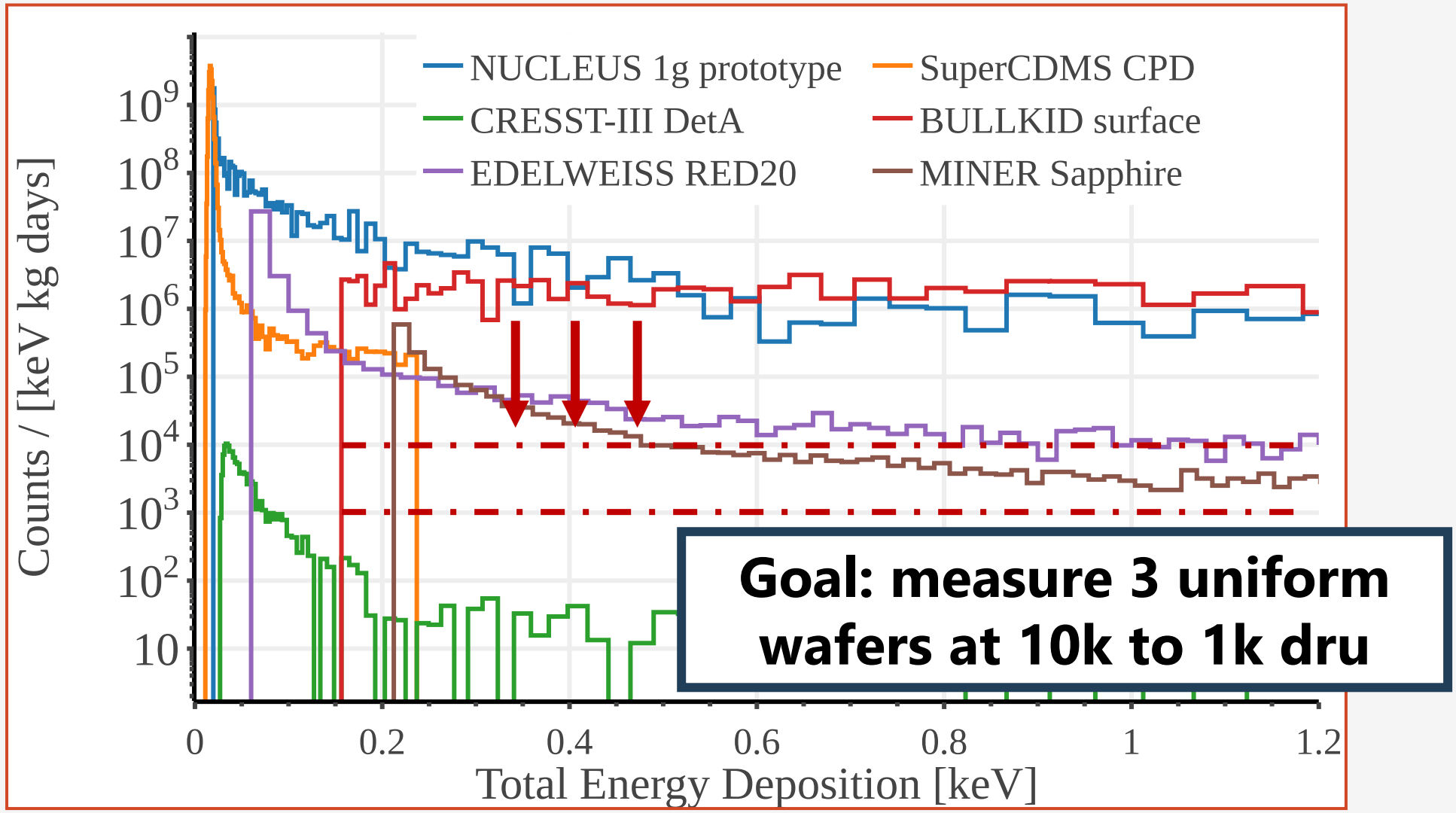
Low energy background analysis, unshielded spectrum



Low energy background analysis, Pb castle spectrum

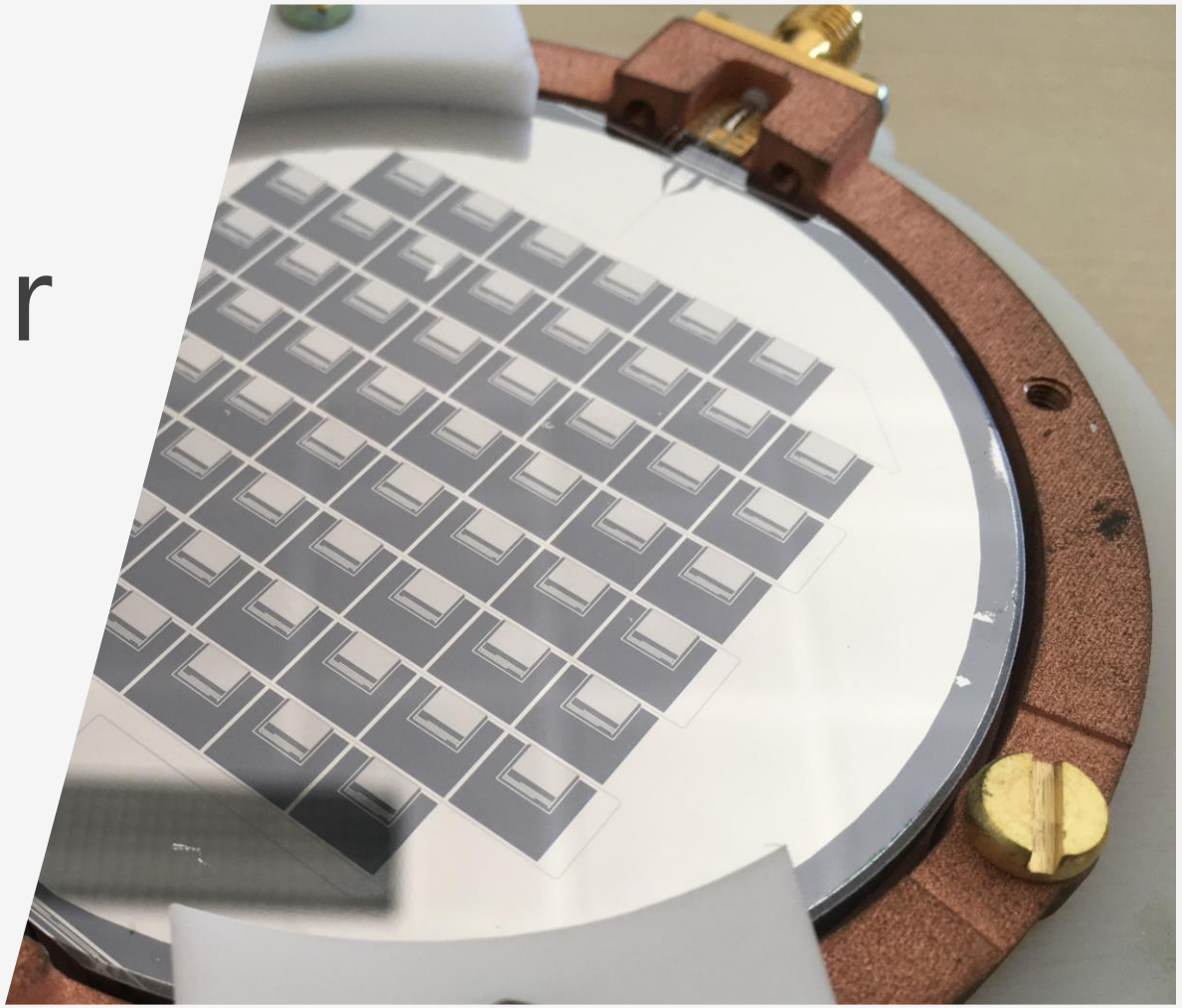


Future background analysis: uniformity and further shielding

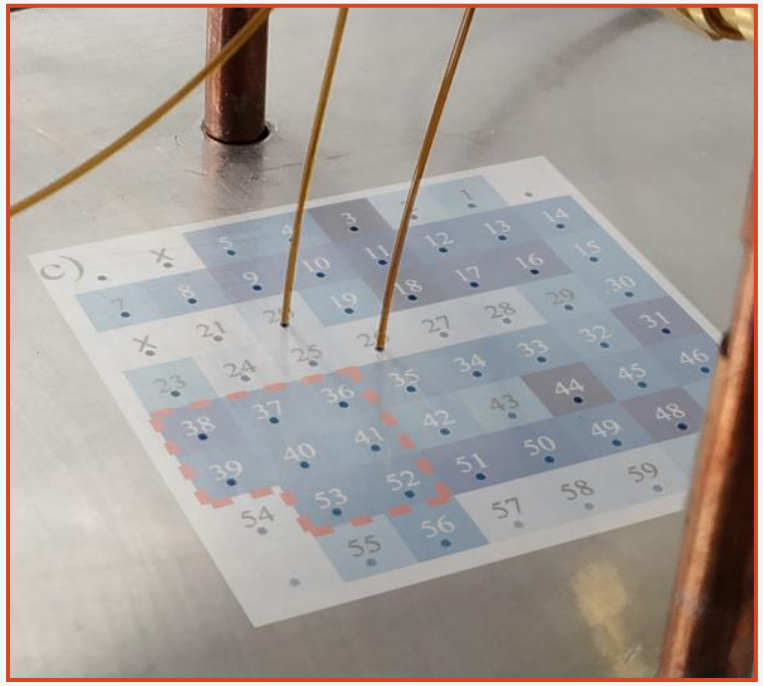


Conclusion

Thank you for your attention!



(Extra) Optical calibration setup

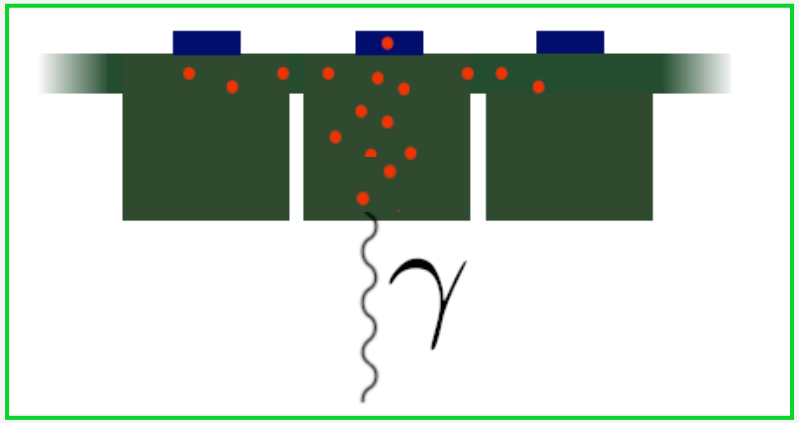


$$\sigma = \sqrt{\sigma_0^2 + \epsilon_{ph} \cdot \frac{\mathrm{d}\phi}{dE} \cdot \mu}$$

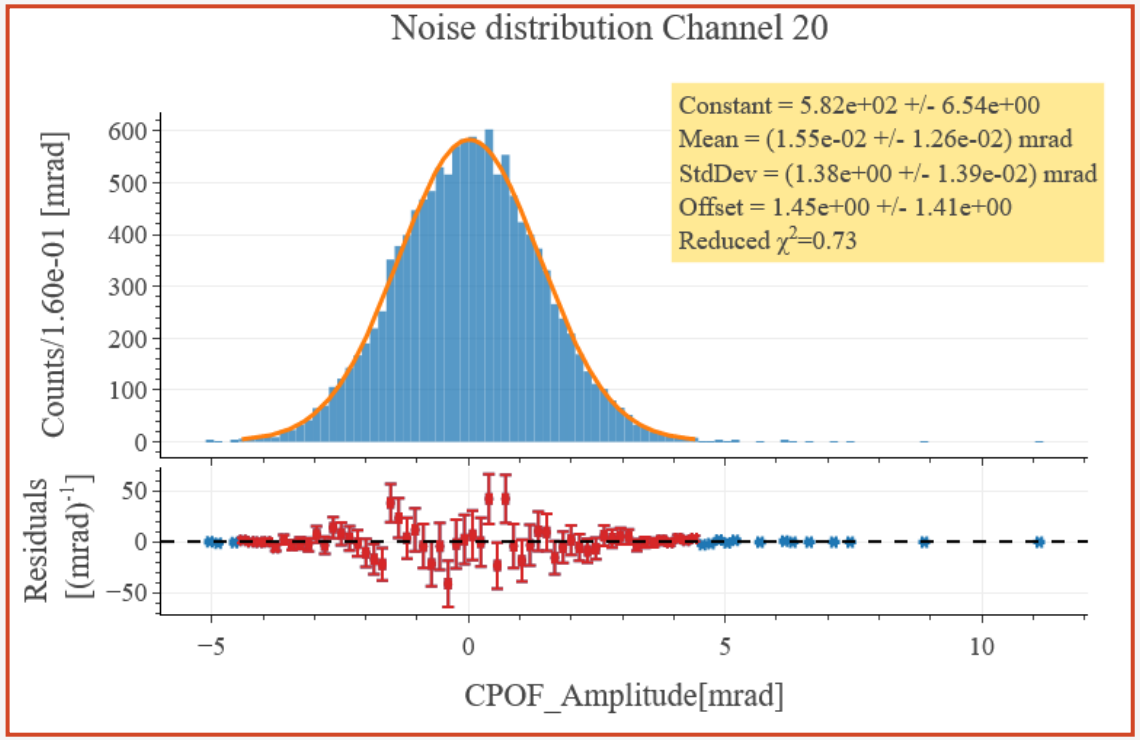
- σ_0 (resolution)
- $\frac{\mathrm{d}\phi}{dE}$ (responsivity)

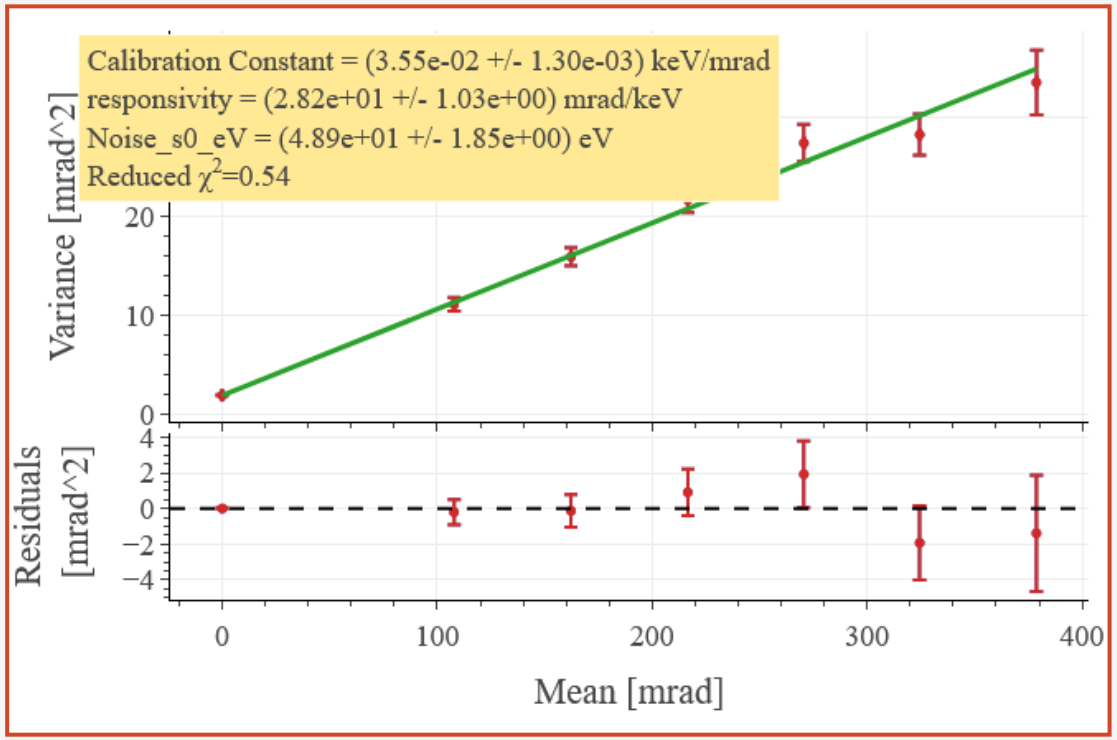
8 optical fibers firing on the diced side of the detector

400 nm UV lamp (ϵ_{ph} = 3.1 eV)

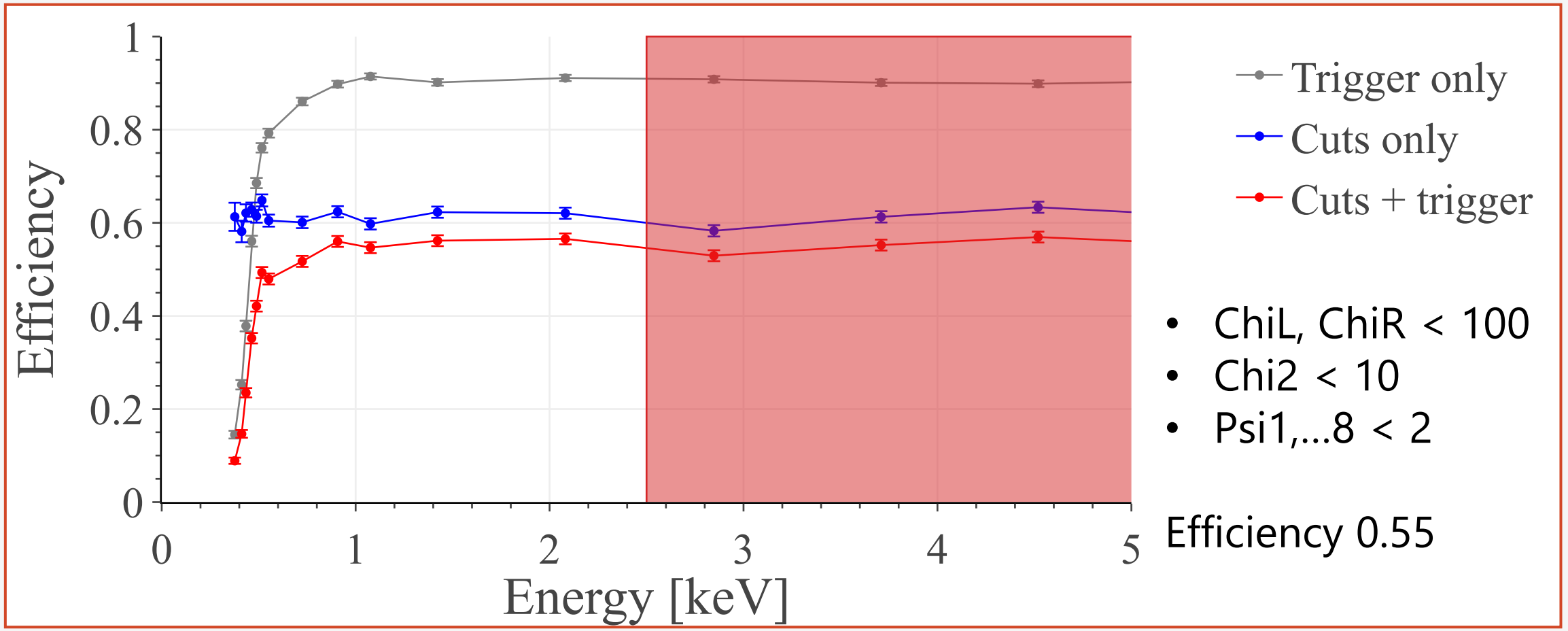


(Extra) Low energy background analysis, chan 20 calibration





(Extra) Low energy background analysis, cuts



- ChiL, ChiR < 100
- Chi2 < 10
- Psi1,...8 < 2

Efficiency 0.55