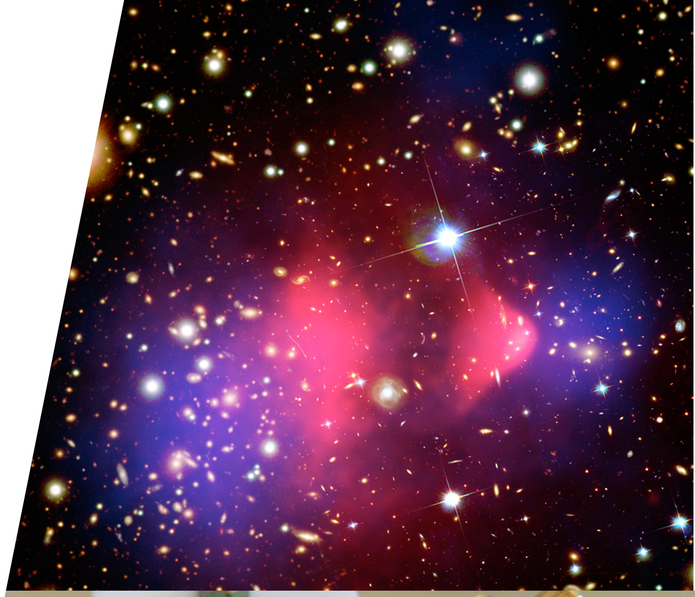
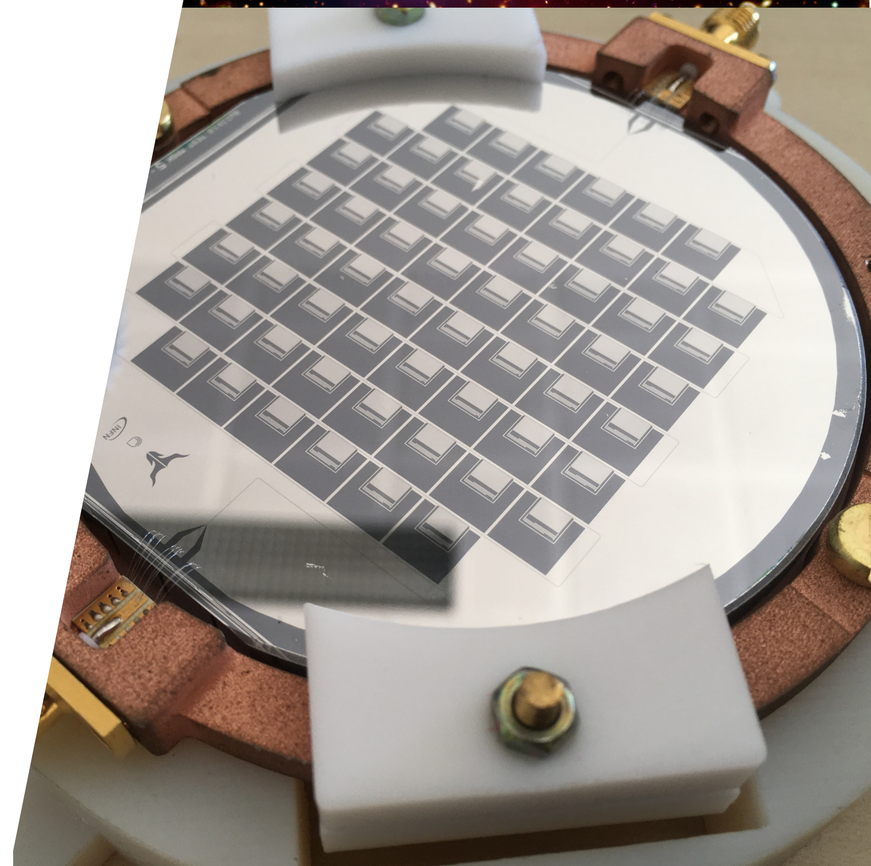
SAPIENZA
UNIVERSITÀ DI ROMA

INFN
Istituto Nazionale di Fisica Nucleare

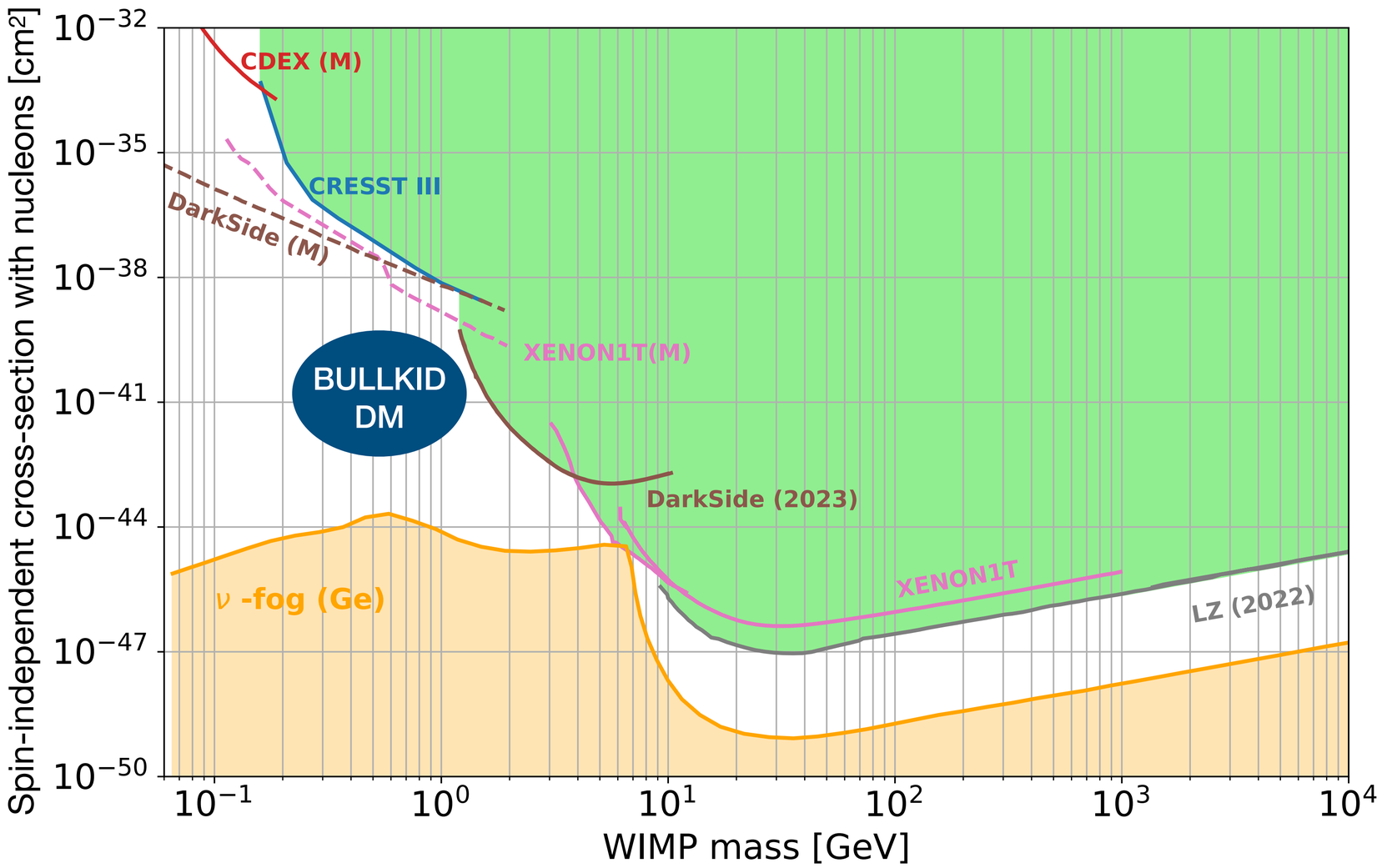




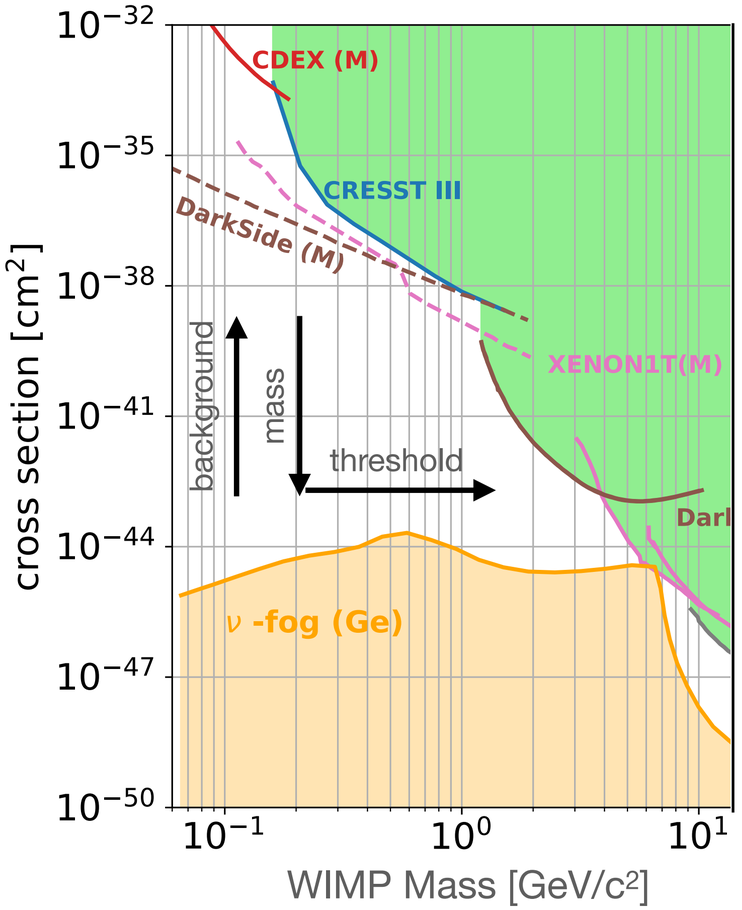
Status of BULLKID-DM

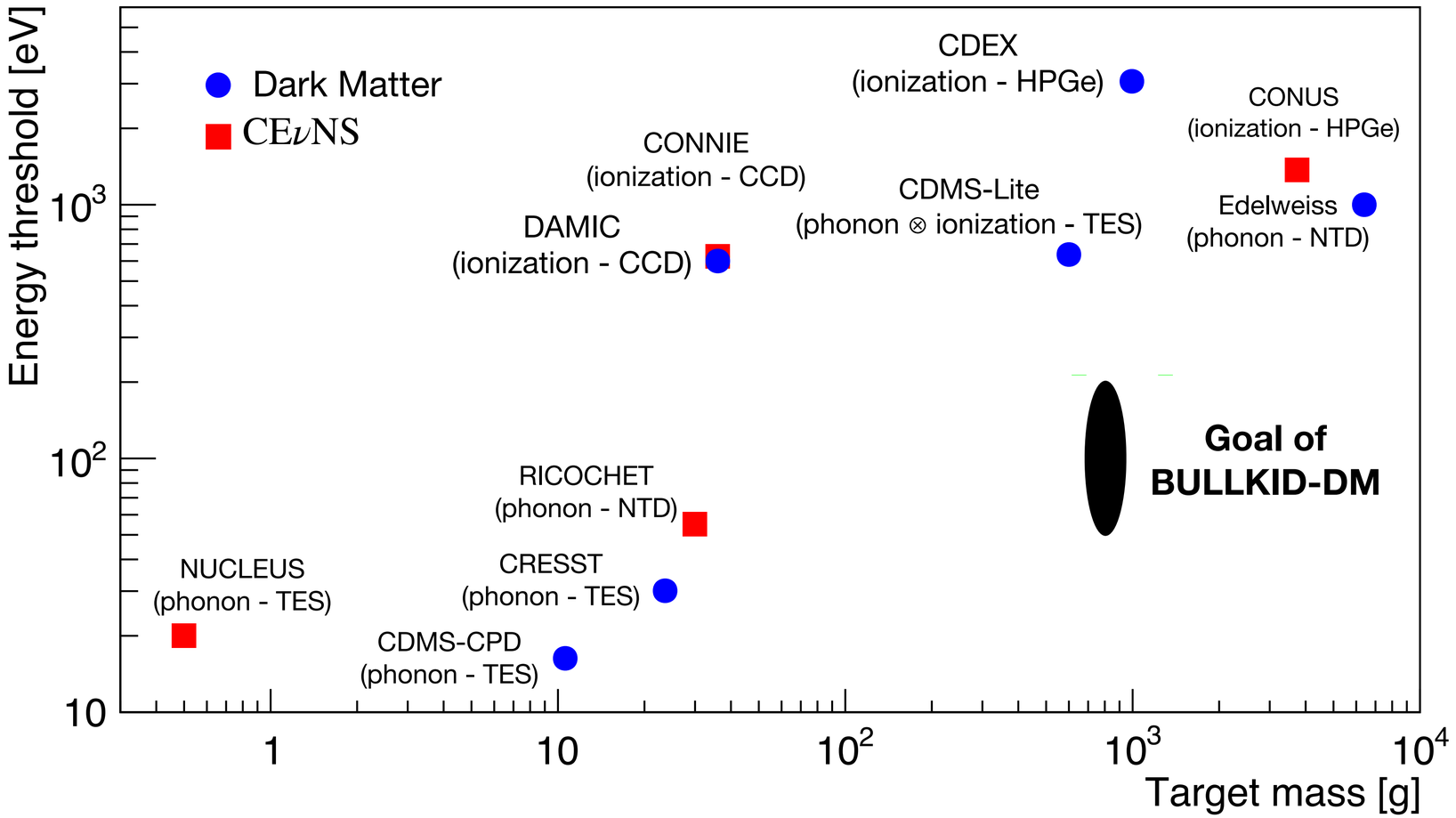
Marco Vignati on behalf of the coll.,
Identification of Dark Matter - L'Aquila - 9 July 2024

Objective


Spin-independent cross-section with nucleons [cm²]
10^{-32}
10^{-35}
10^{-38}
10^{-41}
10^{-44}
10^{-47}
10^{-50}
CDEX (M)
CRESST III
DarkSide (M)
XENON1T(M)
BULLKID DM
DarkSide (2023)
XENON1T
LZ (2022)
ν -fog (Ge)
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
WIMP mass [GeV]

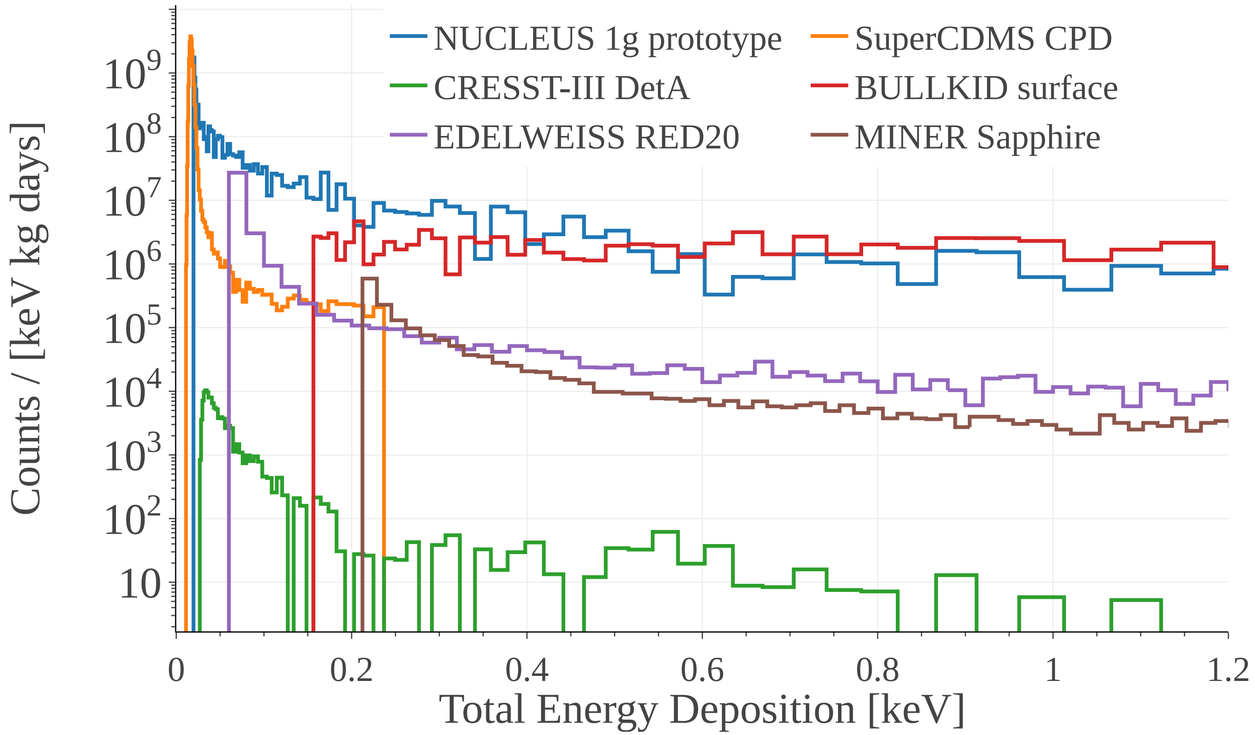
State of the art (solid-state detectors)





Background issue in low-T experiments

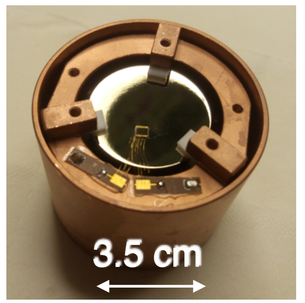
Not understood *excess* background rising at low energies



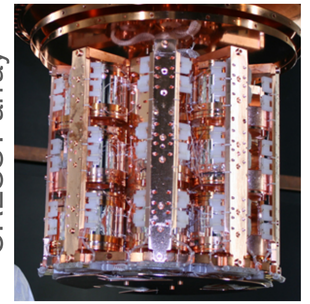
P. Adari, et al.: EXCESS workshop: Descriptions of rising low-energy spectra
SciPost Phys. Proc. 9 (2022) 001 + D. Delicato et al EPJ C 84 (2024) 353

- Phonons from supports or from the sensors?
- Lattice relaxations after cool down?
- ~~Neutrons (cosmic ray induced, radioactivity) ?~~

RED 20 (Ge, 33 g)



CRESST array



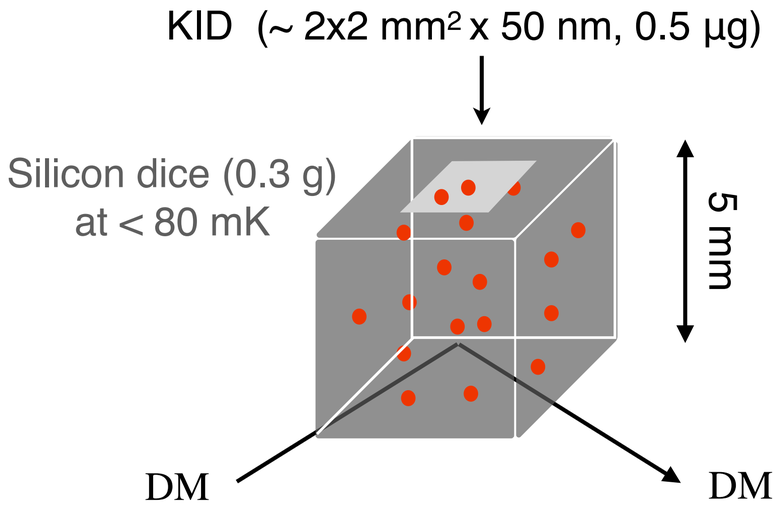
Excess workshop 2024
Roma, 6 July
https://agenda.infn.it/event/39007/

This background limits the sensitivity of present experiments

The BULLKID phonon-detector array

Phonon mediation

detect phonons created by nuclear recoils in a silicon die



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

The BULLKID phonon-detector array

Phonon mediation

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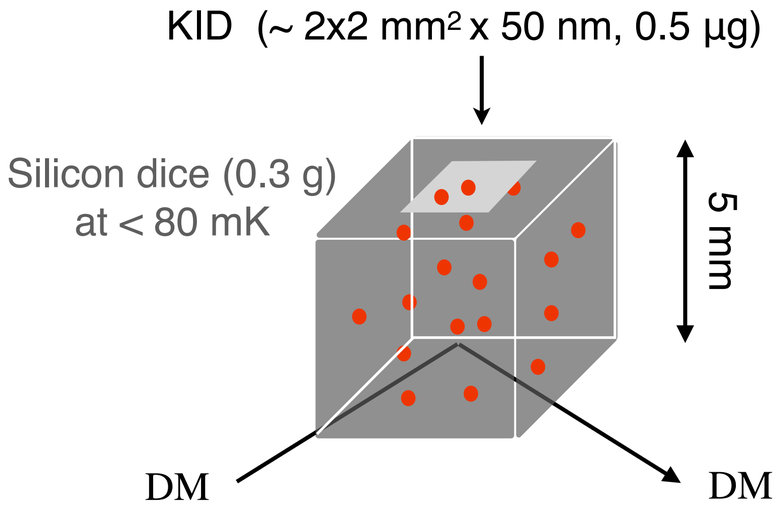
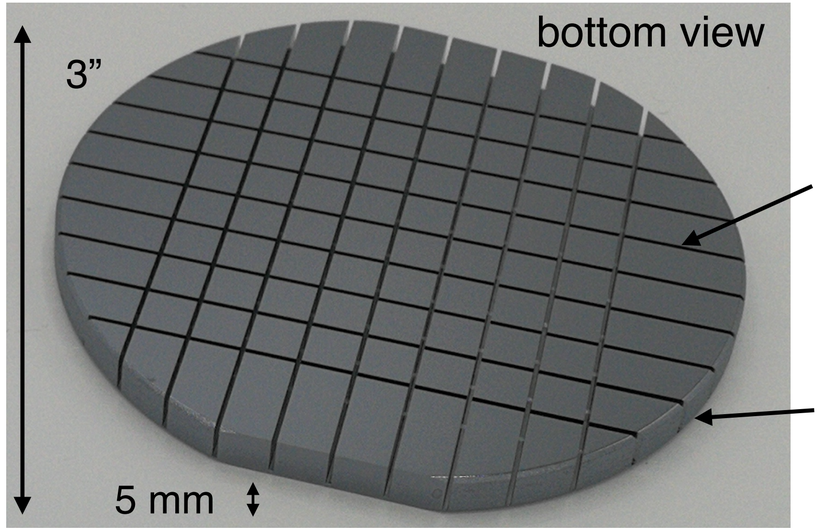


carving of dice in a thick silicon wafer



✓ monolithic

4.5 mm deep grooves
- 6 mm pitch
- chemical etching

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

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

The BULLKID phonon-detector array

Phonon mediation

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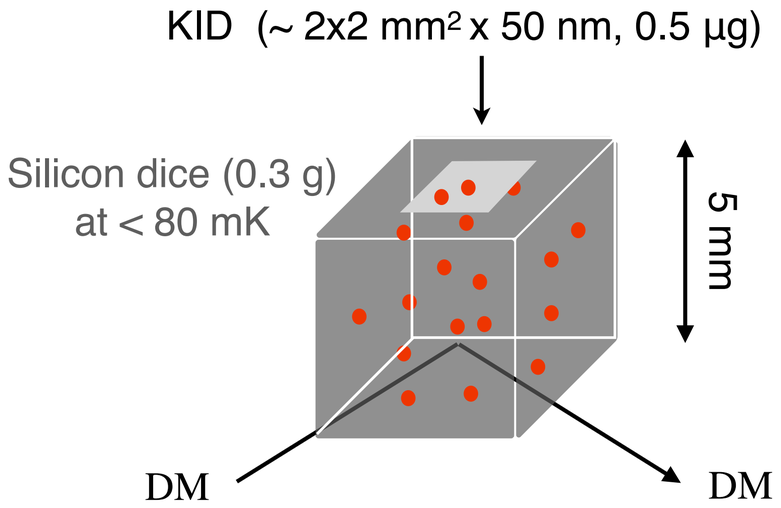
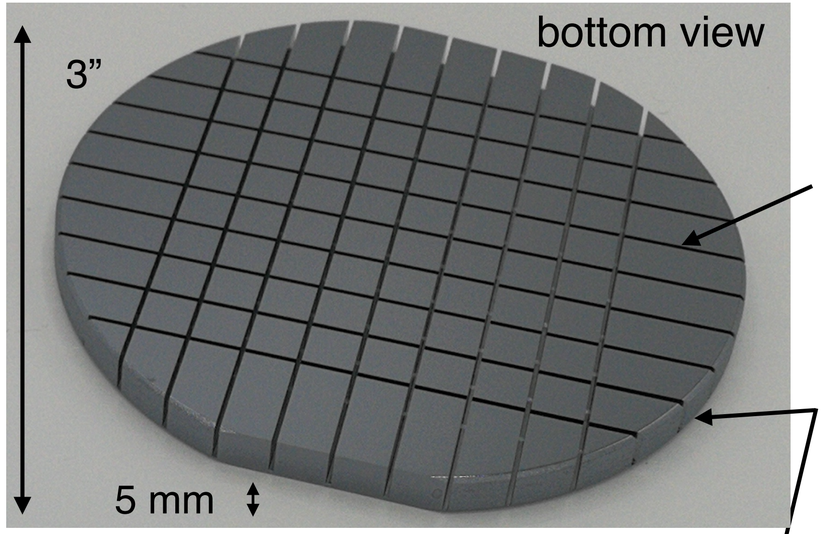


carving of dice in a thick silicon wafer

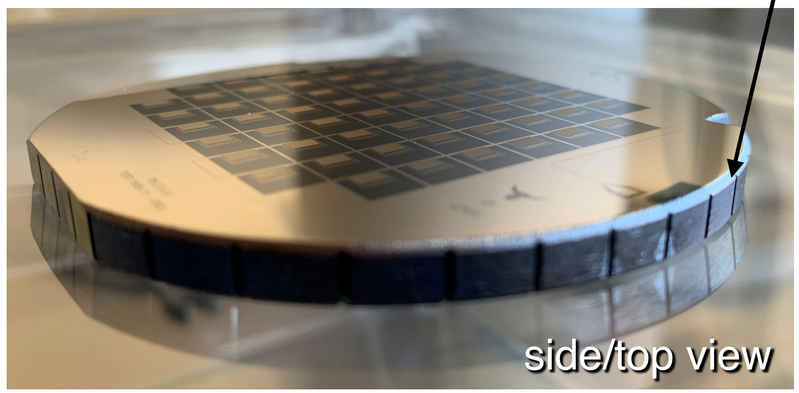


✓ monolithic

4.5 mm deep grooves
- 6 mm pitch
- chemical etching

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

lithography of KID sensors



KID sensor array:
- 60 nm thick aluminum film
- 60 elements (1 per die)

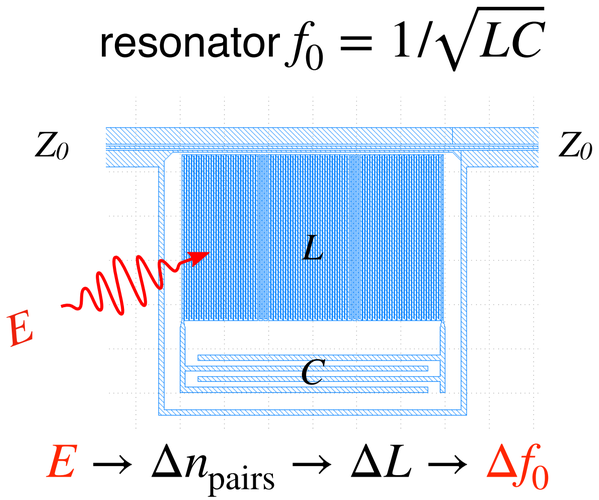
✓ 60 detectors in 1

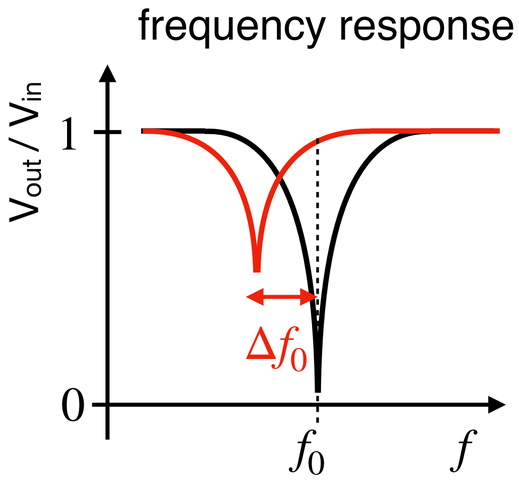
Fully multiplexed
(single readout line)

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

Kinetic Inductance Detectors (KIDs)

- Superconductor at T < 200 mK (Al)
- LC resonator
- Cooper pairs inductance $L_k = \dfrac{m_e}{2\,e^2\,n_{\text{pairs}}}$
- Absorbed energy breaks Cooper pairs





Kinetic Inductance Detectors (KIDs)

- Superconductor at T < 200 mK (Al)
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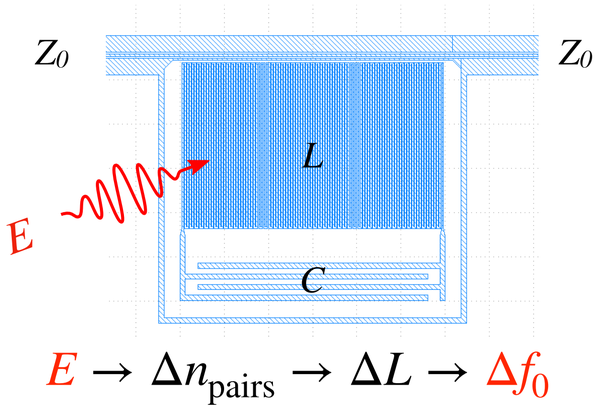
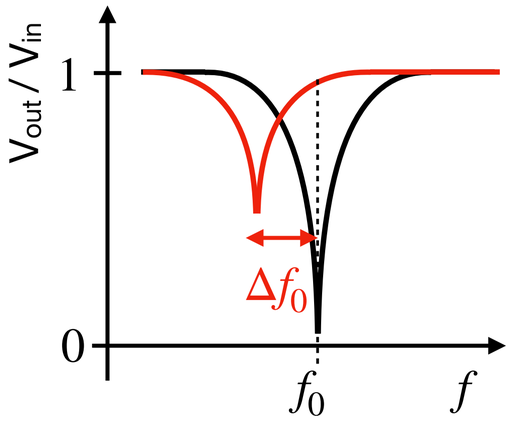
- Cooper pairs inductance $L_k = \dfrac{m_e}{2\,e^2\,n_{\text{pairs}}}$
- Absorbed energy breaks Cooper pairs

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

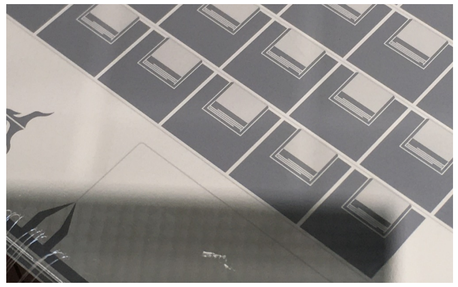


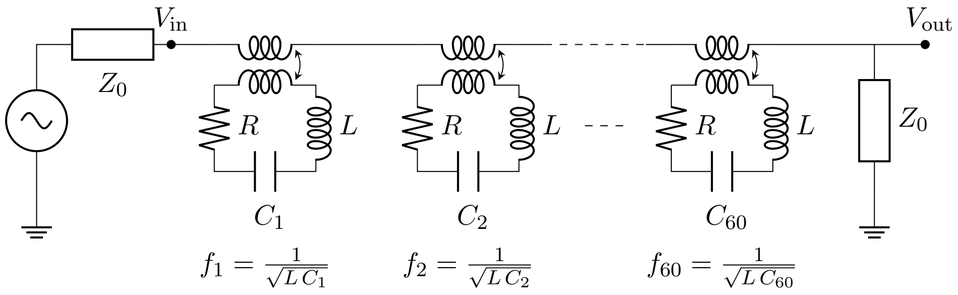
$E \rightarrow \Delta n_{\text{pairs}} \rightarrow \Delta L \rightarrow \Delta f_0$

frequency response

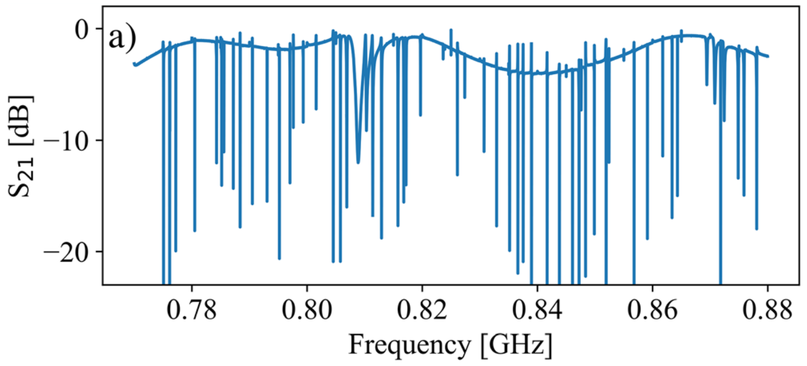


Readout: different KIDs coupled to a the same line



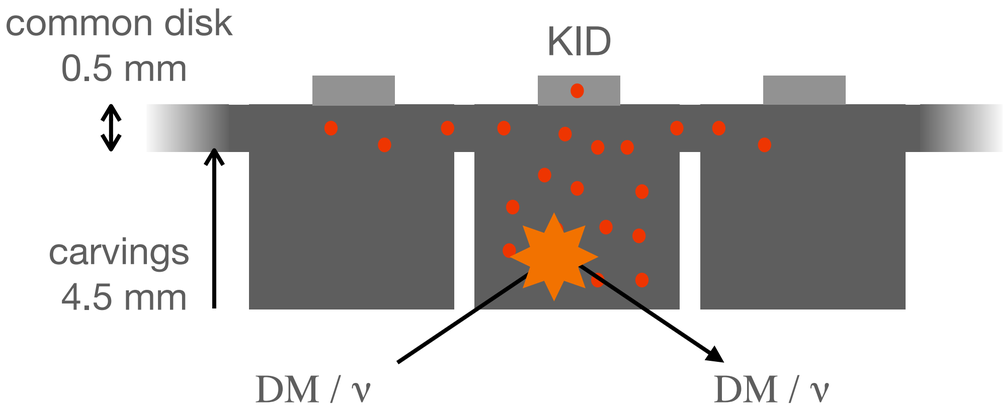


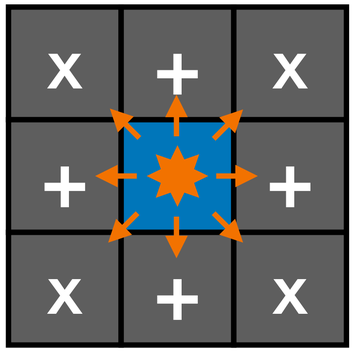
frequency scan of the 60 KIDs of BULLKID

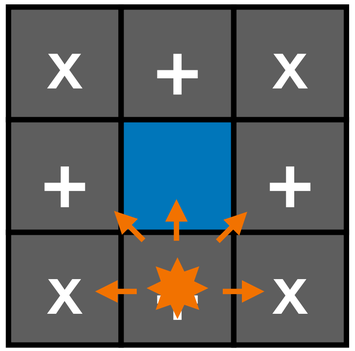


Phonon leakage and mapping

- 50% of phonons is detected in the interaction die
- 50% leaks out and is detected in nearby dice
  - (8 ± 2) % in each “+” die
  - (3 ± 1) % in each “x” die
  - the rest in outer dice

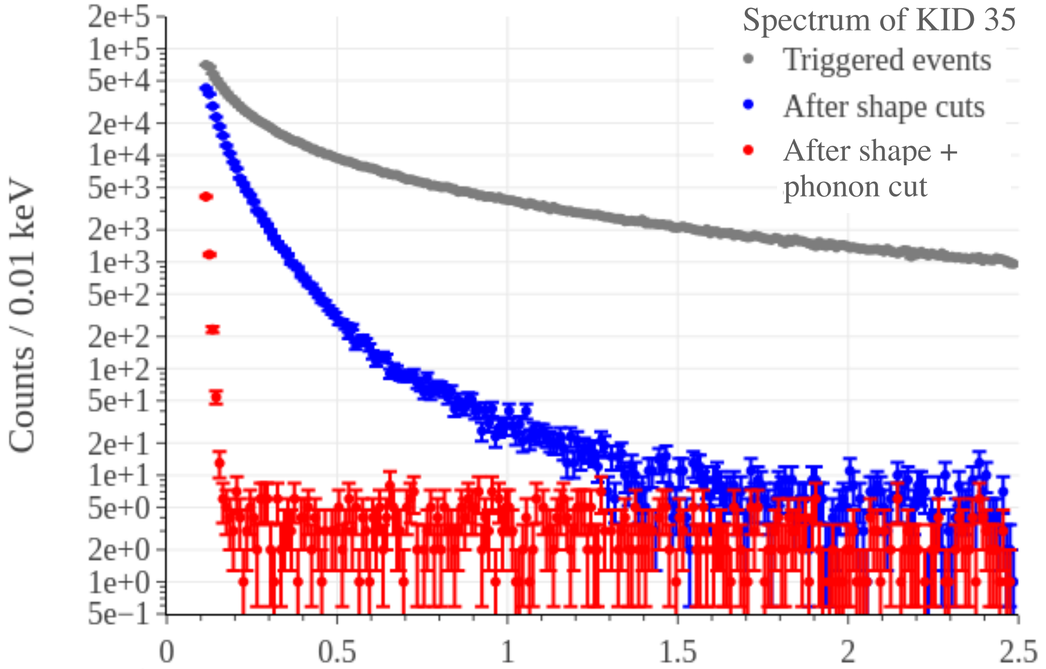


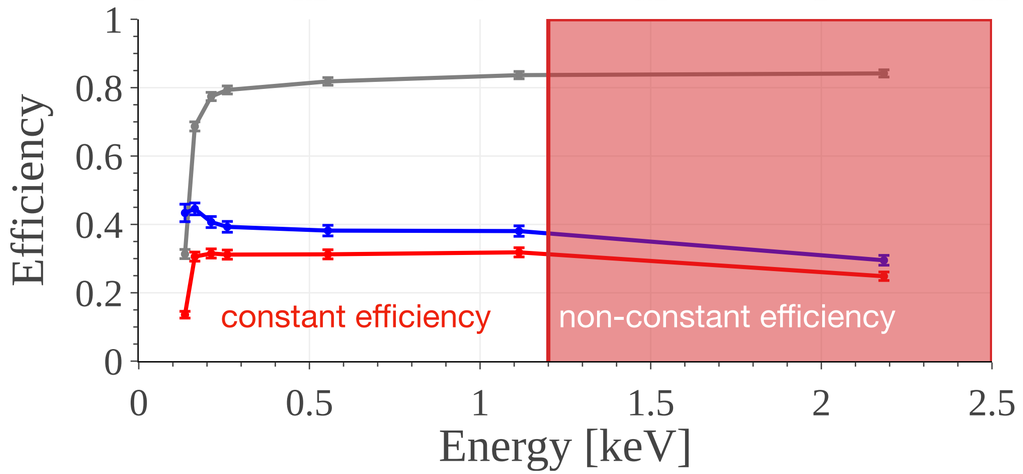




This effect reduces the phonon focusing on the KID but is
exploited to identify the interaction voxel

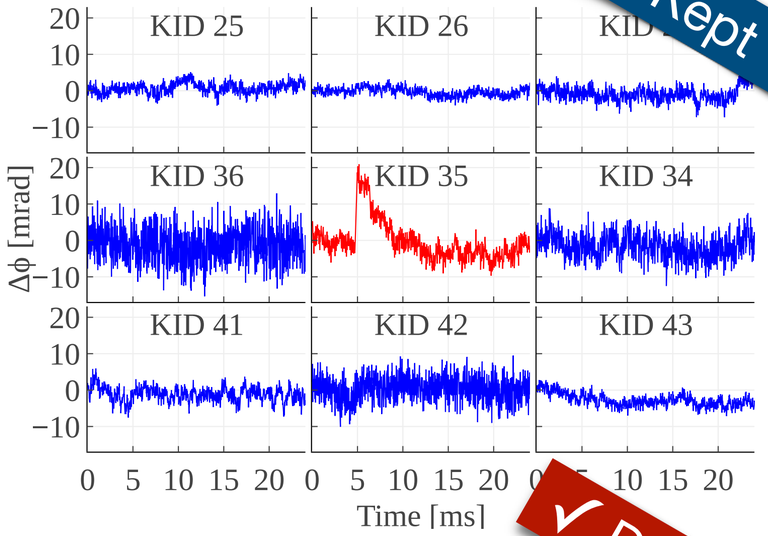
Background: pulse shape + phonon cuts



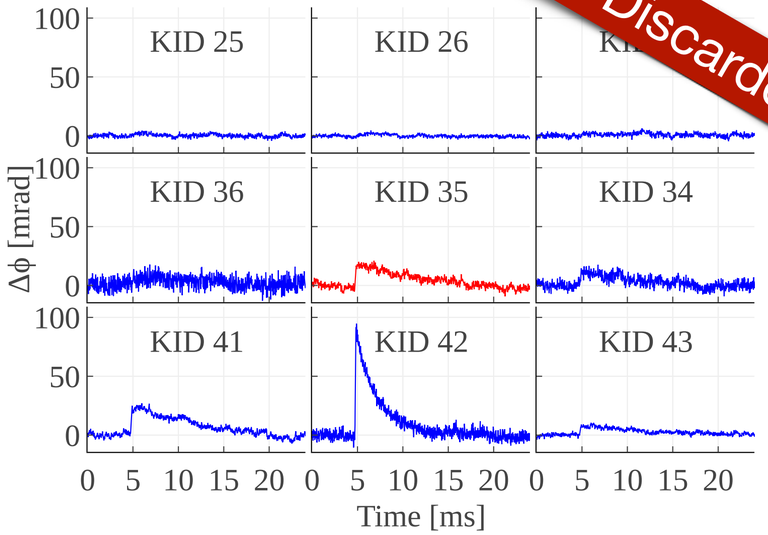


Trigger only
Cuts only
Cuts + trigger

✓ Kept

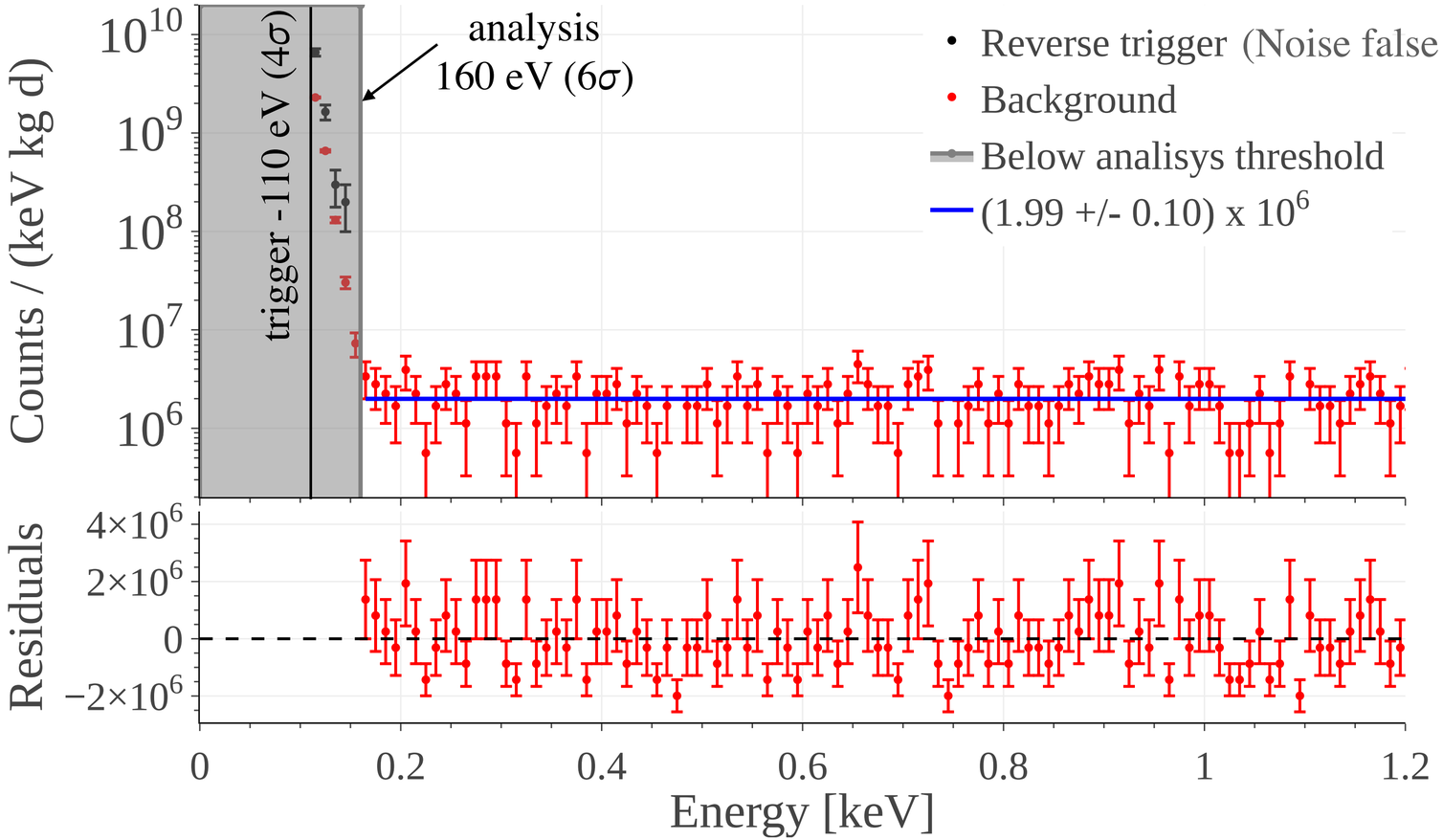


✓ Discarded



Background: result on surface

Above ground lab @Sapienza U., no shield, 39 live hours



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

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

BULLKID-DM Collaboration

March 2024 Coll. meeting at Gran Sasso labs

Roma
Ferrara
LNGS
Pisa

Istituto Nazionale di Fisica Nucleare

BULLKID-DM
Conceptual Design Report (CDR)

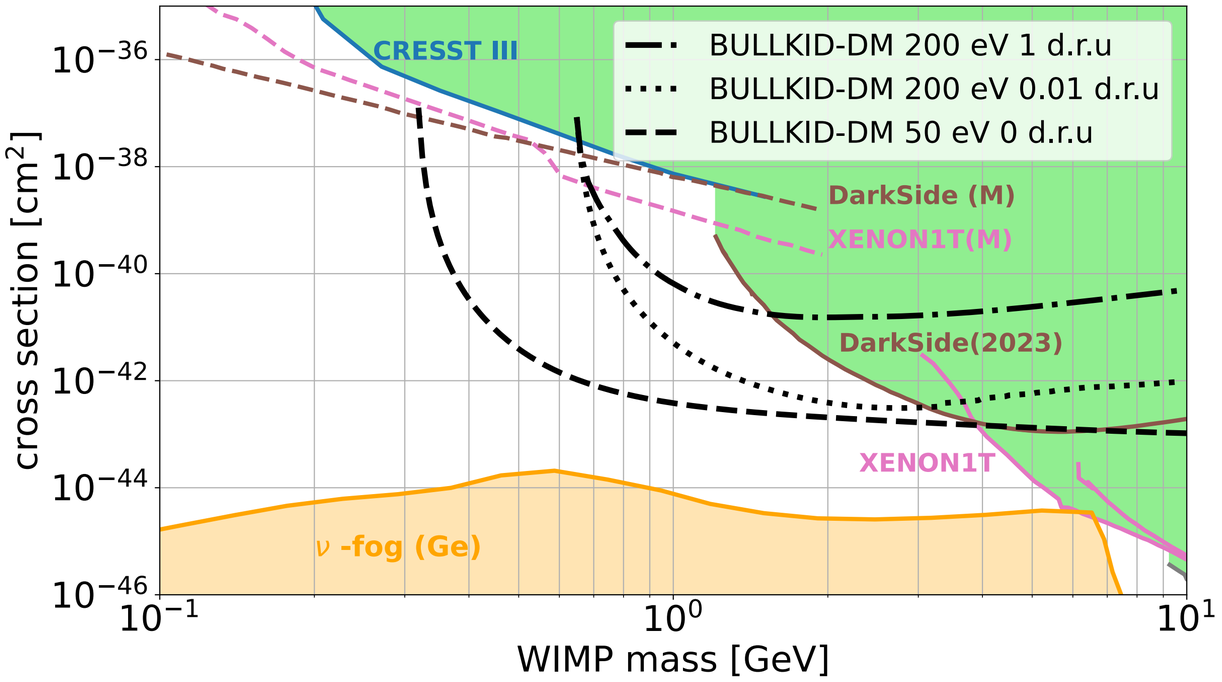
L. Ardila-Perez[1], P. Azzurri[2], L. Bandiera[3], M. Calvo[4], M. Cappelli[8,6], R. Caravita[5], F. Carillo[2], U. Chowdhury[4], A. Cruciani[6], A. D'Addabbo[7], D. Delicato[4,8,6], G. Del Castello[8,6], M. del Gallo Roccagiovine[8,6], M. de Lucia[9,2], F. Ferraro[7], M. Folcarelli[8,6], R. Gartmann[1], M. Grassi[2], V. Guidi[10,3], T. Lari[9,2], L. Malagutti[3], A. Mazzolari[10,3], A. Monfardini[4], T. Muscheid[1], D. Nicolò[9,2], F. Paolucci[2], D. Pasciuto[6], V. Pettinacci[6], C. Puglia[2], C. Roda[9,2], S. Roddaro[2], M. Romagnoni[3], O. Sander[1], G. Signorelli[9,2], F. Simon[1], M. Tamisari[11,3], A. Tartari[2], E. Vázquez-Jáuregui[12], and M. Vignati[8,6]

[1]*Karlsruhe Institute of Technology (KIT), Institute for Data Processing and Electronics (IPE), Hermann-von-Helmholtz-Platz* 1, 76344 *Eggenstein-Leopoldshafen, Germany*
[2]*INFN - Sezione di Pisa Largo Bruno Pontecorvo* 3, 56127 *Pisa, Italy*
[3]*INFN - Sezione di Ferrara Via Saragat* 1, 44121, *Ferrara, Italy*
[4]*Univ. Grenoble Alpes, CNRS, Grenoble INP Institut Néel,* 38000 *Grenoble, France*
[5]*INFN - TIFPA Via Sommarive* 14, 38123 *Povo (Trento), Italy*
[6]*INFN - Sezione di Roma Piazzale Aldo Moro* 2, 00185, *Roma, Italy*
[7]*INFN - Laboratori Nazionali del Gran Sasso, I-*67100 *Assergi (AQ), Italy*
[8]*Dipartimento di Fisica, Sapienza Università di Roma, Piazzale Aldo Moro* 2, 00185, *Roma, Italy*
[9]*Dipartimento di Fisica, Università di Pisa, Largo Bruno Pontecorvo* 3, 56127 *Pisa, Italy*
[10]*Dipartimento di Fisica e Scienze della Terra, c Via Saragat* 1, 44100, *Ferrara, Italy*
[11]*Dipartimento di Neuroscienze e Riabilitazione, Università di Ferrara, Via Luigi Borsari* 46, 44121 *Ferrara, Italy*
[12]*Instituto de Física, Universidad Nacional Autónoma de México, A.P.* 20-364, *Ciudad de México* 01000, *México.*

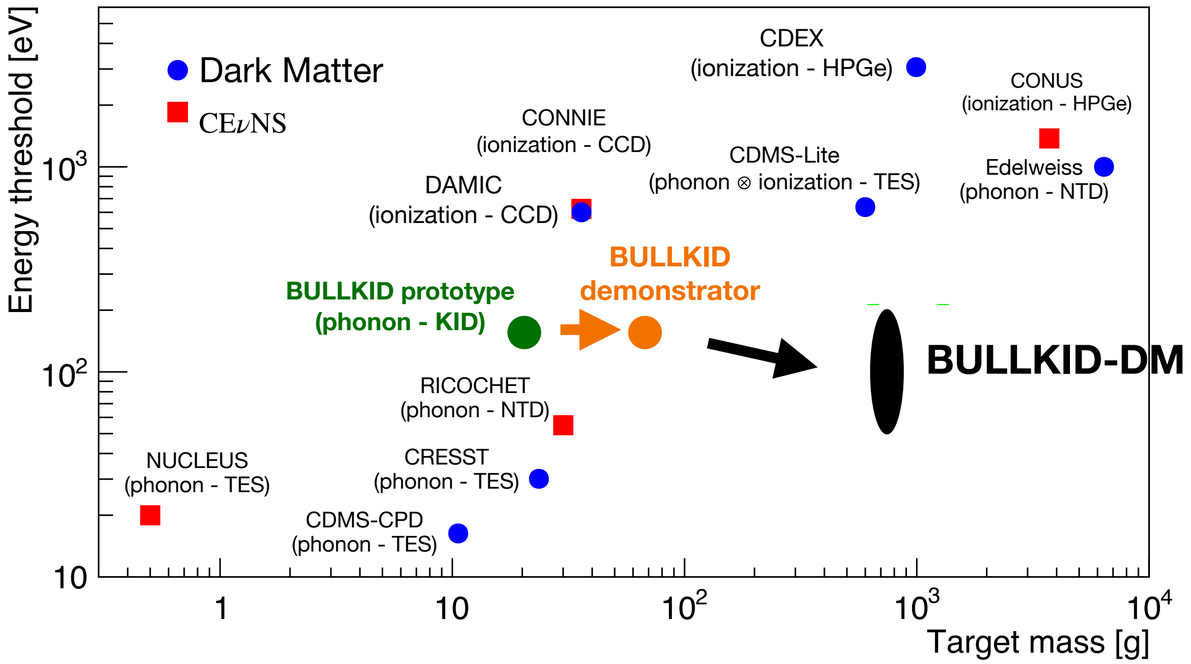
June 28, 2024

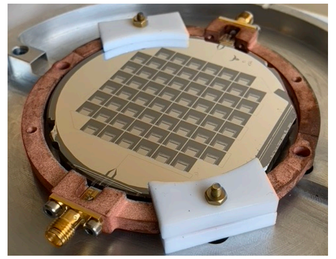
Dark Matter - direct search with BULLKID-DM

	BULLKID prototype	BULLKID-DM demonstrator		BULLKID-DM
mass	20 g	60 g		**800 g**
# of sensors	60	180		**2300**
threshold	160 eV	200 eV		**≤ 200 eV**
bkg (c/keV kg d)	$2x10^6$	$< 10^5$		**1 - 0.01**
laboratory	Sapienza U.	Sapienza	LNGS	**LNGS**
installation	2023	2024	2026	**2027**

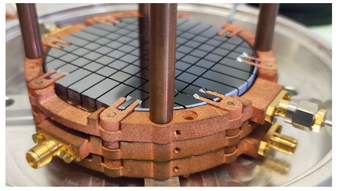


Threshold and mass

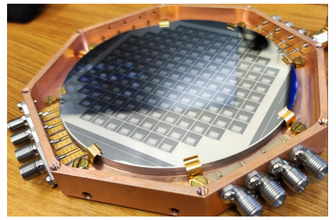




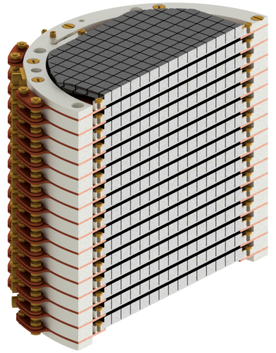
Prototype - 20 g / 60 dice
single 3” wafer
concluded in 2023



Demonstrator - 60 g / 180 dice
3-layer stack of 3” wafers
first operations ongoing

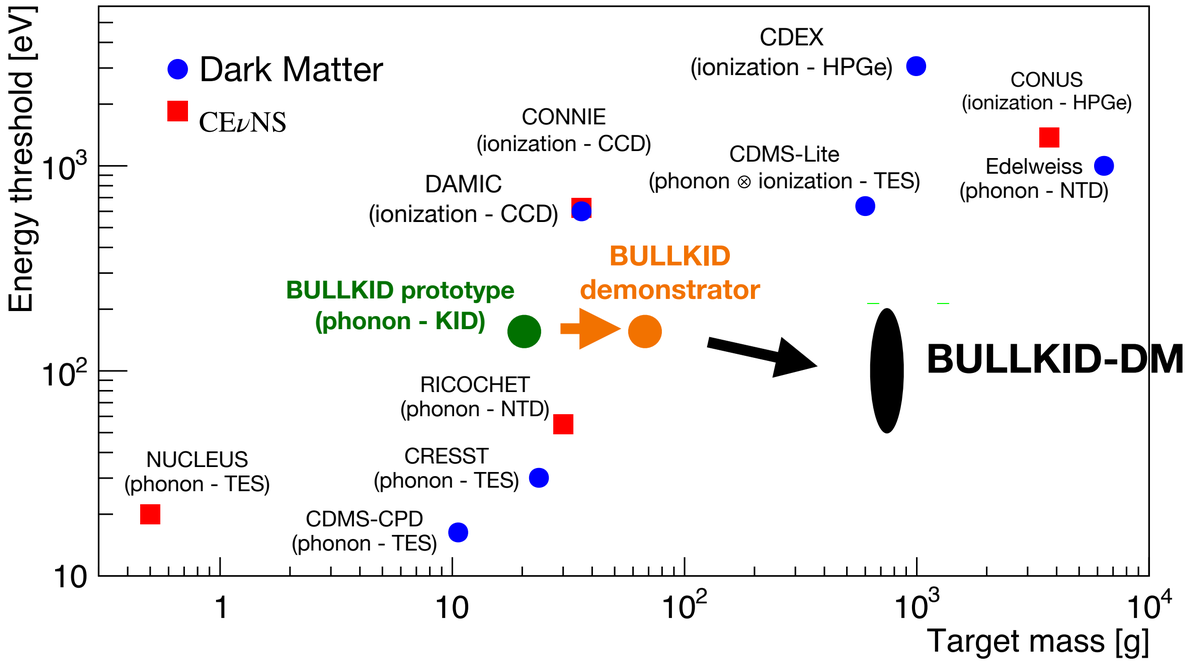


R&D on large wafer 50 g / 145 dice
single 100 mm wafer
first operations fall 2024



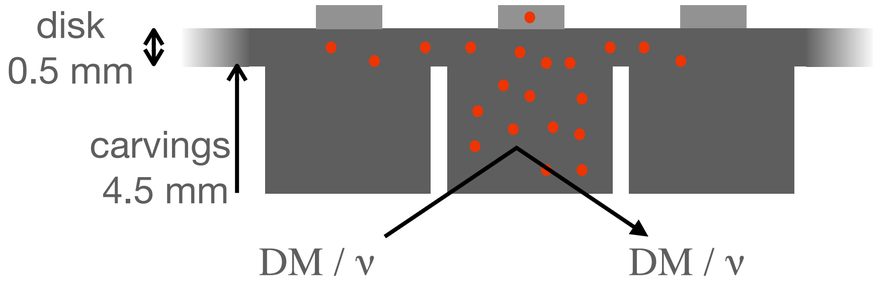
BULLKID-DM - 800 g / 2300 dice
16-layer stack of 100 mm wafers
commissioning in 2026 at Sapienza U.

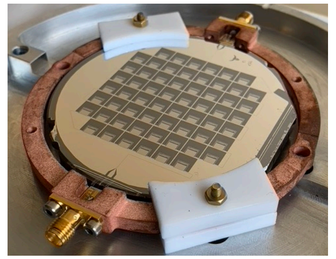
Threshold and mass



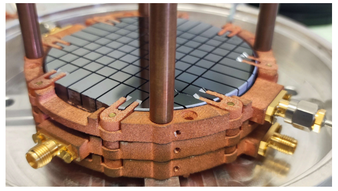
Threshold (ongoing R&Ds):

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

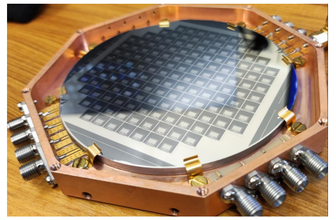




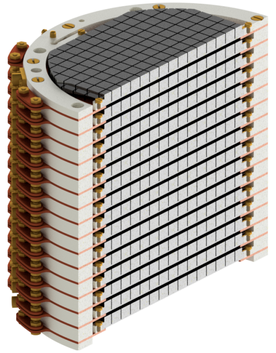
Prototype - 20 g / 60 dice
single 3” wafer
concluded in 2023



Demonstrator - 60 g / 180 dice
3-layer stack of 3” wafers
first operations ongoing



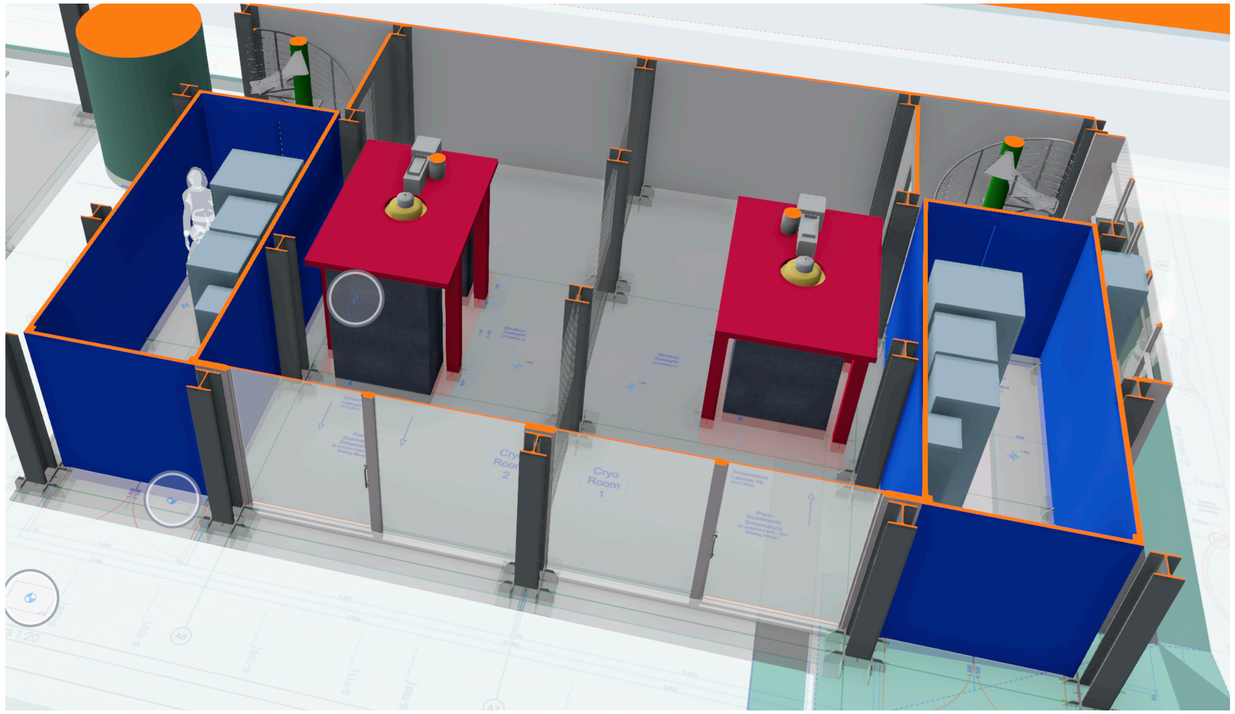
R&D on large wafer 50 g / 145 dice
single 100 mm wafer
first operations fall 2024



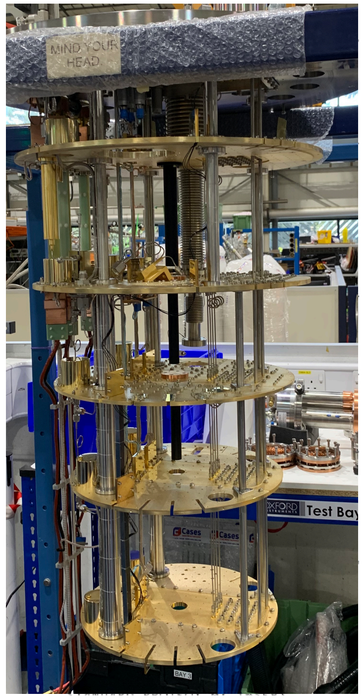
BULLKID-DM - 800 g / 2300 dice
16-layer stack of 100 mm wafers
commissioning in 2026 at Sapienza U.

LNGS Cryogenic facility

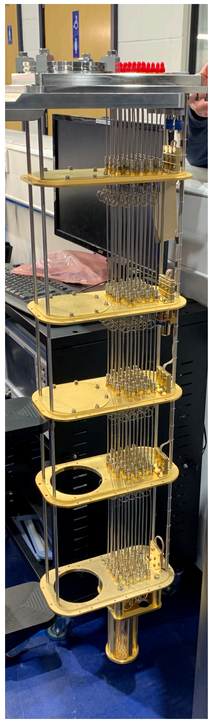
BULLKID-DM intends to be a user of the new facility in Hall B
Additional shielding might be required



Ordered Oxford Proteox fits the needs



Replaceable insert to be instrumented with RF lines

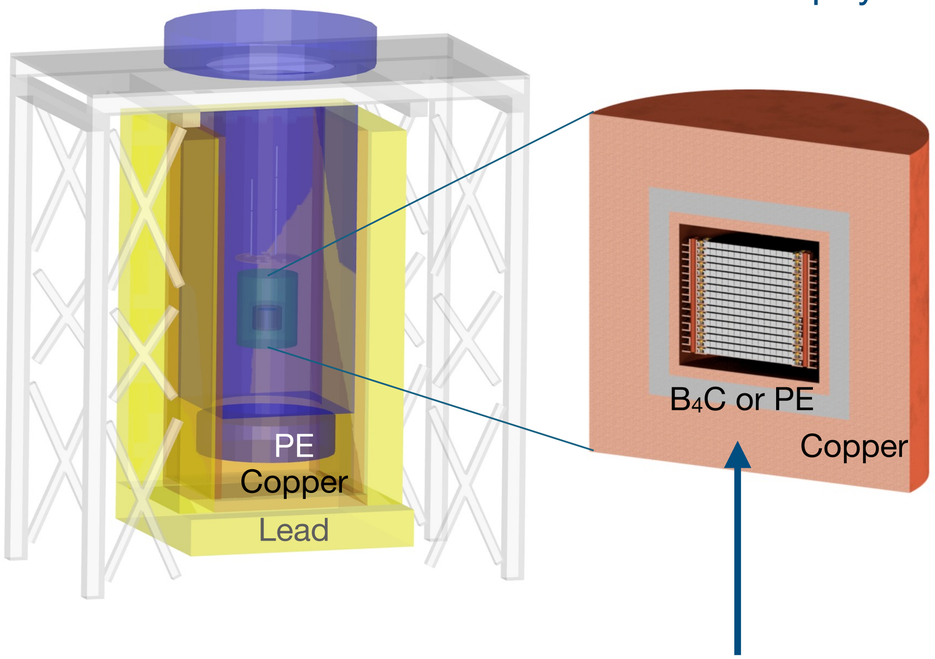


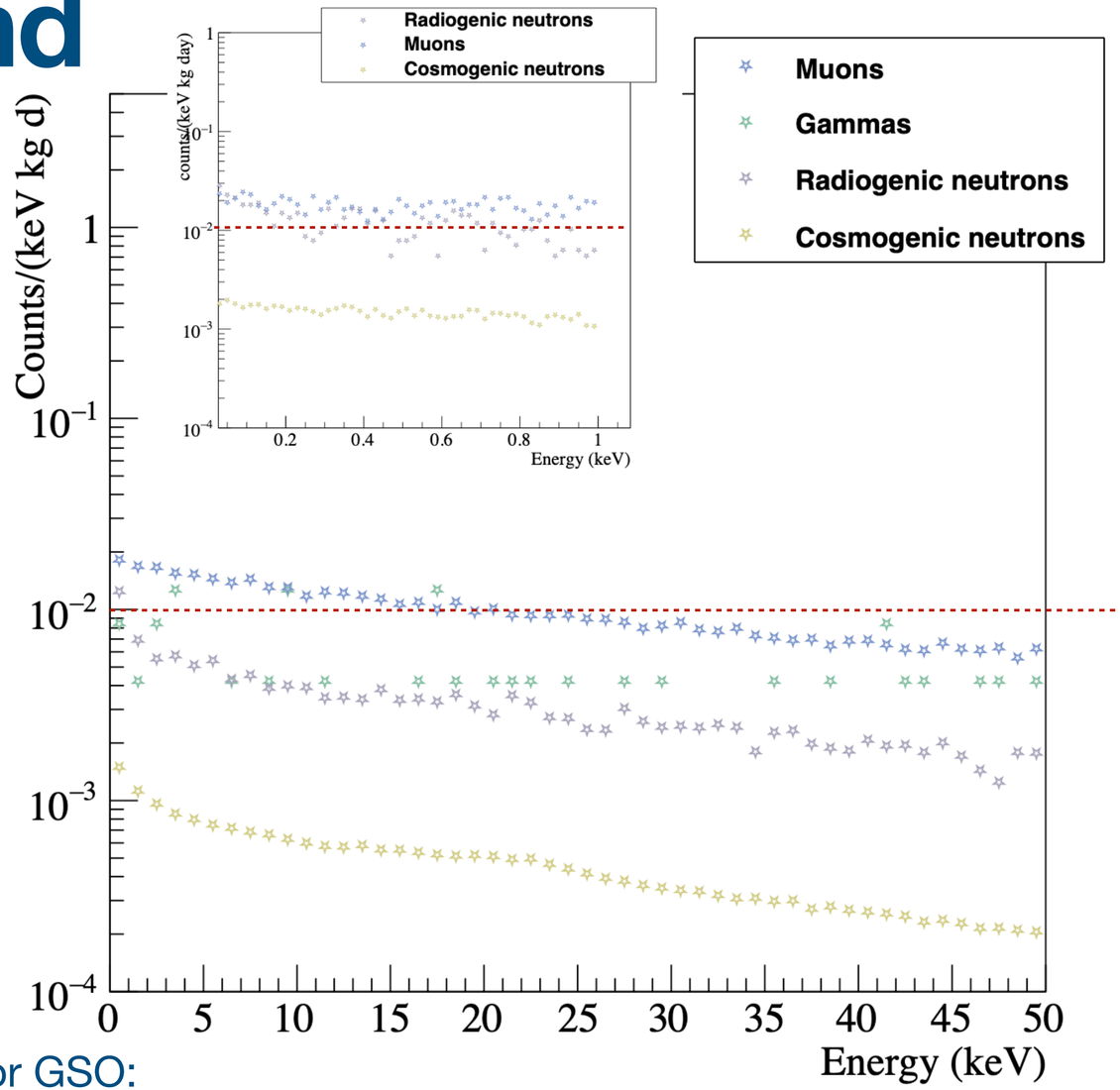
Projected background

muons, gammas and neutrons from:
Astropart. Phys. 33 (2010) 169,
Phys. Rev. D 73 (2006) 053004,
Eur. Phys. J. A 41 (2009) 155,
Astropart. Phys. 22 (2004) 313.

LNGS infrastructure

BULLKID-DM payload





"zero" bkg.

Replacing this with an active veto of BGO or GSO:
Background ~ 10^{-3} counts/(keV kg y)

Currently working on internal contaminations in lead and veto

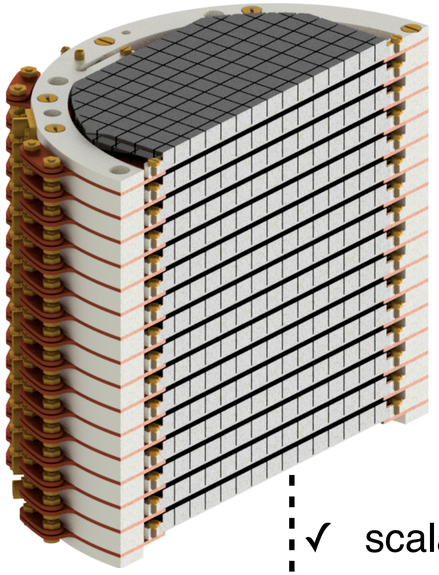
Wrap-up

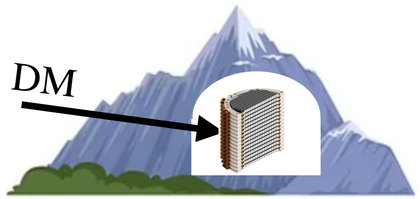
- ✓ 800 g of silicon target
- ✓ 2300 detector units (dice)

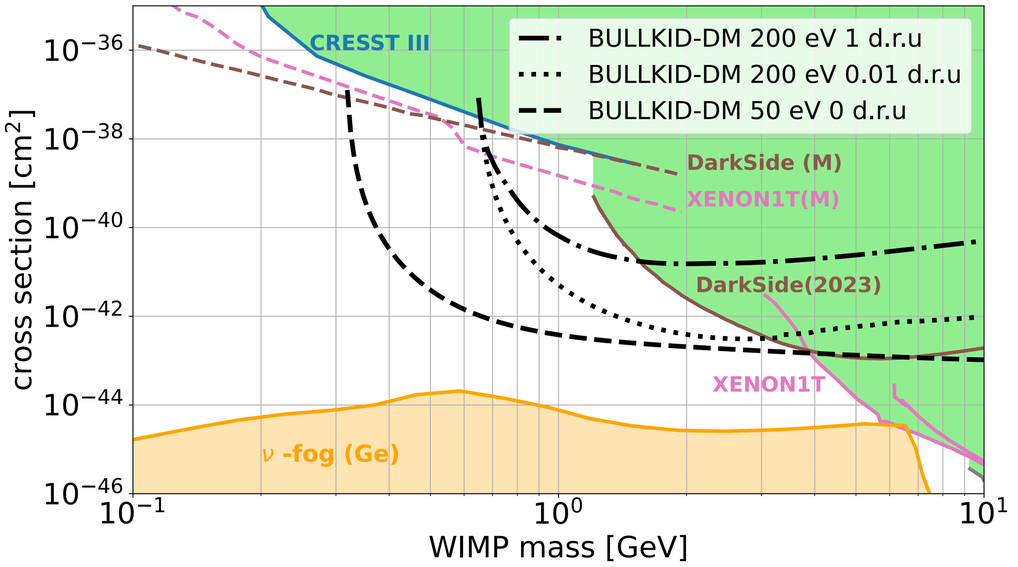
Unique features for bkg. suppression:

- ✓ No inert material in detector volume
- ✓ fully active
- ✓ fiducialization (600 g)

Will it help with the unknown backgrounds?







Prototype works

demonstrator (3 wafer)

demonstrator at LNGS

full detector at Sapienza

installation at LNGS

2023 | 2024 | 2025 | 2026 | 2027

LoI to INFN and LNGS

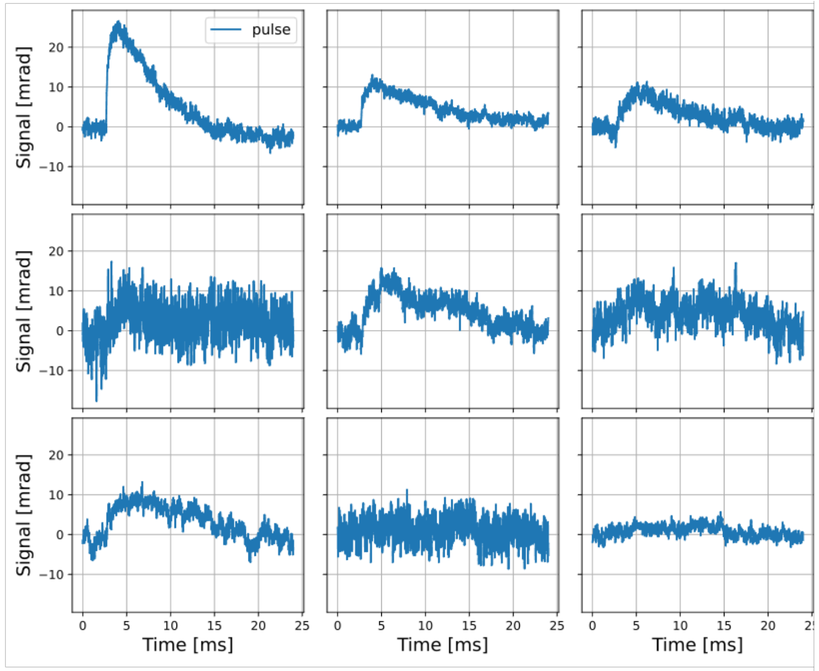
CDR submitted to INFN

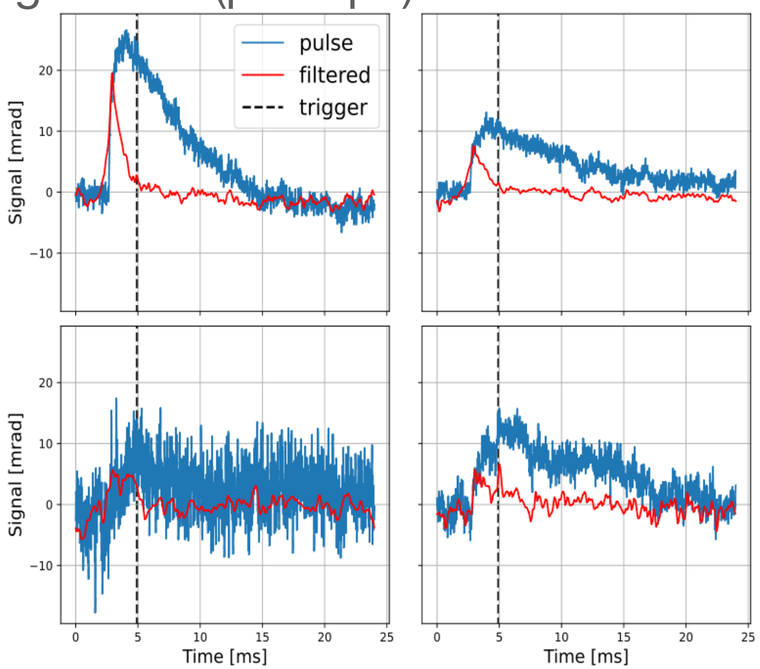
TDR

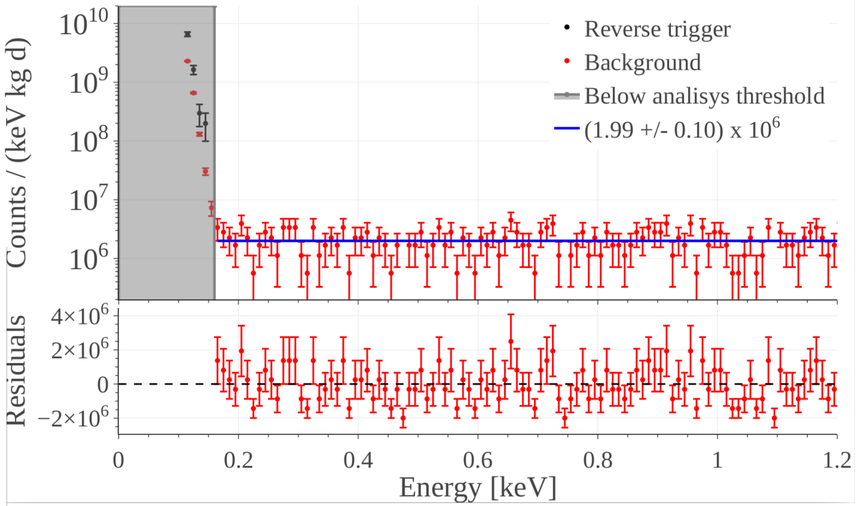
Backup slides

Events below threshold

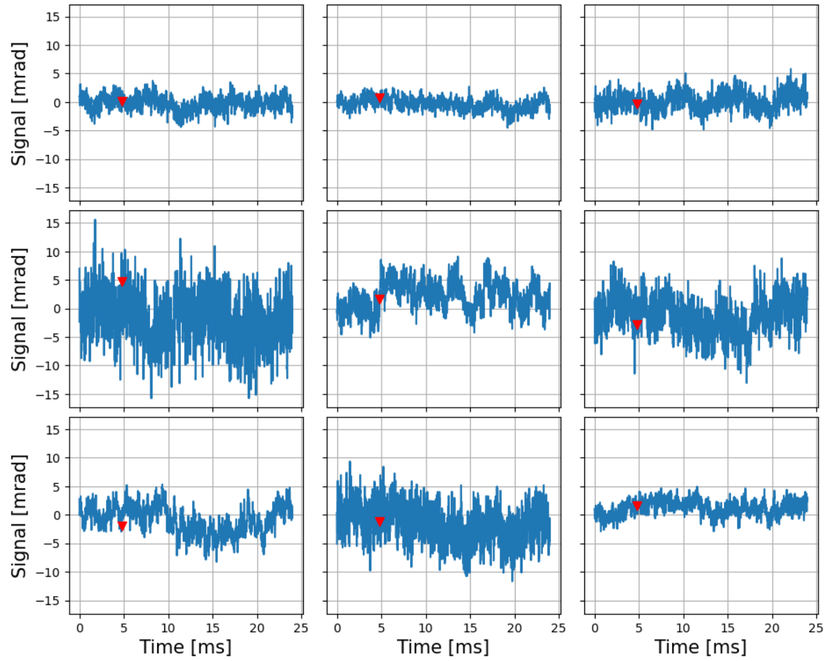
Misidentified leakage event (pile-up?)



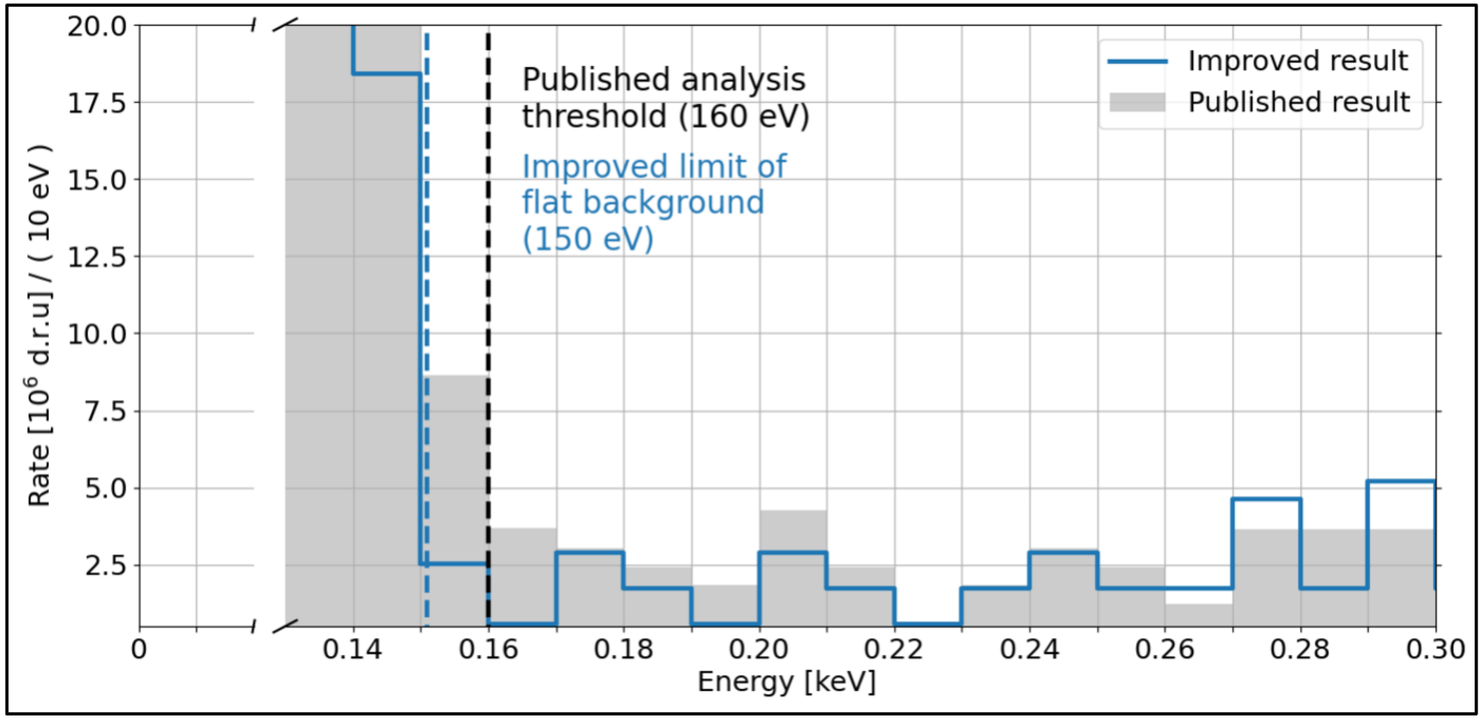




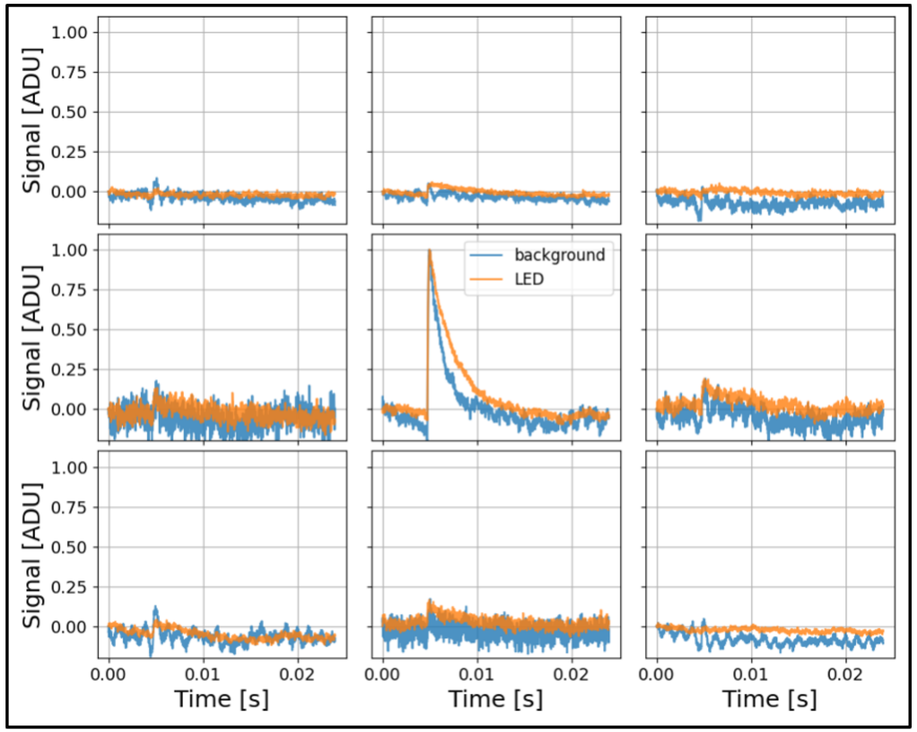
"normal" event



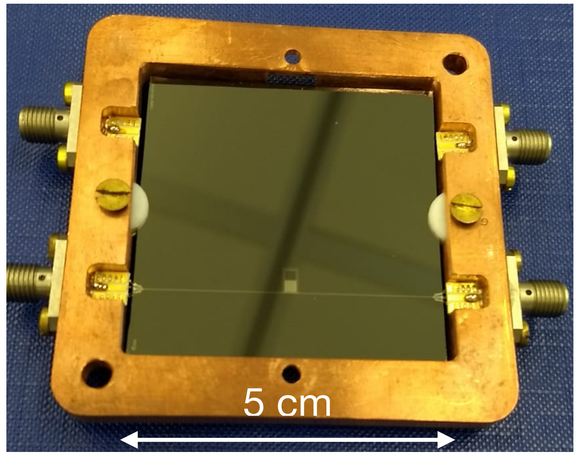
New analysis below threshold



Average of ~100 events below threshold

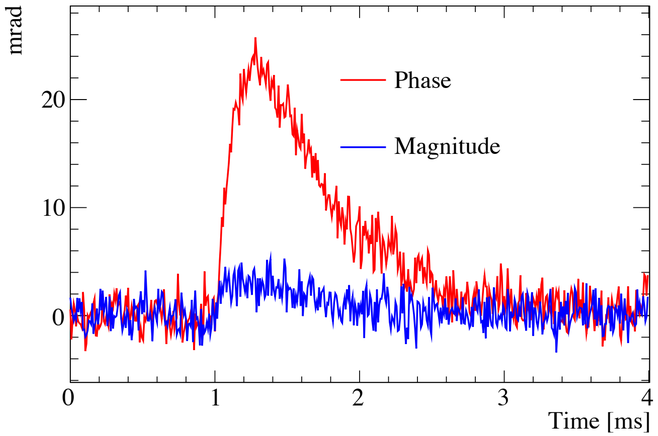


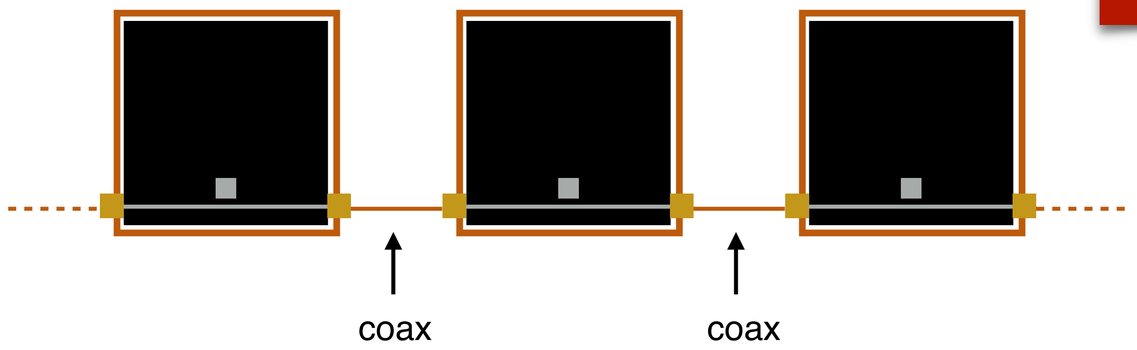
CALDER: light detectors w KIDs



L. Cardani et al, EPJC 81 (2021) 636

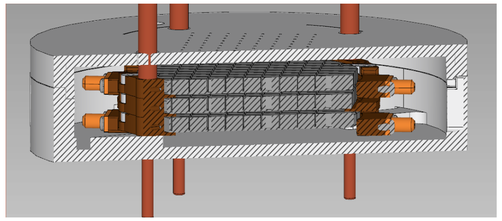
Area [cm²]	25
ΔE [eV RMS]	34 90 w/o vibration decoupling
Response time [ms]	**0.12**
Temperature [mK]	8-120
# detectors	Multiplexing



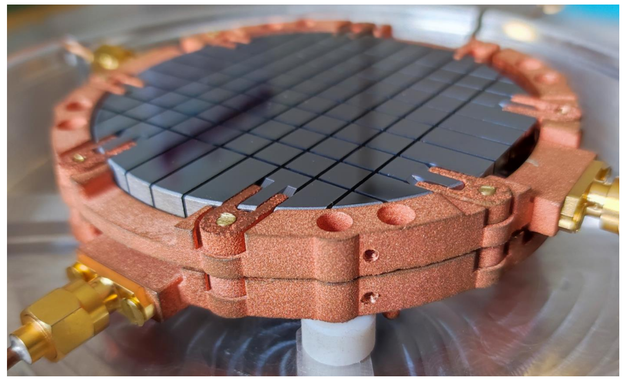


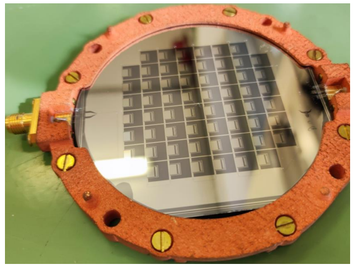
Could be coupled to scintillating crystals for the BULLKID veto

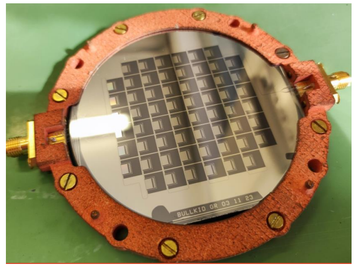
Status of the 3-wafer demonstrator

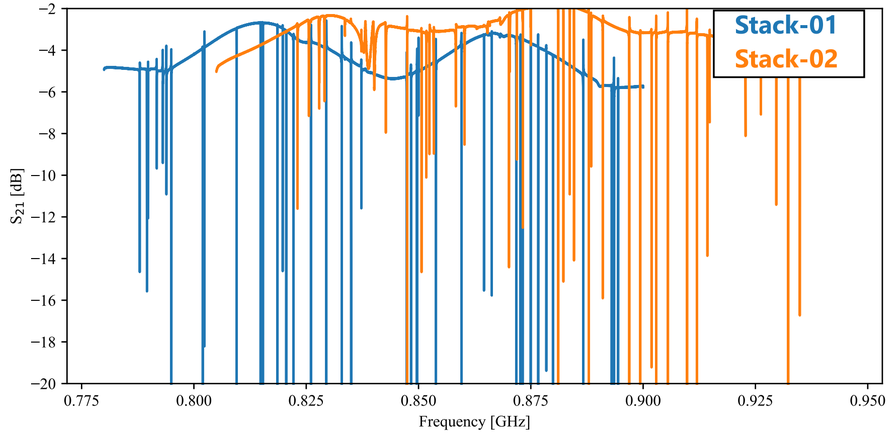


2-wafer stack operated. No issues observed

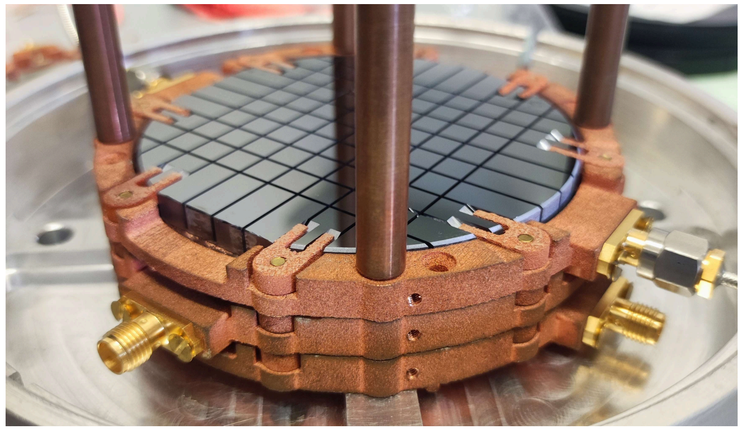




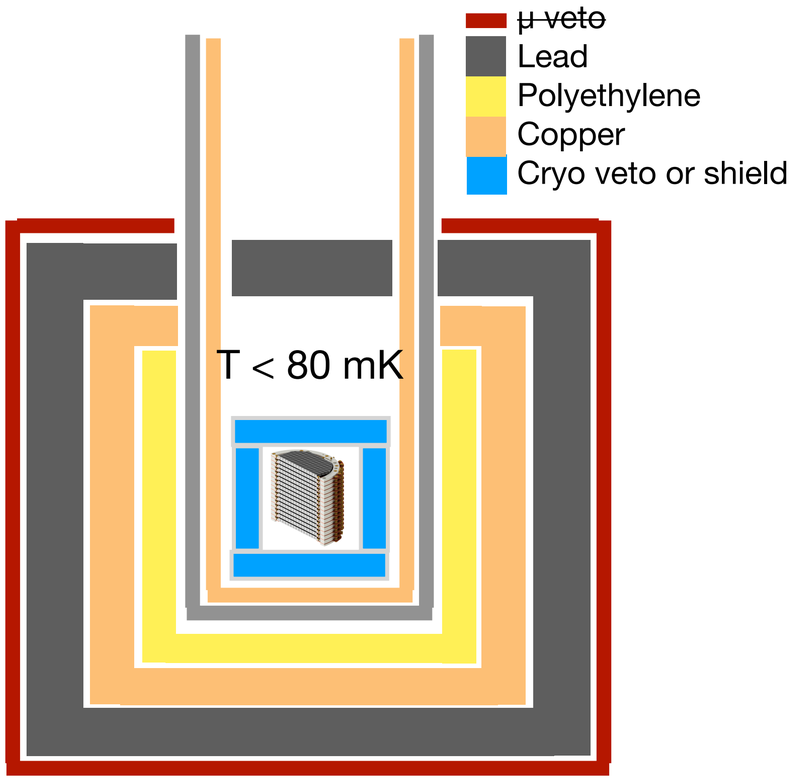




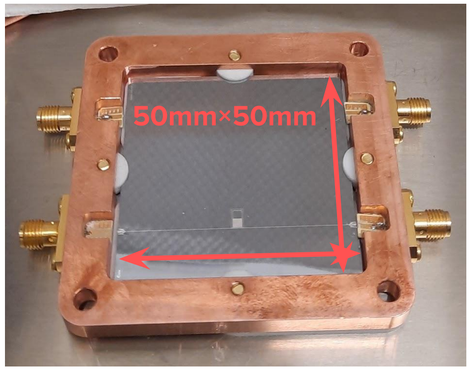
3-wafer stack assembled



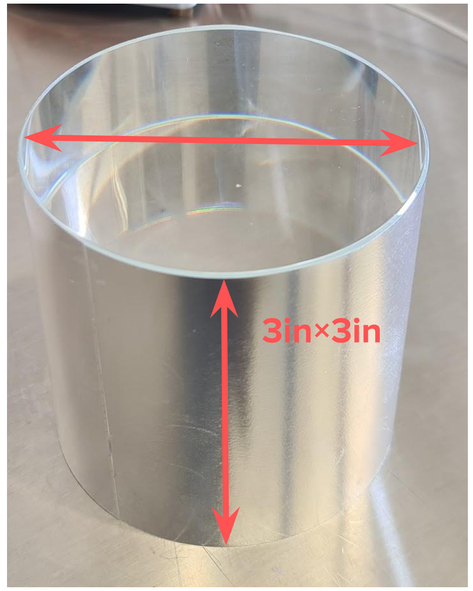
Cryogenic veto: BGO prototype



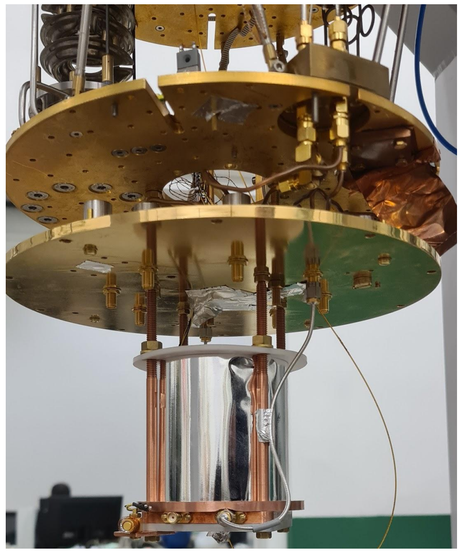
CALDER KID Light detector

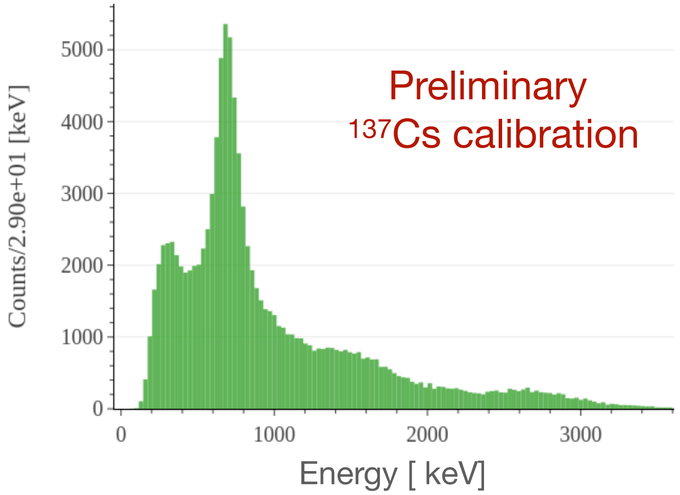


BGO Crystal



Assembly with reflector





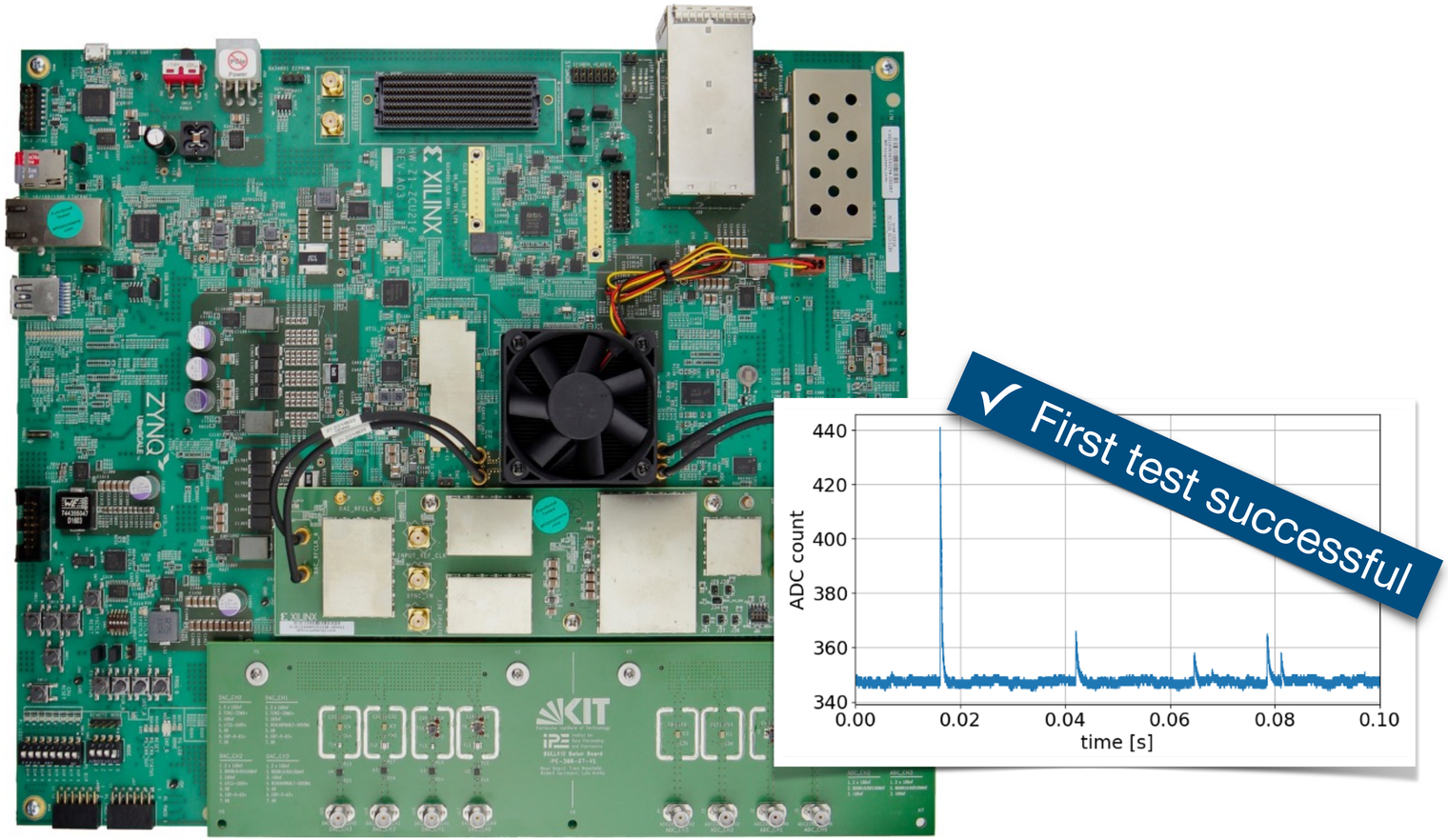
Goal: energy threshold < 50 keV

RF Electronics

Current electronics (Ettus x310):
30 KIDs / line

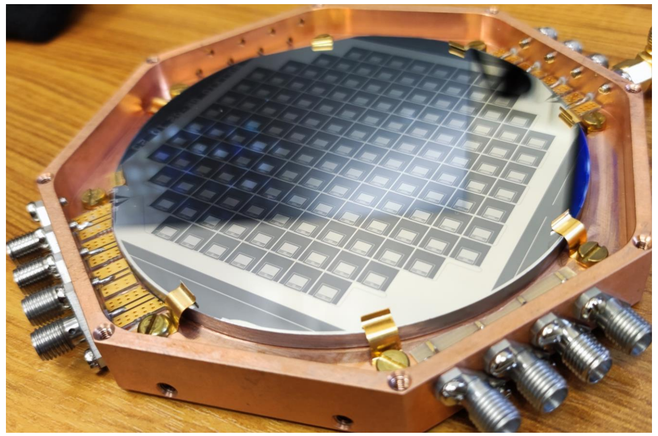
New electronics (ZCU216 Evaluation Board with 16 lines):
Goal >= 150 KIDs / line

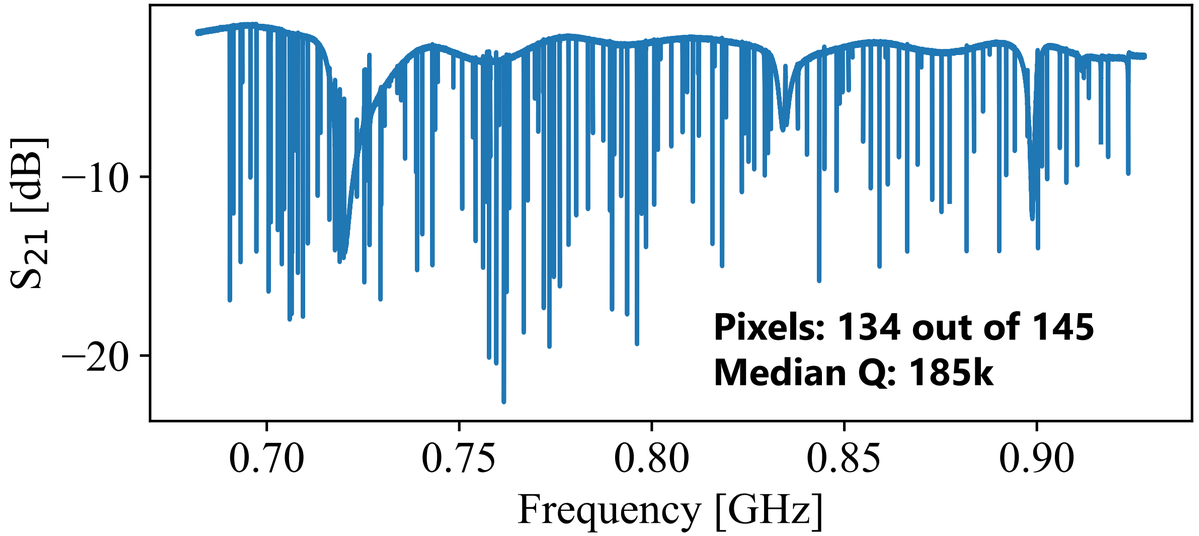
- Custom Analog Front-End and
- Control Firmware by the KIT group
- **Status: first tests on BULLKID-prototype**



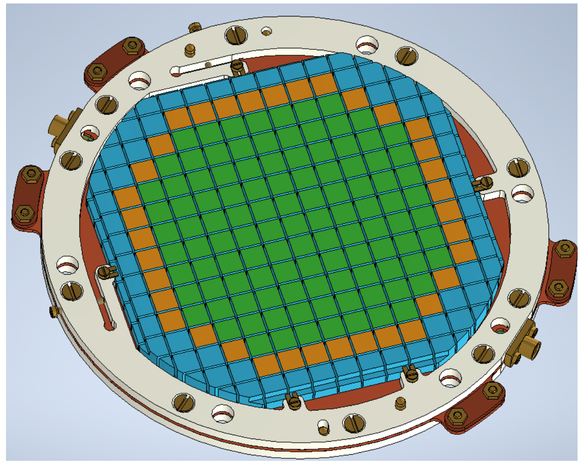
Status of 100 mm wafers

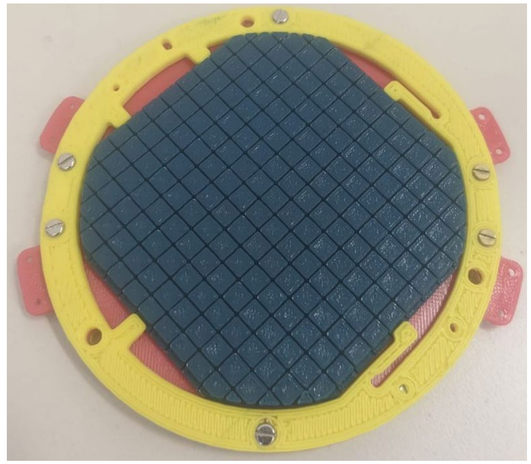
145 KID array test on thin (0.3 mm) wafer successful





Assembly under development





5 mm wafer grooved succesfull

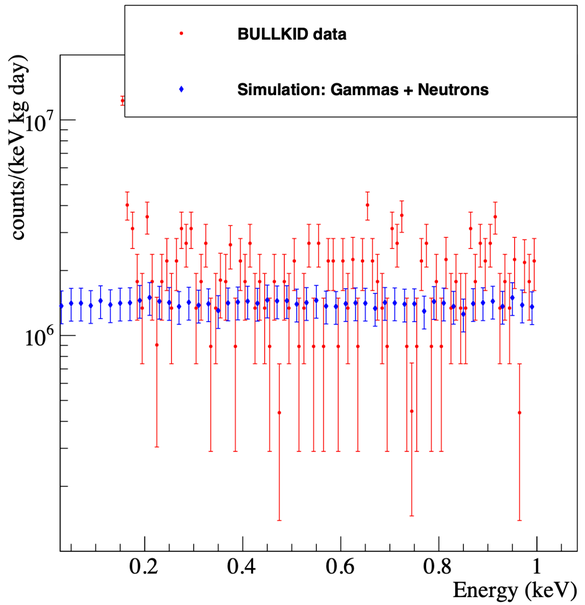
Simulations: validation on Sapienza setup

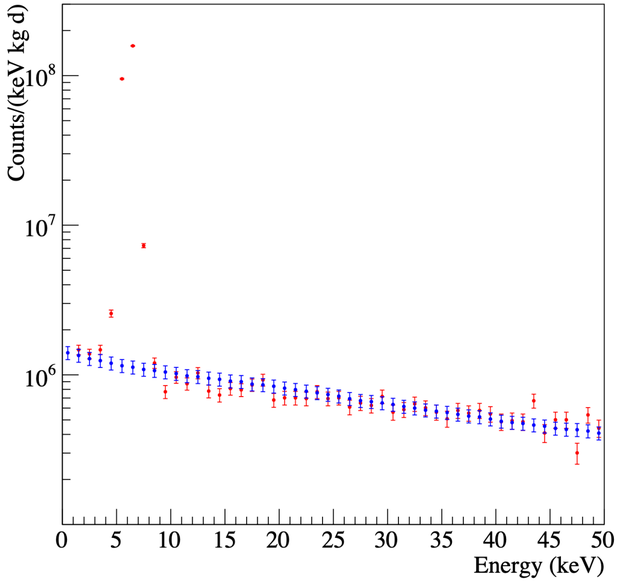
Gammas (99%) and neutrons (1%) measured and used as input for the simulation

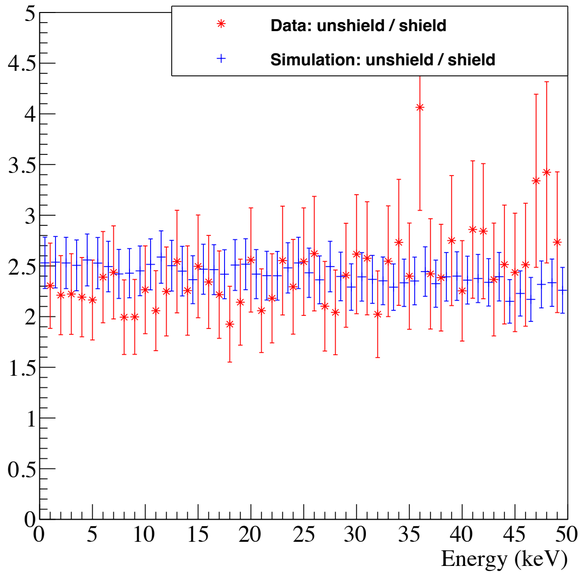
Agreement over wide energy range observed

Mild lead shield added

Reduction of the background agrees with simulations







Future sensitivities