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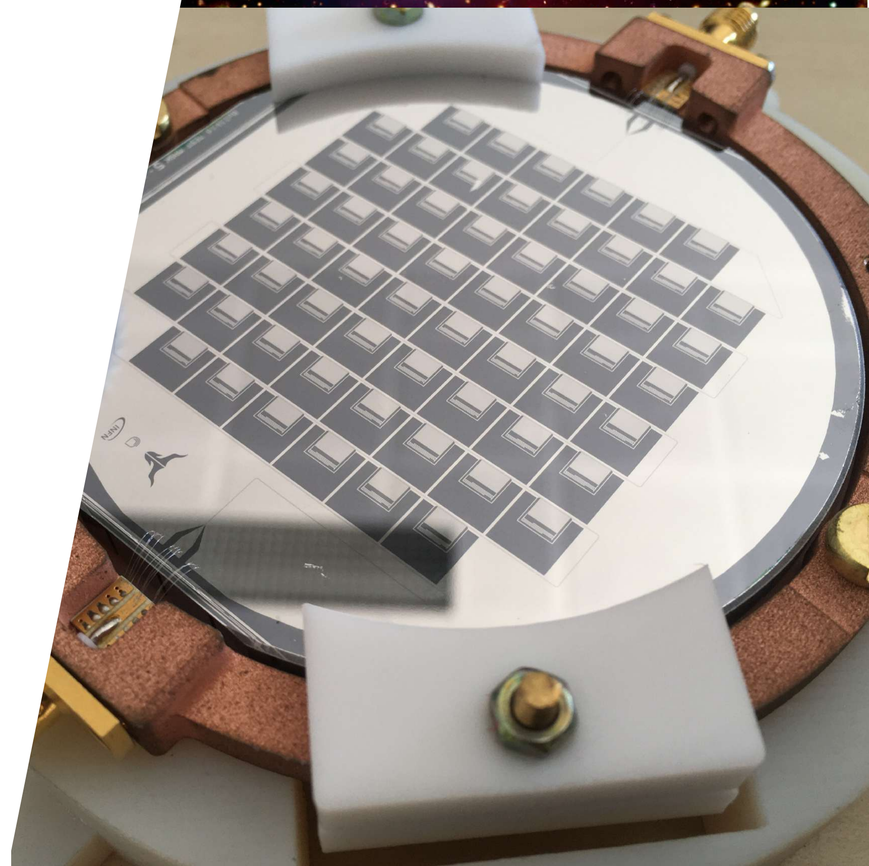
Laboratori Nazionali del Gran Sasso

BULLKID-DM

Antonio D'Addabbo on behalf of the collaboration,
GSSI Science Fair - LNGS - 24 February 2025



BULLKID-DM Collaboration

Istituto Nazionale di Fisica Nucleare

Roma
Ferrara
LNGS
Pisa

Karlsruher Institut für Technologie

BULLKID-DM
Conceptual Design Report (CDR)

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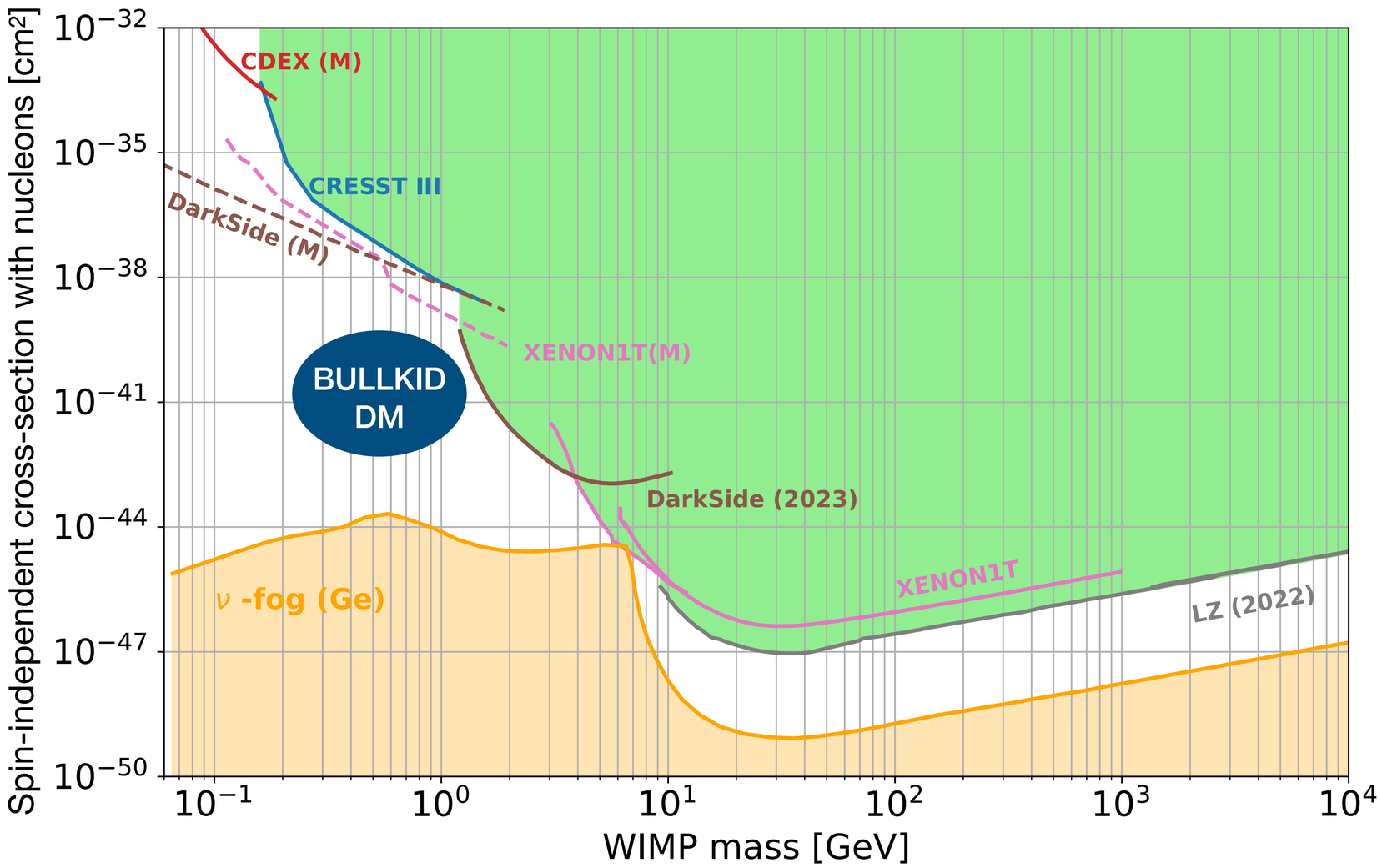
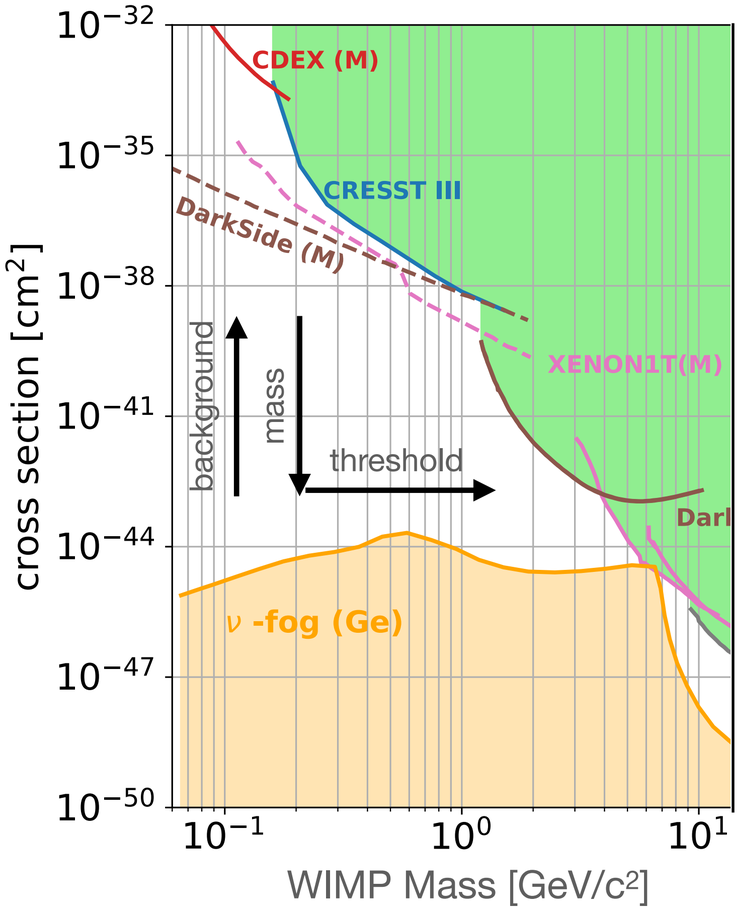
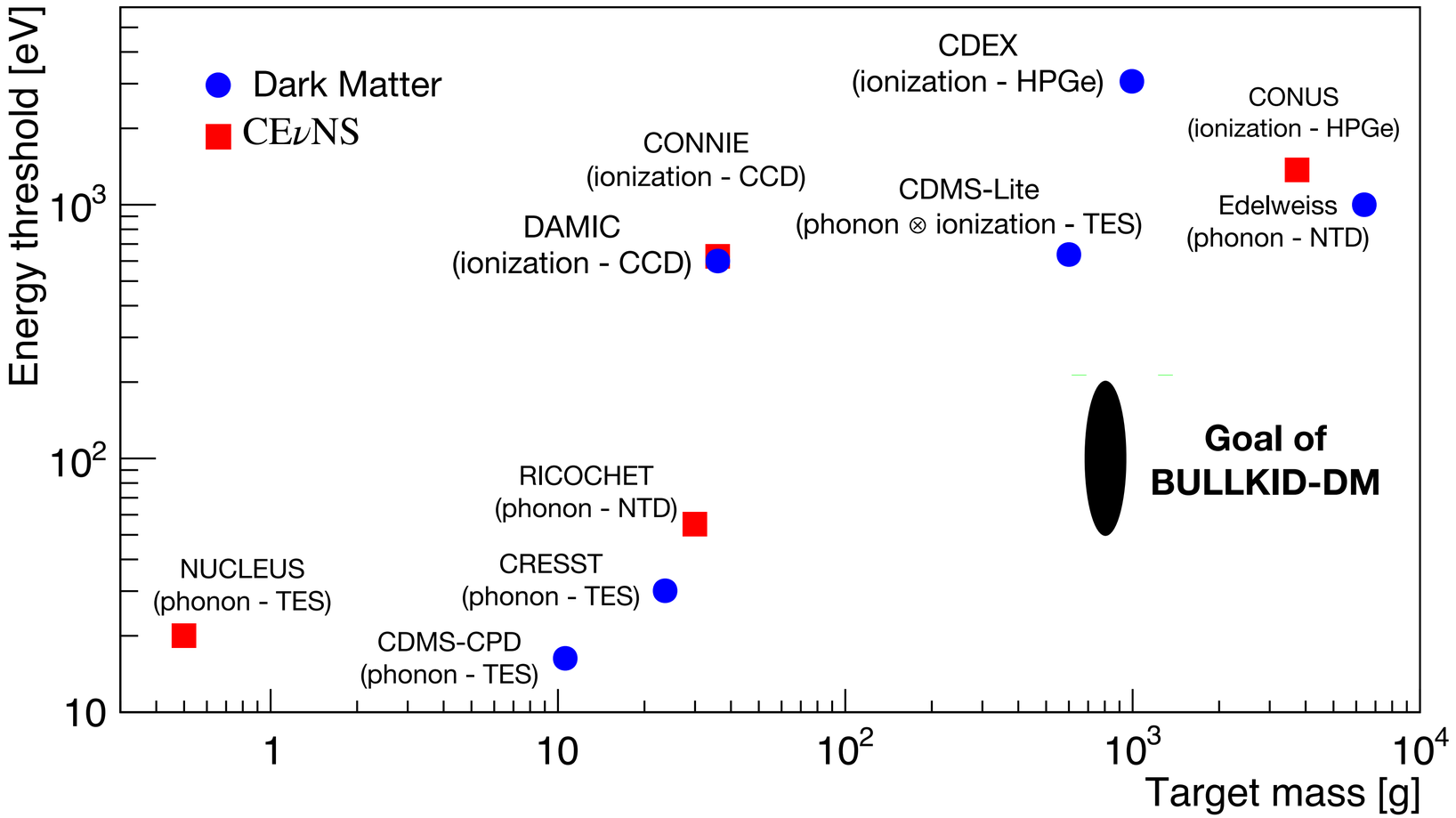
June 28, 2024

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]

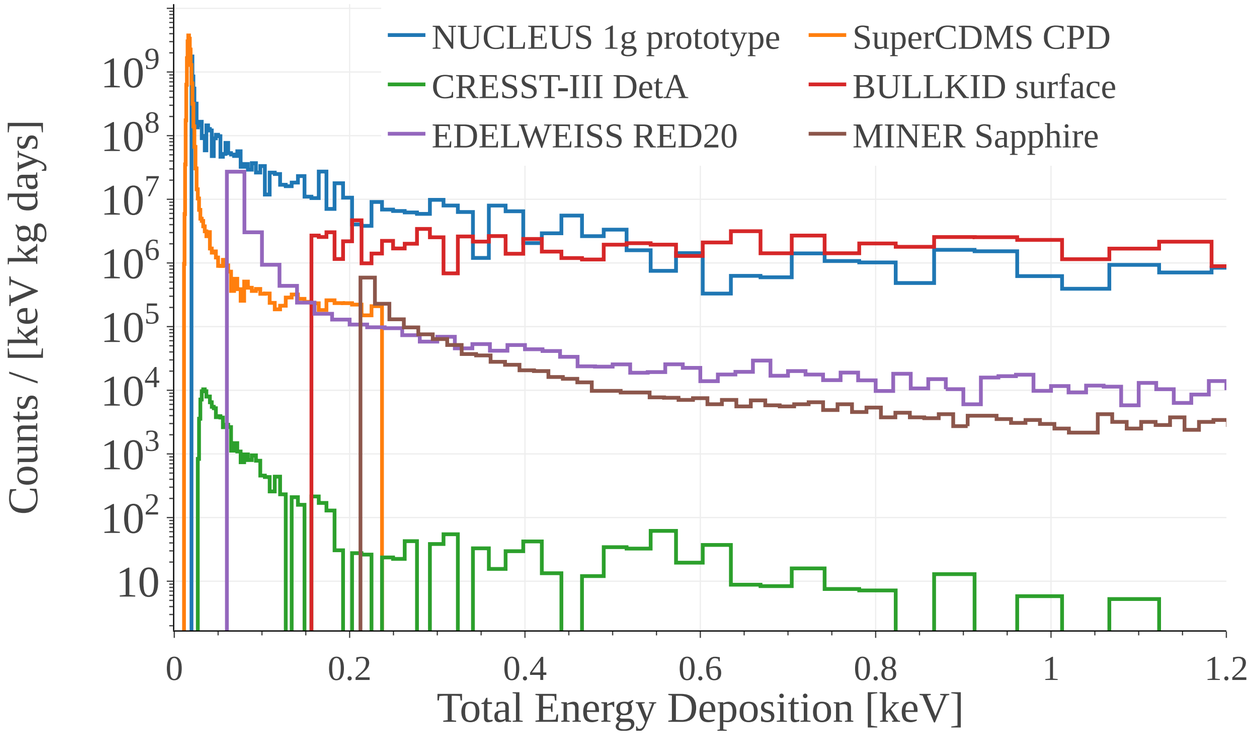
State of the art (solid-state detectors)





Background issue in low-T experiments

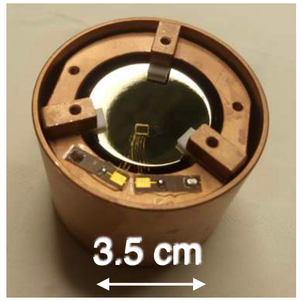
Not understood *excess* background rising at low energies



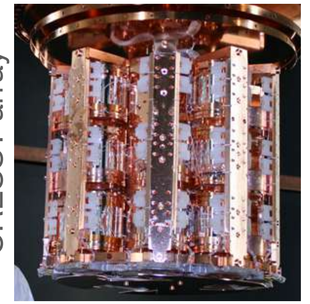
P. Adari, et al.: EXCESS workshop: Descriptions of rising low-energy spectra
SciPost Phys. Proc. 9 (2022) 001 + D. Delicato et al EPJ C 84 (2024) 353

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

RED 20 (Ge, 33 g)



CRESST array



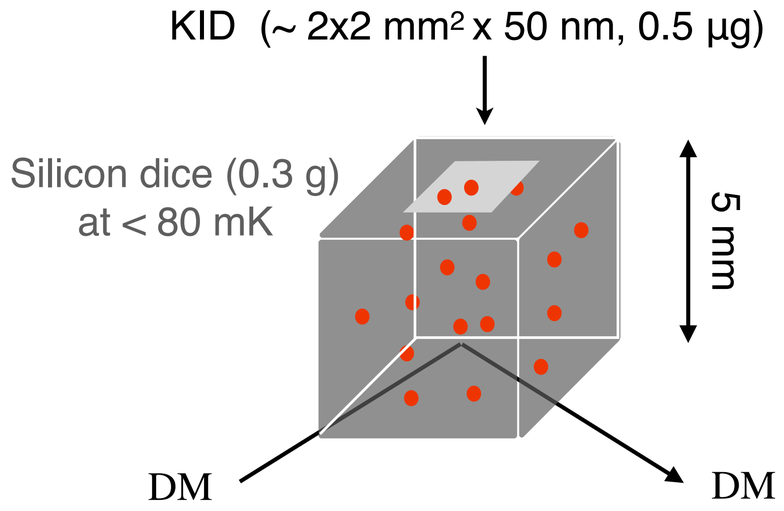
Excess workshop 2024
Roma, 6 July
https://agenda.infn.it/event/39007/

This background limits the sensitivity of present experiments

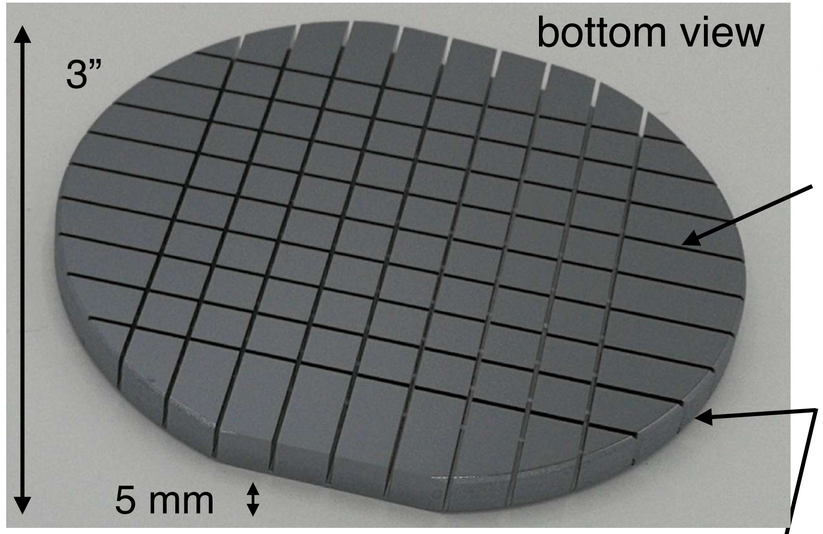
The BULLKID phonon-detector array

Phonon mediation

detect phonons created by nuclear recoils in a silicon die



carving of dice in a thick silicon wafer

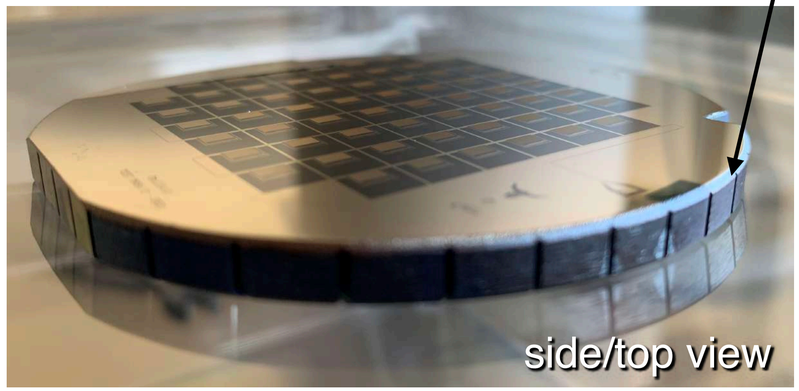


✓ monolithic

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

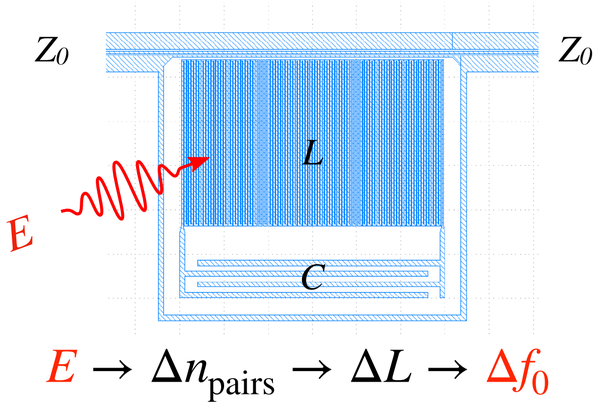
Fully multiplexed
(single readout line)

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

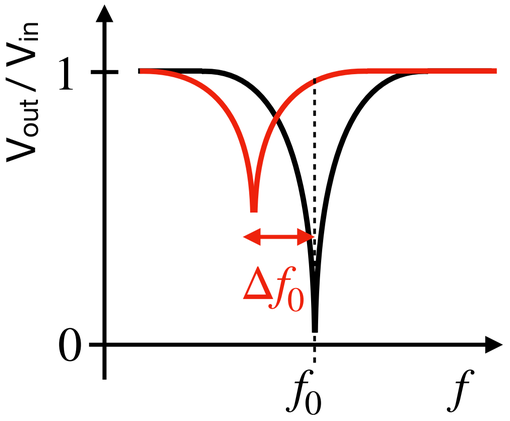
Kinetic Inductance Detectors (KIDs)

- 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

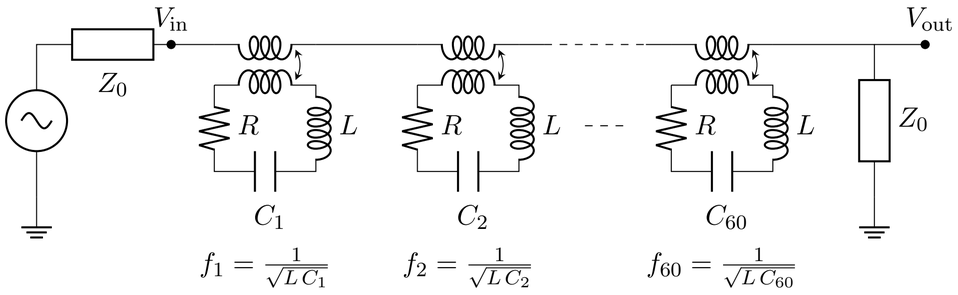
resonator $f_0 = 1/\sqrt{LC}$



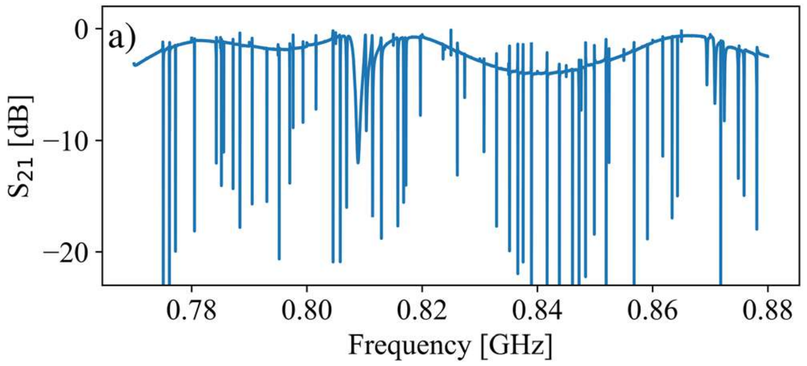
frequency response



Readout: different KIDs coupled to a the same line

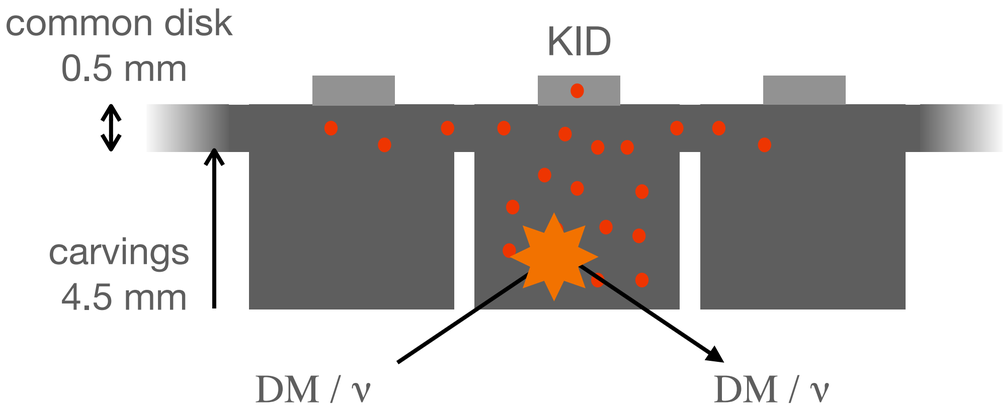


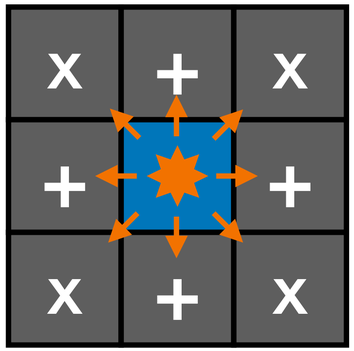
frequency scan of the 60 KIDs of BULLKID

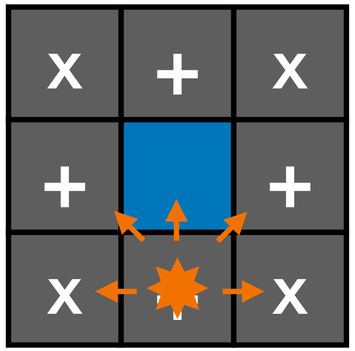


Phonon leakage and mapping

- 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

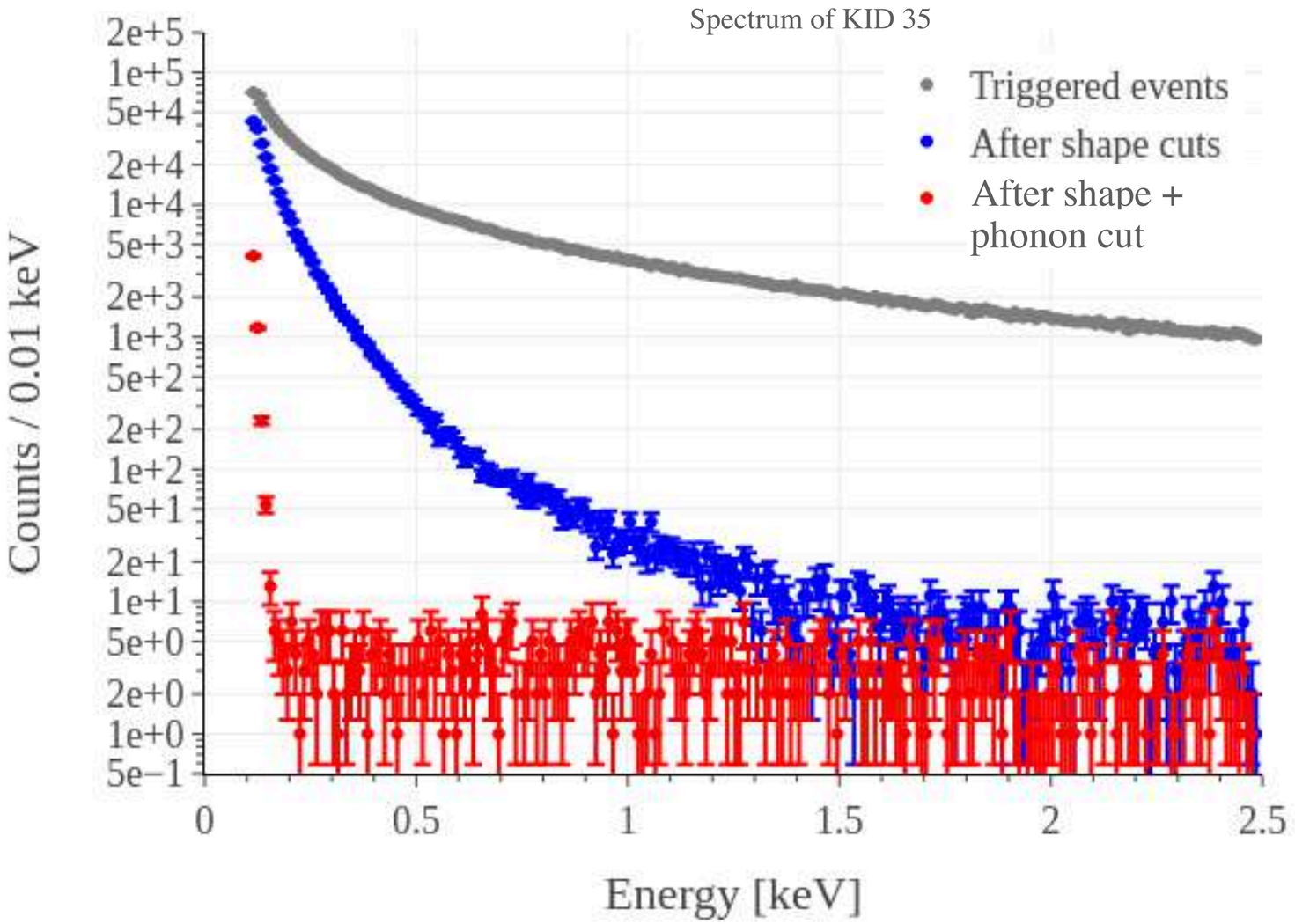


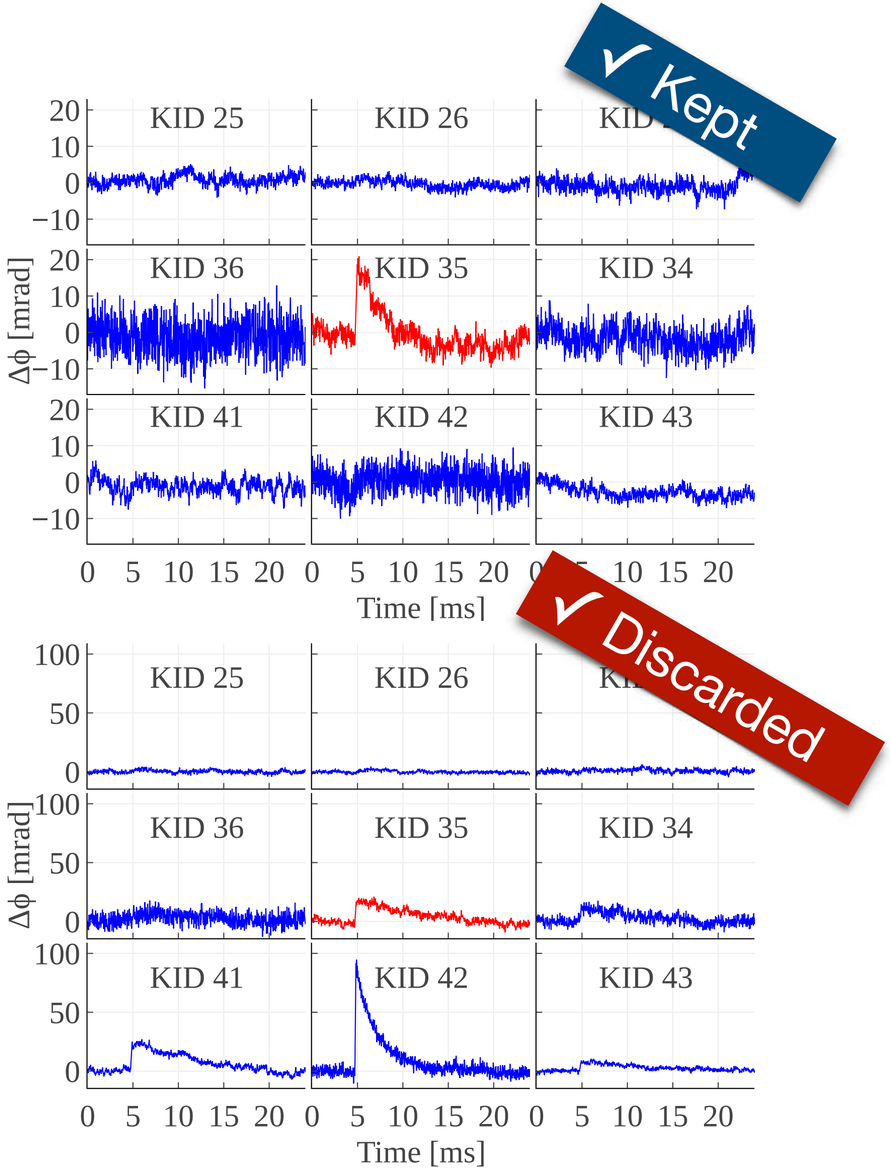




This effect reduces the phonon focusing on the KID but is
exploited to identify the interaction voxel

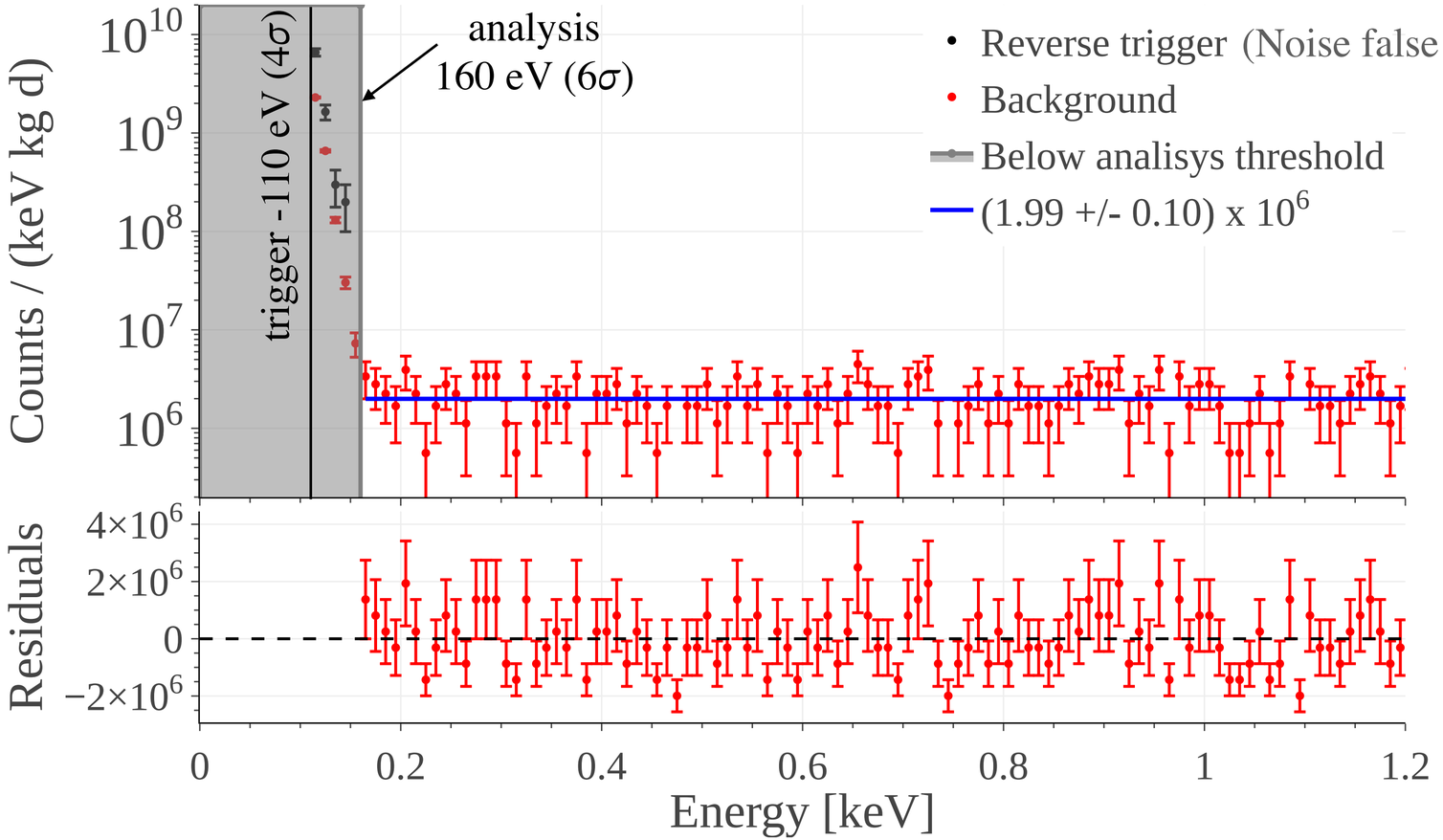
Background: pulse shape + phonon cuts





Background: result on surface

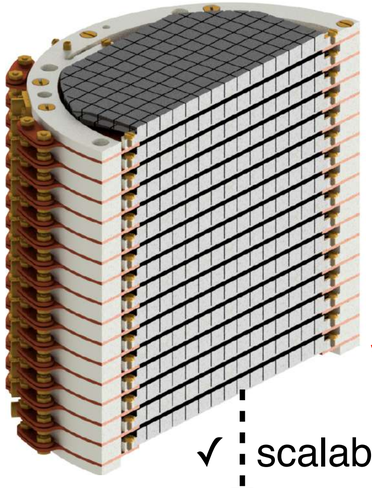
Above ground lab @Sapienza U., no shield, 39 live hours



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.

Detector & the cryogenic facility @LNGS



✓ scalable

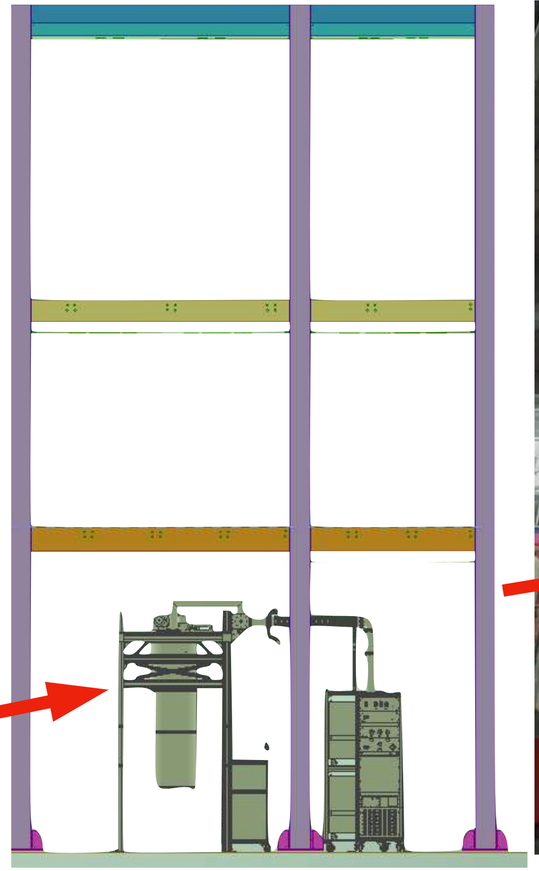
Detector

- ✓ 800 g of silicon target
- ✓ 2300 detector units (dice)
- ✓ No inert material in detector vol
- ✓ fully active
- ✓ fiducialization (600 g)

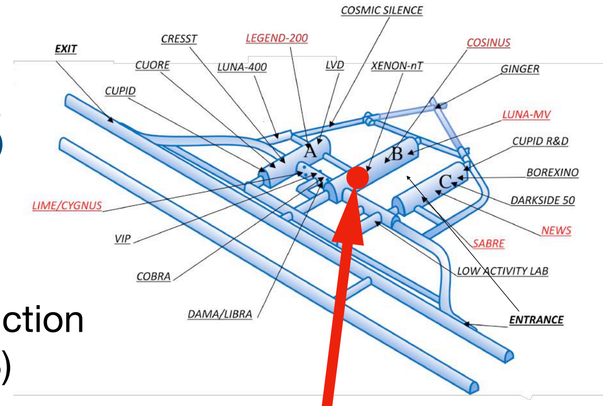
Unique features for bkg suppression

ProteoxMX dilution cryostat
by Oxford Instruments

Shipping in June 2025



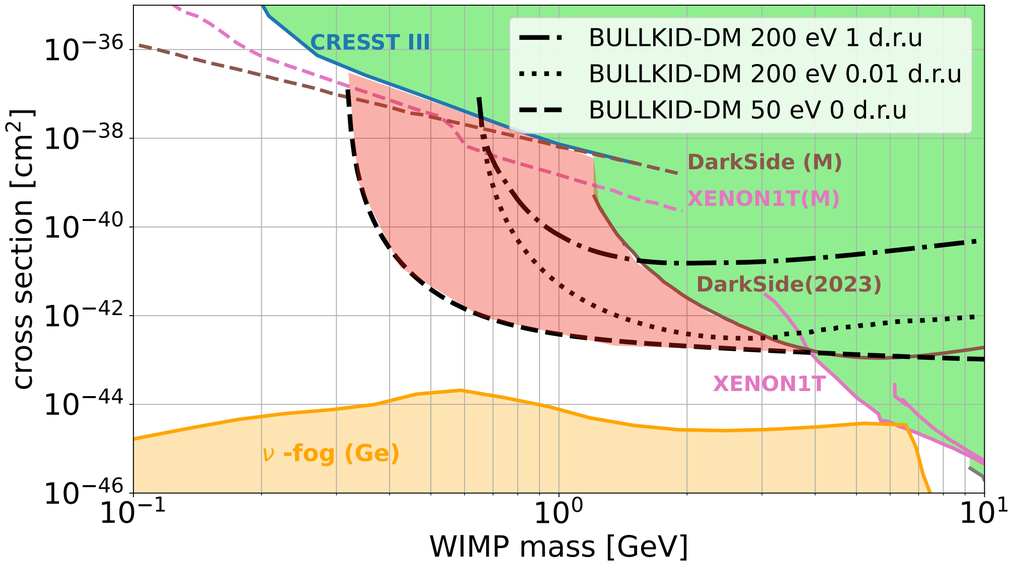
Cryo-Platform facility under construction
in the LNGS underground (Hall-B)



Ready by summer 2025

Activities & timeline

1. Demonstrator commissioning, data taking and analysis
2. Experiment commissioning, data taking and analysis
3. Threshold: from Al to Al-Ti-Al KIDs (5x inductance)
4. Sensitivity: Deeper carvings for higher phonon focussing
5. Background studies

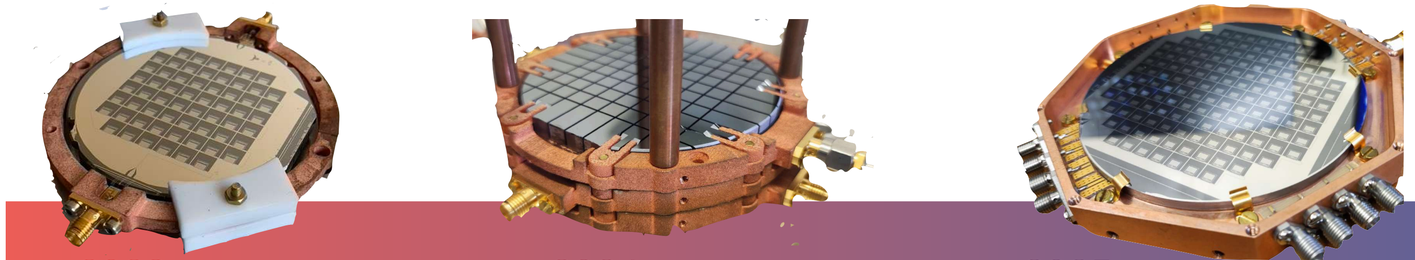


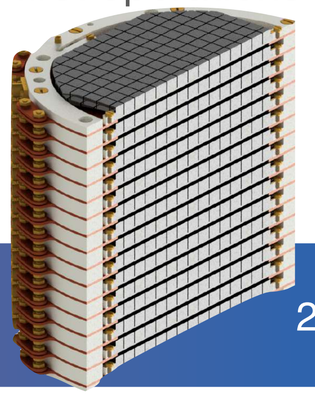
Prototype
20 g / 60 KIDs
single 3” wafer
concluded in 2023

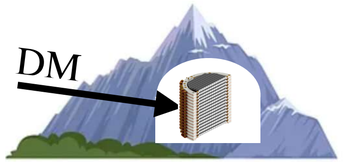
Demonstrator
60 g / 180 KIDs
3-layer stack of 3” wafers
first operations 2024

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

BULLKID-DM
800 g / 2300 KIDs
16-layer stack of 100 mm wafers
first operations 2026







2023 — **Prototype at Sapienza**

2024 — **Demonstrator at Sapienza**

2025 — **Demonstrator at LNGS**

2026 — **Full detector at Sapienza**

2027 — **Full detector at LNGS**

Data taking

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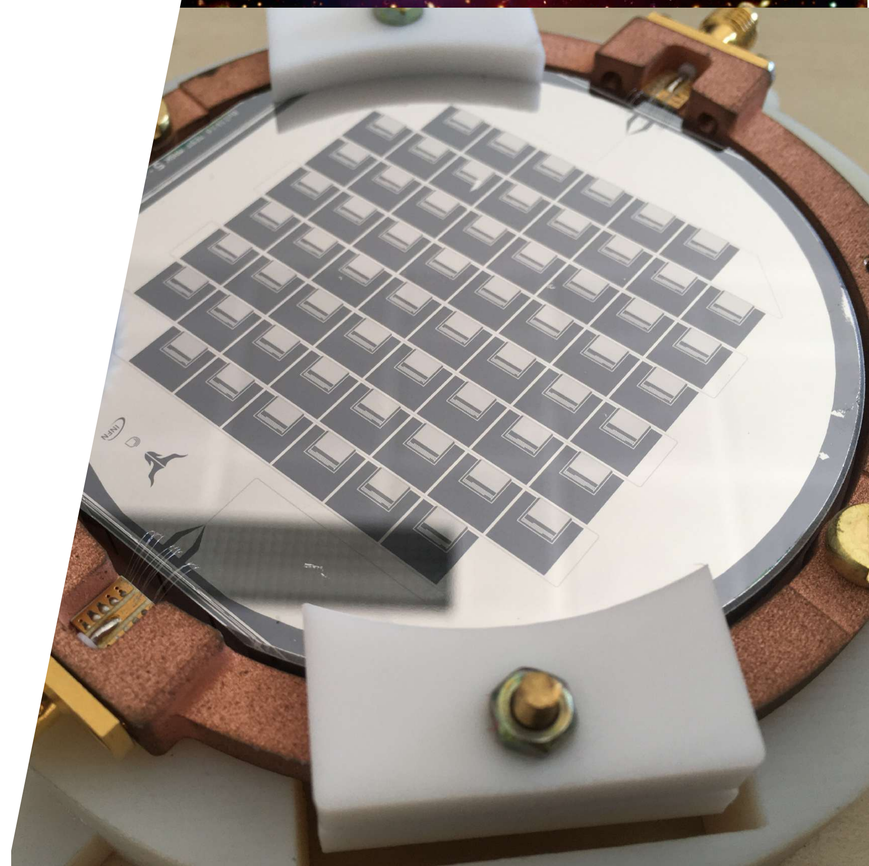
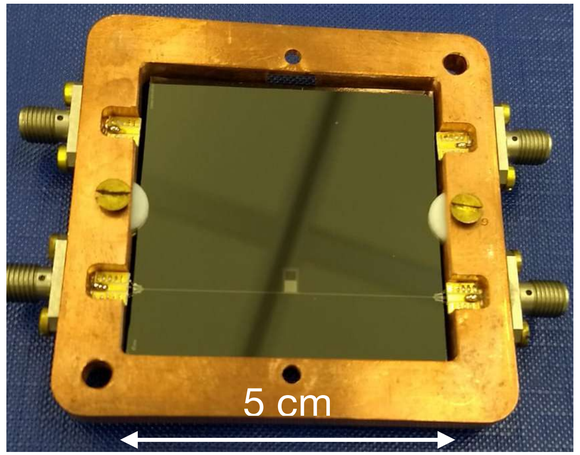
Laboratori Nazionali del Gran Sasso

Thanks

If you are interested please contact me:
antonio.daddabbo@lngs.infn.it

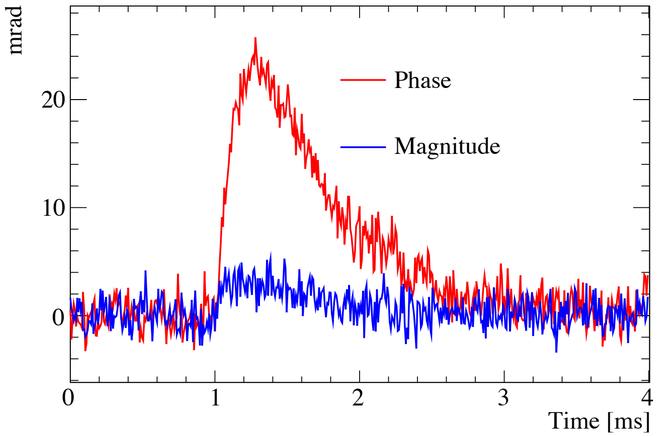


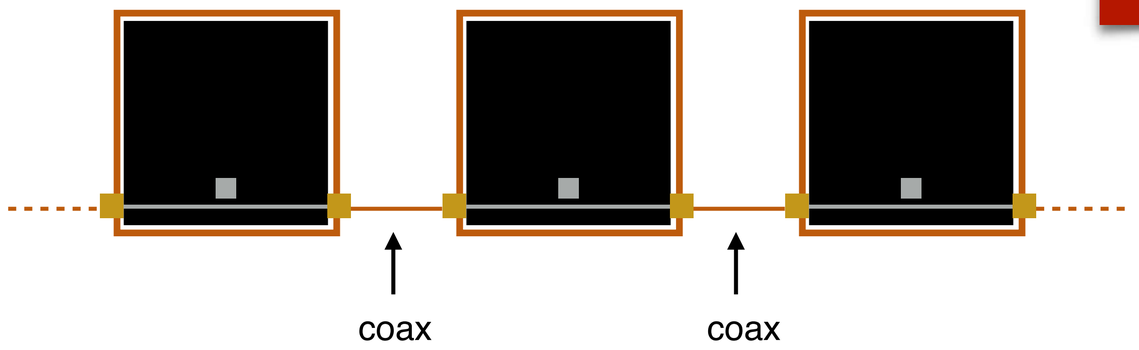
CALDER: light detectors w KIDs



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

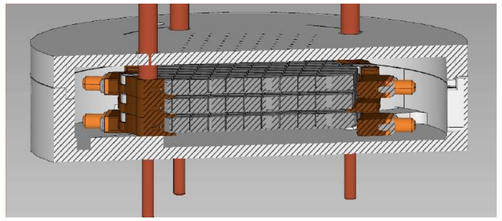
Area [cm²]	25
ΔE [eV RMS]	34 90 w/o vibration decoupling
Response time [ms]	**0.12**
Temperature [mK]	8-120
# detectors	Multiplexing



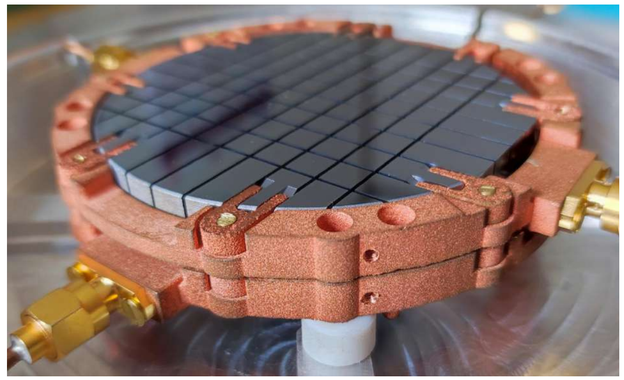


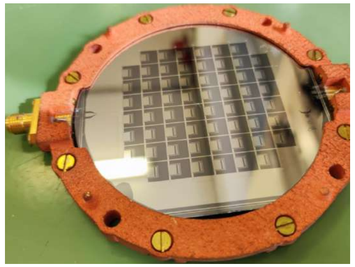
Could be coupled to scintillating crystals for the BULLKID veto

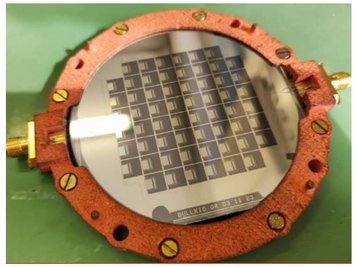
Status of the 3-wafer demonstrator

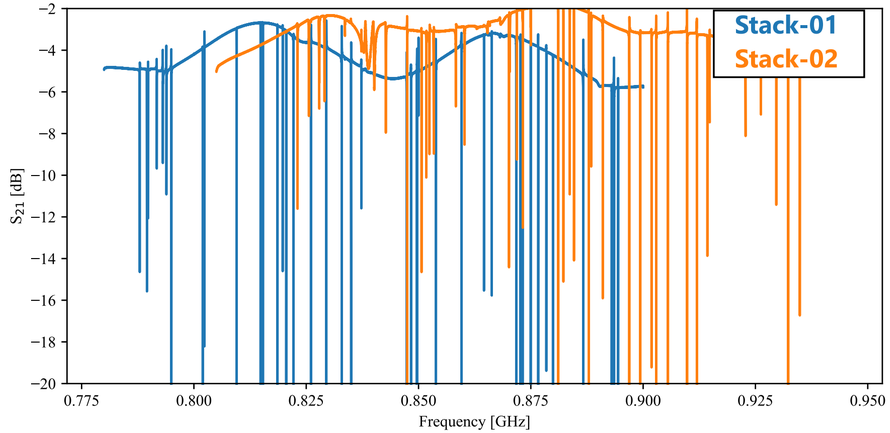


2-wafer stack operated. No issues observed

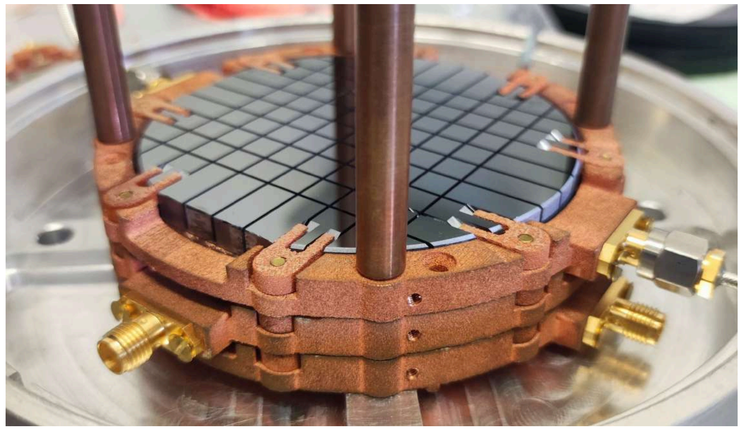




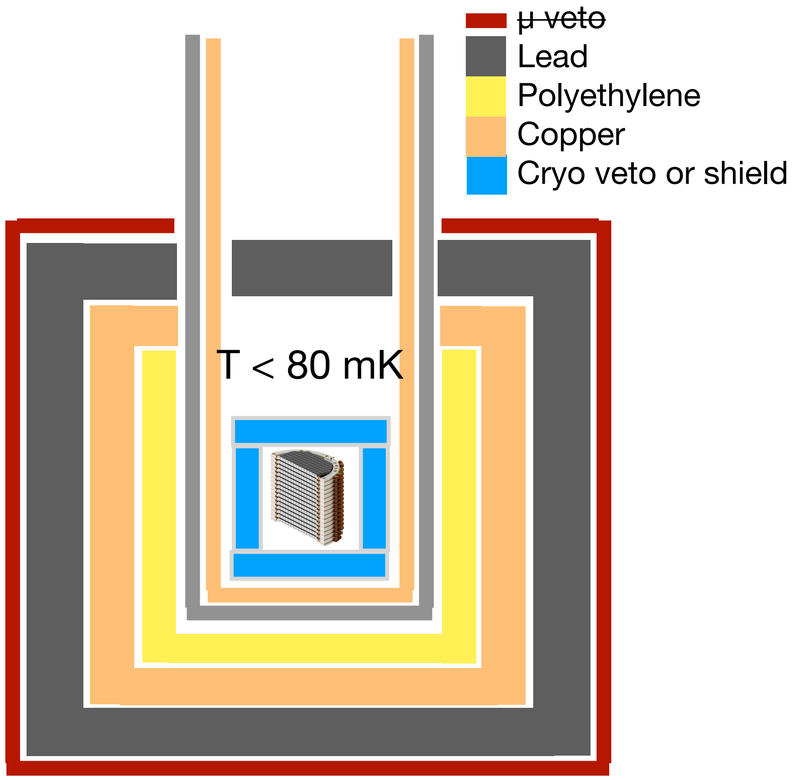




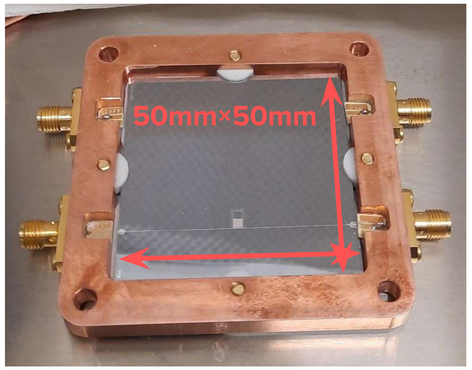
3-wafer stack assembled



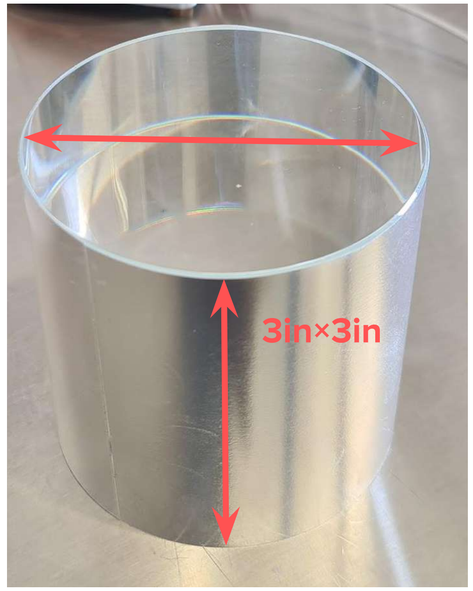
Cryogenic veto: BGO prototype



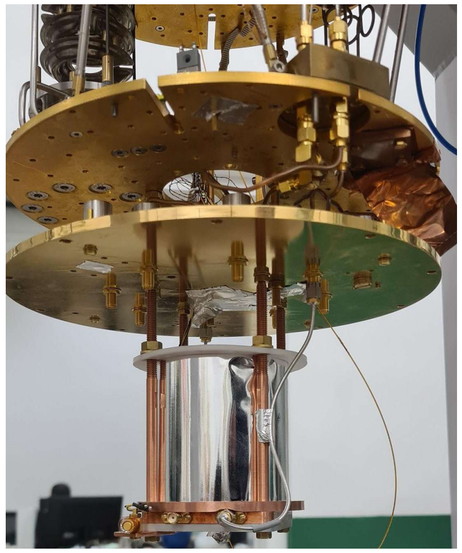
CALDER KID Light detector

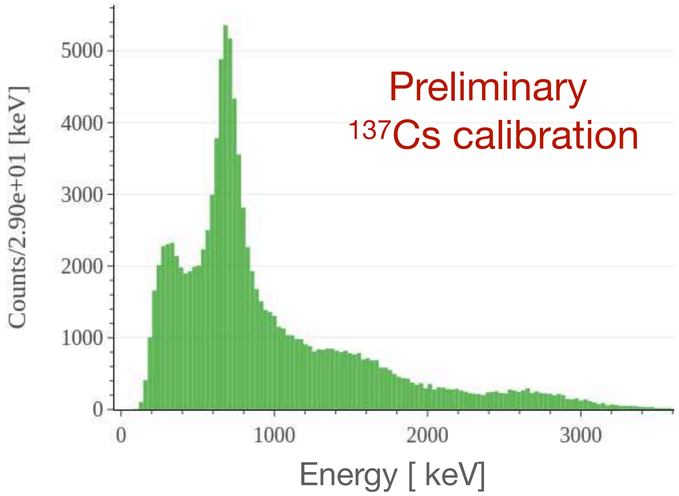


BGO Crystal



Assembly with reflector





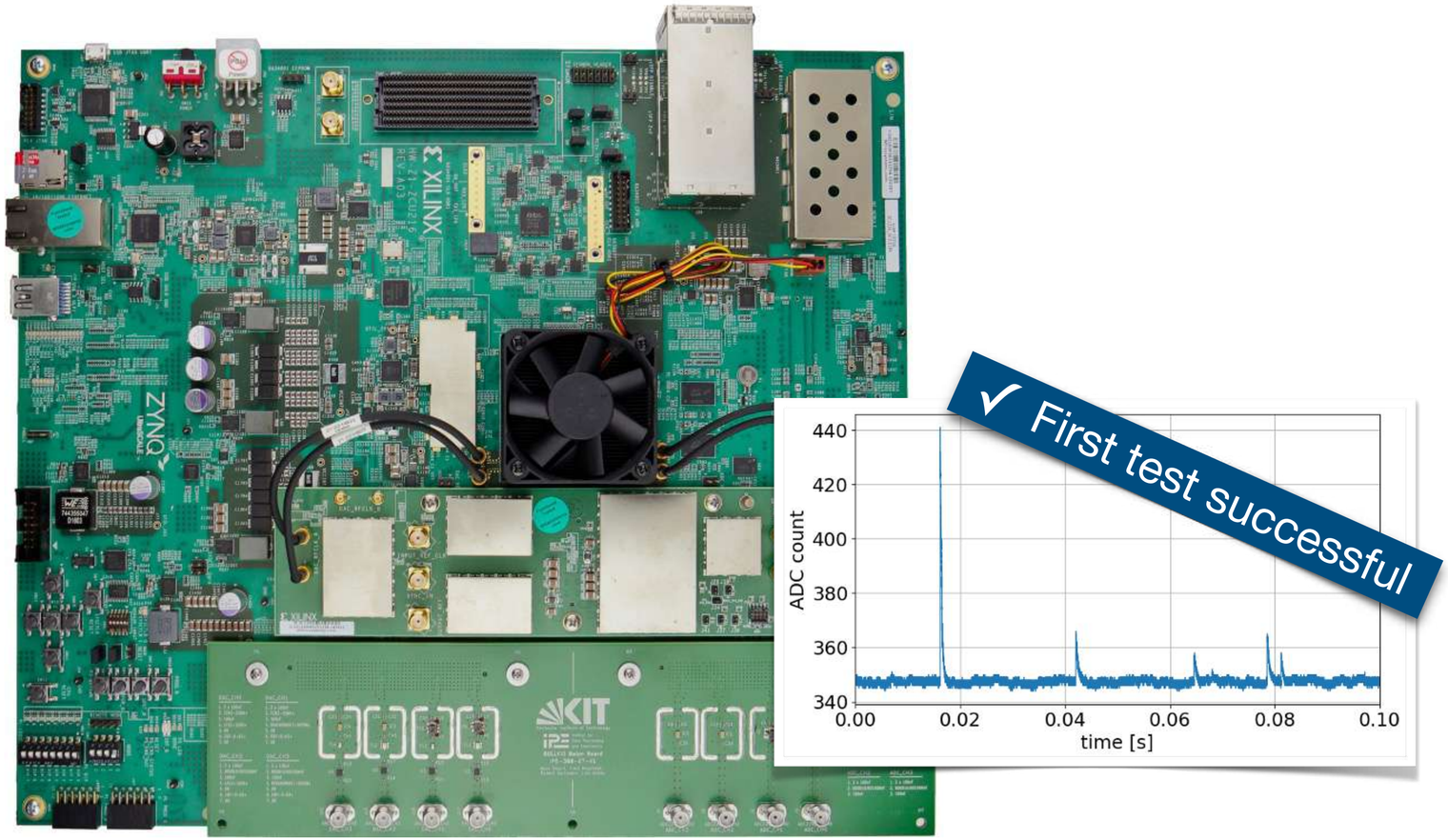
Goal: energy threshold < 50 keV

RF Electronics

Current electronics (Ettus x310):
30 KIDs / line

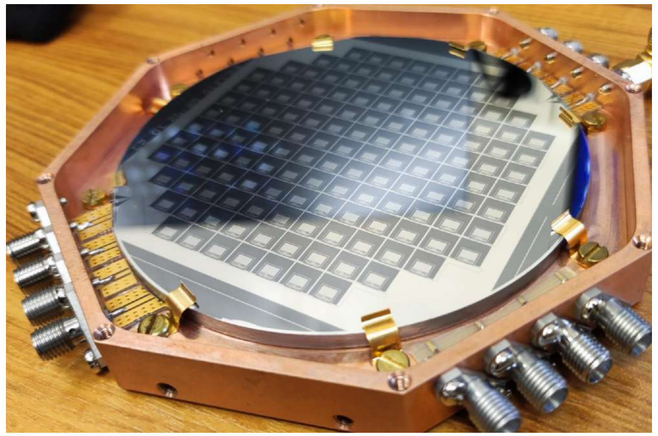
New electronics (ZCU216 Evaluation Board with 16 lines):
Goal >= 150 KIDs / line

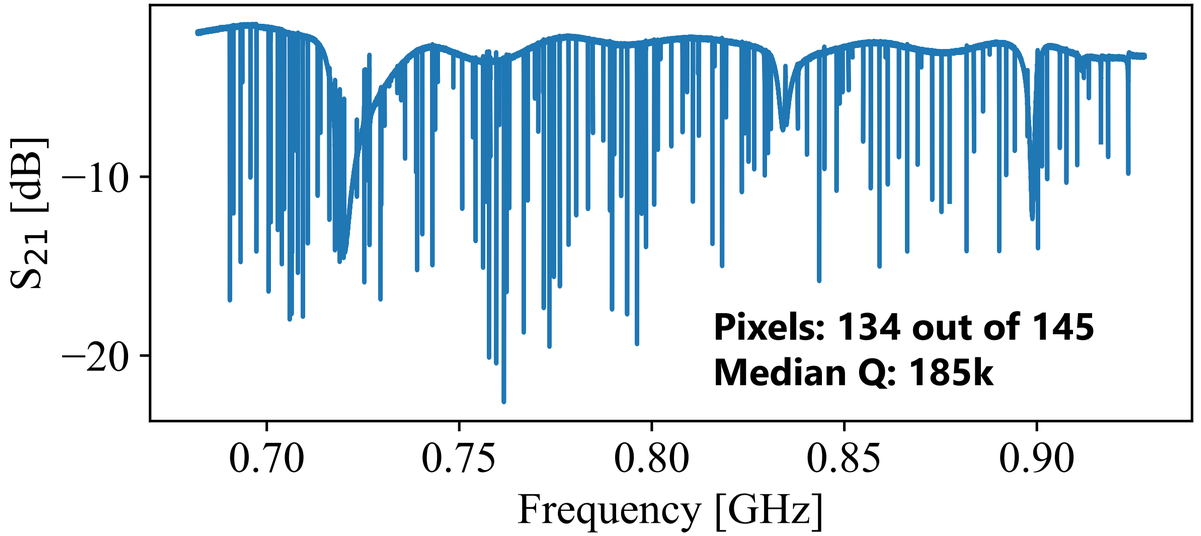
- Custom Analog Front-End and
- Control Firmware by the KIT group
- **Status: first tests on BULLKID-prototype**



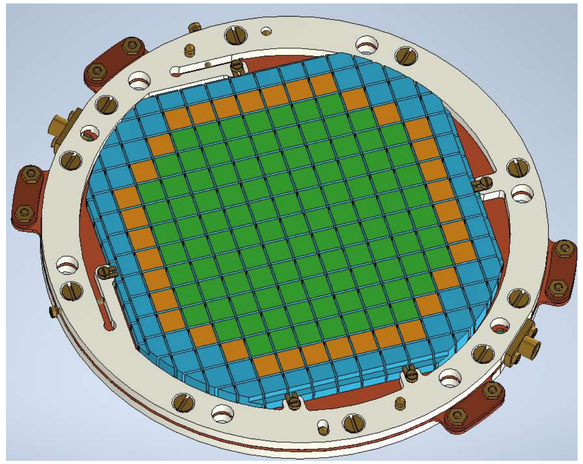
Status of 100 mm wafers

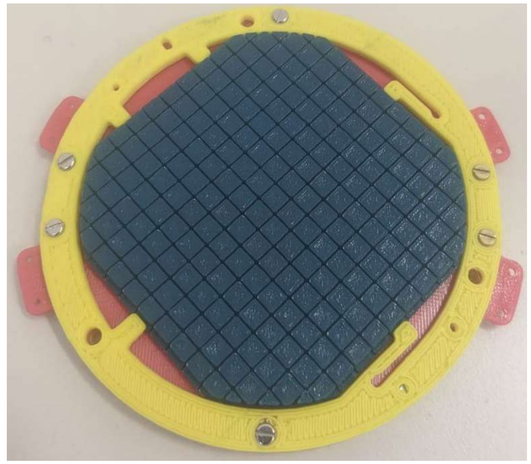
145 KID array test on thin (0.3 mm) wafer successful





Assembly under development





5 mm wafer grooved succesfull

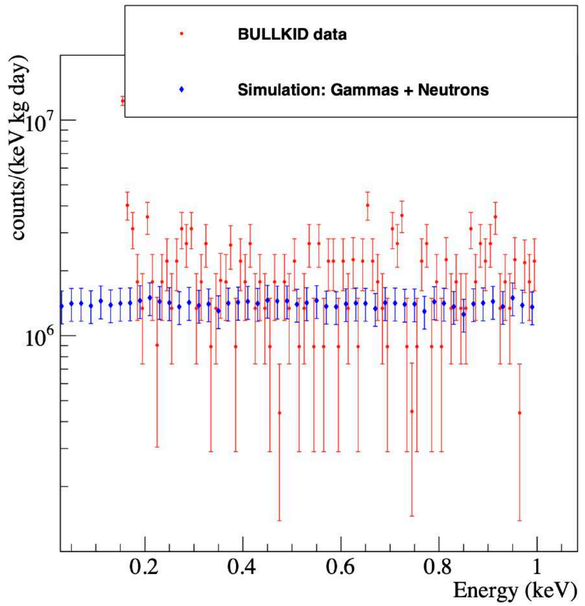
Simulations: validation on Sapienza setup

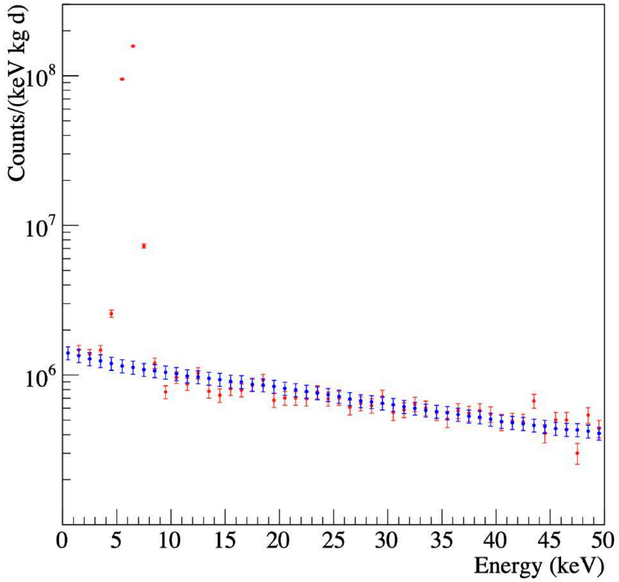
Gammas (99%) and neutrons (1%) measured and used as input for the simulation

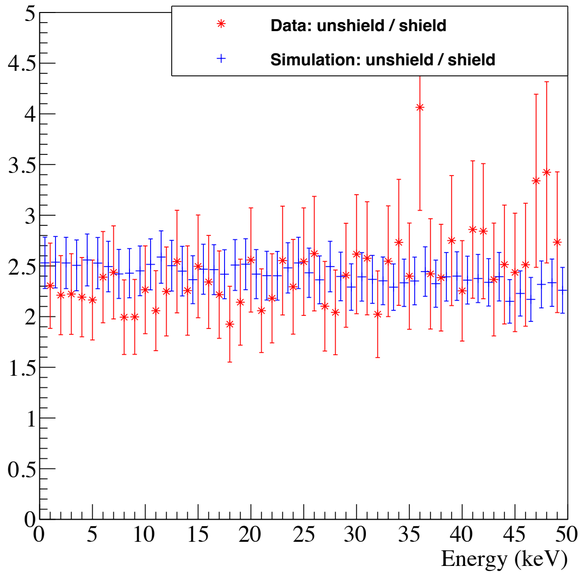
Agreement over wide energy range observed

Mild lead shield added

Reduction of the background agrees with simulations





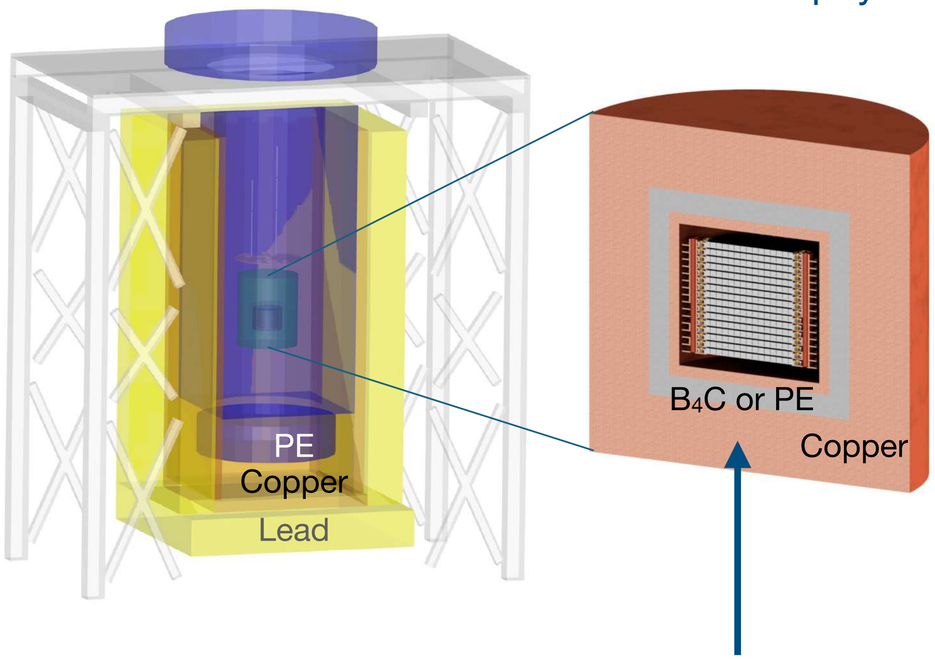


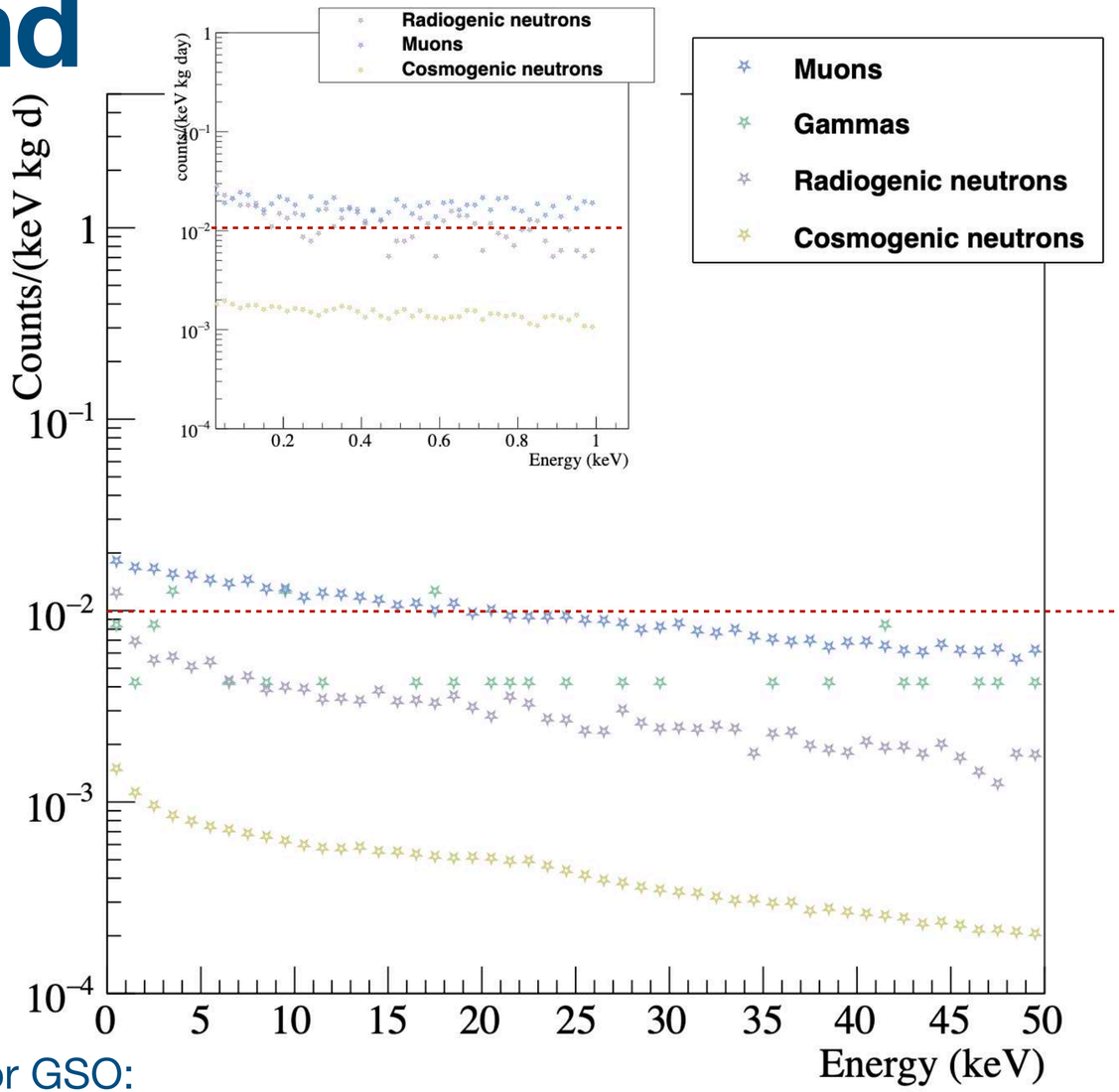
Projected background

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





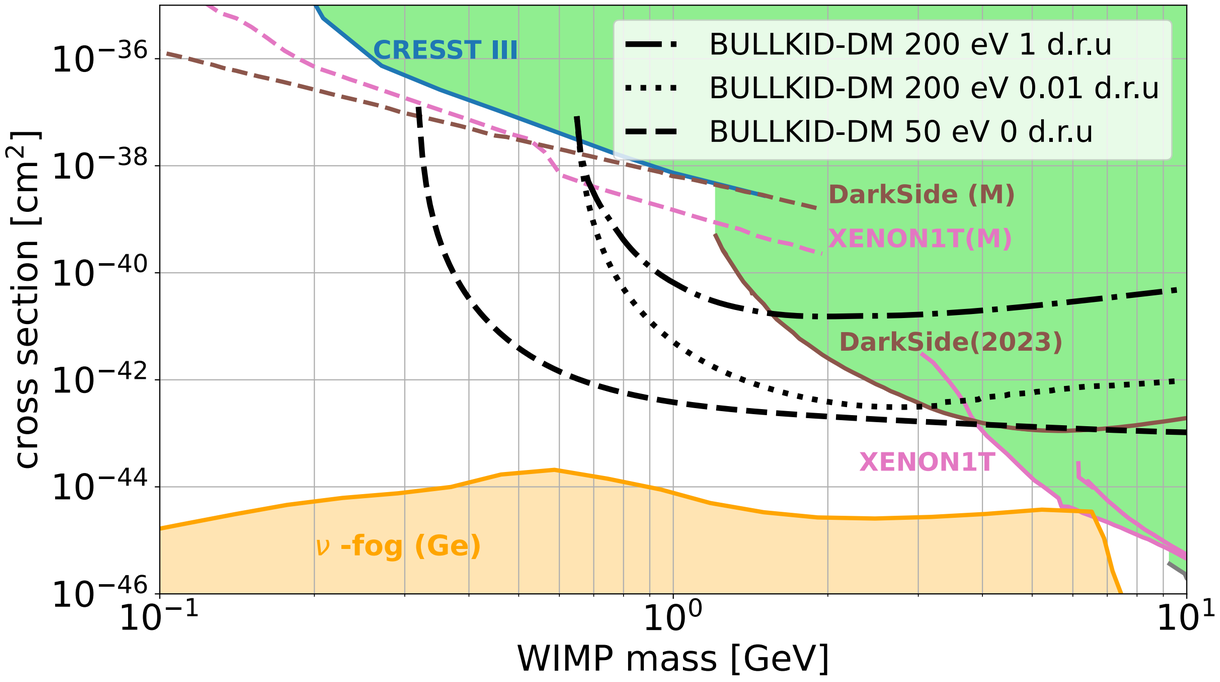
"zero" bkg.

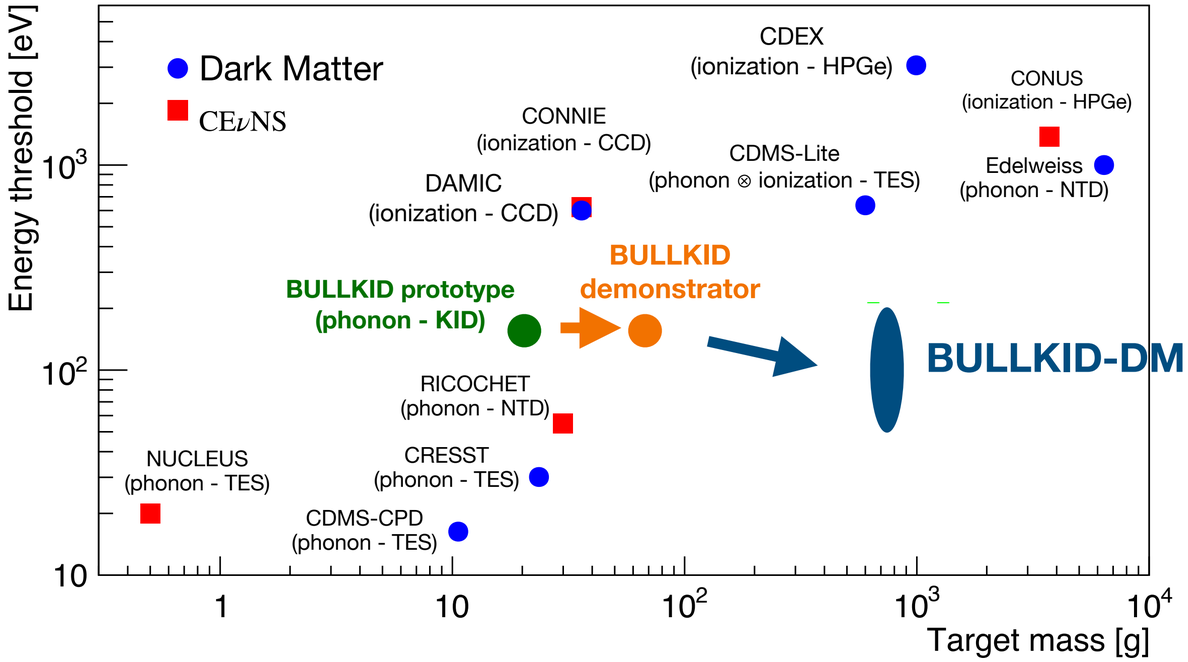
Replacing this with an active veto of BGO or GSO:
Background ~ 10^{-3} counts/(keV kg d)

Currently working on internal contaminations in lead and veto

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)	2×10^{6}	$< 10^{5}$		**1 - 0.01**
laboratory	Sapienza U.	Sapienza	LNGS	**LNGS**
installation	2023	2024	2026	**2027**





Future sensitivities