



UNIVERSITÄT
HEIDELBERG
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SEIT 1386

Direct searches for light dark matter with cryogenic experiments *and the low-energy excess*

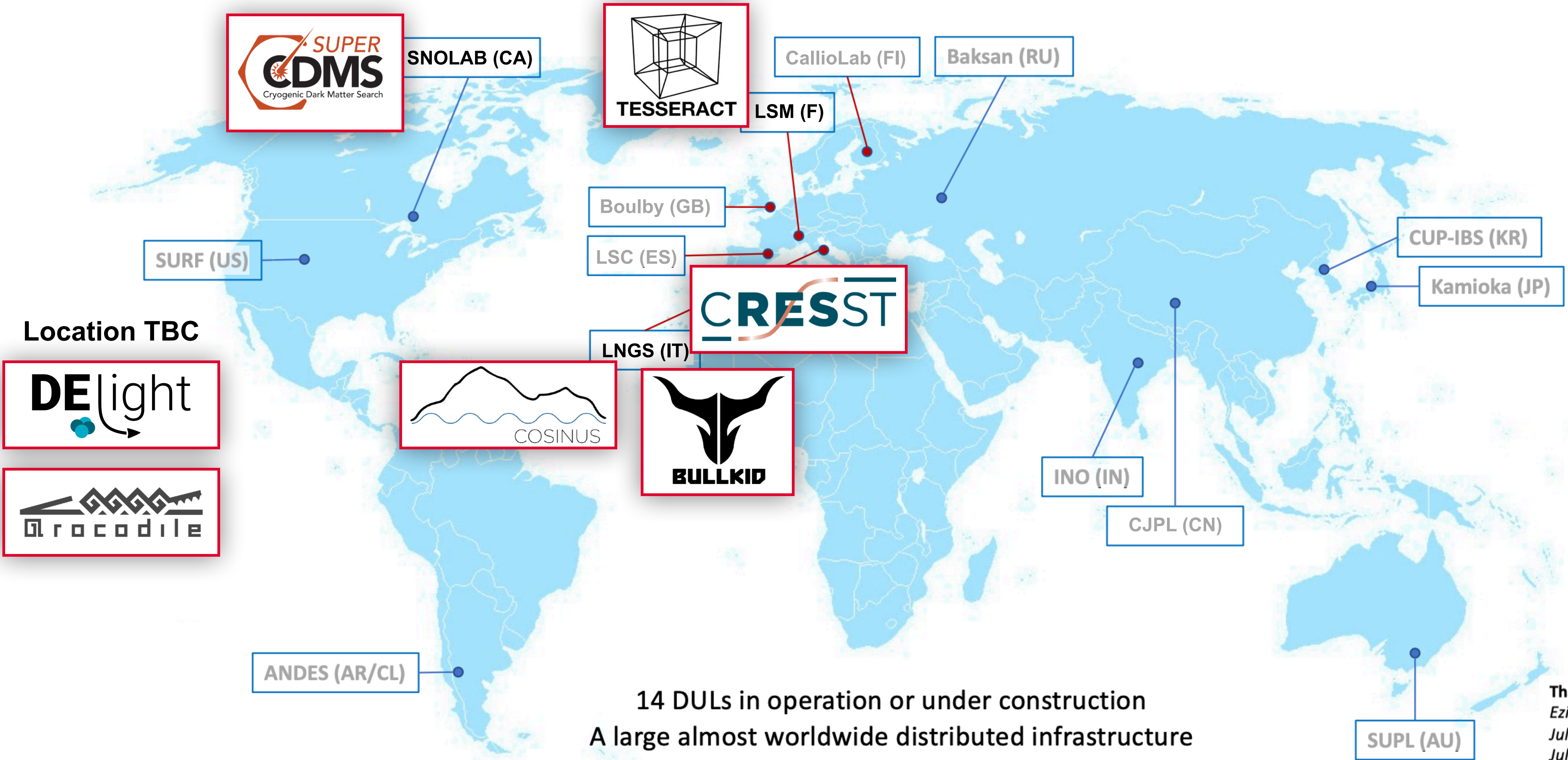
Identification of Dark Matter (IDM), Zaragoza, 03.06.2026

Belina VON KROSIGK (bkrosigk@kip.uni-heidelberg.de)





Experiments in this talk

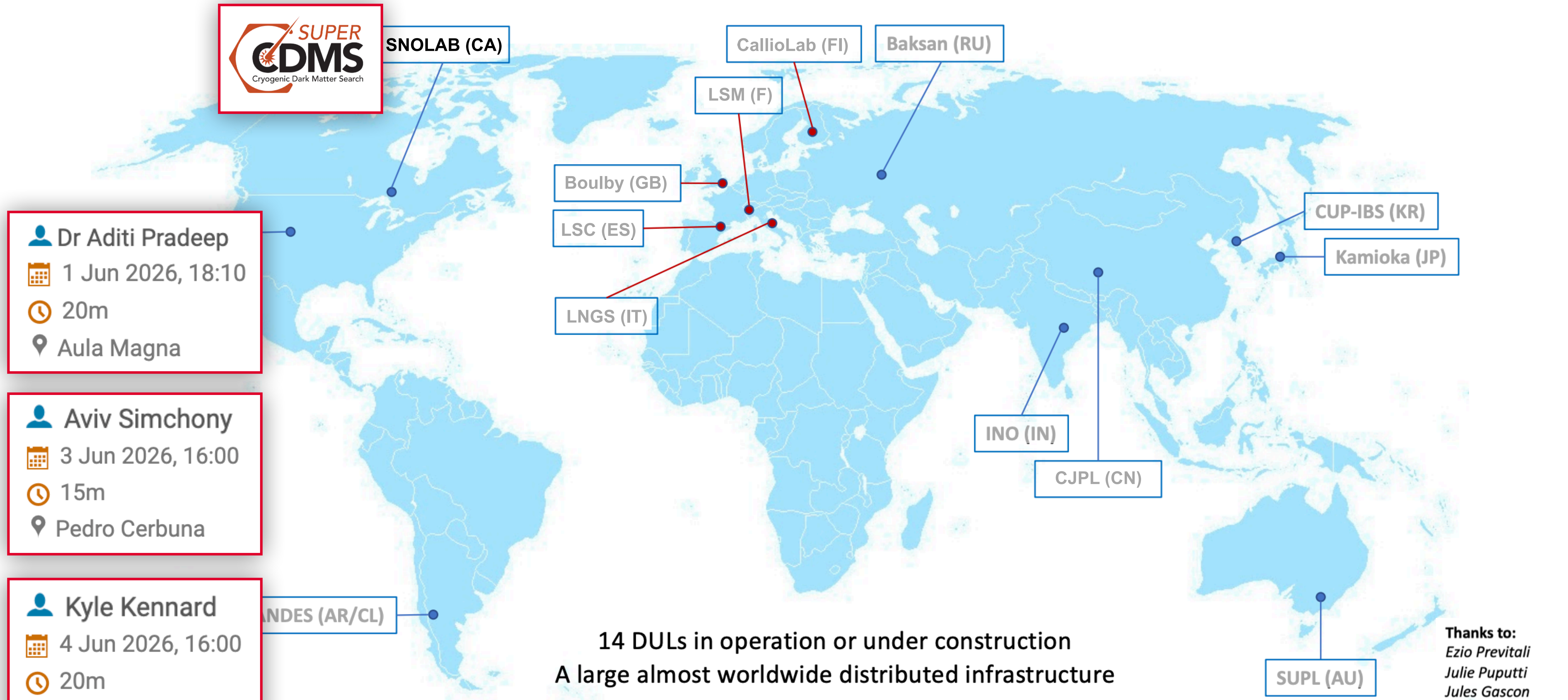


14 DULs in operation or under construction
A large almost worldwide distributed infrastructure

Thanks to:
Ezio Previtali
Julie Puputti
Jules Gascon
Carlos Peña Garay



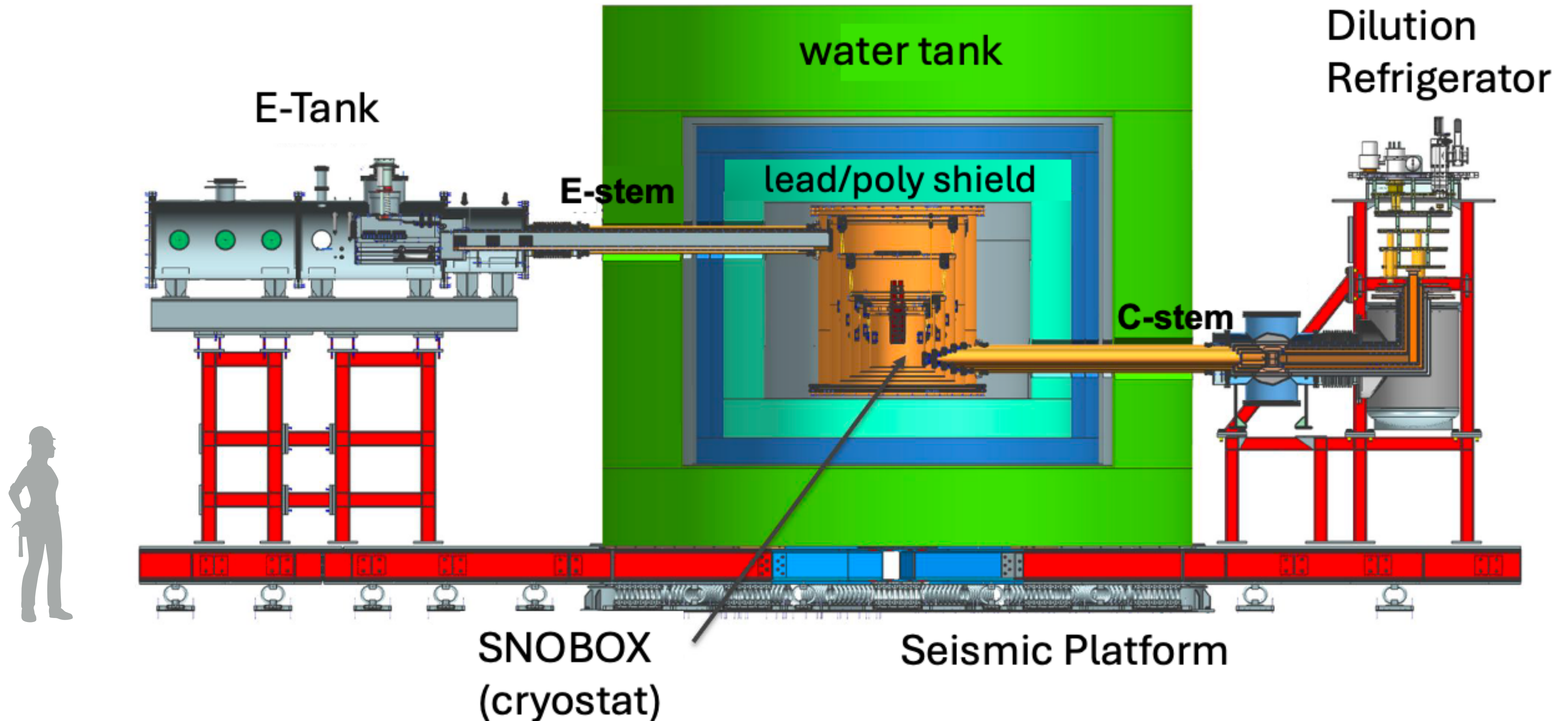
Experiments in this talk



Thanks to:
Ezio Previtali
Julie Puputti
Jules Gascon
Carlos Peña Garay

The SuperCDMS SNOLAB experiment

Slide content thanks to Prisca Cushman

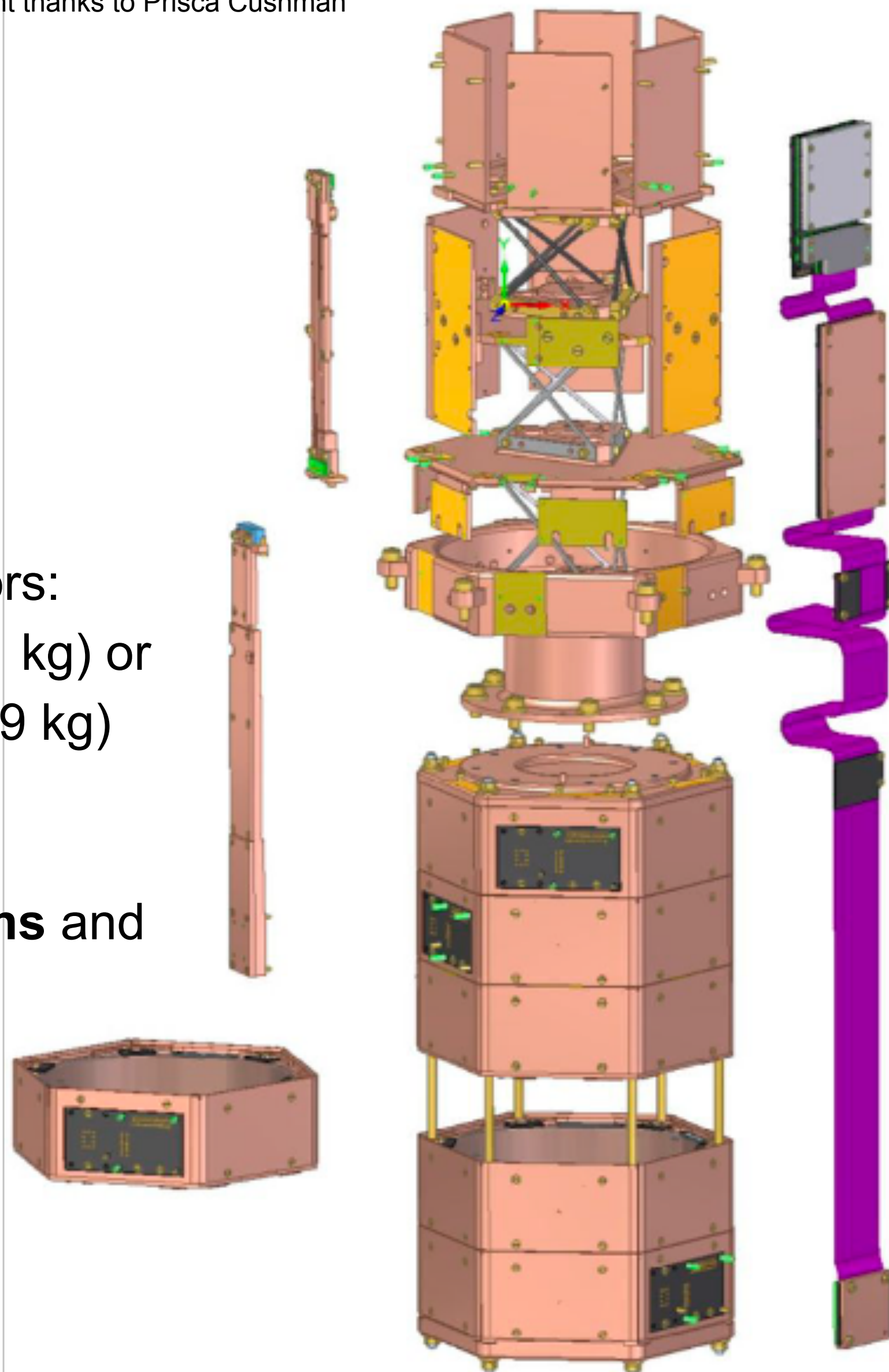


The SNOBOX, towers, and detectors

Slide content thanks to Prisca Cushman

Detectors:
Si (0.61 kg) or
Ge (1.39 kg)

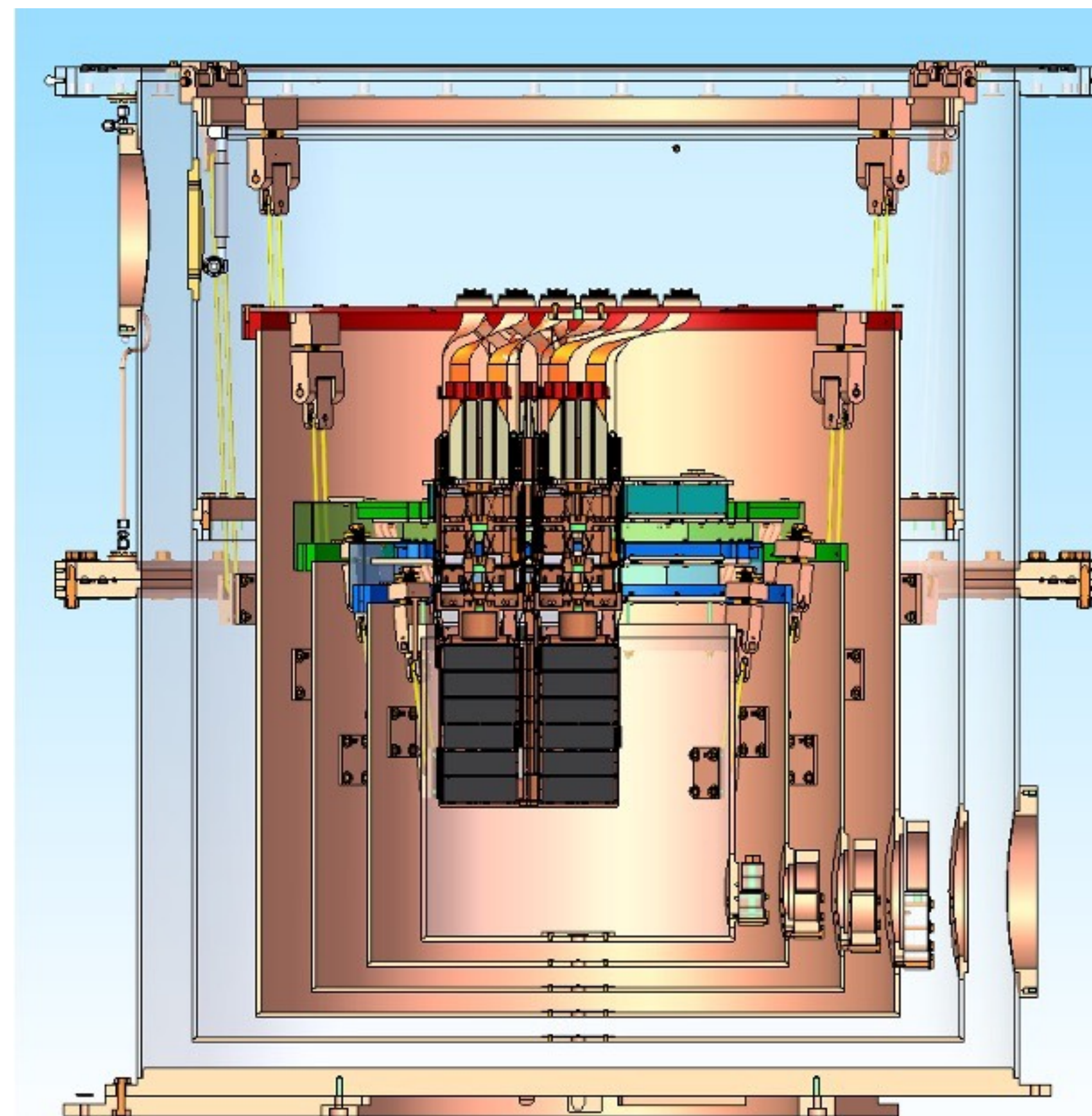
Signal:
phonons and
charge



HEMT: amplifier for
iZIP charge channels
(4K stage)

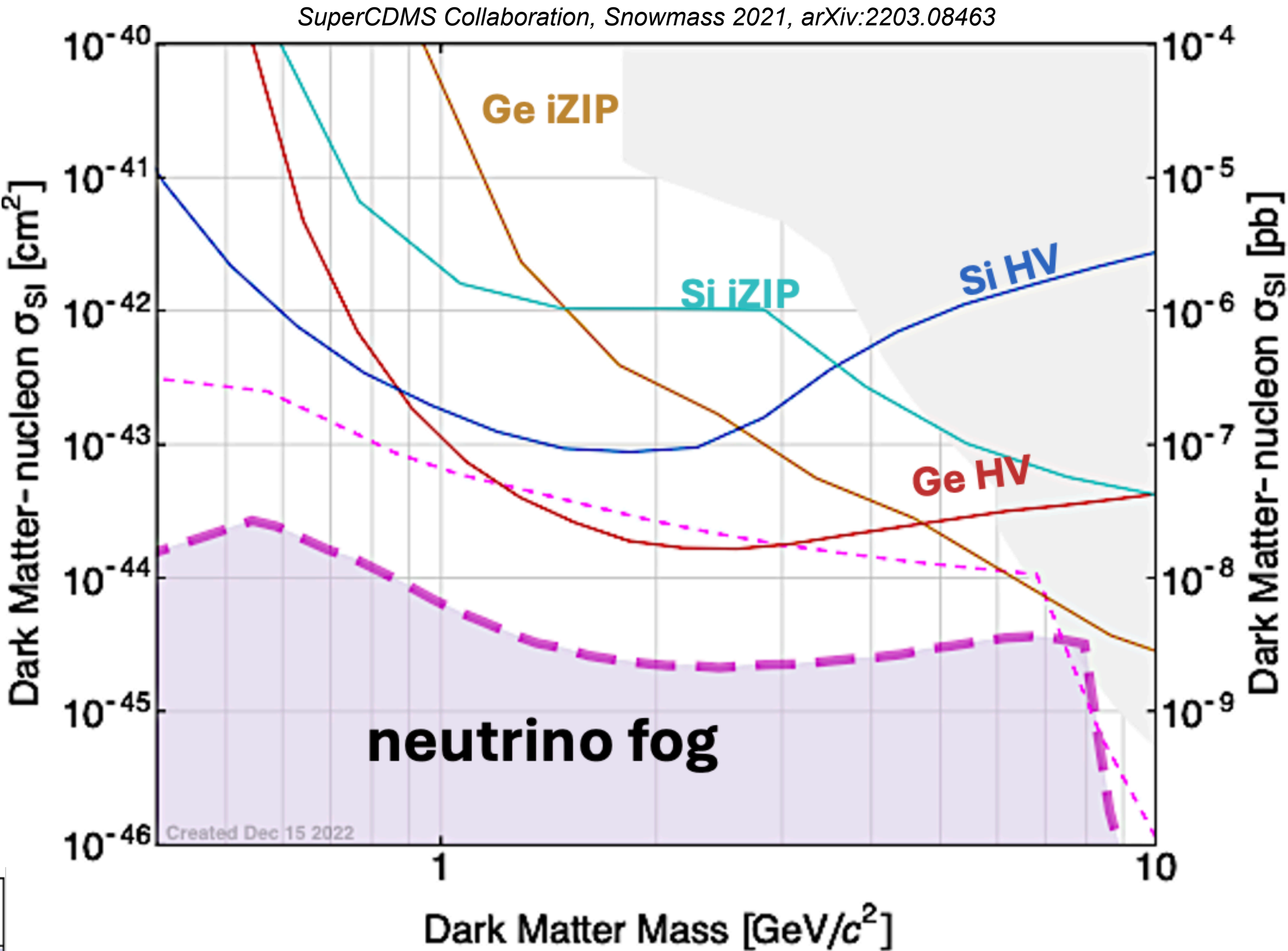
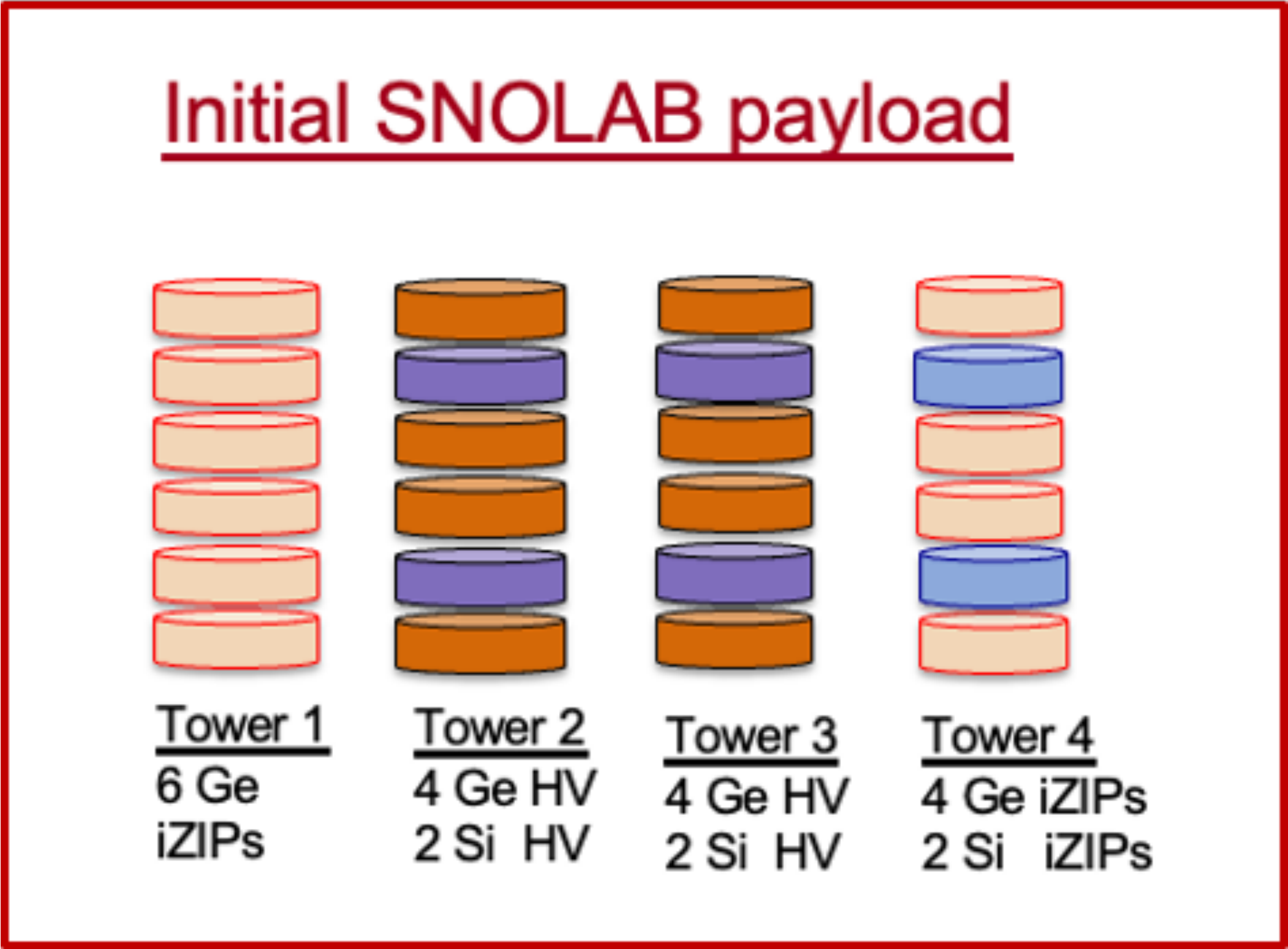
SQUID: **TES**-based
(Transition Edge
Sensor) readout
(1K stage)

Detectors are kept at
the MC stage (base
temperature **~15 mK**)



Sensitivity to DM-nucleon scattering

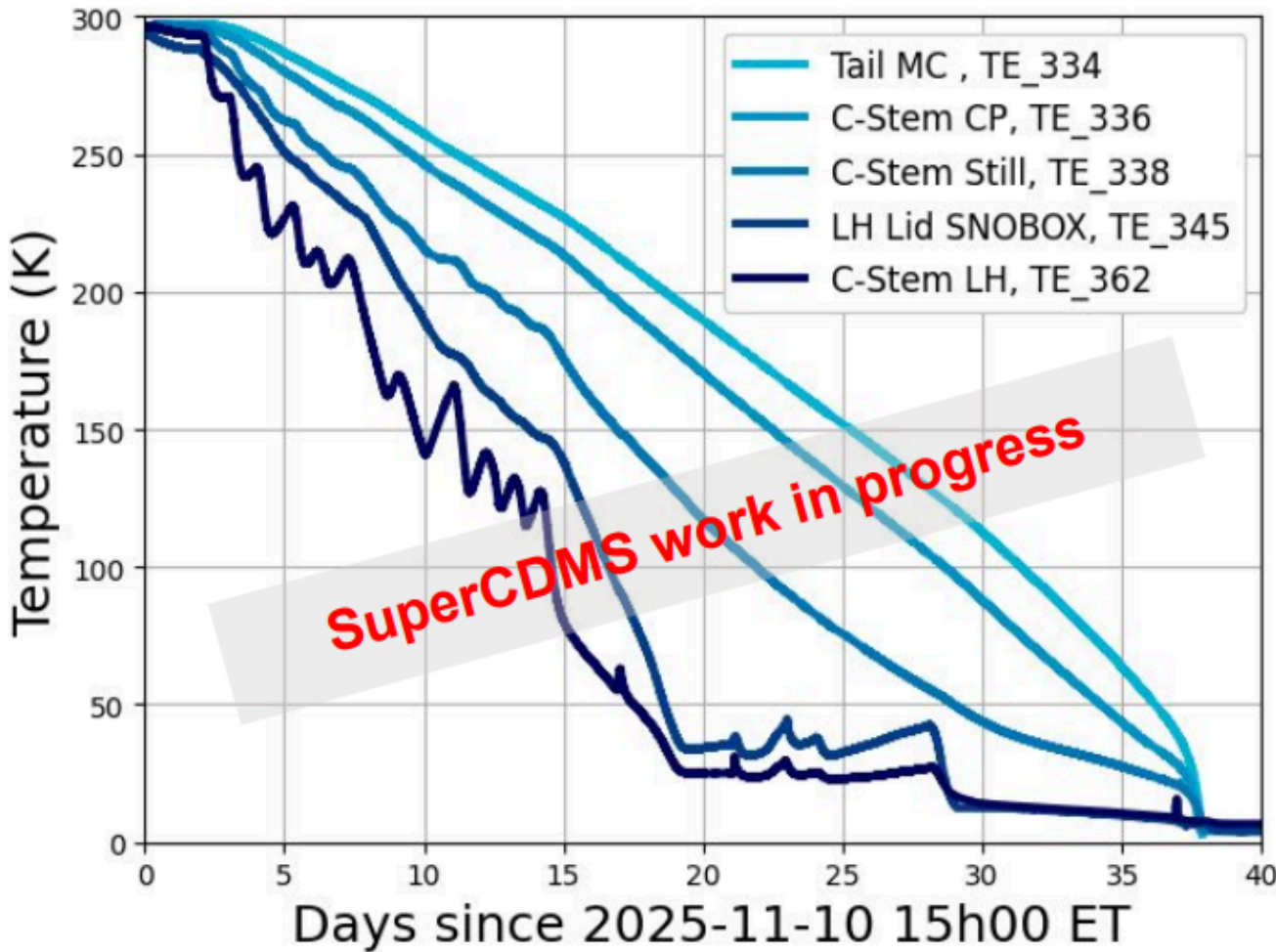
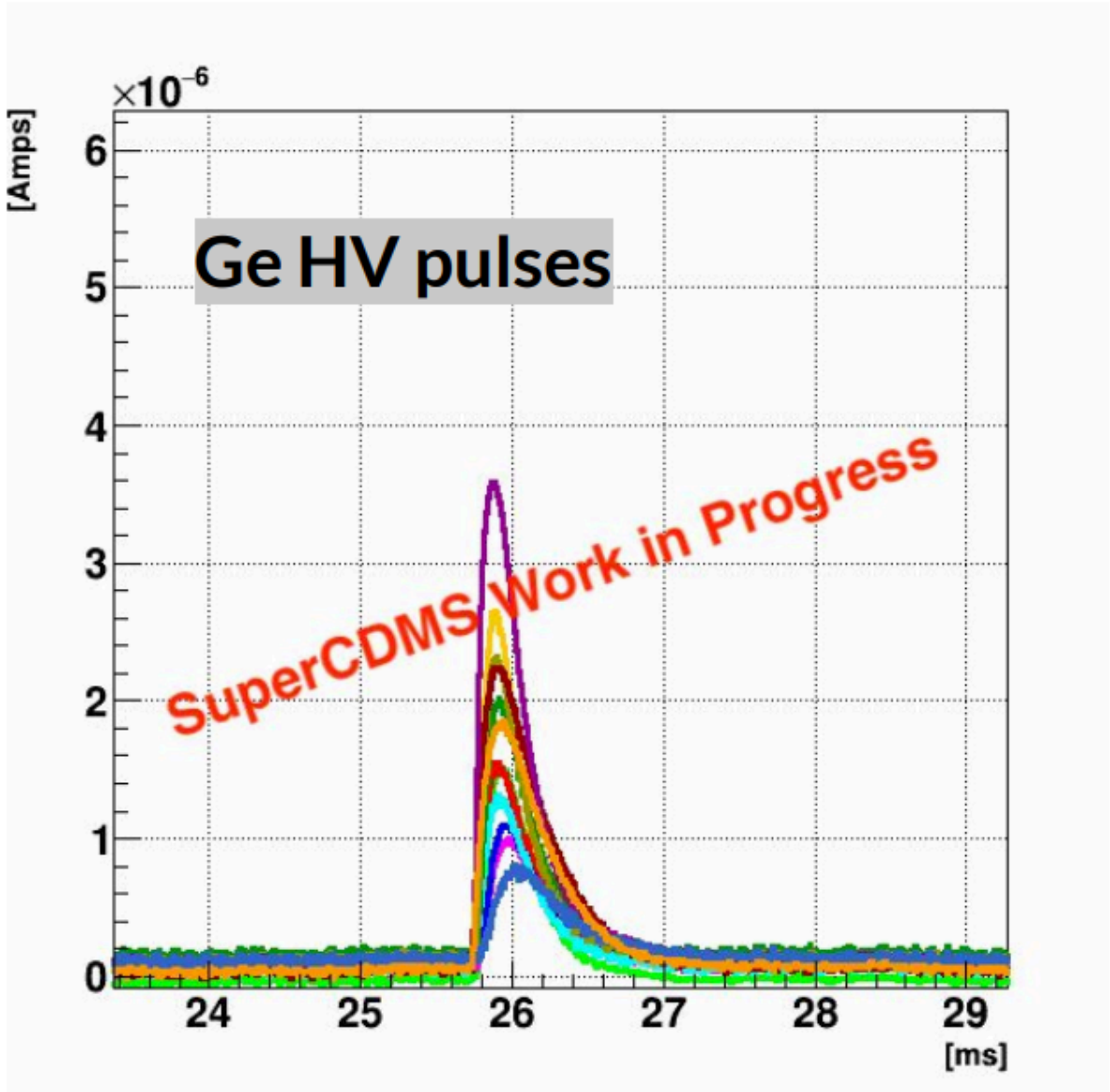
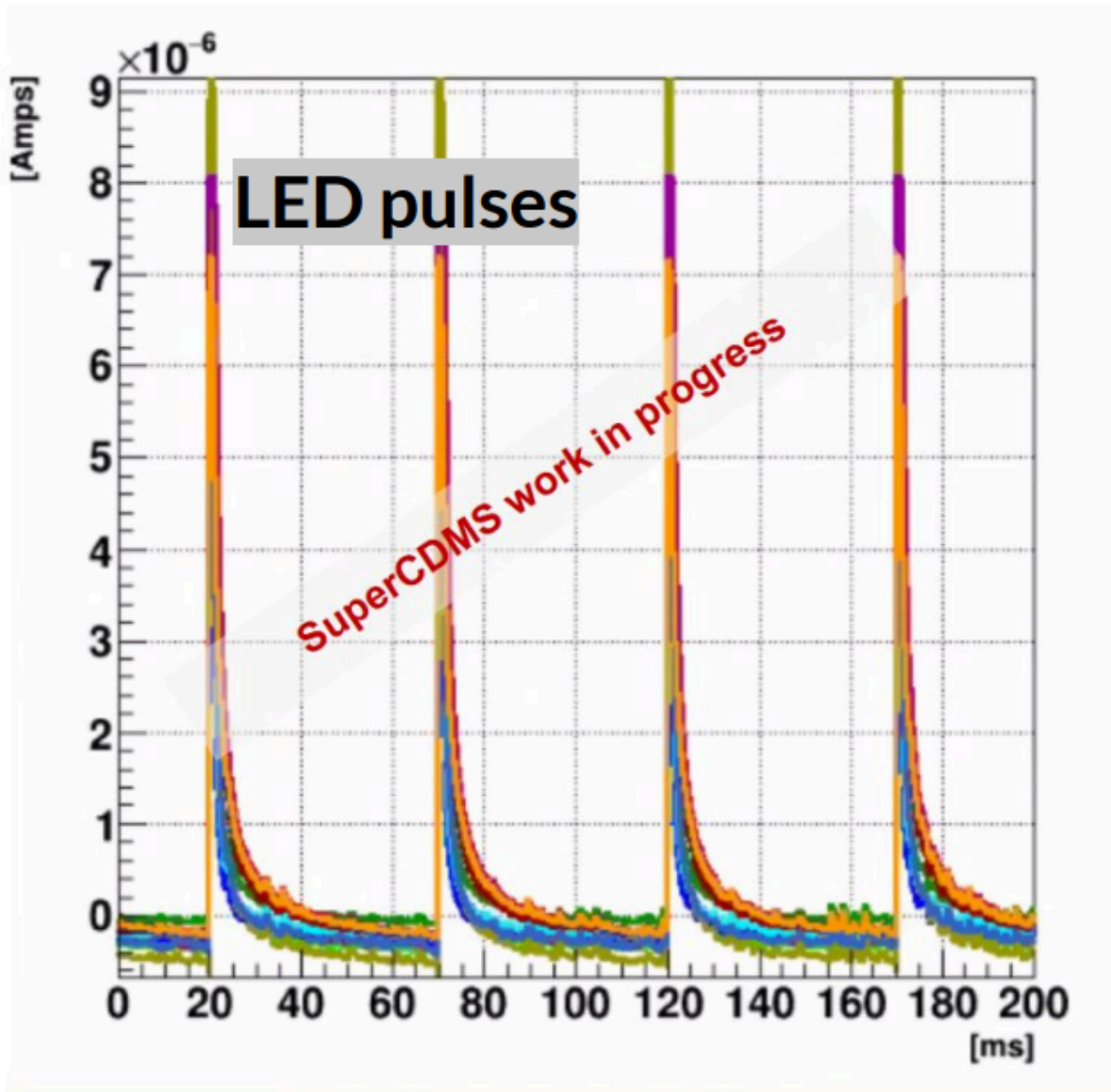
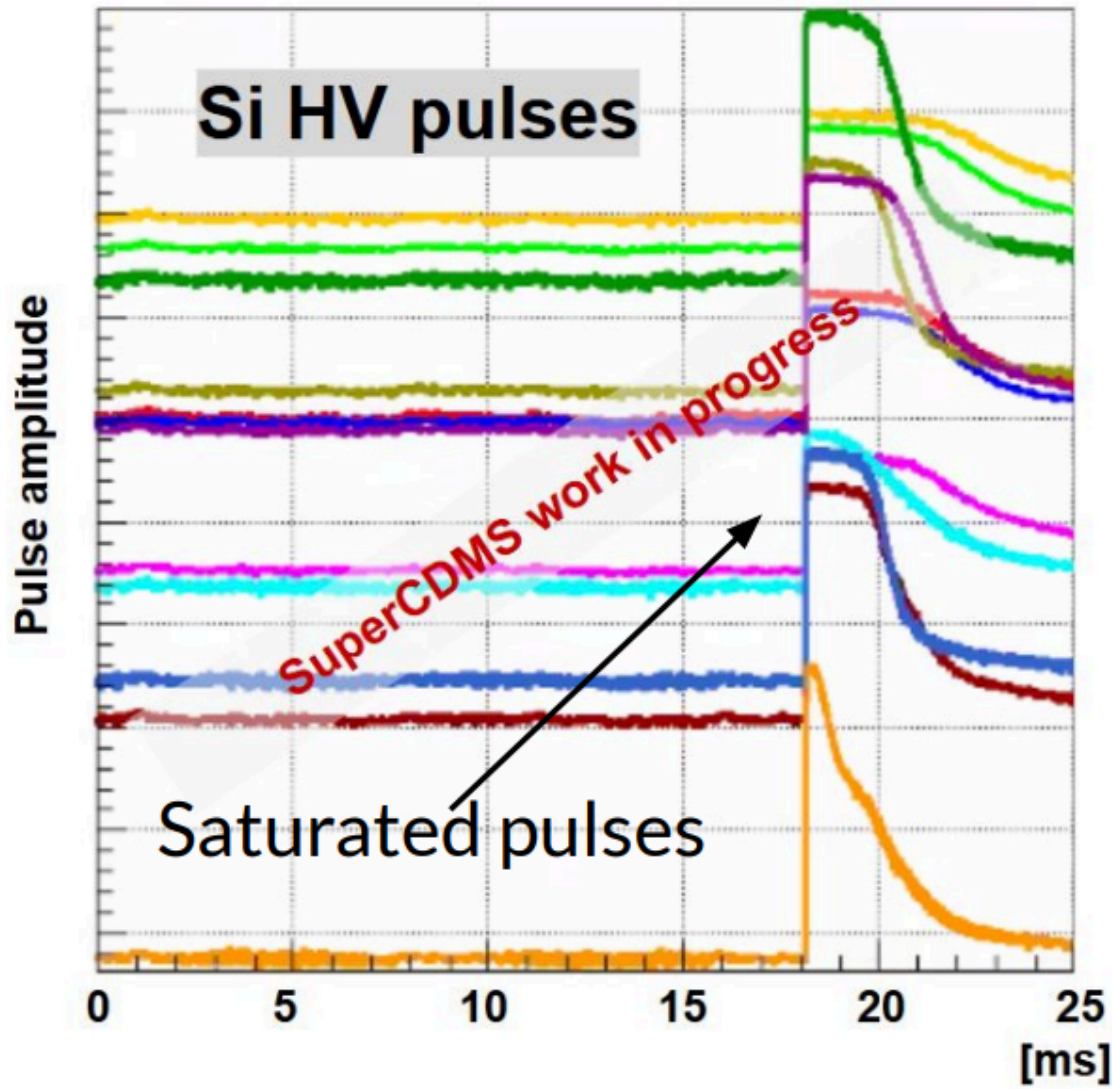
Slide content thanks to Prisca Cushman



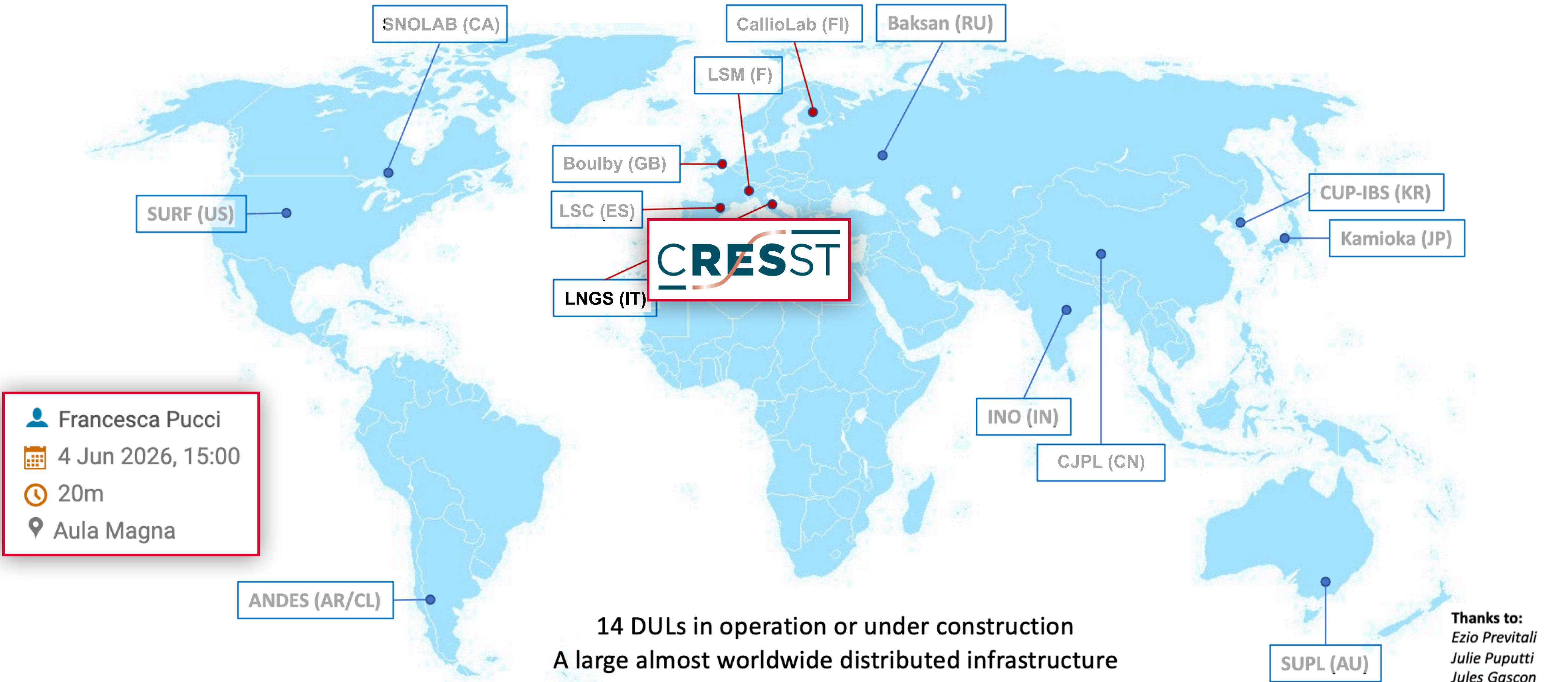
	Germanium	Silicon
HV	Lowest threshold for low mass DM Larger exposure, no ^{32}Si bkgd	Lowest threshold for low mass DM Sensitive to lowest DM masses
iZIP	Nuclear Recoil Discrimination Understand Ge Backgrounds Sensitive to ^8B ν -scatter	Nuclear Recoil Discrimination Understand Si Backgrounds Sensitive to ^8B ν -scatter

SuperCDMS SNOLAB: first pulses Jan 15, 2026 !

Slide content thanks to Aditi Prdeep



Experiments in this talk



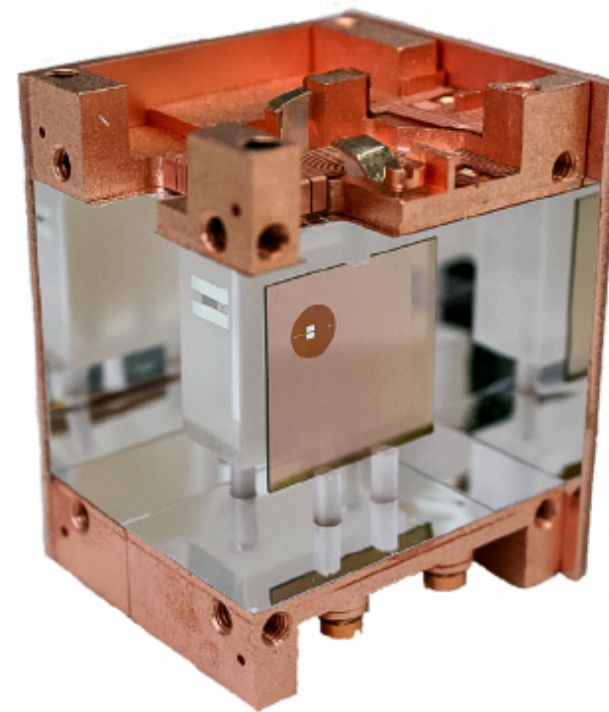
 Francesca Pucci
 4 Jun 2026, 15:00
 20m
 Aula Magna

Thanks to:
Ezio Previtali
Julie Puputti
Jules Gascon
Carlos Peña Garay

The CRESST-III standard detector design

Slide content thanks to Francesca Pucci, Anna Bertolini

- **CaWO₄** crystal as main absorber 2x2x1 cm³
- **Silicon-on-Sapphire (SOS)** wafer as light detector
- Both equipped with **TESs**



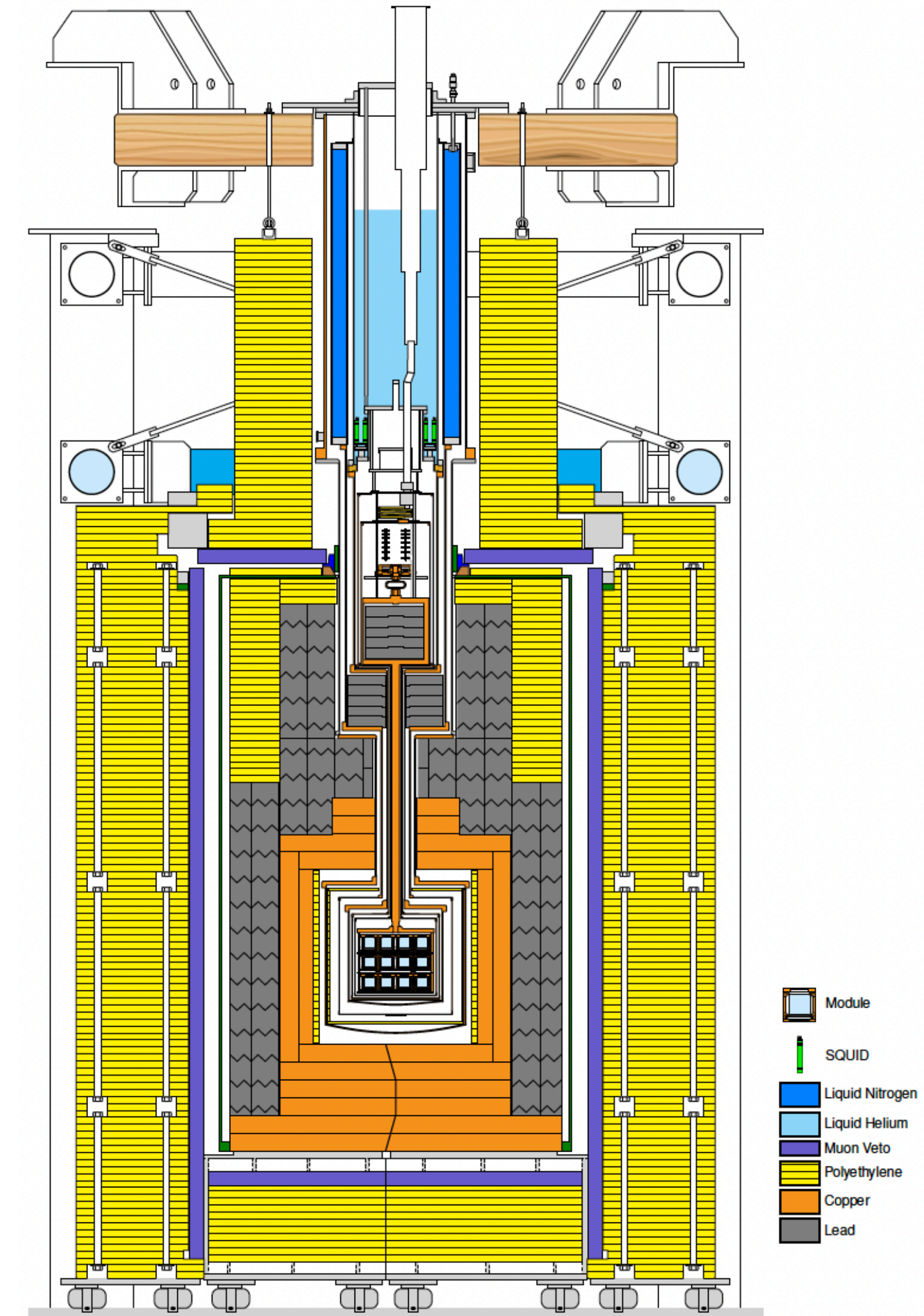
2019

CaWO₄ (Det.A)

$m = 24 \text{ g}$

$E_{\text{th}} = 30.1 \text{ eV}$

Signal: **phonons** and **light**

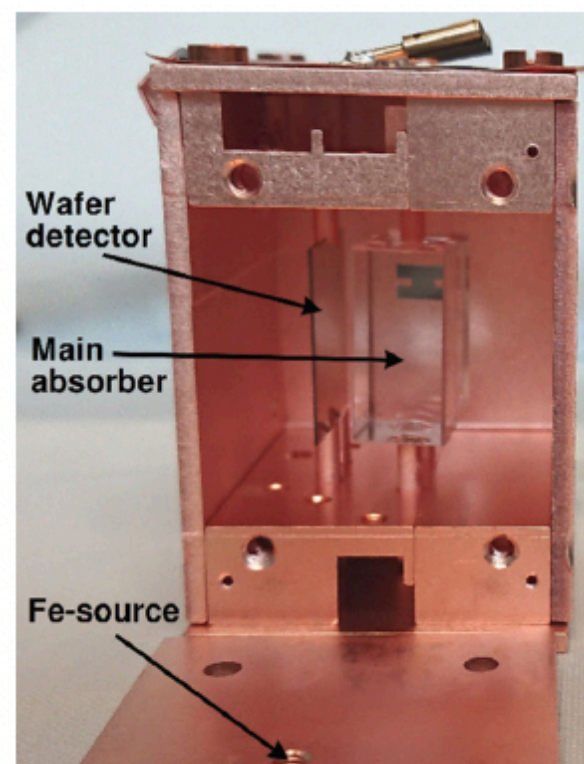


Multiple passive shielding layers

A dedicated low-threshold detector

Slide content thanks to Francesca Pucci, Anna Bertolini

- Al_2O_3 crystal as main absorber $2 \times 2 \times 1 \text{ cm}^3$
- **Silicon-on-Sapphire (SOS)** wafer for DM search
- Both equipped with **TESs**



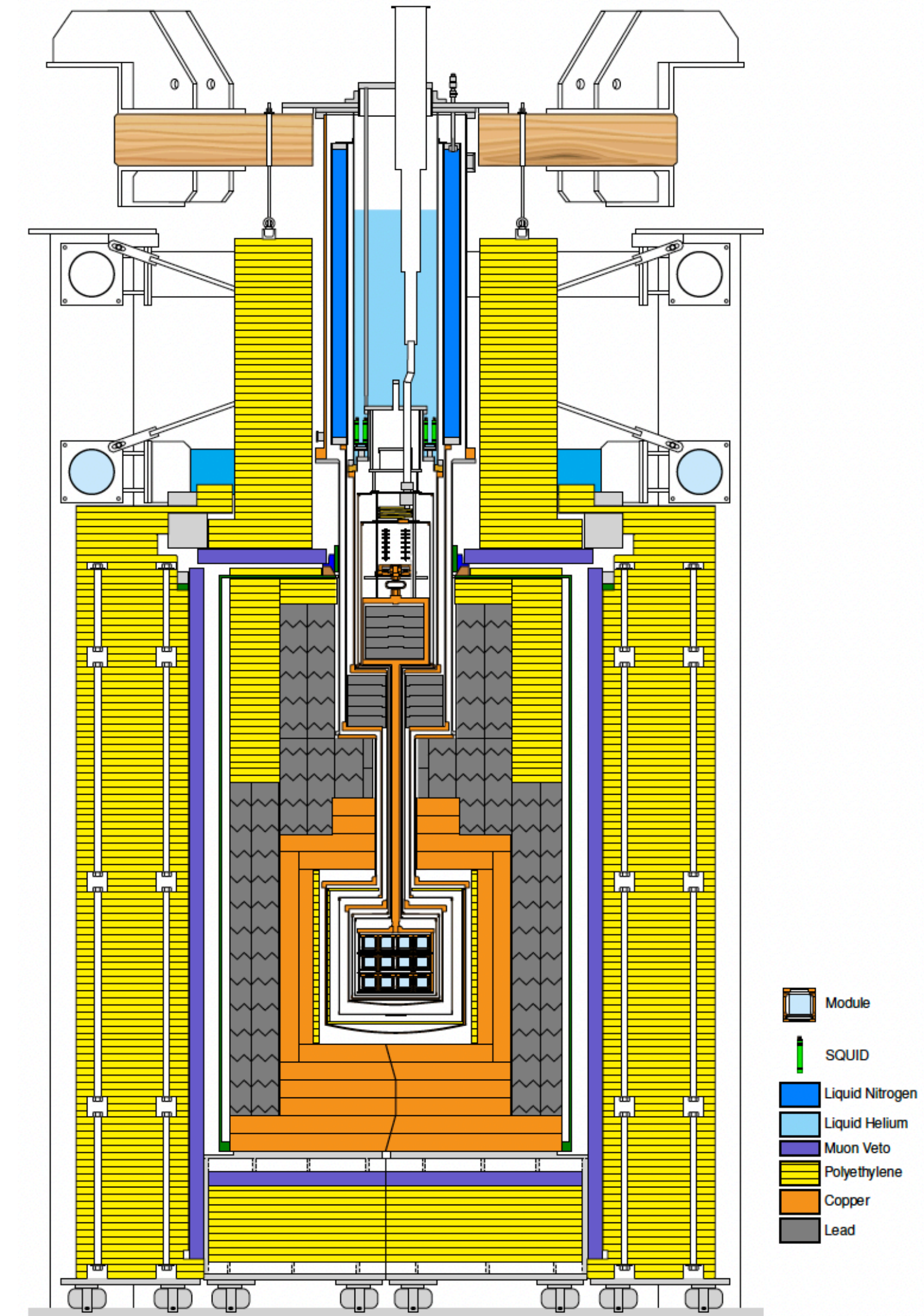
2024

SOS-wafer

$m = 0.6 \text{ g}$

$E_{\text{th}} = 6.7 \text{ eV}$

Signal: **phonons** and **light**

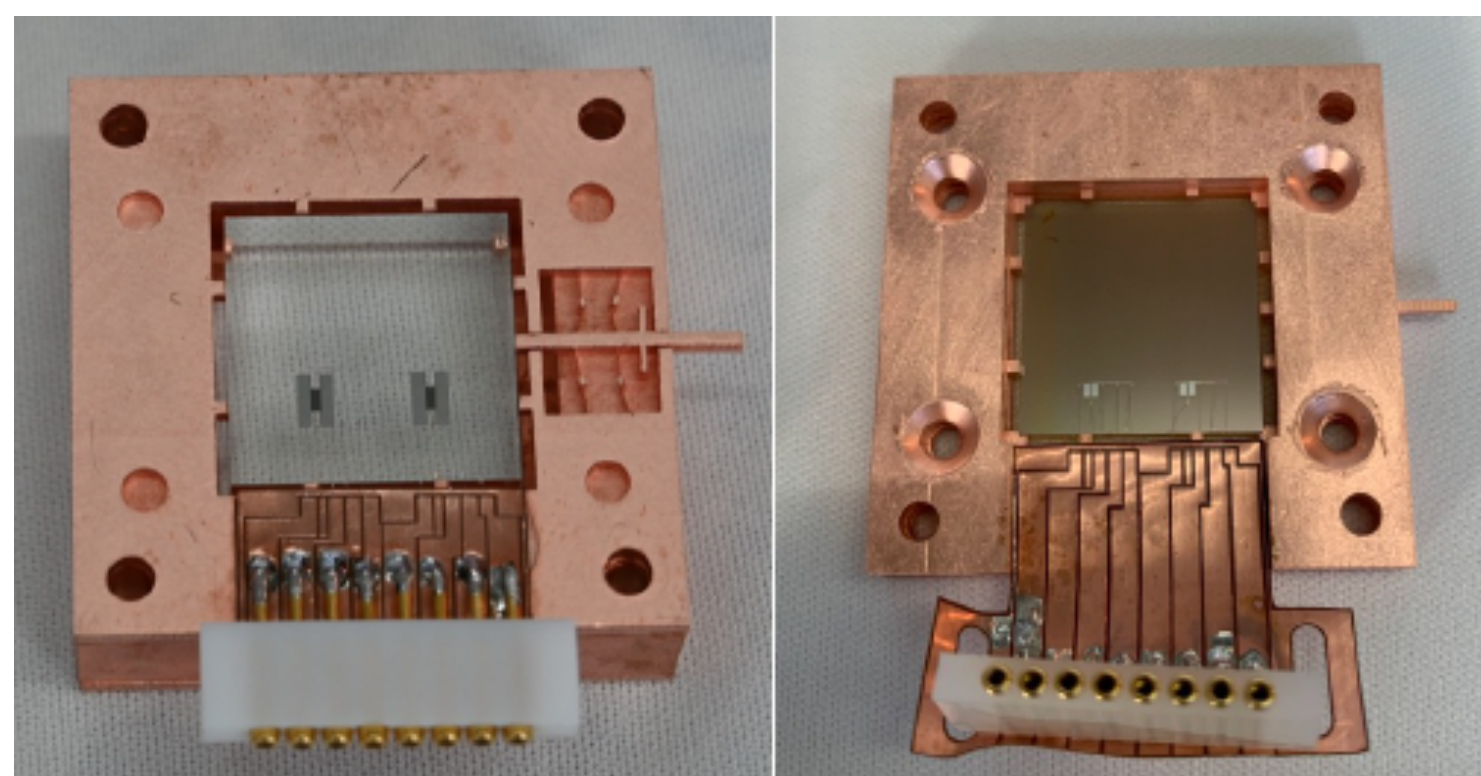


Multiple passive shielding layers

The DoubleTES detectors

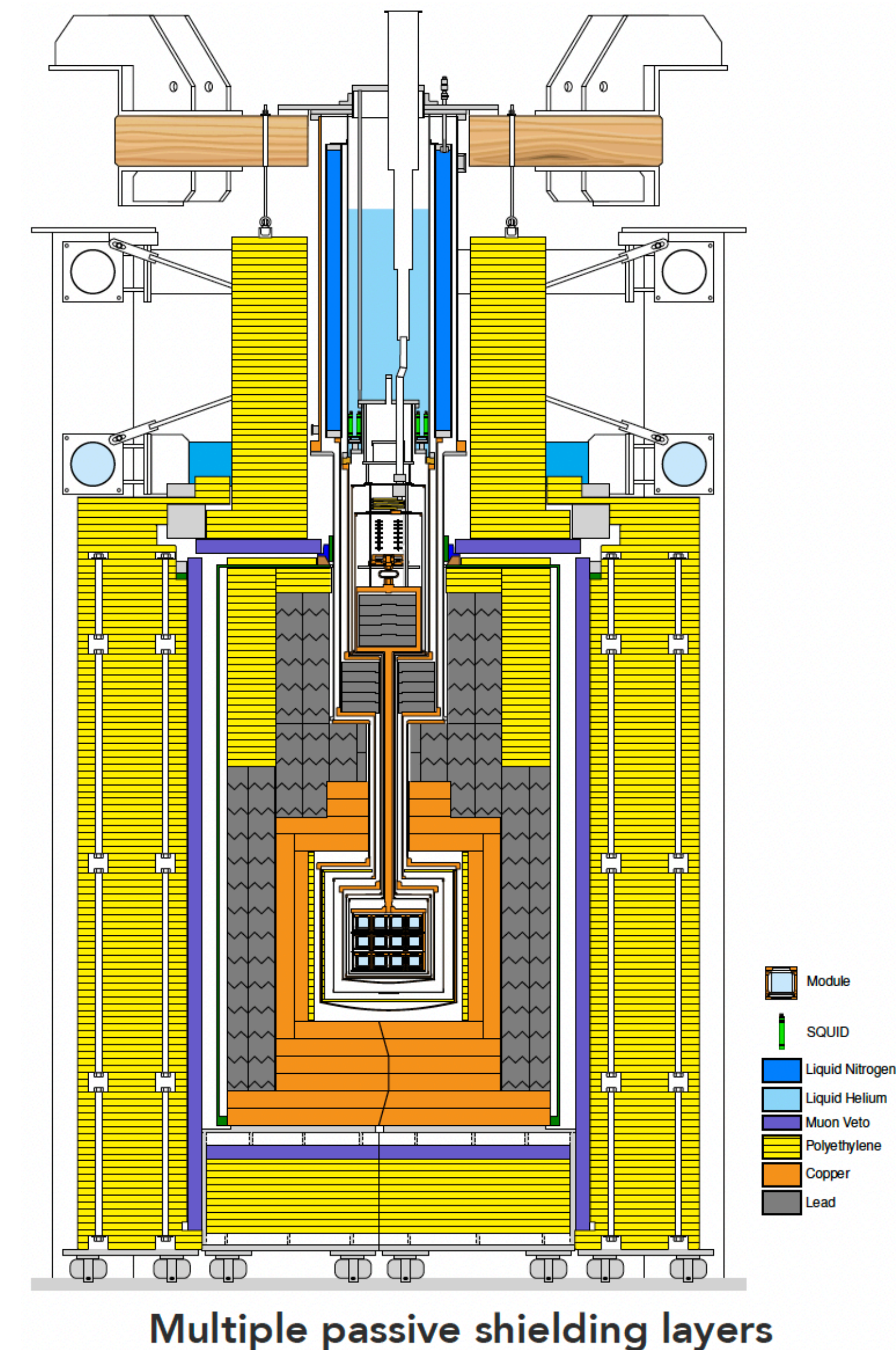
Slide content thanks to Francesca Pucci, Anna Bertolini

- **CaWO₄** or **SOS** as main absorber
- If CaWO₄ : additional SOS wafer as light detector
- If SOS : stack of 4 wafers
- Absorbers equipped with **2 TESs**



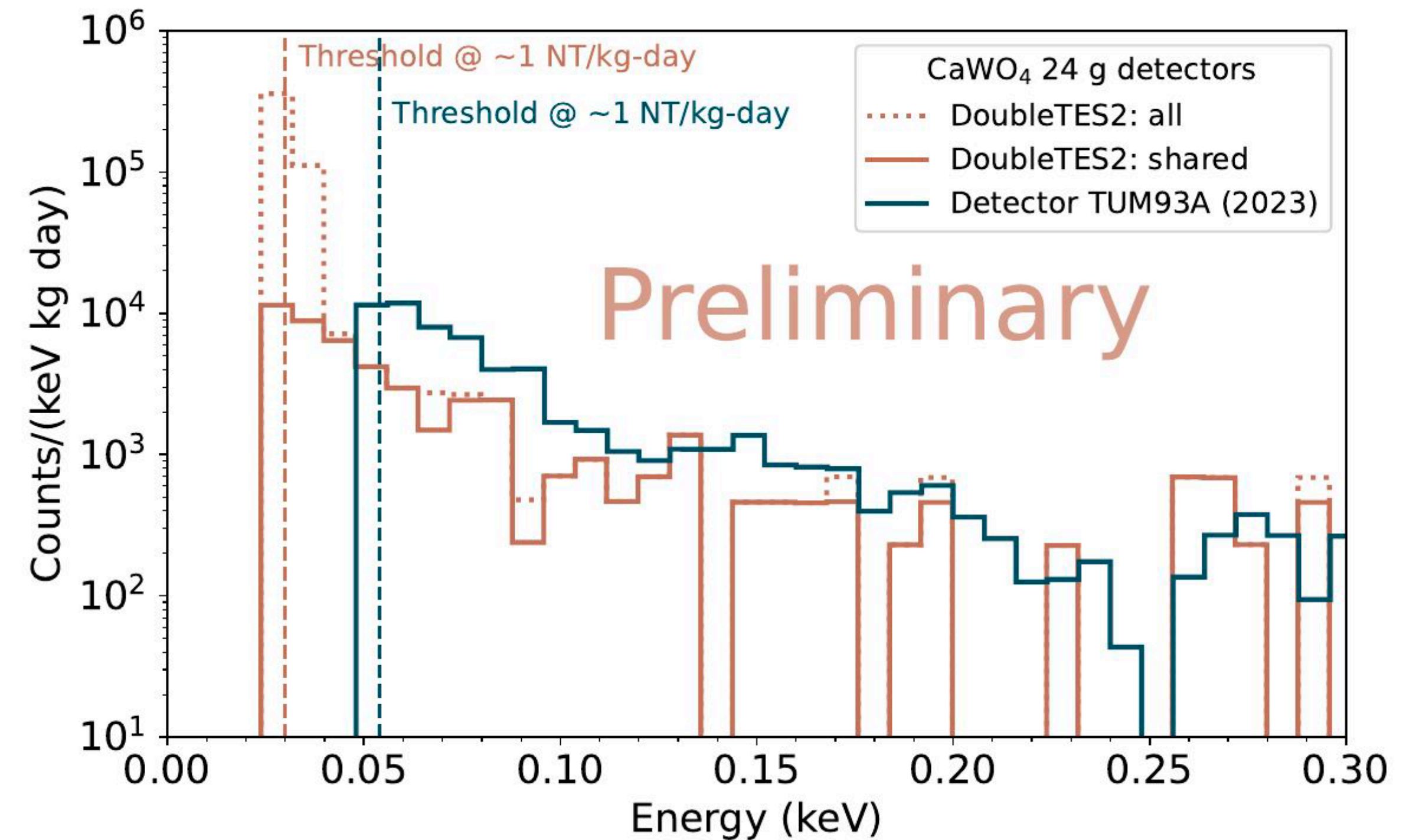
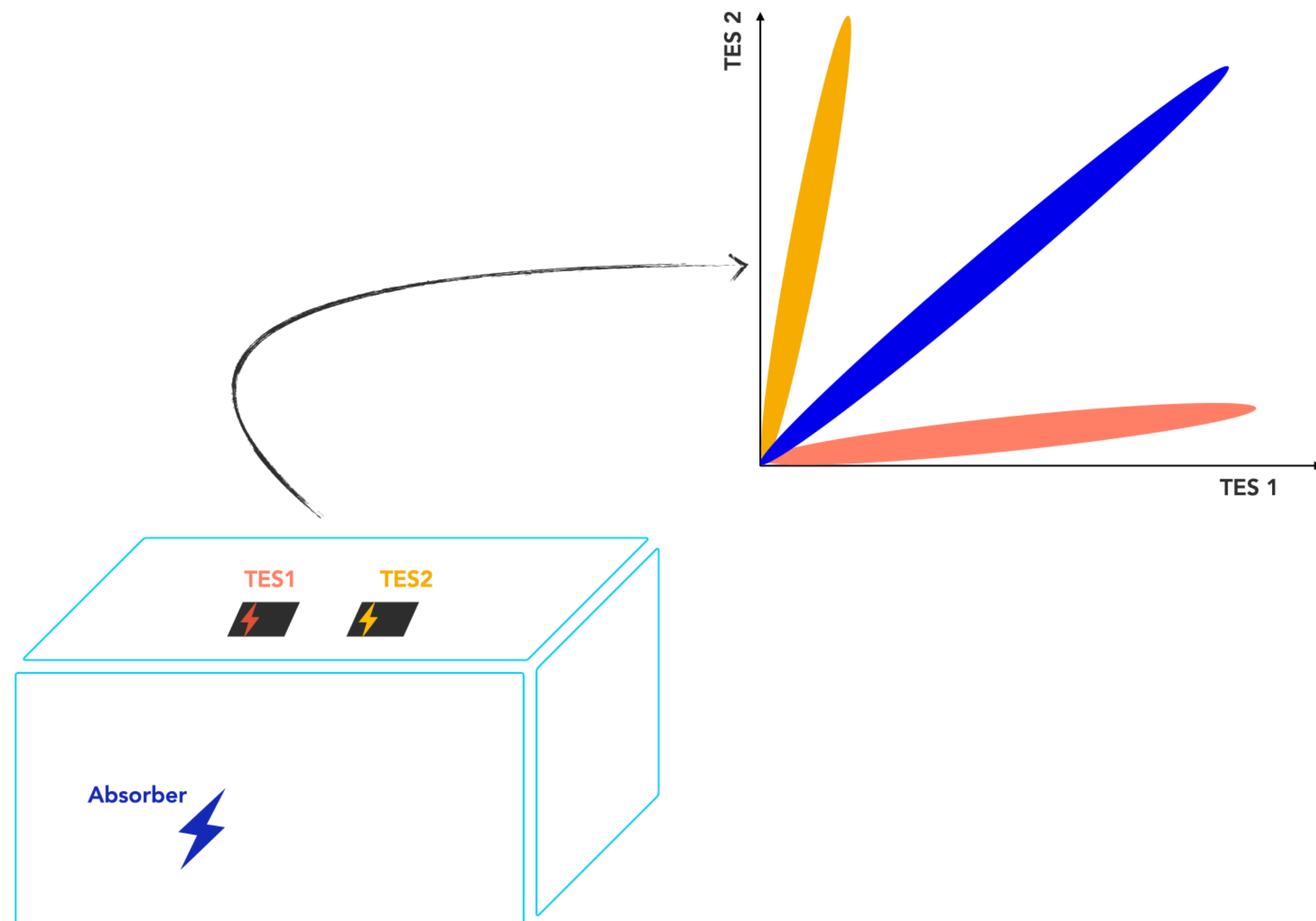
Upcoming
DoubleTES
 $m = 24 \text{ g} / 0.6 \text{ g}$

Signal: **phonons** and **light**



The DoubleTES detectors

Slide content thanks to Francesca Pucci, Anna Bertolini



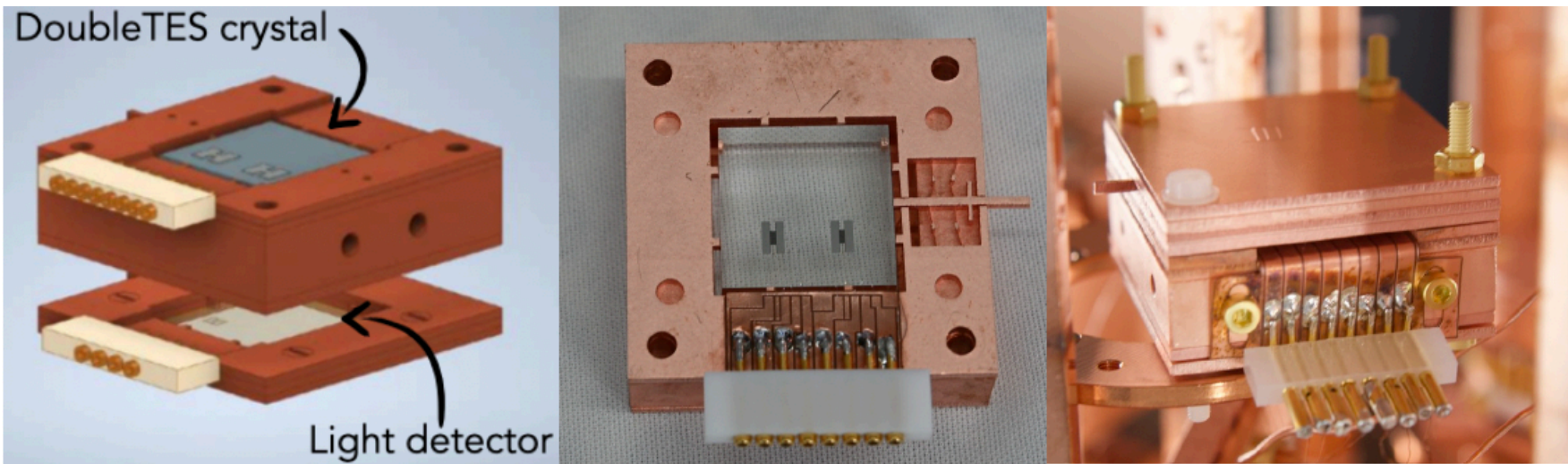
- Reduced threshold motivates first blind data taking with DoubleTES modules
- CRESST is getting ready to take DM data!

CRESST-III results and outlook

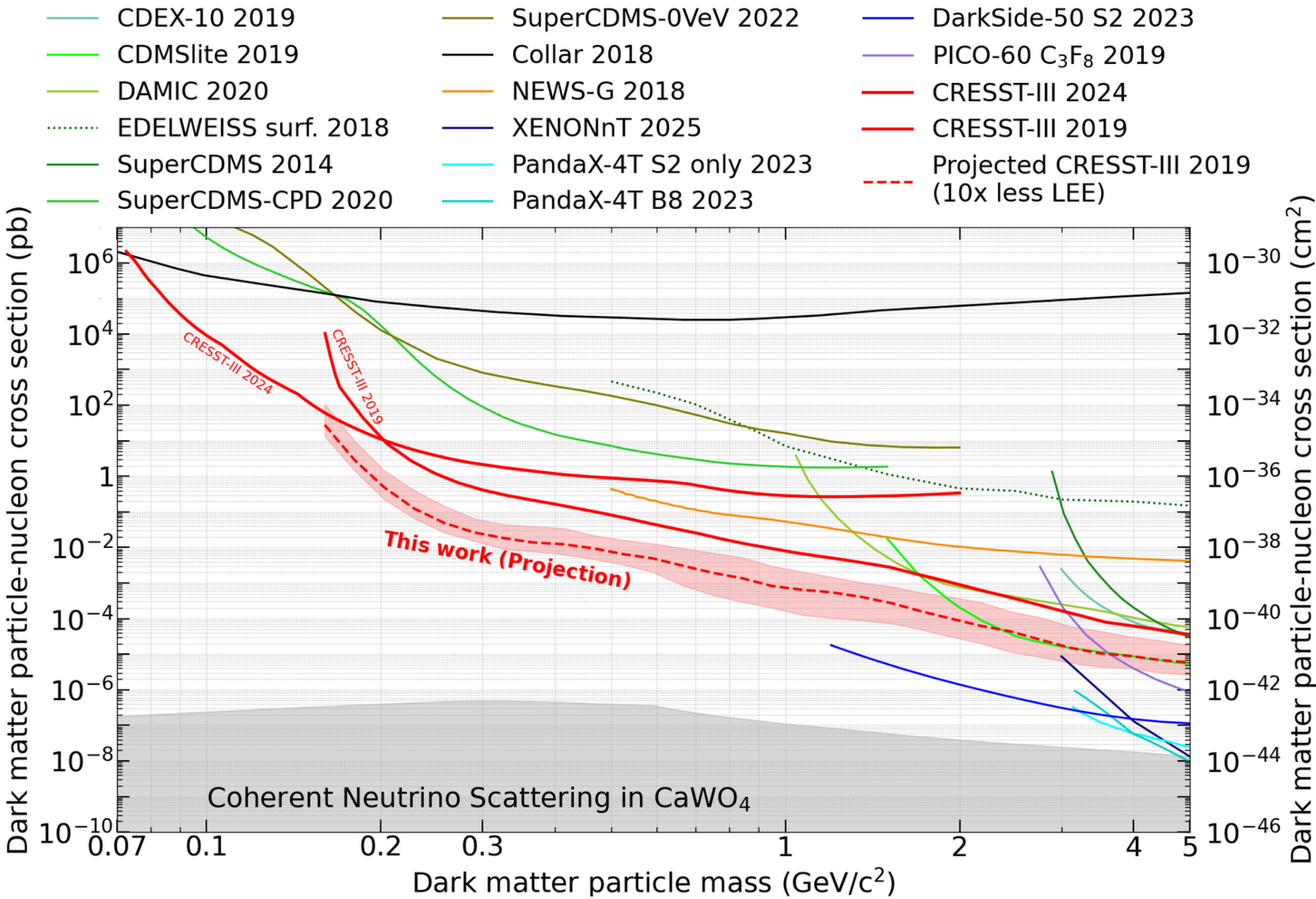
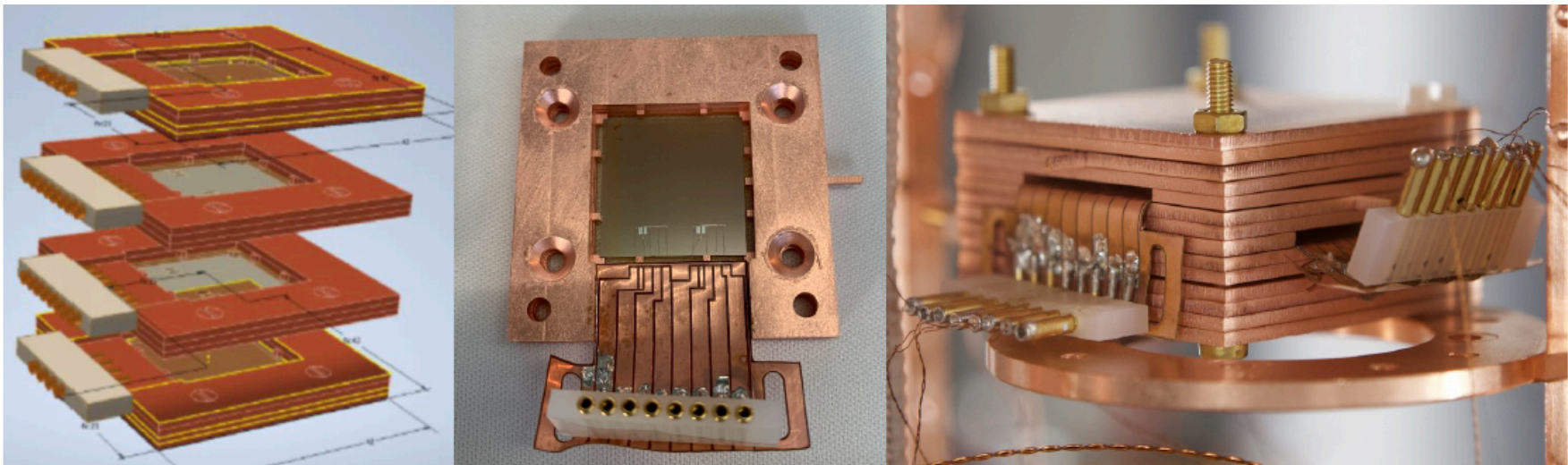
Slide content thanks to Francesca Pucci

Current payload

5 CaWO₄ DoubleTESs (à 24 g)

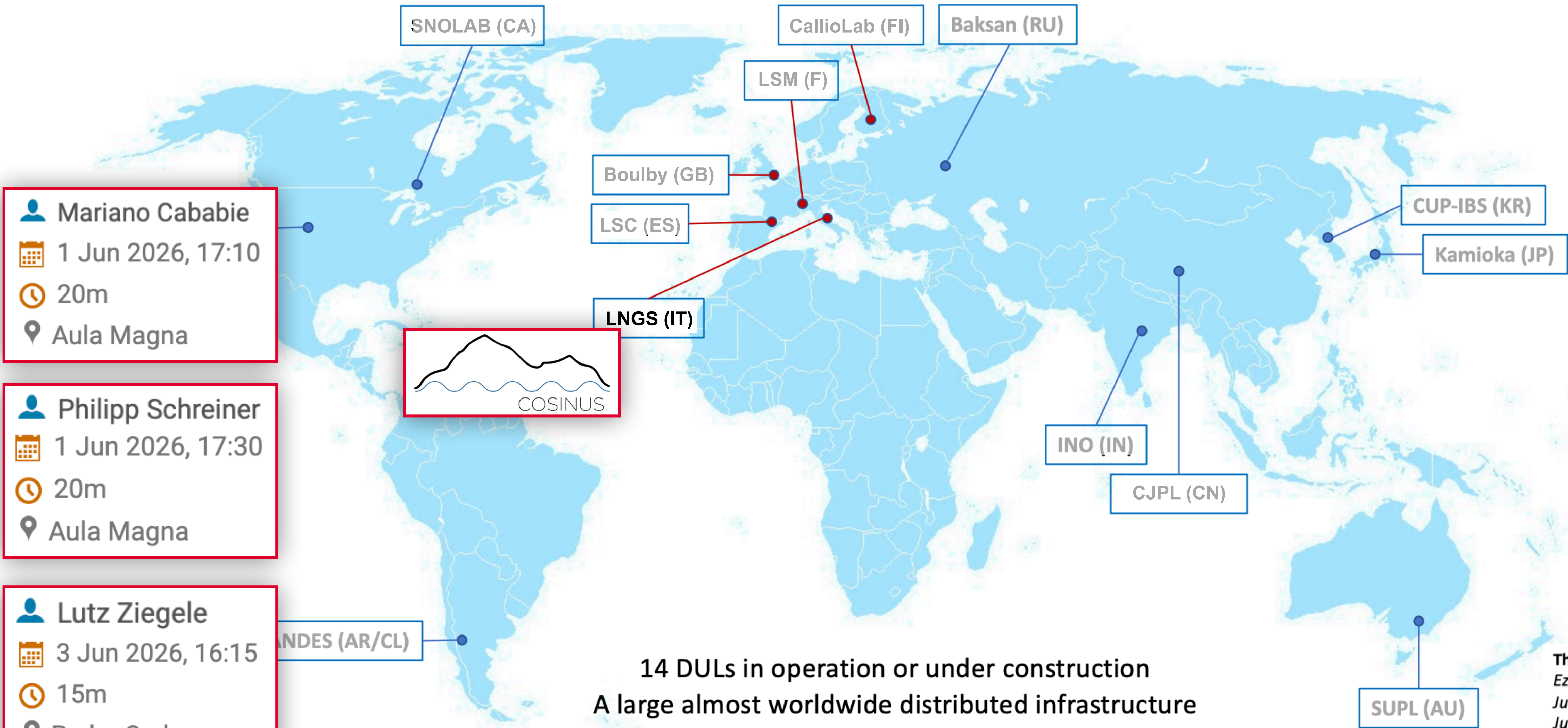


1 SOS wafer stack (4 x 0.6 g)





Experiments in this talk



Mariano Cababie
 1 Jun 2026, 17:10
 20m
 Aula Magna

Philipp Schreiner
 1 Jun 2026, 17:30
 20m
 Aula Magna

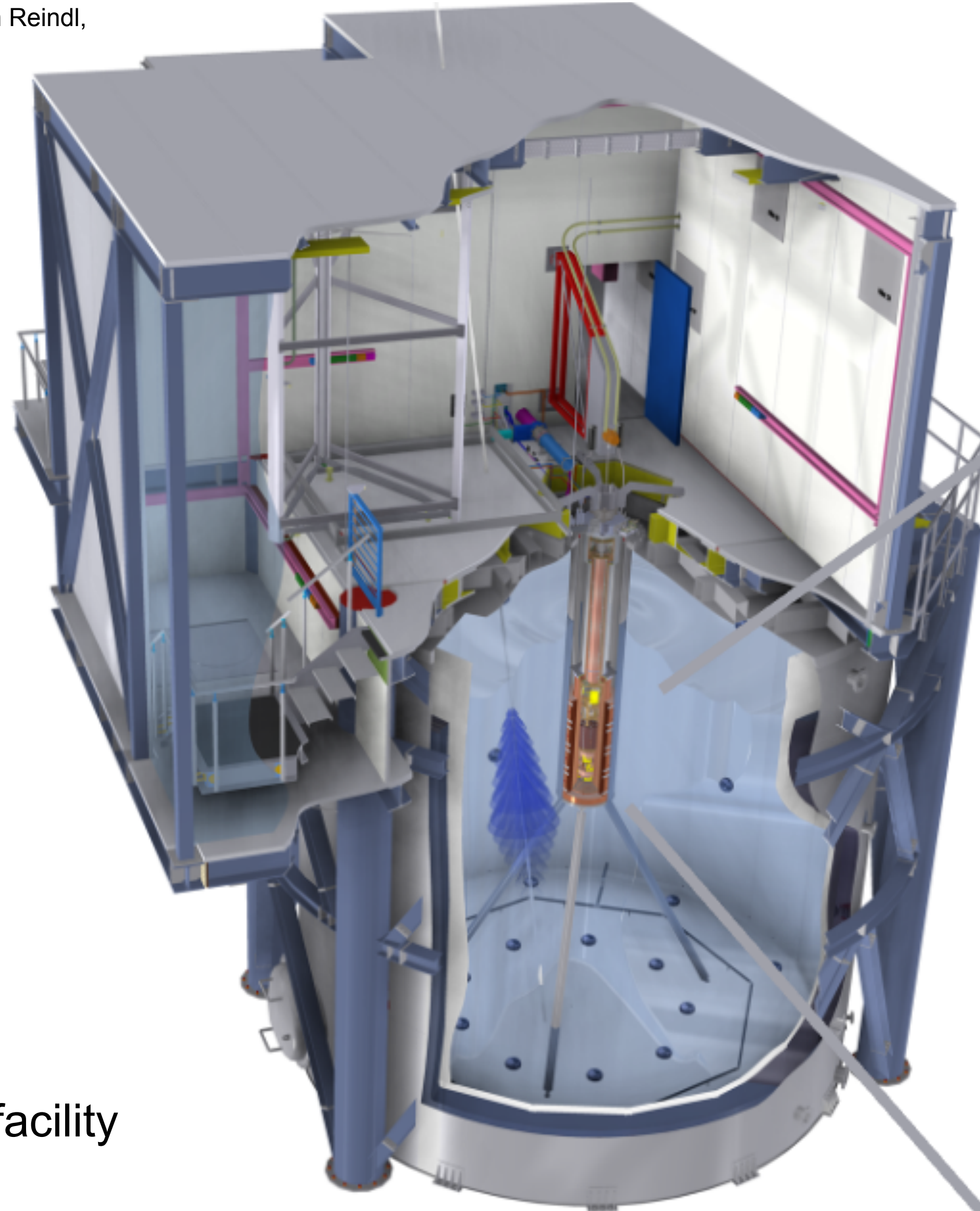
Lutz Ziegele
 3 Jun 2026, 16:15
 15m
 Pedro Cerbuna

14 DULs in operation or under construction
A large almost worldwide distributed infrastructure

Thanks to:
Ezio Previtali
Julie Puputti
Jules Gascon
Carlos Peña Garay

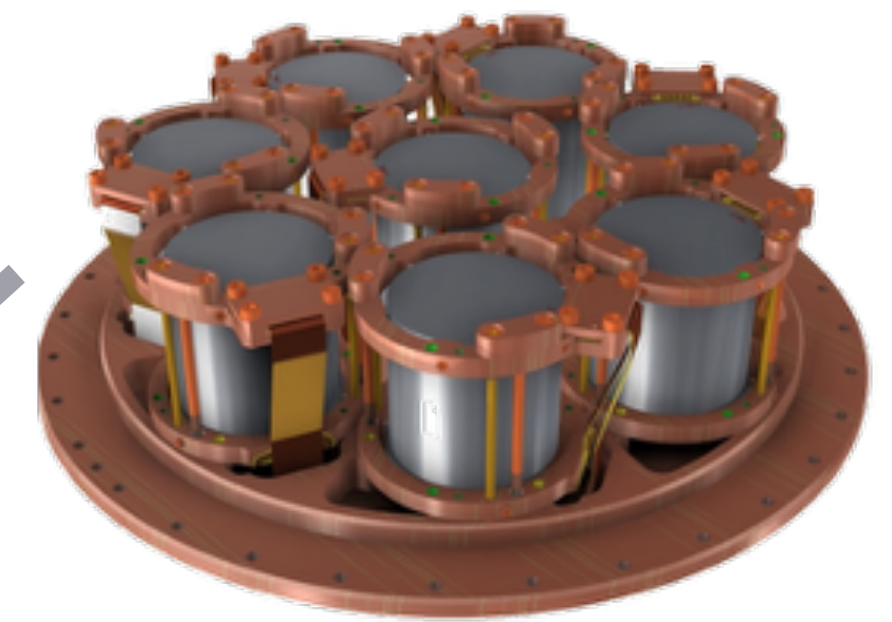
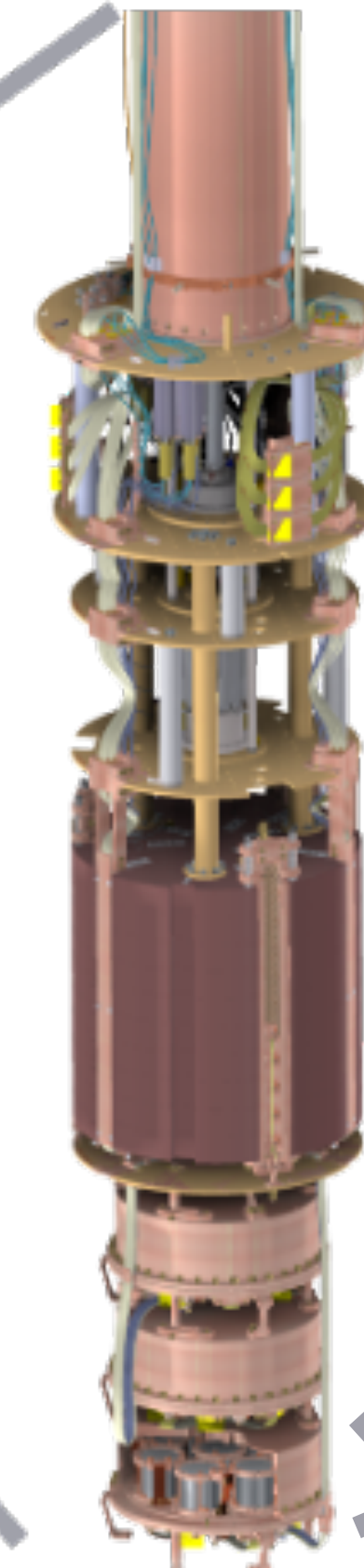
The COSINUS experiment at LNGS

Slide content thanks to Florian Reindl,
Karoline Schäffner

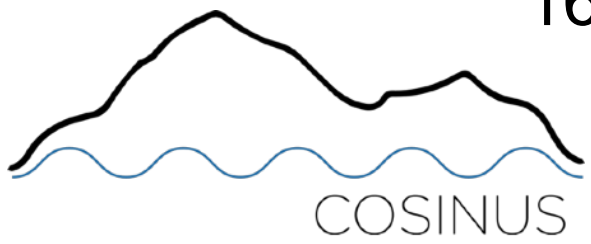


Cryogenic
low-background facility

- water tank as active muon veto
- custom-made dry dilution refrigerator
→ **9 mK**
- 48 channel SQUID-based readout
- clean room
- control building



COSINUS Collaboration, EPJ C 82, (2022)
COSINUS Collaboration, EPJ C 84, (2024)
COSINUS Collaboration, Nature Comm., (2026)

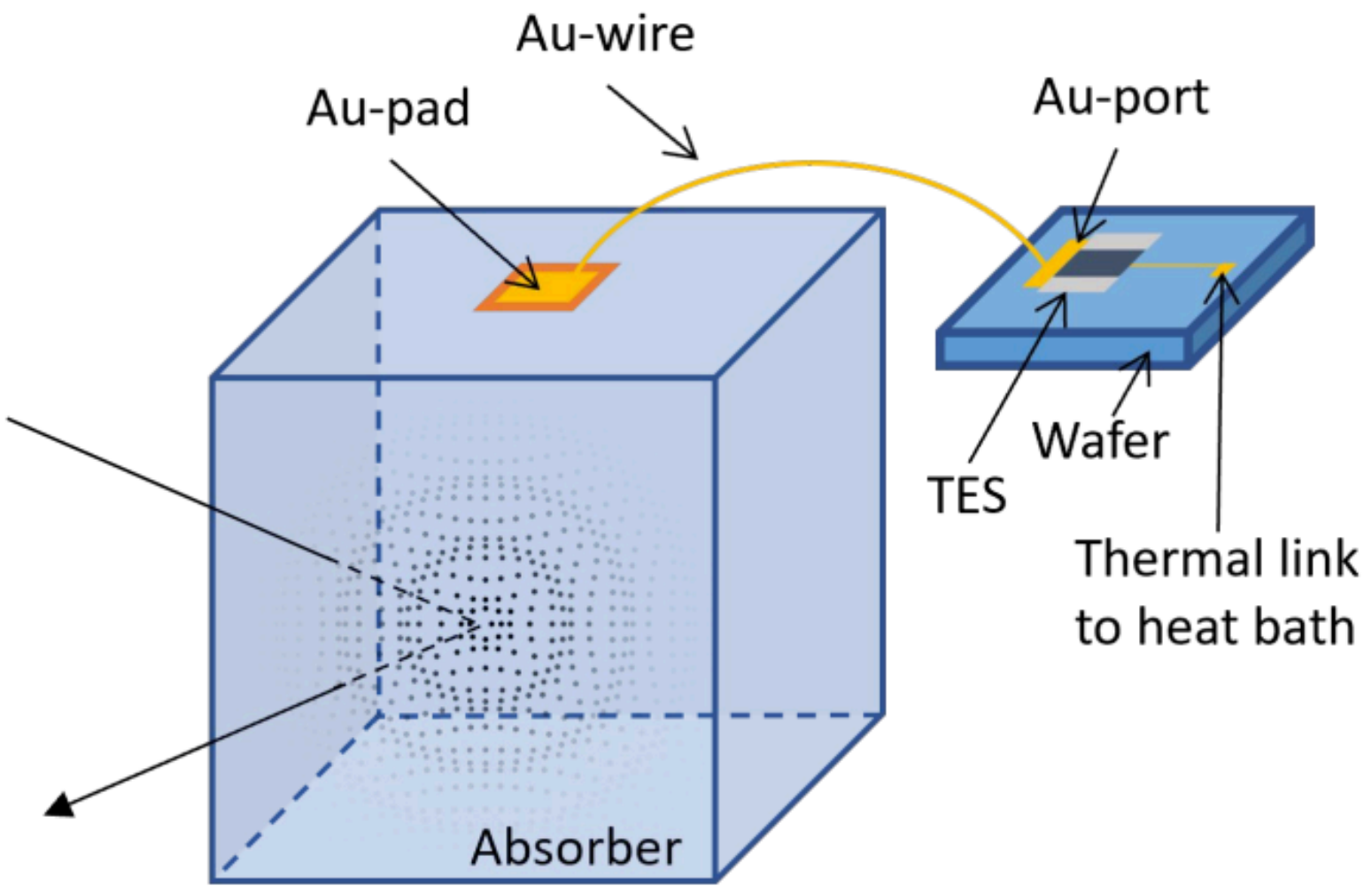
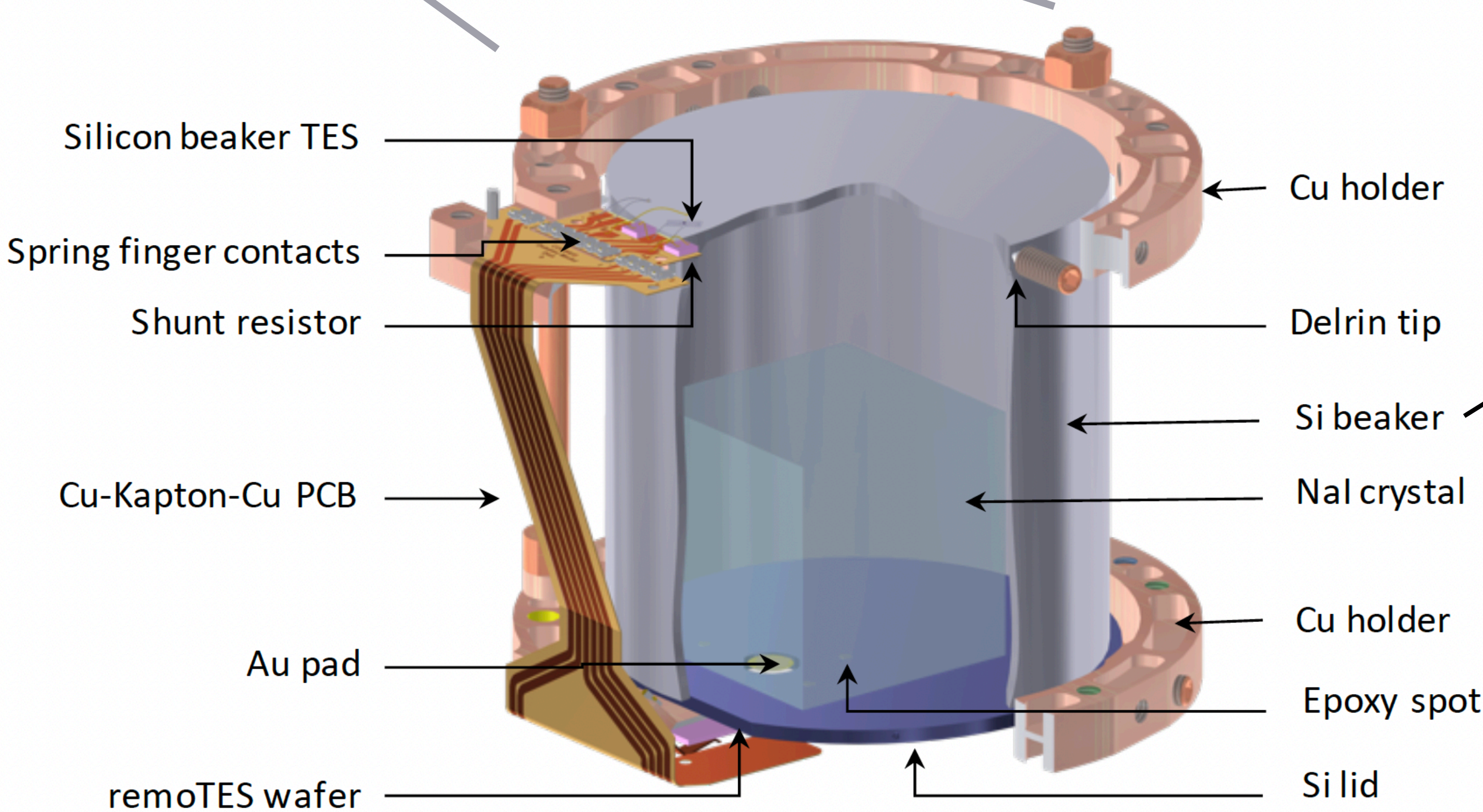
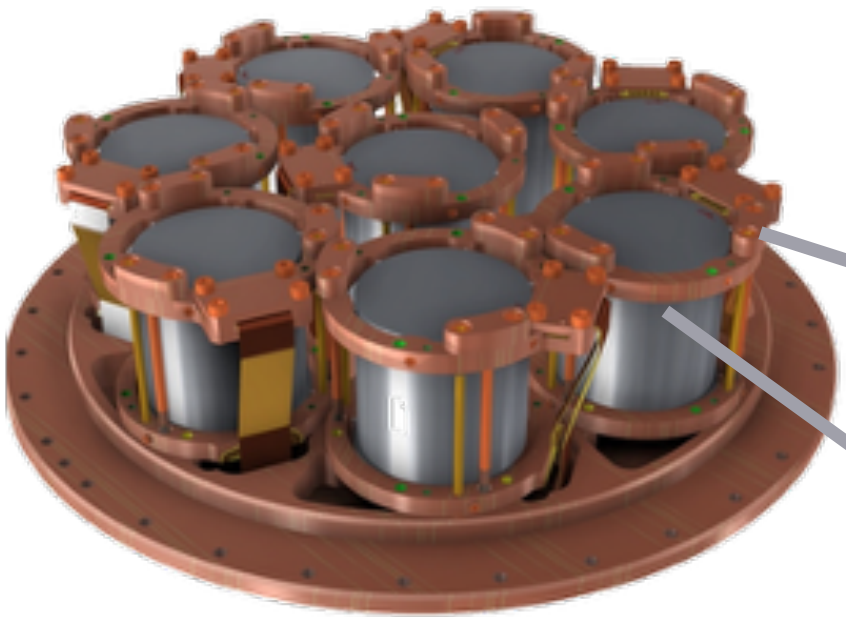


The detector modules

Slide content thanks to Florian Reindl, Karoline Schöffner

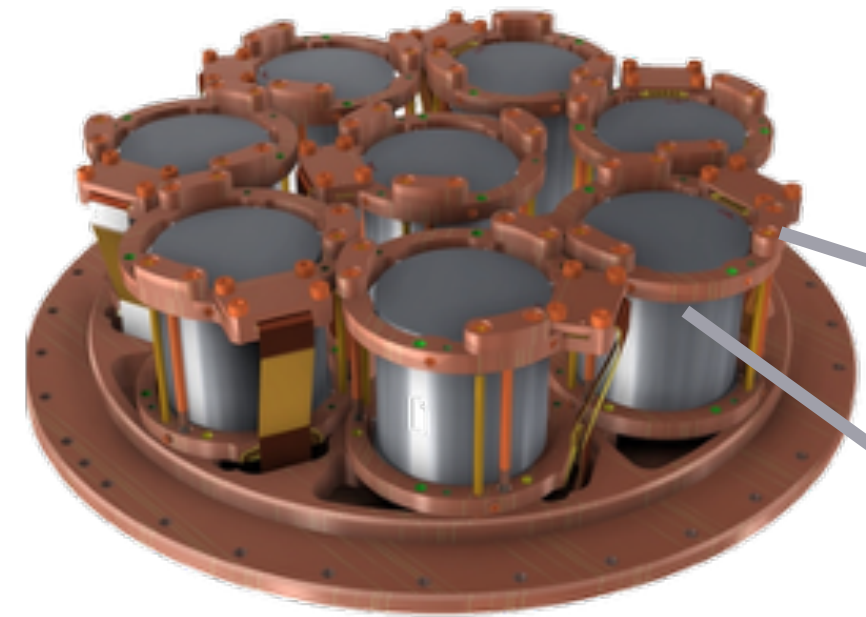
- Si-beaker for 4π around the crystal
- 34 g NaI (undoped), 21x21x21 mm³

Signal: **phonons** and **light**

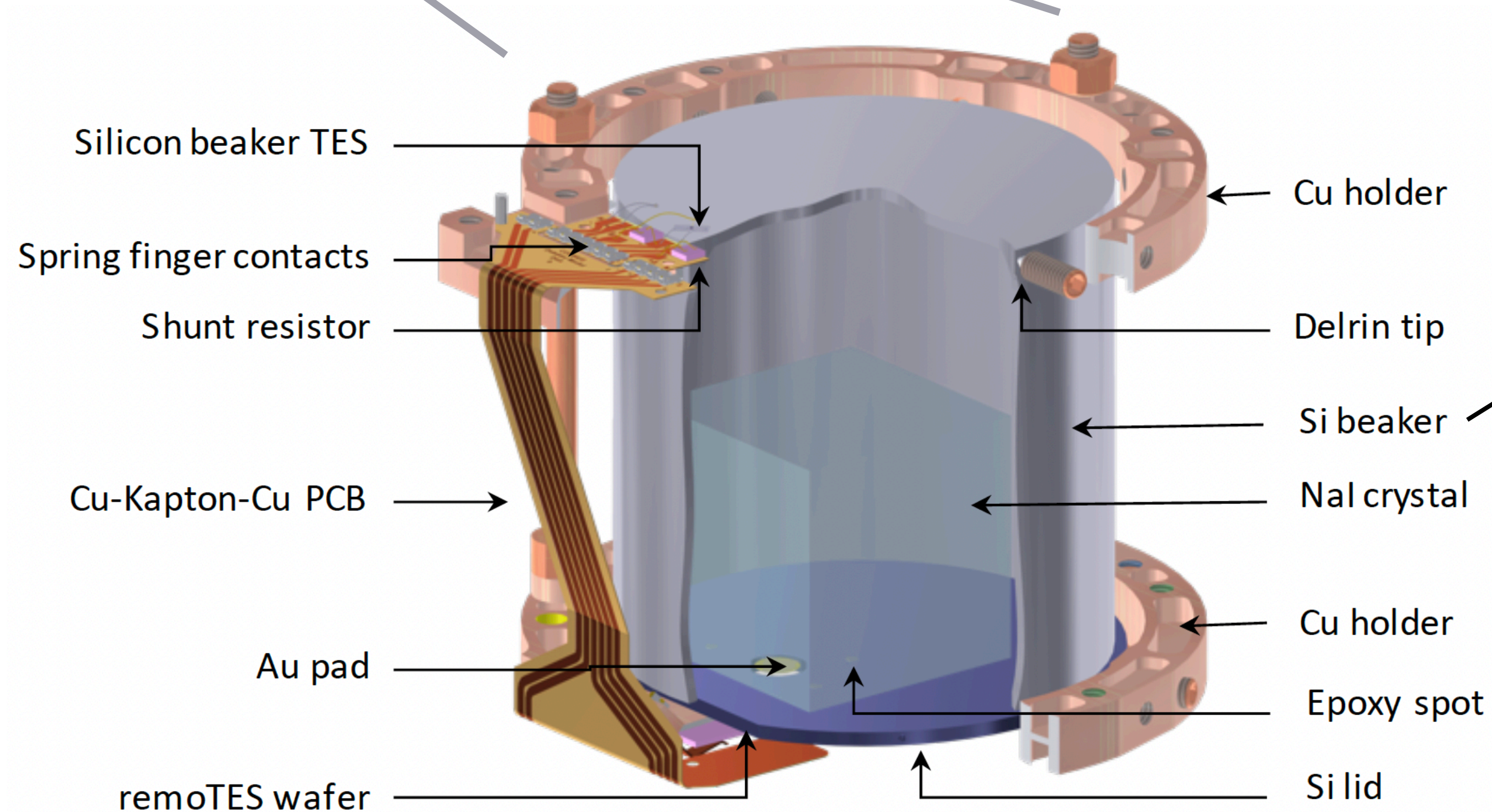


The detector modules

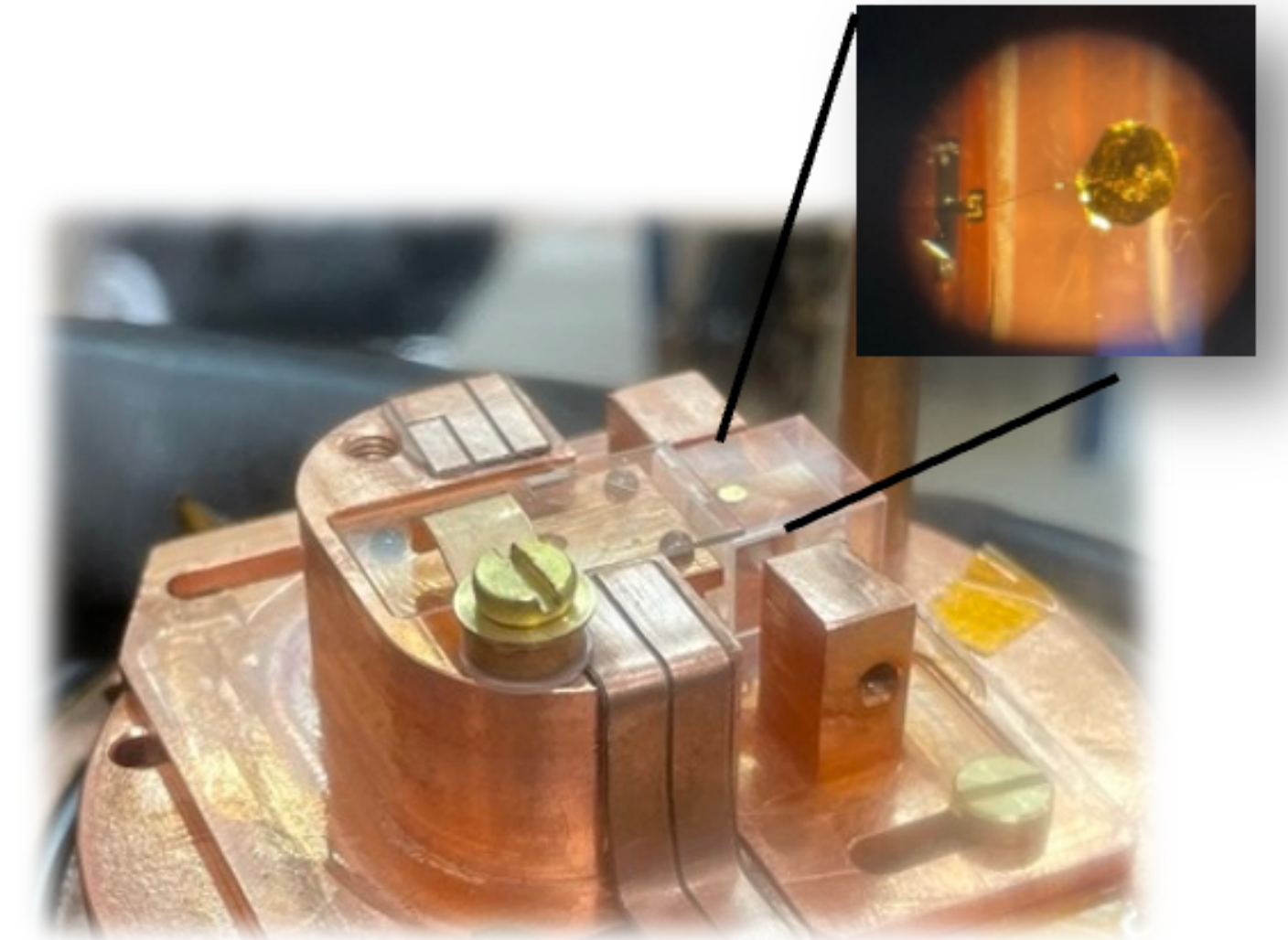
Slide content thanks to Florian Reindl, Karoline Schäffner

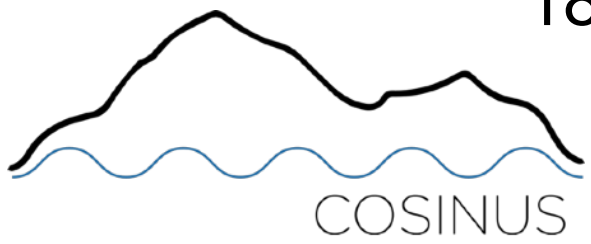


- Si-beaker for 4π around the crystal
- 34 g NaI (undoped), $21 \times 21 \times 21 \text{ mm}^3$



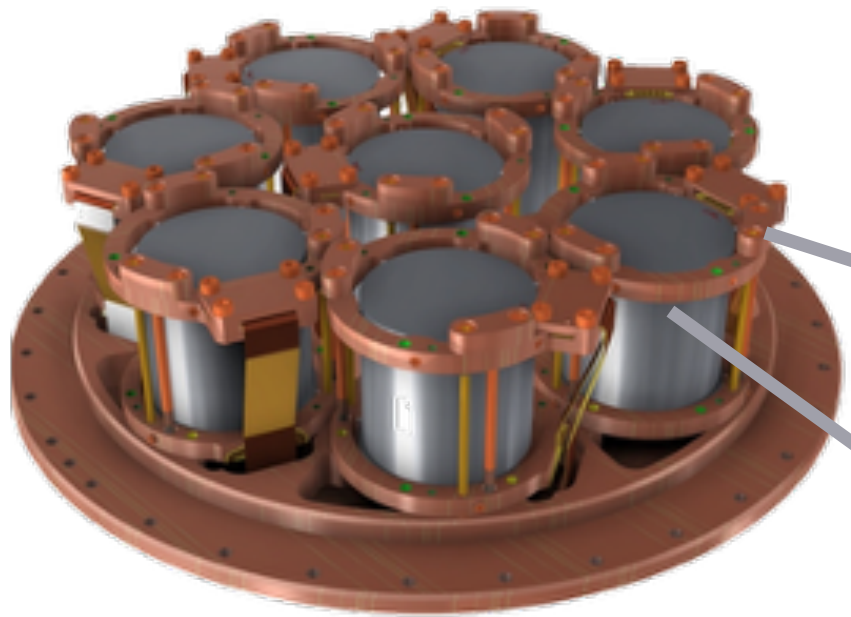
Signal: **phonons** and **light**



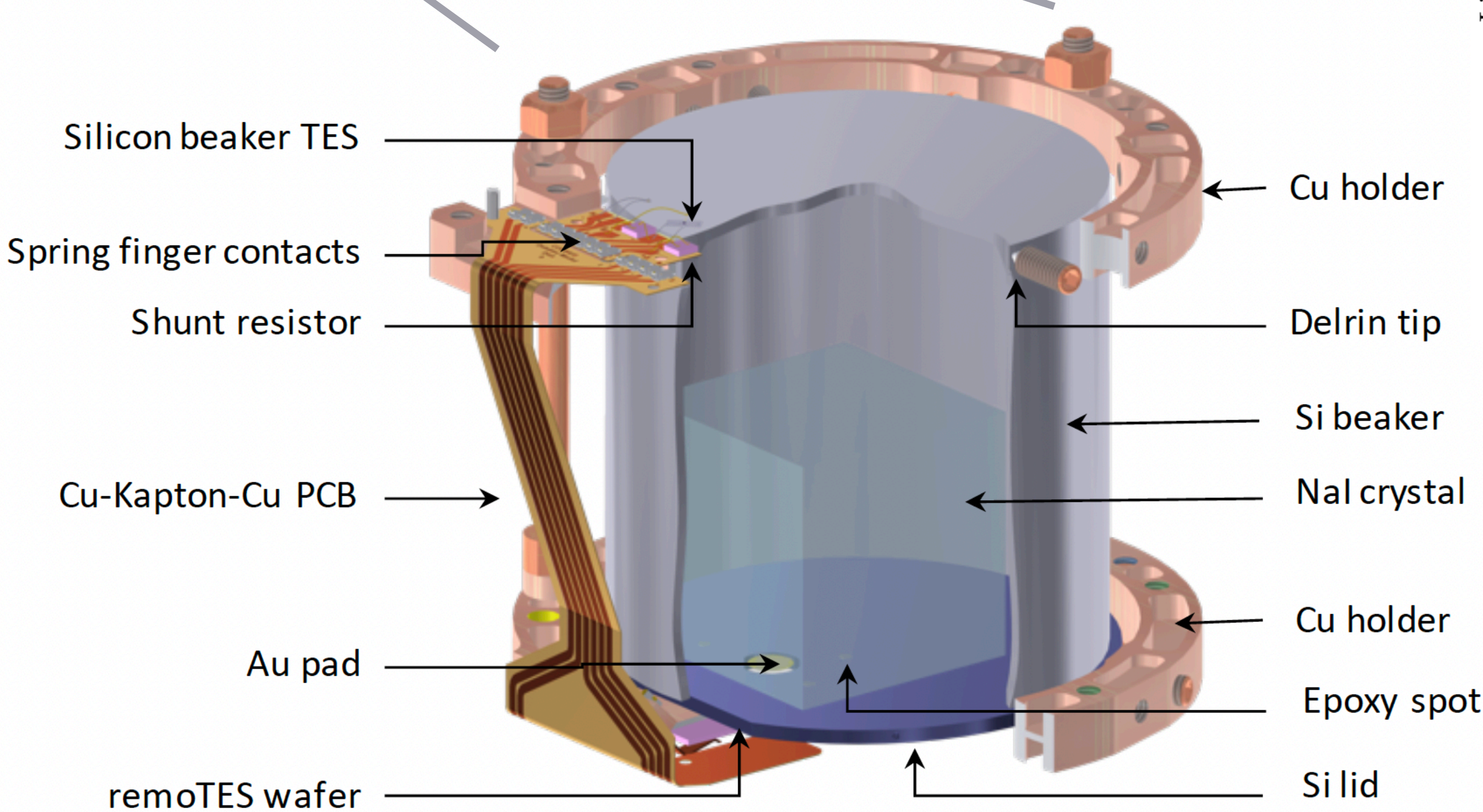


The “cold” DAMA-check

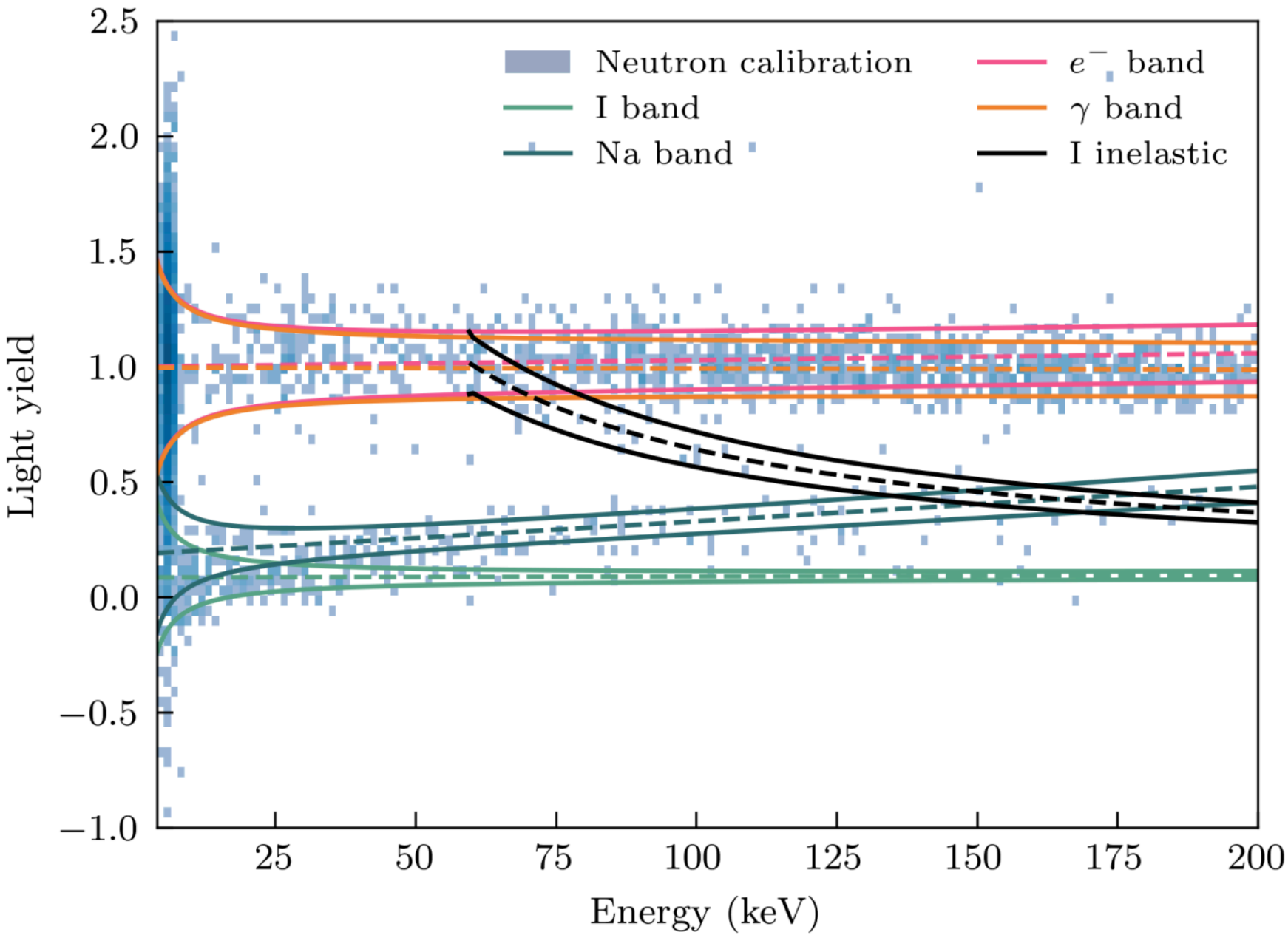
Slide content thanks to Florian Reindl, Karoline Schäffner



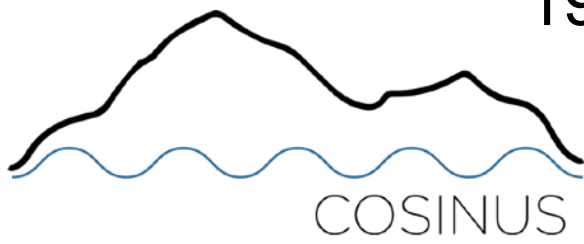
- Si-beaker for 4π around the crystal
- 34 g NaI (undoped), 21x21x21 mm³



Signal: **phonons** and **light**



$\sigma(\text{NaI}) = (0.441 \pm 0.011) \text{ keV}$



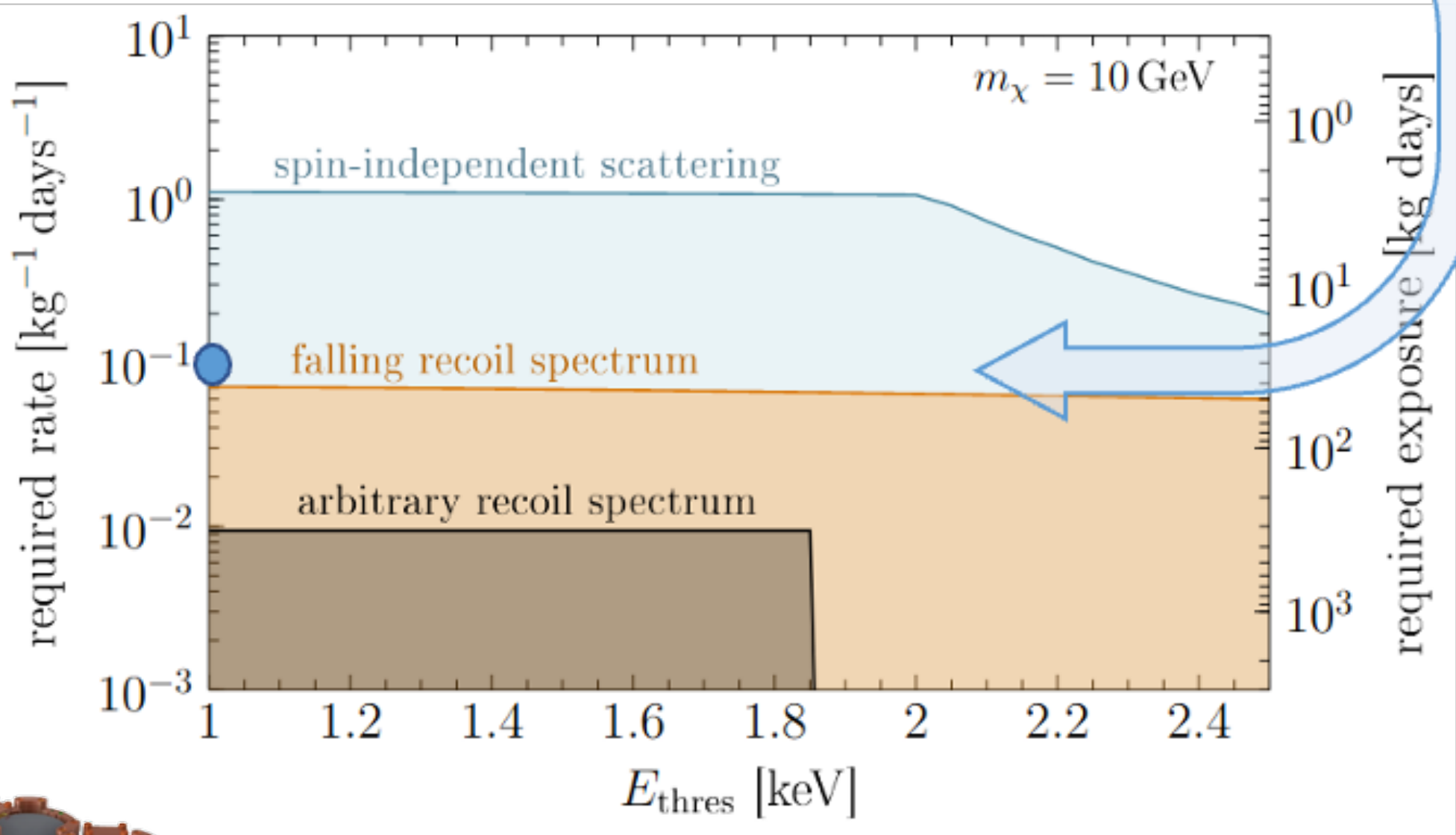
The “cold” DAMA-check

Slide content thanks to Florian Reindl,
Karoline Schäffner

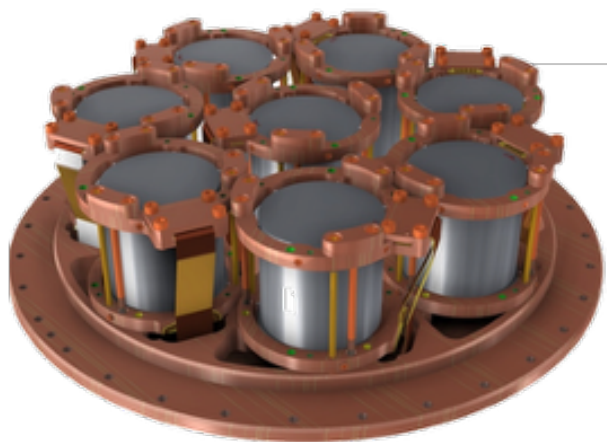
Required total rate to probe DAMA in a halo-independent way
(no modulation measurement)

Run 1: 2026-2027

100 kg days
in 1 year of data taking

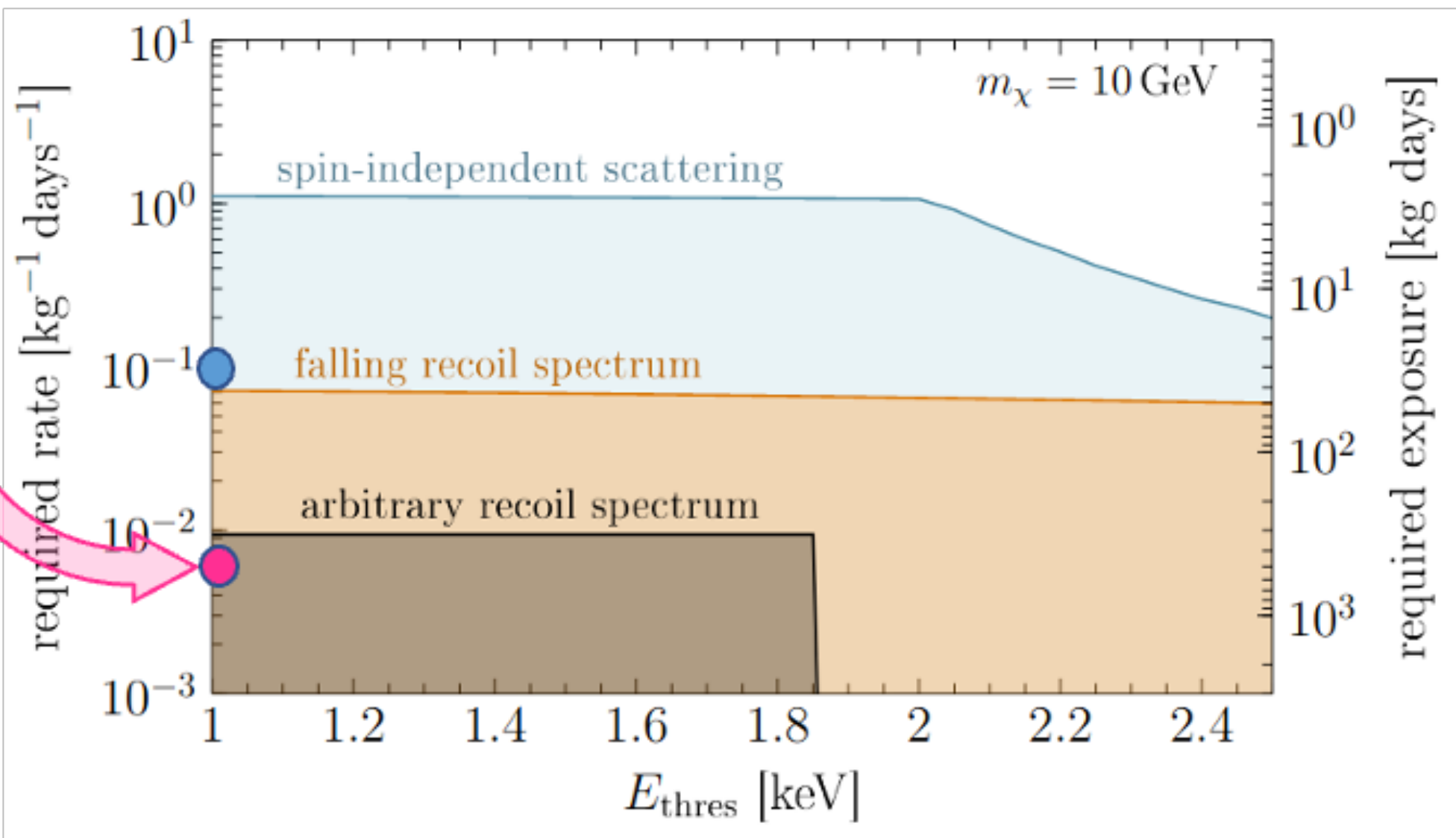


- 8 detector modules
- ~34 g NaI

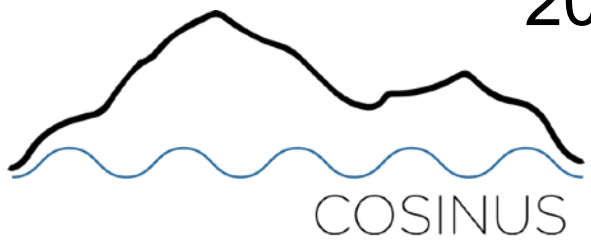


Run 2: > 2027

1000 kg days
in 3-4 years of data taking

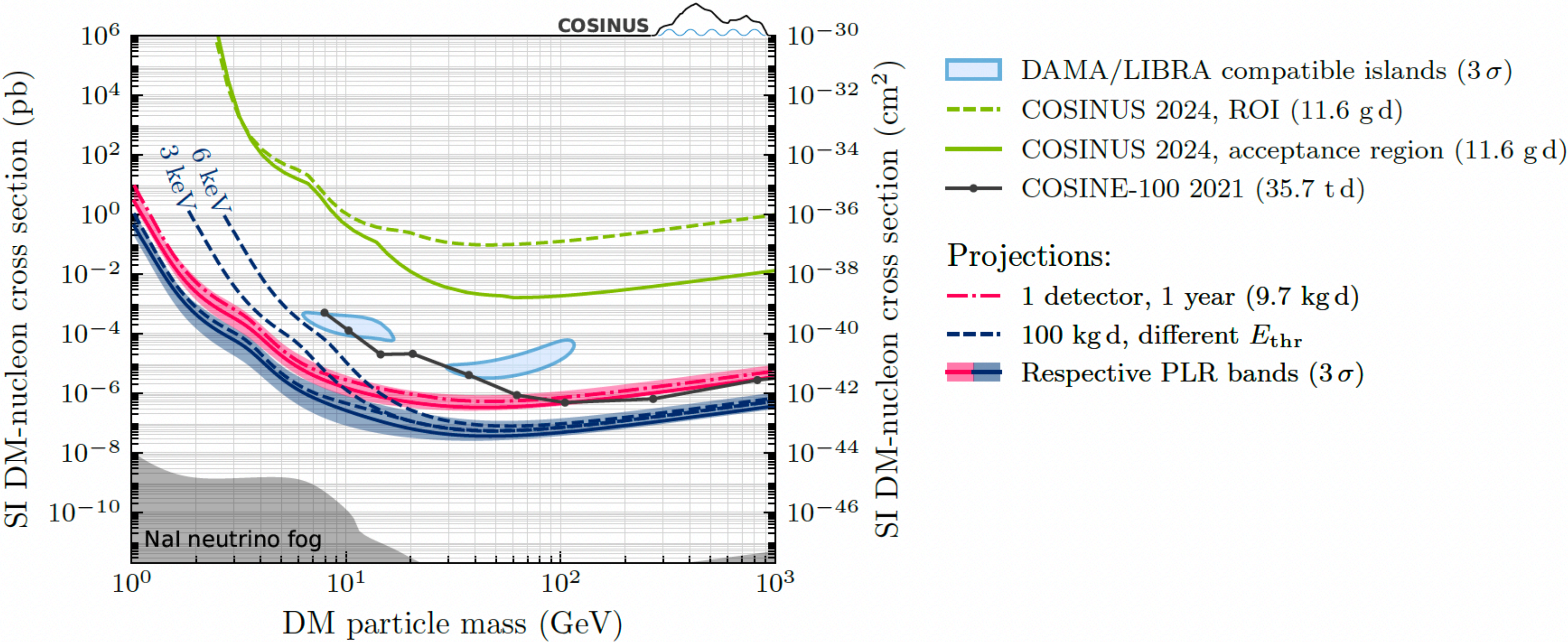


- 24 detector modules
- (30 – 100) g NaI



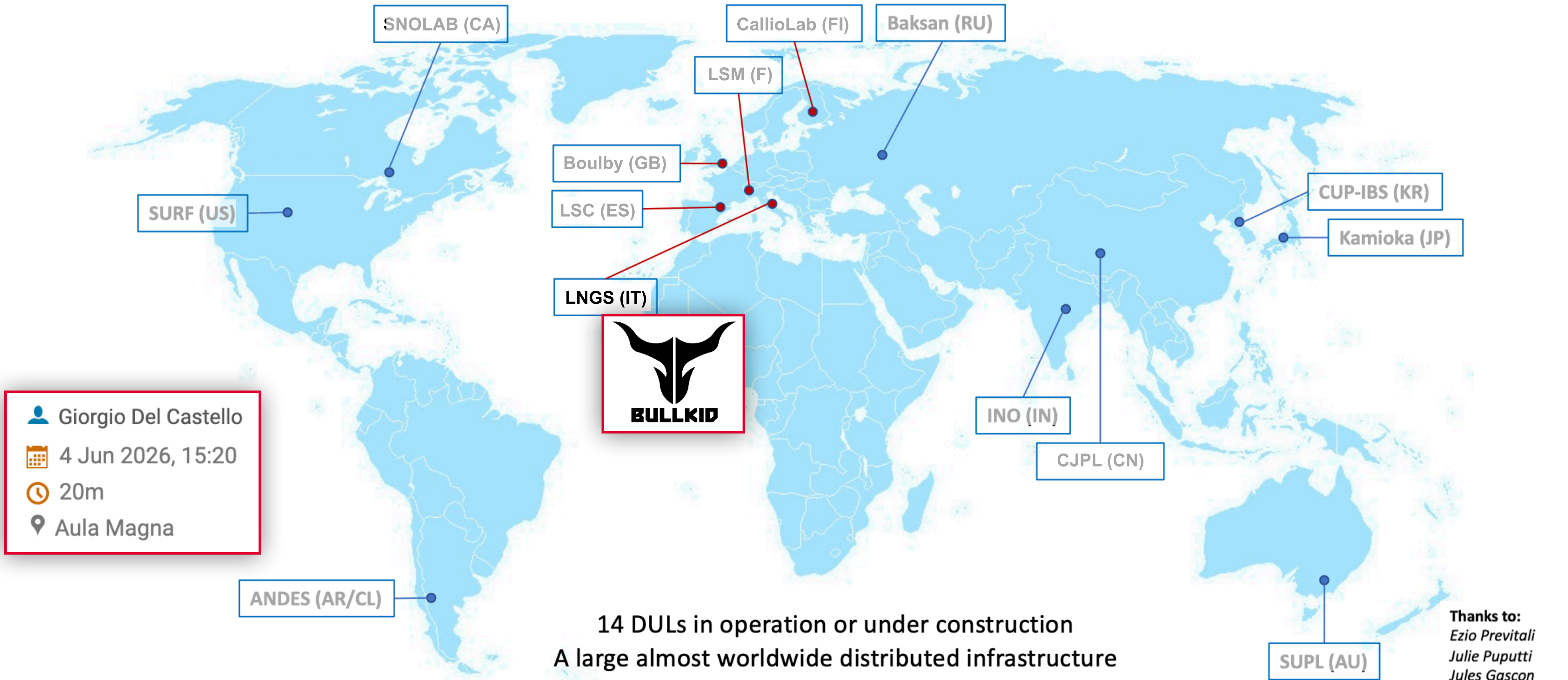
DM-nucleon scattering: results and sensitivity

Slide content thanks to Florian Reindl





Experiments in this talk



Thanks to:
Ezio Previtali
Julie Puputti
Jules Gascon
Carlos Peña Garay

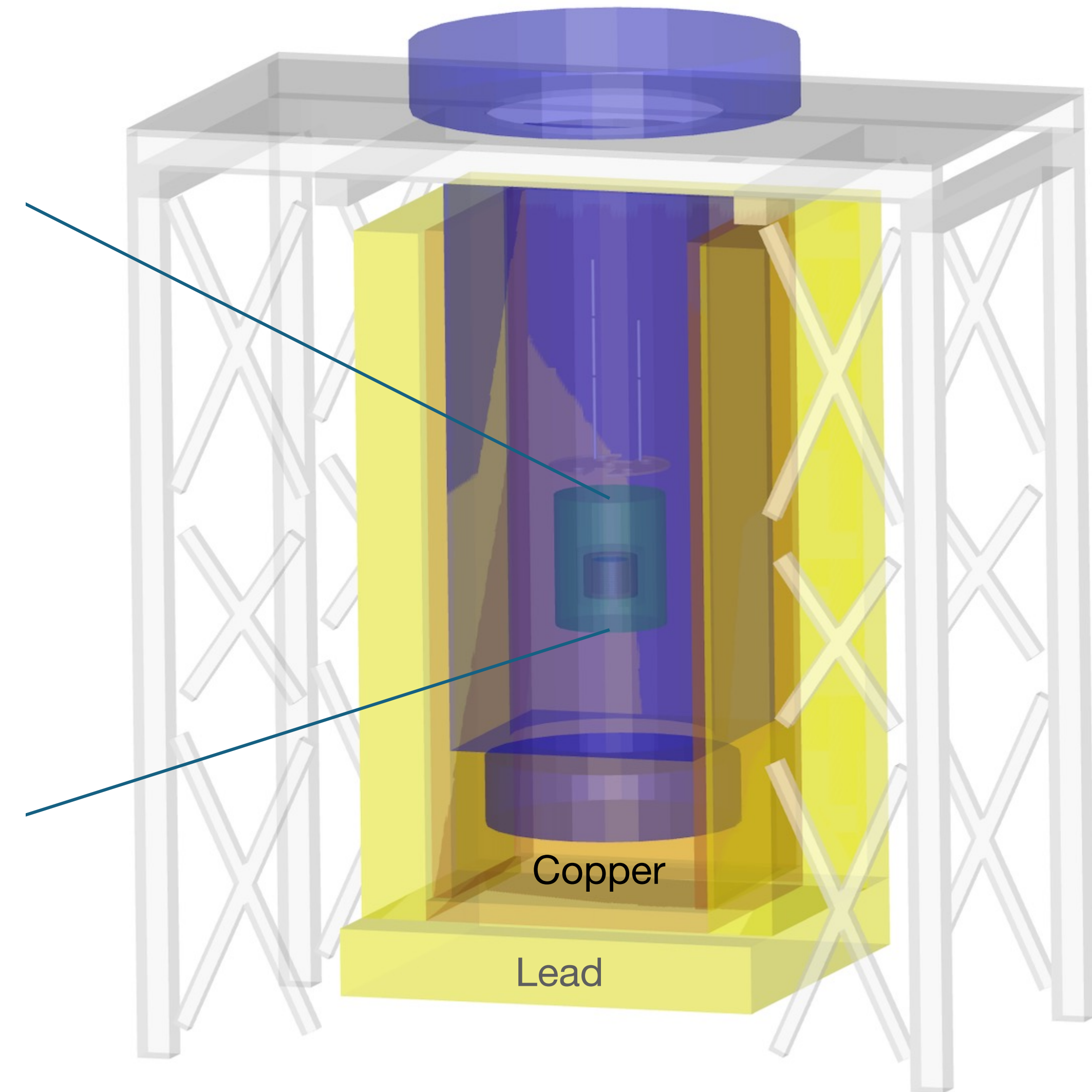
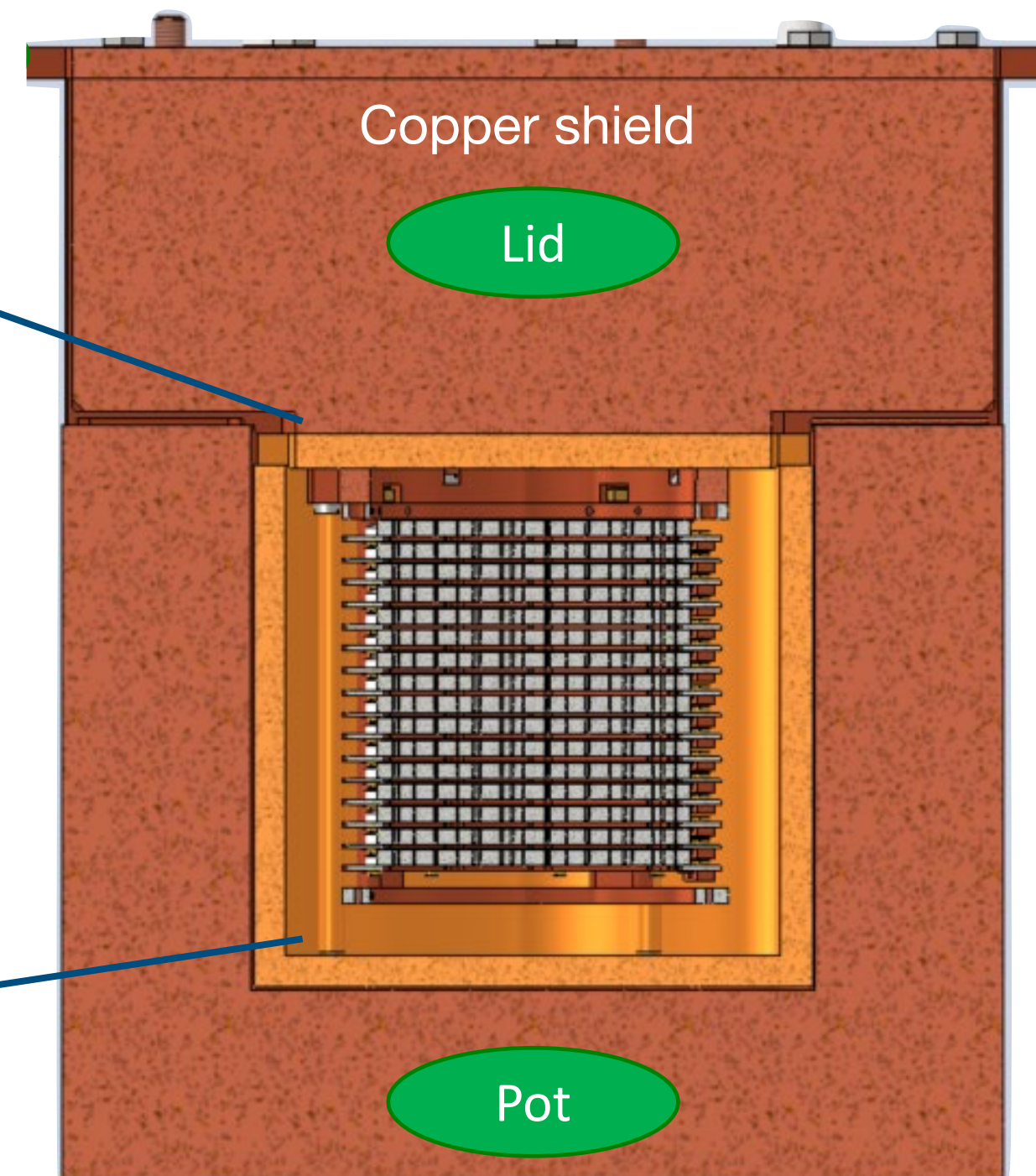
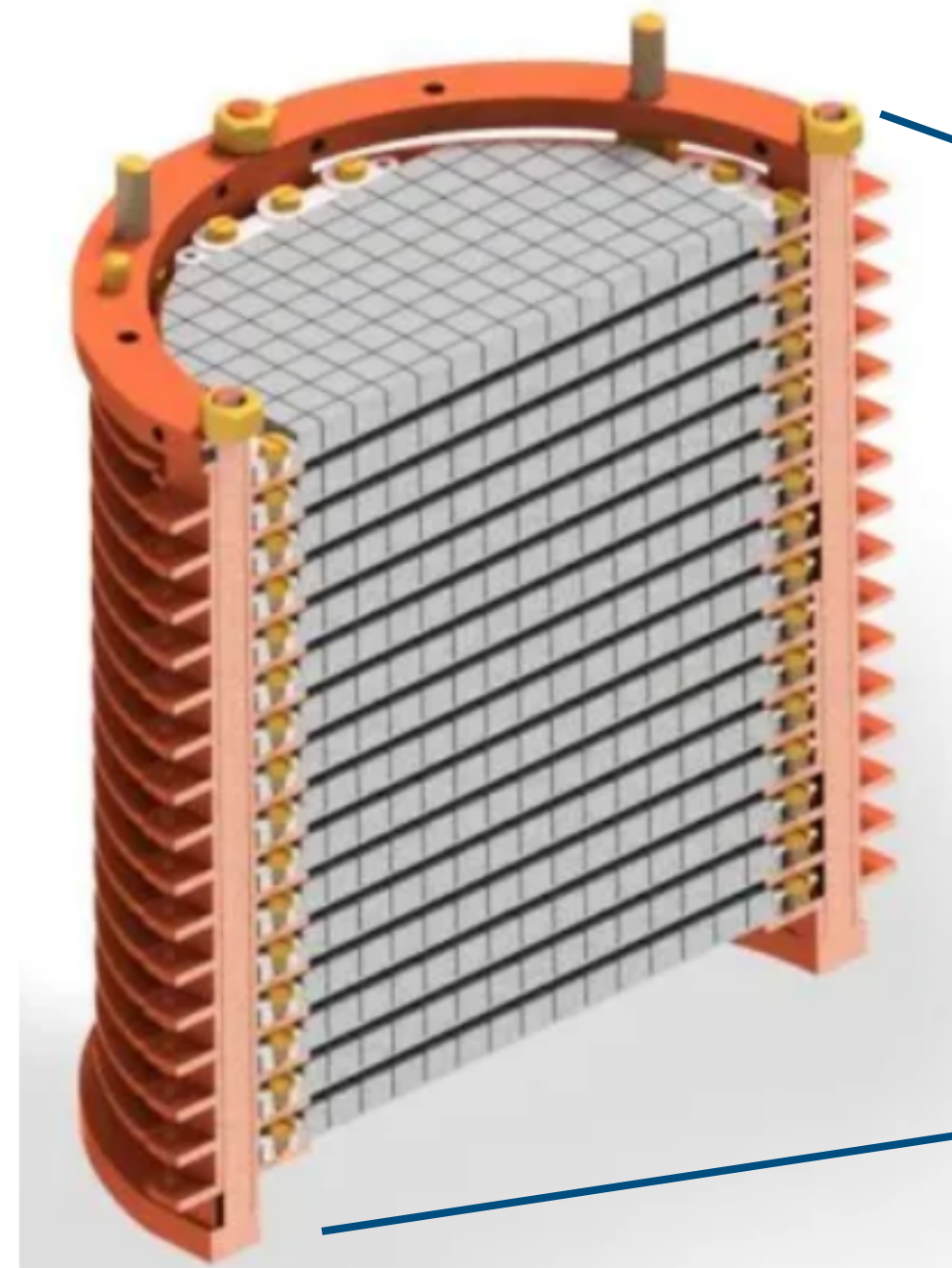
The BULLKID-DM experiment at LNGS

Slide content thanks to Marco Vignati

Cryo-Platform facility

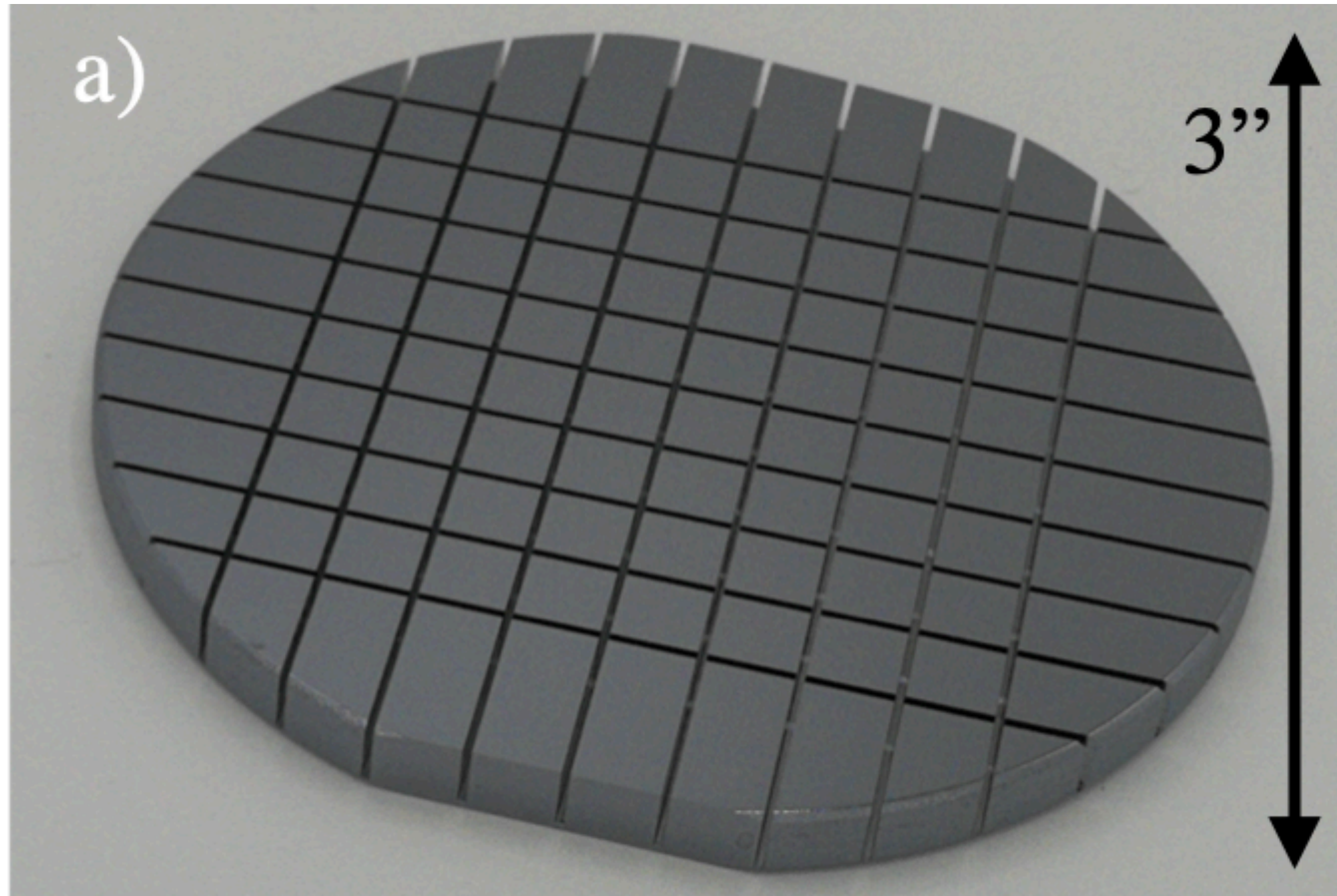
total target
800 g Si

BULLKID-DM payload



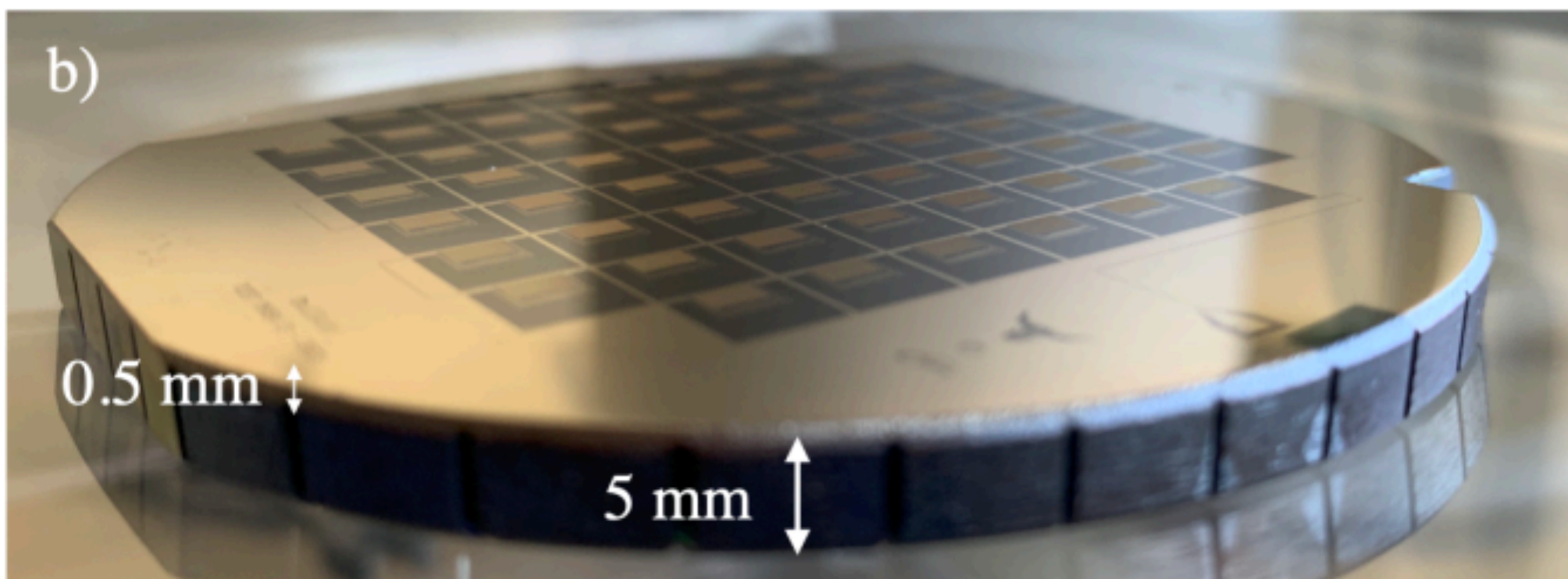
The phonon detector array

Slide content thanks to Marco Vignati, Matteo Folcarelli



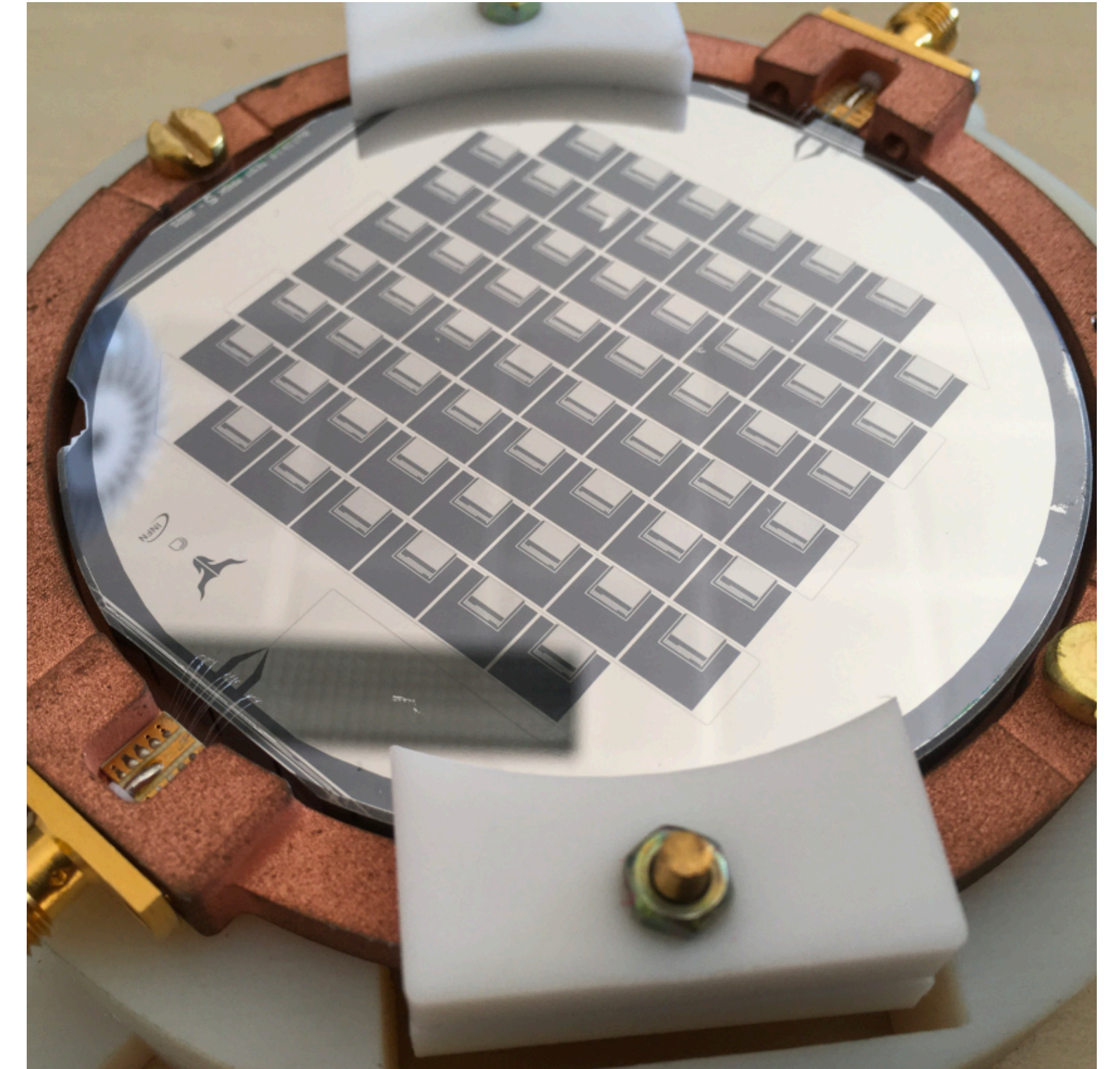
Target

- **Monolithic arrays** of 5 mm cubes of Si
- 60 detectors in 1

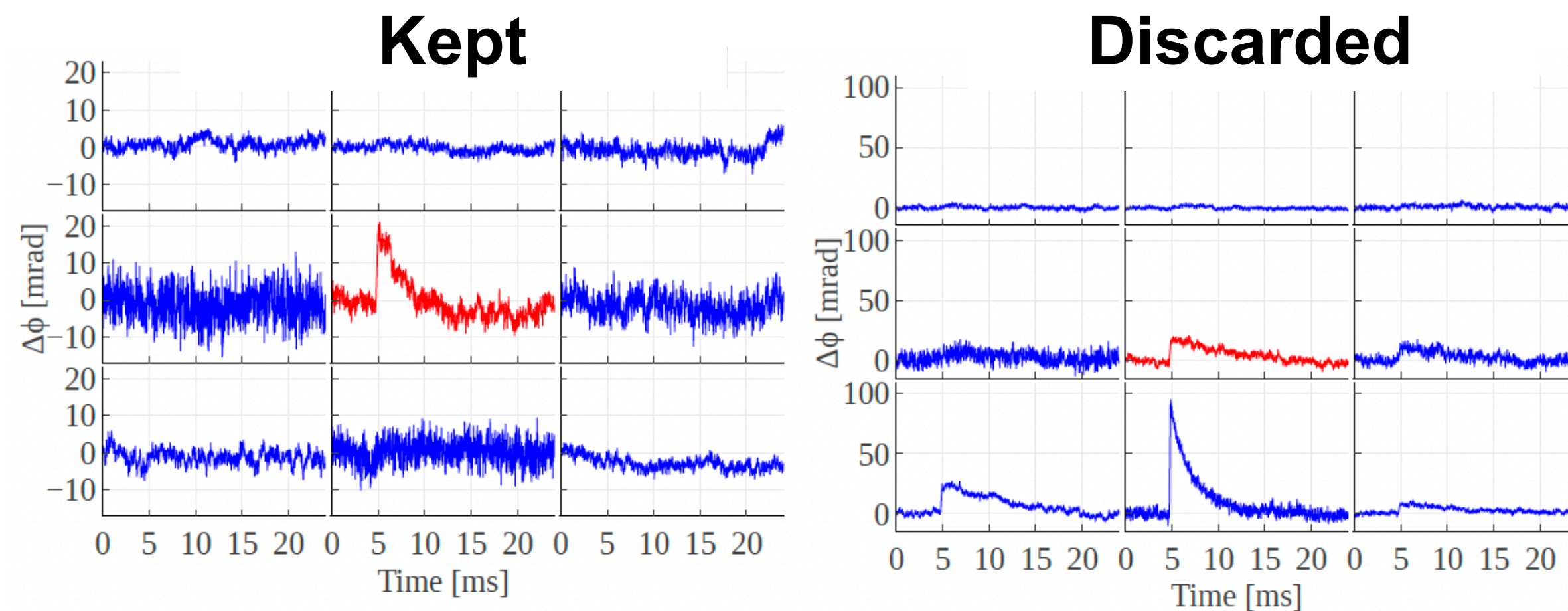


Phonon sensors

- multiplexed **MKIDs** (Microwave Kinetic Inductance Detectors)



Slide content thanks to Marco Vignati, Matteo Folcarelli

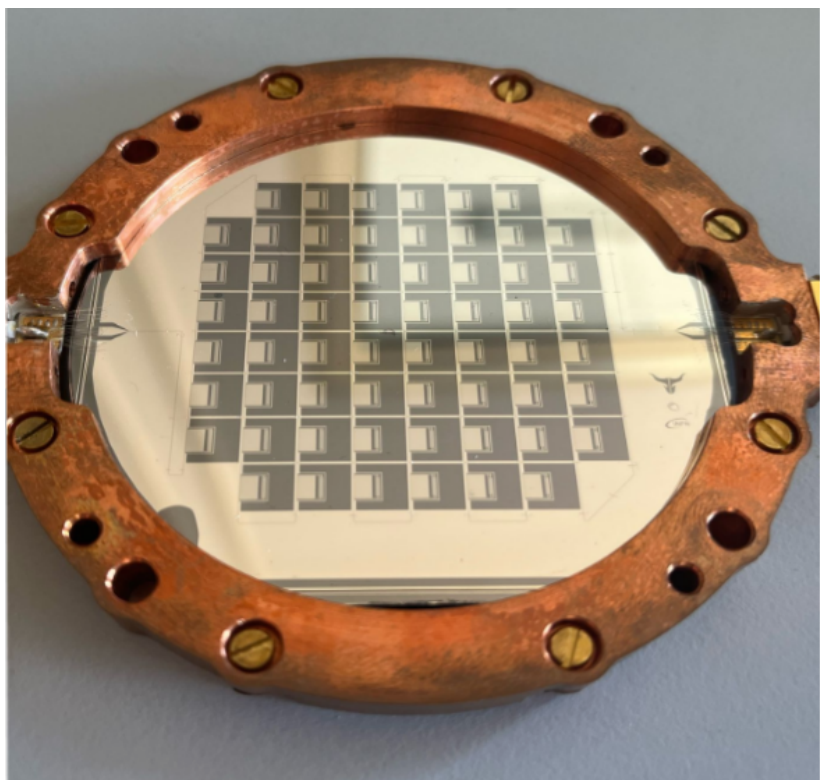


- 50 % of phonons absorbed by the KID
- Rest leaks in nearby voxels

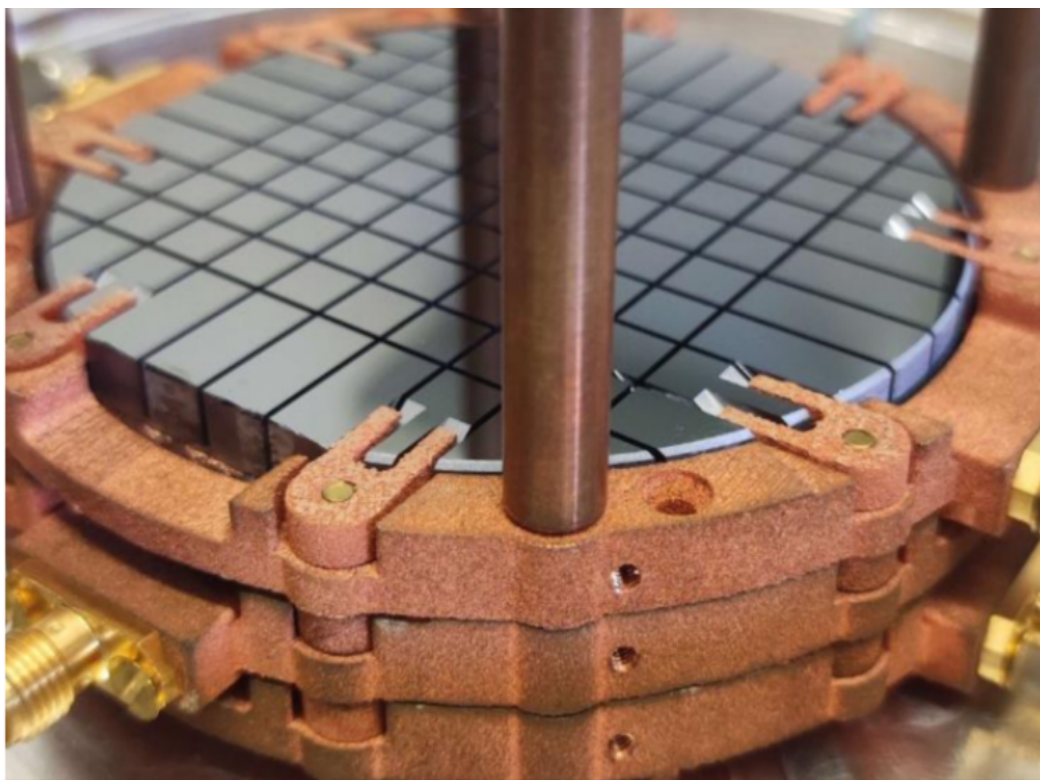
From prototype to experiment

Slide content thanks to Marco Vignati, Matteo Folcarelli

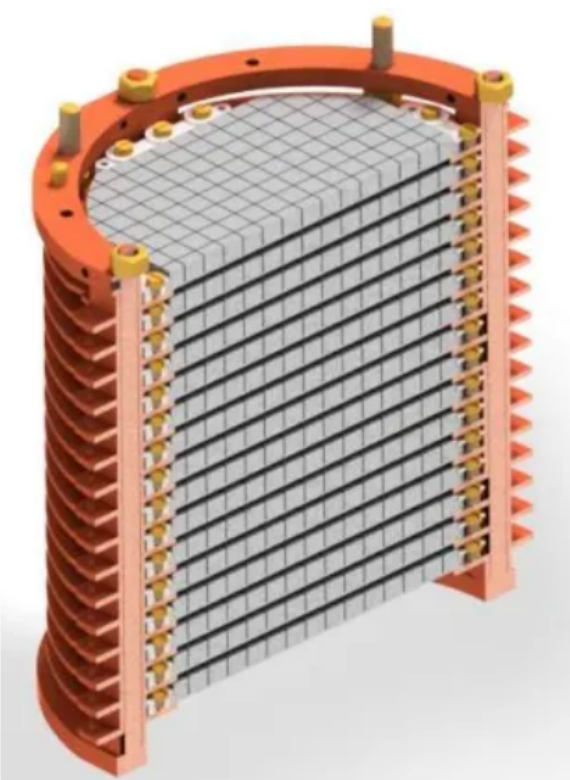
Prototype



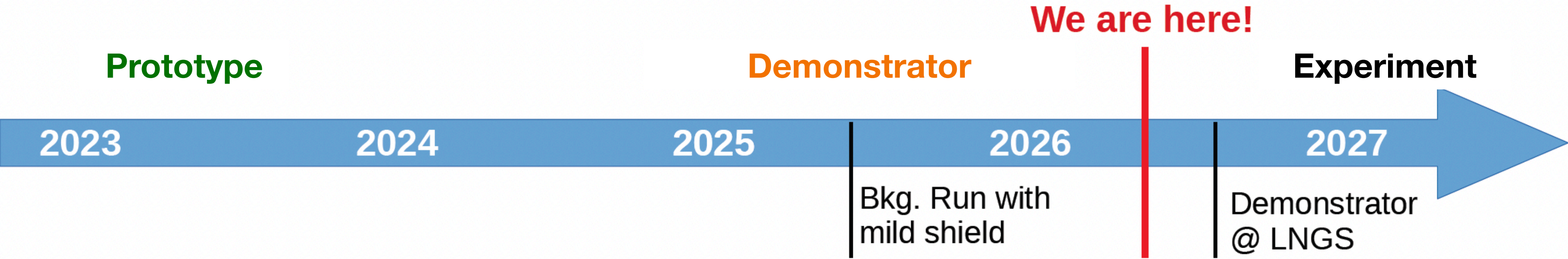
Demonstrator



Experiment



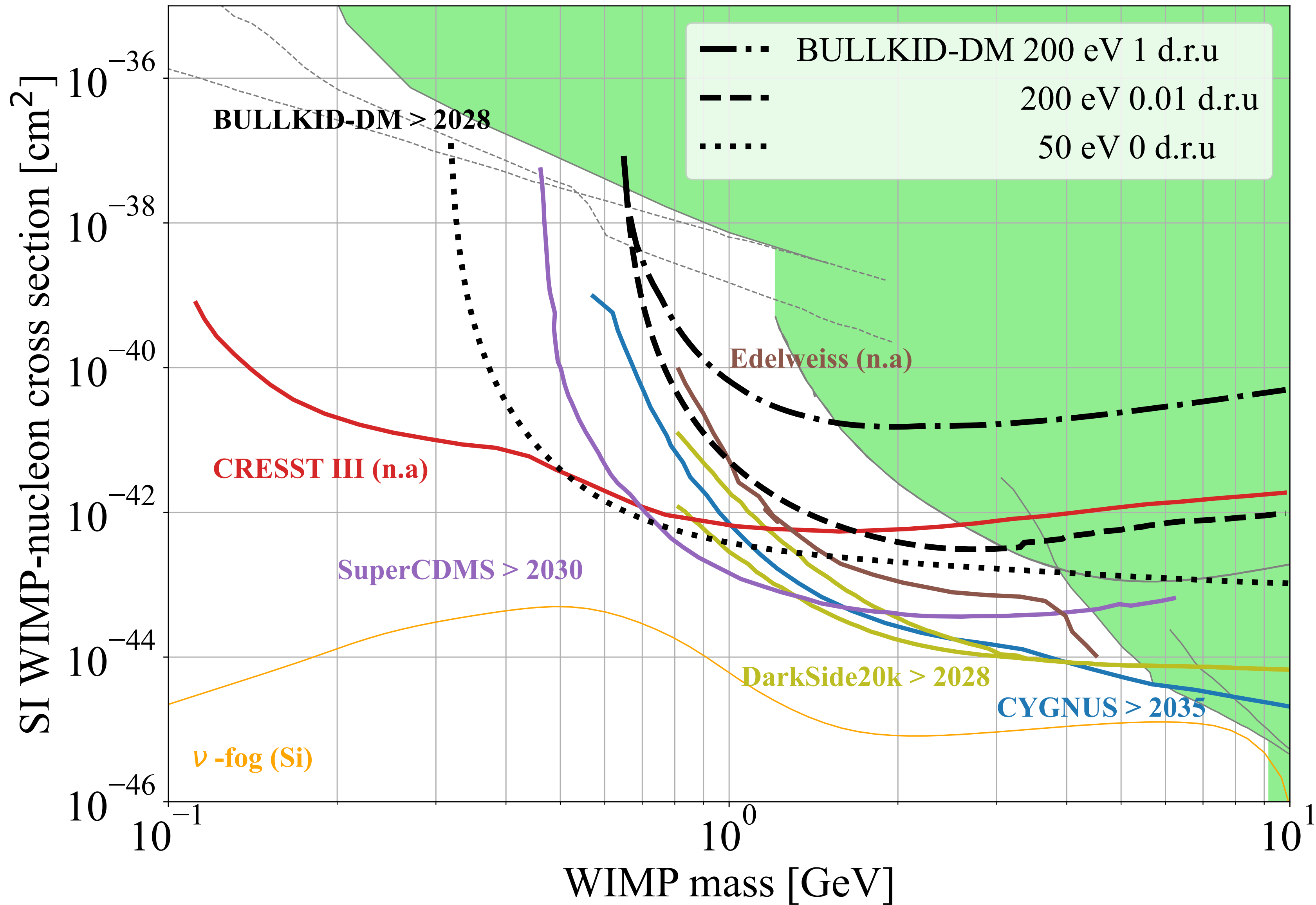
	BULLKID Prototype	BULLKID-DM Demonstrator		BULLKID-DM Experiment
mass [g]	20	60		800
# of sensors	60	180		2300
threshold [eV]	160	200		≤ 200
laboratory	Sapienza	Sapienza	LNGS	LNGS
installation	2023	2024-26	2026	2027 -
bkg [d.r.u]	2x10 ⁶	7x10 ⁴	~10 ⁴	1 - 0.01



D. Delicato et al, Eur. Phys. J. C 84 (2024) 353
M. Folcarelli et al, Eur. Phys. J. C 86 (2026) 301
D. Delicato et al, arXiv:2605.02468

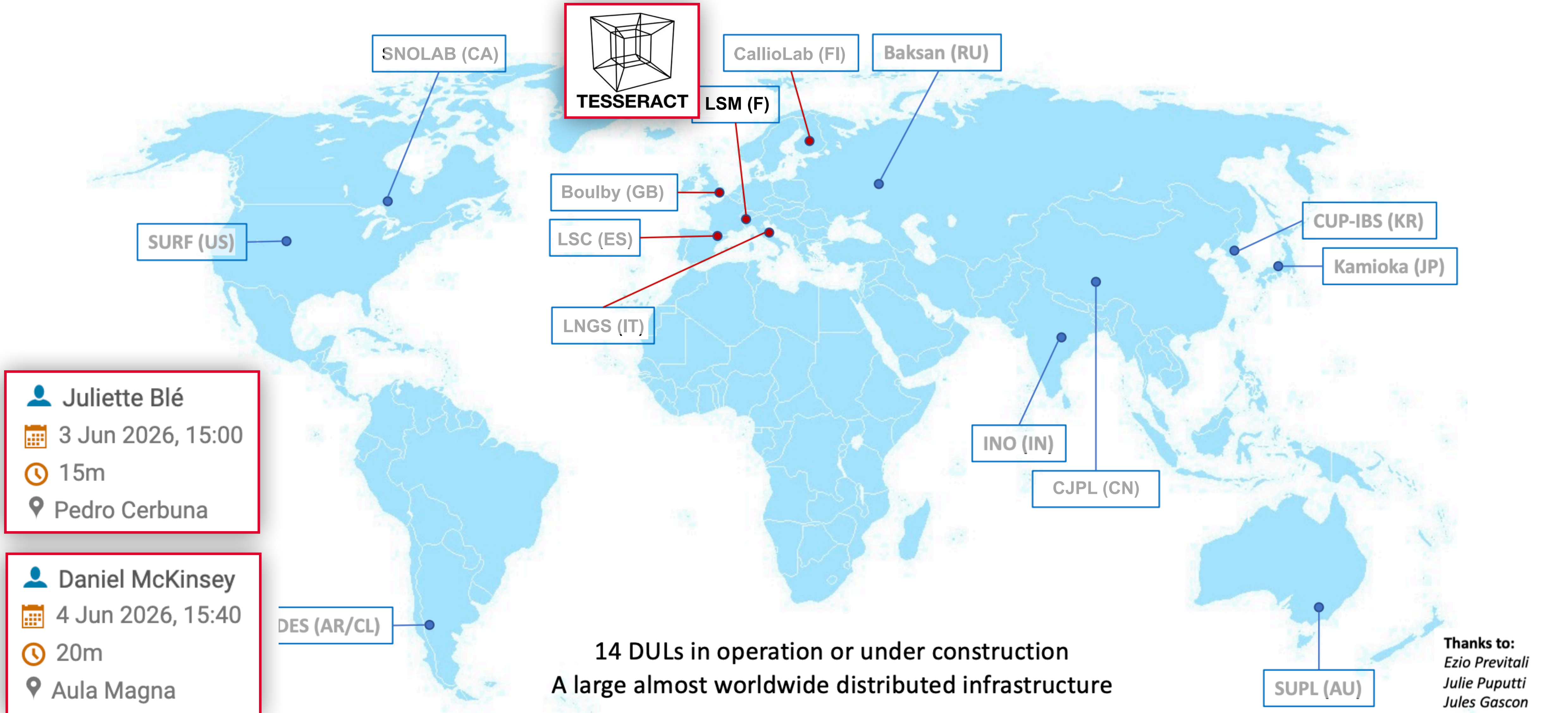
Sensitivity to DM-nucleon scattering

Slide content thanks to Marco Vignati





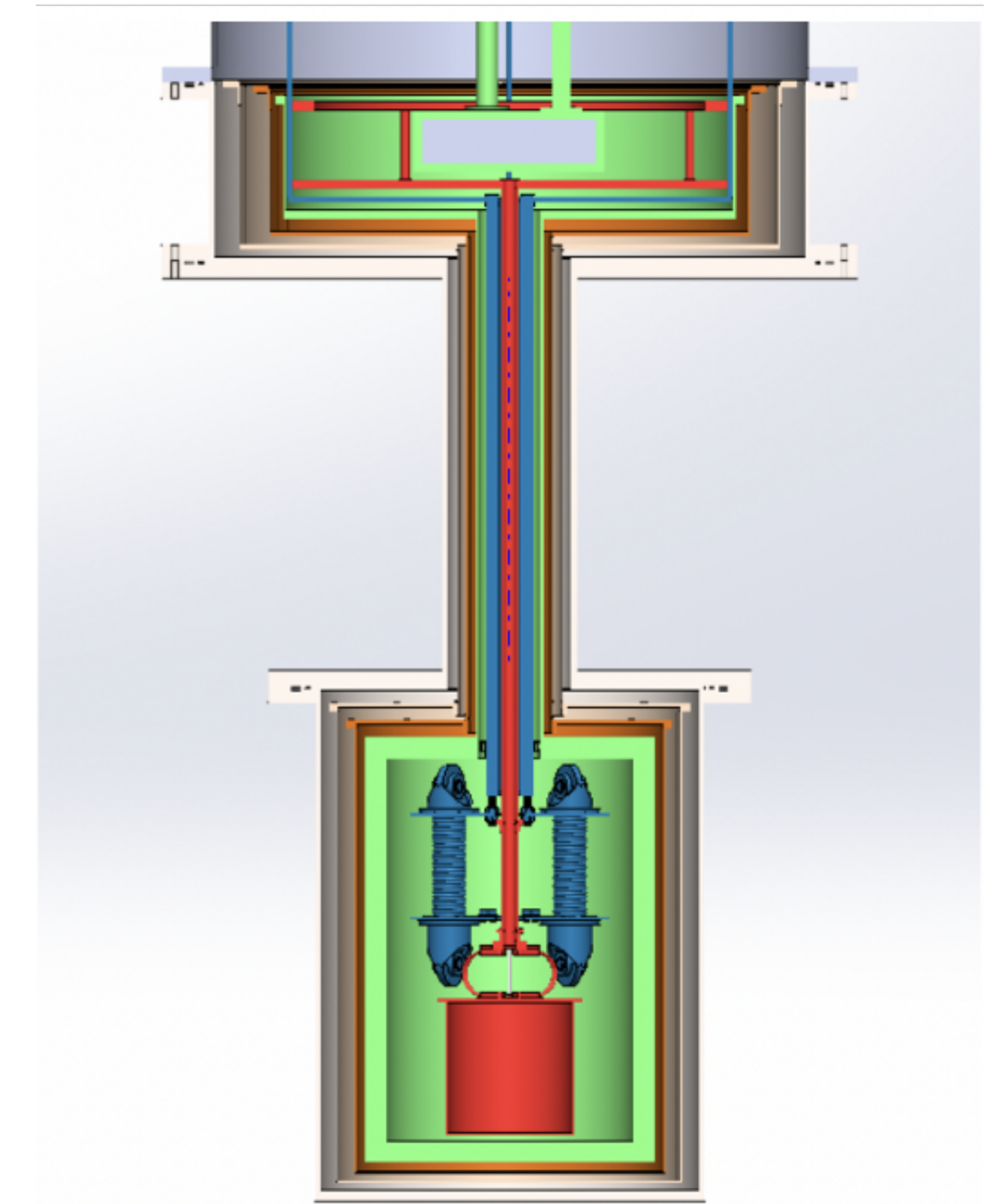
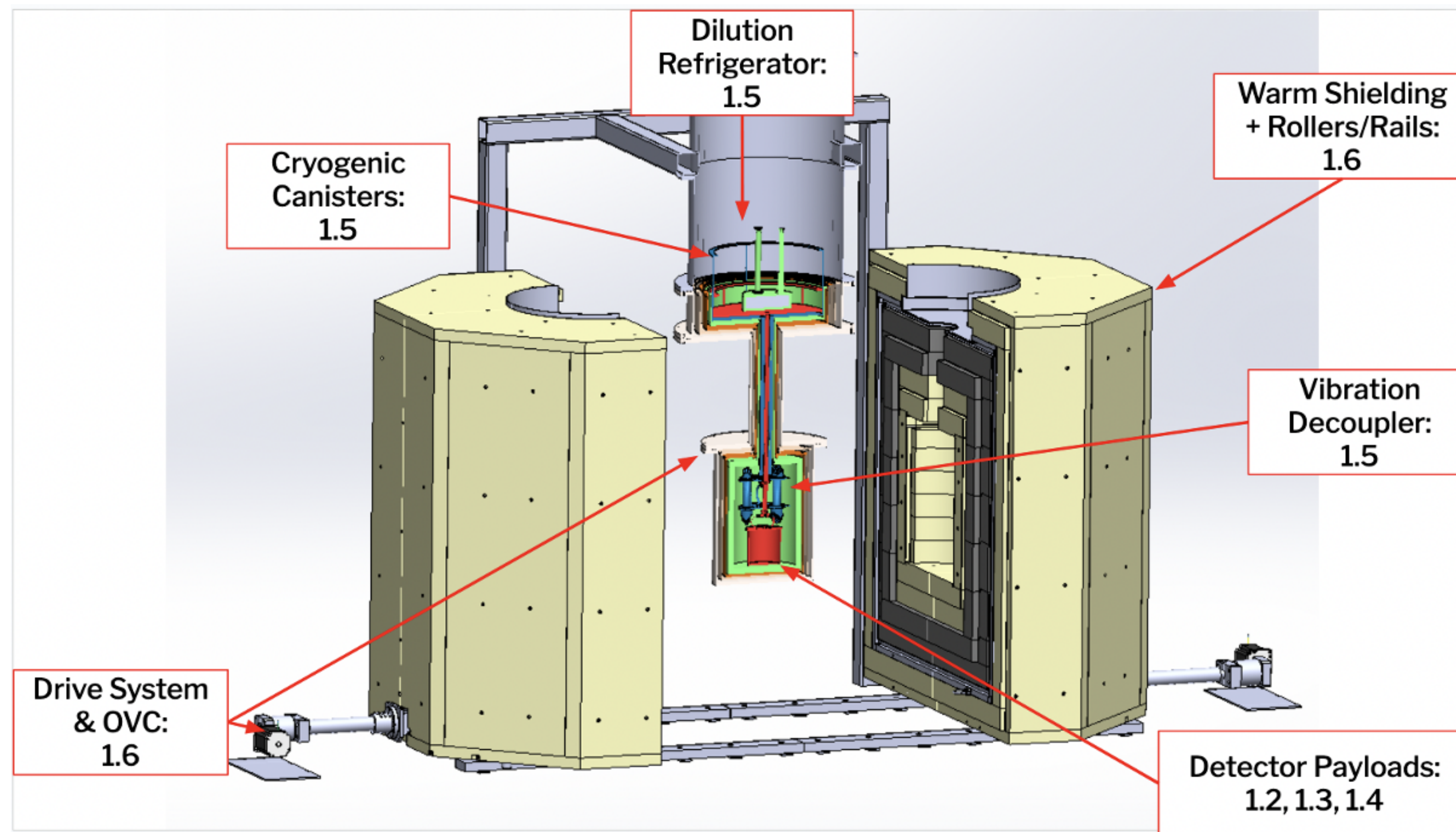
Experiments in this talk



The TESSERACT infrastructure

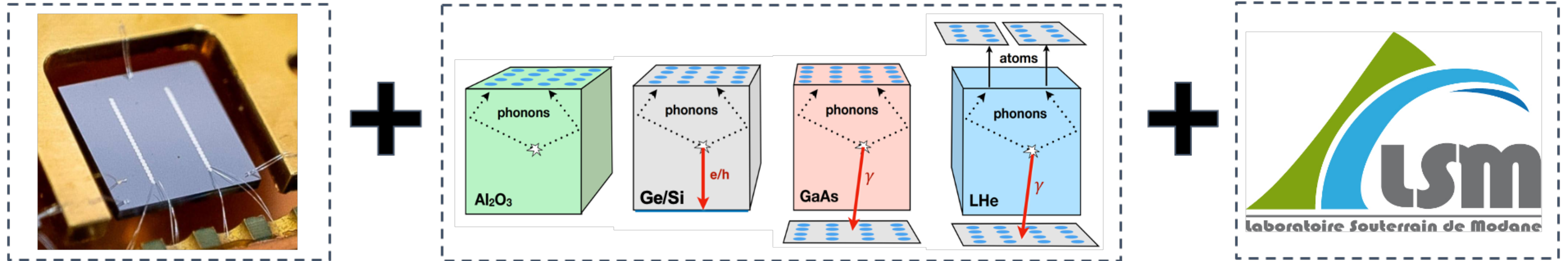
Slide content thanks to Dan McKinsey

- Designed for flexibility and straightforward detector replacement
- 2 identical setups, each to be installed in a deep underground laboratory $\Rightarrow$ **2 simultaneous DM searches!**
- Common infrastructure (shielding, cryostat, dilution refrigerator, vibrational decoupler, cold electronics, DAQ)



The three ingredients to success

Slide content thanks to Dan McKinsey



World-leading,
background-reduced
TES-based sensors
(**QETs**)

Resolution:
 $361.5 \pm .4$ meV from
photon source

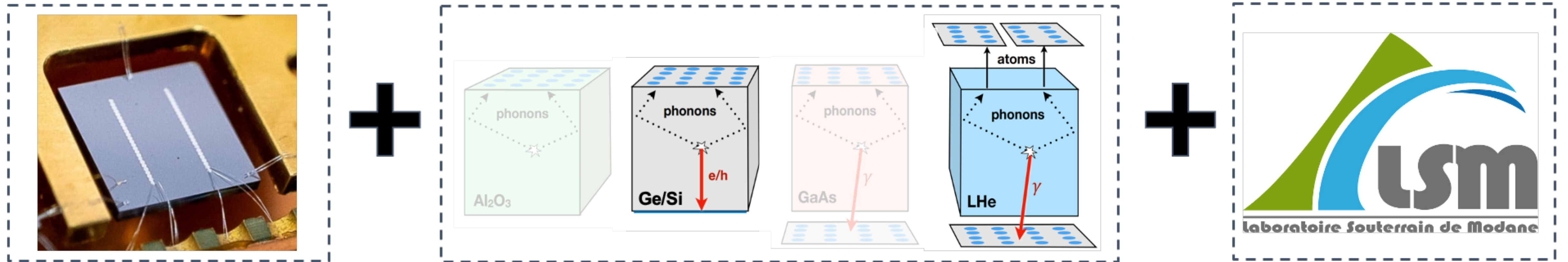
Optimized, complementary
dark matter targets/modules

Long-term,
low-background,
underground searches

The three ingredients to success

Slide content thanks to Dan McKinsey

This talk: Ge/Si and LHe targets



World-leading,
background-reduced
TES-based sensors
(**QETs**)

Resolution:
 $361.5 \pm .4 \text{ meV}$ from
photon source

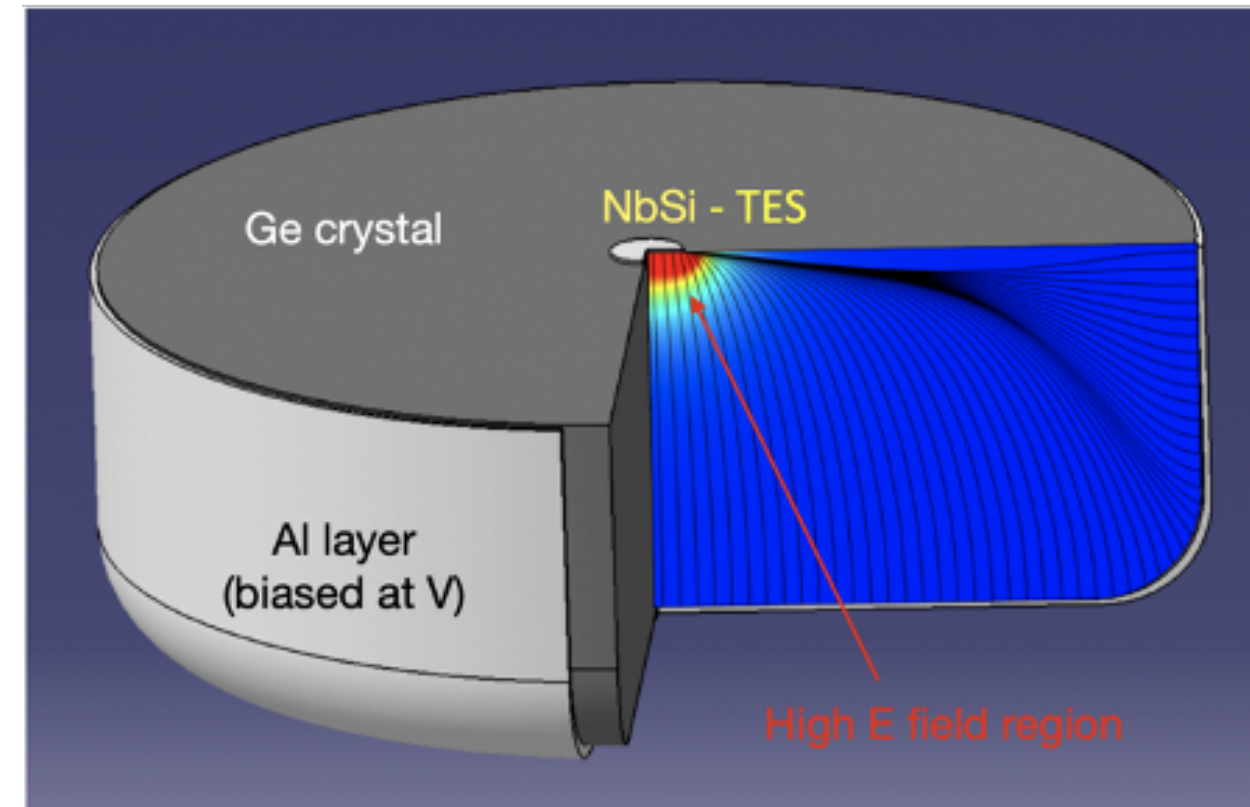
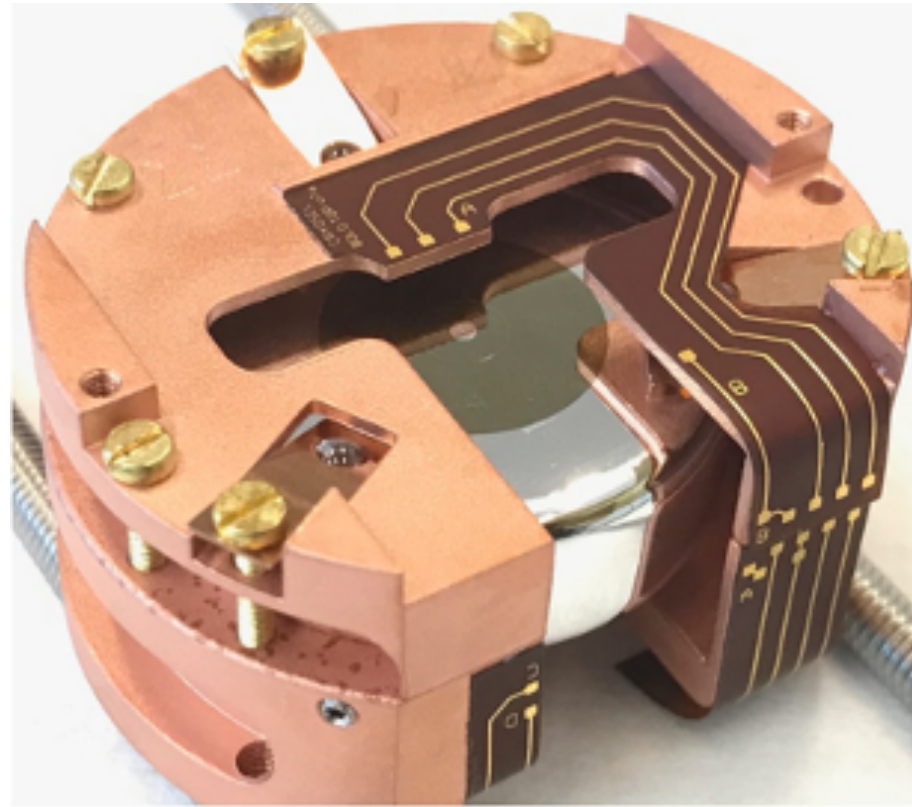
Optimized, complementary
dark matter targets/modules

Long-term,
low-background,
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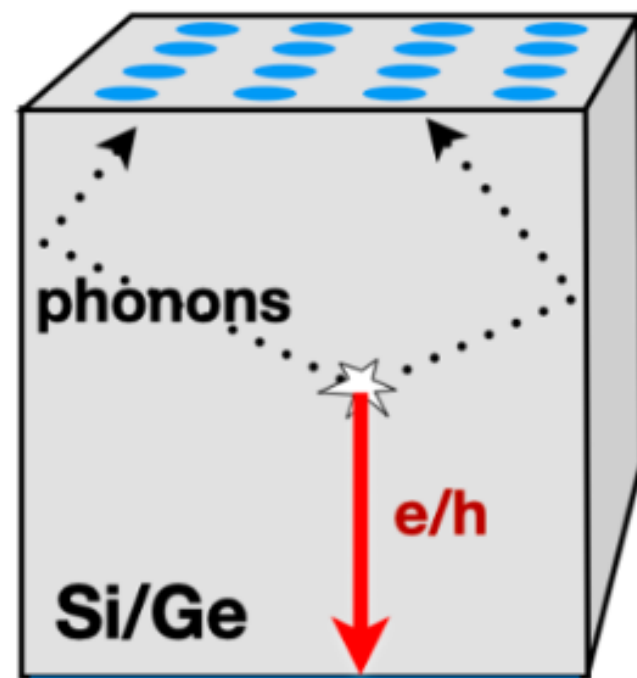
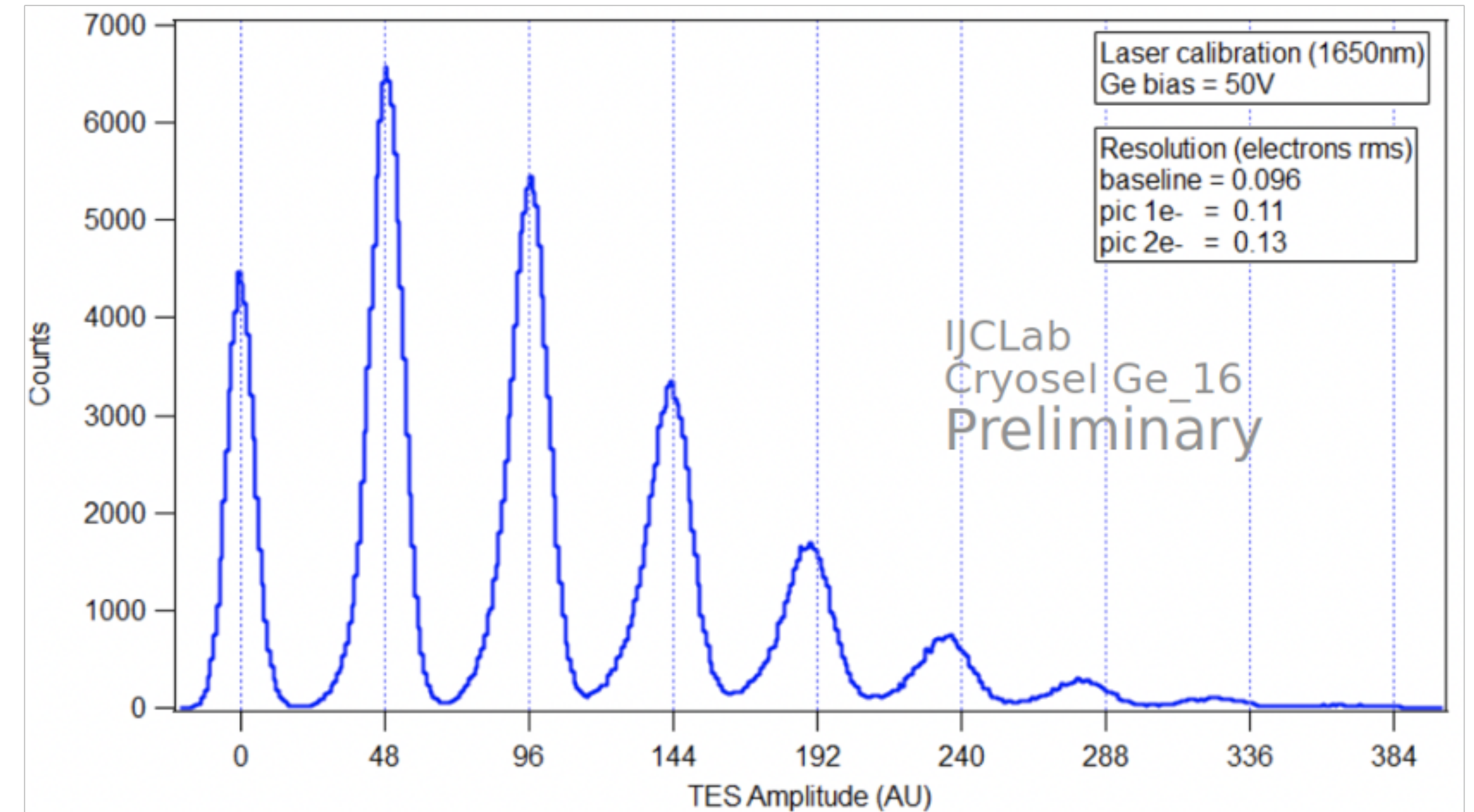
Germanium target

Slide content thanks to Dan McKinsey

Based on **EDELWEISS** and **Ricochet** expertise



Signal: **phonons** and **charge**

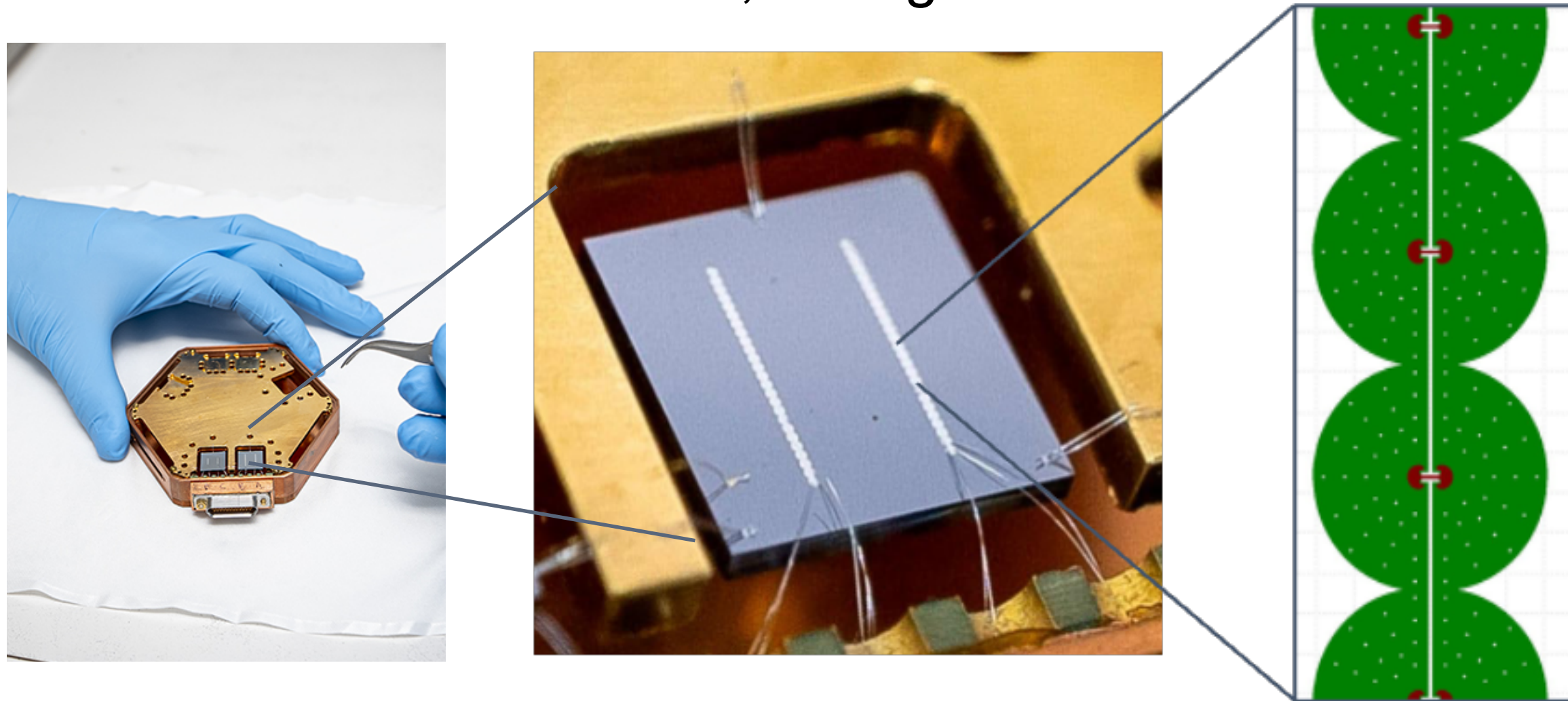


- **First observation of a single-electron sensitivity in a massive (40g) Ge cryogenic detector !**
- For TESSERACT :
 - High control of IR backgrounds and charge leakage
 - Low-energy excess discrimination down to single e/h pair
 - Depending on operation mode, exquisite sensitivity to either DM-e or DM-n scattering

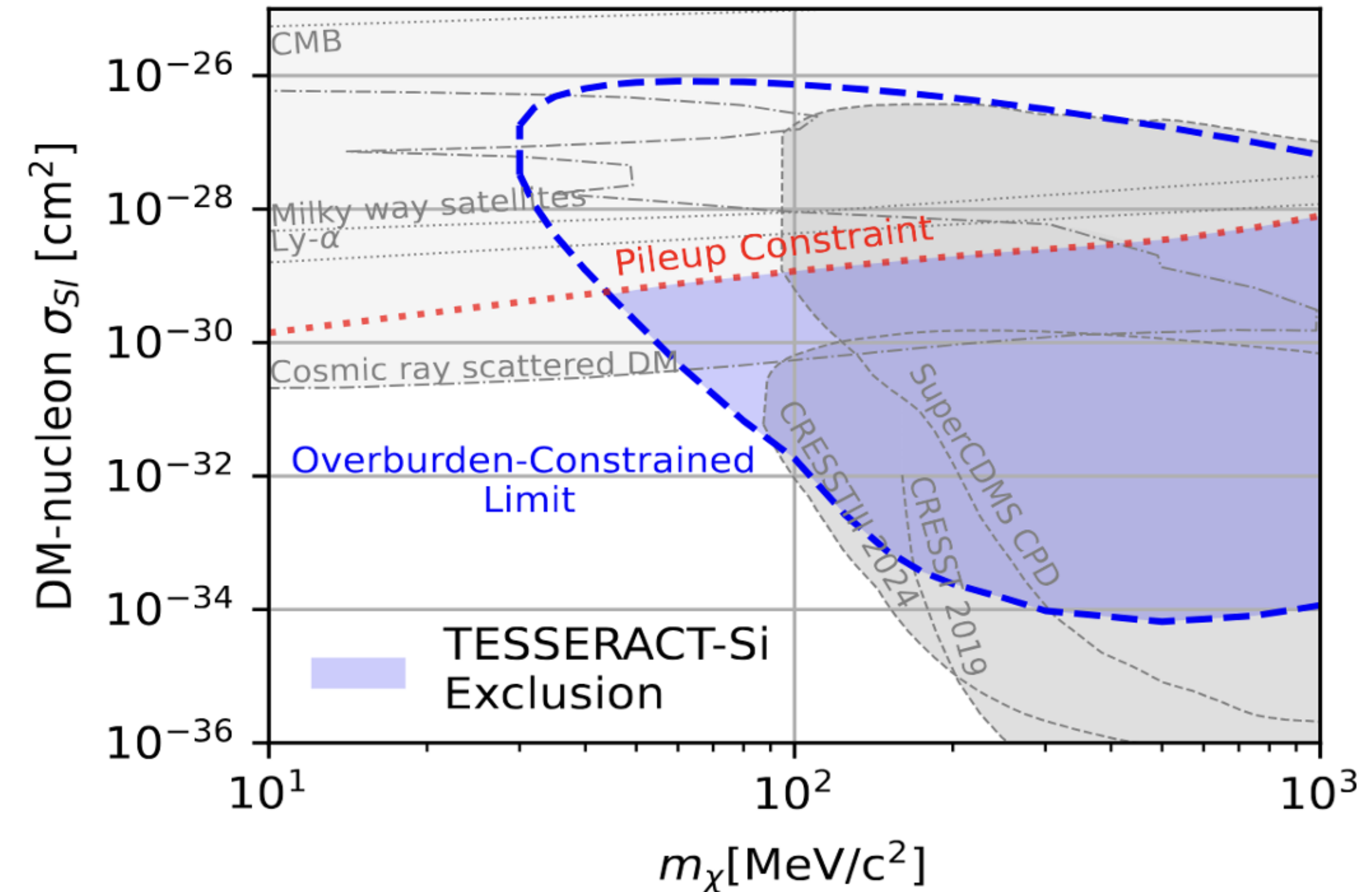
Silicon target

Slide content thanks to Dan McKinsey

Si: 1 cm² x 1mm, 0.23 g



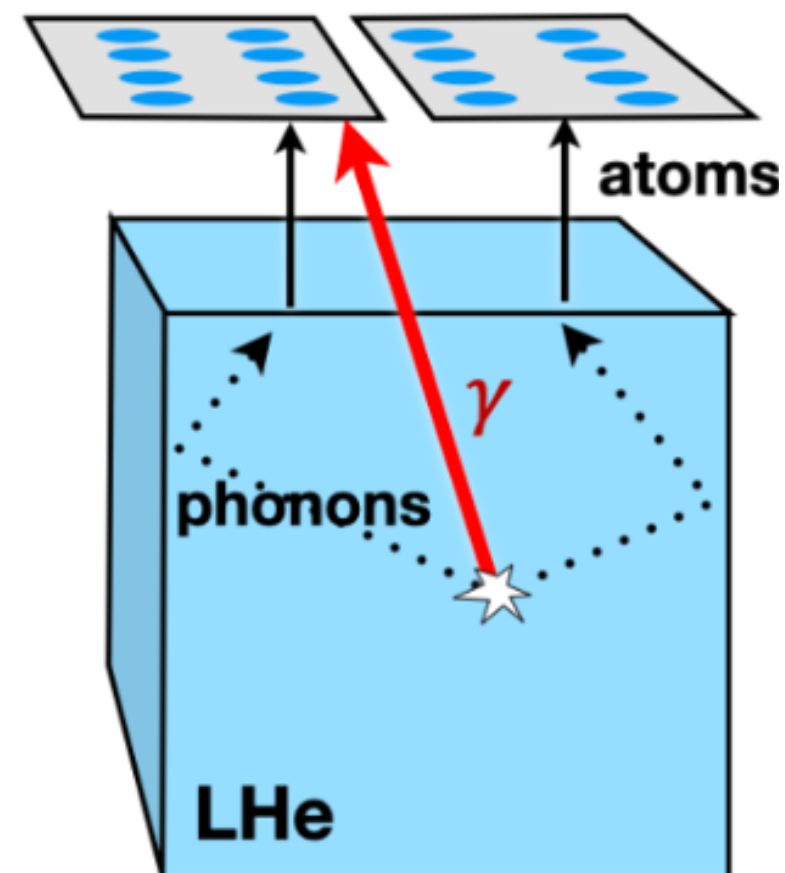
- Especially low energy thresholds
(361.5 meV photon resolution)
 - $\Rightarrow 0.23 \text{ g} \times 12 \text{ hours}$ enough to probe new DM parameter space
- Same detector type will be used for one of the readout pixels for the LHe detector



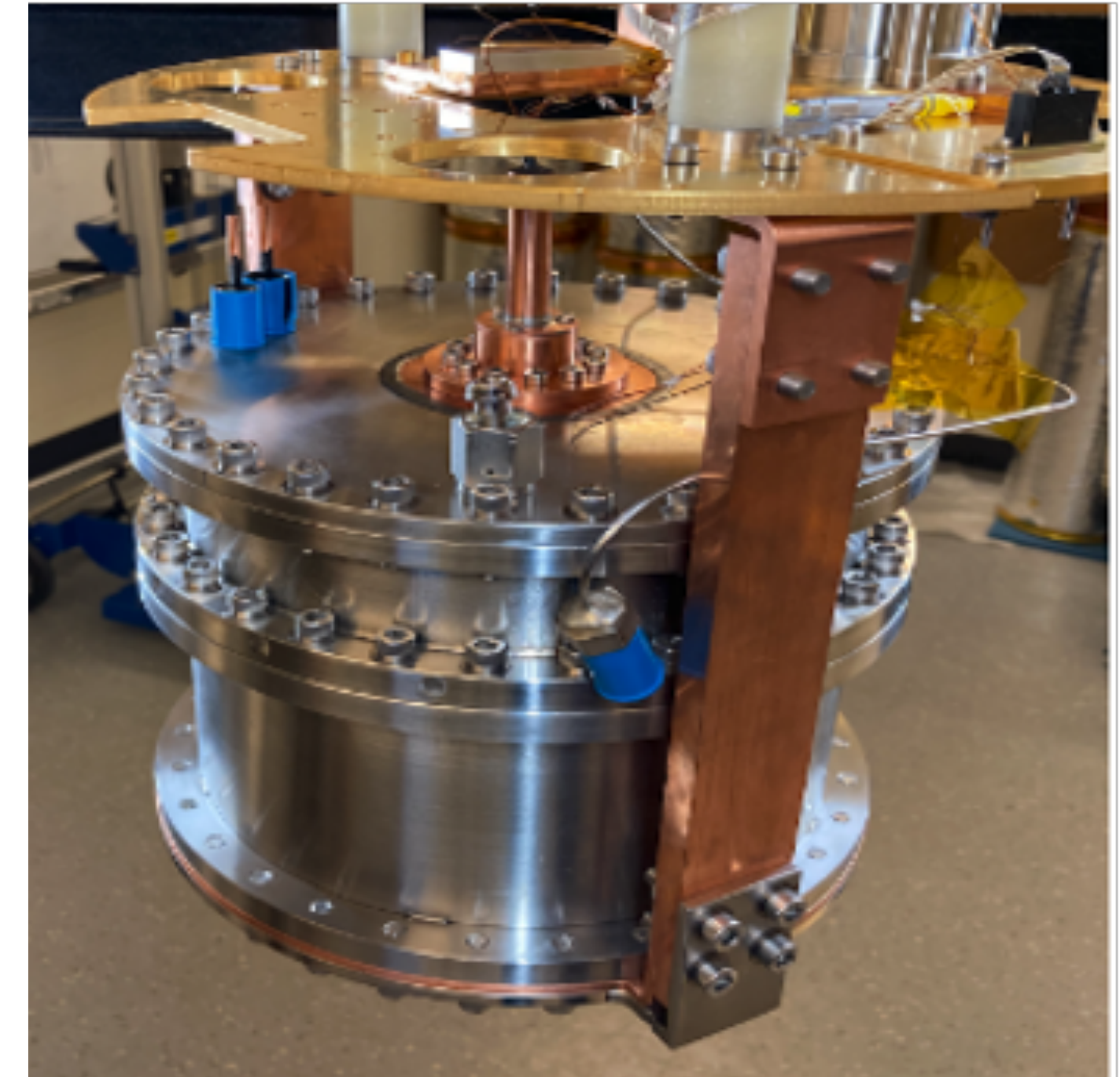
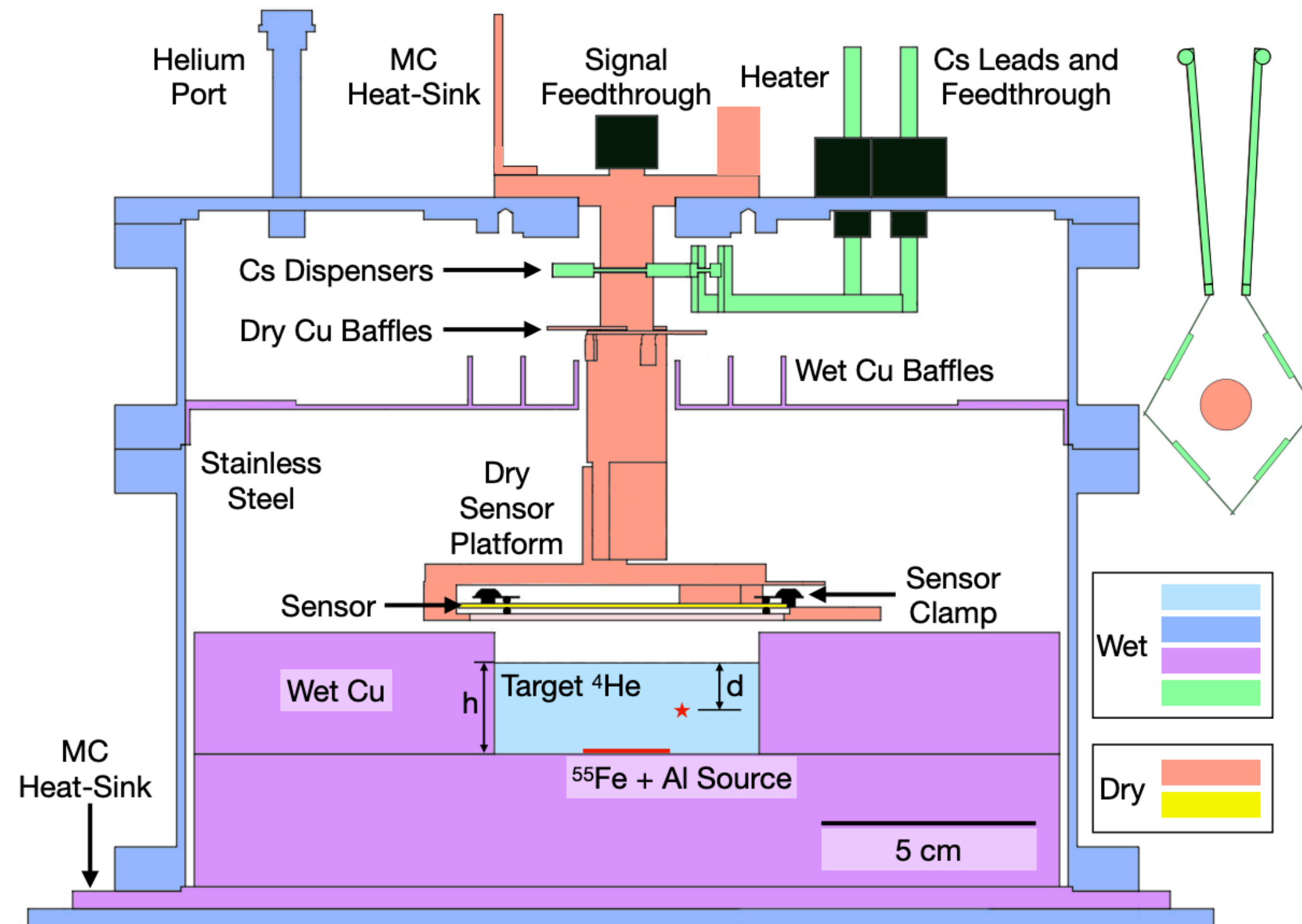
Superfluid helium-4 target

Slide content thanks to Dan McKinsey

- Prototype “HeRALD v0.1” detector (~ 10 g)
- Heat-free He film-blocking via unoxidized Cs film



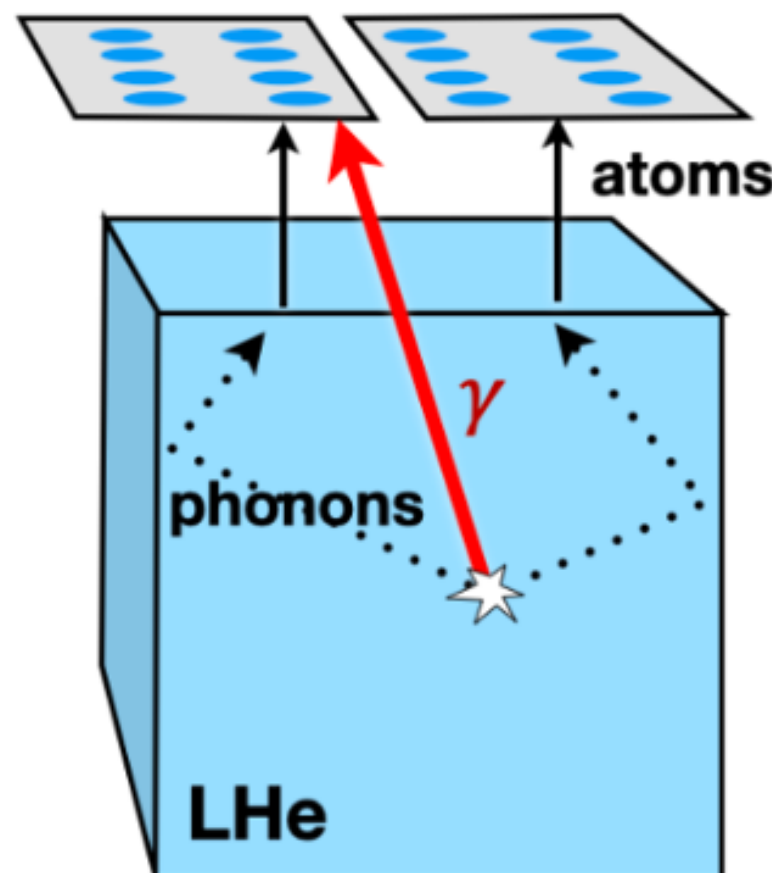
Signal:
phonons/rotons and light



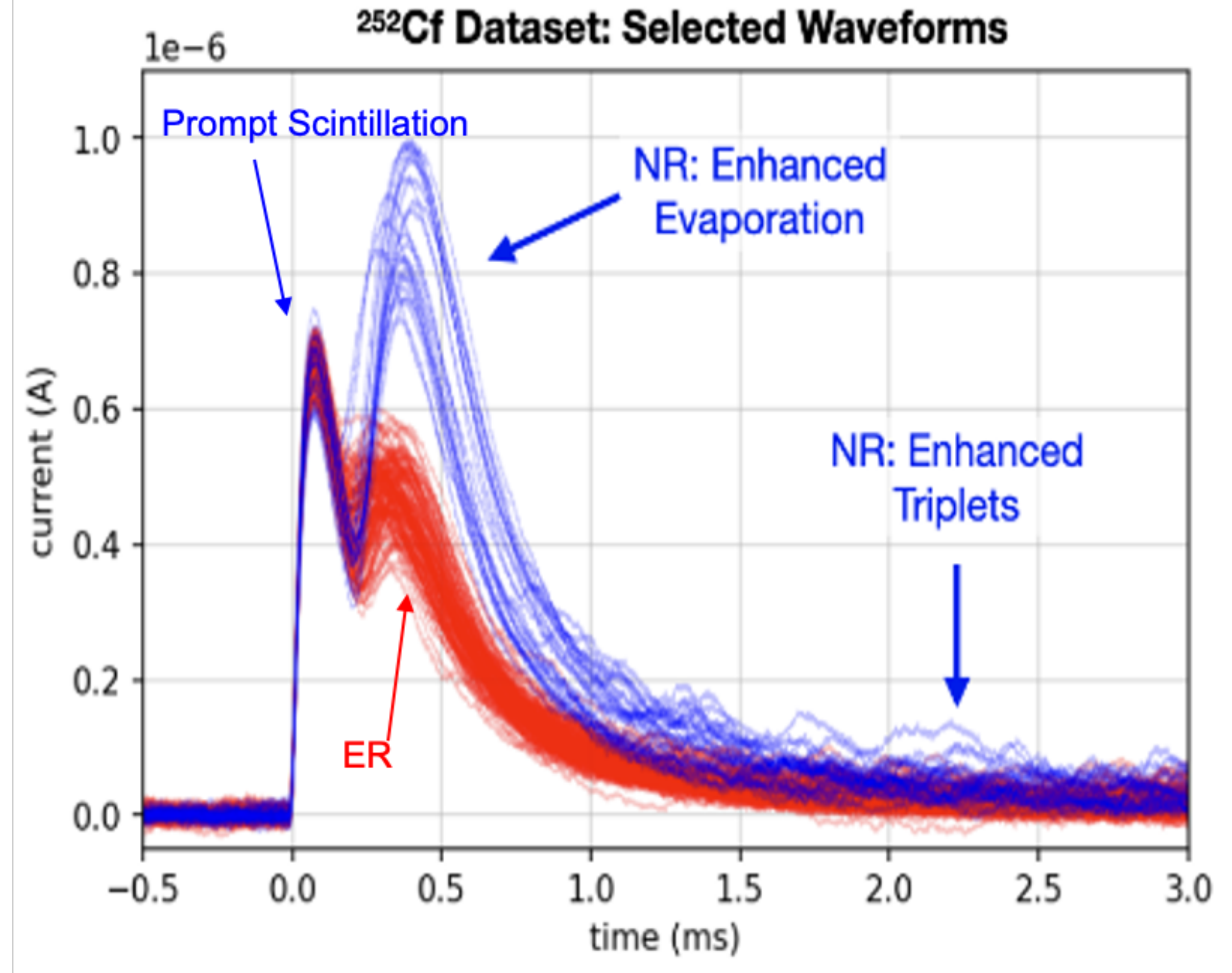
Superfluid helium-4 target

Slide content thanks to Dan McKinsey

- Successful measurement of quantum evaporation signal
- The different signals arrive at different times
 - $\Rightarrow$ Pulse shape discrimination



Signal:
phonons/rotons and light

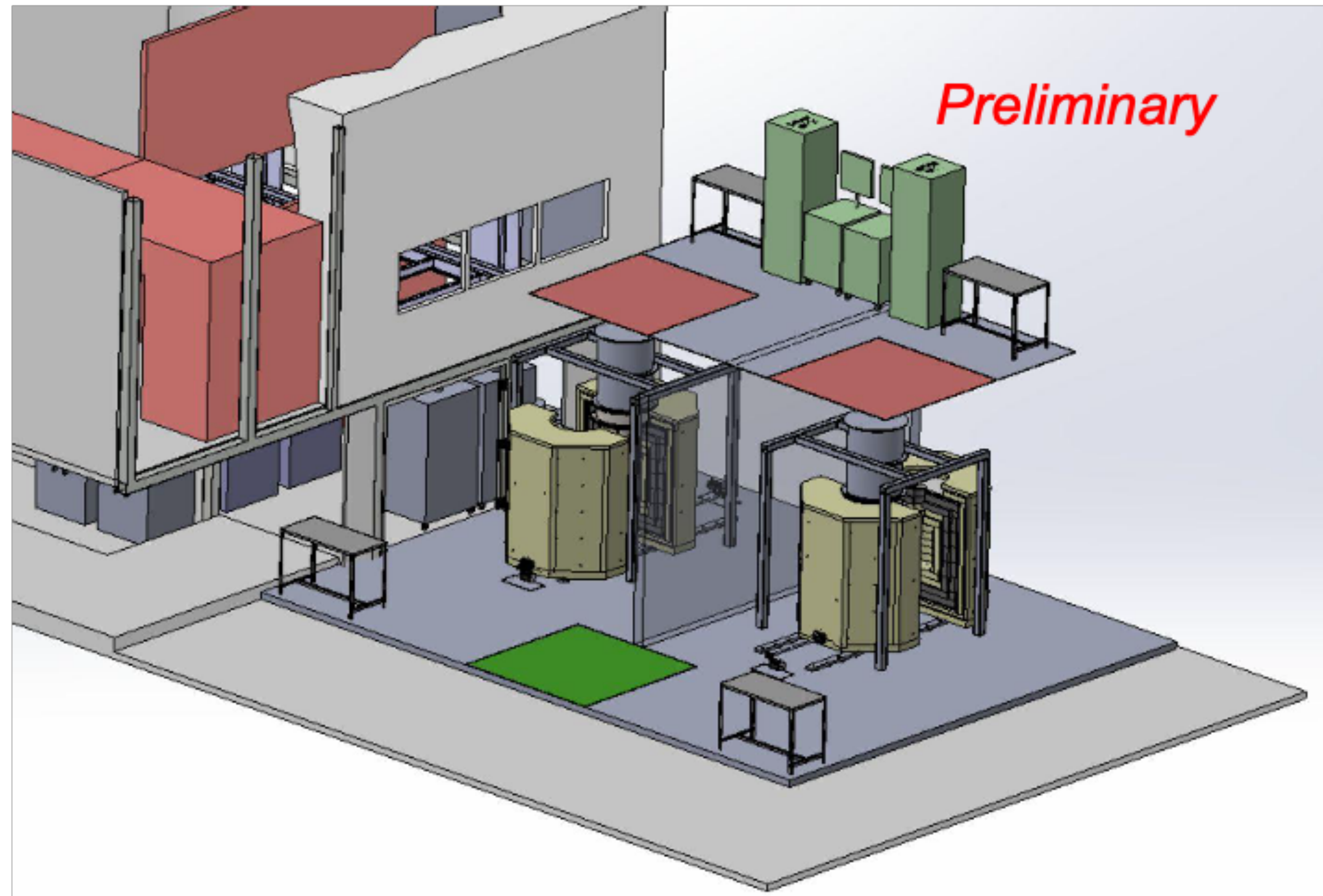


TESSERACT

Slide content thanks to Dan McKinsey

Schedule

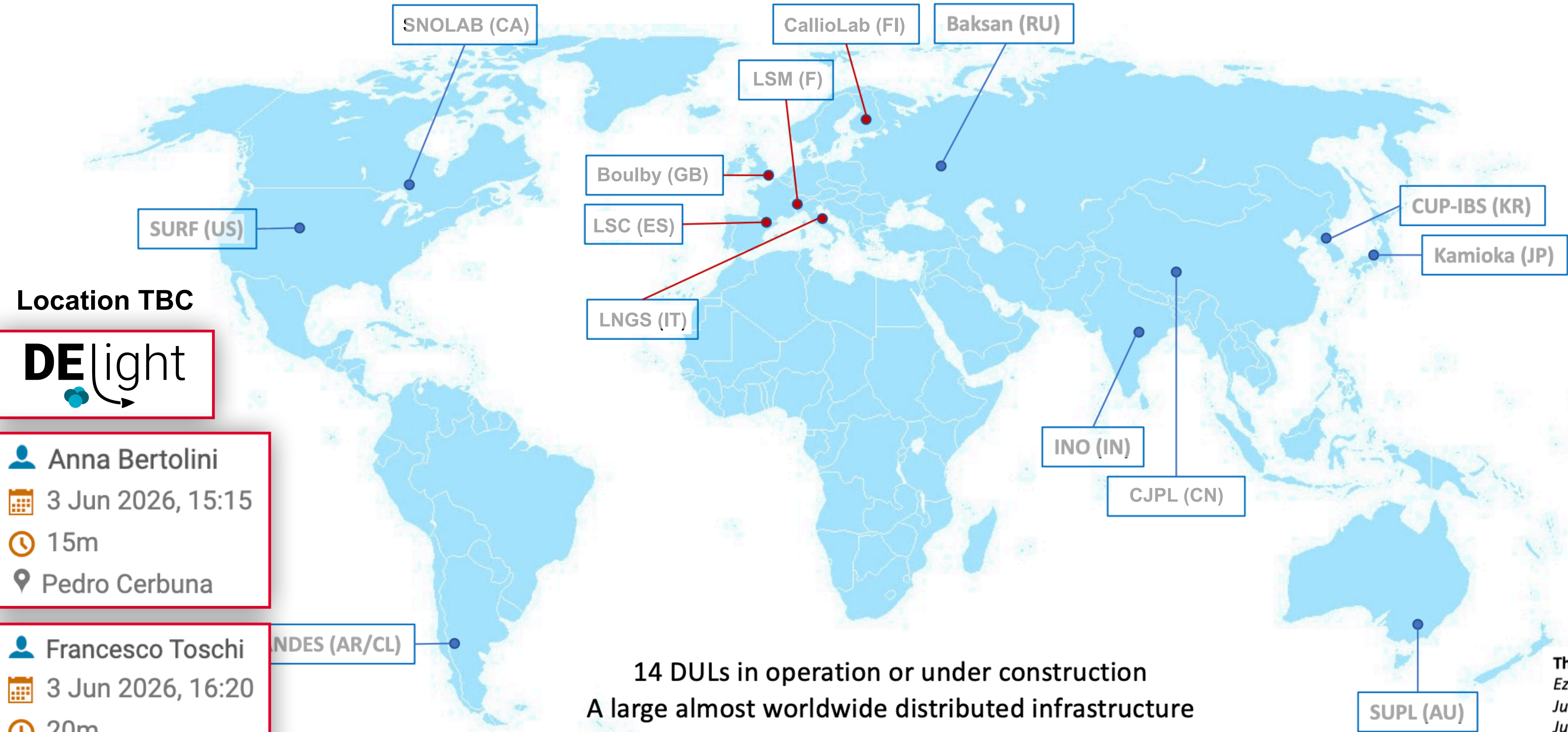
- Project planning stage:
FY2020 - FY2025 (completed)
- **Project phase:**
FY2025 - FY2028 (current)
- Operations phase:
FY2029-FY2031



Moving to the Modane underground lab in **2028** for low-background searches with TESSERACT!

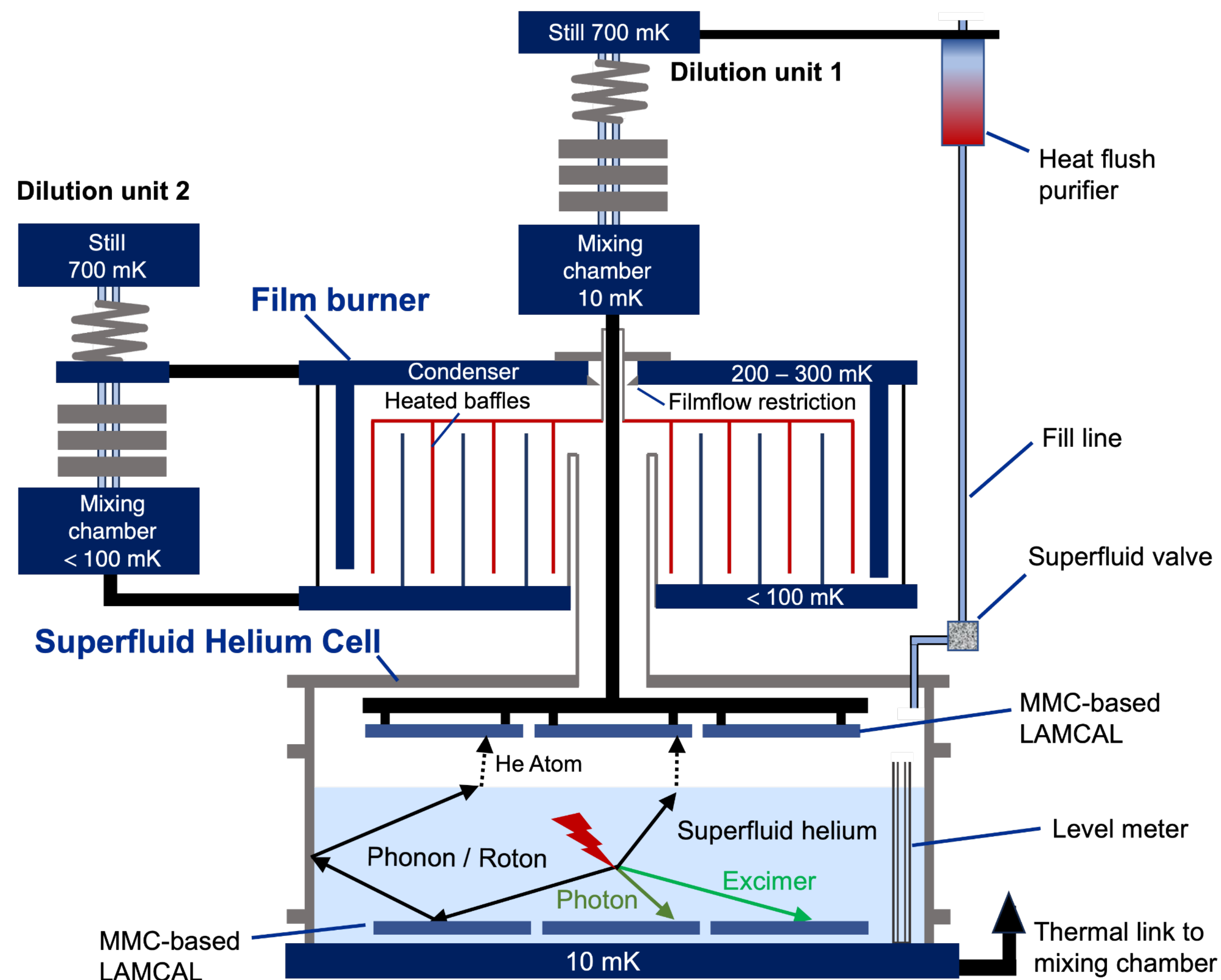


Experiments in this talk

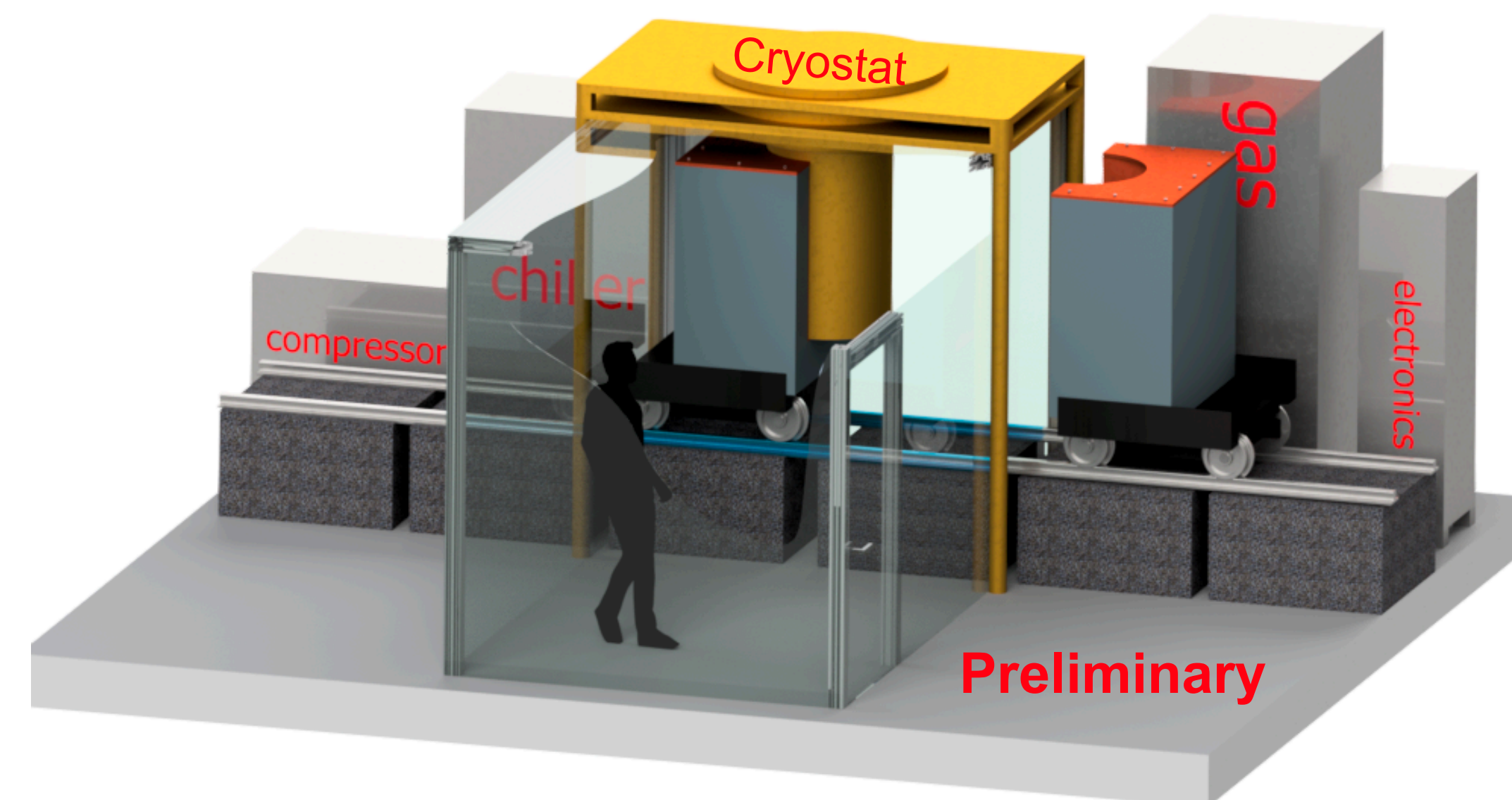


Thanks to:
Ezio Previtali
Julie Puputti
Jules Gascon
Carlos Peña Garay

The DELight experiment (Phase-I)



- Phase-I detector (~ 150 g)
- He film-blocking via film burner

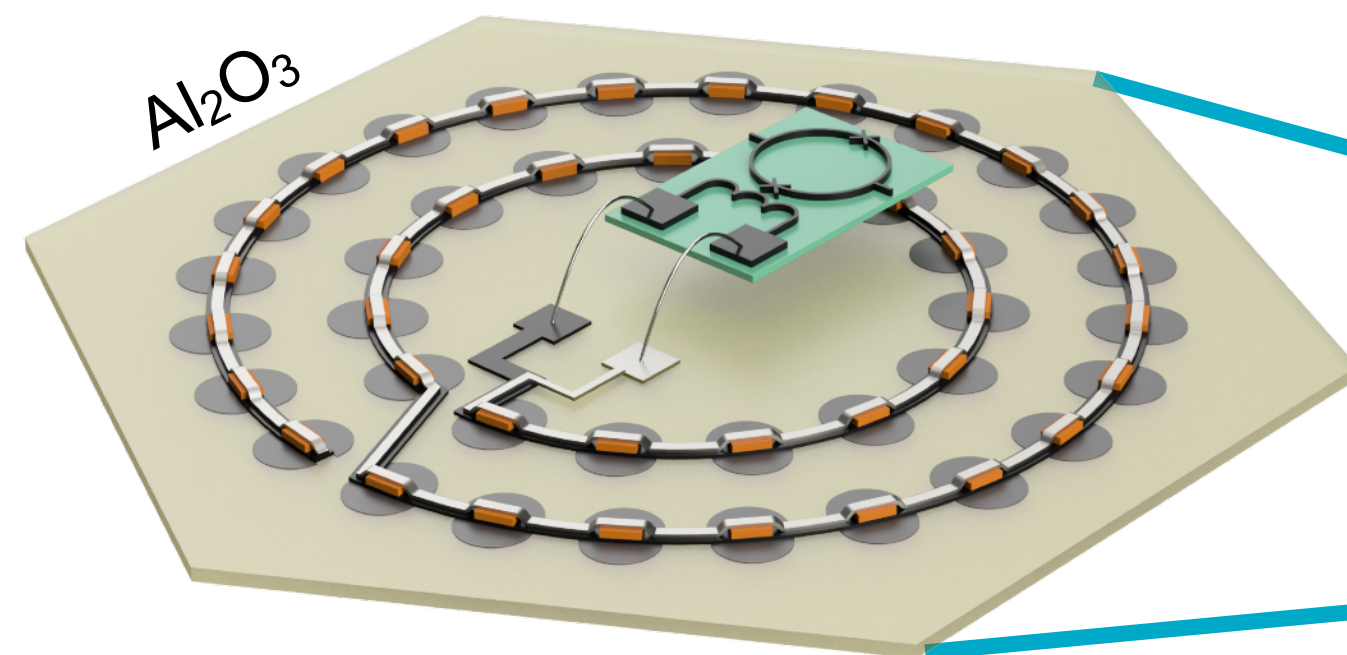


Signal:
phonons/rotons and light

Instrumentation with large-area wafer calorimeters



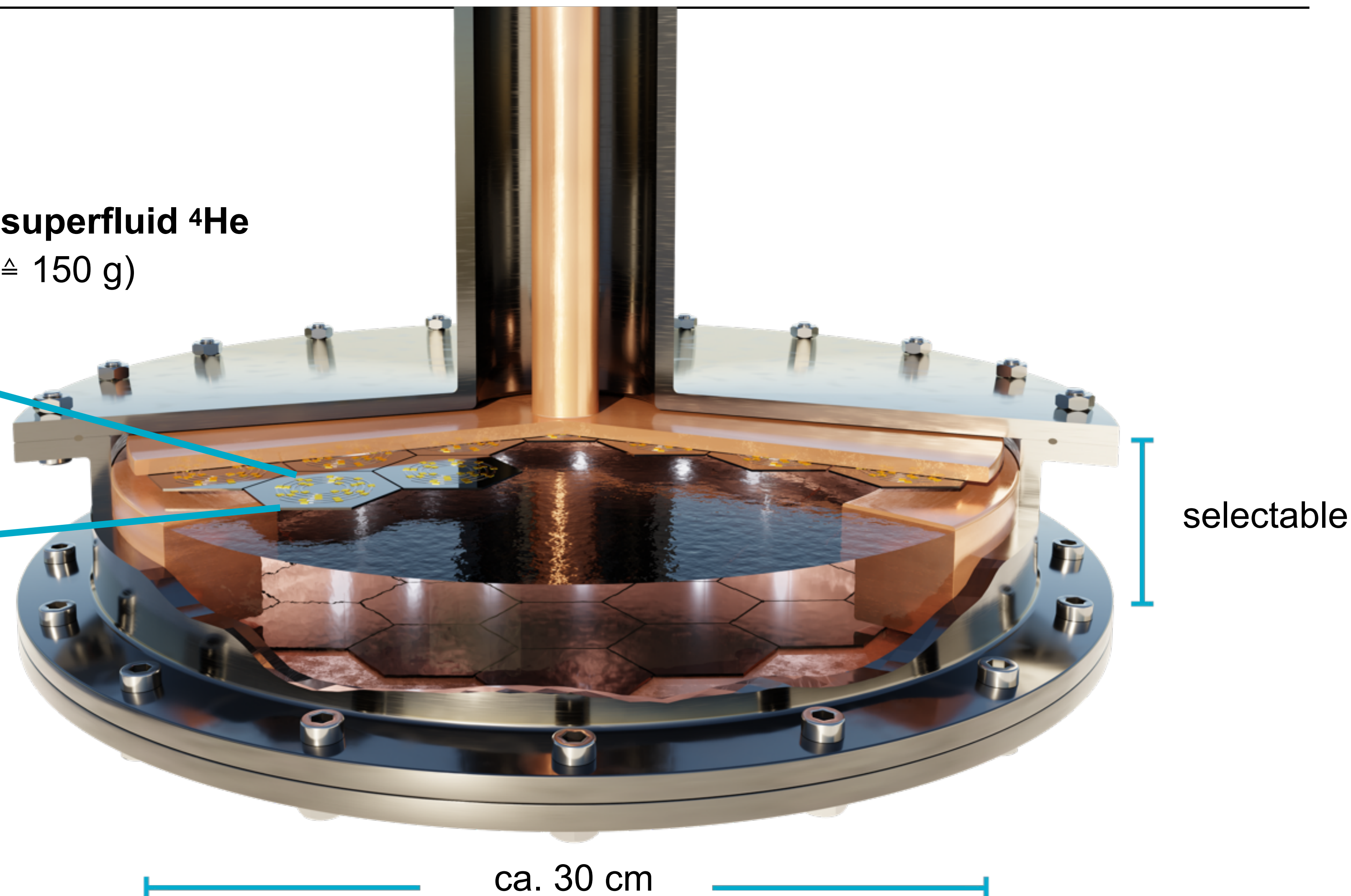
≥1 liter superfluid ^4He
($\triangleq$ 150 g)



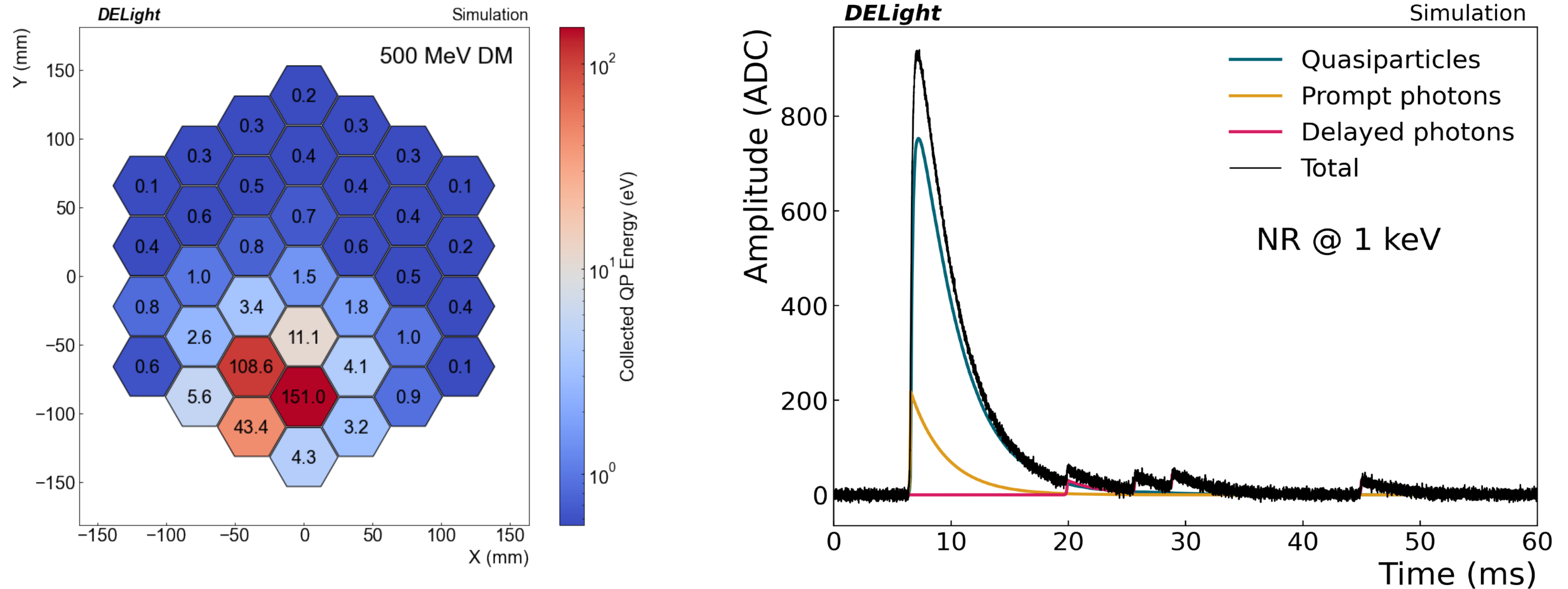
56 LAMCALs

(37 in top-array, 19 in bottom-array)

LAMCAL: Large-Area
cryogenic MicroCALorimeters
based on **MMC**-technology
(Magnetic MicroCalorimeter)



Event reconstruction



- Combining hit pattern and pulse shape information for event reconstruction and background discrimination
- Expected threshold per LAMCAL ~ 5 eV
- Expected nuclear recoil energy threshold at 20 eV

Sensitivity to DM-nucleon scattering

Phase-I (ca. 4 years)

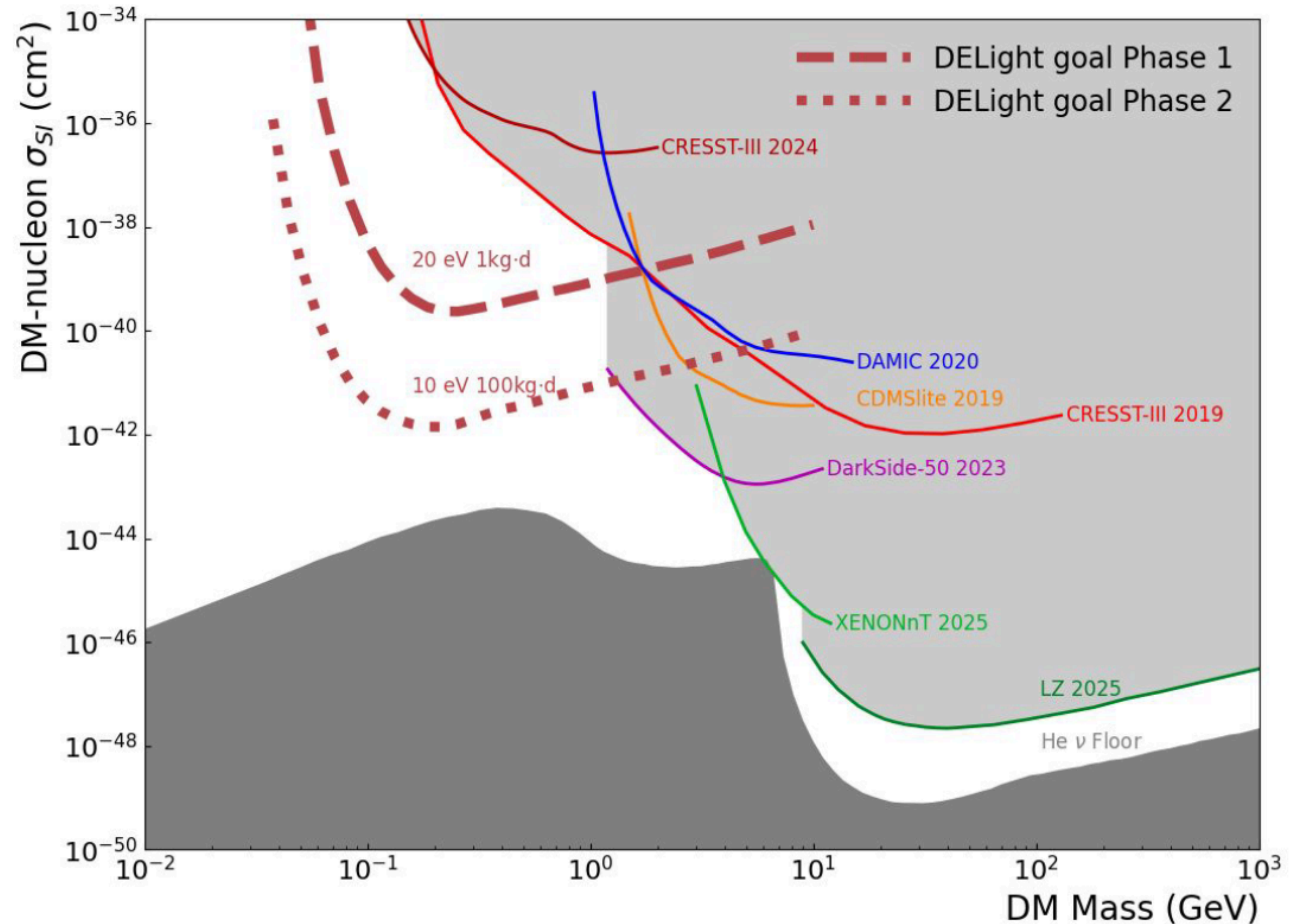
- 1 kg•d exposure
- 20 eV threshold

Phase-II (> 4 years)

- 100 kg•d exposure
- 10 eV threshold

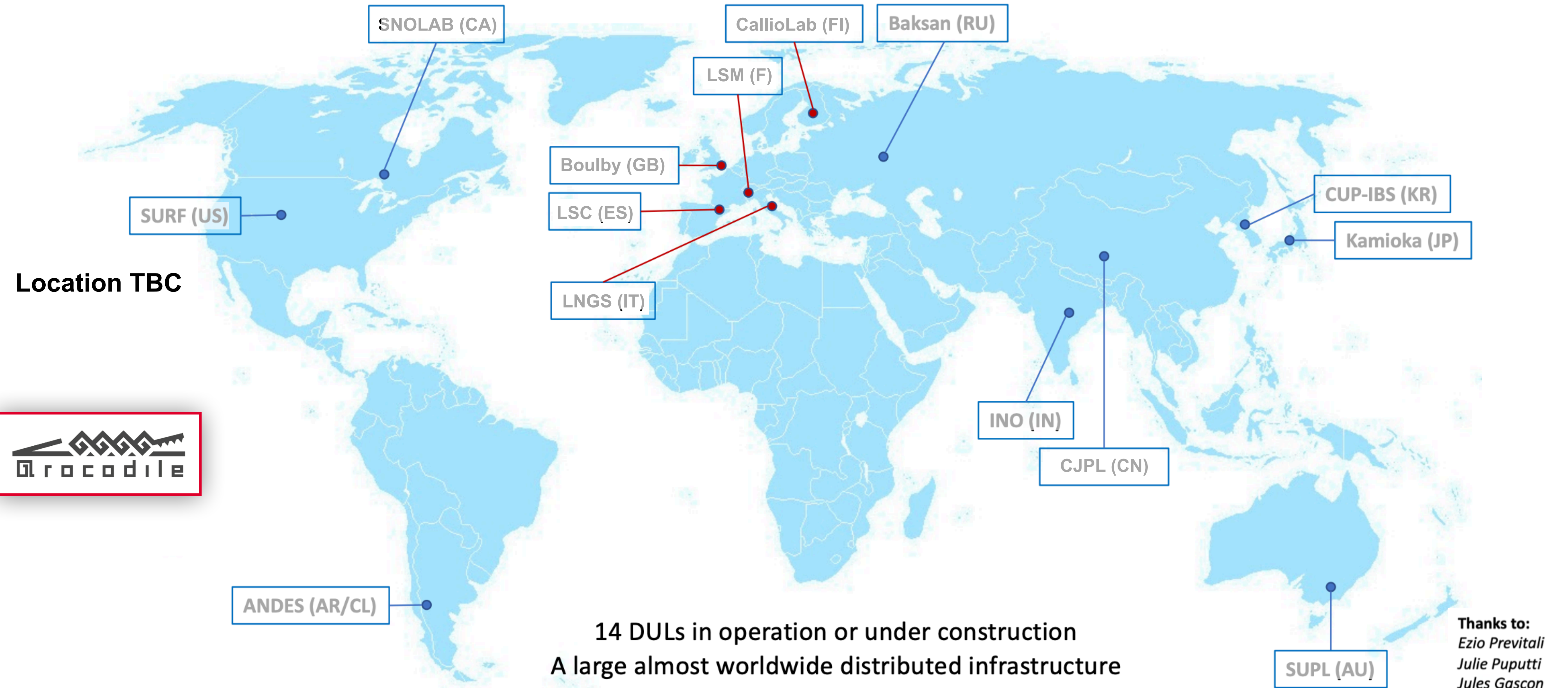
Schedule

- Phase-I has just started
- Cryostat has been ordered
- Currently in design and development phase





Experiments in this talk

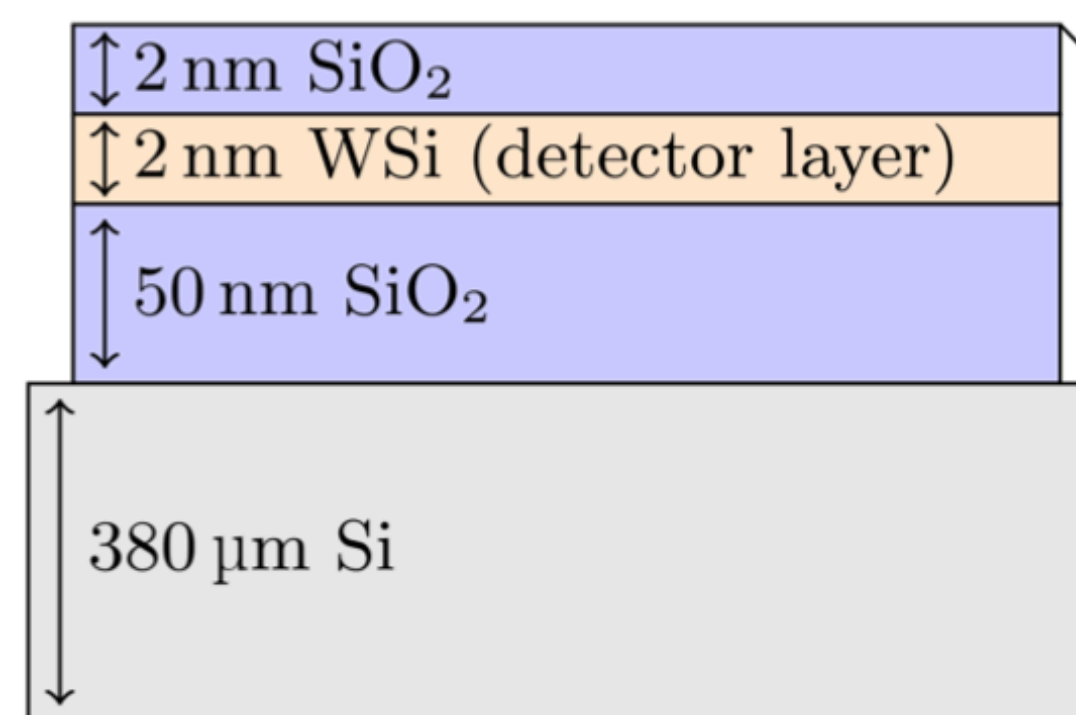
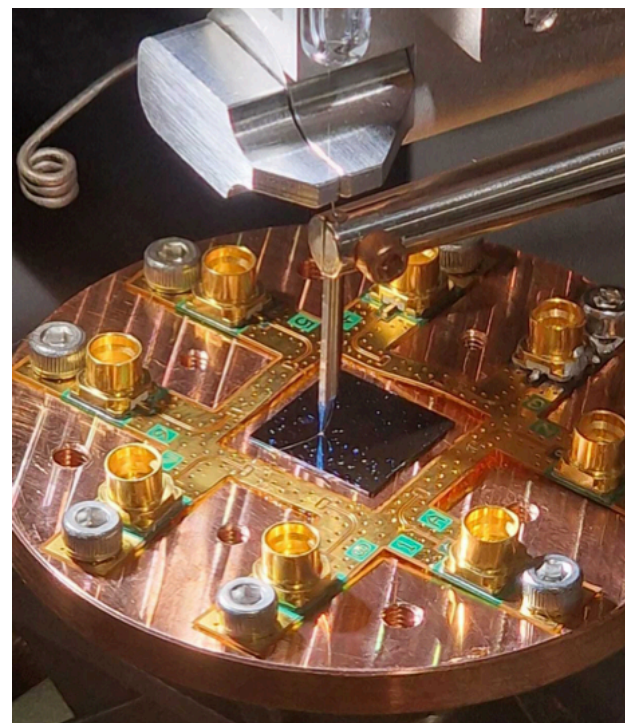


Thanks to:
Ezio Previtali
Julie Puputti
Jules Gascon
Carlos Peña Garay

The QROCODILE experiment

Slide content thanks to Laura Baudis, Chiara Capelli

- 10x10 mm² chip size, **1.67 ng**
- 600x600 μm² active area with 1 μm wire width
- 25% filling factor
- **WSi** 45:55 superconducting layer 2 nm thick
- Transition temperature at 1.73 K
- **Si/SiO₂** substrate

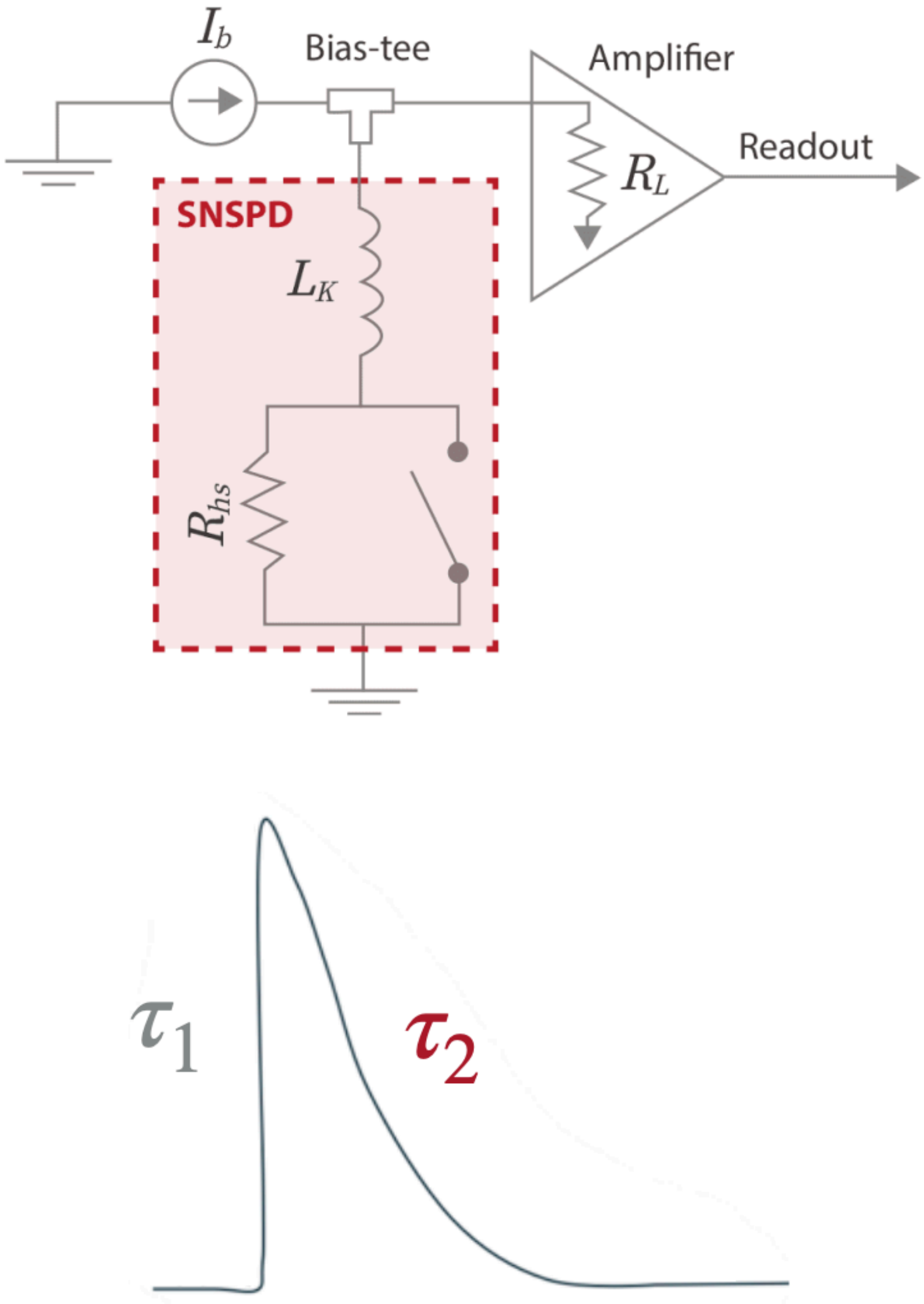
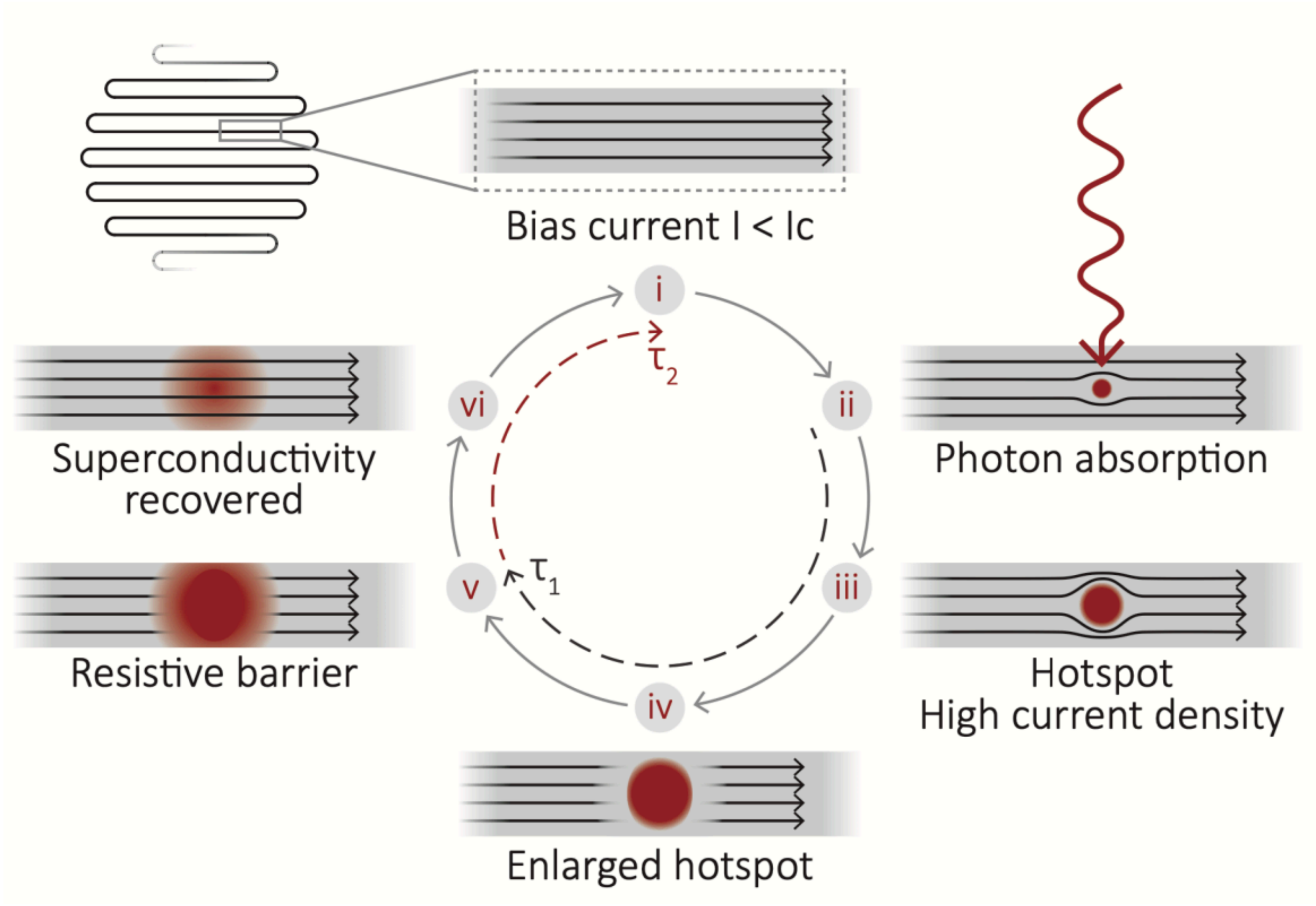




SNSPD working principle

Slide content thanks to Laura Baudis, Chiara Capelli

Superconducting Nanowire Single-Photon Detectors

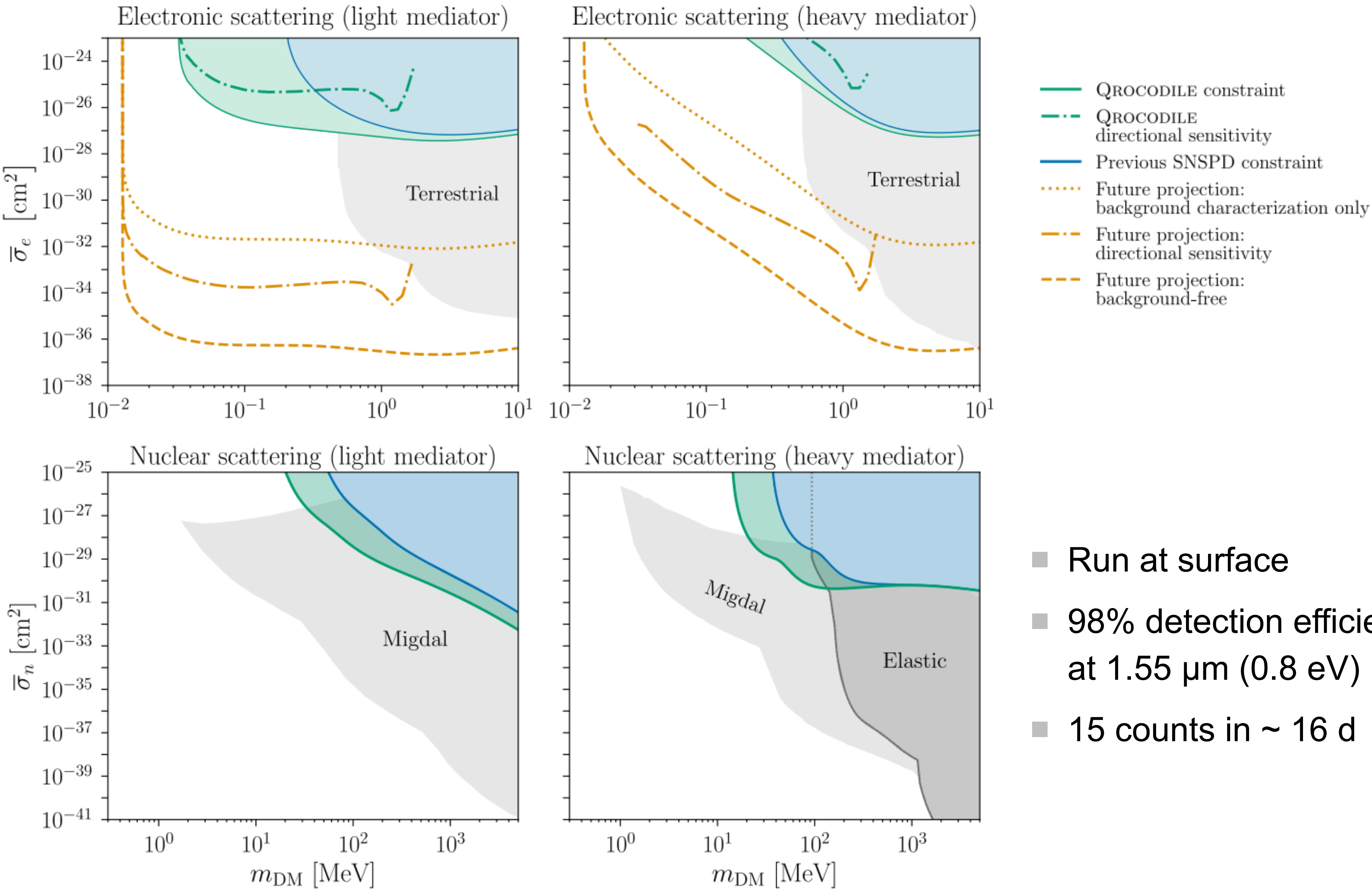


First DM search results and projections

Slide content thanks to Laura Baudis

Plans

- Scale-up SNSPDs' detector mass with areas of $\sim \text{cm}^2$ and beyond
- Extend energy threshold to fundamental limit
- Understand and reduce backgrounds



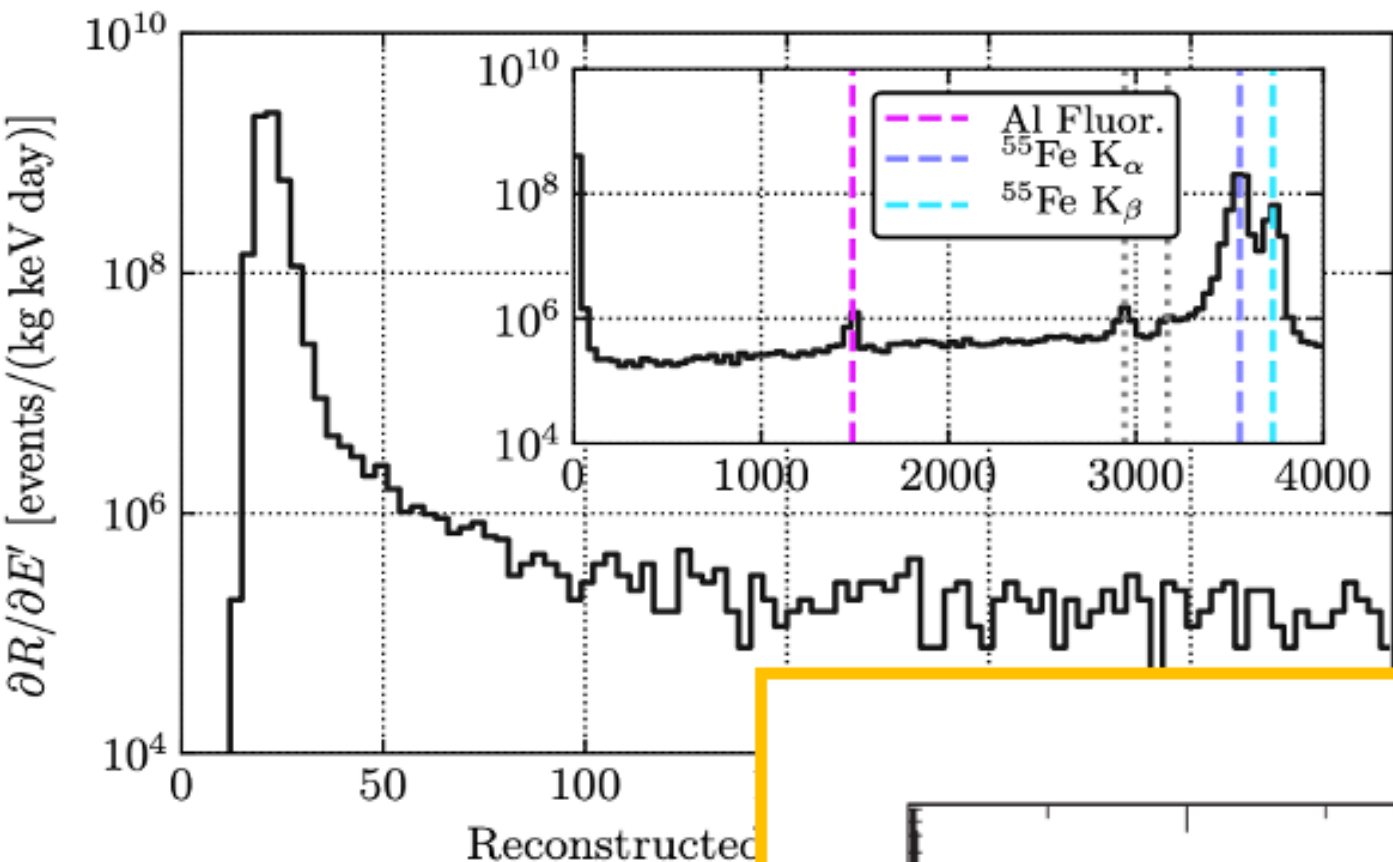
- Run at surface
- 98% detection efficiency at $1.55 \mu\text{m}$ (0.8 eV)
- 15 counts in $\sim 16 \text{ d}$

The low-energy excess (LEE)

The low-energy excess at its beginning

SuperCDMS-CPD

In this search, we see an **excess** of events for recoil energies below about 100 eV, emerging above the roughly flat rate from Compton scattering of the gamma-ray back-

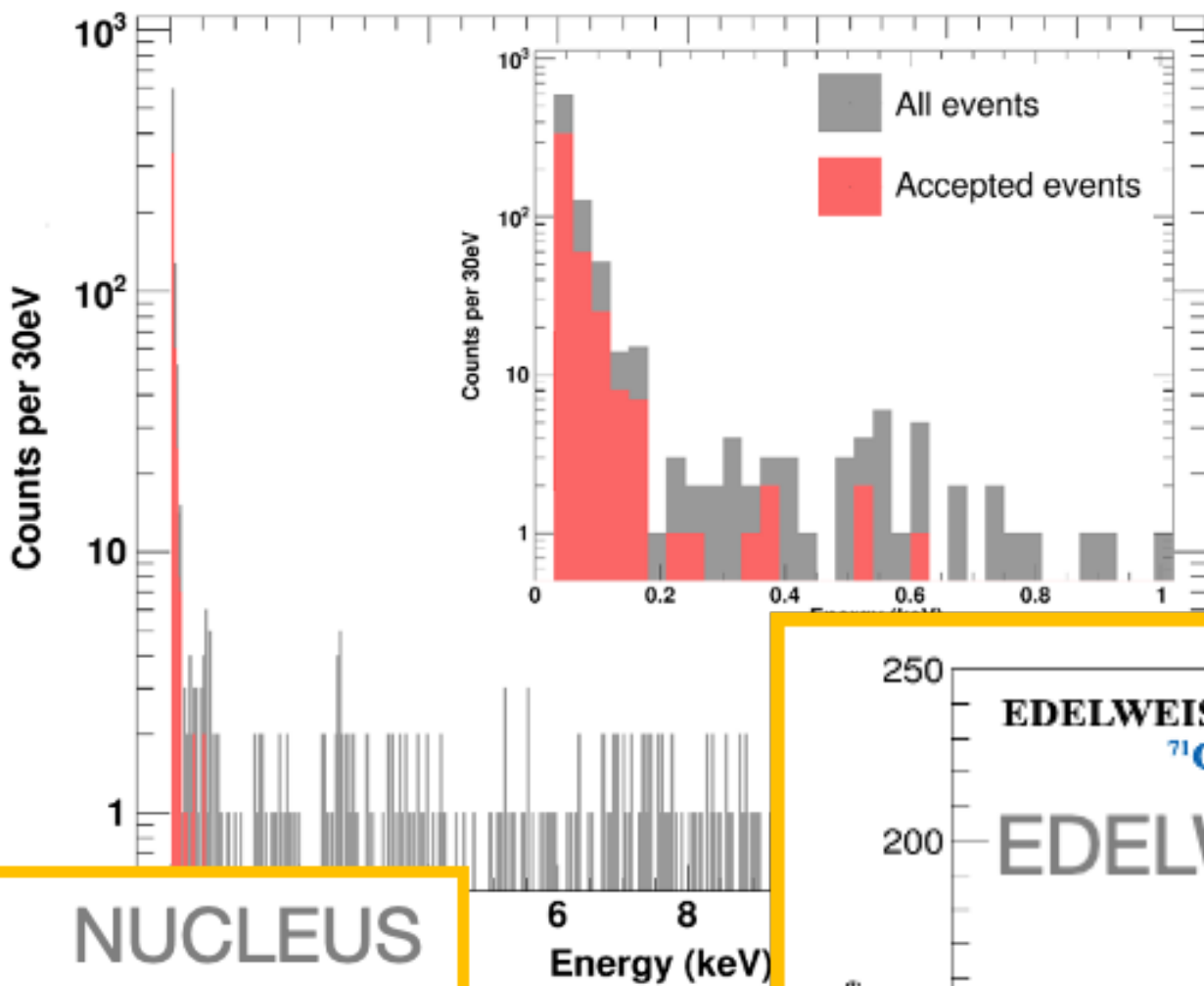


Phys. Rev. Lett. 127, 061801

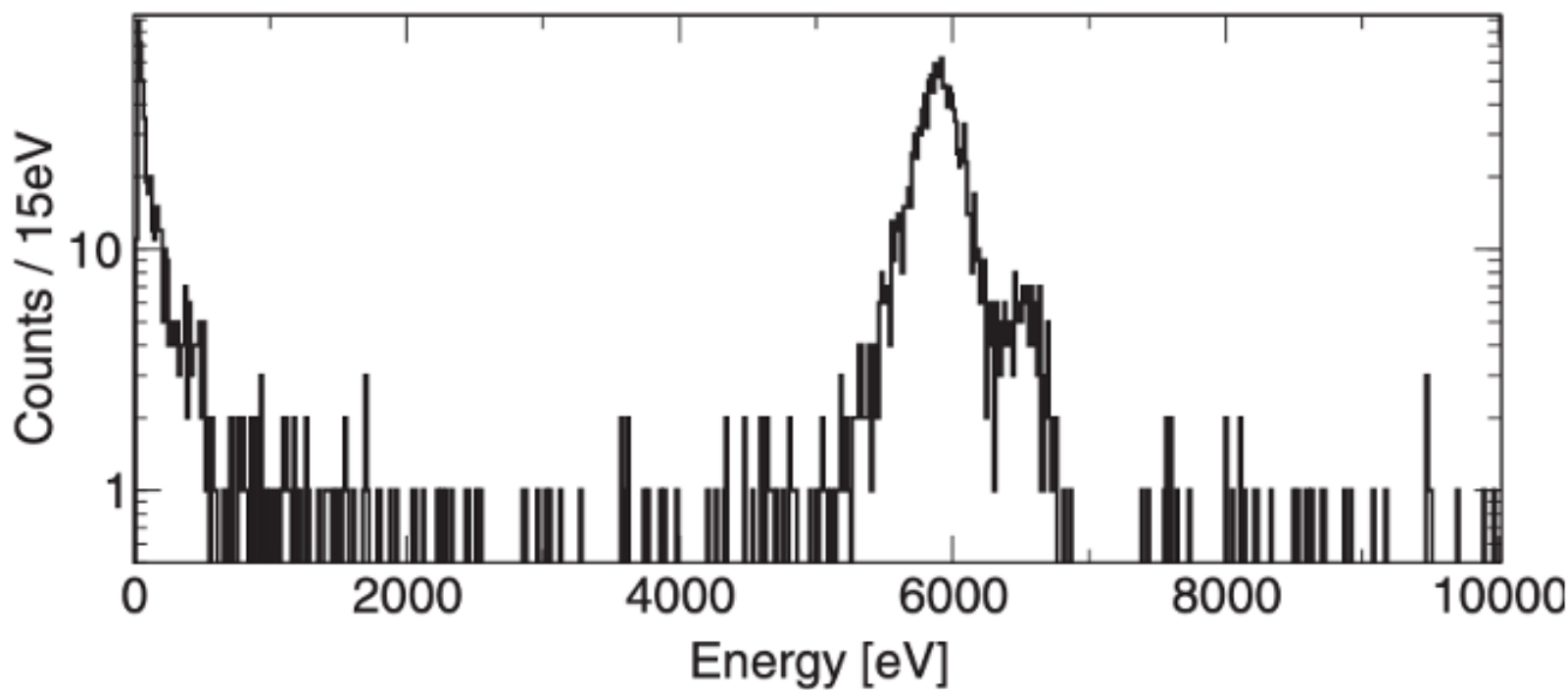
Phys. Rev. D 100, 102002

Below 200 eV, an **excess** of events above the flat back-

ground is visible. Due to decreasing background, the threshold for β/γ events (see triggers) are not far above the threshold of the trigger. Cosmic noise triggers for the detector module serve an **excess** detector module. This **excess** varies as a single common event from the

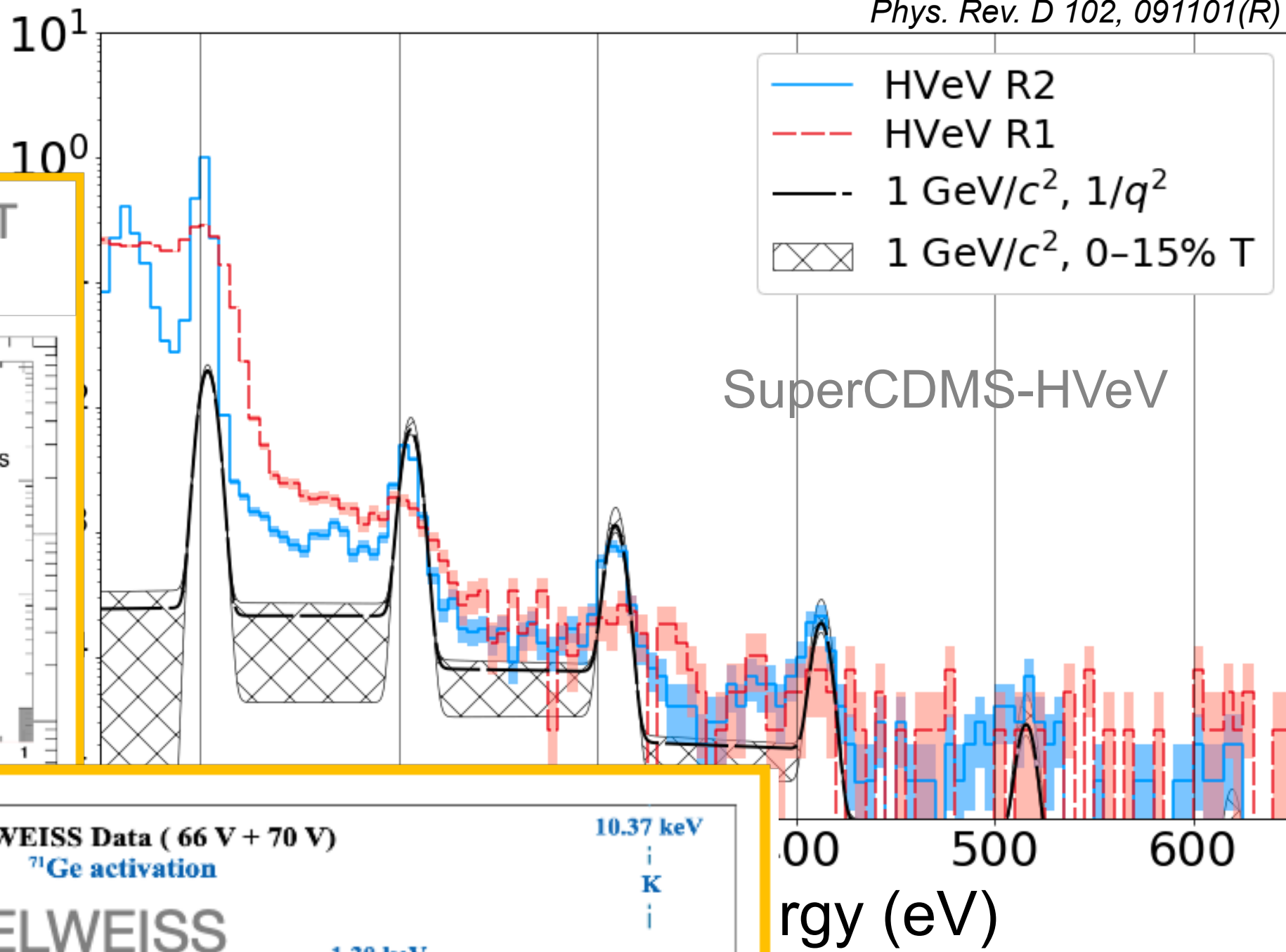


NUCLEUS



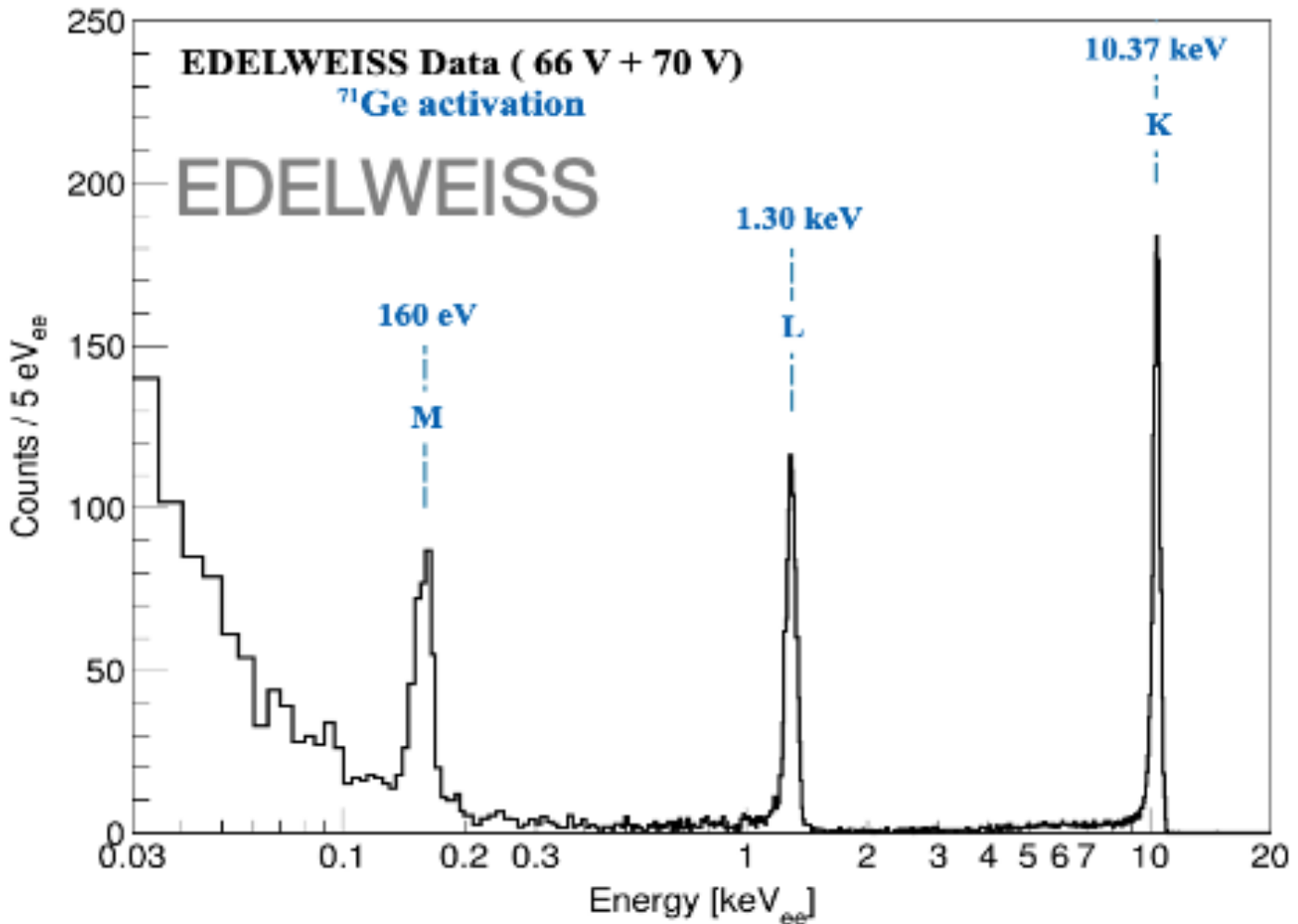
Phys. Rev. D 96, 022009

CRESST



Phys. Rev. D 102, 091101(R)

SuperCDMS-HVeV



Phys. Rev. Lett. 125, 141301

The EXCESS Workshop

JUN 17

15-17 June 2021

📍

Online

Participant List

139 participants

13 talks by 10 collaborations:

CONNIE
CRESST
DAMIC
EDELWEISS
MINER
NEWS-G
NUCLEUS
RICOCHET
SENSEI
SuperCDMS

Chairs:



Alexander Fuss



Felix Wagner



Florian Reindl



Margarita Kaznacheeva

Advisory Board:

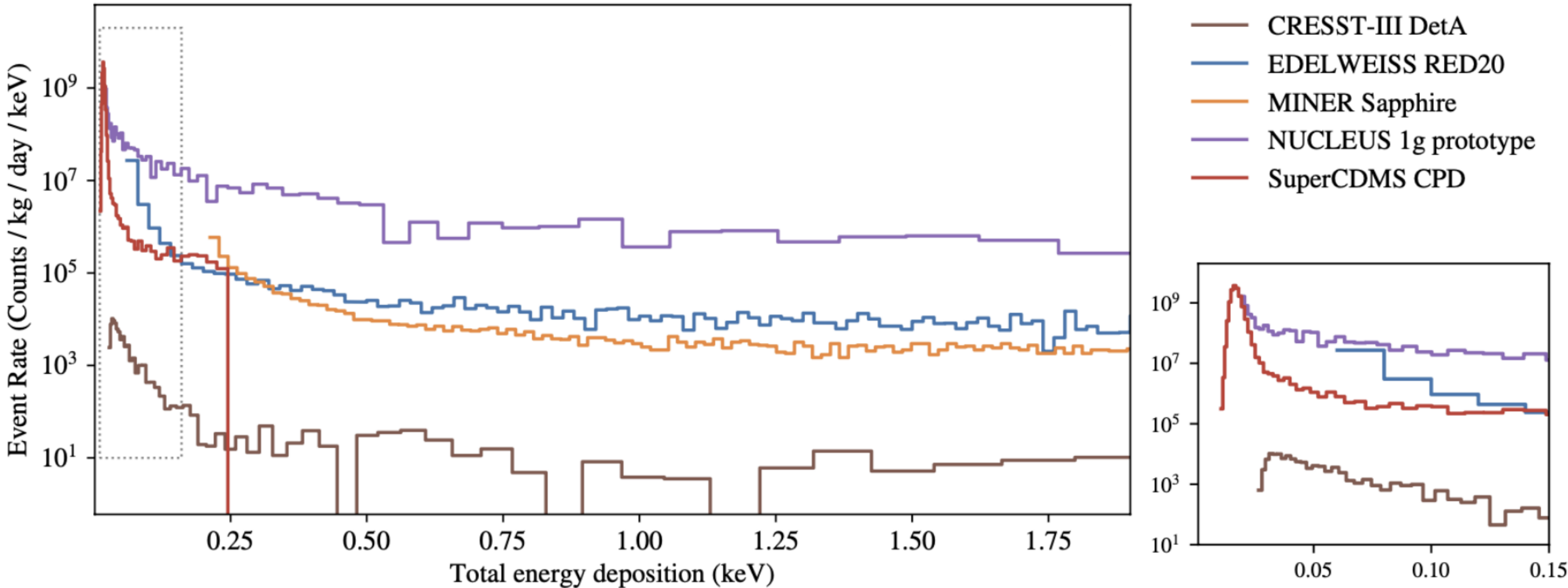
Belina von Krosigk
(SuperCDMS)
Dan Baxter (DAMIC)
Federica Petricca (CRESST)
Guillaume Giroux (NEWS-G)
Guillermo Fernandez Moroni
(CONNIE/Skipper-CCD)
Jules Gascon (EDELWEISS)
Julien Billard (RICOCHET)

Kostas Nikolopoulos (NEWS-G)
Marie-Cecile Piro (PhyStat DM)
Noah Kurinsky (SuperCDMS)
Raimund Strauss (NUCLEUS)
Rouven Essig (SENSEI)
Rupak Mahapatra (MINER)
Vasile Ghete (NUCLEUS)

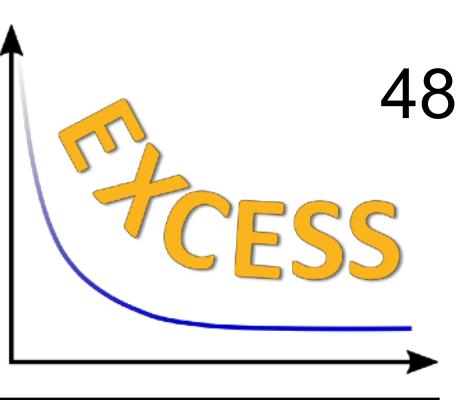
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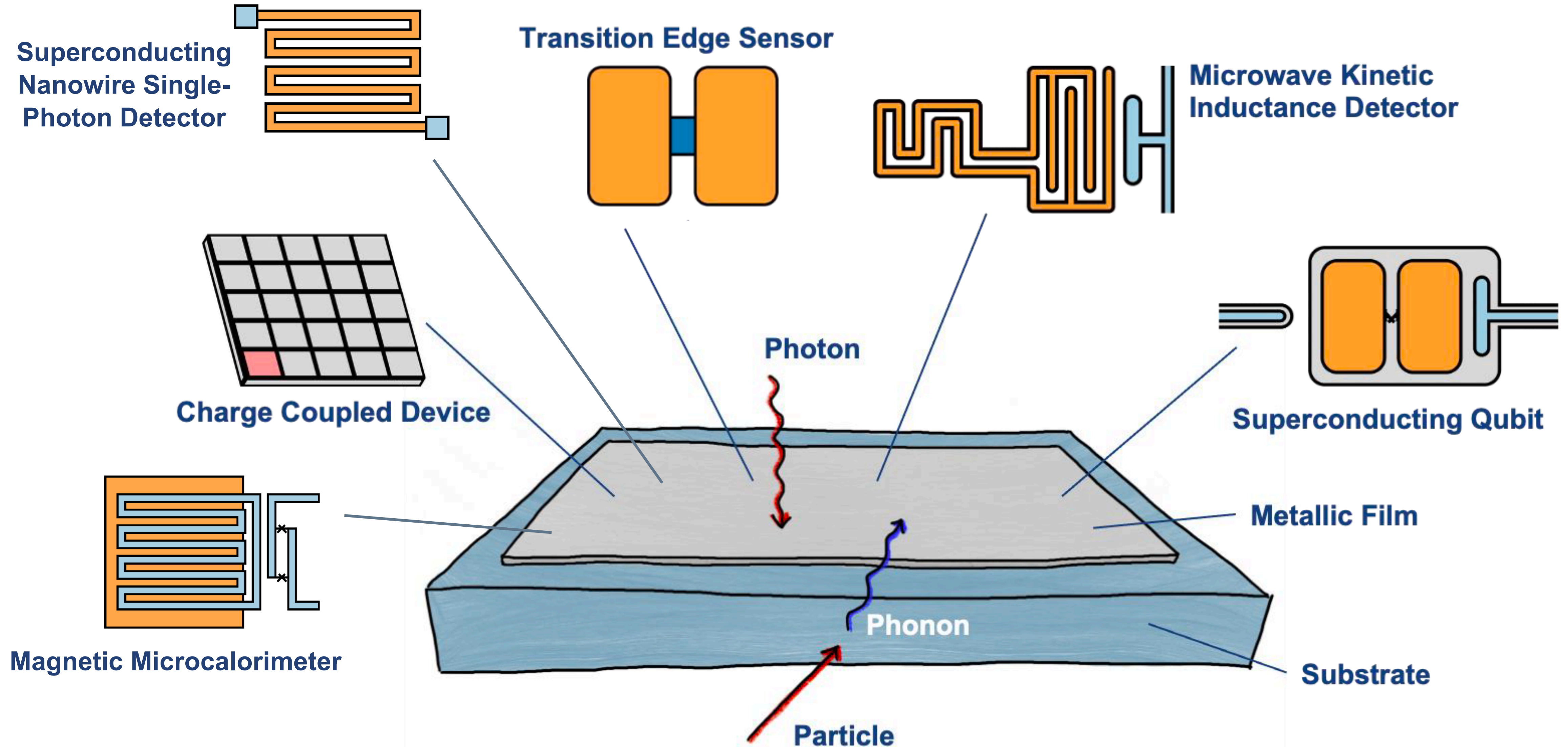
A. Fuss, M. Kaznacheeva, F. Reindl, F. Wagner, et al., SciPost Phys. Proc. 9, 001 (2022)

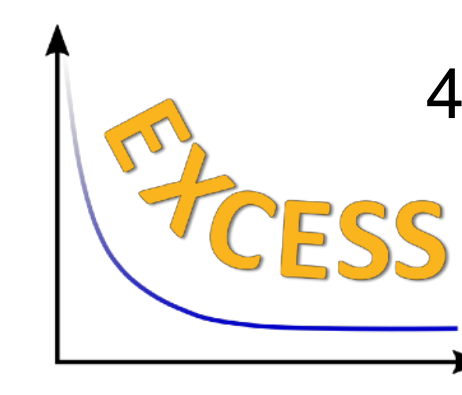


Data to reproduce energy spectra
measured by various experiments:
<https://github.com/fewagner/excess>



Low energy sensors and quantum devices





The EXCESS Workshop

EXCESS 2021

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EXCESS@IDM 2026



Thanks again to our
local organizers!!

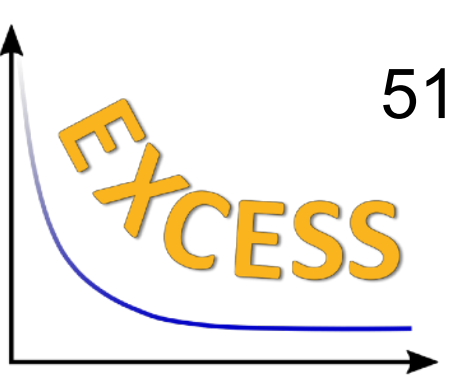


María Martínez Pérez



Iván Coarasa

<https://indico.cern.ch/event/1644935>

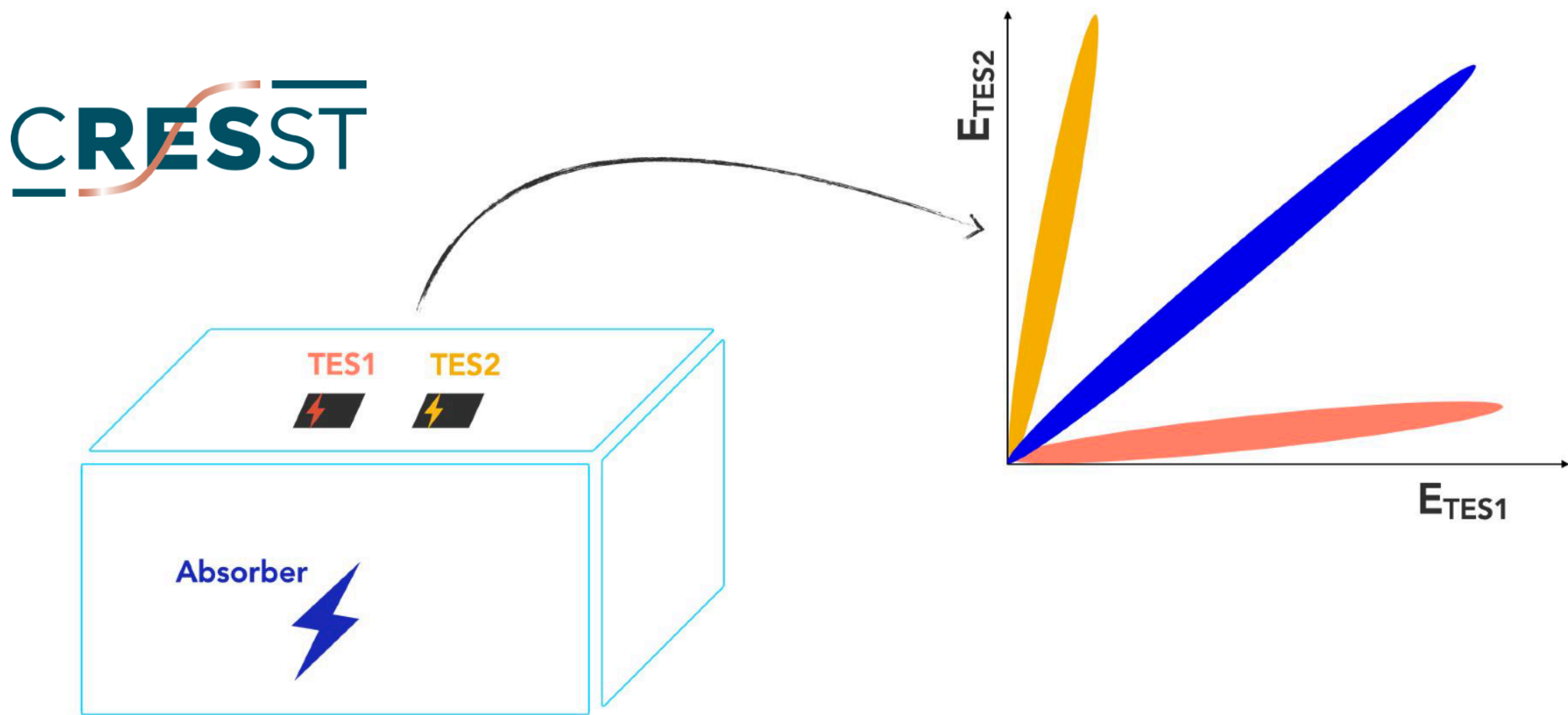
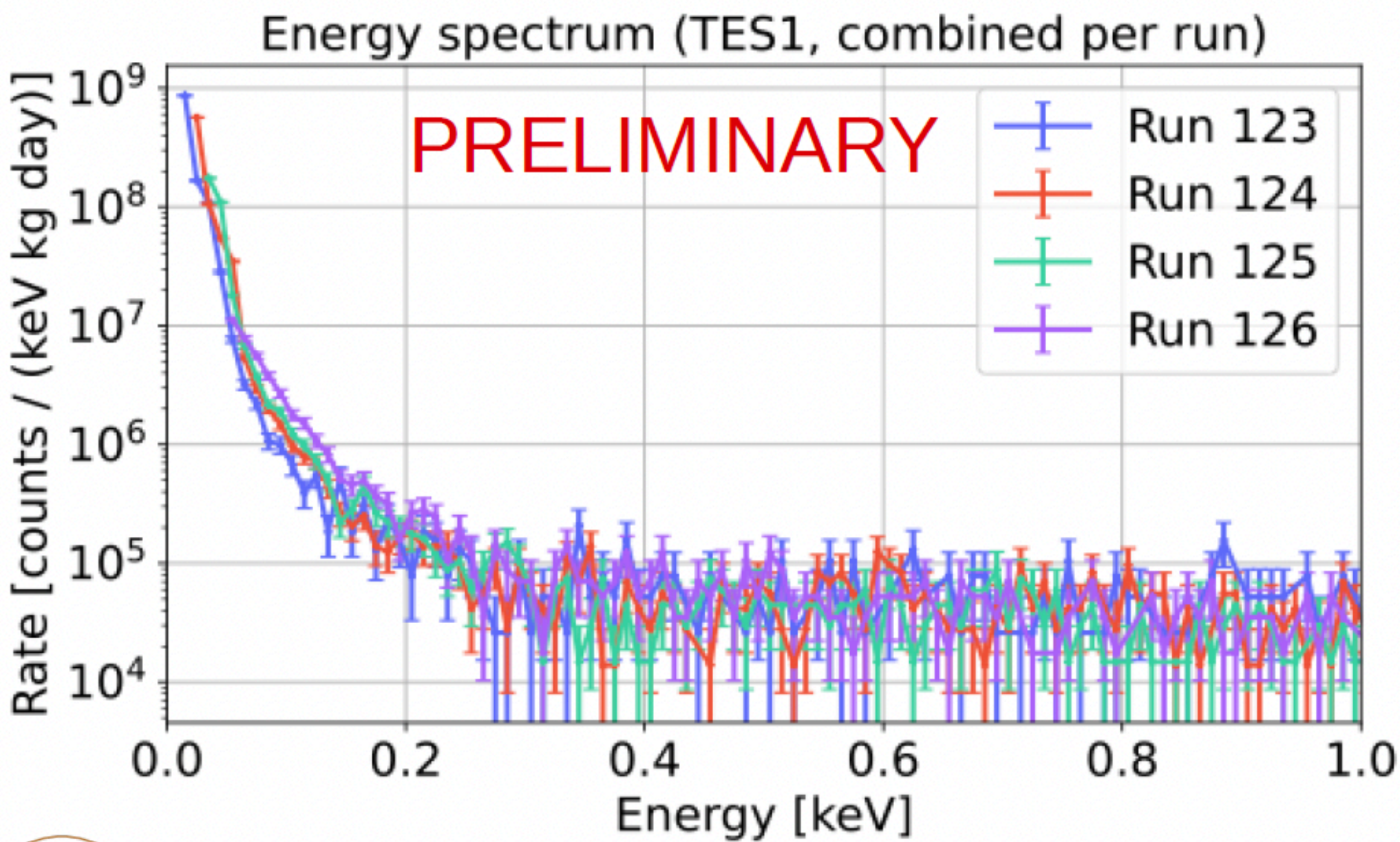
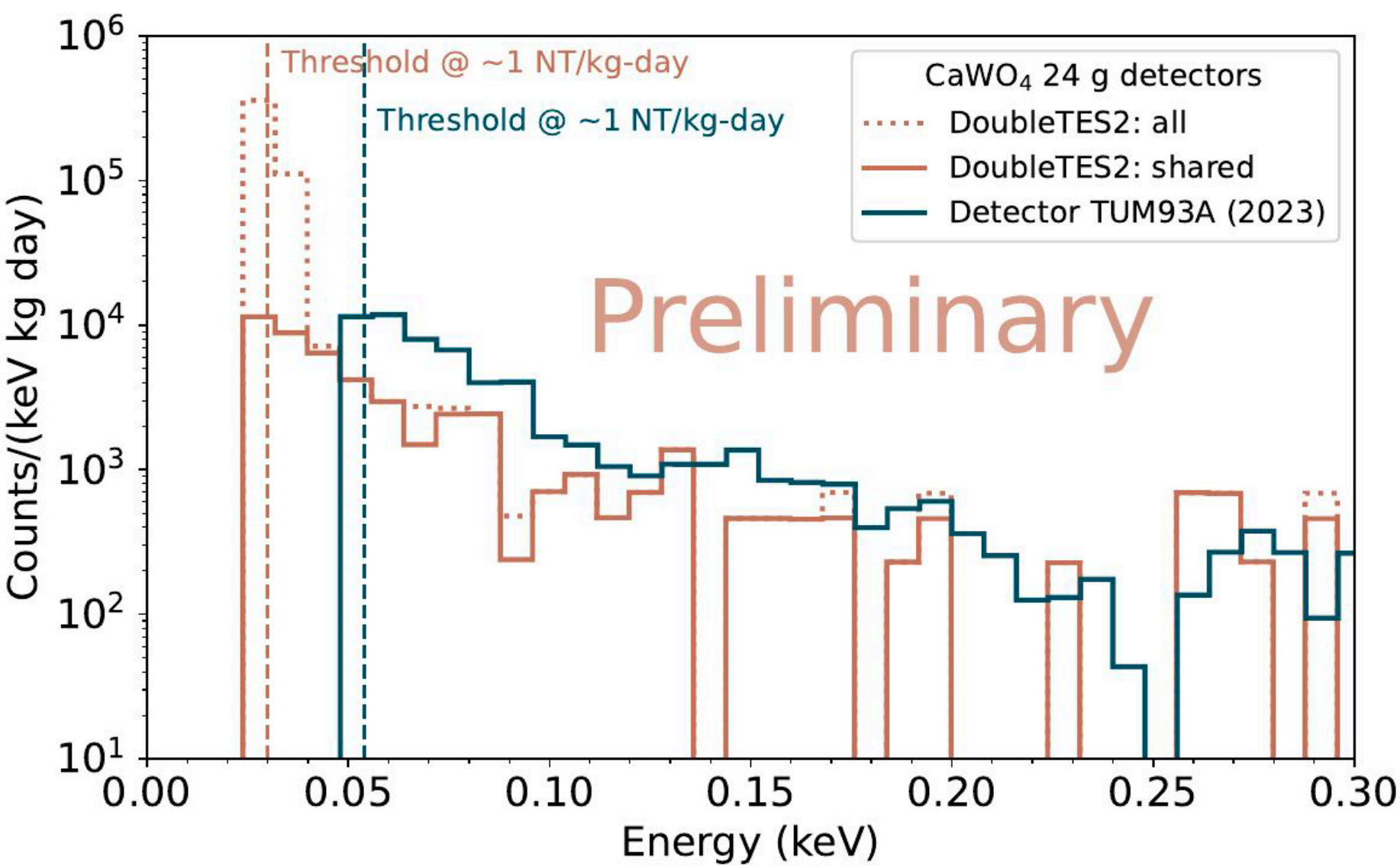


EXCESS@IDM 2026



CRESST
RICOCHET
NUCLEUS
SuperCDMS
TESSERACT
BULLKID
DiCarlo Lab
DMQIS Lab
TREX-DM
DarkQuantum
NEWS-G
CRAB
Nordlund Lab
QUALIPHIDE

EXCESS@IDM 2026: cryogenic crystal detectors



Runs	Slow Temperature Range	Slowed Range Duration
123	Standard Cooldown	Total: 2.5 days
124	150 K - 10 K	~19 days (20x Run 123)
125	10 K – 0.05 K	~5.5 days (10x Run 123)
126	300 K – 200 K	~3 days (3x Run 123)

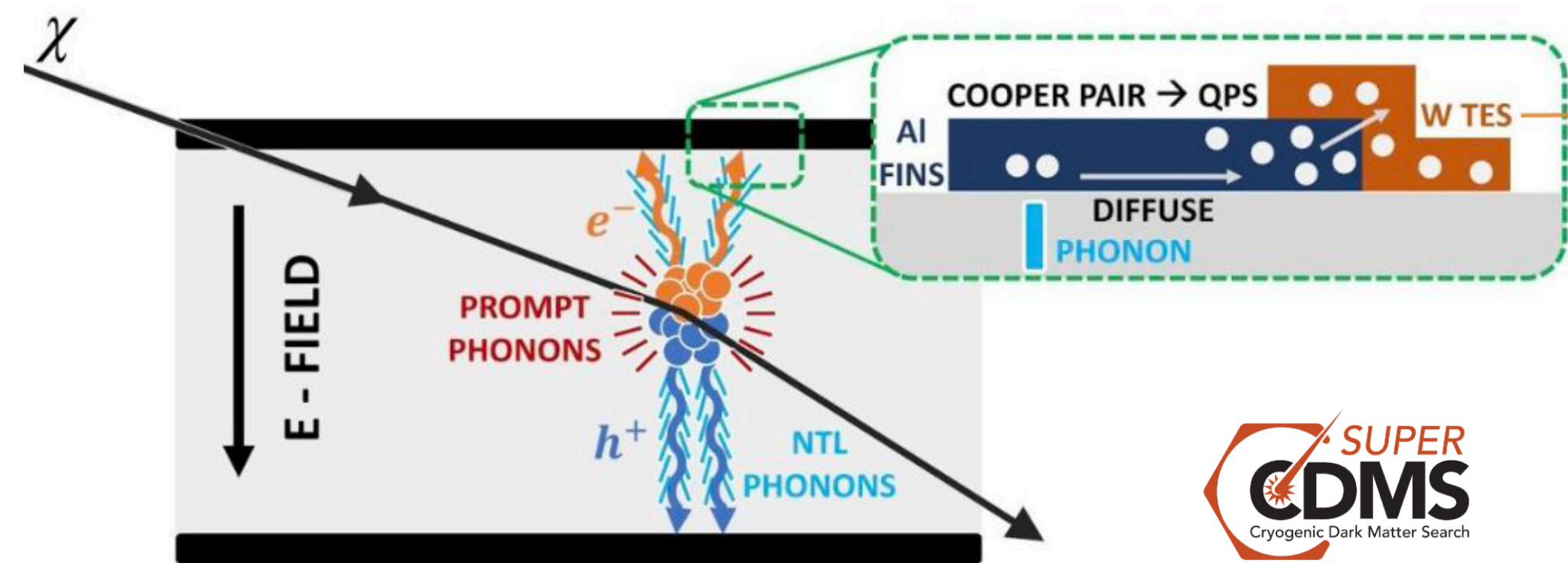
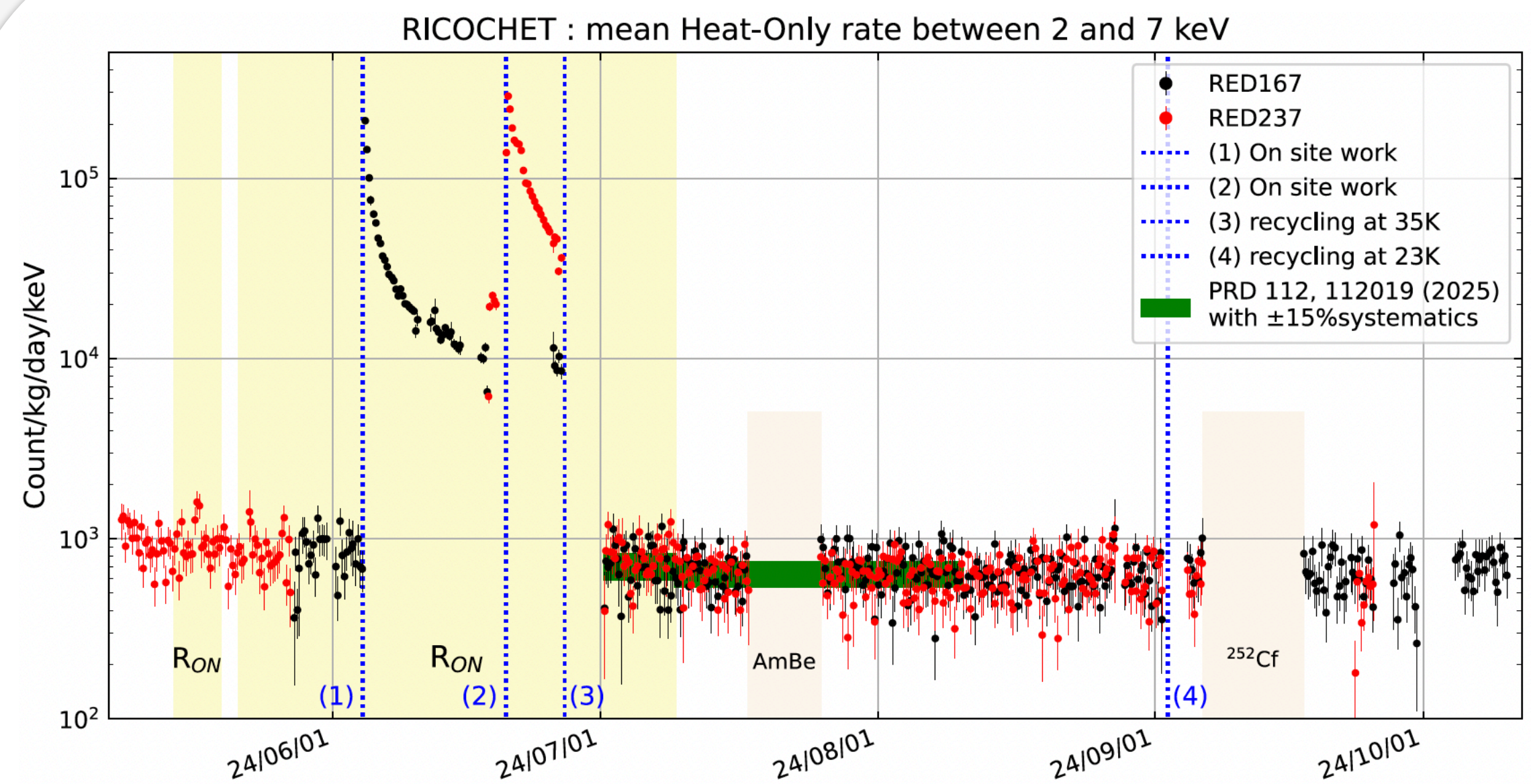
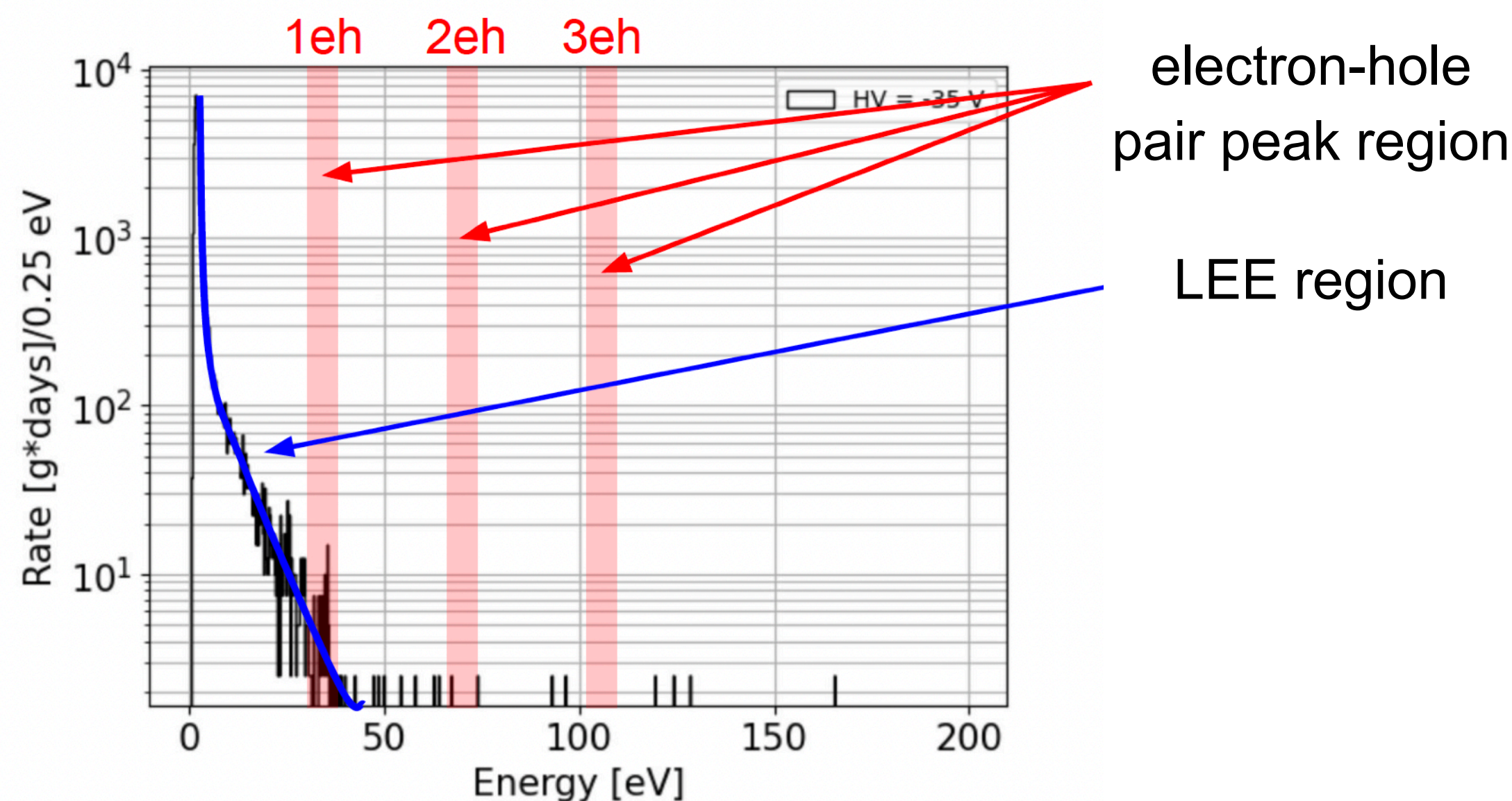
F. Pucci, et al., Eur.Phys.J.C 84 (2024) 10

Credit: Anna Bertolini

M. Kaznacheeva, et al, arXiv 2603.07687 (2026)

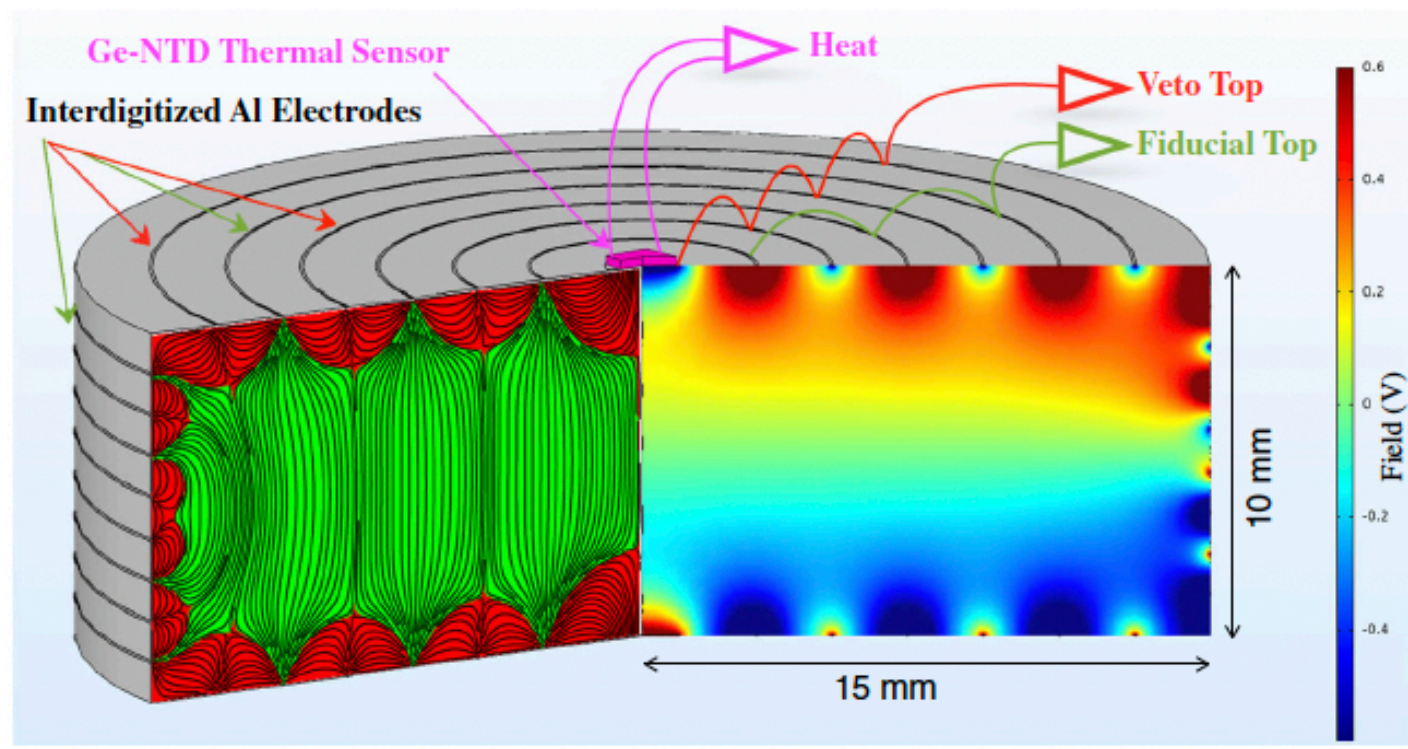
Credit: Giorgio Del Castello

EXCESS@IDM 2026: cryogenic crystal detectors



K. Kennard, A. Pradeep, et al., arXiv:2601.16307 (2026)

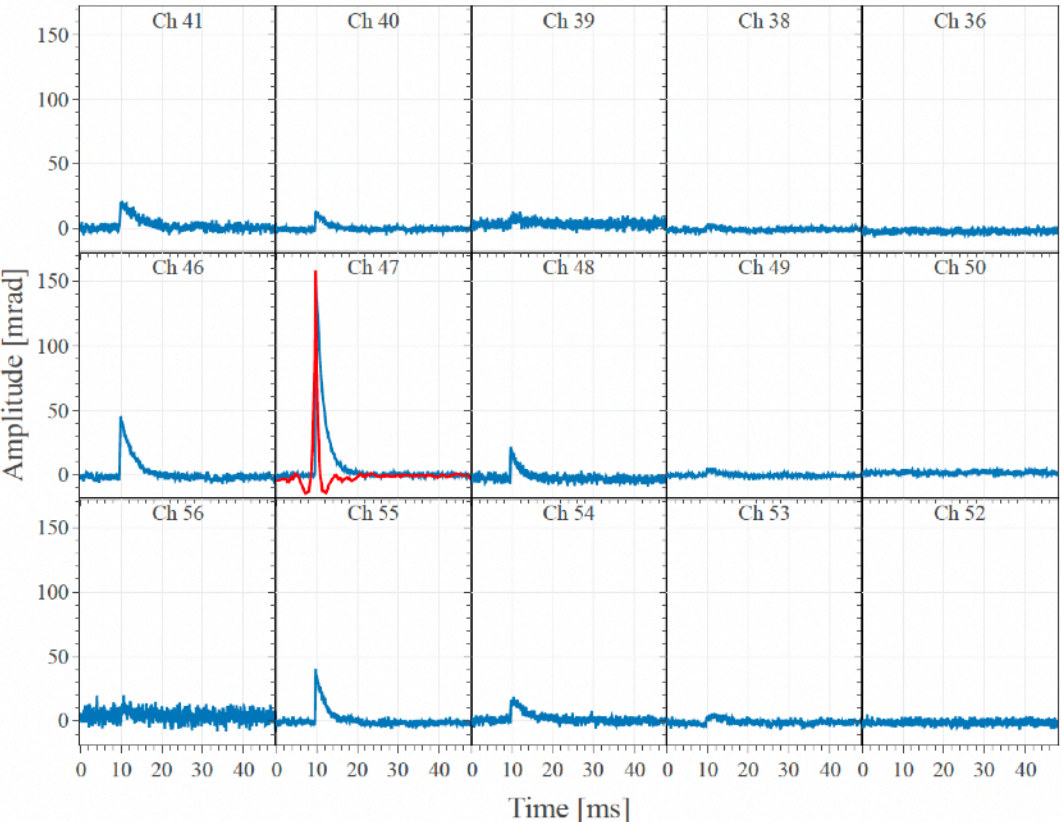
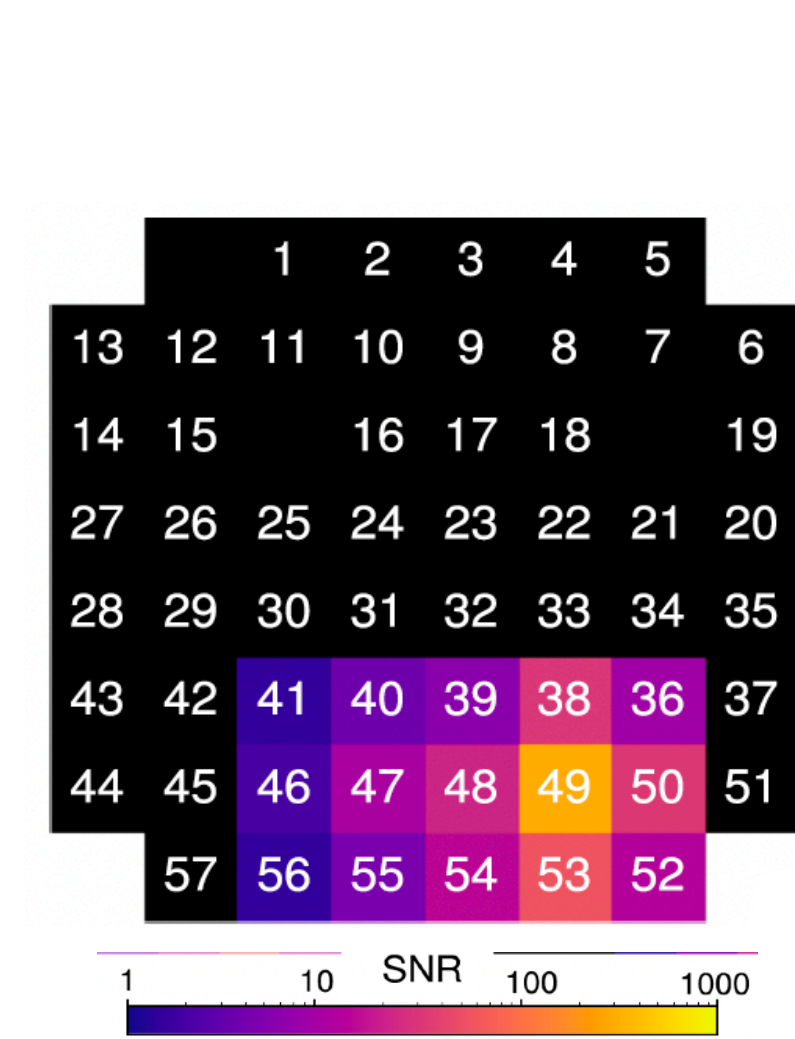
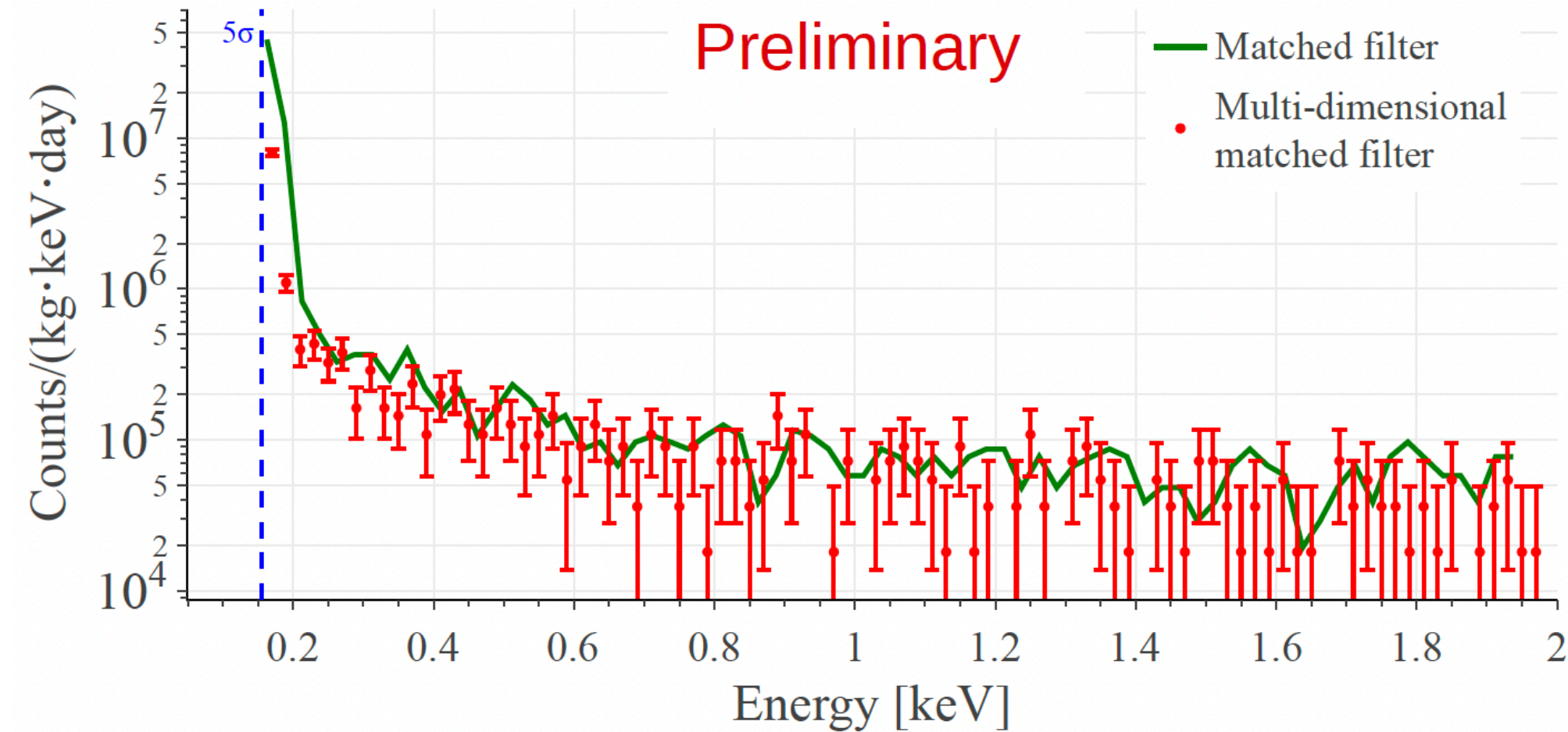
Credit: Kyle Kennard



E. Cudmore, et al, Phys. Rev. D 112, 112019 (2025)

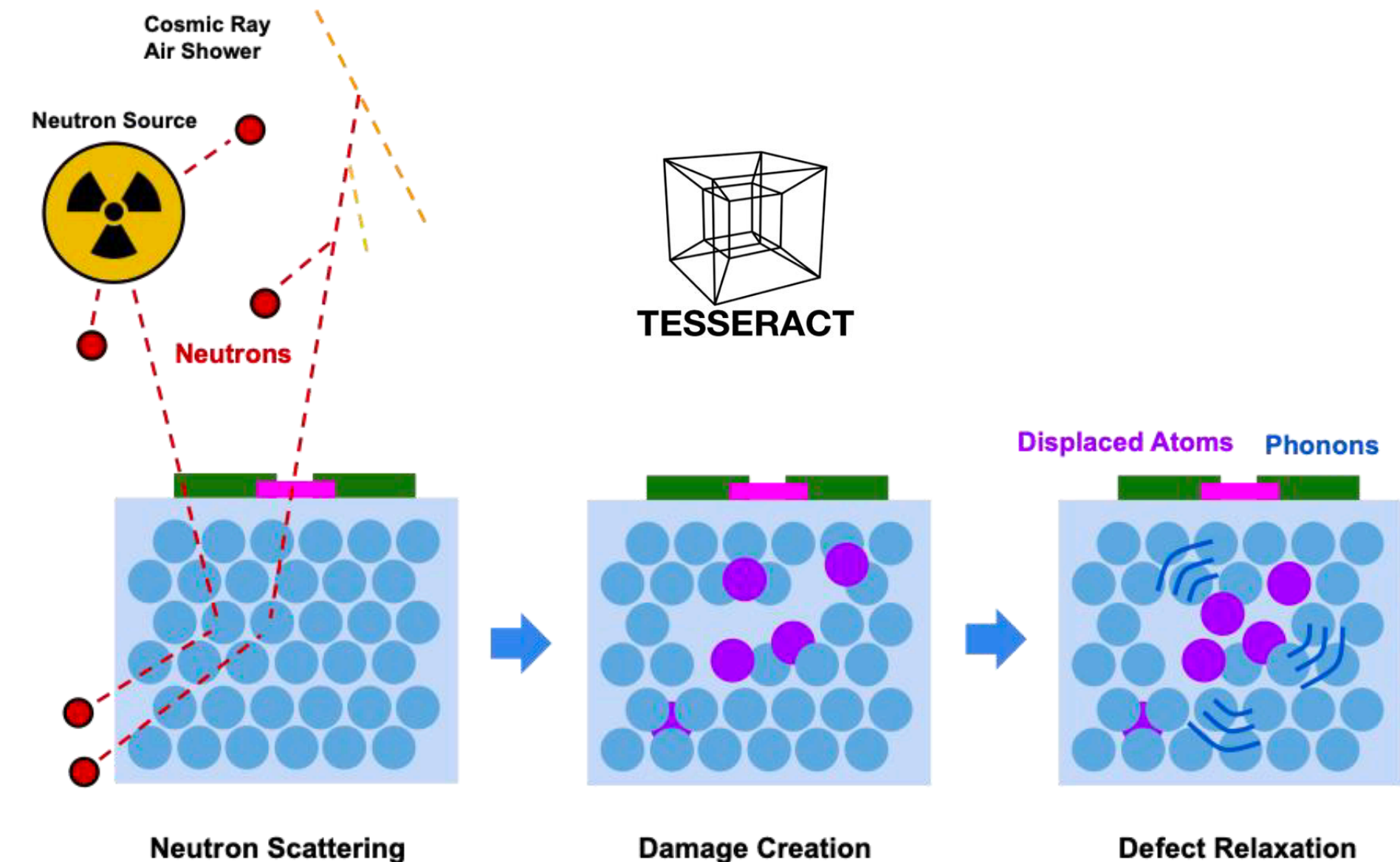
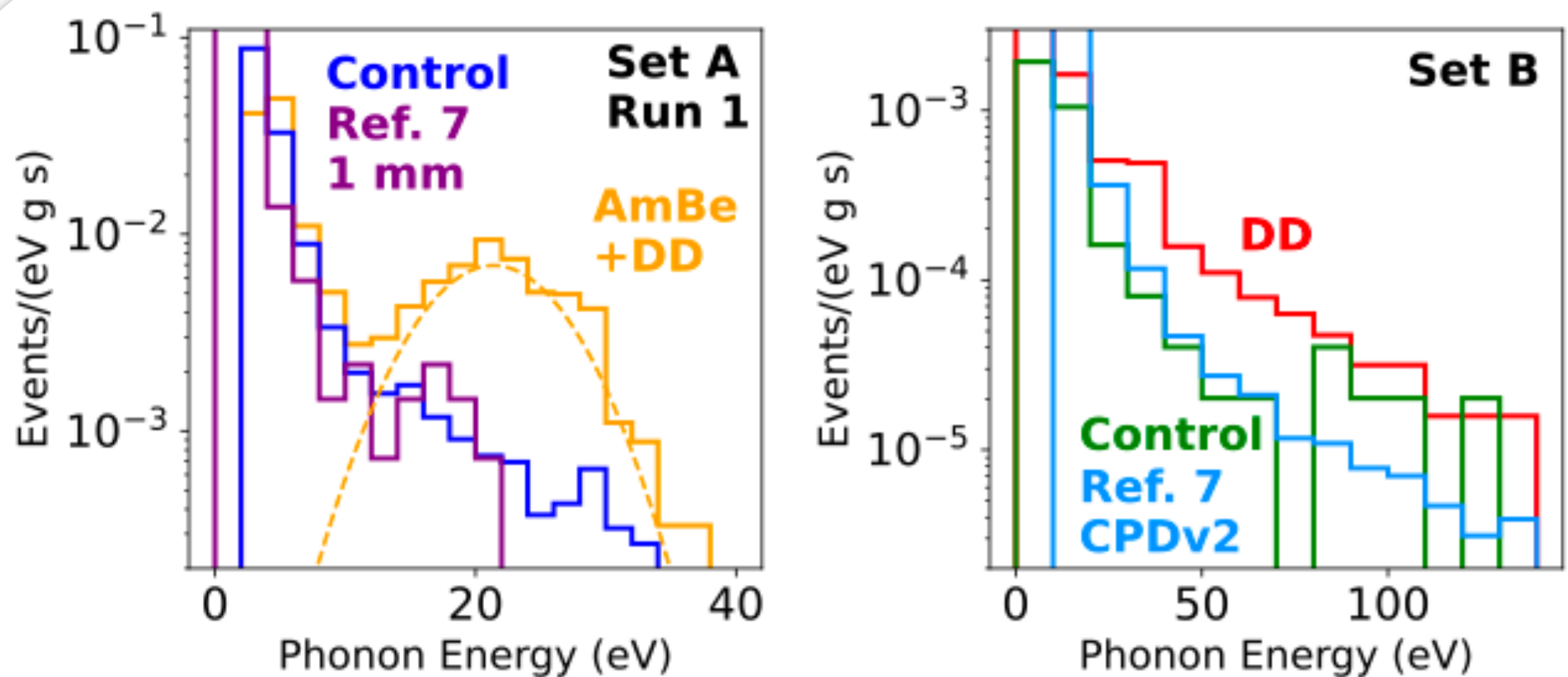
Credit: Alex Juillard

EXCESS@IDM 2026: cryogenic crystal detectors



D. Delicato, et al., arXiv:2605.02468 (2026)

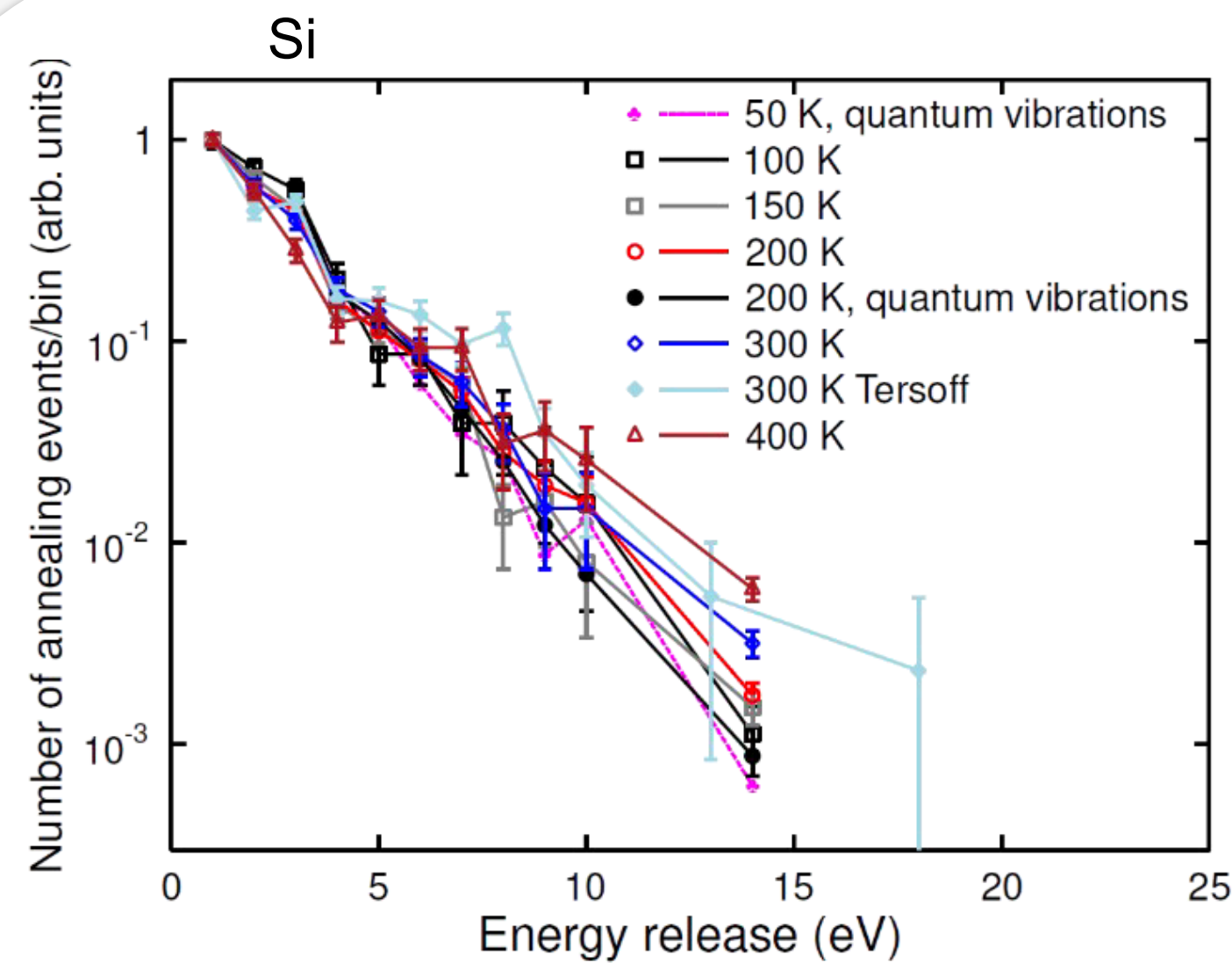
Credit: Matteo Folcarelli



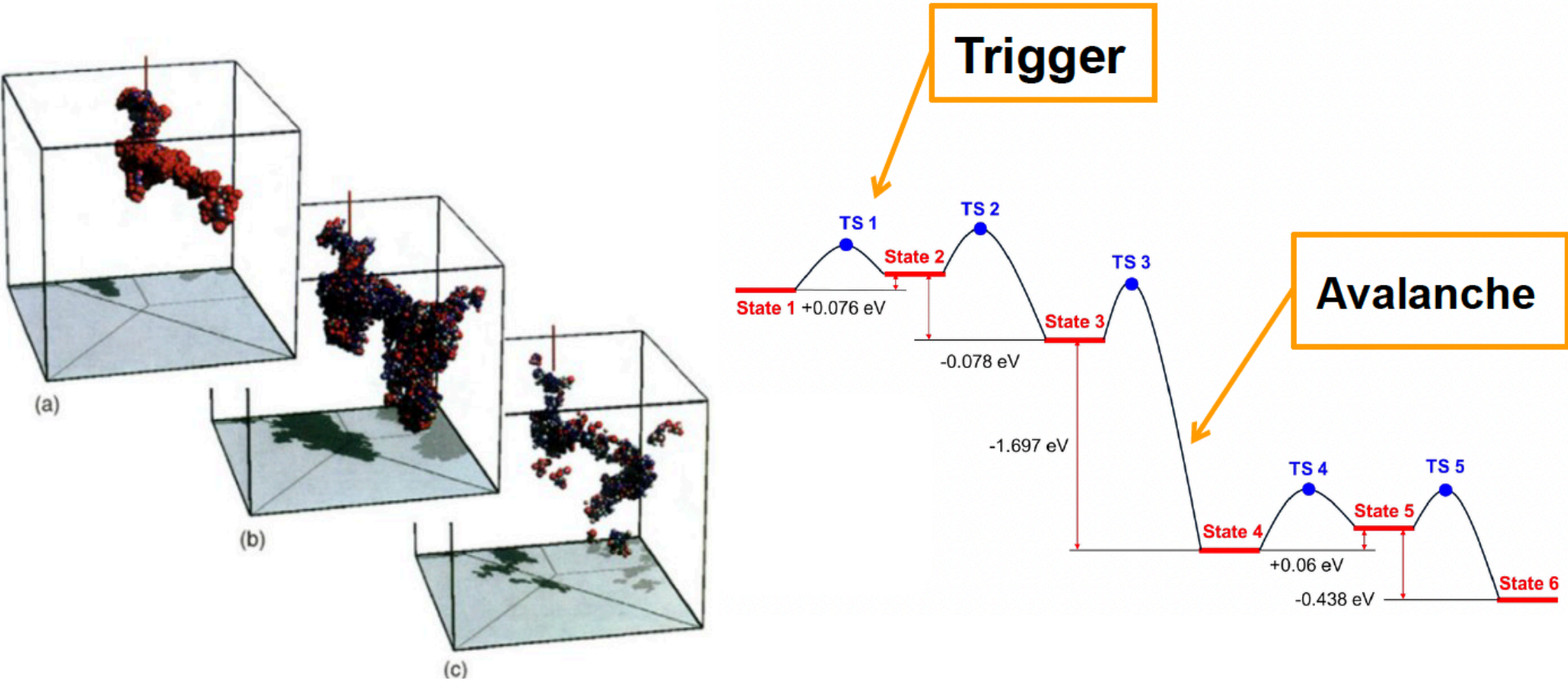
R. Romani, et al, Appl. Phys. Lett. 126, 102601 (2025)

Credit: Matt Pyle

EXCESS@IDM 2026: defects and calibration

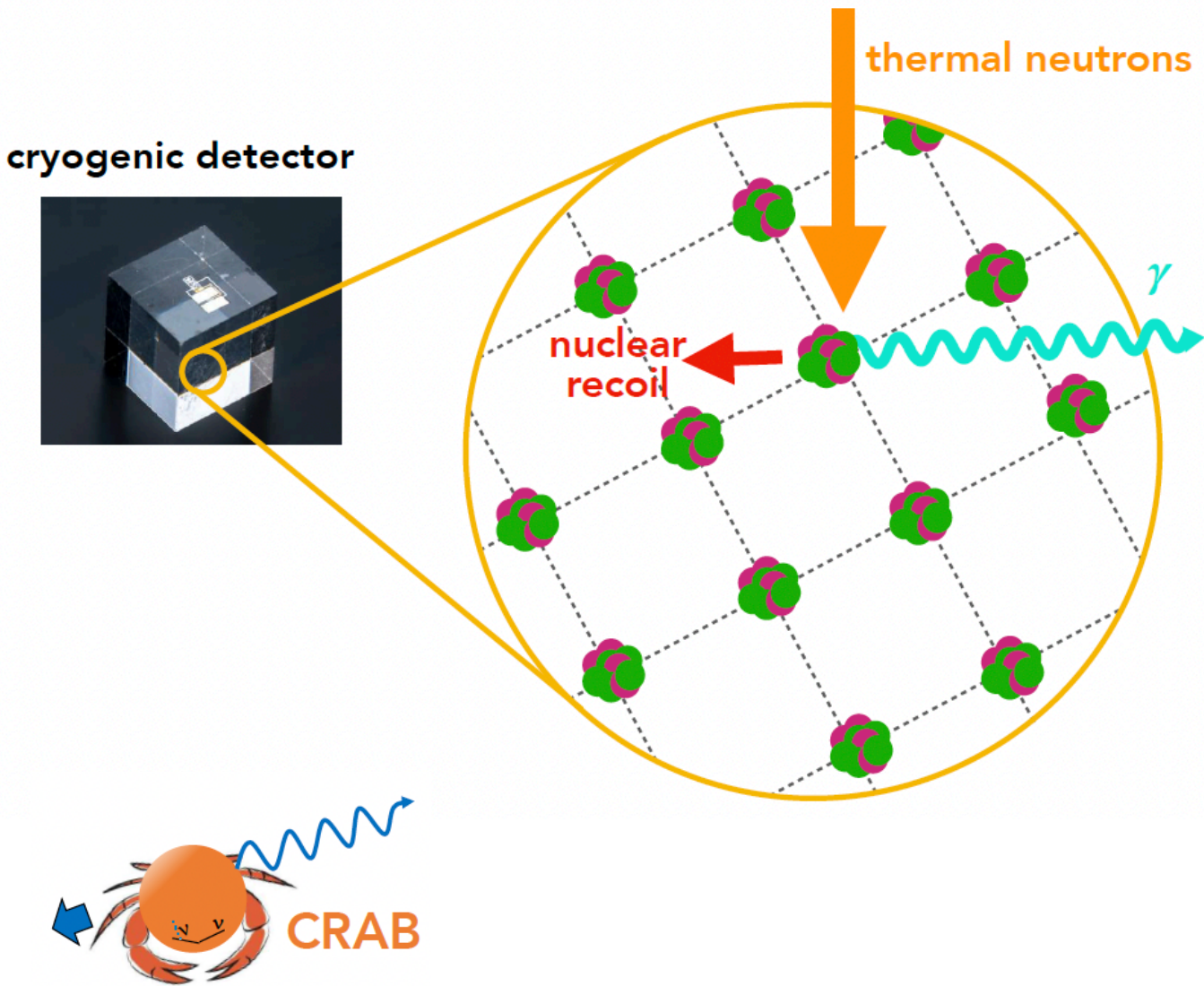
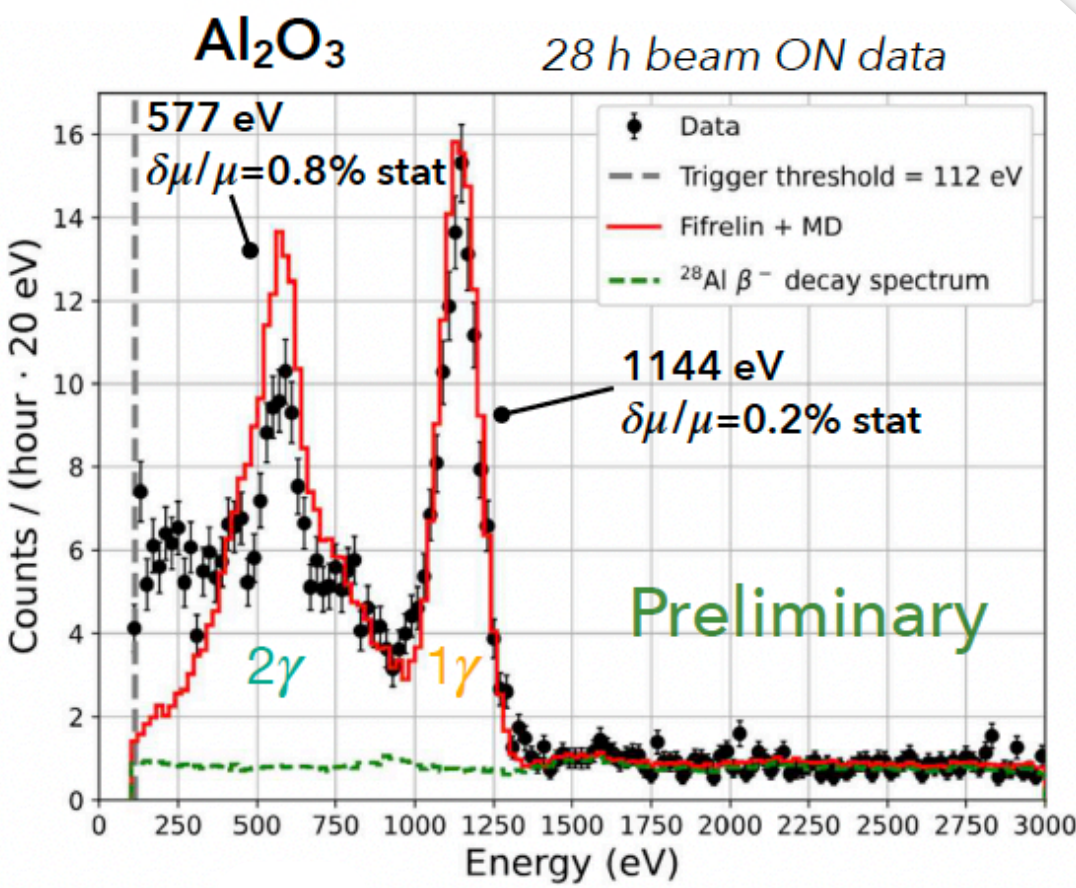
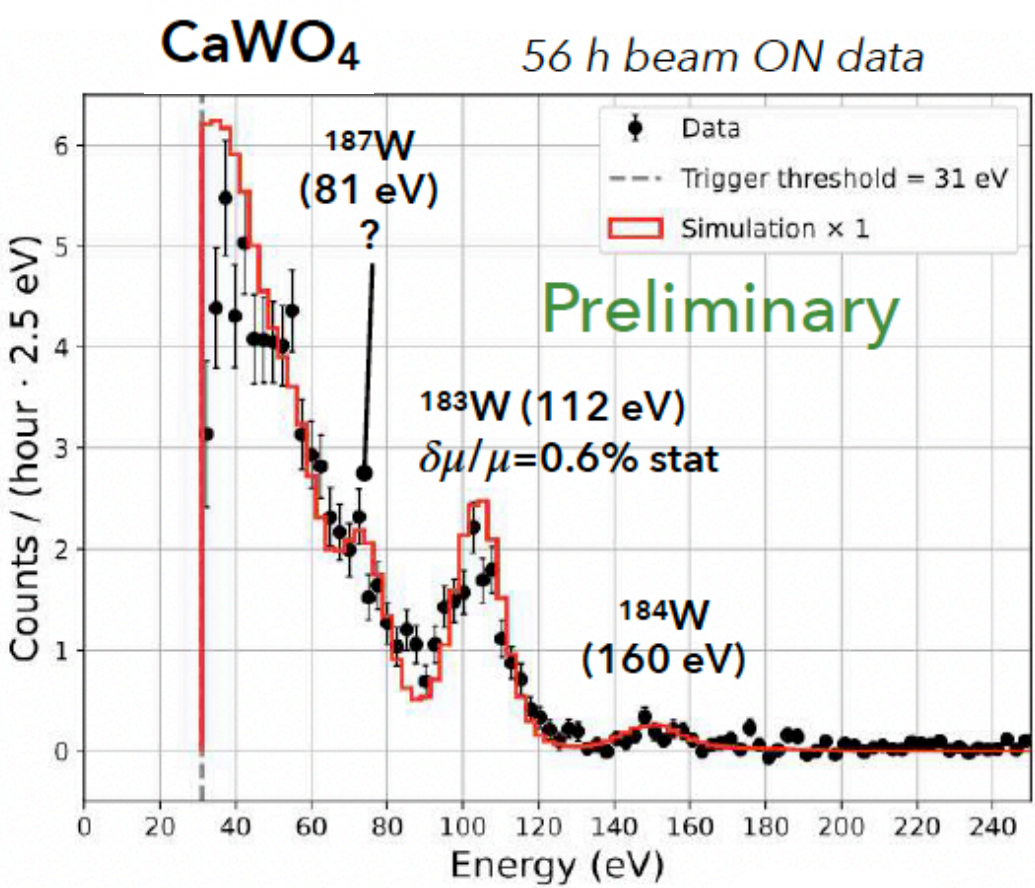


Recombination avalanche after formation of amorphous pockets in primary damage events



K. Nordlund et al, Phys. Rev. B 57, 7556 (1998); K. Nordlund et al, J. Nucl. Mater. 512, 450 (2018)

Credit: Federico Ledda

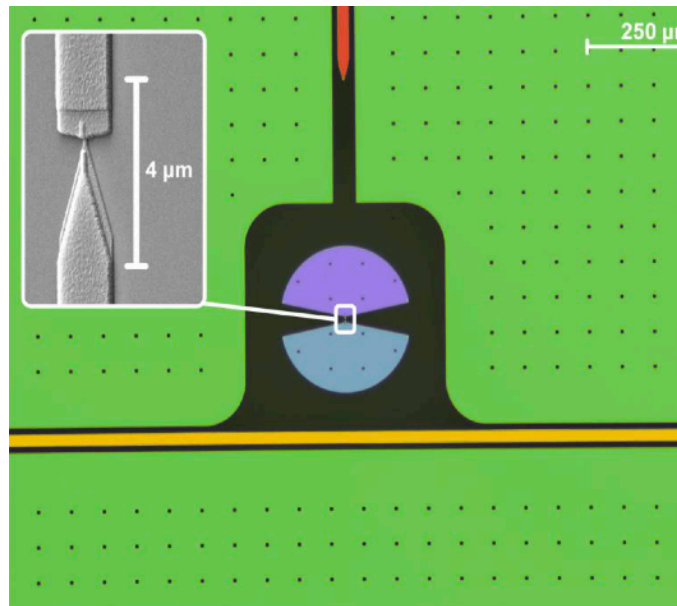
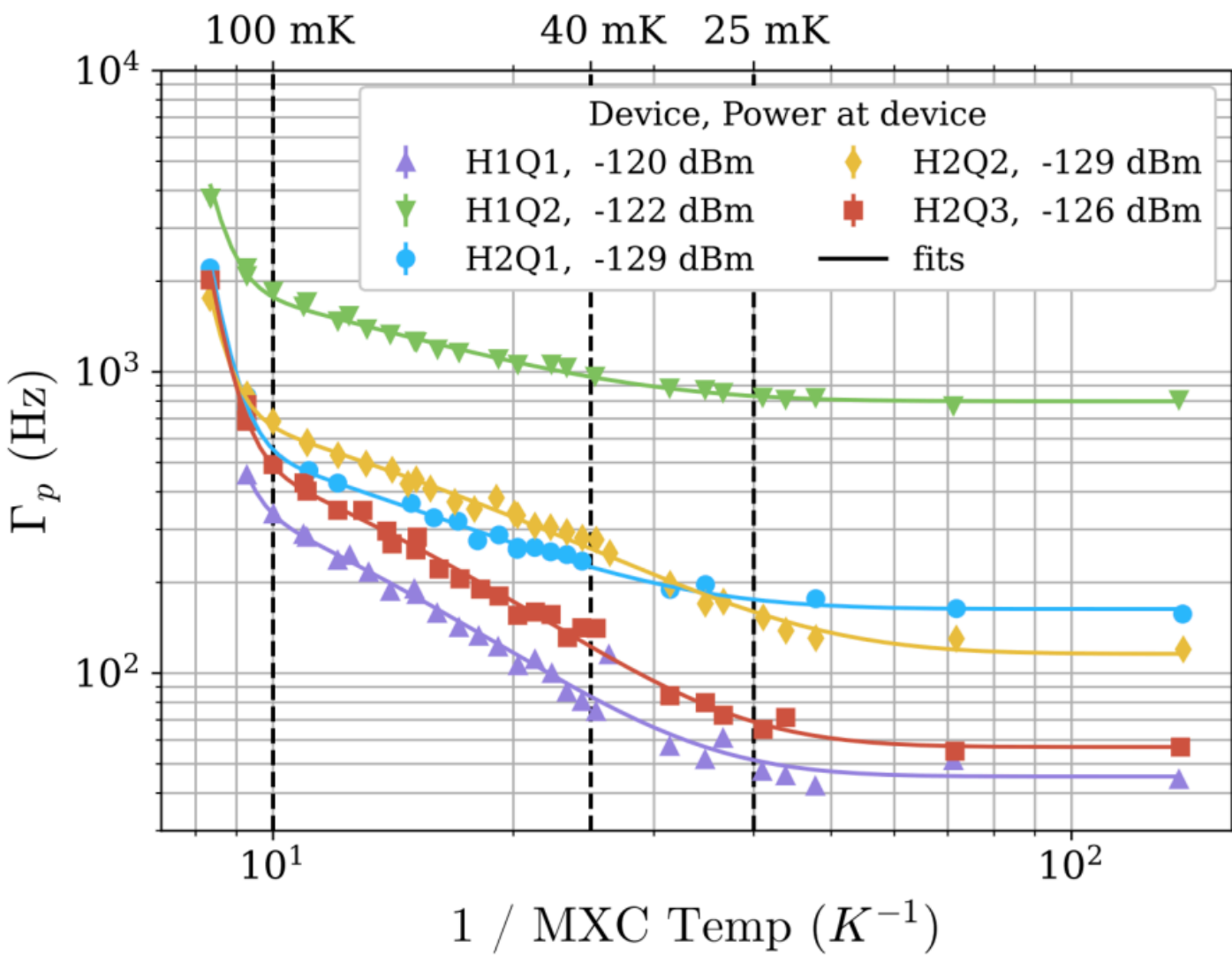


Sub-keV nuclear recoil calibration from thermal neutron capture

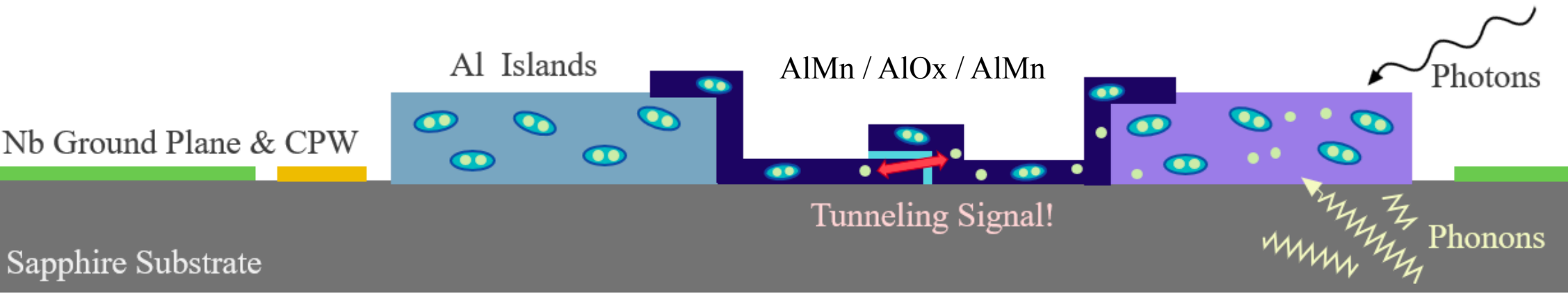
D. Lhuillier, et al, Eur. Phys. J. C 85 (2025) 10, 1188

Credit: Andreas Erhart

EXCESS@IDM 2026: qubit based sensors

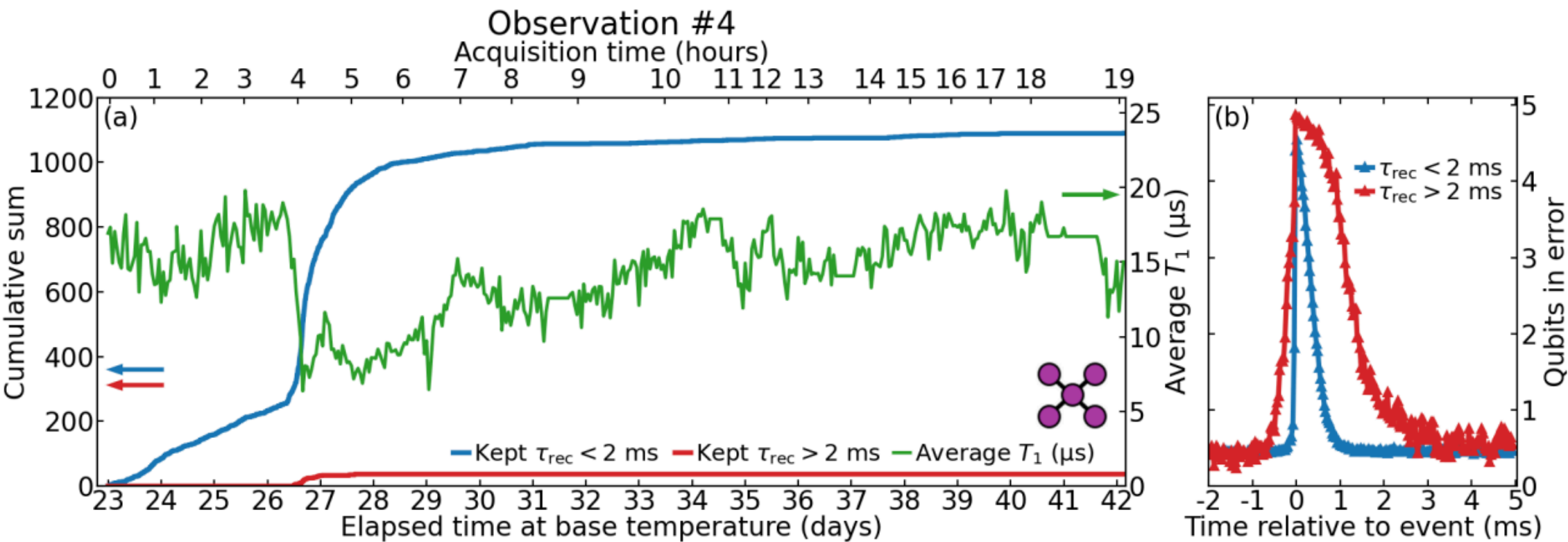


SQUAT: Superconducting Quasiparticle Amplifying Transmon

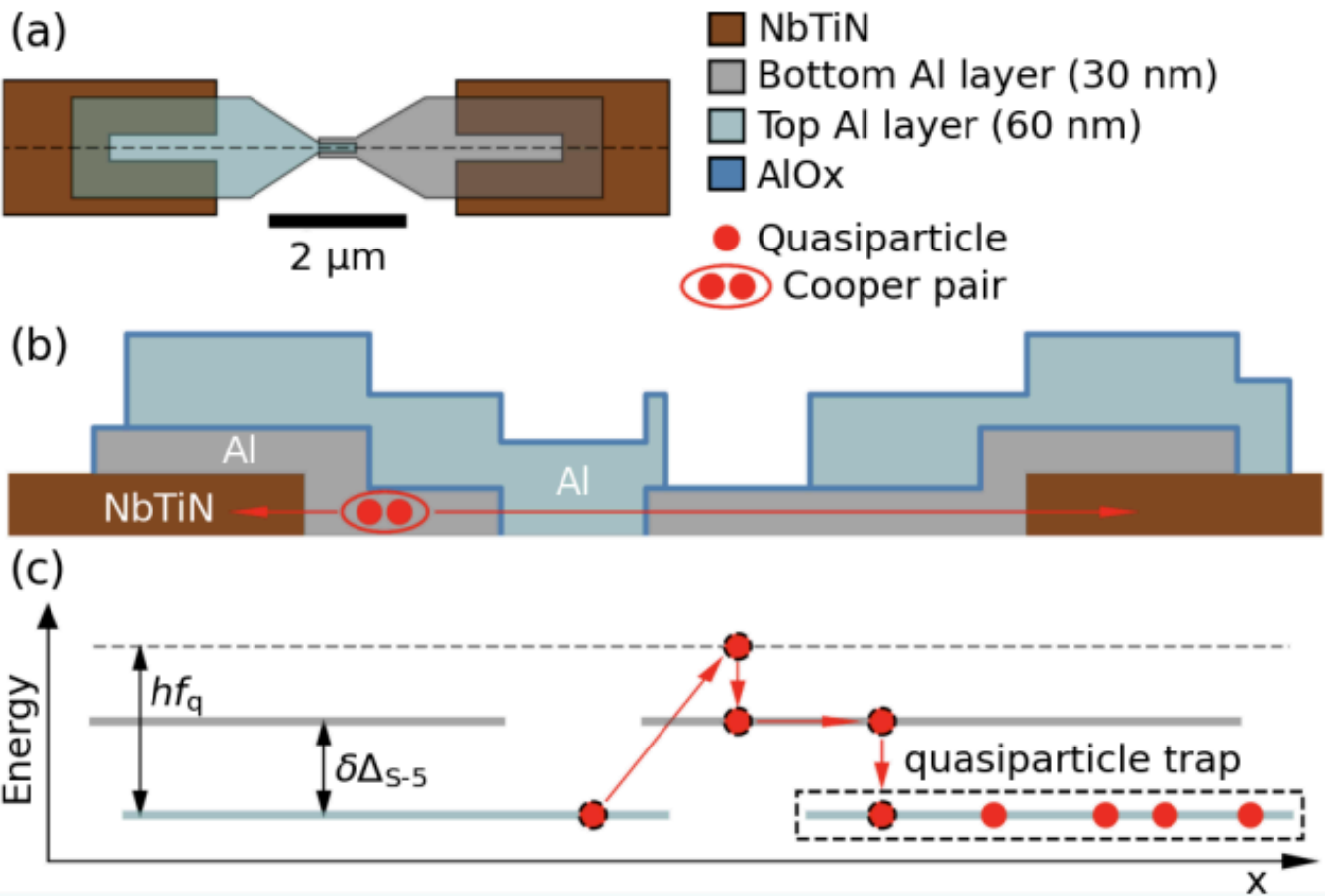


P. Kurilovich, et al, Phys. Rev. Lett. 132, 217001 (2024)

Credit: Aviv Simchony



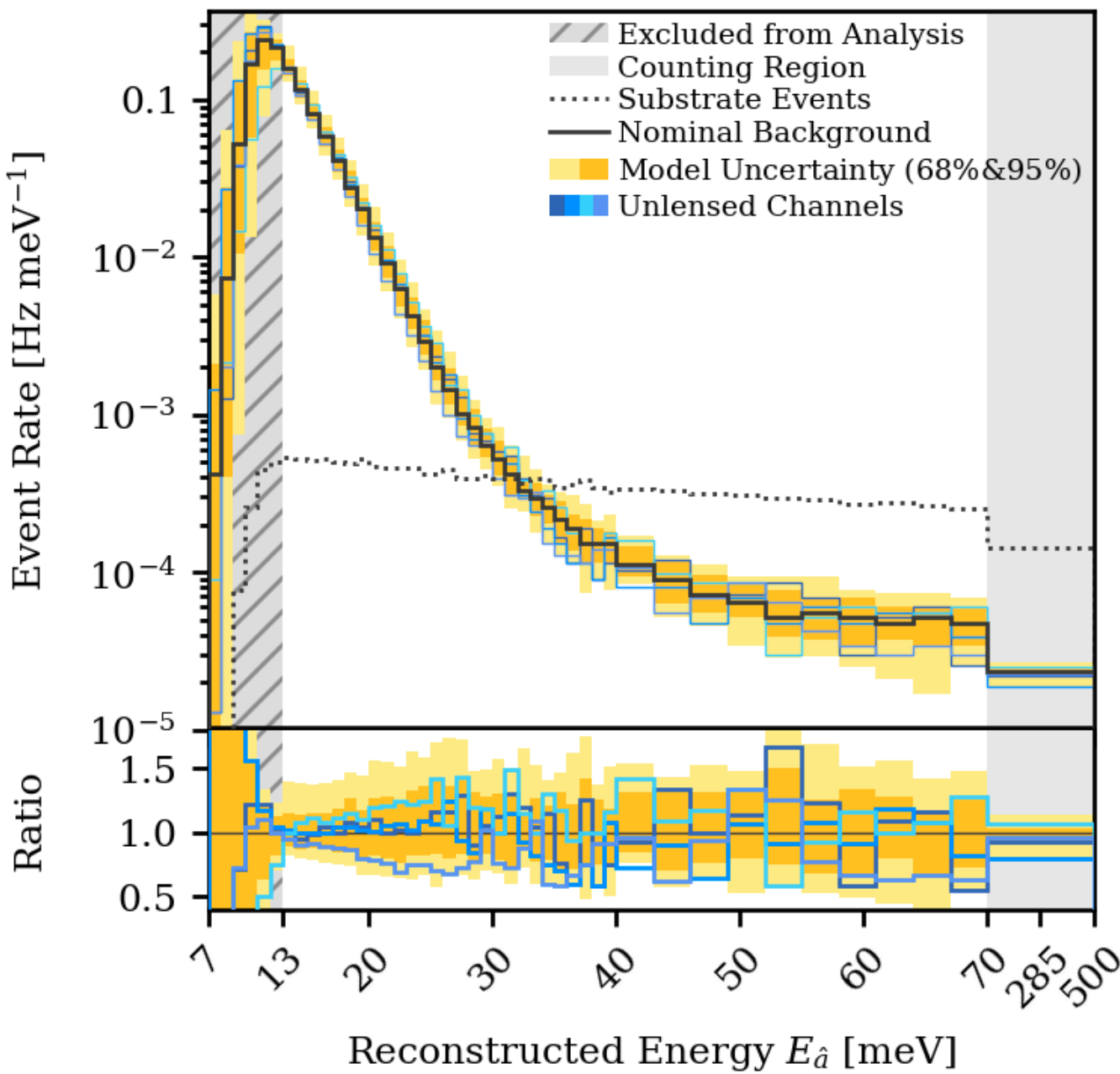
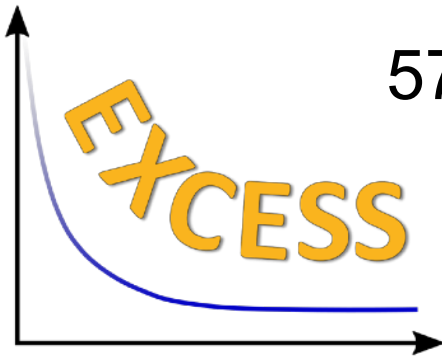
Qubit error bursts in transmon-based processors (Quantum Inspire)



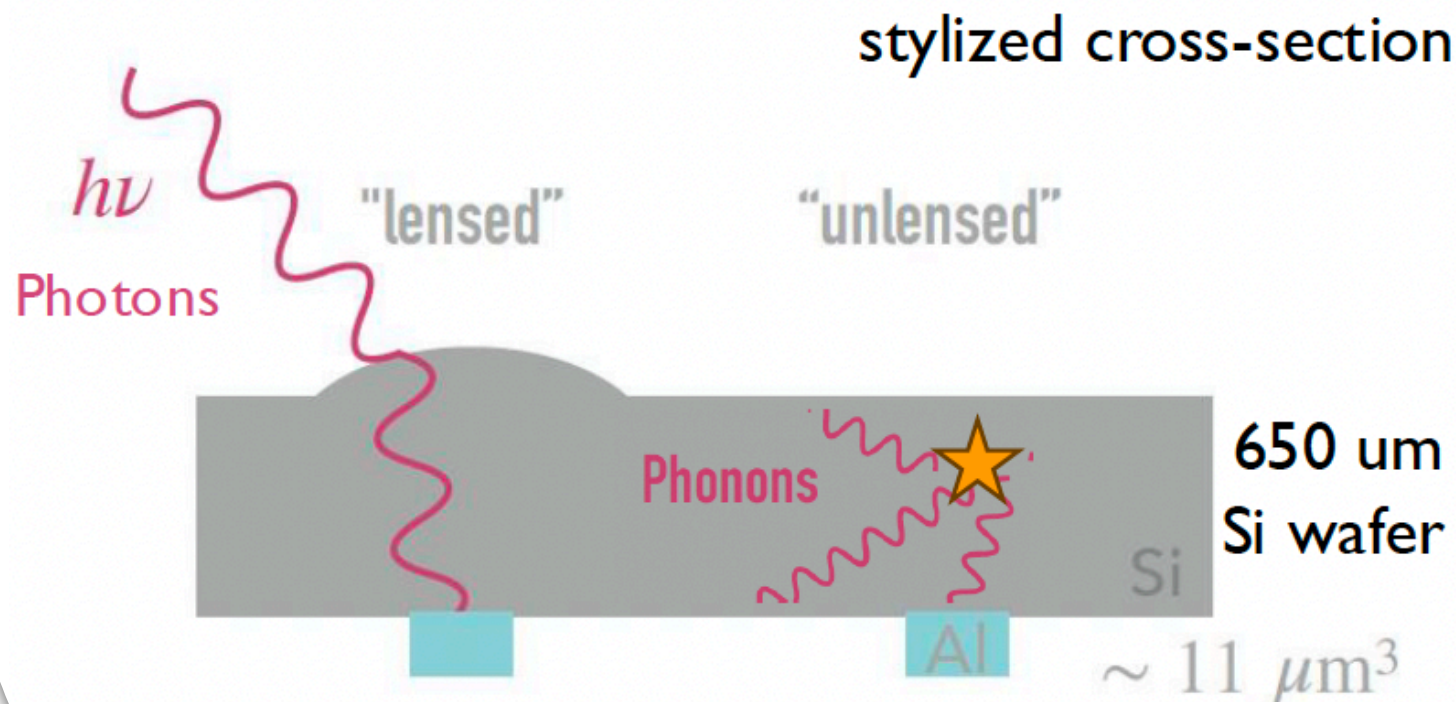
G. R. Di Carlo, et al, arXiv:2602.18388 (2026)

Credit: Ruggero Di Carlo

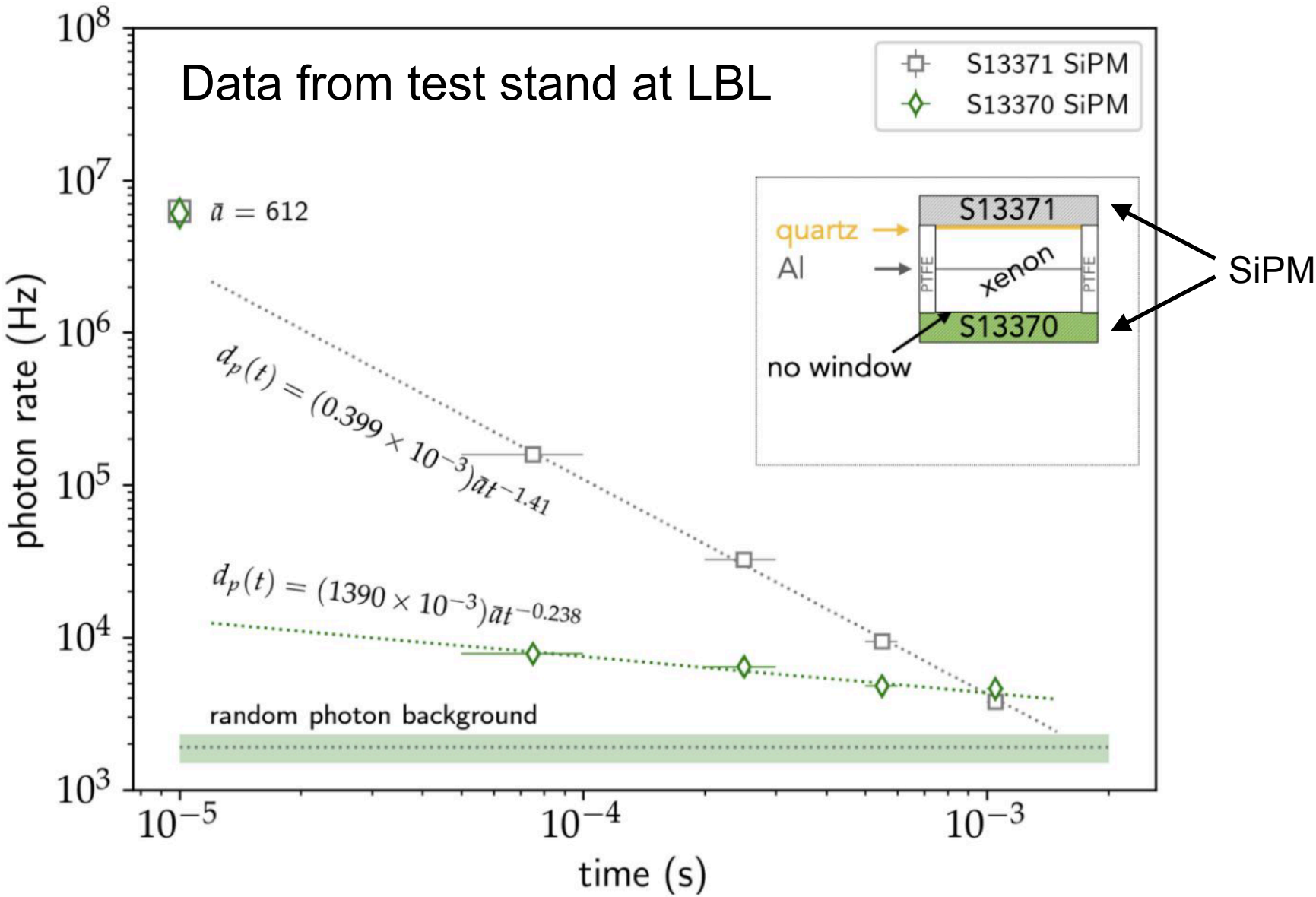
EXCESS@IDM 2026: microwave and liquid detectors



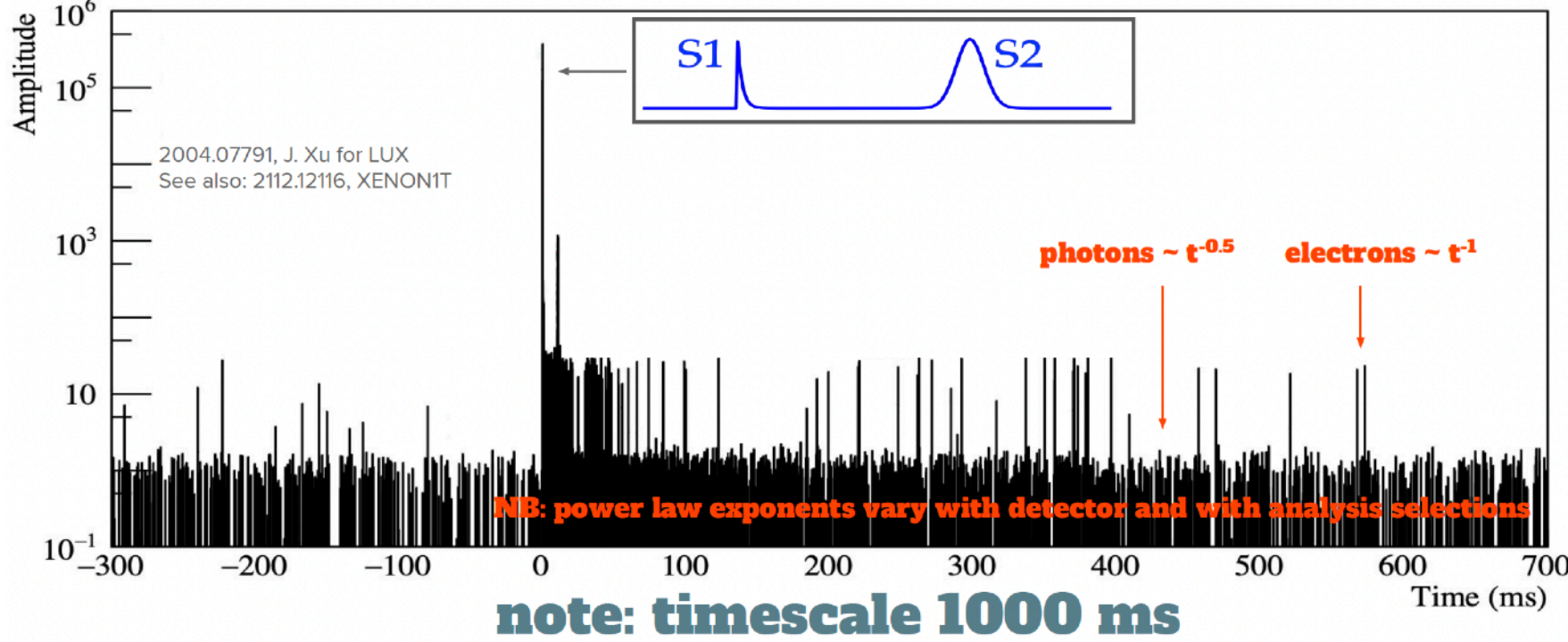
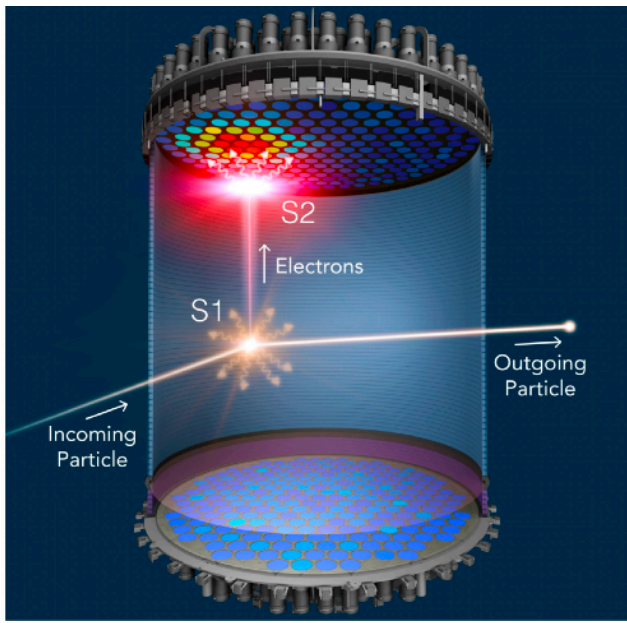
QUALIPHIDE: a new wideband dark photon detector



P. Day, et al., Phys. Rev. X 14, 041005 (2024)
Credit: Karthik Ramanathan

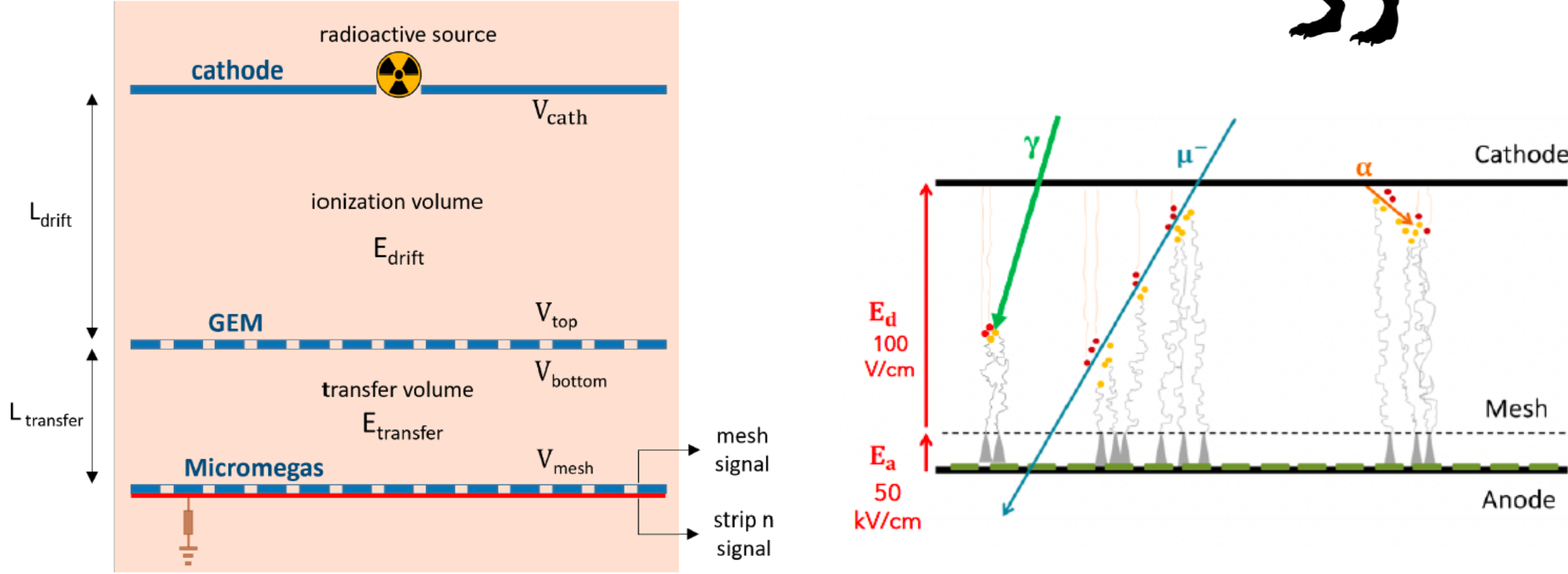
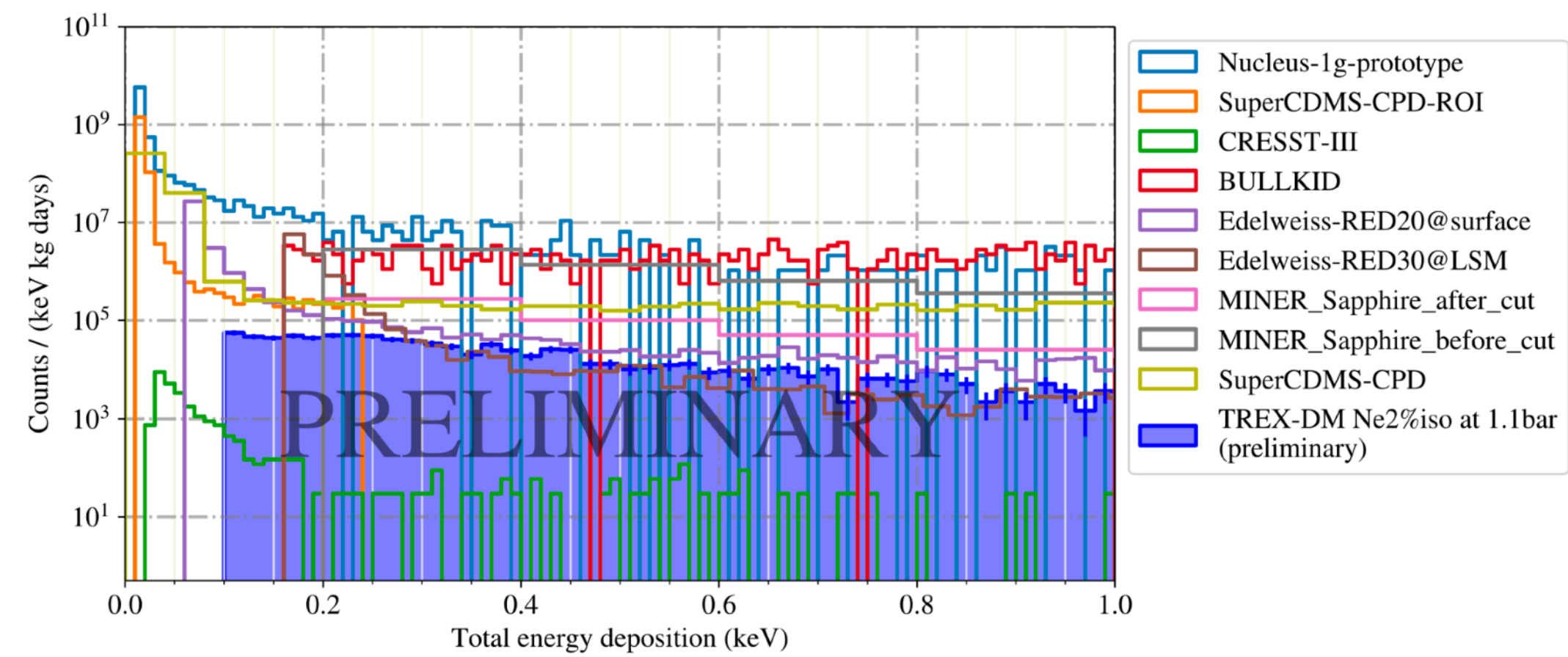


e⁻ and γ excess in Xe TPCs

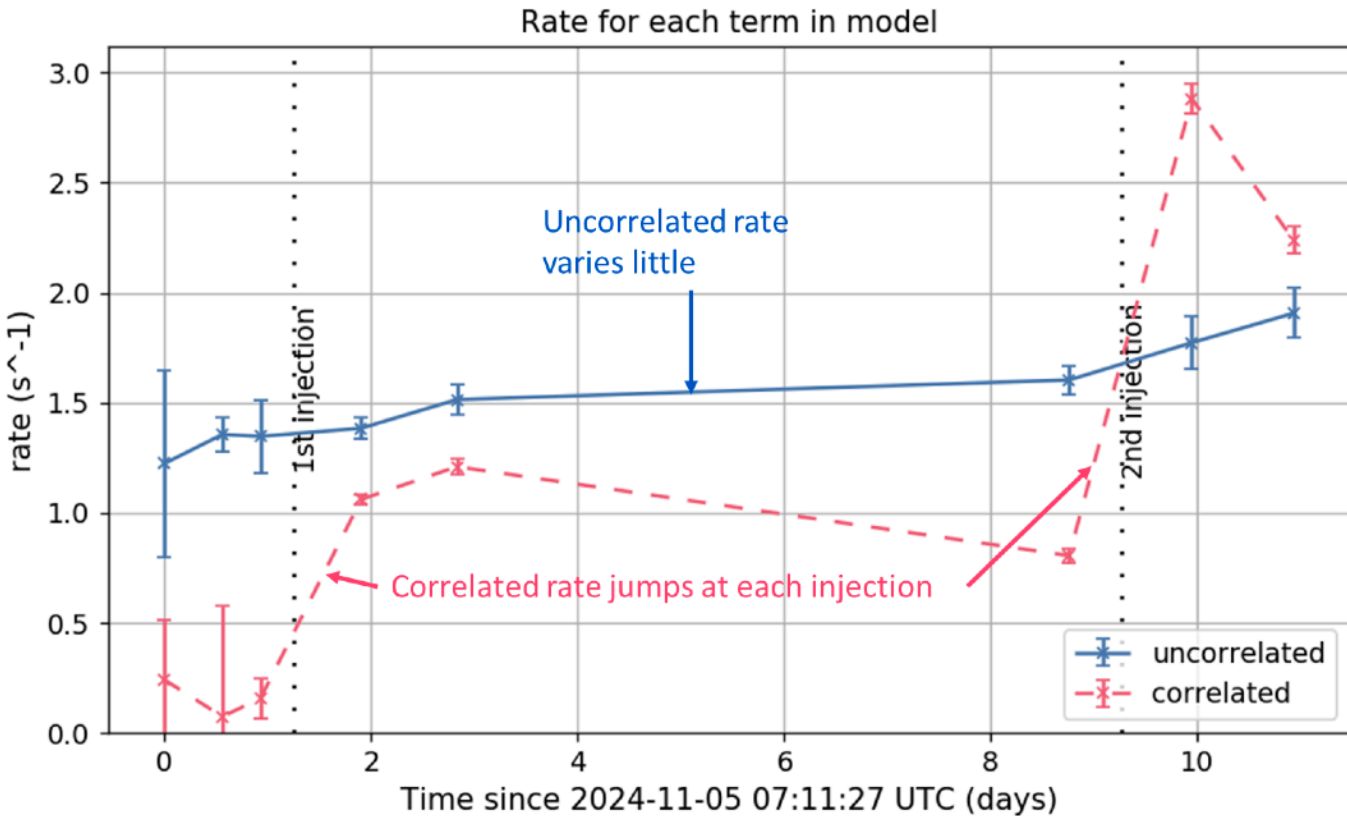
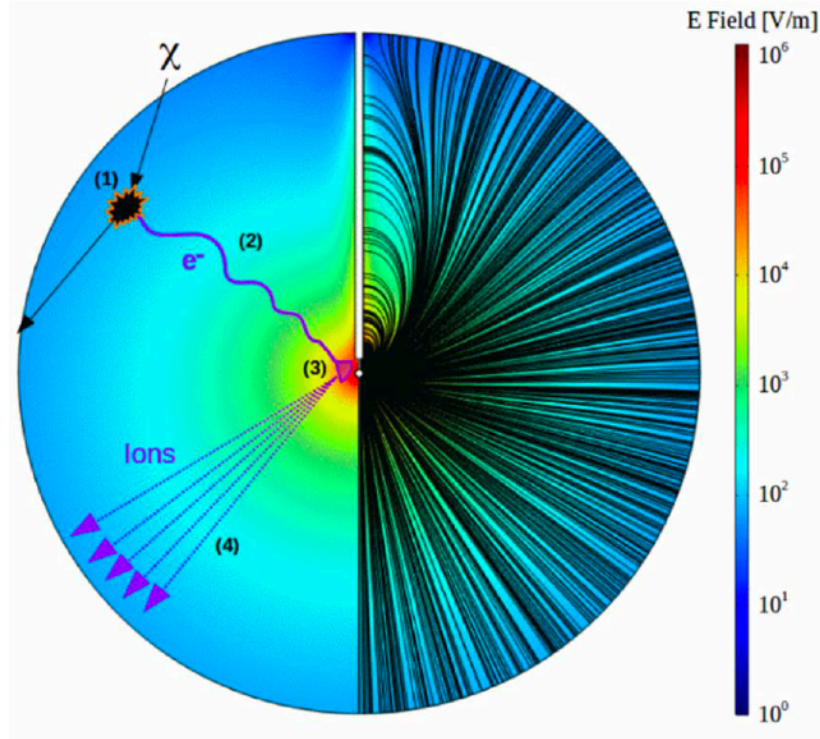
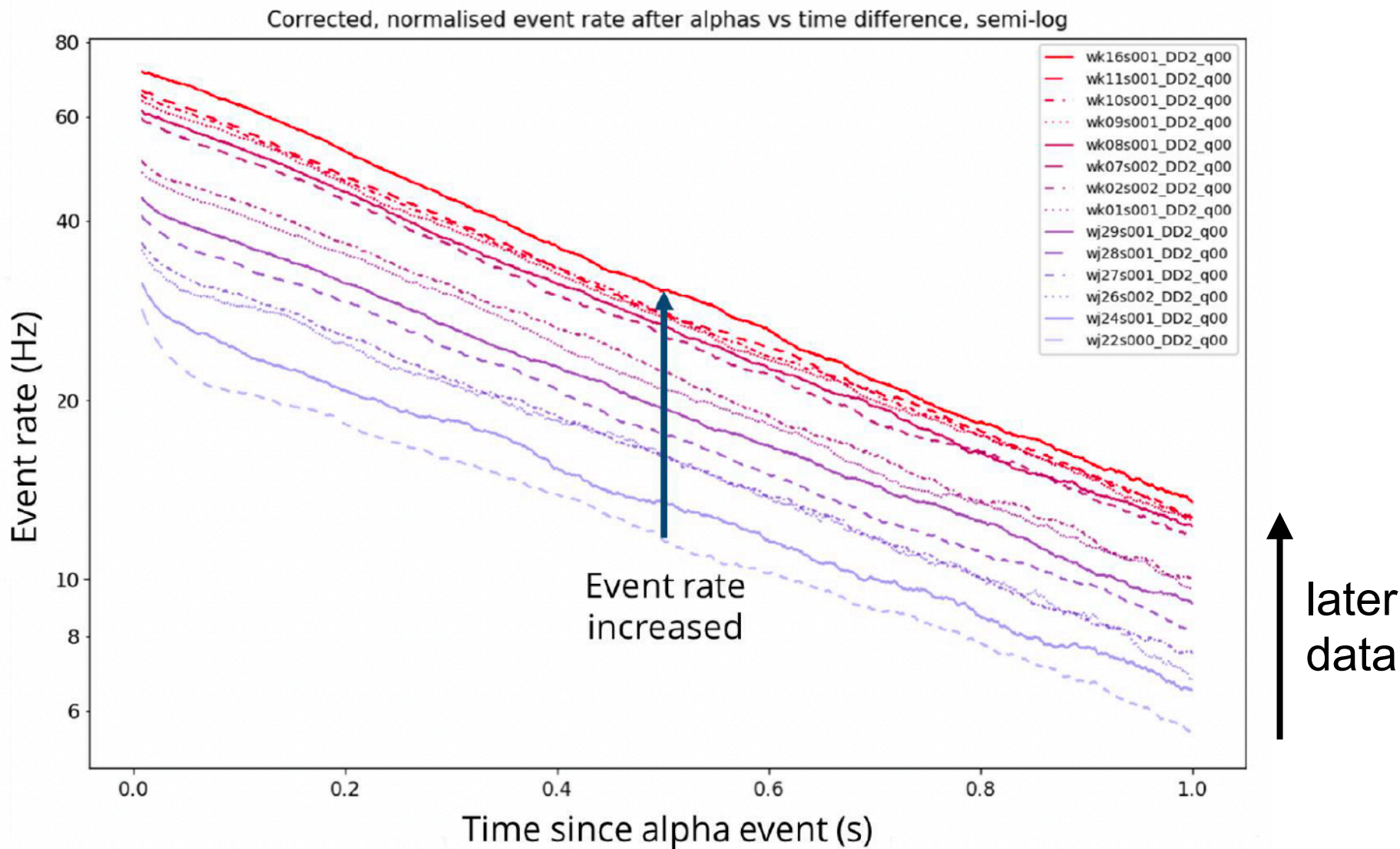


P. Sorensen, R. Gibbons, Phys.Rev.D 112 (2025) 5
Credit: Peter Sorensen

EXCESS@IDM 2026: gas detectors



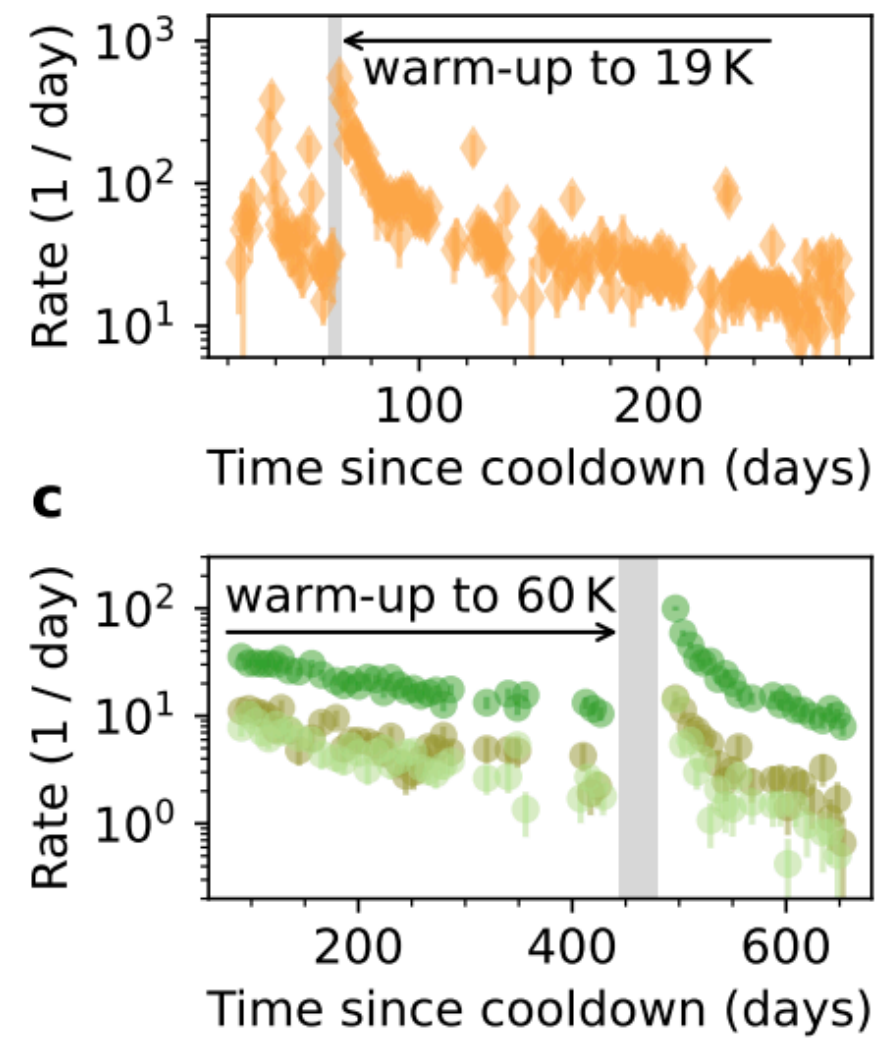
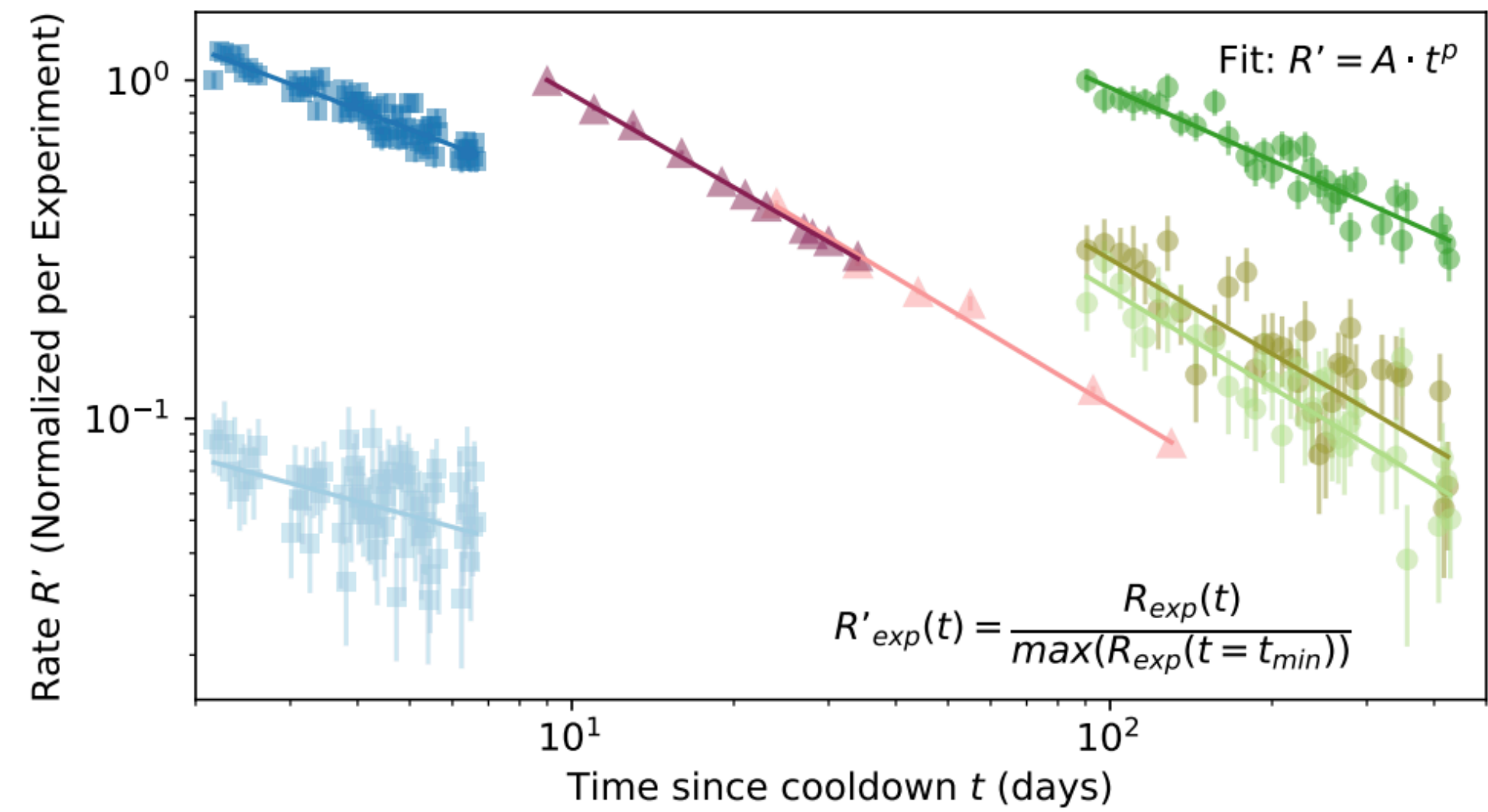
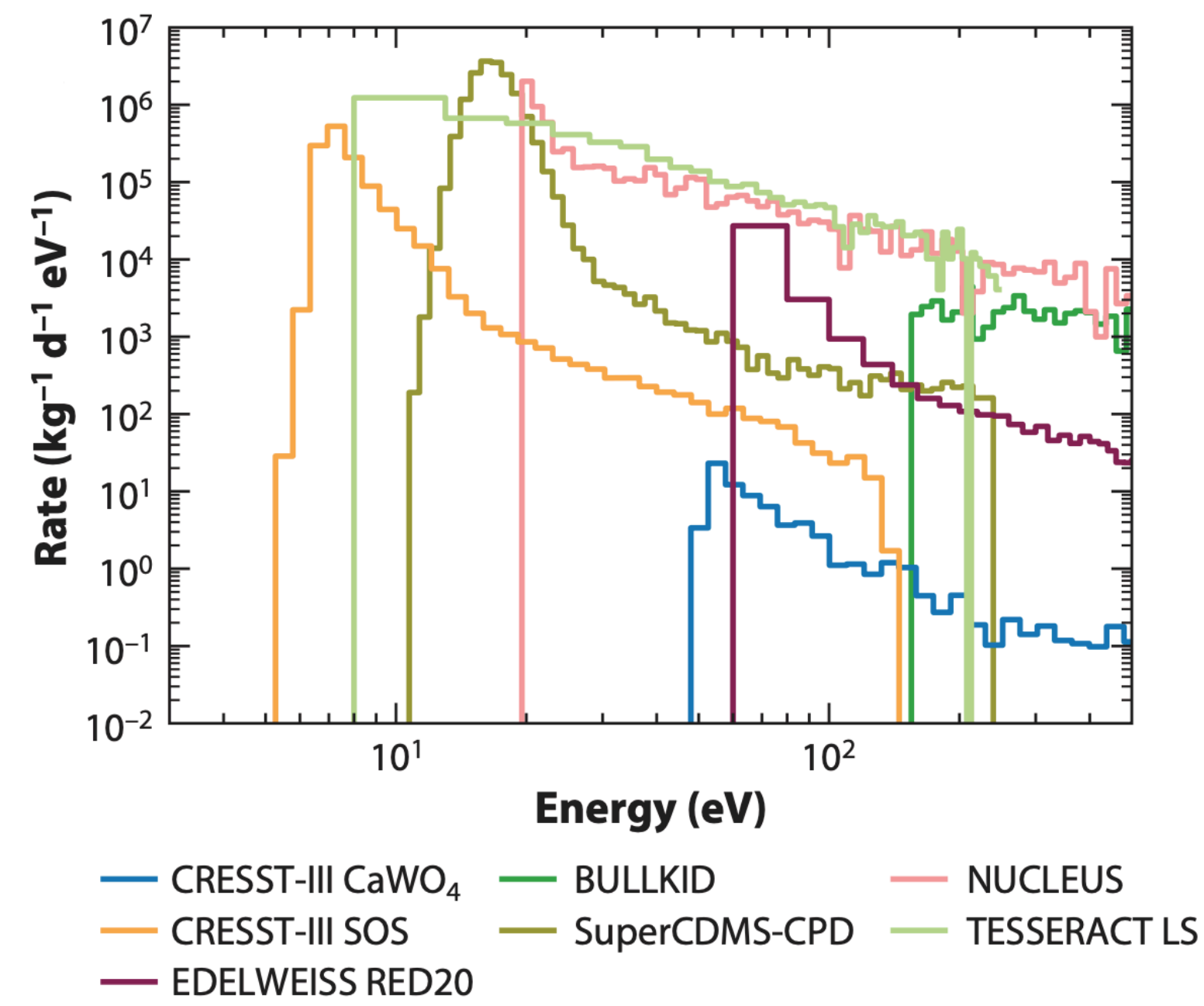
Ó. Pérez, et al., JCAP 04 (2026) 072
Credit: Álvaro Ezquerro Sastre



D. Durnford, et al., Phys. Rev. Lett. 134, 141002 (2025)
Credit: Jon Clarke



The low-energy excesses - a community effort



- TESSERACT LS 3-38 eV $p = -0.60 \pm 0.02$
- TESSERACT LS 38-85 eV $p = -0.43 \pm 0.10$
- Mannila '22 Run 1 $p = -0.95 \pm 0.01$
- Mannila '22 Run 2 $p = -0.91 \pm 0.01$
- CRESST-III CaWO₄ 60-120 eV $p = -0.93 \pm 0.10$
- CRESST-III Al₂O₃ 60-120 eV $p = -0.72 \pm 0.04$
- CRESST-III Si 60-120 eV $p = -0.96 \pm 0.09$
- EDELWEISS-III 5-80 keV

Annual Review of Nuclear and Particle Science

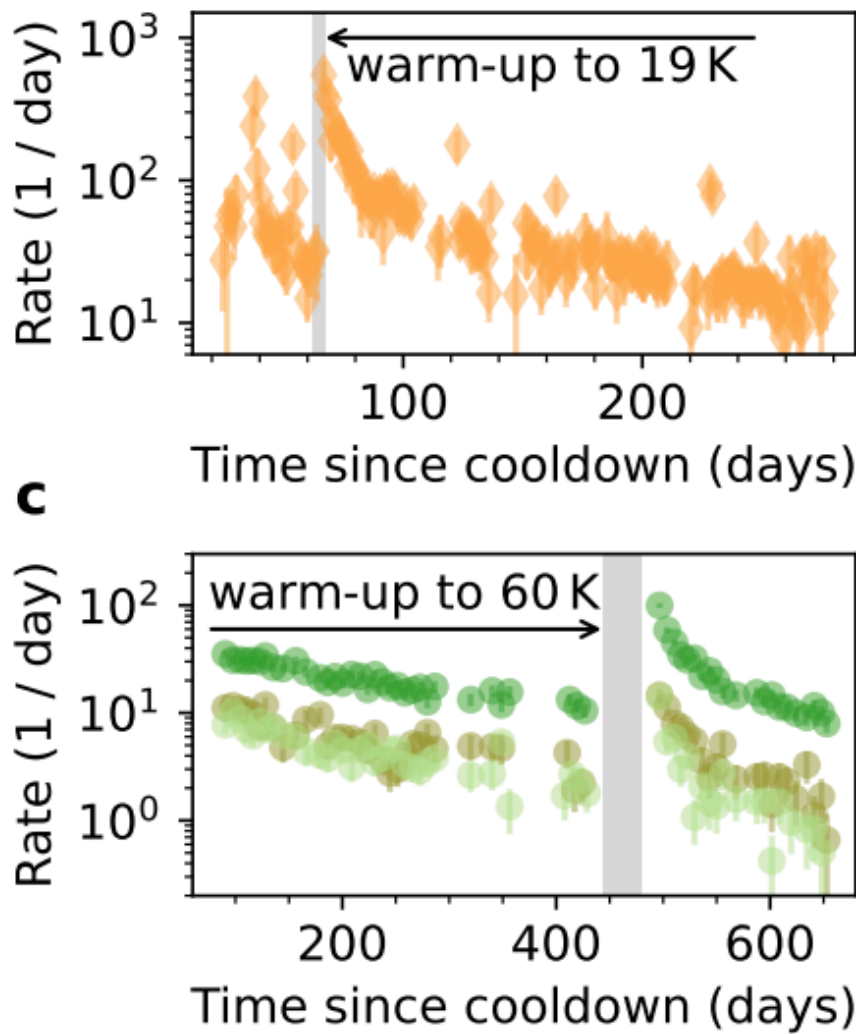
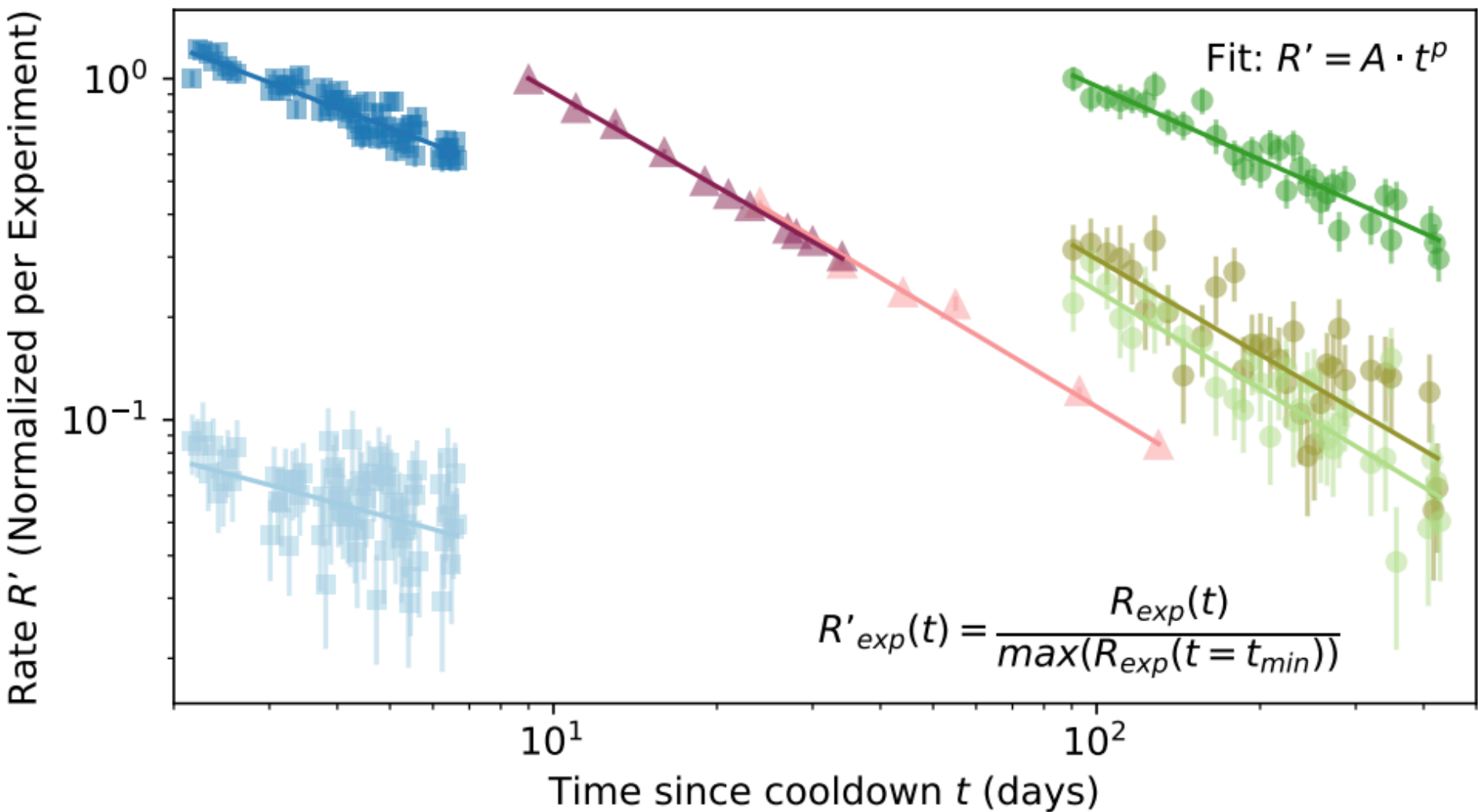
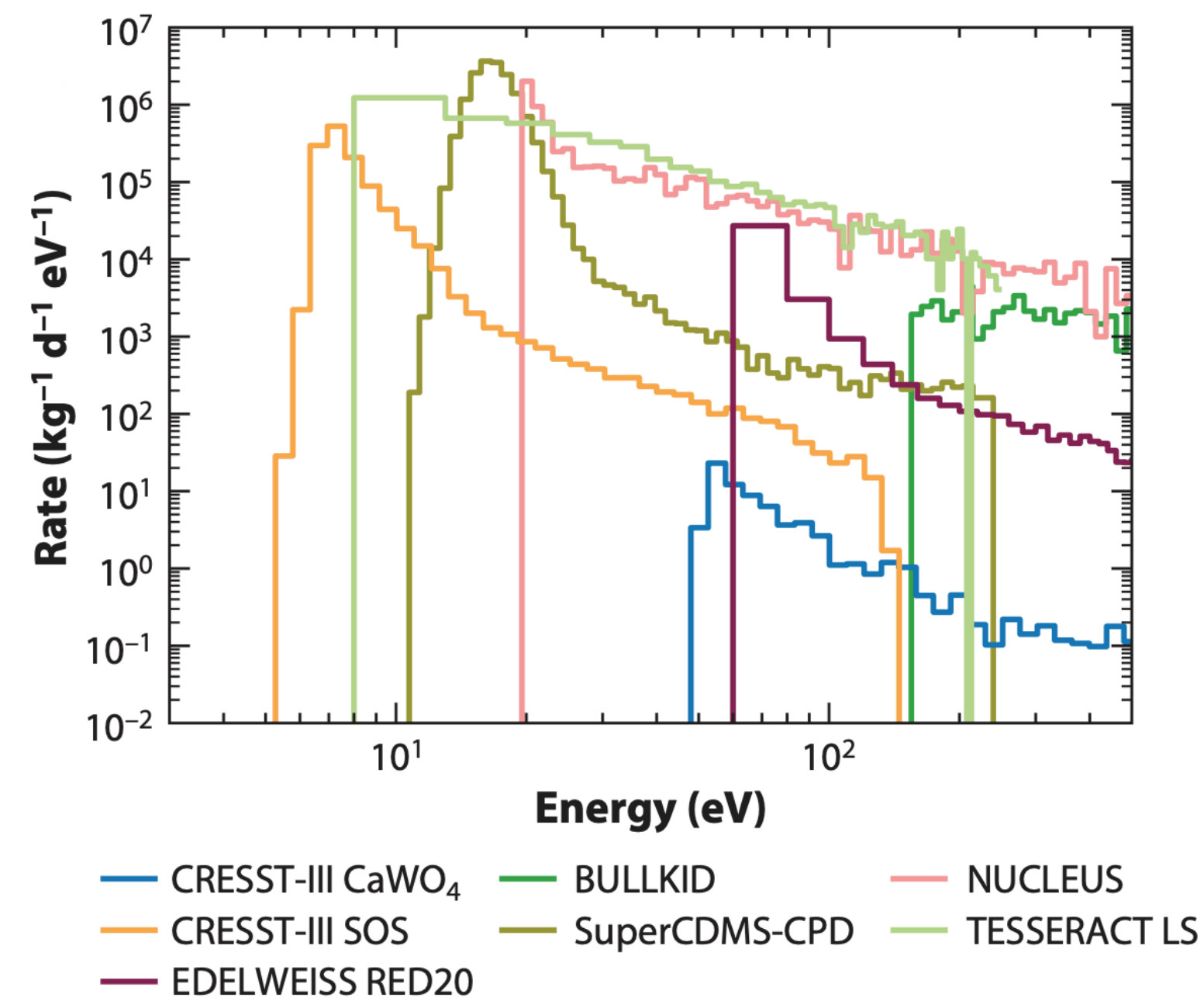
Low-Energy Backgrounds in Solid-State Phonon and Charge Detectors

Daniel Baxter,^{1,2} Rouven Essig,³ Yonit Hochberg,^{4,5} Margarita Kaznacheeva,⁶ Belina von Krosigk,^{7,8} Florian Reindl,^{9,10} Roger K. Romani,¹¹ and Felix Wagner^{12,13}

Experiment	1. Rise	2. Decay	3. Ionization	4. Coincidence	5. Absorber
CRESST-III (43, 63)	Yes	Yes	NA	No	Yes
NUCLEUS (5, 64)	Yes	Yes	NA	NA	Yes
TESSERACT (45, 53)	Yes	Yes	NA	No	Yes
SuperCDMS-CPD (33, 65)	Yes	Yes	NA	NA	NA
EDELWEISS (9, 66, 67)	Yes	Yes	No	NA	Yes
RICOCHET (68)	Yes	NA	No	NA	NA
BULLKID (35)	No	NA	NA	NA	NA
Mannila et al. (69)	Yes	Yes	NA	NA	NA



The low-energy excess^{es} - a community effort



- | | | | |
|---|---|---|---|
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Annual Review of Nuclear and Particle Science
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Next Workshop:

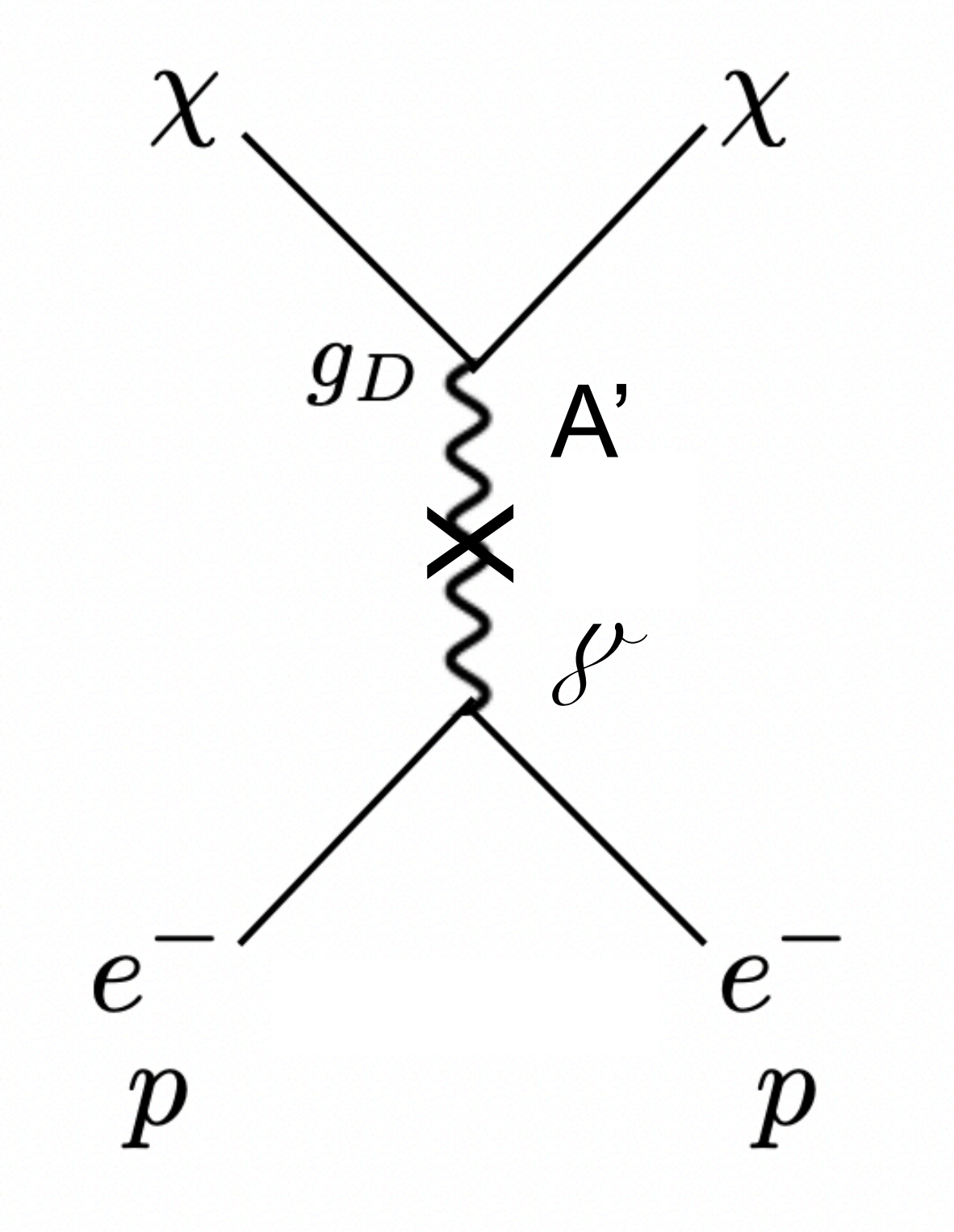
EXCESS27@TAUP

Technical University of Munich

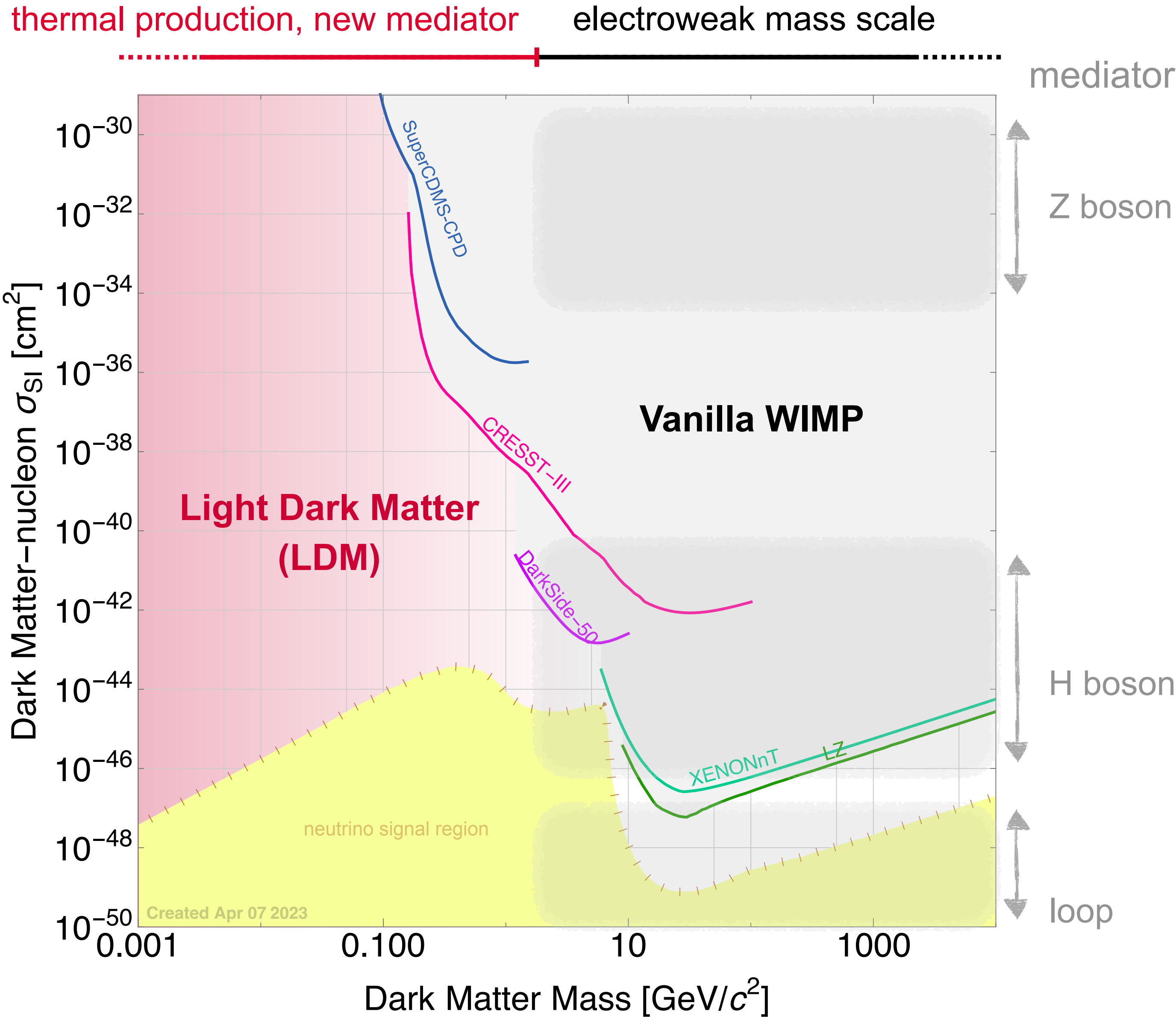
TUM

Additional material

The sub-GeV parameter space

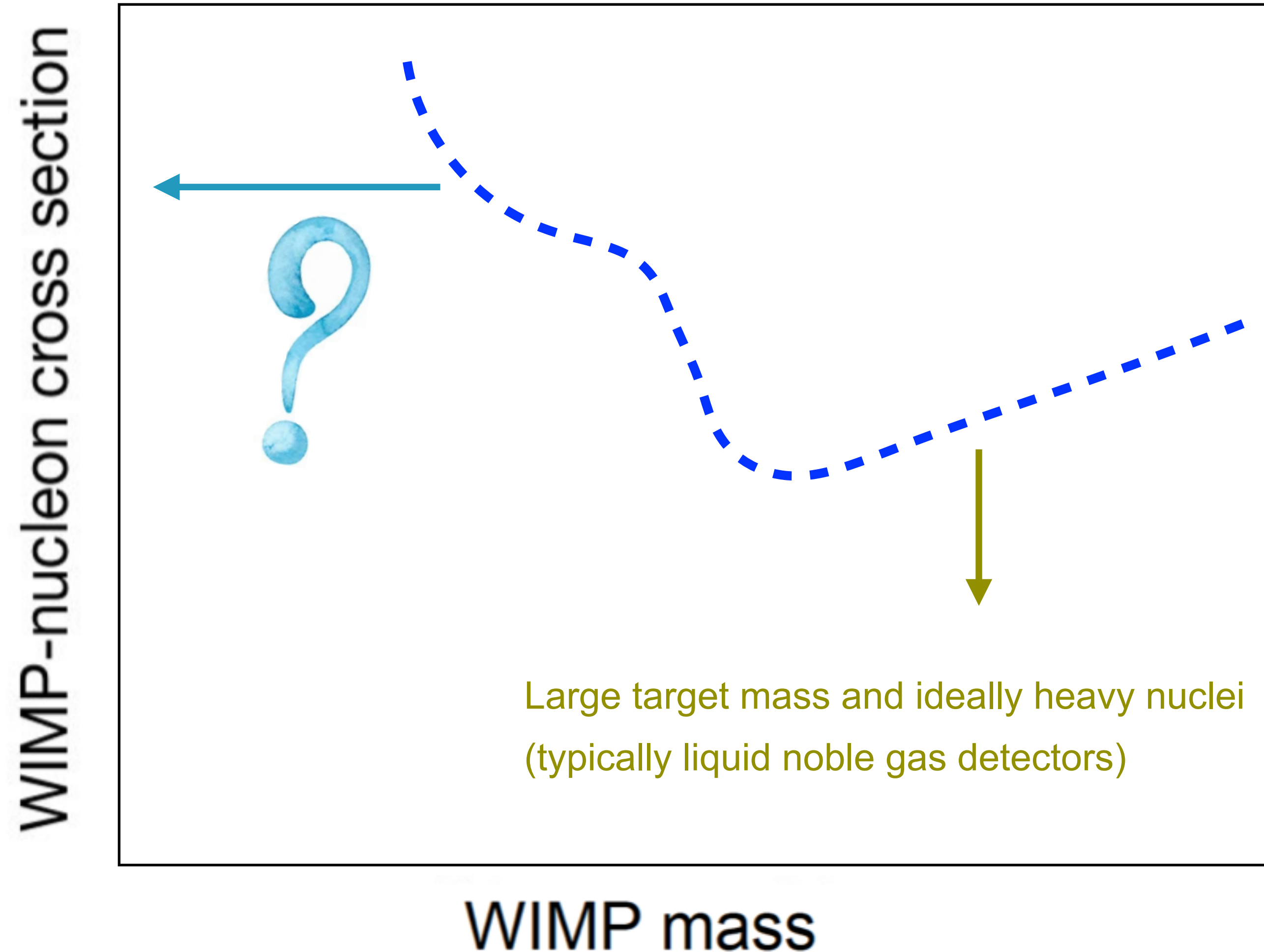


- New mediator, e.g. dark photon A'
- Coupling to electrons and nuclei via kinetic mixing with SM photon



The low-mass challenge

--- Sensitivity of upcoming experiments



- LDM search strategies
 - Lowering the threshold
 - Increasing the recoil energy
 - Exploiting alternate interaction channels