Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

COSINUS

Direct dark matter detection in COSINUS

33rd Rencontres de Blois, May 22-27

Speaker: Moritz Kellermann for the COSINUS Collaboration

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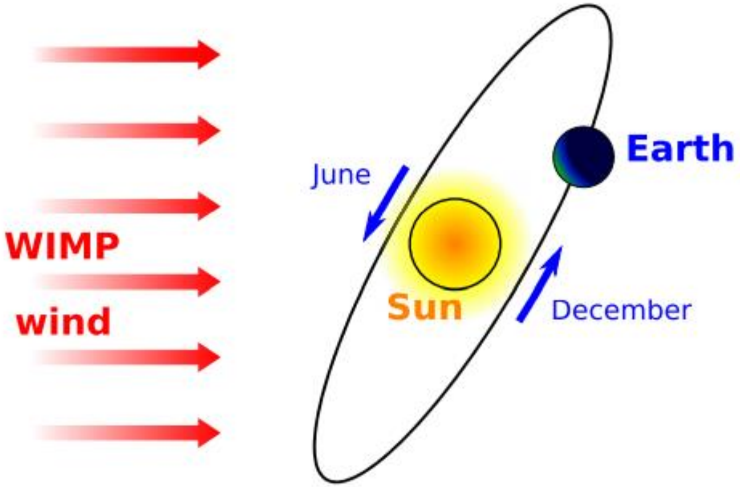
SICCAS

Dark matter in our galaxy

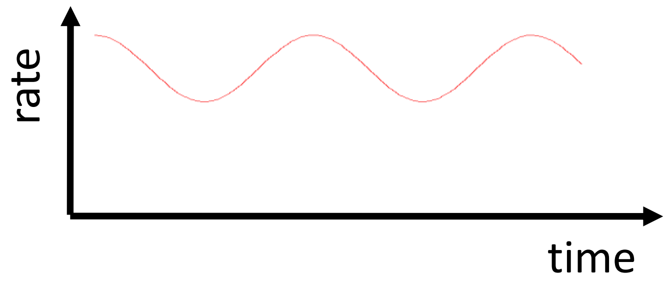
- Dark matter (DM) is expected to be distributed as halo around the galaxy
- Assume DM to be particle-like and interacting with standard model particles
- Motion of Earth causes a modulation of relative velocities

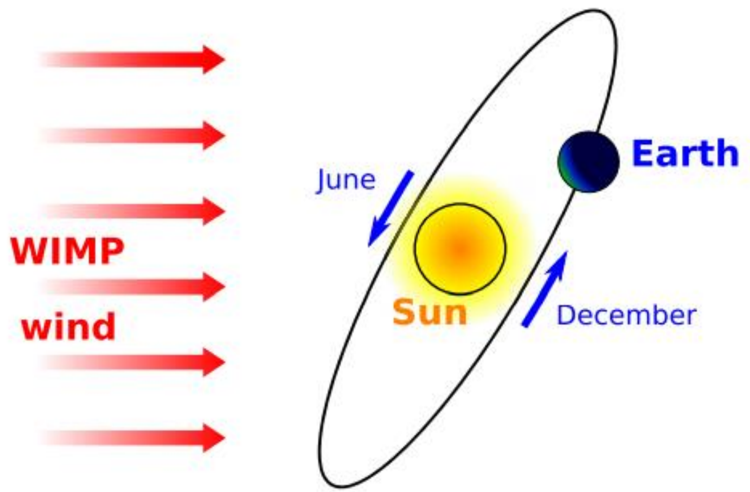


Dark matter in our galaxy

- Dark matter (DM) is expected to be distributed as halo around the galaxy
- Assume DM to be particle-like and interacting with standard model particles
- Motion of Earth causes a modulation of relative velocities

Interaction rate of DM-particles interacting with a detector should show a yearly modulation





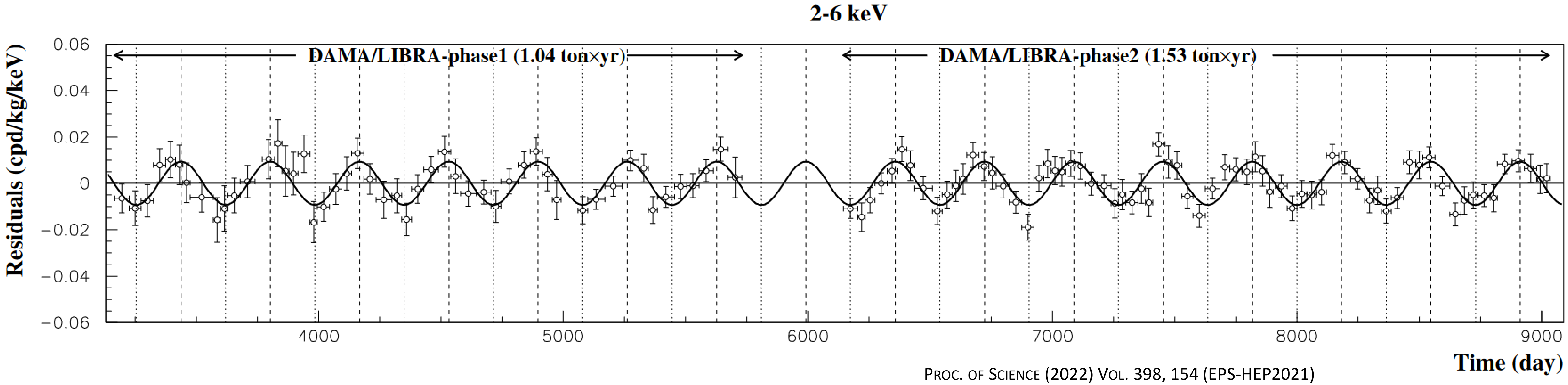
$$\mathbf{v}^{det}_{gal}(t) = \mathbf{v}^{\odot}_{gal} + \mathbf{v}^{det}_{\odot}(t)$$

$\rightarrow f(\mathbf{v}^{gal}_{\chi}(t))$ period 1 year

$$\boxed{\frac{\mathrm{d}R(t)}{\mathrm{d}E_R} = A_0 + \sum_{n=1}^{\infty} A_n \cos n\omega(t - t_0) + \sum_{n=1}^{\infty} B_n \sin n\omega(t - t_0)}$$

DAMA/LIBRA experiment

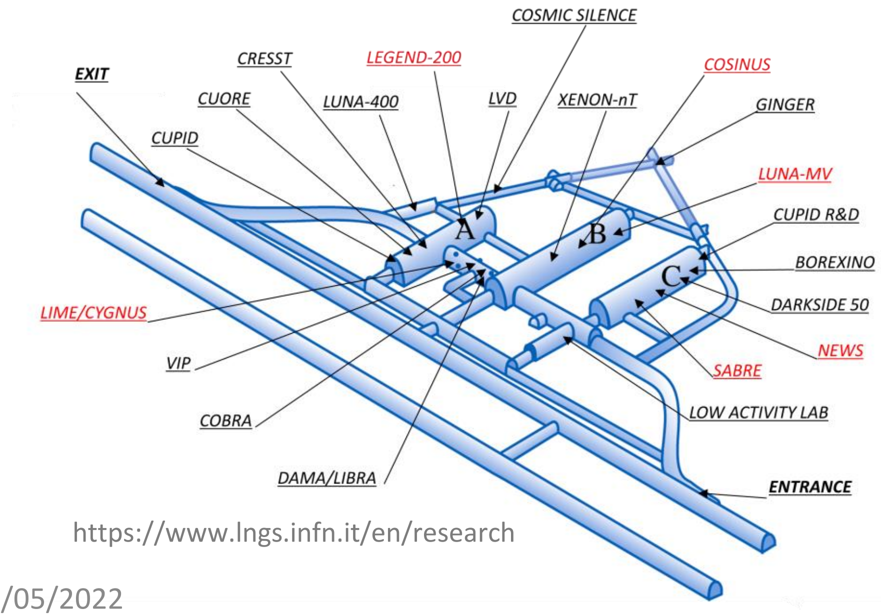
- DAMA/LIBRA measured a modulation using scintillating NaI since 1996 with
    - Period of 0.998 ± 0.001 years (at 2-6 keV)
    - High significance of 13.7 σ
    - Phase peaking on 22nd May ± 5 days
    - **No confirmation by other experiments**



PROC. OF SCIENCE (2022) VOL. 398, 154 (EPS-HEP2021)

COSINUS

- COSINUS is a direct dark matter experiment that will cross-check the results of DAMA/LIBRA
  - It uses the same target material (NaI) operated as low-temperature scintillating calorimeters
  - It will be the first NaI experiment with **particle discrimination**
  - It will be located at the same underground lab as DAMA/LIBRA (LNGS)



https://www.lngs.infn.it/en/research

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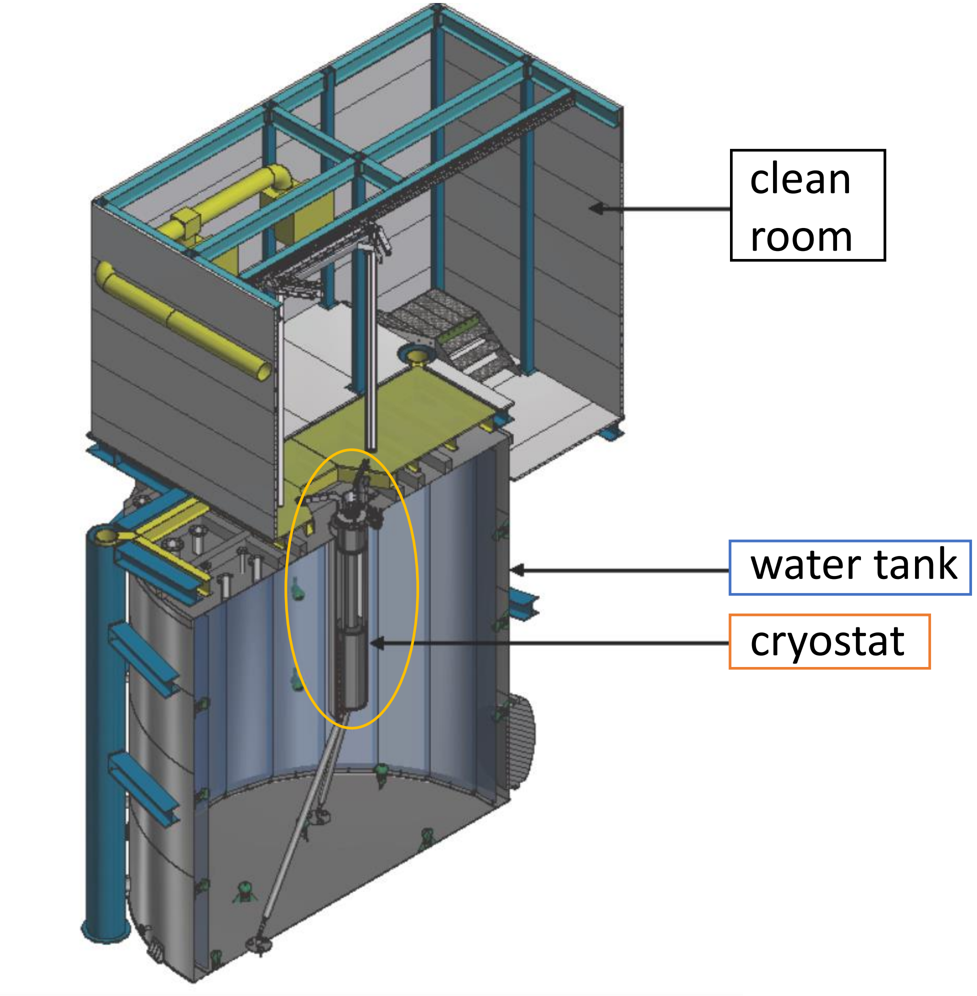
COSINUS facilities



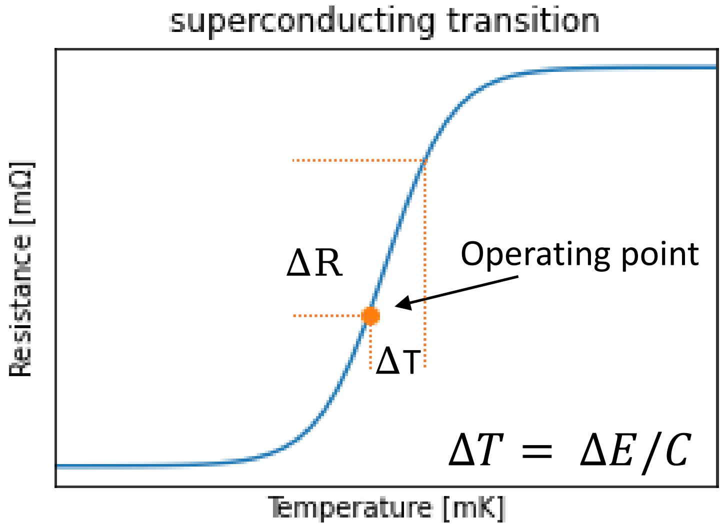
The COSINUS facilities can be divided into 4 units:

- Clean room for mounting and dismounting detectors
  - Glove box for crystal handling
  - Low vibration area
- Water tank for radiation shielding and muon tagging
  - Volume of 269 m^3
  - Will contain up to 28 PMTs
- Cryostat area in a drywell inside of the water tank
  - Dry dilution refrigerator with ~15 mK base temperature
  - 8 cm copper shielding
- Control building
  - Next to water tank (not shown in this depiction)
  - 3 floors equipped with infrastructure for working underground

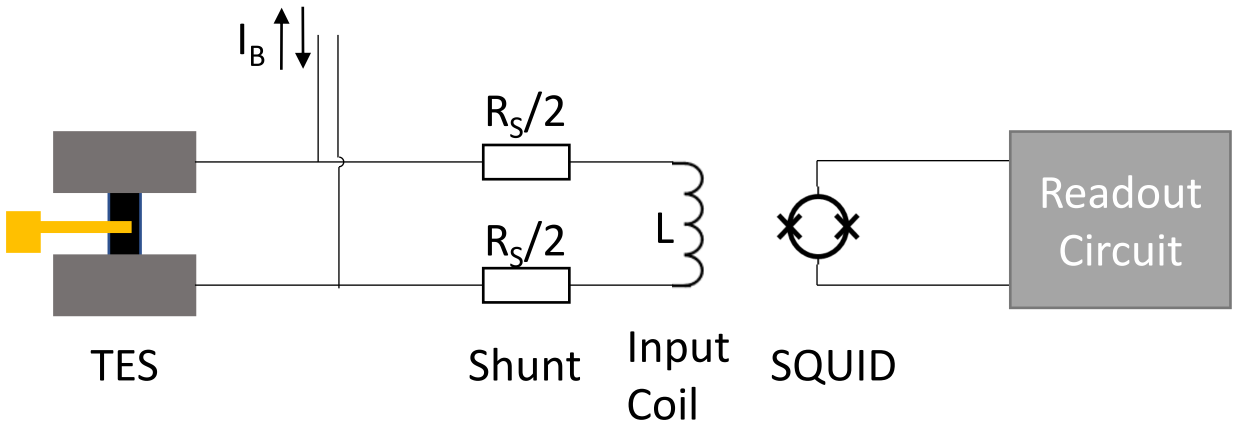
Status & Goal

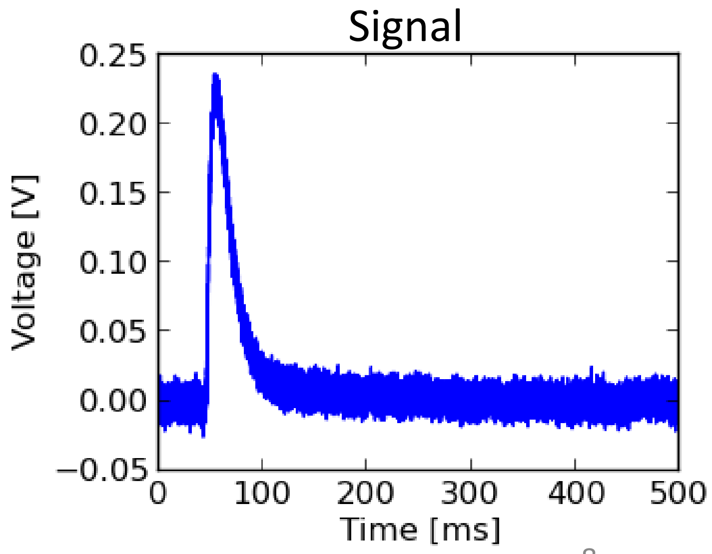
Most complicated part is done!

Operation of superconducting thermometers



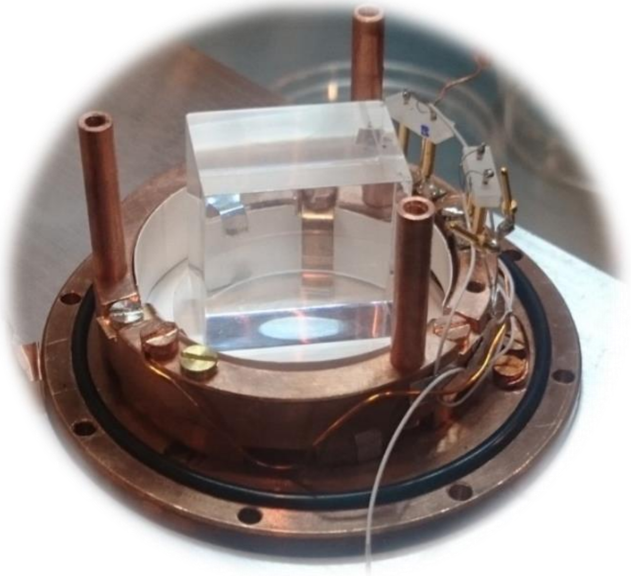
- Measurement of µK-temperature differences with tungsten transition edge sensors (TES)
- Energy deposition leads to change in temperature and thus film resistance
- Electrical readout using "superconducting quantum interference devices" (SQUIDs) as amplifiers





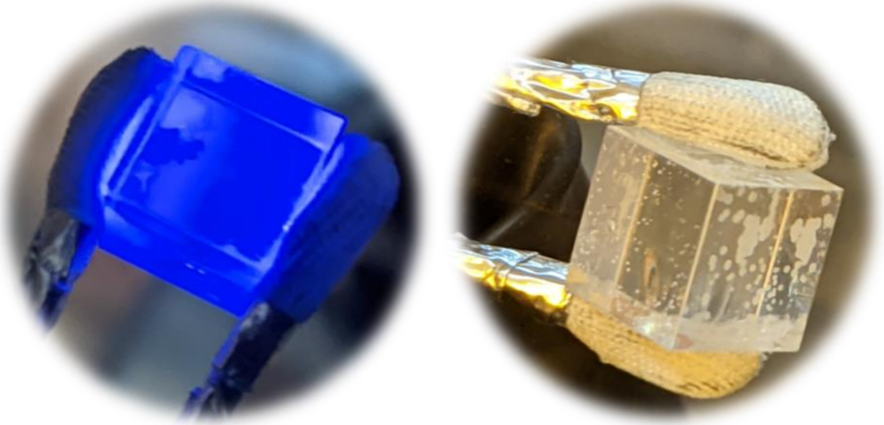
Sodium iodide

23.0 11 Na Sodium	126.9 53 I Iodine

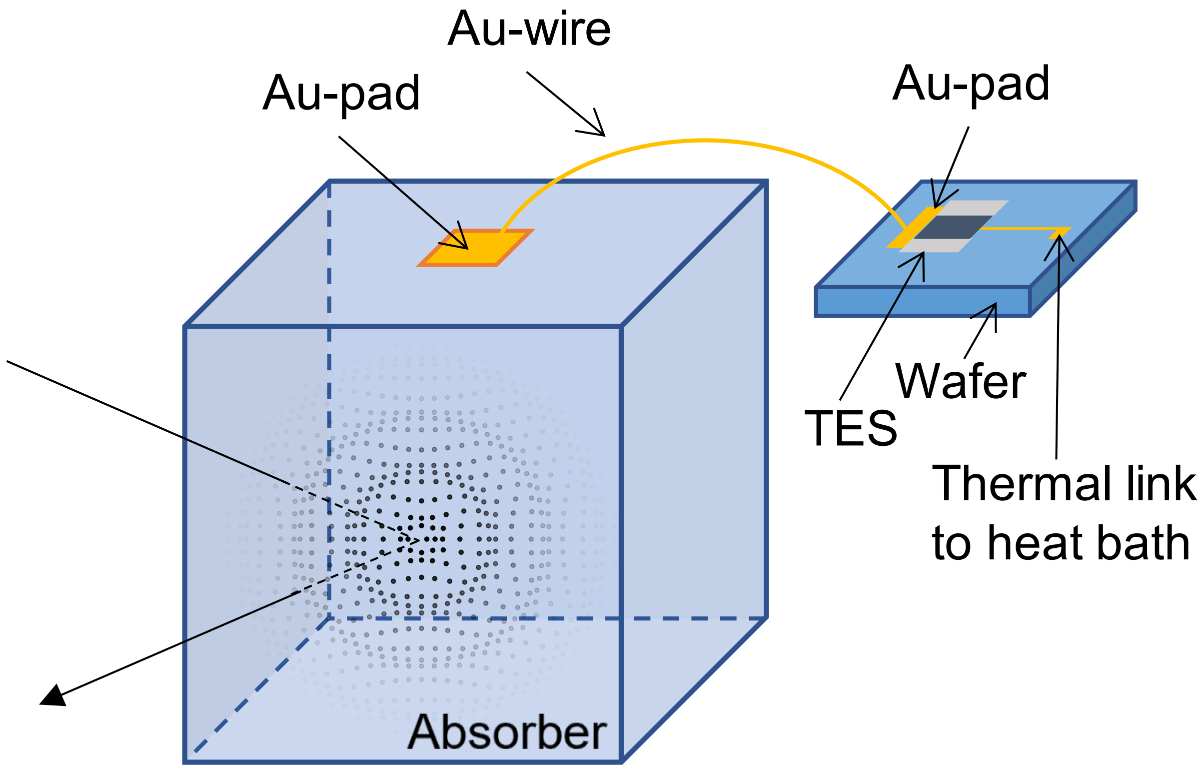


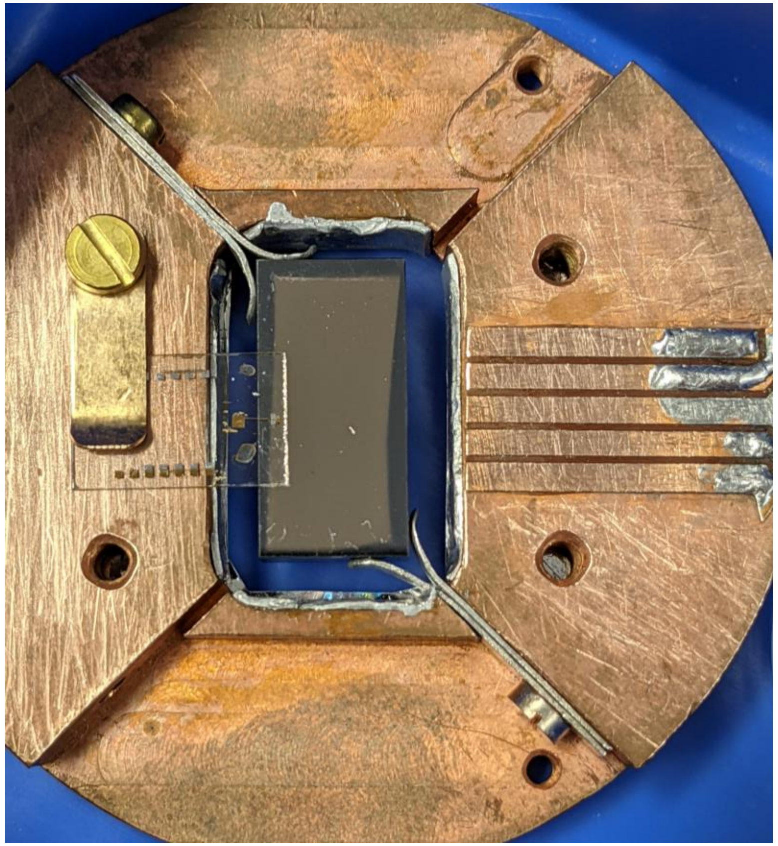
Material	NaI (COSINUS)	$CaWO_4$ (CRESST-III)
Density	3.67 g cm^{-3}	6.06 g cm^{-3}
Melting point	661 °C	1620 °C
Heat capacity @20 mK	91.3×10^{-6} µJ cm^{-3} K^{-1}	28.4×10^{-6} µJ cm^{-3} K^{-1}
Absorber mass	~90 g	~24 g
	Extremely hygroscopic !	
	Extremely soft !	

- NaI cannot survive most of the common deposition processes

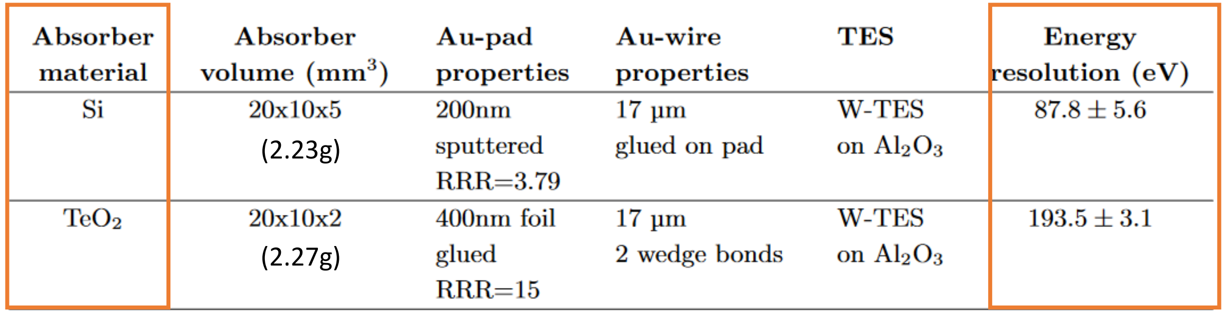


remoTES design





remoTES – first results

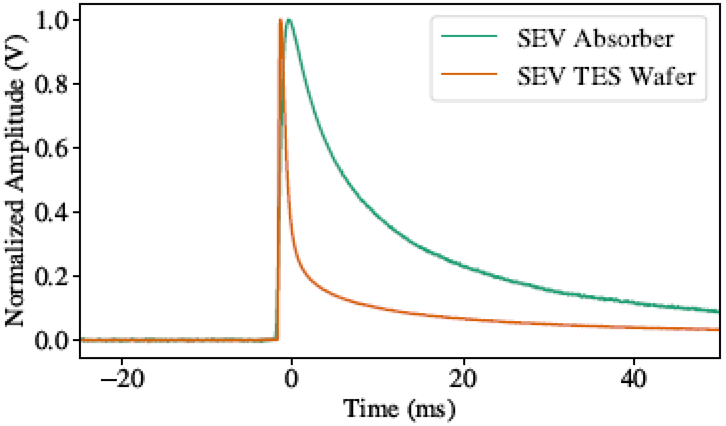


Absorber material	Absorber volume (mm^3)	Au-pad properties	Au-wire properties	TES	Energy resolution (eV)
Si	20x10x5 (2.23g)	200nm sputtered RRR=3.79	17 µm glued on pad	W-TES on Al_2O_3	87.8 ± 5.6
TeO_2	20x10x2 (2.27g)	400nm foil glued RRR=15	17 µm 2 wedge bonds	W-TES on Al_2O_3	193.5 ± 3.1

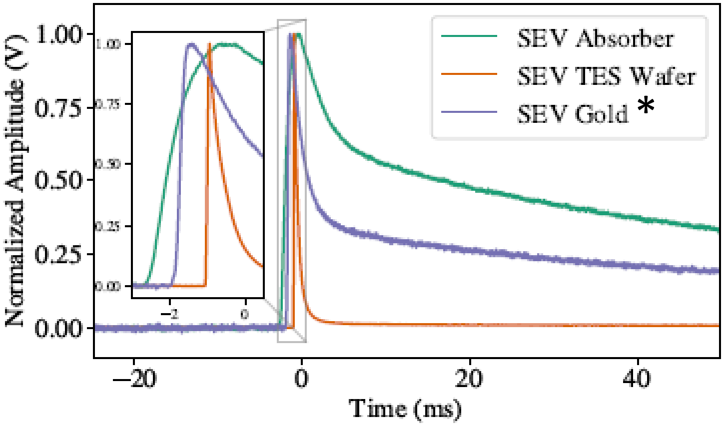
https://arxiv.org/abs/2111.00349

- Test measurements with TeO_2 and Si successful
- Energy calibrated by using ^{55}Fe-sources
- Event types can be discriminated by pulse shape

Silicon

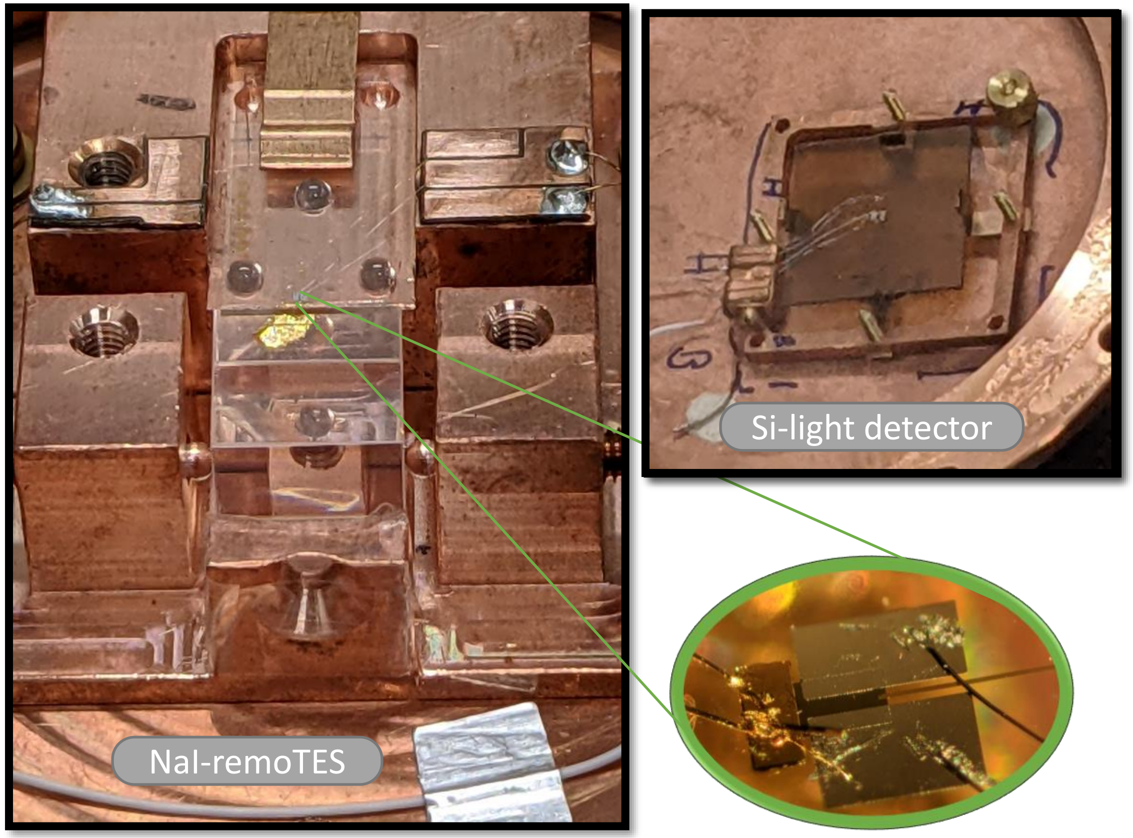


TeO_2



*additional ^{55}Fe source near Au-pad for TeO_2

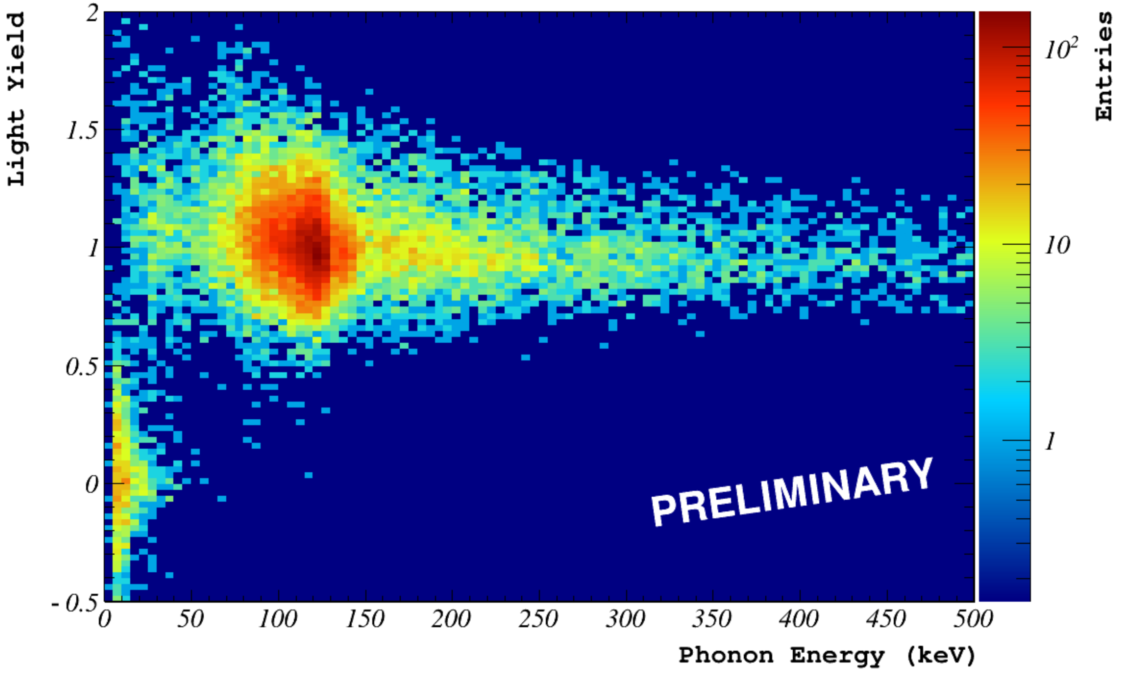
remoTES – NaI-version

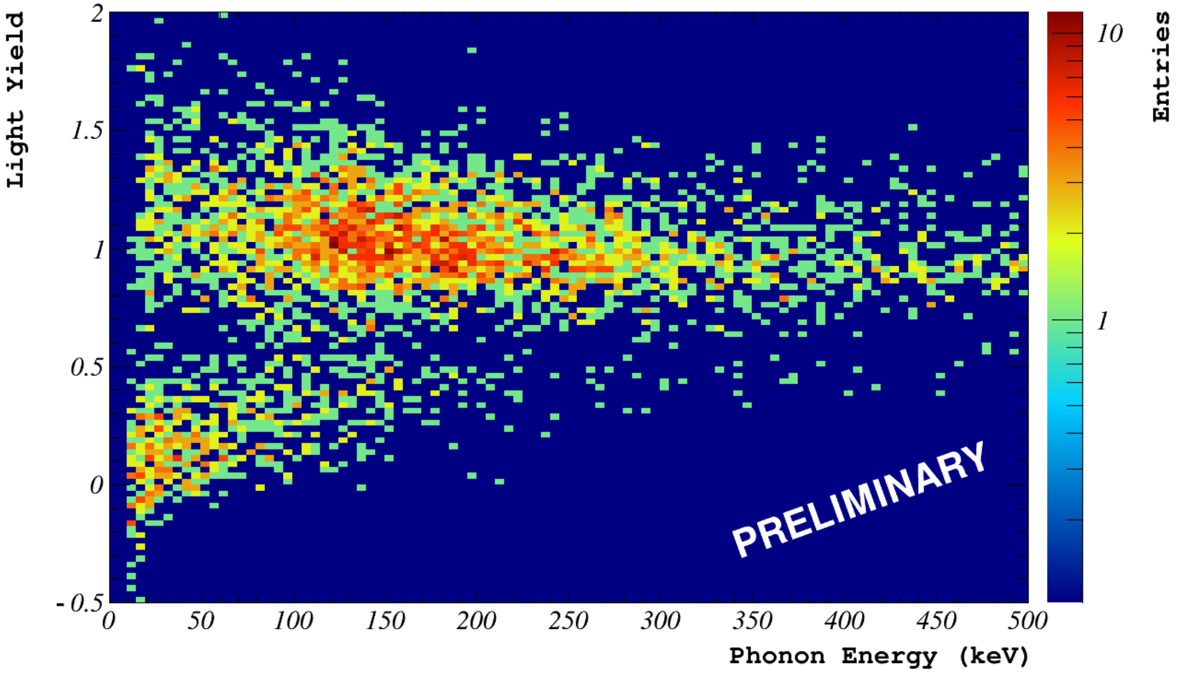


- December 2021: first fully functional remoTES of NaI
    - 1x1x1 cm^3 NaI-cube of 3.6 g
    - 1µm thick glued gold foil for phonon collection
    - 2 Au-wires with ⌀ 17 µm connecting absorber and TES
- Energy resolution in low keV range
- Neutron calibration with Am/Be source
    - **First neutron discrimination with a NaI-remoTES detector**

Particle discrimination

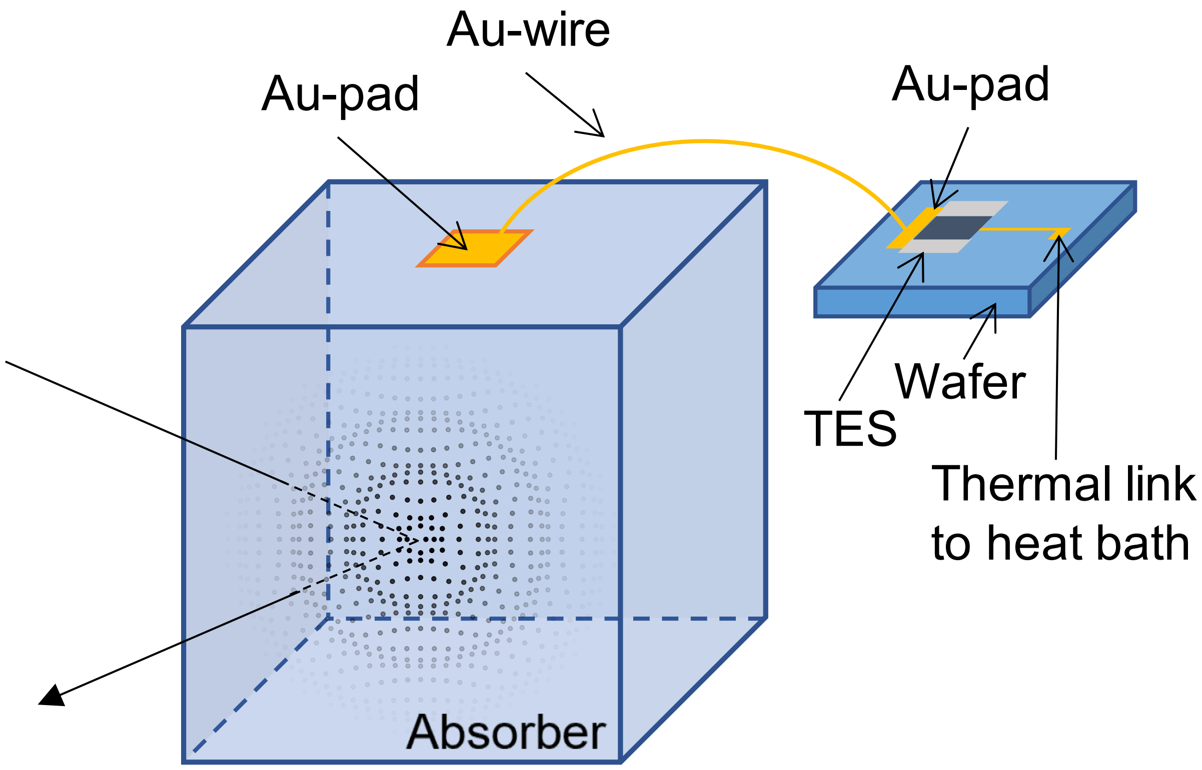
Stay tuned for the paper!


With ^{57}Co γ-source (122 keV)

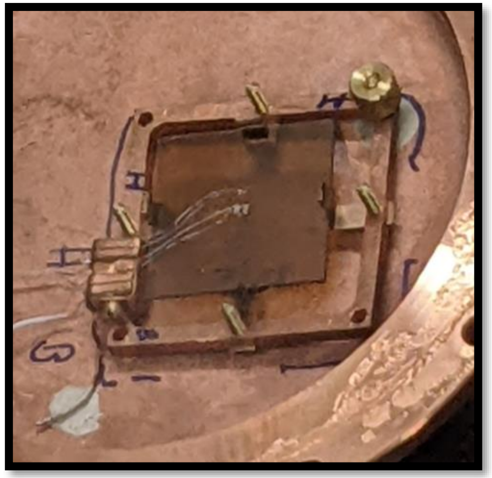

With ^{241}Am/Be n-source

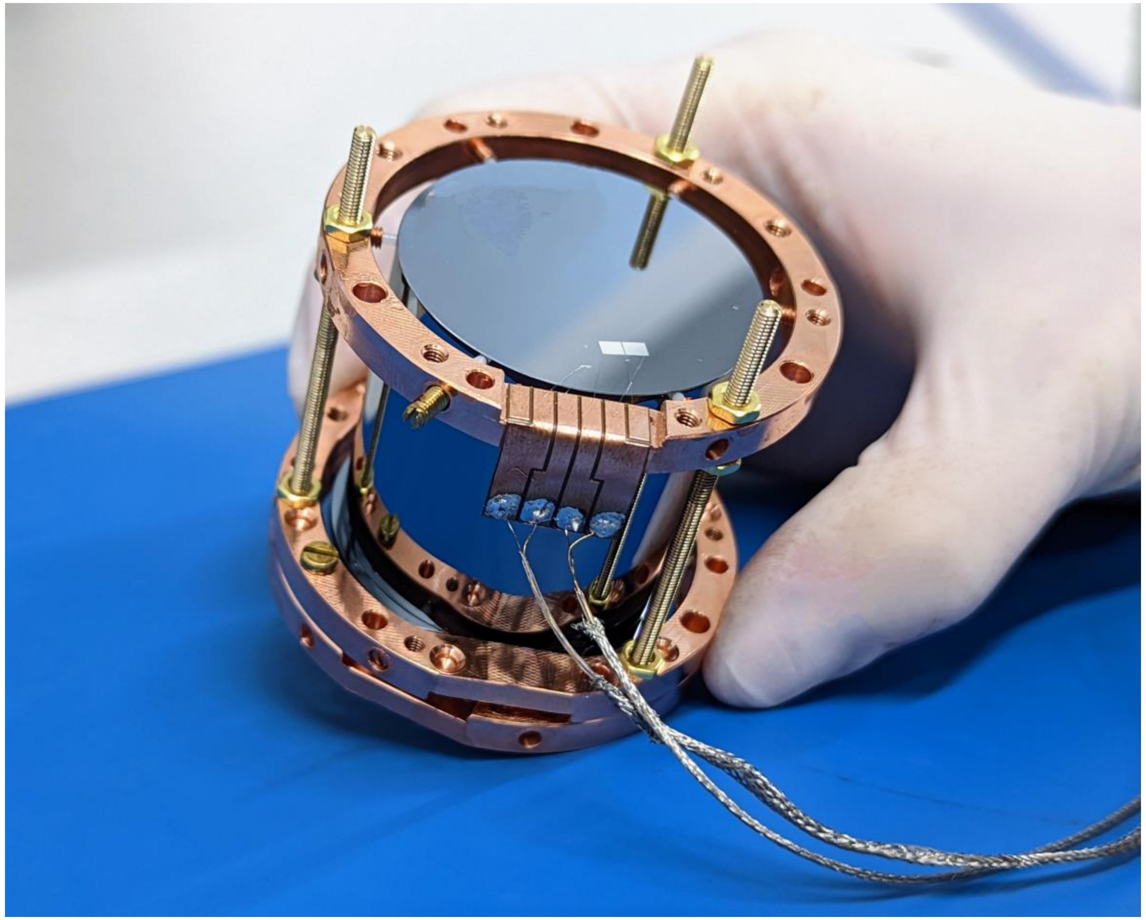
How to improve the threshold

- Glue thickness and reproducibility?
- Gold pad properties
  - Dimensions + geometry? Quality?
- Gold bond properties
  - Thickness? Number? Type?
- Materials
  - Superconducting collector?
- Heat capacity
- Light collection
- …



Light detectors



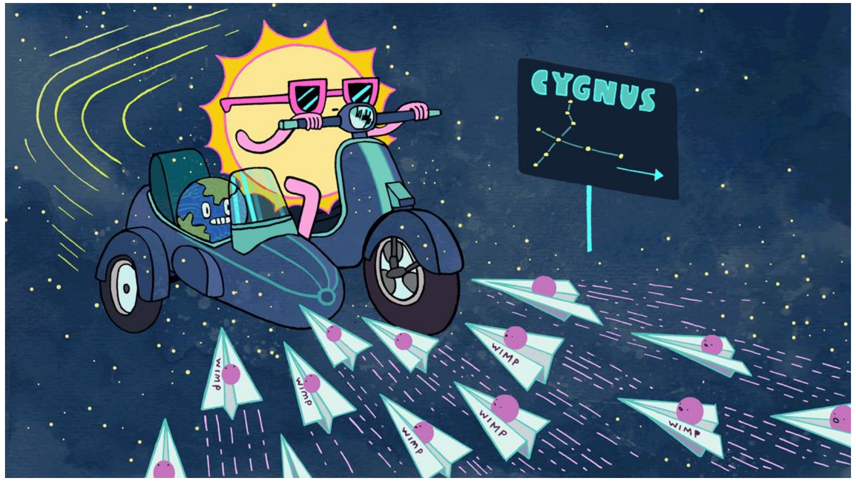


Better light collection will lead to a better particle discrimination

Status of COSINUS today

- A lot of progress in COSINUS:
  - Construction of facilities is going on smoothly
  - **remoTES-Sensor design is tested and working!**
  - Development of detector design including light detectors ongoing
- Big upcoming milestones:
  - August 2022: facility buildings finished (on the outside)
  - Late 2022: delivery and commissioning of new COSINUS cryostat
  - Mid 2023: COSINUS commissioning

Picture: symmetry magazine
Artwork by Sandbox Studio, Chicago with Corinne Mucha



Backup slides

Direct detection methods

*list not complete

Ionization Detectors

Targets: Ge, Si, CS_2, CdTe

GENIUS, HDMS, IGEX NEWAGE, CoGeNT,
CDEX, DAMIC, SENSEI, DANAE,
NEWS-G (noble gas mixture)

Light and Ionization Detectors

Targets: Xe, Ar, CS_2

WARP, ZEPLIN-II, ZEPLIN-III, Panda-X,
LUX/LZ, DRIFT-I, DRIFT-II, XENON100,
XENON1T, XENONnT, DarkSide-50,
DarkSide-20k, ARDM, DARWIN

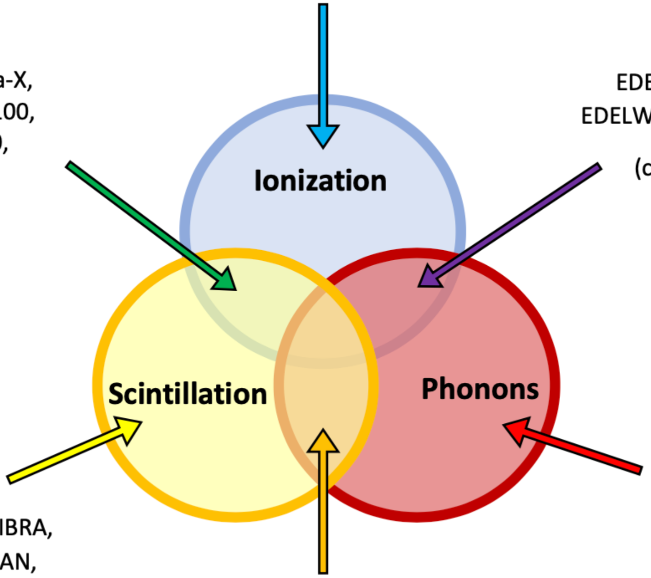
(cold, ~LN_2 temperature)

Heat and Ionization Bolometers

Targets: Ge, Si

EDELWEISS-I, EDELWEISS-II,
EDELWEISS-III, CDMS, SuperCDMS

(cryogenic, T<50mK)



Scintillators

Targets: NaI, CsI, Xe, Ar

ZEPLIN-I, KIMS, NAIAD, DAMA/LIBRA,
ANAIS, DEAP-3600, XMASS, CLEAN,
SABRE, COSINE, KIMS, DM-Ice, PICO-LON

Bolometers

Targets: Al_2O_3, TeO_2

CRESST-I, CUORE

(cryogenic, T<50mK)

Light and Heat Bolometers

Targets: $CaWO_4$, BGO, Al_2O_3, NaI, CsI, Li_2MoO_4

ROSEBUD, CRESST-II, CRESST-III,
COSINUS, CUPID

(cryogenic, T<50mK)

Emulsion

Targets: NIT (silver halides)

NEWSdm

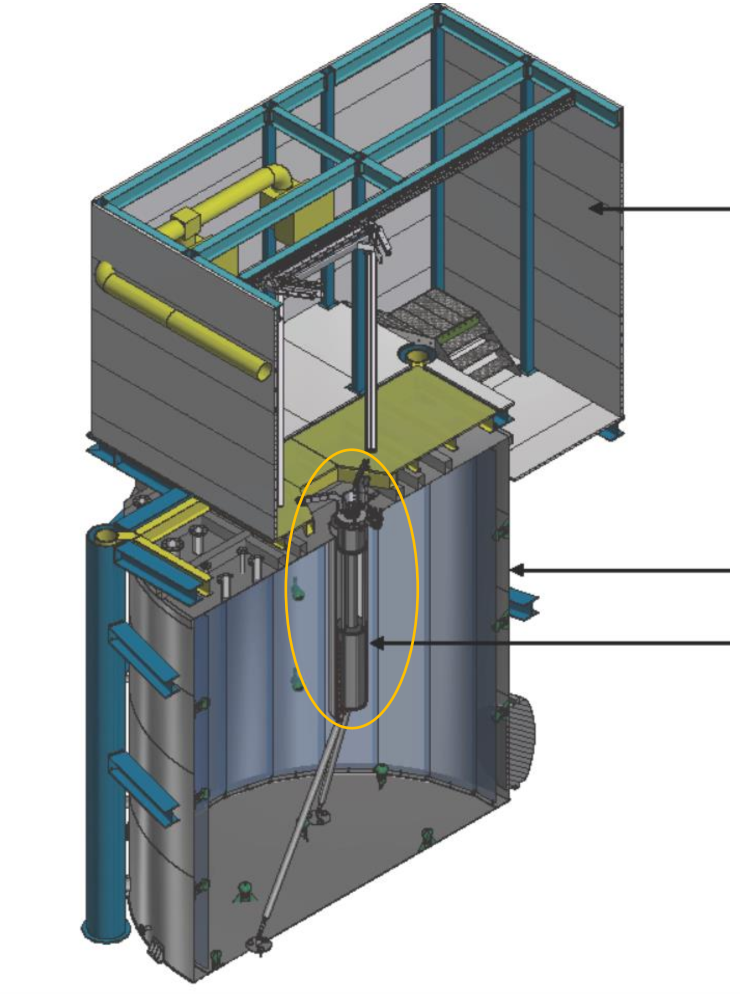
Bubbles and Droplets

Targets: CF_3Br, CF_3I, C_3F_8, C_4F_{10}

COUPP, PICASSO, SIMPLE, PICO-2L,
PICO-60, PICO-250

M. Stahlberg (2020),
https://doi.org/10.34726/hss.2021.45935

COSINUS Setup

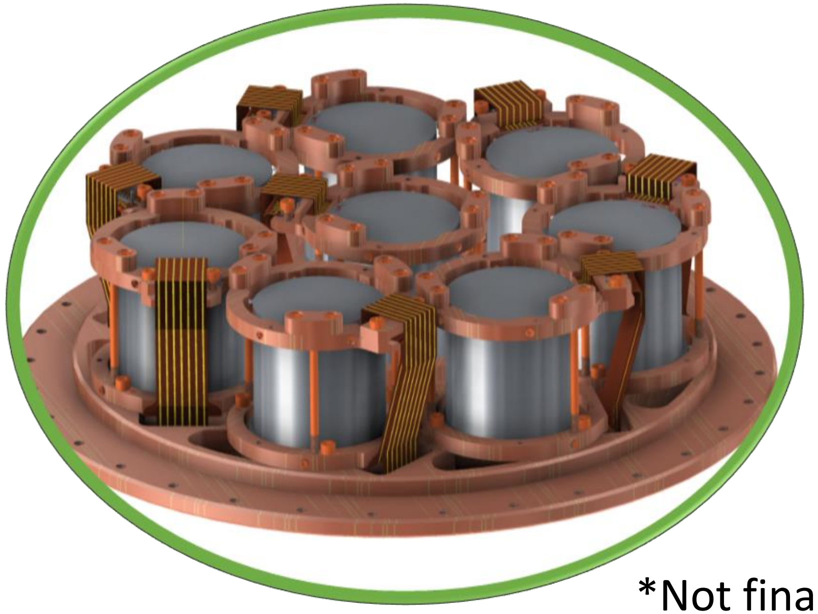


clean room

water tank

cryostat

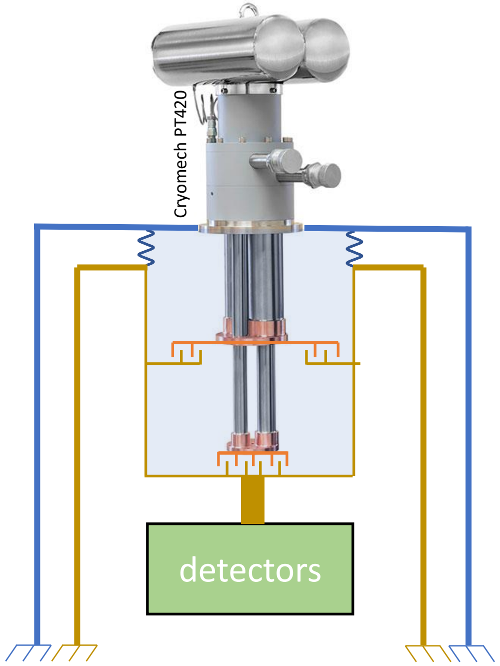
3x



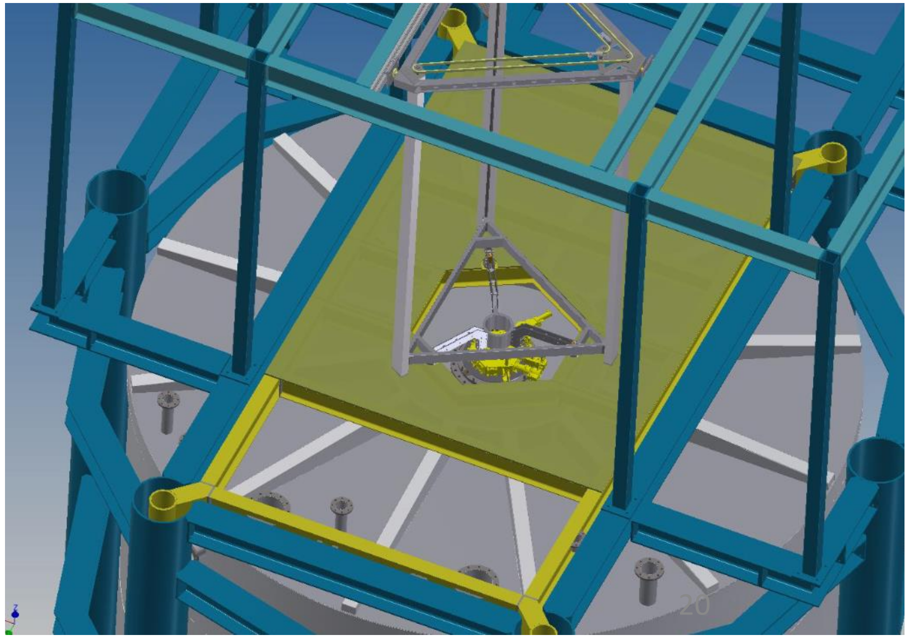
*Not final

Vibration mitigation

- COSINUS will use a dry dilution refrigerator to reach mK-temperatures
  - ➢ Trade-off between lower He-consumption and higher vibration level
- Cryoconcept „ultra quiet technology“ allows for decoupling from machine noise
  - ▪ Use separate frames for noisy machines (e.g. pumps) and cryostat
  - ▪ No physical contact between both frames
  - ▪ Exchange gas for thermalization
  - ▪ @LNGS: build separate building structures instead
- Additional spring-based passive decoupling at the detector stage

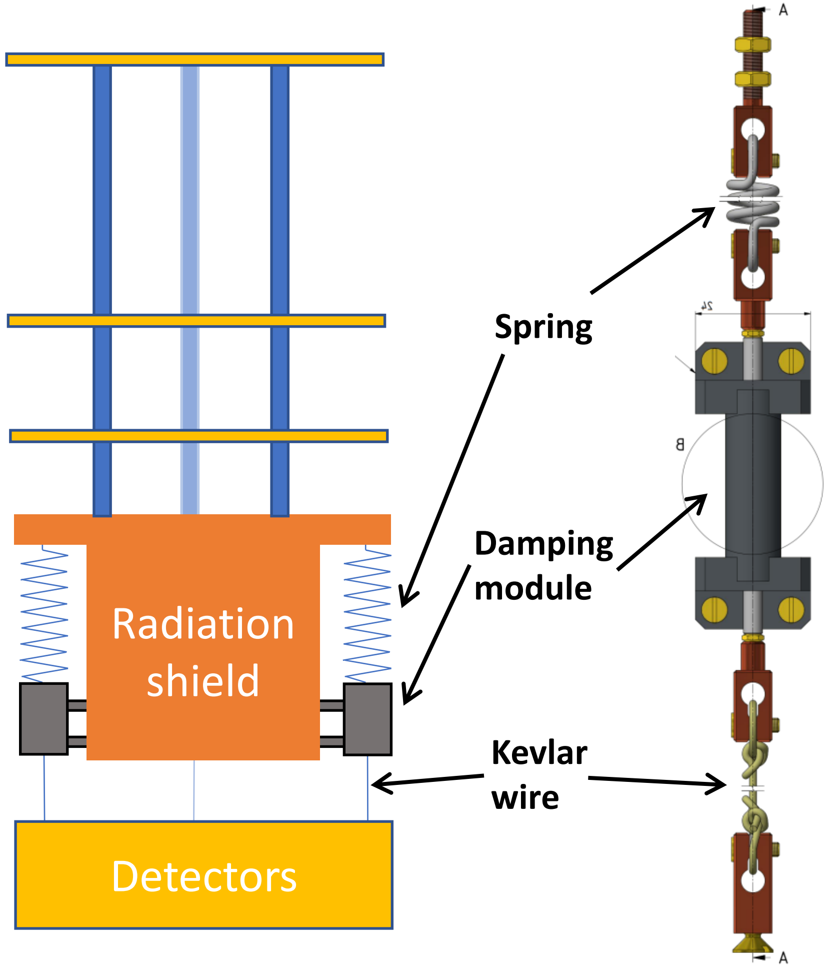


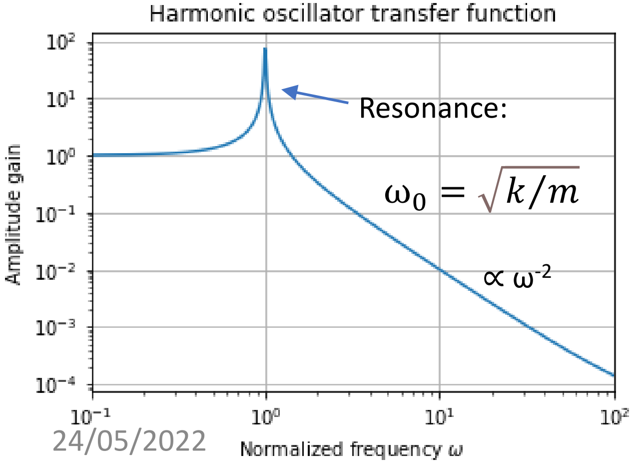
https://cryoconcept.com/product/the-ultra-quiet-technology/

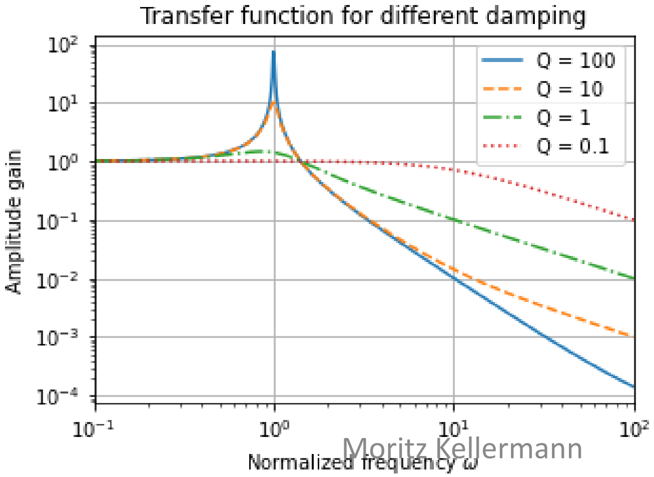


Spring-based passive decoupling

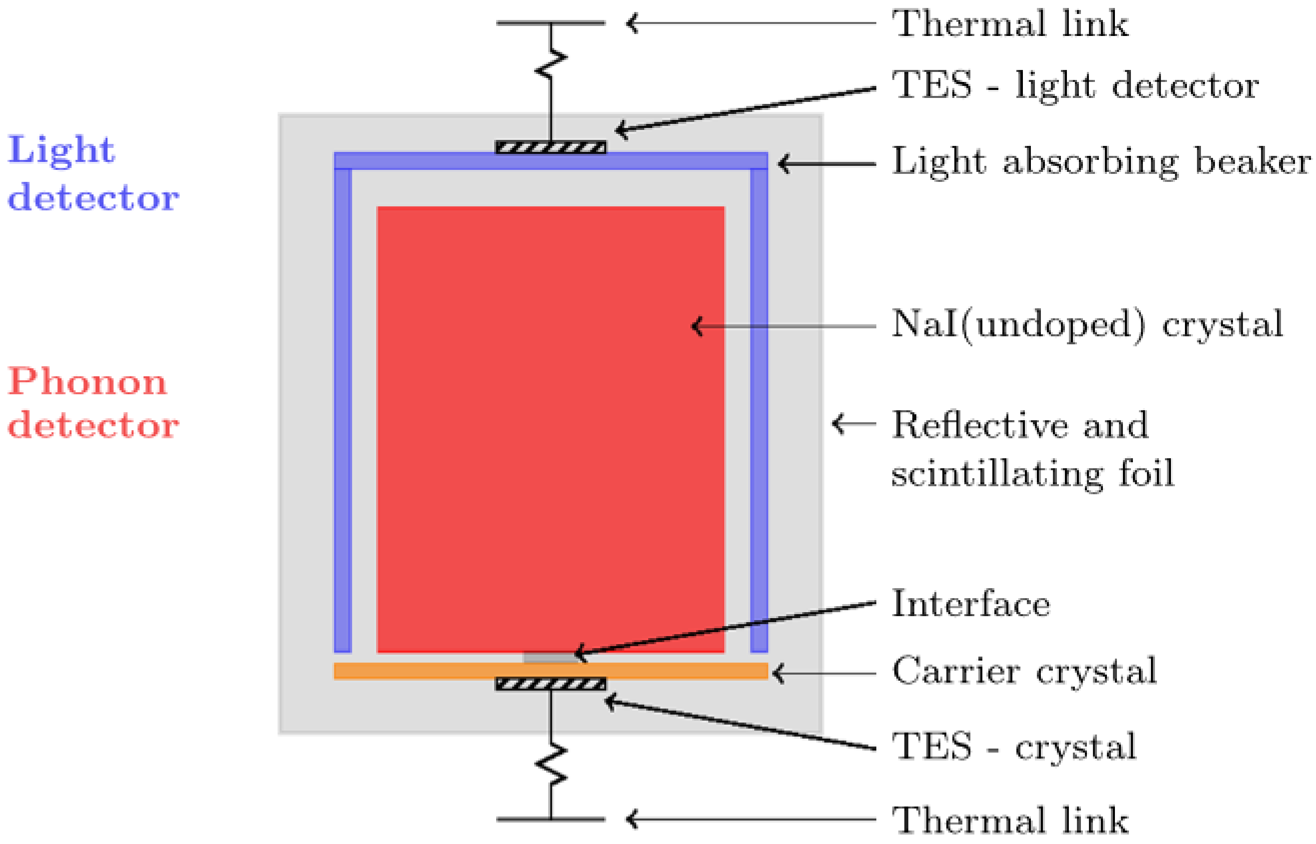
- Use the radiation shield for fixation:
  - ➢ High mass allows for a quiet starting point
  - ➢ Cooling power for the Cu-shield is high
- Decoupling system consists of 3 parts:
  1. Springs to decouple vertical motions
  2. ~10 cm for damping modules
  3. Kevlar to decouple horizontal motions and for thermal decoupling from the detectors



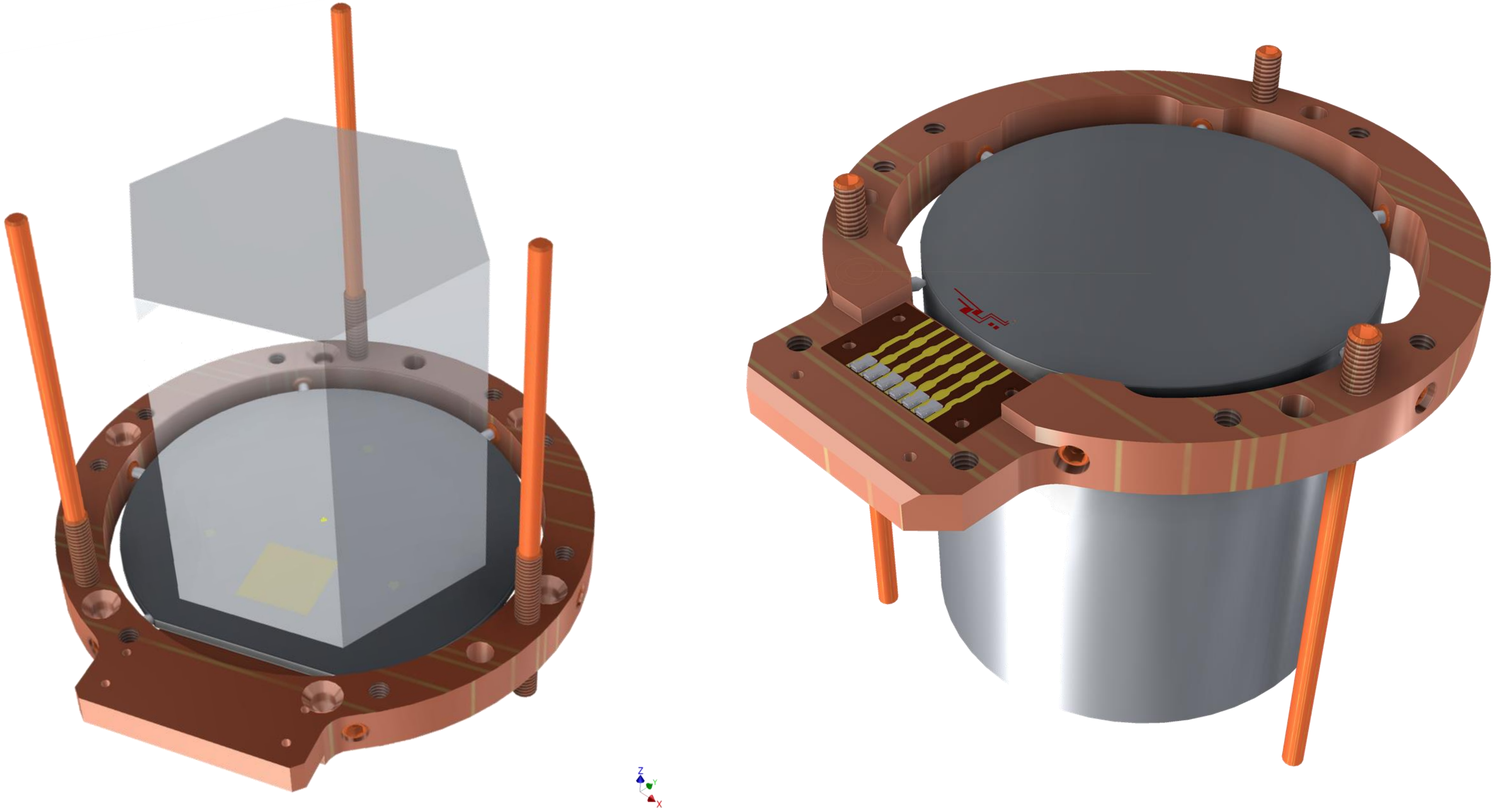




Backup – the abandoned baseline design



Backup – COSINUS detector module



Backup - PSD

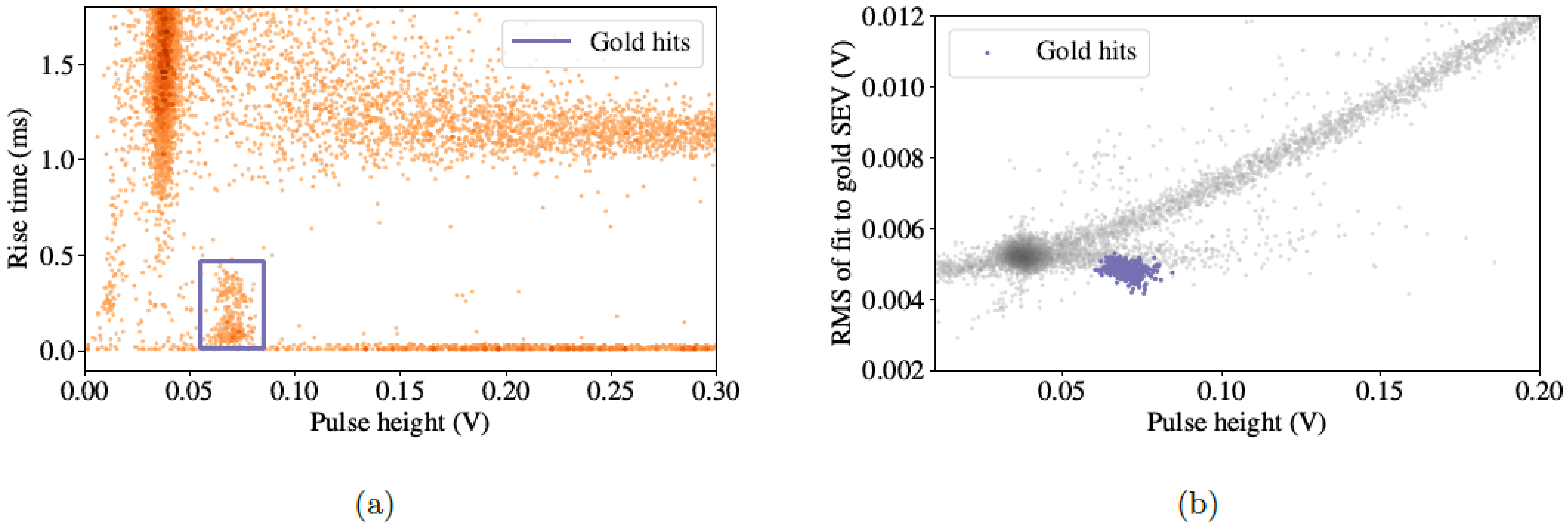


FIG. 3: TeO$_2$-*remoTES* data set: (a) Rise time versus moving average pulse height distribution. The violet box encloses the events in the gold foil produced by the collimated ^{55}Fe- source. (b) Fit RMS for the gold SEV as a function of the pulse height distribution. The events from the violet box in panel (a) are tagged and depicted in violet.

Backup – PSD 2

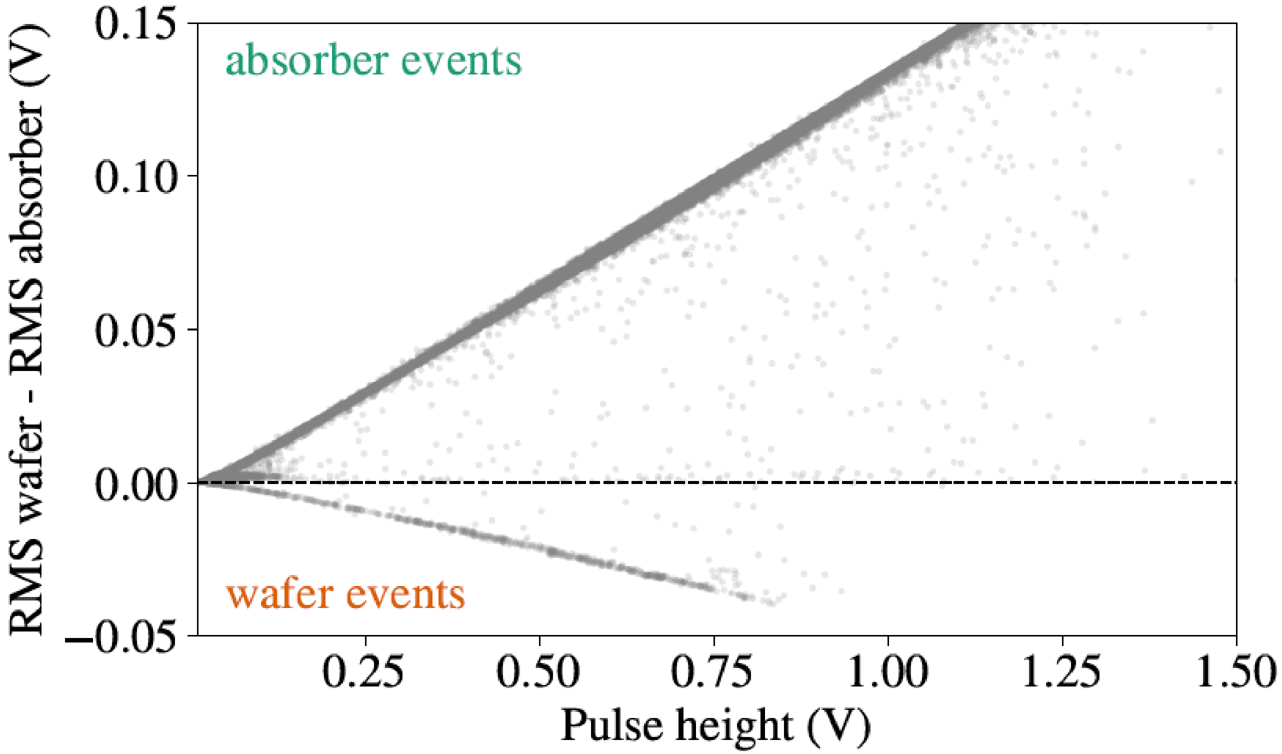
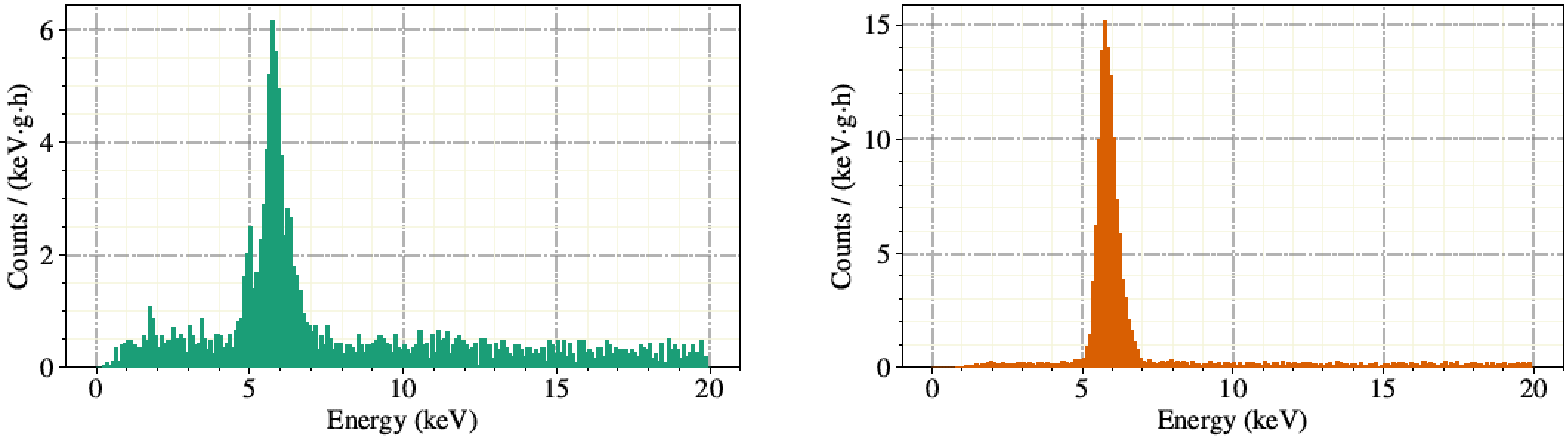


FIG. 4: Difference between RMS values from the wafer SEV fit and the absorber SEV fit as a function of moving-average pulse height for the TeO_2 prototype; different event bands corresponding to the different classes are visible. The event population between the absorber and the wafer band corresponds to the Au hits; its pulse shape is a mixture of the former two classes, and their shapes match it equally well.

Backup - Energy-calibration

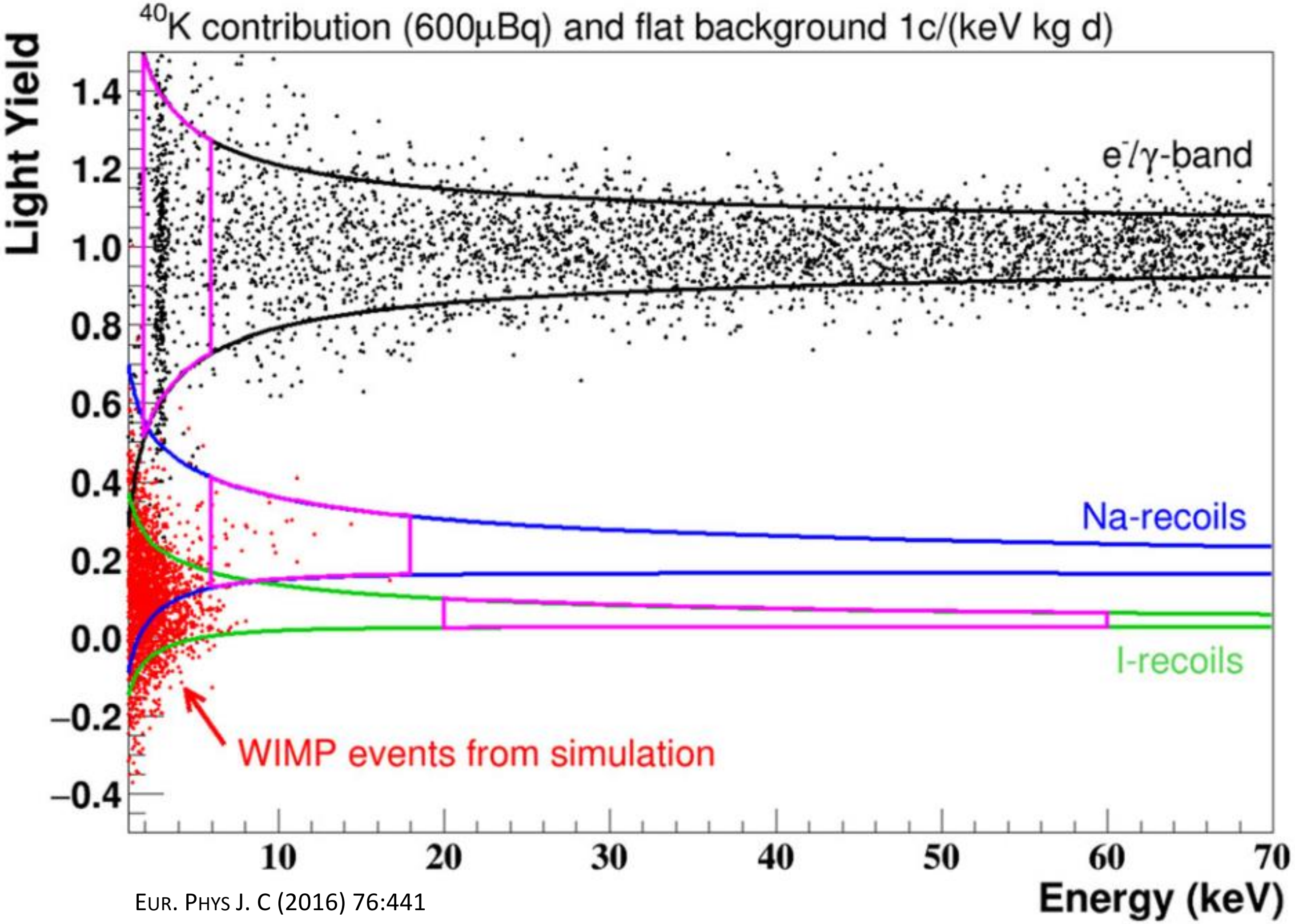


(a)

(b)

FIG. 5: The energy spectra of the two prototype detectors: (a) Si absorber and (b) TeO_2 absorber. The intensity of the ^{55}Fe-source producing X-rays of 5.89 keV (K_α) and 6.49 keV (K_β) was significantly stronger for (b). The additional peaks in the Si detector ($\sim$1.8 keV and $\sim$5 keV) are consistent with x-ray emission from the K-shell of Si (1.84 keV), and an escape line from Cu (L1 at 1.10 keV).

Backup – simulated band-fit



Eur. Phys J. C (2016) 76:441