COSINUS

Progressing towards shedding light on the DAMA/LIBRA claim

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UCLA

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Los Angeles, USA

MAX-PLANCK-INSTITUT FÜR PHYSIK

COSINUS: future cryogenic NaI DM search

~30 scientists, engineers, and technicians are building a **low-background cryogenic dark matter observatory** based on a **sodium iodide (NaI)** target

www.cosinus.it

HEPHY INSTITUTE OF HIGH ENERGY PHYSICS

TU WIEN

MAX-PLANCK-INSTITUT FÜR PHYSIK

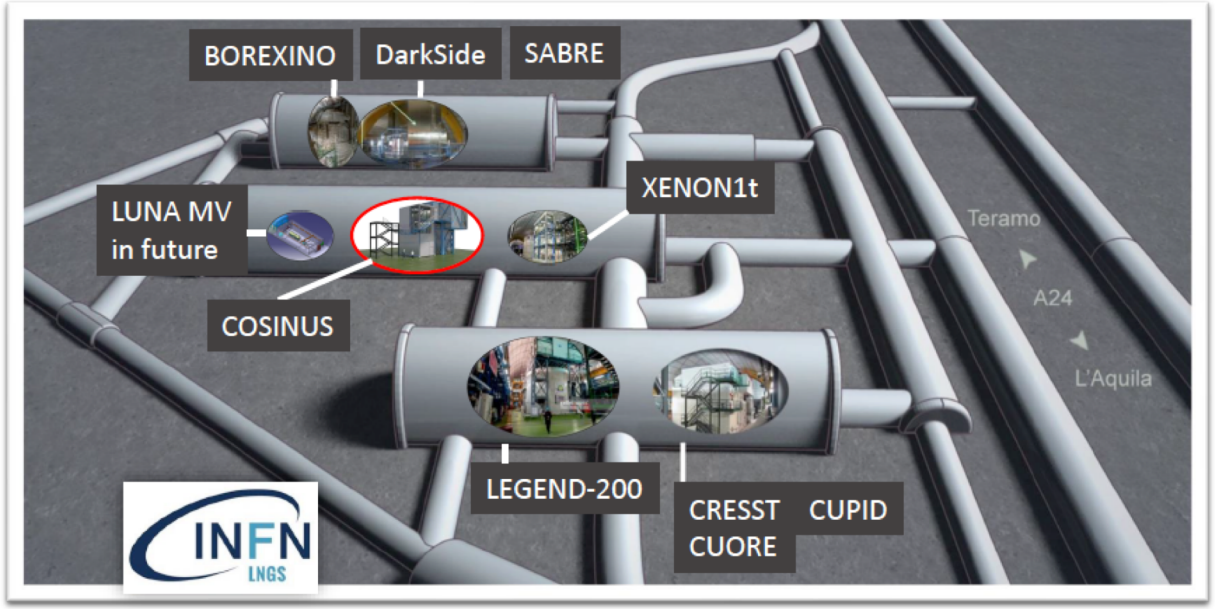
INFN Istituto Nazionale di Fisica Nucleare

HELSINKI INSTITUTE OF PHYSICS

GSSI GRAN SASSO SCIENCE INSTITUTE SCHOOL OF ADVANCED STUDIES Scuola Universitaria Superiore

SICCAS Since 1928

COSINUS experimental site

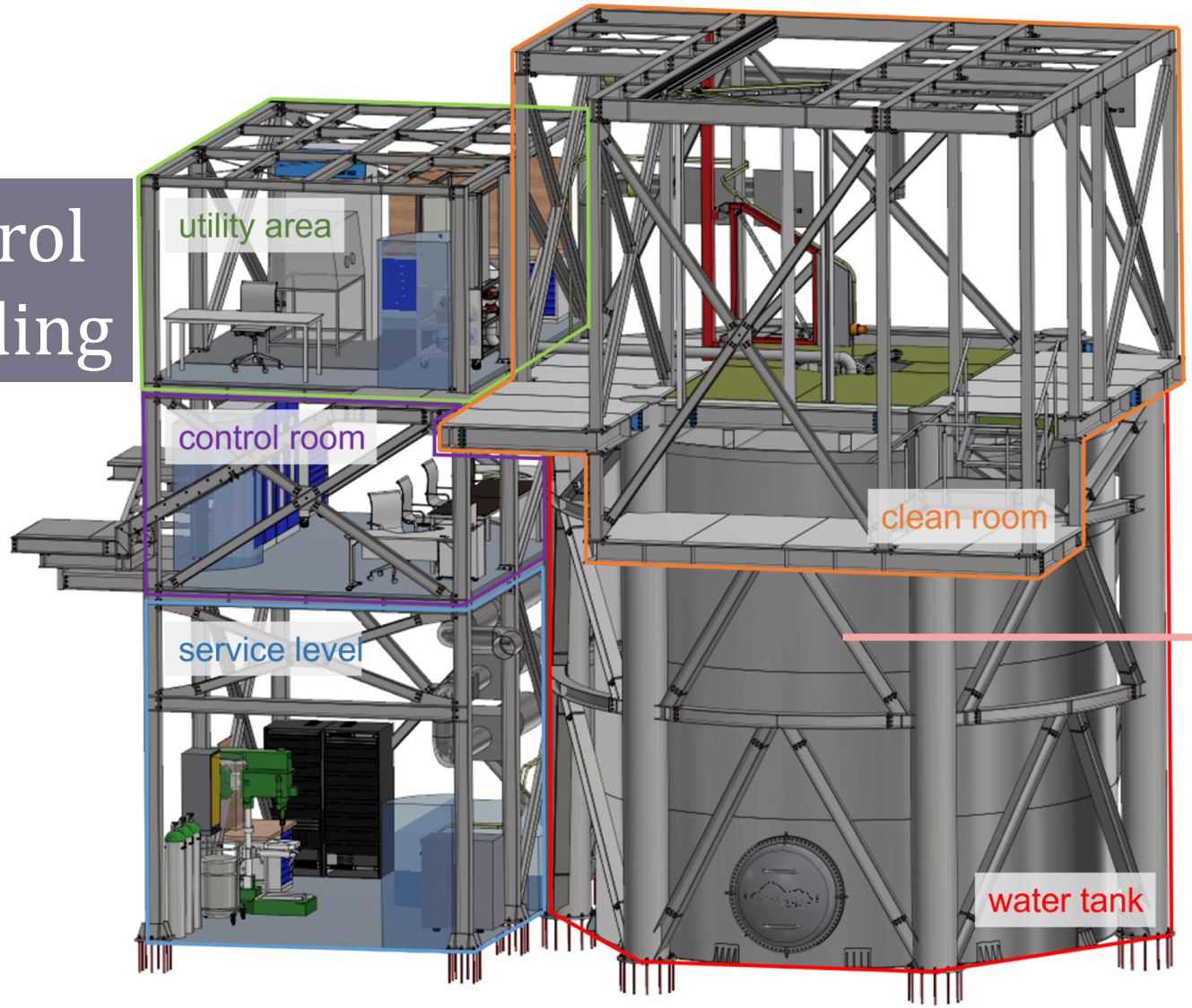


- Laboratori Nazionali del Gran Sasso (LNGS), Italy
- COSINUS is located in hall B
- full approval in 2021

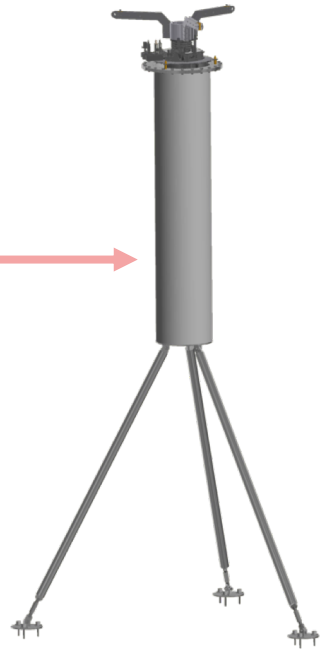
COSINUS experimental facility

Shielding design based on MC simulations: EPJ C 82, 2022

Control building



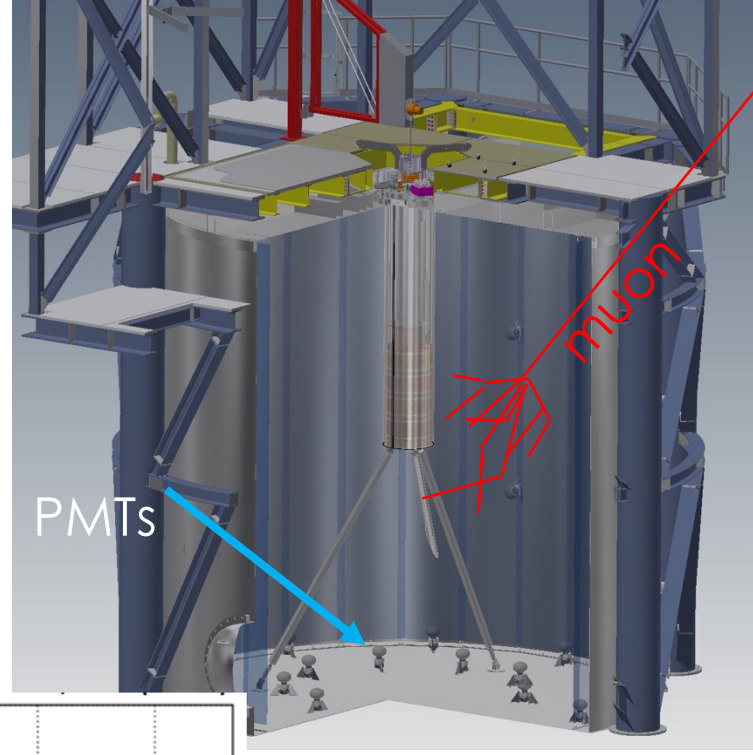
Dry-well supported by tripod



Dry dilution refrigerator + external Cu shield

WHY WE NEED A WATER TANK?

- good moderator for neutrons
- veto of (cosmogenic) muons via Cherenkov light emitted in water → instrumentation of water tank with 28 PMTs



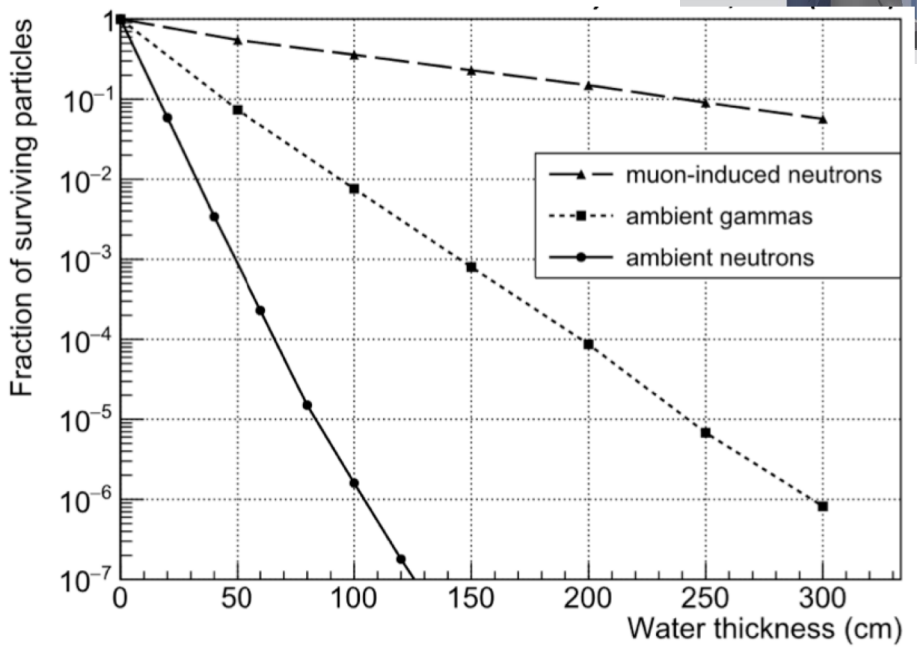
Rate of cosmogenic neutrons:

no veto:

(3.5 ± 0.7) counts kg^{-1} yr^{-1}

with veto:

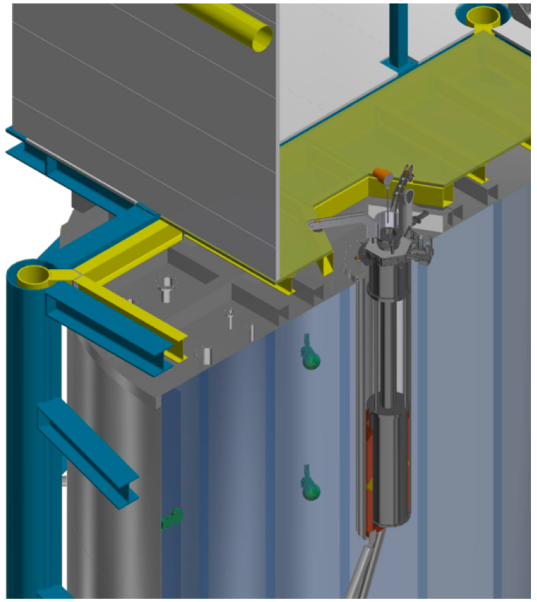
< 0.05 counts kg^{-1} yr^{-1}



EPJ C 82, 2022

VIBRATION MITIGATION: 3 LEVELS

GLOBAL STAGE

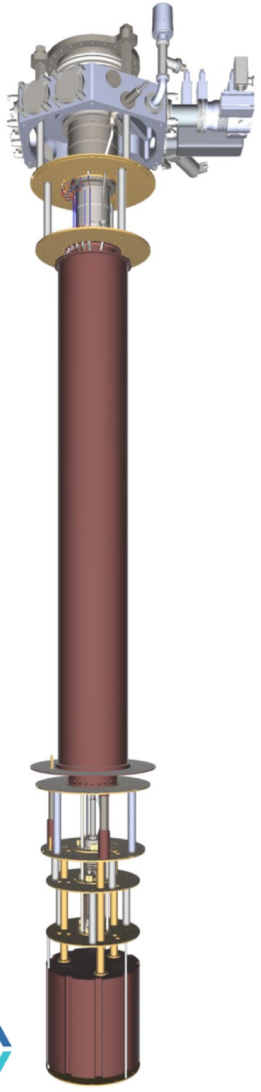


infrastructure on blue frame
→ most “noisy”

pulse tube unit on yellow frame
→ medium

cryostat “rests” in drywell
→ most quiet

CYROSTAT STAGE



UltraQuiet Technology

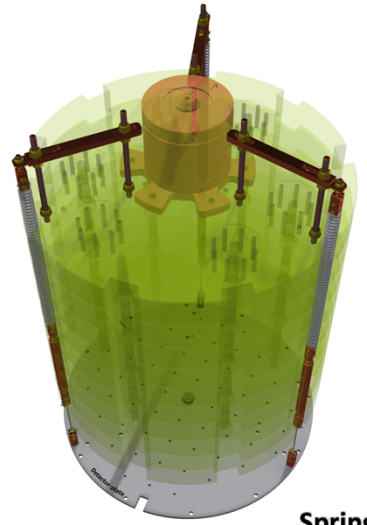
all parts of cryostat are centered

190 kg copper shield below the mixing chamber

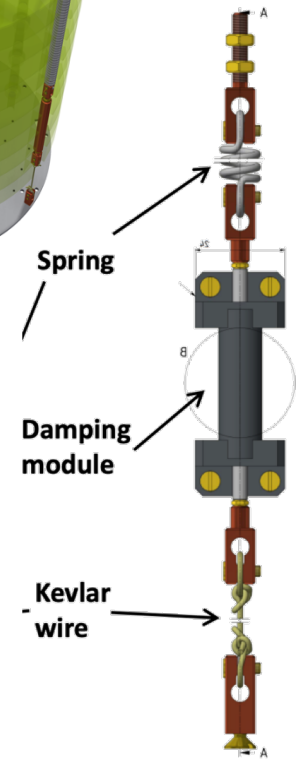
rotary valve of the pulse tube cooler on separate frame

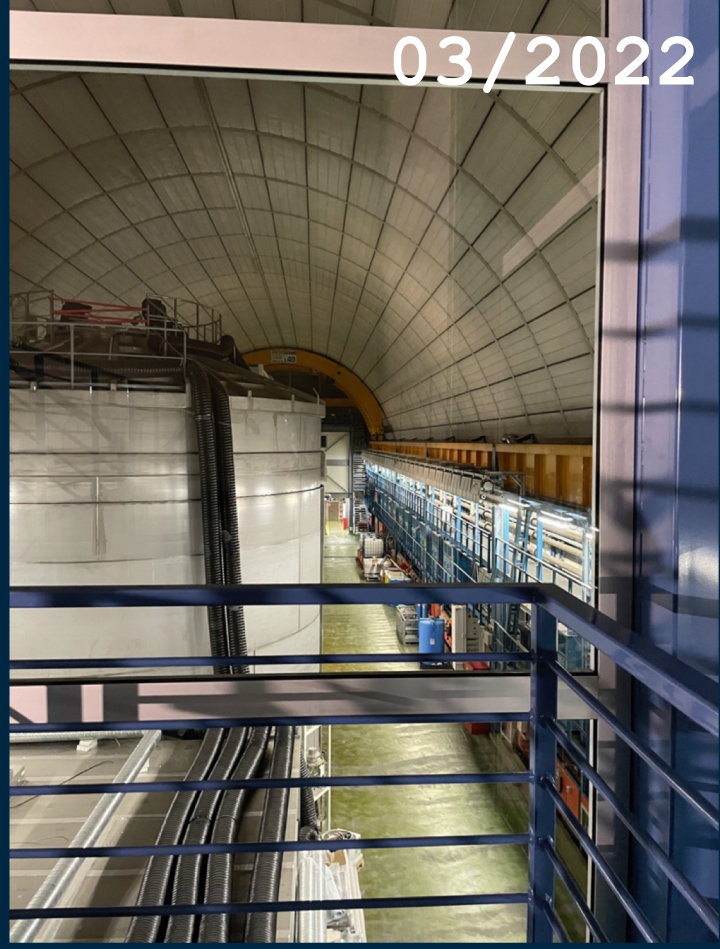
sandbox

DETECTOR STAGE



Spring and damping modules to decouple the detector plate





installation @ LNGS: 11/2021 – ongoing

Water tank, platform equipped with clean room and control building finished !

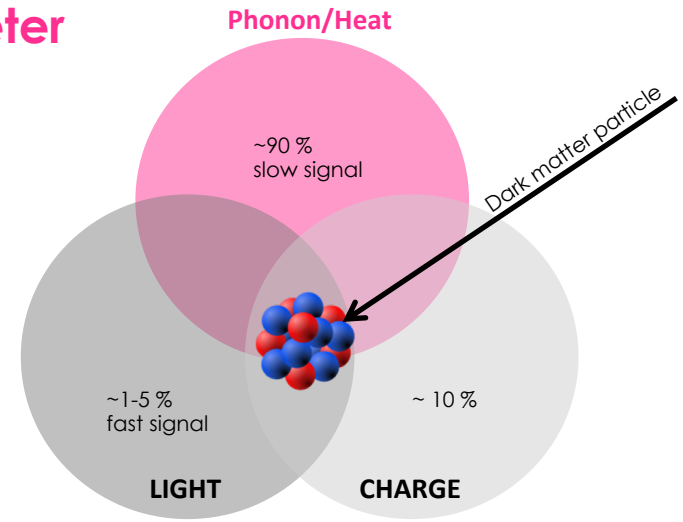
→ this week: installation start of electrical infrastructure

COSINUS SEARCH **STRATEGY**

Model- and target independent test of DAMA

→ *novel* and *unique*: **sodium iodide target as low-temperature calorimeter**

- HEAT CHANNEL: precise energy information
  + low threshold for nuclear recoils



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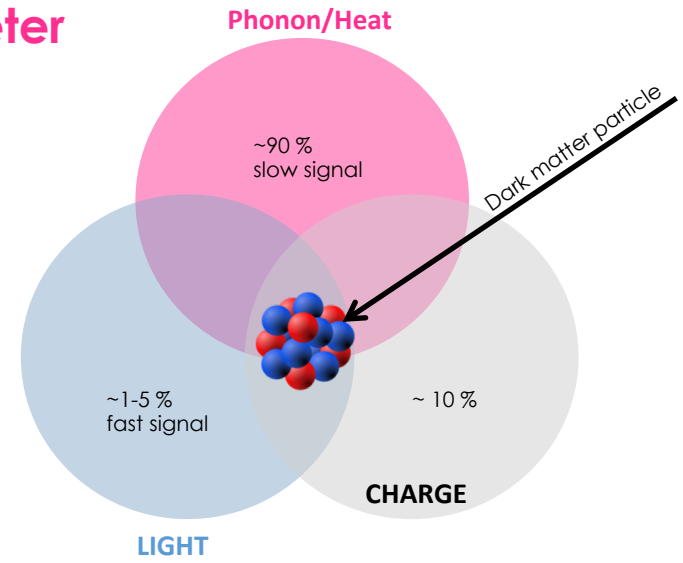

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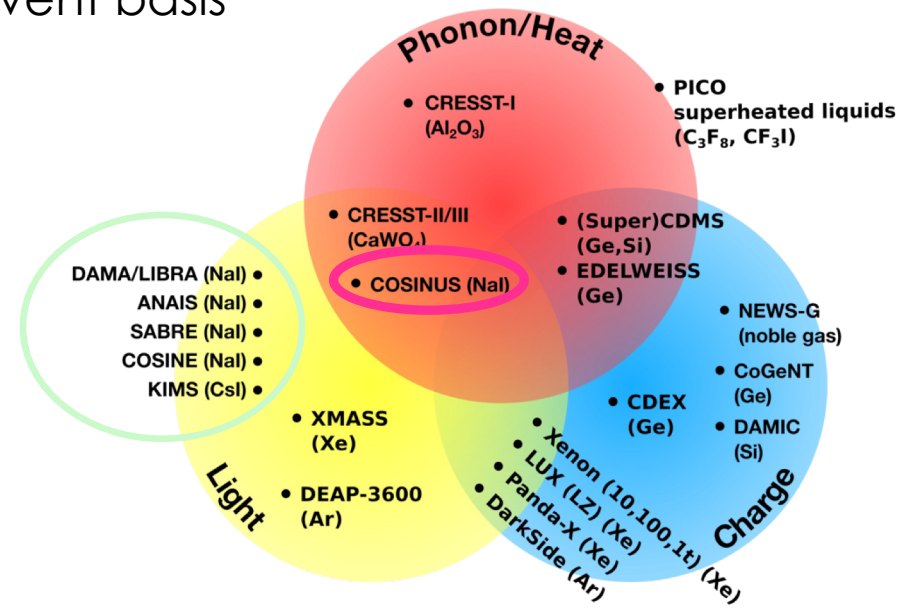
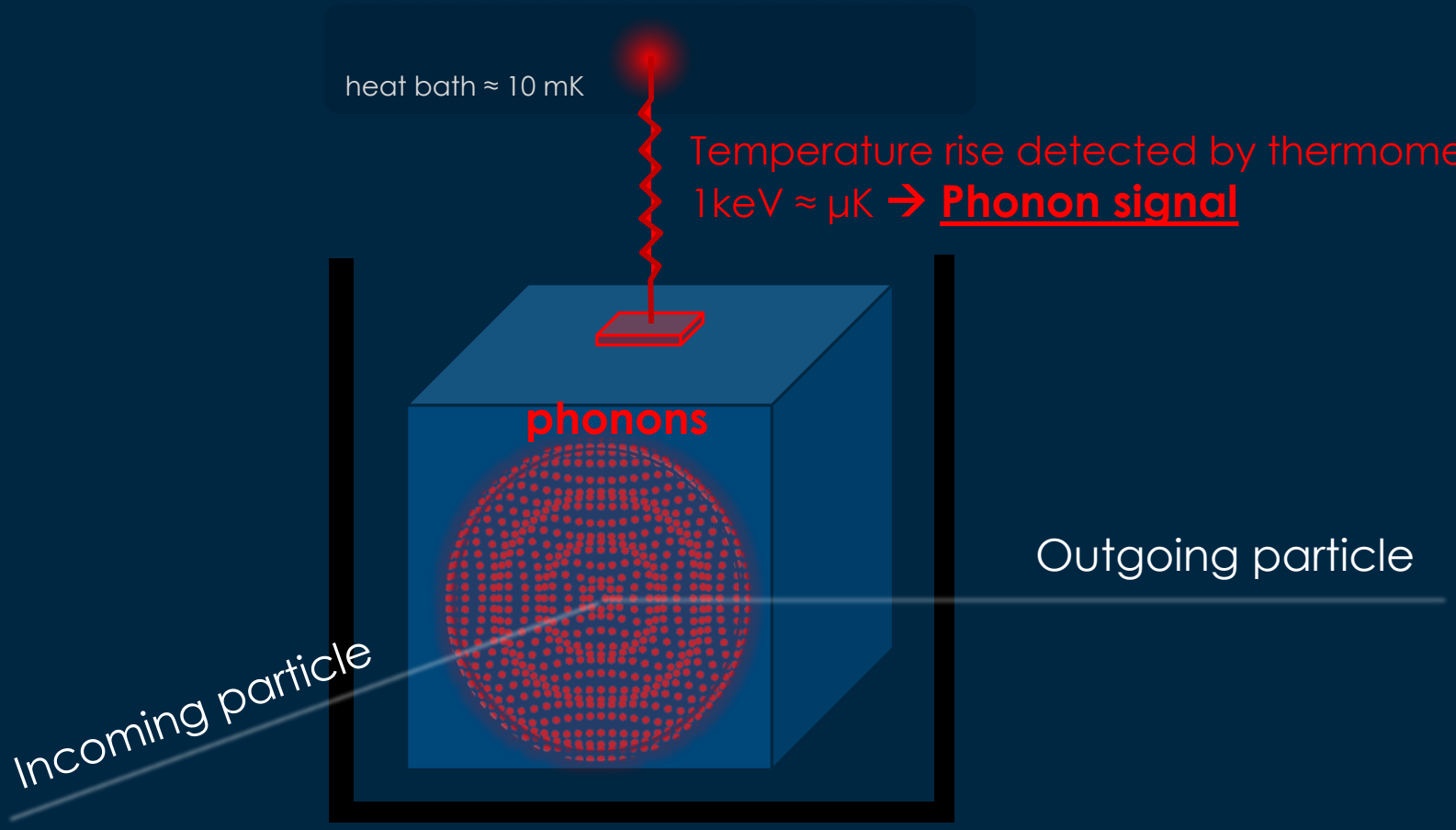
→ Signal-only measurement of potential DM signal

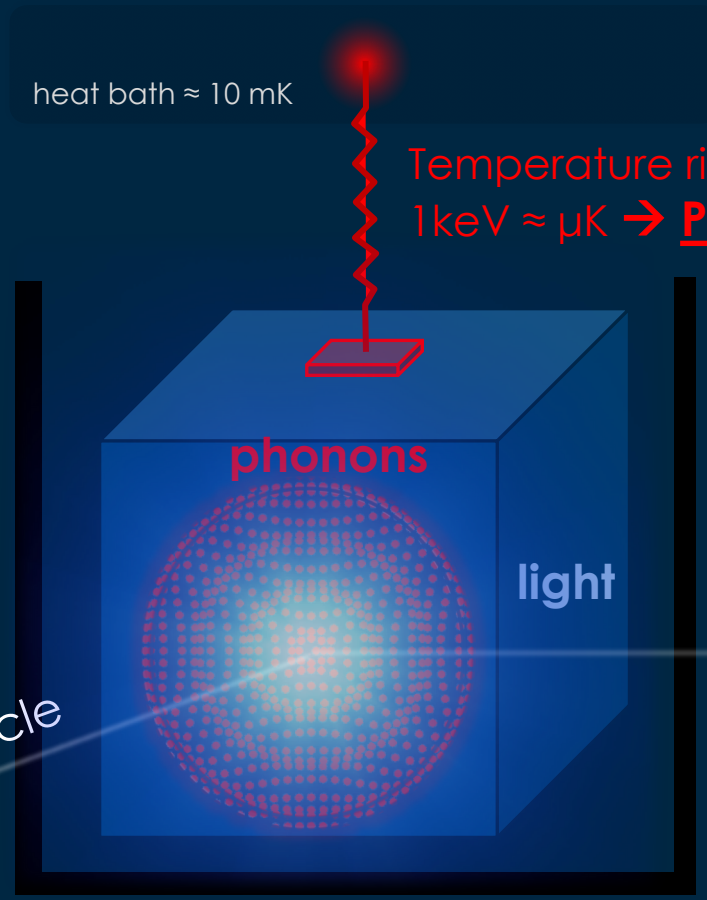


Credits to: F. Reindl

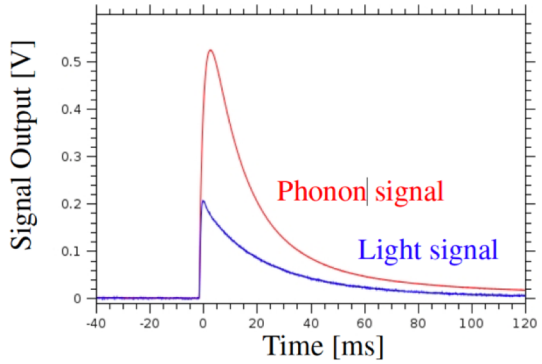
LOW-TEMPERATURE CALORIMETER



LOW-TEMPERATURE CALORIMETER



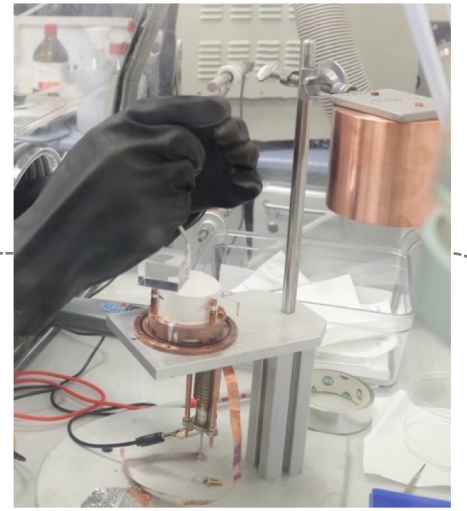
Temperature rise detected by thermometer
1keV ≈ µK → **Phonon signal**



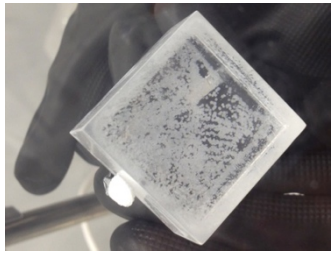
Particle discrimination via the **ratio of light to phonon signal**

Prompt scintillation light detected by separate, cryogenic light absorber → **Light signal**

… NaI is not that NaIce !



hygroscopic nature



handle only in controlled atmosphere

^{40}K in the NaI crystal

NaI grown in collaboration with SICCAS Since 1928

5-9 ppb of K at crystals' nose and 22-35 ppb at crystals' tail

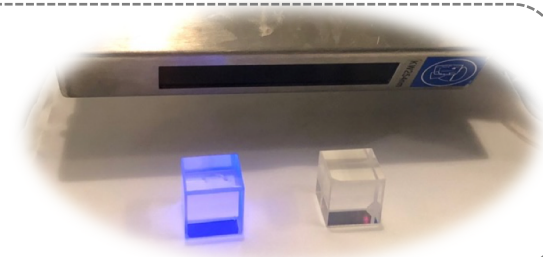
(3-inch crystal, Astrograde powder from Merck) Zhu, Y. et al, IEEE, 2018

low Debye temperature

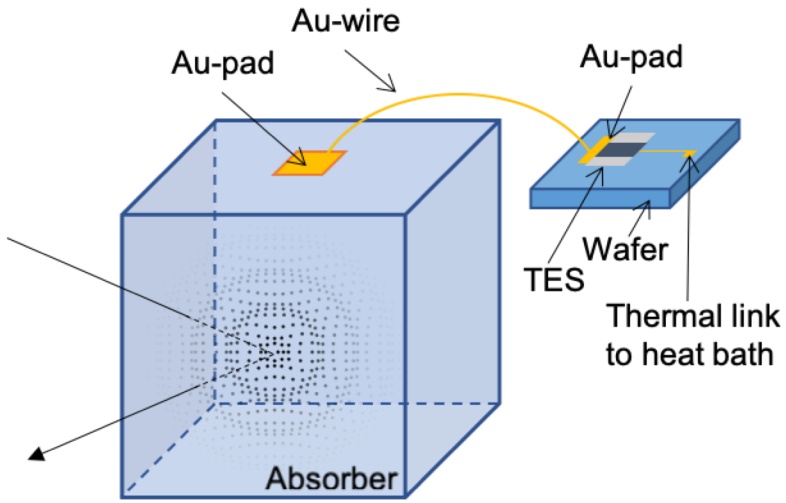
NIM A 1045, 167532

adapted thermometer → remoTES

+ avoid other phonon-loss channels



remoTES DESIGN

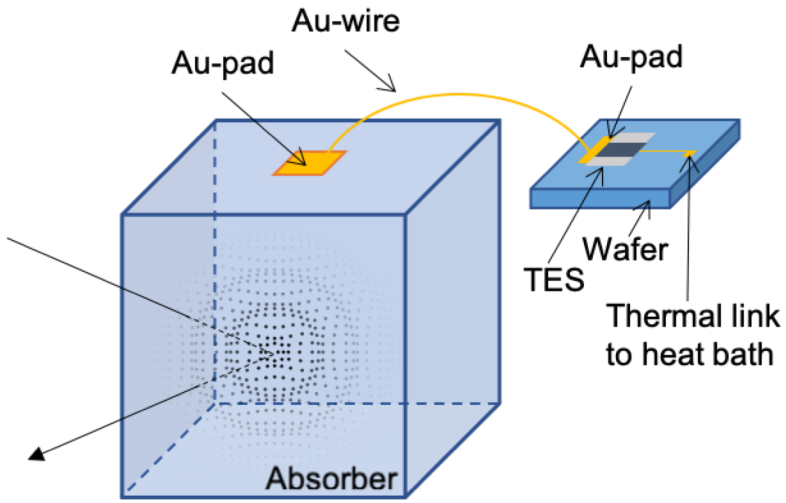


NIM A 1045 2023 167532

- separate wafer
  hosts the thermometer
  (TES = transition edge sensor)
- gold pad glued / evaporated onto NaI crystal
  phonons propagate in NaI and couple to the electron system of the Au pad
- gold bond wire
  connection to the temperature sensor

→ → absorber excluded from fabrication process

remoTES DESIGN

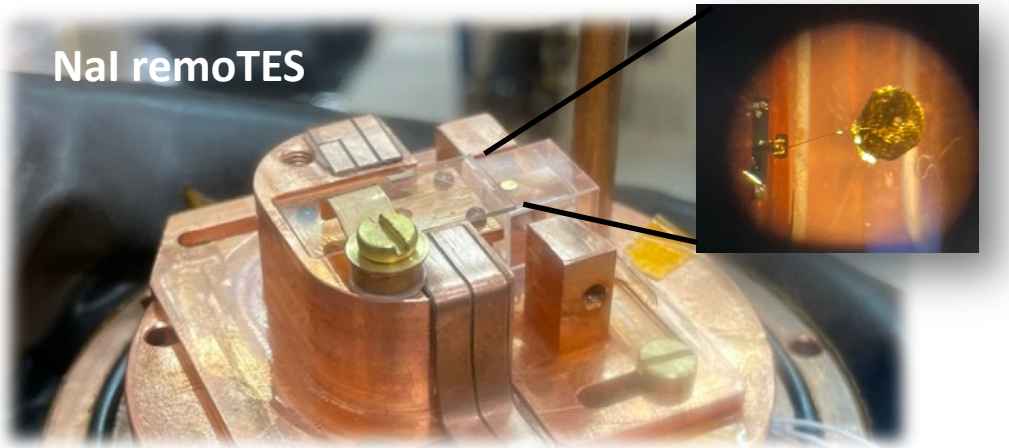


NIM A 1045 2023 167532
→ proof of principle: Si and TeO_2 as targets

Matt Pyle et. al, 2015
arXiv:1503.01200

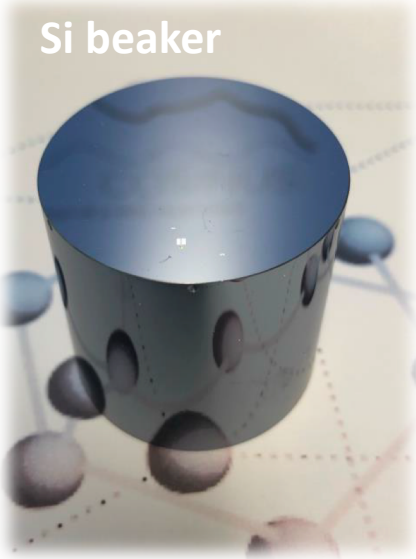
remoTES readout opens field of cryogenic detectors for delicate, non-standard target materials for **dark matter** and **neutrino physics**

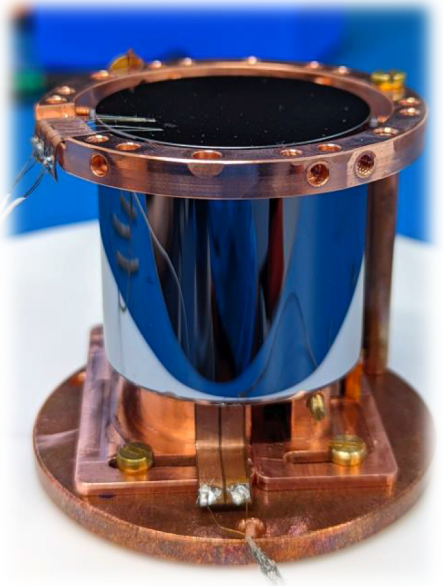
RESULTS FROM NaI-remoTES – June 2022



- NaI (undoped) grown by SICCAS
- dimensions: 10x10x10mm^3; about 4 g
- Au-foil glued with epoxy
- Au-pad size: 4 mm^2
- TES wafer (Al_2O_3) with W-TES

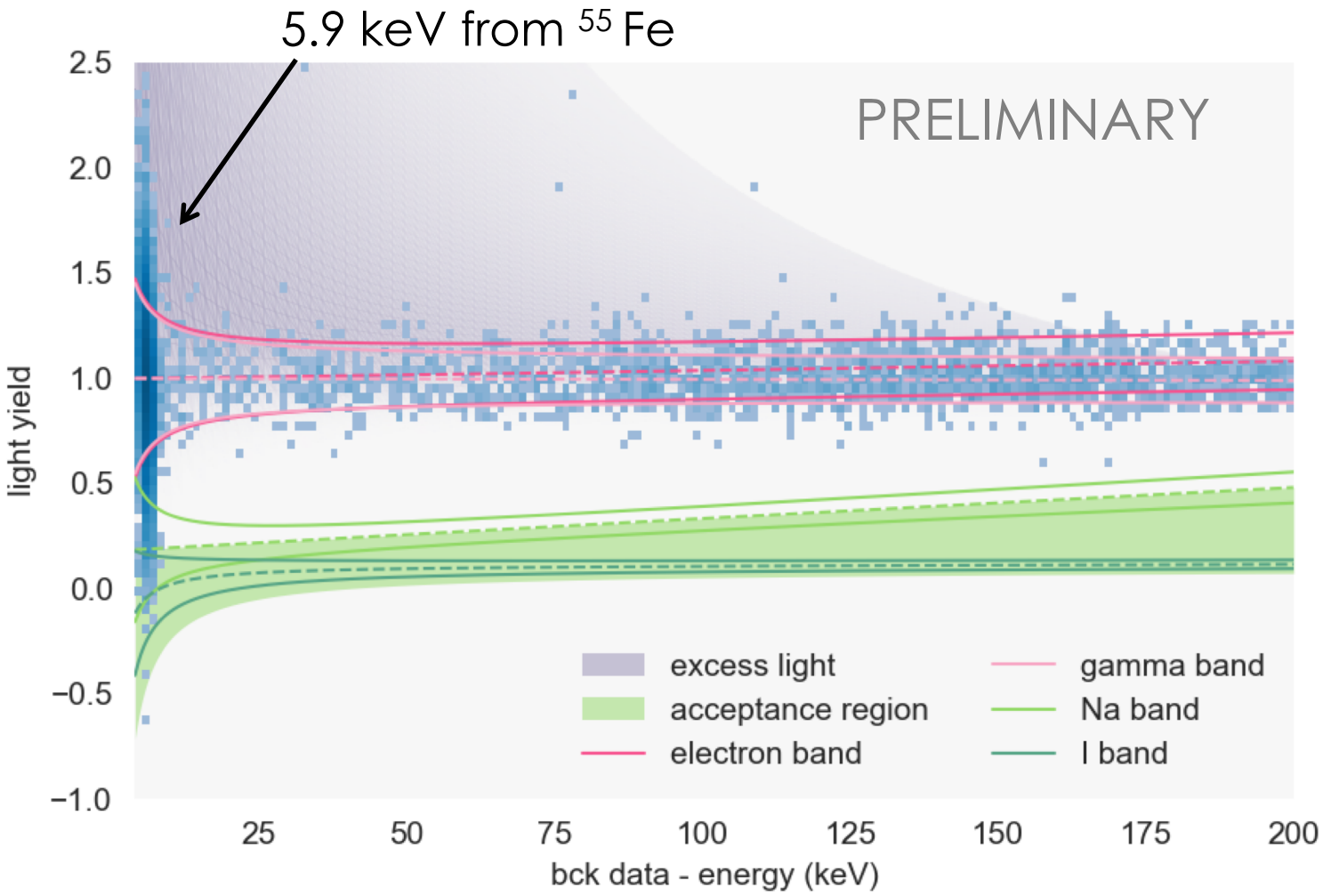
- silicon light absorber of beaker-shape
- dimensions: 40 mm diameter and height, 1 mm thick
- mass: 15.1 g
- W-TES directly evaporated onto the Si beaker
- TES optimized for light detection



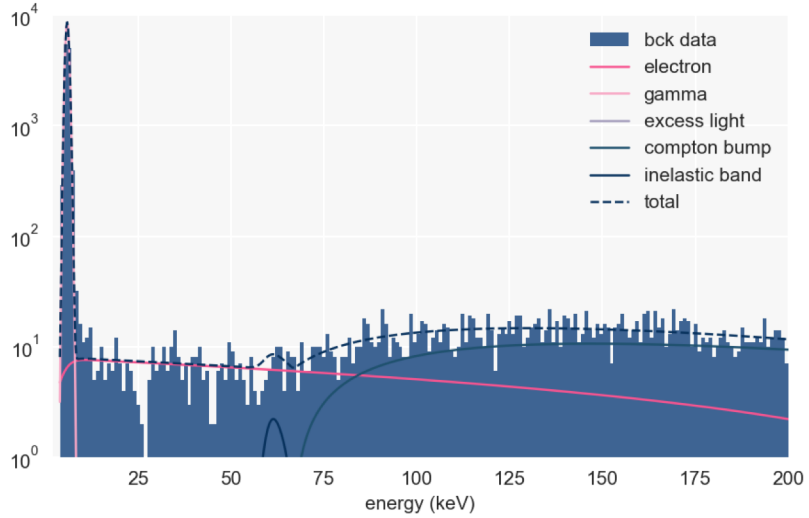


BACKGROUND DATA

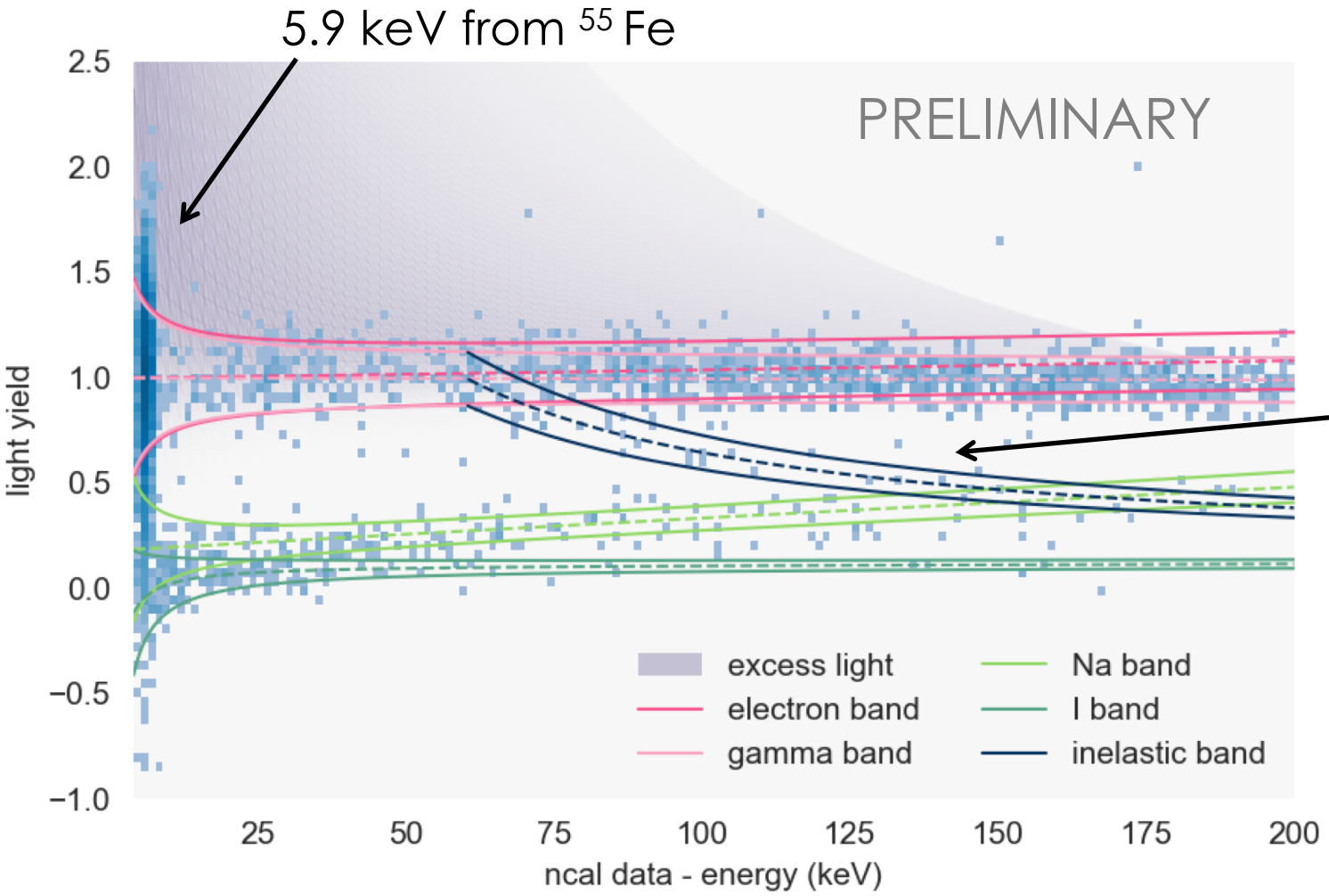
Measurement carried out at the test facility of CRESST @ LNGS

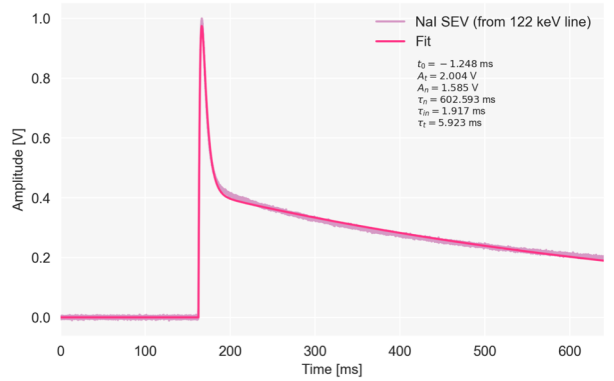


- 58.07 hours of data
- σ_{NaI} = 0.441 +/- 0.11 keV → **E_{thr} < 2 keV**
- σ_{LD} = 0.988 +/- 0.052 eV_{ee}
- $\sigma_{LD\text{-}direct}$ = 23.87 +/- 0.55 eV
- light output NaI: ~ **2.5%**
- energy calibration with ^{55}Fe & ^{57}Co



NEUTRON DATA





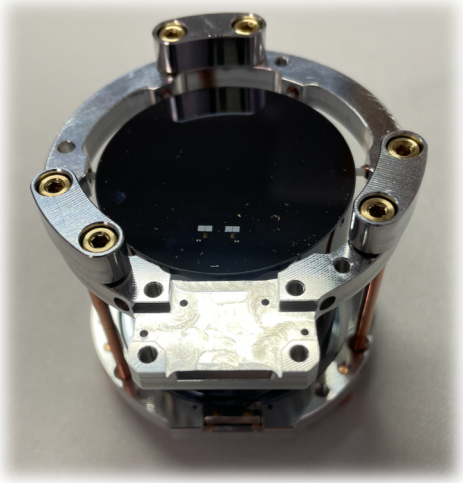
- AmBe neutron source
- 26.0 hours of data

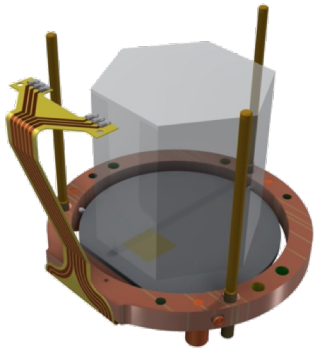
events due to inelastic scattering

Quenching factors
10 keV: Na = 0.2 QF I = 0.03
50 keV: Na = 0.25 QF I = 0.09

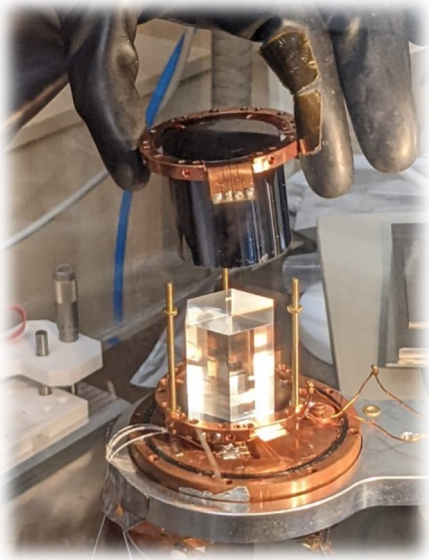
proof of particle identification in a NaI-based detector

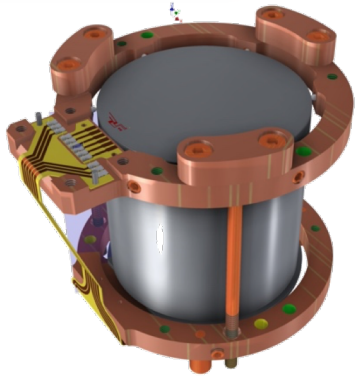
OUTLOOK



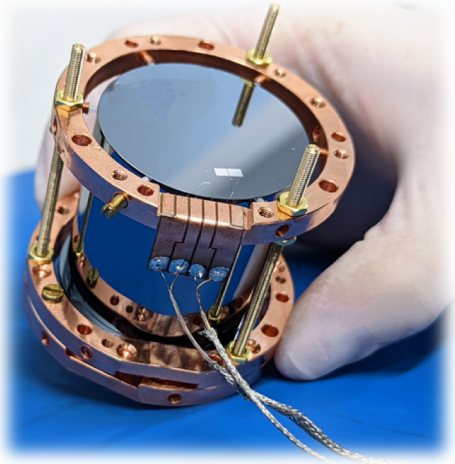


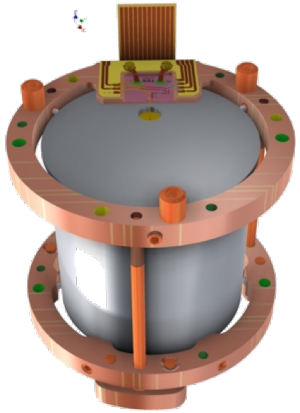
- hexagonal crystal (65 g / 110 g)
- lid to host crystal

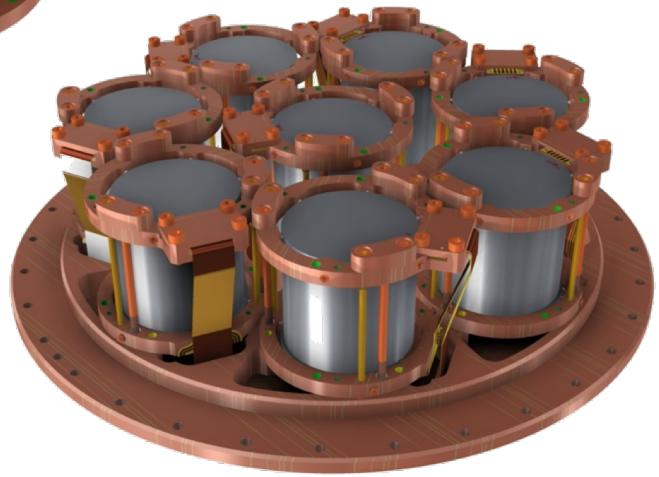




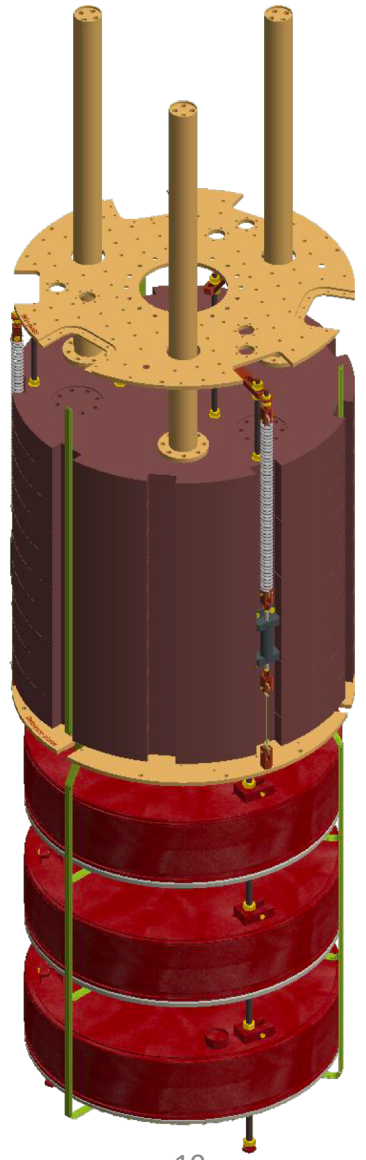
- Si-beaker for 4π active surrounding of the crystal





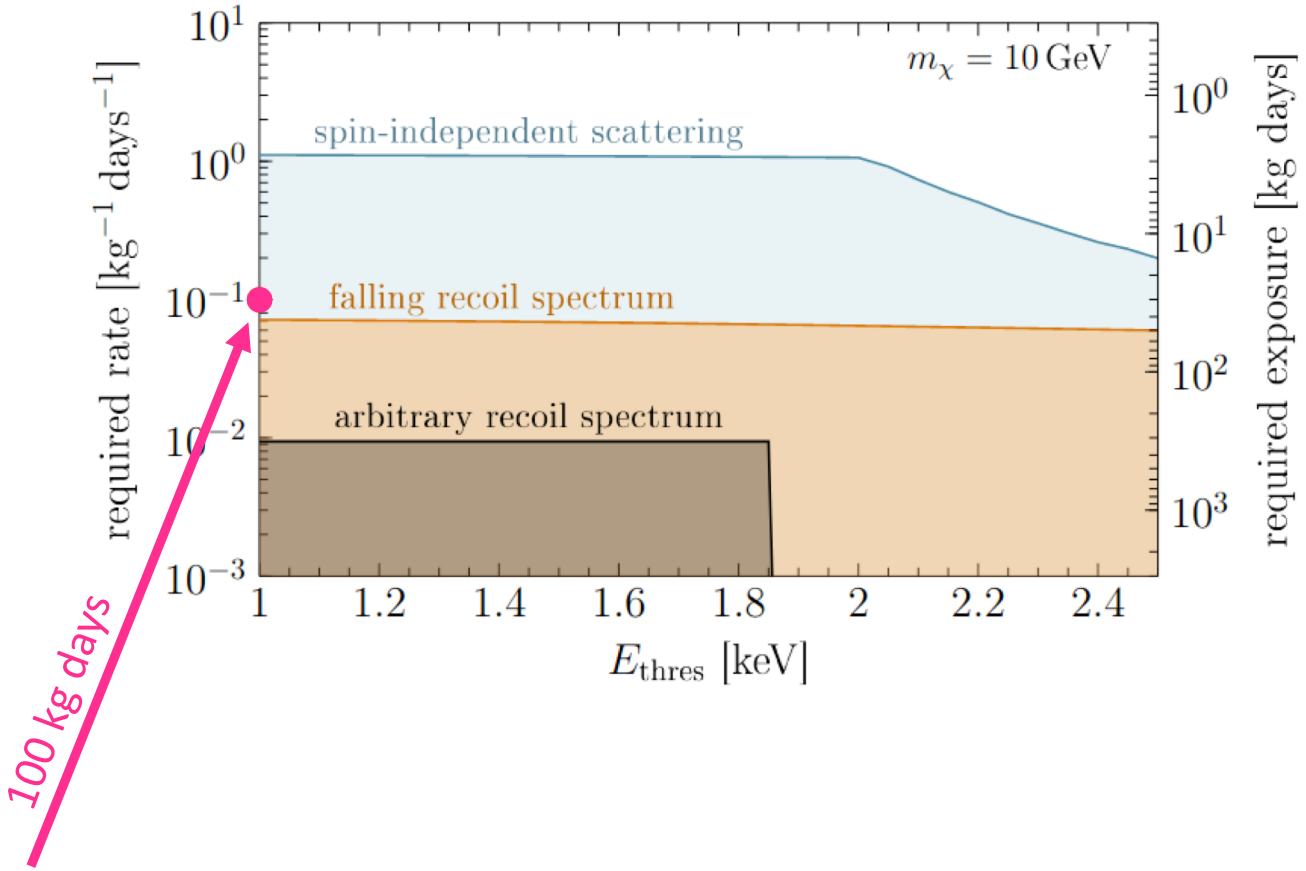


- 8 detector modules per level
- 3 levels in final stage



PHYSICS REACH

F. Kahlhöfer, KS et al., JCAP 1805 (2018) no.05, 074



COSINUS – 1π (2023-2026)

exclude or confirm **nuclear recoil origin** of DAMA:

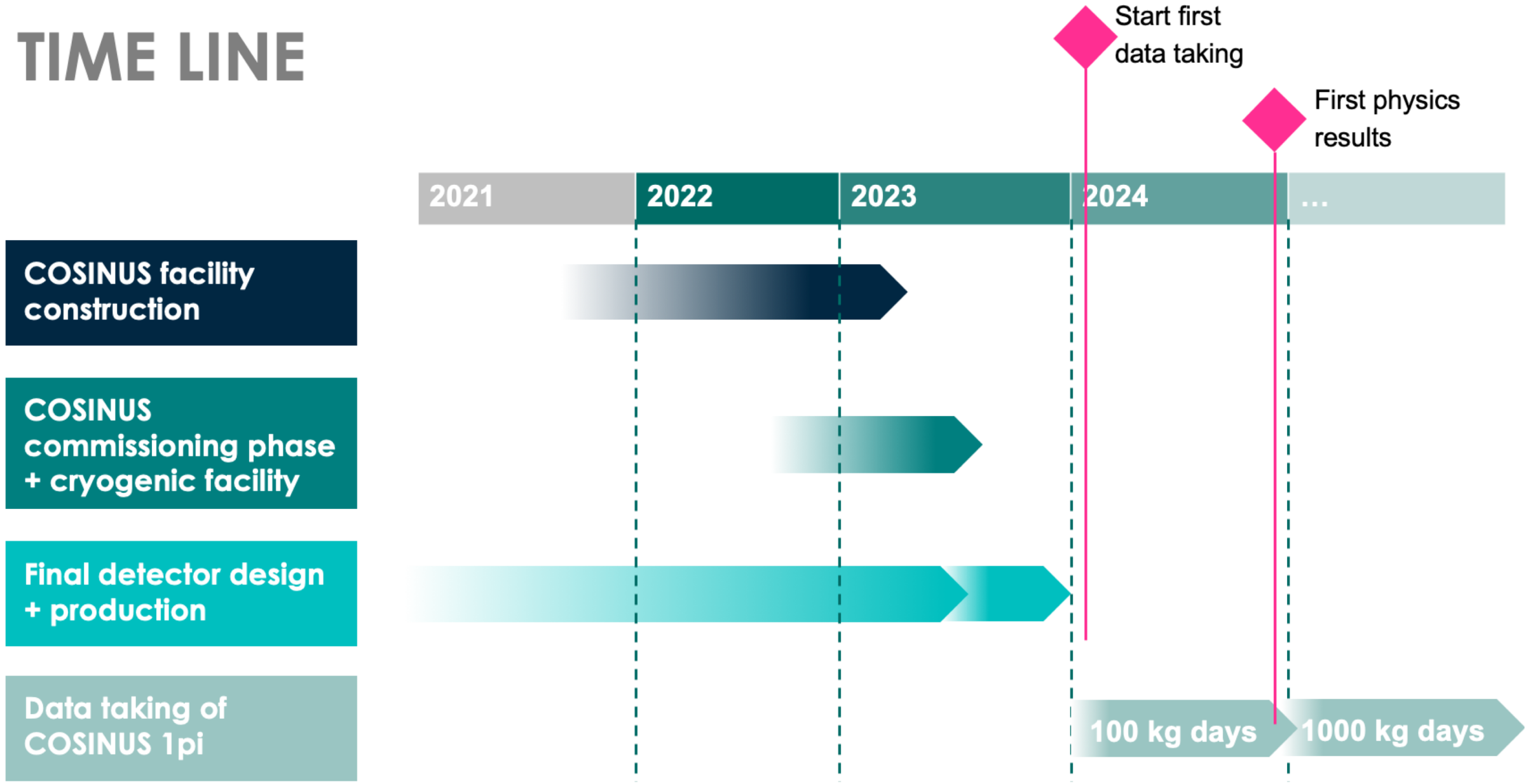
- independent of DM halo
- for any interaction of DM with nuclei

COSINUS – 2π (≥ 2026)

Investigate annual modulation signature with COSINUS

Warning:
Not updated for DAMA result with 1keVee !!

TIME LINE


Start first data taking
First physics results
2021
2022
2023
2024
...
COSINUS facility construction
COSINUS commissioning phase + cryogenic facility
Final detector design + production
Data taking of COSINUS 1pi
100 kg days
1000 kg days

CONCLUSION

Dark matter is a fundamental question of present-day physics and COSINUS can confirm or reject the DAMA/LIBRA claim

COSINUS developed the first NaI dark matter detector with particle discrimination and offers better sensitivity at smaller target mass (~1kg for COSINUS vs. 250 kg for DAMA)

The *remoTES* readout design allowed to produce first NaI calorimeter that achieved the performance goal (E_{thr} < 2keV);
remoTES also of interest for other delicate targets and applications

COSINUS is constructing full steam a unique and modern low-background cryogenic facility at the Gran Sasso underground lab; first data taking is scheduled to start early 2024 !

Stay tuned, promising potential for new discoveries in the coming years !


Thank you for your attention
@Maurizio Verdecchia Photography

EXTRA MATERIAL

RATE vs. MODULATION AMPLITUDE

F. Kahlhöfer, KS et al., JCAP 1805 (2018) no.05, 074

Central idea: modulation amplitude
cannot be larger than (average) absolute rate:

$$\overline{R} \geq S$$

COSINUS

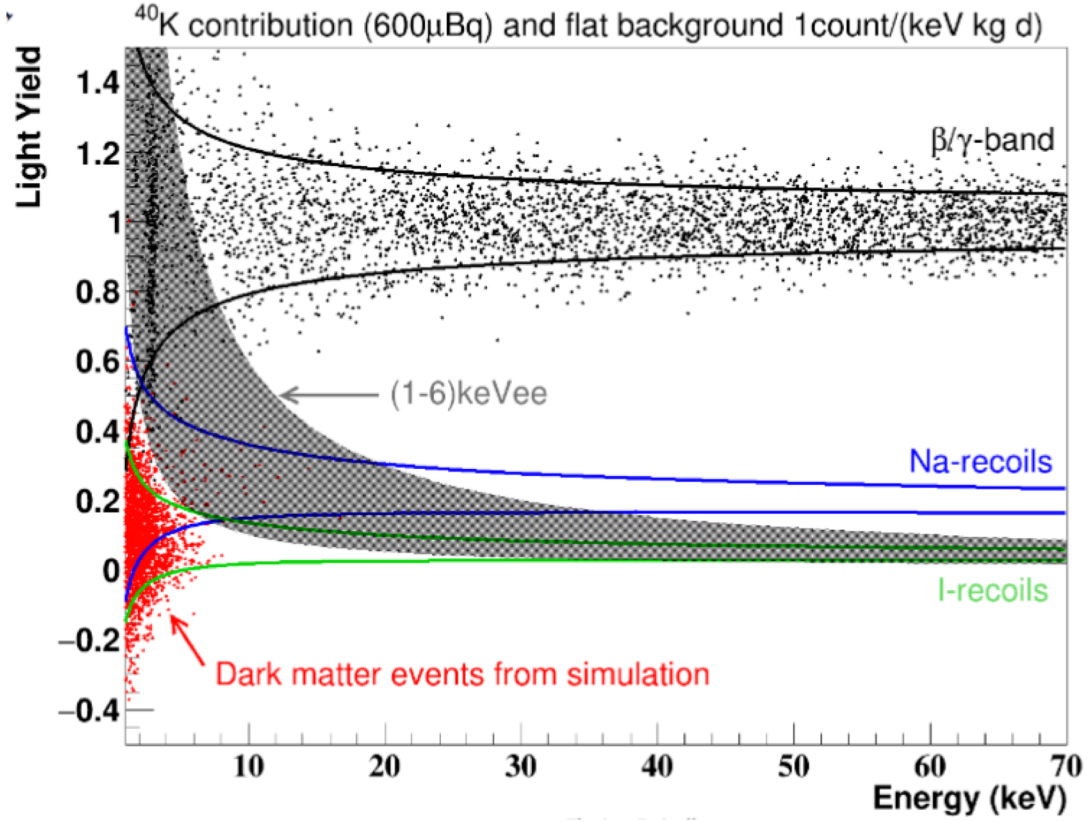
Mean rate $\overline{R} = \frac{1}{2}\,[R(t = \text{June } 1^{st}) + R(t = \text{Dec. } 1^{st})]$

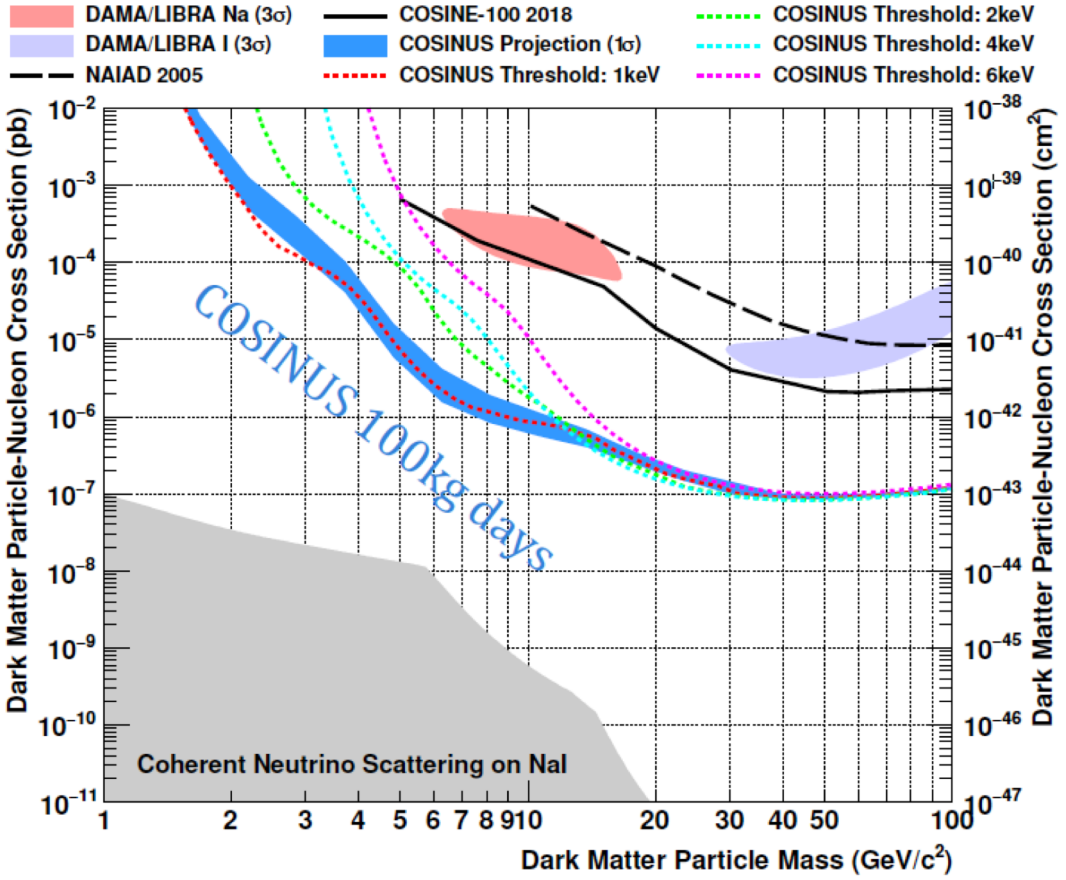
DAMA

Modulation Amplitude $S = \frac{1}{2}\,[R(t = \text{June } 1^{st}) - R(t = \text{Dec. } 1^{st})]$

→ low background condition makes it possible to test DAMA
in a single annual cycle

SIMULATED DATA FOR 100 kg days (gross-exposure)

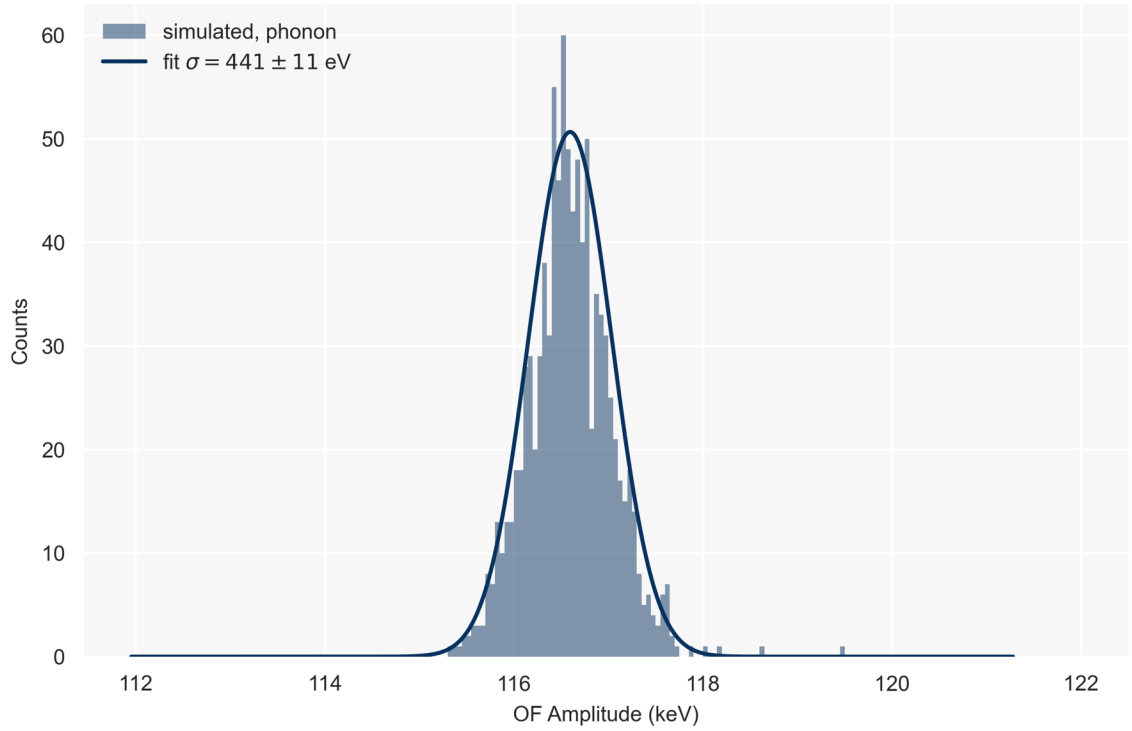


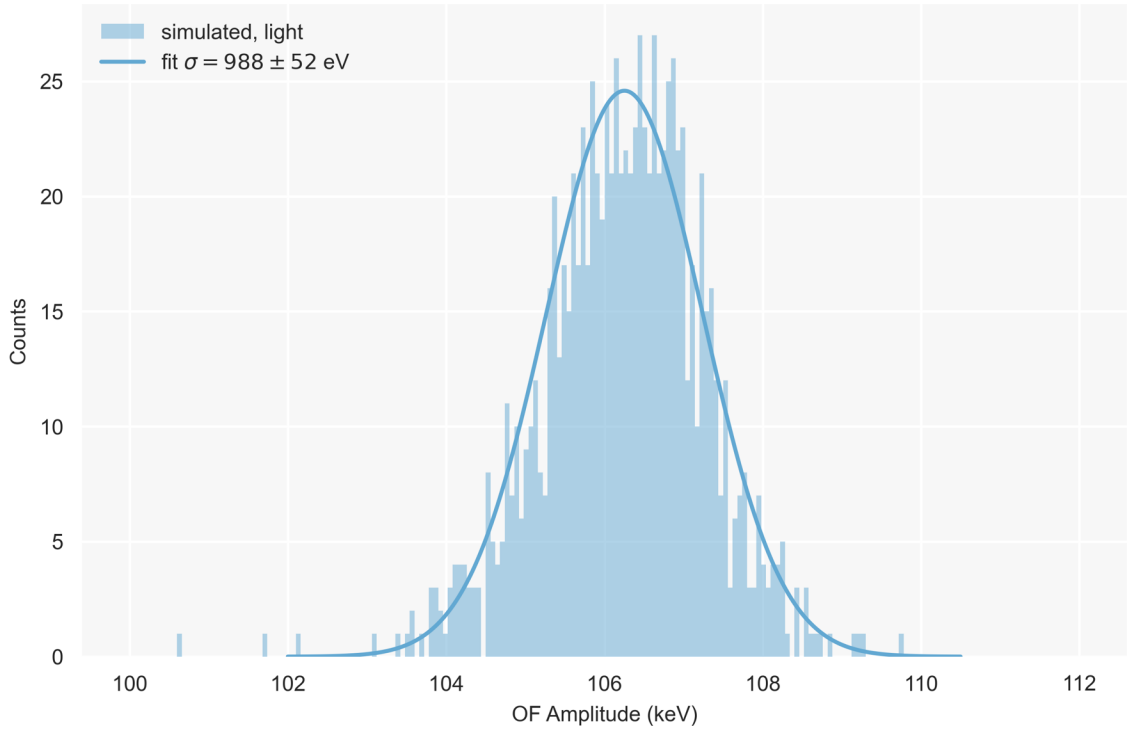


$$\text{LIGHT YIELD} = \frac{\text{LIGHT SIGNAL}}{\text{HEAT SIGNAL}}$$

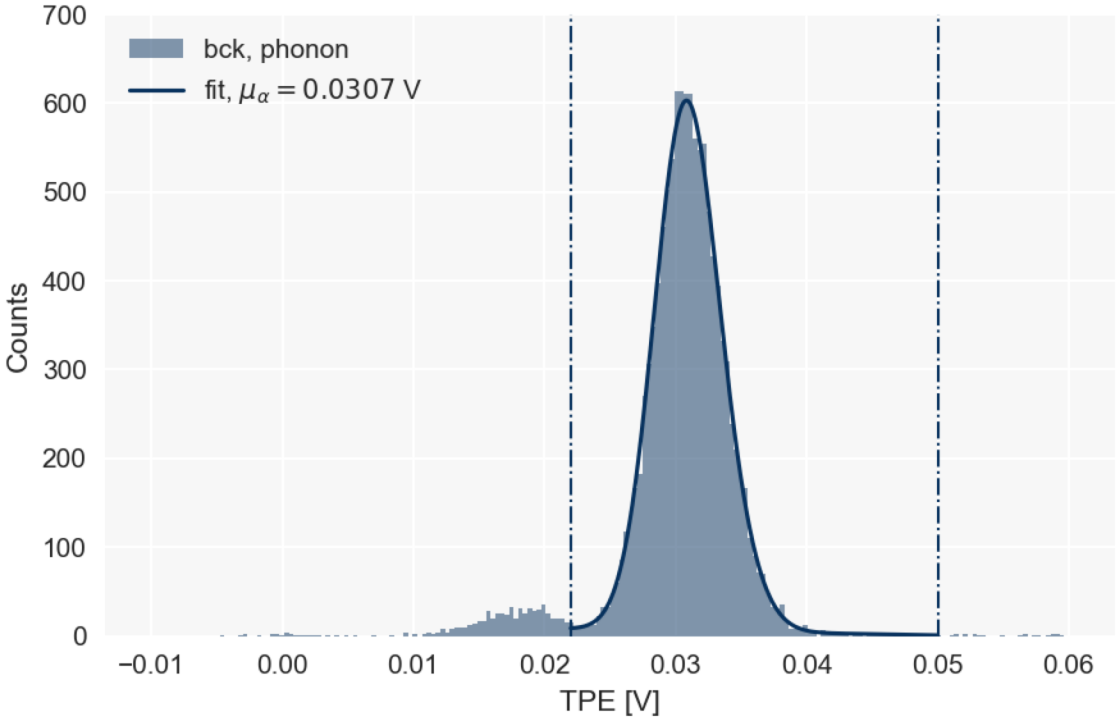
Eur. Phys. J. C (2016) 76:441
DOI 10.1140/epjc/s10052-016-4278-3

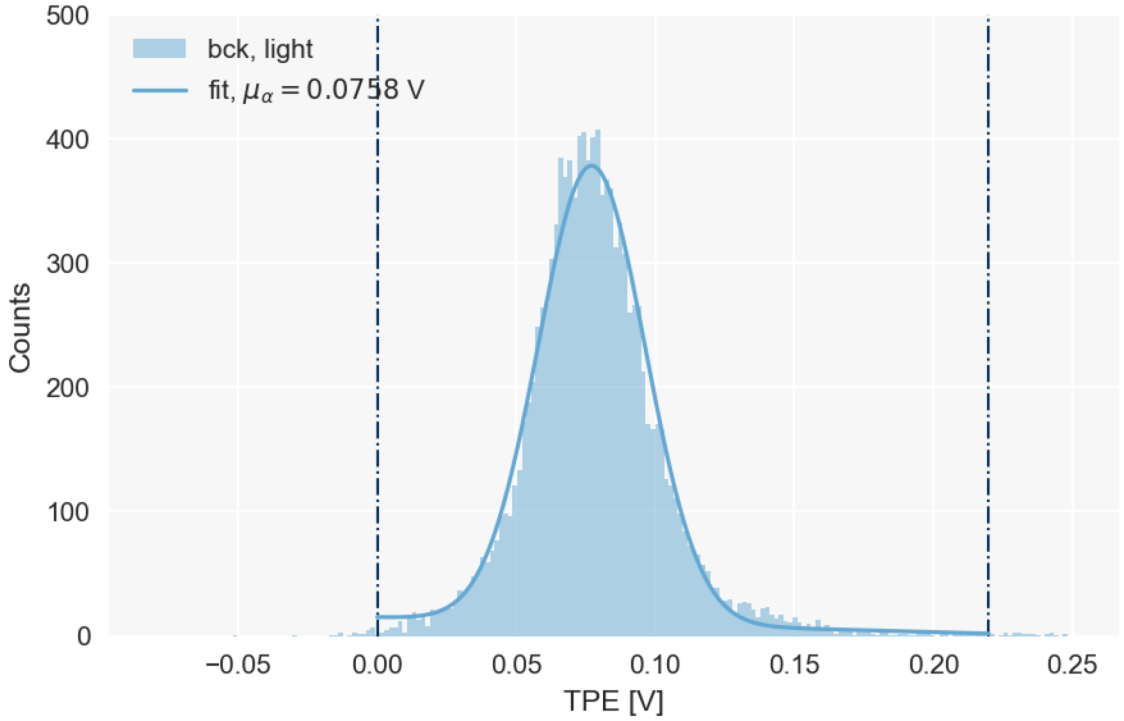
RESOLUTIONS



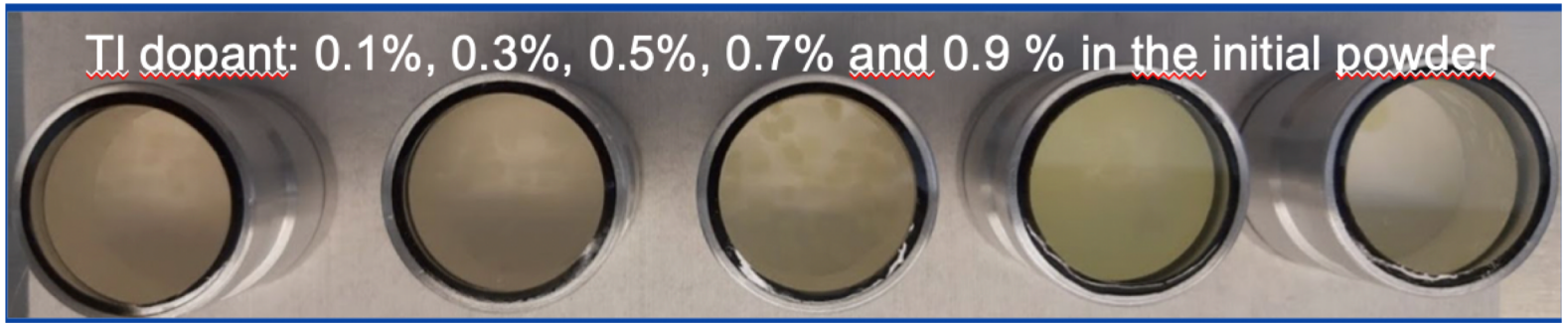


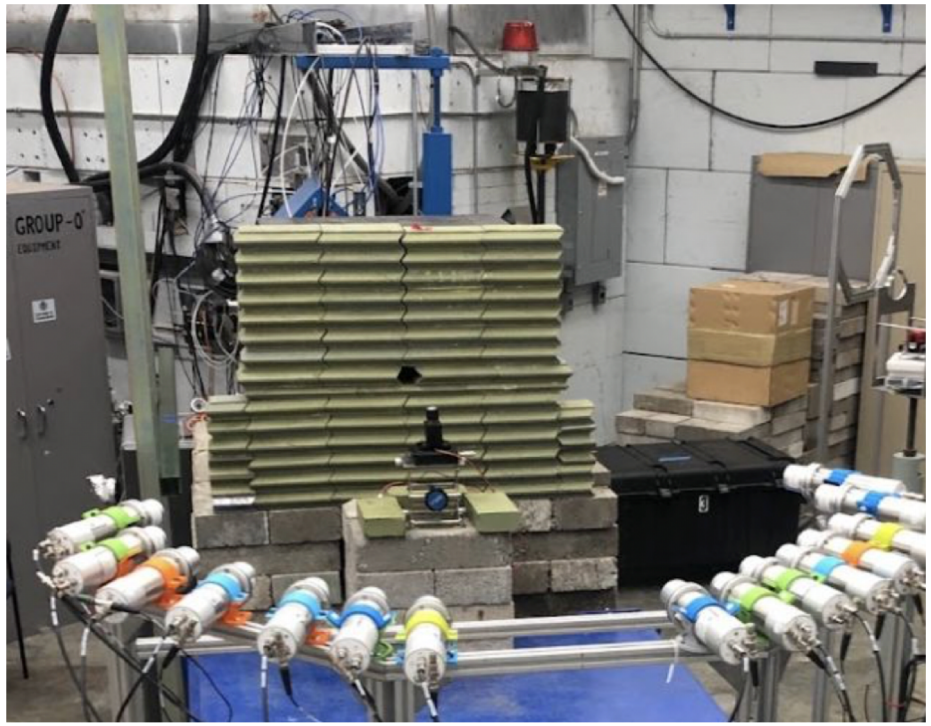
ENERGY CALIBRATION

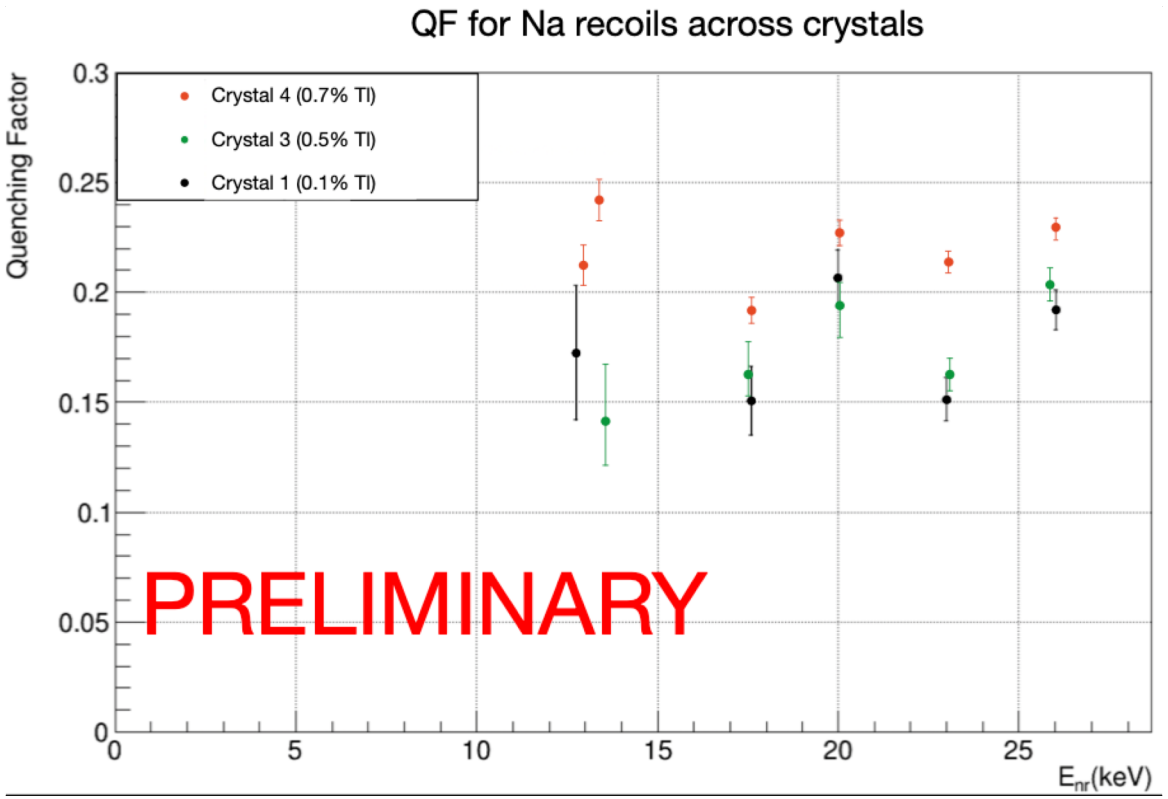




Since 1928 SICCAS







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