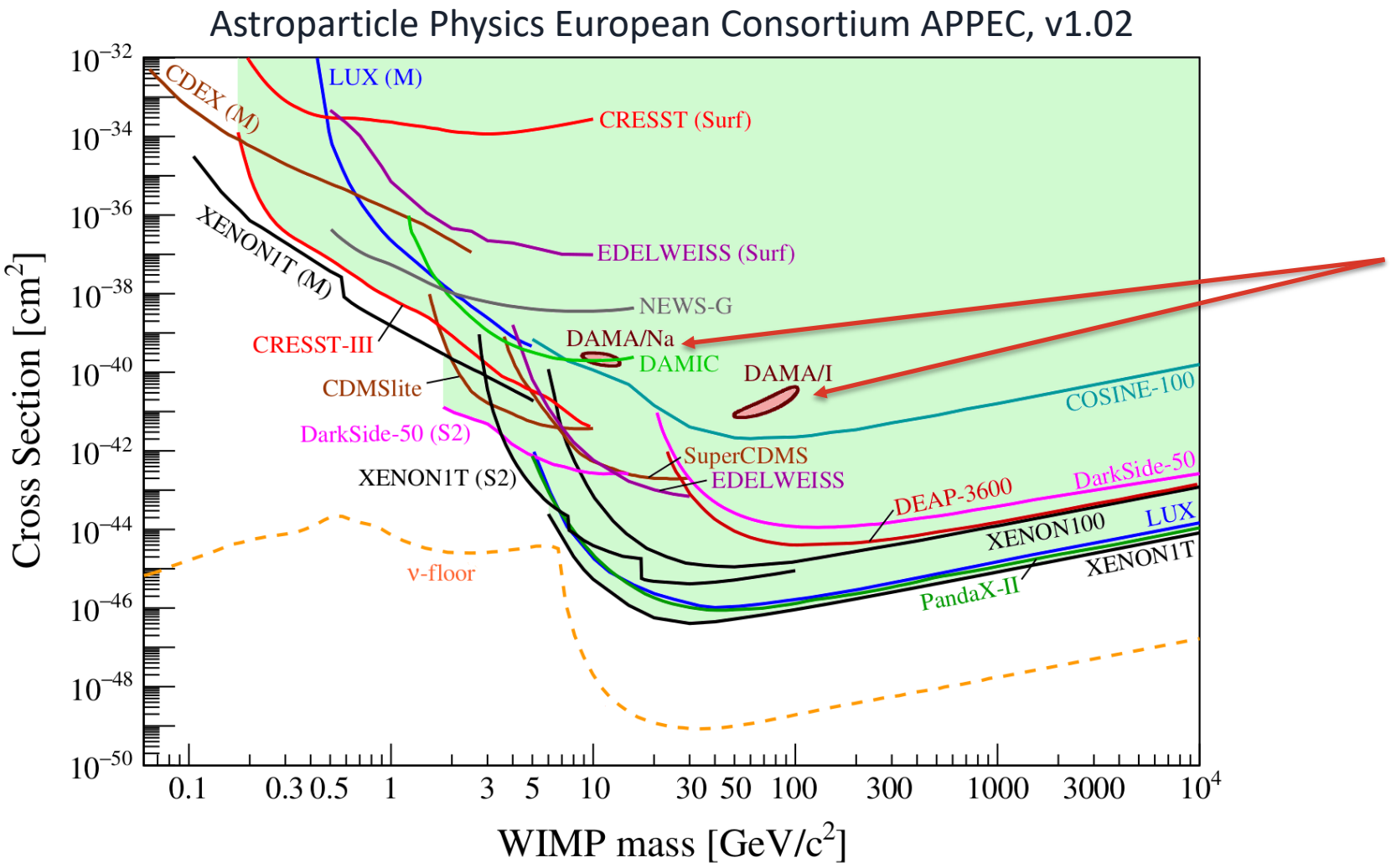
# COSINUS: a new cryogenic dark matter experiment


Florian Reindl, TU Wien & HEPHY

Aug 26, 2024

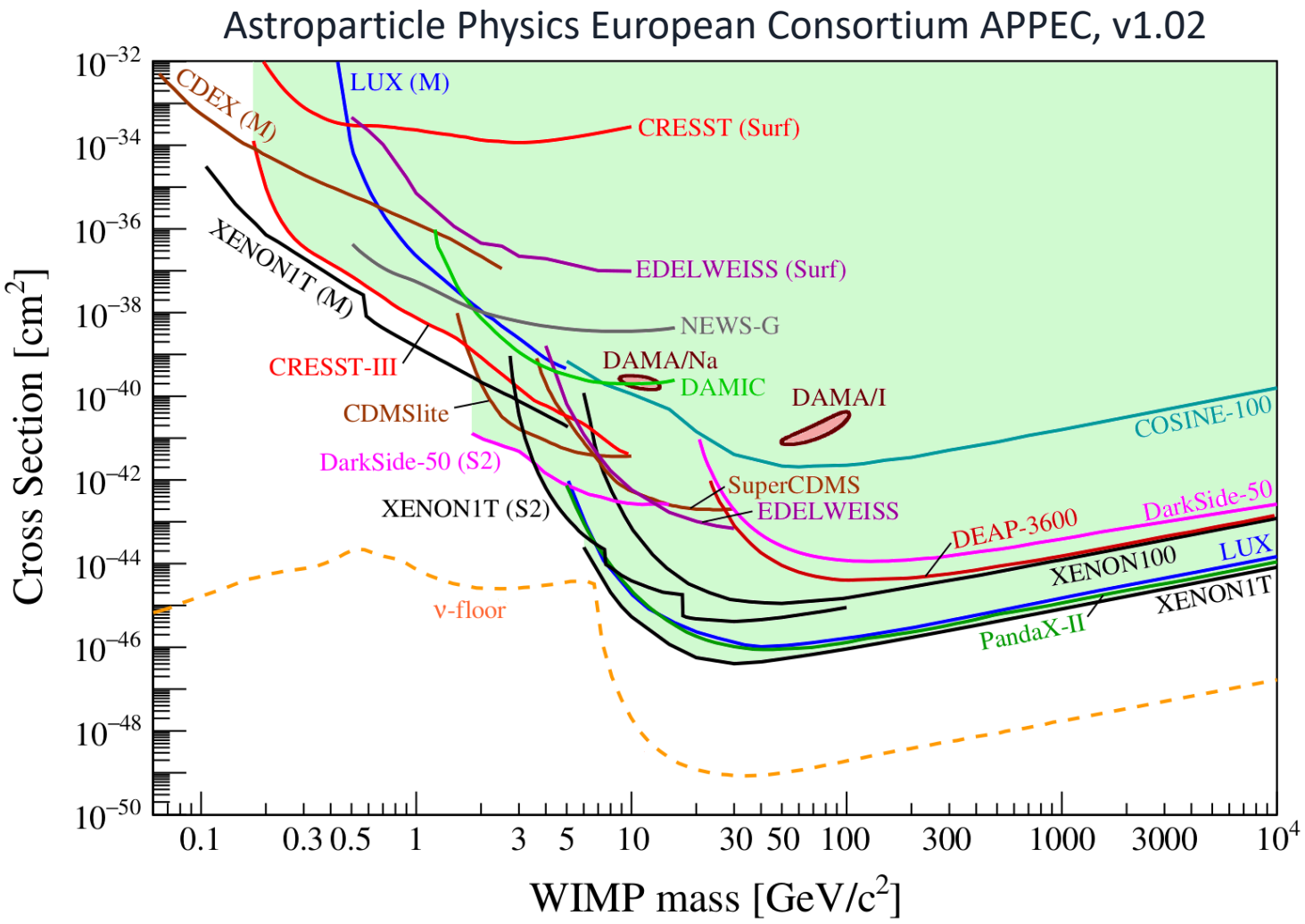
# DAMA/LIBRA AND THE STANDARD SCENARIO

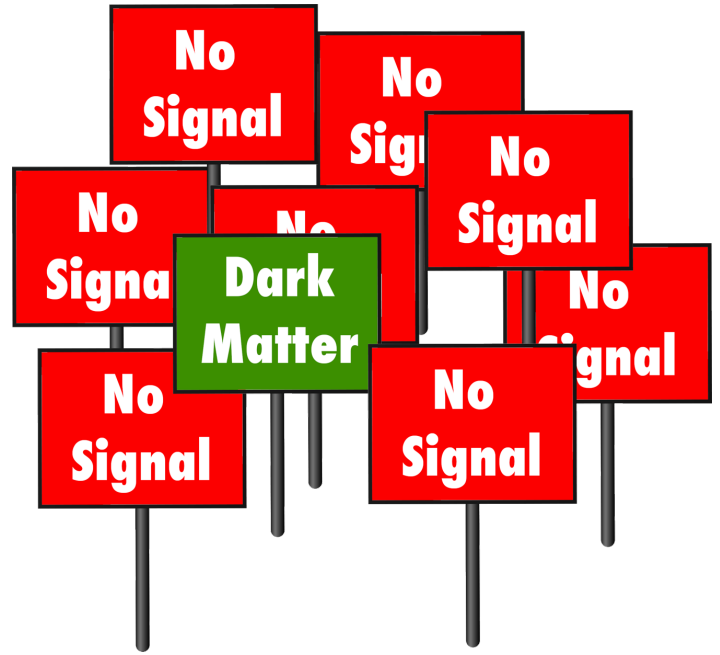



## Islands:

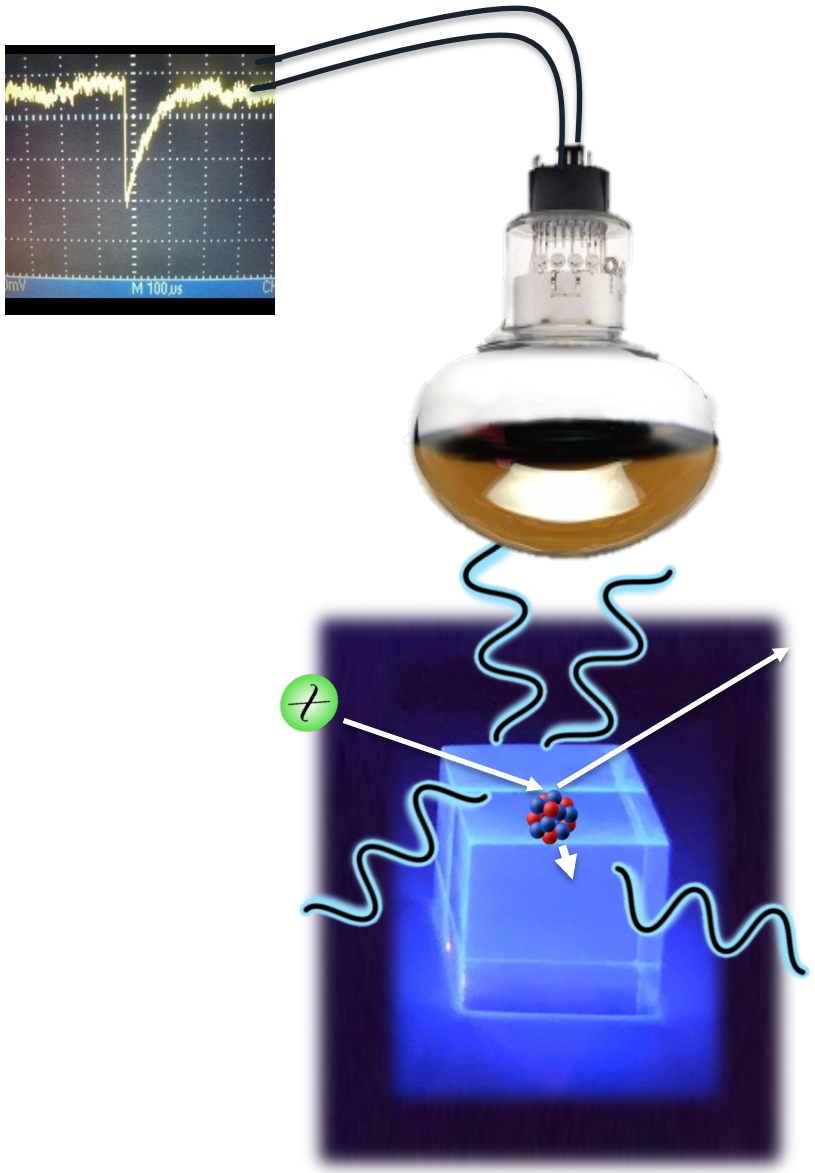
Parameter space compatible with DAMA signal under standard scenario assumptions

# DAMA/LIBRA AND THE STANDARD SCENARIO



# THE DAMA EXPERIMENT



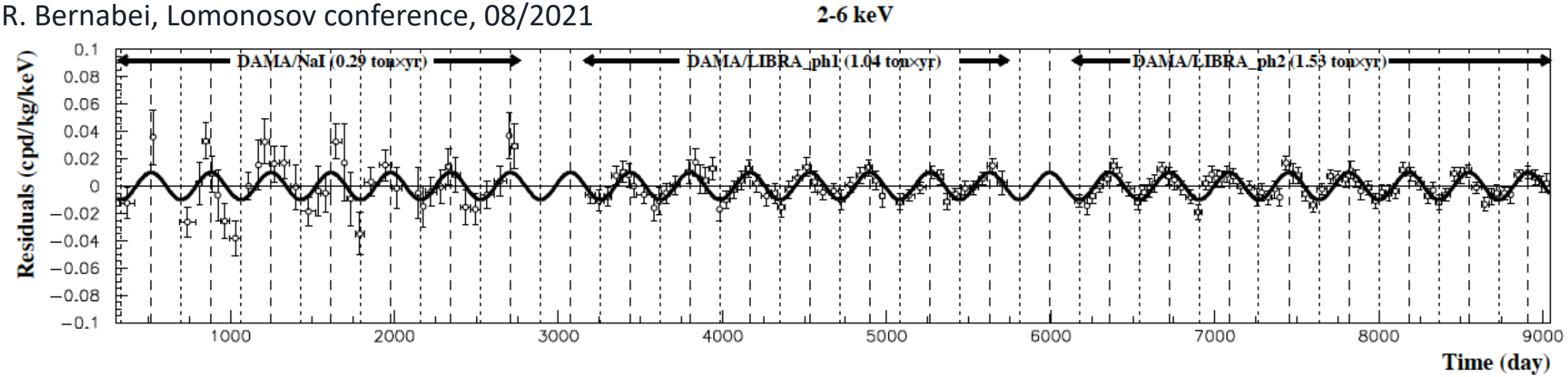

Scintillation light only:

→ Electron-equivalent energy scale

→ No event-by-event discrimination between electron recoils and nuclear recoils off Na and I

# DAMA/LIBRA MODULATION SIGNAL
## TIME DISTRIBUTION

R. Bernabei, Lomonosov conference, 08/2021



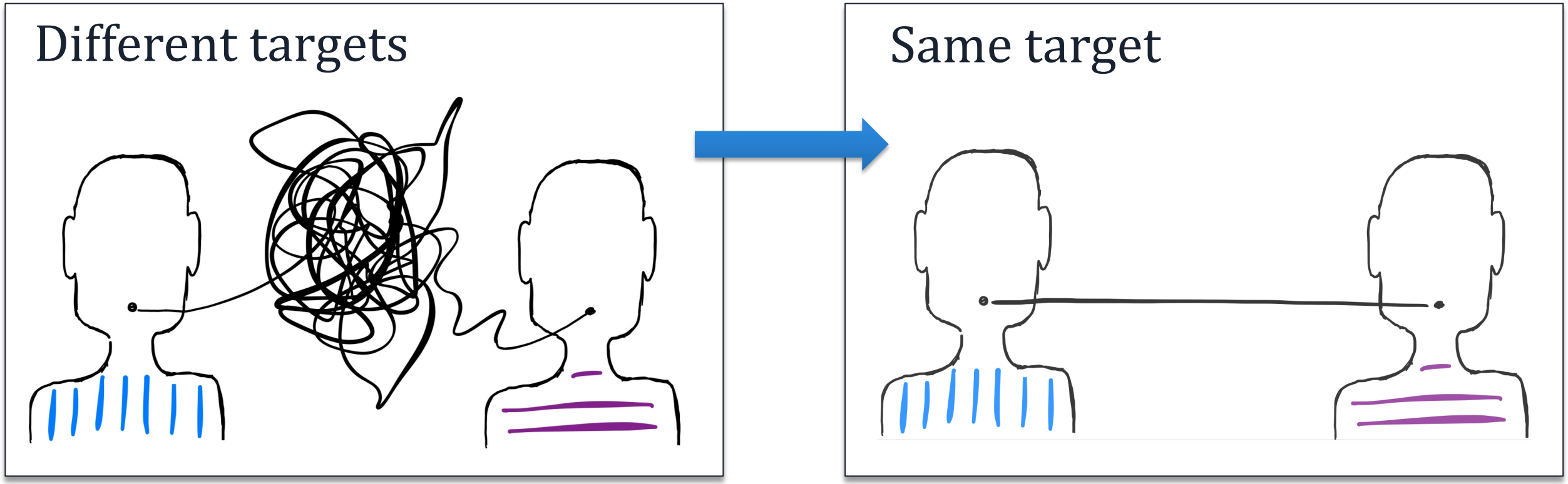

~25years of data

2.86 tonne years exposure

13.7σ statistical significance

compatible with DM particle halo in the milky way

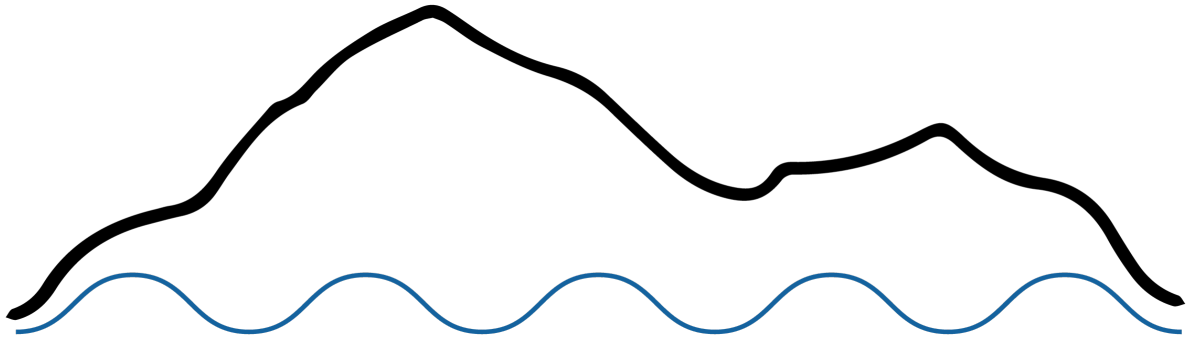
# WHAT ARE THE UNKNOWNS?




→ Target material dependence

→ →Astroparticle Physics European Consortium (APPEC) Recommendation:

*“The long-standing claim from DAMA/LIBRA […] needs to be independently verified using the same target material.”*



# THE COSINUS EXPERIMENT

Aims at a model- and material-independent test of DAMA

Novel and unique: operation of NaI as cryogenic detector
→ Low threshold (in particular for nuclear recoils)
→ Precise energy information
→ Signal-only measurement of potential DM signal

COSINUS


~30 scientists

@COSINUSdm

cosinus.it

HEPHY
INSTITUTE OF HIGH ENERGY PHYSICS

TU WIEN

MAX-PLANCK-INSTITUT FÜR PHYSIK

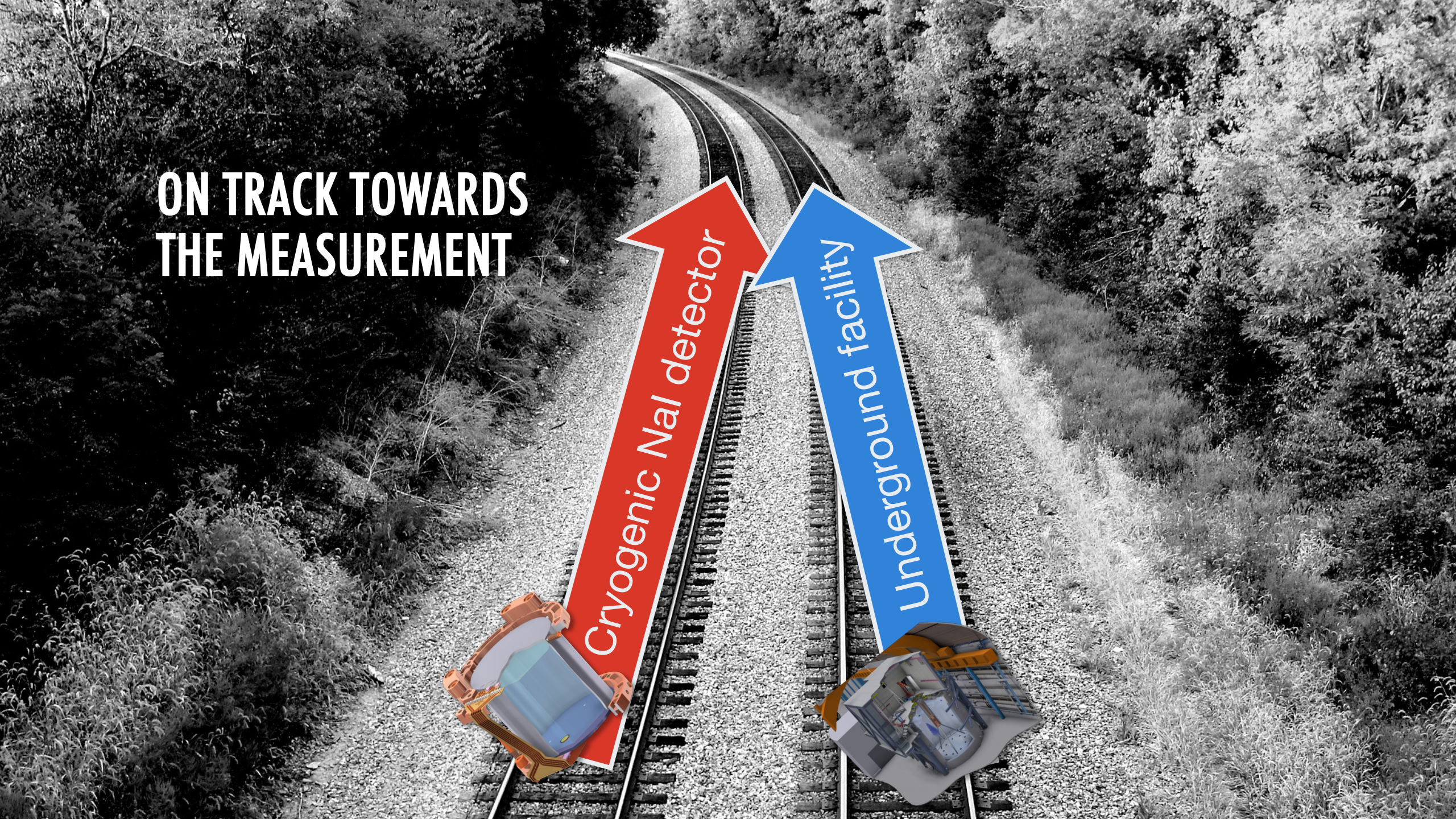
INFN
Istituto Nazionale di Fisica Nucleare

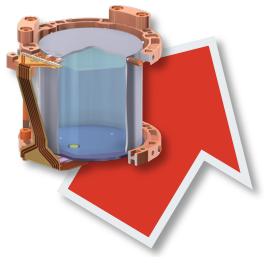
HELSINKI INSTITUTE OF PHYSICS

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

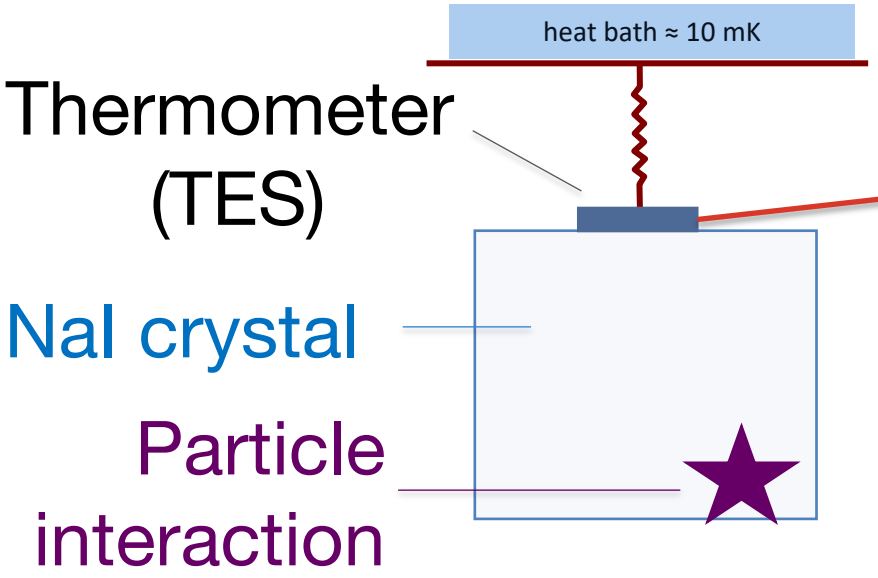
Since 1928
SICCAS

# ON TRACK TOWARDS THE MEASUREMENT

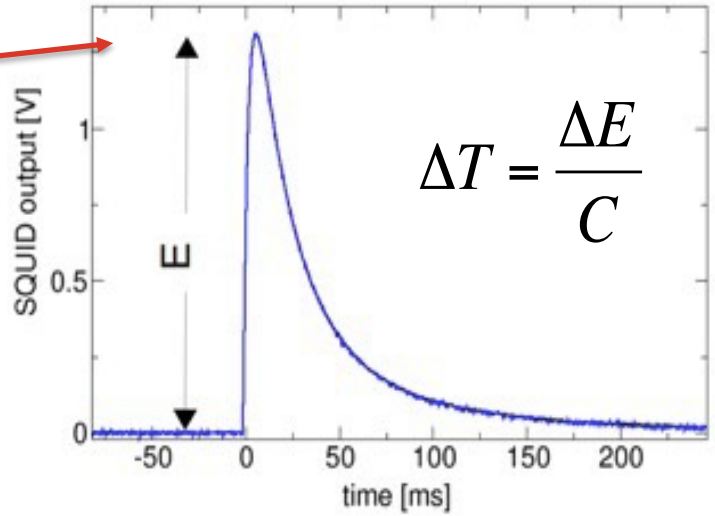




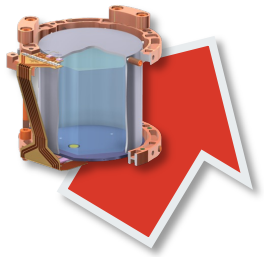
# CRYOGENIC NaI DETECTOR



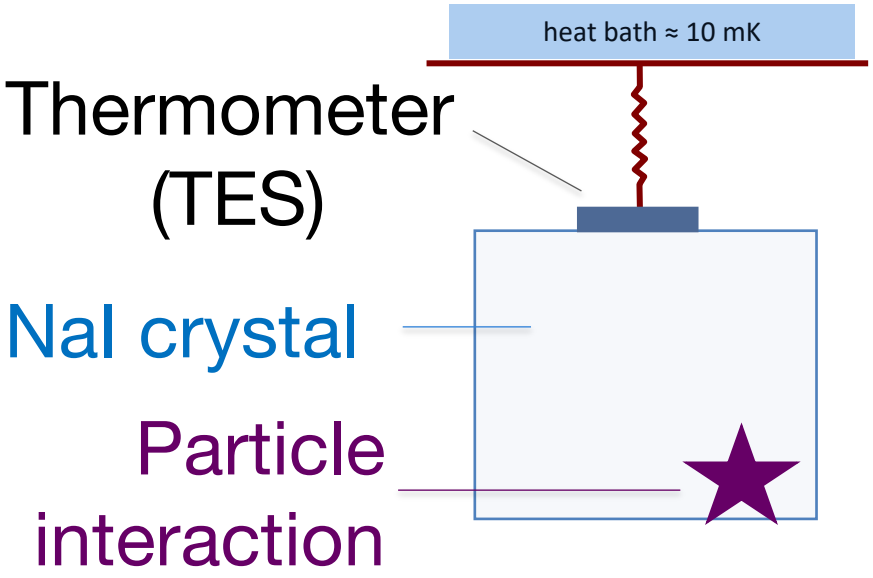

Temperature pulse




$$\Delta T = \frac{\Delta E}{C}$$



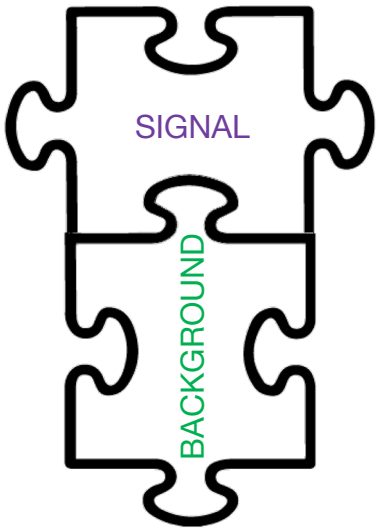
# CRYOGENIC NaI DETECTOR



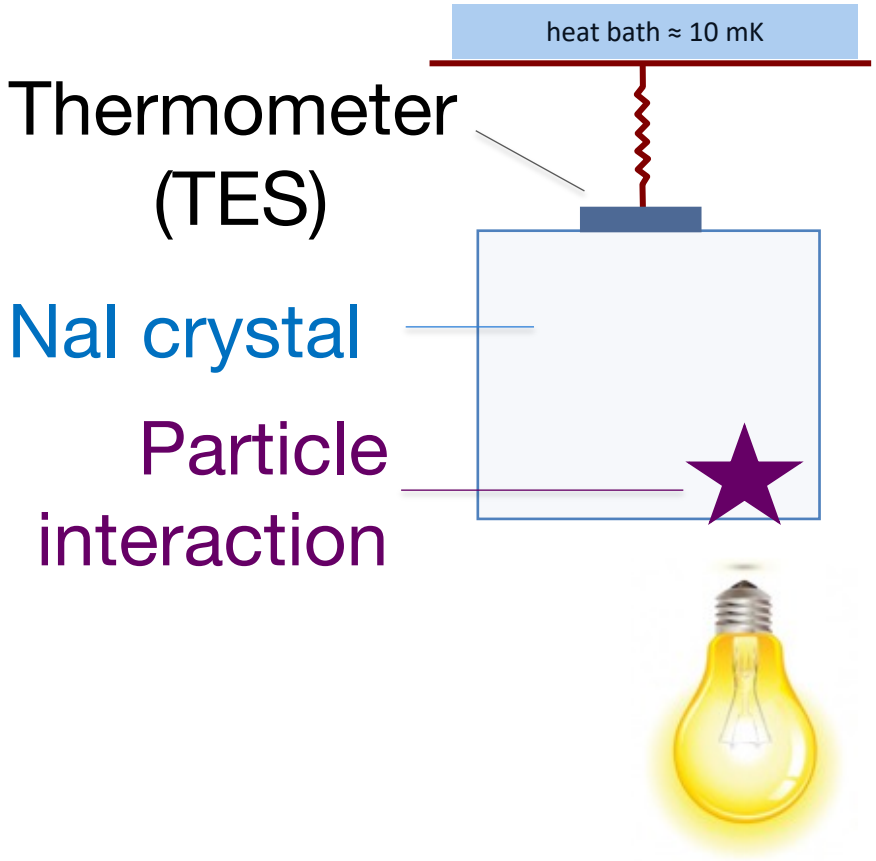

Phonon signal (~90 %)

(Almost) independent of particle type

Precise measurement of the deposited energy



# SCINTILLATING NaI CALORIMETER

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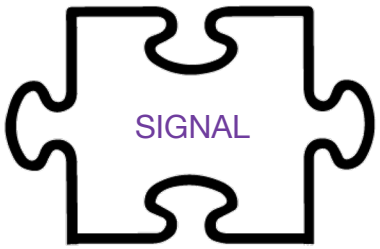
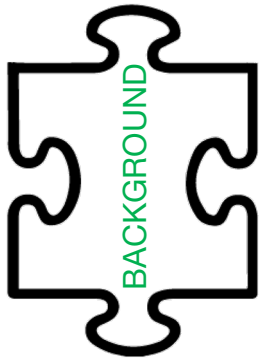
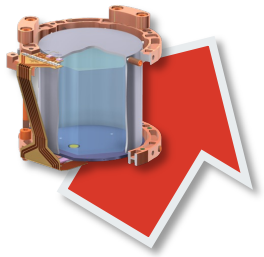



Scintillation light (few %)

Particle-type dependent
→ LIGHT QUENCHING





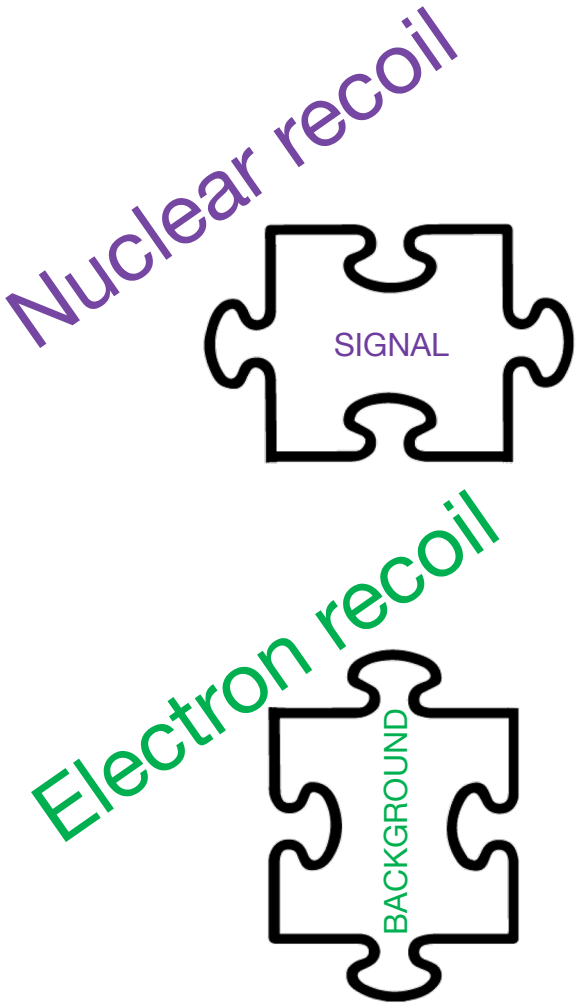
# SCINTILLATING NaI CALORIMETER

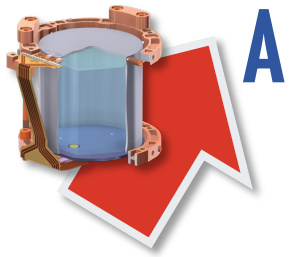
## Two-channel readout

(phonon + scintillation light):

- Low nuclear recoil threshold
- Signal to background discrimination on an event-by-event basis

→ Signal-only measurement





# A CRYOGENIC NaI DETECTOR IS AWESOME: WHY DID IT NOT EXIST?
# → BECAUSE NaI IS NOT NaICE!

## PROBLEM

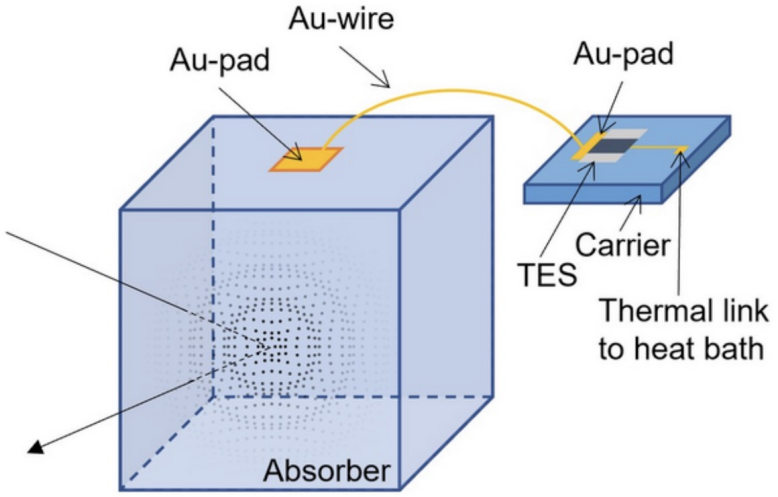
### Low Debye temperature

| Properties | NaI(pure) | CsI(pure) | $CdWO_4$ | $CaWO_4$ |
|---|---|---|---|---|
| Density [g/cm$^3$] | 3.67 | 4.51 | 7.9 | 6.12 |
| Melting point [°C] | 661 | 894 | 1598 | 1650 |
| Structure | CsCl | CsCl | Wolframite | Scheelite |
| $\lambda_{max}$ at 300 K [nm] | ~300 | ~315 | ~475 | 420-425 |
| Hygroscopic | yes | slightly | no | no |
| $\Theta_D$ [K] | 169 | 125 | - | 335 |
| Photons per keV at 3.4 K | 19.5 ±1.0 | 58.9±5.6 | - | - |
| Mean energy of emitted photon [eV] | 3.3 | 3.9 | - | 3.14 |

### Small signal amplitudes

## SOLUTION

### remoTES detector design

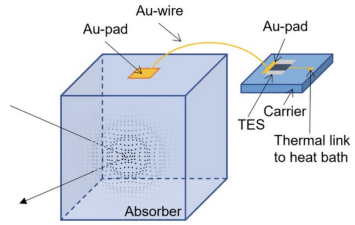



NaI → Au-wire/pad → TES

Phonons couple directly to electron system of Au-pad

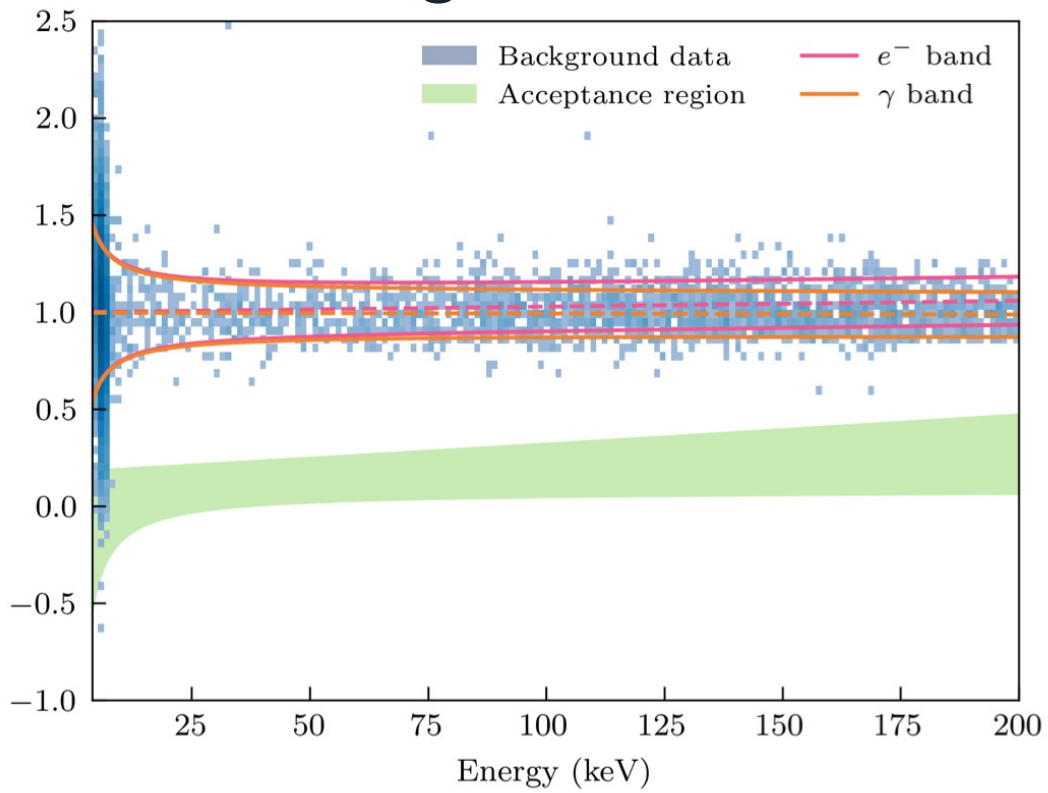
arxiv:2111.00349v1 NIMA, 1045, 2023

# remoTES MEASUREMENT WITH NaI TARGET



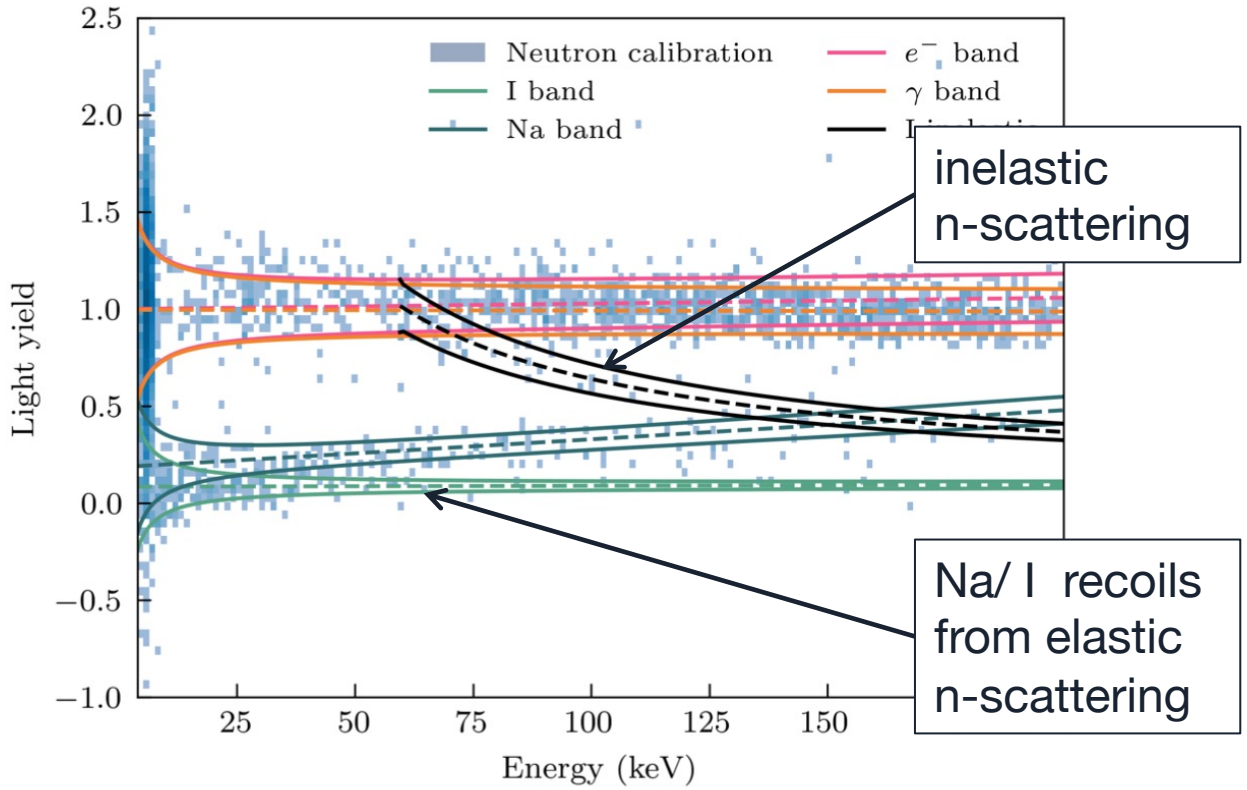

arXiv:2307.11066, PRD 109, 082003
arXiv:2307.11139, PRD 110, 043010

## Background data




nuclear recoil threshold: <2keV

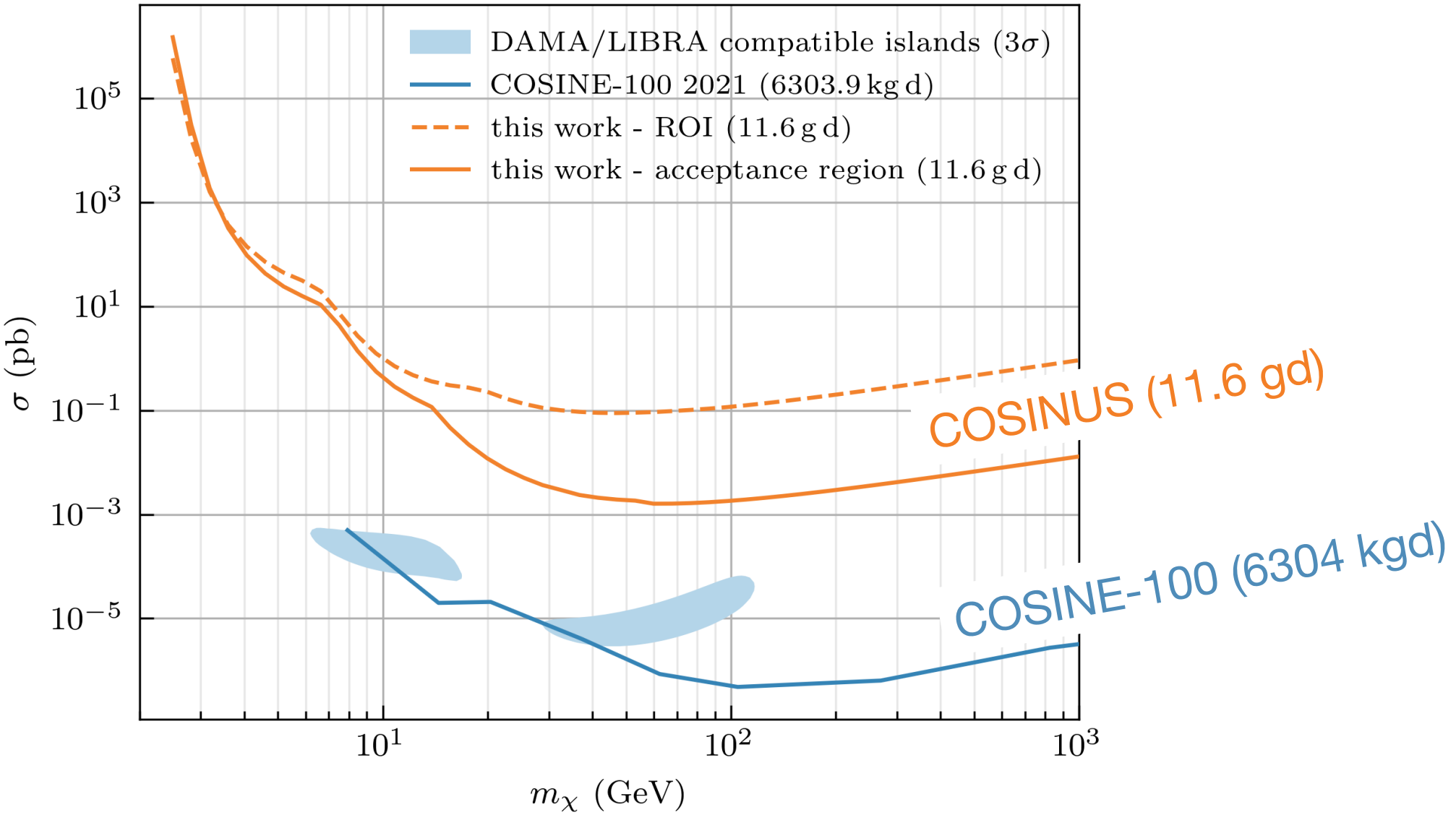
## Neutron calibration




first NaI detector with particle identification on event-by-event basis

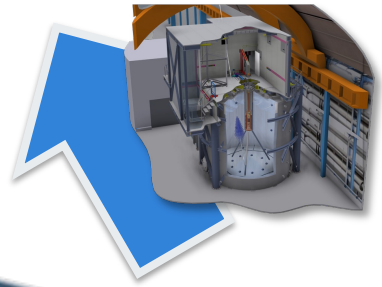
# FIRST COSINUS DARK MATTER RESULTS

arXiv:2307.11139, PRD 110, 043010



# The COSINUS FACILITY @ LNGS

## approved 2020

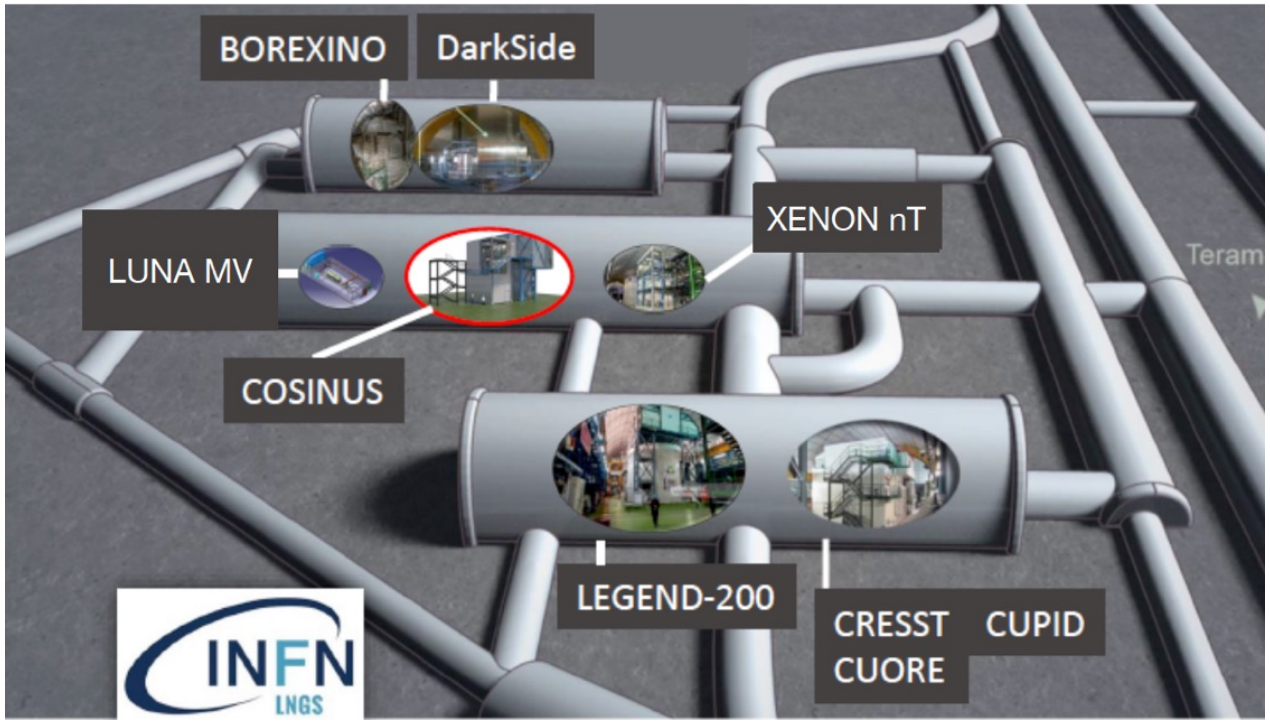


Clean room

Water tank

# LNGS – HALL B


View from XENONnT, 2019


BOREXINO
DarkSide
XENON nT
LUNA MV
COSINUS
LEGEND-200
CRESST
CUPID
CUORE
INFN
LNGS

# WHY WATER?

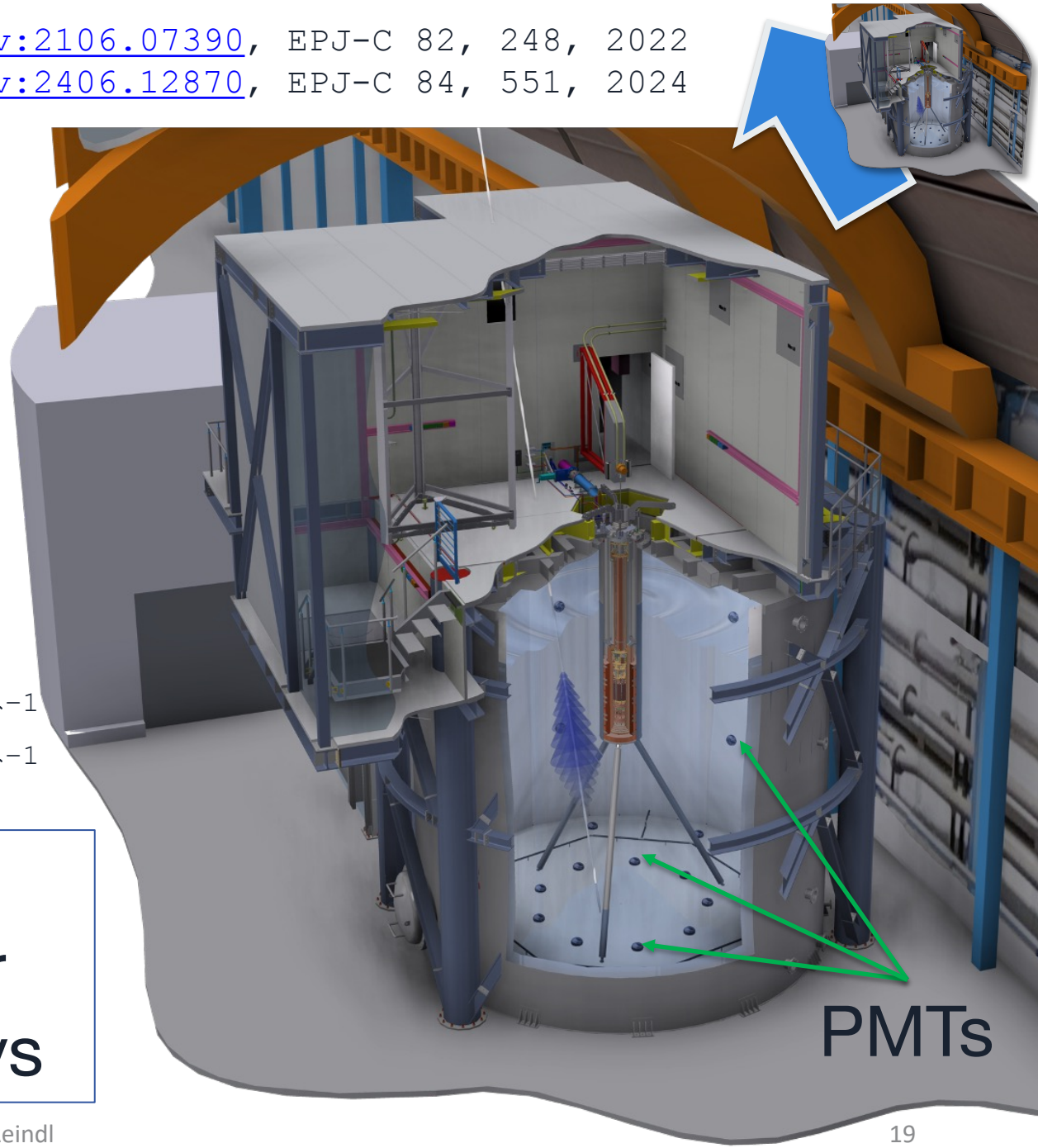
arXiv:2106.07390, EPJ-C 82, 248, 2022
arXiv:2406.12870, EPJ-C 84, 551, 2024

1. Good moderator for neutrons
2. Veto of (cosmogenic) muons via Cherenkov light emitted in water → Instrumentation of water tank with 30PMTs

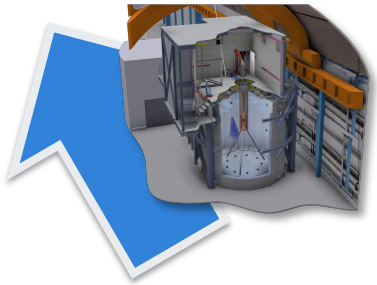
Rate of cosmogenic neutrons:

No veto: ( 3.5 ± 0.7) cts $kg^{-1}$ $yr^{-1}$
With veto: <(0.30 ± 0.02) cts $kg^{-1}$ $yr^{-1}$

With veto: < 1 expected cosmogenic neutron event for target exposure of 1000 kg days

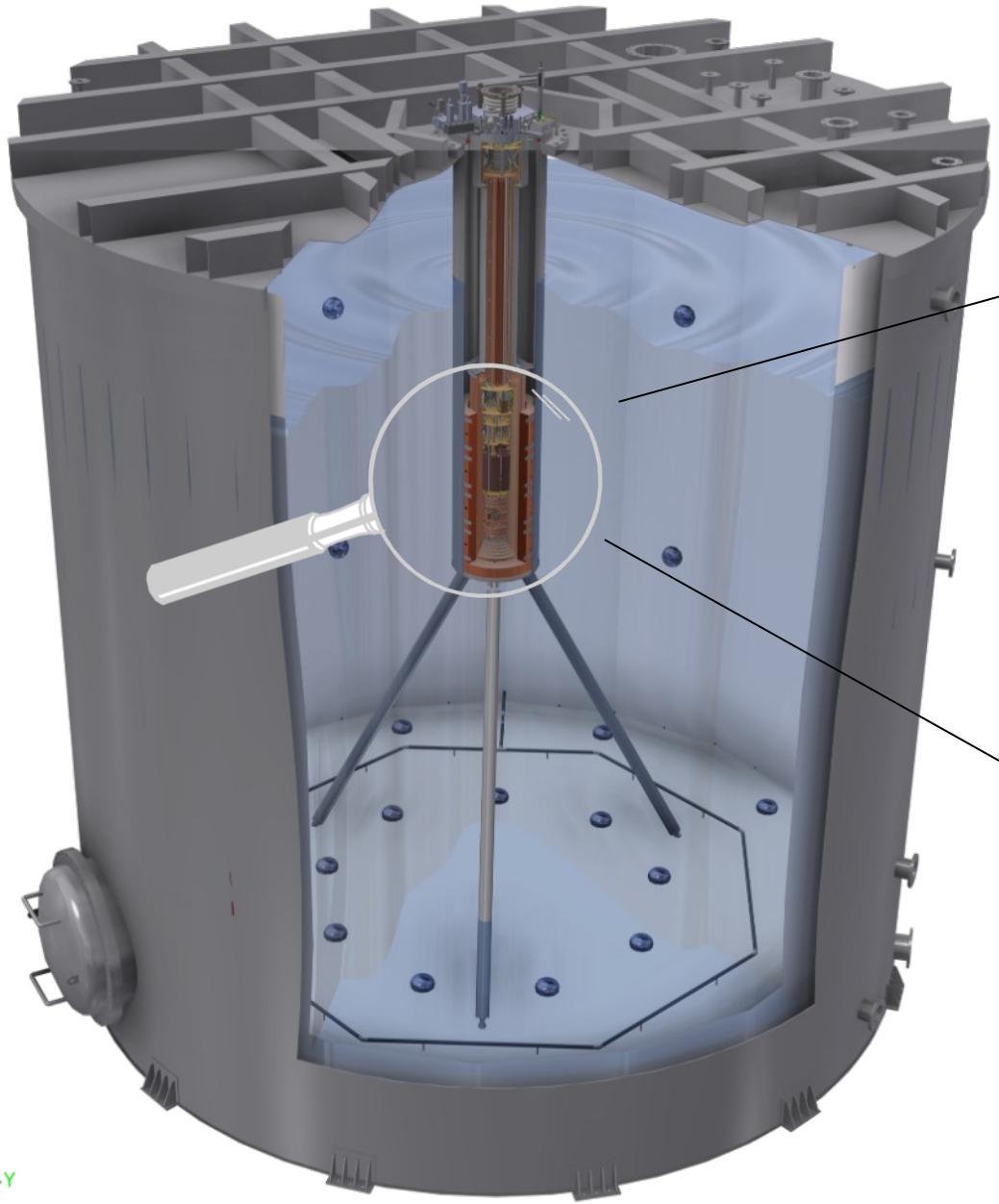


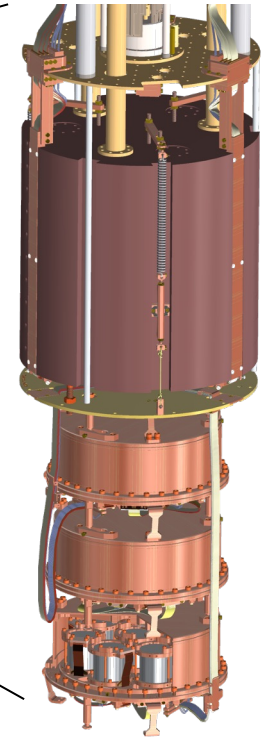
# CRYOSTAT



**Dry dilution refrigerator to reach 10 mK:**

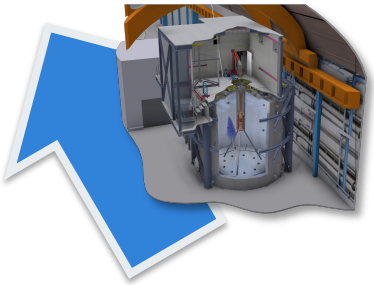
- 3500 mm total length
- custom-made design
- UltraQuiet Technology (UQT)
- internal copper shield (190 kg)





CryoConcept
an Air Liquide affiliate

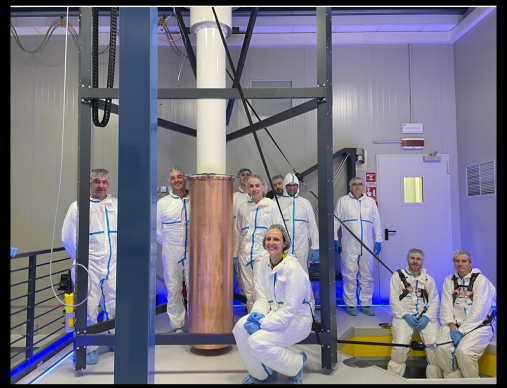
# FROM DRAWINGS TO REALITY



Water tank
2021

Buildings finished
2022

Cryostat delivered
2023

Cryostat installed
and cooled to 9mK
2024

# THE COSINUS FACILITY

View to XENONnT, 2019

Aug 2023

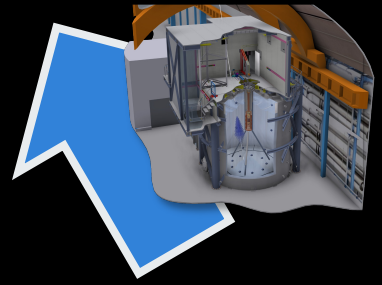
Aug 2023

Dec 2023
Delivery of the cryostat!

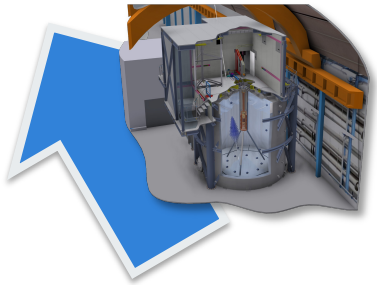

18
04
24

# COSINUS Inauguration

Laboratori Nazionali del Gran Sasso

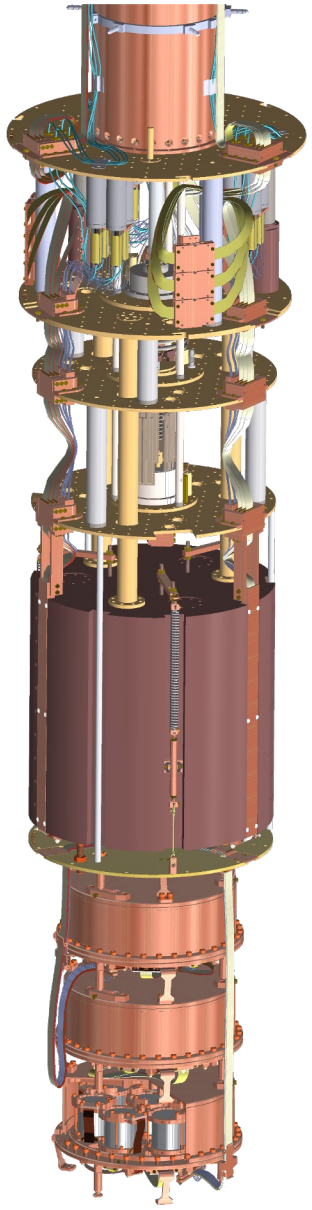


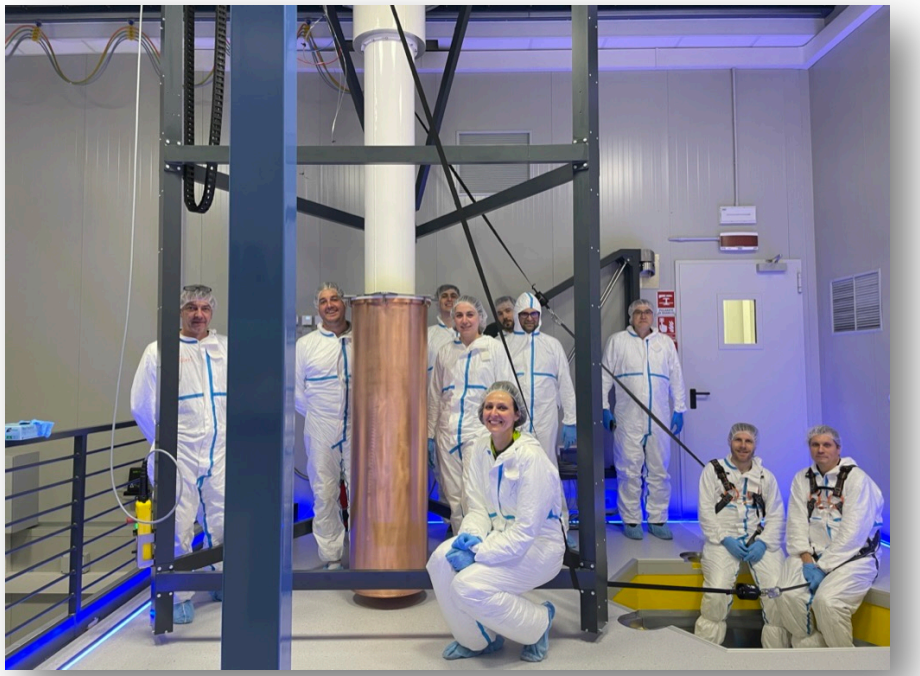
# FINALIZE IT!
## THE CRYOSTAT



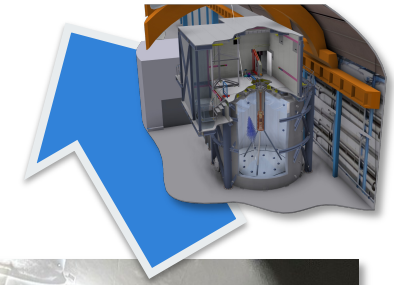
Cryostat commissioning ongoing

Reached 9mK with Cu-shield installed





# FINALIZE IT!
## THE MUON VETO

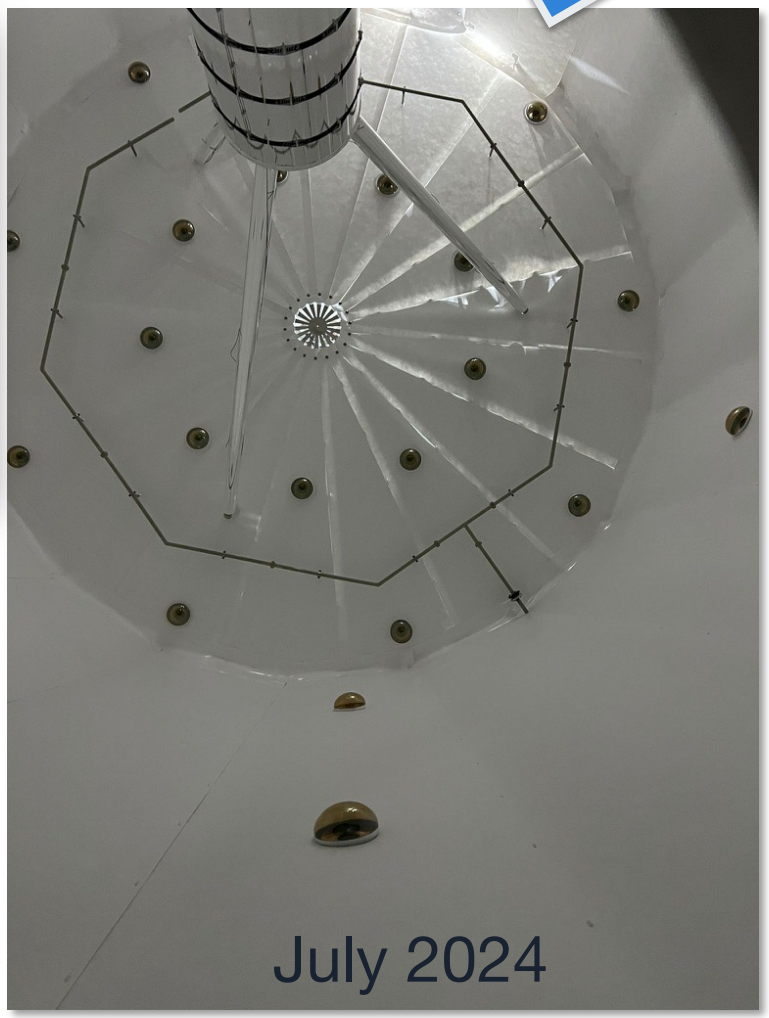


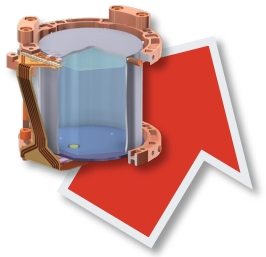
PMT successfully tested above ground at LNGS

Installation of PMTs and TYVEK curtain (dead layer) in water tank finished

→ Filling of tank in a few weeks





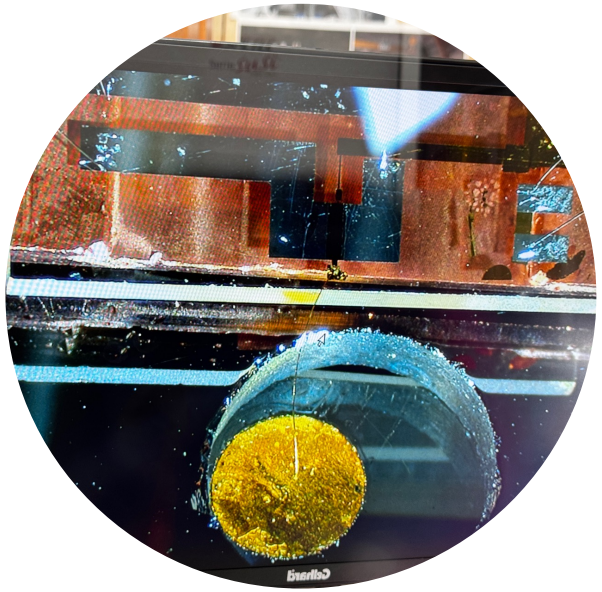


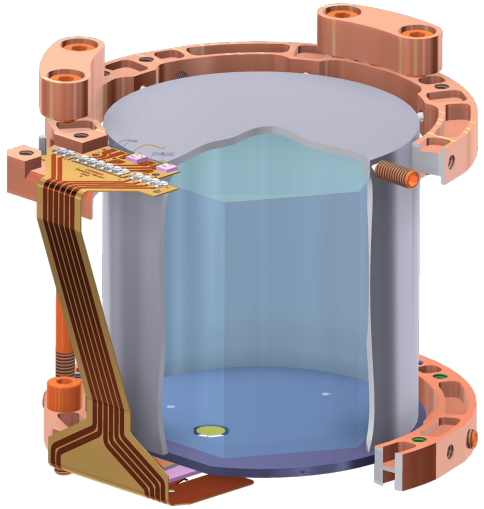
# FINALIZE IT!

## THE DETECTOR

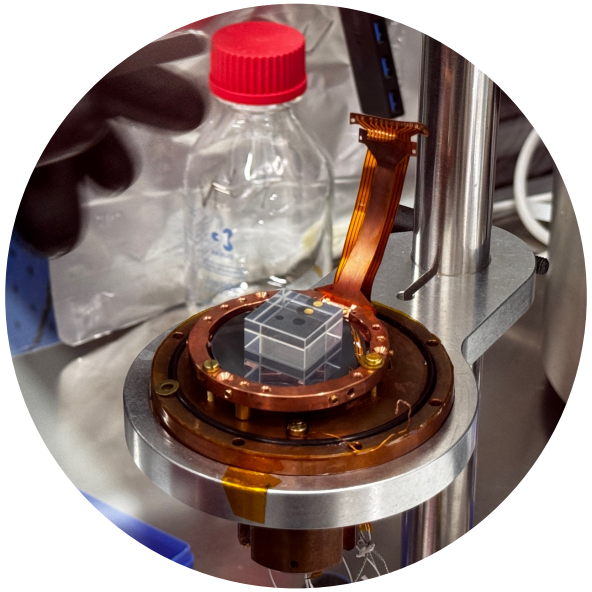
NaI crystals are in production at SICCAS

Test of final detector design ongoing





Si-beaker for 4π active surrounding of the crystal

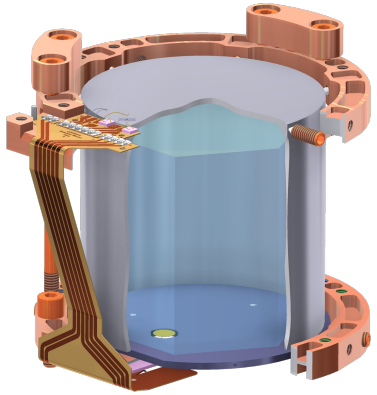


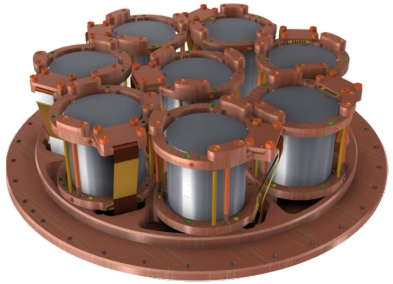
# TAKE DATA
# STAGED APPROACH: RUN 1

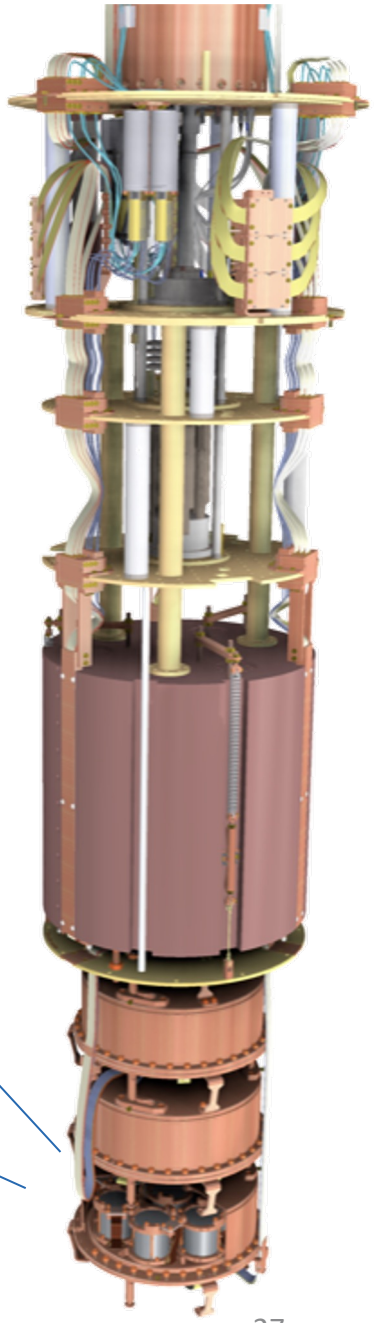
Production and assembly of **8 detector modules** for Run 1

Start data taking @LNGS beginning 2025

→ collect **100 kg days**





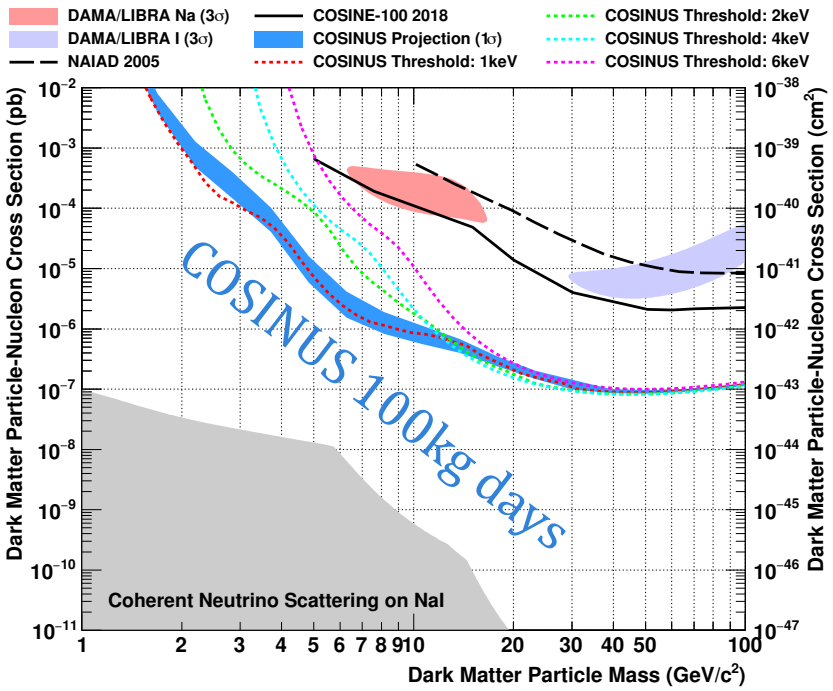


- 8 detector modules per level
- 3 levels in final stage

# PHYSICS REACH

arXiv:1802.10175, JCAP05(2018)074

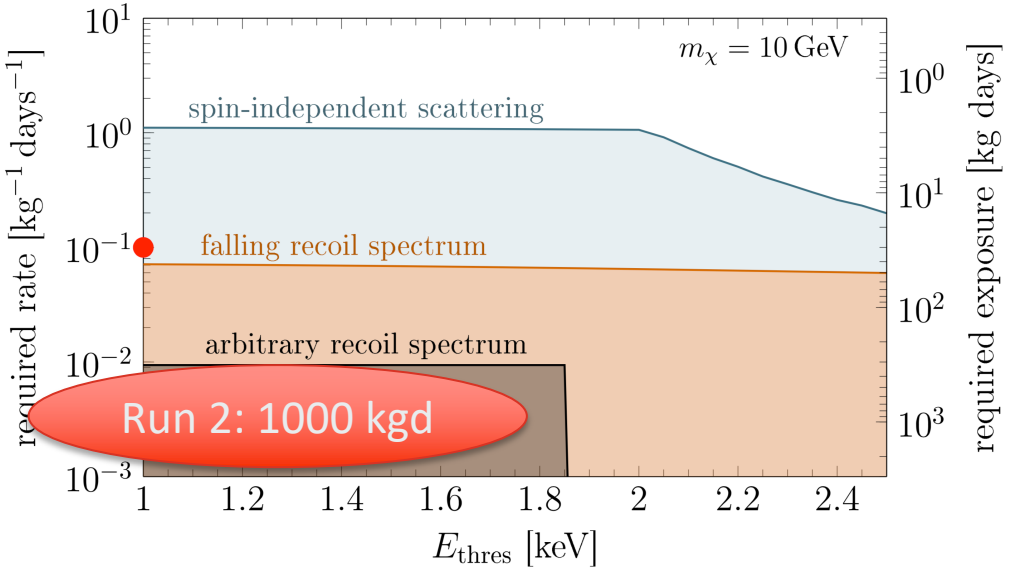
## Run 1: 2025-2026




First DM results clarifying standard scenario

## Run 2: ≥2026

Total rate R ≥ S Modulation amplitude




Final model-independent cross-check

# COSINUS KEY FACTS TO REMEMBER

Start data taking: 2025

Signal only measurement

Cryogenic NaI detectors with event-by-event particle discrimination

In-situ determination of quenching factors

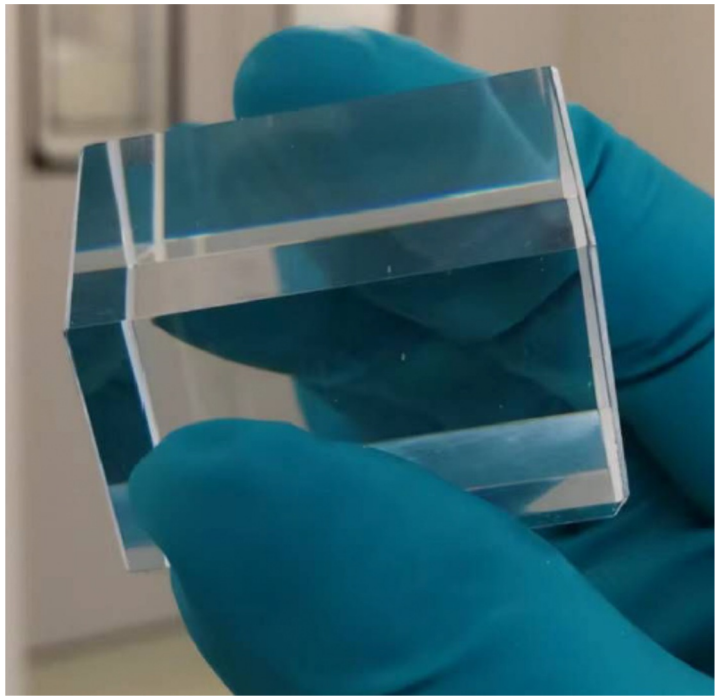
Model-independent cross-check of the DAMA/LIBRA signal

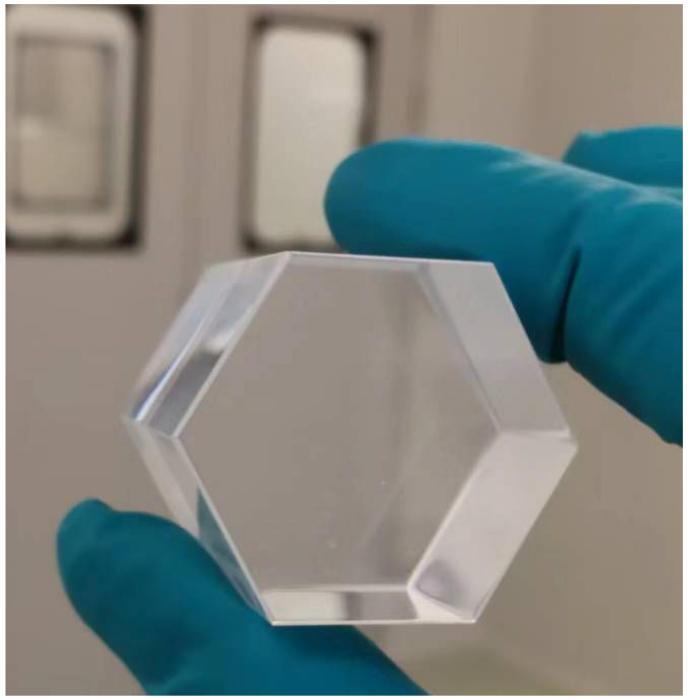
Modern low-background facility with water shielding at LNGS

# Thank you!

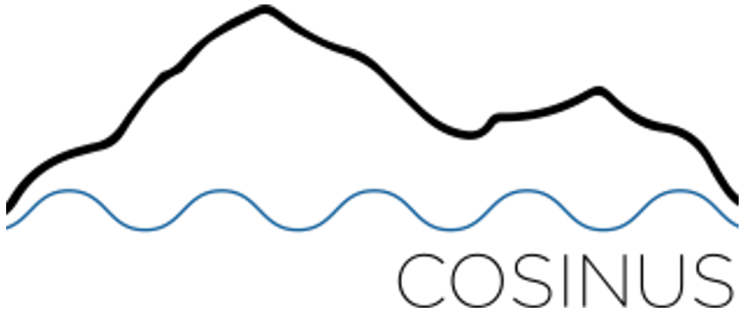

ENRICO BELLOTTI
ION BEAM FACILITY
18
04
24
COSINUS Inauguration
Laboratori Nazionali del Gran Sasso

# COSINUS HEXAGONAL CRYSTALS





# CRYSTAL PRODUCTION FOR COSINUS




The COSINUS NaI crystals will be produced in 2024/2025 by SICCAS (Shanghai Institute of Ceramics, Chinese Academy of Sciences), using ASTROGRADE powder, according to the following scheme:

In 2024

- 24 (phase 1 detector): cubic crystals (2.1 x 2.1 x 2.1) $cm^3$ - 35 g each

In 2025

- 24 (phase 2 detector): hexagonal crystals - 108 g each

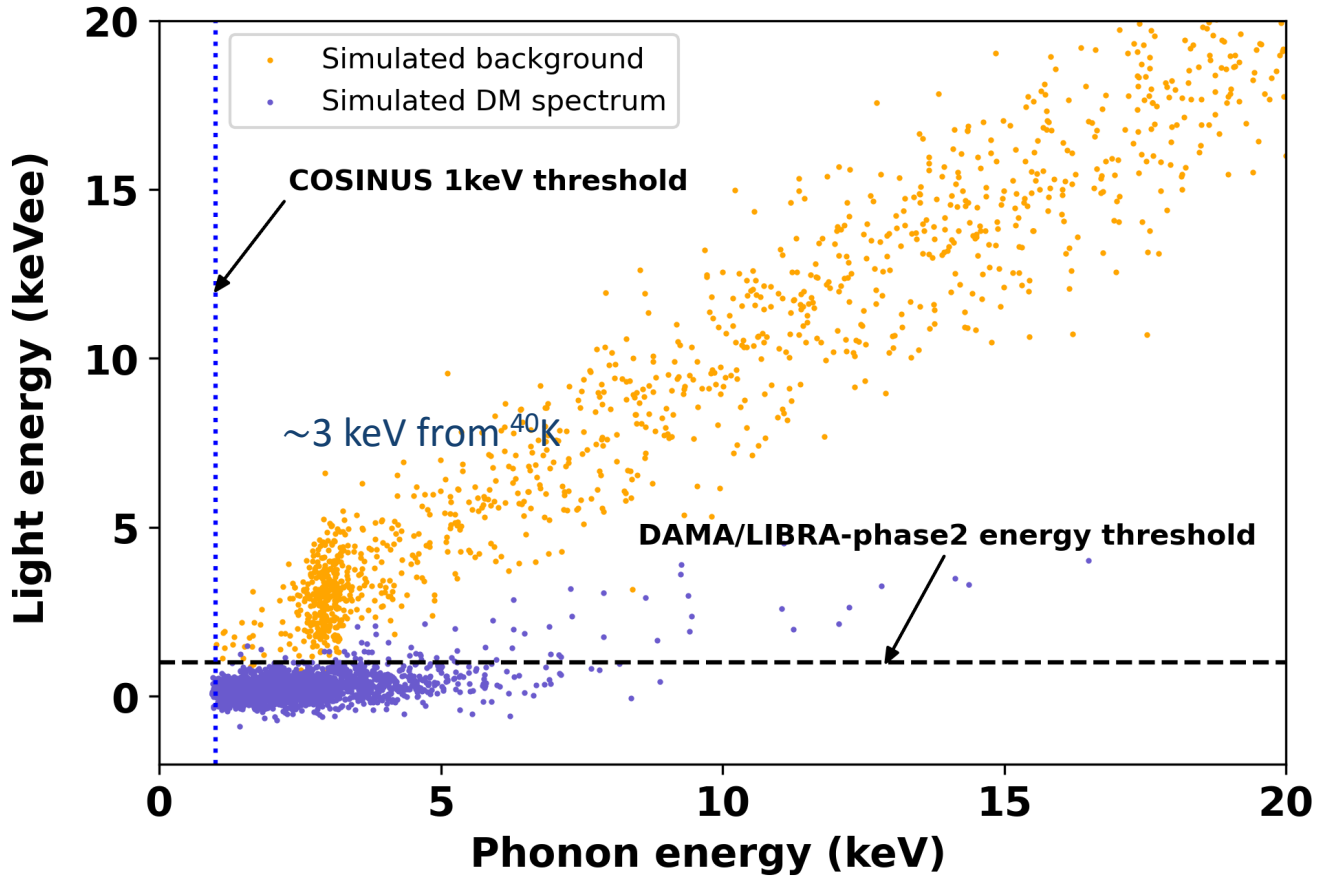
| Test crystals | K | Th | U |
|---|---|---|---|
| ICPMS@LNGS | 6-22 ppb | <1 ppb | <1 ppb |

https://arxiv.org/pdf/2307.11139

INFN LNGS
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Gran Sasso

Since 1928 SICCAS

# SIMULATED DATA FOR 100 kg days (gross-exposure)

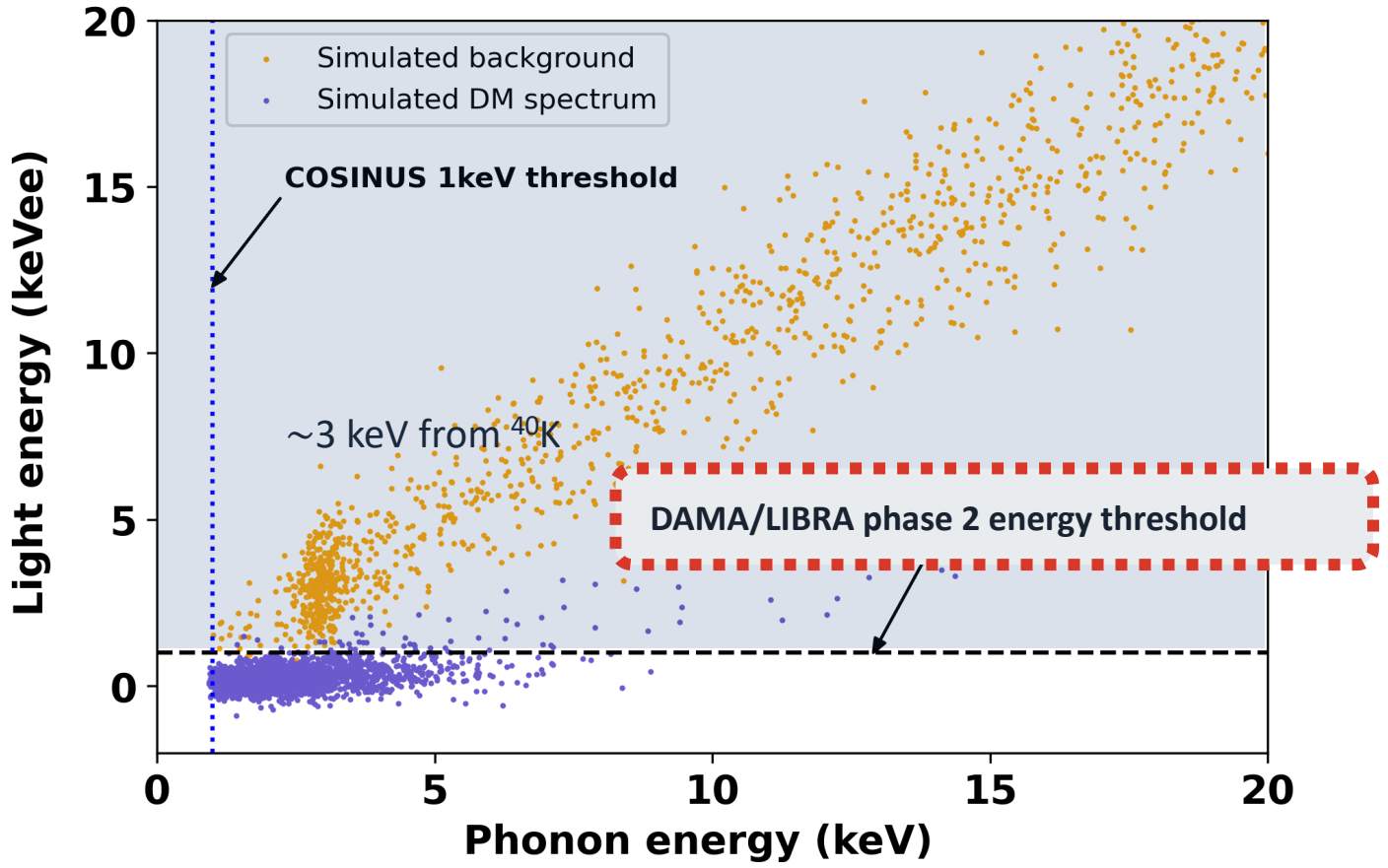



- 1keV nuclear recoil threshold
- flat background: 1 /(keV kg d)
  + $^{40}$K background: 600μBq/kg
- dark matter spectrum:
  10 GeV/c$^2$, 2x10$^{-4}$ pb
- values for quenching factors from:

  Tretyak, Astropart. Phys. 33, 40 (2010)

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

# WHAT DAMA/LIBRA SEES …

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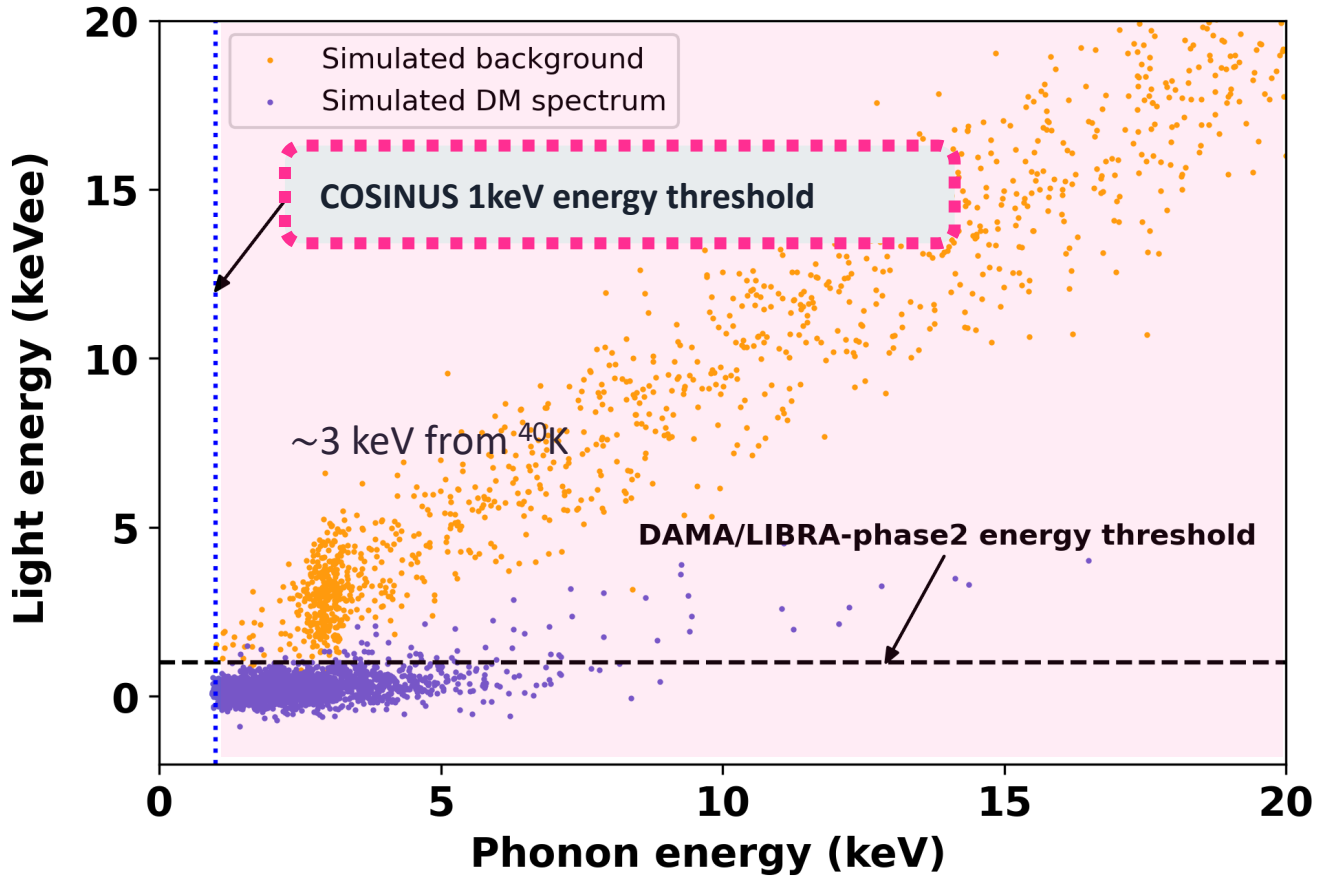


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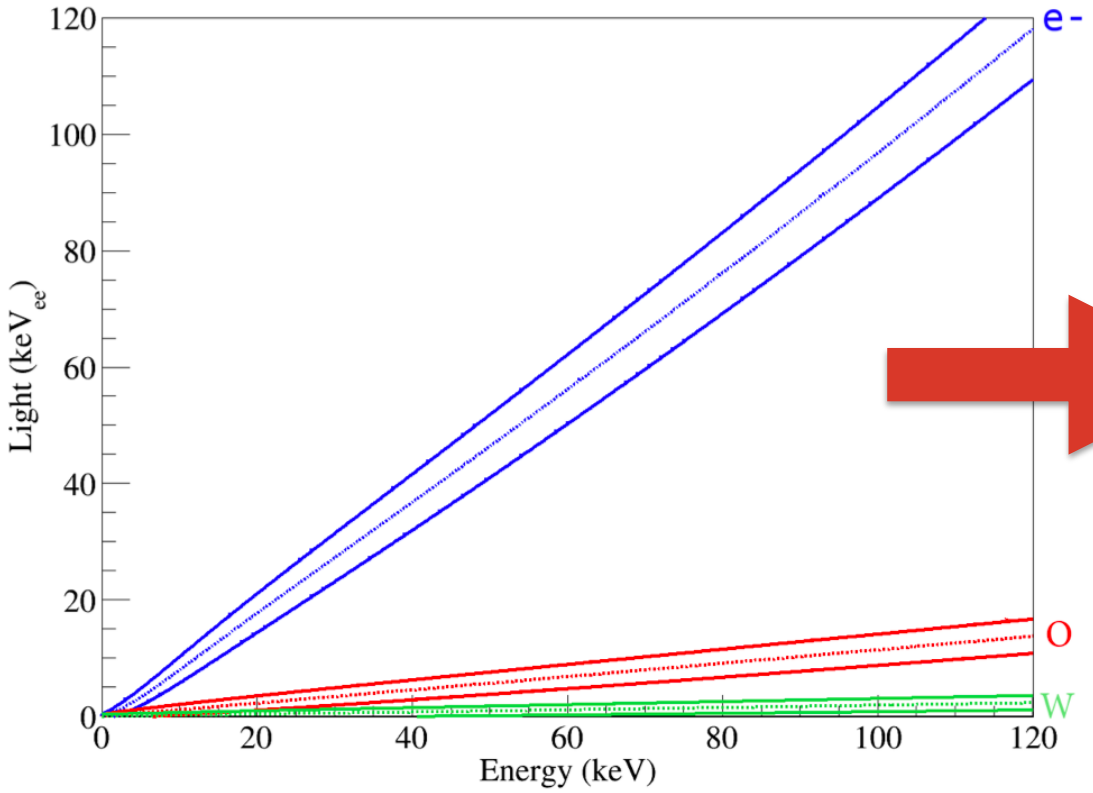
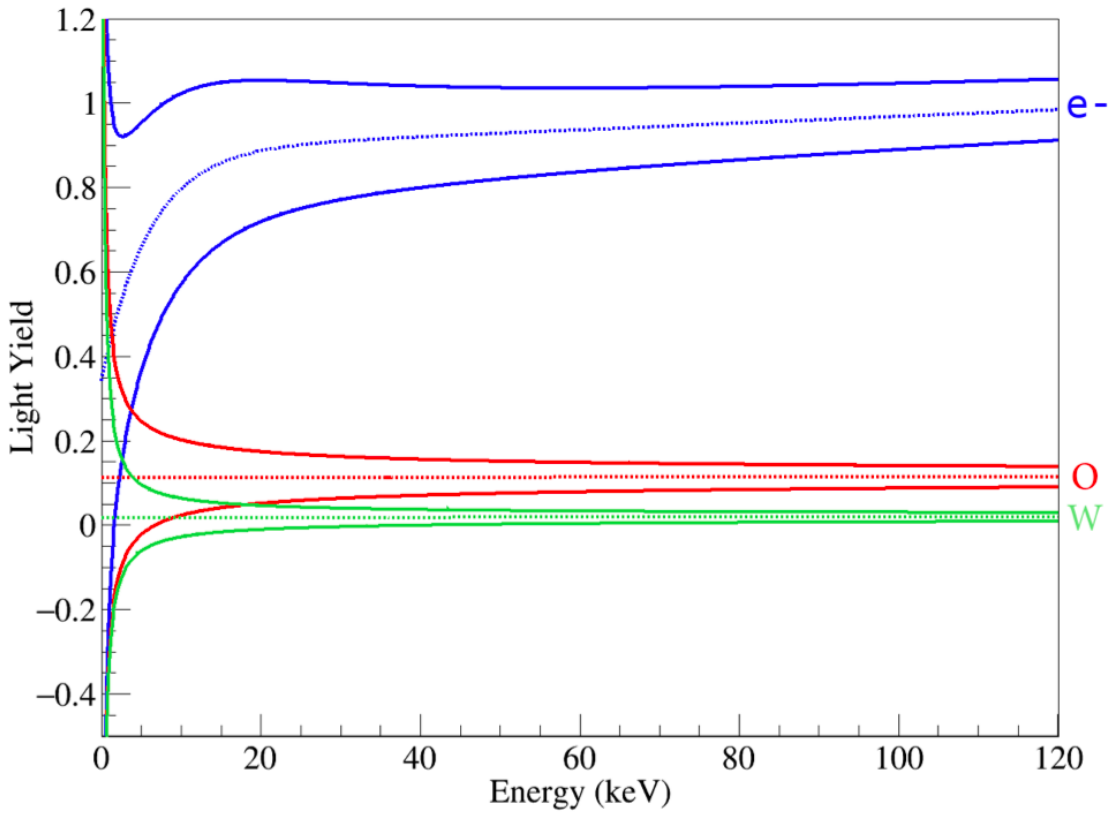
# LIGHT YIELD
# Example from CRESST using $CaWO_4$

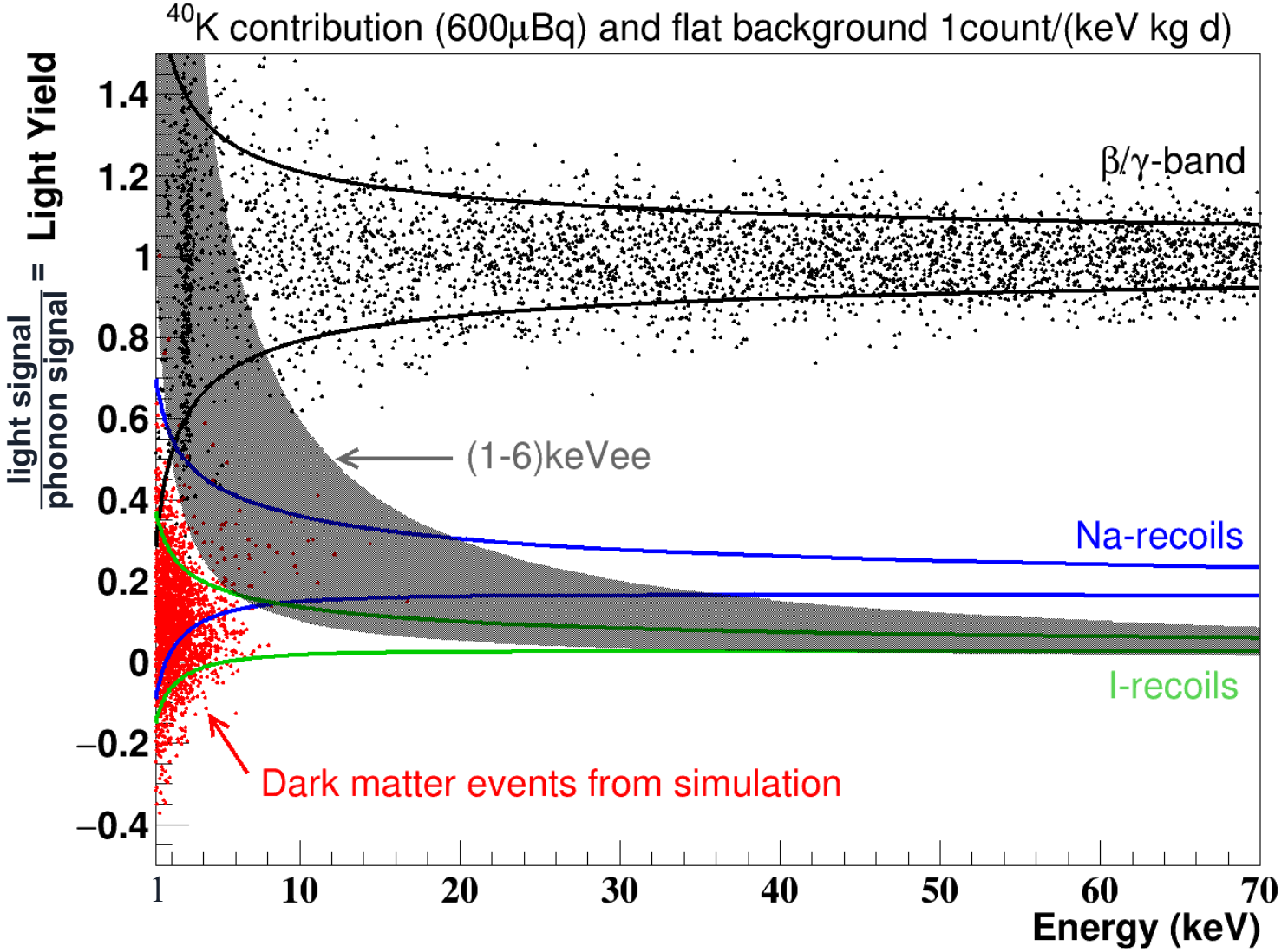



Light Yield = Light / Phonon Energy



# SIMULATION

100 KG-DAYS BEFORE CUTS
1KEV NUCLEAR RECOIL THRESHOLD




(1-6)keVee
=
modulation
signal in
DAMA