

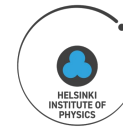
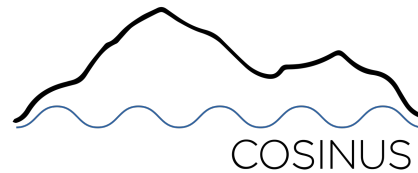
Illuminating the Invisible

COSINUS Commissioning at LNGS and remoTES Scale-up through PIRATES

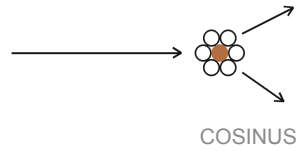
TeVPA 2026 · Tendo, Yamagata, Japan · September 2nd, 2026

Mukund Bharadwaj

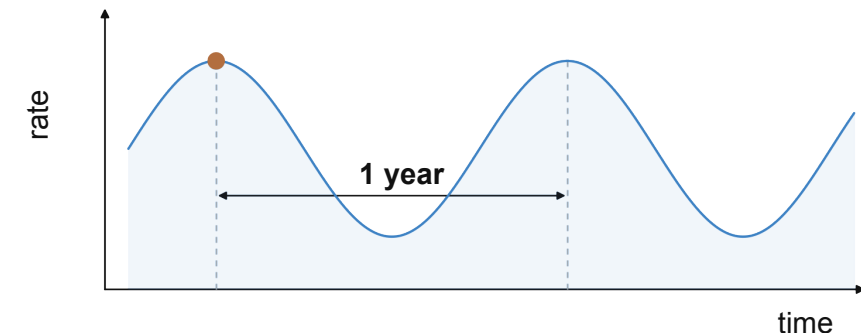
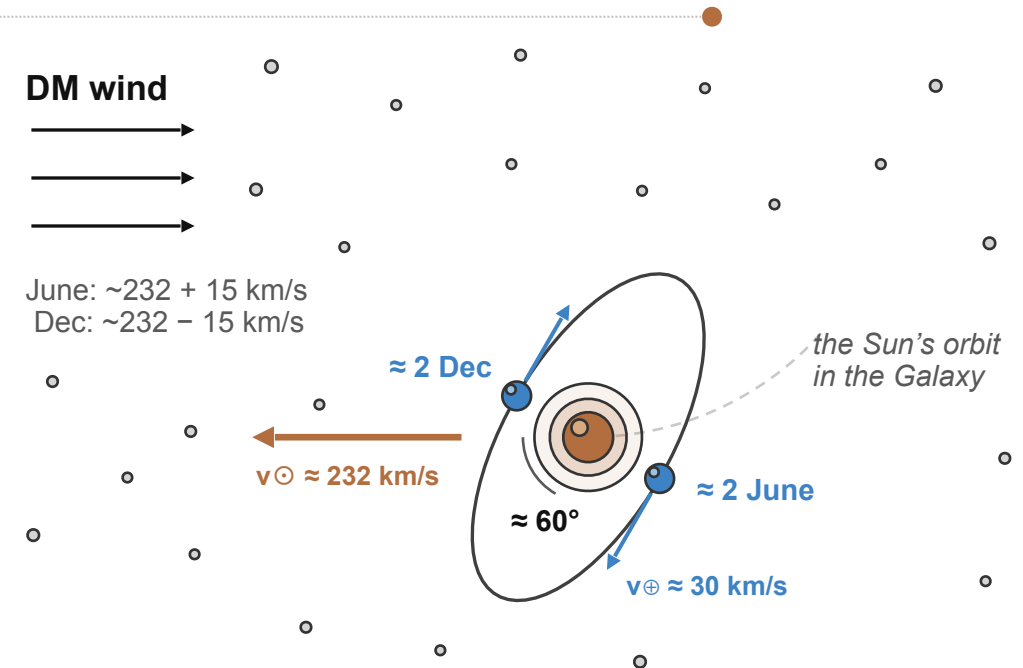
On behalf of the COSINUS collaboration



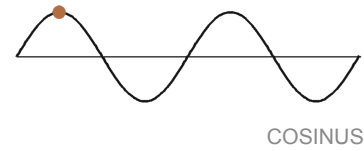
Direct Detection and Annual Modulation



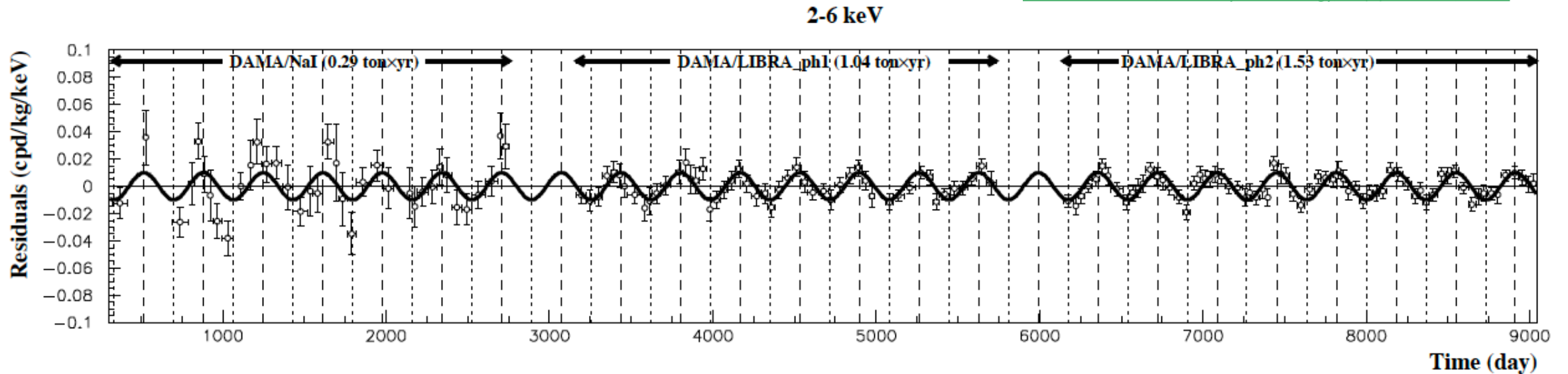
- Look for rare **nuclear recoils** * from galactic dark matter scattering off a target
- Decades of progress across **many targets and technologies**
- Motion through the DM halo imprints an **annually modulating rate** on the signal
- No confirmed detection to date, with one long-standing claim: **DAMA/LIBRA**



The DAMA/LIBRA Signal



R. Bernabei et al., Nucl. Phys. At. Energy, 22(4):329-342, 2022.



$>13 \sigma$

modulation significance at (2-6) keVee

0.998 yr

period: (0.99834 ± 0.00067) years

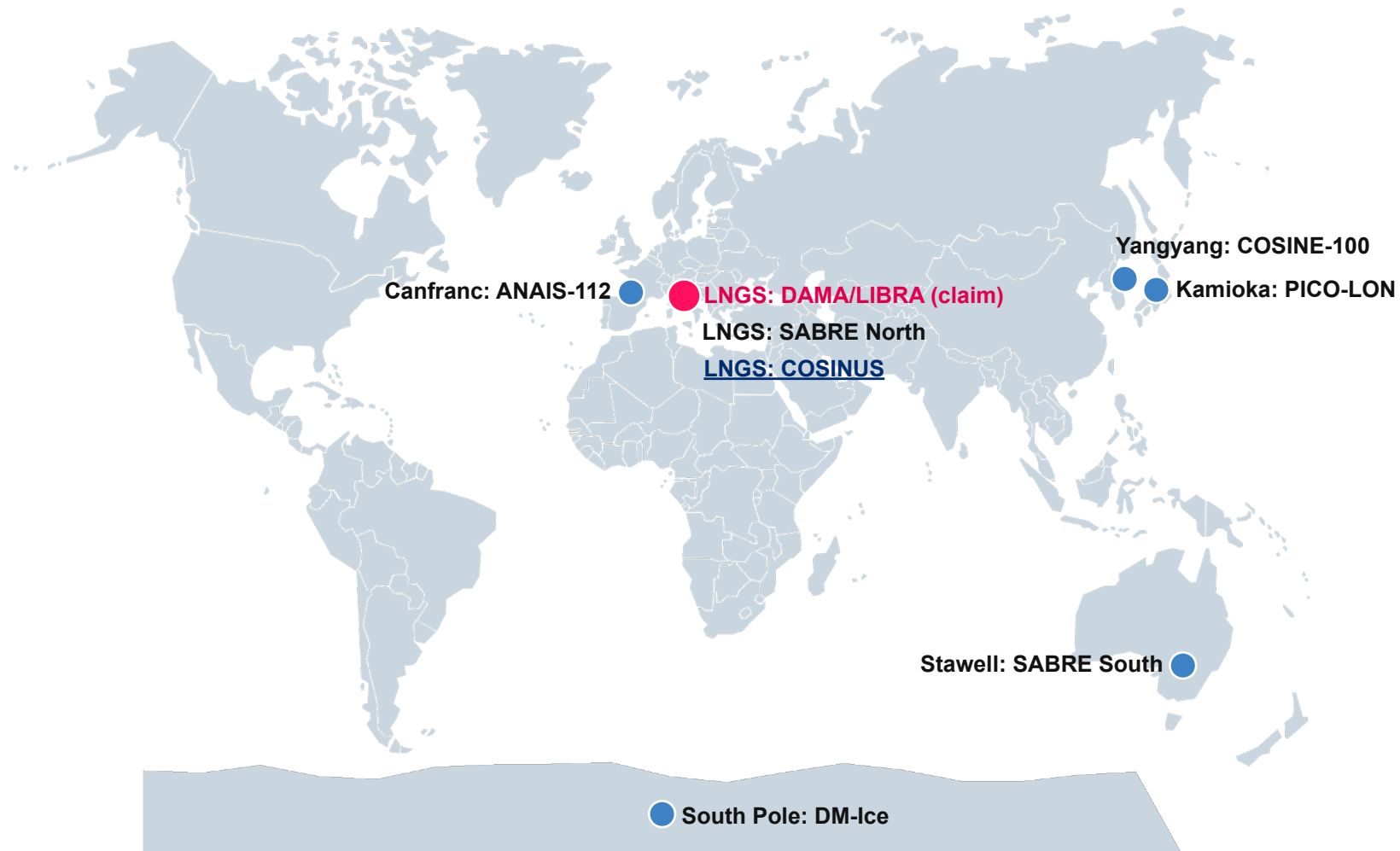
22 May

phase of the maximum, ± 4 days

**Not confirmed by other
experiments**

No convincing explanation without dark matter has been found

The NaI Landscape



Only one NaI experiment is
cryogenic

● DAMA/LIBRA: annual modulation at $>13\sigma$

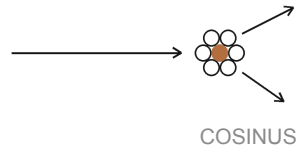
● Room temperature, scintillation only

COSINUS: **phonon and light** in every event

The quenching-factor catch:
scintillation-only searches must
convert observed energy-scale
into nuclear-recoil energy:
CRYSTAL DEPENDENT

A same-target, model-independent cross-check requires NaI itself

The Quenching Factor Problem



1 Scintillation experiments measure light

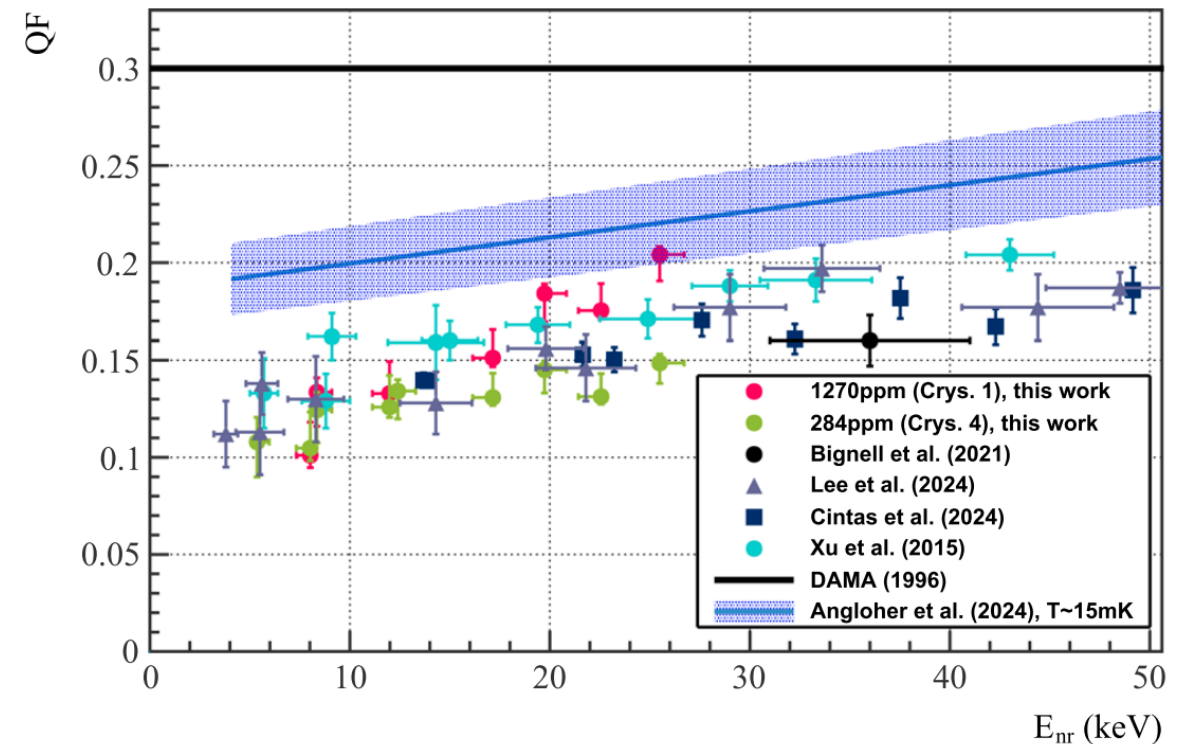
Energies are calibrated with γ sources, in electron-equivalent units (keVee)

2 Nuclear recoils give less light

The quenching factor (QF) converts keVee into nuclear-recoil energy

3 The conversion is uncertain

Measured NaI quenching factors spread between datasets and depend on energy



[Eur. Phys. J. C **86**, 485 \(2026\)](#)

Cryogenic Observatory for Signatures seen in Next-generation Underground Searches

- Ultrapure NaI operated as **cryogenic scintillating calorimeters*** at millikelvin temperatures
- Two readout channels per event: **phonons** and **scintillation light**
- Located at **Laboratori Nazionali del Gran Sasso**, Italy



COSINUS inauguration, 2024



***See also:** OvDES - Probing Solar Neutrino BSM Physics with Cryogenic Scintillating Calorimeters, Elisa Gaido



Anatomy of a COSINUS Module

1 34 g NaI target crystal

Cube of (21 x 21 x 21 mm)

2 Si disk below the crystal

Serves as an α -background shield

3 Si beaker around the crystal

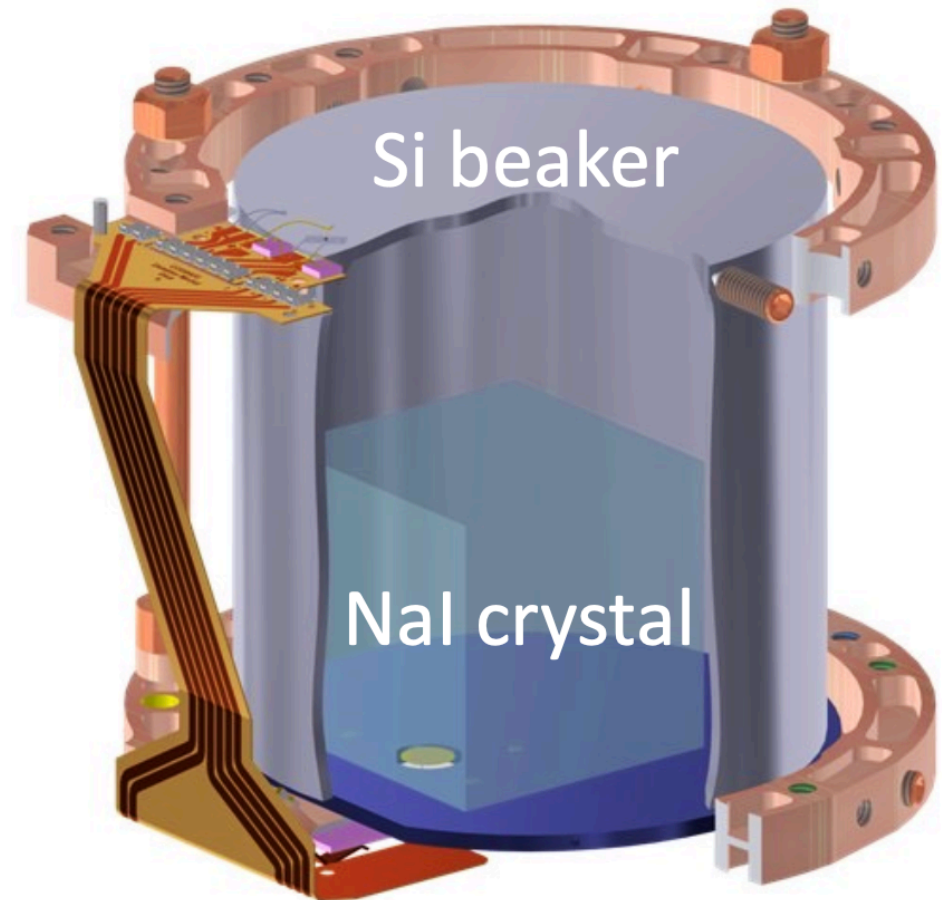
Collects the scintillation light; read out by a directly deposited TES

4 Au pad on the crystal

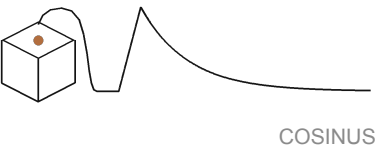
Evaporated interface for the phonon signal

5 Au bond wire to the TES wafer

Transmits the phonon signal to the remote TES sensor



Latest Results



~500 eV

baseline resolution, 34g NaI-remoTES prototype
(to be published)

Phonon channel

<5 eV

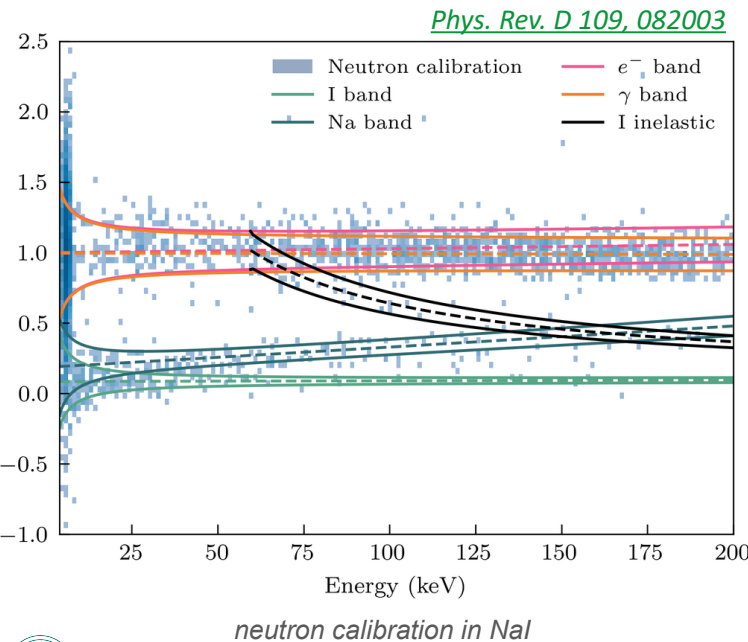
baseline resolution, 15g Si benchmark
(to be published)

Light channel

<10 eV

baseline resolution, 2.33g Si benchmark
(to be published)

Optimisation tests



The e/γ band and the nuclear-recoil bands are resolved in NaI



See also: Demonstration of new analysis tools developed in the COSINUS collaboration, Maximilian Gapp's talk later in this session

Low-Background Facility

Dilution refrigerator and muon veto commissioned; Run 1 data-taking begins in Q1 2027

Shielding, from the outside in:

- 1 3600 m w.e. of rock overburden
- 2 Water tank, 7 m in diameter and height
- 3 Active muon veto within the water
- 4 8 cm of copper around the dilution refrigerator



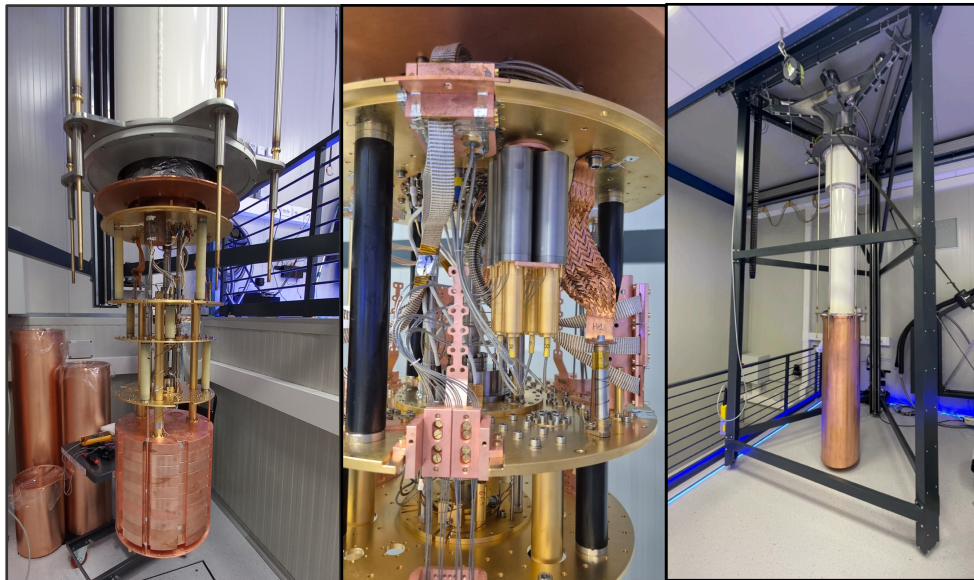
The commissioned facility in Hall B, LNGS



A Dry Cryostat Inside an active veto

The cold “heart”: a custom dry dilution refrigerator

- 48 TES channels for the Run 1 array and beyond
- Pulse-tube precooled, with vibration decoupling for detector stability
- Magnetic field compensation for the sensors



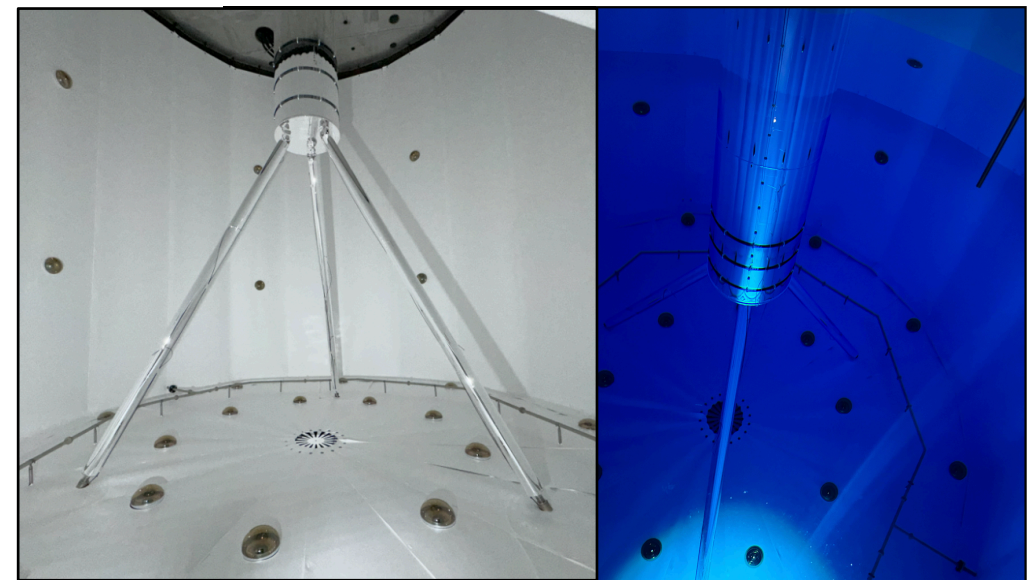
The dilution refrigerator during installation

The active veto: a water Cherenkov muon veto

- Active muon tagging with PMTs in 7m of water
- Doubles as a supernova neutrino monitor

[*G. Angloher et al Eur. Phys. J. C 84, 551 \(2024\)*](#)

[*G. Angloher et al JCAP03\(2025\)037*](#)

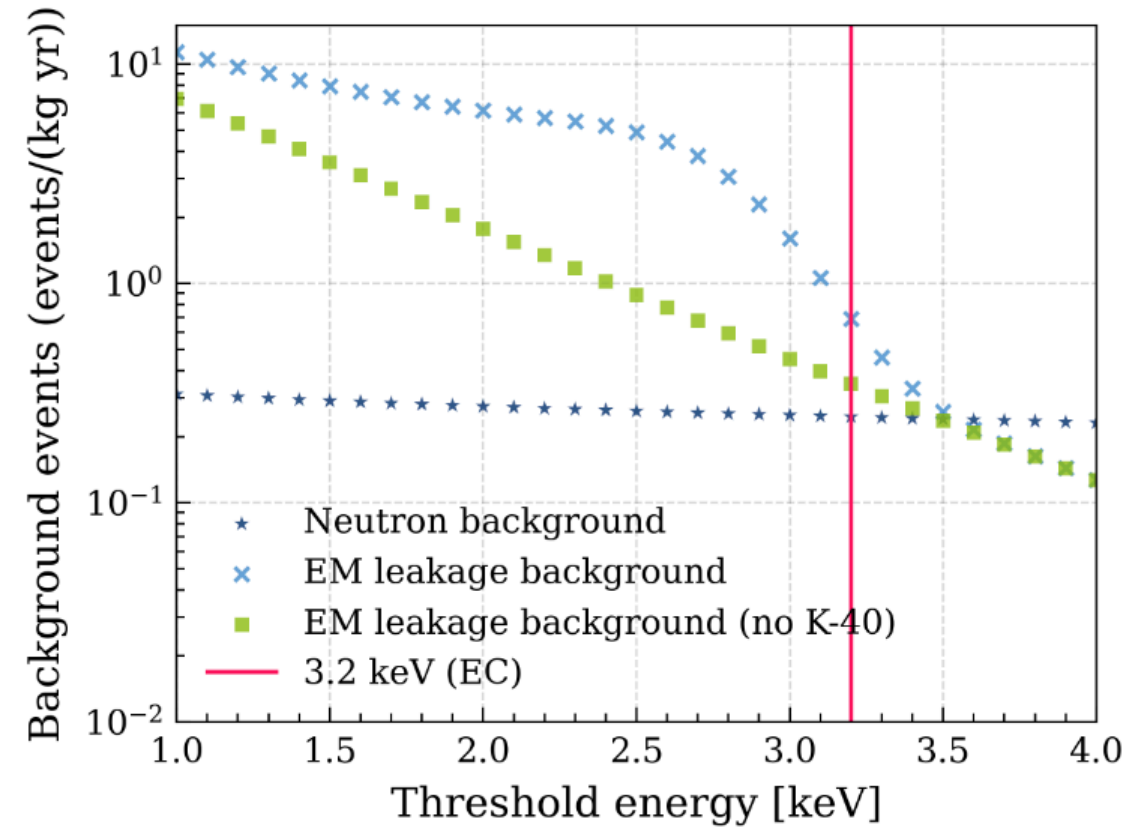


The veto tank: dry and filled

Screening and Background Simulation

- Material selection based on an extensive screening campaign
- Complete background simulation carried out in GEANT4

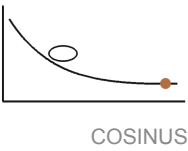
Publication soon!



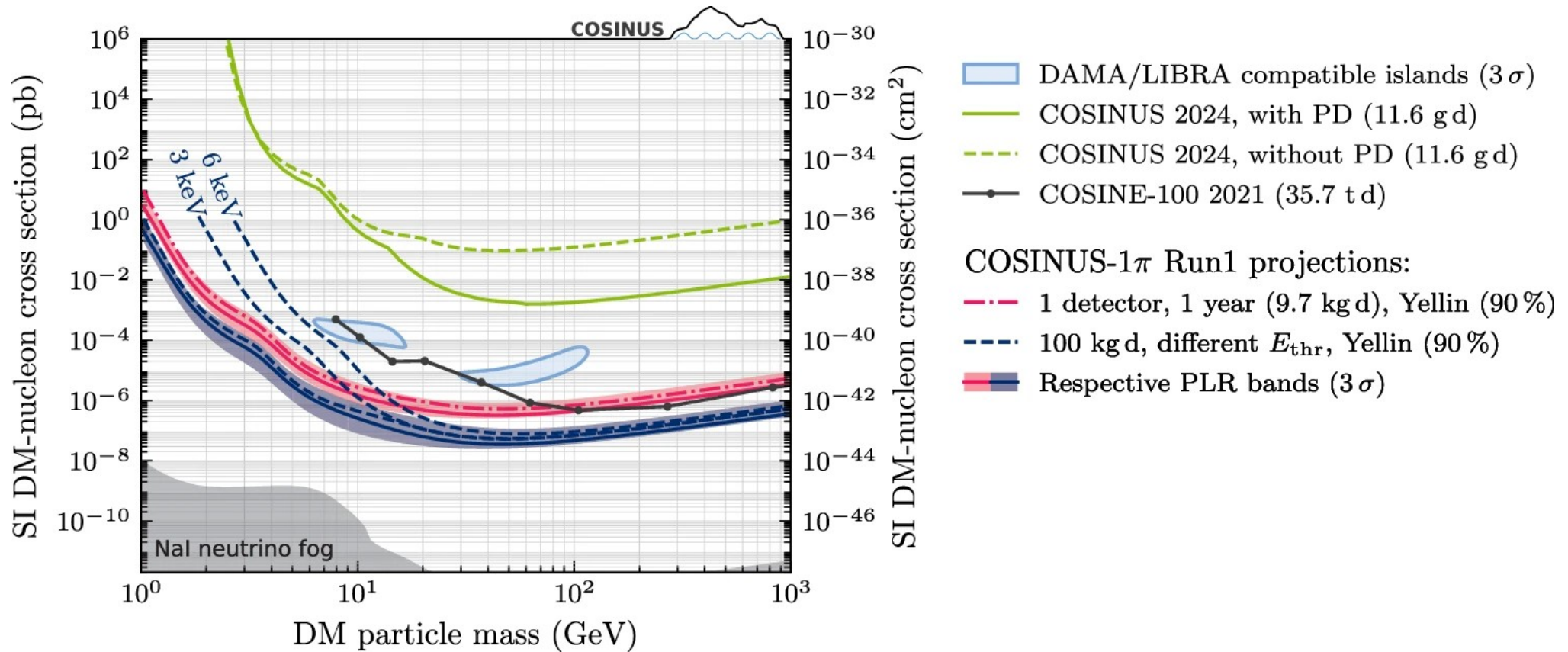
0.21
neutron events per kg per year, for a 1 keV threshold

100×
below the DAMA/LIBRA modulation amplitude

Run 1: Testing DAMA/LIBRA Head-On



100 kg d planned exposure **8 × 34.8 g** NaI modules **1 year** to strong statements on DAMA/LIBRA



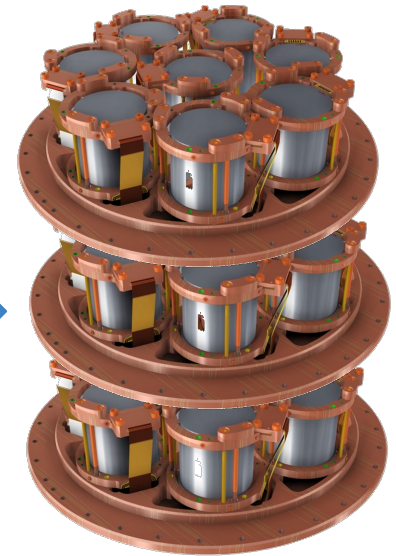
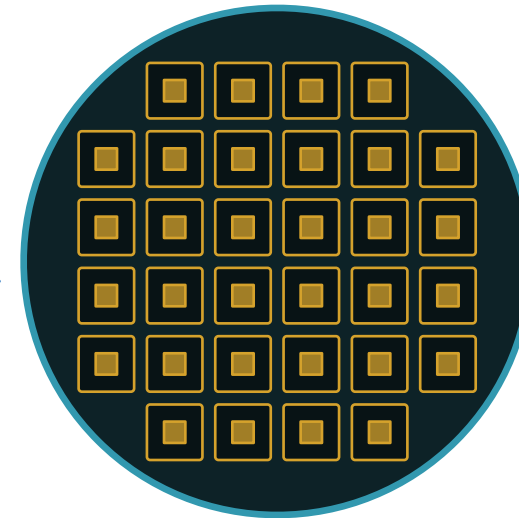
G. Angloher et al, Commun Phys 9, 213 (2026)

Prospects In Rare-event-searches with Advanced Transition Edge Sensors

COSINUS-driven fabrication program at the Max Planck Semiconductor lab (HLL)

- TES and remoTES production on **150 mm Si wafers** at the MPG Halbleiterlabor, Munich, Germany
- **Semi-industrial fabrication**: standardised protocols, quality checks
- Characterising and tuning of **TES sensors** and pairing them with **novel targets** for rare-event searches
- The path to **large arrays** beyond Phase 1

from single chips to wafer-scale arrays



HLL



Funded by
the European Union



European Research Council
Established by the European Commission

Project: 101231292 · ERC Consolidator Grant · PI: K. Schäffner

Conclusion

1 A model-independent cross-check

COSINUS tests DAMA/LIBRA with the same target and is the only NaI experiment with dual-channel readout

2 Quasi-background-free

In the region of interest; one year of data allows strong statements on the DAMA/LIBRA signal

3 Commissioned and scaling up with PIRATES

Facility ready; Phase 1 data-taking begins in Q1 2027, first results within about a year



Commissioning at LNGS



Thank you!

Questions?

First dark matter results expected within one year of data-taking



More COSINUS at TeVPA 2026

- Kumrie Shera: Demonstration of eV-Scale Energy Resolution with the remoTES Detector Design (this session)
- Maximilian Gapp: Demonstration of new analysis tools developed in the COSINUS collaboration (this session)
- Elisa Gaido: OvDES - Probing Solar Neutrino BSM Physics with Cryogenic Scintillating Calorimeters (Thursday, DM parallel session)

Backup slides



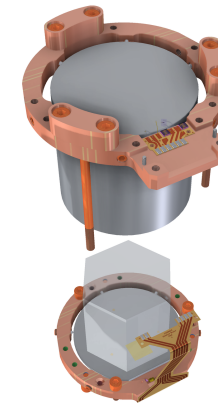
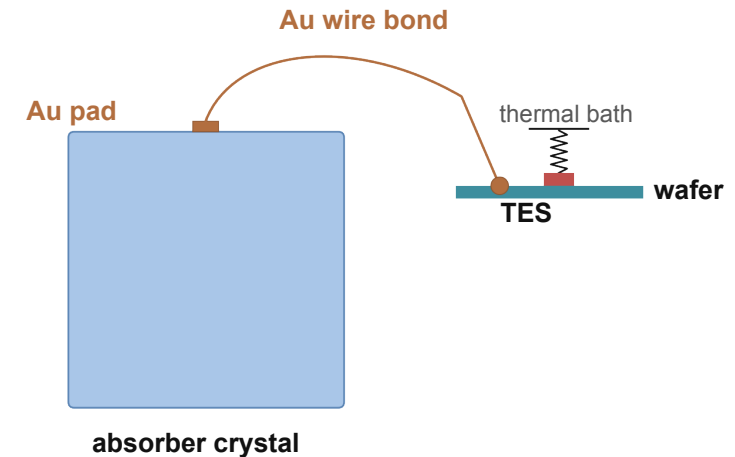
Appendix: Why remoTES?

Problem: NaI is hygroscopic and has a low melting point; direct TES deposition on the crystal is not viable

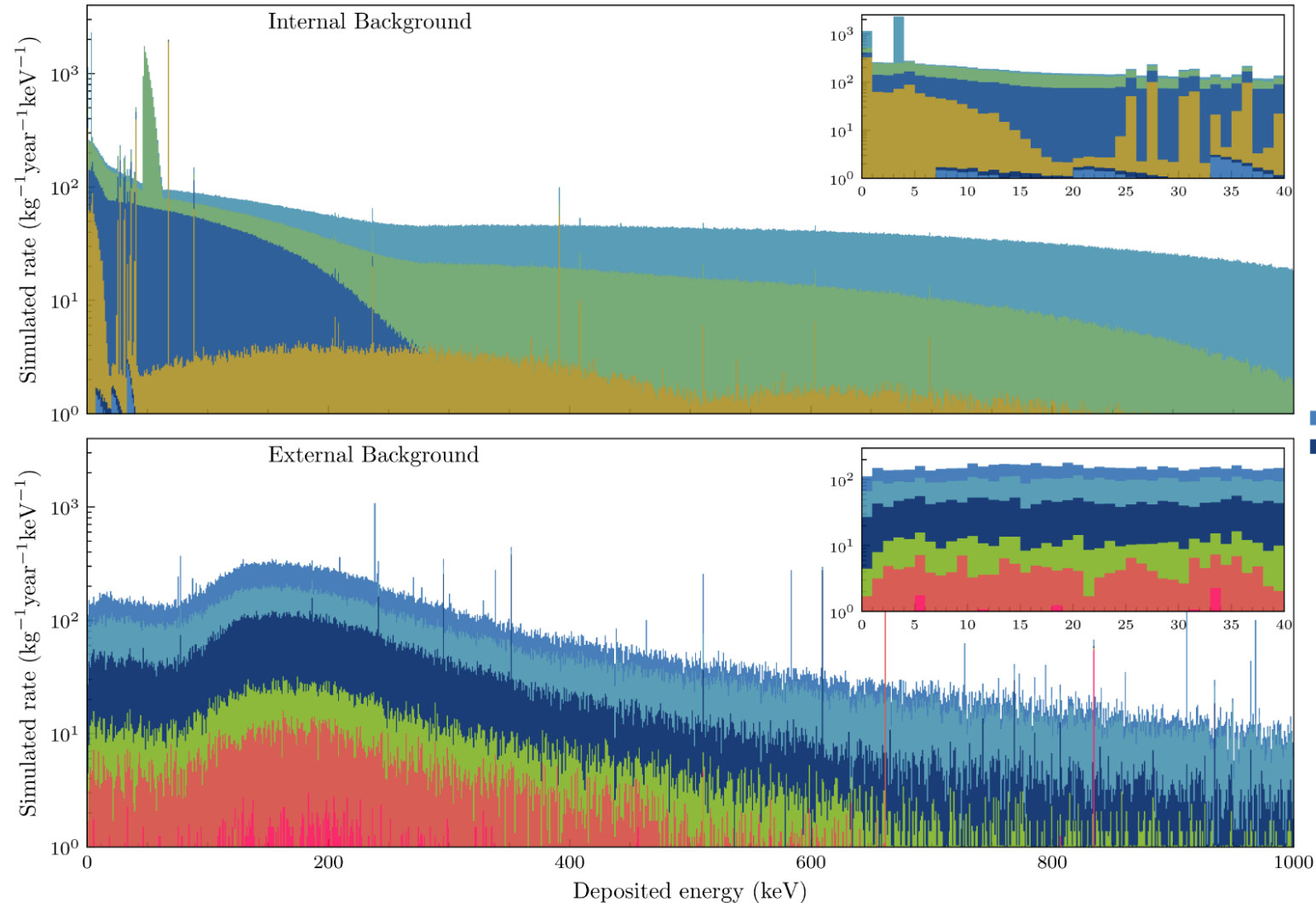
Solution: remoTES: the TES sits on a separate wafer and couples to the absorber through a gold link

Advantages: Absorber untouched by fabrication; broad choice of target materials; reproducible production of large arrays

 **See also:** remoTES optimisation, Kumrie Shera's talk right after this one

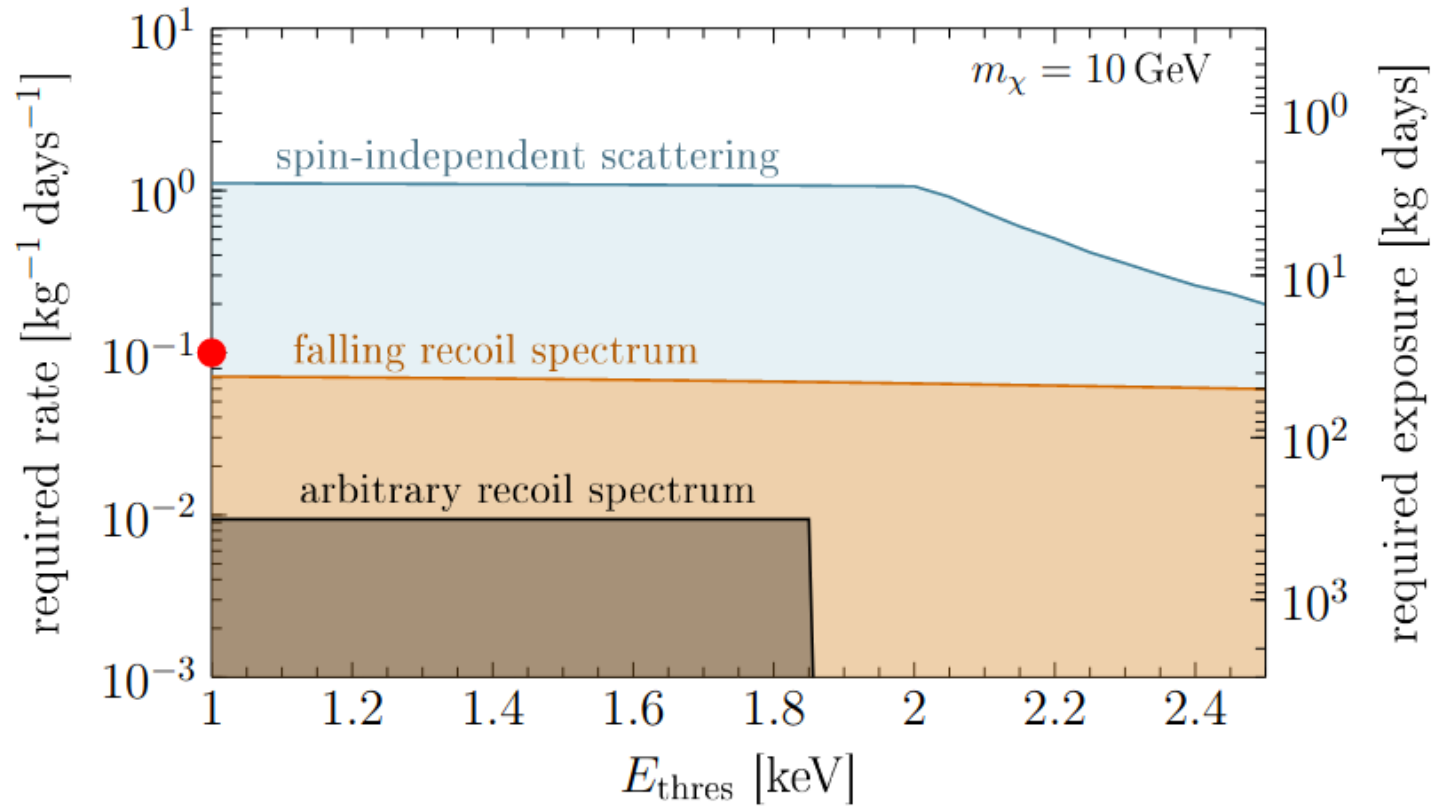


Appendix: EM Background



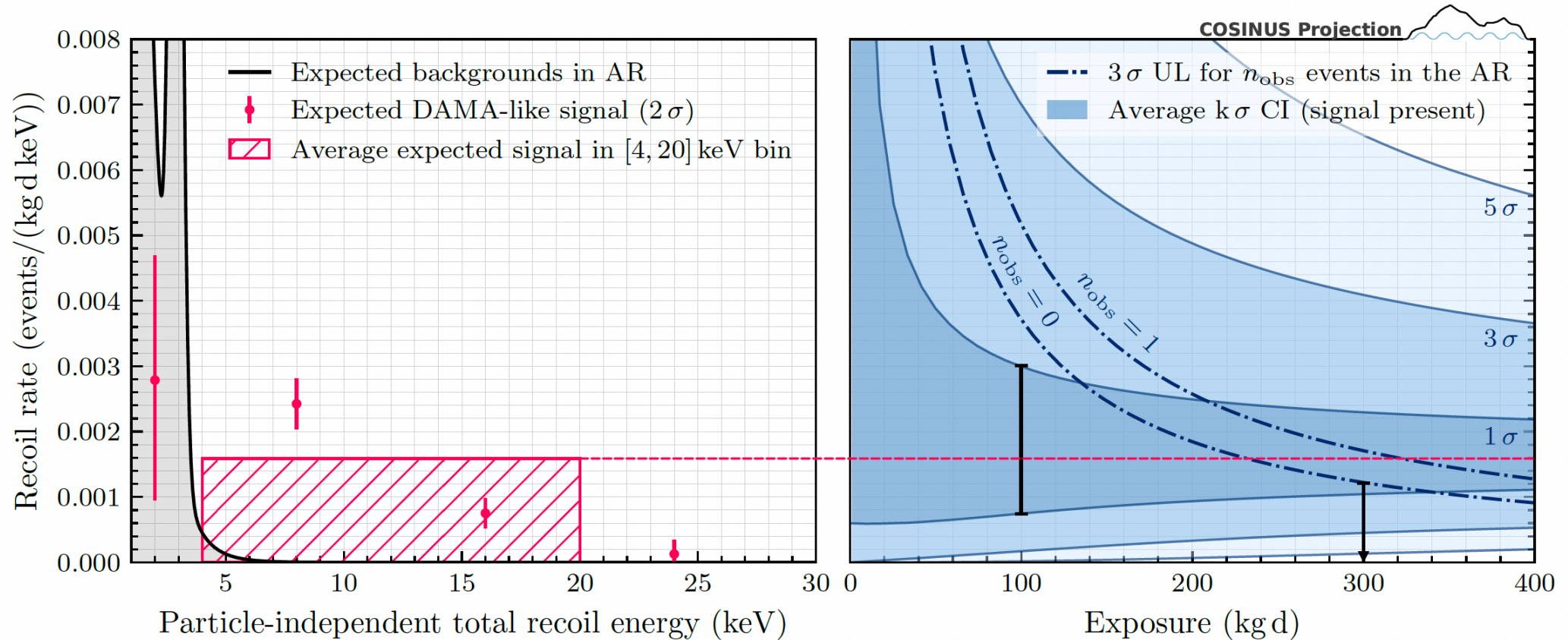
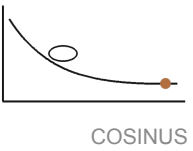
Appendix: Beyond Run 1

1000 kg d with 24 modules



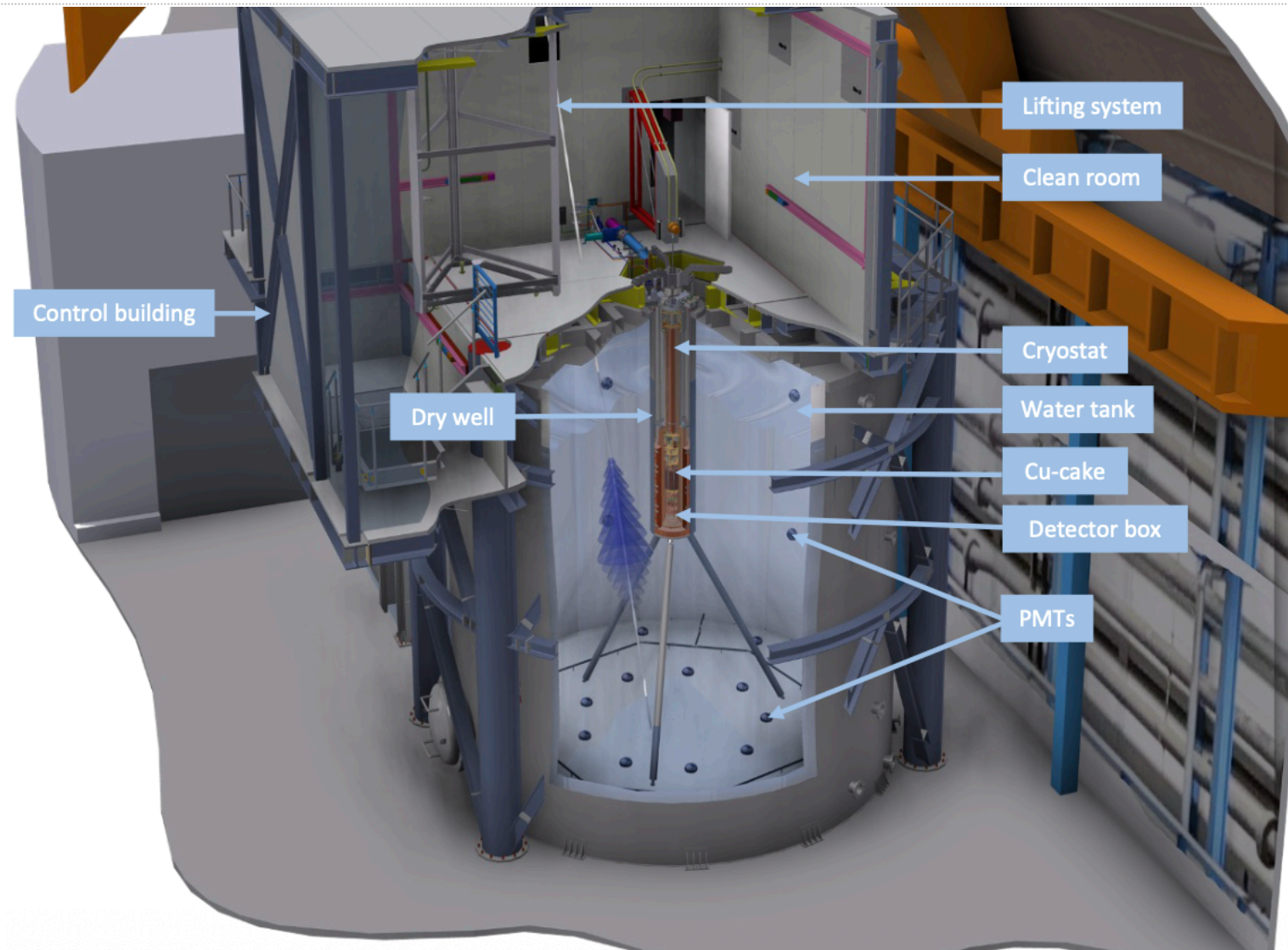
→ Aim for exclusion of an arbitrary recoil spectrum

Appendix: DAMA-like Signal versus Exposure

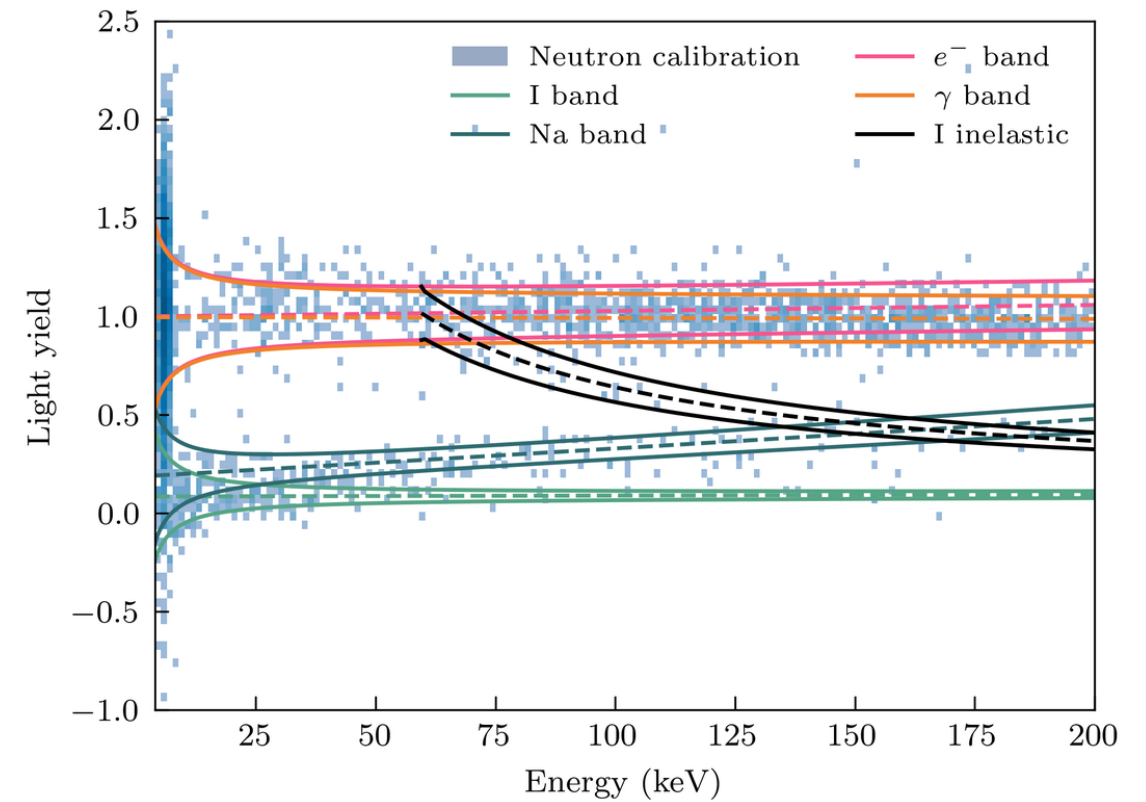
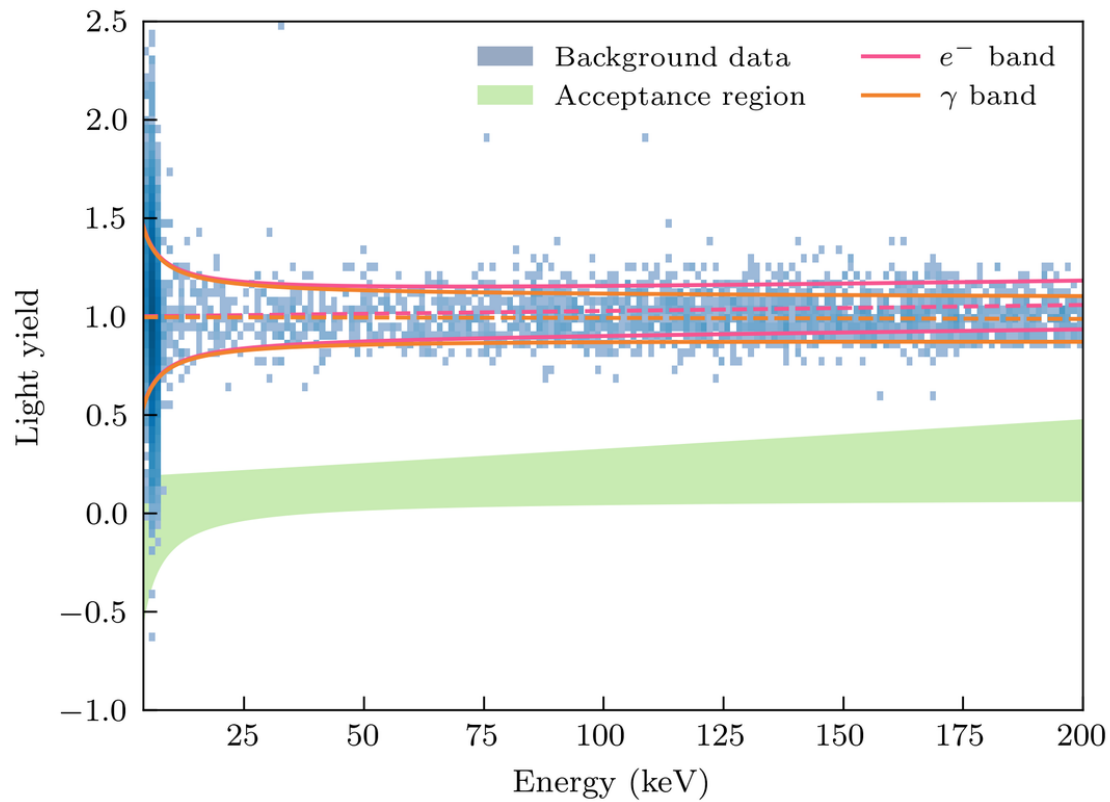
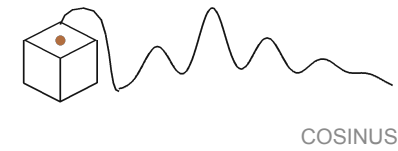


COSINUS projection: expected sensitivity to a DAMA-like signal as a function of exposure

Appendix: Facility in Detail



Appendix: Light-Yield Bands



background data (left) and neutron calibration (right) in NaI