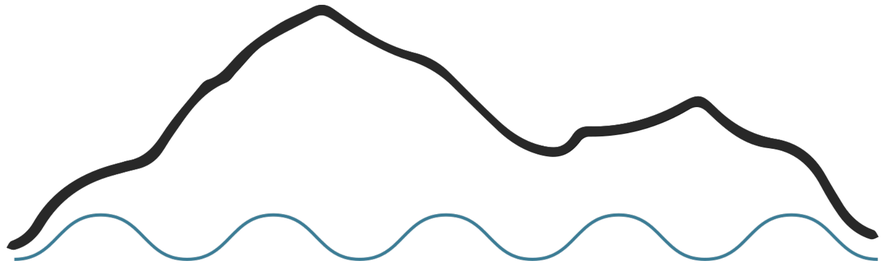


COSINUS

Report from the **C**ryogenic **O**bservatory for **SI**gnatures seen in **N**ext-generation **U**nderground **S**earches

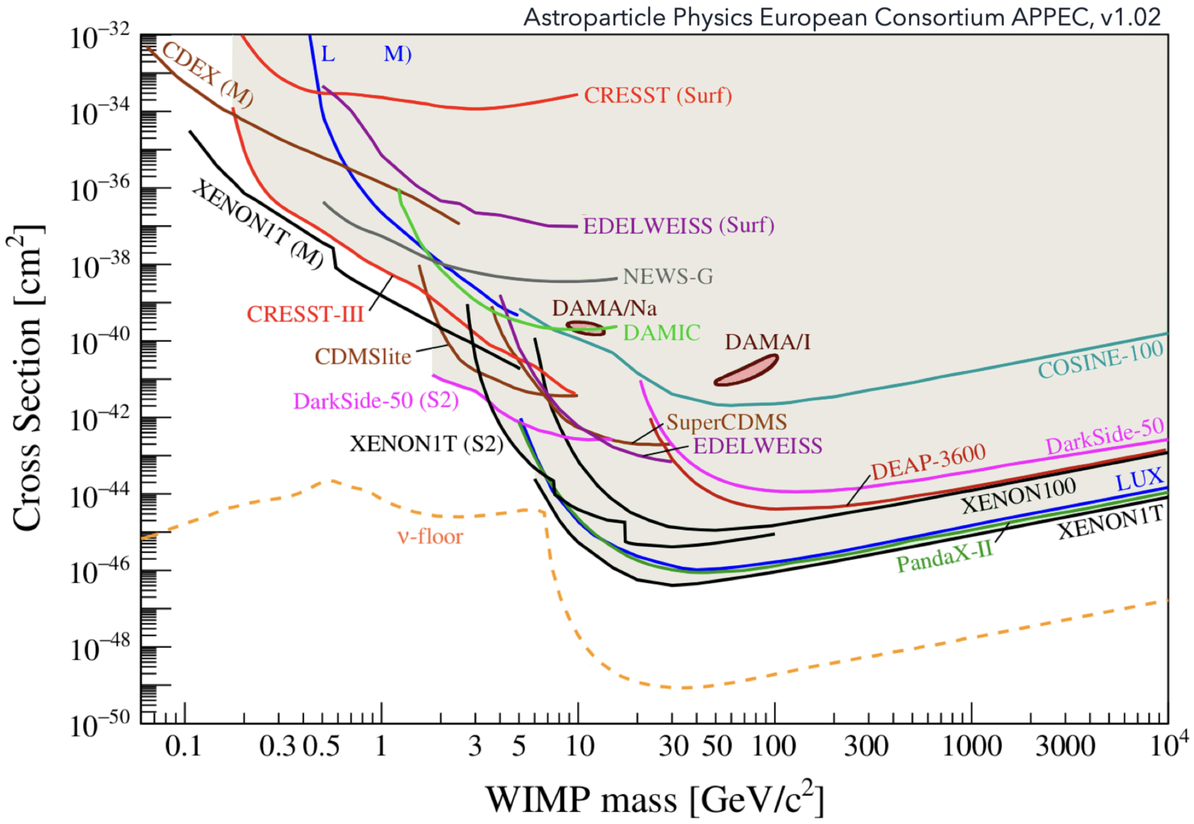
Leonie Einfalt

TECHNISCHE UNIVERSITÄT WIEN

HEPHY INSTITUT FÜR HOCHENERGIEPHYSIK

Motivation

- Vast number of DM direct detection experiments employing different detection methods
- Large region of **parameter space** already **excluded** for DM-nucleus elastic standard scenario scattering
- One experiment claims a signal: **DAMA/LIBRA**



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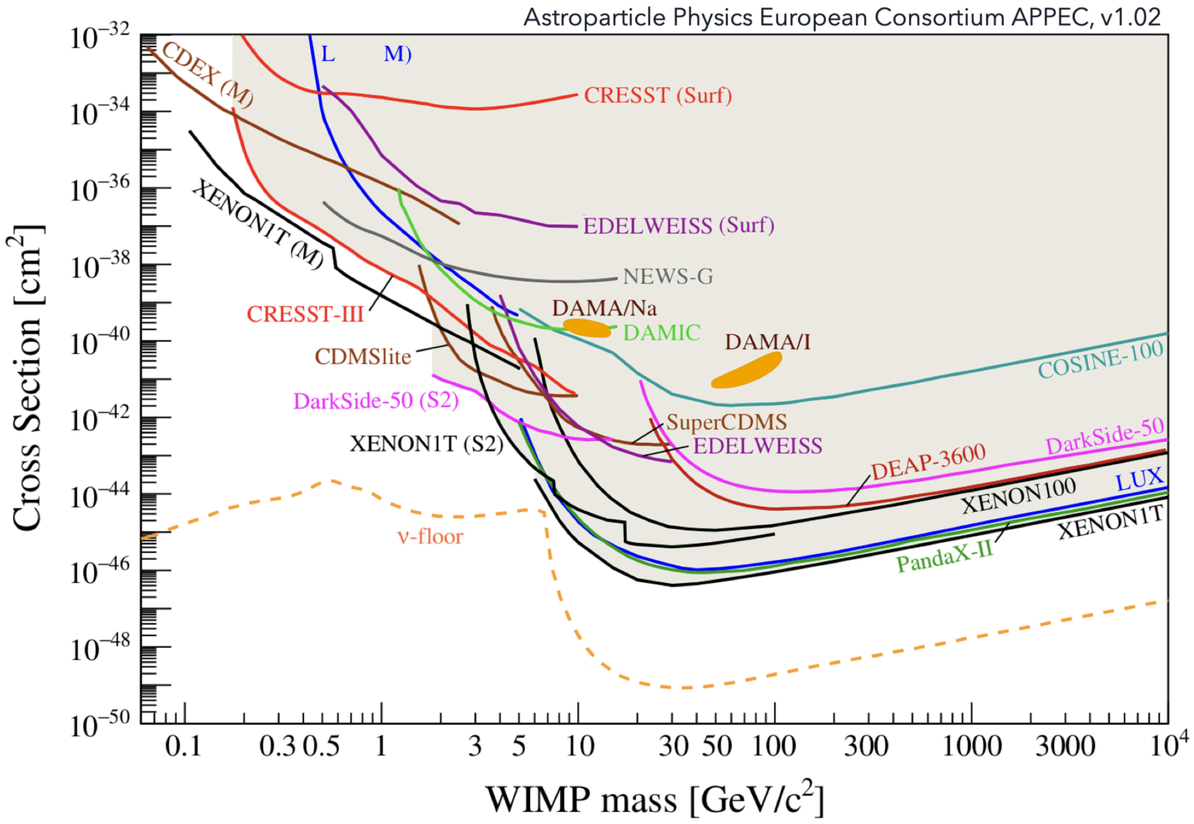
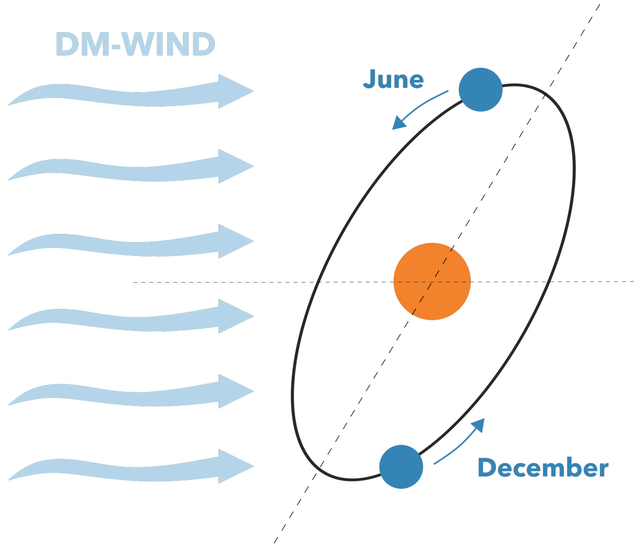
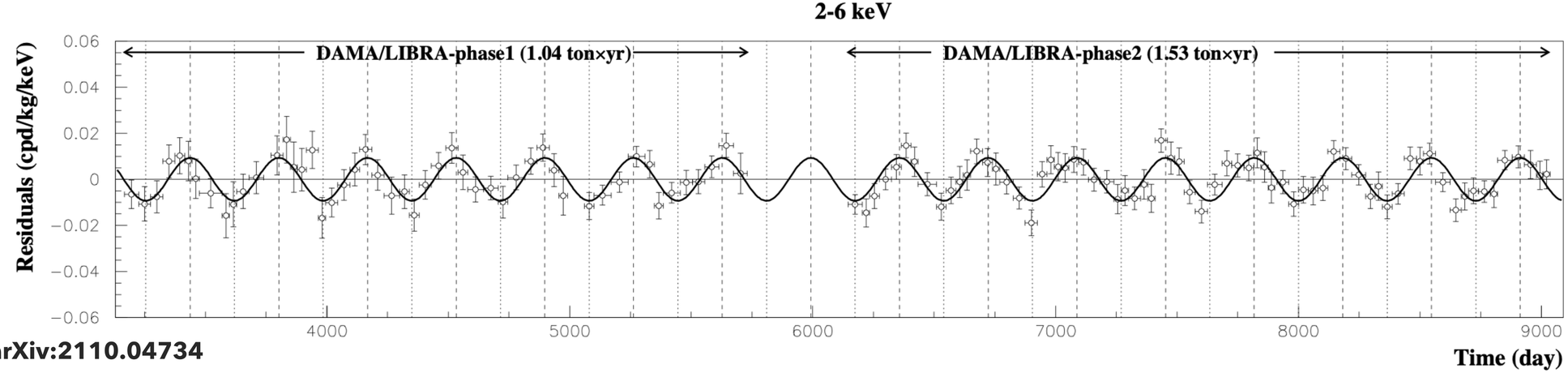


DAMA/LIBRA signal

- DAMA/LIBRA sees a **modulation signal** as predicted by Earth's movement through the DM-wind in the Milky Way with a **statistical significance of 13.7σ**
- Light signal (PMTs) in **250 kg NaI** with a **threshold of 1keVee**
- Located at Gran Sasso Underground Lab (LNGS), data taking since 1996
- Period: **0.9983 ± 0.0007** (in the 2-6 keVee region)
- Phase: **22nd May +/- 4 days** (cosine peaking June 2nd)





arXiv:2110.04734

Theory prediction & unknowns

ρ_0

$f(\mathbf{v})$

Uncertainties in many astrophysical parameters, DM density and DM distribution at Earth's position in the Milky Way

$\frac{d\sigma}{dE_R}$

Possible non-trivial dependence on target material in the cross section

→ need to use **same target material** to probe DAMA/LIBRA signal

NaI based experiments:

ANAIS, SABRE South/North, COSINE, KIMS, PICO-LON, DM-Ice & COSINUS

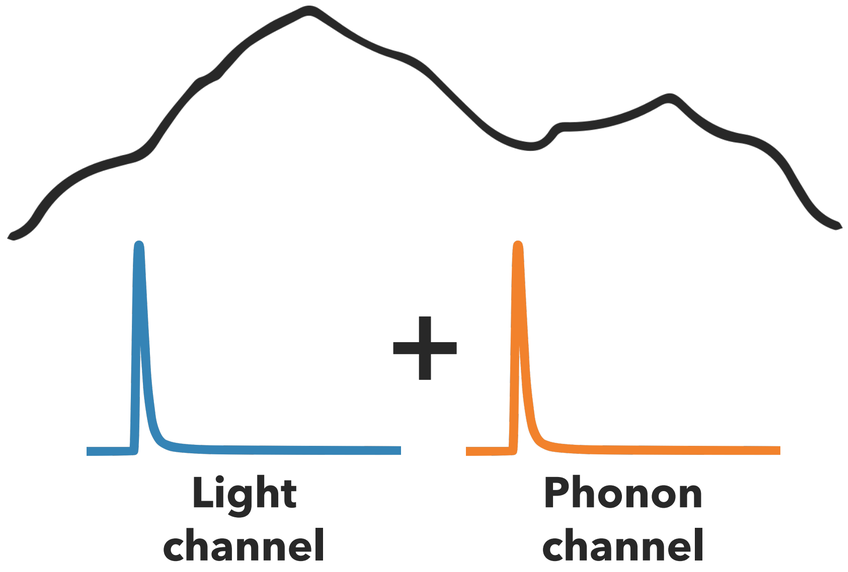
$$\frac{dR}{dE_R} = \sum_T N_T \frac{\rho_0}{m_\chi} \int_{v_{\min}}^{|\mathbf{v}|<v_{\text{esc}}} d^3v\, f(\mathbf{v}) v \frac{d\sigma}{dE_R}$$

annual modulation enters here

particle physics input

COSINUS experiment

- Aims at **model independent** test of DAMA
- Uses **same material: NaI**
- In the **same underground lab at Gran Sasso**
- Novel and **unique** operation of NaI as **cryogenic detector** with Transition Edge Sensors (TES)
  - Detecting phonon and light signal simultaneously
  - Particle discrimination (electron/gamma vs. nuclear recoil) on event-by-event basis
  - Lower threshold in **nuclear recoil energy**

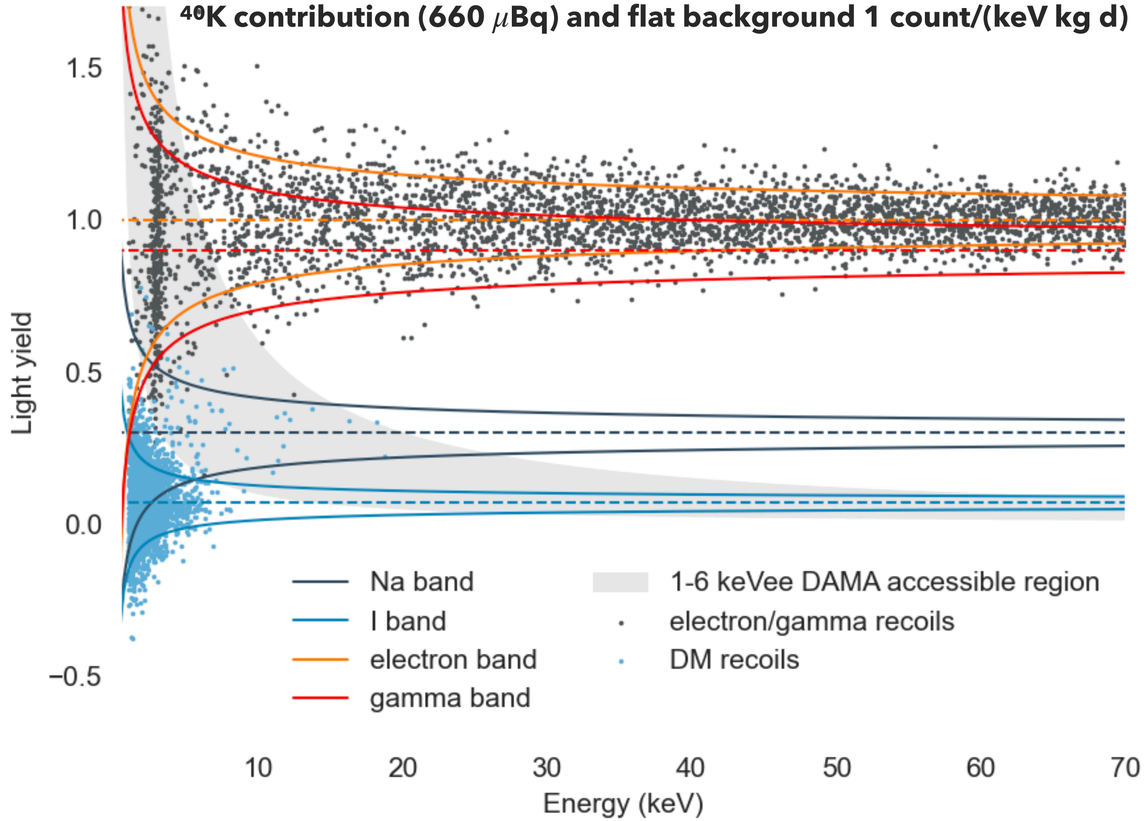


Particle discrimination

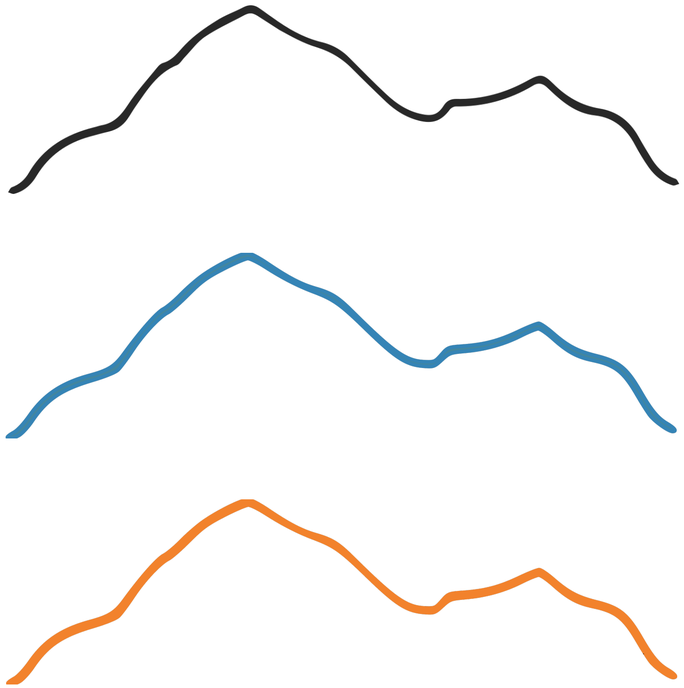
- Light-quenching → different bands in the light yield vs. phonon energy plane

$$LY = \frac{\text{light energy}}{\text{phonon energy}}$$

- Intrinsic measurement of quenching factors possible
- **Simulation** for 100 kg days exposure before cuts for **1keV nuclear recoil threshold**
- Same sensitivity at smaller target mass (~1 kg for COSINUS vs. 250 kg for DAMA)



Status of the experiment



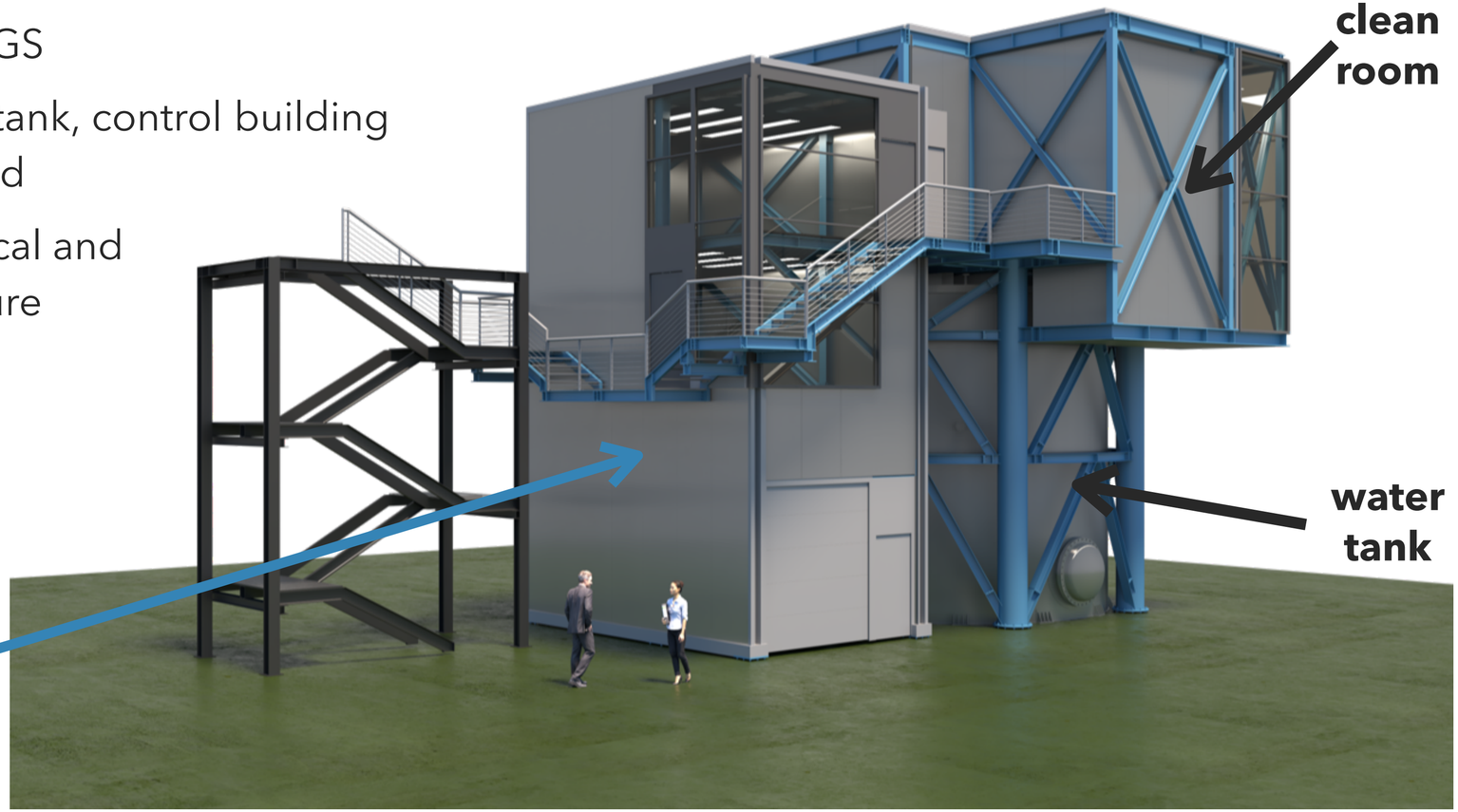
Experimental facility on-site

Simulation and Screening

Detector R&D

Construction of the facility

- Located in hall B at LNGS
- Construction of water tank, control building and clean room finished
- Construction of electrical and clean room infrastructure currently ongoing
- Dry cryostat delivery autumn 2023



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Shielding concept

- Cryostat surrounded by 8cm Cu shield
- Dry-well supported by tripod
- Water tank as passive shielding
- PMTs for active Cherenkov muon veto

Simulation study on passive shielding concept: Eur. Phys. J. C (2022) 82: 248

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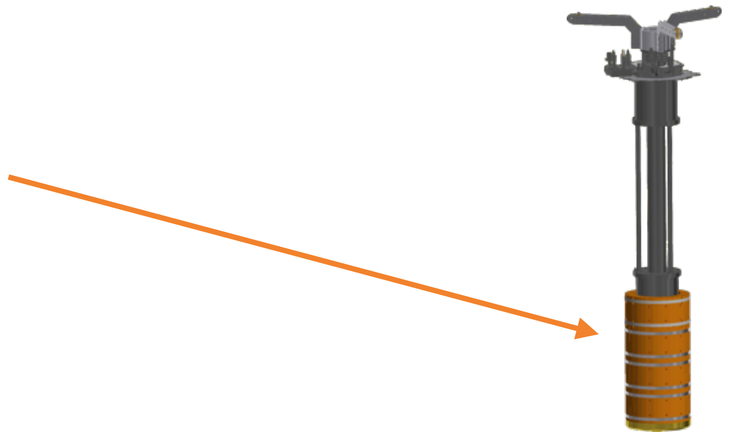

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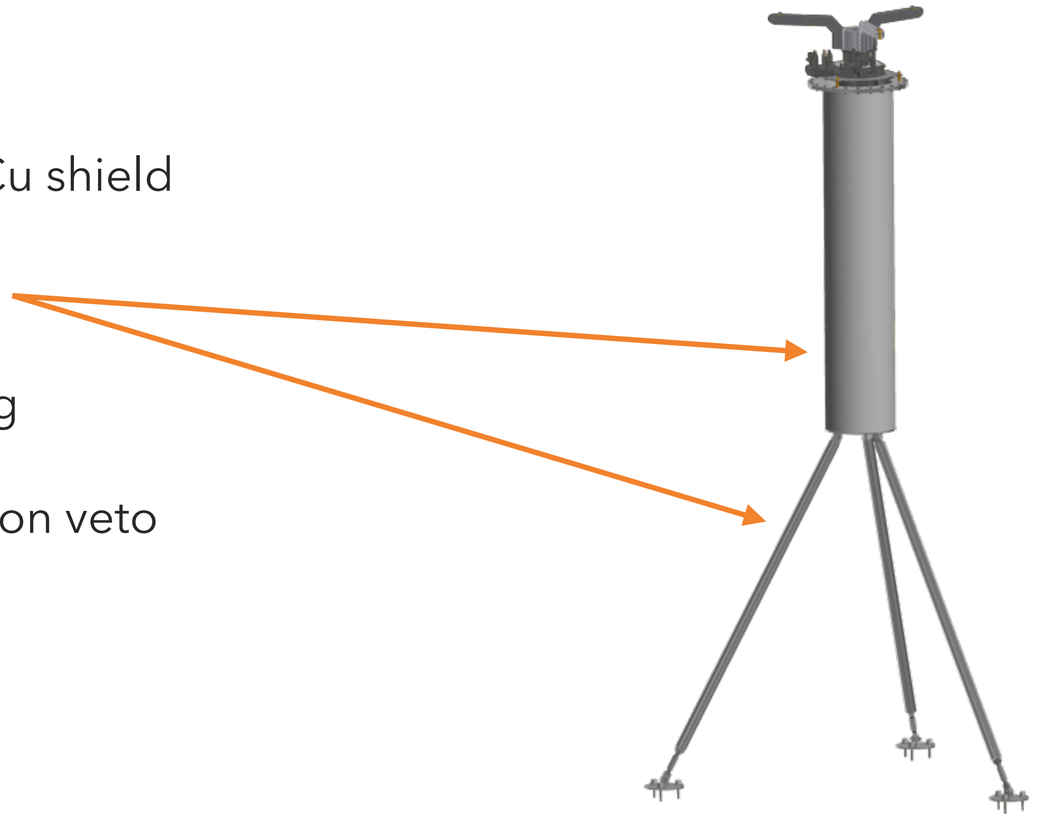

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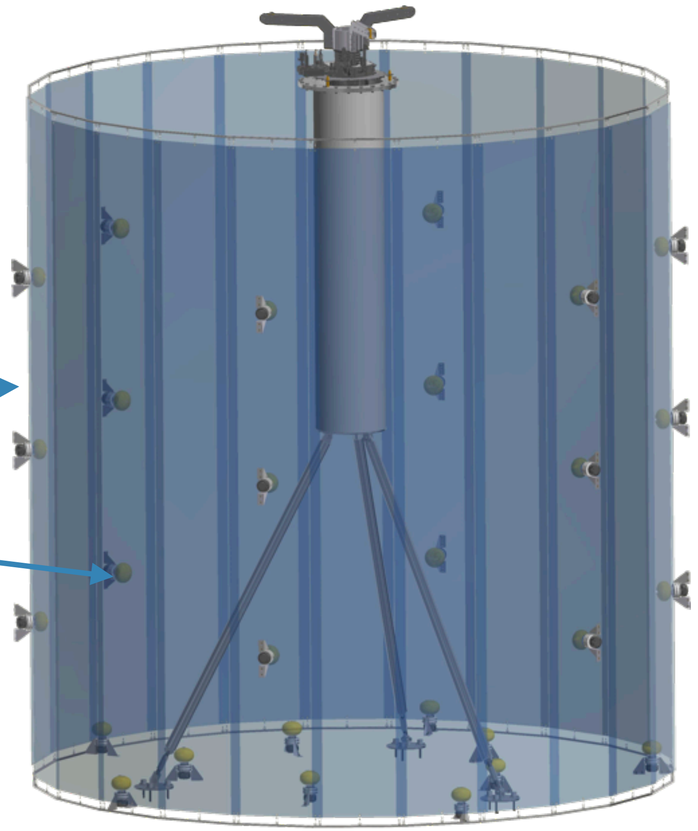

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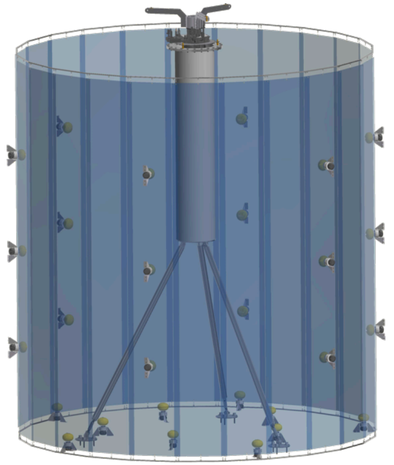
Simulation and Screening

Active muon veto simulation

- PMT Veto to tag muons
- Monte Carlo simulation to find most efficient PMT & dead layer placement
- For single muon and shower events



Intrinsic radiation background

- Use the ICP-MS measurements of crystal and setup (copper, holders, cables,…) contaminants to determine the intrinsic radiogenic background

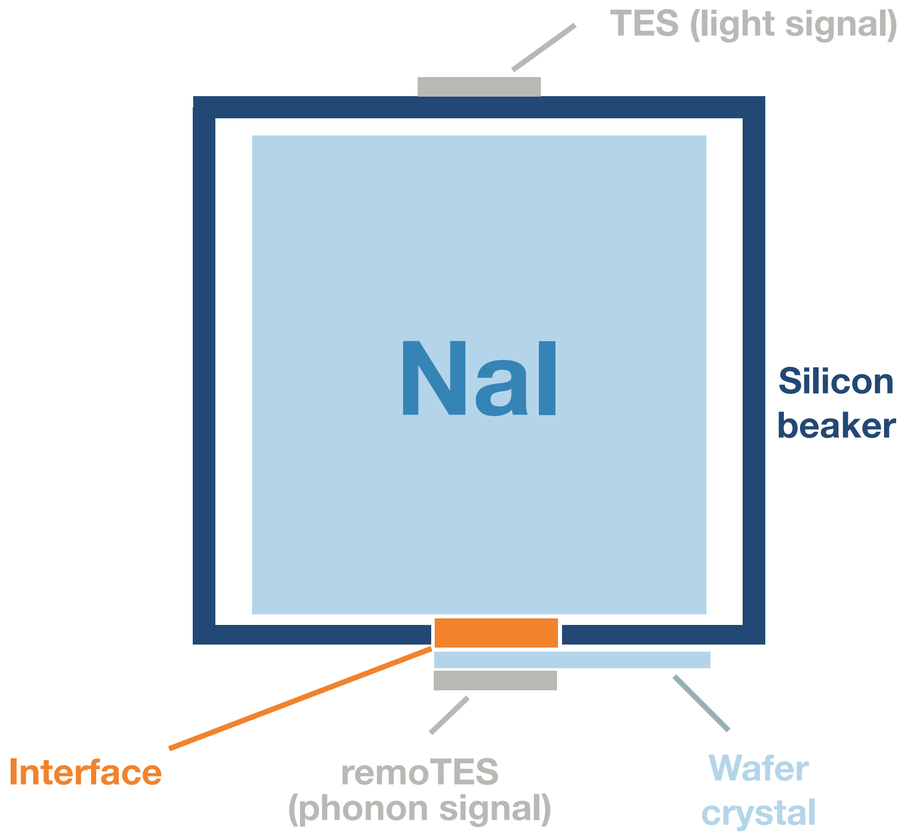
	K40 Cont. (ppb)	U Cont. (ppb)	Th Cont. (ppb)
NaI 2018 Astrograde Powder	<15	<0.01	<0.005
NaI 2018 MLL V2.	110	<0.015	<0.015

preliminary

Detector R&D

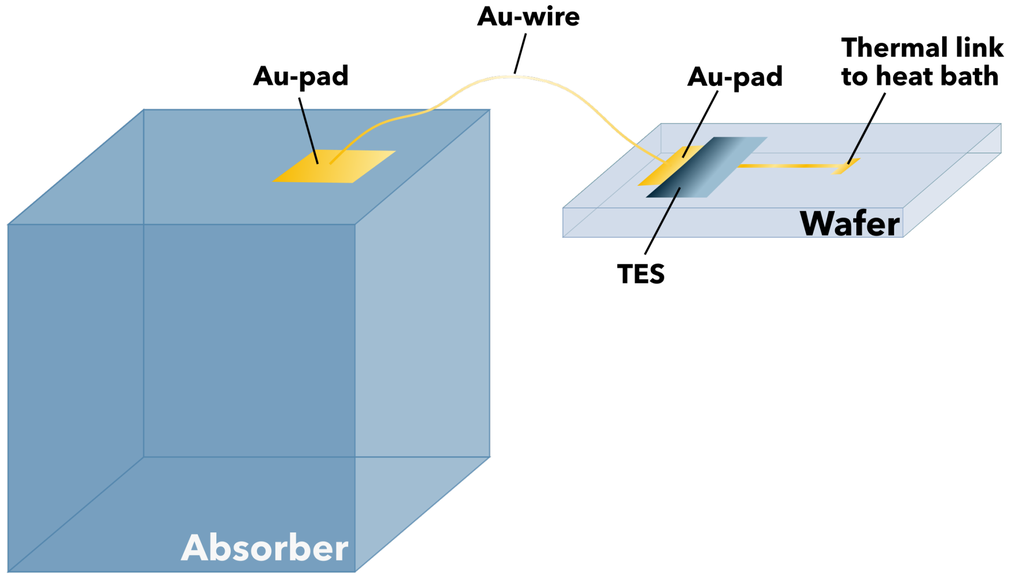
- **Two channel read-out** via TESs: light (silicon beaker) and phonon signal (NaI crystal)
- Problem: attaching TES directly to the crystal as NaI is
  - Hygroscopic
  - Very soft
  - Has a low melting point

→ attach TES to external structure and create some kind of connection



Detector R&D

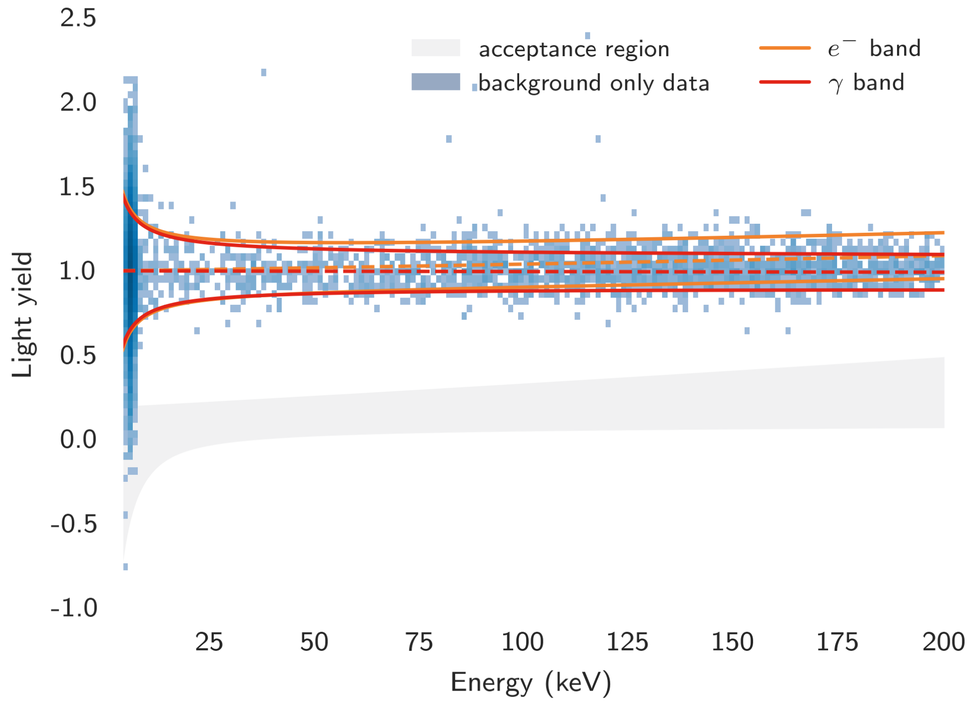
- Solution: the **remoTES design**
  - TES is attached to remote Al_2O_3 wafer
  - Wafer is connected to the NaI via gold pads and a gold bonding wire
  - Tested by the COSINUS collaboration for Si, TeO_2 and **NaI crystals**

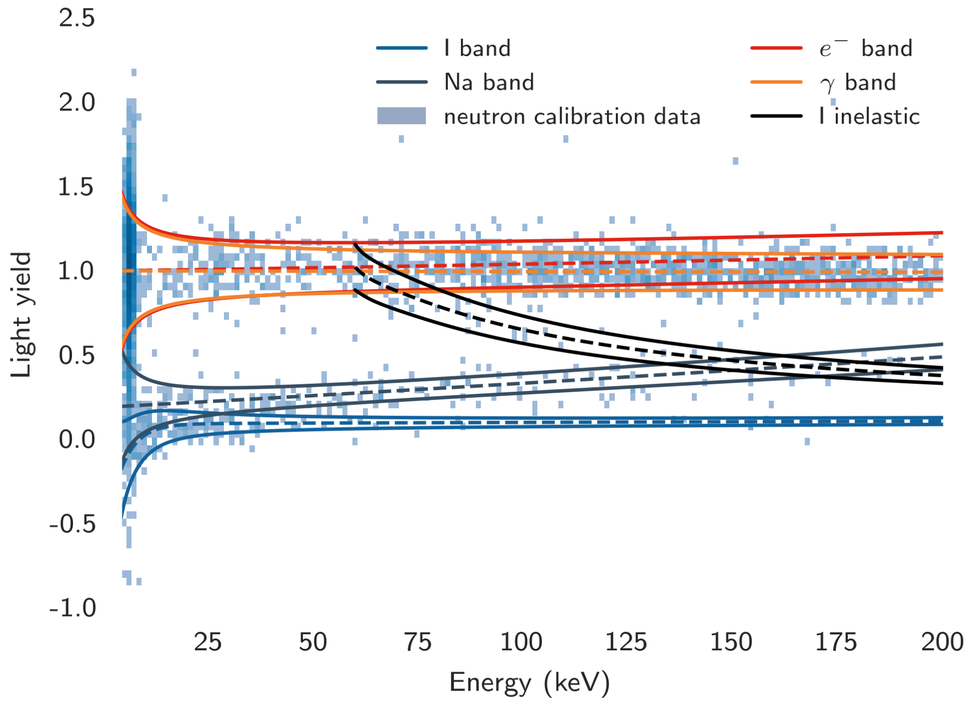


NIMA 1045 (2023) 167532

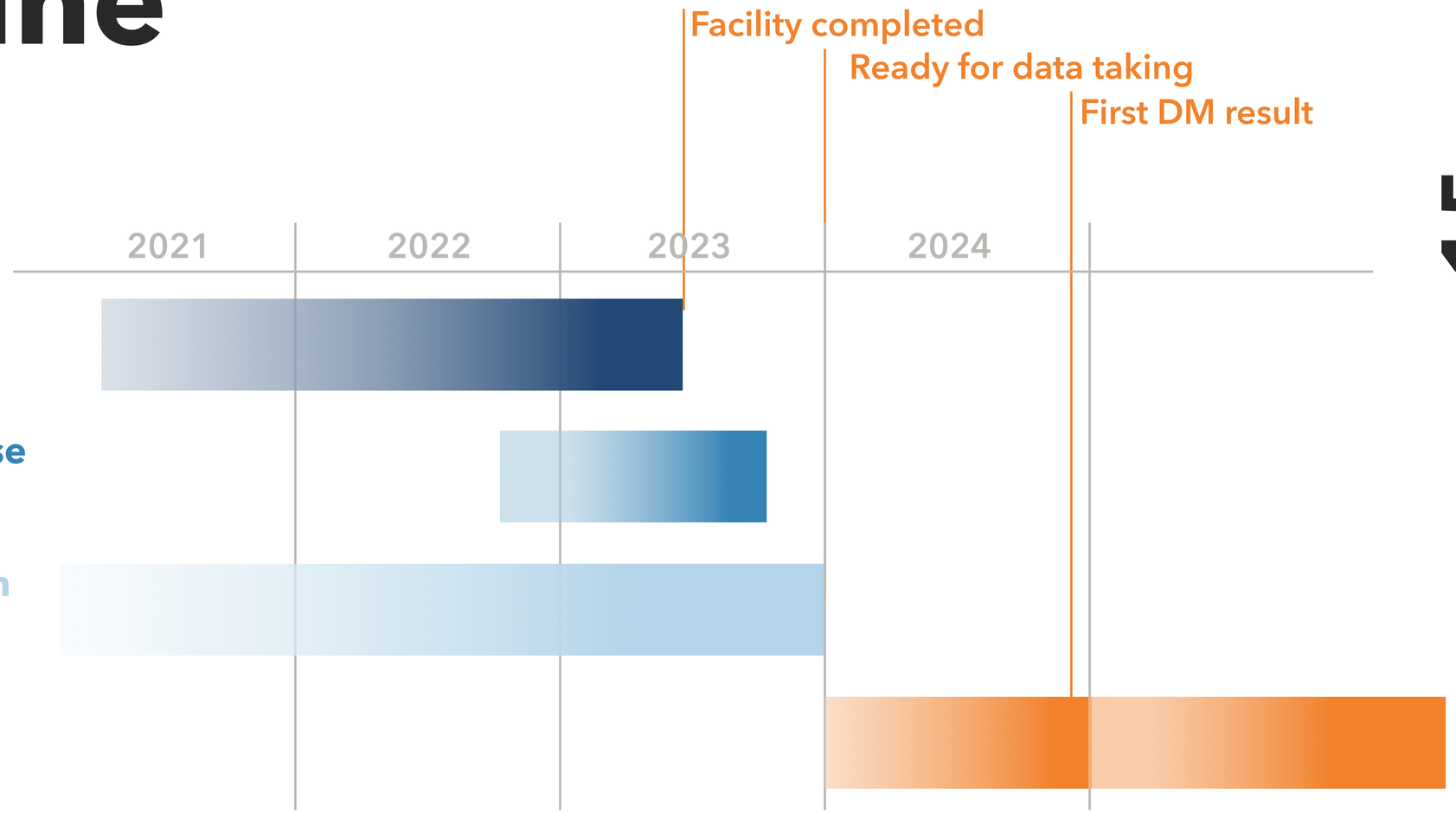
NaI remoTES results

- Multiple successful operations of NaI as a cryogenic detector
- Most performant measurement so far carried out at CRESST test facility at LNGS (underground)
  - $\sigma_{\mathbf{NaI}}$ **= 0.441 +/- 0.11keV (threshold < 2keV)**, σ_{LD} = 0.988 +/- 0.052 keVee
  - **Clear particle discrimination between nuclear and electron/gamma recoils** (publication in progress)





Timeline


Facility completed
Ready for data taking
First DM result
2021
2022
2023
2024
Facility Construction
Commissioning phase + cryogenic facility
Final detector design + production
Data taking

Thank you for your attention!

@COSINUSdm

HEPHY
INSTITUT FÜR
HOCHENERGIEPHYSIK

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

Since 1928
SICCAS

TU
WIEN

HELSINKI
INSTITUTE OF
PHYSICS

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

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DELL'AQUILA

Back Up

LEONIE EINFALT

Physics reach

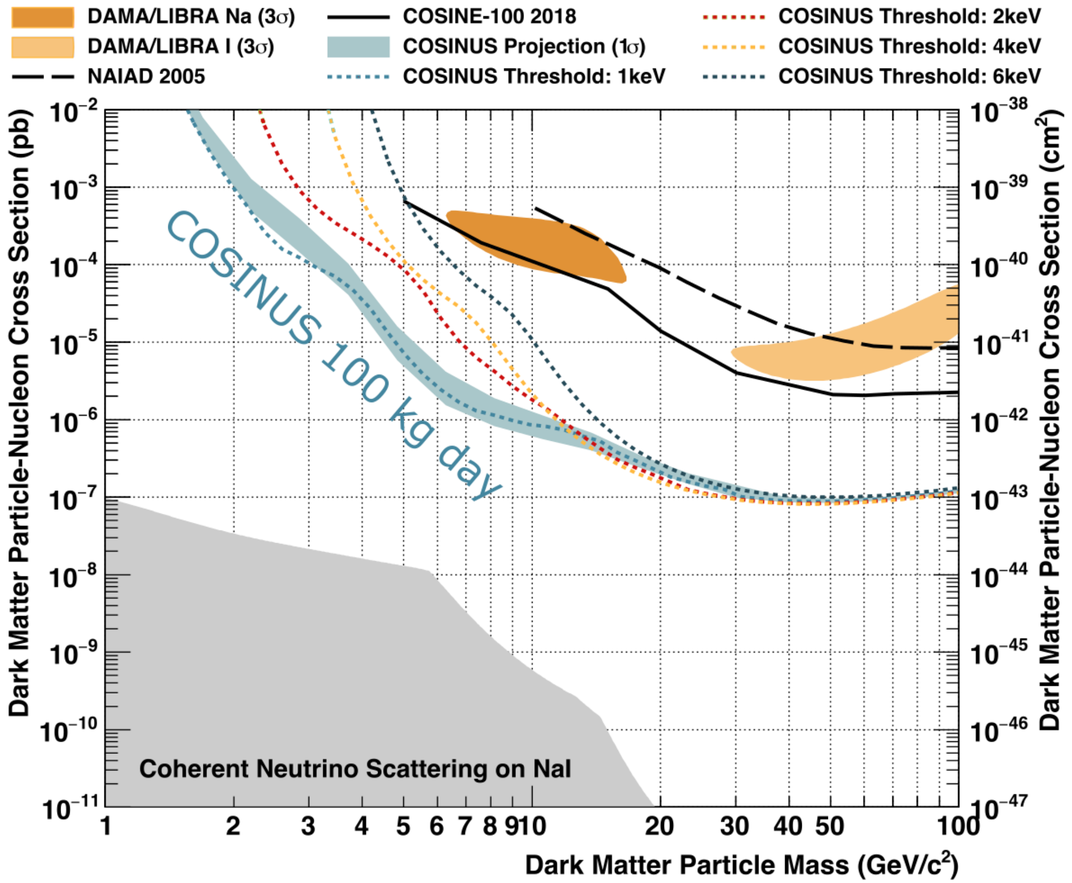
COSINUS 1π

- 2023 - 2025
- Exclude or confirm **nuclear recoil origin** of the DAMA signal (no rate no DM modulation)
- Independent of dark matter halo model and DM-SM interaction
- Set strong limit on standard scenario scattering with only 100 kg d exposure

COSINUS 2π

- Investigate annual modulation signature with COSINUS

More detailed model-independent physics reach study in Kahlhoefer et al JCAP05(2018)074

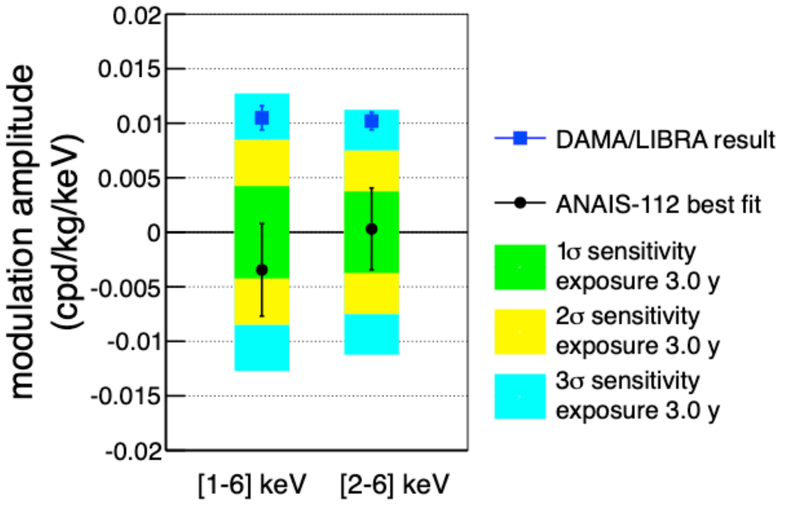


ANAIS vs. COSINUS

ANAIS experiment published results from **3 years** of data taking -> amplitude estimate supports non-modulation hypothesis and is **incompatible with the DAMA result at 3.3σ**

BUT:

- Not a DM-SM model independent result
- 3.3σ vs 13σ
- Still uncertainties present due to NaI quenching factor -> not an issue for COSINUS with particle discrimination

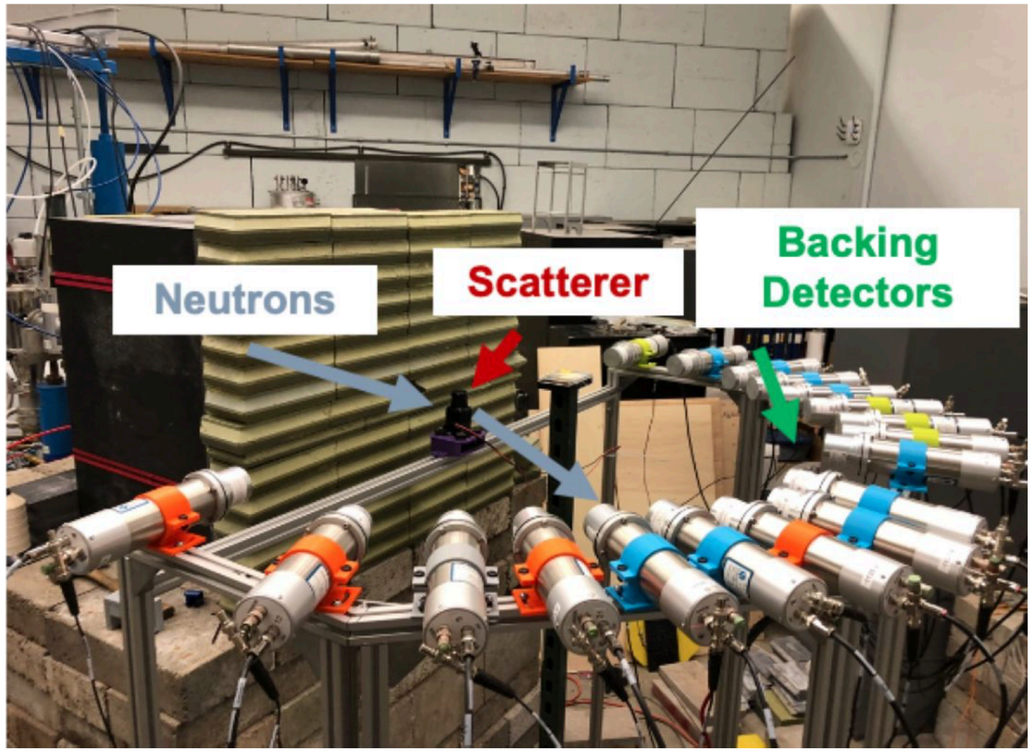


arXiv:2103.01175

LEONIE EINFALT

COSINUS at TUNL

- NaI crystals of different Tl-doping levels produced inside collaboration at **SICCAS**
- Measurement of quenching factors of NaI performed by **TUNL**
- Simulation and analysis ongoing



Measurement setup at TUNL

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