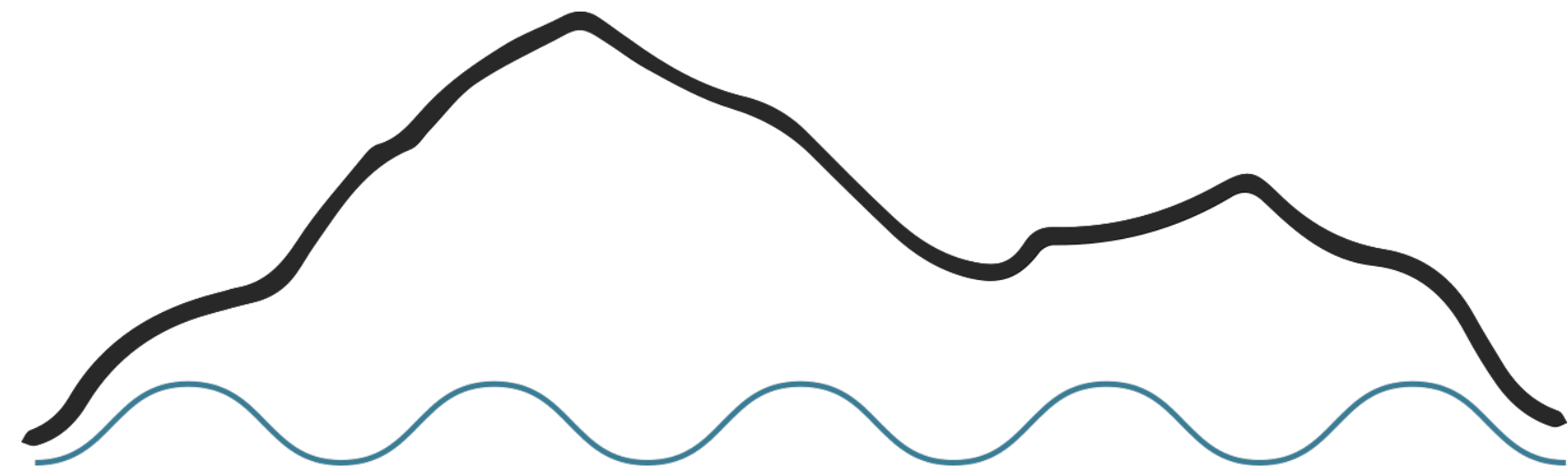


ICHEP JUNE 9<sup>TH</sup> 2022



# COSINUS

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

**Leonie Einfalt**



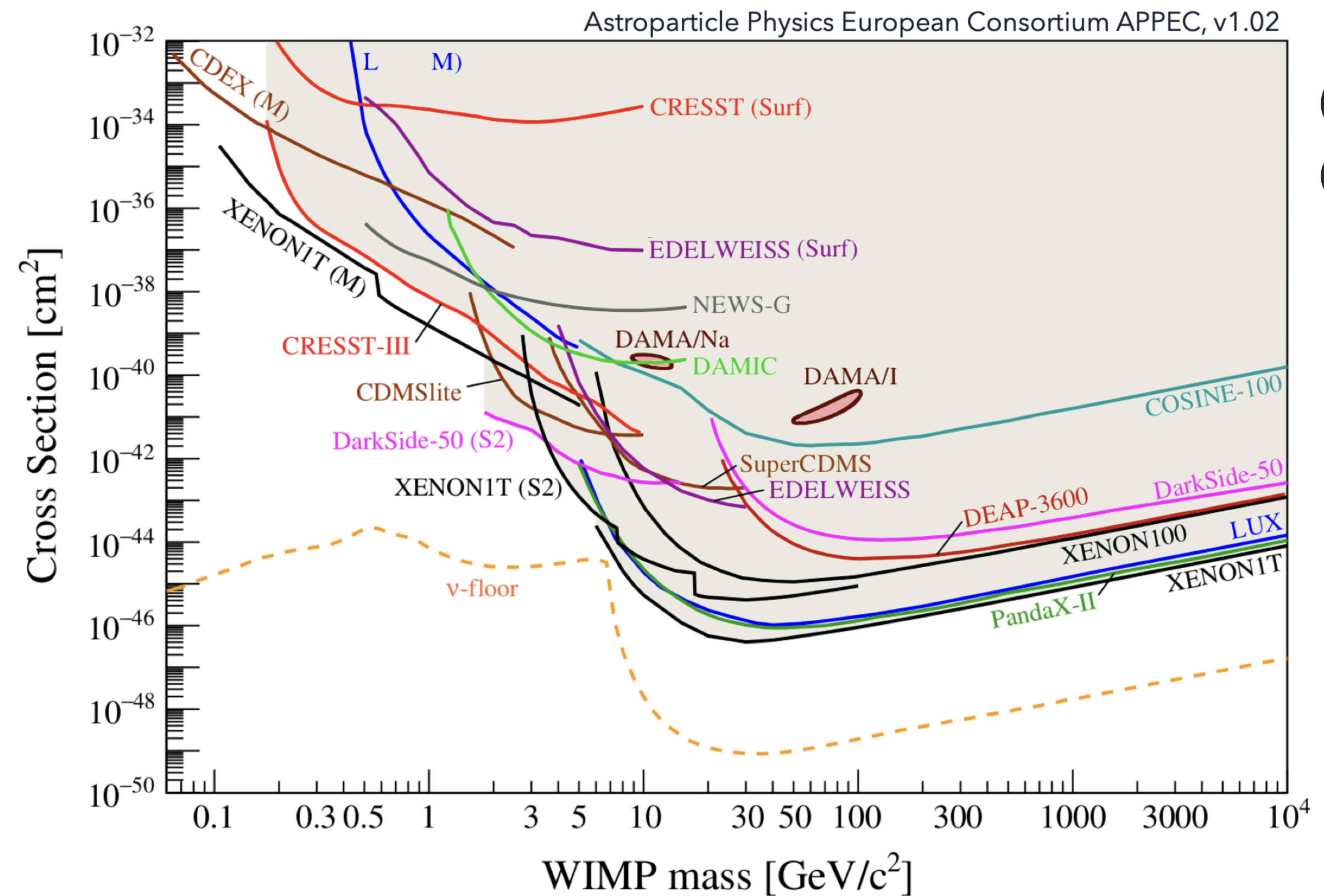
TECHNISCHE  
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WIEN



**HEPHY**  
INSTITUT FÜR  
HOCHENERGIEPHYSIK

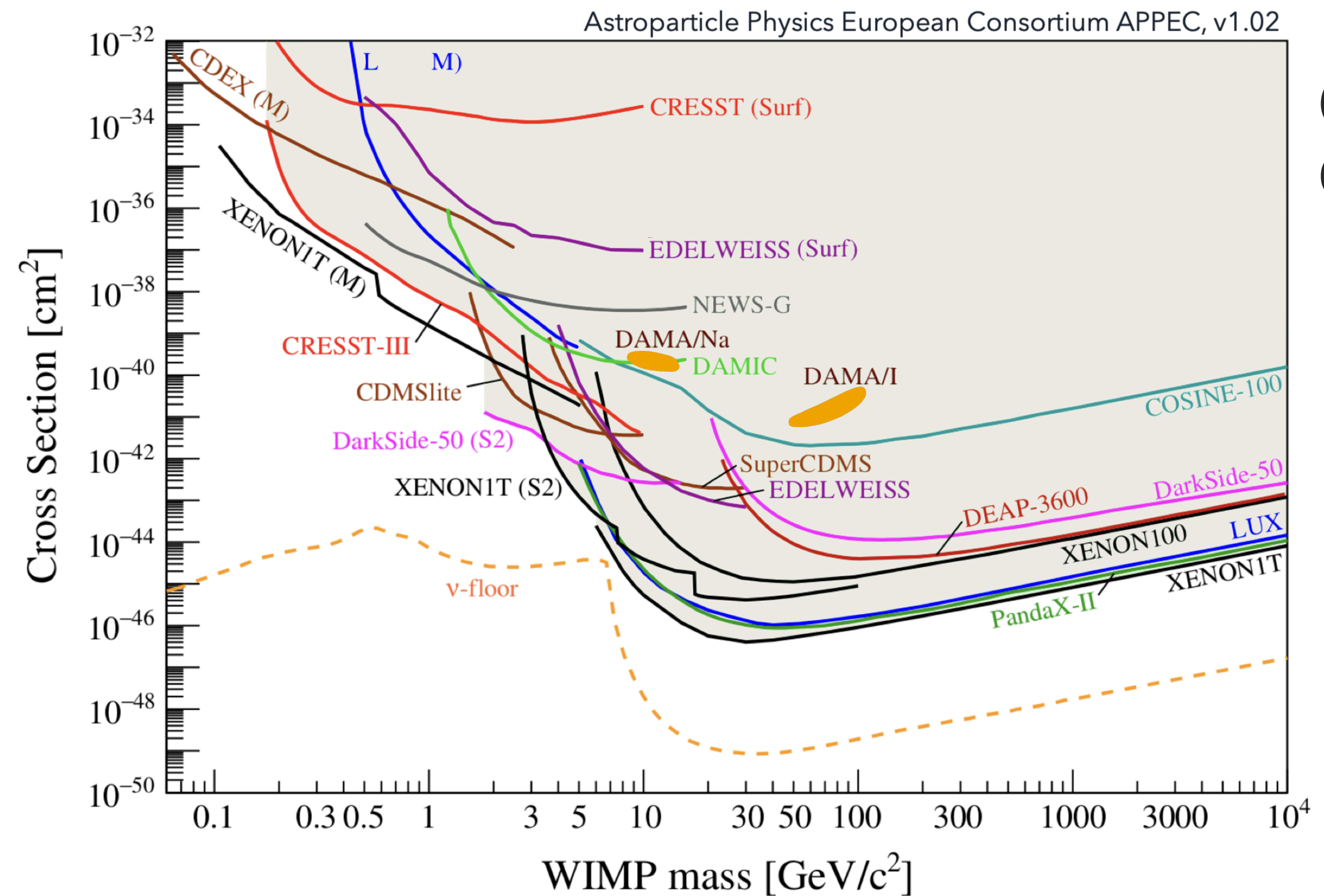
# Motivation

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



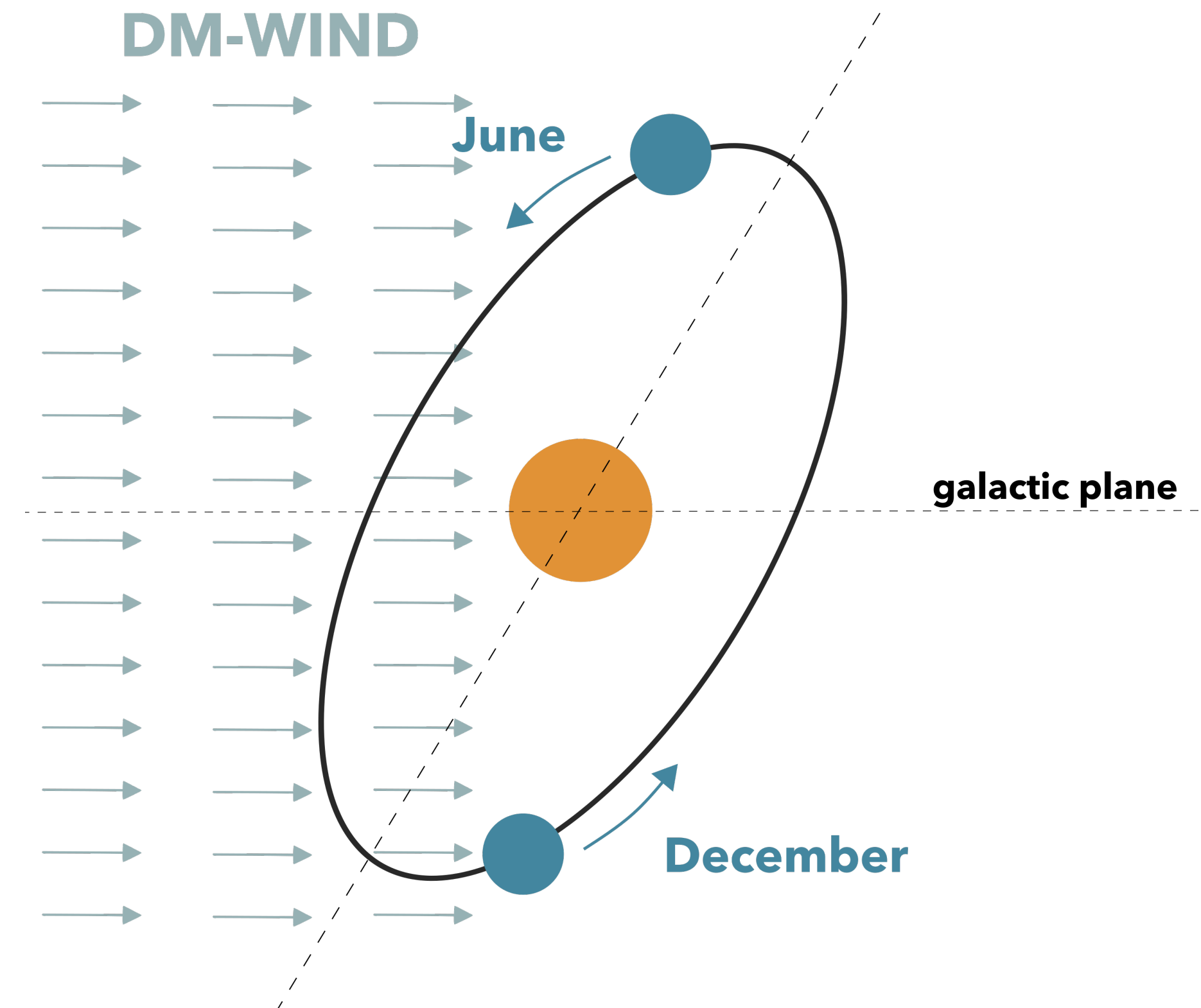
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# DAMA/LIBRA signal

- ▶ DAMA/LIBRA sees a **modulation signal** as predicted by Earth's movement through the DM-wind in the Milky Way
- ▶ Light signal (PMTs) in **250 kg NaI** with a **threshold of 1keVee**
- ▶ Located at LNGS, data taking since 1996



# DAMA/LIBRA signal

Statistical significance over 25 years: **13.7 $\sigma$**

Period: **0.9983  $\pm$  0.0007** (in the 2-6 keVee region)

Phase: **22<sup>nd</sup> May  $\pm$  4 days** (cosine peaking June 2<sup>nd</sup>)

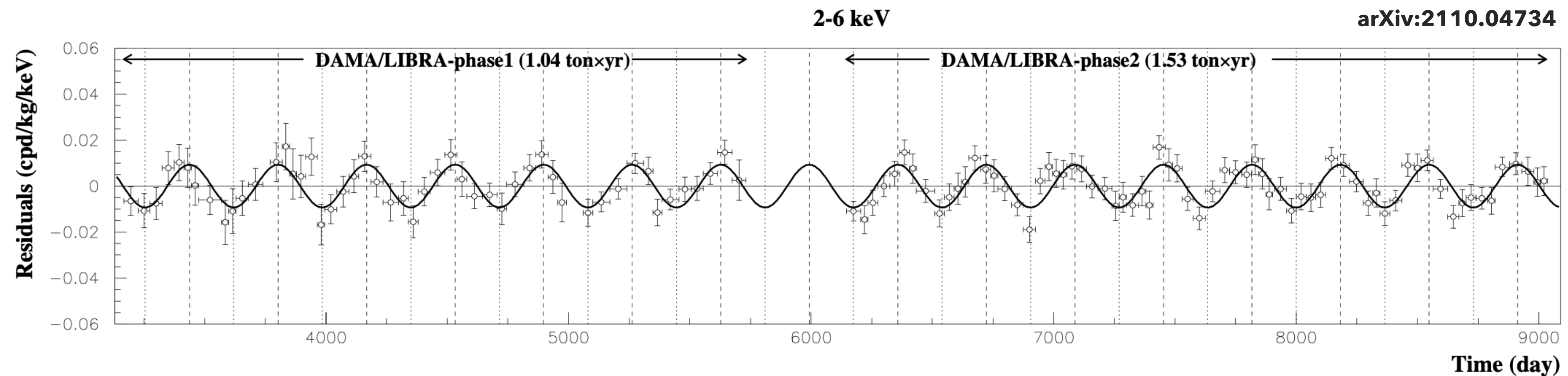
No convincing non-DM explanation



**Need for verification  
or falsification**

**04**

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# Theory prediction & unknowns

05

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 $\rho_0$   
 $f(\mathbf{v})$ 

Uncertainties in astrophysical parameters, DM density and 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

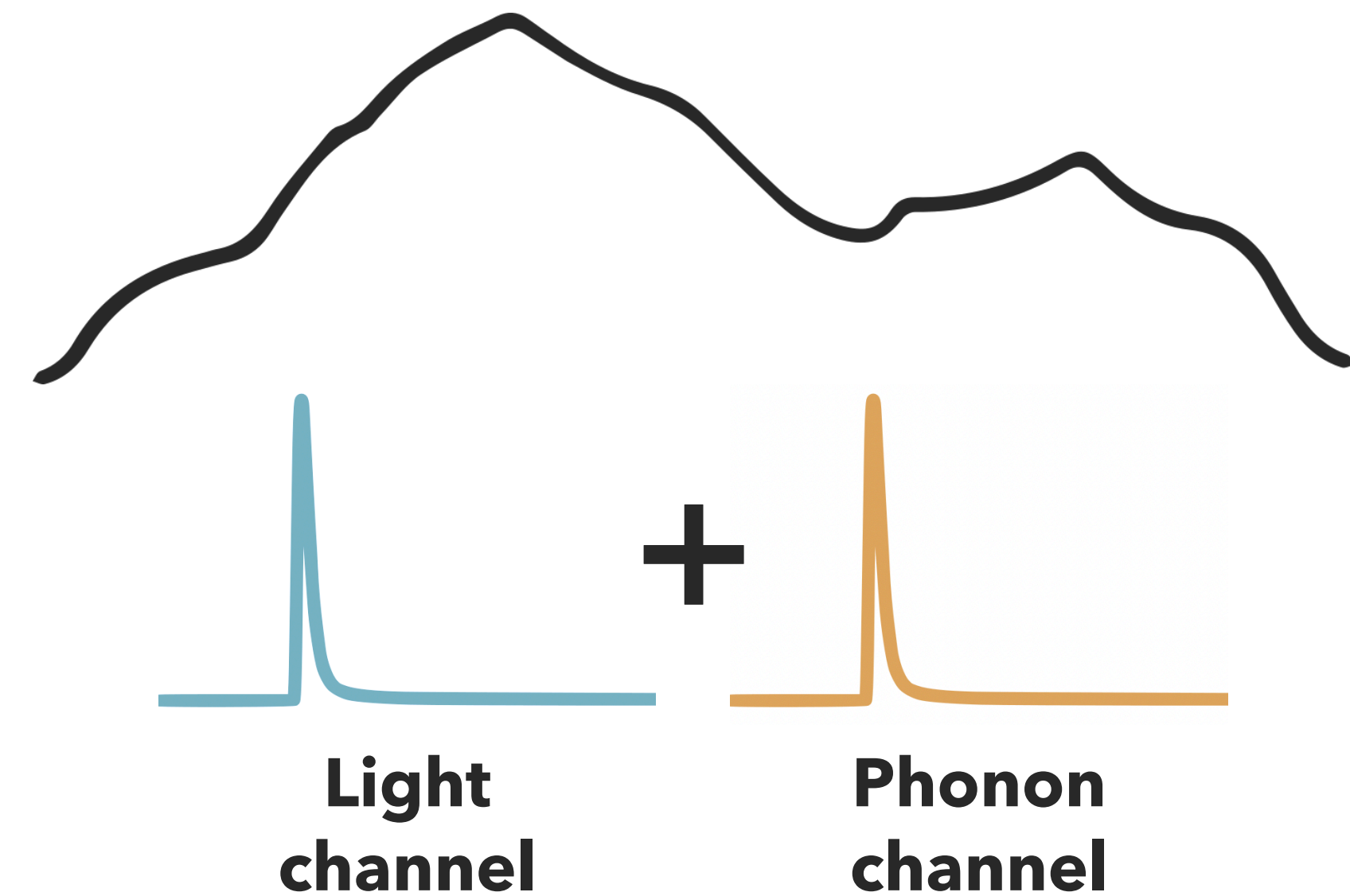
$$\frac{dR}{dE_R} = \sum_T N_T \frac{\rho_0}{m_\chi} \int_{v_{\min}}^{|\mathbf{v}| < v_{\text{esc}}} d^3v f(\mathbf{v}) v \frac{d\sigma}{dE_R}$$

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)
  - ▶ Particle discrimination (electron/gamma vs. nuclear recoil) on event-by-event basis
  - ▶ Lower threshold in nuclear recoil energy

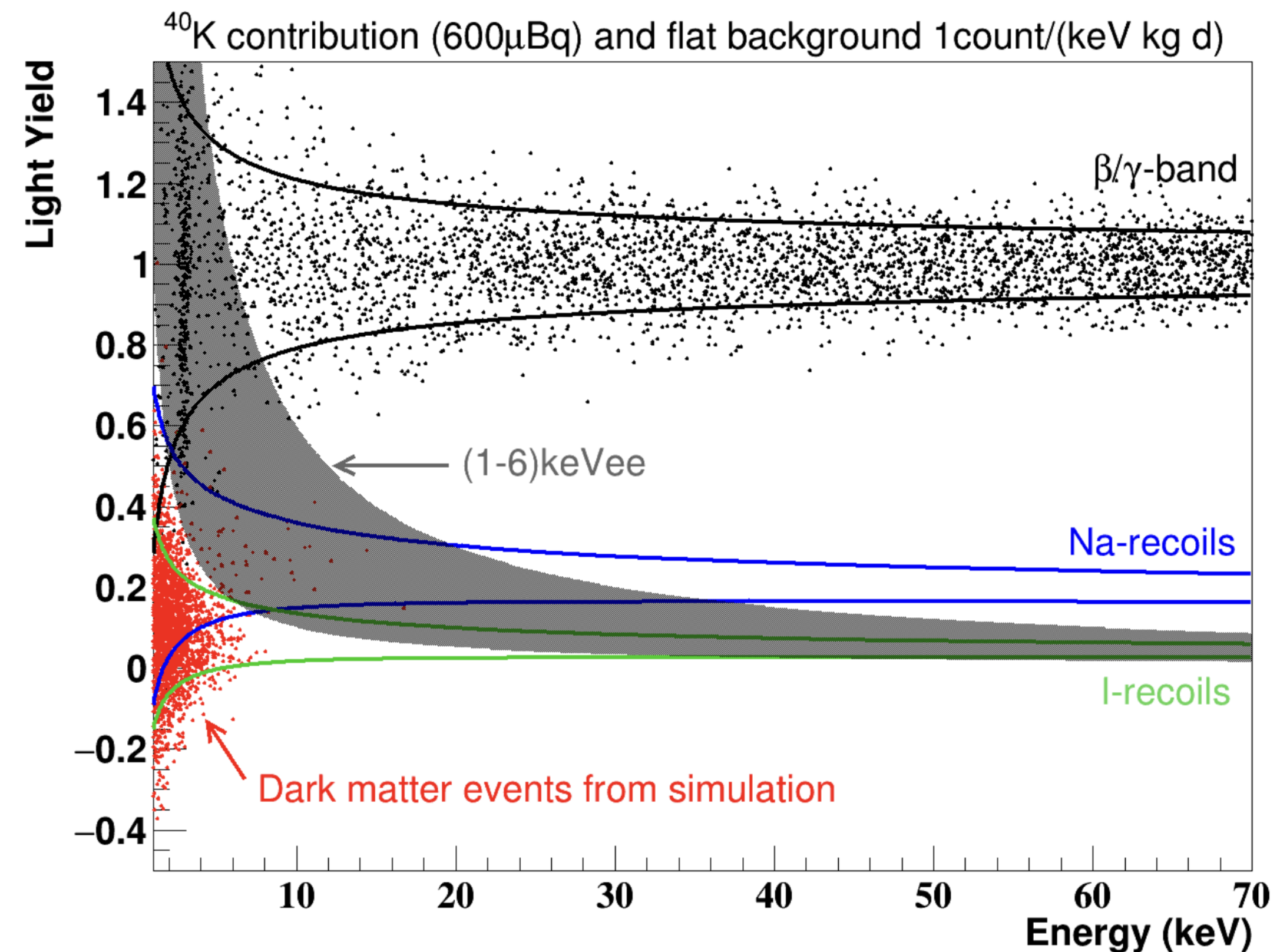


# Particle discrimination

- ▶ **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)
- ▶ Light-quenching → different bands in the Light Yield - Phonon energy plane

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

- ▶ Intrinsic measurement of quenching factors possible



# Physics reach

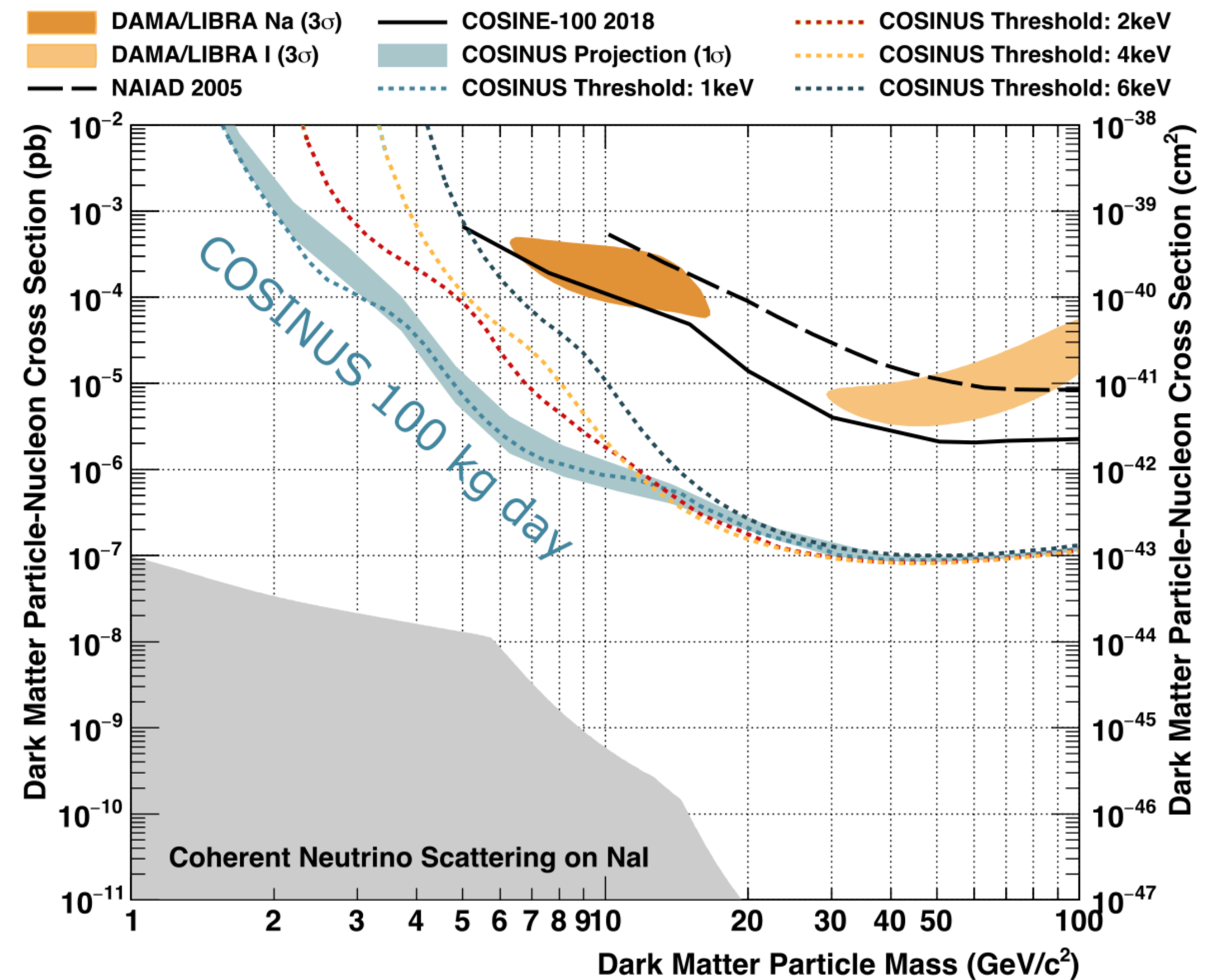
## COSINUS $1\pi$

- 2022 - 2025
- Exclude or confirm **nuclear recoil origin** of the DAMA signal (no rate  $\rightarrow$  no DM modulation)
- Independent of dark matter halo model and DM-SM interaction

## COSINUS $2\pi$

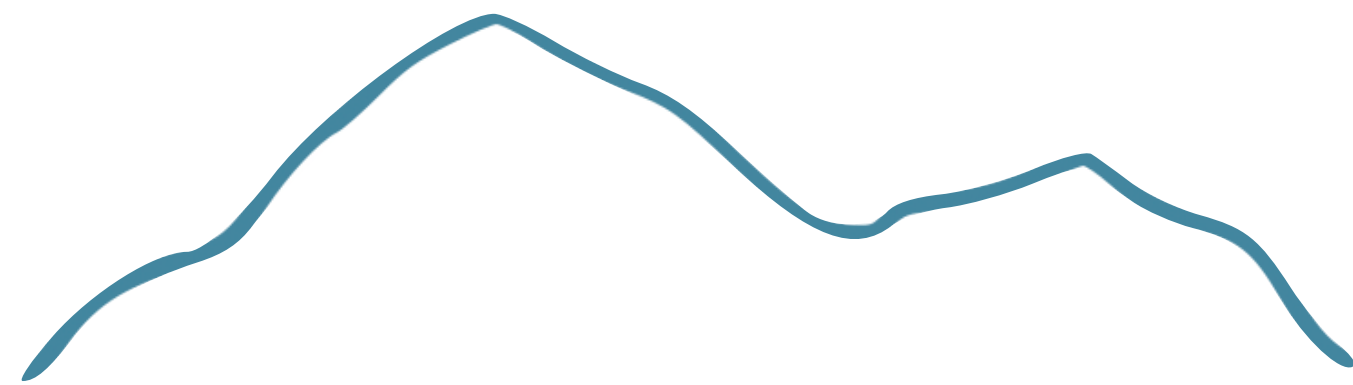
- Investigate annual modulation signature with COSINUS

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

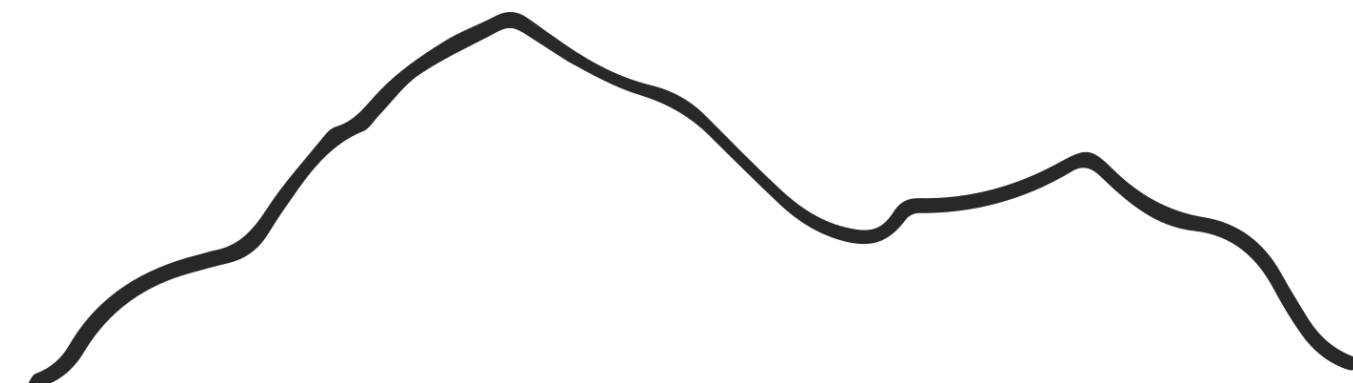


# Status of the experiment

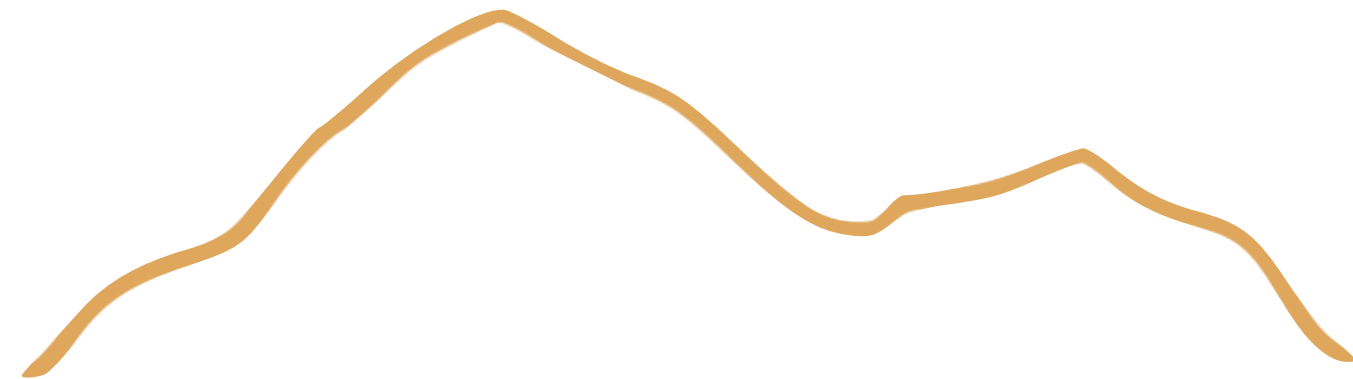
We are working on multiple projects in parallel:



**Detector development**



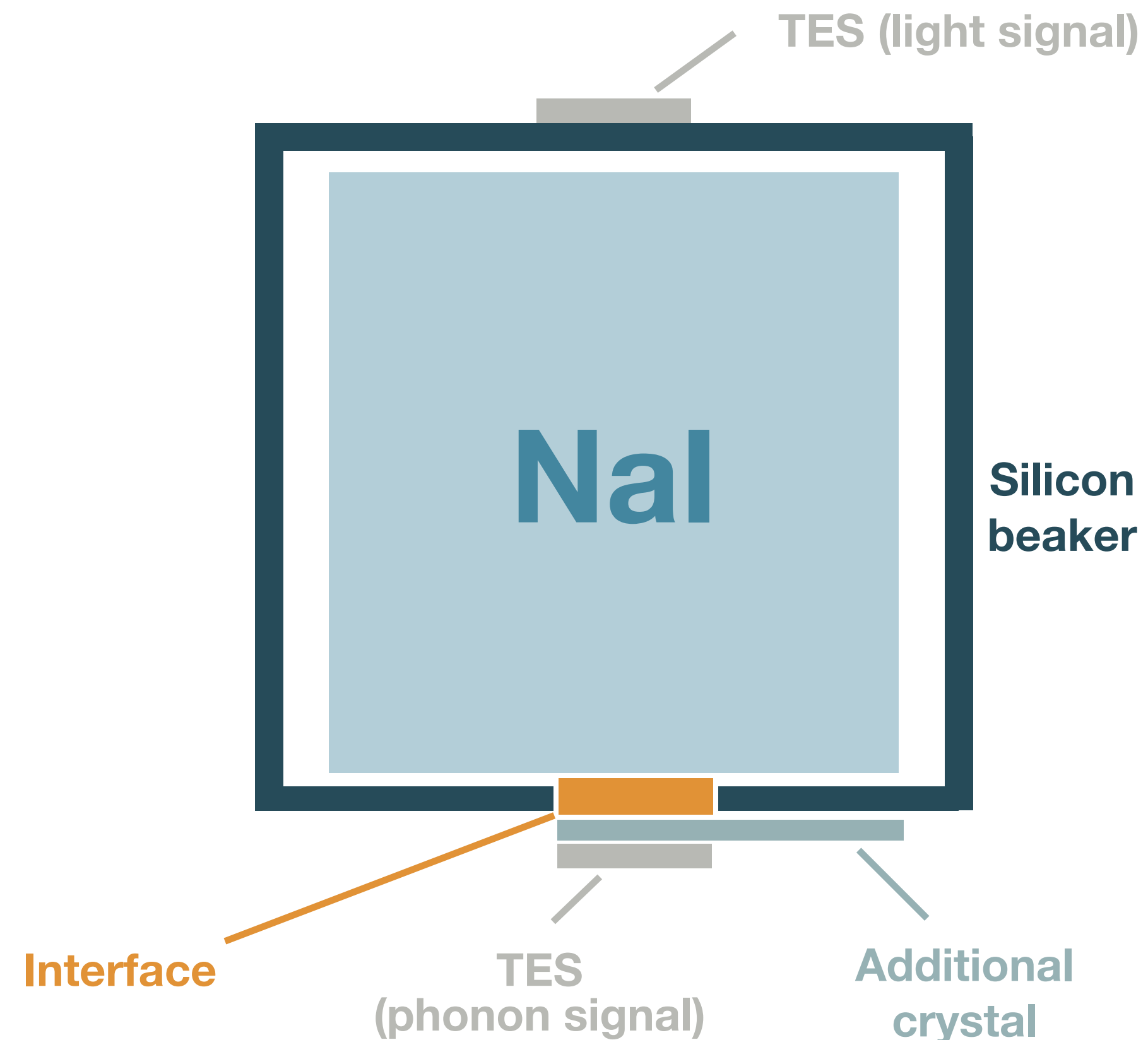
**Construction of the facility**



**Studies of NaI as target material**

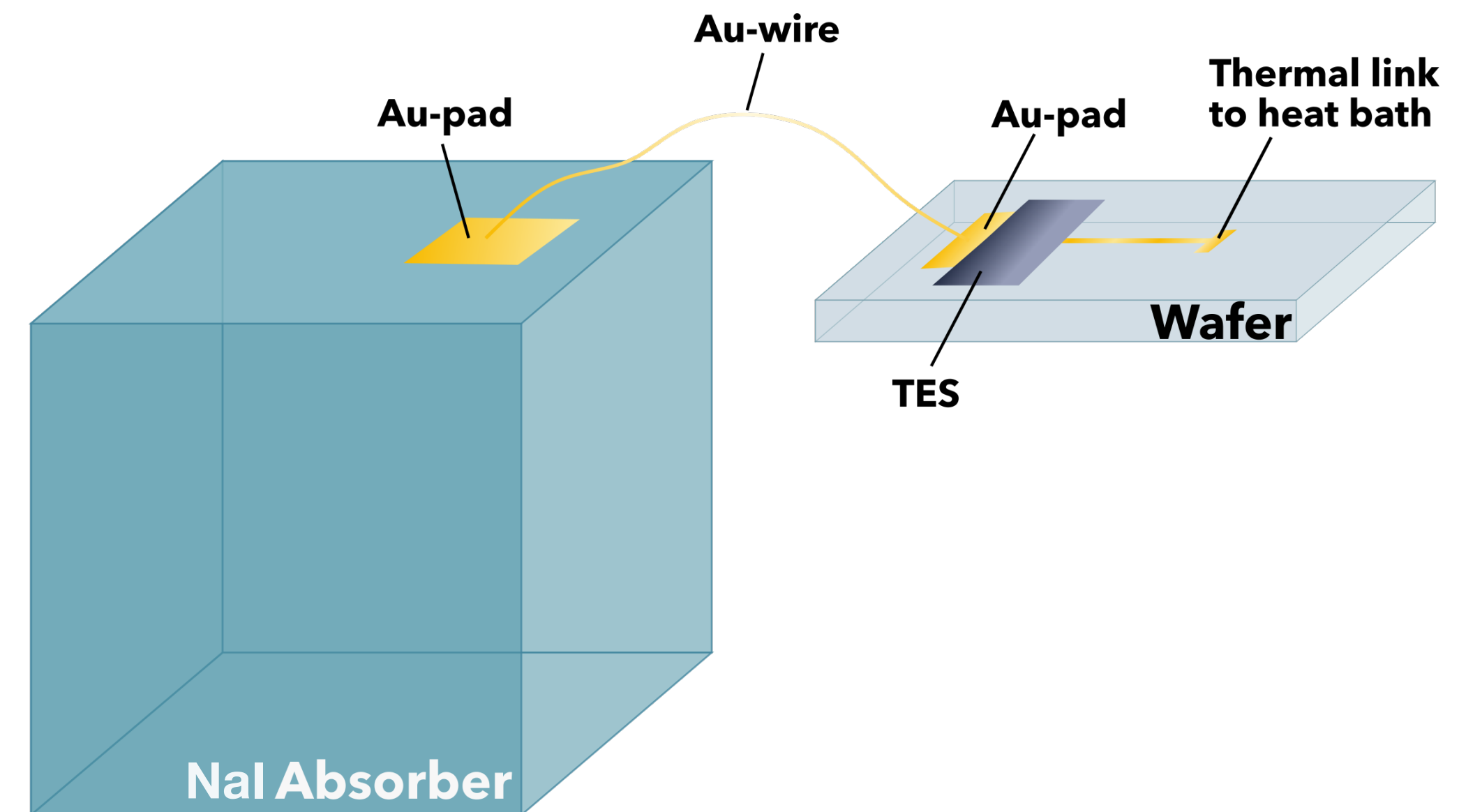
# Detector development

- Two channel read-out via TES: light (silicon beaker) and phonon signal
  - 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



# remoTES design

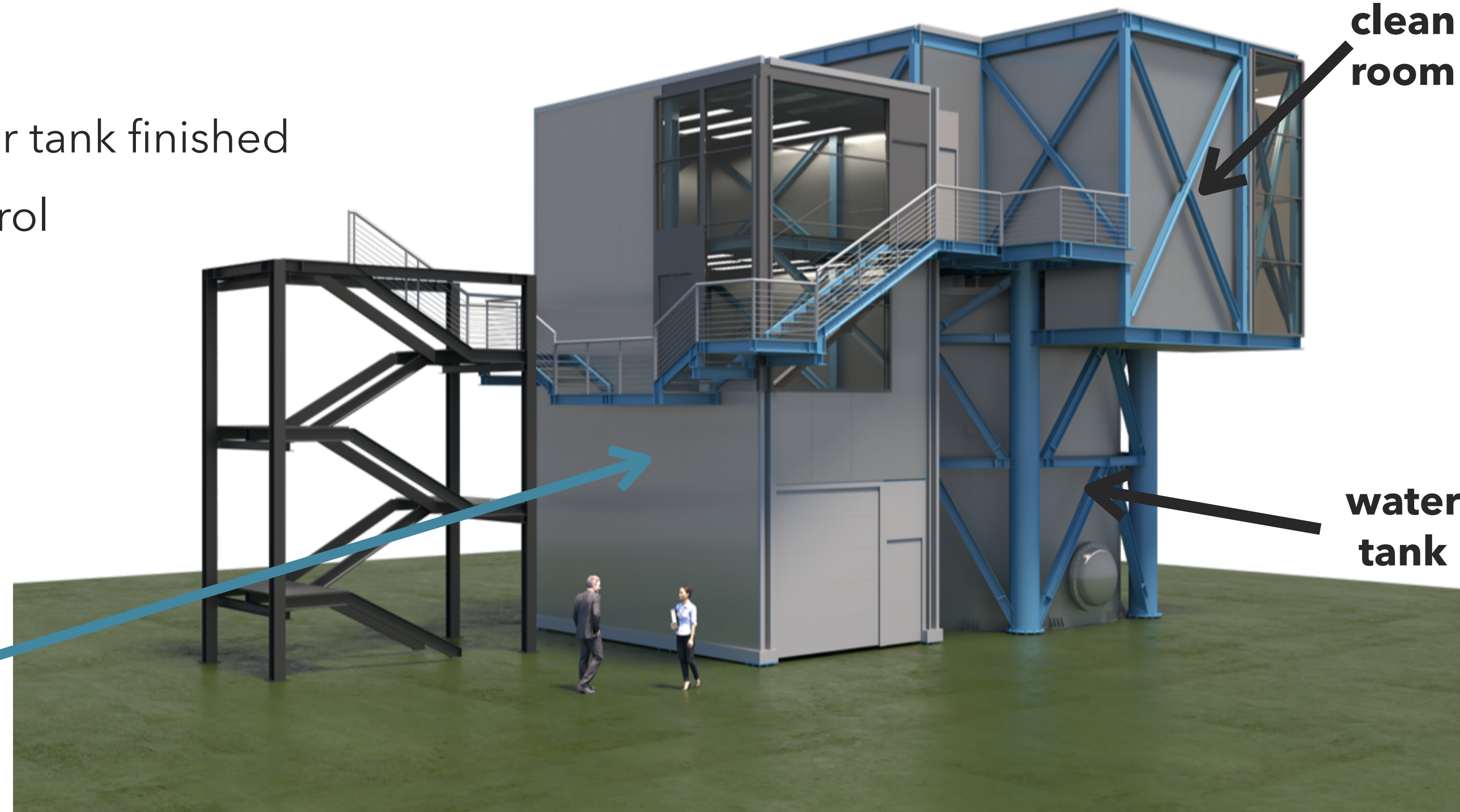
- Solution: the remoTES design
- TES is attached to remote  $\text{Al}_2\text{O}_3$  Wafer crystal
- Wafer is connected to the NaI via gold pads and a gold bonding wire
- Tested by the COSINUS collaboration for Si and  $\text{TeO}_2$  crystals  
→ [arXiv:2111.00349](https://arxiv.org/abs/2111.00349)
- **Successfully used for particle discrimination with a NaI target** (publication in progress)



# Construction of the facility

- Construction of water tank finished
- Construction of control building ongoing
- Cryostat delivery end of 2022

**control  
building**



**clean  
room**

**water  
tank**

**12**

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# Onsite progress



Water tank (April 2022)



Dry Well (April 2022)



Control Building (June 2022)

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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



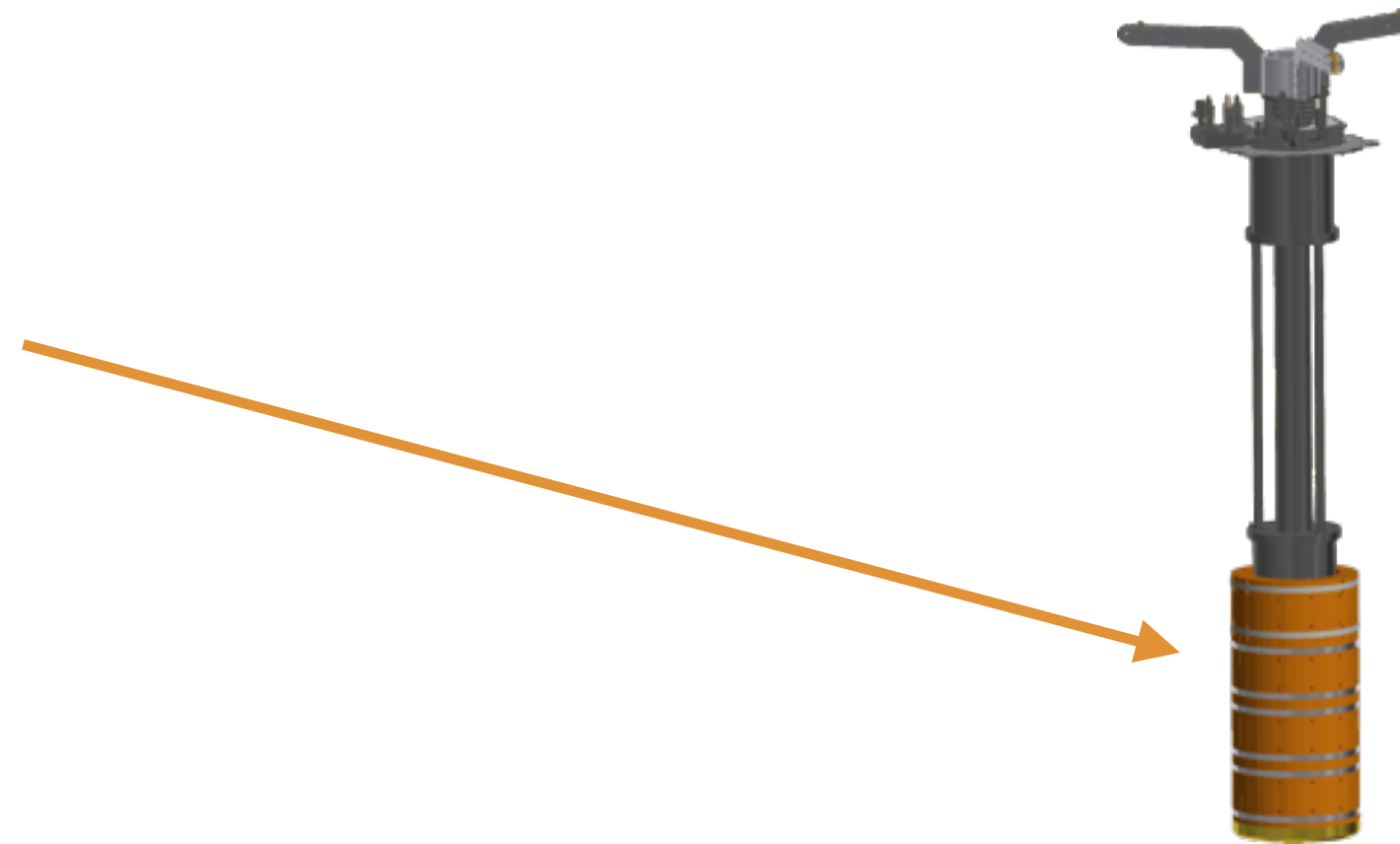
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**Simulation study on passive  
shielding concept: [arXiv:2106.07390](#)**

# Shielding concept

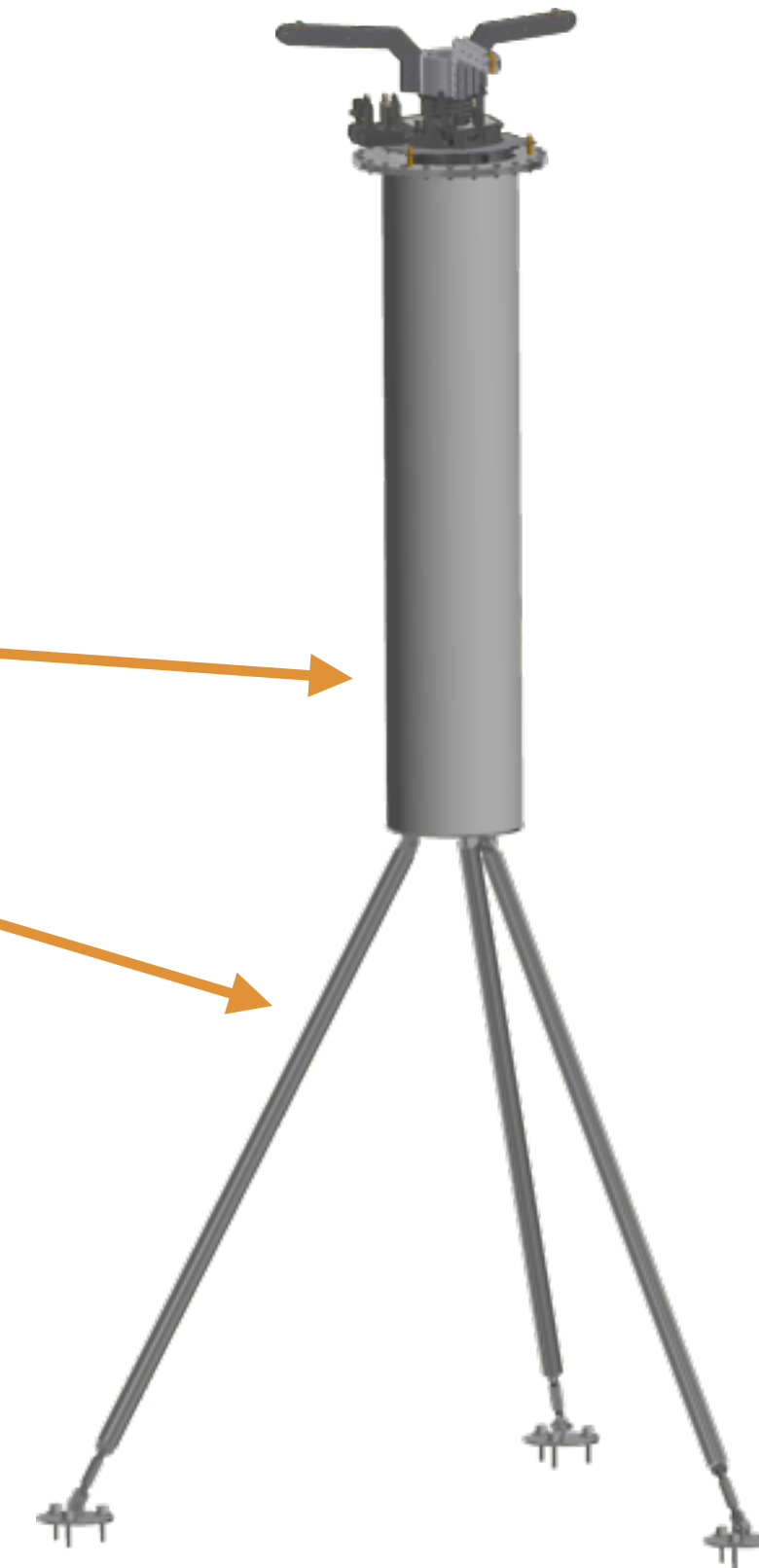
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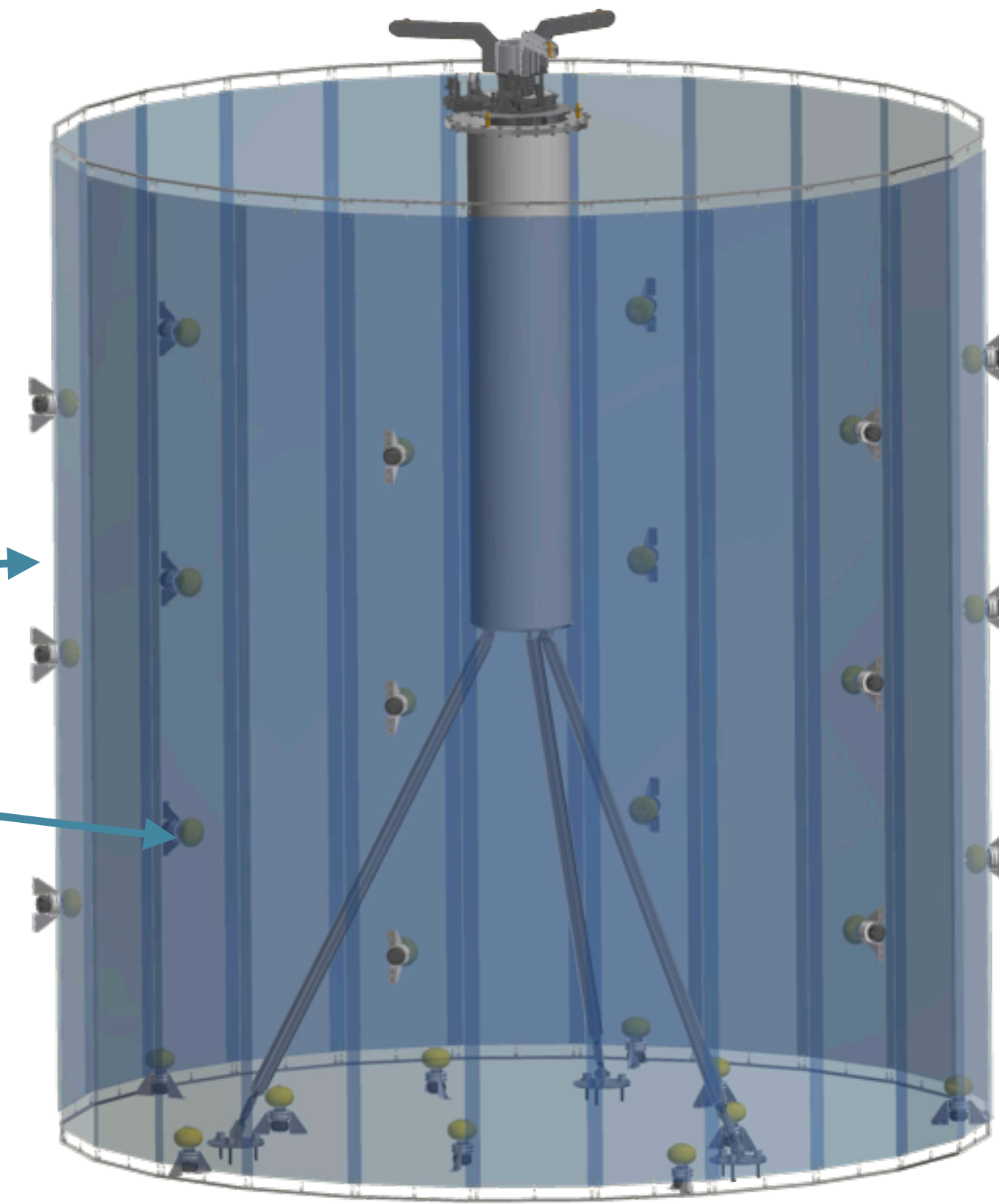
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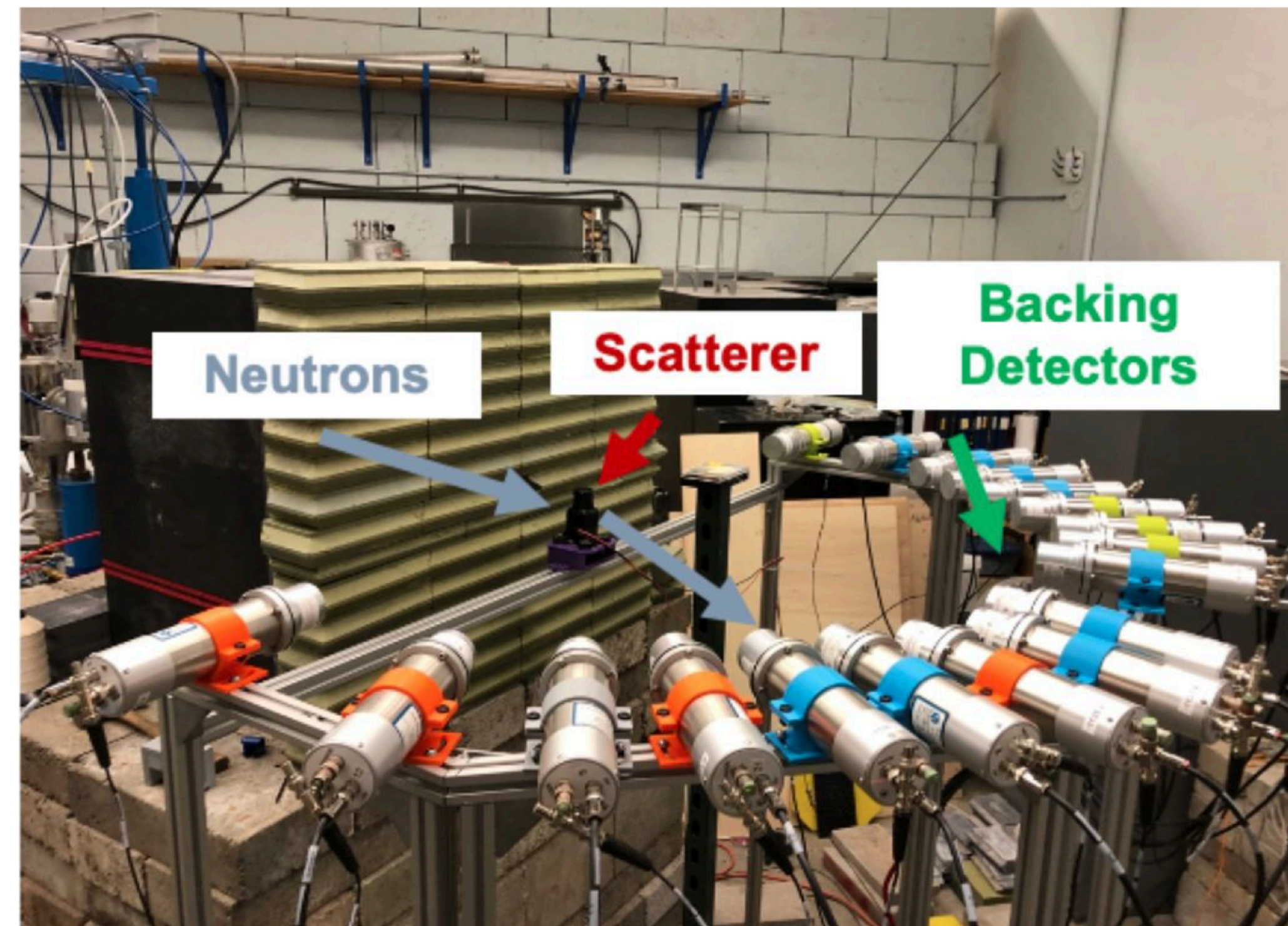
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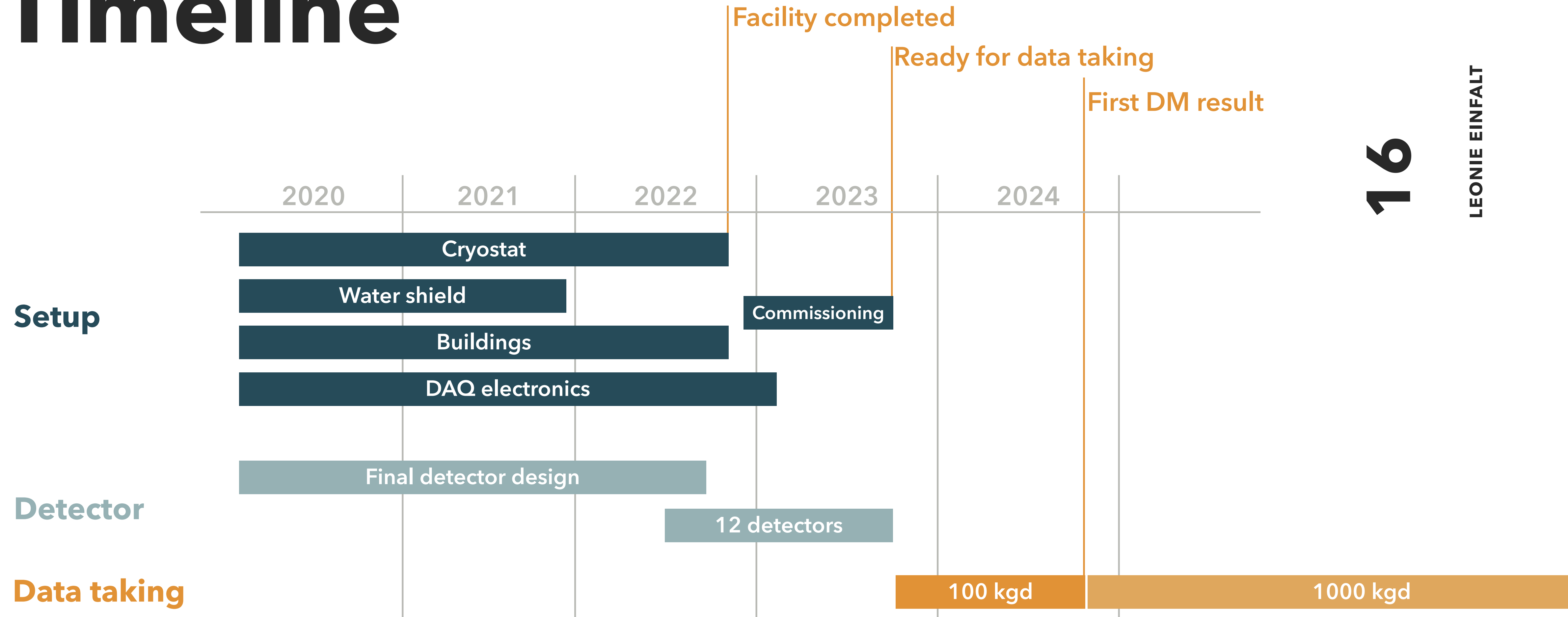
# Nal as target material

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

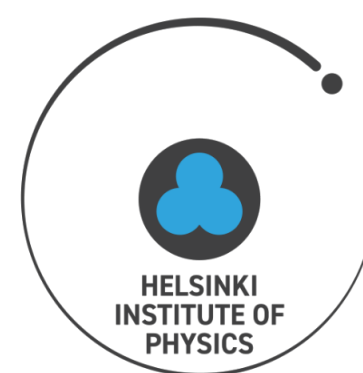
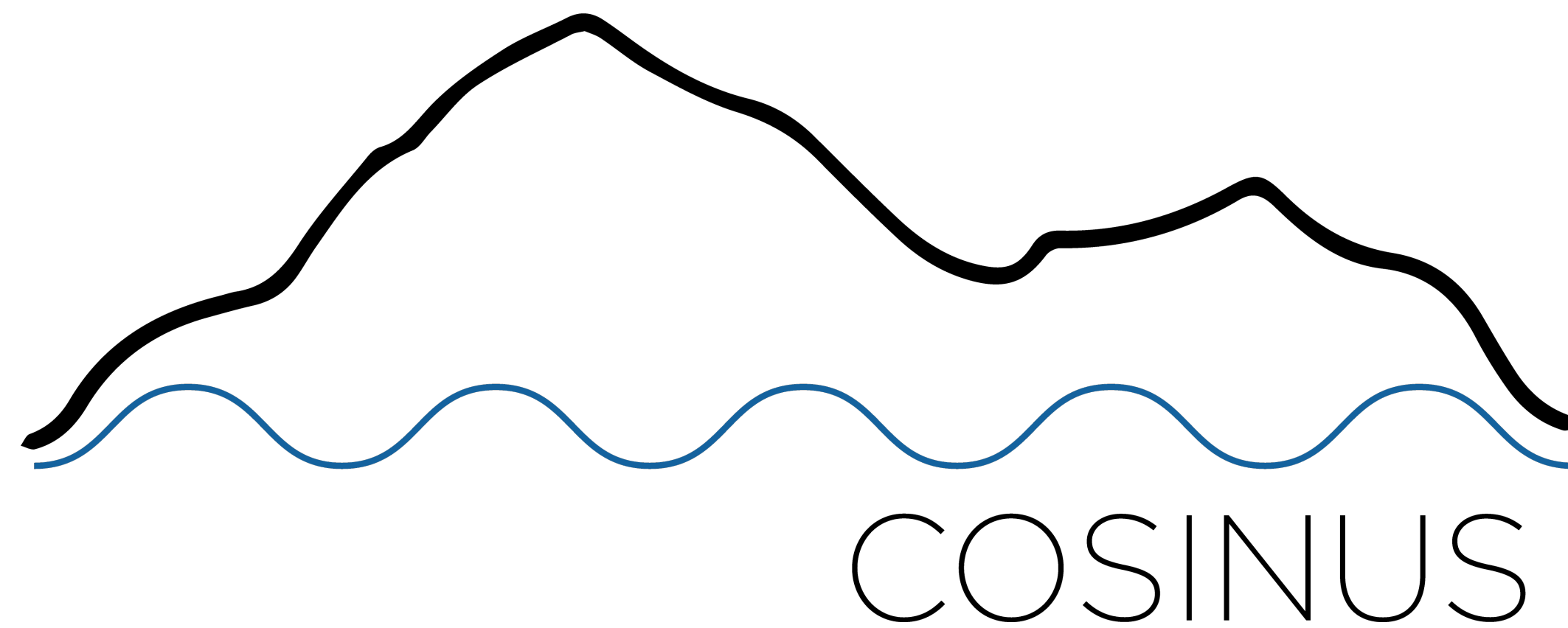


Measurement setup at TUNL

# Timeline



# Thank you for your attention!

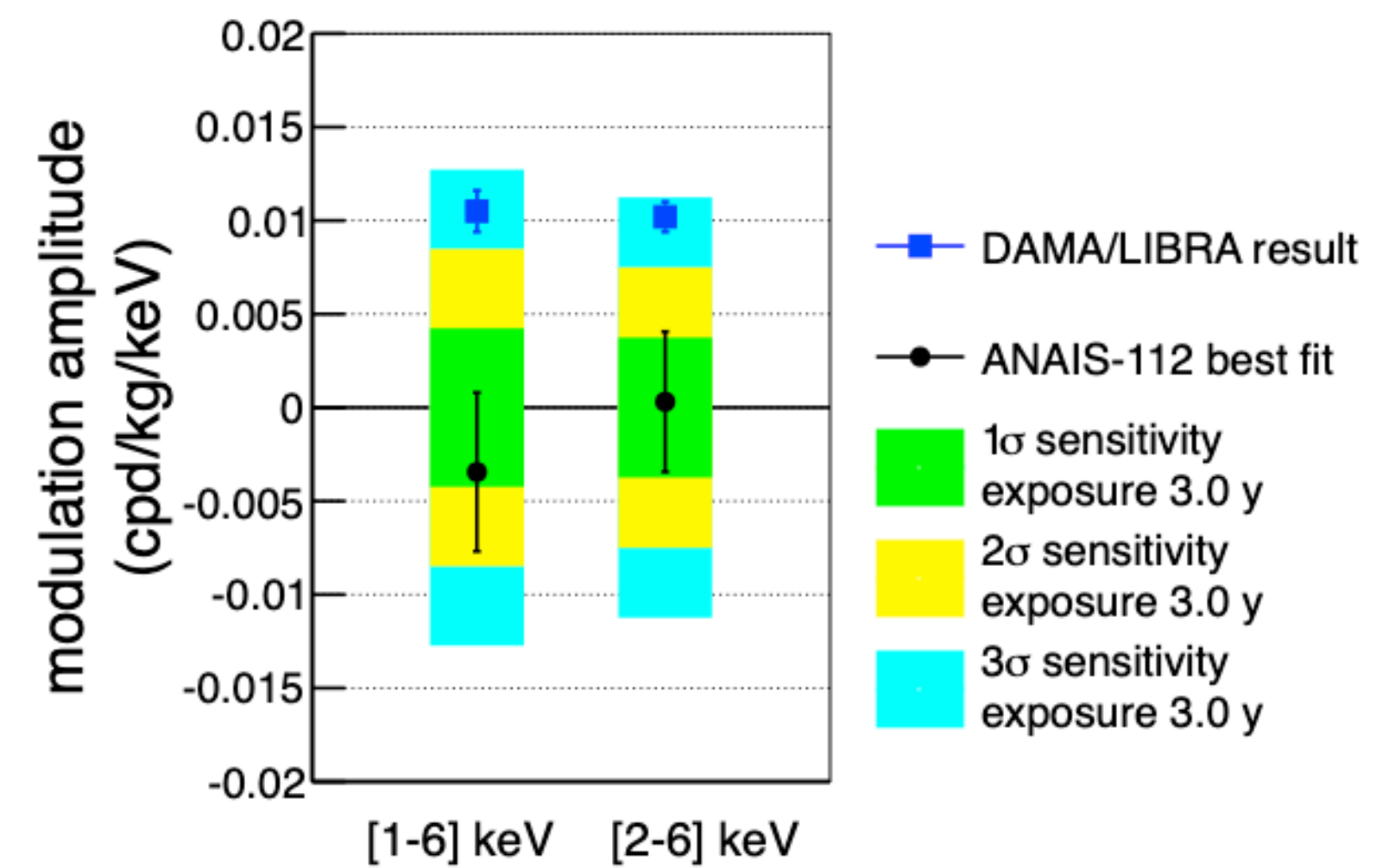


# ANAIS vs. COSINUS

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

## BUT:

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



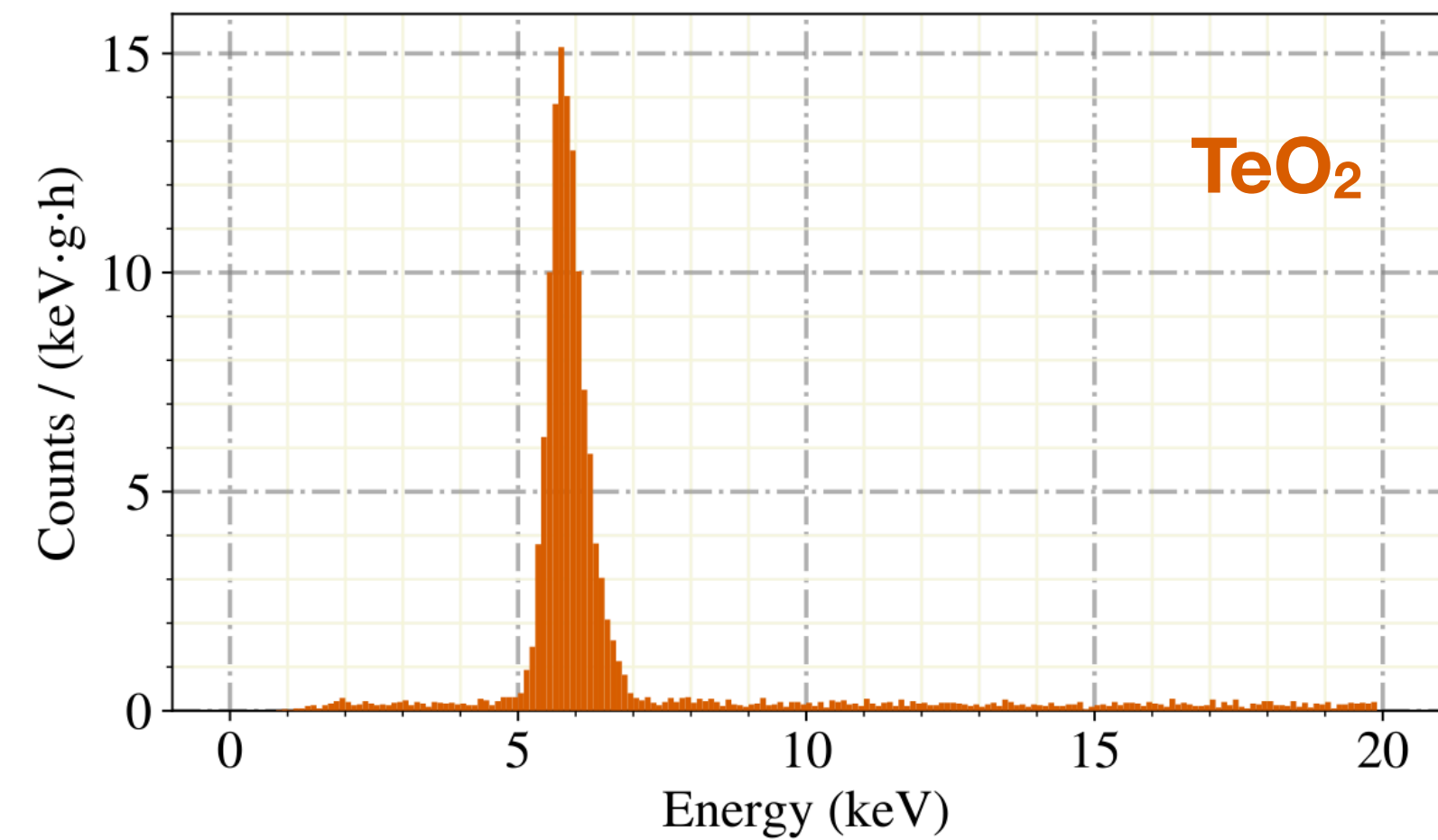
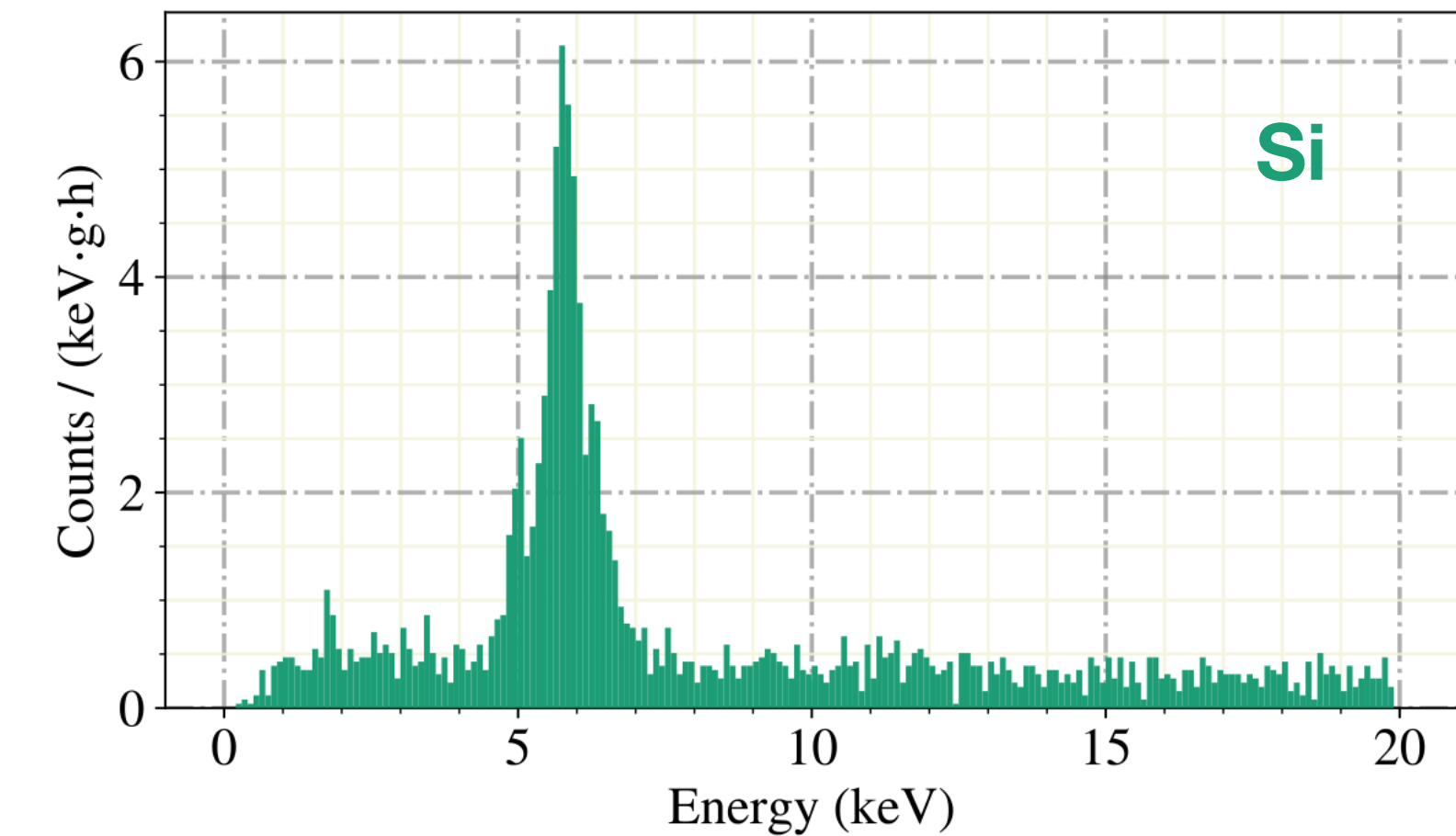
arXiv:2103.01175

# remoTES results

- ▶ Above ground R&D runs with Silicon and TeO<sub>2</sub>
- ▶ Calibration with <sup>55</sup>Fe source
- ▶ Resolutions

**Si** ( $87.8 \pm 5.6$ ) eV

**TeO<sub>2</sub>** ( $193.5 \pm 3.1$ ) eV



# remoTES PSD

- ▶ **Two types of events** (in both light and phonon channel) from the wafer and the absorber crystal
- ▶ Can be easily discriminated via their rise and decay times at higher energies
- ▶ At low energies separation via a "standard event fit" is possible

