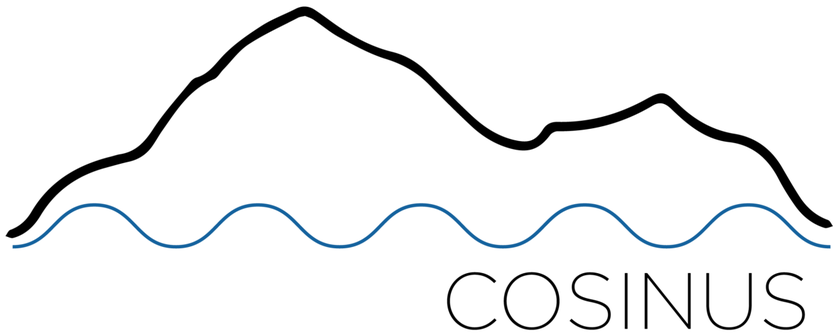
COSINUS dark matter search experiment using NaI cryogenic calorimeters

Presented by: Matthew Stukel
For the Kashiwa Dark Matter Symposium 2023



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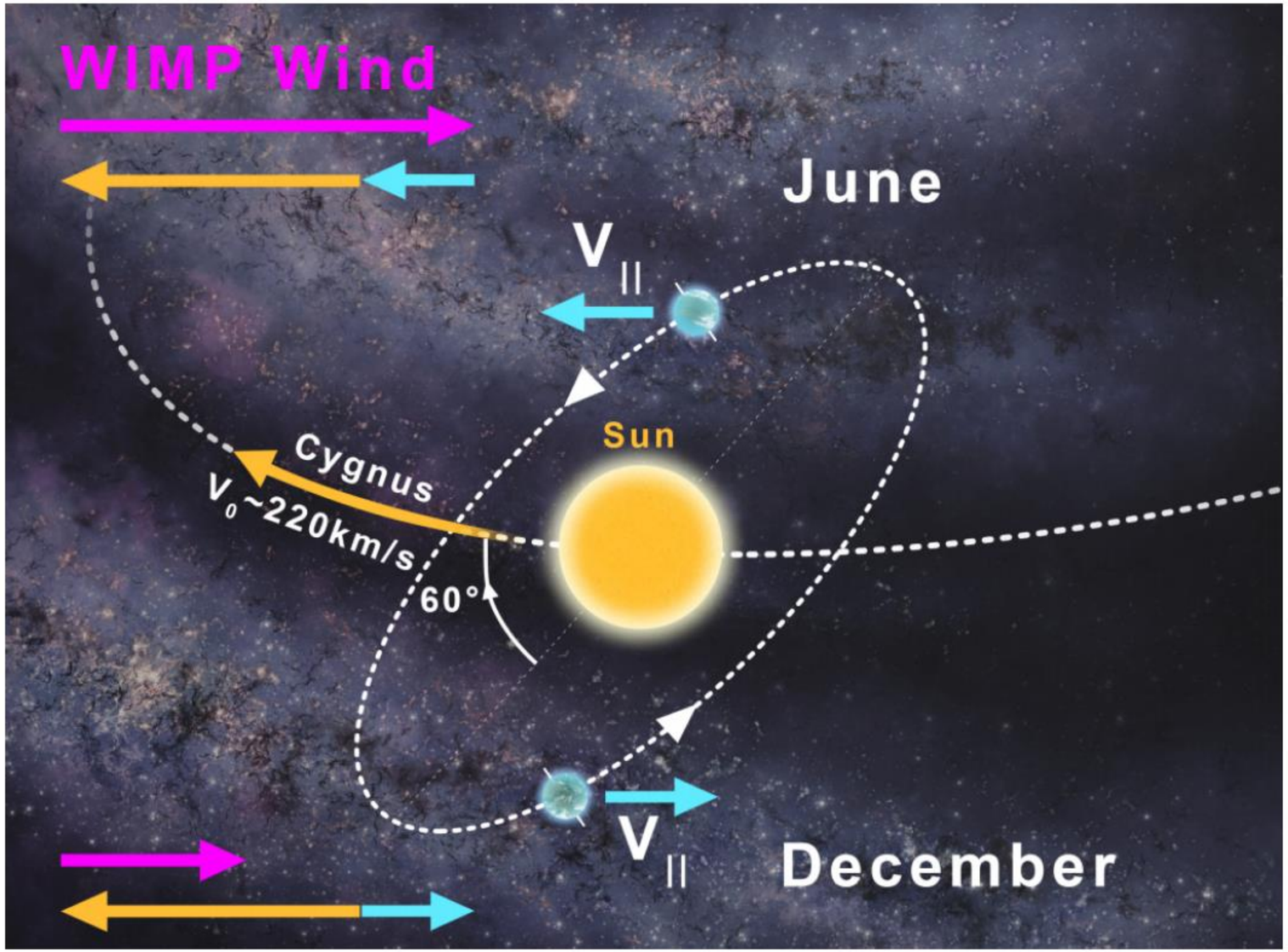
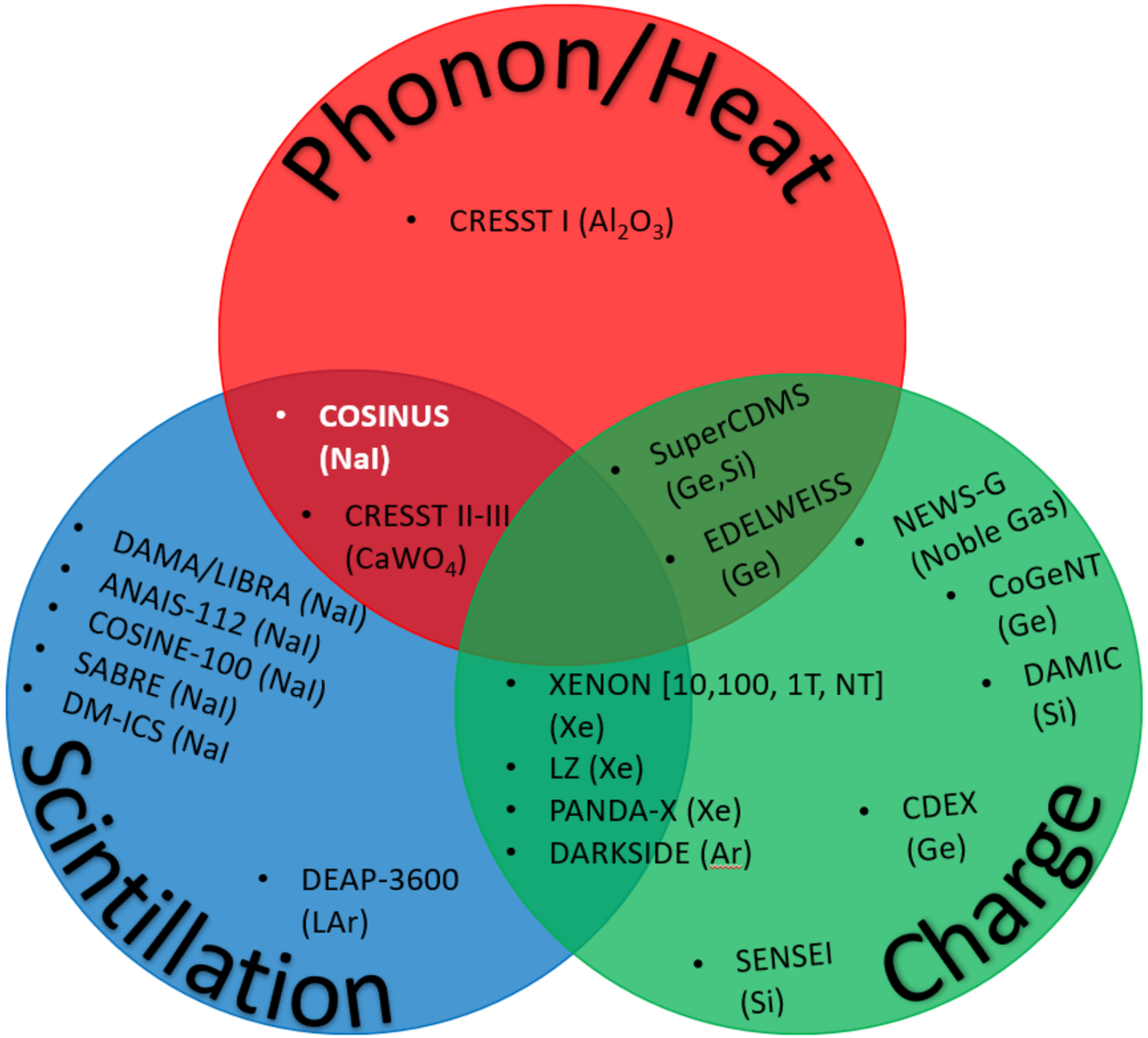
Direct Detection: Annual Modulation



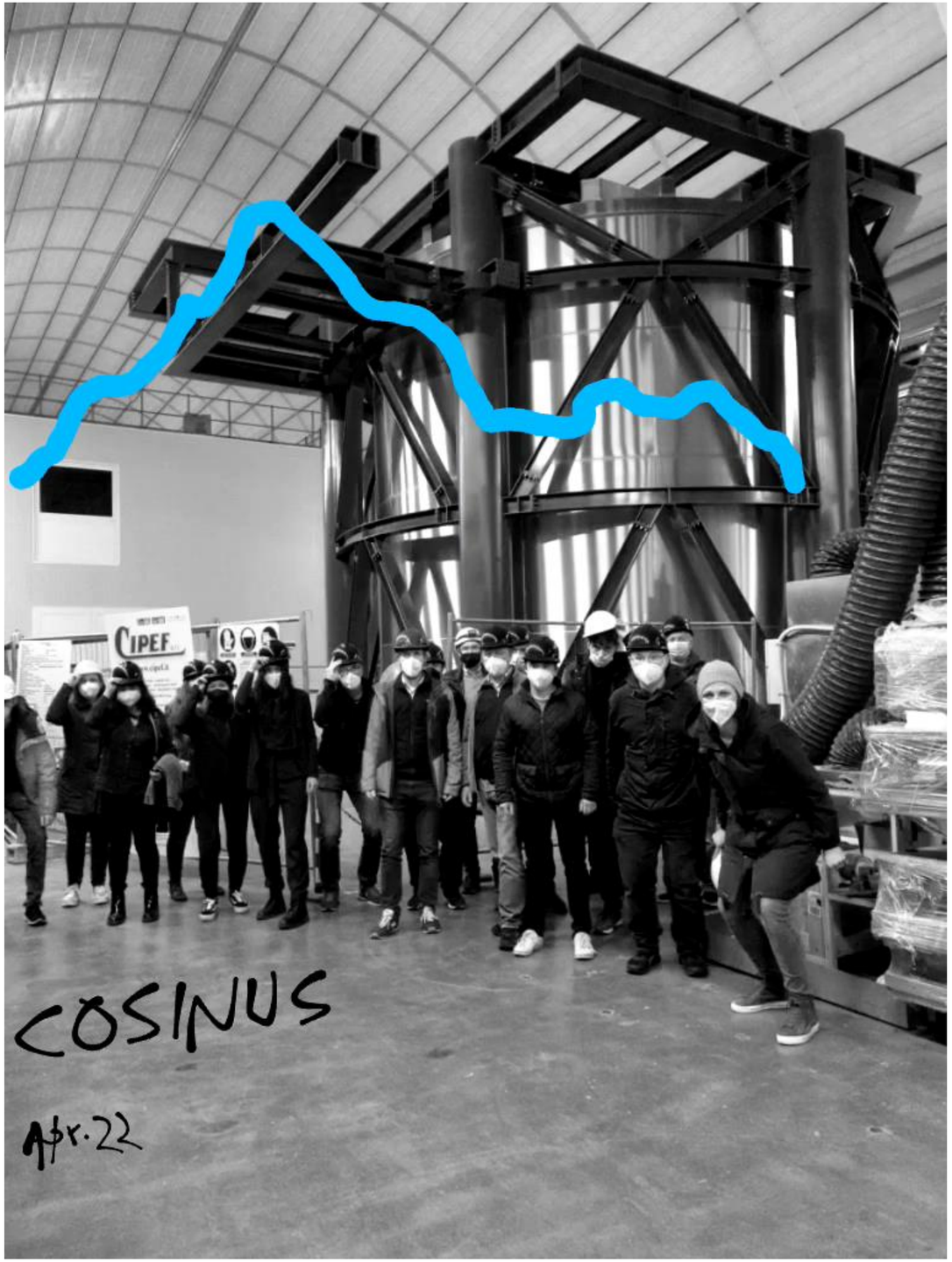
https://iopscience.iop.org/article/10.1088/1361-6471/ab8e93/meta

- The sun moves through the galactic dark matter halo
- The earth rotates around the sun
- Induces a change in the dark matter flux throughout the year
- The DAMA collaboration has detected a peculiar annual modulation signal since 1997
- **Unique** and **detectable** signal for dark matter
  - Period of one year
  - Peaks around June 2nd
  - Signal expected in low energy region (O(keV))

Direct Detection of Dark Matter Experiments



- **COSINUS Goal:** Aims at a model independent test of the DAMA/LIBRA experiment
  - Same material (NaI)
  - Same location (LNGS)
  - Need 1000 kg days
- **Unique Technique:** Operate NaI as a cryogenic detector (First ever!!)
  - Dual Channel: Phonon (90%) and Light (10%) signal for **event-by-event particle discrimination**



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

Since 1928
SICCAS

TU WIEN

HEPHY
INSTITUTE OF HIGH ENERGY PHYSICS

HELSINKI INSTITUTE OF PHYSICS

$\Delta p \cdot \Delta q \geq \frac{1}{2}\hbar$
Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

The Group

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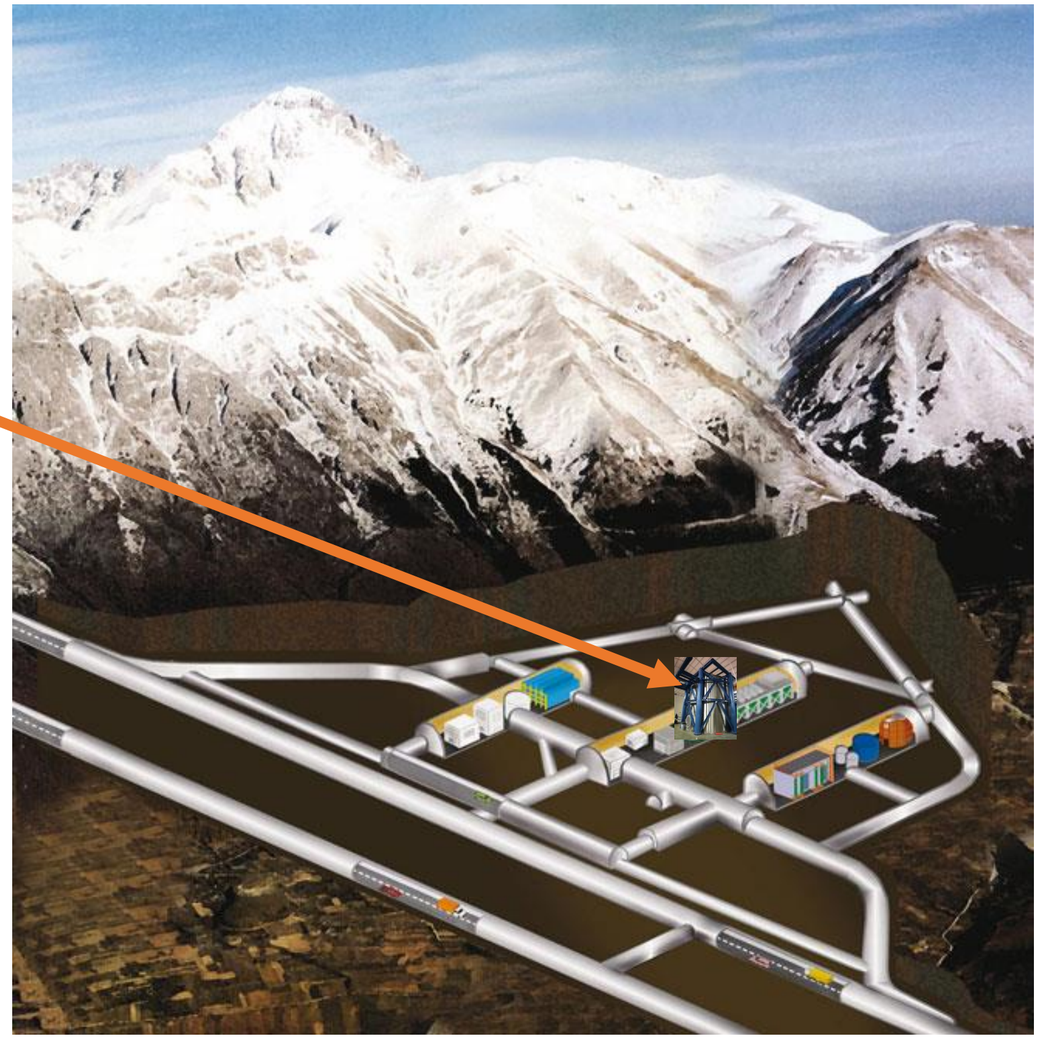
Gran Sasso National Laboratory (LNGS)

https://www.planetware.com/map/italy-italy-republic-map-i-i37.htm

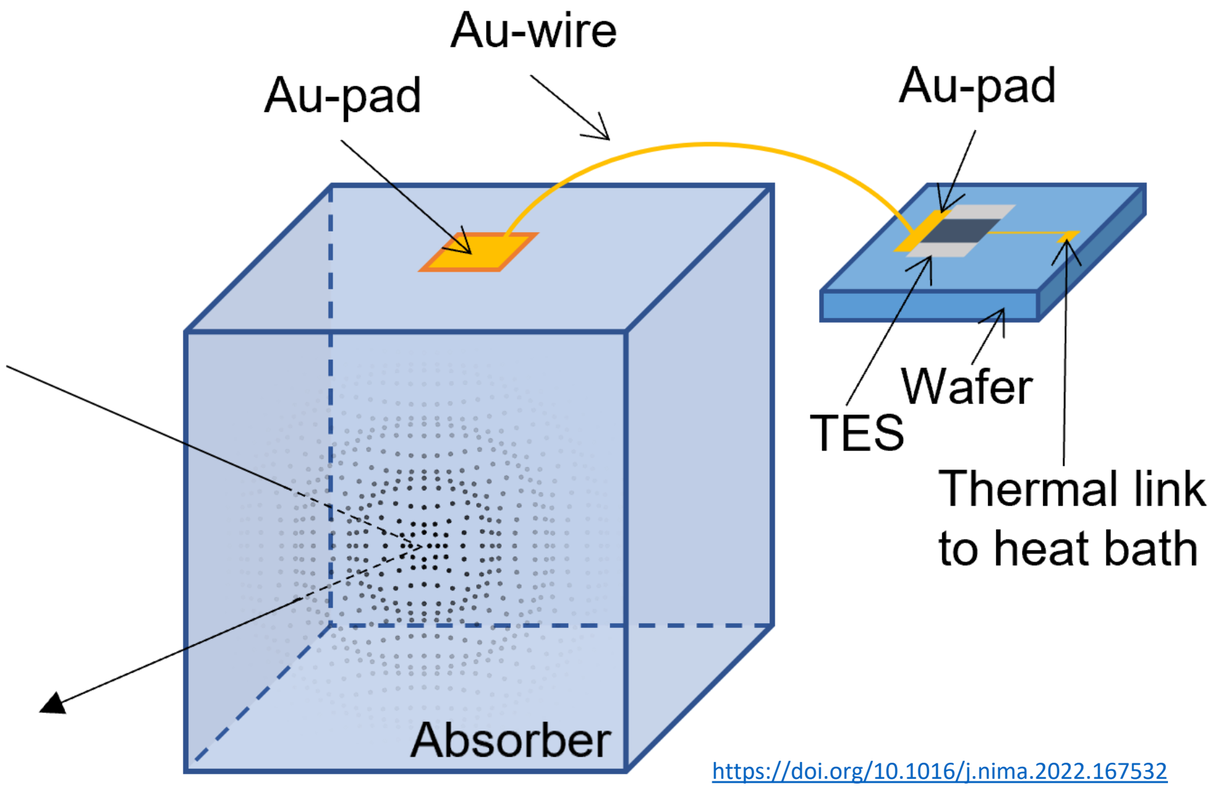
COSINUS Location

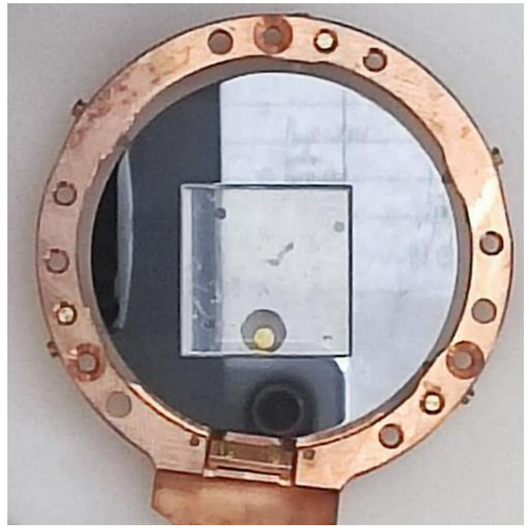


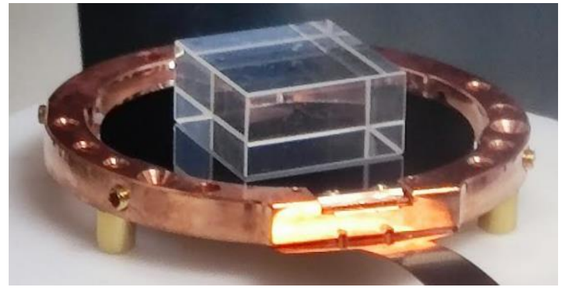
https://www.appec.org/news/hands-on-experimental-underground-physics-at-lngs

- LNGS provides 3500 m of water equivalent shielding from cosmic radiation

NaI- remoTES design



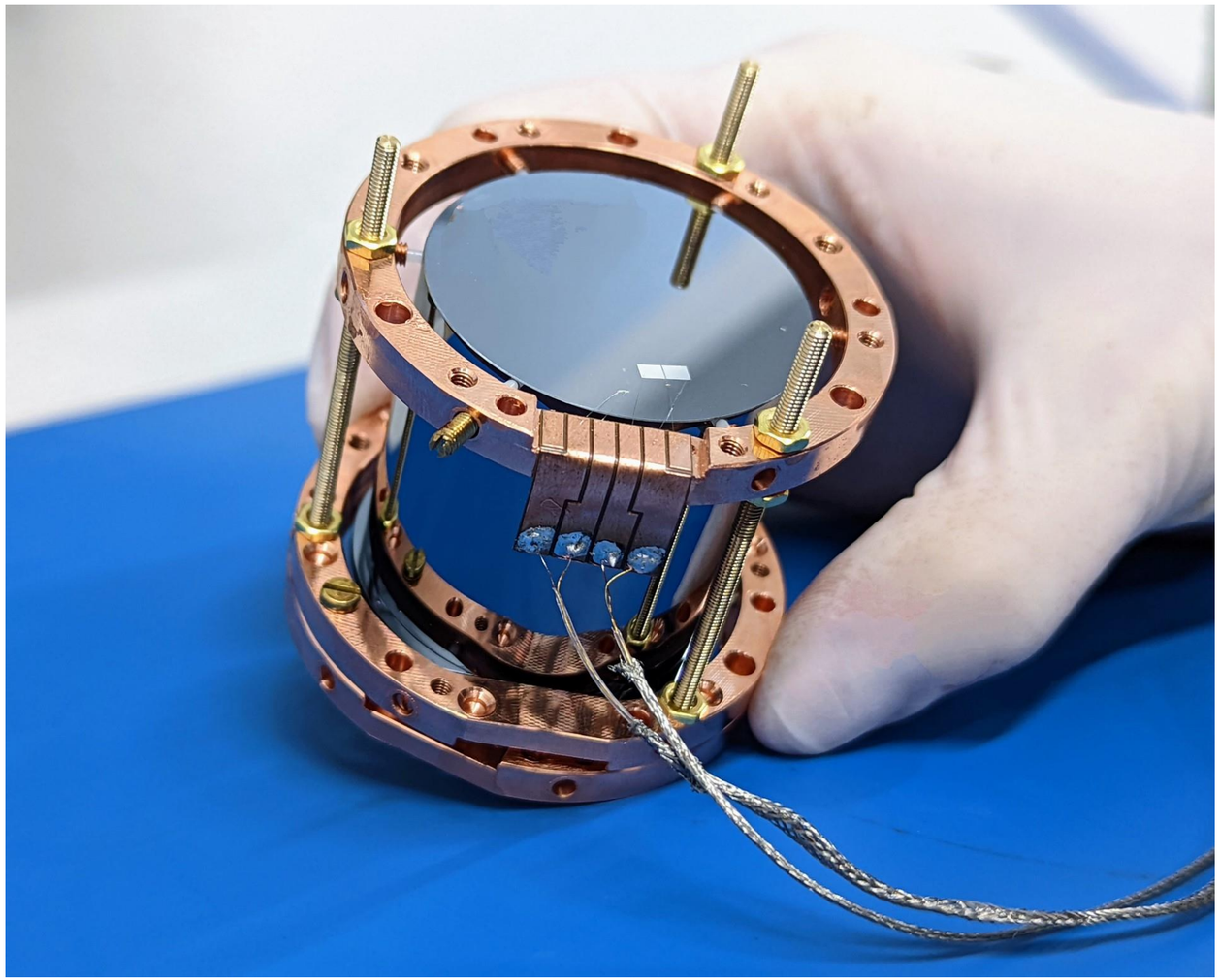




https://doi.org/10.1016/j.nima.2022.167532

- Implement **remoTES** design
  - NaI is hygroscopic (should not come into contact with humid air)
  - Very soft and low melting point (easy to damage when handling)
  - Not suited for traditional thin film deposition
- Separate wafer that holds the TES: Wafer: Al_2O_3
- Gold pad on absorber with a gold bonding wire connected to TES

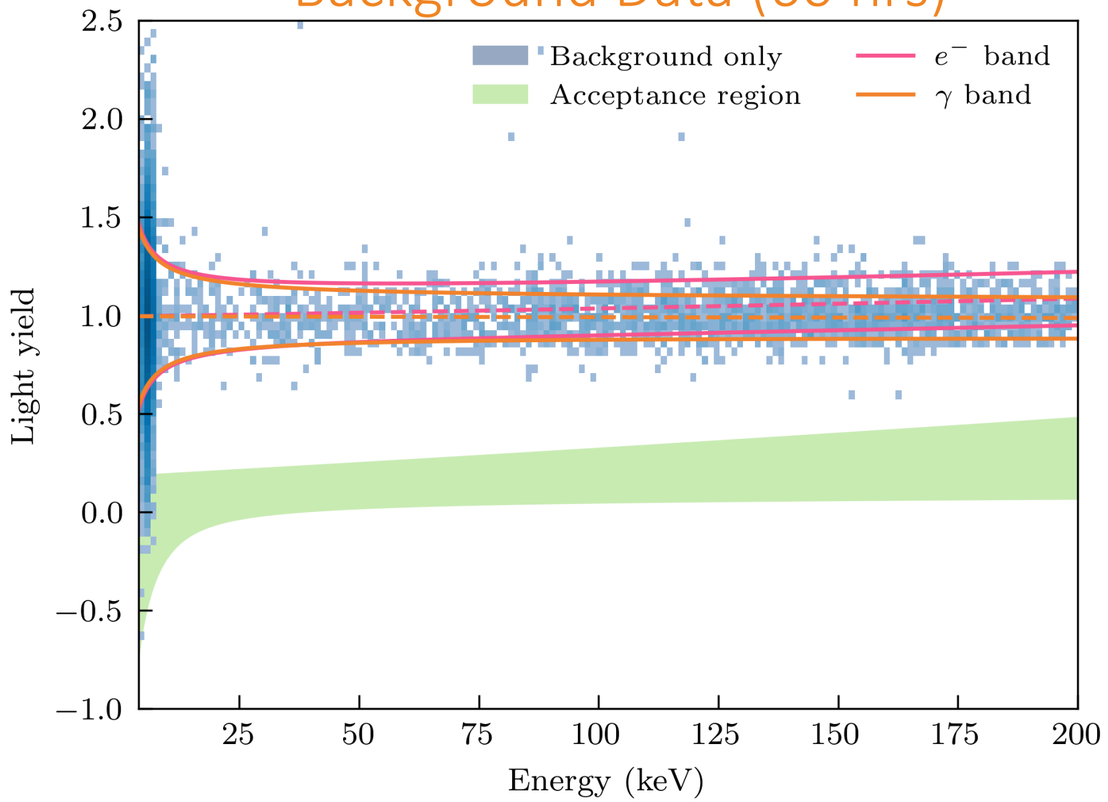
NaI – Light Detector



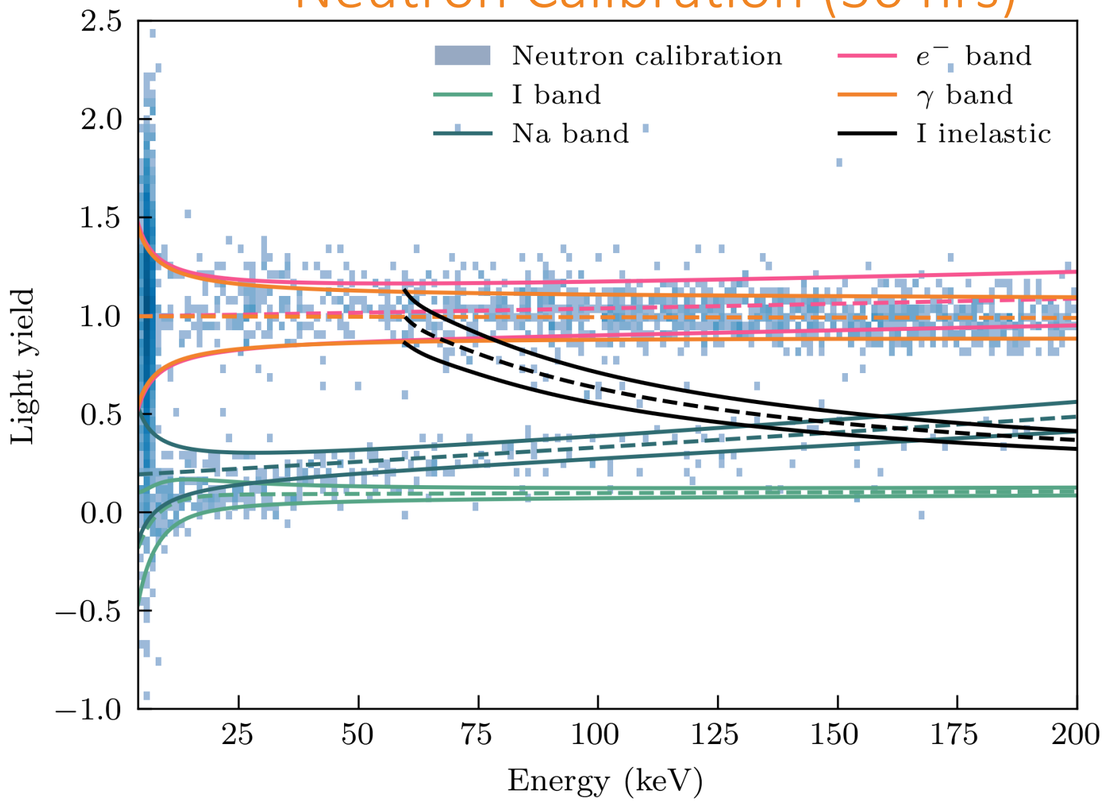
- Scintillation light is detected by a surrounding silicon beaker
  - 1mm thick, 40mm in diameter
- 4π coverage to maximize light collection
- TES is evaporated directly onto the silicon
- Resolution: 990 eV_{ee}

COSINUS: Particle Discrimination

Background Data (60 hrs)



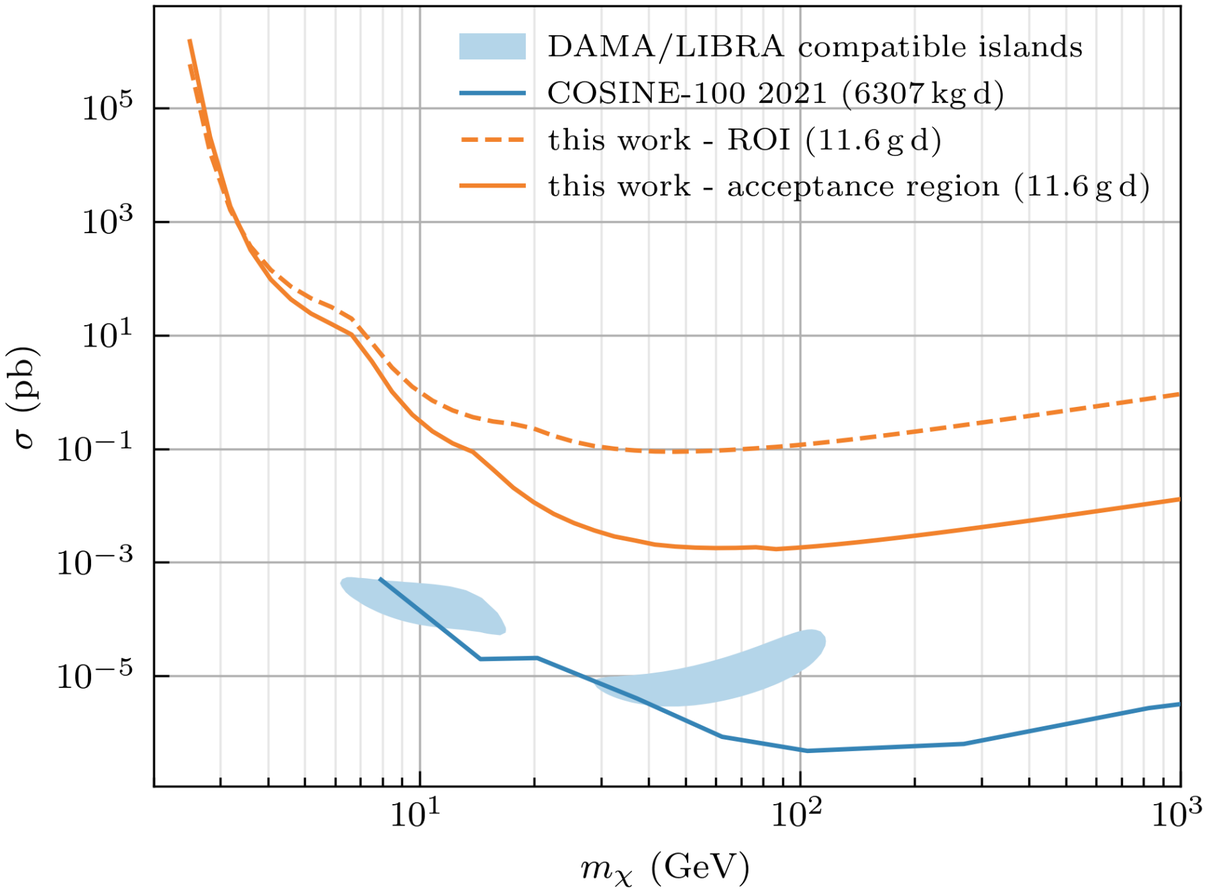
Neutron Calibration (30 hrs)



- December 2021: Demonstrated the first particle discrimination in NaI at a surface setup
- June 2022: Measurement was carried out using a CRESST test facility at the Gran Sasso National Laboratory (underground)
- Plots by Leonie Einfalt, publication on arXiv https://doi.org/10.48550/arXiv.2307.11139
- NaI phonon resolution: 440 eV_{nr}
- Neutron band is clearly visible, **proof of particle discrimination in NaI**

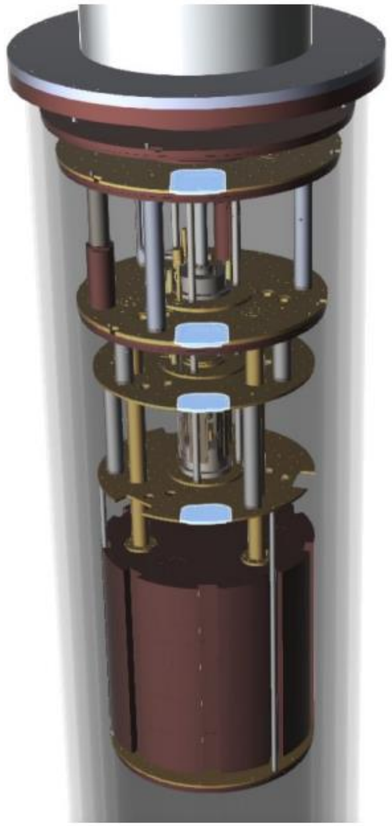
$$\text{Light Yield} = \frac{\text{Light Energy}}{\text{Phonon Energy}}$$

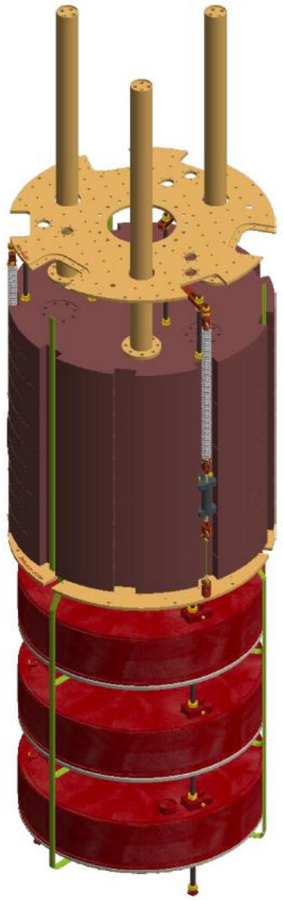
COSINUS: Current Status

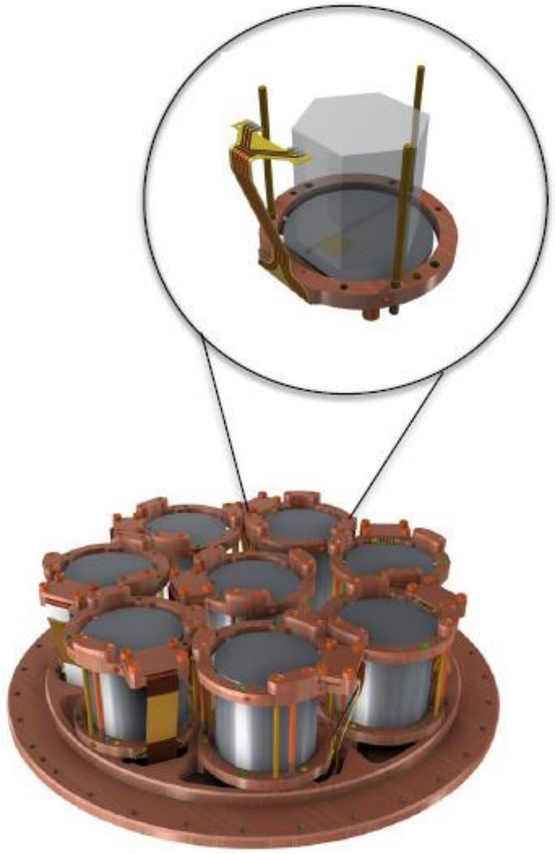


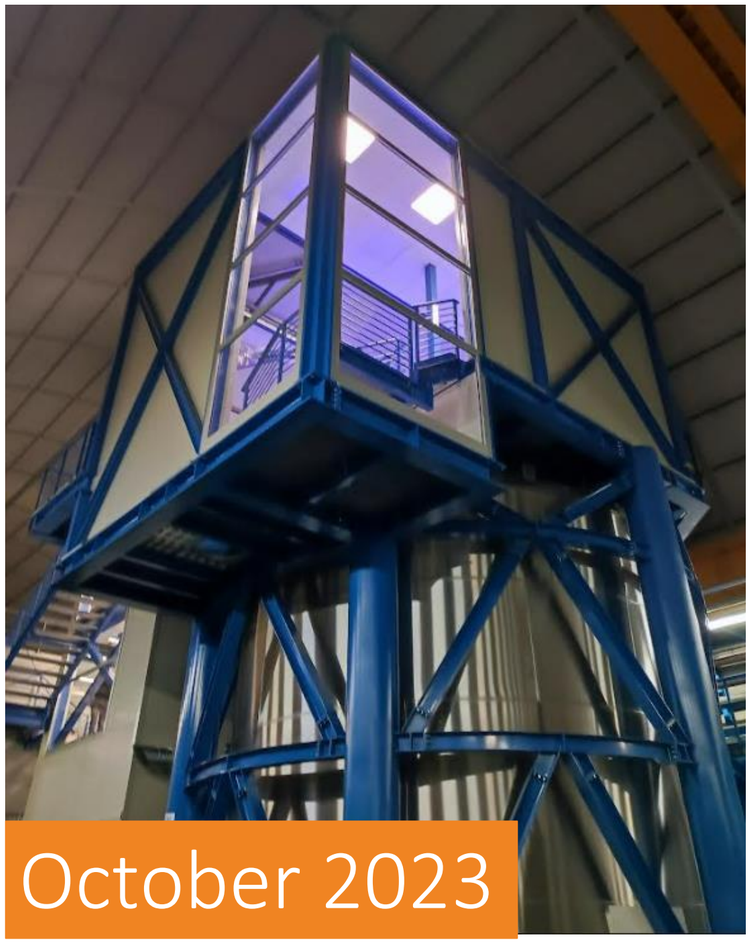
- 1 module (3.6g) of NaI
- 11.6 g·d exposure
- 1 order of magnitude away from DAMA/LIBRA
- 3 order of magnitude higher then COSINE-100
  - They have 10^5 times larger exposure

COSINUS: Dry Dilution Refrigerator



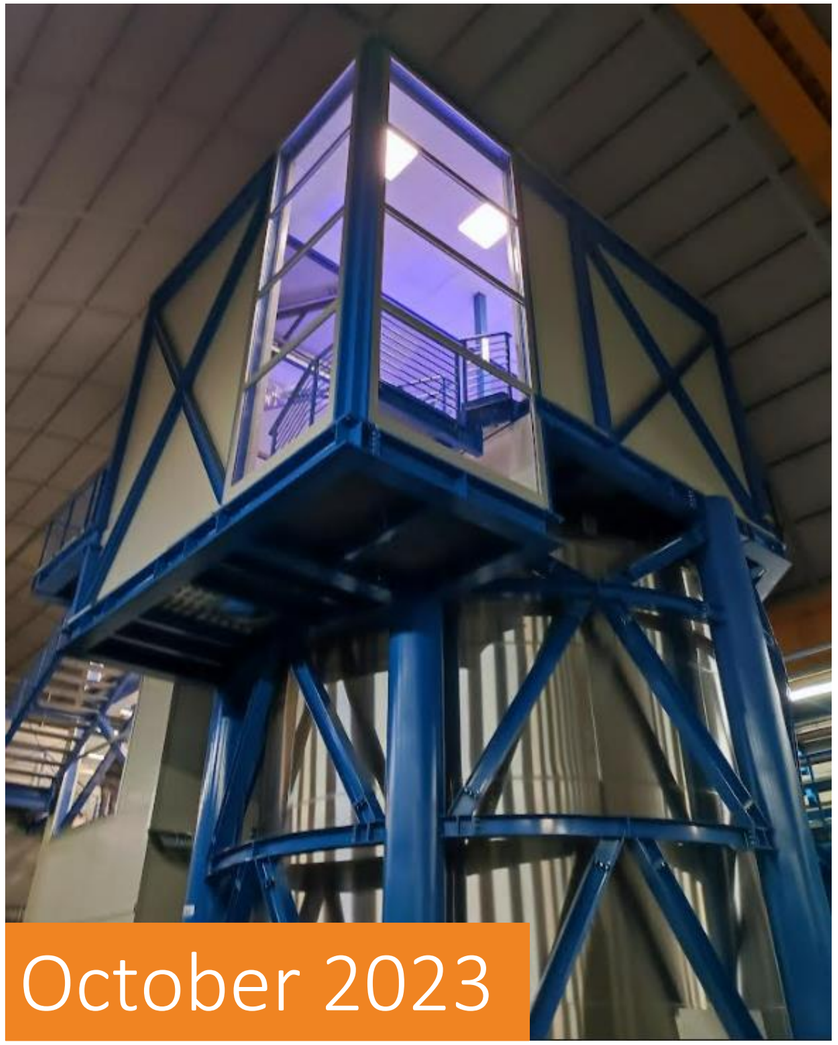






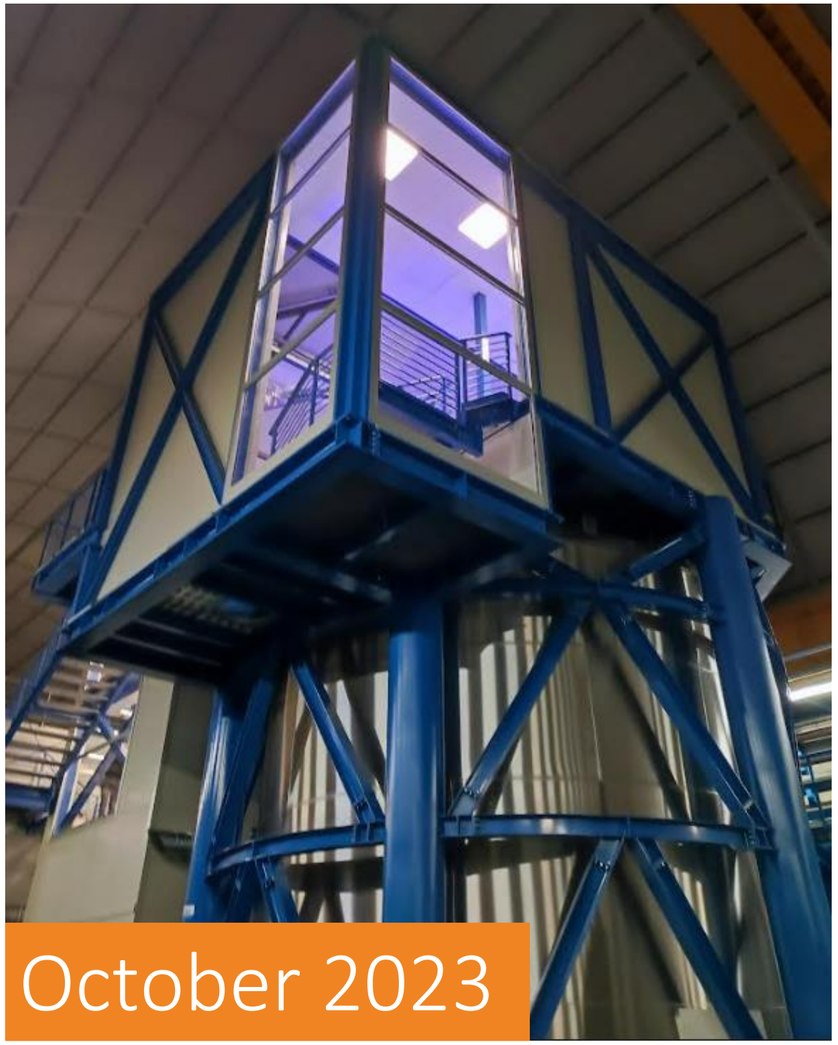
- Detectors housed in a pulse tubed assisted dilution refrigerator (mK)
  - Each module will support a 30g crystal
- Vibration decoupling: Isolated cryostat support stage, spring-based passive decoupling system,
- Ultra-pure copper for shielding the detectors from cryostat radiogenics

Experimental Setup I



Experimental Setup II

Dry Well



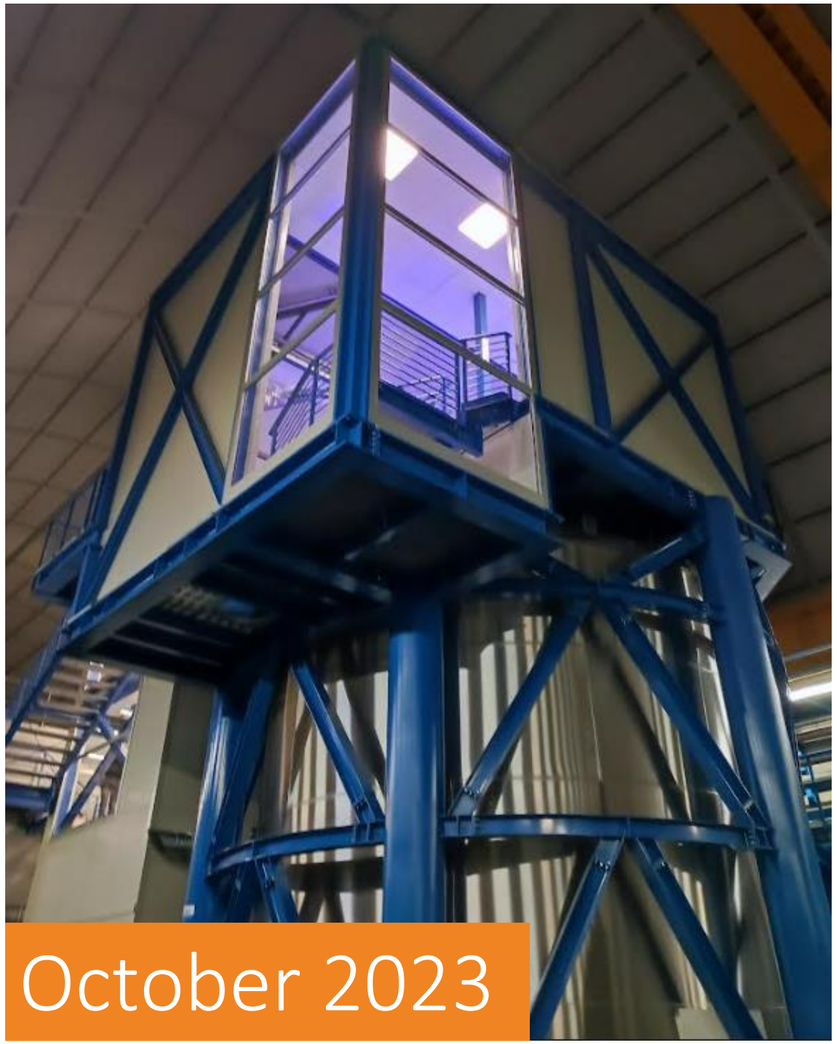
October 2023

Experimental Setup III

Control Room

Clean Room

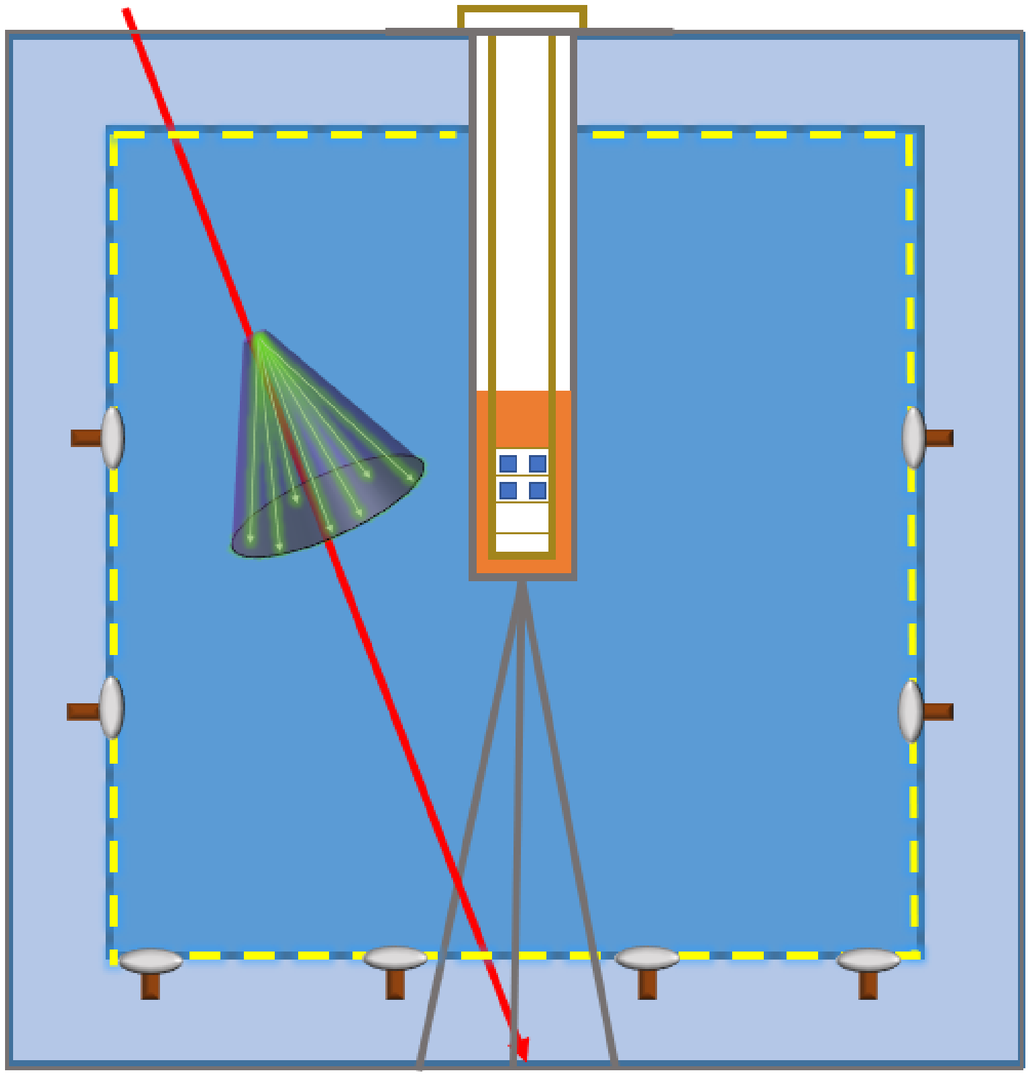
Water Tank



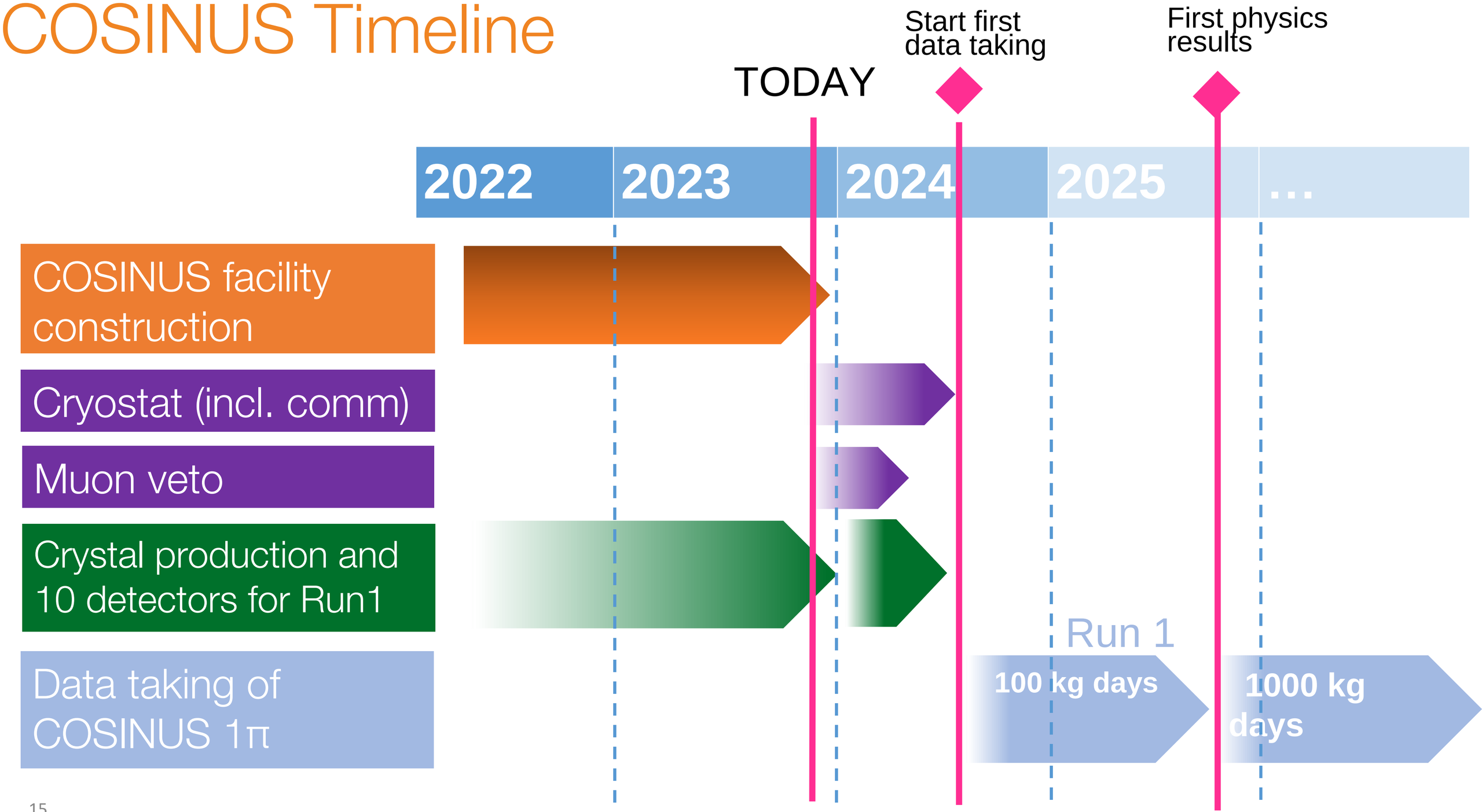
October 2023

COSINUS Water Tank I

- 230 tonne water tank (7x7 m^2 cylinder)
- Instrumented with 28, 8-inch R5912-30 PMTs from Hamamatsu
  - 18 along the bottom and 10 along the wall
- Optical dead layer for the muon veto
  - Reduce the spurious triggers of PMT from ambient background and triggers
  - Need a trigger rate less then 1 Hz to be viable
- Detailed optical simulation created with ImpCRESST to optimize PMT placement, detector efficiency and background rate
- Achieve a total muon veto efficiency of 97(2)%
- Also sensitive to Supernova neutrinos!
- Papers in progress



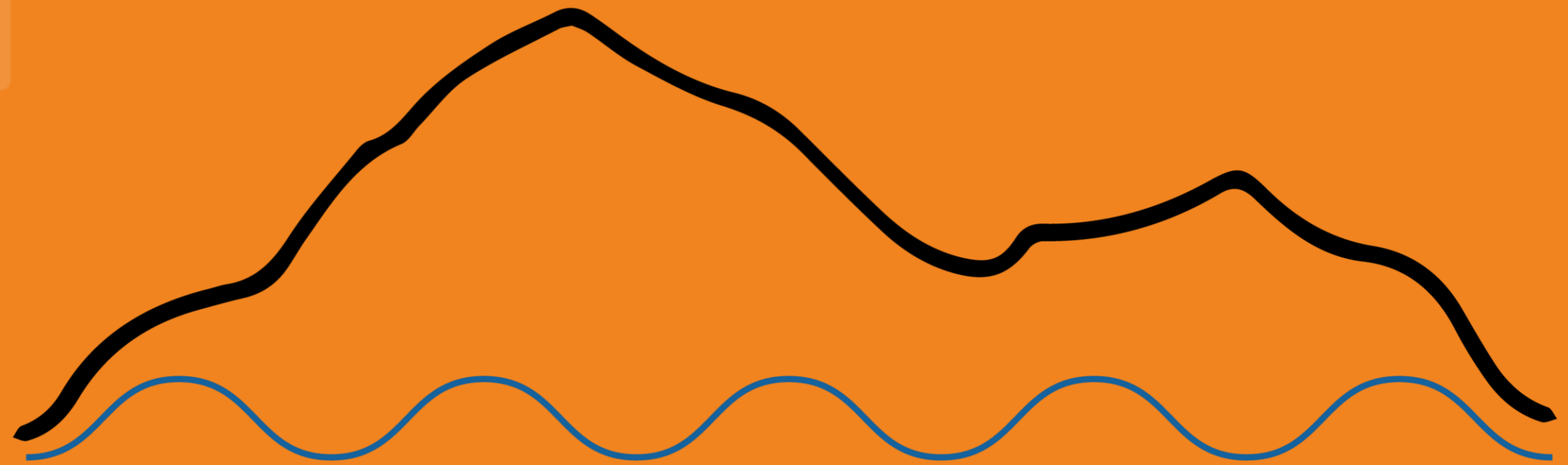
COSINUS Timeline



Conclusion/Future Work

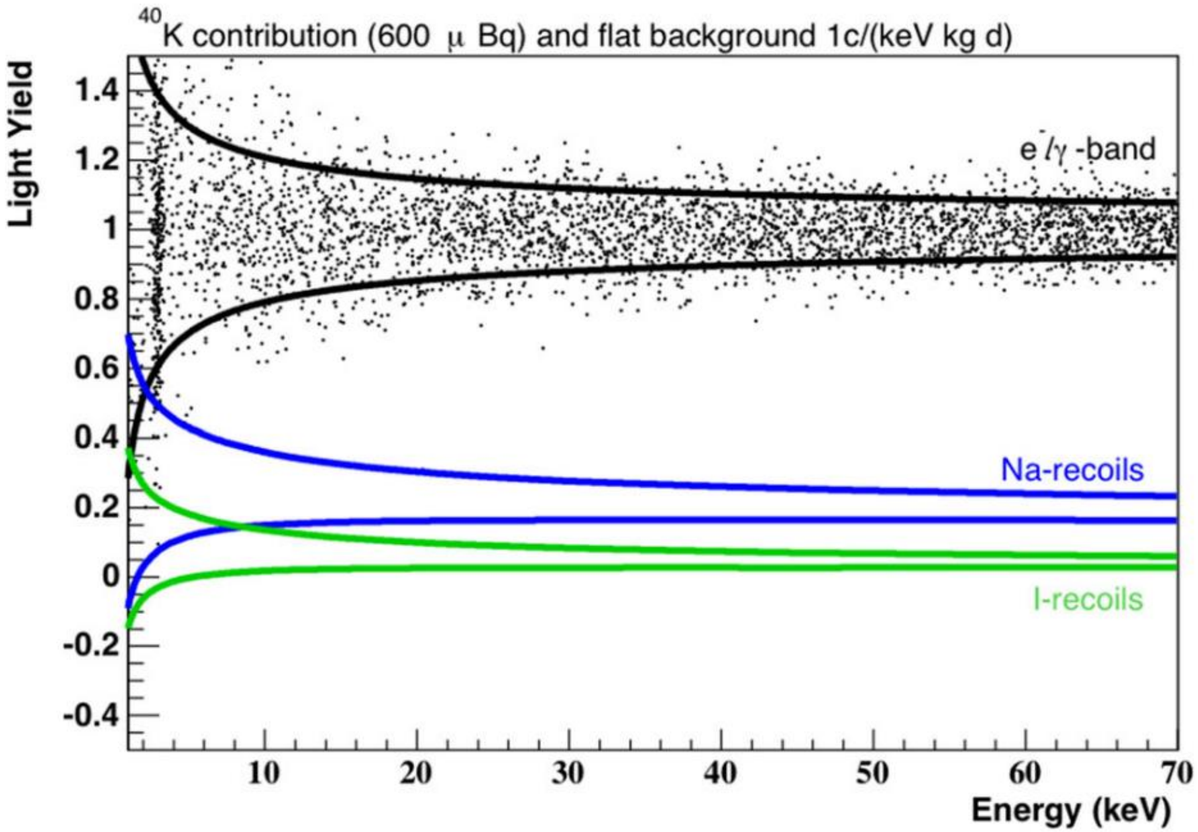
- COSINUS is a cryogenic NaI dark matter experiment whose goal is to evaluate the longstanding DAMA/LIBRA dark matter claim
- COSINUS uses the novel “remoTES” setup to operate NaI as cryogenic calorimeters
  - Gives powerful, event-by-event, particle discrimination
- COSINUS will begin data taking in 2024 and we look forward to great results!!
- Follow us on X (Twitter) : @COSINUSdm

Thank You!



COSINUS

COSINUS: Particle Discrimination



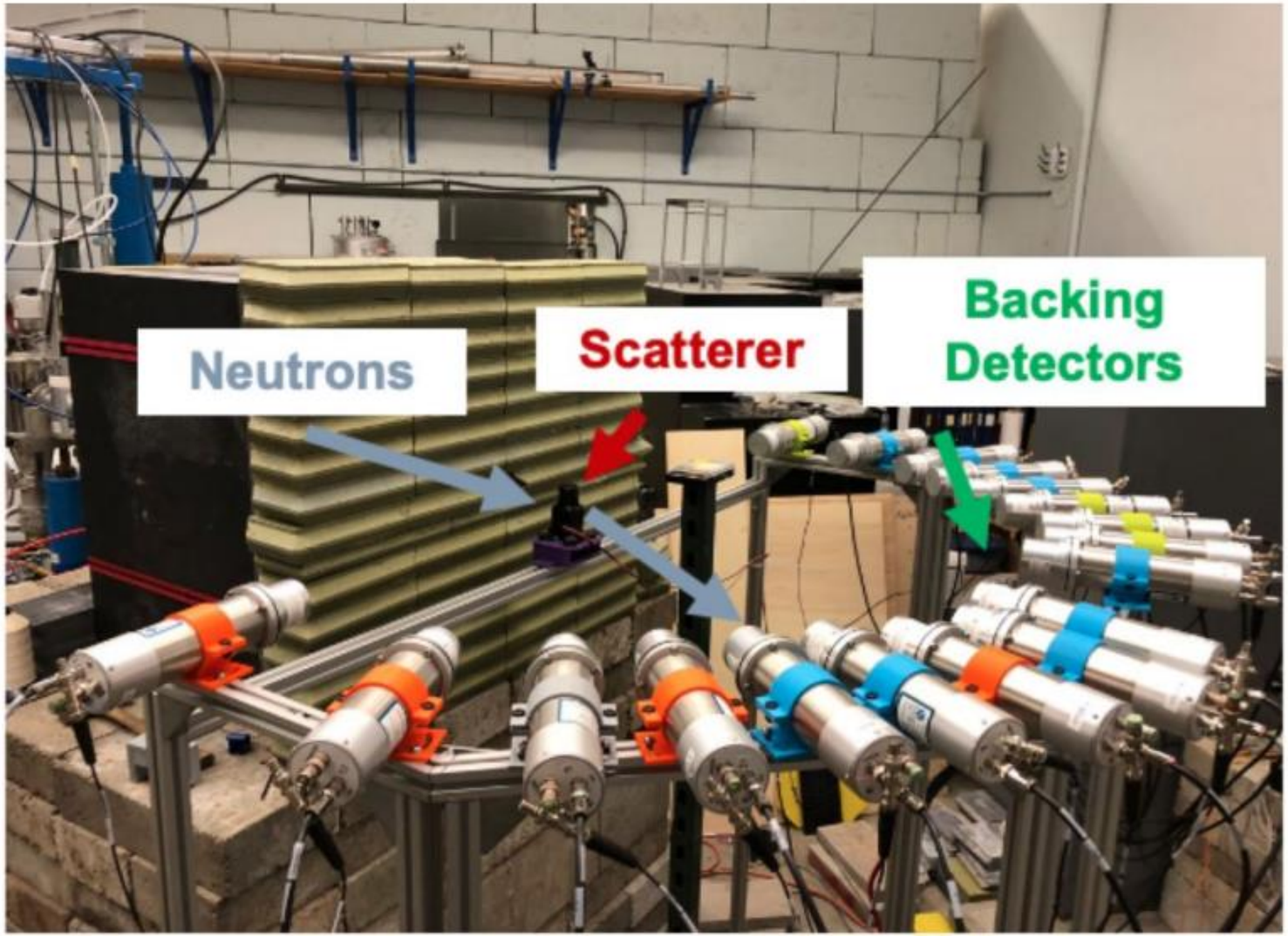
Angloher, G., et al. "Simulation-based design study for the passive shielding of the COSINUS dark matter experiment." *The European Physical Journal C* 82.3 (2022): 1-11

- Particle discrimination is the COSINUS advantage

$$\text{Light Yield} = \frac{\text{Light Energy}}{\text{Phonon Energy}}$$

- Electromagnetic interactions will emit more light than nuclear recoils
- Use for **particle discrimination** on an event-by-event basis
- Left is simulated data
- Position of the bands is very dependent on the quenching factor (QF)
  - Dedicated QF performed at TUNL (See backup slide)

Quenching Factor Measurement



- Performed at TUNL (Triangle Universities Nuclear Laboratory)
- 5 NaI crystals with different Tl doping (0.1-0.9%)
- Neutron beam scatters in the crystal and arrives at backing detector
- Based on the angle we know the actual energy of the recoil
- Can then compare to energy measured and determine the <u>QF!!</u>

Crystal Growth

- Crystals are grown in collaboration with SICCAS using Astrograde powder in a modified Bridgeman technique
- Keep isotope contamination down (K, Th, U)