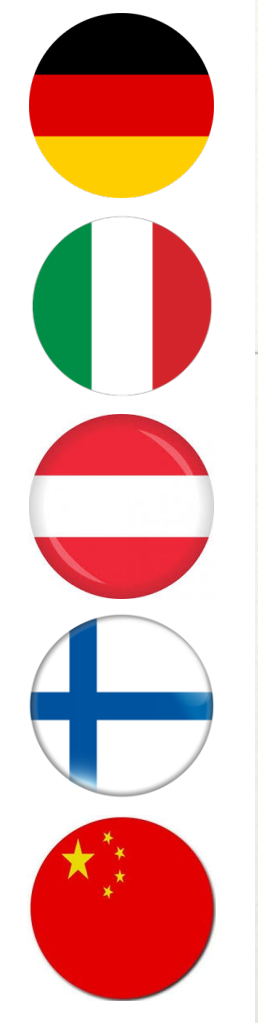


MPP Project Review 2024 - COSINUS Group

Updates from COSINUS

M.Stahlberg
Postdoctoral Researcher

December 9, 2024

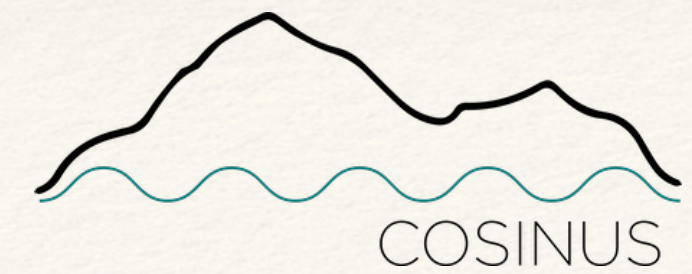


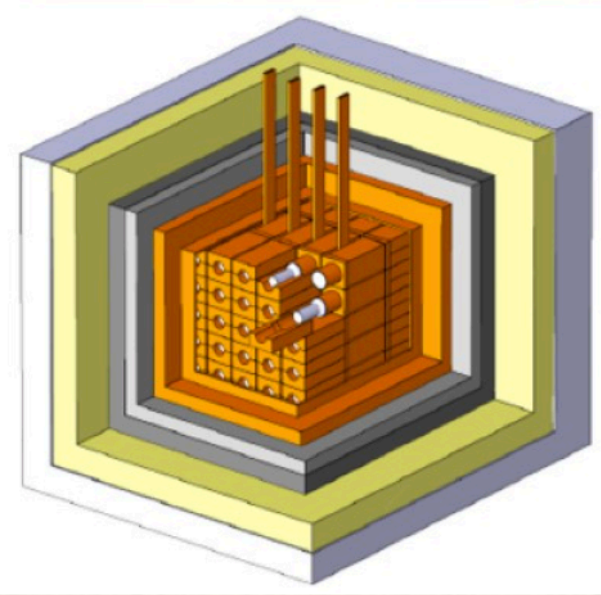
The COSINUS Collaboration

Founded in 2018;
 Construction of experiment approved in 2020
 ~40 Scientists from 8 institutes in 5 countries

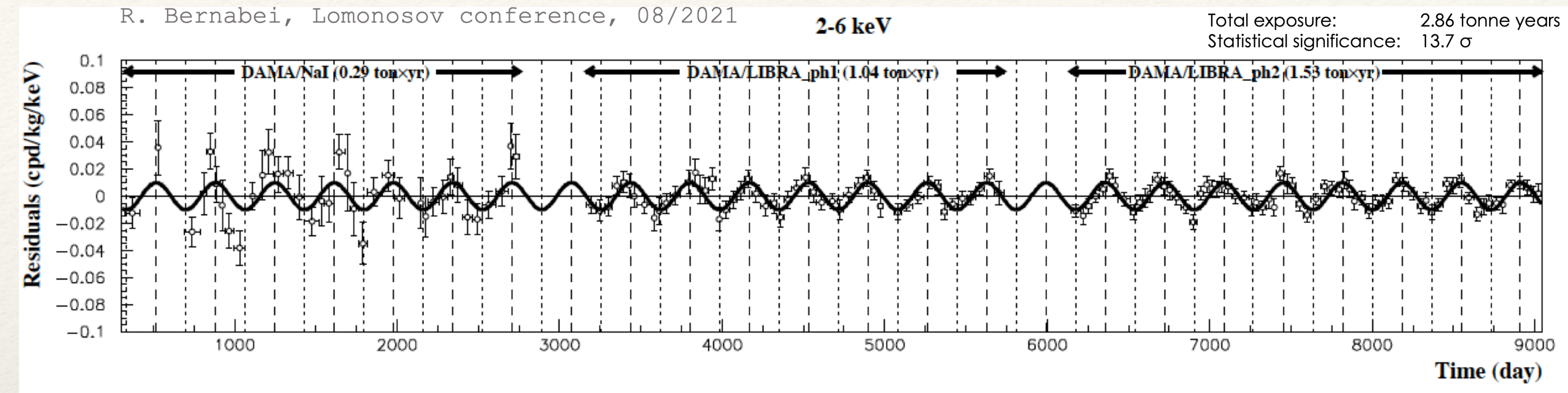
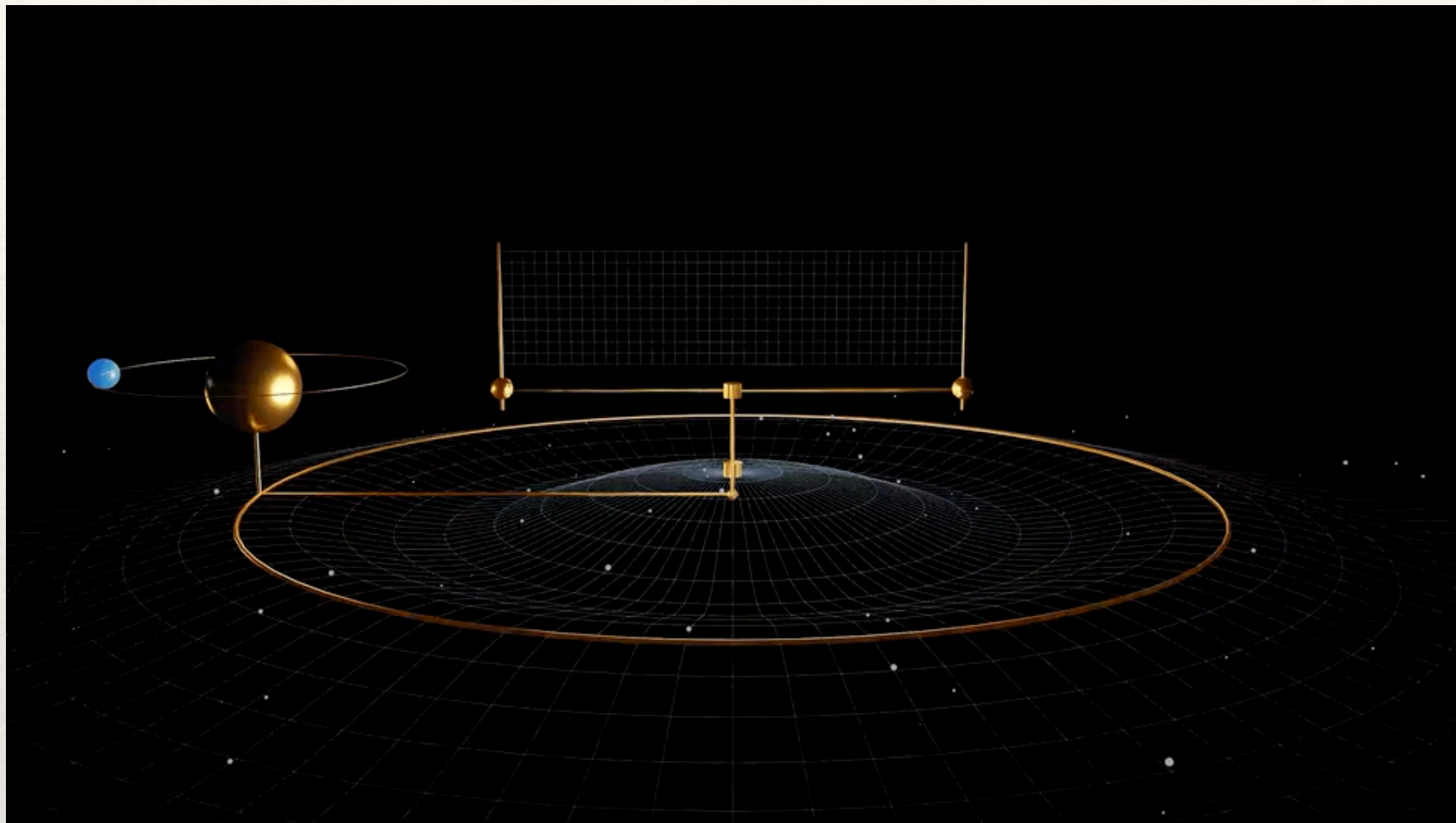


Inauguration on April 18, 2024!

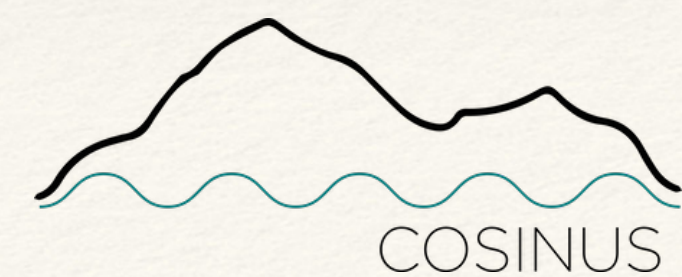
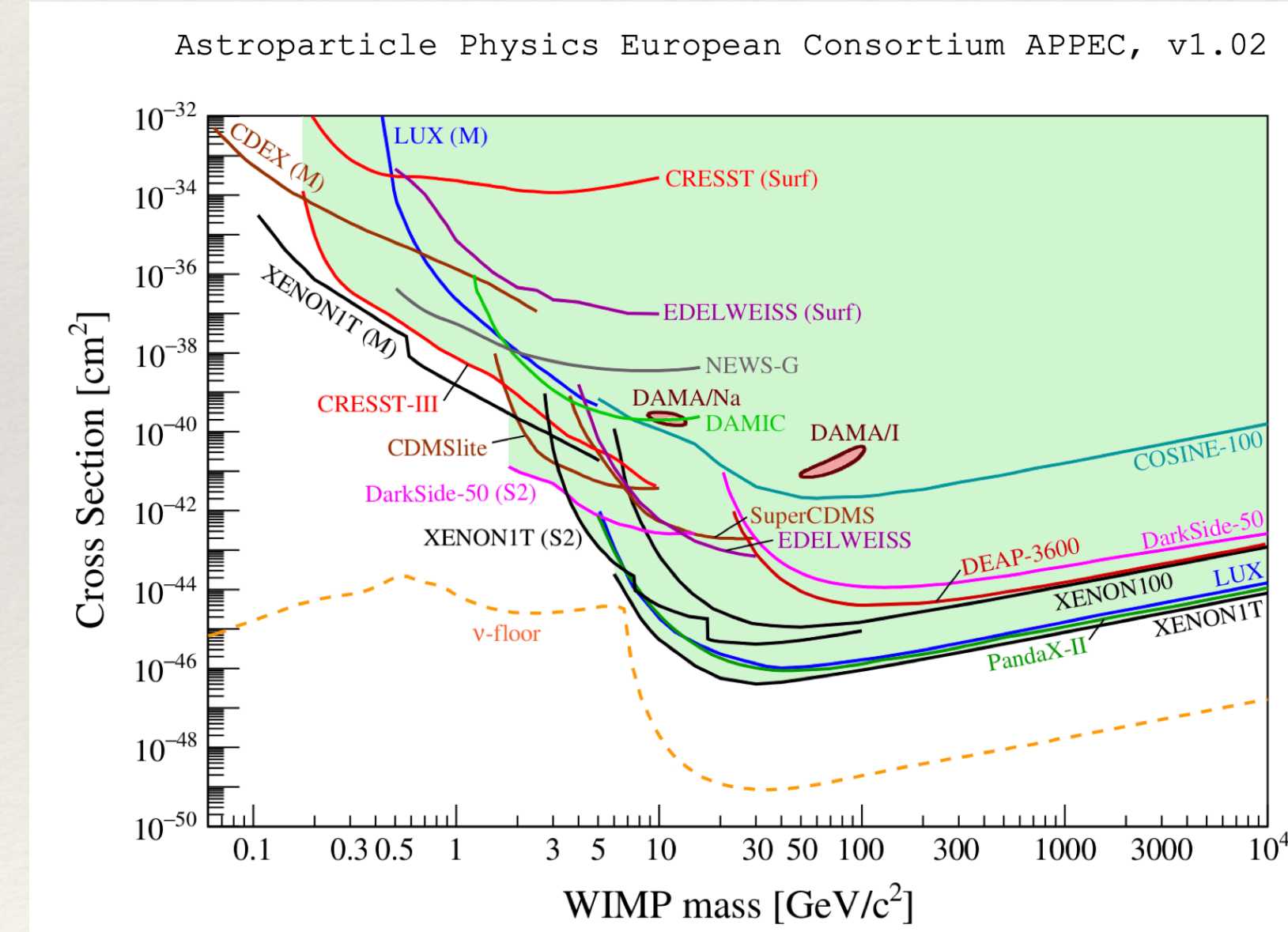




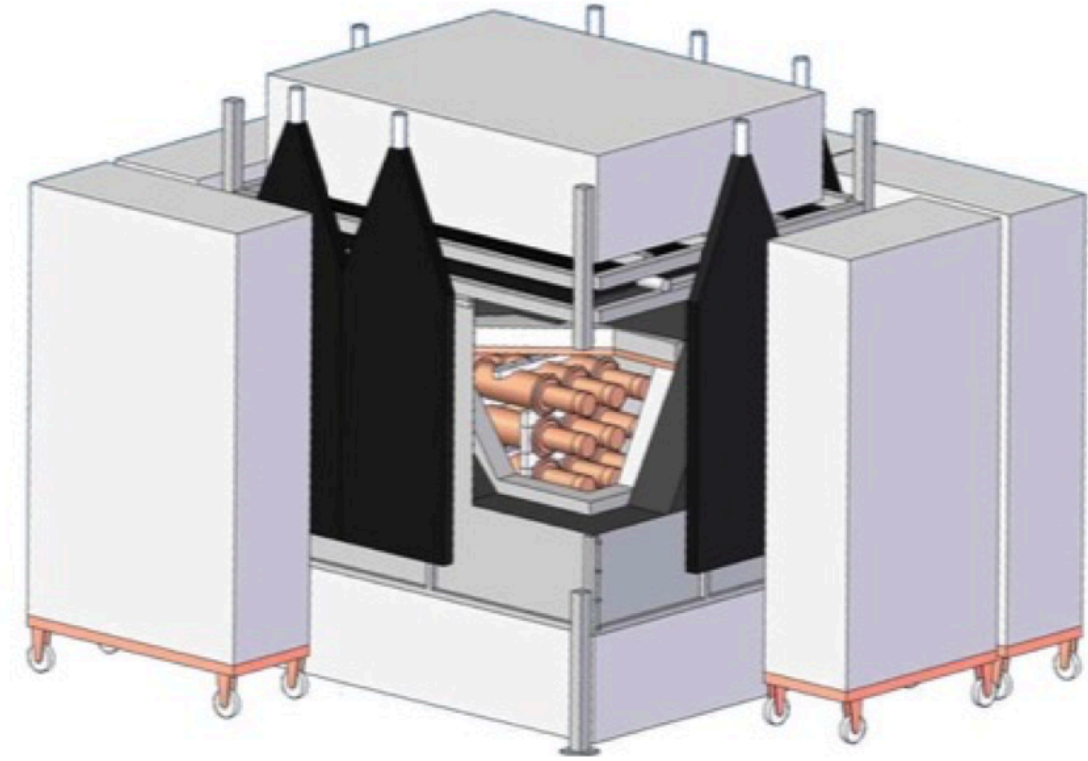
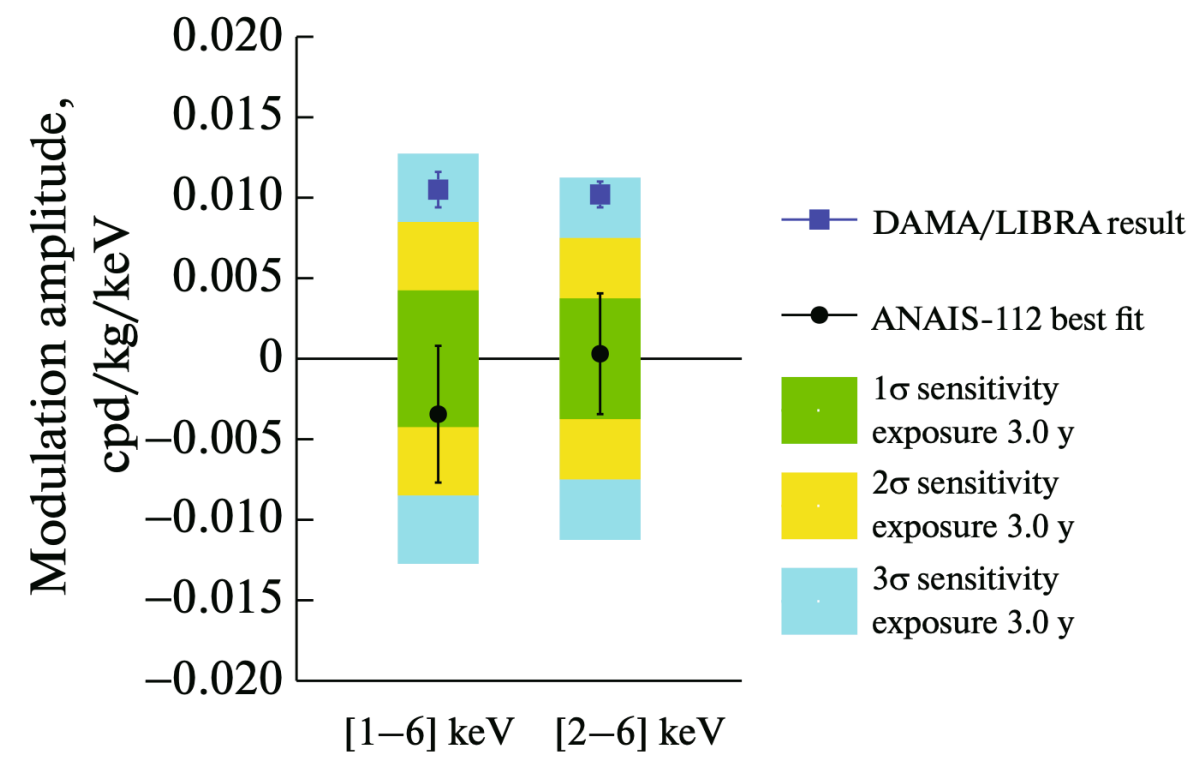
Why COSINUS? - The „puzzle“ of DAMA/LIBRA



- ❖ Direct search for dark matter (DM): halo of particles causes **modulating rate** of interactions in earth-bound detector
- ❖ Observed by DAMA/LIBRA since ~25 years (period + **phase** !)
- ❖ Incompatible with other direct detection experiments in „standard“ scenario
- ❖ DAMA/LIBRA measures **scintillation light** from NaI crystals
- ❖ Recent improvement of threshold to ~1keV, experiment **switched off**

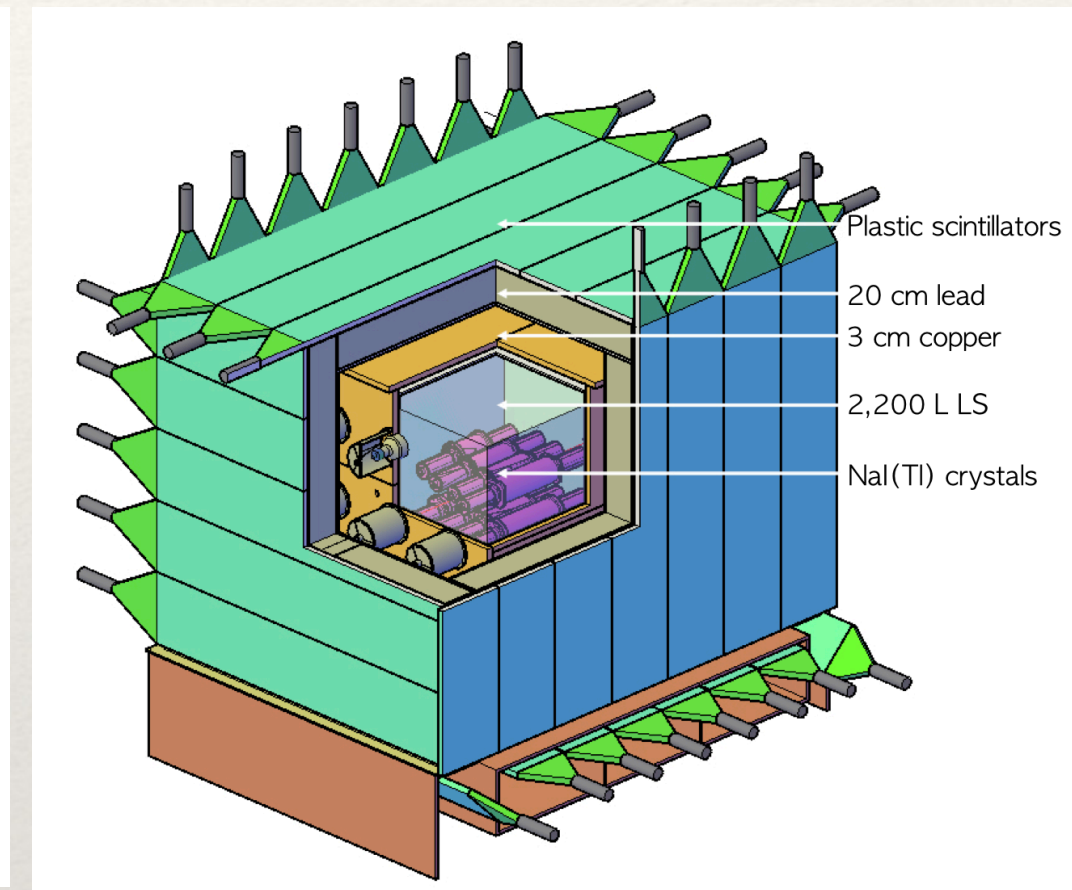
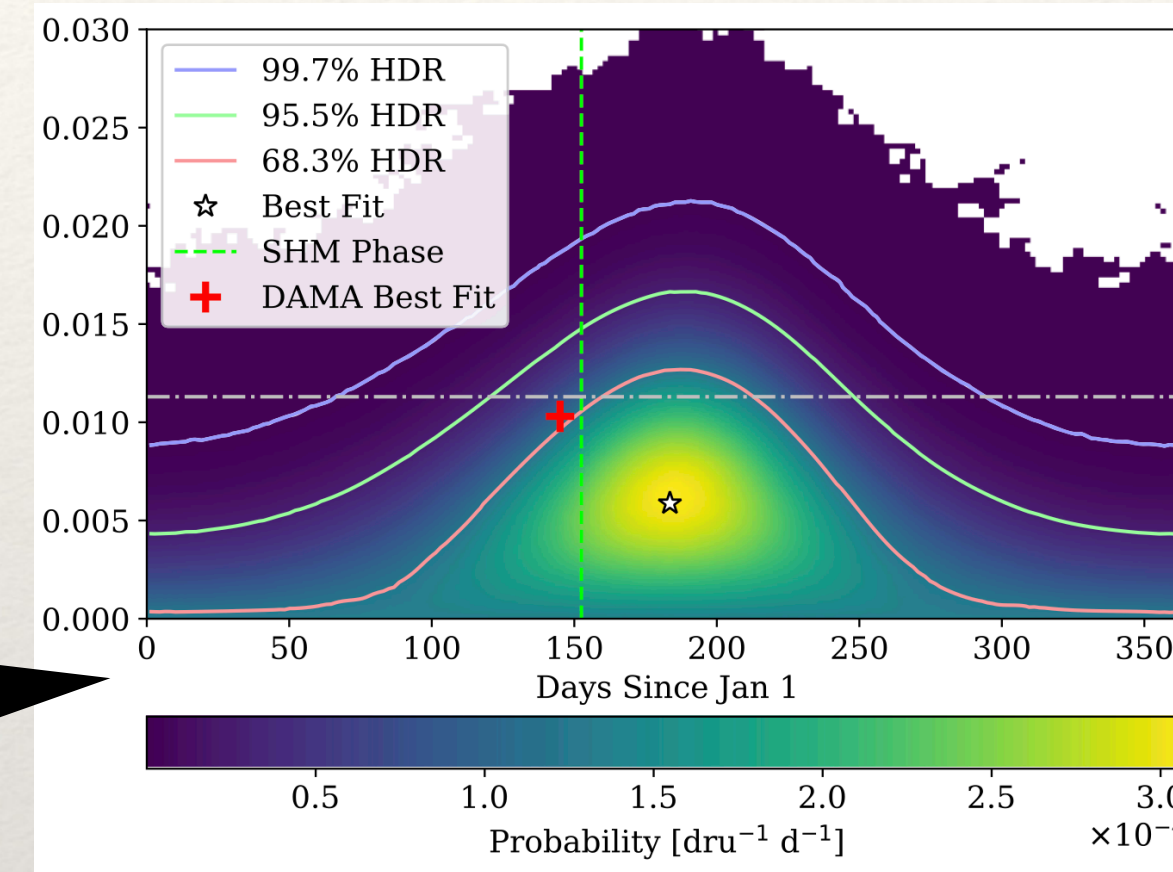


AMARÉ et al.

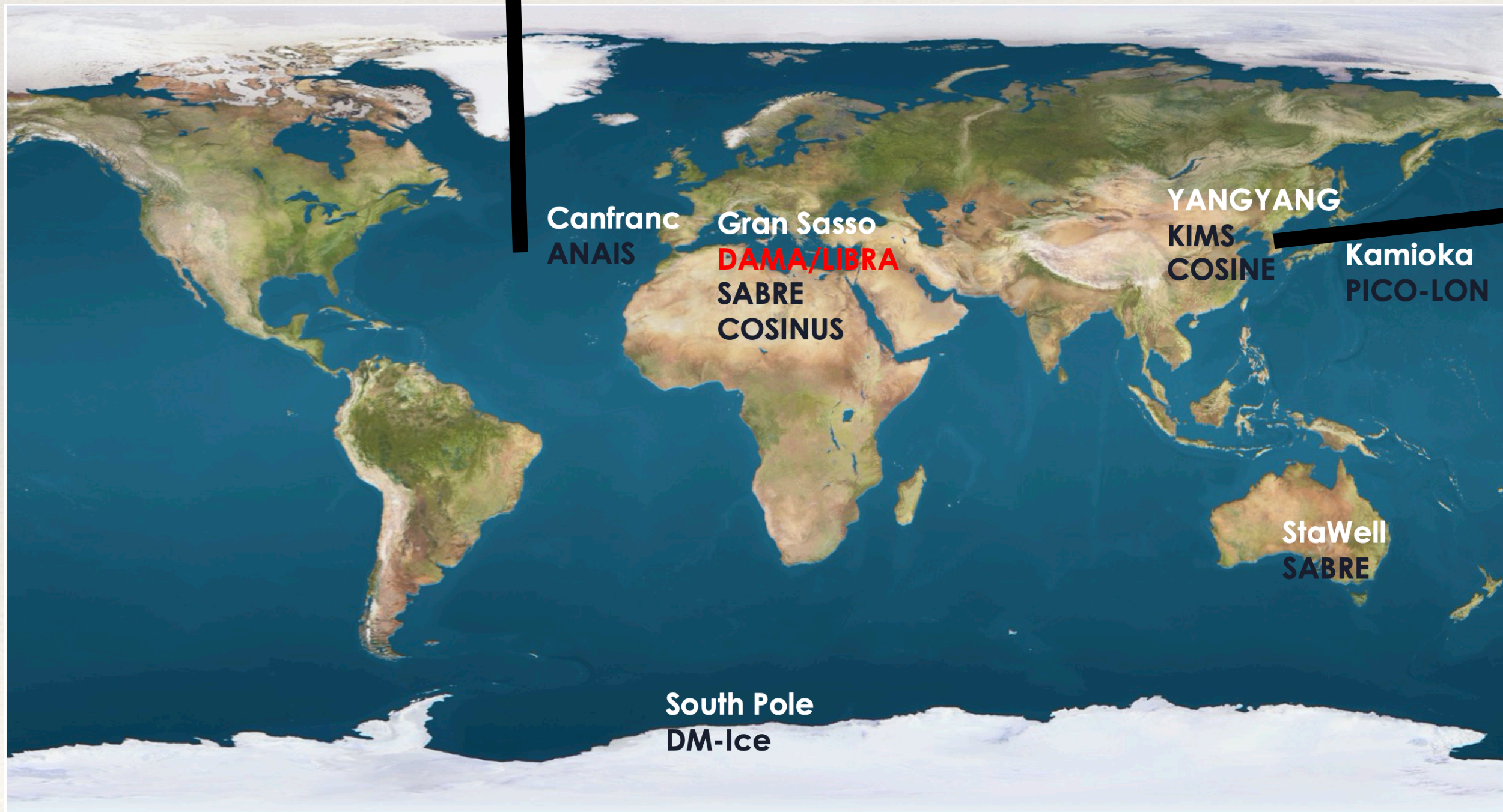


Direct Search for Dark Matter with NaI

...does the choice of NaI as target material have an influence?

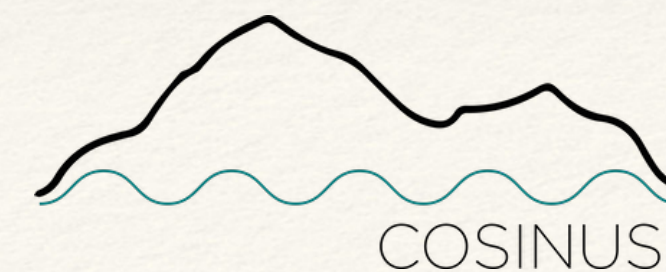


Adhikari, G., et al. "Three-year annual modulation search with COSINE-100." *Physical Review D* 106.5 (2022): 052005.

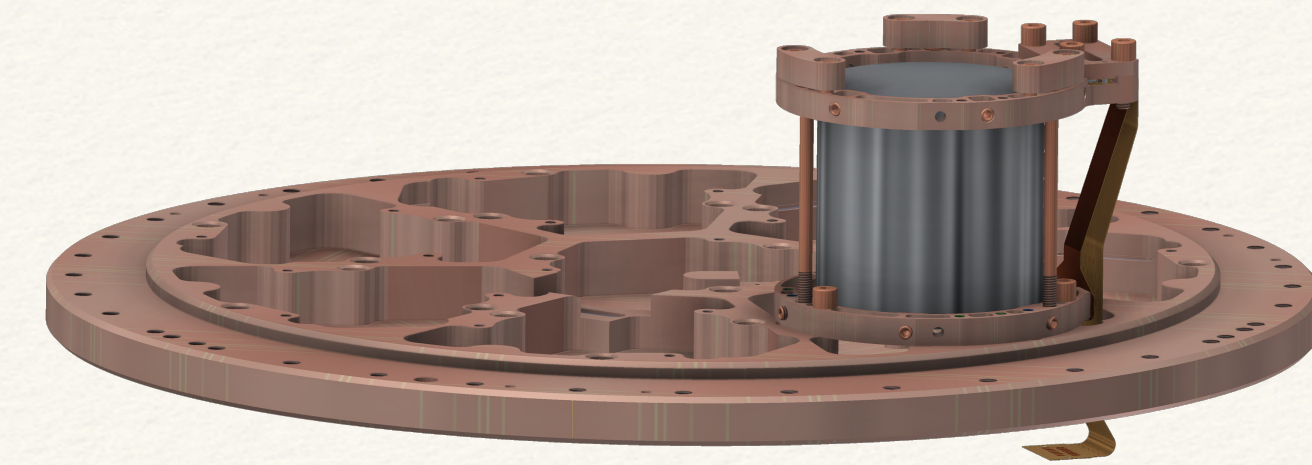


Caveats:

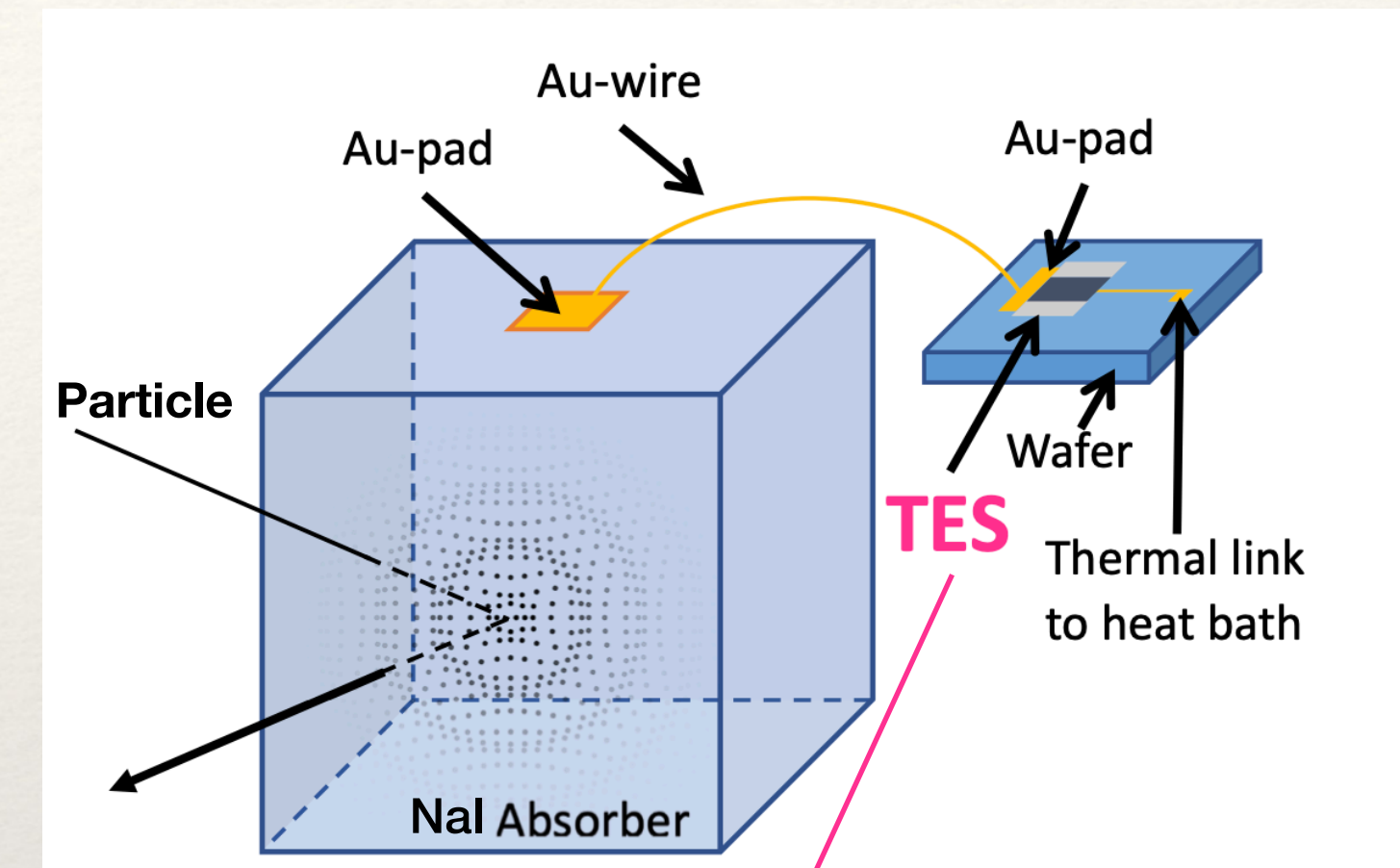
- ❖ Influence of threshold/efficiency
- ❖ Limited by exposure (annual modulation)
- ❖ Quenching Factor; amount of light observed for NR events
- ❖ Location?



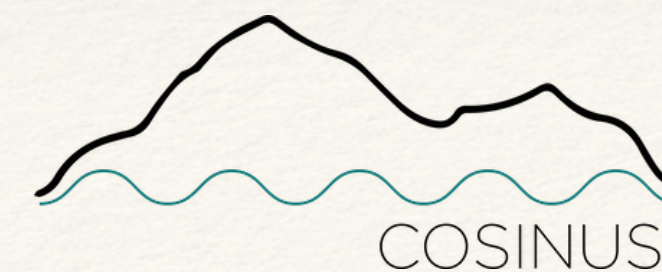
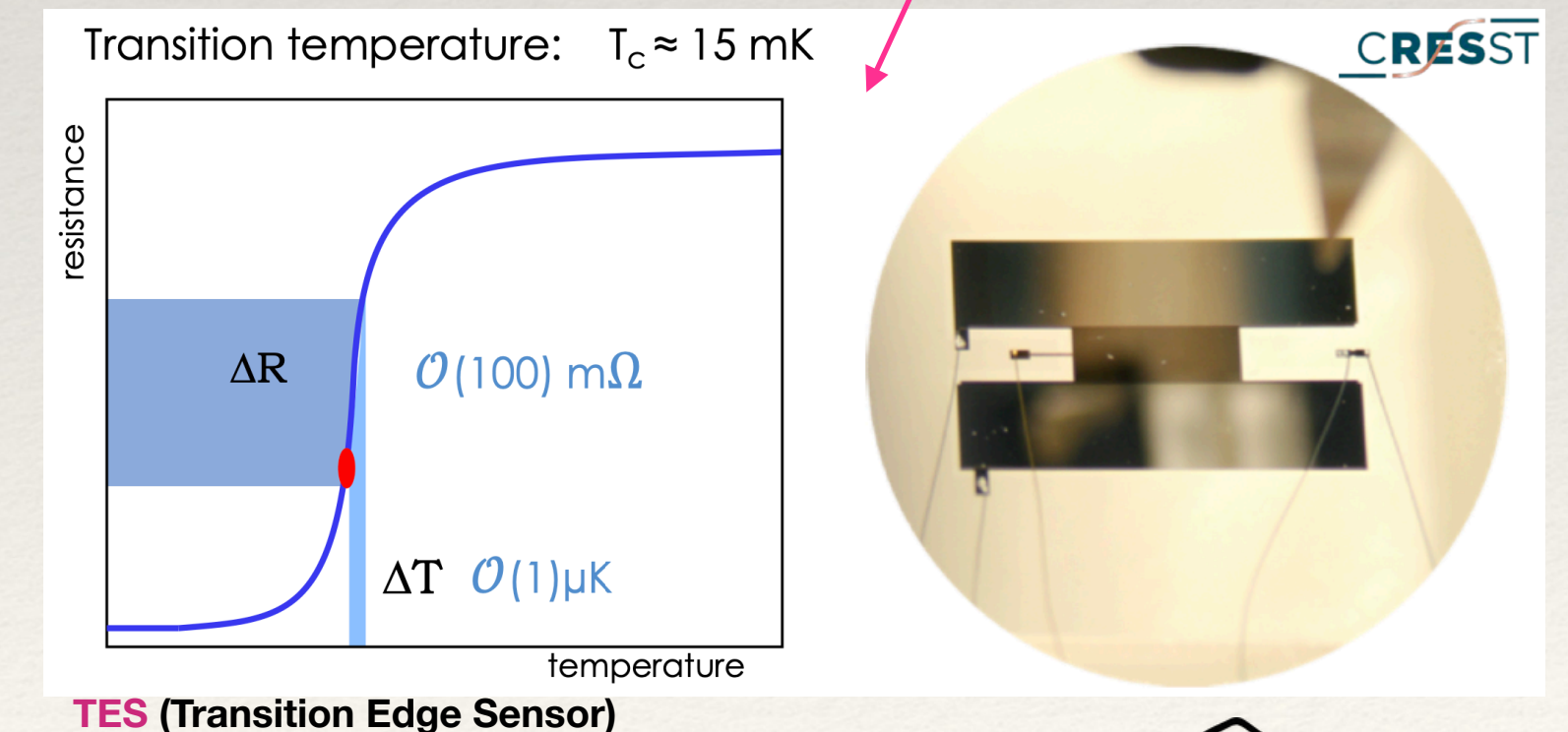
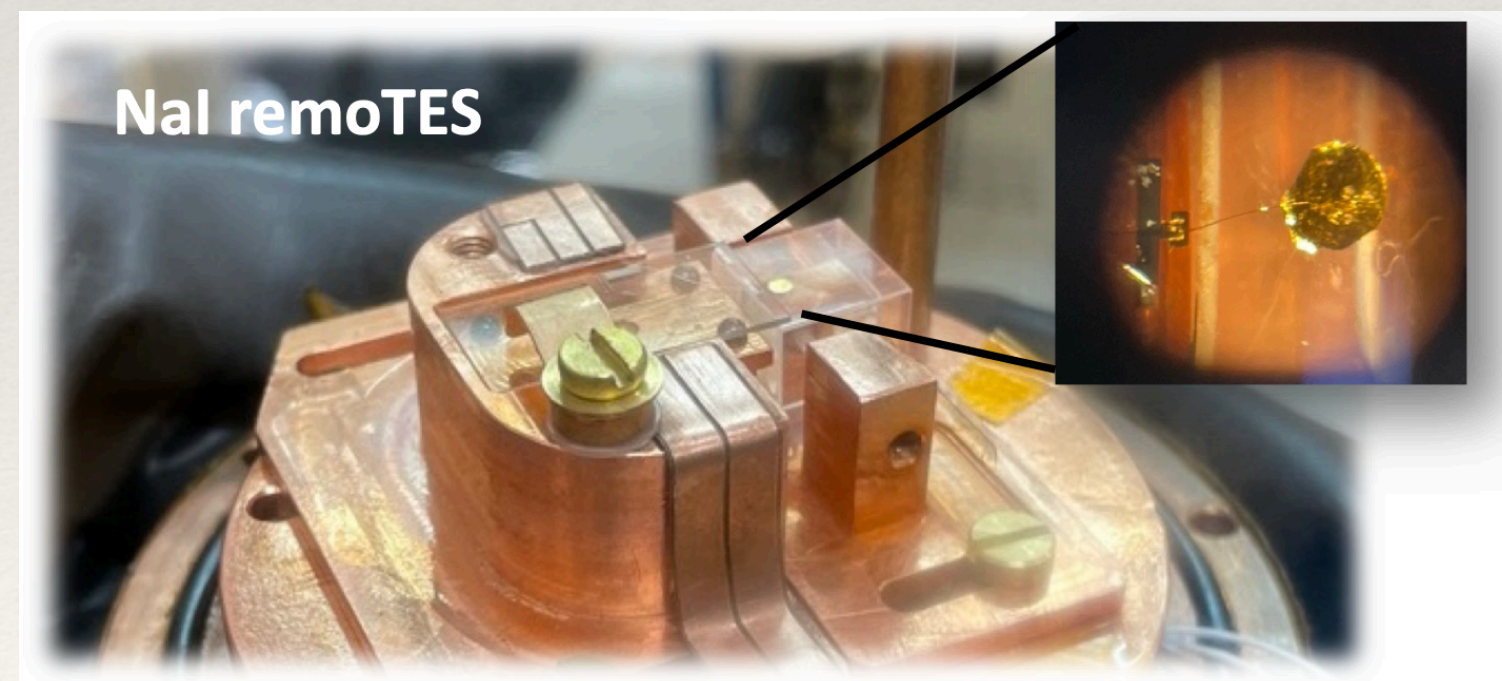
COSINUS Detectors



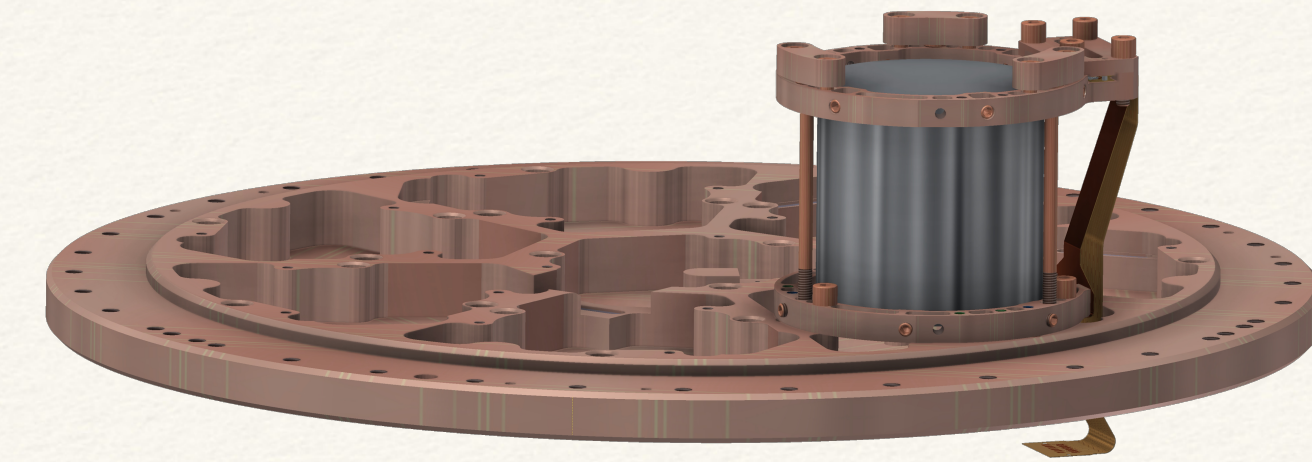
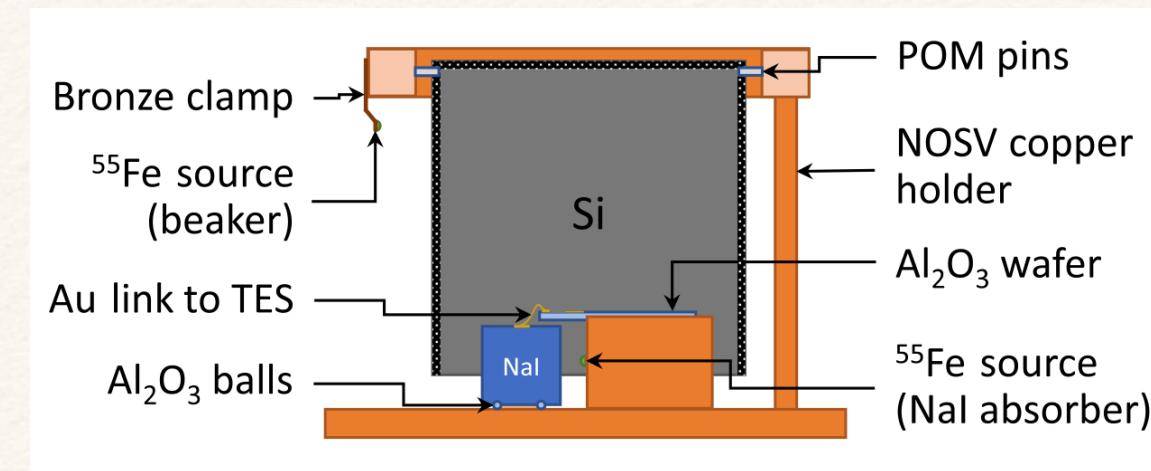
- ❖ Read out phonon signal in addition to scintillation light
-> NaI as cryogenic bolometer/calorimeter
- ❖ Use existing sensor technology & expertise (TES) from CRESST
- ❖ Modified for „difficult“ materials as NaI -> remoTES



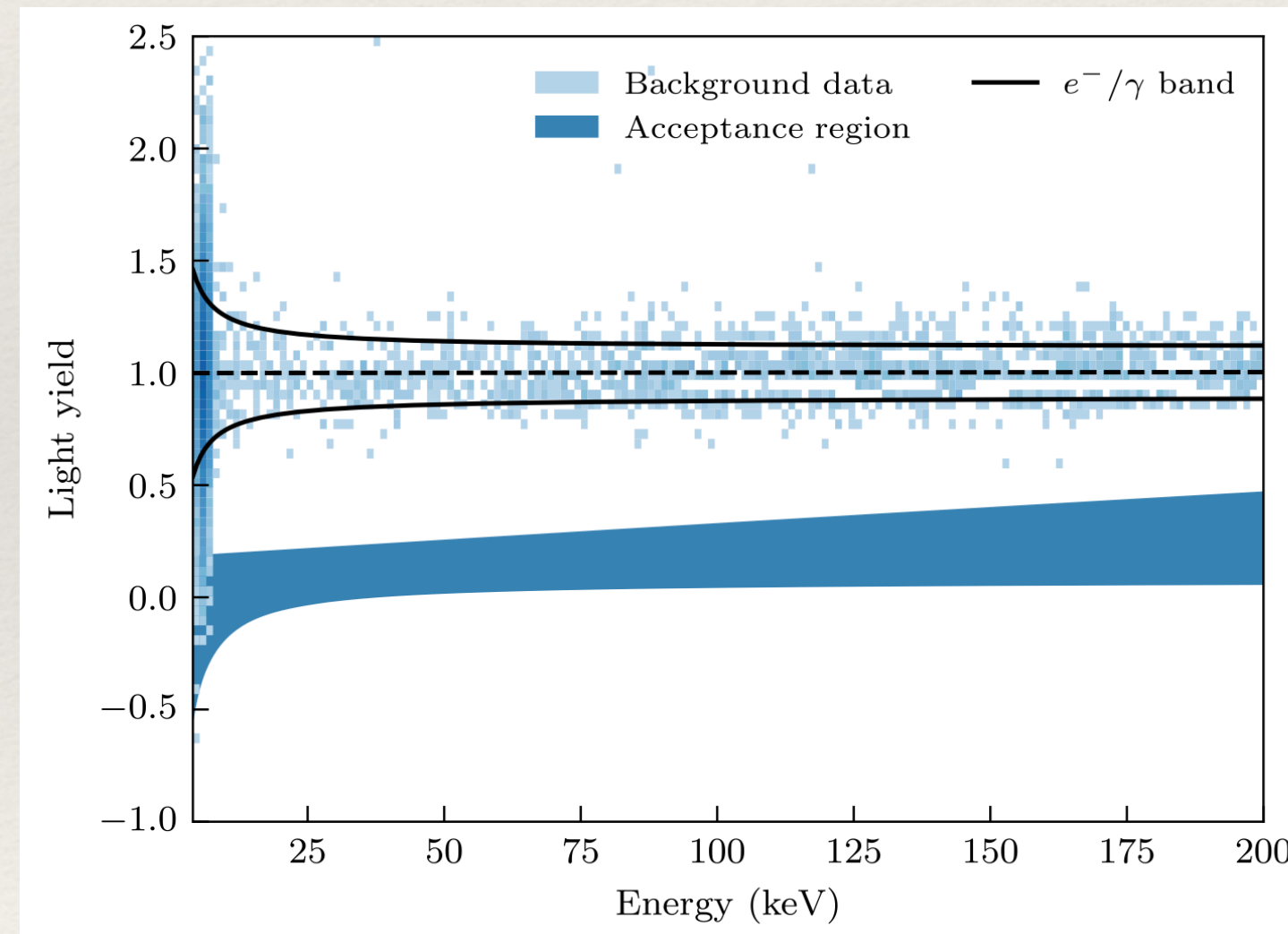
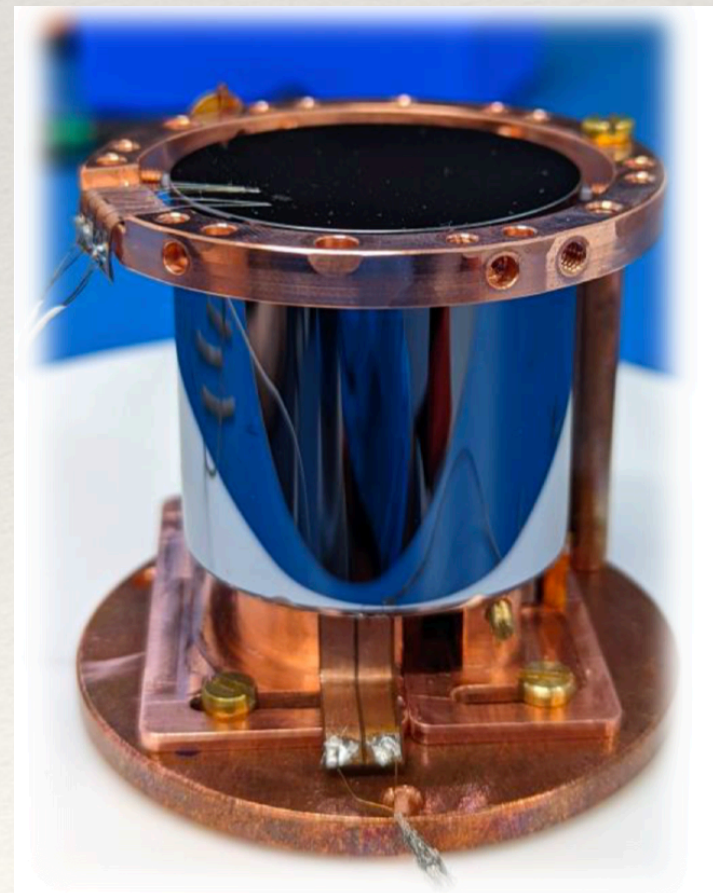
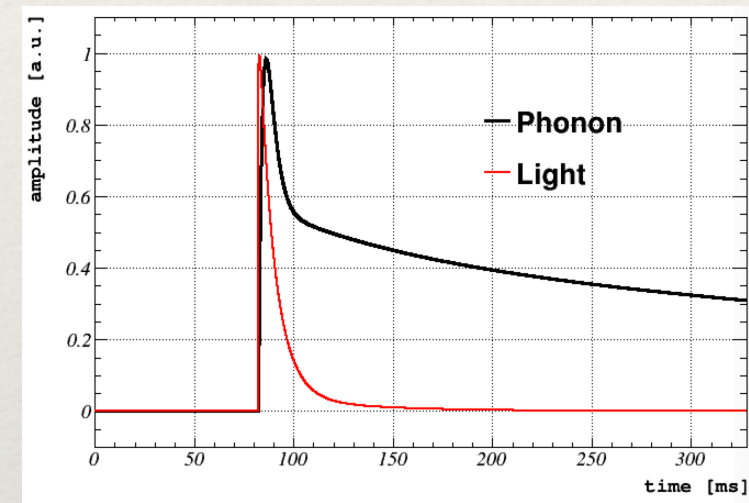
Angloher, G., et al. "First measurements of remoTES cryogenic calorimeters: easy-to-fabricate particle detectors for a wide choice of target materials." *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 1045 (2023): 167532.



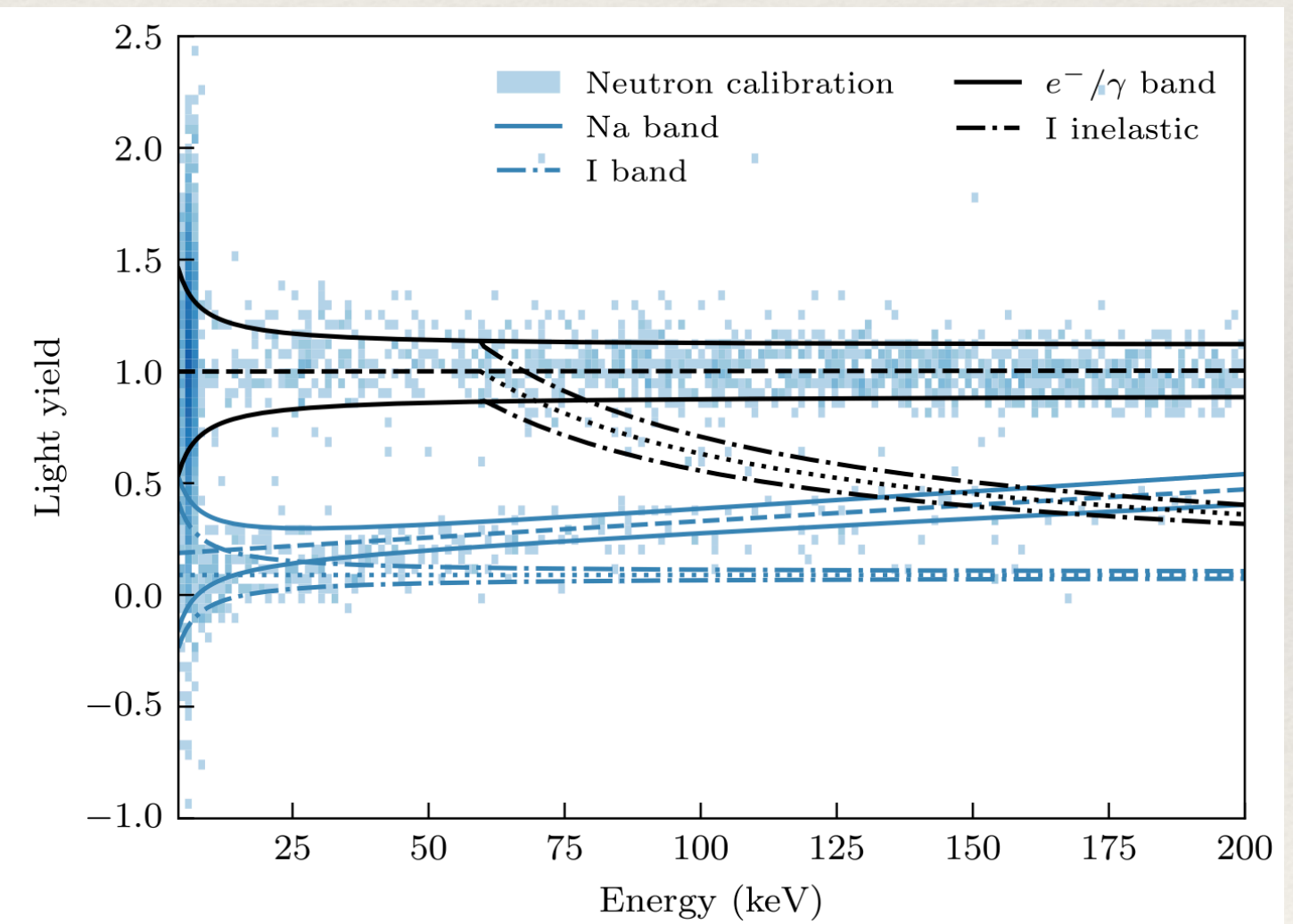
COSINUS Detectors



- ❖ Nuclear recoils from DM interactions produce **less scintillation light** than electron interactions („quenching“) -> **Identification of individual nuclear recoil events** (instead of modulation search)

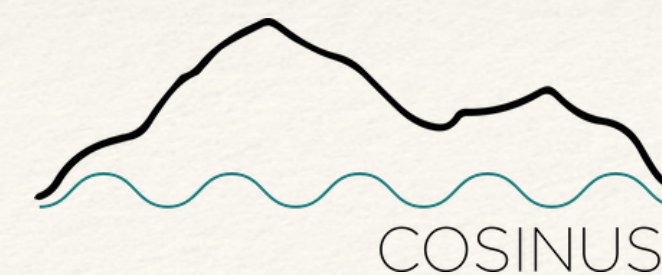


(background only)



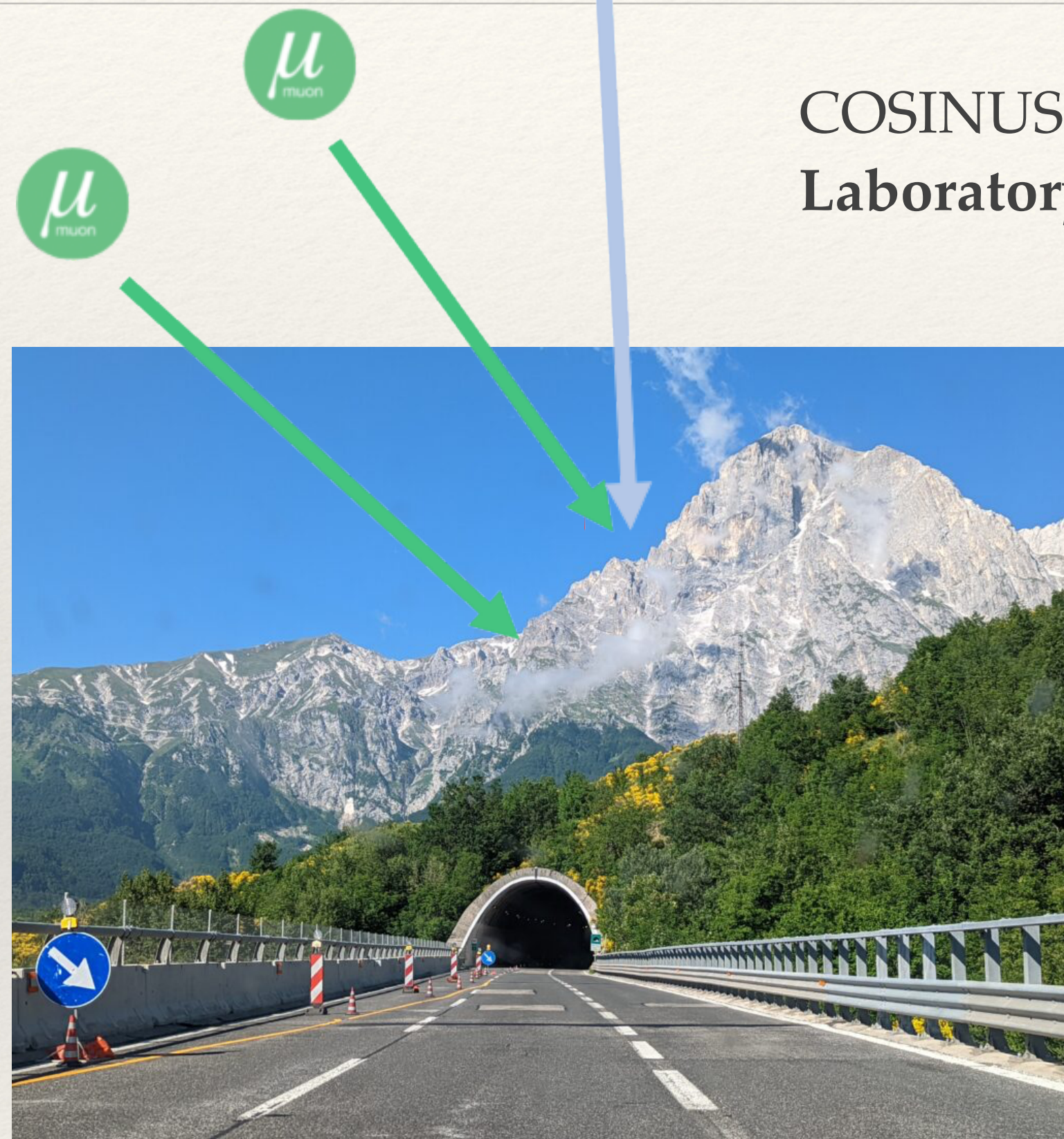
(with neutron source)

Angloher, G., et al. "Deep-underground dark matter search with a COSINUS detector prototype." Physical Review D 110.4 (2024): 043010.



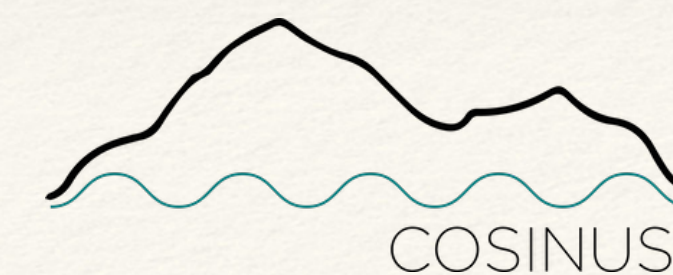
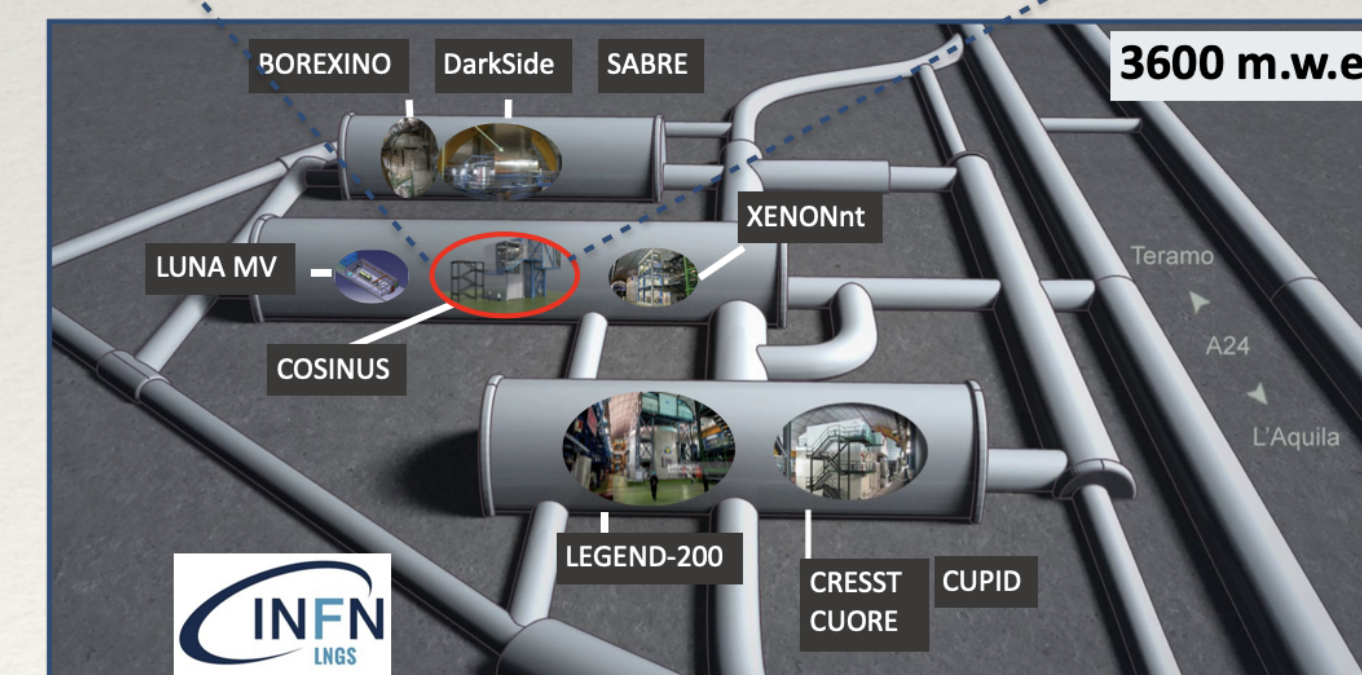
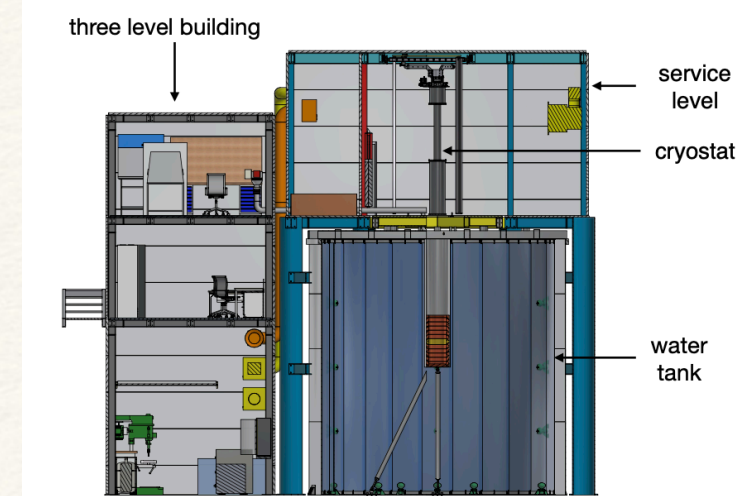
Going Underground

COSINUS Experimental facility at
Laboratory Nazionali del Gran Sasso

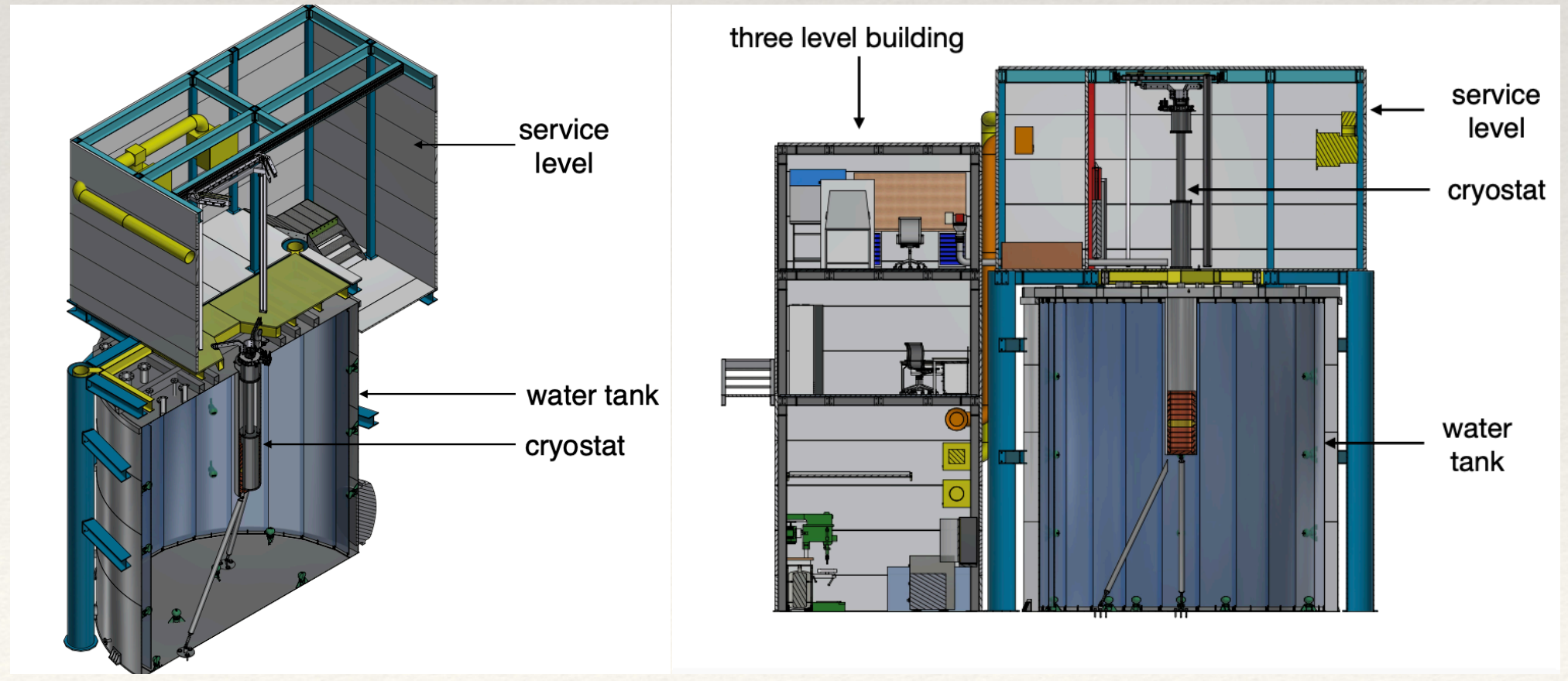


Featuring:

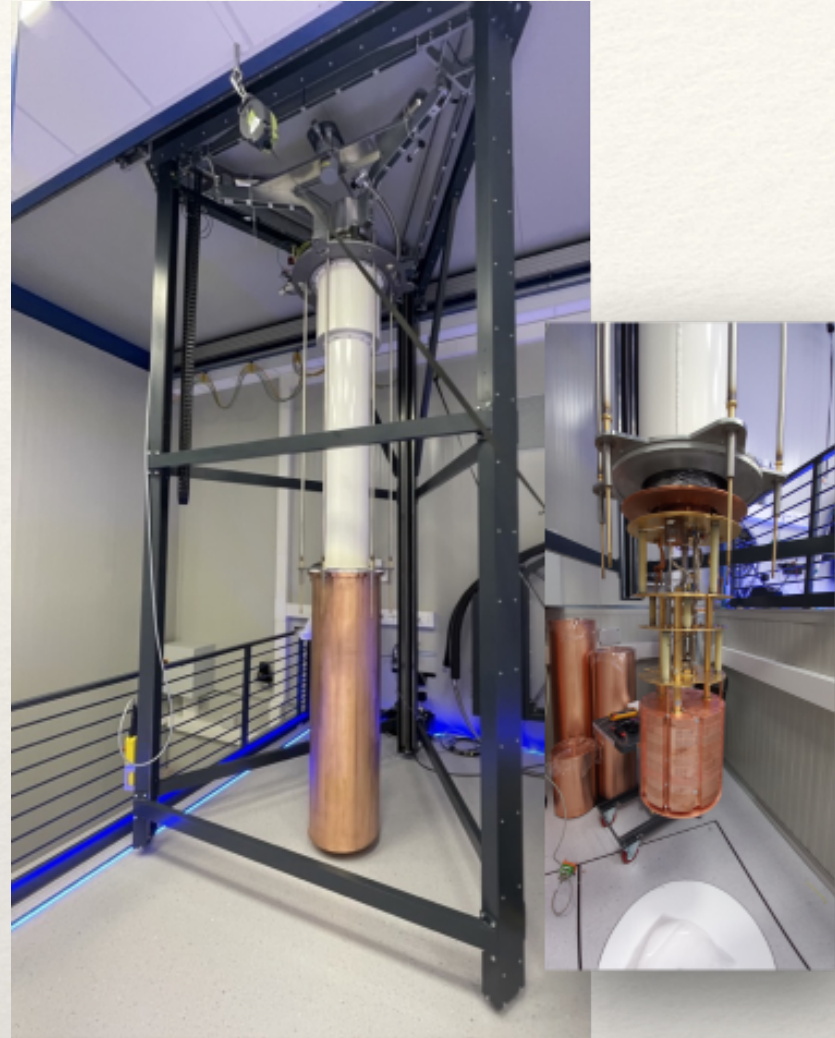
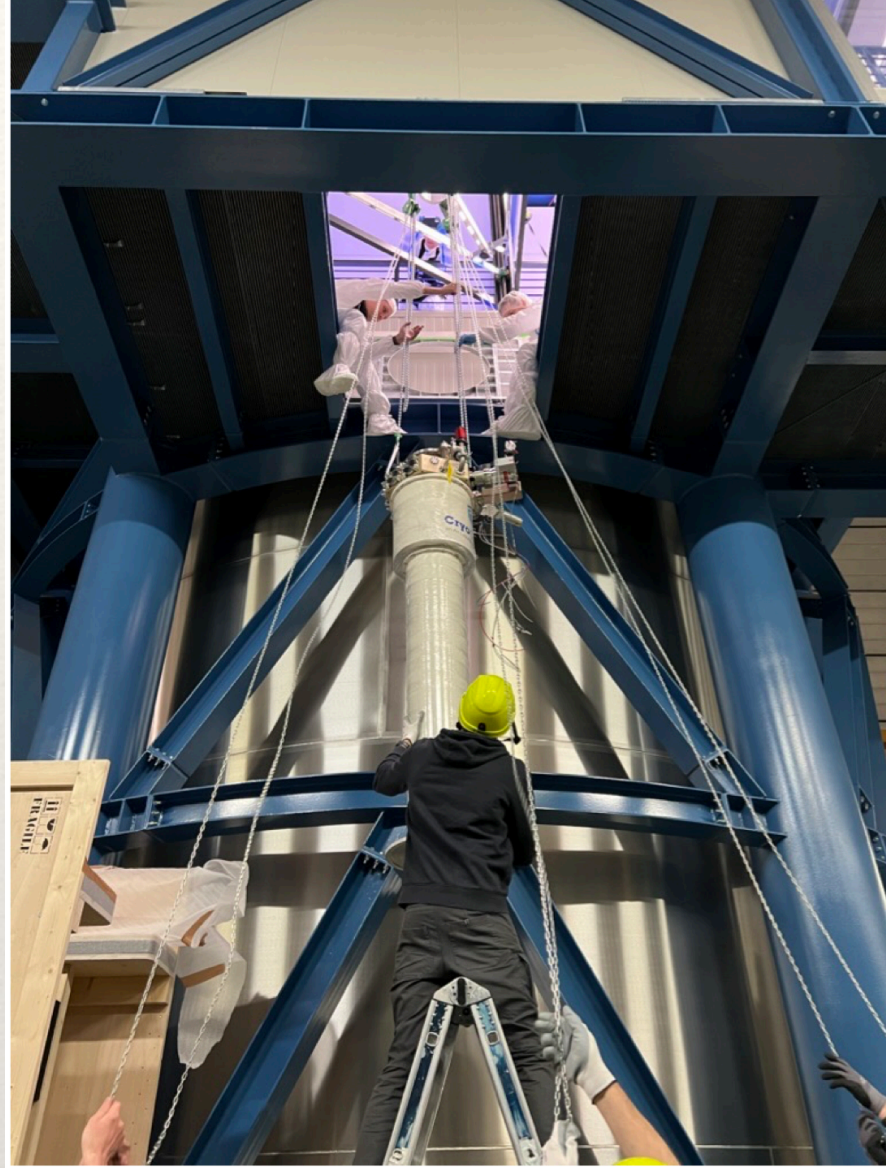
- ❖ 3600m w.e. overburden to shield cosmic radiation
- ❖ Water Cherenkov muon veto
- ❖ Dry dilution refrigerator (precooling via pulse tube)

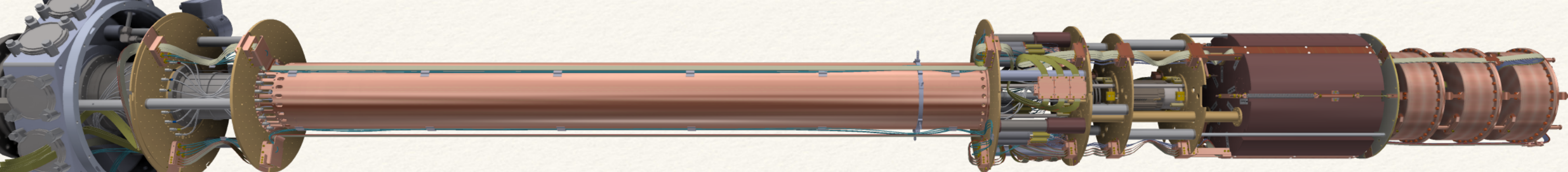


Experimental Setup at LNGS

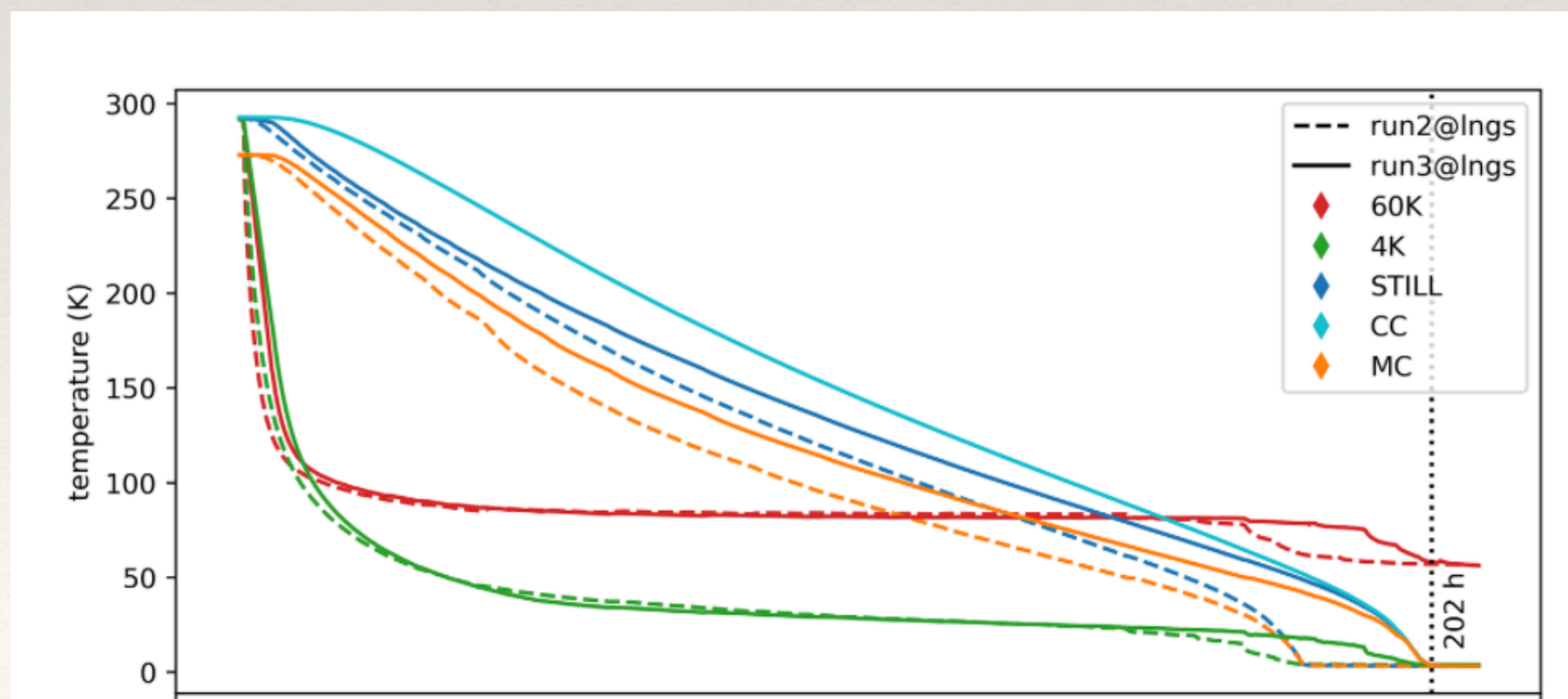
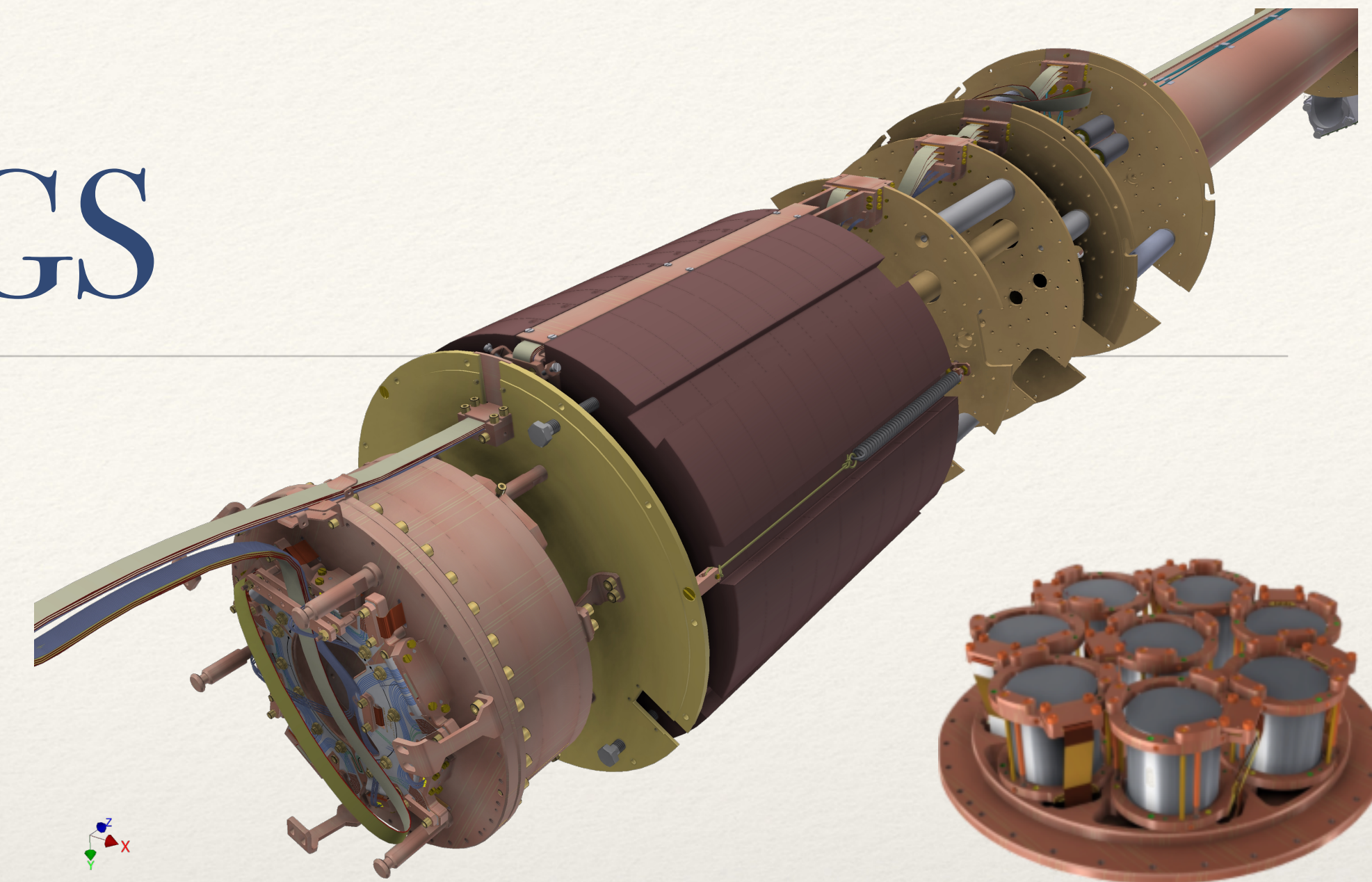


Experimental Setup at LNGS

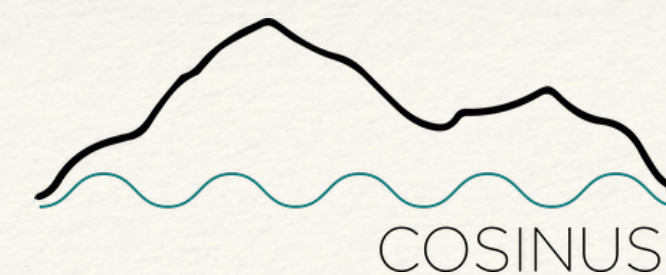




Cryogenic Facility at LNGS

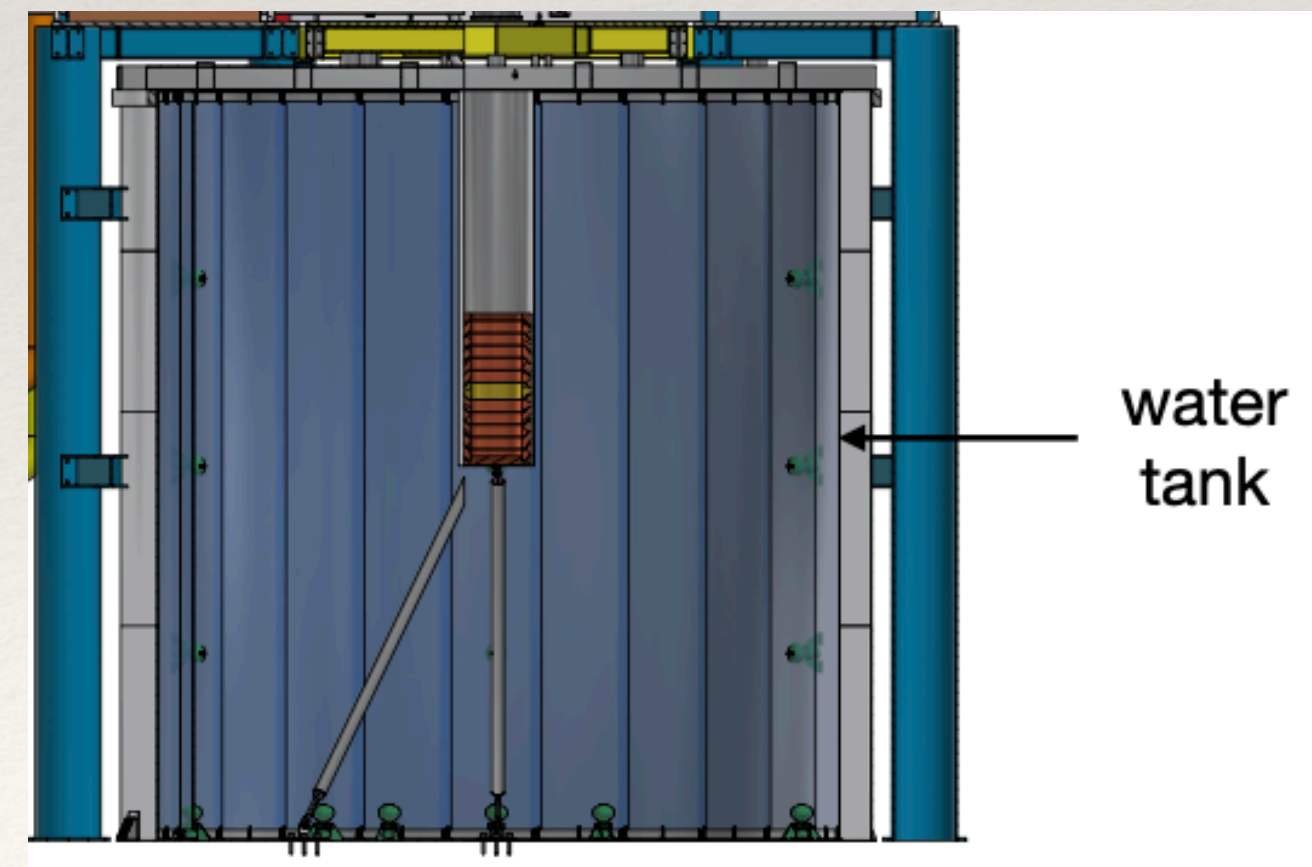


- ❖ Dry dilution refrigerator by Cryoconcept
- ❖ Reached base temperature of 9.4mK in March 2024
- ❖ Final commissioning step ongoing
- ❖ Currently at 9.6mK !



Cherenkov Muon Veto

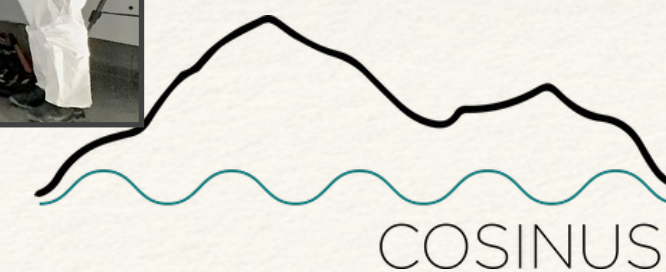
- ❖ Setup modelled & tested at MPP
- ❖ PMTs tested & alive after closing of tank
- ❖ Installed water purification system
- ❖ Will start filling end of this year / early next year



Rate of cosmogenic neutrons:

No veto: (3.5 ± 0.7) cts per (kg yr)

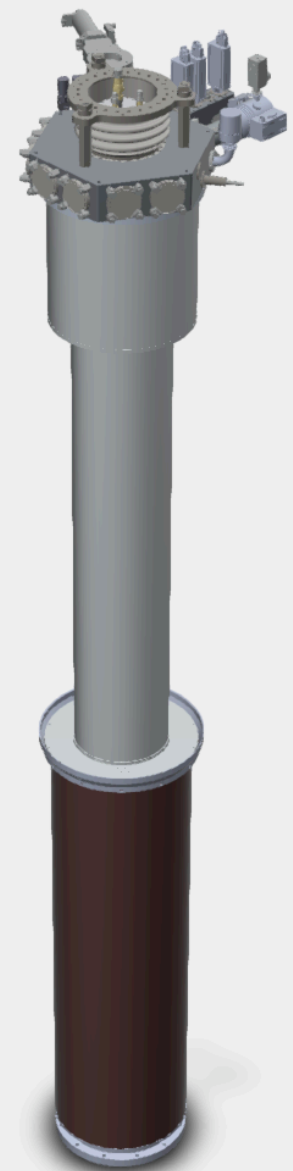
With veto: $<(0.30 \pm 0.02)$ cts per (kg yr)



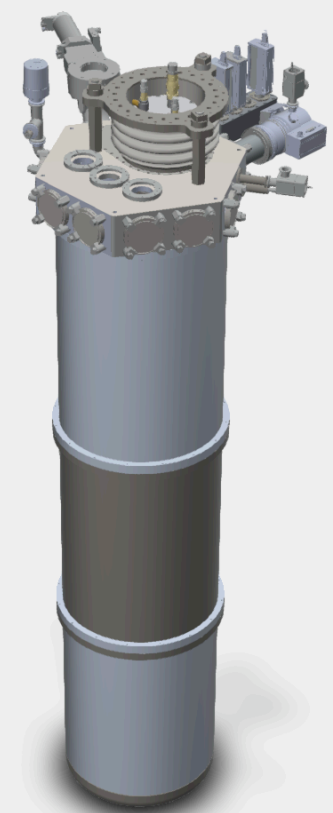
COSINUS Cryogenic Facility at MPP



LNGS system



MPP system



„GG“ cryostat in the old lab

- ❖ Cryostat delivered in July 2023
- ❖ Installed and operated before the move!
- ❖ Base temperature below 7mK

Move to Garching - February 2024

Jan 29



Feb 5

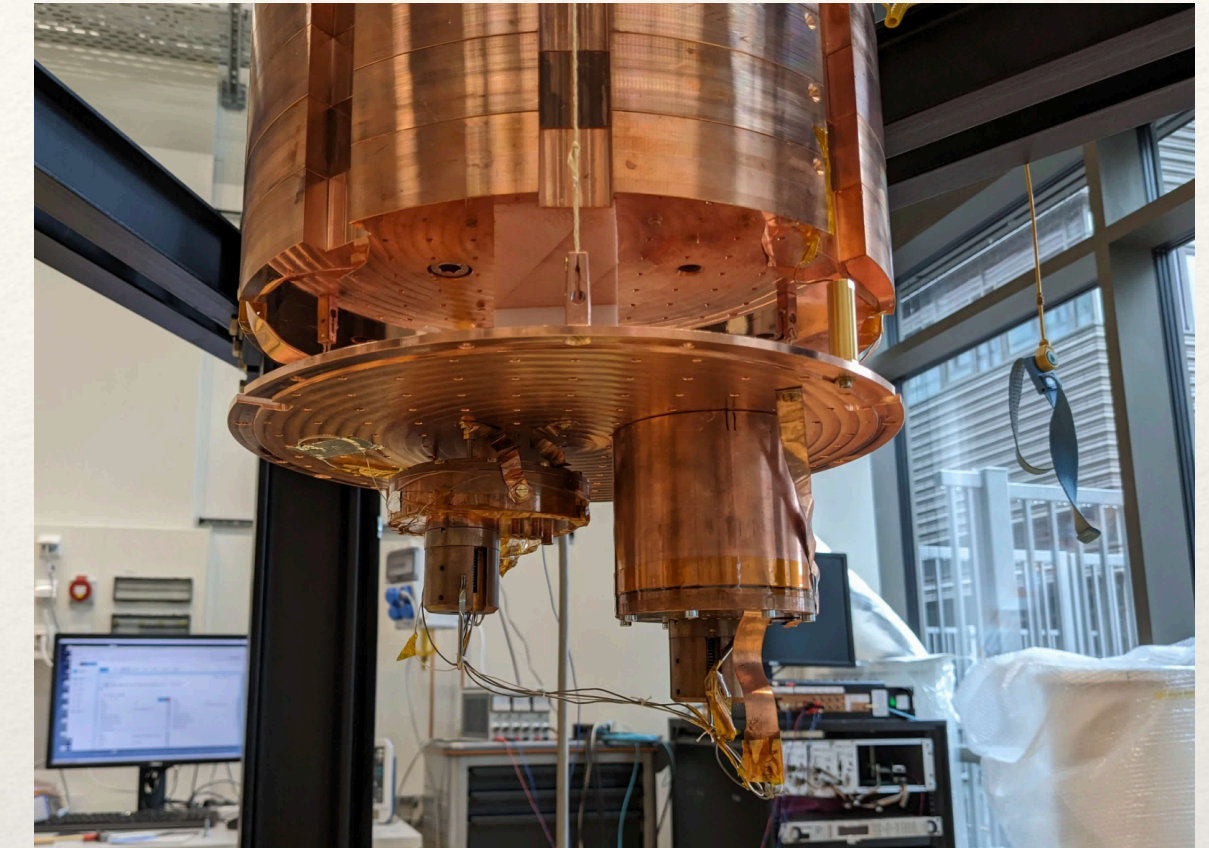
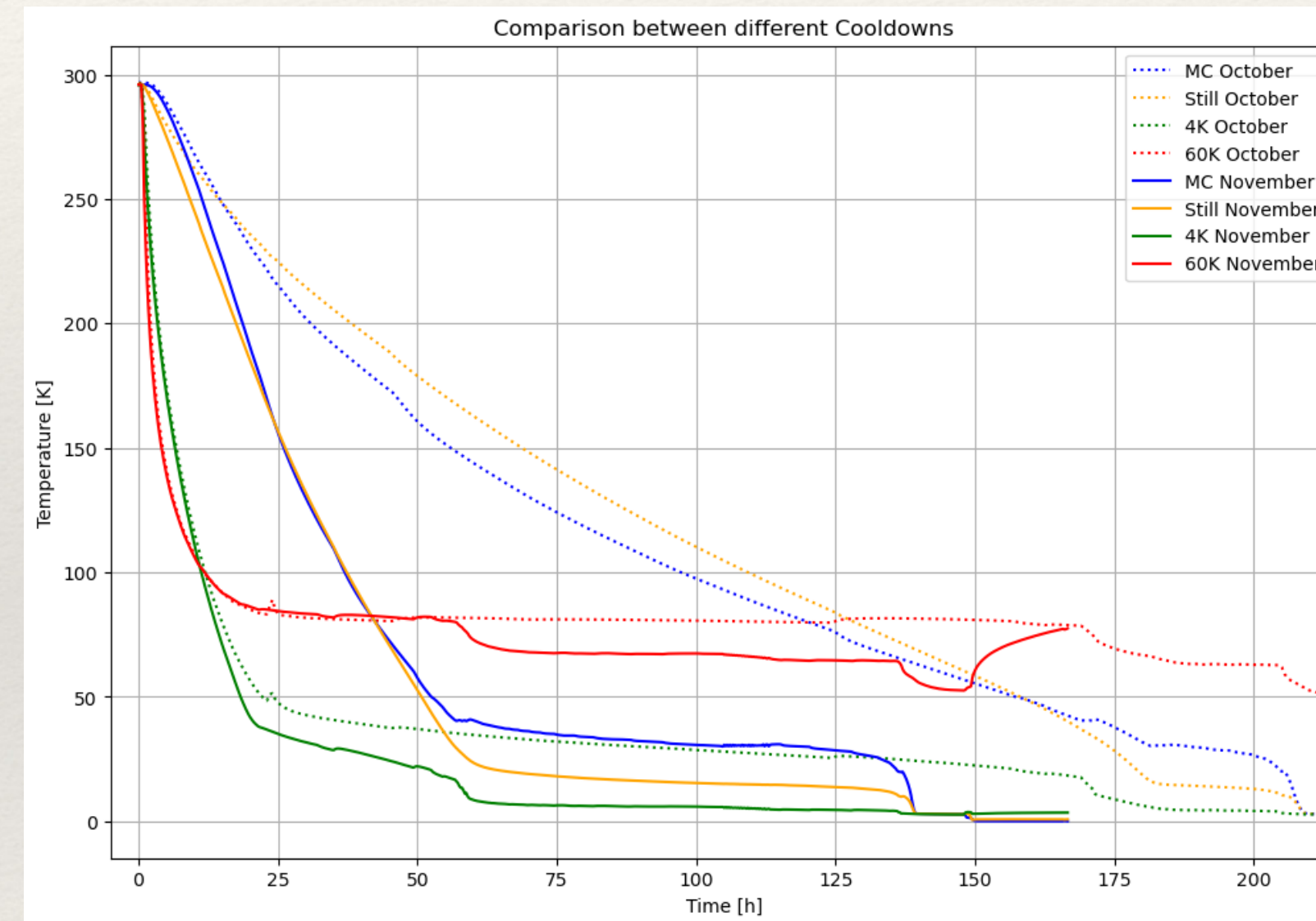


Feb 6



Operation in Garching

- ❖ COSINUS Cryostat at MPP fully commissioned!
- ❖ Move of the lab completed quickly
- ❖ Base temperature below 6mK
- ❖ Further optimizing noise conditions (vibration decoupling)

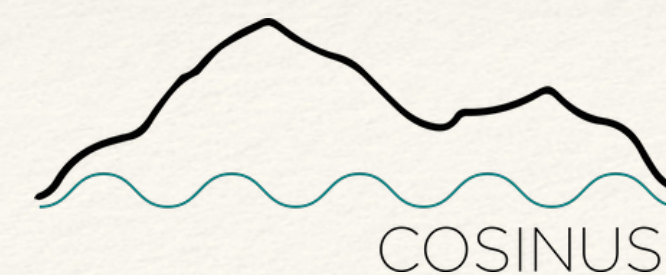
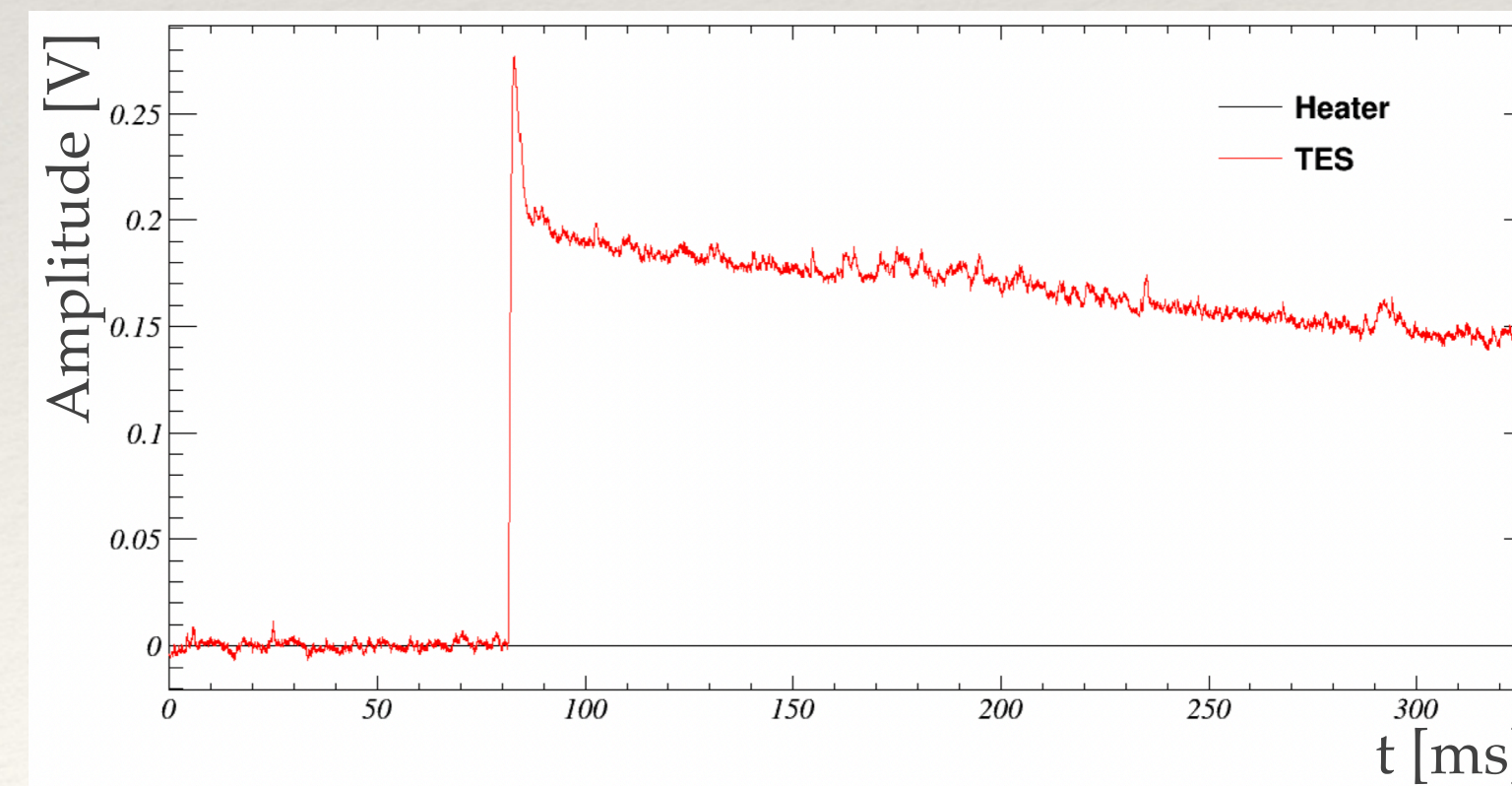
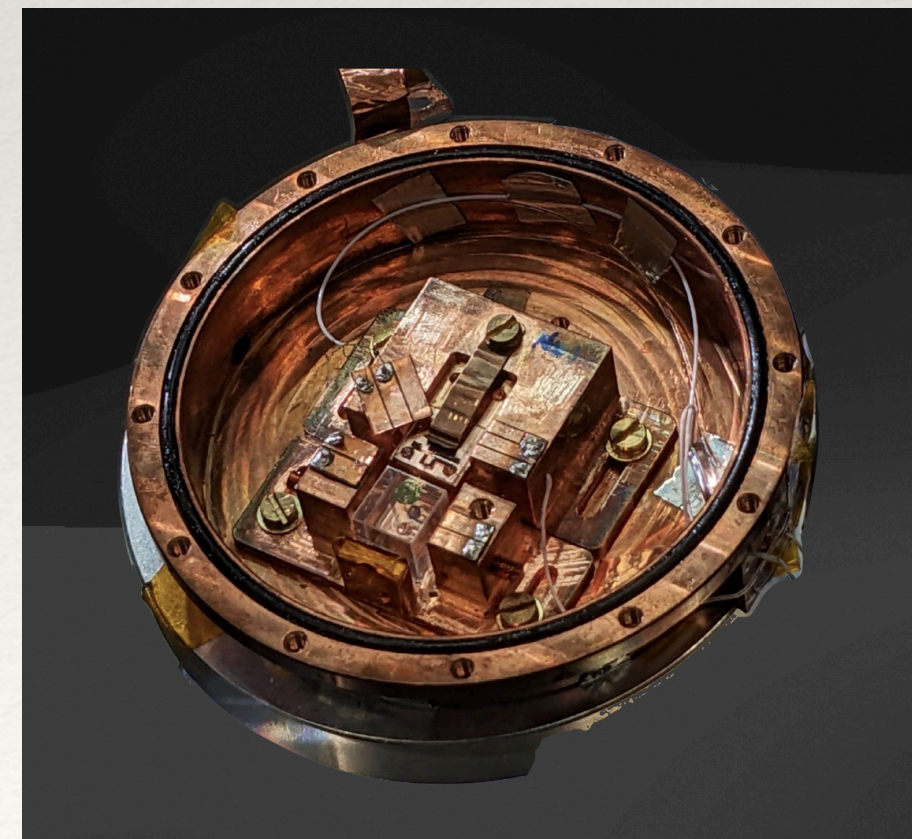
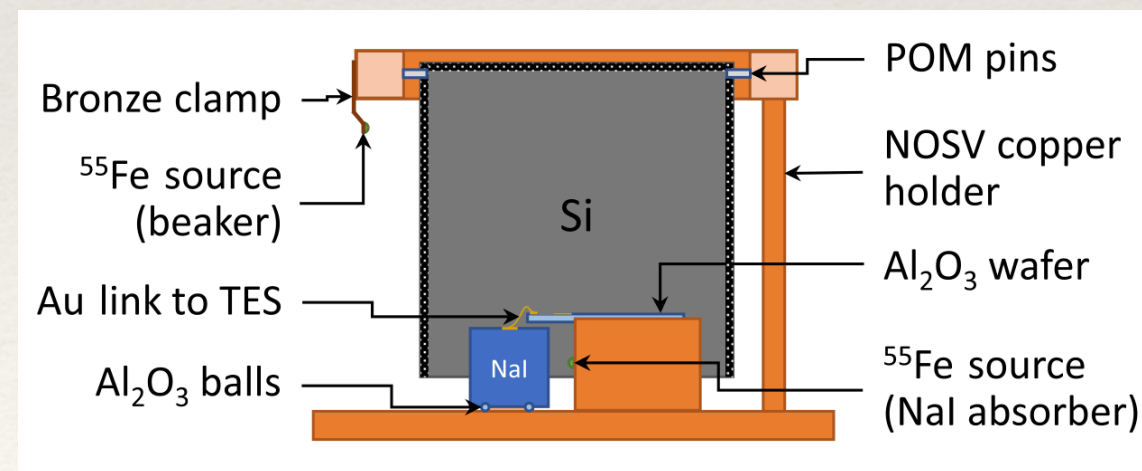
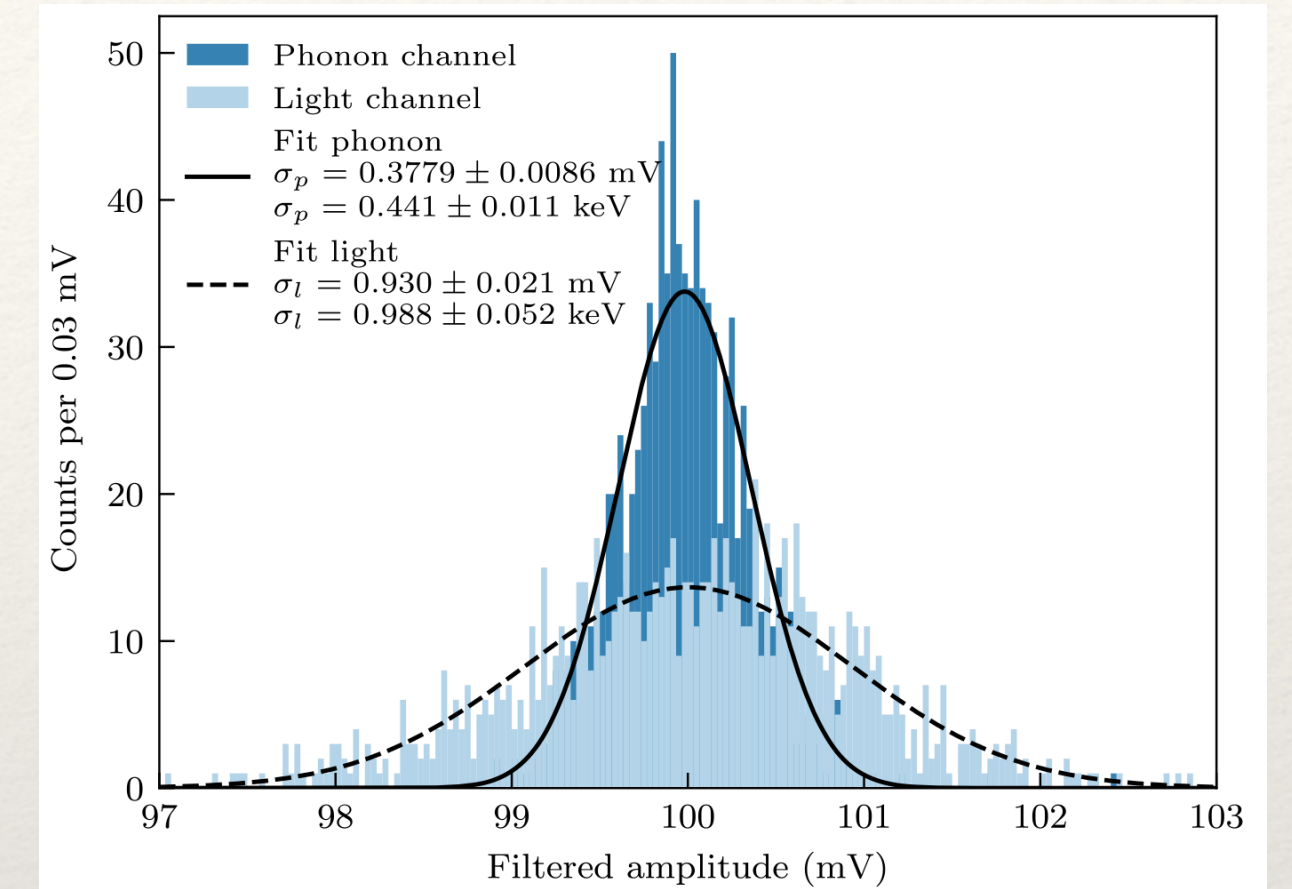


-> Successful measurements with new prototypes!

Prototype Results

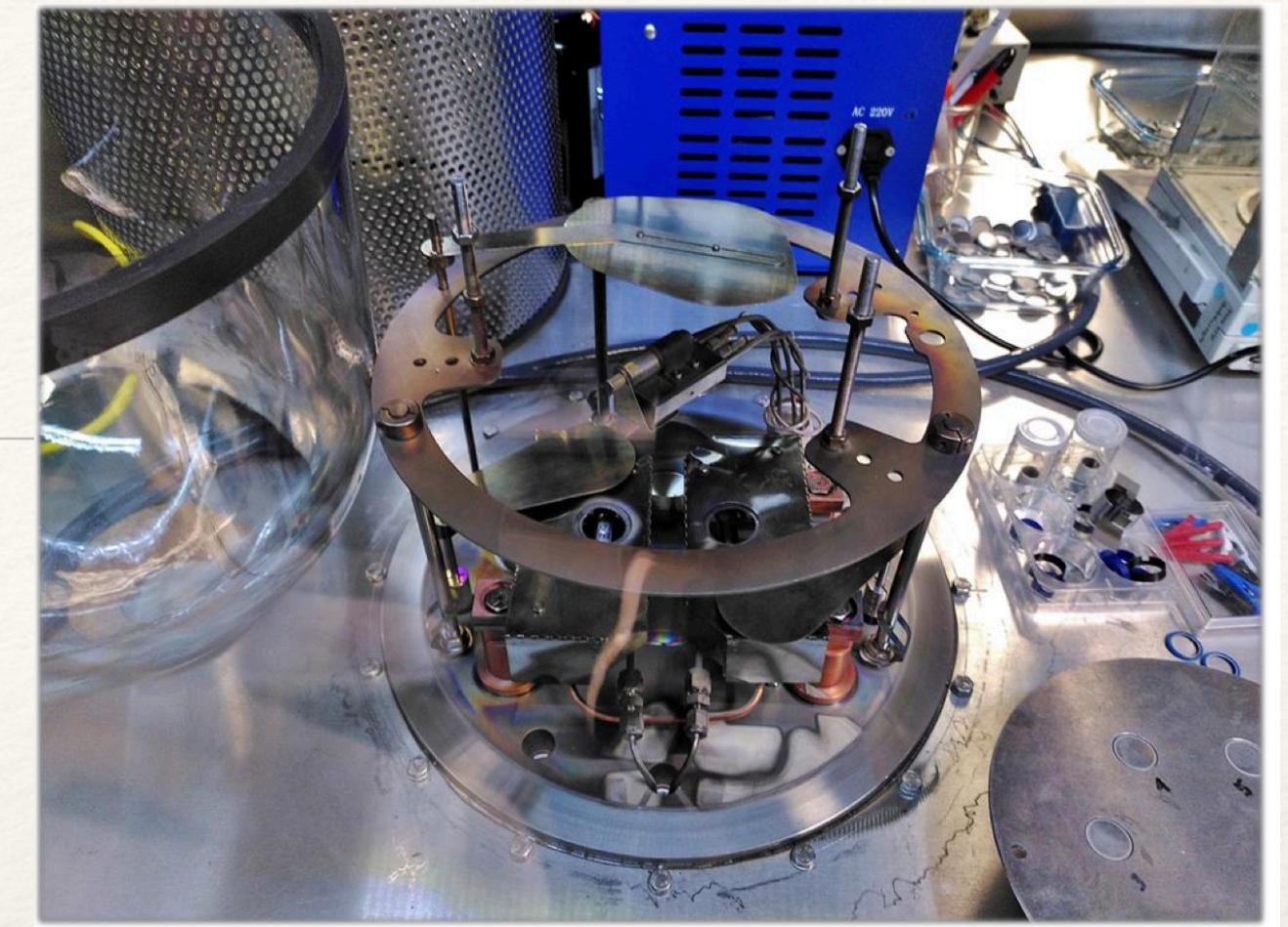
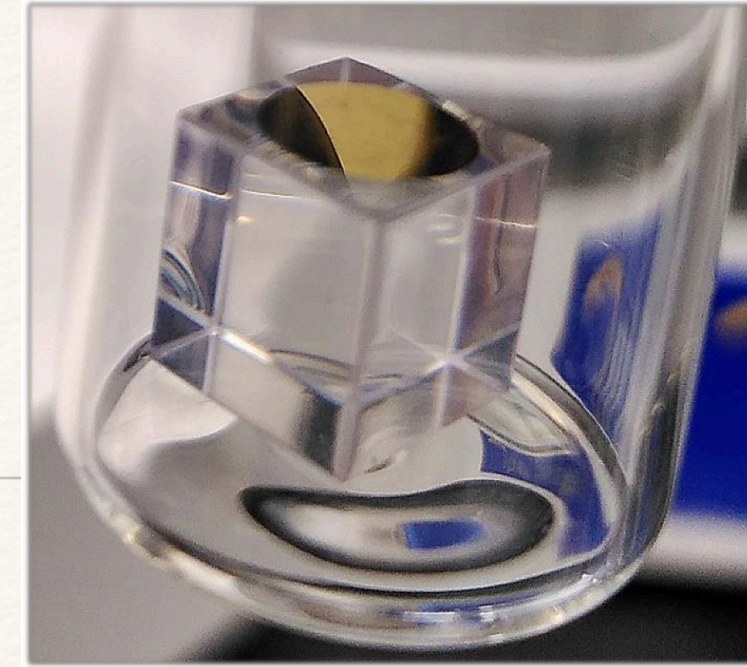
Angloher, G., et al. "Particle discrimination in a NaI crystal using the COSINUS remote TES design." *Physical Review D* 109.8 (2024): 082003.
 Angloher, G., et al. "Deep-underground dark matter search with a COSINUS detector prototype." *Physical Review D* 110.4 (2024): 043010.

- ❖ Previous measurements with Si and TeO2 absorbers to optimize detector design
- ❖ Series of measurements with Si beaker light detectors
- ❖ Published results from two NaI prototypes measured in 2022
- ❖ Resolution improved from 2keV to 400eV with 3.7g crystal
- ❖ Recent prototype: resolution ~100eV with 3.7g

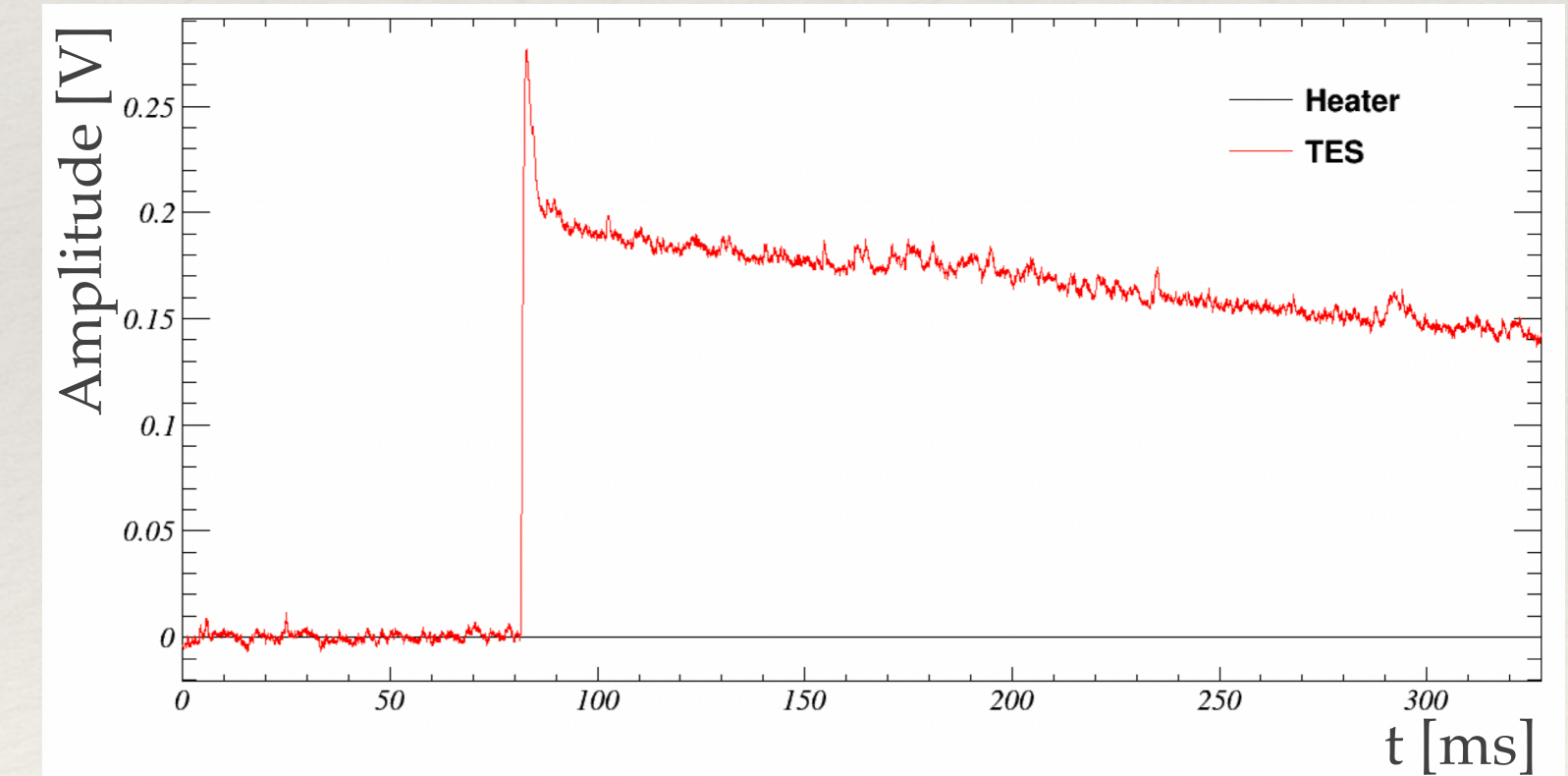


NaI + Evaporated Au

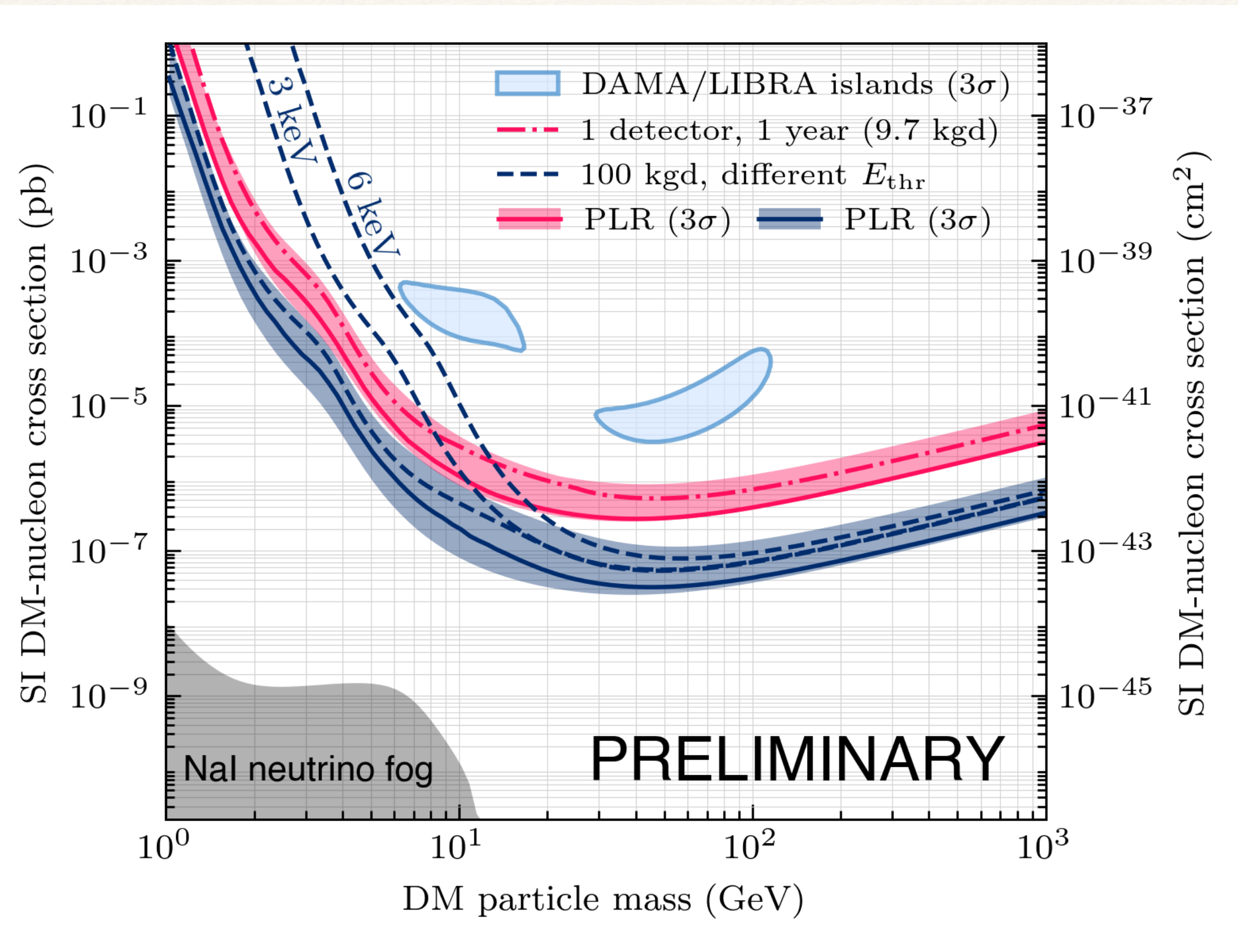
Tetra evaporation machine @TUM



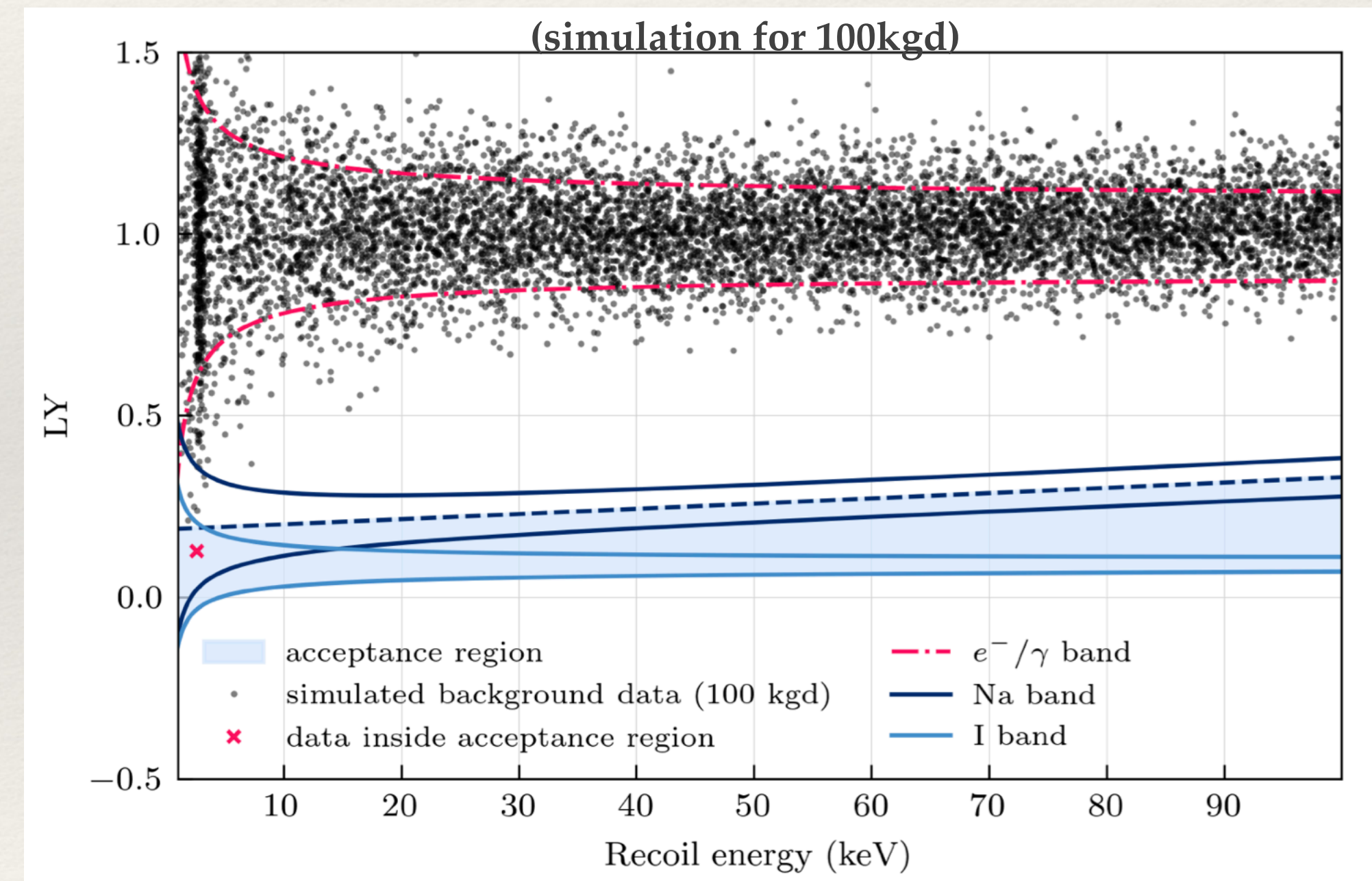
- ❖ Reproducible process
- ❖ Fabrication of thin films possible
- ❖ Recent prototype: resolution $\sim 100\text{eV}$ with 3.7g



Physics Reach of COSINUS



- ❖ Advantage through low energy threshold and event-by-event background discrimination
- ❖ First phase: 10 modules with 30g of NaI each



-> Will be featured in Nature collection about direct DM search

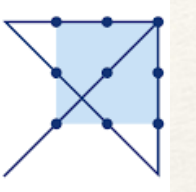
R&D Projects & Synergies

- ❖ Search for Dark Matter-Electron scattering with cryogenic light detectors

Zema, V., et al. "Dark matter-electron scattering search using cryogenic light detectors."

Physical Review D 110.12 (2024): 123012.

Klaus Tschira
Stiftung



- ❖ Support of the COSINUS & CRESST DAQ infrastructure by the „Beratende Ausschuss für EDV-Anlagen in der Max-Planck-Gesellschaft“ (BAR)

MAX PLANCK
GESELLSCHAFT



- ❖ Planned collaboration with the HLL (HalbLeiterLabor) for TES production



MAX PLANCK
HALBLEITERLABOR

- ❖ Measurement of COSINUS NaI crystals in a neutron beam facility at Triangle Universities National Laboratory (TUNL)



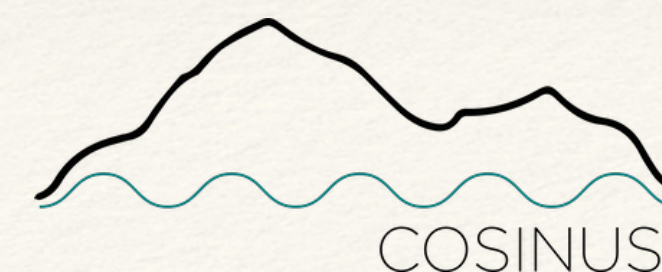
- ❖ CRYOCLUSTER group of experiments (CRESST, COSINUS, NUCLEUS)



- ❖ Collaboration with groups at TUM for measurements, DAQ testing & prototype preparation



- ❖ Increasing importance of cryogenic facilities & detectors with respect to quantum computing applications



COSINUS Group at MPI Physics

Support from CRESST



Federica Petricca
(Senior scientist)



Franz Proebst
(Senior scientist)



Michele Mancuso
(Staff scientist)

Lead: K. Schäffner (supported by MPRG program, recently appointed by Lise-Meitner-Exzellenzprogramm)

Postdocs: Vanessa Zema*, Maximilian Hughes, Martin Stahlberg

PhD students: Moritz Kellermann, Mukund Bharadwaj, Clemens Dittmar, Kumrie Shera

Master students: Maximilian Gapp, Kilian Heim, Sarah Braun, Lutz Ziegele

Working students: Elisa Gaido*, Pablo Figueroa Falla*, Henrik Ansorge

Part time: K. Ackermann, G. Angloher, T. Frank

*funded by Klaus Tschira foundation

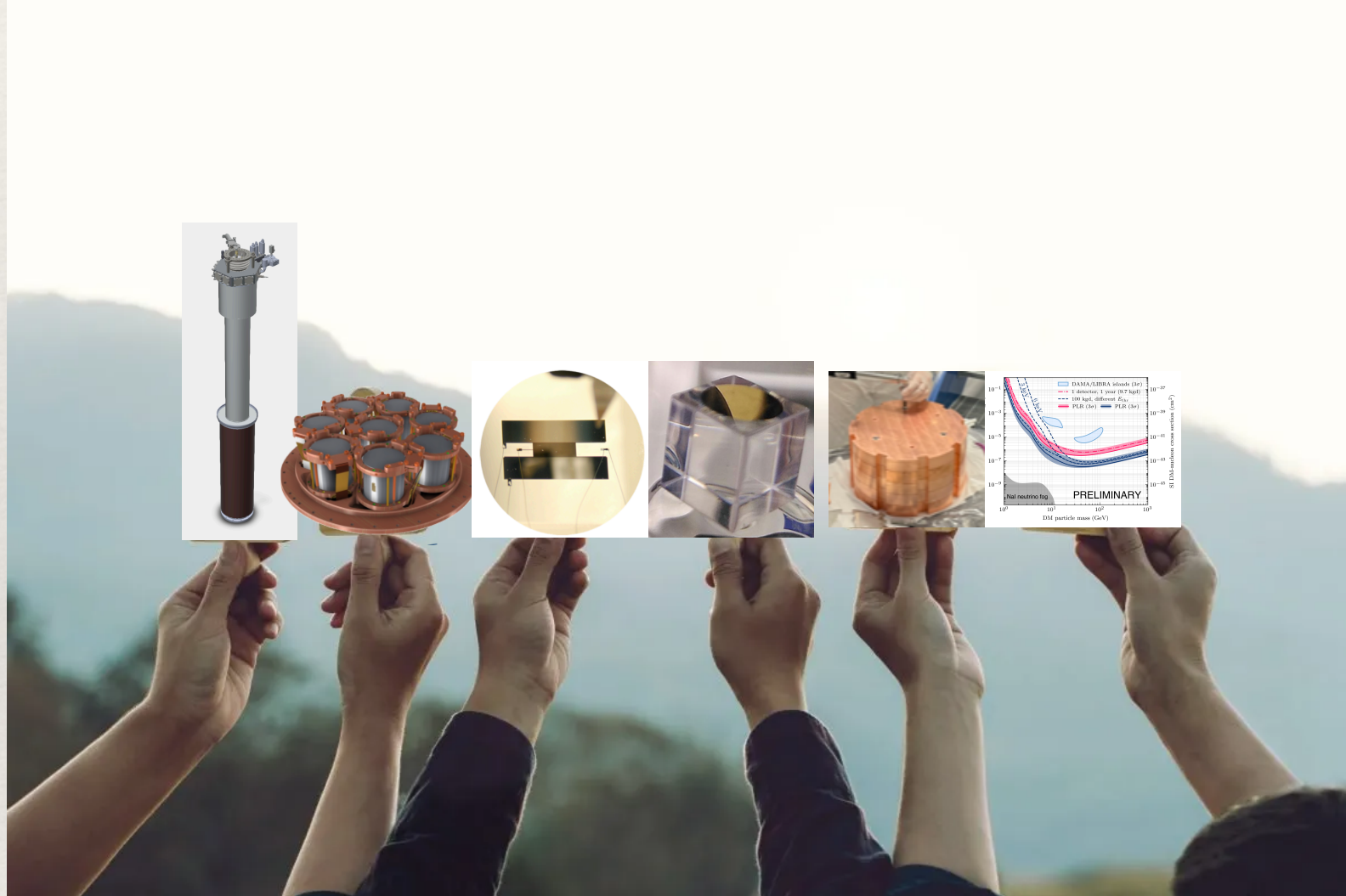
+ A lot of support from everyone at the institute

(Administration, workshops, PR team, IT, Haustechnik ...)

-> THANK YOU! <-

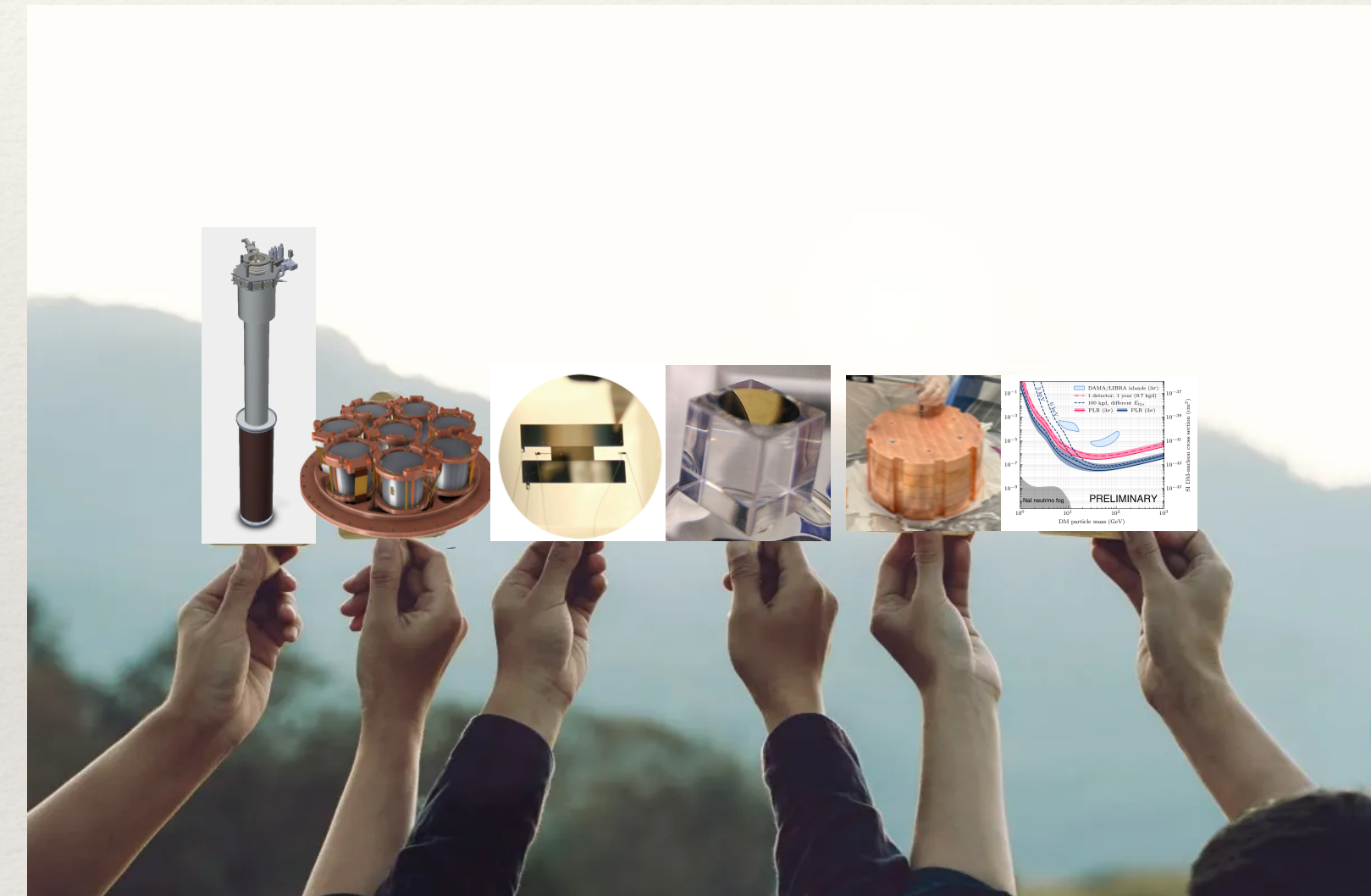
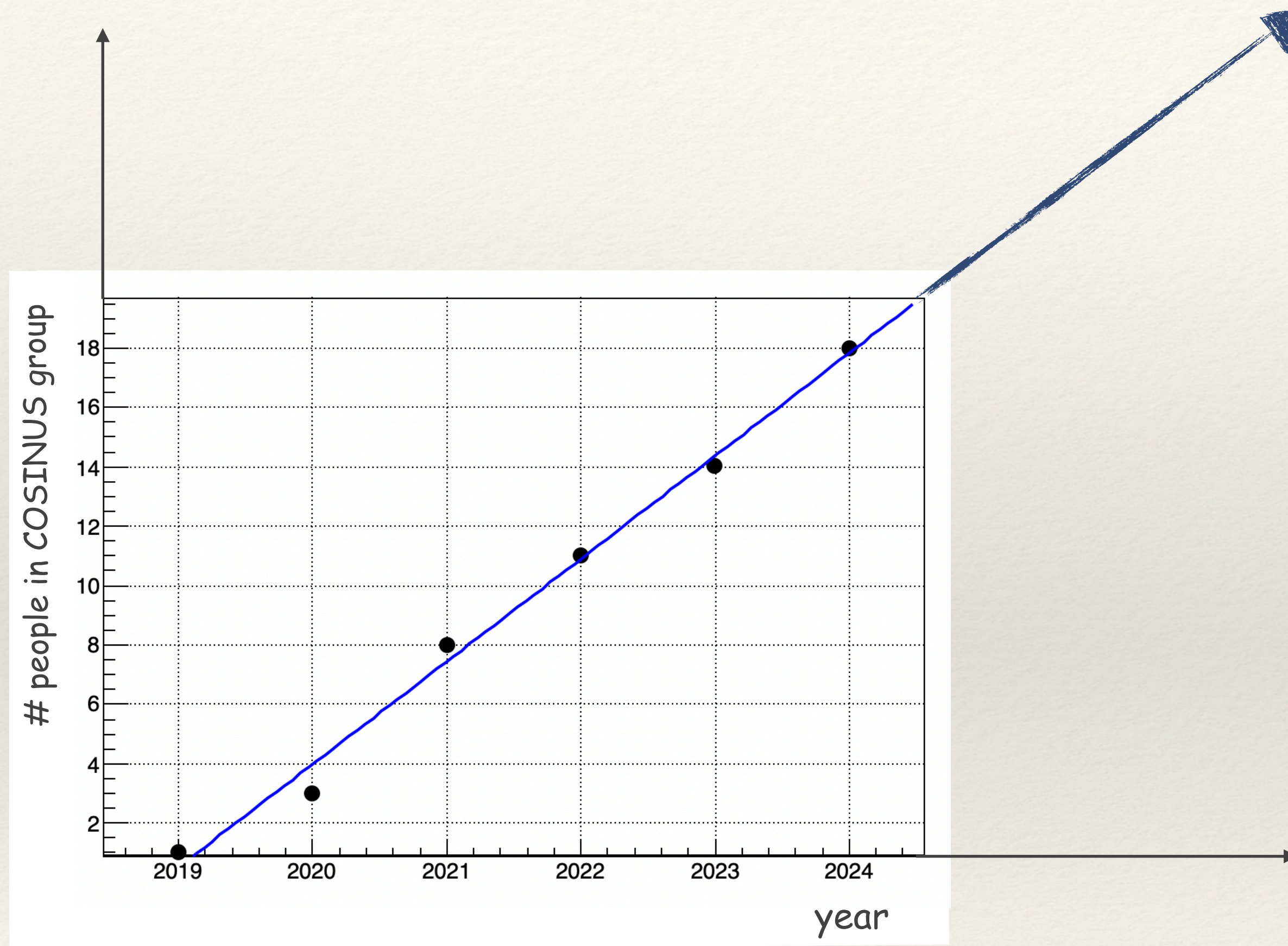


Summary & Outlook

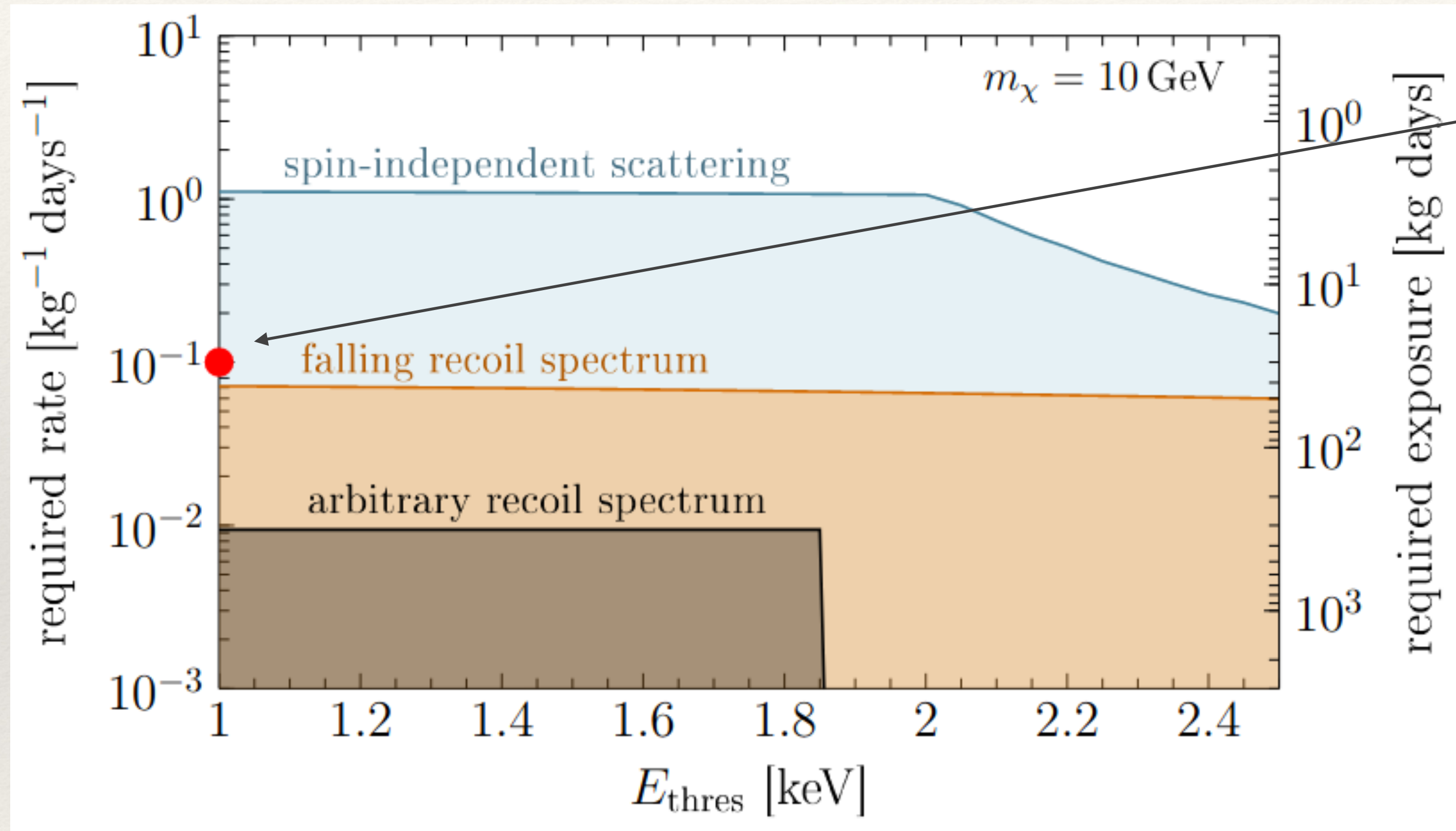


- ❖ COSINUS experimental facility at LNGS completed
- ❖ Final commissioning steps ongoing
- ❖ Promising results from detector prototypes
- ❖ Preparation of final detectors ongoing
- ❖ Datataking early-mid 2025 (!)
- ❖ Many R&D projects and interconnections in COSINUS group

Thank you for your attention!



Backup: Physics Reach, MI comparison



Kahlhoefer, Felix, et al. "Model-independent comparison of annual modulation and total rate with direct detection experiments." *Journal of Cosmology and Astroparticle Physics* 2018.05 (2018): 074.

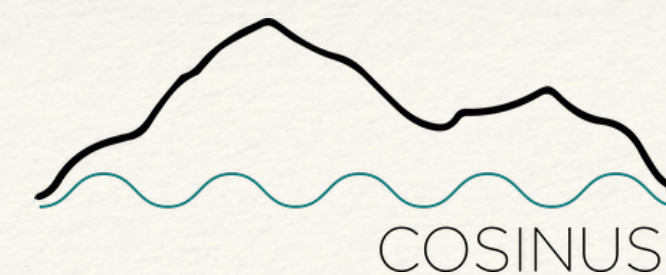
Run 1: 2025-2026

- 8 detector modules
- 30 g NaI

Increasing exposure & lowering threshold allows
model-independent (i.e. halo-independent)
 comparison to DAMA / LIBRA

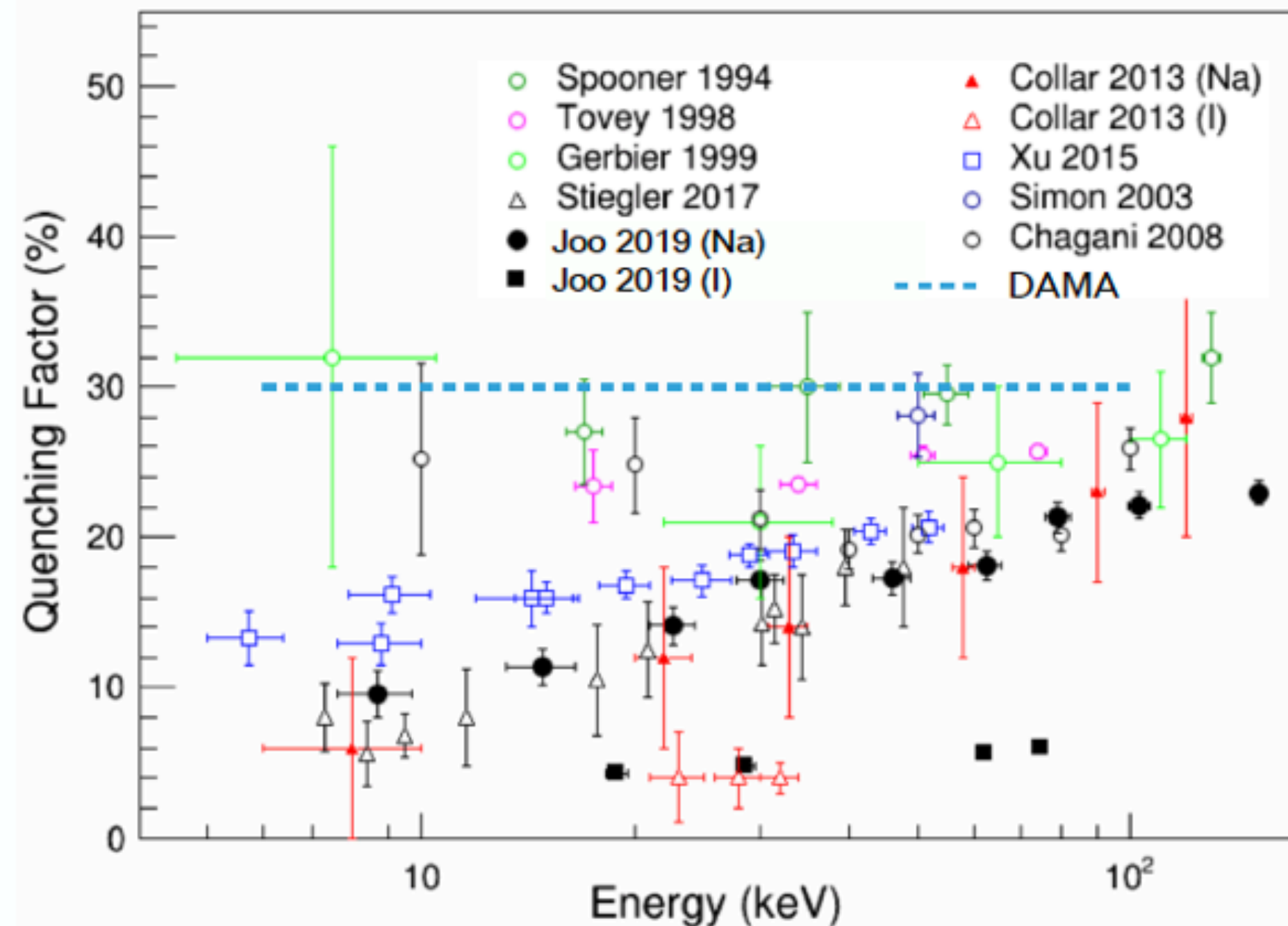
-> exclusion of **arbitrary recoil spectrum**

→ total rate $R \geq S$ modulation amplitude



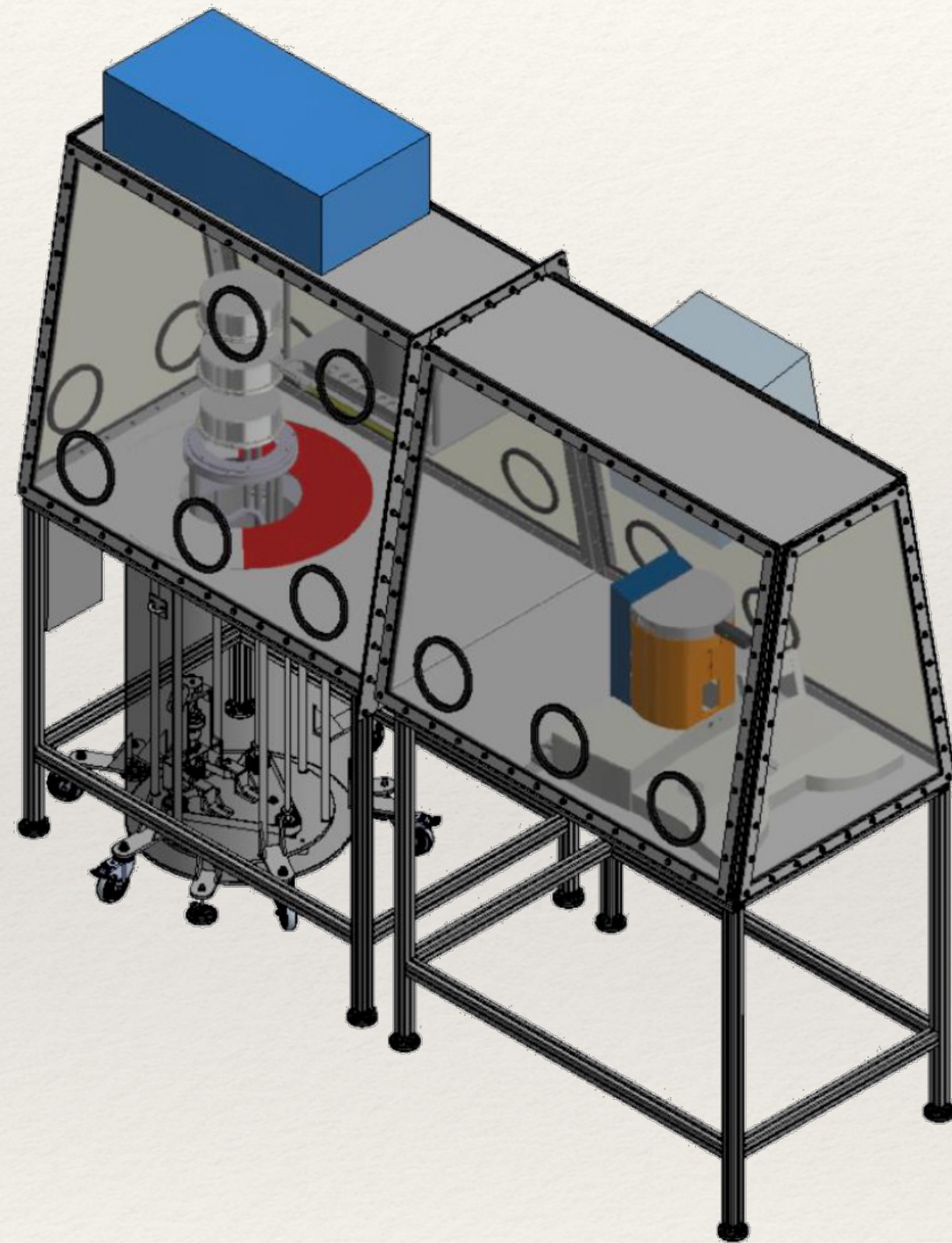
Backup: Quenching Factor

Modified from: Joo, H. W., et al. "Quenching factor measurement for NaI (TI) scintillation crystal." *Astroparticle Physics* 108 (2019): 50-56.



- ❖ Interpretation of energy scale **necessary** for scintillation light-only experiments such as DAMA / LIBRA
- ❖ Quenching factor : conversion between electron equivalent and nuclear recoil energy scale
- ❖ Energy-dependent!
- ❖ Discrepancy between literature values

Backup: COSINUS Glovebox



- ❖ Dedicated, custom-built glovebox for detector handling & assembly
- ❖ Includes space for bonding machine
- ❖ NaI is hygroscopic -> N₂ atmosphere
- ❖ Dockable transport box for finished detectors