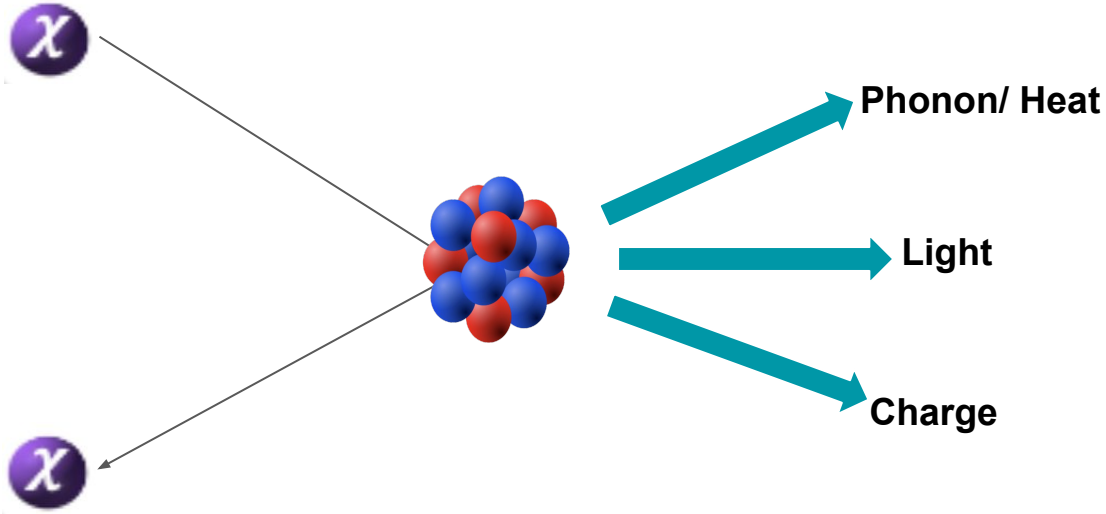
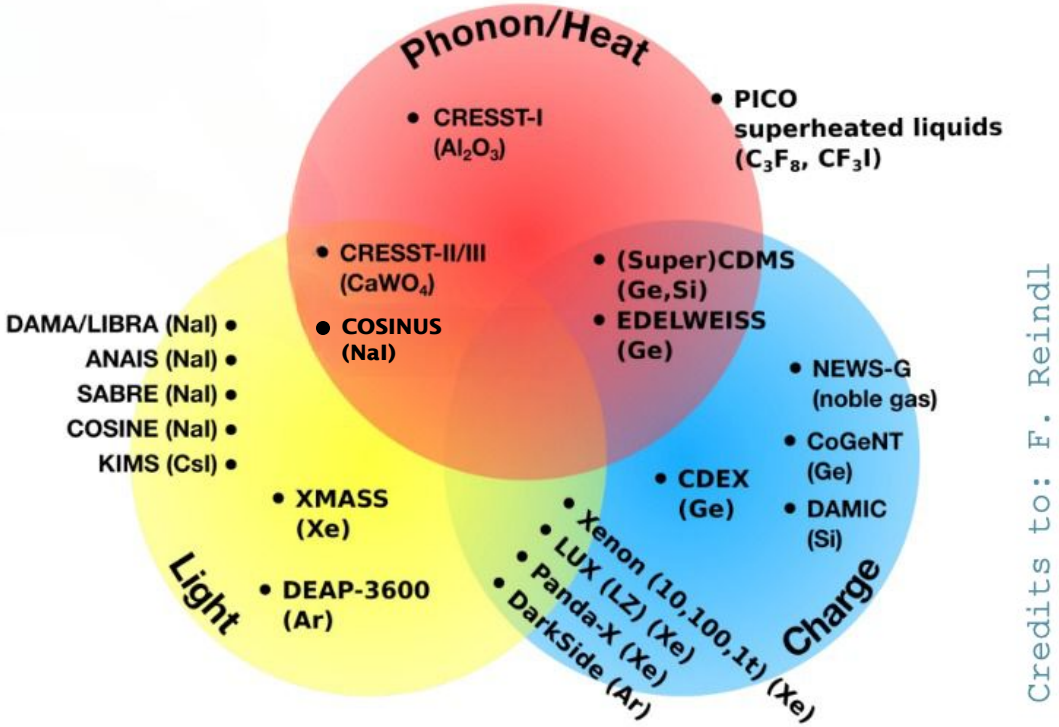
# COSINUS: Investigating the Dark Matter Origin of DAMA/LIBRA Results Using NaI as a Cryogenic Calorimeter


Rituparna Maji on behalf of the COSINUS collaboration
HEPHY and TU Wien, Austria | rituparna.maji@oeaw.ac.at

# Direct dark matter detection channels



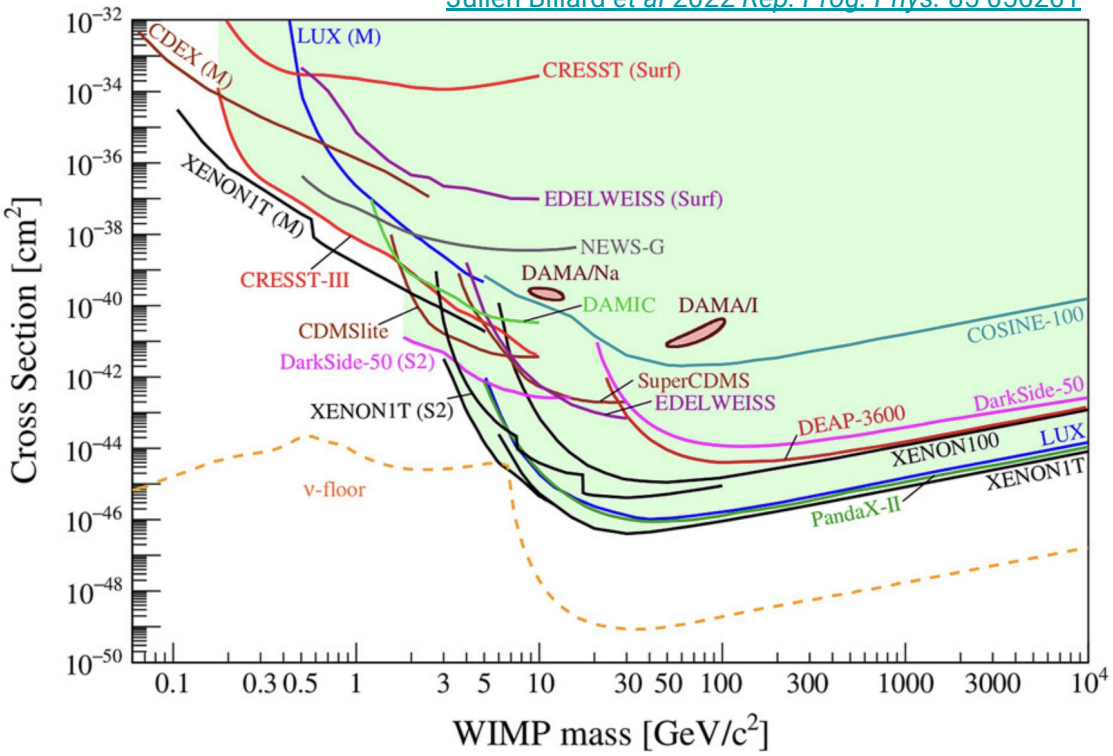
# Direct dark matter detection experiments




*List not complete

# Status of direct dark matter search

Julien Billard *et al* 2022 *Rep. Prog. Phys.* 85 056201




- No DM signal observed by most of the experiments!

# Status of direct dark matter search

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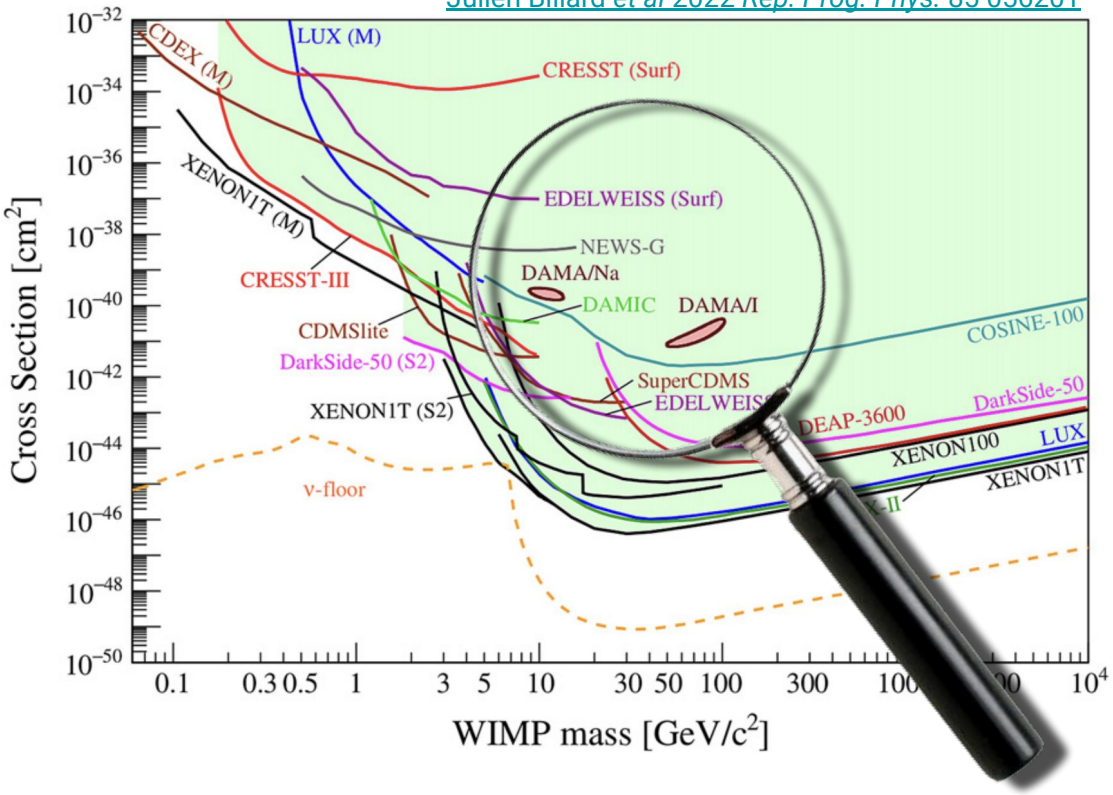
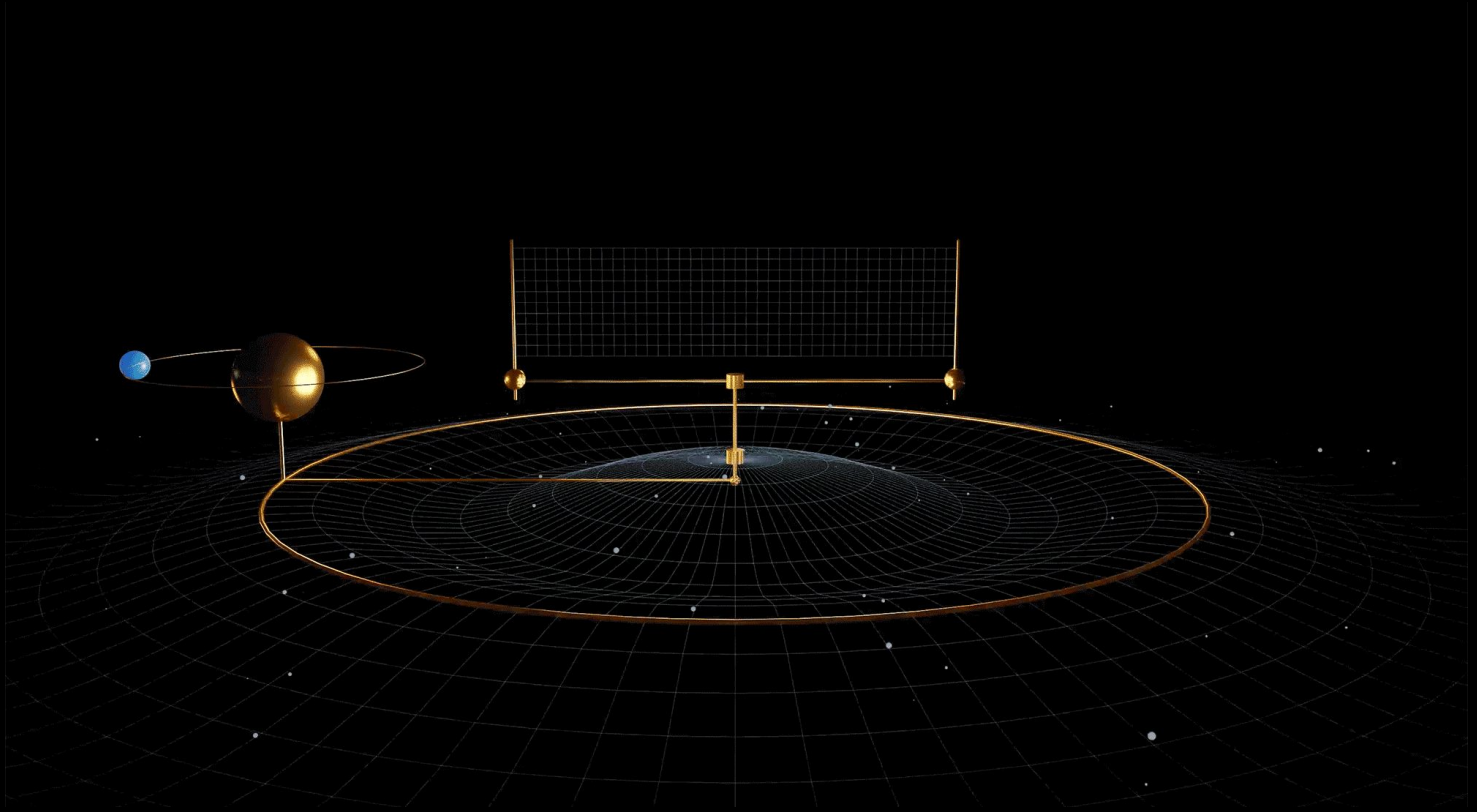


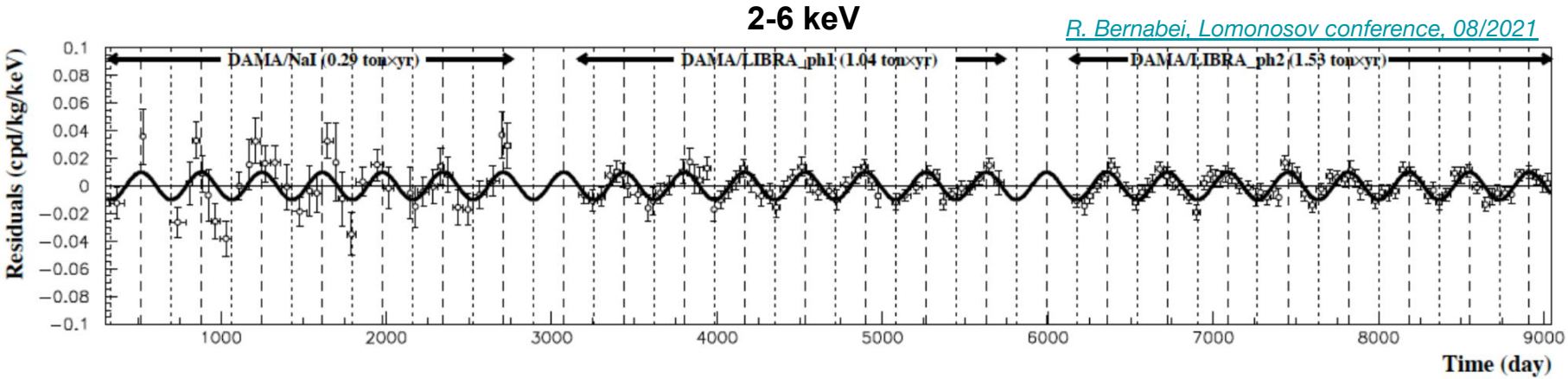

- No DM signal observed by most of the experiments!
- DAMA/LIBRA experiment reported to see a DM signal

# Annual modulation of dark matter

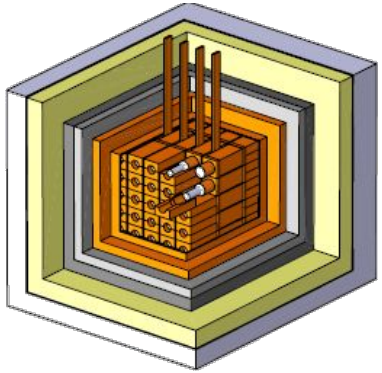


Video courtesy: quantamagazine.org

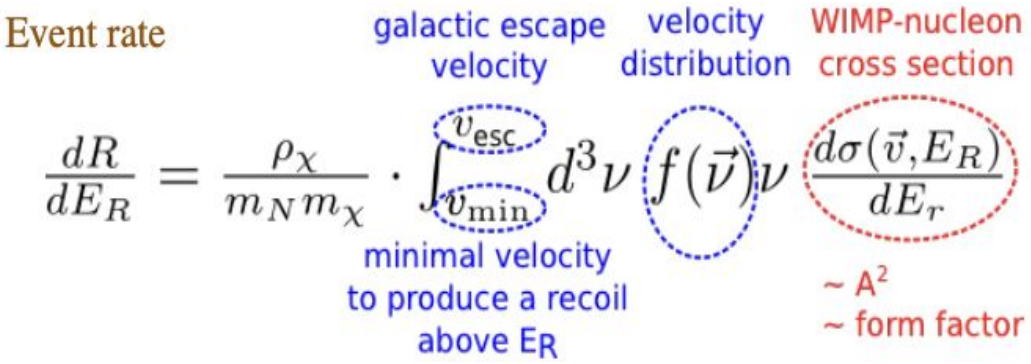
# The DAMA/LIBRA signal




- Statistical significance: ~ 13.7 σ
- Over 25 years of data
- Total exposure: 2.86 tonne years
- Period and phase match with DM expectation
- No convincing non-DM explanation



# Material dependence of dark matter rate




- DM event rate is material-dependent
- APPEC Recommendation: *"The long-standing claim from DAMA/LIBRA [...] needs to be independently verified using the same target material."*

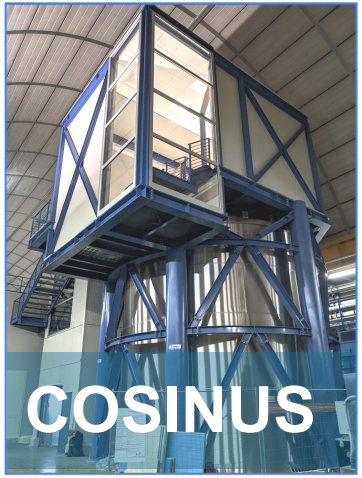
# NaI based direct detection DM experiments

### Single channel readout experiments

- ❏ DAMA
- ❏ ANAIS
- ❏ COSINE
- ❏ PICOLON
- ❏ SABRE

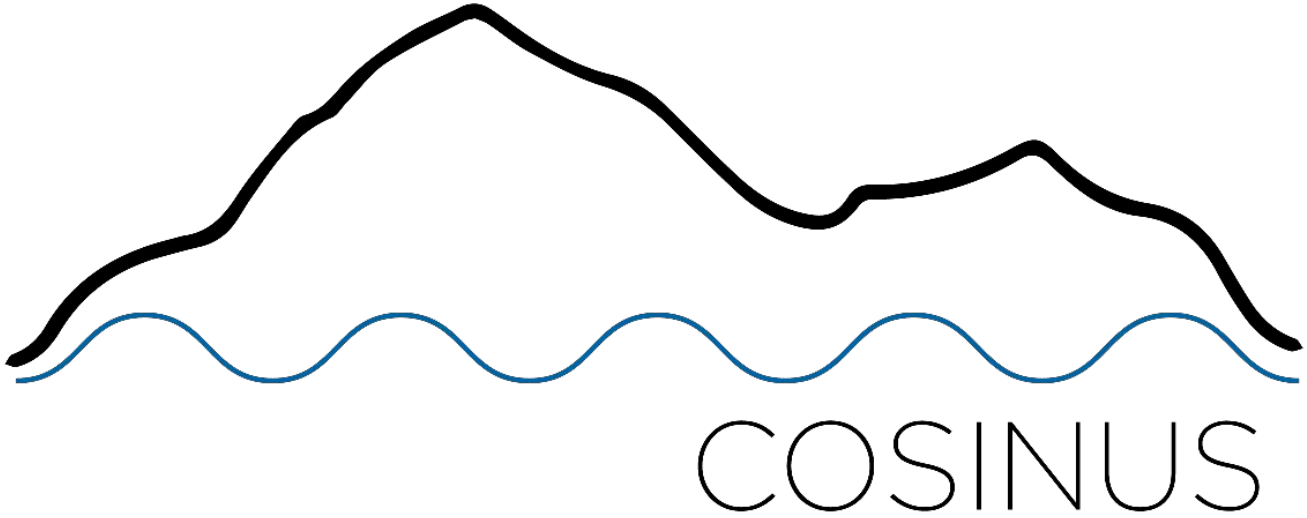
- Room temperature scintillators
- detects light using NaI(Tl)
- no particle discrimination
- nuclear recoil energy scale depends on Quenching Factor (QF)

### Dual channel readout experiment




- Cryogenic scintillating calorimeter
- detects light+heat using NaI
- signal to background discrimination
- in-situ Quenching Factor (QF) measurement

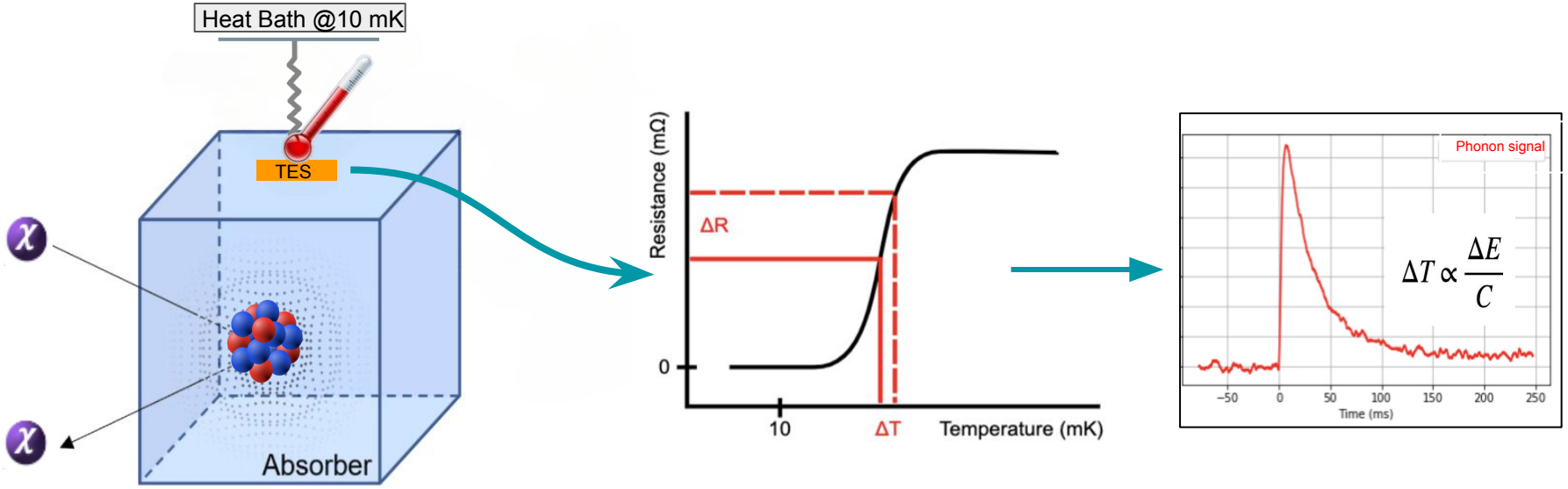
www.cosinus.it




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

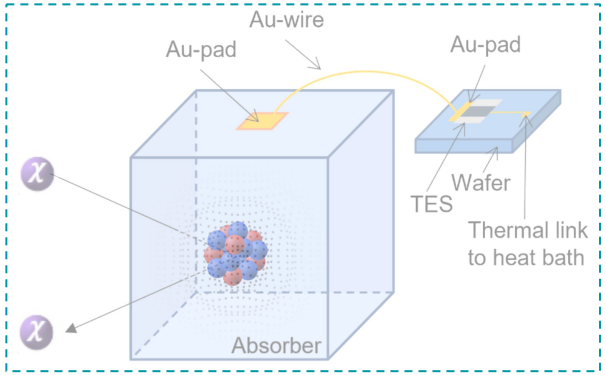
Eur. Phys. J. C (2016) 76:441

# Cryogenic detector: Transition edge sensor(TES)

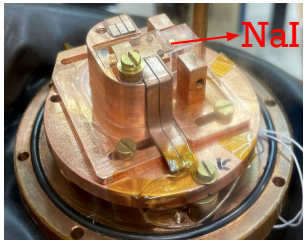



- Transition edge sensor (TES) can detect a very small rise in temperature induced by a small energy deposition

# Dual channel read out: phonon + light detector

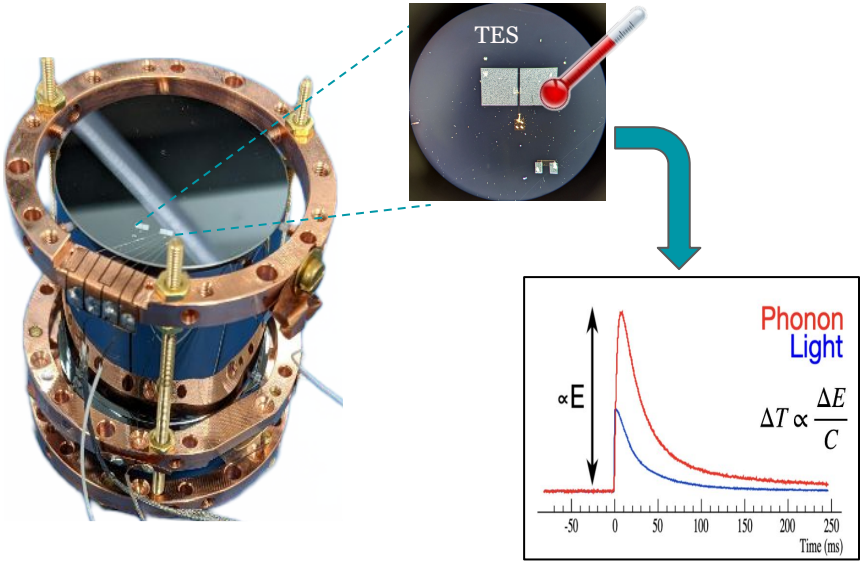



- Phonon signal is independent of particle type
- Precise measurement of the deposited energy
- Scintillation light signal strongly depends on the particle type
- Dual channel read-out enables **event discrimination**

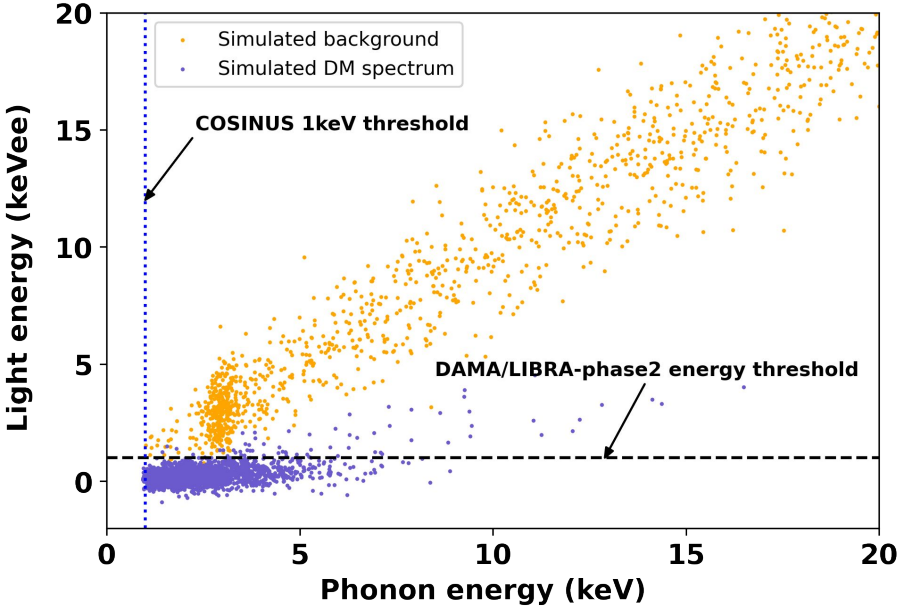



Phonon detector


light detector



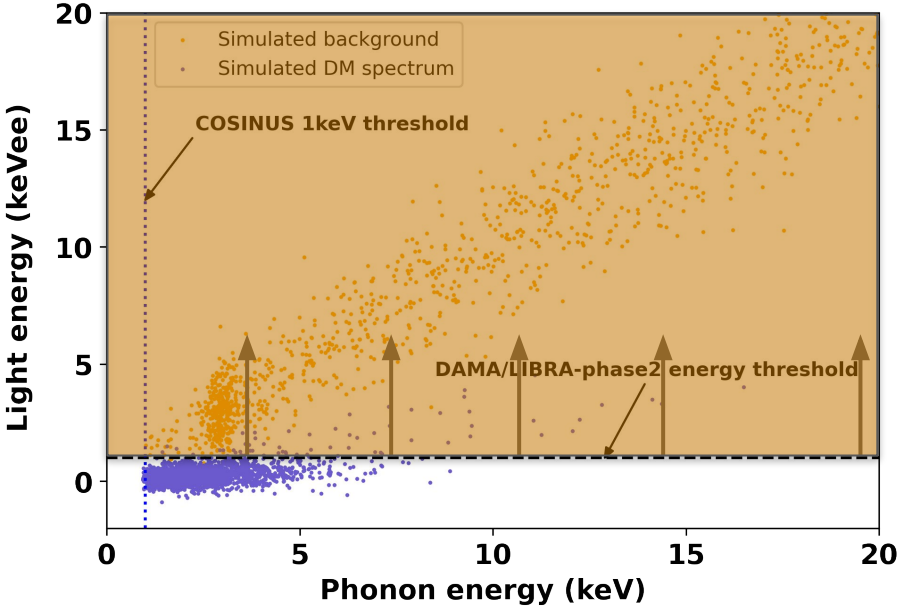
# Signal to background discrimination




Simulated data of 100 kgd gross exposure

# Signal to background discrimination

What DAMA/LIBRA observes

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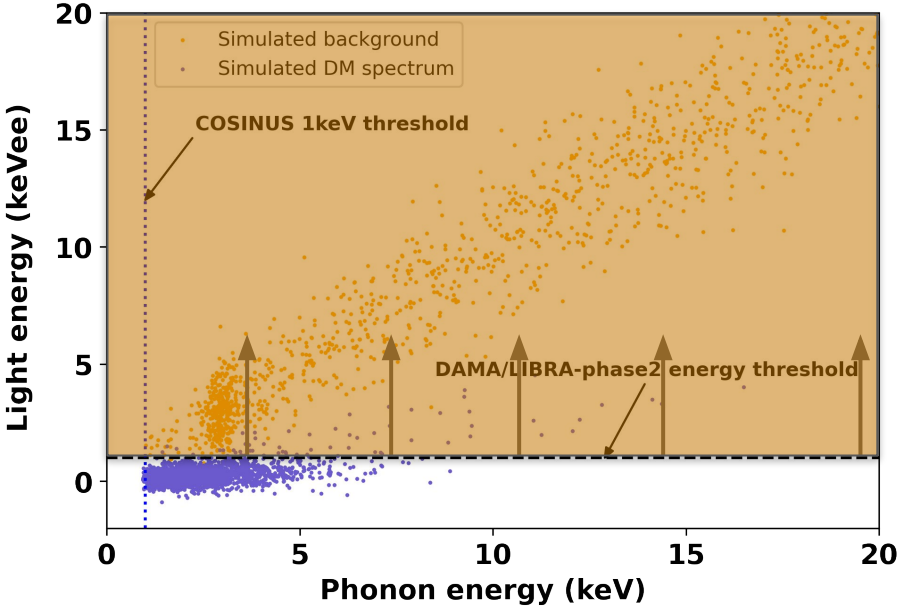
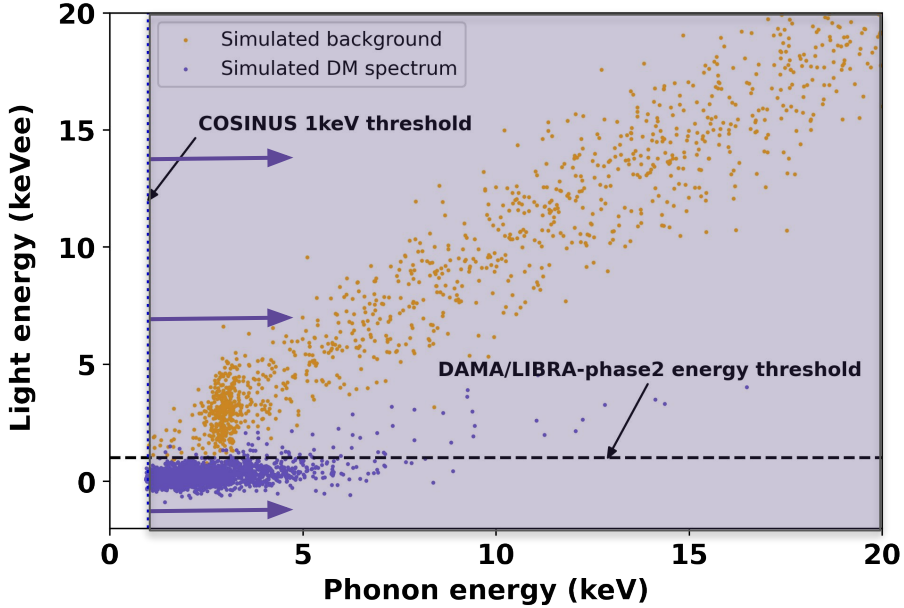



What COSINUS observes

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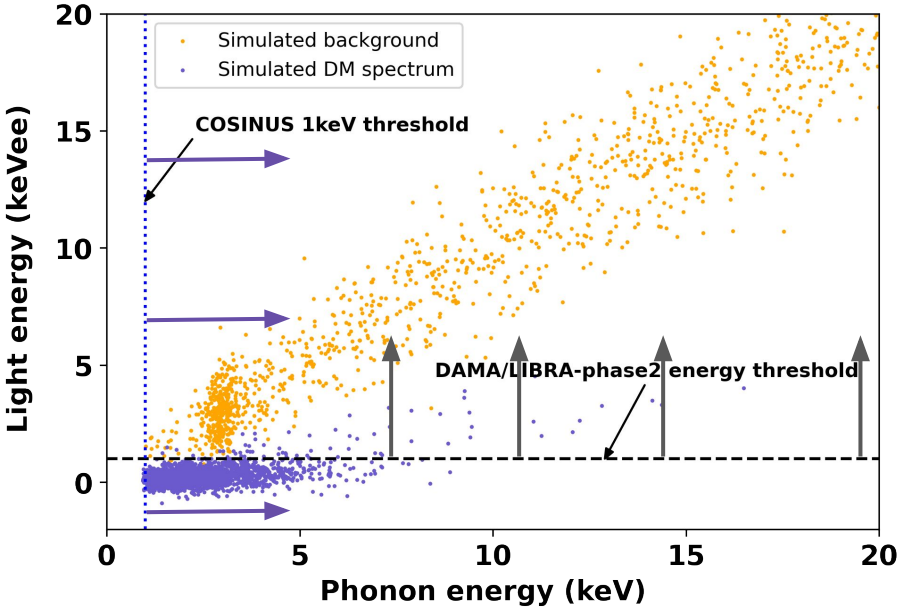
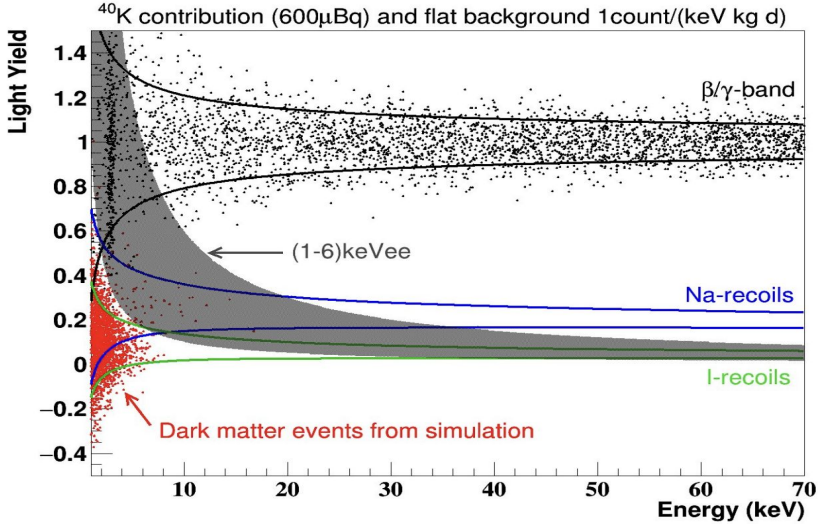
# Signal to background discrimination




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

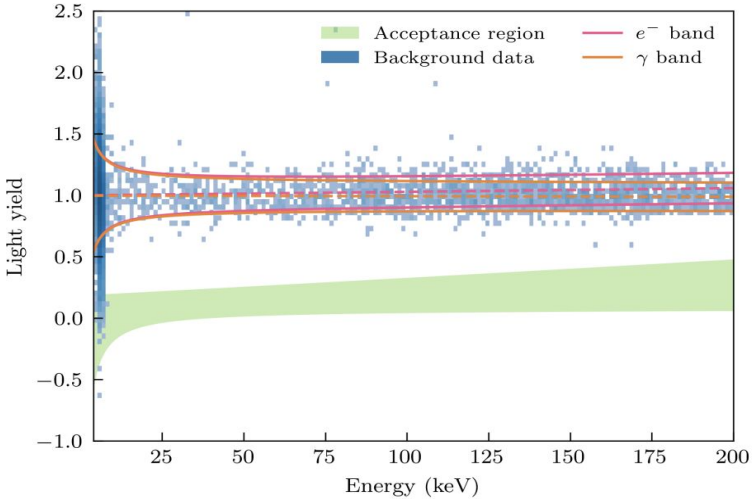



G.Angloher et al. - Eur.Phys.J. C, 82(3), 248(2022)

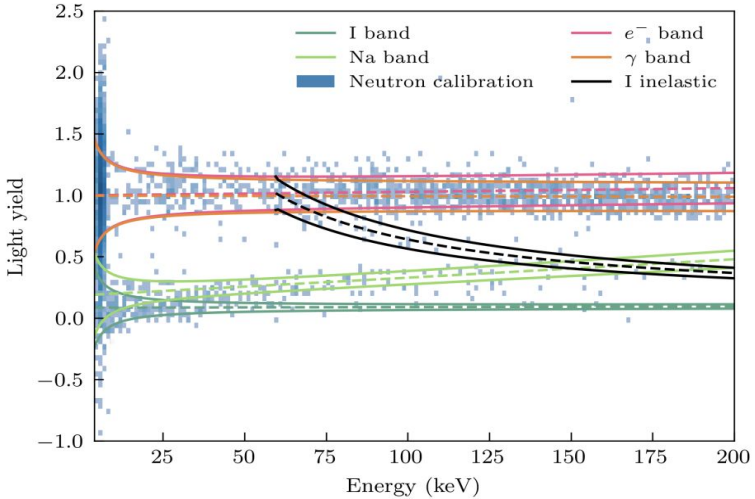
Simulated data of 100 kgd gross exposure

# First event discrimination with NaI detector

Background data




Neutron calibration data

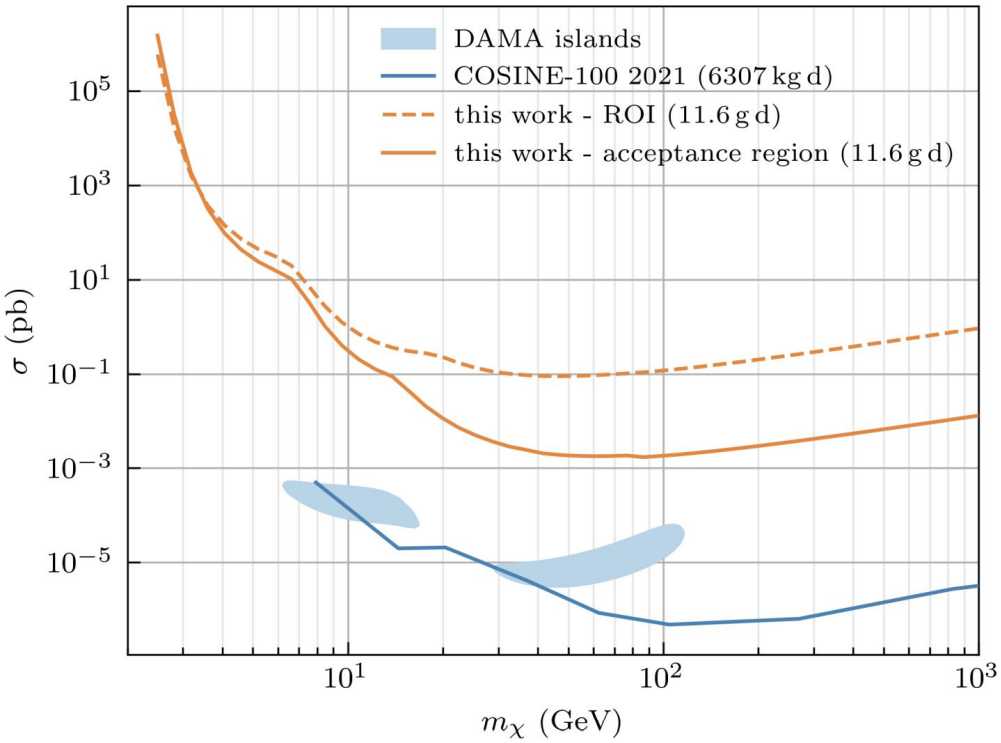



- Underground run in June 2022 @LNGS, Italy
- Nuclear recoil threshold: 2.656 keV (with 3.67g NaI absorber + Si light detector)
- **First underground measurement demonstrating particle discrimination with a NaI detector**

arXiv:2307.11139

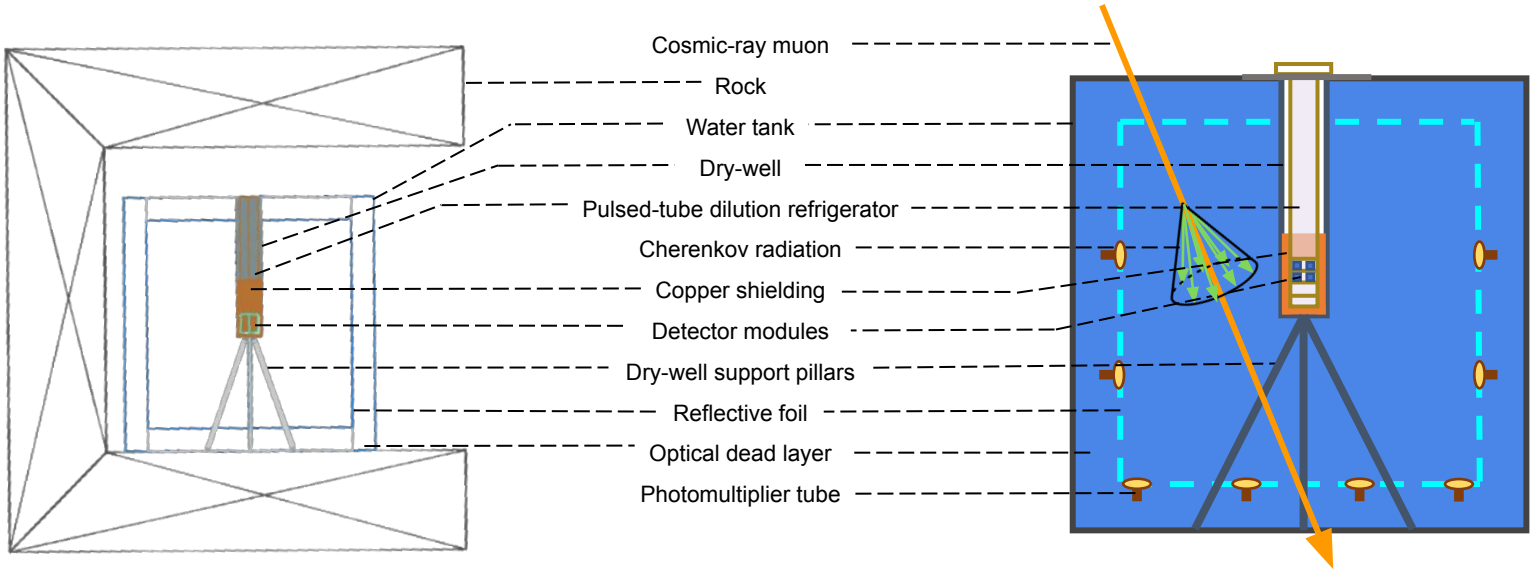
# Performance

- Exposure of 11.6 g d
- QF of Na(10 keV): 0.2002 ± 0.0093
- QF of I(10 keV): 0.0825 ± 0.0034
- First limit on the standard DM-nucleus scattering scenario




arXiv:2307.11139

# Simulation: passive and active shielding




- Water tank as **passive shield** against radiogenic and ambient radiation- G.Angloher et al. - Eur.Phys.J. C. 82(3), 248(2022)

**Active muon veto (28 PMTs)**

- Estimated **total veto efficiency of 97.0 ± 2.2 %** to tag muon induced neutrons
- Estimated cosmogenic neutron background reduced from 3.5 ± 0.7 cts·kg−1·year−1 to **0.11 ± 0.8 cts·kg−1·year−1**
- Estimated total background trigger rate of **less than 1 Hz**

*Work to be published soon

# Experimental facility @LNGS, Italy


LNGS: Laboratori Nazionali del Gran Sasso

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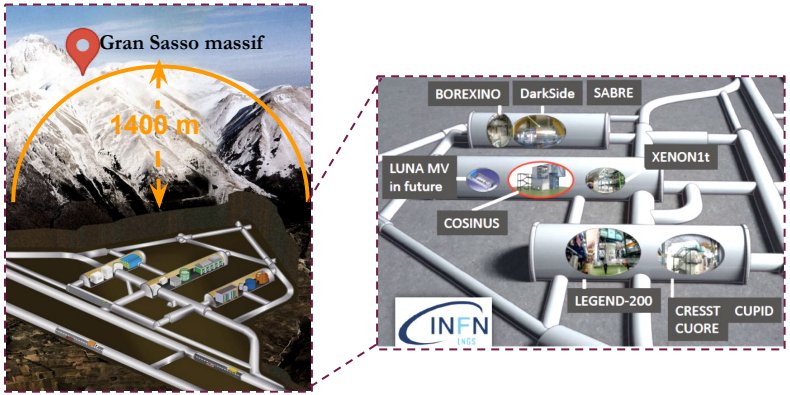


LNGS: Laboratori Nazionali del Gran Sasso

# Experimental facility @LNGS, Italy



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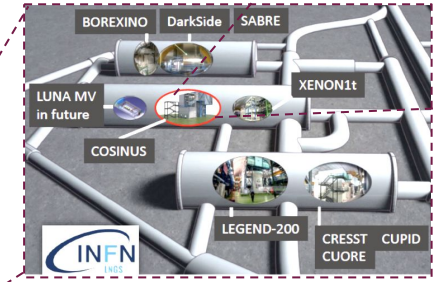


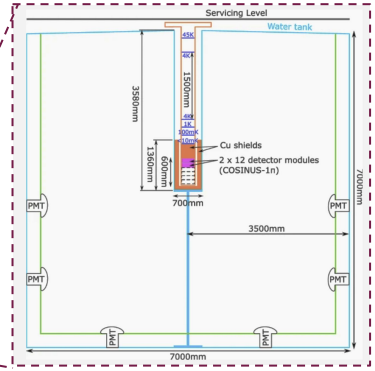


LNGS: Laboratori Nazionali del Gran Sasso

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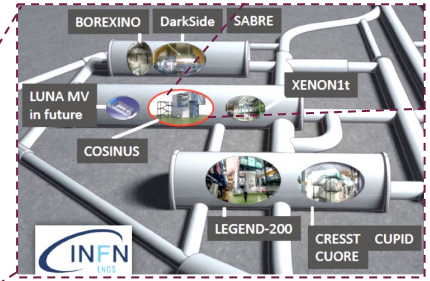
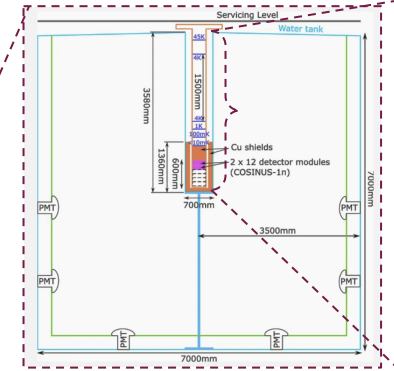
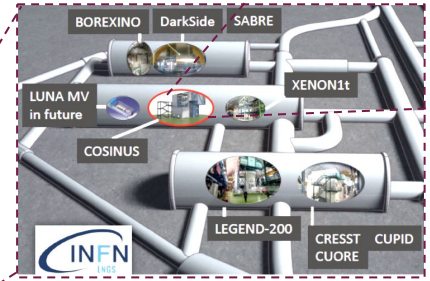
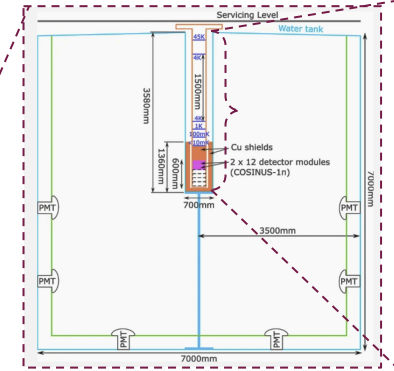


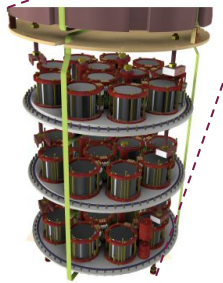




LNGS: Laboratori Nazionali del Gran Sasso

# Experimental facility @LNGS, Italy

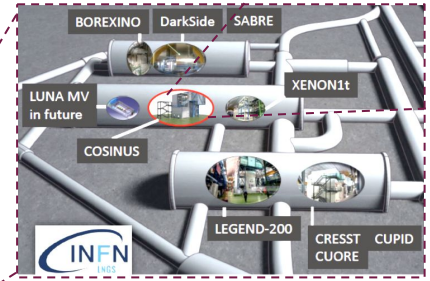



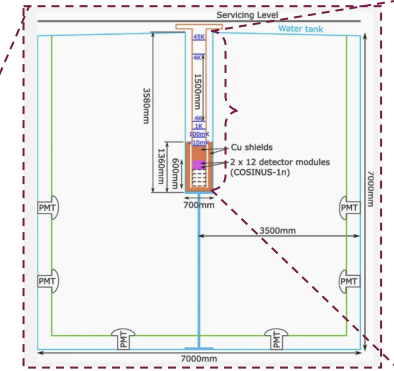



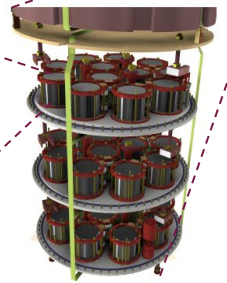
LNGS: Laboratori Nazionali del Gran Sasso

# Experimental facility @LNGS, Italy





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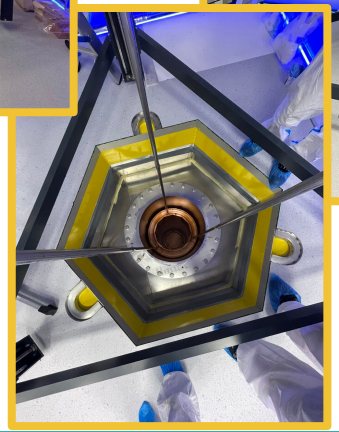
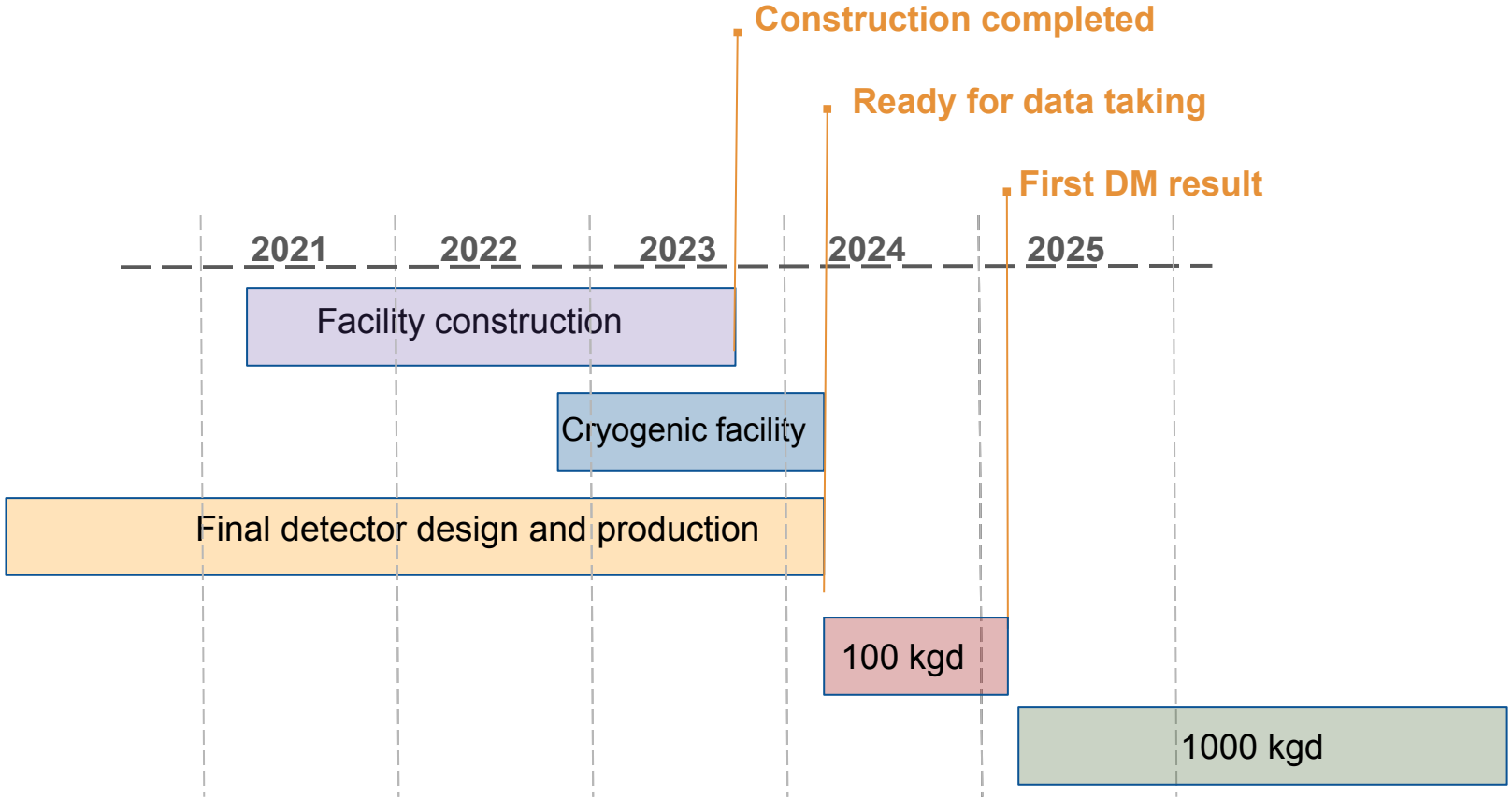
# Current status of the experimental facility



# COSINUS time schedule



# The COSINUS collaboration

www.cosinus.it

COSINUS

TU WIEN

HEPHY

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

UNIVERSITÀ DEGLI STUDI DELL'AQUILA

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

GSSI

HELSINKI INSTITUTE OF PHYSICS

Since 1928
SICCAS

Twitter(X): @COSINUSdm

Collaboration meeting @Helsinki, April 2023

COSINUS

# Thank you

## for your attention

Rituparna Maji | rituparna.maji@oeaw.ac.at

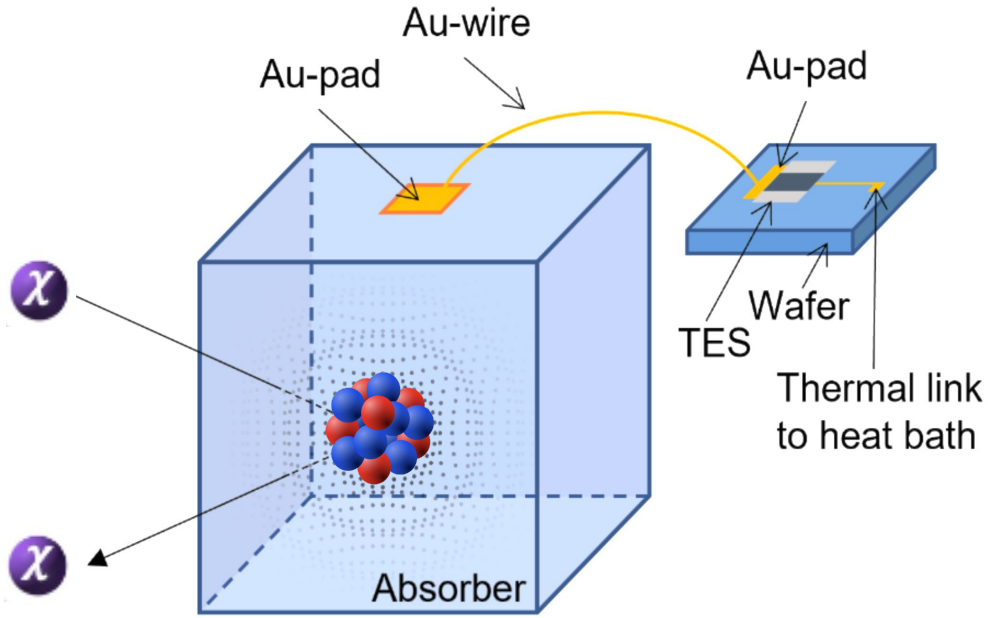
TECHNISCHE UNIVERSITÄT WIEN

HEPHY

ÖAW ÖSTERREICHISCHE AKADEMIE DER WISSENSCHAFTEN

FWF Der Wissenschaftsfonds.

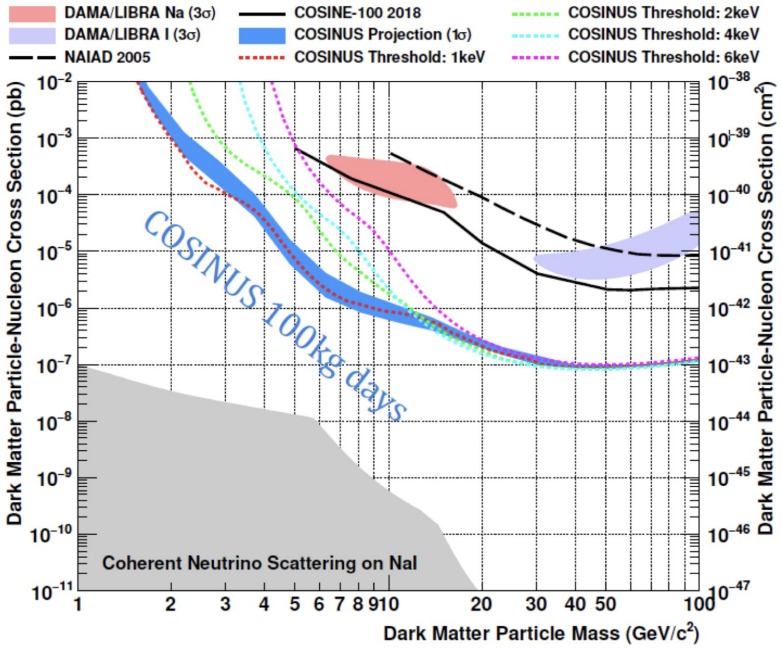
# remoTES detector




- Direct deposition of TES on NaI is non-trivial (Hygroscopic, low melting point, soft)
- Phonons are guided through a gold wire to a separate material: Remote TES (**remoTES**)
- **First idea** of remoTES: *M. Pyle et al. in 2015 arXiv:1503.01200*
- **First successful operation** of the working design of remoTES by COSINUS: *j.nima.2022.167532*

# Physics reach of COSINUS 1π

COSINUS aims to cross-check the DAMA/LIBRA with a model-independent test:
*Felix Kahlhoefer, Florian Reindl,et al JCAP05(2018)074*

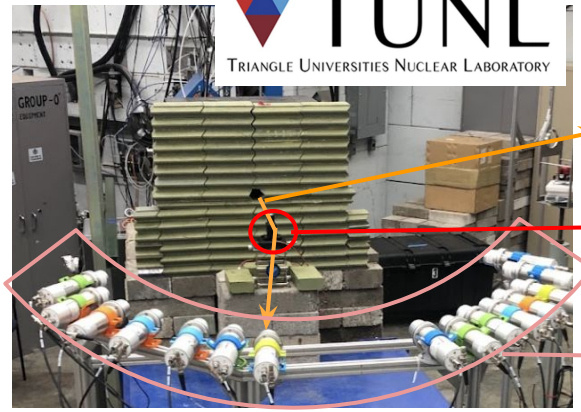


# Quenching factor mystery!

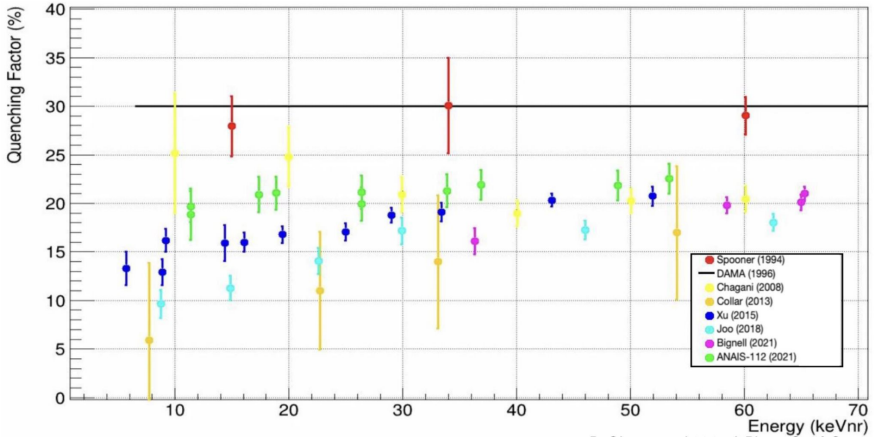
- Quenching factor (QF): The ratio of the scintillation light produced by nuclear recoil and electron recoil

$$QF(E) = \frac{L_{nr}(E)}{L_{ee}(E)}$$

- **Precise QF measurement is crucial** to get the correct nuclear recoil energy in **scintillation-only experiments**
- Measurement of QF of NaI do not agree, especially in the low energy region
- **Aim:** to study the effect of **QF in low energy region and to study the effect of TI dopant on QF**




Reported Quenching factor values for Na recoils




D. Cintas et al 2021 J. Phys.: Conf. Ser. 2156 012065

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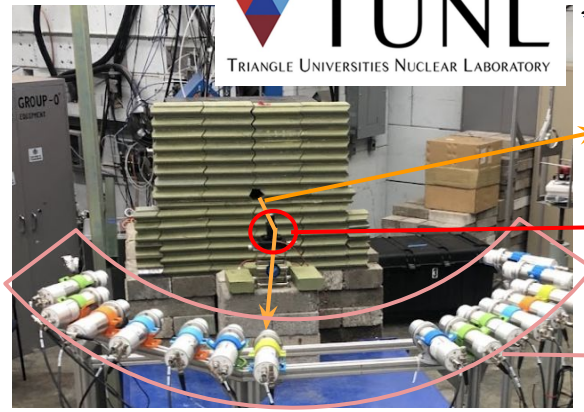
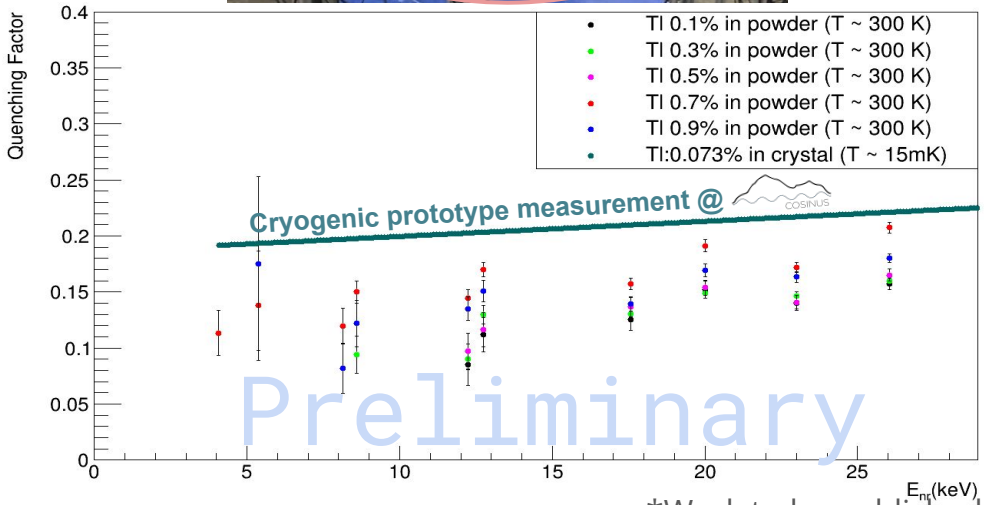
- Measurement of QF of NaI do not agree, especially in the low energy region
- **Aim:** to study the effect of **QF in low energy region and to study the effect of Tl dopant on QF**
- **5** radio-pure **NaI(Tl)** crystals measured
- **Result:** QF(Na) depends on energy, Tl dopant concentration; QF is sensitive to calibration and resolution methods used




*Work to be published soon