COSINUS

Progressing towards shining light on the long-standing dark matter claim of DAMA/LIBRA

14th International Conference on Identification of Dark Matter

IDM 2022

18-22 July 2022
Vienna, Austria

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MPP, Munich, Germany

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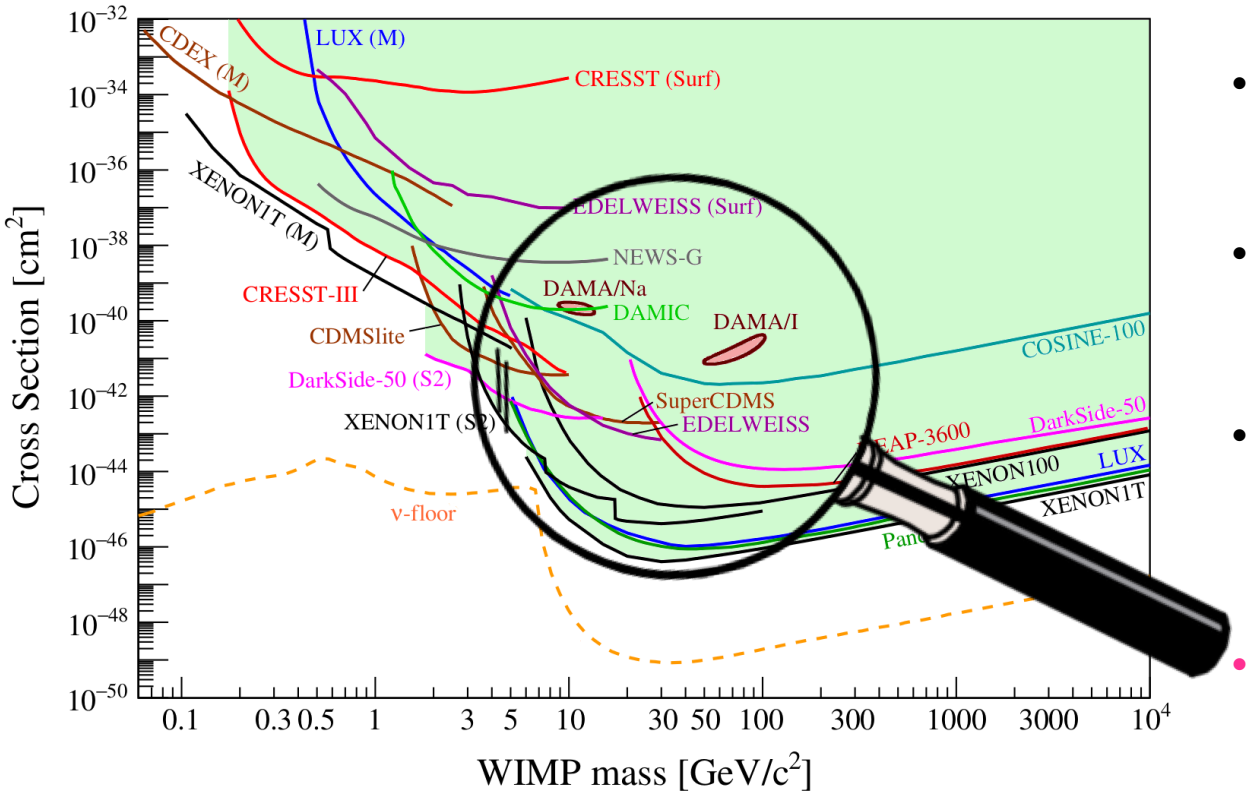
MAX-PLANCK-INSTITUT FÜR PHYSIK

CLAIM BY DAMA/LIBRA

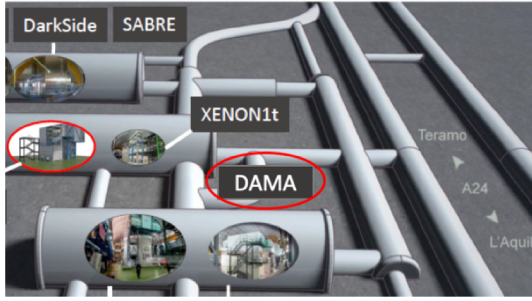
Astroparticle Physics European Consortium APPEC, v1.02



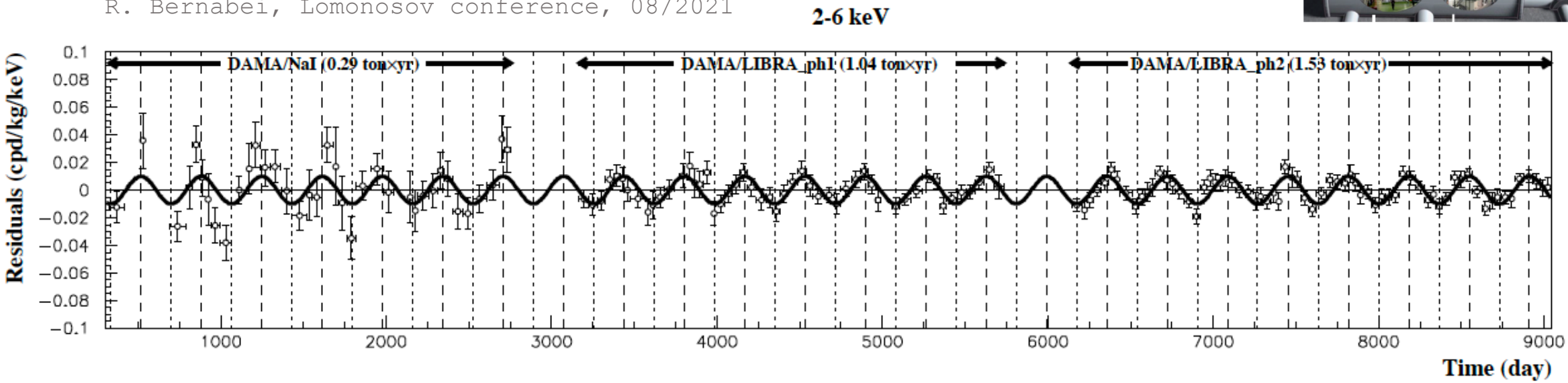
- World-wide effort with enormous progress in the last decade
- extremely rare interaction rate
  current limit: $\mathcal{O}$ **(0.01) cts/(keV tonne year) ***
- no signal observed by most experiments
- positive evidence reported by DAMA/LIBRA

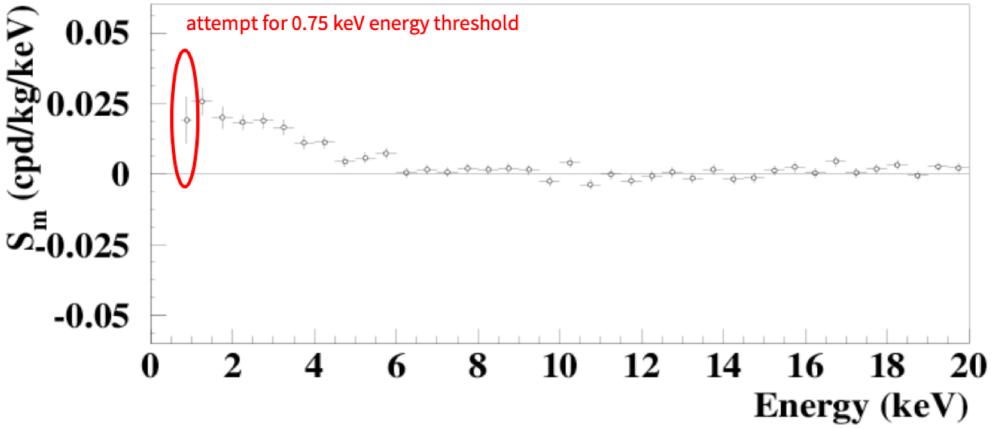
* Xenon1t: PRL 119, 181301 (2017)

DAMA/LIBRA **RESULT**



R. Bernabei, Lomonosov conference, 08/2021





Total exposure: 2.86 tonne years
Statistical significance: 13.7 σ

Claim:
positive evidence for the presence of DM particles in the galactic halo

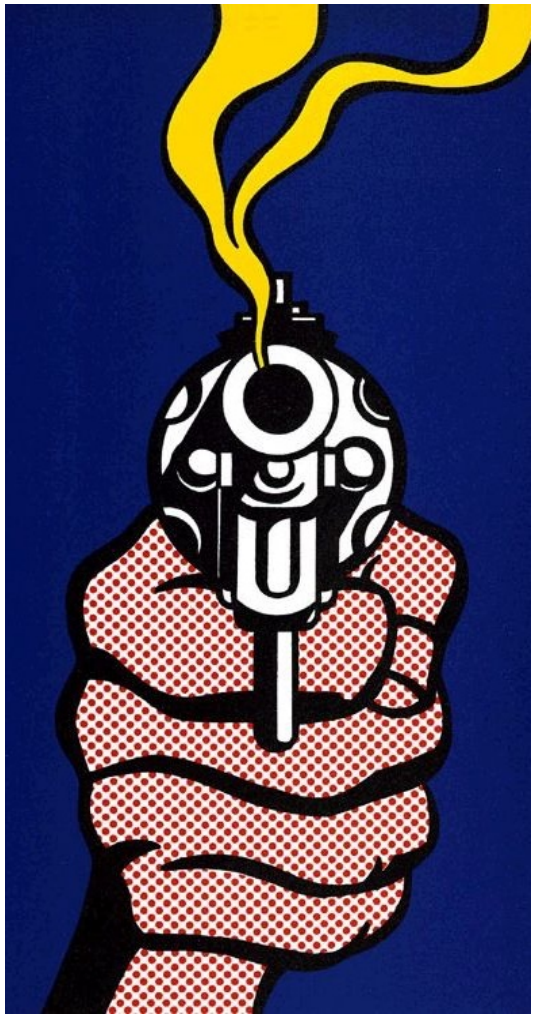
THE SMOKING GUN EVIDENCE?

Statistics: 13.7 σ ✓

Period: 0.99834 ± 0.00067 years * ✓

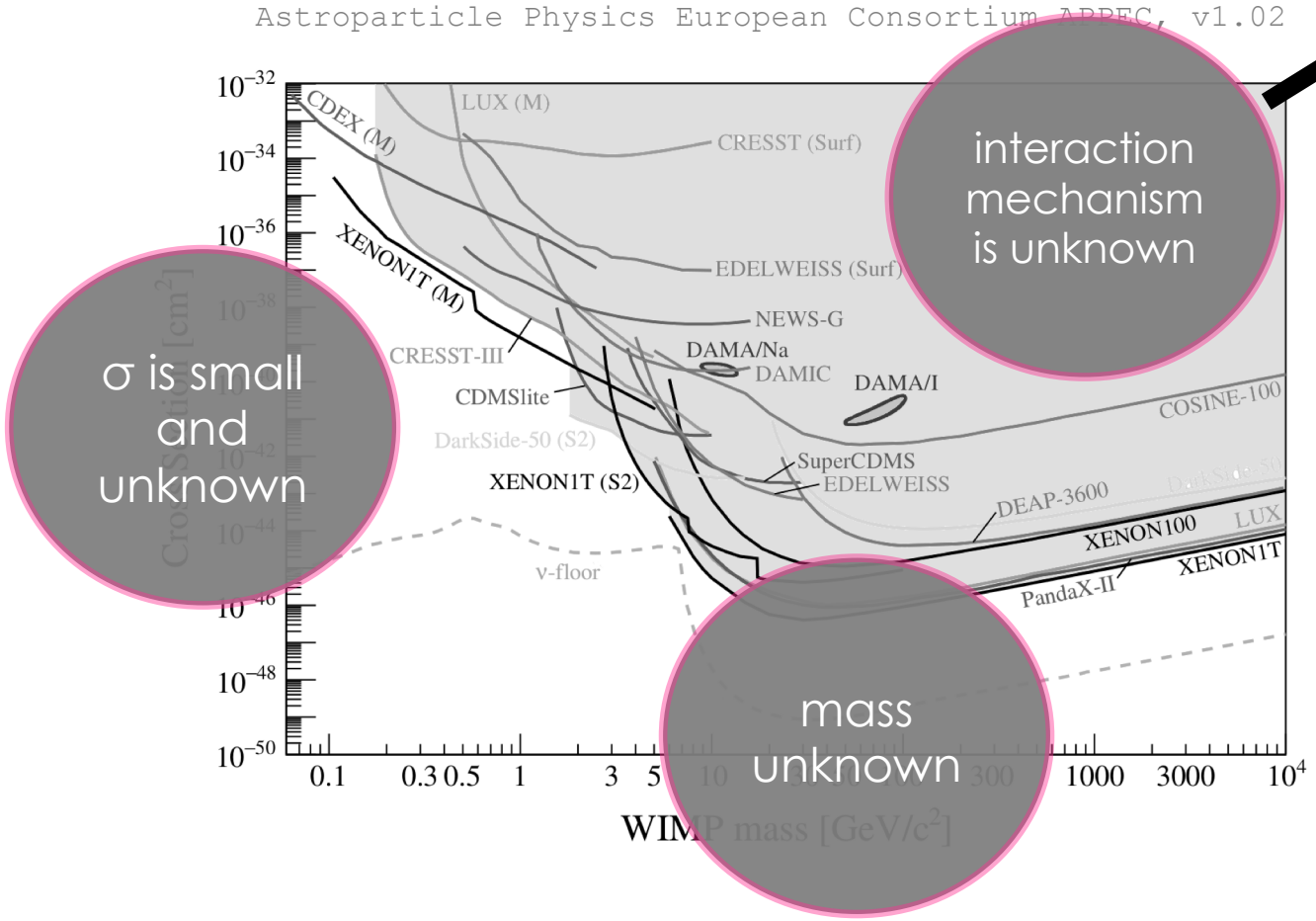
Phase: 22th May +/- 4 days ✓
(cosine peaking June 2nd)

Convincing non-DM explanation ✗



*in (2-6) keV_{ee} interval

WHAT ARE THE **UNKNOWNS**?



interaction mechanism is unknown

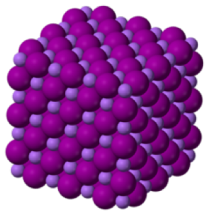
σ is small and unknown

mass unknown

$$\frac{dR}{dE_r} = \frac{\rho_\chi}{m_N m_\chi} \cdot \int_{v_{min}}^{v_{esc}} d^3v\, f(v)\, v \frac{d\sigma(v, E_r)}{dE_r}$$

~ A^2
~ form factor

→ **dependence on target material**



Sodium Iodide:
NaI

^{11}Na 53I

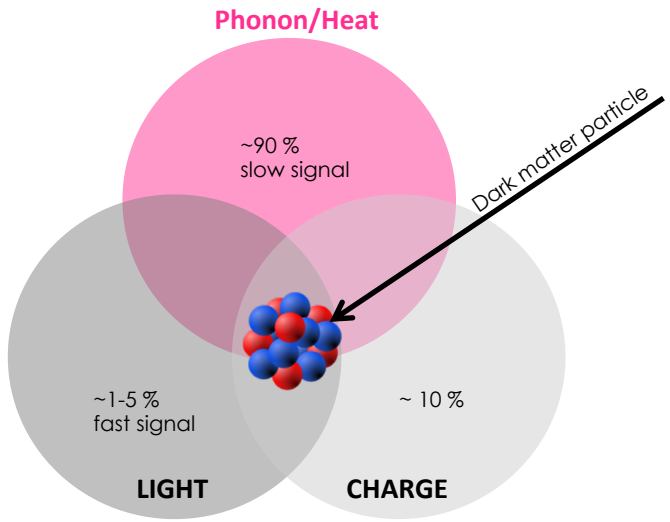
APPEC Recommendation:
"The long-standing claim from DAMA/LIBRA […] needs to be independently verified using ***the same target material****."*

COSINUS SEARCH **STRATEGY**

Model- and target independent test of DAMA

→ *novel* and *unique*: operation of **NaI as low-temperature calorimeter**

- HEAT CHANNEL: precise energy information
  + low threshold for nuclear recoils



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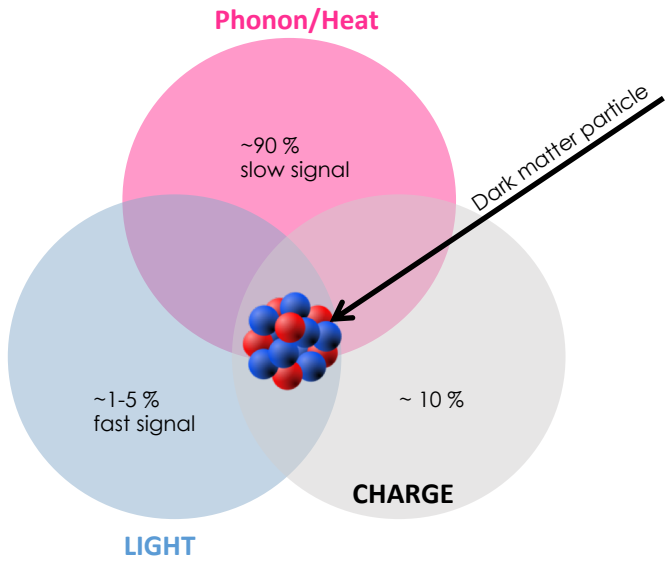

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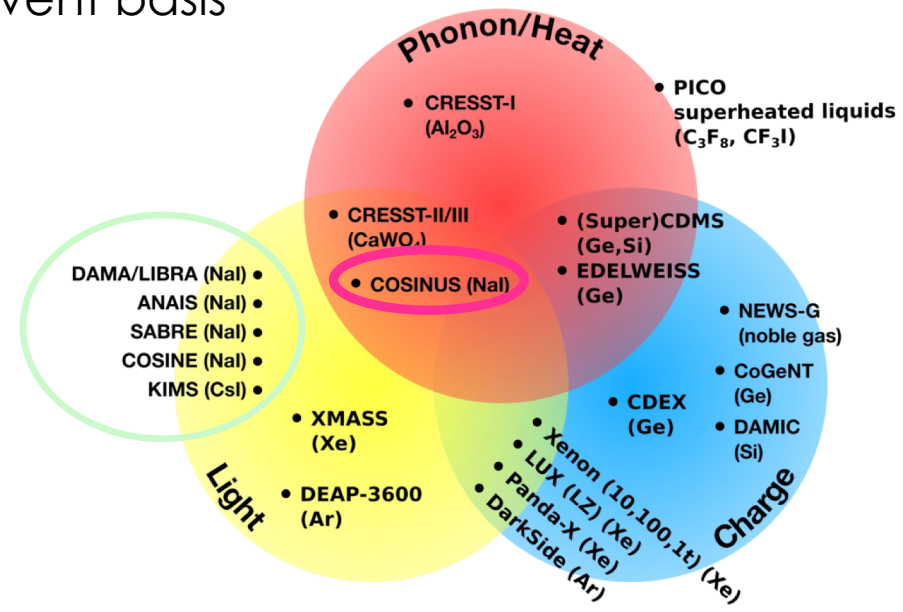
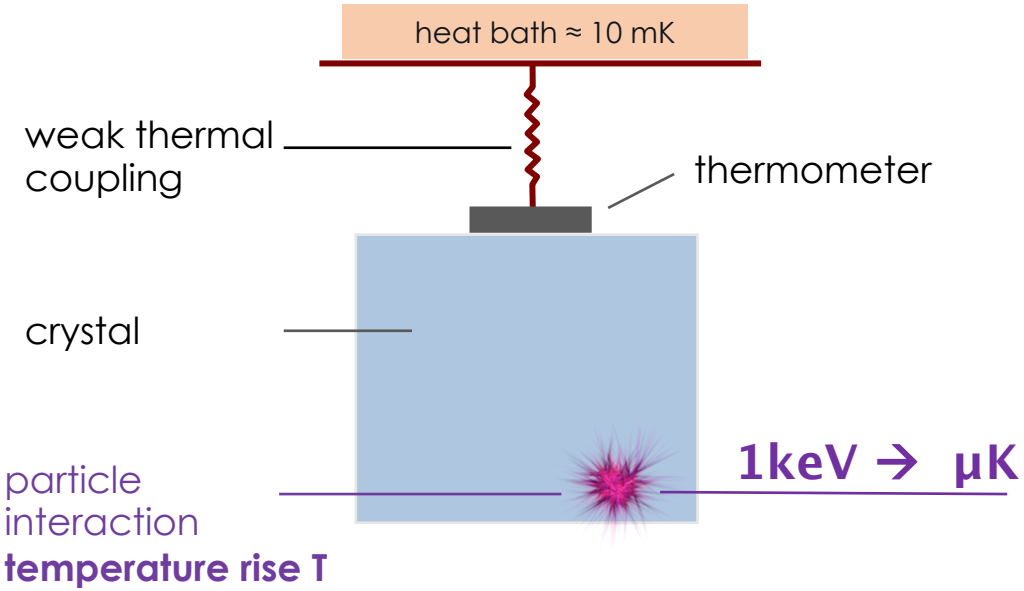
→ Signal-only measurement of potential DM signal

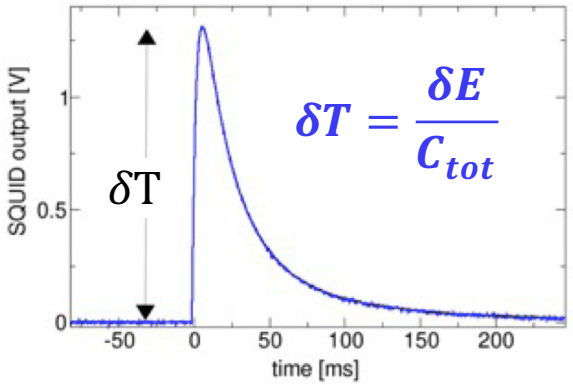


Credits to: F. Reindl

LOW-TEMPERATURE CALORIMETER



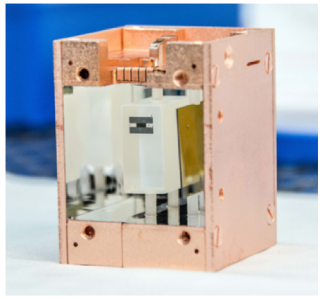
Temperature pulse



Phonon signal (~ 90 %)

- (almost) independent of particle type
- **precise measurement** of the deposited energy

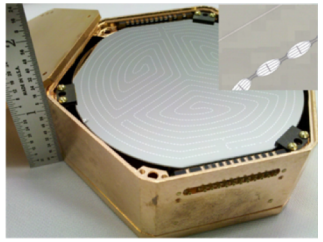
CRYOGENIC DETECTORS IN THE FIELD



CRESST @ LNGS

PRD 100, 102002 (2019)

- Phonon and light
- $CaWO_4$, Si, Al_2O_3, $LiAlO_2$



CDMS, SuperCDMS

PRD 97, 022002 (2018) PRD 99, 062001 (2019)

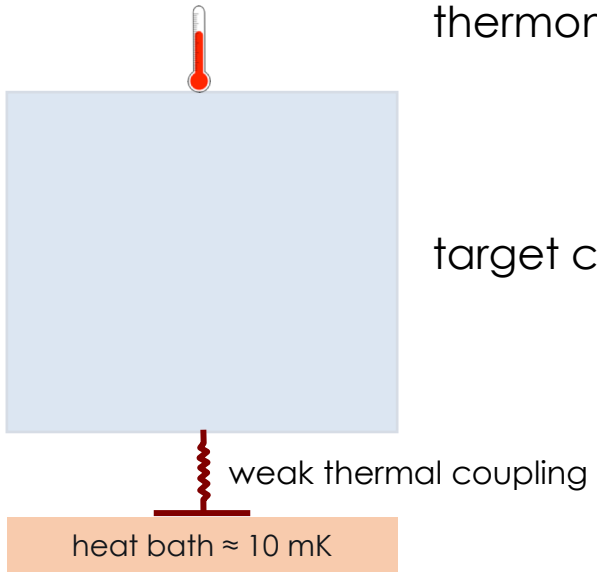
- Phonon and charge
- Si, Ge

EDELWEISS @ LSM

PRD 97 (2018) 022003

- Phonon and charge
- Ge

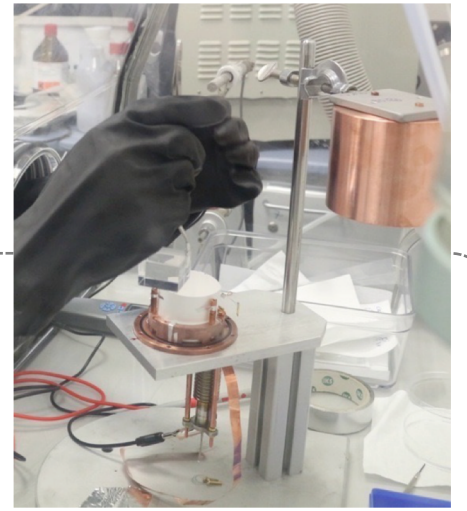
Established technology:



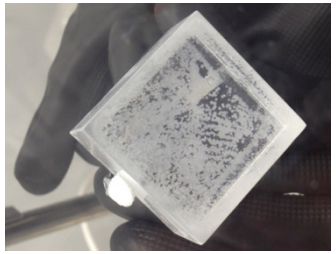
+ particle identification via:

phonon/charge or phonon/light measurement

… but NaI is not that NaIce !



hygroscopic nature



handle only in controlled atmosphere

^{40}K in the NaI crystal

NaI grown in collaboration with SICCAS Since 1928

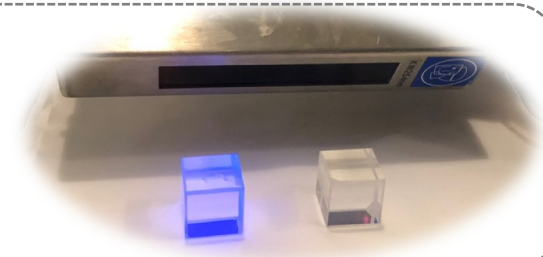
5-9 ppb of K at crystals' nose and 22-35 ppb at crystals' tail

(3-inch crystal, Astrograde powder from Merck) Zhu, Y. et al, IEEE, 2018

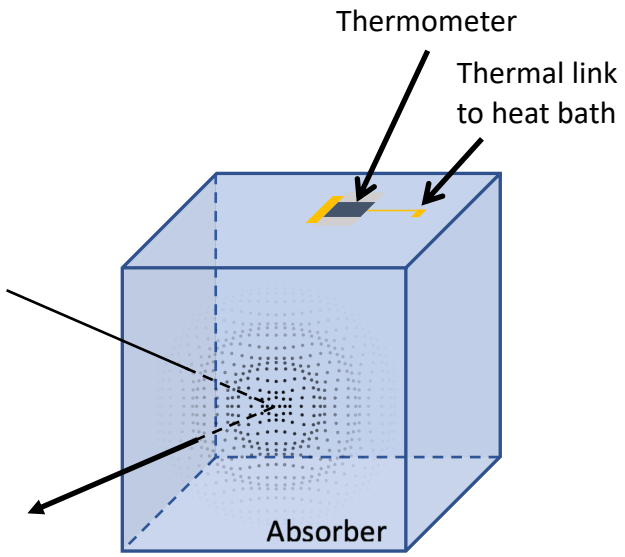
low Debye temperature

adapted thermometer → remoTES

+ avoid other phonon-loss channels

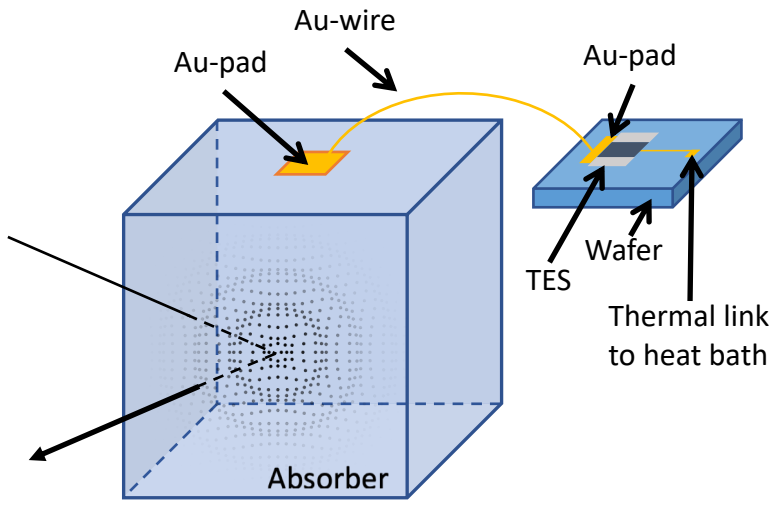


BASELINE DESIGN



remoTES DESIGN

arXiv:2111.00349v1



- separate wafer

→ hosts the tungsten based TES

- Au-pad on absorber

→ phonons propagate in NaI and couple to the electron system of the Au pad

- Au bond wire

→ connection to the temperature sensor

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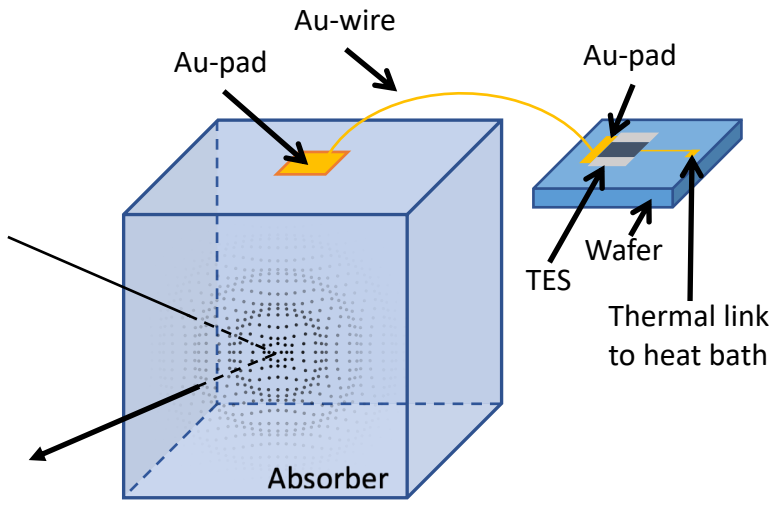

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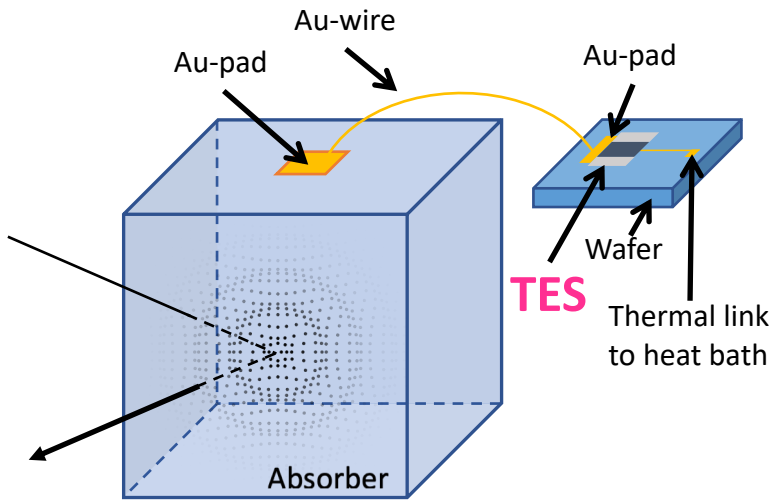
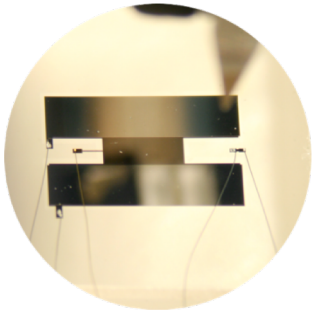
Matt Pyle et. al, 2015
arXiv:1503.01200

remoTES – TRANSITION EDGE SENSORS

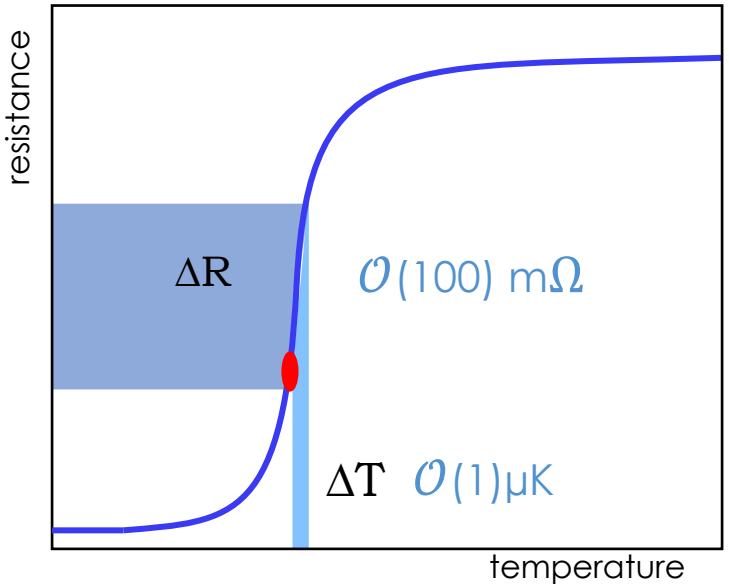




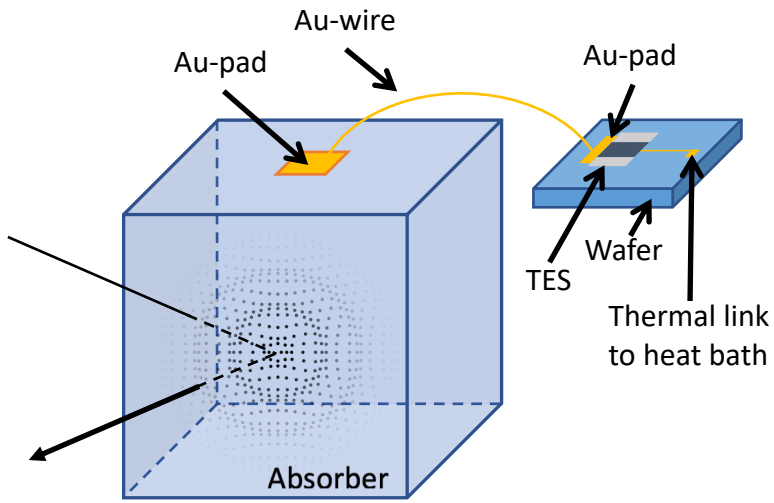
Transition edge sensors (TES)

tungsten superconducting thin films
→ technology developed by CRESST

Transition temperature: $T_c \approx 15$ mK



remoTES – FIRST EXPERIMENTAL RESULTS



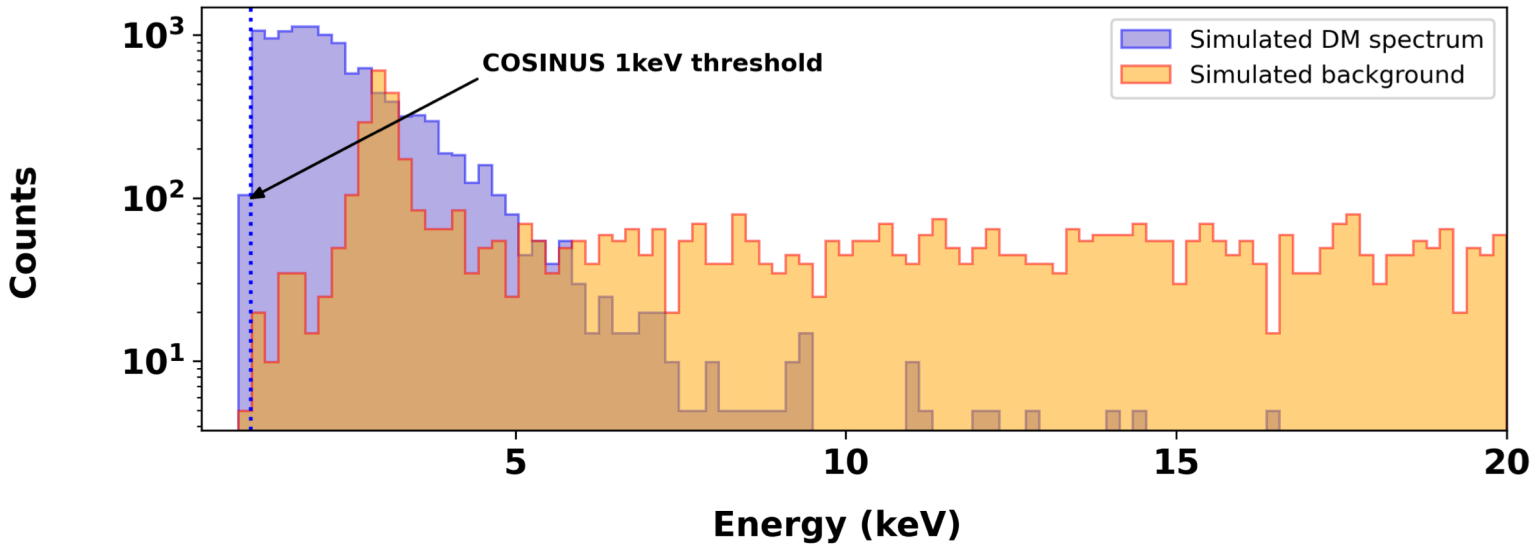
→ First experimental results for:

- Si absorber ($\sigma_{Si} = 87.8\ eV$)
- TeO_2 absorber ($\sigma_{TeO2} = 193.5\ eV$)

arXiv:2111.00349v1

Talk by Leonie Einfalt
Parallel3A Jul 21, 2:00 PM

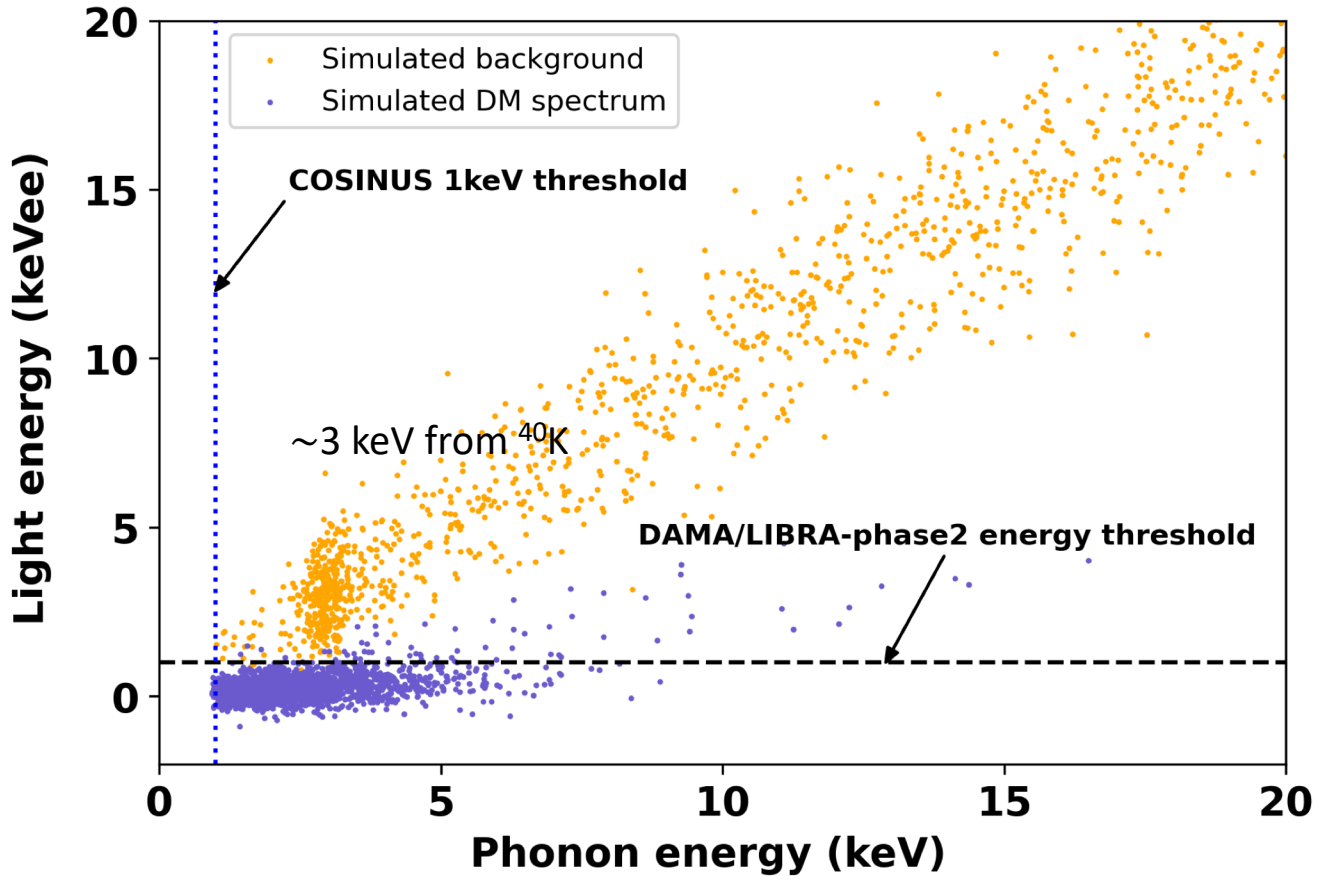
SIMULATED DATA: ENERGY SPECTRUM ONLY



- 1keV nuclear recoil threshold
- flat background: 1 /(keV kg d)
  + ^{40}K background: 600µBq/kg
- exposure before cuts: 100 kg-days
- dark matter spectrum:
  10 GeV/c^2, 2x10^{-4} pb

Eur. Phys. J. C (2016) 76:441
DOI 10.1140/epjc/s10052-016-4278-3

SIMULATED DATA: DUAL CHANNEL READOUT



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  10 GeV/c^2, 2x10^{-4} pb
- **values for quenching factors** from:

  Tretyak, Astropart. Phys. 33, 40 (2010)

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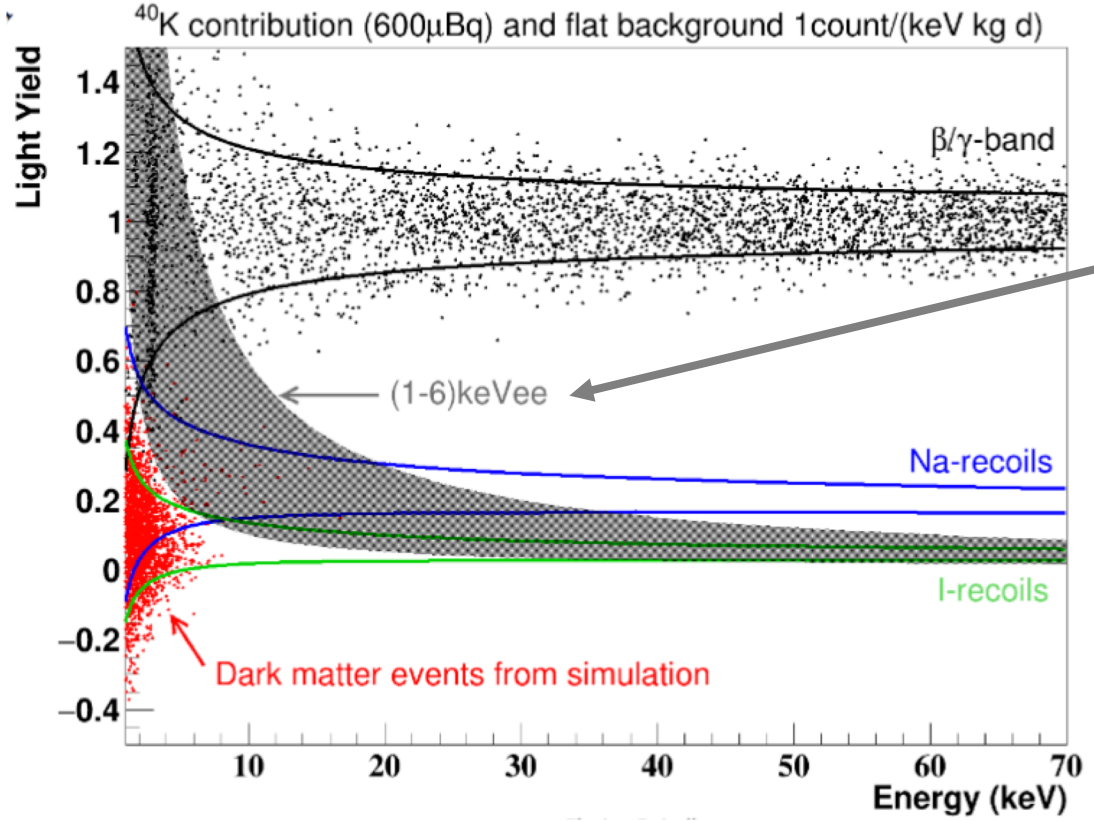
SIMULATED DATA FOR 100 kg days (gross-exposure)



modulation signal in

DAMA/LIBRA = (1-6) keV_{ee}

Talk by Mukund Bharadwaj
Parallel2C Jul 19, 6:20 PM

$$\text{LIGHT YIELD} = \frac{\text{LIGHT SIGNAL}}{\text{HEAT SIGNAL}}$$

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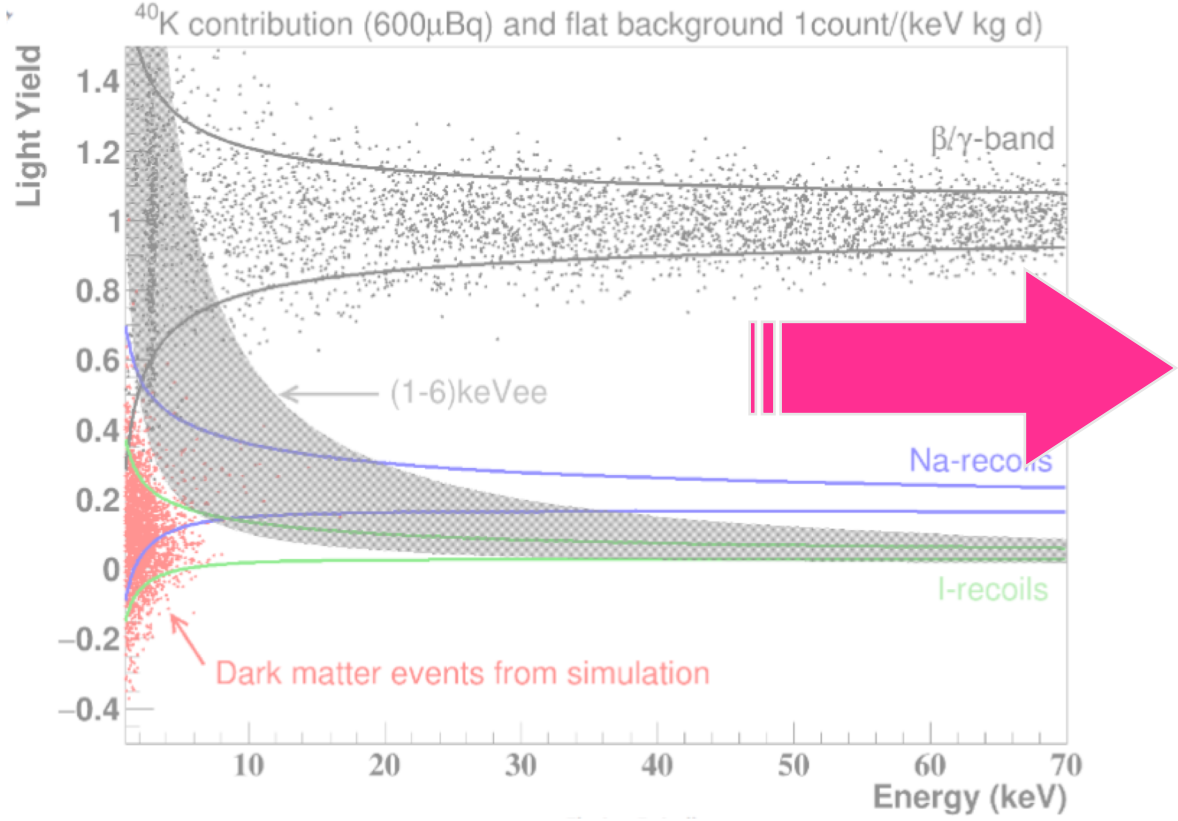

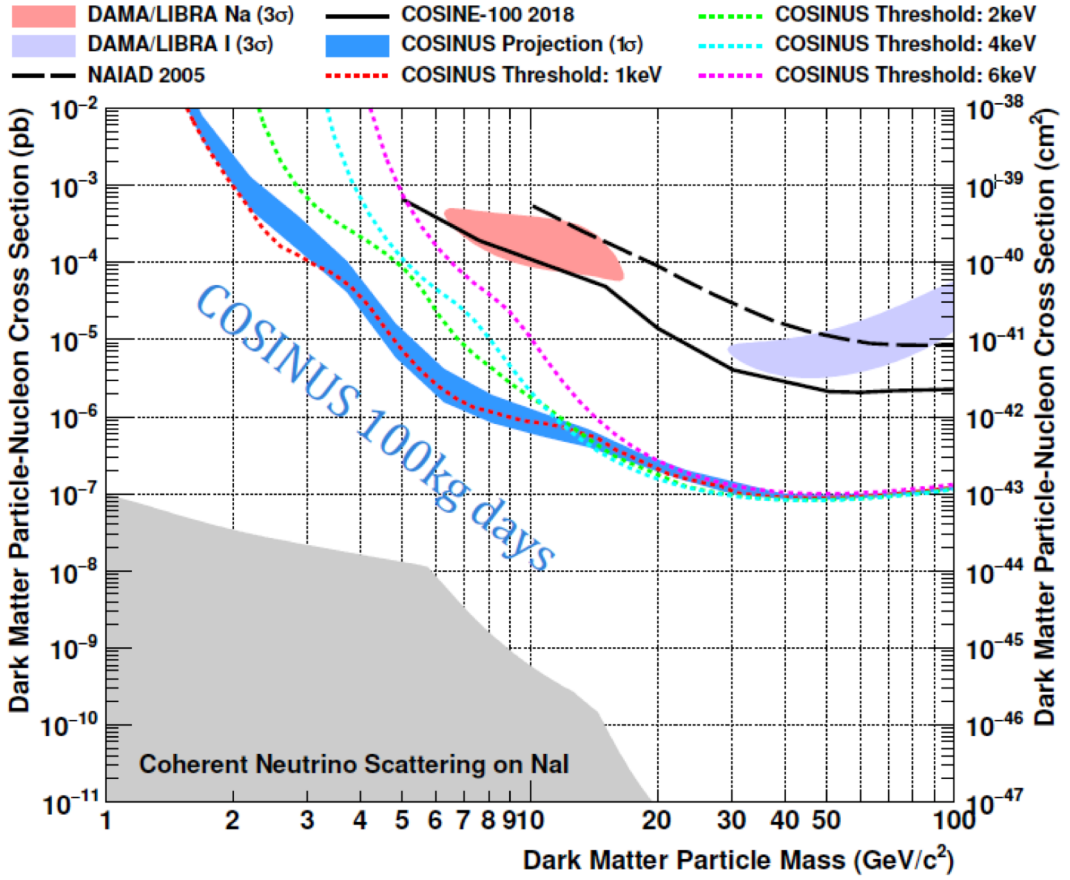

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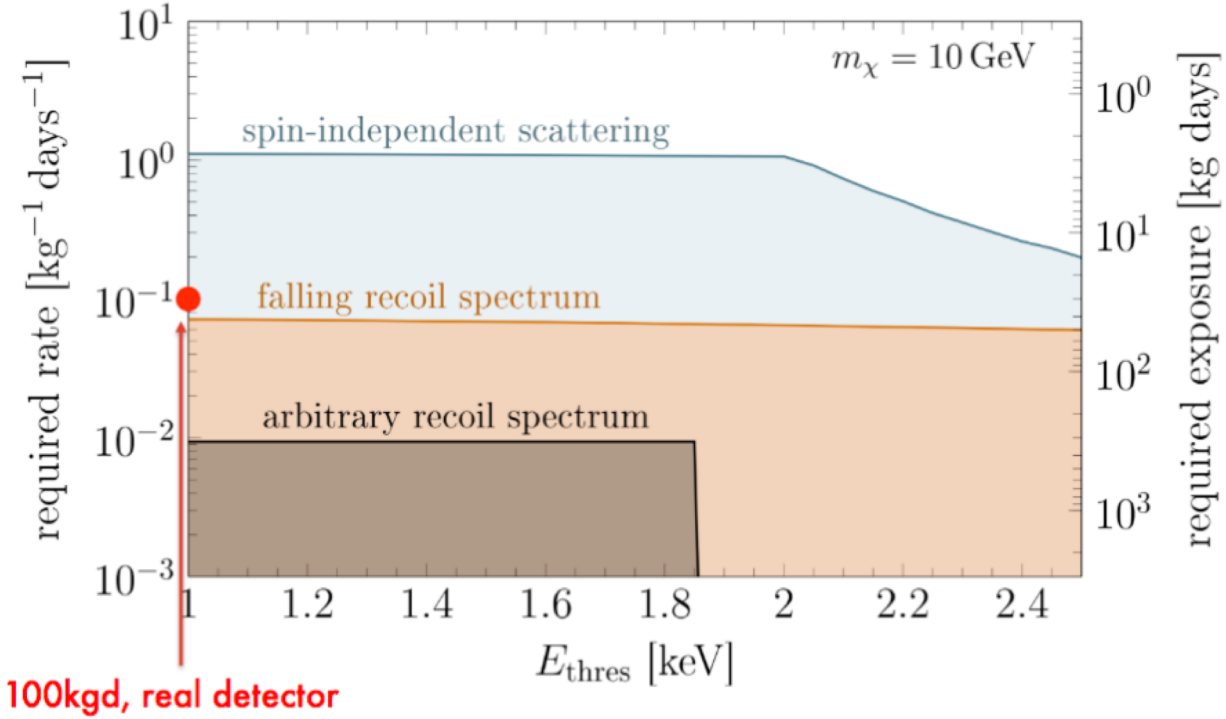
PHYSICS REACH

F. Kahlhöfer, KS et al., JCAP 1805 (2018) no.05, 074



COSINUS – 1π (2023-2025)

exclude or confirm nuclear recoil origin of DAMA:

- independent of DM halo
- for any interaction of DM with nuclei

COSINUS – 2π (≥ 2025)

Investigate annual modulation signature with COSINUS

Warning:
Not updated for DAMA result with 1keVee !!

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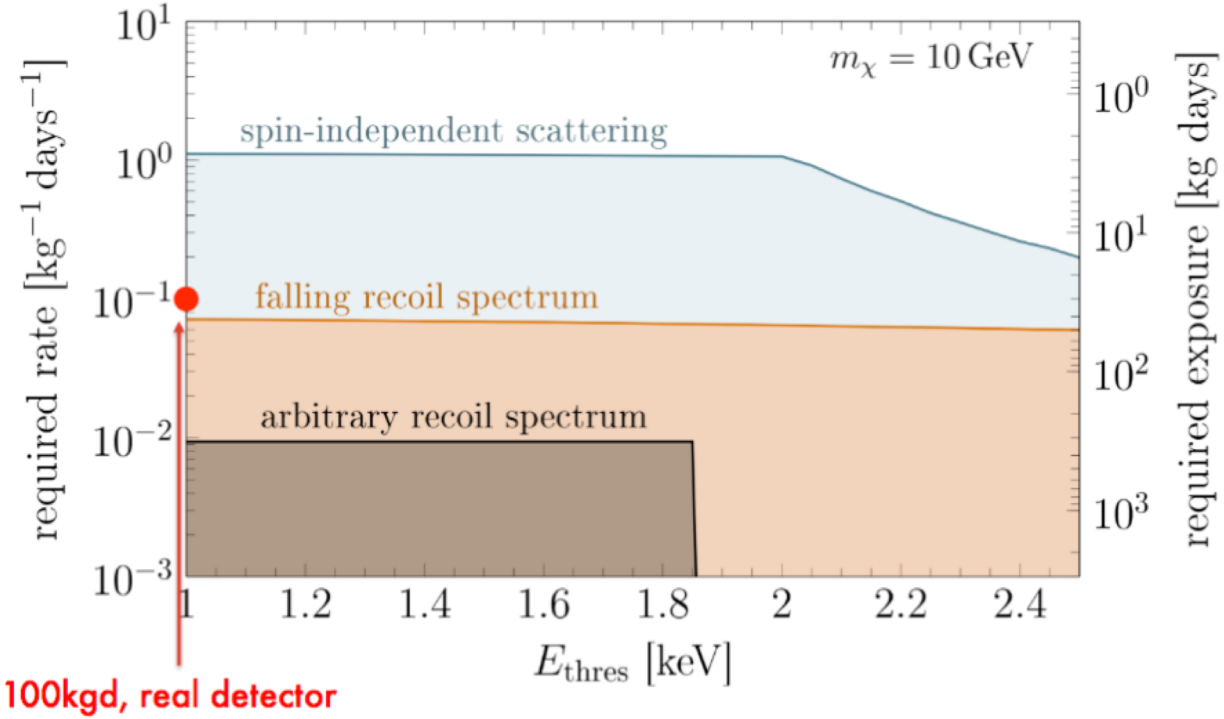

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Poster by Vanessa Zema

1. Detectors

2. Underground site

3. Facility

2016-2021

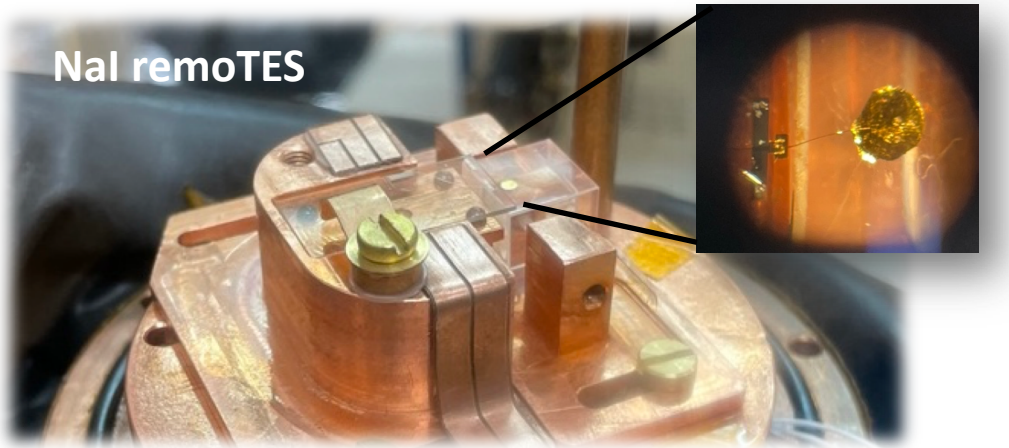
1. Detectors

2. Underground site

3. Facility

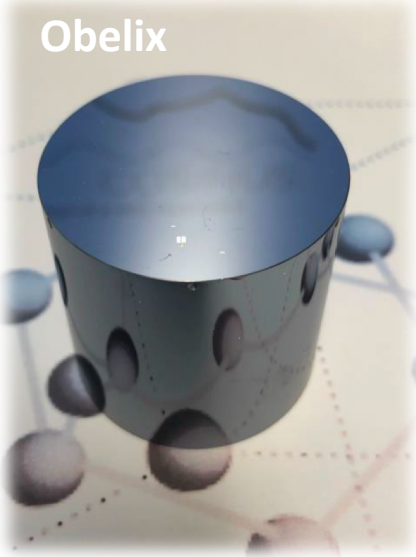
>2021

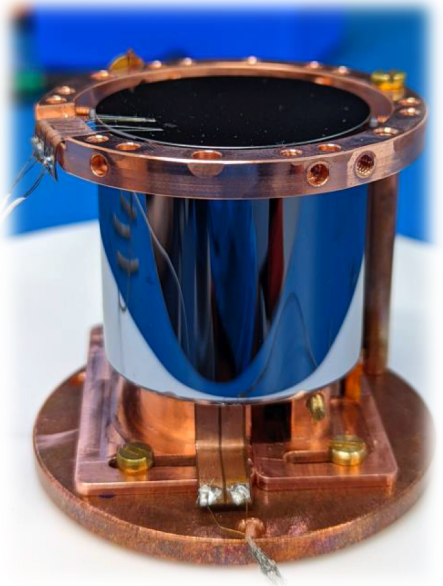
RESULTS FROM NaI-remoTES – June 2022



- NaI (undoped) grown by SICCAS
- dimensions: 10x10x10mm^3; about 4 g
- Au-foil glued with epoxy
- Au-pad size: about 4mm^2
- TES wafer (Al_2O_3) with W-TES

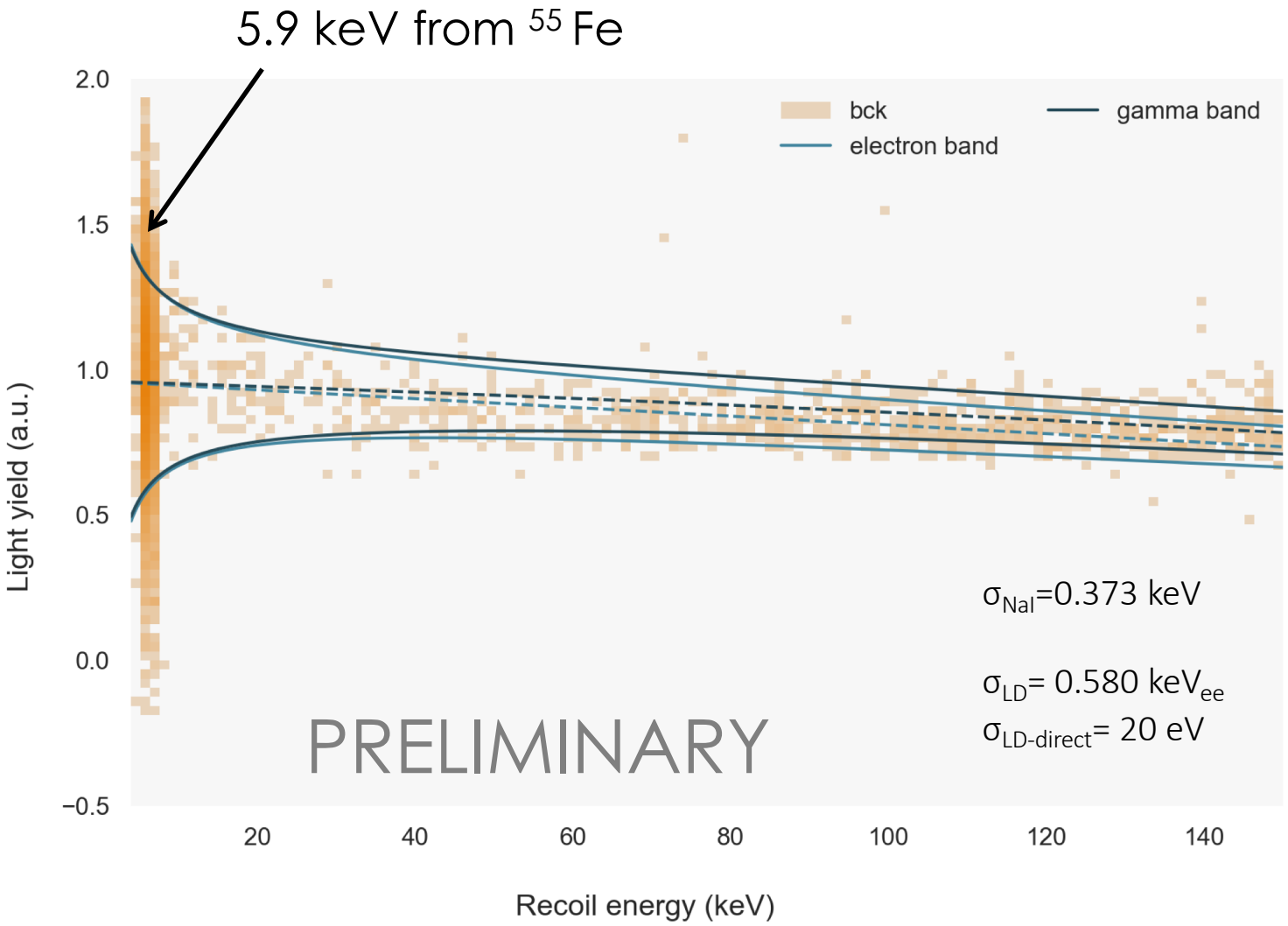
- silicon light absorber of beaker-shape
- dimensions: 40 mm diameter and height, 1 mm thick
- mass: about 15g
- W-TES directly evaporated onto the Si beaker
- TES optimized for light detection
- achieved baseline resolution of 10.2 eV





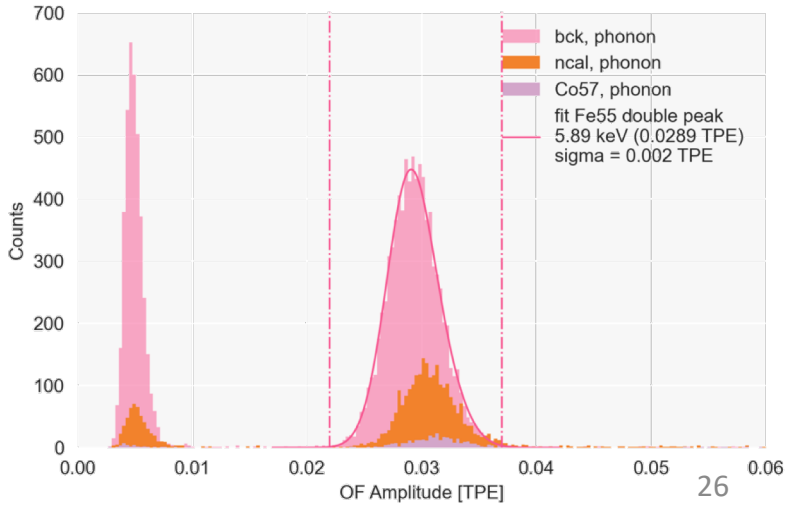
BACKGROUND DATA

Measurement carried out at the test facility of CRESST @ LNGS

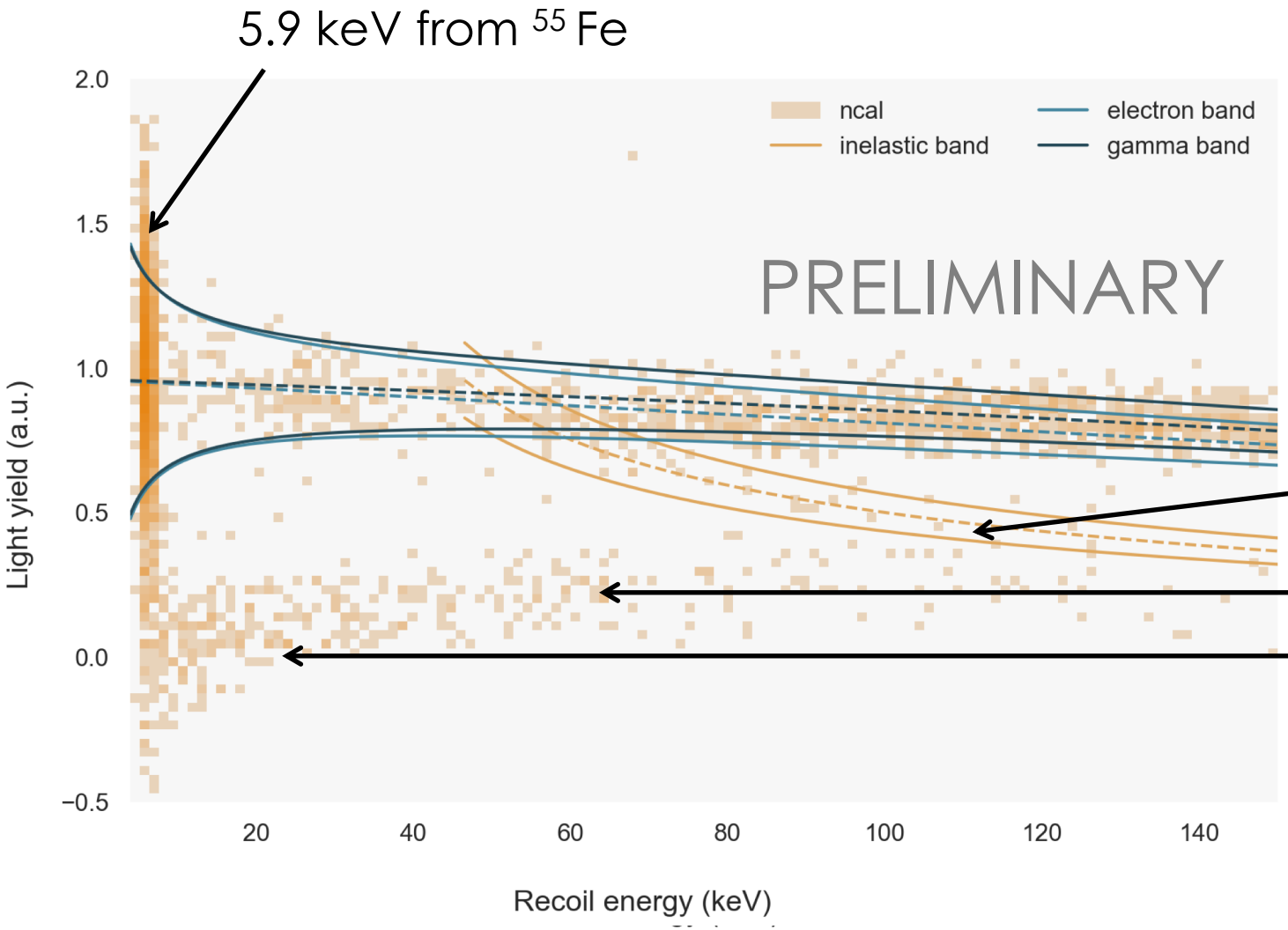


- 58.07 hours of data
- NaI baseline res. = 373 eV

  → E_{thr} < 2 keV
- Obelix baseline res. = 581 eV$_{ee}$
- Obelix direct hits res. = 20 eV
- Light output NaI: **3.5%**
- energy calibration with ^{55}Fe & ^{57}Co



NEUTRON DATA



- AmBe neutron source
- 26.0 hours of data

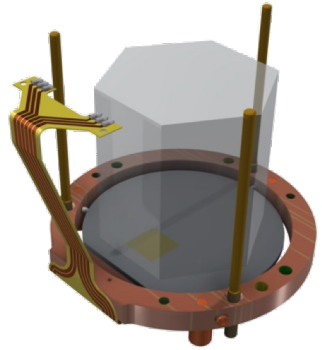
events due to inelastic scattering

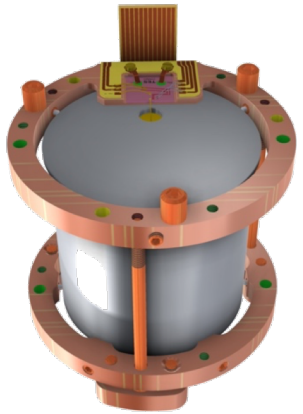
Na recoil events from elastic scattering

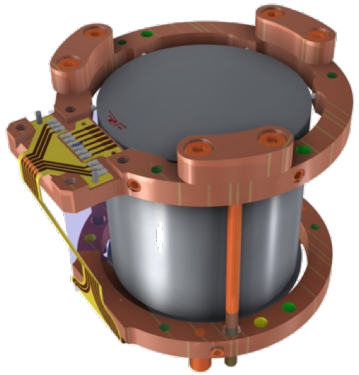
I recoil events from elastic scattering

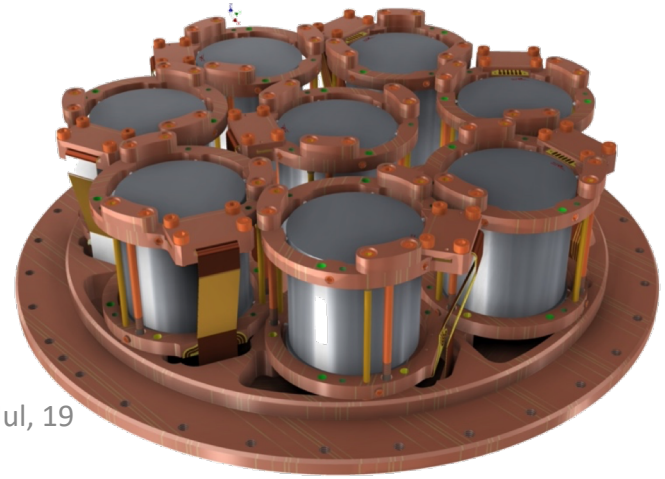
proof of particle identification in a NaI-based detector

OUTLOOK

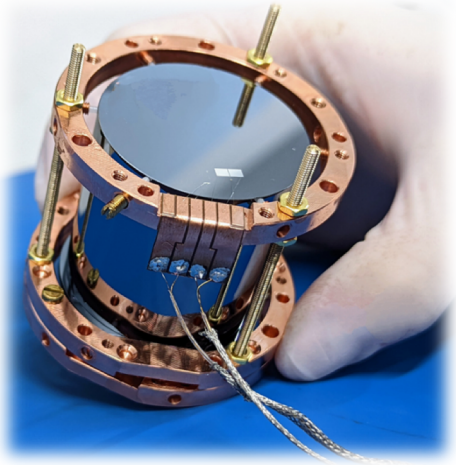




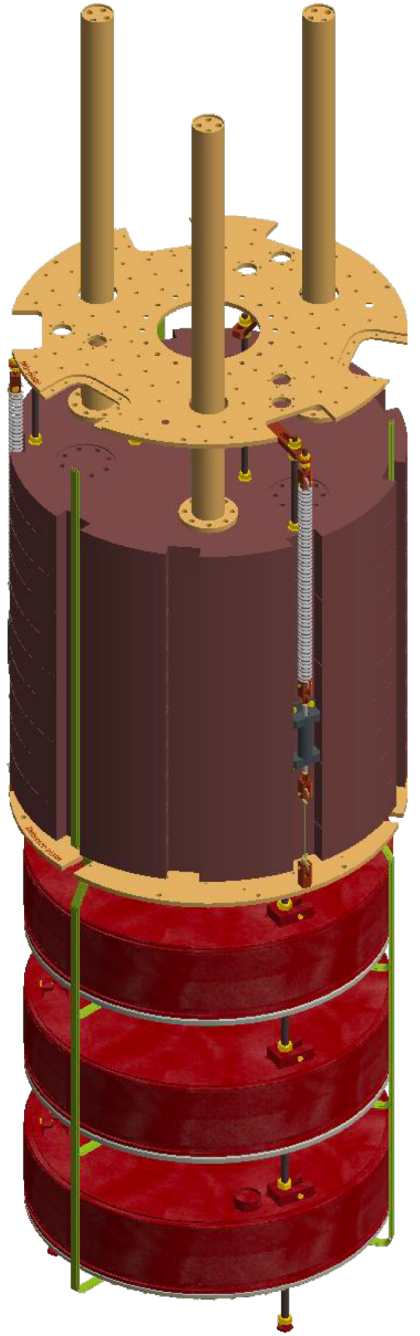




- hexagonal crystal (65 g / 110 g)
- lid to host crystal

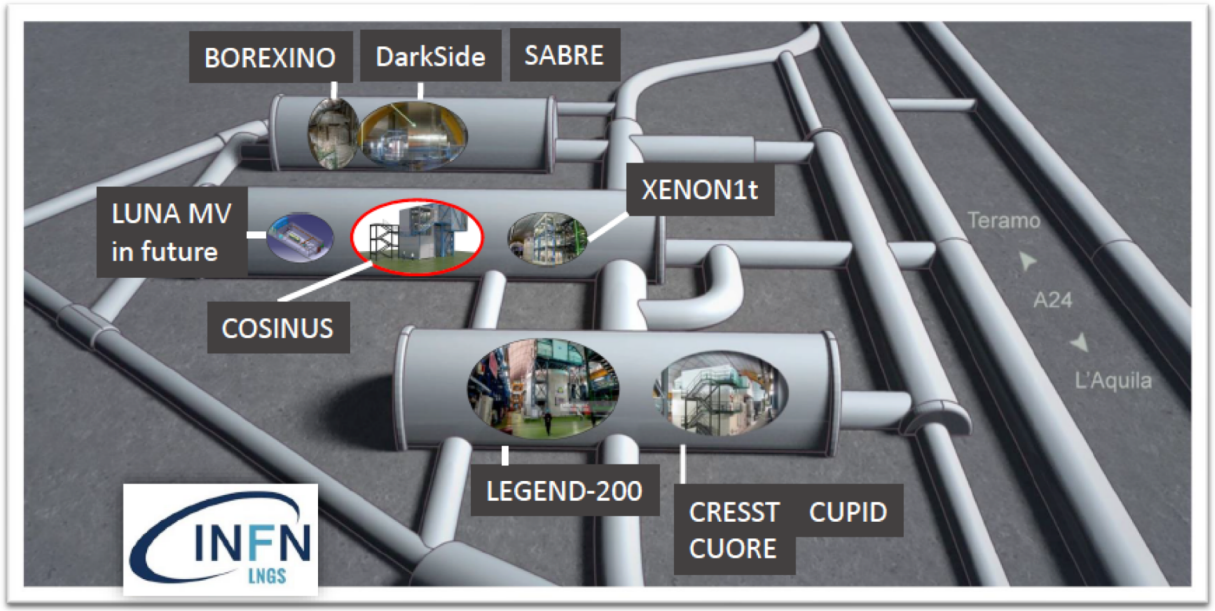


- Si-beaker for 4π active surrounding of the crystal



- 8 detector modules per level
- 3 levels in final stage

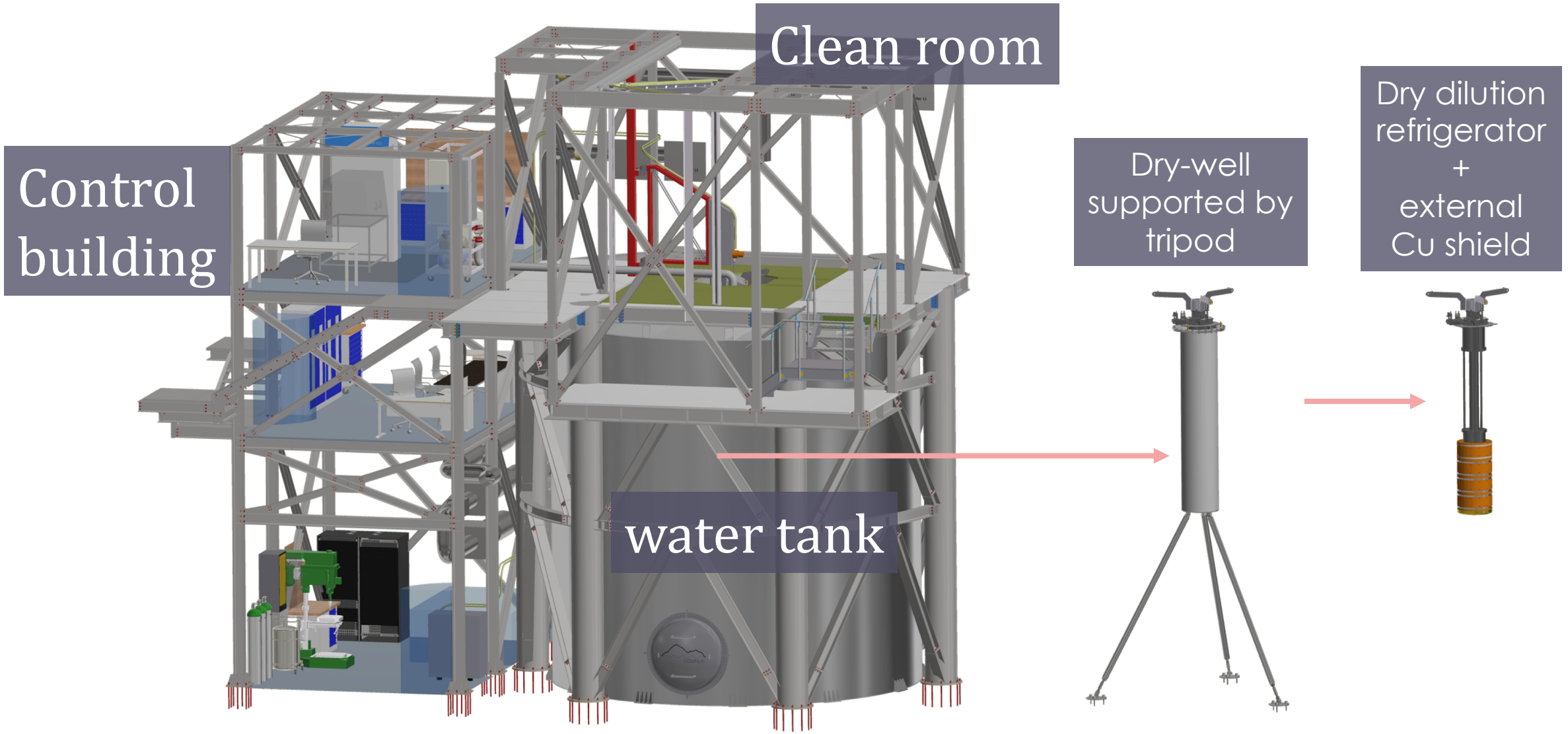
COSINUS experimental site



- Laboratori Nazionali del Gran Sasso (LNGS)
- COSINUS is located in hall B
- full approval in 2021

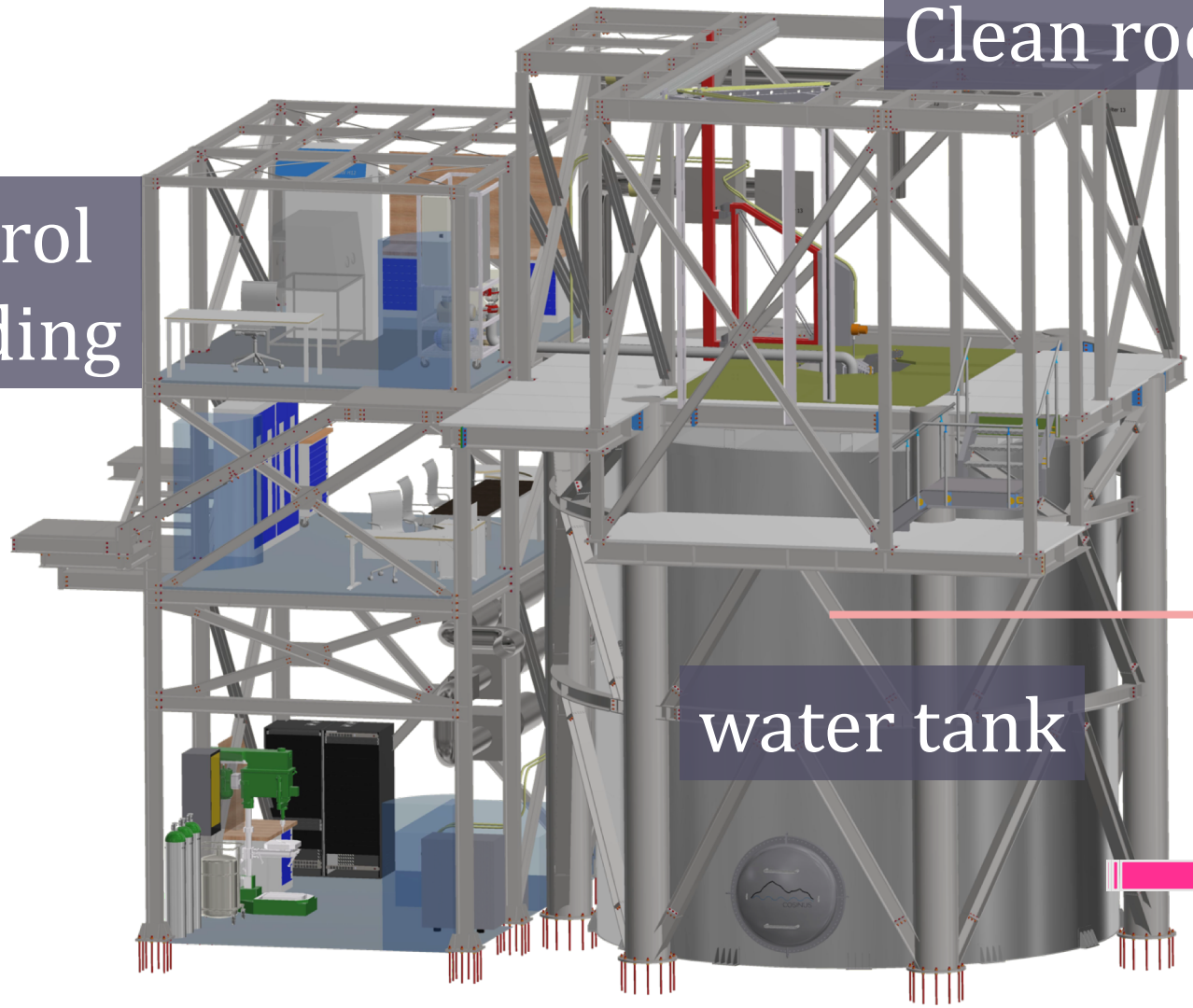
COSINUS experimental facility

Shielding design based on MC simulations: EPJ C 82, 2022



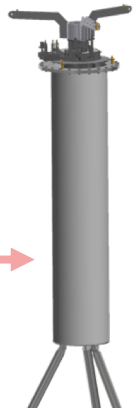
COSINUS experimental facility

Shielding design based on MC simulations: EPJ C 82, 2022



Dry-well supported by tripod

Dry dilution refrigerator + external Cu shield



Poster by Martin Stahlberg

WHY WE NEED A WATER TANK?

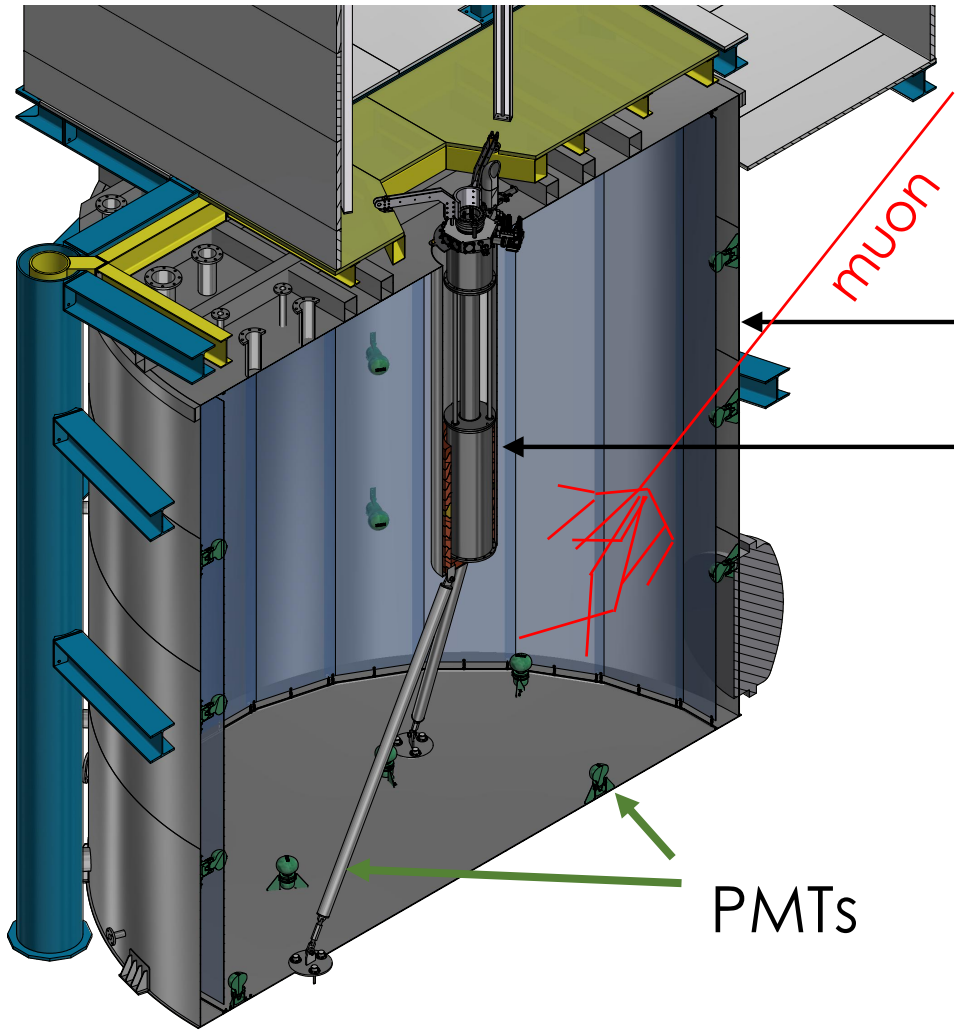
- good moderator for neutrons
- veto of (cosmogenic) muons via Cherenkov light emitted in water
  → instrumentation of water tank with ~30 PMTs

Rate of cosmogenic neutrons:

no veto: (3.5 ± 0.7) cts kg^{-1} yr^{-1}

with veto: < 0.05 cts kg^{-1} yr^{-1}

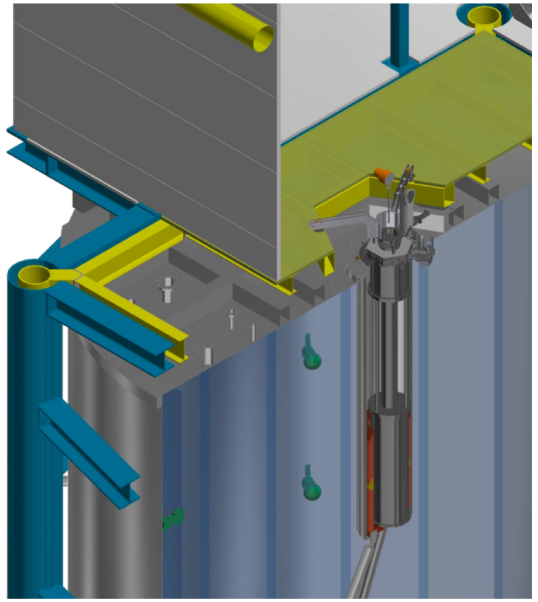
Shielding based on MC simulations:
EPJ C 82, 2022



Poster by Matthew Stukel

VIBRATION MITIGATION: 3 LEVELS

GLOBAL STAGE

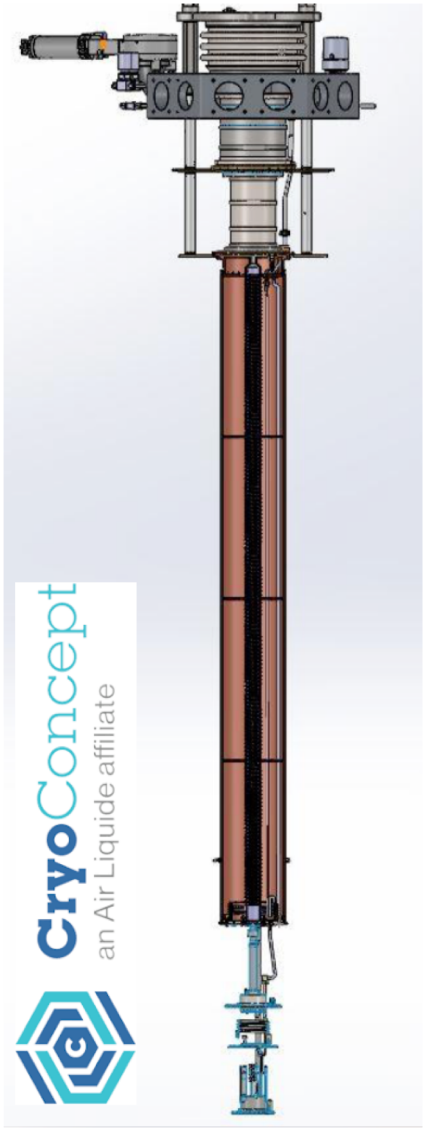


infrastructure on blue frame
→ most "noisy"

pulse tube unit on yellow frame
→ medium

cryostat "rests" in drywell
→ most quiet

CYROSTAT STAGE



UltraQuiet Technology

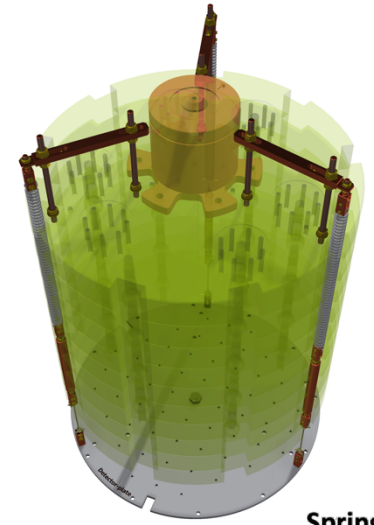
all parts of cryostat are centered

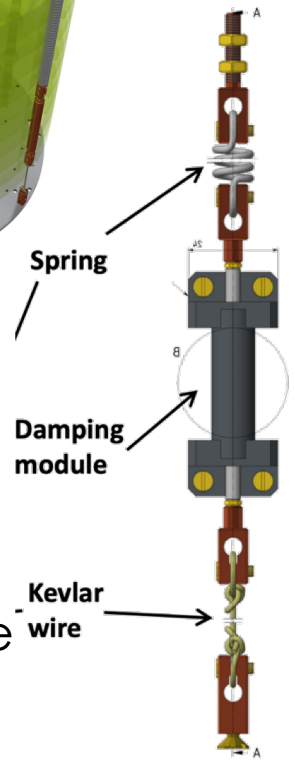
190kg copper shield below the mixing chamber

rotary valve of the pulse tube cooler on separate frame

sandbox

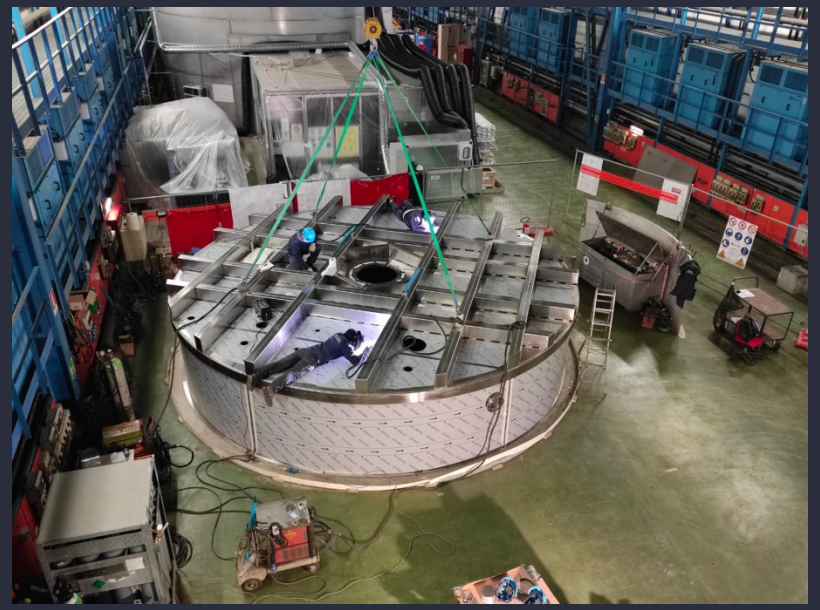
DETECTOR STAGE





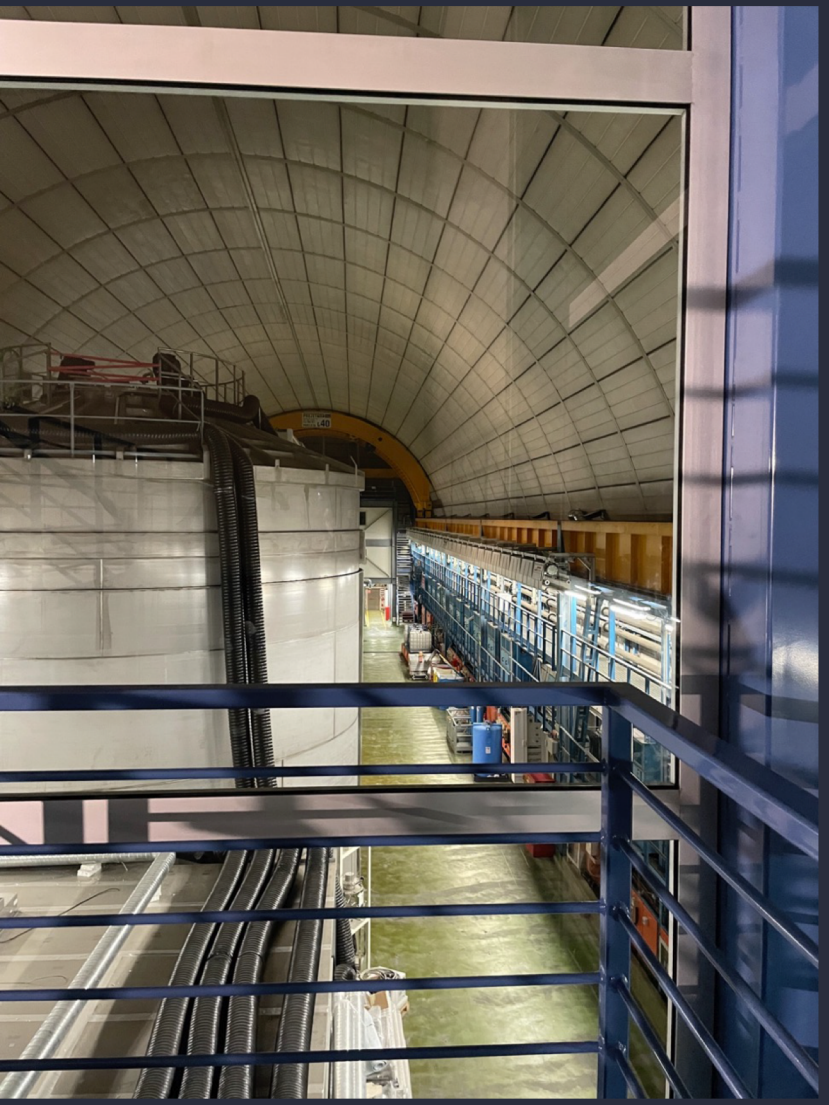
Spring and damping modules to decouple the detector plate

magnetic eddy current damping



installation @ LNGS: 10/2021 – 12/2021

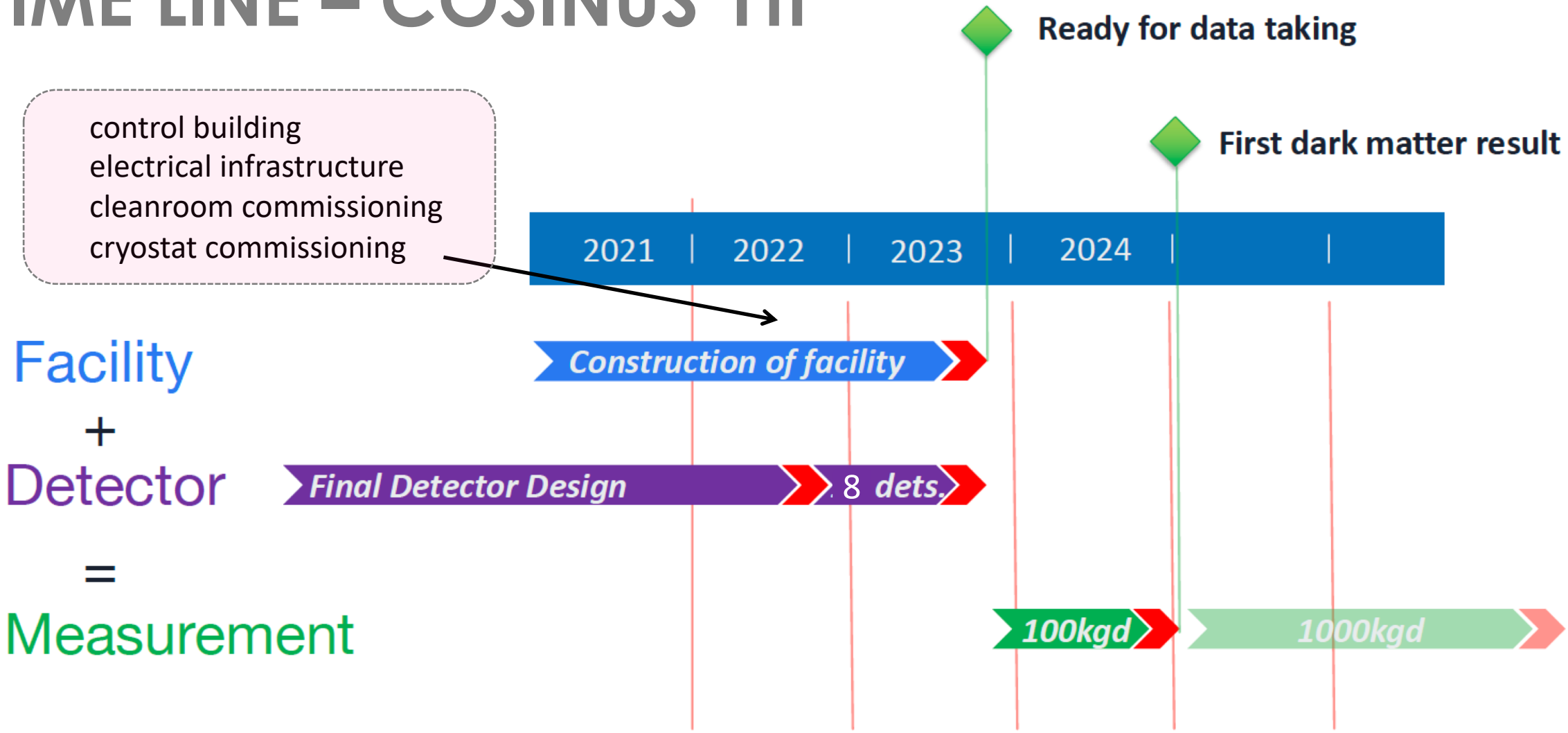
12/2021: water tank finished



installation @ LNGS: 04/2021 – ongoing

07/2022:
platform and clean room finished
→ control building in construction

TIME LINE – COSINUS 1π




TEAMWORK
MAKES THE
DREAM WORK

COSINUS COLLABORATION

~25 Scientists

www.cosinus.it

HEPHY INSTITUTE OF HIGH ENERGY PHYSICS

TU WIEN

MAX-PLANCK-INSTITUT FÜR PHYSIK

INFN Istituto Nazionale di Fisica Nucleare

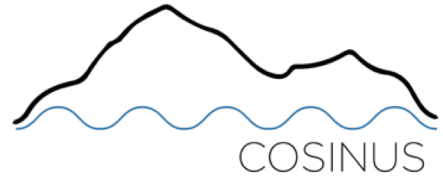
HELSINKI INSTITUTE OF PHYSICS

GRAN SASSO SCIENCE INSTITUTE

SCHOOL OF ADVANCED STUDIES Scuola Universitaria Superiore

Since 1928 SICCAS

SUMMARY



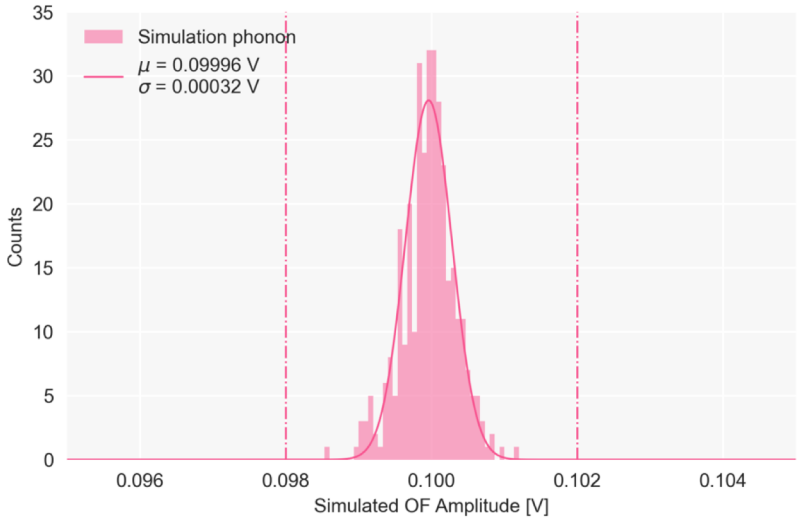
- Dark matter is a fundamental question of present-day physics and COSINUS can, after more than two decades, confirm or reject the DAMA claim
- COSINUS is approved and funded and the construction of the experimental facility at LNGS has started in October 2021and is going on full steam
- COSINUS developed the first NaI dark matter detector with particle discrimination and offers better sensitivity at smaller target mass (~1kg for COSINUS vs. 250kg for DAMA)
- remoTES readout allowed to produce first NaI calorimeter that achieved the performance goal (E_{thr} < 2keV); remoTES also of interest for other applications
- Stay tuned, exciting times ahead!

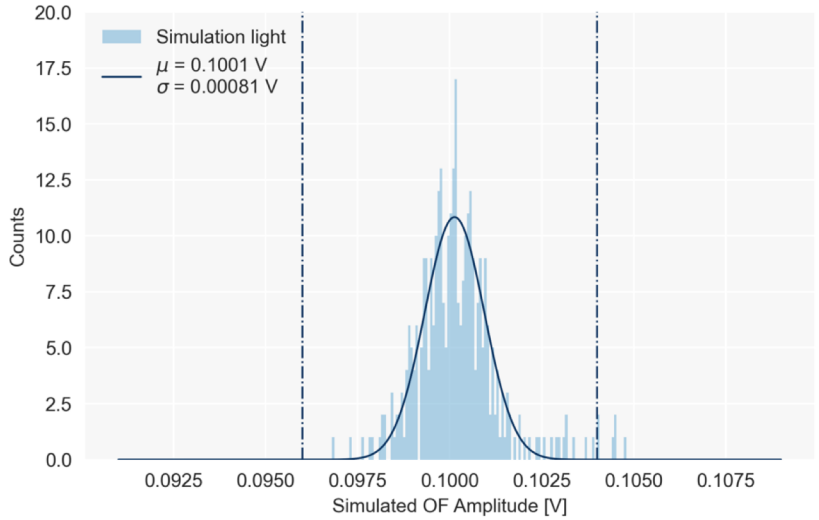

Thank you for your attention
@Maurizio Verdecchia Photography

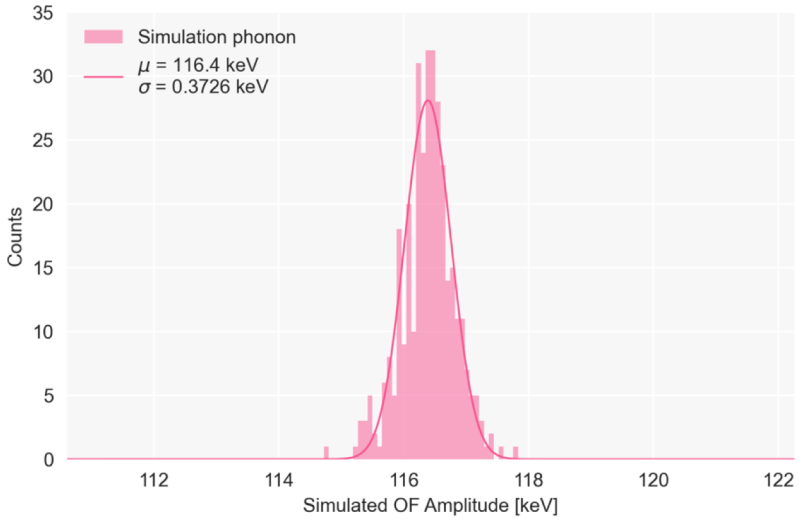
EXTRA MATERIAL

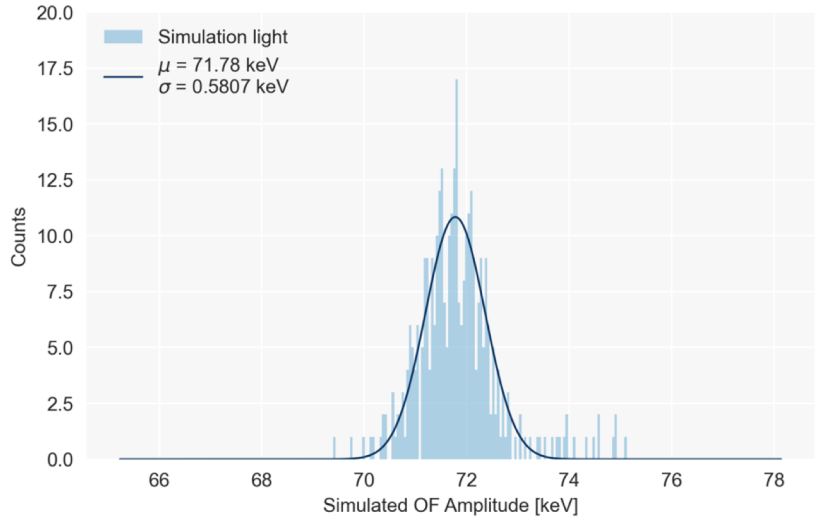
RESOLUTIONS

	NaI	Obelix
Resolution in V	0.32 mV	0.81 mV
Resolution	3731 eV	581 eVee

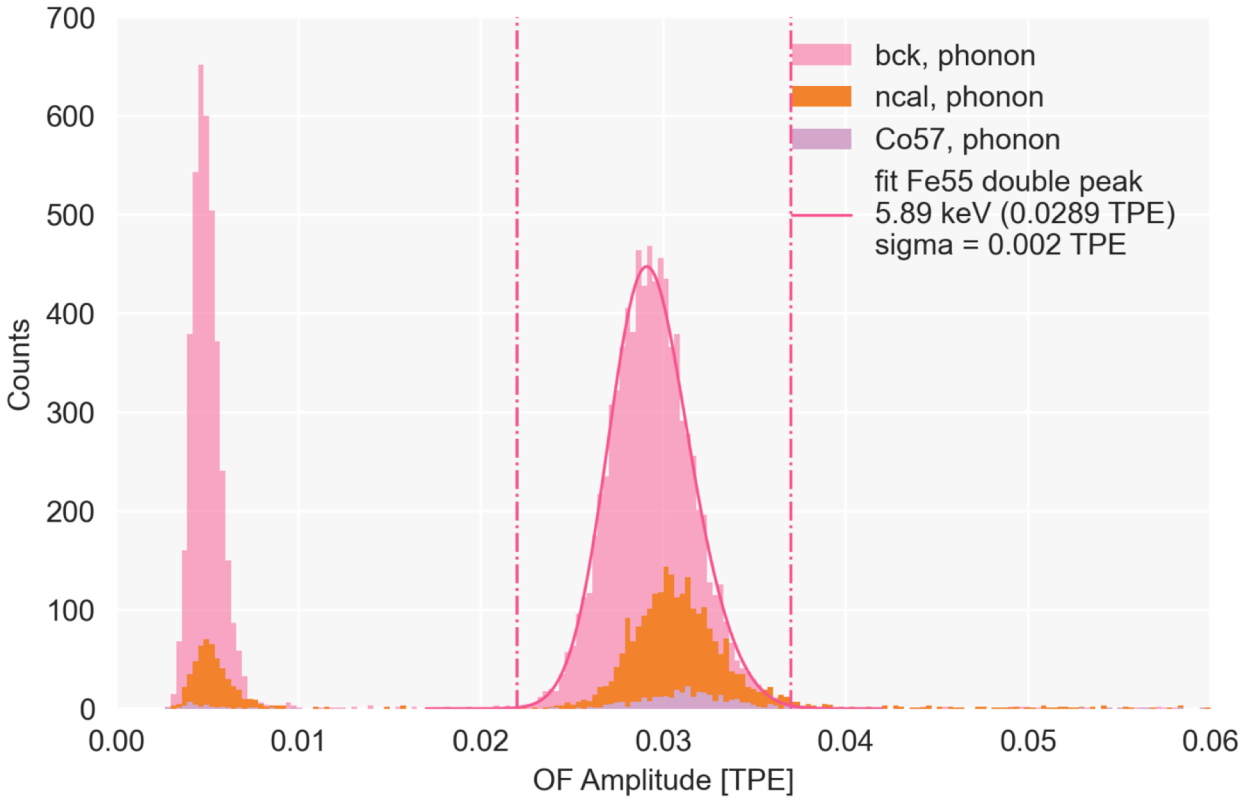


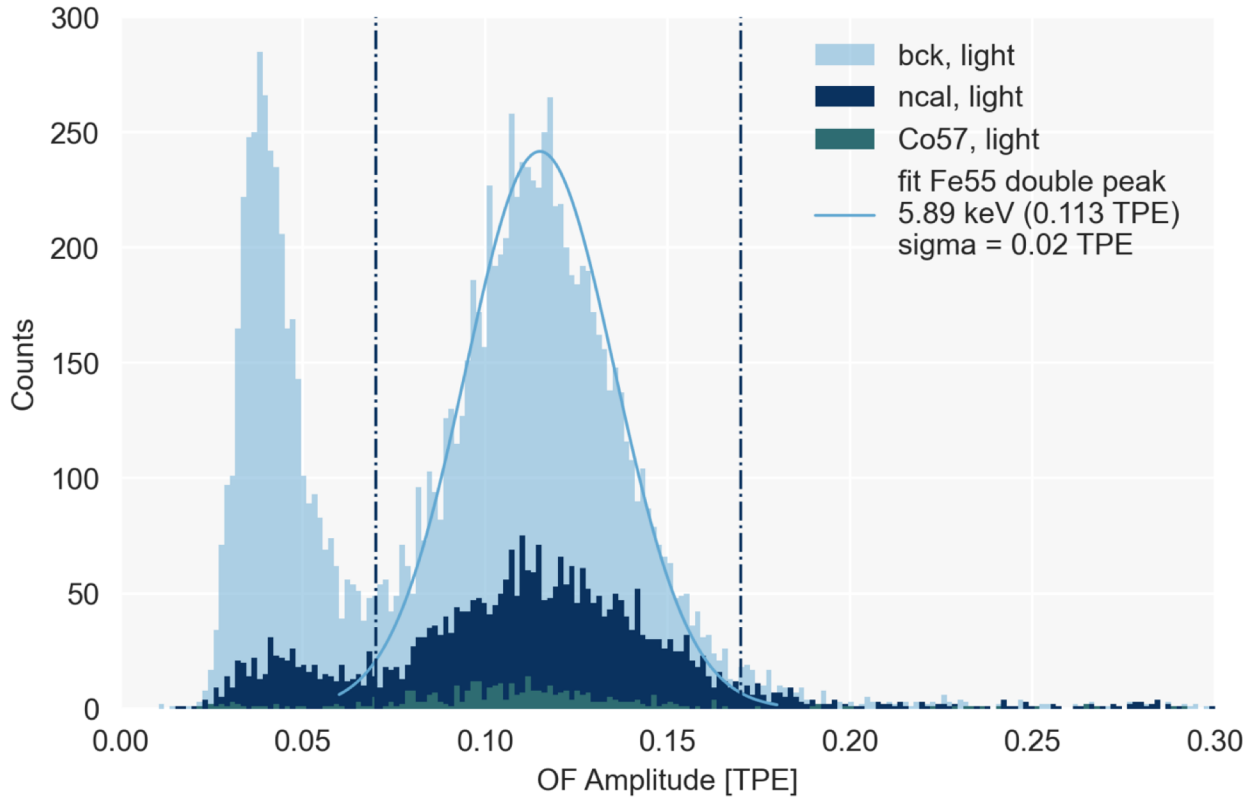






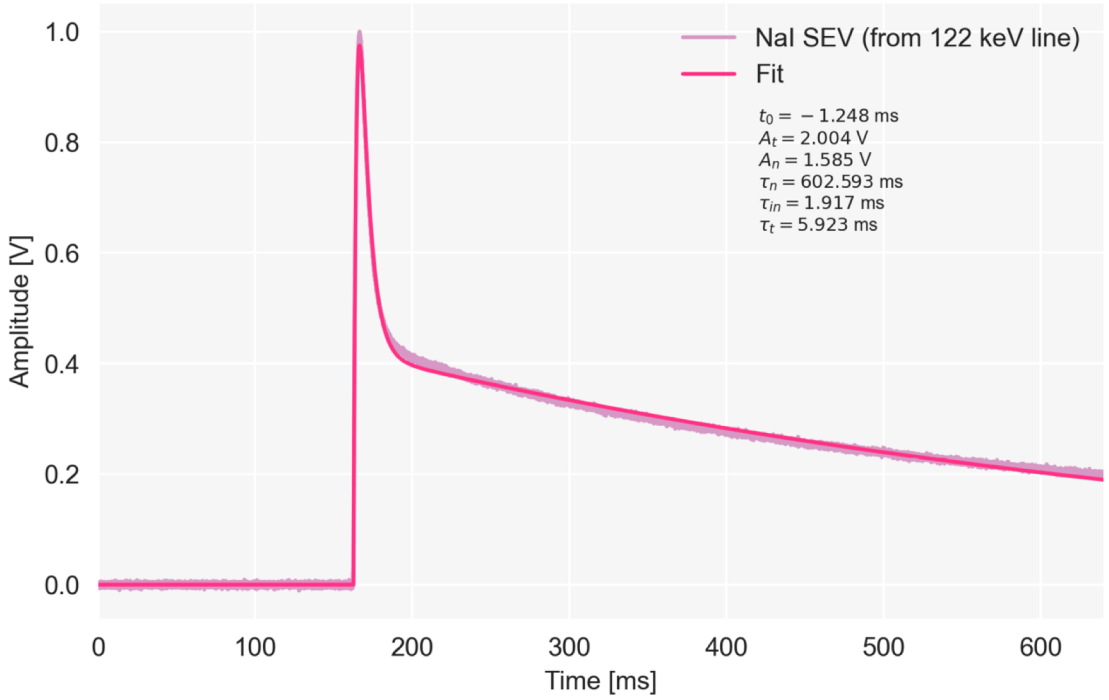
ENERGY CALIBRATION



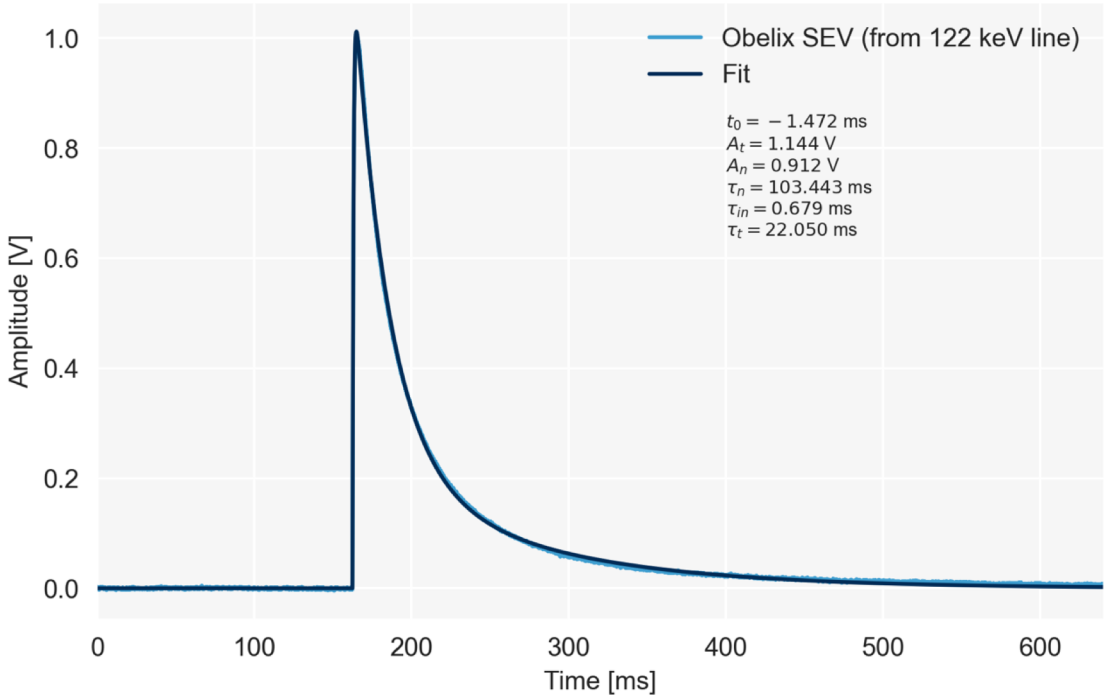


PULSE SHAPE

NaI-remoTES



Obelix



PHYSICS REACH

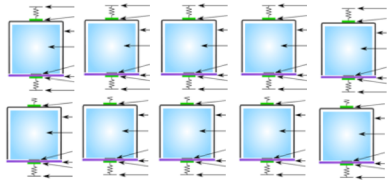
COSINUS has the unique potential to clarify a nuclear recoil origin of the DAMA/LIBRA signal

CONFIRM

+ not **too exotic** dark matter

Good chance for exposure $\mathcal{O}$ (100 kg days)

10 detector modules
about 50 g each



1 year of data taking
50% overall efficiency

Low-background cryogenic facility
underground lab, shields, dilution refrigerator

RULE-OUT

$\mathcal{O}$ (100 kg days): strong statement

$\mathcal{O}$ (1000 kg days): fully model-independent

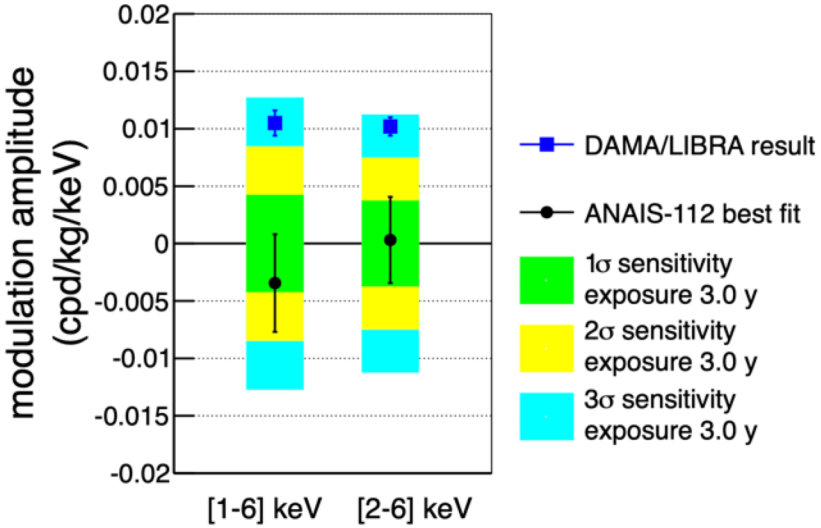
JCAP 1805 (2018) no.05, 074

ANAIS-112

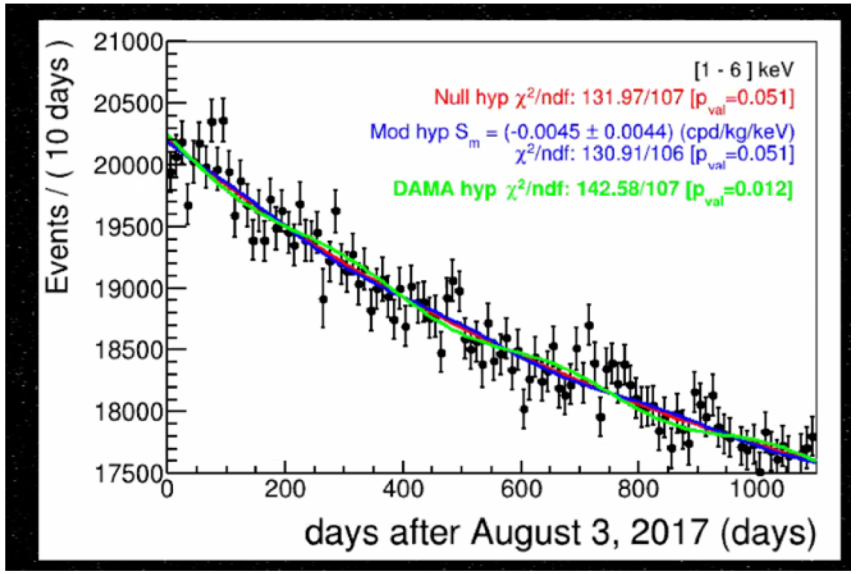
PRD 103.10 (2021): 102005

No modulation observed

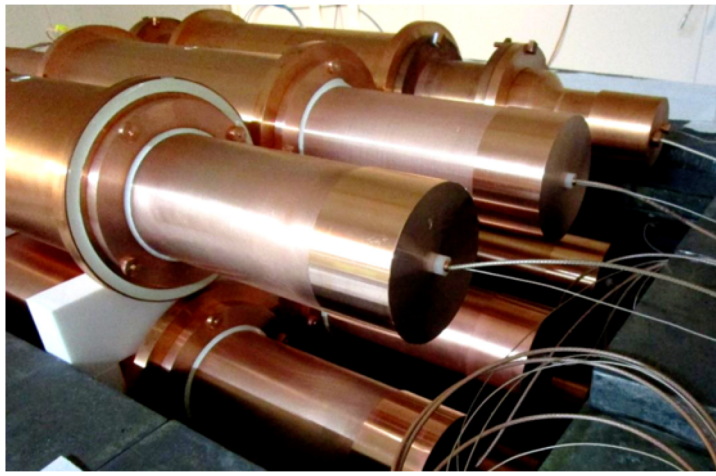
incompatible with DAMA at 3.3σ [1-6 keV]



3 years of data = 314 kg year



Moriond 2021: M.L. Sarsa



COSINE-100

- excludes DAMA interpreted as SI interaction with standard halo model

  Nature 564, 83 (2018)
  PRL 123, 031302 (2019)

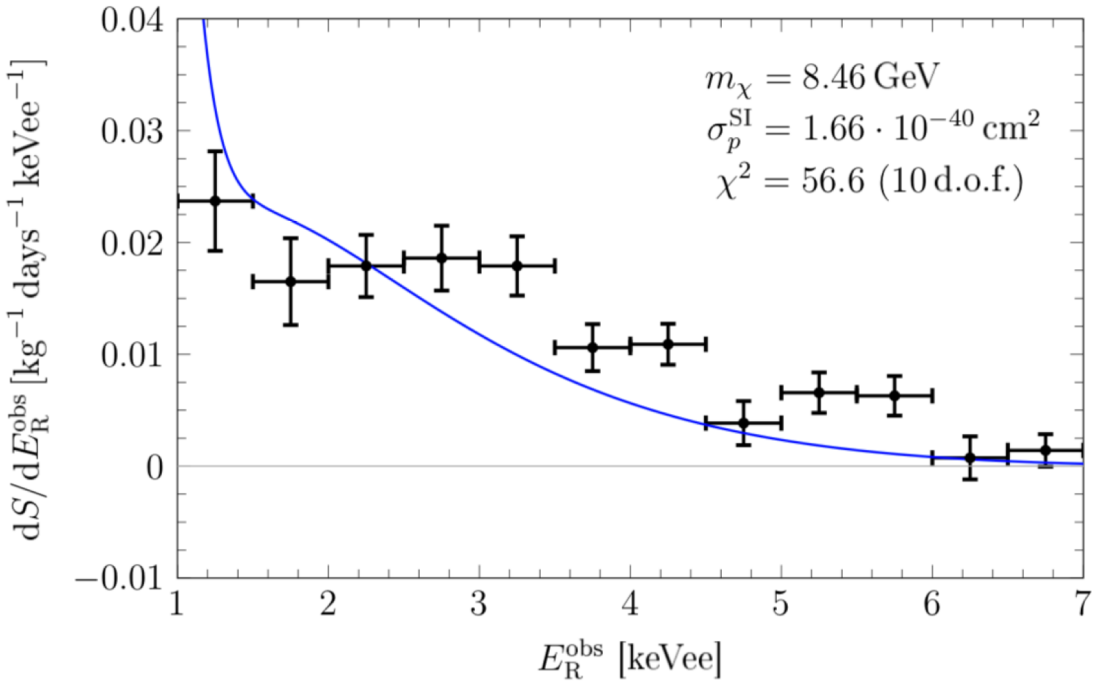
- modulation analysis of 3 years of data (173 kg year) is consistent both with and without modulation

  arXiv:2111.08863

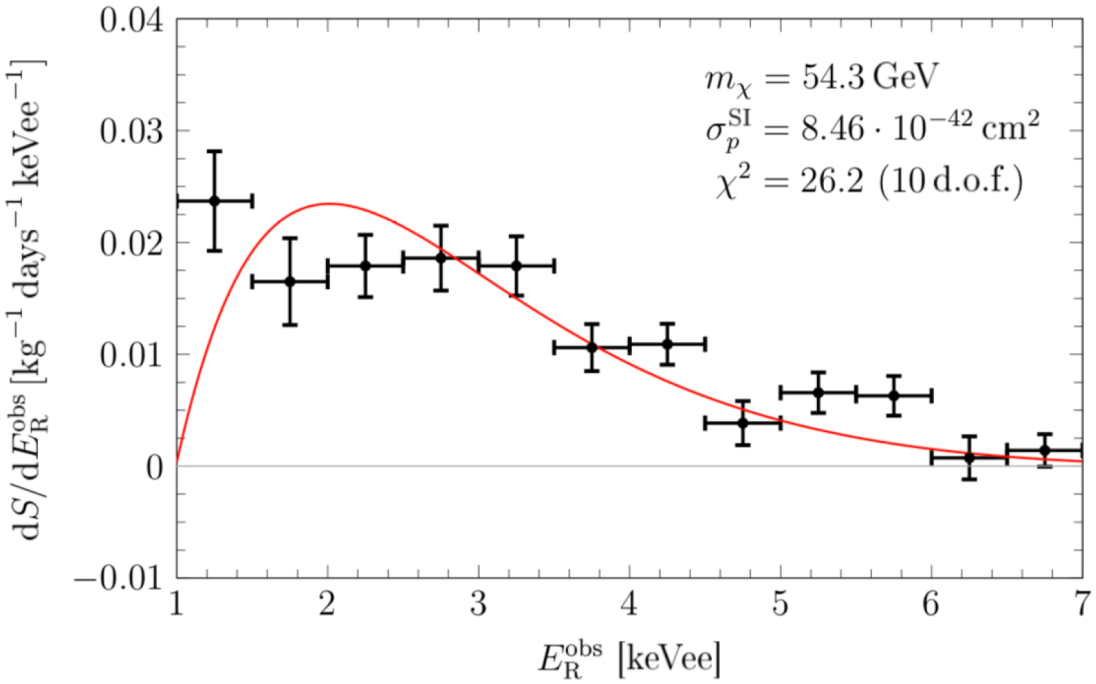
(Felix Kahlhoefer, FR et al JCAP05(2018)074)

DAMA in the standard scenario

Best fit for scattering off Na



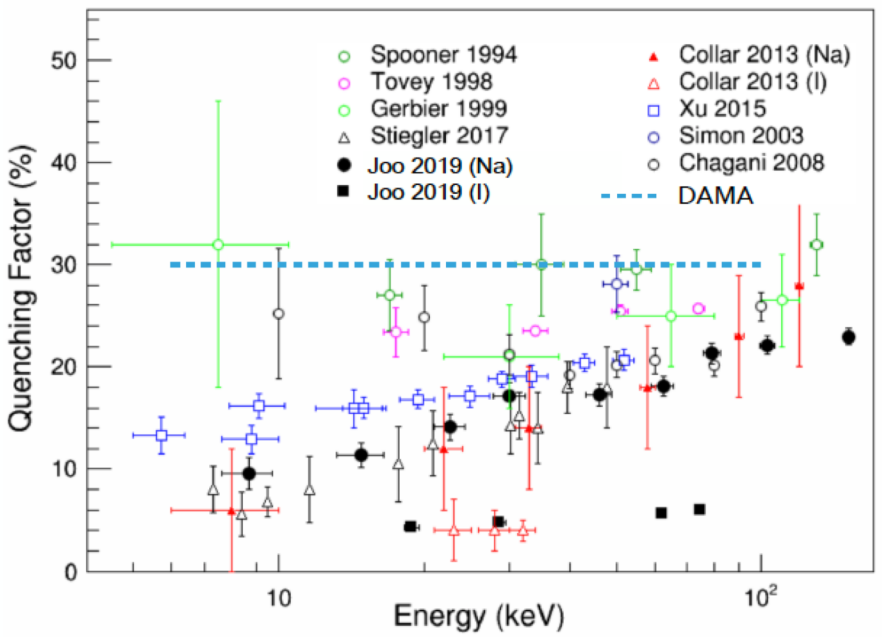
Best fit for scattering off I



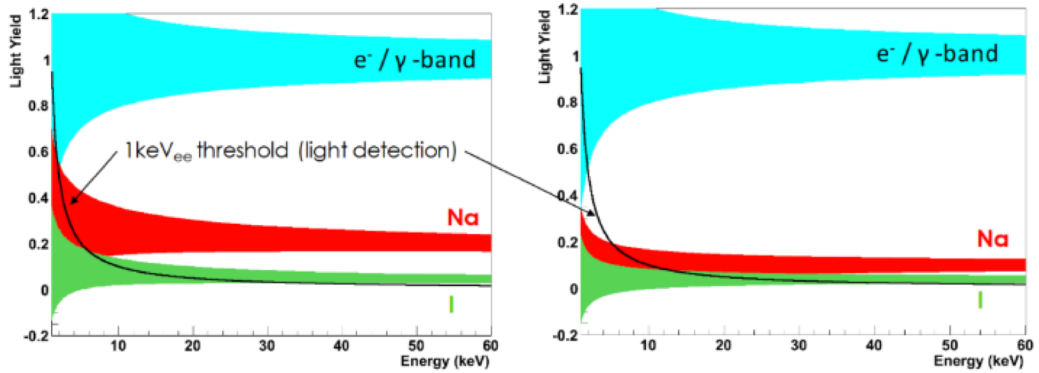
Warning: Depends on Quenching Factors

„QUENCHING FACTOR MYSTERY"

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



- Measurements of quenching factors (QF) at room temperature do not agree
- In particular, role of Tl is unclear (usually crystals are doped)
- Strong influence of QF on NR energy scale -> comparability of modulation studies (!)
- COSINUS will provide the first cryogenic QF measurement for NaI



recoils off Na → factor ~ 0.3

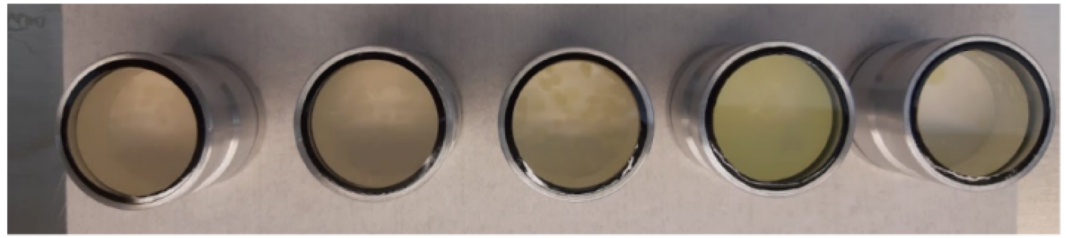
recoils off I → factor ~ 0.1

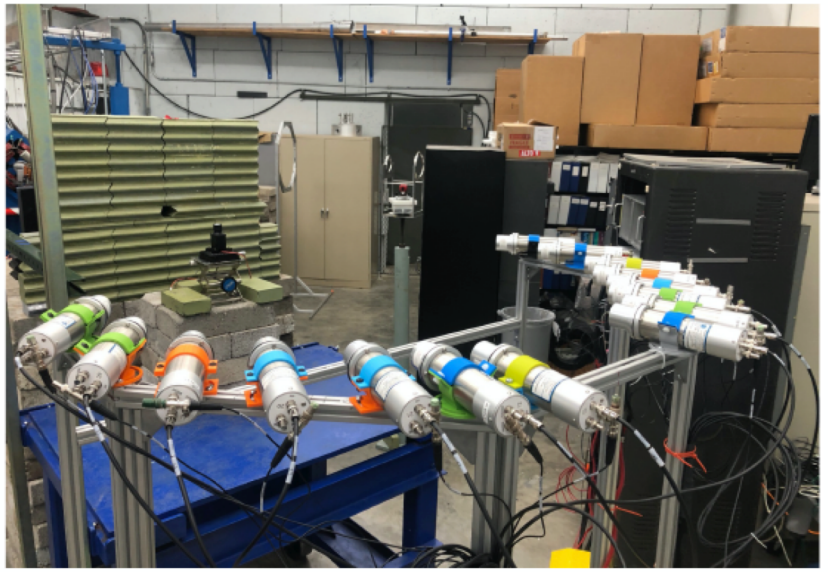
recoils off Na → factor ~ 0.1

recoils off I → factor ~ 0.04

„QUENCHING FACTOR MYSTERY"

- Initiated QF Measurement at TUNL (Triangle Universities Nuclear Laboratory), performed in September 2021 by the Barbeau group
- Monoenergetic neutron beam (~3.3MeV) , detectors at different scattering angles
- Five ultrapure crystal samples from SICCAS with different Tl dopant levels tested
- Analysis ongoing!

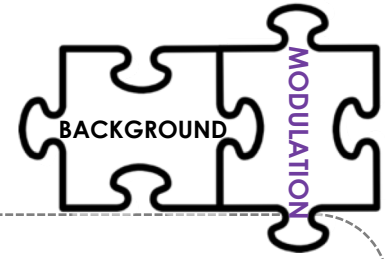




Since 1928 SICCAS

COSINUS

NaI EXPERIMENTS *incomplete list!*

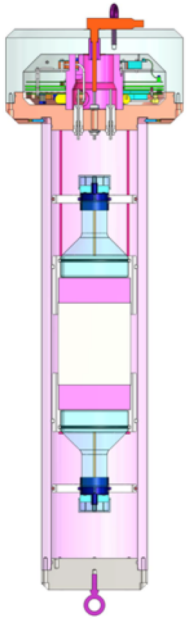


DM-Ice17

South pole
17 kg NaI

energy: 4 keV_{ee}

3.5 y physics run
no hint

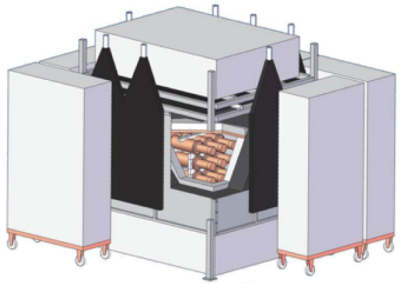


ANAIS-112

LSC - Spain
112.5 kg NaI

energy: < 1 keV_{ee}

spring 2017



COSINE-100

Y2L Korea
KIMS NaI + DM-Ice
106 kg

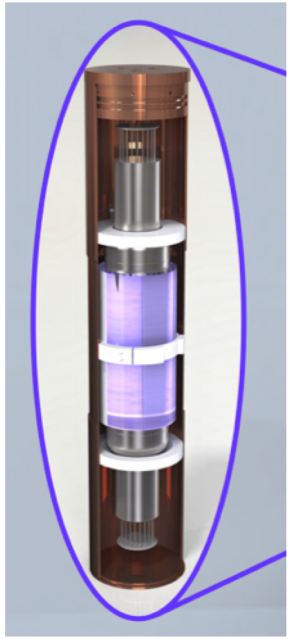
energy: ~ 2 keV_{ee}

since Sept. 2016

SABRE

Gran Sasso/Australia
40-50 kg NaI

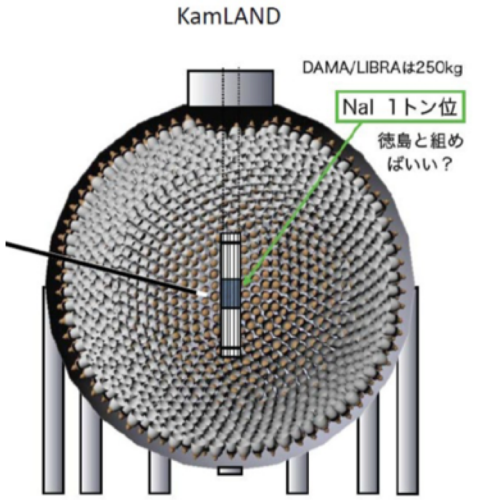
construction phase
PoP 2020



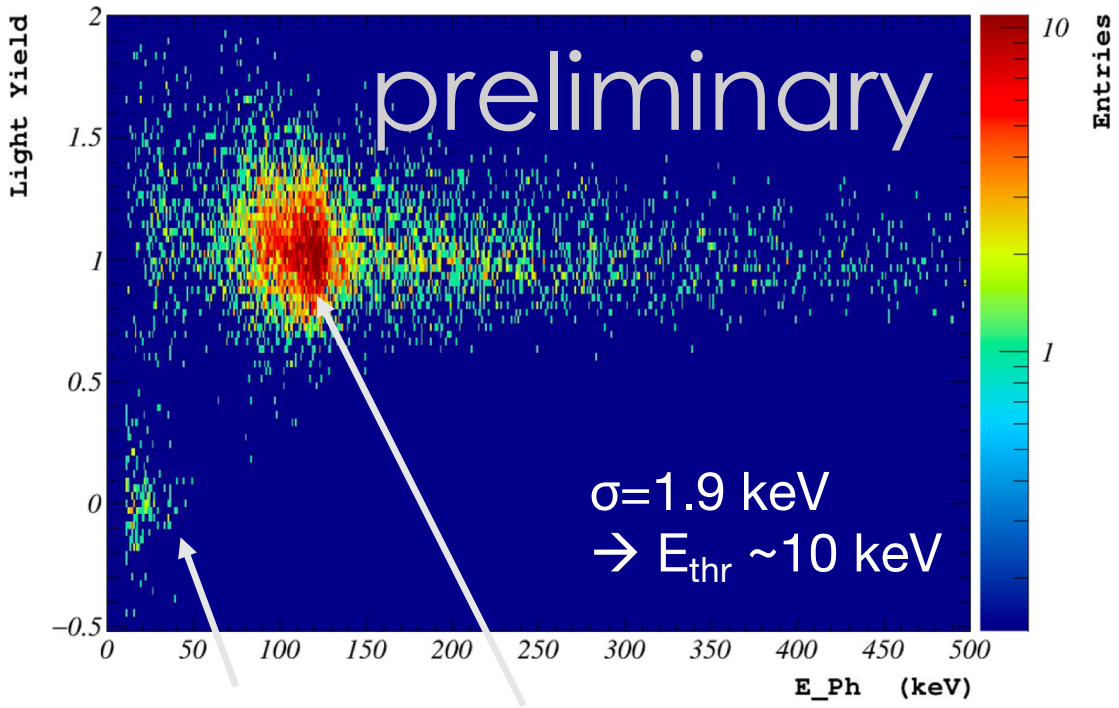
KamLand-PICO-Ion

KamLand/Japan
1t NaI

planning/
prototyping phase



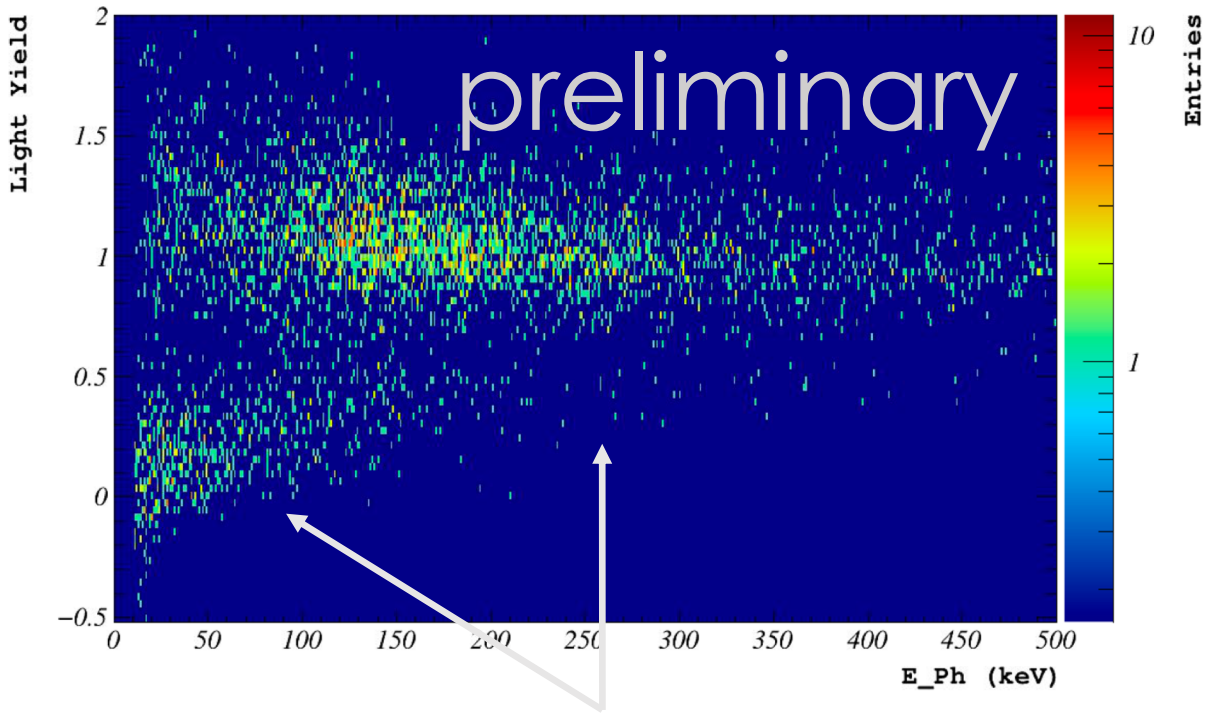
Co^{57} gamma calibration



direct TES wafer hits

122 keV

neutron calibration



neutron-induced events on Na, I