COSINE dark matter search

Resolving DAMA/LIBRA

Hyunsu Lee

Institute for Basic Science

Center for Underground Physics

CPNR Workshop 2026 @ CAU

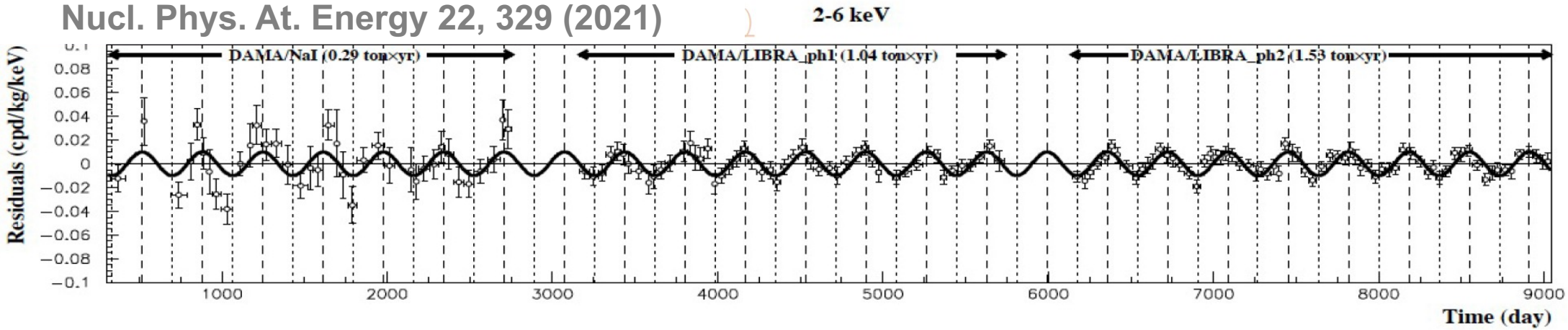
October 26th, 2026

DAMA/LIBRA

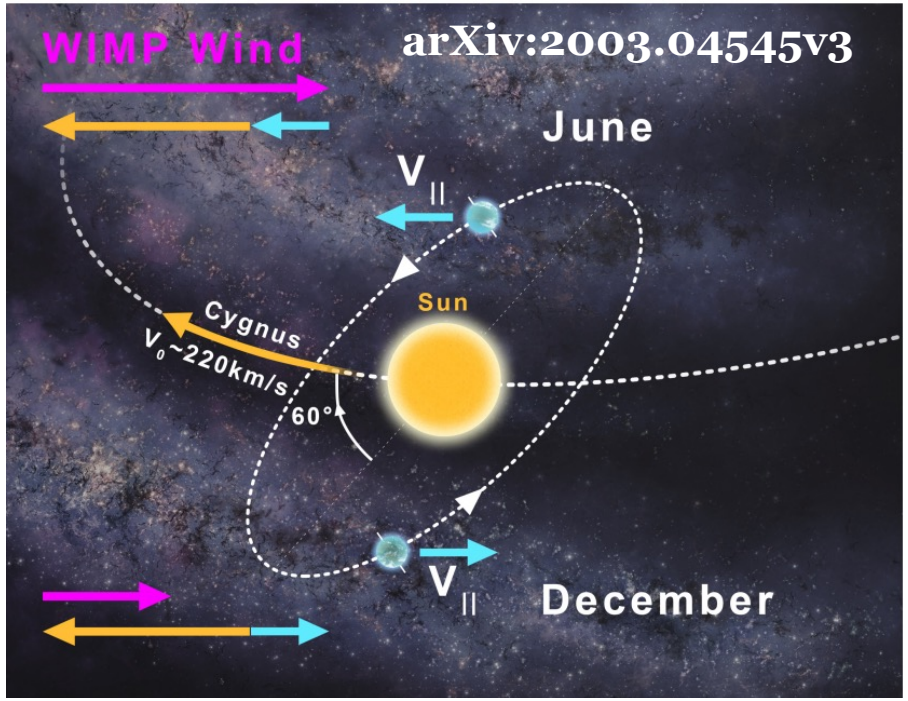
- Dark matter discovery (more than 25 years old story)?
- Annual modulation signature of relic dark matter
- 250 kg **NaI(Tl) crystal** array at Gransasso (Italy)



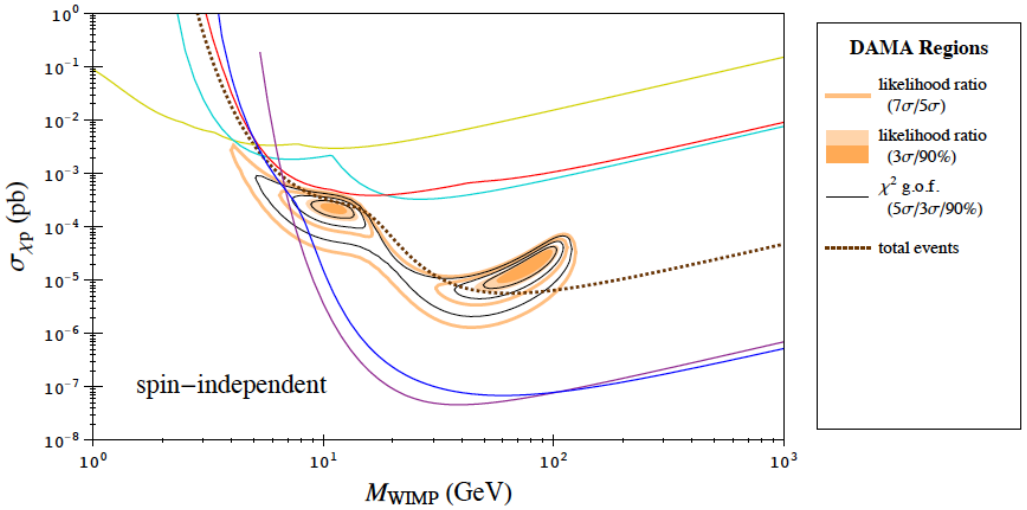
Nucl. Phys. At. Energy 27, 105 (2026)
Nucl. Phys. At. Energy 22, 329 (2021)



DAMA/LIBRA

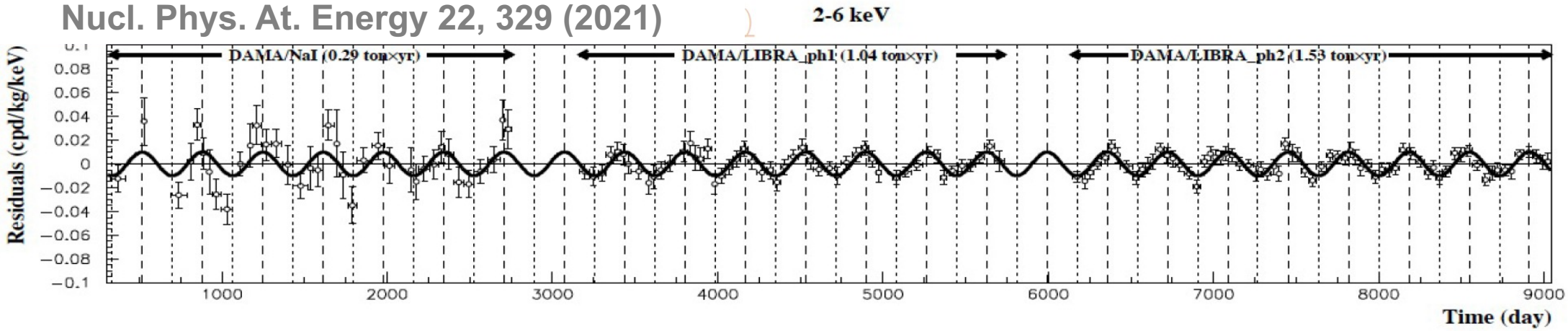


JCAP 04, 010 (2009)



Greatly matched with Standard-halo model of the dark matter distribution

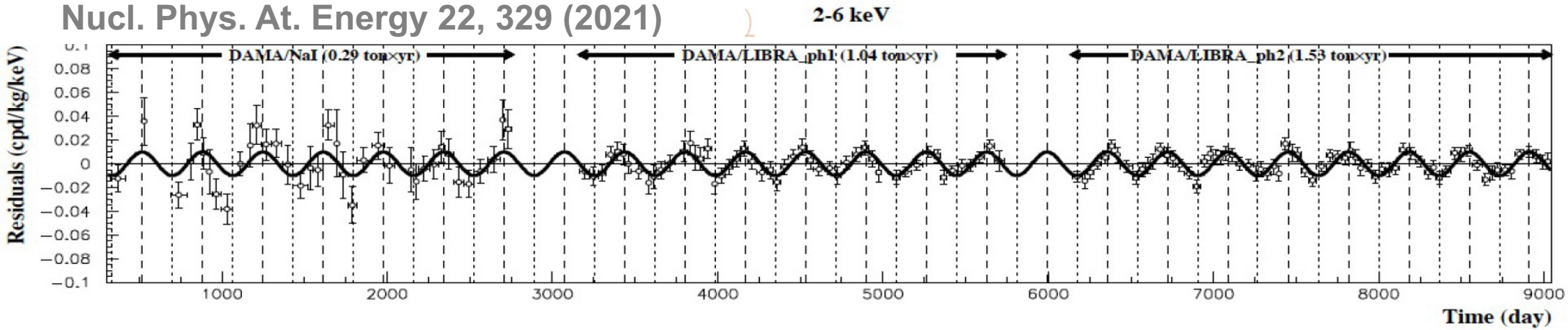
Nucl. Phys. At. Energy 22, 329 (2021)



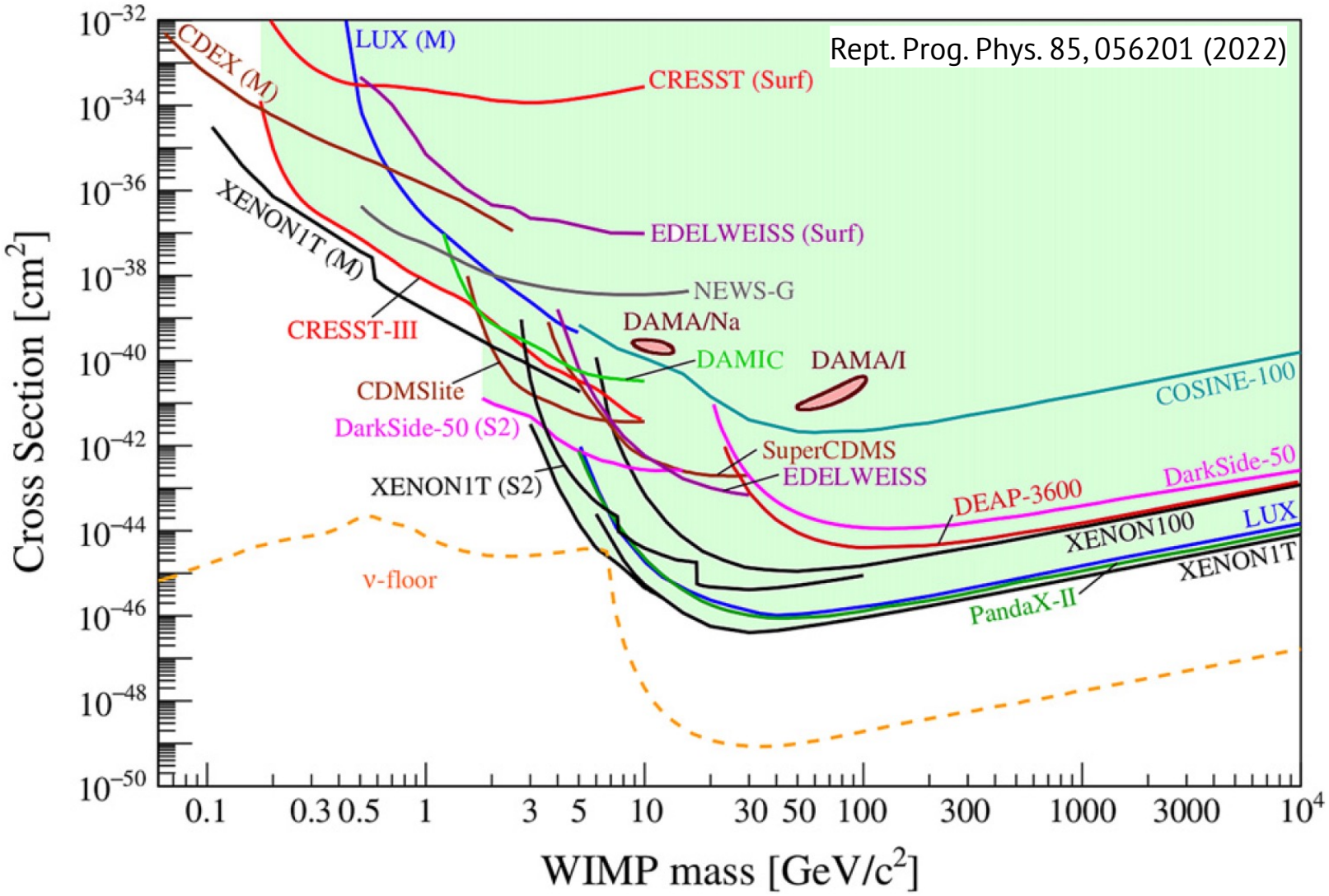
DAMA/LIBRA

E (keV)	A (counts/day/kg/keV)	ϕ (day)	C.L.
$1 \sim 3$	0.0191 ± 0.0020	152.5 **(fixed)**	9.7σ
	0.0191 ± 0.0020	149.6 ± 5.9	9.6σ
$1 \sim 6$	0.01048 ± 0.00090	152.5 **(fixed)**	11.6σ
	0.01058 ± 0.00090	144.5 ± 5.1	11.8σ
$2 \sim 6$	0.00996 ± 0.00074	152.5 **(fixed)**	13.4σ
	$0.01014 + 0.00074$	142.4 ± 4.2	13.7σ

Nucl. Phys. At. Energy 22, 329 (2021)

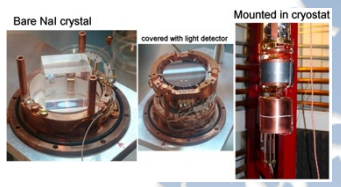


However…

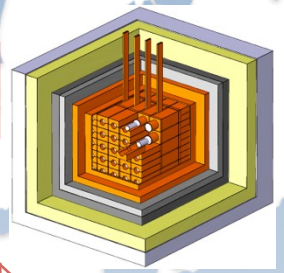


Requiring Model-independent test with same NaI(Tl) crystals

World-wide efforts on NaI(Tl)

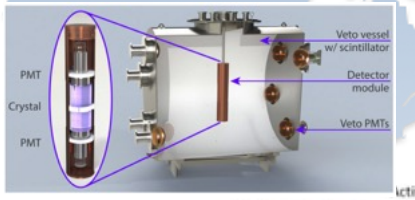


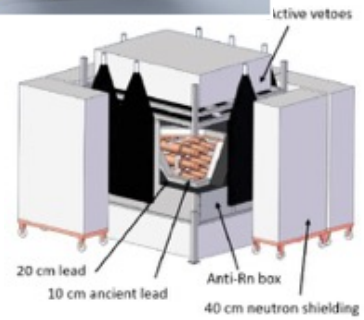
COSINUS @ LNGS

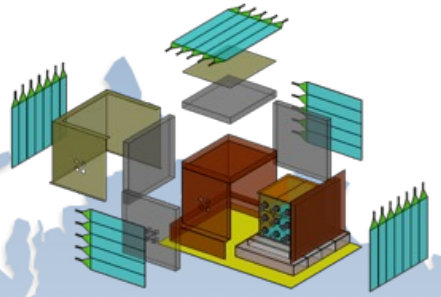


DAMA @ LNGS

SABRE @ LNGS







KIMS/COSINE @ Yangyang

Data-taking (2016-2023)

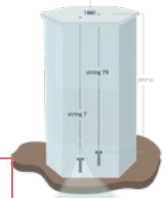
PICO-LON @ Kamioka



ANAIS @Canfranc

Data-taking (2017~present)

SABRE @ Stawell



DM-Ice @ South Pole

COSINE collaboration



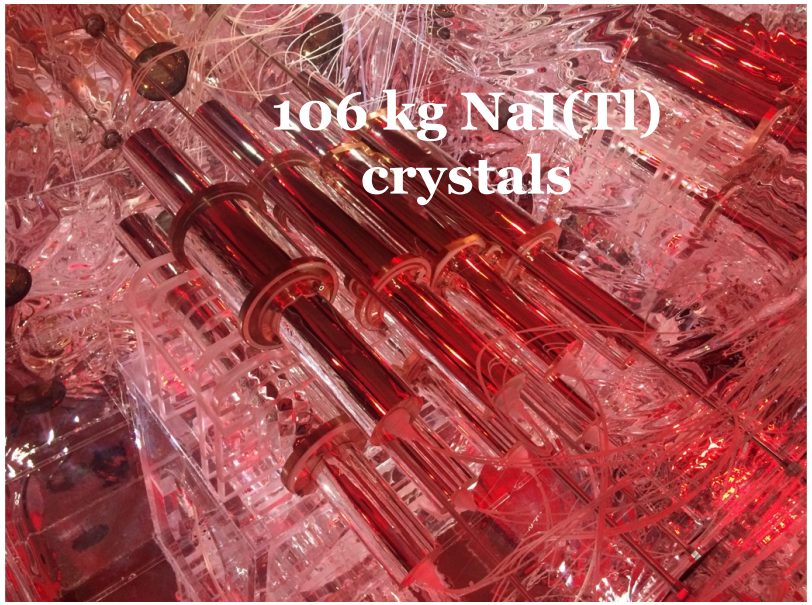
- To reproduce **DAMA/LIBRA** with the same NaI(Tl) crystals

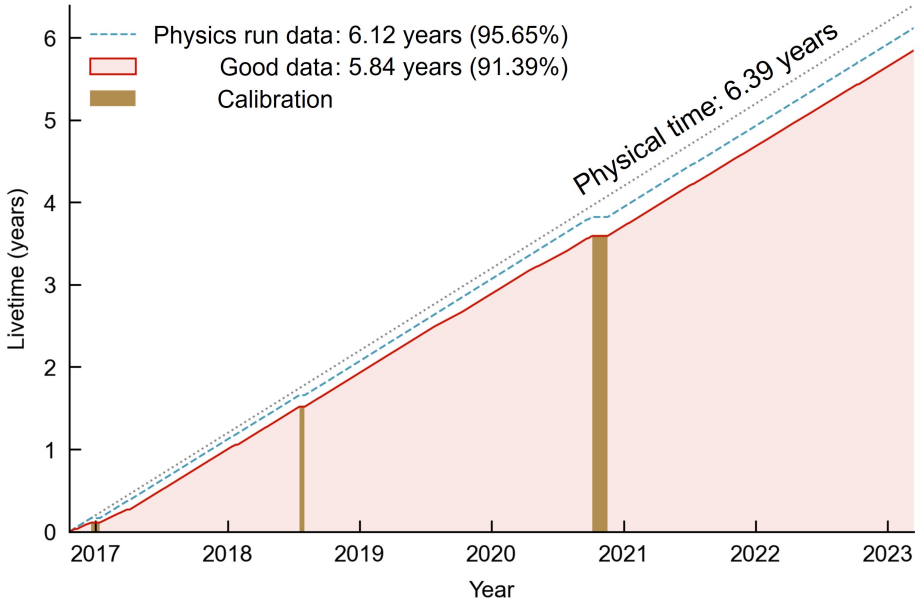
15 institutes
~60 members

KIMS + DM-ICE = COSINE

COSINE-100 experiment (2016-2023)



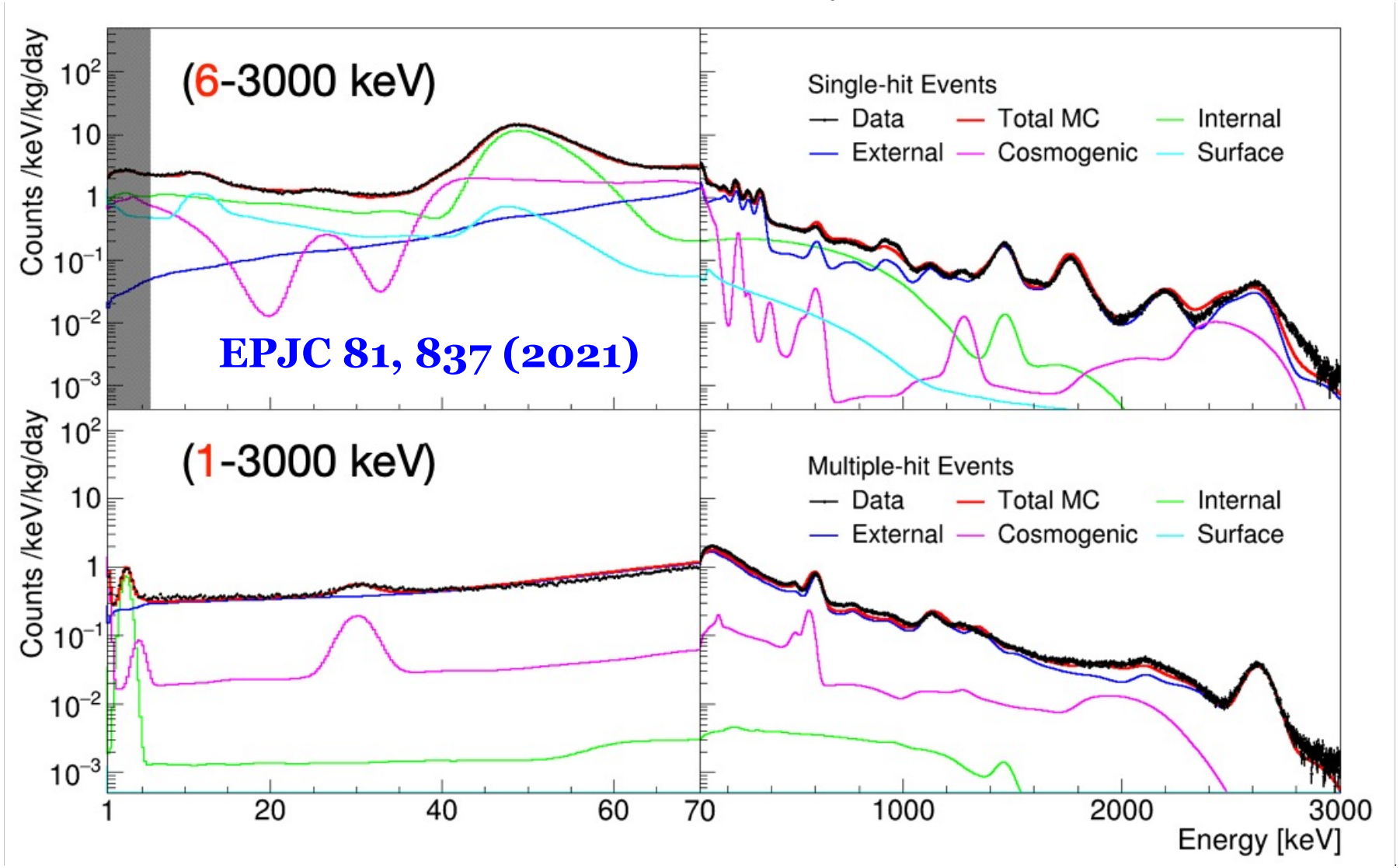




- Yangyang underground laboratory
  - ❖ **October/2016 ~ March/2023**
- Decommissioning
  - ❖ Moved to **Yemilab**
  - ❖ Upgrade of detector for **high light yield**

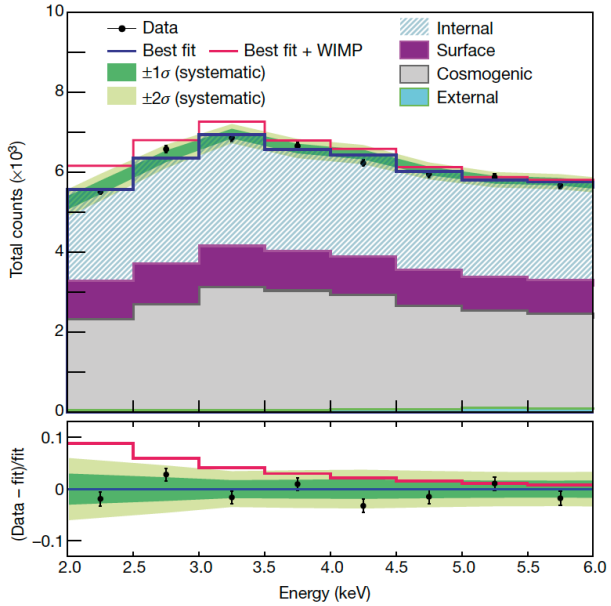
Background understanding

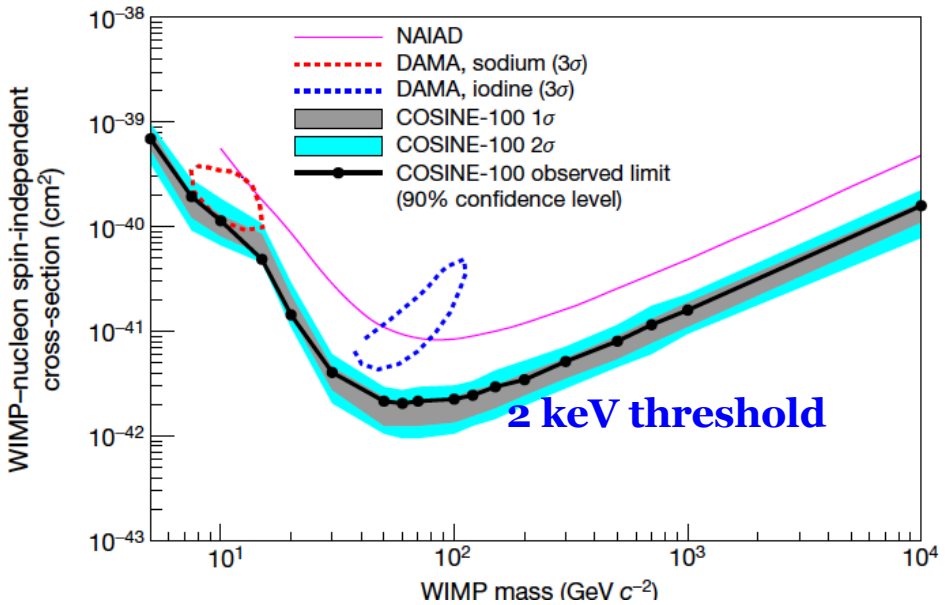
Background modeling **1.7 years data**



Dark matter search from energy spectra

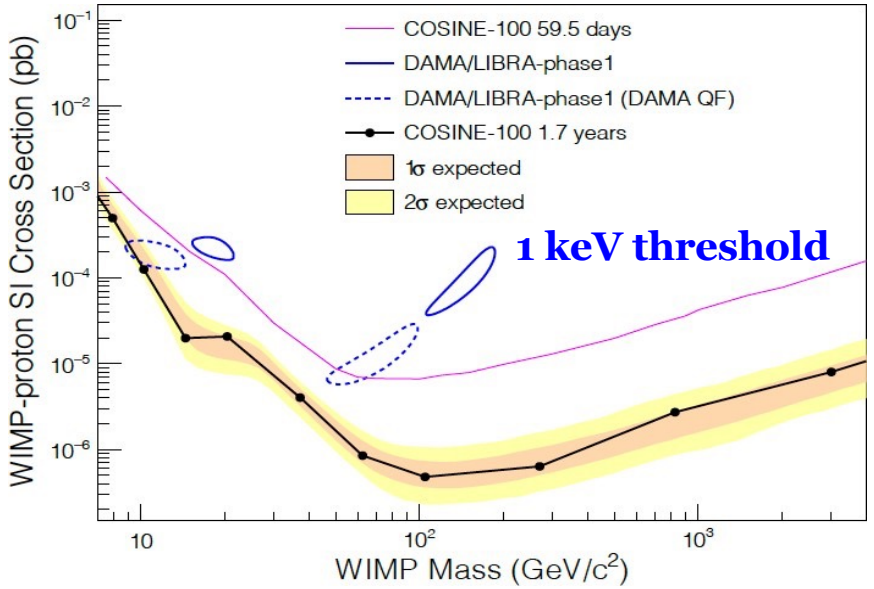
Nature 564, 83 (2018)





59 days data

Sci. Adv. 7, eabk2699 (2021)

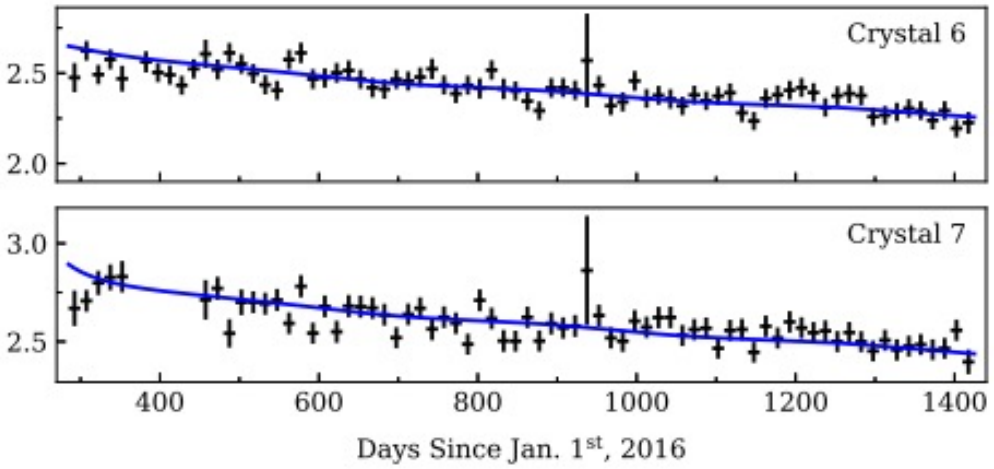


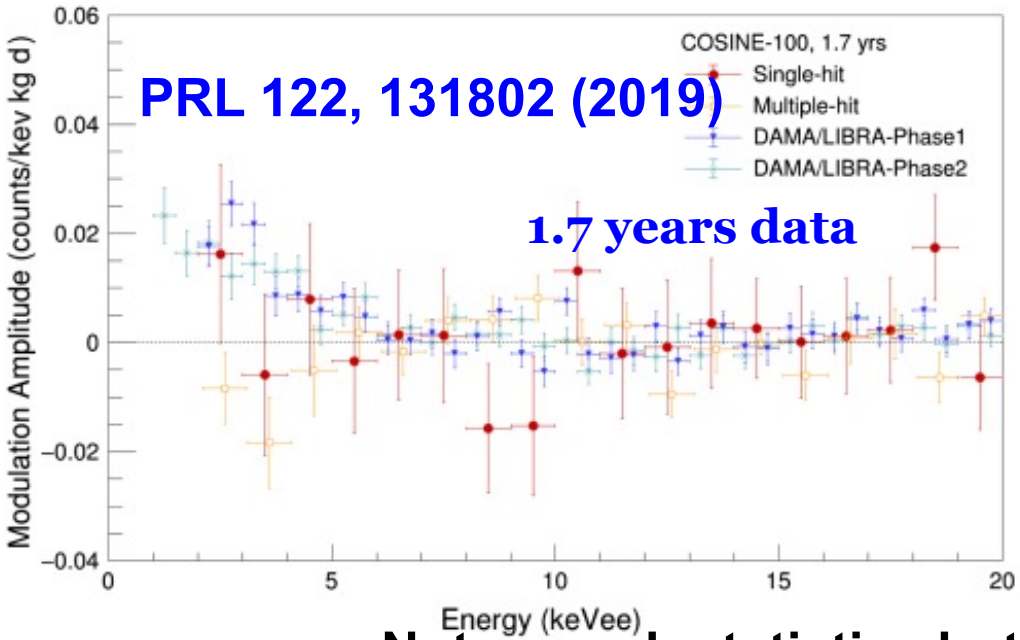
1.7 years data

These are unique analyses in COSINE compared to other NaI-based experiments

Model-dependent test **ruled out DAMA/LIBRA** with the same NaI(Tl)

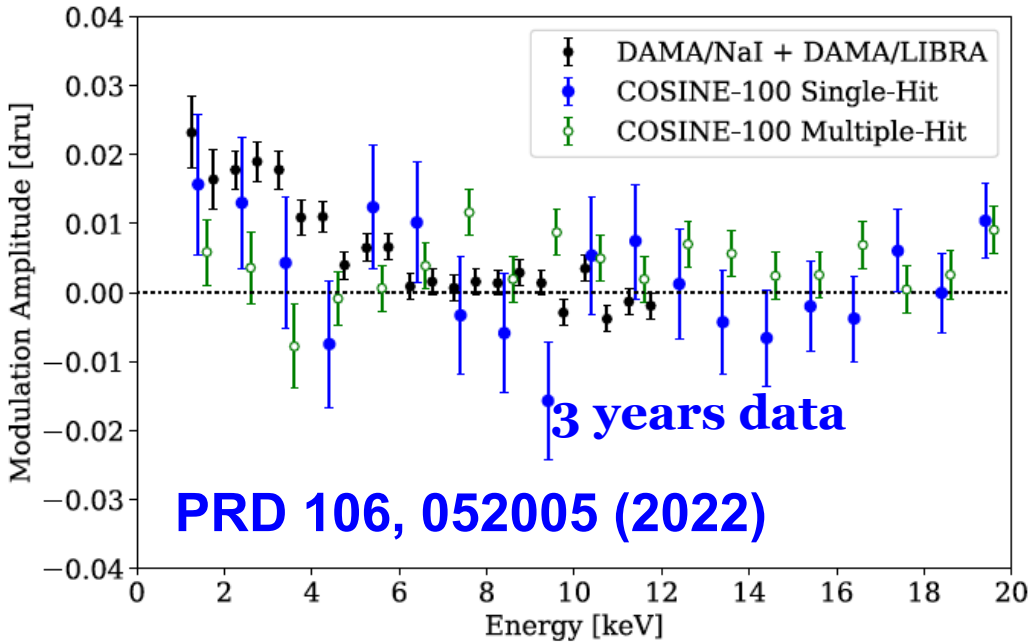
Annual modulation searches





1-6 keV modulation amplitude

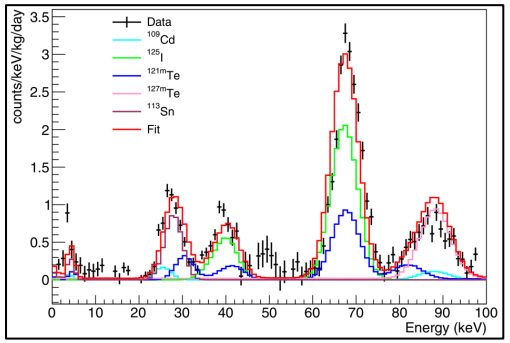
COSINE-100	0.0067 ± 0.0042
DAMA/LIBRA	0.0105 ± 0.0011
ANAIS-112	-0.0034 ± 0.0042



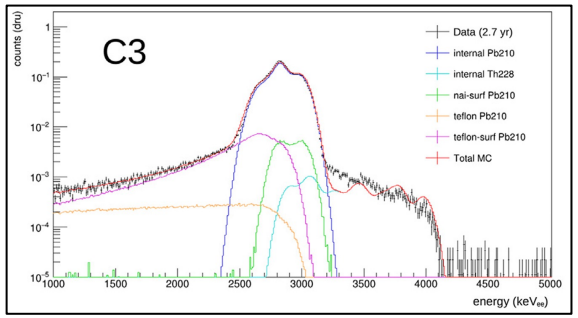
Not enough statistics but, we have full 6.4 years data

Improvement of NaI(Tl) detector understanding

ASP 115, 102390 (2020)



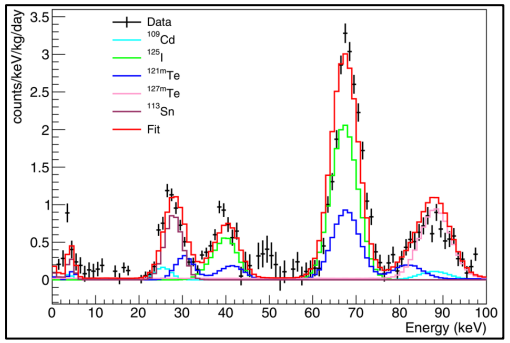
ASP 158, 102945 (2024)



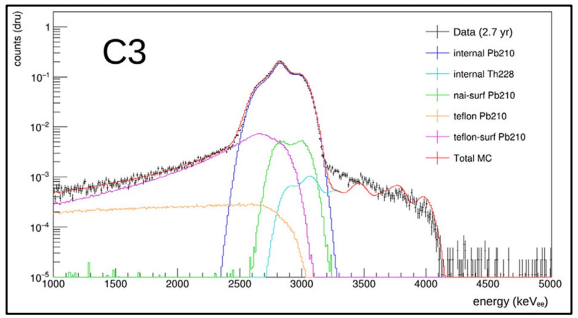
Background components

Improvement of NaI(Tl) detector understanding

ASP 115, 102390 (2020)

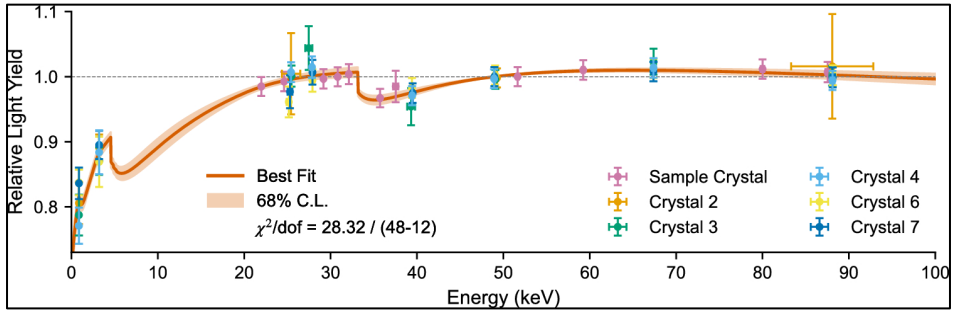


ASP 158, 102945 (2024)



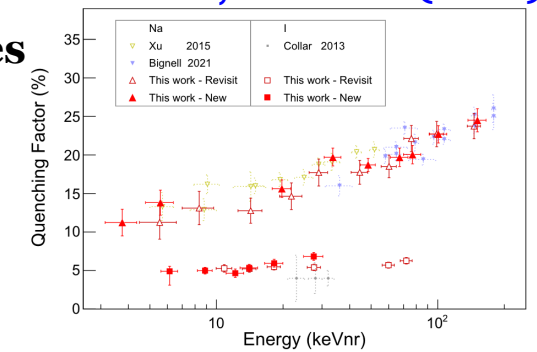
Background components

EPJC 84, 484 (2024)



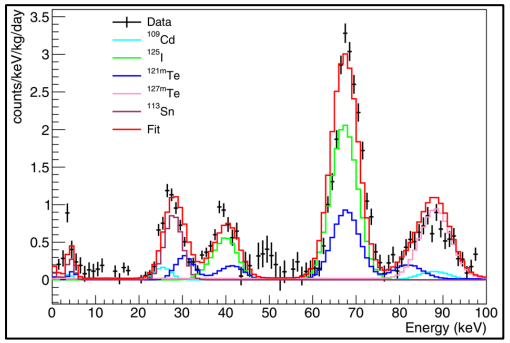
Detector responses

PRC 110, 014614 (2024)

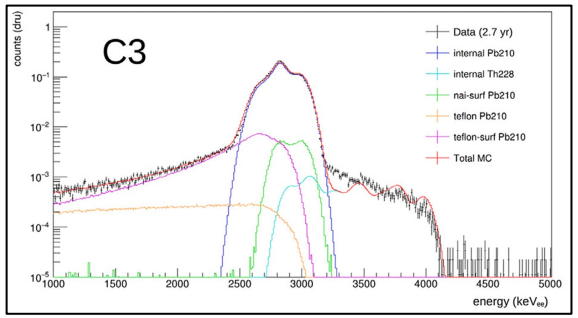


Improvement of NaI(TI) detector understanding

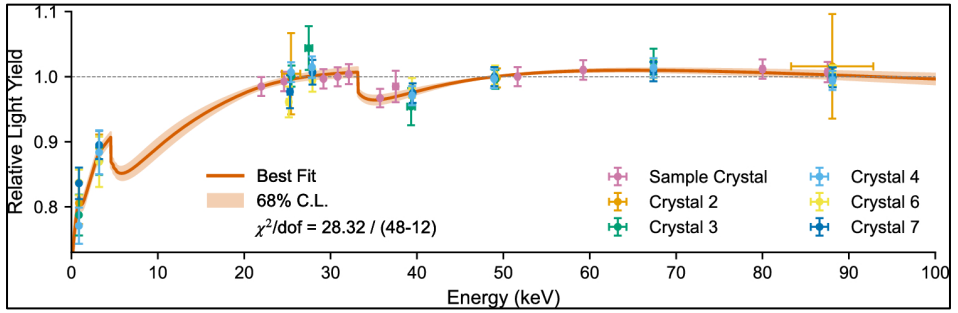
ASP 115, 102390 (2020)



ASP 158, 102945 (2024)



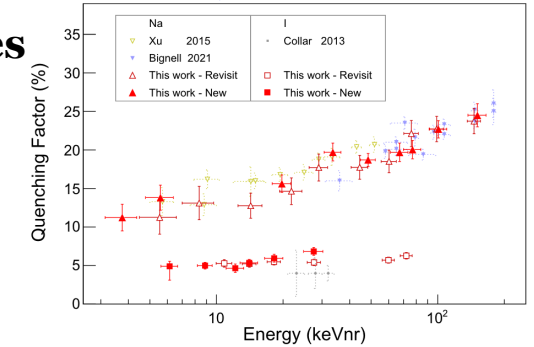
EPJC 84, 484 (2024)



Background components

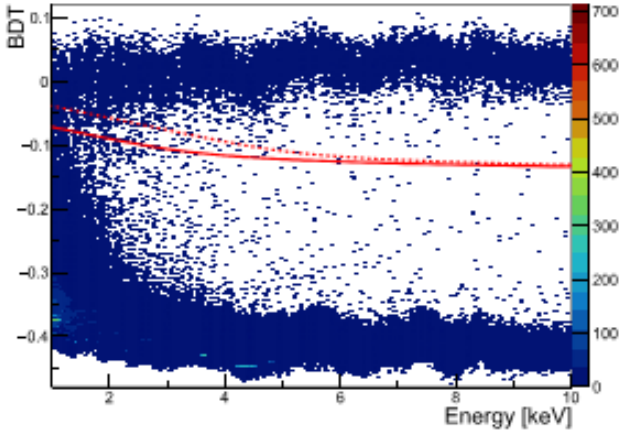
Detector responses

PRC 110, 014614 (2024)

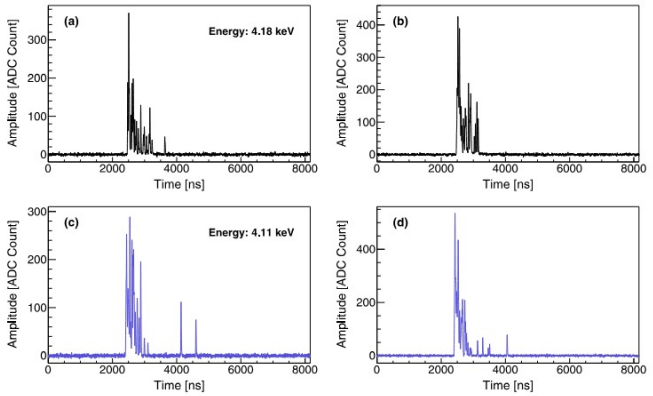


Low energy scintillation responses

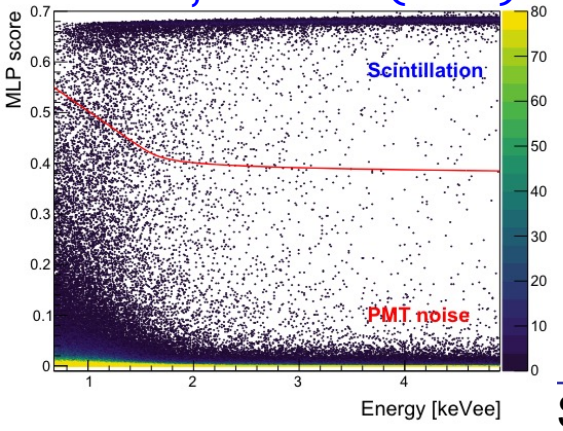
ASP 130, 102581 (2021)



NIMA 1065, 169489 (2024)



JINST 19, P12013 (2024)



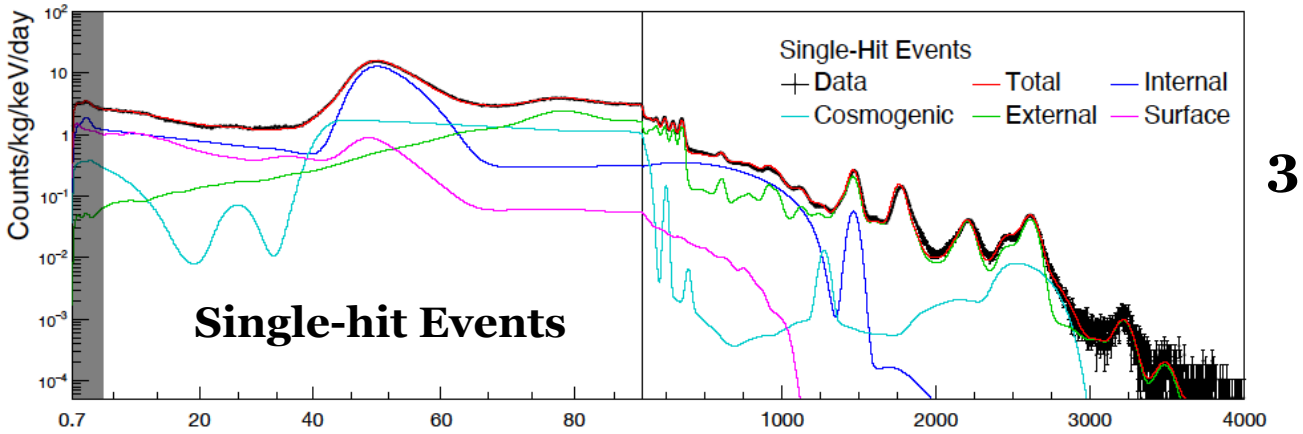
Improvement of NaI(Tl) detector understanding

Detector responses

Background components

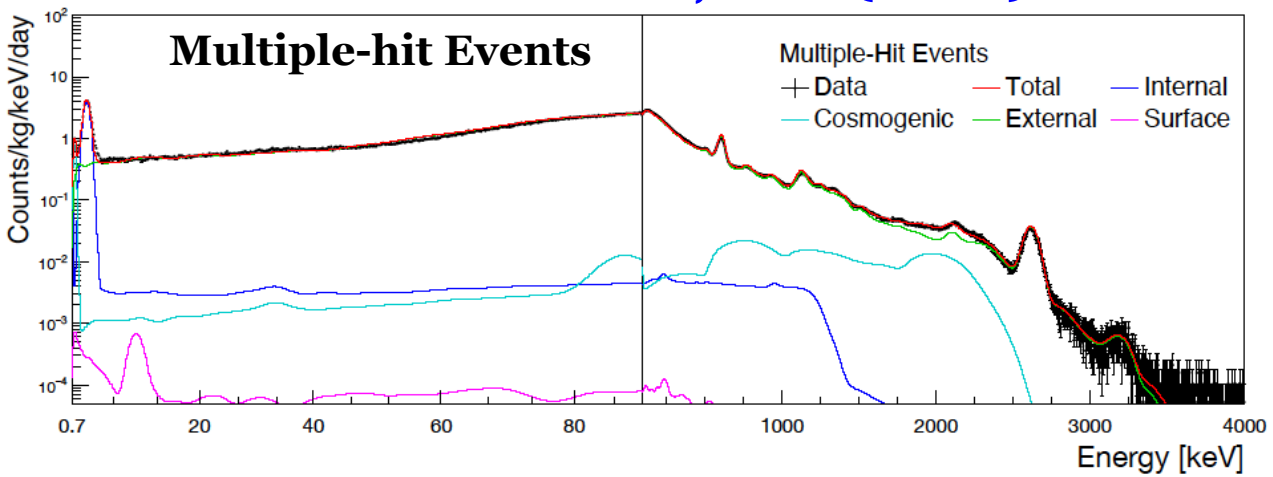
Low energy scintillation responses

Improved understanding of NaI(Tl) backgrounds in extended energy range 0.7 – 4000 keV



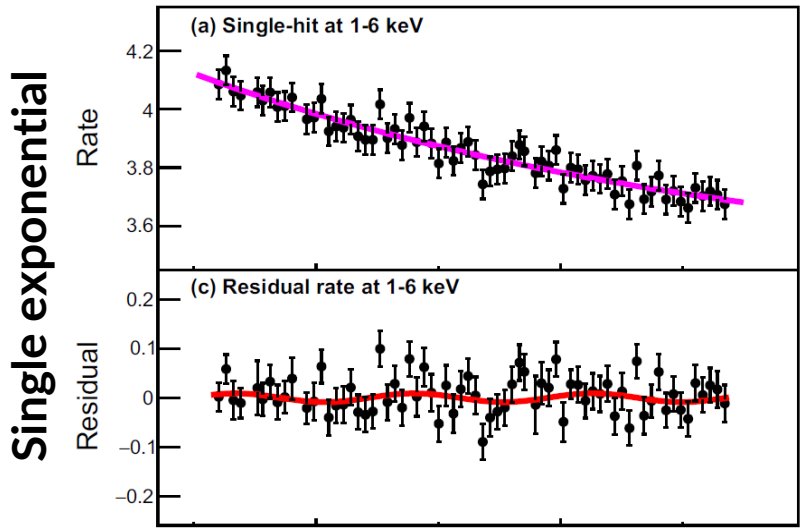
3 years data

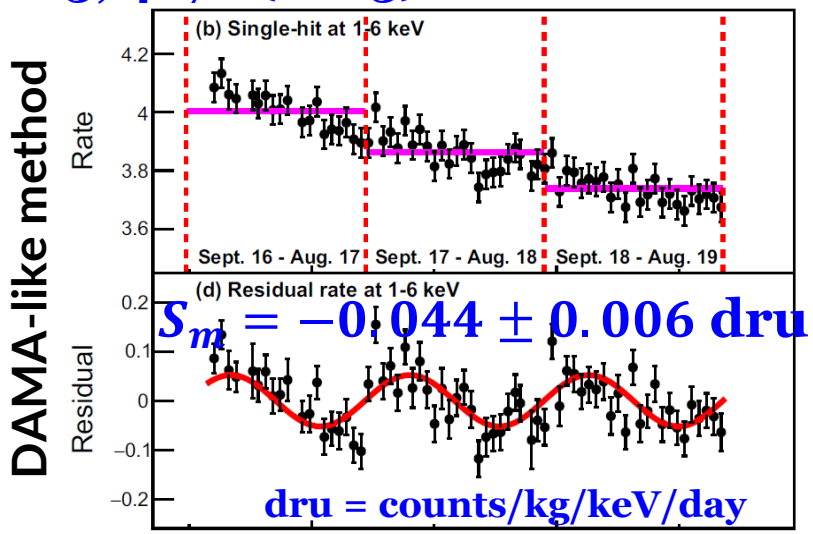
EPJC 85, 32 (2025)

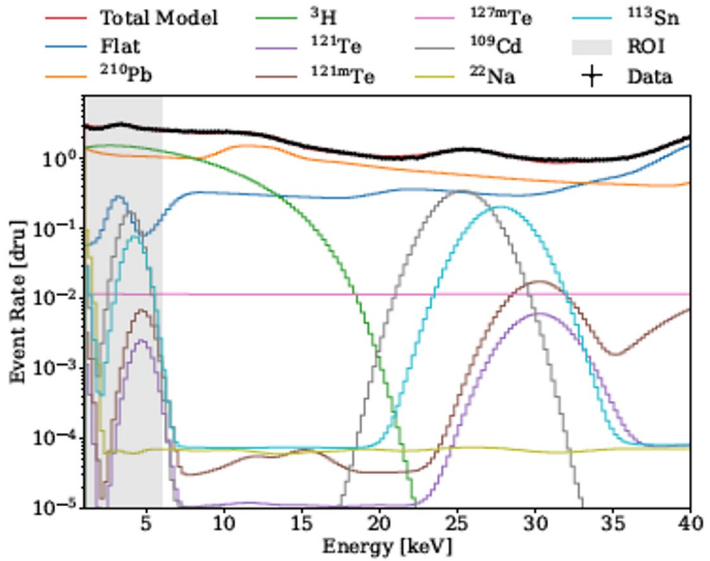


Time-dependent background models

Sci. Rep. 13, 4676 (2023)

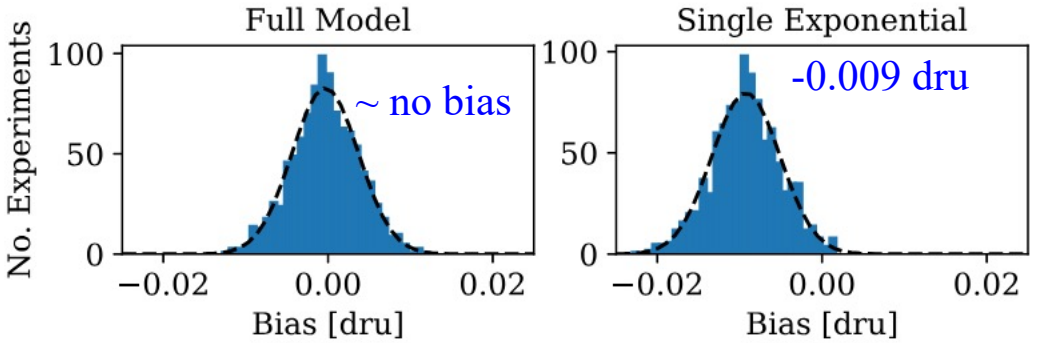






PRD 106, 052005 (2022) (3 years modulation search)

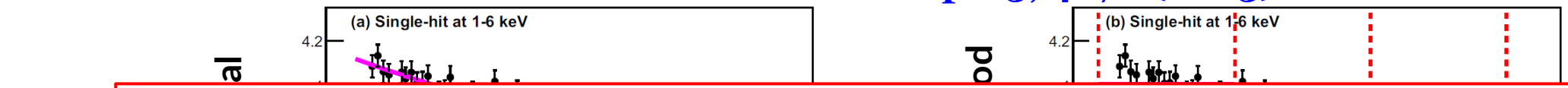
Full model : eight exponential components



DAMA/LIBRA : 0.010 ± 0.001 dru

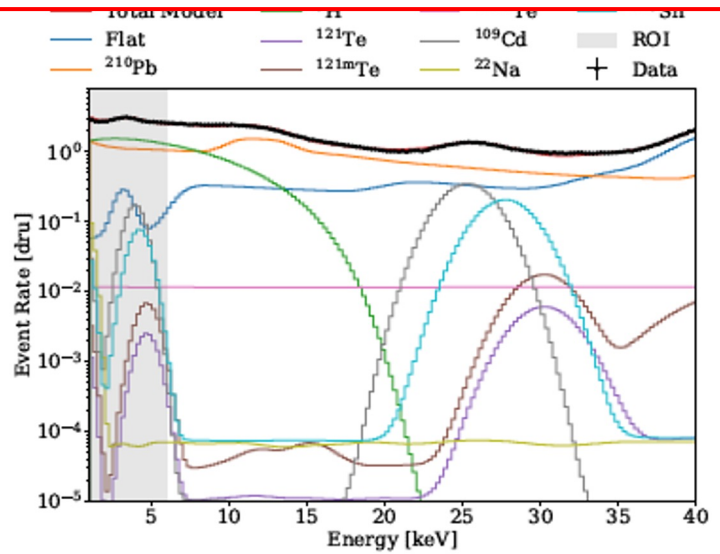
Time-dependent background models

Sci. Rep. 13, 4676 (2023)



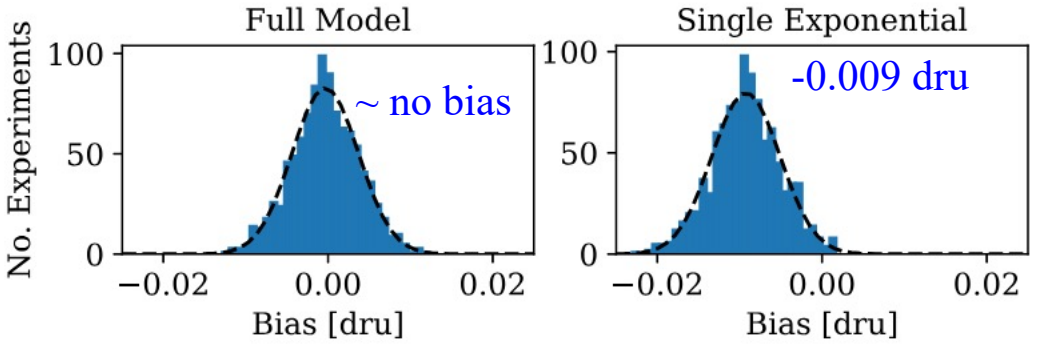
Caveat : Understanding of time-dependent background is crucial for the annual modulation analysis

COSINE-100 is **a unique experiment** achieving precise background understanding of NaI(Tl) crystals



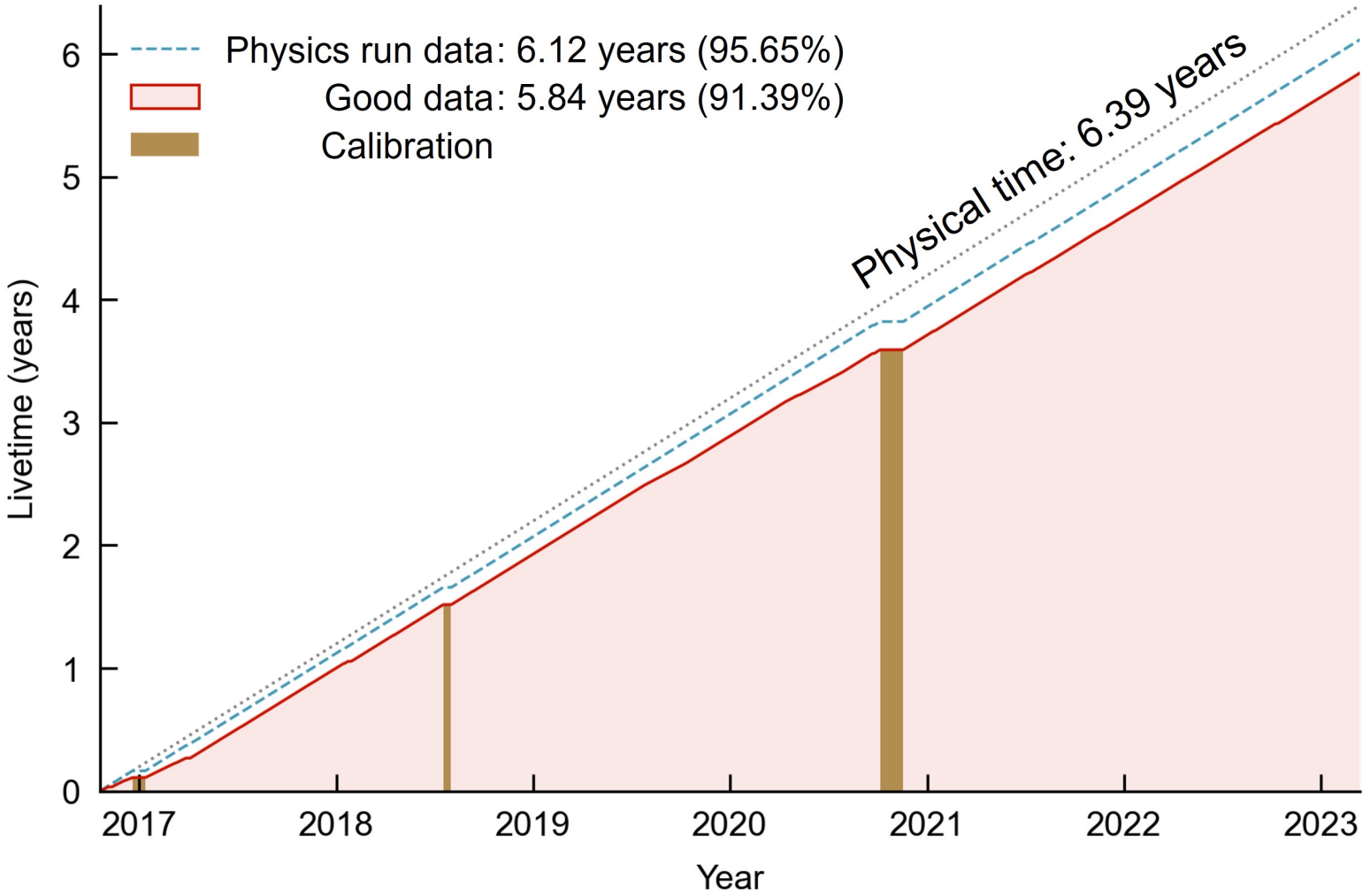
PRD 106, 052005 (2022) (3 years modulation search)

Full model : eight exponential components



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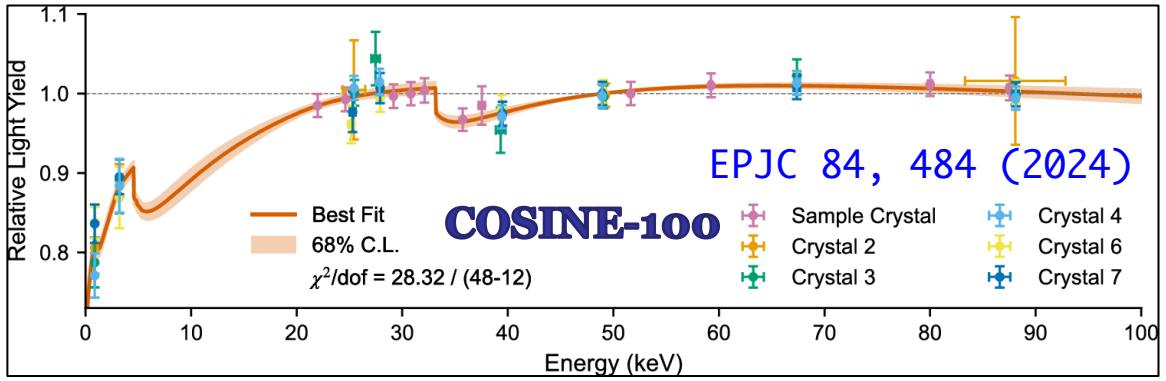
COSINE-100 full dataset

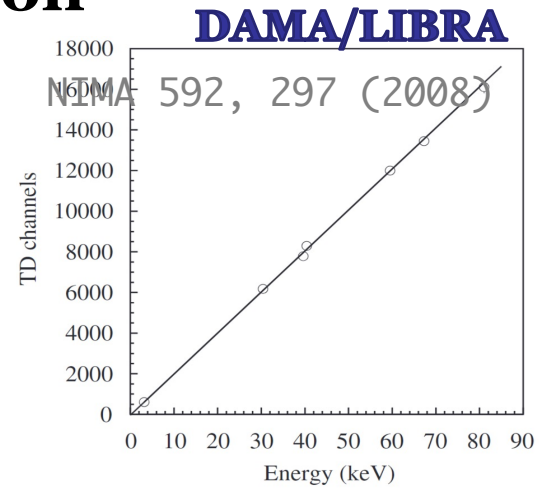


- Importance : Apple-to-apple comparison with **DAMA/LIBRA**

Comparison with DAMA : Energy calibration

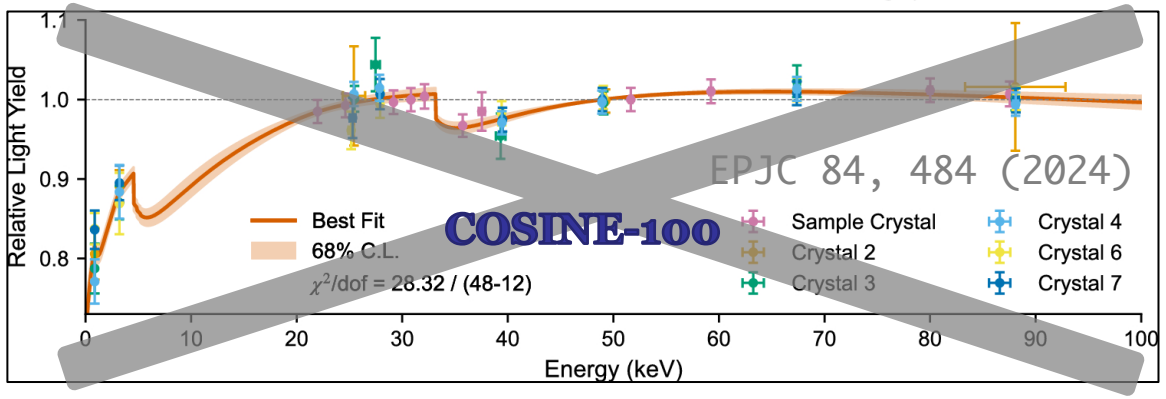
Electron-recoil energy calibration

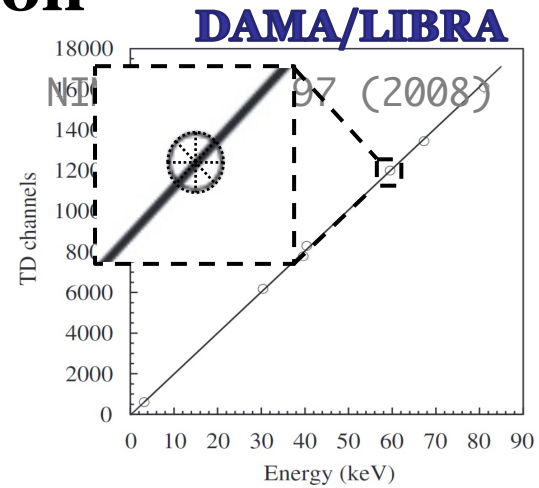




Comparison with DAMA : Energy calibration

Electron-recoil energy calibration

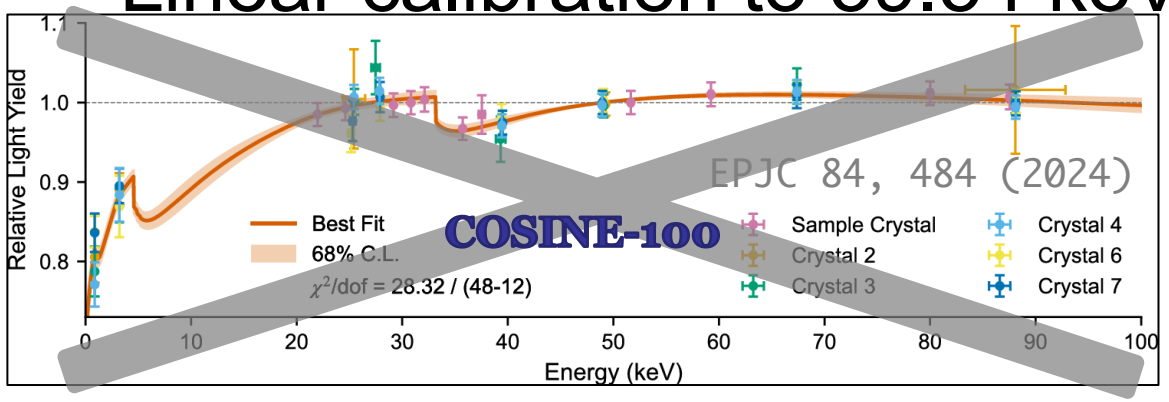


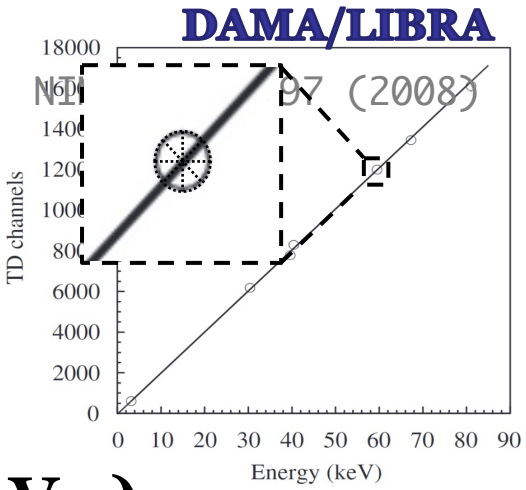


Linear calibration to 59.54 keV : keV_{ee}

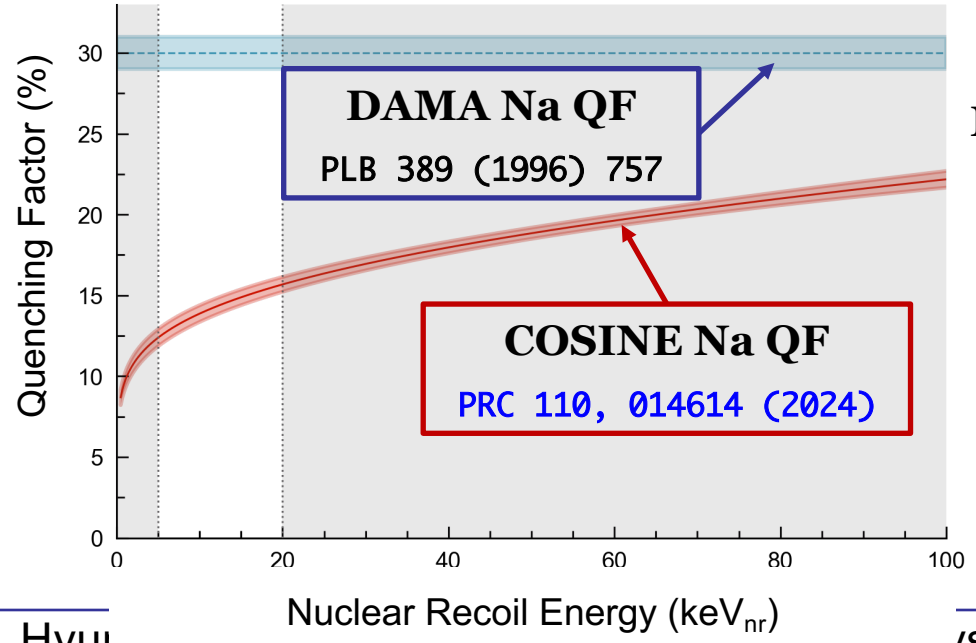
Comparison with DAMA : Energy calibration

Linear calibration to 59.54 keV :





Nuclear-recoil energy calibration (keV_{nr})



Quenching factor (QF)

Measured electron-equivalent energy/True nuclear recoil energy

Signal region : 6.7-20 keV_{nr}

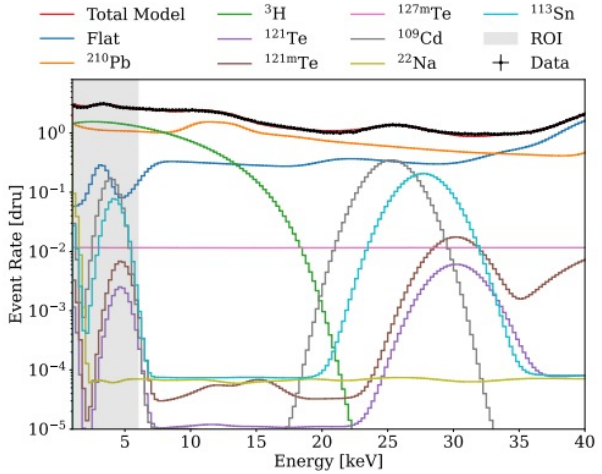
DAMA/LIBRA : 2-6 keV_{ee}

COSINE-100 : 0.85-3.12 keV_{ee}

Modulation fit

$$R_i(t) = A\cos\left(\frac{2\pi(t-\phi)}{T}\right) + \sum_j C_{ij}e^{-\lambda_{ij}t}.$$

Modulation signals 10 time-dependent components



Simulated experiments

Pull Factor

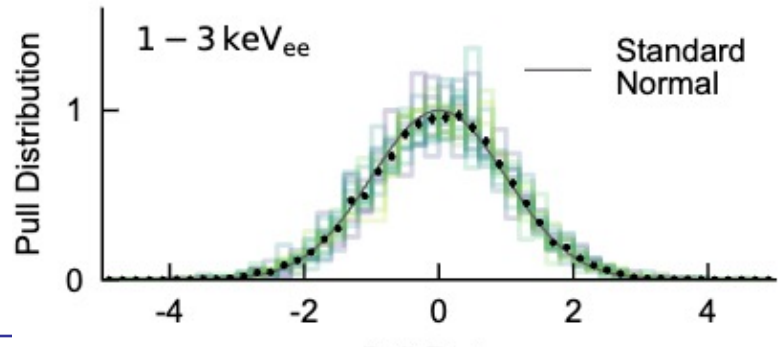
Measured signal

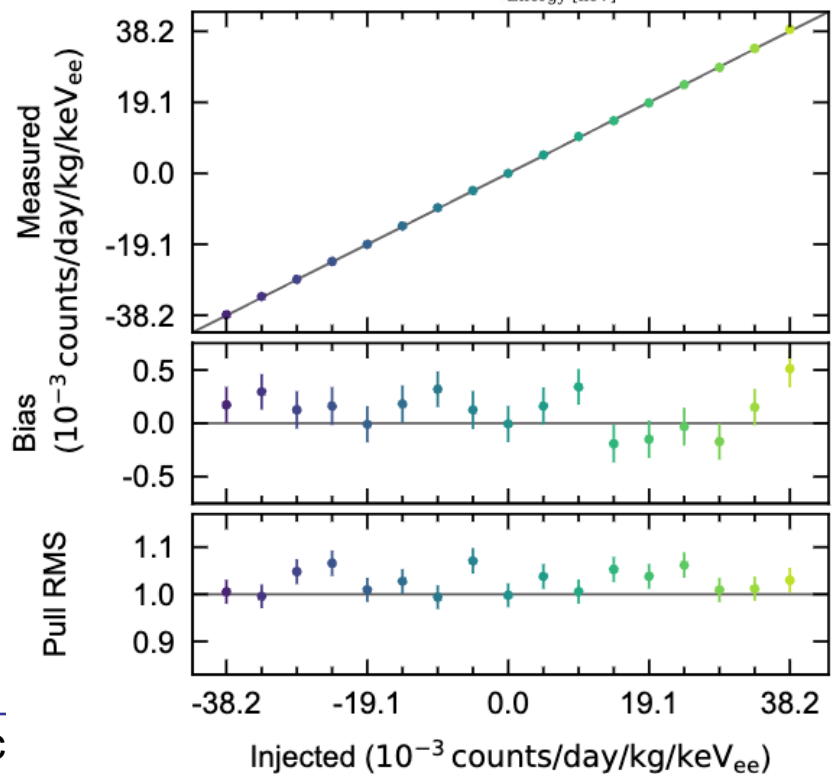
Input signal

$$z = \frac{m_A - I_A}{\sigma_A}$$

Measured uncertainty

No Bias





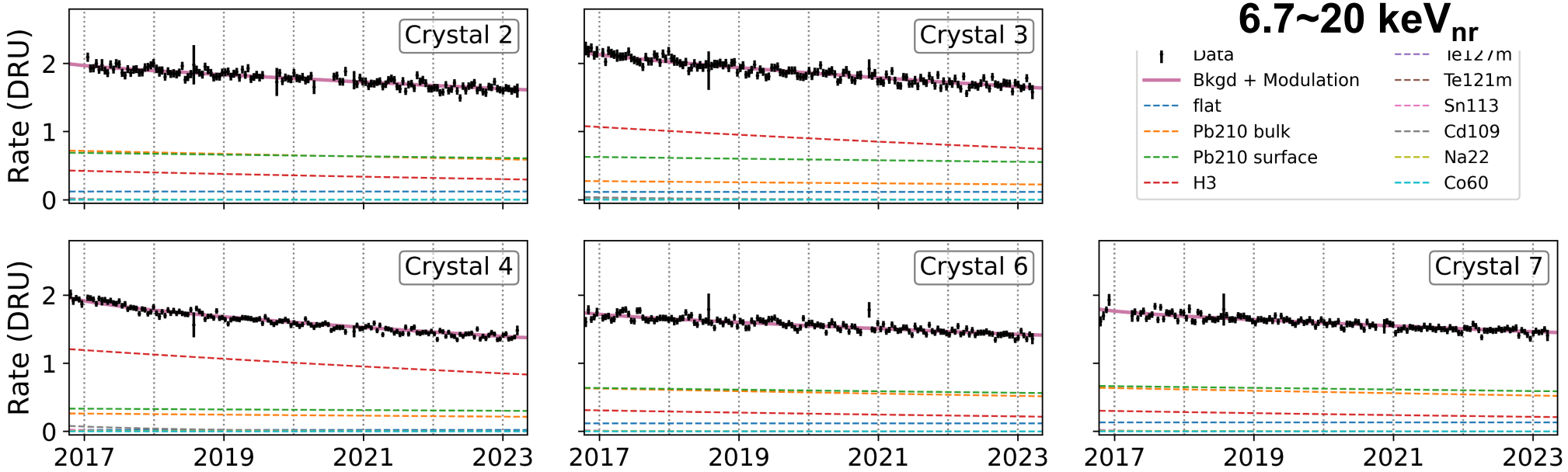
Modulation fit

$$R_i(t) = A\cos\left(\frac{2\pi(t-\phi)}{T}\right) + \sum_j C_{ij}e^{-\lambda_{ij}t}.$$

Modulation signals 10 time-dependent components

COSINE-100 full dataset

DRU = counts/kg/keV/day

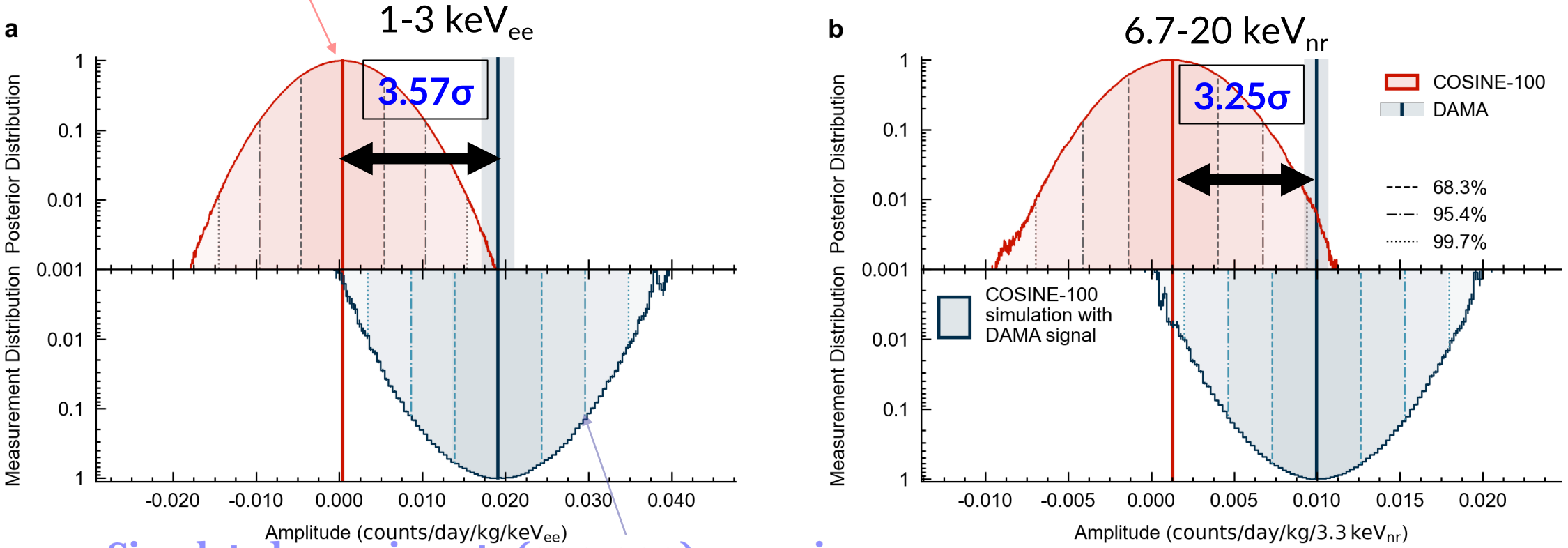


No modulation signal observed !!

COSINE-100 full dataset fits

Posterior of COSINE-100 full dataset

(2-6 keVee in DAMA/LIBRA)



Simulated experiments (300,000) assuming DAMA/LIBRA modulation signals

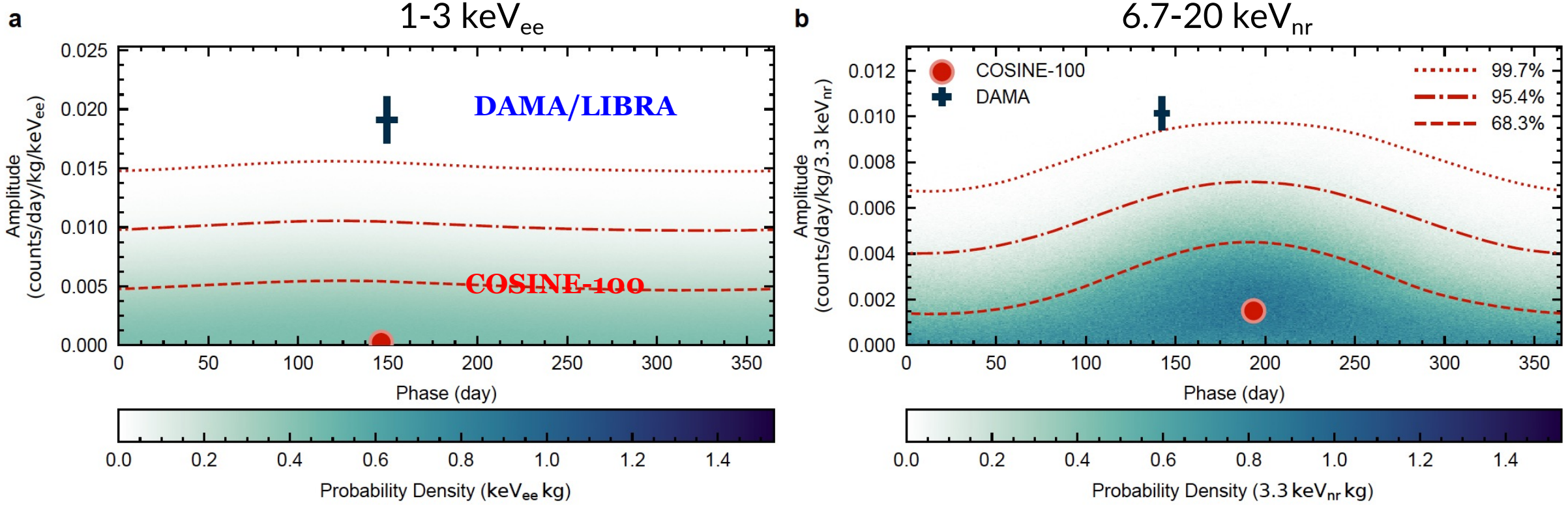
Sci. Adv. 11, eadv6503 (2025)

COSINE-100 full dataset disfavors DAMA/LIBRA in both electron recoil and nuclear recoil

COSINE-100 full dataset fits

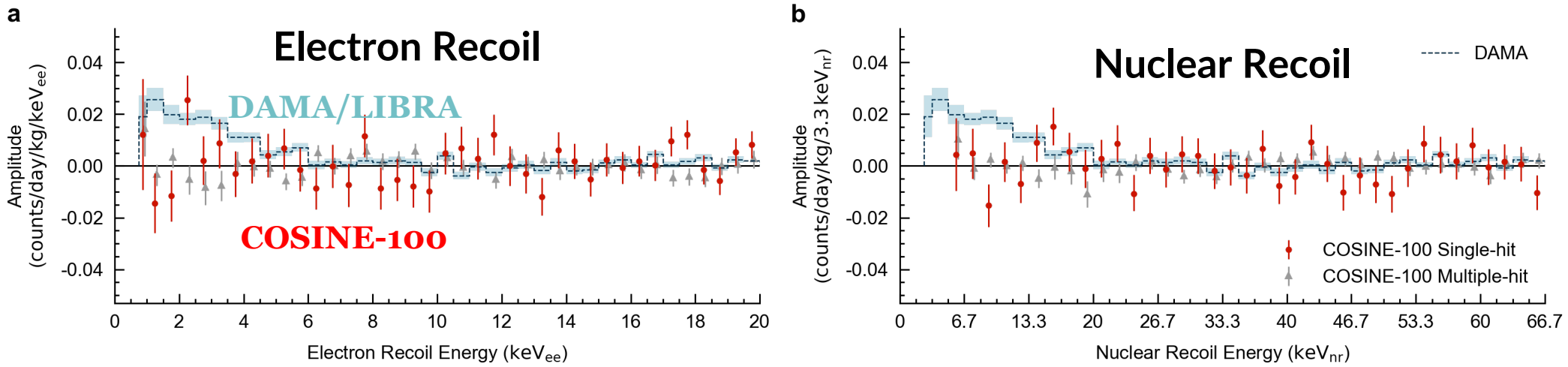
Phase floated 2-dimensional fit for COSINE-100 full dataset

Sci. Adv. 11, eadv6503 (2025)



COSINE-100 full dataset disfavors DAMA/LIBRA in both electron recoil and nuclear recoil

COSINE-100 full dataset fits



Sci. Adv. 11, eadv6503 (2025)

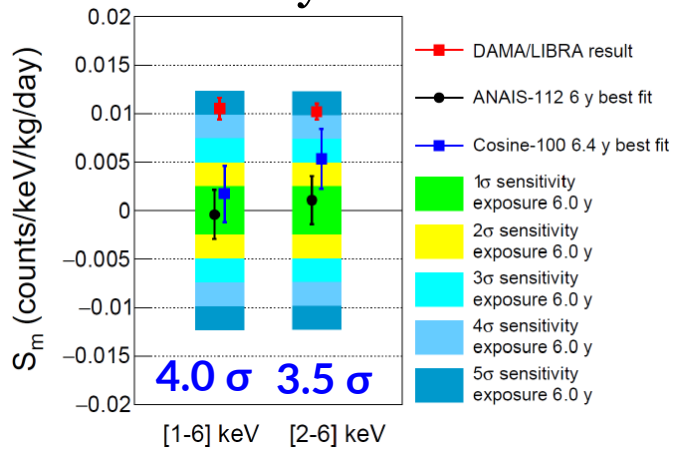
E (keV$_{ee}$)	A (counts/day/kg/keV$_{ee}$)	
	COSINE-100	DAMA/LIBRA
1~3	$\mathbf{0.001 \pm 0.005}$	0.019 ± 0.002
1~6	$\mathbf{0.002 \pm 0.003}$	0.010 ± 0.001
2~6	$\mathbf{0.005 \pm 0.003}$	0.010 ± 0.001

E (keV$_{nr}$)	A (counts/day/kg/3.3 keV$_{nr}$)	
	COSINE-100	DAMA/LIBRA
6.7~20	$\mathbf{0.001 \pm 0.003}$	0.010 ± 0.001

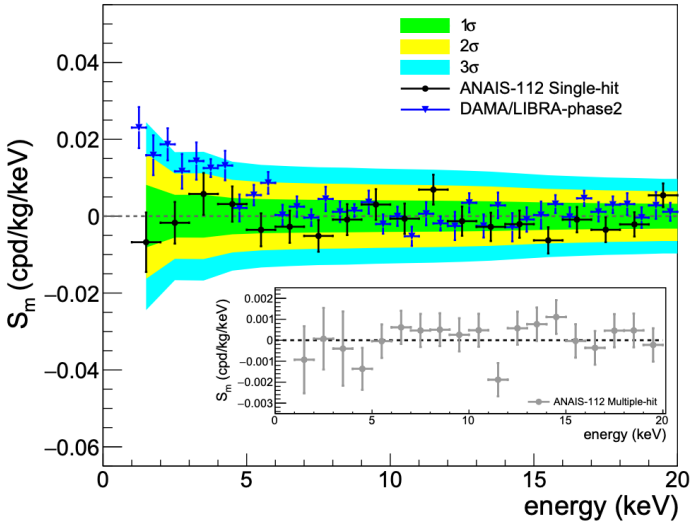
COSINE-100 full dataset disfavors DAMA/LIBRA in both electron recoil and nuclear recoil

Combining with ANAIS-112

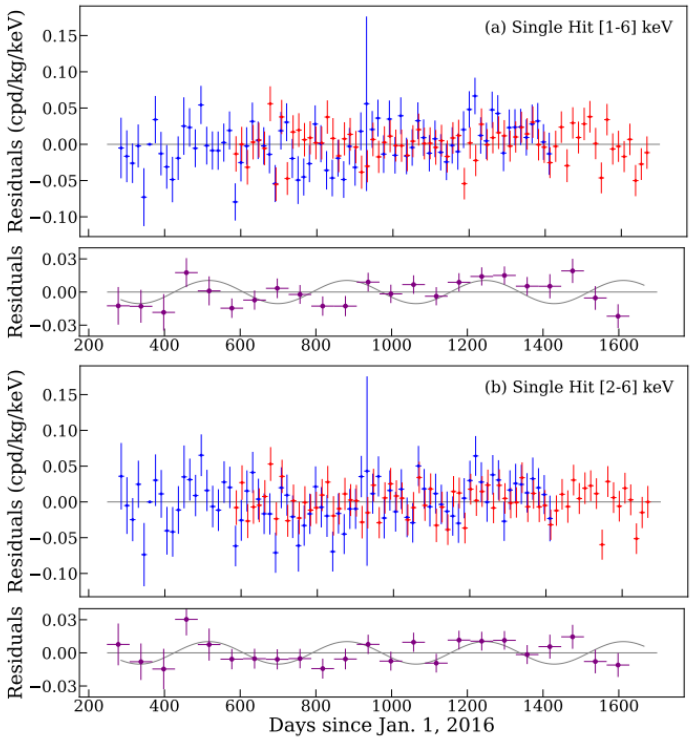
ANAIS-112 6 year data

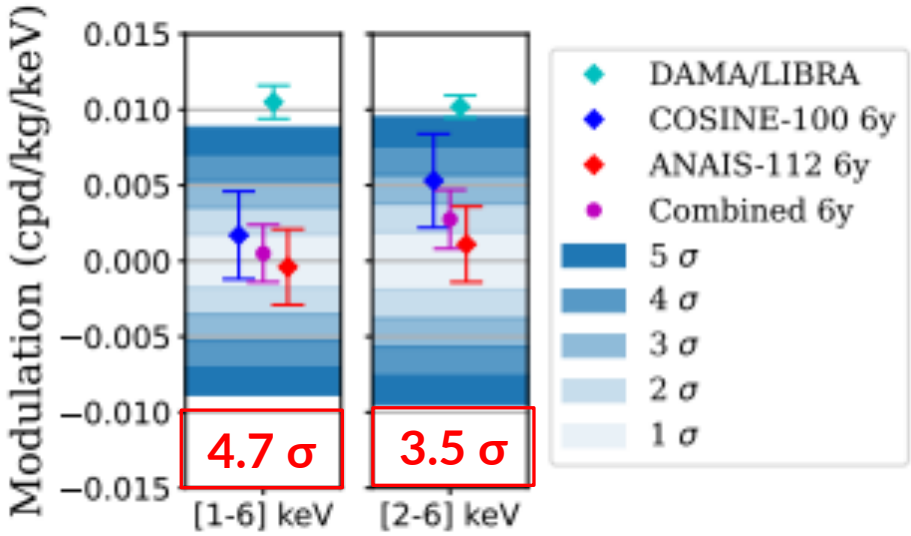


PRL 135, 051001 (2025)



Combined data analysis between ANAIS-112 and COSINE-100





Phys. Rev. Lett. 135, 121002 (2025)

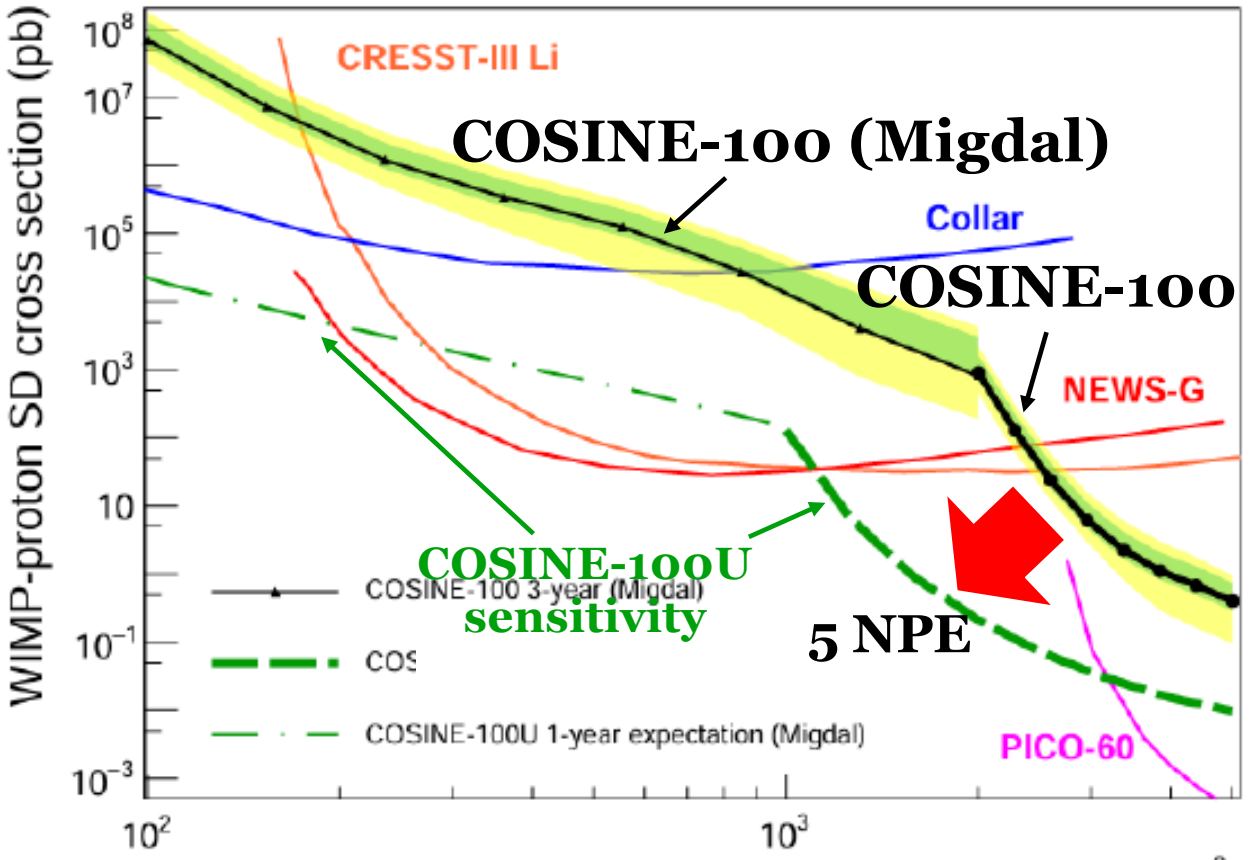
Model-independent test also **ruled out DAMA/LIBRA** with the same analysis method

Toward low-mass dark matter era

- Na (Z = 11) and I (Z=53)
  - ❖ Good for spin-dependent WIMP-proton interactions
  - ❖ Si (Z = 14), Ge (Z = 32), Ar (Z = 18), Xe (Z = 54)
  - ❖ Good for low-mass (sodium)

- Reduced threshold
  - ❖ Current threshold : **8 NPE** (0.7 keV)
  - ❖ **COSINE-100 goal : 5 NPE (0.5 keV)**
    - ❑ Ongoing analysis with full dataset
  - ❖ Higher light yield
    - ❑ Improved detector encapsulation

WIMP-proton spin-dependent interaction



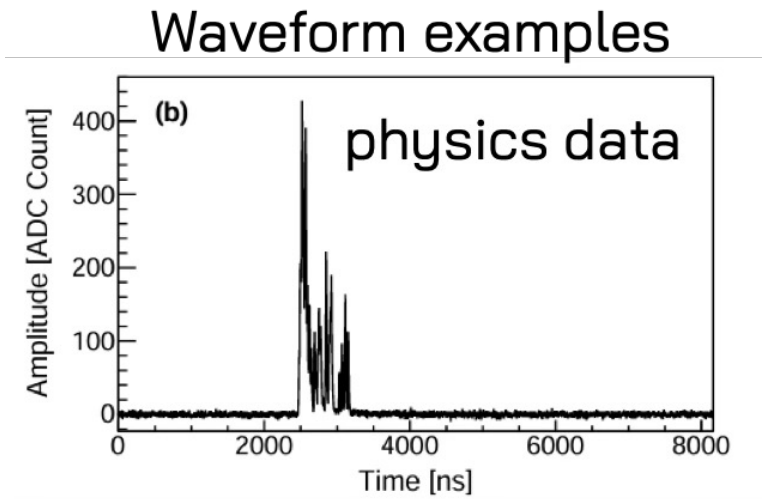
COSINE-100 3 years data

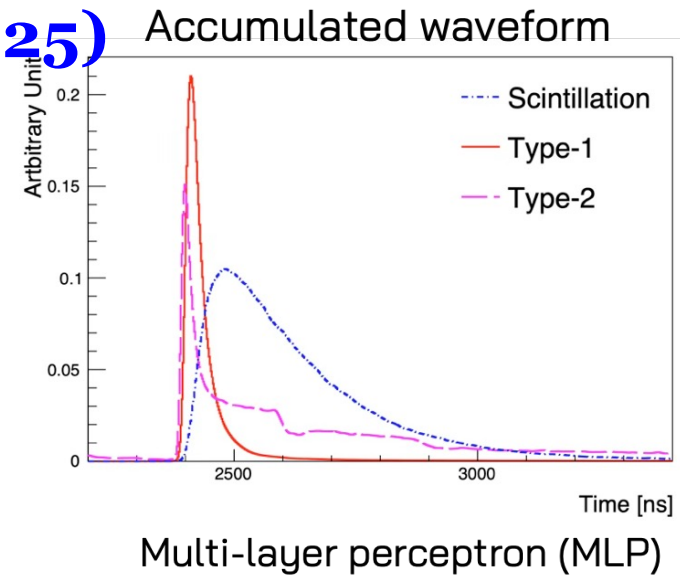
8 NPE threshold

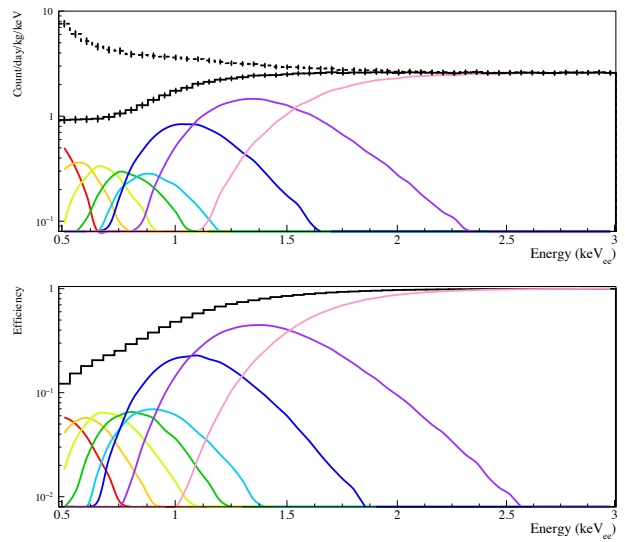
Phys. Rev. Lett. 135, 231001 (2025)

Achieving 5 NPE threshold with COSINE-100

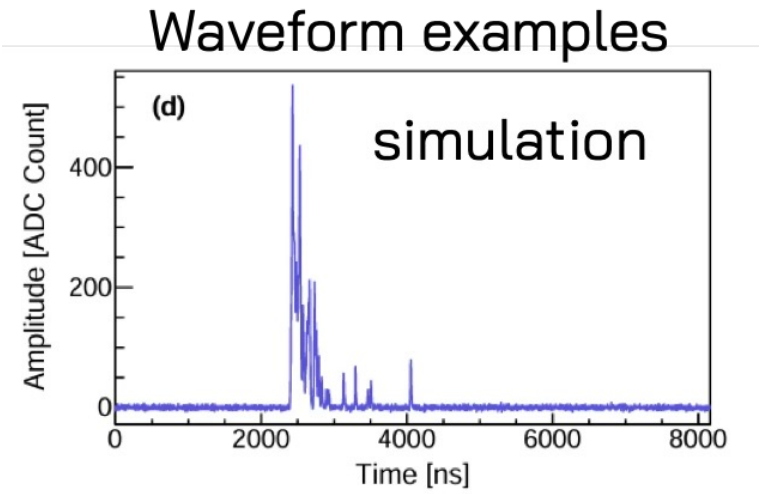
NIMA. 135, 231001 (2025)

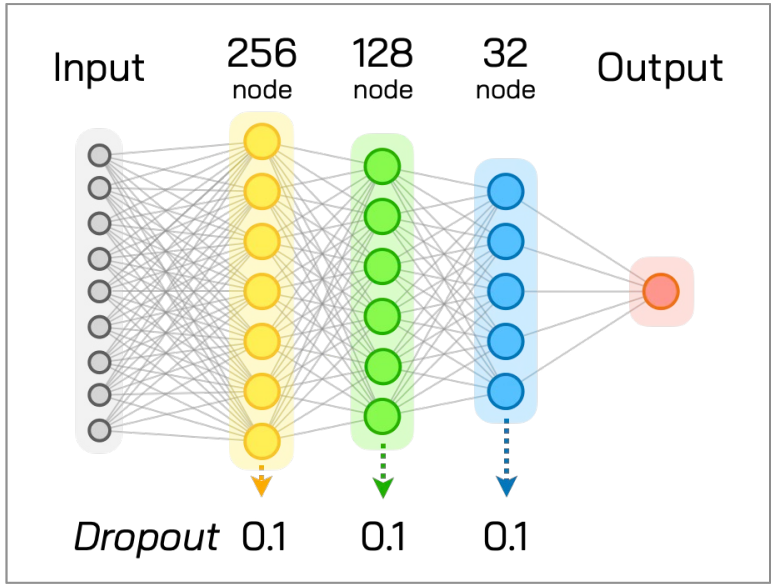


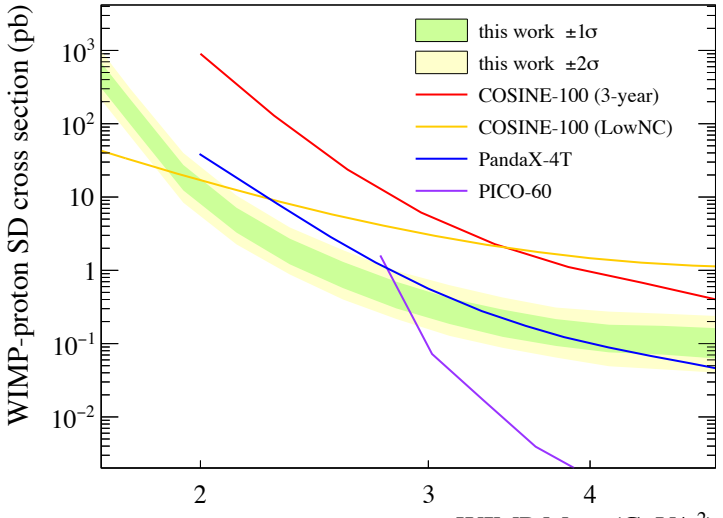




arXiv:2610.19668

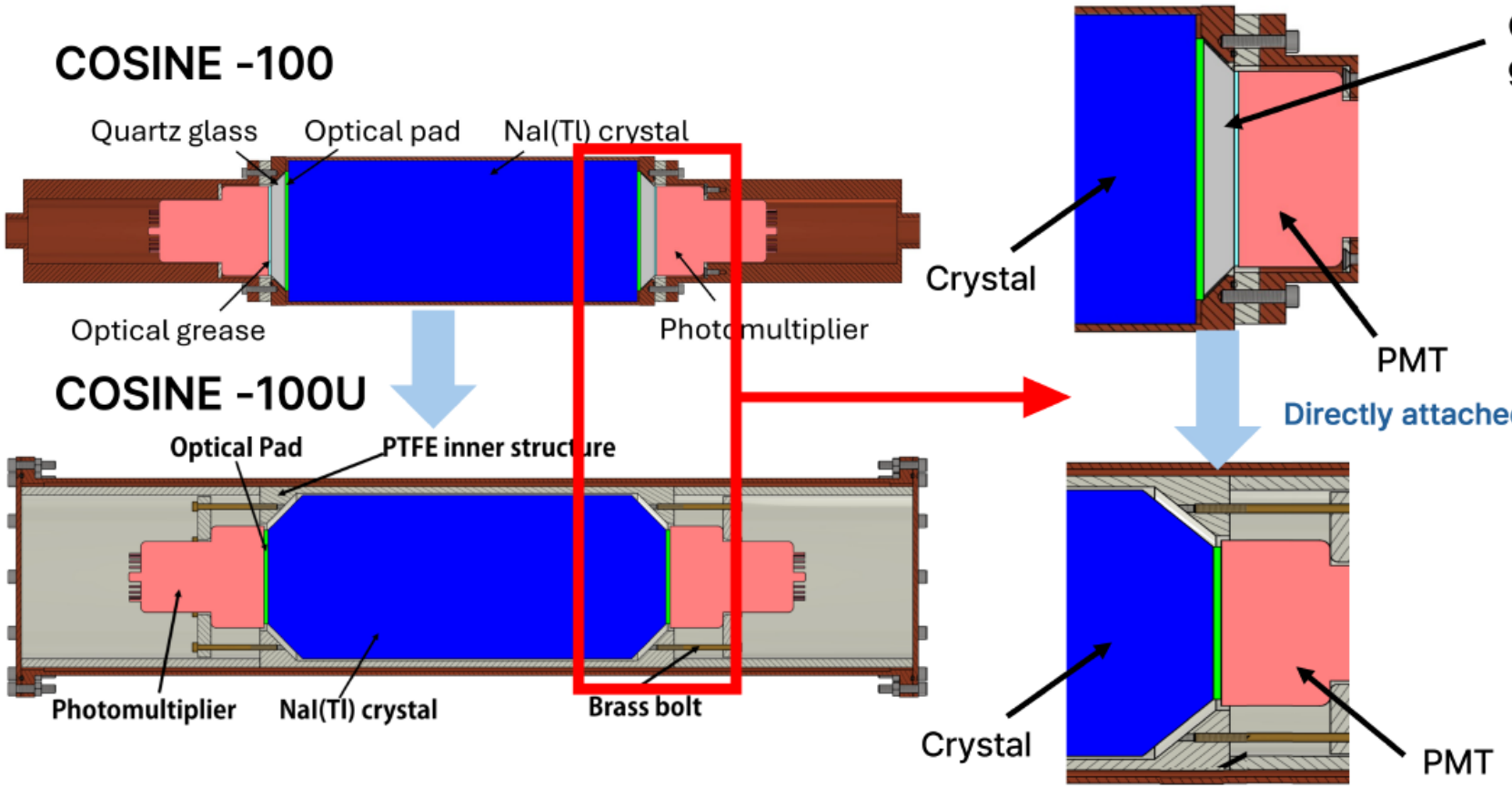






Moving forward to COSINE-100Upgrade

Upgraded detector assembly for high light output



NIMA 981 (2020) 164556

JINST 19 (2024) P10020

Commun. Phys. 8 (2025) 135

~60% increased light collection

Moving forward to COSINE-100Upgrade

- Upgrade detector assembly for high light yield



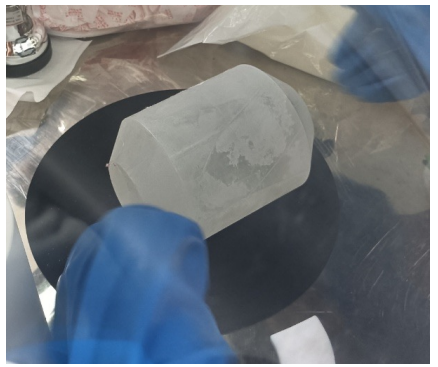
Crystal machine



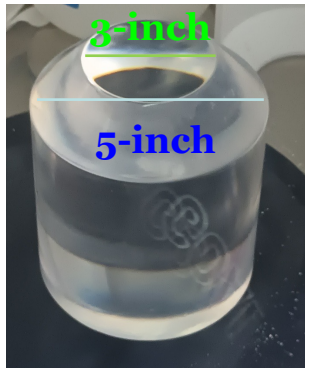
8.26 kg

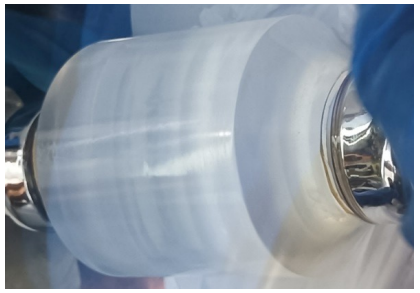
7.19 kg

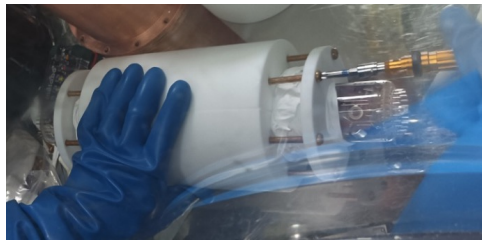
Deliver to glove box

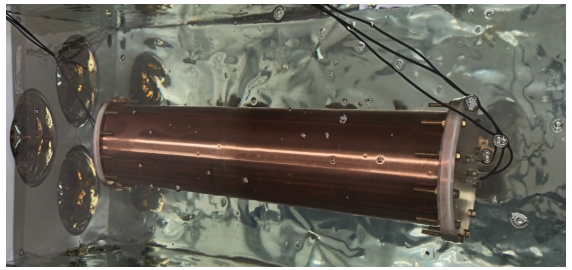


COSINE crystal-1

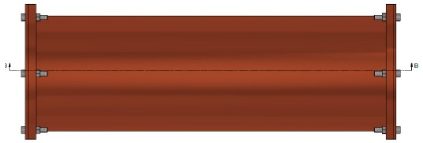


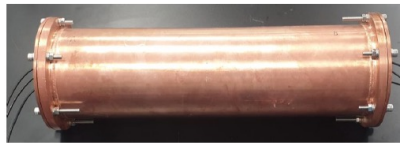


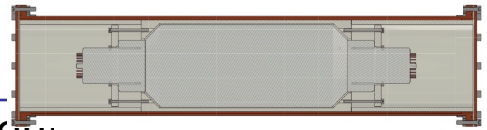




Measurement

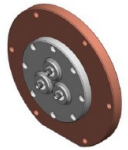






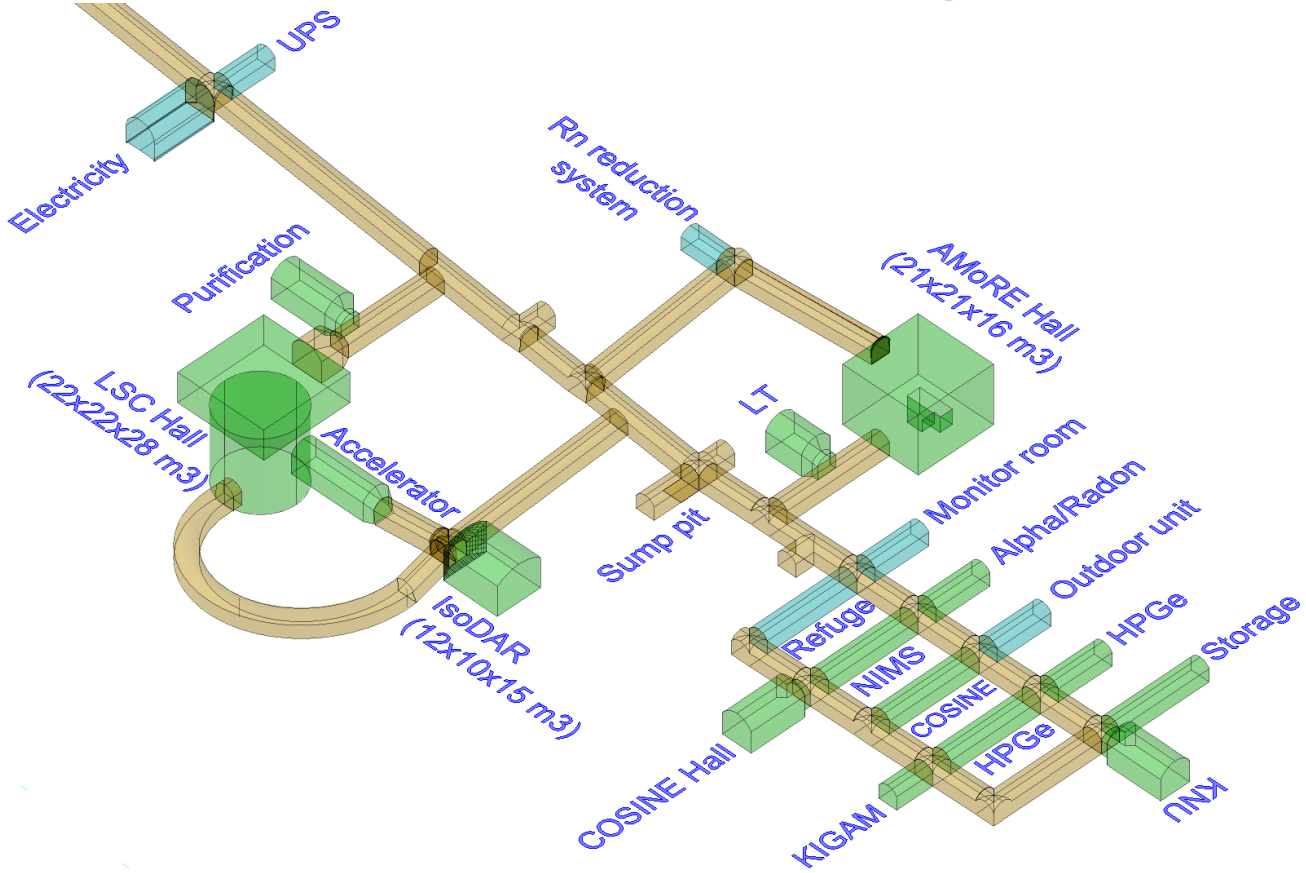


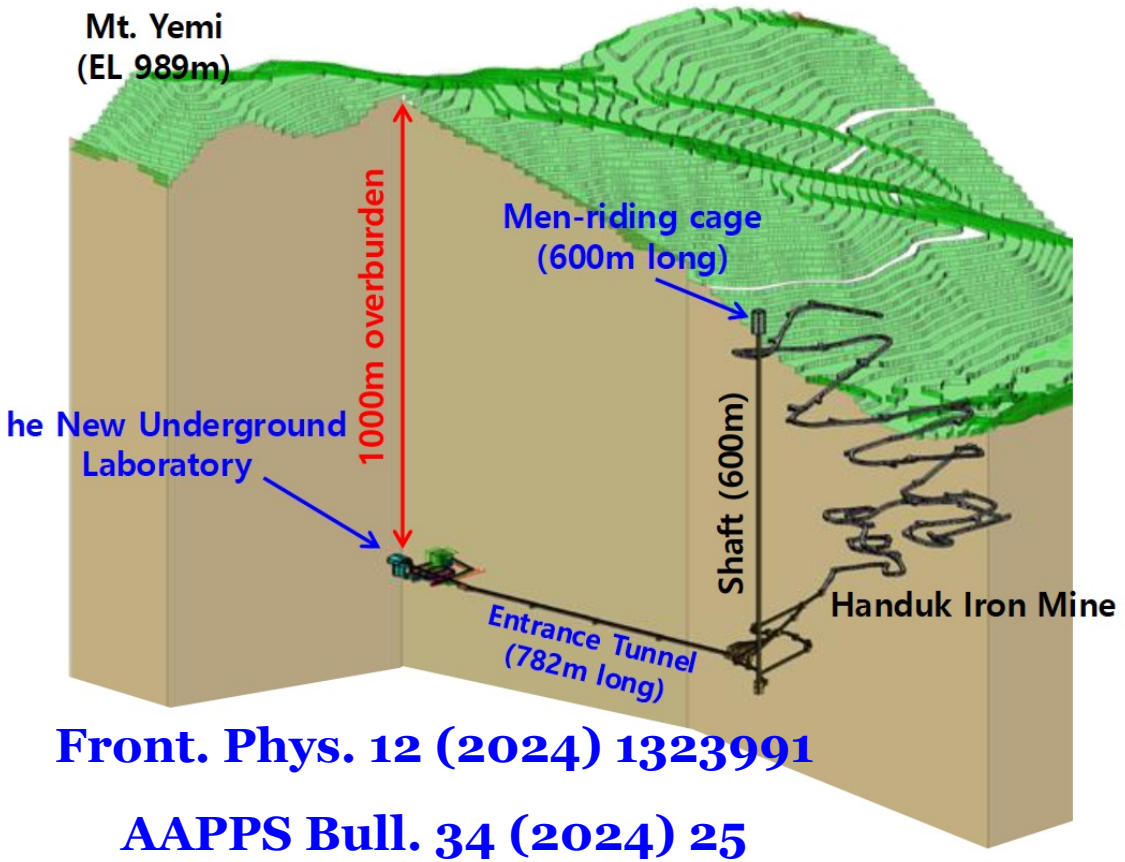
Cover design



Yemilab (Since 2022)

- **Dedicated underground laboratory for basic science**





Front. Phys. 12 (2024) 1323991

AAPPS Bull. 34 (2024) 25

- **Large experimental space (~3000 m^2)**
- Available space to host next-generation experiments

COSINE-100U @ Yemilab

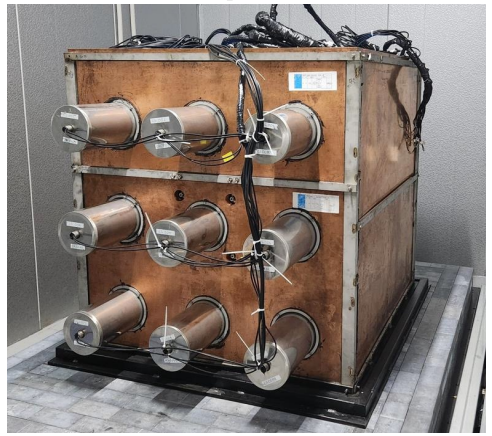
Freeze room for -20°C operation



Astropart. Phys. 141, 102709 (2022)

Detector upgrade for high light yield

Liquid scintillator veto





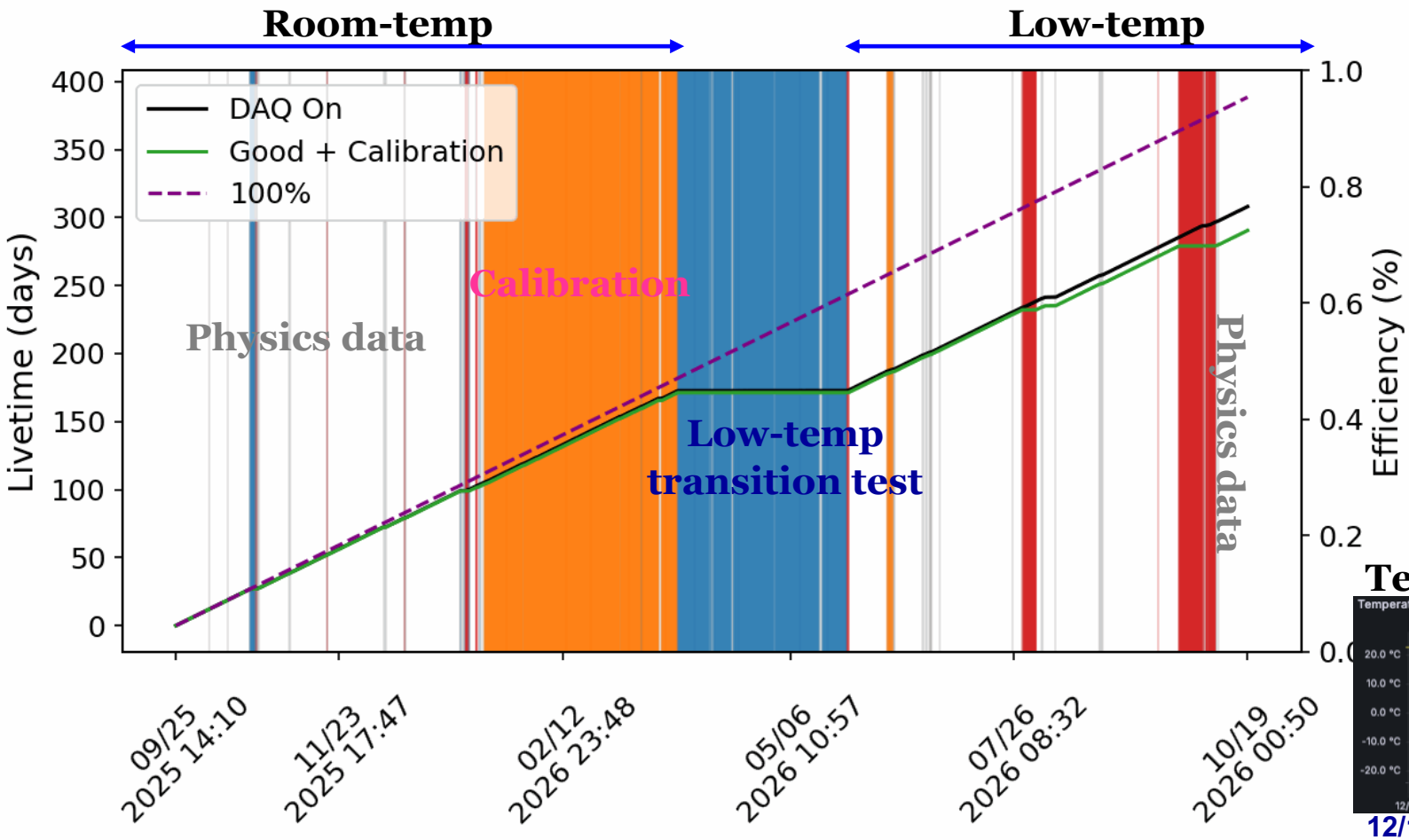
Crystal & LS install

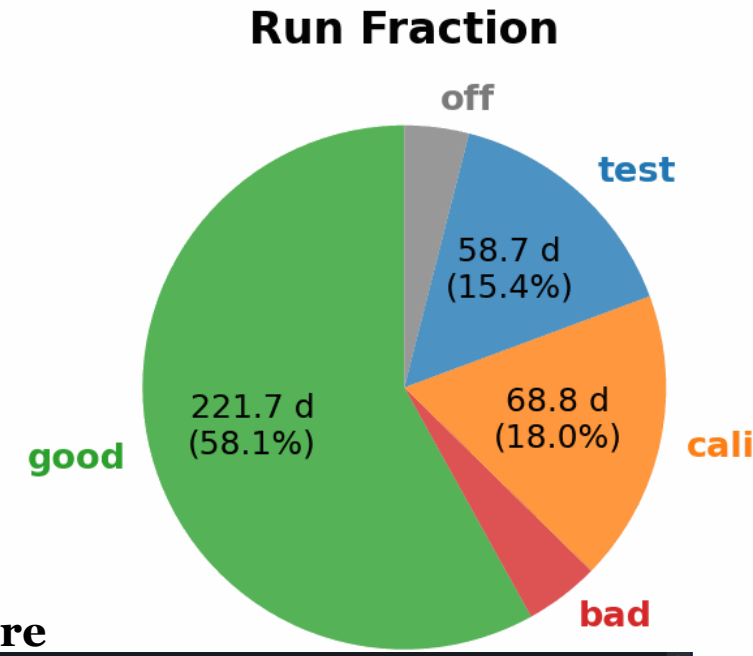


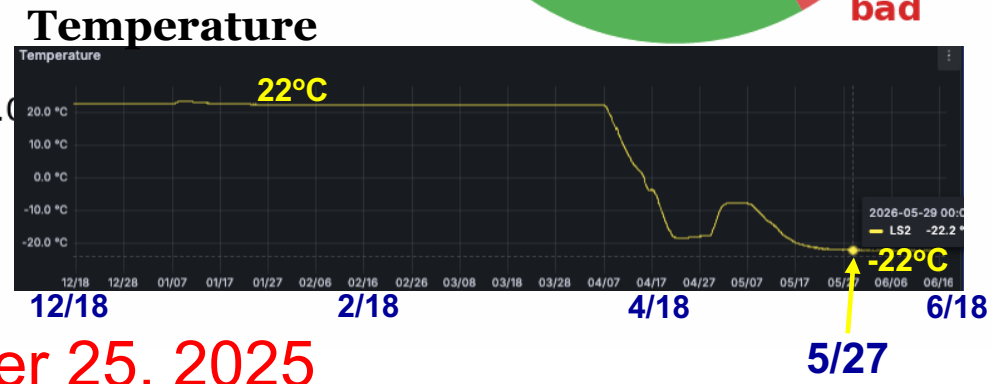


Most shields and electronics were reused from COSINE-100 (Y2L) for COSINE-100U (Yemilab)

COSINE-100U operation

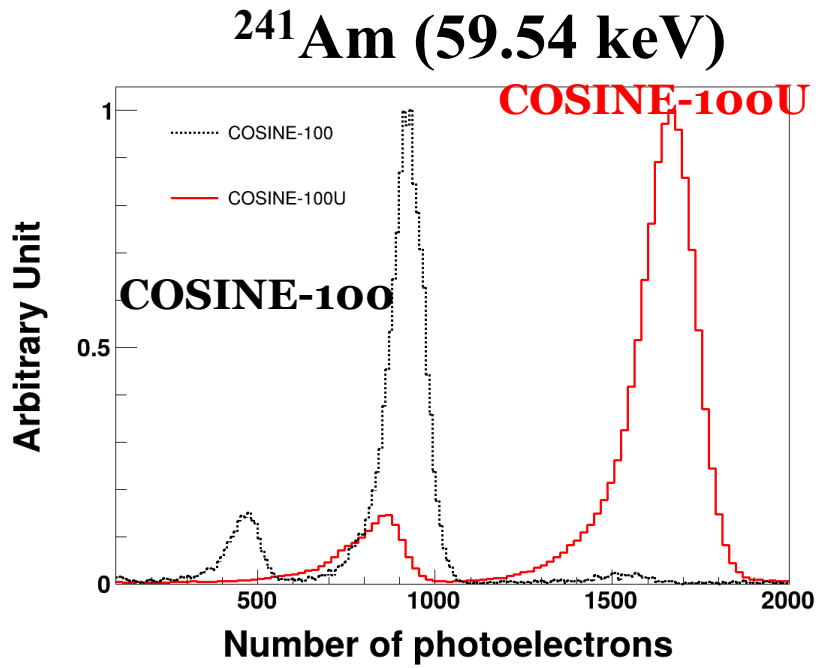


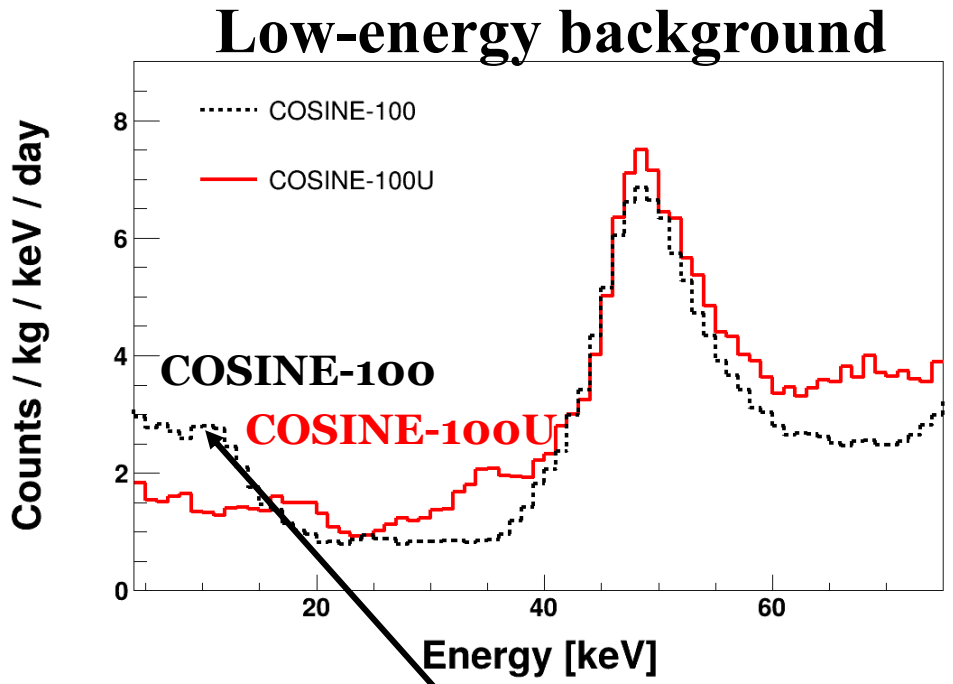




- Room-temp operation commenced on September 25, 2025
- With ~100 days of physics data and 67 days of ^{22}Na calibration data, we switch to low-temp (-22°C) operation, **starting the physics run on May 27, 2026**

COSINE-100U Data (Room-temp)

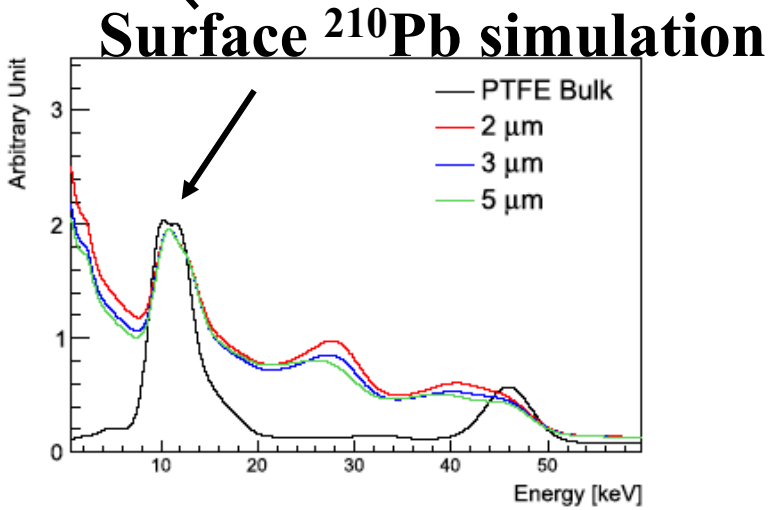




~60% increased light collection

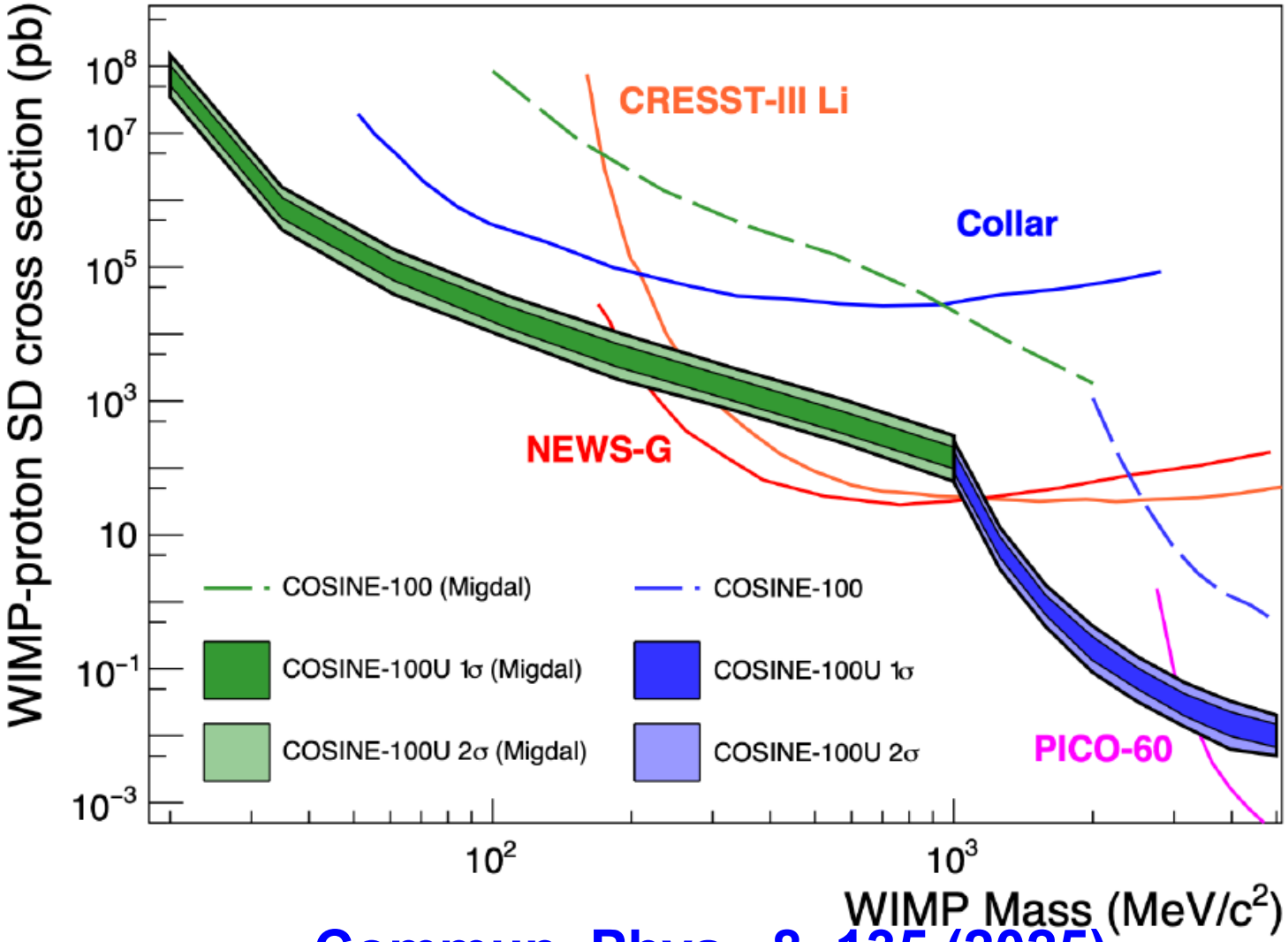
~ 1 count/kg/keV/day reduction in background from surface contamination

(Our own surface treatment of NaI(Tl) works much better than the company's)



COSINE-100U sensitivity

WIMP-Proton spin-dependent interaction



Commun. Phys. 8, 135 (2025)

Assumptions

- 20 NPE/keV light yield
- 8 Crystals, total 99.0 kg
- 1-year exposure
- 5 NPE threshold
- Same background as COSINE-100

- ~23 NPE/keV
- ~ 1 dru reduced background
- Low-temp operation

Toward COSINE-200: Powder

- Initial Goal : Background level less than DAMA/LIBRA (~1 dru)

Recrystallization of powder



^{40}K and ^{210}Pb are the main contaminants

	K (ppb)	Pb (ppb)	U (ppb)	Th (ppb)
Initial NaI	248	19.0	<0.01	<0.01
Purified NaI	11.1	0.4	<0.01	<0.01

K.A. Shin et al., J. Rad. Nucl. Chem. 317, 1329 (2018)

K.A. Shin et al., JINST 15, C07031 (2020)

K.A. Shin et al., Front. Phys. 11, 1142849 (2023)

- Mass production of purified powder ~ **35 kg / 2 weeks**
- **400 kg** of low-background powder is available
- IBS/CUP is currently **the only facility worldwide producing low-background NaI powder** (**K < 20 ppb**)
- Global collaboration for low-background NaI(Tl) crystals with low-background powder and other halide crystals

Toward COSINE-200: Crystal Growth

- Initial Goal : Background level less than DAMA/LIBRA (~1 dru)

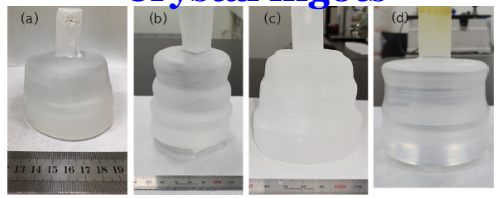
Kyropoulos





K : ~13 ppb, ^{210}Pb: 0.1 mBq/kg

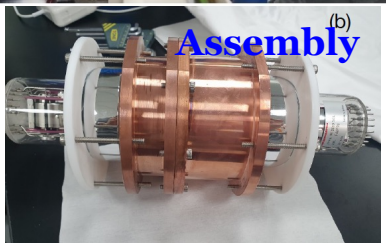
Crystal ingots

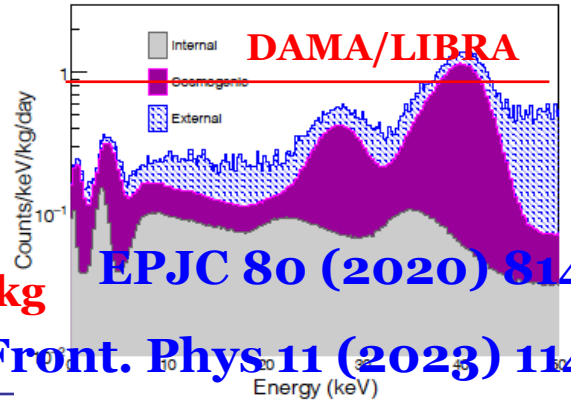


Machining



Assembly





EPJC 80 (2020) 814

Front. Phys 11 (2023) 1142765

Bridgman



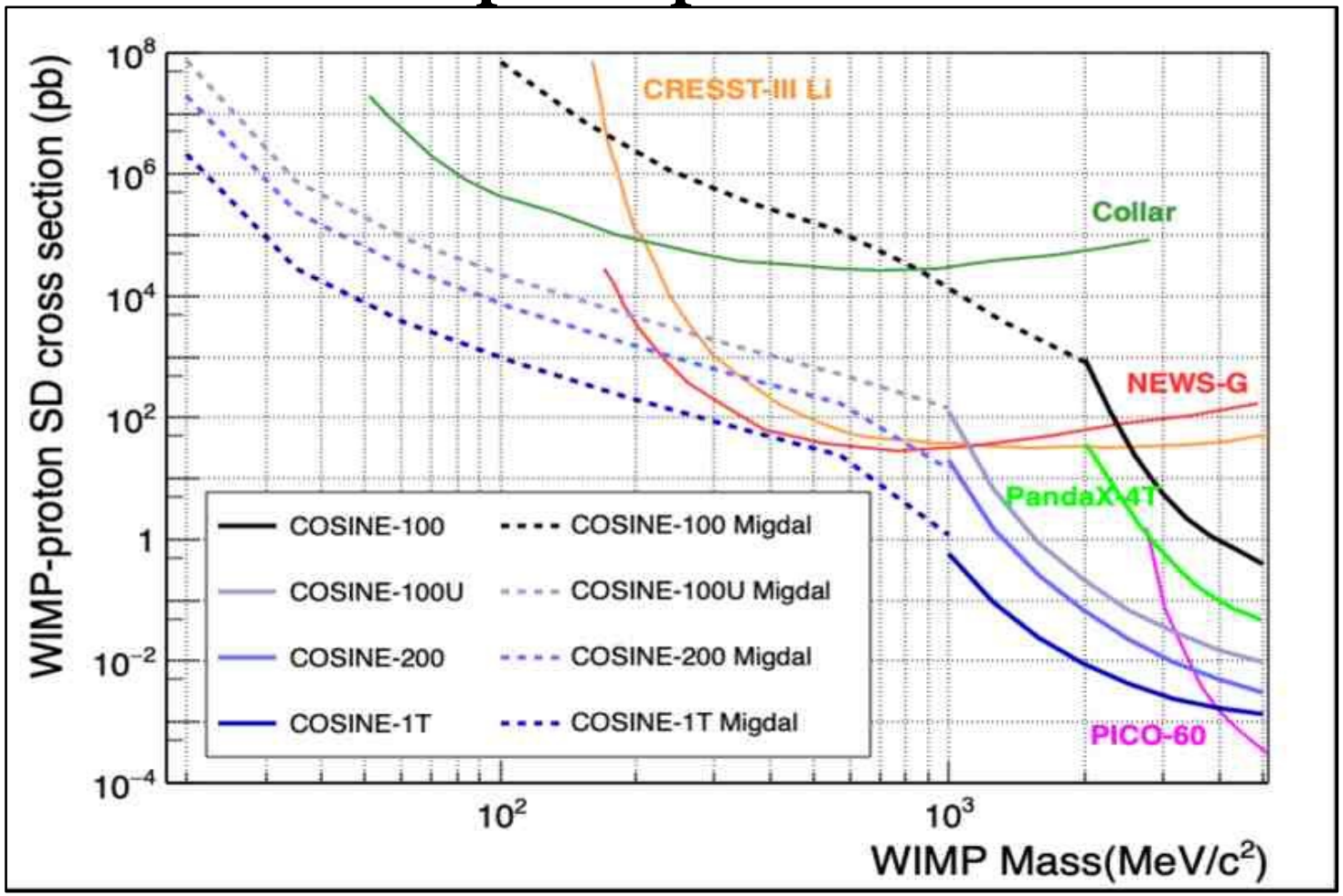
- **Proof of concept for low-background NaI(Tl)**
- Large-size crystal growing is ongoing

Full stack of low-background NaI(Tl) detector

Physics reach of COSINE

In addition to DAMA/LIBRA verification…

WIMP-Proton spin-dependent interaction



Exploring uncovered low-mass dark matter parameter space

Summary

- COSINE-100 ruled out DAMA/LIBRA with significance above 3 sigma in model-independent analysis

- Combined analysis with ANAIS-112 reach to 5 sigma level exclusion

- COSINE-100U/COSINE-200 will have world competitive sensitivities for low-mass dark matter searches

Thank you for your attention