

COSINE dark matter search

Resolving DAMA/LIBRA



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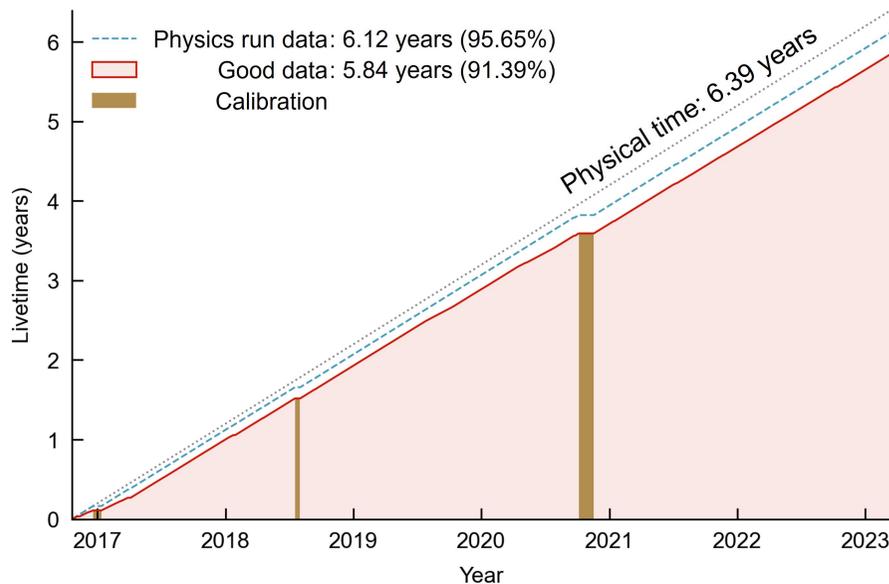
On Behalf of the COSINE-100 Collaboration

TeV Particle Astrophysics 2024

University of Chicago, August 27, 2024



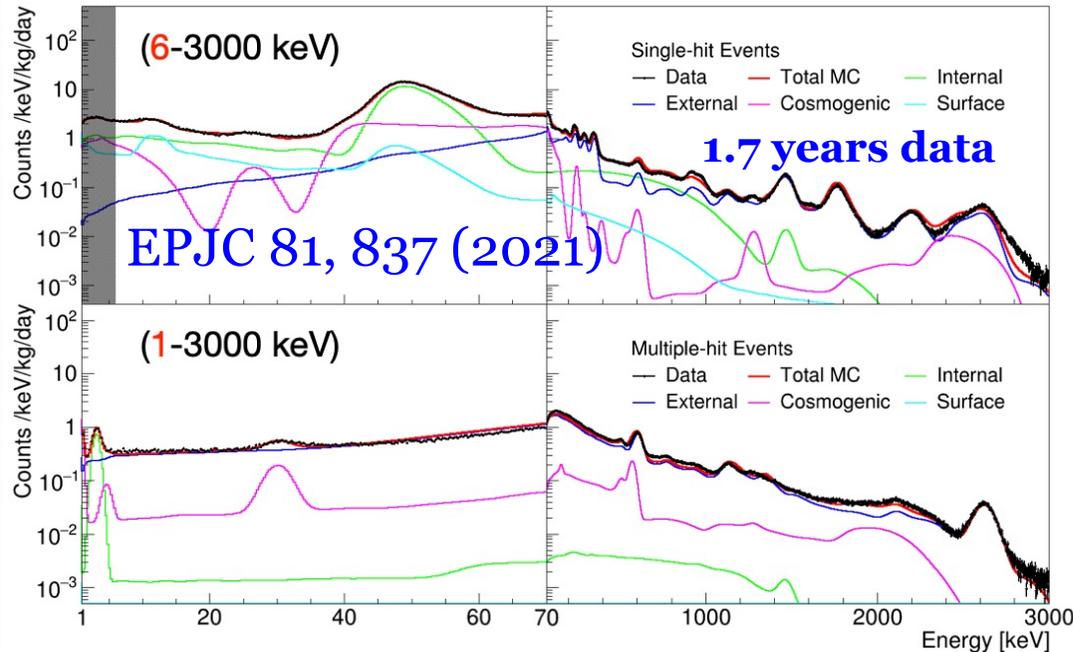
COSINE-100 experiment (2016~2023)



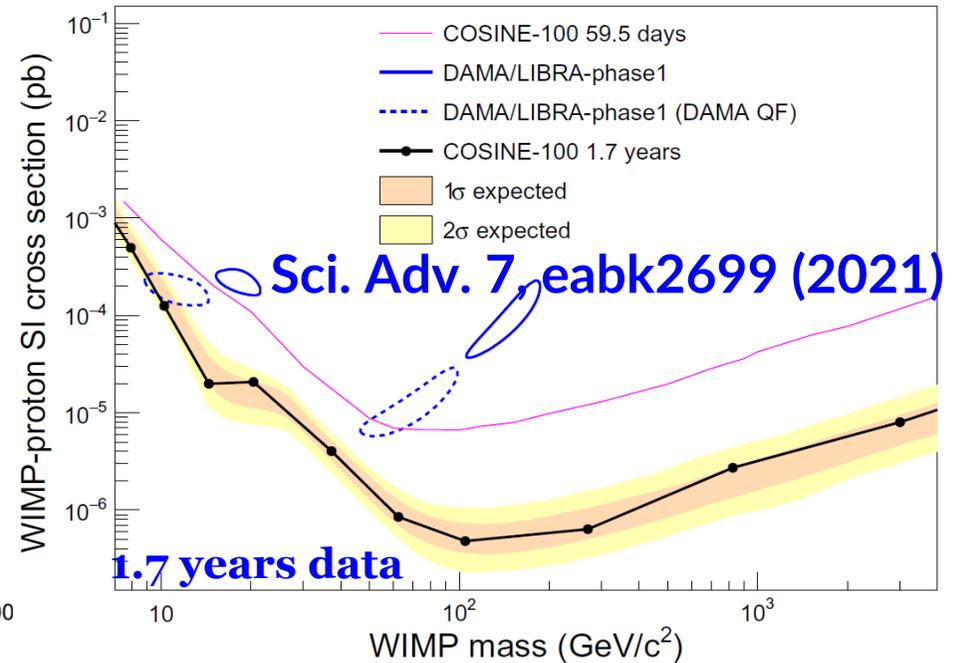
- YangYang underground laboratory
 - ❖ **October/2016 ~ March/2023**
- Decommissioning and preparation of COSINE-100Upgrade
 - ❖ **Move to Yemilab**
 - ❖ **Upgrade of detector for high light yield**

Model-dependent tests of DAMA/LIBRA

Background modeling



WIMP dark matter interpretation



Model independent annual modulation searches could not resolve DAMA/LIBRA yet

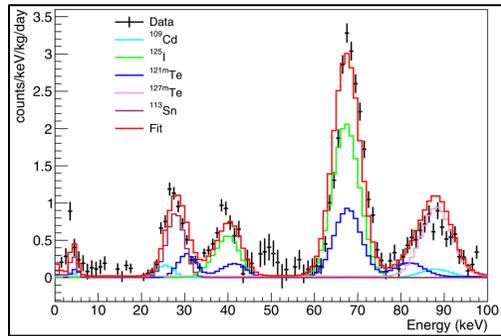
1.7 years data analysis [Phys. Rev. Lett. 123, 031302 \(2019\)](#)

3 years data analysis [Phys. Rev. D 106, 052005 \(2022\)](#)

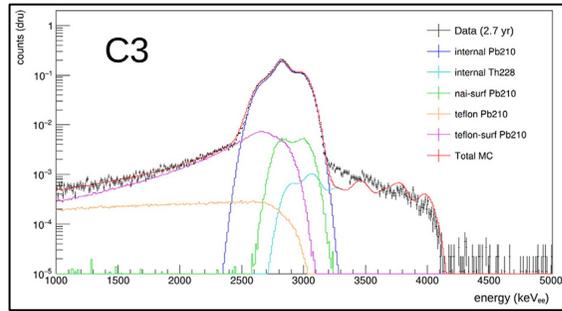
Full 6.4 years data are available

Improvement of NaI(Tl) detector understanding

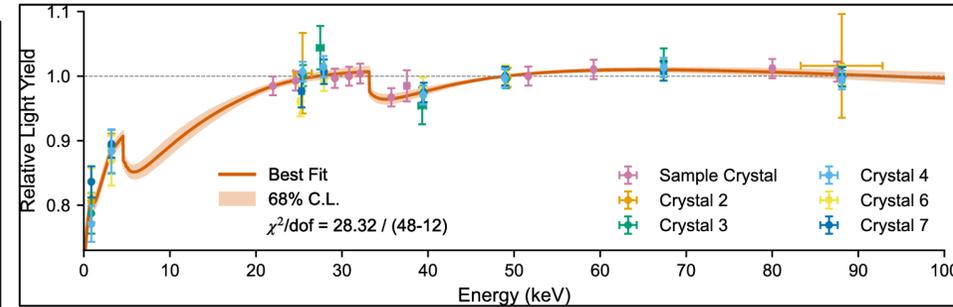
ASP 115, 102390 (2020)



ASP 158, 102945 (2024)



EPIC 84, 484 (2024)

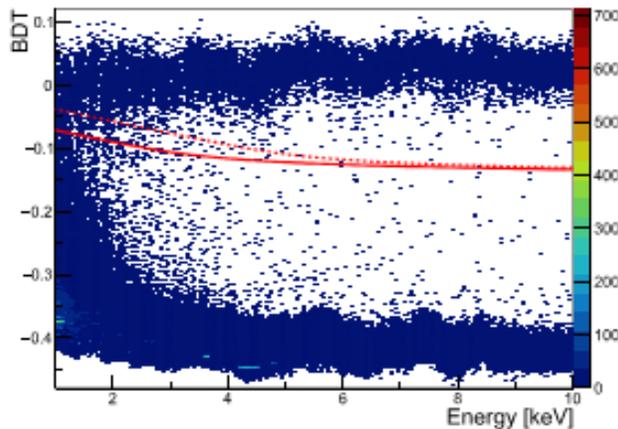


Background components

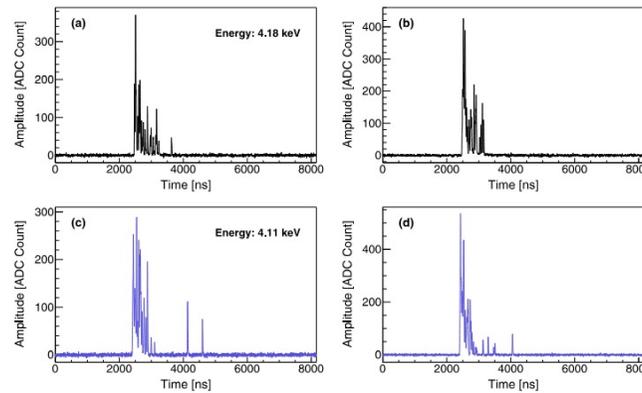
Detector responses

Low energy scintillation responses

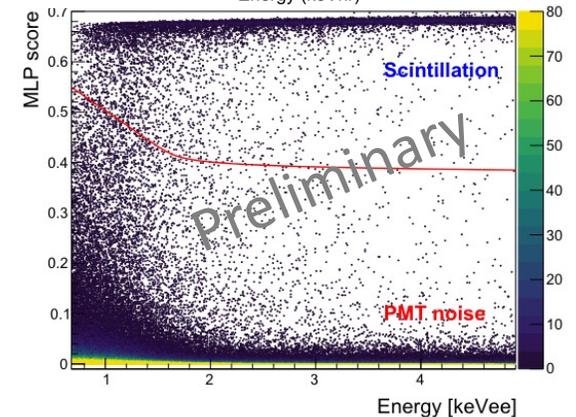
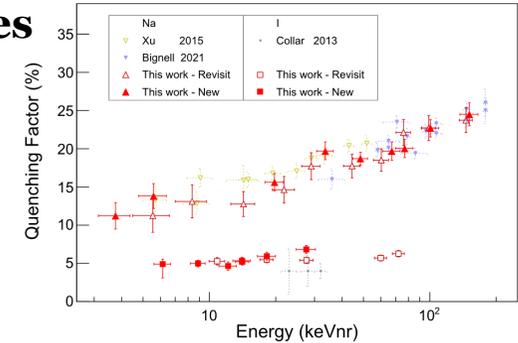
ASP 130, 102581 (2021)



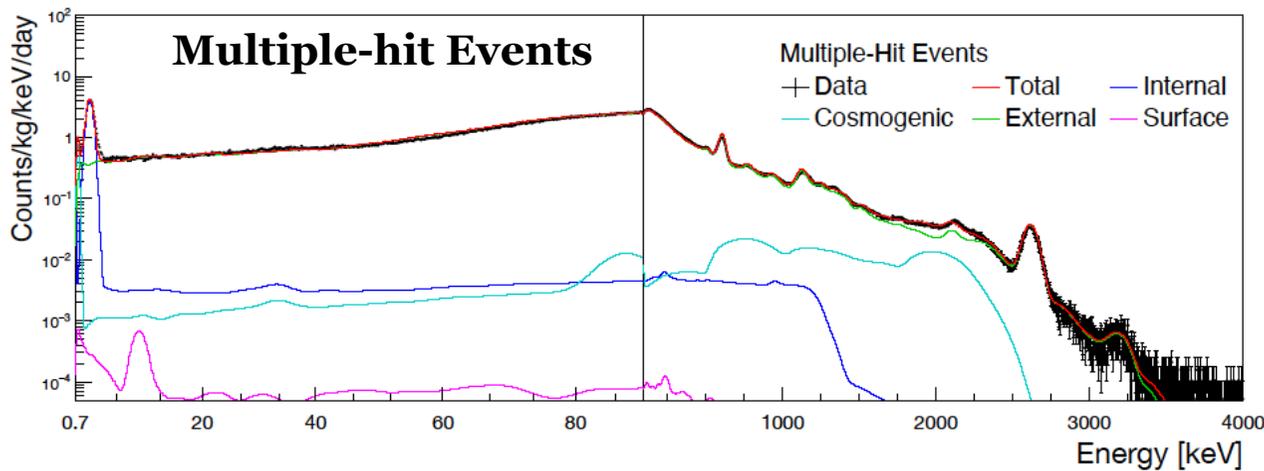
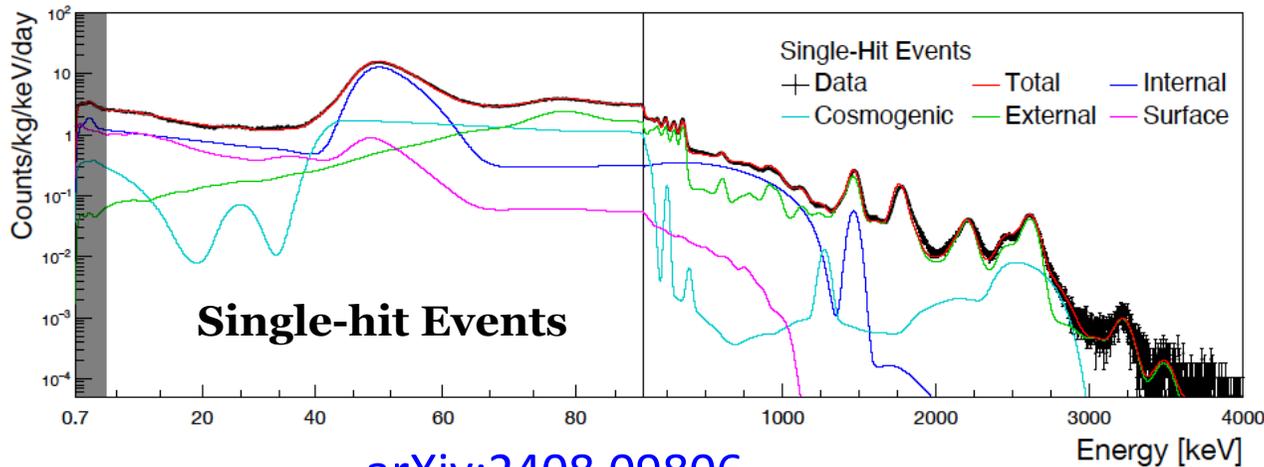
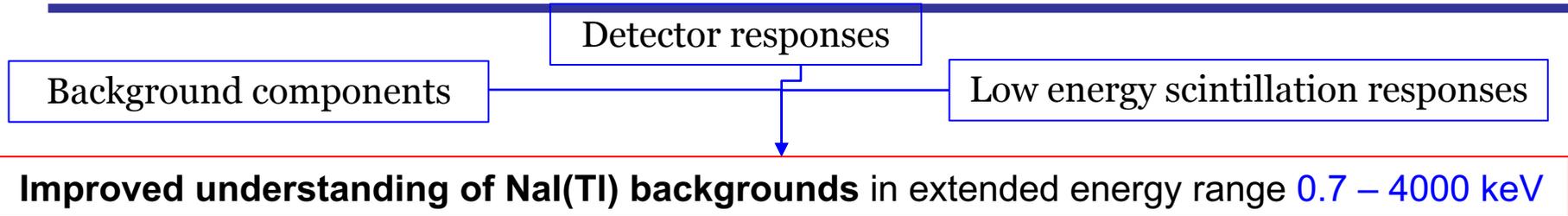
NIMA 1065, 169489 (2024)



PRC 110, 014614 (2024)

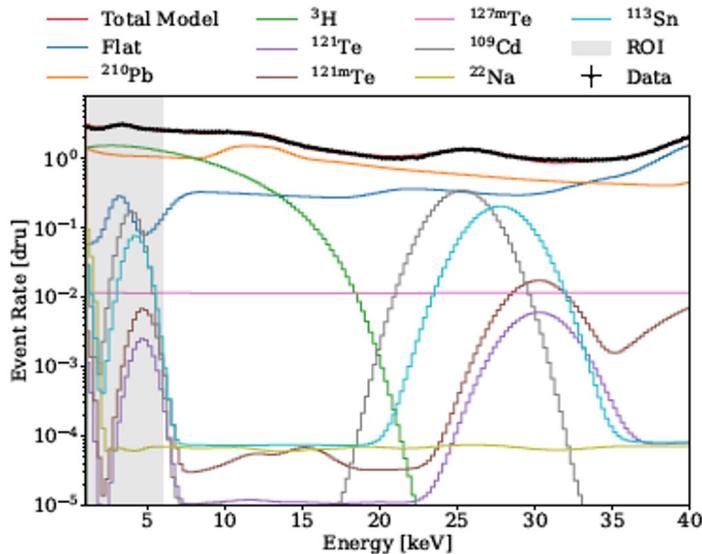
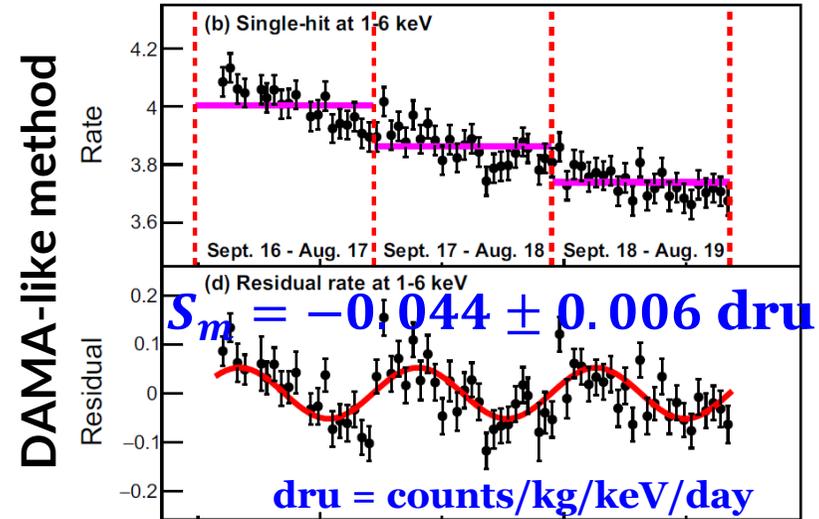
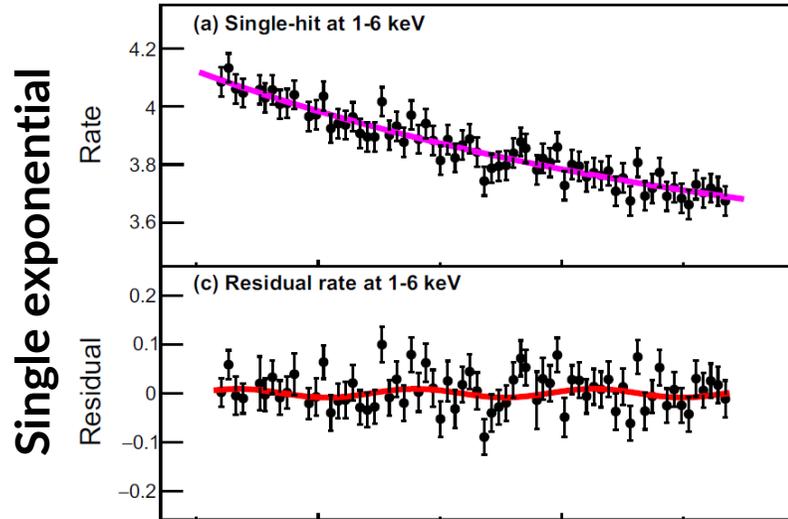


Improvement of NaI(Tl) detector understanding



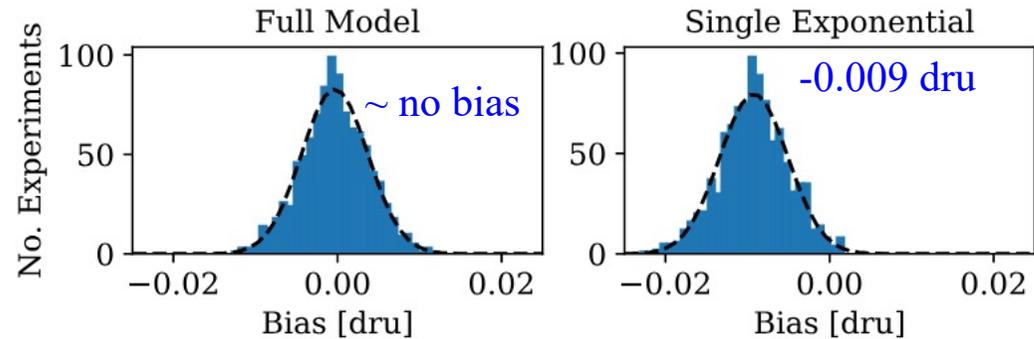
Time-dependent background models

Sci. Rep. 13, 4676 (2023)



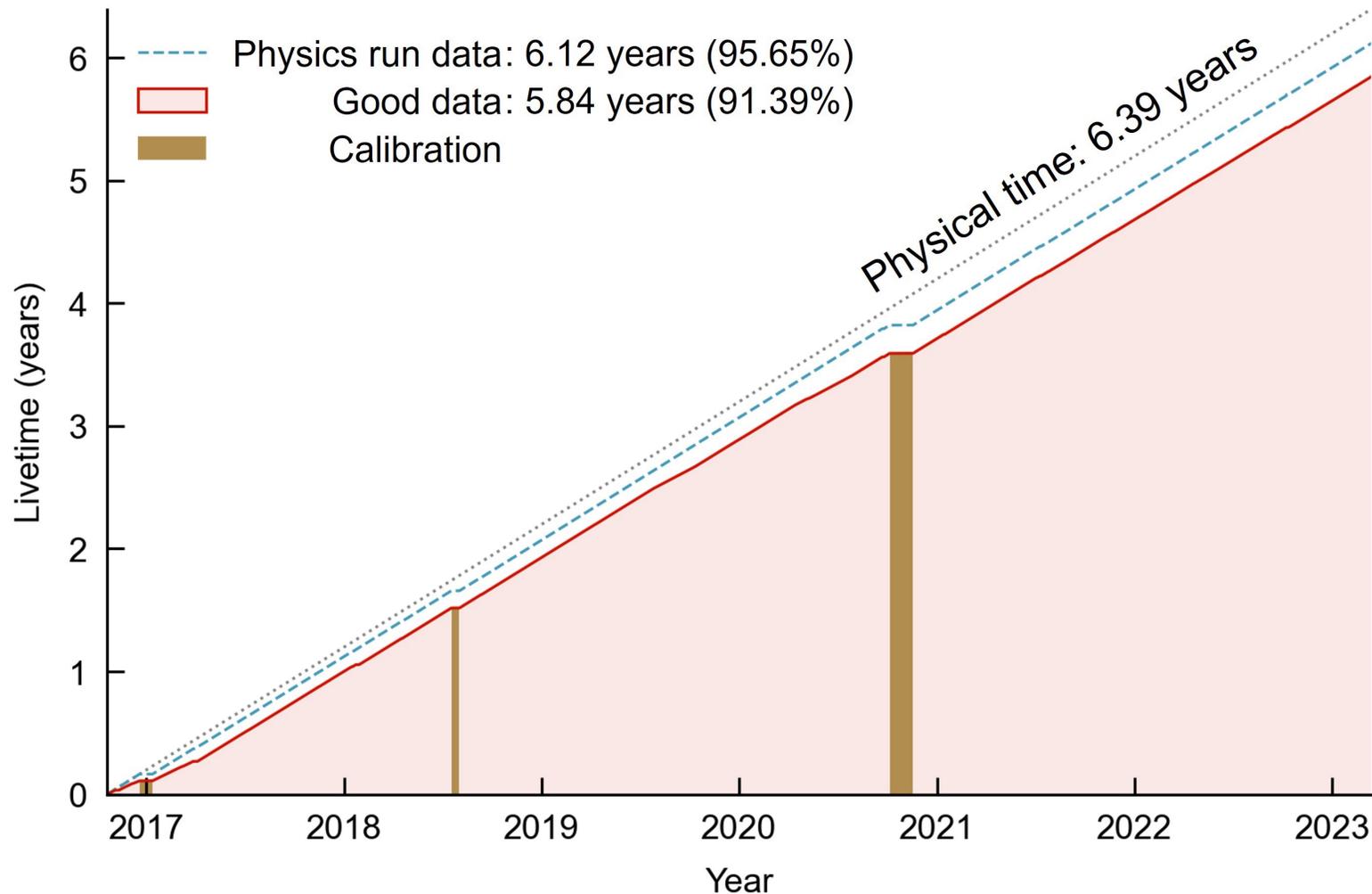
PRD 106, 052005 (2022) (3 years modulation search)

Full model : eight exponential components



DAMA/LIBRA : $0.010 \pm 0.001 \text{ dru}$

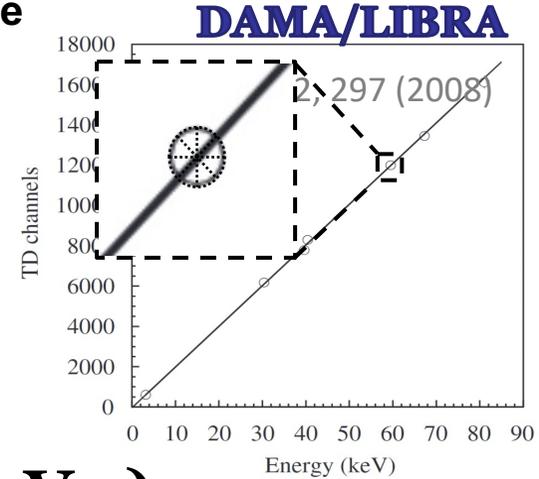
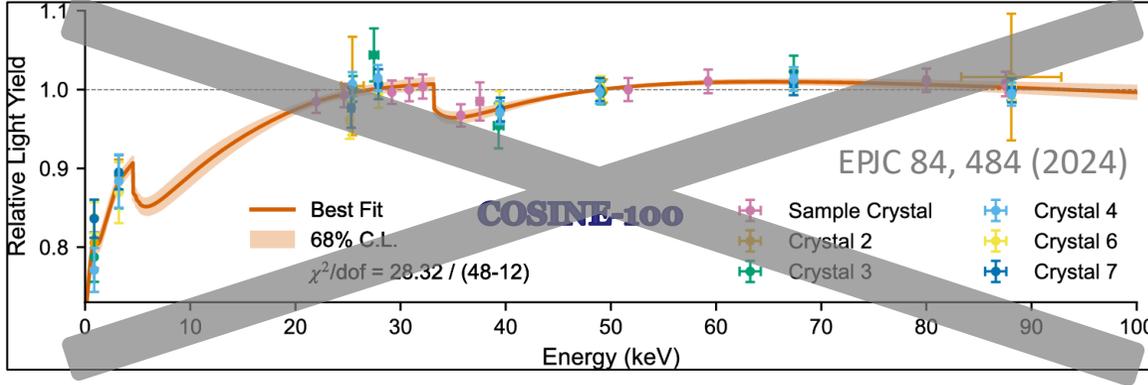
COSINE-100 full dataset



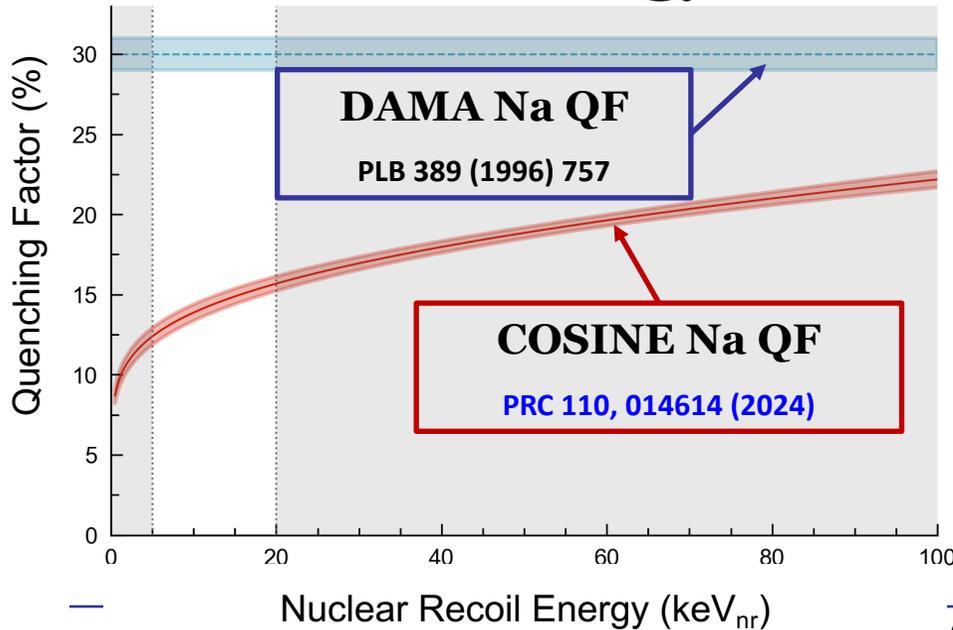
- Importance : [Apple-to-apple](#) comparison with **DAMA/LIBRA**

Comparison with DAMA : Energy calibration

Linear calibration to 59.54 keV : keV_{ee}



Nuclear-recoil energy calibration (keV_{nr})



Quenching factor (QF)

Measured electron-equivalent energy/True nuclear recoil energy

Signal region : 6.7-20 keV_{nr}

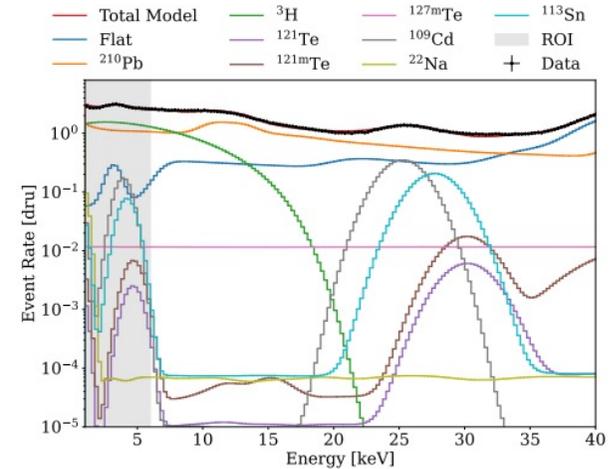
DAMA/LIBRA : 2-6 keV_{ee}

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

Measured signal

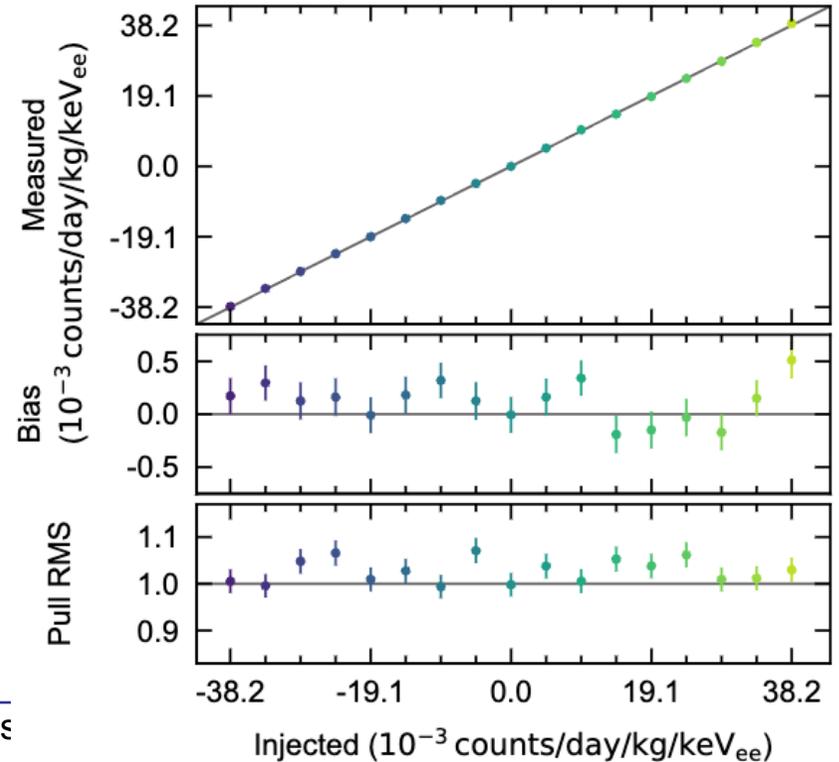
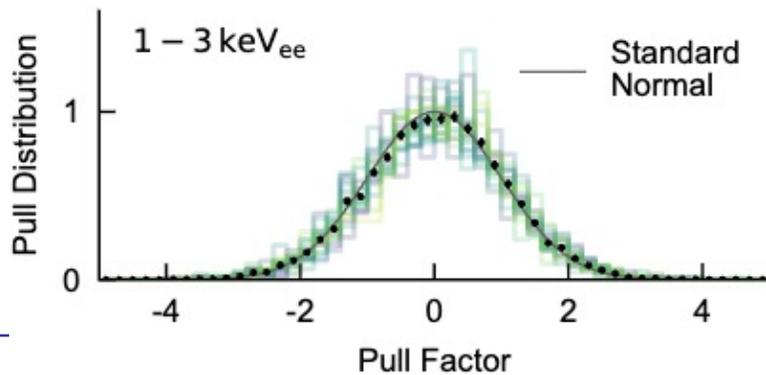
Pull Factor

Input signal

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

Measured uncertainty

No Bias

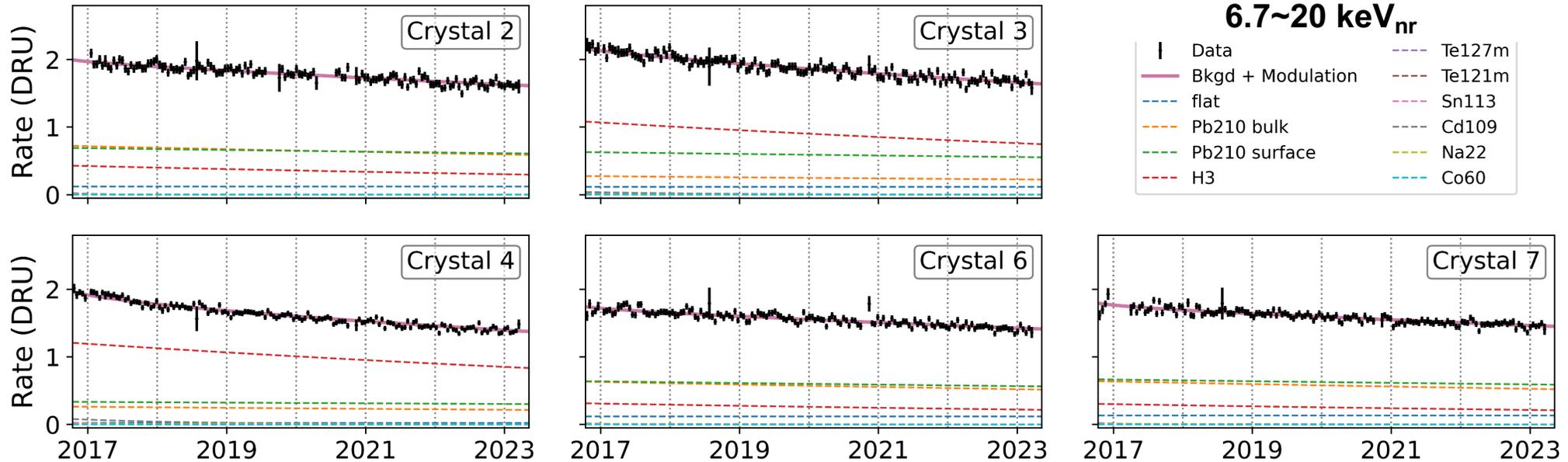


Modulation fit

$$R_i(t) = \underbrace{A \cos\left(\frac{2\pi(t - \phi)}{T}\right)}_{\text{Modulation signals}} + \underbrace{\sum_j C_{ij} e^{-\lambda_{ij}t}}_{\text{10 time-dependent components}}$$

COSINE-100 full dataset

DRU = counts/kg/keV/day

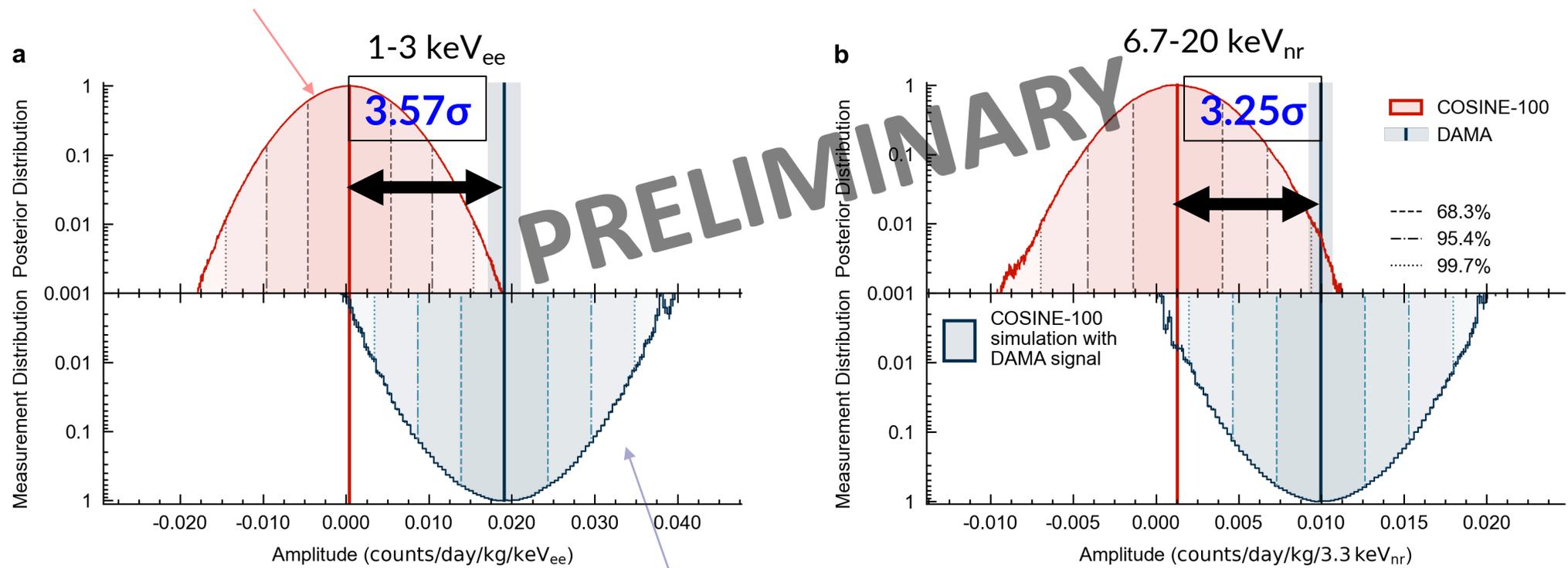


No modulation signal observed !!

COSINE-100 full dataset fits

Posterior of COSINE-100 full dataset

(2-6 keV_{ee} in DAMA/LIBRA)

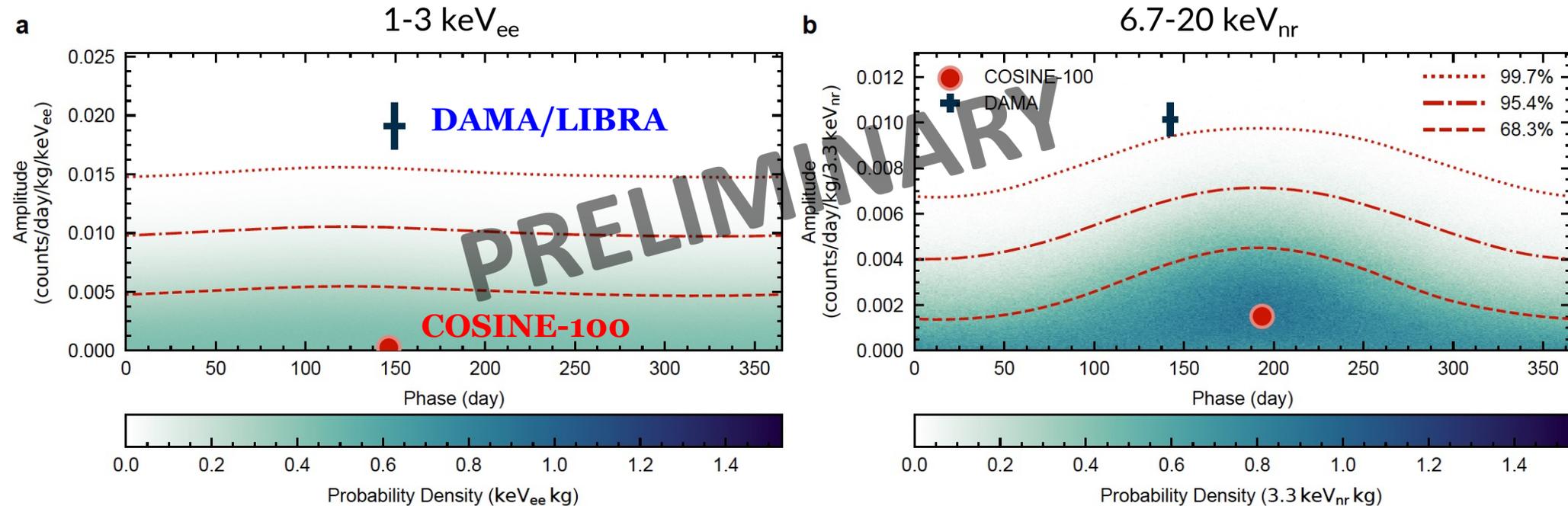


Simulated experiments (25,000) assuming DAMA/LIBRA modulation signals

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

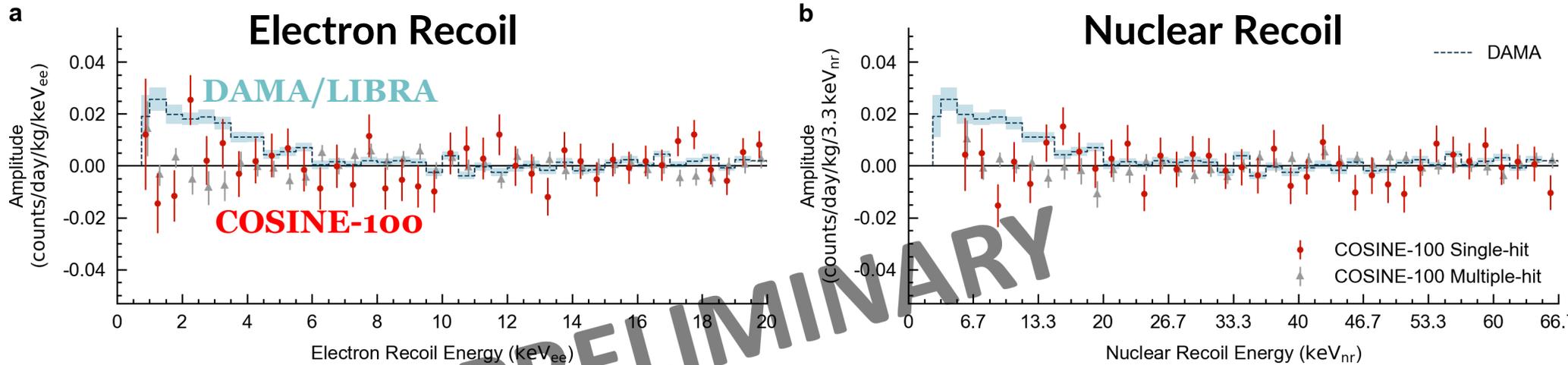
COSINE-100 full dataset fits

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



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

COSINE-100 full dataset fits



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

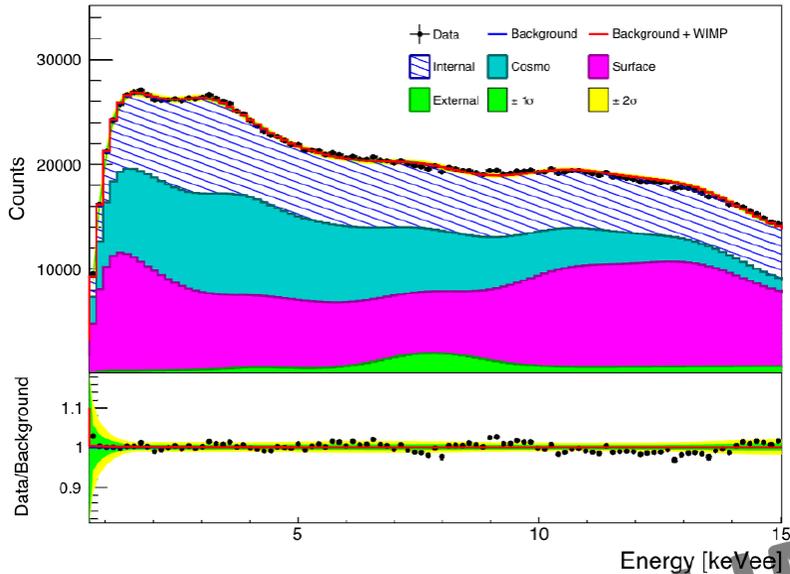
E (keV _{nr})	A (counts/day/kg/3.3 keV _{nr})	
	COSINE-100	DAMA/LIBRA
6.7~20	0.001 ± 0.003	0.010 ± 0.001

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

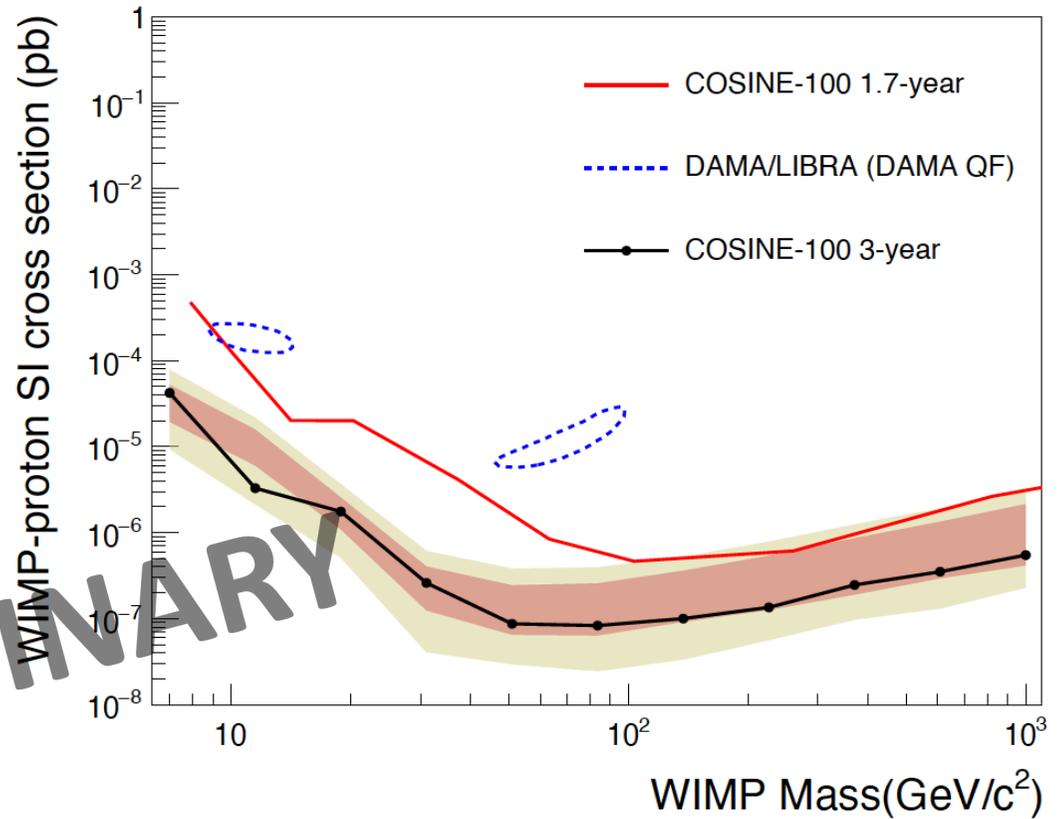
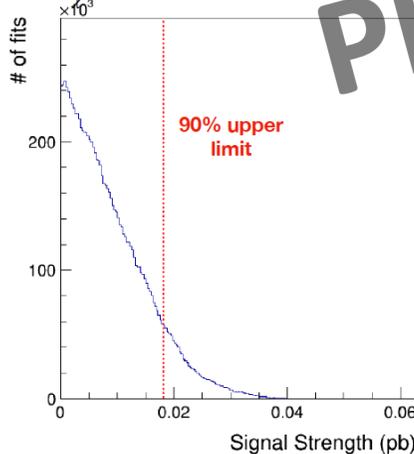
Model-dependent searches

COSINE-100 3 years data

Example of WIMP presence test in $M_\chi = 12.92 \text{ GeV}/c^2$ SD model



90% upper limit of data fit in
 $M_\chi = 12.92 \text{ GeV}/c^2$ SD model



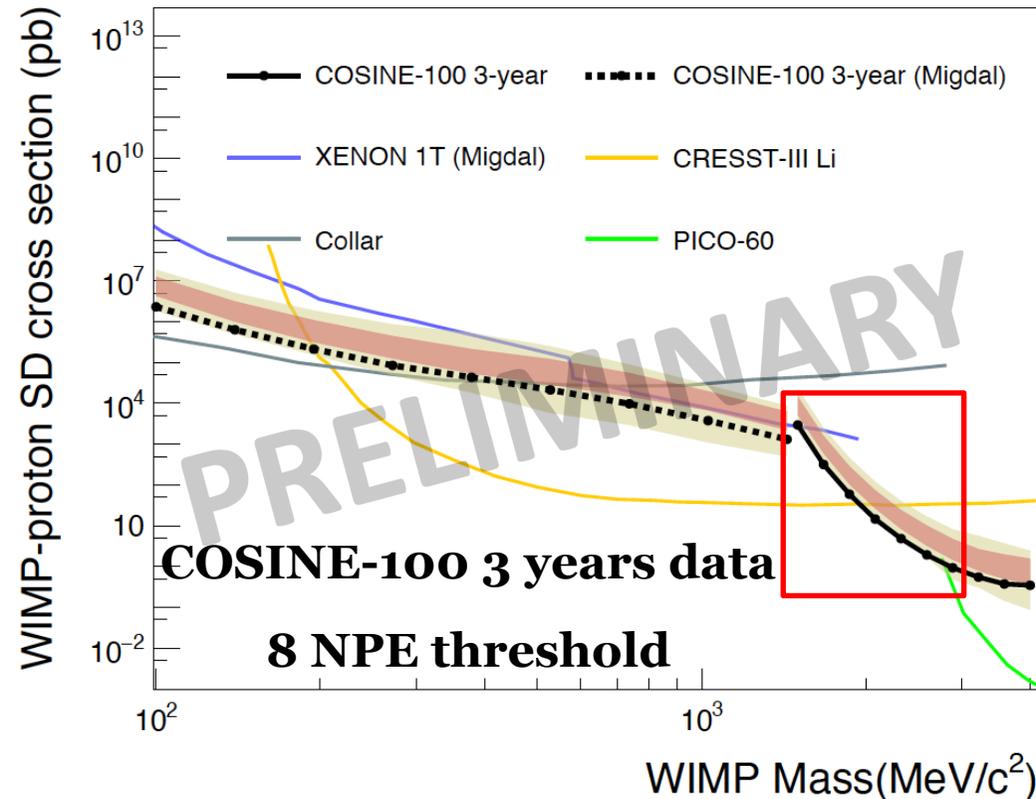
COSINE-100 full dataset disfavors DAMA/LIBRA in model-dependent search

Low-mass dark matter search with COSINE-100

- 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)**
 - Waveform simulation
 - Improving machine learning
 - Employ deep learning

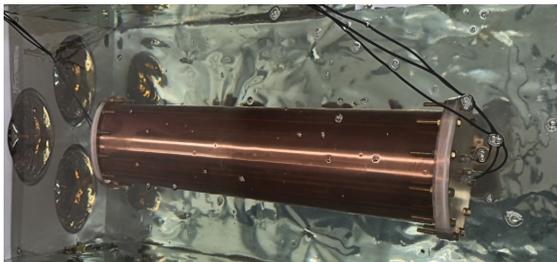
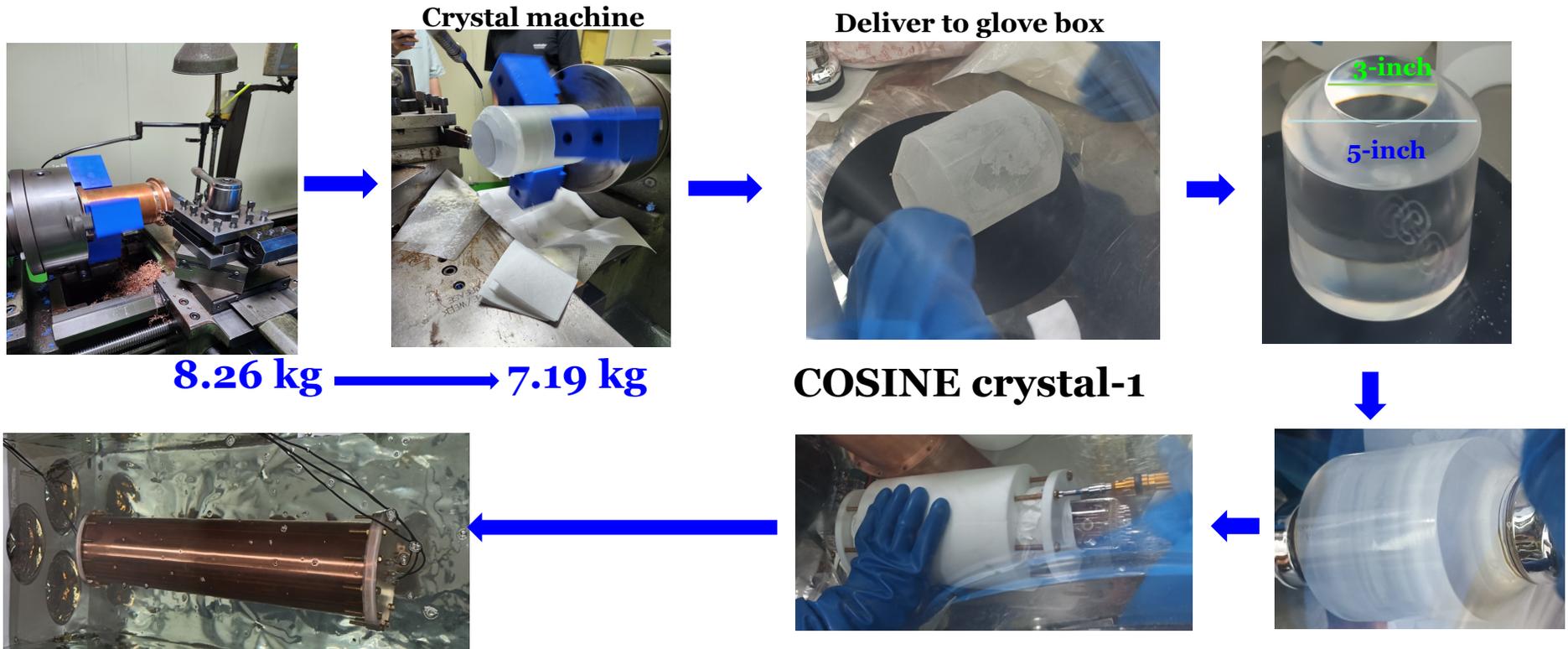
NPE = number of photoelectrons

WIMP-proton spin-dependent interaction

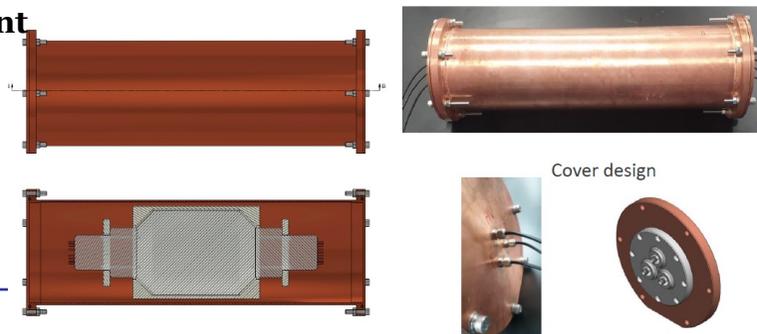


Moving forward to COSINE-100U_pgrade

- Upgrade detector assembly for **high light yield**



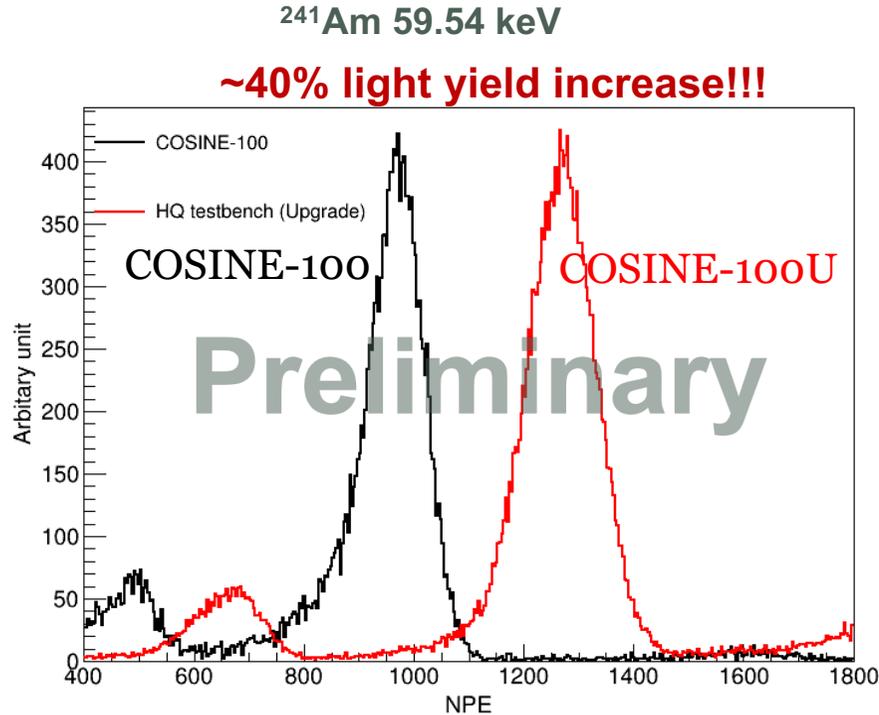
Above ground measurement



NIMA 981 (2020) 164556
arXiv:2404.03691

COSINE-100U : Detector upgrade

- Light yield @ 59.54 keV



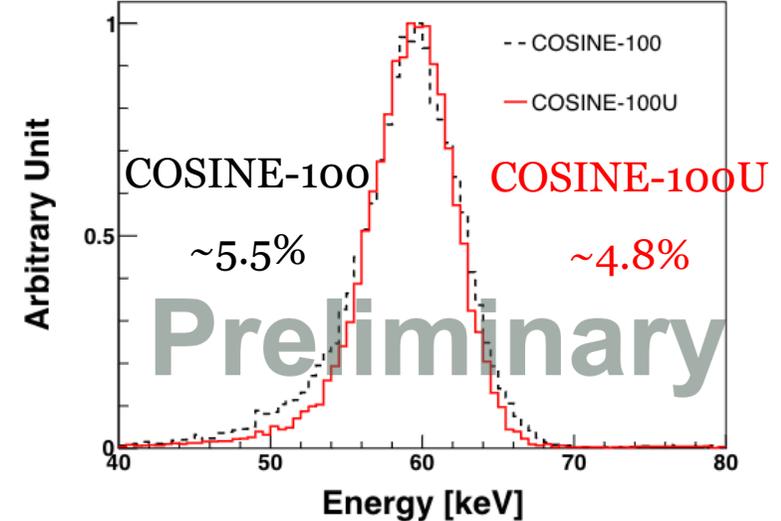
NPE = Number of photoelectrons

14.9 ± 1.5 \rightarrow **21.5 ± 0.6 NPE/keV**

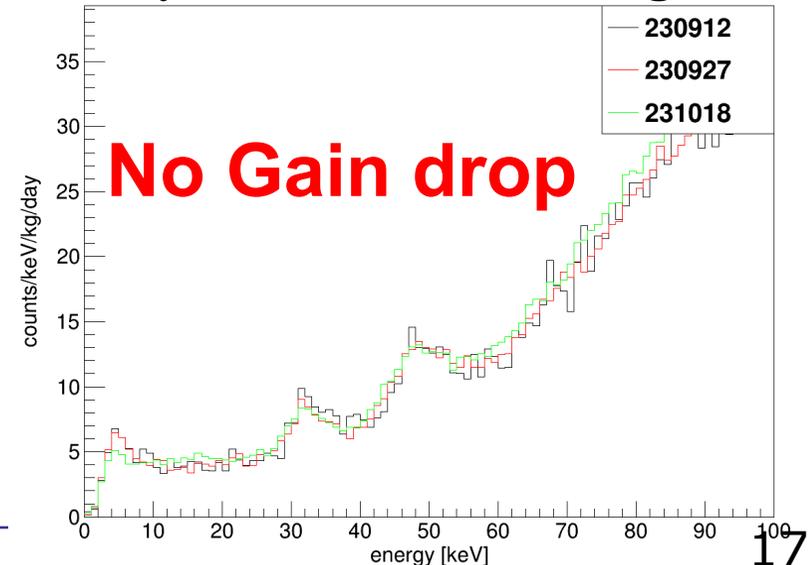
COSINE-100 C2 COSINE-100U C2

All crystals were assembled and delivered to Yemilab

RMS resolution @ 59.54 keV for C3



Stability of ~ 1 month (Above-ground)



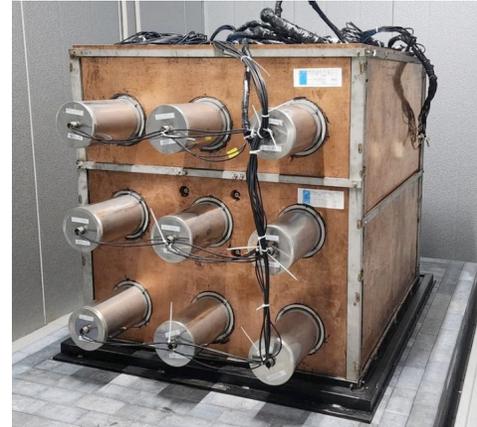
COSINE-100U : Yemilab installation

Freeze room for -30°C operation

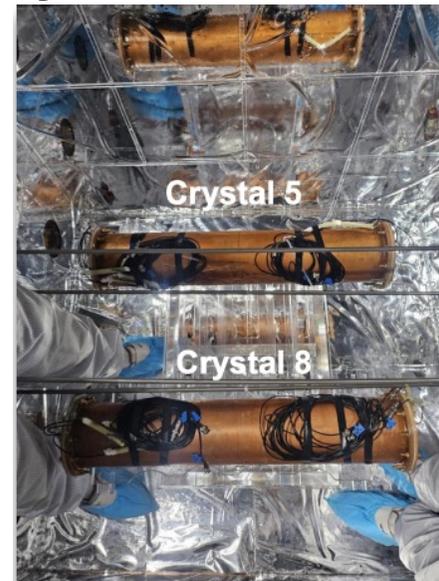


[Astropart. Phys. 141, 102709 \(2022\)](#)

Liquid scintillator veto Lead shield

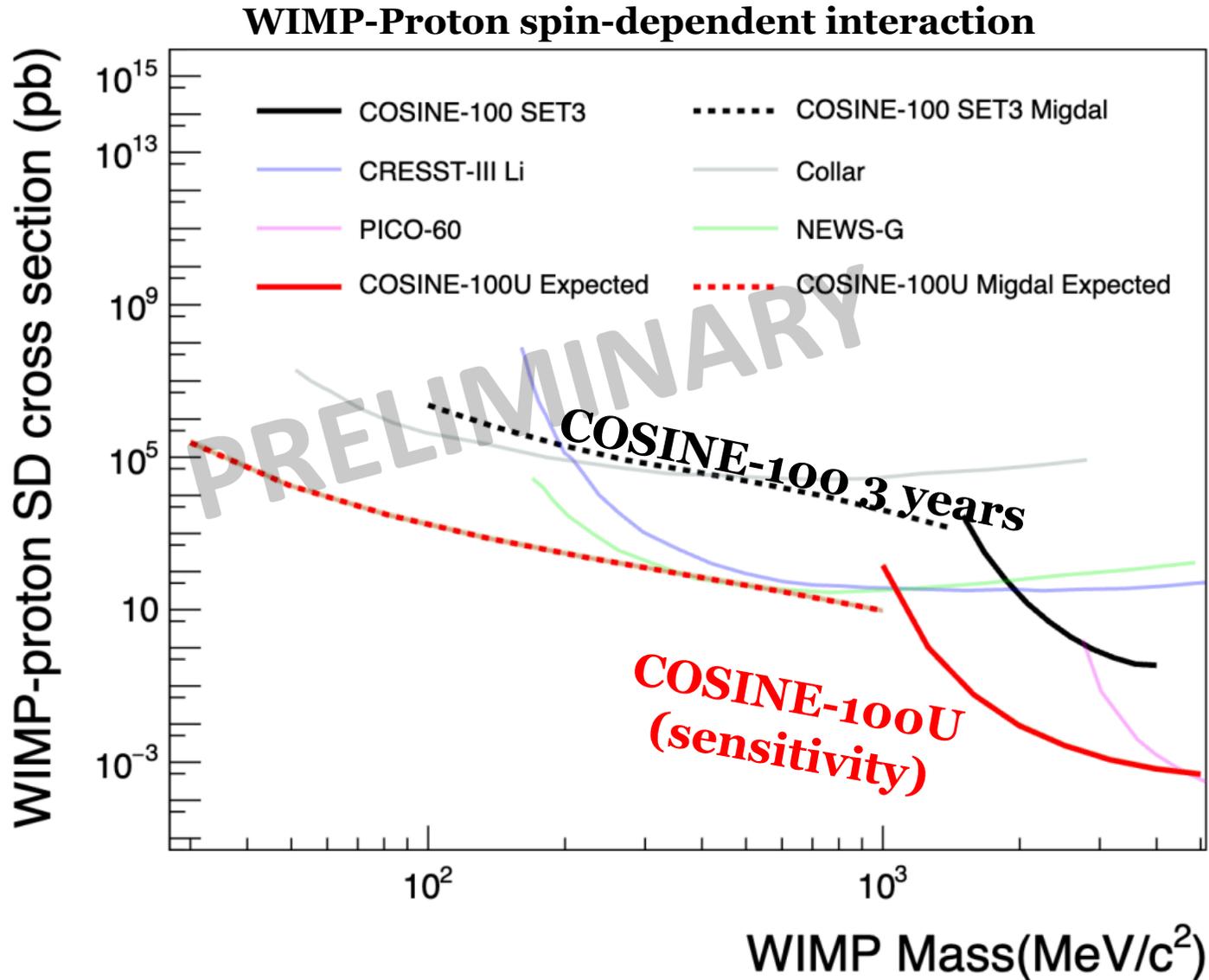


Crystal installation



We plan to start physics operation soon

Sensitivity of COSINE-100U



Summary

- COSINE-100 ruled out DAMA/LIBRA with significance above 3 sigma in model-independent analysis
- **COSINE-100U** is well progressed to start physics run
 - ❖ World competitive sensitivities for low-mass dark matter in the WIMP-proton spin-dependent interaction

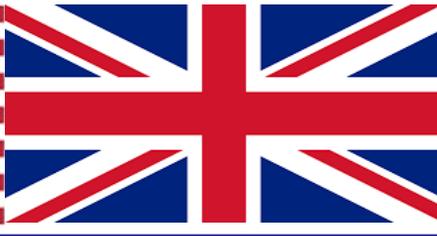
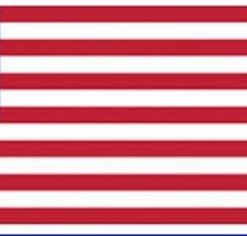
COSINE collaboration



15 institutes
~60 members



+ DM-ICE =



Hyun Su Lee,

Center for Underground Physics (CUP),

Institute for Basic Science (IBS)