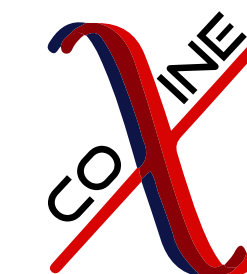


Overview and Prospects of COSINE-100U : Upgrade NaI(Tl) Dark Matter Search in Yemilab

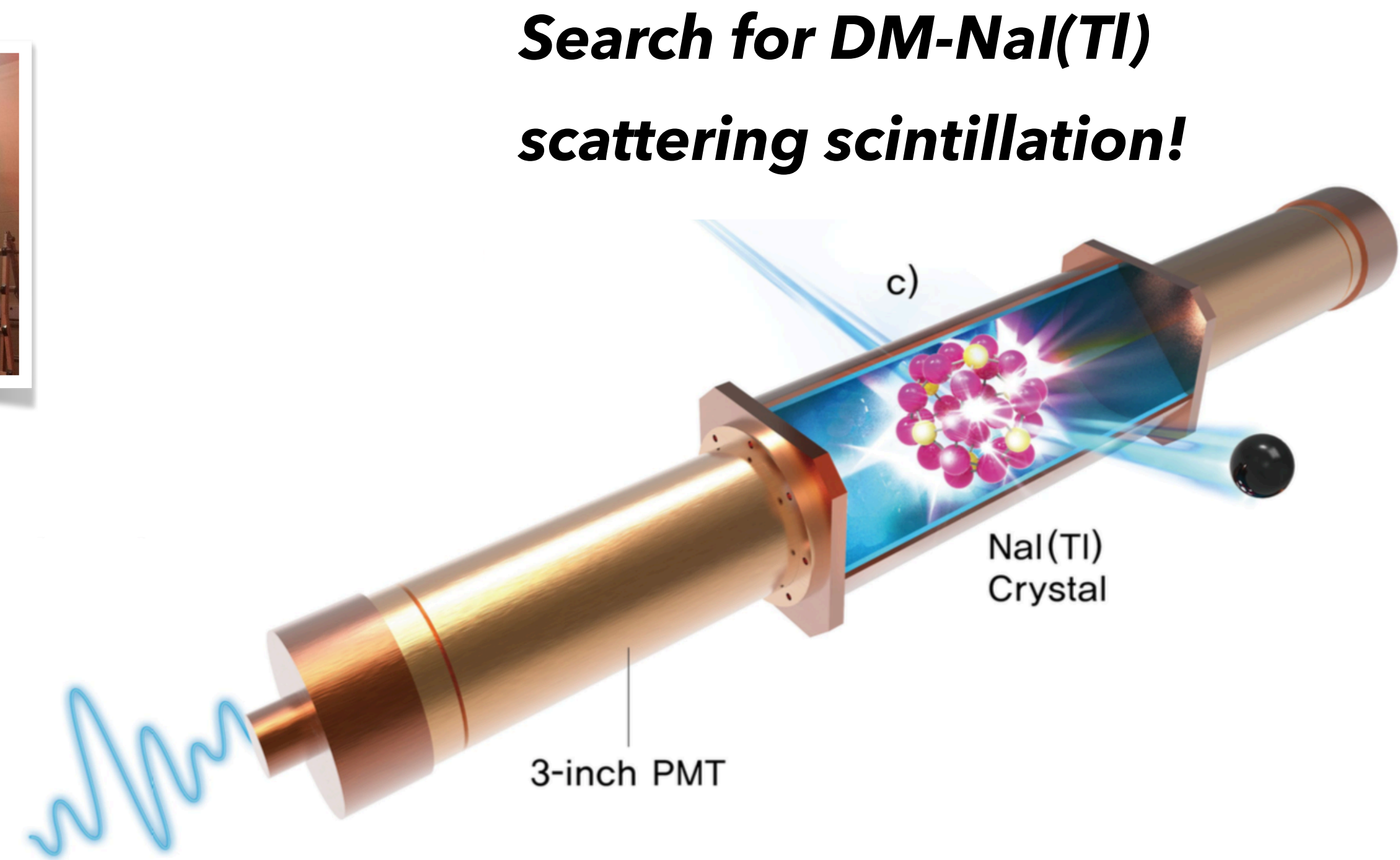
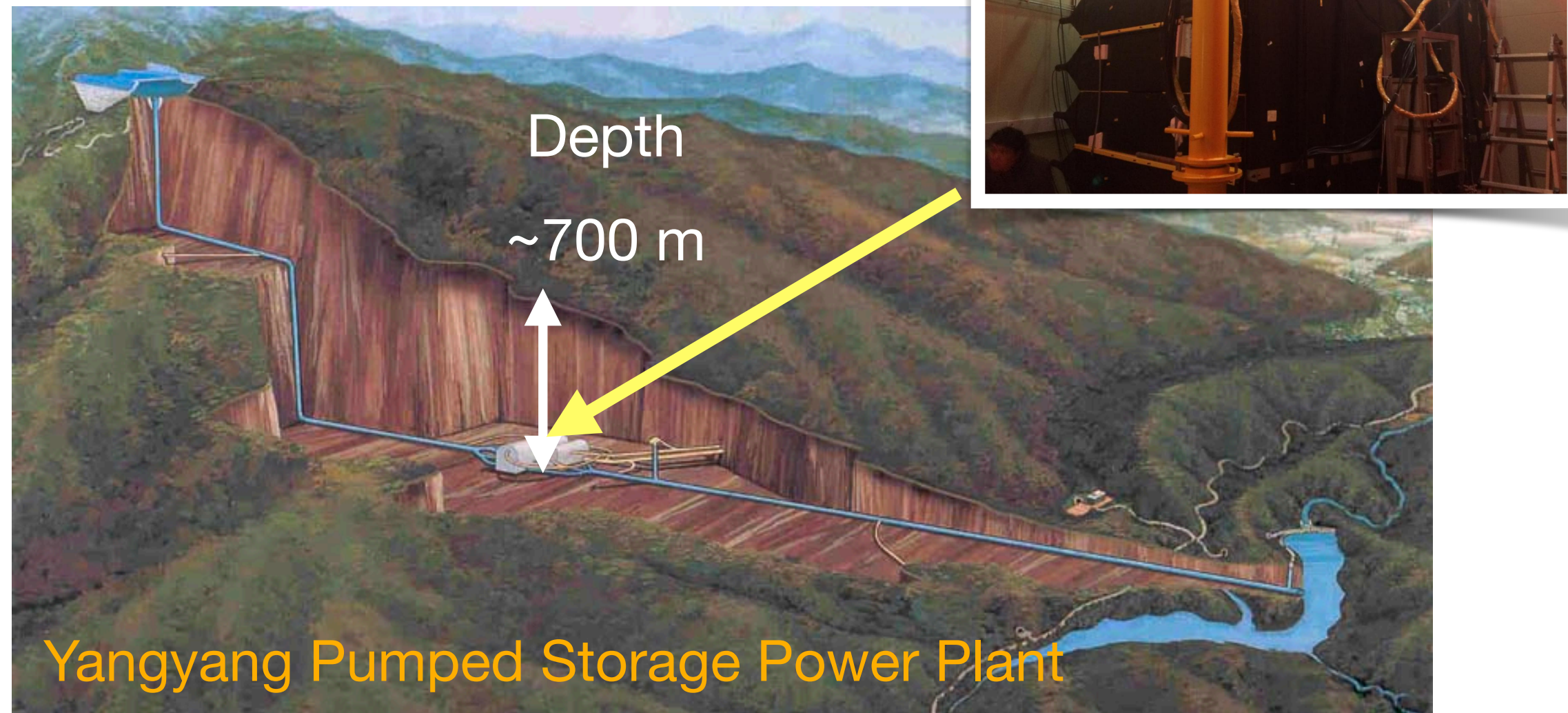
Gyunho Yu

Institute for Basic Science (Center for Underground Physics)

On behalf of COSINE Collaboration

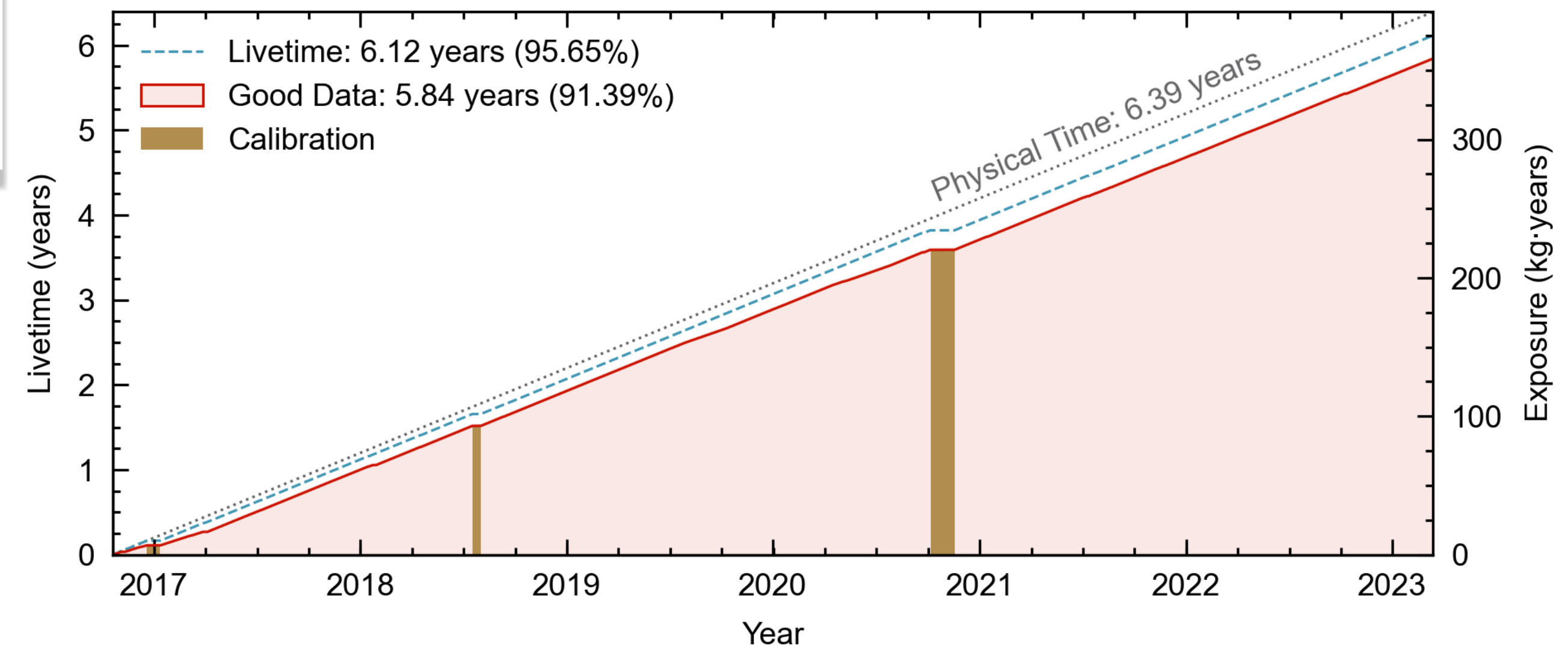
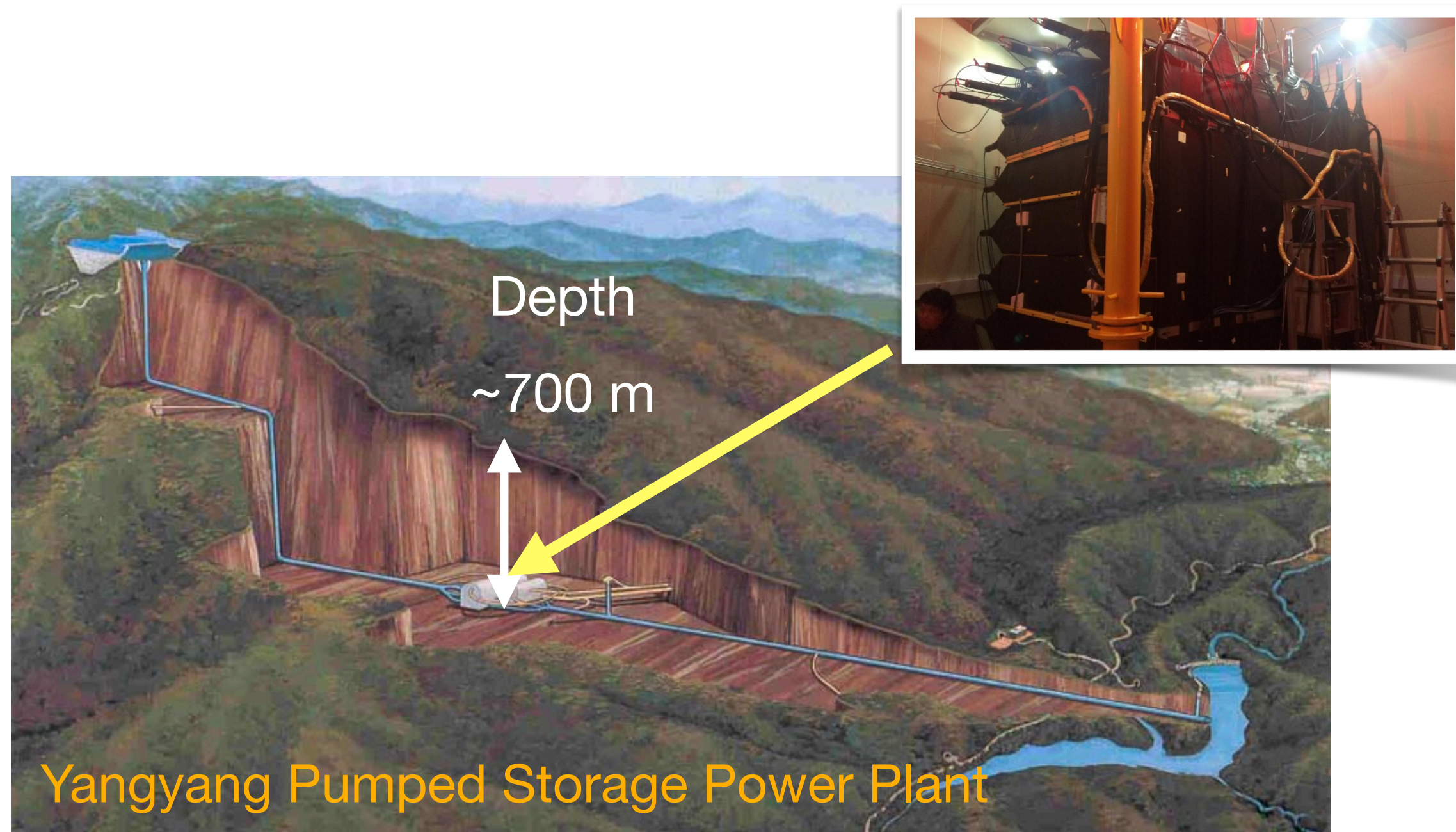


COSINE-100 experiment



- Direct dark matter search experiment, **based on NaI(Tl) crystals**
- Located in Yangyang Underground Laboratory (Y2L), Korea (**Depth : ~ 700m**)

COSINE-100 experiment

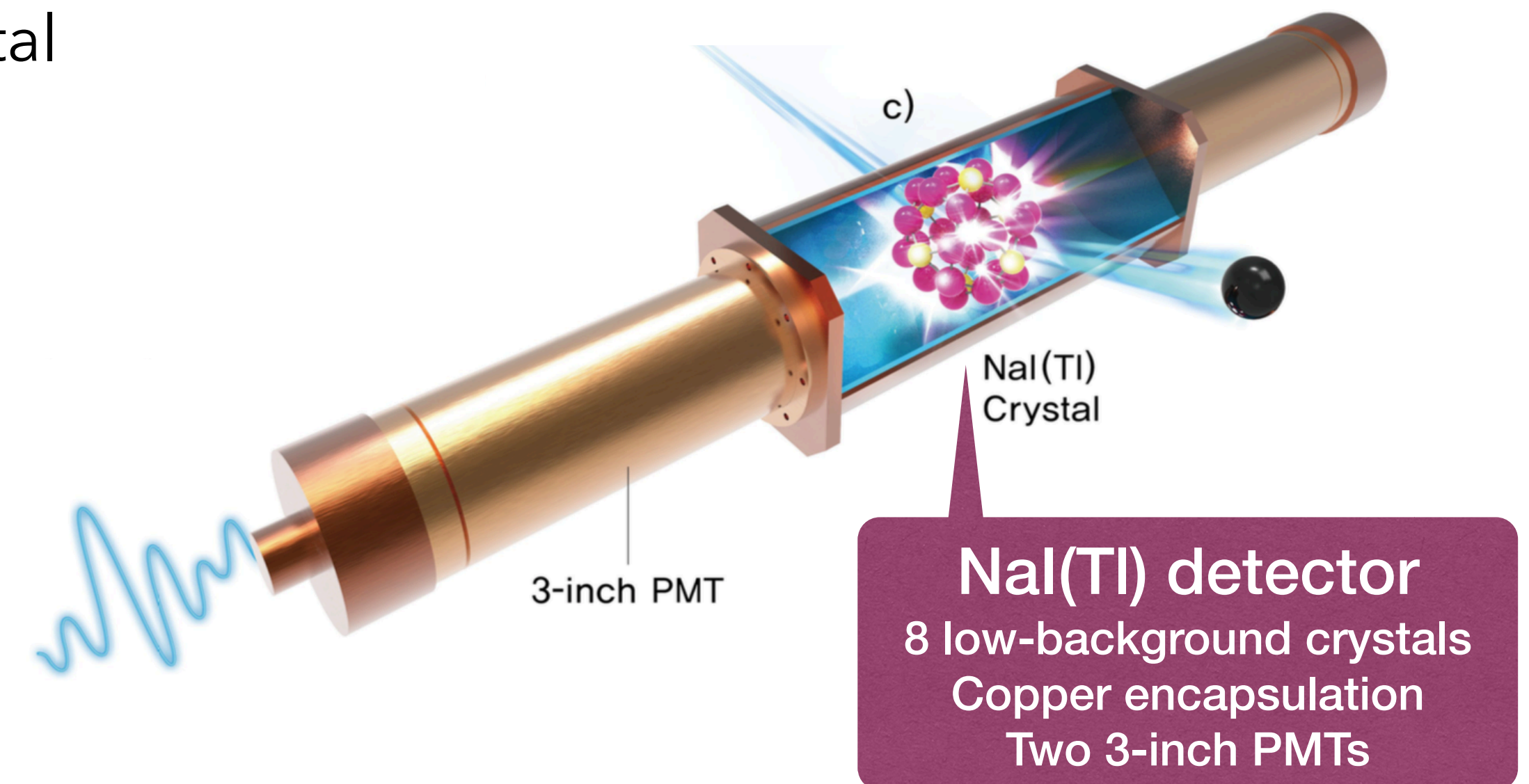
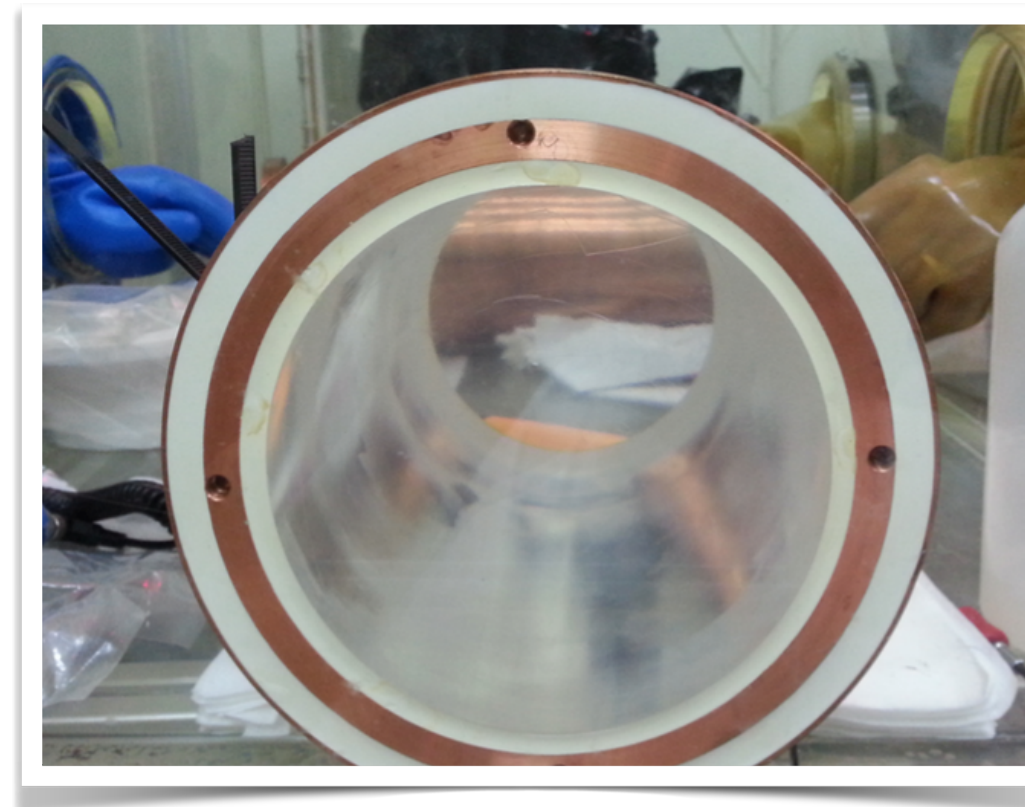


- Direct dark matter search experiment, **based on NaI(Tl) crystals**
- Located in Yangyang Underground Laboratory (Y2L), Korea (**Depth : ~ 700m**)
- Finished with **~6 year data taking** (October 2016 ~ March 2023)

COSINE-100 experiment

Detector details : NaI(Tl) crystals

- 8 Low background NaI(Tl) crystals (106 kg mass)
 - U/Th/K levels are less than DAMA, but total alphas ($\sim 2^{10}\text{Pb}$) are higher than DAMA.
 - Total background is 2-3 times that of DAMA.
 - High light yield (15 p.e./keV) compared to DAMA (10 p.e./keV)
- Two 3-inch PMTs (R12669SEL) are attached to each crystal

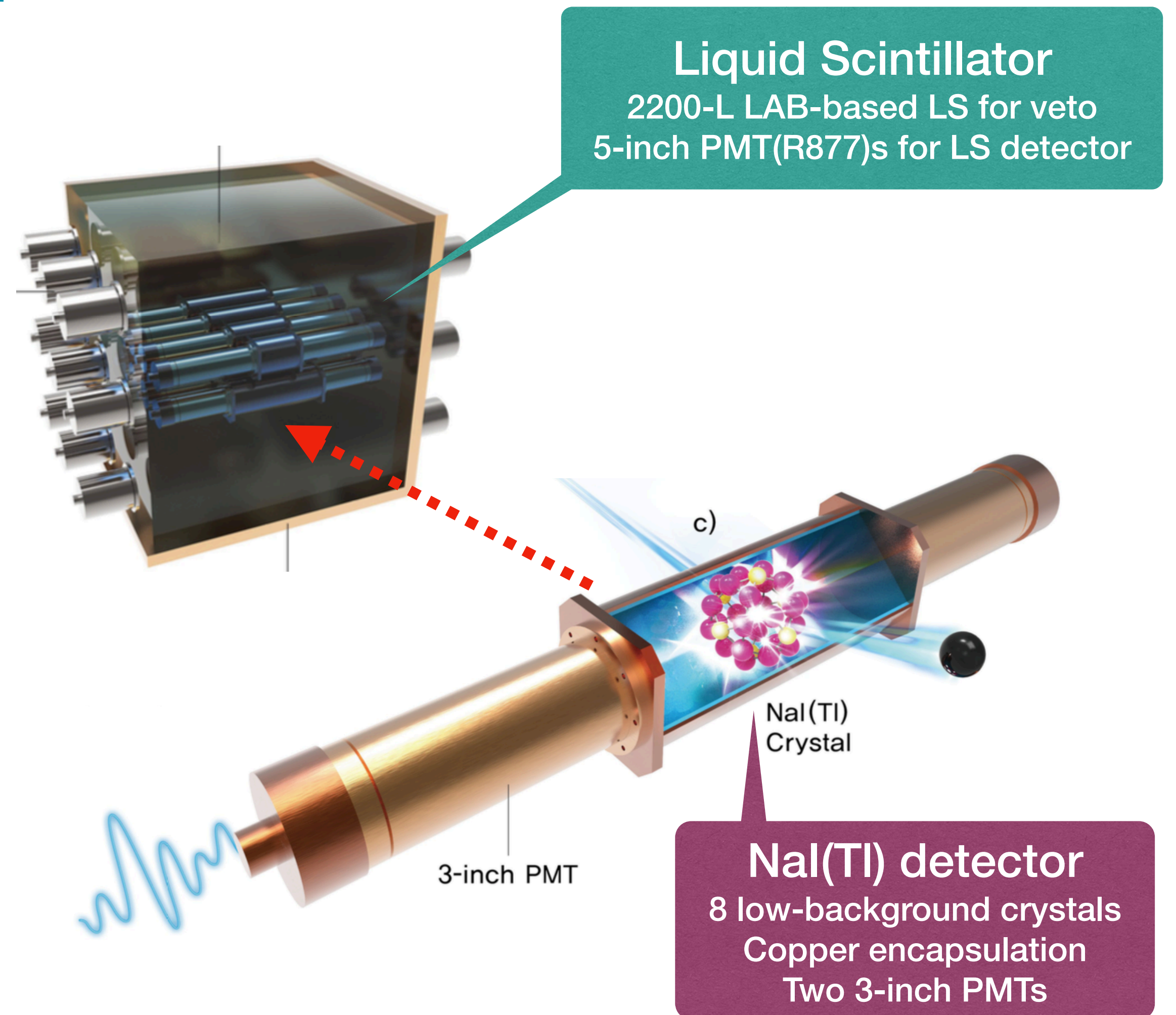


Eur. Phys. J. C. 78 490 (2018)

COSINE-100 experiment

Detector details : Liquid Scintillators (LS)

- 8 Crystals immersed into LS passive veto
- LS signal collected with 18 PMTs
- Gives an efficient method for **background rejection**, with **time-coincident** cut with LS signal.



Eur. Phys. J. C. 78 490 (2018)

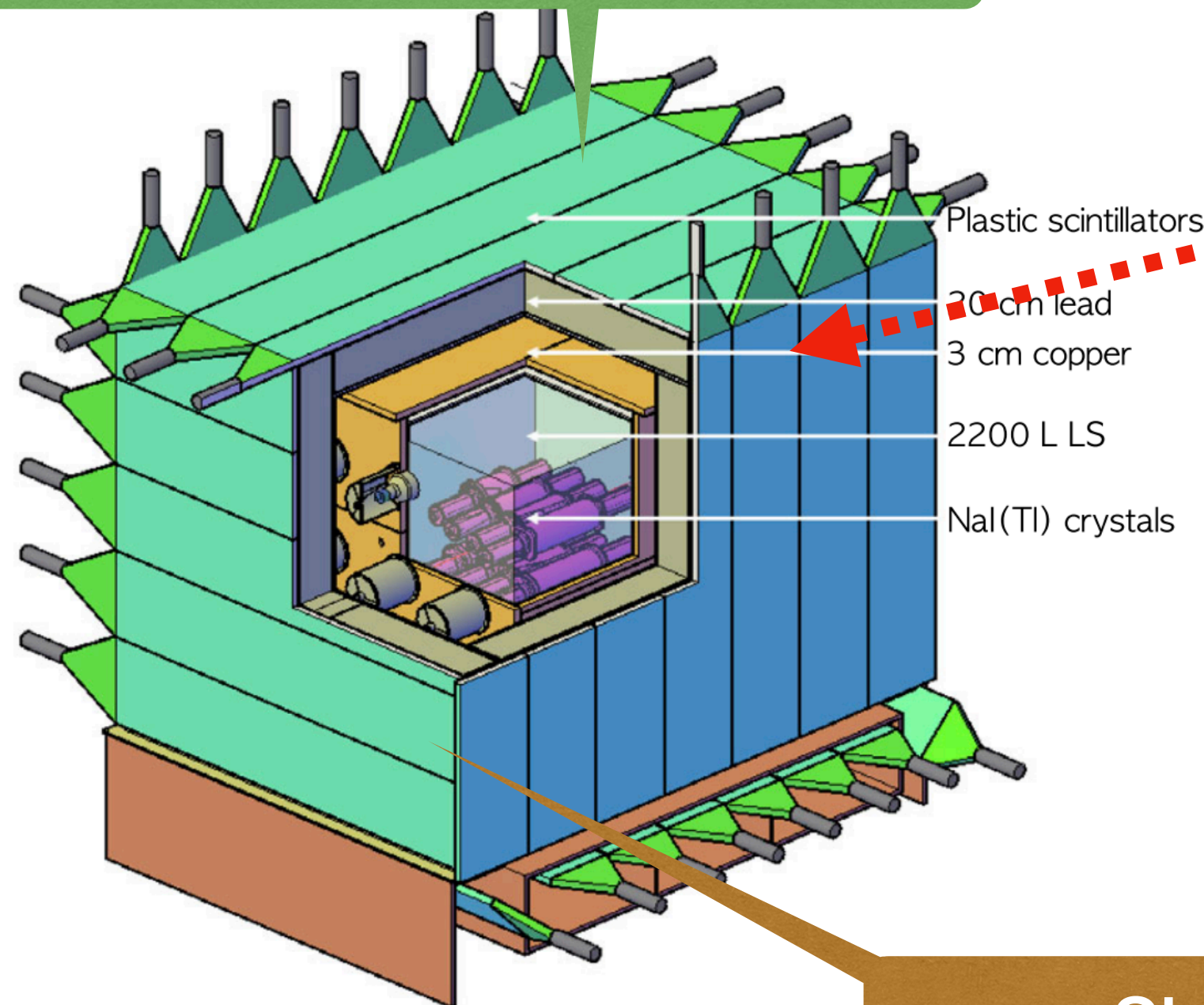
COSINE-100 experiment

Detector details : Shield & 4 π Muon veto

JCAP 02, 013 (2021) , JINST 13 T02007 (2018)

4 π Muon Counter

37 plastic scintillator panels
2-inch PMT(H7195)s for muon counter

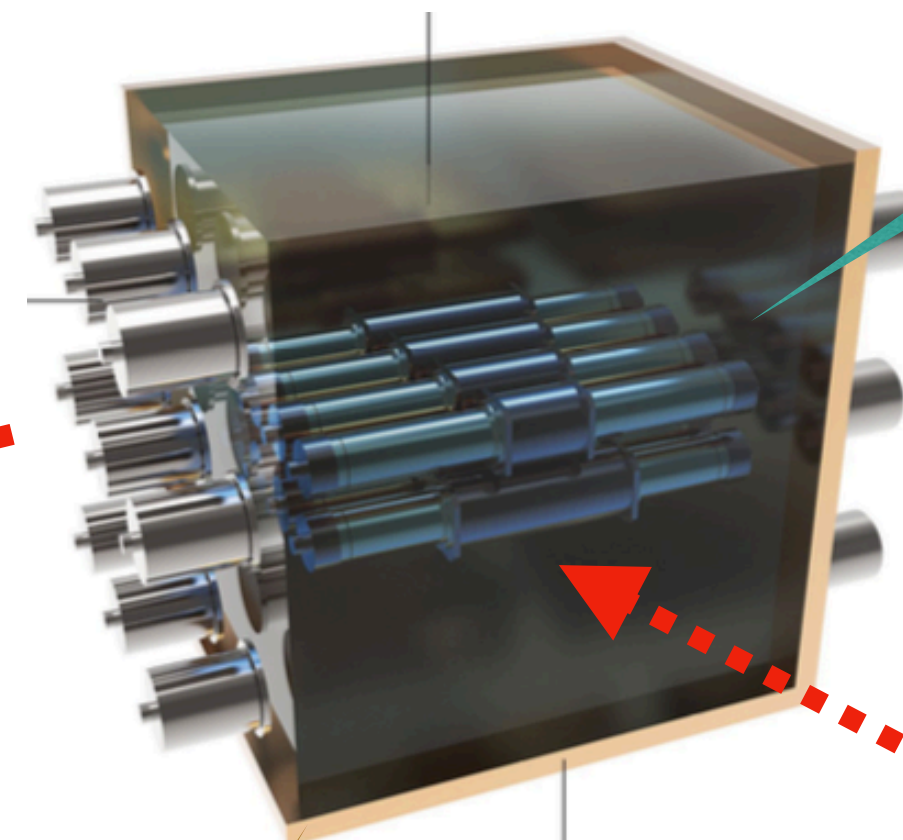


Shields

3-cm thick copper box
20-cm thick lead shielding

Liquid Scintillator

2200-L LAB-based LS for veto
5-inch PMT(R877)s for LS detector



c)

NaI(Tl)
Crystal

3-inch PMT

NaI(Tl) detector

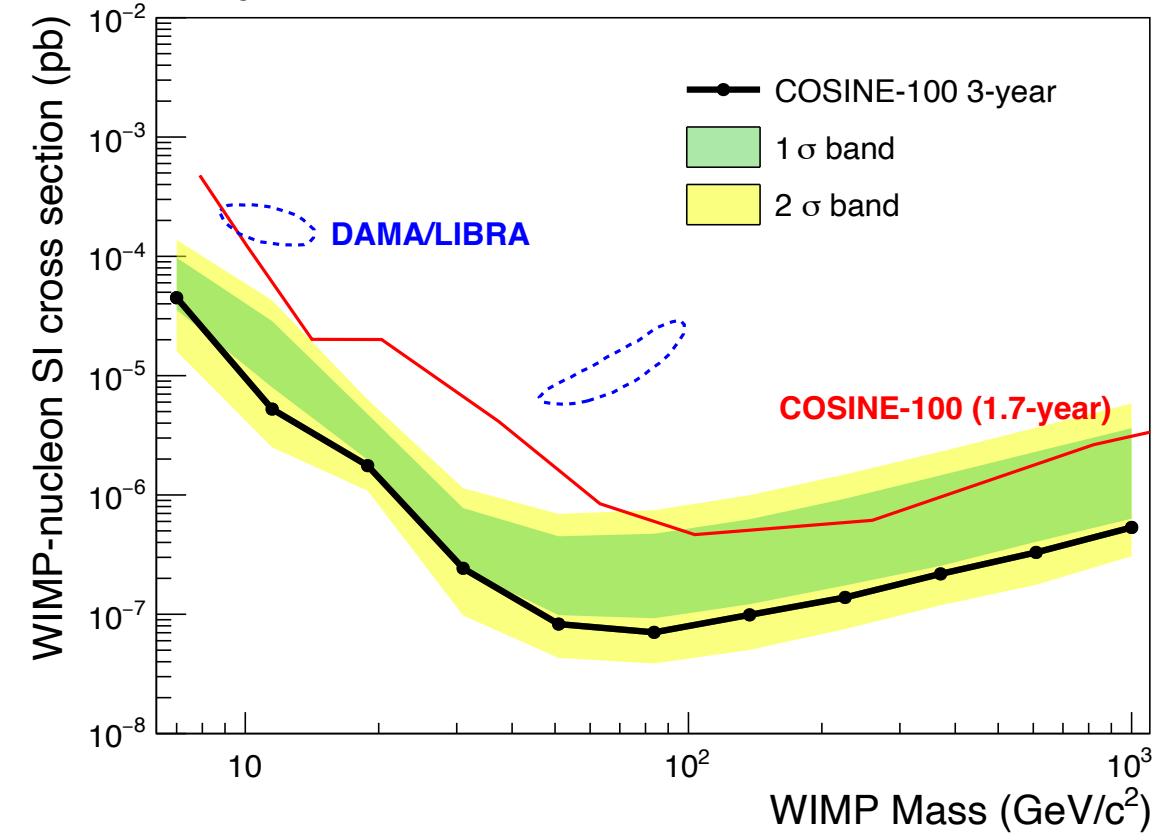
8 low-background crystals
Copper encapsulation
Two 3-inch PMTs

Eur. Phys. J. C. 78 490 (2018)

Physics Results from COSINE-100

WIMP spectral analysis

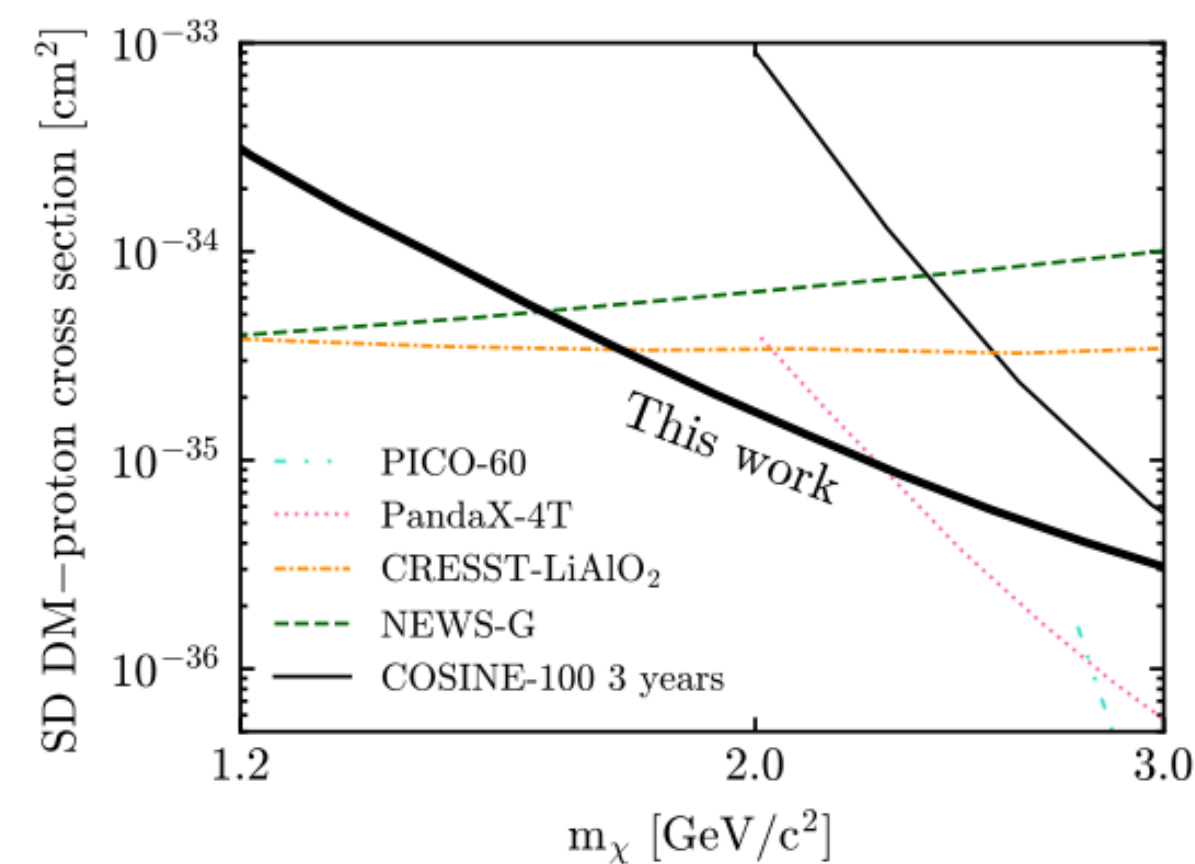
Phys. Rev. Lett. **135**, 231001 (2025)



Updates in IDM 2026 (JY Kim, This session)

Low-mass WIMP search

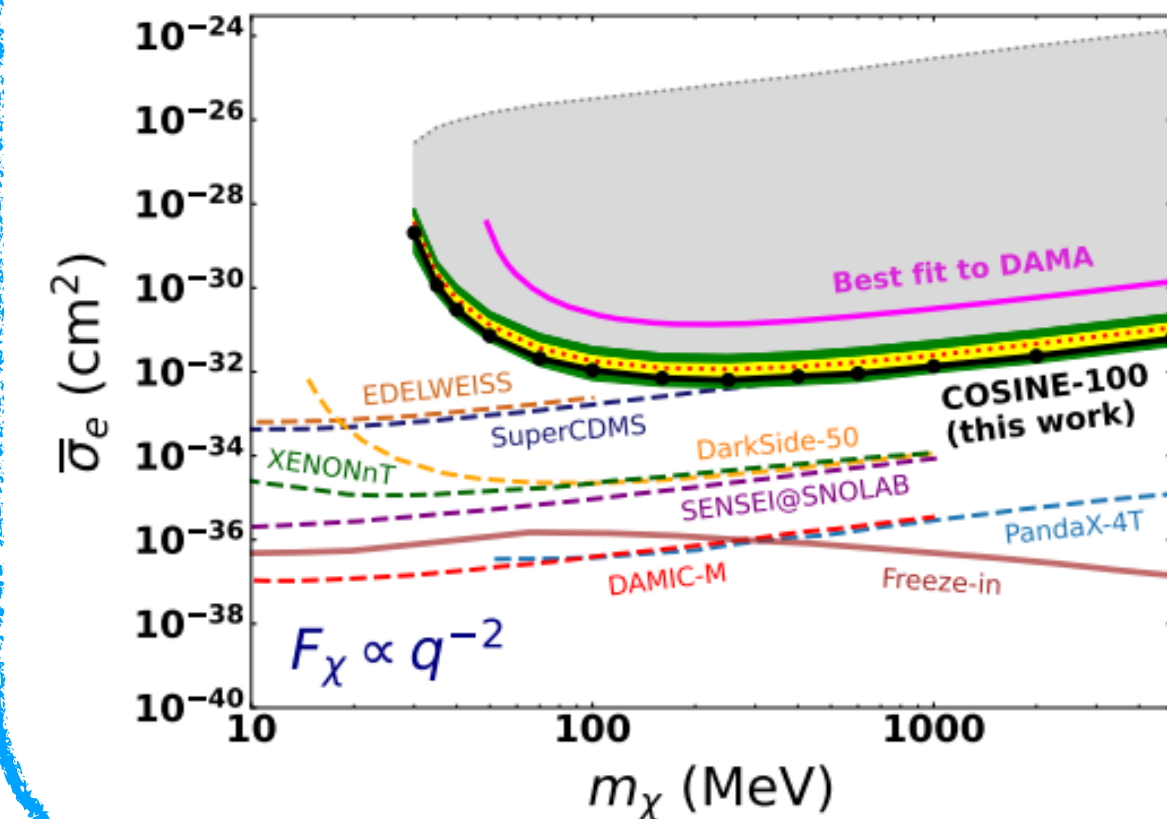
arXiv:2603.22411 (2026)



IDM 2026 (WK Kim, Tomorrow session)

DM -electron scattering

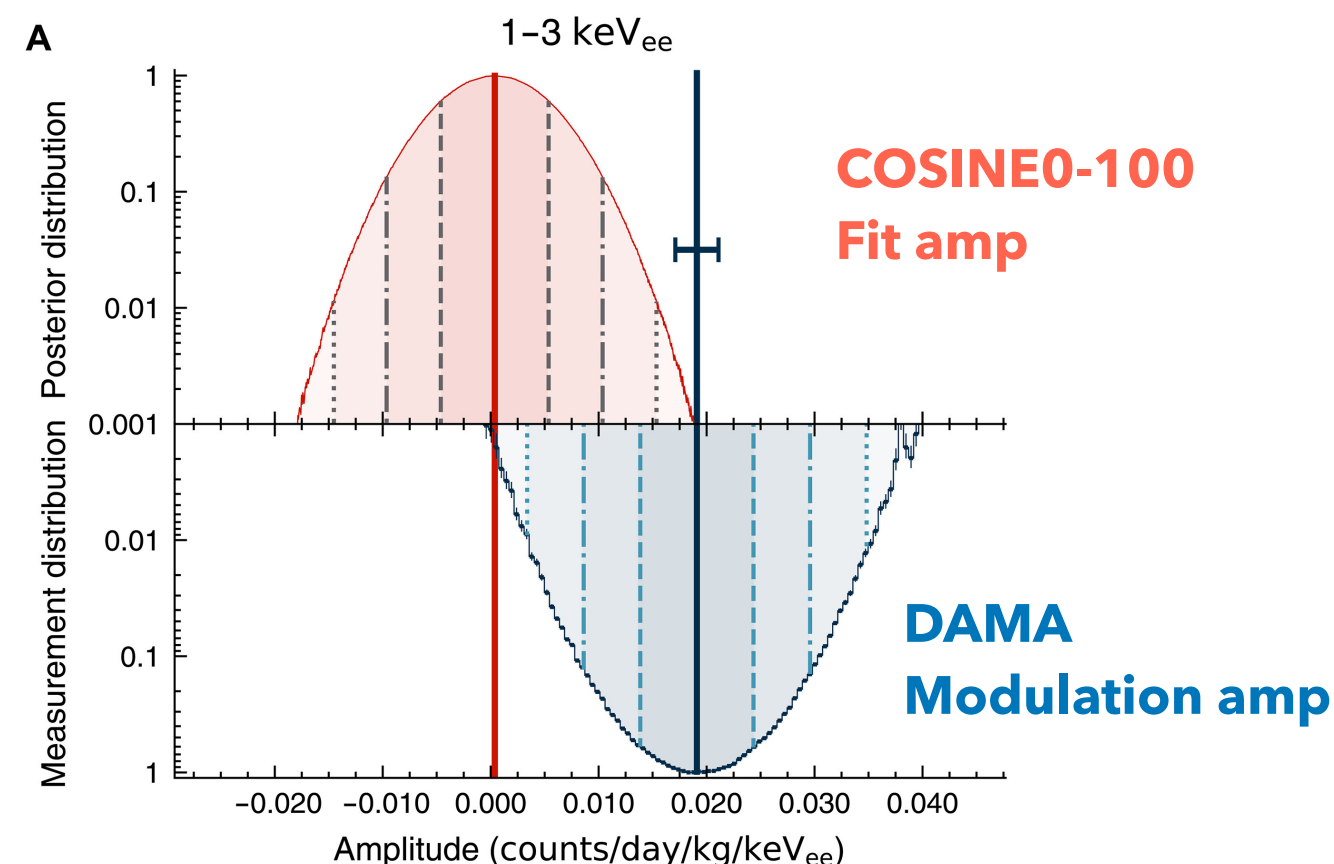
Phys. Rev. D **113**, 072012 (2026)



IDM 2026 (L.E. Franca, Poster session)

DM Modulation search

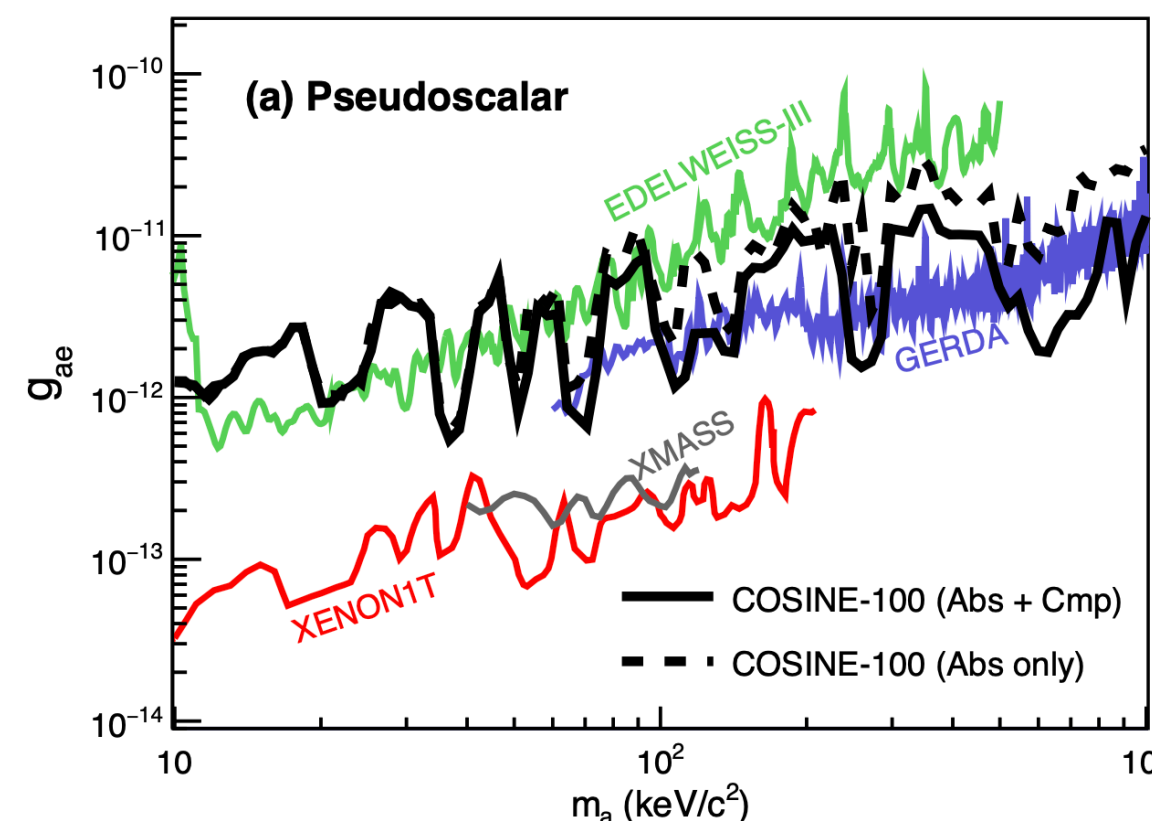
Sci. Adv. 11 eadv6503 (2025)



IDM 2026

Bosonic super WIMPs

Phys. Rev. D 108 (2023) L041301

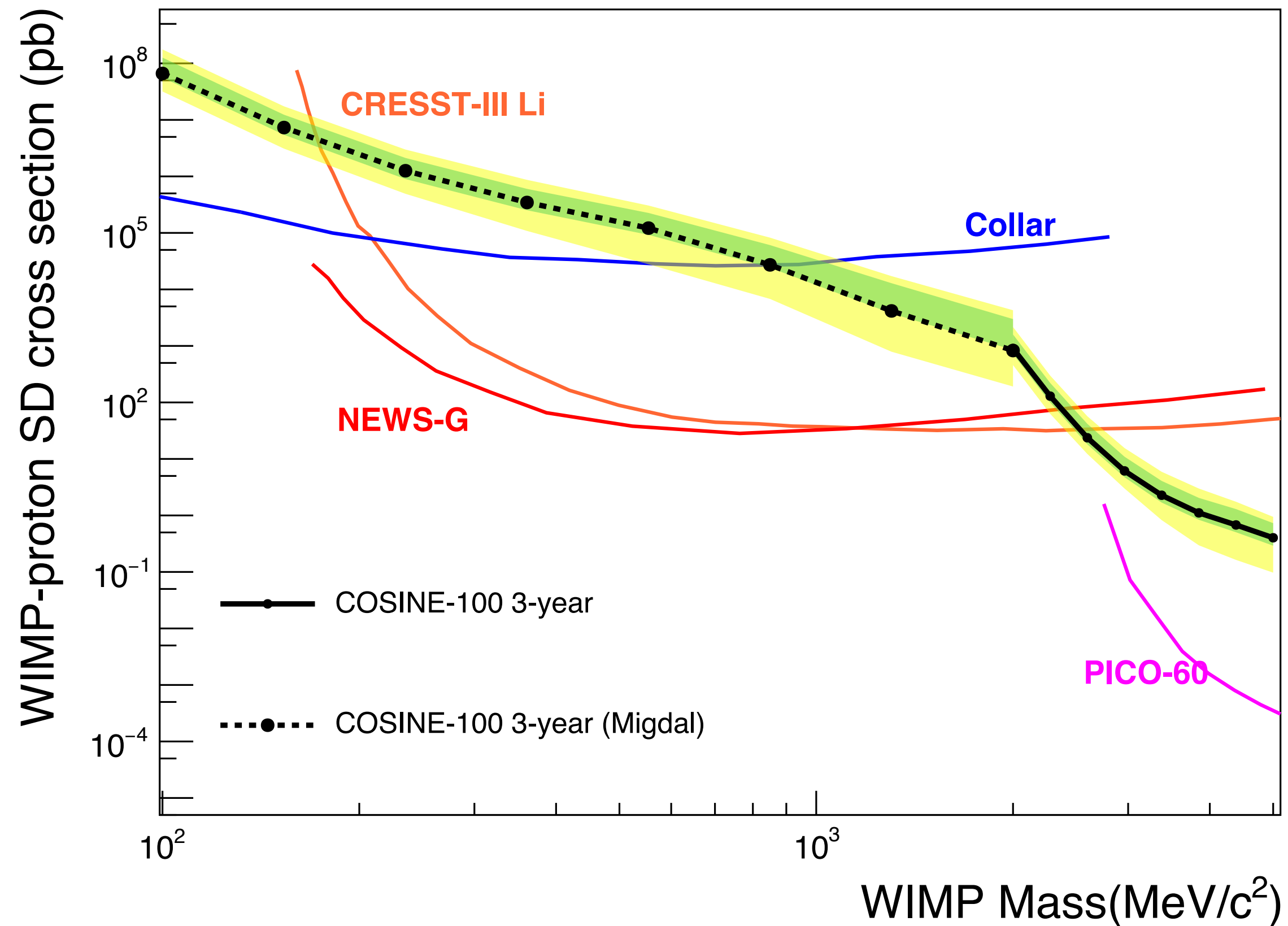


- And many other various DM search analysis has been conducted in COSINE-100
- And **further analysis are still going on with 6-year data sets.**

COSINE-100

Effective at WIMP-proton SD

COSINE-100 3-year WIMP-proton SD channel

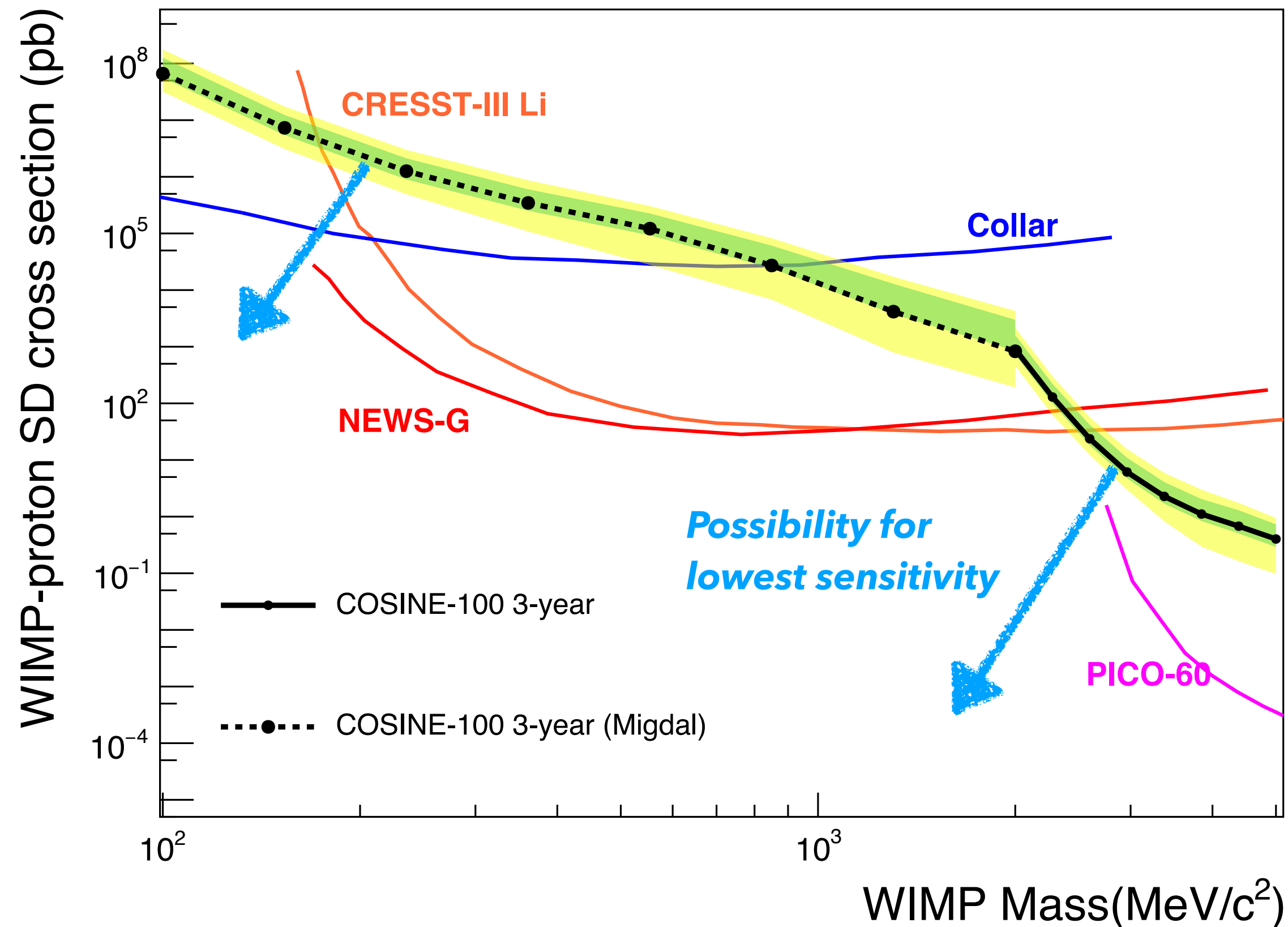


- **COSINE-100 : effective at low-mass SD detection**
 - High sensitivity to low-mass SD from **WIMP-Na** interaction (**Na : proton odd , low-mass target**)
 - Migdal effect enables **sub-GeV** channel.

COSINE-100U

More Effective at WIMP-proton SD ?

COSINE-100 3-year WIMP-proton SD channel



- **COSINE-100 : effective at low-mass SD detection**

- High sensitivity to low-mass SD from **WIMP-Na** interaction (Na : proton odd , low-mass target)
- Migdal effect enables **sub-GeV** channel.

***Upgrade to better sensitivity
has been required !***

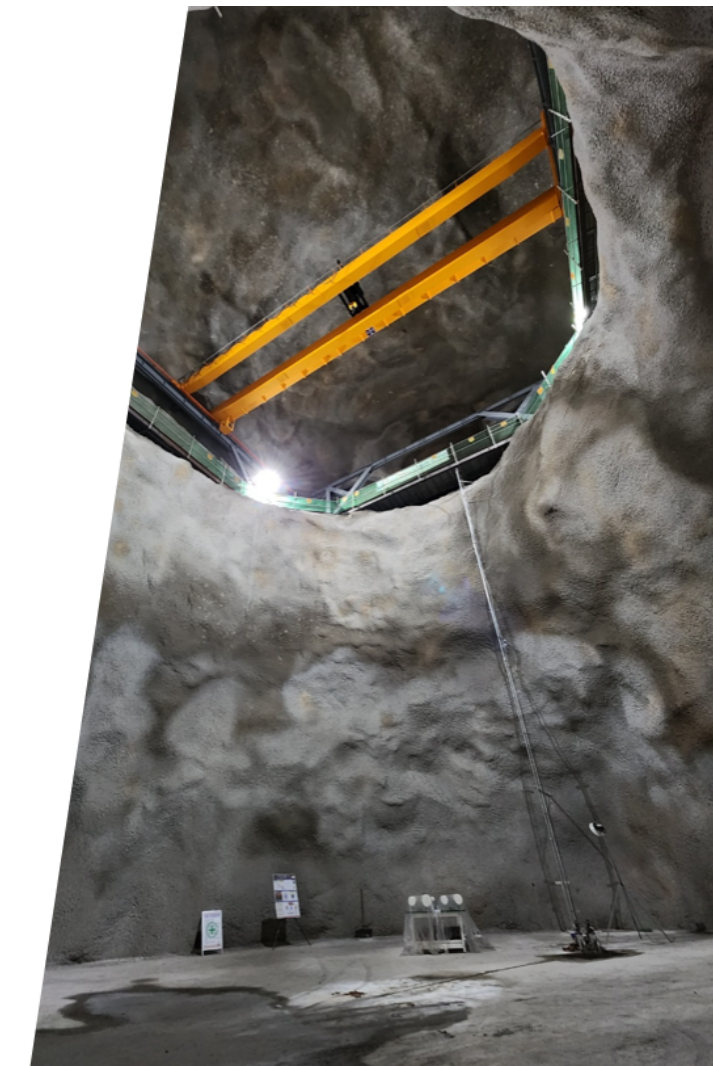
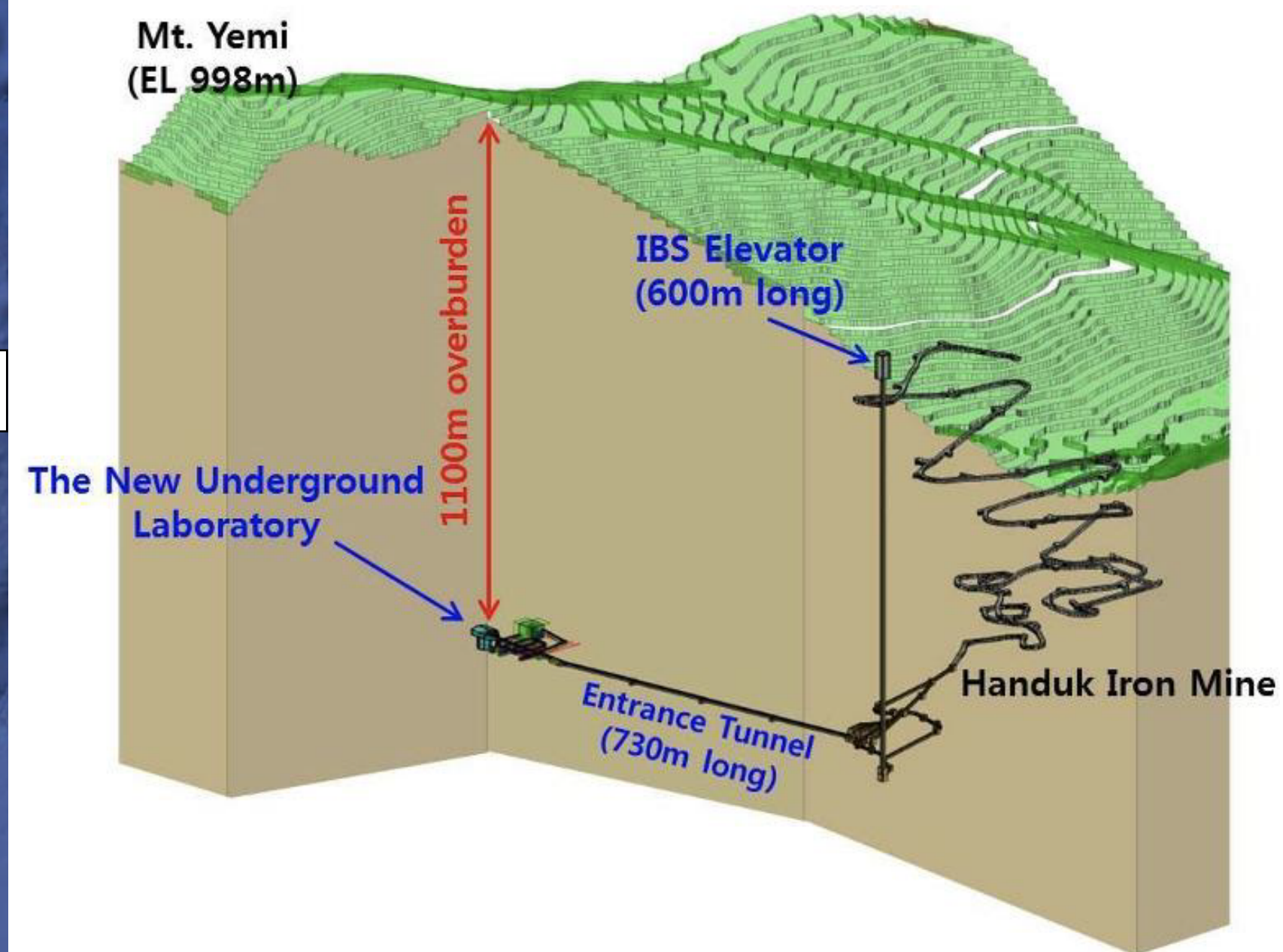
COSINE-100U

1. New experimental site : Yemilab

Front. Phys. 12:1323991. (2024)



Nature News



- New underground laboratory has been recently launched in Korea.
(Jeongseon county)
- **700m (Y2L) → 1100m (Yemilab)**

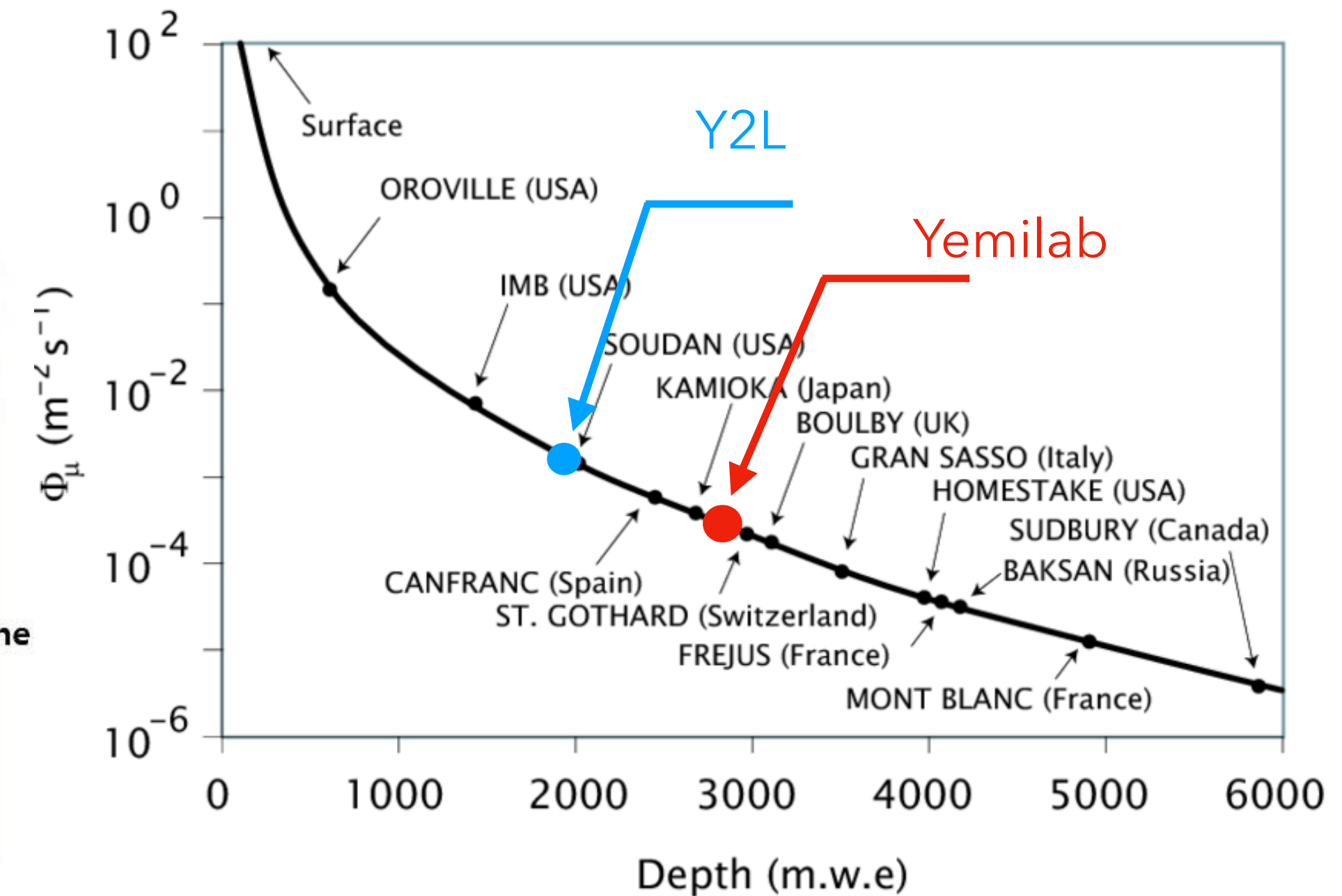
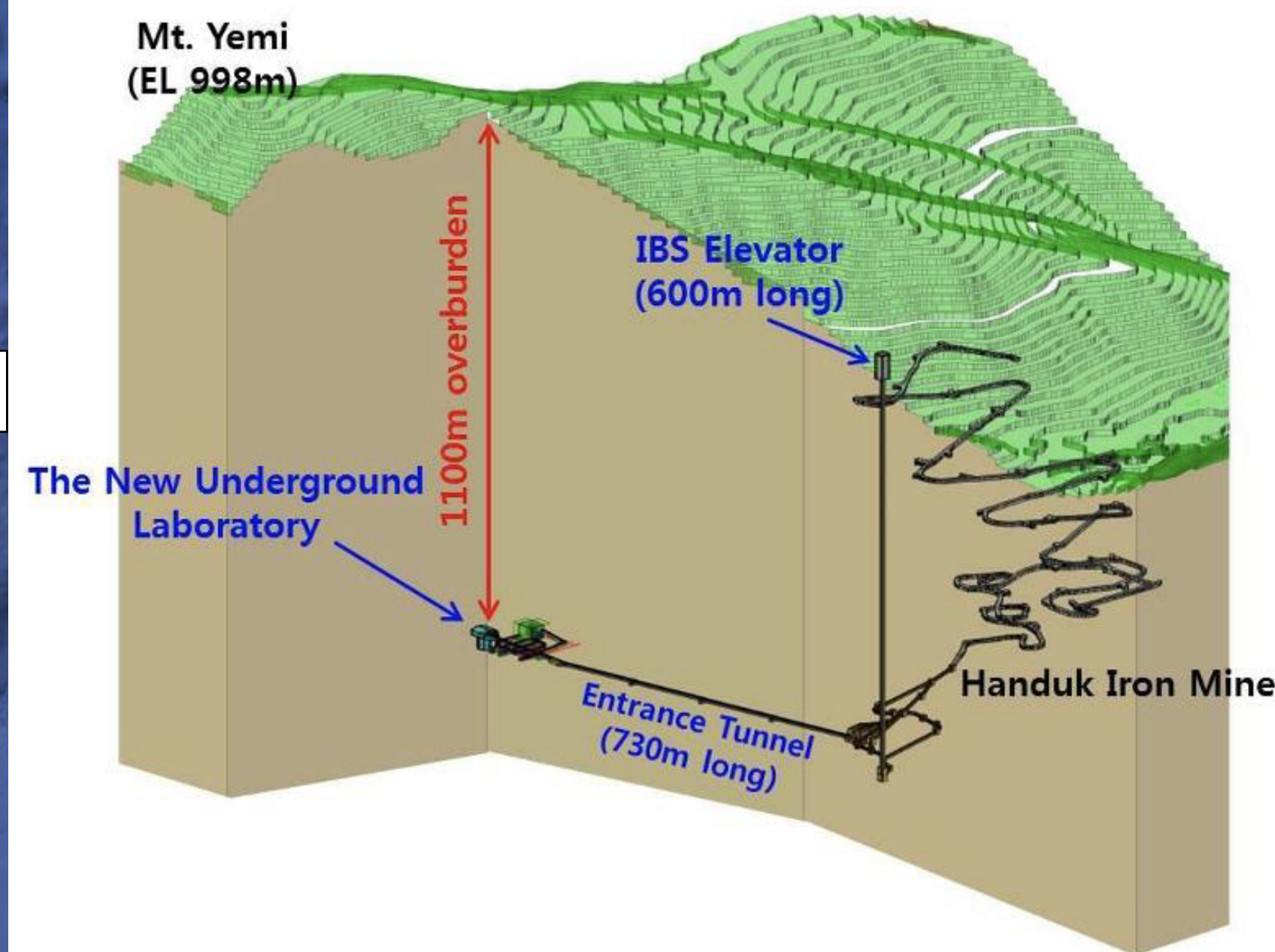
COSINE-100U

1. New experimental site : Yemilab

Front. Phys. 12:1323991. (2024)



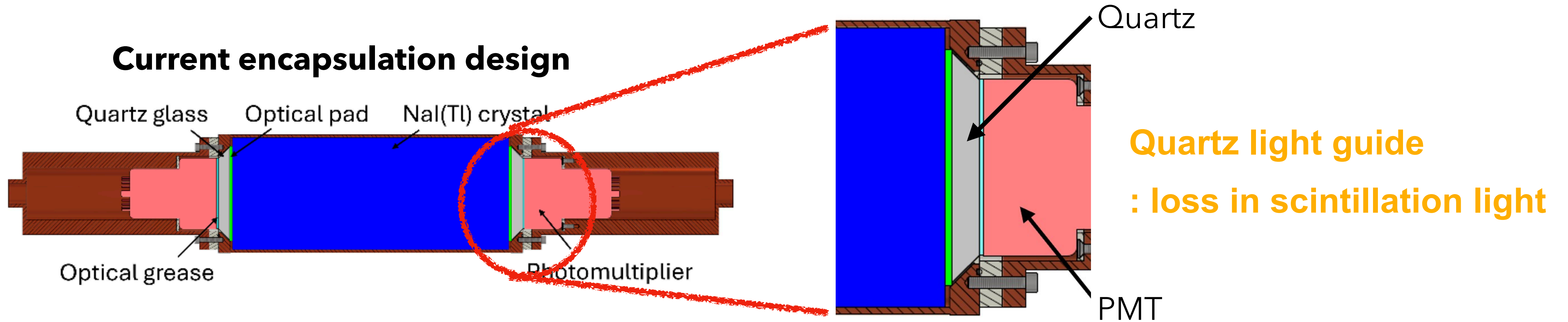
Nature News



- New underground laboratory has been recently launched in Korea. (Jeongseon county)
- **700m (Y2L) → 1100m (Yemilab)**
- **5 times smaller muon flux**

COSINE-100U

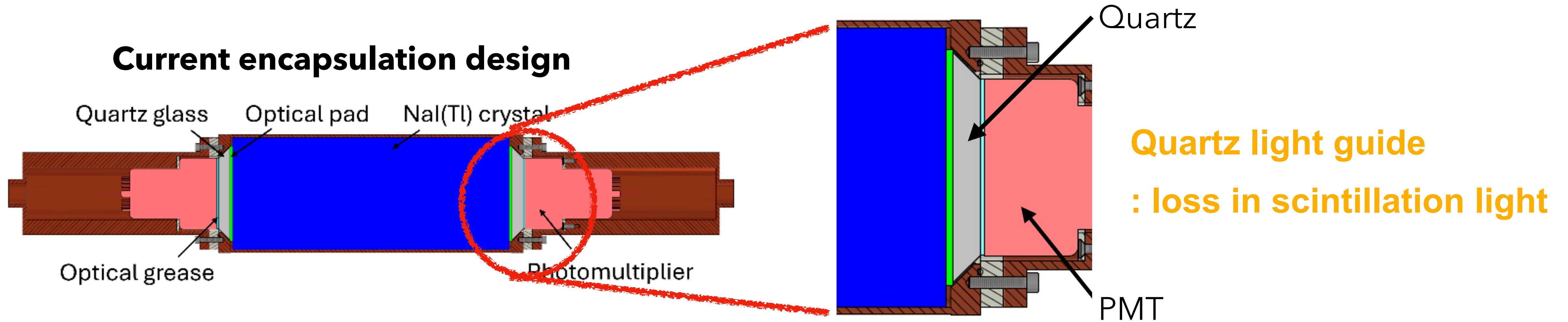
2. Higher light yield : New encapsulation design



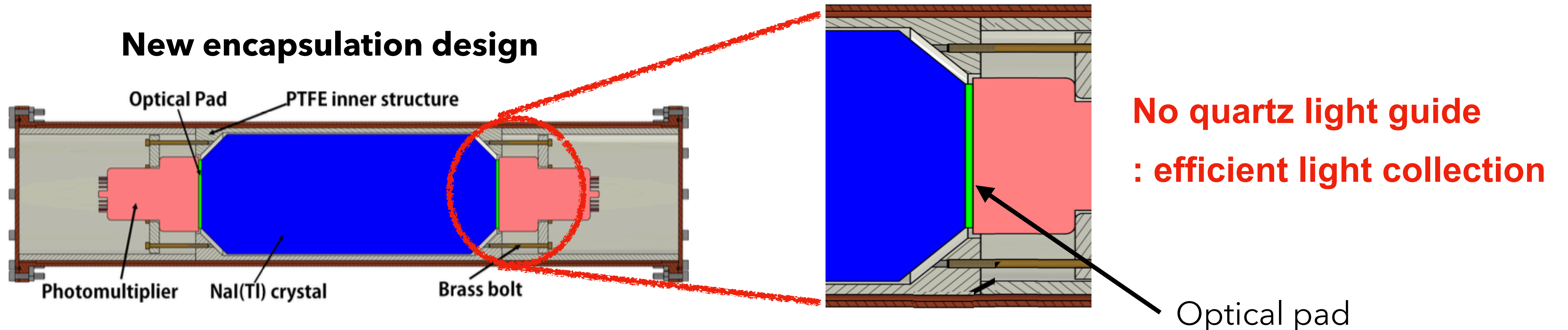
COSINE-100U

2. Higher light yield : New encapsulation design

Current encapsulation design

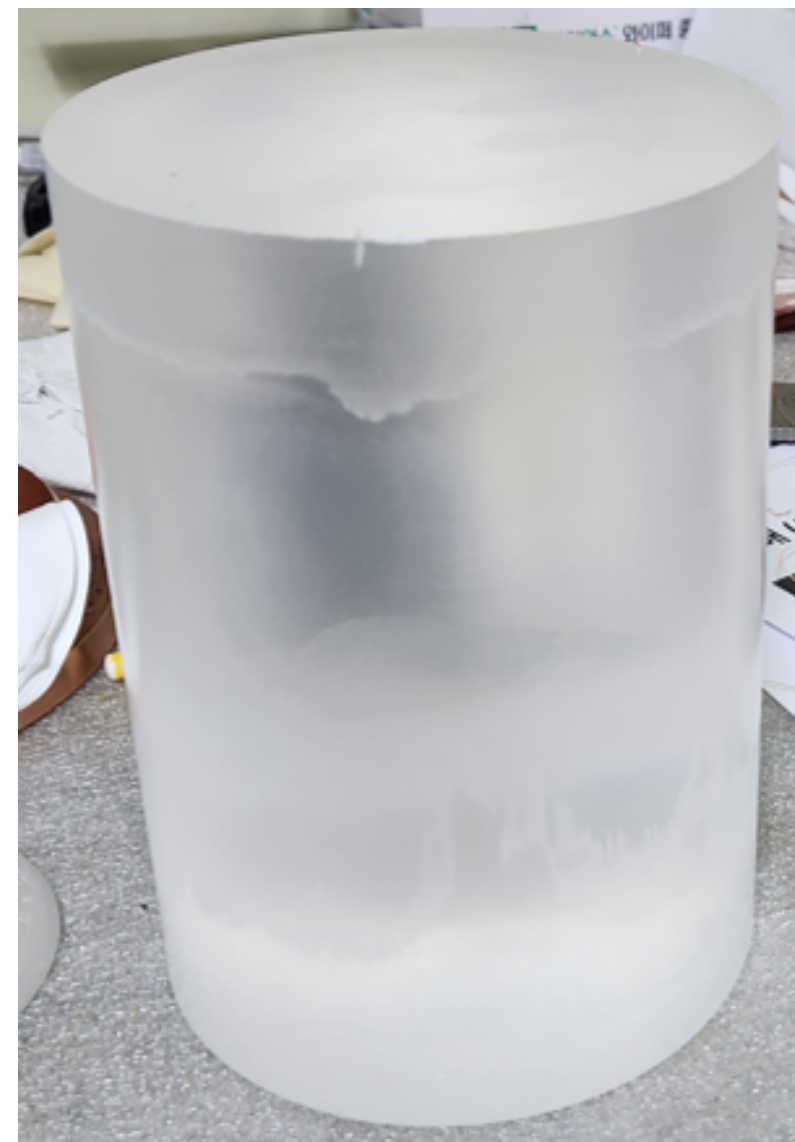


New encapsulation design

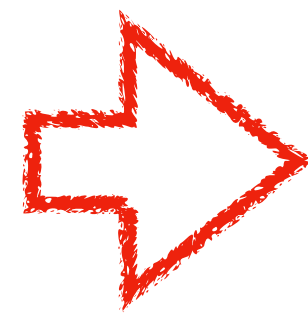


COSINE-100U

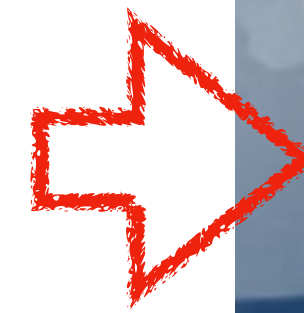
2. Higher light yield : New encapsulation design



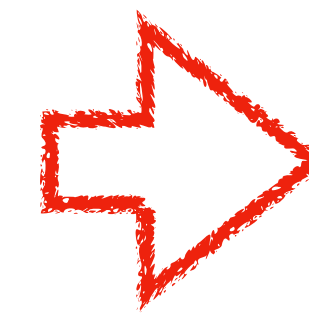
Original



Cut edge



Direct PMT attachment



Encapsulation

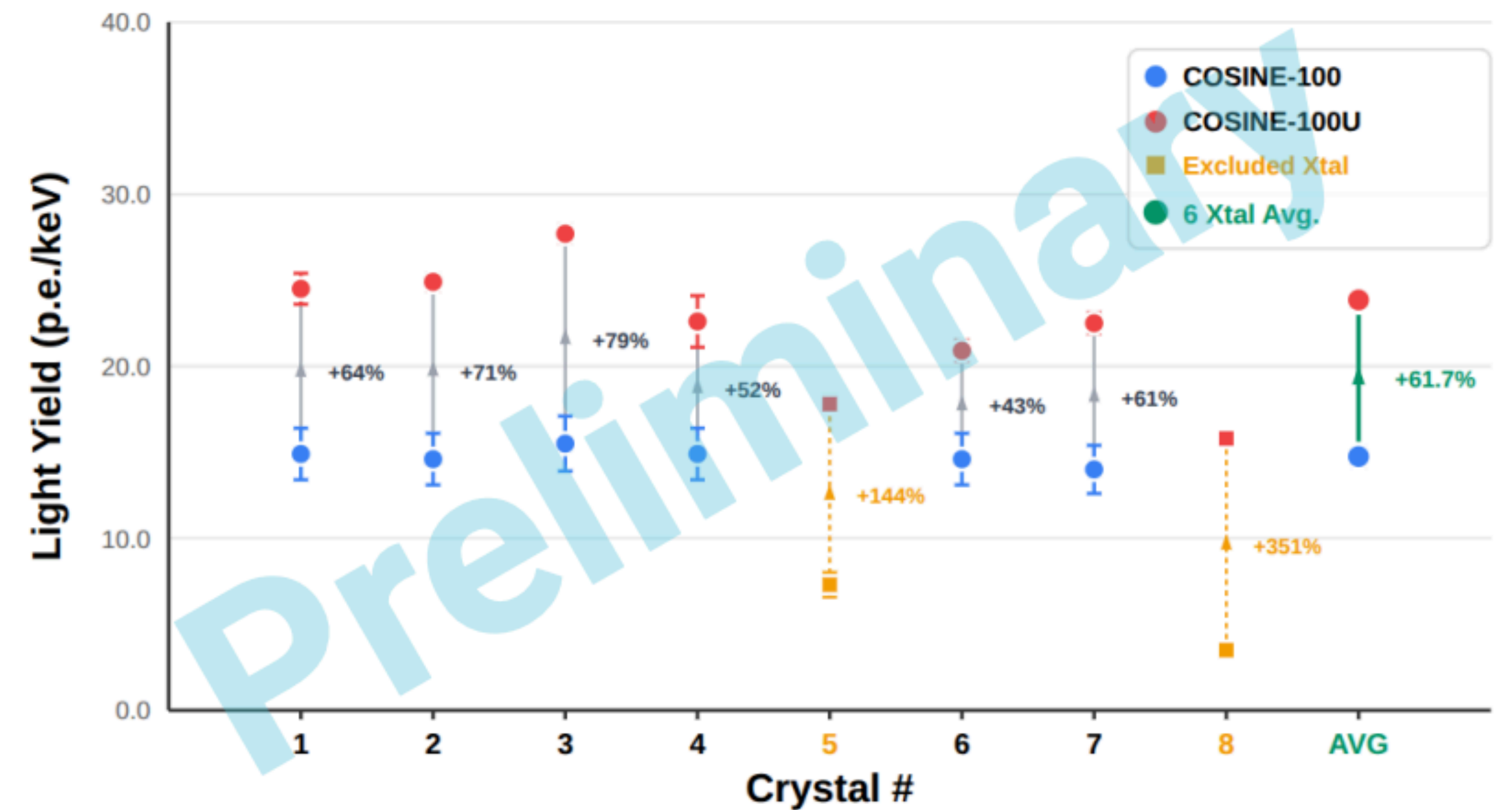
COSINE-100U

2. Higher light yield : New encapsulation design

Crystal #	Size (inches)	Light Yield (p.e./keV)	
1	5.0 × 7.0	14.9 ± 1.5	24.5 ± 0.9
2	4.2 × 11.0	14.6 ± 1.5	24.9 ± 0.5
3	4.2 × 11.0	15.5 ± 1.6	27.7 ± 0.5
4	5.0 × 15.3	14.9 ± 1.5	22.6 ± 1.5
5	5.0 × 15.2	7.3 ± 0.7	17.8 ± 0.5
6	4.8 × 11.8	14.6 ± 1.5	20.9 ± 0.6
7	4.8 × 11.8	14.0 ± 1.4	22.5 ± 0.6
8	5.0 × 15.5	3.5 ± 0.3	15.8 ± 0.3

COSINE-100

COSINE-100U

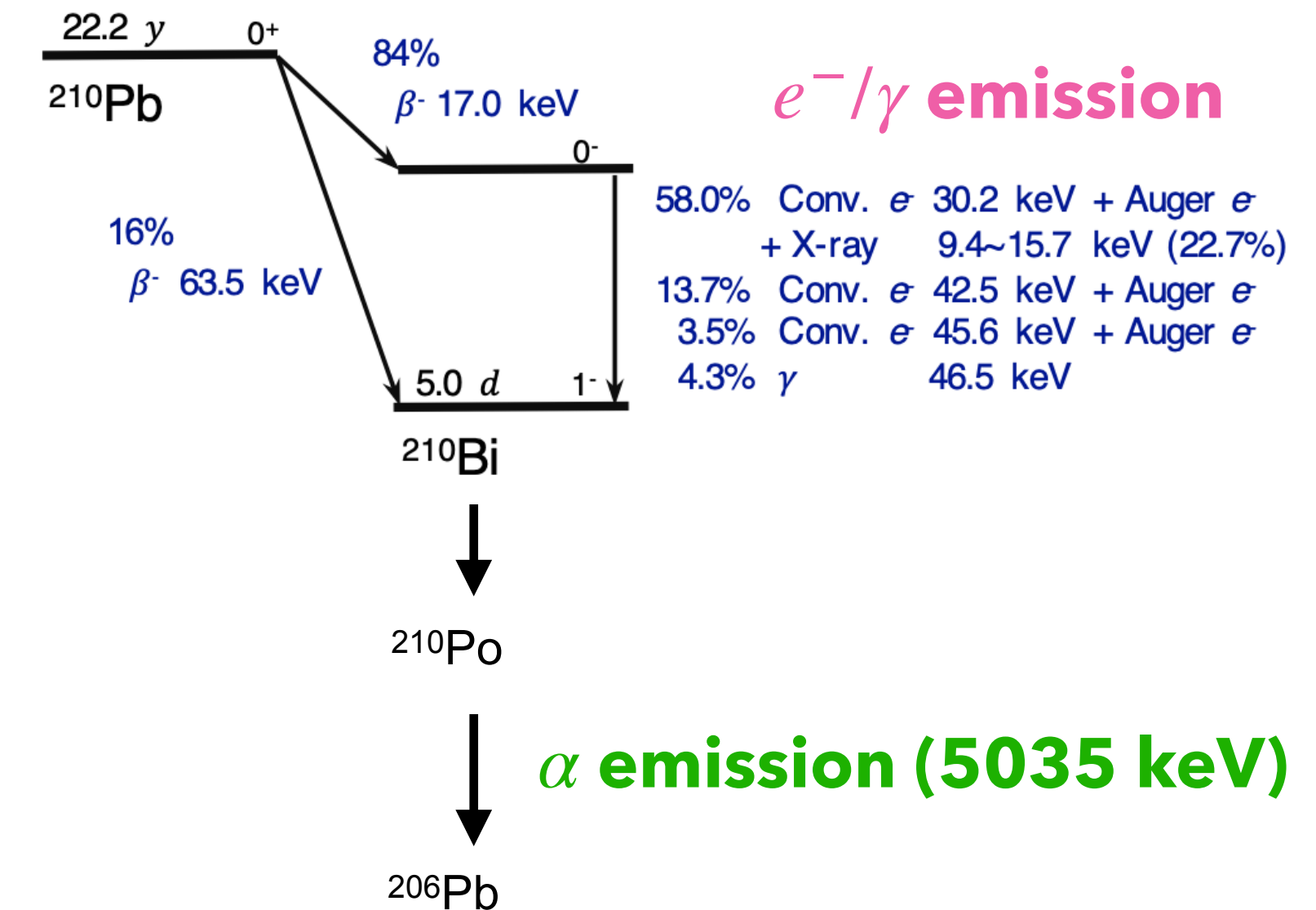
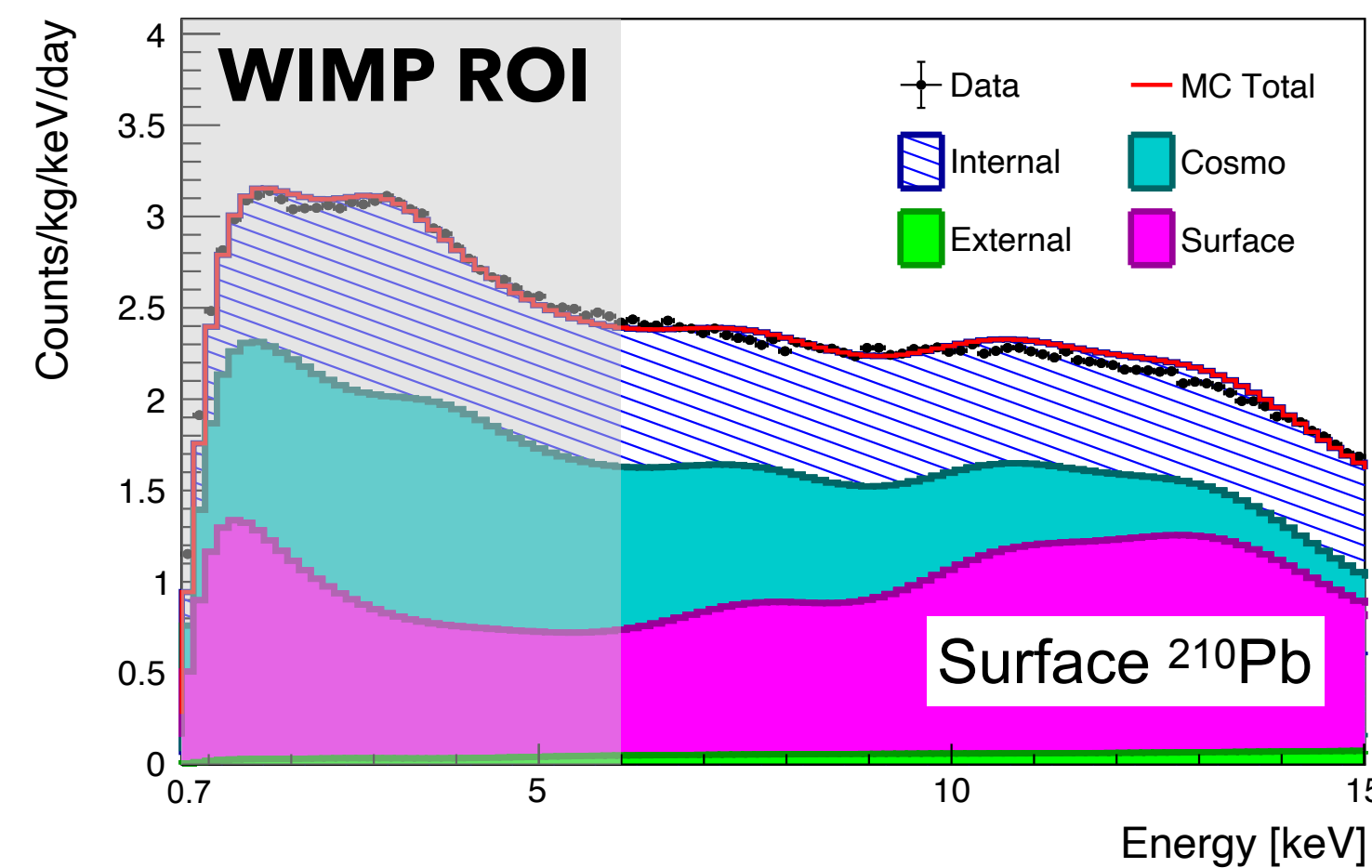
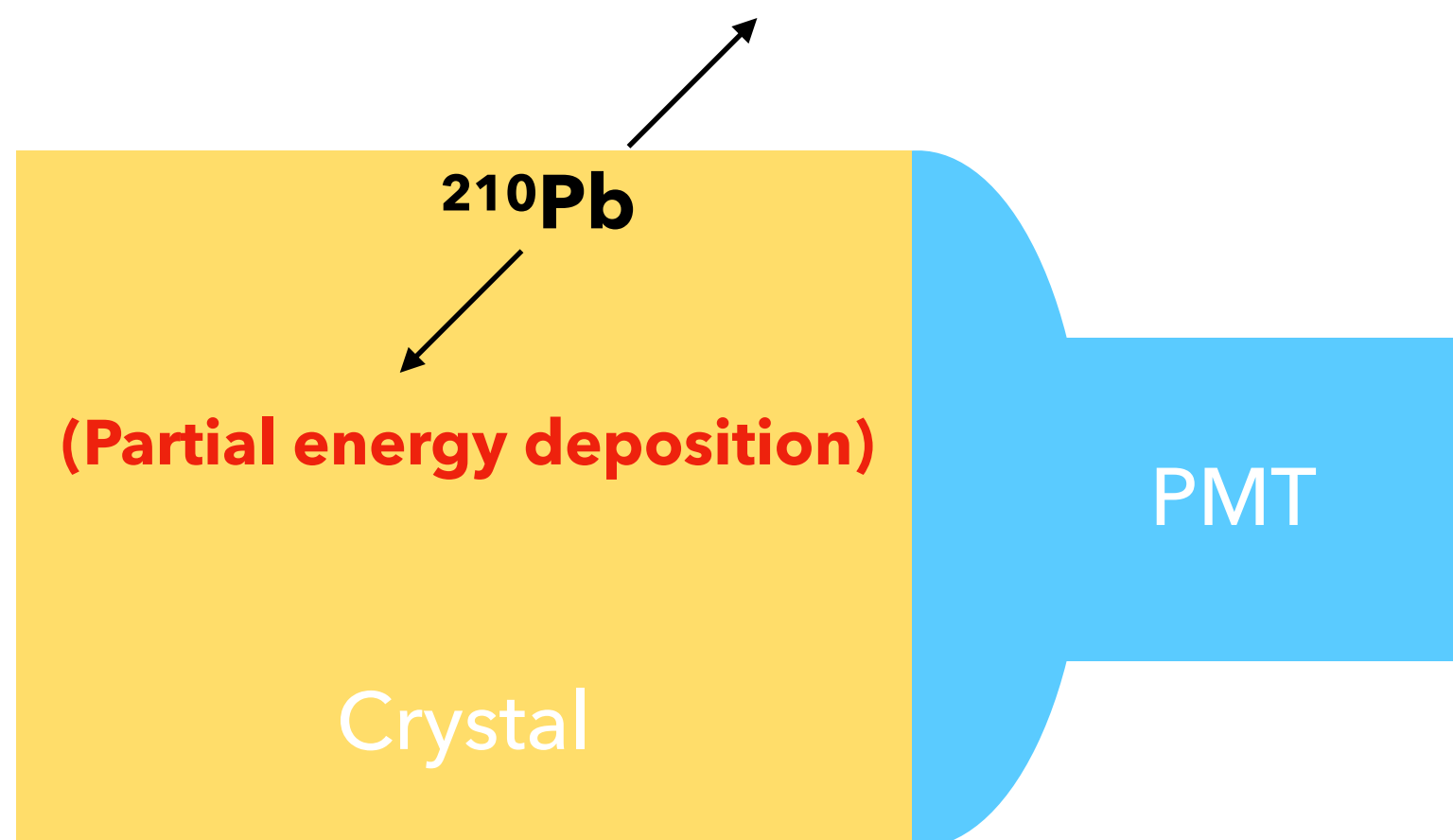


**Overall ~60 % enhancement
in Light yield**

COSINE-100U

3. Reduced background

COSINE-100 3-year background modeling

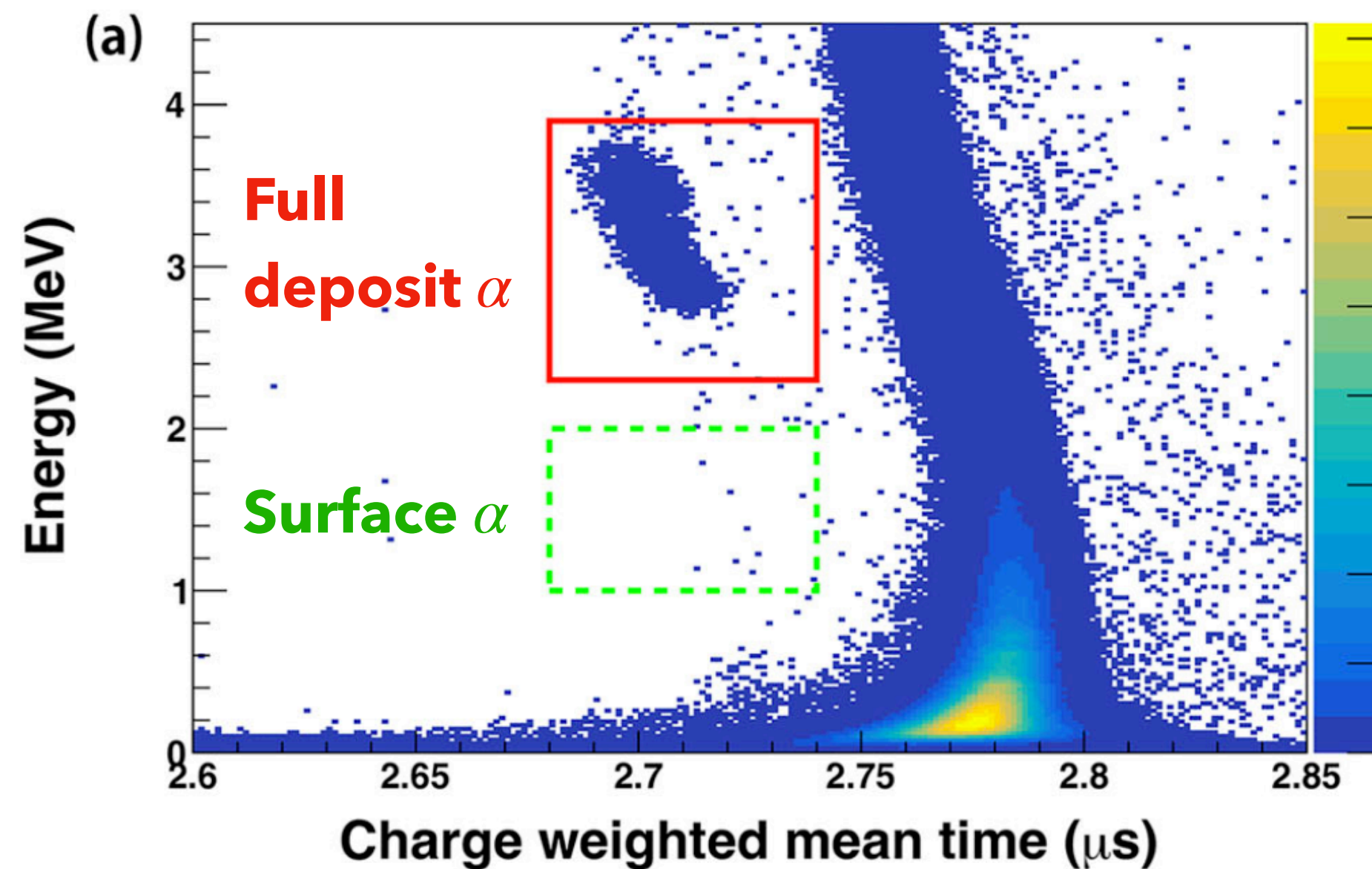


- ^{210}Pb at the surface of the crystal makes partial energy deposition
- In COSINE-100, surface ^{210}Pb is one of the dominant background in WIMP ROI
- **surface $^{210}\text{Pb} \propto$ Surface alpha**

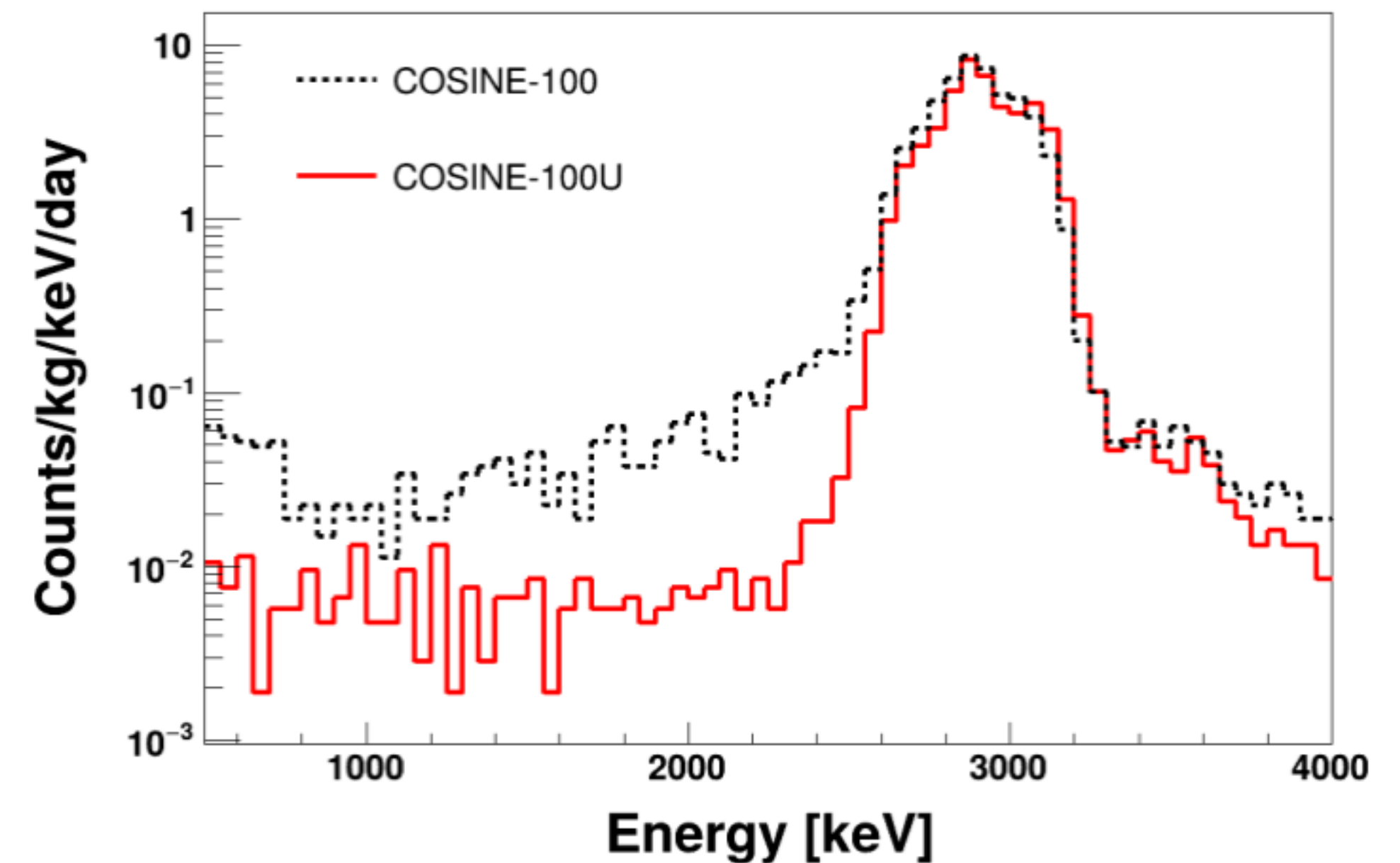
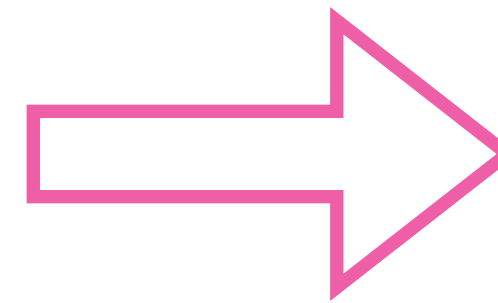
COSINE-100U

3. Reduced background

Alpha spectrum of COSINE-100 vs COSINE-100U



α selection



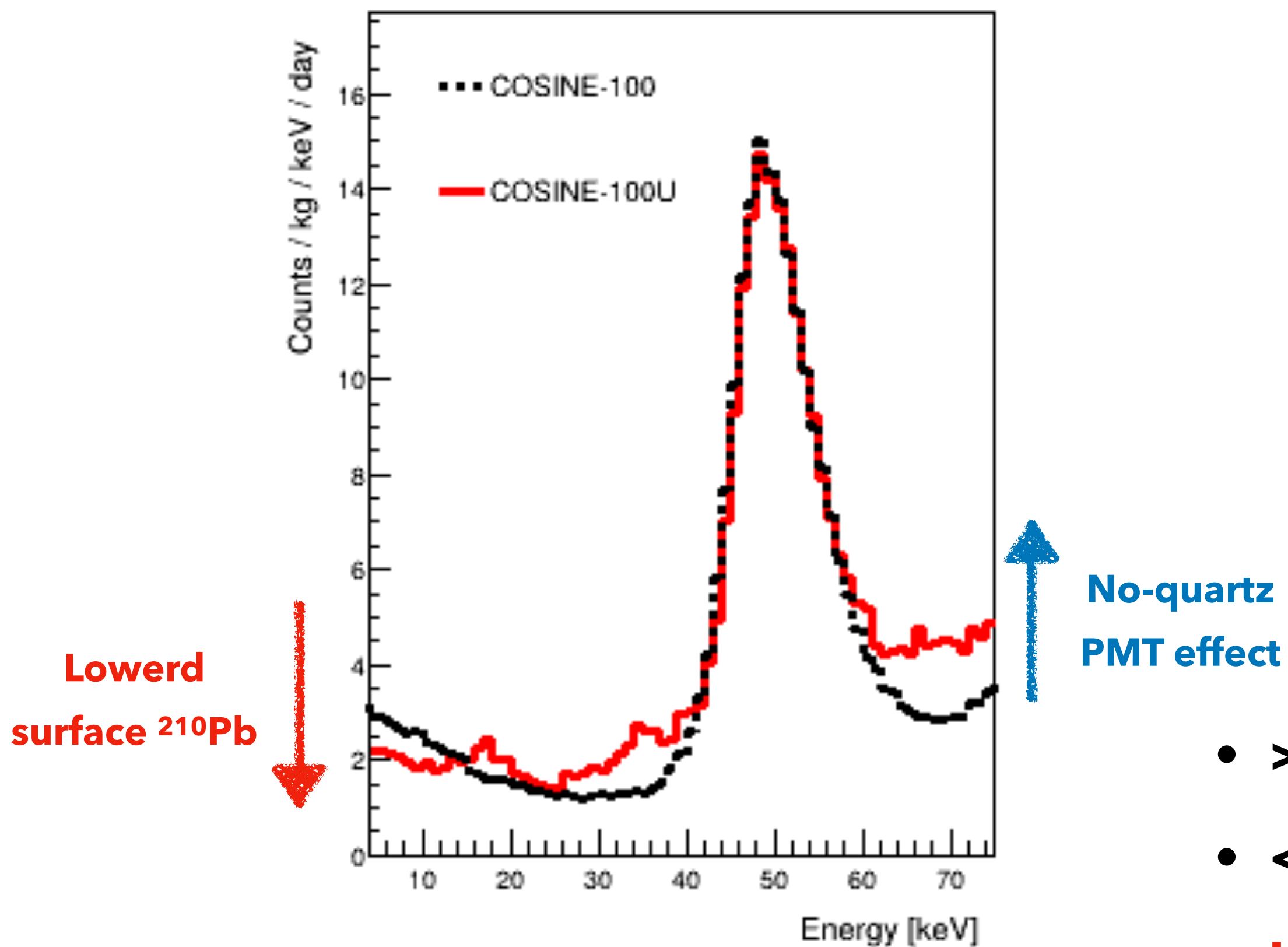
- With the new encapsulation, **reduced surface alpha rate** observed
- Can **expect a lowered background rate** in WIMP ROI

COSINE-100U

3. Reduced background

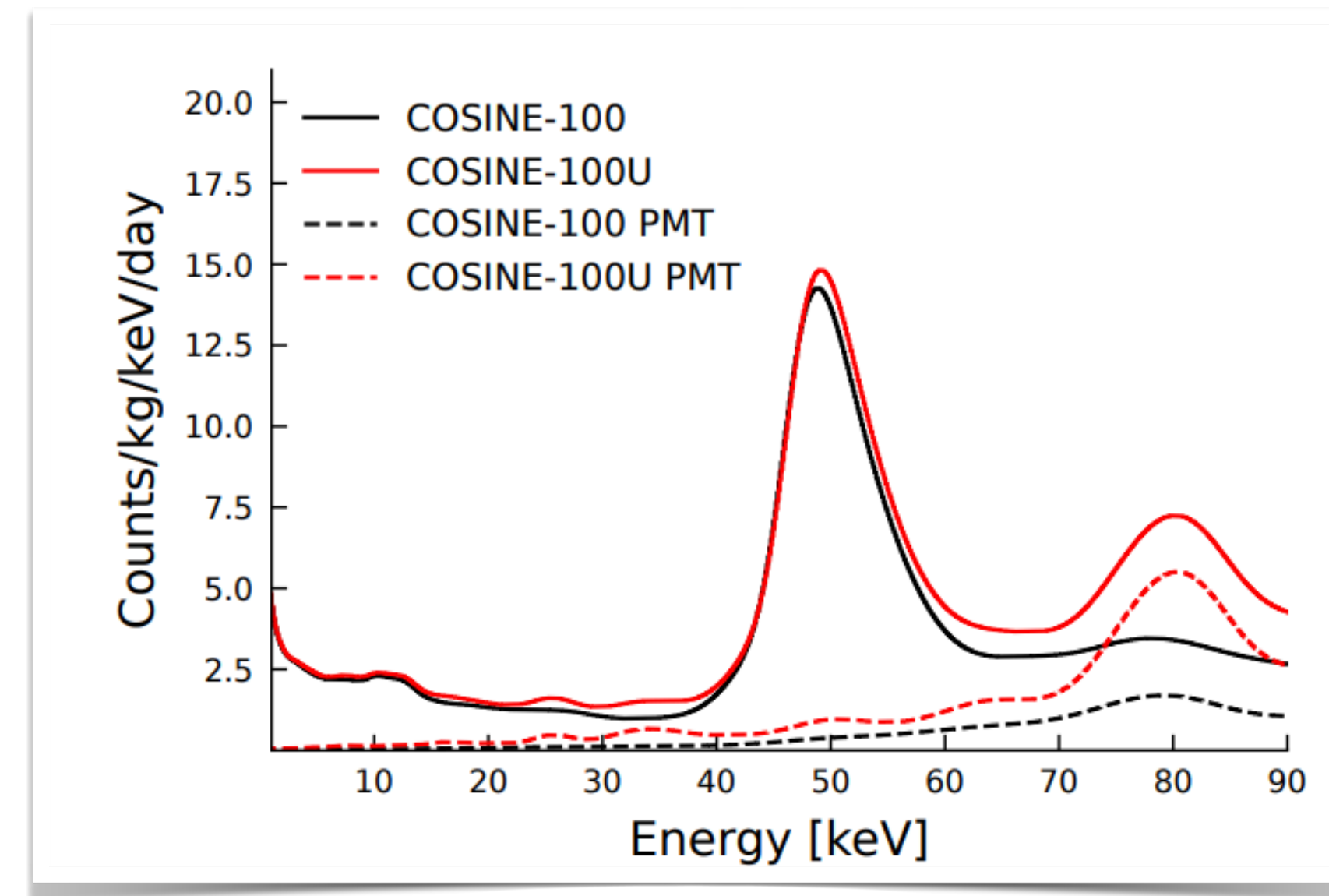
COSINE-100U initial data example

Crystal 2



Expectation in Geant4 Simulation

Commun. Phys. 8, 135 (2025)



- **> 30 keV** : Increased from no-quartz effect (consistent with simulation)
- **< 20 keV** : lowered from **reduced surface ^{210}Pb**
- **Lowerd background rate in WIMP ROI**

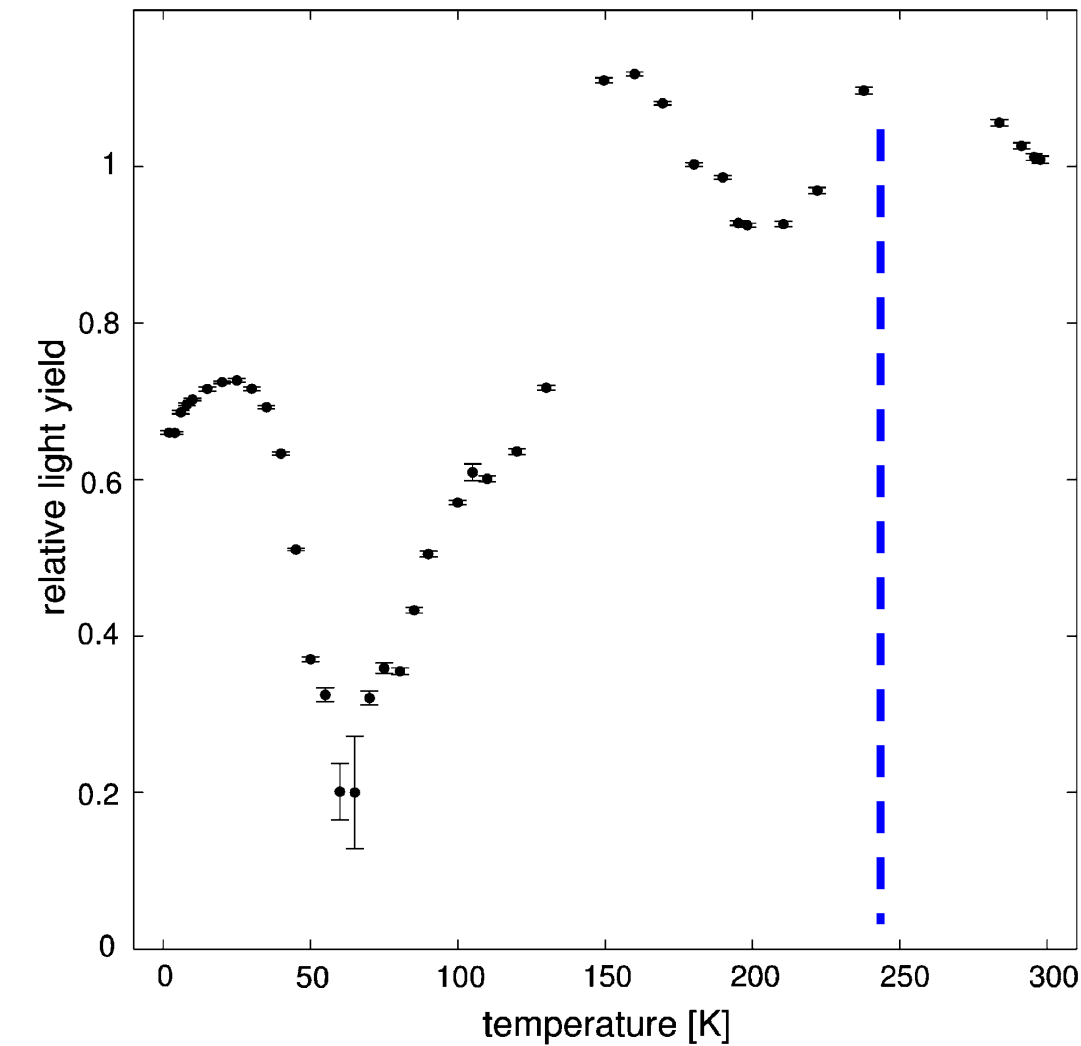
COSINE-100U

4. Low temperature operation



Nal(Tl) LY's temperature dependency

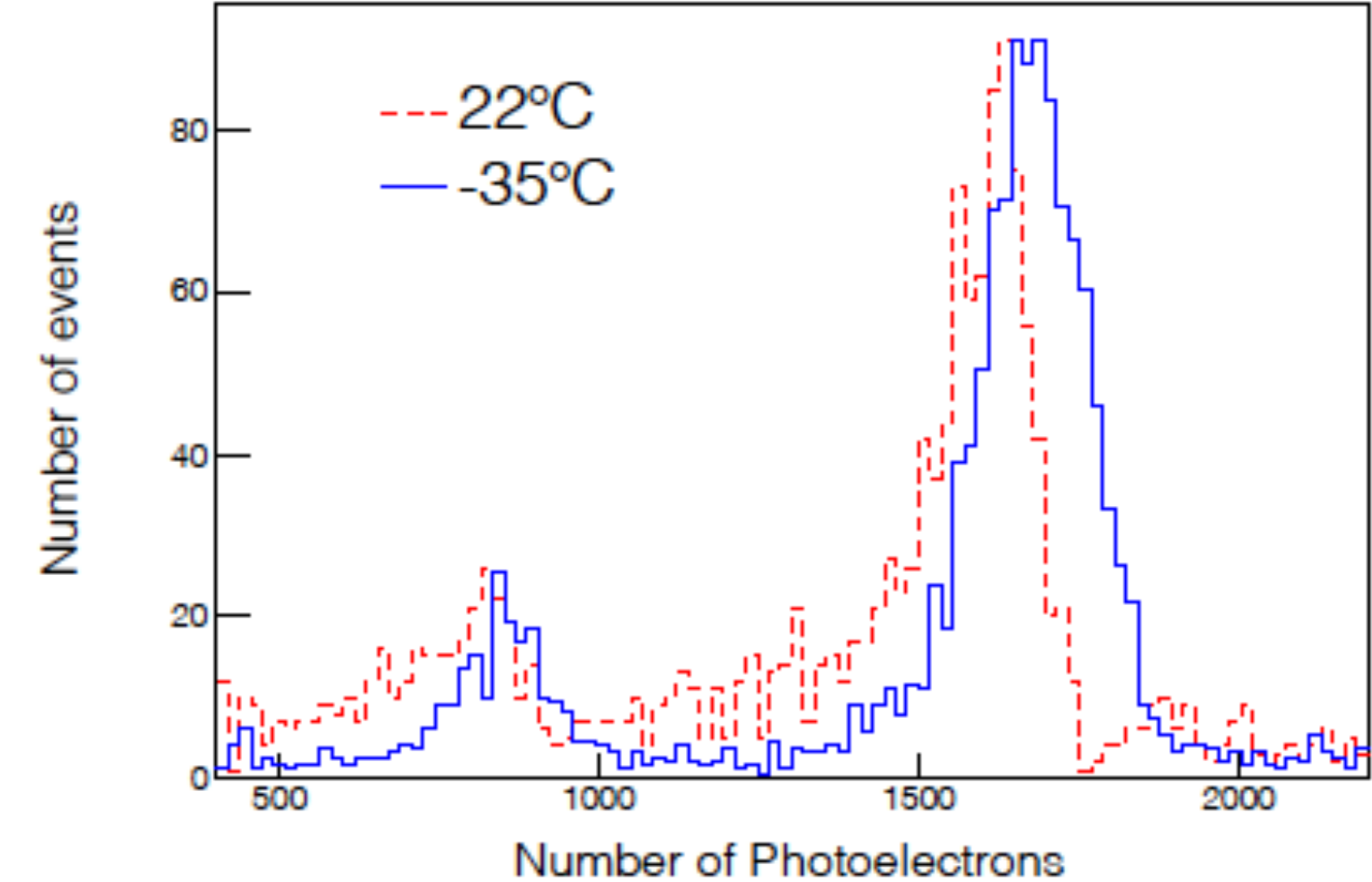
Eur. Phys. J. C **72**, 2061 (2012)



It is known to have higher
Light yield in $\sim -30^\circ\text{C}$

NPE Measurement in -35°C

Astropart. Phys. **141** (2022) 102709



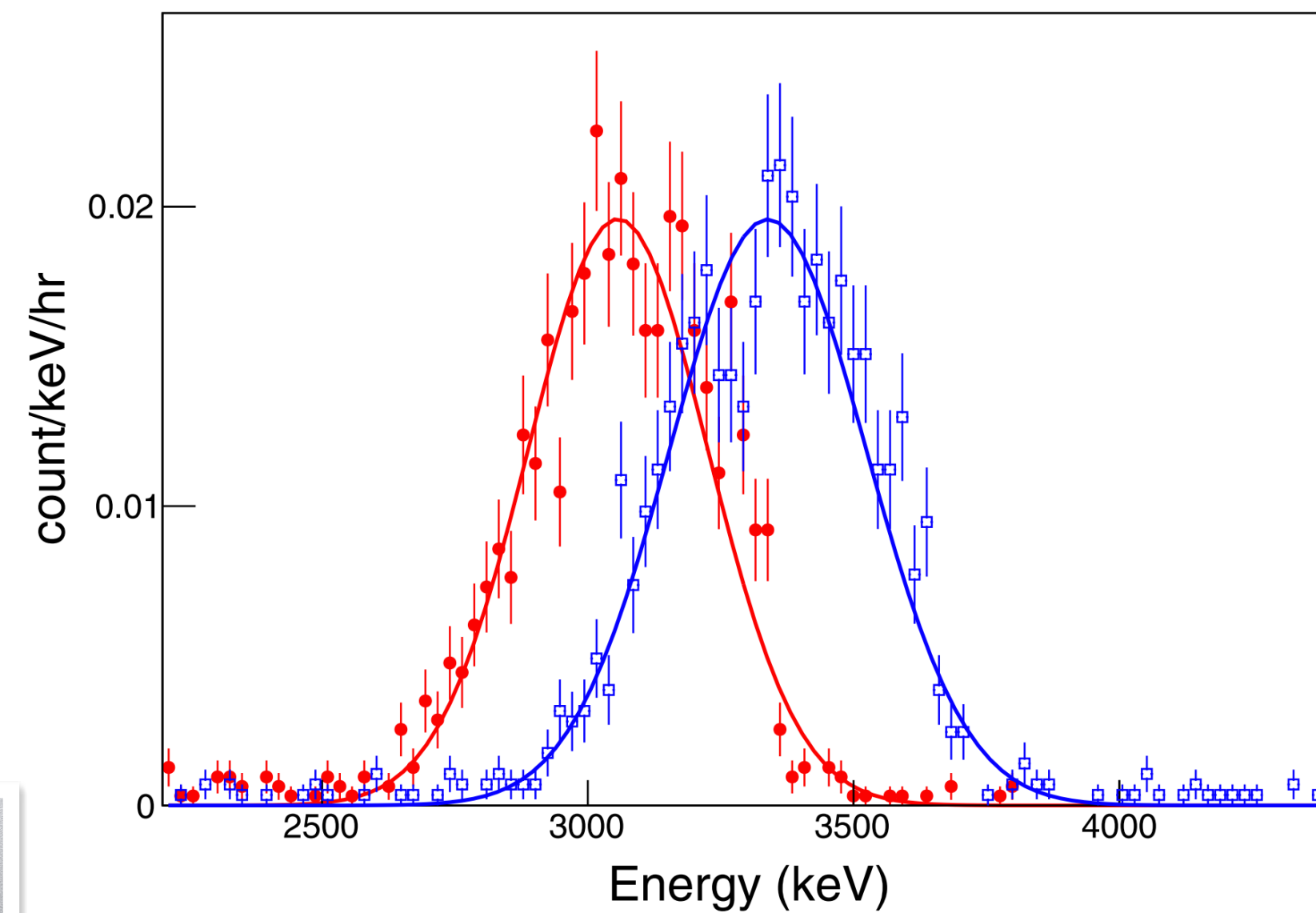
**~5% increased
Light yield measured**

COSINE-100U

4. Low temperature operation



Alpha spectrum using ^{210}Po in $-35\text{ }^{\circ}\text{C}$
Astropart. Phys. **141** (2022) 102709



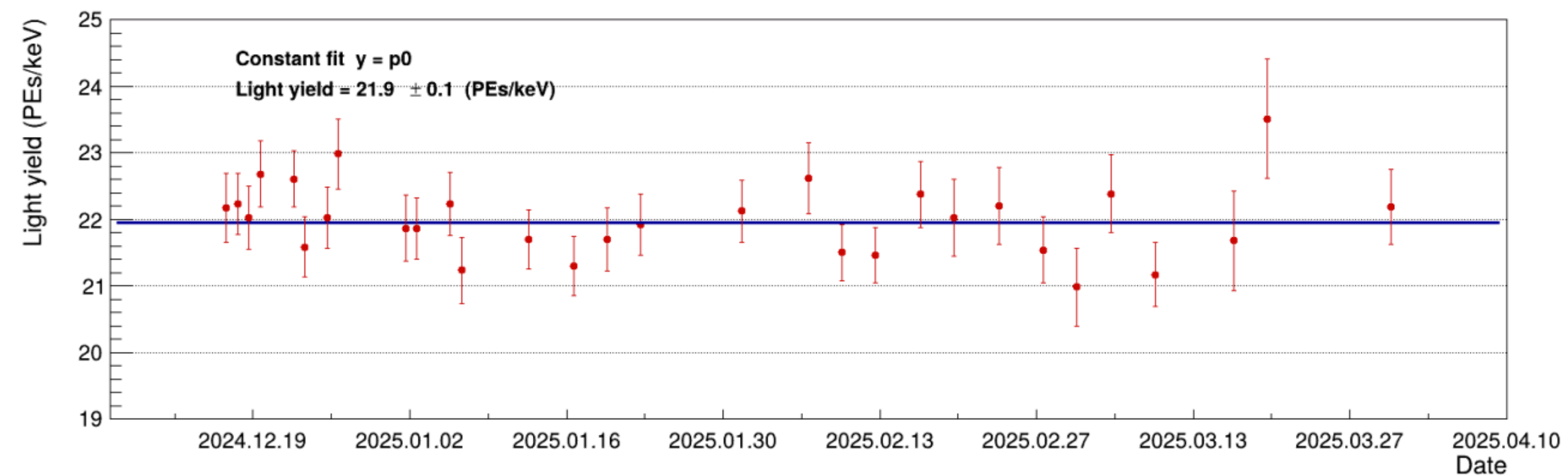
Quenching factor also
can be improved

~9 % higher alpha-QF
has been measured

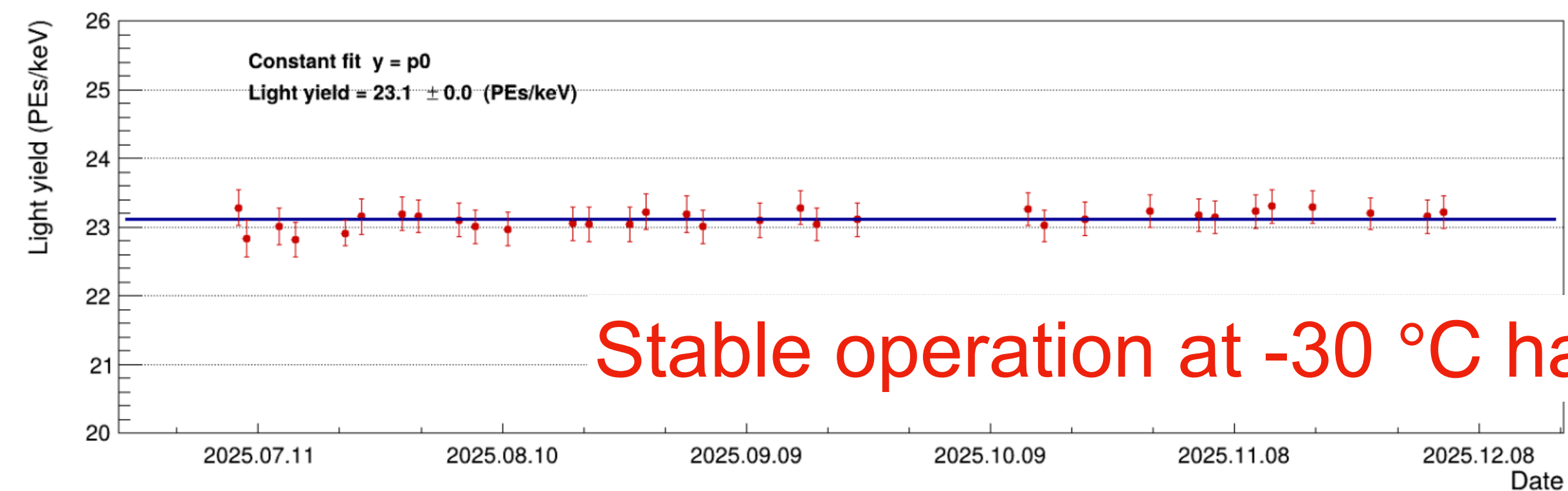
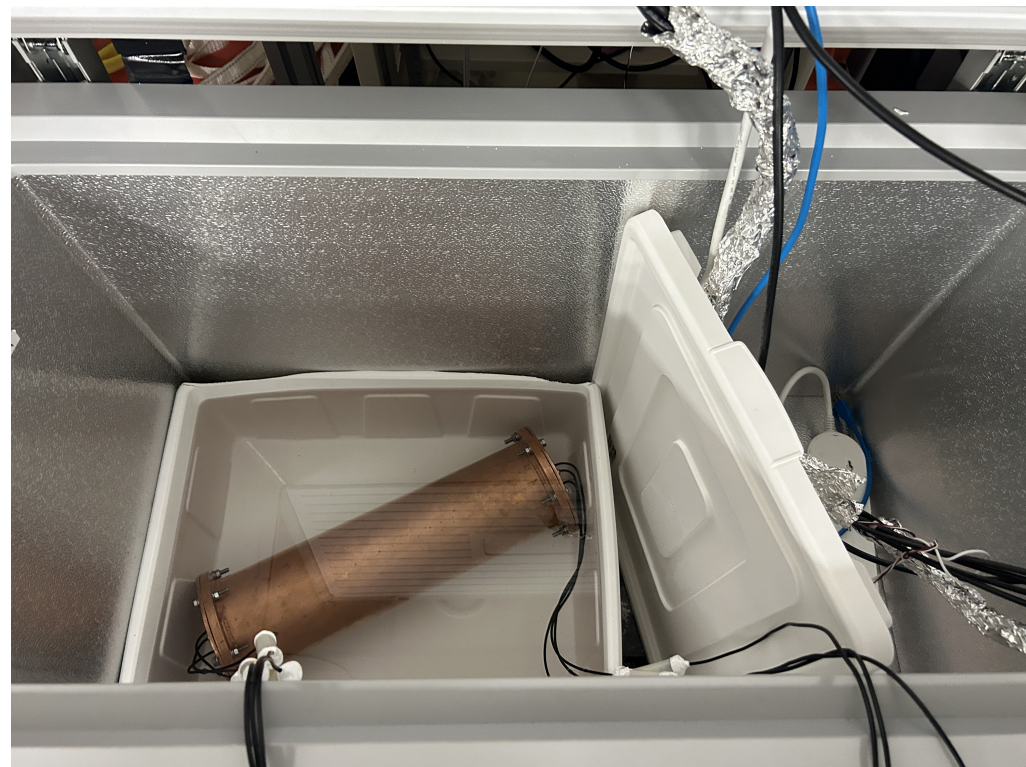
COSINE-100U

4. Low temperature operation : Stability check

Room temperature stability check in Air (~ 4 Months)



-33 °C stability check in LS (~ 5 Months) *JINST 21 (2026) T03010*



Stable operation at -30 °C has been tested

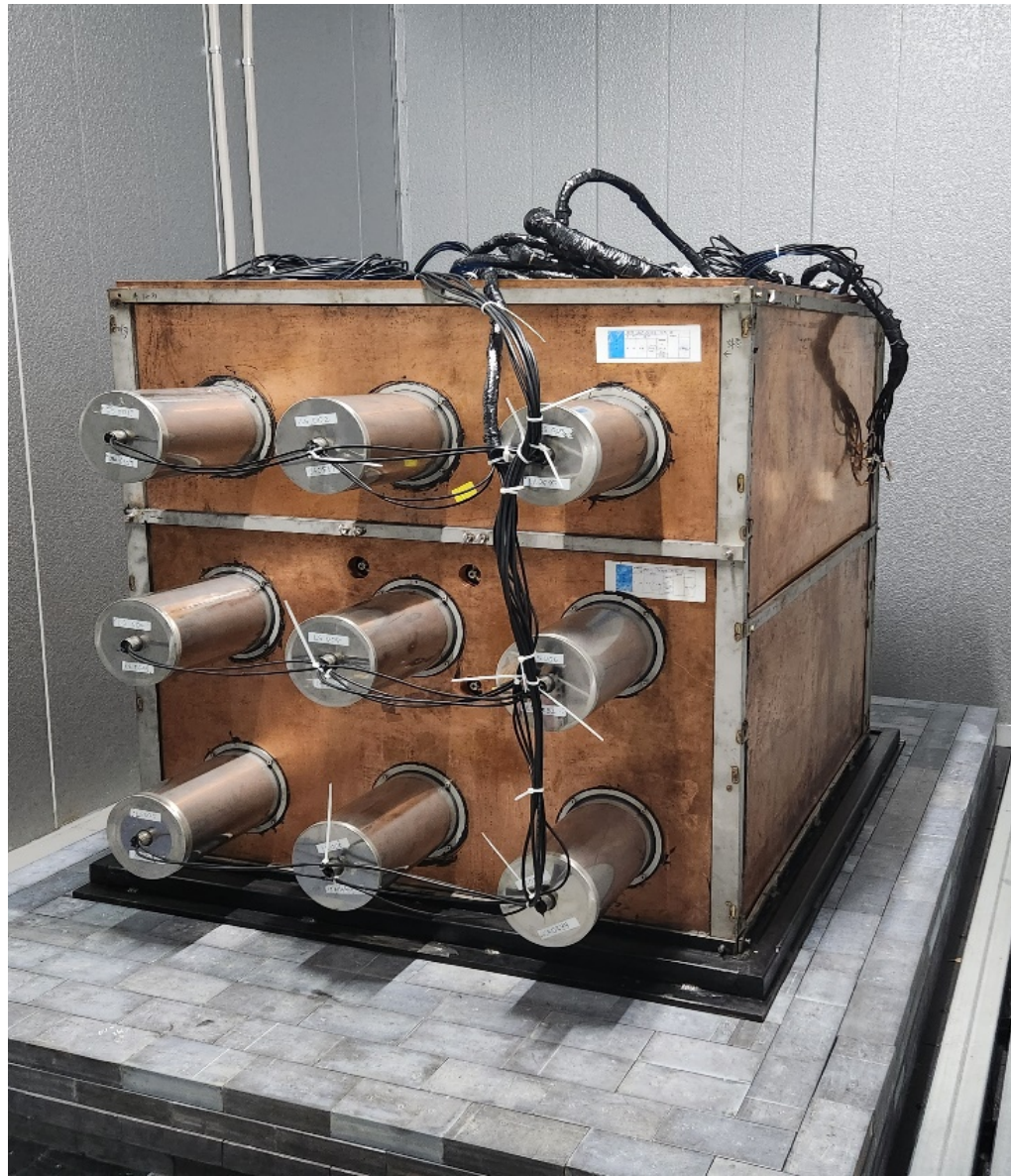
COSINE-100U

Installation detail

	2024	2025				2026		
	4/4	1/4	2/4	3/4	4/4	1/4	2/4	3/4
Installation	←				→			



Detector room



Cooper box & LS PMT



Install side lead shield

COSINE-100U

Installation detail

	2024	2025				2026		
	4/4	1/4	2/4	3/4	4/4	1/4	2/4	3/4
Installation								

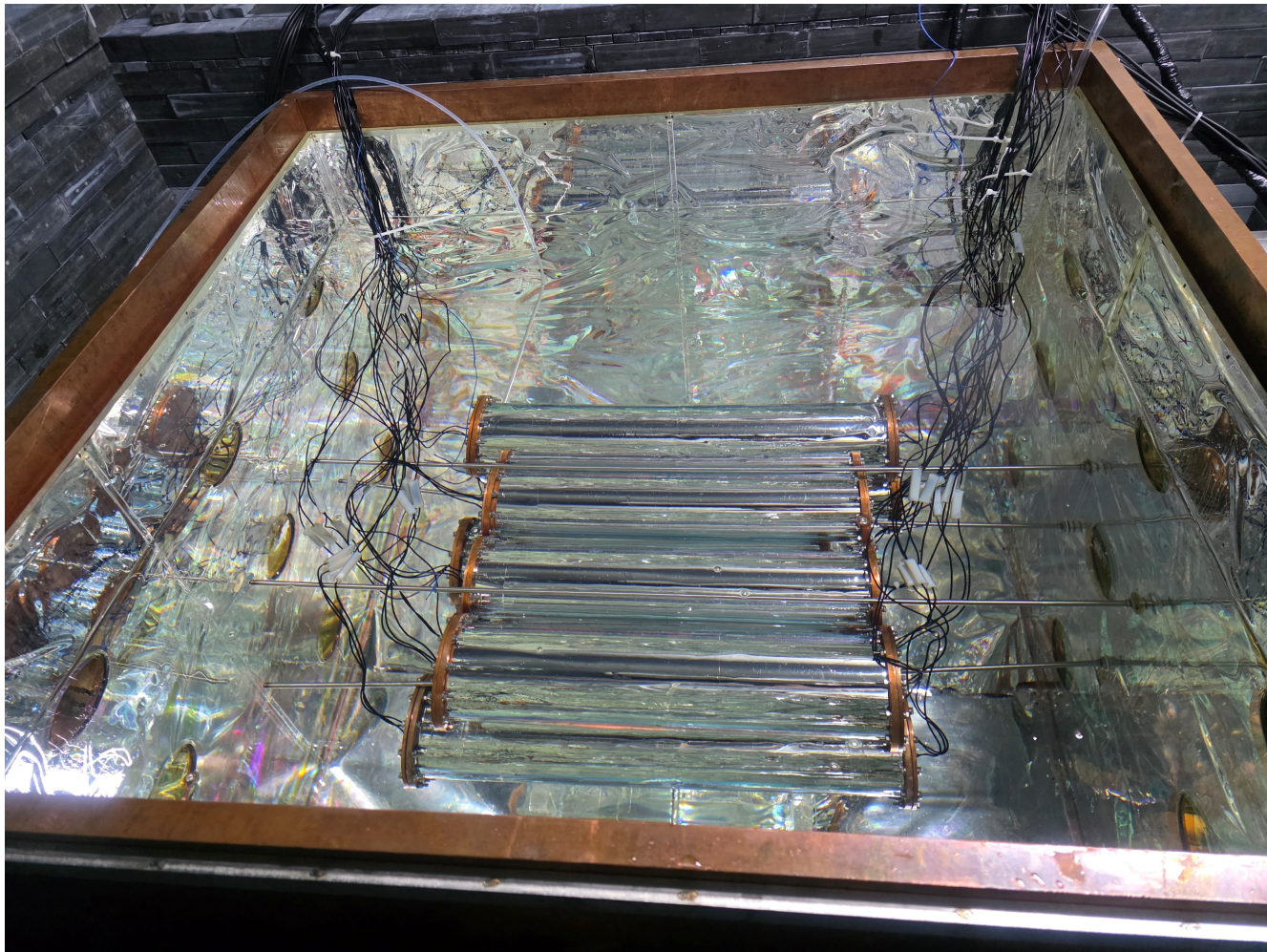
20th May 2025

26th May 2025

28th May 2025



Crystal Installation



Fill Liquid Scintillator



Cover the top lead

COSINE-100U

Installation detail

	2024	2025				2026		
	4/4	1/4	2/4	3/4	4/4	1/4	2/4	3/4
Installation								

28th May 2025



Wrapping the shield to prevent air contamination

28th July 2025



Install Plastic scintillator for muon veto

25th Sep 2025

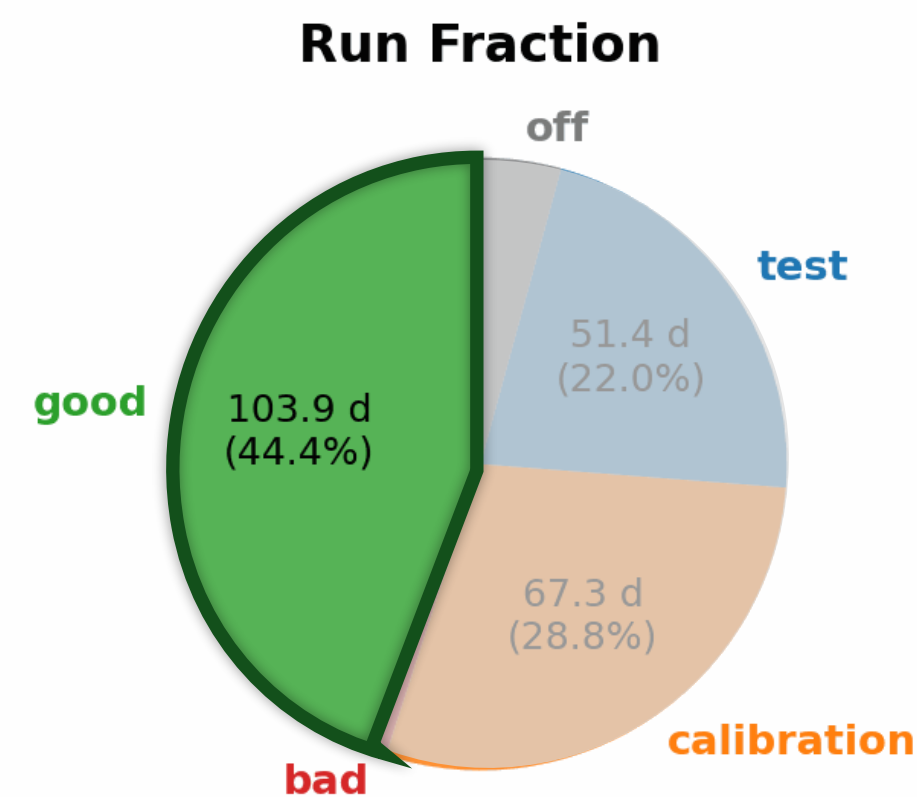
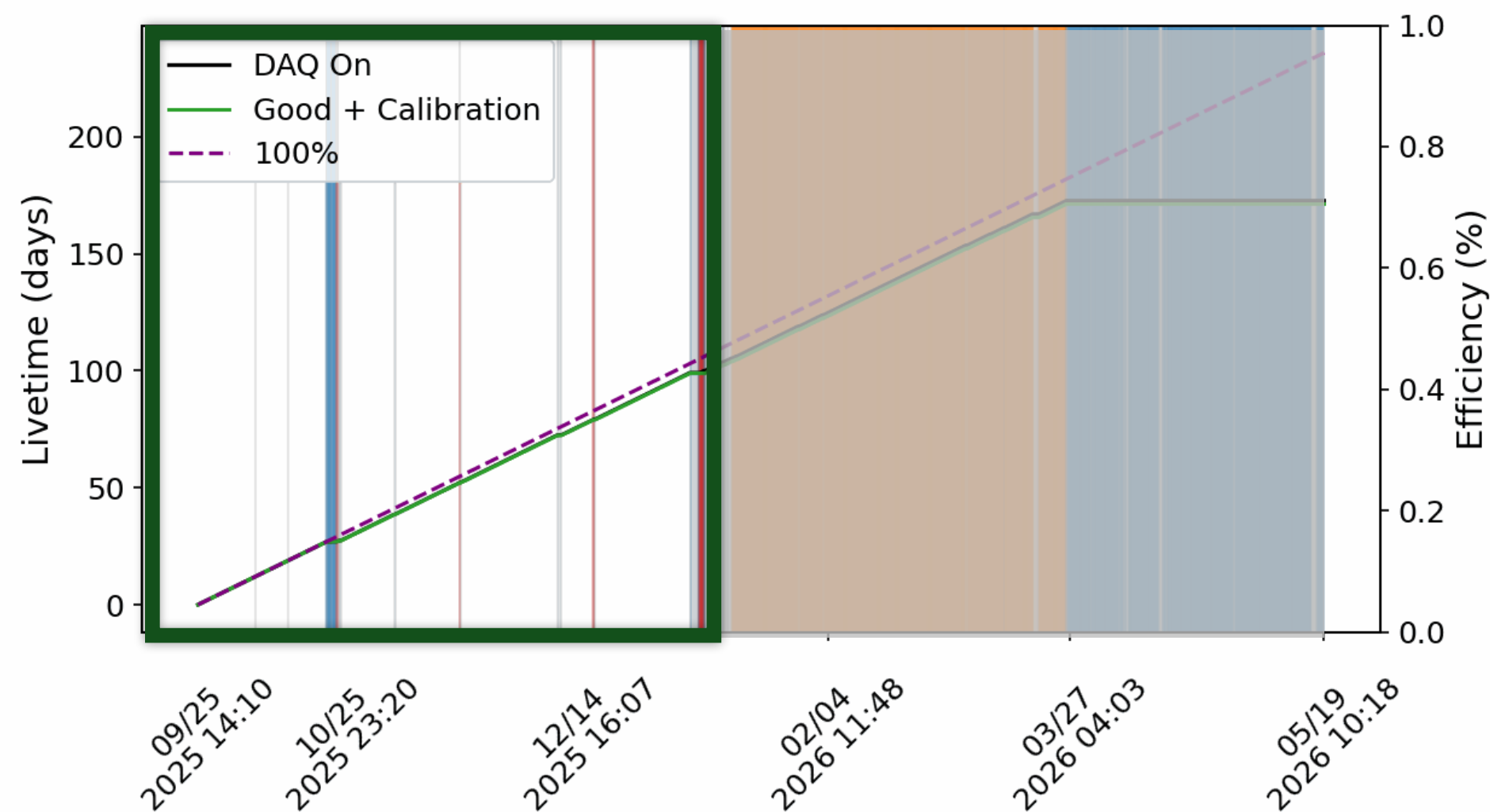


Start physics run !

COSINE-100U

1st data taking finished

	2024	2025				2026		
	4/4	1/4	2/4	3/4	4/4	1/4	2/4	3/4
Installation	←————→							
Calibration @ R.T.				↔				
Physics run @ R.T.				←————→				



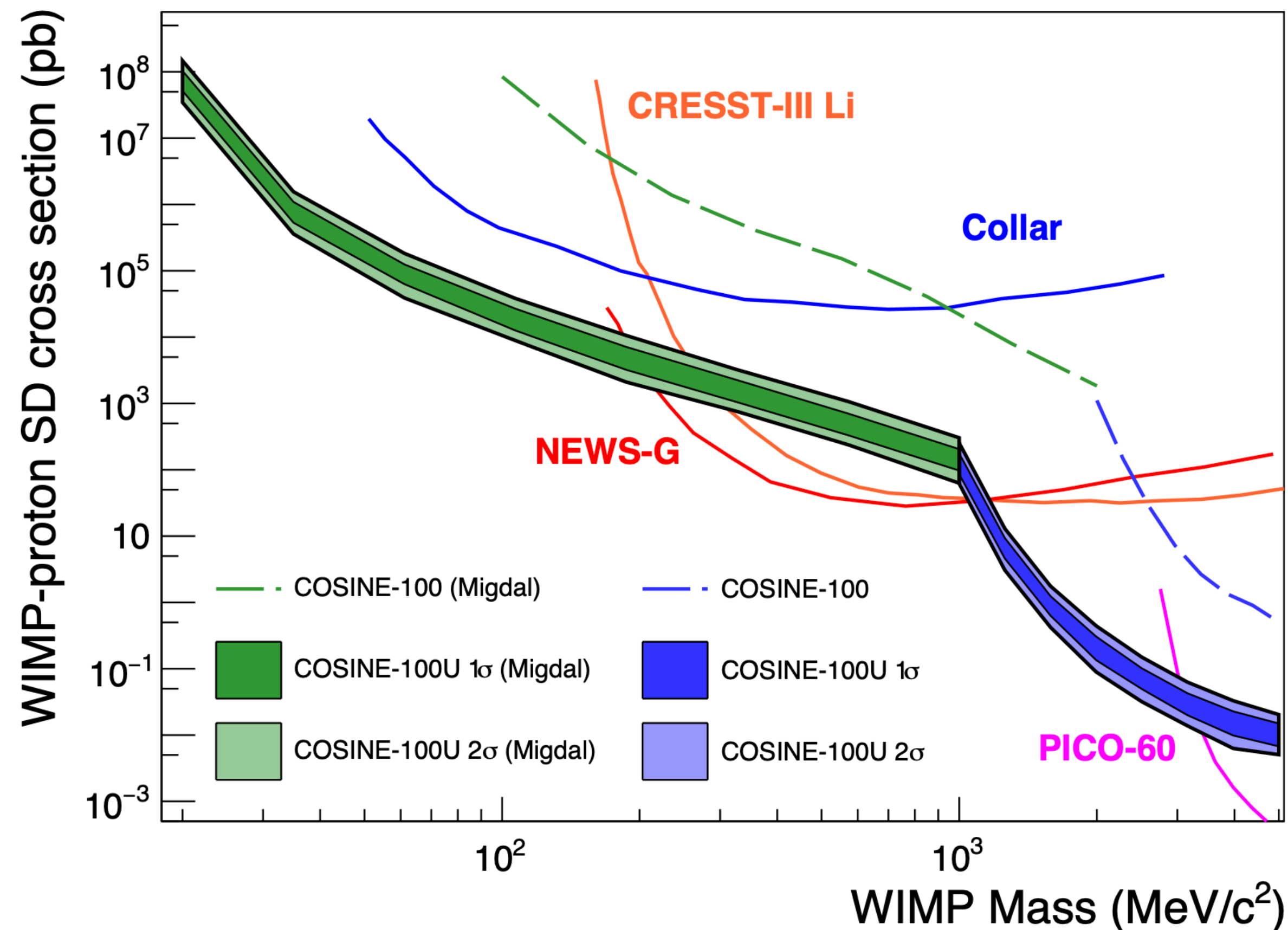
Started physics run Sep. 2025

- **~100 days data in room-temperature** finished, and **analysis going on**

COSINE-100U

Expected sensitivity in SD model

COSINE-100U sensitivity
: 1-year operation & 0.35 keV threshold

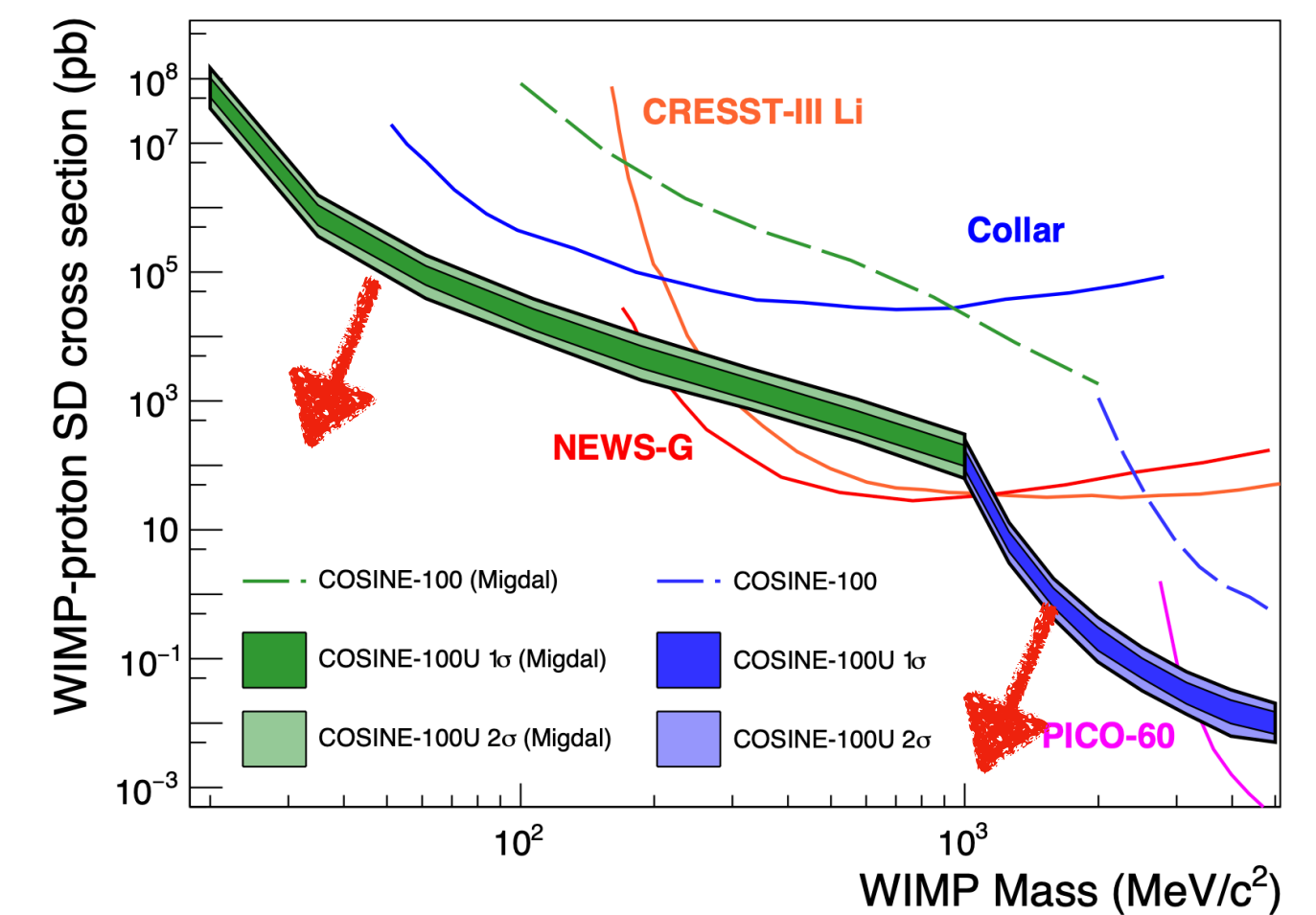


- Can cover world-best sensitivity in MeV scale SD WIMP search.
- Details of COSINE-100U can be found in [Commun. Phys. **8**, 135 \(2025\)](#)

COSINE-100U

Lowering temperature

	2024	2025				2026		
	4/4	1/4	2/4	3/4	4/4	1/4	2/4	3/4
Calibration @ L.T.							↔	
Physics run @ L.T.							→	



- In April 2026, we started to lower the temperature down to -25 °C
- Even **lower sensitivity** can be possible with low-temperature operation

Summary

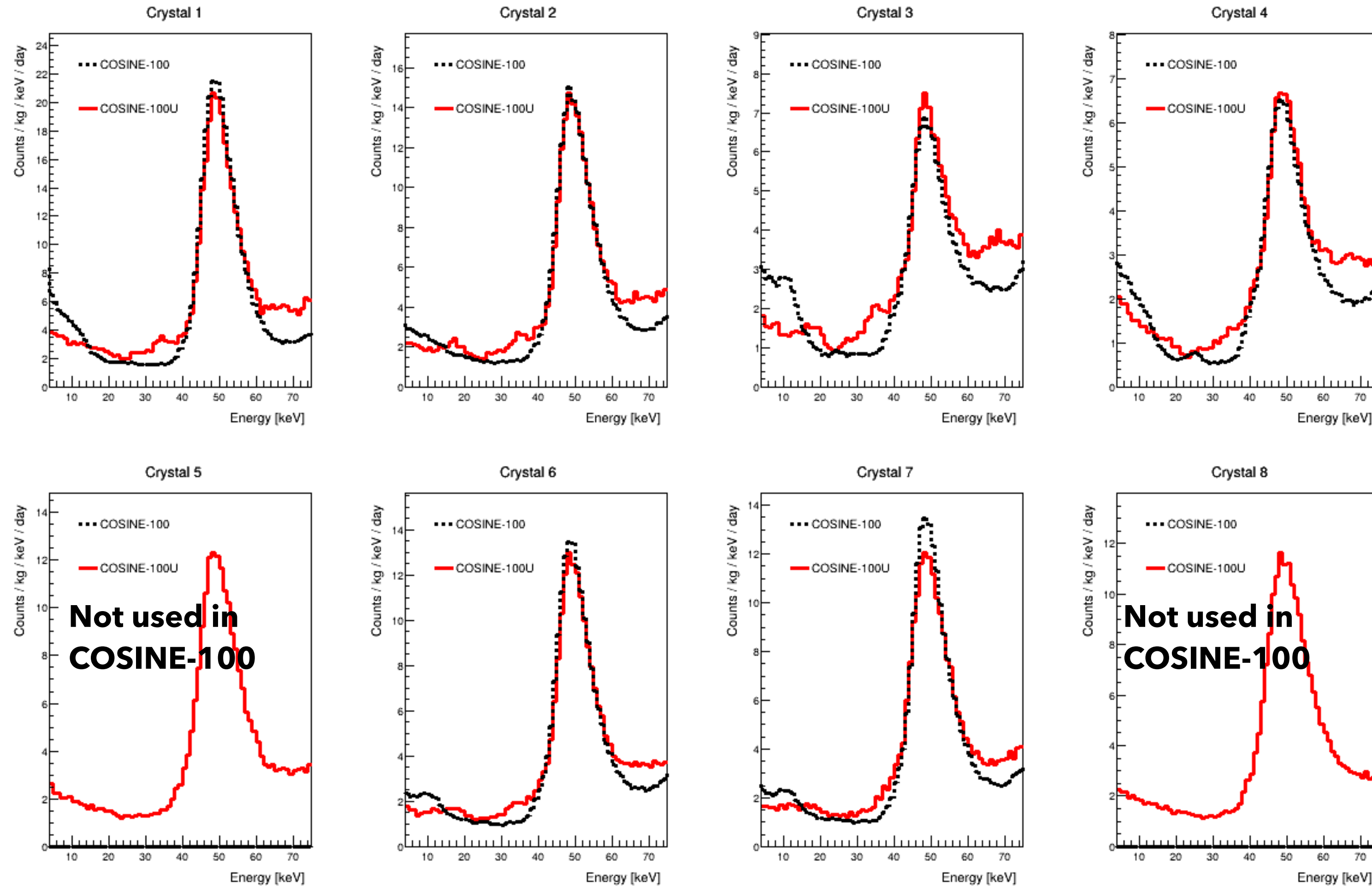
- COSINE-100 has moved to its upgrade experiment, COSINE-100U
- Upgrades in COSINE-100U
 1. New underground laboratory : Yemiliab
 2. Higher light yield with new encapsulation
 3. Lower background rate in WIMP ROI
 4. Low temperature operation condition
- **~100 days of room-temperature data** is collected so far.
- **World best SD WIMP-proton scattering sensitivity** is expected.

Thanks for listening!

COSINE-100U

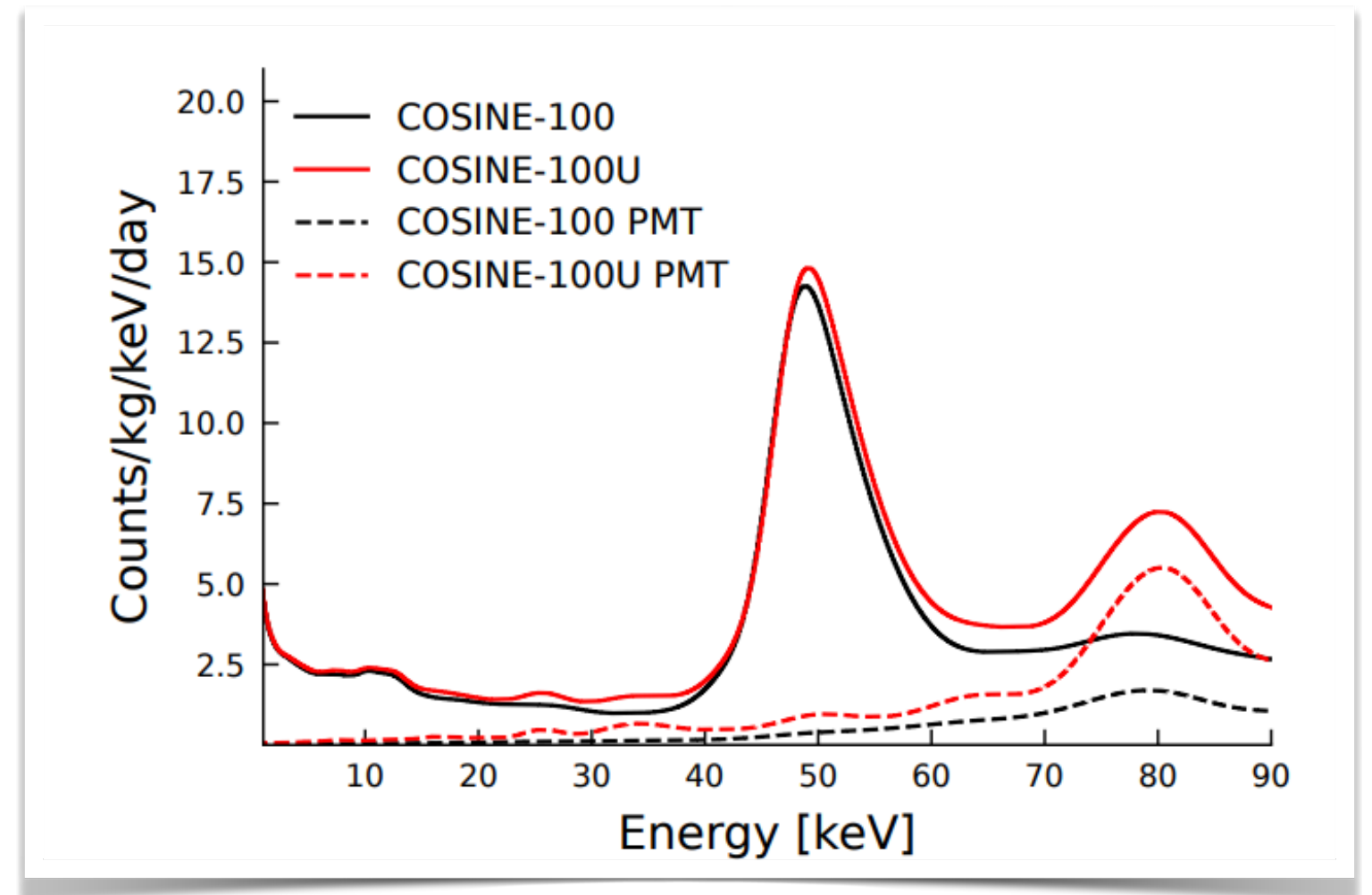
Lowered background

COSINE-100U initial data



Expectation in Simulation

Commun. Phys. **8**, 135 (2025)



- **> 30 keV** : Increased from no-quartz effect (consistent with simulation)
- **< 20 keV** : lowered from **reduced surface**

²¹⁰Pb

COSINE-100 experiment



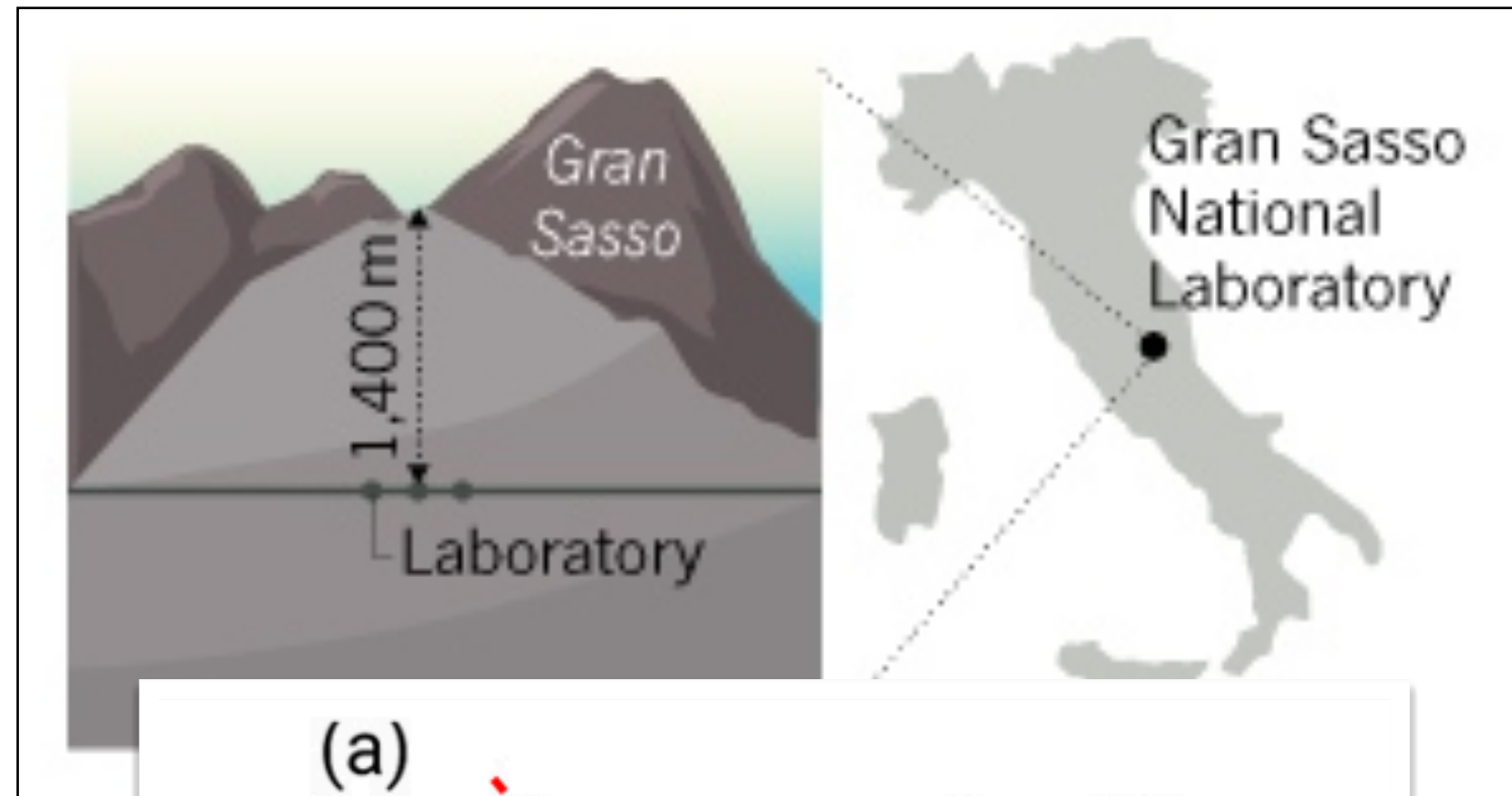
15 institutes ~60
members

$$\text{DM-ICE} + \text{KIMS} = \text{COSINE}$$

The equation shows 'DM-ICE' followed by a plus sign, then the 'KIMS' logo (which includes the text 'Korea Invisible Mass Search Experiment'), followed by an equals sign, and finally the 'COSINE' logo (which features a stylized 'X' shape with the word 'COSINE' written across it).



COSINE-100 Motivation : DAMA/LIBRA's claim



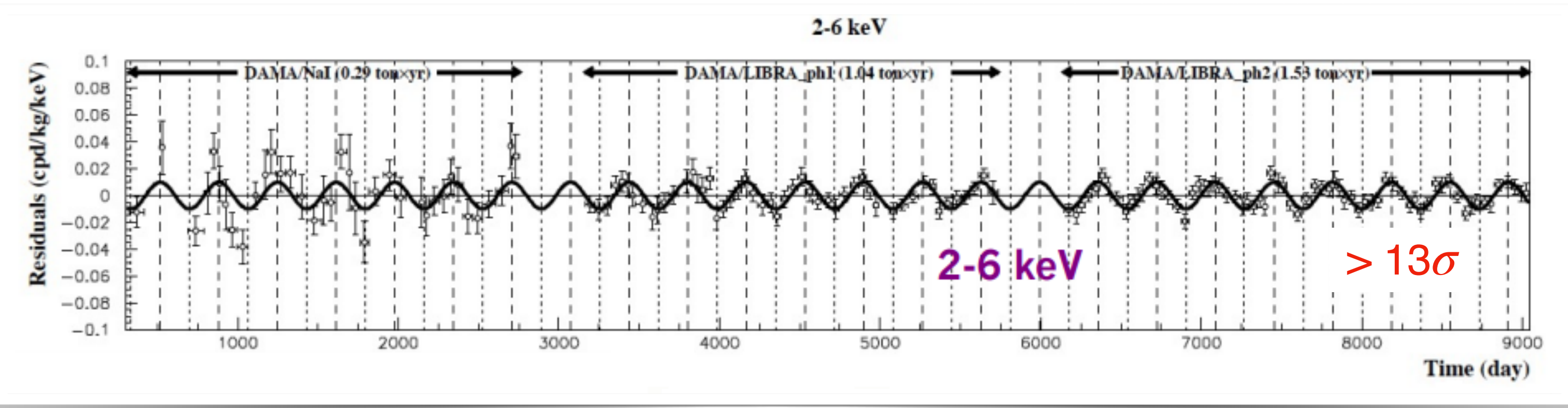
DAMA/LIBRA Modulation signal

P.Belli, EPS-HEP Conference (2021)

$$A = 0.0096 \pm 0.0008 \text{ counts/day/kg/keV,}$$

$$\varphi = 145 \pm 5 \text{ days}$$

$$T = 0.9987 \pm 0.0008 \text{ yr)}$$



- **DAMA/LIBRA** : NaI(Tl) based direct dark matter search in Gran Sasso
- **Claimed to find annual modulation**, compatible with the nature of DM candidate

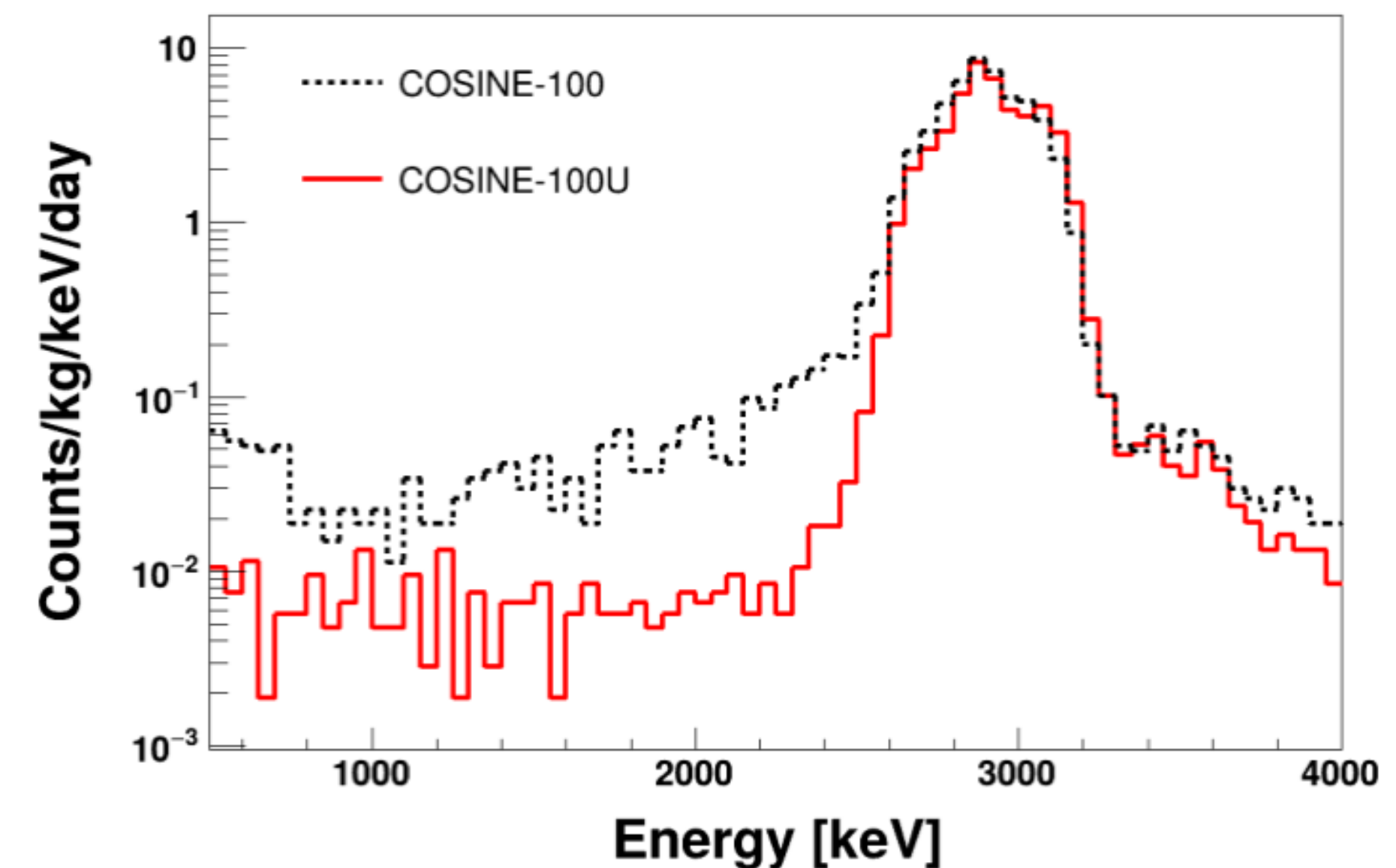
COSINE-100U

Reduced low-energy & surface ^{210}Pb

Surface alpha rate in **COSINE-100** → **COSINE-100U**

Crystal #	LowE Alpha (nBq/cm ²)	
1	33.07 ± 3.70	38.31 ± 5.98
2	39.61 ± 3.76	20.07 ± 4.10
3	71.73 ± 5.06	20.91 ± 4.18
4	24.27 ± 2.31	14.95 ± 2.78
5	—	10.71 ± 2.34
6	120.9 ± 5.90	14.05 ± 3.07
7	95.35 ± 5.24	19.41 ± 3.60
8	—	16.32 ± 2.89

Alpha spectrum of **COSINE-100** vs **COSINE-100U**



- With the new encapsulation, **reduced surface alpha rate** observed
- Can expect the lowered background rate in WIMP ROI

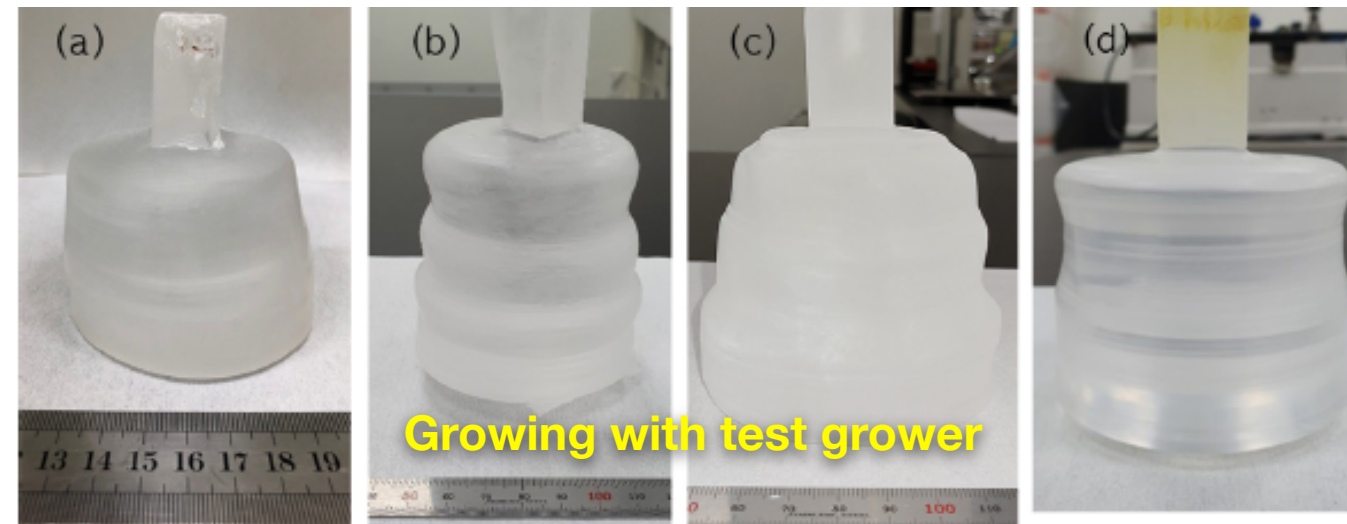
Beyond COSINE-100U

Development for ultra-pure NaI(Tl)

New crystal development



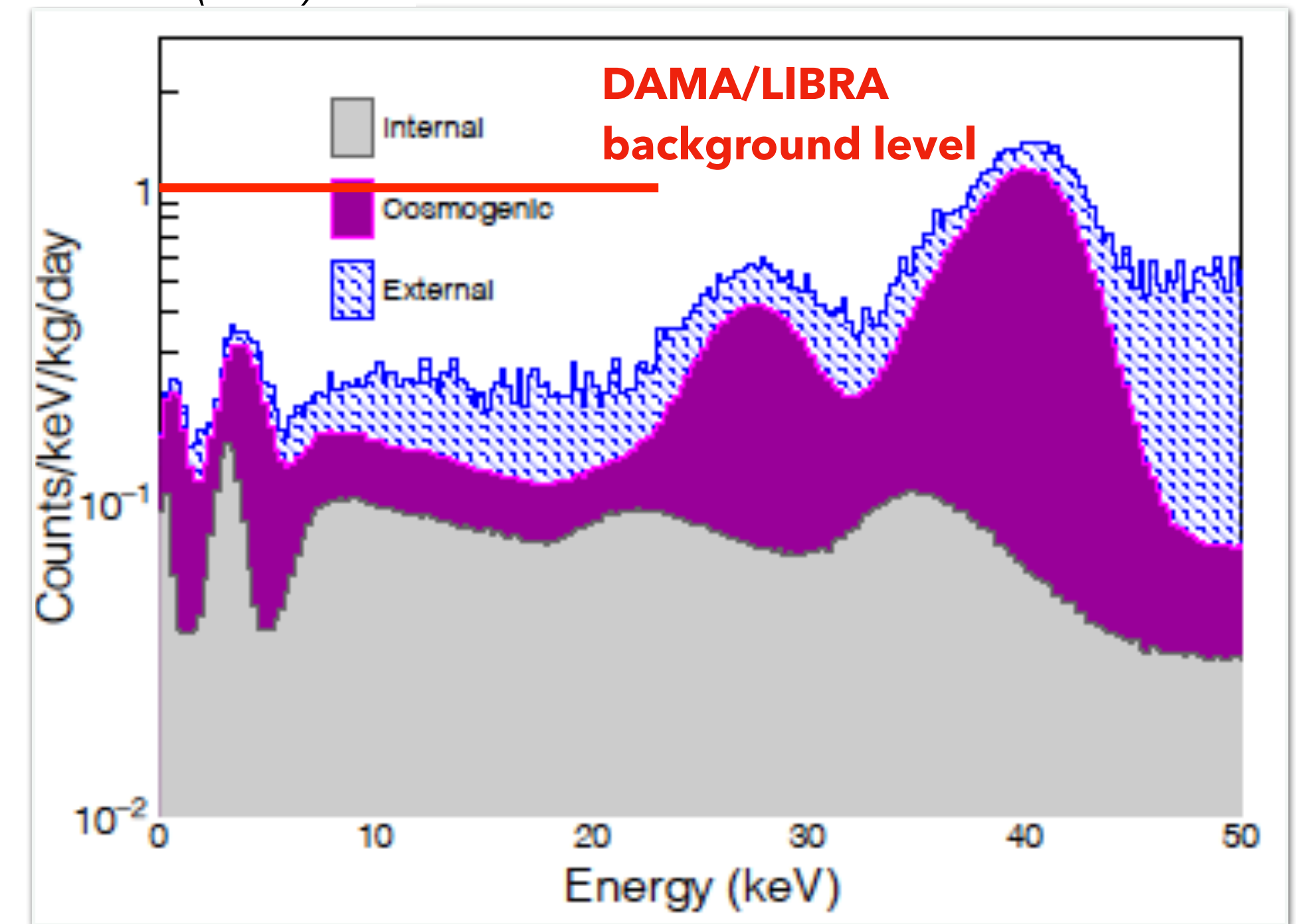
K.A. Shin et al., J. Rad. Nucl. Chem. 317, 1329 (2018)
K.A. Shin et al., JINST 15, C07031 (2020)
K.A. Shin et al., Front. Phys. 11, 1142849 (2023)



R&D for big & pure crystals are ongoing

Simulation of background in new crystal

EPJC 80 (2020) 814

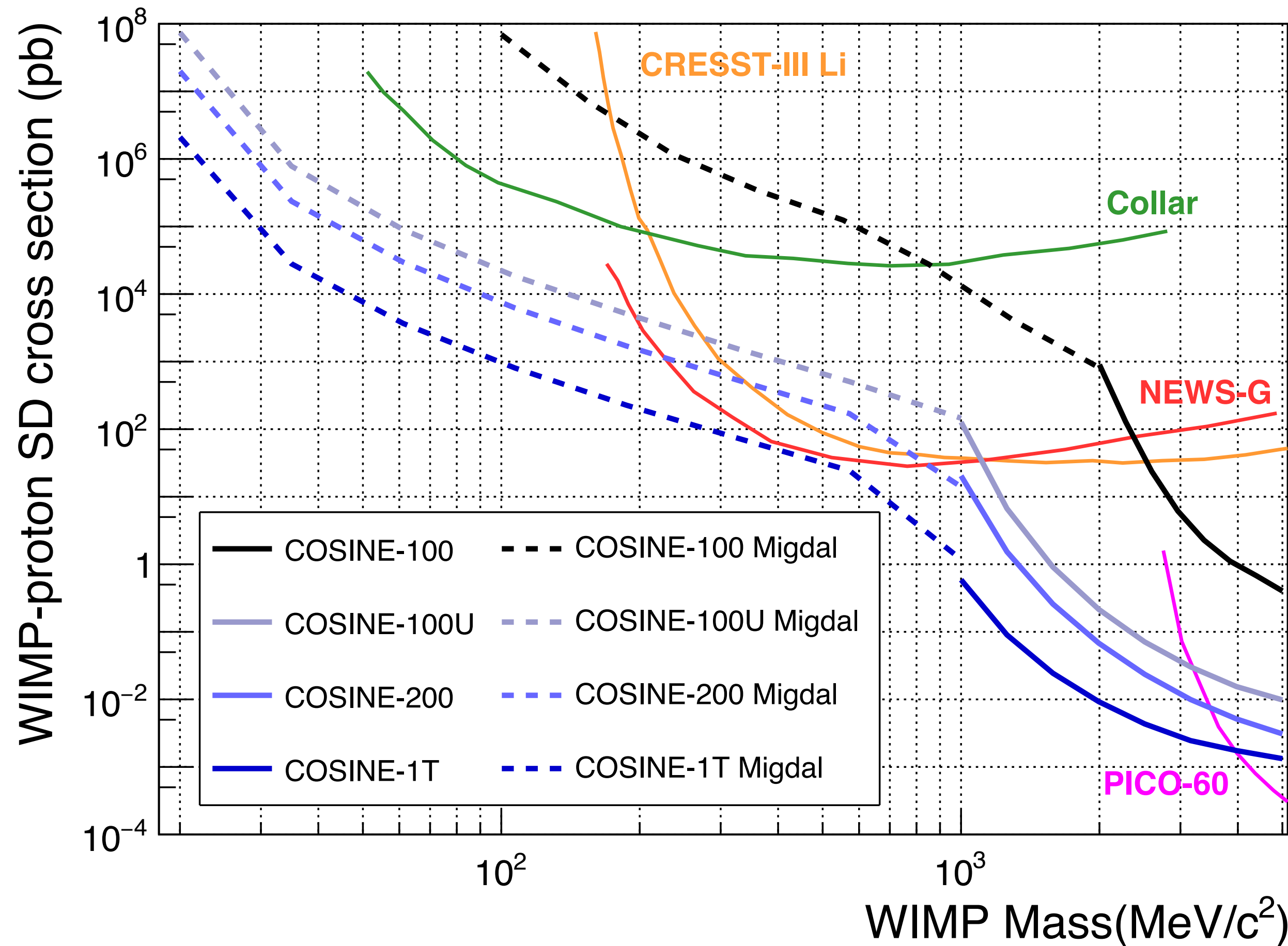


Ultra pure background is expected

Beyond COSINE-100U

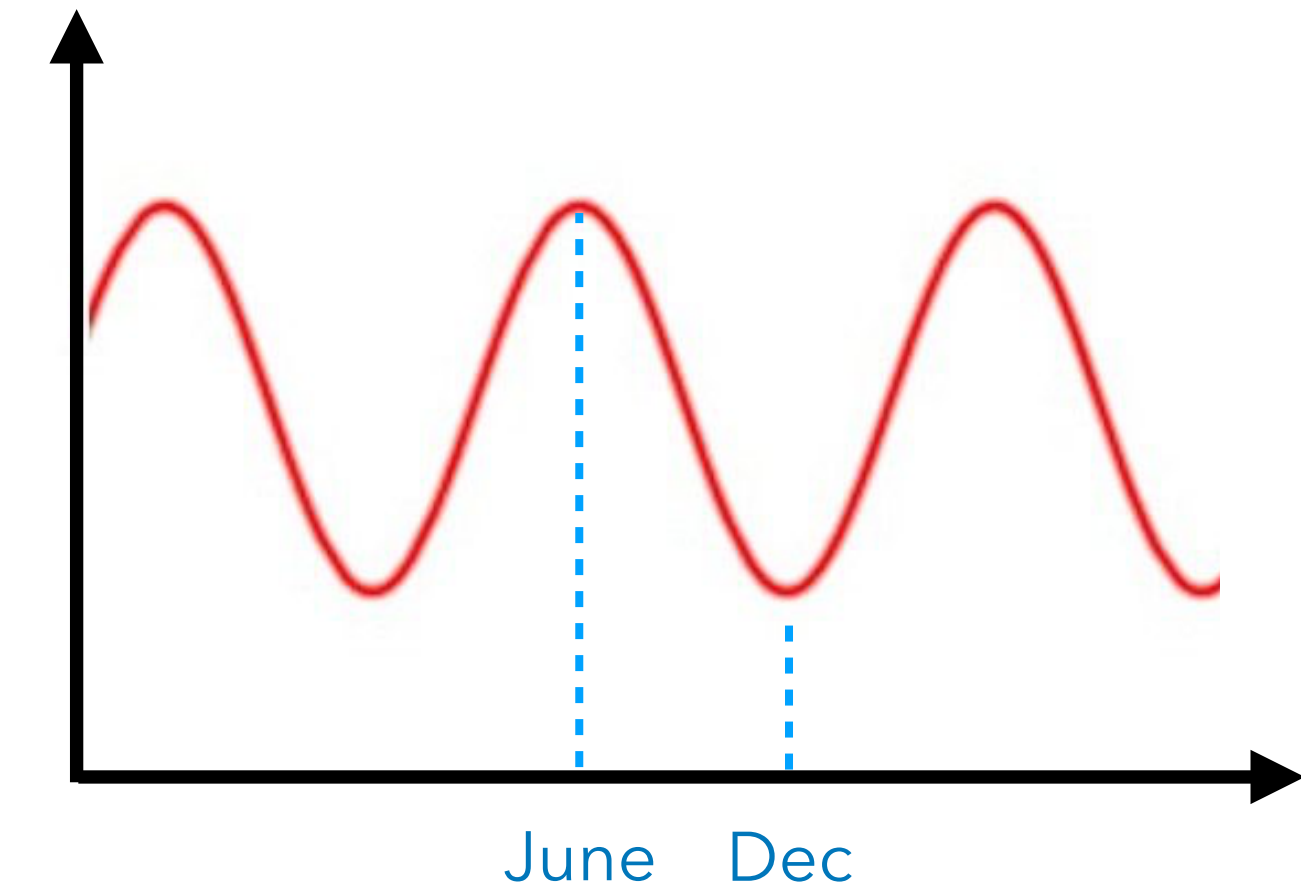
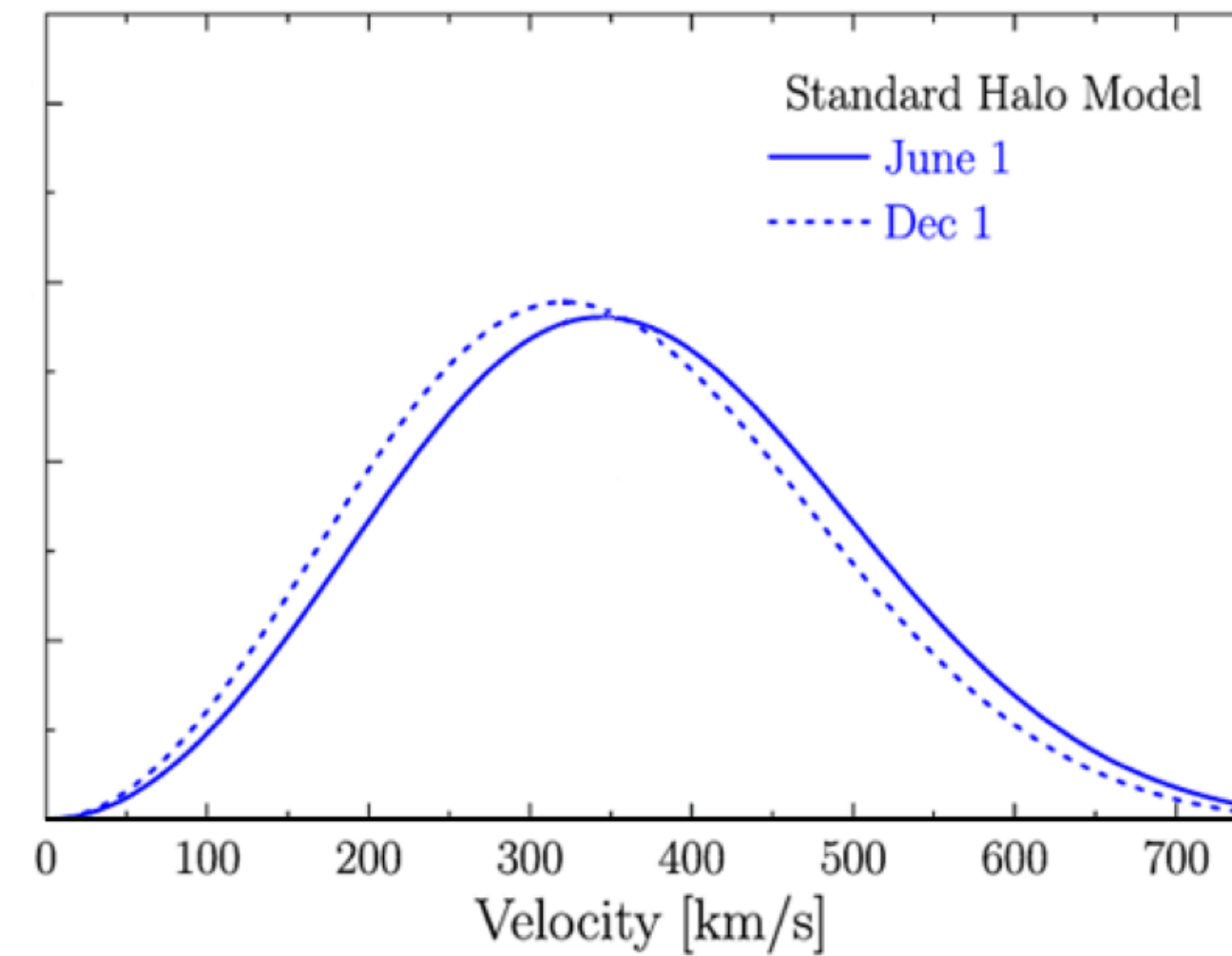
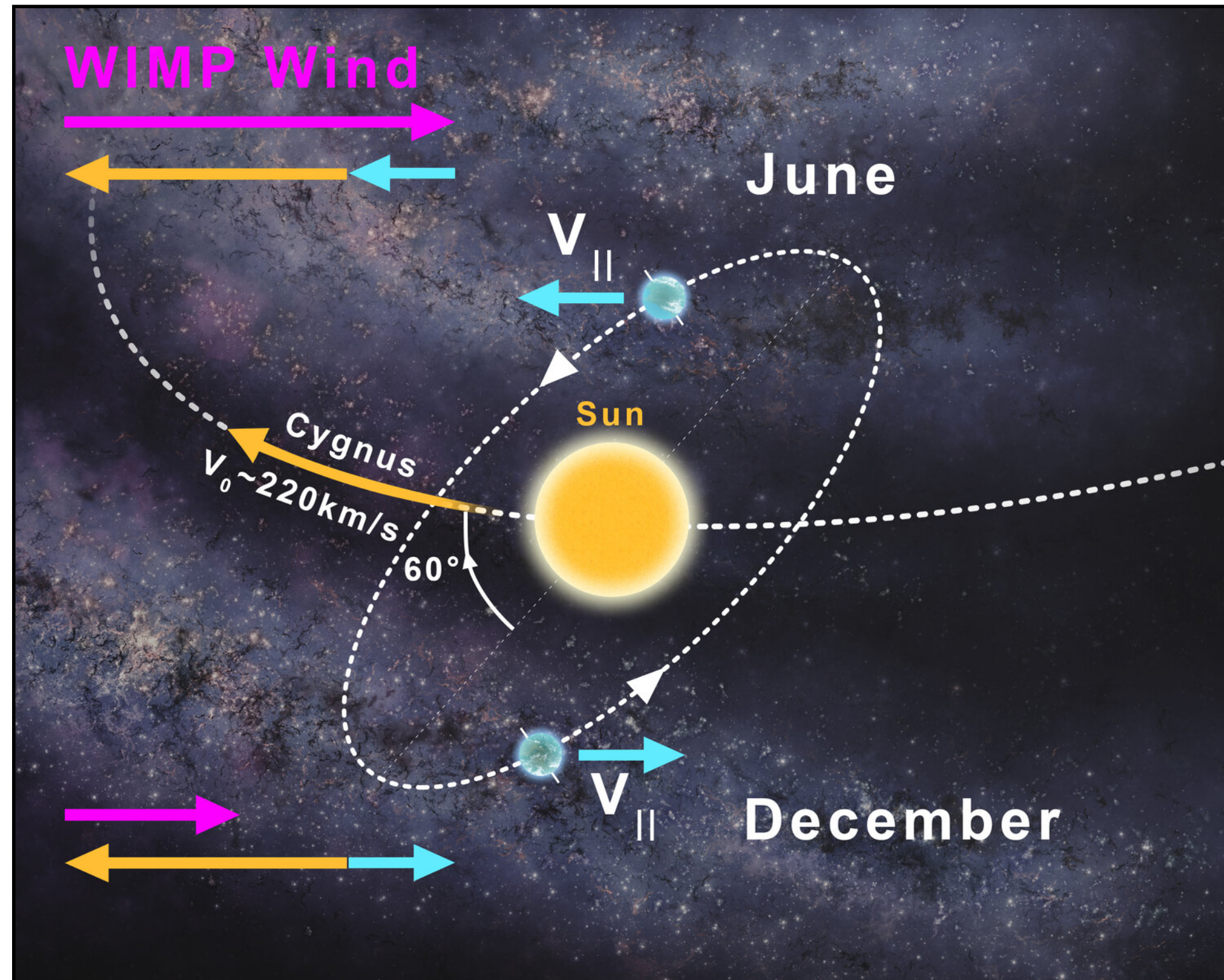
COSINE-200 & 1T sensitivity

Sensitivity for COSINE-200 & 1 T



- 200 kg and 1T experiment with improved light-yield can be possible.

WIMP Annual modulation

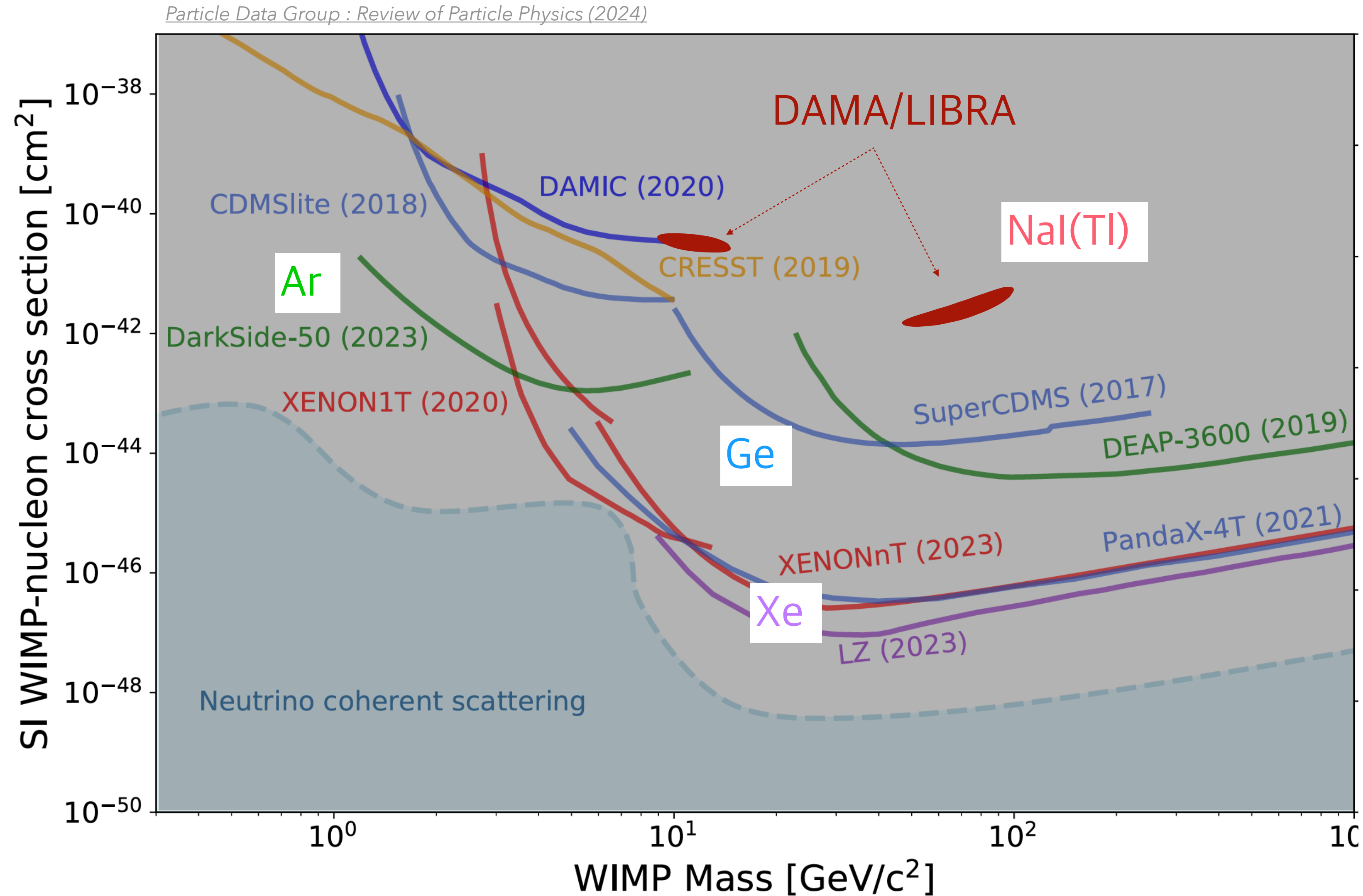


Rate of WIMP elastic scattering

$$R \propto N_T \cdot \sigma_{\chi^N} \cdot \frac{\rho_{\chi}}{m_{\chi}} \int_{v_{min}} \frac{f(v)}{v} dv$$

- In Standard Halo Model (SHM), WIMP wind velocity modulates in the Earth frame.
- Modulating velocity → **Modulating WIMP scattering rate**

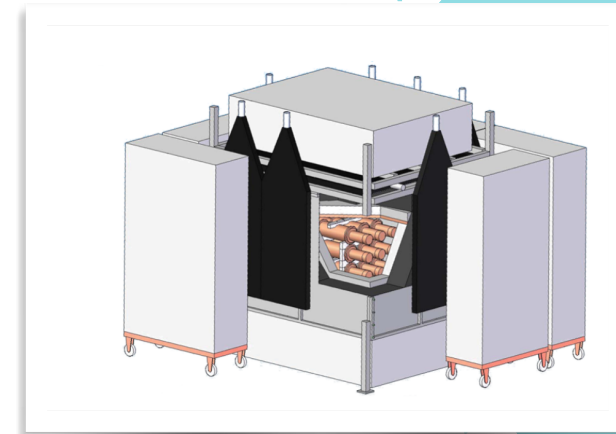
Contradictions from other experiments



Already excluded by
many experiments

Maybe,, NaI(Tl)
detector is something
special for DM
interaction?

NaI(Tl) DM searches in the world



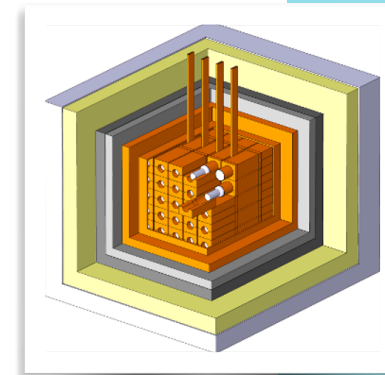
ANAIS (Canfranc)



COSINE (Y2L)



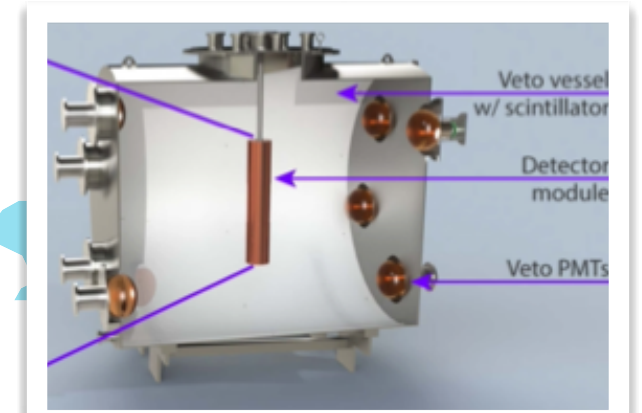
**PICO-LON
(Kamioka)**



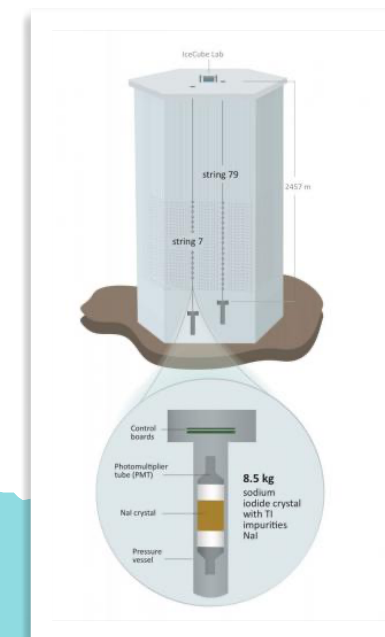
DAMA (LNGS)

SABRE (LNGS)

COSINUS (LNGS)



SABRE(Stawell)



DM Ice (South Pole)

Latests results with

DAMA/LIBRA

ANAIS-112

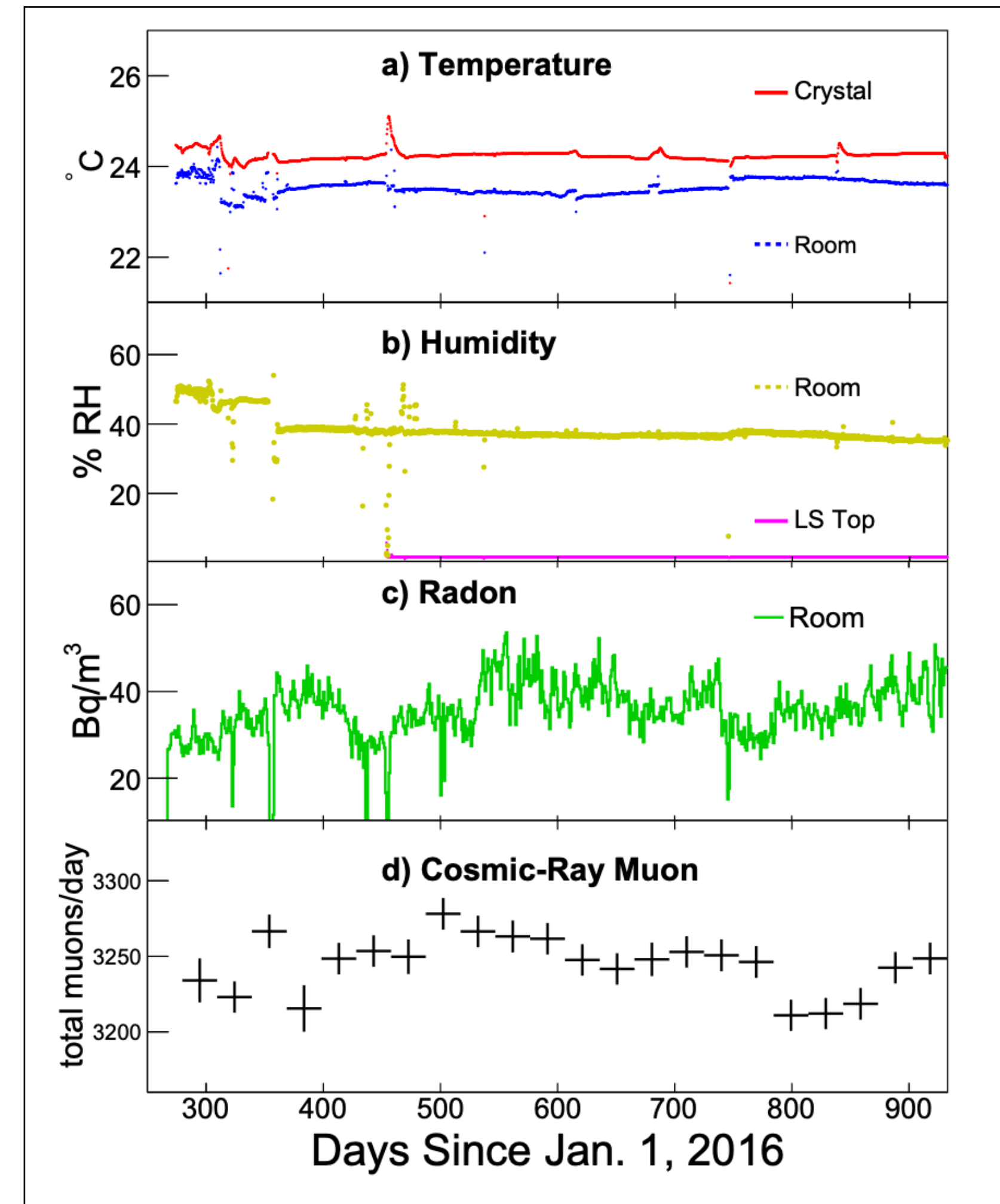
COSINE-100

COSINE-100 experiment

Data taking

Data Monitoring >200 parameters

- Real-time monitoring for stable data taking
- DAQ system: High voltage, PMT current ..
- Environment parameters : Temperature, Humidity ..



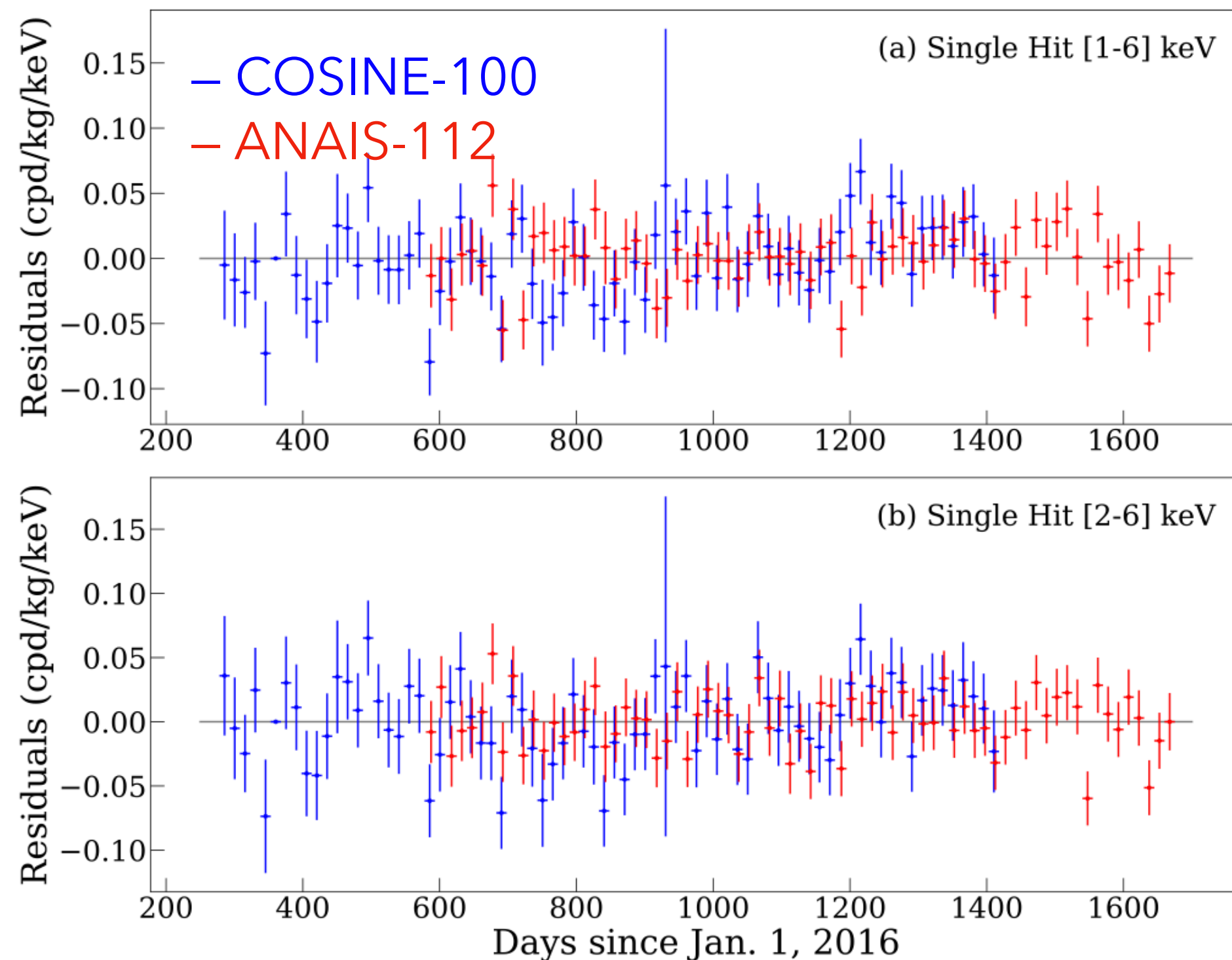
Phys. Rev. Lett. **123**, 031302 (2019)

COSINE-100 + ANAIS-112

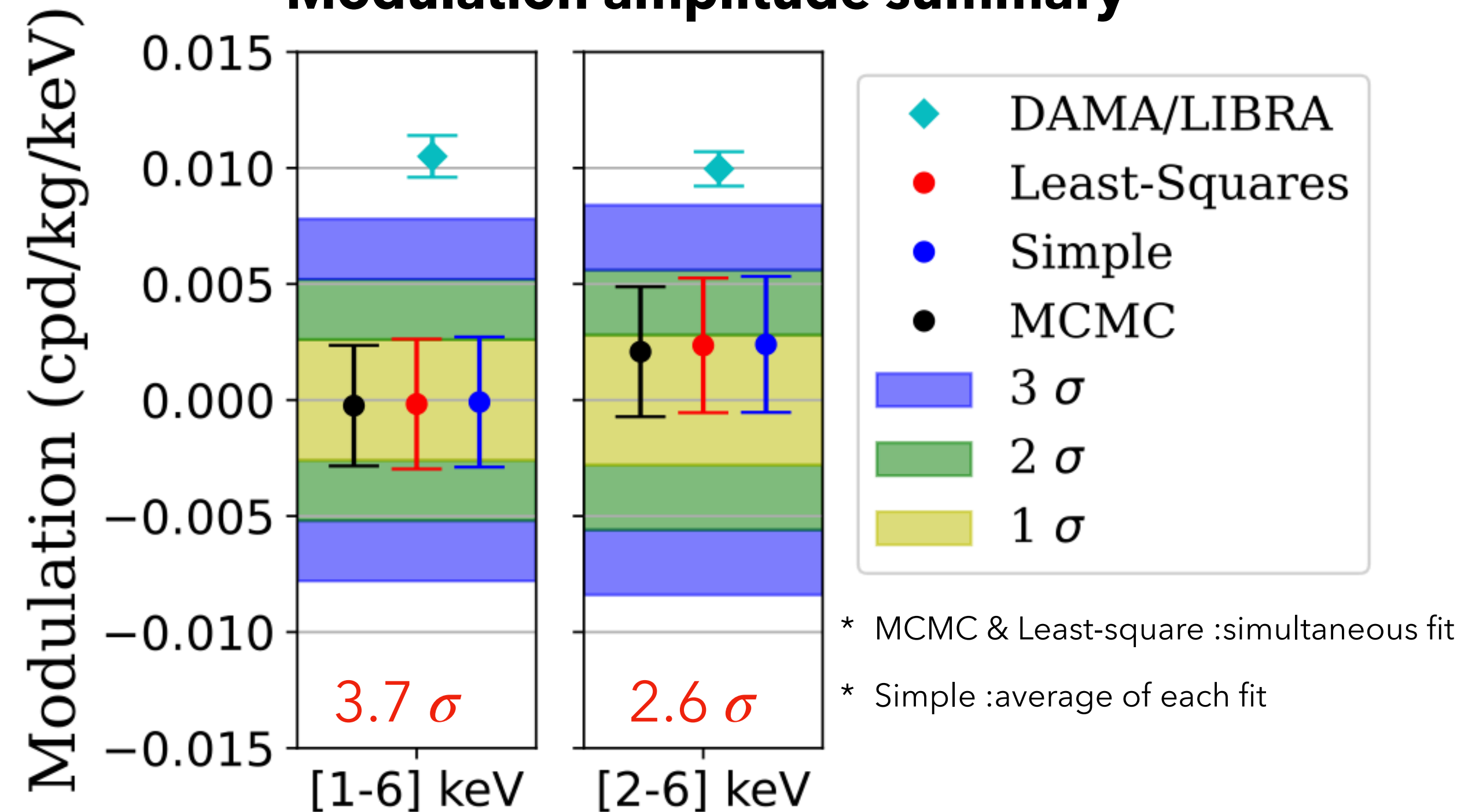
Simultaneous fit of each 3-year data

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

Background subtracted residuals



Modulation amplitude summary

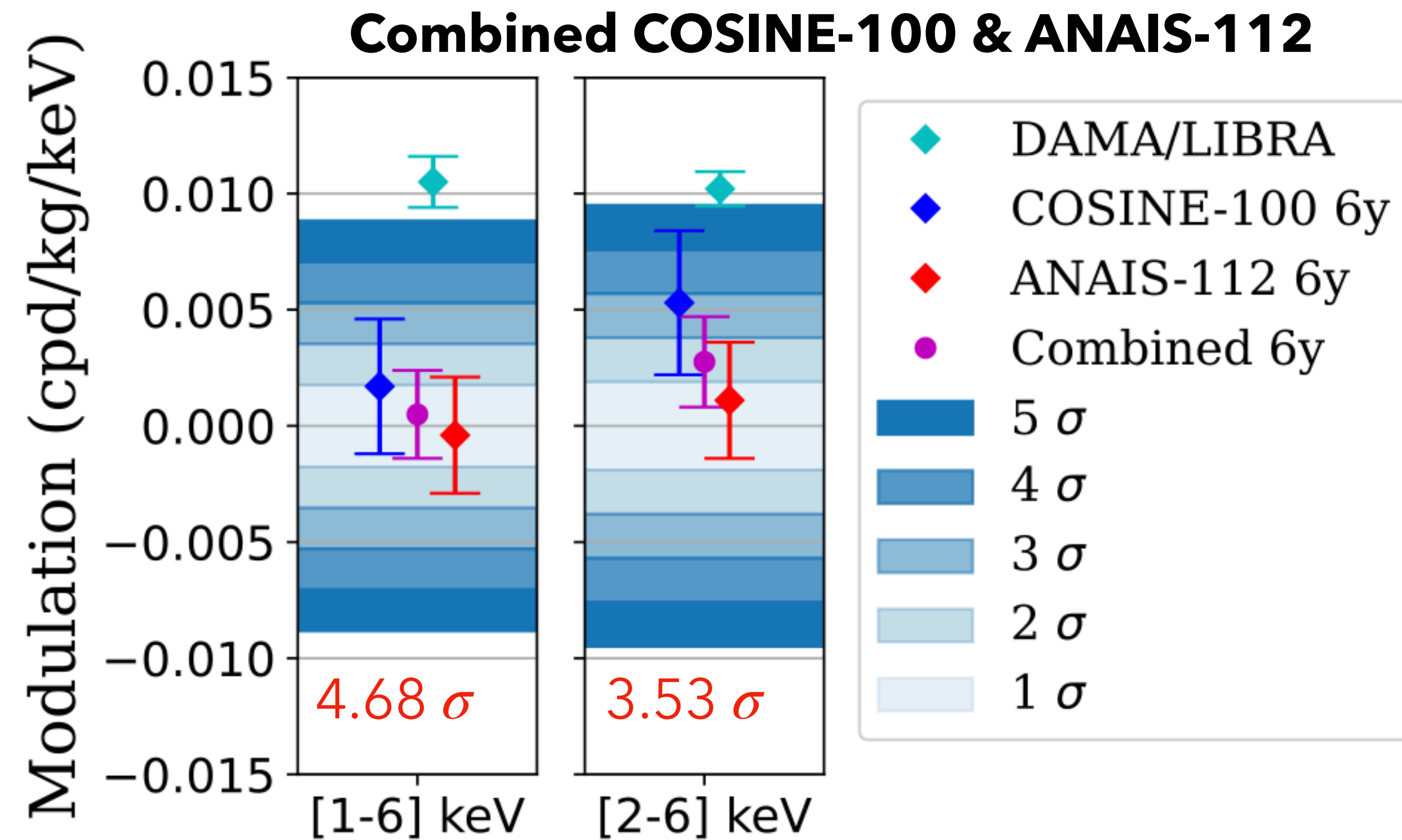


Used first 3-years of COSINE-100 & ANAIS-112 → **disfavors DAMA 3 σ**

COSINE-100 + ANAIS-112

Average of each 6-year modulation fit

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



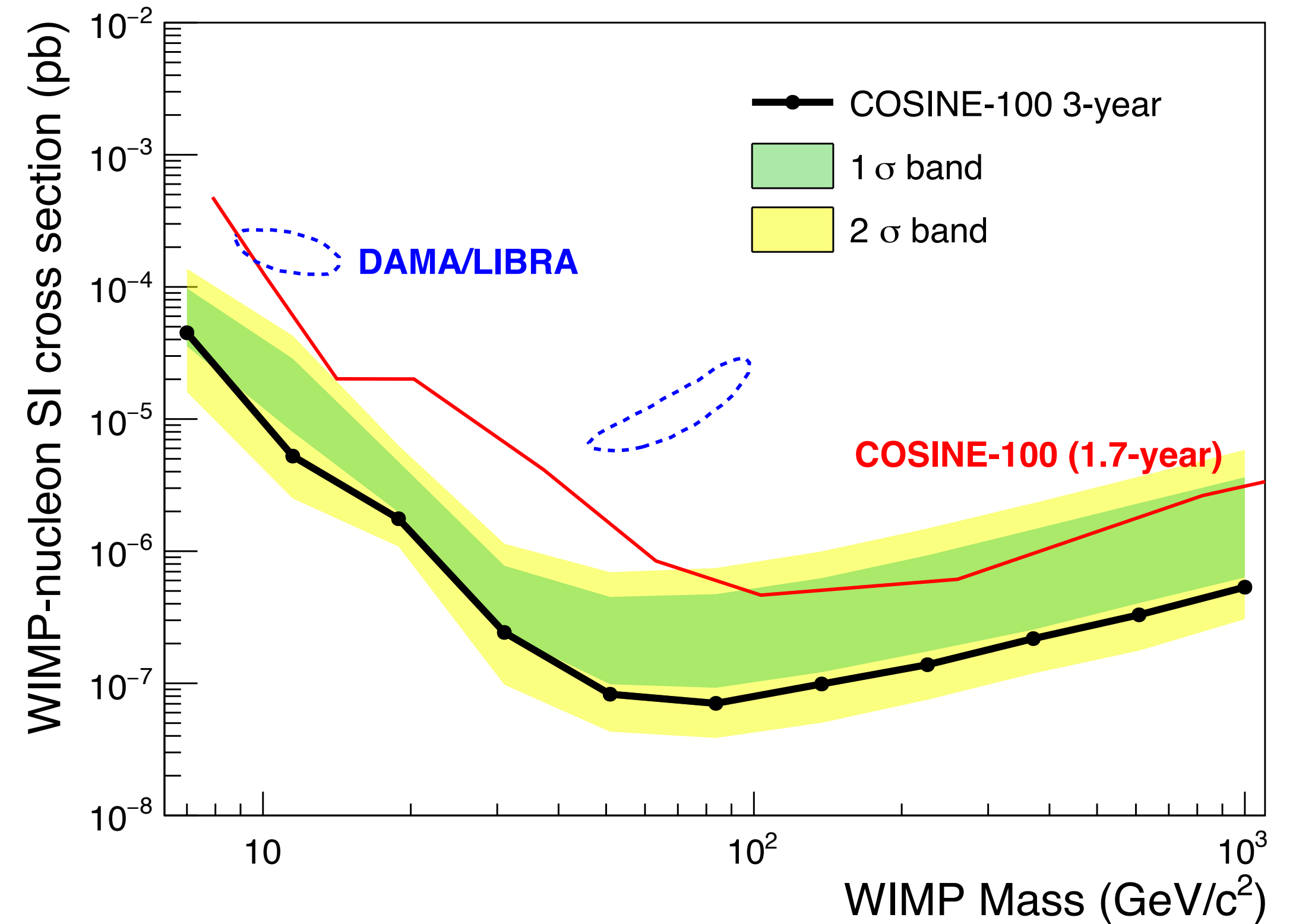
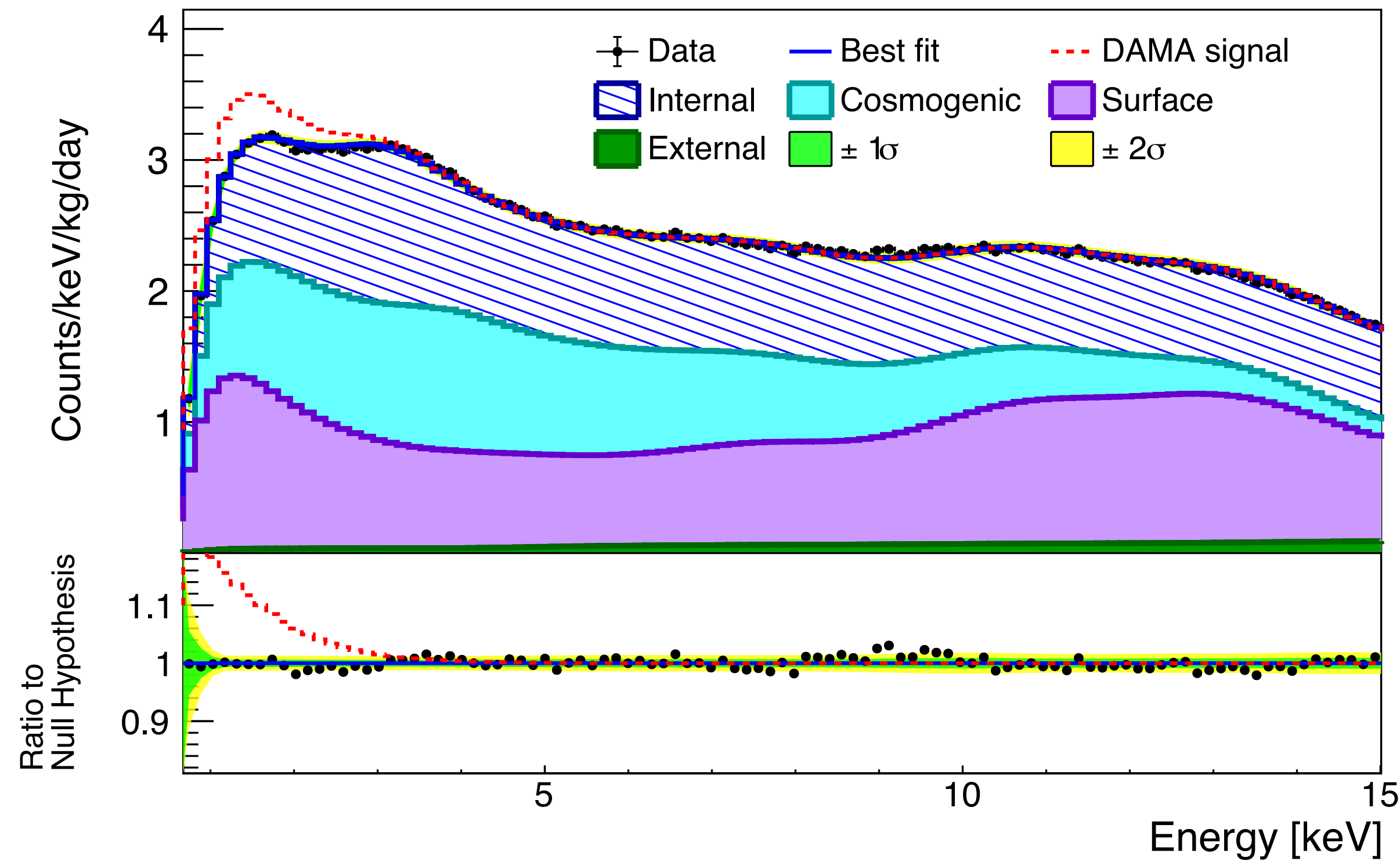
Average of each COSINE-100 & ANAIS-112 6-year result → **disfavors DAMA 4 σ**

Model-dependent analysis

Spectral analysis in 3-year data : SI model

arXiv:2501.13665

Accepted in PRL



Bayesian test of WIMP spectrum using MCMC fit.

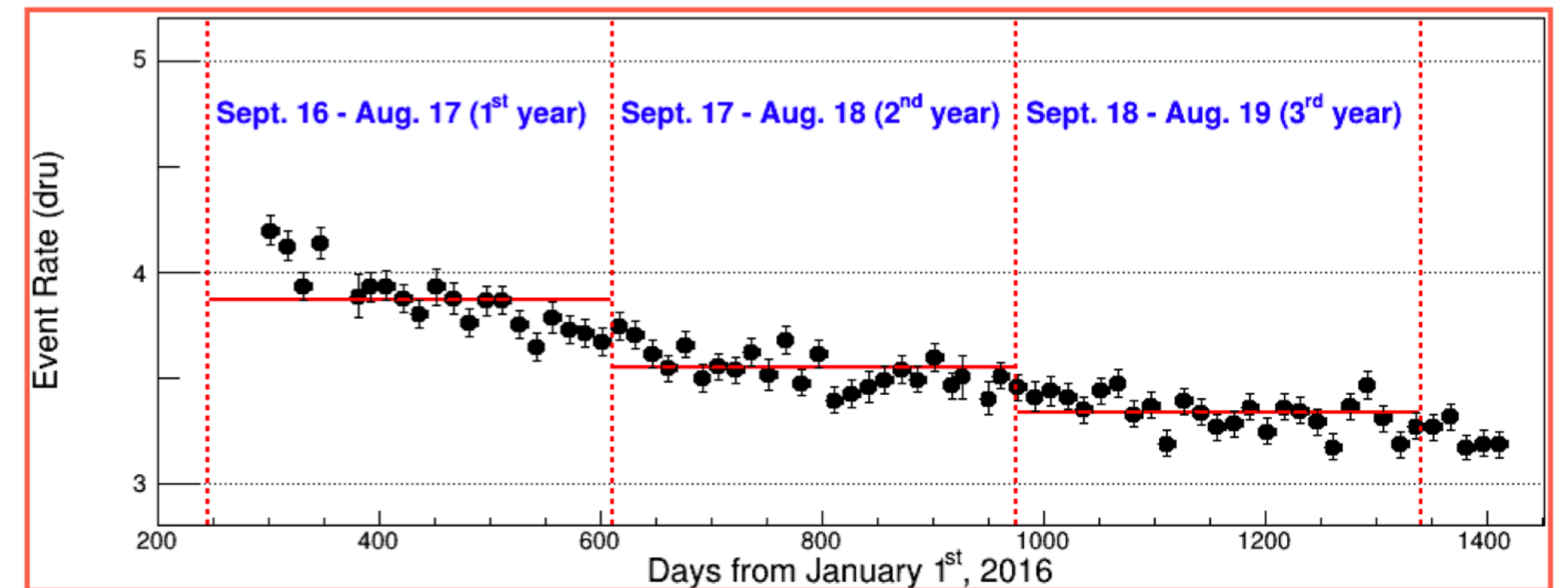
Full exclusion of DAMA/LIBRA 3σ region

Possible DAMA explanation

Bias from DAMA's method ?

DAMA/LIBRA's analysis method

- No LS Veto
- No Muon Veto
- DAMA parameter for event selection
- 600 ns waveform integration window.
- **Yearly averaged background rate model**



Possible bias from rate model

suggested at JHEP 20, 137 (2020)

Possible DAMA explanation

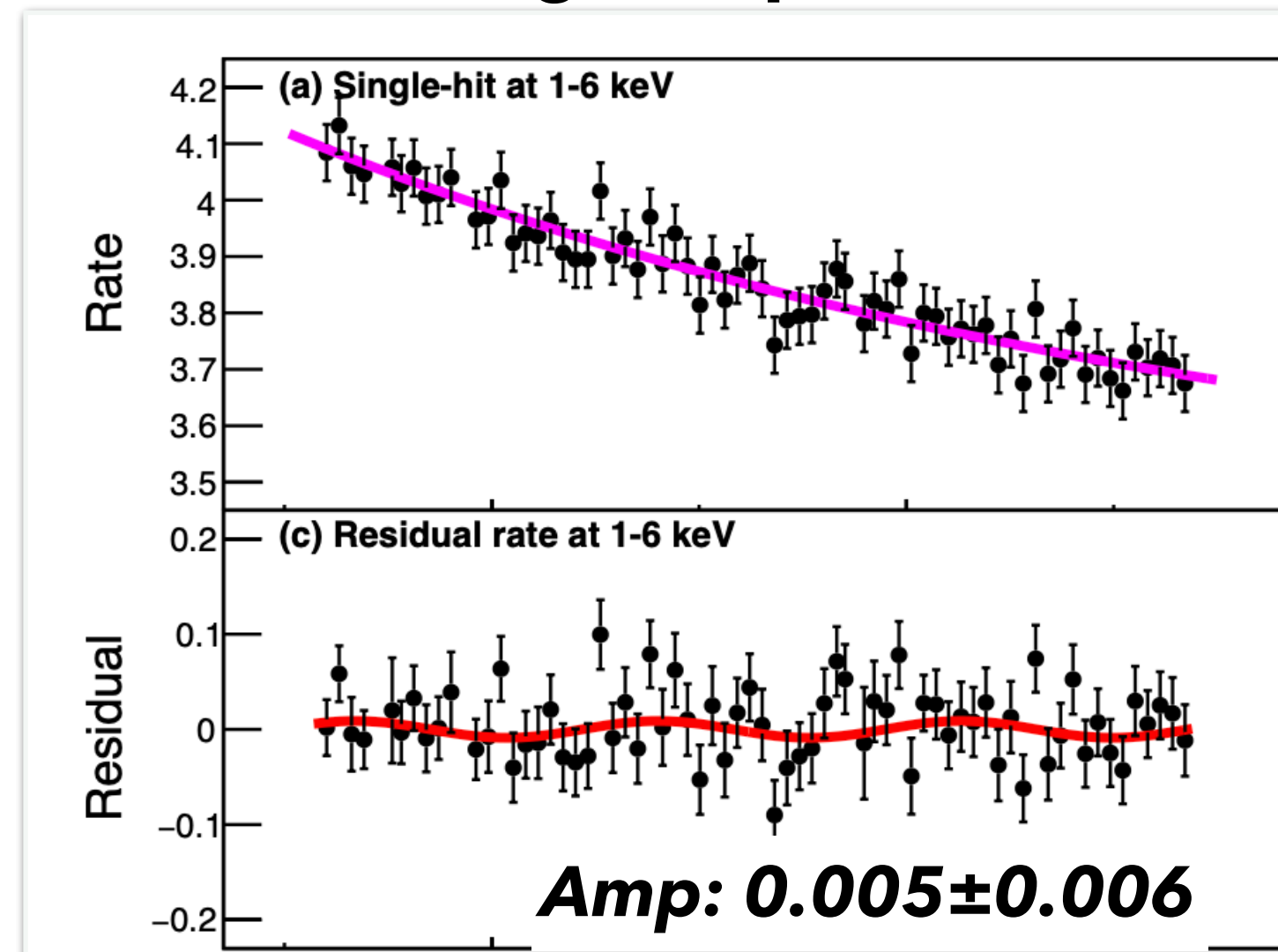
Bias from DAMA's method ?

Scientific Reports **13**, 4676 (2023)

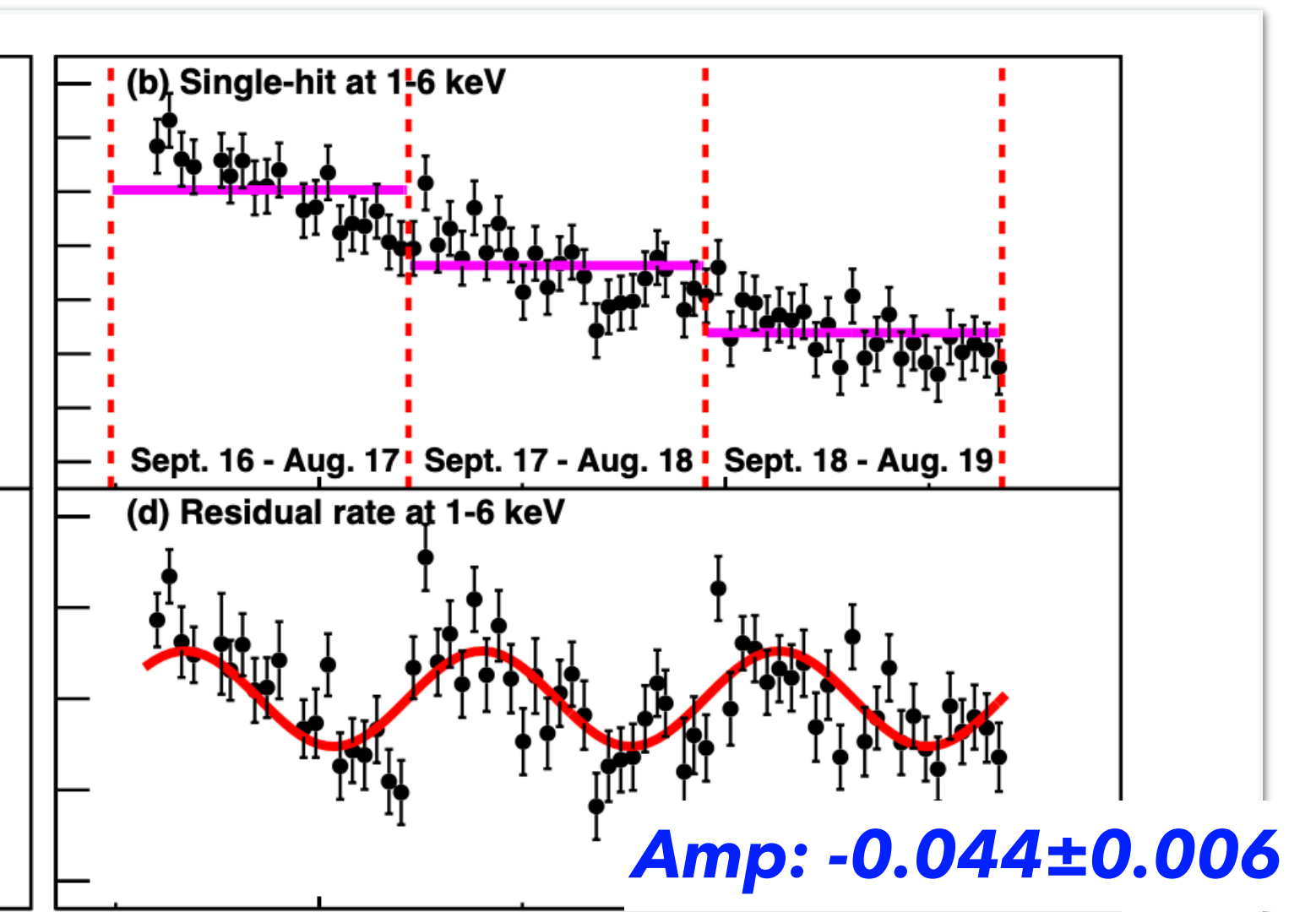
DAMA/LIBRA's analysis method

- No LS Veto
- No Muon Veto
- DAMA parameter for event selection
- 600 ns waveform integration window.
- **Yearly averaged background rate model**

Single exponential



Yearly Averaged (DAMA model)



COSINE-100 data applying *DAMA method* gives *clear modulation*
($\sim 7\sigma$, opposite phase)

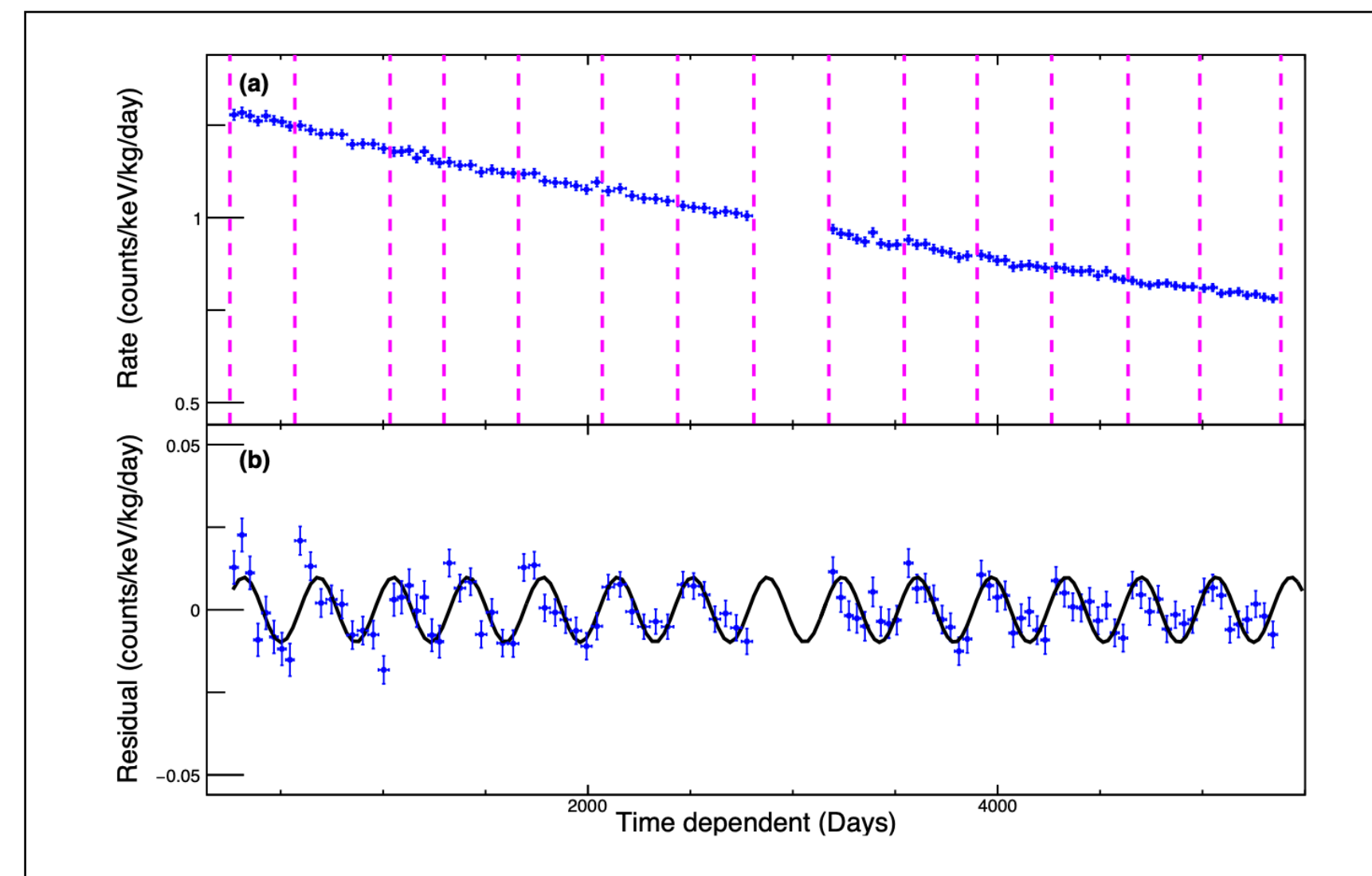
Possible DAMA explanation

Bias from DAMA's method ?

Scientific Reports **13**, 4676 (2023)

DAMA/LIBRA's analysis method

- No LS Veto
- No Muon Veto
- DAMA parameter for event selection
- 600 ns waveform integration window.
- **Yearly averaged background rate model**



Pseudo data	-0.0098 ± 0.0008
DAMA/LIBRA	0.0105 ± 0.0011

Pseudo data analysis based on **DAMA's background rate** & **COSINE-100 background composition** shows similar modulation amplitude (opposite phase)

Search for low-mass WIMP

Spectral analysis in 3-year data : SD model

arXiv:2501.13665

Accepted in PRL

Na ($Z = 11$) & I ($Z = 53$)

- Proton-odd targets

→ sensitive in SD model

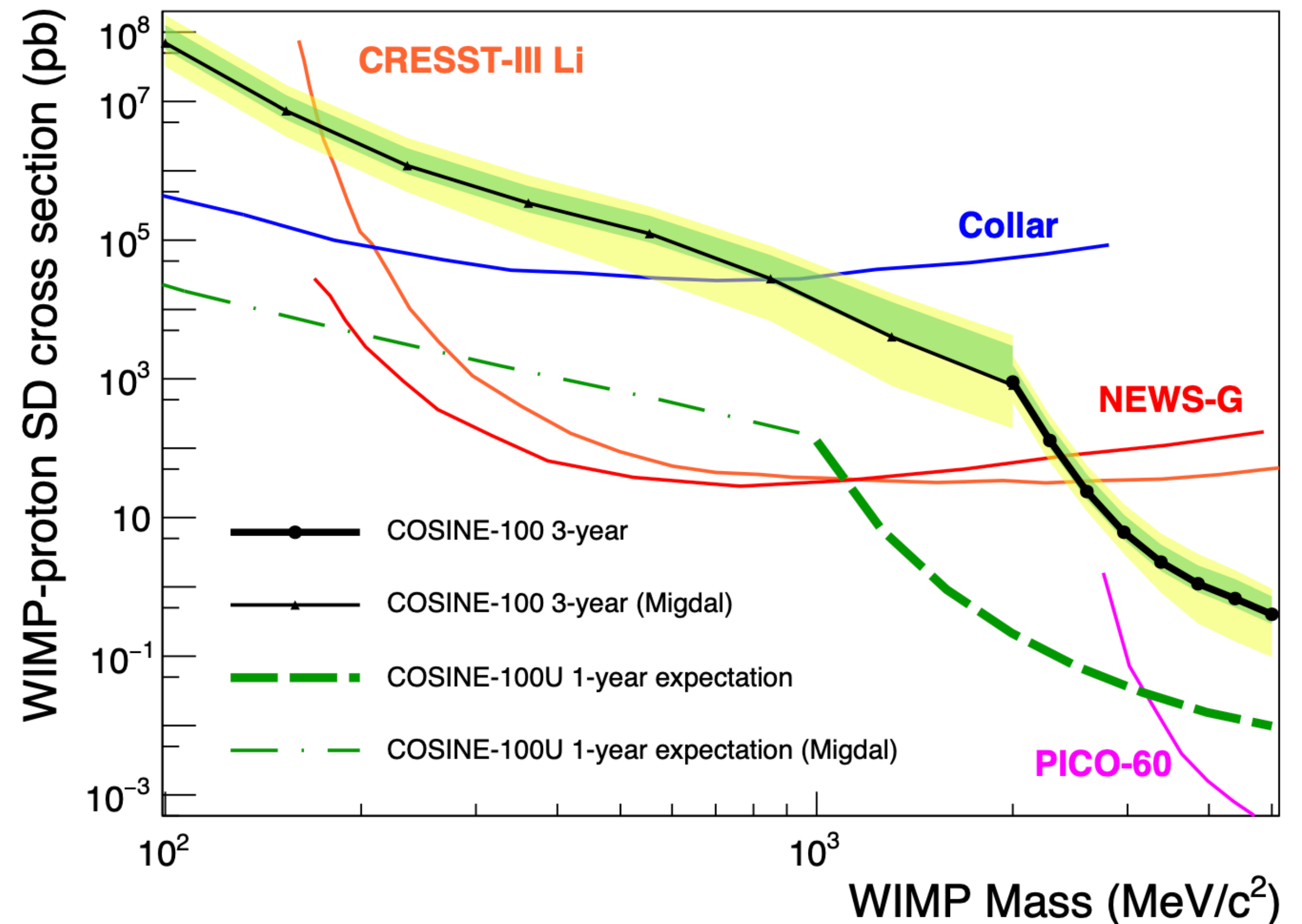
- Low-mass target (Na)

→ sensitive in low-mass WIMP

(Secondary radiation of recoil)

Searching for **Migdal effect of WIMP**

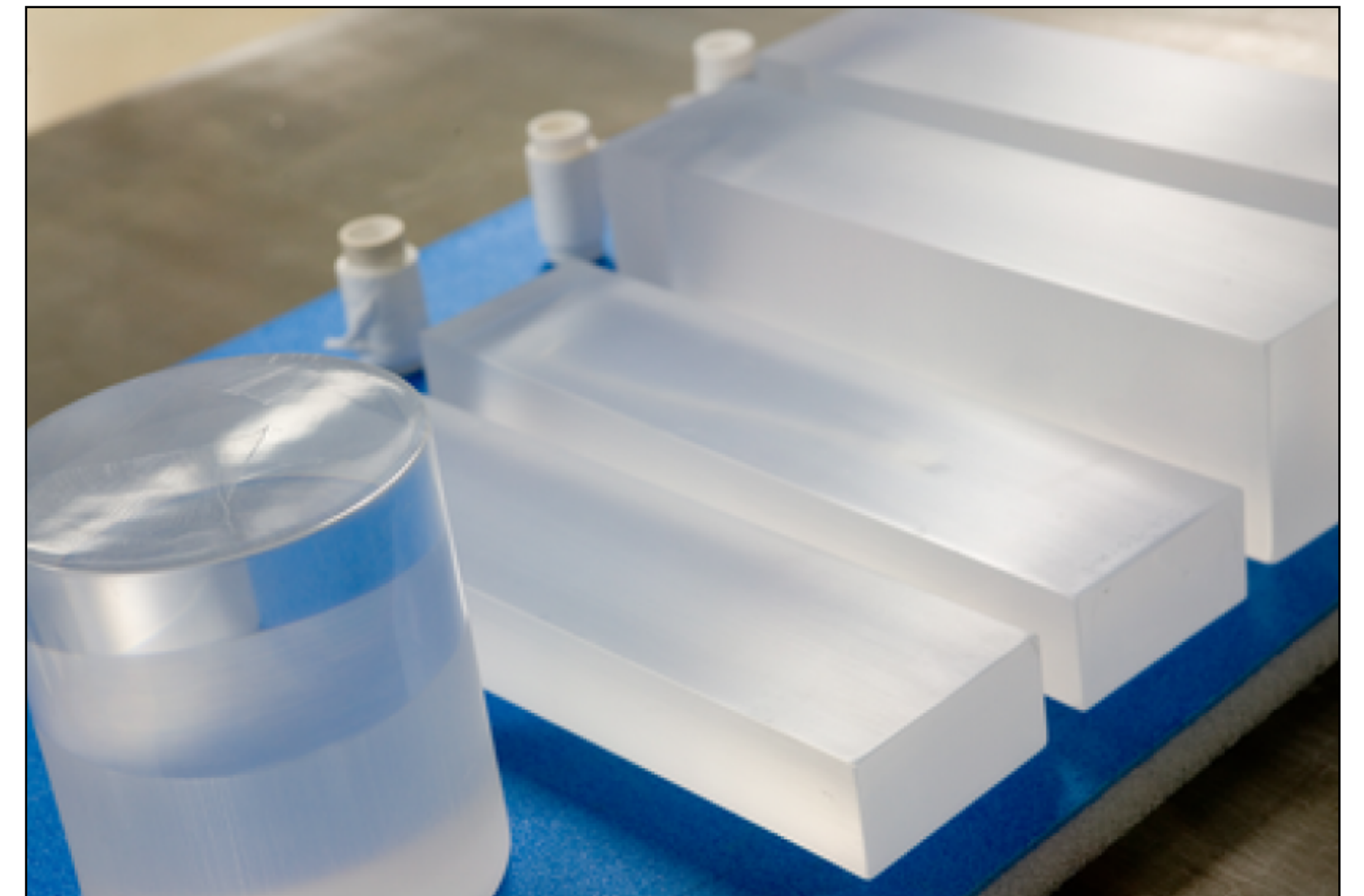
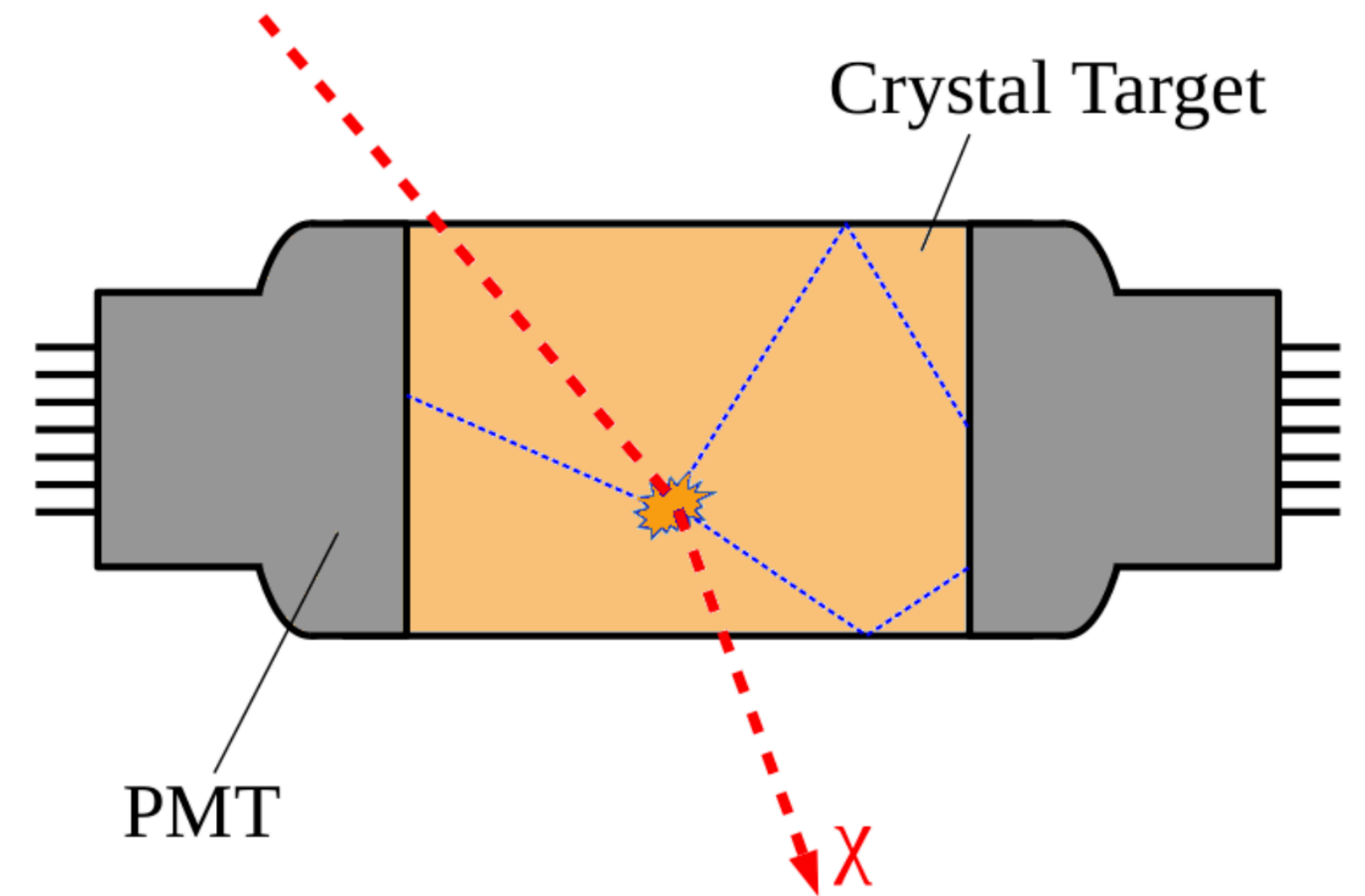
→ Down to sub-GeV WIMP



Competitive results in low-mass WIMP search

WIMP Search with NaI(Tl)

- High luminescence efficiency ($\sim 10^4$ p.e. / MeV)
- Easy to grow & Cheap
- Can be produced in large size
→ Increase statistics



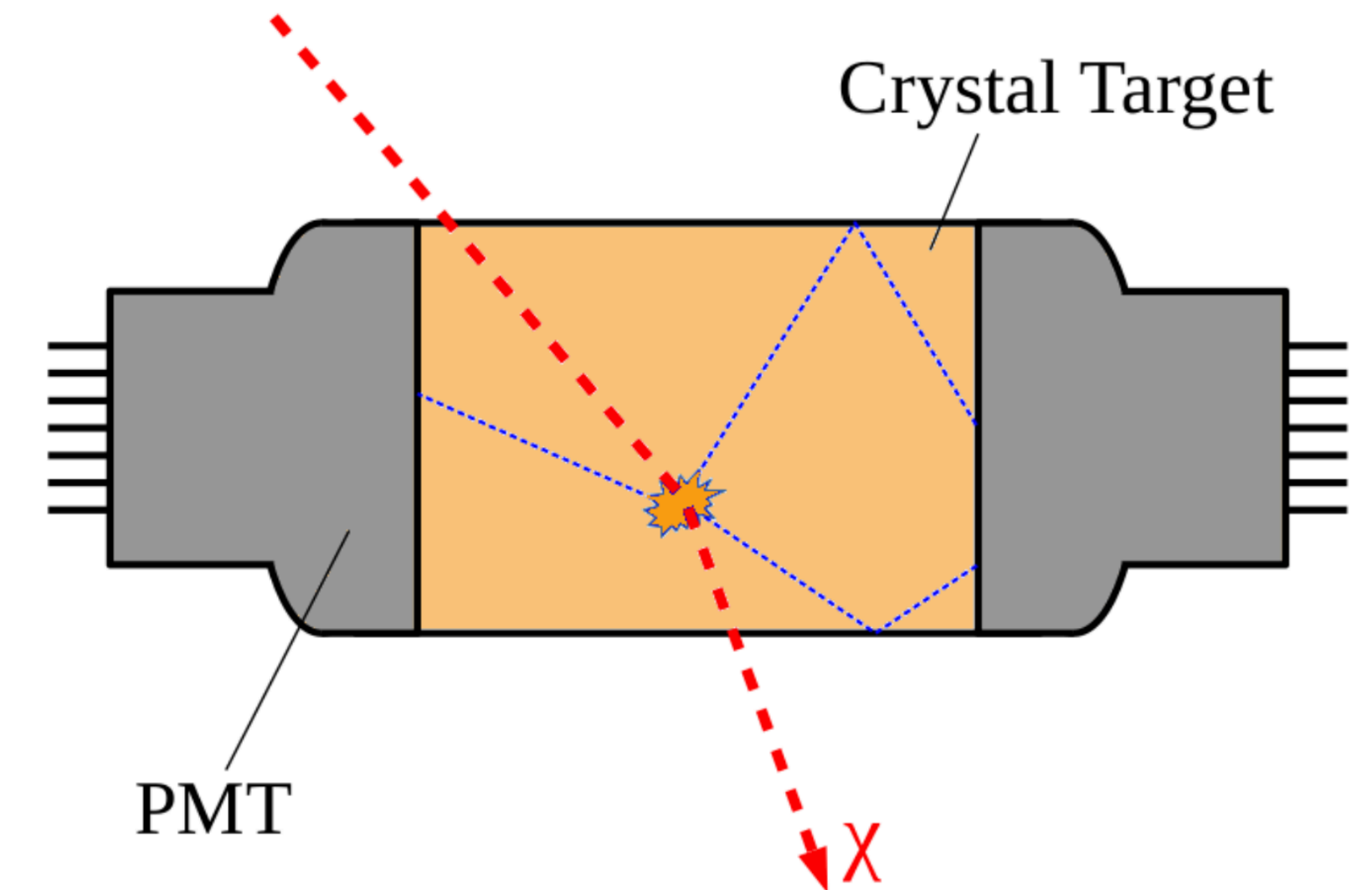
WIMP Search with NaI(Tl)

- High luminescence efficiency (~ 104 p.e. / MeV)
- Easy to grow & Cheap
- Can be produced in large size
→ Increase statistics
- **Advantages at WIMP detection**
 - Can search both SI / SD interaction channel.
 - High sensitivity to SD interaction : 100% proton-odd nuclei

$$\sigma^{SD} = \left(\frac{32}{\pi}\right) G_F^2 \mu^2 \left(\frac{J+1}{J}\right) [\langle S_p \rangle a_p + \langle S_n \rangle a_n]^2,$$

$\langle S_p \rangle$: average proton spin contribution

a_p : WIMP-proton coupling



	$\langle S_p \rangle$	$\langle S_n \rangle$
^{127}I		
Experiment		
Bonn A	0.309	0.075
Nijmegen II	0.354	0.064
	$\langle S_p \rangle$	$\langle S_n \rangle$
^{23}Na		
Experiment		
Calculation	0.2477	0.0198
OGM	0.1566	0.0

Canonical WIMP scattering concept

Differential rate of WIMP scattering

$$\frac{dR}{dE_{nr}} = \frac{1}{2m_\chi \mu^2} \sigma(q) \rho_\chi \int_{v_{min}} d^3v \frac{f(\mathbf{v}, t)}{v};$$

WIMP-nucleus

Scattering

Cross-section

WIMP Velocity requirement term

ρ_χ : local DM density = 0.3 GeV/cm³

$f(v, t)$: time-dependent velocity distribution (SHM)

E_{nr} : Nuclear recoil energy

μ : Reduced mass

WIMP scattering total cross section : dependency on target material

$$\sigma(q) \equiv \sigma_0 F^2(q) = \sigma_{SI} F_{SI}^2(q) + \sigma_{SD} F_{SD}^2(q); \quad F(q) : \text{nucleus form factor}$$

Spin-independent

$$\sigma^{SI} = \frac{4}{\pi} \mu^2 [Z f_p + (A - Z) f_n]^2$$

f_p or f_n : proton or neutron coupling constant

a_p : axial four-fermion WIMP-nucleon couplings

Spin-dependent

$$\sigma^{SD} = \left(\frac{32}{\pi}\right) G_F^2 \mu^2 \left(\frac{J+1}{J}\right) [\langle S_p \rangle a_p + \langle S_n \rangle a_n]^2;$$

$\langle S_p \rangle$: average proton spin contribution