

Opening the Yemilab Era : New Horizons in Dark Sector and Neutrino Physics in Korea

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Institute for Basic Science (IBS)

On Behalf of the COSINE, NEON, and AMoRE collaborations

Korea Society of High Energy Physics 2026 Spring Meeting

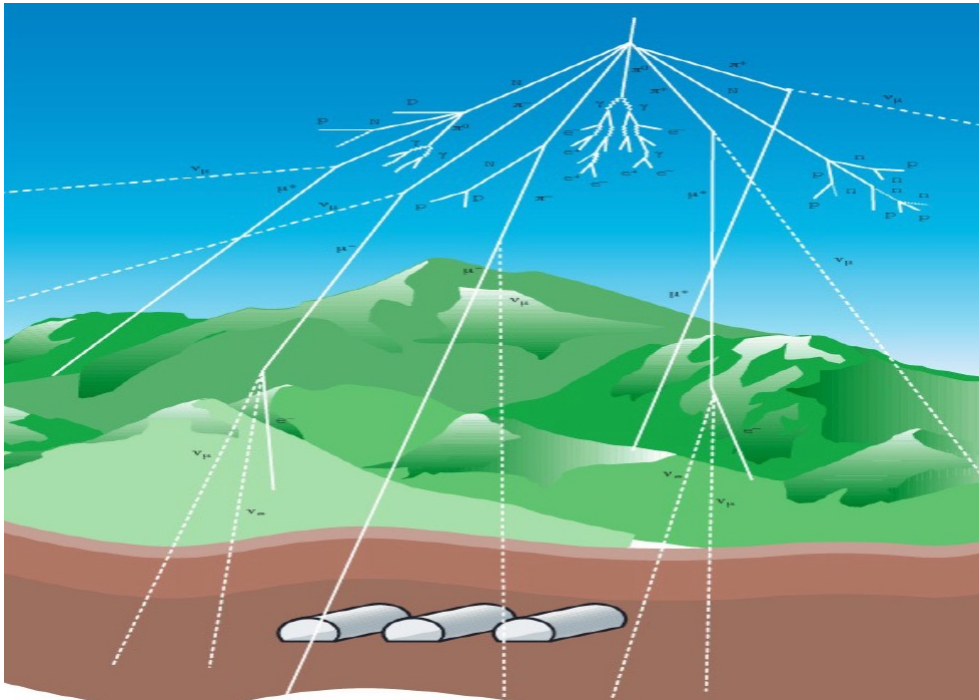
June 11, Jeju University

Rare event searches deep underground

A **rare event** is a physical process that occurs with extremely **low probability** only a **handful of interactions per ton of target material per year**.

- **Two major open questions in modern physics**

- ❖ **Neutrinos** — are they their own antiparticle? **Neutrinoless double beta decay?**
- ❖ **Dark Matter** — what is it made of? **Particle dark matter (WIMP)?**



Due to large cosmic muon background at sea level, a **deep underground laboratory** is naturally required for the rare event searches

Outline

From the Y2L legacy to the Yemilab era

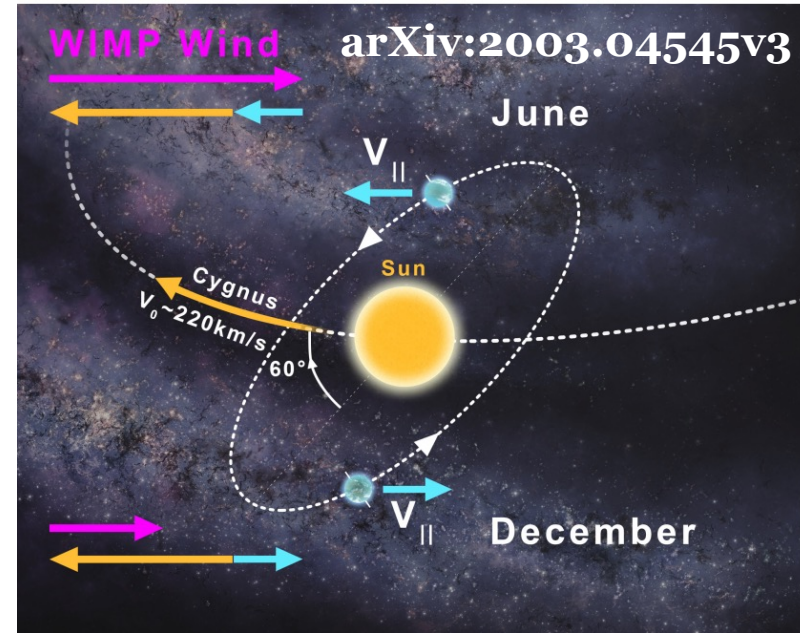
- **Part 1 — The Y2L legacy**
 - ❖ COSINE-100: testing **DAMA/LIBRA** with NaI(Tl)
 - ❖ NEON: expanding frontiers to **reactor-based search** with NaI(Tl)
 - ❖ AMoRE-I: $0\nu\beta\beta$ search of **^{100}Mo** with MMC technology
- **Part 2 — Opening the Yemilab Era**
 - ❖ COSINE-100U: low-mass dark matter search at the new lab
 - ❖ COSINE-200: **world-unique low-background NaI(Tl)**
 - ❖ AMoRE-II: reaching the **inverted mass ordering**

Part 1-1 · The Y2L legacy

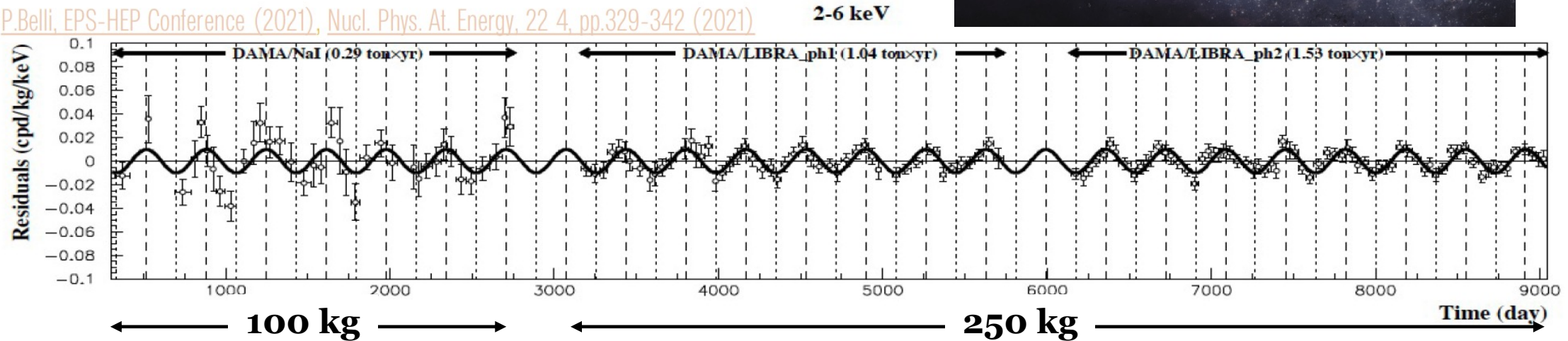
DARK MATTER: COSINE

DAMA/NaI and DAMA/LIBRA puzzle

Observation of **annual modulation since 1998** using NaI(Tl) crystals



P.Belli, EPS-HEP Conference (2021), Nucl. Phys. At. Energy, 22 4, pp.329-342 (2021)



Yangyang underground laboratory (Y2L)

YangYang(Y2L) Underground Laboratory

(Upper Dam) YangYang Pumped Storage Power Plant


Since 2003

1000m

700m

(Power Plant)

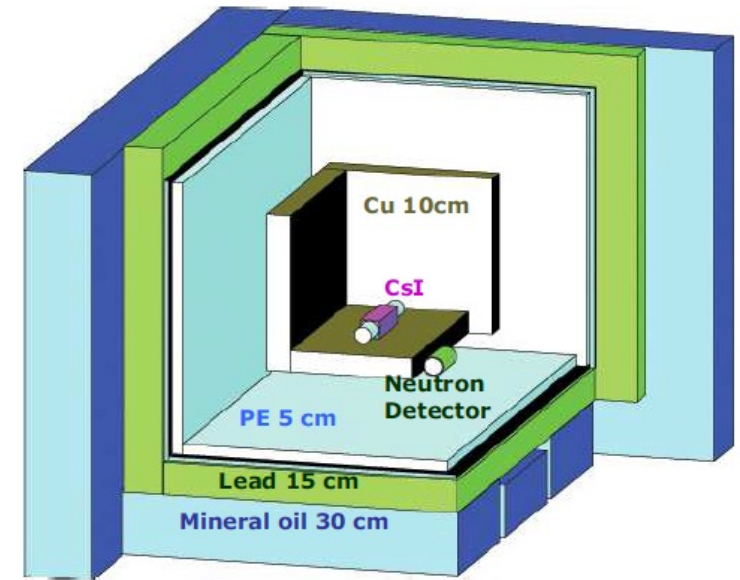
Since 2014



Since 2003

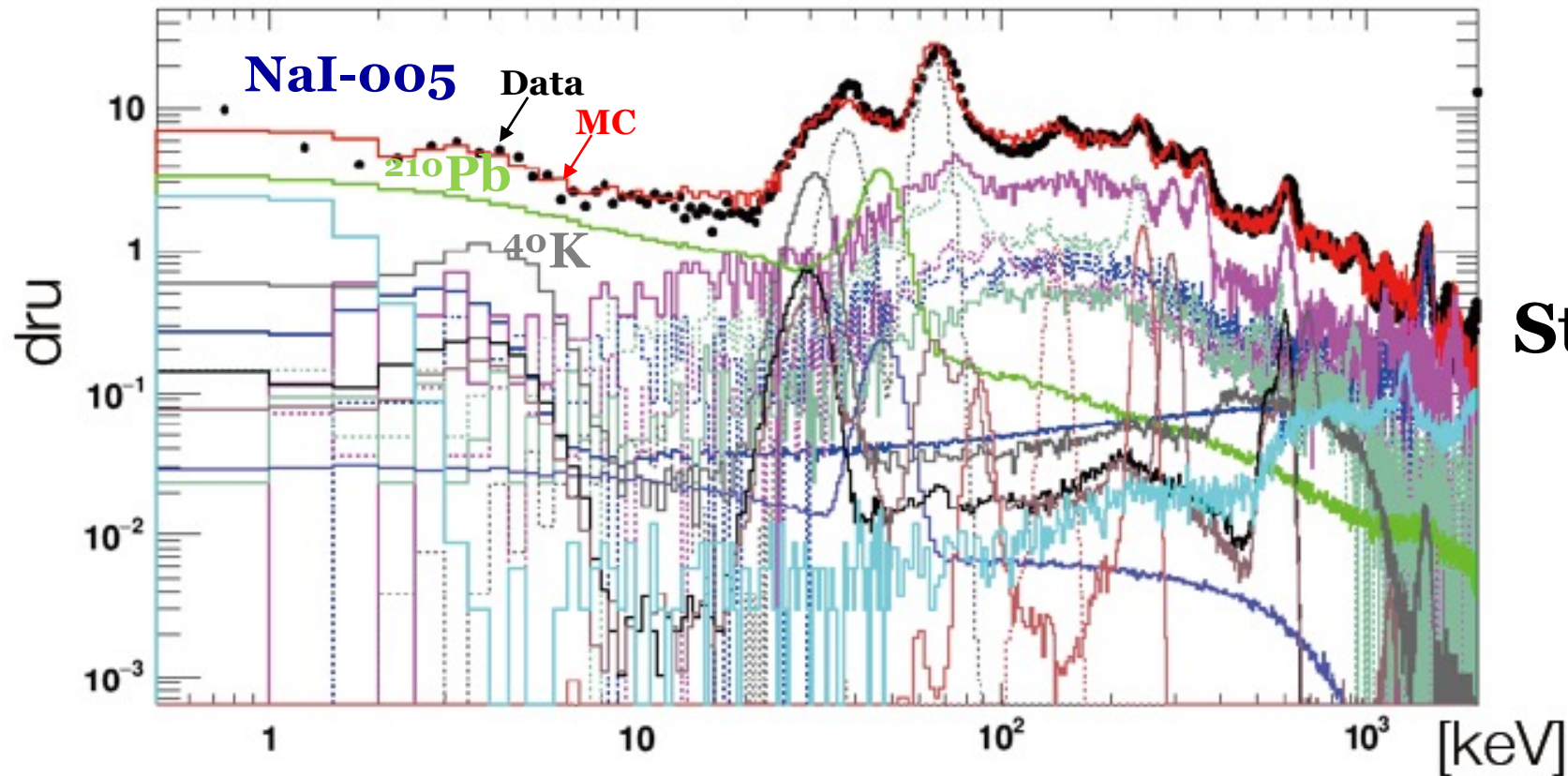
KIMS/COSINE (Dark Matter Search)
AMoRE (Double Beta Decay Experiment)

Minimum depth : 700 m / Access to the lab by car (~2km)



Low-background NaI(Tl) crystal development

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



Starting from **2013**

EPJC 77 (2017) 437

- Internal ^{40}K and ^{210}Pb are main backgrounds
- Goal : $\text{K} < 20 \text{ ppb}$, $^{210}\text{Pb} < 0.5 \text{ mBq/kg}$

COSINE collaboration (Since 2015)

<https://cosine.ibs.re.kr>



Youngju Ko

Spokespersons: Reina Maruyama , Hyun Su Lee

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

15 institutes
~60 members

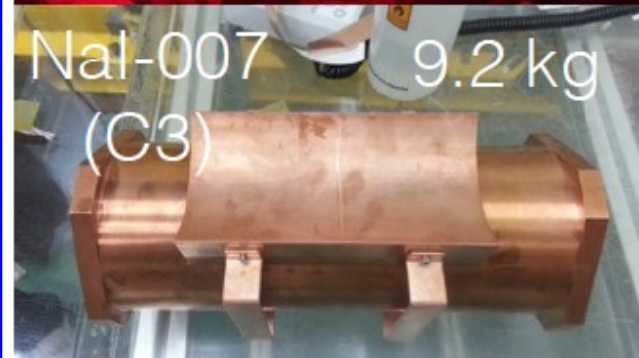
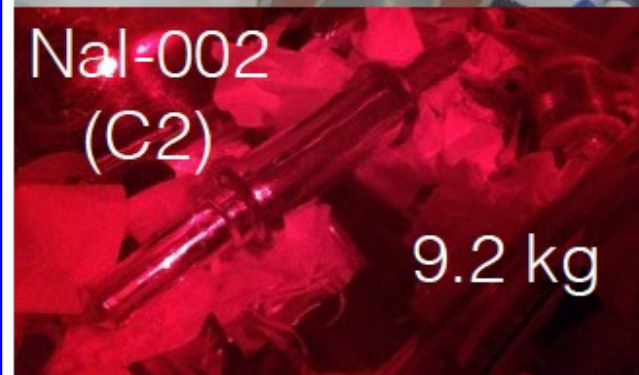


+ DM-ICE =

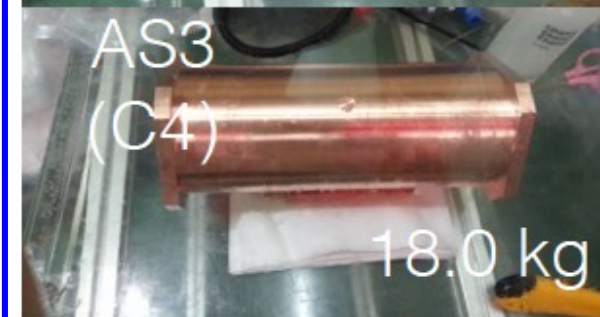
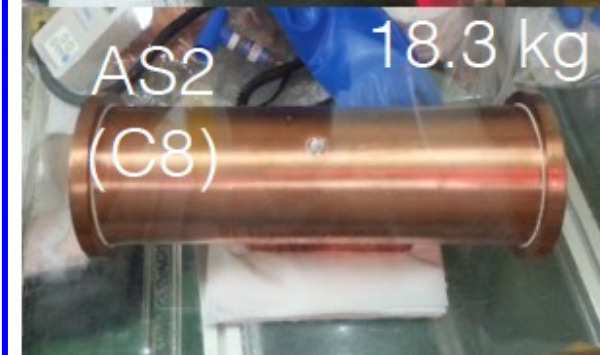


COSINE-100 detectors

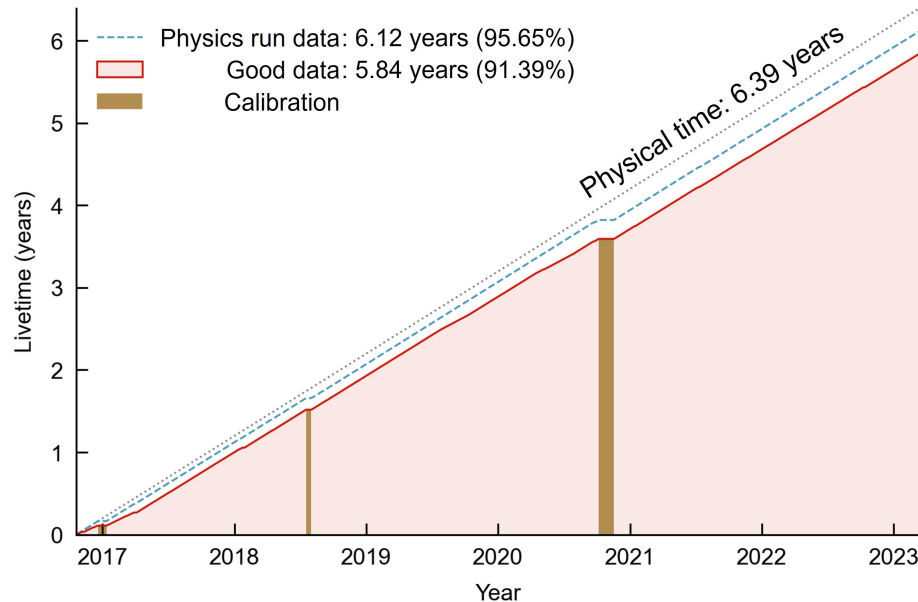
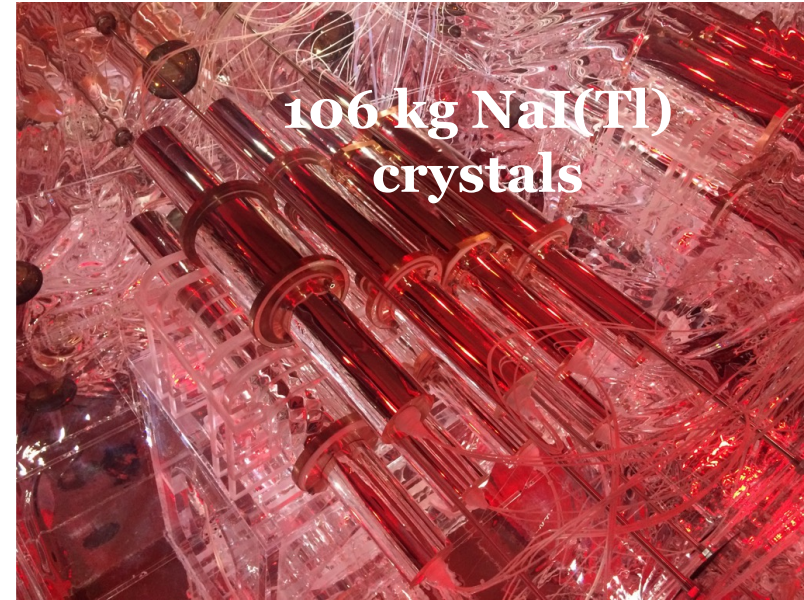
- **~106 kg crystals** running since Sept/2016 **From DM-ICE**



From KIMS



COSINE-100 experiment (2016-2023)

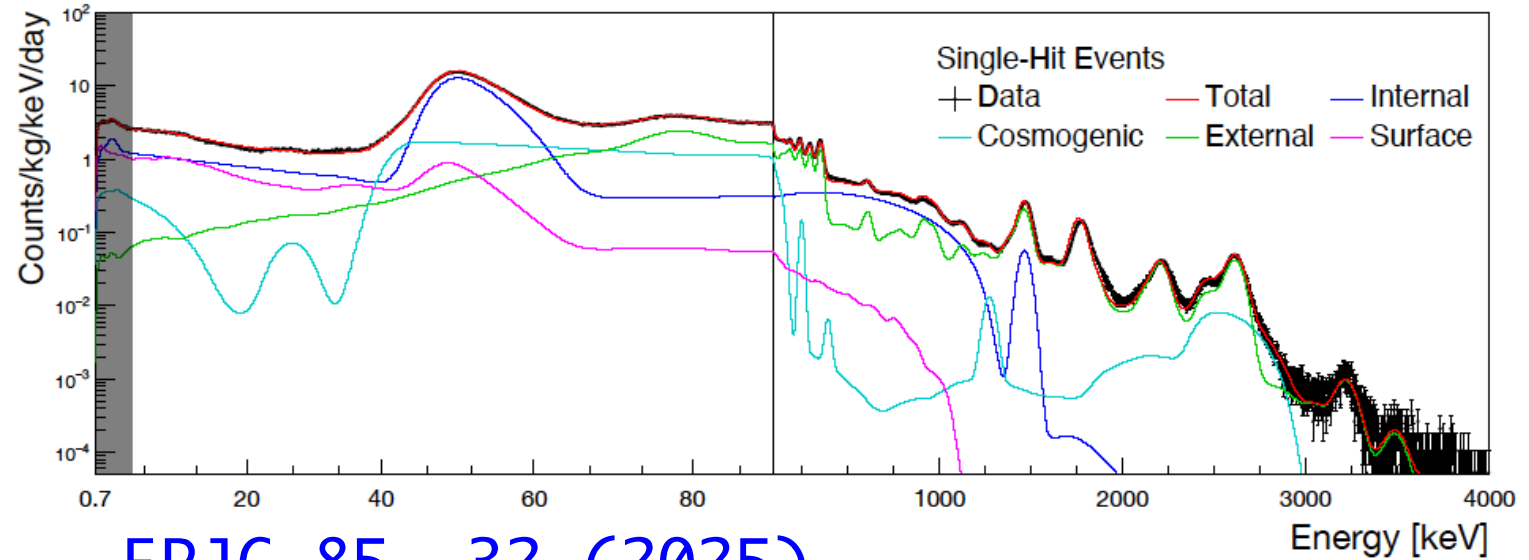


- Yangyang underground laboratory
 - ❖ **October/2016 ~ March/2023**
- Decommissioning
 - ❖ Moved to **Yemilab**
 - ❖ Upgrade of detector for **high light yield**

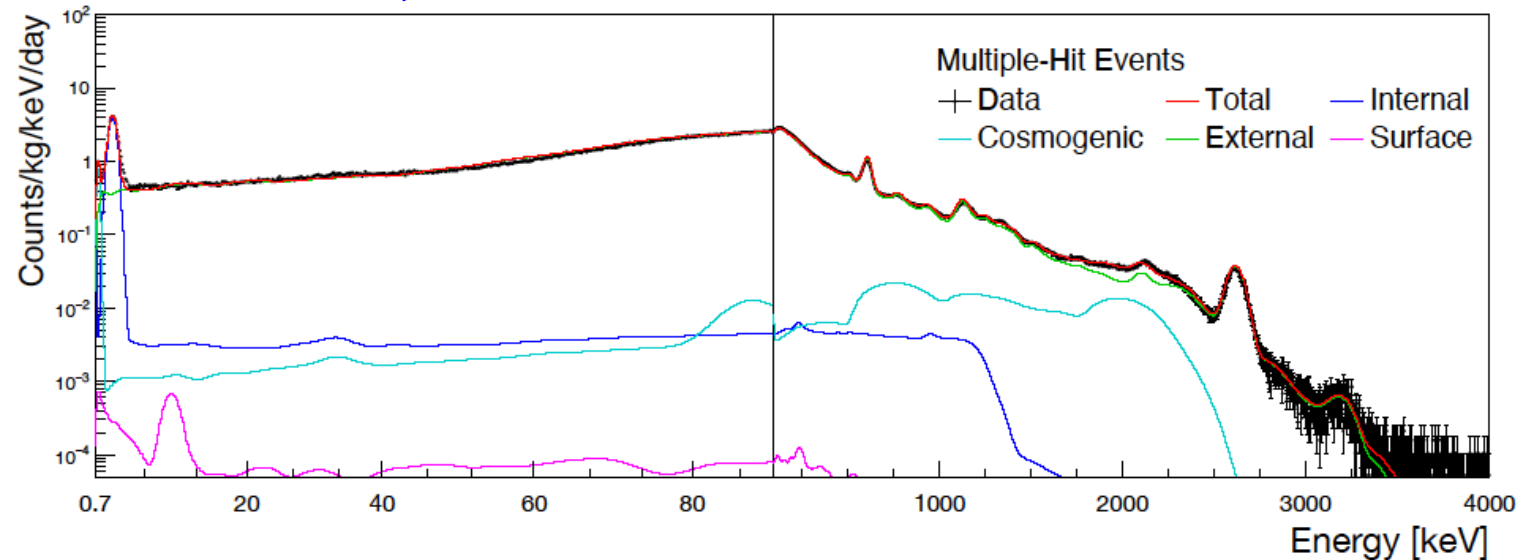
COSINE-100 detectors

3 years data

**Single-hit Events
(6 – 4000 keV)**

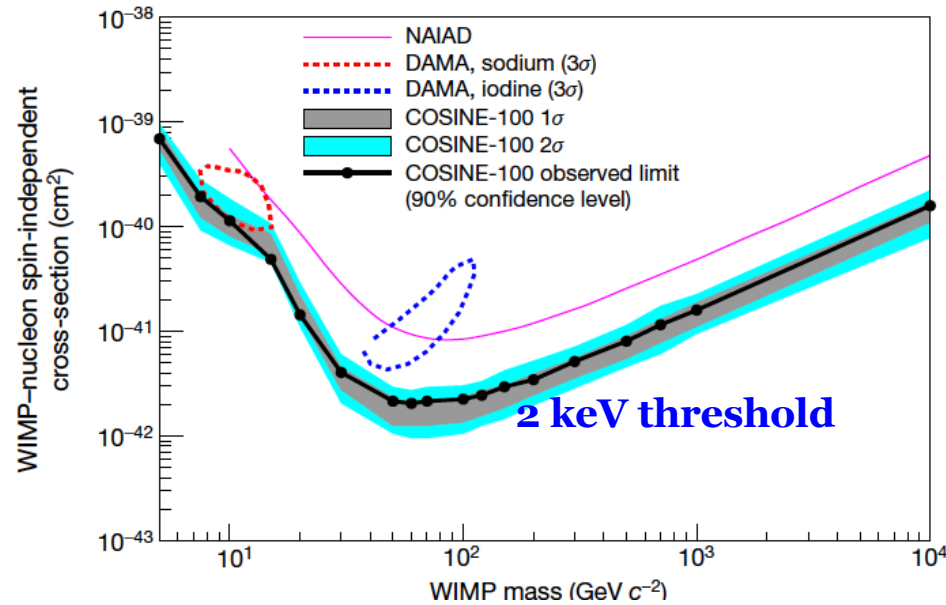
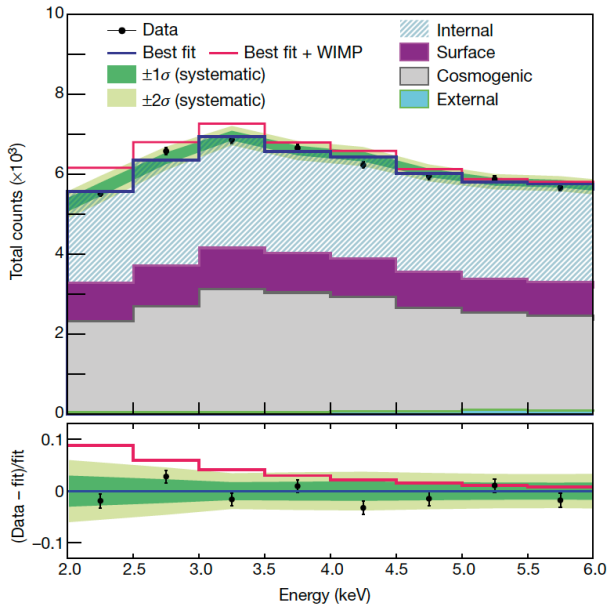


**Multiple-hit Events
(0.7 – 4000 keV)**



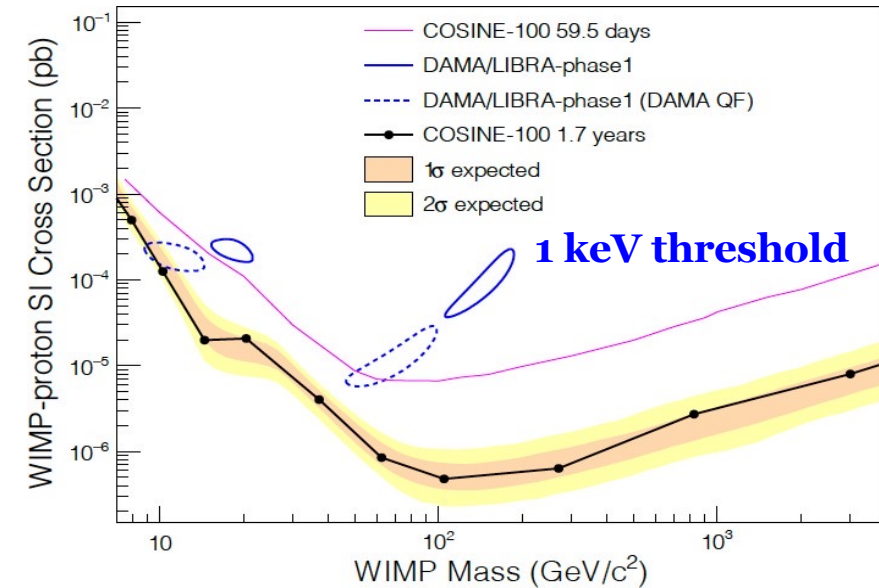
Dark matter search with energy spectra fit

Nature 564, 83 (2018)



59 days data

Sci. Adv. 7, eabk2699 (2021)

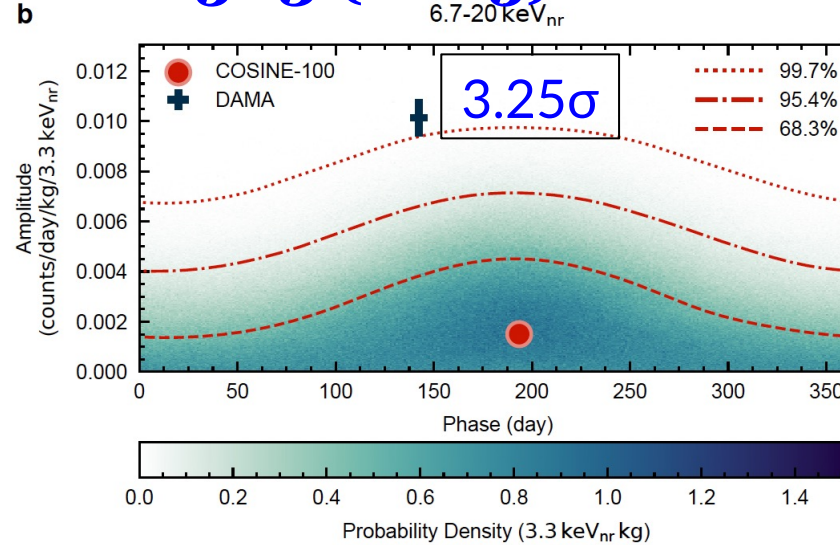
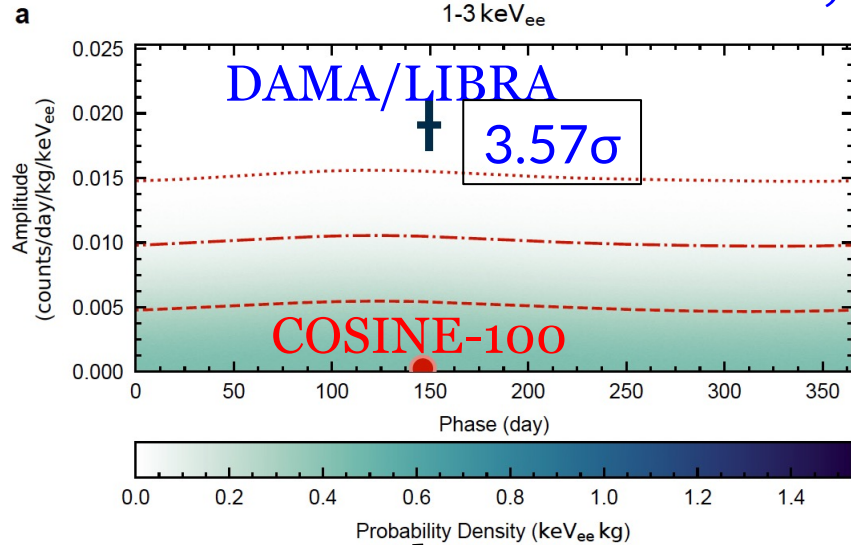


1.7 years data

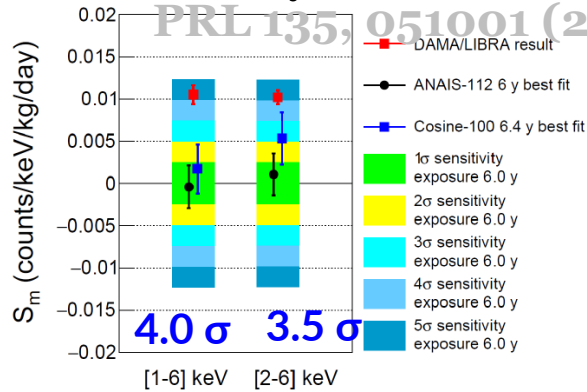
Model-dependent test ruled out DAMA/LIBRA with the same NaI(Tl)

Recent annual modulation search results

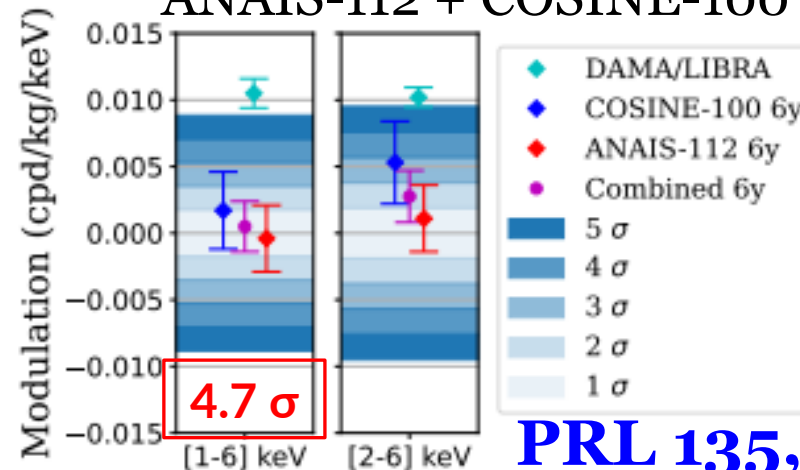
COSINE-100 full data **Sci. Adv. 11, eadv6503 (2025)**



ANAIS-112 6 year data



ANAIS-112 + COSINE-100

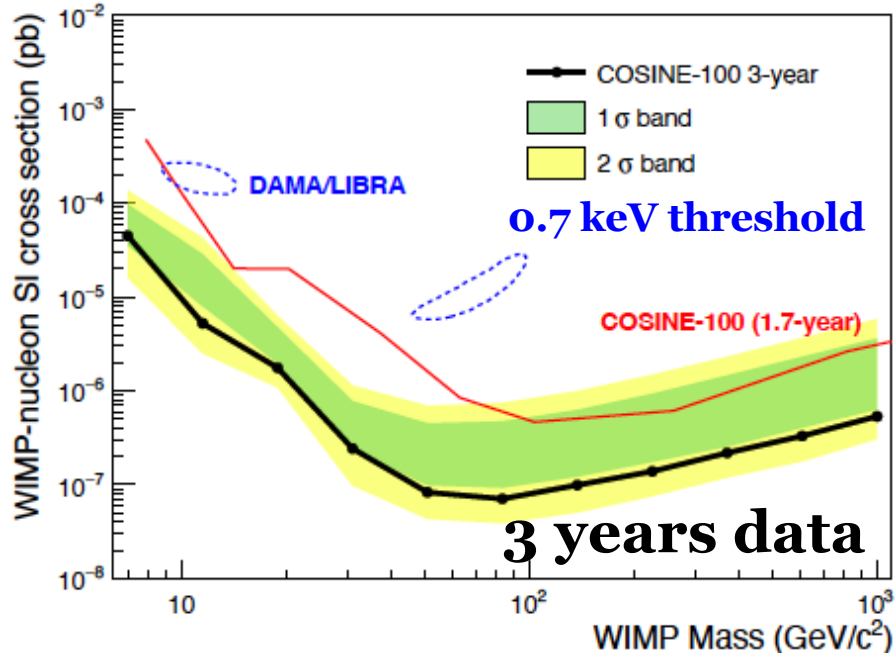


PRL 135, 121002 (2025)

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

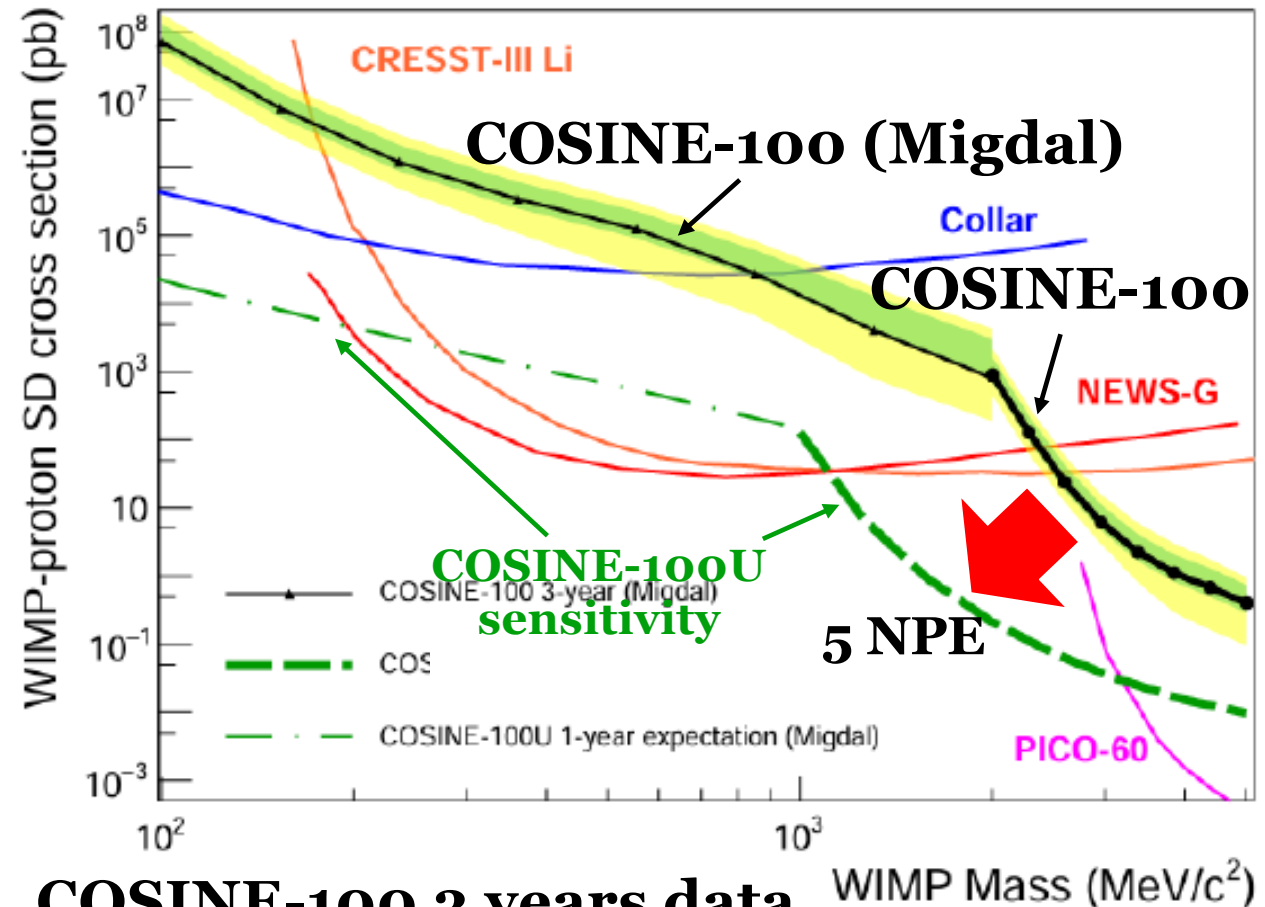
Toward low-mass dark matter era

WIMP-nucleon spin-independent interaction



- 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



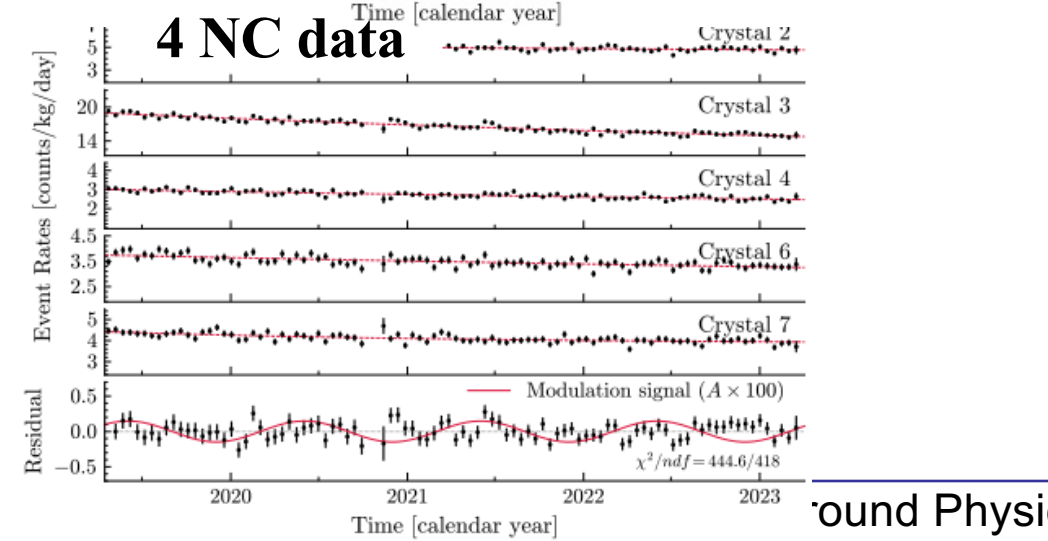
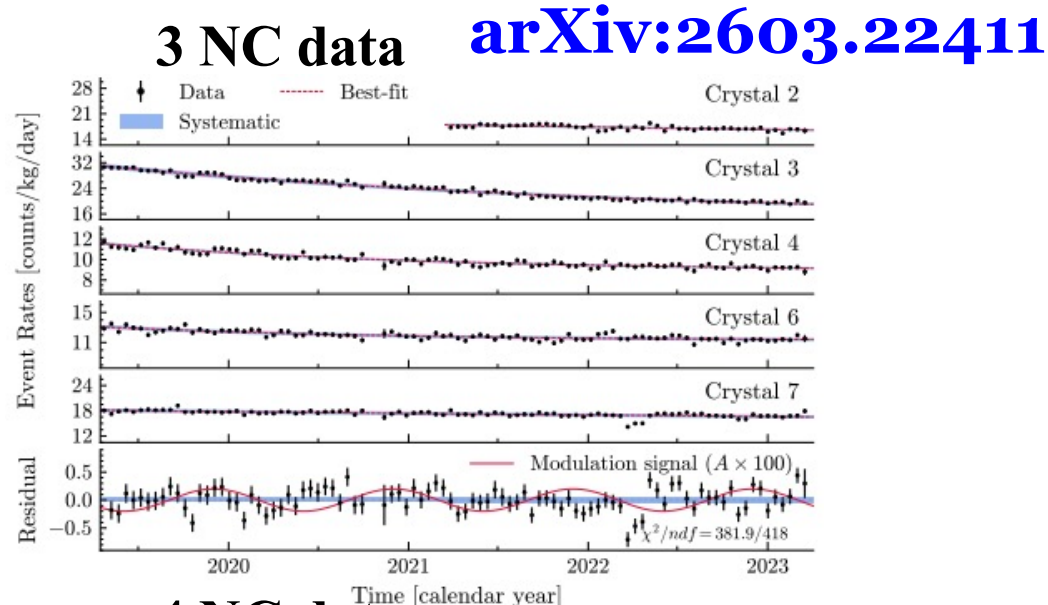
COSINE-100 3 years data

8 NPE threshold

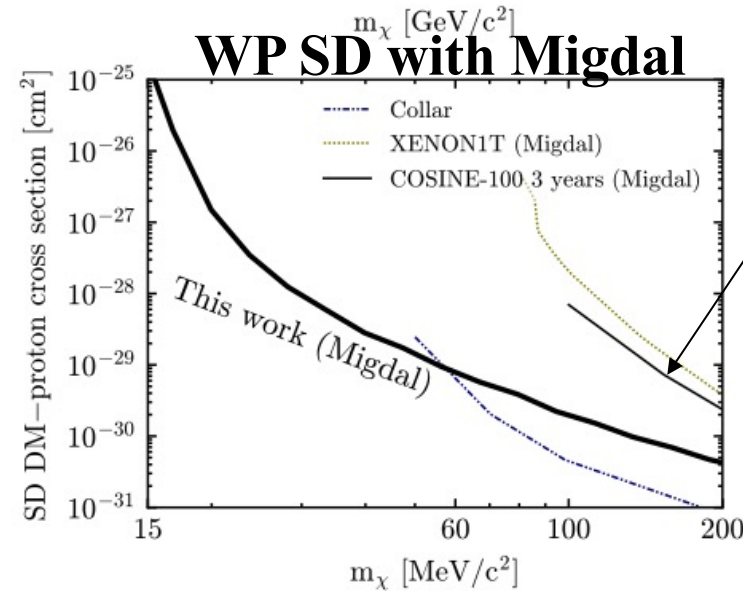
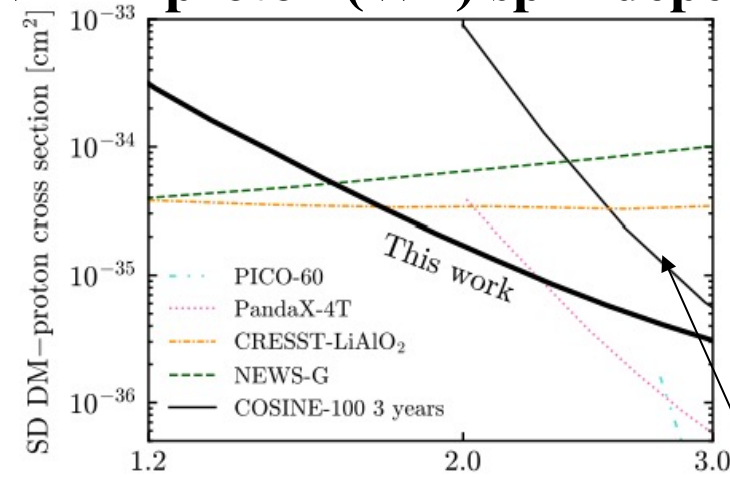
PRL 135, 231001 (2025)

3-4 NC (\approx NPE) analysis

- **Annual modulation** study of the 3 NC and 4 NC dataset, assuming a single exponential plus constant background



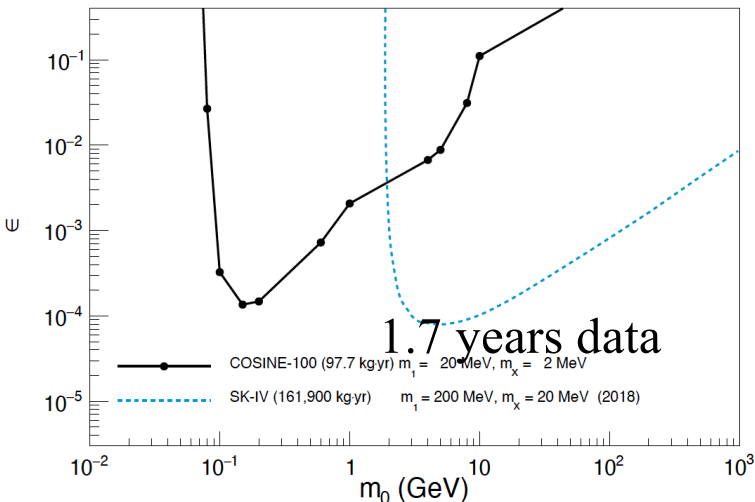
WIMP-proton (WP) spin-dependent (SD)



**COSINE-100 3 years
(8 NPE)**

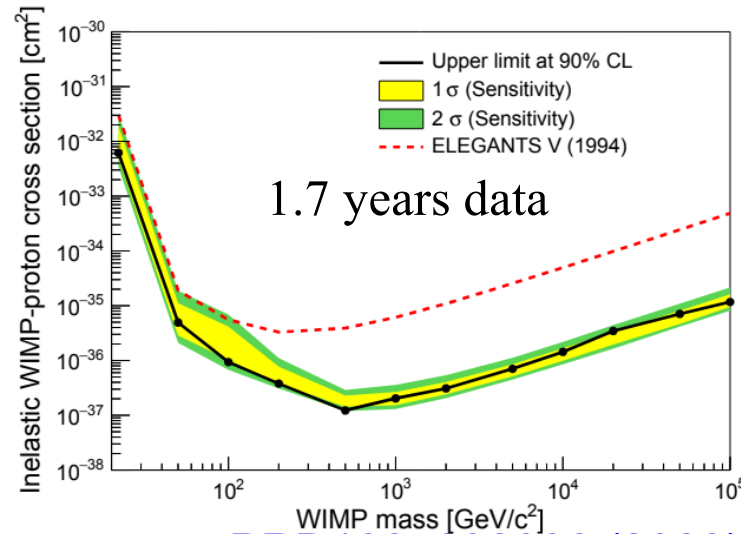
Other physics program

Boosted dark matter



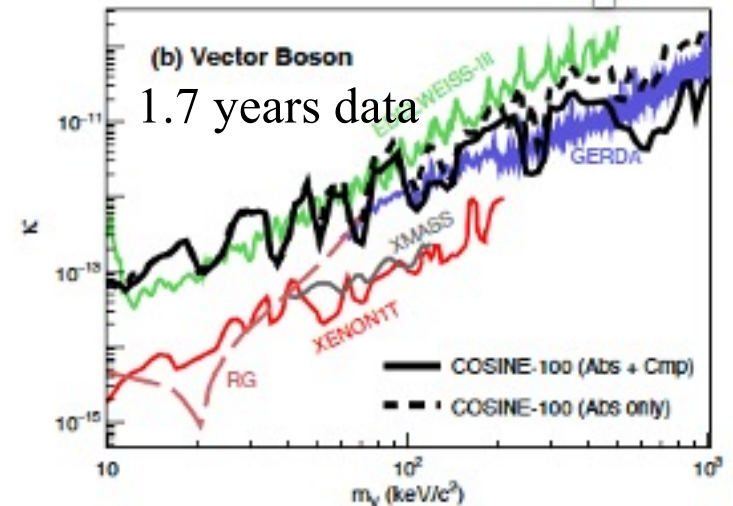
PRL131, 201802 (2023)

WIMP- ^{127}I inelastic interaction



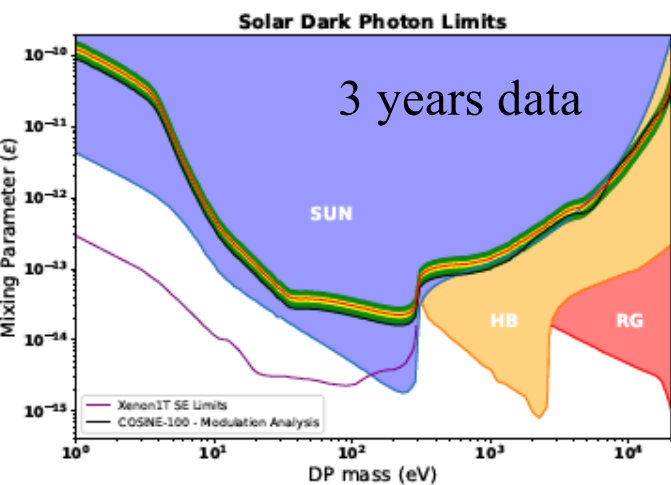
PRD108, 092006 (2023)

Bosonic SuperWIMP



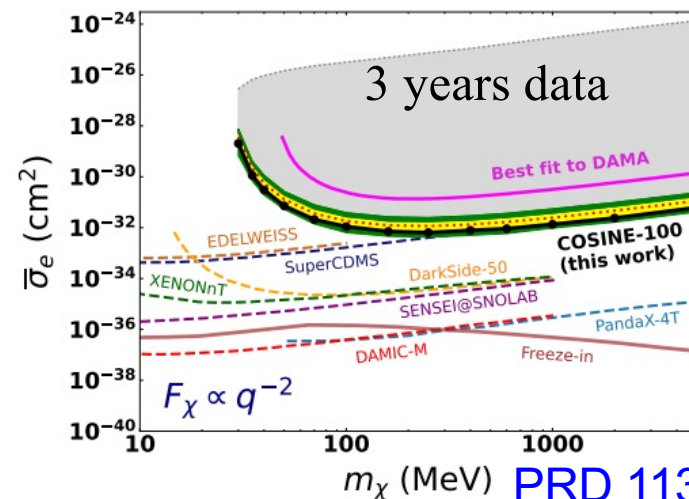
PRD108, L041301 (2023)

Solar bosonic dark sector particle

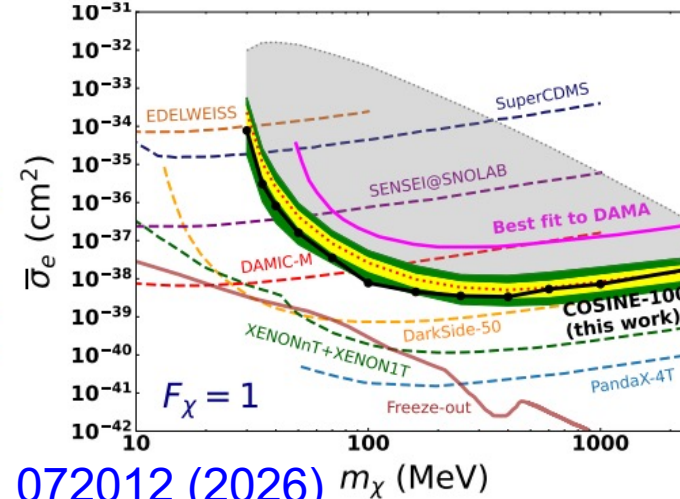


PRD 107, 122004 (2023)

WIMP-electron scattering (0.7 keV threshold)



PRD 113, 072012 (2026)



m_χ (MeV)

Ongoing

ν BDM

CRBDM

^{23}Na Axion

MIMP

....

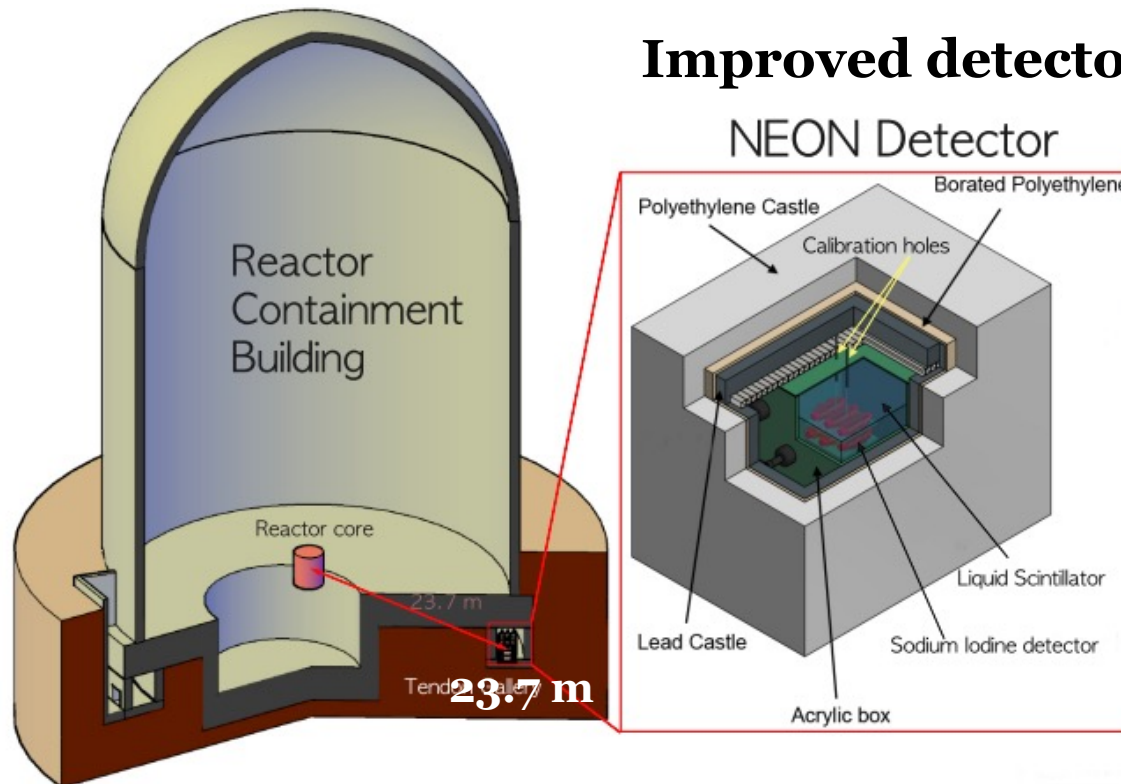
Part 1-2 · The Y2L legacy

NEON : EXPANDING FRONTIER

NEON experiment (2022 ~ current)

- Purpose

- ❖ Observation of coherent neutrino nucleus scattering (CEvNS) of Na target
- ❖ Dark sector particle searches from nuclear reactor
- ❖ Precursor for detector development for the COSINE project
 - Proves stability of upgraded detector encapsulation



Improved detector encapsulation for high light yield

16.7 kg NaI(Tl) target

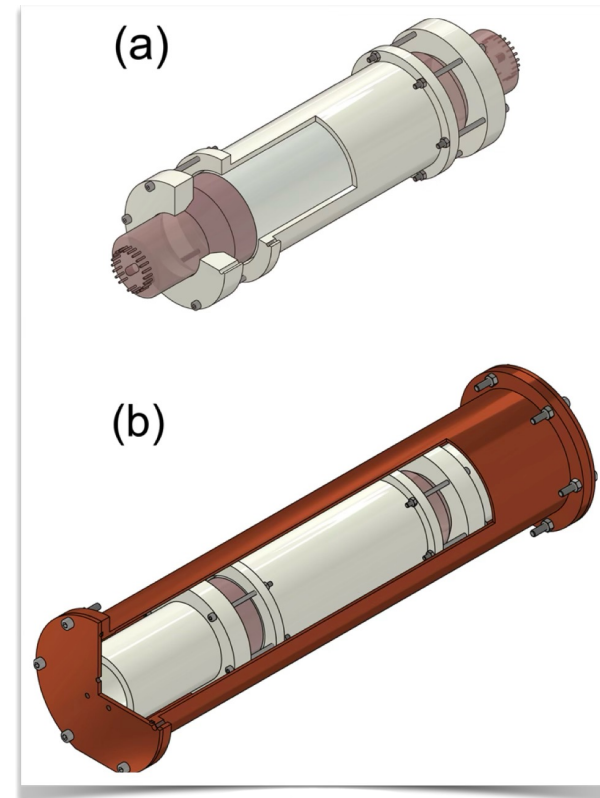
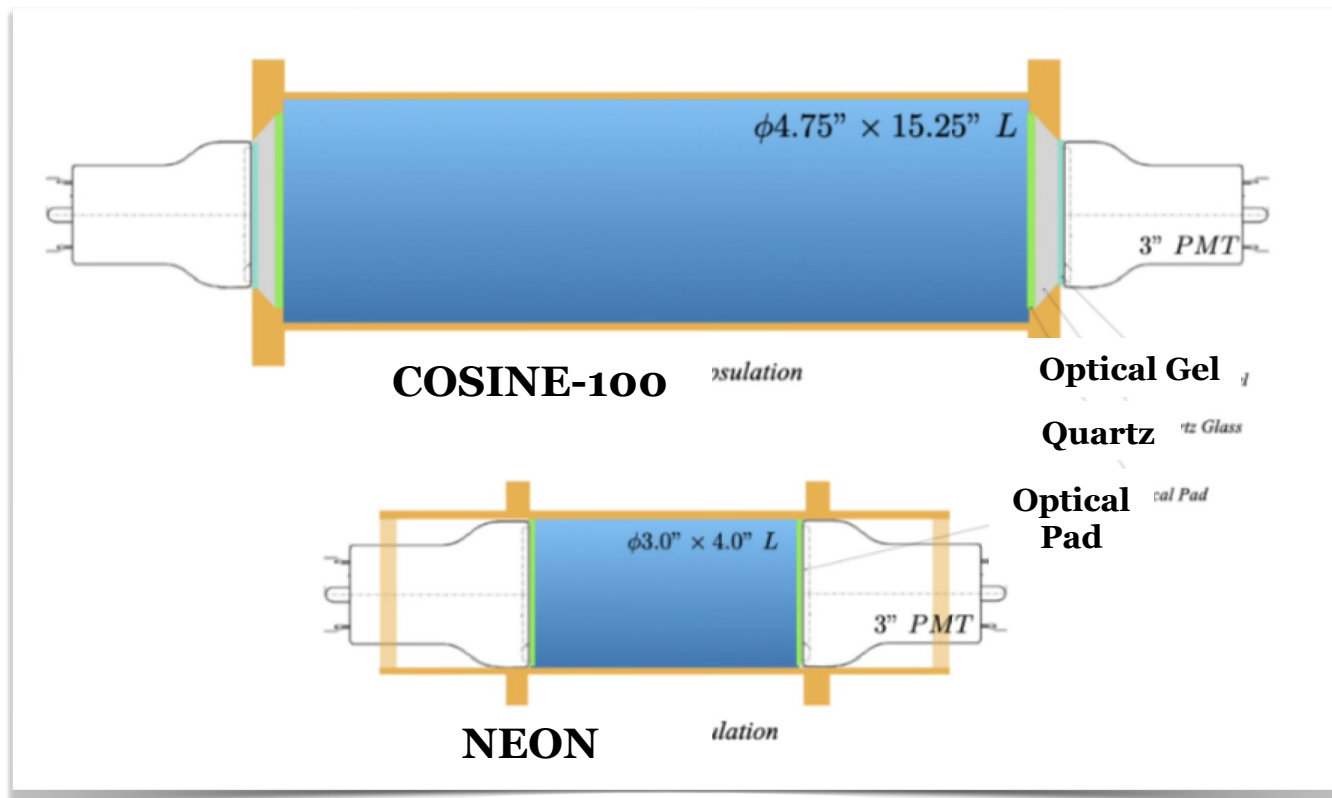
EPJC 83, 226 (2023)

886 days reactor **on** data

226 days reactor **off** data

$$\phi_{\bar{\nu}} = 8.09 \times 10^{12} / \text{cm}^2 / \text{s}$$

NEON NaI(Tl) detectors



Improved light collection

COSINE-100 ~ 15 NPE/keV

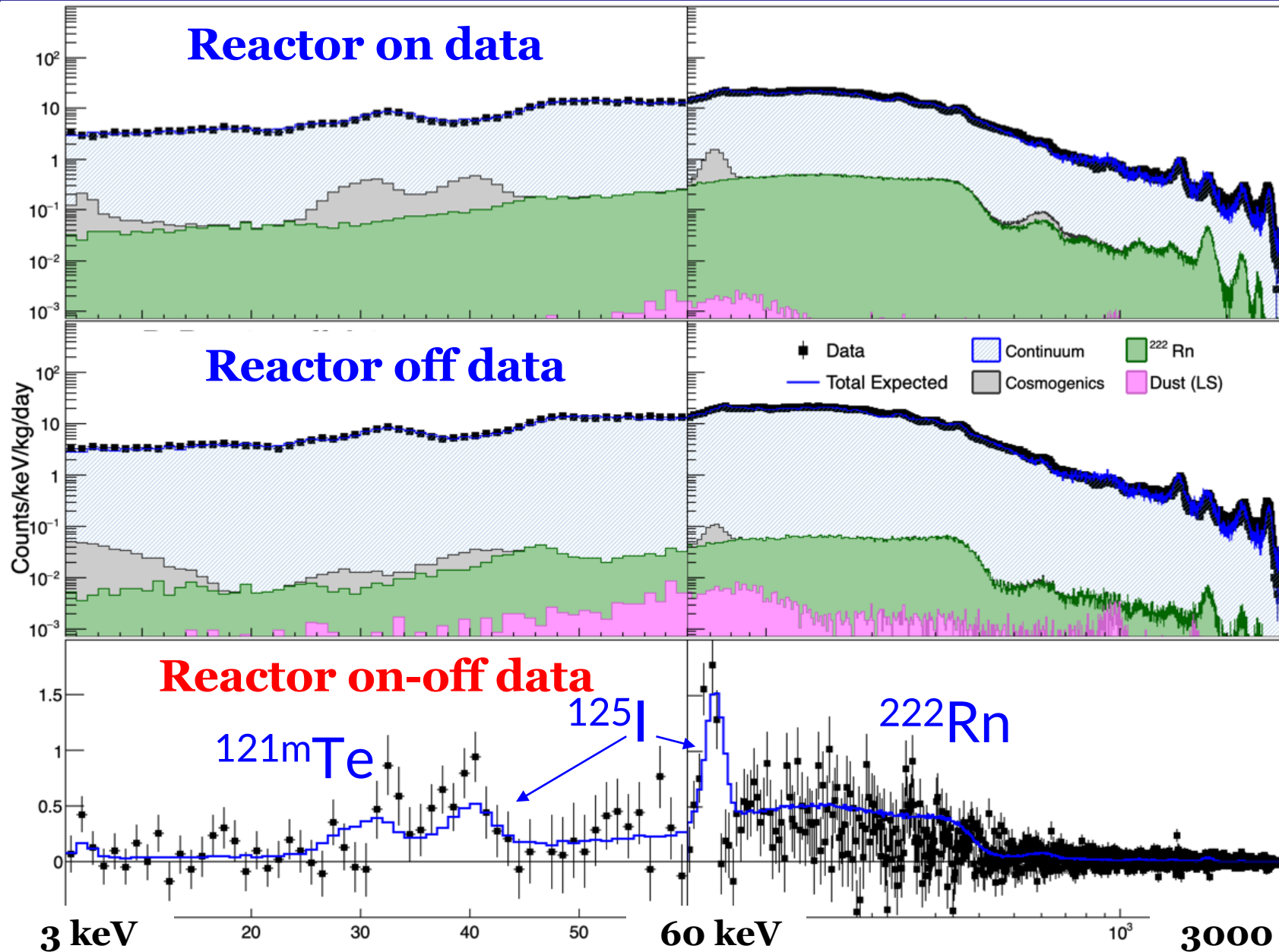
NEON ~ 24 NPE/keV

Nucl. Instrum. Meth. A 981 (2020) 164556

JINST 19 (2024) P10020

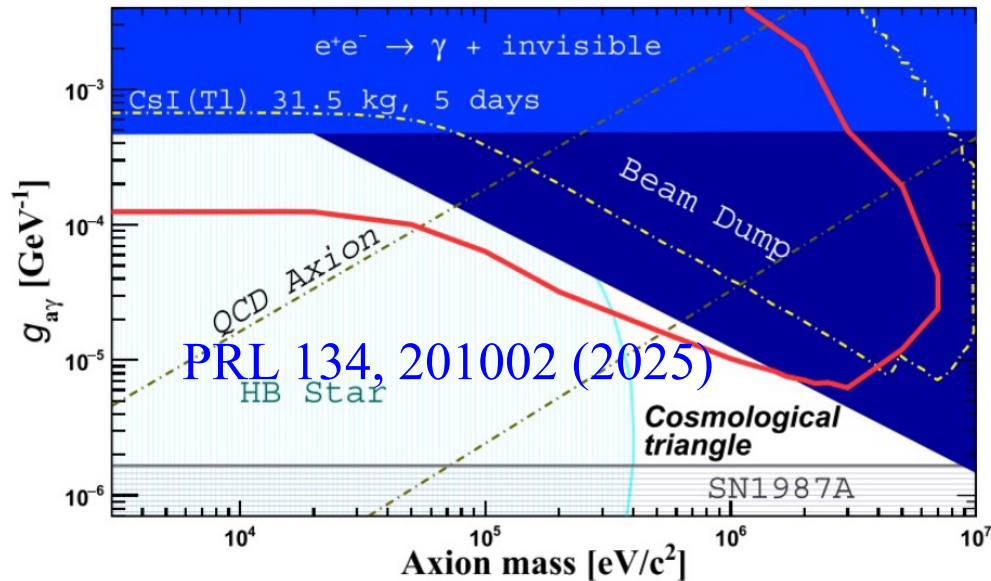
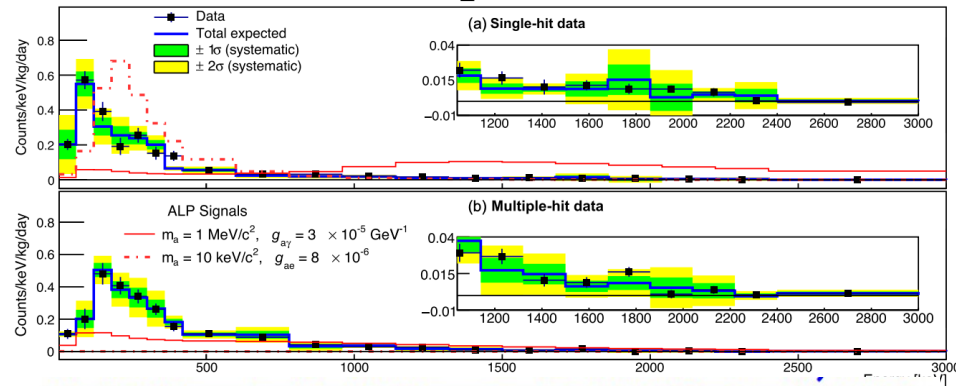
A similar upgrade has been applied to **COSINE-100U @ Yemilab**

NEON detector understanding (~400 days data)



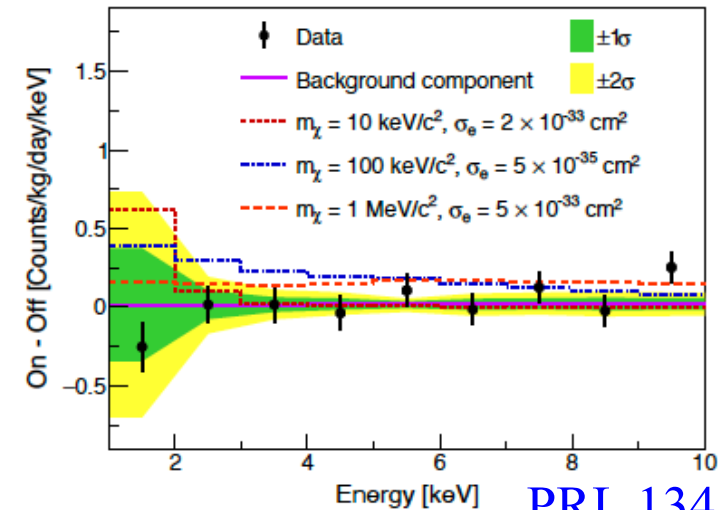
Dark Sector Particle Searches

Axion-like particle search

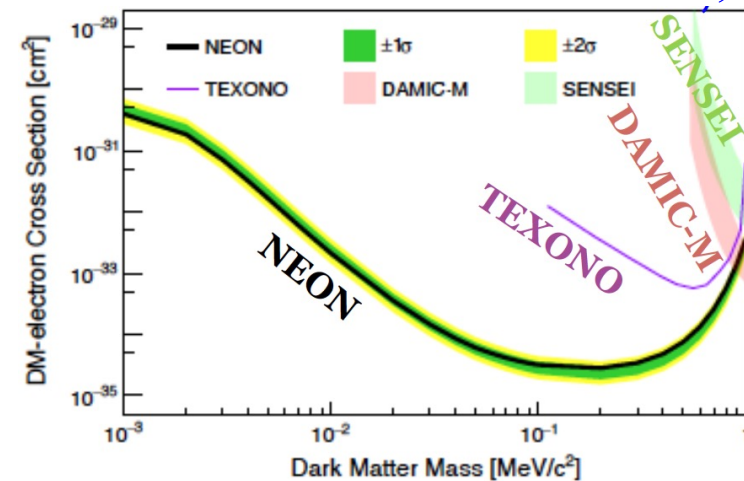


(a) Axion-photon coupling

Low-mass dark matter search



PRL 134, 021802 (2025)



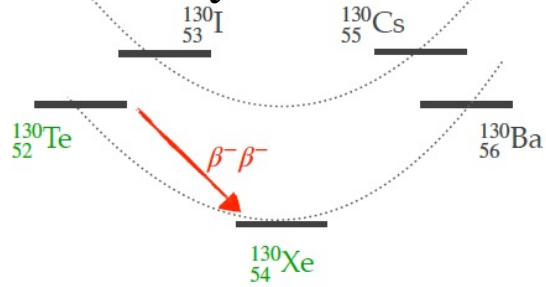
- Continuing dark-sector particle search including **dark photon** and **astrophysical axion** from ^{23}Na
- Low-energy **CEvNS** search analysis is ongoing

Part 1-3 · The Y2L legacy

$0\nu\beta\beta$: **AMORE**

Neutrinoless double beta decay ($0\nu\beta\beta$)

Beta decay is forbidden

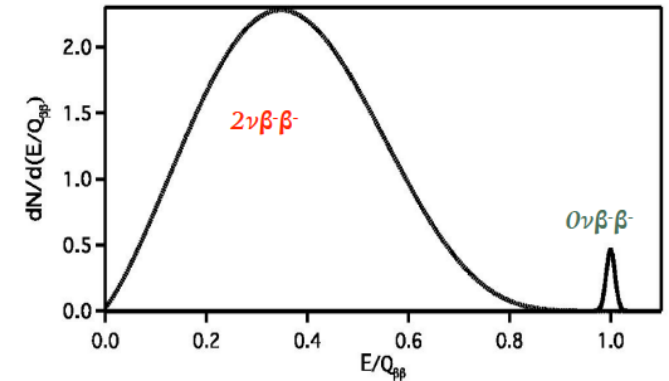
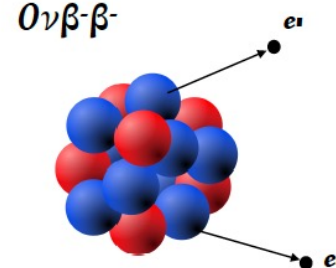
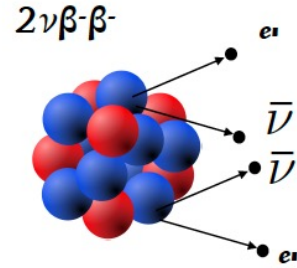


~35 candidates

- If neutrinos are **Majorana**
- **Lepton number violation**
- $Q > 2 \text{ MeV}$ (only 11 candidates)
- Measure **absolute neutrino mass**

$$\Gamma_{\beta\beta}^{0\nu} = \frac{1}{T_{\beta\beta}^{0\nu}} = G^{0\nu} \cdot |M^{0\nu}|^2 \cdot \langle m_{\beta\beta} \rangle^2$$

Good energy resolution & low background are required



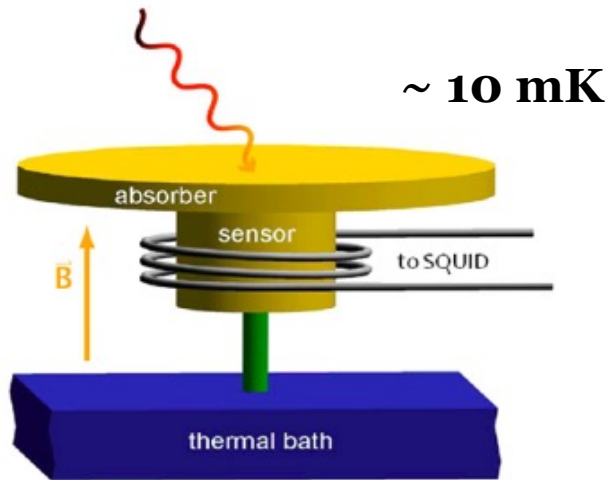
AMoRE collaboration



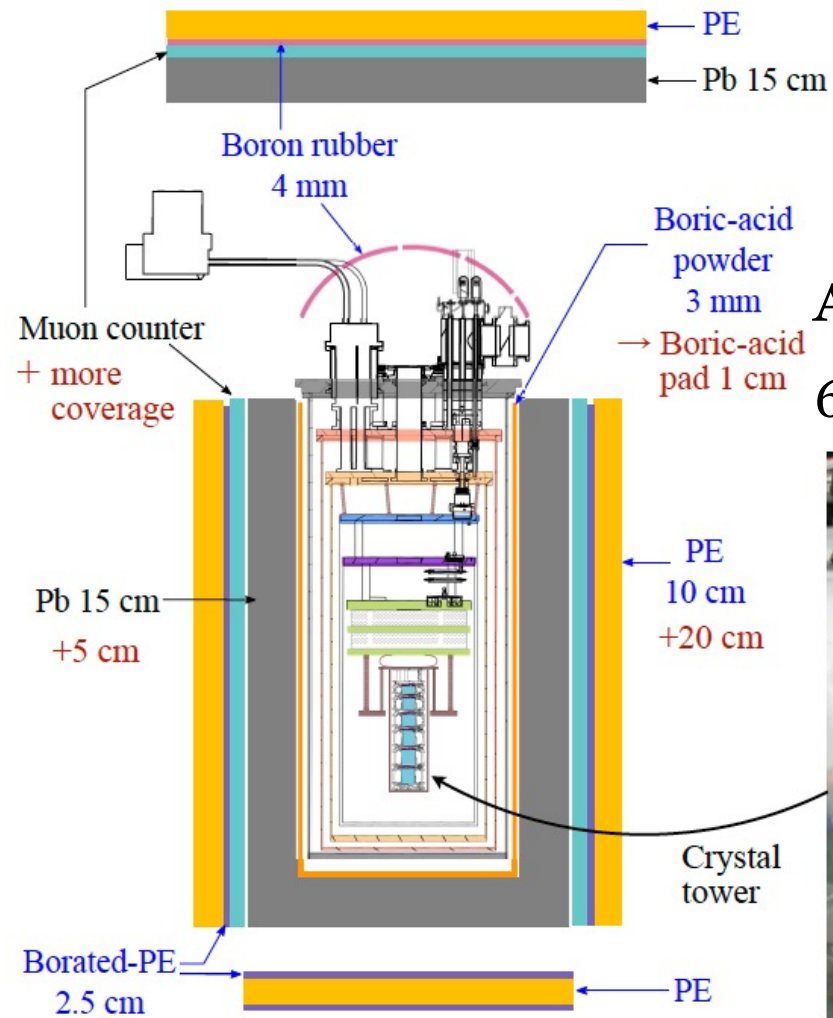
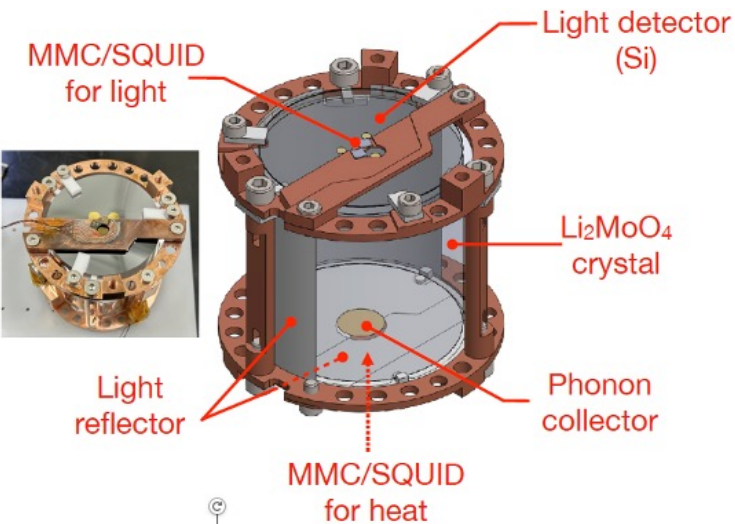
- **10 Countries, 26 Institutions, ~110 researchers**
- Korea, Germany, Ukraine, USA, Russia, China, Thailand, Indonesia, India, Pakistan



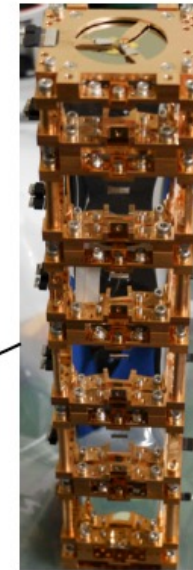
AMoRE $0\nu\beta\beta$ searches @ Y2L



Metallic Magnetic Calorimeter (MMC)
Figure courtesy of D. Hengstler et al (2015)

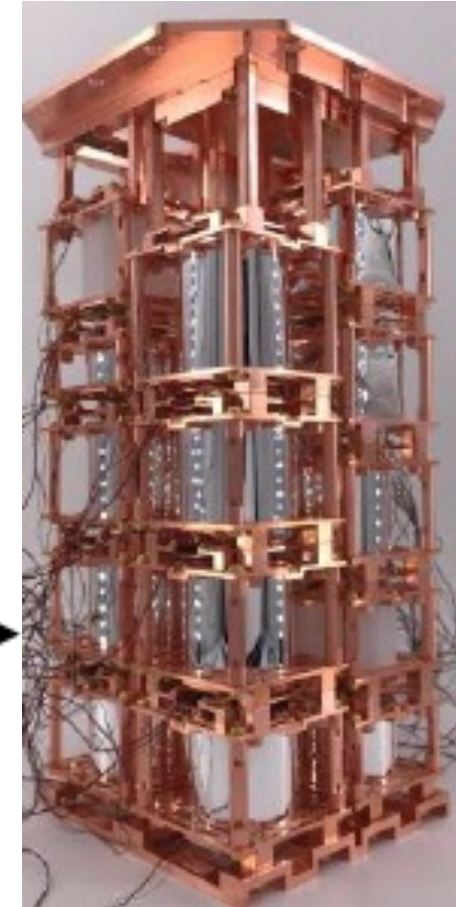


AMoRE-pilot
6 CMO (1.9 kg)



2015-2018

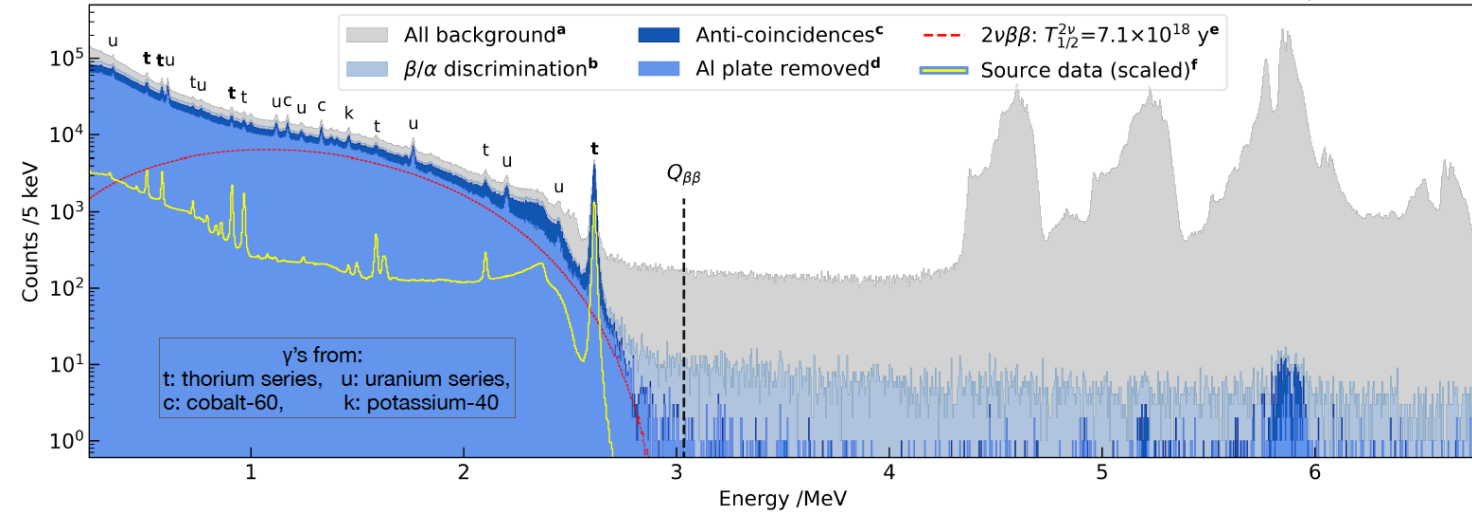
AMoRE-I
13 CMO, 5 LMO (6kg)



2020-2023

AMoRE-I physics results

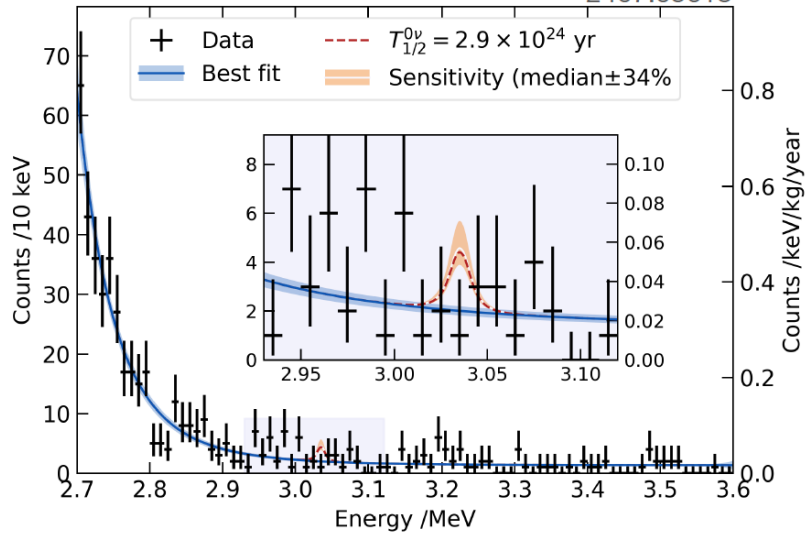
AMoRE-I, 2407.05618



Phys. Rev. Lett. 134, 082501 (2025)

- First use of MMC technologies for multi-channel underground experiments
- **Technology validation**

2407.05618



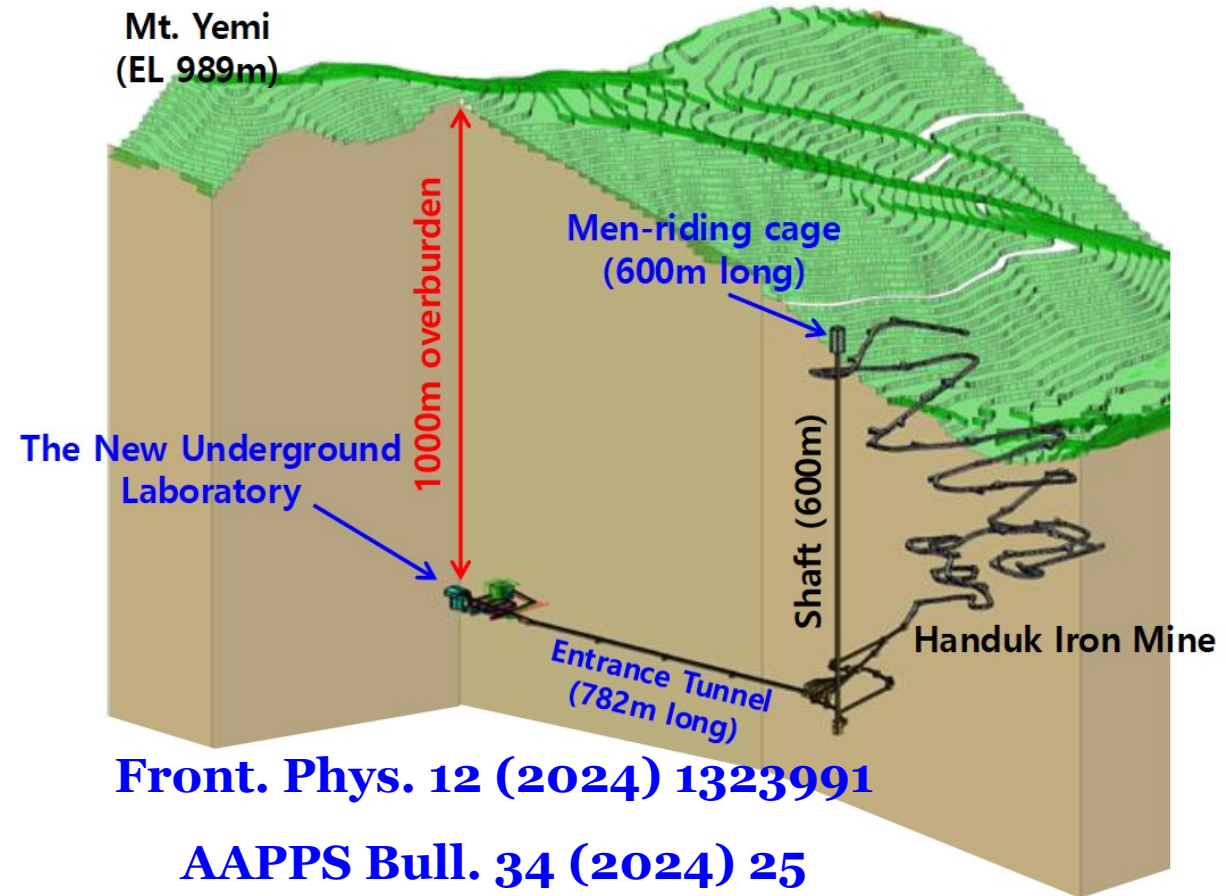
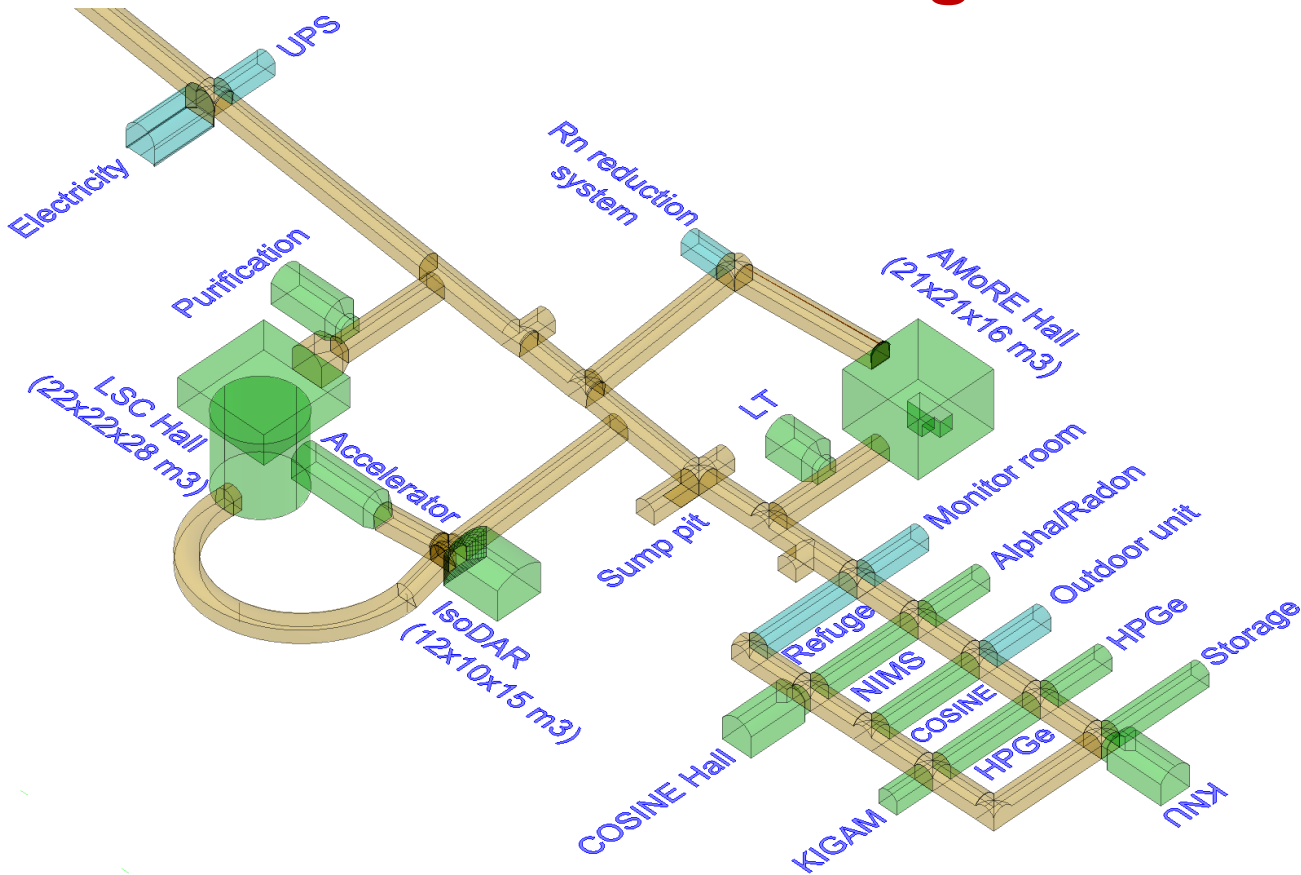
- Exposure: **4 kg·yr** of ^{100}Mo
- Background: **0.025 counts/keV/kg/yr**
- Reduction from pilot **(1/12)**

$$T_{1/2}^{0\nu} > 2.9 \times 10^{24} \text{ yr at 90\% CL}$$

The best half-life limit for ^{100}Mo

Yemilab (Since 2022)

- **Dedicated underground laboratory** for basic science



- **Large experimental space**
- **Available space to host next-generation experiments**

Part 2 · From Y2L to Yemilab

OPENING THE YEMILAB ERA

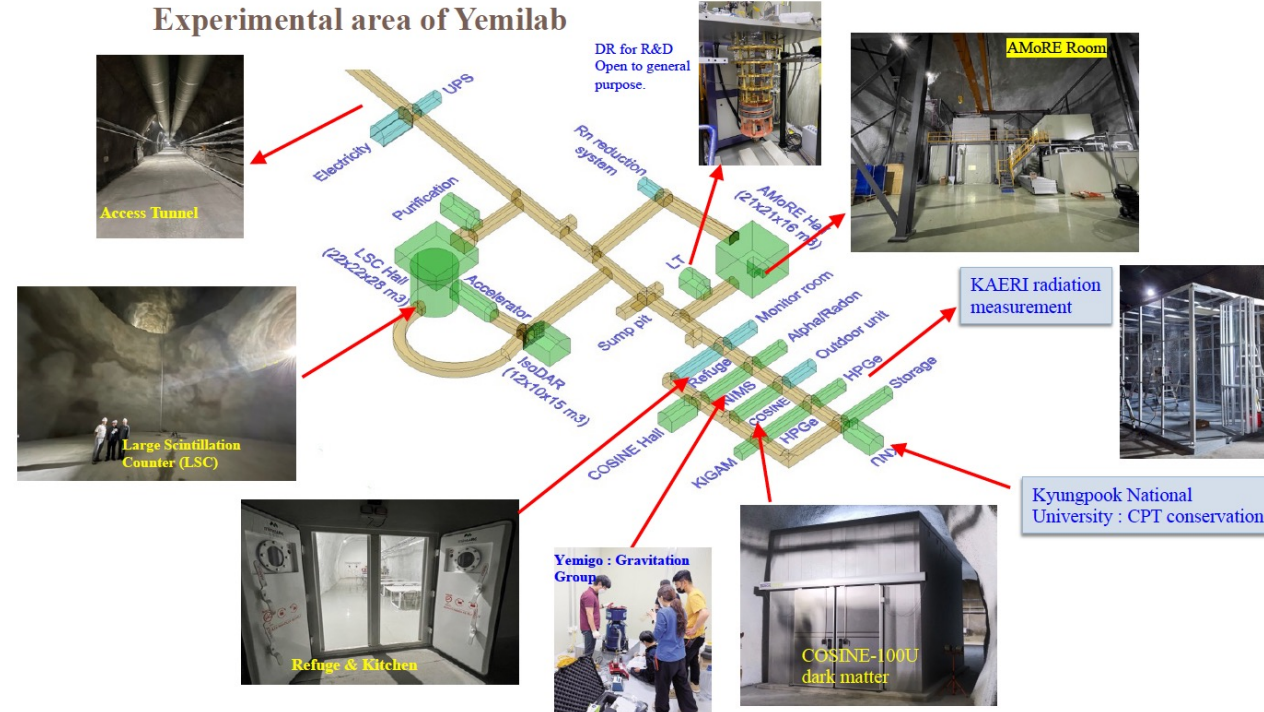
From Yangyang to Yemilab

Yangyang Underground Laboratory (Y2L) (2003-2025)



- **Yangyang Underground Lab (Y2L):** The foundation of Korean dark matter & neutrino searches (KIMS, COSINE-100, AMoRE-I)
- Limited space (~200 m²) & shallow depth (~700 m)

Yemilab (Since 2022)



- **Yemilab Era: 1,000 m deep underground**
- **Over 3,000 m² of dedicated experimental space (15× expansion)**
- Successful massive relocation of core experiments (2024–2025)

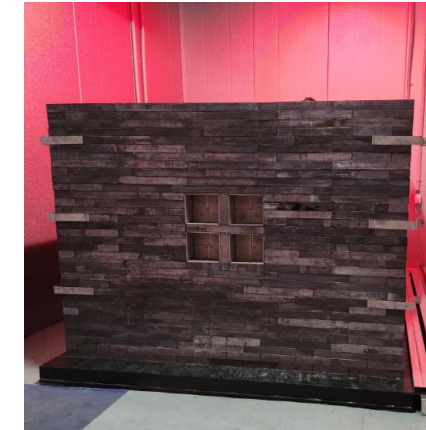
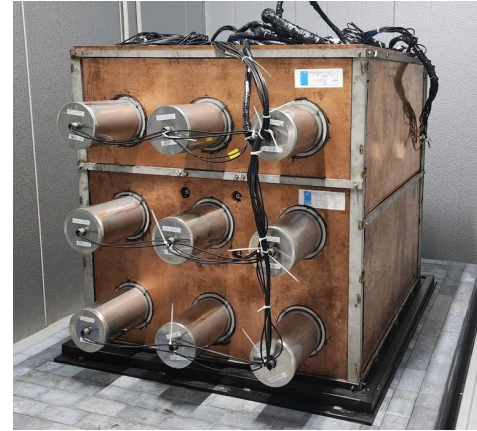
Yemilab's First Flagship: The COSINE-100U

Freeze room for -20°C operation

Detector upgrade for high light yield
Liquid scintillator veto



Astropart. Phys. 141, 102709 (2022)



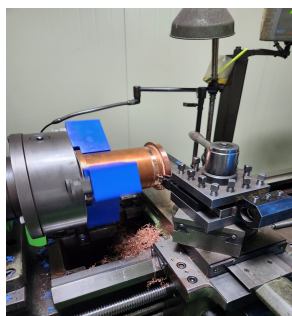
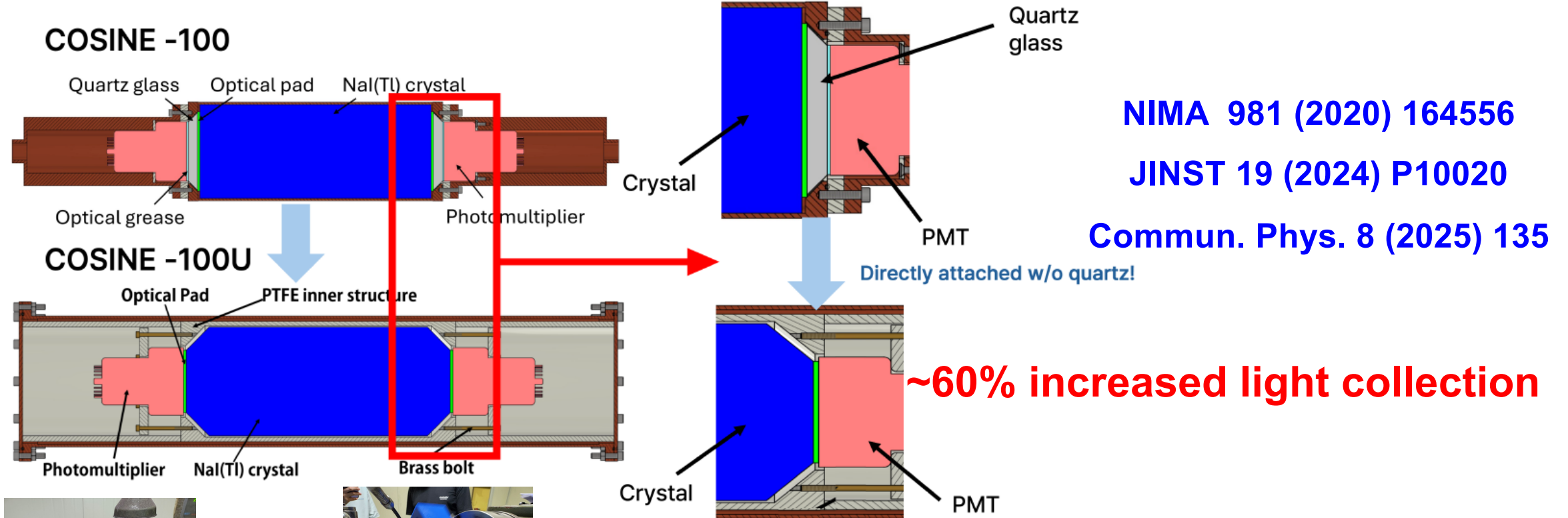
Crystal & LS install



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

Detector upgrade for the COSINE-100U

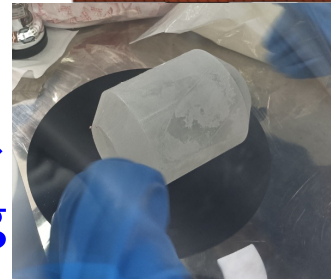
- Similar encapsulation to the NEON detector
- **Upgraded detector assembly for high light output**



8.26 kg



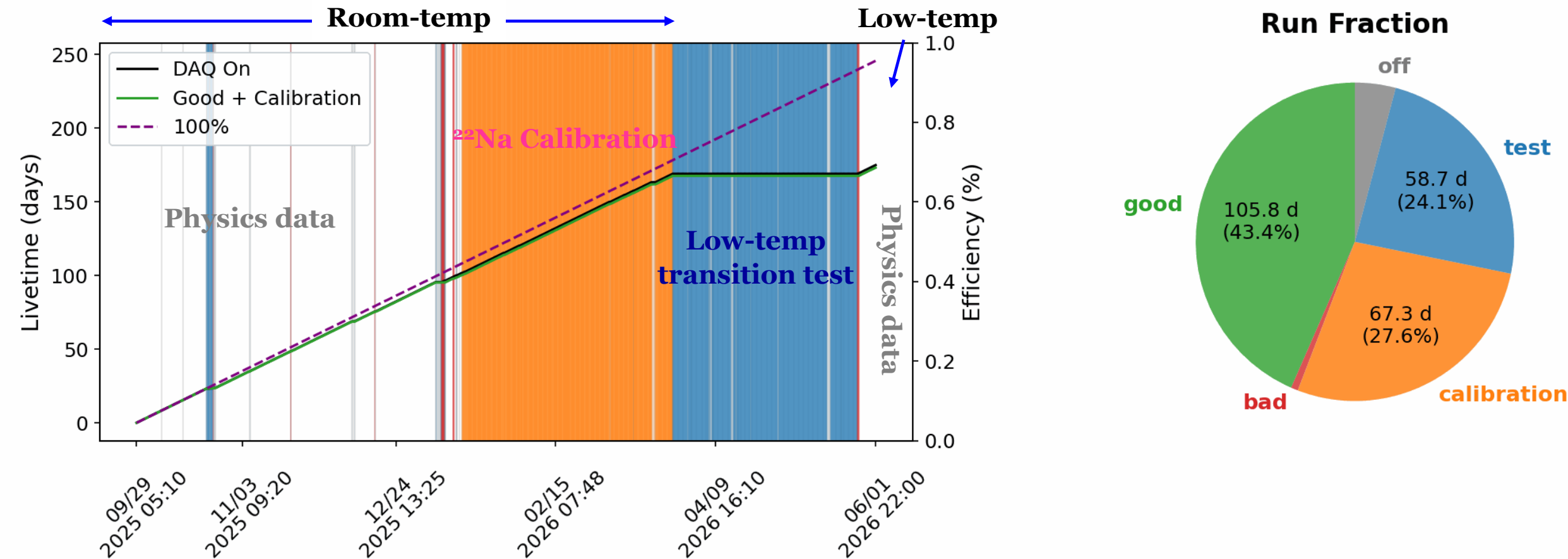
7.19 kg



**Polishing
Assembly**

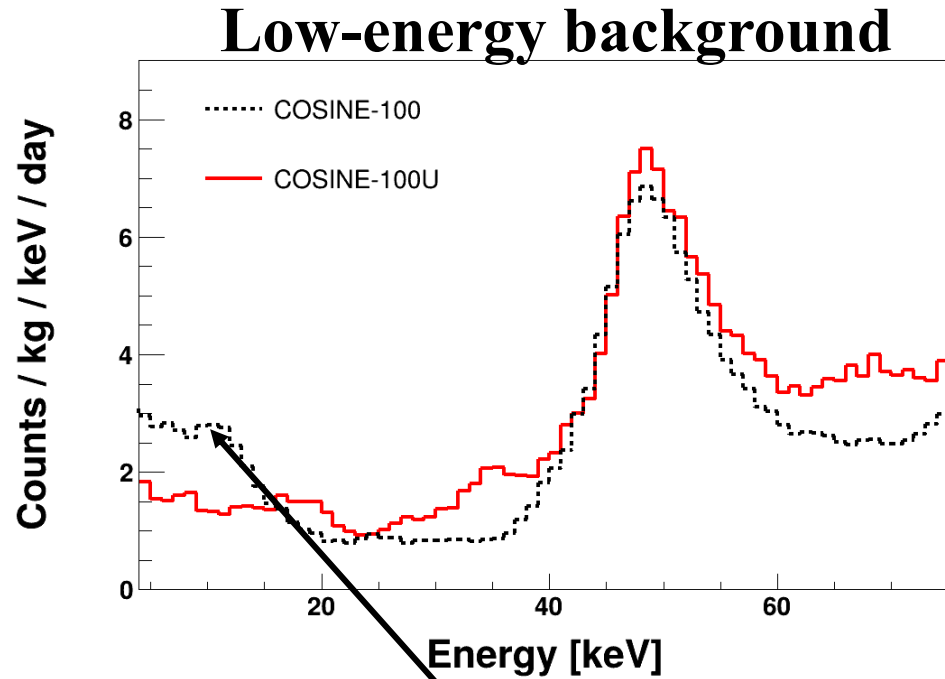
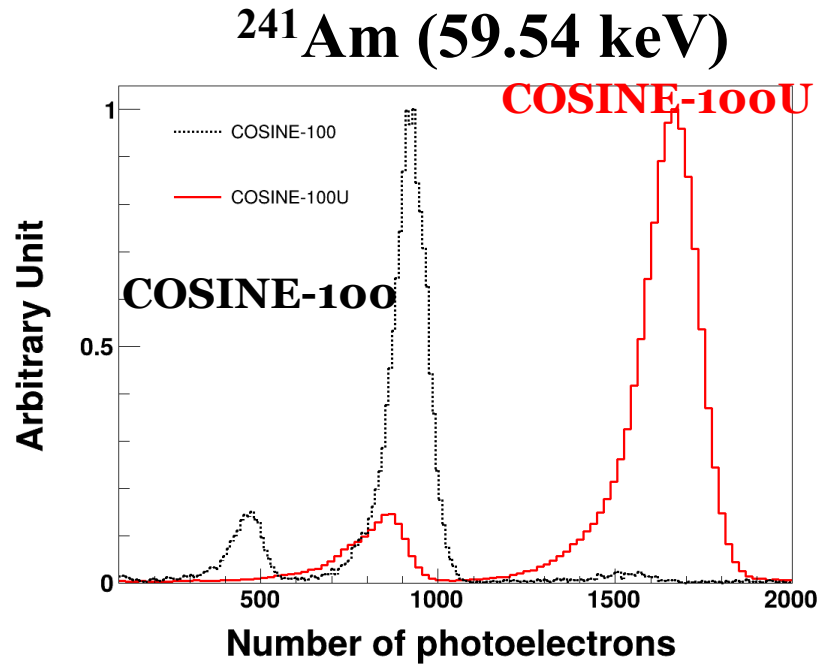


COSINE-100U operation



- Room-temp operation commenced on **September 25, 2025**
- With ~100 days of physics data and 67 days of scintillation data, we will switch to **low-temp (-20°C) operation**, starting the physics run on **May 27, 2026**

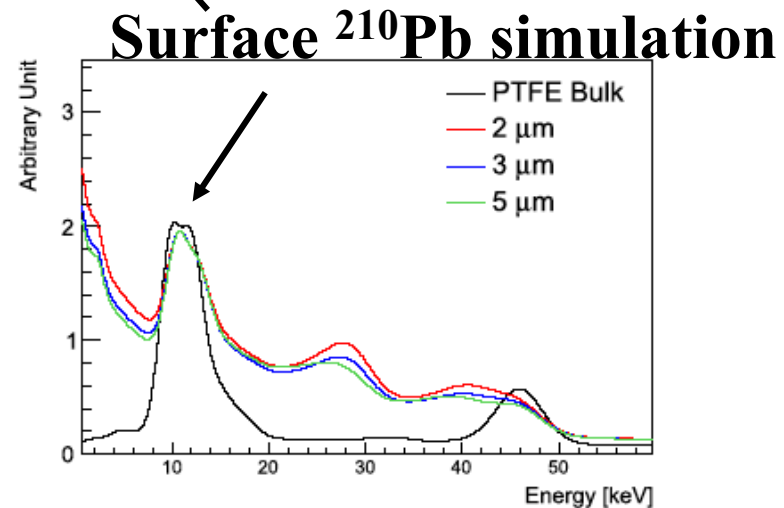
COSINE-100U Data (Room-temp)



~60% increased light collection

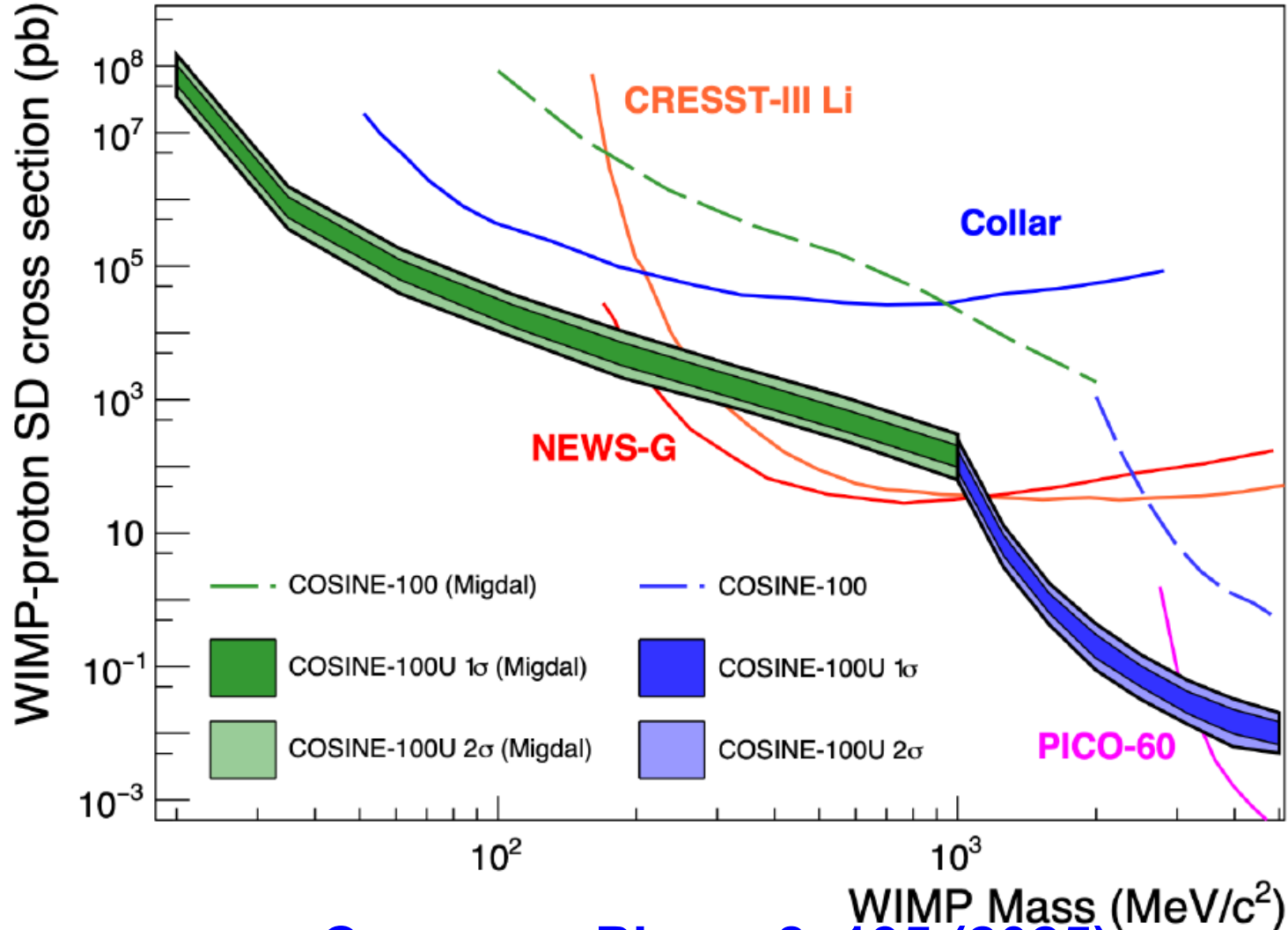
~ 1 count/kg/keV/day reduction in background from surface contamination

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



COSINE-100U sensitivity

WIMP-Proton spin-dependent interaction



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 (5-10% increased light)**

Commun. Phys. 8, 135 (2025)

Low-background crystal : Powder

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

Recrystallization of powder

^{40}K and ^{210}Pb are main contamination

	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(Tl) powder (**K < 20 ppb**)
- Global collaboration for low-background NaI(Tl) crystals with low-background powder



**Purification
factory ~ 70 kg
powder load**

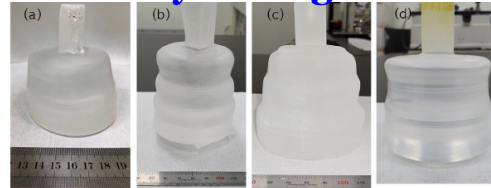
Low-background crystal : Crystal Growing

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

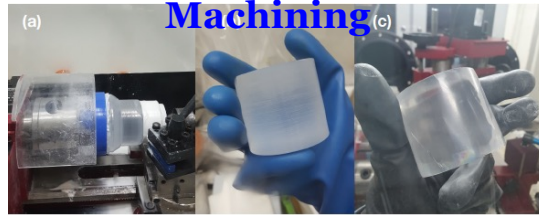
Kyropoulos



Crystal ingots



Machining

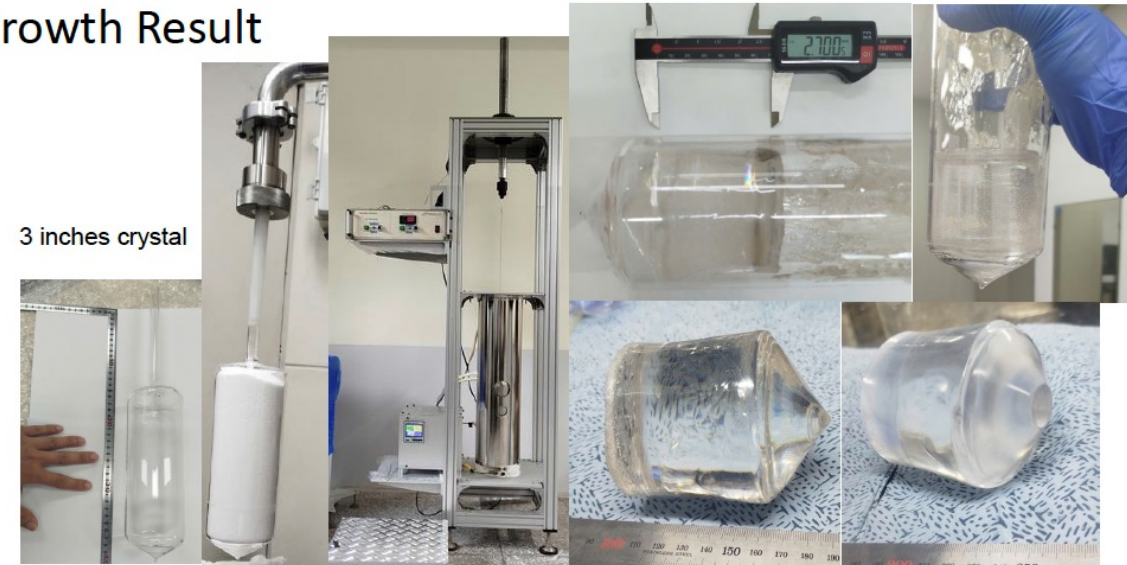


Assembly

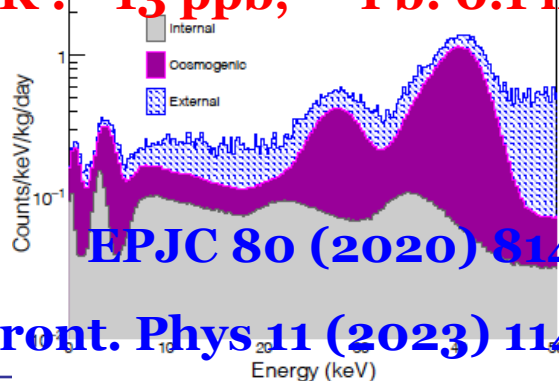


Bridgman

Growth Result



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



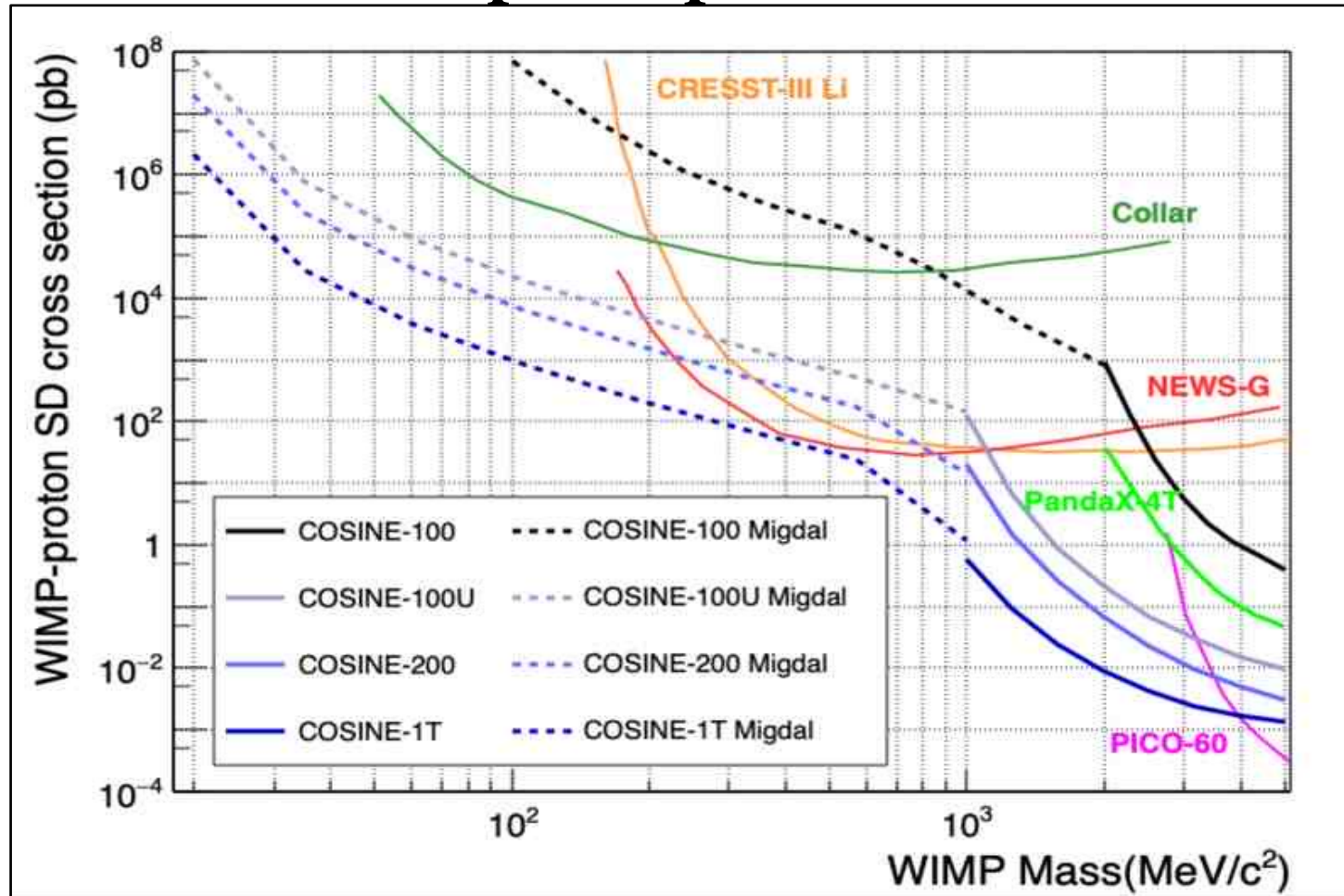
Front. Phys. 11 (2023) 1142765

- Proof of concept** for low-background NaI(Tl)
 - Large-size crystal growing is going on
- Full stack of low-background NaI(Tl) detector**

Physics reach of COSINE

In addition to DAMA/LIBRA verification...

WIMP-Proton spin-dependent interaction



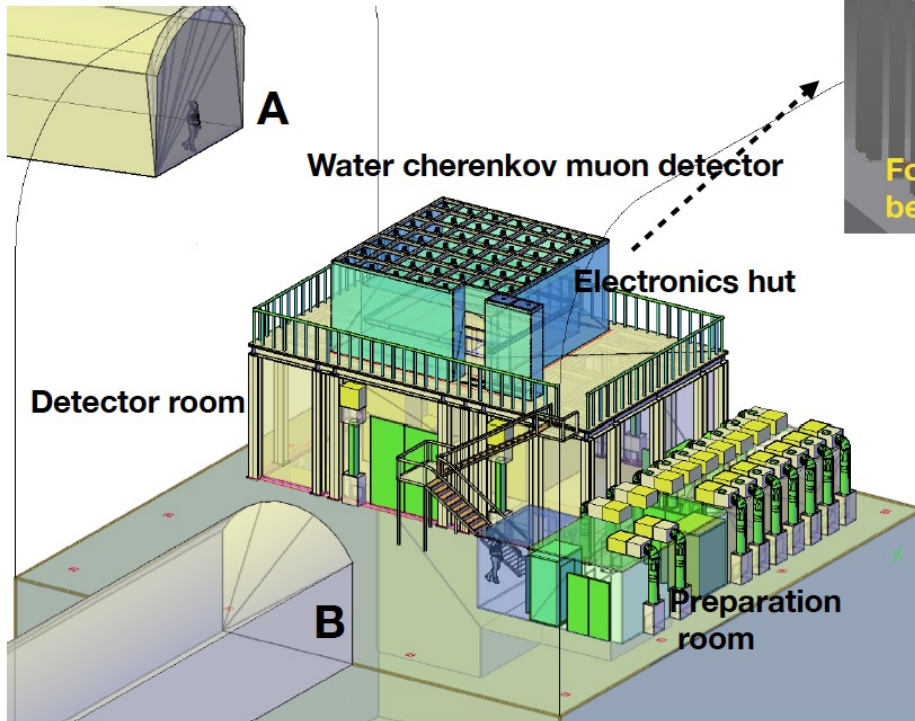
Exploring uncovered low-mass dark matter parameter space

AMoRE-II · Yemilab's $0\nu\beta\beta$ flagship

TOWARD THE INVERTED MASS ORDERING

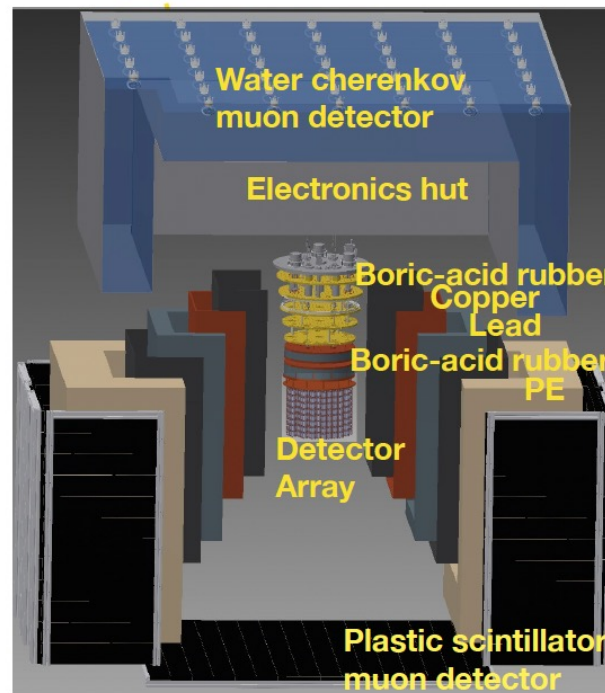
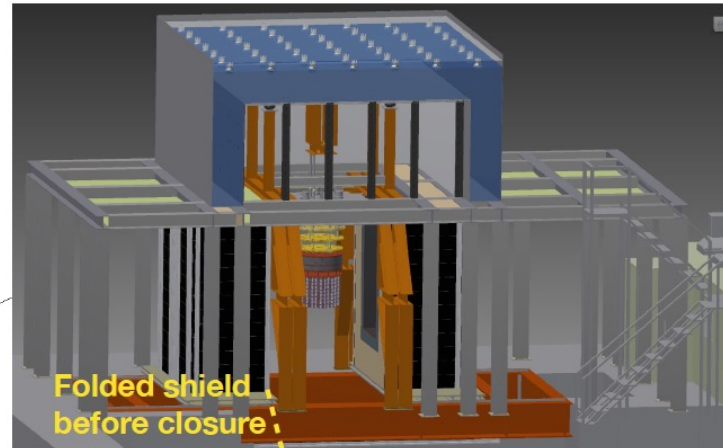
Yemilab's Flagship : AMoRE-II

AMoRE Hall in Yemilab

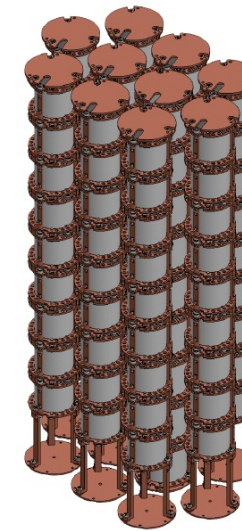


Radon reduction system:
Rn-less ($\sim 10\text{Bq/m}^3$) / Rn-free ($< 0.1\text{Bq/m}^3$) air

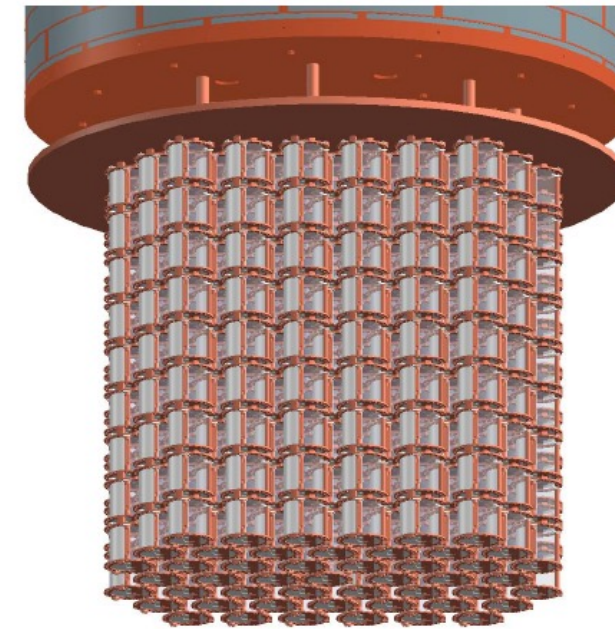
Clean room:
Class 100 for Detector & Preparation room



Phase 1
90 LMOs (27 kg)



Phase 2
360 LMOs (157 kg)



Yemilab's Flagship : AMoRE-II

AMoRE Hall in Yemilab

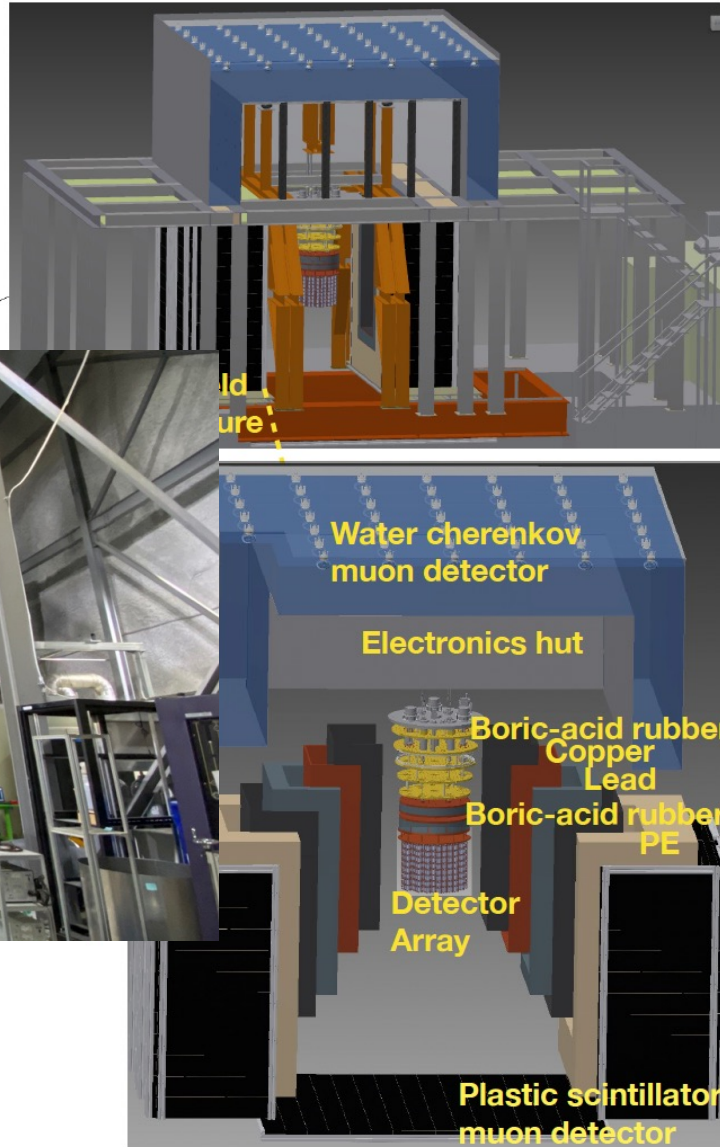


Recent view of AMoRE Hall

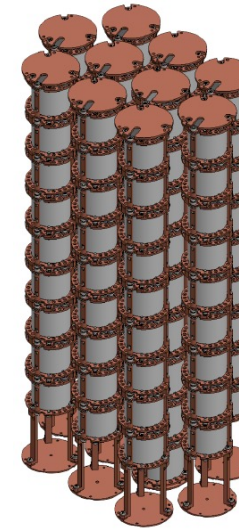


Radon reduction system:
Rn-less ($\sim 10\text{Bq/m}^3$) / Rn-free ($< 0.1\text{Bq/m}^3$) air

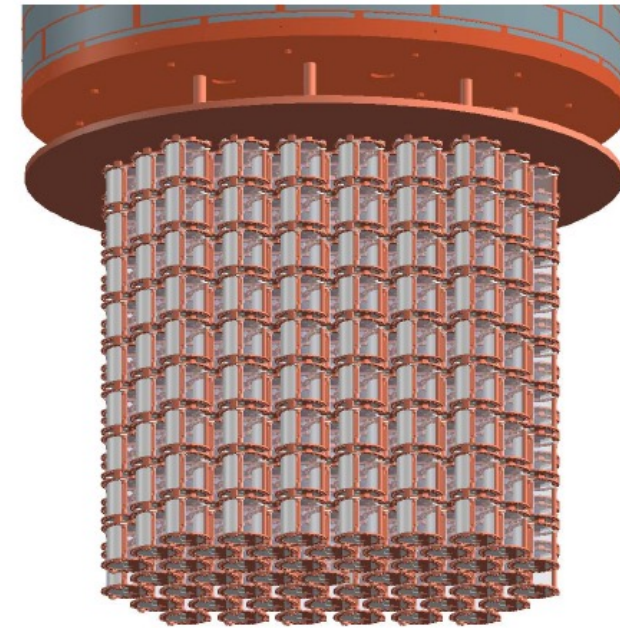
Clean room:
Class 100 for Detector & Preparation room



Phase 1
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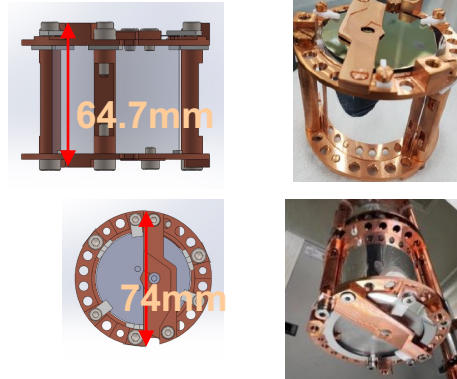


Preparation of AMoRE-II

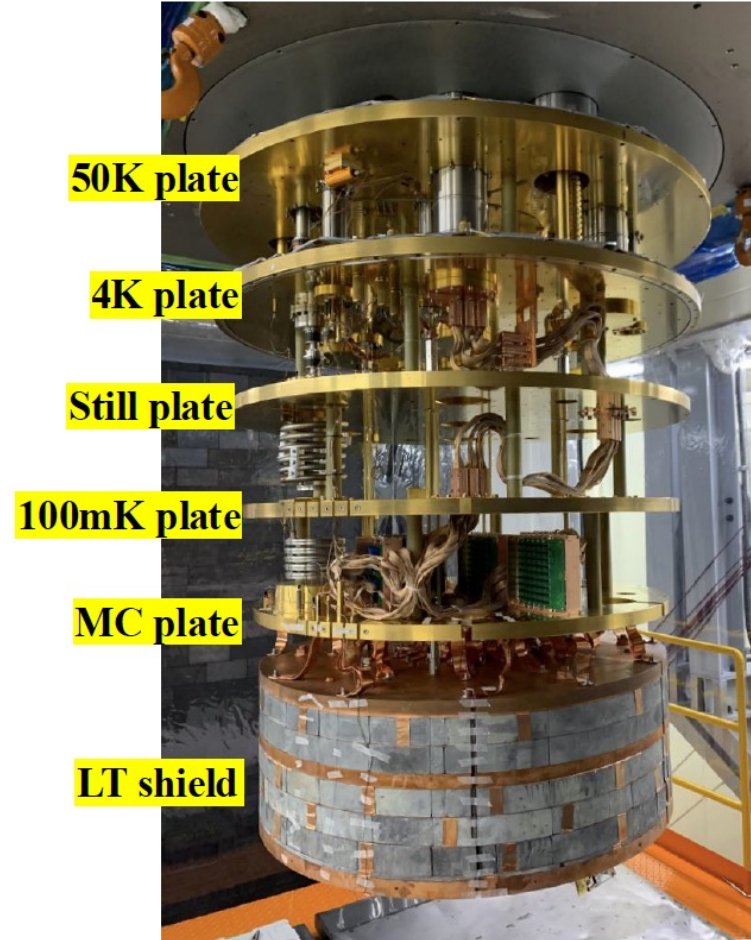
Muon Counter



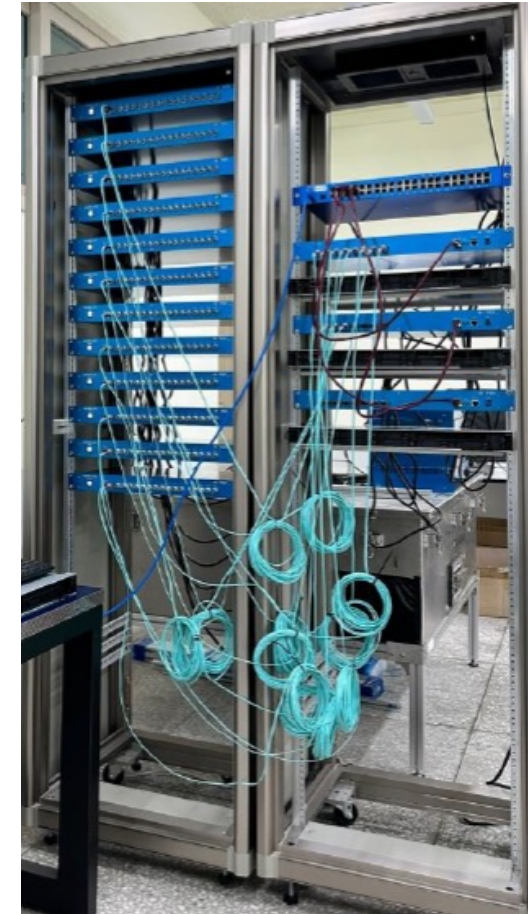
Module design



Cryostat



DAQ



NIMA 1039 (2022) 167123

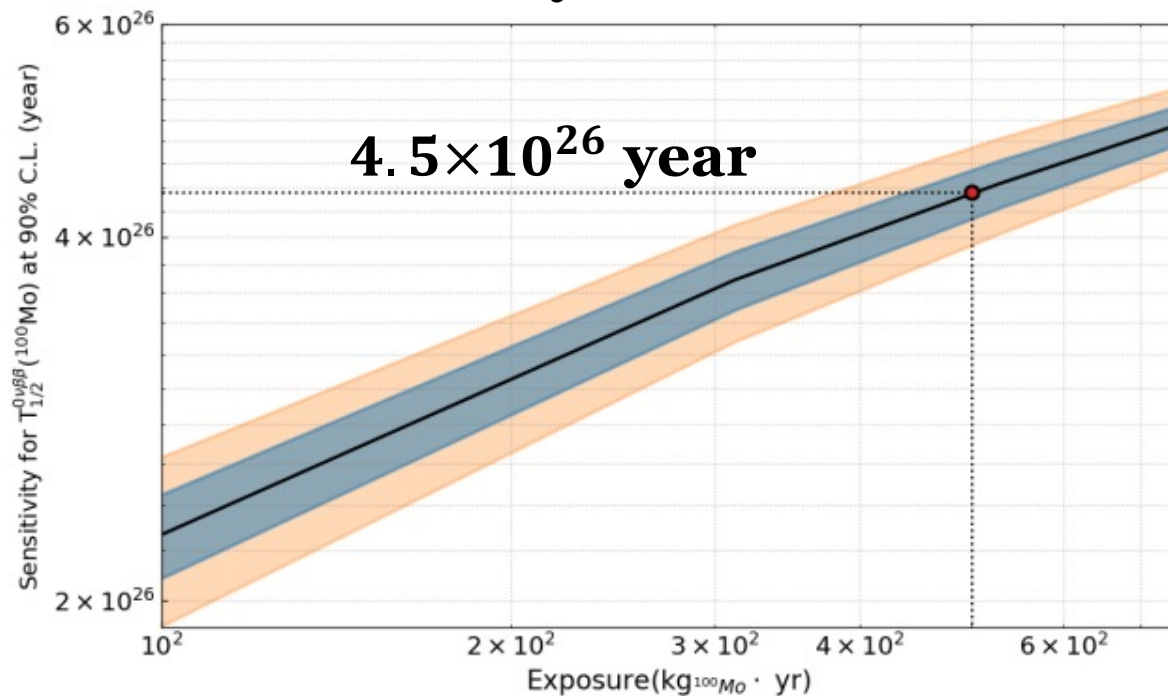
Plan to start the physics run (**Phase-1**) this fall

Phase-2 (full scale) will start in 2027

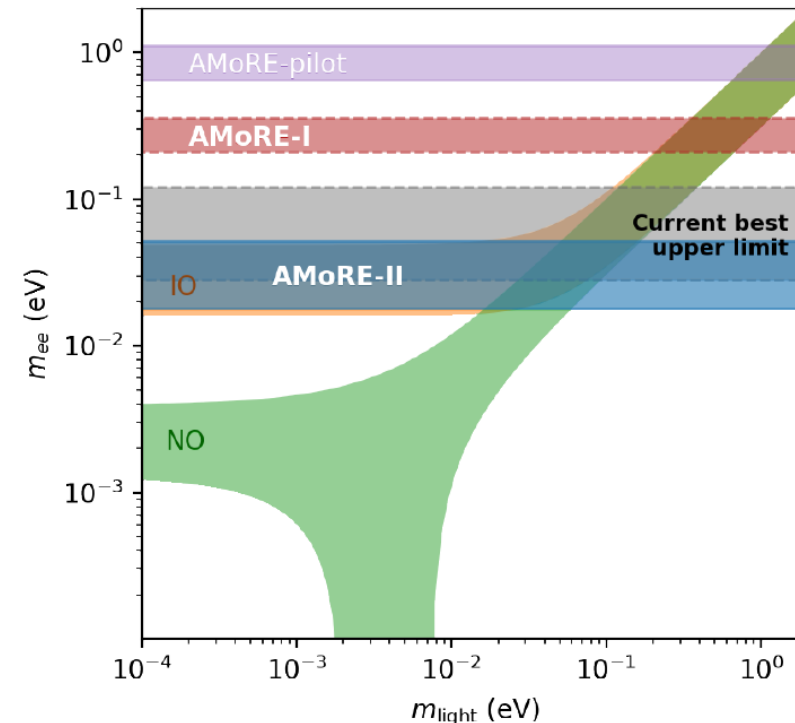
Physics reach of AMoRE-II

- Background assumption : 2×10^{-4} counts/keV/kg/yr,
- FWHM energy resolution ~ 10 keV at ROI
- ~ 5 -year operation (full scale) can cover the inverted mass ordering
[Eur. Phys. J. C 85, 9 \(2025\)](#)

Sensitivity for half-life



Sensitivity for effective neutrino mass



$$\langle m_{\beta\beta} \rangle \sim 18 - 52 \text{ meV}$$

Conclusion

From Y2L to Yemilab — a new era for rare event searches in Korea

- Two decades of underground physics in Korea
 - ❖ KIMS pioneered the field; COSINE-100 **ruled out DAMA/LIBRA** with the same NaI(Tl) target
 - ❖ NEON established a reactor antineutrino program with NaI(Tl) — synergy with COSINE detector R&D
 - ❖ AMoRE-I set the **best half-life limit on $^{100}\text{Mo } 0\nu\beta\beta$** , validating MMC technology
- Yemilab opens new horizons
 - ❖ **1,000 m deep, 3,000 m²** — 15× expansion over Y2L, dedicated to basic science
 - ❖ **COSINE-100U** in physics run since Sep 2025 — targeting low-mass dark matter
 - ❖ **COSINE-200** with new crystals within a few years — expanded searches for low-mass dark matter
 - ❖ **AMoRE-II** Phase-1 this fall, Phase-2 in 2027 — to cover the **inverted mass ordering**
- What's next
 - ❖ **World-unique low-background scintillation crystals** for uncovered area of dark matter and neutrino
 - ❖ Yemilab as an **international hub for next-generation dark sector & neutrino physics**