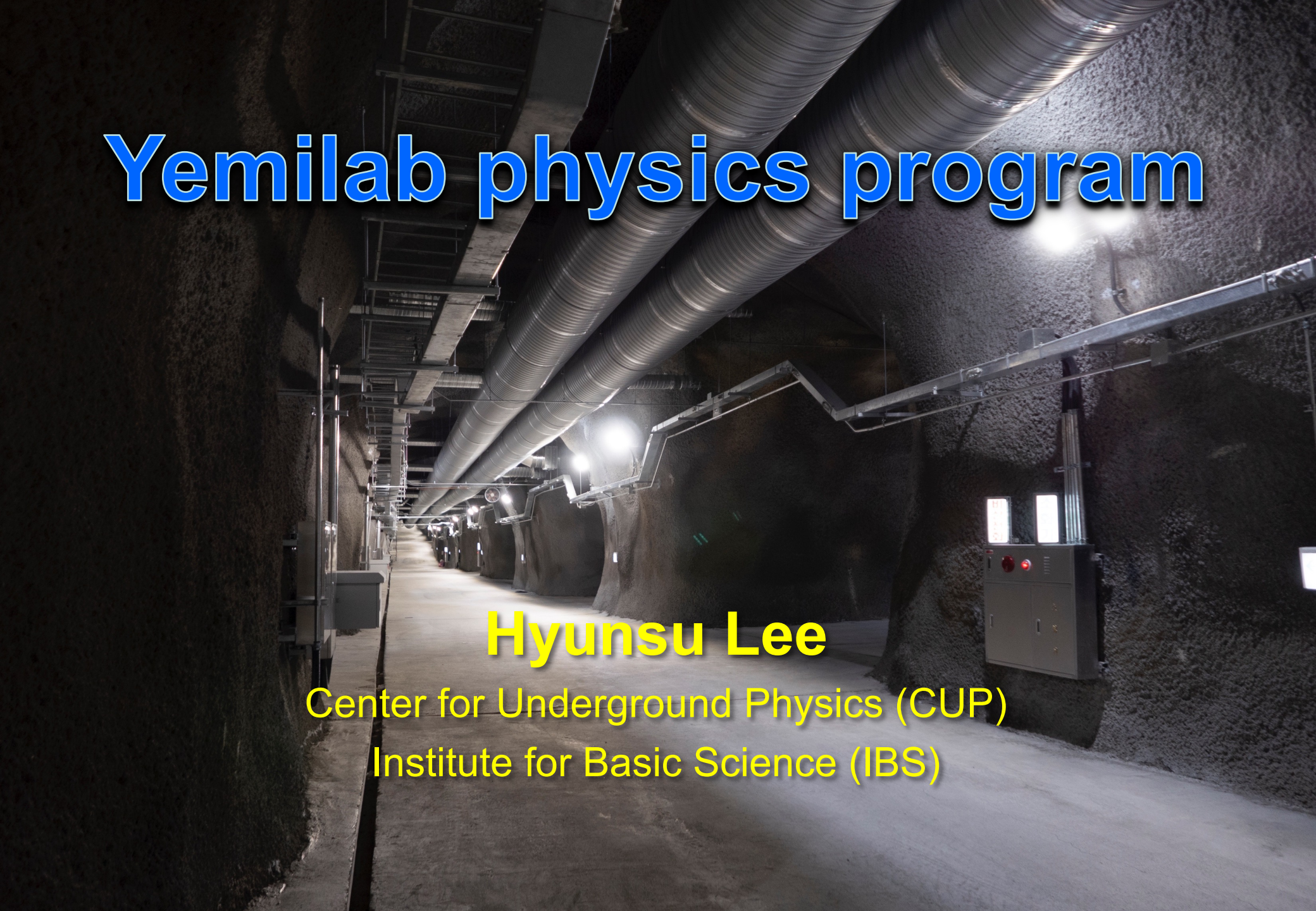


Yemilab physics program

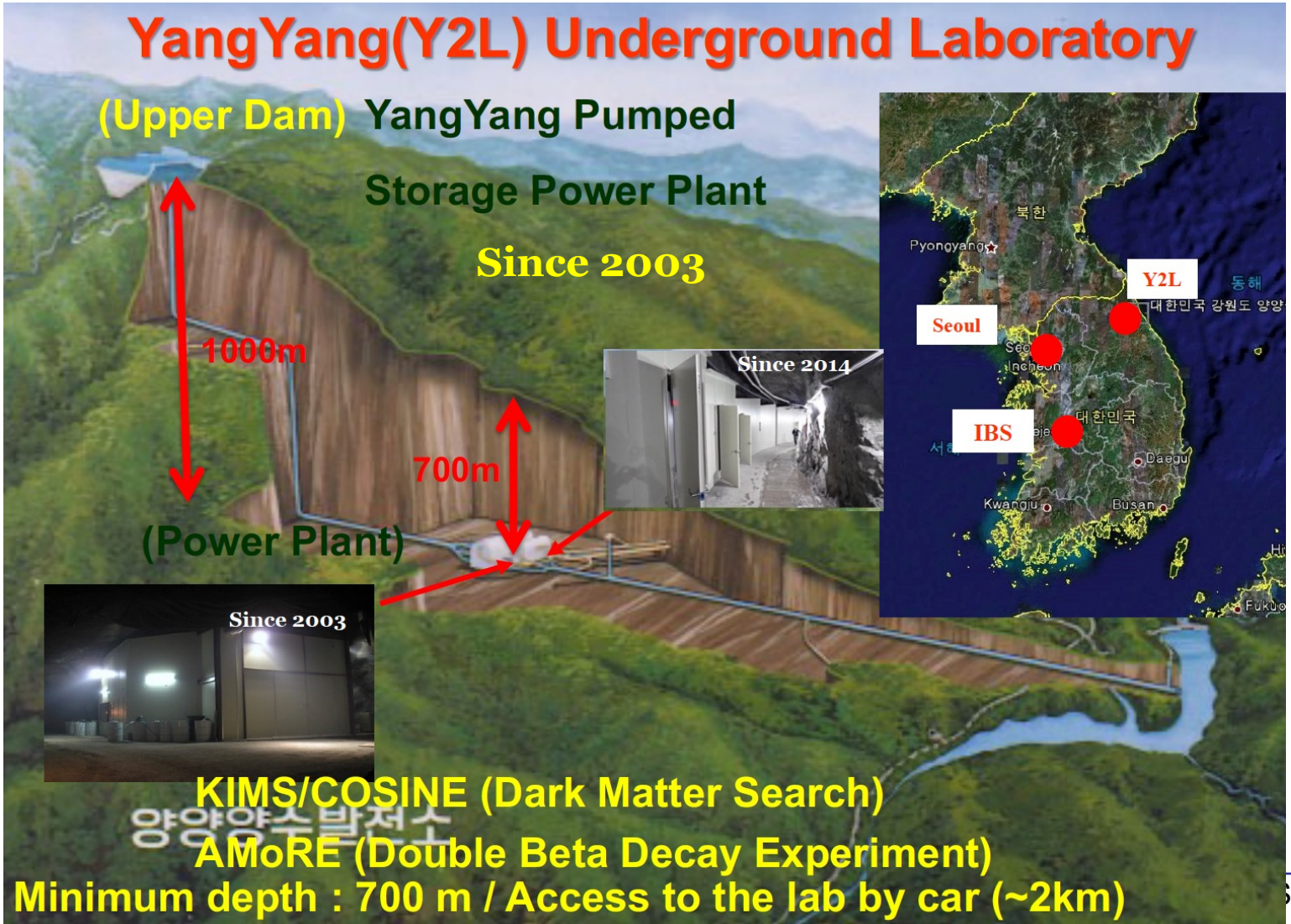
Hyunsu Lee

Center for Underground Physics (CUP)

Institute for Basic Science (IBS)

Introduction

- Korea has Yangyang underground laboratory (Y2L) with about 200m^2 space since 2003. **20 years anniversary!!!**



KIMS (2003-2012)

COSINE-100 (2015-2023)

AMoRE-pilot, I (2015-2023)

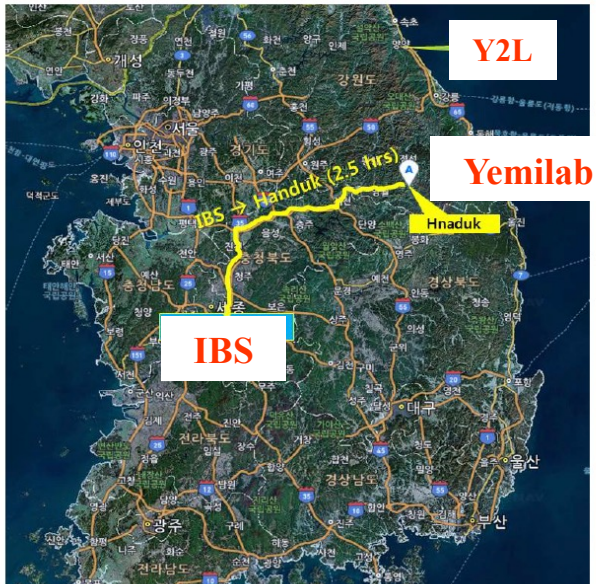
Shallow depth

No expendable

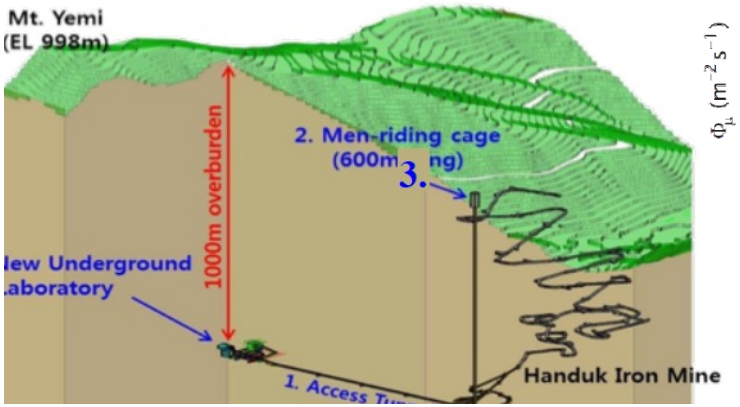
Yemilab for new discoveries

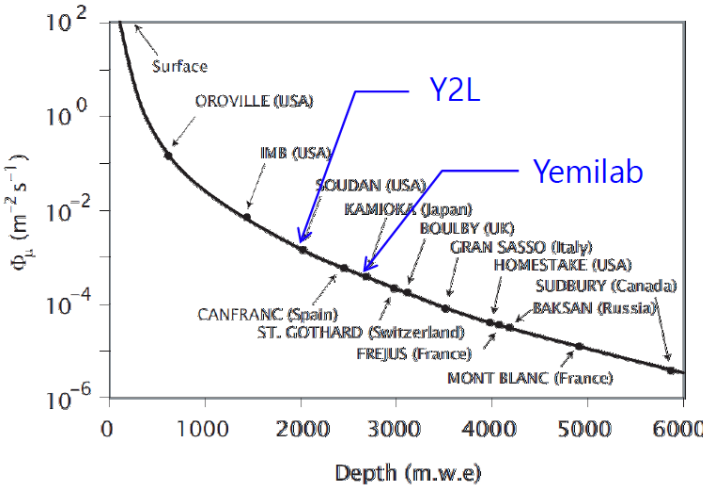
- New underground laboratory in Korea is one of the most important milestone of the **CUP/IBS** – 10 years journey

Handeok iron mine, Jeongseon, Gangwon, Korea

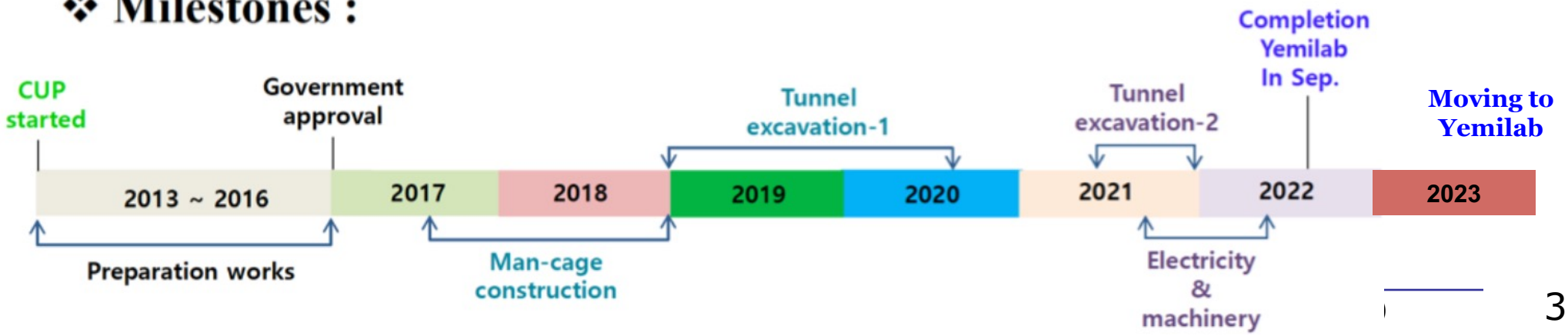


- 1000 meter underground.
- Construction cost ~30 M$
- 2018-2022



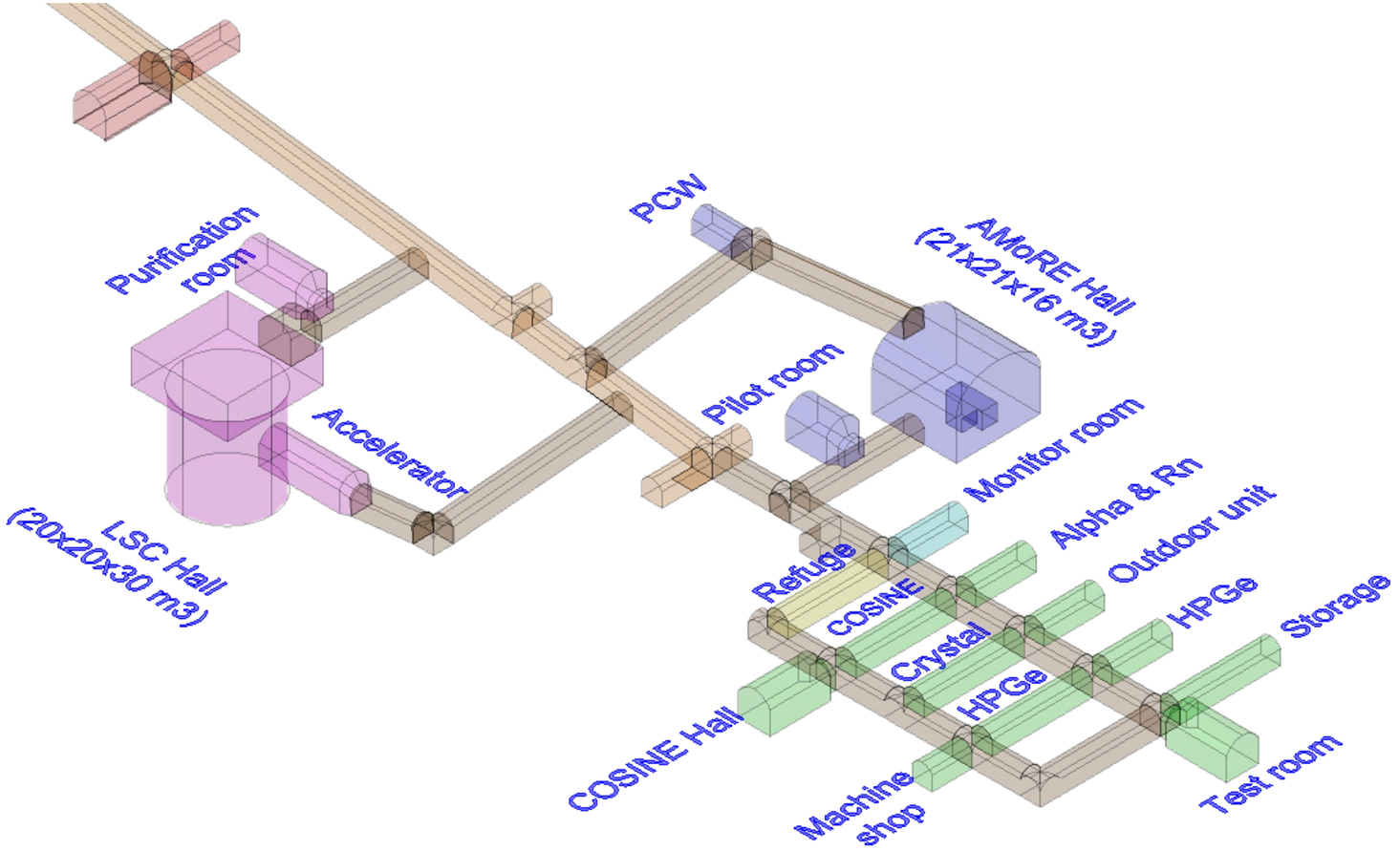


❖ Milestones :



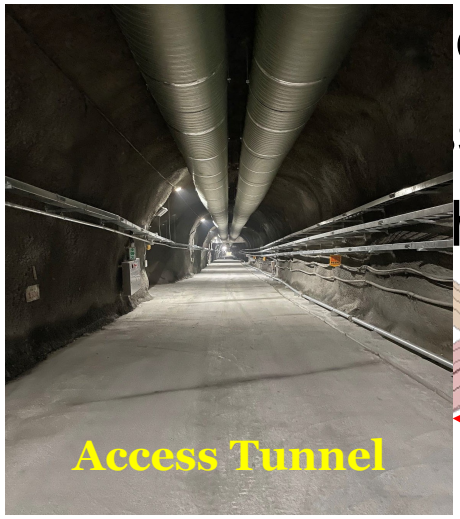
Yemilab

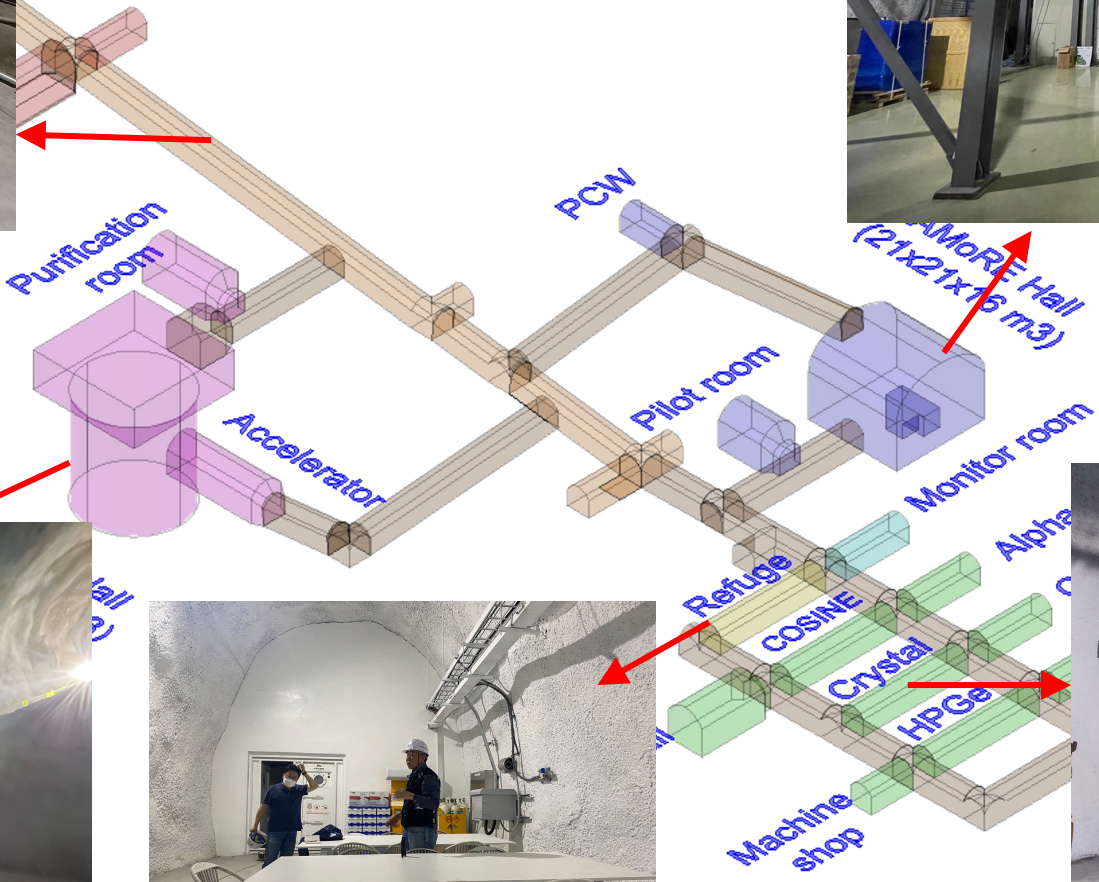
- ~1000 m depth, more than 3000 m^2 space
- Two access ways, ramp-way (30 min) and elevator (3 min)
- Open to other researchers



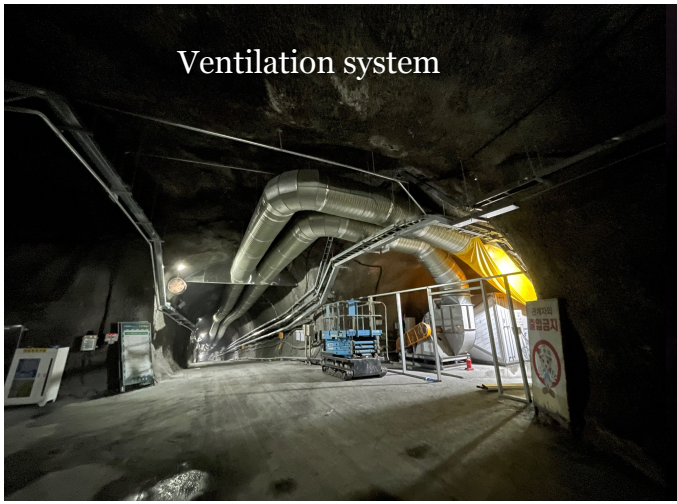
Yemilab

epth, more than 3000 m^2 spa
s ways, ramp-way (30 min) a
her researchers



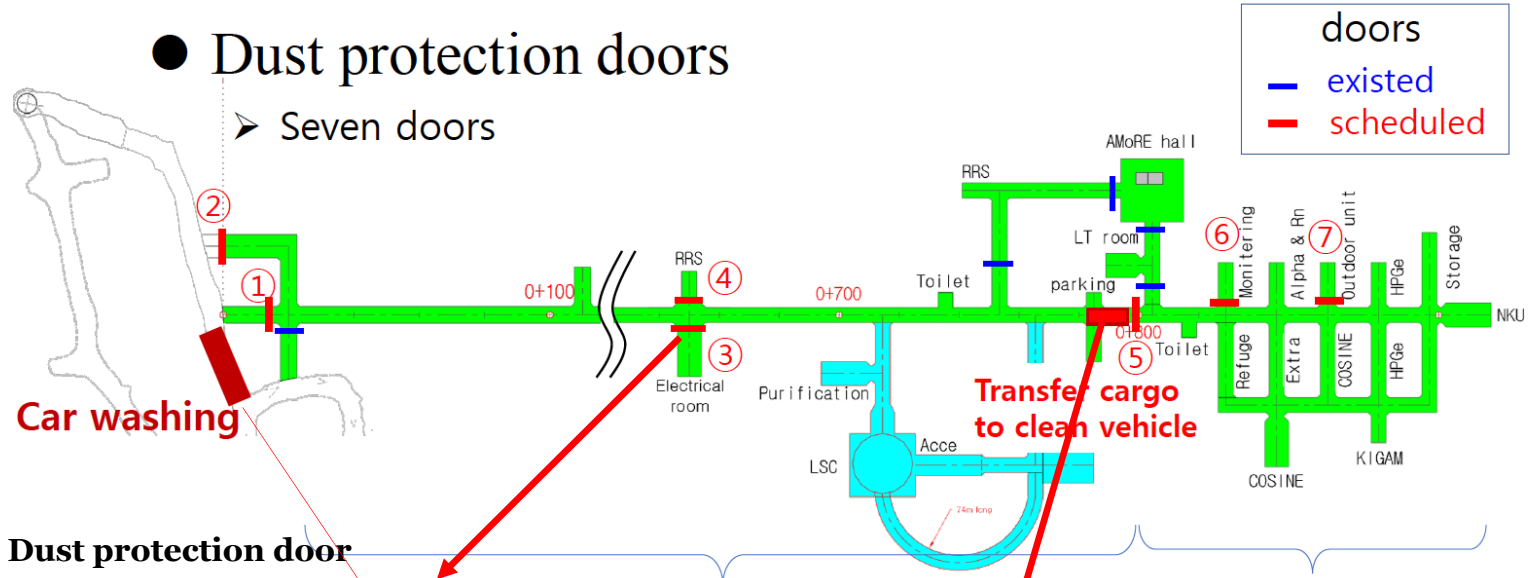


Underground facilities



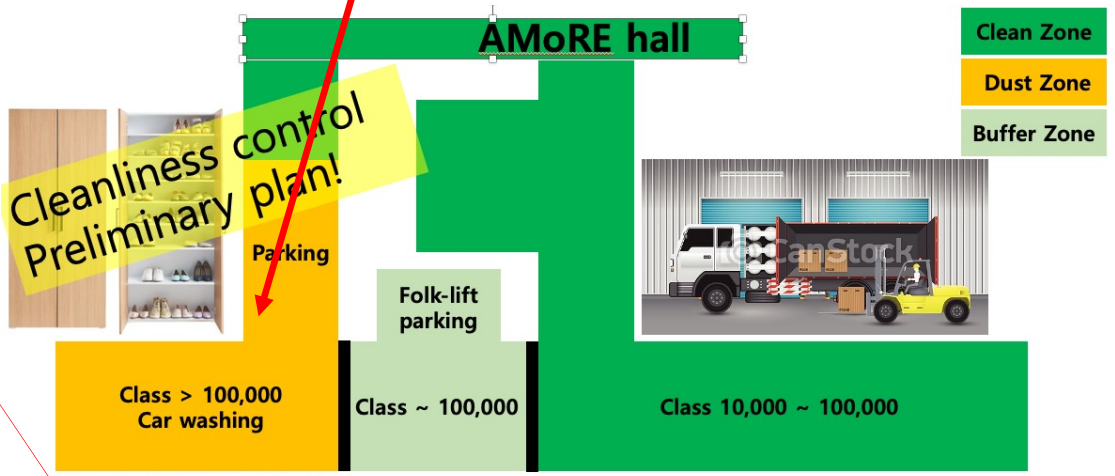
Clean environment concept at Yemilab

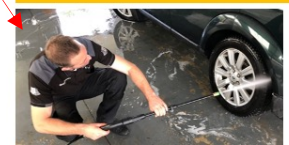
- Dust protection doors
  - Seven doors



Dust protection door

Protected area

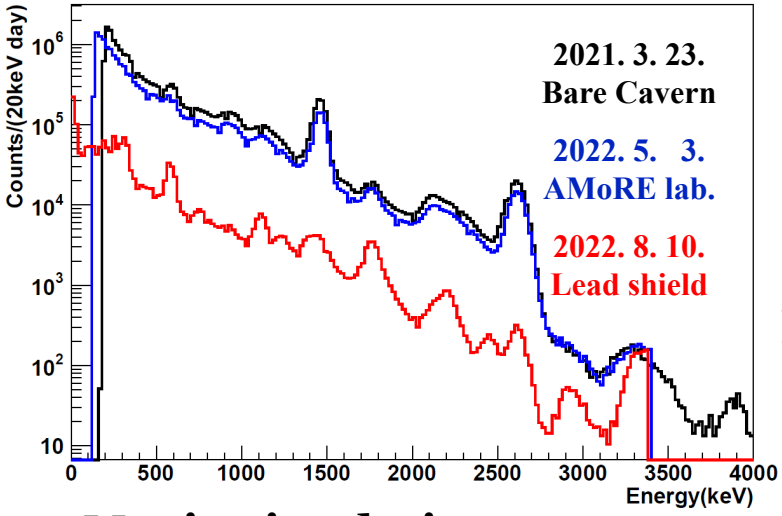




1. **Safety clothing** change to **lab clothing**
   - **Safety clothing : helmet, safety shoes, long jacket and pants**
   - **Lab clothing : free helmet, lab shoes**
2. **Cargo transferring** by trailer from clean zone

Environmental measurement and monitoring

Gamma background with NaI(Tl)



ICP-MS/HPGe measurements of rock and dust samples

	238U	232Th	40K
Rock (lab)	10.4Bq/kg	13.3Bq/kg	366Bq/kg
Dust (cage)	24.6Bq/kg	15.2Bq/kg	226Bq/kg
Dust (lab)	25.0Bq/kg	23.1Bq/kg	407Bq/kg

Neutron and muon flux measurements are ongoing

Monitoring device

Temperature & Humidity

Radon

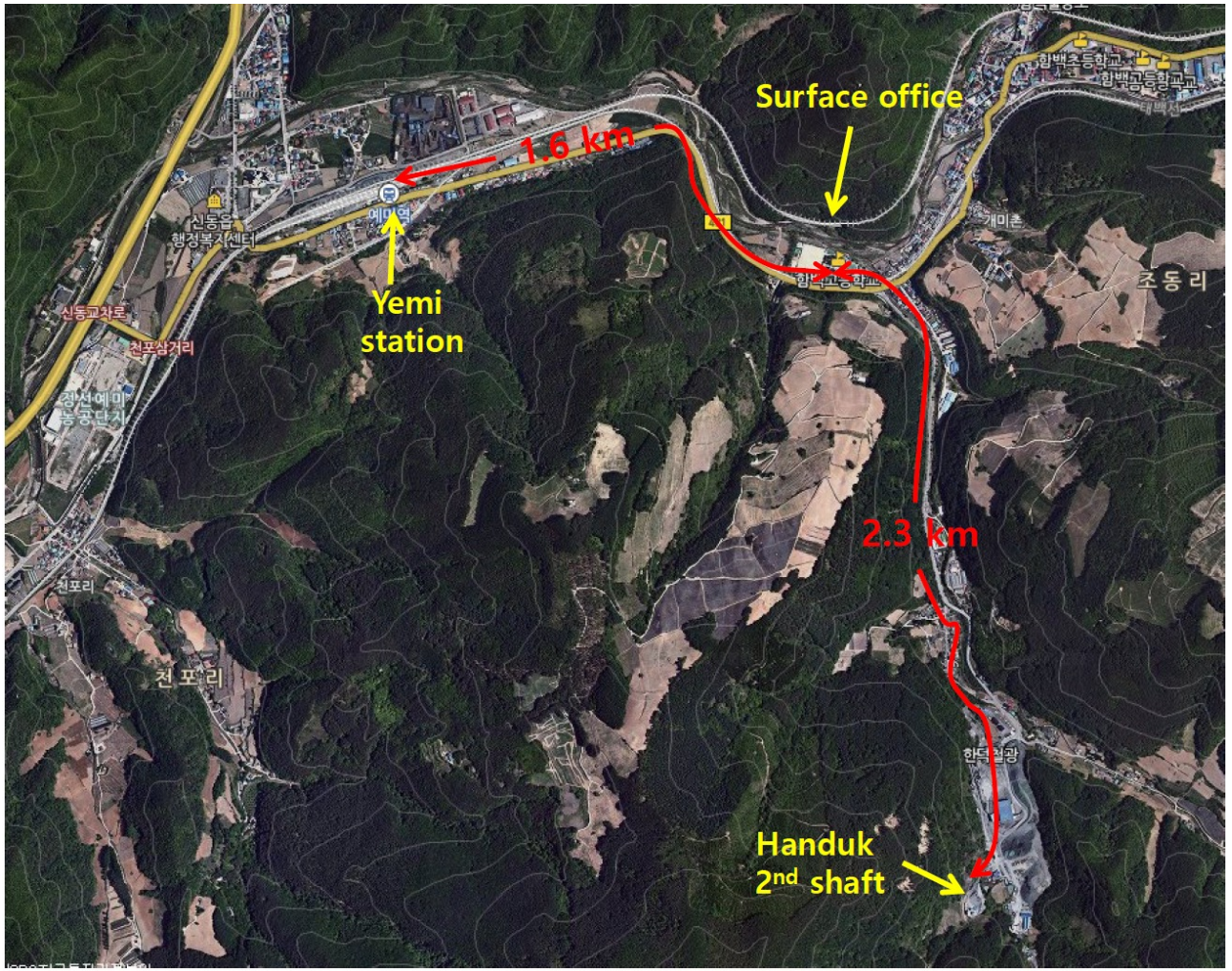
Dust level

CO, CO2, and O2

Online monitoring

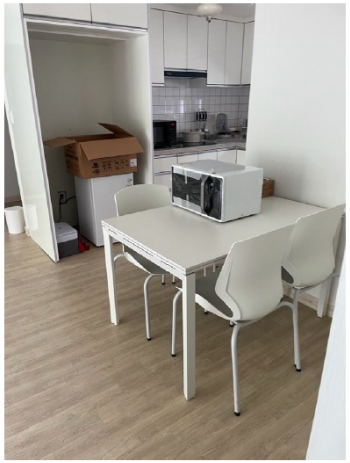
Yemilab ground

Yemilab ground



Yemilab ground

Jeonseon-gun (local city) provide 12 houses apartment



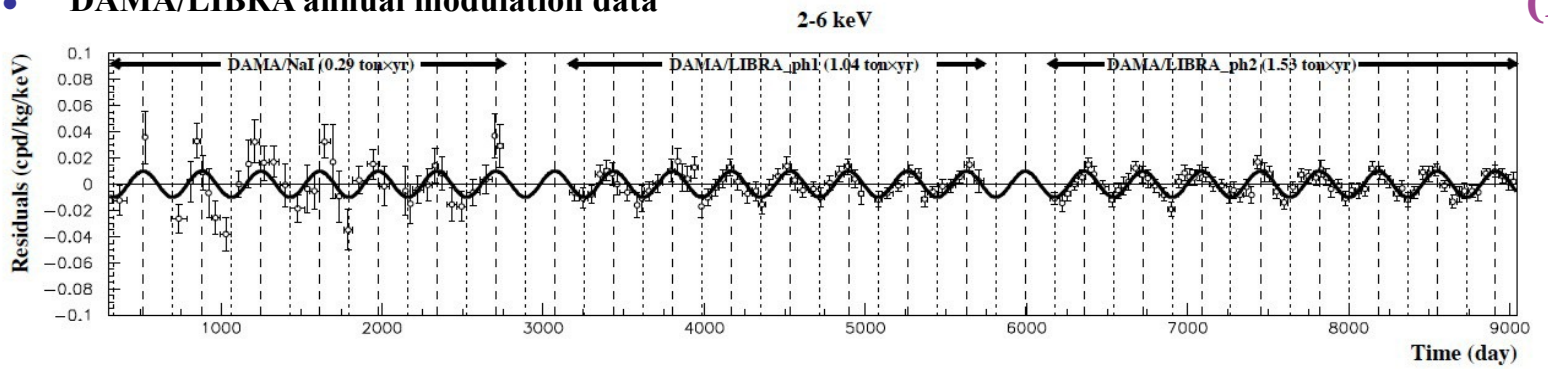
Physics program at Yemilab

COSINE-100 (2016-2023) @ Y2L

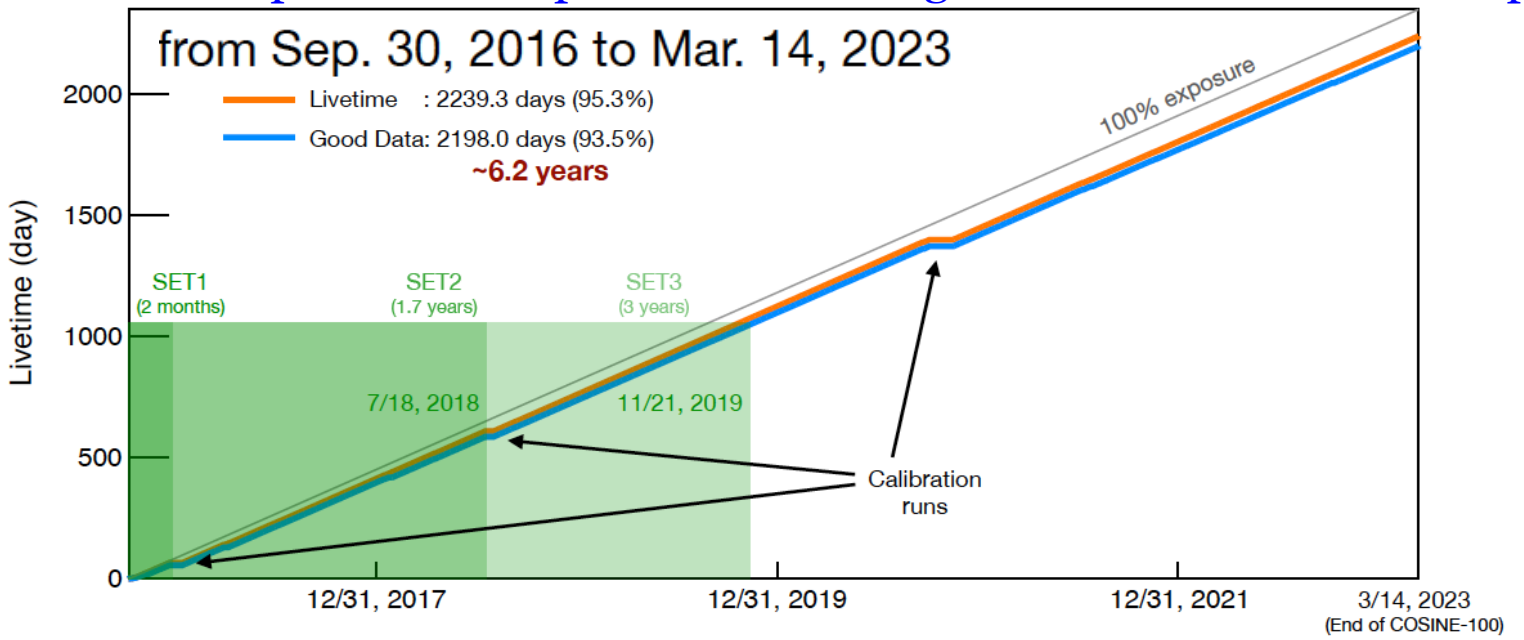
- To verify the DAMA/LIBRA conundrum

Youngju's talk (Monday)

- **DAMA/LIBRA annual modulation data**

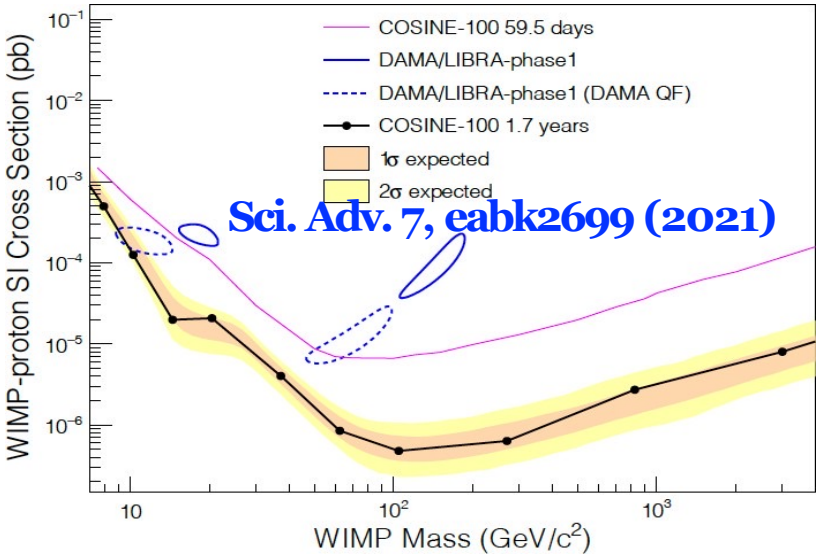


COSINE-100 operation was paused for moving to Yemilab and detector upgrades

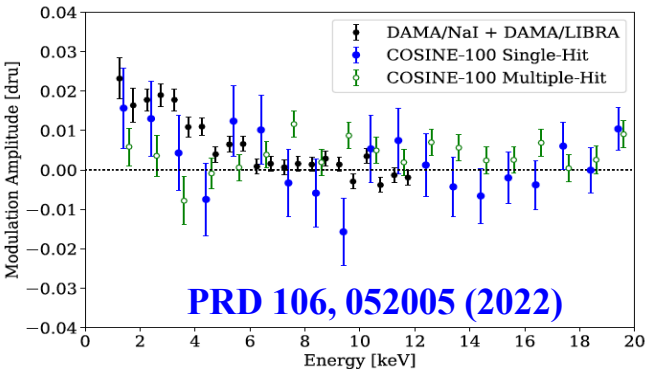


COSINE-100 results testing DAMA/LIBRA

WIMP-nucleus recoil



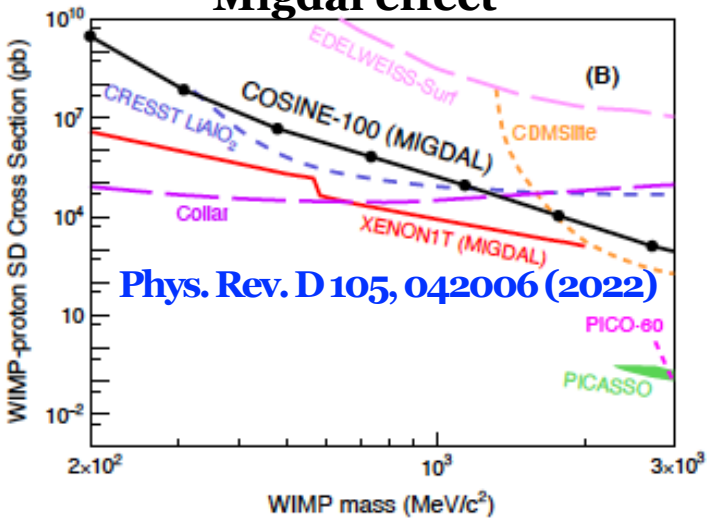
Annual modulation



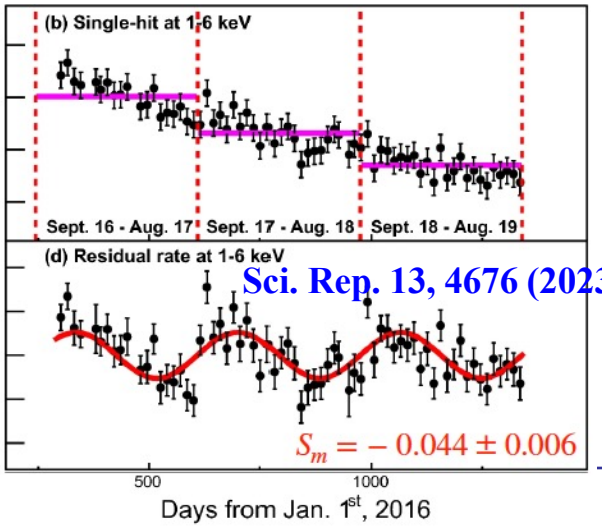
1-6 keV modulation amplitude

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

Migdal effect

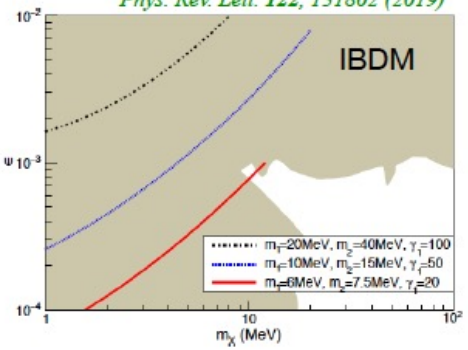


DAMA/LIBRA's analysis method

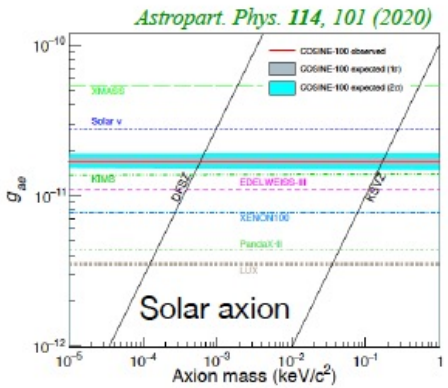


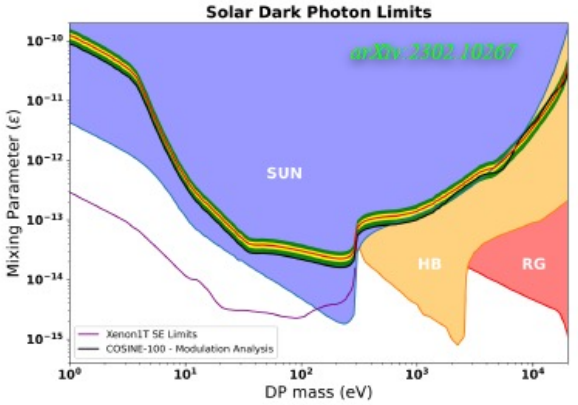
COSINE-100 to search dark sector particles

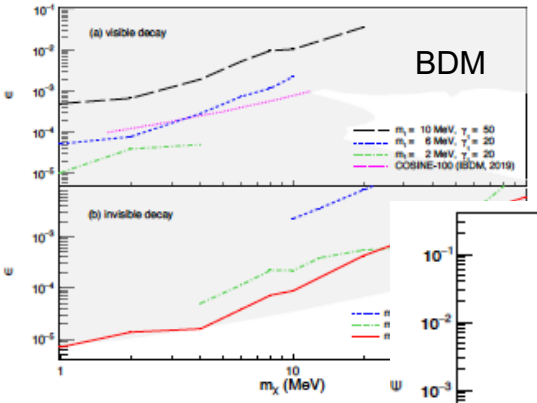
Phys. Rev. Lett. 122, 131802 (2019)



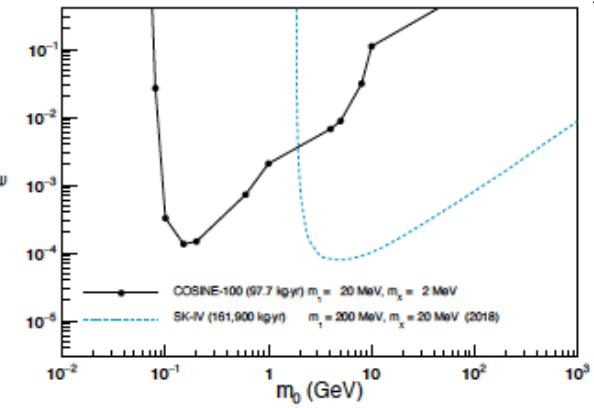
Astropart. Phys. 114, 101 (2020)





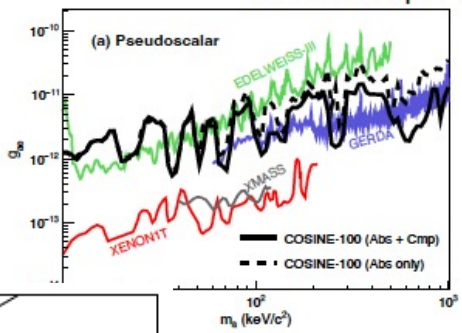


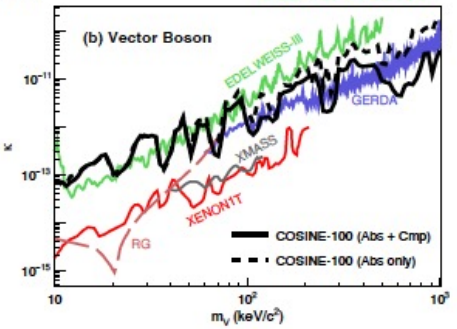
arXiv:2306.00322



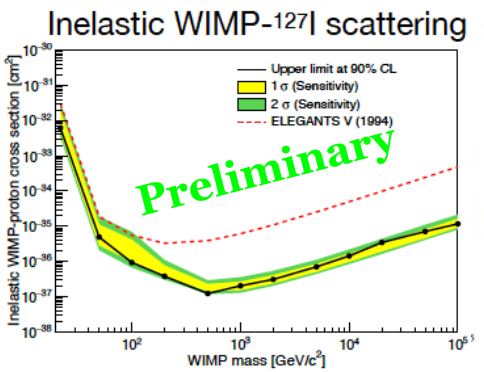
Bosonic super-WIMP

arXiv:2304.01460

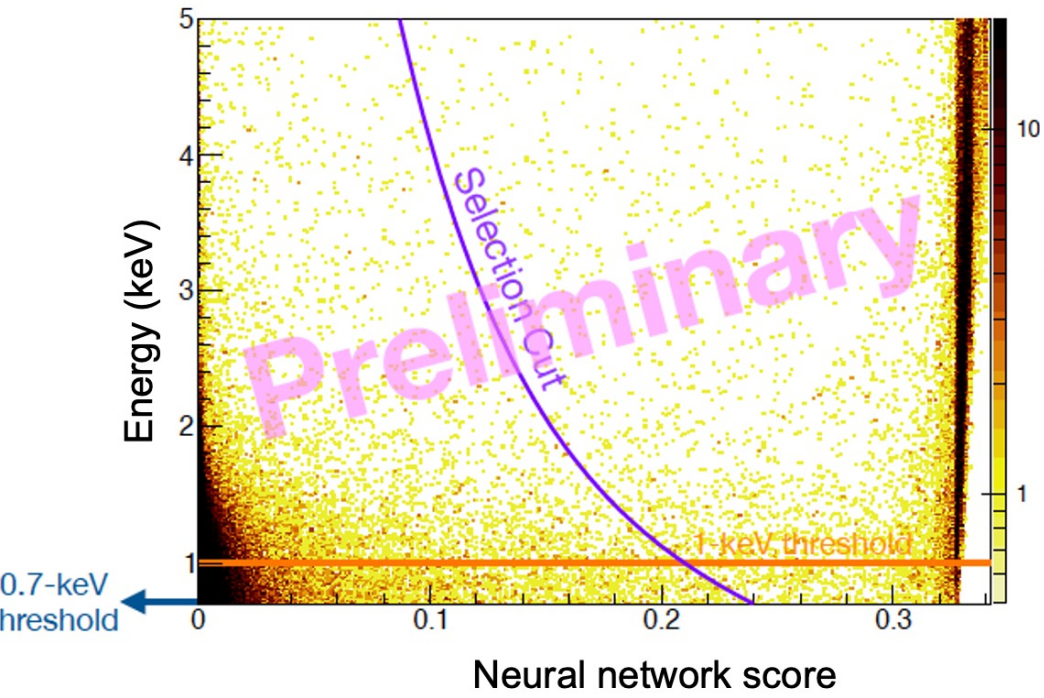




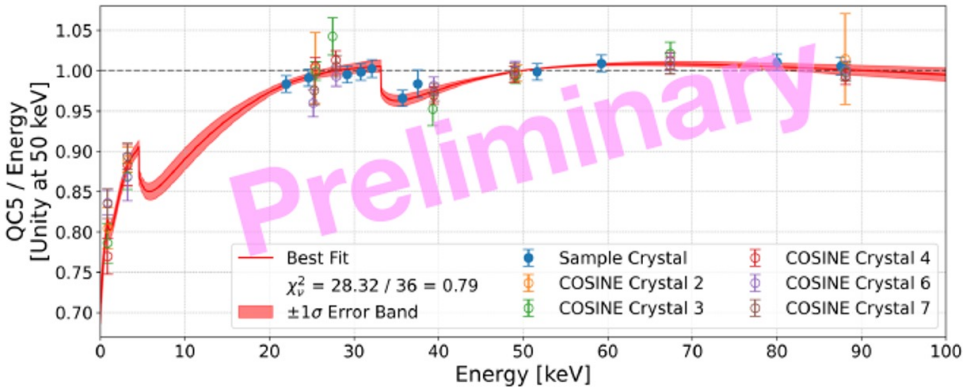
Inelastic WIMP-^{127}I scattering



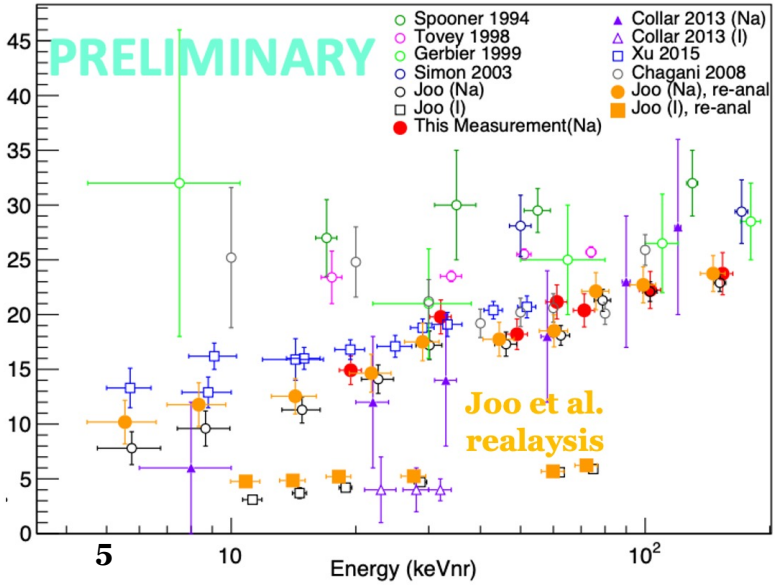
Understanding low energy detector response



Nonproportionality of NaI(Tl) for γ or x-ray

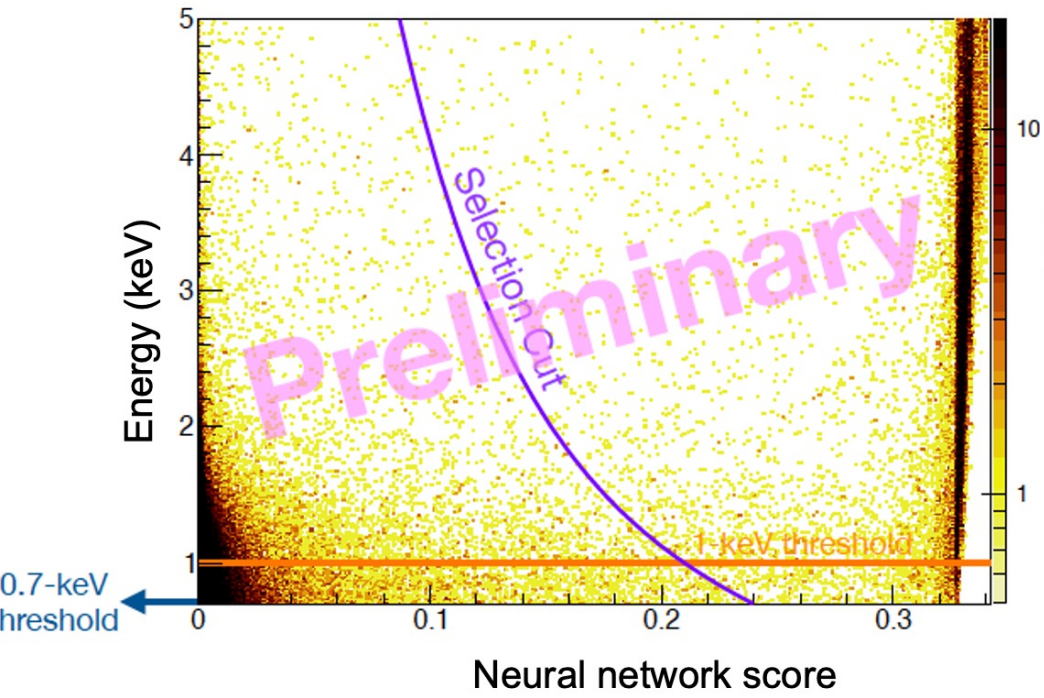


Nuclear recoil quenching factor

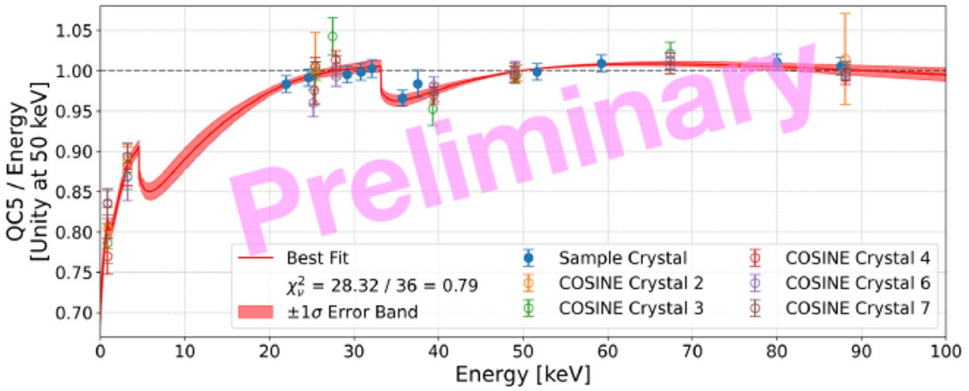


- Improving low-energy selection using neutral network and reduce the analysis threshold to 0.7 keVee
- Low-energy calibration for the electron recoil (keVee) and the nuclear recoil (keVnr)
  - ❖ Make ready for low-mass DM search

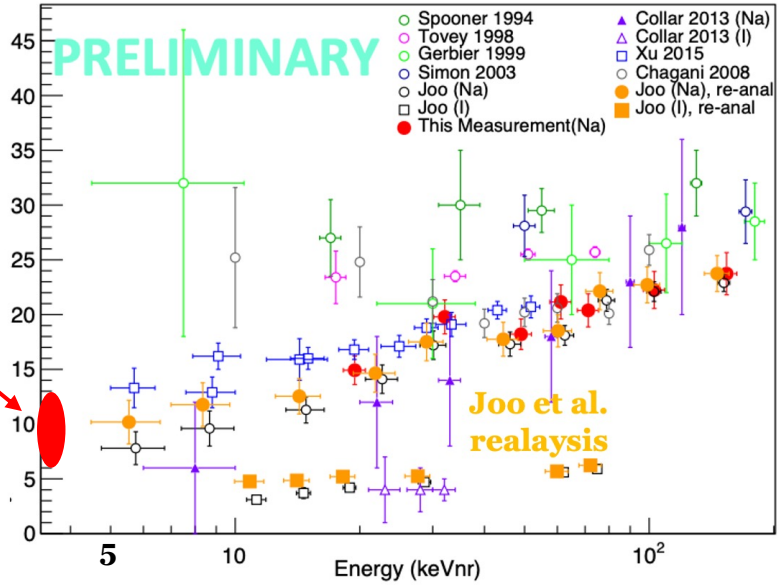
Understanding low energy detector response



Nonproportionality of NaI(Tl) for γ or x-ray

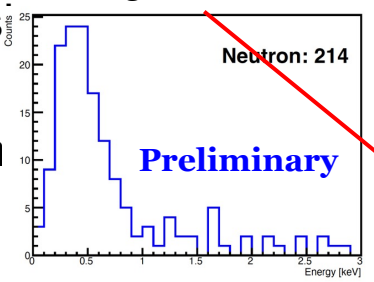


Nuclear recoil quenching factor



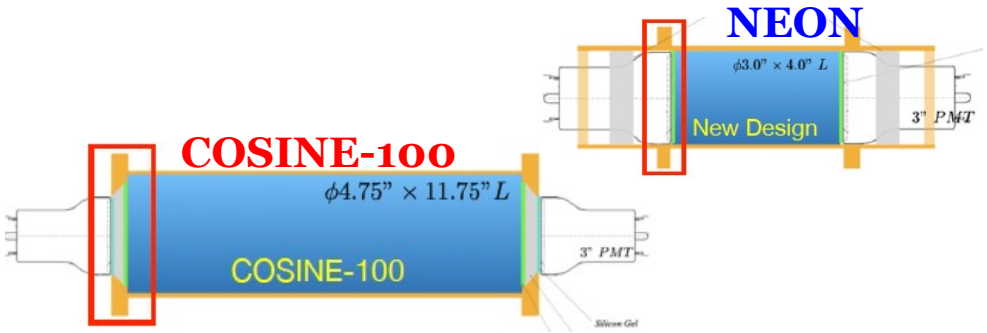
- Improving low-energy selection using neutral network and reduce the analysis threshold to 0.7 keVee
- Low-energy calibration for the electron recoil (keVee) and the nuclear recoil (keVnr)
  - Make ready for low-mass DM search

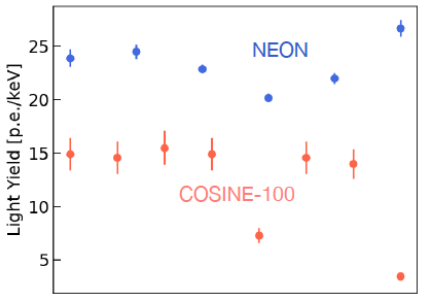
3.6 keVnr



COSINE-100U (upgrade) @ Yemilab

- Novel technique of crystal encapsulation (applied to NEON)

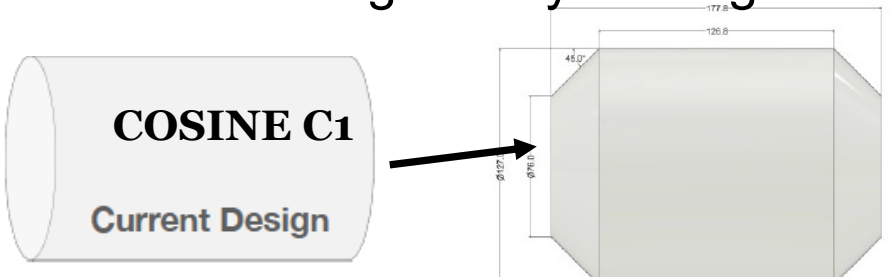


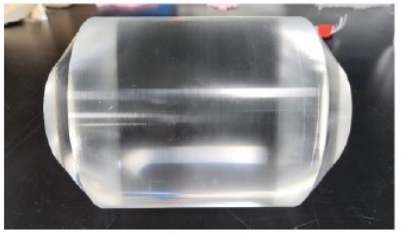


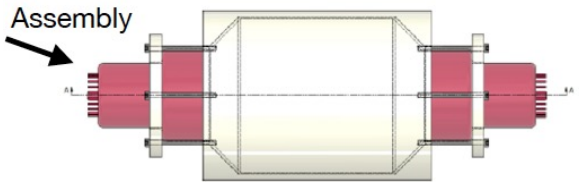
NIMA 981, 164556 (2020)

Jaejin's talk (Monday)

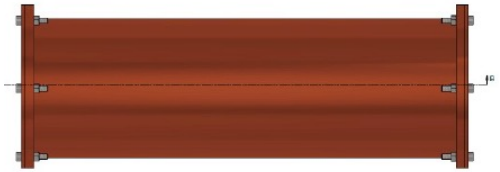
Machining the crystal edges to couple with 3" PMTs

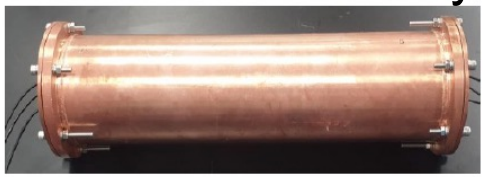


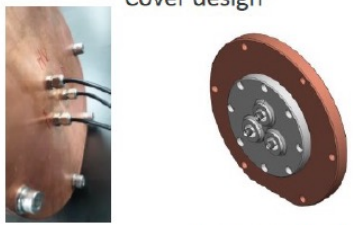




Direct attachment of PMTs to the crystal





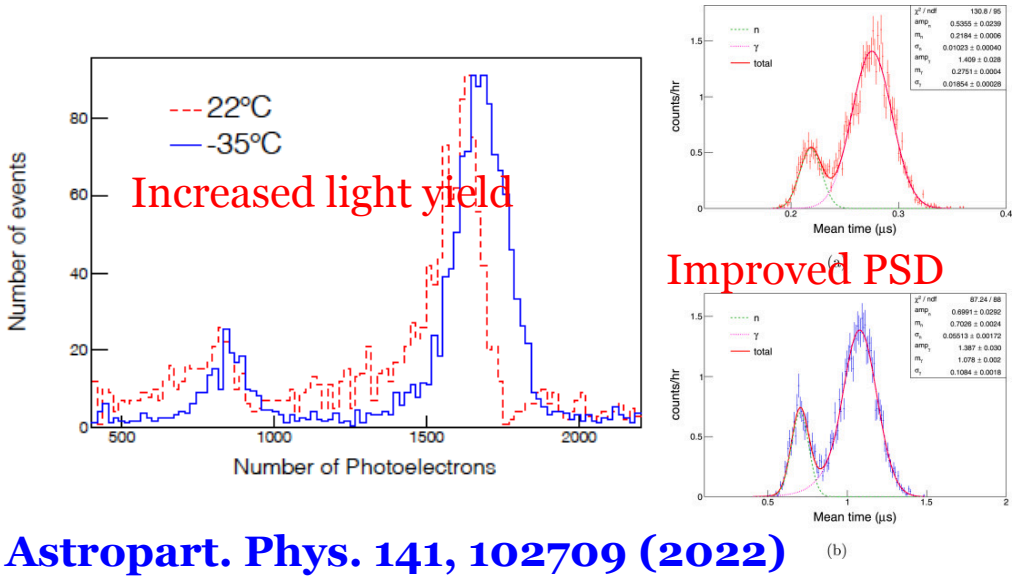


Increased light yield above 20 photoelectrons/keV expected

Similar design was applied to NEON experiment and proved the long-term stability

-35°C operation at Yemilab

-35°C operation



Astropart. Phys. 141, 102709 (2022)

- 5% gamma light yield increase
- 10% alpha quenching increase
  - ❖ Will measure nuclear recoil quenching
- Pulse shape discrimination is significantly improved

Warehouse freezer at Yemilab

Shielding base for muon detector

To start COSINE-100U at Yemilab October/2023

COSINE-200 crystal development

Powder purification performance

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

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

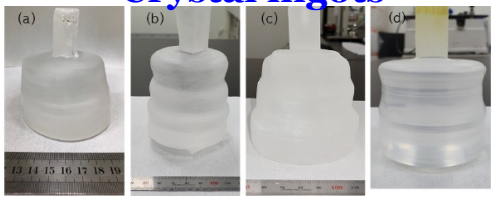
K.A. Shin et al., Front. Phys. 11, 1142849 (2023)

	K (ppb)	Pb (ppb)	U (ppb)	Th (ppb)
Initial NaI	248	19.0	<0.01	<0.01
Purified NaI	<16	0.4	<0.01	<0.01

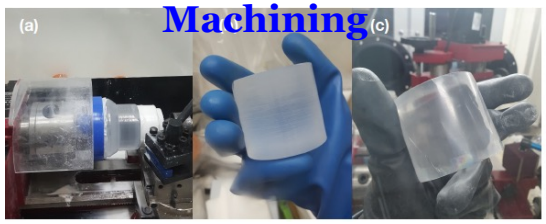
We produced ~ 400 kg low-background NaI powder

(Maximum production rate ~ 100 kg/month)

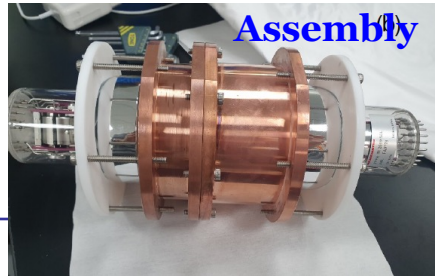
Crystal ingots

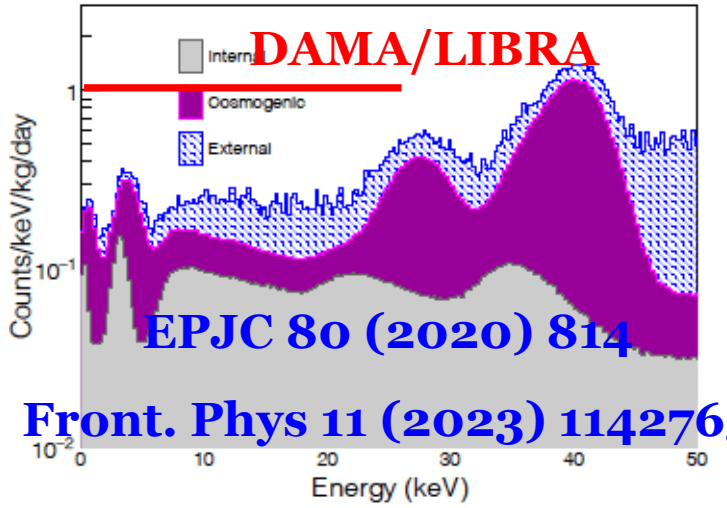


Machining



Assembly



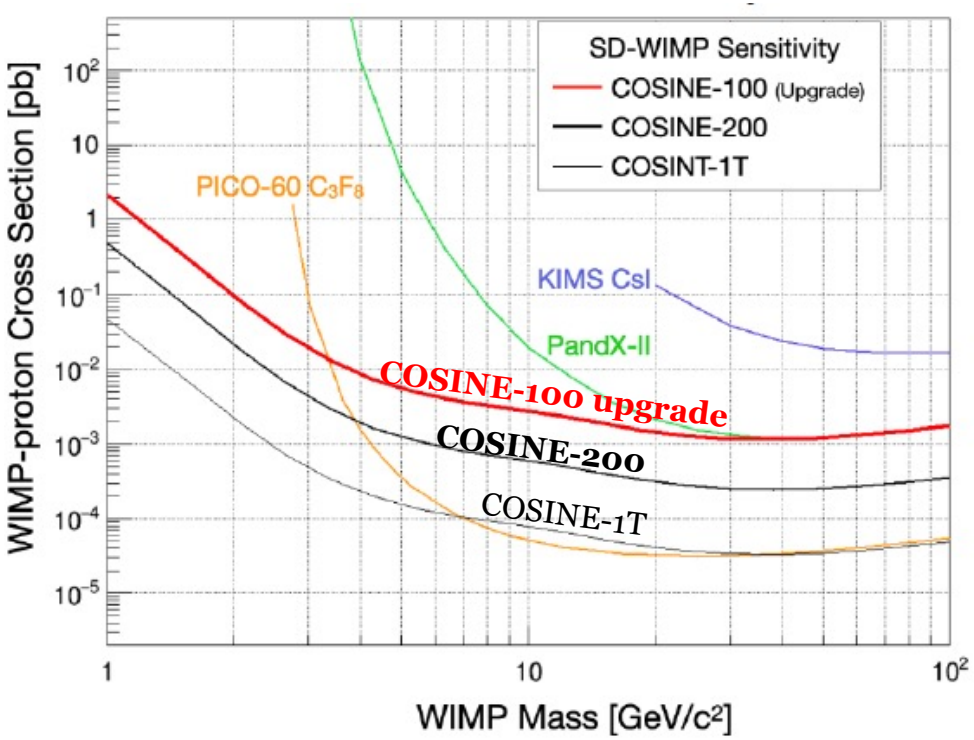


A proof of principle for low background NaI

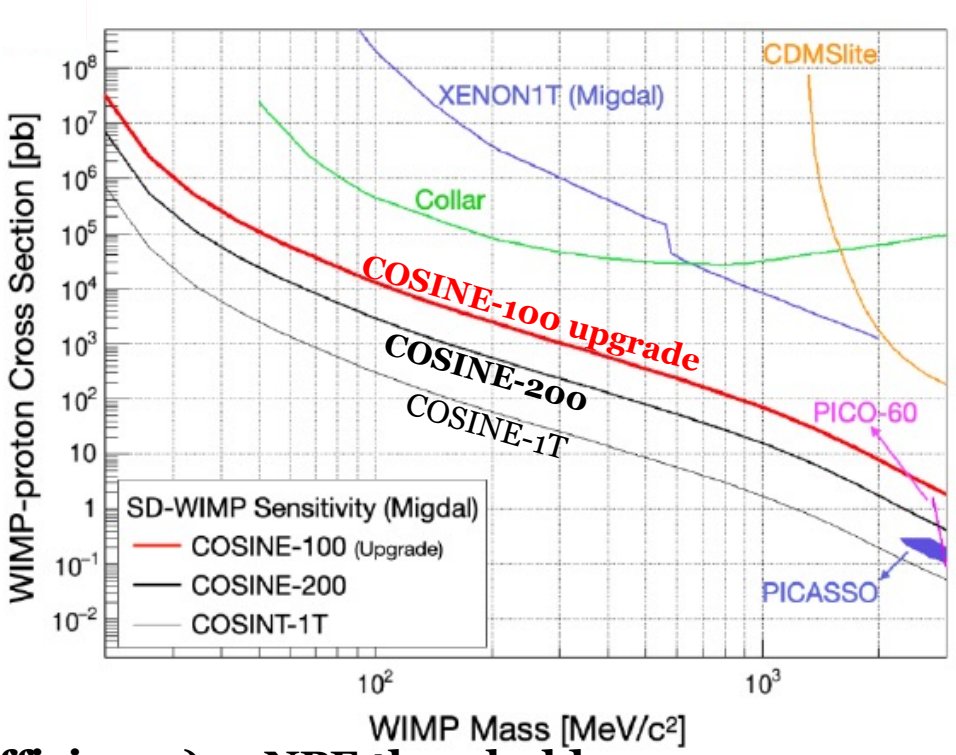
Large crystal growing is going on

COSINE-100U sensitivities

WIMP-proton spin-dependent



Low mass search with Migdal



22 NPE/keV, 1 year operation (100% efficiency), 5 NPE threshold

- A world best sensitive detector for low-mass WIMP-proton spin-dependent interaction
- Feasibility test for the COSINE-200 & 1T experiments

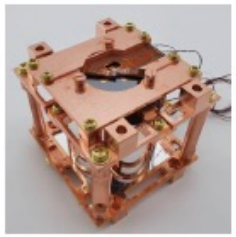
AMoRE experiment

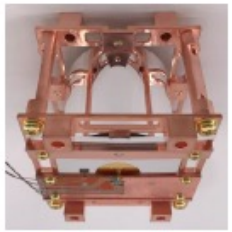
Simultaneous detection of heat/light signals

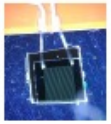
To observed the neutrinoless double beta decay of ^{100}Mo

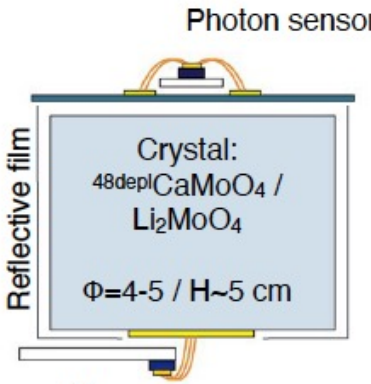
Yoomin's talk (Monday)

- Metallic magnetic calorimeter (MMC) and SQUID:
  - Fast signal response ➔ less random coincidence (pile-up) bkg.
  - Energy resolution ~ 10 keV FWHM at 2.6 MeV.
- Operation at 10-20 mK temperature for AMoRE.

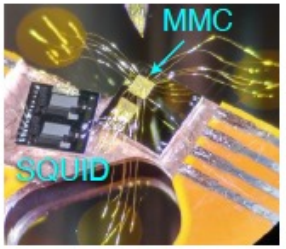






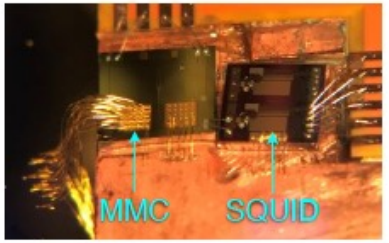


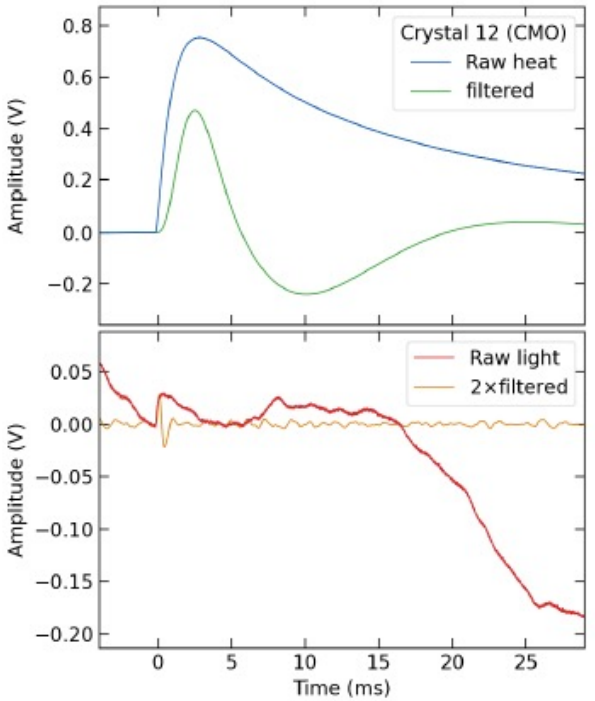
Light absorber (Ge/Si wafer)



Stabilization heater

Phonon collector (Au/Au film)



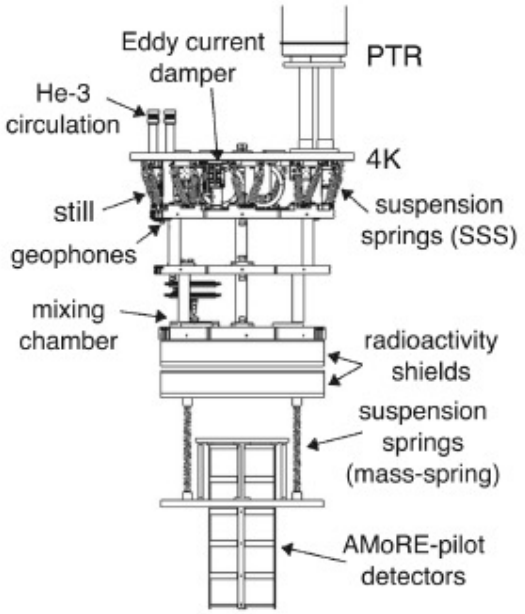


AMoRE-pilot @ Y2L

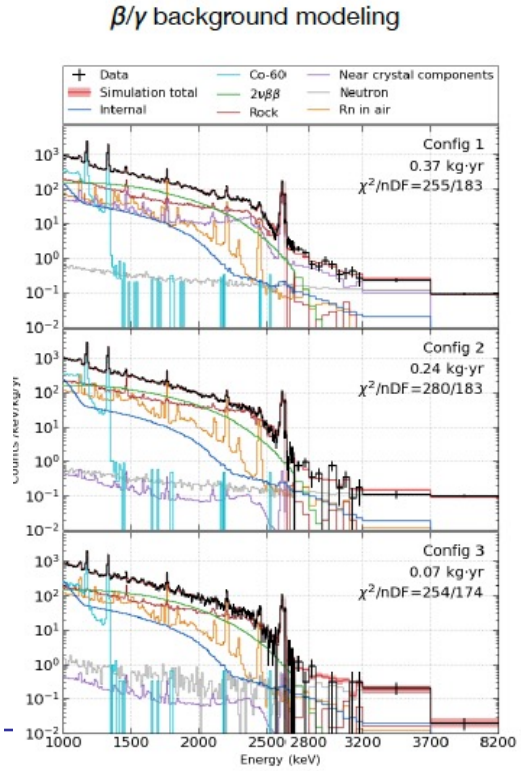
- 6 $Ca^{100}MoO_4$ crystals (1.9 kg)
- Operated 2015-2018
- Understand vibration noise
- Understand radioactive backgrounds

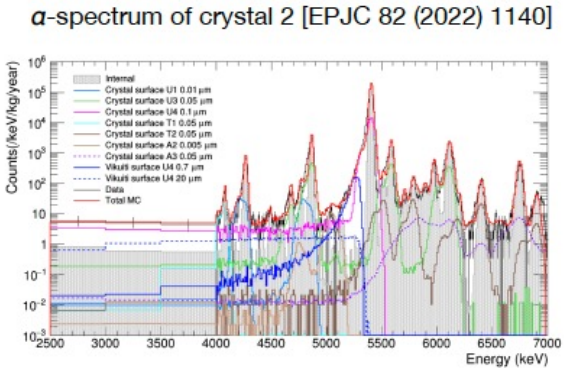
0.5 ckky(counts/kg/keV/year) @ ROI

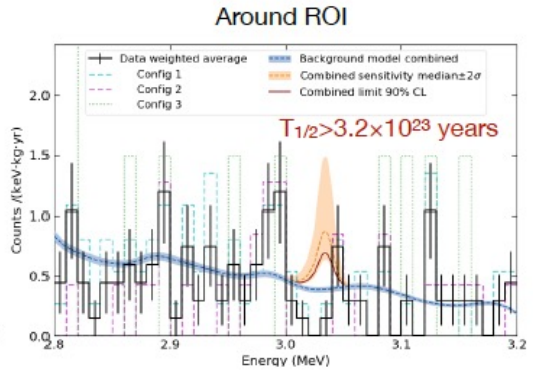
- $T_{1/2} > 3.2\times10^{23}$ years

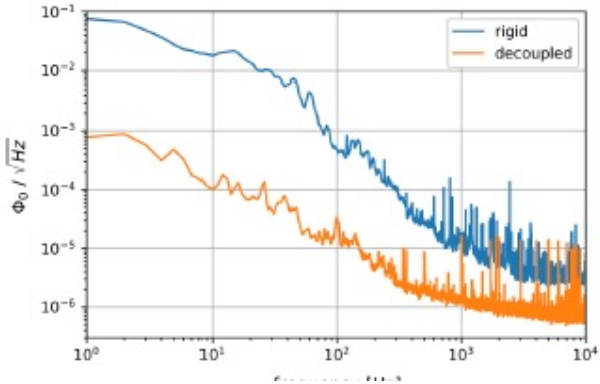


JLTP 193 (2018) 786-792



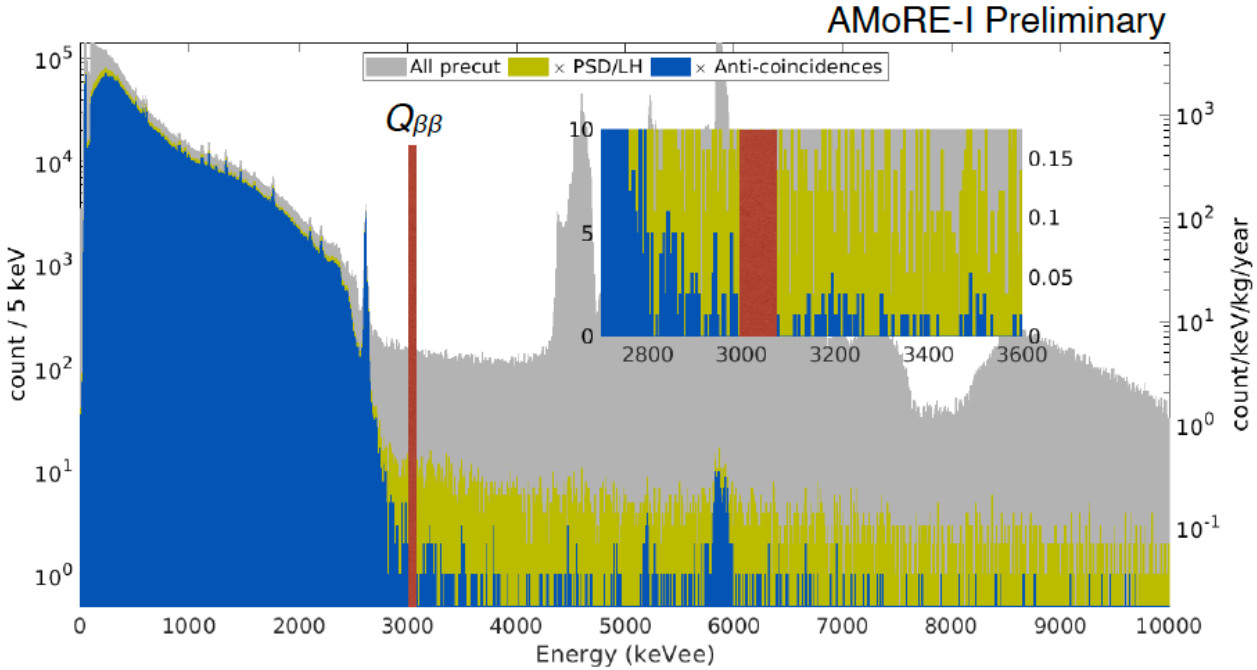


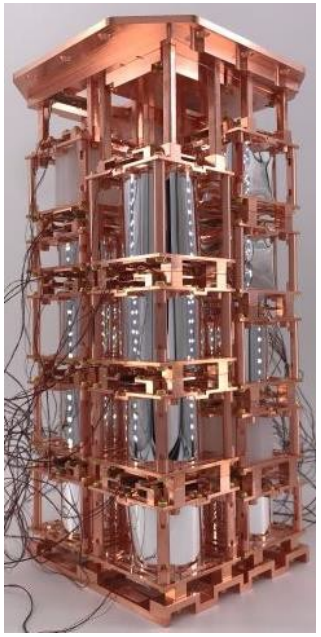




AMoRE-I progress

- **AMoRE-I began Aug. 2020 @ Y2L and runs stably until May/2023**
- 13 $Ca^{100}MoO_4$ crystals and 5 $Li_2{}^{100}MoO_4$ crystals, ~6 kg (3 kg of ^{100}Mo)





Full data set

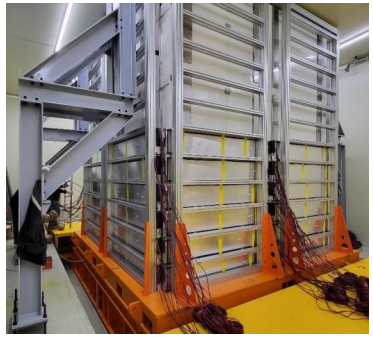
~10 kg years crystal exposure

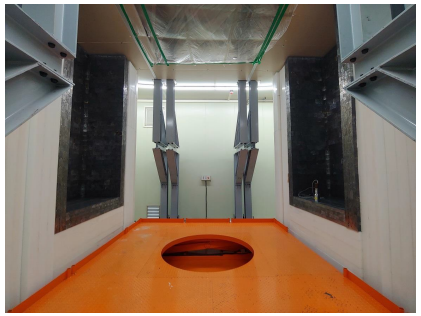
~5 kg years ^{100}Mo exposure

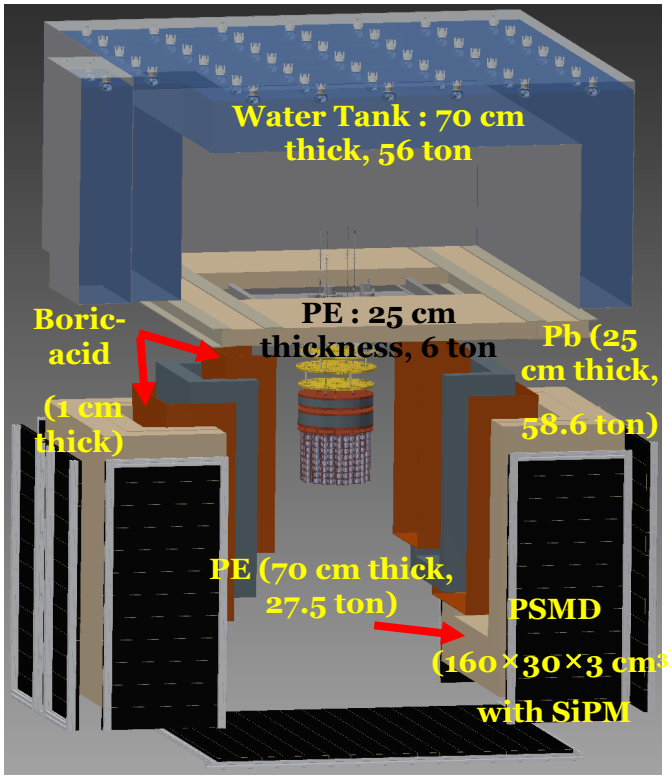
- Background around ROI ~ 0.03 count/kg/keV/year (ckky)
  - Finalizing result using full dataset : soon will be released!!
- AMoRE-I stopped physics operation May/2023 and AMoRE-II @ Yemilab is under preparation to start phase1 at early 2014

AMoRE-II @ Yemilab

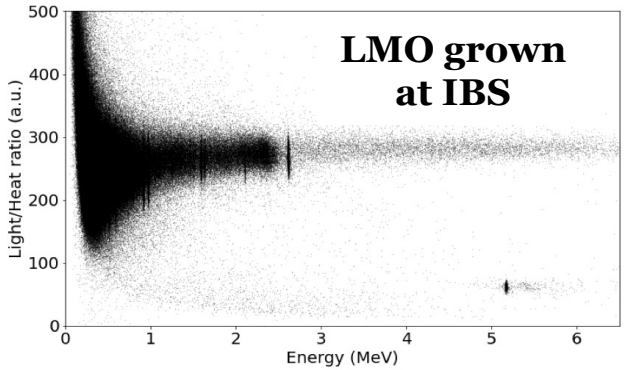
- 100 kg of ^{100}Mo @ Yemilab for 5 years
- $Li_2{}^{100}MoO_4$ crystals in 5 and 6 cm cylinder. (~ 400 crystals)
- DR inside heavy shielding with Pb, PE, and water.
- Muon detectors installed.
  - 132 Plastic Scintillator Muon Detectors (PSMD)
  - Water Cherenkov Muon Detector(WCMD) with 48 PMTs, 70 cm thick water.

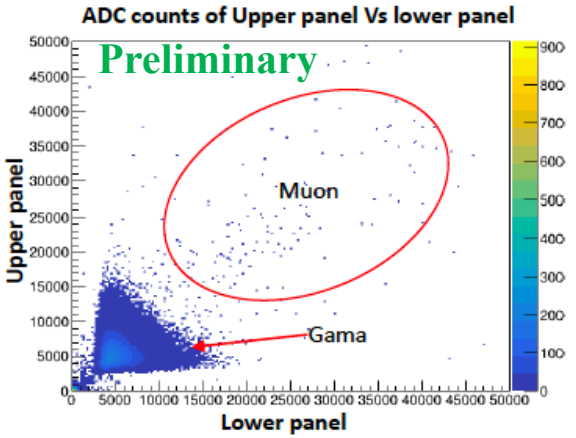




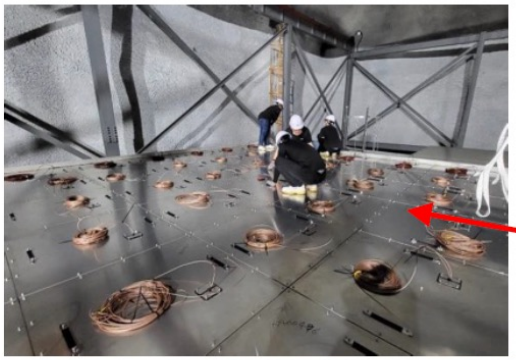


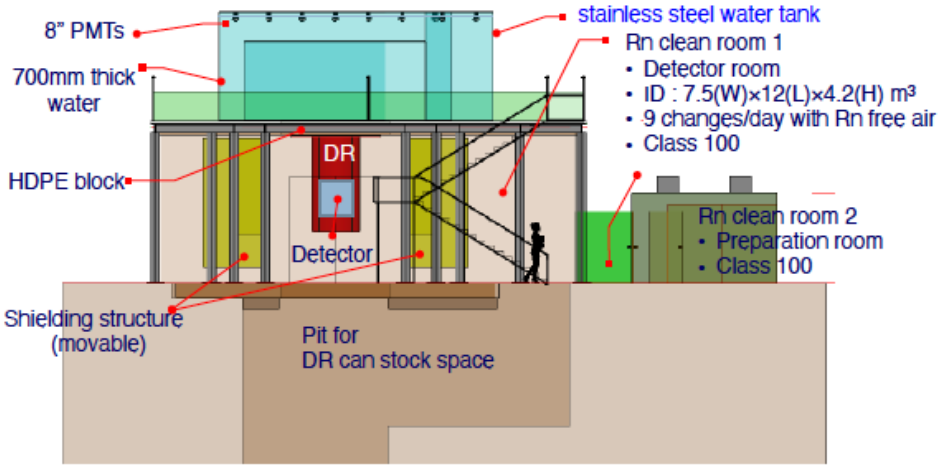
For the first time, $Li_2{}^{100}MoO_4$ enriched crystal grown at IBS(Daejeon) shows satisfactory performance. Alpha rejection power is over 10 & low contamination of U and Th



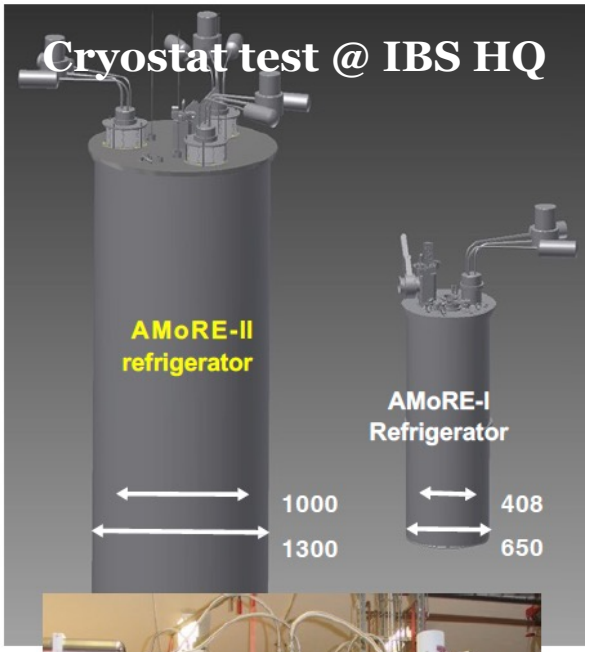


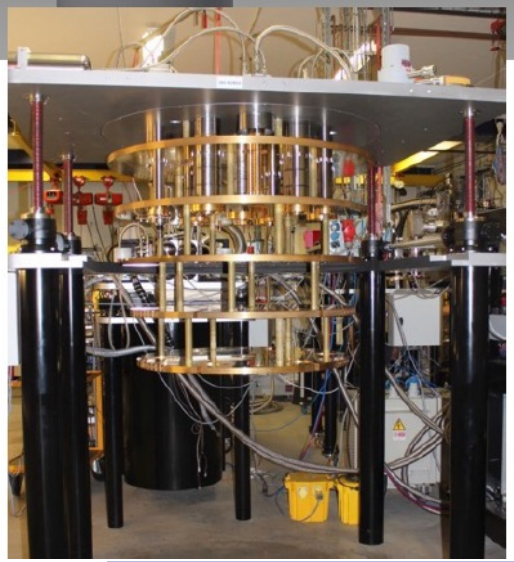
AMoRE-II preparation @ Yemilab



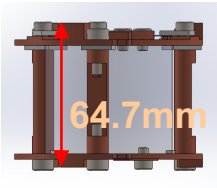


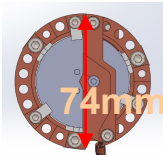
AMoRE-II preparation

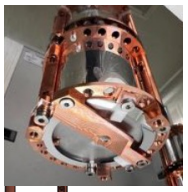


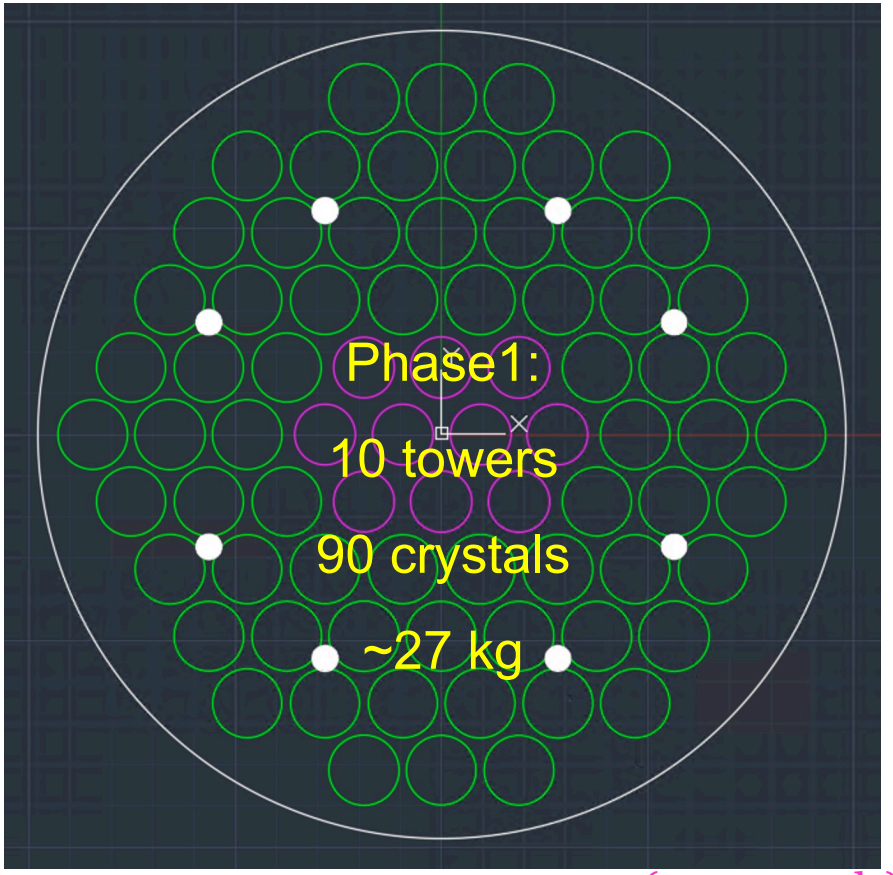


Module design







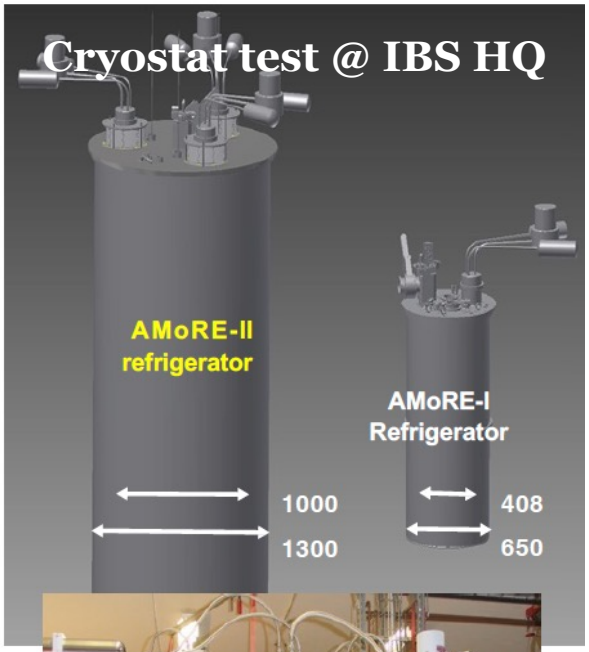


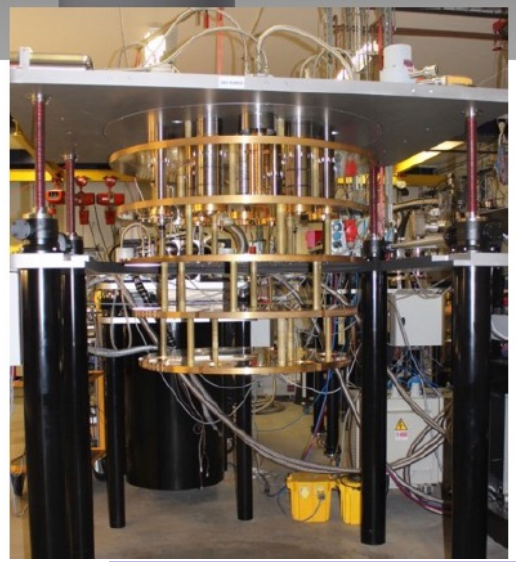
Phase2: 10 +35 towers = 50 towers (450 crystals)

Maximum: 50+26 towers·12 crystal/tower ~ 912 crystals

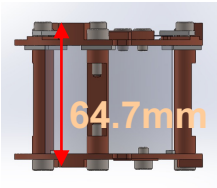
Phase1 start around early 2014

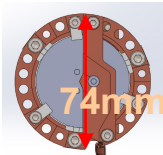
AMoRE-II preparation

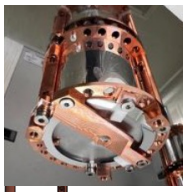


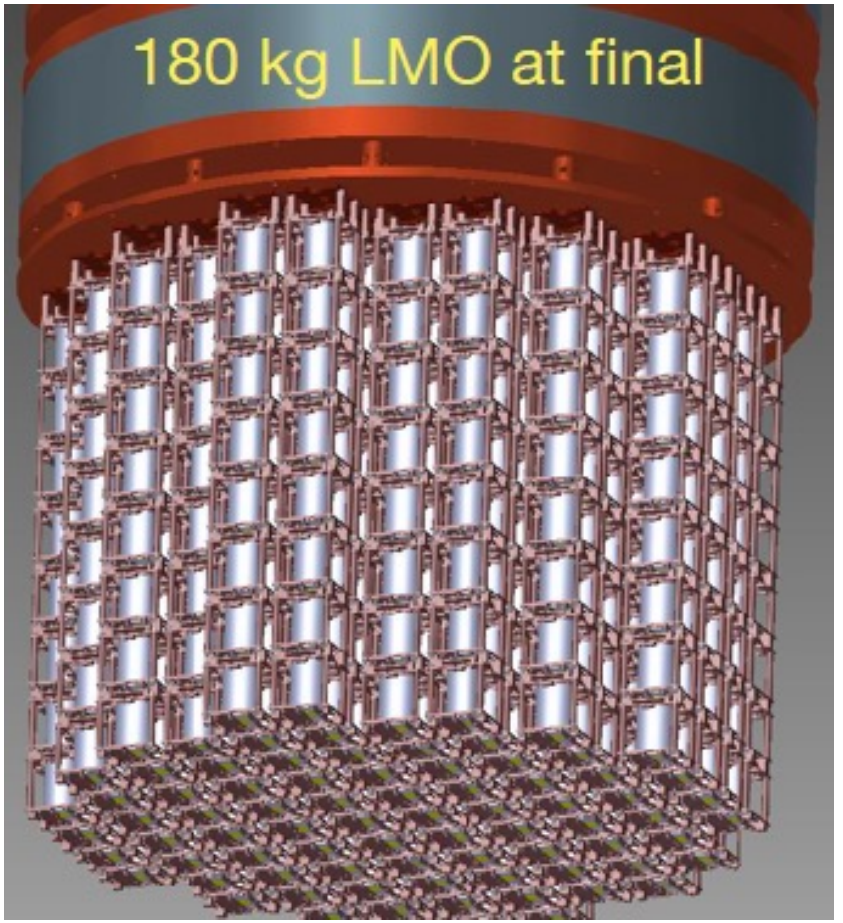


Module design









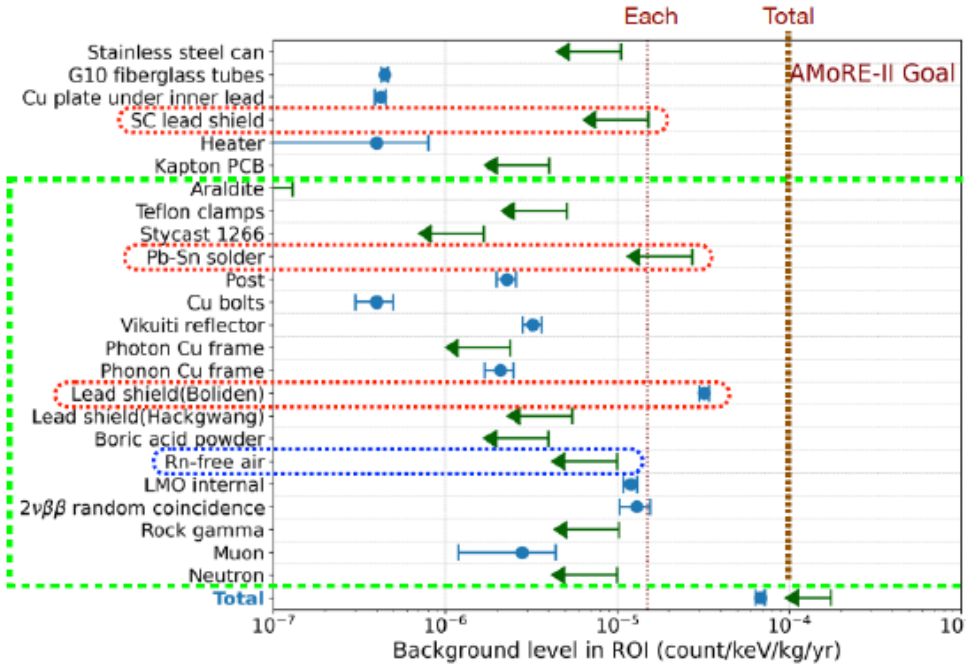
Phase2: 10 +35 towers = 50 towers (450 crystals)

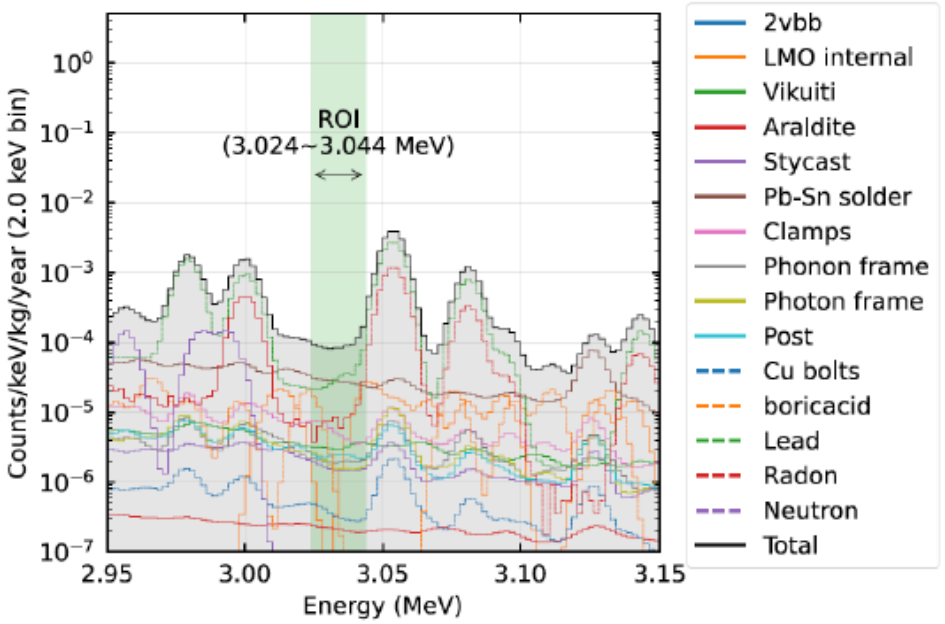
Maximum: 50+26 towers·12 crystal/tower ~ 912 crystals

Phase1 start around early 2014

Phase2 start at 2015-2016

AMoRE-II background





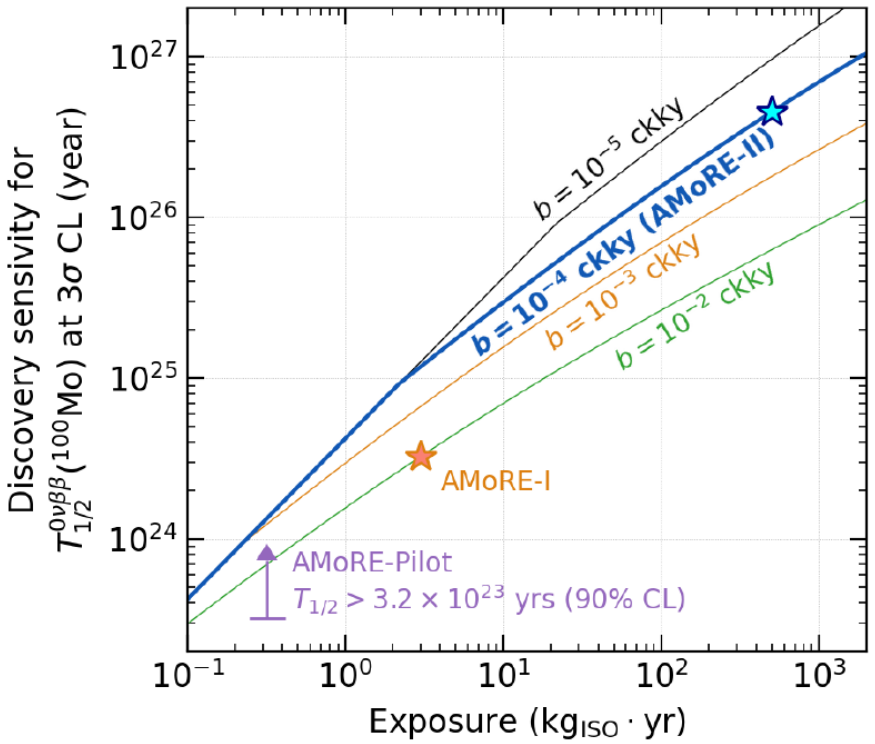
- Background understanding from AMoRE-pilot & I
- Various measurements of detectors & detector components
- ~10^{-4} ckky at ROI is achievable

AMoRE-II sensitivity

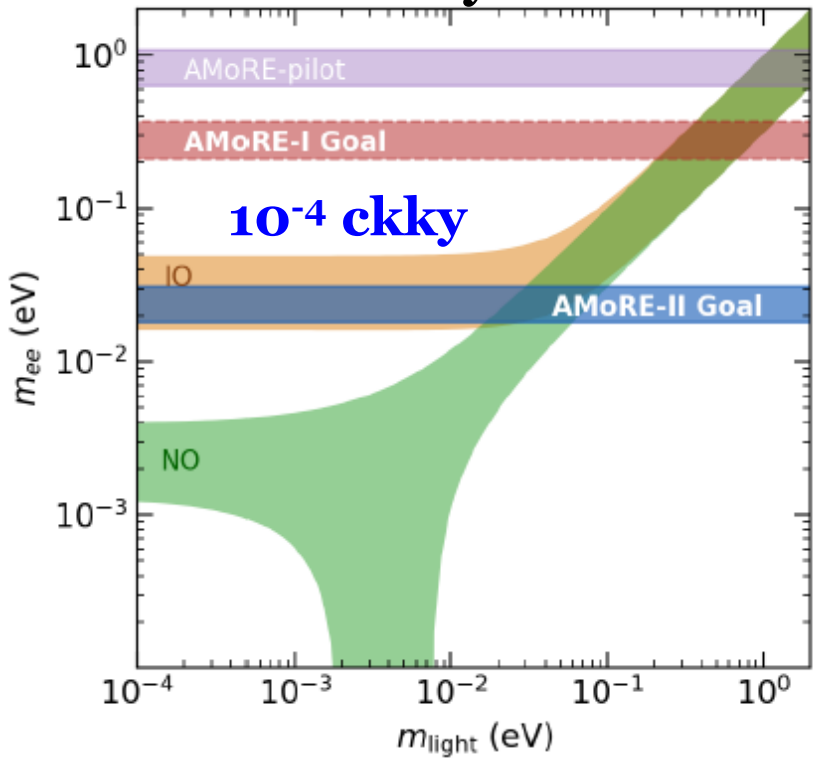
- Discovery sensitivity
  - The half-life for which an experiment has a 50% chance to measure a signal above background with a 3 sigma significance

Background unit : ckky = counts/(keV kg year)

Discovery potential

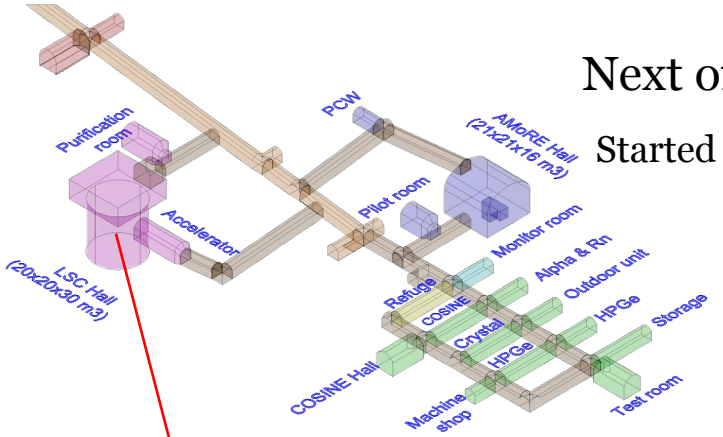


Sensitivity limit



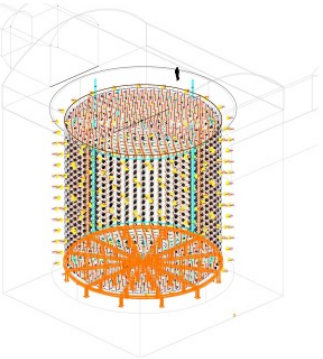
Liquid Scintillator Counter (LSC) @ Yemilab

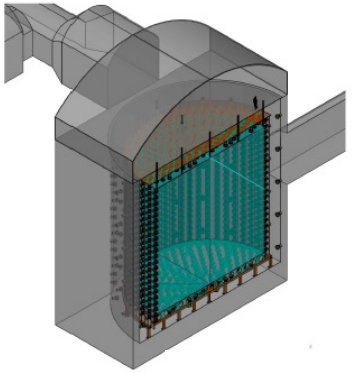
The largest cavern @ Yemilab for future neutrino telescope



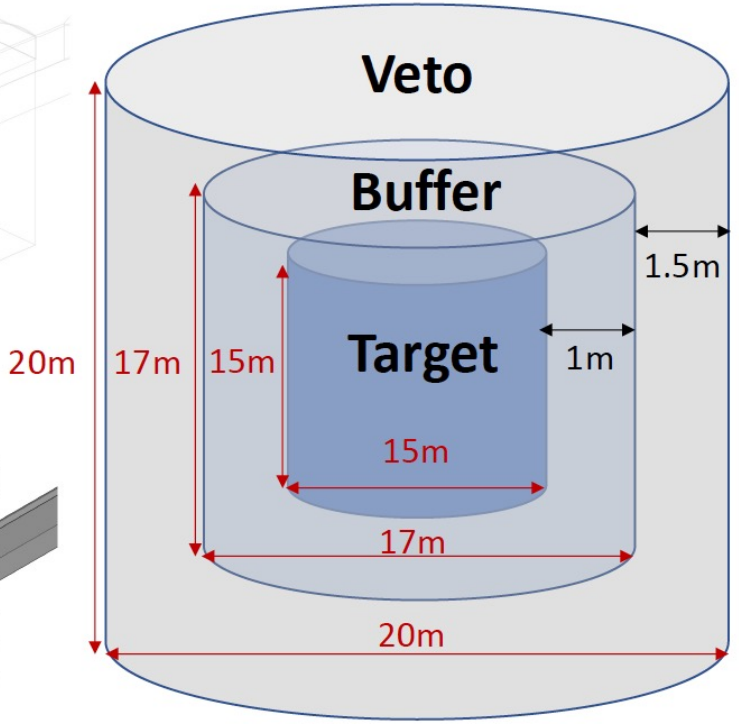
Next of Borexino?

Started detector R&D





Conceptual design



Target: **2.26 kton LS**

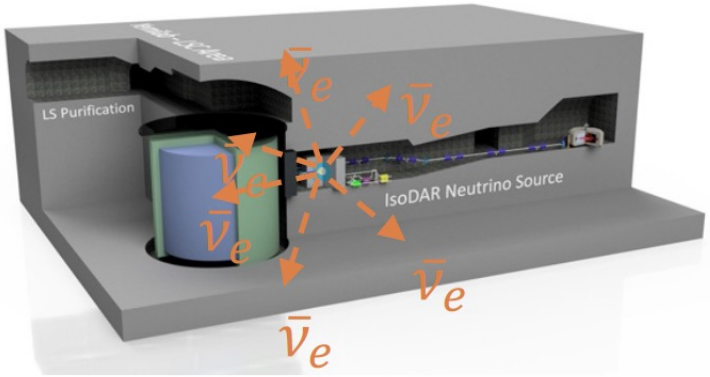
Buffer: 1.14 kton mineral oil

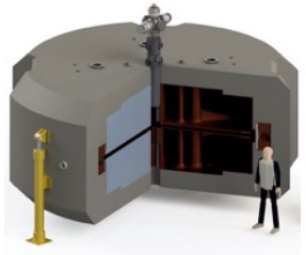
Veto: 2.41 kton water

LSC with IsoDAR

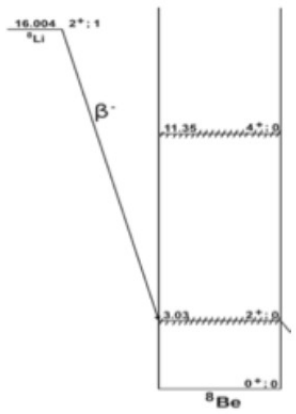
JINST 17, P09042 (2022) : "IsoDAR@Yemilab"

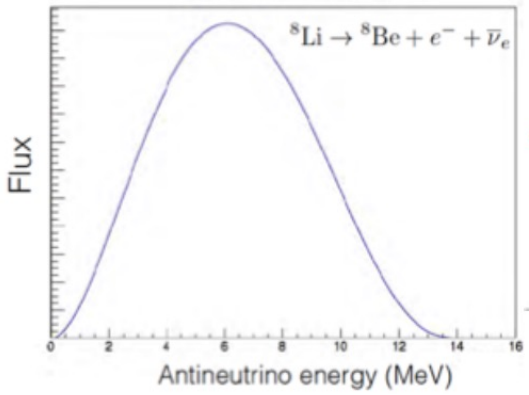
IsoDAR uses ^{8}Li Isotope Decay-at-rest

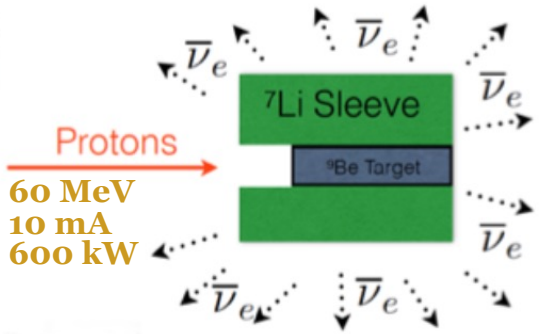




New J.Phys. 24 (2022) 2, 023038, https://arxiv.org/abs/2103.09352







$$p + {}^9\mathrm{Be} \rightarrow {}^8\mathrm{Li} + 2p$$

$$p + {}^9\mathrm{Be} \rightarrow {}^9\mathrm{B} + n$$

$$n + {}^7\mathrm{Li} \rightarrow {}^8\mathrm{Li} + \gamma$$

$$^8\mathrm{Li} \rightarrow {}^8\mathrm{Be} + e^- + \bar{\nu}_e$$

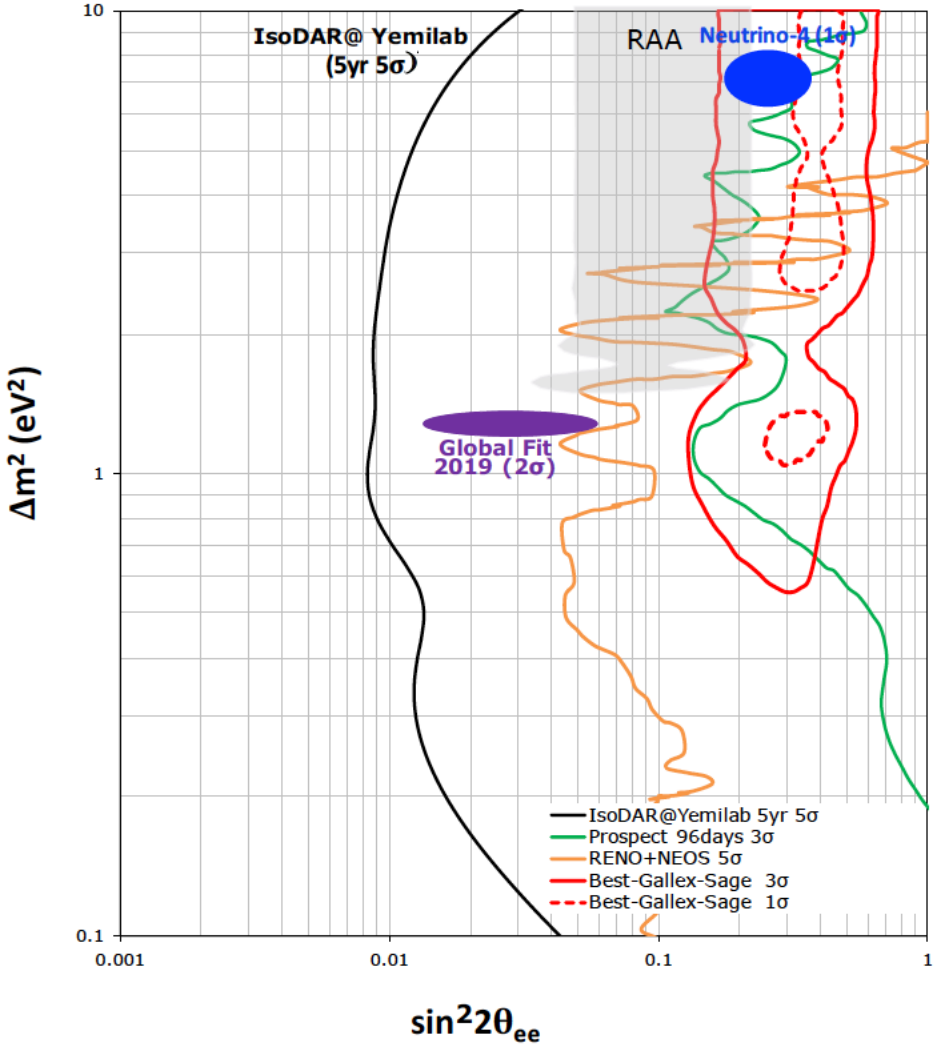
2M IBD events in 5 years.
~ 1000 events/day

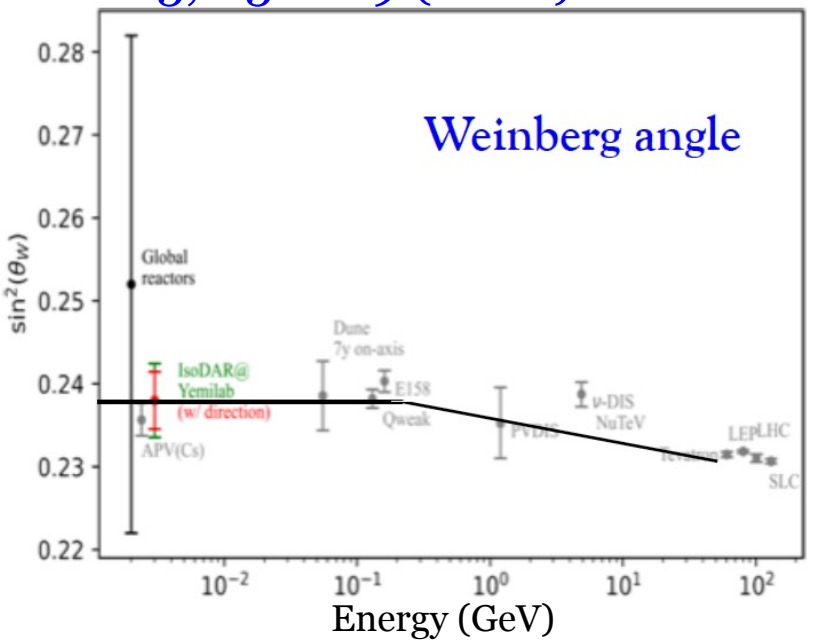
Runtime	5 calendar years
IsoDAR duty factor	80%
Livetime	4 years
Protons on target/year	$1.97 \cdot 10^{24}$
^{8}Li/proton ($\bar{\nu}_e$/proton)	0.0146
$\bar{\nu}_e$ in 4 years livetime	$1.15 \cdot 10^{23}$
IsoDAR@Yemilab mid-baseline	17 m
IsoDAR@Yemilab depth	985 m (2700 m.w.e.)

IsoDAR @ Yemilab

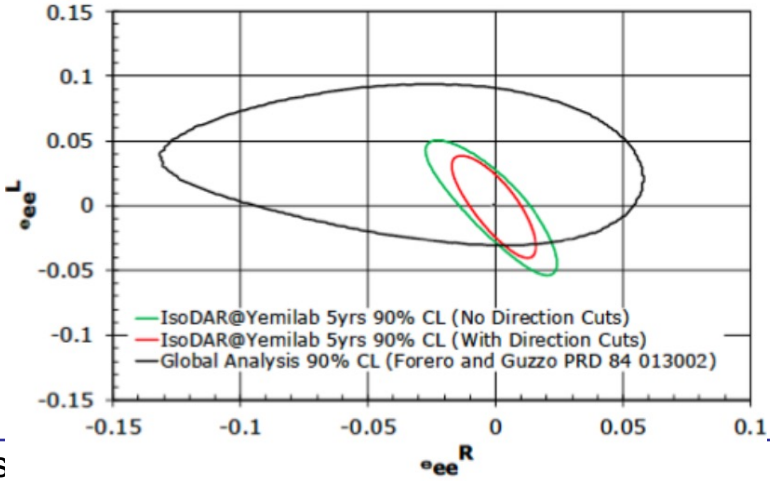
Phys. Rev. D 105, 052009 (2022)

Sterile neutrino search

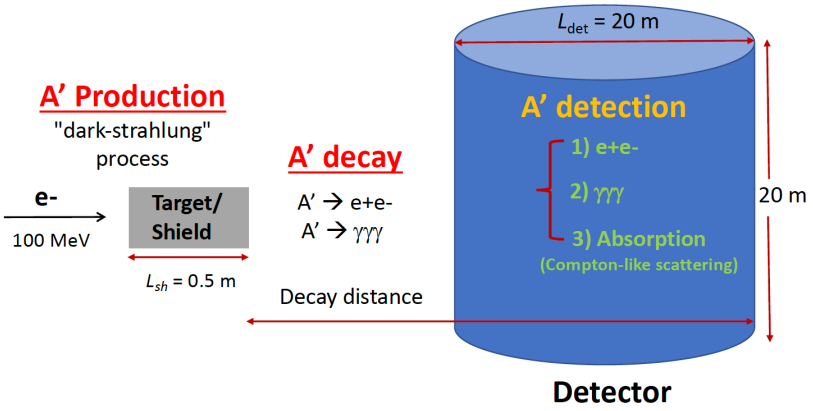




Non-standard interaction

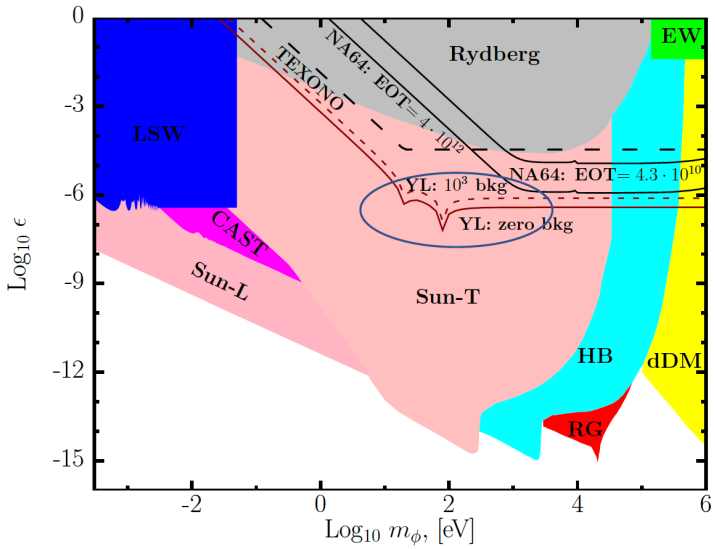


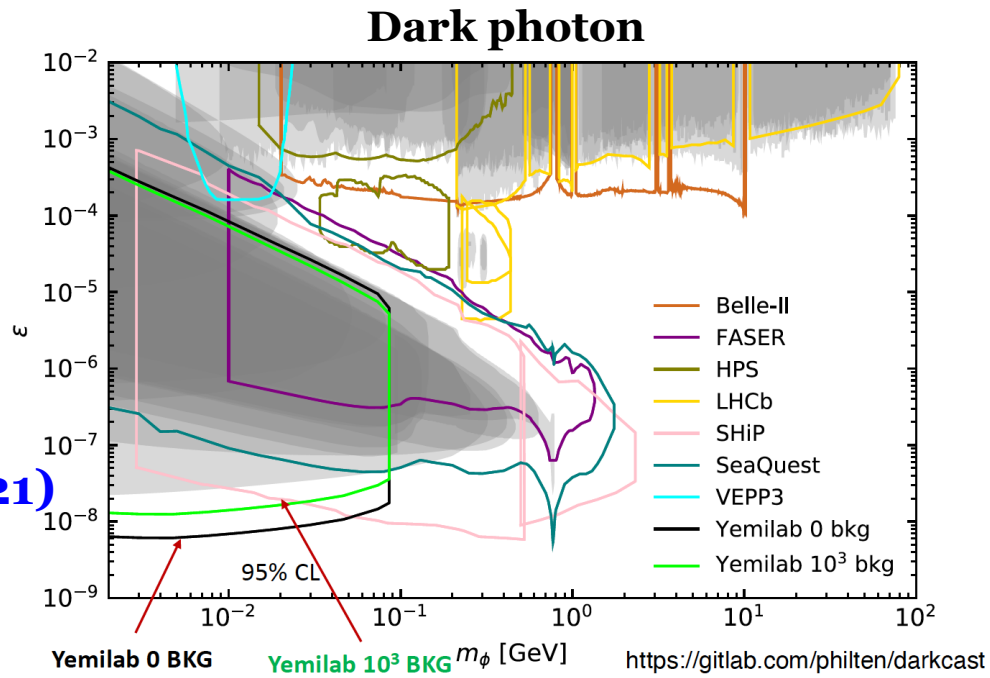
Electron collider @ Yemilab



Sunny Seo et al., JHEP 04, 135 (2021)

γ → A' Oscillation Sensitivity

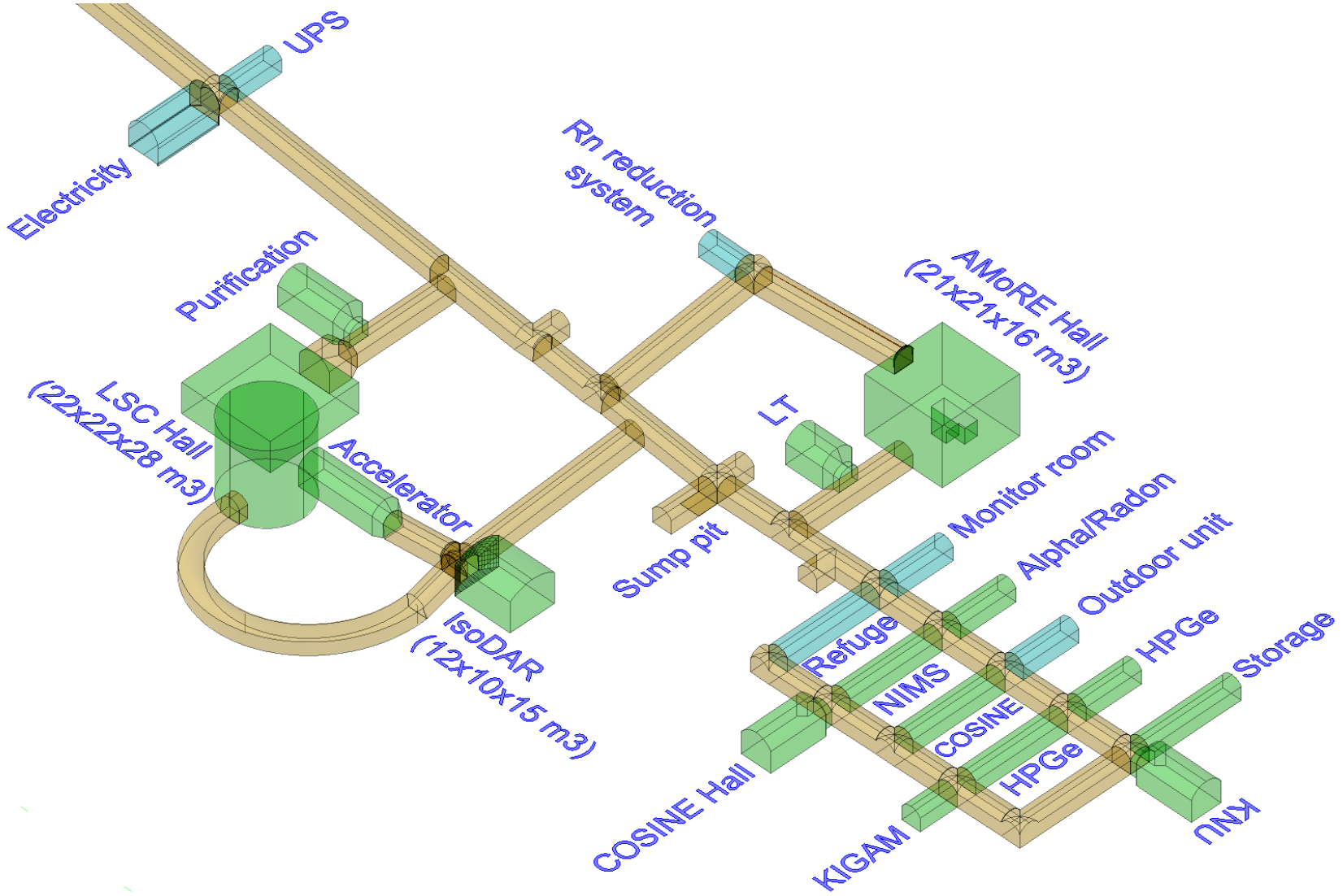




- Best Direct search sensitivities for the low dark photon masses
- Any other possibilities to use LSC cavern for important basic science research are still open and welcome

Yemilab

- There are new underground space waiting for your idea!!



Summary

- Yemilab is new underground laboratory utilized for basic science research in Korea
- COSINE-100U, 200 and AMoRE-II will be operated at Yemilab starting from 2023
- LSC cavern is ready for future neutrino telescope with various possibilities
- We welcome researchers who utilize Yemilab for basic science