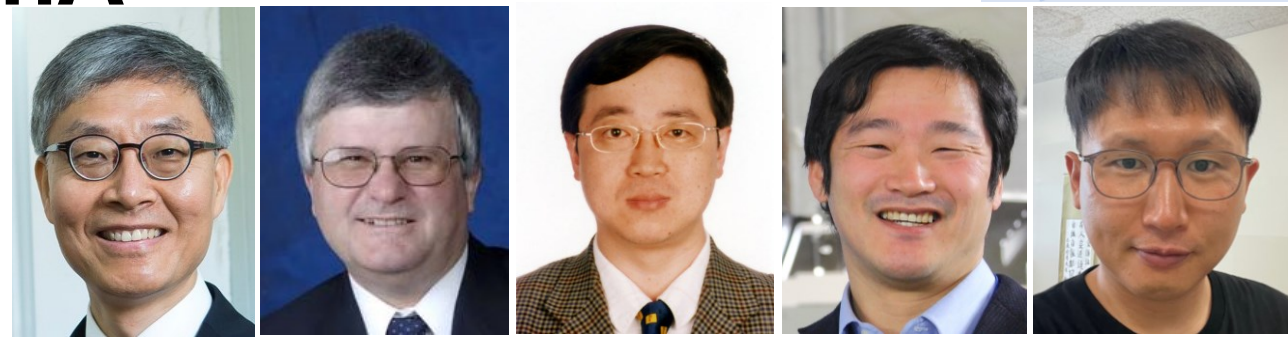
News from ANPhA
-Nuclear Physics Facilities in Asia-

Byungsik Hong (Korea University)
Chair of Asian Nuclear Physics Association (ANPhA)
https://asiannuclearphysic.wixsite.com/anpha

IUPAP WG9/C12 Annual General Meeting 2024
TRIUMF, Vancouver, Canada, 21 June 2024

Overview of ANPhA


Chair | Vice Chairs | Secretary

- **Current management (2023-2025)**
  - Chair: Byungsik Hong (Korea)
  - Vice Chairs: A. Thomas, G. Xiao, T. Uesaka
  - Secretary: Yongsun Kim (Korea)
- **Board members (14 member countries/regions)**
  - Australia: Anthony Thomas (Univ. of Adelaide)
  - China: Furong Xu (Peking Univ.), Guoqing Xiao (IMP), Yugang Ma (Fudan Univ.), Bing Guo (CIAE)
  - India: Avinash C. Pandey (IUAC), Sumit Som (VECC), Vandana Nanal (TIFR)
  - Japan: Kazuhiro Tanaka (KEK), Atsushi Hosaka (RCNP), Hirokazu Tamura (Tohoku Univ.), Tomohiro Uesaka (RIKEN)
  - Korea: Byungsik Hong (Korea Univ.), Jin-Hee Yoon (Inha Univ.), Eun-Joo Kim (Jeonbuk Nat. Univ.)
  - Taiwan: Wen-Chen Chang (Academia Sinica)
  - Vietnam: Phan Viet Cuong (VINATOM)
  - Myanmar: Nyein Wink Lwin (Univ. of Mandalay)
  - Kazakhstan: Kairat A. Kuterbekov (Eurasian Nat. Univ.)
  - Hong Kong (China): Jenny Hui Ching Lee
  - Mongolia: To be determined
  - The Philippines: Denny Lane Sombillo (Univ. of the Philippines)
  - Uzbekistan: Bakhadir Irgaziev (National University of Uzbekistan)
  - Singapore: Andrew Anthony Bettiol (National University of Singapore)
- **Observers**
  - Weiping Liu, Kazuhiro Tanaka, Dong-Pil Min, Yanlin Ye, Hideyuki Sakai, Shoji Nagamiya, Tohru Motobayashi, Marek Lewitowicz (NUPECC)

■ Uzbekistan and Singapore joined ANPhA in 2023.

Overview of ANPhA

- Previous ANPhA Board Meeting & Symposium, IBS, Daejeon, Korea, 10-11 Nov. 2023

- Next meeting: SCNT, Huizhou City, Guangdong Province, China, 14-16 Nov. 2024

Overview of ANPhA

- White paper of ANPhA
  - Catalog of the existing and planned accelerator facilities in the Asia-Pacific region
  - https://kds.kek.jp/indico/category/1706/
  - Presently, we are updating the data.

- Long-Range Plan (LRP) Committee
  - Chair: Kazuhiro Tanaka (Japan)
  - Members:
    - Bing Guo (China), Tomohiro Uesaka (Japan), Vandana Nanal (India), Yongsun Kim (Korea)
    - More members will be invited.
  - Ex-officio: Byungsik Hong

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In this presentation

- I will not cover
  - HIAF (→ Jiangchen Yang)
  - J-PARC (→ Naohito Saito)
  - RIBF (→ Hiroyoshi Sakurai)
  - RAON (→ Seung-Woo Hong)

- I will summarize the status of
  - Underground facilities
  - Accelerator facilities except those listed above
  - Activities for LHC
  - Activities for EIC

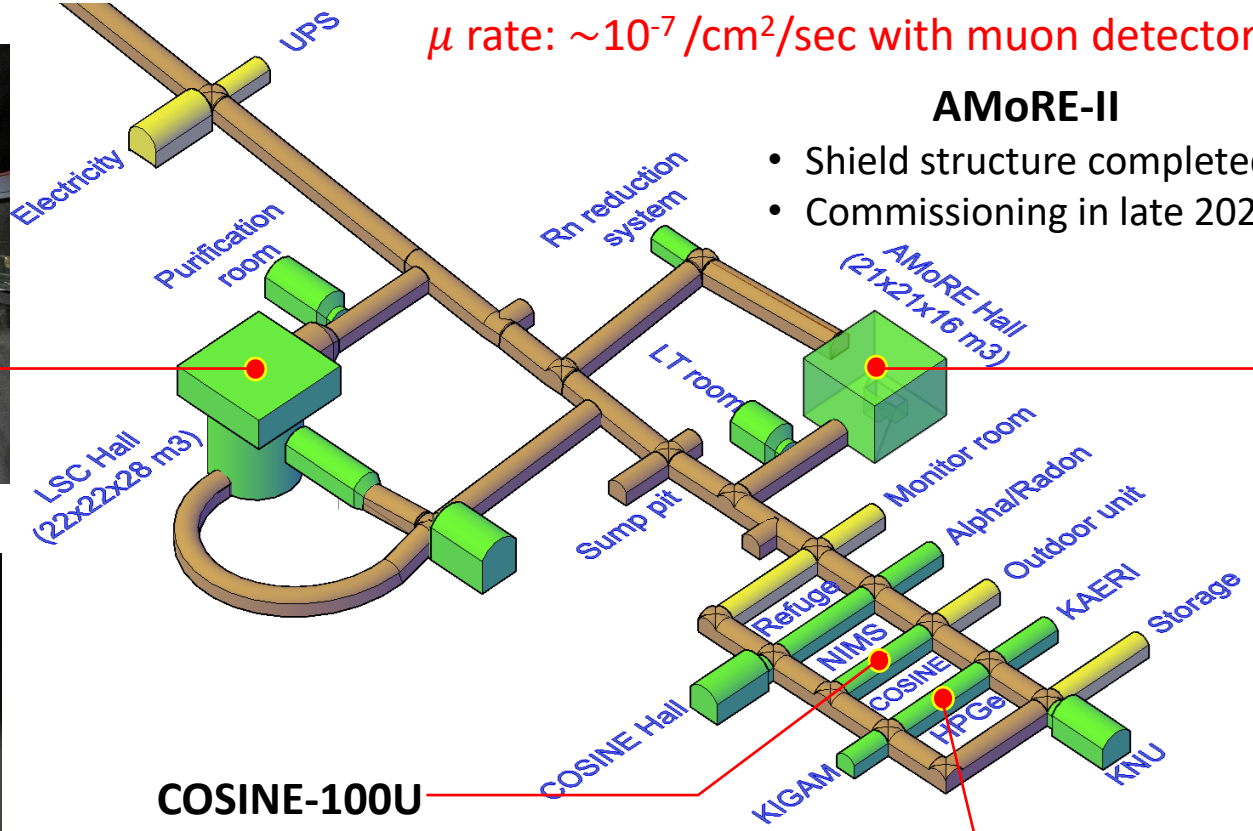
Underground laboratories

Yemilab: a new underground laboratory in Korea

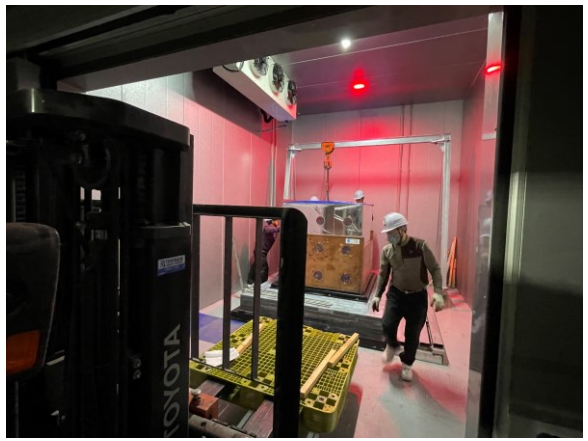
- Y2L (700 m deep): Constructed in 2003 to house the KIMS setup for dark matter search experiment
- Yemilab (1,000 m deep): Constructed in 2022 and run by the Center for Underground Physics (CUP) of IBS

LSC Hall
- 10-ton crane installed in June 2023

μ rate: ~10^{-7} /cm^2/sec with muon detectors



AMoRE-II
- Shield structure completed
- Commissioning in late 2024



COSINE-100U
- -30℃ low-temperature room
- Commissioning in early 2024

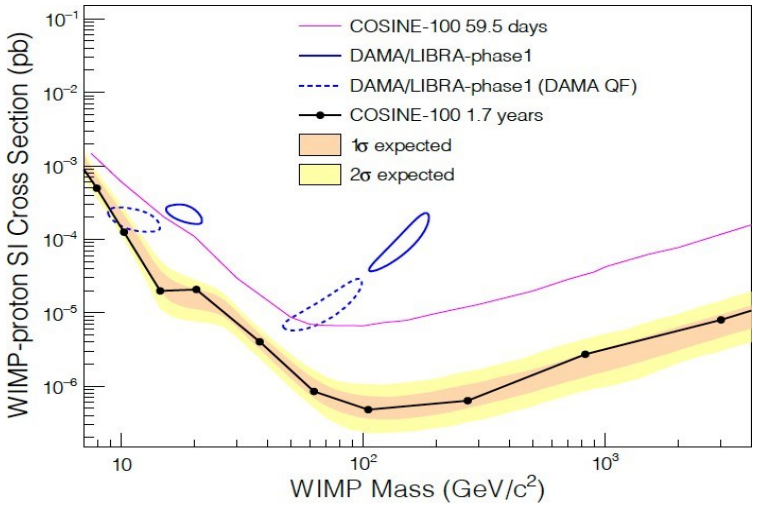
HPGe
- Relocation from Y2L started in Feb. 2024

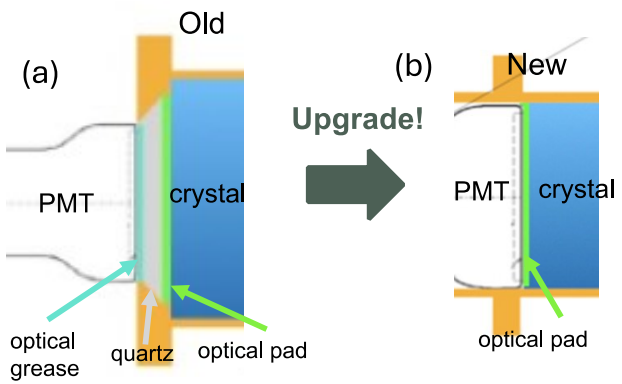
Underground laboratories

Dark matter search

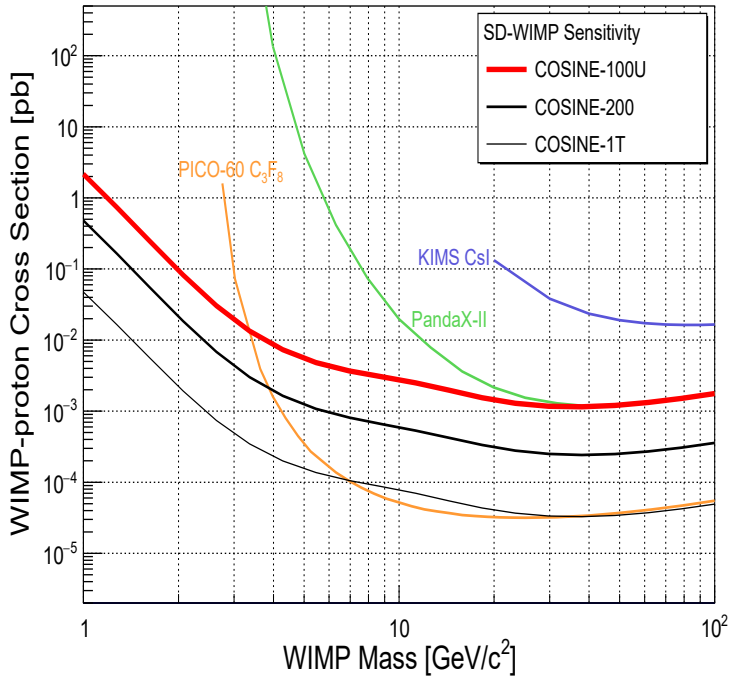
- COSINE-100 experiment @ Y2L
  - DAMA/LIBRA annual modulation of standard halo model was rejected.
- Relocation of COSINE-100: Y2L→Yemilab
- Upgrade COSINE-100 to COSINE-100U
  - Improving the light collection capability by modifying the geometry and PMT attachment method: NIMA 981, 164556 (2020)
  - 21.6±0.6 NPE/keV (30% ↑)
  - Commissioning in early 2024

Sci. Adv. 7, 2699 (2021)





- Future experiment: COSINE-200
  - Development of **ultra-low background NaI crystals**
  - Aims a world best limit for low-mass WIMP-proton cross section



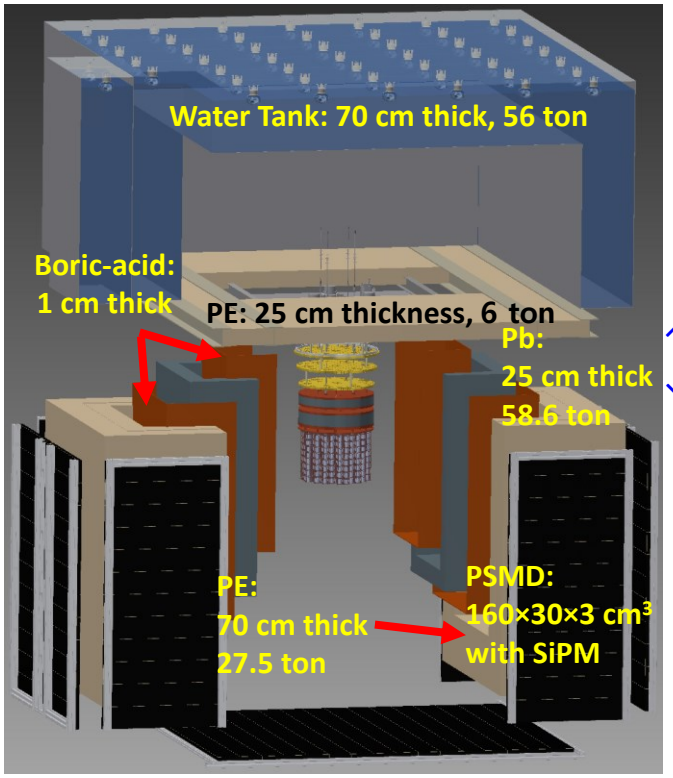
Underground laboratories

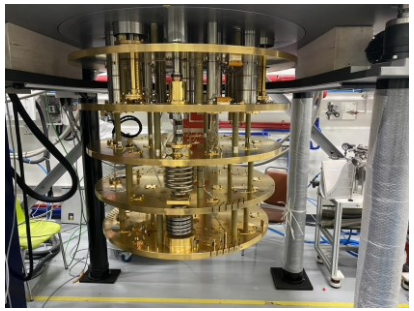
Neutrinoless double beta decay

- AMORE-II experiment @ Yemilab

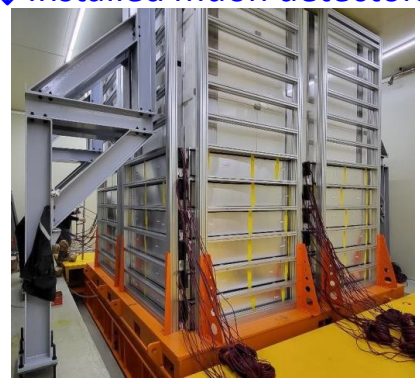
Cf.) CUPID @ LNGS with 240 kg of ^{100}Mo

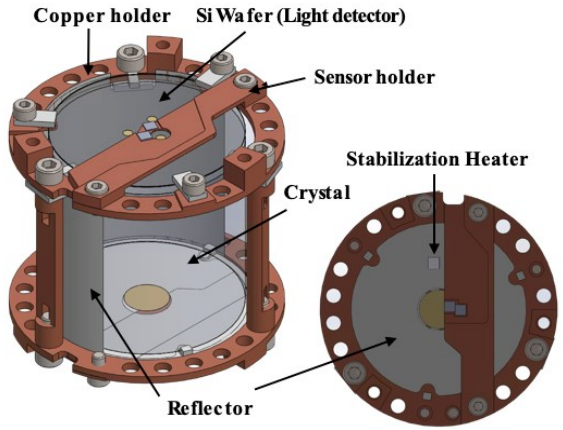
  - 100 kg of ^{100}Mo to reach $T_{1/2}^{0\nu\beta\beta} > 4.5 \times 10^{26}$ years for 5 years: both phonons & photons measured by MMC+SQUID
  - So far 300 $Li_2{}^{100}MoO_4$ cylindrical crystals were grown.
  - Commissioning run with 90 crystals in 2024 ⇒ Full scale run with 100 kg of ^{100}Mo is expected in 2026.

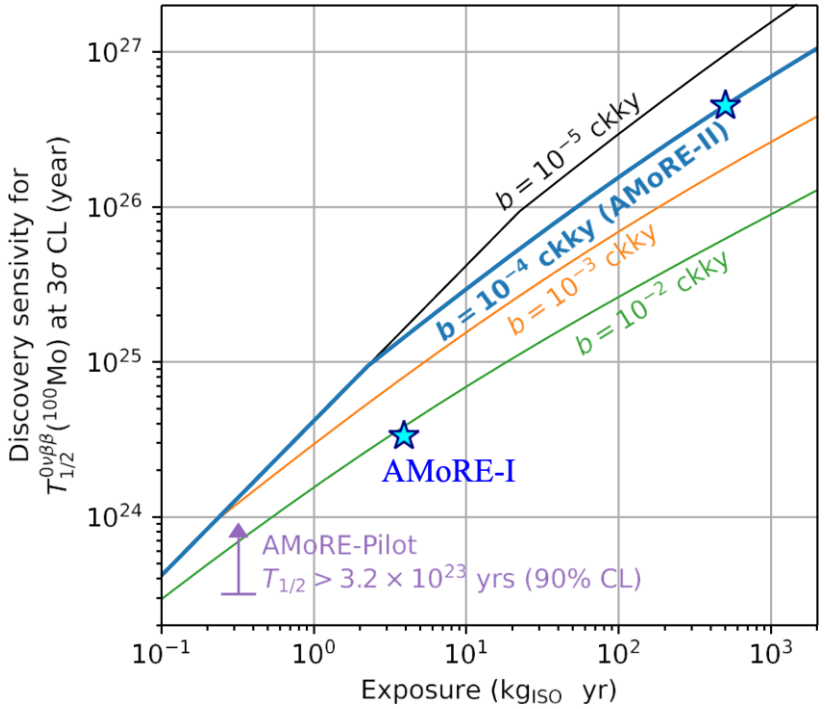




↑Dilution refrigerator (DR)
↓Installed muon detectors



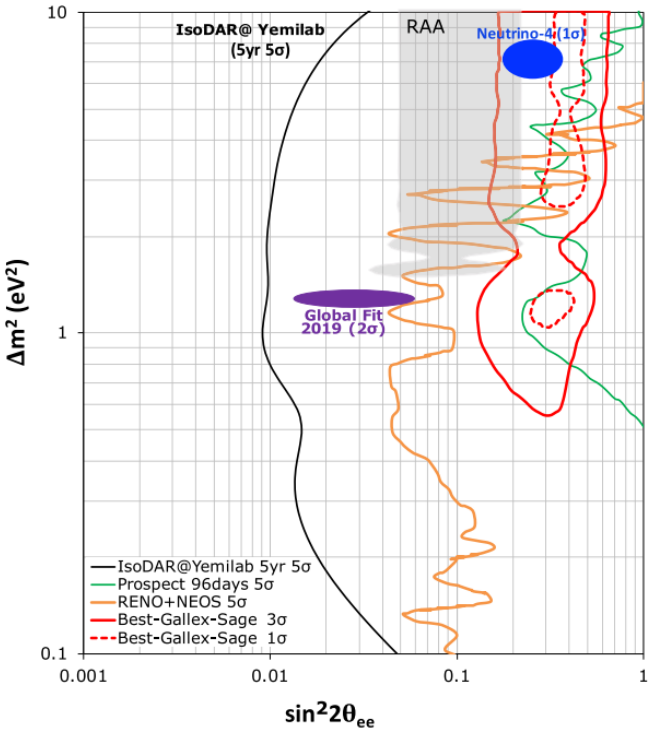




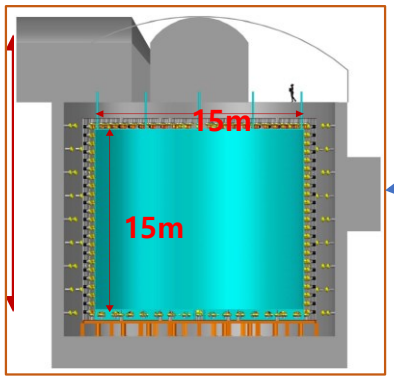
Underground laboratories

Large Neutrino Detector: "Neutrino physics opportunities with the IsoDAR source at Yemilab",
https://www.nevis.columbia.edu/daedalus/exp/isodar.html, PRD 105, 052009 (2022)

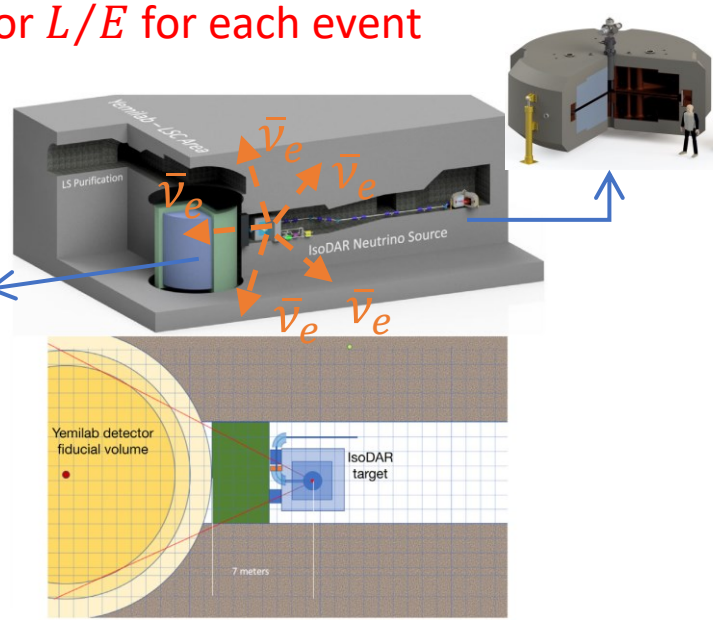
- IsoDAR@Yemilab plans to use ~10^{23} $\bar{\nu}_e$s from decay of ^{8}Li, bombarding p beams from cyclotron on Be target
  - Sterile neutrino search using the inverse beta decay (IBD) $\bar{\nu}_e p \rightarrow e^+ n$
  - Nonstandard interaction search using elastic scattering off atomic electrons ($\bar{\nu}_e e \rightarrow \bar{\nu}_e e$)
  - Precision test of weak interaction (weak mixing angle) with very short baseline oscillation ($\bar{\nu}_e \rightarrow \bar{\nu}_e$)
  - Search for new particles such as a light X boson, etc.



Measurement of the energy (E) and vertex (L) of neutrinos for L/E for each event

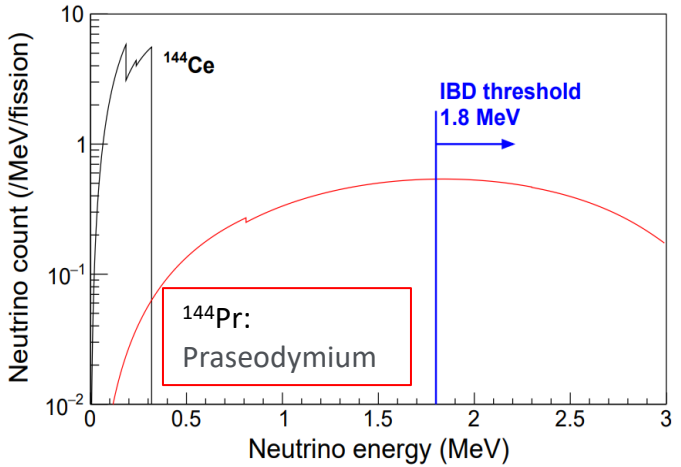


~2 kton
Liquid Scintillator
Counter (LSC)



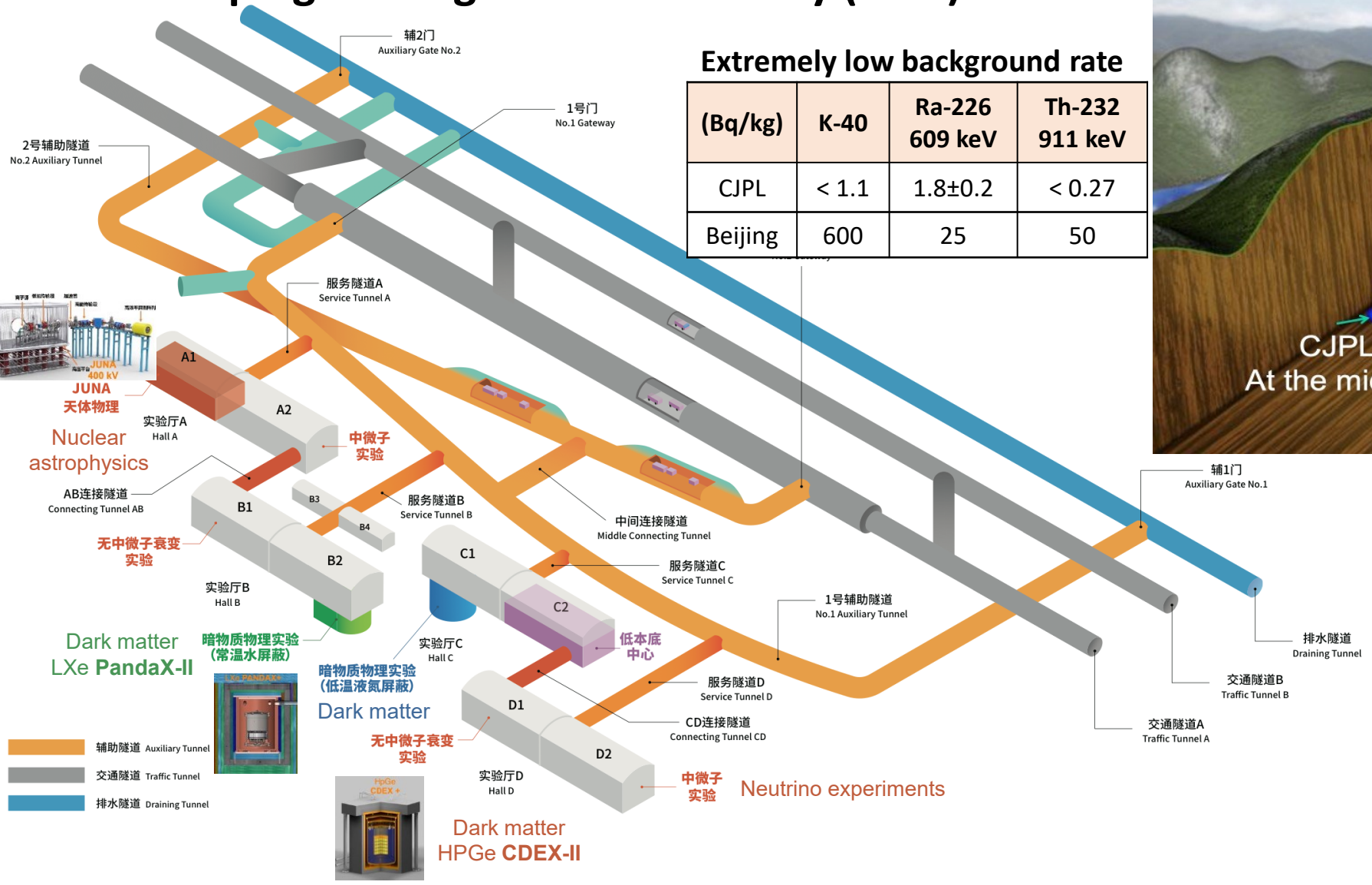
Alternatively, 100 kCi ^{144}Ce can be used: $^{144}_{58}\mathrm{Ce} \rightarrow {}^{144}_{59}\mathrm{Pr} \rightarrow {}^{144}_{60}\mathrm{Nd}$
Decay processes emit $\bar{\nu}_e$s.

arXiv:2401.1321



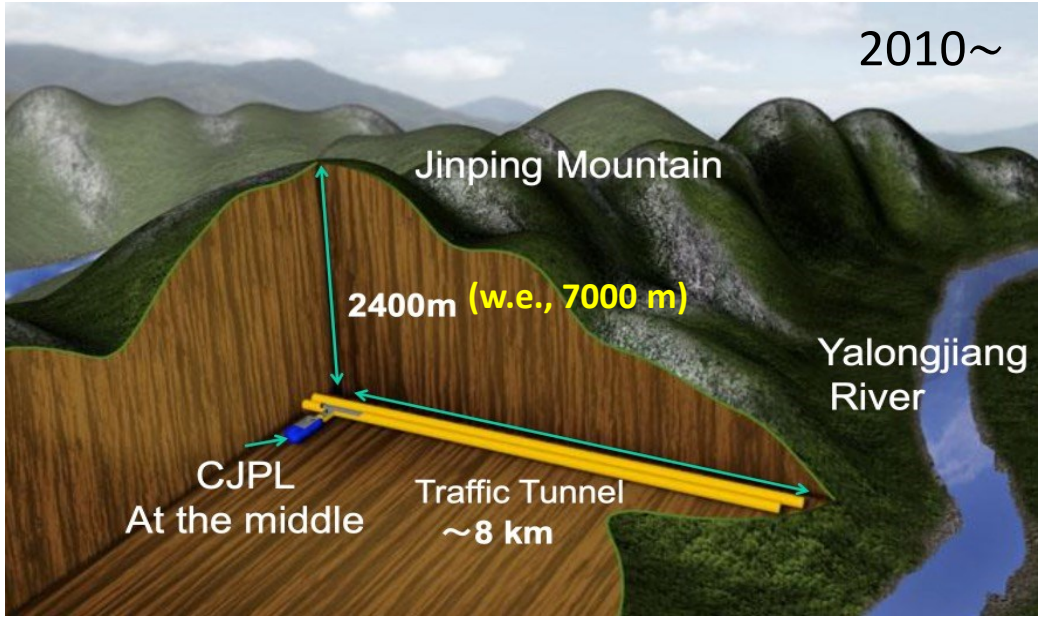
Underground laboratories

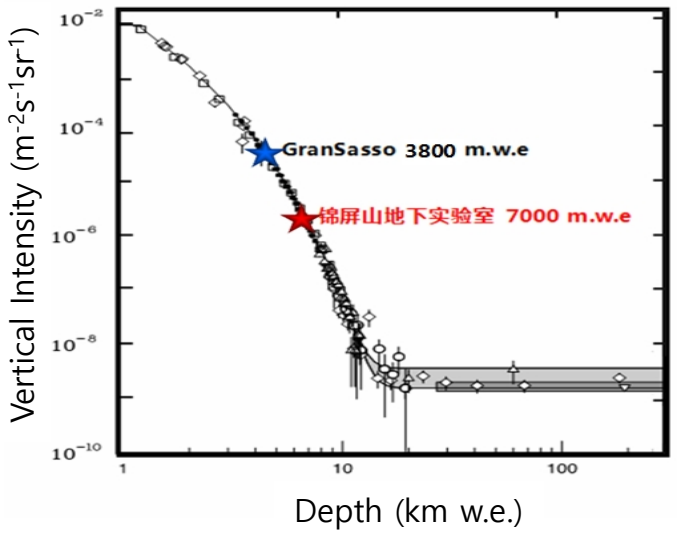
China Jinping Underground Laboratory (CJPL)



Extremely low background rate

(Bq/kg)	K-40	Ra-226 609 keV	Th-232 911 keV
CJPL	< 1.1	1.8±0.2	< 0.27
Beijing	600	25	50

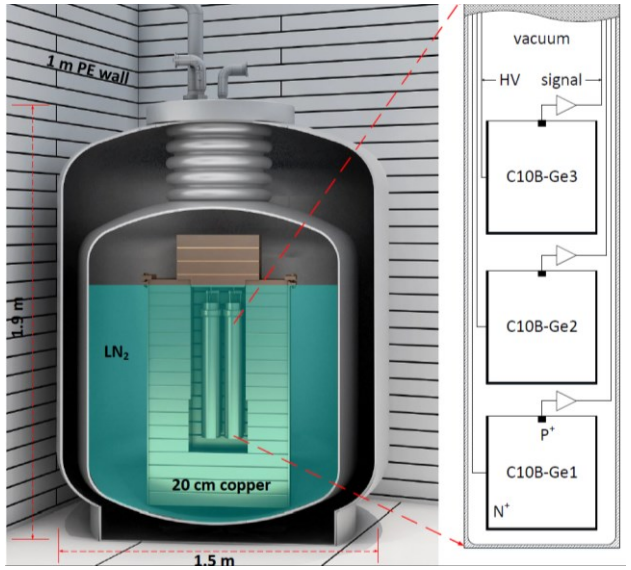




Underground laboratories

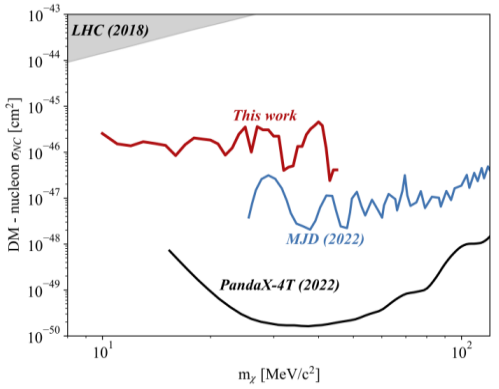
China Dark Matter Experiment (CDEX)

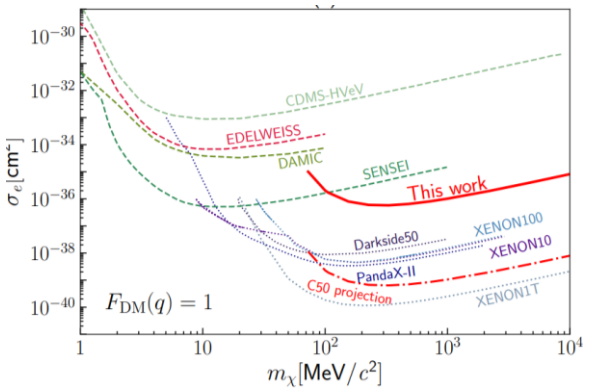
Ge to search for light-WIMP: PRL 123, 221301 (2019) PRL 129, 221802 (2022), PRL 129, 221301 (2022)



- **CDEX-10 (2016):** 10-kg Point Contact Ge detectors immersed into liquid nitrogen
- CDEX-50 (in-preparation)
- CDEX-300 (≳2027)
- CDEX-1T

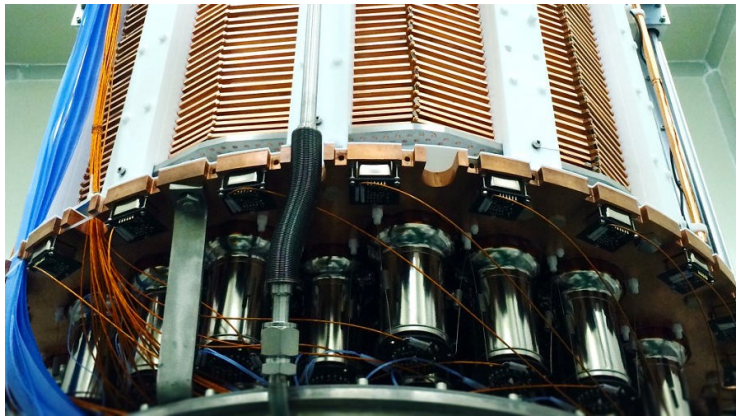
Cf.) LEGEND-200
LEGEND-1000





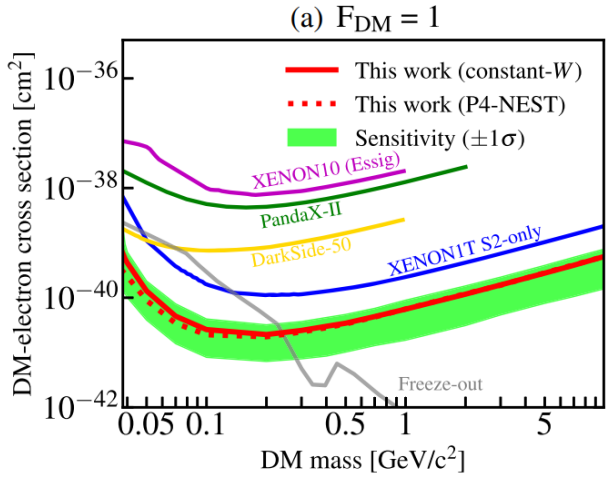
Particle and Astrophysical Xenon Experiment (PandaX)

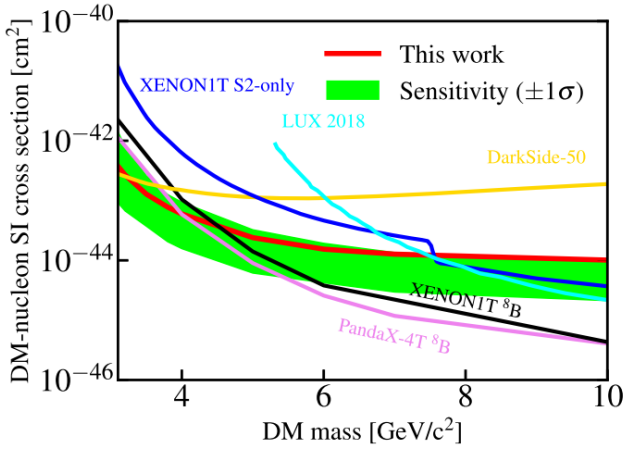
Xe to search for dark matter: Nature 618, 47 (2023), PRL 130, 261001 (2023), PRL 130, 021802 (2023)



- PandaX-II (2014-2019): Dual-phase TPC with half-ton of ultra-high purity liquid ^{136}Xe
  120 kg in 2014
  → 580 kg in 2018
- **PandaX-4T (2021-):** 5.75 tons of Xe

Cf.) nEXO

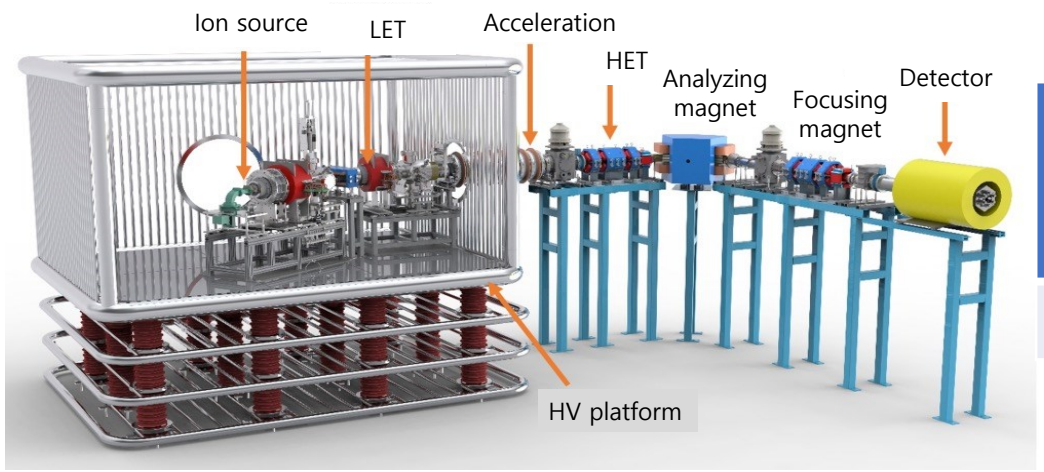




Underground laboratories

JUNA nuclear astrophysics facility at CJPL

W.P. Liu, et al., Sci. China 59, 5785 (2016)



Experimental conditions for JUNA

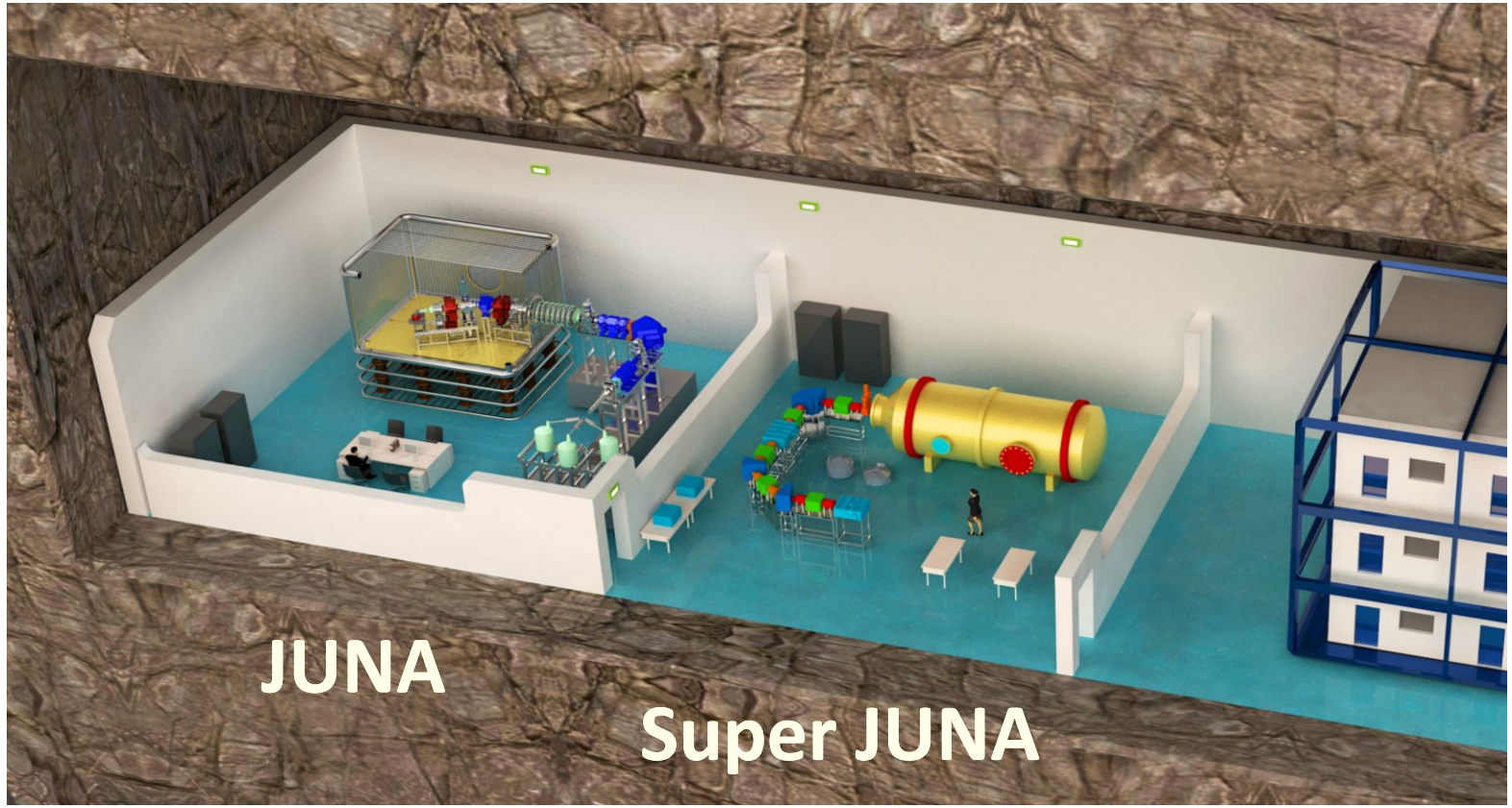
Cosmic muon Bkg. ($cm^{-2}s^{-1}$)	Beam energy (keV) / Maximum beam intensity (emA)			Energy stability
	H^+	He^+	He^{2+}	
2×10^{-10}	50-400 / 2-10	50-400 / 2-10	100-800 / 1-2	0.04%

List of experiments from the first run (2020-2021)

Reaction	Crucial parameters	Prior to JUNA	JUNA data	Publication
Holy grail $^{12}C(\alpha,\gamma)^{16}O$	Lowest energy (keV)	891	552	In preparation
	Cross section (b)	10^{-11}	10^{-12}	
Neutron source $^{13}C(\alpha,n)^{16}O$	Energy range (keV)	230-300	240-1900	PRL 129, 132701 (2022)
	s-process	50%	20%	
^{26}Al abundance $^{25}Mg(p,\gamma)^{26}Al$	Uncertainty	21%	8%	Science Bulletin 67, 2 (2022) Cover paper
F abundance $^{19}F(p,\alpha\gamma)^{16}O$	Lowest energy (keV)	189	72	PRL 127, 152702 (2021) Editor's suggestion
	Uncertainty	80%	5%	
Ne isotope ratio $^{18}O(\alpha,\gamma)^{22}Ne$	Uncertainty	472±18 keV	474.1±1.1 keV	PRL 130, 092701 (2023)
CNO breakout $^{19}F(p,\gamma)^{20}Ne$	Lowest energy (keV)	300	200	Nature 610, 656 (2022)

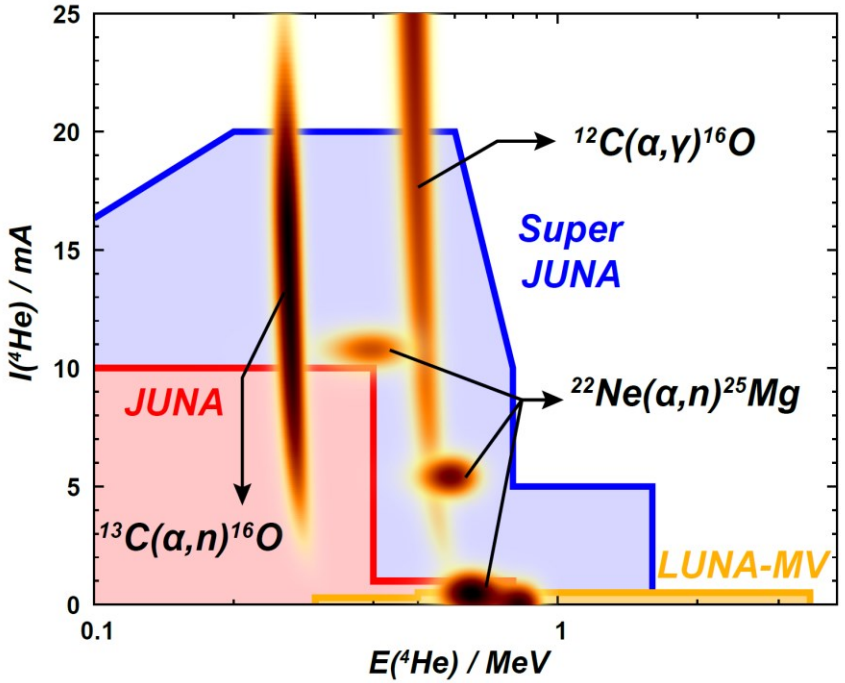
Underground laboratories

Plan for Super JUNA



To cover various nuclear processes in He burning

- Higher intensity: 20 mA
- Higher energy: 800 keV



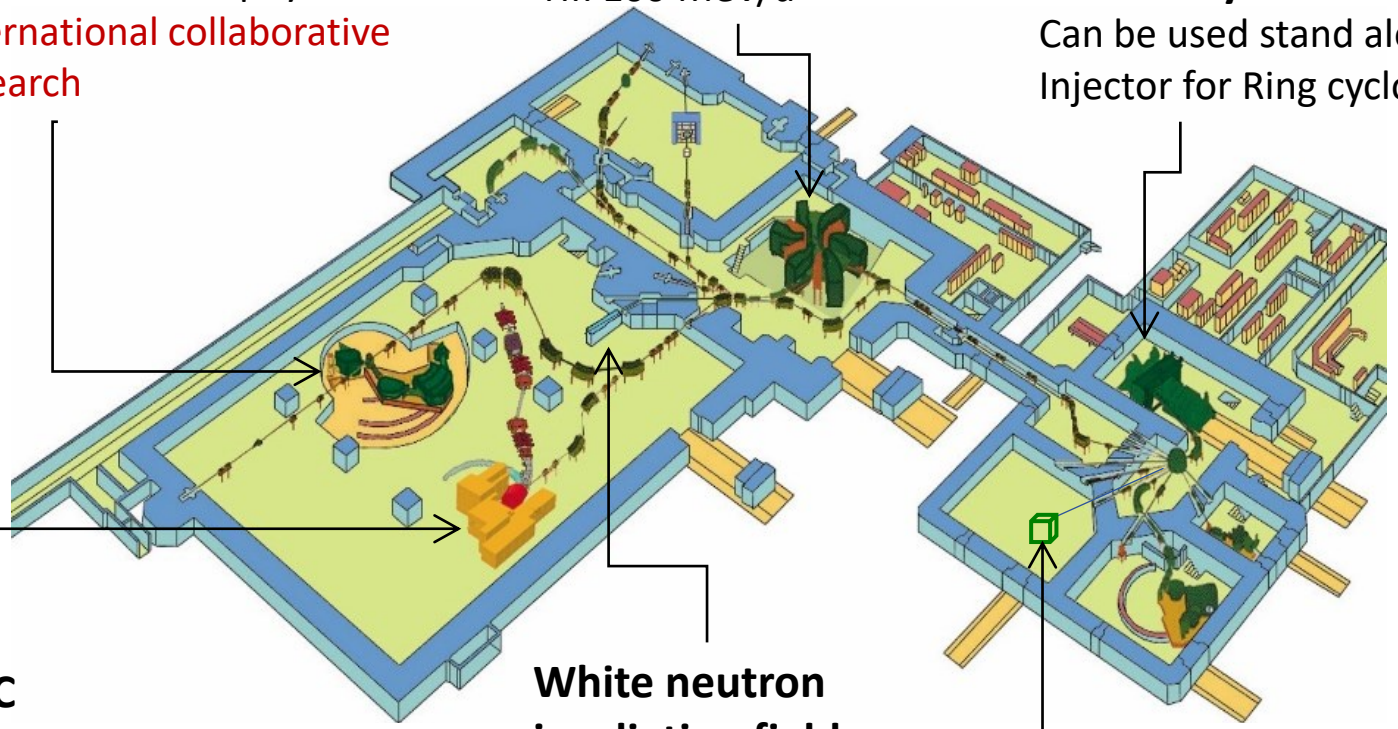
RIB accelerator facilities

Research Center for Nuclear Physics (RCNP) @ Osaka Univ. in Japan

Grand Raiden
Precision nuclear physics
International collaborative research

K400 Ring cyclotron
p: 400 MeV
HI: 100 MeV/u

K140 AVF cyclotron
Can be used stand alone
Injector for Ring cyclotron



MuSIC
Continuous muon beam
Interdisciplinary research

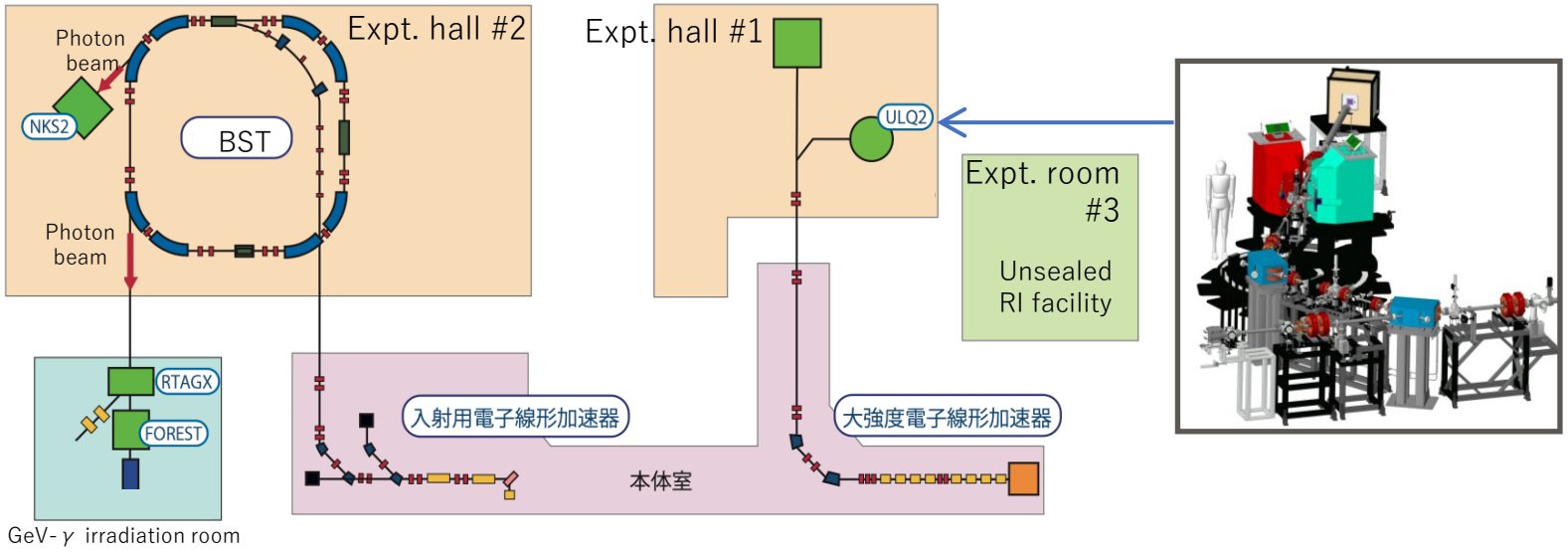
White neutron irradiation field
Semiconductor software error evaluation

Short half-life radio-isotope production
Targeted alpha therapy

- Completion of the upgrade of AVF (Azimuthally-Varying Field) cyclotron
  - Beam delivery started in 2022 with 10 times larger beam intensity
- Independent use of AVF
  - Mass production of short-lived radio isotopes
  - ^{211}At (Astatine) to clinical trials of targeted alpha therapy
- AVF + Ring cyclotron
  - Precision nuclear physics
  - Promotion of muon science
  - Semiconductor software error evaluation tests

RIB accelerator facilities

Research center for ELectron PHoton science (ELPH) @ Tohoku Univ. in Japan

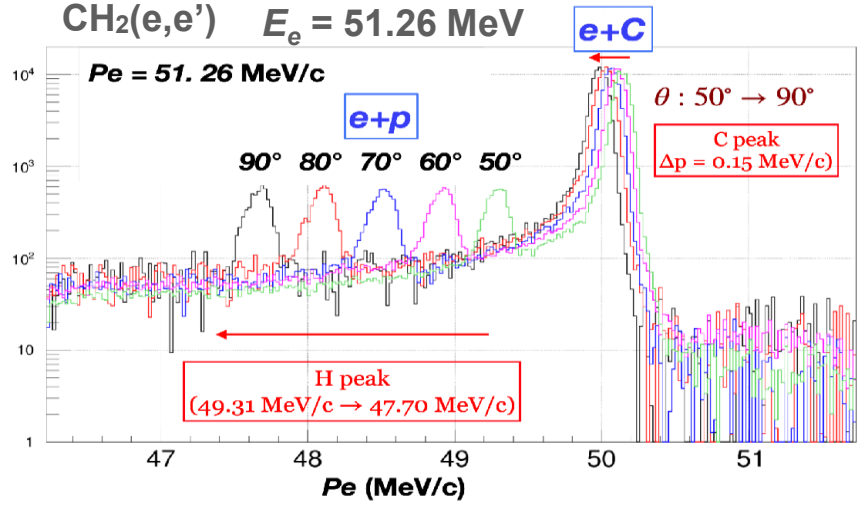


- New ULQ2 beamline
  - $e + p$ with the lowest-ever E_e of 10~50 MeV
  - Lowest-ever Q^2 of 10^{-4}~10^{-3} (GeV/c)^2
  - Charge radius:

$$\langle r^2 \rangle \equiv -6 \frac{dG_E(Q^2)}{dQ^2}\bigg|_{Q^2 \to 0}$$

with $G_E(Q^2)$ charge form factor and $Q^2 = 4E_e E_{e'} \sin^2(\theta/2)$

- **High-intensity electron beam irradiation station for RI production**
- ELPH is also a hadron-physics facility:
  - Spectrometer for Ultra-Low Q^2 (ULQ2) electron-scattering experiment
  - Neutral Kaon Spectrometer II (NKS2)
  - Multi-gamma ray detector system (FOREST)

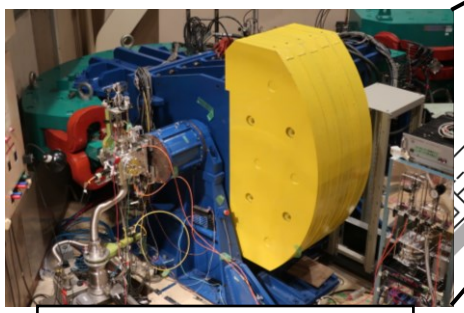


RIB accelerator facilities

CYRIC: Cyclotron and Radioisotope Center @ Tohoku Univ. in Japan

930 AVF cyclotron

- K number: 110 MeV
- Magnet
  - Weight: 200 t
  - Max Field: 19.6 kG
  - Max power: 230 kW
- RF
  - D-electrode: 2
  - Frequency: 11-22 MHz
  - Max voltage: 50 kV
  - Max power: 70 kW×2



Beam swinger system

→ Irradiation system of quasi-monoenergetic neutrons

RI production system

HM12 cyclotron

- Proton: 12 MeV, 60 μA
- Deuteron: 6 MeV, 30 μA
- Ion-source: PIG internal ion-source
- Beam port: 2

PET/CT

https://www.cyric.tohoku.ac.jp/en/

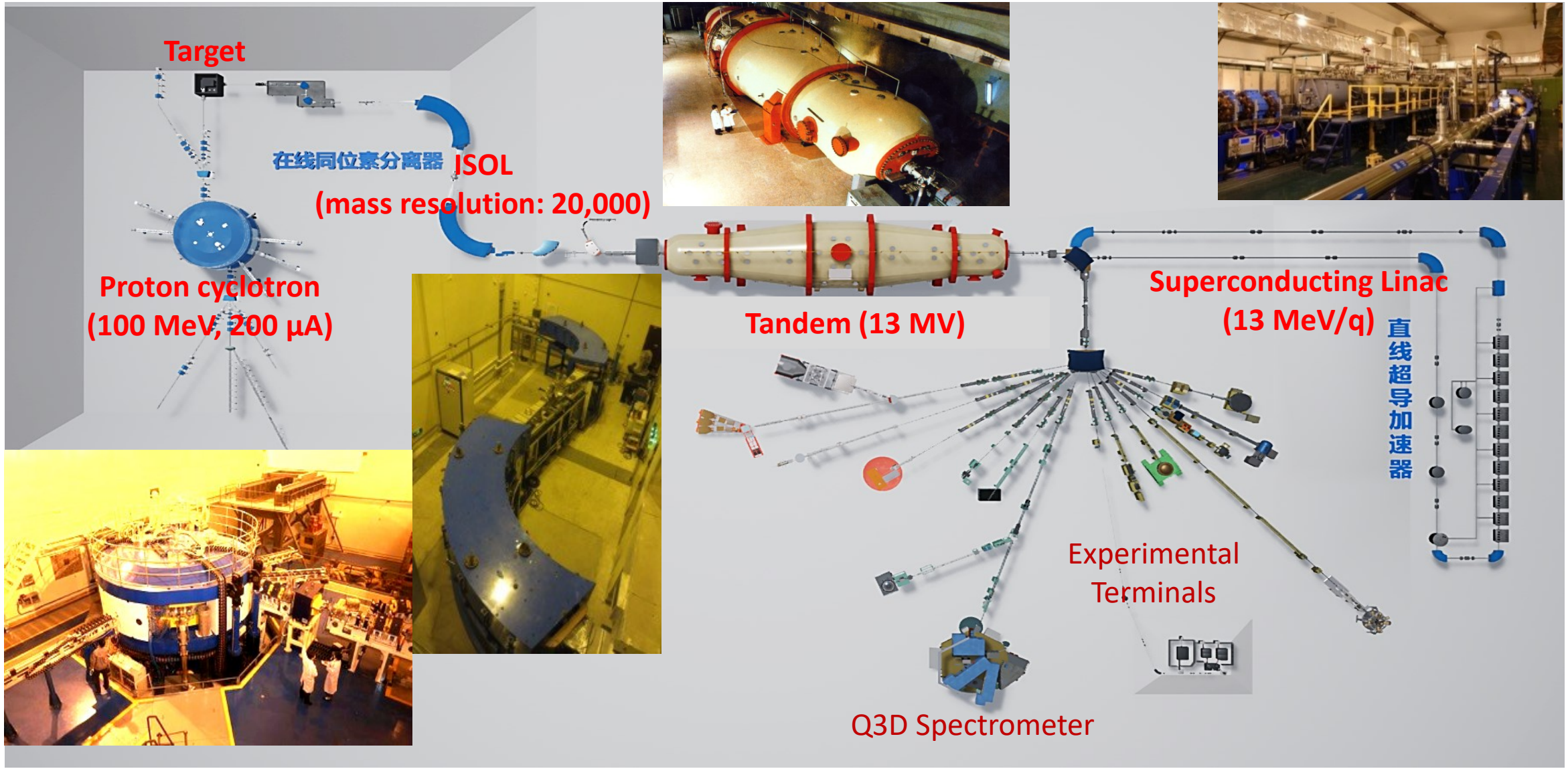
CYRIC + ELPH = Research center for Accelerator science and RadioIsotope Science (RARIS):

Joint organization from April 2024

RIB accelerator facilities

Beijing Radioactive Ion beam Facility (BRIF) @ CIAE in China

Construction started in 2011
Commissioning in 2016
Day-1 experiment in 2018

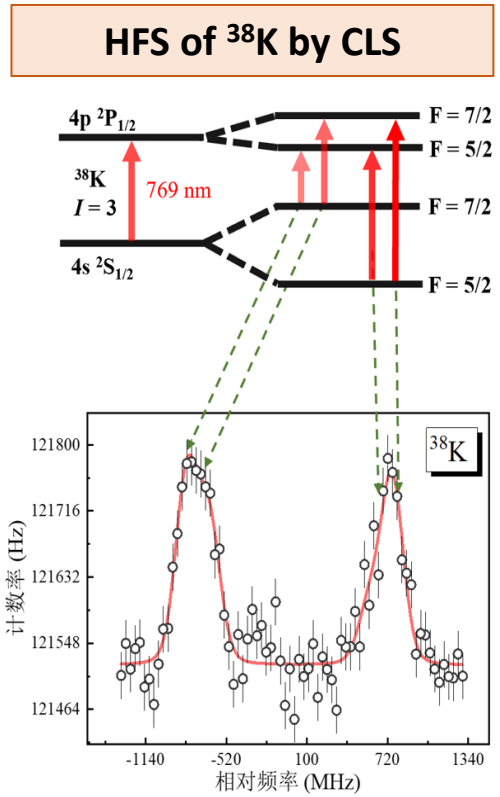


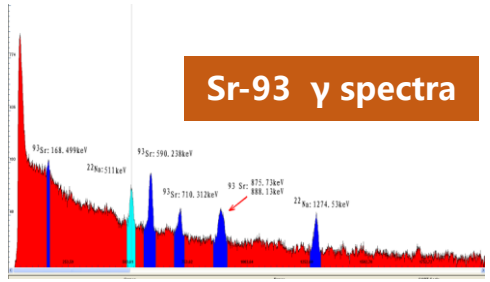
RIB accelerator facilities

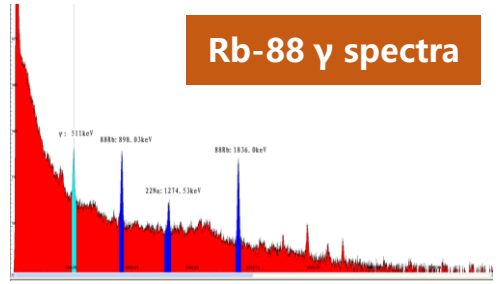
Beijing Radioactive Ion beam Facility (BRIF) @ CIAE in China

- Production of fission fragment RIBs (Rb, Sr, etc.)
- Number of RIB types: 24 (2021) → 55 (2022)
- The shortest half-life of RIB with ISOL: 0.45 sec → 0.17 sec
- Beam intensity: $10^3 \sim 10^{10}$ pps

- Recent achievements
  - First RIB experiment: 3 β-γ-α exotic decays in ^{20}Na [PRC103, L011301 (2021)]
  - Elastic scattering of the post-accelerated $^{21\text{-}23}$Na beams on ^{40}Ca target [NST32, 53 (2021)]
  - Total Absorption Gamma-ray Spectroscopy (TAGS) for ^{88,90}Rb and ^{140,142}Cs using LArge Module BGO Detector Array (LAMBDA)
  - First CLS experiment [NIMA1032, 166622 (2022)]

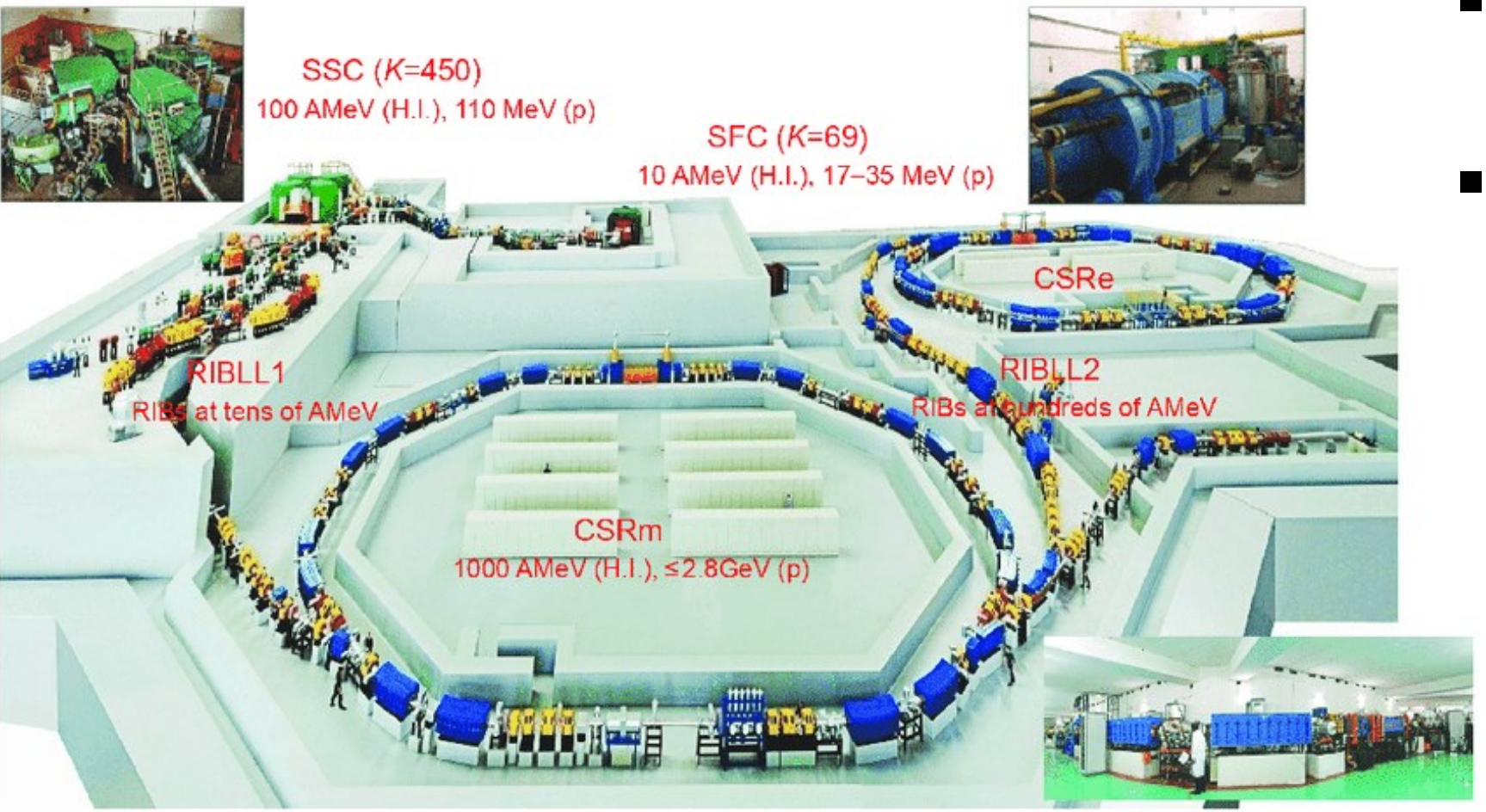






RIB accelerator facilities

Heavy Ion Research Facility in Lanzhou (HIRFL) @ IMP in China



- Beam species & energies
  - From protons to U
  - From keV to ~1 GeV/u
- Main nuclear experiments
  - Spectrometer for Heavy Atom and Nuclear Structure (SHANS) gas-filled recoil separator
  - Double ToF detector for Isochronous Mass Spectrometry (IMS) at CSRe
  - Electron target for Dielectronic Recombination (DR) at CSR
  - New isotopes synthesis at China Accelerator Facility for SHE (CAFÉ2) from 2022 with CW-SCL: 4.5~6 MeV/u, 5~10 pμA, and A/Q~3 for Ca~Zn

Heavy-ion collisions at LHC

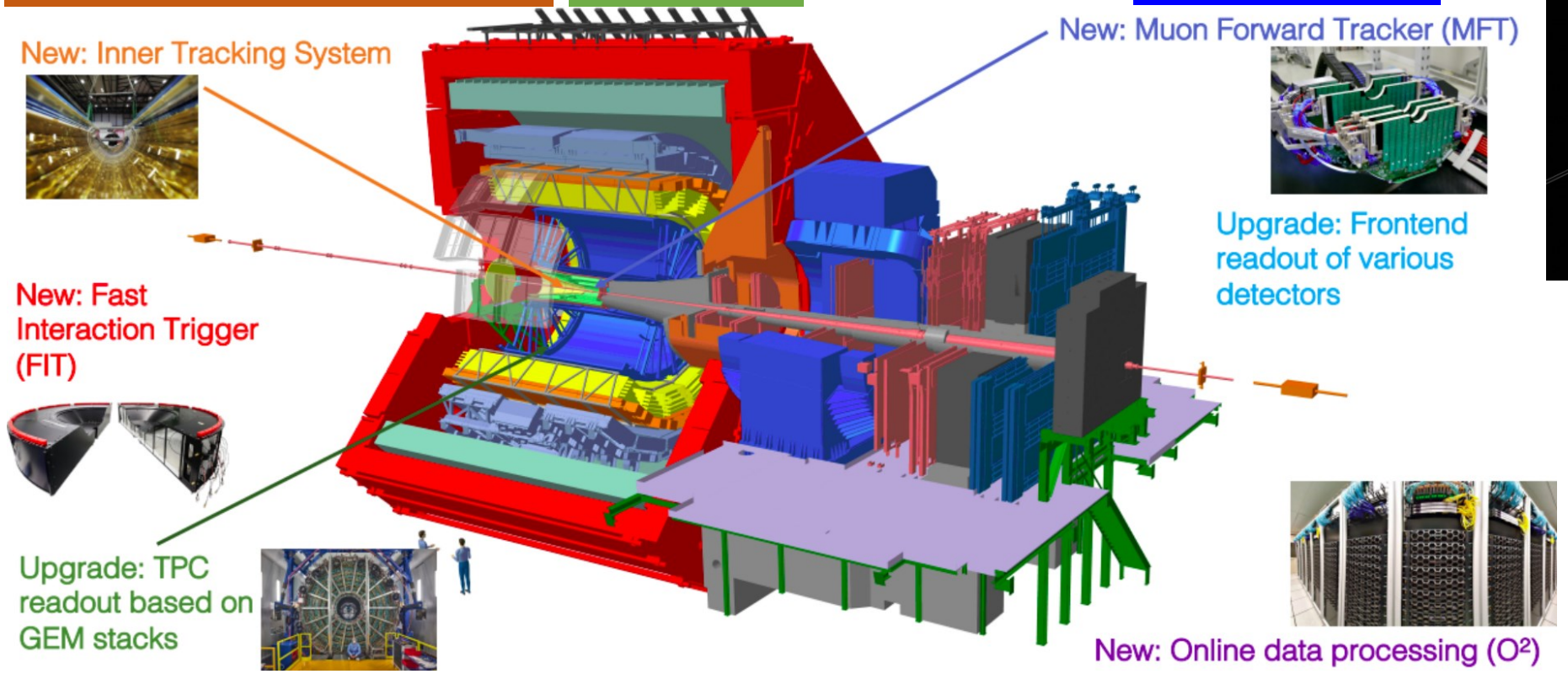
ALICE: A Large Ion Collider Experiment at LHC, CERN

Asian contribution to detector upgrade during LS2 (2018～2021)

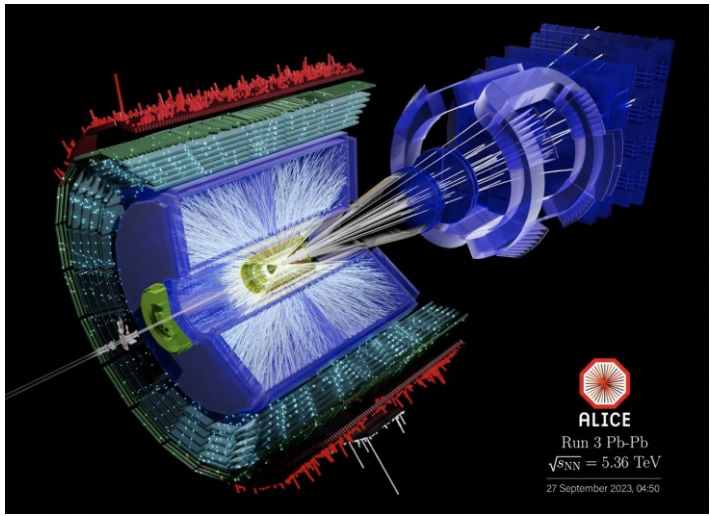
Korea: Inha, Pusan Nat., Yonsei

China: CCNU

Japan: Hiroshima



Japan: Tokyo, Nagasaki

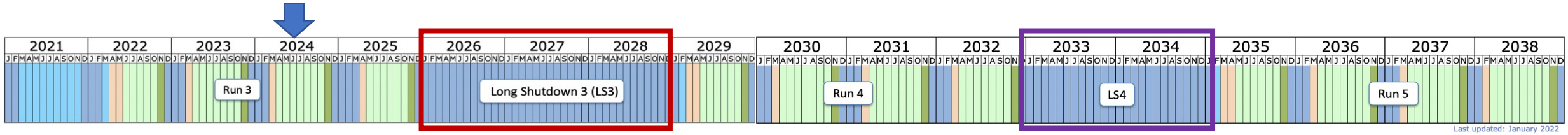


First Pb-Pb run in RUN3 (Sep.-Oct. 2023)

- ~45 kHz Had. Int. rate
- All 15 detectors included
- Data processing (reconstruction & compression) from 750 GB/s to 186 GB/s fully under control

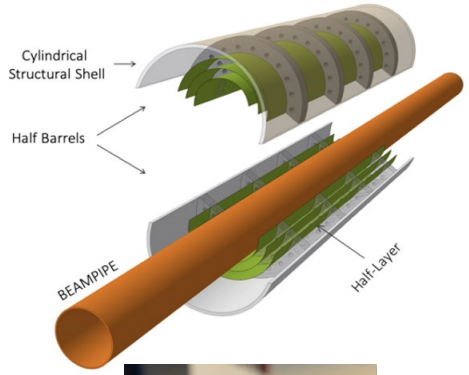
Heavy-ion collisions at LHC

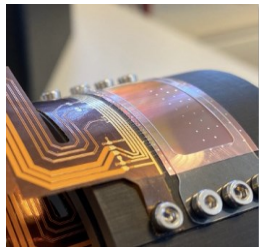
Future of ALICE ⇒ ALICE3



ITS3 upgrade (Inha, Pusan Nat., Yonsei)

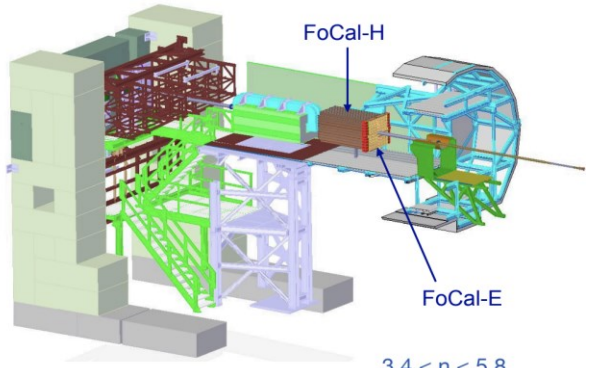
Bent MAPS Si pixel sensor

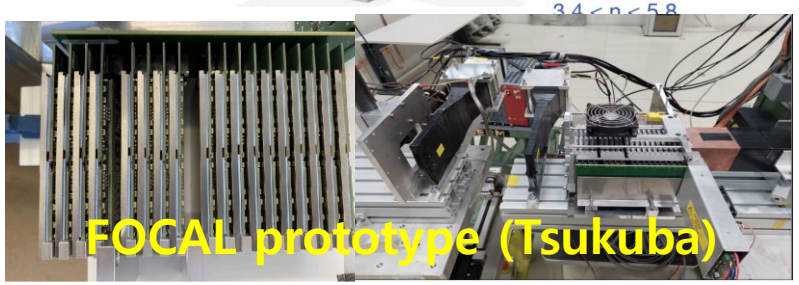




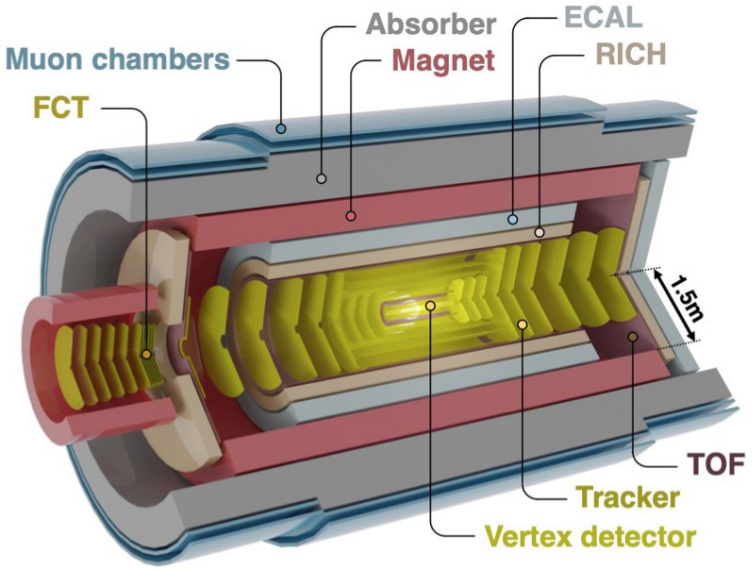
FoCAL upgrade (Tsukuba, Nagasaki, Nara)

Si+W EM Calorimeter + H-Cal





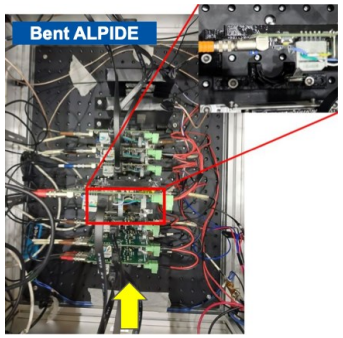
ALICE3 detector

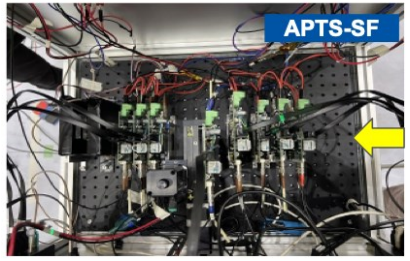


- **Silicon-only detector system**
- Large acceptance: $|\eta| < 4$ and $p_T > 50$ MeV
- Japan, Korea (outer) and China (inner) will contribute to the Si-tracker (MAPS Si-pixel layers).

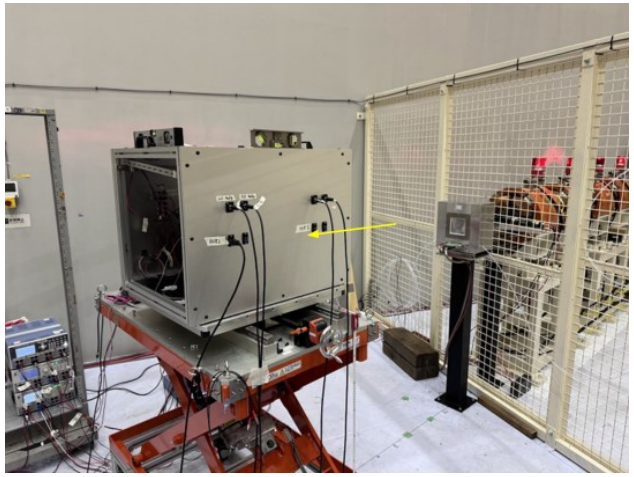
Heavy-ion collisions at LHC

Collaborative effort between Korea and Japan: KEK Beam test for R&D of ITS3





Test chips prepared in Korea & Japan



ITS3 telescope in Korea

EIC-Asia Collaboration

- EIC Users Group
  - 1321 Collaborators
  - 292 Institutions
  - 39 Countries
  (Need to update!)

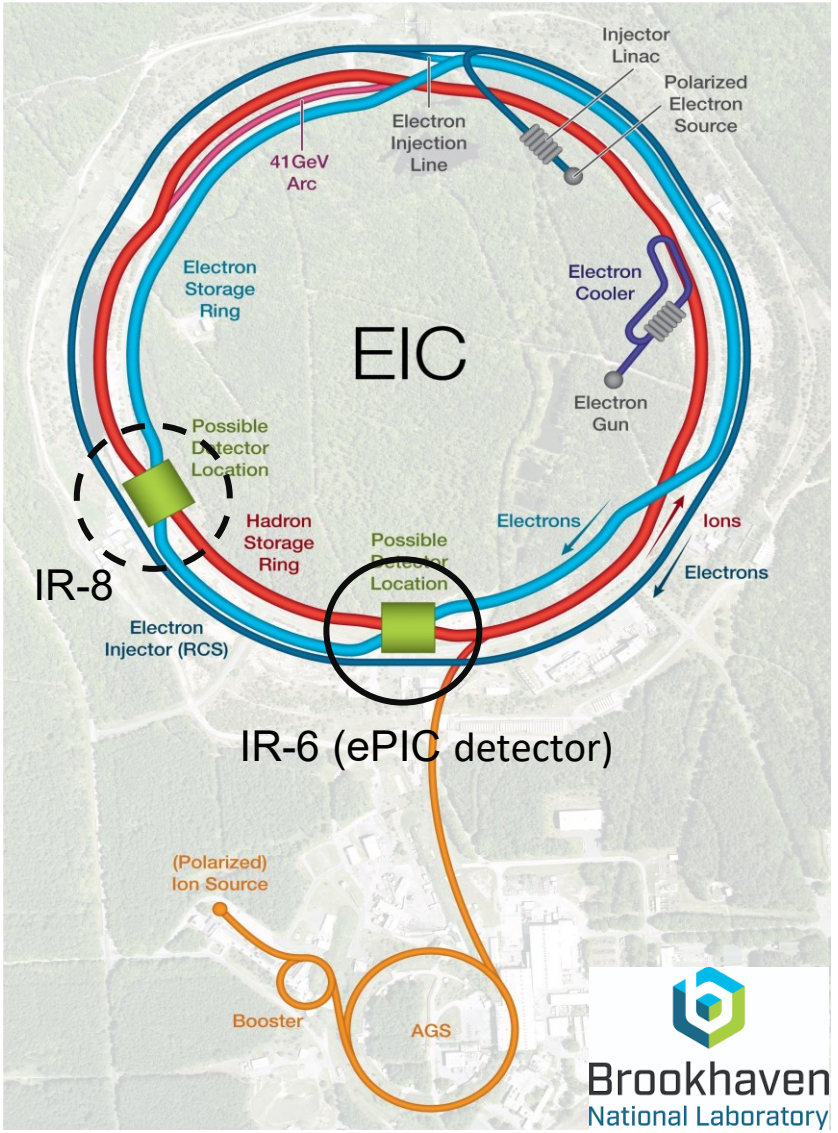
- EIC hosted at Brookhaven National Laboratory
- 80% polarized electrons from 5-18 GeV
- 70% polarized protons from 40-275 GeV
- Ions from 40-110 GeV/u
- Polarized light ions 40 -184 GeV (He^3)
- 100-1000 x HERA luminosities:10^{33}-10^{34} $cm^{-2}s^{-1}$
- Center-of-mass energies: $\sqrt{s}$=29-140 GeV
- CD1 obtained in July 2021
- foreseen to start operation in early 2030's

- Asian fraction
  - Asian fraction: 12% per members/26% per institutions
  - EIC-Asia: China, India, Japan, Korea, Taiwan

- Activities
  - Monthly online meeting
  - Workshops
    - NCKU, Taiwan, Jan. 29-31, 2024
    - RIKEN, Japan, Mar. 16-18, 2023
    - NEU, Taiwan, Dec. 9-10, 2022
    - APCTP, Korea, Nov. 2-4, 2022

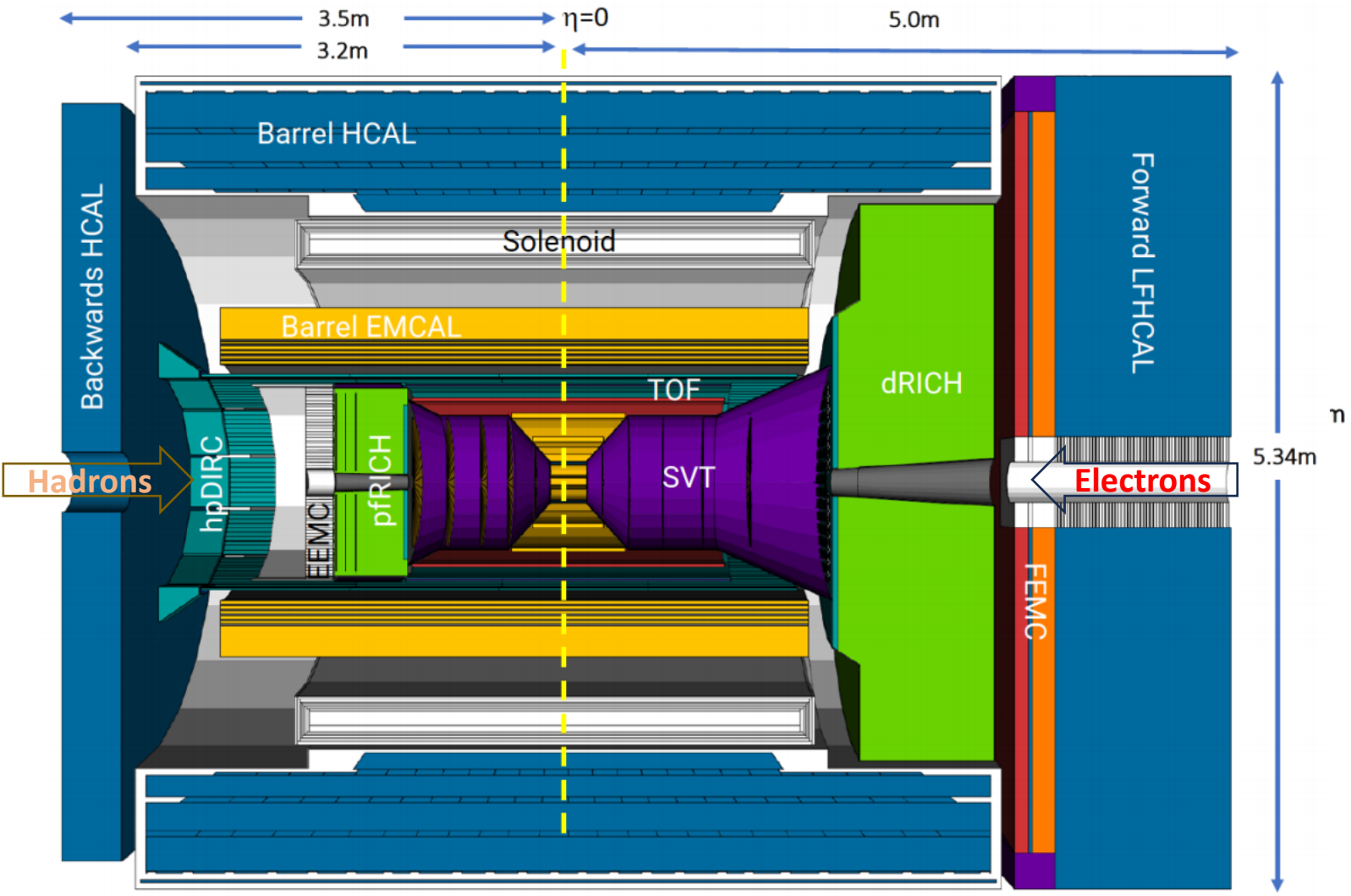
Physics Goals of EIC

- 3D imaging of protons & nuclei
- Solving the proton spin puzzle
- Search for gluon saturation
- Quark and gluon confinement
- Quarks and gluons in nuclei



EIC-Asia Collaboration

From T. Gunji @ ANPhA Symposium (Nov. 2023)



Tracking:

- New 1.7T solenoid
- Si MAPS Tracker
- MPGDs (μRWELL/μMegas)

PID:

- hpDIRC
- pfRICH
- dRICH
- AC-LGAD (~30ps TOF)

Calorimetry:

- Imaging Barrel EMCal
- PbWO4 EMCal in backward direction
- Finely segmented EMCal +HCal in forward direction
- Outer HCal (sPHENIX re-use)
- Backwards HCal (tail-catcher)

Summary

- Several nuclear physics facilities in Asia are in the construction, commissioning, operational or upgrade stage:
  - Underground facilities: SUPL (Australia), CJPL-II (China), Yemilab (Korea)
  - RIB accelerators: BRIF, JUNA/CJPL, HIRFL, HIAF (China), RIBF, RCNP, ELPH & CYRIC/RARIS (Japan), RAON (Korea)
  - Hadron accelerators: HIAF (China), J-PARC (Japan)
  - Photon & electron accelerators: Spring-8, ELPH/RARIS (Japan)
- Significant contributions to the LHC heavy-ion program (ALICE and CMS) from Asia
  - China, India, Japan, Korea, Taiwan, etc.
- EIC-Asia for more effective regional collaboration

- *The nuclear physics facilities in Europe, U.S.A., and Asia are complimentary.*
- *The closer collaborations are not only beneficial to us, but also required for better physics output, which should be a sufficient motivation to work together!*