CDEX-300ν program for ^{76}Ge 0νββ search

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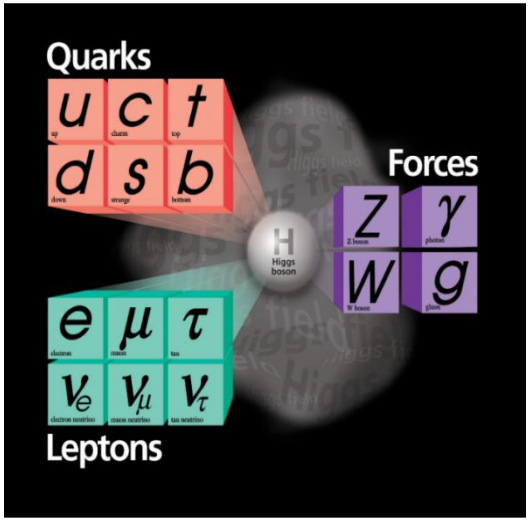
第二届地下和空间粒子物理与宇宙物理前沿问题研讨会

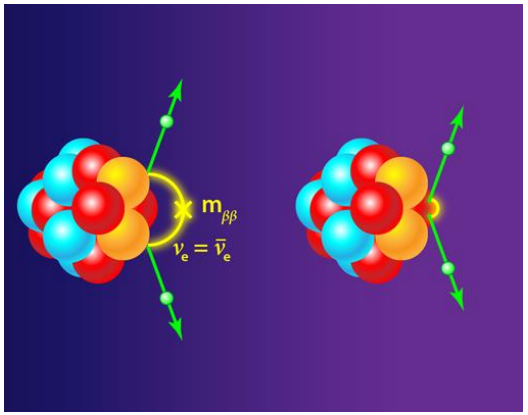
Outline

- Neutrinoless double beta decay ($0\nu\beta\beta$)
- Introduction to CDEX and CDEX-300ν
- $0\nu\beta\beta$ result from CDEX
- Pre-Conceptual design of CDEX-300ν
- Future plan of CDEX-300ν

Neutrinoless double beta decay

- **Questions for neutrino physics:**
  - Neutrino mass and mass hierarchy
  - Dirac or Majorana nature of neutrino
  - Neutrino species
  - …
- **If 0νββ decay observed:**
  - Neutrino behaves as a Majorana particle
  - Lepton number conservation violated
  - Neutrino absolute mass
  - …





$$(A, Z) \rightarrow (A, Z+2) + 2\,e^- + Q_{\beta\beta}$$

Neutrinoless Double Beta Decay Exp.

- **Germanium as 0νββ detector**
  - Intrinsic high-purity crystal ~13N
  - Source = detector (high ε)
  - Industrial enrichment to ≥86% (A)
  - Excellent E resolution (σ) ~0.1% @ 2MeV
  - Background rejection (b): PSD, LAr veto, multiplicity…

Detecting efficiency

Mass of target

$$T_{1/2}^{0\nu} \propto \varepsilon \cdot A \cdot \sqrt{\frac{M \cdot t}{b \cdot \sigma}}$$

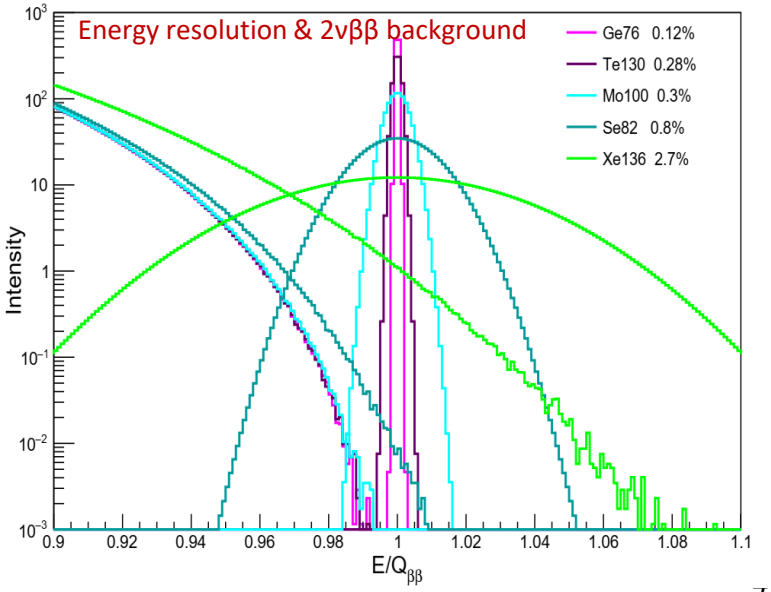
Isotopic fraction

Energy resolution

Background

- Current best $T_{1/2}$ result achieved by Gerda
- Energy resolution crucial for irreducible 2νββ background

Experiment	Iso	Exposure [kg-yr]	Half life [10^{25} yr]	$\langle m_{\beta\beta} \rangle$ [meV]
Gerda	^{76}Ge	127.2	18	80 - 182
KamLAND-Zen	^{136}Xe	594	10.7	61 - 165
CUORE	^{130}Te	115.9	1.5	110 - 520



CDEX Roadmap

- Persistently focused on DM direct detection
- Extended to ^{76}Ge 0νββ search
- Multiple physics goals…

详见5.10杨丽桃报告

CDEX-1 → CDEX-10 → CDEX-50（DM） + CDEX-300v（0νββ） → CDEX-1T

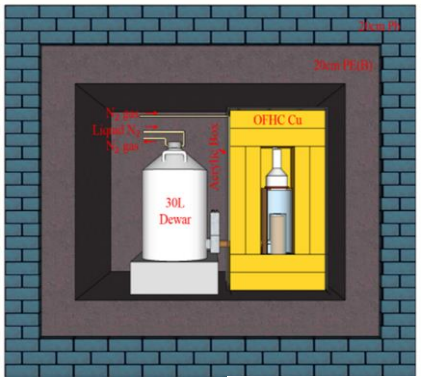
First 0νββ result by CDEX

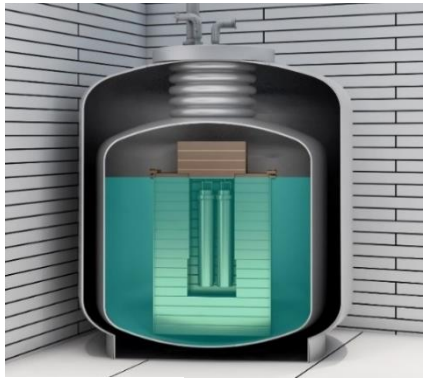
2009-2016

2016-2020

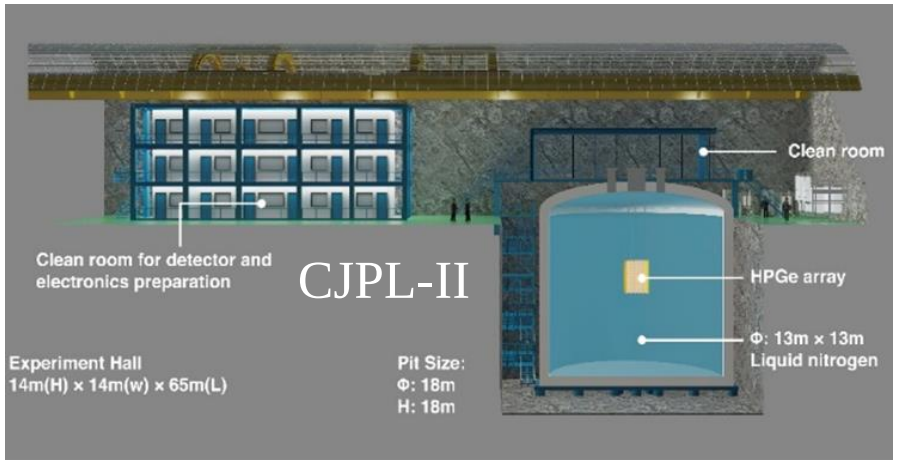
2021-

First stage of CDEX ^{76}Ge 0νββ search project @ CJPL





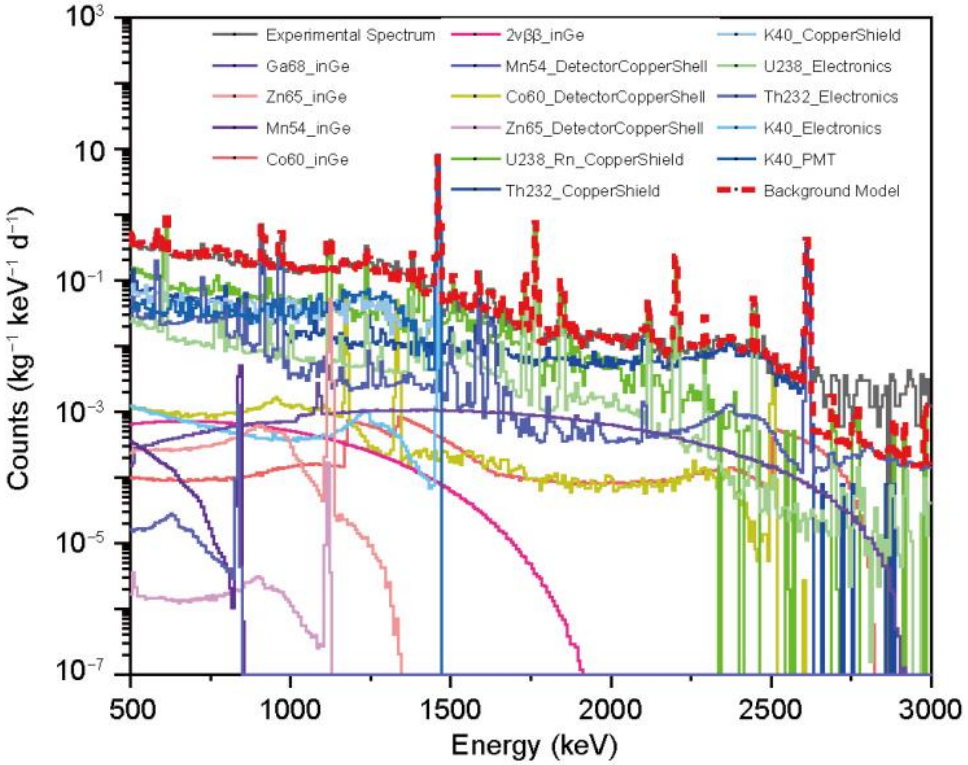
CJPL-I

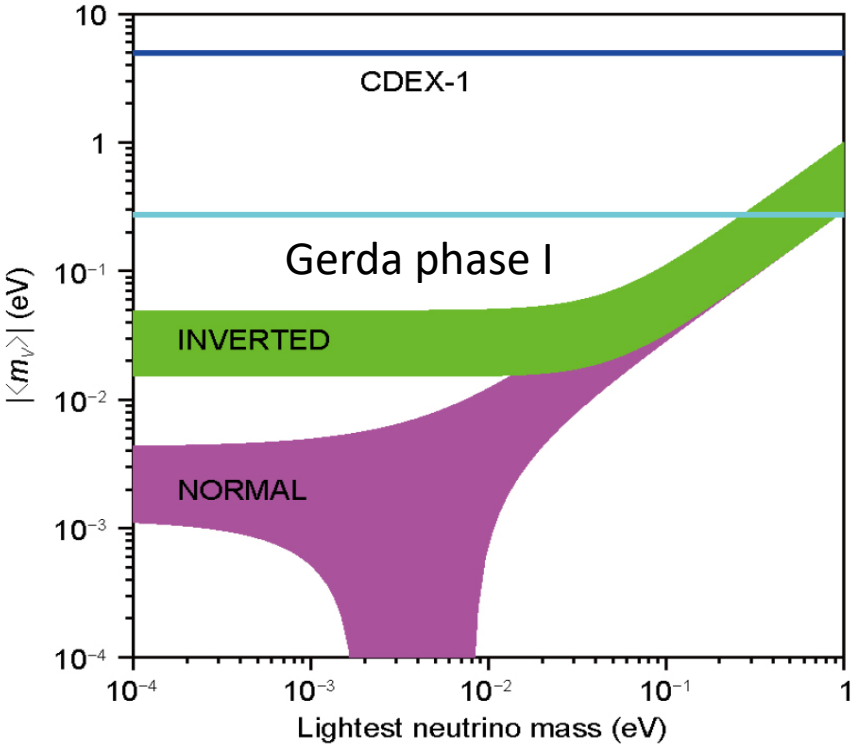


0νββ result from CDEX

- First ^{76}Ge 0νββ result in China.
- Exposure: 304 kg·day, CDEX-1 PPC (natural crystal)
- $T_{1/2}^{0\nu} \geq 6.4 \times 10^{22}$ yr, 90% C. L.

L. Wang et al, Science China P.M.A. (2017) 071011

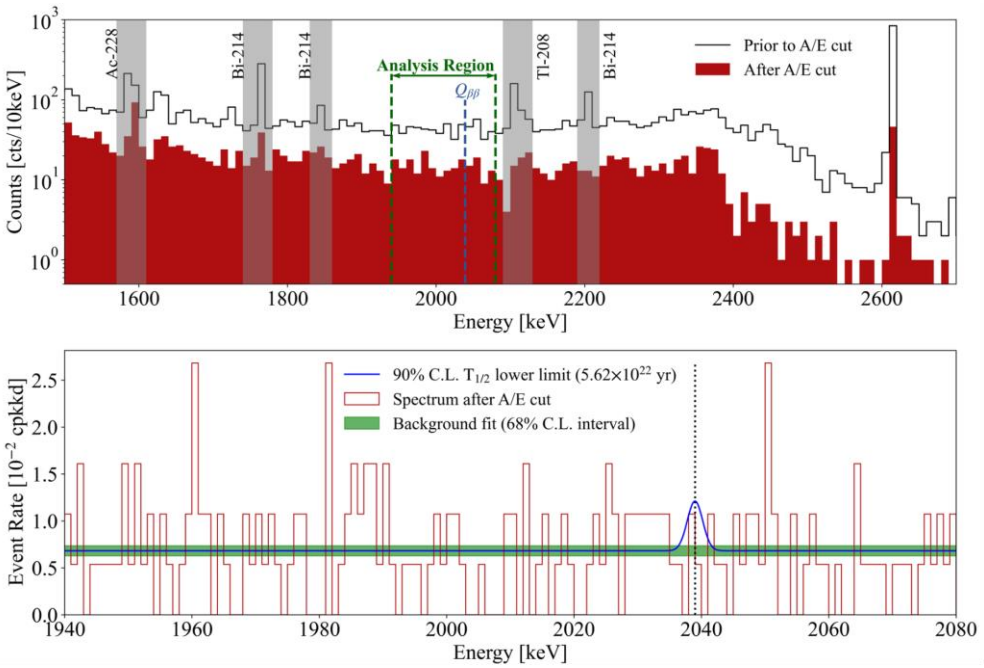


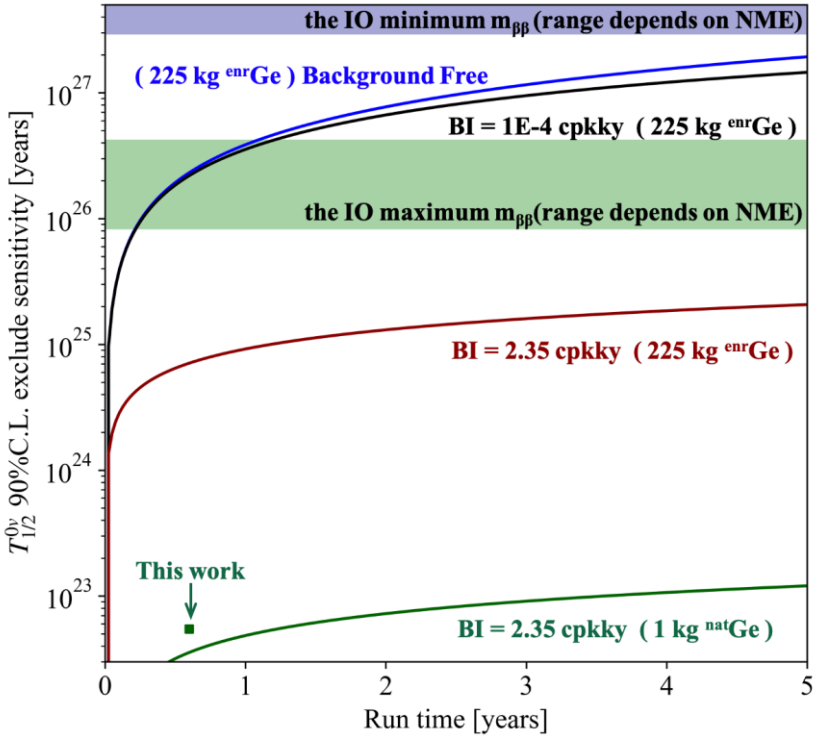


New 0νββ result from CDEX

- Natural BEGe, 1.1kg, 186.4 kg·day exposure
- Establish data analysis procedure and PSD method, 50% reduction of background in ROI than CDEX-1
- First CDEX result from BEGe, $T_{1/2}^{0\nu} \geq 5.6 \times 10^{22}$ yr,90% C. L.

W. Dai et al, Physical Review D 106, 032012 (2022)





CDEX-300: Physics goal and technical route

- First stage of CDEX ^{76}Ge 0νββ search project
- Physics goal: **$T_{1/2} > 10^{27}$ yr, $\langle m_{\beta\beta} \rangle$: 30-70 meV**

$$T_{1/2}^{0\nu} \propto \varepsilon \cdot A \cdot \sqrt{\frac{M \cdot t}{b \cdot \sigma}}$$

- Technical route:

Enriched Ge Array

- ✓ Enriched ^{76}Ge (A)
- ✓ ~ 225kg Ge (M)
- ✓ Energy resolution (σ)

+

LAr veto + LN_2 shield

- ✓ LAr as active shield
- ✓ LN_2 as passive shield

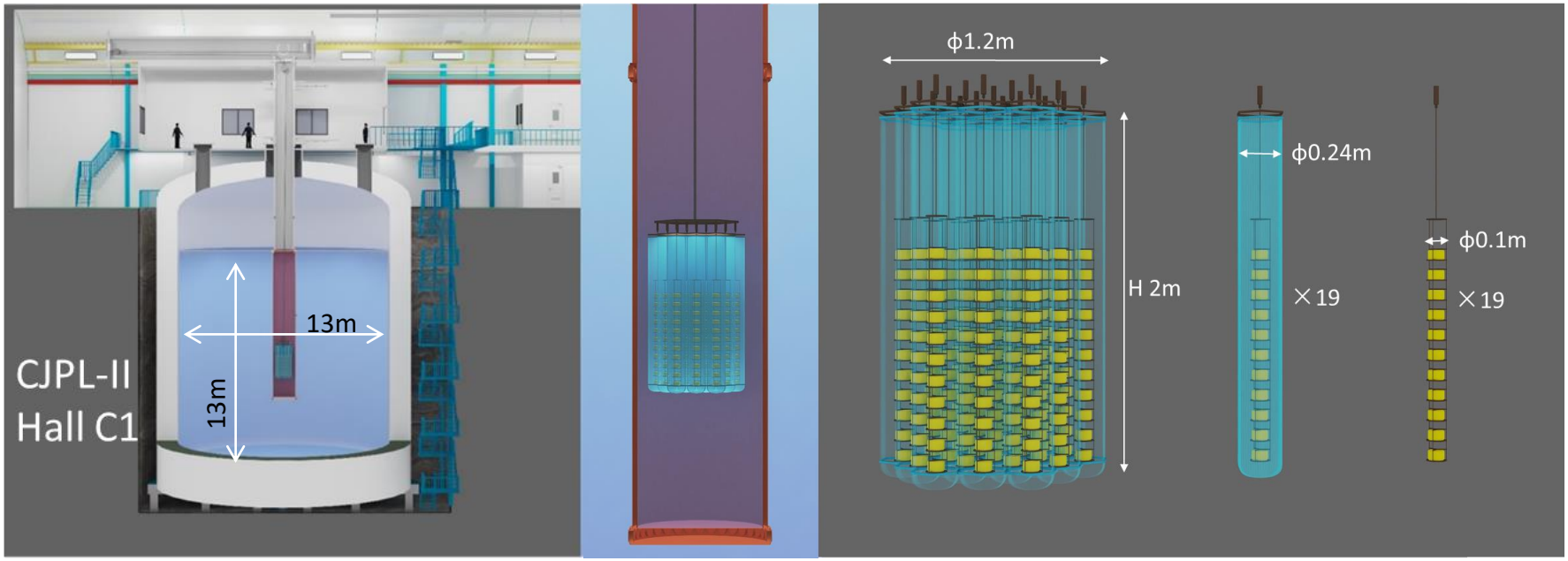
Material bkg control

- ✓ Cosmogenic radioactivity in Ge
- ✓ Materials near Ge crystal
- ✓ Rn in LAr & LN_2…

CDEX-300ν pre-Conceptual Design

Overview

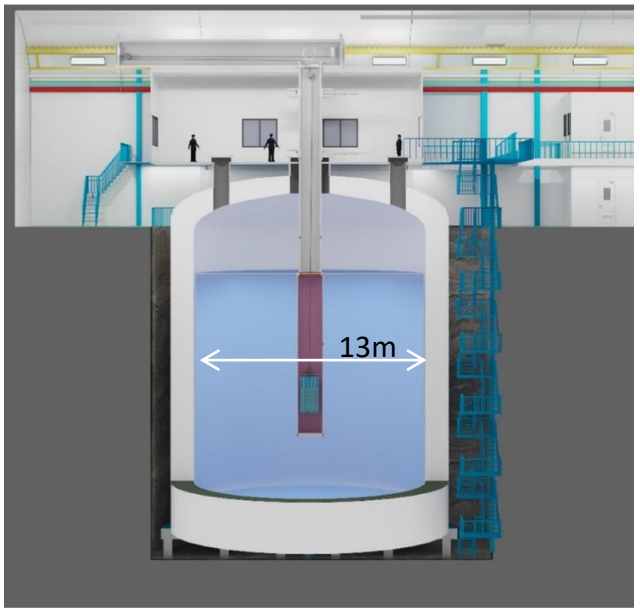
- LN_2 tank shared with CDEX-50
- Reentrant tube containing LAr submerged in LN_2
- Ge detector array immersed in LAr (veto) tube
- Ge detectors divided into 19 strings (10-11 det/string, 200 in total)



LN_2 tank

Specification

- Total volume: 1976m^3
- LN_2 volume: Φ13m × H13m, ~1725 m^3
- LN_2 as Passive Shield & Cryogen
- Five top flanges for detector deployment
  - 1×φ1.5m, centrally
  - 4×φ750mm, on a 6m-diameter circle



1725 m^3 Liquid Nitrogen

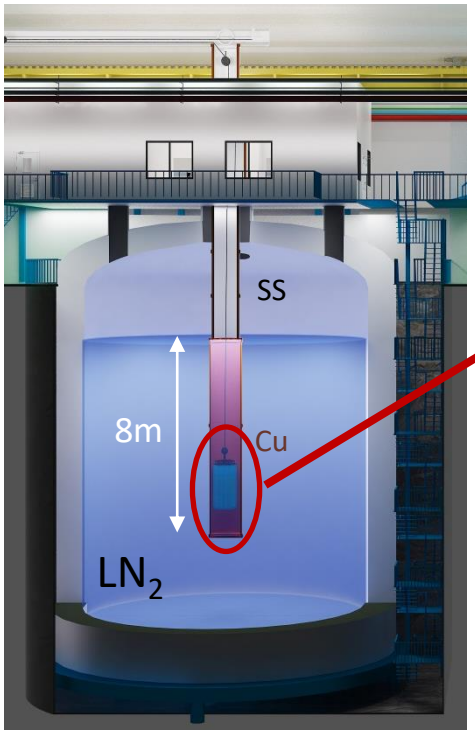
Background

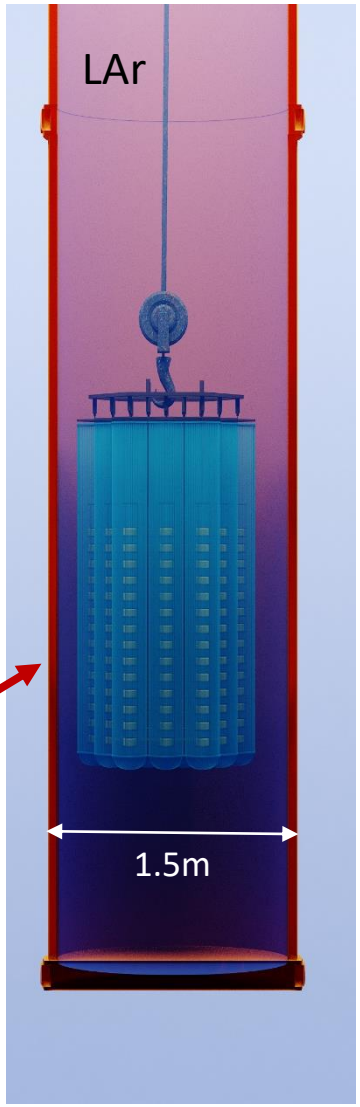
- >4m LN_2 shields most bkg from surroundings
- Rn in LN_2 controlled by purification

CDEX-300v LAr System (1)

Baseline Design:

- ~20 t LAr held by **Cu** / SS cryostat
- LAr constantly purified
- LAr cryostat immersed in LN_2
- LAr light read out by WLS Fiber + SiPM





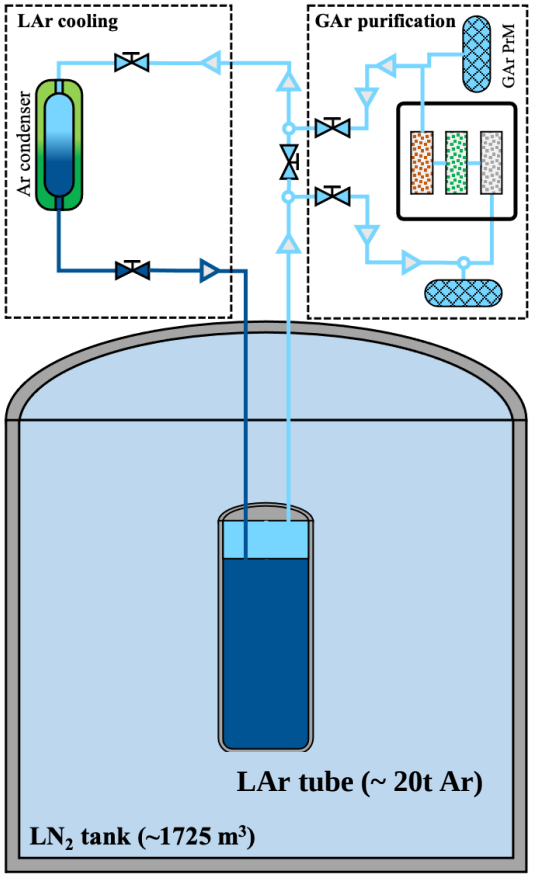
CDEX-300v LAr System (2)

LAr Purification:

- Removing O_2 / H_2O / N_2 from GAr (~10ppb impurity)
- Maintaining high light yield & transmission length
- Removing Rn by active carbon (~μBq/m^3)
- Possible underground Argon (Ar-42 depleted)

LAr Cooling:

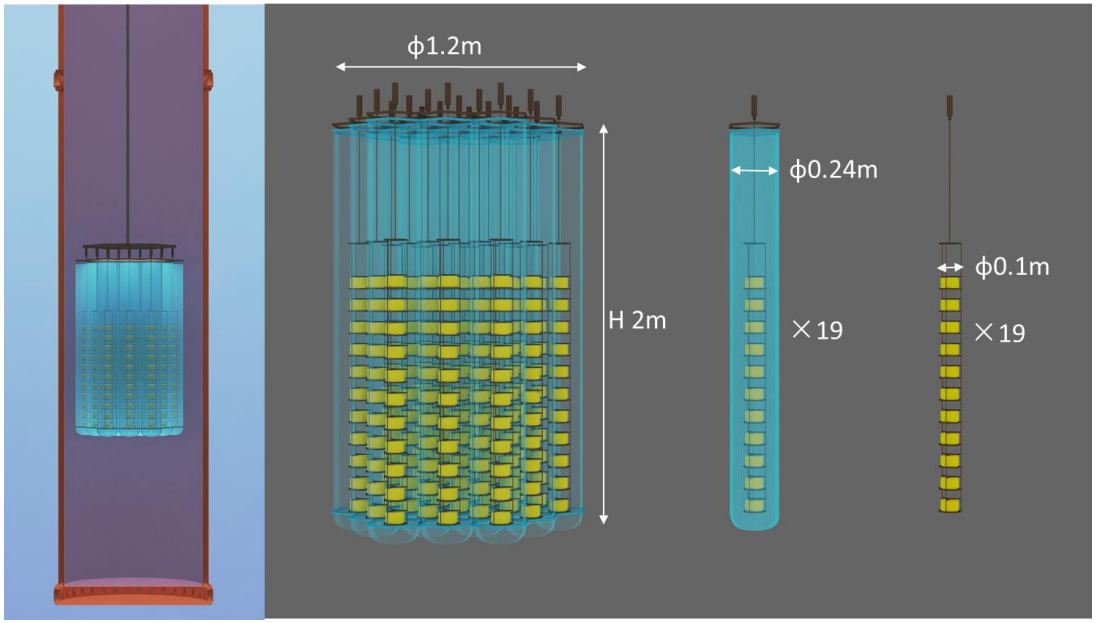
- Cooling purified GAr to LAr
- Heat exchanger + electrical condenser
- Backup LN_2 cooling module



CDEX-300v LAr System (3)

LAr Scintillation Light Readout

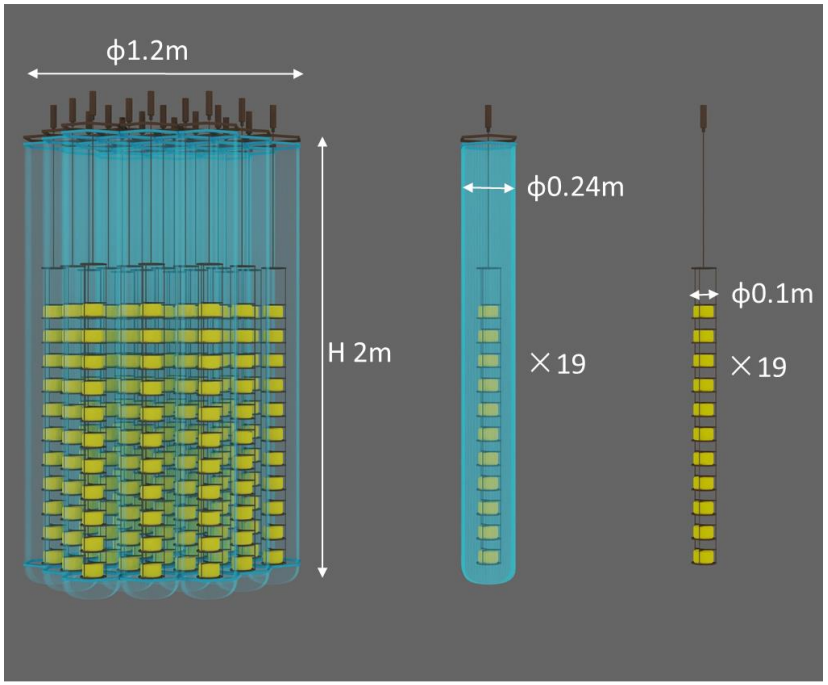
- Detector strings surrounded by fiber curtains to collect light
- Read out via top SiPM

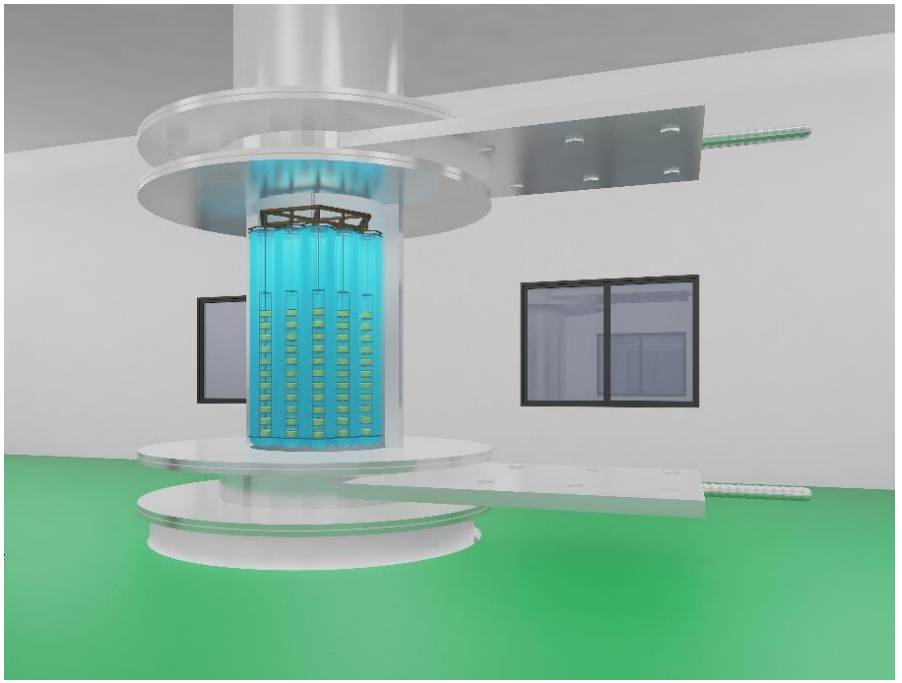


Ge detector Array

Baseline Design:

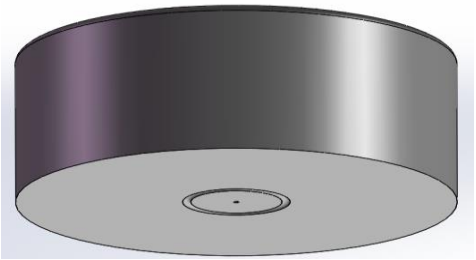
- 200 Ge det, 19 strings, 10-11 det/string,
- Total mass of Ge detectors: ~225kg
- Top clean room for Ge detector and fiber installation



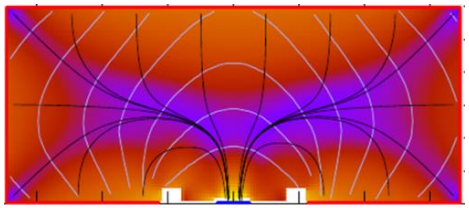


Ge detectors

- **Enriched BEGe (Baseline)**
  - Mass: 1-1.2 kg； Ge-76 > 86%
  - Size: φ80×40 mm
  - Dead layer: 0.6 mm
  - FWHM : <0.15% @2MeV (~2.5keV)
  - Commercial / Home-made

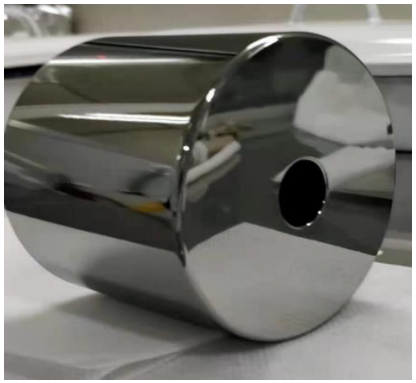


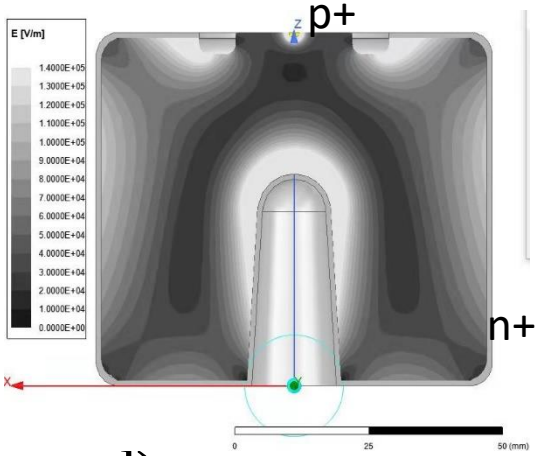
BEGe: Broad Energy Germanium



ICPC: Inverted Coaxial Point Contact

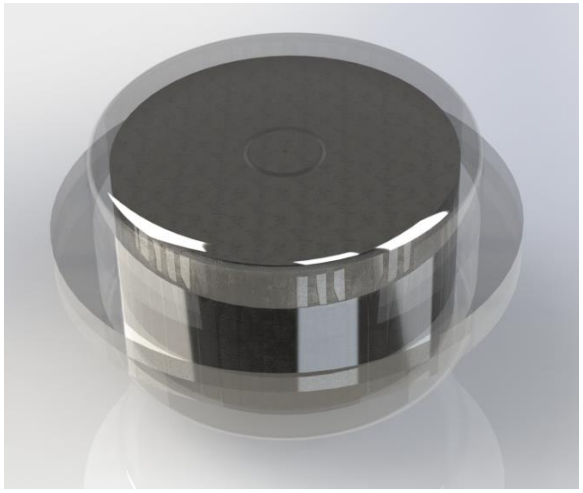
- **ICPC (optional)**
  - Mass: ~2 kg
  - Size: φ80×80 mm
  - Dead layer: 0.6 mm
  - Home-made
  - Bigger Detector → Less Electronics (background)

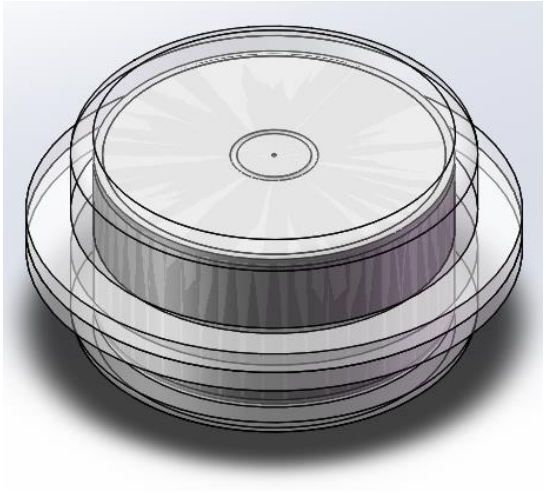


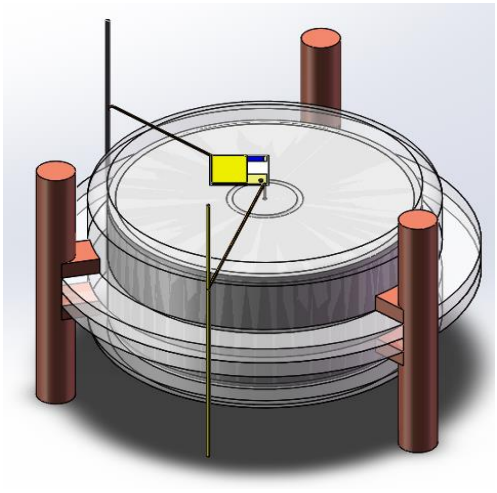


Ge Detectors

- **Baseline design**
  - Naked enr-BEGe immersed in LAr (veto)
  - Free of traditional vacuum-related structure
- **R&D** (reduce bkg from $^{42}Ar/^{42}K$)
  - Ge crystal sealed in LB acrylic capsule and isolated from LAr
  - Front Electronics on the outer surface of acrylic shell

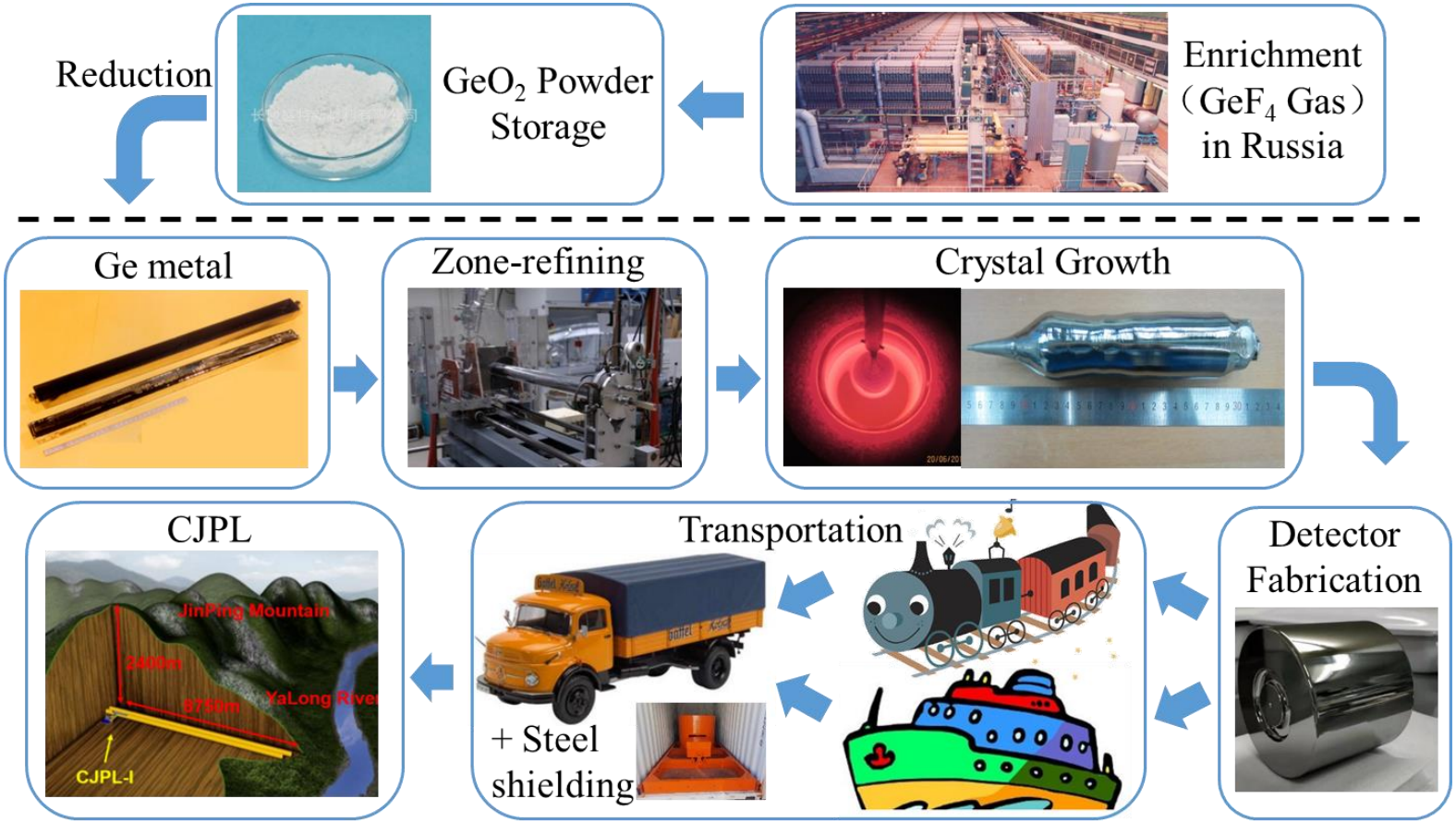






Enriched Ge detector procurement

- Enriched germanium dioxide (^{76}Ge >86%) from Russia in 2021
- Whole technical chain established
- 90kg enriched material arrived and sent to subsequent process



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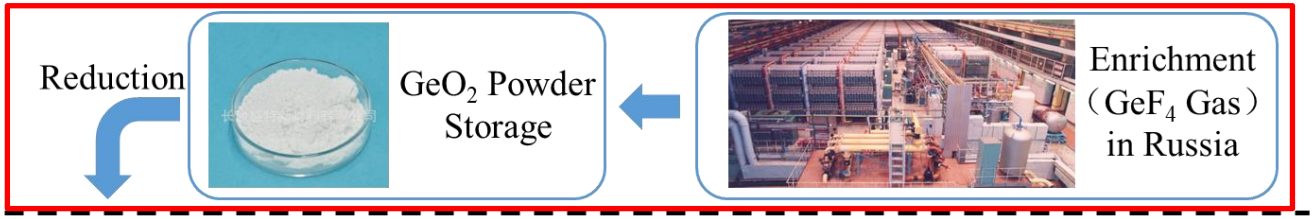
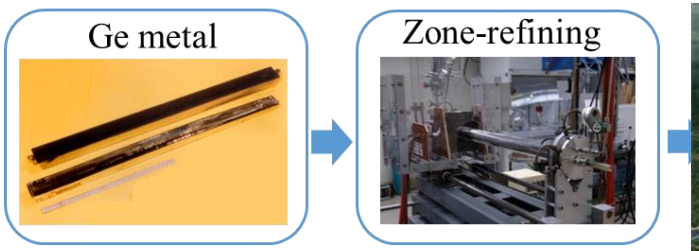
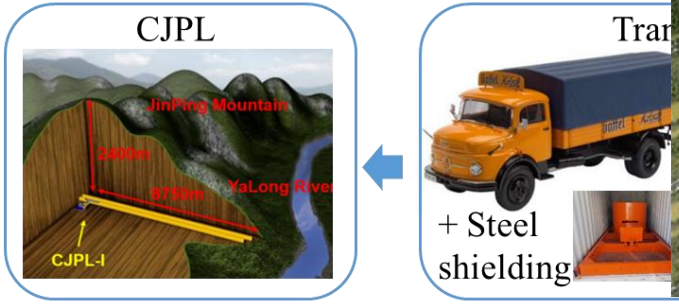


CNNC in China now a good alternative for Ge-76 enrichment






Plan graph of enrichment factory area

详见5.9谢全新报告

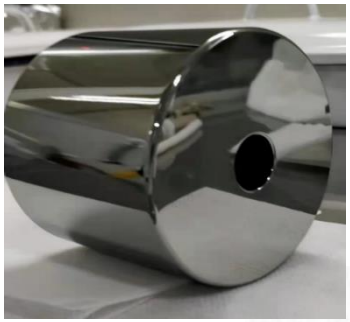
Detector R&D

- **Home-made Ge detector**
  - Co-axial/BEGe/PPC/ICPC
  - Cold finger/Naked immersion

详见5.8李玉兰报告

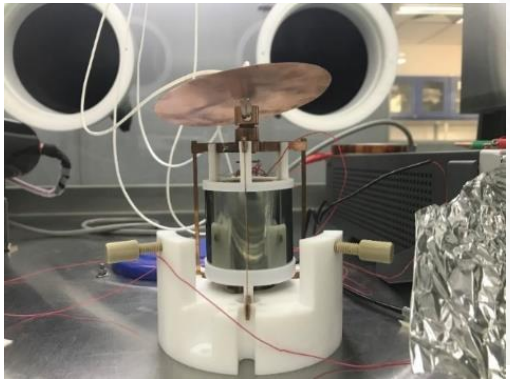
BEGe

PPC

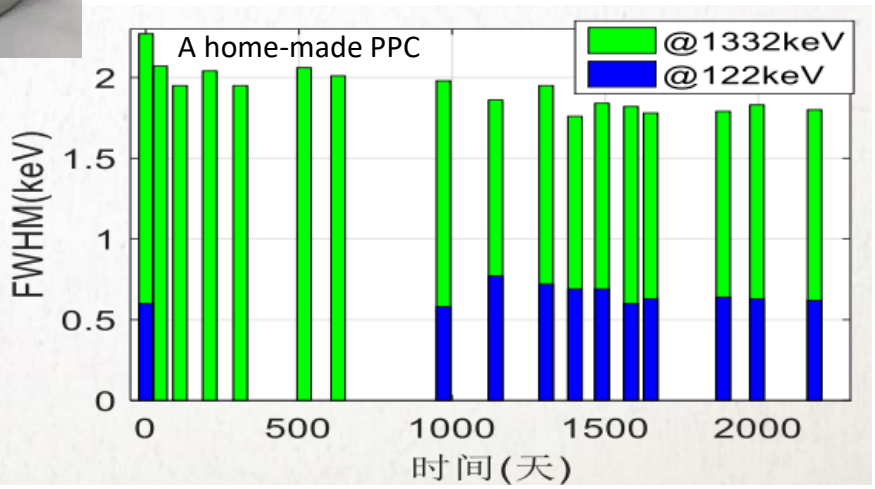


ICPC

Cold finger cooling



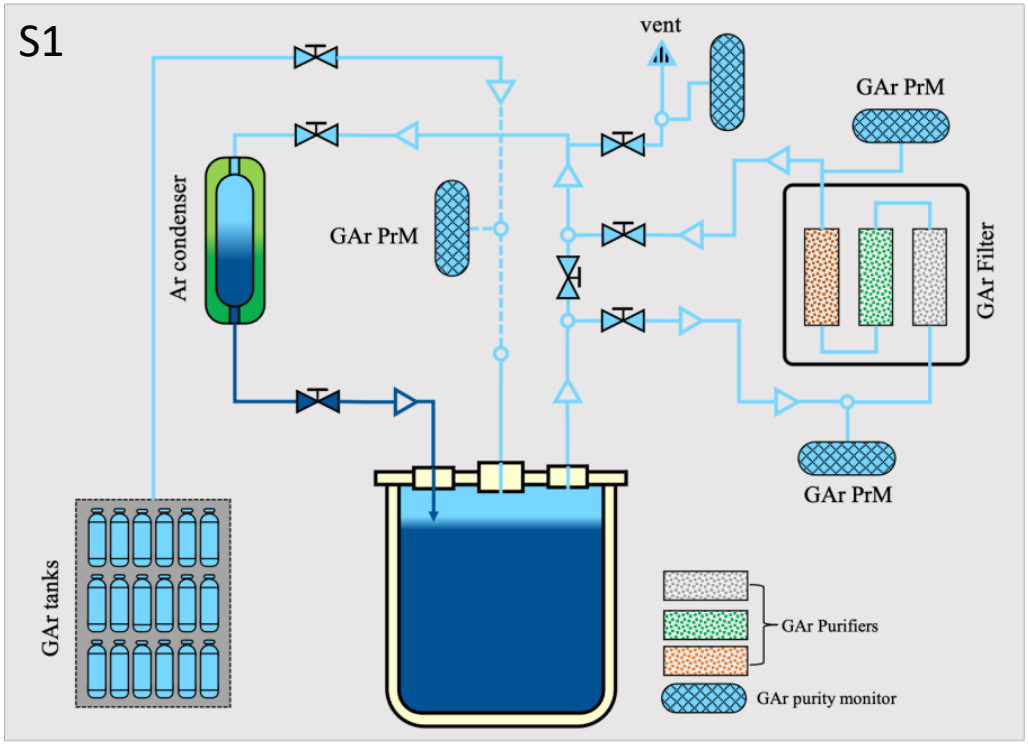
Naked crystal to LN_2

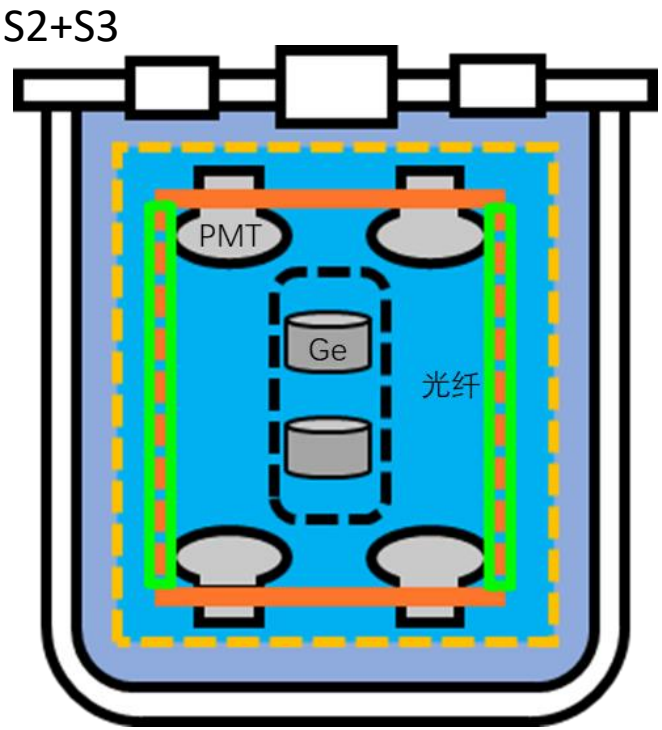


Long-term stability: energy resolution

LAr Test Facility

- **S1**: Operating & Purifying 200L LAr in a closed cycle （2023.12-）
- **S2**: Studying light yield / transmission of LAr in different impurity levels
- **S3**: Deploying Ge detectors to test veto efficiency



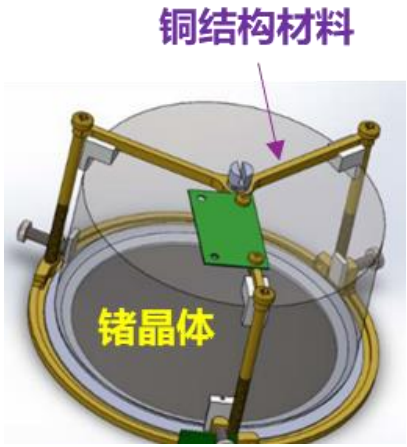


Material Background Control

ALL materials to be screened and selected

Ge detector & FEE:

- Mitigation of cosmic activation on the ground
- Low mass & pure detector structures
- Low background cables or flexible PCB
- CMOS ASIC Front-end Electronics
- Underground fabrication of Ge detectors



Underground Electro-forming copper

- U/Th activity <10 μBq/kg
- Free of cosmogenic radioactivity

Th/U: ~1.6/10.7 μBq/kg

CDEX-300v Plan

- Enr-Ge detectors test started in 2022 @ CJPL-I
- Test and operate LAr test facility at the end of 2023
- Hall C1 expected to be ready for experiment this fall
- Experimental setup in 2024
- First batch of Ge detector installation and test in 2024

Hall C1 of CJPL-II

Summary

- Searching for 0νββ decay plays an essential role in understanding the nature of neutrinos
- CDEX-300ν for ^{76}Ge 0νββ
  - 225kg enriched Ge detector system at CJPL-II
  - physics goal : $T_{1/2}>10^{27}$ yr, 90% C.L.
  - first batch of detectors deployed in 2024
- R&D in progress
  - Detector and electronics
  - LAr purification and scintillation light readout
  - Material screening and selection
  - ……

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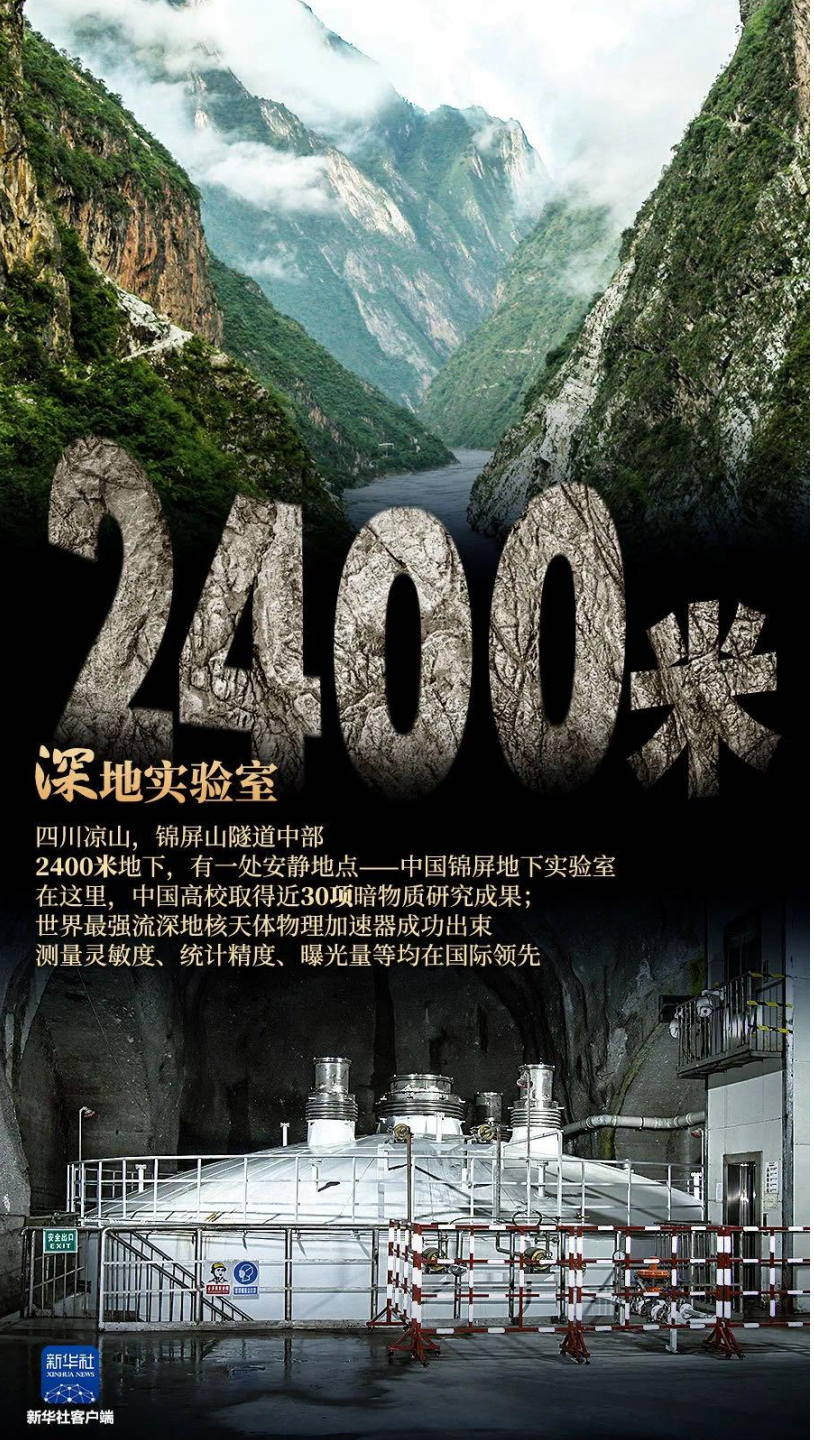

Thanks for your attention!

中国暗物质实验
China Dark matter EXperiment

http://cdex.ep.tsinghua.edu.cn

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CJPL
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