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

Litao YANG (杨丽桃)

Tsinghua University

On behalf of CDEX Collaboration

CJPL
中国锦屏地下实验室
China Jinping Underground Laboratory
清华大学·雅砻江流域水电开发有限公司

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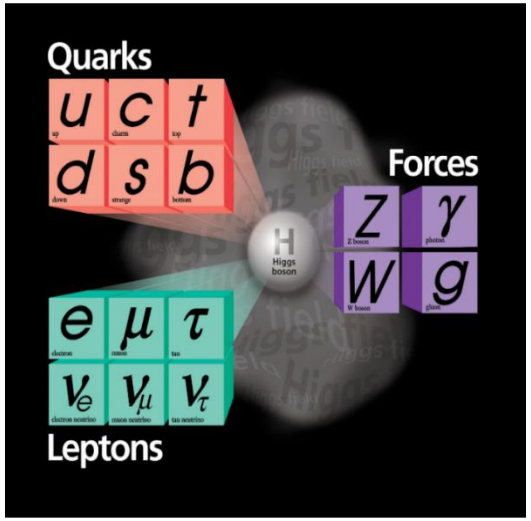
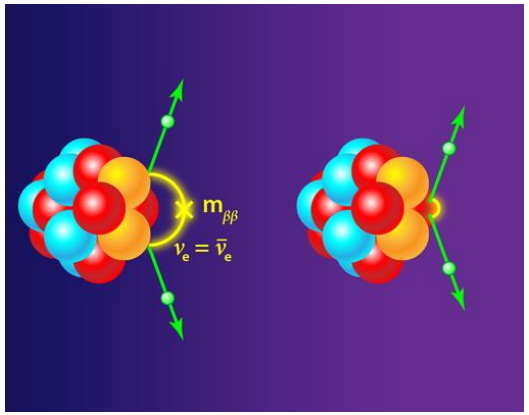
Outline

- Introduction to CDEX and CDEX-300v
- $0\nu\beta\beta$ results from CDEX
- Pre-Conceptual design of CDEX-300v
- Future plan of CDEX-300v

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
  - …

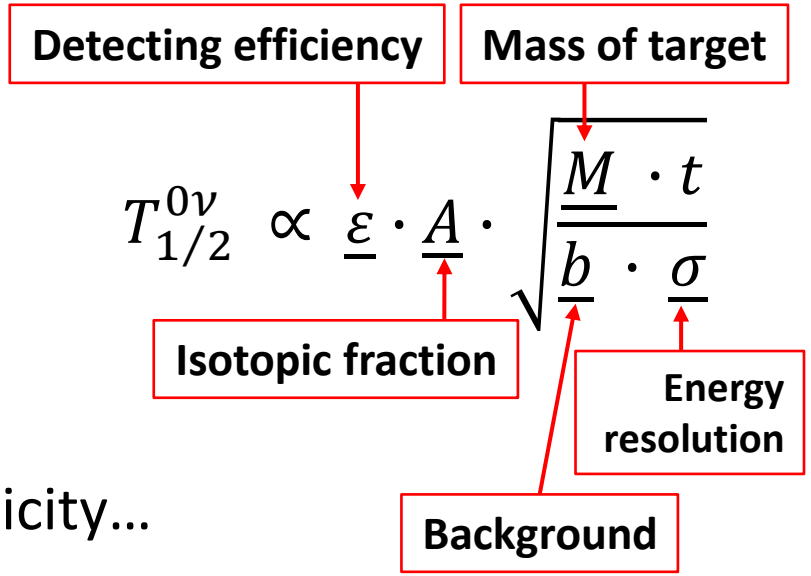




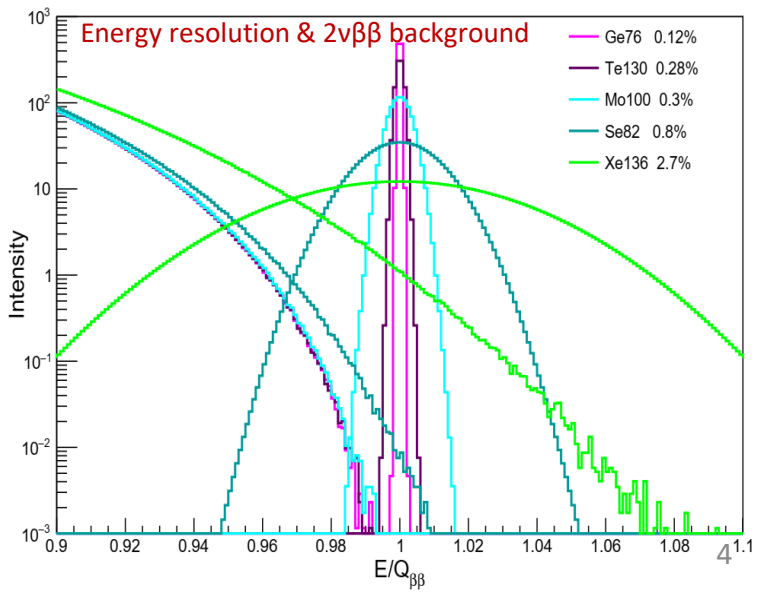
$$(A, Z) \rightarrow (A, Z+2) + 2\,e^- + Q_{\beta\beta}$$

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…
- Current best $T_{1/2}$ result achieved by GERDA
- Energy resolution crucial for irreducible 2νββ bkg



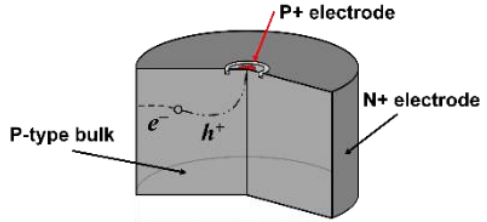
Experiment	Iso	Exposure [kg-yr]	Half life [10^{25} yr]	$\langle m_{\beta\beta} \rangle$ [meV]
Gerda	^{76}Ge	127.2	18	80 - 182
KamLAND-Zen	^{136}Xe	594	10.7	61 - 165
CUORE	^{130}Te	115.9	1.5	110 - 520

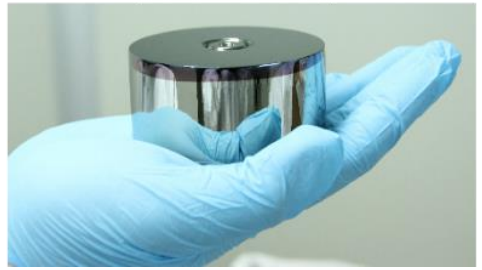


China Dark matter EXperiment

- Formed in 2009, 11 institutions and ~100 people now
- **Key technology:** High Purity Germanium detectors
- **Physics targets:** Direct detection of light DM + **Ge-76 0νββ**

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

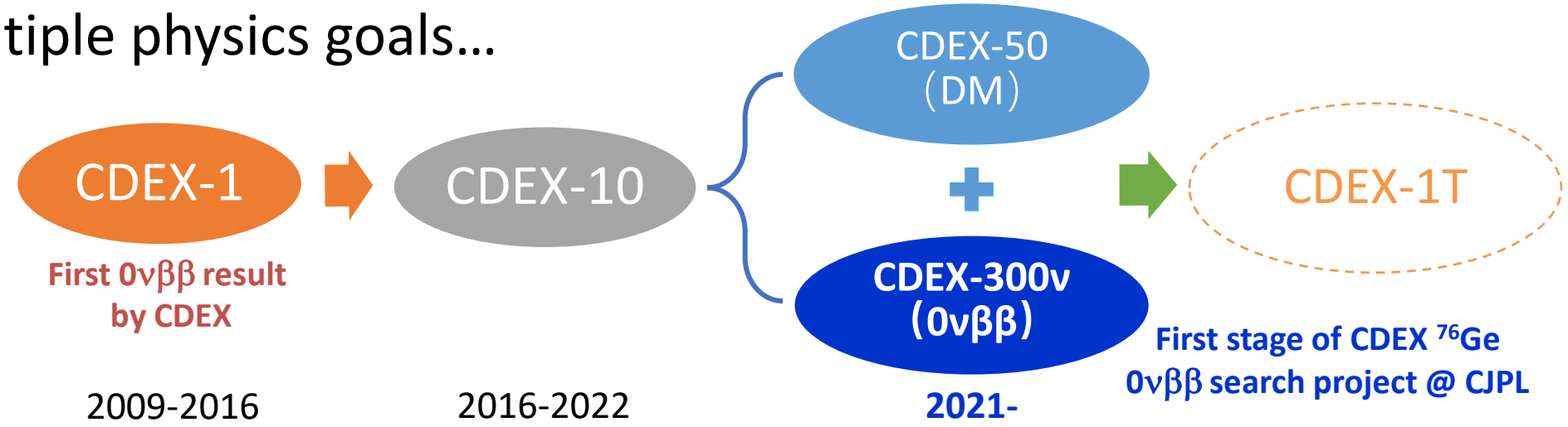


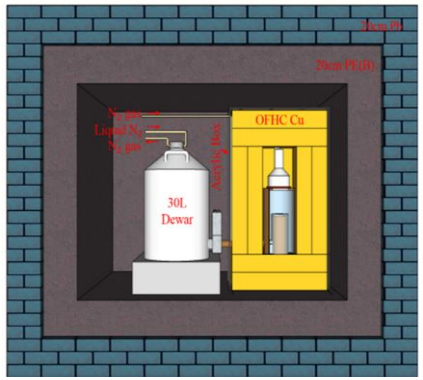


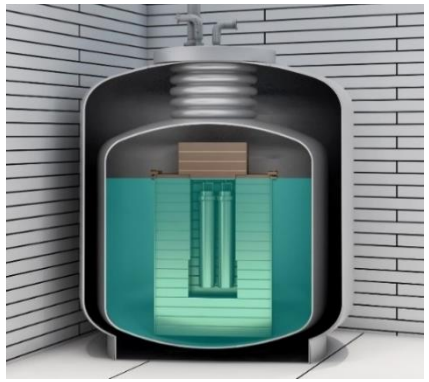
- ✓ Best energy resolution (~0.12% FWHM@$Q_{\beta\beta}$)
- ✓ Low energy threshold
- ✓ Low background

CDEX Roadmap

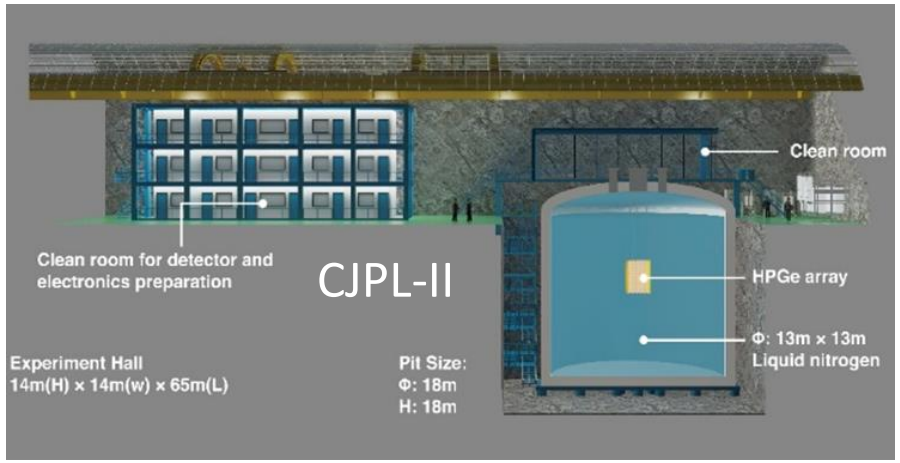
- Persistently focused on DM direct detection
- Extended to ^{76}Ge 0νββ search
- Multiple physics goals…







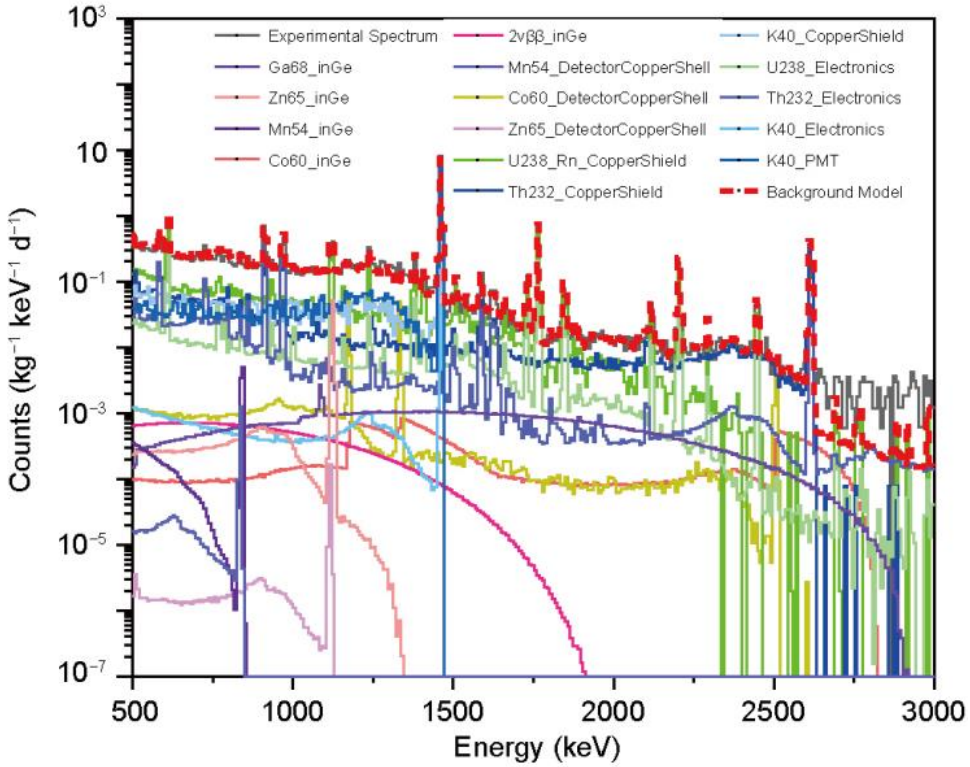
CJPL-I

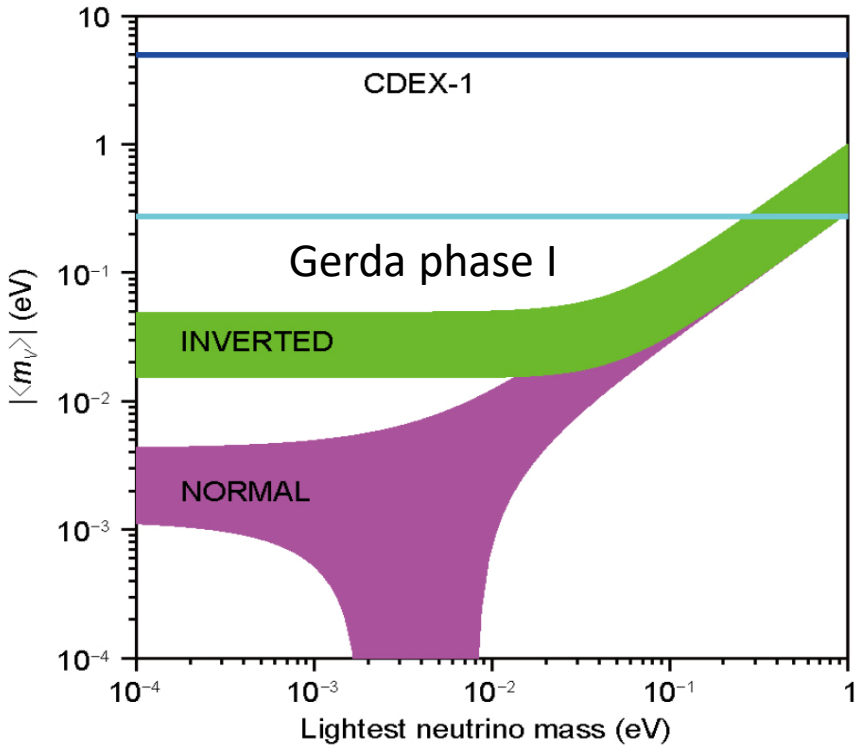


New 0νββ result from CDEX

- 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

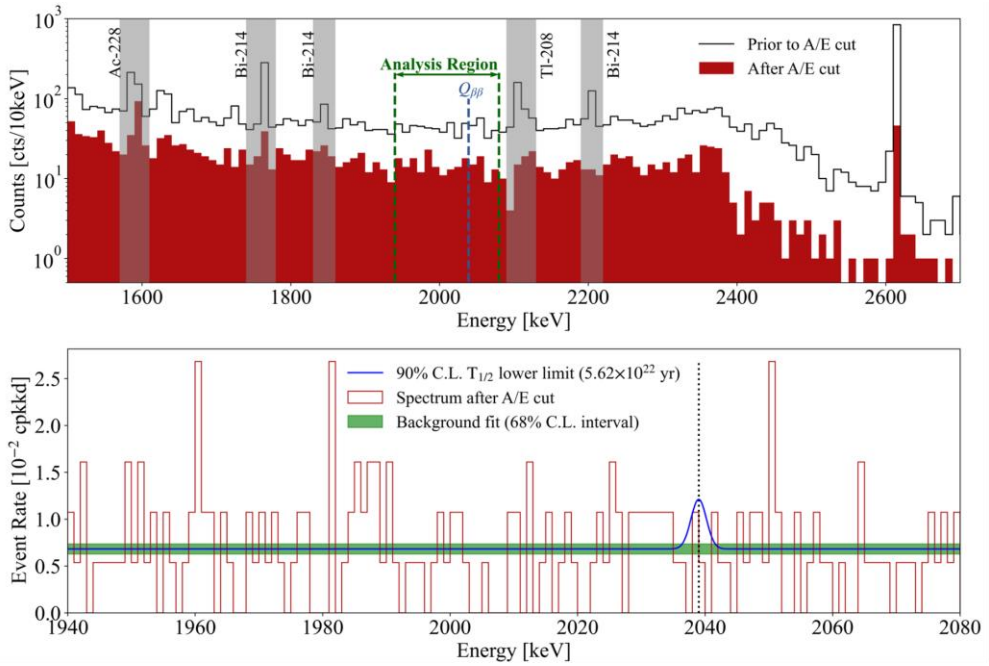


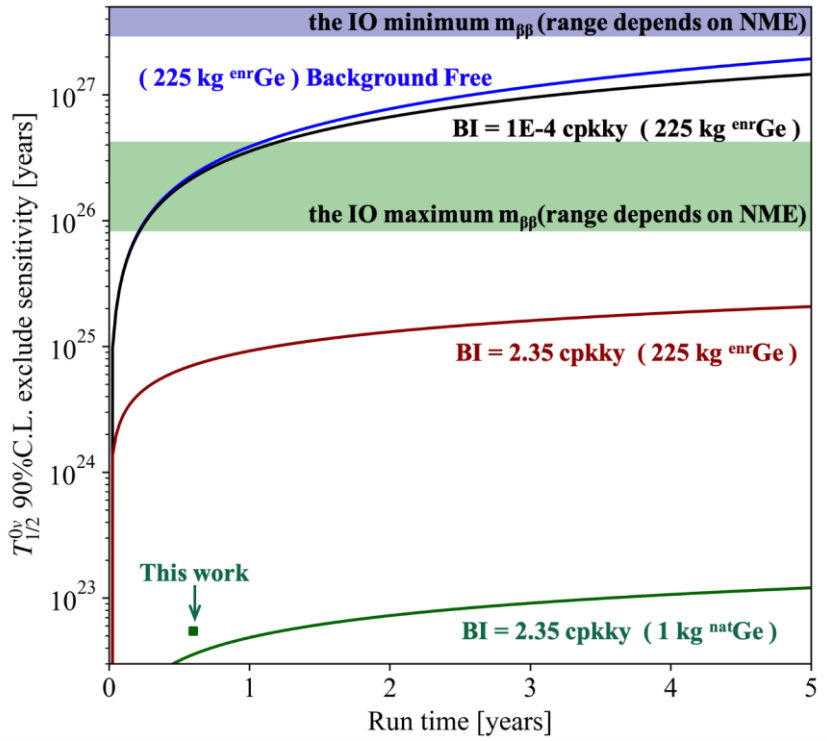


New 0νββ result from CDEX

- 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-300v Overview

- First stage of CDEX ^{76}Ge $0\nu\beta\beta$ search project
- Physics goal: **$T_{1/2} > 10^{27}$ yr, $\langle m_{\beta\beta} \rangle$: 28.5-68.0 meV**

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

- 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

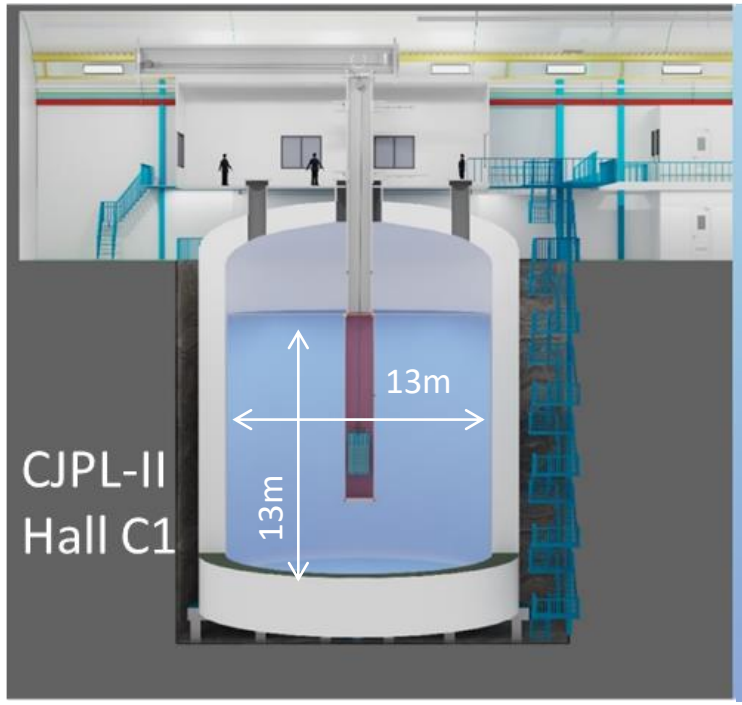
+

Material bkg control

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

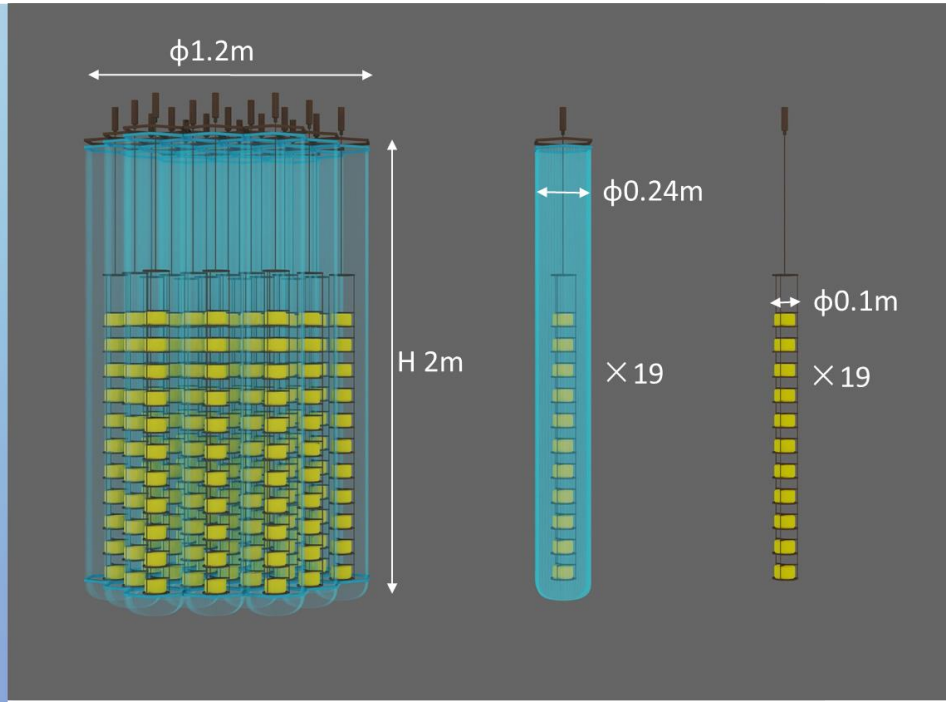
CDEX-300v Overview

- LN_2 tank in Hall C @ CJPL-II
- 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)



1725 m^3 Liquid Nitrogen

LAr tube

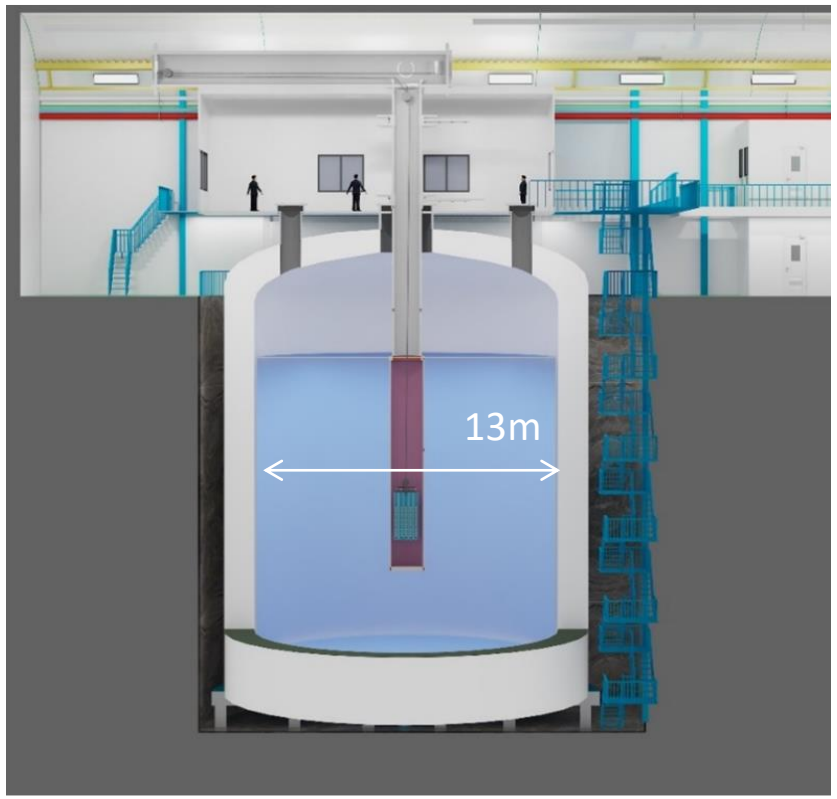


Enriched Ge array

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

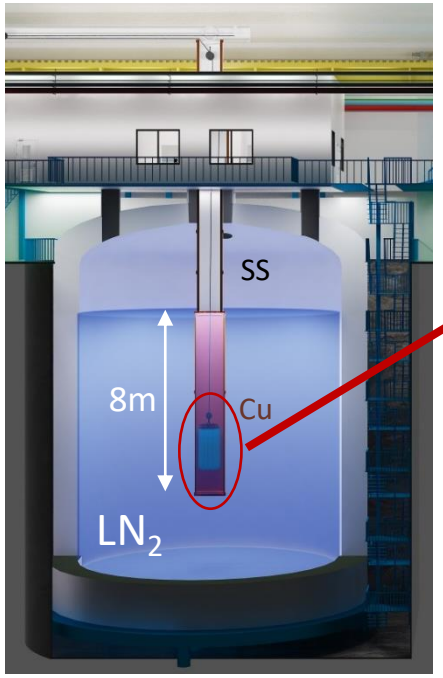
- >4m LN_2 shields most bkg from surroundings

CDEX-300v LAr System (1)

Baseline Design:

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

- purification system
- circulation system
- readout system



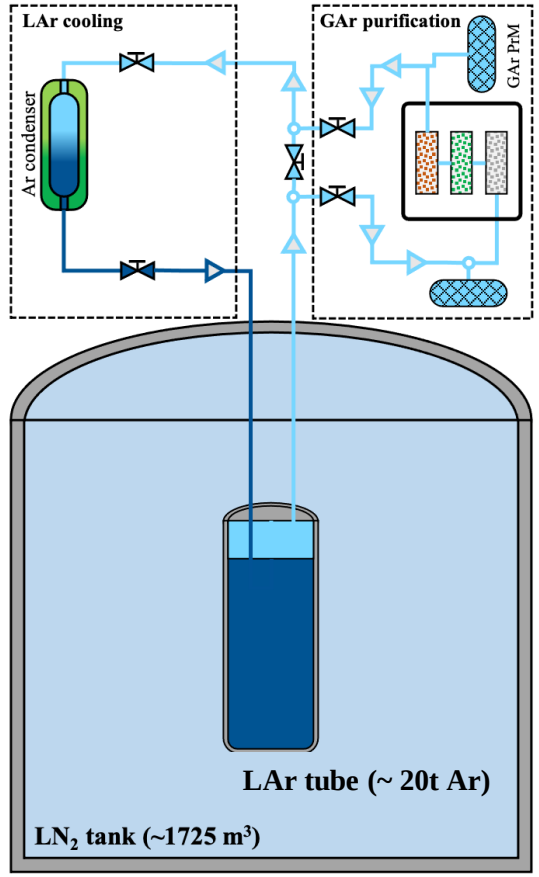
CDEX-300v LAr System (2)

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/m³)
- Possible underground Argon (Ar-42 depleted)

LAr Cooling:

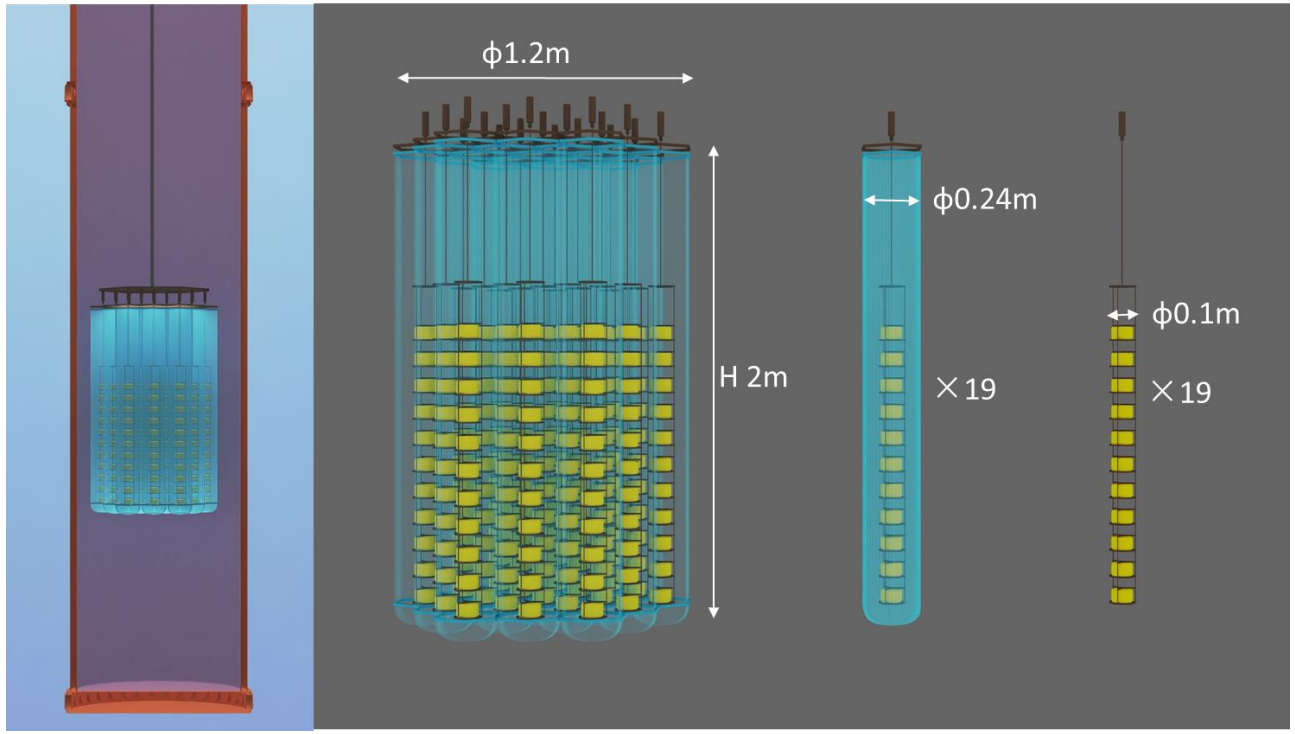
- Cooling purified GAr to LAr
- Heat exchanger + electrical condenser
- Backup LN_2 cooling module



CDEX-300v LAr System (3)

LAr Scintillation Light Readout

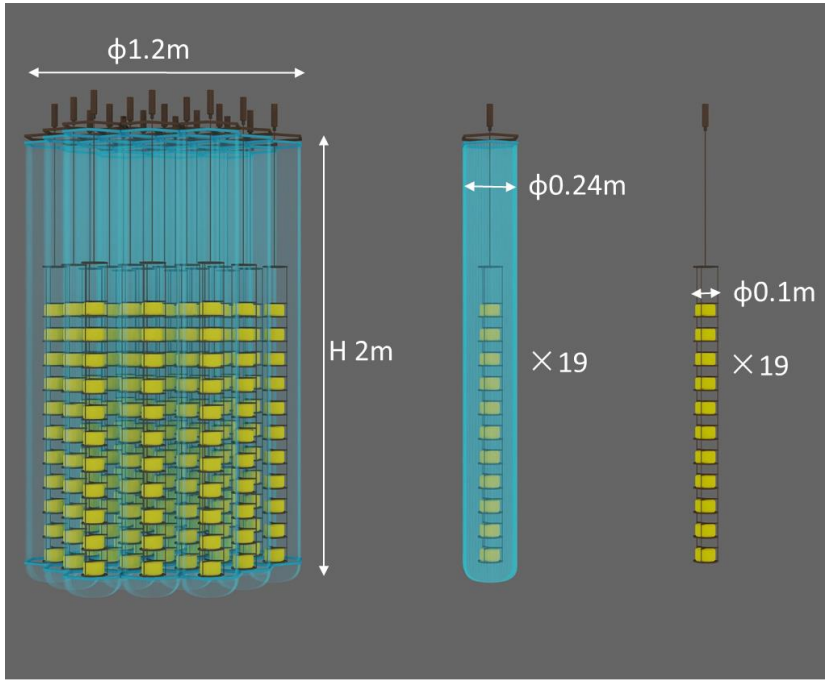
- Detector strings surrounded by fiber curtains to collect light
- Read out via top SiPM

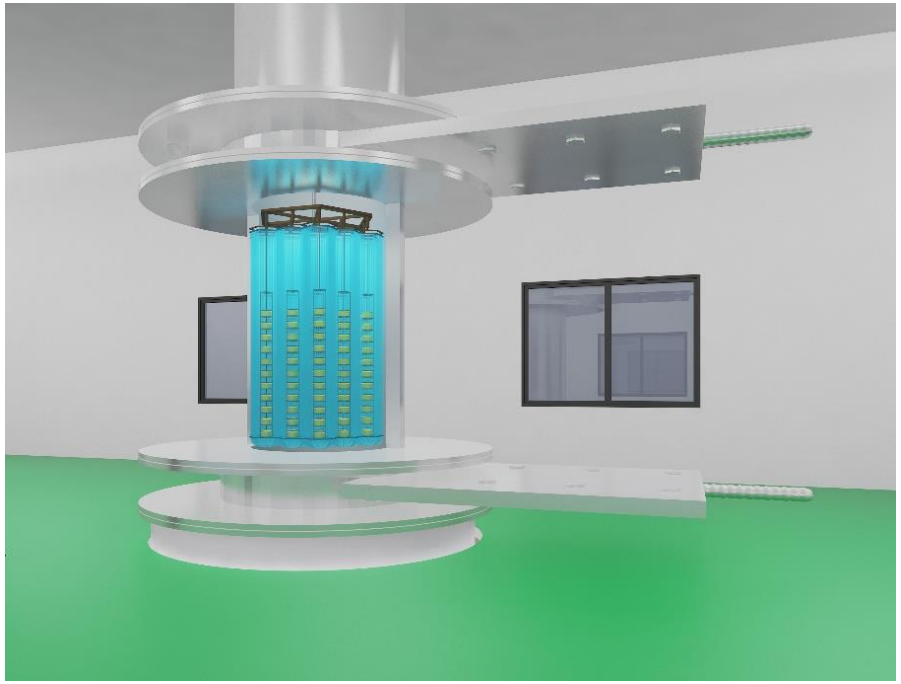


Ge detector Array

Baseline Design:

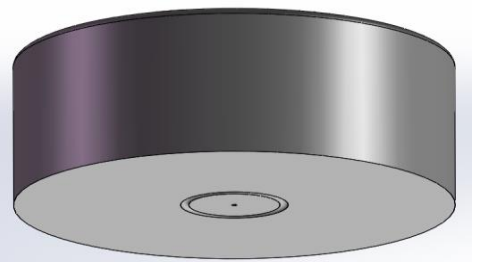
- 200 Ge detectors, 19 strings, 10-11 det/string
- Total mass of Ge detectors: **~225kg**
- Top clean room for Ge detector and fiber installation



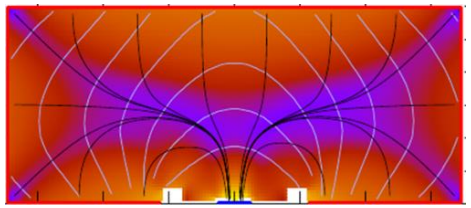


Ge Detectors

- **Enriched BEGe (Baseline)**
  - Mass: ~1.12 kg； Ge-76 > 86%
  - Size: ϕ80×40 mm
  - Dead layer: 0.6 mm
  - FWHM : <0.15% @2MeV (~2.5keV)
  - Commercial / Home-made

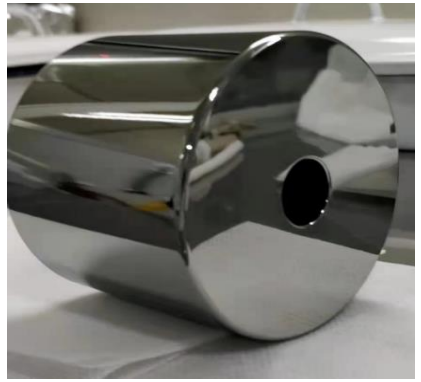


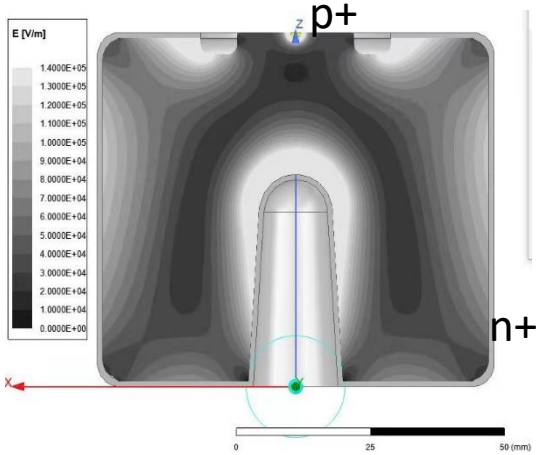
BEGe: Broad Energy Germanium



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

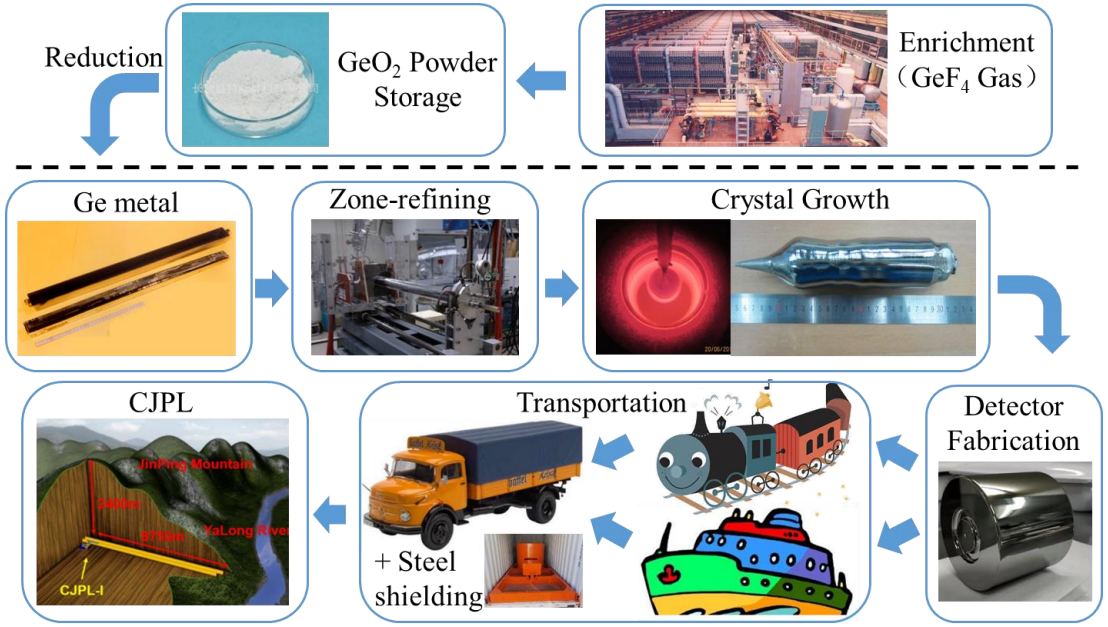
ICPC: Inverted Coaxial Point Contact





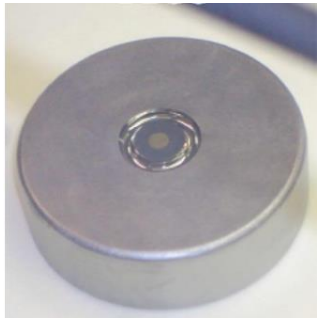
Enriched Ge material

- 200kg ^{76}Ge (>86%) arrived, half from Russia and half from China
- Whole technical chain established
- The mass production power (hundreds of kg per year) of enriched ^{76}Ge material has been setup in China and it is an important contribution to international ^{76}Ge 0νββ experiment community



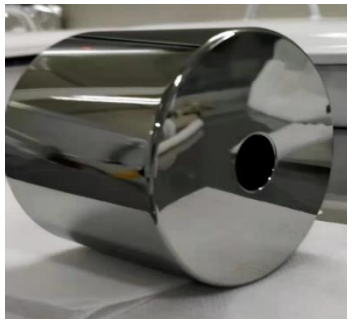
Detector R&D

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



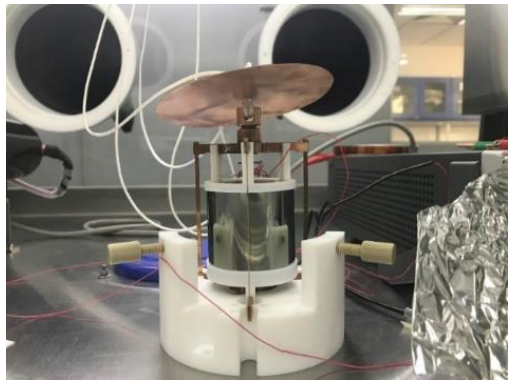
BEGe

PPC

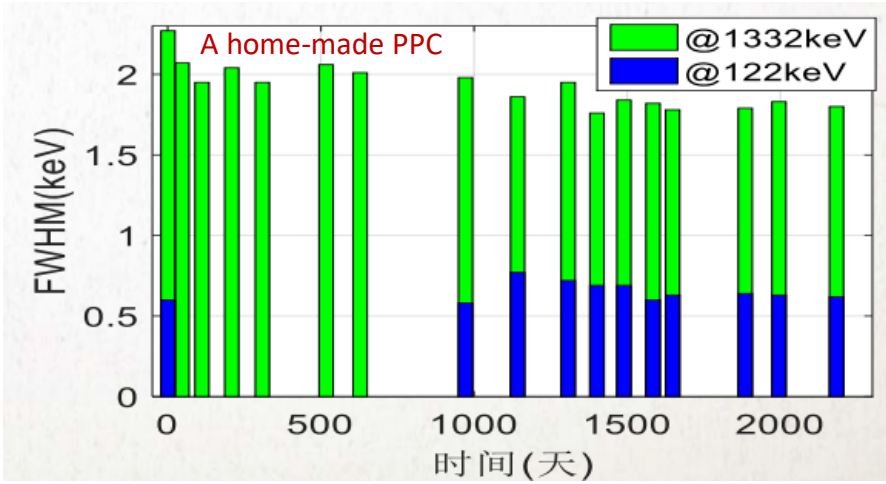


ICPC

Cold finger cooling



Naked crystal to LN_2

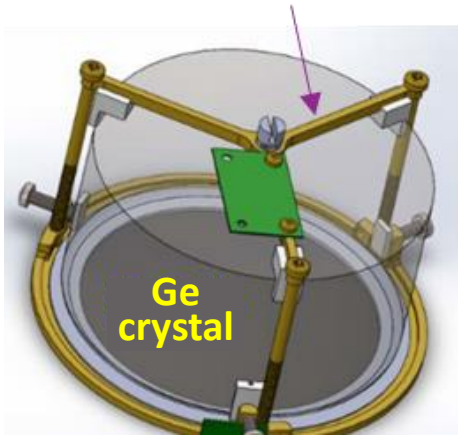


Long-term stability: energy resolution

Material Background Control

All materials to be screened and selected

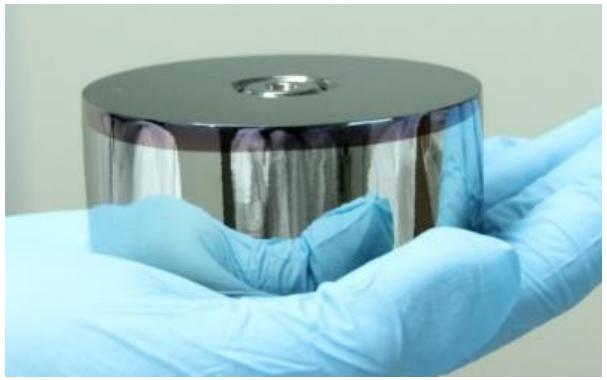
- **Ge detector & FEE:**
  - Mitigation of cosmic activation on the ground
  - Low mass & pure detector structures
  - Low background cables or flexible PCB
  - CMOS ASIC Front-end Electronics
  - Underground fabrication of Ge detectors
- **Underground Electro-forming copper**
  - U/Th activity goal ~ O(0.1μBq/kg)
  - Free of cosmogenic radioactivity

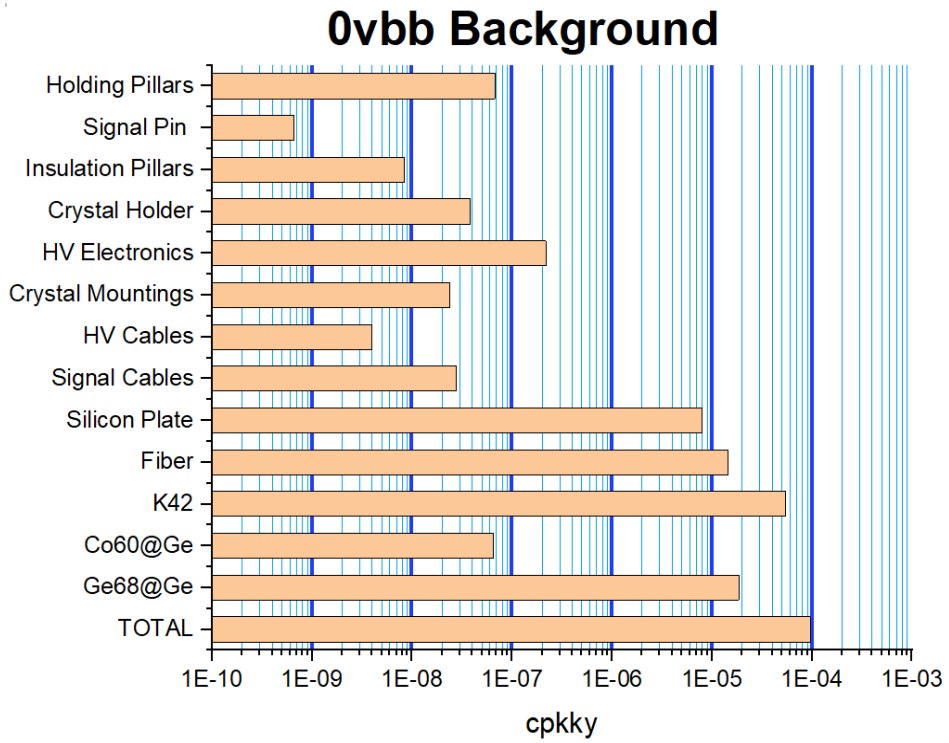


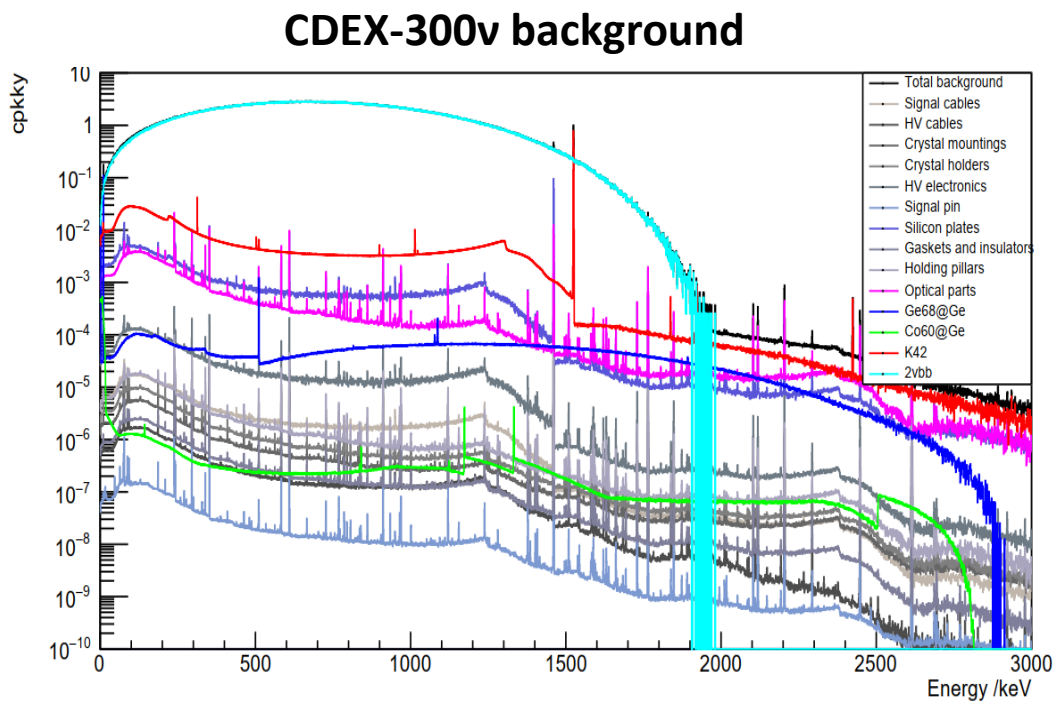
Th/U: ~1.6/10.7 μBq/kg

CDEX-300v Background Model and Simulation

- Detector prototype: BEGe / ICPC
- Energy resolution: 0.12% FWHM@2.039MeV
- Background Index： 1×10^{-4} cts/(keV·kg·year)@$Q_{\beta\beta}$







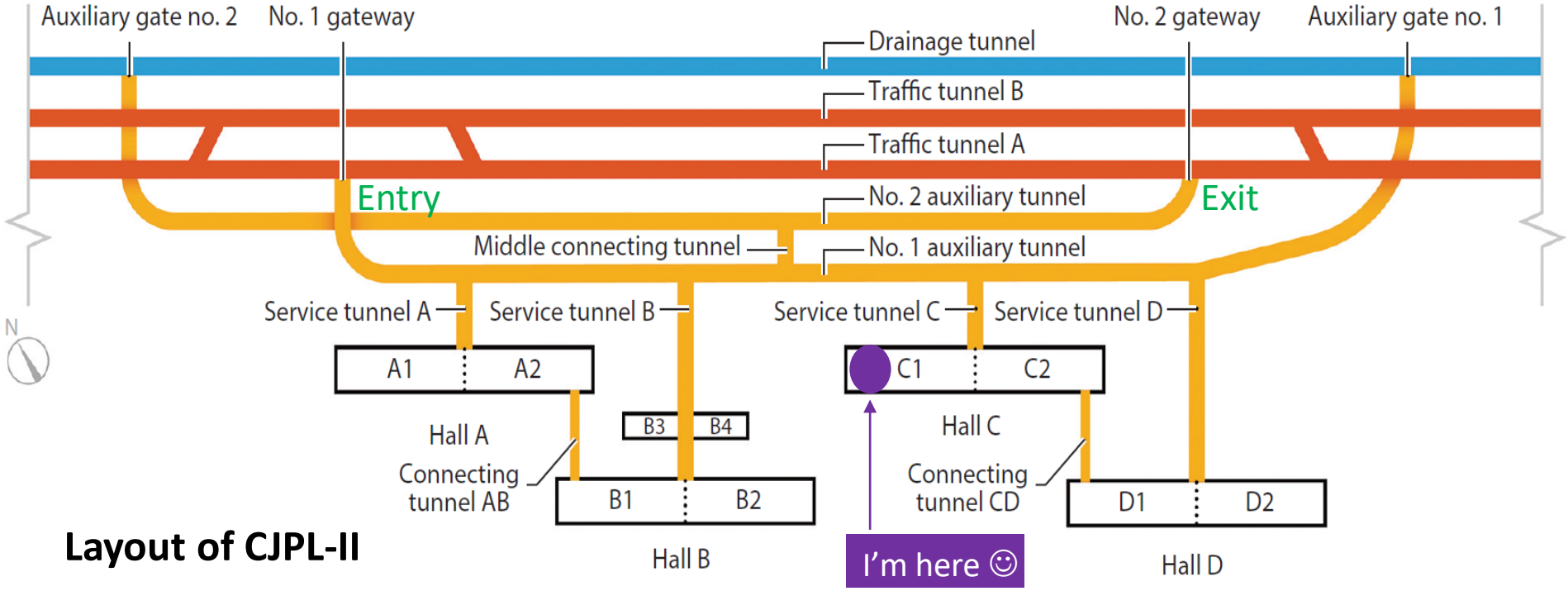
CDEX-300v projected sensitivity

- Construction time: 2021-2026, Run time: 2027-2031 (5 years)
- An exposure for ^{76}Ge 0νββ: >1t·y, $T_{1/2} > 10^{27}$y

Parameter	CDEX-300
^{76}Ge mass	>225 kg
BI@2039keV	10^{-4} cpkky
E_R@2039keV	2.5 keV (FWHM)
Run time	5 y (2027-2031)
Exposure	1.125 t·y
$T_{1/2}$	>1×10^{27}y
$m_{\beta\beta}$	28.5~68.0 meV

CDEX-300v Location

- **C1 Hall @CJPL-II**
  - Total Volume: 300,000 m^3;
  - 8 main halls (14x14x60m each);
  - Additional pit for next-generation CDEX;



Layout of CJPL-II

CDEX-300v Location

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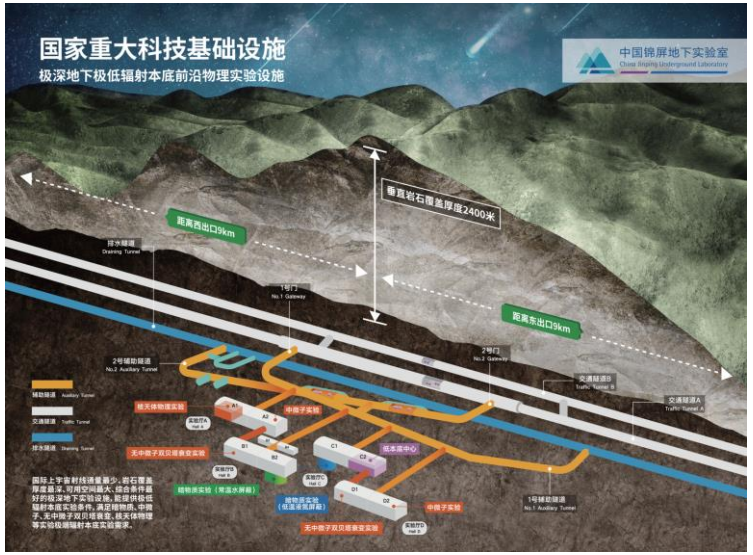
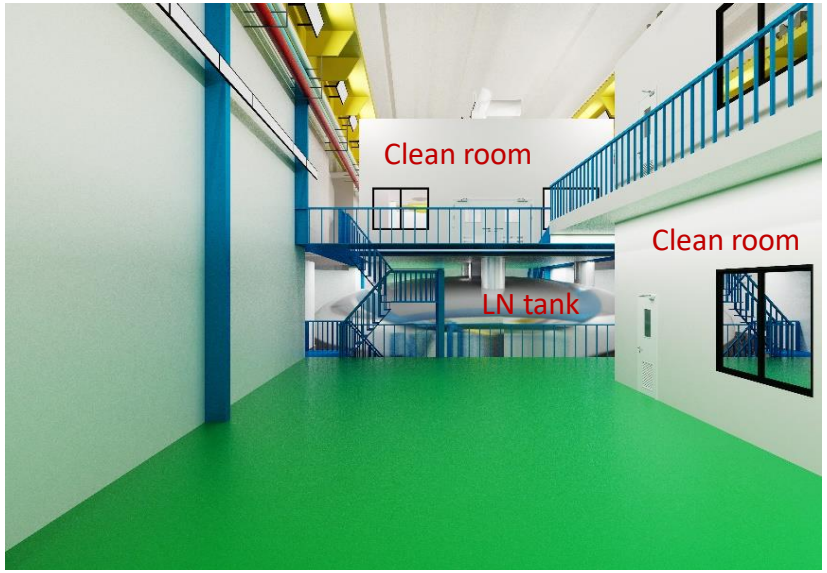


CDEX-300v Location

- **C1 Hall @CJPL-II**
  - Total Volume: 300,000 m^3;
  - 8 main halls (14x14x60m each);
  - Additional pit for next-generation CDEX;

CDEX-300v status

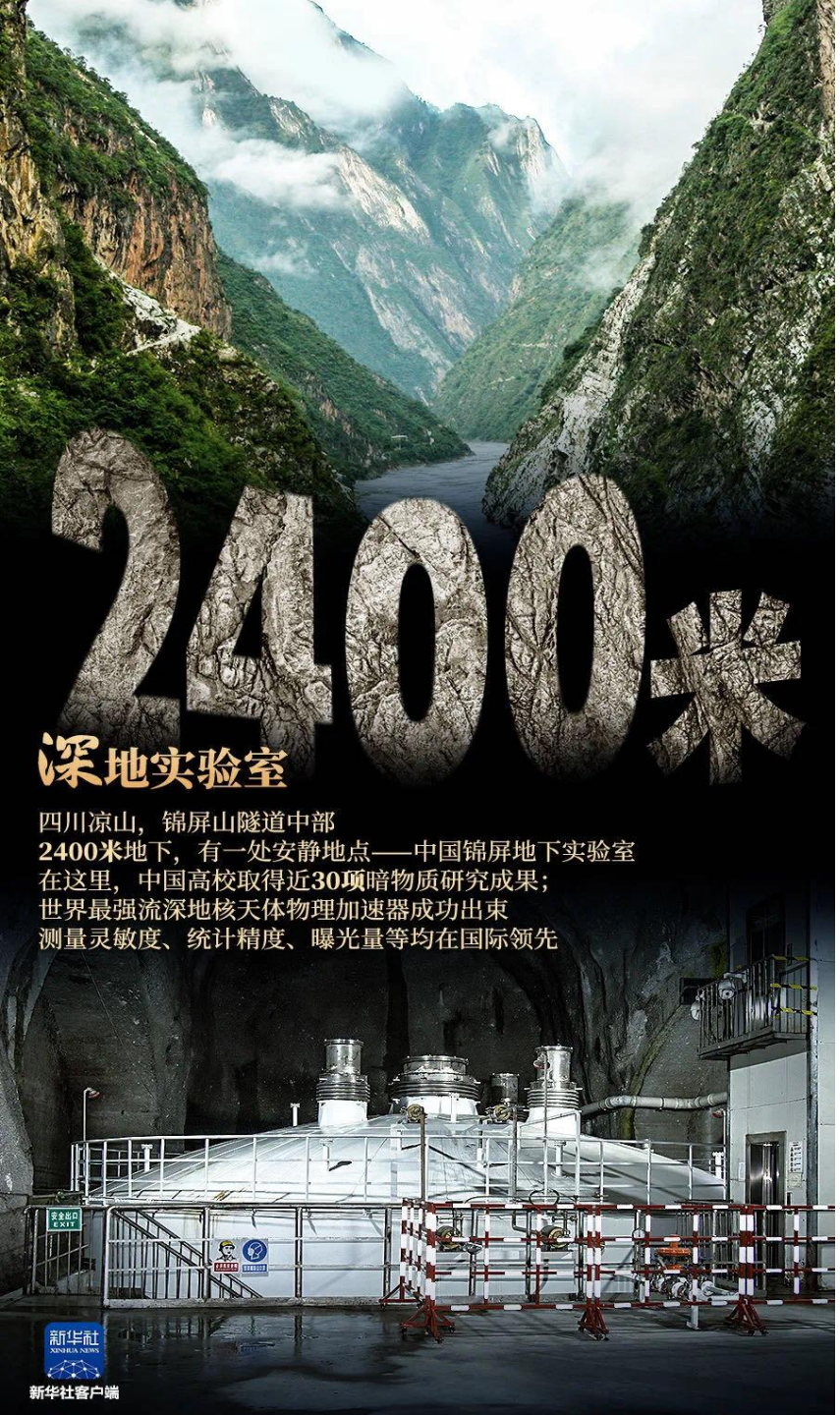
- Enriched Ge detectors test started in 2022 @ CJPL-I
- Hall C1 @CJPL-II will be ready for experiment at the end of 2023
- Experimental setup in 2024
- First batch of Enriched Ge detector installation and test in 2024



Hall C1 of CJPL-II

Summary

- Searching for $0\nu\beta\beta$ decay plays an essential role in understanding the nature of neutrinos
- CDEX-300v for ^{76}Ge $0\nu\beta\beta$
  - 225kg enriched Ge detector system at CJPL-II
  - Physics goal : $T_{1/2}>10^{27}$ yr; $m_{\beta\beta}$: 28.5-68.0 meV
  - First batch of Enriched Ge detectors deployed in 2024
- R&D in progress
  - Detector and electronics
  - LAr purification and scintillation light readout
  - Material screening and selection
  - ……



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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