



CDEX-300v program for ^{76}Ge $0\nu\beta\beta$ search

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On behalf of CDEX Collaboration



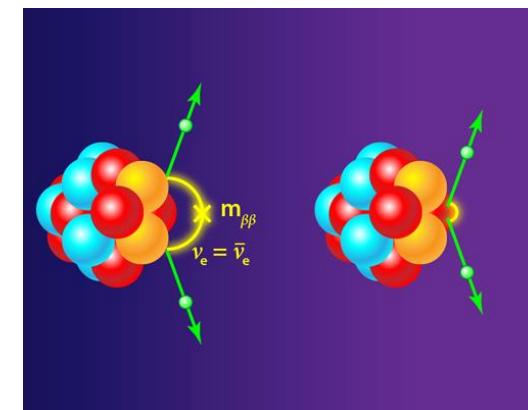
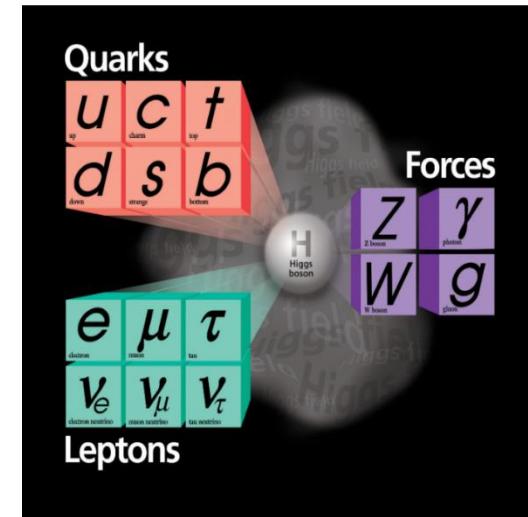
Outline

- 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 $0\nu\beta\beta$ 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 $0\nu\beta\beta$ detector
 - Intrinsic high-purity crystal $\sim 13\text{N}$
 - Source = detector (high ε)
 - Industrial enrichment to $\geq 86\%$ (A)
 - Excellent E resolution (σ) $\sim 0.1\%$ @ 2MeV
 - Background rejection (b): PSD, LAr veto, multiplicity...
- Current best $T_{1/2}$ result achieved by GERDA
- Energy resolution crucial for irreducible $2\nu\beta\beta$ 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

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

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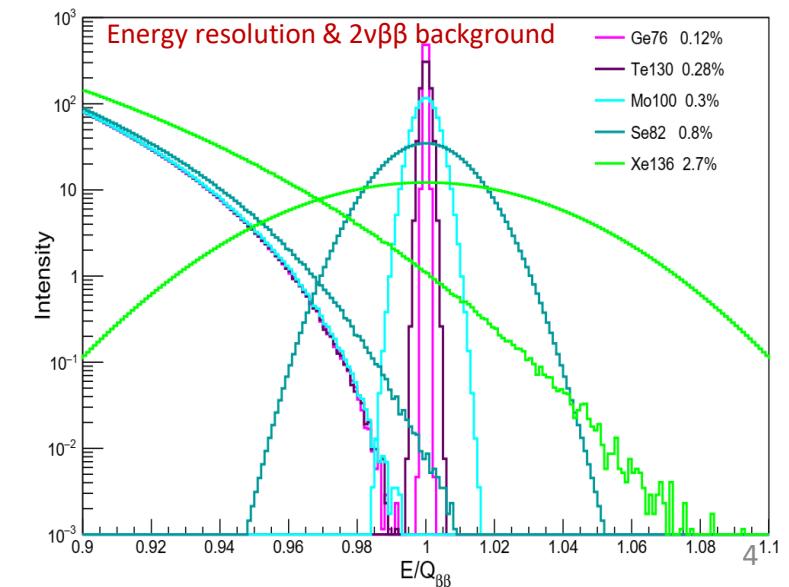
Detecting efficiency

Mass of target

Isotopic fraction

Energy resolution

Background



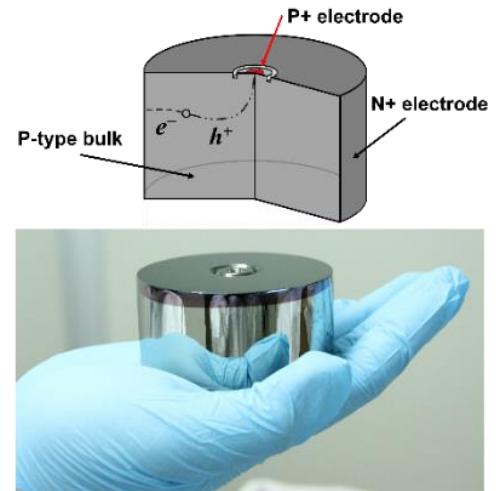


China Dark matter EXperiment

- Formed in 2009, 11 institutions and ~100 people now;
- **Key technology:** P-type Point-Contact (PPC) Ge detectors;
- **Physics targets:** Direct detection of light DM + **Ge-76 0v $\beta\beta$**



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

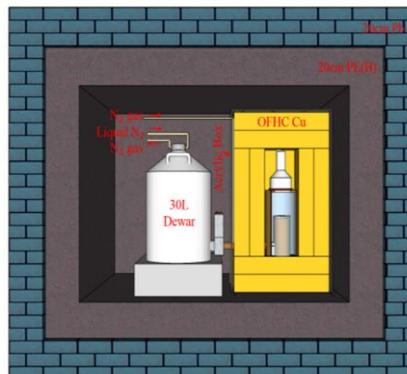
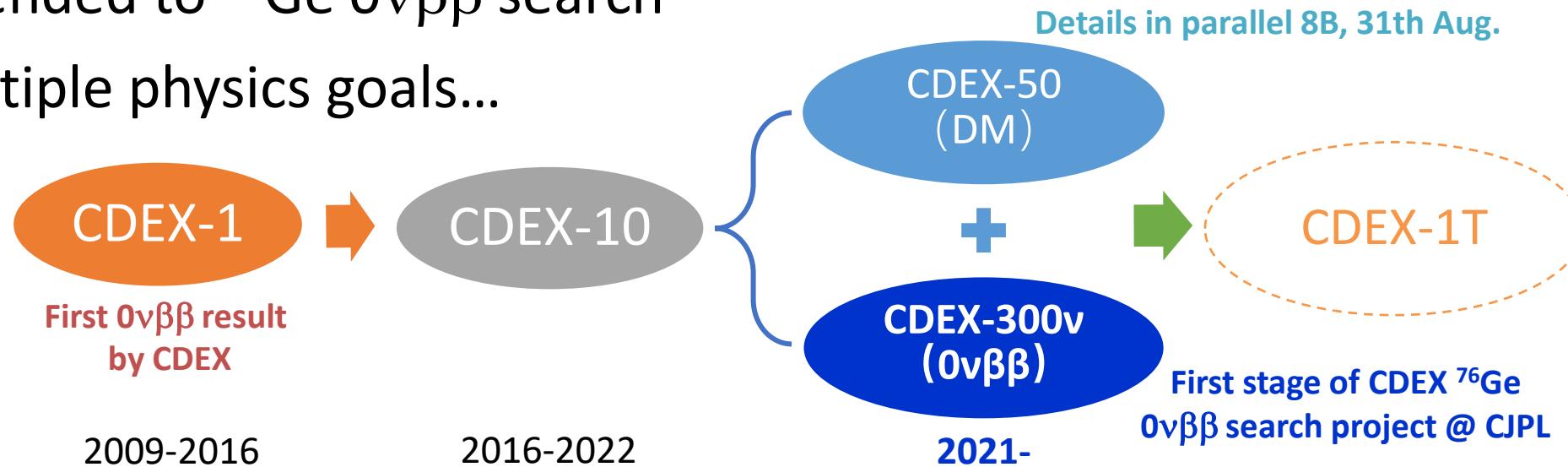


- ✓ Best energy resolution (~200 eV @ 10.37 keV)
- ✓ Low energy threshold (~100 eV)
- ✓ Low background

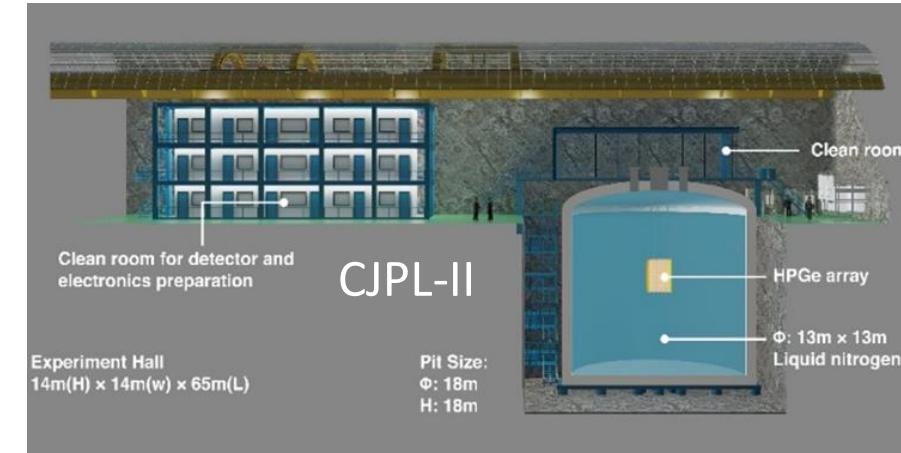
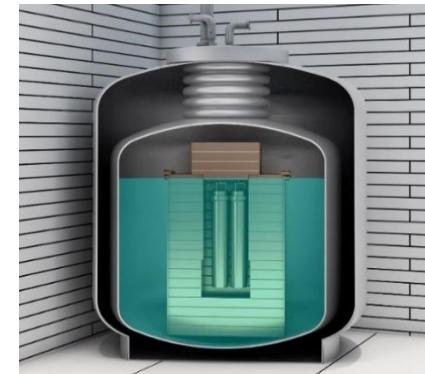


CDEX Roadmap

- Persistently focused on DM direct detection
- Extended to ^{76}Ge $0\nu\beta\beta$ search
- Multiple physics goals...



CJPL-I

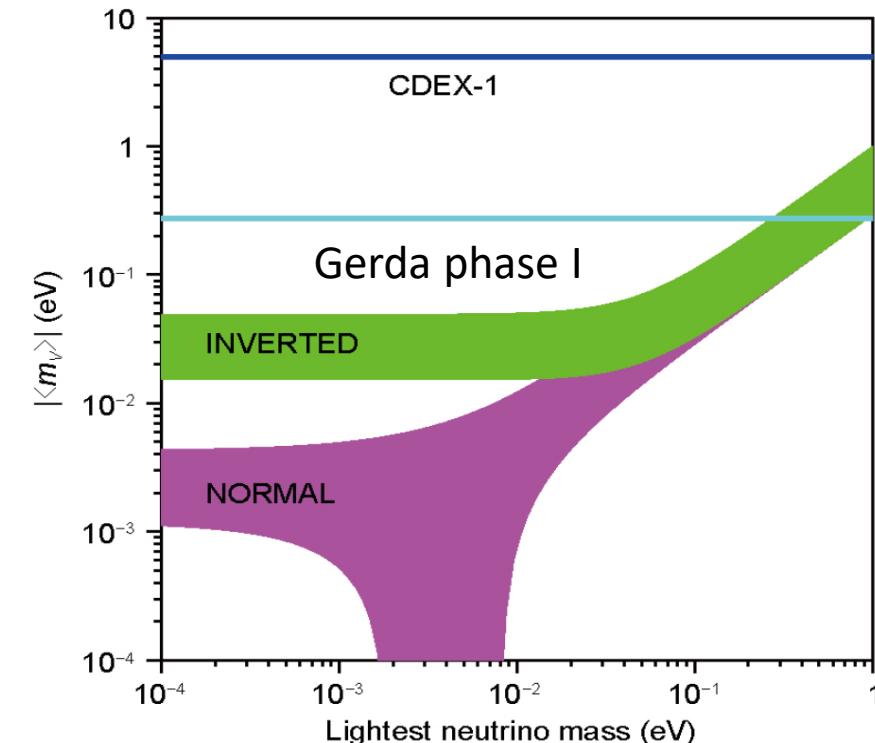
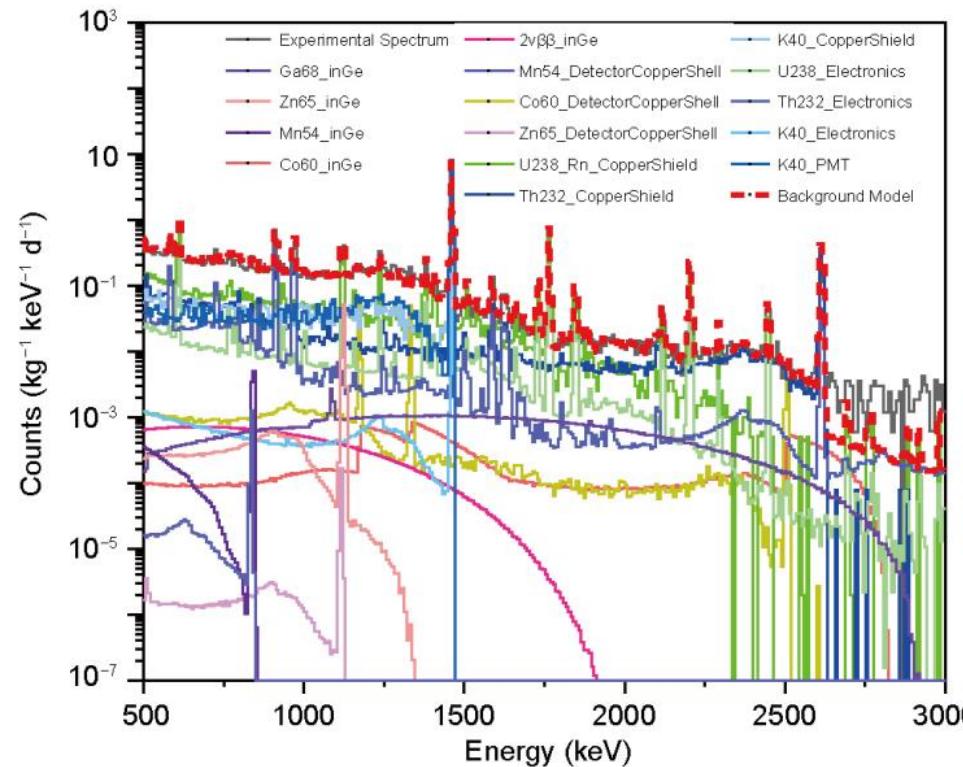




New $0\nu\beta\beta$ result from CDEX

- First ^{76}Ge $0\nu\beta\beta$ 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.

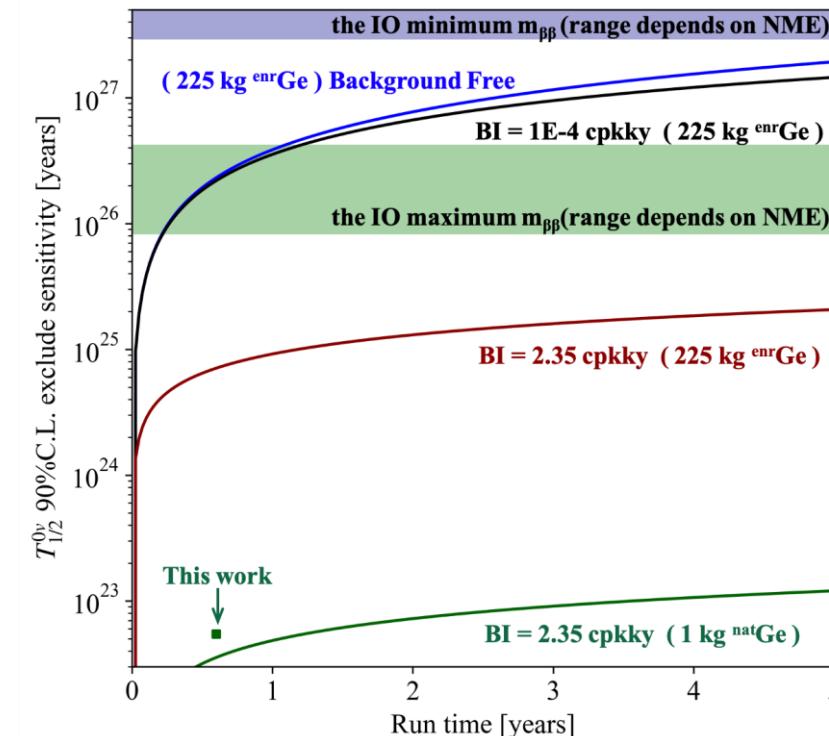
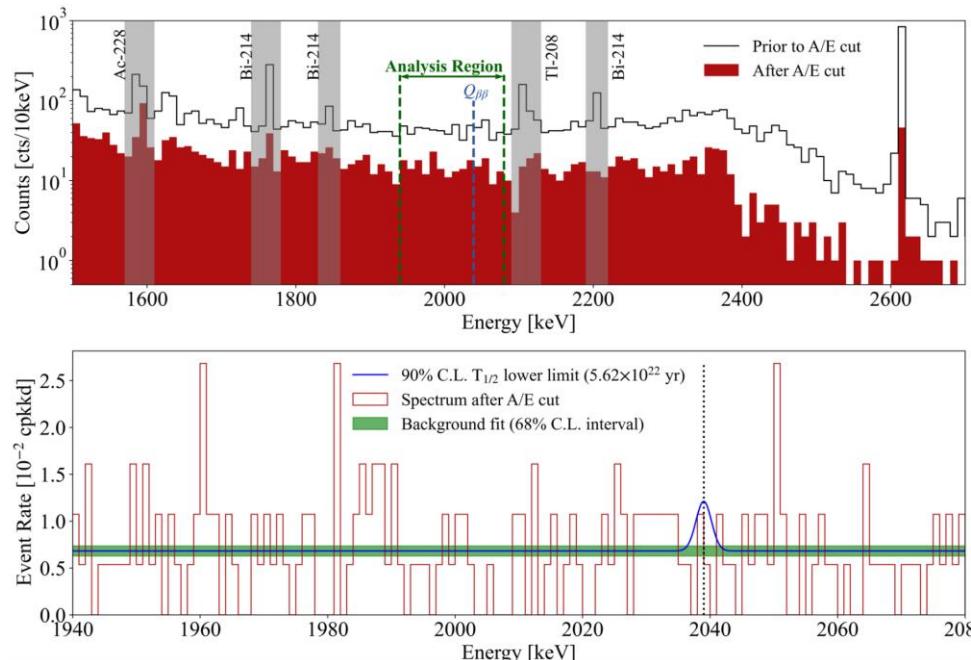
L. Wang et al, *Science China P.M.A.* (2017) 071011



New $0\nu\beta\beta$ 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 pre-Conceptual Design

- First stage of CDEX ^{76}Ge $0\nu\beta\beta$ search project
- Physics goal: $T_{1/2} > 10^{27}$ yr, $\langle m_{\beta\beta} \rangle: 28.5\text{-}68.0$ 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)
- ✓ $\sim 225\text{kg}$ Ge (M)
- ✓ Energy resolution (σ)

LAr veto + LN₂ shield

- ✓ LAr as active shield
- ✓ LN₂ as passive shield

+ Material bkg control

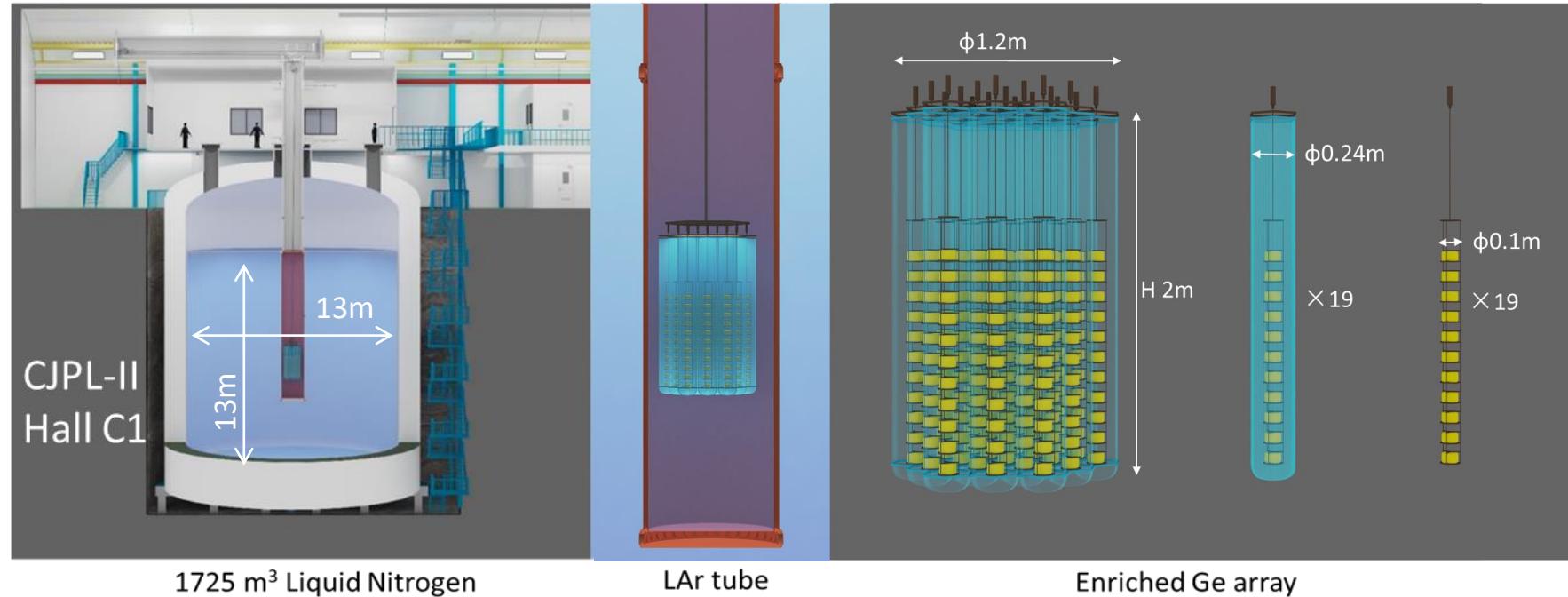
- ✓ Cosmogenic radioactivity in Ge
- ✓ Materials near Ge crystal
- ✓ Rn in LAr & LN₂...



CDEX-300v pre-Conceptual Design

Overview

- LN₂ tank in Hall C @ CJPL-II
- Reentrant tube containing LAr submerged in LN₂
- Ge detector array immersed in LAr (veto) tube
- Ge detectors divided into 19 strings (10-11 det/string, 200 in total)

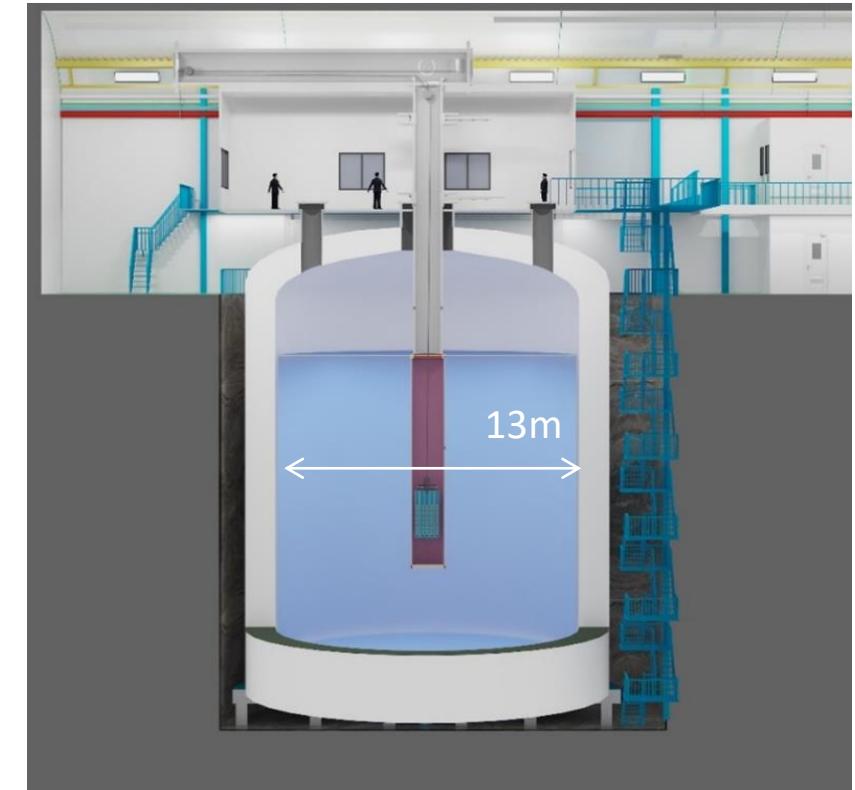




LN_2 tank

Specification

- Total volume: 1976m^3
- LN_2 volume: $\phi 13\text{m} \times \text{H}13\text{m}$, $\sim 1725 \text{ m}^3$
- LN_2 as Passive Shield & Cryogen
- Five top flanges for detector deployment
 - $1 \times \phi 1.5\text{m}$, centrally
 - $4 \times \phi 750\text{mm}$, on a 6m -diameter circle



1725 m^3 Liquid Nitrogen

Background

- $>4\text{m}$ LN_2 shields most bkg from surroundings

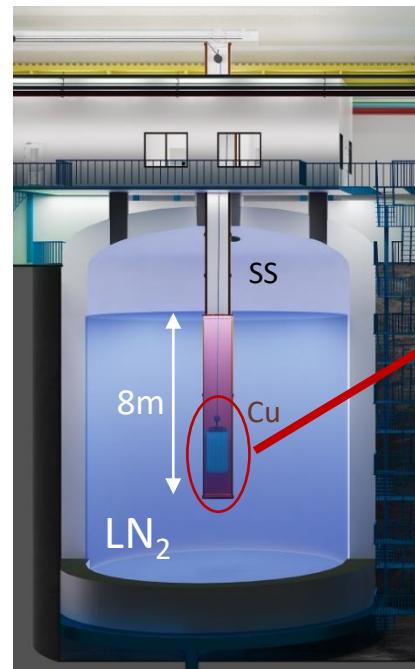


CDEX-300v LAr System (1)

Baseline Design:

- ~20 t LAr held by Cu / Stainless steel cryostat
- LAr cryostat immersed in LN₂
- LAr light read out by WLS Fiber + SiPM
- LAr constantly purified

- purification system
- circulation system
- readout system



CDEX-300v LAr System (2)

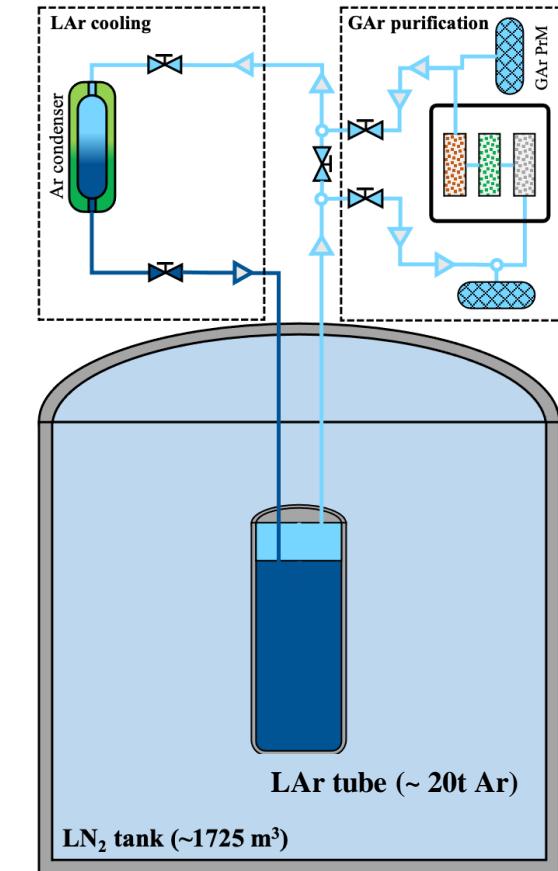


LAr Purification:

- Removing O₂ / H₂O / N₂ from GAr ($\sim 10\text{ppb}$ impurity)
- Maintaining high light yield & transmission length
- Removing Rn by active carbon ($\sim \mu\text{Bq}/\text{m}^3$)
- Possible underground Argon (Ar-42 depleted)

LAr Cooling:

- Cooling purified GAr to LAr
- Heat exchanger + electrical condenser
- Backup LN₂ cooling module

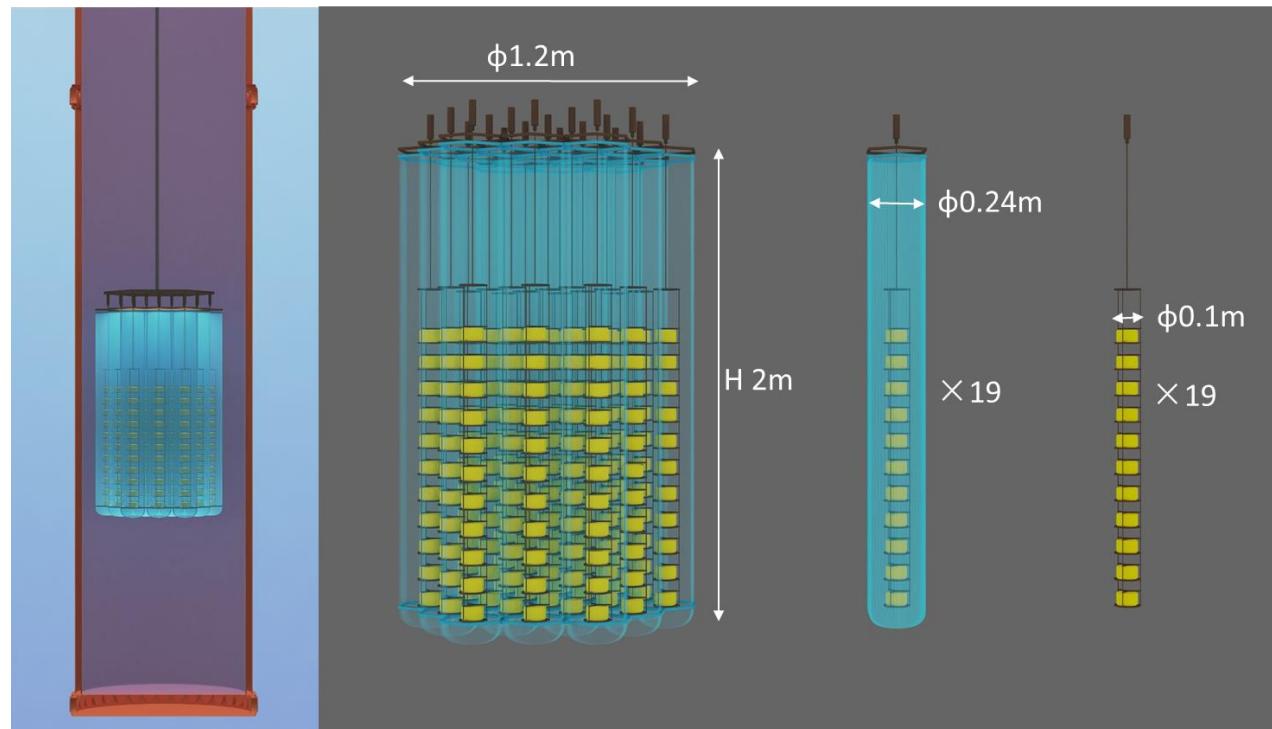




CDEX-300v LAr System (3)

LAr Scintillation Light Readout

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

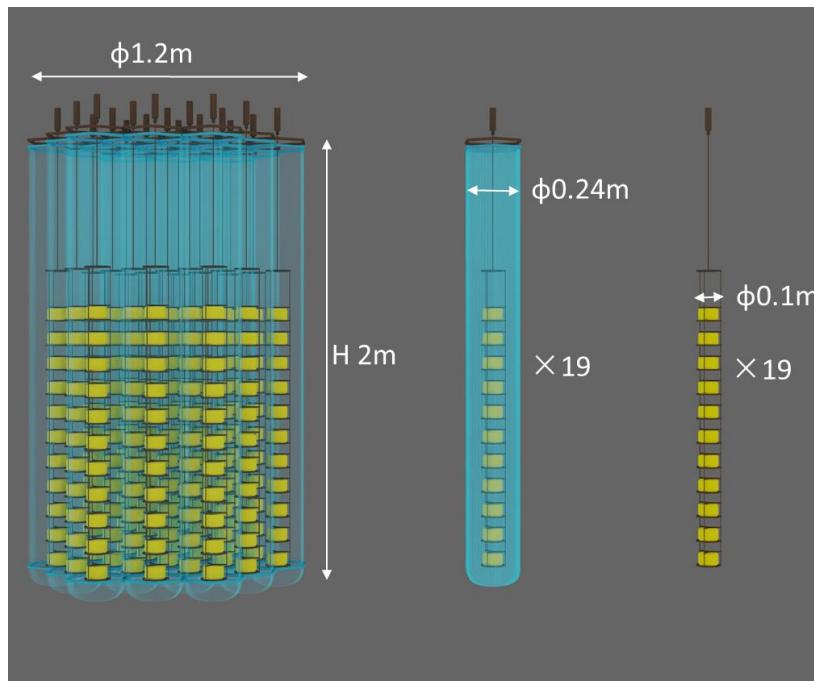




Ge detector Array

Baseline Design:

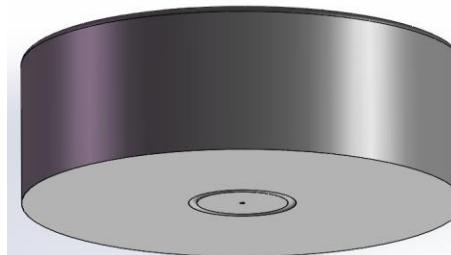
- 200 Ge detectors, 19 strings, 10-11 det/string
- Total mass of Ge detectors: **~225kg**
- Top clean room for Ge detector and fiber installation



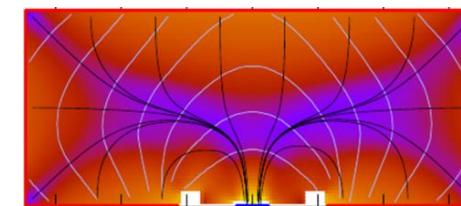


Ge Detectors

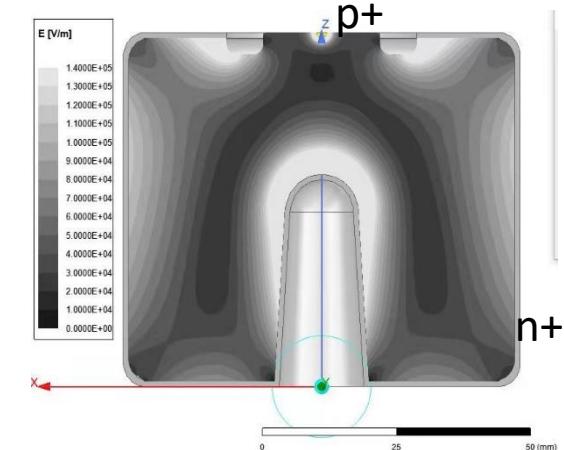
- **Enriched BEGe (Baseline)**
 - Mass: ~1.12 kg; Ge-76 > 86%
 - Size: $\phi 80 \times 40$ mm
 - Dead layer: 0.6 mm
 - FWHM : <0.15% @2MeV (~2.5keV)
 - Commercial / Home-made
- **ICPC (optional)**
 - Mass: ~2 kg
 - Size: $\phi 80 \times 80$ mm
 - Dead layer: 0.6 mm
 - Home-made
 - Bigger Detector → Less Electronics (background)



BEGe: Broad Energy Germanium



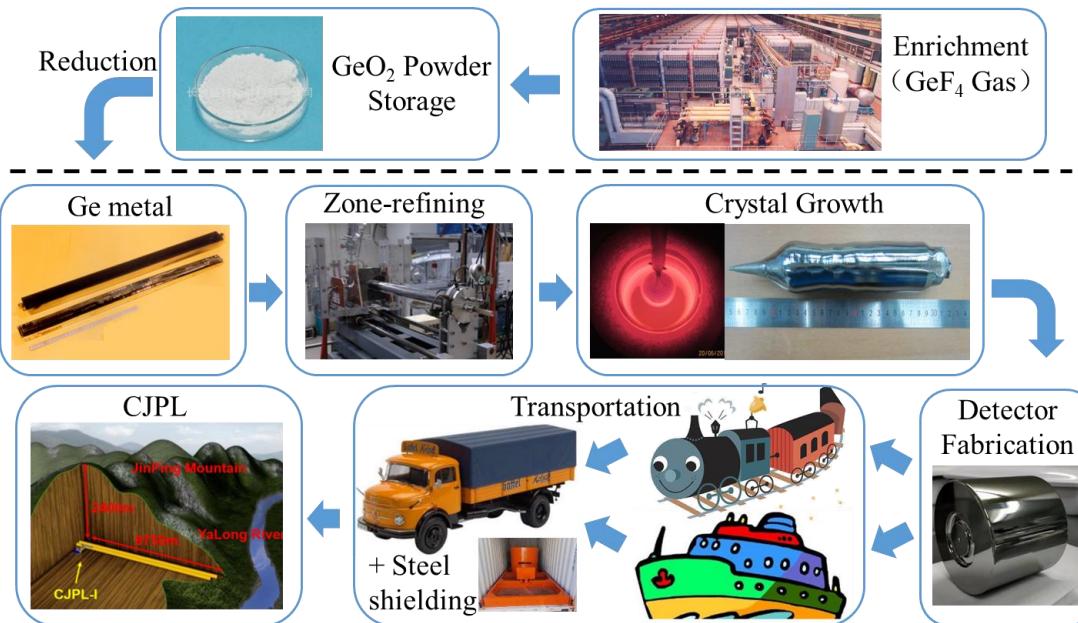
ICPC: Inverted Coaxial Point Contact





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 $^{76}\text{Ge} \text{Ov}\beta\beta$ experiment community**



Detector R&D

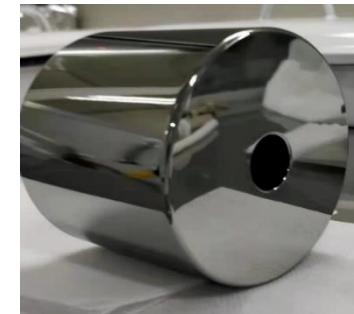
- Home-made Ge detector
 - Co-axial/BEGe/PPC/ICPC
 - Cold finger/Naked immersion



BEGe



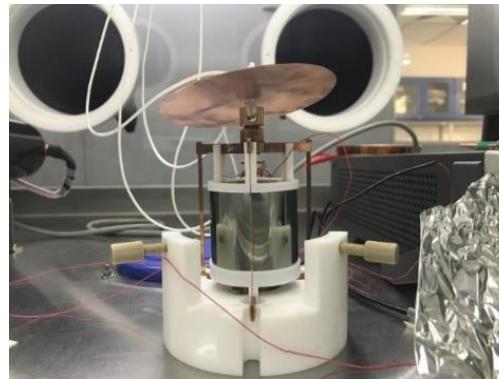
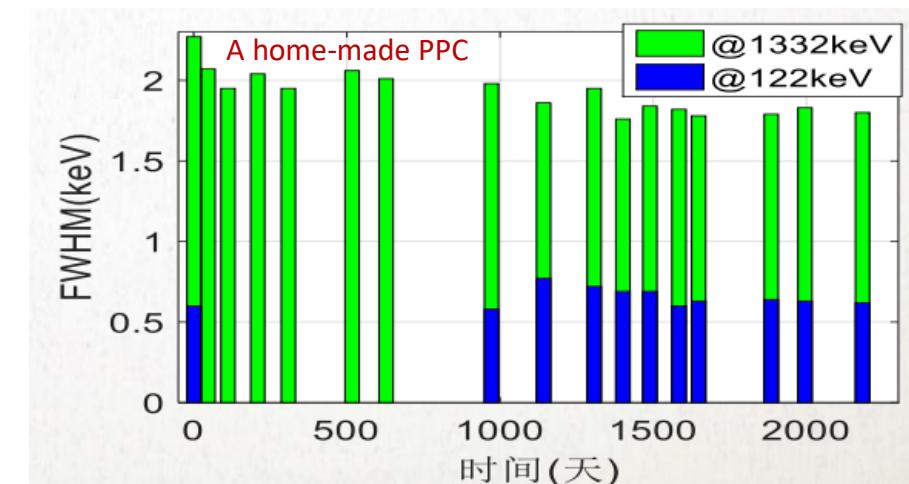
PPC



ICPC



Cold finger cooling

Naked crystal to LN₂

Long-term stability: energy resolution

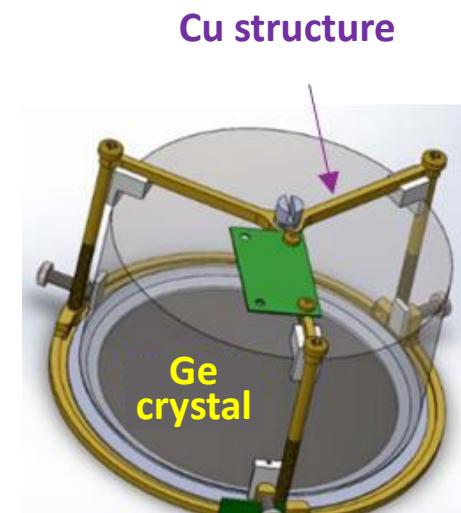


Material Background Control

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 $<10 \mu\text{Bq/kg}$
- Free of cosmogenic radioactivity

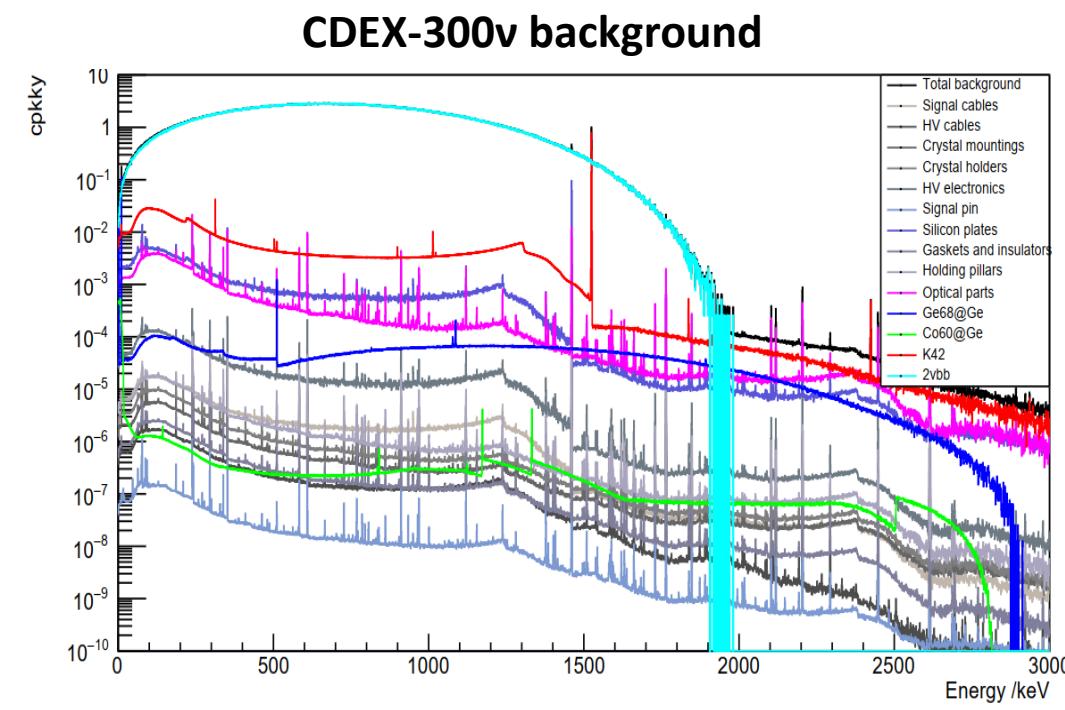
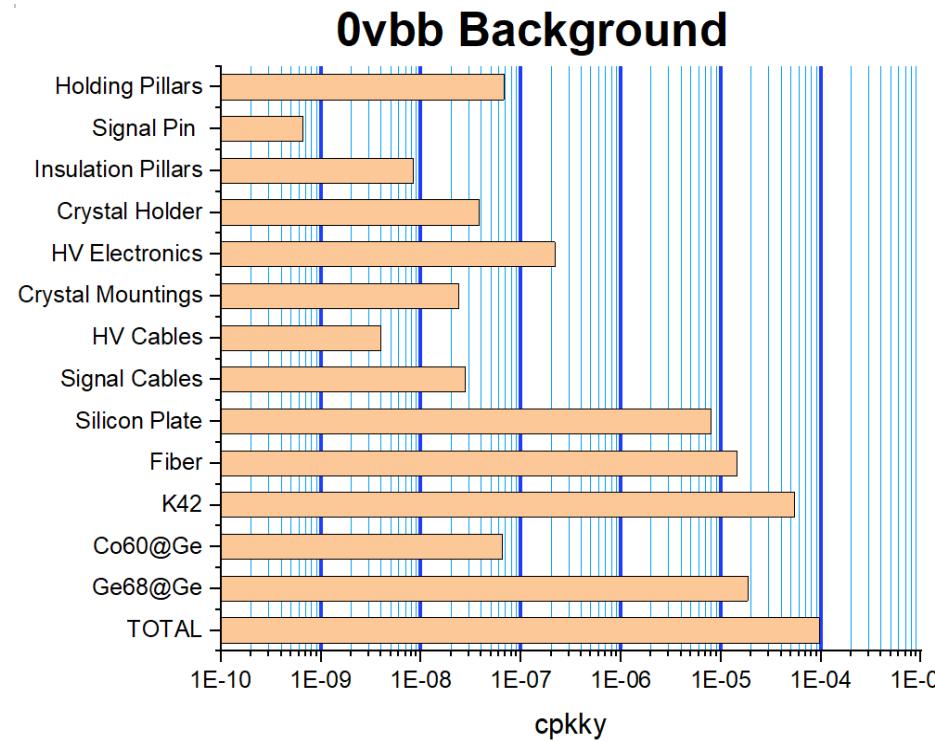
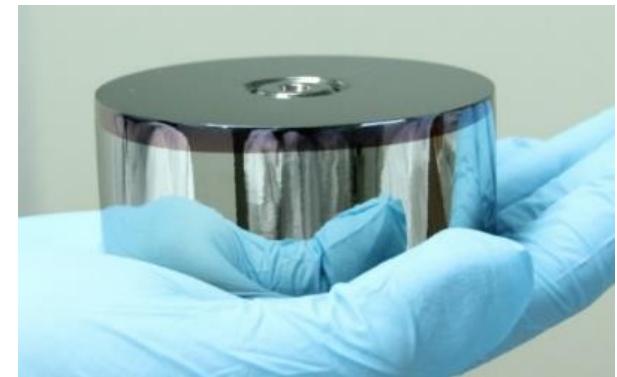


Th/U: $\sim 1.6/10.7 \mu\text{Bq/kg}$



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_{ββ}





CDEX-300v projected results

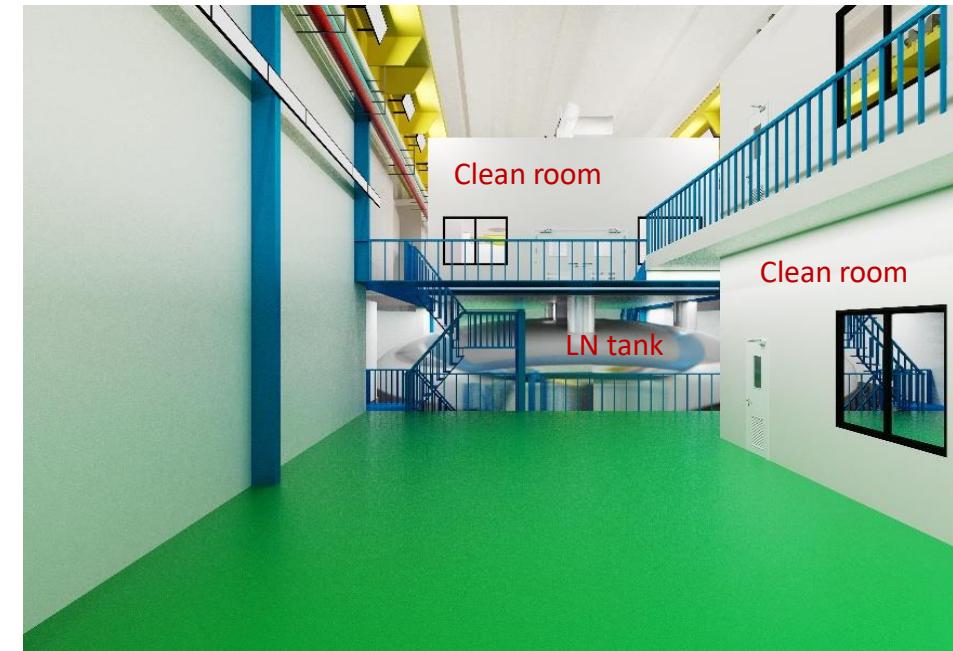
- Construction time: 2021-2026, Run time: 2027-2031 (5 years)
- An exposure for ${}^{76}\text{Ge}$ $0\nu\beta\beta$: $>1\text{t}\cdot\text{y}$, $T_{1/2} > 10^{27}\text{y}$

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



CDEX-300v status

- Enriched Ge detectors test started in 2022 @ CJPL-I
- Hall C1 expected to be ready for experiment this fall
- Experimental setup in 2024
- First batch of Ge detector installation and test in 2024

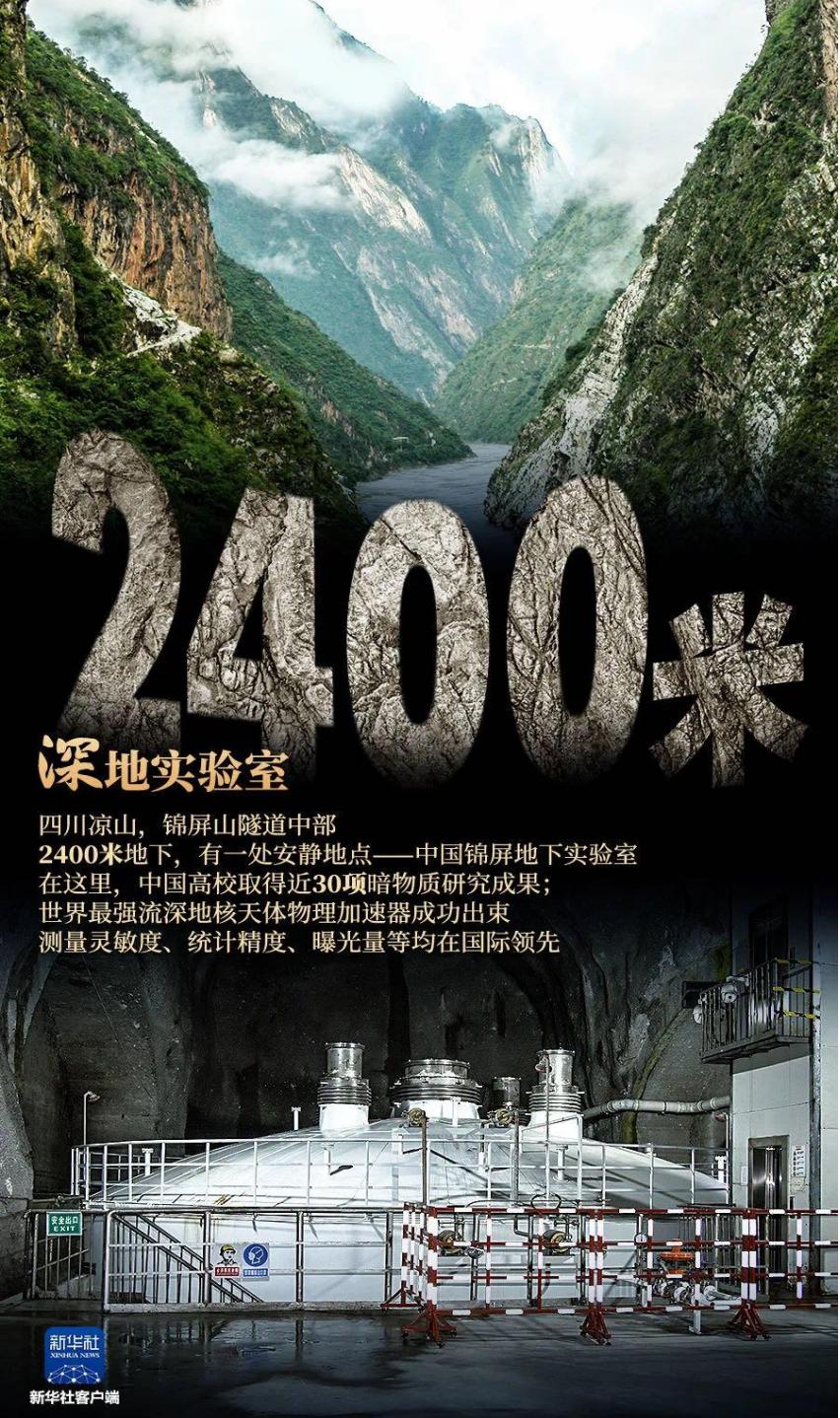


Hall C1 of CJPL-II



Summary

- Searching for $0\nu\beta\beta$ 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 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>



中国锦屏地下实验室
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