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

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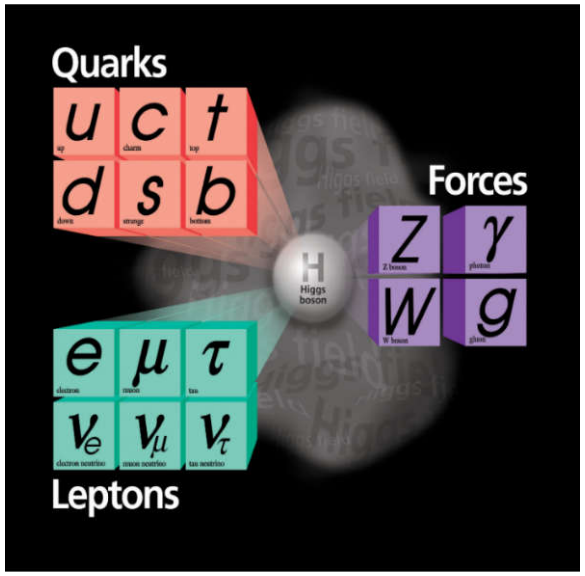
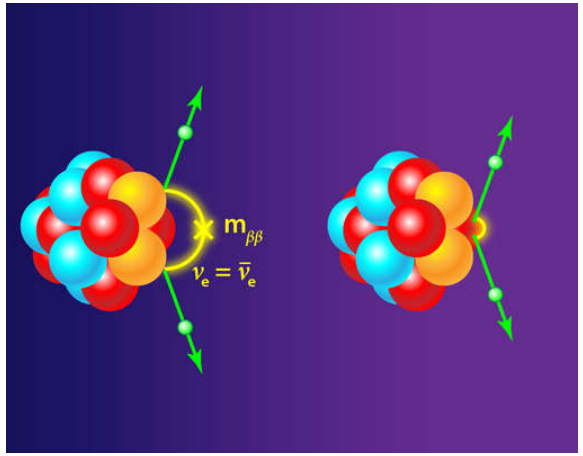
Outline

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

Neutrinoless double beta decay

- **Important 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

- **Germanium as 0νββ detector:**
  - Intrinsic high-purity crystal
  - Source = detector (high ε)
  - Ability to be enriched to 86% (A)
  - Excellent E resolution (σ) ~0.1%@2MeV
  - Background rejection (b): multiplicity, PSD…

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

Detect efficiency

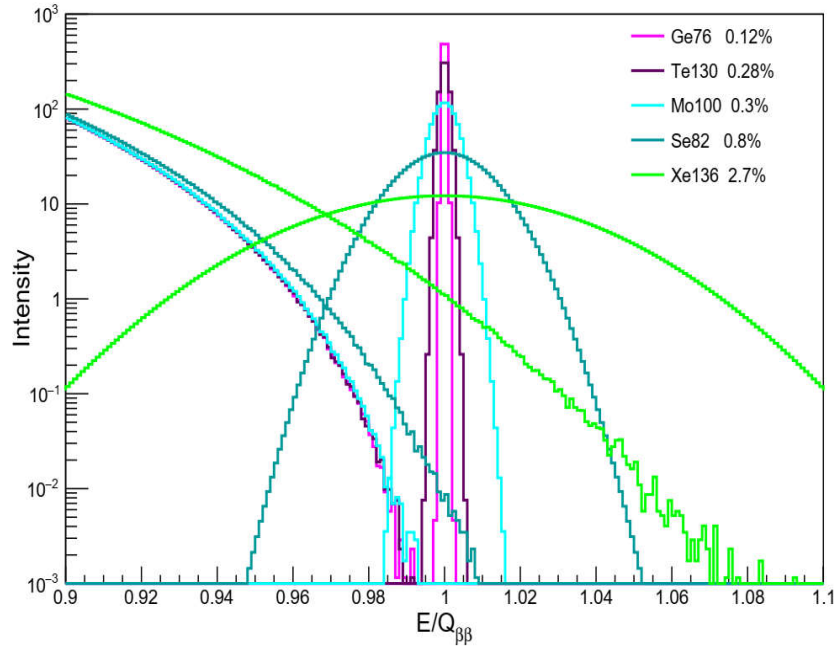
Mass of target

Isotopic fraction

Background

Energy resolution

Experiment	Iso	Exposure [kg-yr]	Half life [10^{25} yr]	$<m_{\beta\beta}>$ [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



- Current best $T_{1/2}$ result achieved by Gerda
- Energy resolution means not only "money", but also physics

CDEX Collaboration

- Formed in 2009, 11 institutions and ~80 people now
- Direct detection of dark matter with Germanium detectors.

CDEX Roadmap

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

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

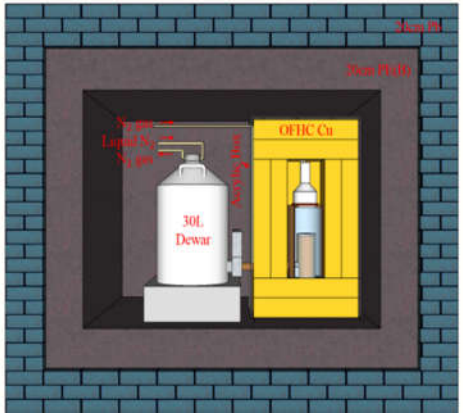
First 0νββ result by CDEX

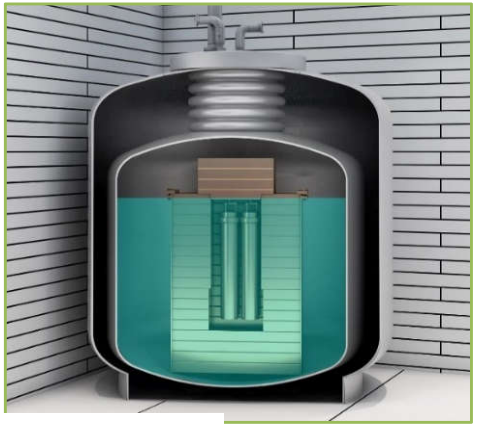
2009-2016

2016-2020

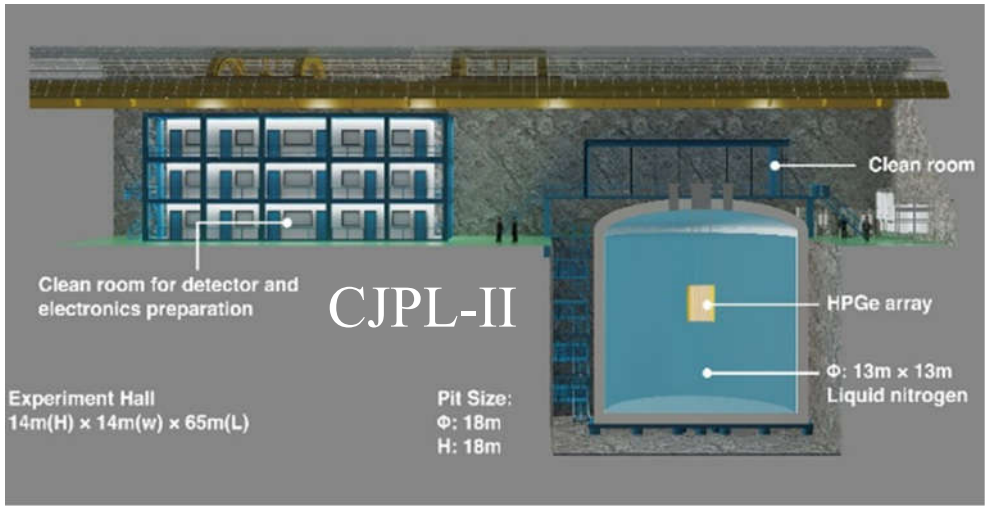
2021-

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





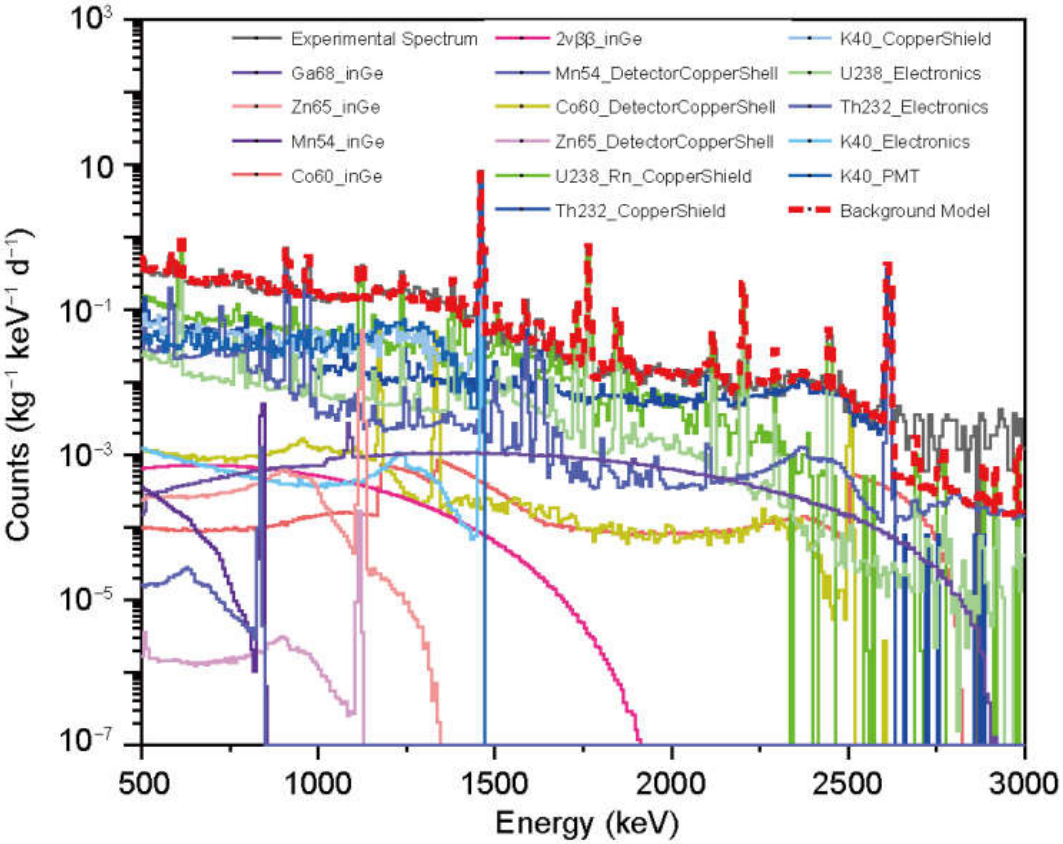
CJPL-I

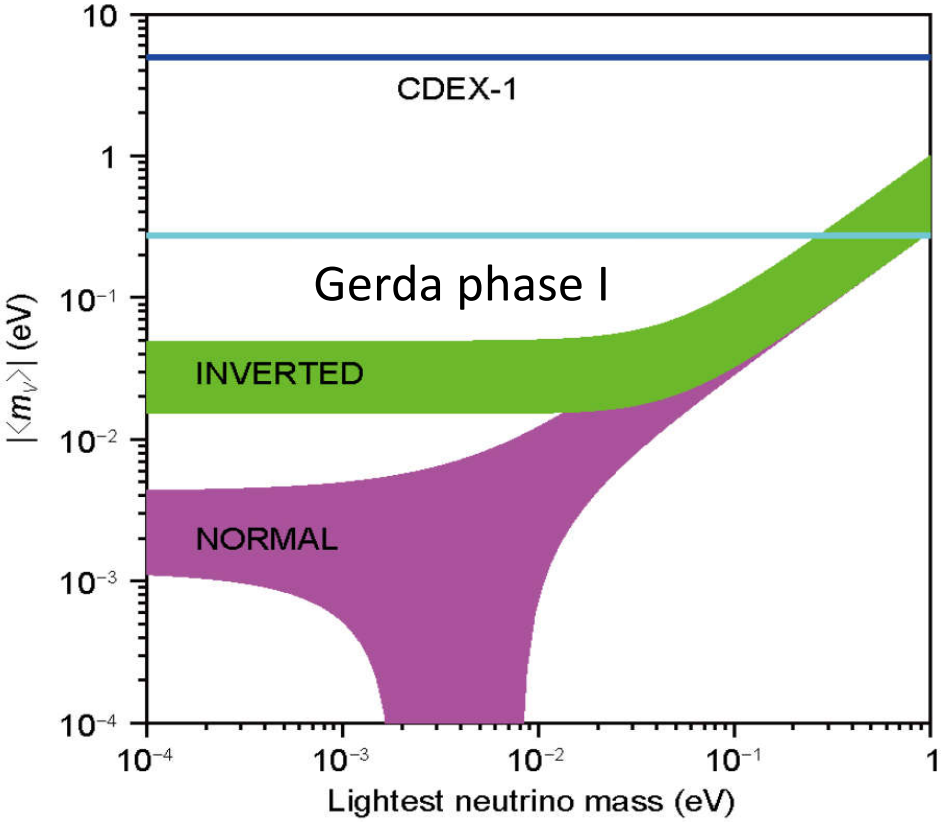


0νββ result from CDEX

- 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.

Science China P.M.A. (2017) 60: 071011





Physics goal and technical route

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

$$T_{1/2}^{0\nu} \propto \varepsilon \cdot A \cdot \sqrt{\frac{M \cdot T}{b \cdot \sigma}} \qquad \left(T_{1/2}^{0\nu}\right)^{-1} = G^{0\nu}(E_0, Z)|M^{0\nu}| < m_{\beta\beta} >^2$$

- Technical route:

Enriched Ge Array

- ✓ Enriched ^{76}Ge (A)
- ✓ ~ 300kg Ge (M)
- ✓ Energy resolution (σ)

+

LAr veto + LN_2 shield}

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

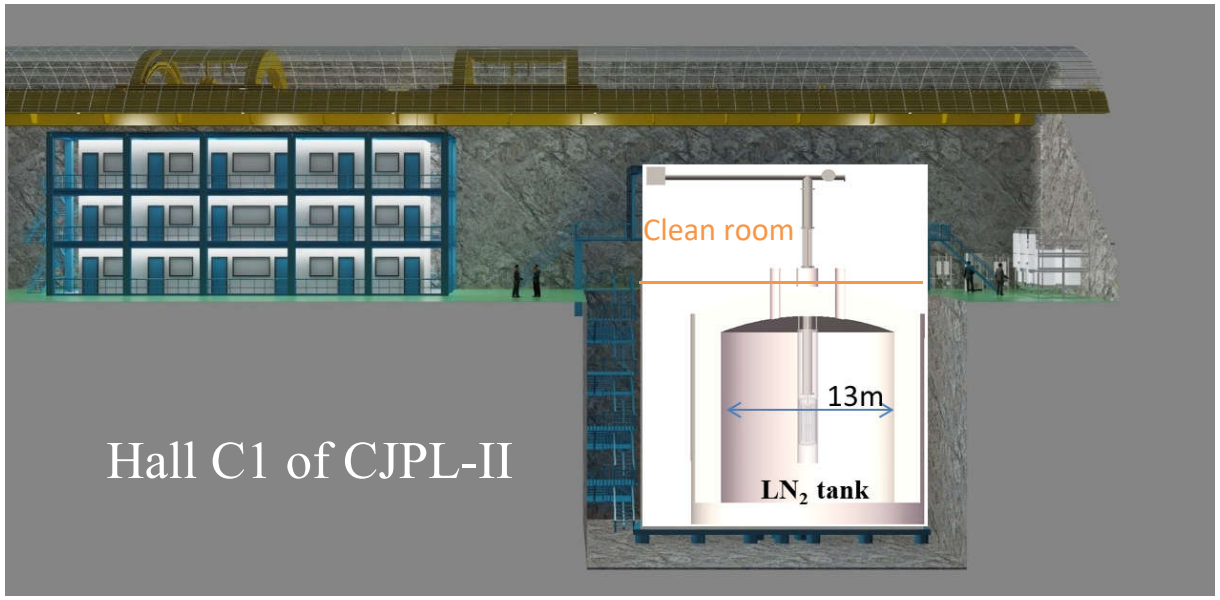
Material bkg control

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

CDEX-300v Conceptual Design

Overview

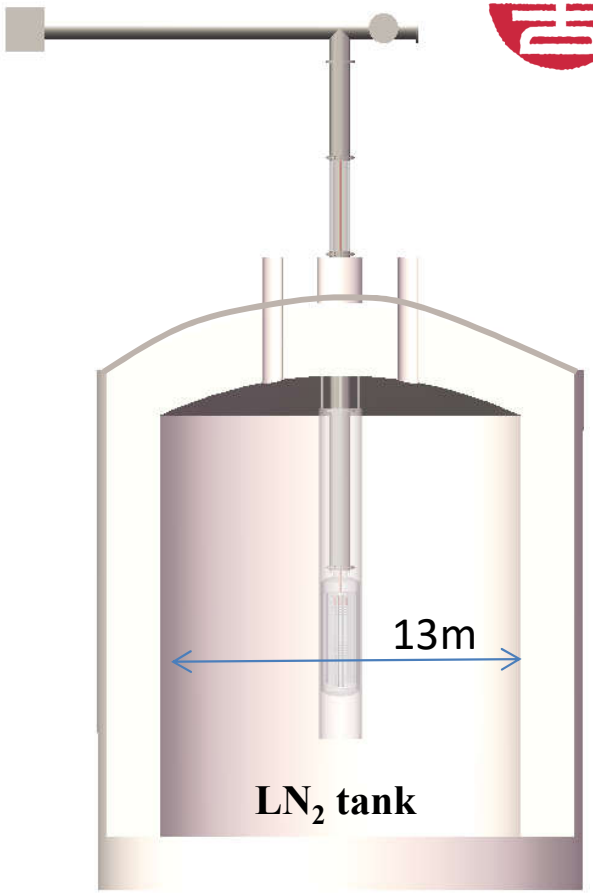
- LN_2 tank shared with CDEX-50
- Reentrant tube containing LAr submerged in LN_2
- Ge detector array immersed in LAr (veto) tube
- Ge detectors divided into 3 modules (~100kg each)



LN_2 tank

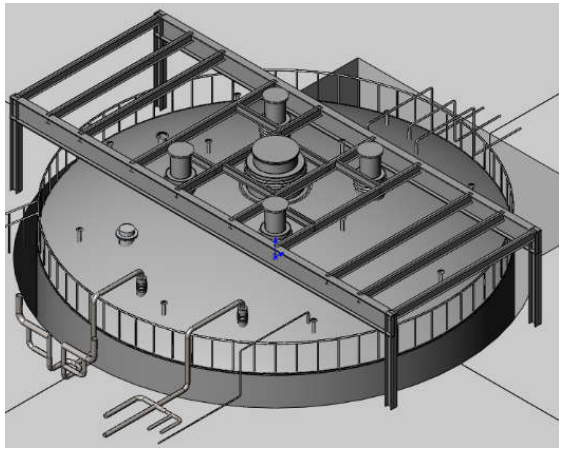
Specification

- 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



Background

- >4m LN_2 can shield most bkg from surroundings
- Rn in LN_2 will be controlled by purification*

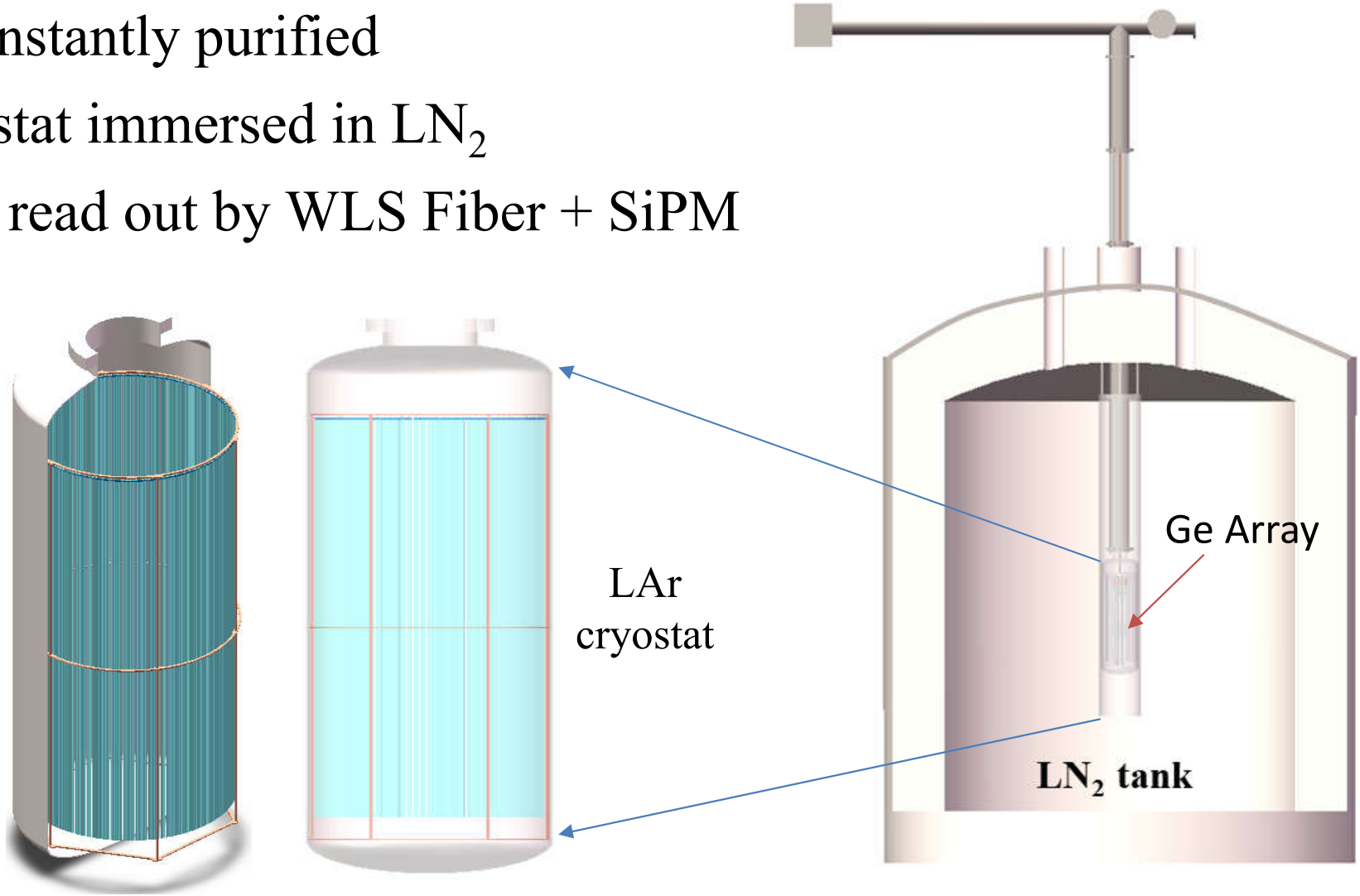


*详见李任明杰，大型液氮低温系统氡测量与抑制
https://indico.ihep.ac.cn/event/10906/session/2/contribution/190

CDEX-300v LAr System(1)

Baseline Design:

- 8 t (5.7m^3) LAr held by **Cu** / Ti /steel cryostat
- LAr is constantly purified
- LAr cryostat immersed in LN_2
- LAr light read out by WLS Fiber + SiPM



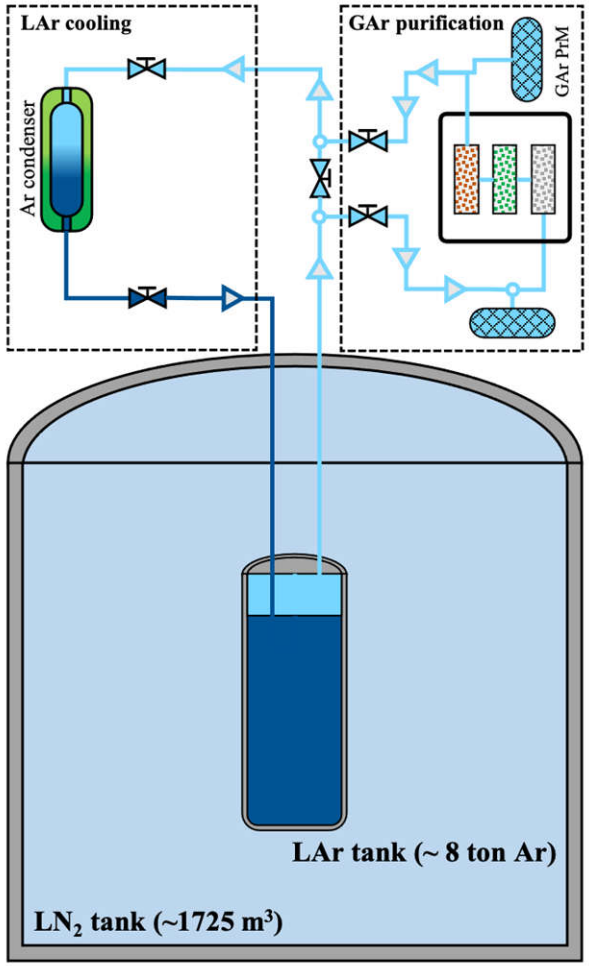
CDEX-300v LAr System(2)

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:

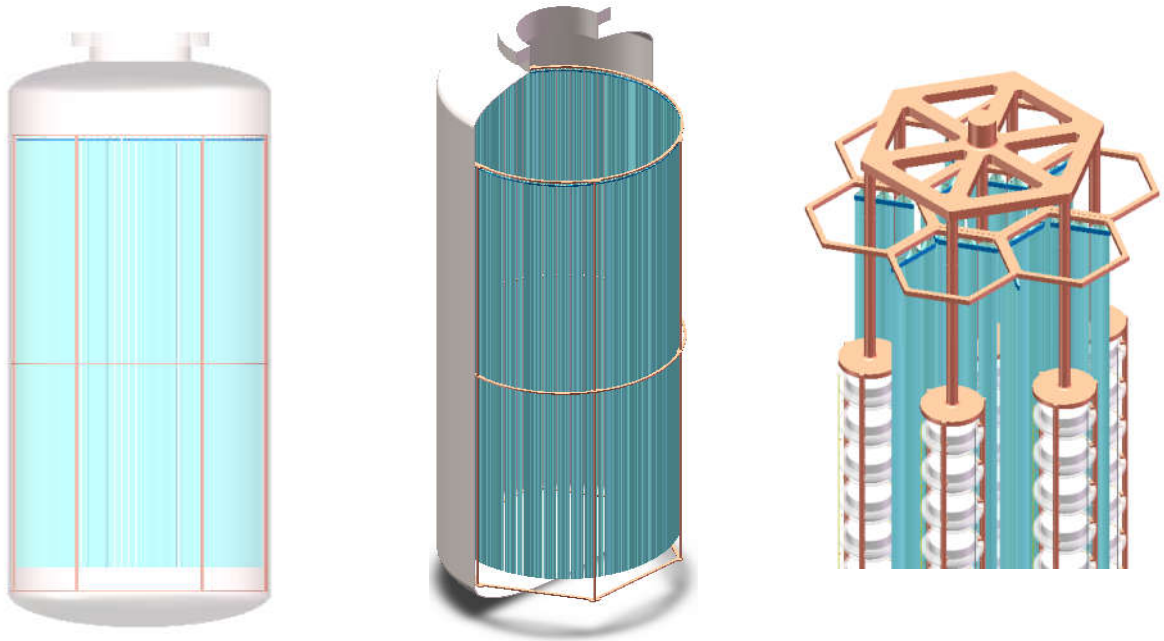
- Cooling purified GAr to LAr
- Heat exchanger + electrical condenser
- Backup LN_2 cooling module



CDEX-300v LAr System(3)

LAr Scintillation Light Readout

- Read out via SiPM + Fiber
- Inner fiber curtain placed between detector strings to collect light near Ge detectors
- Outer-layer fiber curtain to ensure maximum light collection
- Optional: Ge strings inside light guide tubes*

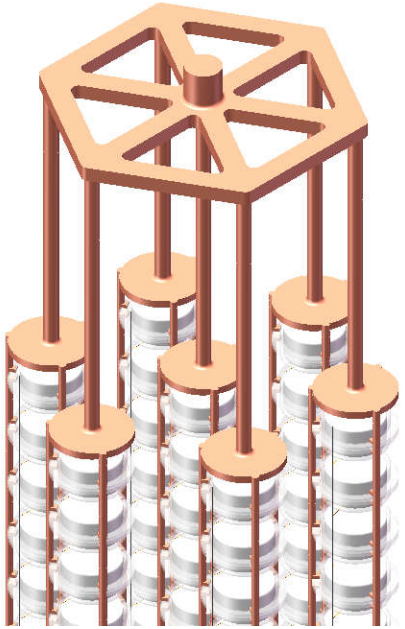


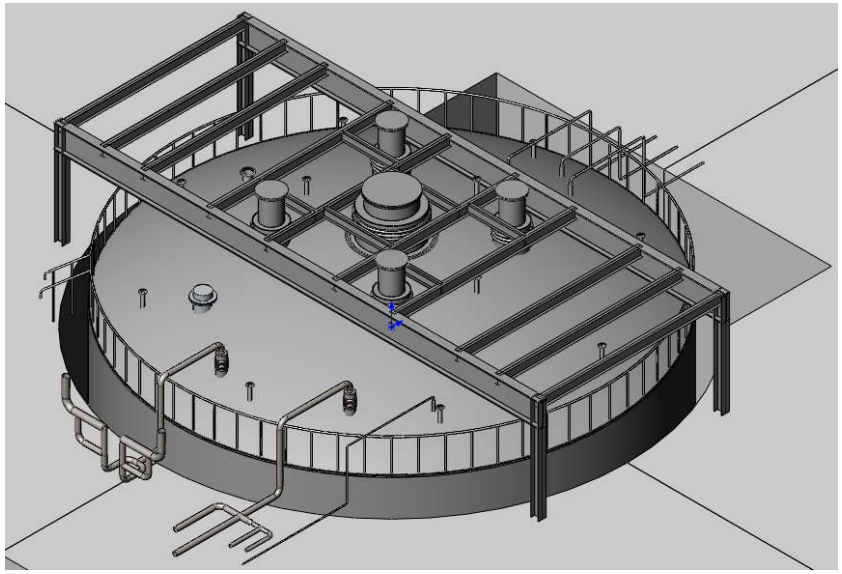
*详见张震宇, CDEX-300v实验中的液氩反符合技术预研 https://indico.ihep.ac.cn/event/10906/session/2/contribution/197

Ge detector Array

Baseline Design:

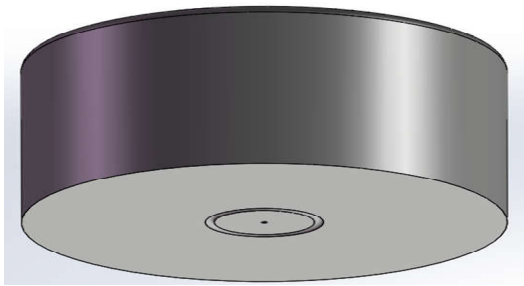
- 3 modules, ~100kg/module
- 7 strings/module, ~15 detectors/string
- Total mass of Ge detectors: ~300kg
- Top clean room for Ge detector and fiber installation



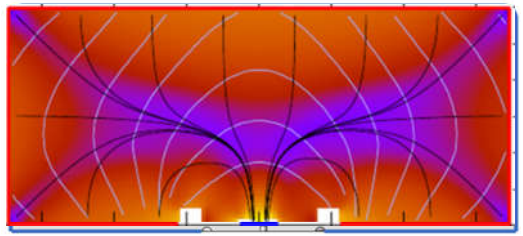


Ge detectors

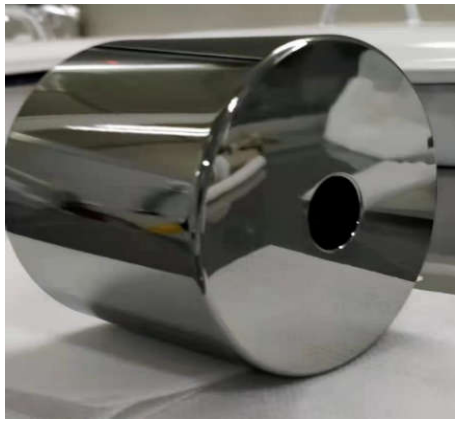
- **Enriched BEGe (Baseline)**
  - Mass: 1-1.2 kg；Ge-76 > 86%
  - Size: φ80×40 mm
  - Dead layer: 0.6 mm
  - E_r: <0.15% @2MeV
  - Commercial / Home-made

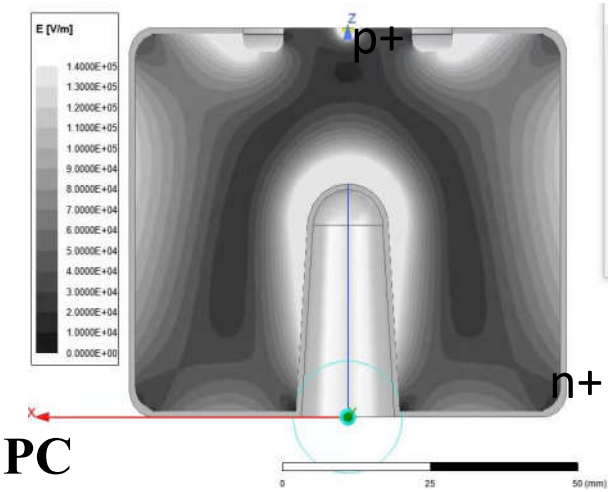


BEGe



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



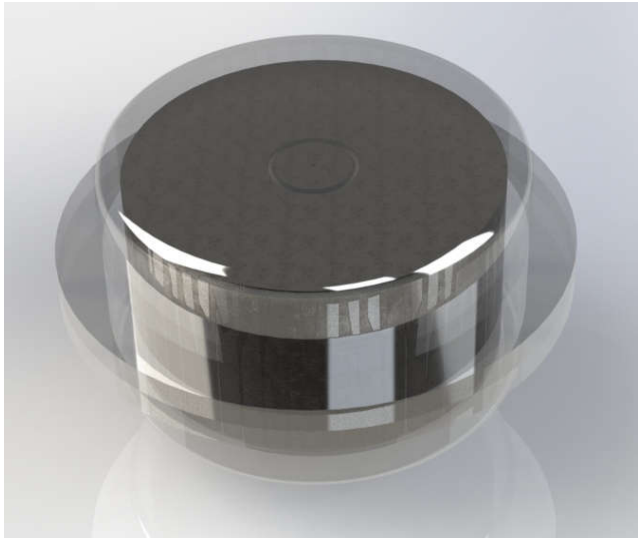


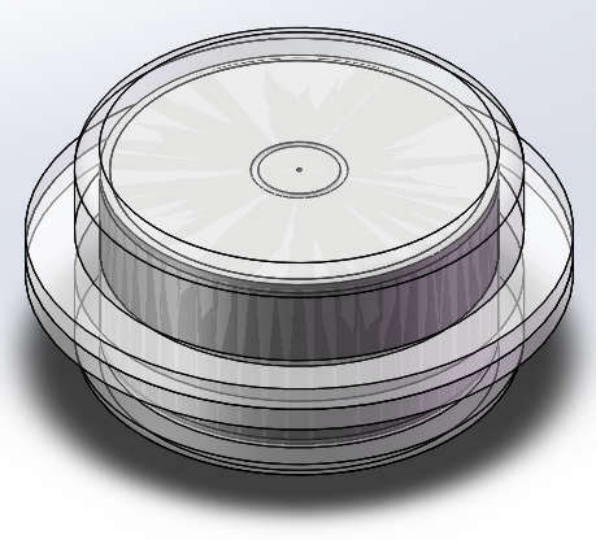
ICPC

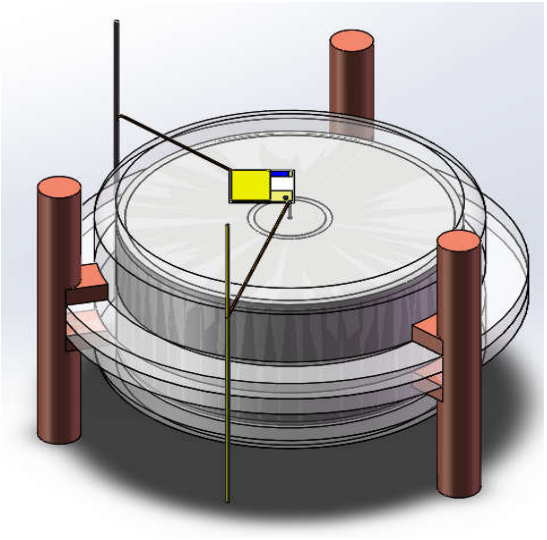
Ge Detectors

- **Baseline design**
  - Naked enr-BEGe immersed in LAr (veto)

- **R&D**
  - Ge crystal sealed in LB acrylic capsule and isolated from LAr
  - Front Electronics on the outer surface of acrylic shell

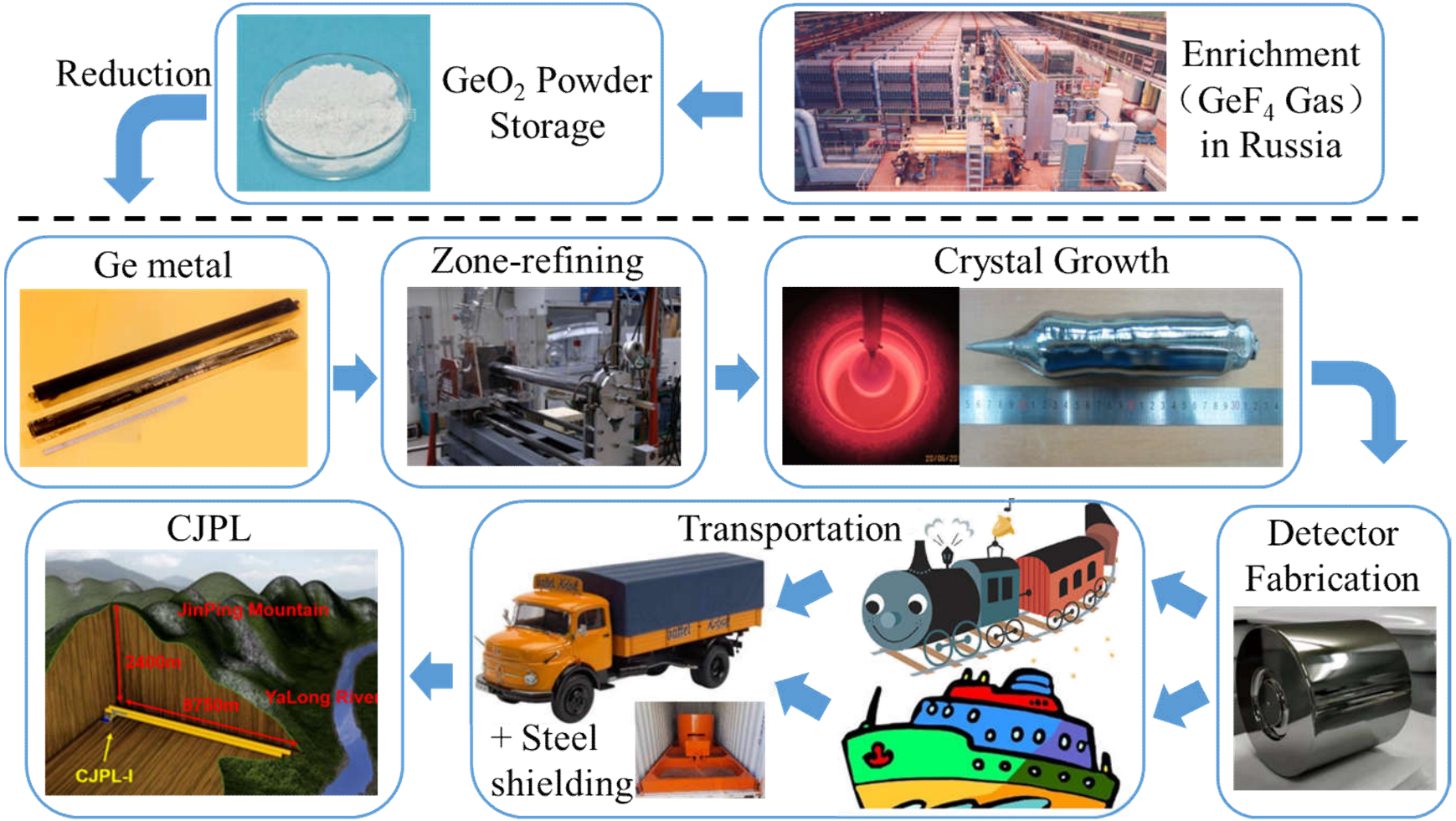






Enriched Ge detector procurement

- Enriched germanium dioxide (^{76}Ge >86%) from Russia in 2021
- Whole technical chain established
- To start enr-Ge detector production in 2021

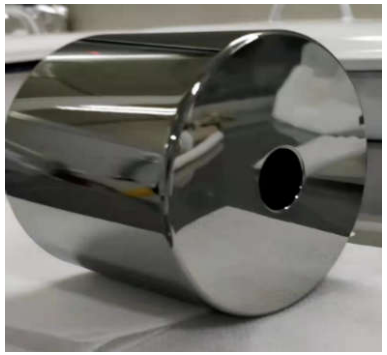


Detector R&D

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

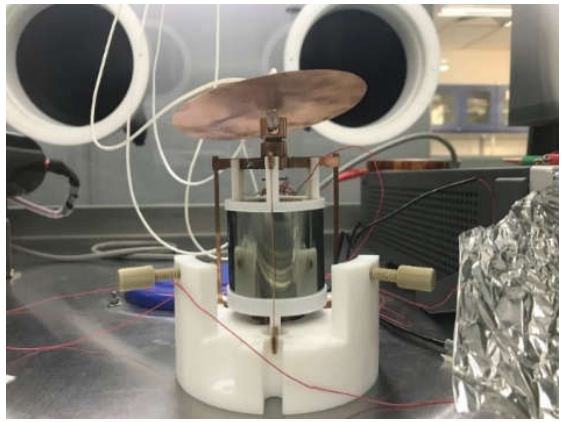
BEGe

PPC

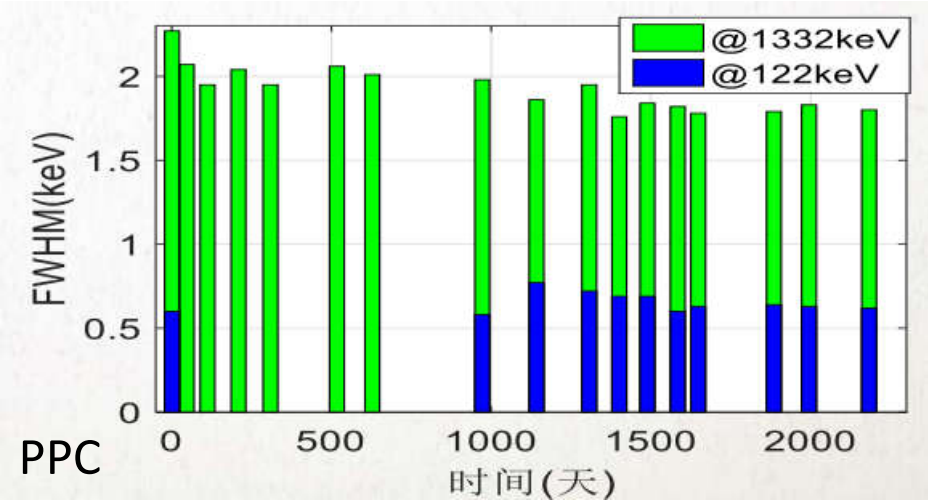


ICPC

Cold finger cooling



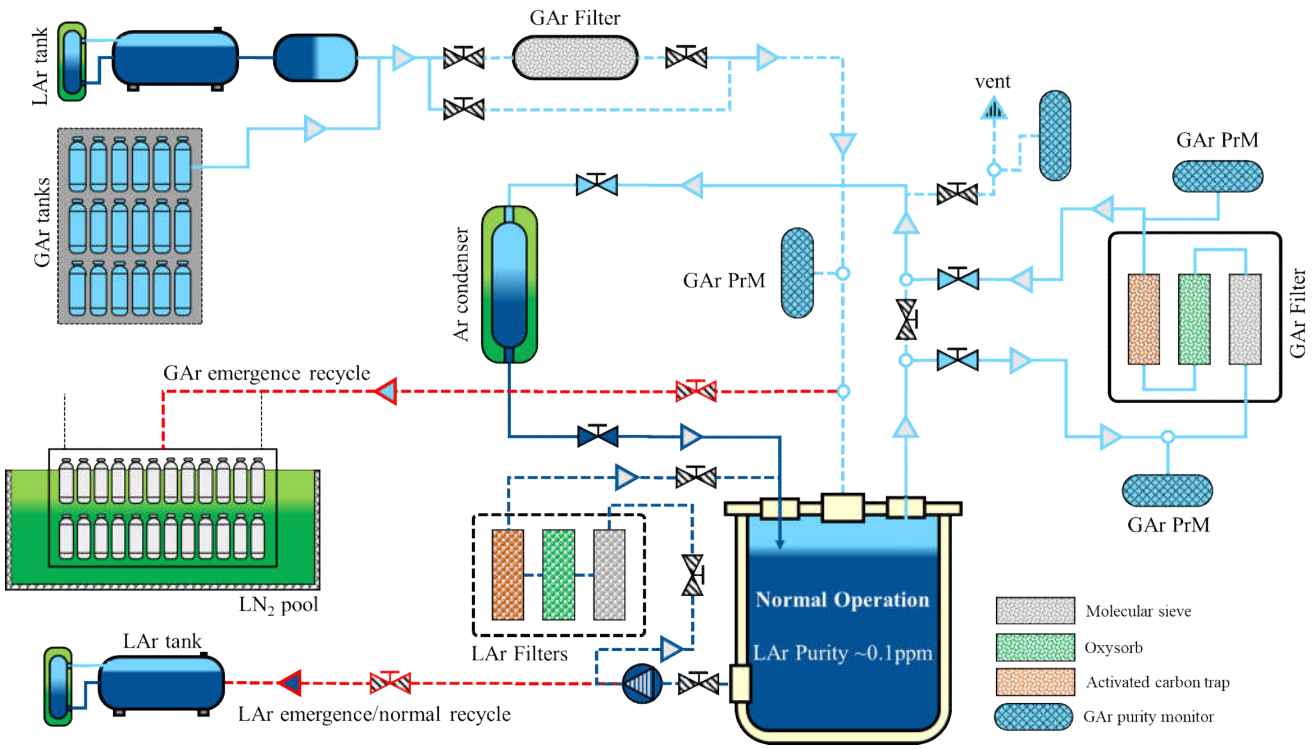
Naked crystal to LN_2



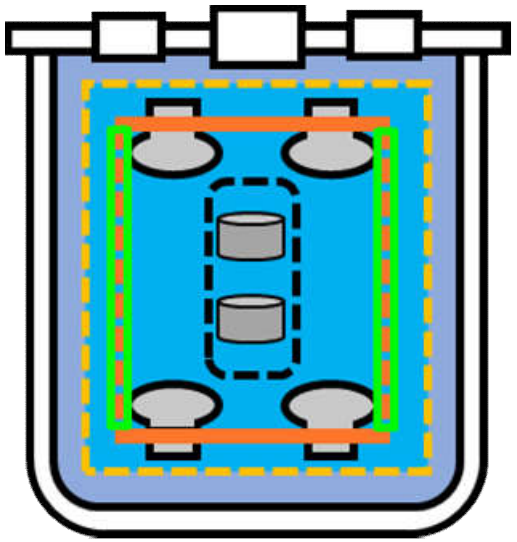
Long-term stability: energy resolution

LAr Test Facility

- S1: Operating & Purifying 200L LAr in a closed cycle（2021-）
- S2: Studying the light yield / transmission of LAr in different impurity levels（2022-）
- S3: Deploying Ge detectors to test veto efficiency（2023-）



S1



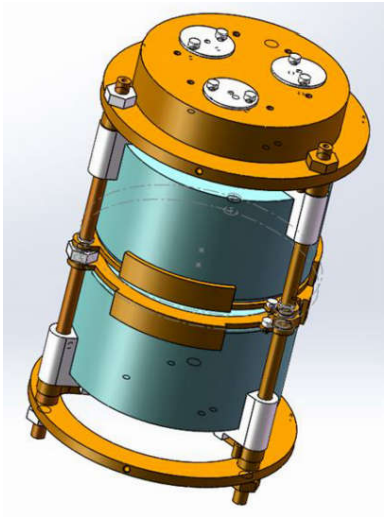
S2+S3

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 <10μBq/kg
- Free of cosmogenic radioactivity in copper

CDEX-300v Plan

- Test and operate LAr test facility in 2022
- Enr-Ge detectors test to start in 2022
- Hall C1 of CJPL-II ready for experiment in Mid 2023
- Experimental setup before 2024
- Ge detector installation and test in 2024

Hall C1

Service tunnel

Summary

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

Thanks for your attention!

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China Dark matter EXperiment

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