

Recent status and prospects of CDEX @CJPL

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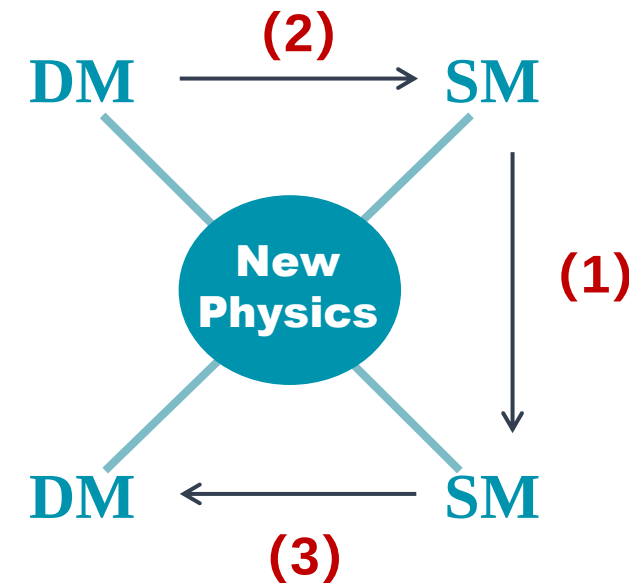
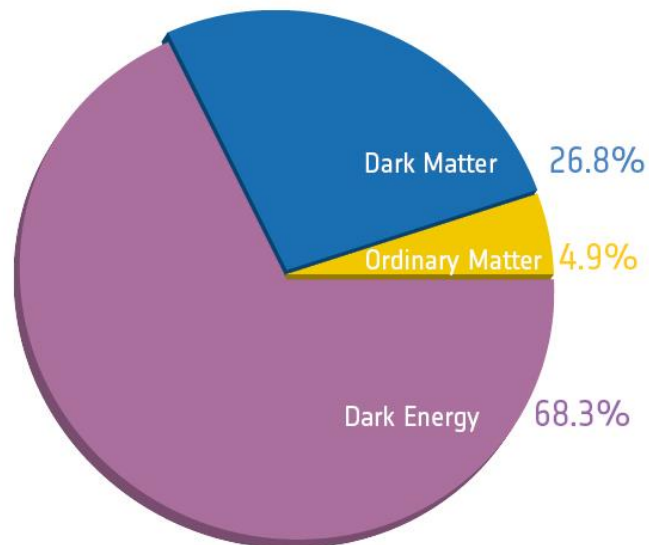
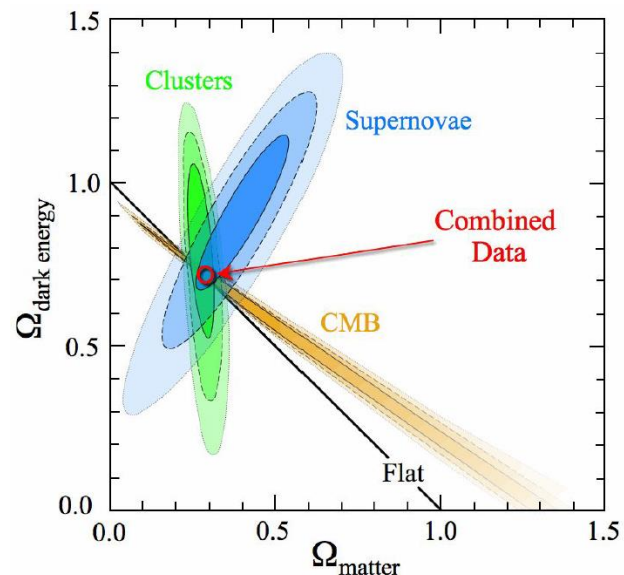
On behalf of CDEX Collaboration

OUTLINE

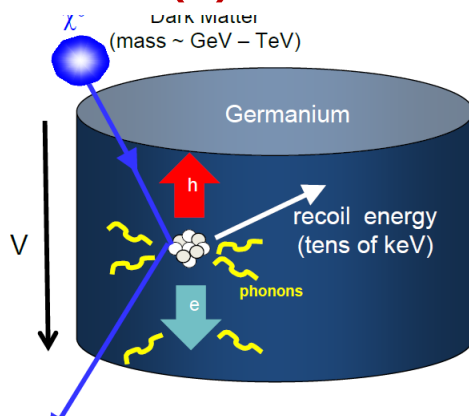


- Introduction to CDEX
- Recent status of CDEX-1 and CDEX-10 @CJPL-I
- Future CDEX-50 and CDEX-300 @CJPL-II
- Summary

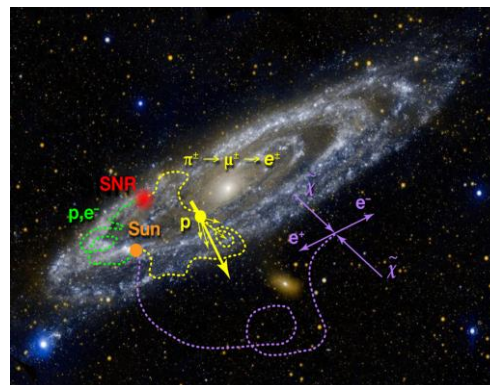
Dark Matter in Cosmology



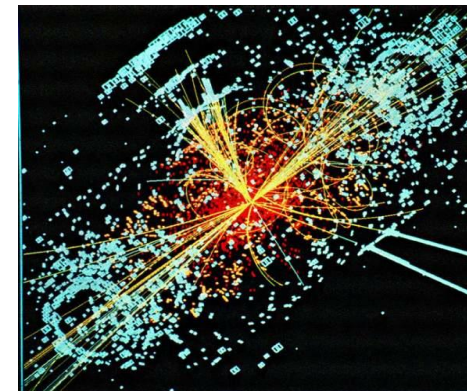
(1) Direct



(2) Indirect



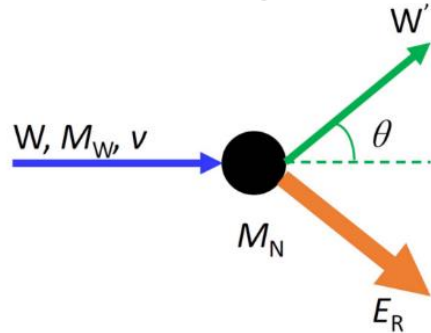
(3) Accelerator



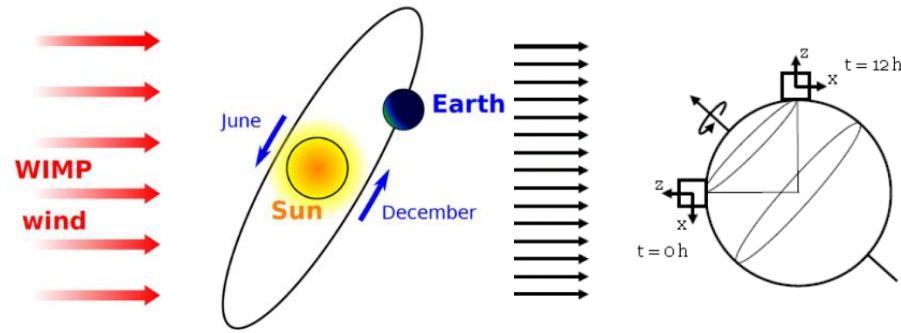
Direct detection of DM



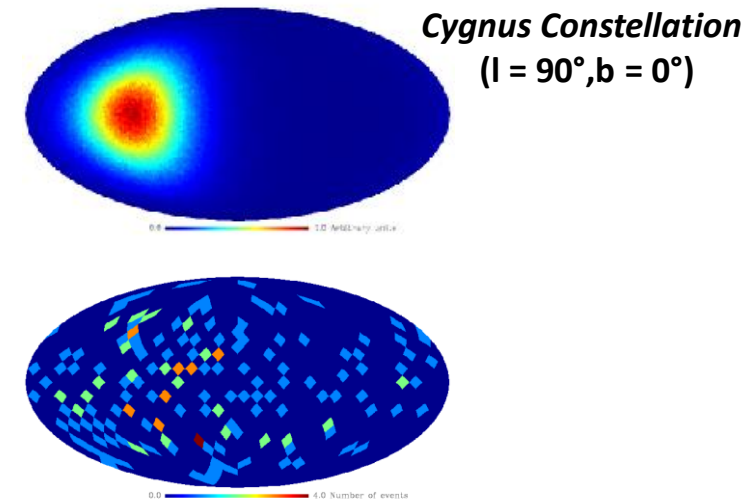
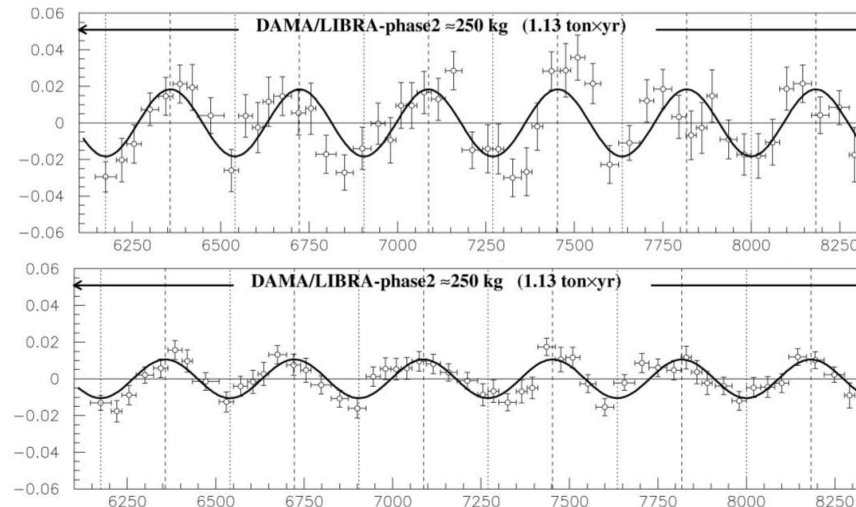
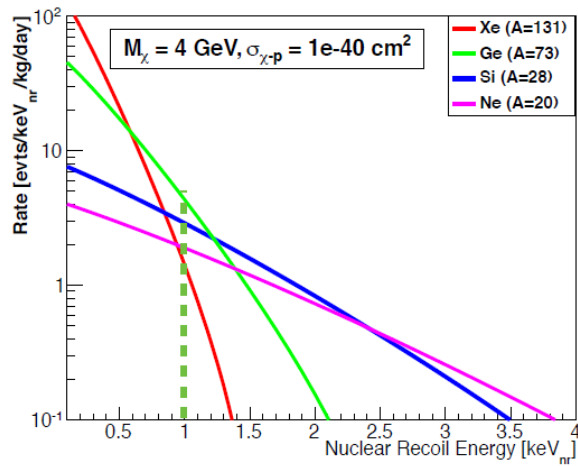
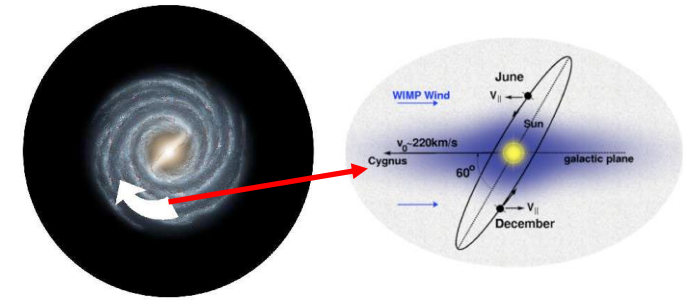
Elastic Scattering



Annual/ Diurnal Modulation



Direction Detection



- ☐ Lower Background
- ☐ Lower Energy threshold
- ☐ Larger Exposure (Mass*Time)

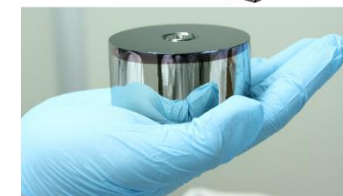
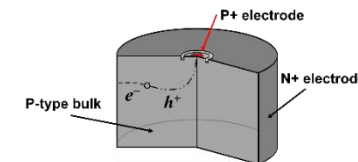
- ☐ Lower Background
- ☐ Lower Energy threshold
- ☐ Long-time stability

- ☐ Lower Background
- ☐ Lower Energy threshold
- ☐ Good Angular Resolution

China Dark matter Experiment



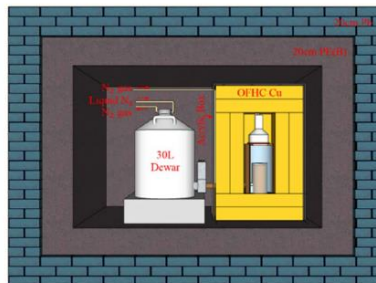
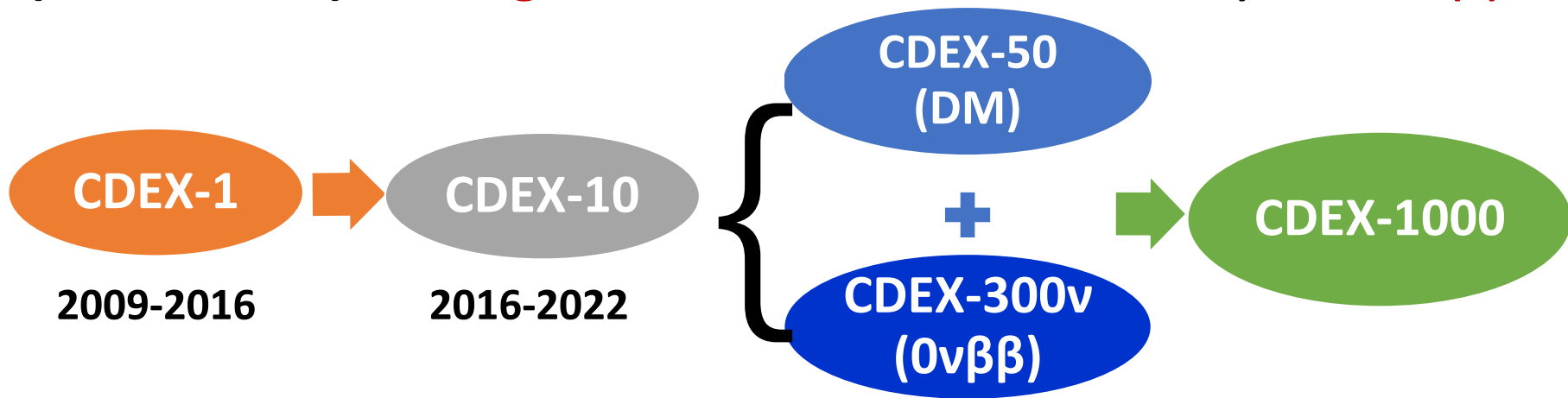
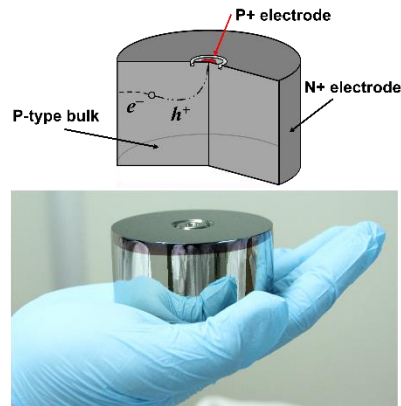
- Formed in 2009, 11 institutions and ~100 people now; <http://cdex.ep.tsinghua.edu.cn/>
- **Key technology:** P-type Point-Contact (PPC) Ge detectors;
- **Physics targets:** Direct detection of light DM + Ge-76 $0\nu\beta\beta$



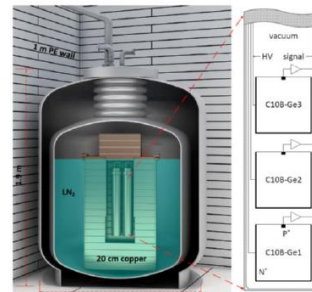
CDEX Roadmap



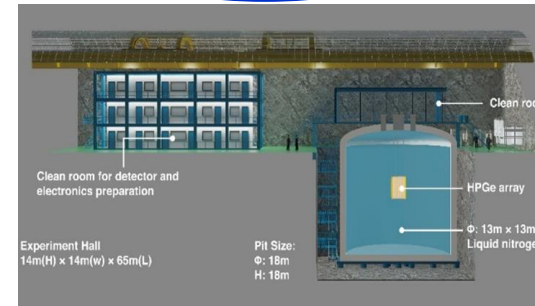
- **CDEX-1 (2009-2016):** Development of **PPC Ge detector**, bkg understanding
- **CDEX-10 (2016-2022):** Performances of **Ge array detector immersed in LN₂**
- **CDEX-50 (2021-202X):** **50kg Ge** detector arrays for **DM searches**
- **CDEX-300v (2021-202X):** **300kg enriched Ge** detector arrays for **0νββ Exp.**



CDEX-1A&B: 1kg PPC Ge×2



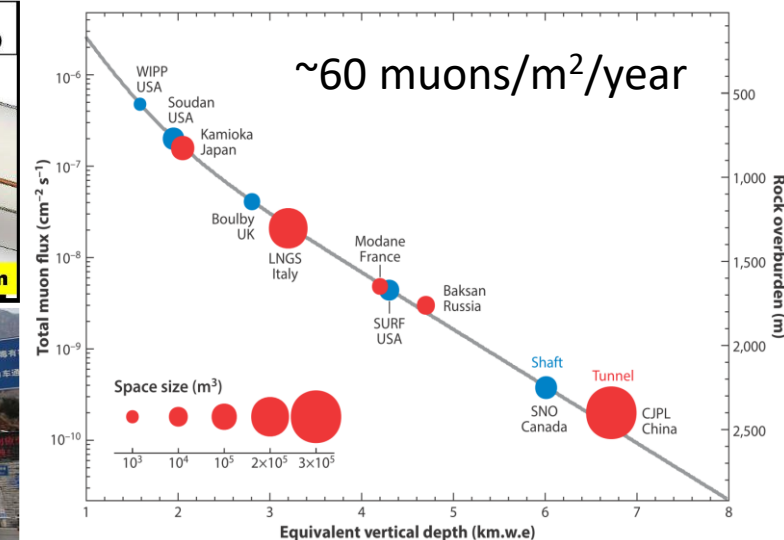
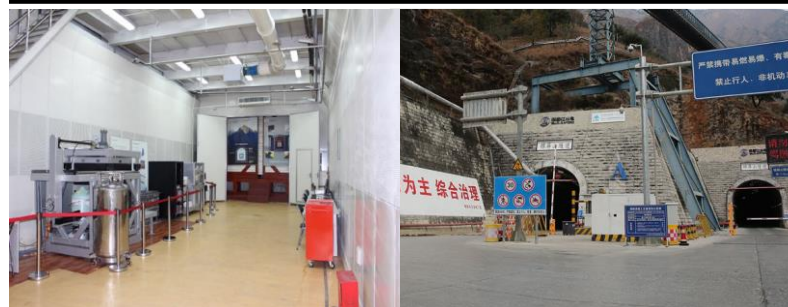
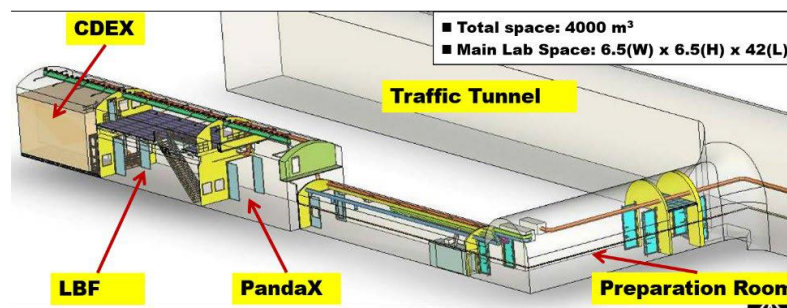
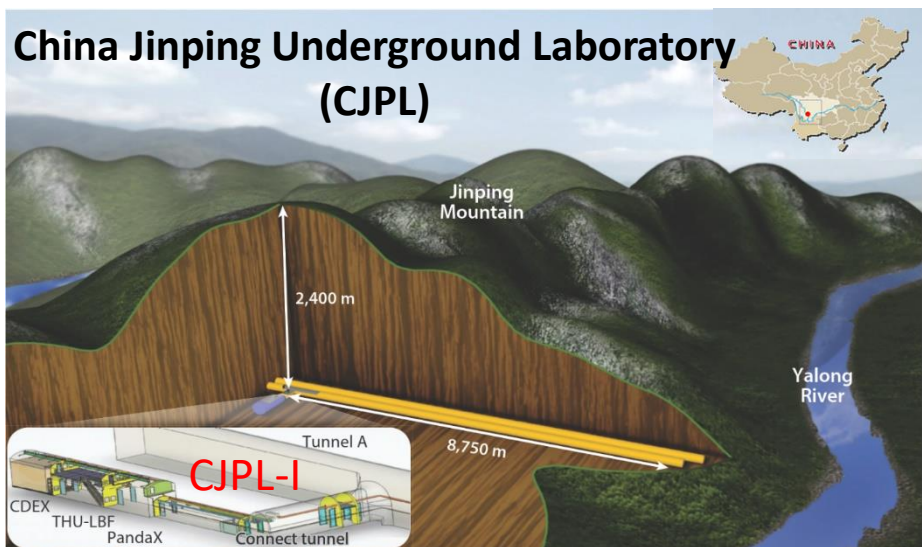
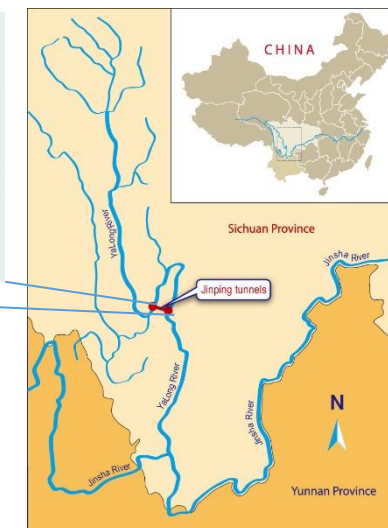
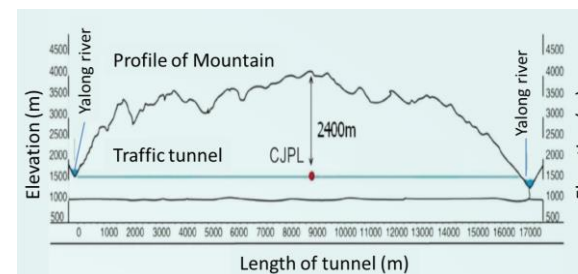
CDEX-10: ~10kg PPC Ge array



China Jinping Underground Laboratory



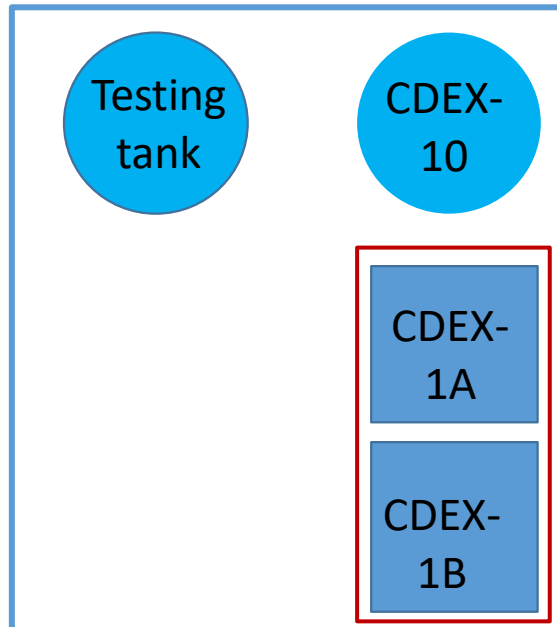
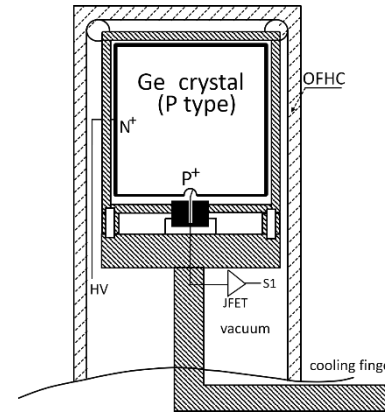
- World's deepest underground lab, CJPL
 - ✓ Near Xichang city, Sichuan Province, Southwest China
 - ✓ Rock overburden: 2400m (~6720 m. w. e.)
 - ✓ CJPL-I Main Hall: 6.5m(W) x 6.5m(H) x 42m(L), Total space: ~4000 m³
 - ✓ Two DM exp. (CDEX, PandaX)+LBF(radio-assay) operated in CJPL-I
 - ✓ Extension project, CJPL-II, final exam and expected to be completed in 2025



CDEX-1



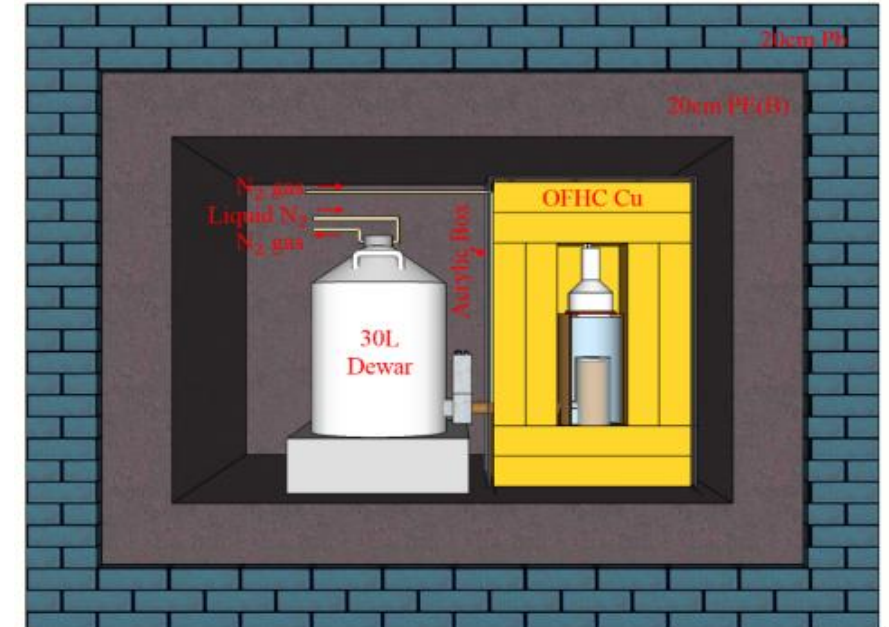
- Two single-element 1kg pPCGe detectors;
- Traditional cold finger refrigeration;
- Passive shield: Low-bkg Pb, OFHC Cu, PE;
- NaI(Tl) anti-Compton detector;
- Located in PE room at CJPL-I;



Layout of PE room, CJPL-I



CDEX-1 inside PE room



CDEX-1A&B: 1kg PPC Ge $\times$ 2

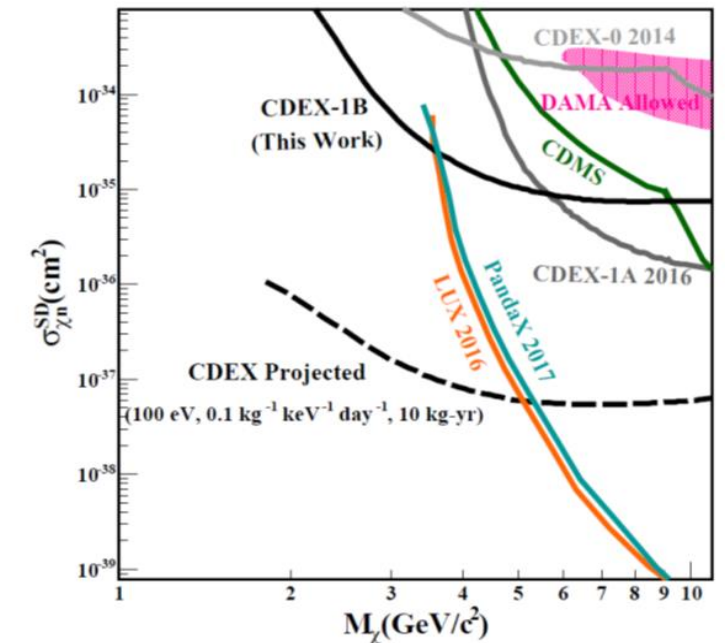
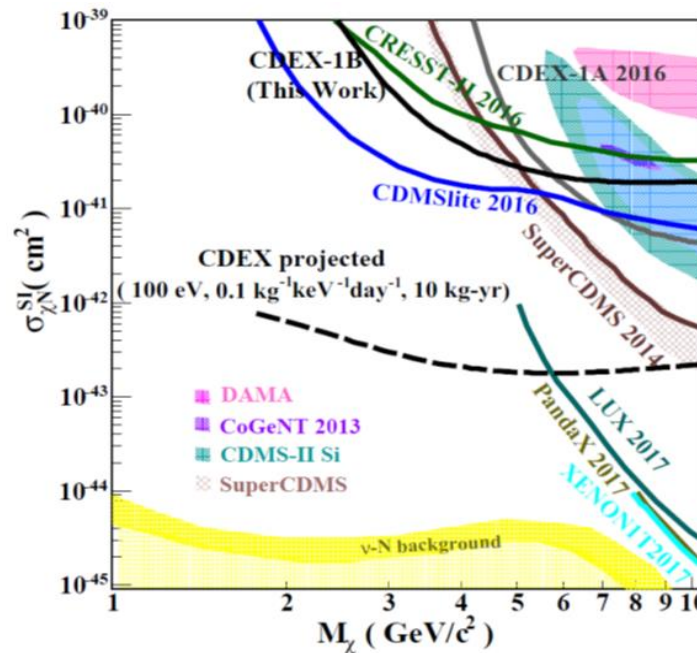
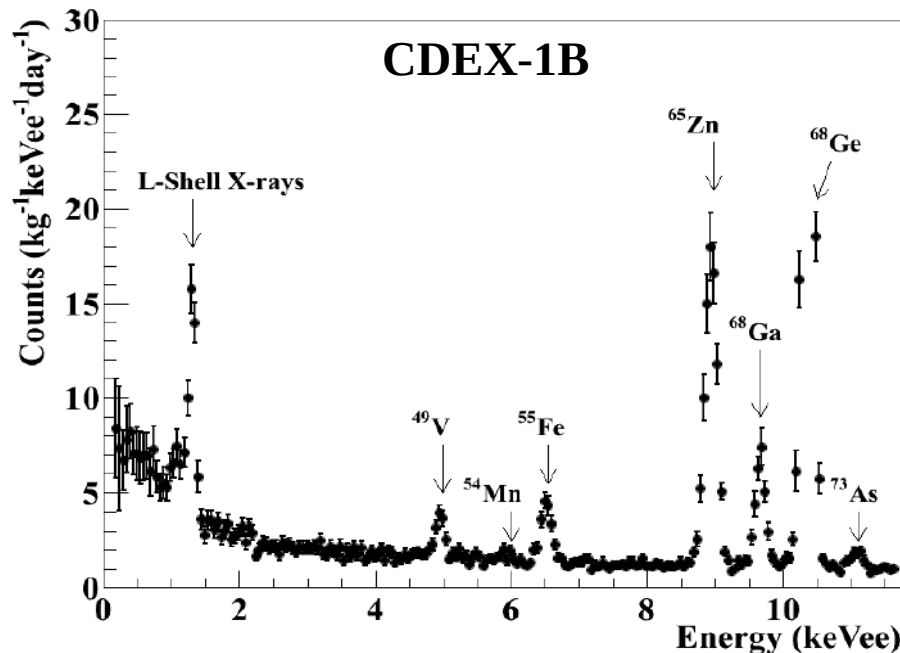
CDEX-1B Results



- Detector upgraded w/ lower JEFT noise and material bkg;
- >4 years run (Run-1&Run-2), >1200 kg·day exposure;
- Achieving 160 eVee energy threshold;
- Sensitivity improved and extending to 2 GeV/c².

Detector	FWHM of pulser
CDEX-1A	130 eVee
CDEX-1B	80 eVee

Run-1 Time-integrated (TI) analysis: *Chinese Physics C* 42, 023002 (2018)

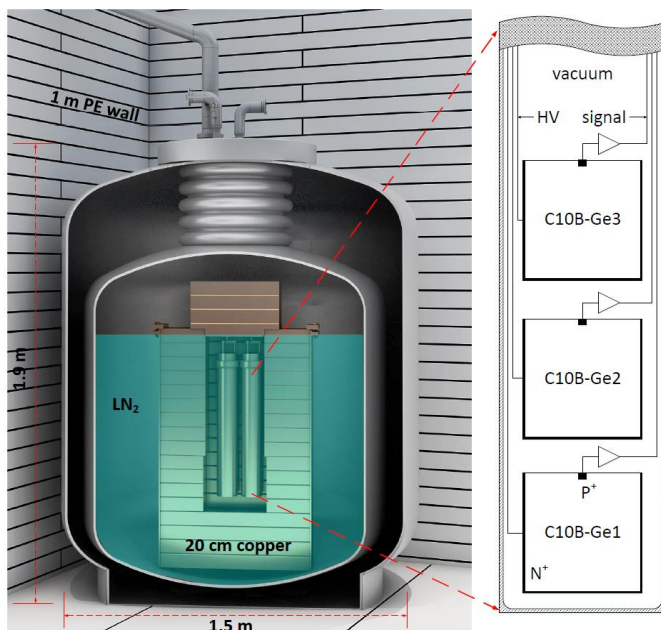


CDEX-10

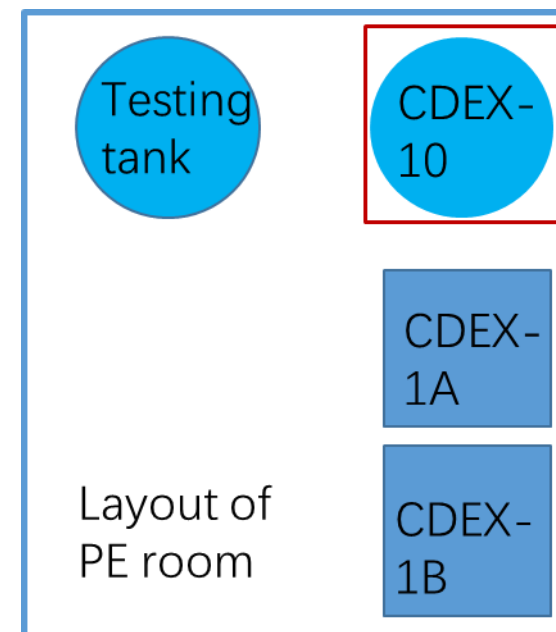


- Array detectors: 3 strings with 3 detectors each, ~10kg total;
- Direct immersion in LN_2 ;
- Prototype system for future hundred-kg to ton scale experiment
 - ✓ Light/radio-purer LN_2 replacing heavy shield i.e. Pb/Cu;
 - ✓ Arraying technology to scalable capability;

Science China-PMA 62, 031012 (2019)



CDEX-10: ~10kg PPC Ge array

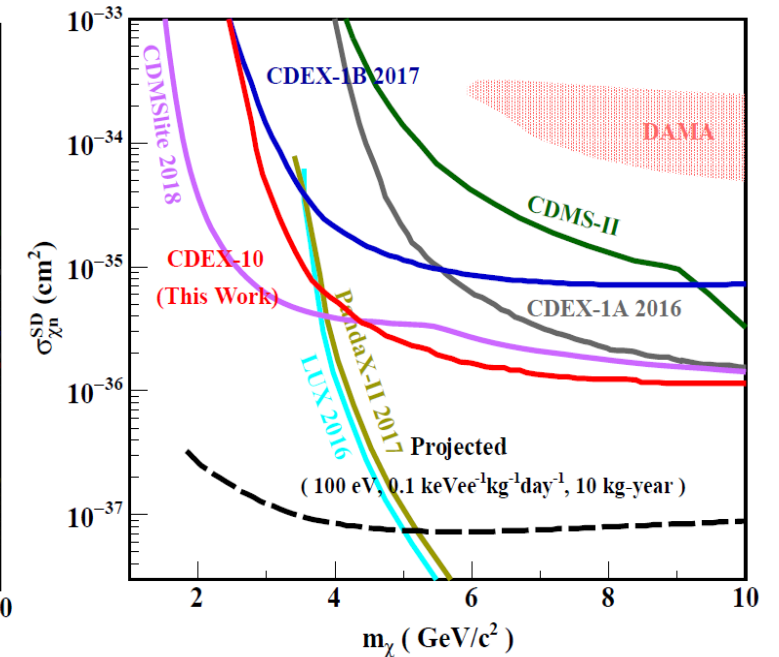
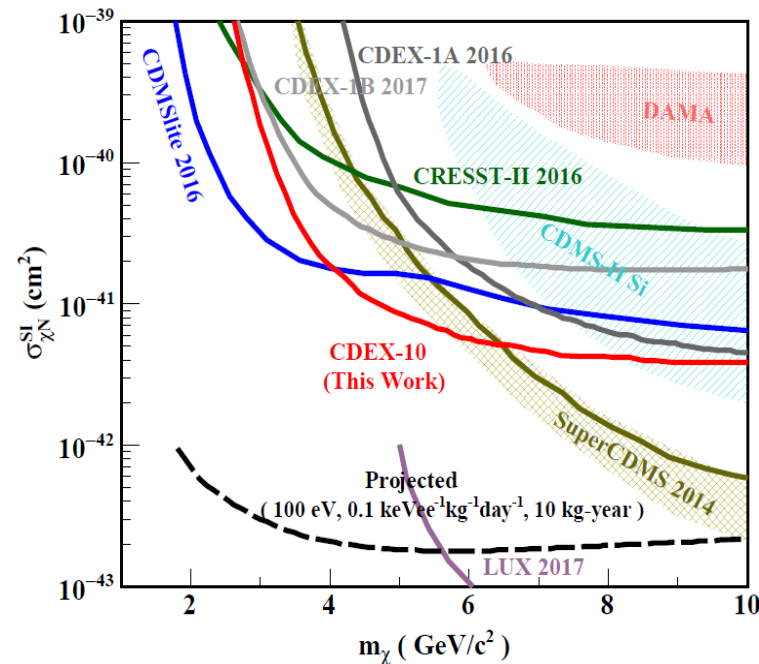
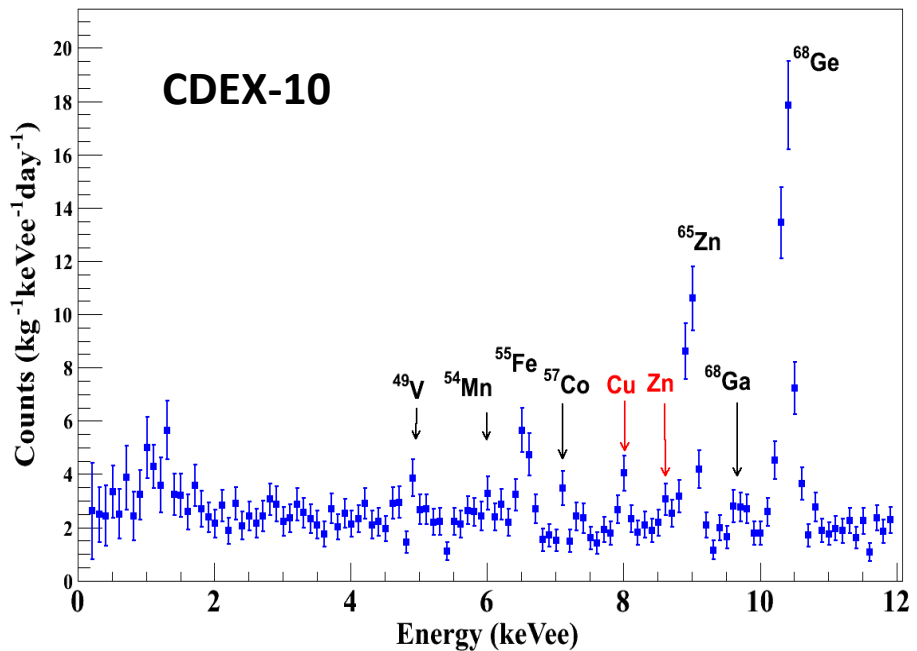


CDEX-10 Results



- First results from 102.8 kg·day exposure w/ Eth 160 eVee;
- Bkg level: ~ 2 cpkkd @ 2-4 keV;
- New SI limit on 4-5 GeV/c^2 ;

Phys. Rev. Lett. 120, 241301 (2018)



Dark Matter Direct Detection



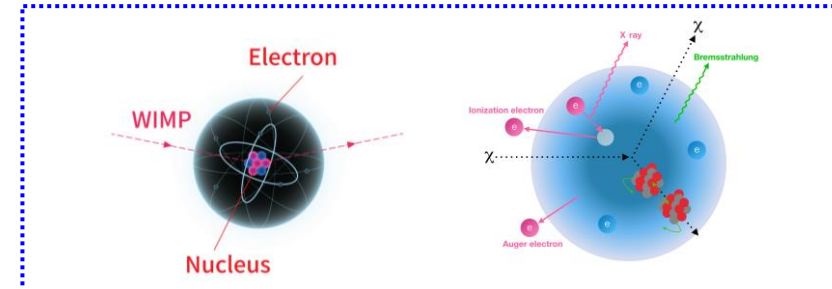
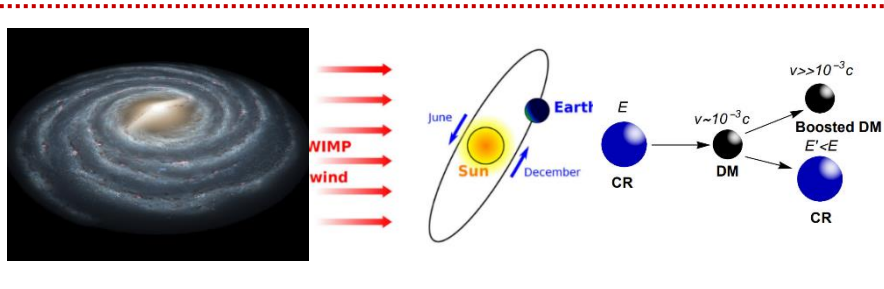
$$\frac{dR}{dE_R} = N_T \frac{\rho_\chi}{m_\chi} \int d^3\vec{v} v f_v(\vec{v} + \vec{v}_E) \frac{d\sigma}{dE_R}$$

DM sources related:

- ✓ WIMP (Standard Halo Model)
- ✓ Annual Modulation (velocity change)
- ✓ Boosted DM
- ✓ Dark Photon, axions et al.

Interaction process:

- ✓ DM-nucleus elastic scattering
- ✓ DM-nucleus inelastic scattering
- ✓ DM-electron scattering
- ✓ Others (All energy deposited)

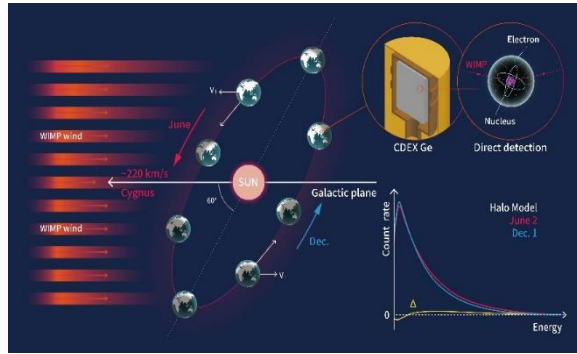


*WIMP: weakly interaction massive particles

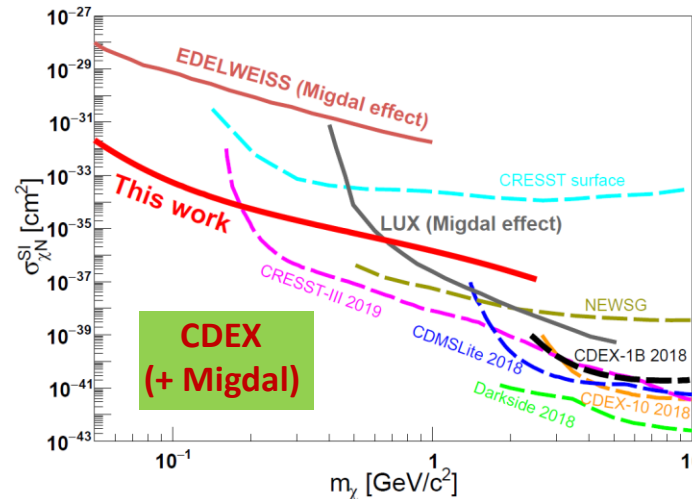
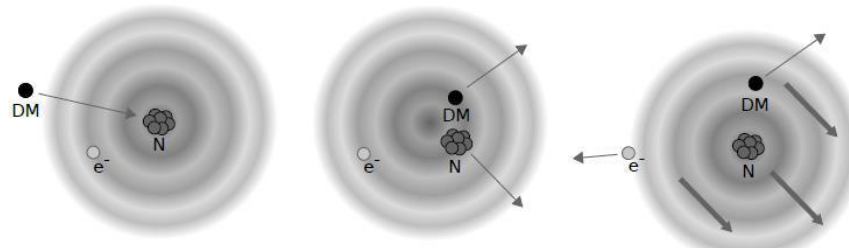
More physics analysis



Annual Modulation + DM-nucleus elastic scattering

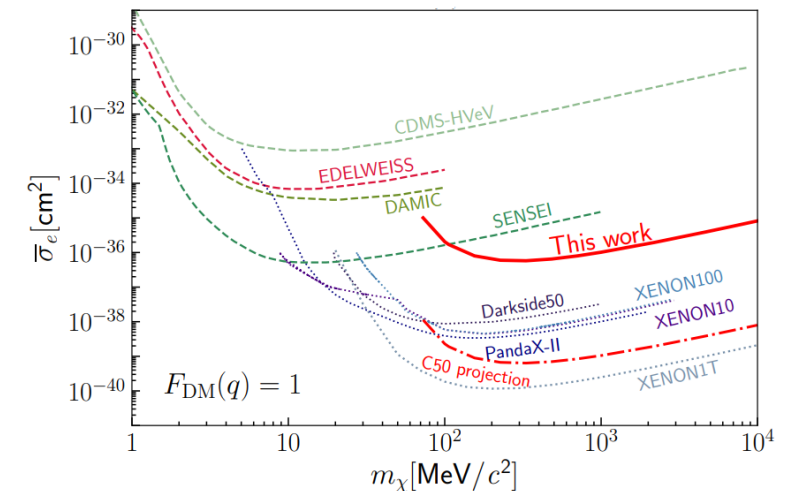
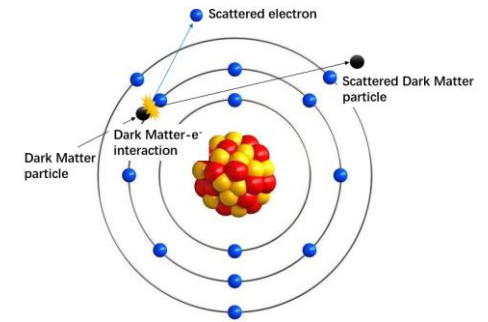


WIMP (Standard Halo Model) + Migdal effect

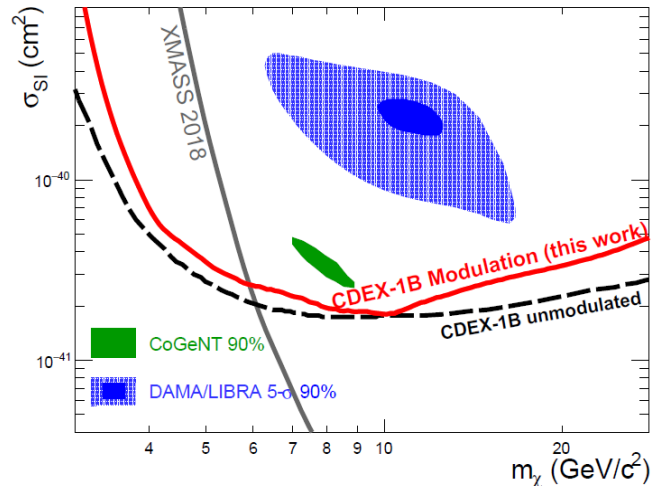


PRL 123:161301 (2019)

WIMP (Standard Halo Model) + DM-Electron Scattering



PRL 129:221301 (2022)

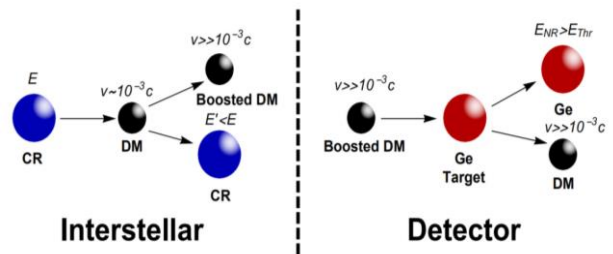


PRL 123:221301 (2019)

More physics analysis

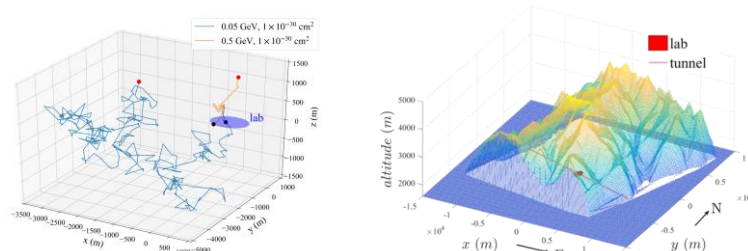


CR Boosted DM + DM-nucleus elastic scattering

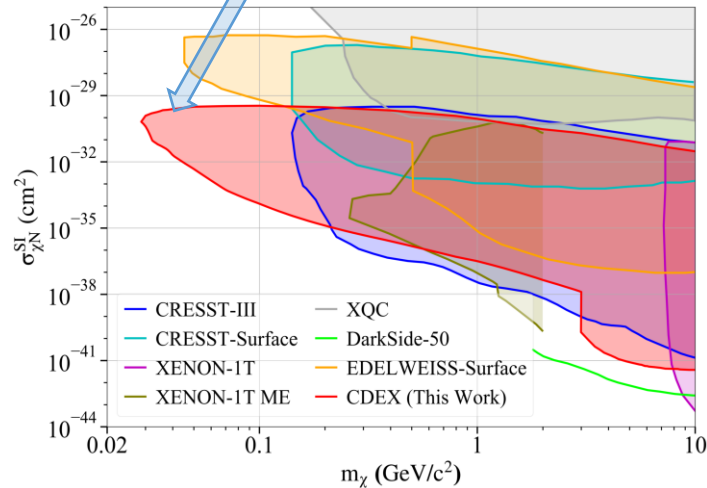


CRDM

WIMP (Standard Halo Model) + Earth shielding, Migdal effect

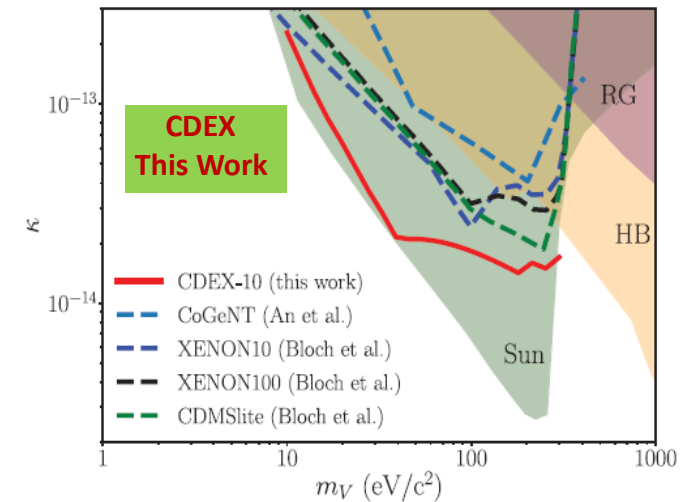
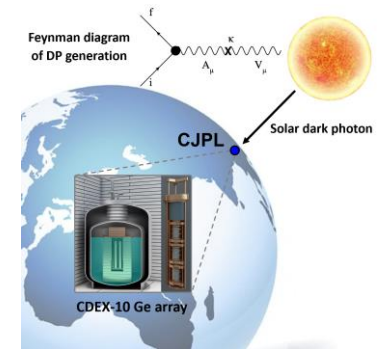


Earth shielding

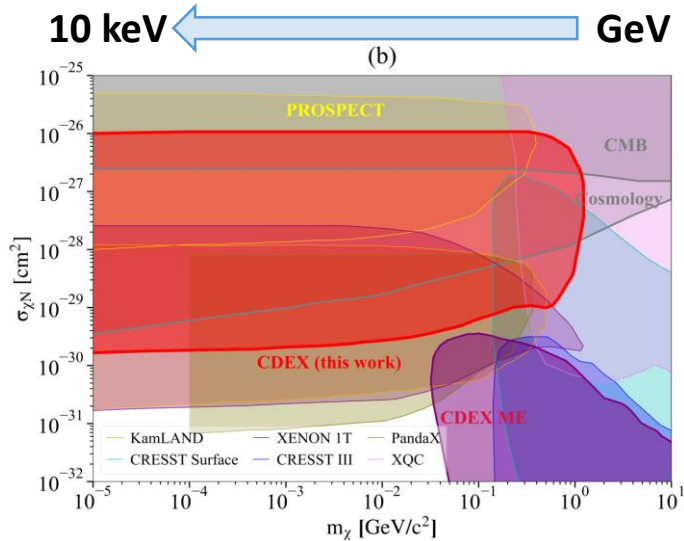


PRD 105:052005 (2022)

Solar dark photon + All energy deposited

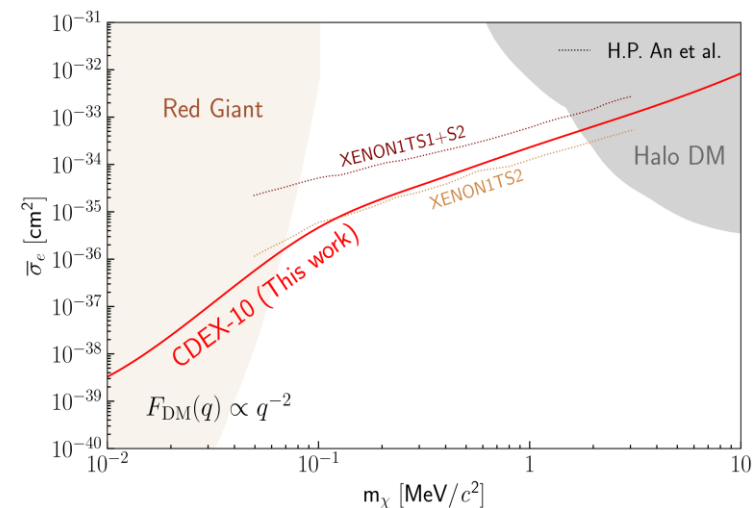
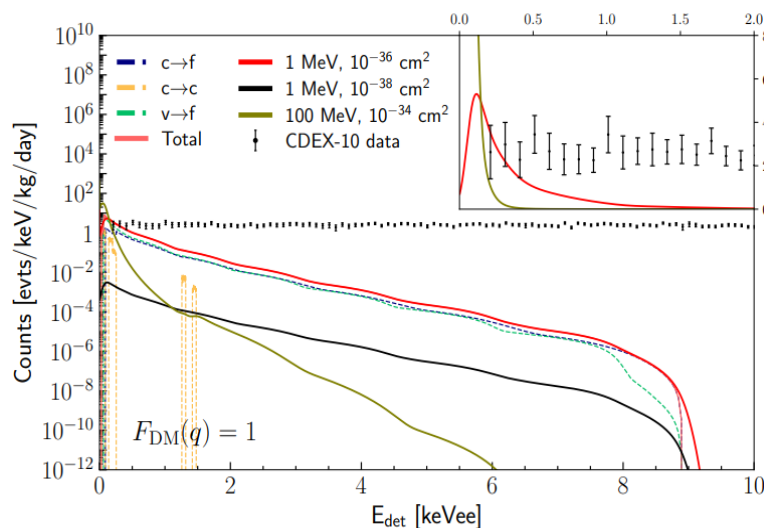
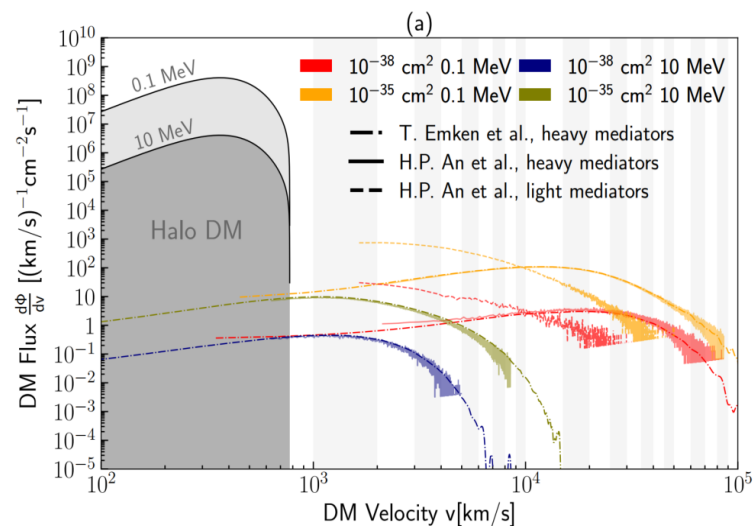
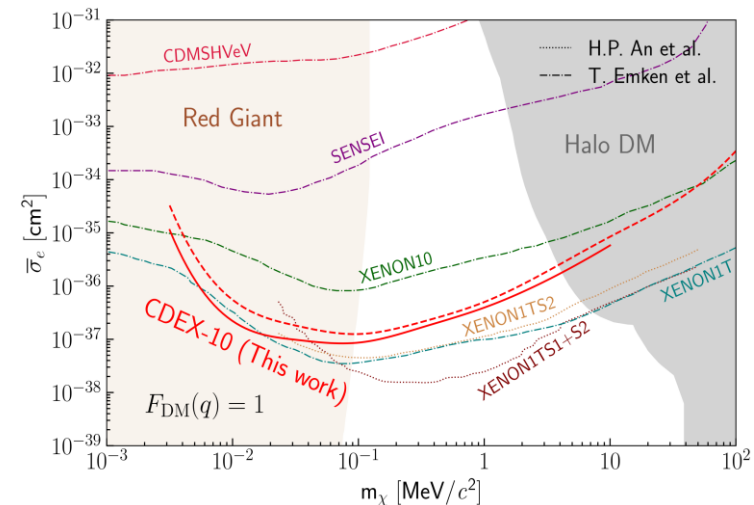
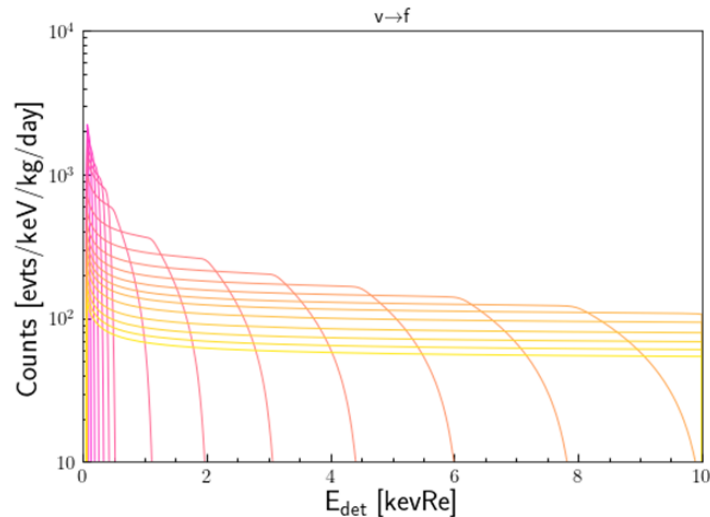
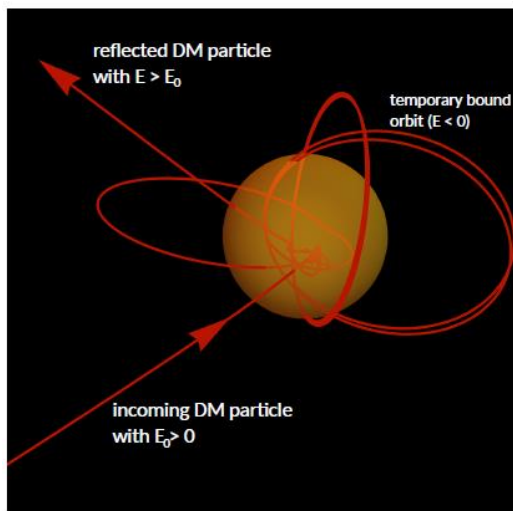


PRL 124:111301 (2020)



PRD 106:052008 (2022)

Boosted DM-electron: SRDM



**Solar Reflected Dark Matter
velocity distribution**

PRL 132:171001 (2024)

CDEX-10 SRDM results

CDEX Fermionic Dark Matter Search



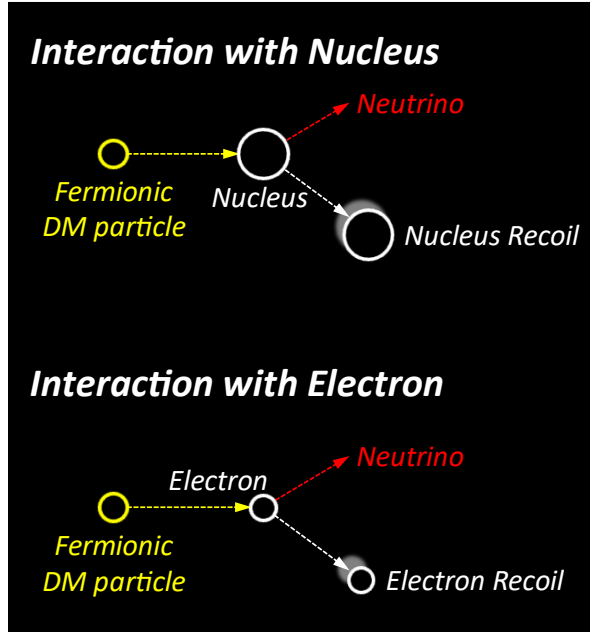
If DM particles are **Fermion**, they can induce neutral current absorption with **nucleus** or **electron**

- **Limits on Nucleus Absorption Cross-Section (σ_{NC}):**

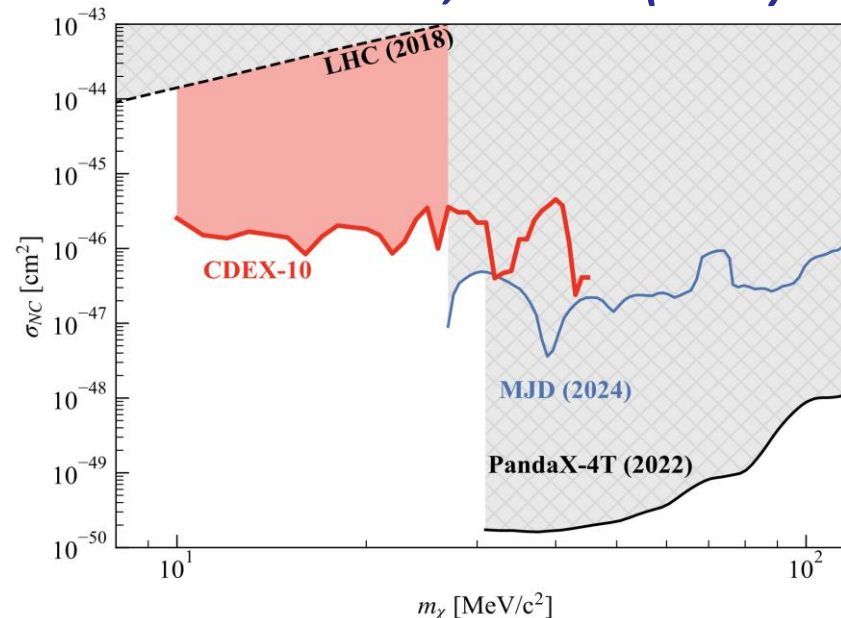
CDEX achieves the **lowest DM mass reach (10 MeV)** among direct detection experiments to date

- **Limits on Electron Absorption Cross-Section ($\sigma_e v_\chi$):**

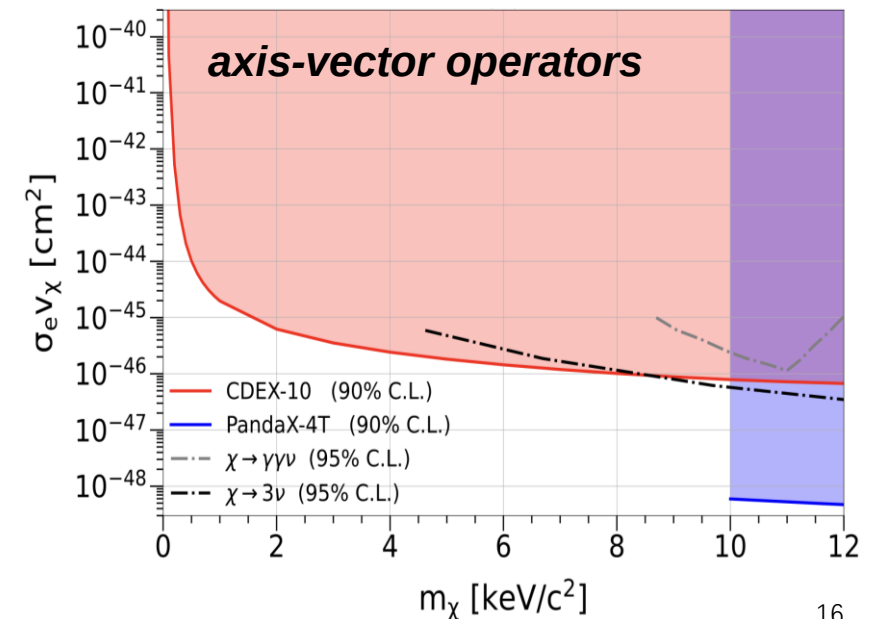
For vector and axis-vector operators: **New Experiment results for $m_\chi = 0.1 \sim 10$ keV**



PRL 129, 221802 (2022)



arXiv:2404.09793

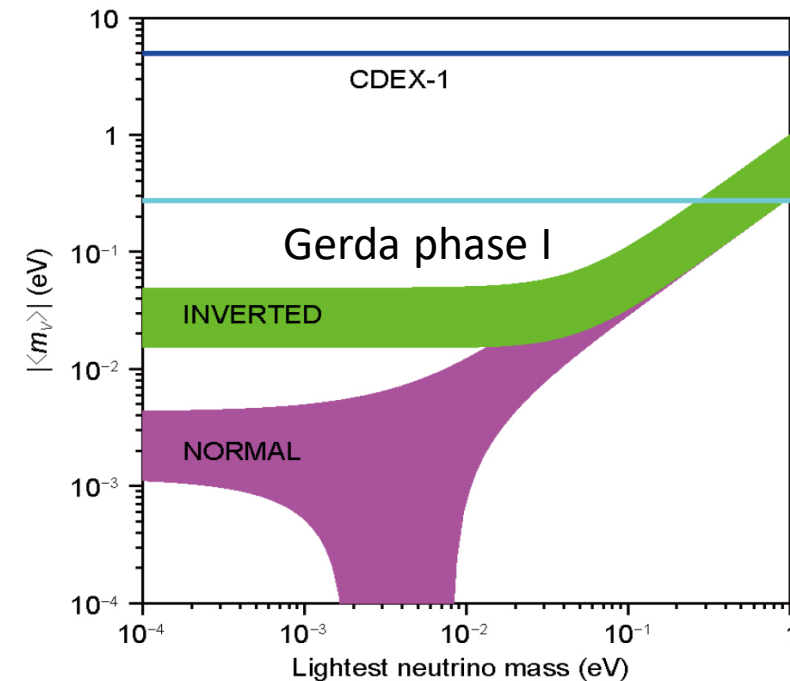
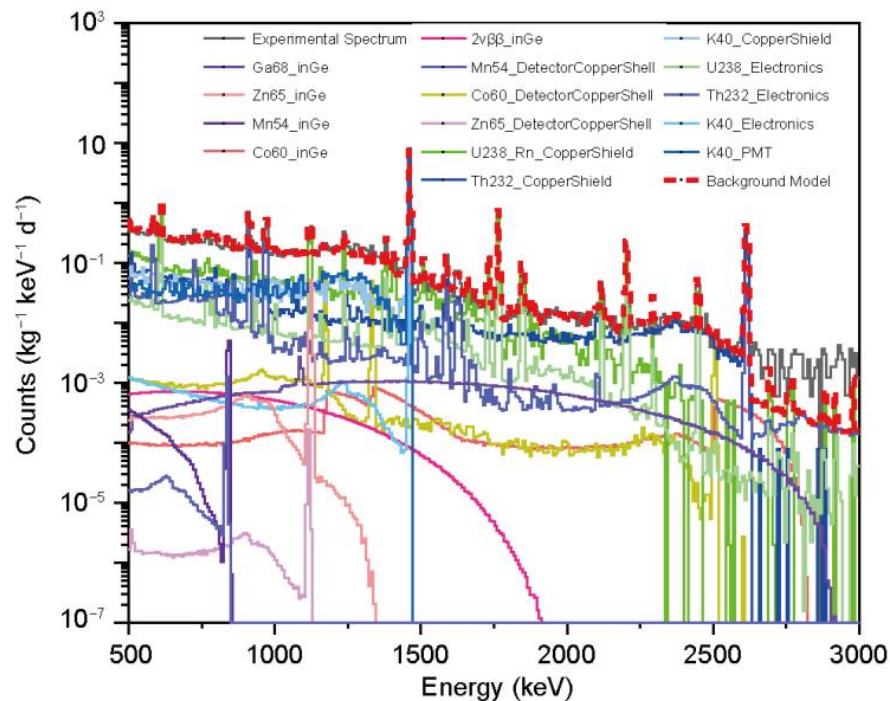


First $0\nu\beta\beta$ result from CDEX



- 2017: 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.

Science China PMA 60, 071011 (2017)

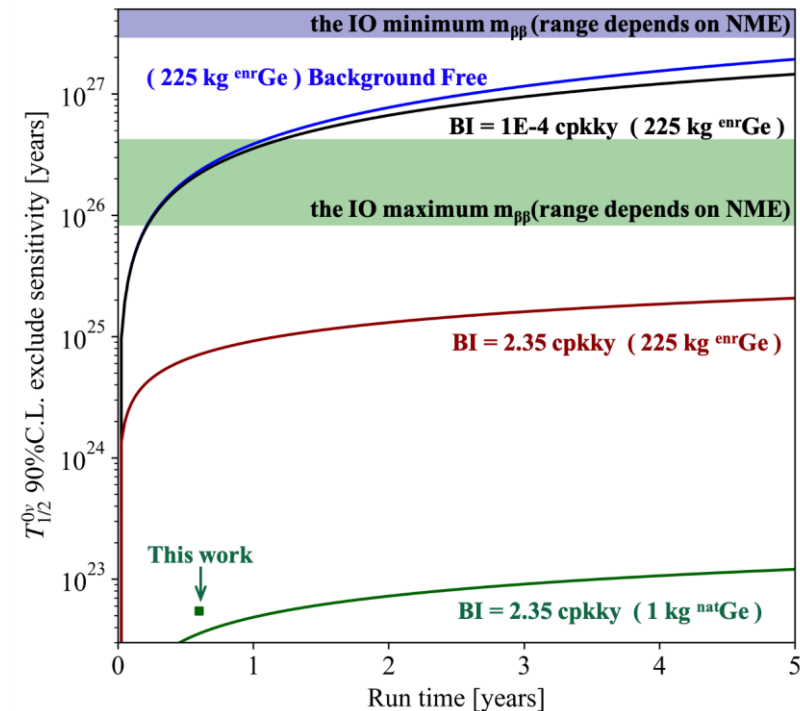
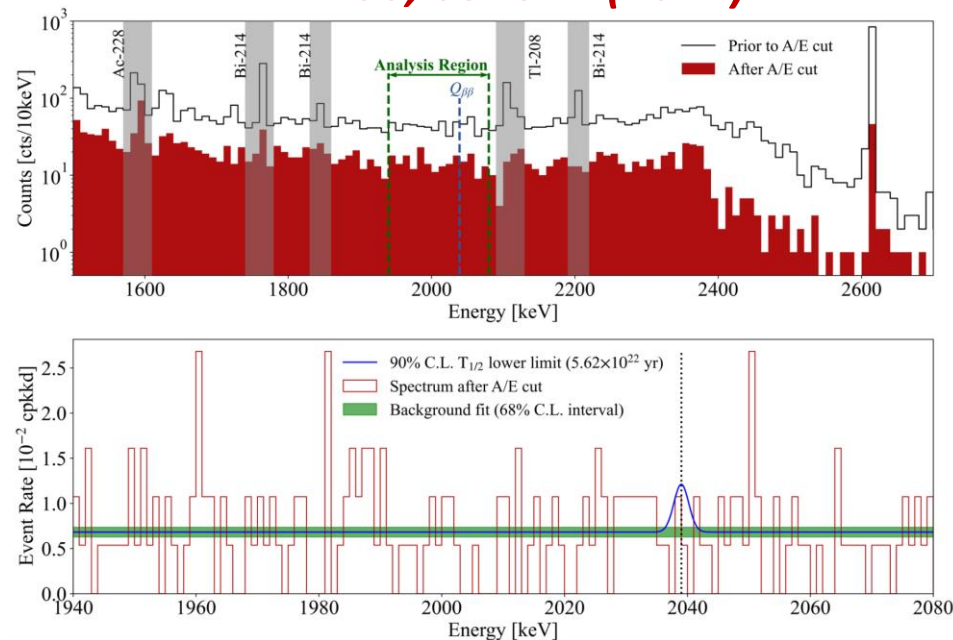


New $0\nu\beta\beta$ result from CDEX



- 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.

PRD 106, 032012 (2022)

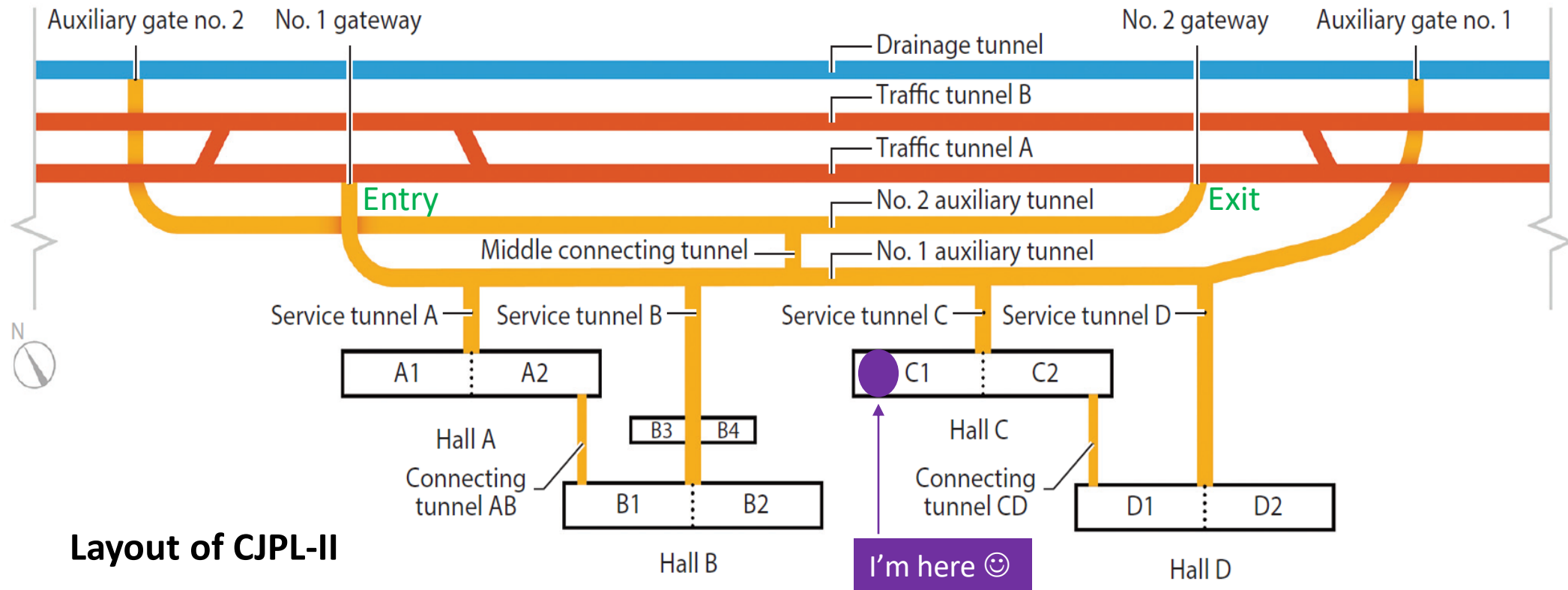


Future Plan – New location



- CJPL-I to CJPL-II

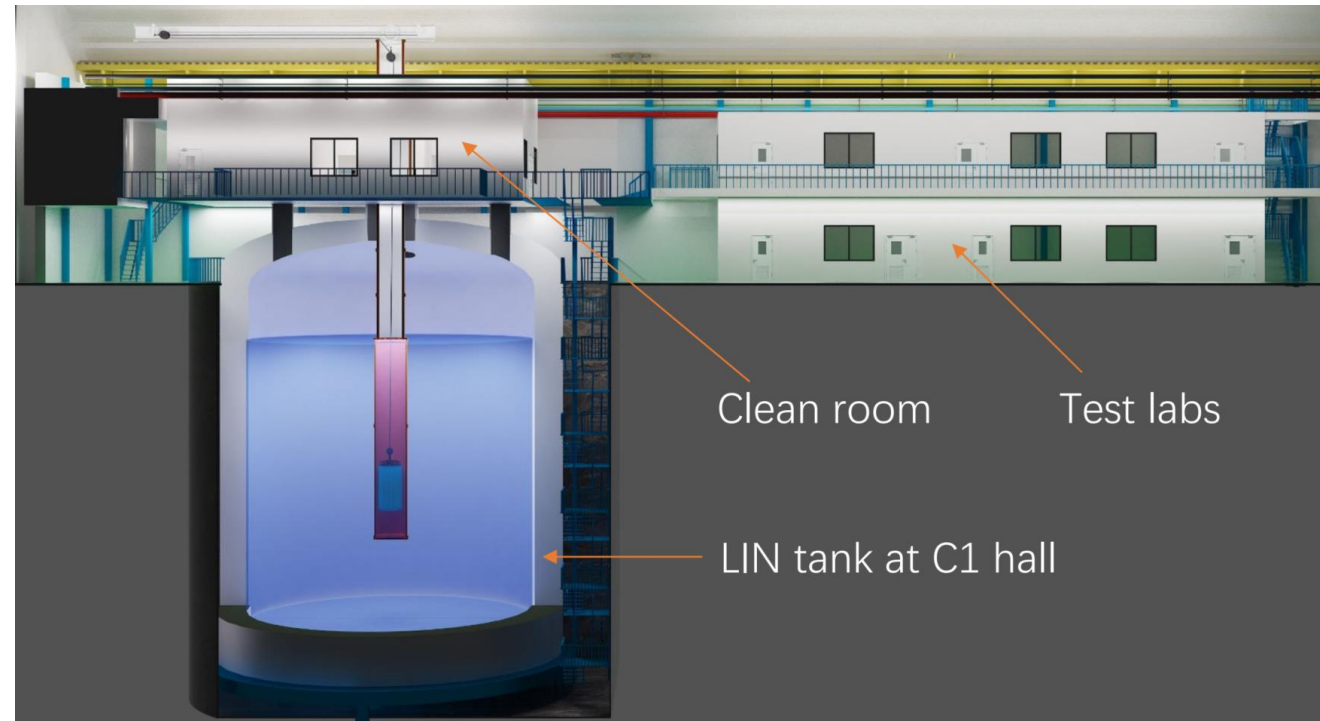
- Volume: 4000 m³ to 300,000 m³;
- 1 main hall (6.5x6.5x42m) to 8 main halls (14x14x60m each);
- Additional pit for next-generation CDEX;



Future Plan - CDEX @CJPL-II



- Prepare for HPGe experiment in Hall C1 @ CJPL-II
- 1725m³ liquid nitrogen, shielding and cooling system (inner: $\phi 13\text{m} \times H13\text{m}$)
- Inner bkg level: $<10^{-4}$ cpkkd@1keV, $<10^{-6}$ cpkkd@2MeV
- 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



Future Plan - CDEX @CJPL-II



- Construction of LN₂ tank has completed at end of 2019
- A new steel working platform has been constructed in October 2022
- Liquid nitrogen filling is expected to complete at the end of 2024



CJPL-II C1 hall



LIN tank

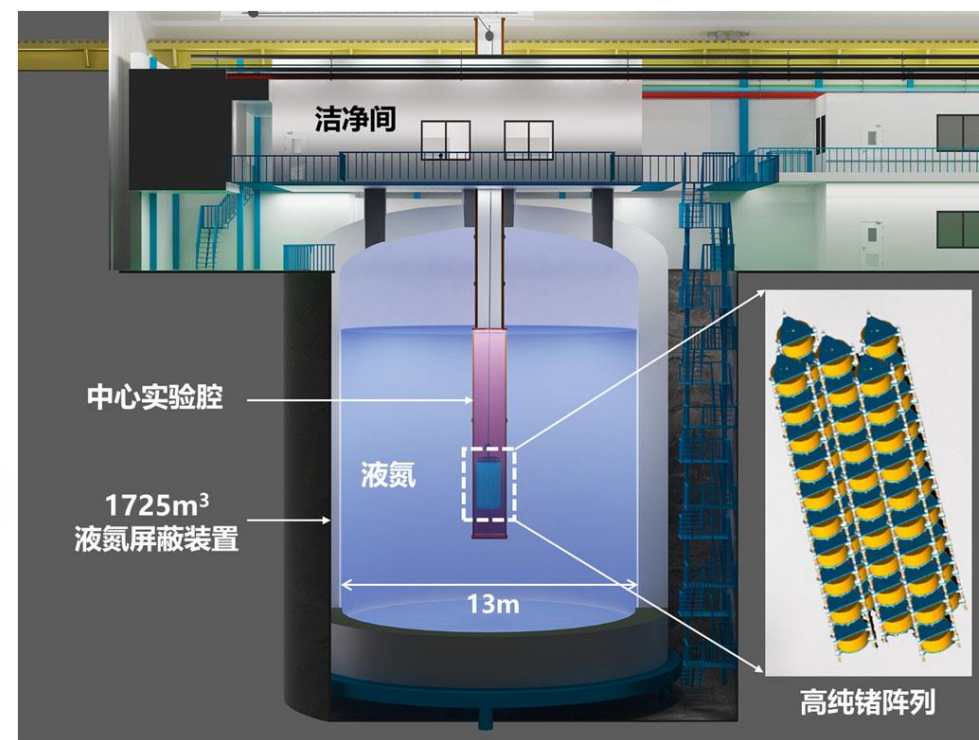
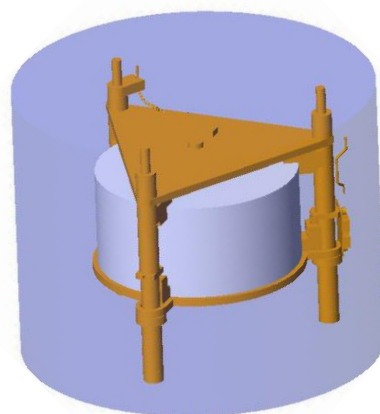
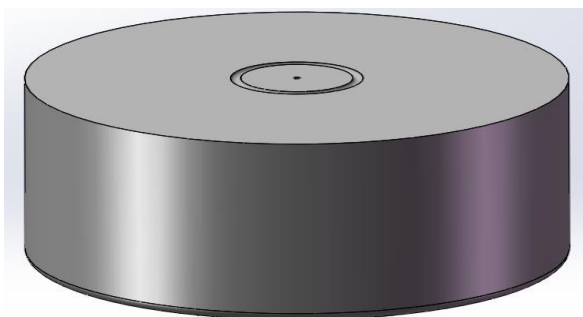


Clean room above LIN tank

CDEX-50



- **Ge detectors** array directly immerse into **LN₂** for cooling and shielding
- Detector type: BEGe + PPCGe (present)
- Composed of **5 strings, 10 detectors/string**
- target mass (Ge) reaches ~50kg

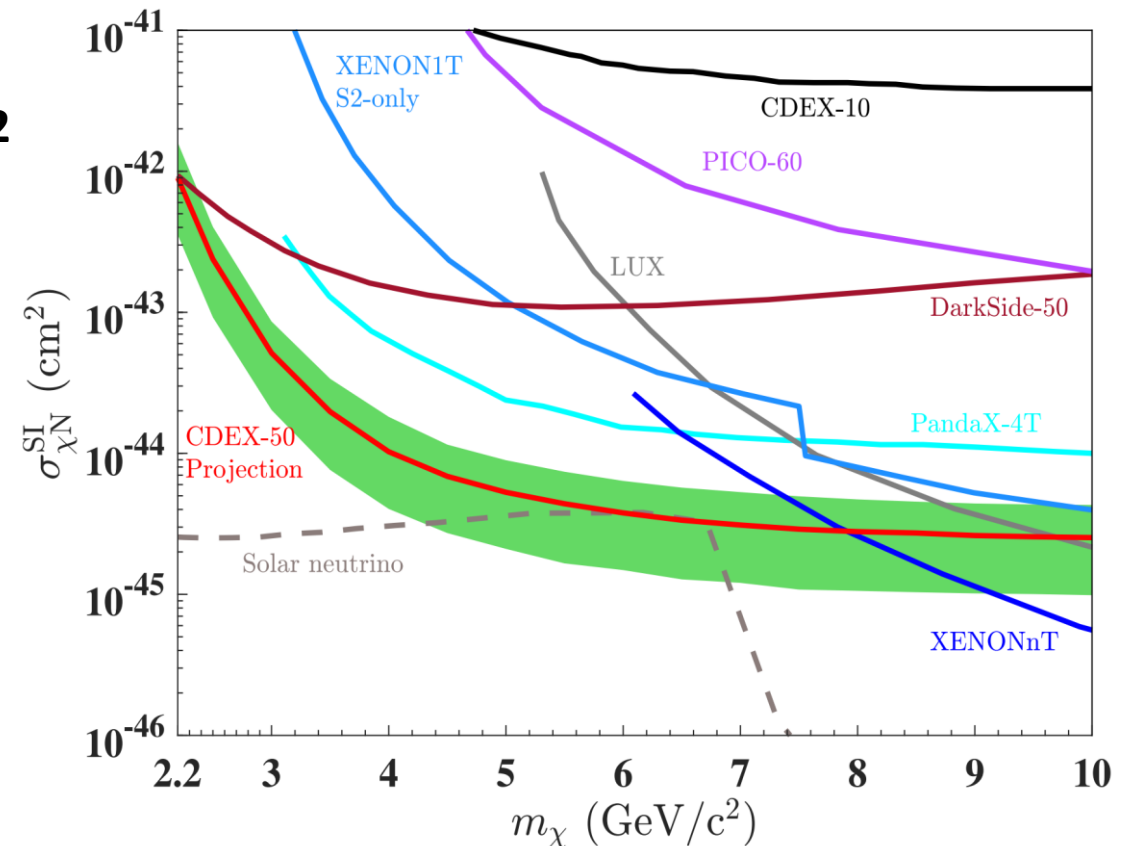


CDEX-50 Projected sensitivity



- Bkg level: **<0.01 cts/(keV·kg·day) @1 keV**
- Energy threshold for data analysis: **160 eV**
- Exposure reaches **~50 kg·year**
- WIMP SI sensitivity reaches **10^{-44} cm^2**
- **Multi physics channel analysis:**
 - axion
 - dark photon
 - ...

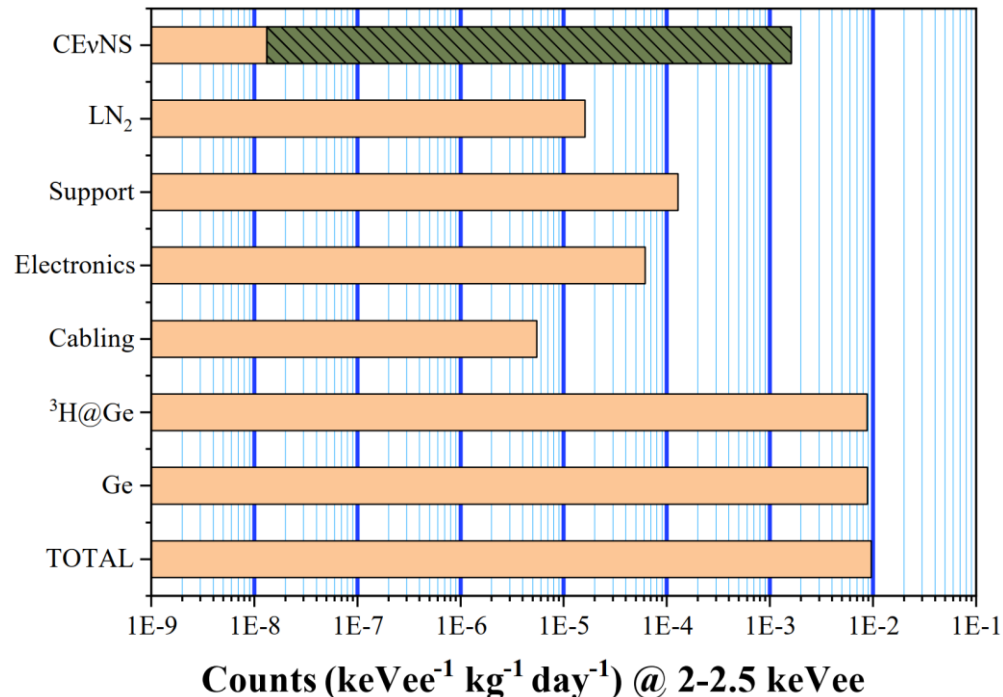
JCAP 07 (2024) 009



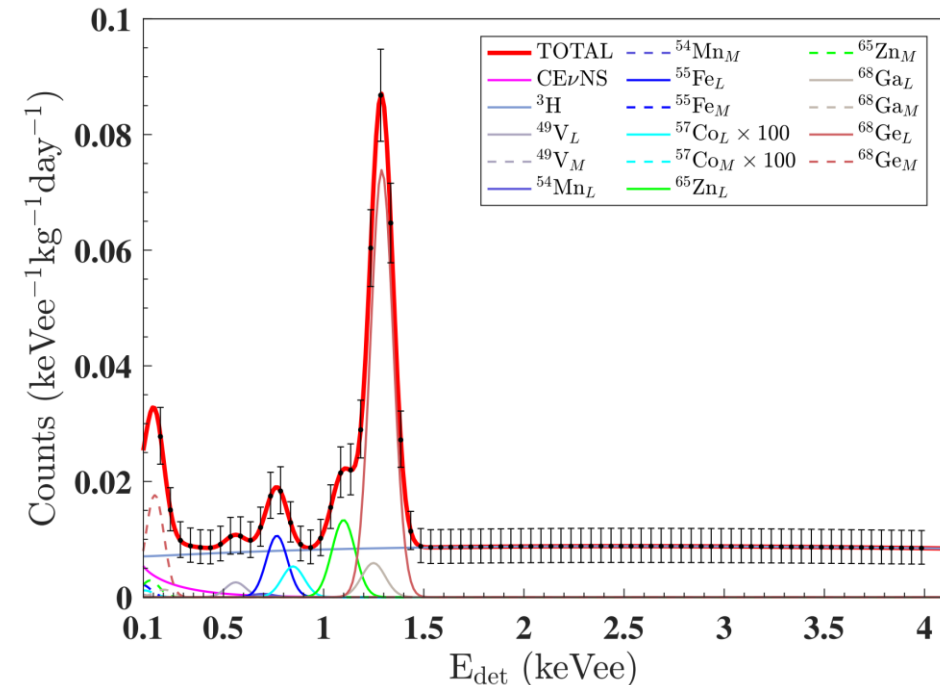
CDEX-50 Background Model and Simulation



- Bkg level: **<0.01 cts/(keV·kg·day) @1 keV** JCAP 07 (2024) 009
- Mainly comes from the ^3H and cosmogenic radionuclides in crystal
- Contribution from **CEvNS** and **M-shell X-rays** should be well understood



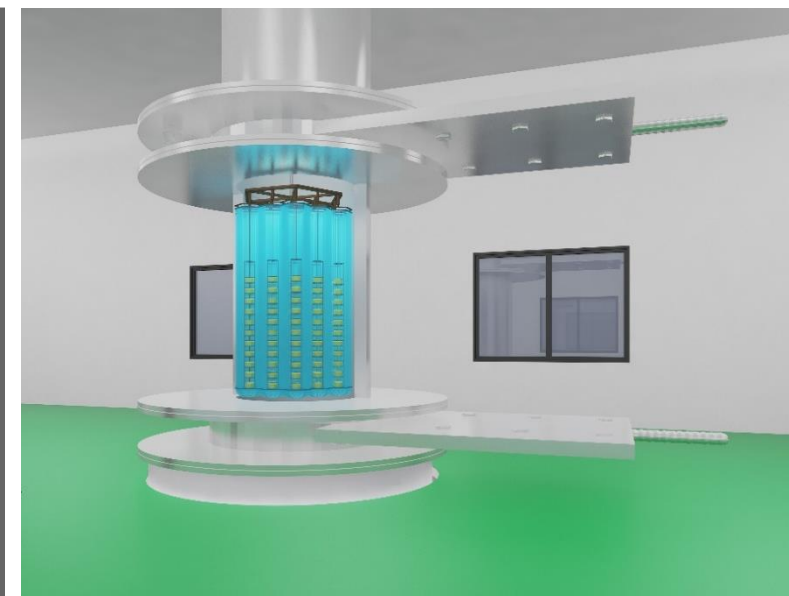
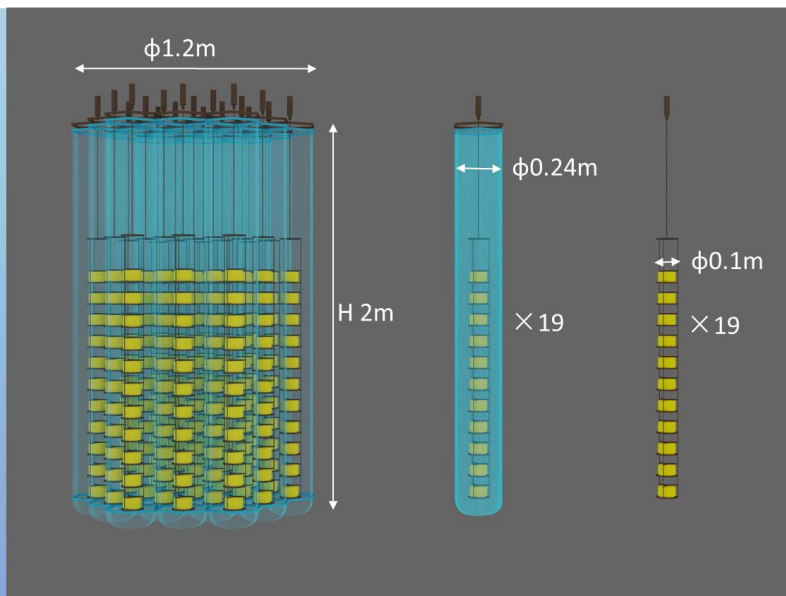
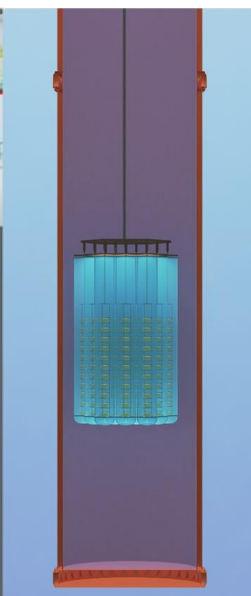
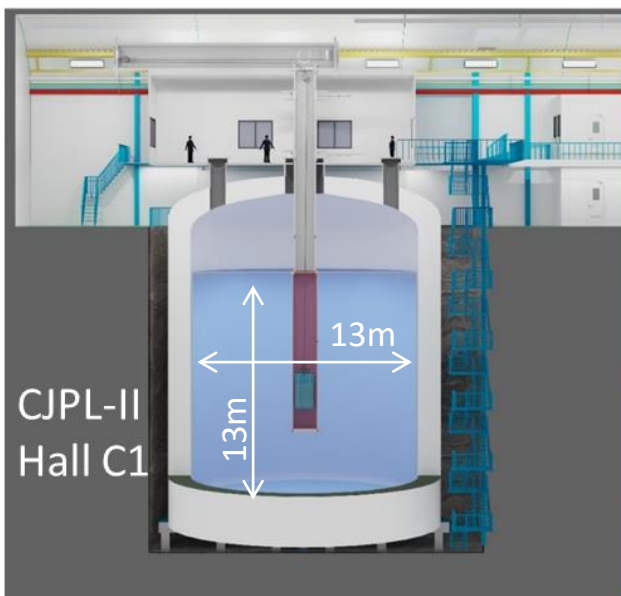
 contribution of CEvNS in 0.16–0.5 keVee



CDEX-300v Overview



- LN_2 tank shared with CDEX-50, in Hall C @ CJPL-II
- Reentrant tube containing LAr submerged in LN_2
- Ge detector array immersed in LAr (veto) tube
- Ge array divided into 19 strings (10-11 det/string, 200 det. in total $\sim 225\text{kg}$)
- Top clean room for Ge detector and fiber installation



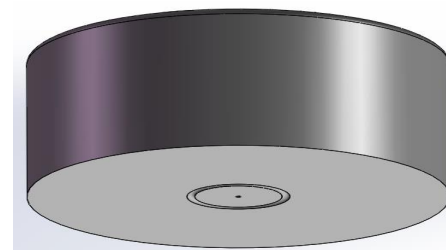
1725 m³ Liquid Nitrogen

Ge detectors

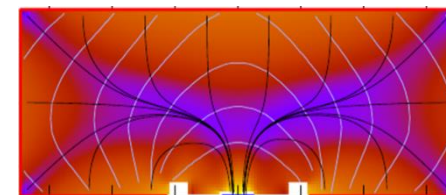


- **Enriched BEGe (Baseline)**

- Mass: ~ 1.12 kg; Ge-76 $> 86\%$
- Size: $\phi 80 \times 40$ mm
- Dead layer: 0.6 mm
- FWHM : $< 0.15\%$ @2MeV (~ 2.5 keV)
- Commercial / Home-made

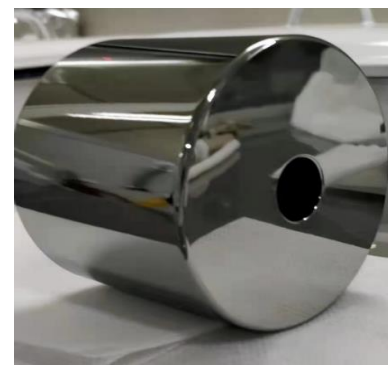


BEGe: Broad Energy Germanium

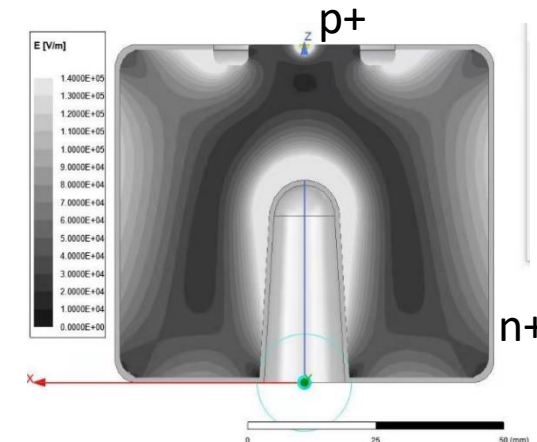


- **ICPC (optional)**

- Mass: ~ 2 kg
- Size: $\phi 80 \times 80$ mm
- Dead layer: 0.6 mm
- Home-made
- Bigger Detector $\rightarrow$ Less electronics and structure material (background)



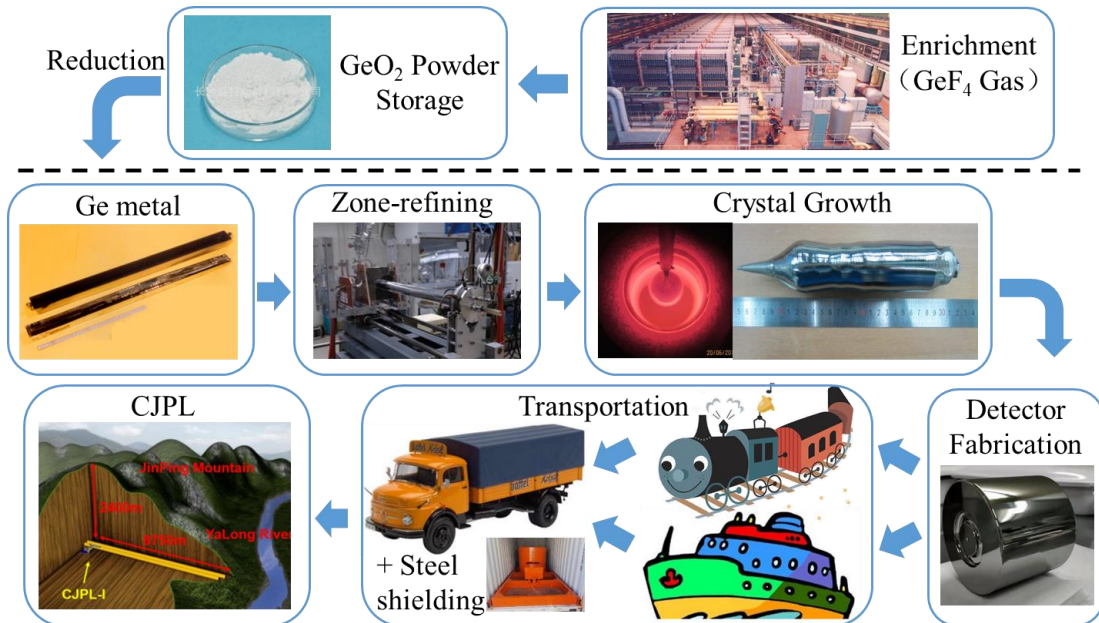
ICPC: Inverted Coaxial Point Contact



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



Enriched Ge detector test



- First batch Enriched Ge detectors are under testing in CJPL-I
- Ge detector + CMOS ASIC Front-end Electronics test is ongoing
- Bkg in large LN₂ tank hoped to be confirmed at the beginning of 2025

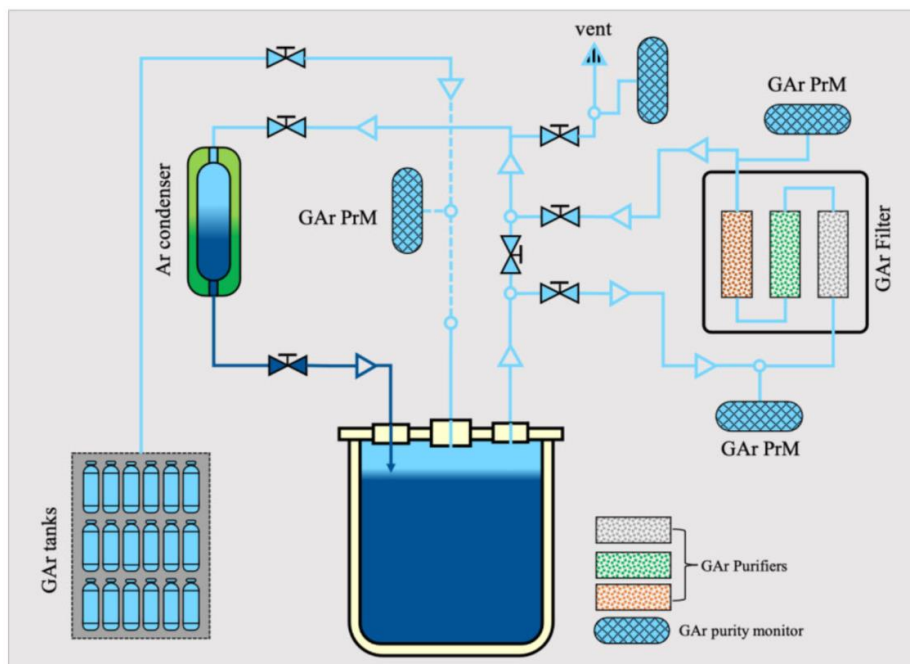


LAr Test Facility

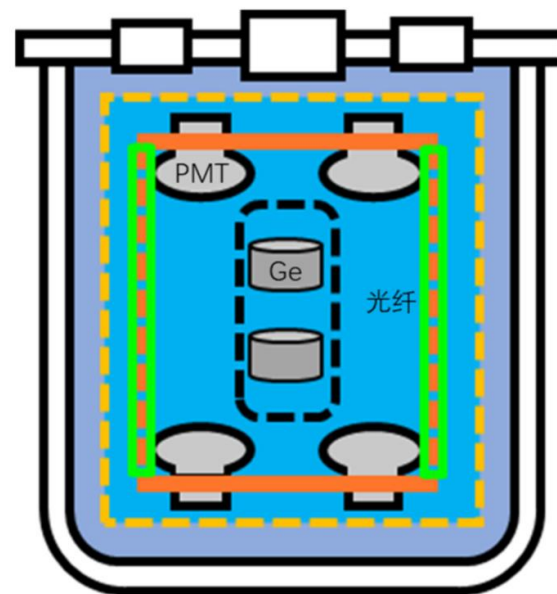


- S1: Operating & Purifying 200L LAr in a closed cycle
- S2: Studying light yield / transmission of LAr in different impurity levels
- S3: Deploying Ge detectors to test veto efficiency

S1



S2+S3



Prototype LAr test facility



Summary



- CDEX: unique advantages of Ge detectors for light DM search at CJPL;
- Recently CDEX has made great progress, published many leading results for low mass DM, with multi physics channels analysis and different DM candidates;
- CDEX-50 has started and will locate in Hall C1 of CJPL-II;
- Many key technologies R&D are ongoing and have made very good progress.

Summary



- CDEX: unique advantages of Ge detectors for light DM search at CJPL;
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Thanks for your attention!

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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
China Jinping Underground Laboratory
清华大学·二滩水电开发有限责任公司

<http://cjpl.tsinghua.edu.cn>

CDEX-300v projected results



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

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
$T_{1/2}$	$>1\times 10^{27}\text{y}$
$m_{\beta\beta}$	28.5~68.0 meV