Status and prospects of CDEX

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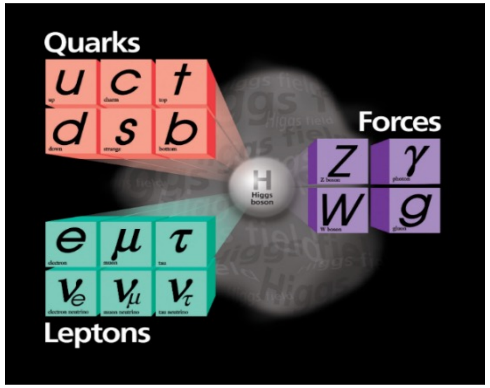
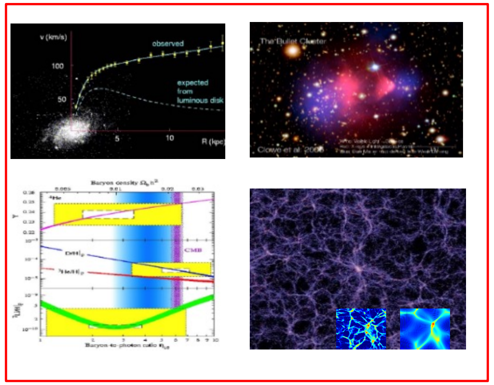
Outline

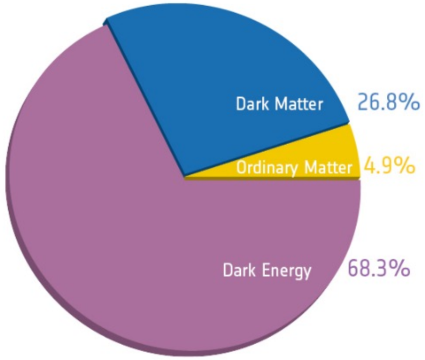
- Scientific Motivations
- Introduction to CDEX
- Recent status of CDEX
- Future plan of CDEX@CJPL-II
- Summary

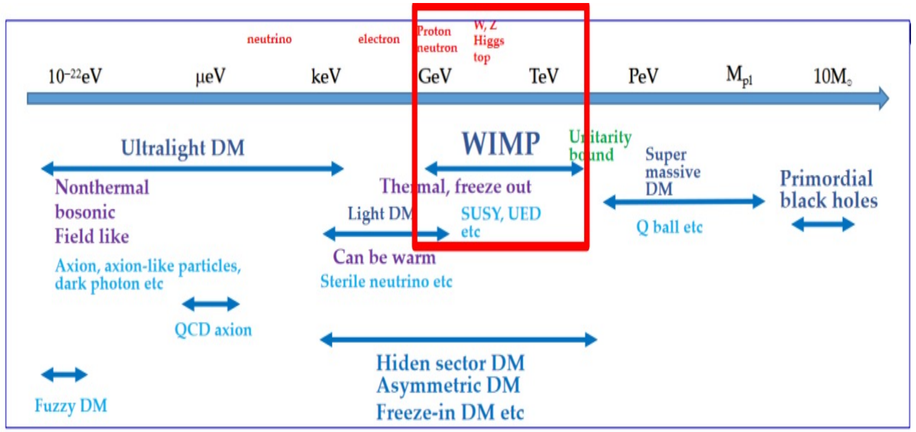
Dark Matter in Cosmology

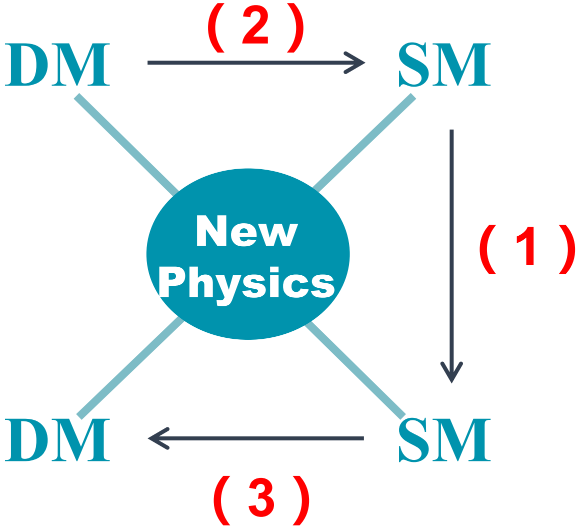
CDEX



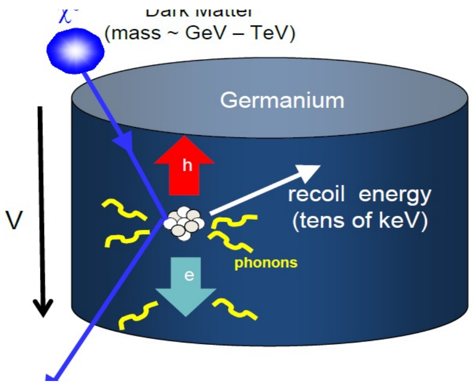




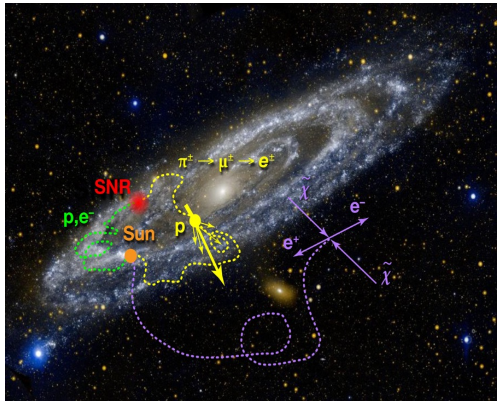




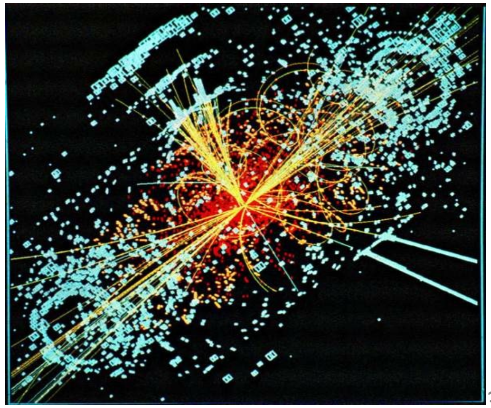
(1) Direct



(2) Indirect



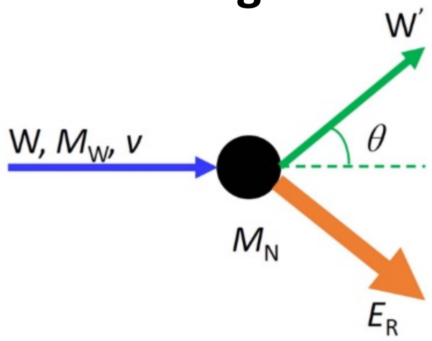
(3) Accelerator



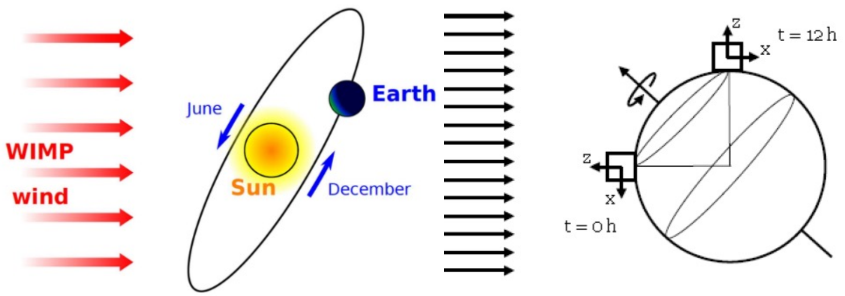
Direct detection of WIMPs---Principles

CDEX

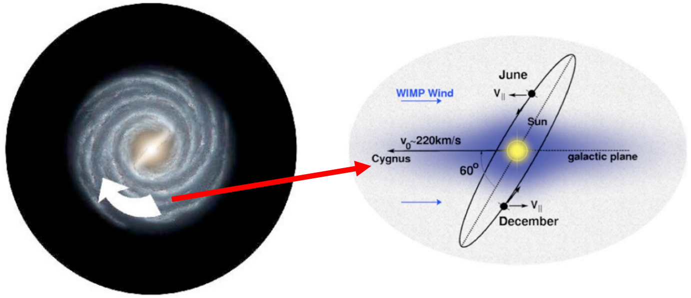
Elastic Scattering

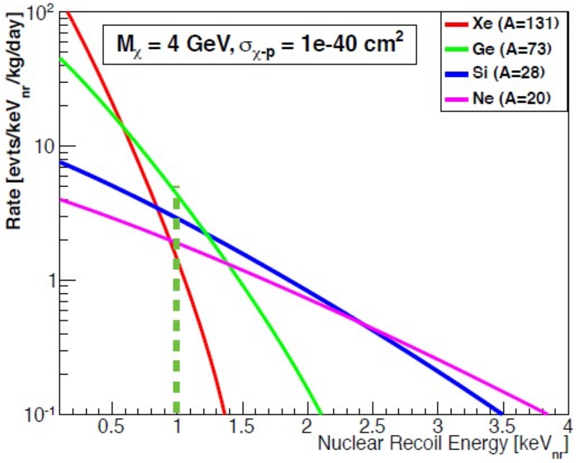


Annual/ Diurnal Modulation

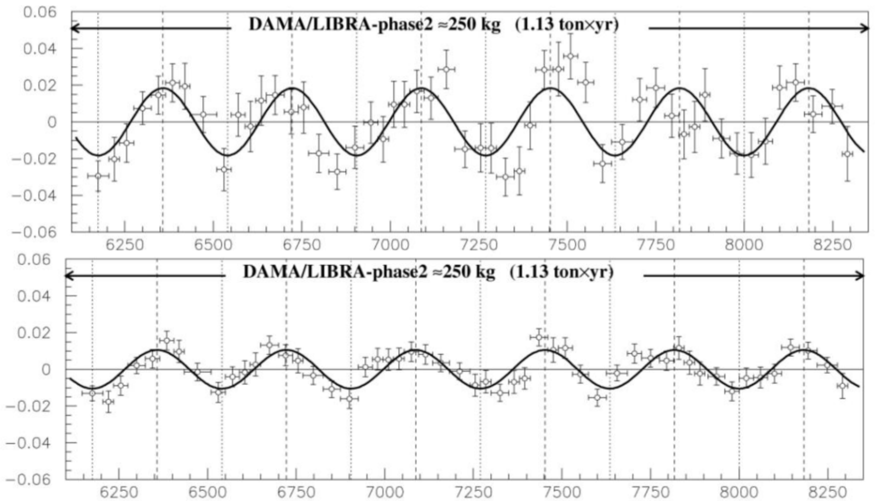


Track and Direction

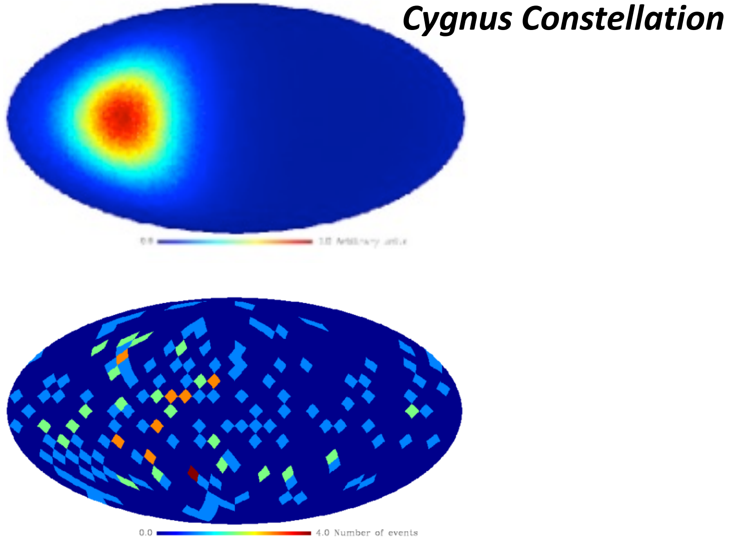




- Lower Background
- Lower Energy threshold
- Long-time stability



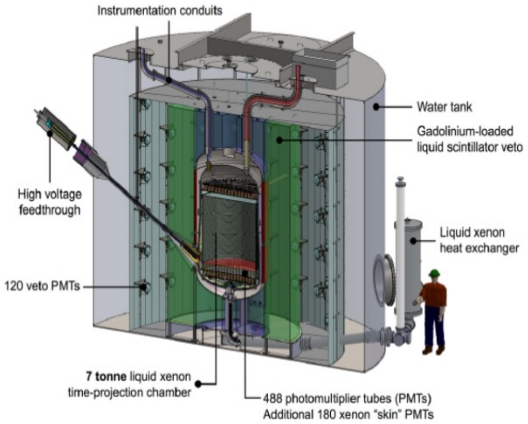
- Lower Background
- Long-time stability



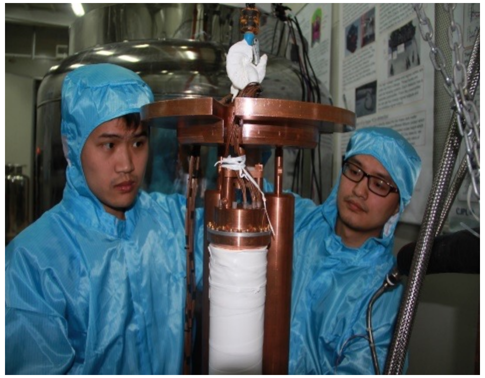
- Angular Resolution (<20°)

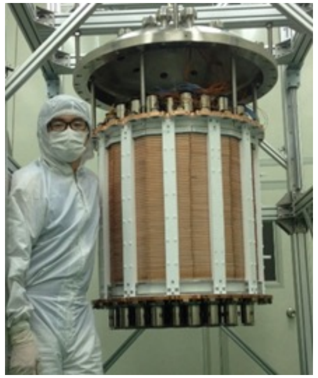
Key technologies for DM experiments

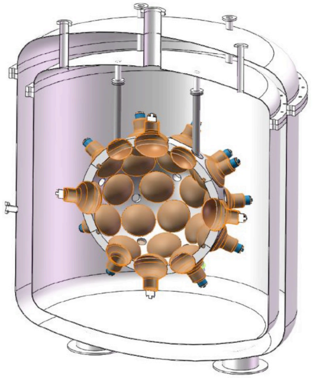
International



China







Less Than 10GeV
Ge——CDEX

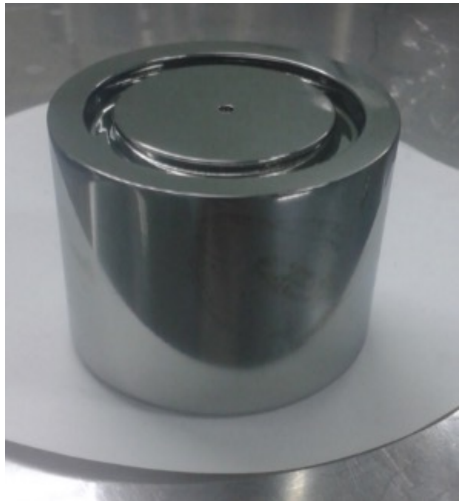
10~500GeV
LXe——PandaX

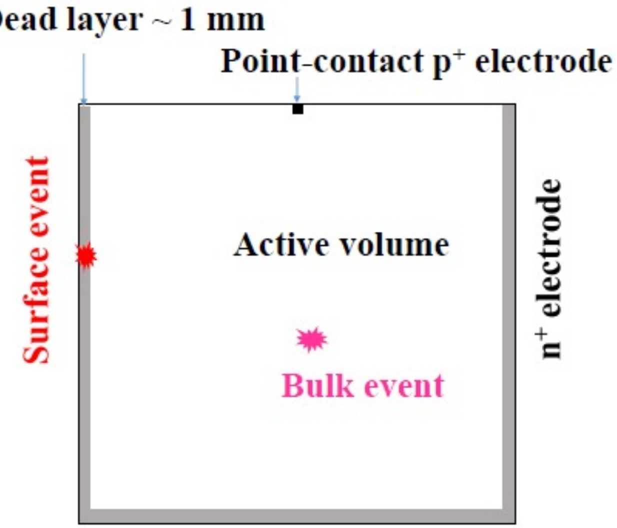
100~1000GeV
LAr——IHEP

DM Detection based on Ge Array

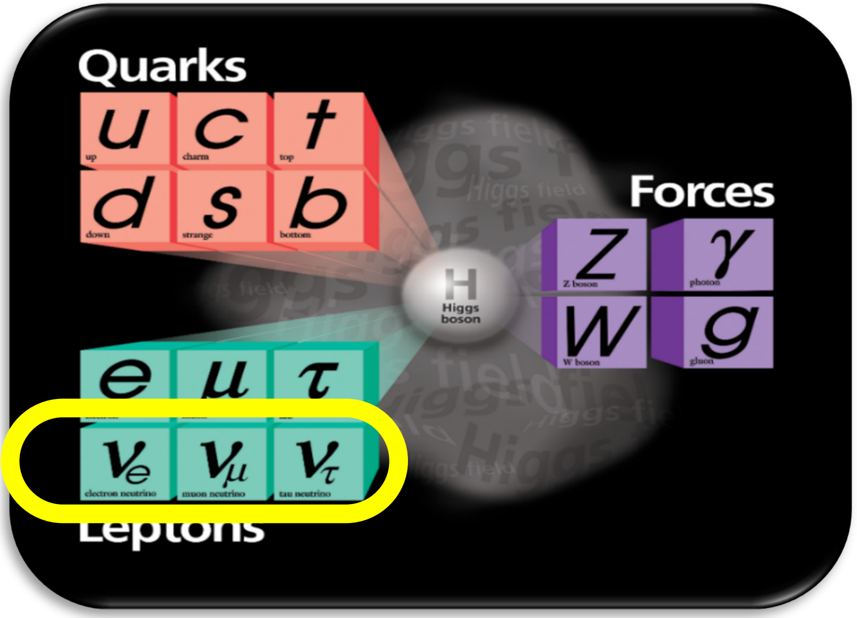
CDEX

- High purity Ge crystal： >12N;
- High Efficiency: “Source”=“Target”;
- Ultra-low Energy threshold and Excellent E_R : PPCGe ~100eV;
- Modular and easy scale-up technically;
- Powerful background rejection: multiplicity, timing, PSD,…





0νββ---Scientific Motivations



Takaaki Kajita

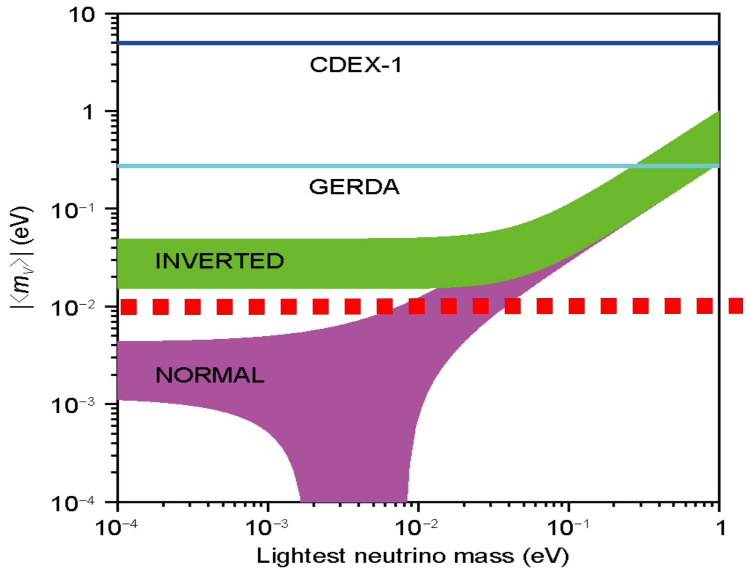
Arthur B. McDonald

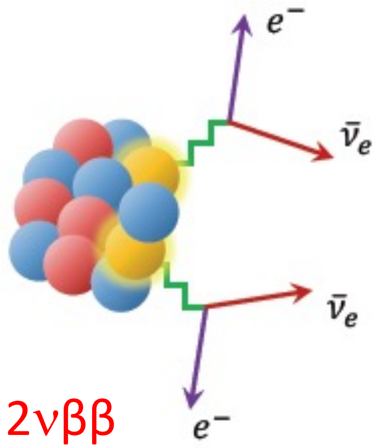
"For the discovery of neutrino oscillations, which shows that neutrinos have mass"

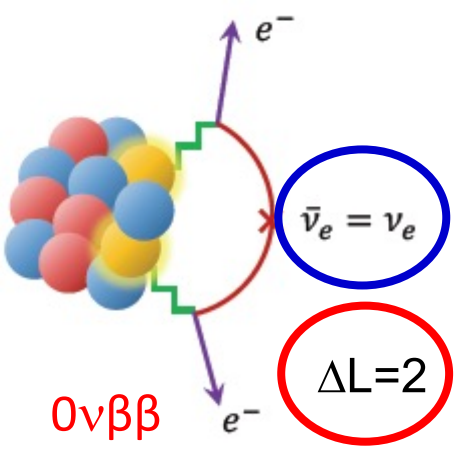
- The discovery of neutrino oscillation in 1998 is a strong indication of new physics beyond SM.
- Studies of neutrino properties: the forefront in particle physics, and intensely pursued by the major research groups.
- One of the fundamental nature of neutrinos is: They are **Majorana or Dirac particles?**
- **Neutrino mass hierarchy, neutrino mass, …**

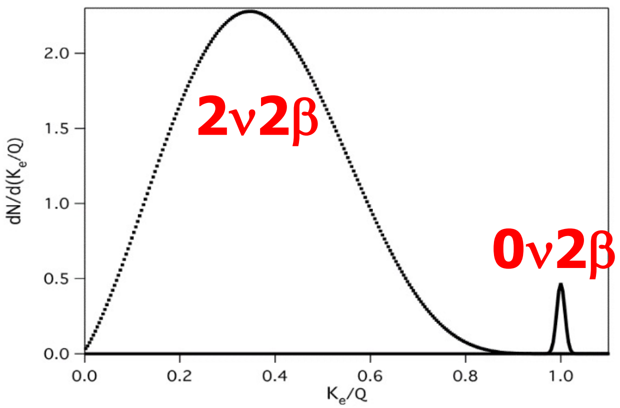
0νββ experiment

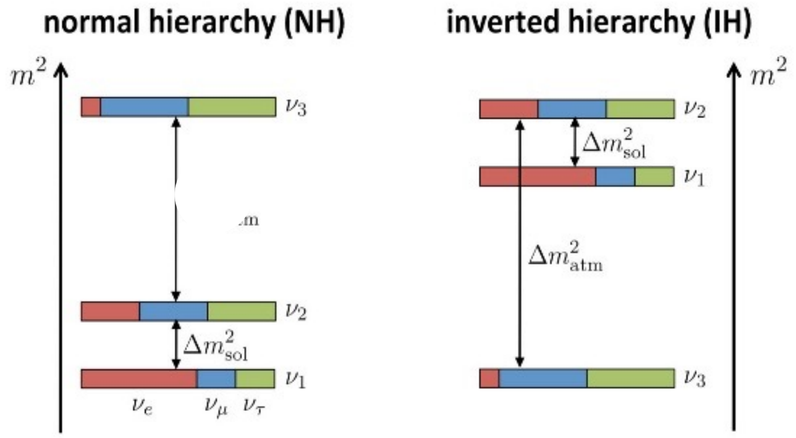
- 0νββ experiment: the most sensitive way to probe the Majorana-Dirac nature of the neutrinos.
- ν mass ordering measured by 0νββ experiment if the sensitivity of $m_{\beta\beta}$ reaches ~10meV.
- If there is a positive signature of 0νββ event, it will be a lepton number violation process. A scientific discovery of historical importance if it is true.











0νββ experiment principle

CDEX

- In order to get $m_{\beta\beta}$, need to experimentally measure $T_{1/2}^{0\nu}$.
- The recent sensitivities: $m_{\beta\beta}$ <100meV.
- **BI, ΔE, M, t, A, ε** are important parameters for 0νββ experiments.
- Signature: Energy peak at known Q value of transitions.

$$T_{1/2}^{0\nu} = \left(G\,|\mathcal{M}|^2 \langle m_{\beta\beta}\rangle^2\right)^{-1} \simeq 10^{27-28}\left(\frac{0.01\ \text{eV}}{\langle m_{\beta\beta}\rangle}\right)^2 \text{year}$$

Phase space factor　NME

$$T_{1/2}^{0\nu} \propto \varepsilon \cdot A \cdot \sqrt{\frac{M \cdot t}{BI \cdot \Delta E}}$$

Target mass　Time

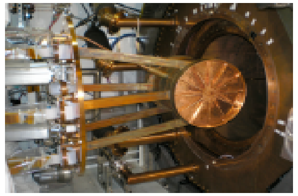
Detection Efficiency　Isotope abundance　Background　Energy resolution

Isotope	$Q_{\beta\beta}$ Energy (KeV) (E_{γ}^{bk}=2615 KeV)	Natural abundance (%)
$^{48}Ca \rightarrow ^{48}Ti$	4271	0.187
$^{76}Ge \rightarrow ^{76}Se$	2039	7.8
$^{82}Se \rightarrow ^{82}Kr$	2995	9.2
$^{96}Zr \rightarrow ^{96}Mo$	3350	2.8
$^{100}Mo \rightarrow ^{100}Ru$	3034	9.6
$^{124}Sn \rightarrow ^{124}Te$	2.228	5.64
$^{130}Te \rightarrow ^{130}Xe$	2.528	34.5
$^{136}Xe \rightarrow ^{136}Ba$	2.479	8.9
$^{150}Nd \rightarrow ^{150}Sm$	3.367	5.6

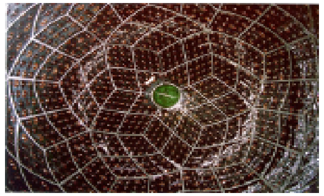
0νββ experiments

CUORE

EXO200

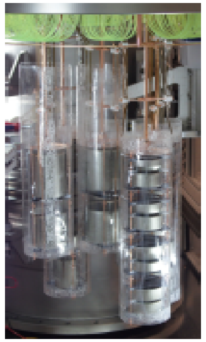


KamLAND Zen

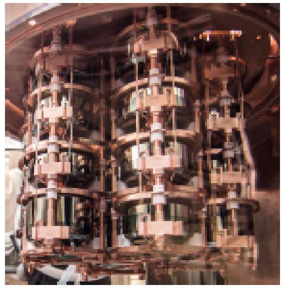


Collaboration	Isotope	Technique	mass (0νββ isotope)	Status
CANDLES	Ca-48	305 kg CaF_2 crystals - liq. scint	0.3 kg	Construction
CARVEL	Ca-48	$^{48}CaWO_4$ crystal scint.	~ ton	R&D
GERDA I	Ge-76	Ge diodes in LAr	15 kg	Complete
GERDA II	Ge-76	Point contact Ge in LAr	31	Operating
MAJORANA DEMONSTRATOR	Ge-76	Point contact Ge	25 kg	Operating
LEGEND	Ge-76	Point contact with active veto	~ ton	R&D
NEMO3	Mo-100 Se-82	Foils with tracking	6.9 kg 0.9 kg	Complete
SuperNEMO Demonstrator	Se-82	Foils with tracking	7 kg	Construction
SuperNEMO	Se-82	Foils with tracking	100 kg	R&D
LUCIFER (CUPID)	Se-82	ZnSe scint. bolometer	18 kg	R&D
AMoRE	Mo-100	$CaMoO_4$ scint. bolometer	1.5 - 200 kg	R&D
LUMINEU (CUPID)	Mo-100	$ZnMoO_4$ / Li_2MoO_4 scint. bolometer	1.5 - 5 kg	R&D
COBRA	Cd-114,116	CdZnTe detectors	10 kg	R&D
CUORICINO, CUORE-0	Te-130	TeO_2 Bolometer	10 kg, 11 kg	Complete
CUORE	Te-130	TeO_2 Bolometer	**206 kg**	Operating
CUPID	Te-130	TeO_2 Bolometer & scint.	**~ ton**	R&D
SNO+	Te-130	0.3% ^{nat}Te suspended in Scint	**160 kg**	Construction
EXO200	Xe-136	Xe liquid TPC	79 kg	Operating
nEXO	Xe-136	Xe liquid TPC	**~ ton**	R&D
KamLAND-Zen (I, II)	Xe-136	2.7% in liquid scint.	**380 kg**	Complete
KamLAND2-Zen	Xe-136	2.7% in liquid scint.	**750 kg**	Upgrade
NEXT-NEW	Xe-136	High pressure Xe TPC	5 kg	Operating
NEXT-100	Xe-136	High pressure Xe TPC	100 kg - **ton**	R&D
PandaX - III	Xe-136	High pressure Xe TPC	~ ton	R&D
DCBA	Nd-150	Nd foils & tracking chambers	20 kg	R&D

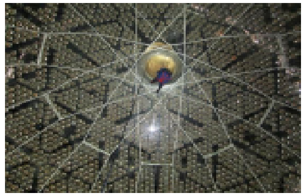
GERDA



MAJORANA



SNO+

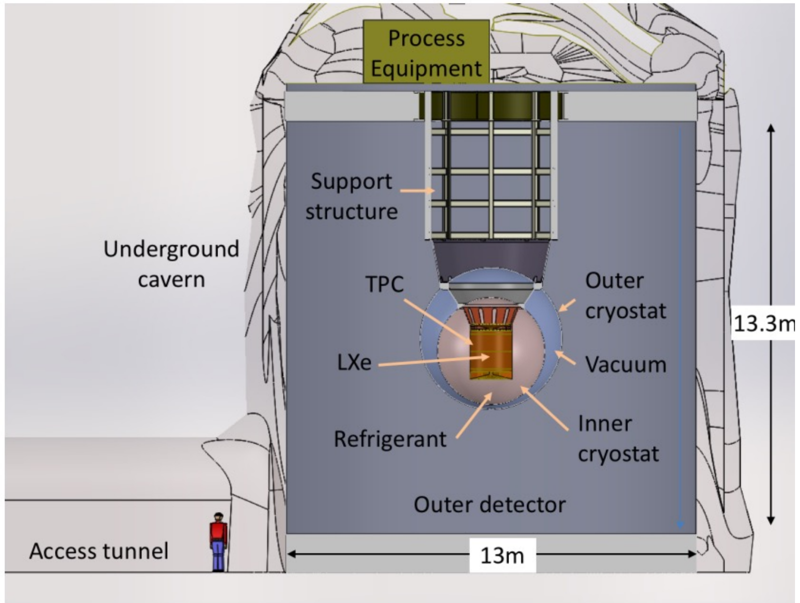


0νββ experiments

CDEX

nEXO (EnXe136)

ΔE=47keV

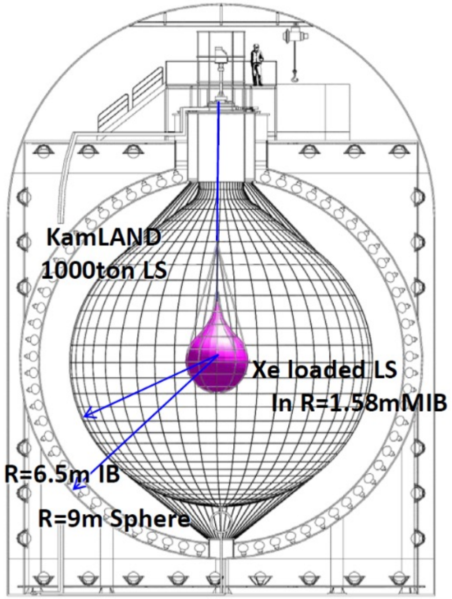


PandaX-xT (NXe)

XLZD-100T (NXe)

KamLAND-Zen (EnXe136)

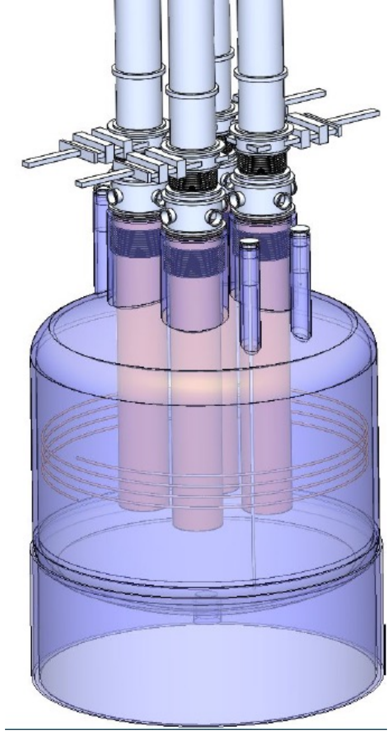
ΔE=269keV



JUNO-0vbb (EnXe136)

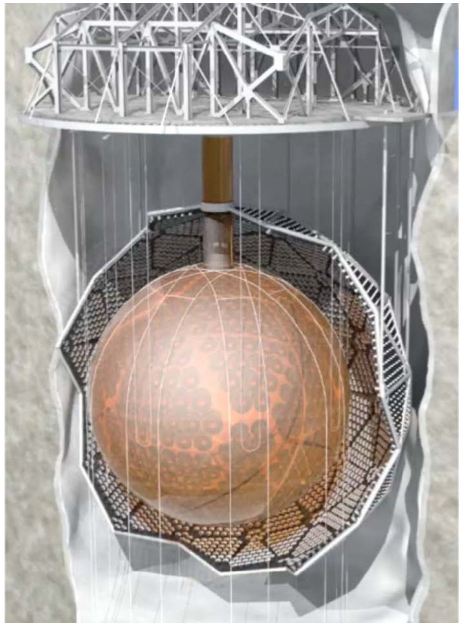
LEGEND(EnGe76)

ΔE=2.5keV



CDEX (EnGe-76)

SNO+ (Te-130)



JUNO-0vbb (NTe-130)

Sensitivities of 0νββ experiments

CDEX

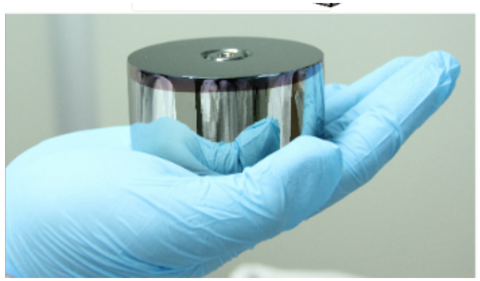
- ^{76}Ge 0νββ exp. achieved best E_R, lowest BI, w/o 2ν2β background contamination, ……
- HPGe: one of the most competitive 0νββ experiment techniques.

Collaboration	Isotope	Target mass	Exposure (kg·y)	Half life (10^{25}y)	$m_{\beta\beta}$ (meV)
GERDA	^{76}Ge	44.2 kg	127.2	> 18	< 79-180
Majorana	^{76}Ge	44.1 kg	26	> 2.7	< 200-433
KamLAND-Zen	^{136}Xe	400 kg - 750kg	~970	> 23	< 36-156
EXO-200	^{136}Xe	74.7 kg	234.1	> 3.5	< 93-286
CUORE	^{130}Te	206 kg	372.5	> 3.2	< 90-305
CUPID-Mo	^{100}Mo	4.2 kg	1.17	> 0.15	< 310-540

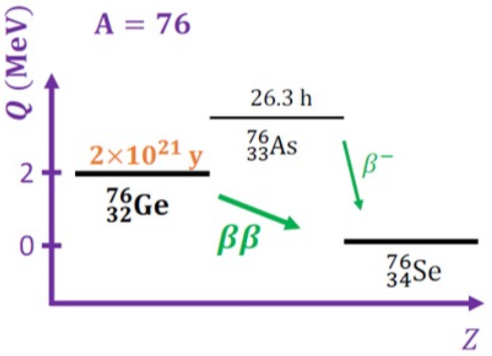
Advantages of ^{76}Ge 0νββ experiment

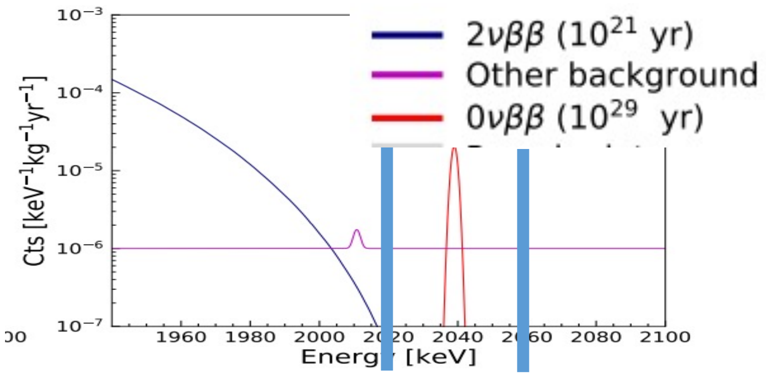
CDEX

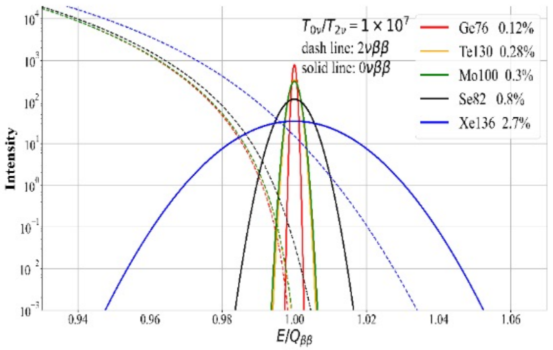
- **Excellent E_R with high $Q_{\beta\beta}$ value**: <0.12% FWHM @2039keV:
  - ✓Precisely measured Energy peak at known $Q_{\beta\beta}$ value： smoking-gun signature;
  - ✓NO irreducible 2νββ background contamination;
  - ✓suppress ambient background within narrow ROI energy window.



- **High Efficiency:** "Source"="Target" with no self-shielding needed;
- **High purity Ge crystal** >12N, **and mutual Isotopic abundance** technology: >86%;
- **Modular and easy scale-up** technically; multi-site, multi-detector configurations possible without loss of fiducial mass.







Ref:

MJD: PRL 120 132502 (2018)
CUORE: PRL 124 122501 (2020)
CUPID-Mo: EPJC 80 44 (2020)
CUPID-0: EPJC 78 734 (2018)
EXO-200: PRL 123 161802 (2019)

CDEX Collaboration

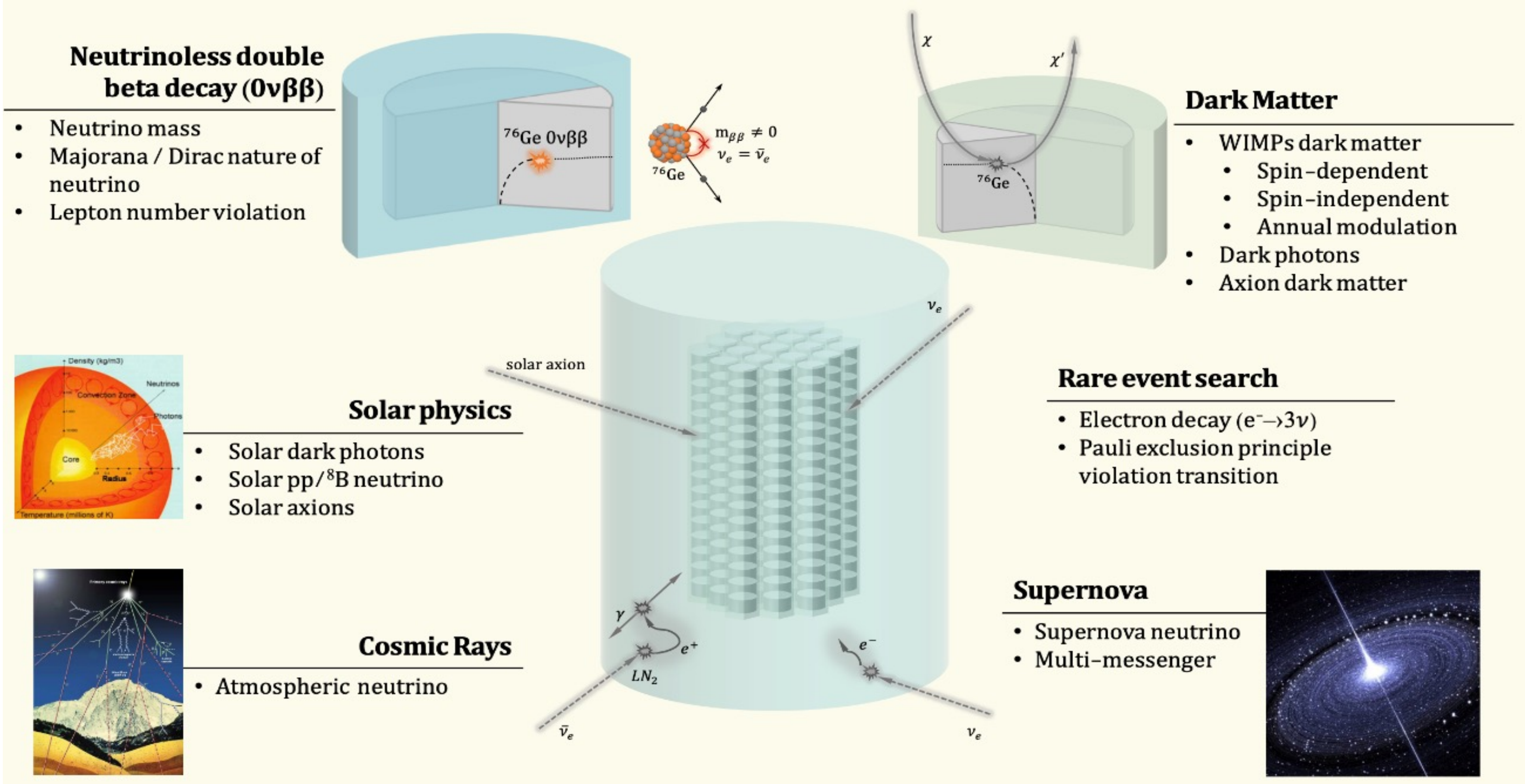
CDEX

- Established in 2009, 11 institutes, >100 members.
- $0\nu\beta\beta$ and DM experiment based on Ge detectors at CJPL.
- Many world-level DM physics results published in last 10 years.

CDEX-1	CDEX-10	CDEX-300	CDEX-1T	CDEX-10T
2009-2016	2016-2020	2021-	2028-	2035-

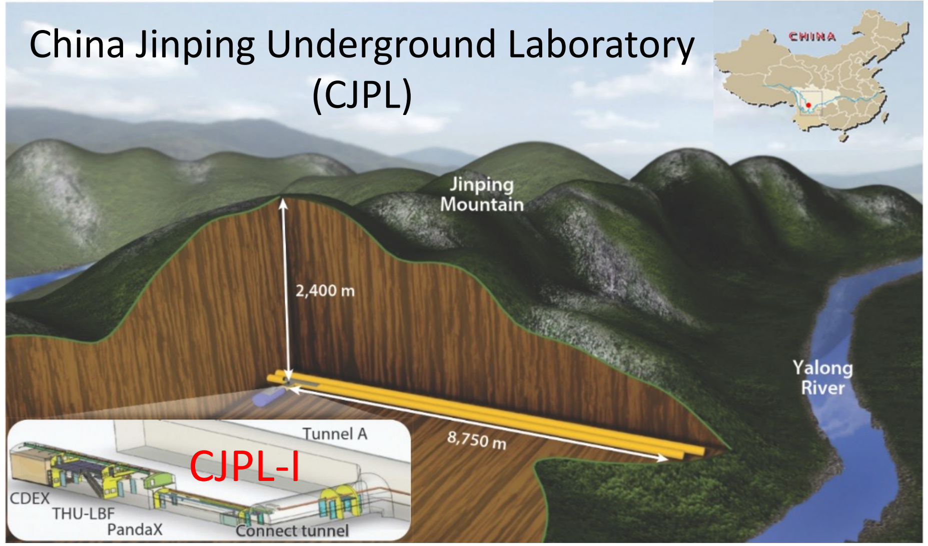
CDEX Program (Enriched-Ge Array)

CDEX

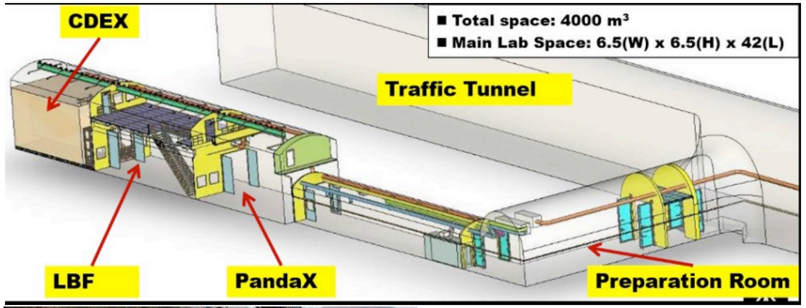


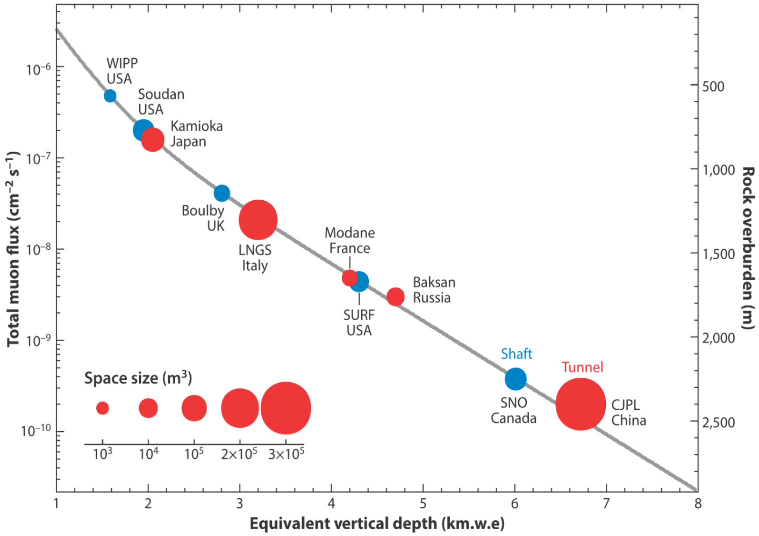
China Jinping Underground Laboratory

- World's deepest underground lab, CJPL
- Near Xichang city, Sichuan Province, Southwest China
- Constructed by Tsinghua U. and Yalong Hydropower Company in 2009-2010
- Two DM exp. (CDEX, PandaX)+LBF(radio-assay)operated now

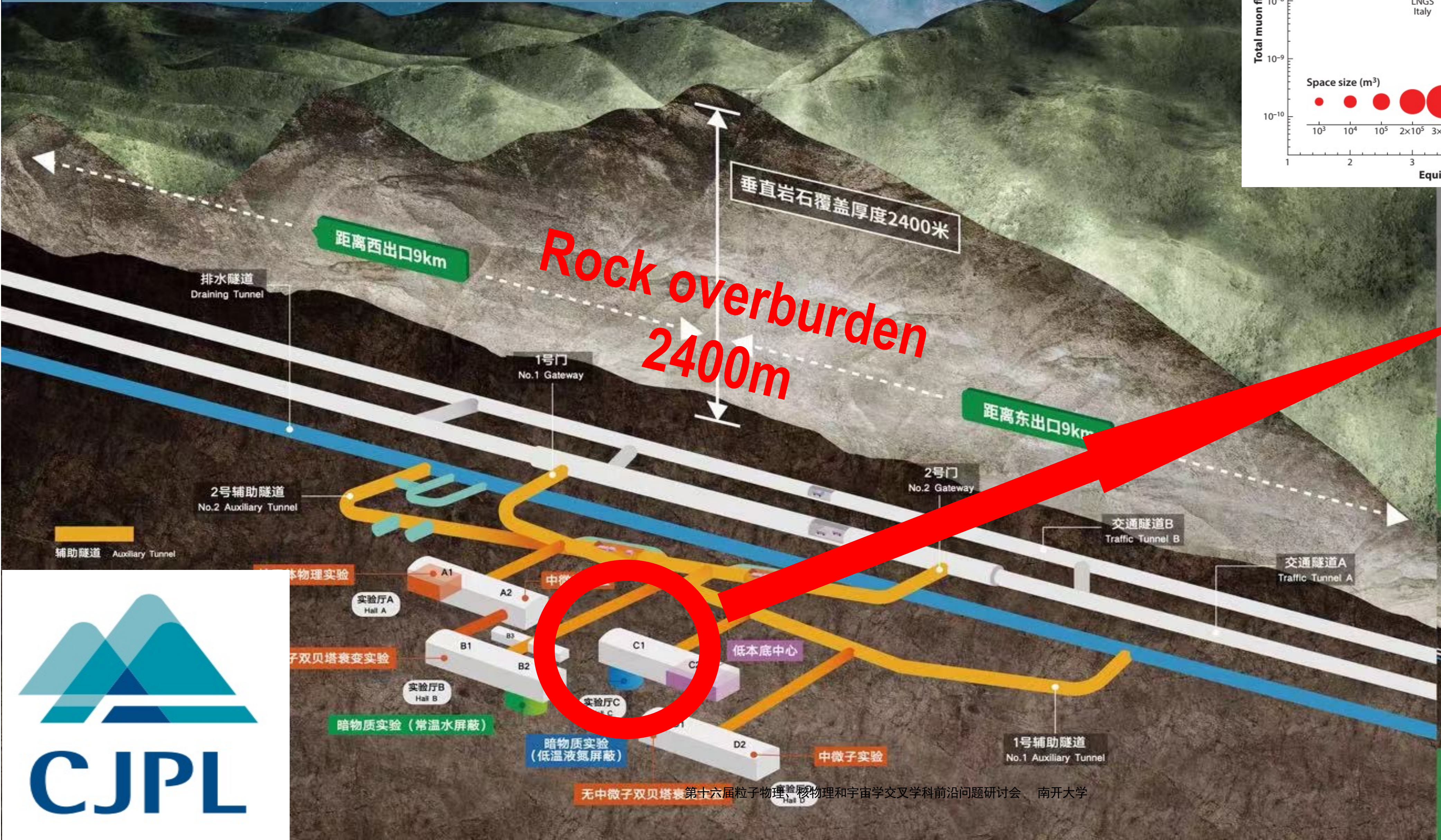


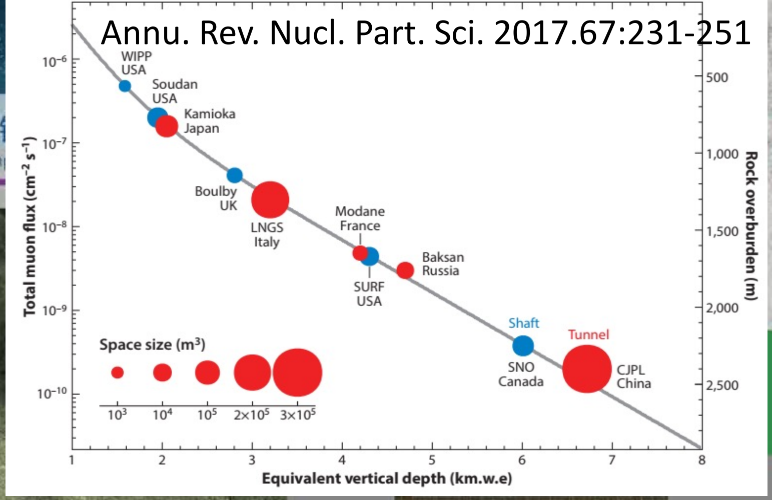
Cheng et al., Annu. Rev. Nucl. Part. Sci. 2017. 67:231

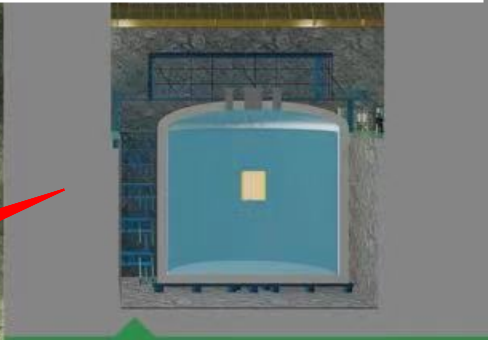




CJPL: A National Key Scientific and Technological Infrastructure







CDEX-300 Cooling System

CJPL with normal scale

CJPL

CJPL Construction

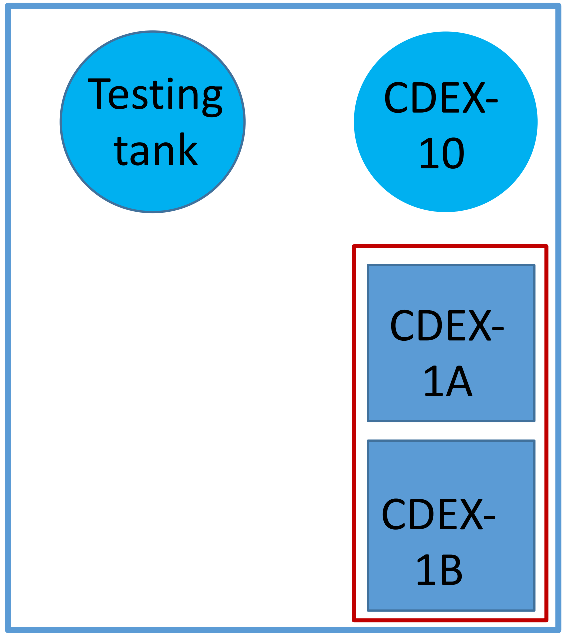
CDEX

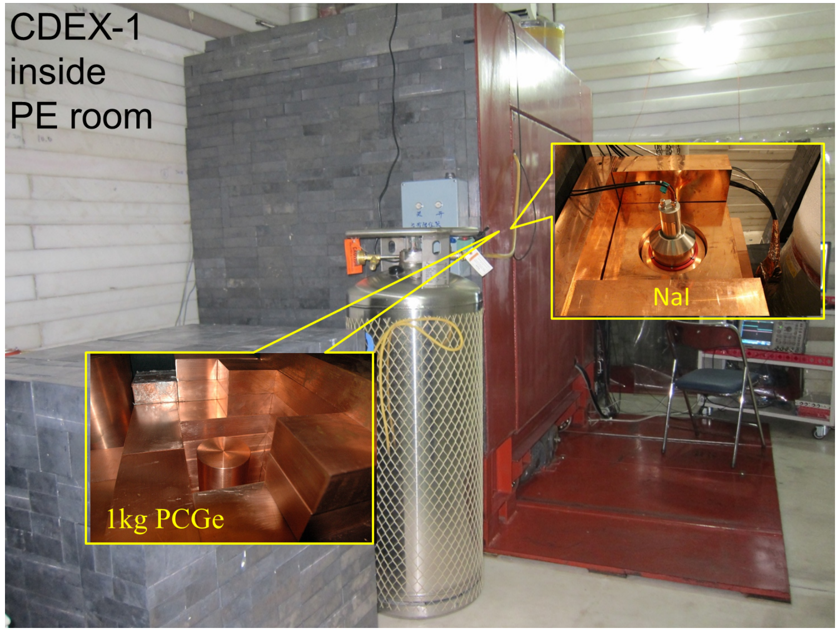
- Currently under construction
- major infrastructure construction will be completed by the end of 2023.
- Expected the construction of the laboratory will be completed by the end of 2024

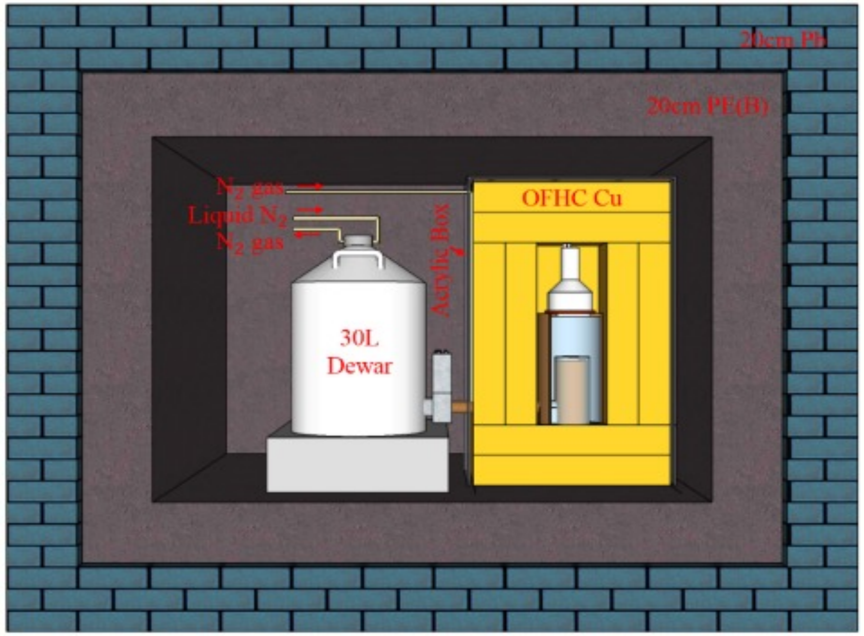
CDEX-1&CDEX-10

CDEX

- 2 sub-stages: CDEX-1(prototype, 2011)→CDEX-10(upgraded, 2013);
- Traditional single-element ~1kg PPC Ge detector;
- Low-bkg Pb&Cu passive shield + NaI veto detector;
- Located in PE room at CJPL-I.



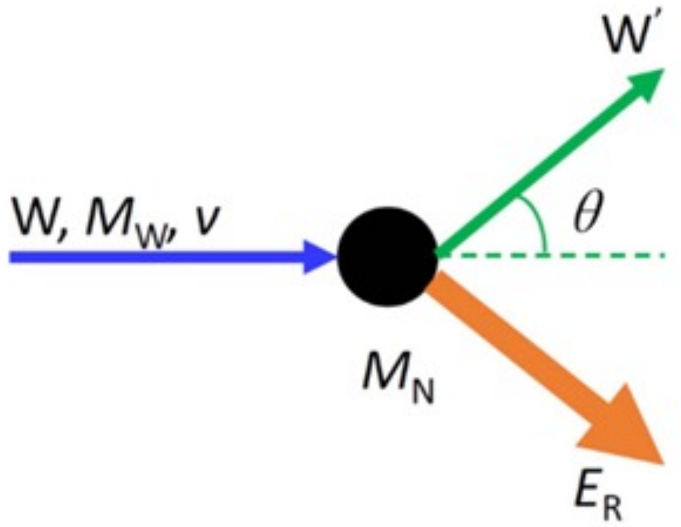




CDEX-1A&B: 1kg PPC Ge × 2

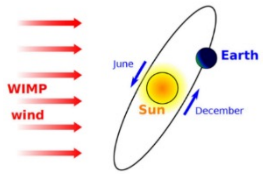
The principle of DM direct detection

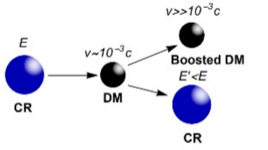
$$\frac{dR}{dE_R} = N_T \frac{\rho_\chi}{m_\chi} \int d^3\vec{v} v f_v(\vec{v} + \vec{v}_E) \frac{d\sigma}{dE_R}$$



暗物质源项：

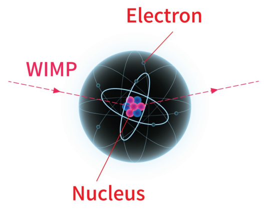
- ✓ WIMP（标准暗物质晕模型）
- ✓ 年度调制效应（速度导致）
- ✓ 加速暗物质
- ✓ 暗光子、轴子等

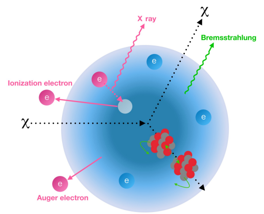




相互作用过程：

- ✓ 暗物质-核子 弹性散射
- ✓ 暗物质-核子 非弹性散射
- ✓ 暗物质-电子 弹性散射
- ✓ 其他（全能量沉积）





*WIMP: 弱相互作用大质量粒子

CDEX WIMP detection

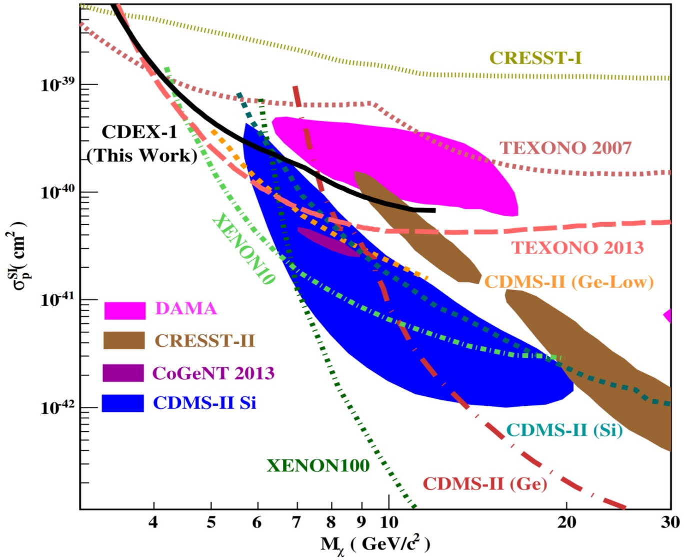
CDEX

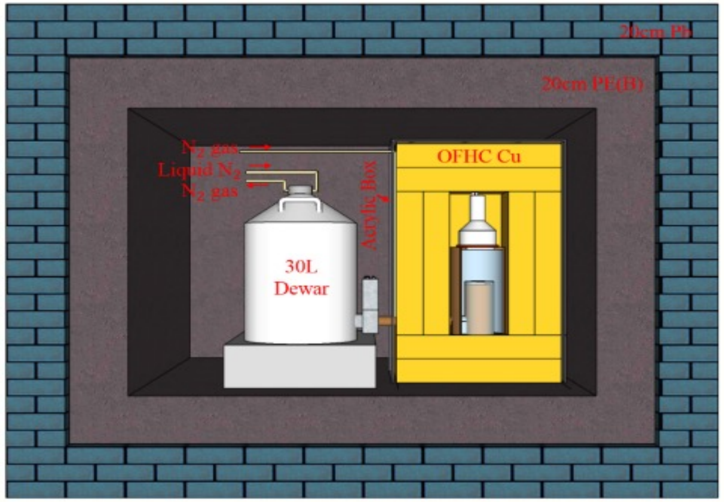
- CDEX-1 detector system established in 2011.
- The first DM direct detection result from China in 2013.
- The CDEX-1 best sensitivity below 6 GeV in 2016 .

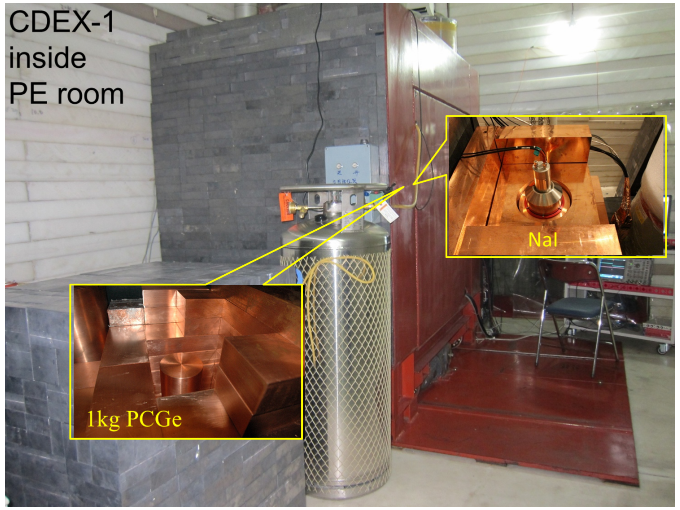
暗物质源项：
- ✓ WIMP (标准暗物质晕模型)
- ✓ 年度调制效应 (速度导致)
- ✓ 加速暗物质
- ✓ 暗光子、轴子等

相互作用过程：
- ✓ 暗物质-核子 弹性散射
- ✓ 暗物质-核子 非弹性散射
- ✓ 暗物质-电子 弹性散射
- ✓ 其他 (全能量沉积)

PRD ***88, 052004(2013)***







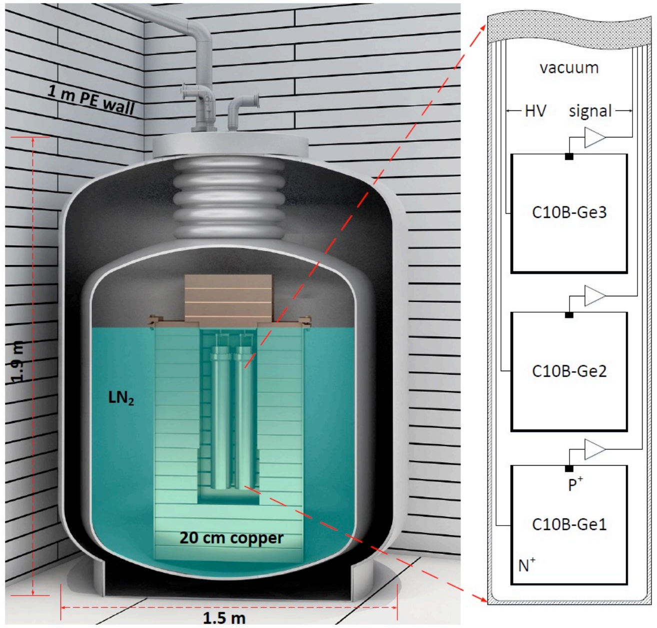
CDEX-1A&B: 1kg PPC Ge×2

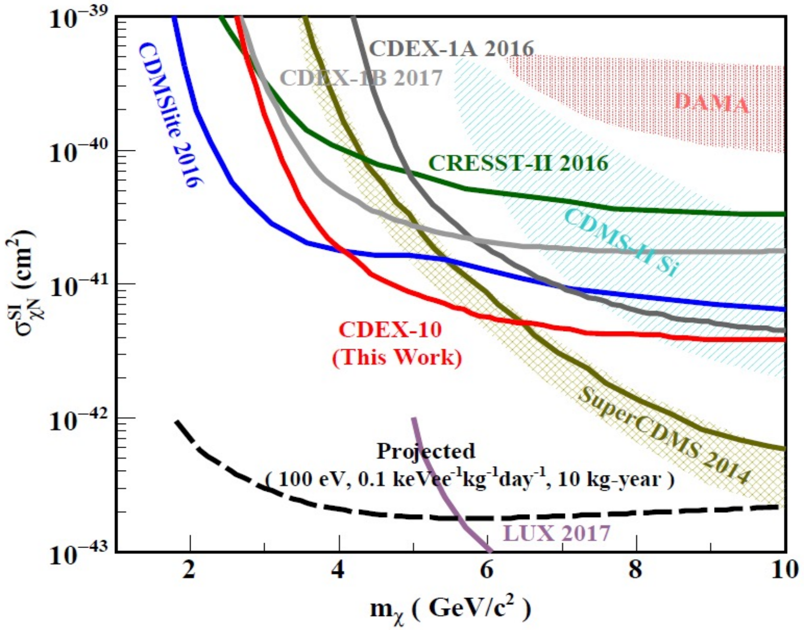
WIMP detection with CDEX-10

- CDEX-1 to CDEX-10: scale up to detector array and directly immersed in LN_2 for cooling and shielding.
- In 2018, the best SI sensitivity at 4-5GeV energy region from CDEX-10.

暗物质源项：
- ✓ **WIMP (标准暗物质晕模型)**
- ✓ 年度调制效应 (速度导致)
- ✓ 加速暗物质
- ✓ 暗光子、轴子等

相互作用过程：
- ✓ **暗物质-核子 弹性散射**
- ✓ 暗物质-核子 非弹性散射
- ✓ 暗物质-电子 弹性散射
- ✓ 其他 (全能量沉积)





PRL ***120, 241301 (2018)***

DM Annual modulation detection

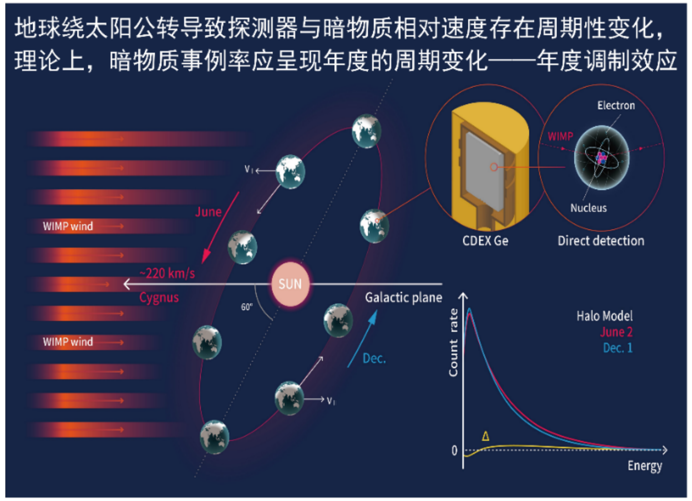
CDEX

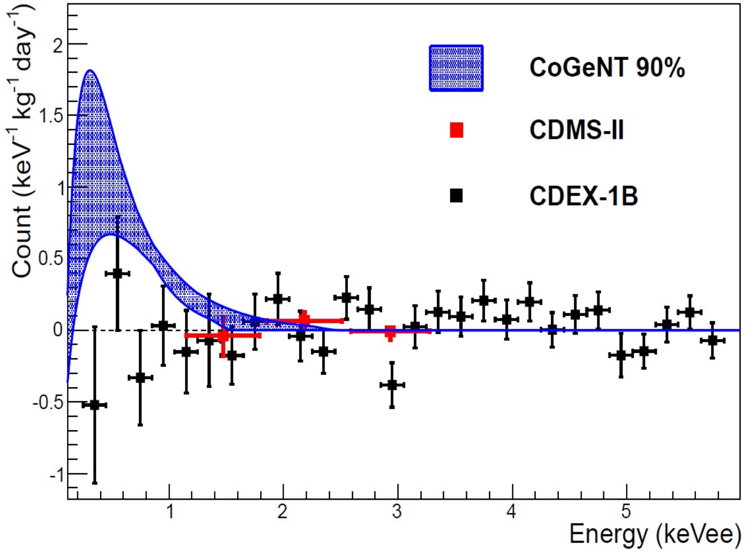
- Based on CDEX 4-year data, achieved the best AM result below 6 GeV;
- Exclude the possible region favored by CoGeNT and DAMA；

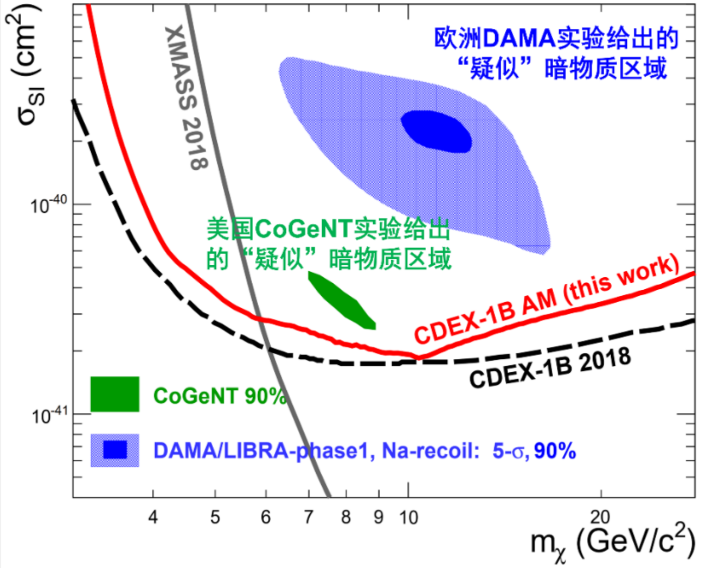
暗物质源项：
- ✓ WIMP (标准暗物质晕模型)
- ✓ **年度调制效应 (速度导致)**
- ✓ 加速暗物质
- ✓ 暗光子、轴子等

相互作用过程：
- ✓ **暗物质-核子 弹性散射**
- ✓ 暗物质-核子 非弹性散射
- ✓ 暗物质-电子 弹性散射
- ✓ 其他 (全能量沉积)

PRL 123, 221301 (2019)







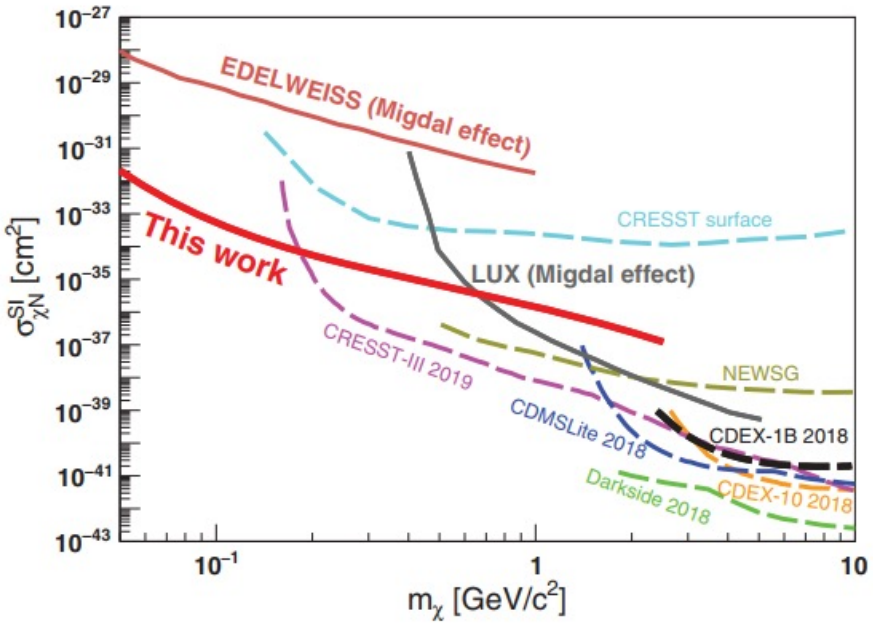
DM detection with Migdal Effect

- With Migdal effect, CDEX pushed the DM sensitivity down to 50MeV and achieved the best results at 50-180 MeV region.
- Cited by European Astroparticle Physics Strategy 2017-2026.

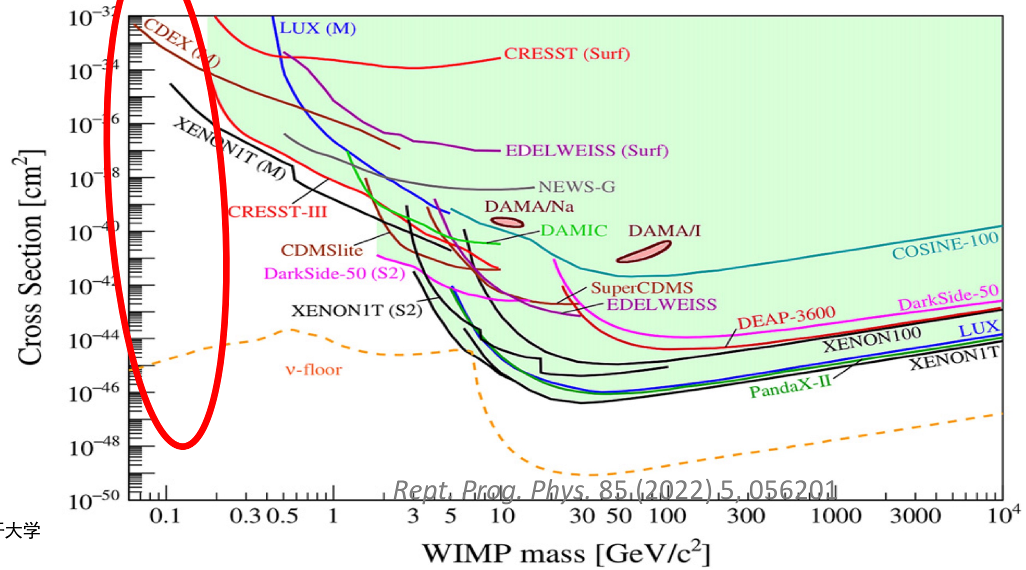
暗物质源项：
- ✓ **WIMP (标准暗物质晕模型)**
- ✓ 年度调制效应 (速度导致)
- ✓ 加速暗物质
- ✓ 暗光子、轴子等

相互作用过程：
- ✓ 暗物质-核子 弹性散射
- ✓ **暗物质-核子 非弹性散射**
- ✓ 暗物质-电子 弹性散射
- ✓ 其他 (全能量沉积)

PRL ***123, 161301 (2019)***

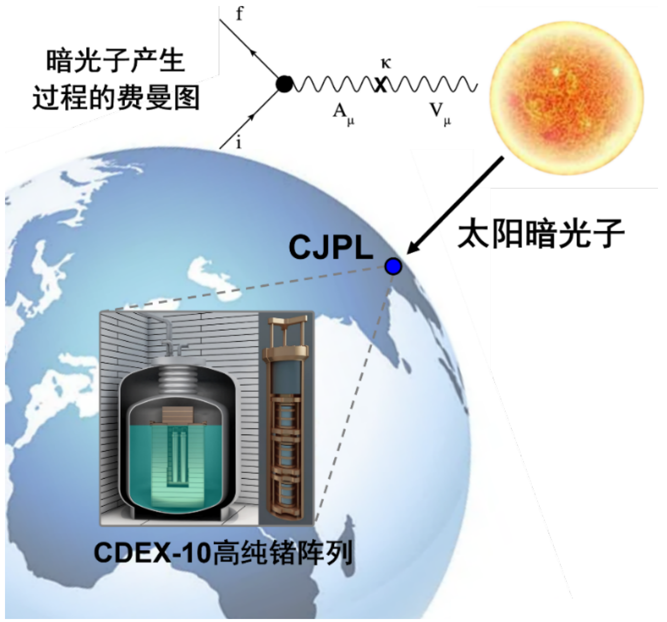


Several results using this effect were already published with the **strongest ones being from** XENON1T and **CDEX** above and below 110 MeV/c^2, respectively.

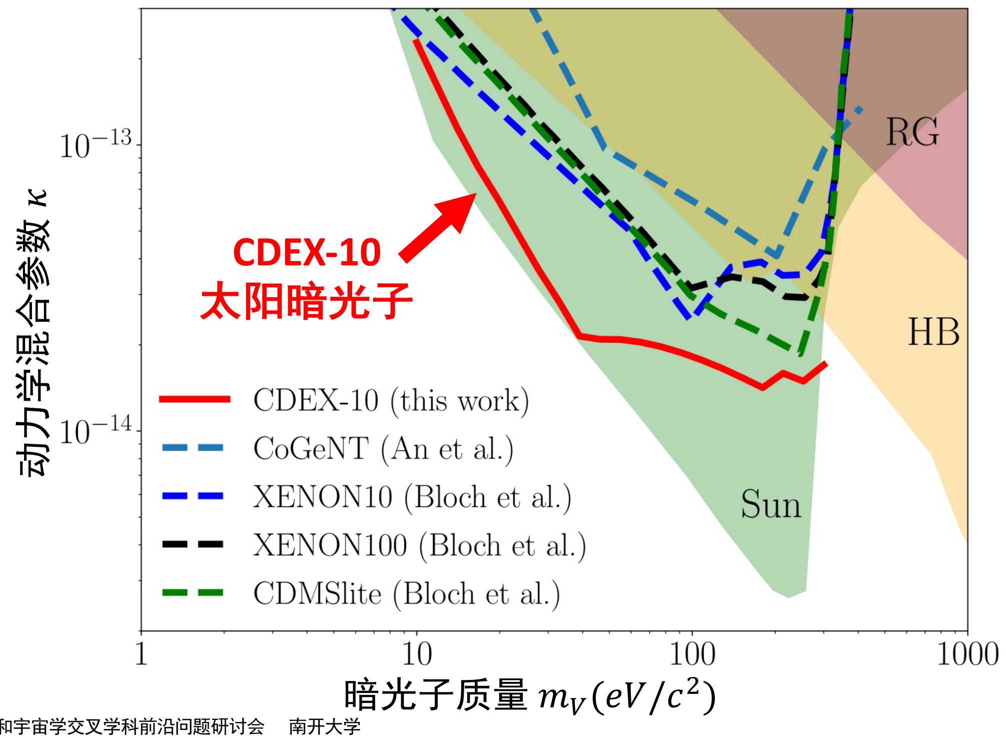


Dark Photon

- Dark photon Analysis: 205.4 kg-d, w/ E_{th} 160 eVee;
- Leading sensitivity in m_V ~10-300 eV for solar dark photon;



PRL ***124, 111301 (2020)***



CR-DM detection

暗物质源项：
- ✓ WIMP (标准暗物质晕模型)
- ✓ 年度调制效应 (速度导致)
- ✓ **加速暗物质**
- ✓ 暗光子、轴子等

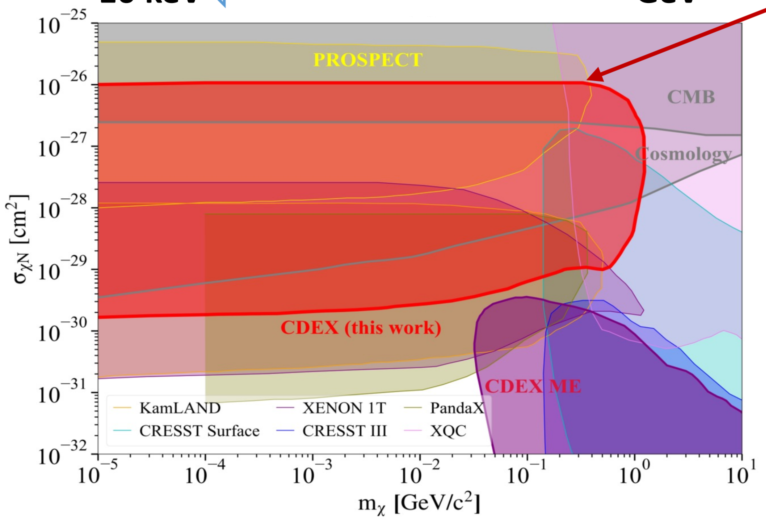
相互作用过程：
- ✓ **暗物质-核子 弹性散射**
- ✓ 暗物质-核子 非弹性散射
- ✓ 暗物质-电子 弹性散射
- ✓ 其他 (全能量沉积)

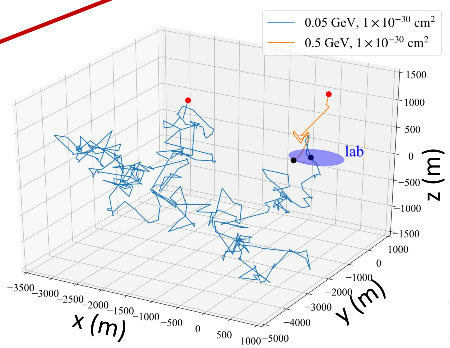
- Detected the cosmic-ray accelerated DM and scaned the new light-mass parameter region;
- Considering the Earth shield effect, provide the upper limit of DM detection.

地球屏蔽效应给出的排除区域上限

宇宙线加速暗物质

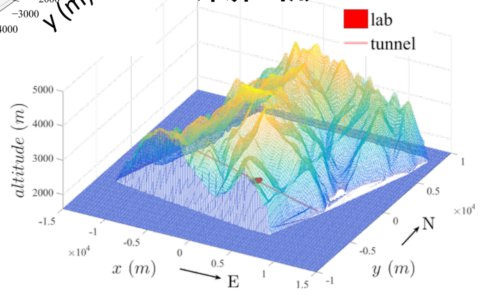
10 keV ← GeV



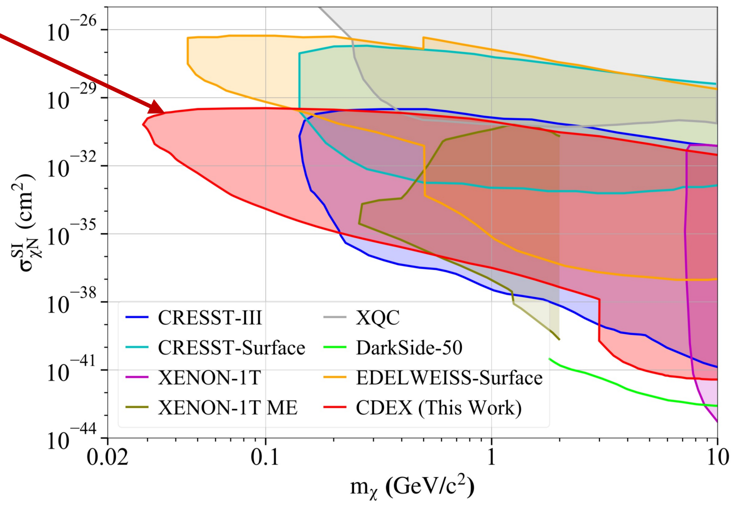


暗物质在地壳内的散射径迹（模拟）

锦屏山形



Migdal效应轻暗物质探测



PRD 106, 052008 (2022)

PRD 105, 052005 (2022)

DM-electron Interaction

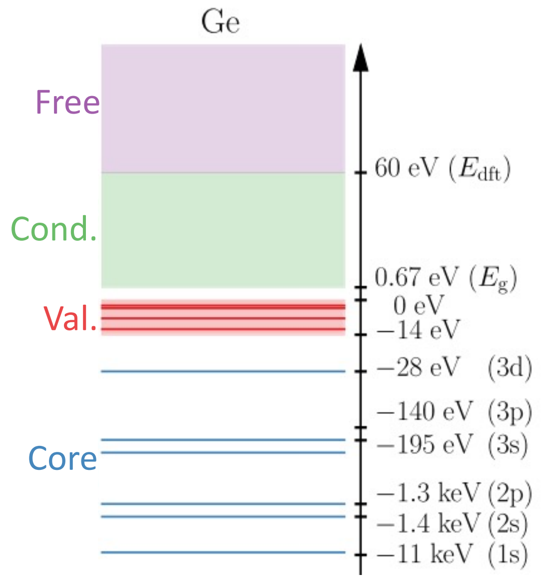
CDEX

- ➢Study DM-Electron recoil with HPGe and the most sensitive result above 100 MeV for solid detector;
- ➢The first result from HPGe at LN temperature level；

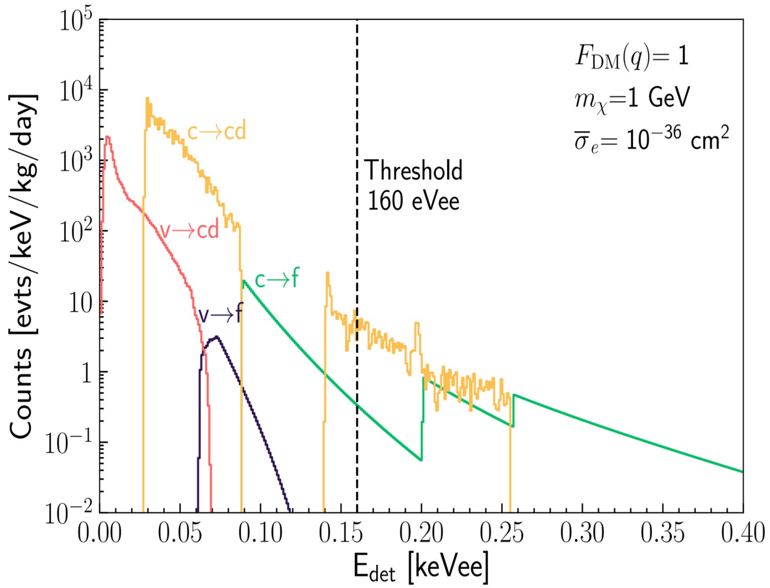
暗物质源项：
- ✓ **WIMP (标准暗物质晕模型)**
- ✓ 年度调制效应 (速度导致)
- ✓ 加速暗物质
- ✓ 暗光子、轴子等

相互作用过程：
- ✓ 暗物质-核子 弹性散射
- ✓ 暗物质-核子 非弹性散射
- ✓ **暗物质-电子 弹性散射**
- ✓ 其他 (全能量沉积)

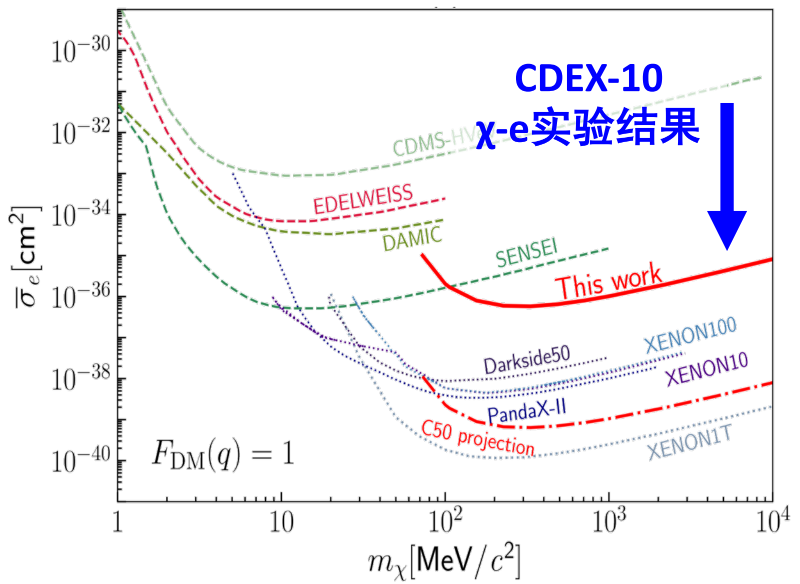
***PRL* 129, 221301 (2022)**



Ge壳层电子



Ge预期能谱



CDEX-10实验结果

DM detection data

CDEX

- **Review of Particle Physics**：全球粒子物理、天体物理宇宙学等相关研究的**权威综述**
  - ✓国际粒子数据组Particle Data Group编著
  - ✓每两年更新一次

REVIEW OF PARTICLE PHYSICS*

Particle Data Group

CPC 2018 (暗物质-核子)

PRL 2018 (暗物质-核子)

PRL 2019 (年度调制)

PRL 2019 (Migdal效应)

PRL 2020 (暗光子)

……

[14] KOBAYASHI 19 search for sub-GeV WIMP annual modulation in Xe via brems; no signal; limits placed in $\sigma^{SI}(\chi N)$ vs. m(χ) plane for m ∼ 0.3–1 GeV; quoted limit is for m(χ) = 0.5 GeV.

[15] LIU 19B seach for sub-GeV DM using Migdal effect on Ge at CDEX-IB; no signal, require $\sigma^{SI}(\chi N) < 7 \times 10^2$ pb for m(χ) = 0.1 GeV.

[16] AGNES 18 search for 1.8–20 GeV WIMP SI scatter on Ar; quoted limit is for m(χ) = 5 GeV.

[17] AGNESE 18 search for GeV scale WIMPs using CDMSlite; limits placed in $\sigma^{SI}(\chi N)$ vs. m(χ) plane for m ∼ 1.5–20 GeV; quoted limit is for m(χ) = 5 GeV.

[18] APRILE 18 search for WIMP scatter on 1 t yr Xe; no signal, limits set in $\sigma(\chi N)$ vs. m(χ) plane for m(χ) ∼ 6–1000 GeV; quoted limit is for m = 6 GeV.

[19] ARNAUD 18 search for low mass WIMP scatter on Ne via SPC at NEWS-G; limits set in $\sigma^{SI}(\chi N)$ vs. m(χ) plane for m ∼ 0.5–20 GeV; quoted limit is for m = 5 GeV.

[20] JIANG 18 search for GeV scale WIMP scatter on Ge; limits placed in $\sigma^{SI}(\chi N)$ vs. m(χ) plane for m(χ) ∼ 3–10 GeV; quoted limit is for m(χ) = 5 GeV.

[21] YANG 18 search for WIMP scatter on Ge; limits placed in $\sigma^{SI}(\chi N)$ vs. m(χ) plane for m(χ) ∼ 2–10 GeV; quoted limit is for m(χ) = 5 GeV.

[22] AKERIB 17 search for WIMP scatter on Xe; limits placed in $\sigma^{SI}(\chi N)$ vs. m(χ) plane for m(χ) ∼ 5–1 × 10^5 GeV; quoted limit is for m(χ) = 5 GeV.

WIMP and Dark Matter Searches

We omit papers on CHAMP's, millicharged particles, and other exotic particles.

GALACTIC WIMP SEARCHES

These limits are for weakly-interacting stable particles that may constitute the invisible mass in the galaxy. Unless otherwise noted, a local mass density of 0.3 GeV/cm^3 is assumed; see each paper for velocity distribution assumptions. In the papers the limit is given as a function of the X^0 mass. Here we list limits only for typical mass values of sub-GeV, GeV, 20 GeV, 100 GeV, and 1 TeV. Specific limits on supersymmetric dark matter particles may be found in the Supersymmetry section.

Spin-Independent Cross Section Limits for Dark Matter Particle (X^0) on Nucleon

For m_{χ^0} in GeV range

We provide here limits fo m_{χ^0} < 5 GeV

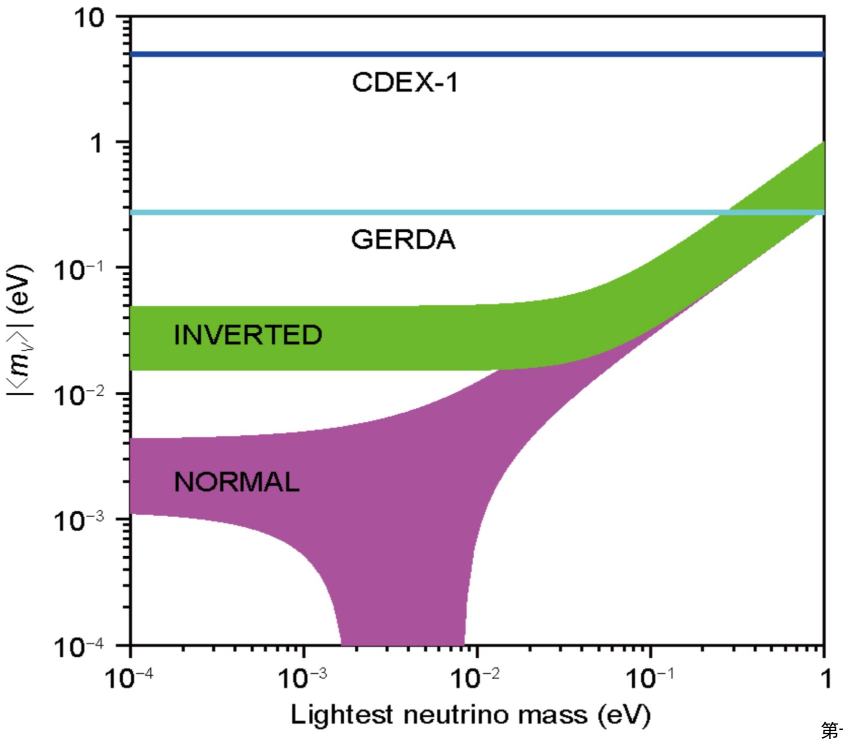
VALUE (pb)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<2 \times 10^{-7}$	95	[1] AKERIB	21A	LUX	low mass WIMPs
$<5 \times 10^{6}$	90	[2] ALKHATIB	21	SCDM	light DM
$<1 \times 10^{8}$	95	[3] ANDRIAMIR...	21A		sub-GeV DM on nucleon
$<1 \times 10^{-8}$	90	[4] APRILE	21	XE1T	GeV scale DM
$<8 \times 10^{-4}$	90	[5] AGUILAR-AR...	20C	DMIC	WIMP SI scatter on Si
$<8 \times 10^{-4}$	90	[6] AKERIB	20A	LUX	GeV-scale WIMP search
$<1 \times 10^{-2}$	90	[7] ABDELHAME..	19A	CRES	$CaWO_4$
$<5.4 \times 10^{-6}$	90	[8] AGNESE	19A	SCDM	GeV-scale WIMPs on Ge
<1	90	[9] AKERIB	19	LUX	light DM on Xe via Migdal/brem effect
$<1 \times 10^{-6}$	90	[10] AMOLE	19	PICO	C_3F_8
$<1.6 \times 10^{-3}$	90	[11] APRILE	19C	XE1T	DM on Xe
$<1 \times 10^{-7}$	90	[12] APRILE	19D	XE1T	DM on Xe
<0.1	90	[13] ARMENGAUD	19	EDEL	GeV-scale WIMPs on Ge
$<1.6 \times 10^{3}$	90	[14] KOBAYASHI	19	XMAS	annual modulation Xe
$<7 \times 10^{2}$	90	[15] LIU	19B	CDEX	Ge; sub-GeV DM via Migdal
$<7 \times 10^{-7}$	90	[16] AGNES	18	DS50	GeV-scale WIMPs on Ar
$<1.5 \times 10^{-5}$	95	[17] AGNESE	18	SCDM	GeV-scale WIMPs on Ge
$<2 \times 10^{-8}$	90	[18] APRILE	18	XE1T	Xe, SI
$<4.5 \times 10^{-3}$	90	[19] ARNAUD	18	NEWS	low mass WIMP, Ne
$<8 \times 10^{-6}$	90	[20] JIANG	18	CDEX	GeV-scale WIMPs on Ge
$<3 \times 10^{-5}$	90	[21] YANG	18	CDEX	WIMPs on Ge
$<1 \times 10^{-6}$	90	[22] AKERIB	17	LUX	Xe

*Particle Data Group, Prog. Theor. Exp. Phys. 2022, 083C01 (2022) Page 1230, 2249-2250

CDEX ^{76}Ge 0νββ results

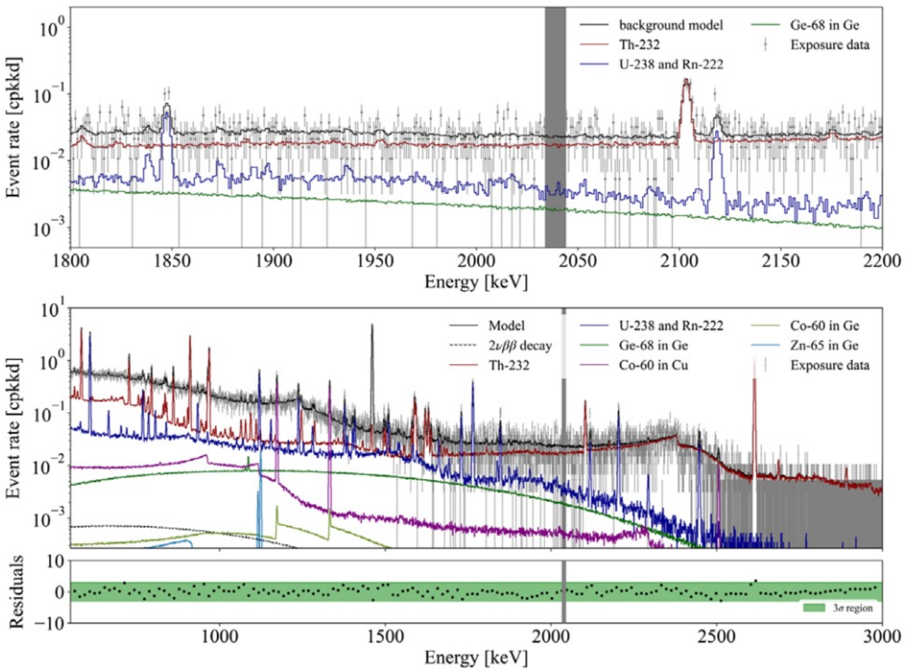
- Based on the CDEX-1 natural PCGe detector, first ^{76}Ge 0νββ result in 2017.
- $<m_{\beta\beta}>$ sensitivity: one order less than GERDA-I at that time.
- Develop new BEGe detector for CDEX-0vbb experiment。

Science China PMA (2017) 60: 071011



Prototype Future BEGe Detector Operated

PRD 106, 032012, 2022



Next stage of CDEX

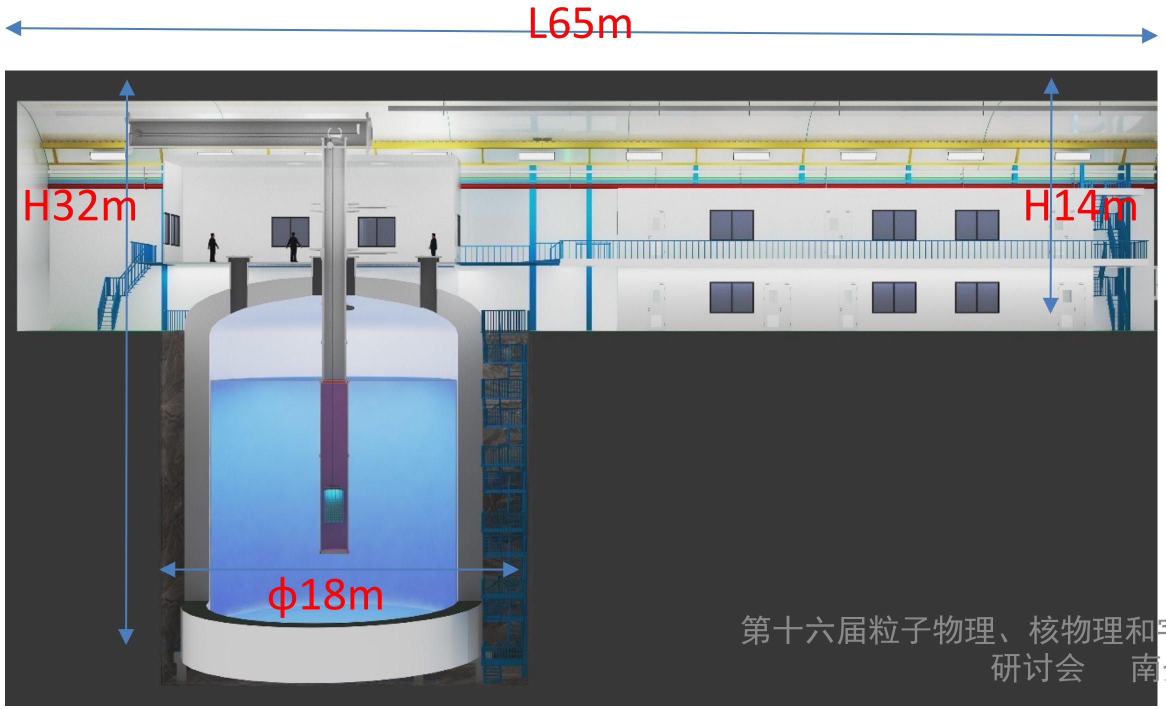
CDEX

- Underground space;
- Key HPGe technologies;
- Background understanding and suppression;
- International collaborations;
- CDEX-50 DM and CDEX-300 0vbb experiment.

New Underground Space at CJPL

CDEX

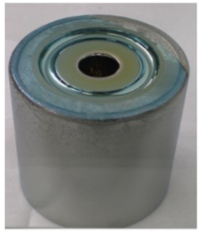
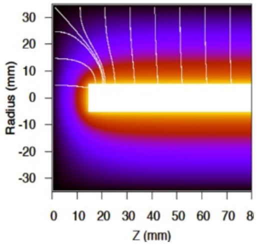
- A space of L65m*W14m*H14m at CJPL-II to be used by CDEX, optimized with a pit of ϕ18m at the end of Hall C1, a space of ϕ18m*H32m;
- Excellent technical support including electronic power, LN_2, LAr, Radon-free air to clean room, and good logistics.



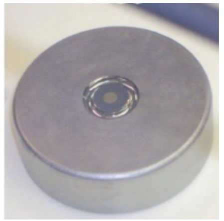
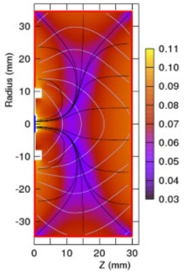
HPGe Technology---Ge Detector Fabrication

CDEX

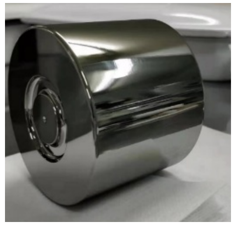
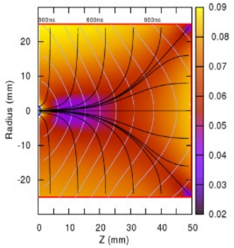
- Home-made different Ge detectors by CDEX group;
- Detector performances are same with commercial products with long-term stability.

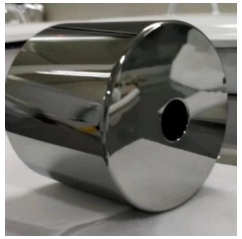
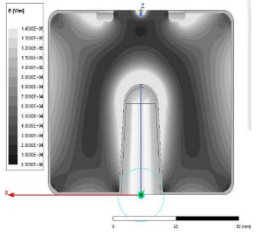
Co-axial

BEGe

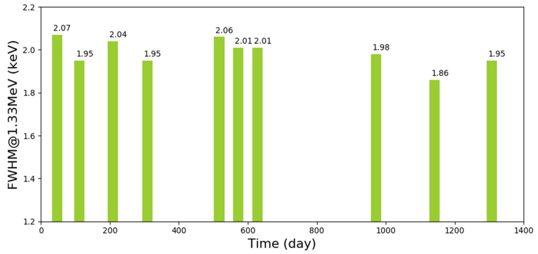



PCGe

ICPC

Key technical Steps:
- ✓ Commercial Ge crystal;
- ✓ Structure machining;
- ✓ Li-drift and B-implanted;
- ✓ Home-made ASIC PreAmp;
- ✓ Underground EF-Cu;
- ✓ Underground assemble;
- ✓ Underground testing…



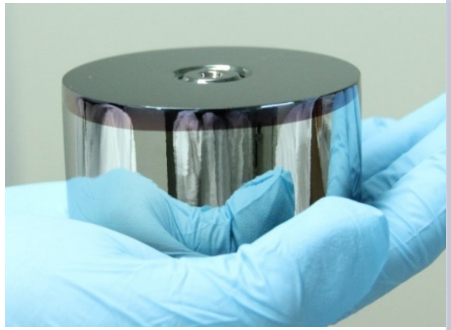
HPGe Technology---ASIC PreAMP + LN_2 Cryostat

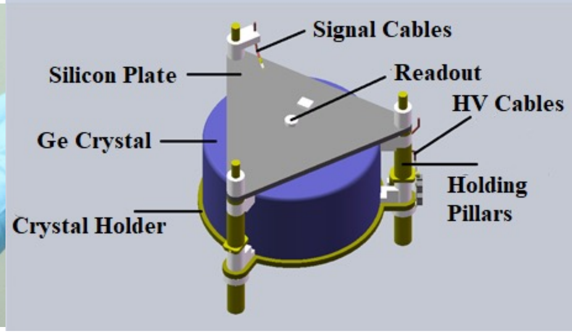
CDEX

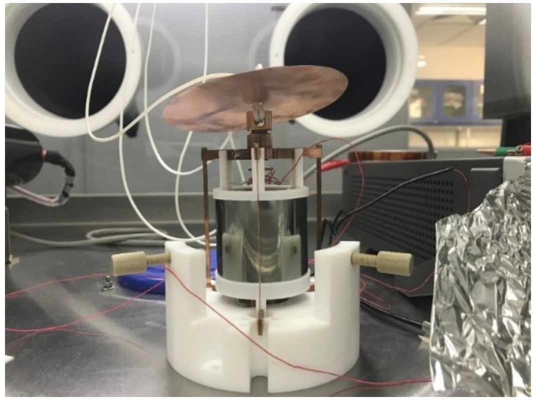
- The first Ge+ASIC+LN_2 detector in the world:

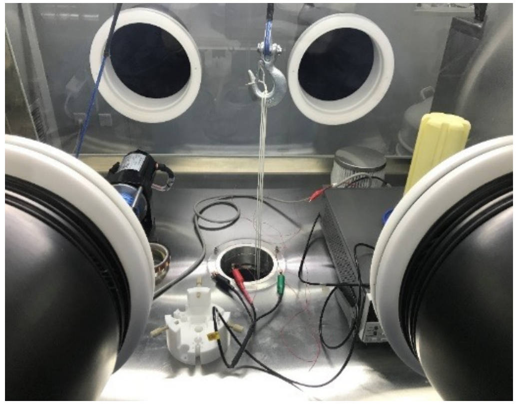
  500g Ge + home-made CMOS ASIC preamp immersed into LN_2

- Works with expected performances!

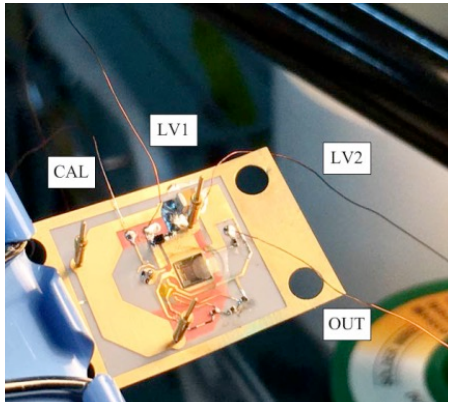




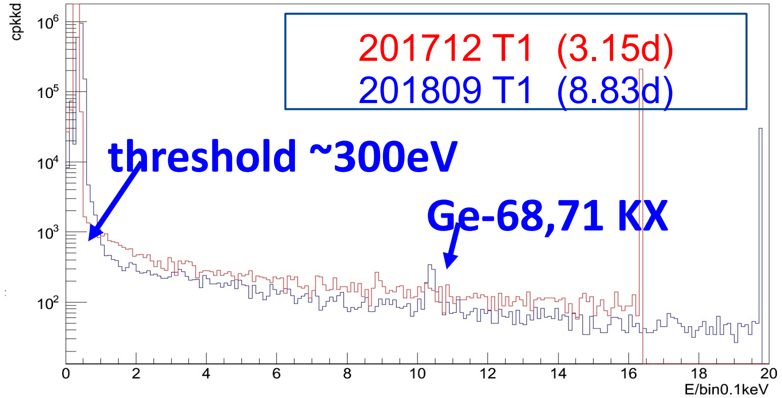




Fabricated and Tested in CJPL-I



ASIC PreAMP

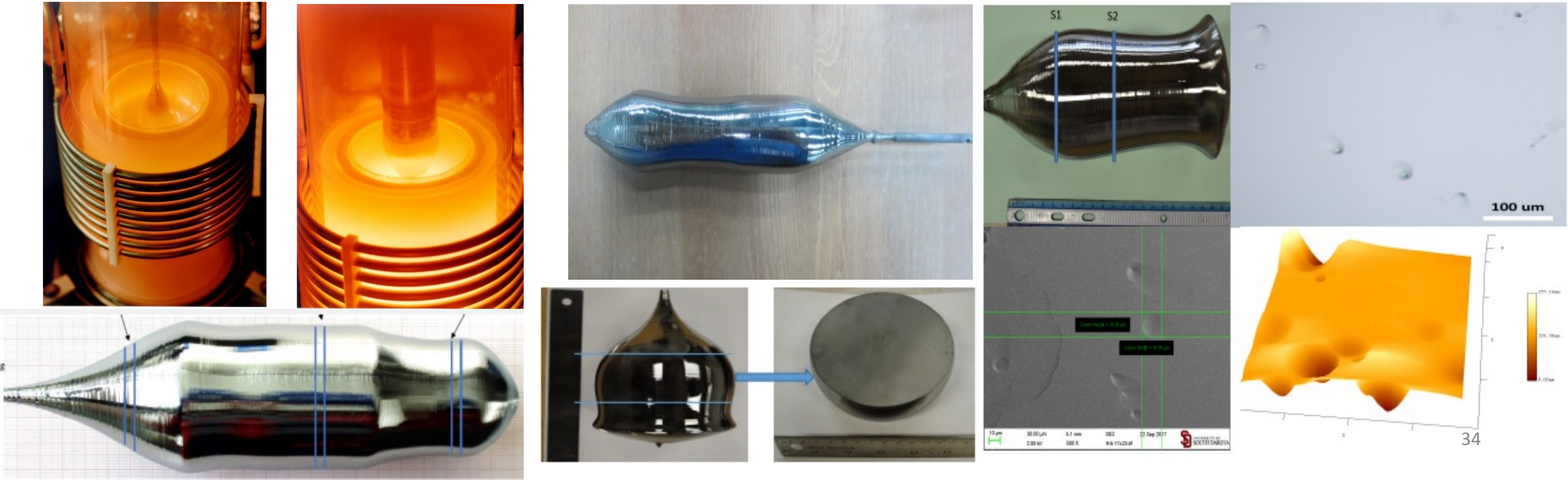


Background spectrum @CJPL

HPGe Technology---Ge Crystal Growth

CDEX

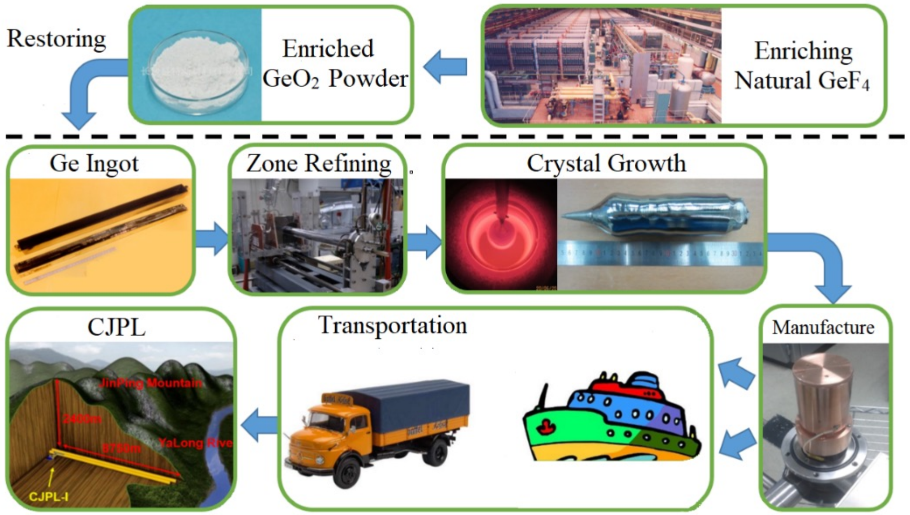
- Long-term work to grow Ge crystal at ground Lab by CDEX group;
- Ge crystal growth and detector fabrication at CJPL **funded**.



HPGe Technology---Enriched ^{76}Ge Material Supply

CDEX

- 200kg ^{76}Ge (>86%) stored at CJPL, half from Russia and half from China.
- CDEX has the largest amount of $^{76}GeO_2$ powder in hand now in the world.
- The mass production power (Hundreds of kg each year) of enriched ^{76}Ge material has been setup in China and it is an important contribution to International ^{76}Ge 0νββ experiment community.

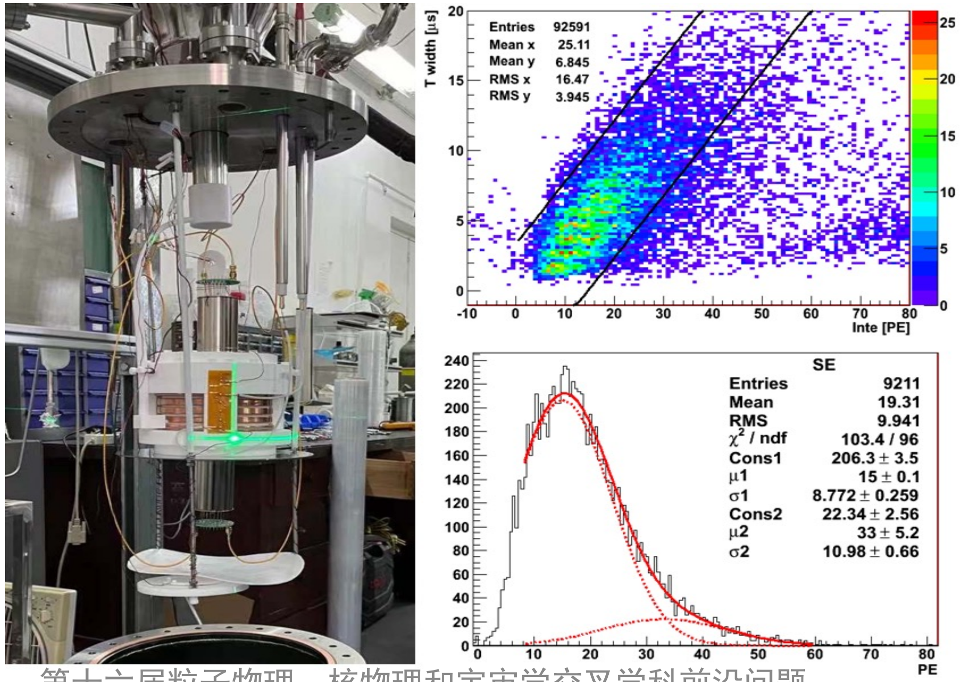


Crucial technologies

CDEX

- Successfully electro-form copper production by CDEX at CJPL-1;
- Involving into LAr/SAr veto detector technology for many years

Electro-form copper



LAr TPC

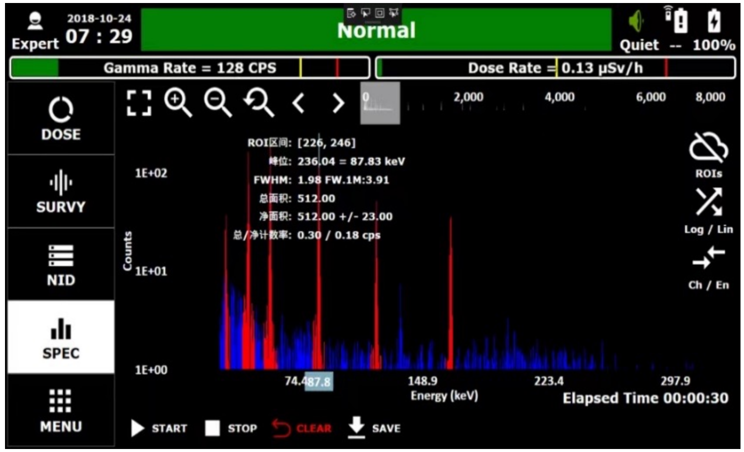
第十六届粒子物理、核物理和宇宙学交叉学科前沿问题研讨会 南开大学

Solid Argon R&D

Strong industry connection

- Nuctech (Company on world class radiation detector with experience of supplying major detector systems to high energy physics) is part of CDEX Collaboration
- Mass production by THU + Nuctech will be much helpful for international Ge community.
- Several kinds of commercial products have been developed and enter the commercial market.

LN2 dewar	Electrical and LN2 Cooling dewar	Portable Electrical cooling	Mini-dewar
			



LEGEND Collaboration and PIRE group meetings

CDEX

Oct. 2016, Atlanta, LEGEND established

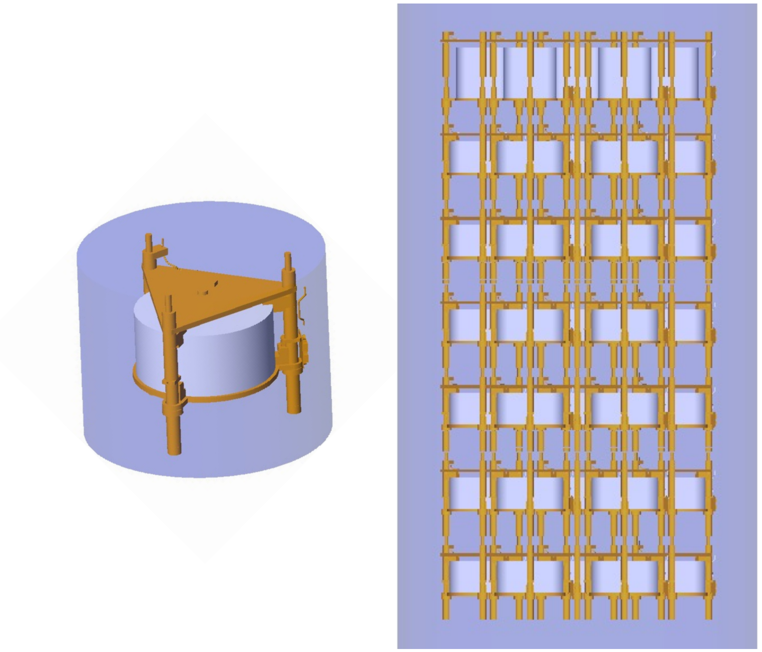
Nov. 2018, Knoxville, LEGEND

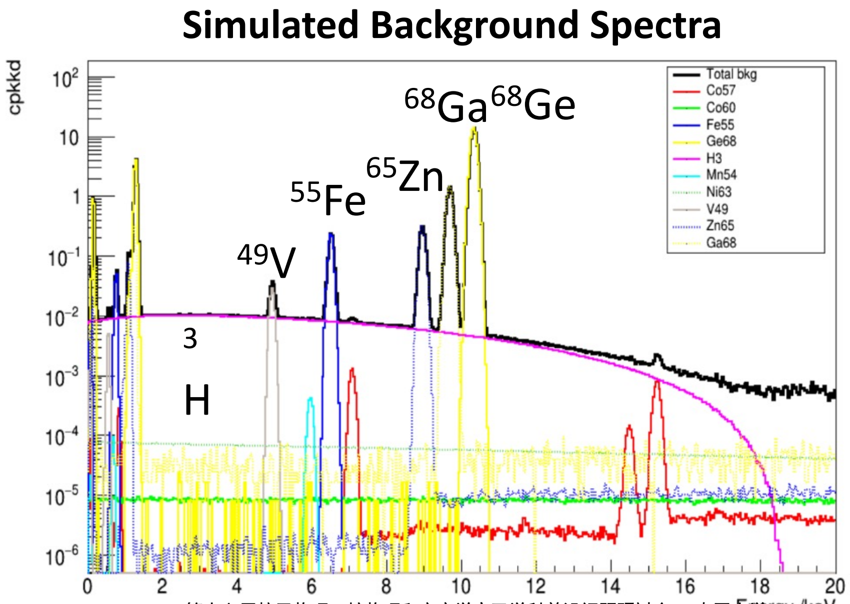
July, 2018, PIRE group meeting at Xichang, China

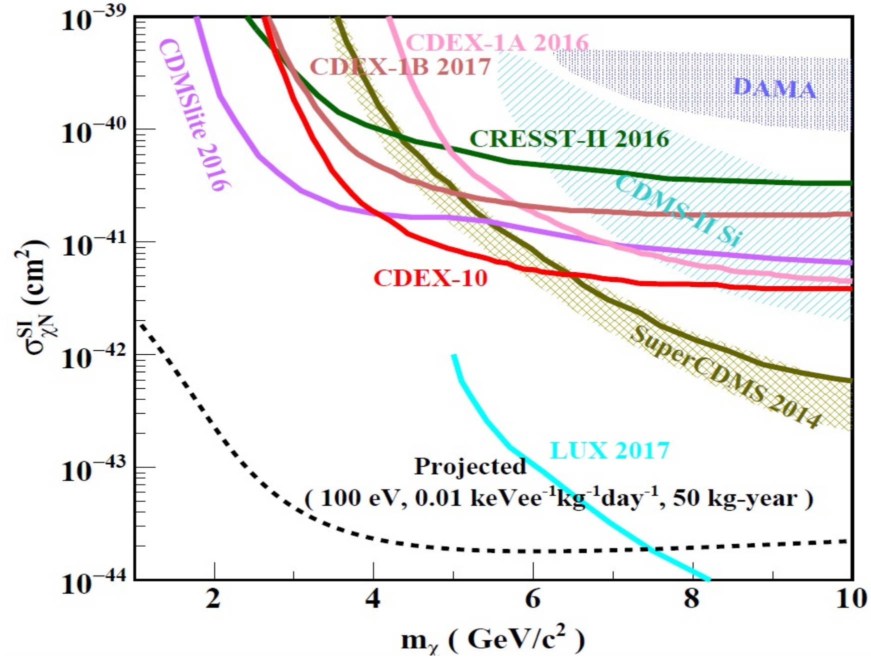
PIRE group Photo at Jinping Dam near CJPL, July, 2018

Sensitivities of CDEX-50 WIMP detection

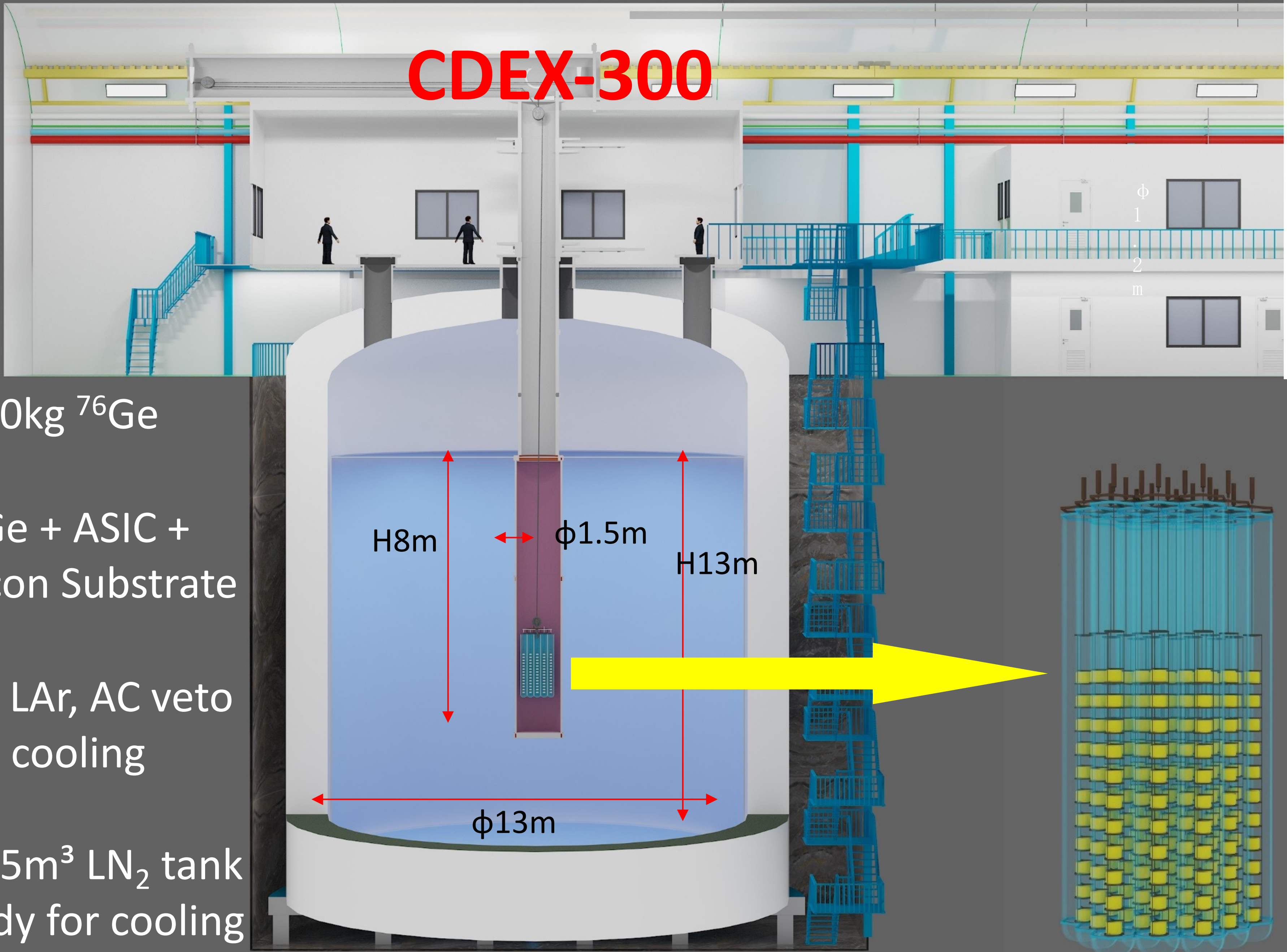
- Energy threshold: ~100eV;
- Background Level: 0.01 keV (~100 times less then CDEX-10)
- Next step: 50kg natural germanium detector array in liquid nitrogen, not LAr;
- The sensitivities of CDEX-50: 10^{-44} cm^2 level @ 4-8GeV WIMP mass.



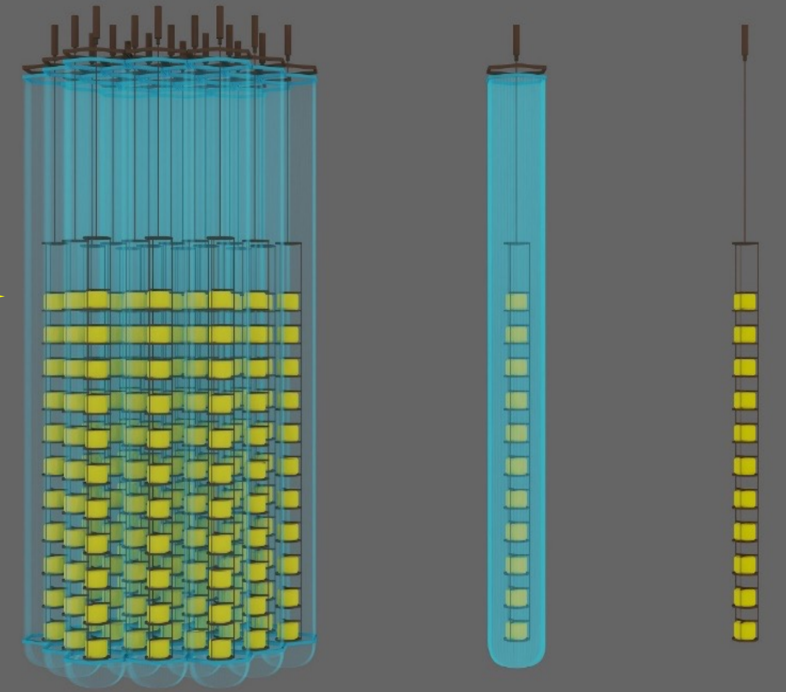




CDEX-300



- ~300kg ^{76}Ge
- BEGe + ASIC + Silicon Substrate
- 20T LAr, AC veto and cooling
- 1725m³ LN_2 tank ready for cooling and shielding

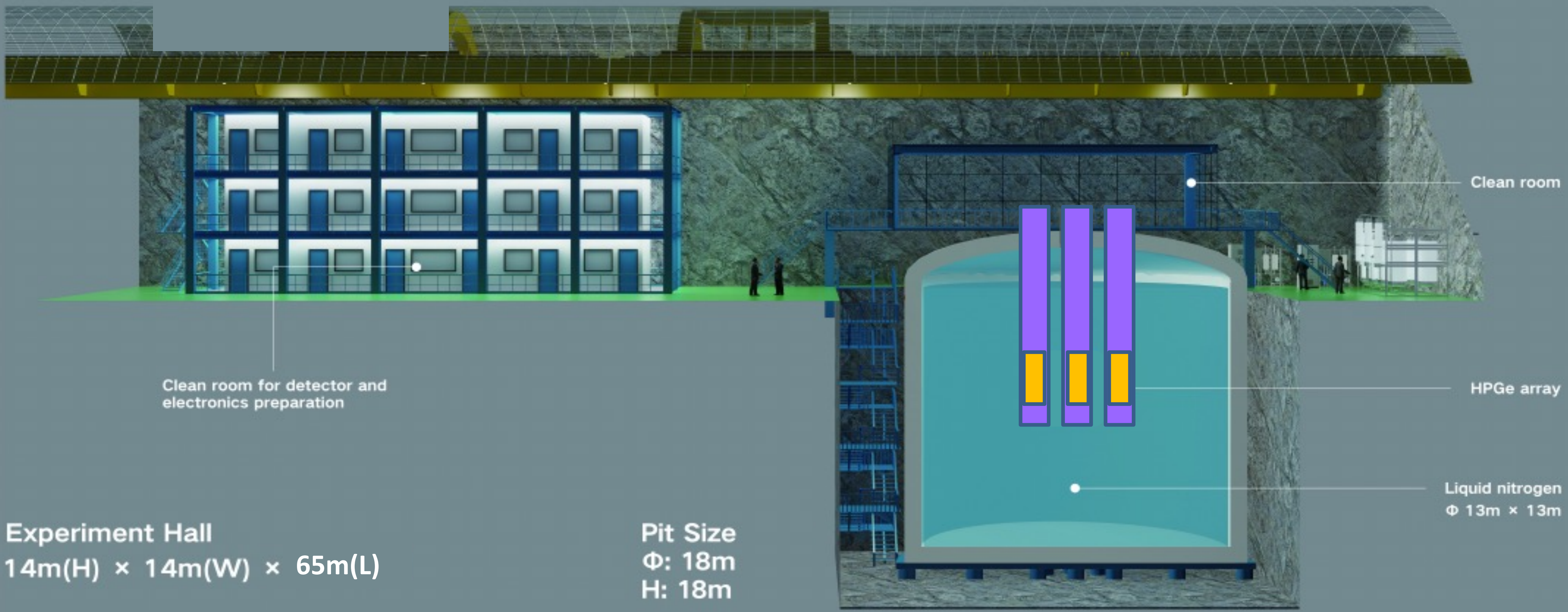


CDEX

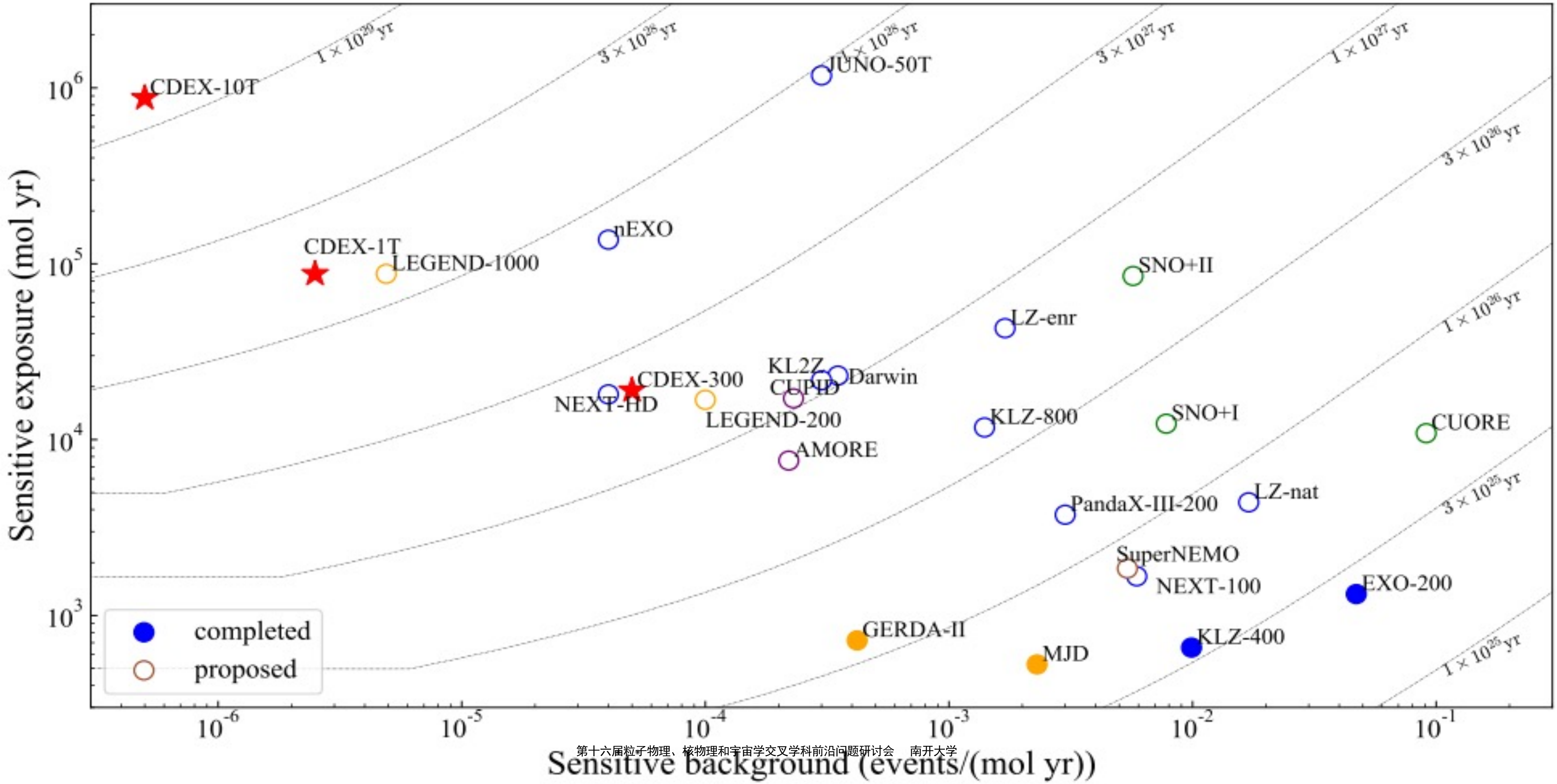
CDEX-1T and CDEX-10T Conceptual Layout

中国暗物质实验
China Dark matter EXperiment

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



Sensitivities of CDEX DM and 0νββ experiments



Summary

CDEX

- DM and $0\nu\beta\beta$ search： the top scientific questions in particle and astroparticle physics.
- Based on ^{76}Ge, HPGe is one of the most competitive techniques: E_R, BI, ……
- CDEX: a staged ^{76}Ge Large-Science-Facility (CDEX-300, CDEX-1T and CDEX-10T).
- CDEX has made great contribution to the international ^{76}Ge community including:

    (1) Mass production of ^{76}Ge isotope material and Ge detectors;

    (2) ASIC-PreAMP-Ge detectors;

    (3) Large underground space at the deepest CJPL in the world;

    (4) Underground Ge crystal growth and detector fabrication for cosmogenic background control.