# Status and prospects of CDEX @CJPL


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On behalf of CDEX Collaboration

CJPL
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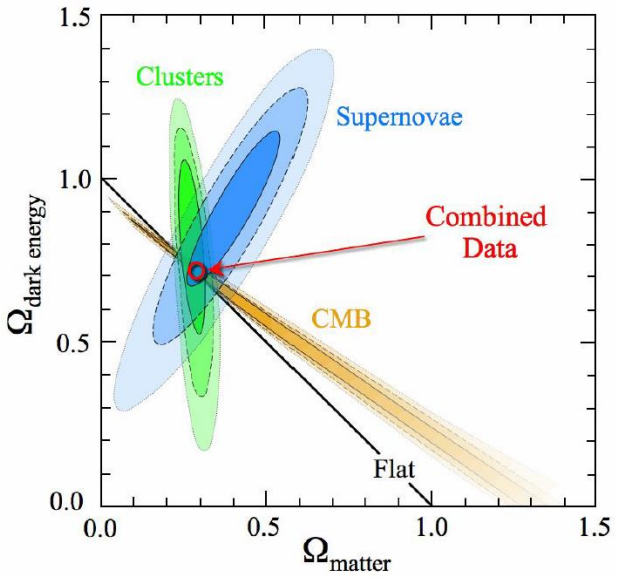
清华大学·雅砻江流域水电开发有限公司

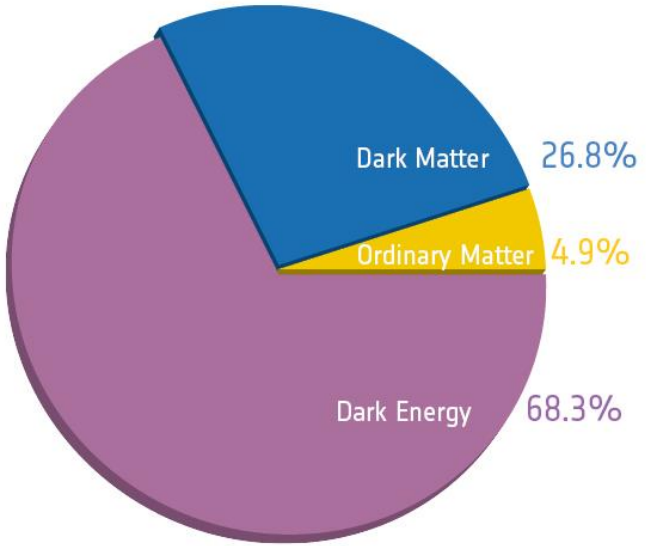
The 8th workshop on Flavor Symmetries and Consequences in Accelerators and Cosmology,
22-27 July 2019, ShangHai & HeFei

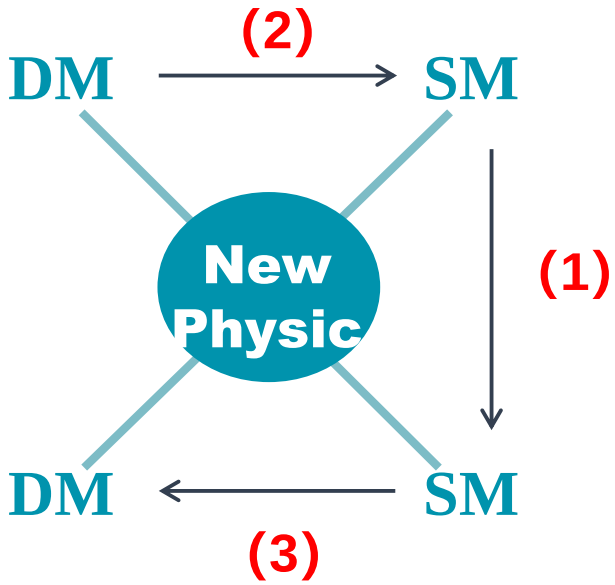
# OUTLINE

- Dark Matter (DM) and its Direct detection
- Introduction to CDEX
- Recent status of CDEX-1 and CDEX-10
- R&D of key technologies
- Future plan of CDEX @CJPL-II
- Summary

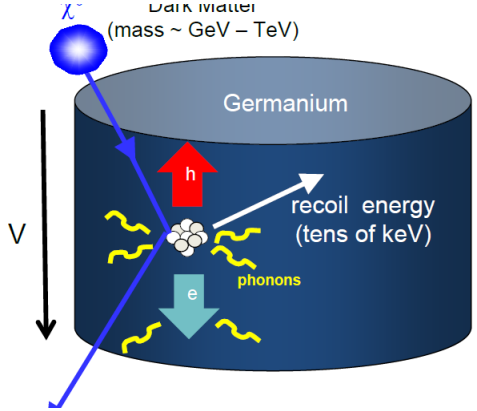
# Dark Matter in Cosmology



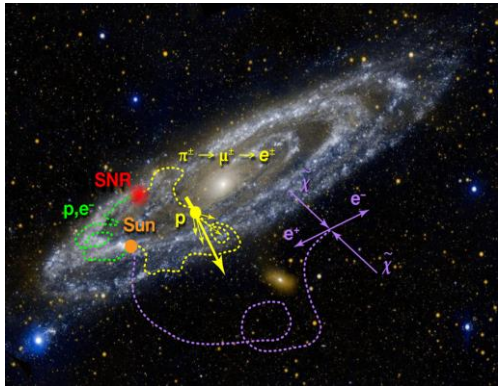



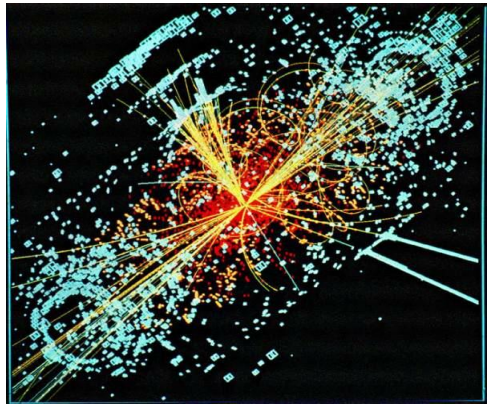

## (1) Direct




## (2) Indirect

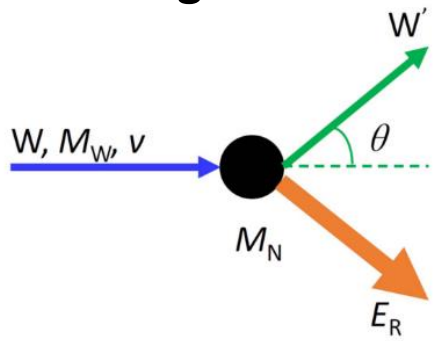



## (3) Accelerator

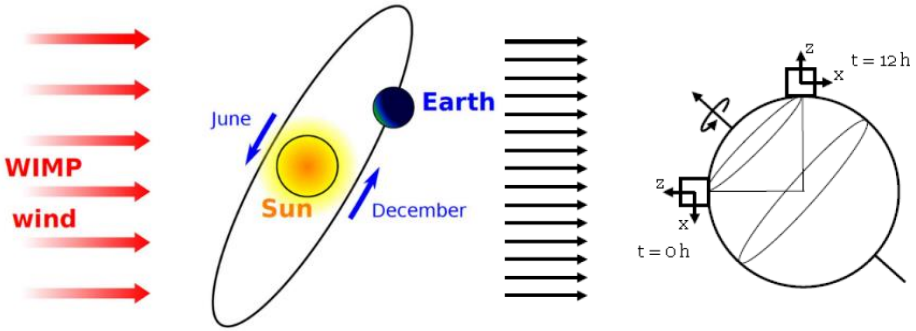


# Direct detection of DM---Principle

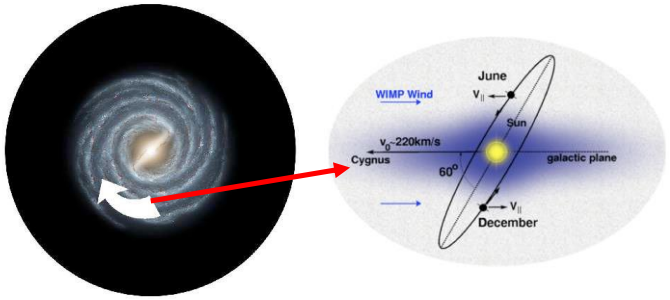
## Elastic Scattering

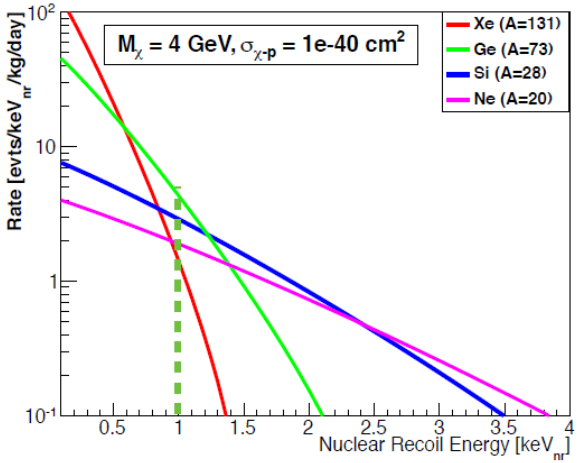



## Annual/ Diurnal Modulation

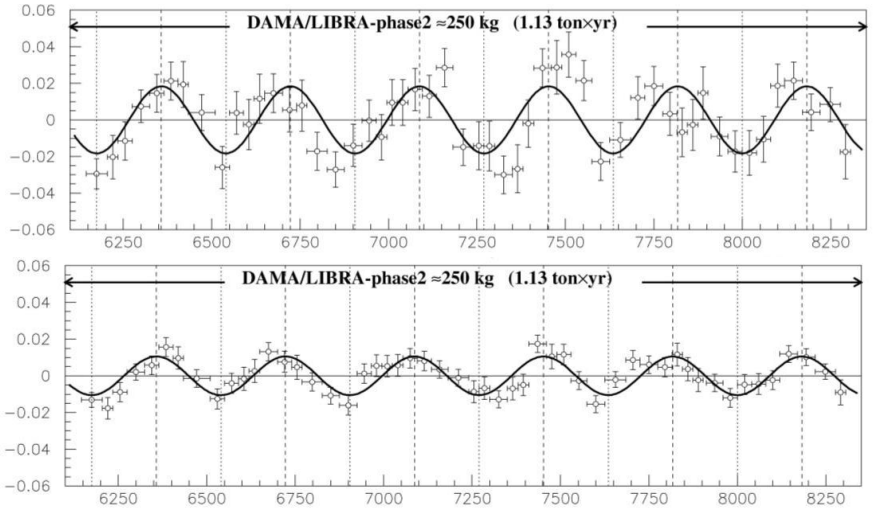



## Direction Detection

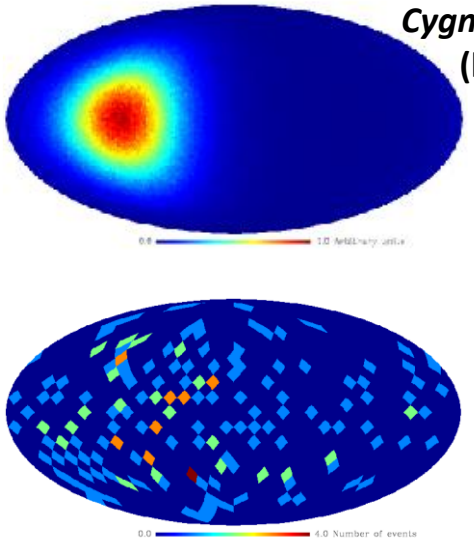



- Lower Background
- Lower Energy threshold
- Long-time stability




- Lower Background
- Long-time stability



*Cygnus Constellation*
(l = 90°,b = 0°)

- Angular Resolution (<20°)

# China Dark matter EXperiment

- Formed in 2009, now ~70 scientists and graduate students;
- Direct detection of light DM by P-type Point-Contact (PPC) Ge detectors.

清華大學 Tsinghua University

四川大學 SICHUAN UNIVERSITY

北京師範大學 BEIJING NORMAL UNIVERSITY

中國原子能科學研究院 CHINA INSTITUTE OF ATOMIC ENERGY

南開大學 Nankai University


雅砻江水电 YALONG HYDRO

北京大學 PEKING UNIVERSITY

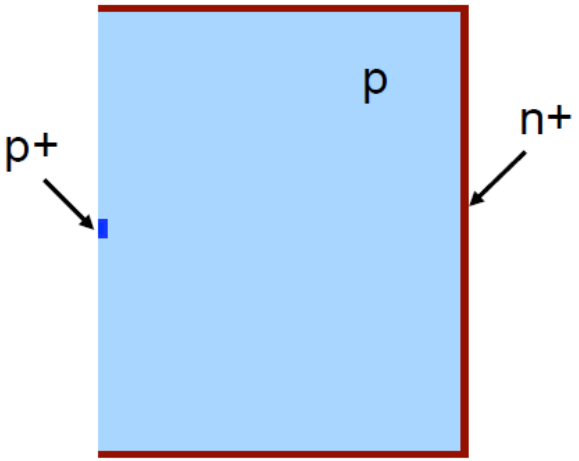
中山大學 SUN YAT-SEN UNIVERSITY

TEXONO

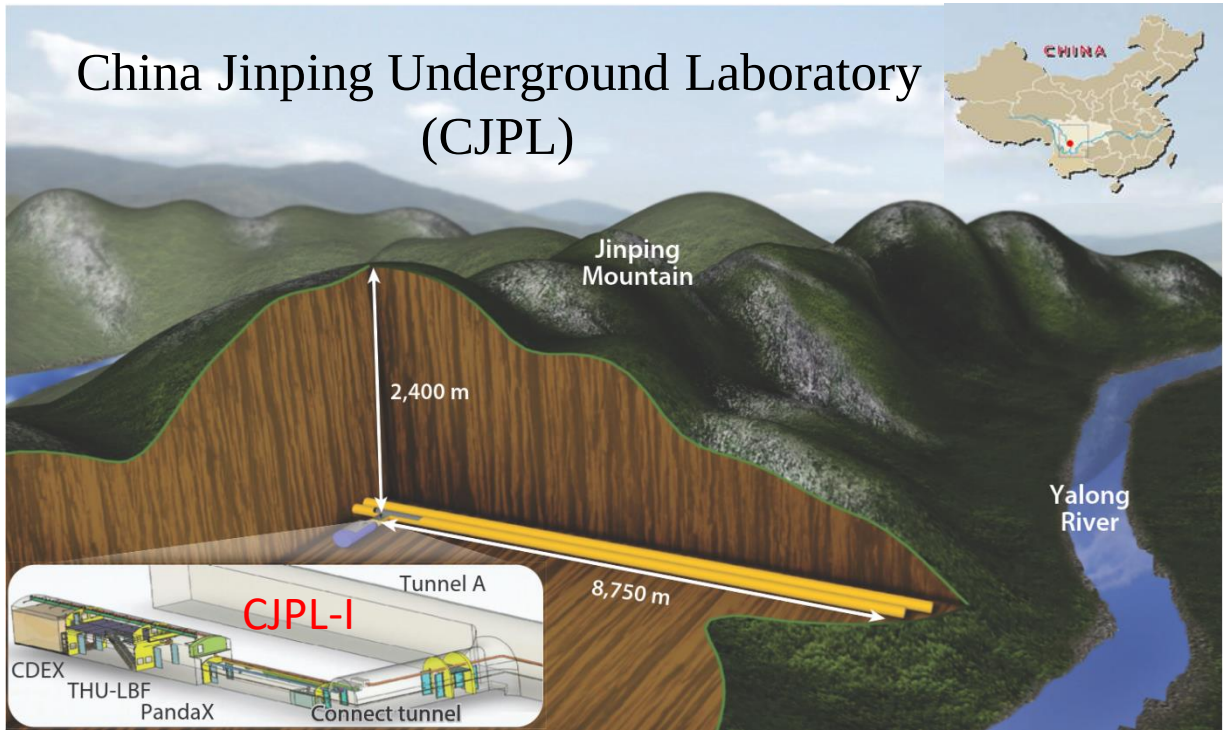
# CDEX Stages

- DM detection w/ Ge prepared since 2003 and started in 2005 in Y2L (5g);
- **CDEX-1:** Development of PPC Ge detector, bkg understanding, since 2011;
- **CDEX-10:** Performances of Ge array detector immersed in $LN_2$, since 2016;
- **CDEX-10X:** Home-made Ge detector and Ge crystal growth;

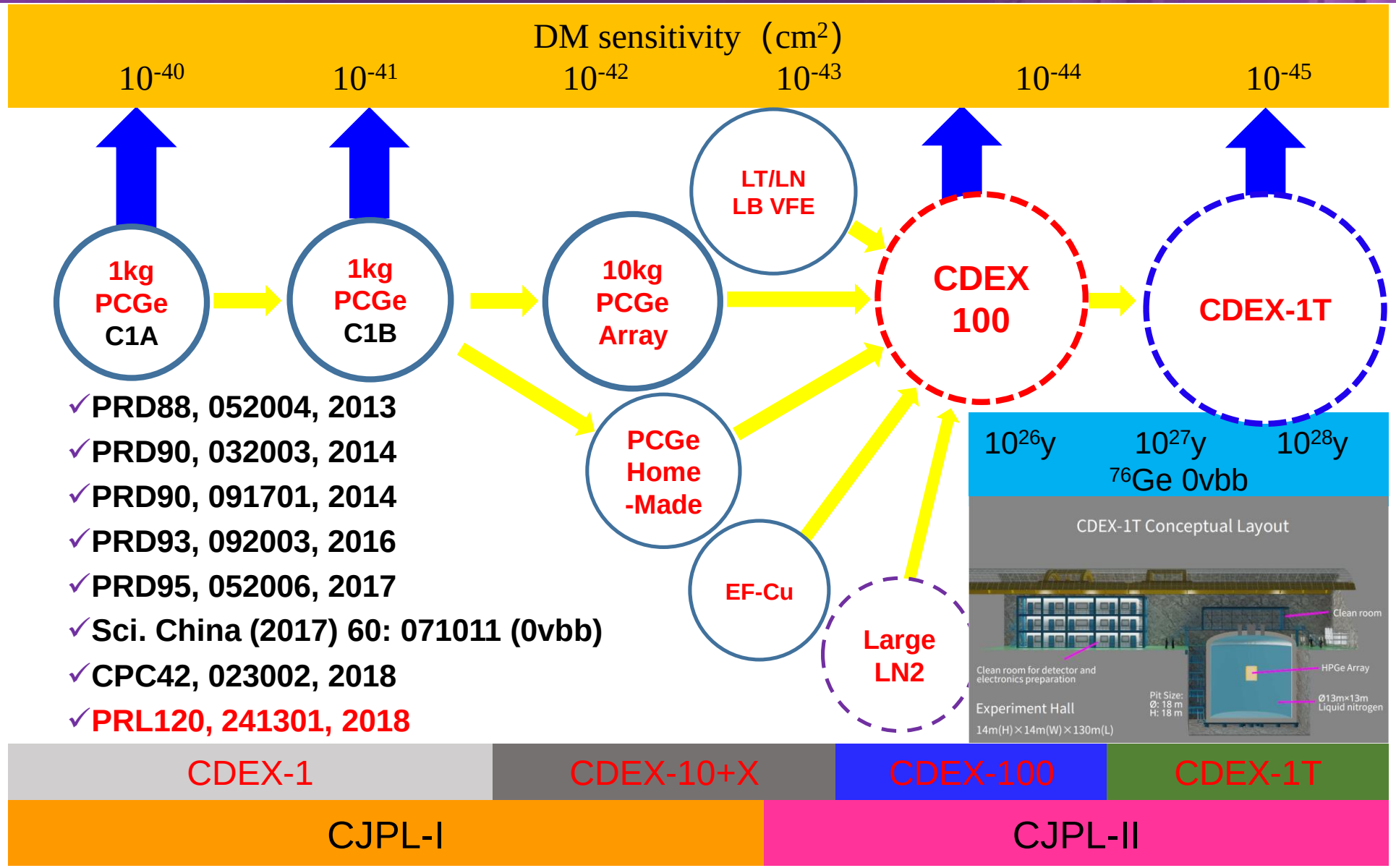
P-type Point-Contact(PPC)
Germanium detector




Direct detection of low-mass WIMPs w/ Ge detector at CJPL.

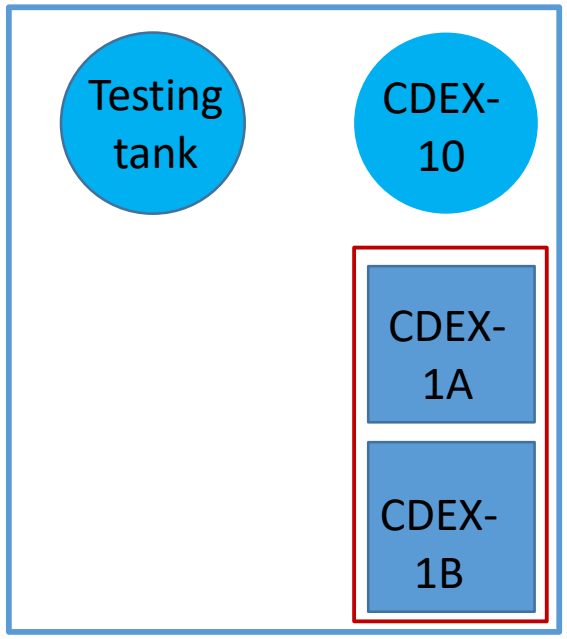


# CDEX Roadmap

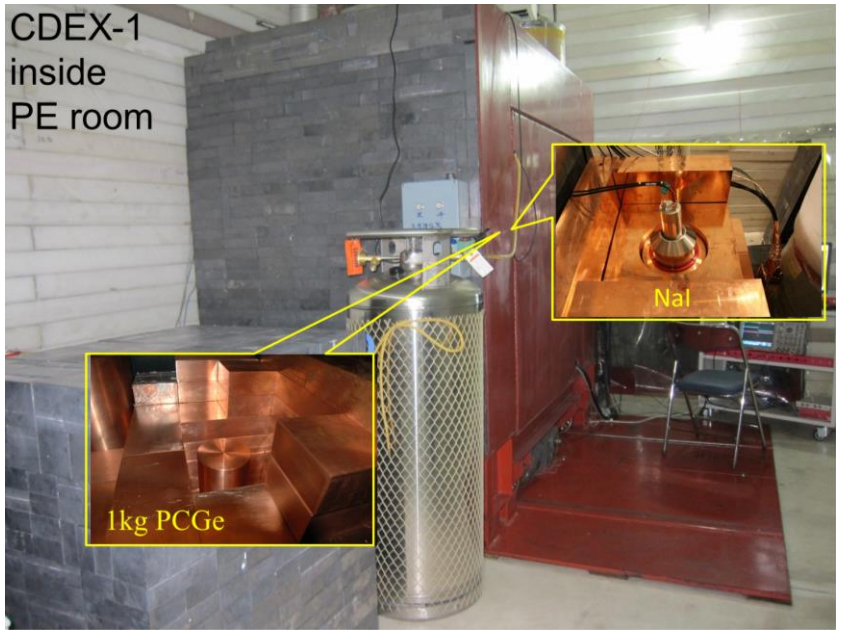


# CDEX-1 stage

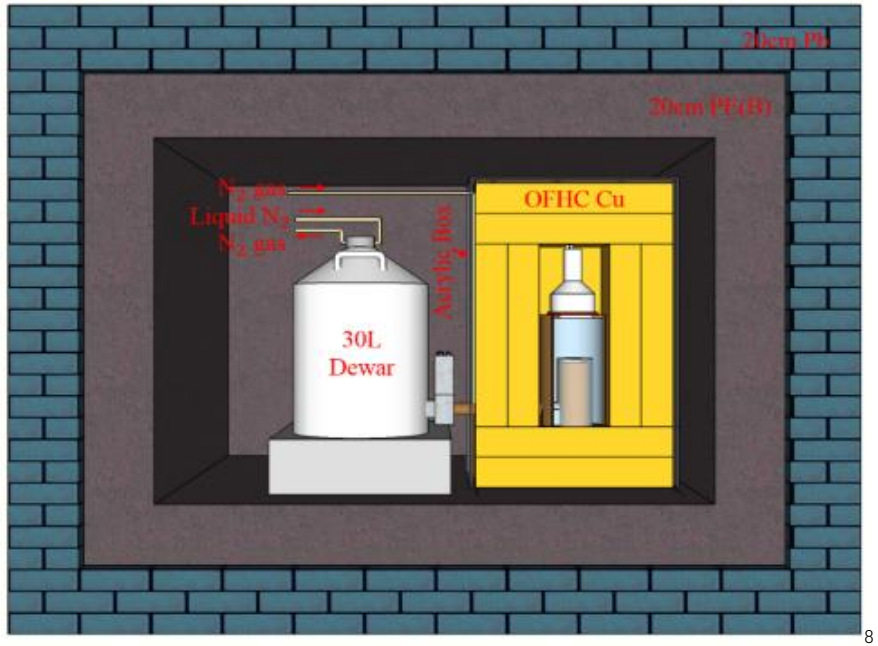
- 2 sub-stages: CDEX-1A(prototype, 2011)→1B(upgraded, 2013);
- Traditional single-element ~1kg PPC Ge detector;
- Low-bkg Pb&Cu passive shield + NaI veto detector;
- Located in PE room at CJPL-I;




Layout of PE room, CJPL-I



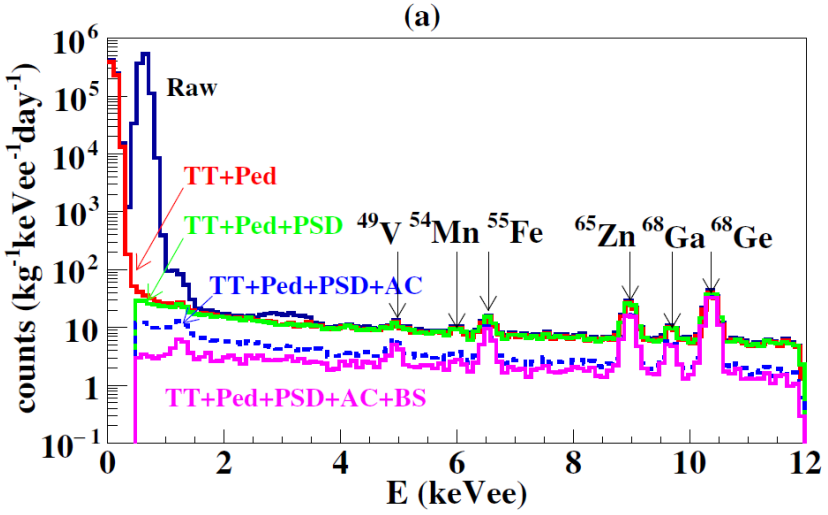

CDEX-1 inside PE room



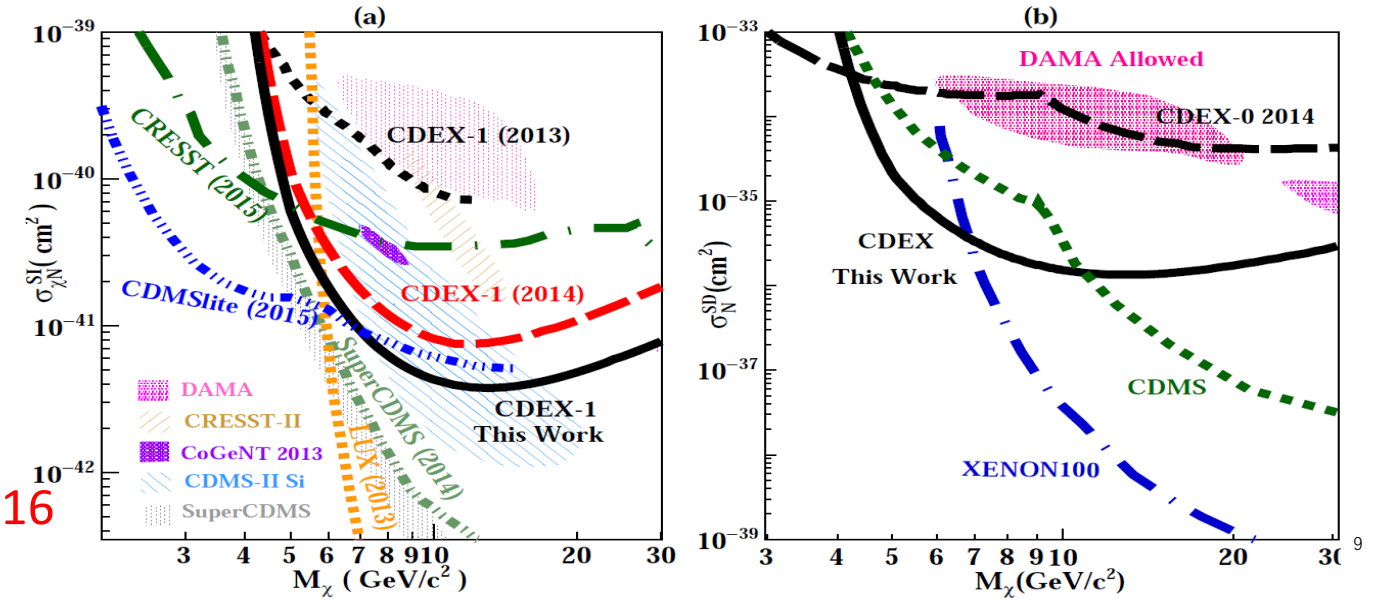

CDEX-1A&B: 1kg PPC Ge×2

# CDEX-1A Results

- >500 days run, ~336 kg·day dataset;
- Energy threshold: 475 eVee;
- Bulk/Surface disc. to cut events with slow rise-time and partial charge collection;
- K/L X-rays from Cosmogenic nuclides to trace crystal history;




- SI sensitivity improved;
- SD best below 6 GeV then;

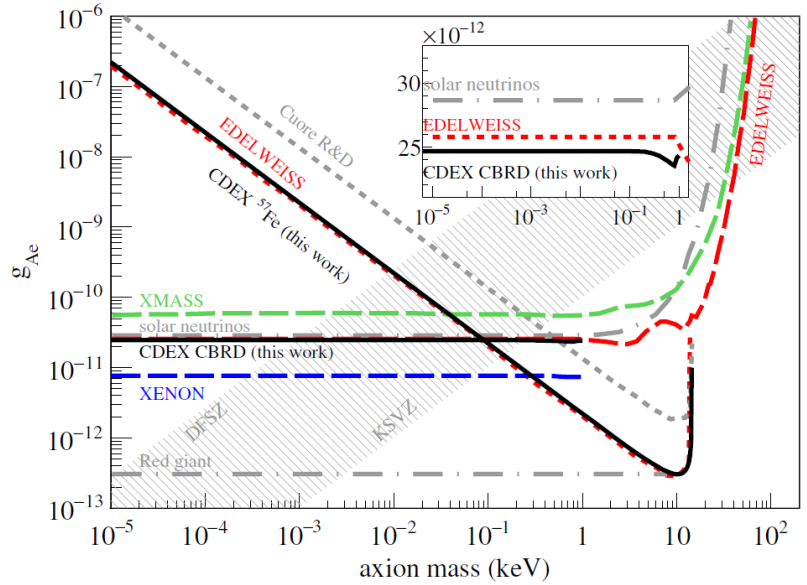


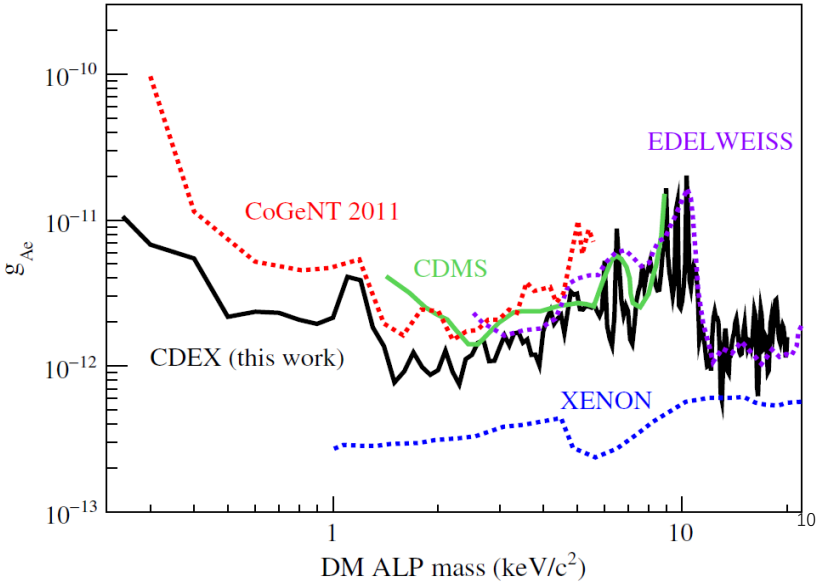

PRD93, 092003, 2016

# CDEX-1A Results

*PRD95, 052006, 2017*

- Axion (335.6 kg·day data)
  - Solar axions: CBRD processes and $^{57}$Fe M1 transition;
  - ALPs: more stringent constraint below 1 keV;



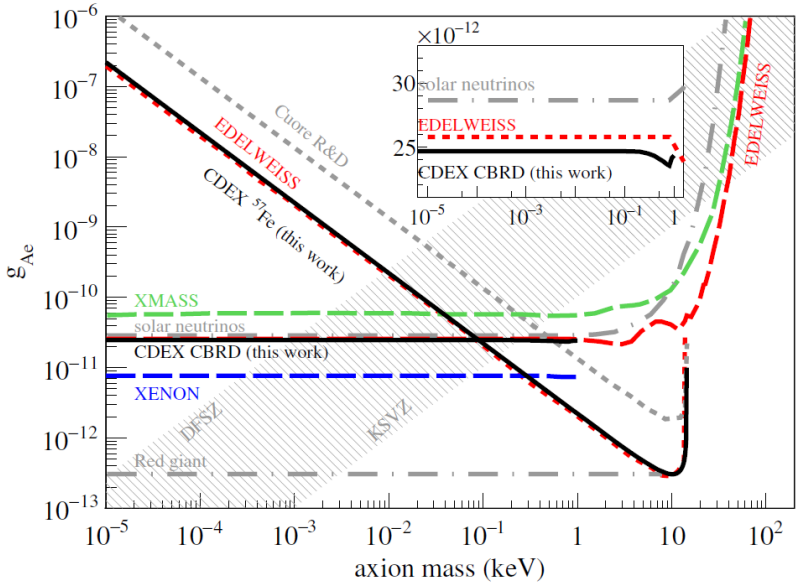
# CDEX-1A Results

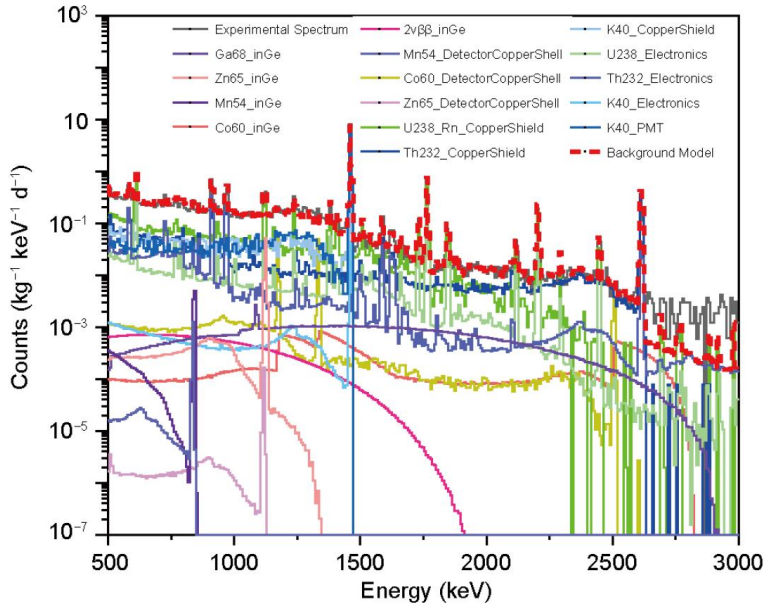
*PRD95, 052006, 2017*

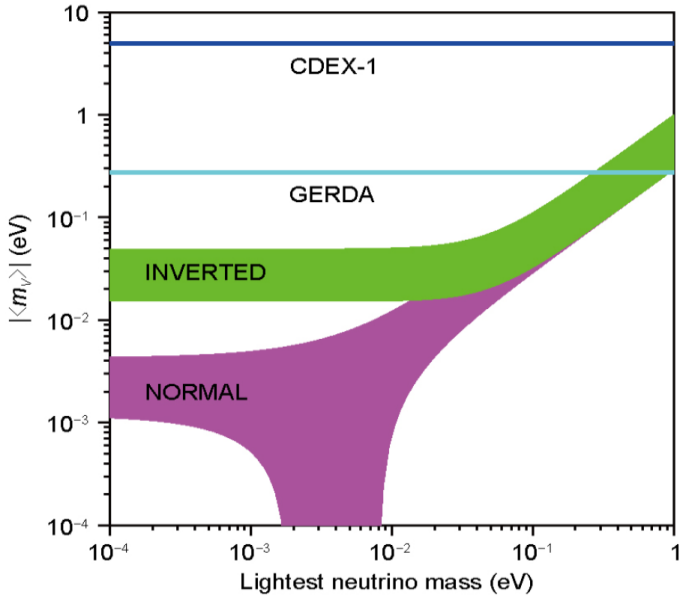
- Axion (335.6 kg·day data)
  - Solar axions: CBRD processes and $^{57}$Fe M1 transition;
  - ALPs: more stringent constraint below 1 keV;
- 0νββ (304 kg·day data)
  - Natural Ge crystal;

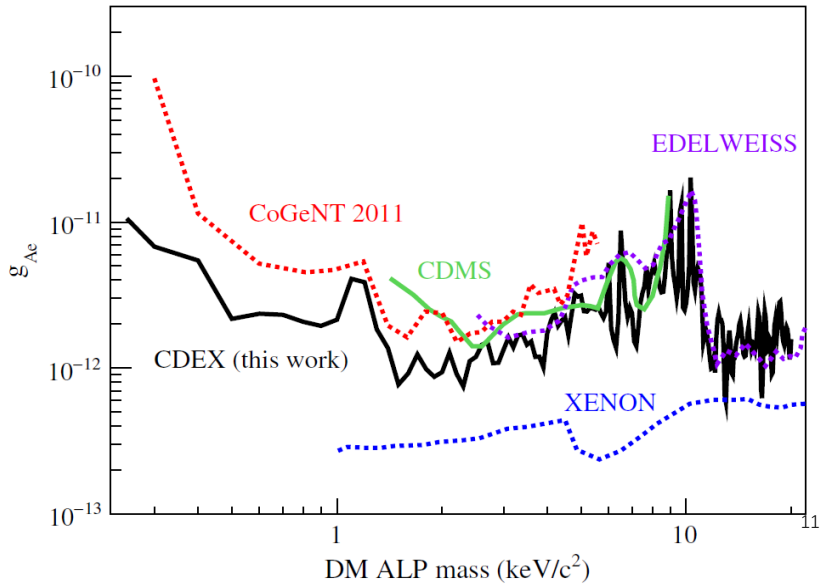
$$T_{1/2}^{0\nu} \geq 6.43\times10^{22}\ yr,\ 90\%\ C.L.$$

*Science China PMA (2017) 60: 071011*



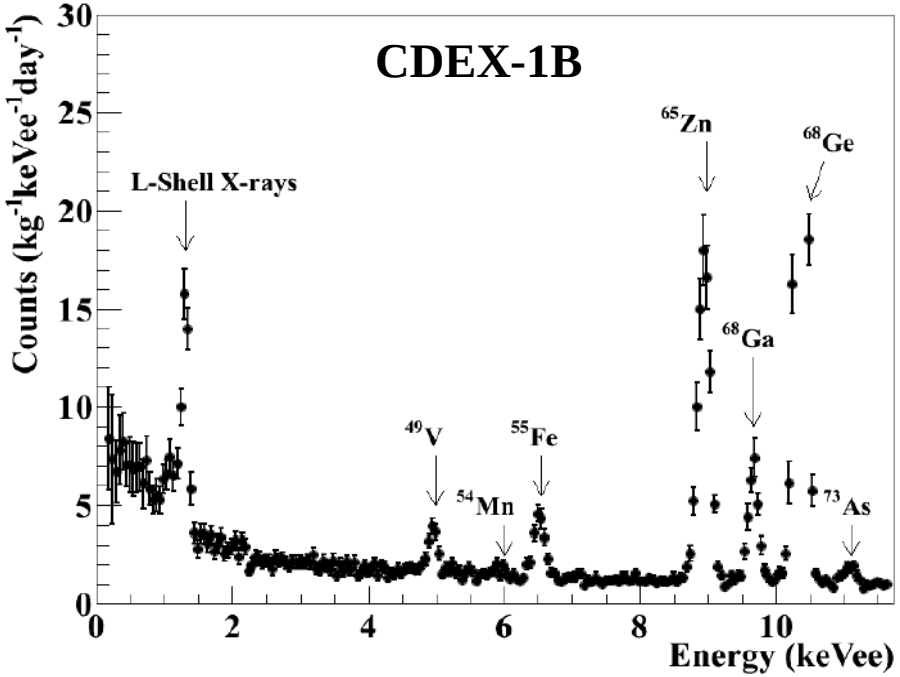
# CDEX-1B Results

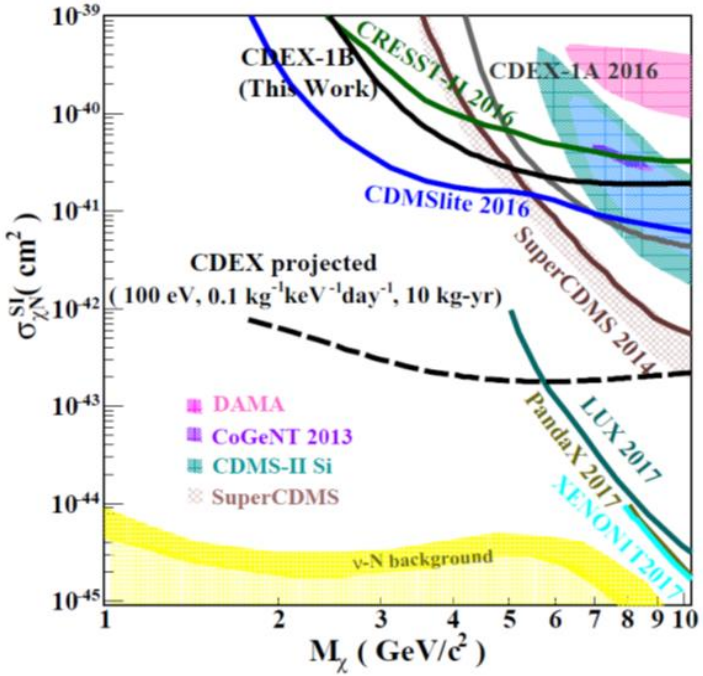
*CPC 42, 023002, 2018*

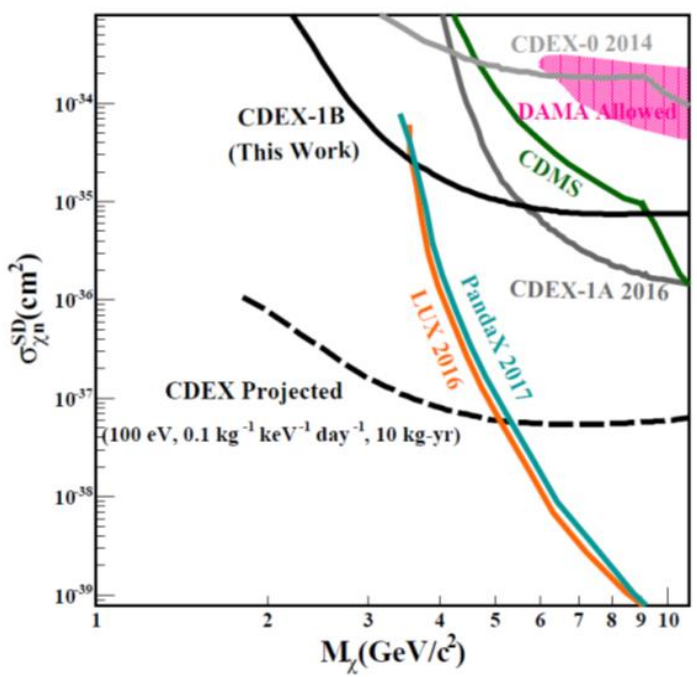
- Detector upgraded w/ lower JEFT noise and material bkg;
- >4 years run (Run-1&Run-2), >1200 kg·day exposure;
- Achieving 160 eVee energy threshold;
- Sensitivity improved and extending to 2 GeV/$c^2$.

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

Run-1 Time-integrated (TI) analysis: CPC 42, 023002, 2018



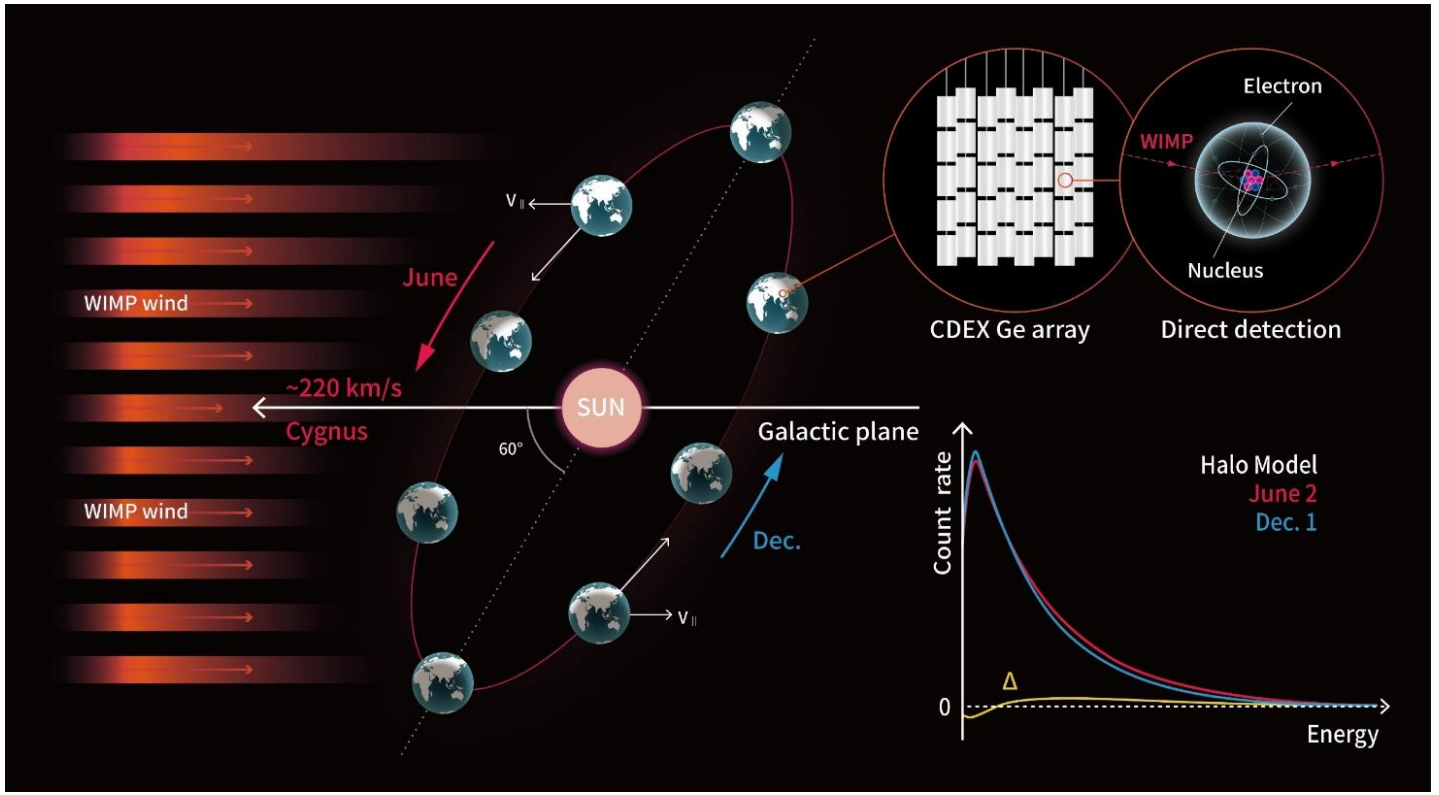



# WIMPs: Annual Modulation analysis from CDEX-1B

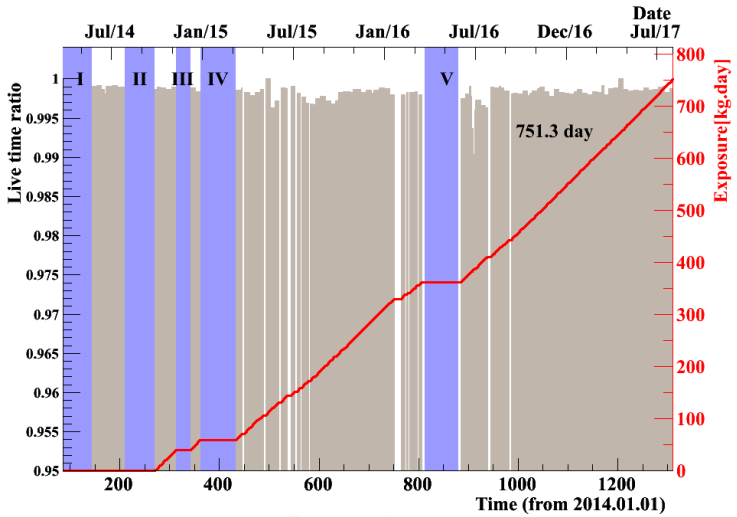
[ arxiv: 1904.12889 ]

- AM provide smoking-gun signatures for WIMPs independent of astrophysics models, while only requires **background** at relevant energy range is **stable with time;**
- The χN rates have distinctive AM features with maximum intensity in June due to Earth's motion relative to the galactic WIMP-halo.

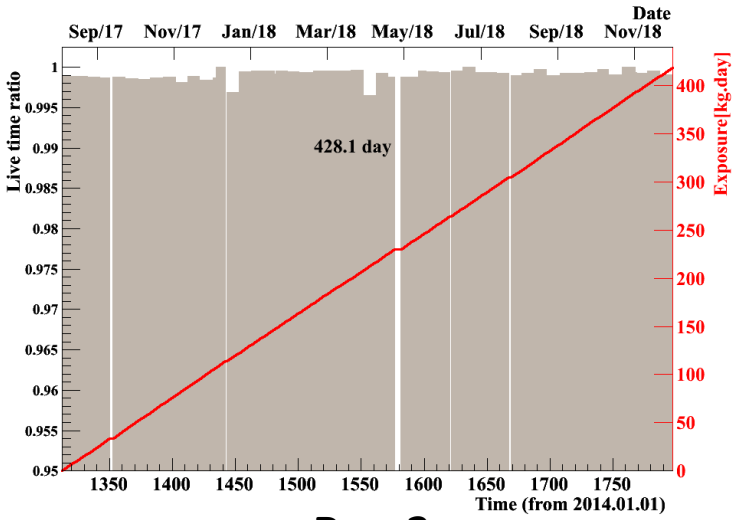


# CDEX-1B Annual Modulation analysis

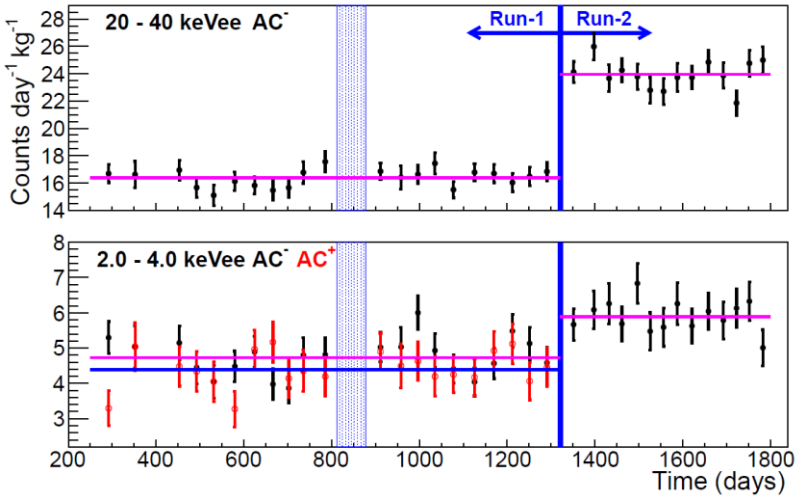
[ arxiv: 1904.12889 ]



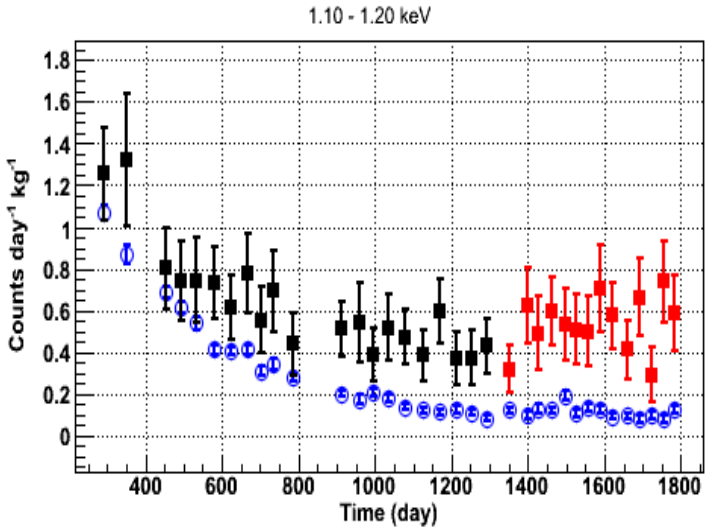

**Run-1**



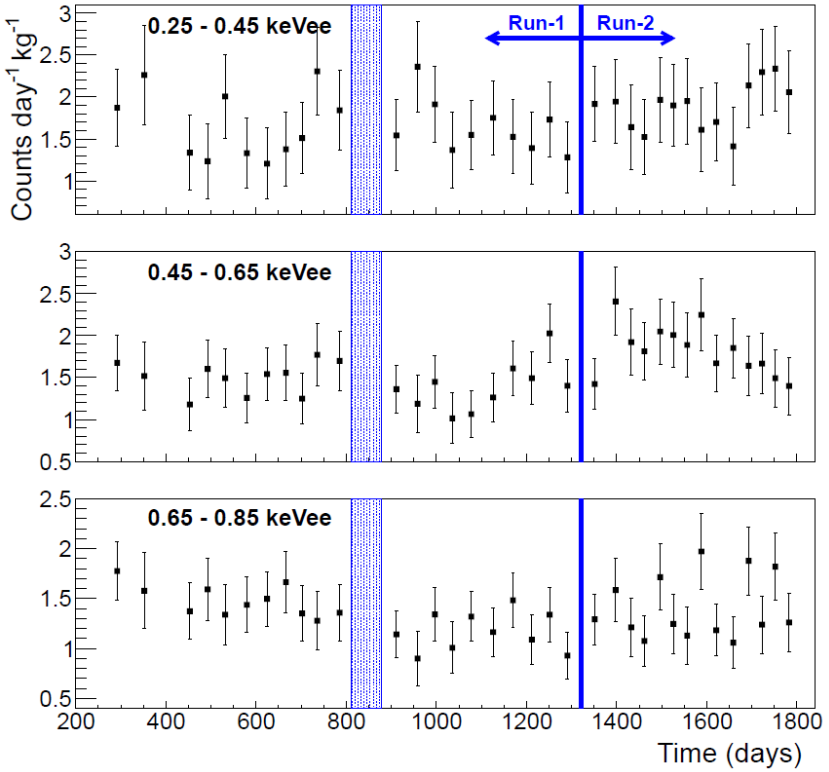

**Run-2**




**Compton contribution from High-energy gammas**



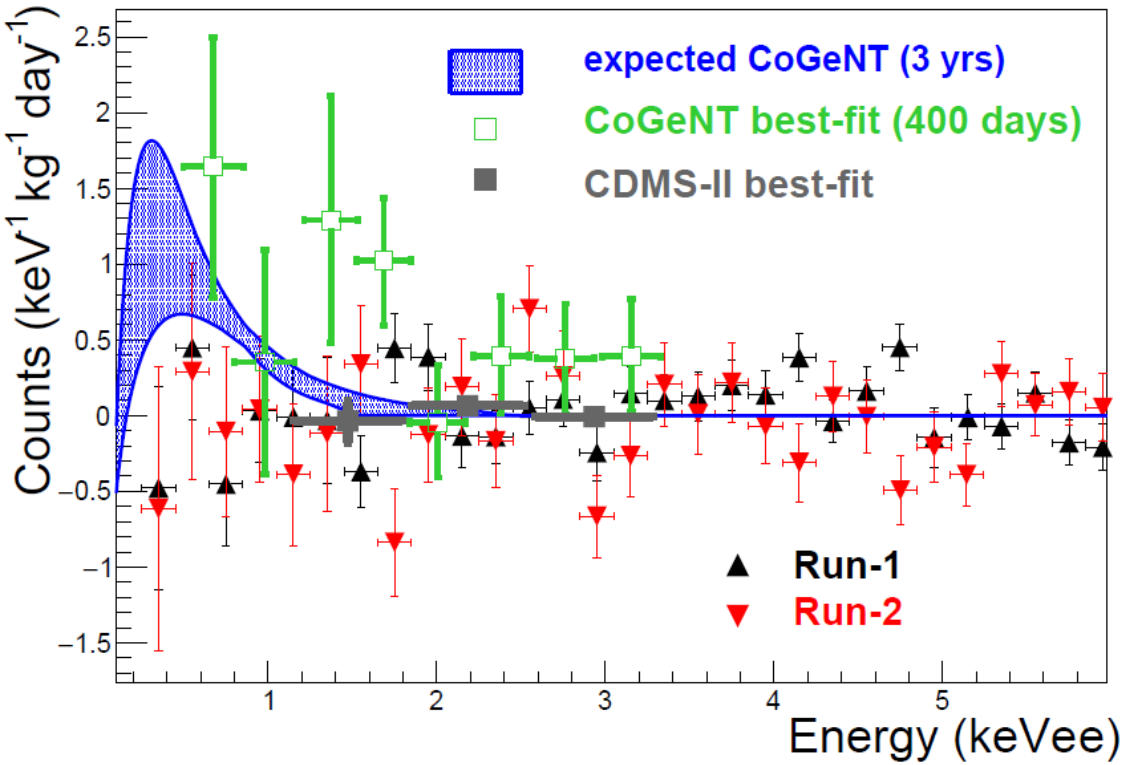

**L-Shell X-ray contribution – time varying**

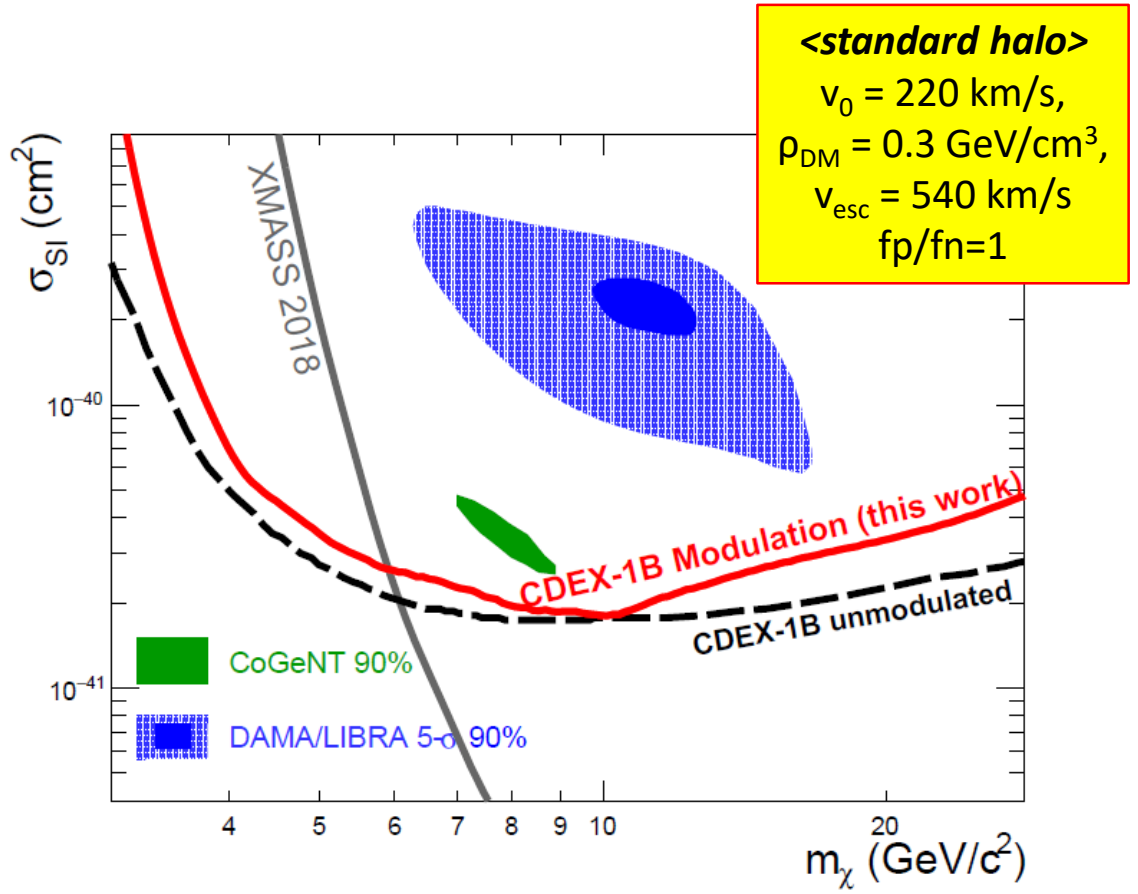



$$\chi^2_{ik} = \sum_{j\in \mathrm{Time}}^{N} \frac{(n_{ijk} - P_{ijk} - B_{ik} - A_{ik}cos(\frac{2\pi(t_j-\phi)}{T_{yr}}))^2}{\Delta^2_{ijk}}$$

# CDEX-1B Annual Modulation analysis

[ arxiv: 1904.12889 ]



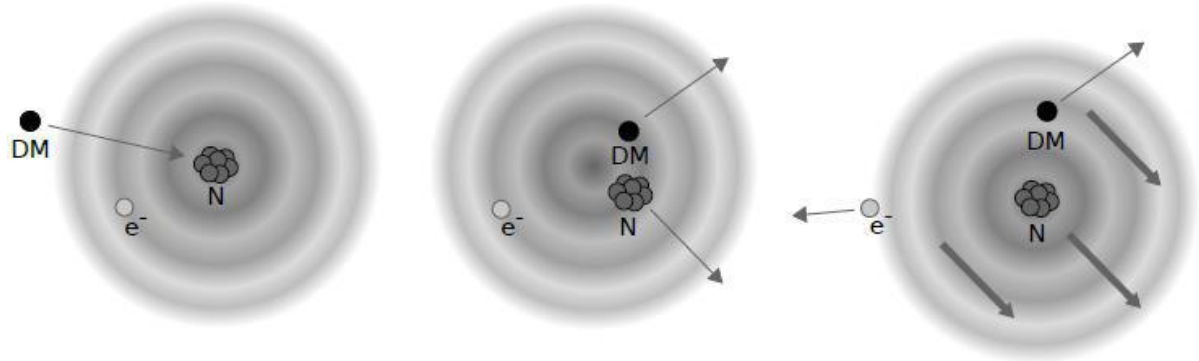




✓ **CDEX-1B excludes DAMA/LIBRA phase-1's interpretation with the spin-independent WIMP interaction with Standard Halo model in Germanium crystal.**

# sub-GeV WIMPs: Migdal effect analysis

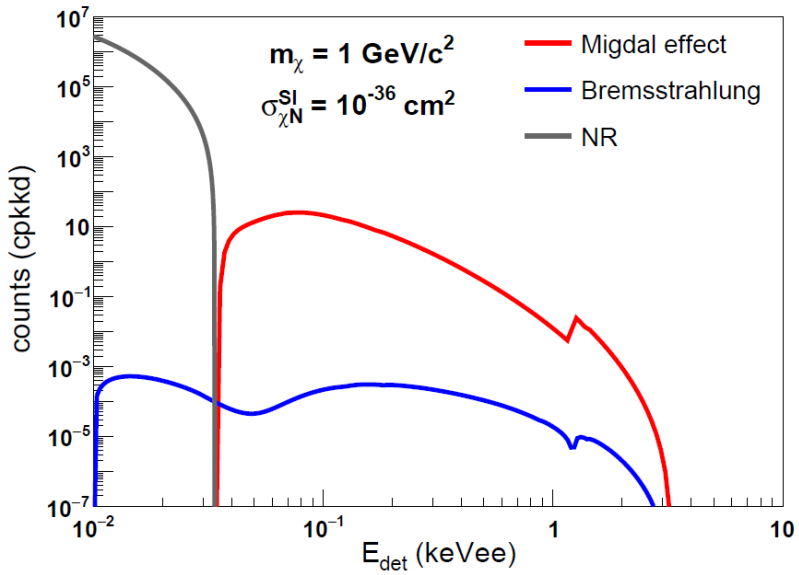
[ arxiv: 1905.00354 ]

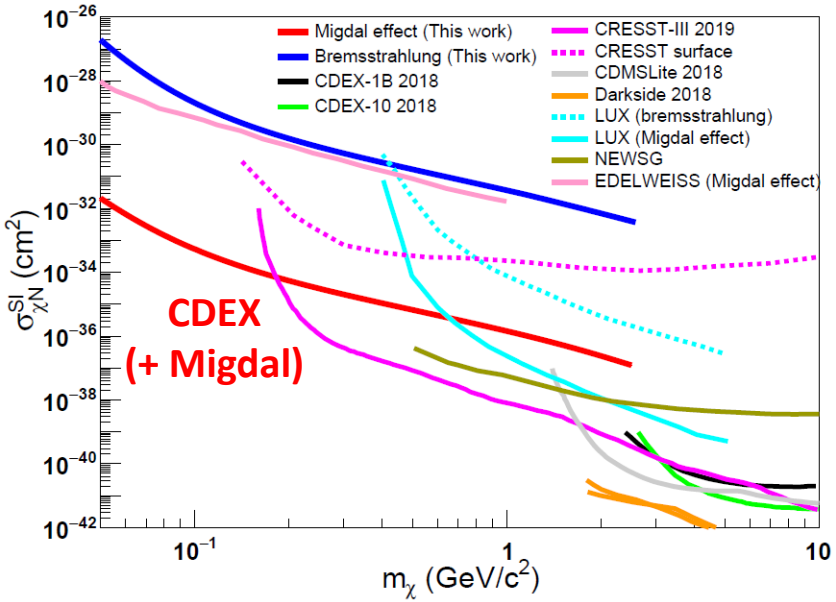
Migdal effect

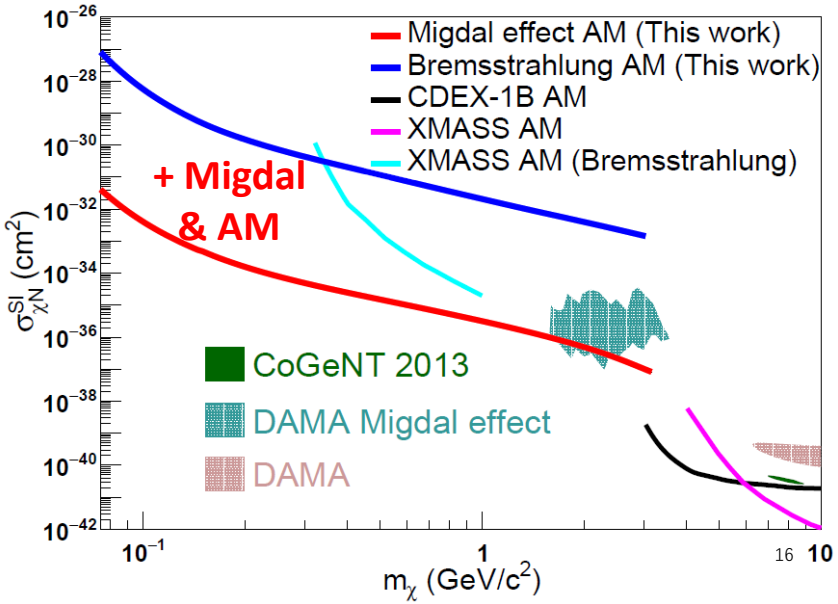



- Time-Integrated Analysis with Migdal: 737.1 kg-d ; 160 eVee threshold
- AM Analysis: 1107.5 kg-d ; 250 eVee threshold.
- Lead sensitivity in $m_{DM}$ ~ 50-180 MeV

**Expected measureable spectra** **[ arxiv: 1905.00354 ]**

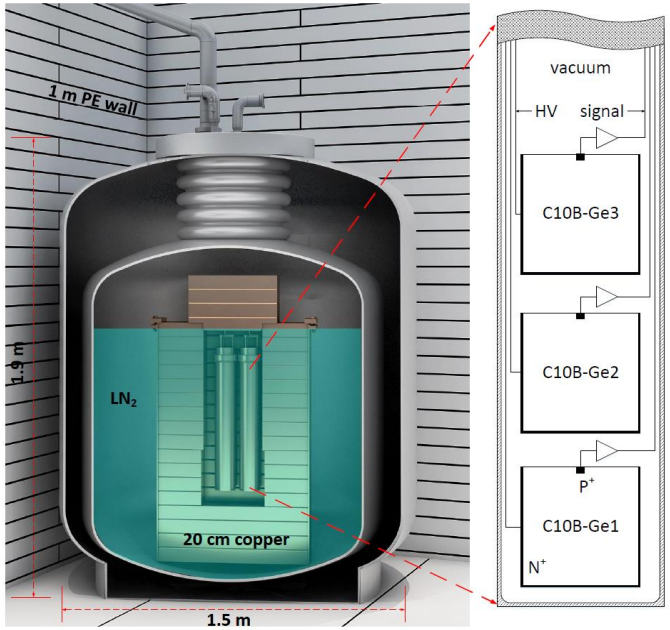


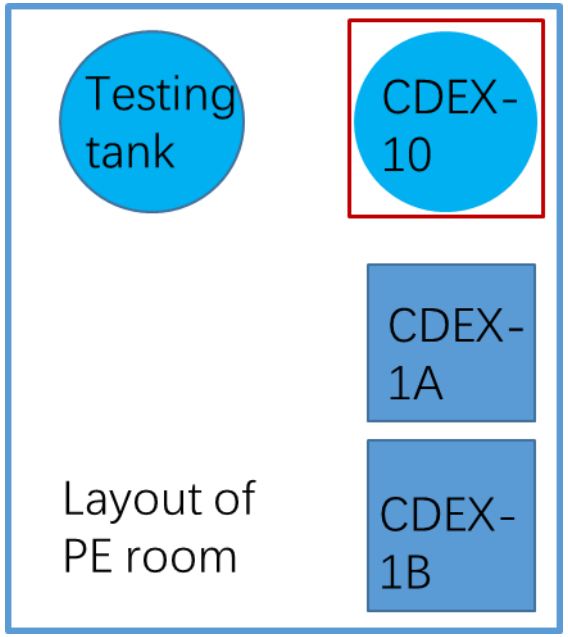



# CDEX-10 stage

- 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;



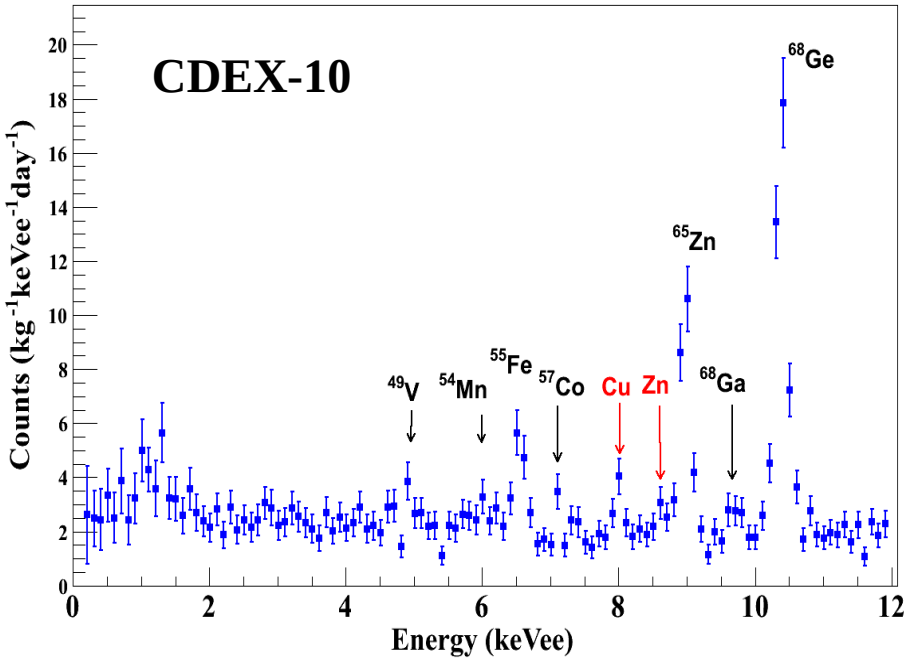

CDEX-10: ~10kg PPC Ge array

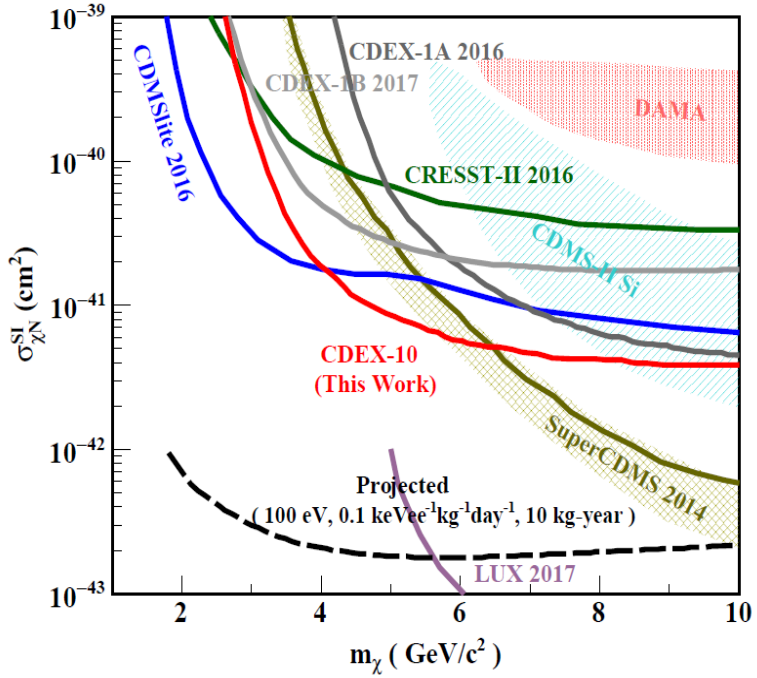


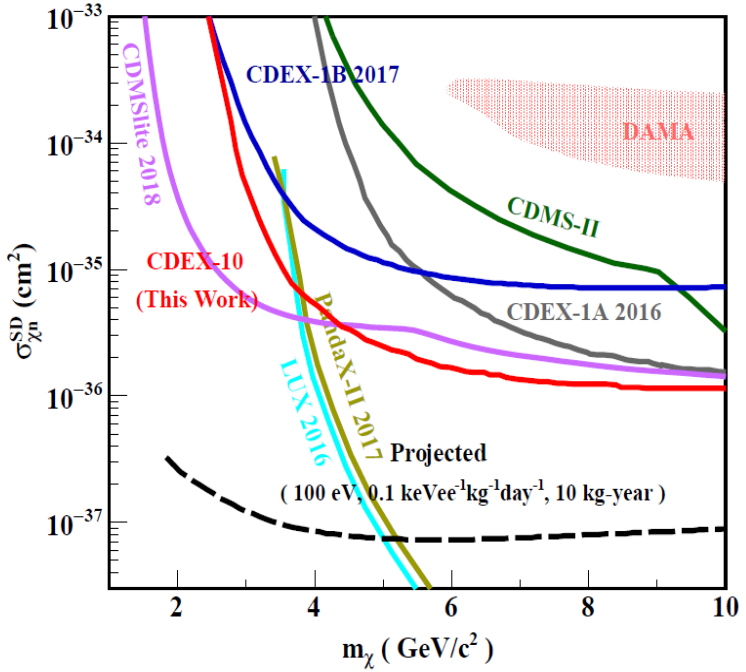
# CDEX-10 First Results

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

PRL120, 241301, 2018



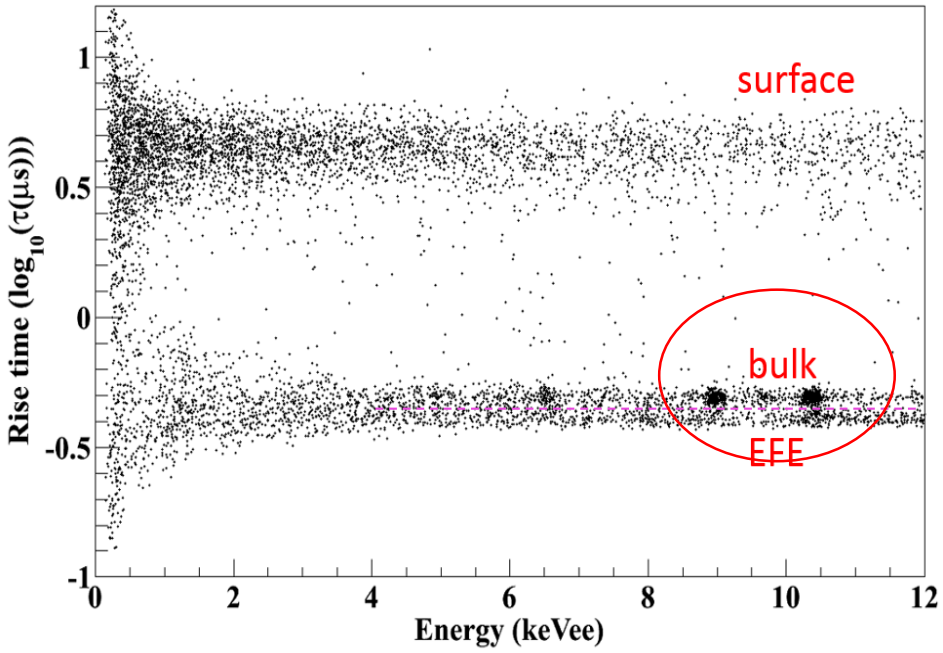



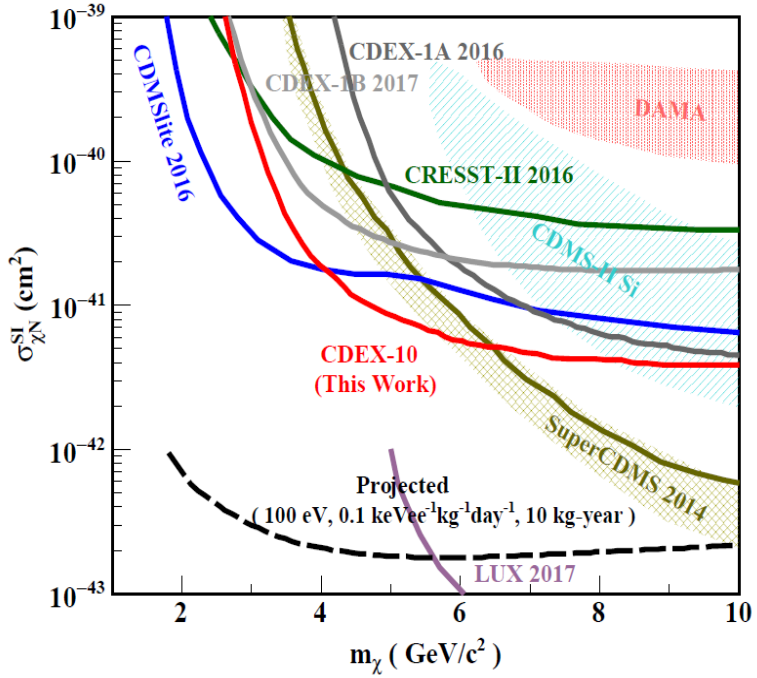
# CDEX-10 First Results

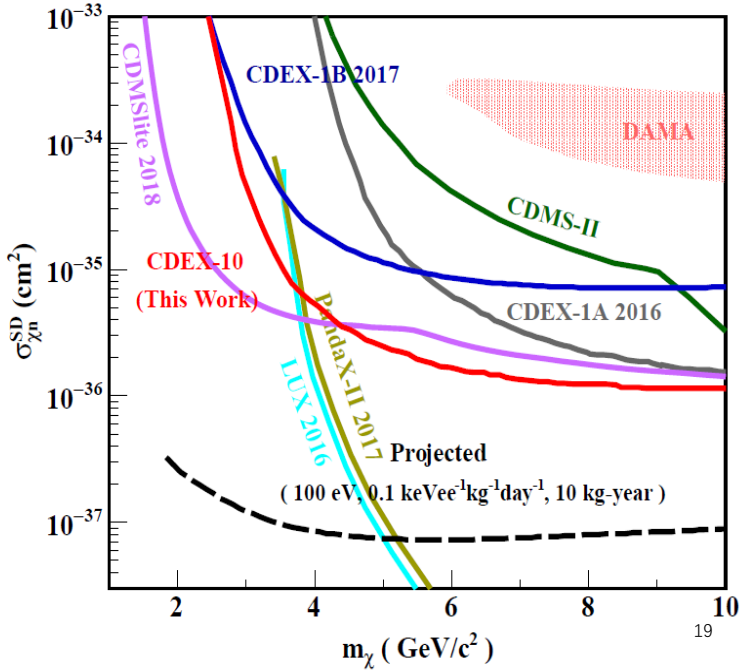
- First results from 102.8 kg·day exposure w/ Eth 160eV;
- Bkg level: ~2 cpkkd @ 2-4 keV;
- New SI limit on 4-5 GeV/$c^2$;
- Ultra-fast events observed in bulk;

Sci. China-Phys. Mech. Astron. 62, 031012 (2019 )




PRL120, 241301, 2018



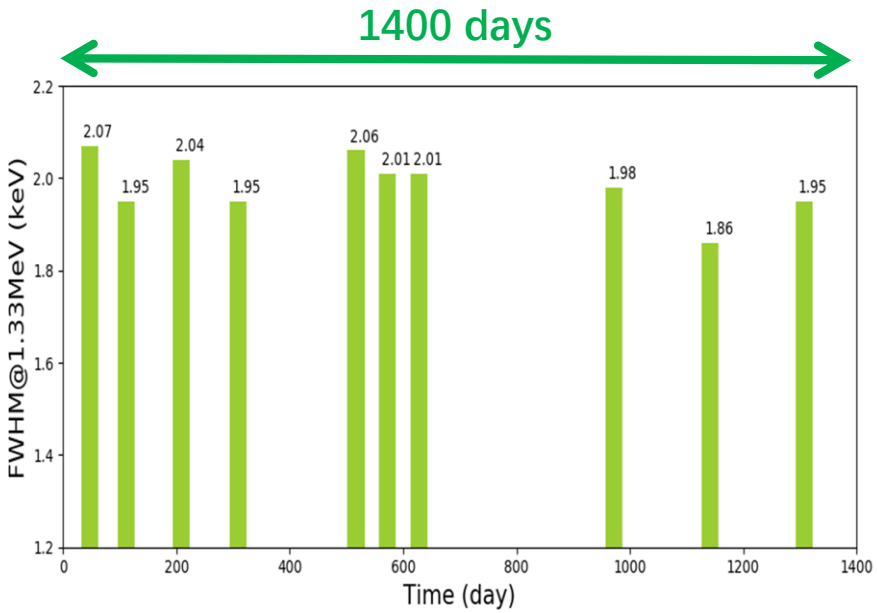



# CDEX-10X: Ge detector fabrication

- CDEX10+X home-made Ge detectors;
- Understand & reduce detector intrinsic bkg;
- Various types, ~20 detectors
  - P-type planar/coaxial;
  - P-type point contact/ BEGe;
- Long time stability

✓ Commercial Ge crystal;
✓ Structure machining;
✓ Li-drift and B-implanted;
✓ Home-made ULB PreAmp;
✓ Underground EF-Cu;
✓ Underground assemble;
✓ Underground testing…

good performance keeping, >1400 days

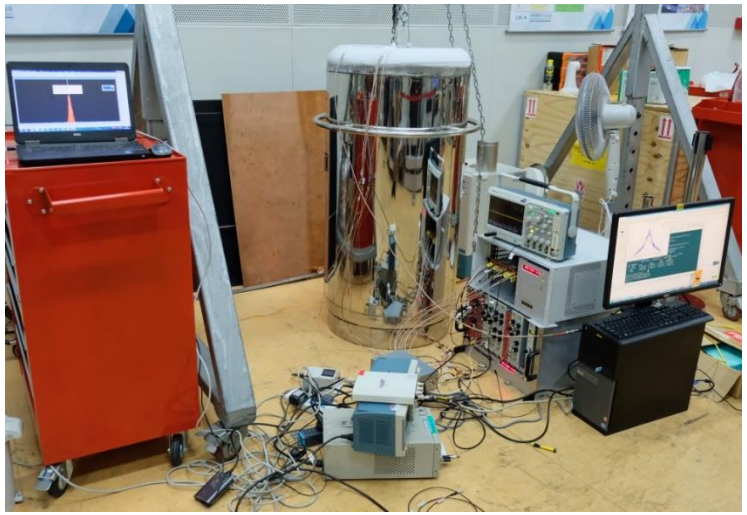




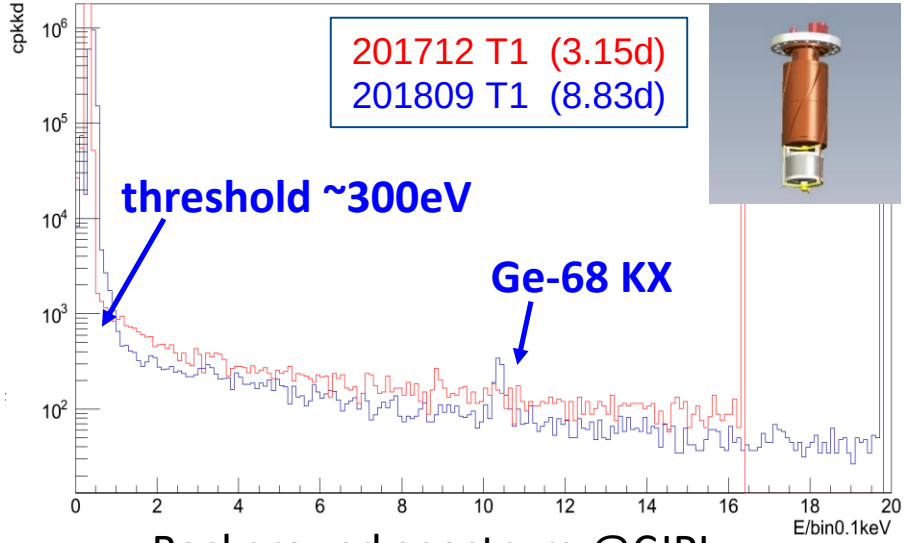
Vacuum systems

# CDEX-10X Detector (T1)

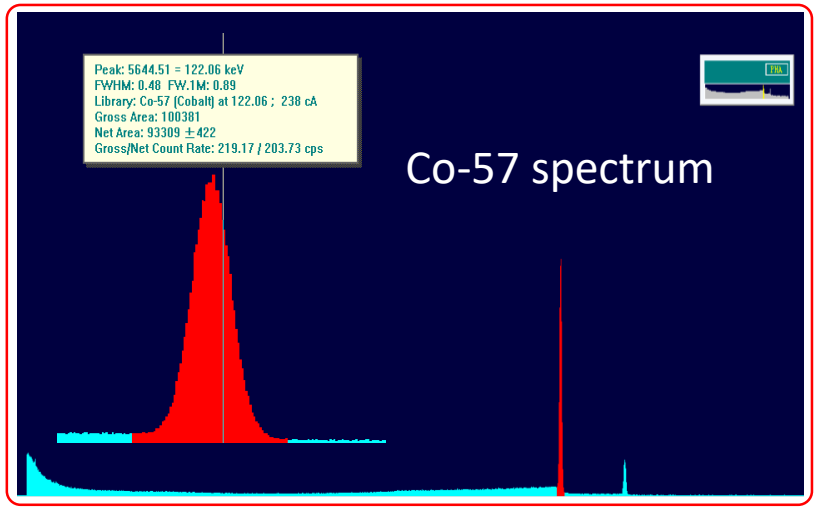
- Commercial Ge crystal + stainless steel canister;
- T1 detector: 500g Ge(φ50×50mm) + CMOS ASIC preAmp;
- Works, and Performance expected;
- Going on to improve bkg, low-noise electronics…



Tested in CJPL-I




Background spectrum @CJPL



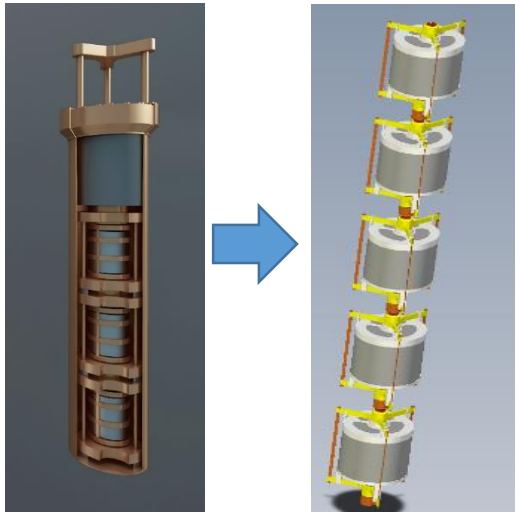

FWHM=0.48keV@122keV_Co57

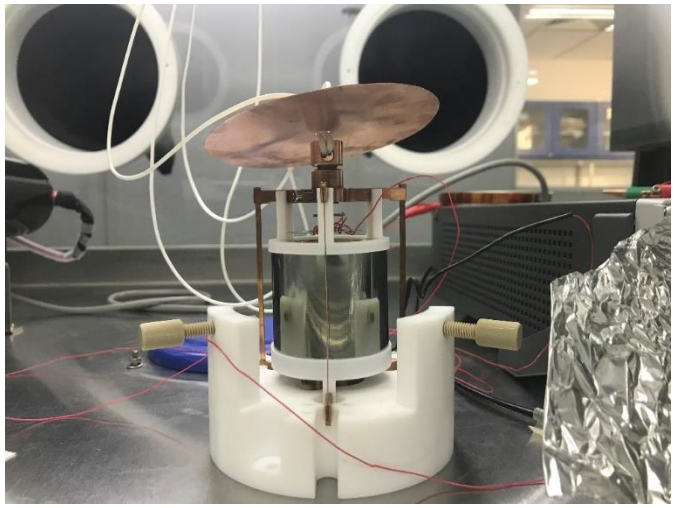
# CDEX-10X Detector (Bare HPGe detectors in $LN_2$)

- Vacuum chamber, structure materials, not conducive to further reduce the radioactive background;
- ASIC-based preamplifiers can work well in liquid nitrogen;

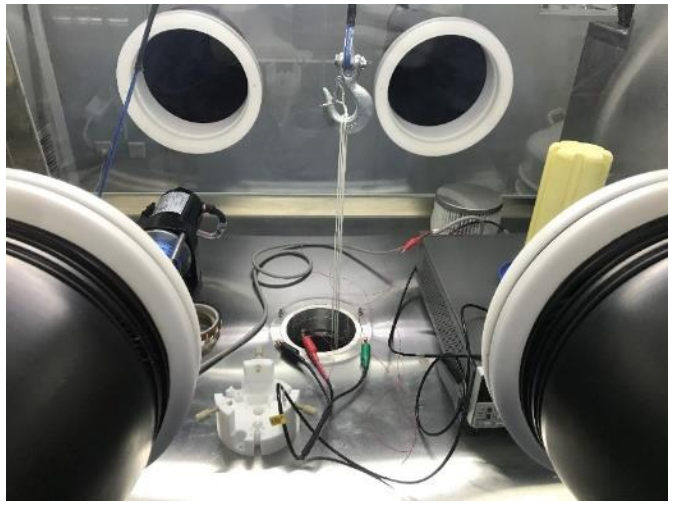
✓ Develop bare HPGe detectors immersed into $LN_2$!

✓ Immerse the detector into liquid nitrogen for about 8 hours, we got a stable leakage current ~10 pA for 1000V bias voltage.



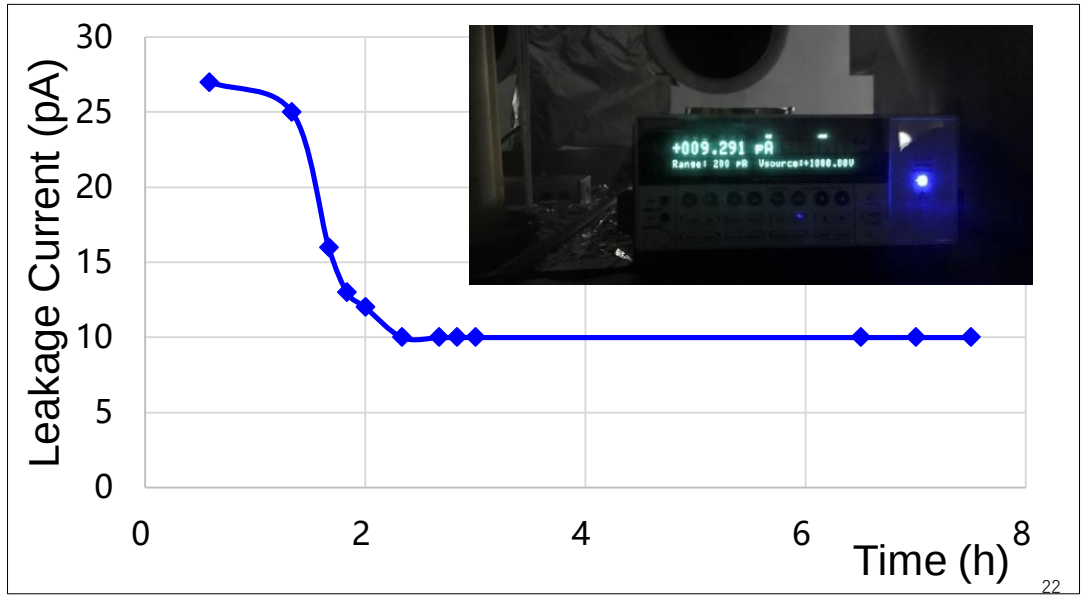


Bare HPGe detectors



Bare HPGe in $LN_2$

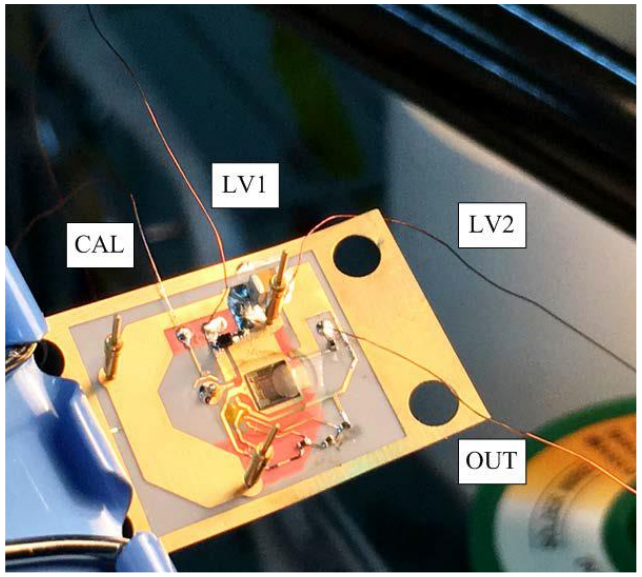
PPC: ϕ50mm x 50mm, Depleted voltage: ~800V

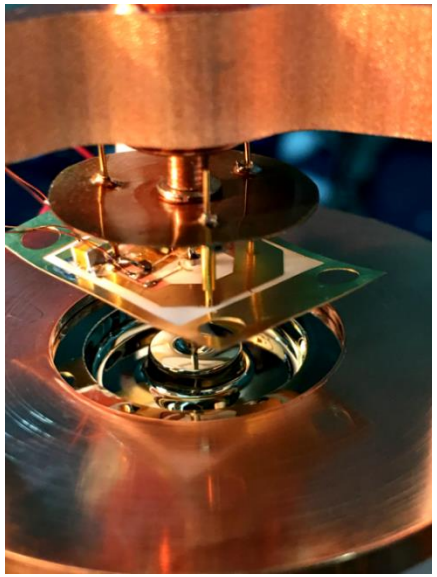


# CMOS ASIC Front-end Electronics

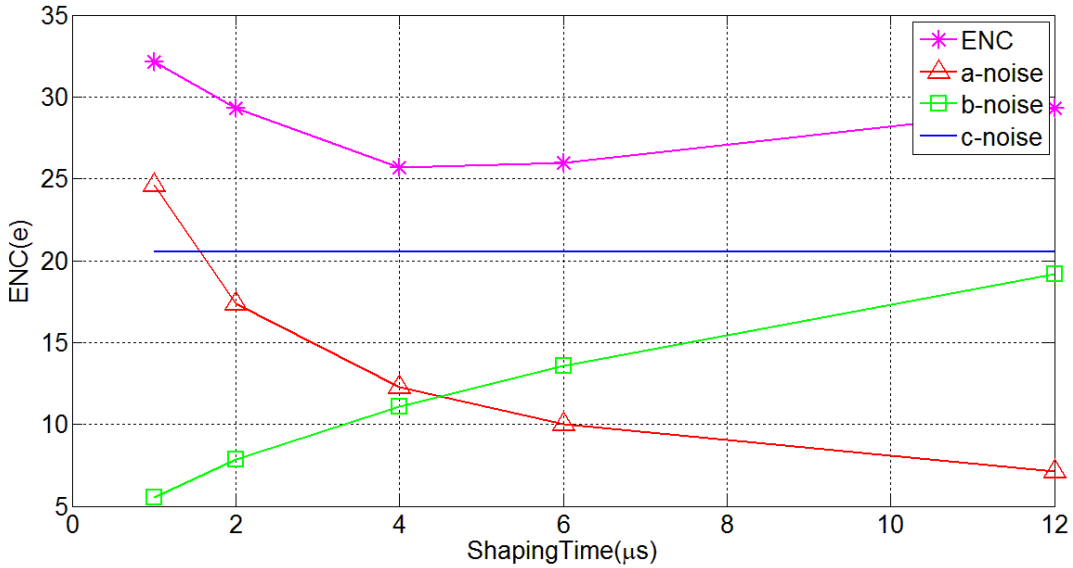
- Light DM search →low noise/threshold (low capacity, etc)
- Very close to Ge detectors →low bkg (radiopure, low-mass, etc)
- ASIC preamplifier @ 77K
  - PCB material: PTFE(Rogers 4850);
  - ENC ~26e(<200eV) w/ 4μs shaping time, mainly from 1/f noise (~21e);

JINST (2018) 13: 8019



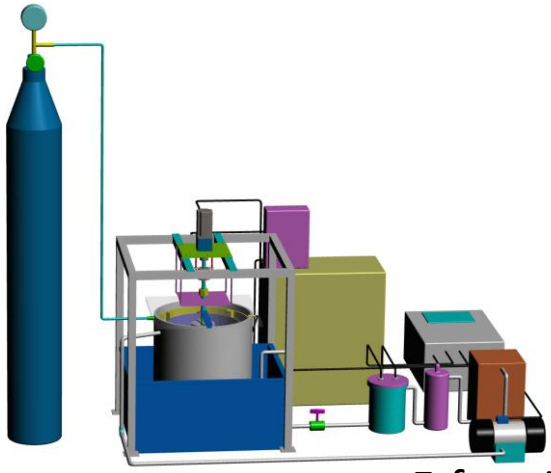
Noise components analysis



# Underground E-forming copper and Assay

- Prototype setup for underground EF-Cu production
  - Cathode mandrel: 316L stainless steel, φ95x380mm;
  - Plating bath: PE, φ400x500mm;
  - Goal: Majorana copper, U/Th content ~ O(0.1μBq/kg);
- Test run in Tsinghua U. and moved to CJPL-I;
- U/Th Analysis by ICP-MS
  - Wet chemistry testing… , blank sensitivity ~$10^{-13}$g/g

UG copper e-forming facilities@CJPL-I



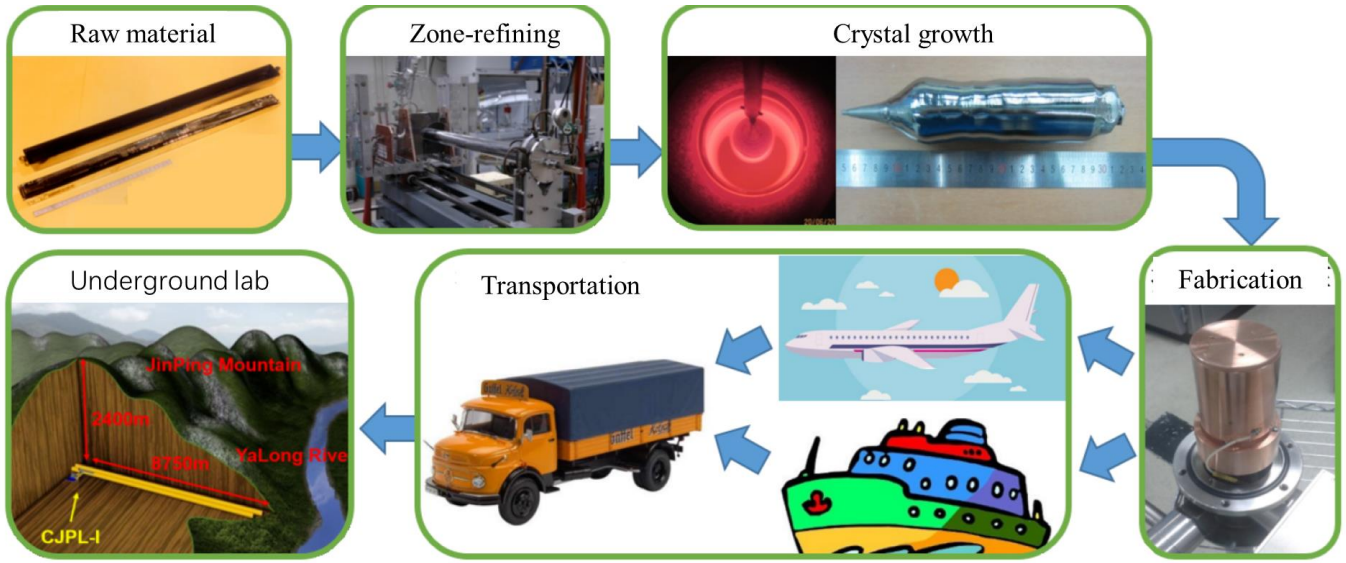
E-forming setup

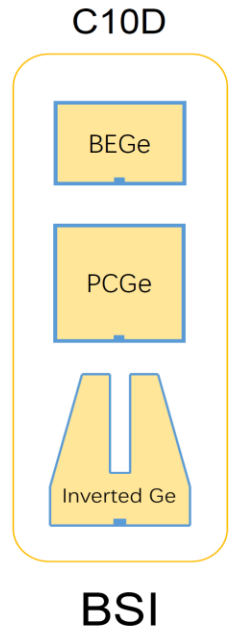

optimized electrical parameters

ICP-MS

# Future Plan - Detector

- New detectors cooperated with commercial companies
  - 3kg from BSI, 2kg from ORTEC, planning 5kg from CANBERRA/ORTEC;
  - Particular control of detector fabrication process above ground;
- Home-made detectors
  - Improve T1 w/ low bkg material and low noise electronics;
  - Set up underground fabrication and testing facility;



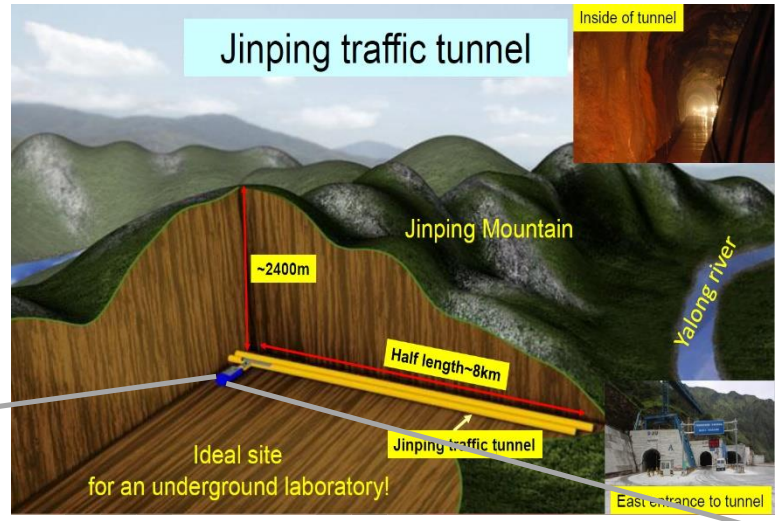



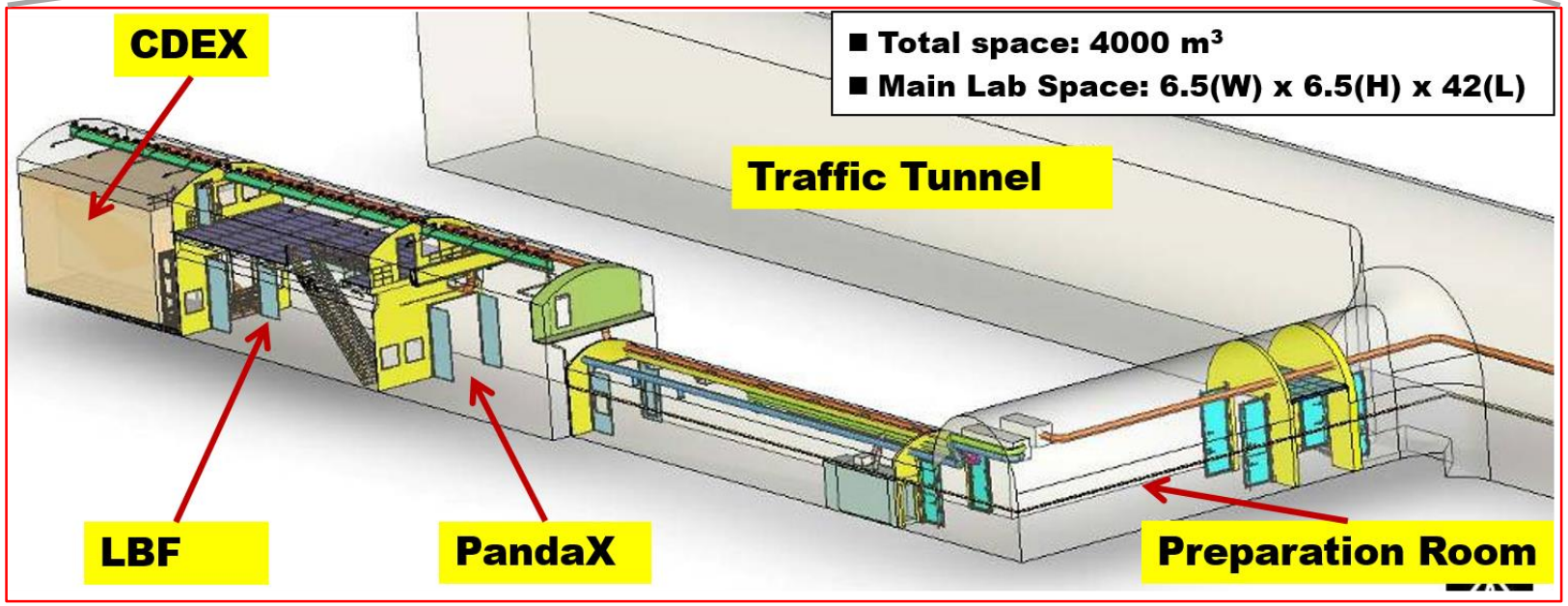

Detector production: 45days +
Ground transportation: 60 days +
Underground cooling: 180days →

Cosmogenic bkg: 0.03cpkkd(sim.)

# Future Plan - Lab

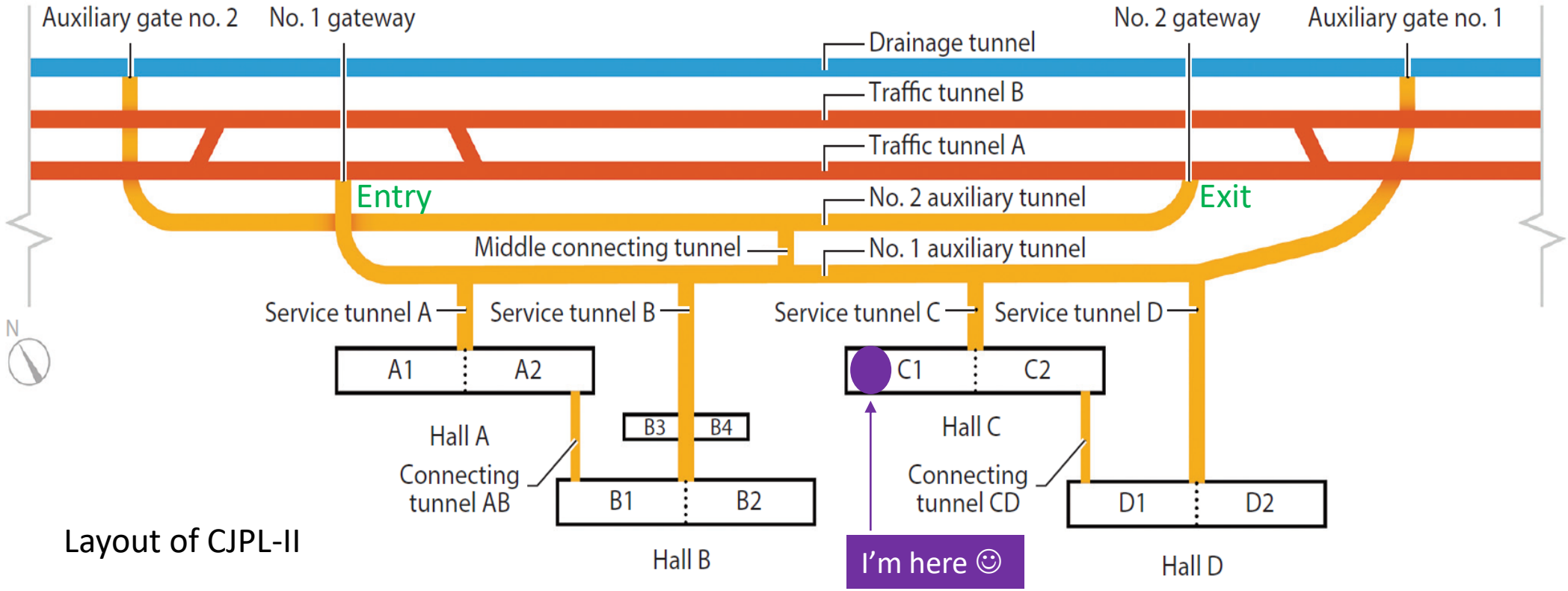
- CJPL-I
  - Volume: 4000 $m^3$
  - 1 main hall (6.5x6.5x42m)




# Future Plan - Lab

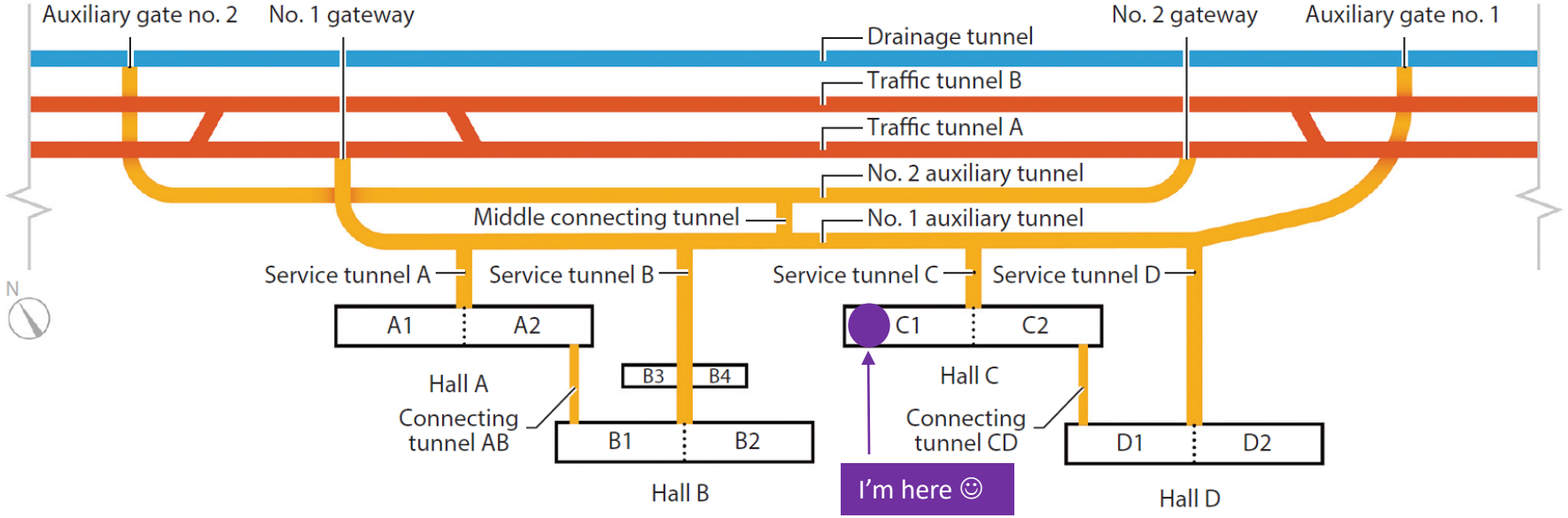
- CJPL-I to CJPL-II
  - Volume: 4000 $m^3$ to 300,000 $m^3$;
  - 1 main hall (6.5x6.5x42m) to 8 main halls (14x14x60m each);
  - Additional pit for next-generation CDEX;




Layout of CJPL-II

# Future Plan - Lab

- CJPL-I to CJPL-II
  - Volume: 4000 $m^3$ to 300,000 $m^3$;
  - 1 main hall (6.5x6.5x42m) to 8 main halls (14x14x60m each);
  - Additional pit for next-generation CDEX;
- CJPL-II status
  - Civil engineering from Dec. 2014 to May 2016;
  - Ventilation system: 3 nine-km-long PE pipes till Jun. 2018;





Ventilation pipes

# CJPL-II construction next plan

Main Hall

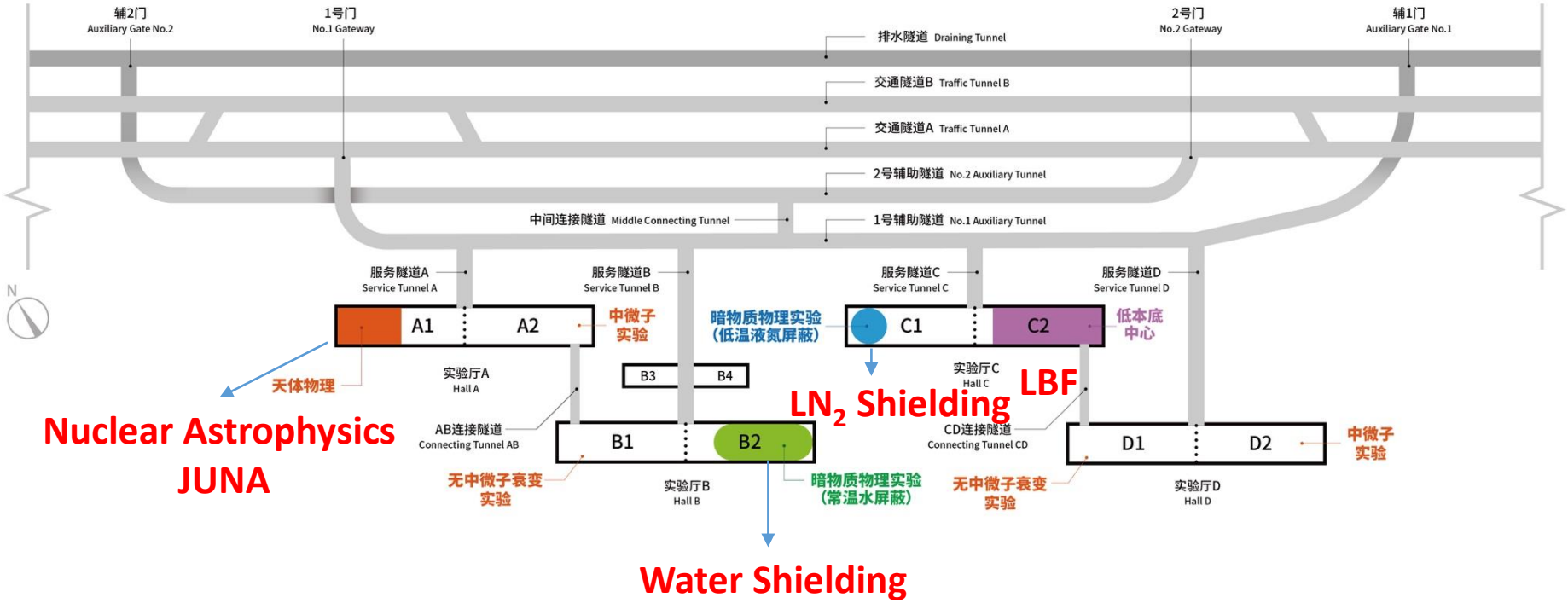
Service tunnel

- CJPL was selected to be a candidate project of **National Major S&T infrastructure of China** in 2016.
- Proposal has been approved in Dec. 2018. The funding, **~$180M**, just for the construction of the facility including the infrastructure, shielding, instrument and so on.
- Possible users:
  - CDEX-1T(DM, 0νββ), PandaX-xT, LAr DM, CUPID-China
  - Nuclear astroparticle physics
  - Solar neutrino experiment
  - Rock mechanics experiment
  - ……
- Service
  - Low background counting
  - Ultra pure copper
  - popularization of science

Ground campus

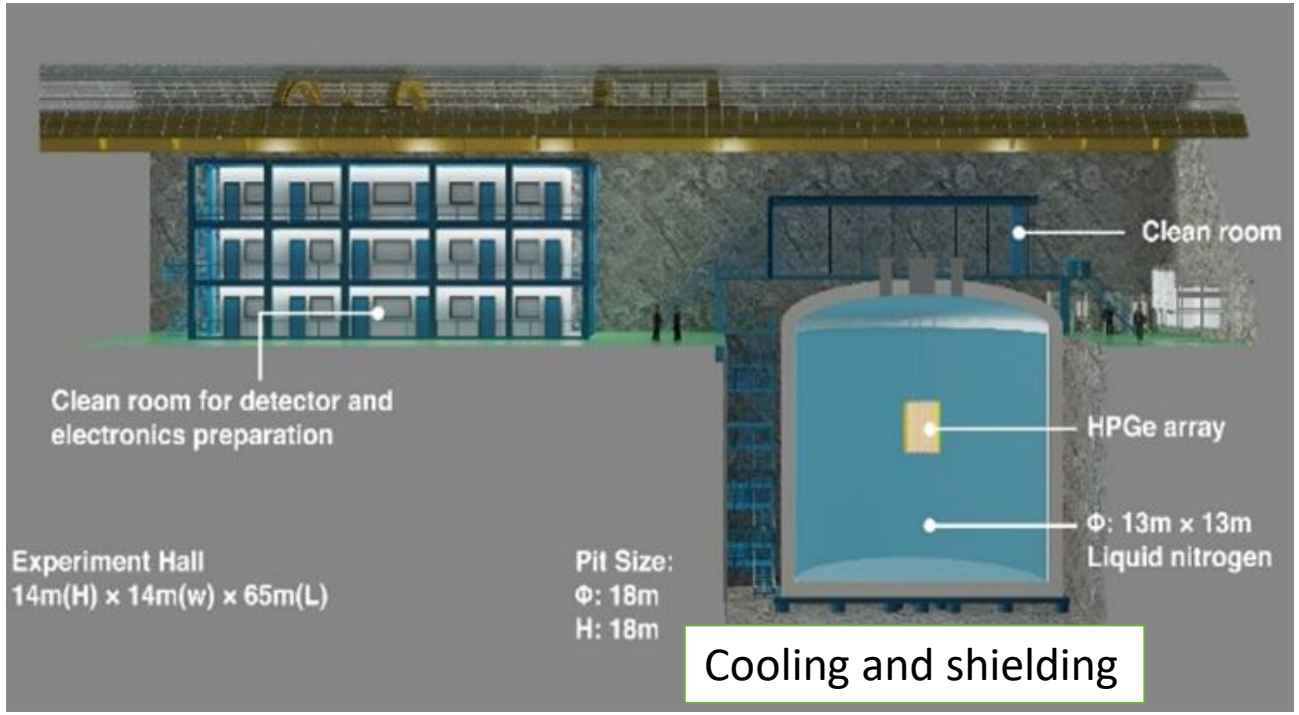
# CJPL-II construction next plan

- CJPL will be an international platform for particle physics, nuclear physics, and so on.
- CJPL will aim to provide services to the researchers performing experiments there, and to develop it into an open and world-class research facility with first-rate working conditions used by internationally leading research teams.
- World-leading experiments will be highly encouraged to locate in CJPL-II.



# Future Plan - CDEX

- CDEX10X moving to a 1725m$^3$ $LN_2$ tank (φ13x13m) located in the pit;
- Construction of $LN_2$ tank kicked off in Nov. 2018;
- 10+X kg detectors direct-immersion and then operation in $LN_2$ in 2019;
- CDEX-100 stage under technical design, report comes soon.

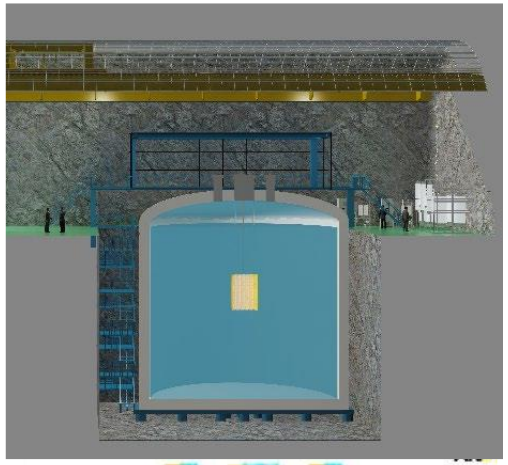
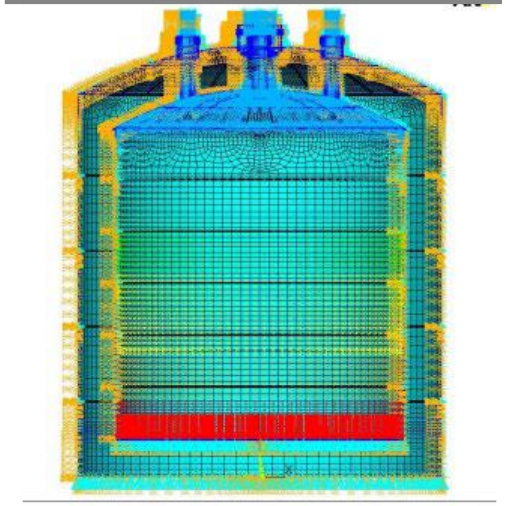


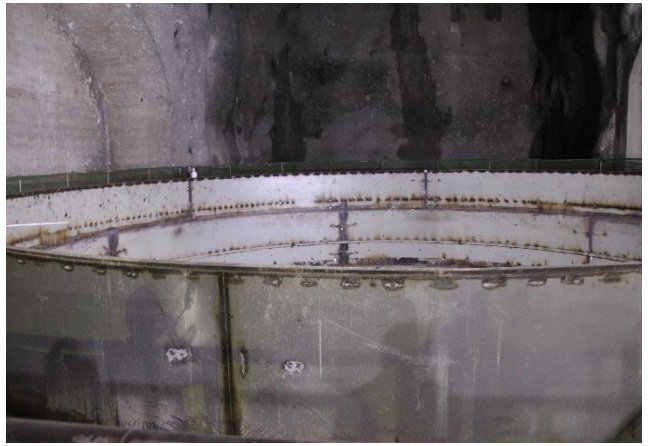
Cooling and shielding

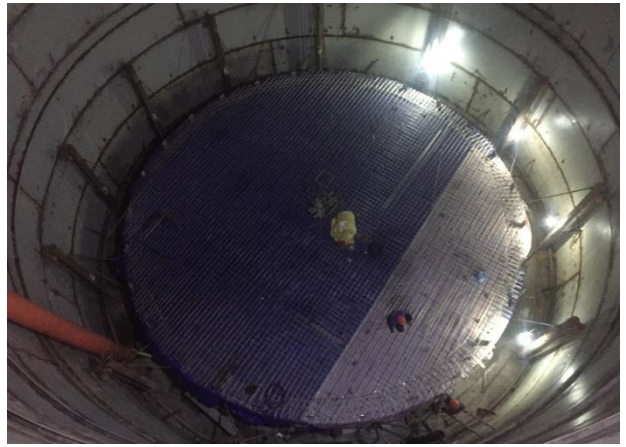

CDEX Pit (top view)

# Future Plan - CDEX@CJPL-II

- Progress of the 1725m$^3$ $LN_2$ tank (φ13x13m) @ CJPL-II C1;

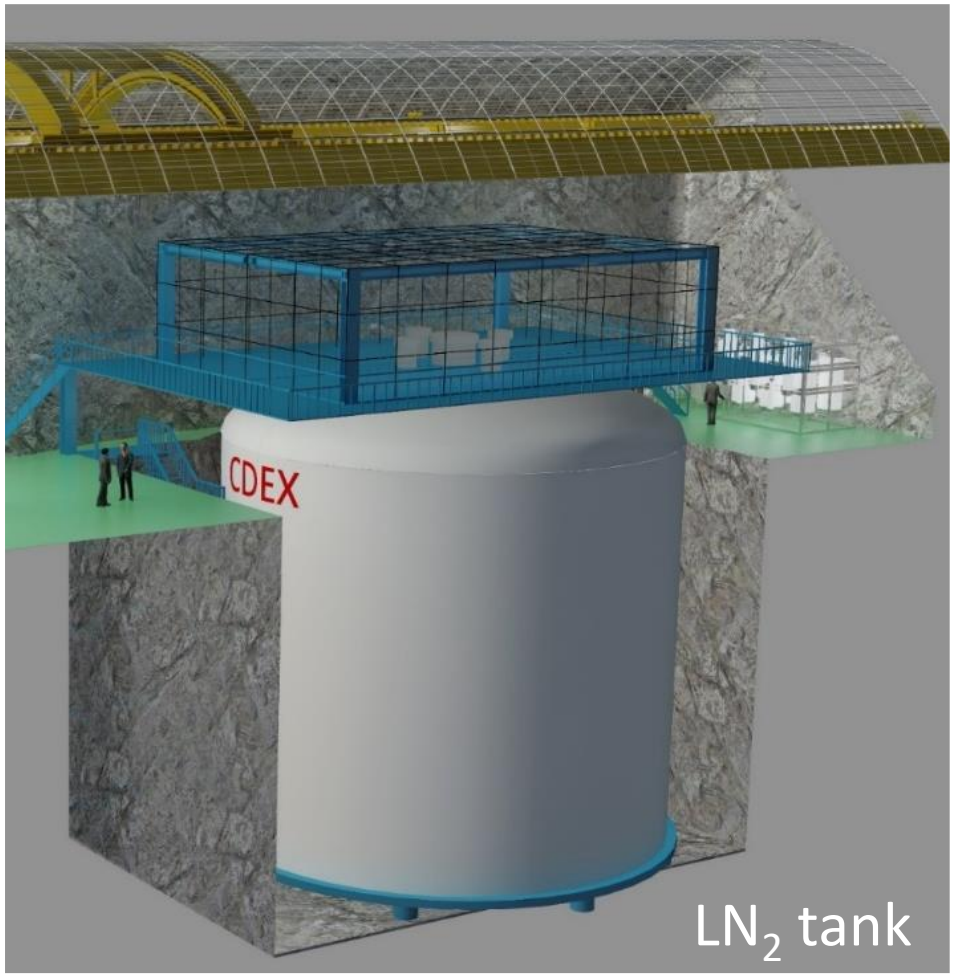






# Future Plan - CDEX@CJPL-II

- Progress of the 1725m$^3$ $LN_2$ tank (φ13x13m) @ CJPL-II C1;

# Future Plan - CDEX

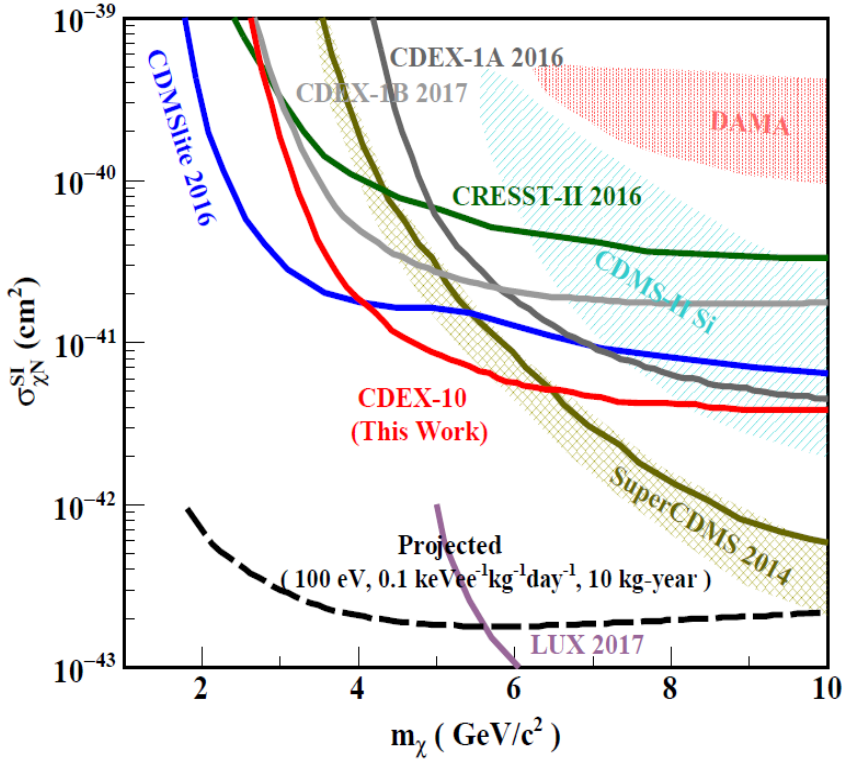


$LN_2$ tank

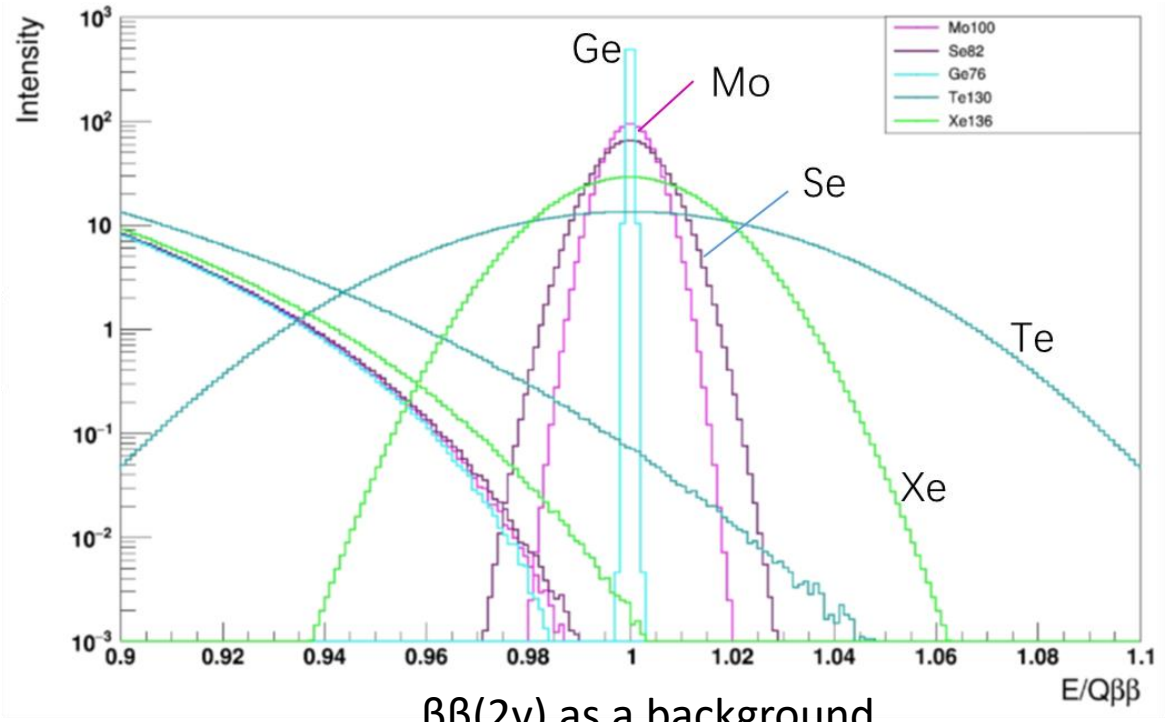

$LN_2$ tank at C1

# Future Plan - CDEX

- DM
  - WIMPs, include AM;
  - Axion, Dark Photon…




- 0νββ
  - Taking advantages of Ge detectors;
  - Combined with Legend-1T
  - Location Undetermined!

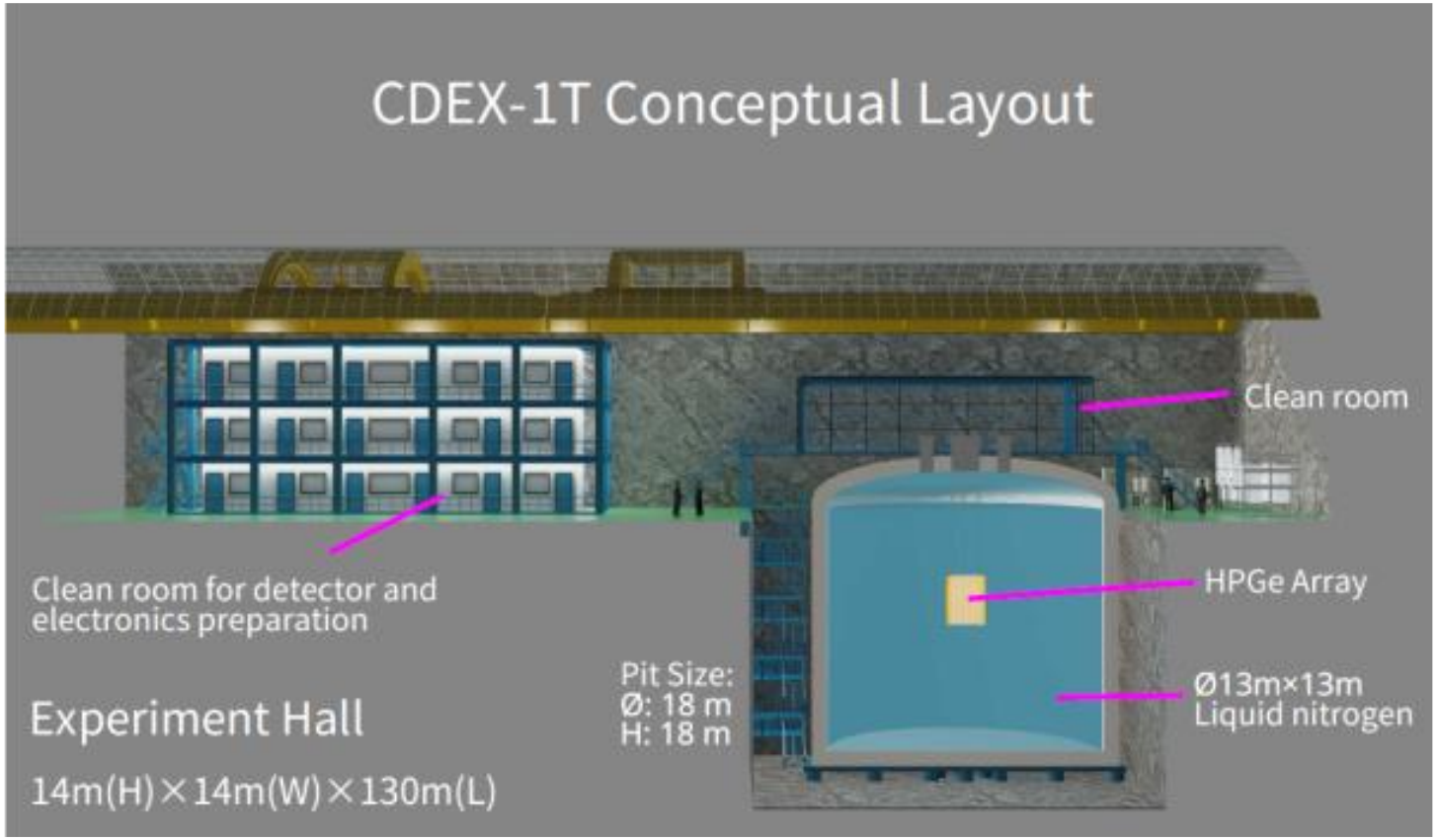


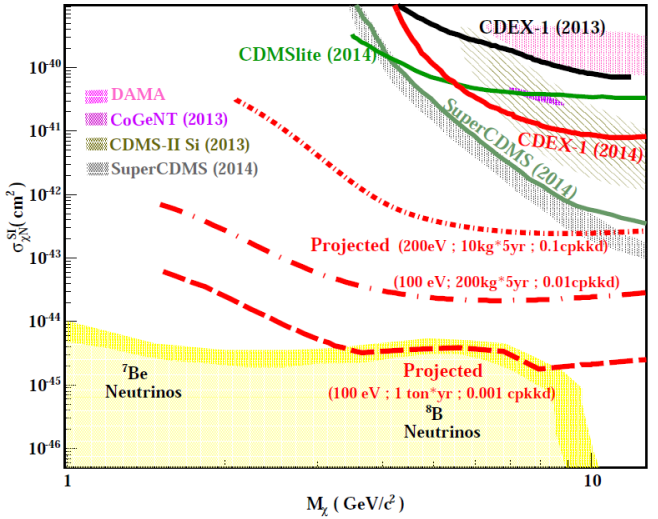

ββ(2v) as a background

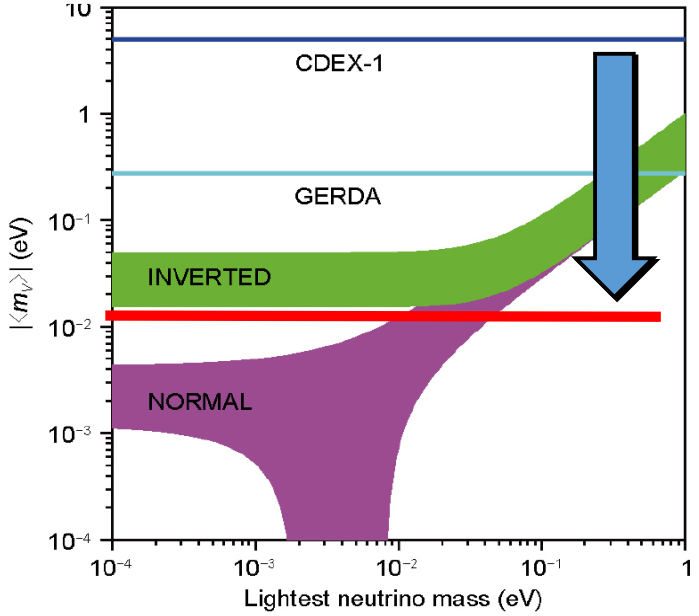
Assuming $T_{0\nu}/T_{2\nu} = 1 \times 10^6$

# CDEX: China Dark Matter Experiment

- Based on Ge technologies, to directly detect DM;
- For 0νββ, Combined with L1T.

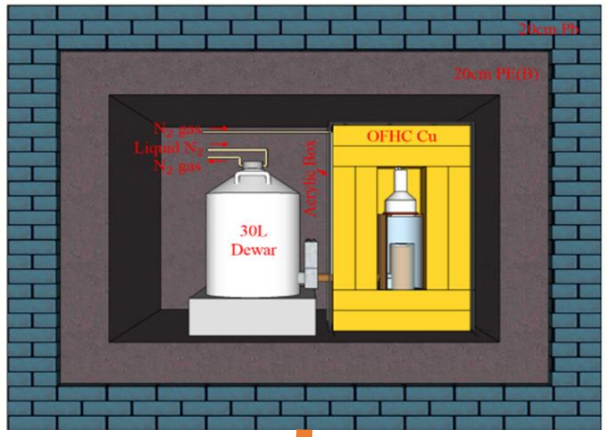


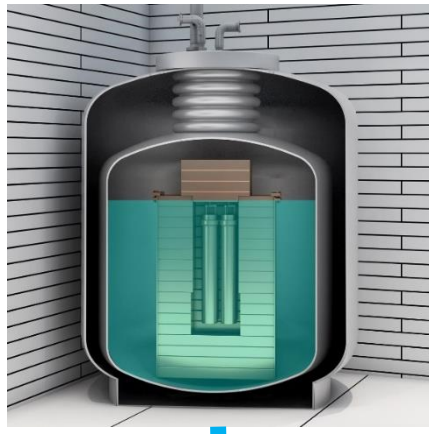



# CDEX Roadmap

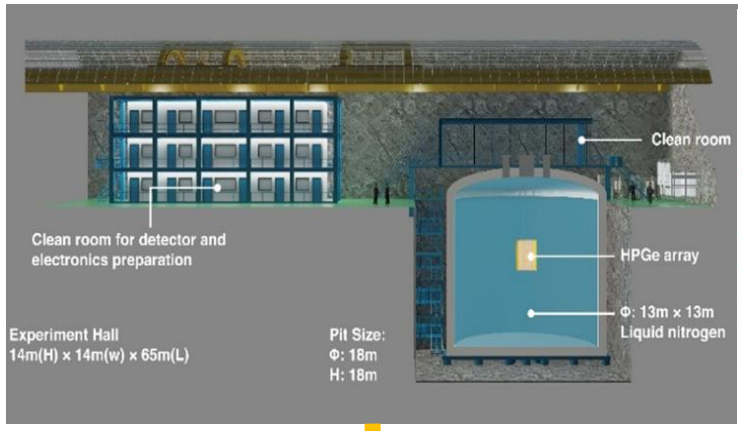
## CDEX-1A/B

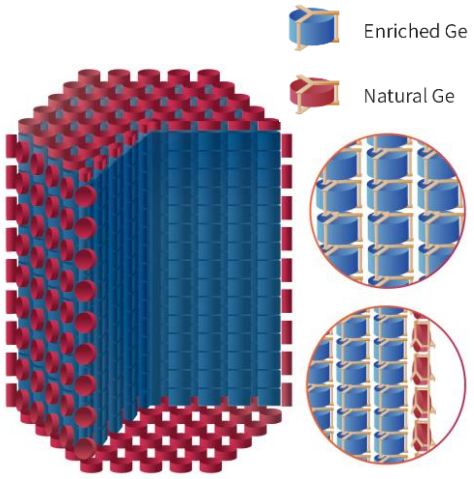



## CDEX-10



## CDEX-100 / CDEX-1T




CJPL-I

CJPL-II

2011

- ❑ PPC Ge detector with a mass of up to ~1 kg
  - ✓PRD88, 052004, 2013
  - ✓PRD90, 032003, 2014
  - ✓PRD90, 091701, 2014
  - ✓PRD93, 092003, 2016
  - ✓PRD95, 052006, 2017 (Axion)
  - ✓Sci. China (2017) (0νββ)
  - ✓CPC42, 023002, 2018

2016

- ❑ 10 kg PPC Ge detector array immersed into $LN_2$
  - ✓PRL120, 241301, 2018

202X

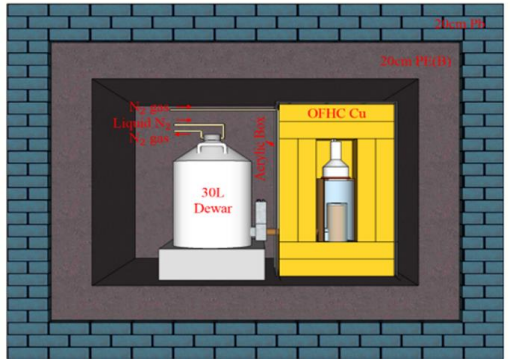
- ❑ Ge array in large-volume $LN_2$
- ❑ multi-purpose: DM and 0νββ

Key technologies:

- ✓Ge crystal growth and $^{76}$Ge enrichment
- ✓Ge detector fabrication
- ✓Ultra-low background VFE
- ✓Ultra-pure copper for structure and cables
- ✓Natural Ge detectors as veto
- ✓……

# CDEX Roadmap

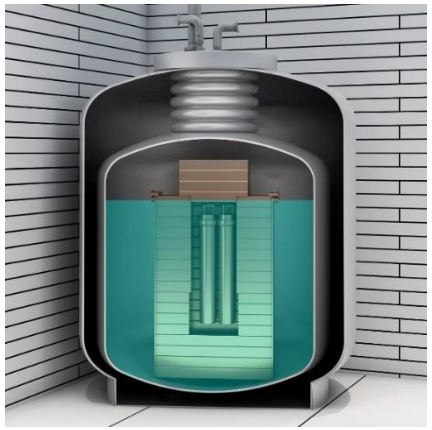
**CDEX-1A/B**




**2011**

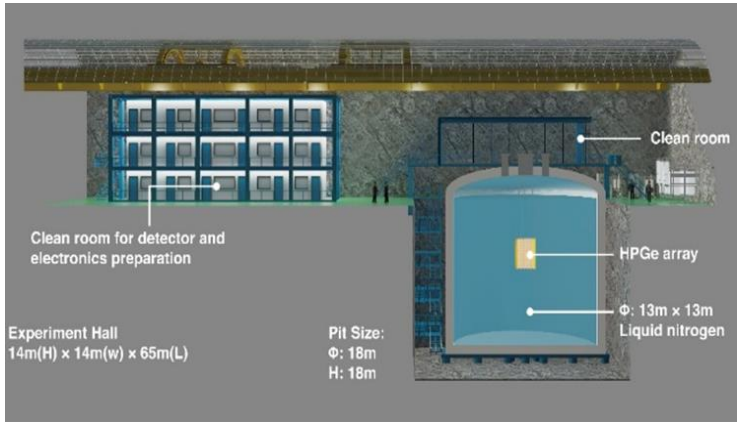
- Lower Background Level
- Lower Threshold
- Larger target mass

**CDEX-10**



**2016**

**CDEX-100 / CDEX-1T**

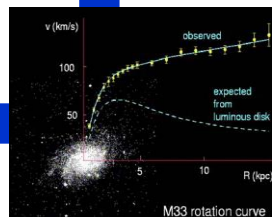



**202X**

- More key technologies in control
- More physics channels opened…
- More fun, more exciting…

**Threshold**

**Background Level**



# Summary

- CDEX:  unique advantages of PPC Ge detectors for light DM search at CJPL;
- New SI limit $8\times10^{-42}cm^2$ at 4-5GeV by CDEX-10 first results;
- AM analysis based on CDEX-1B's 4-year data ruled out DAMA/LIBRA phase1 and CoGeNT, obtained the best sensitivity below 6 GeV;

- New site in Hall C1 of CJPL-II project;
- Easy scalability and lower bkg expected w/ new large cryo-tank;
- Home-made Ge detector, FE electronics, crystal growth, UG copper e-forming ongoing…
- More detectors coming w/ particular control of cosmogenic bkg;

- Other physics: Axion, dark photon, $0\nu\beta\beta$,…


Thanks for your attention!
锦屏一级水电站世界最高坝