清華大學
Tsinghua University

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

OUTLINE

- Introduction to CDEX
- Recent status of CDEX-1 and CDEX-10
- R&D of key technologies
- Future plan of CDEX @CJPL-II
- Summary

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

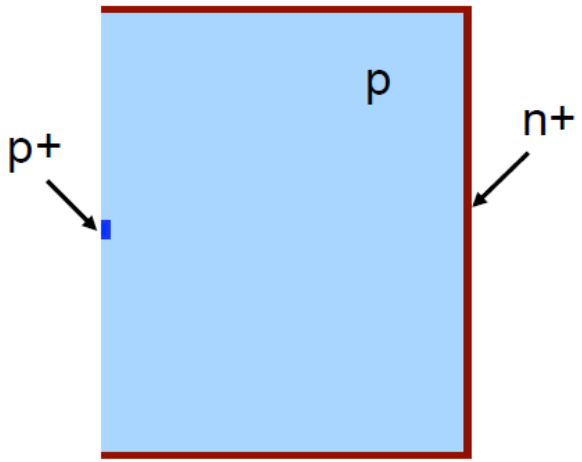
TEXONO

中山大學 SUN YAT-SEN UNIVERSITY

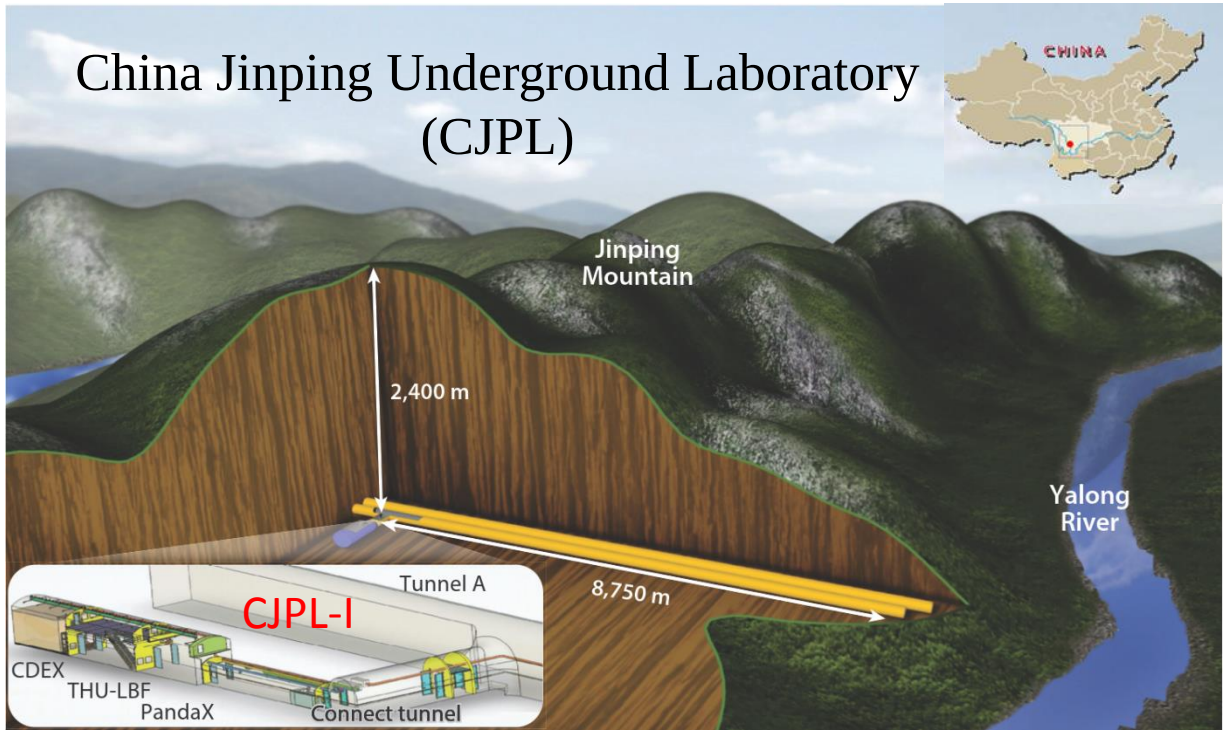
CDEX Stages

- 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

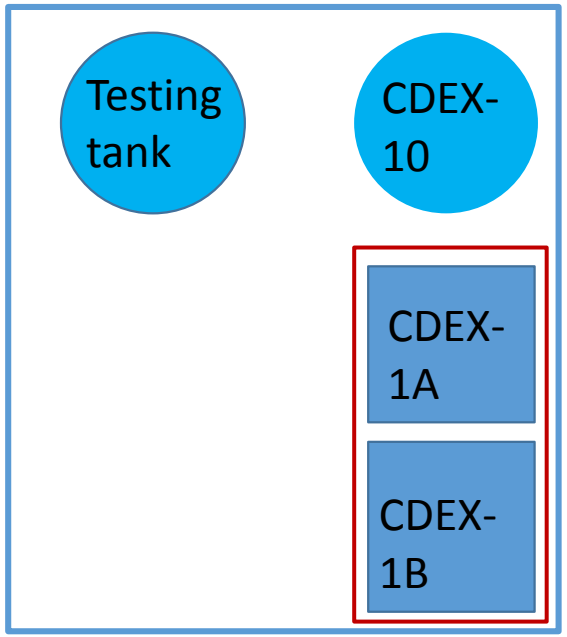


Direct detection of low-mass WIMPs w/ Ge detector at CJPL.

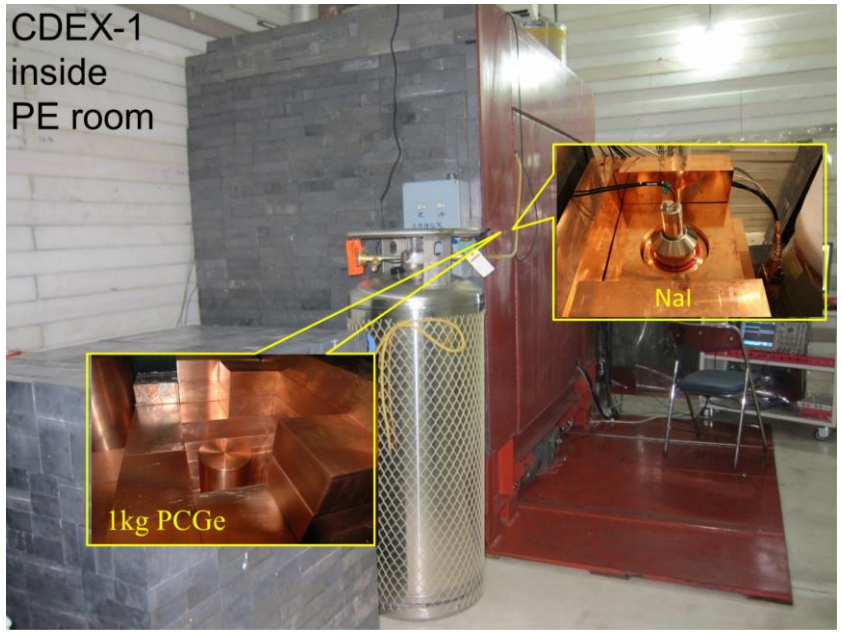


CDEX-1 stage

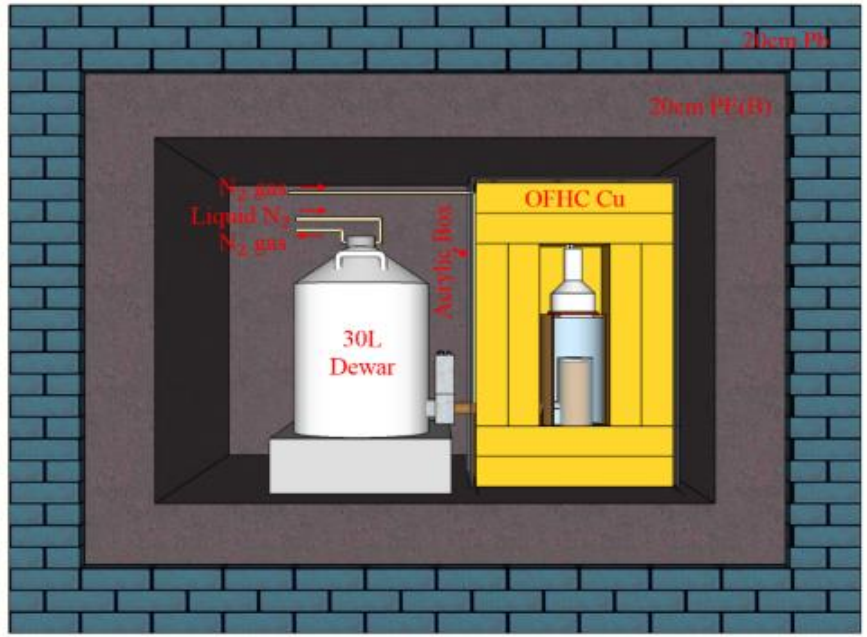
- 2 sub-stages: CDEX-1A(prototype, 2011)→1B(upgraded, 2013);
- Traditional single-element ~1kg PPC Ge detector;
- Low-bkg Pb&Cu passive shield + NaI veto detector;
- Located in PE room at CJPL-I;



Layout of PE room, CJPL-I



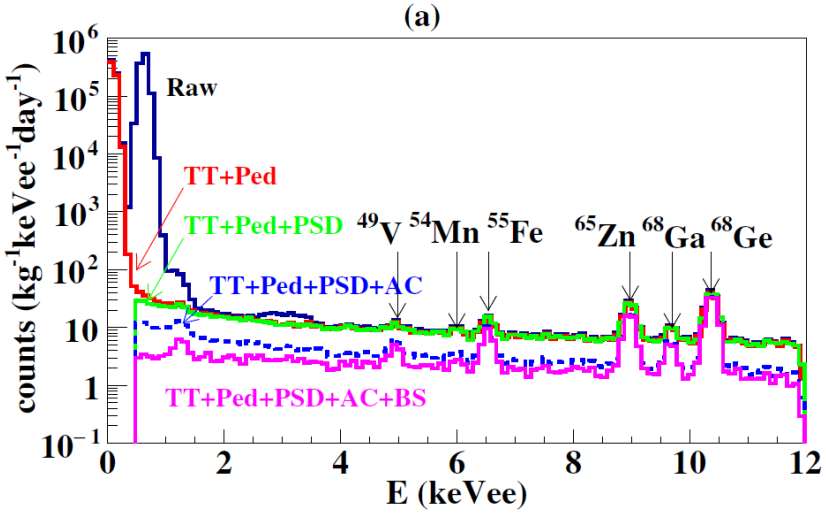
CDEX-1 inside PE room



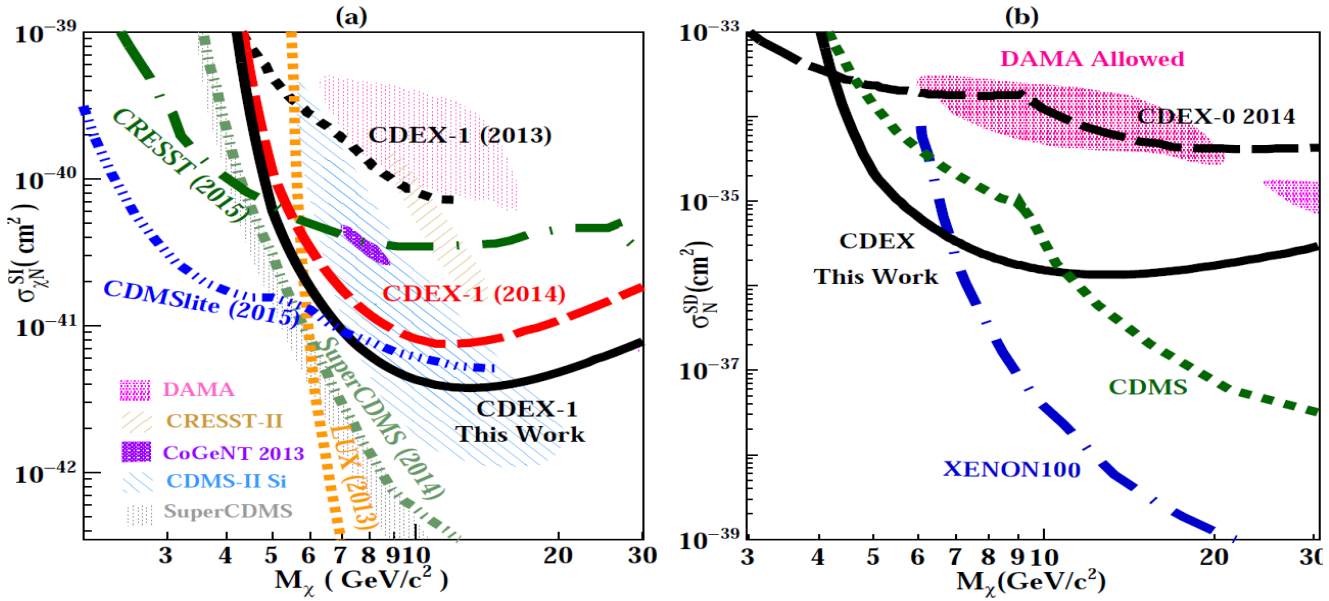
CDEX-1A&B：1kg PPC Ge×2

CDEX-1A Results

- >500 days run, ~336 d·kg 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;

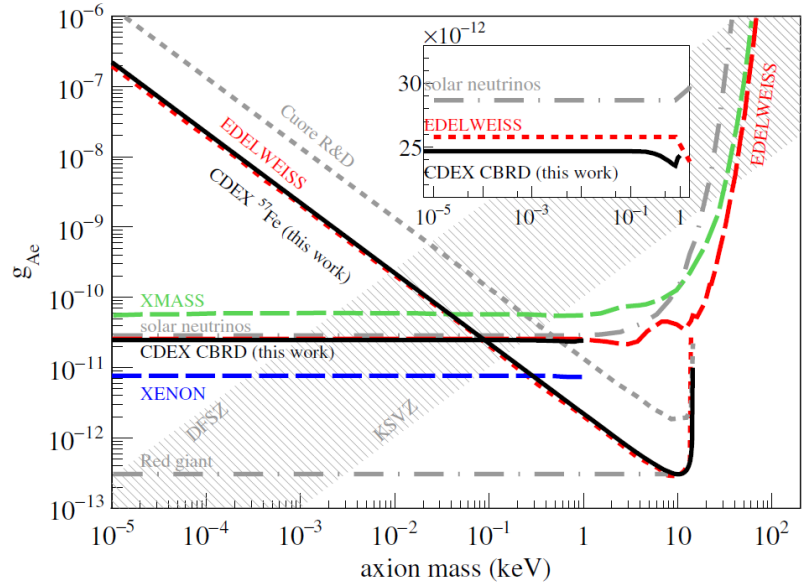


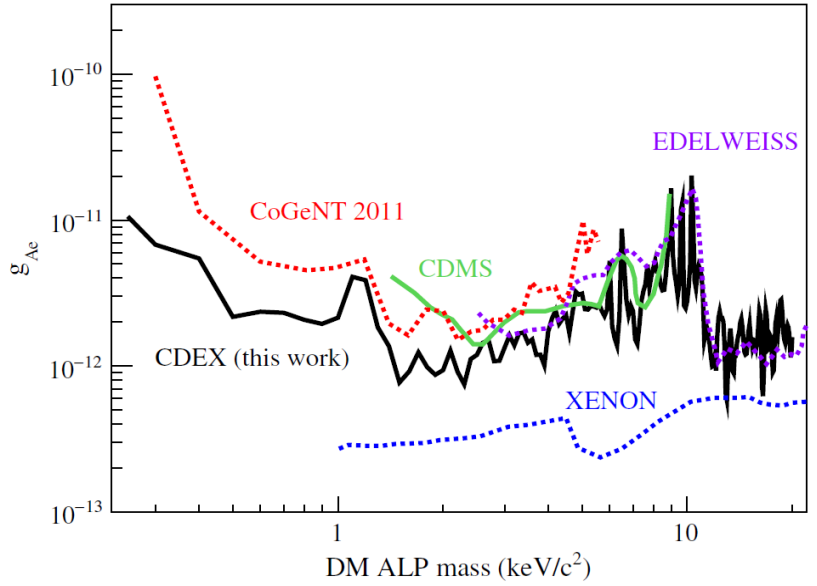
PRD93, 092003, 2016

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 1keV;





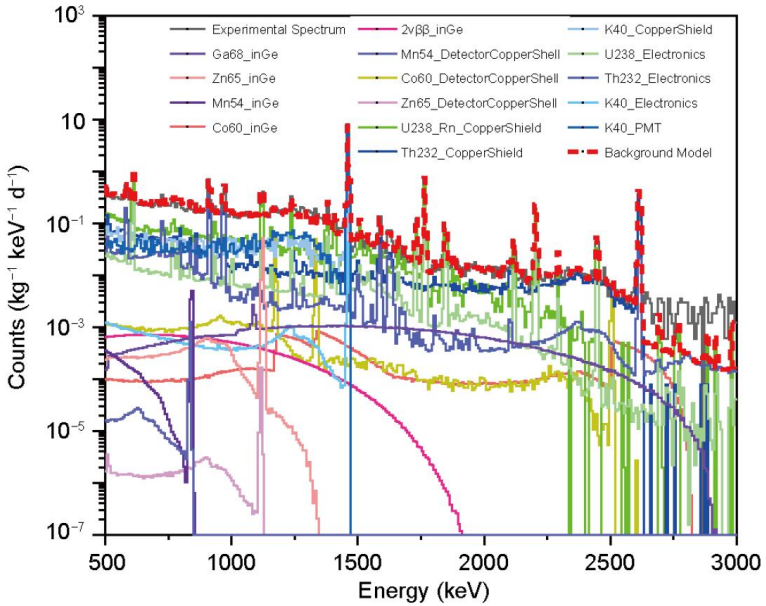
CDEX-1A Results

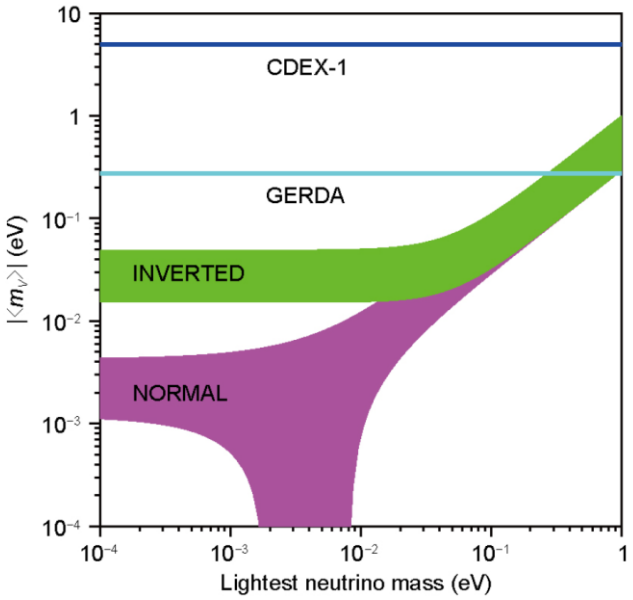
PRD95, 052006, 2017

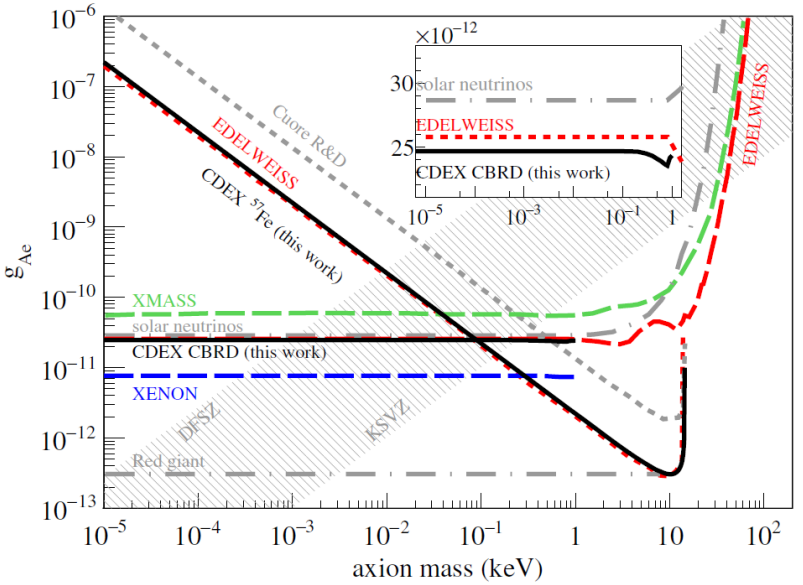
- Axion (335.6 kg·day data)
  - Solar axions：CBRD processes and ^{57}Fe M1 transition;
  - ALPs: more stringent constraint below 1 keV;
- 0νββ (304 kg·day data)
  - Natural Ge crystal;

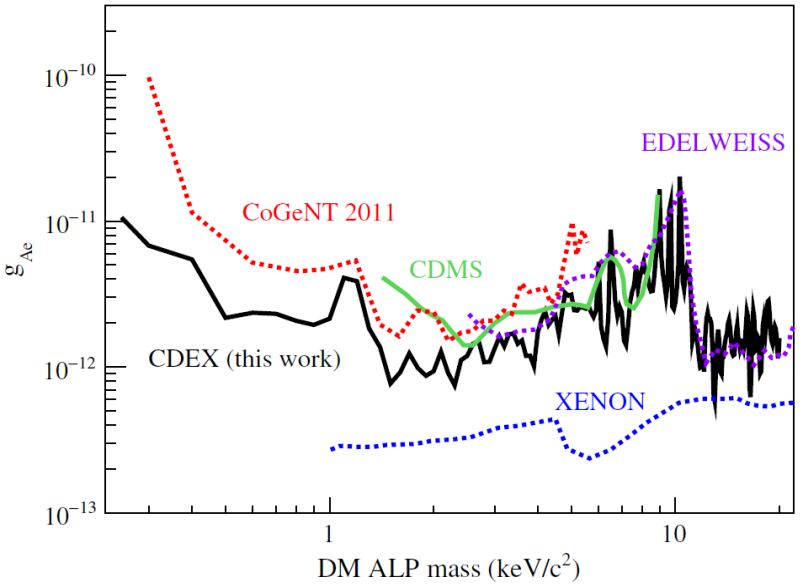
$$T_{1/2}^{0\nu} \geq 6.43\times10^{22}\, yr,\ 90\%\ C.L.$$

Science China PMA (2017) 60: 071011







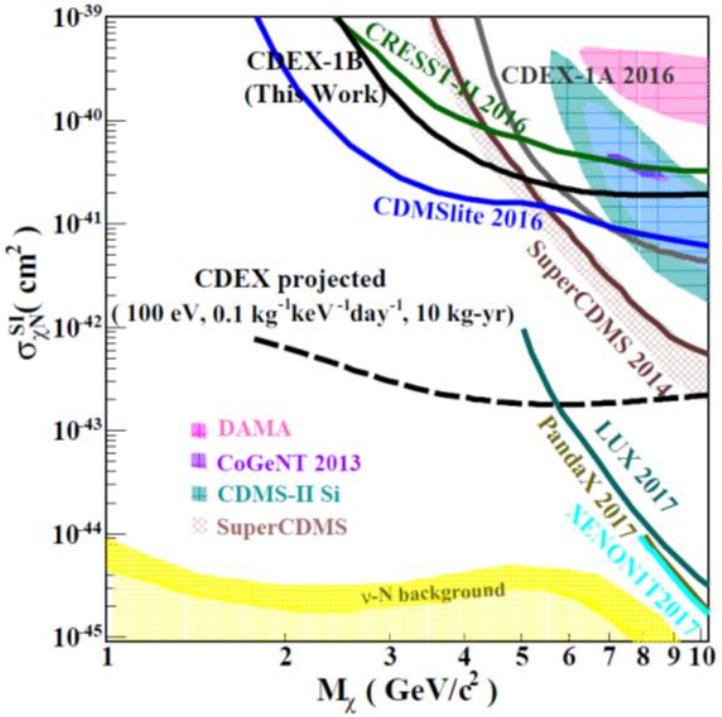


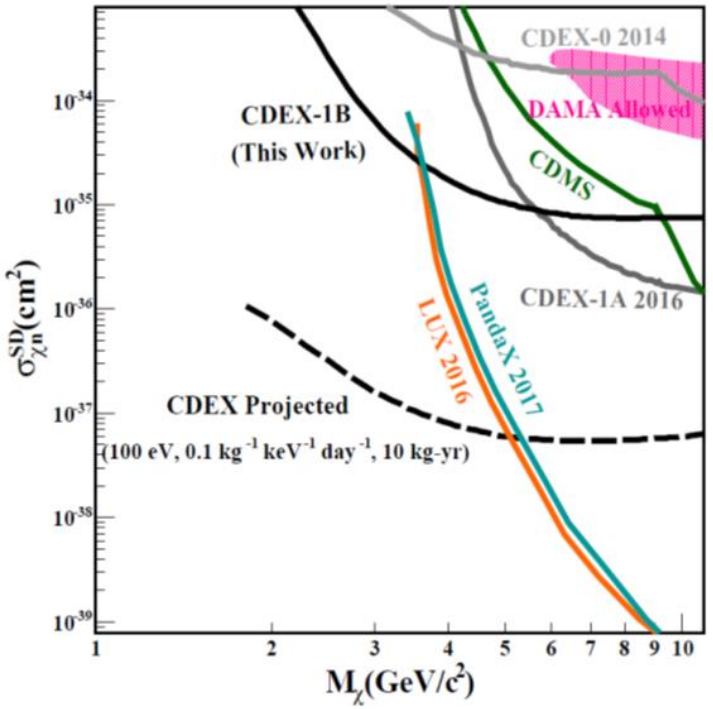
CDEX-1B Results

- Detector upgraded w/ lower JEFT noise and material bkg;
- Run 3.3 years, totally 737.1 kg·d exposure;
- Achieving 160 eVee energy threshold;
- Sensitivity improved and extending to 2 GeV/c^2.

CPC 42, 023002, 2018

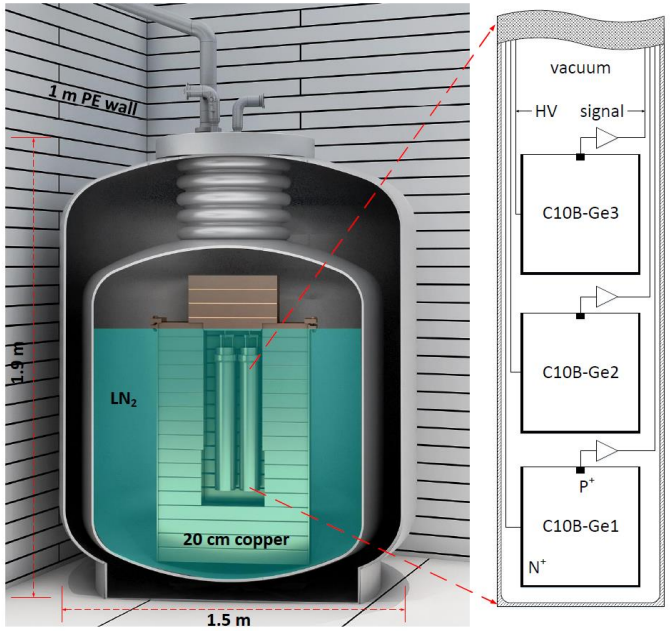
Detector	FWHM of pulser
CDEX-1A	130 eVee
CDEX-1B	80 eVee



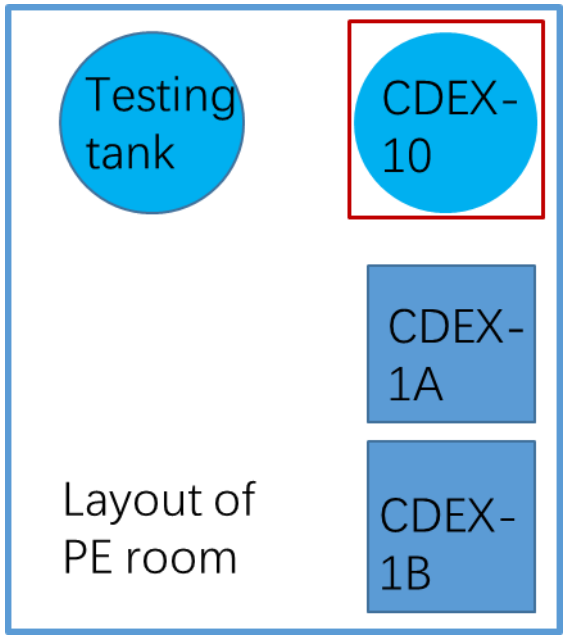


CDEX-10 stage

- Array detectors: 3 strings with 3 det. 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;



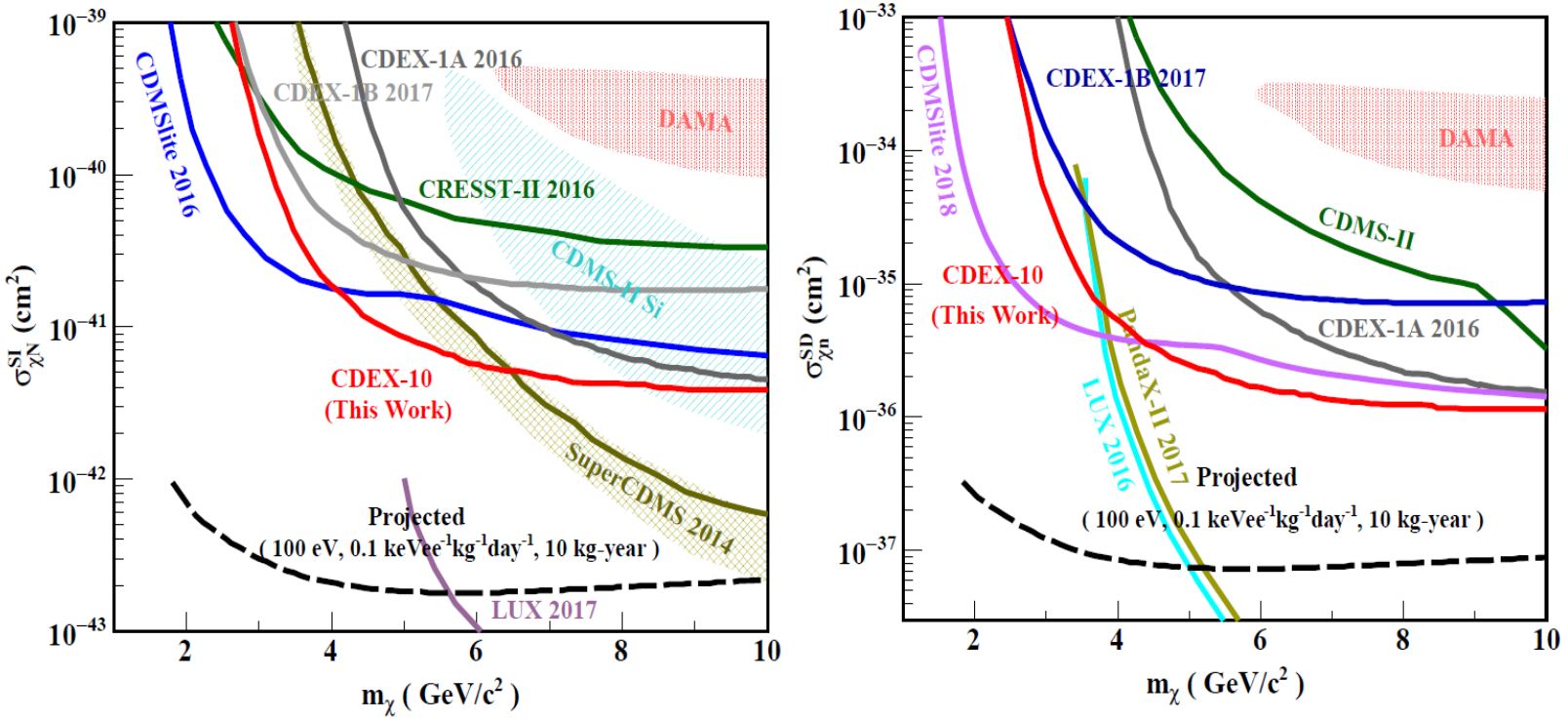
CDEX-10: ~10kg PPC Ge array



CDEX-10 First Results

- First results from 102.8 kg·day exposure w/ E_{th}=160eV;
- Bkg level: 2 cpkkd @ 2-4 keV;
- New SI limit on 4-5 GeV/c^2.

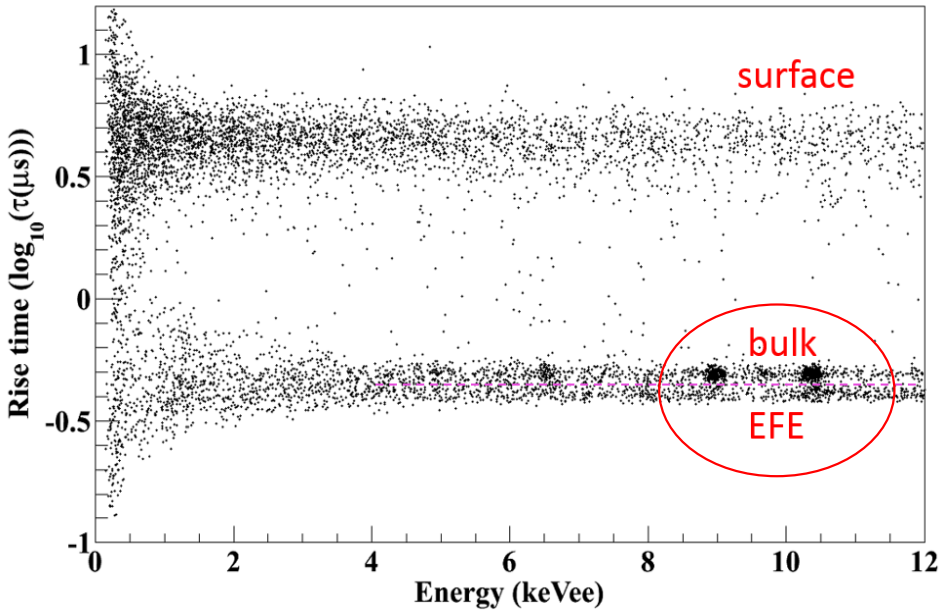
PRL120, 241301, 2018

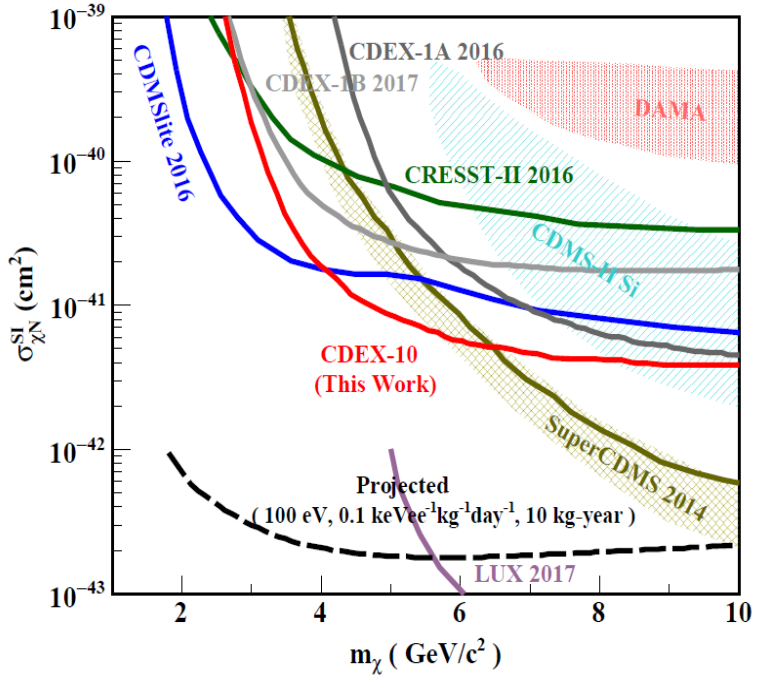


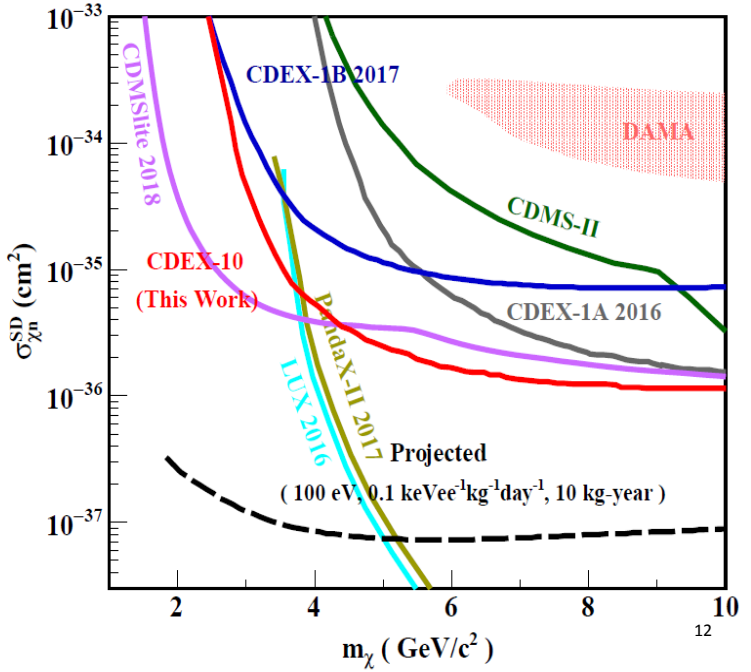
CDEX-10 First Results

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

PRL120, 241301, 2018

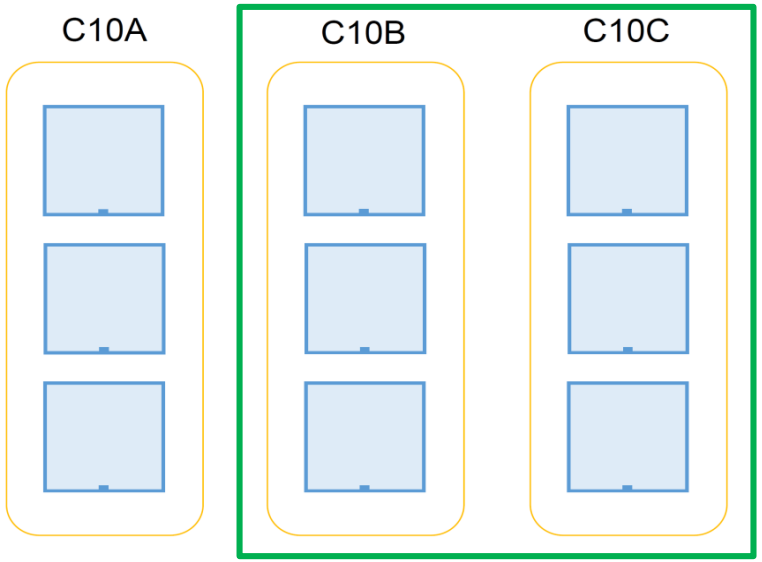






CDEX-10 Detectors

- C10A-1 upgrade:
  - new Cu canister;
  - new front-end electronics…
- Testing underway @ CJPL-I



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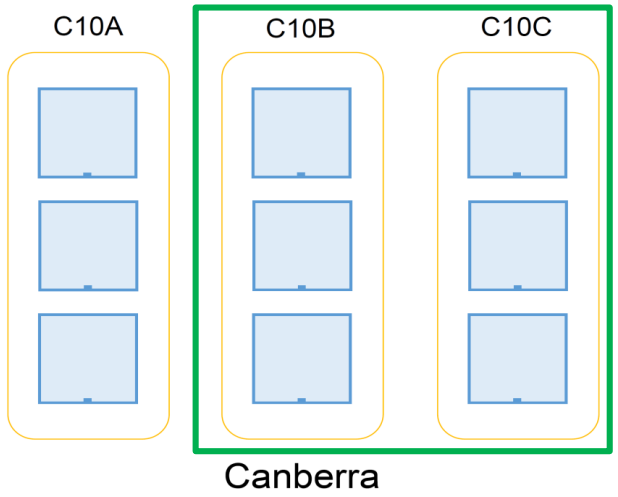
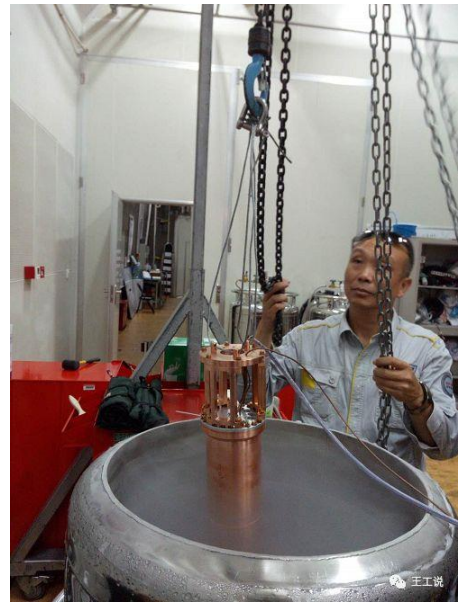


Preliminary

C10A-1 parameters	
Diameter	62mm
Height	62mm
High Voltage	+2500V
FWHM	70eV@Pulser
	430eV@122keV

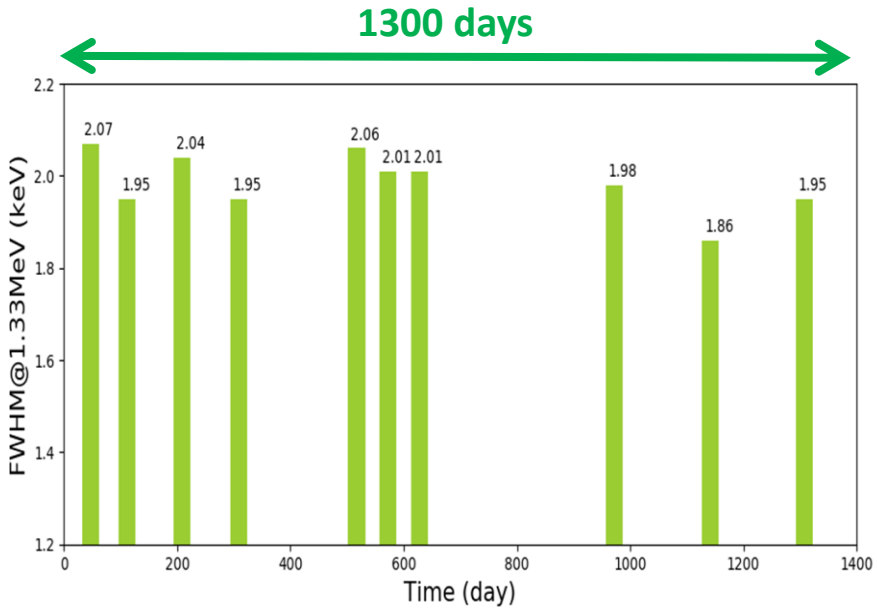


CDEX-10X: Ge detector fabrication

- 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…

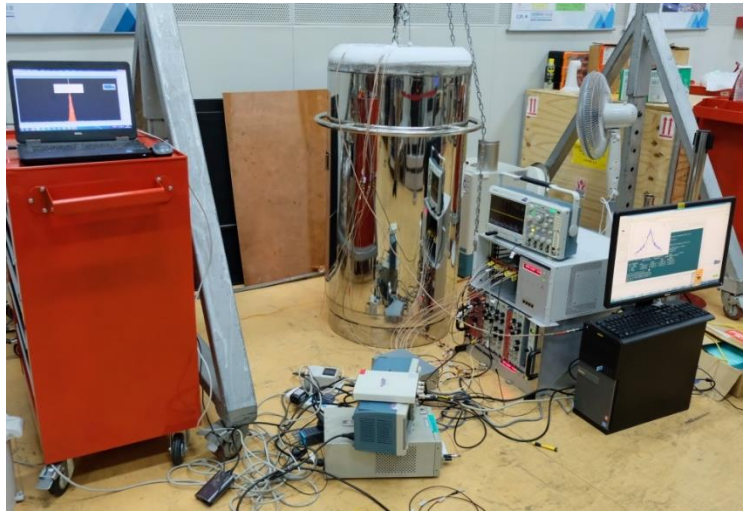
Stored at room temperature, cooled down for test, good performance keeping, >1300 days



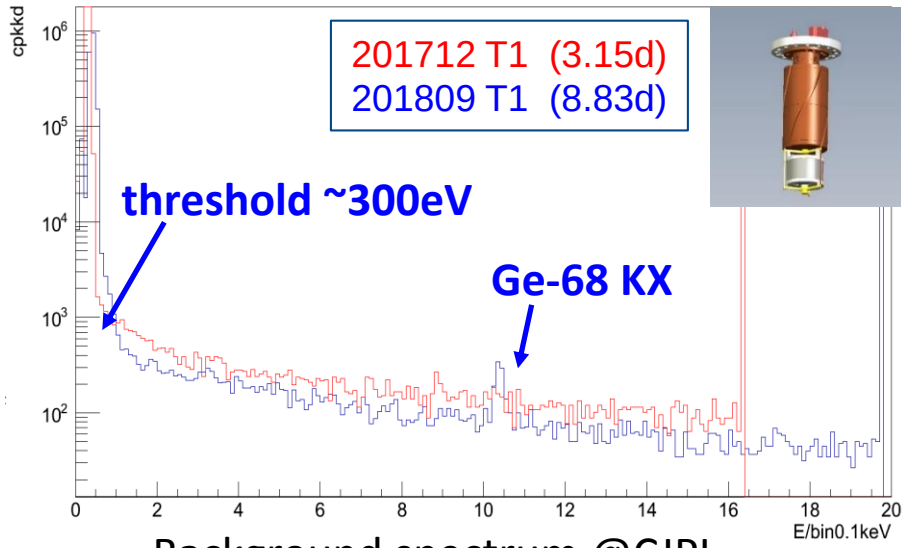
Vacuum systems

CDEX-10X Detector (T1)

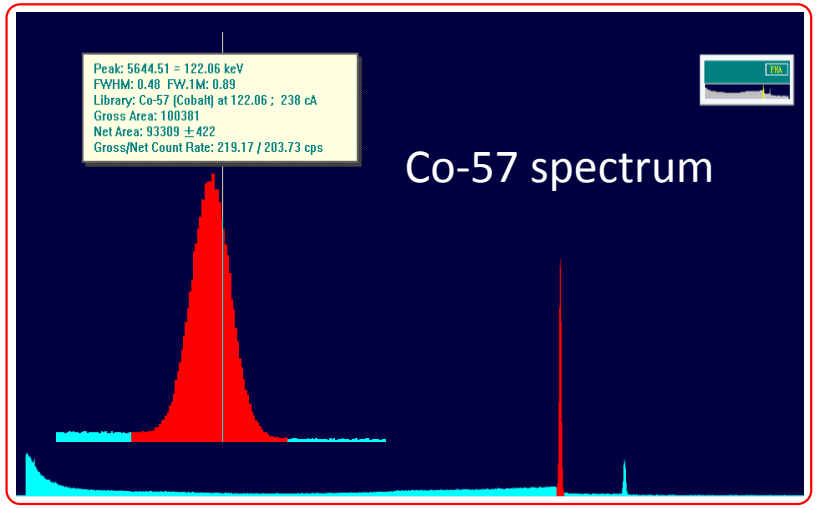
- Commercial Ge crystal + stainless steel canister;
- T1 detector: 500g Ge(φ50×50mm) + CMOS ASIC preAmp;
- Works, and Performance expected;
- Going on to improve bkg, low-noise electronics…



Tested in CJPL-I



Background spectrum @CJPL



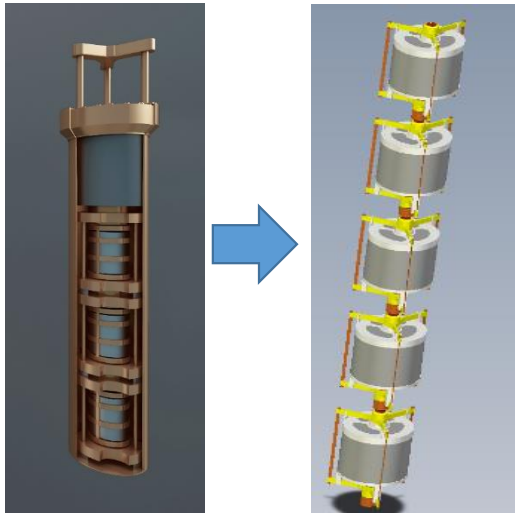
FWHM=0.48keV@122keV_Co57

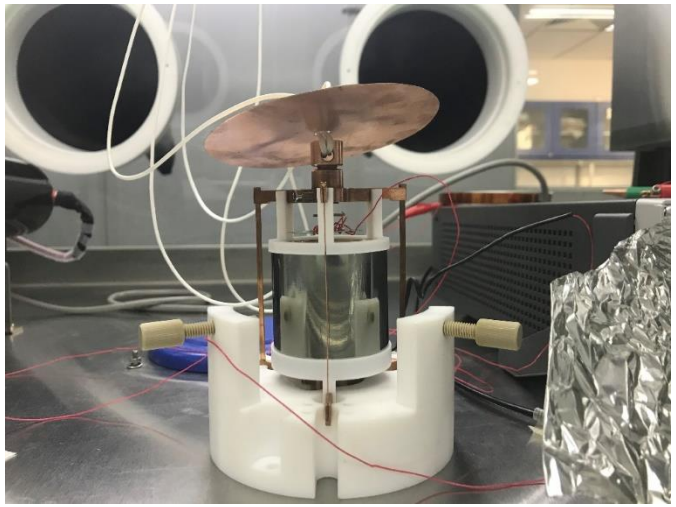
CDEX-10X Detector (Bare HPGe detectors in LN_2)

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

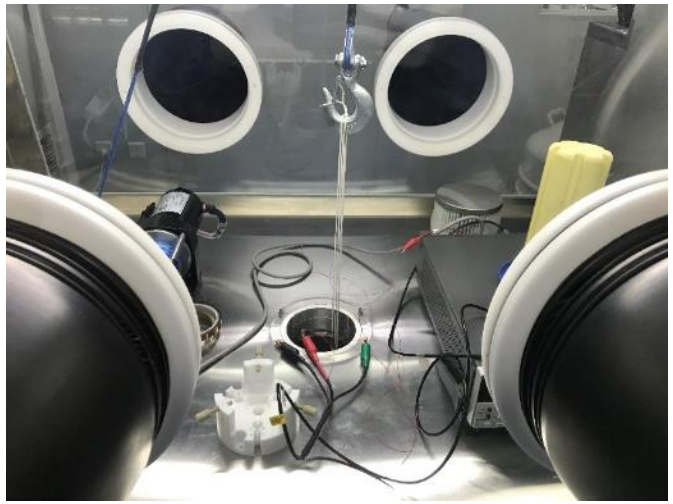
✓ Develop bare HPGe detectors immersed into LN_2!

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



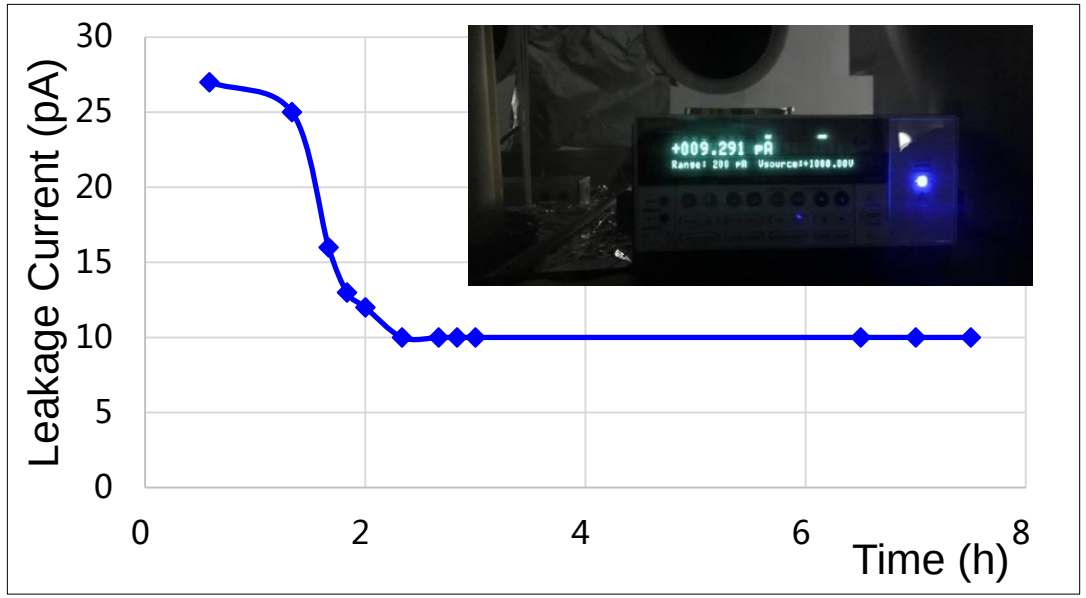


Bare HPGe detectors



Bare HPGe in LN_2

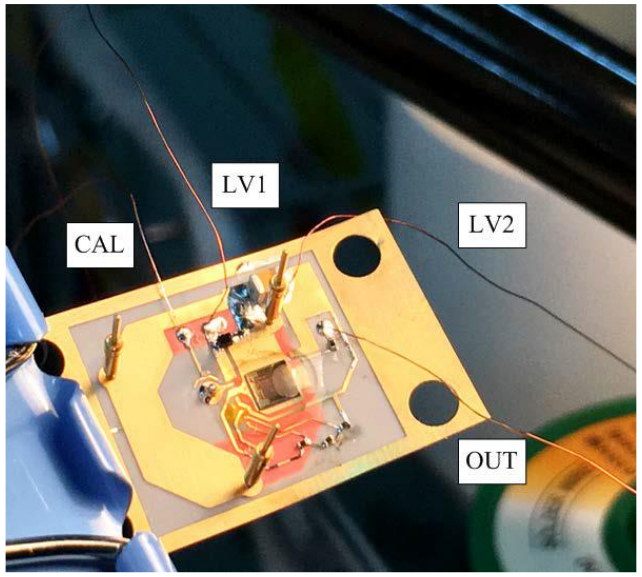
PPC: ϕ50mm x 50mm, Depleted voltage: ~800V

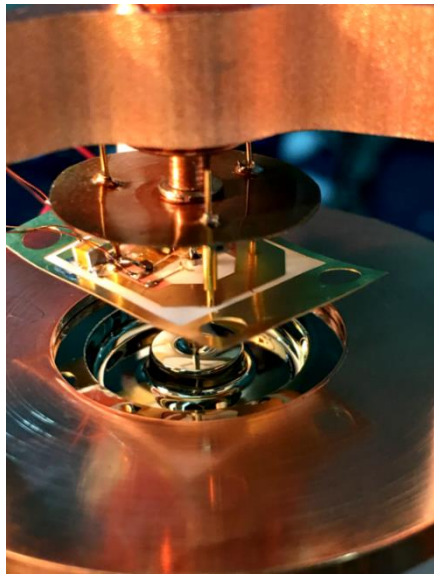


CMOS ASIC Front-end Electronics

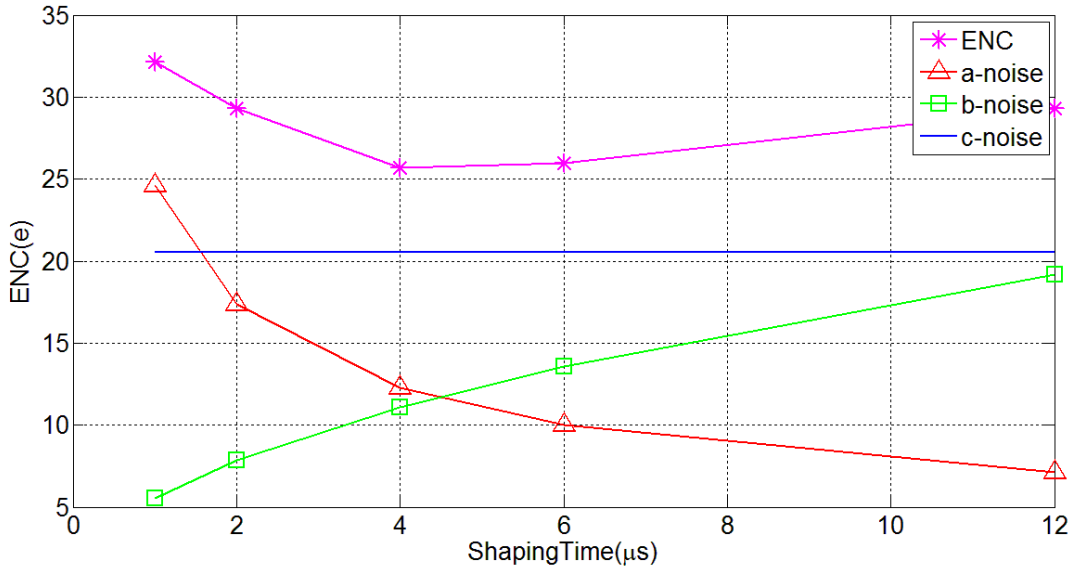
- Light DM search →low noise/threshold (low capacity, etc)
- Very close to Ge detectors →low bkg(radiopure, low-mass, etc)
- ASIC preamplifier @ 77K
  - PCB material: PTFE(Rogers 4850);
  - ENC ~26e(<200eV) w/ 4μs shaping time, mainly from 1/f noise (~21e);

JINST (2018) 13: 8019



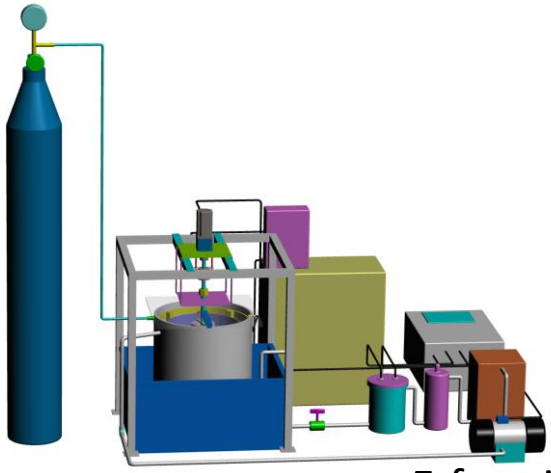


Noise components analysis



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 (Administrative Approval);
- U/Th Analysis by ICP-MS
  - Wet chemistry testing… , blank sensitivity ~10^{-13}g/g



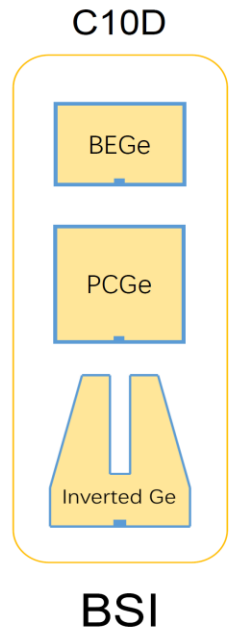
E-forming setup

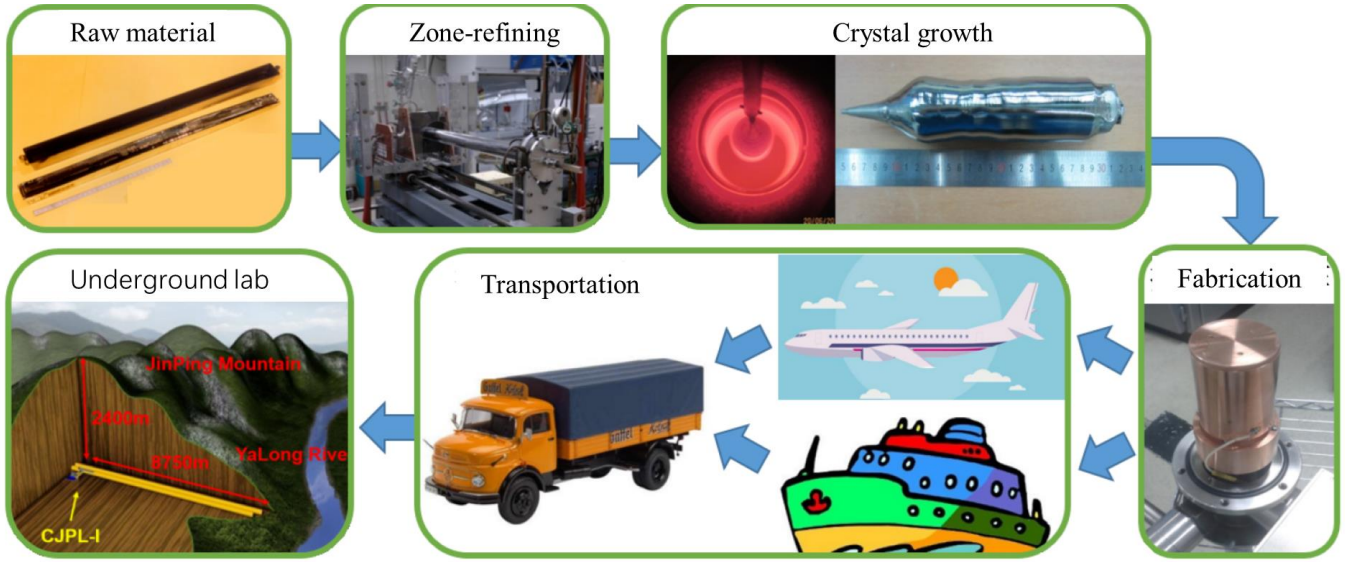
optimized electrical parameters

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;



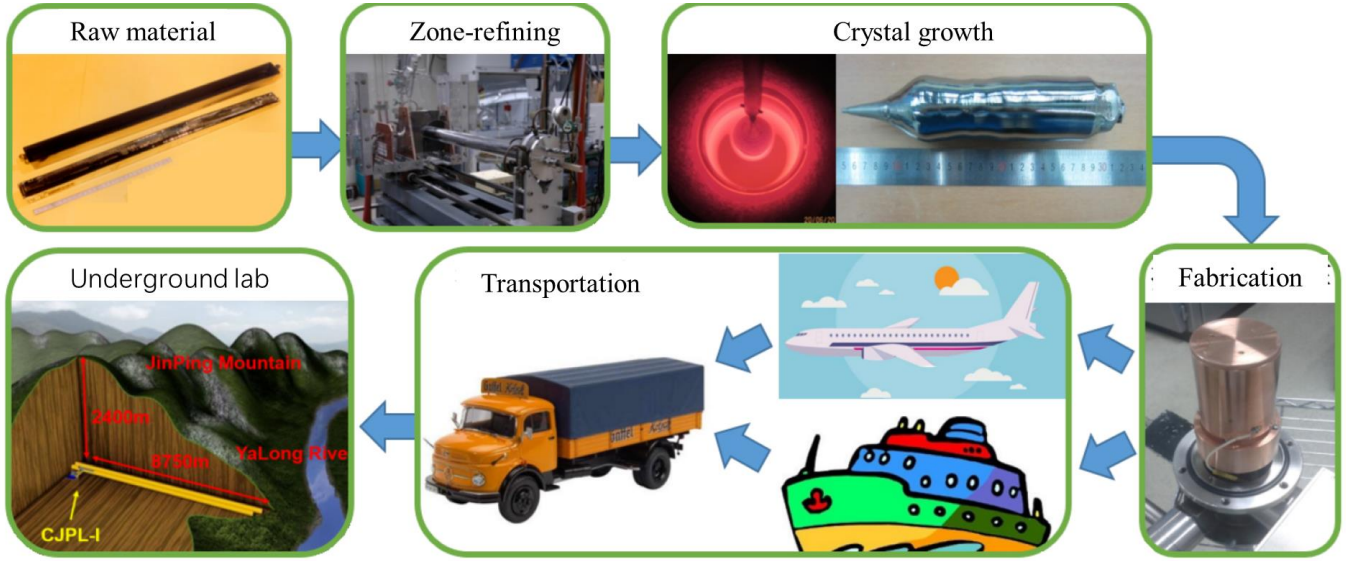


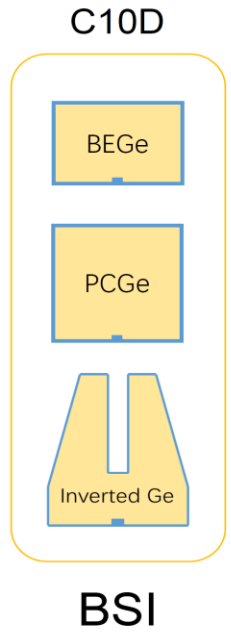
Detector production: 45days +
Ground transportation: 60 days +
Underground cooling: 180days →

Cosmogenic bkg: 0.03cpkkd(sim.).

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 +
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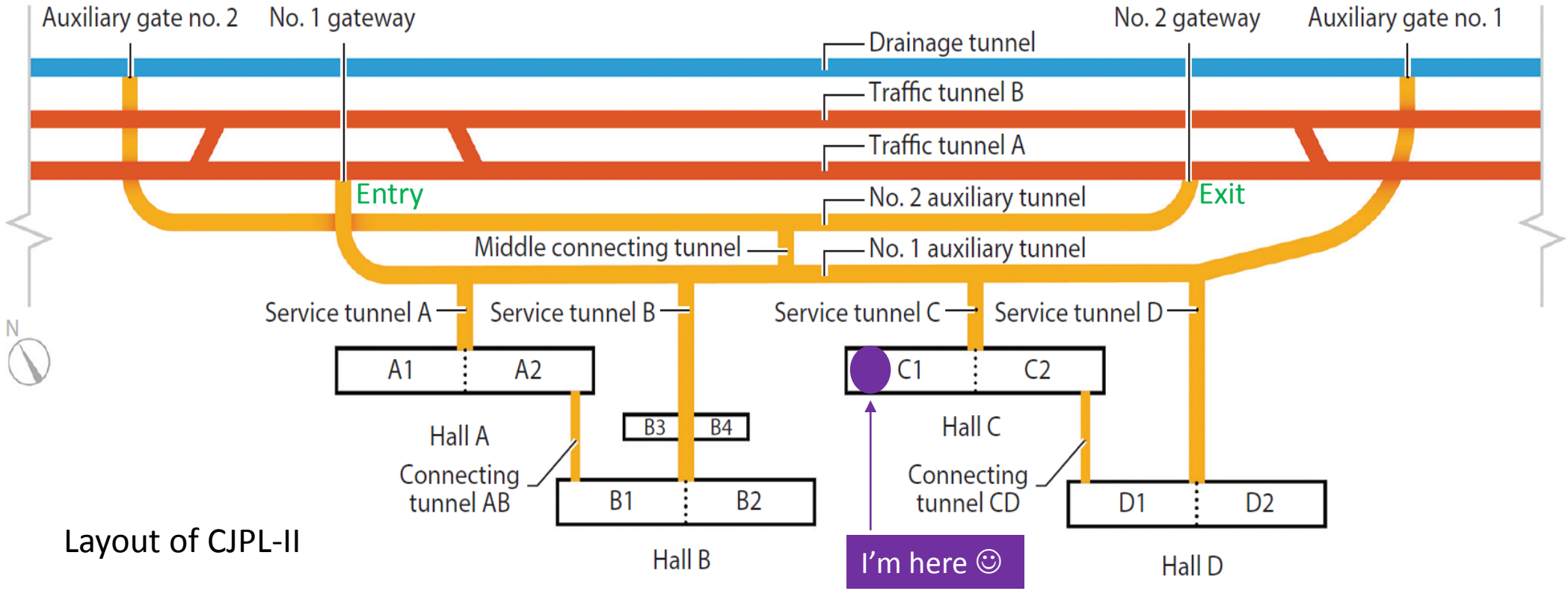
Cosmogenic bkg: 0.03cpkkd(sim.).

Future Plan - Lab

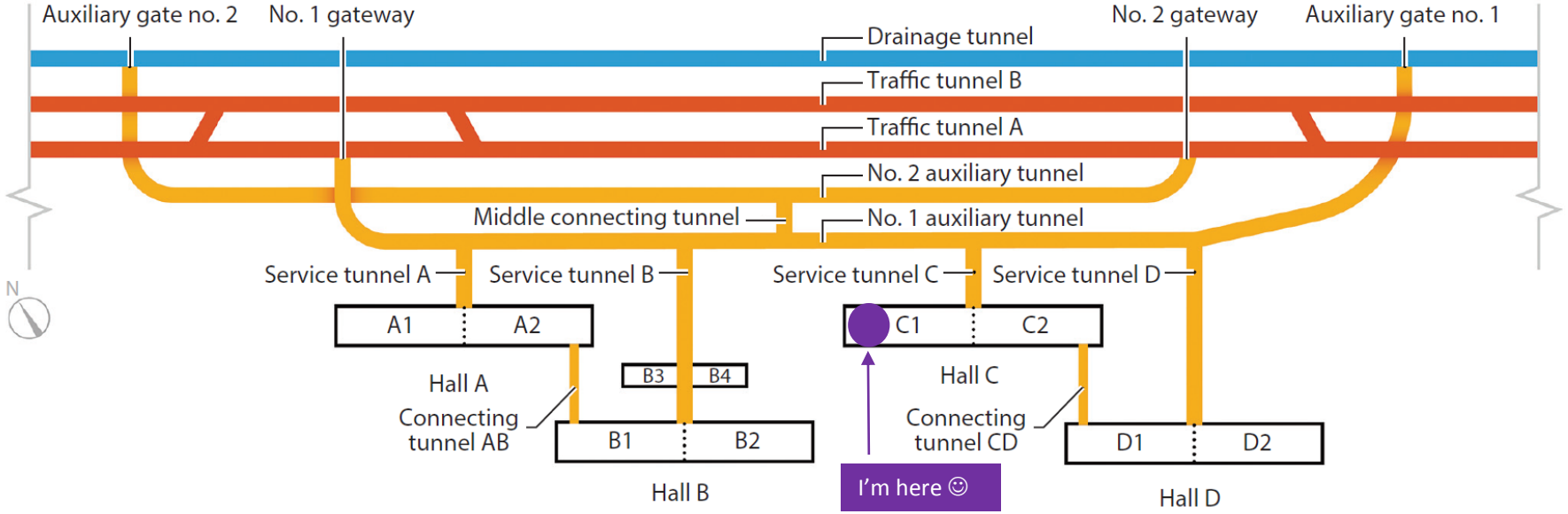
- CJPL-I to CJPL-II
  - Volume: 4000 to 300,000 m^3;
  - 1 main hall (6.5x6.5x42m) to 8 main halls (14x14x60m each);
  - Additional pit for next-generation CDEX;



Layout of CJPL-II

Future Plan - Lab

- CJPL-I to CJPL-II
  - Volume: 4000 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

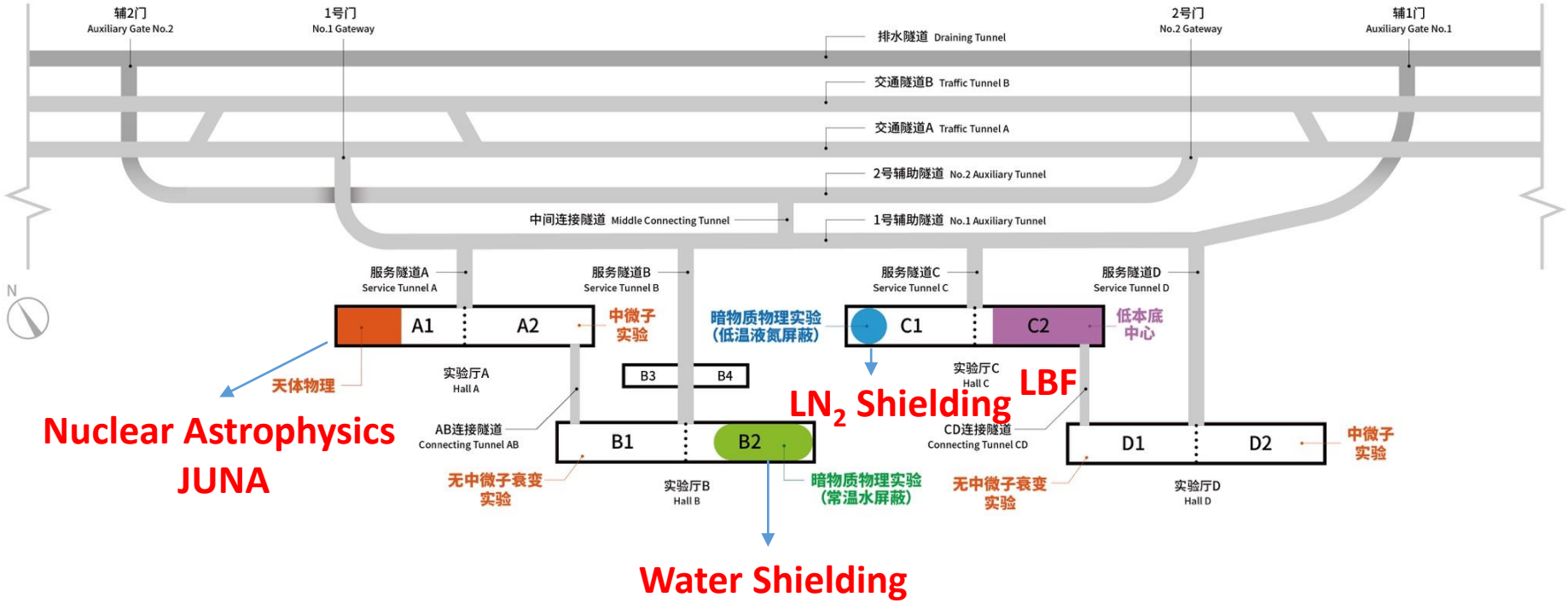
Service tunnel

- 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 fecility including the infrastructure, shielding, instrument and so on.
- Possible users:
  - CDEX-1T(DM, 0νββ), PandaX-4T, 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

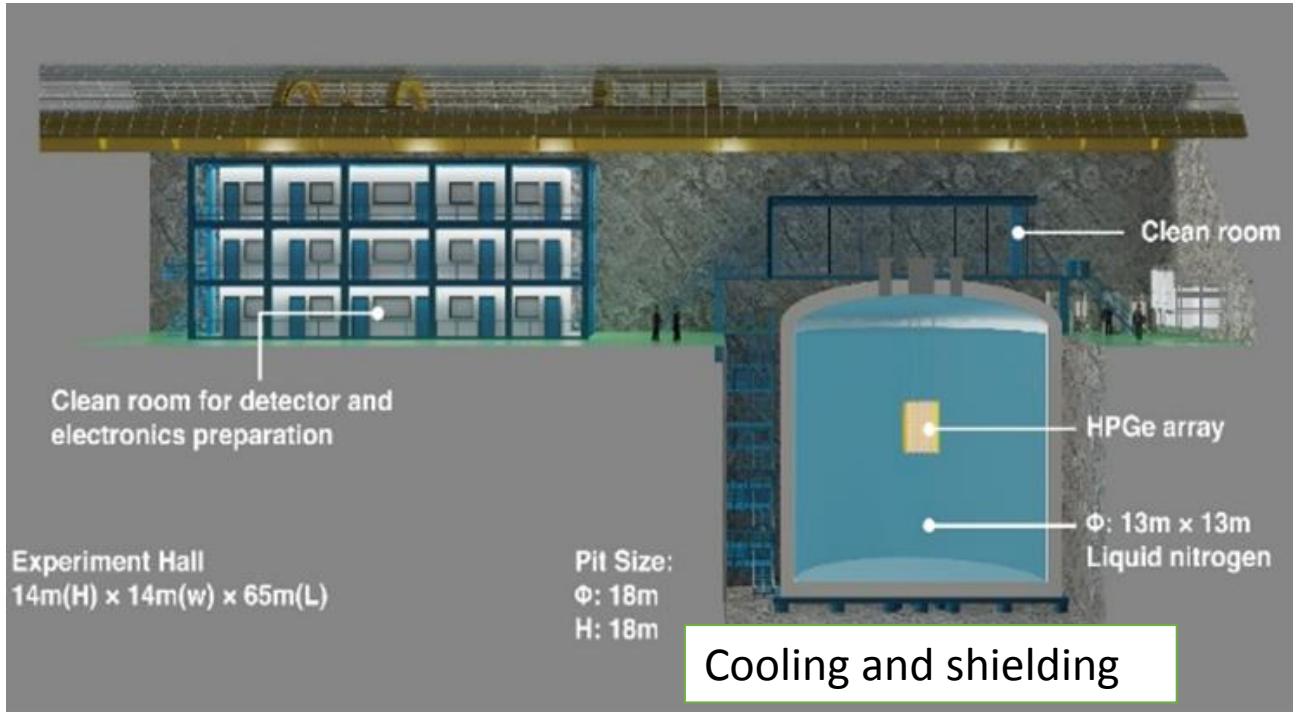
CJPL-II construction next plan

- 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.

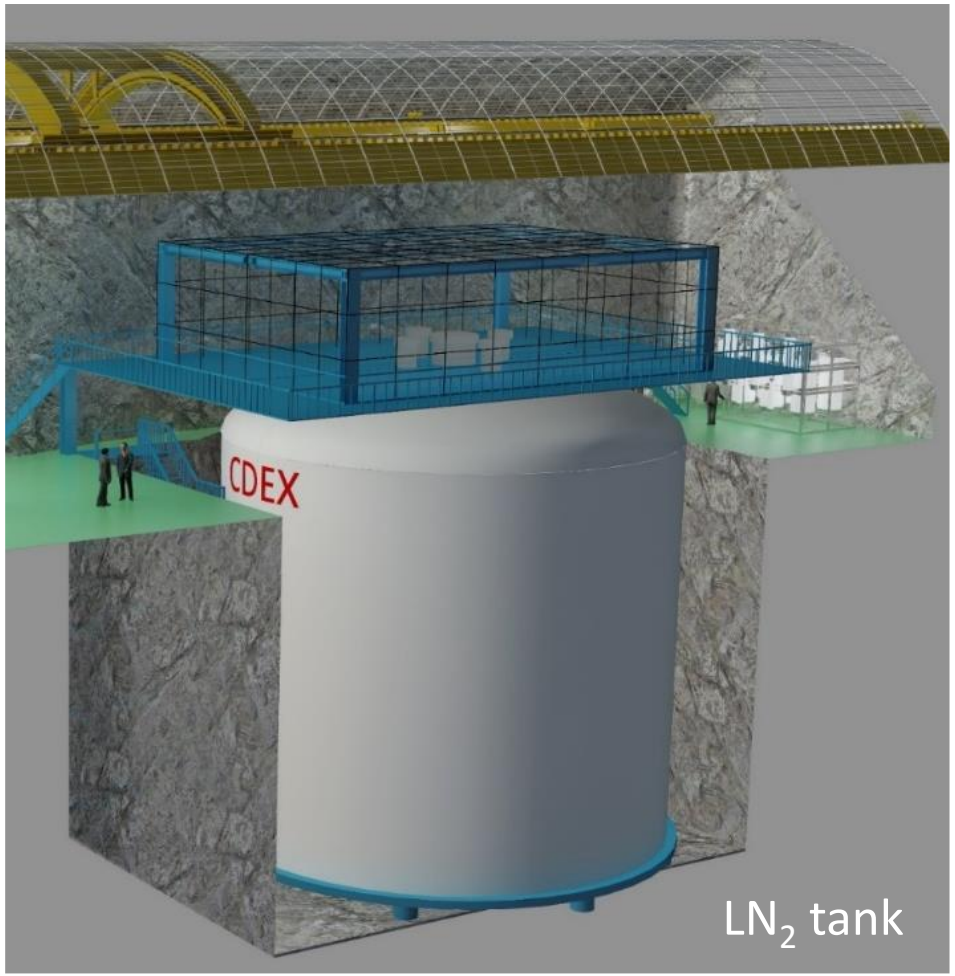


Future Plan - CDEX

- 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.



Future Plan - CDEX

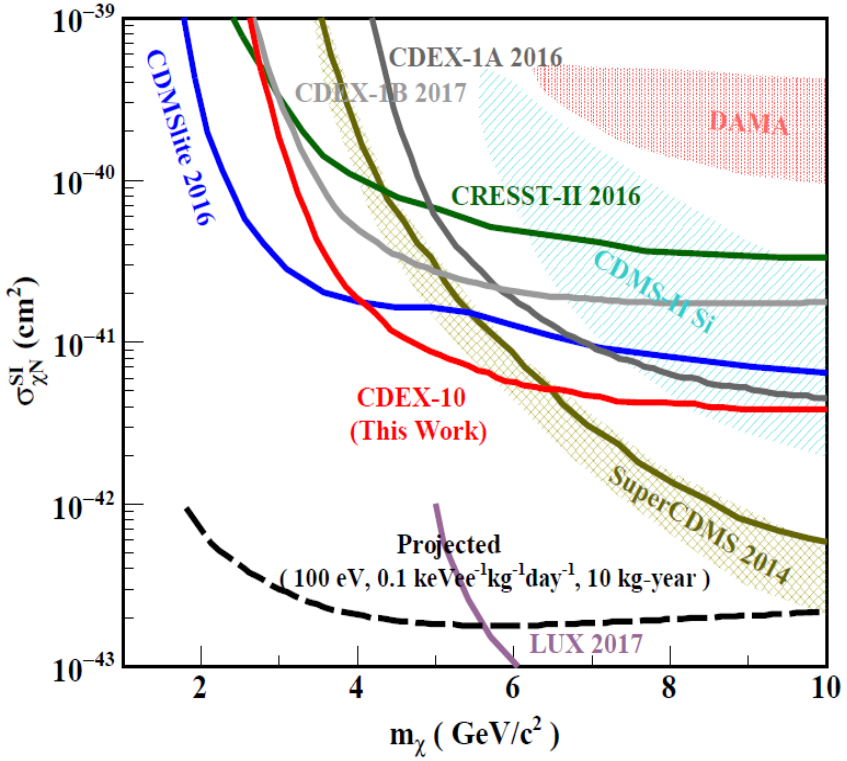


LN_2 tank

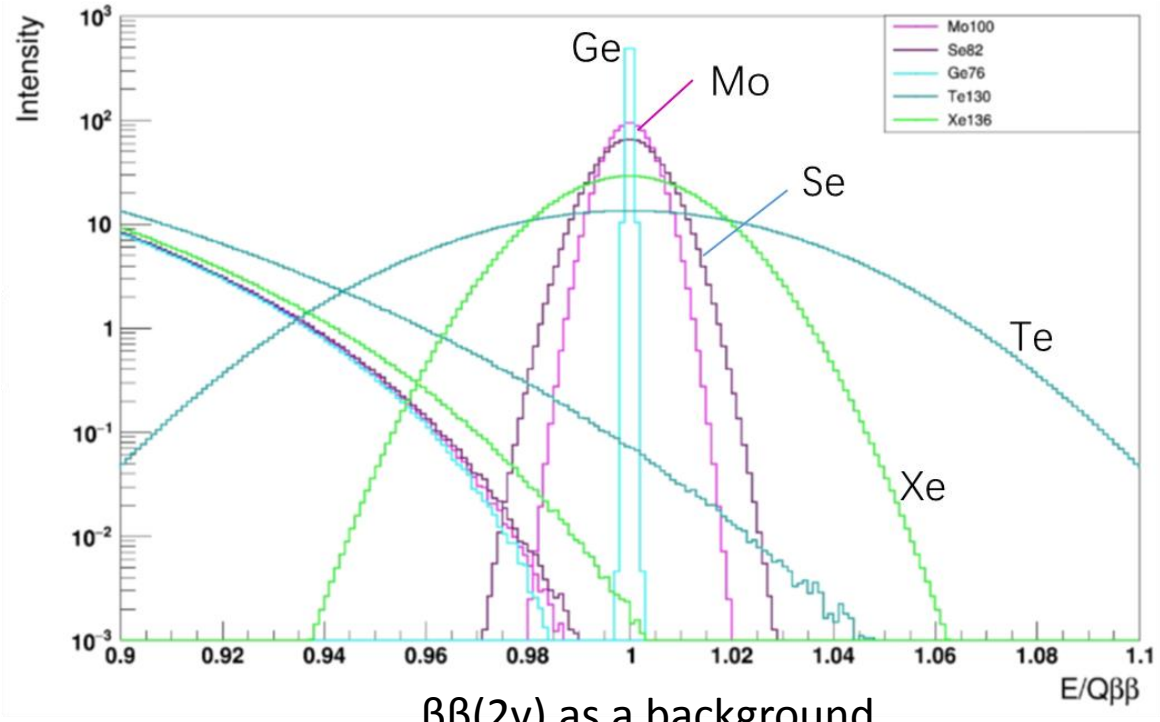

LN_2 tank at C1

Future Plan - CDEX

- DM
  - WIMPs, incl. AM;
  - Axion
  - Dark photon…



- 0νββ
  - Taking advantages of Ge detectors;
  - Combined with Legend-1T@CJPL?

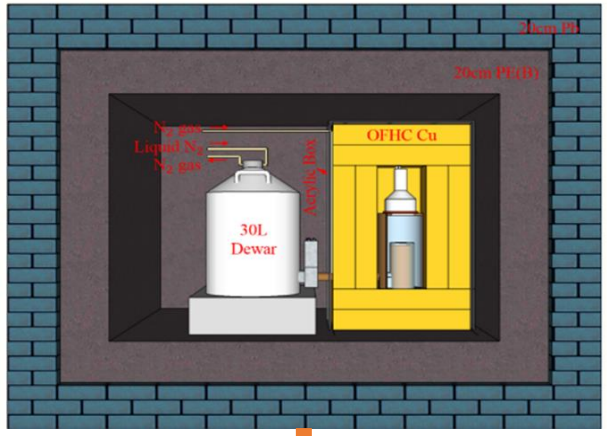


ββ(2v) as a background

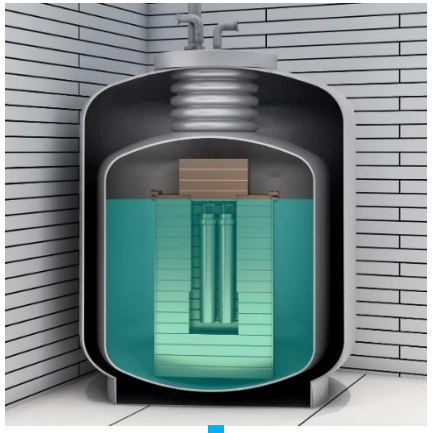
Assuming $T_{0\nu}/T_{2\nu} = 1 \times 10^6$

CDEX Roadmap

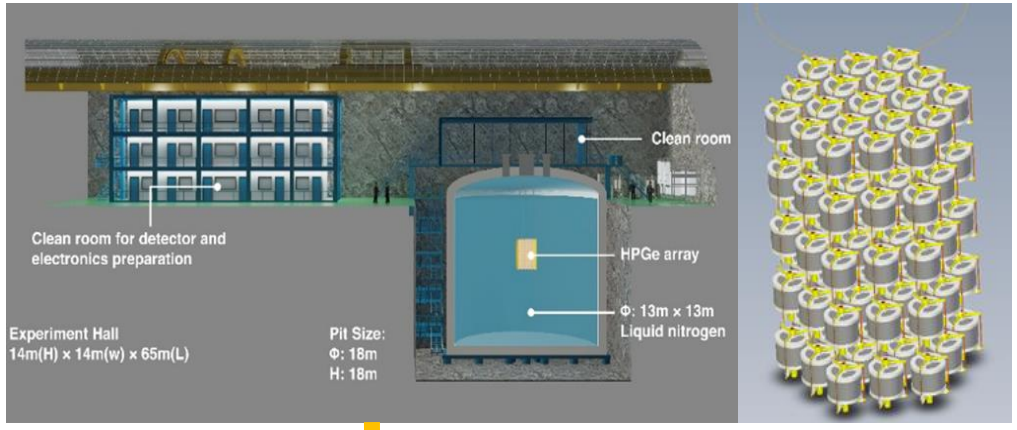
CDEX-1A/B



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
- ✓……

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;

- 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, $0\nu\beta\beta$,…


Thanks for your attention!
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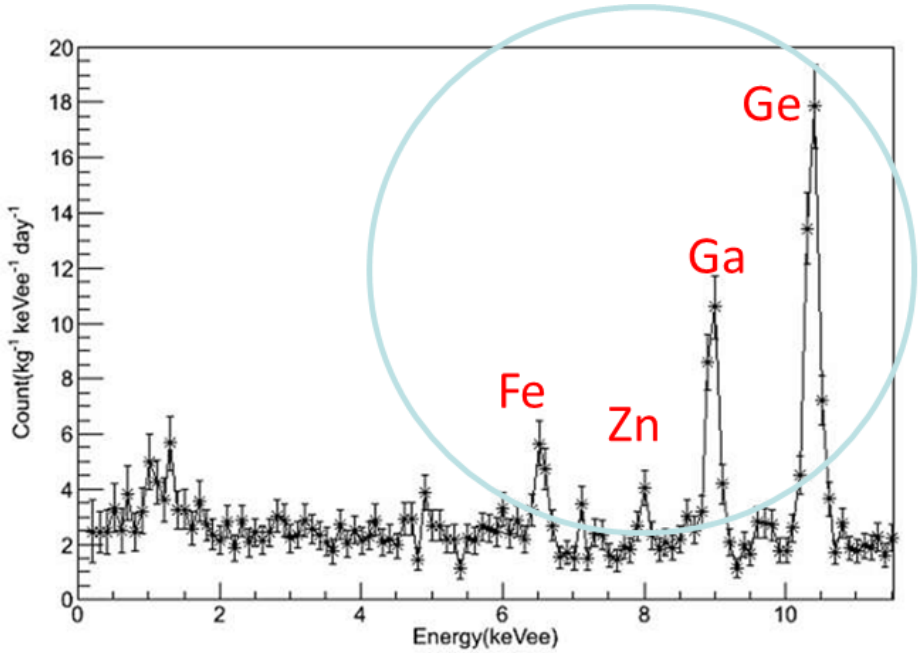
Backup

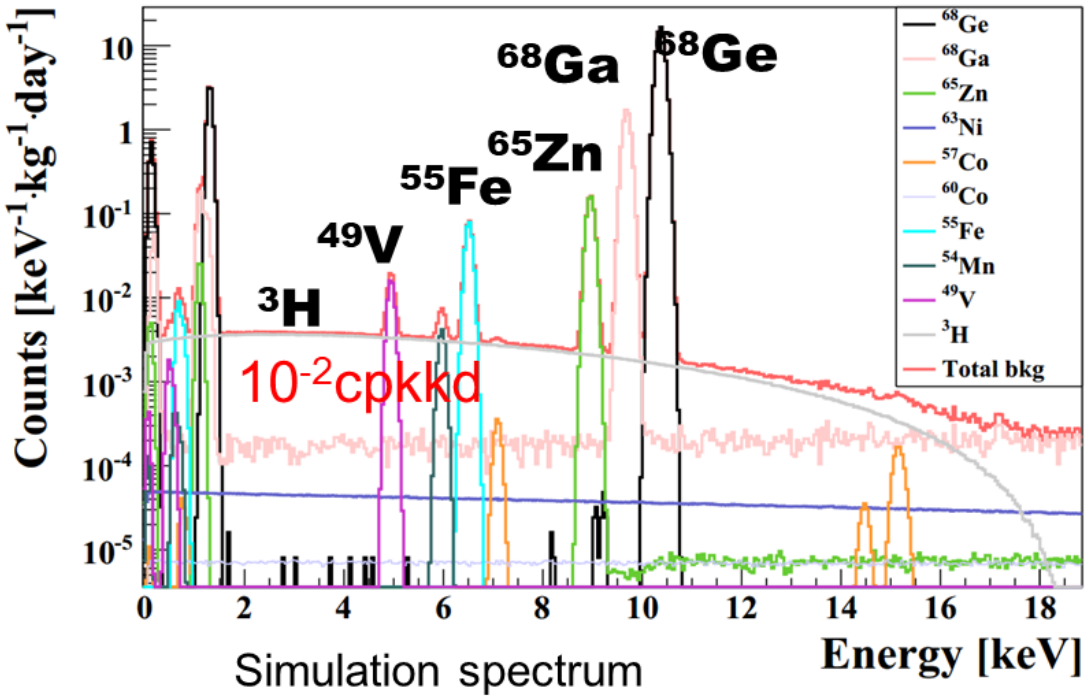
Cosmogenic bkg of Ge crystal

- Long-time ground preparation of detector induces high cosmogenic bkg;
- Based on simulation, 2 months ground fabrication and transportation could decrease the ^{3}H continuous bkg level to ~10^{-2}cpkkd @ 2-4 keV.



CDEX-10 background spectrum

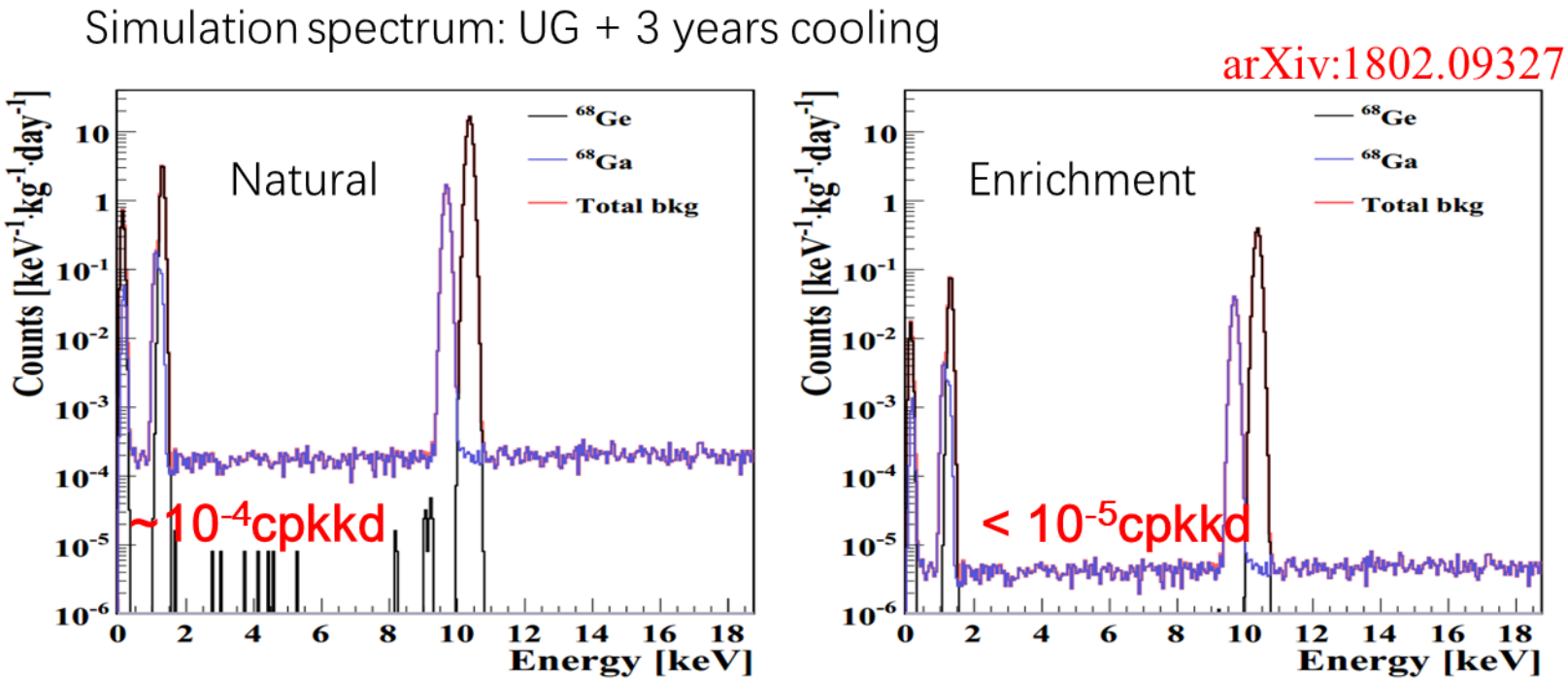
arXiv1802.09327 /Sci. China Phys. Mech. Astron. (2019) 62:11011



Simulation spectrum

Cosmogenic bkg of Ge crystal

- Underground germanium crystal growth and detector fabrication could dramatically decrease the cosmogenic bkgs from non-Ge isotopes, such as ^{3}H, ^{65}Zn(…$^{68}Ge/^{68}Ga$ left);

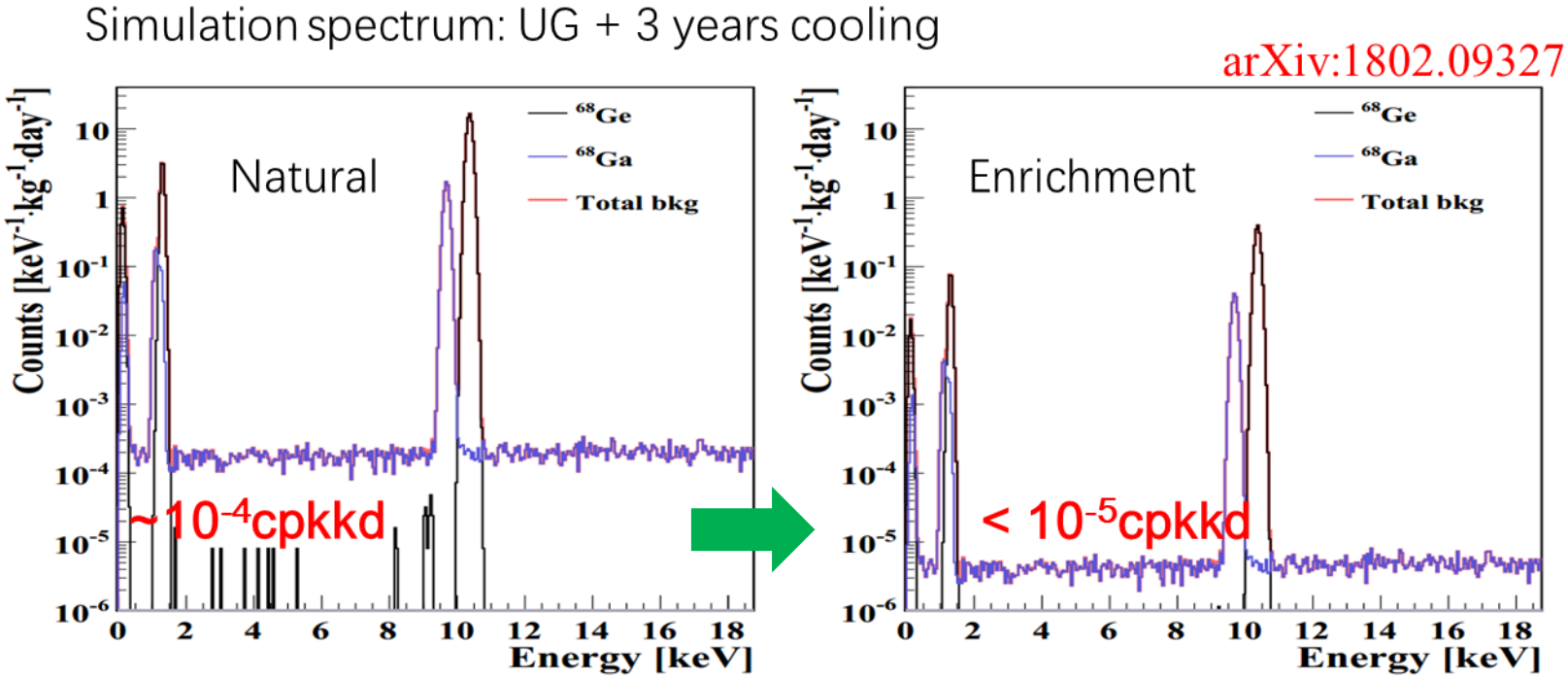


arXiv:1802.09327 /*Sci. China Phys. Mech. Astron. (2019) 62:11011*

Cosmogenic bkg of Ge crystal

- Underground germanium crystal growth and detector fabrication could dramatically decrease the cosmogenic backgrounds from non-Ge isotopes, such as ^{3}H, ^{65}Zn(^{68}Ge/^{68}Ga left);
- ^{76}Ge Enriched Ge material could further help to decrease ^{68}Ge(^{68}Ga).

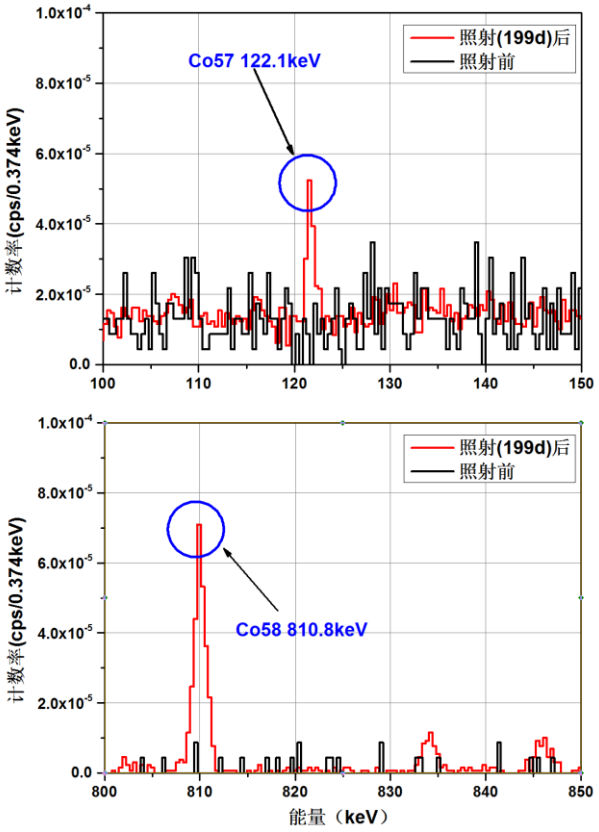
^{76}Ge abundance
7.6%→86.6%

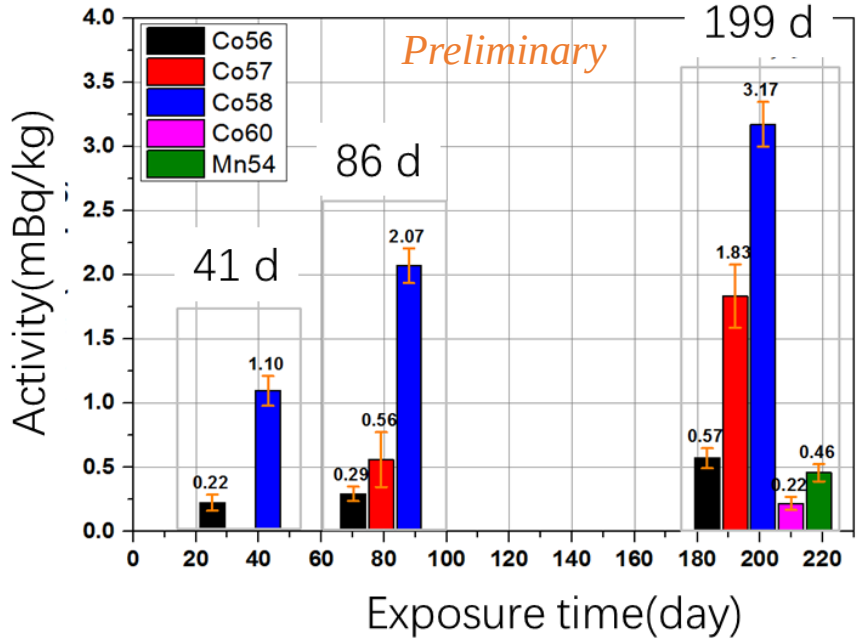


arXiv:1802.09327 /*Sci. China Phys. Mech. Astron. (2019) 62:11011*

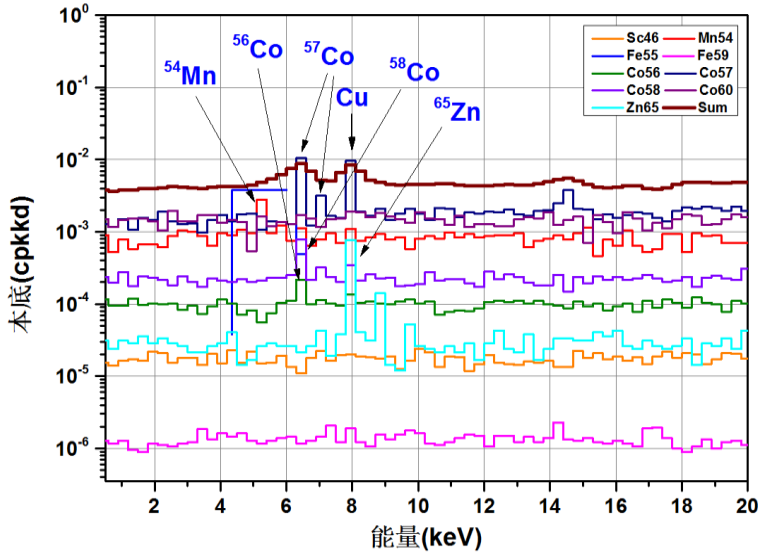
Cosmogenic bkg of Copper

- Cosmic shower @~2500m altitude near CJPL;
- Gamma spectrometry by GeTHU-1;
- Paper preparation…and vs. simulation





Cosmogenic background in det. Induced by copper



Copper samples to be exposed