Direct Dark Matter Search with CDEX at CJPL

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On behalf of CDEX Collaboration
2018.7.25

OUTLINE

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

China Dark matter EXperiment

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

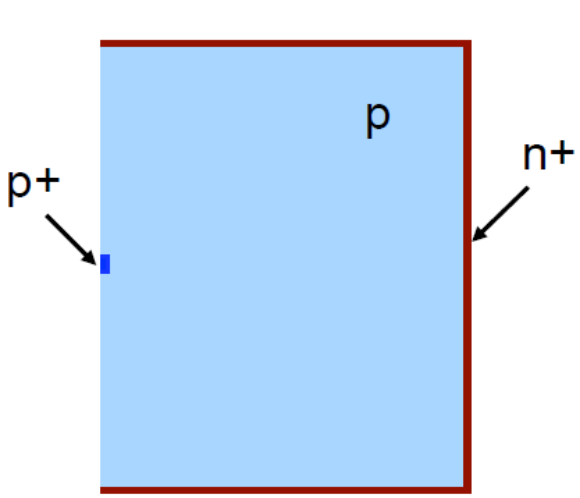
清華大學 Tsinghua University
北京師範大學 BEIJING NORMAL UNIVERSITY
南開大學 Nankai University
北京大學 PEKING UNIVERSITY (new member, Rn issues)
四川大學 SICHUAN UNIVERSITY
中國原子能科學研究院 CHINA INSTITUTE OF ATOMIC ENERGY
雅砻江水电 YALONG HYDRO

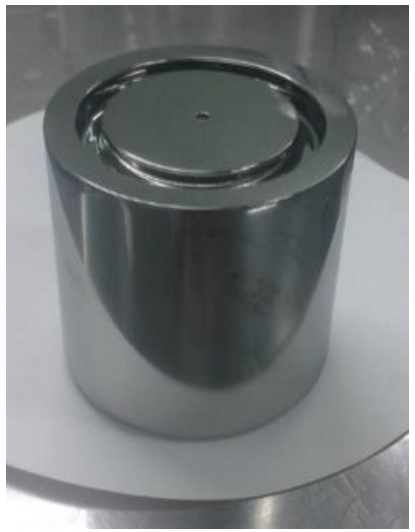
\+ TEXONO Collaboration

CDEX Stages

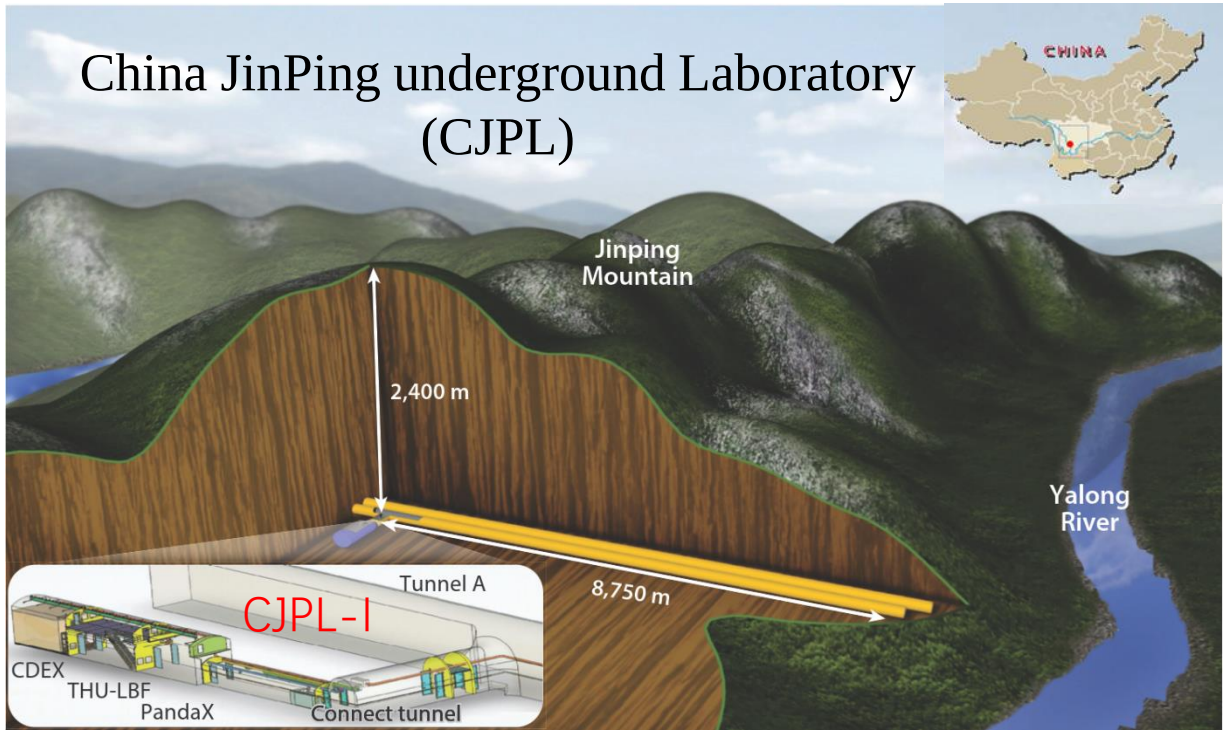
- DM detection w/ Ge prepared since 2003 and started in 2005 in Y2L (5g);
- CDEX-1: Development of PPC Ge detector, bkg understanding, since 2011;
- CDEX-10: Performances of Ge array detector immersed in LN_2, since 2016;
- CDEX-10X: Home-made Ge detector and Ge crystal growth;

P-type Point-Contact(PPC)
Germanium detector



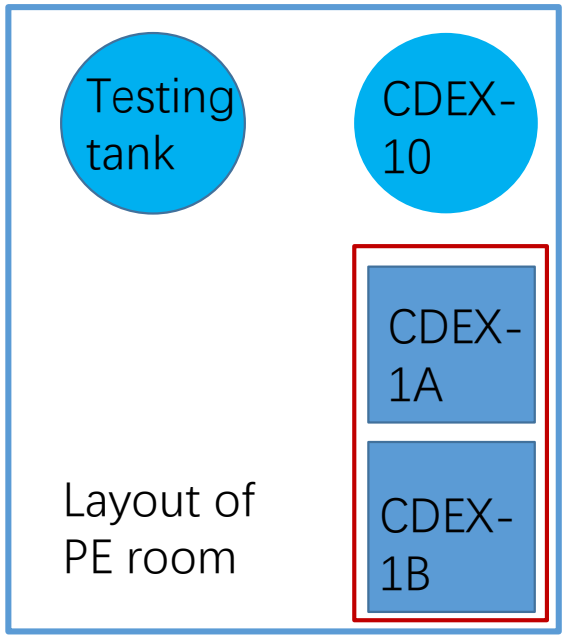


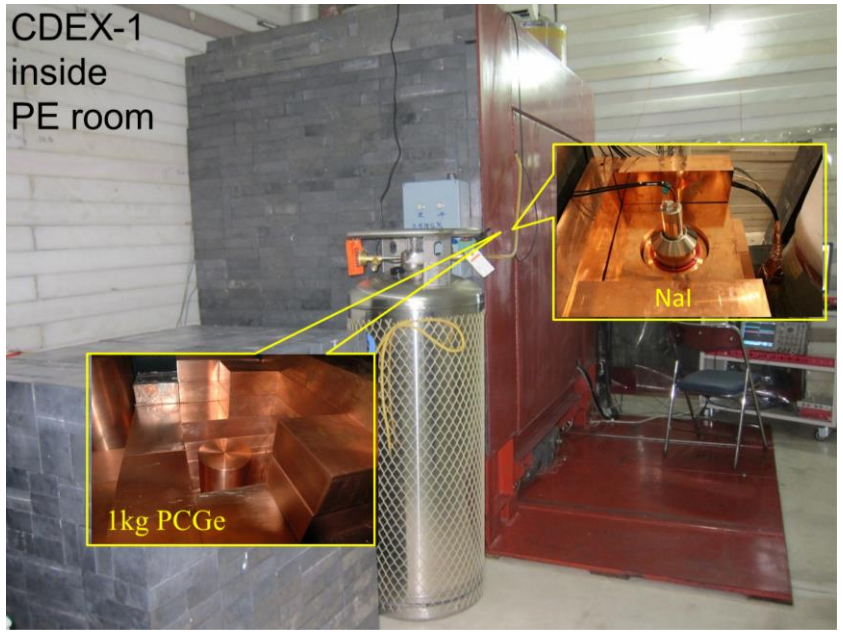
Direct detection of low-mass WIMPs w/ Ge detector at CJPL.



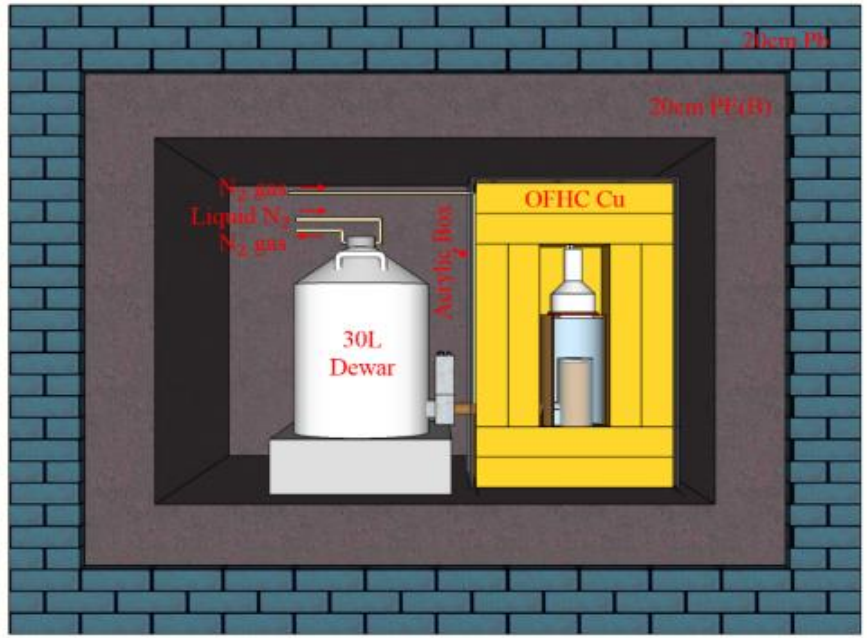
CDEX-1 stage

- 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;



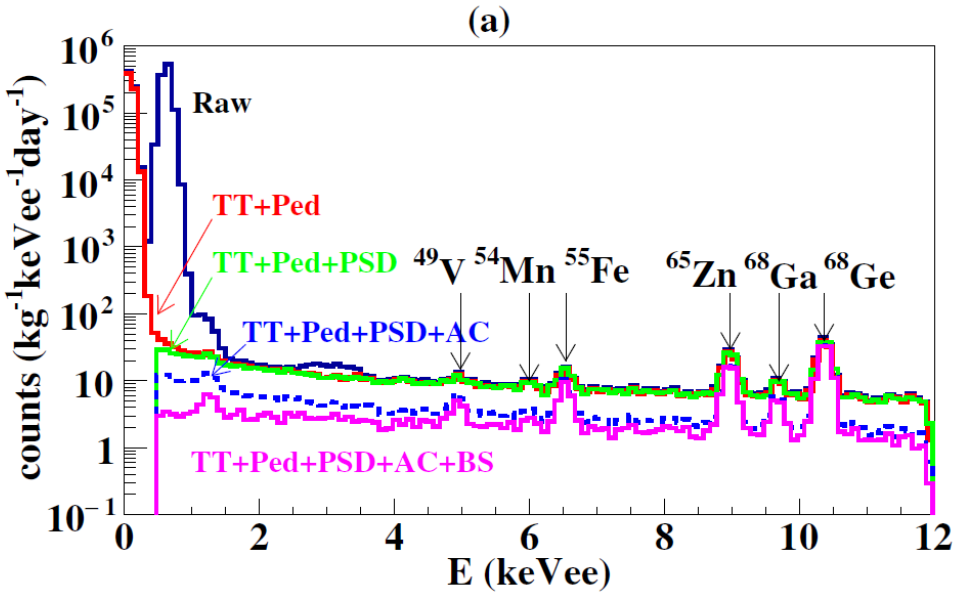


CDEX-1A&B：1kg PPC Ge×2



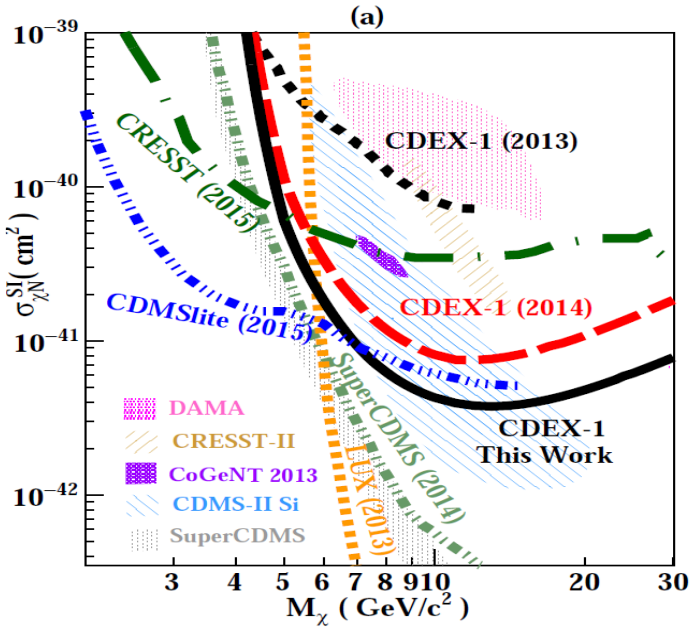
CDEX-1A Results

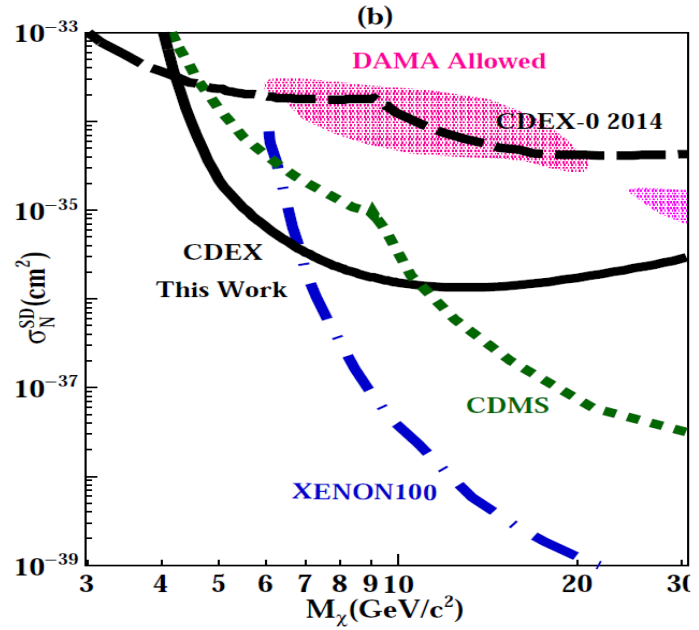
- >500 days run, ~336 d·kg dataset;
- Energy threshold: 475 eVee;
- Bulk/Surface disc. to cut events with slow rise-time and partial charge collection;
- K/L X-rays from Cosmogenic nuclides to trace crystal history;



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

See *PRD93, 092003, 2016*

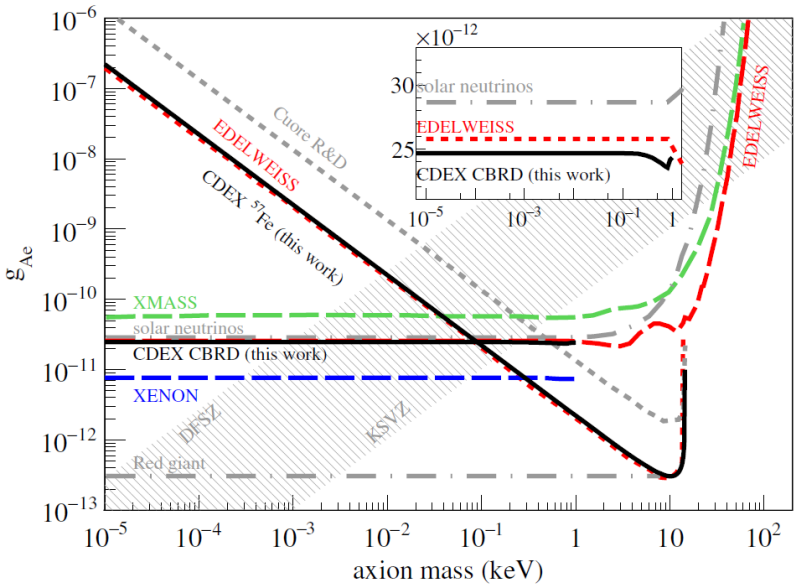


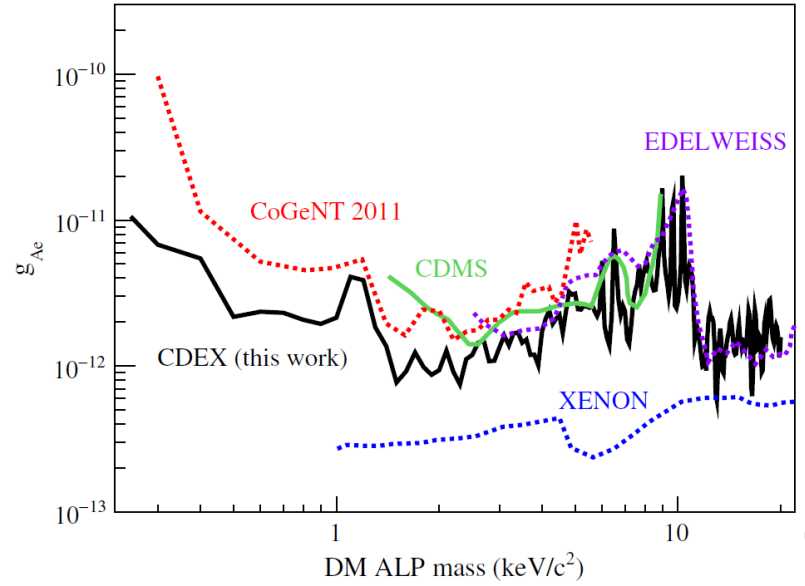


CDEX-1A Results

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

PRD95, 052006, 2017



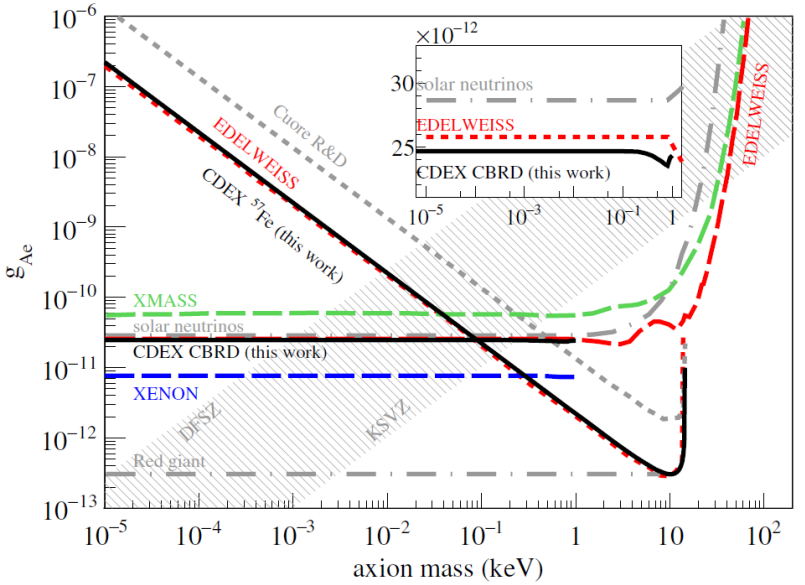


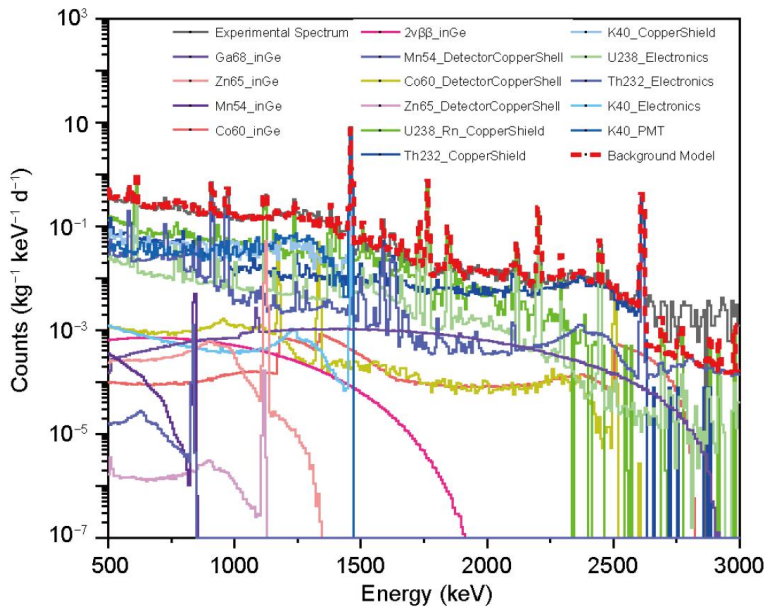
CDEX-1A Results

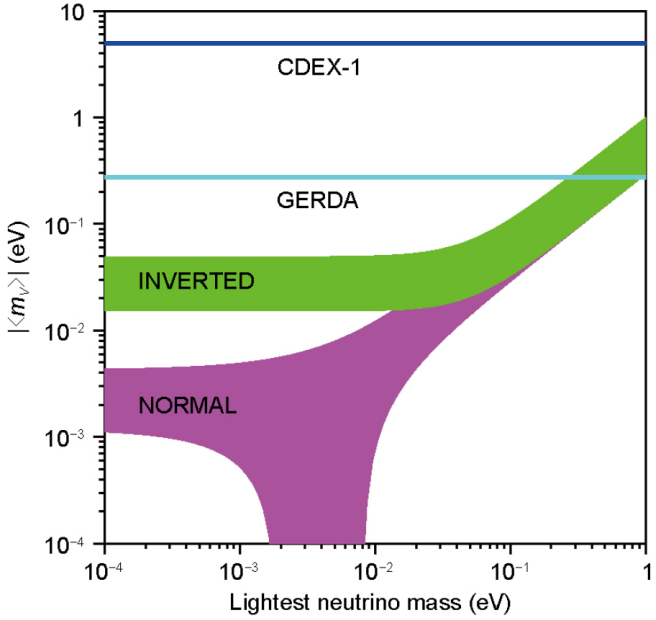
- Axion (335.6 kg·day data)
  - Solar axions：CBRD processes and ^{57}Fe M1 transition;
  - ALPs: more stringent constraint below 1keV;
- 0νββ (304 kg·day data)
  - Natural Ge crystal;

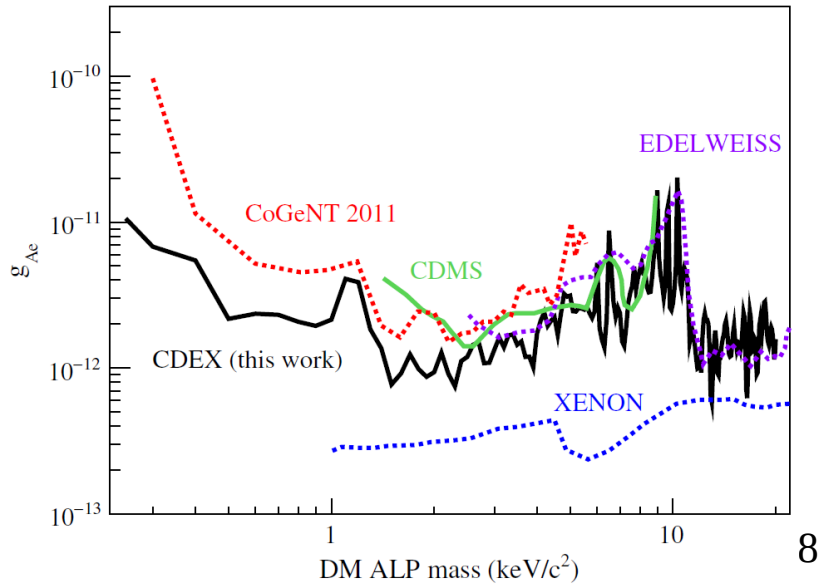
$$T_{1/2}^{0\nu} \geq 6.43\times10^{22}\, yr,\ 90\%\ C.L.$$

PRD95, 052006, 2017









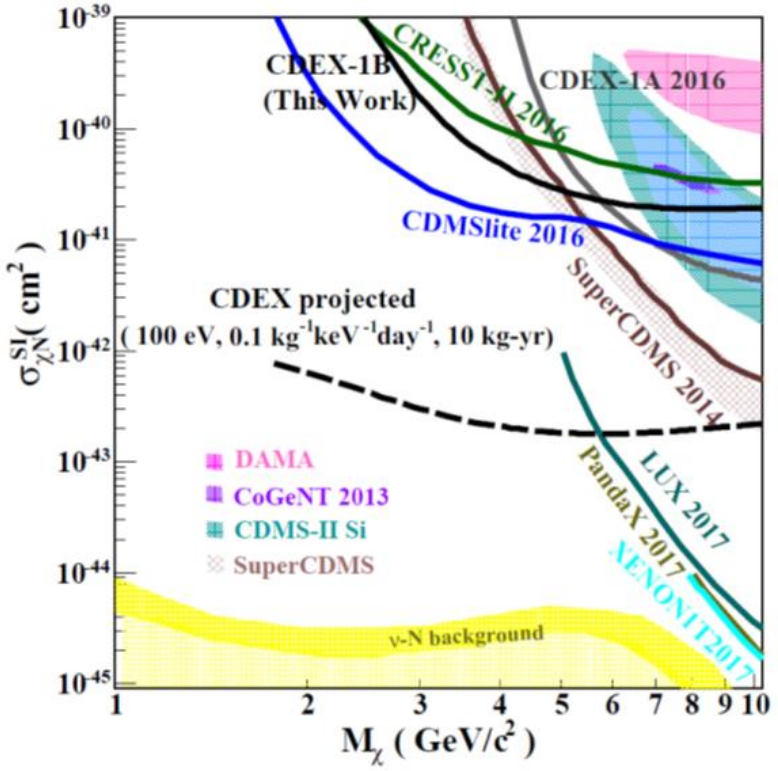
Science China PMA (2017) 60: 071011

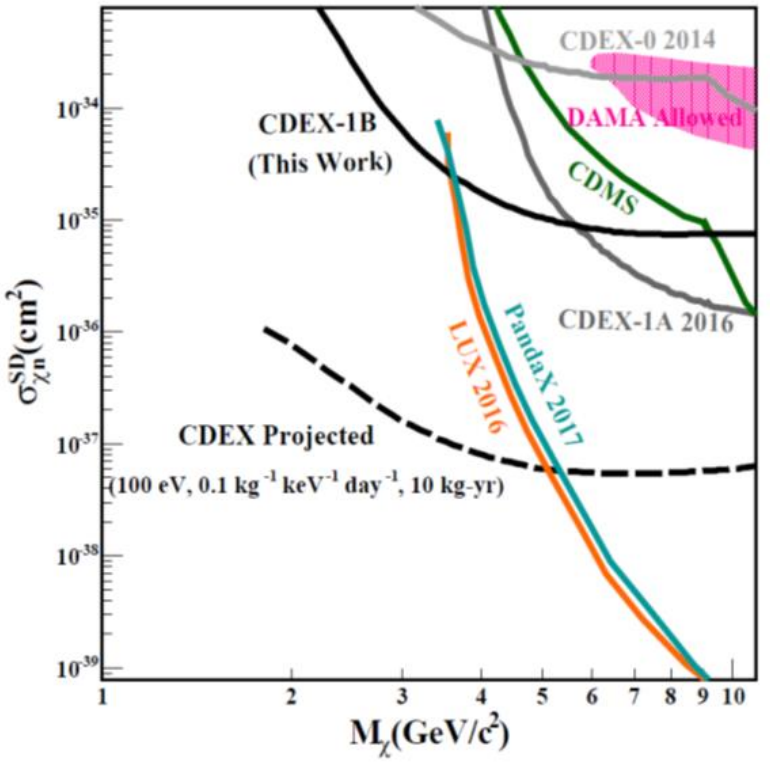
CDEX-1B Results

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

Chinese Physics C 42, 023002, 2018

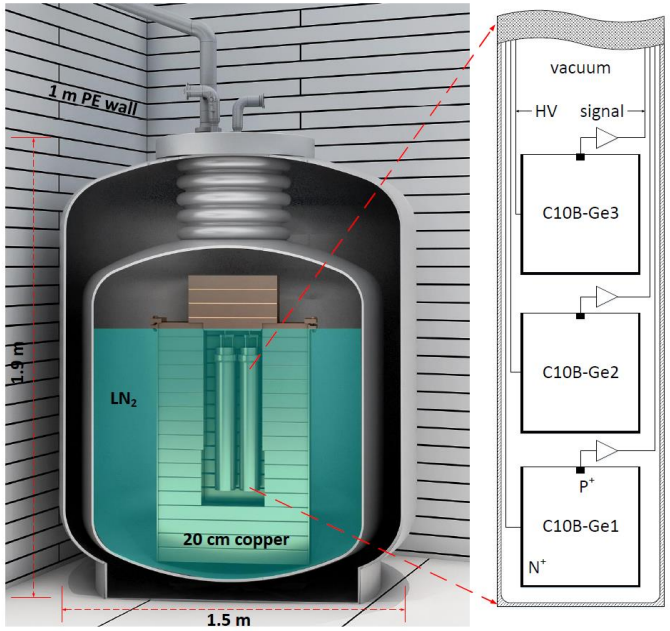
Detector	FWHM of pulser
CDEX-1A	130 eVee
CDEX-1B	80 eVee



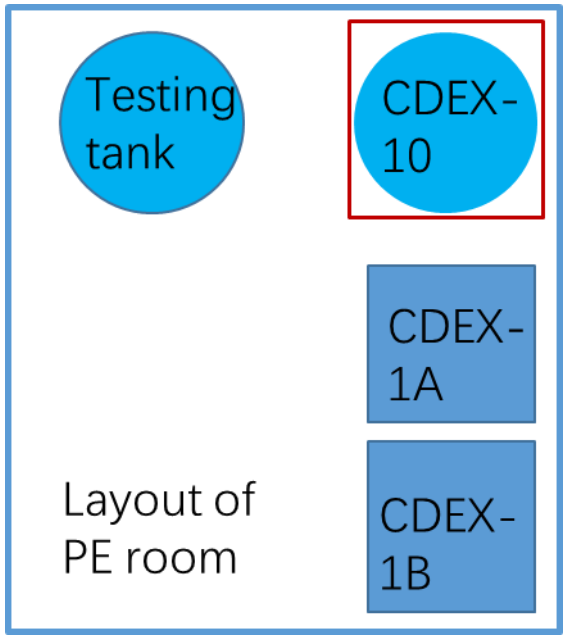


CDEX-10 stage

- 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;

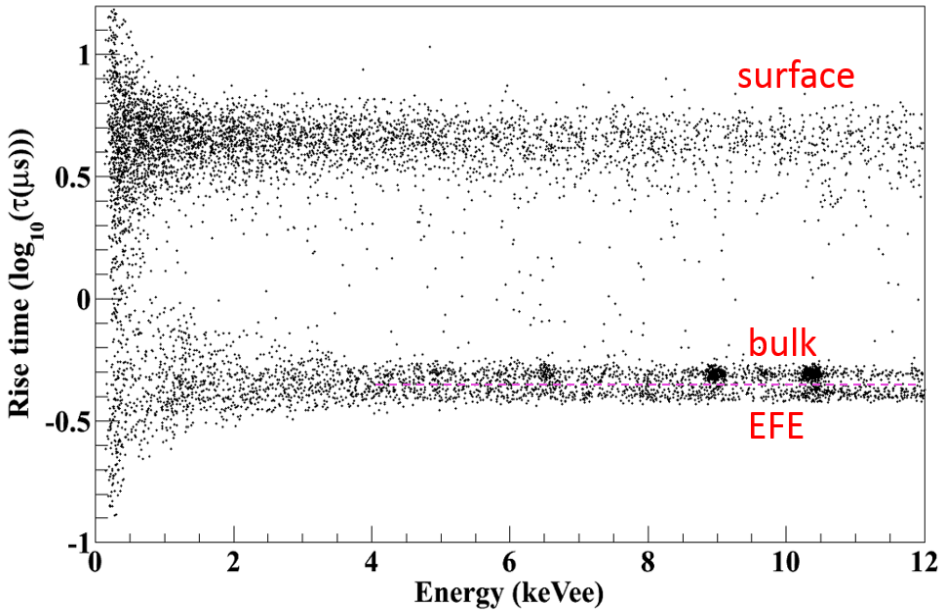


CDEX-10: ~10kg PPC Ge array

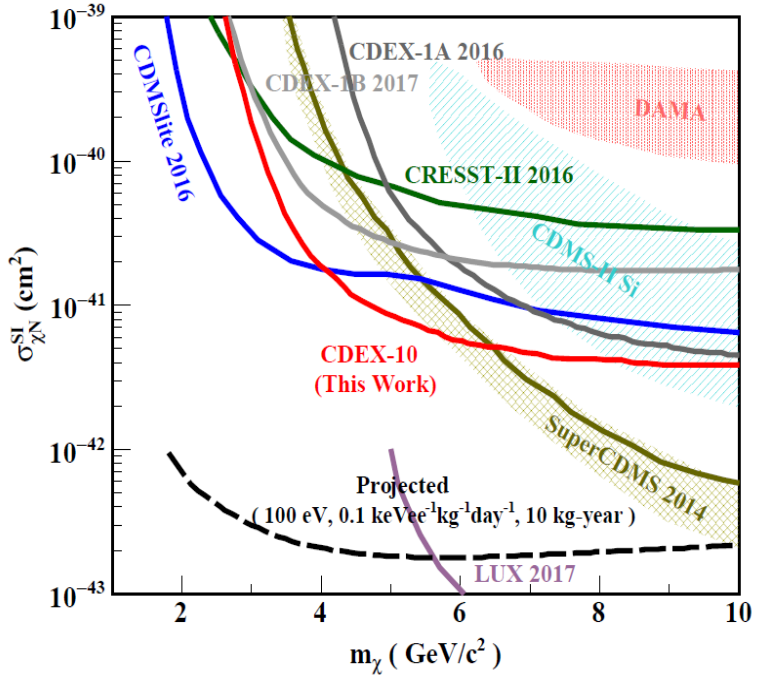


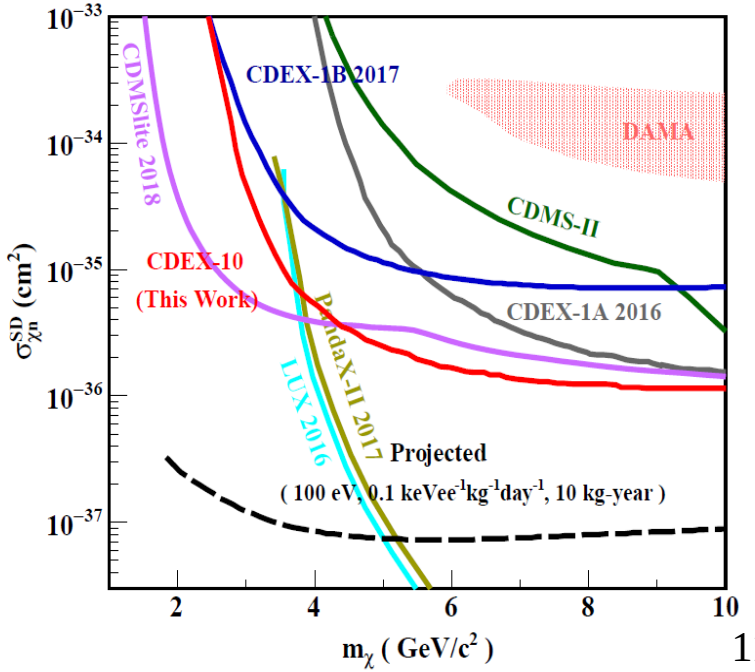
CDEX-10 First Results

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



PRL120, 241301, 2018

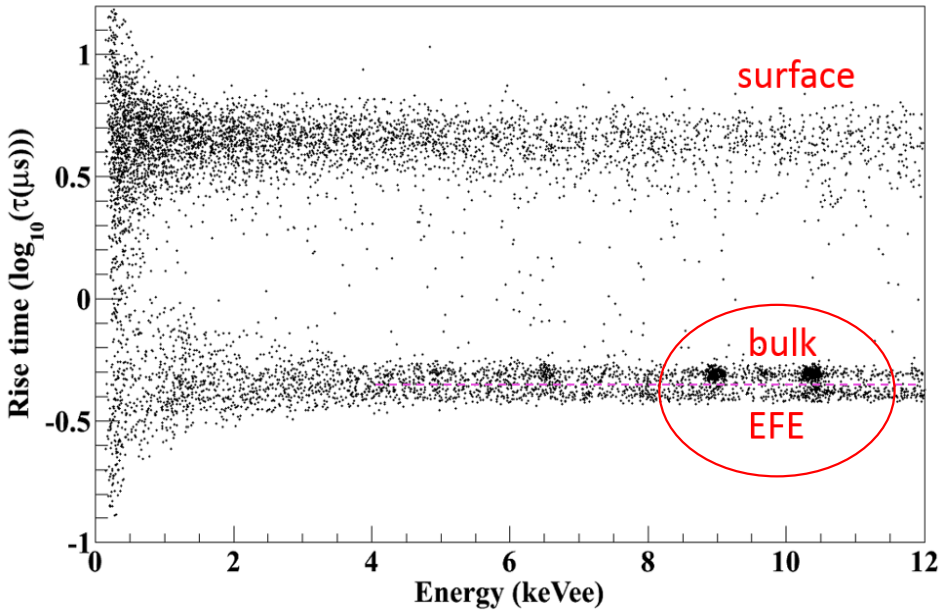


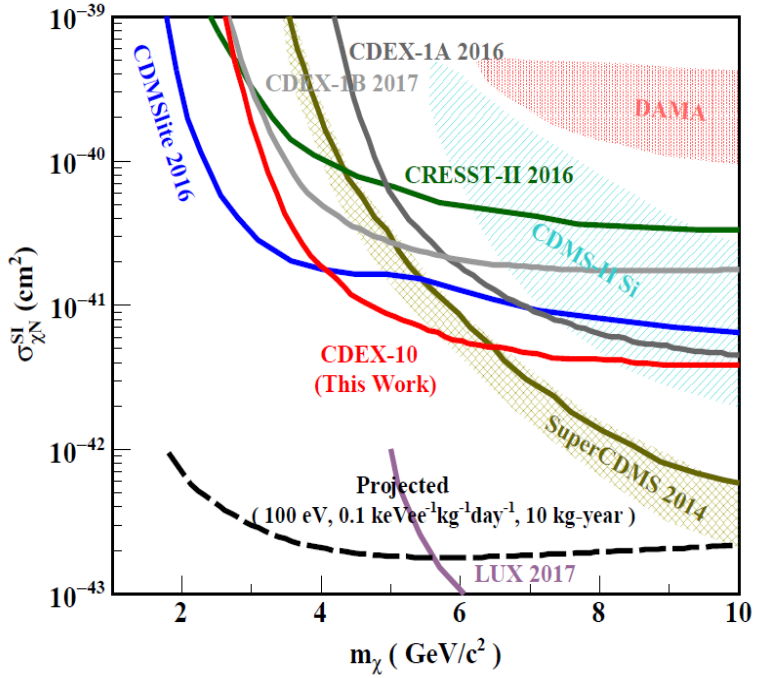


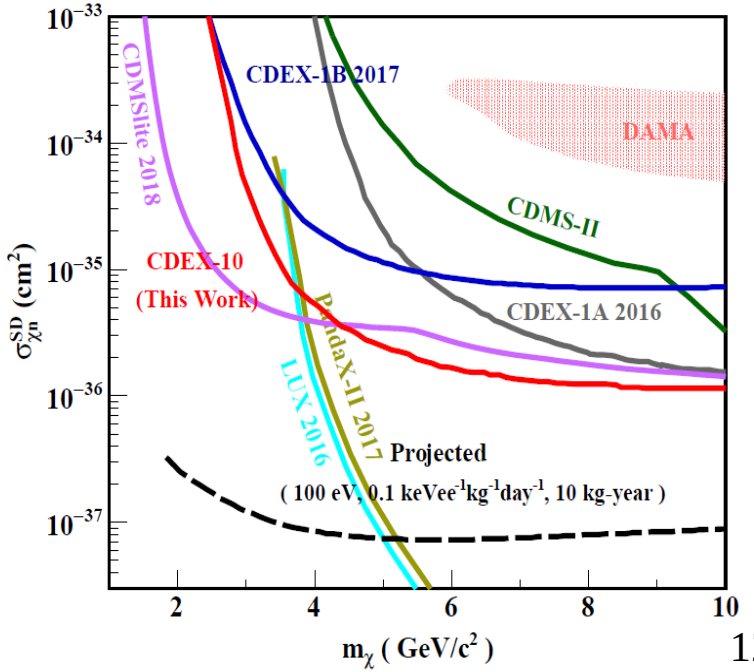
CDEX-10 First Results

- 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 band(See L. T. Yang's talk Thu. pm);

PRL 120, 241301, 2018

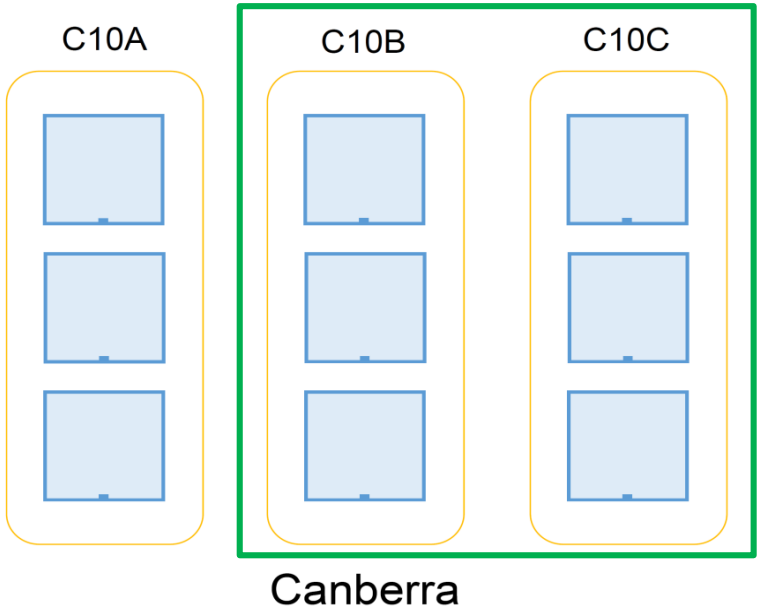






CDEX-10 Detectors

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



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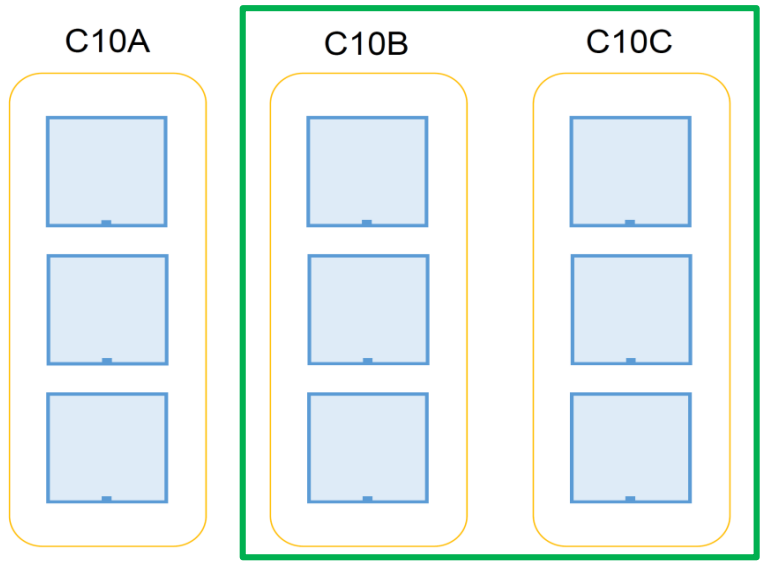
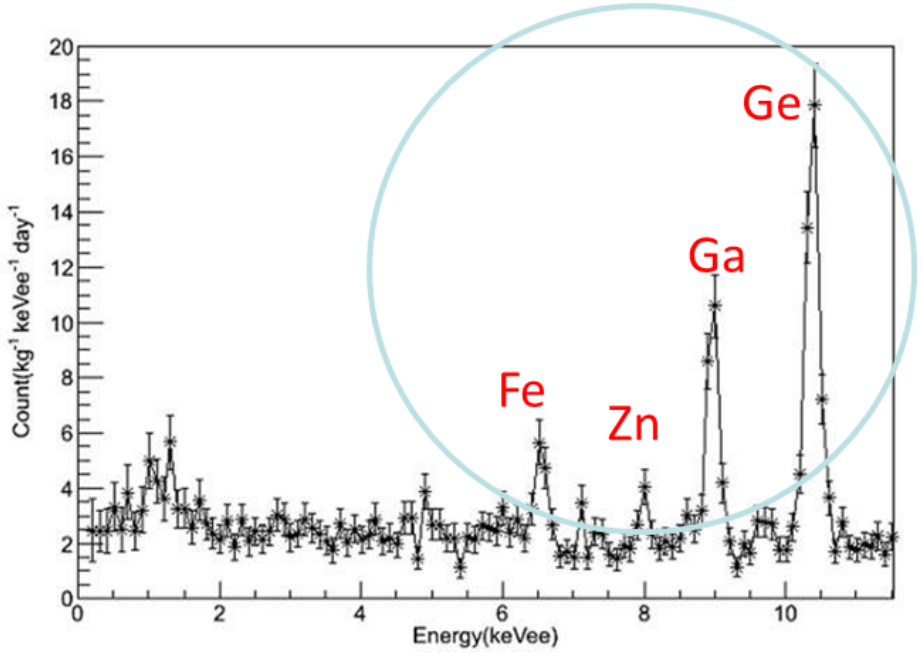


Preliminary

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

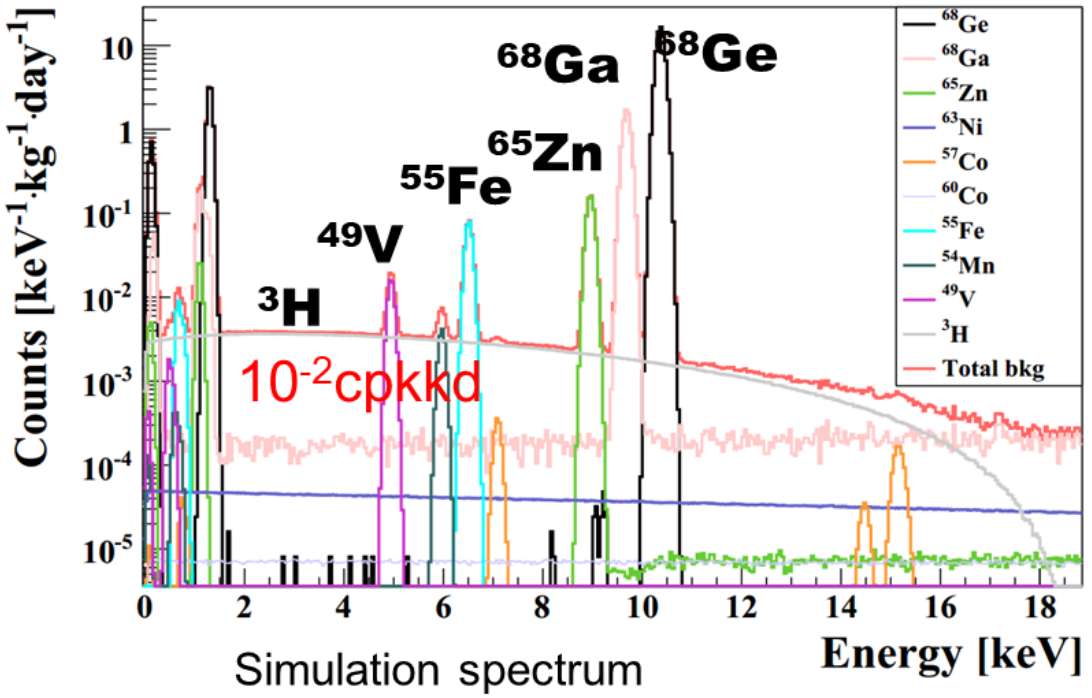
Cosmogenic bkg of Ge crystal

- 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

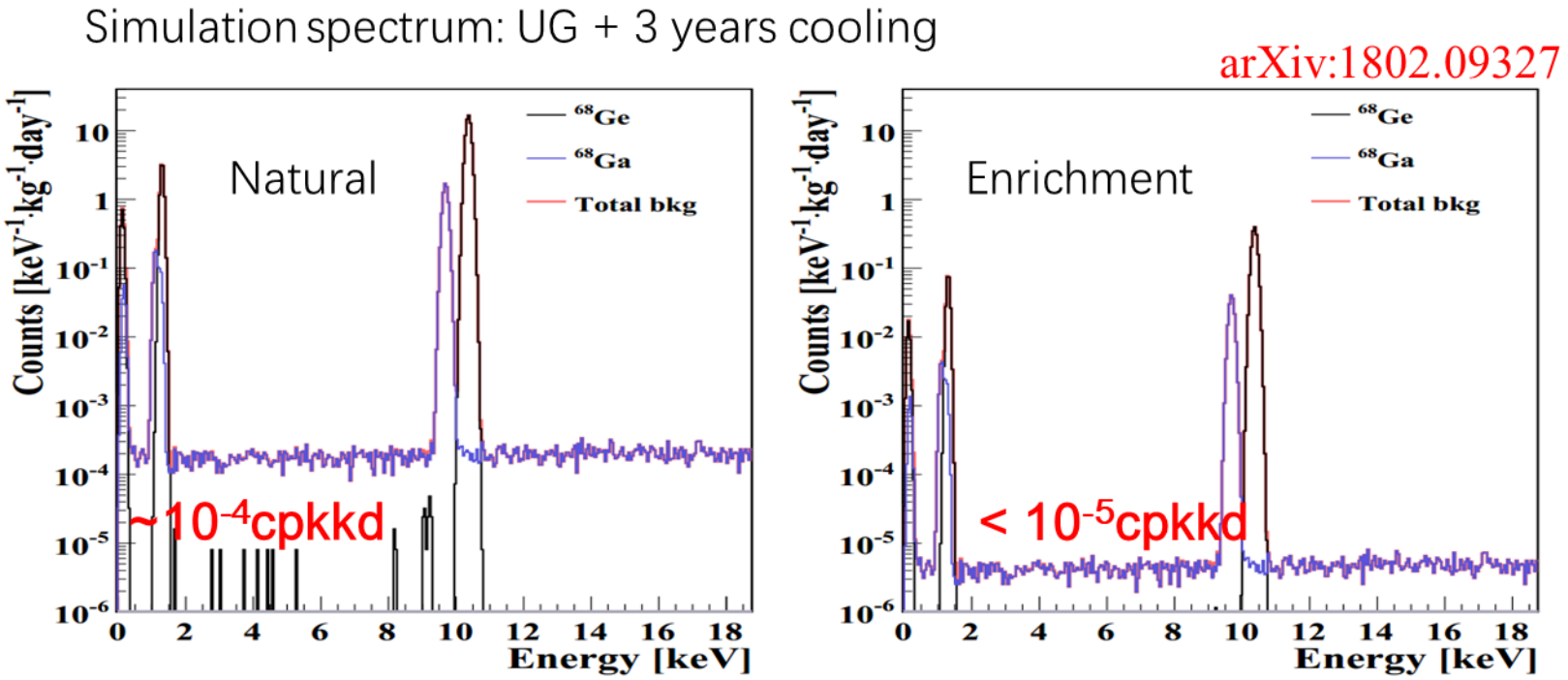
arXiv1802.09327



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);

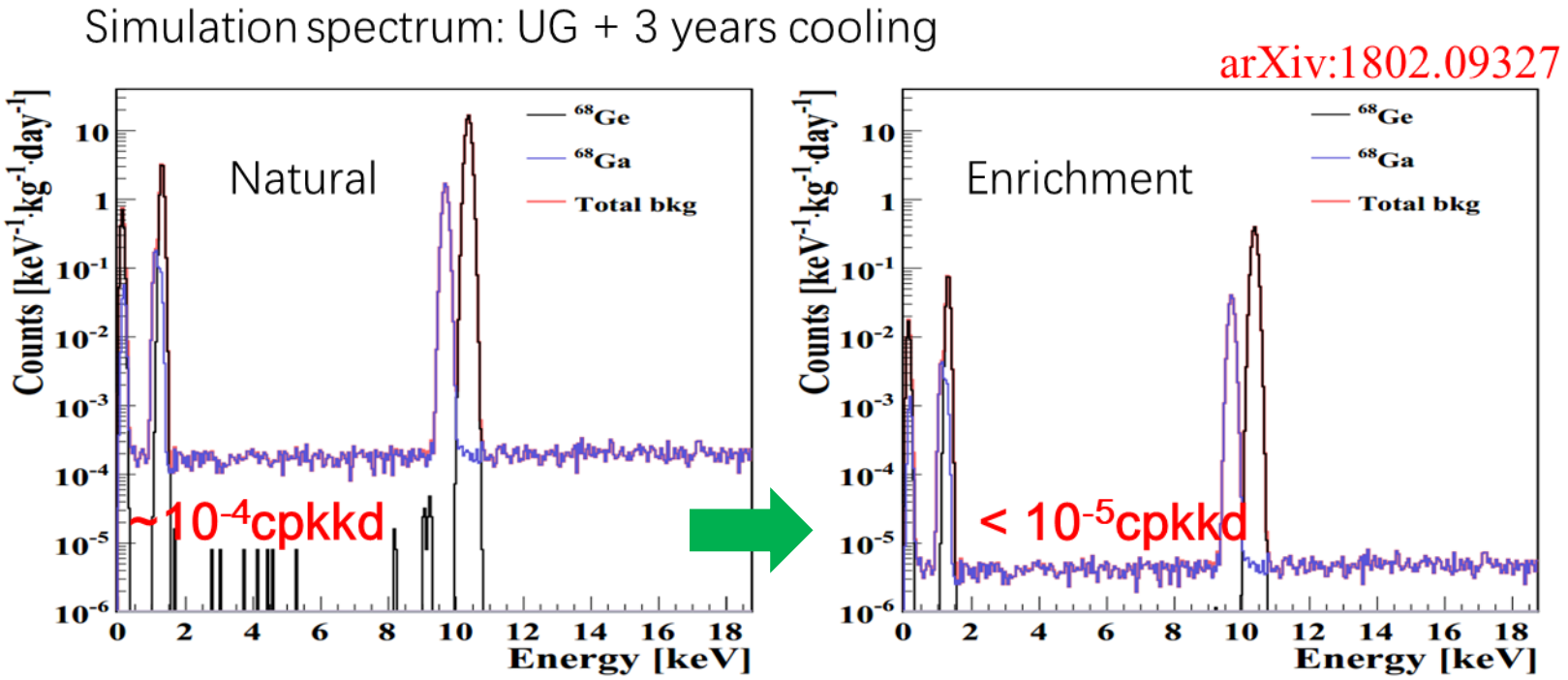


Cosmogenic bkg of Ge crystal

- 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);

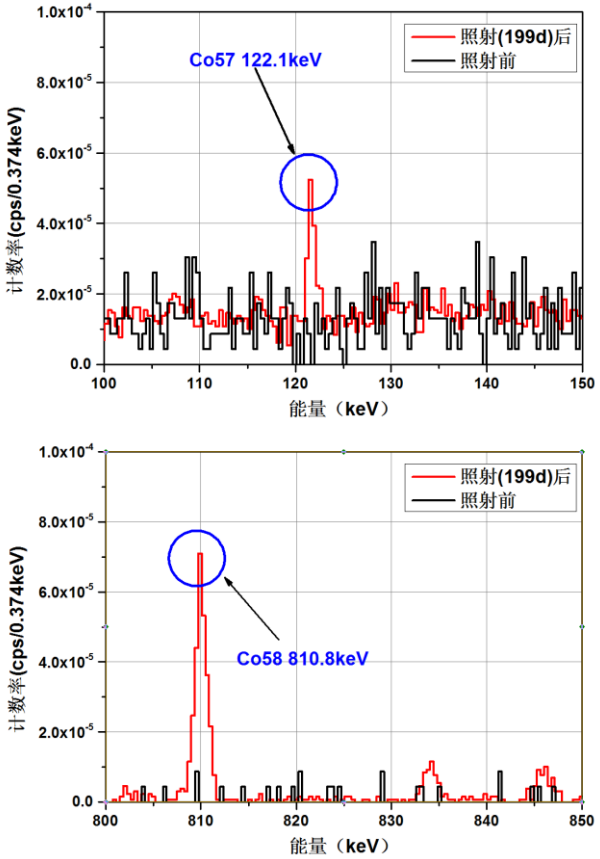
- ^{76}Ge Enriched Ge material could further help to decrease ^{68}Ge(^{68}Ga).

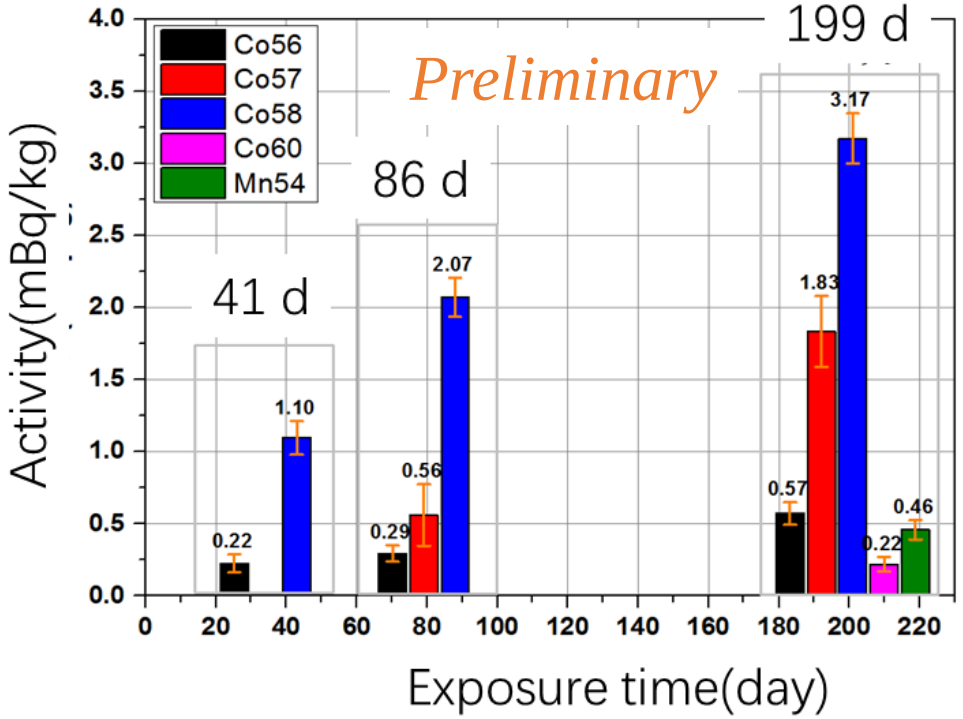
^{76}Ge abundance
7.6%→86.6%

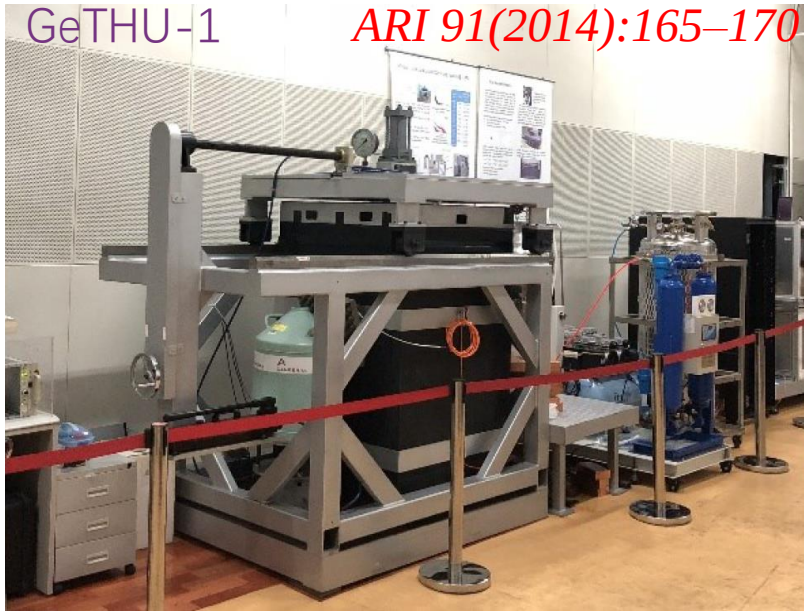


Cosmogenic bkg of Copper

- Cosmic shower @~2500m altitude outside CJPL;
- Gamma spectrometry by GeTHU-1;
- Data under analysis…and vs. simulation



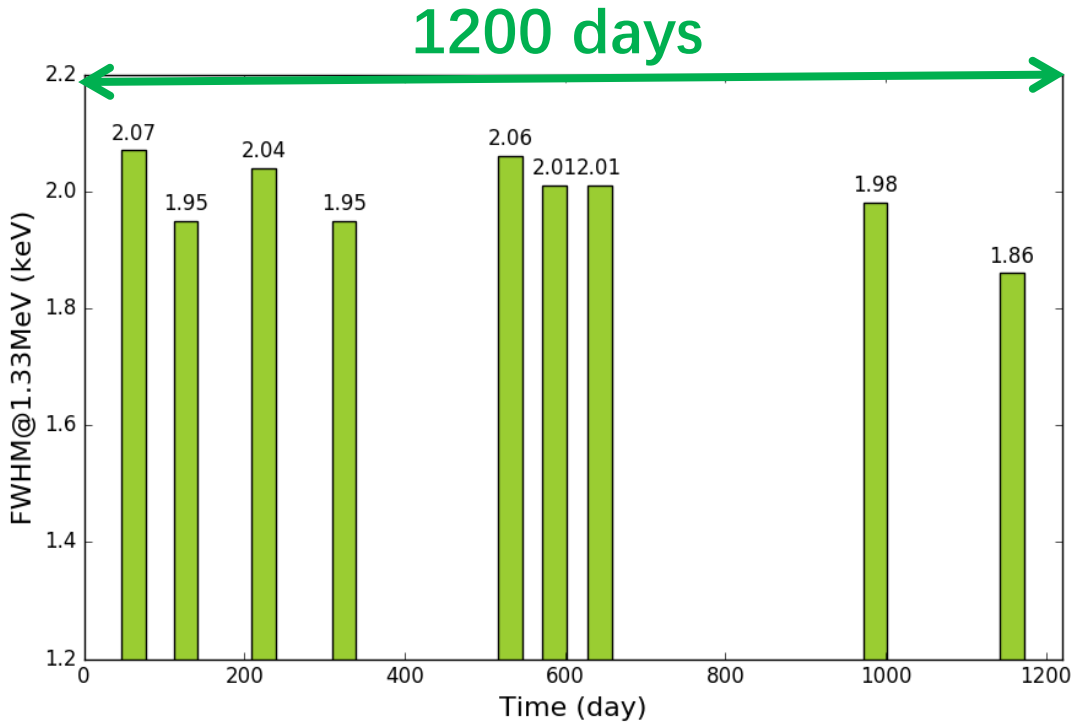




Underground more than 3 years

CDEX10X: 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

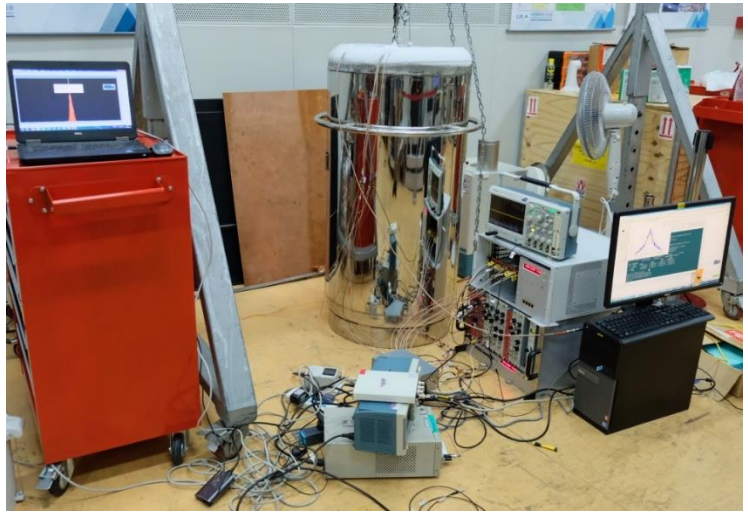


Vacuum systems

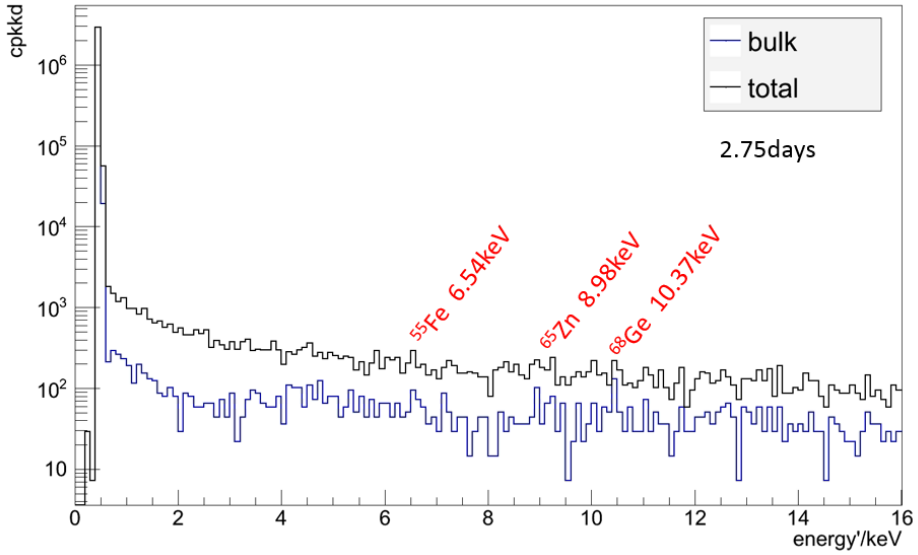
CDEX-10X Detector (T1)

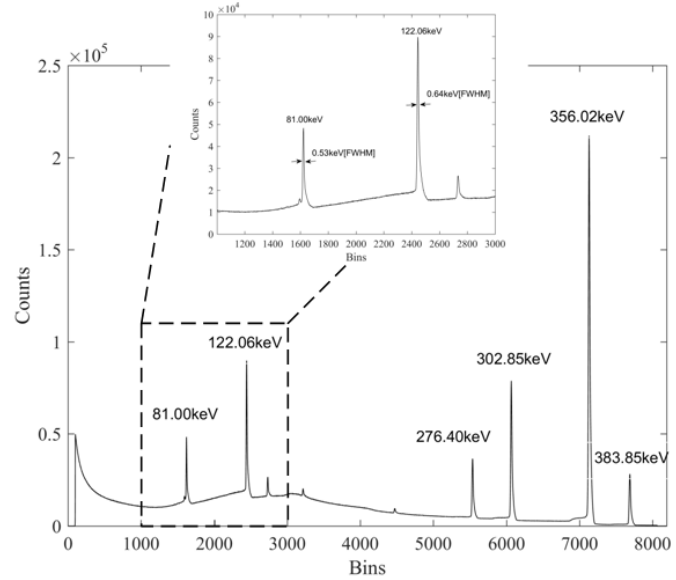
- Commercial Ge crystal + stainless steel canister;
- T1 detector: 500g Ge(φ50x50mm) + CMOS ASIC preAmp;
- Works, and Performance expected；
- Next step to improve bkg, low-noise electronics…

From Y.L. Li, PIRE-GEMADARC Collaboration Summer Meeting, 2018



Tested in CJPL-I



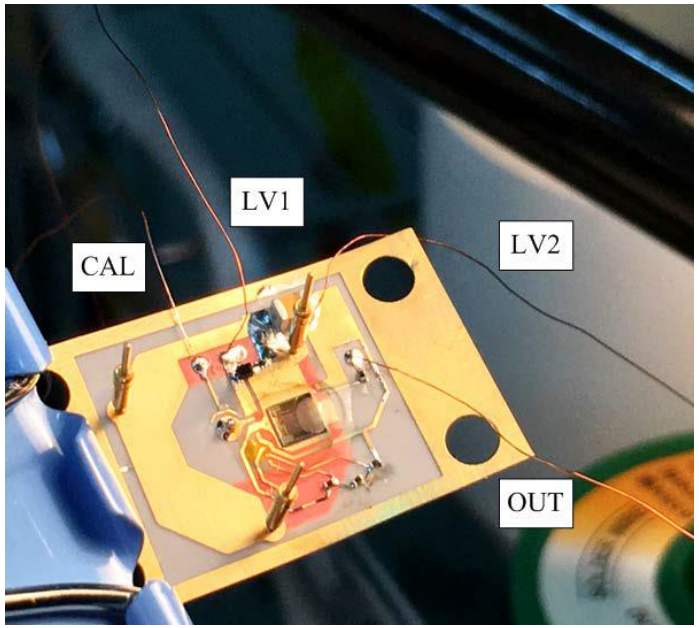


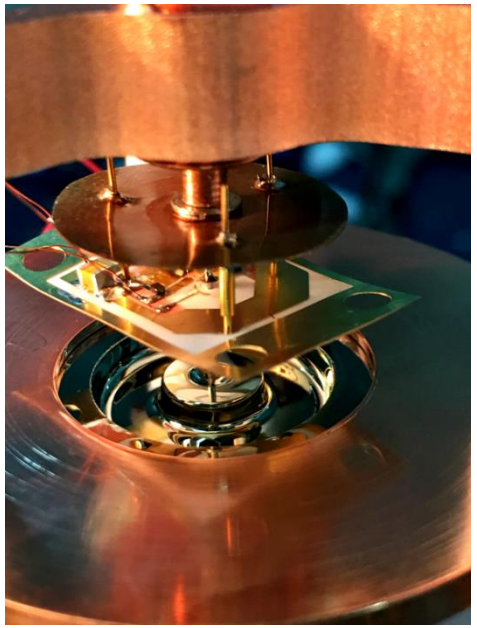
FWHM=0.64keV@122keV_Co57

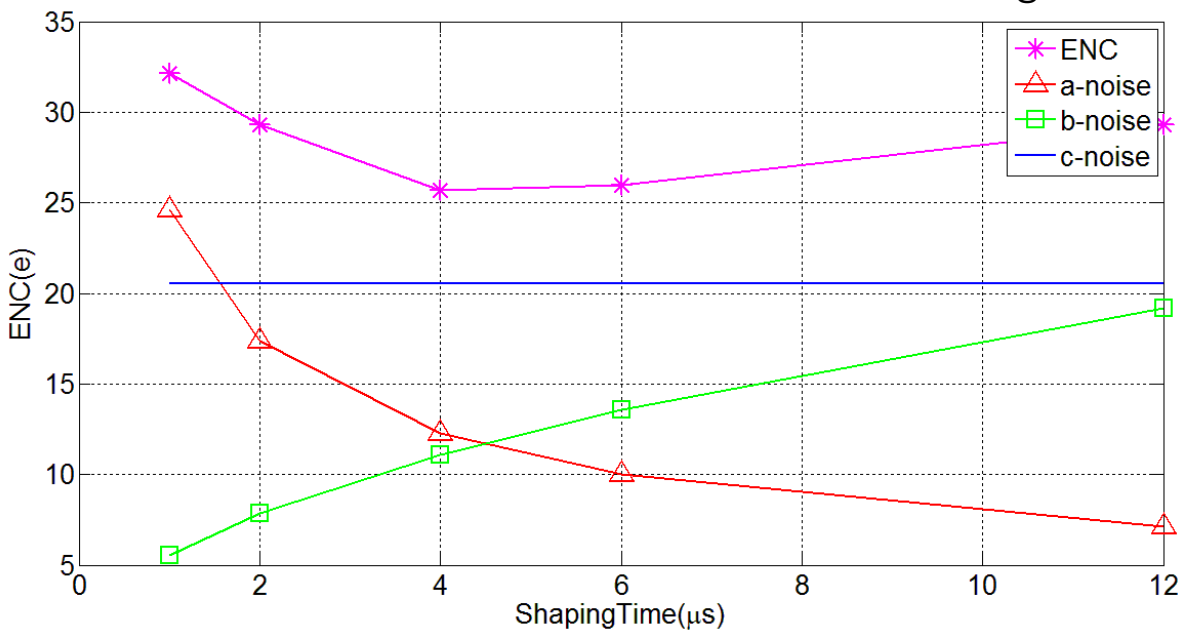
CMOS ASIC Front-end Electronics

- 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);

From L. He, PIRE-GEMADARC Collaboration Summer Meeting, 2018

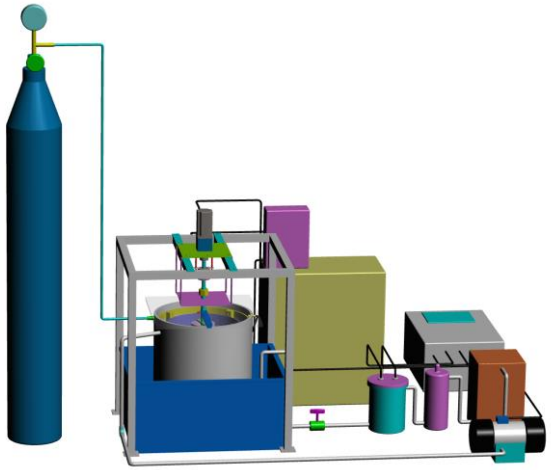






Underground e-forming copper and Assay

- Prototype setup for underground e-forming 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;
- U/Th Analysis by ICP-MS
  - preConcentration procedure testing… , blank sensitivity ~10^{-13}g/g



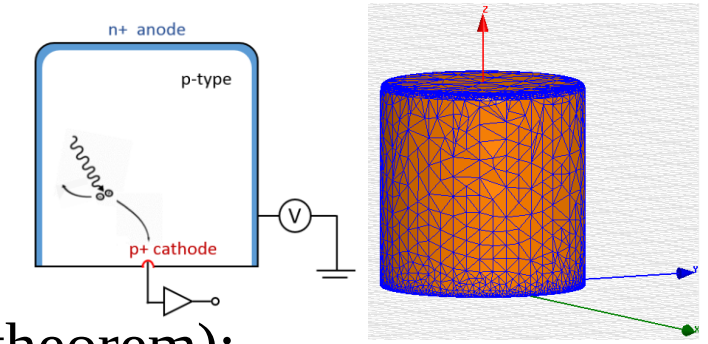
E-forming setup

optimized electrical parameters

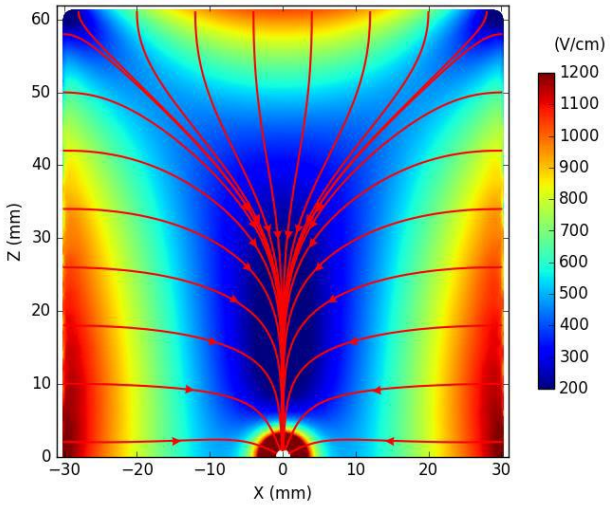
ICP-MS

Detector simulation

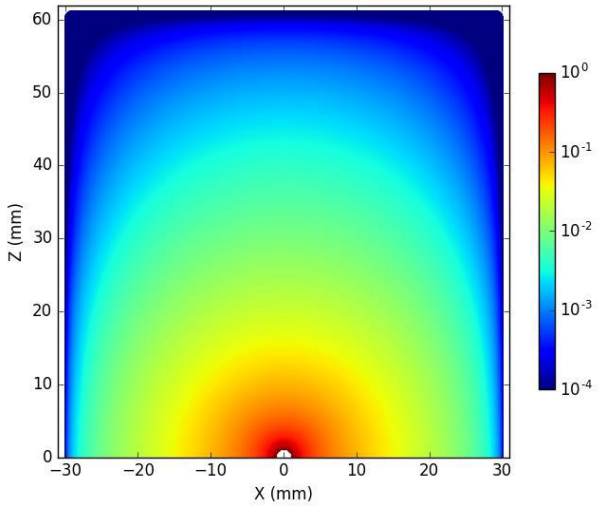
- Optimize detector design on charge collection & bkg reduction;
- Understand physics behind experimental phenomena;
- Pulses generated by
  - Geant4: interaction & energy deposition;
  - ICC package: Induced Charge/Current signal (Shockley-Ramo theorem);
  - Both PPC Ge and BEGe detector;



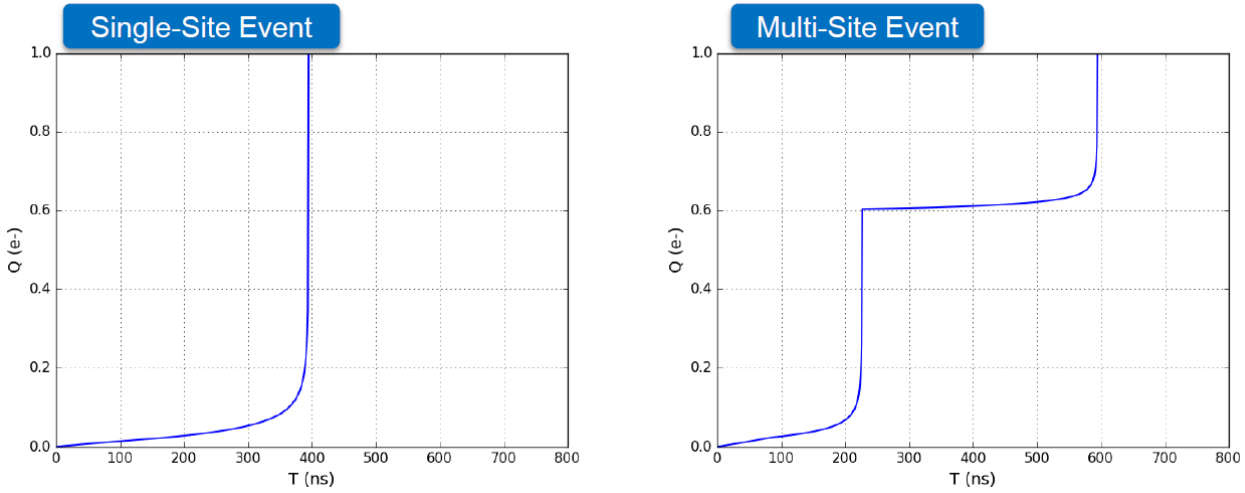
Finite element analysis of e-field



Electric field



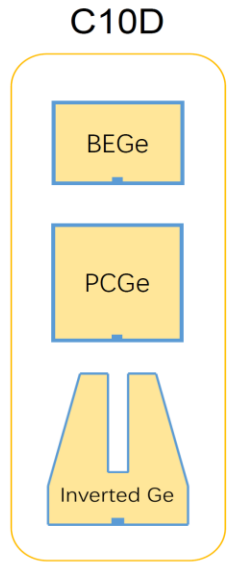
Weighting potential

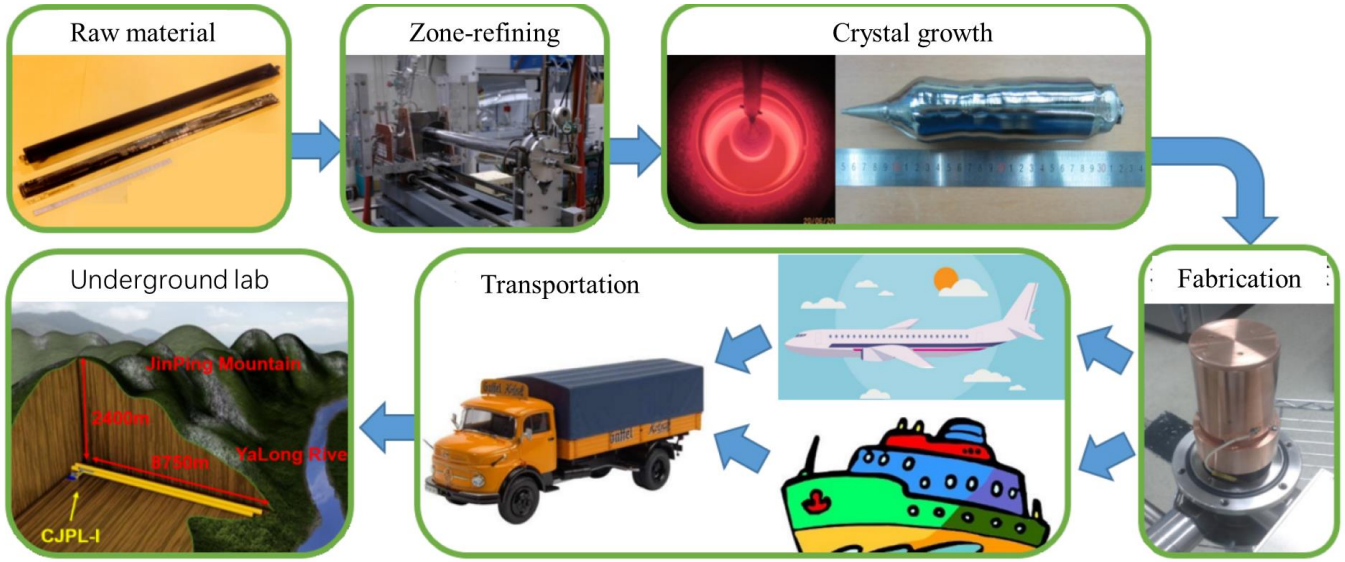


Simulated pulses

Future Plan - Detector

- New detectors cooperated with companies
  - 3kg from BSI, 2kg from ORTEC, planned 5kg from CANBERRA/ORTEC;
  - Particular control of detector fabrication process above ground;



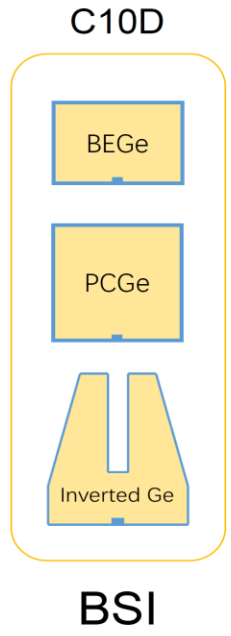


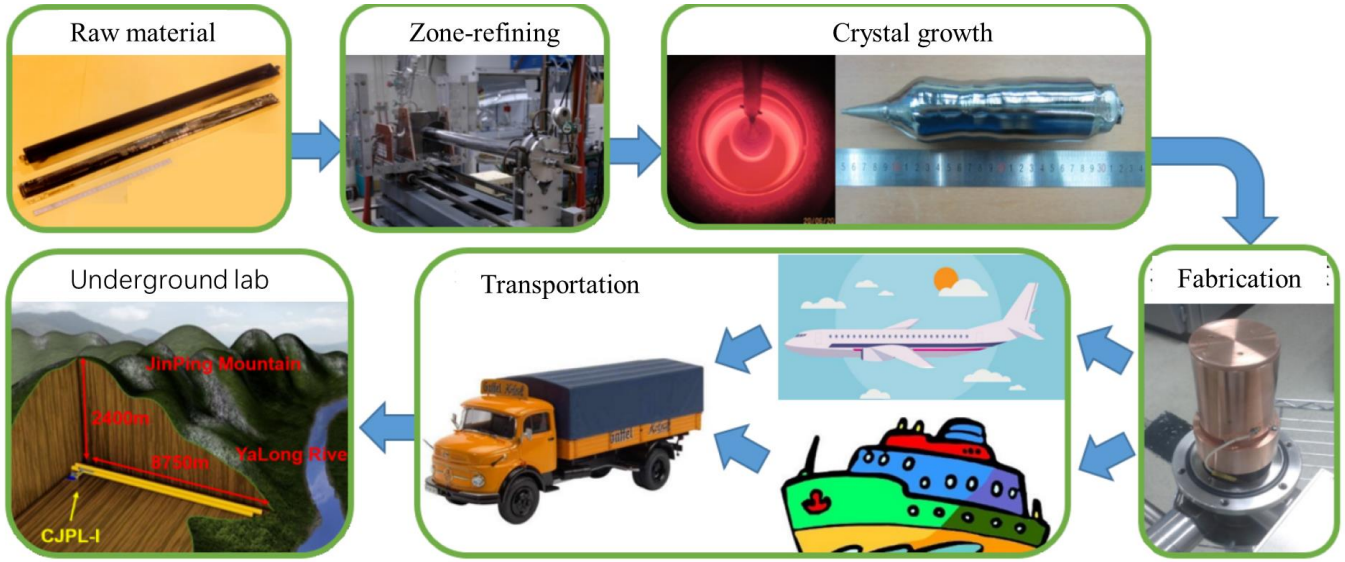
Detector production: 45days +
Ground transportation: 60 days +
Underground cooling: 180days →

Cosmogenic bkg: 0.03cpkkd(sim.).

Future Plan - Detector

- New detectors cooperated with companies
  - 3kg from BSI, 2kg from ORTEC, planned 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;
  - Setup the facility for underground fabrication and testing;





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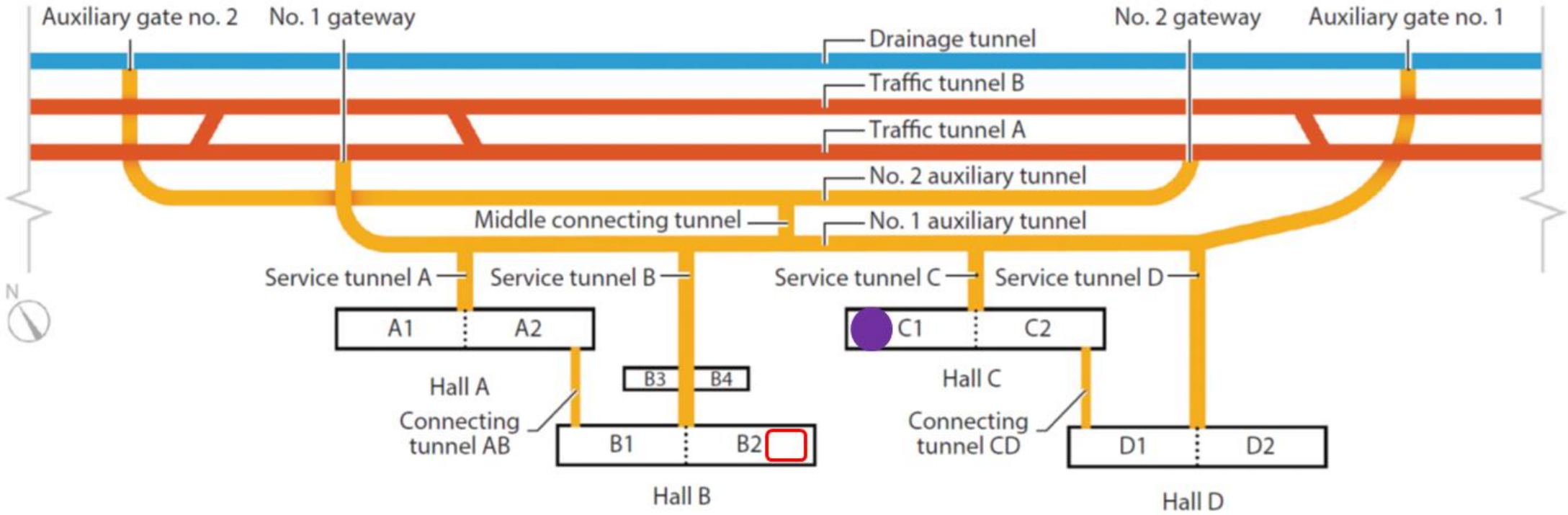
Future Plan - Lab

- CJPL-I to CJPL-II
  - Volume: 4000 to 300,000 m^3;
  - 1 main hall (6.5x6.5x42m) to 4 main halls (14x14x130m each);
  - 2 additional pits for next generation CDEX and PandaX;

Y. Yang's talk yesterday



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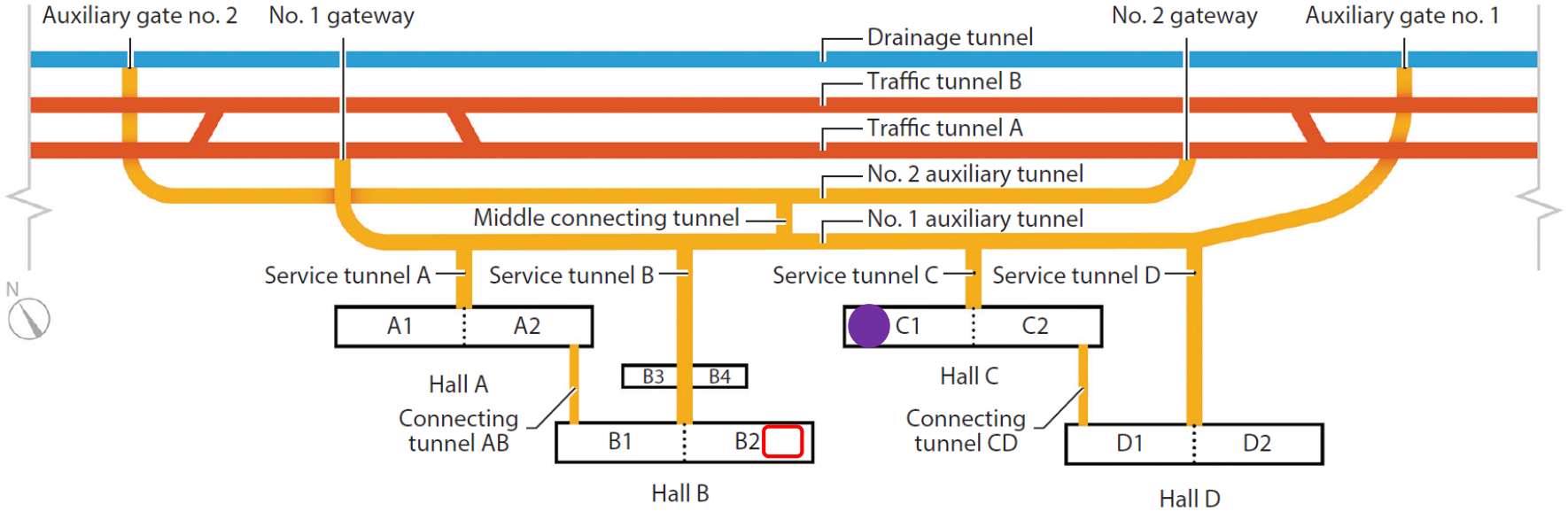
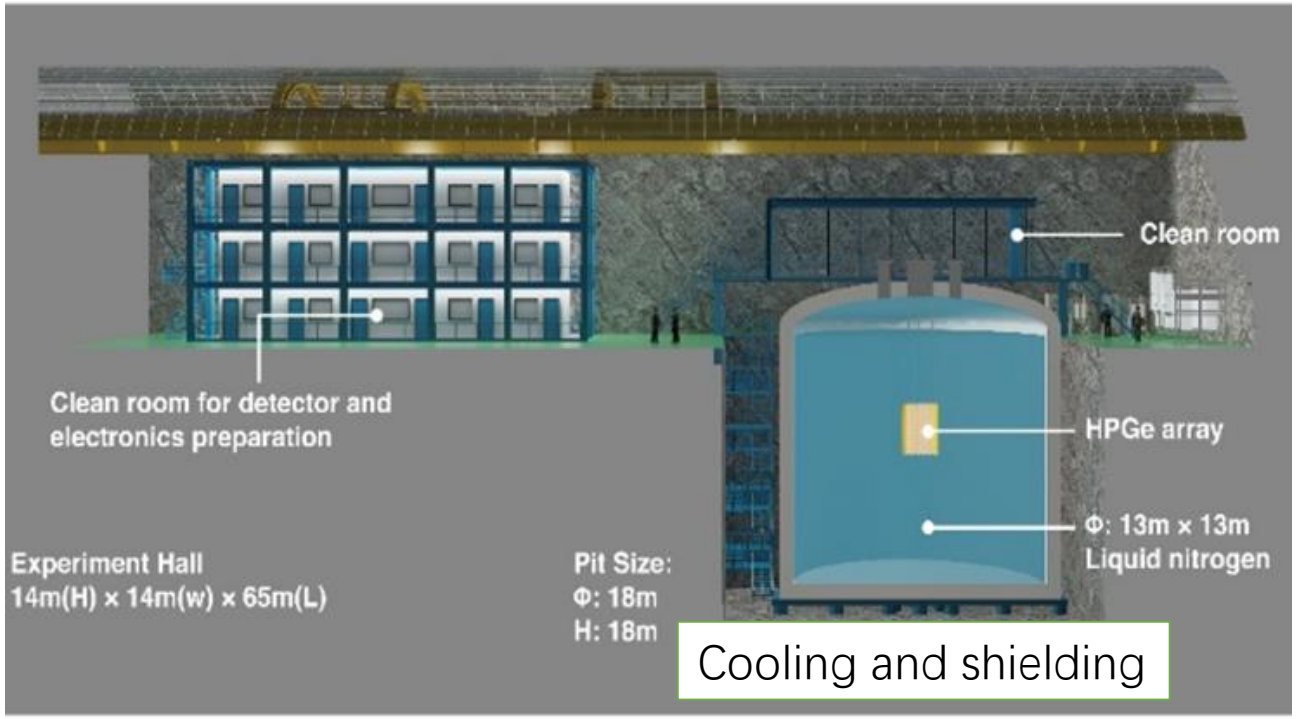
  - 1 main hall (6.5x6.5x42m) to 4 main halls (14x14x130m each);
  - 2 additional pits for next generation CDEX and PandaX;
- CJPL-II status
  - Civil engineering from Dec. 2014 to May 2016;
  - Ventilation system: 3 nine-km-long PE pipes till Jun. 2018;

Y. Yang's talk yesterday



Future Plan - CDEX

- CDEX10X moves to a 1700m^3 LN_2 tank (φ13x13m) located in the pit;
- Construction of LN_2 tank will kick off in Aug. 2018;
- 10+X kg detectors direct-immersion and then operation in LN_2 in 2019;
- CDEX-100 stage under technical design, report expected by the end of 2018.



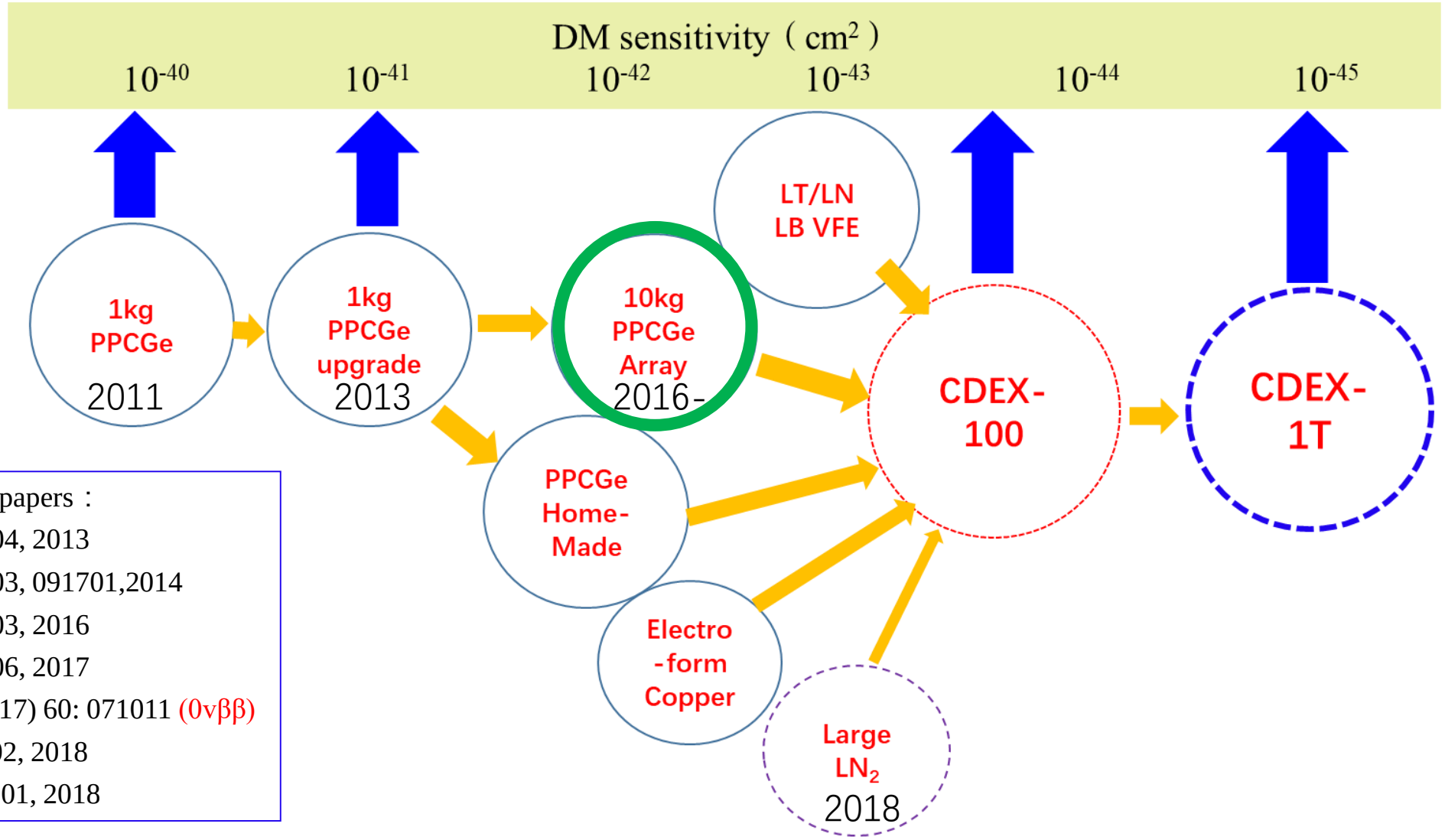
Summary

- 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 on the way w/ particular consideration and control of cosmogenic bkg.

- Other physics: Axion, 0νββ,…

CDEX Roadmap



CDEX physical papers：

- ✓PRD88, 052004, 2013
- ✓PRD90, 032003, 091701,2014
- ✓PRD93, 092003, 2016
- ✓PRD95, 052006, 2017
- ✓Sci. China (2017) 60: 071011 (0νββ)
- ✓CPC42, 023002, 2018
- ✓PRL120, 241301, 2018


Thanks for your attention!
Welcome to CJPL!
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