CDEX experiment: status and prospect

中国锦屏地下实验室
China Jinping Underground Laboratory
CJPL
清华大学 · 雅砻江流域水电开发有限公司

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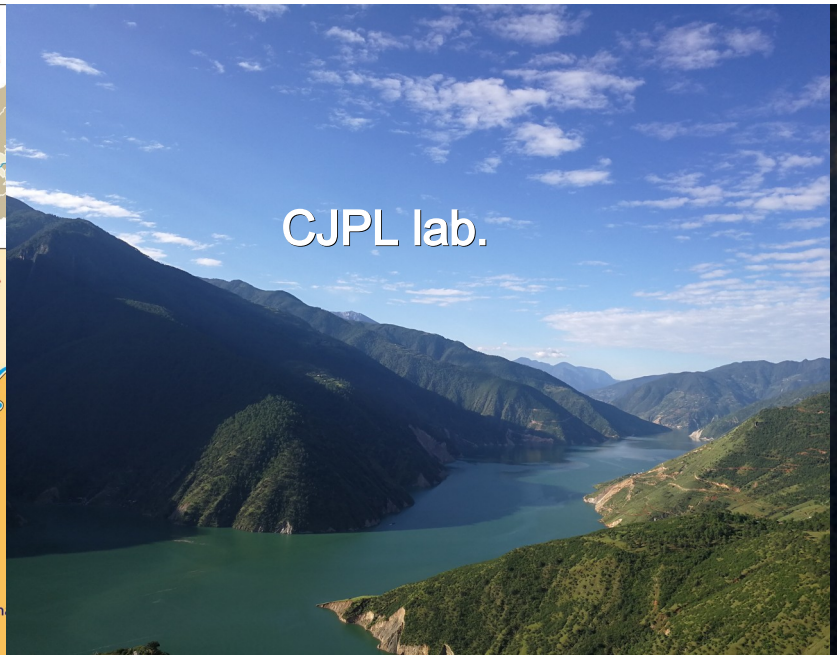
(Taiwan)

OUTLINE

- CDEX experiments: overview.
- CDEX-1, CDEX-10 results.
- Plan: CDEX-50 for Dark Matter, CDEX-300ν for 0νββ.
- summary



CDEX: China Dark matter EXperiment

Established in 2009

- Tsinghua University (THU)
- Sichuan University (SCU)
- Beijing Normal University (BNU)
- Nankai University (NKU)
- Sun Yat-Sen University (SYSU)
- Peking University (PKU)
- China Institute of Atomic Energy (CIAE)
- Yalong River Company

+

- Academia Sinica, Taiwan
- Banaras Hindu University, India
- Dokuz Eylül University, Turkey

PCGe data/physics analysis, etc.

- Ge: good resolution, low threshold, ideal for low mass WIMP.

Jinping Hydroelectric Power Plants

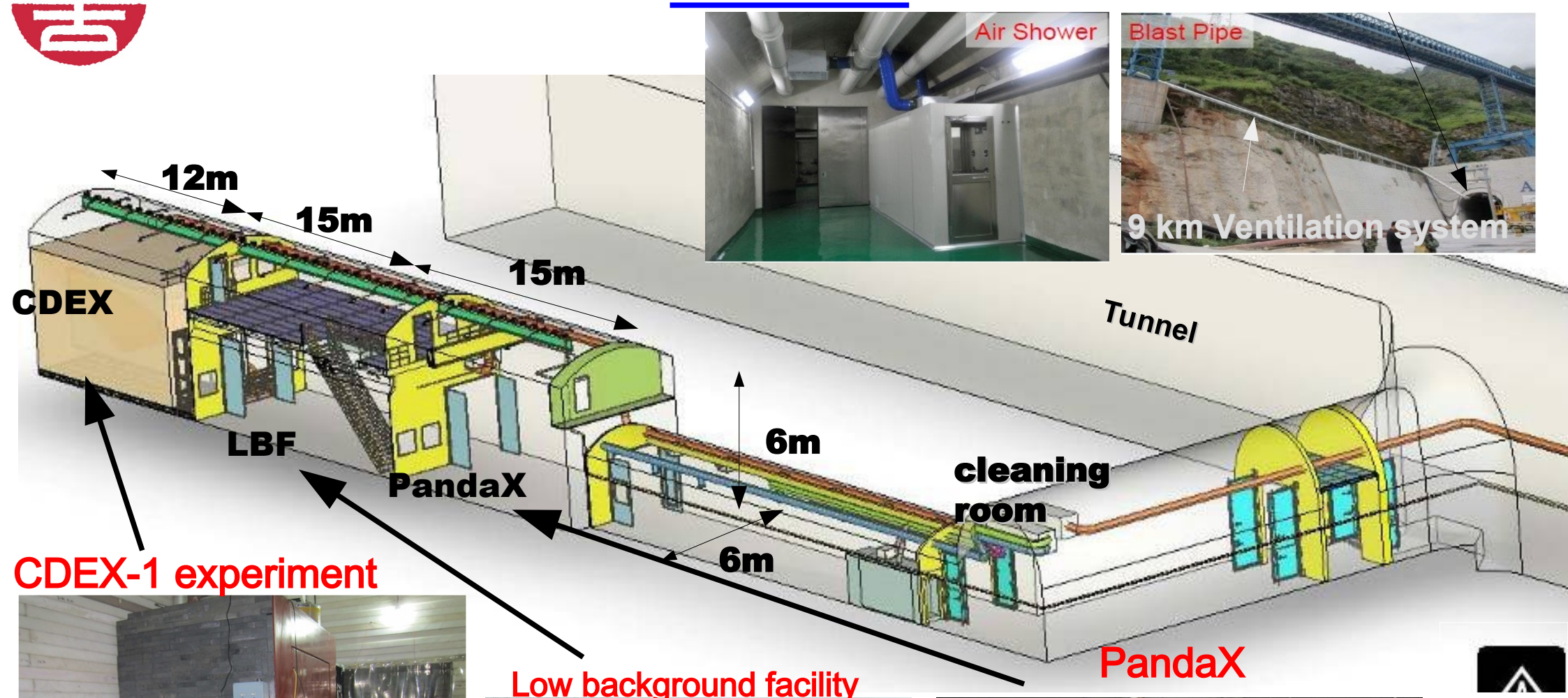
4 hydraulic tunnels
Φ13m×16.6km

Jinping-II Power Plant 4800MW (8×600MW)

Jinping-I Power Plant 3600MW (6×600MW)

CJPL lab.

CJPL-I


tunnel entrance
Air Shower
Blast Pipe
9 km Ventilation system
12m
15m
15m
CDEX
Tunnel
LBF
PandaX
6m
6m
cleaning room
CDEX-1 experiment
Low background facility
PandaX

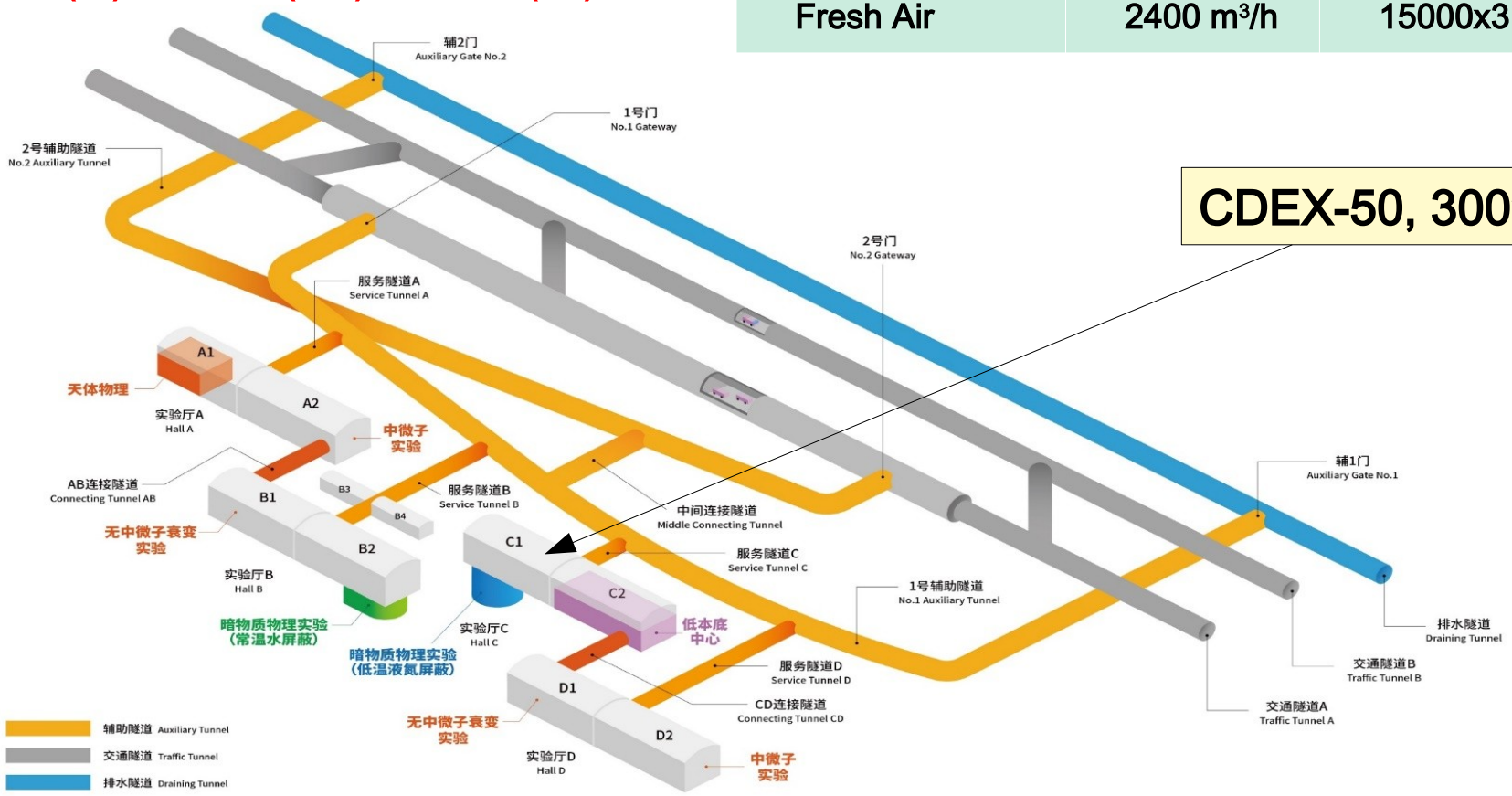

System Picture
Internal space:
8mX4.5mX4m(H)

PCGe
20cm Copper

CJPL-II

- 4 main halls : 14m(H)×14m(W)×130m(L);
- Total Volume: 300K m³;
- Two expanded spaces:
  C1--ϕ18m×32m(H)→CDEX-1T
  B2--27m(L)×14m(W)×30m(H)

	CJPL-I	CJPL-II
Rock Work	4100 m³	210000+151000m³
Electric Power	70x2 kVA	10x2 MVA
Fresh Air	2400 m³/h	15000x3 m³/h



CDEX history and future

achieved | "goals"

10^{-40} 10^{-41} 10^{-42} DM sensitivities (cm²) 10^{-43} 10^{-44} 10^{-45}

10^{27}y —— 10^{28}y for 0νββ

2011-2018

CDEX-1

340 kg-day + 1110 kg-day

2016-2022

CDEX-10
immersed in LN2

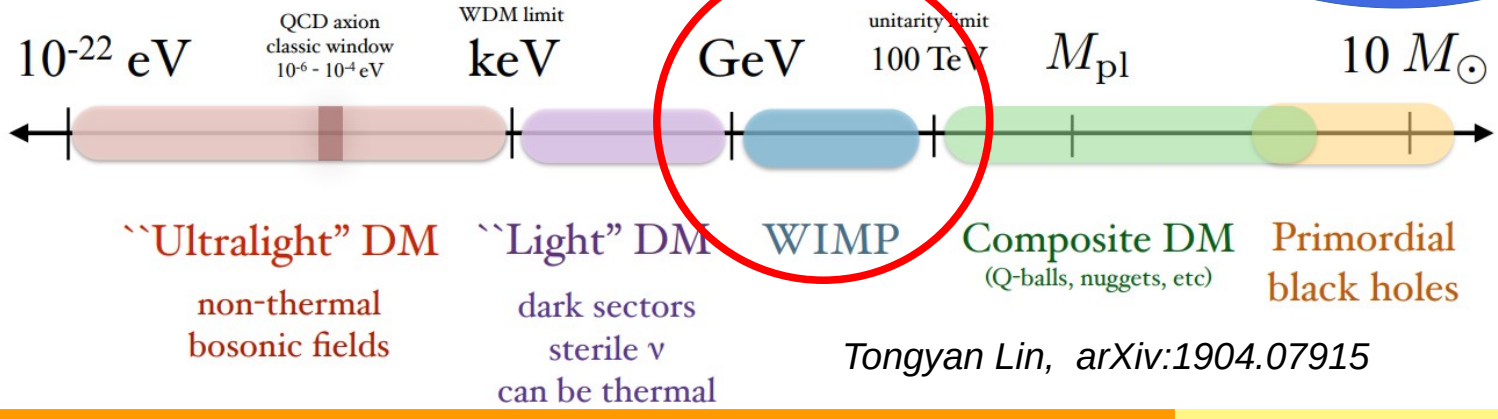
450 kg-day

2021(installing)-2025? (data taking)

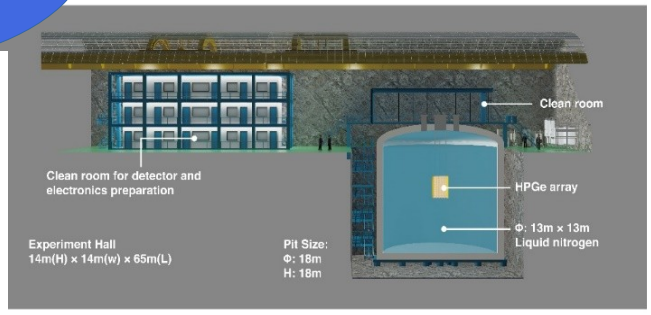
CDEX-50
for DM

CDEX-300ν
for 0νββ

CDEX-1000
for 0νββ & DM



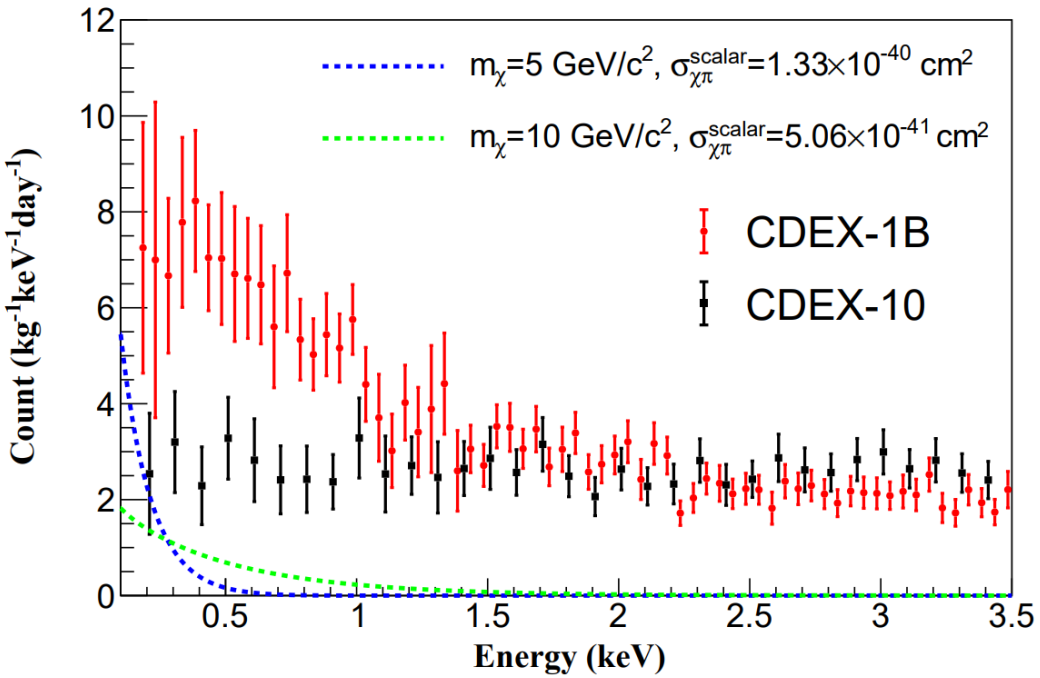
Tongyan Lin, arXiv:1904.07915

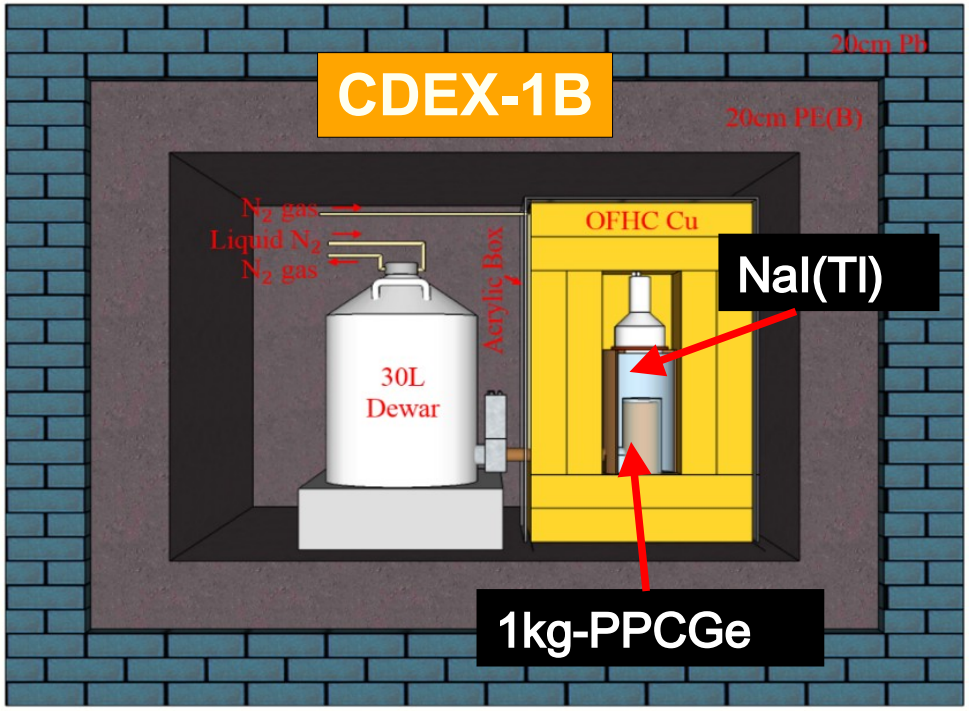


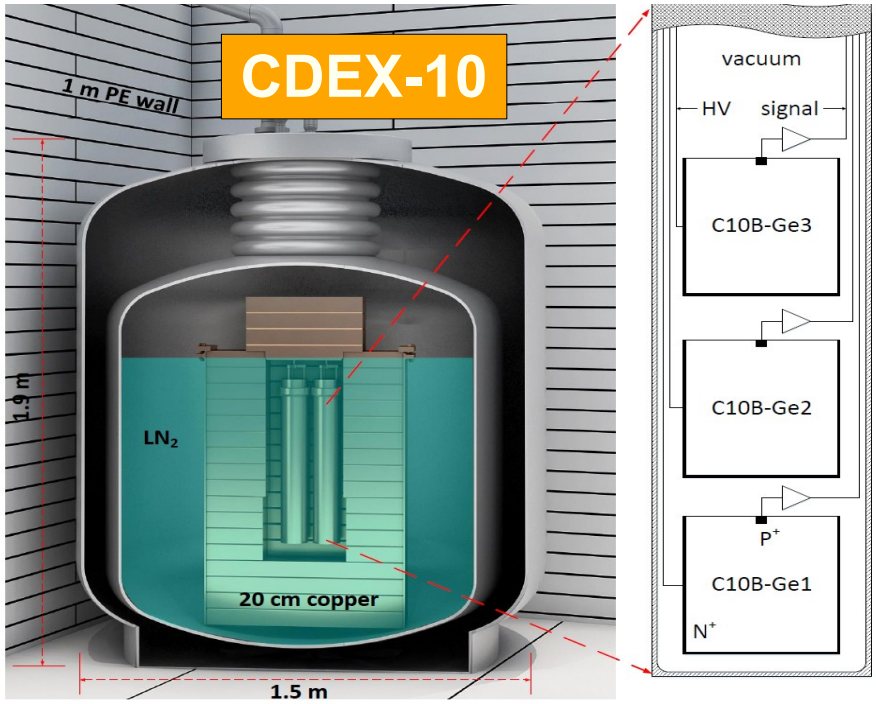
CJPL-I CJPL-II

CDEX-1 & 10 configuration

1. CDEX-1B
   - ✓ with or w/o NaI(Tl), 1kg point-contact-Ge
   - ✓ heat-guide cooling.
   - ✓ 700 kg-day, threshold~160-250 eV
   - ✓ annual modulation results.
2. CDEX-10
   - ✓ immersed in LN2, array format.
   - ✓ threshold ~ 160 eV.
   - ✓ results based on 200 kg-day on 1 kg Ge.

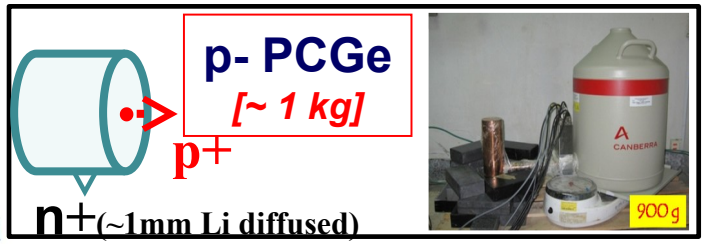


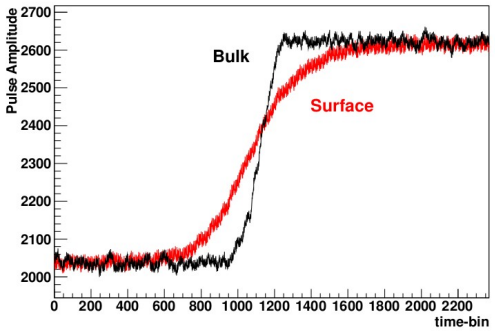


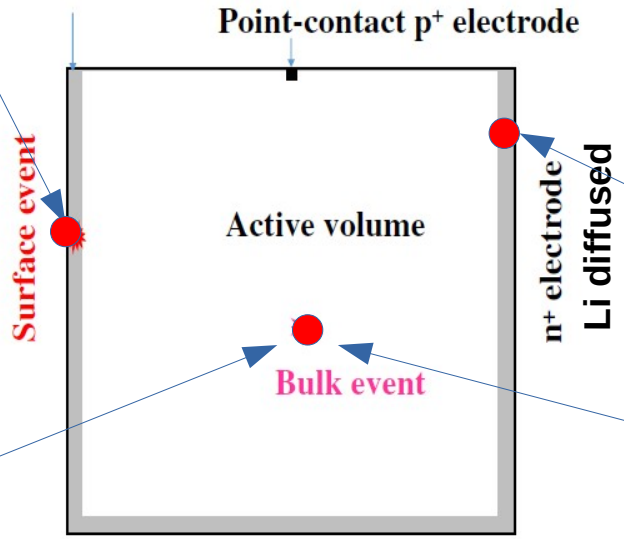


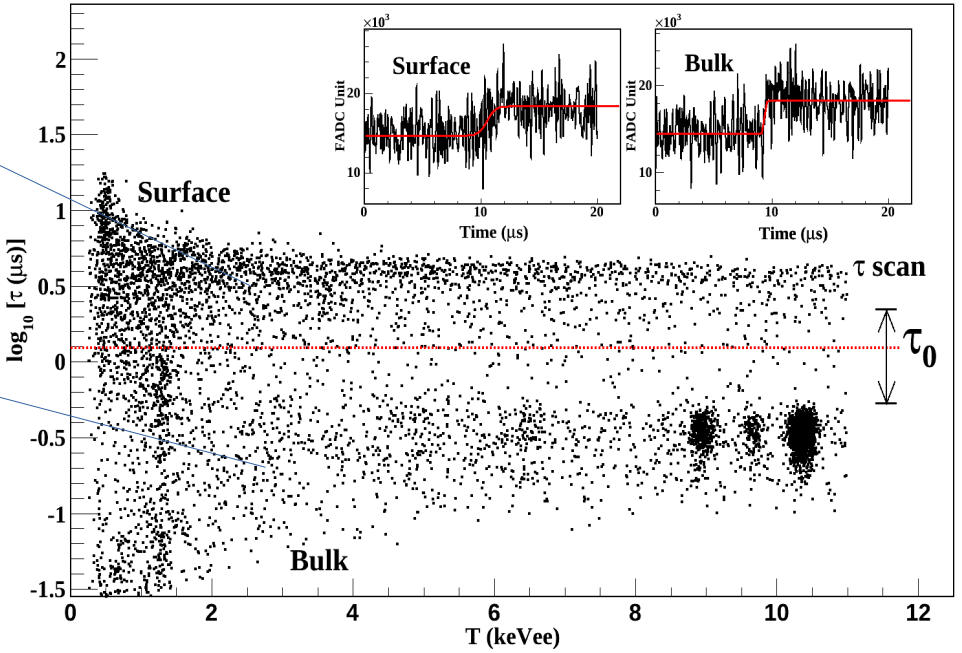
largest sources of uncertainties: bulk/surface separation

surface
- partial energy deposit
- diffuse and drift → slow







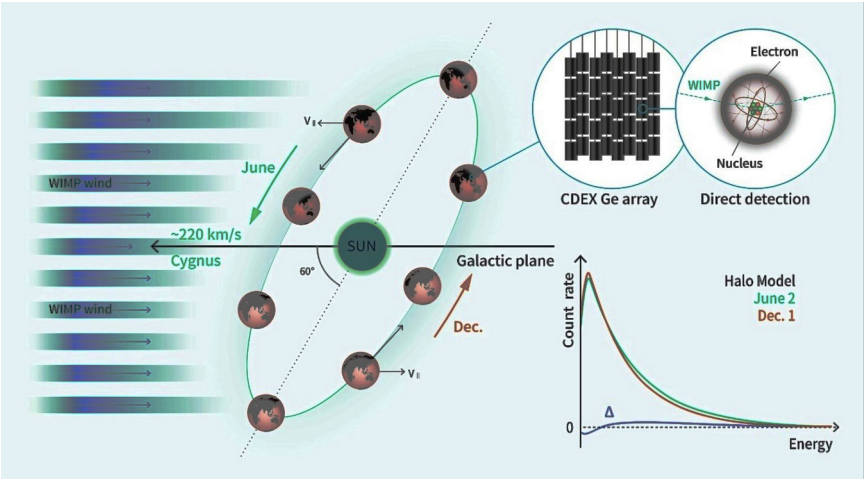


bulk
- full energy deposit
- drift → fast

- **a bless : gamma background veto and**
- **a curse : contaminate low energy spectrum**

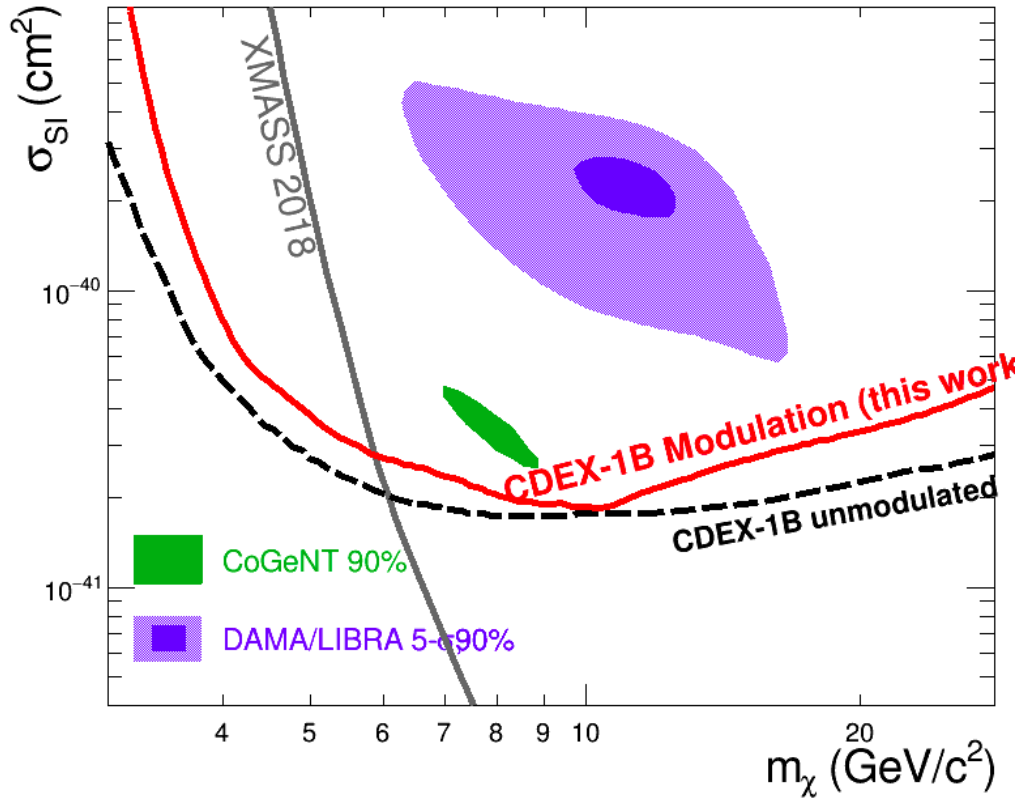
Astropart. Phys. 56, p1-8 (2014) : based on understanding of energy spectrum
NIMA 886, p13-23 (2018) : comparing rise-time of different sources
+ ongoing: Machine learning and improve τ measurement for bulk/surface

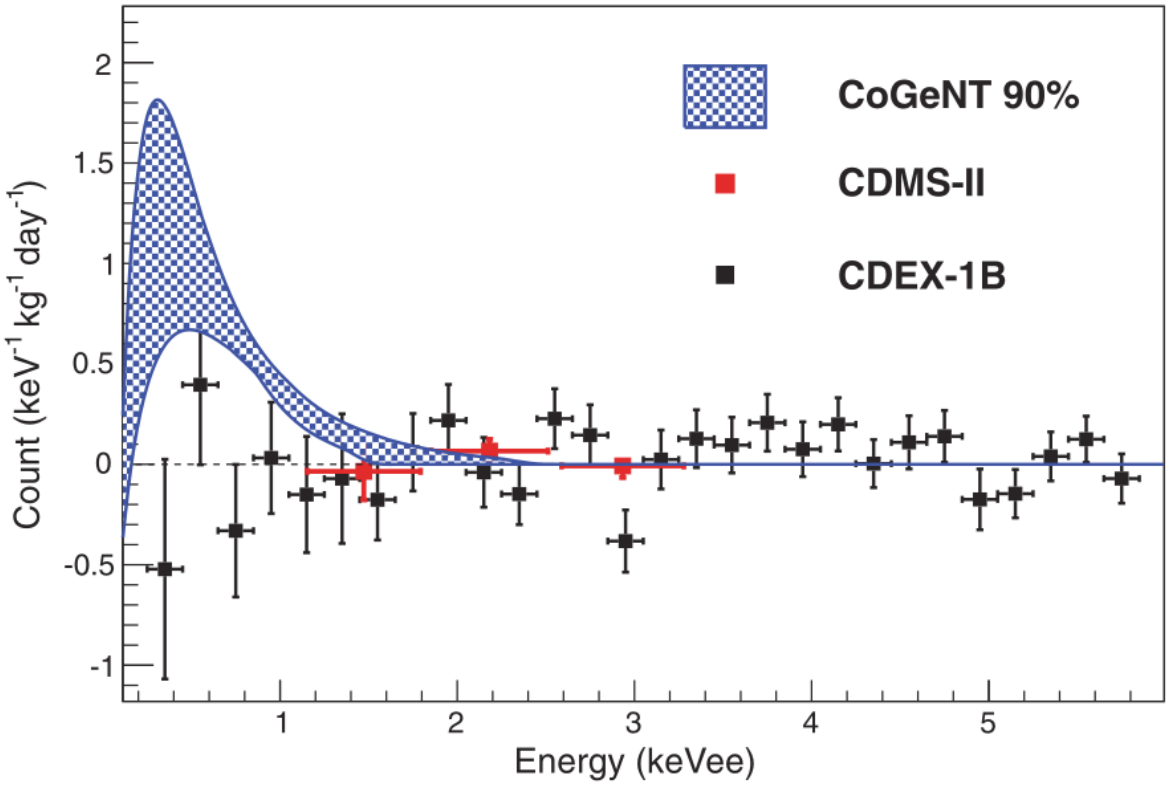
CDEX-1B: annual modulation



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

- not exclude I-recoil of DAMA/LIBRA

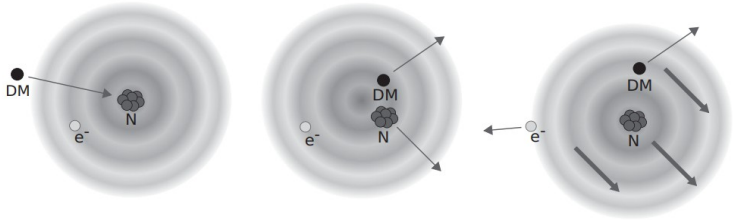


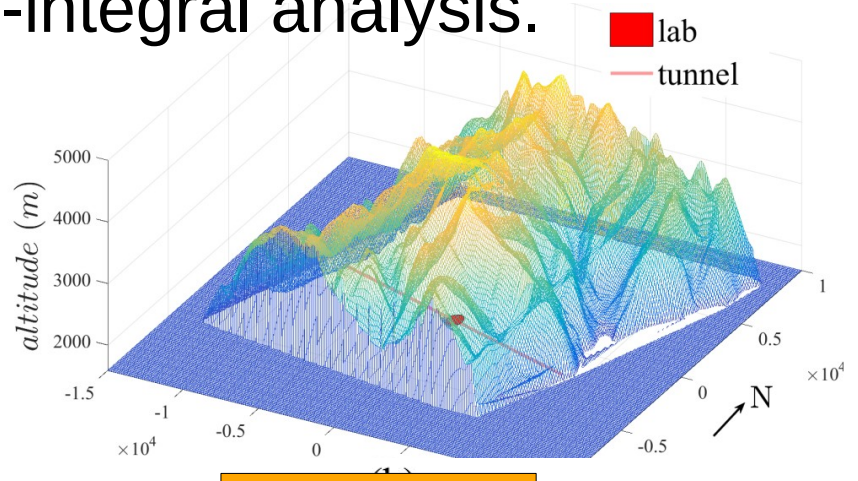


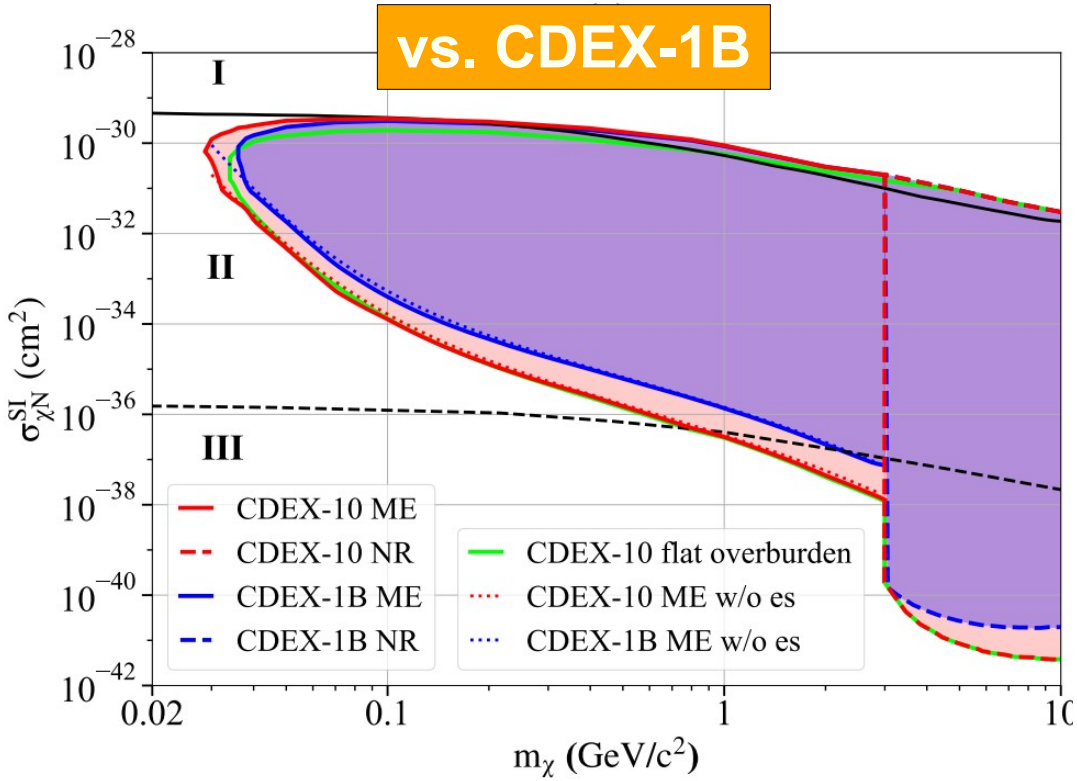
Phys. Rev. Lett. 123, 221301 (2019)

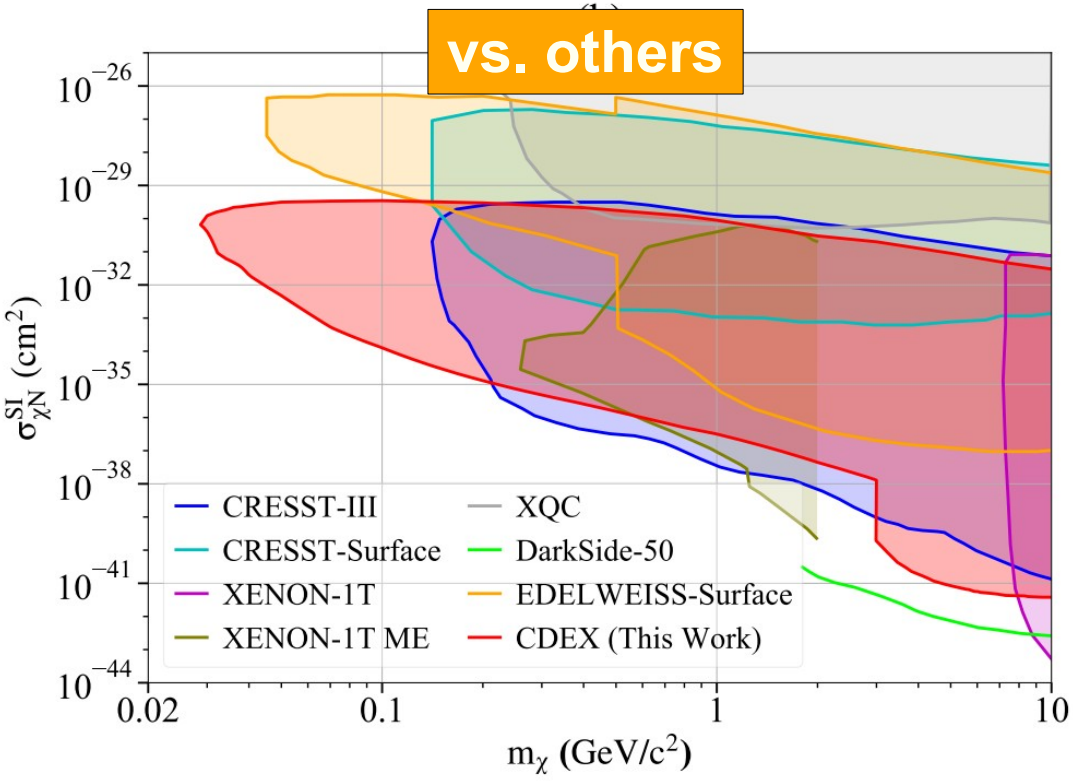
CDEX-10

- + Migdal-effect and earth scattering, time-integral analysis.





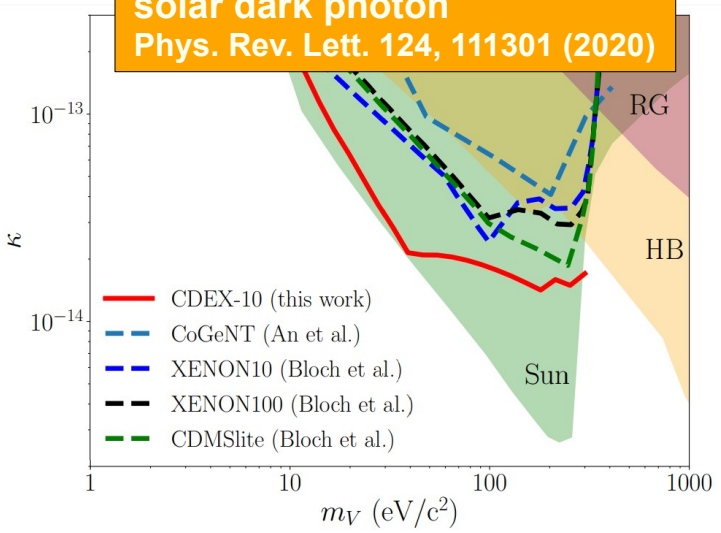




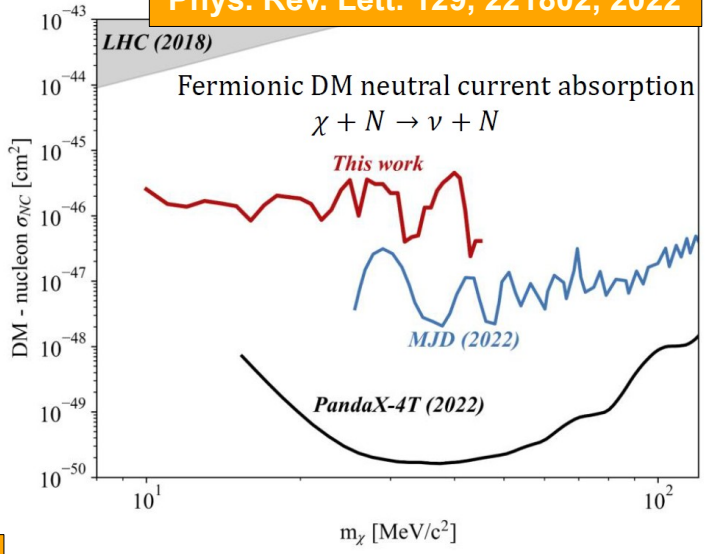
Phys. Rev. D 105, 052005 (2022)

DM related analysis on CDEX-1B and CDEX-10

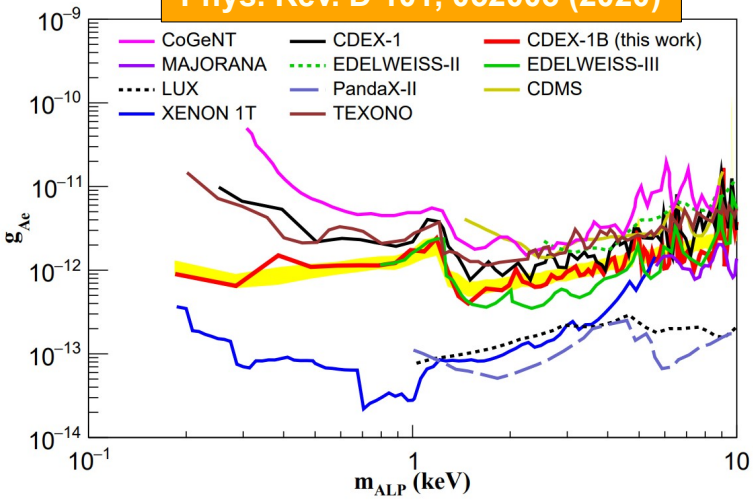
solar dark photon
Phys. Rev. Lett. 124, 111301 (2020)



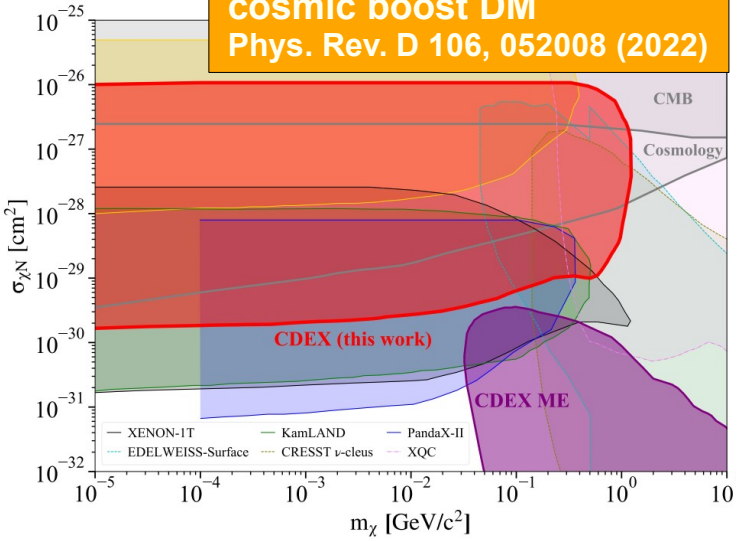
Fermionic DM
Phys. Rev. Lett. 129, 221802, 2022



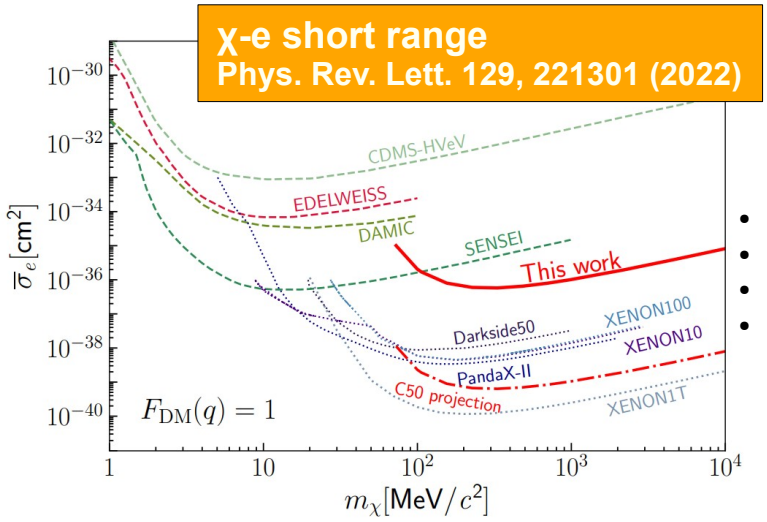
galatical Axion-like particle
Phys. Rev. D 101, 052003 (2020)



cosmic boost DM
Phys. Rev. D 106, 052008 (2022)



χ-e short range
Phys. Rev. Lett. 129, 221301 (2022)



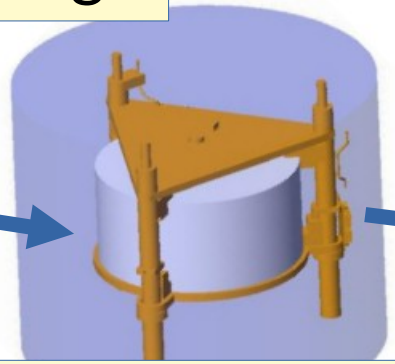
other:

- CDEX-10: Phys. Rev. Lett. 120, 241301 (2018).
- sterile neutrino: arXiv:2210.01604.
- Dark Matter from black hole:arXiv:2211.07477.
- 0νββ: Phys. Rev. D 106, 032012 (2022)

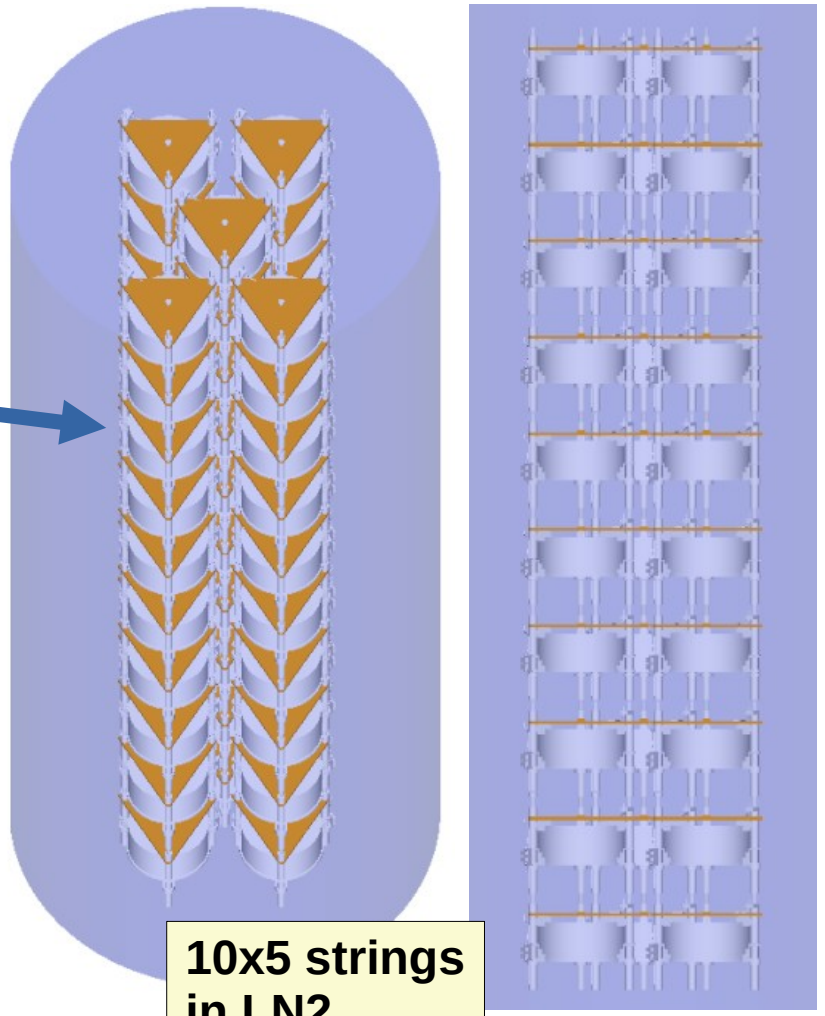
CDEX-50 at CJPL-II

under technical design

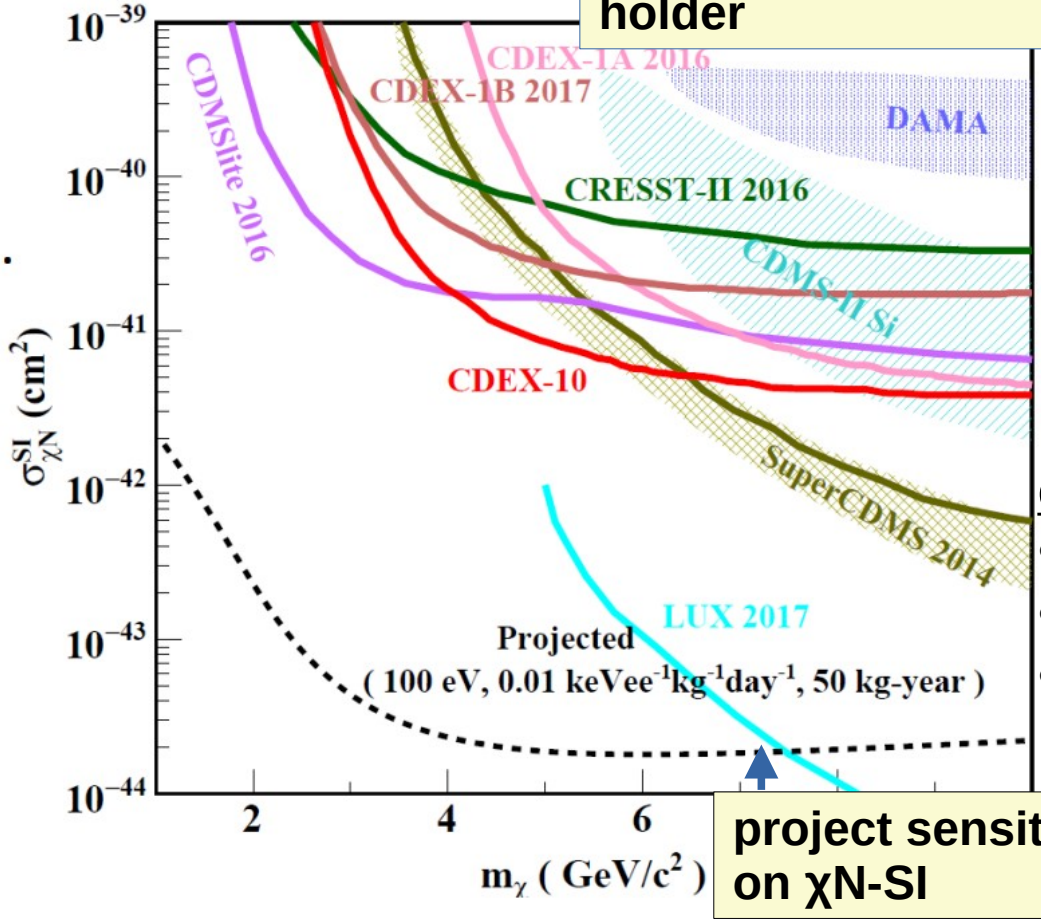
1kg PCGe or BEGe



79 g Cu + 10 g PTFE holder



10x5 strings in LN2



project sensitivities on χN-SI

expect:

- 0.01 count keV^{-1}kg^{-1}day^{-1} background at 1 keV
- threshold ~ 100 eV
- ~10^{-44}cm^2 for spin-independent interaction.

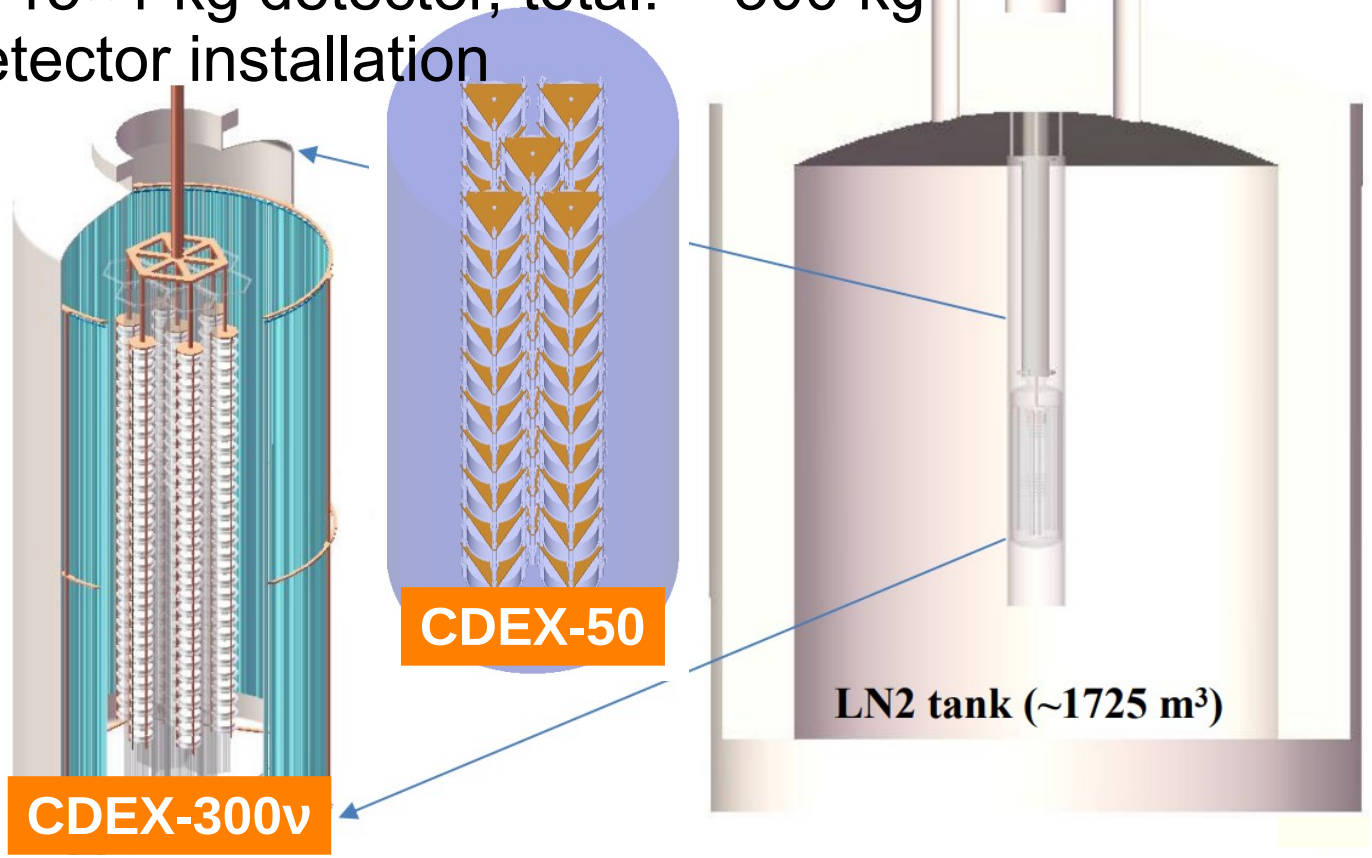
CDEX-50 & CDEX-300v at CJPL-II

CDEX-50 (~2025-)

- 10 strings, with 10×1 kg detectors per string, total:~50kg

CDEX-300v (~2028-)

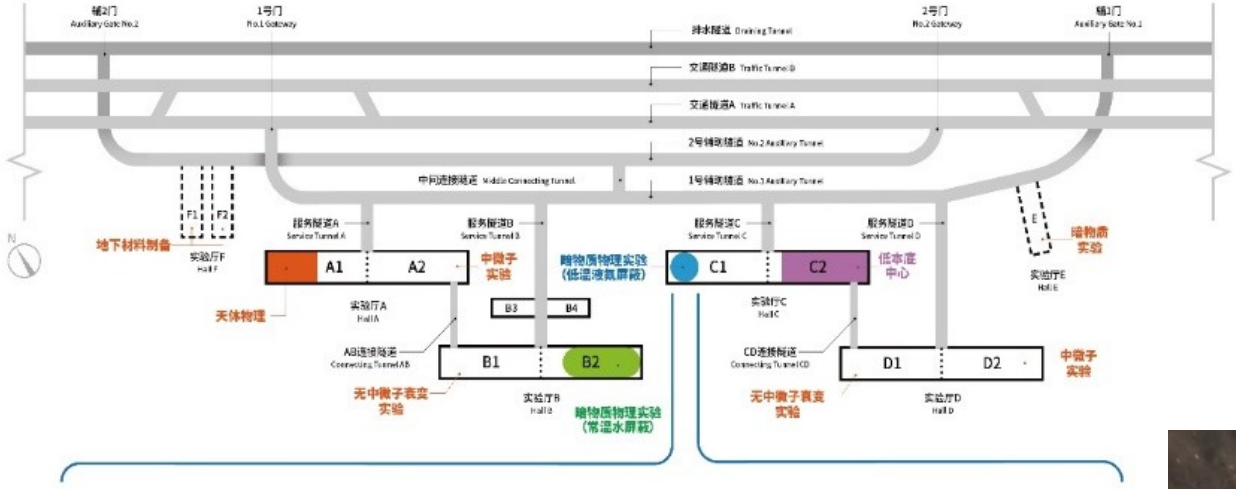
- 3 module × 7 string × 15×1 kg detector, total: ~ 300 kg
- Top clean room for detector installation
- immersed in LN2

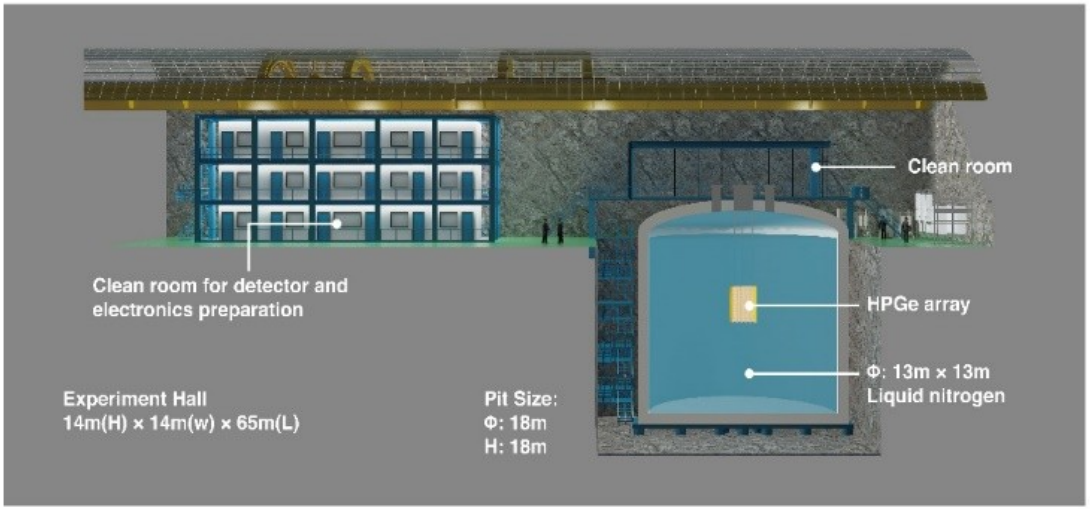


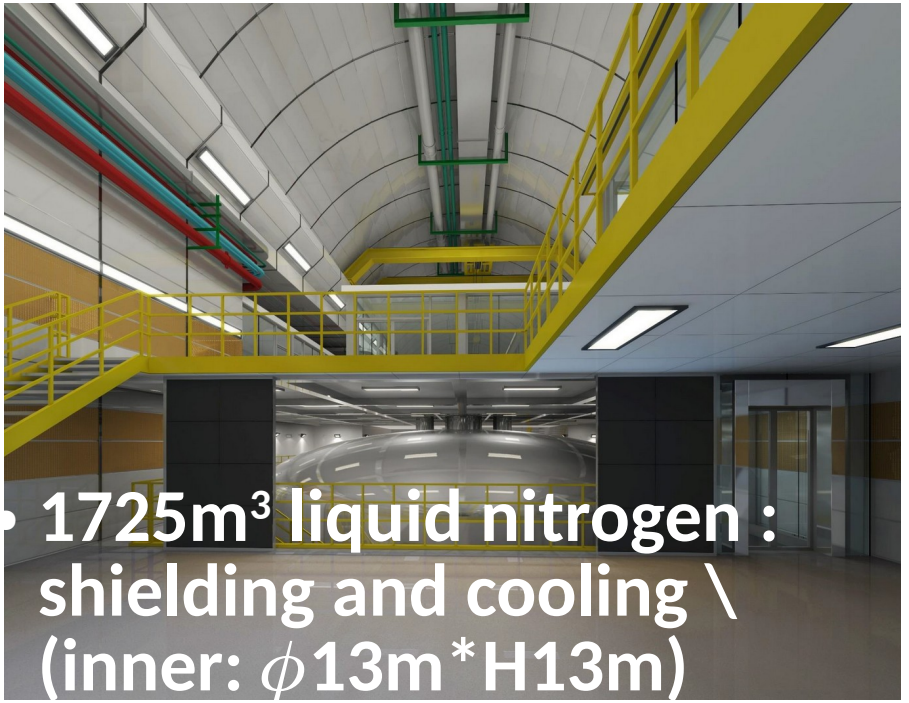
LAr cryostat (~keV background?) with PMT/SiPM readout

CJPL

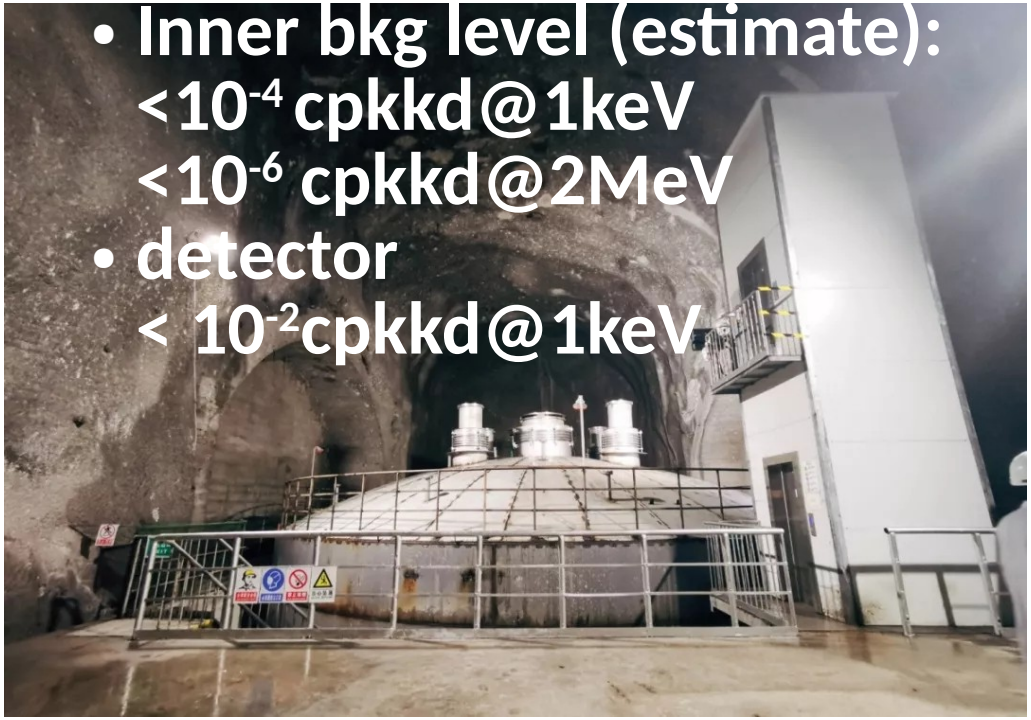
CJPL-II: the lab.







- 1725m^3 liquid nitrogen : shielding and cooling \ (inner: ϕ13m*H13m)



- Inner bkg level (estimate):
  <10^{-4} cpkkd@1keV
  <10^{-6} cpkkd@2MeV
- detector
  < 10^{-2}cpkkd@1keV

CJPL

Ge detector : Dark matter vs. 0νββ

- detector suitable for dark matter is also suitable for 0νββ (?)

	Dark Matter experiment	**0νββ experiment**
low background good resolution	at <~ keV	at ~2 MeV
low threshold	noise edge reduction needed	not needed
^{76}Ge : least cosmogenic isotope	could reduce cosmogenic induced background.	reduce cosmogenic induced background, and ββ sources.
underground Ge growth	crucial for ~1 keV	crucial for ~2 MeV

- CDEX-50 will use natural Ge (mostly) ~10^{-2} cpkkd (control transportation & fabrication).
- explore: underground Ge growth and manufacturing ~10^{-4} - 10^{-5} cpkkd.

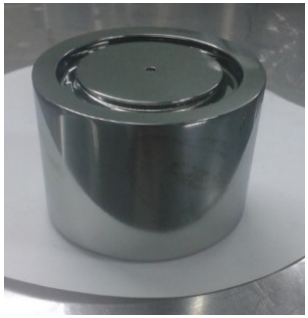
summary

- low threshold Ge detector dark matter searches.
- CDEX-1 + CDEX-10 results.
- CDEX-50 with 50 kg Ge immersed in LN2: installing.
- CDEX-300ν for 0νββ (+DM ?): soon.
- CDEX-1000 for dark matter and 0νββ: future plan.

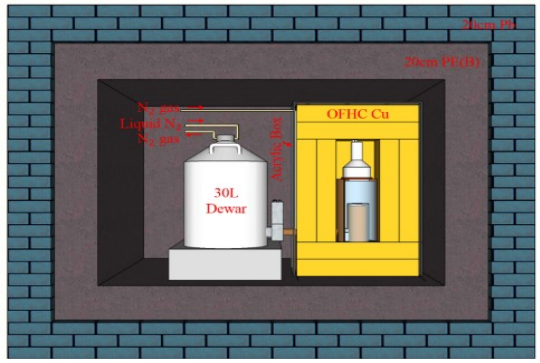
Thanks

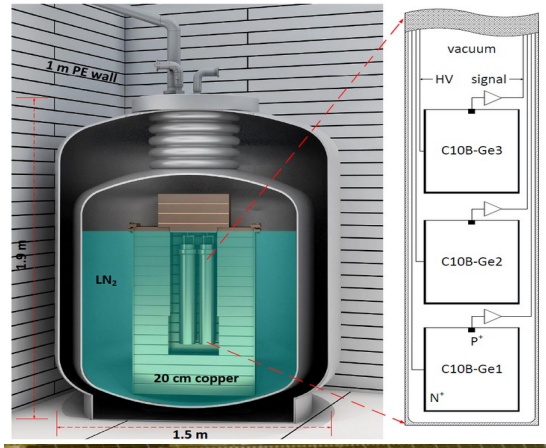
backup

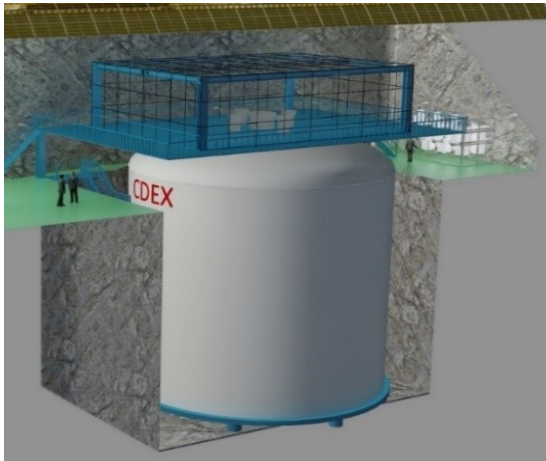
CDEX stages



- Light WIMP mass searches on Ge
- CDEX-1: Development of pPC-HPGe detector, its background understanding, annual modulation results.
- CDEX-10: Ge immersed on LN2, various DM results.
- CDEX-50: Ge immersed on LN2 array for DM, plan.
- CDEX-300v: ^{76}Ge enriched array for 0νββ, plan.
- CDEX-1000: Multi-purpose experiment for dark matter and double beta decay.







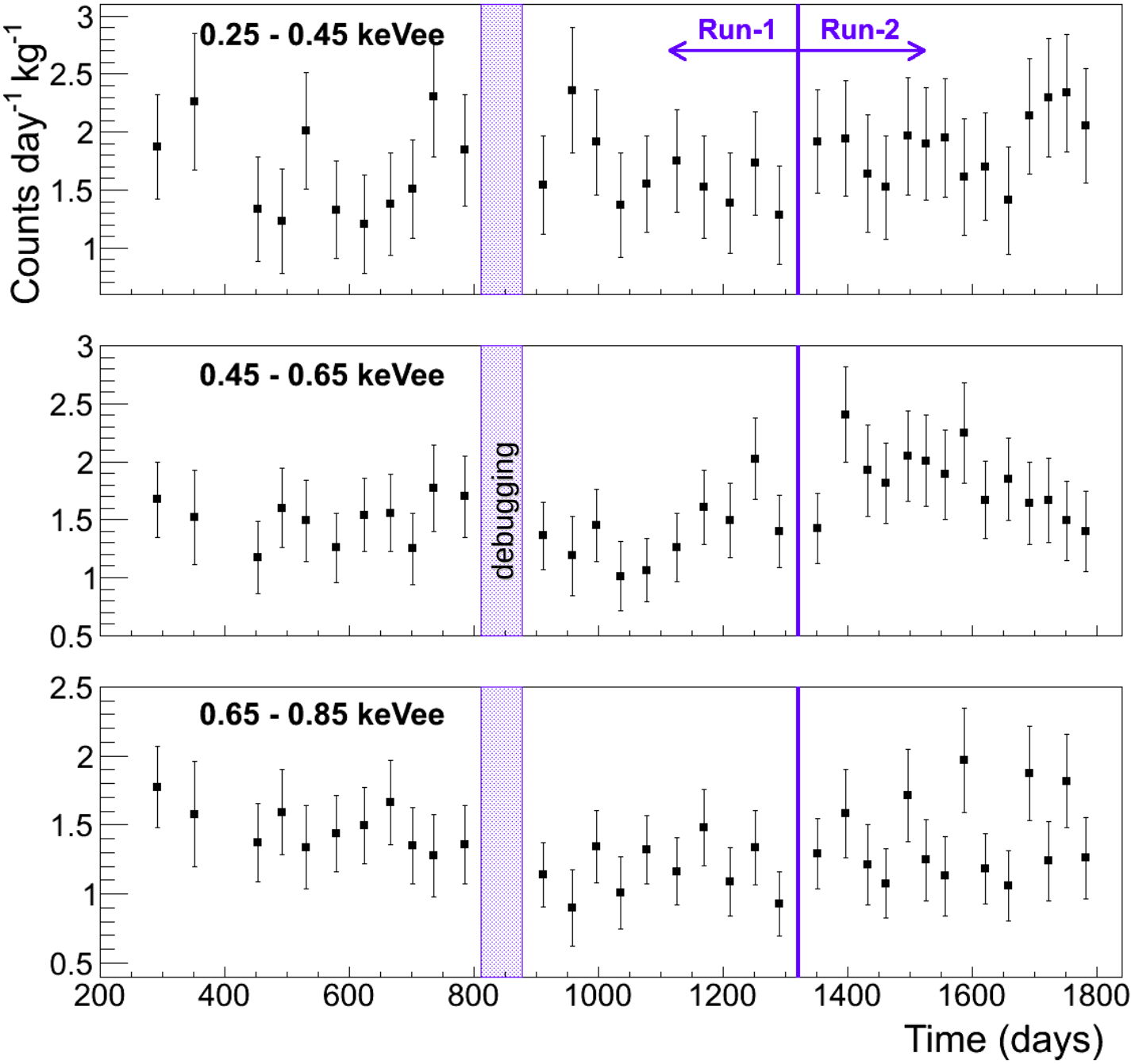
CDEX-1

CDEX-1A 1kg PCGe

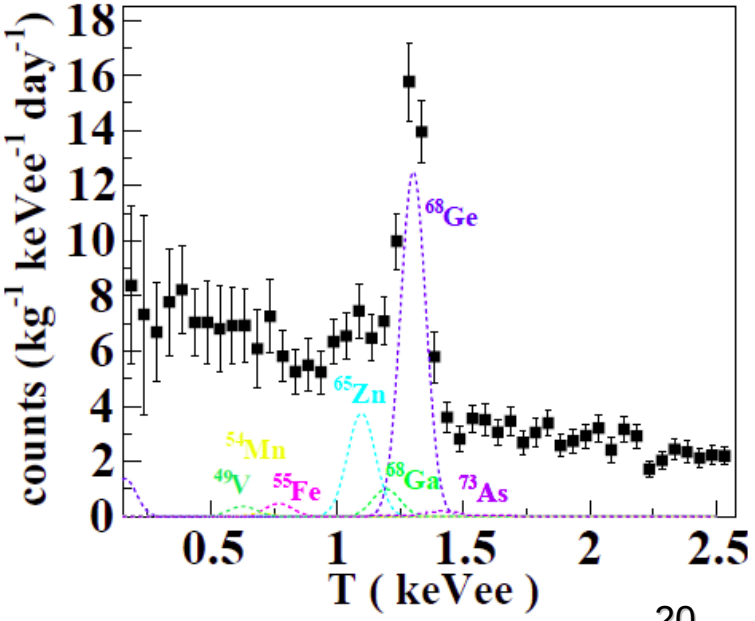
CDEX-1B 1kg PCGe

20cm OFHC Copper
+20cm Lead

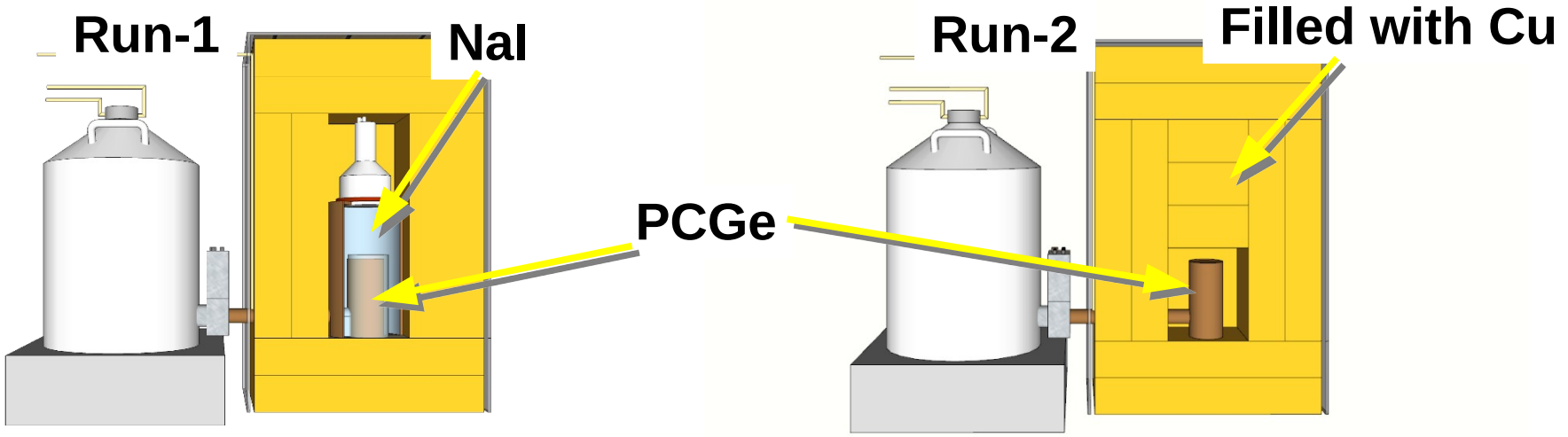
CDEX-1B data < 0.85 keV



- run-1 to run-2: change of shielding.
- 0.25 – 0.85 keV: most important region for low mass WIMP
- χ^2 test consistent with null-hypothesis.



CDEX-1B experiment

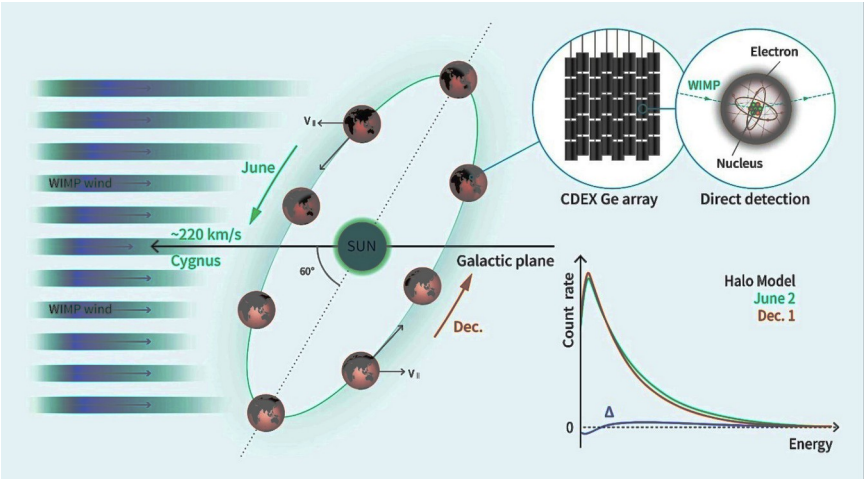


2014/09 – 2017/08
671 kg-days

2017/08 – 2018/12 →
340 kg-days

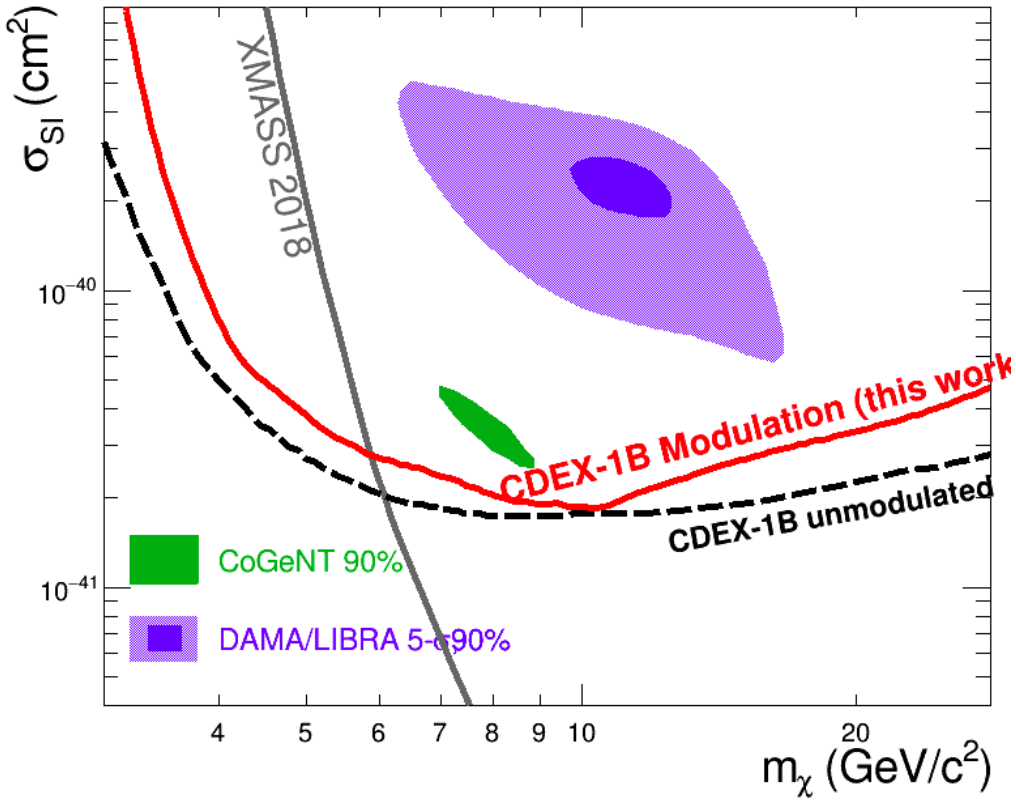
- 1 kg-scale-mass HPGe detector, cooled by cold finger.
- A NaI(Tl) detector is used as active shielding to veto the gamma-ray induced background events.
- The detector has been under stable data taking conditions since March 27th, 2014.
- Threshold ~ 160 eVee. For modulation analysis, threshold ~ 250 eVee.
- Largest analysis uncertainties: bulk/surface separation at low energy.

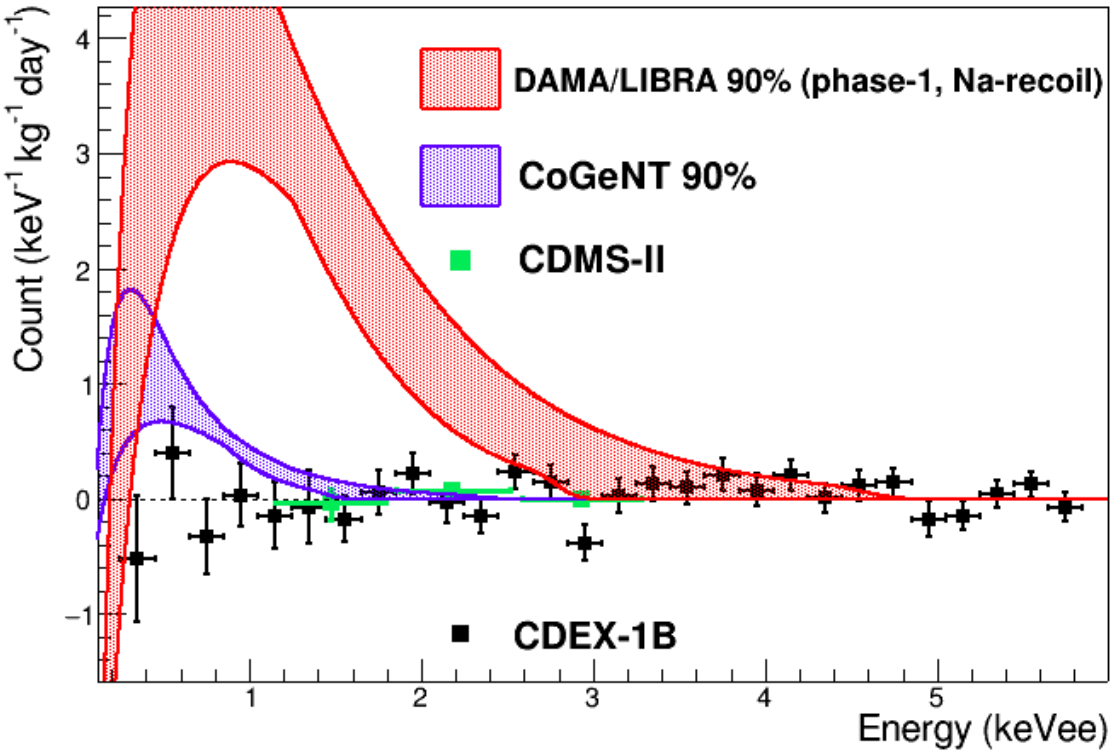
CDEX-1B: annual modulation



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

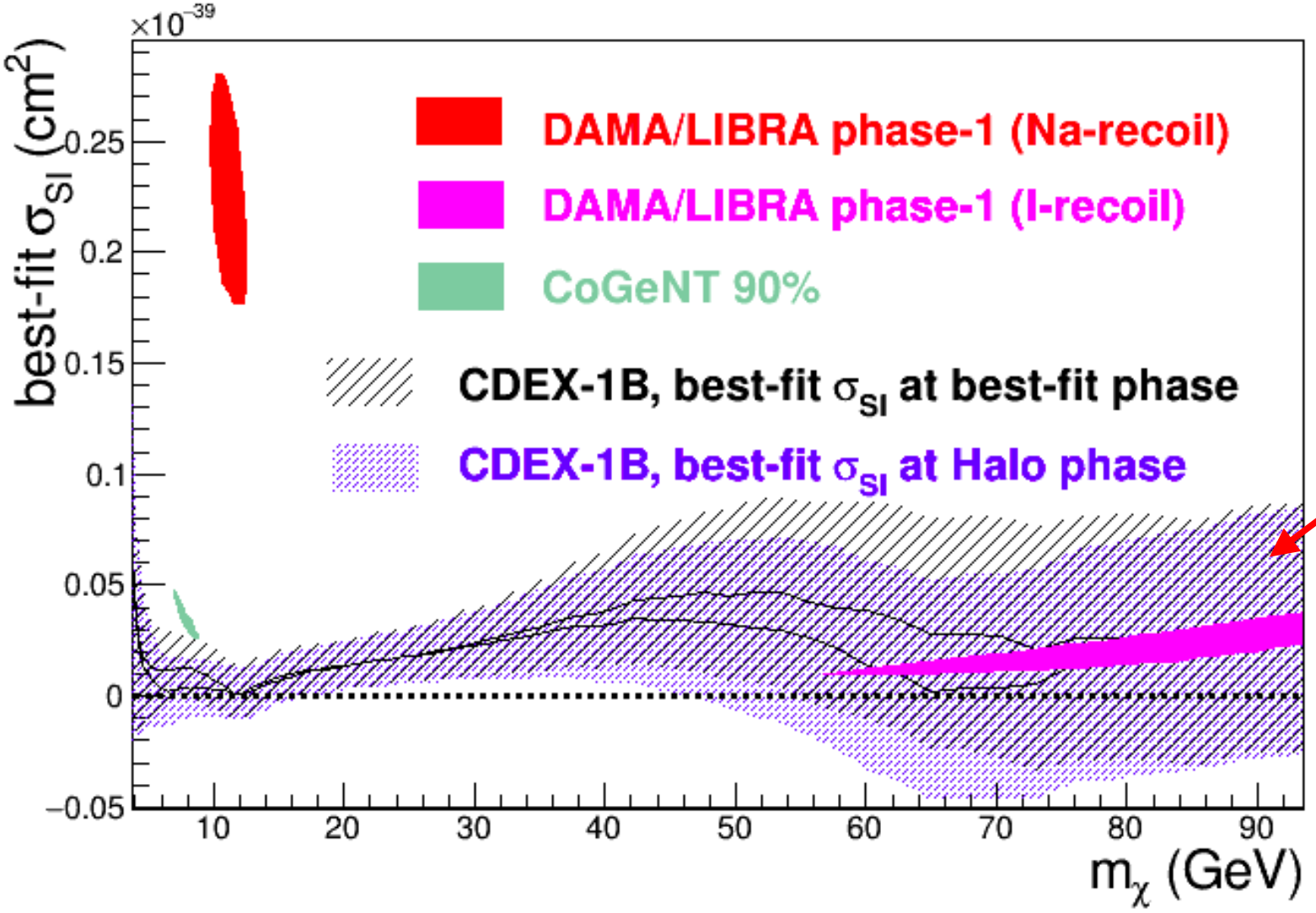
- not exclude I-recoil of DAMA/LIBRA





Phys. Rev. Lett. 123, 221301 (2019)

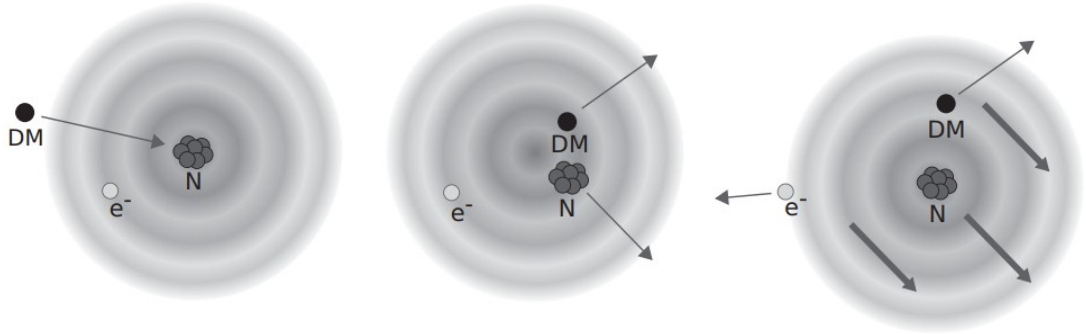
σ_{SI} at fixed/best-fit phase



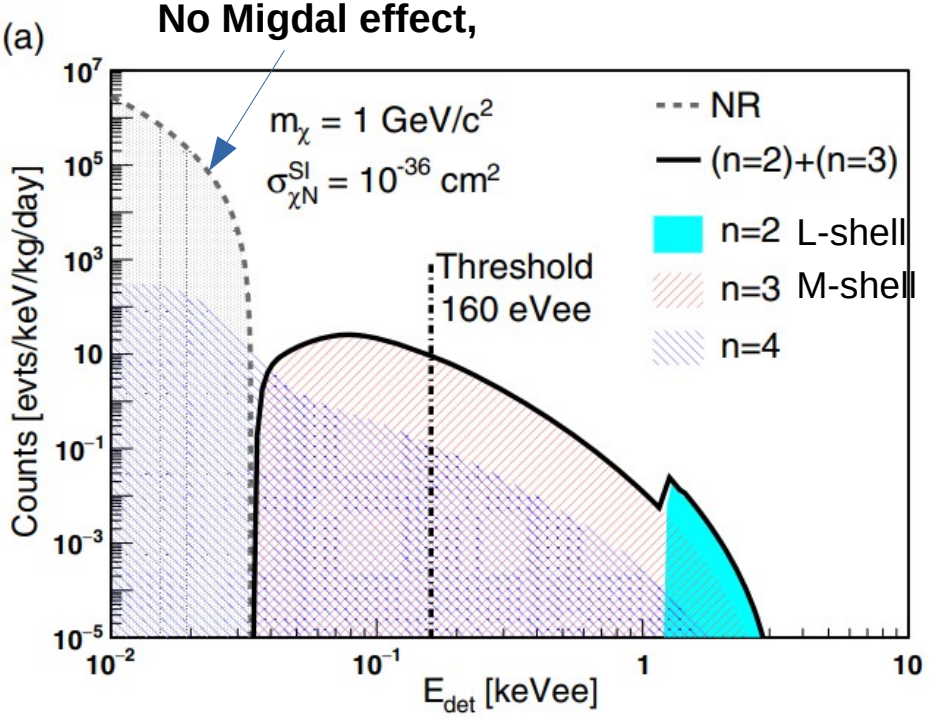
- The results consistent with null-hypothesis at any phases (within 2-σ) up to 100 GeV.

Migdal effect

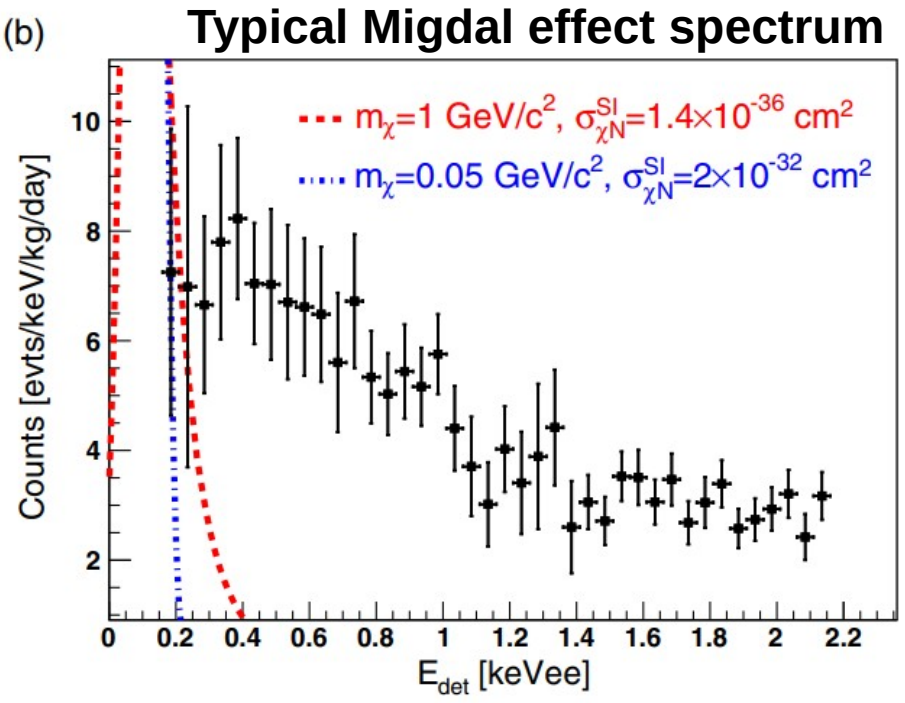
nuclear recoil → electrons cloud move, except one e- → ionization



No Migdal effect,

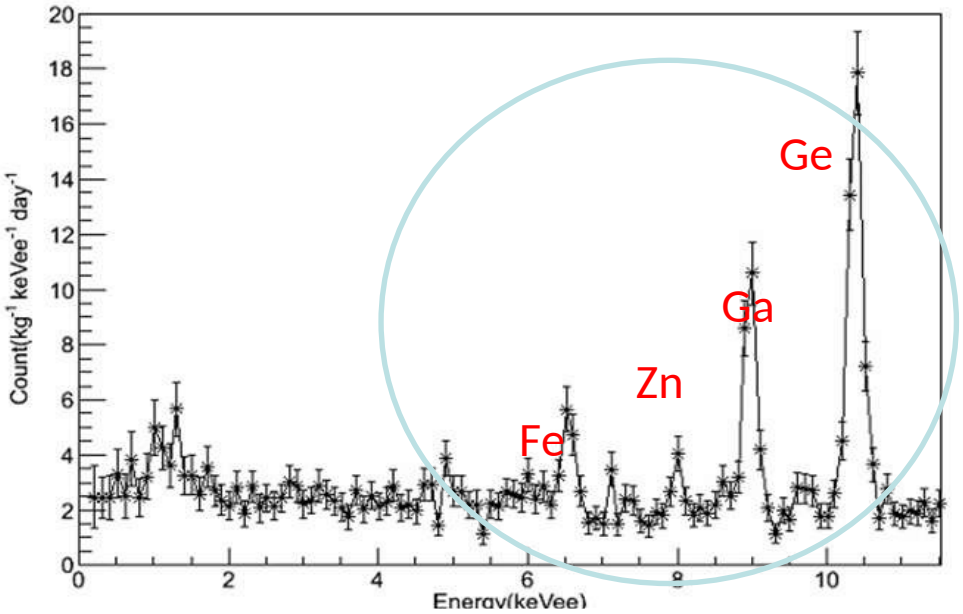


Typical Migdal effect spectrum

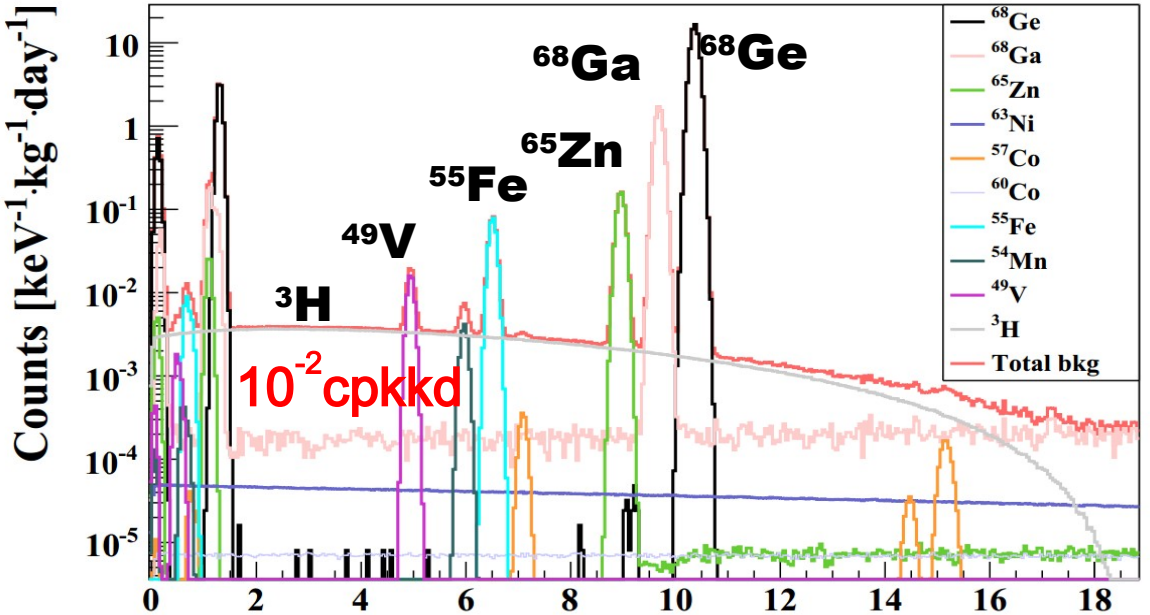


Cosmogenic Background of Ge detector

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



CDEX-10 background spectrum



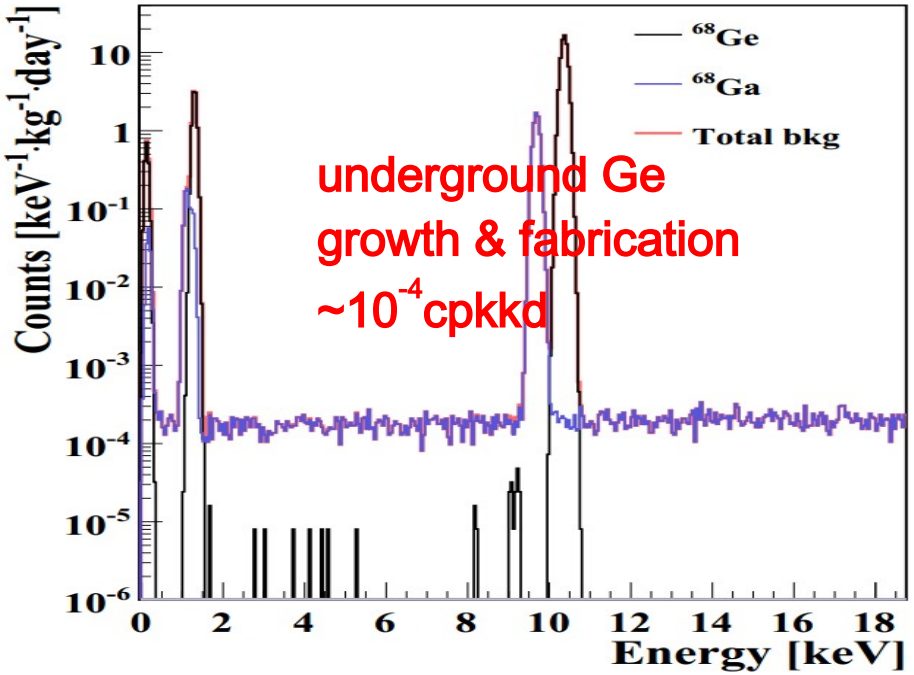
Simulation spectrum

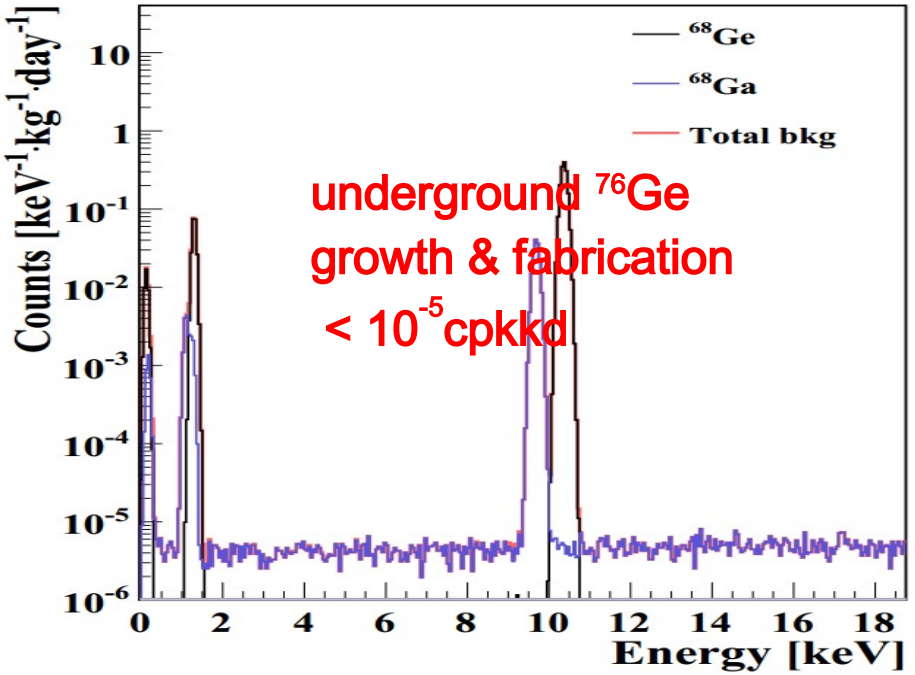
CJPL

arXiv:1802.09327

Cosmogenic Background of U-Ge detector

- Underground germanium crystal growth and detector fabrication could dramatically decrease the cosmogenic backgrounds from non-Ge isotopes, such as ^{3}He, ^{65}Zn;
- ^{76}Ge Enriched germanium material could help to decrease ^{68}Ge(^{68}Ga) cosmogenic backgrounds too. (2nu background ~ 10^{-5}cpkkd at 1keV)





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arXiv:1802.09327