The status of dark matter search experiments in China

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C O N T E N T S

Outline

01 Introduction

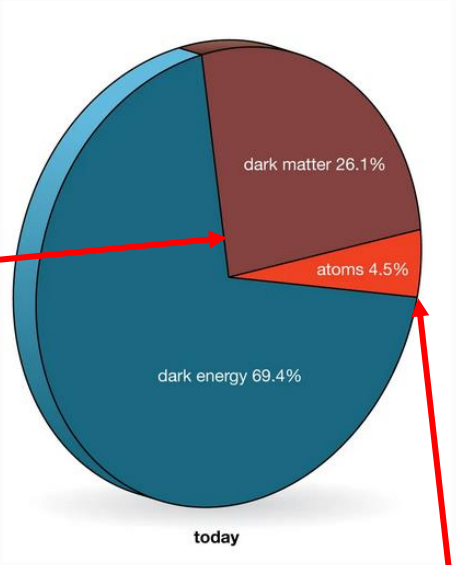
02 Dark matter direct detection at CJPL

03 Dark matter indirect detection in space

04 Summary

1.1 Introduction

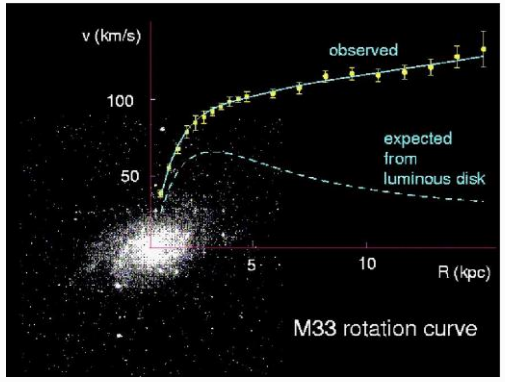
1) Many astronomical observation experiments indicate **exiting of "dark matter"** ;
2) A standard model of the cosmology reveals the content of the universe: **~26% of cold dark matter; ~4.5% of baryonic matter.**
3) **"Dark"** matter: a) does not interact with light or electromagnetism; b) interacts gravitationally; c) stable; d) slow: ~0.001c; e) Local density: ~0.3Gev/cc.
4) One of **candidates** (**highly motivated**): **WIMPs** (Weakly Interacting Massive Particles), MeV~100TeV scale particle, weak interaction leads to correct density today.



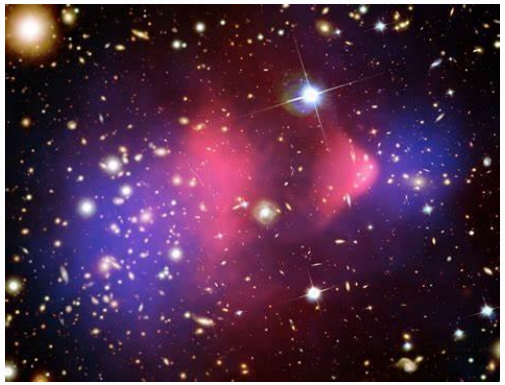
Standard Model of particle physics

Gravitational interactions

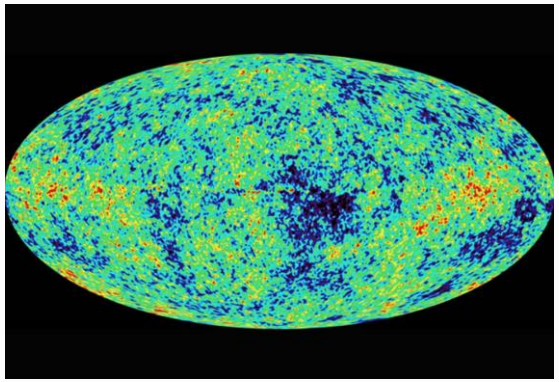
galactic rotation curve



Bullet cluster



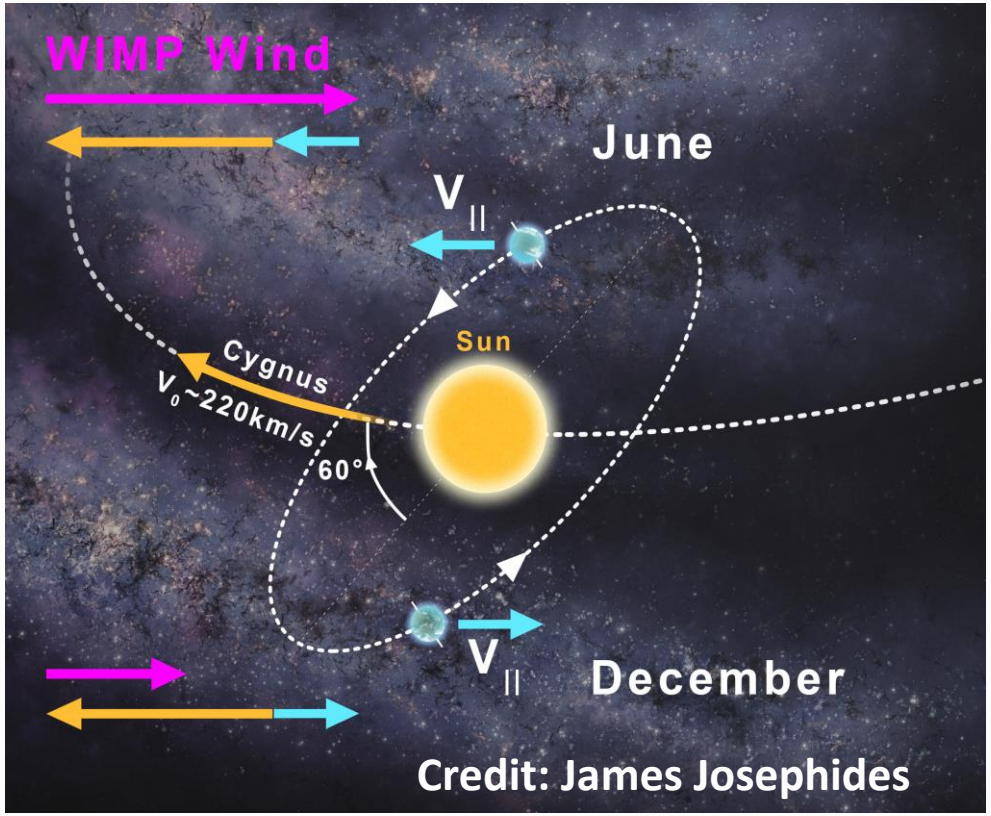
cosmic micro wave background

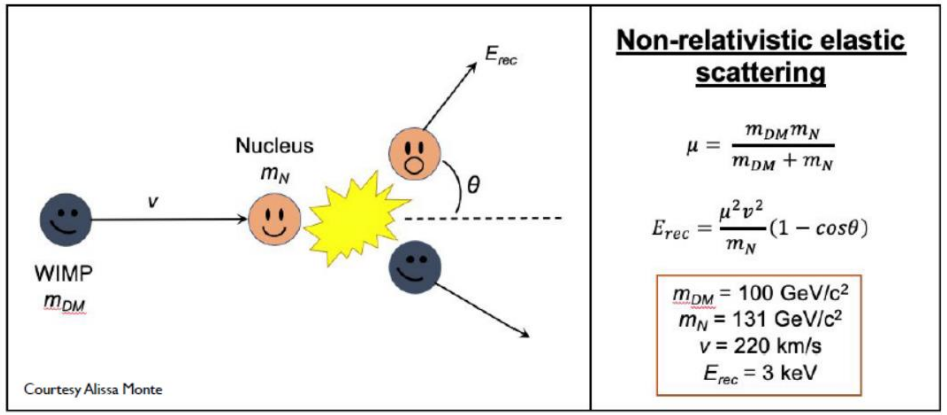


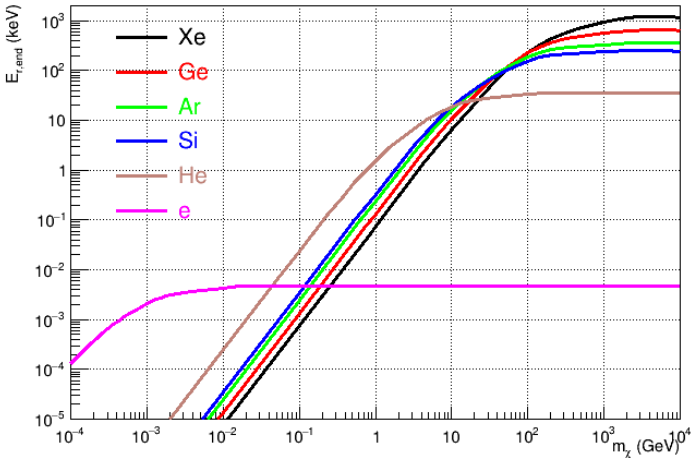
1.2 Detection Method of Dark matter

Direct Method: Classical beam experiment,

The **scattering of dark matter particles with normal matters** can be **approximated** as a non-relativistic two-body scattering.





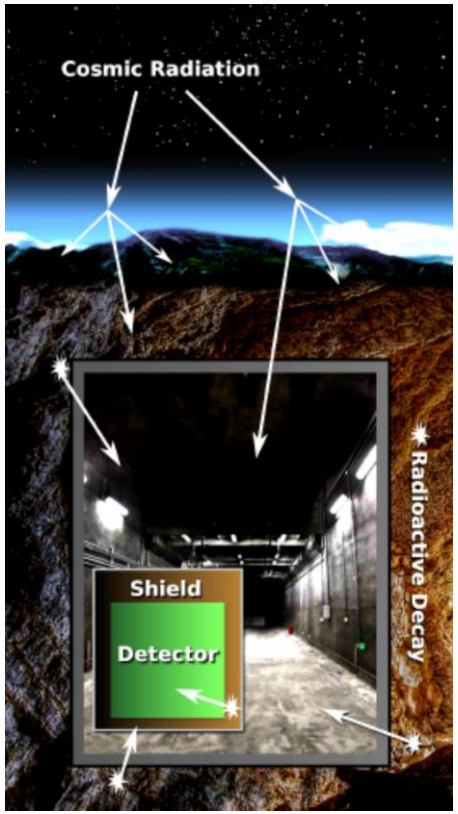


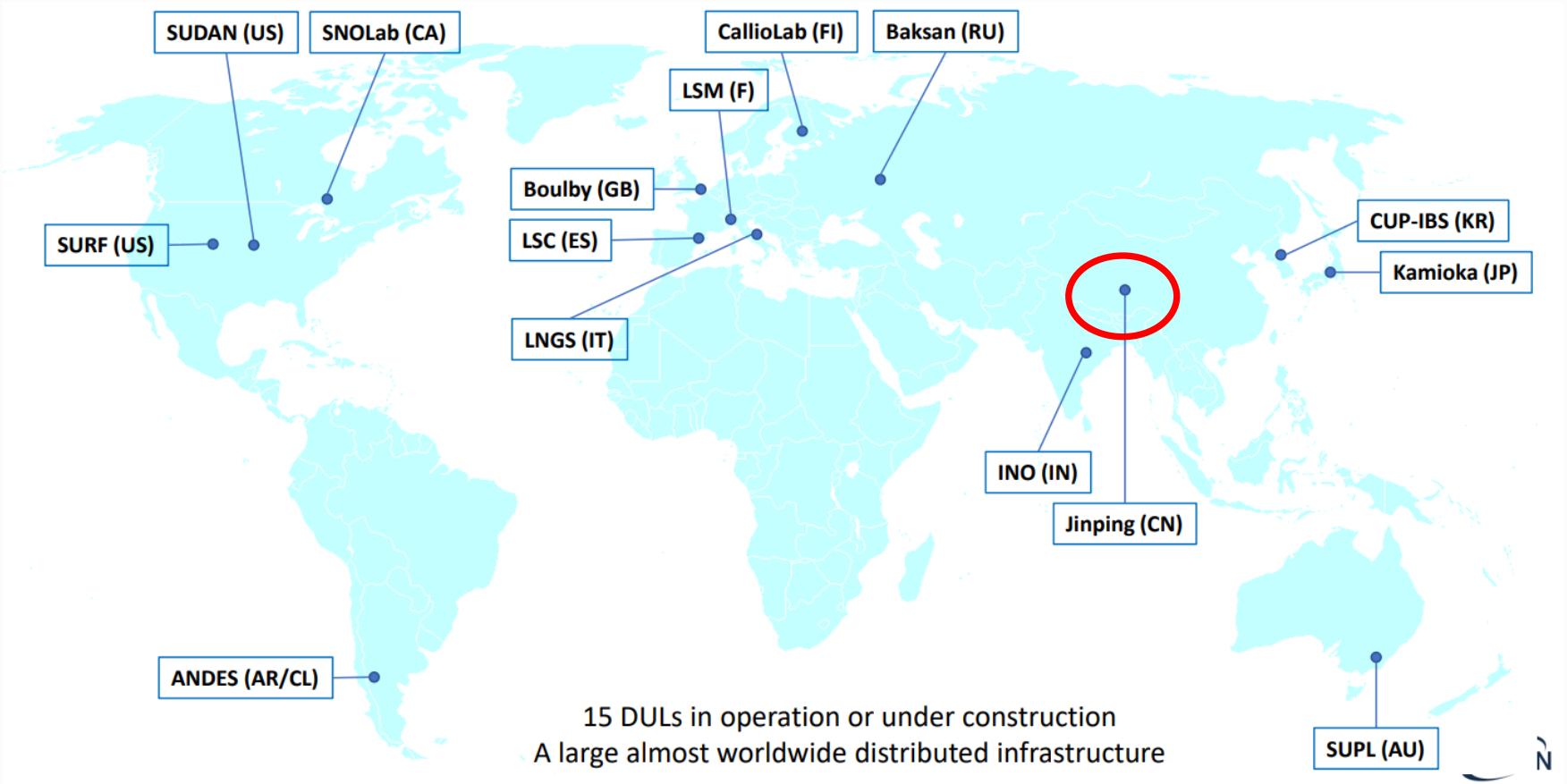
The energy recoils of nucleus struck rarely by WIMPs for **different targets**.

Endpoint recoil energy, v_{max} = 650 km/s, free targets

1.3 Deep Underground labs

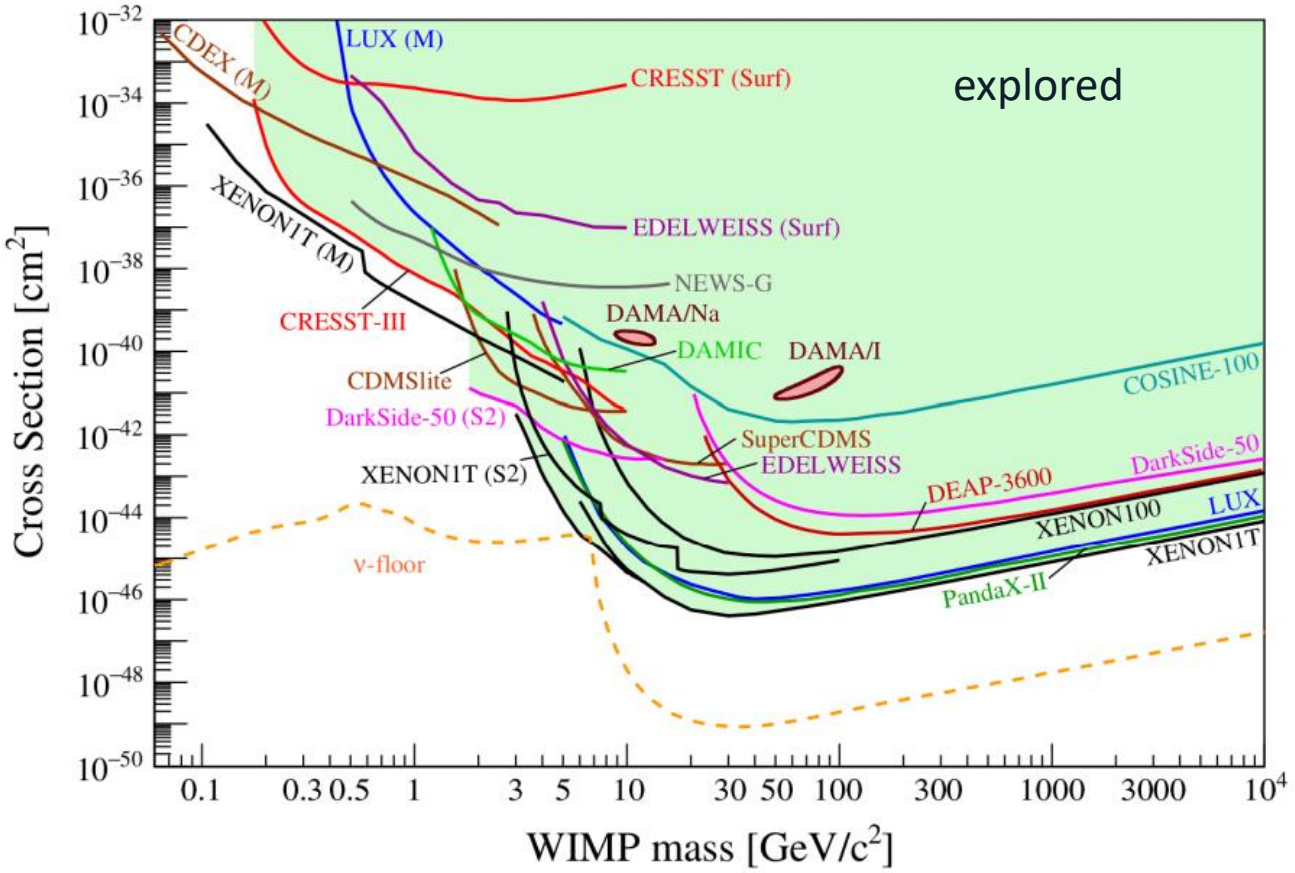
- **The signal** of direct detection dark matter is **small and rare**, its experiments operate underground.
- **15 Deep undergournd labs in operation or under construction in the world.**
- **CJPL (in China) came at 21 century.**



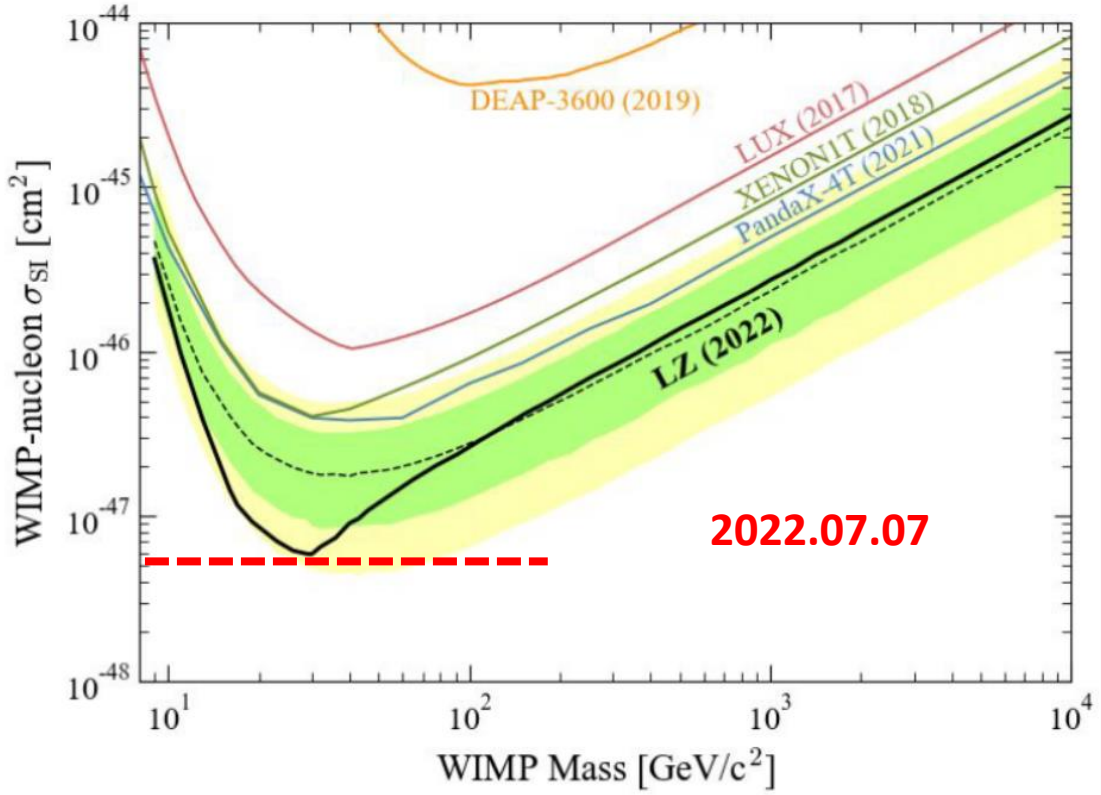


1.4 Global status: hide & seek

- **Many dark matter experiments in the world. They keep breaking records of detection limit. Close to the neutrino floor.**
- **Last month, the best cross section of WIMPs is released by LZ experiment.**

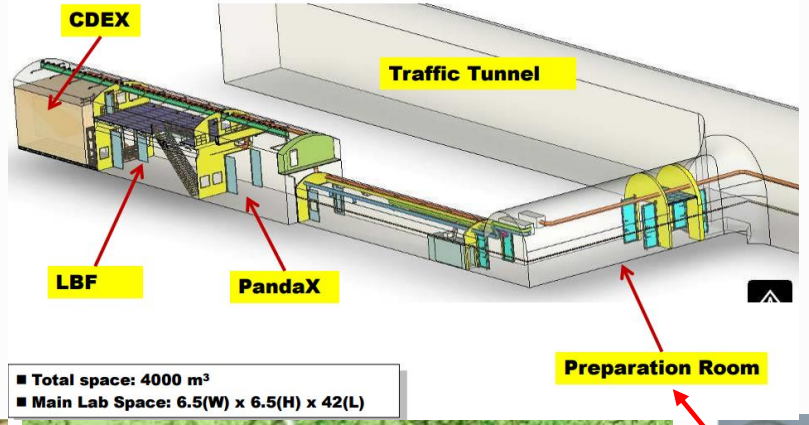


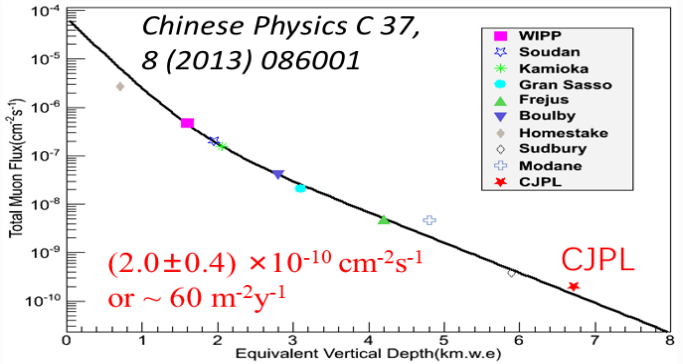
Best cross section(cm^2): 6×10^{-48}

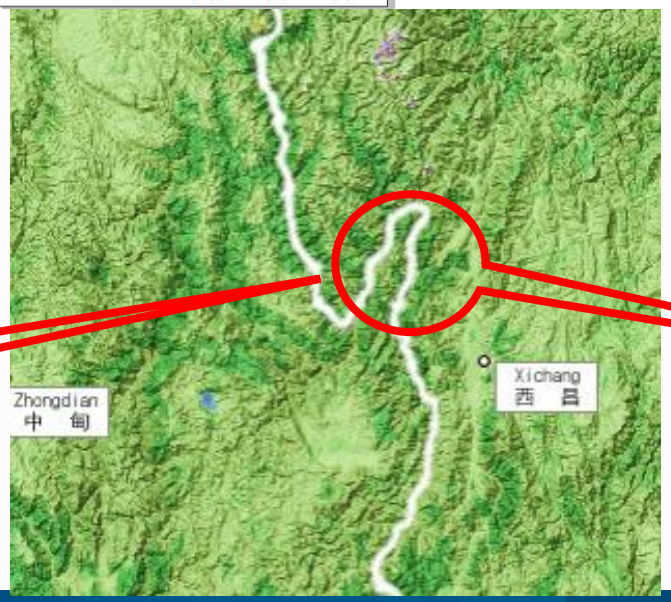


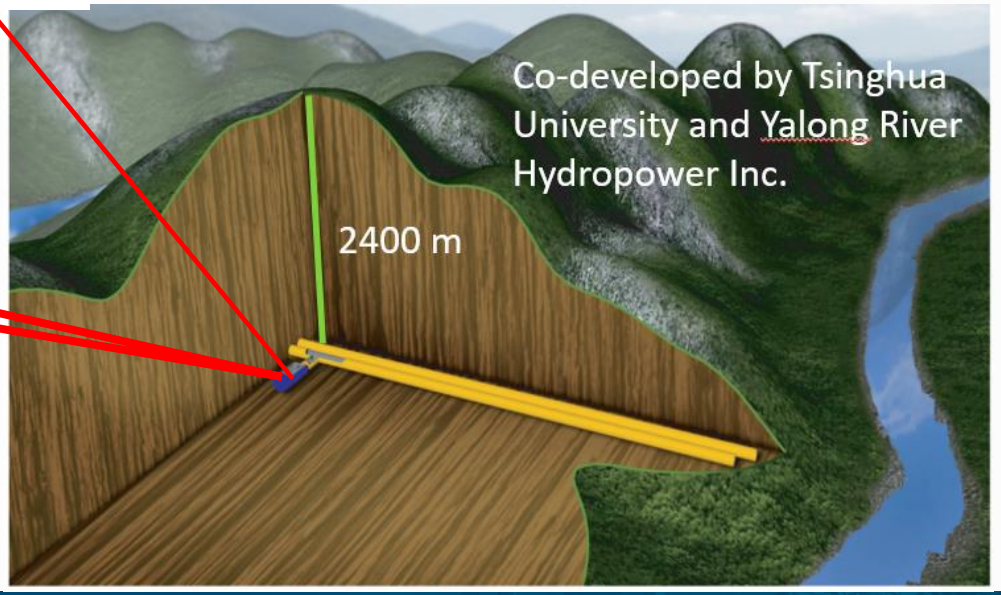
2.1 China Jiping Underground Laboratory (CJPL)

1) CJPL is located in Sichuan province of south-west China, CJPL-I (inaugurated in 2010): ~4000 m3.
2) China Dark matter search experiment: CDEX and PandaX









2.2 CJPL-II

CJPL-I was extended in 2014,

CJPL-II (75* CJPL-I) : ~300k m^3 with 8 main halls of 14x14x65 m.

CJPL: CJPL-I+CJPL-II, **the deepest and largest DUL in the world currently**.

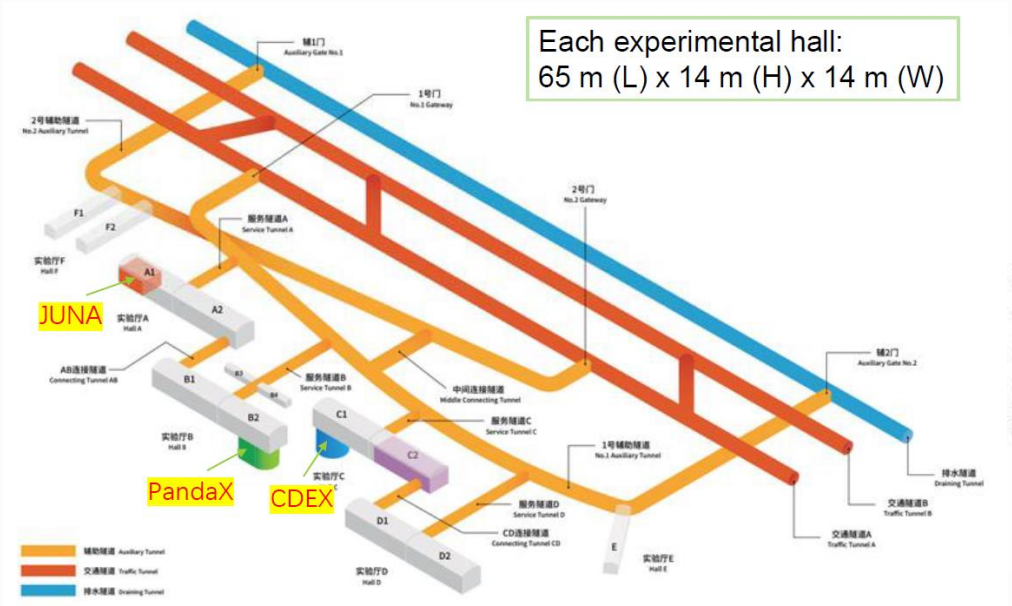
Science, Nov. 30, 2014

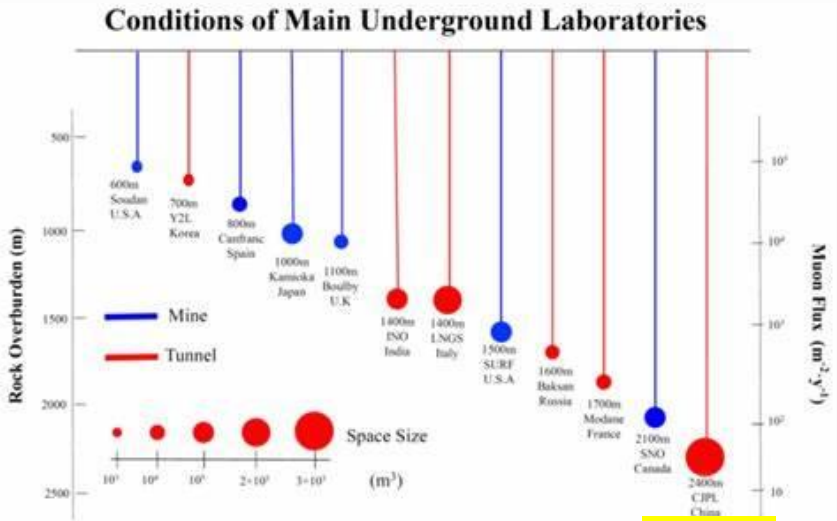
PHYSICS

China supersizes its underground physics lab

Planned expansion could pave way for "ultimate dark matter experiment"

The world's deepest physics laboratory is about to become one of its largest. Early next year, workers will start carving four cavernous experiment halls along a tunnel through Jinping Mountain in China's Sichuan province. Once the science at the China Jinping Underground Laboratory (CJPL) is scaled up as well, "it will be a milestone for Chinese physics," says Nigel Smith, director of the underground SNOLAB in Sudbury, Canada.





CJPL

2.3 DURF @ CJPL-II

- ✓ **DURF @ CJPL-II**: **D**eep **U**nderground and ultra-low **R**adiation background **F**acility for frontier physics experiments
- ✓ **July 2019, DURF** project commencement
- ✓ **Second half of 2022**, electromechanical equipment installation
- ✓ **Early 2025, formal operation of DURF.**

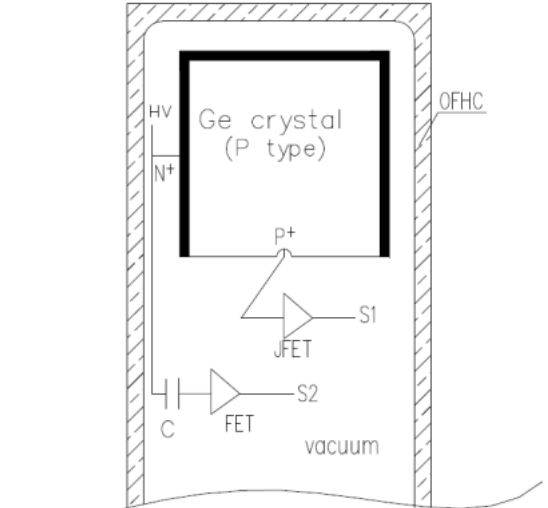
C1 Hall, 18 m pit

B2 Hall, Ultrapure water tank

2.4 CDEX Collaboration

China Dark Matter EXperiment

- ✓ Formed in 2009, 11 institutions and ~70 people; Leaded by Tsinghua university.
- ✓ Searching for light DM by **P-type Point-Contact Germanium detectors**

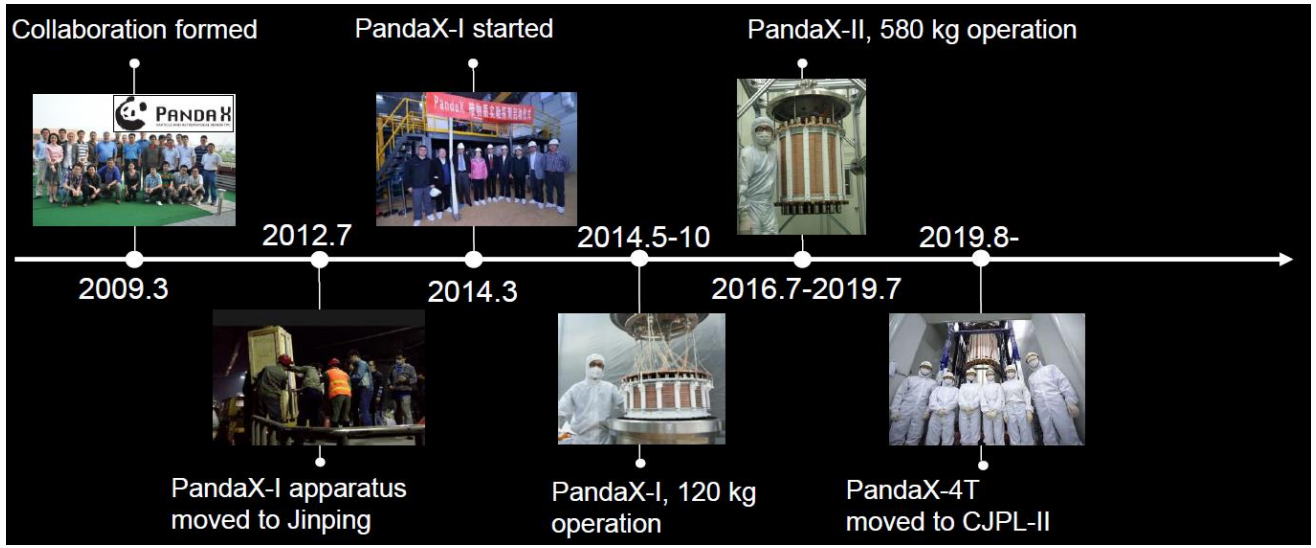


CPC 37, 126002 (2013)

2.5 PandaX Collaboration

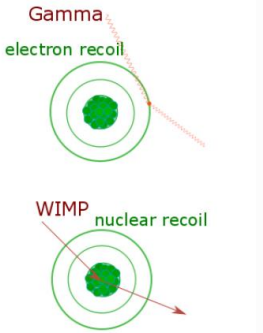
Particle and Astrophysical Xenon observatory

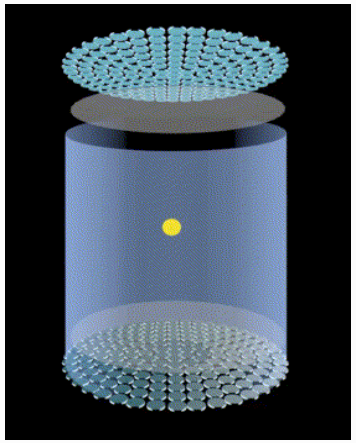
- ✓ Formed in 2009, 14 institutions and ~100 people;
- ✓ Searching for DM by **Liquid Xenon.**

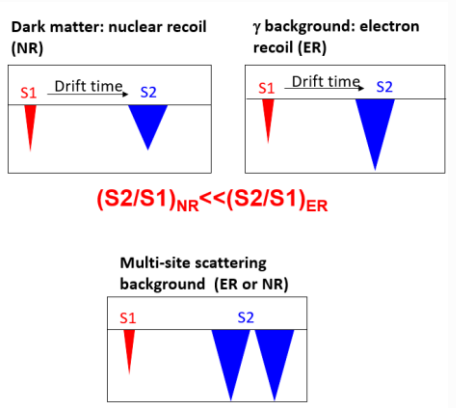


2 phase Xenon Detector:

- Large monolithic target
- 3D reconstruction and fiducialization
- **Good ER/NR rejection**
- **Calorimeter capable of seeing a couple of photons/electrons**

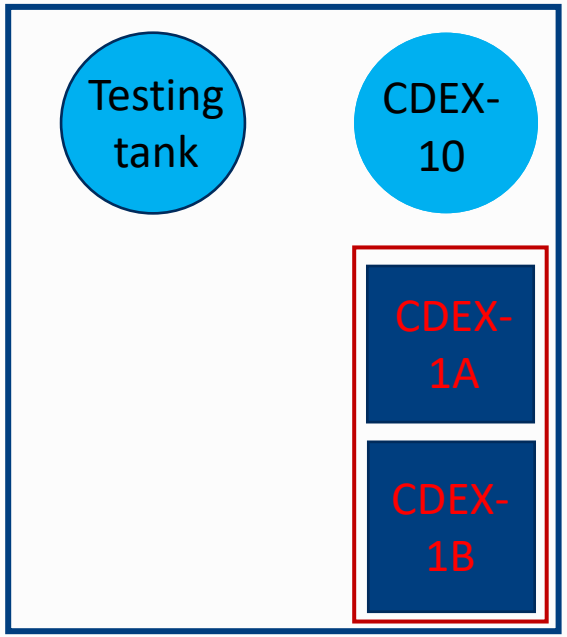


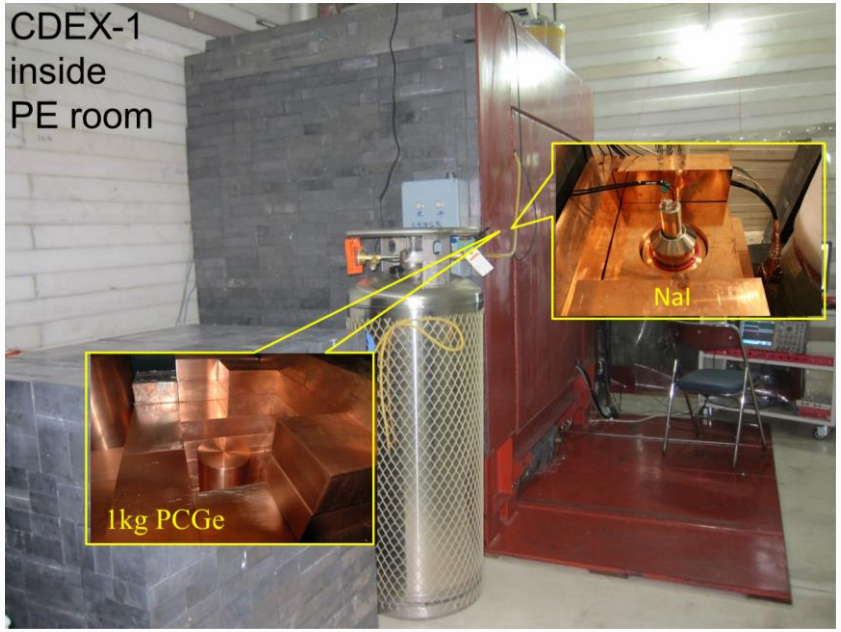


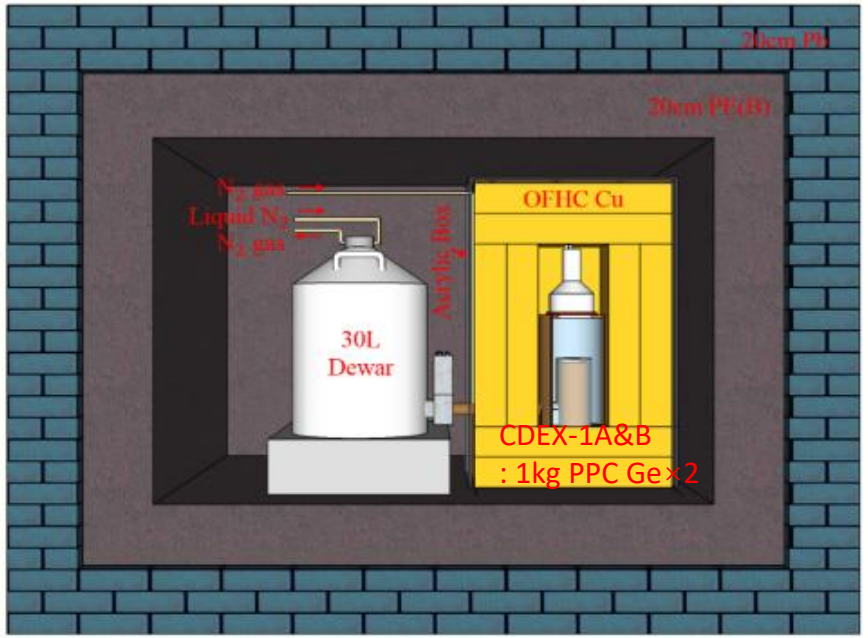


2.6 Light dark matter search in China (CDEX)

① 2 sub-stages: CDEX-1A (prototype, 2011) → CDEX-1B(upgraded, 2013);
② Single-element ~1kg PPC Ge detector with cold finger;
③ Low-background Pb&Cu passive shield + NaI veto detector;
④ Located in PE room at CJPL-I.

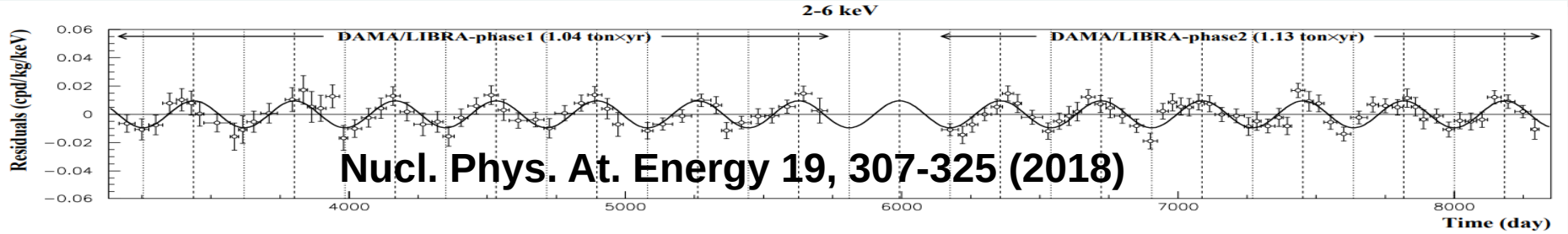


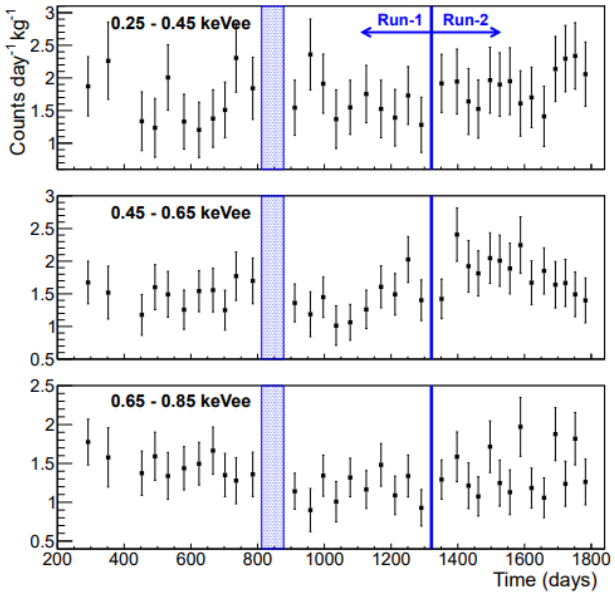


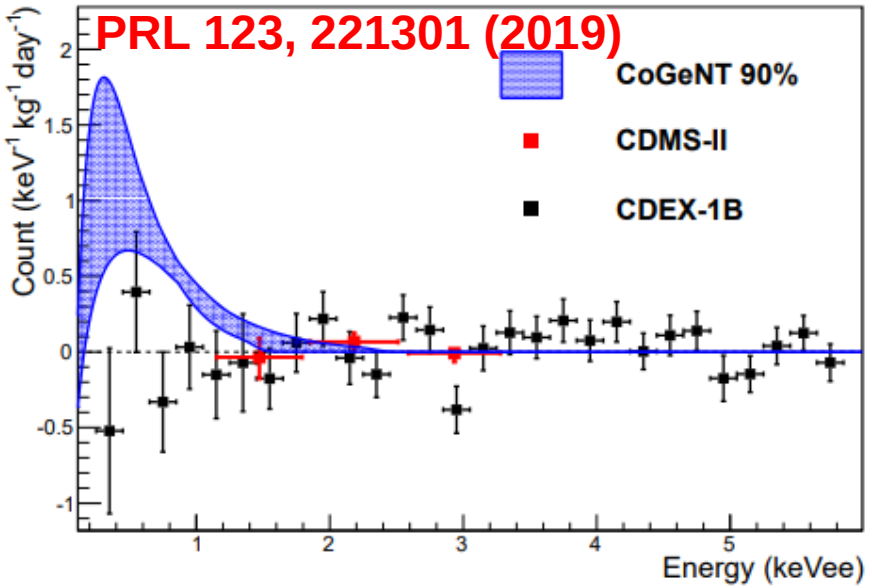


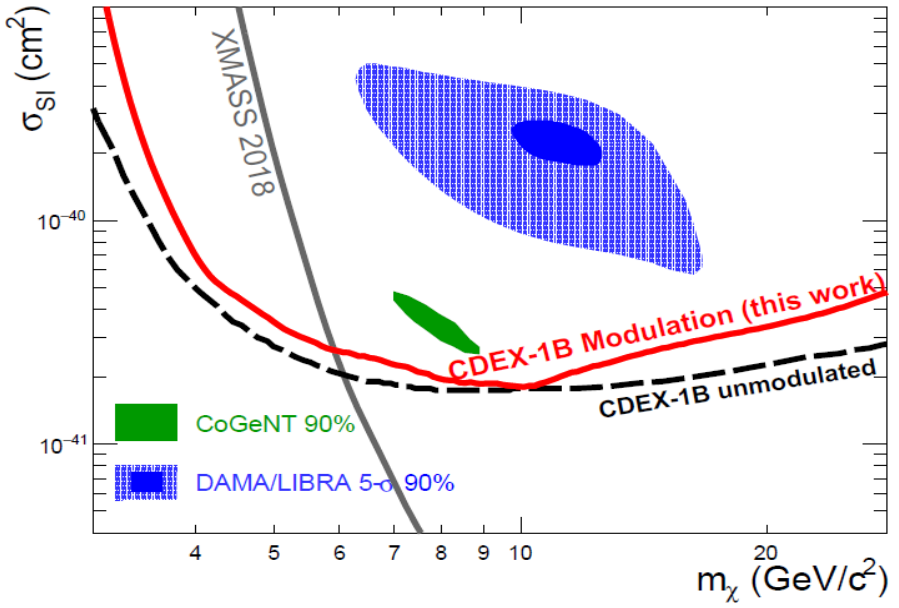
2.7 Light dark matter search in China (CDEX)

HightLight of CDEX-1B: Annual Modulation analysis from more than 4 years of data, excluding CoGeNT and DAMA/LIBRA interpretation





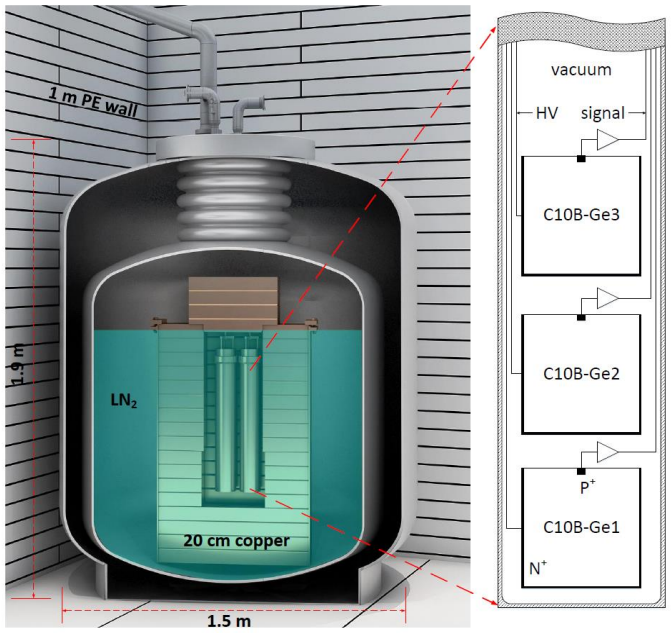




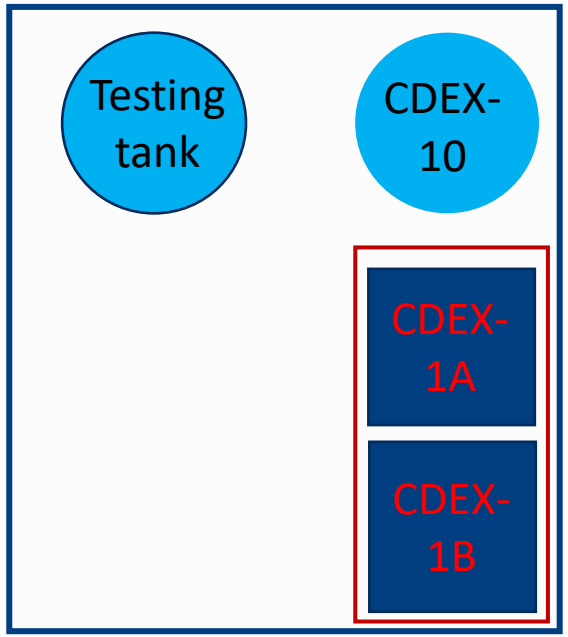
2.8 Light dark matter search in China (CDEX)

CDEX-10

① Array detectors: 3 strings with 3 detectors each, ~10 kg total;
② Direct immersion in LN_2;
③ Light/radiation-purer LN_2 replacing heavy shield i.e. Pb/Cu;
④ Prototype system for future hundred-kg to ton scale experiment



CDEX-10: ~10kg PPC Ge array



2.9 Light dark matter search in China (CDEX)

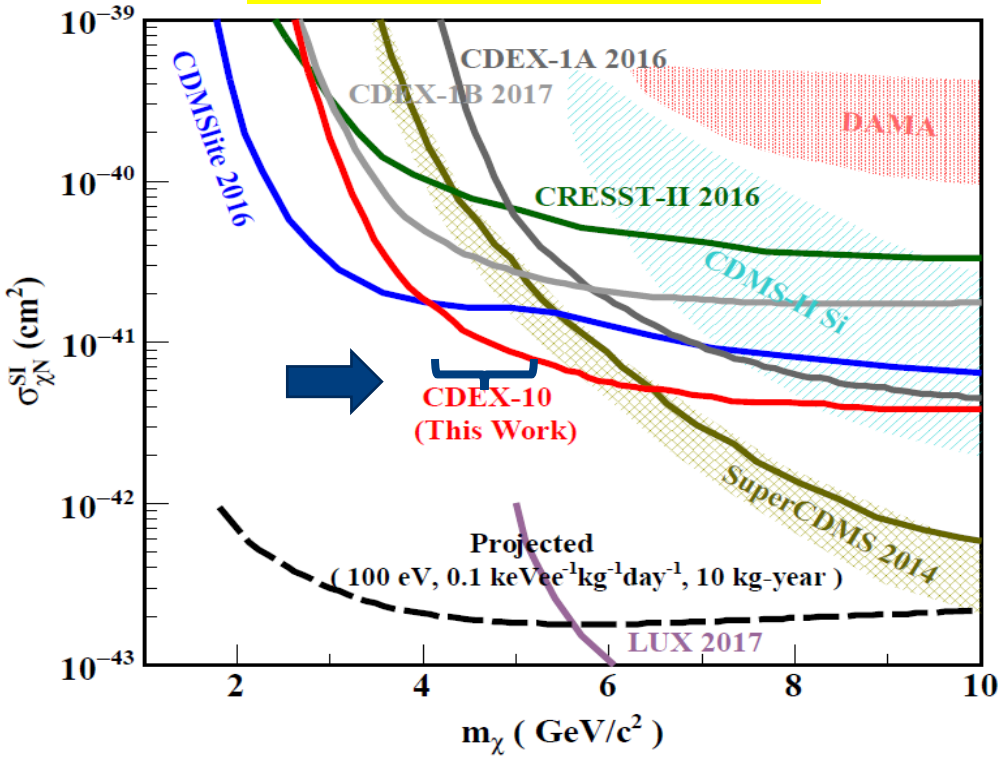
Highlights of CDEX-10:

① **Lower Threshold: 160 eV**

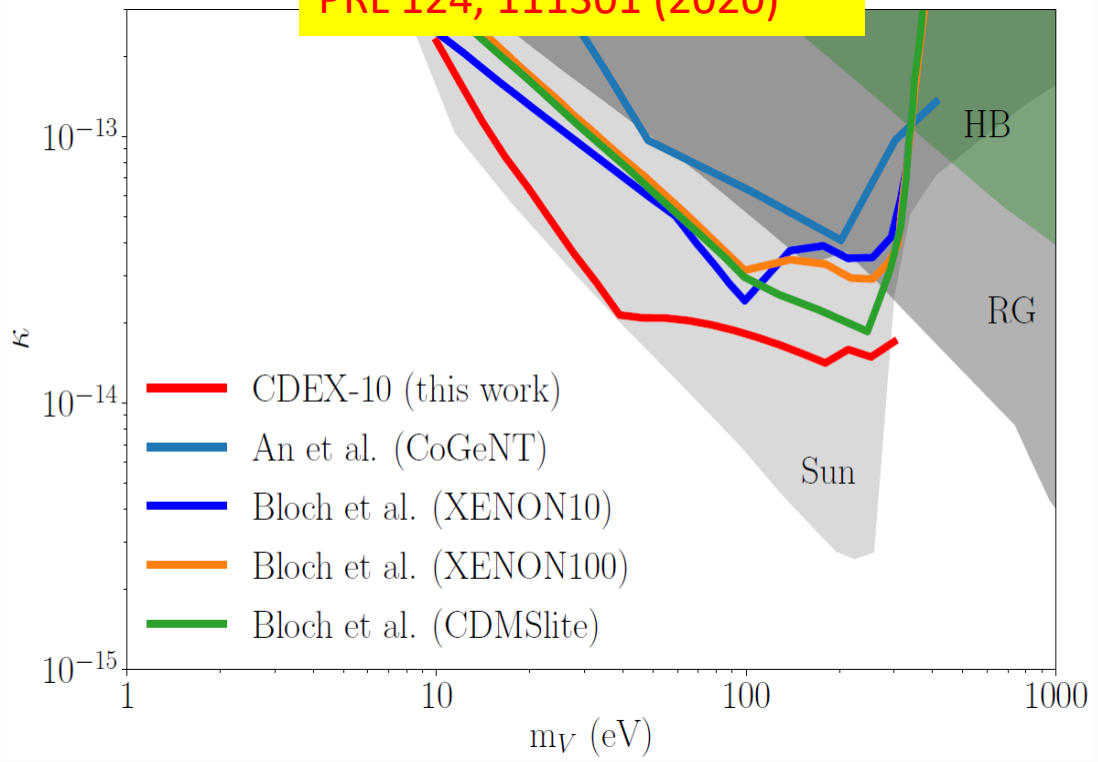
② Cross section of Spin-independent WIMP-Nucleus: **competitive in 4-5 GeV/c^2**

③ Solar dark photon limit: **improving direct detection results in 10-300 eV/c^2**

PRL 120, 241301 (2018)



PRL 124, 111301 (2020)



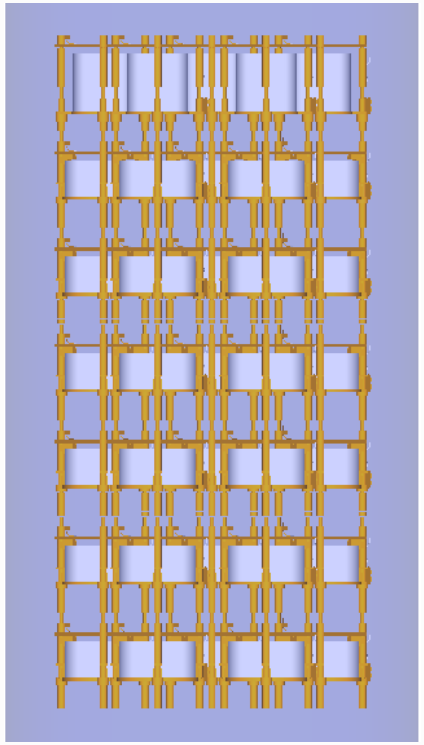
2.10 Light dark matter search in China (CDEX)

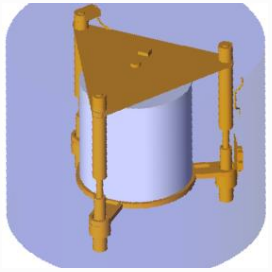
CDEX-50 Plan:

① Natural Ge; Immersed in LN2

② PPC+BEGe detectors

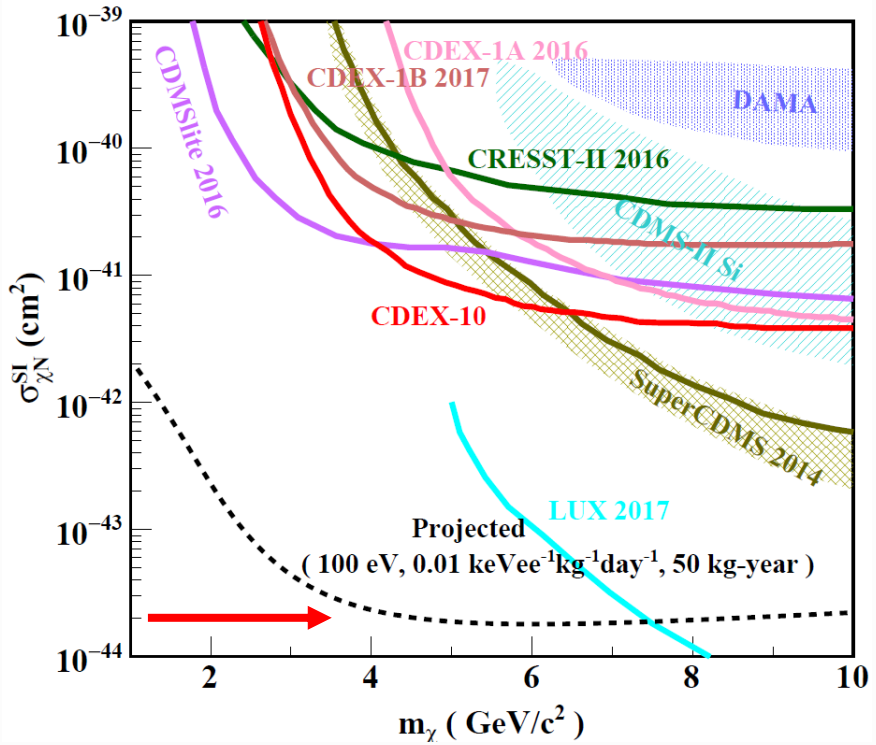
③ 50kg-y, 0.01cpkkd BKG: **expected sensitivity ~10^{-44}cm^2**

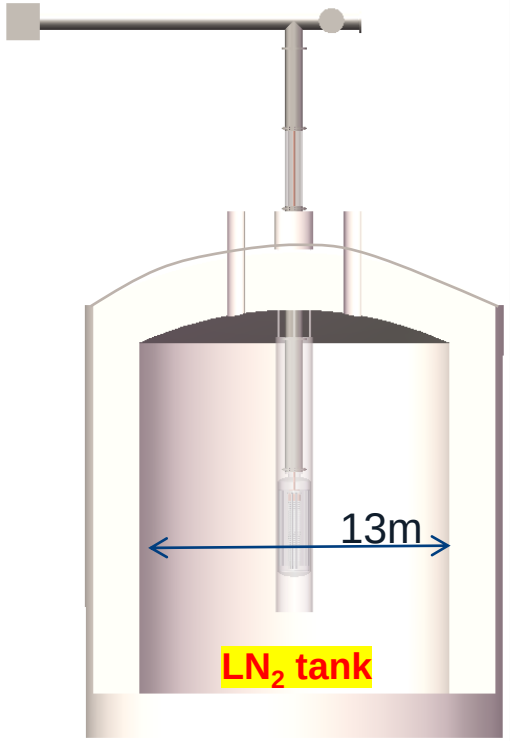




PPC

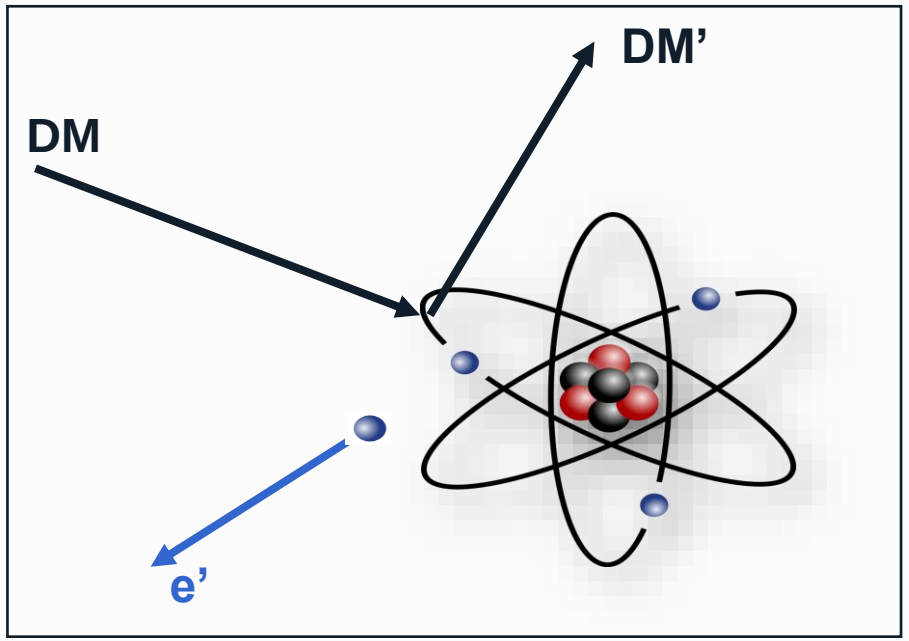
BEGe

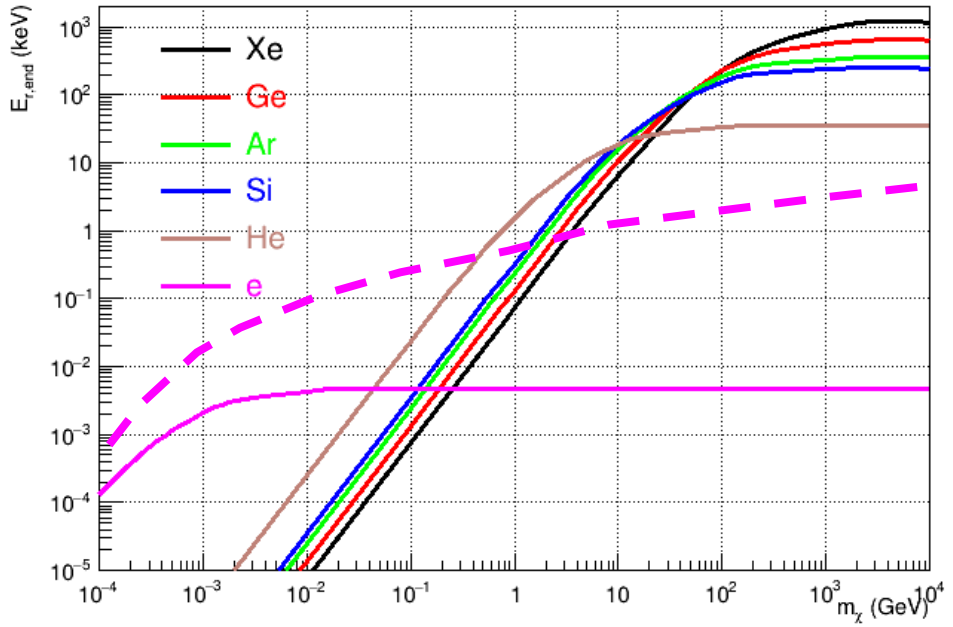




2.11 interaction between DM and electrons

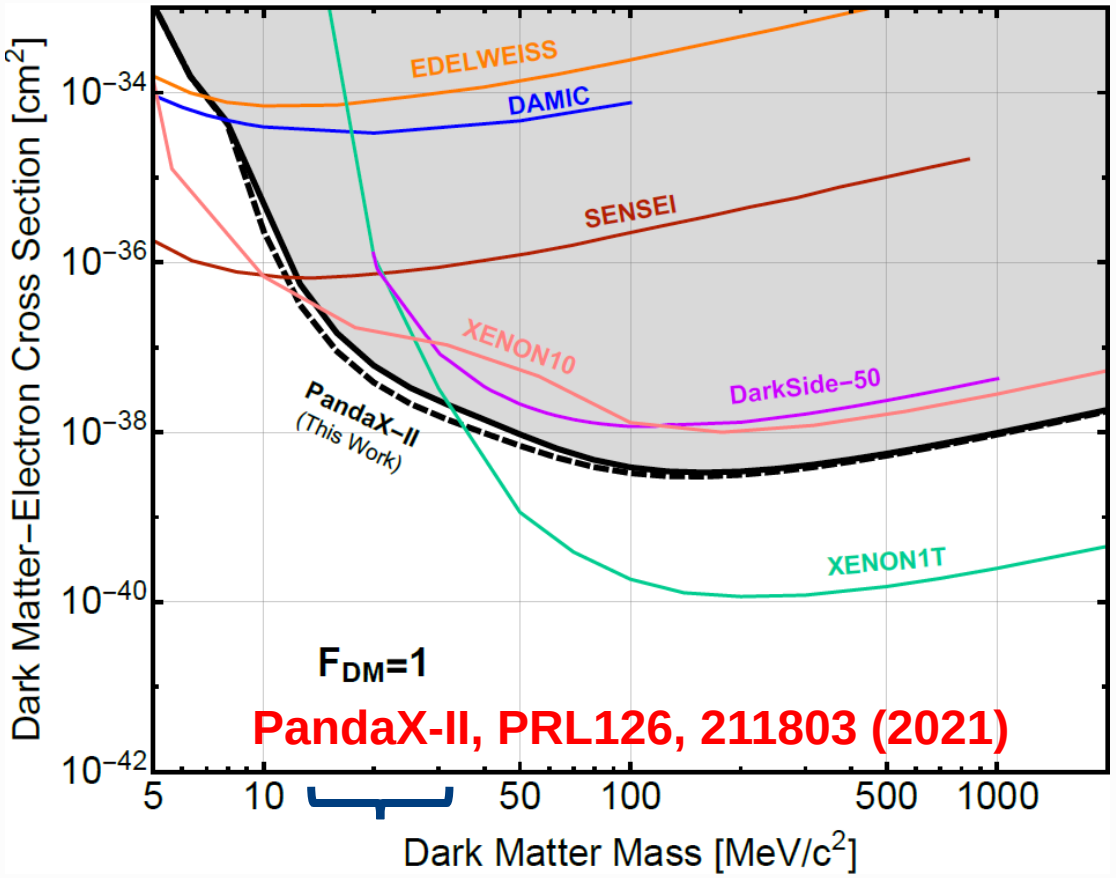
- DM could certainly interact directly with electrons
- Bound electrons in the atomic, leading to **sizable energy deposition** from electron ionization. Essig, Mardon, Volansky, PRD 85, 076007 (2012)





2.11 interaction between DM and electrons (PandaX)

- Ionization-only signals (S2) in LXe TPC can see single e^-!
- Large target mass
- Lowered threshold to 80 eV
- Best constraint to DM-e interaction between 15-30 MeV/c^2

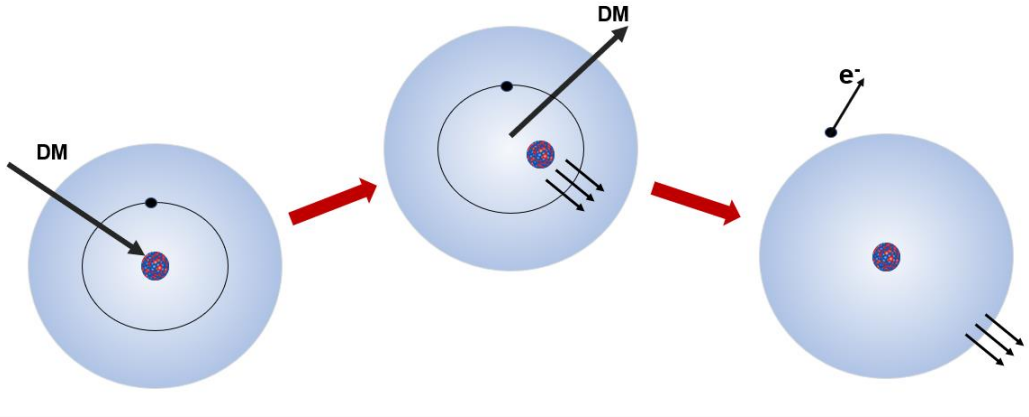


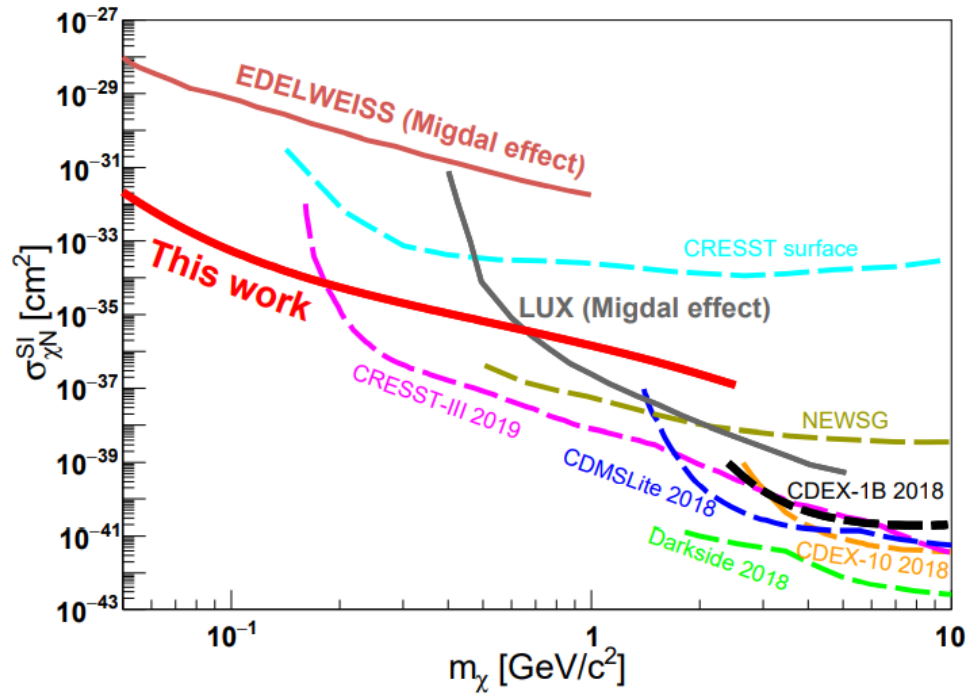
2.12 Migdal effect in DM-N scattering (CDEX)

①Searches using expected signals from Migdal effect: XENON, LUX, EDELWEISS, **CDEX**

②**Significant extension** of DM-N interaction to the **low mass region**

③Number of experimental efforts to really see such an effect: Majewski, TAUP 2021; Nakamura et al., PTEP 1, 013C01 (2021); arXiv:2112.08514





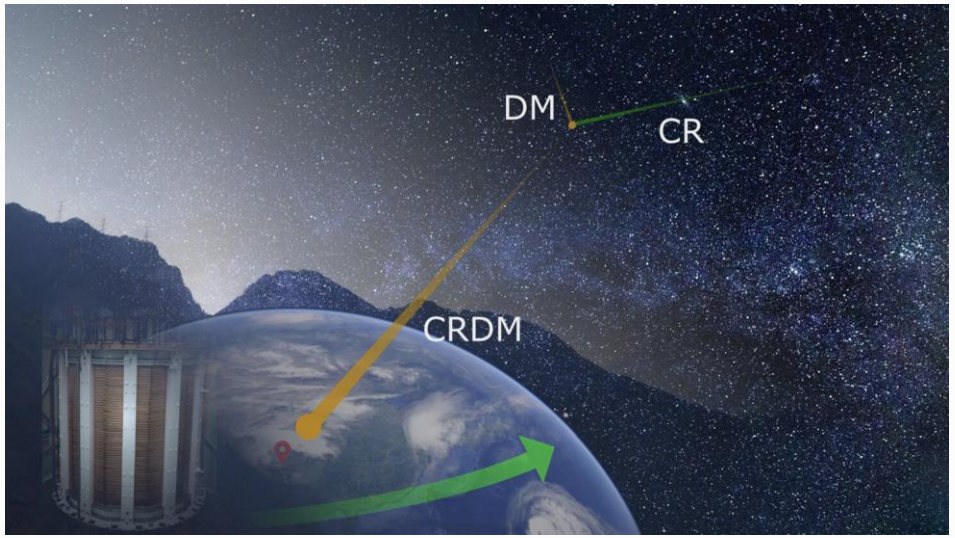
- Reformulated: Abe et al., JHEP 2018, 194 (2018); Dolan et al., PRL 121, 101801 (2018)
- Direct DM-e ionization and Midgal-induced ionization probability are closely related. Essig, Pradler, Sholapurkar, and Yu, PRL 124, 021801 (2020)

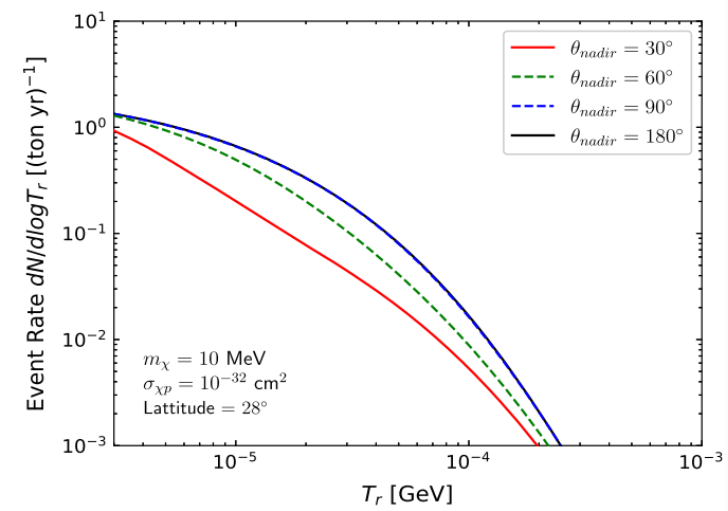
2.13 Cosmic Ray Boosted DM (PandaX, CDEX)

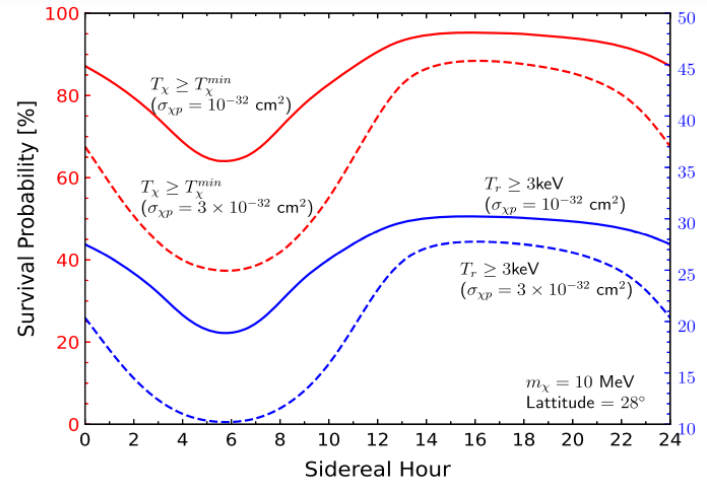
- **CR mostly p/He**
- **For finite DM-N scattering, DM acceleration by CR is inevitable!**

- **Bringmann and Pospelov, PRL 122, 171801 (2019)**
- A boost in recoil energy + a diurnal modulation in rate and E spectrum, Ge, Liu, Yuan, Zhou, PRL 126, 091804 (2021)

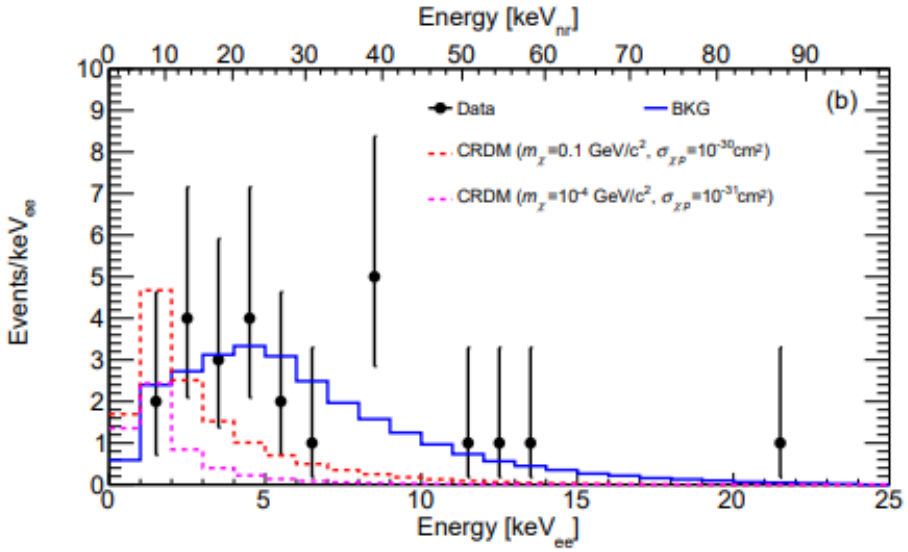
Diurnal effects





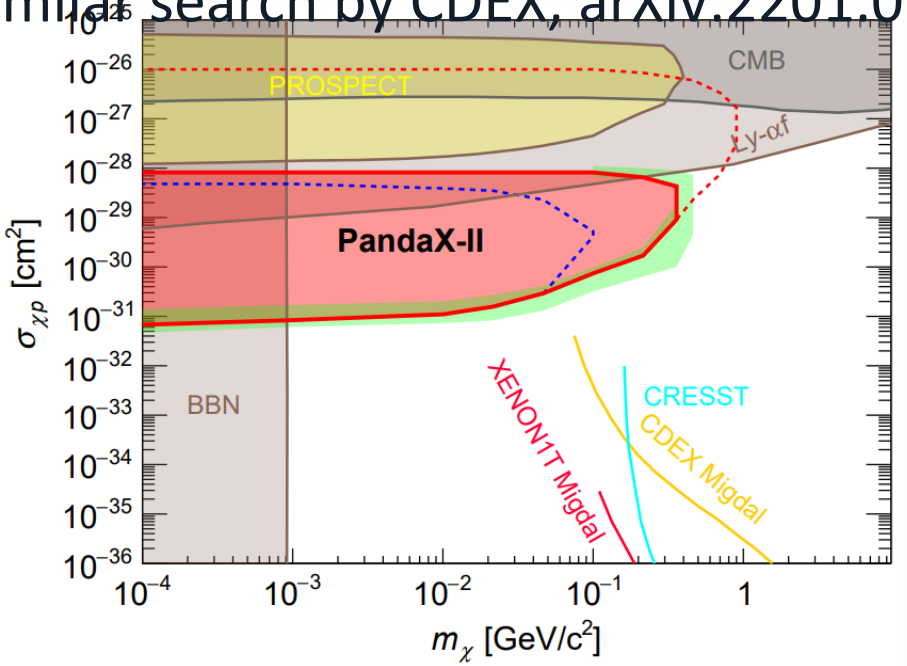


2.14 Cosmic Ray Boosted DM (PandaX, CDEX)



No significant CRDM signal is found above background.

- First diurnal search carried by PROSPECT, PRD 104, 012009 (2021)
- **PandaX: PRL 128, 171801 (2022)**
- Similar search by CDEX, arXiv:2201.01704



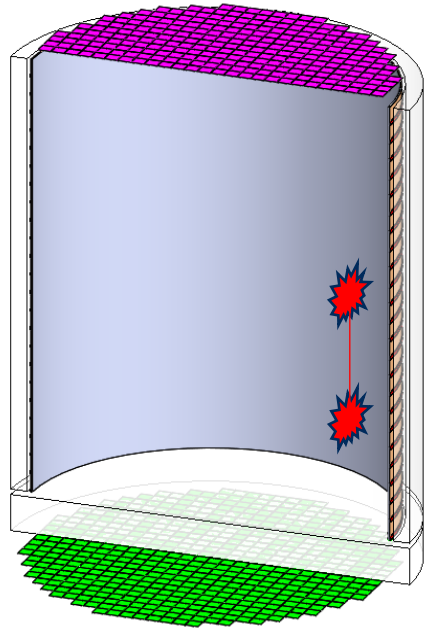
2.15 Heavy DM search (>10 GeV or so, PandaX)

Scalable large detectors in the world:
1) Sanford Lab (at USA): **LZ**, 7 T Xe(active region) ;
2) LNGS (at Italy) : **XENONnT**, 6.5 T Xe (active region) ;
3) CJPLat China) : **PandaX-4T**, 3.7 T Xe (active region).

Material background (gammas/neutrons)

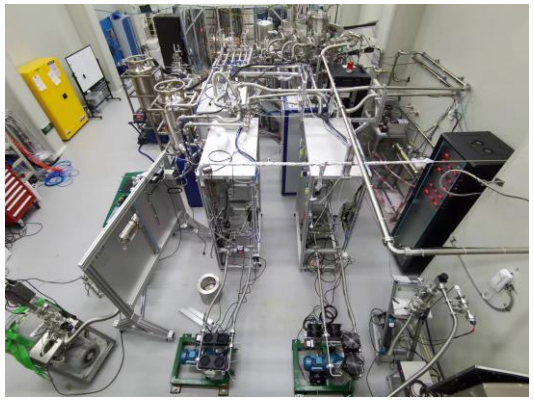
- Cluster @ boundary
- Multi-site
- Low energy scatter deep in target without high E scattering in outskirt further suppressed

⇒ “self-shielding” if reconstruct vertex.



2.16 Pictures of PandaX-4T

Cooling tower and online purifying

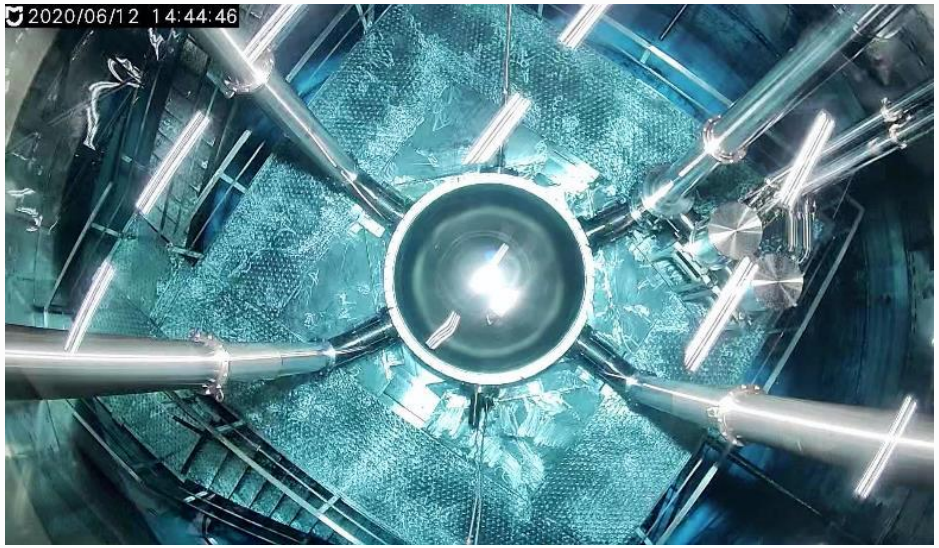


Distillation tower

Infrastructure,

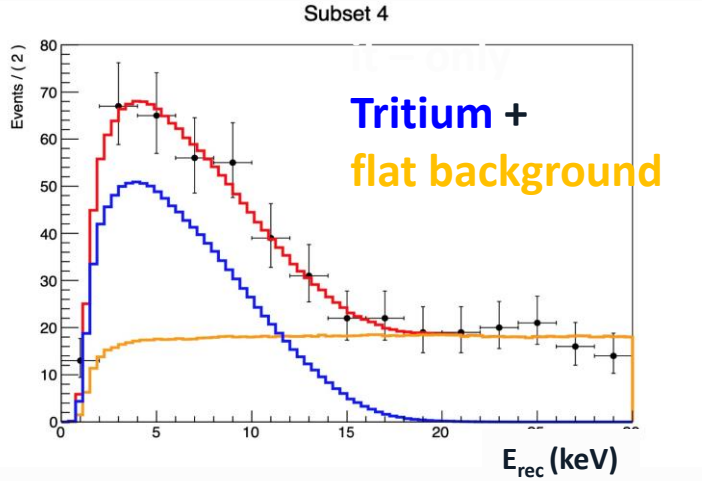
TPC is put in the inner vessel.

Pure water is filled.



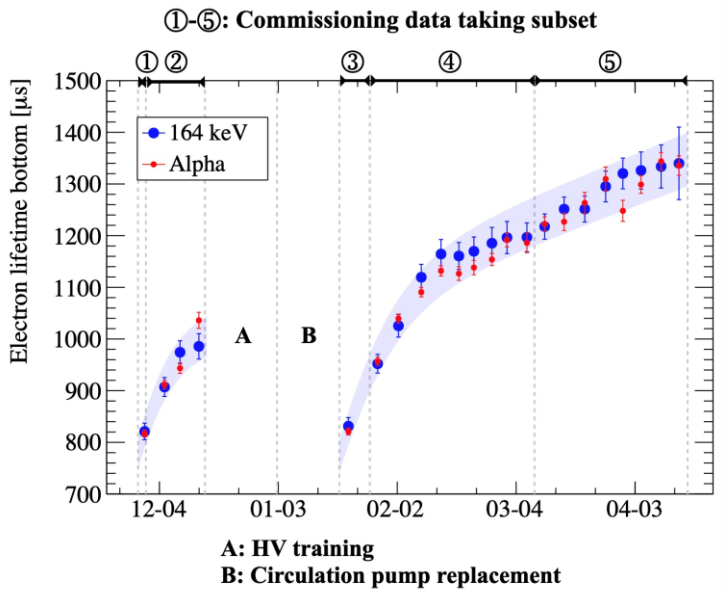
2.17 Dominated background (RUN0) of PandaX-4T

- **Tritium spectrum identified in the data**
- **Likely originated from a tritium calibration at the end of PandaX-II**
- **Level floating in the final dark matter fit: 5(0.3)x10^{-24} (mol/mol)**

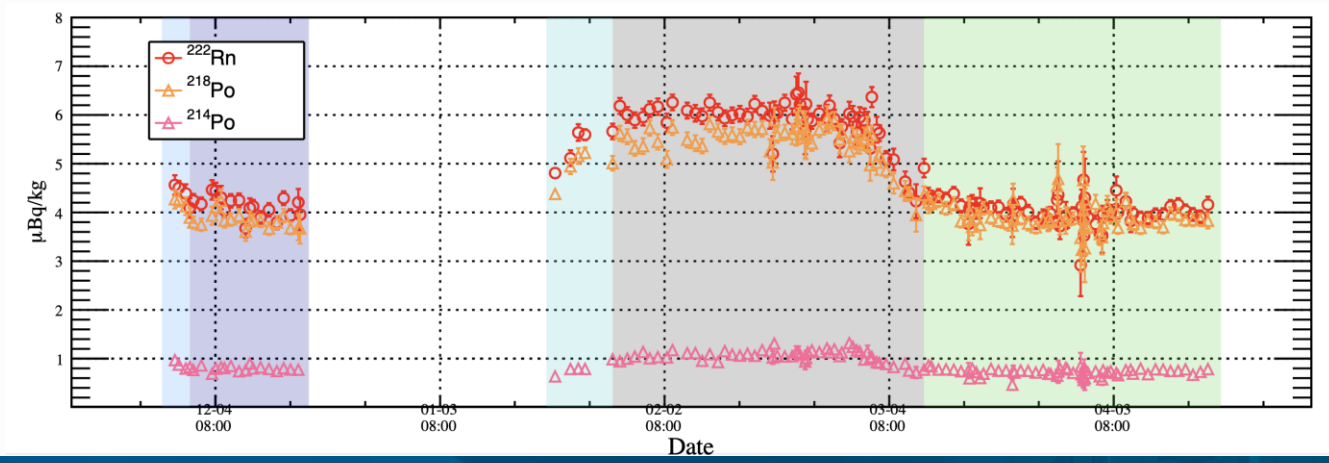


E_lifetime: Max, 1350us

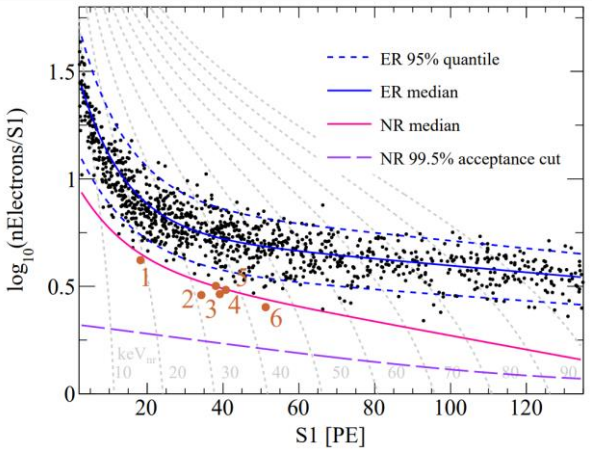
Radon Level: 4.2 uBq/Kg



- Set 3→4: online Kr distillation (10 SLPM)
- Set 4→5: distillation off to reduce Rn emanation from the tower
- Rn level reduced from PandaX-II by 6 times



2.18 Results from RUN0 of PandaX-4T

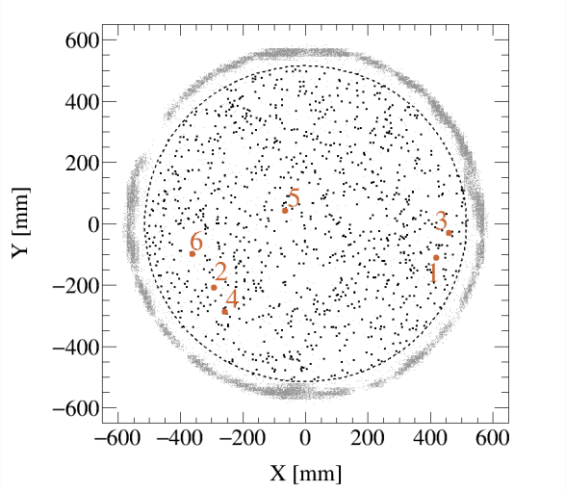


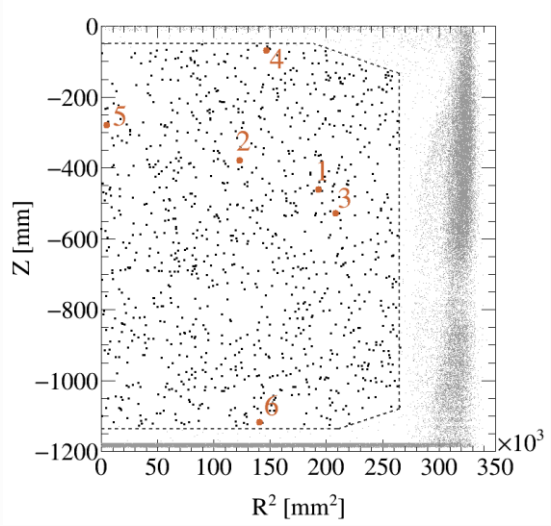
- Events uniformly distributed in the FV, expected if dominated by tritium and radon.
- In FV, 1058 candidates, 6 below NR median line (~-1σ downward fluctuation from expected 9.8 evts)

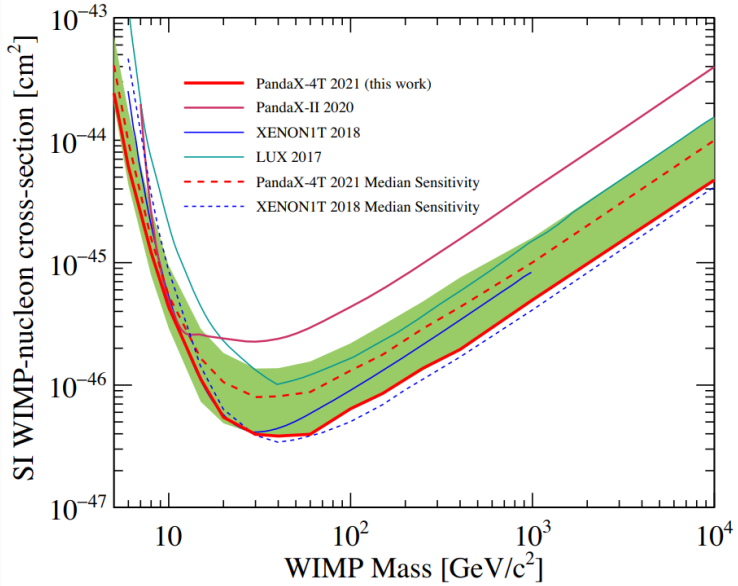
① Exposure: 0.63 tonne•year

② Sensitivity improved from PandaX-II final analysis by 2.6 times (40 GeV/c^2)

③ **Strongest exclusion limit** at that time (downward background fluctuation by -1σ)



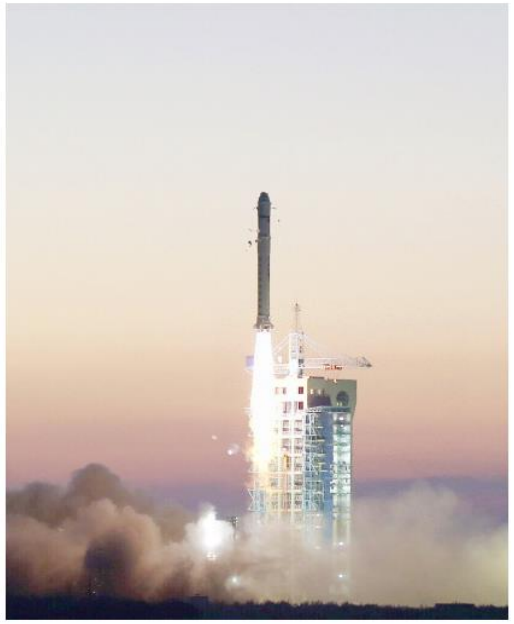


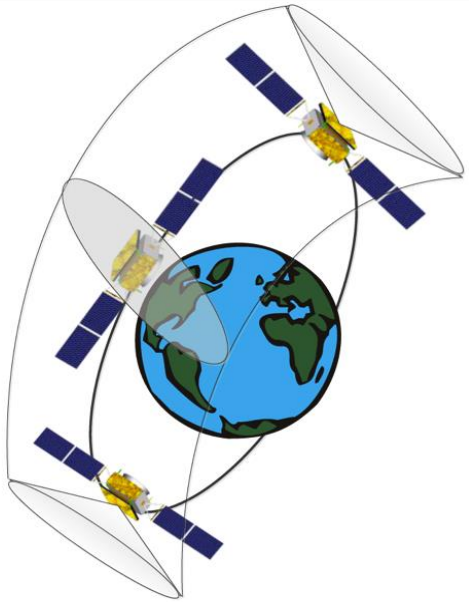


3.1 dark matter indirect detection in space

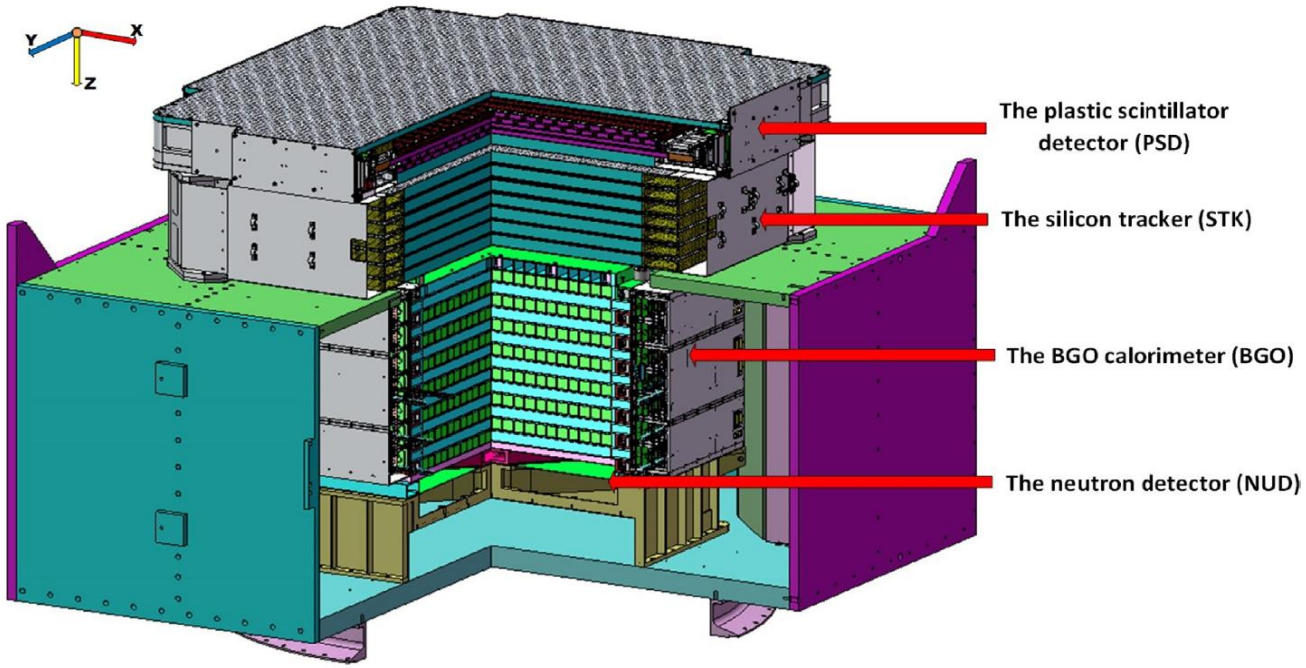
DArk Matter Particle explorer (DAMPE), (“Wukong” Satellite), lanuched on Dec. 17, 2015

- **Altitude: 500 km**
- **Inclination: 97.4°**
- **Period: 95 minutes**
- **Orbit: Sun-synchronous**





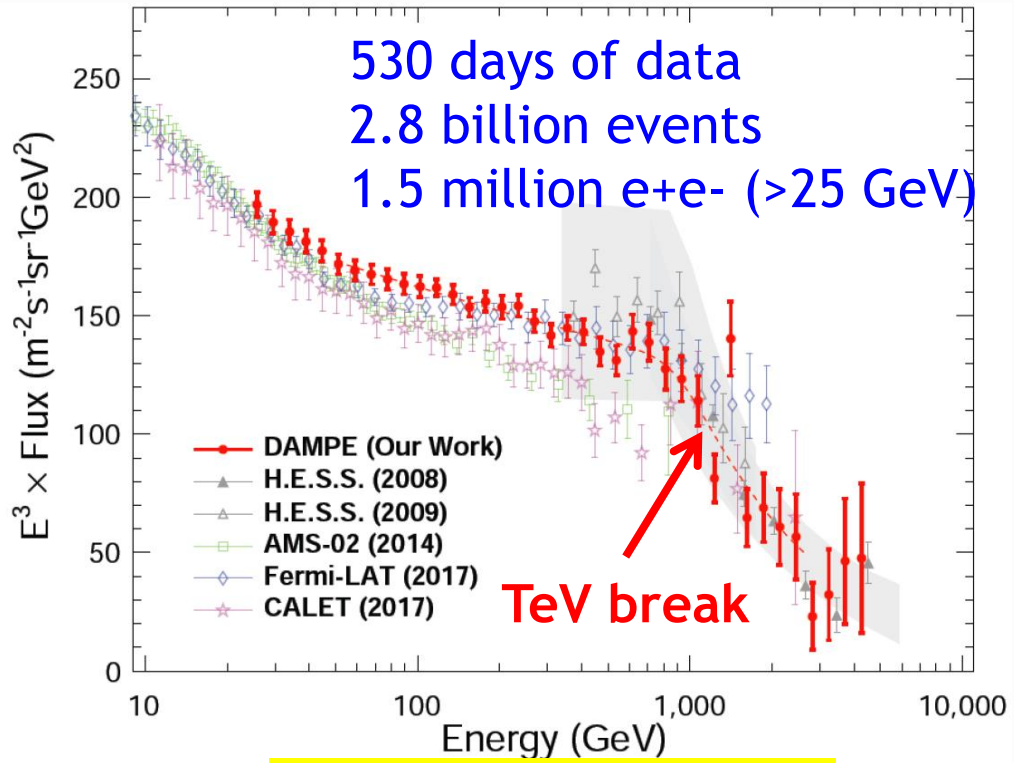
DAMPE detector Structure



3.2 other dark matter indirect experiments (DAMPE)

Results: e^++e^- spectrum

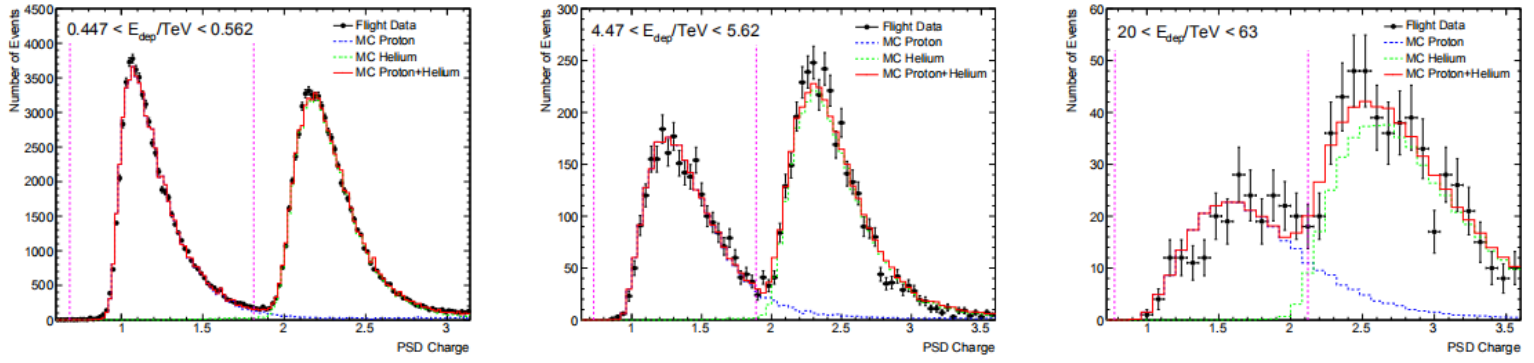
- Three different PID methods give very consistent results on event-by-event level.
- Direct detection of **a spectral break at ~1 TeV** with 6.6σ confidence level
- Analysis with new data is on-going



Nature, 552, 63 (2017)

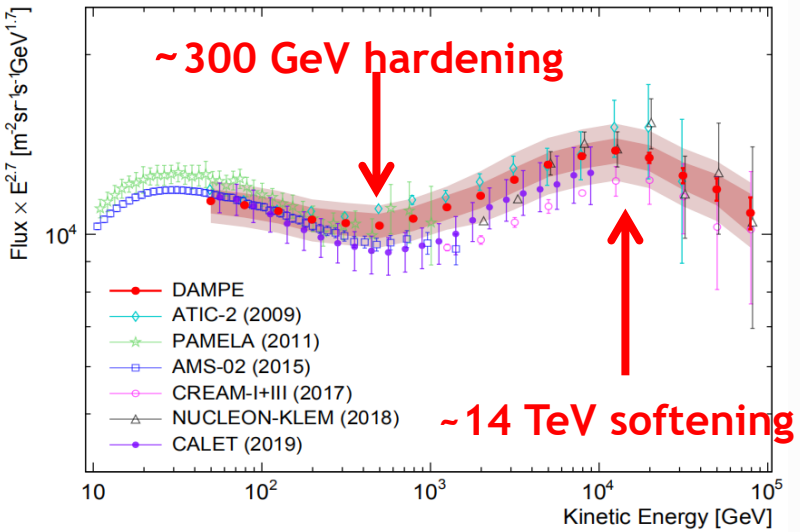
3.3 Proton and Helium spectrum (DAMPE)

- **Proton:** softening at $14^{+4.1}_{-4.8}$ TeV
- **Helium:** softening at $34^{+6.7}_{-9.8}$ TeV
- **A nearly Z-dependent softening**

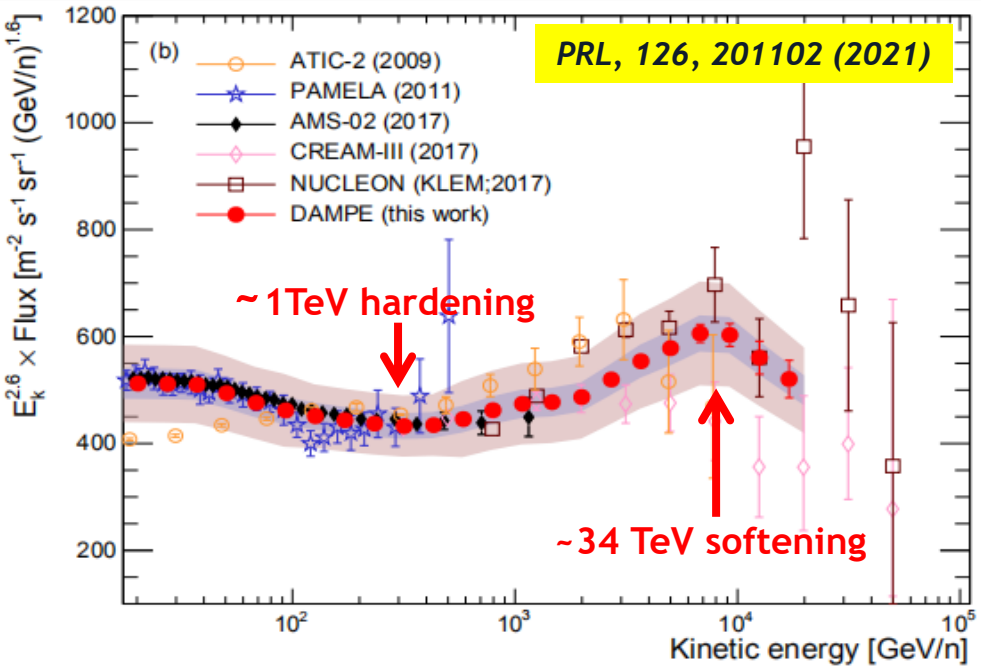


Results: proton spectrum

Science Advances, 5, eaax3793 (2019)



Results: helium spectrum (4.5 years of data)

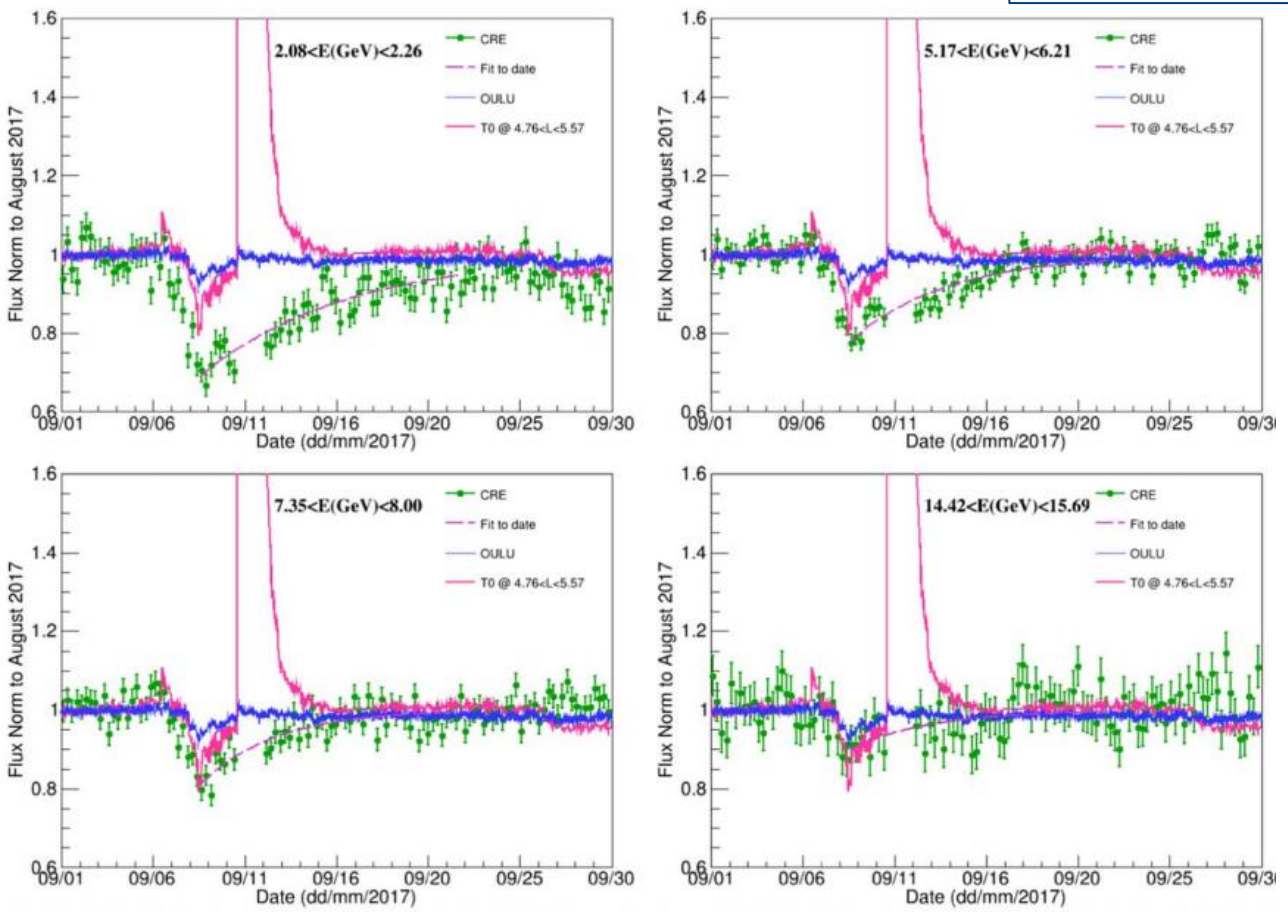


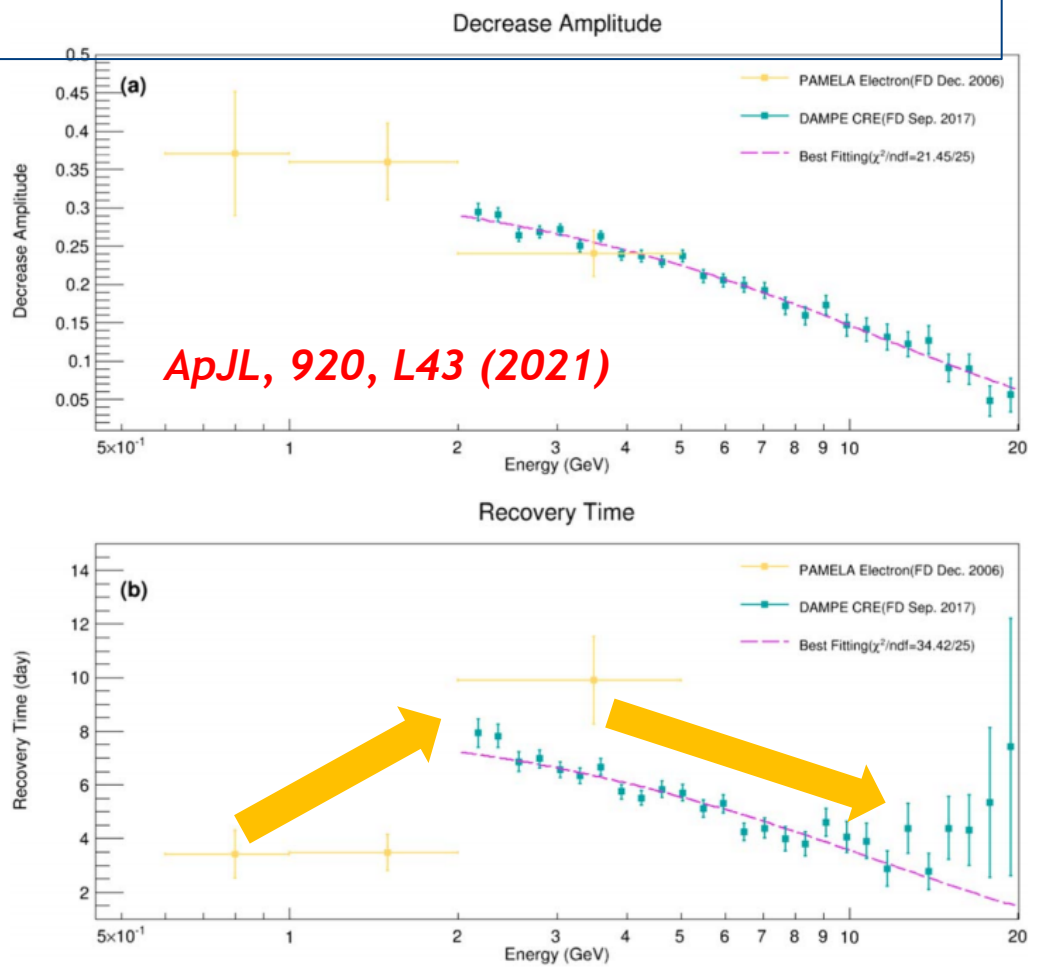
- Hundreds of GeV hardening consistent with previous measurements
- Newly detecting a softening at ~14 TeV with high significance

3.4 Results: Forbush decrease of cosmic ray (DAMPE)

- DAMPE observed the Forbush decrease of cosmic ray e+e- with high precision
- Reveal new features of the recovery time

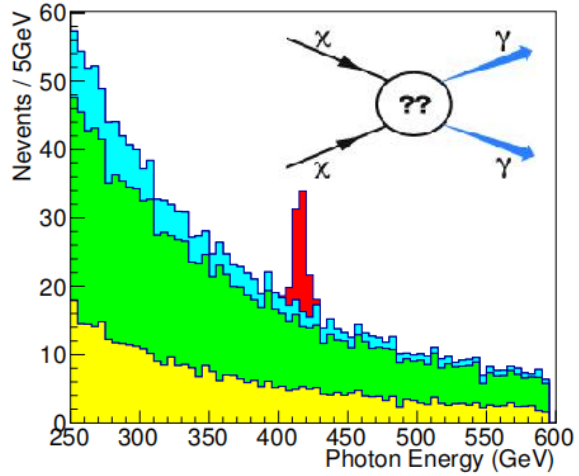
Parker's equation works in the energy of from 2 to 20Gev. It **can not explain** behaviors of the data **at lower or higher energies.**

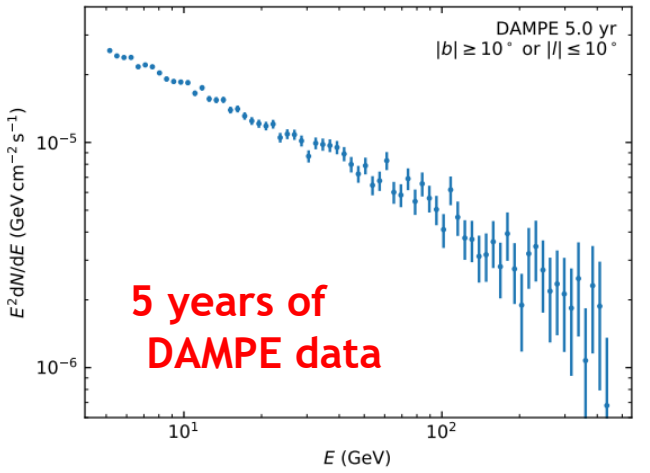


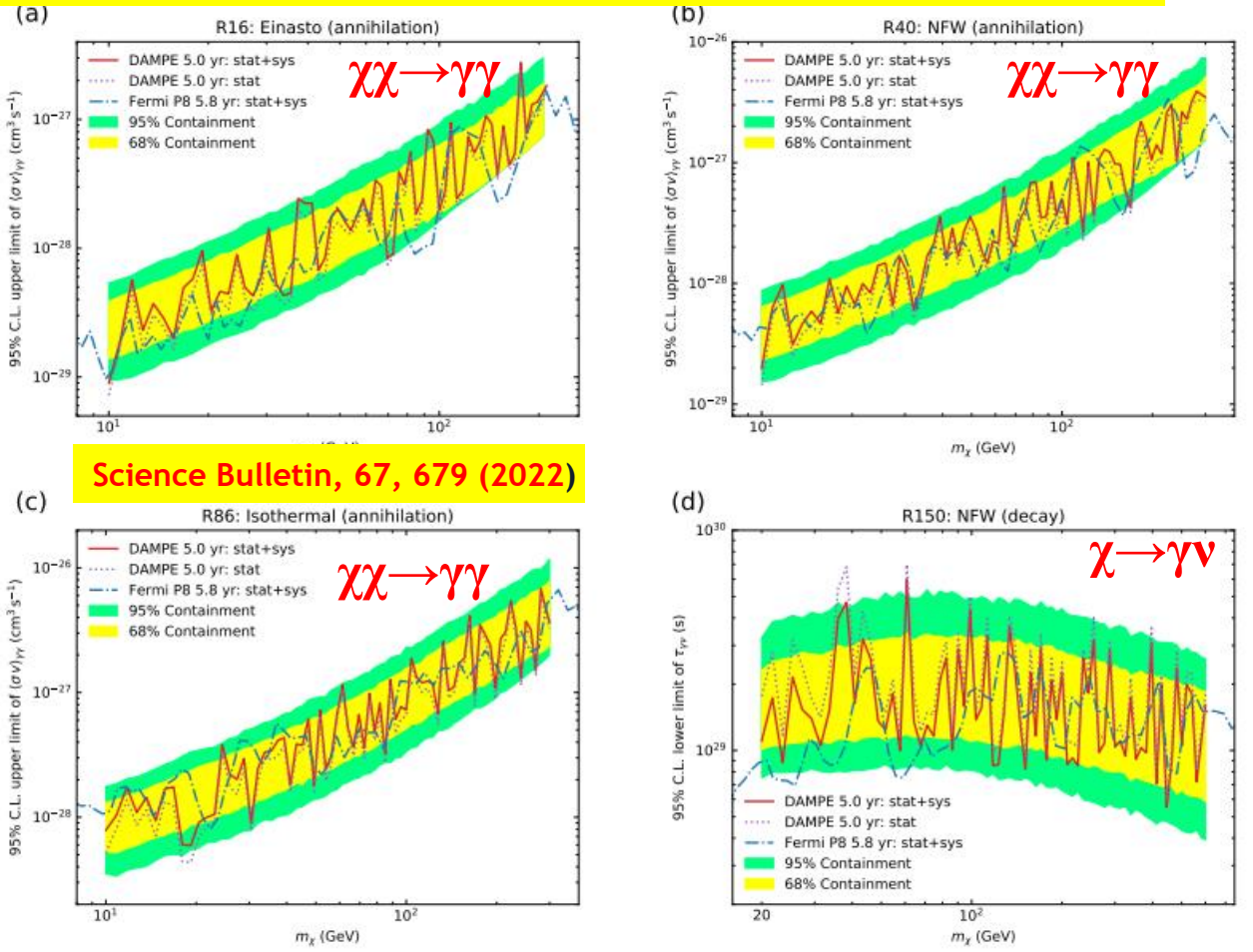


3.5 Results: γ-ray line searches (DAMPE)

1）The model is that Dark matter annihilates into gamma，DAMPE has better energy resolution.
2）Obtain the most stringent constraints on dark matter annihilation cross section or decay lifetime for the mass less than 100 GeV.





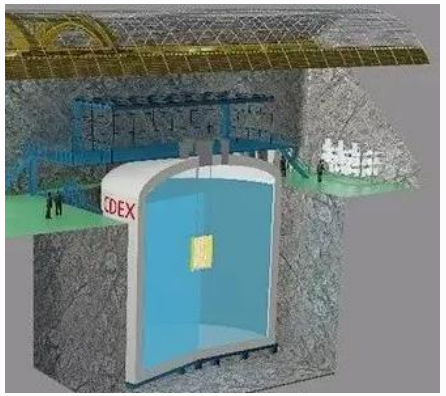


Science Bulletin, 67, 679 (2022)

4 Summary

Dark matter search experiments in **China** were developed quickly in the past ten years, **from underground to space**:

1) Direct detection experiments in deep underground lab (CJPL): **CDEX and PandaX**;
2) Indirect detection in space: **DAMPE**;
3) They achieves **significant detection accuracy** although not finding dark matter particles.



SJTUPA
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Dark Matter search is still hot in China

T H A N K Y O U