Dark Matter Search at Jinping Underground Laboratory

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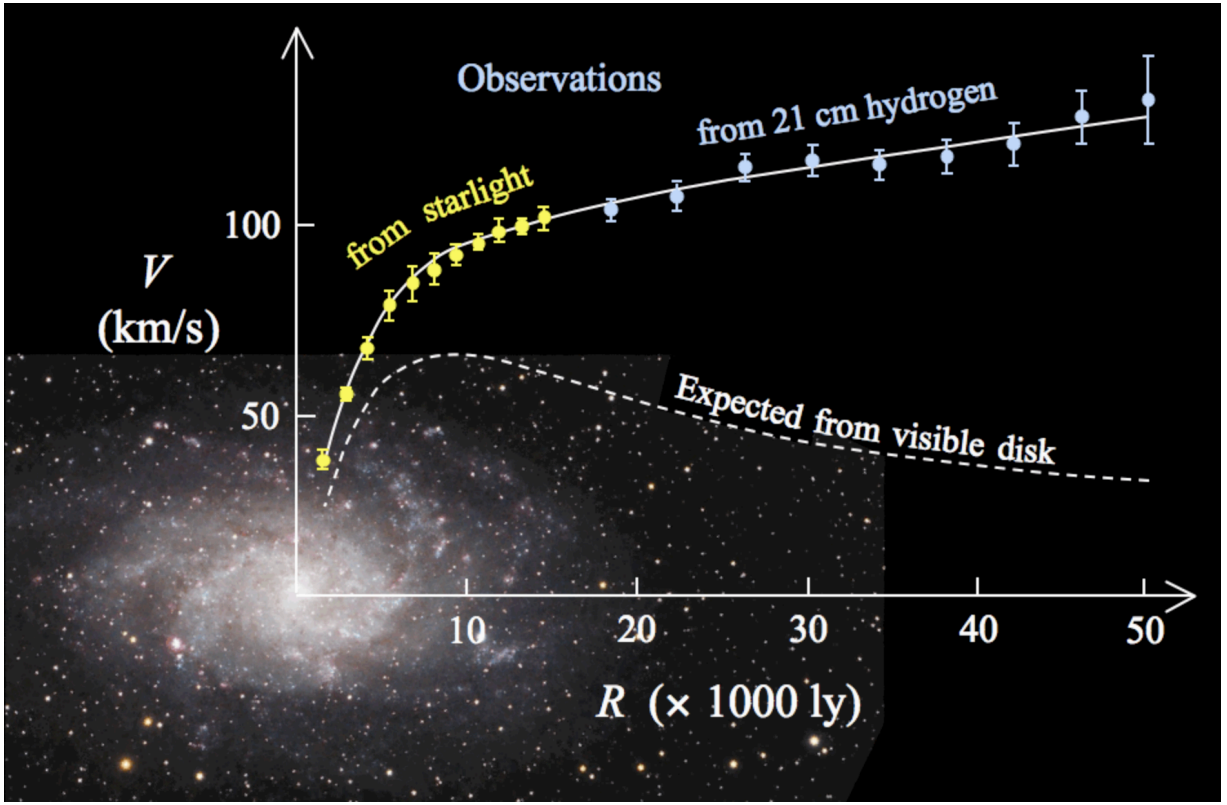
Outline

- Dark matter evidence
- Dark matter detection technologies
- Jinping underground laboratory (CJPL)
- PandaX and CDEX experiments
- Summary

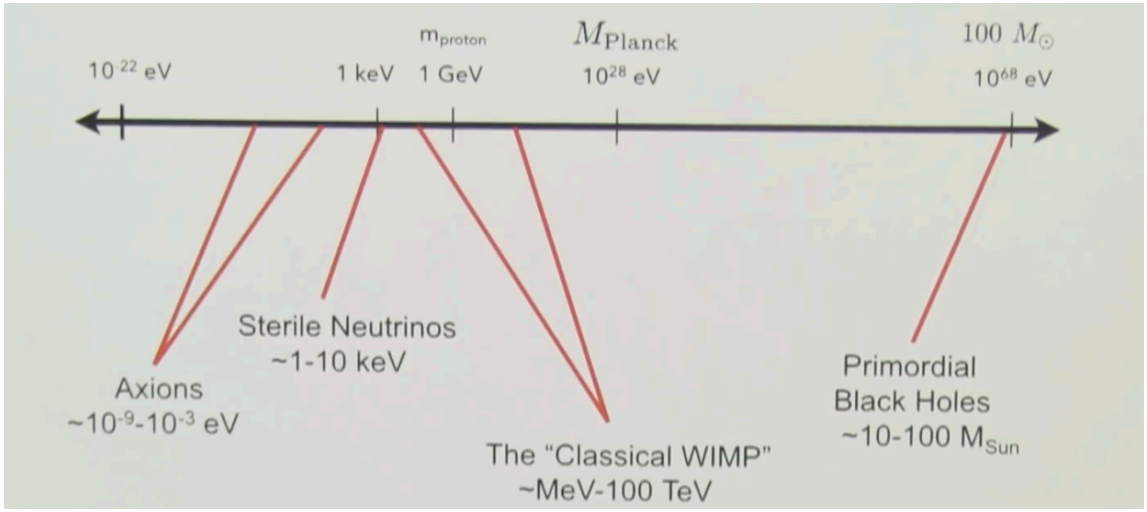
Dark matter evidence

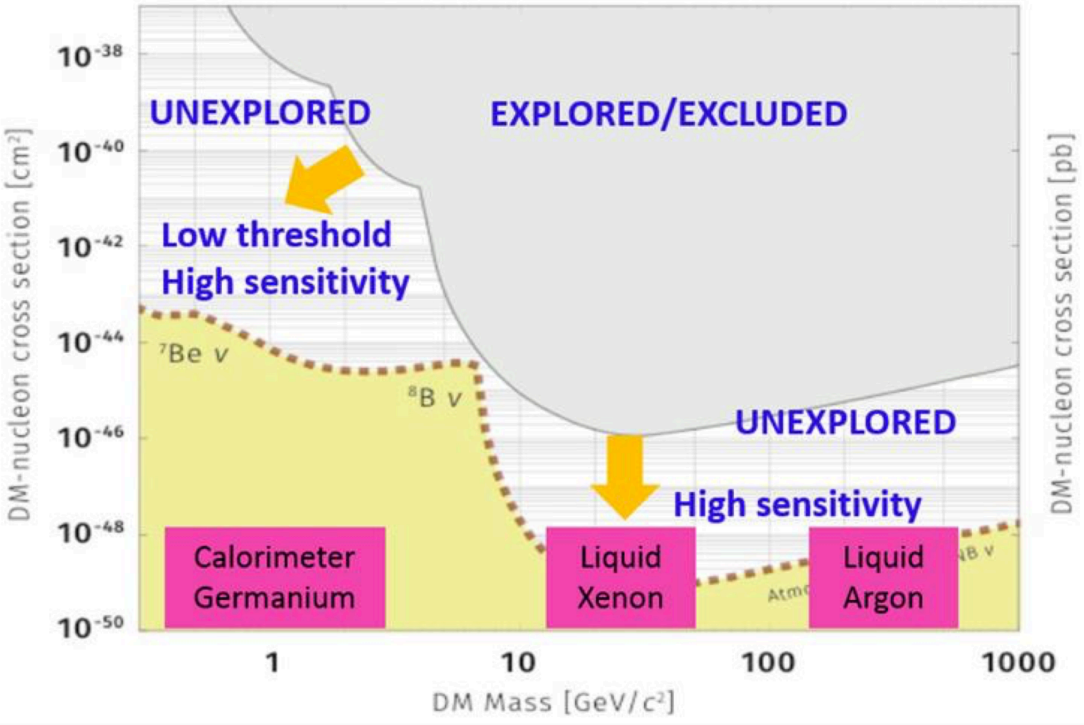
Rotation curve of spiral galaxy M33



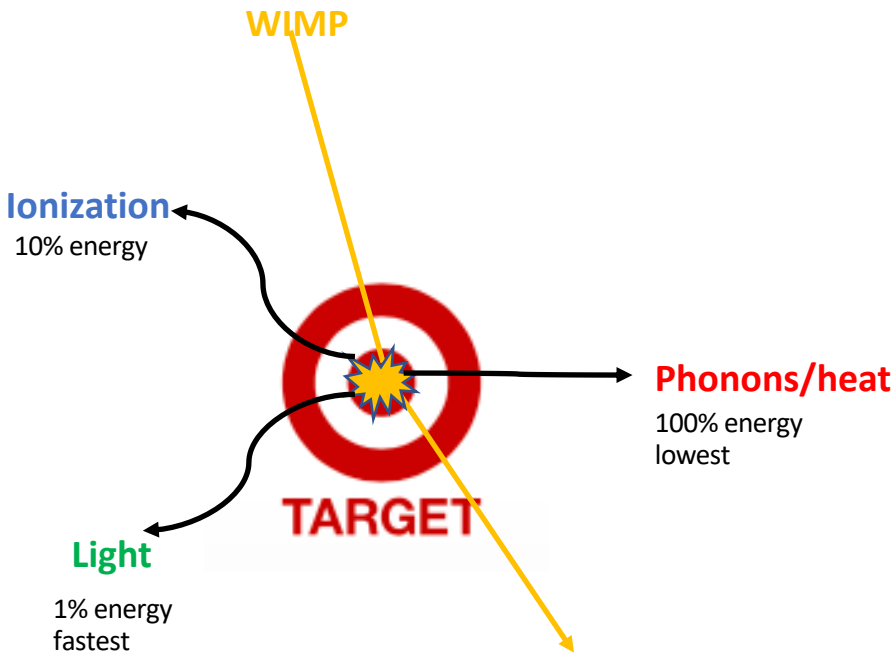
From Wikipedia

The dark matter landscape

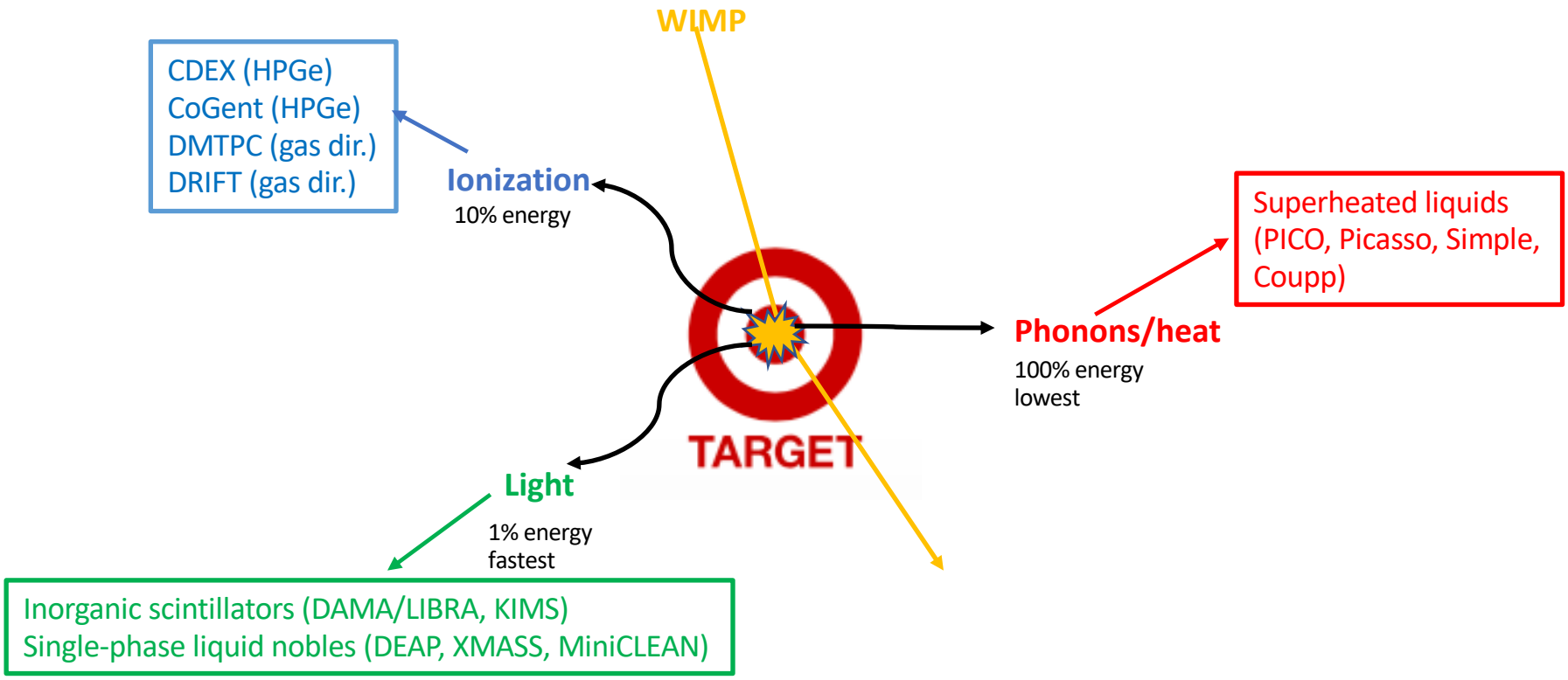




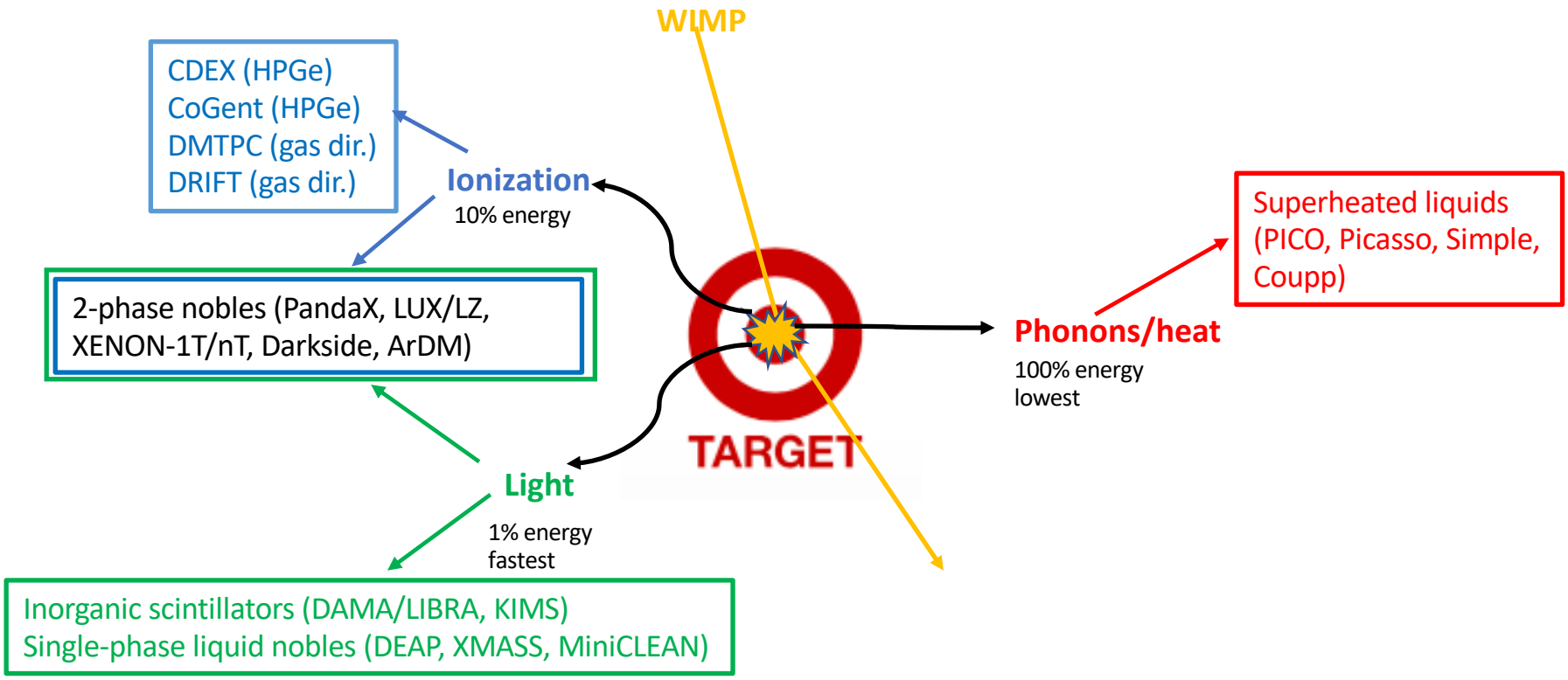
Dark matter detection technologies



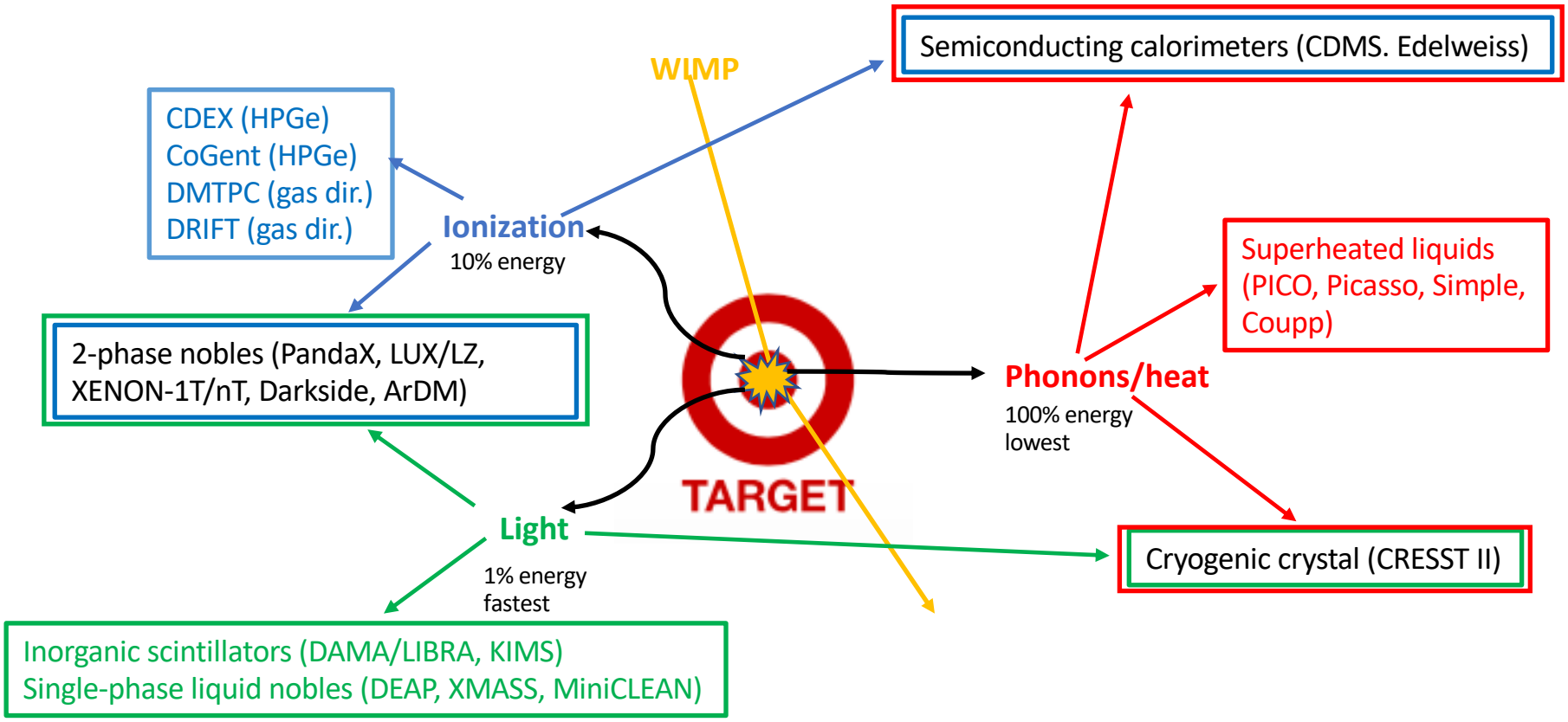
Dark matter detection technologies



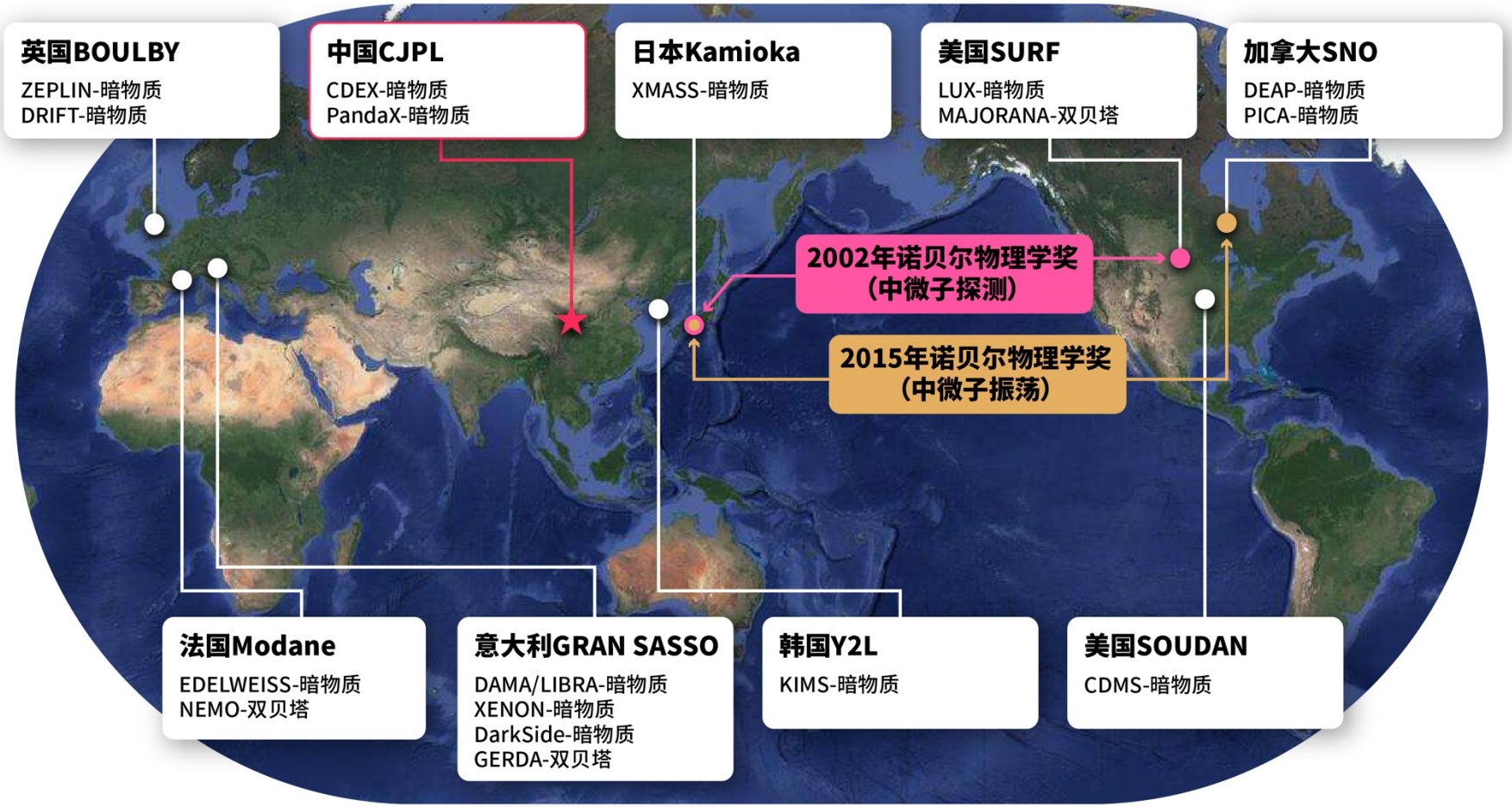
Dark matter detection technologies



Dark matter detection technologies



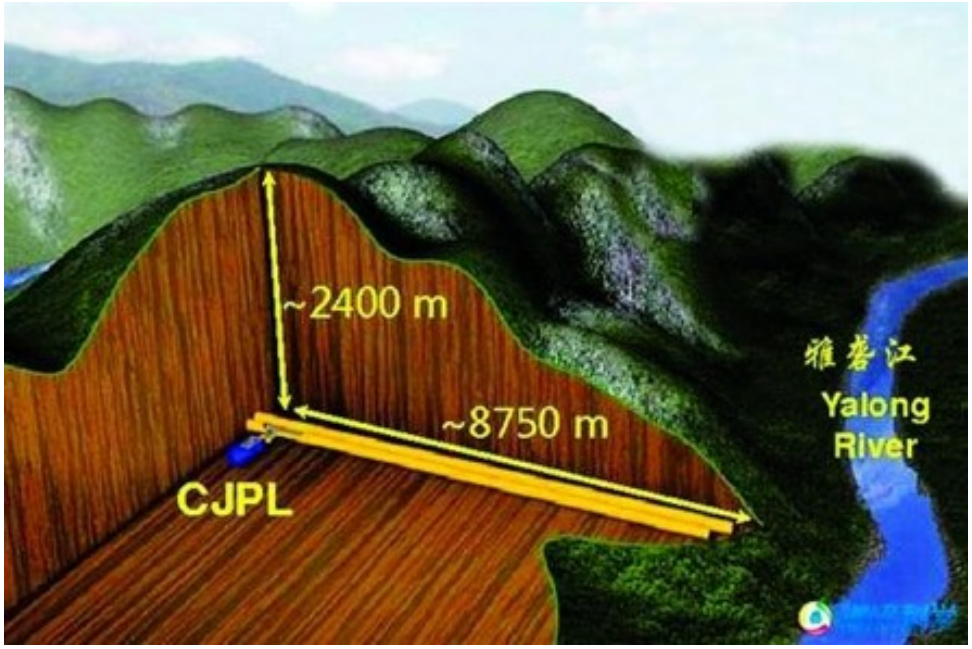
Worldwide underground laboratories

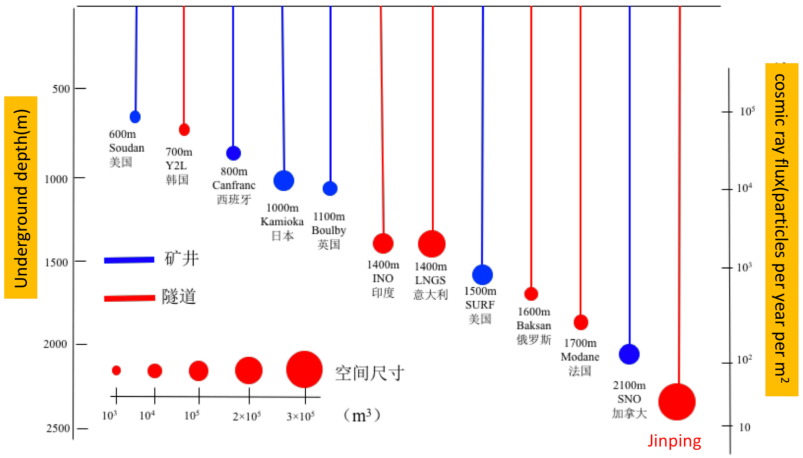


From Hao Ma's slides in China-LRT 2019

China Jinping Underground Laboratory (CJPL)

- Deepest (6800 m.w.e)
- Horizontal access
- **Muon rate: 1 count/week/m^2**





CJPL

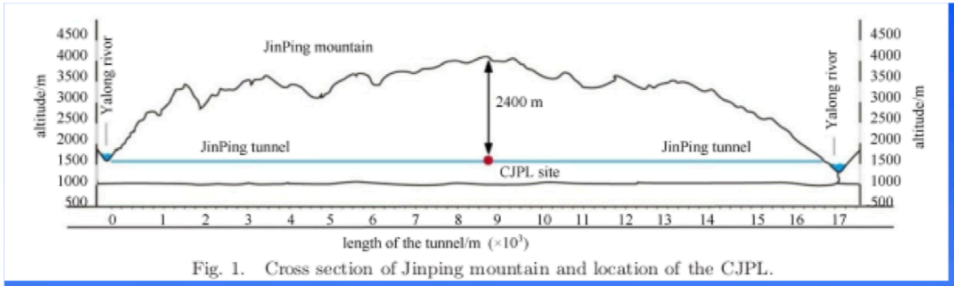


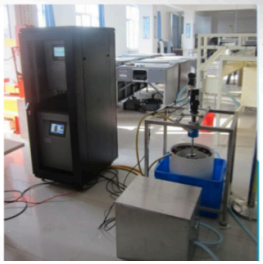
Fig. 1. Cross section of Jinping mountain and location of the CJPL.

CJPL-I

- Space:~4000m^3;
- Experimental hall:7.5 x 6.5 x 40 m;

PandaX

LBF



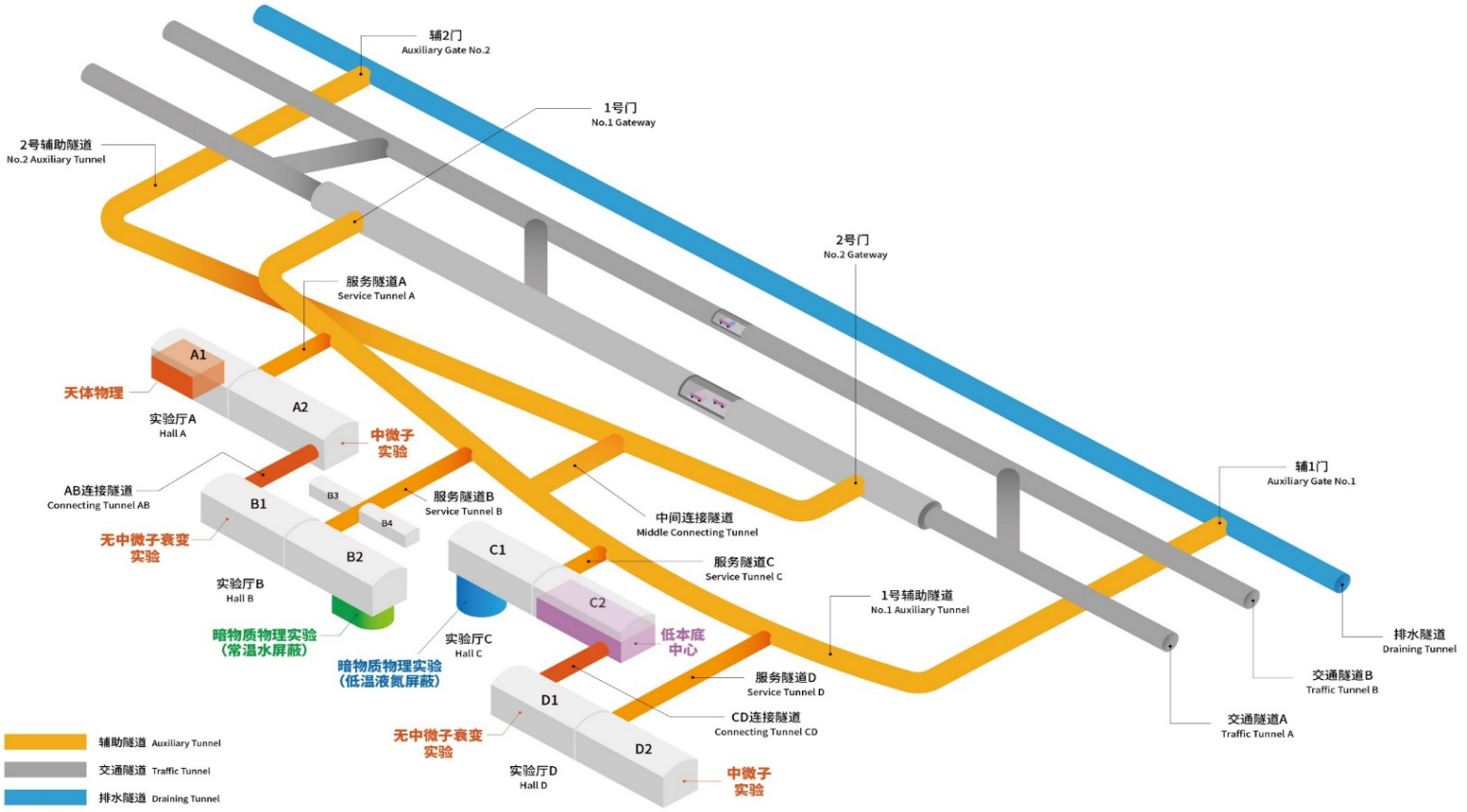
Copper EForming

Prototype of Jinping neutrino experiment

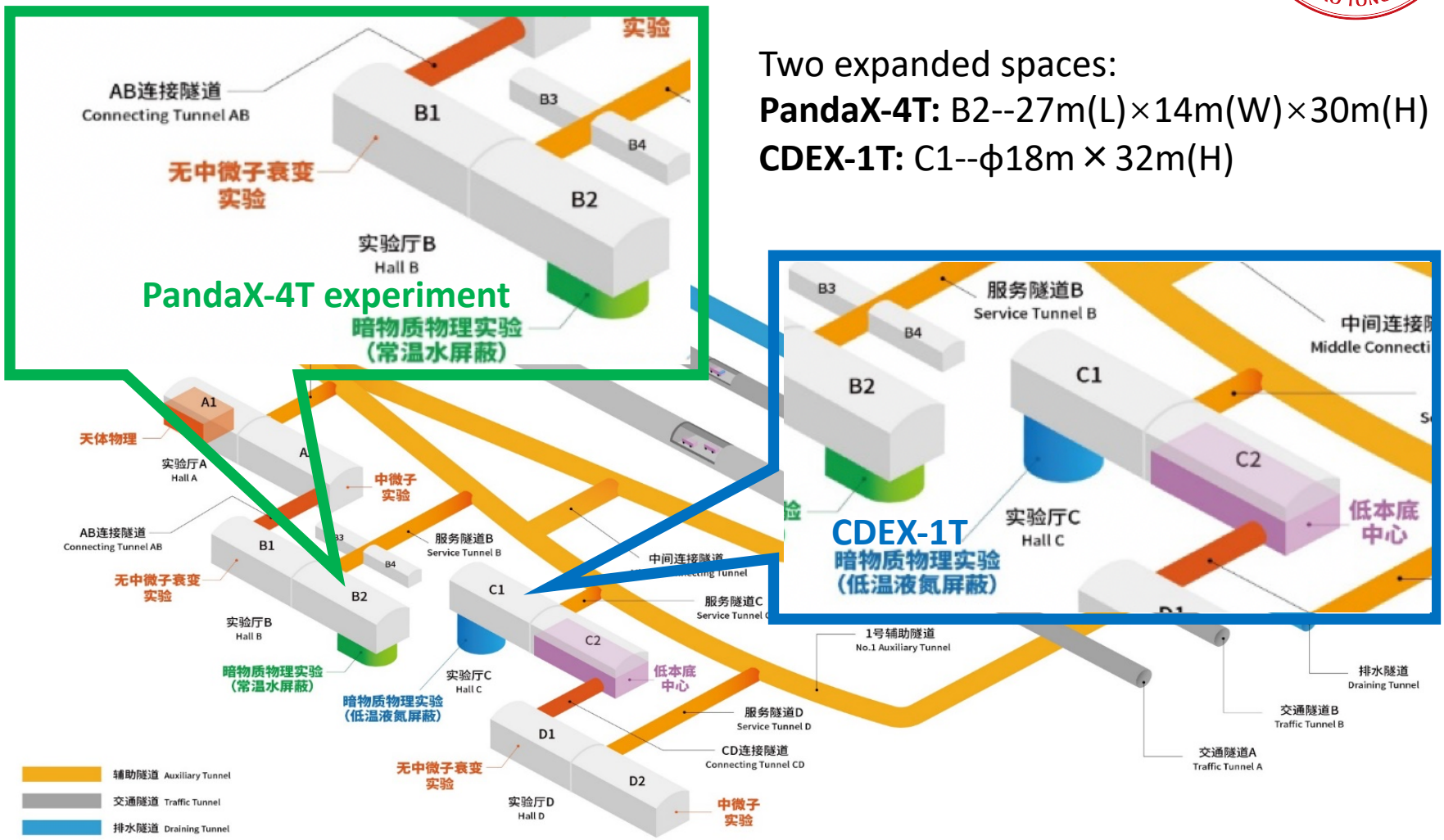
From Hao Ma's slides in Chin LRT 2019

CJPL-II

- 4 main halls: 14m(H)×14m(W)×130m(L)
- Total Volume: 300K m³



PandaX and CDEX experiments



Two expanded spaces:

PandaX-4T: B2--27m(L)×14m(W)×30m(H)

CDEX-1T: C1--ϕ18m × 32m(H)

PandaX experiment

-- Slides from Ning Zhou and Yue Meng

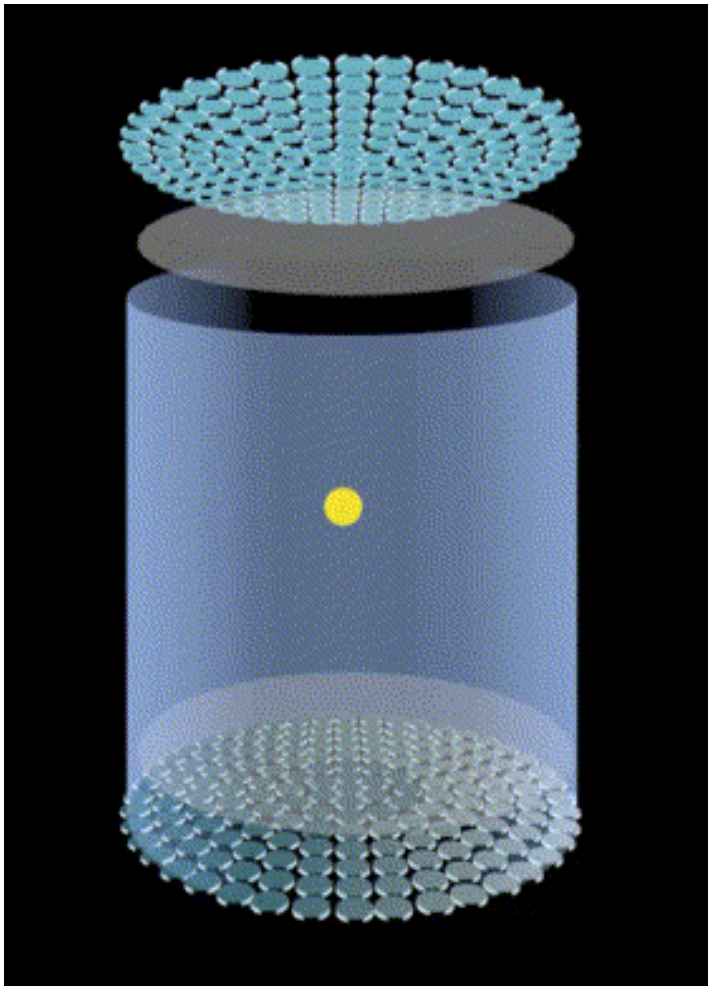
PandaX collaboration

- Particle and Astrophysical Xenon Experiment
  - Formed in 2009, ~50 members

PANDA X

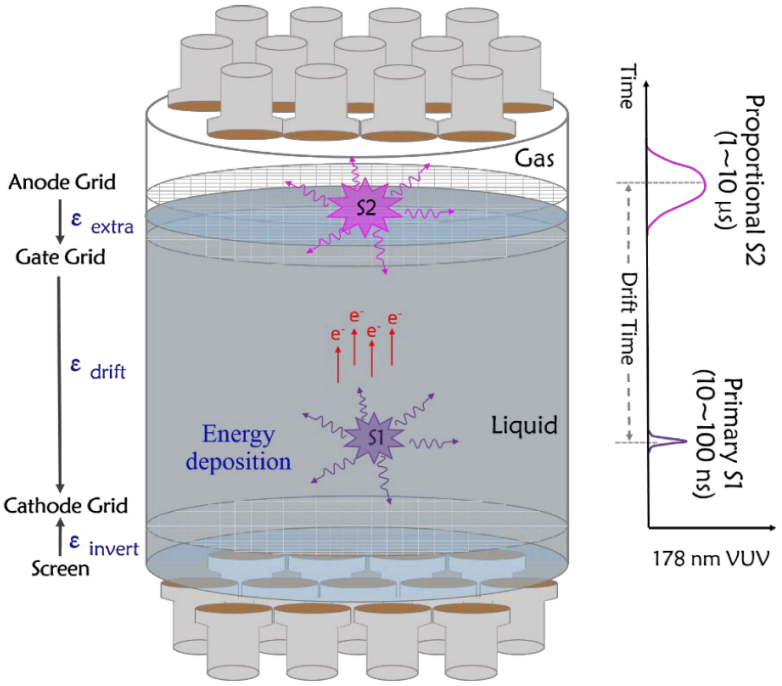
Two-phase TPC techniques

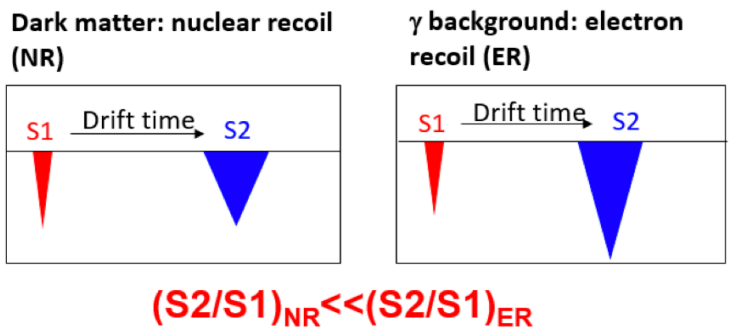
- **High purity Xe target**
- **S1: prompt scintillation signal**
  - High light yield
- **S2: delayed ionization signal**
  - Electroluminescence in vapor phase
  - Sensitive to single ionization electrons

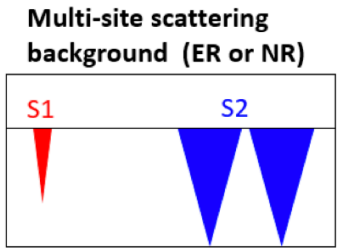


Two-phase TPC techniques

- **S1 + S2 event by event**
  - Electron recoil background rejection by ratio of charge(S2)/light(S1)
- **3D event reconstructions**
  - Z position from S1-S2 drift time
  - X-Y positions from S2 light pattern
  - reject external background

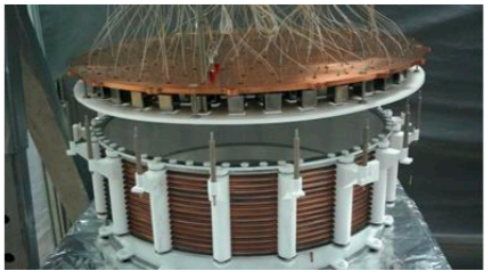




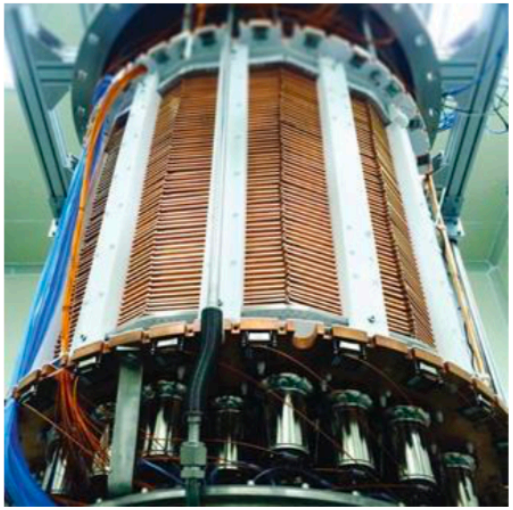


PandaX roadmap

- series of experiments base on xenon, searching for dark matter with dual-phase time project chamber (TPC)



PandaX-I
120kg Liquid xenon
(2009-2014)



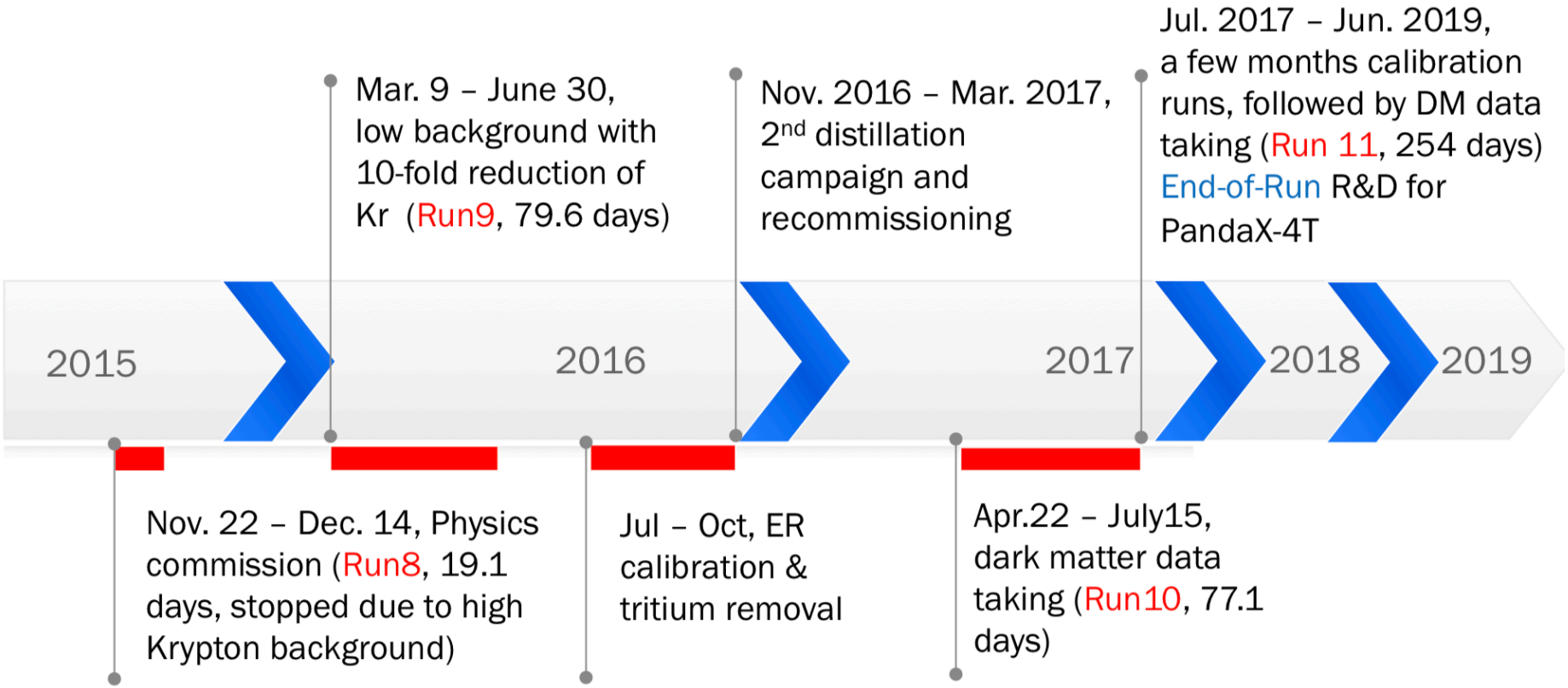
PandaX-II:
580kg Liquid xenon
(2014-2019.6)

PandaX-4T:
4ton LXe
(future)

PandaX-II onsite

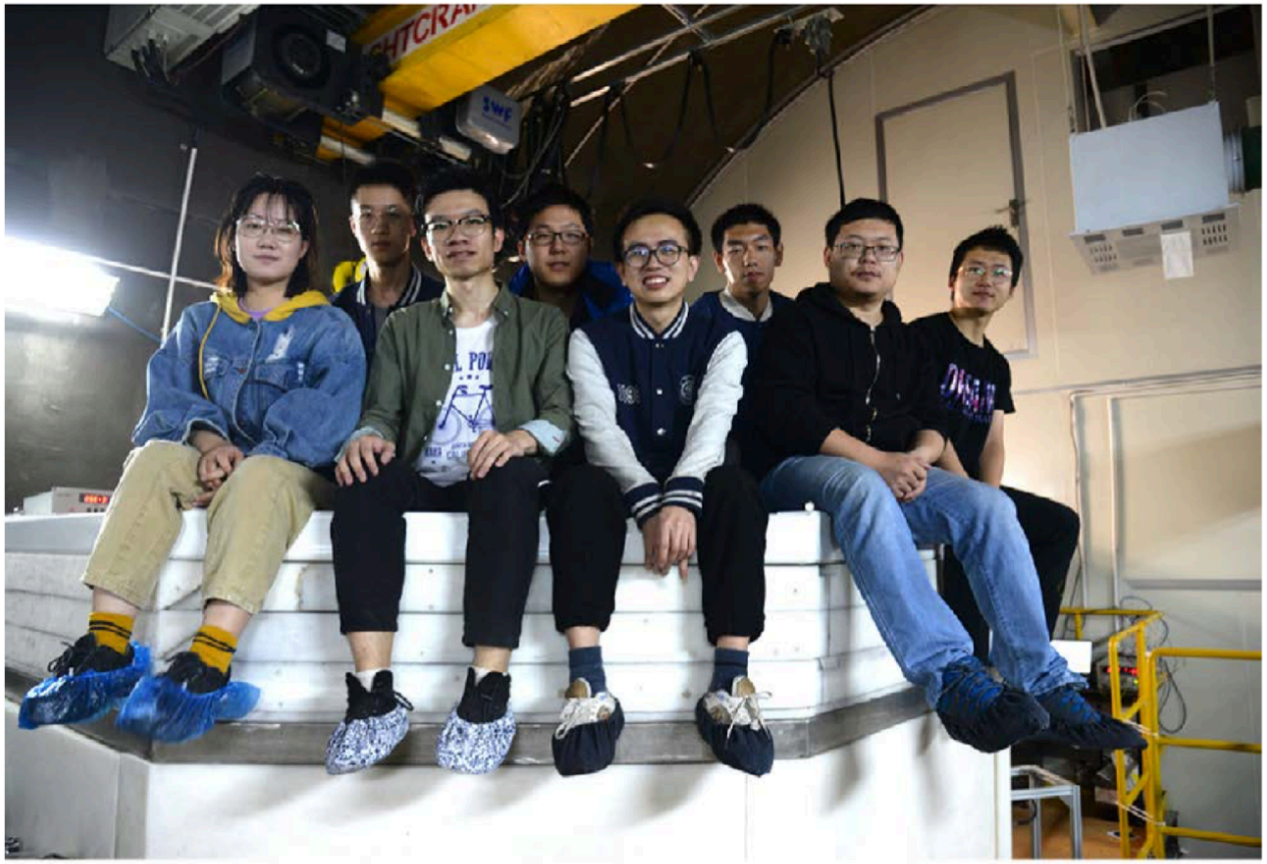
PandaX-II experiment history

- Run 9: 79.6 days, exposure 26.2 ton-day
- Run 10: 77.1 days, exposure 27.9 ton-day
- Run 11: ~254 days, exposure ~92 ton-day



PandaX-II wrap-up

- 2019.06 “End-of-Run” completed
  - 1.16 ton of liquid xenon recuperated

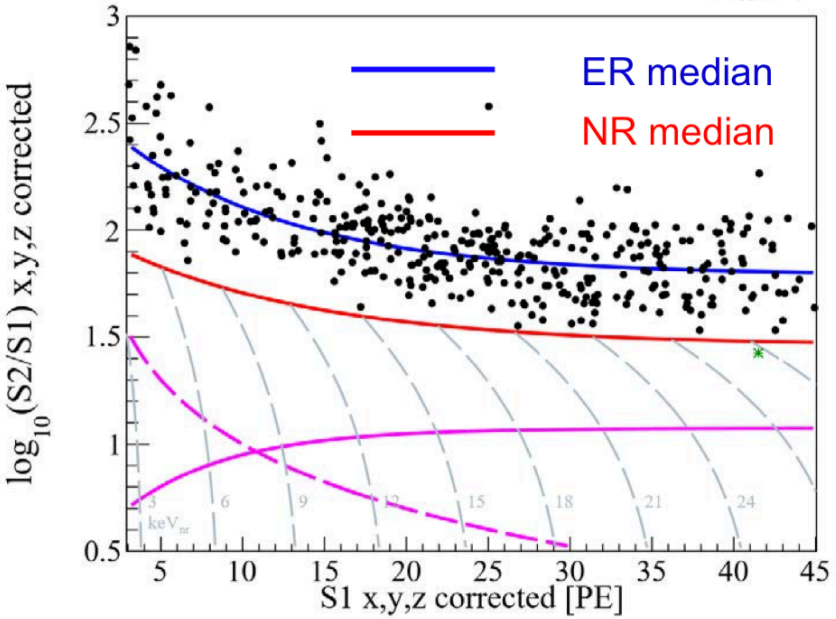


Highlight of PandaX-II results

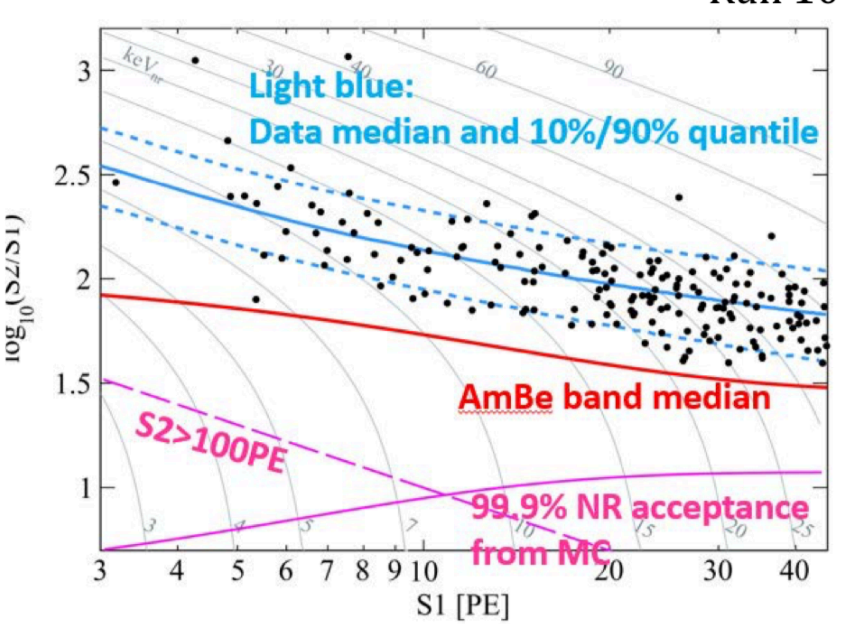
Models	Dataset	Publications
WIMP-nucleon Spin-independent	33 ton-day	PRL 117, 121303 (2016)
WIMP-nucleon Spin-dependent	33 ton-day	PRL 118, 071301 (2017)
Inelastic Scattering	27 ton-day	PRD 96, 102007 (2017)
Axion and ALP	27 ton-day	PRL 119, 181806 (2017)
Spin-Independent	54 ton-day	PRL 119, 181302 (2017)
DM models with light mediator (*)	54 ton-day	PRL 121, 021304 (2018)
EFT models and Spin-dependent (*)	54 ton-day	PLB 792, 193-198 (2019)
$0\nu2\beta$ decay with ^{136}Xe	8.1 ton-day	arXiv: 1906.11457

PandaX-II 54-ton-day data

- Run 9



Run 10

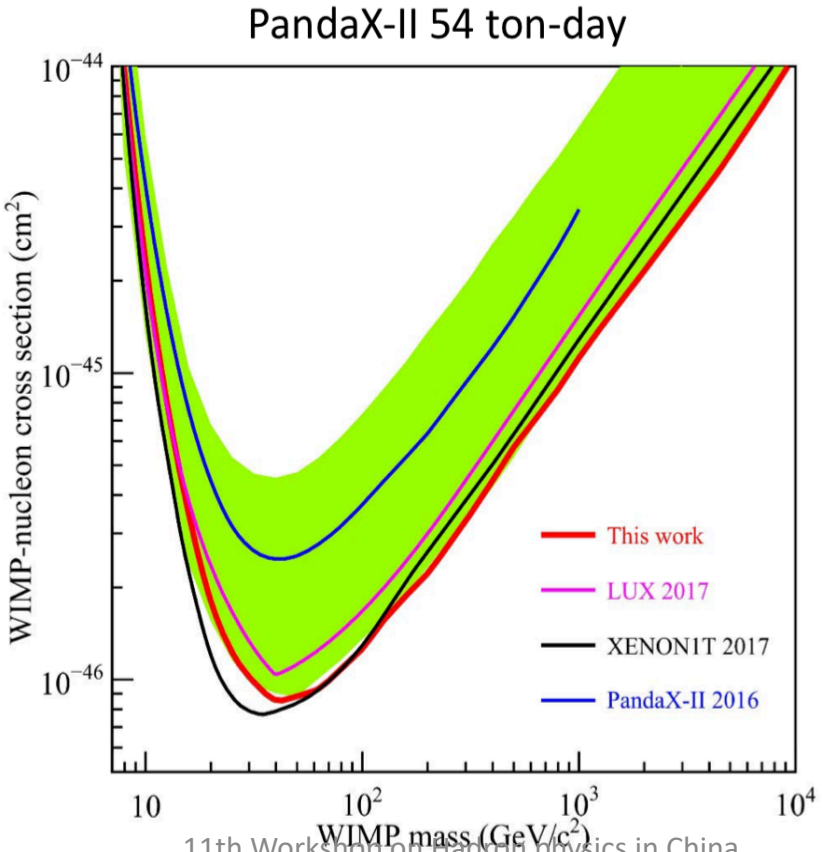


Item	Run 9 (mDRU)	Run 10 (mDRU)
^{85}Kr	1.19 ± 0.20	0.20 ± 0.07
^{127}Xe	0.42 ± 0.10	0.021 ± 0.005
^{3}H	0	0.27 ± 0.08
^{222}Rn	0.13 ± 0.07	0.12 ± 0.06
^{220}Rn	0.01 ± 0.01	0.02 ± 0.01
ER (material)	0.20 ± 0.10	0.20 ± 0.10
Solar ν	0.01	0.01
^{136}Xe	0.0022	0.0022
Total	1.96 ± 0.25	0.79 ± 0.16

	ER	Accidental	Neutron	Total Fitted	Total Observed
Run 9	376.1	13.5	0.85	390 ± 50	389
Below NR median	2.0	0.9	0.35	3.2 ± 0.9	1
Run 10	172.2	3.9	0.83	177 ± 33	177
Below NR median	0.9	0.6	0.33	1.8 ± 0.5	0

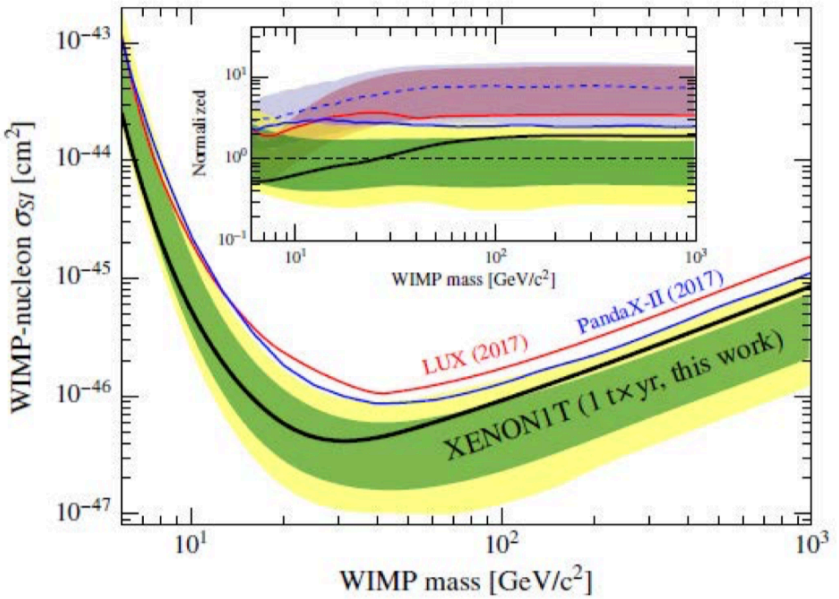
Spin-independent WIMP-nucleon

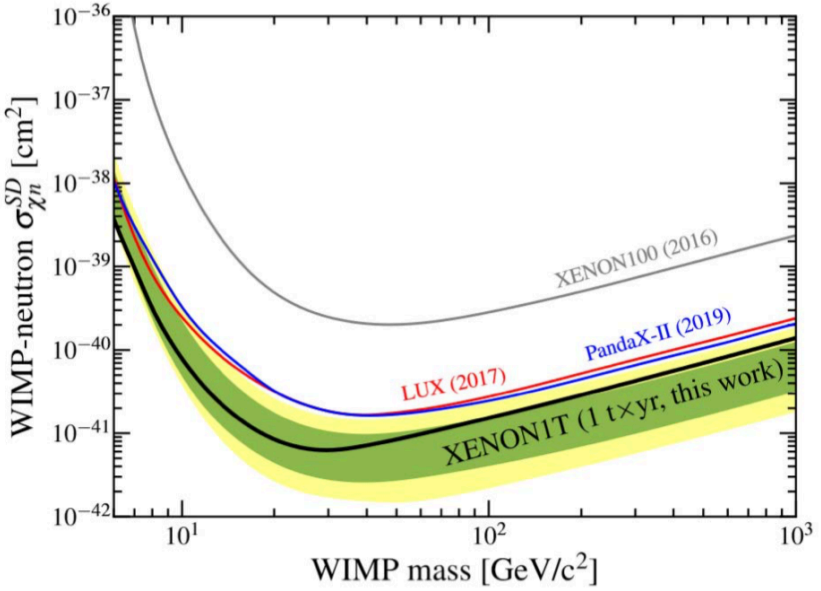
- Improved from PandaX-II 2016 limit about x2.5 at high masses
- Lowest exclusion at $8.6 \times 10^{-47}\text{cm}^2$ at 40GeV, most stringent for $m_\chi > 100$ GeV when published



Dark matter search campaign

- LUX, XENON and PandaX: dual-phase xenon detectors
- Push the SI and SD limits down further



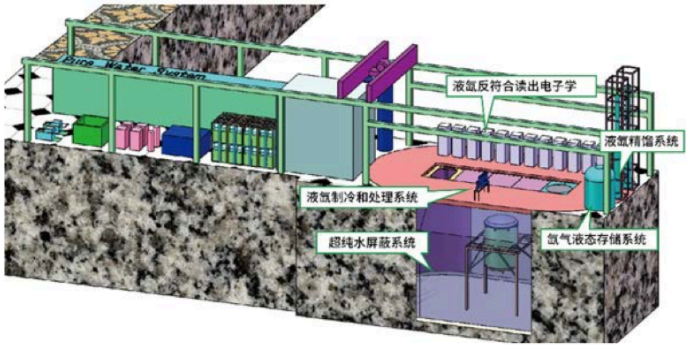


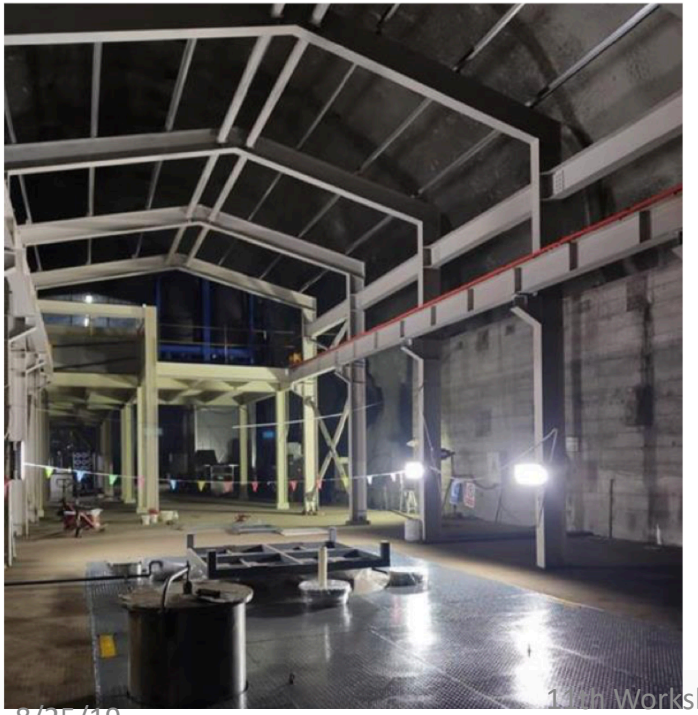
Spin-independent:
LUX, PRL 118, 021303 (2017)
PandaX-II, PRL 119, 181302 (2017)
XENON1T, PRL 121, 111302 (2018)

Spin-dependent:
LUX, PRL118, 251302 (2017)
PandaX-II, PLB 792, 193–198 (2019)
XENON1T, PRL 122, 141301 (2019)

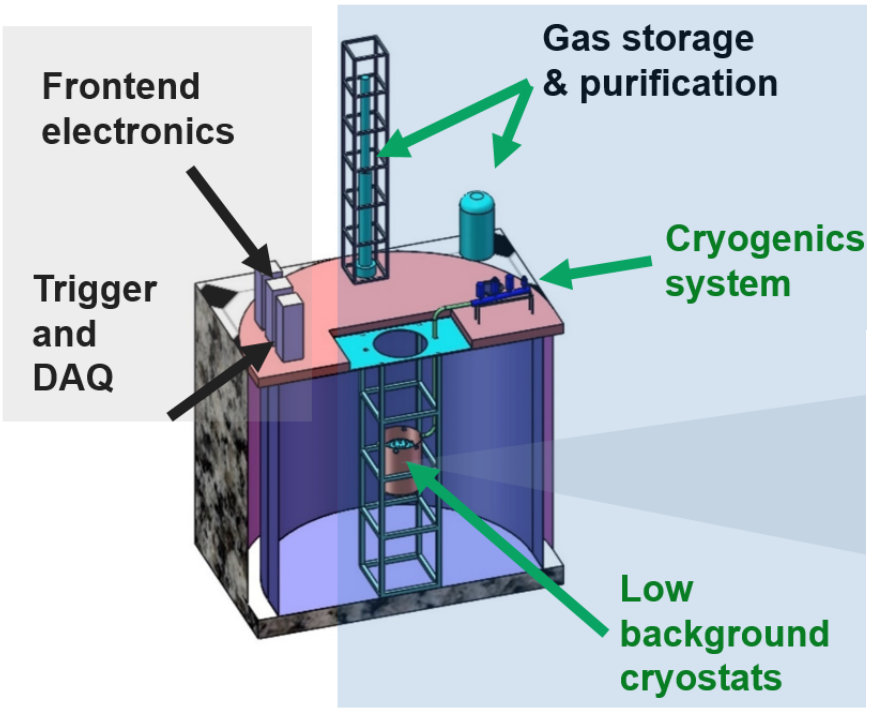
Experimental hall for PandaX-4T

- B2 Hall: 14m(H)x14m(W)x65m(L)
- Water Shielding
  - $900m^3$ pure water
  - $^{238}U/^{232}Th/^{40}K$ <2μBq/kg
  - ^{222}Rn < 2μBq/kg



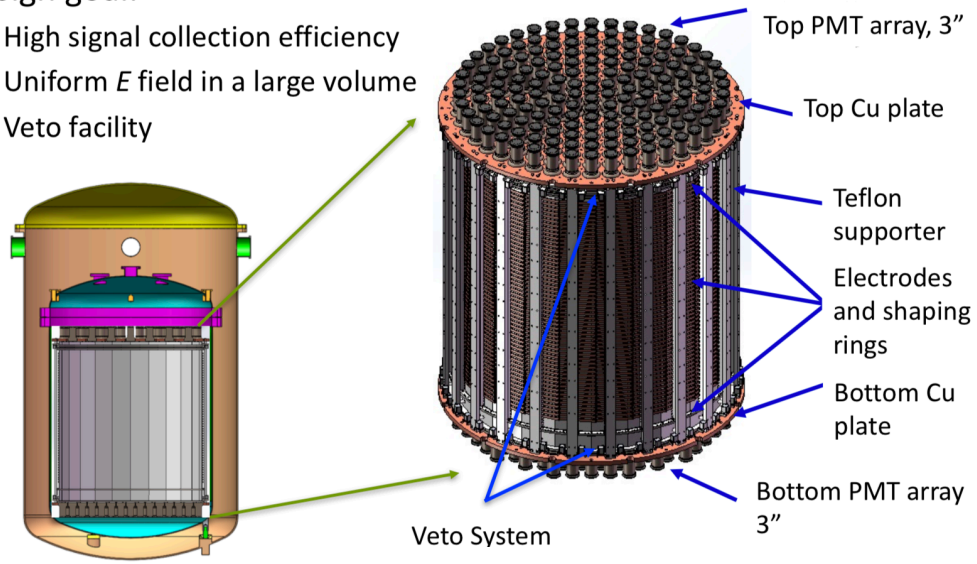


PandaX-4T experiment



Design goal:

- High signal collection efficiency
- Uniform *E* field in a large volume
- Veto facility



– PandaX-4T(4-ton LXe in sensitive volume)
– SI sensitivity ~ 10^{-47} cm^2 with 2 years’ run
– On-site assembly and commissioning: 2019-2020

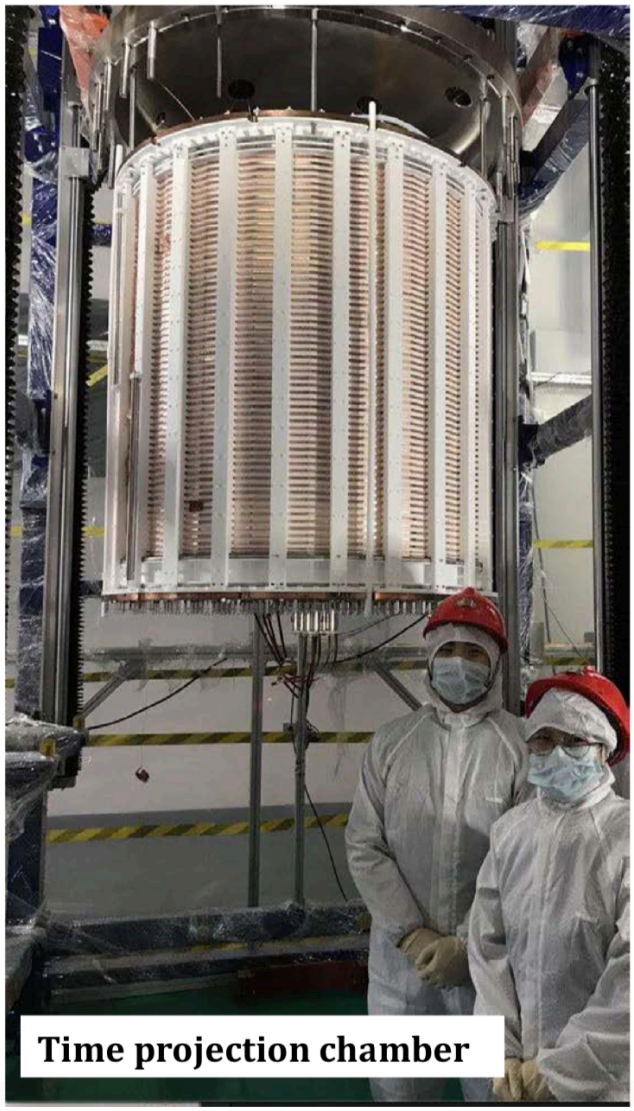
TPC Drift region: Φ~1.2m, H ~1.2m

PandaX-4T TPC and cryostats

PandaX-4T experiment

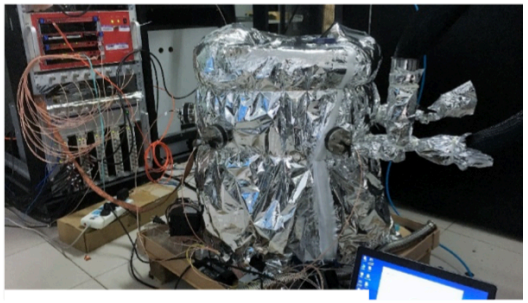
Cooling bus

Cryostat Vessels

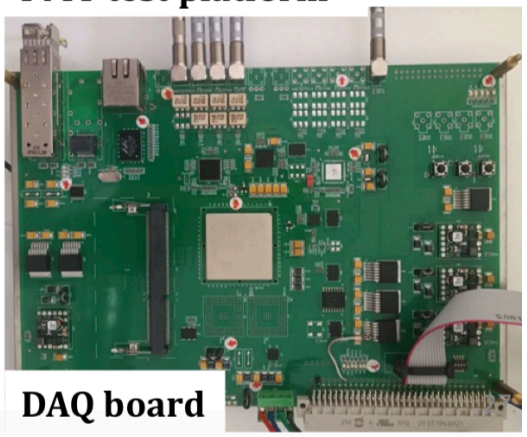


Time projection chamber

Kr System and Distillation



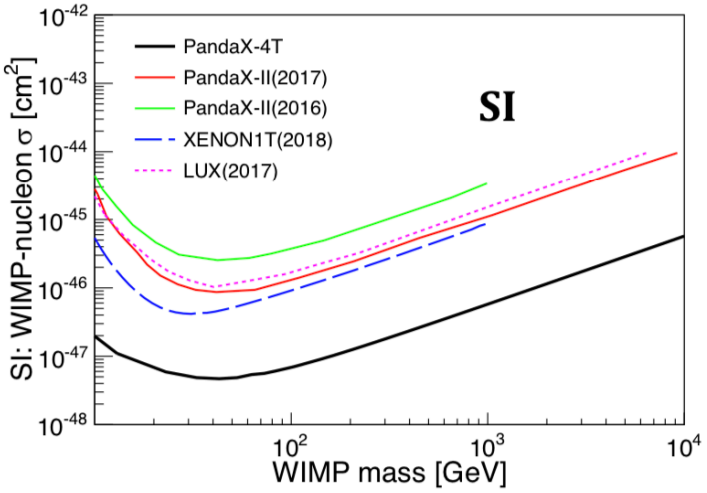
PMT test platform

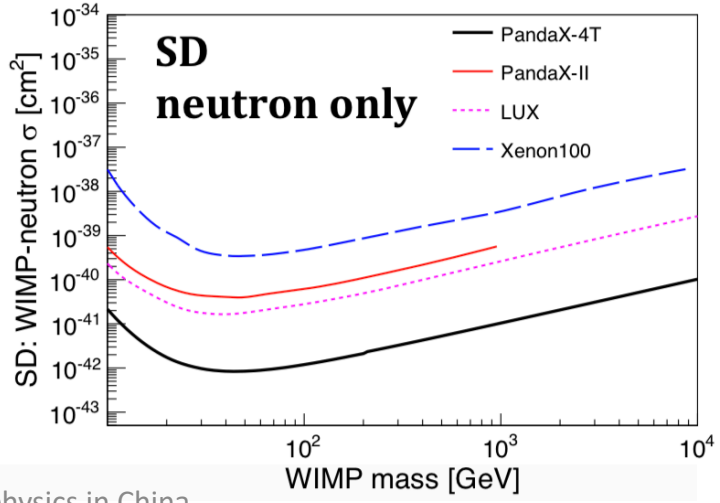


DAQ board

PandaX-4T projected sensitivity

- TPC detector : Φ ~1.2m， H ~1.2m
  - 4-ton LXe in sensitive volume
- Background sources
  - Detector materials
  - Radioactive impurities in xenon
    - ^{85}Kr, ^{222}Rn, ^{136}Xe
  - Neutrino
- Expected background level
  - Total ER: 0.05 mDRU
  - Total NR: 1 event/(ton-year)
- Expected sensitivity on SI cross-section 10^{-47} cm^2 from 5.6 ton-year





Sci. China-Phys. Mech. Astron. 62, 031011 (2019)

PandaX experiment summary

- PandaX experiment with 580kg Xenon has reached the world frontier of dark matter direct detection.
  – PandaX-II complete the task in 2019.06
  – Recently, light mediator, EFT and 0vbb(see Ke's talk) results are obtained

- The future PandaX-4T experiment R&D is work-in-progress.
  – Expected sensitivity to SI interaction could reach 10^{-47} cm^2
  – Detector assembly and commissioning is scheduled in 2019-2020

CDEX experiment

-- Slides from Qian Yue and Litao Yang

From Qian Yue and Litao Yang

CDEX: China Dark matter EXperiment

Established in 2009.

- Tsinghua University (THU)
- Sichuan University (SCU)
- Nankai University (NKU)
- China Institute of Atomic Energy (CIAE)
- Beijing Normal University (BNU)
- Yalong River Company

From Qian Yue and Litao Yang

CDEX stages

DM sensitivity (cm^2)

10^{-40} 10^{-41} 10^{-42} 10^{-43} 10^{-44} 10^{-45}

1kg PCGe C1A

1kg PCGe C1B

10kg PCGe Array

LT/LN LB VFE

PCGe Home-Made

EF-Cu

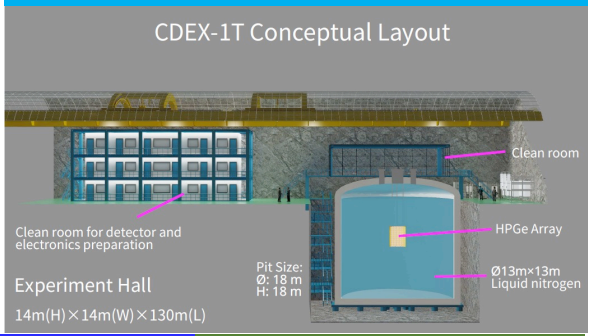
Large LN2

CDEX 100

CDEX-1T

10^{26}y 10^{27}y 10^{28}y

^{76}Ge 0vbb



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

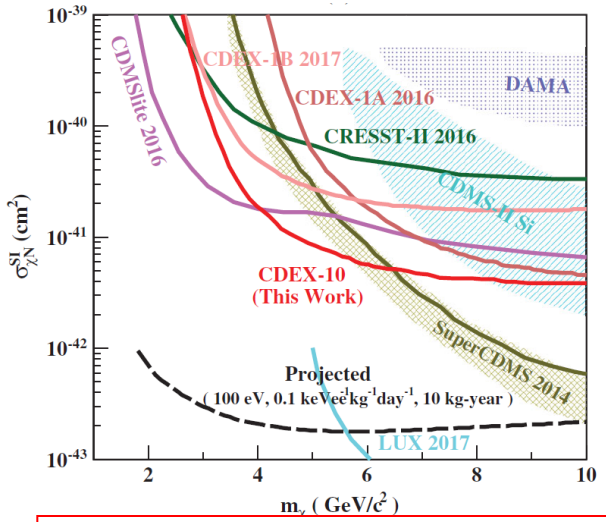
CDEX-1 | CDEX-10+X | CDEX-100 | CDEX-1T

CJPL-I | CJPL-II

From Qian Yue and Litao Yang

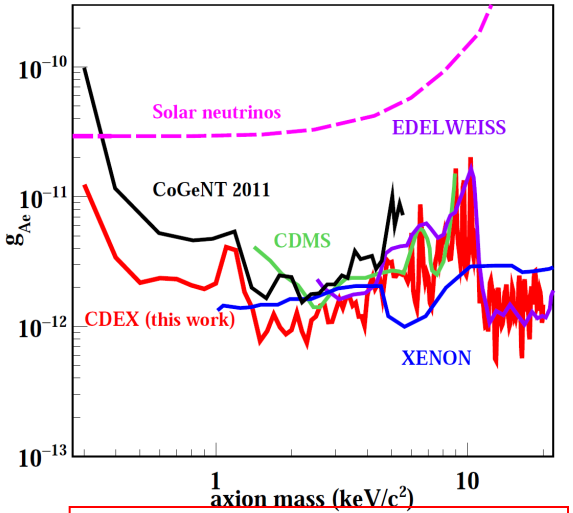
CDEX progress

PRL120, 241301, 2018



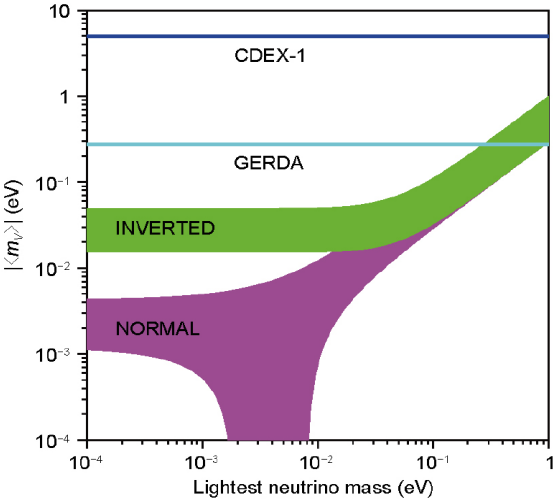
2013年我国首个暗物质直接探测成果；2018年文章当时WIMP自旋无关相互作用4-5GeV国际最好结果！

PRD95, 052006, 2017



我国首篇轴子实验文章；轴子暗物质与电子相互作用测量给出1keV以下国际最好实验结果！

Sci. China (2017) 60: 071011



发表我国第一个^{76}Ge无中微子双贝塔衰变实验结果，开启我国^{76}Ge双贝塔衰变研究序幕！

CDEX-1

From Qian Yue and Litao Yang

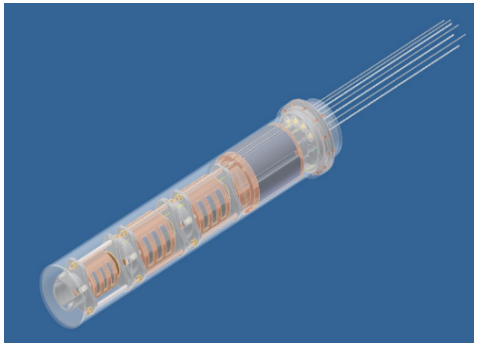
CDEX-1A 1kg PCGe

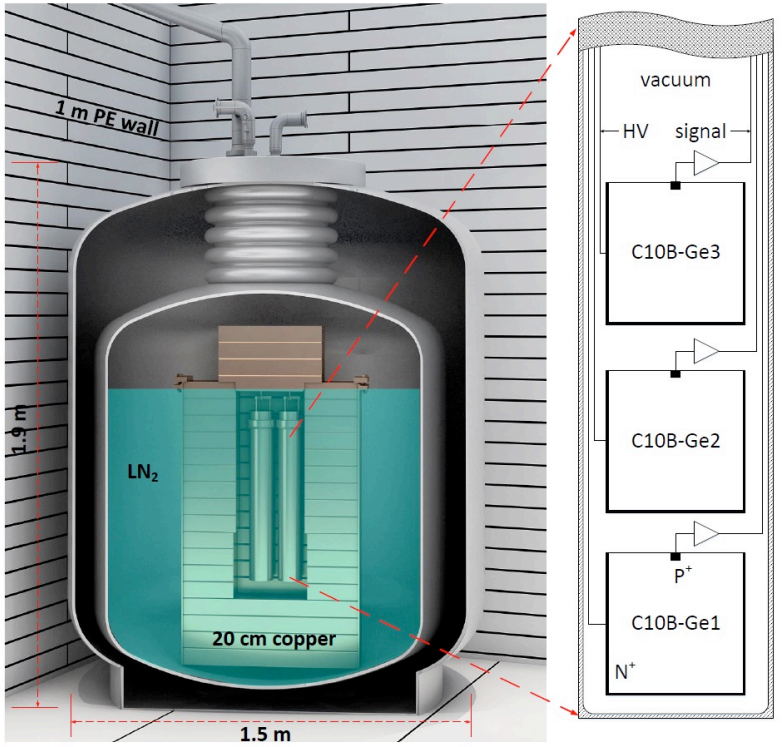
CDEX-1B 1kg PCGe

20cm OFHC Copper
+20cm Lead

CDEX-10 experiment

- The important stage towards large-scale Ge experiment;
- Directly immersed into liquid nitrogen for cooling;
- Dataset: 102.8kg·d.

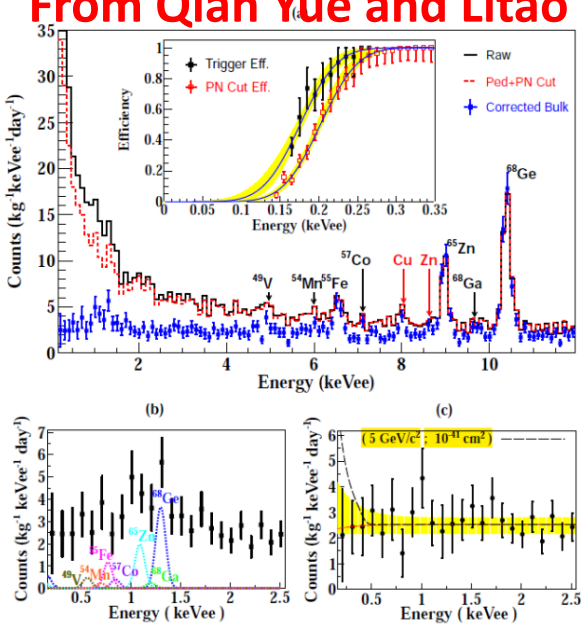




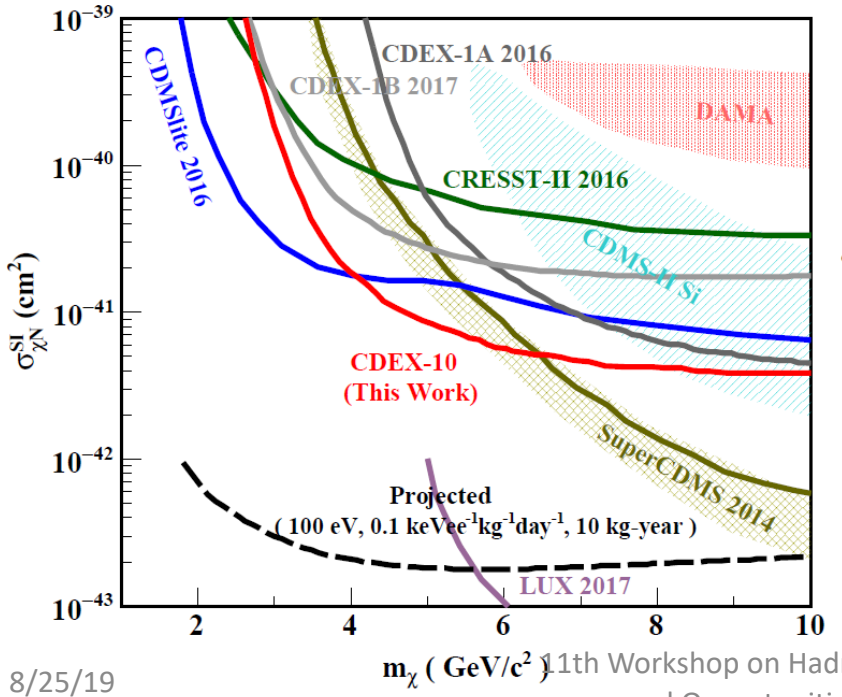
From Qian Yue and Litao Yang

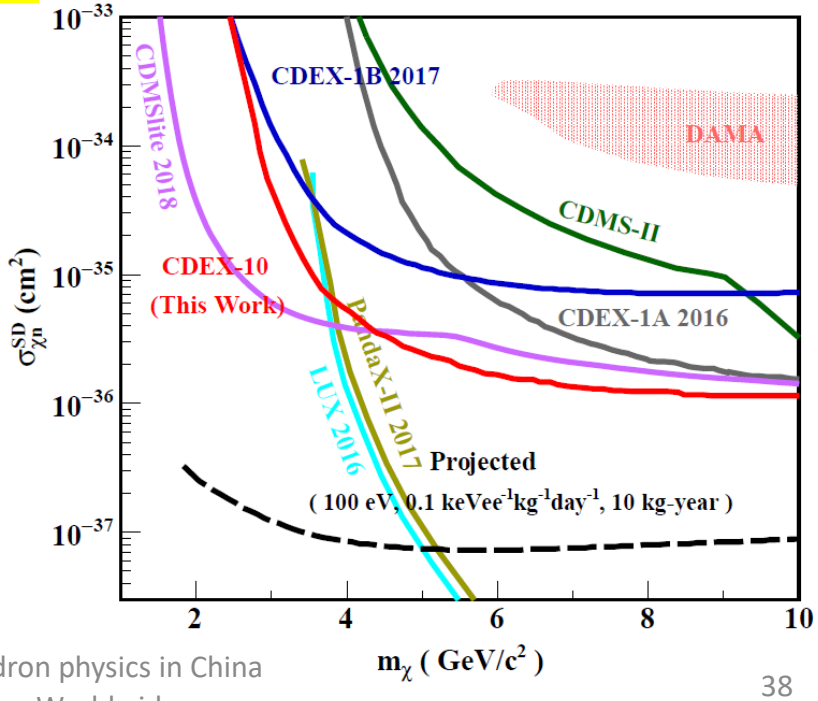
CDEX-10 results

- ✓ E_{th} down to 160eV,
- ✓ The best SI results @ 4-5GeV;
- ✓ The best SD results < 4GeV.



PRL 120, 241301 (2018)

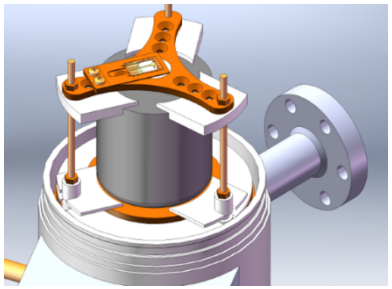


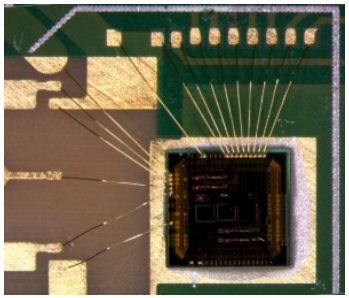


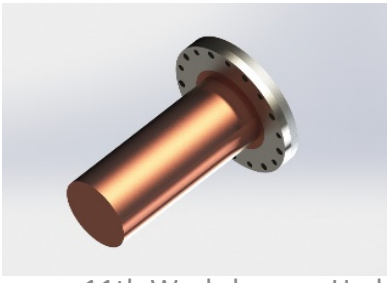
From Qian Yue and Litao Yang

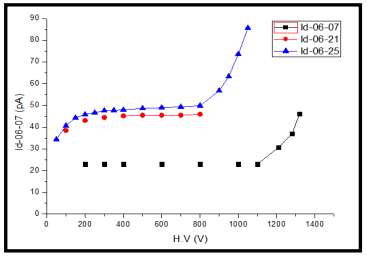
Key technologies towards CDEX-1T

- Ge purification and crystal growth;
- HPGe detector fabrication;
- Ultra-low background VFE and FADC;
- Ultra-pure Cu for structure and cables;
- Large-volume cooling tank.









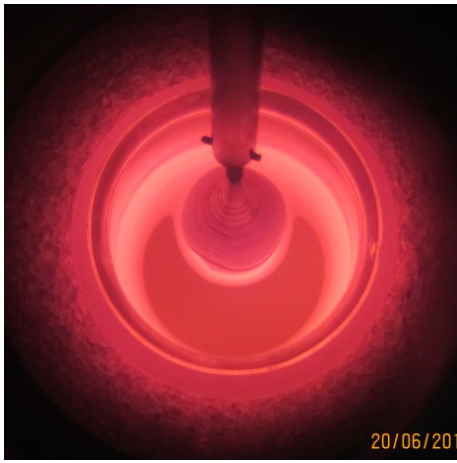
From Qian Yue and Litao Yang

CDEX-1T –Ge crystal growth

Zone refining machine

Czochralski machine

Cutting & Polishing

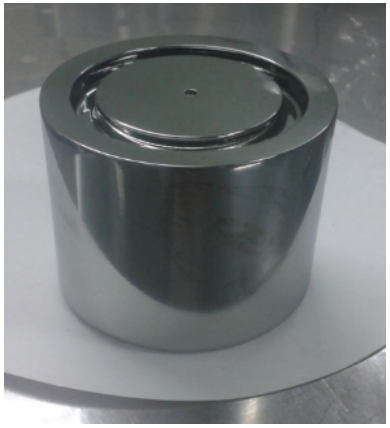


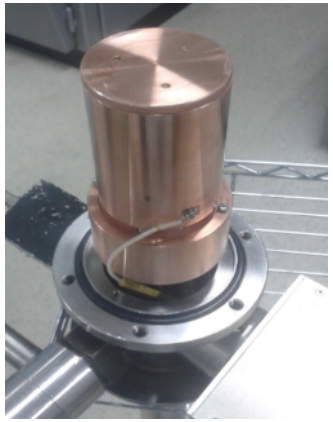
Crystal growth

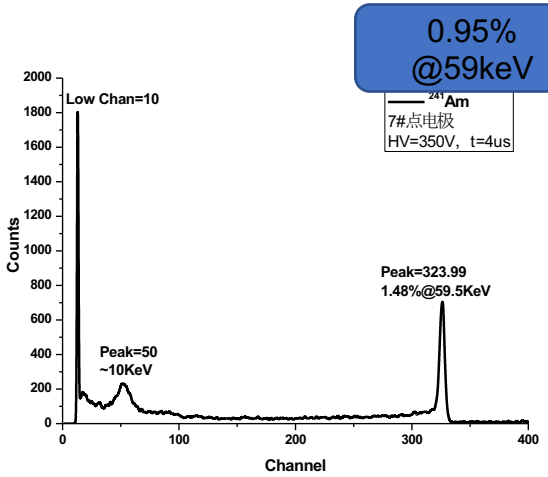
- ✓ The requirement for making P-type Ge detector
  - ✓ Impurity density: ~10^{10} cm^{-3}
  - ✓ Dislocation: <5000 cm^{-2}
- ✓ CDEX are working on this two points.

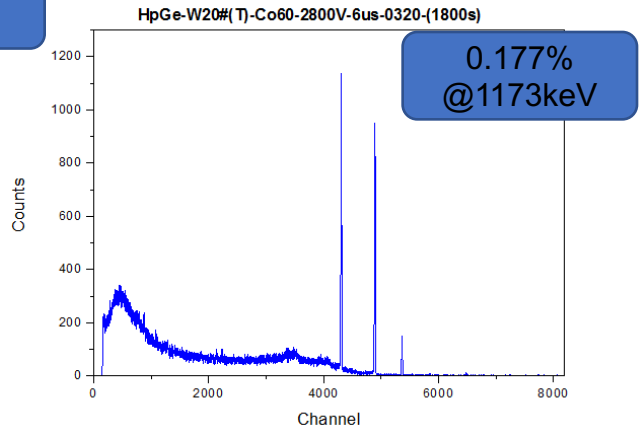
HPGe detector fabrication

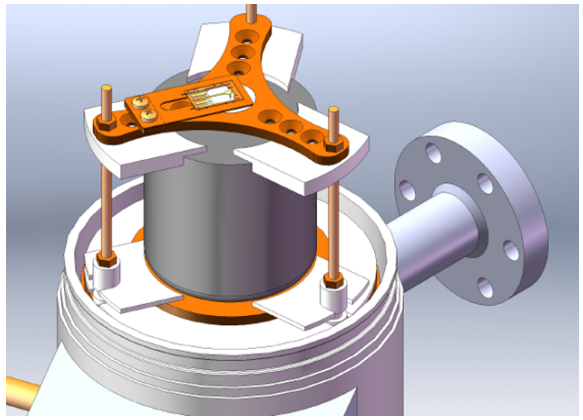
- First 500g home-made pPCGe+ASIC finished testing, energy resolution and energy threshold compared with commercial one.











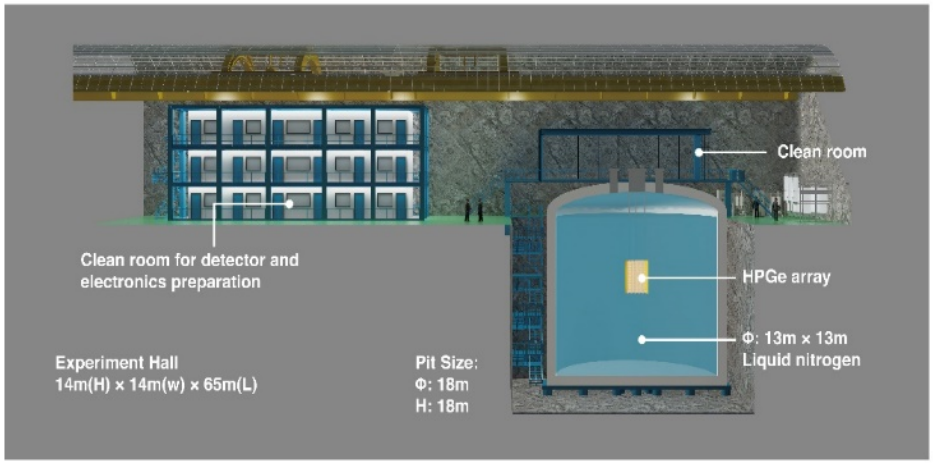
From Qian Yue and Litao Yang

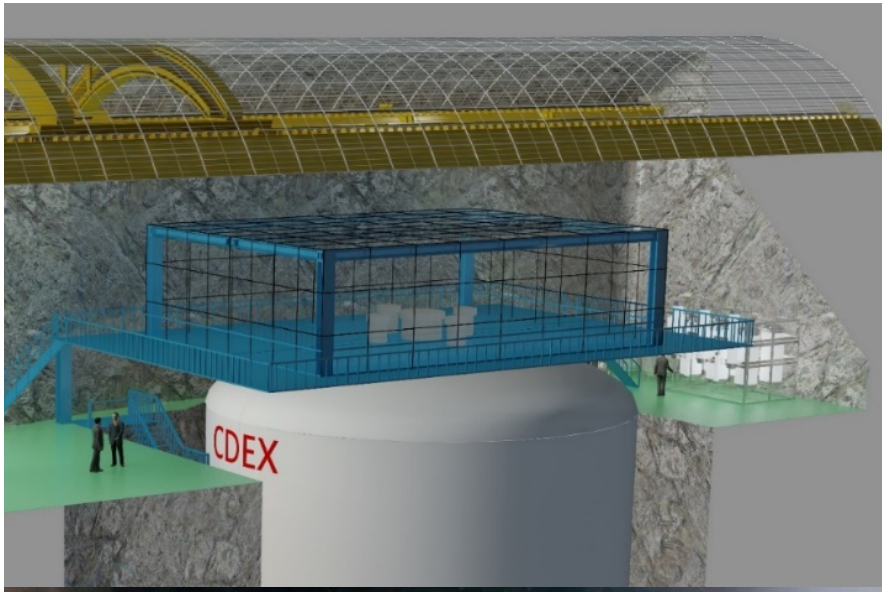
CDEX ULB-Cu @ CJPL

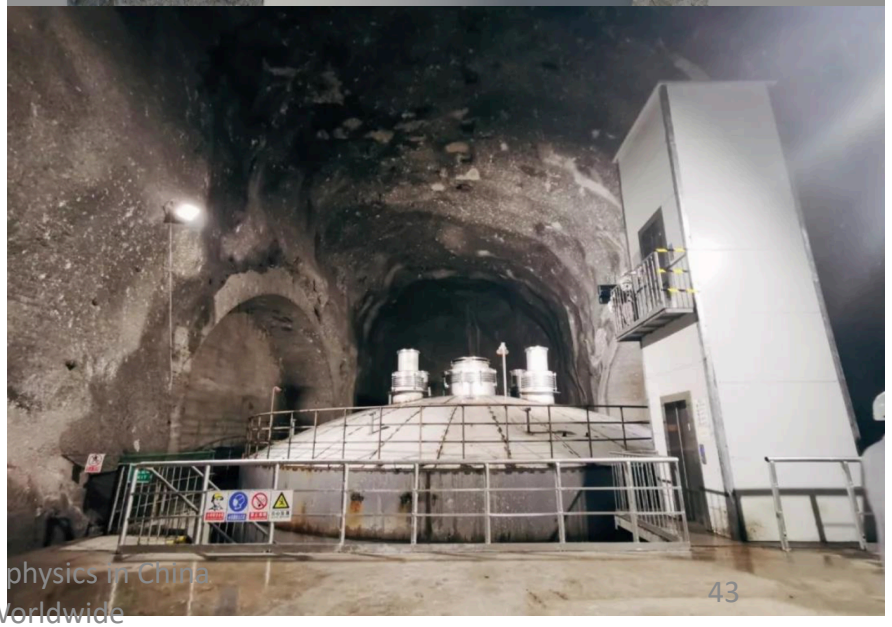
- Setting up the facilities for ULB-Cu production;
- CDEX copper goal will be the Majorana EFCu purification: Th<0.06 μBq/kg、 U<0.17 μBq/kg.
- Shielded by LN2, Structure materials used as little as possible in order to lower the background contribution.

From Qian Yue and Litao Yang

CDEX-1T Plan

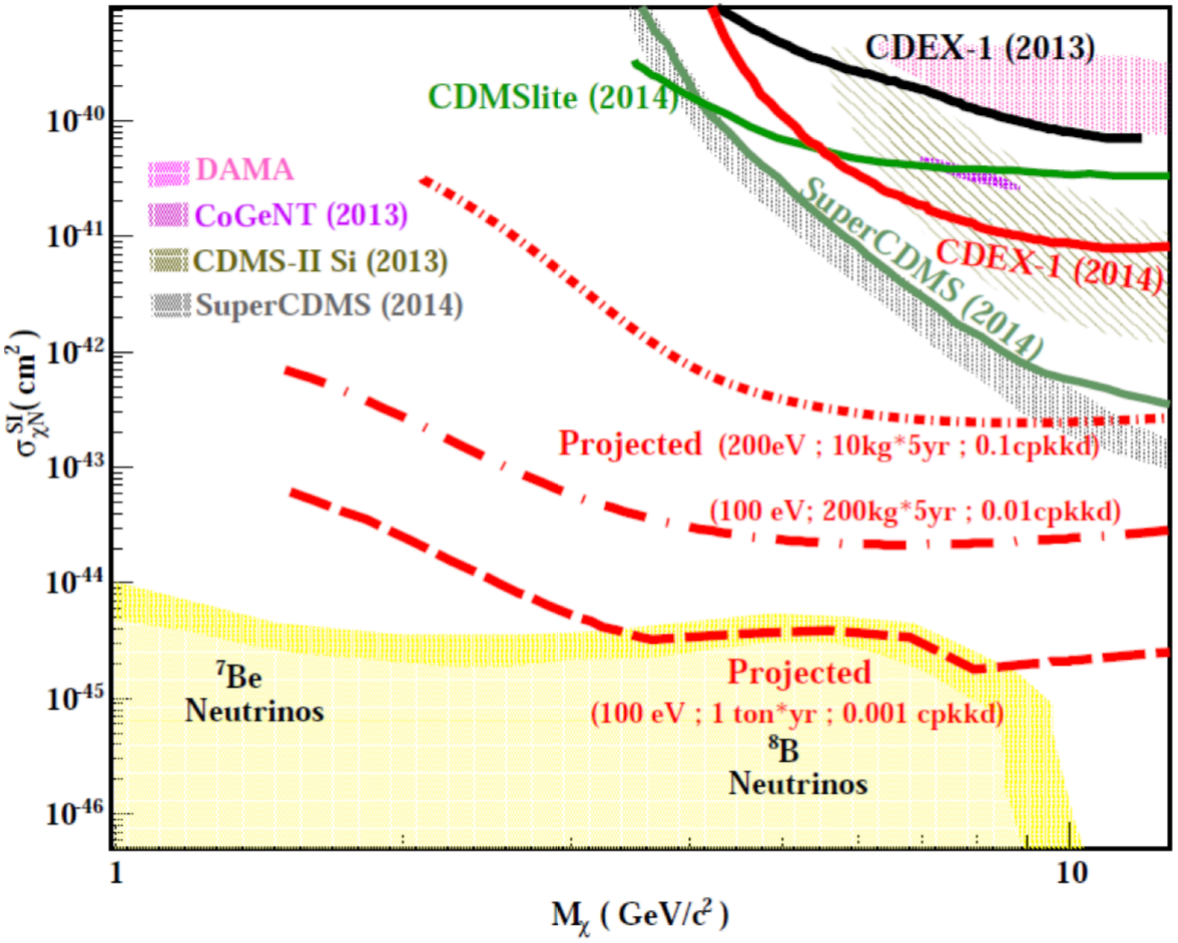






From Qian Yue and Litao Yang

CDEX experiment projected sensitivity

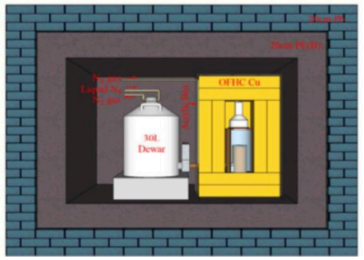


CDEX experiment summary

- Lower Background Level
- Lower Threshold
- Larger target mass

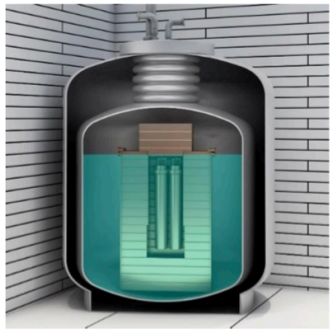
Threshold

CDEX-1A/B



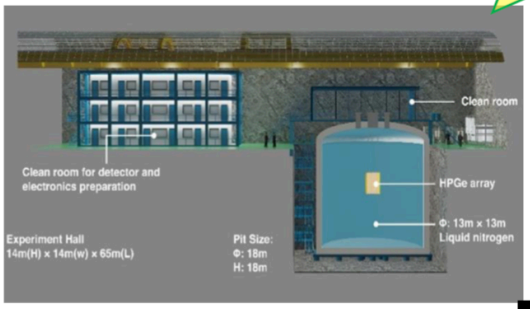
2011

CDEX-10

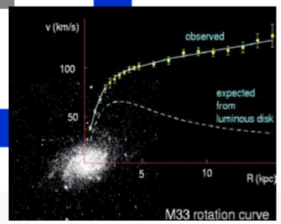


2016

CDEX-100 / CDEX-1T



202X

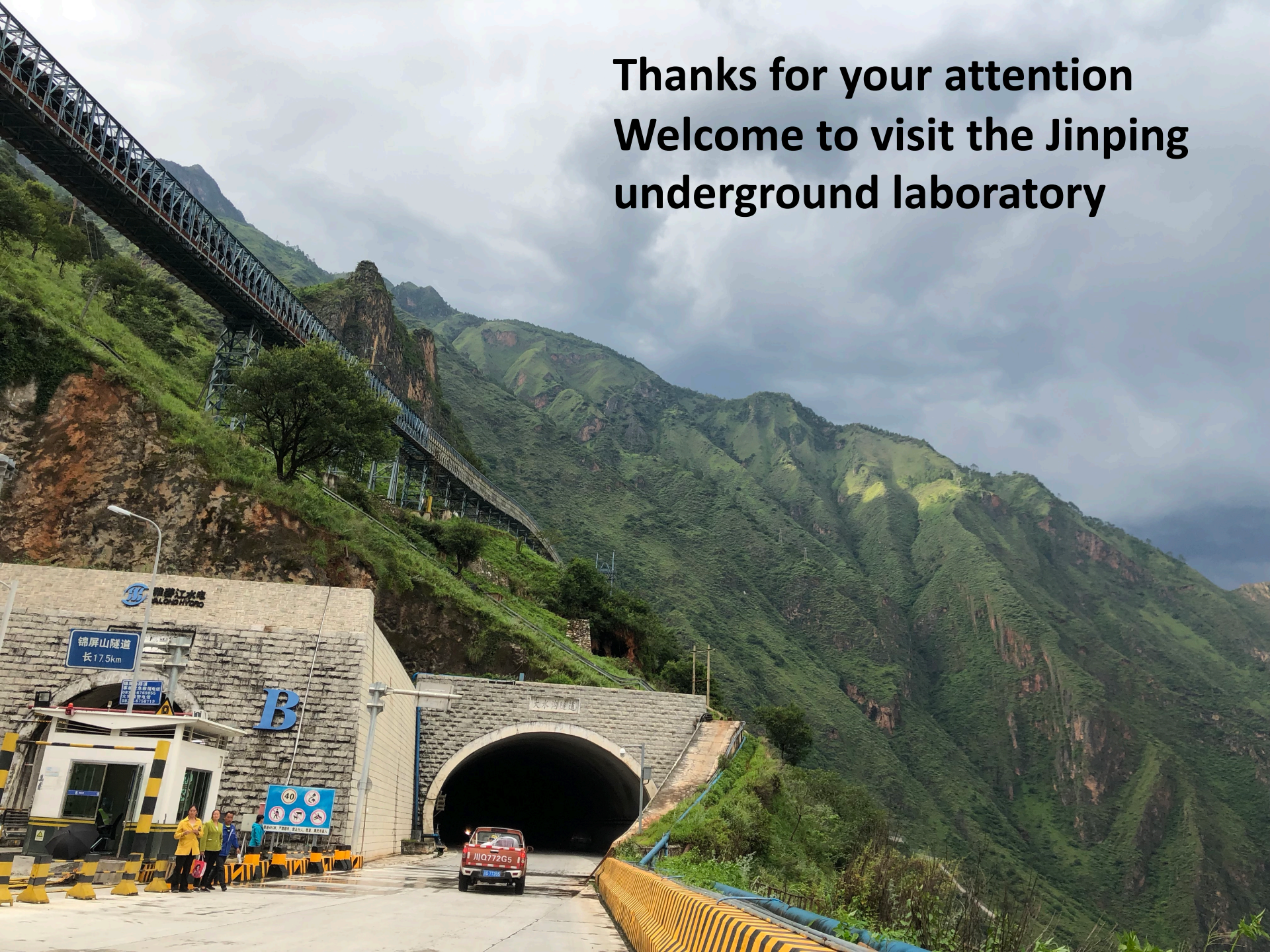


- More key technologies in control
- More physics channels opened…
- More fun, more exciting…

Background Level

Summary

- CJPL provides an excellent low radioactive background environment to detect dark matter.
- Both PandaX-II and CDEX-10 experiments has reached the world frontier of dark matter direct detection in the few GeV to 1000 GeV energy range.
- PandaX-4T and CDEX-1T experiments are in a good progress.


Thanks for your attention
Welcome to visit the Jinping underground laboratory
锦屏山隧道
长17.5km
B