

# Dark Matter Search\* in China

**Jianglai Liu 刘江来**

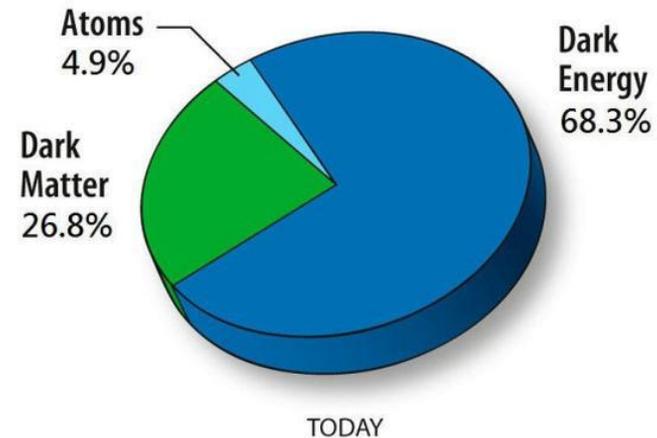
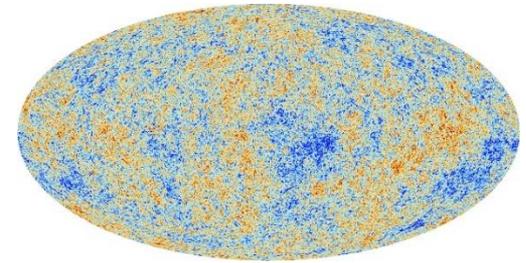
**Shanghai Jiao Tong University**

**Member of the PandaX collaboration**

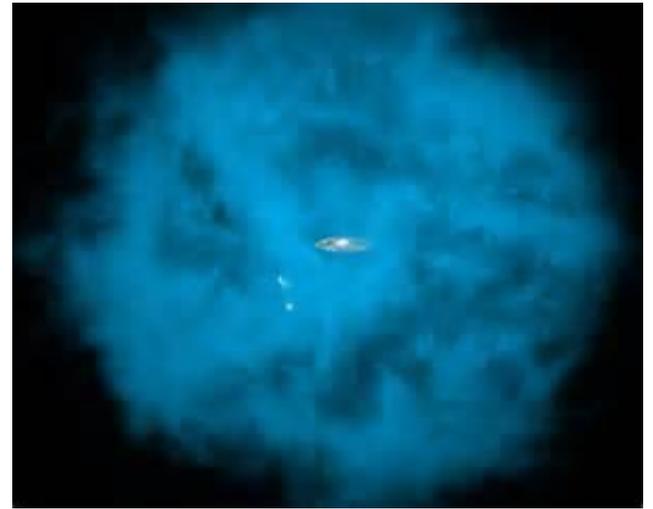
**\*Disclaimer: focused on direct detection**

# What is dark matter?

**Based on many different astronomical observations, the normal visible matter makes up 5% of the energy of the universe, the rest of 27% is dark matter (the particle properties of which are unknown), and 68% is dark energy**



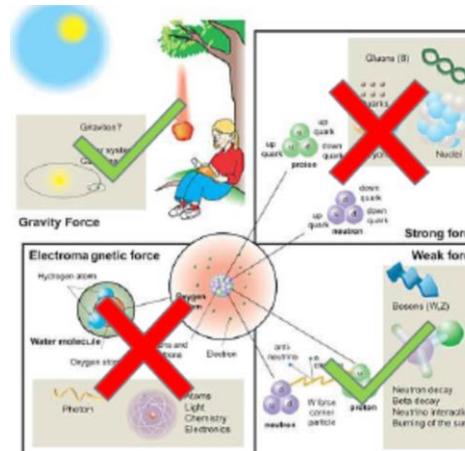
# Standard halo



**Local density around us:  $0.3 \text{ GeV/cm}^3$**

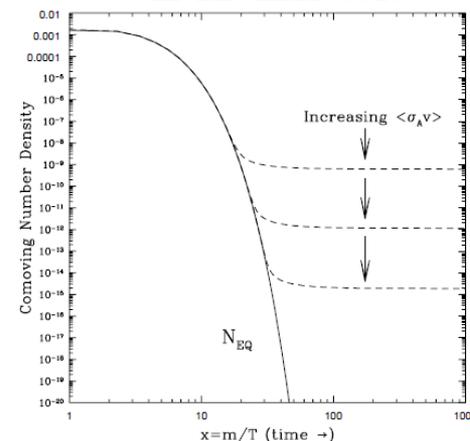
# Know “known”

- No EM and strong interactions
- Very long lived (half-life longer than the age of the universe)
- Not part of the Standard Model
- Most popular: weakly-interacting-massive-particle (WIMPs)



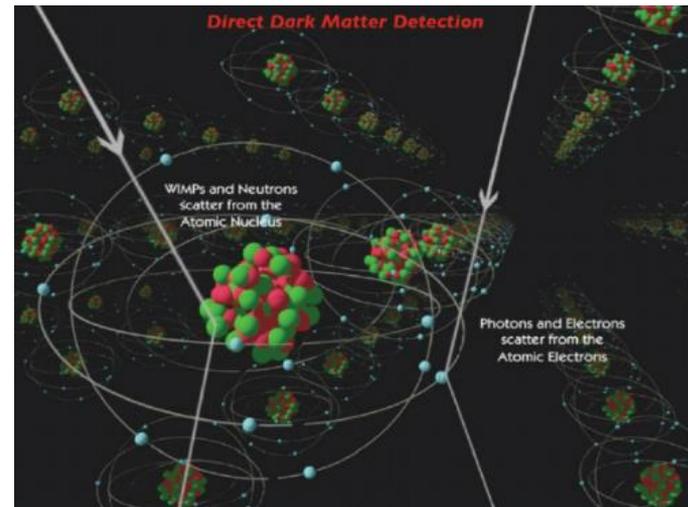
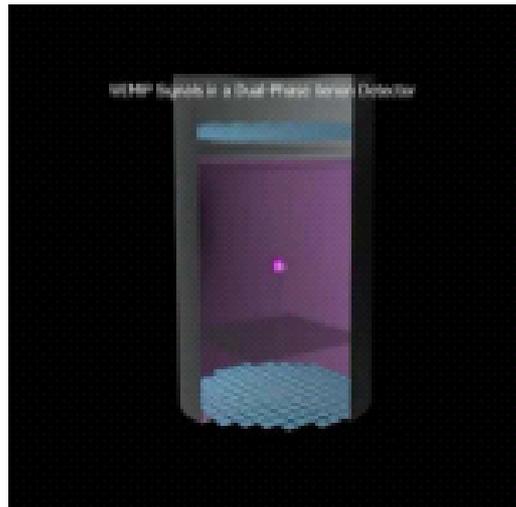
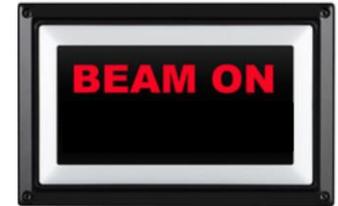
Quarks	$u$	$c$	$t$	Bosons	$\gamma$
	$d$	$s$	$b$		$g$
Leptons	$\nu_e$	$\nu_\mu$	$\nu_\tau$		$Z$
	$e$	$\mu$	$\tau$		$W$
					$H$
	?	?			?
	?	?			?
	?	?			?

“WIMP miracle”



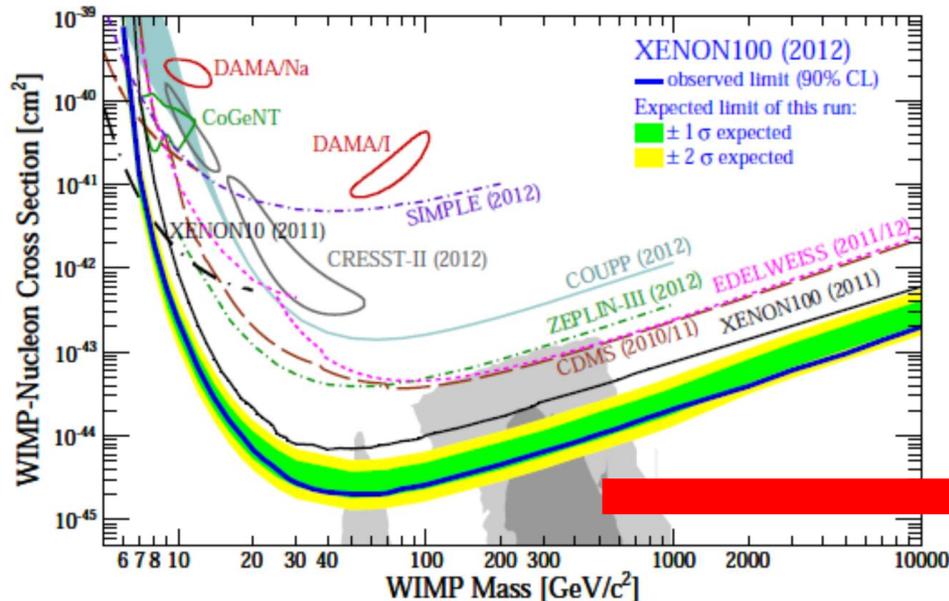
# Dark matter: direct detection

- **Solar system moves in the galaxy (DM halo) with a speed of 220 km/s**
- **DM direct detection: wait for DM interacting atomic nucleus in the detector, and detect its recoil**



# Dark matter “gold rush”

- **COUPP, PICASSO, XENON, CoGENT, DEAP/CLEAN, ZEPLIN, DRIFT, LUX, KIMS, XMASS, CDMS, WARP, EDELWEISS, MIMAC...**

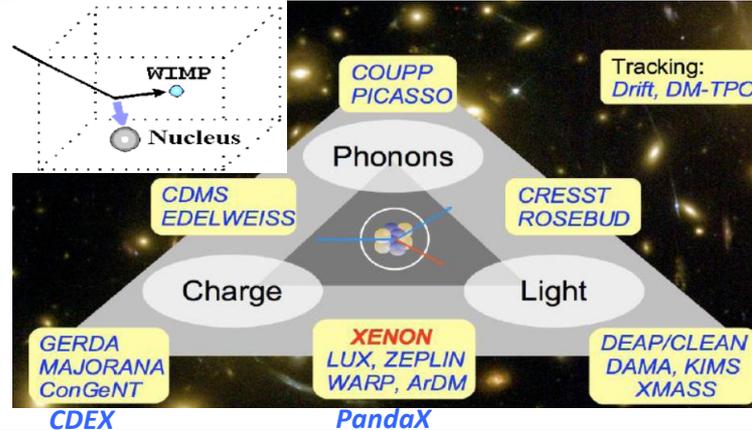
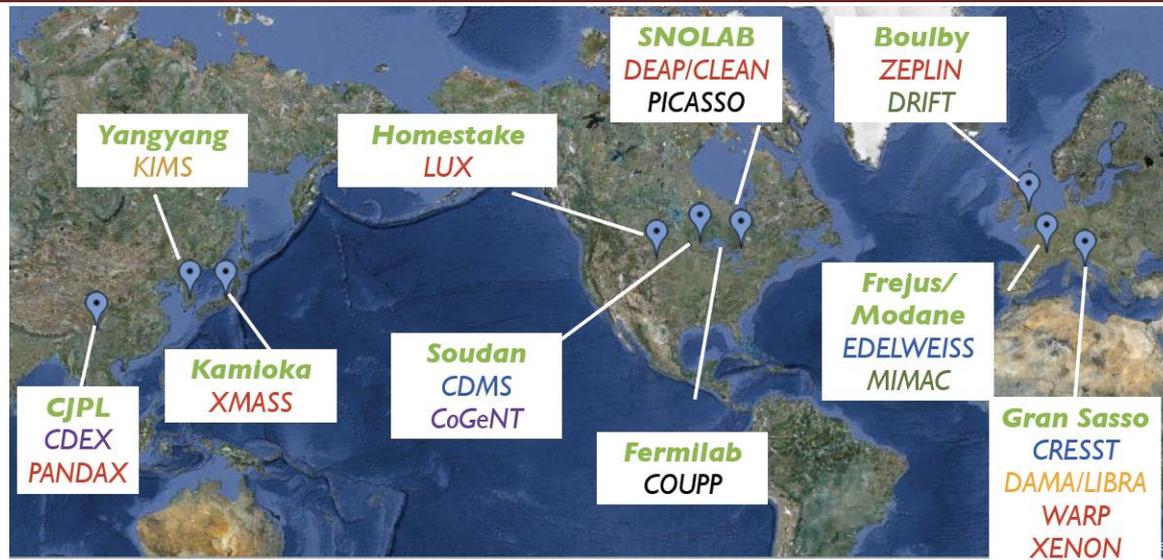


E.g. XENON100 2012 results

Sensitivity are approaching  
<1 evt/100kg/year

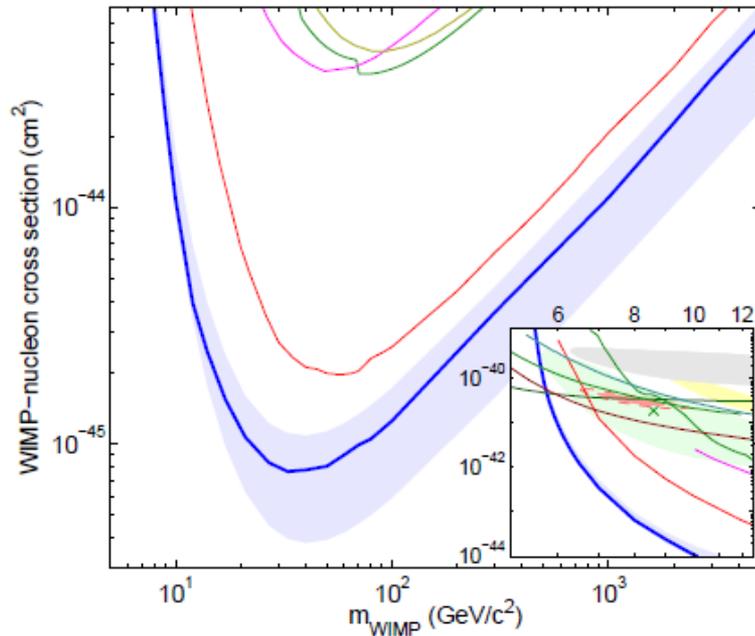
“WIMP miracle” (SUSY)

# Dark matter "gold rush"

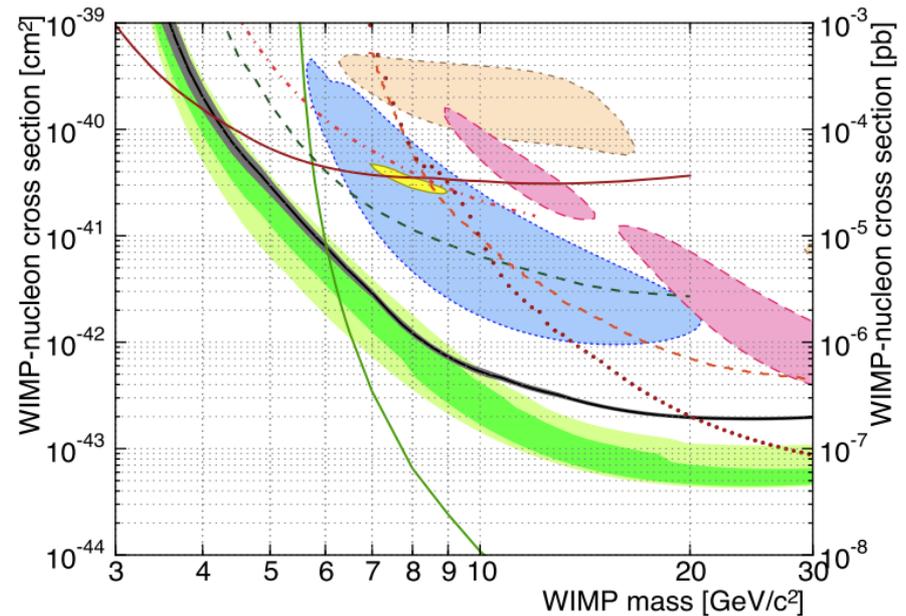


# Direct detection: global pictures

LUX 2013, PRL 112, 091303 (2014)



SuperCDMS, PRL 112, 241302 (2014)



- **Some claims at low to median mass**
- **Xenon/LUX/SuperCDMS/CDEX strongly disfavor low energy claims**
- **Xenon experiments carve into the “mainstream” supersymmetry theory predictions**

# Dark-matter hunt gets deep

China launches world's deepest particle-physics experiment — but it joins a crowded field.

Eugenie Samuel Reich

20 February 2013 | Corrected: 21 February 2013

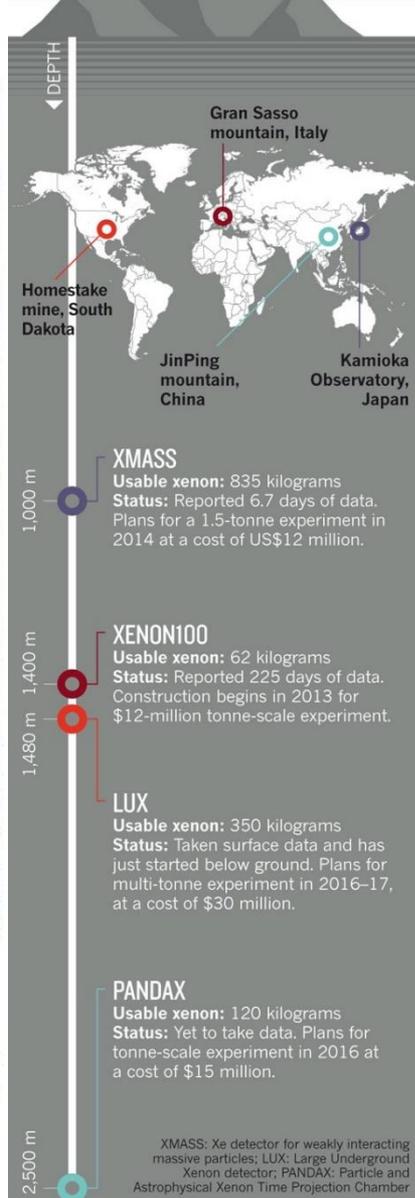
NATURE | NEWS



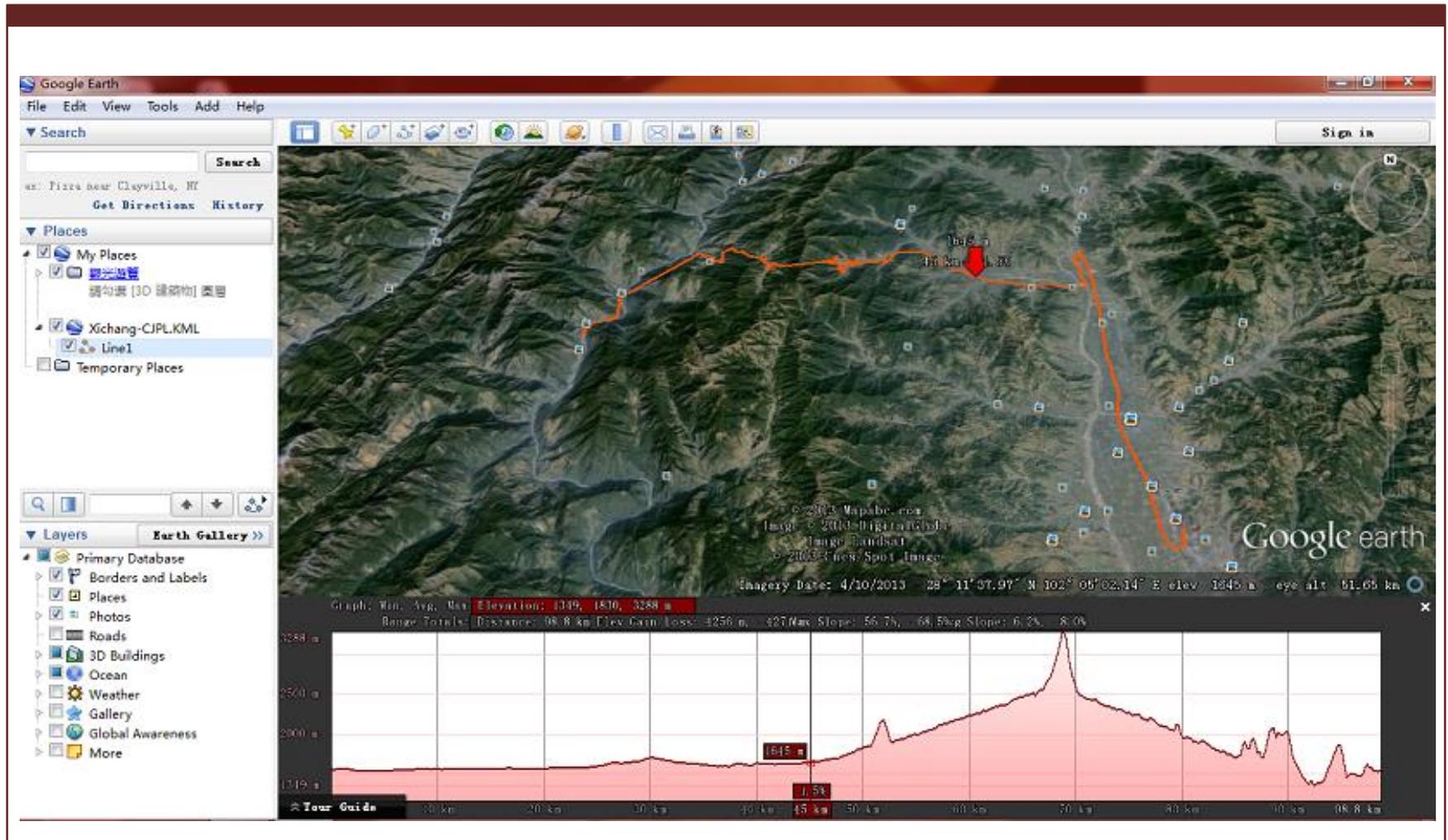
Ongoing experiments in Italy, the United States and Japan are now being joined by a fourth in China, called PandaX (see ['Dark and deep'](#)). Installed in the deepest laboratory in the world, 2,500 metres under the marble mountain of JinPing in Sichuan province, PandaX will this year begin monitoring 120 kilograms of xenon. The team hopes to scale the tank up to 1 tonne by 2016, which would mean that the experiment had developed more quickly than any other dark-matter search. "We want to demonstrate that world-class research in dark matter is possible in China," says Xiangdong Ji, a physicist at Shanghai Jiao Tong University in China and a spokesman for PandaX.

## DARK AND DEEP

Shielded from cosmic rays by the bedrock, four experiments are using giant tanks of liquid xenon in a race to detect particles of dark matter.

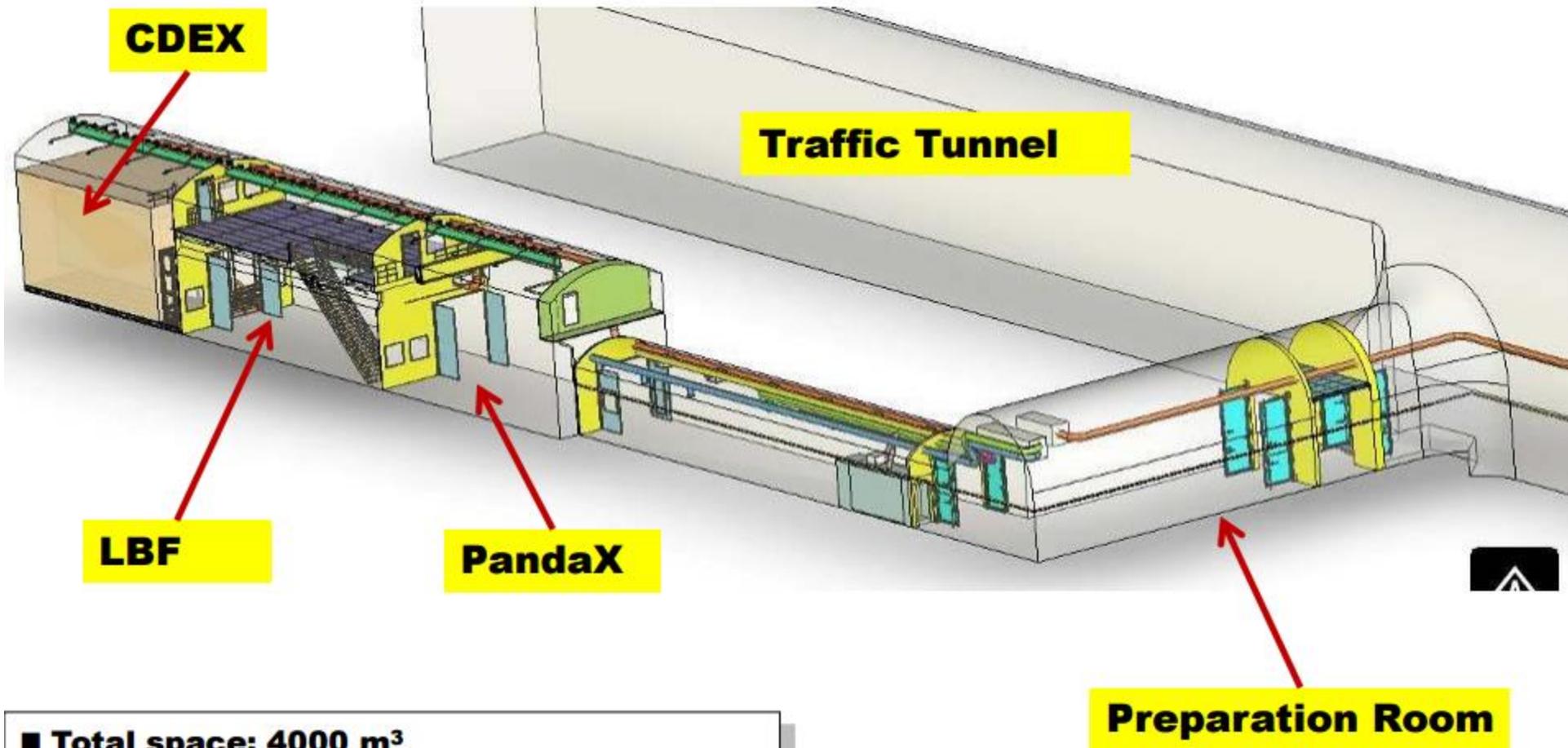


# Winding road



Aug. 3-7, 2015

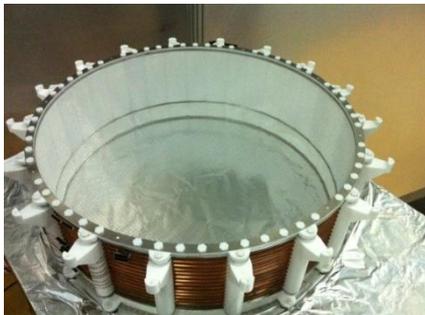
# The recent status of CJPL-I



- Total space: 4000 m<sup>3</sup>
- Main Lab Space: 6.5(W) x 6.5(H) x 42(L)

# PandaX实验

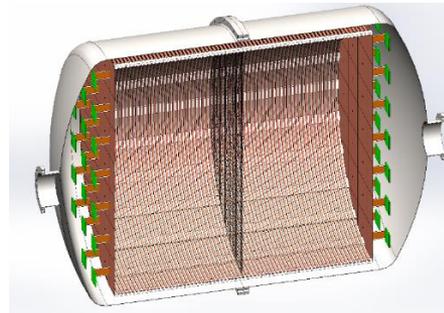
**PandaX = Particle and Astrophysical Xenon Experiments**



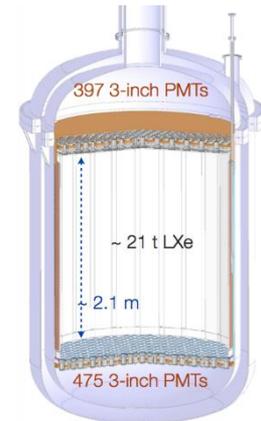
**Phase I: 120 kg  
DM  
2009-2014**



**Phase II: 500  
kg DM  
2014-2016**



**Phase III: 200 kg  
to 1 ton  $^{136}\text{Xe}$   
0vDBD  
2016-2020**



**Phase IV: 20  
ton DM  
2020-2025**

# PandaX Collaboration

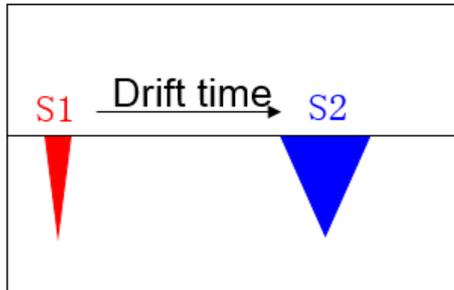
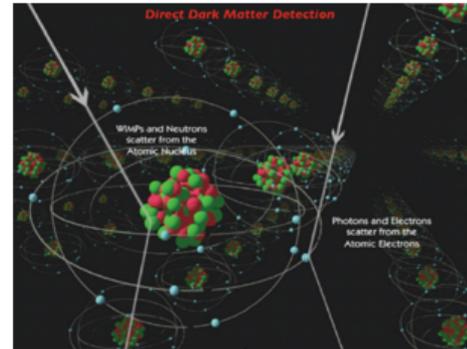
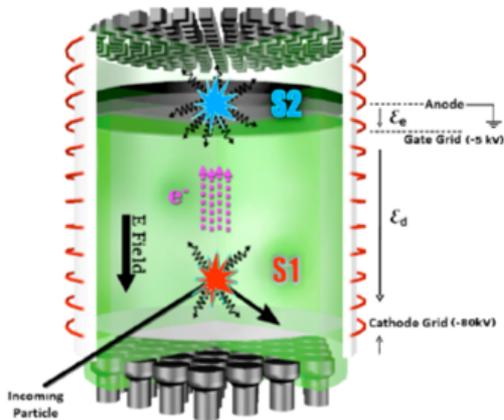
~40 people



**Started in 2009**

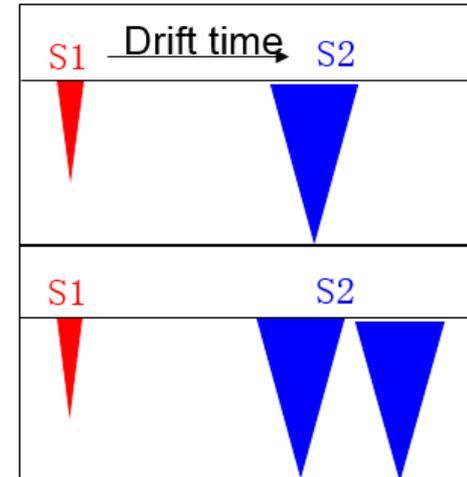
- **Shanghai Jiao Tong University**
- **Peking University**
- **Shangdong University**
- **Shanghai Institute of Applied Physics, CAS**
- **University of Science & Technology**
- **China Institute of Atomic Energy**
- **University of Maryland**
- **University of Michigan**

# Dual phase liquid xenon detector



**Dark matter: nuclear recoil (NR)**

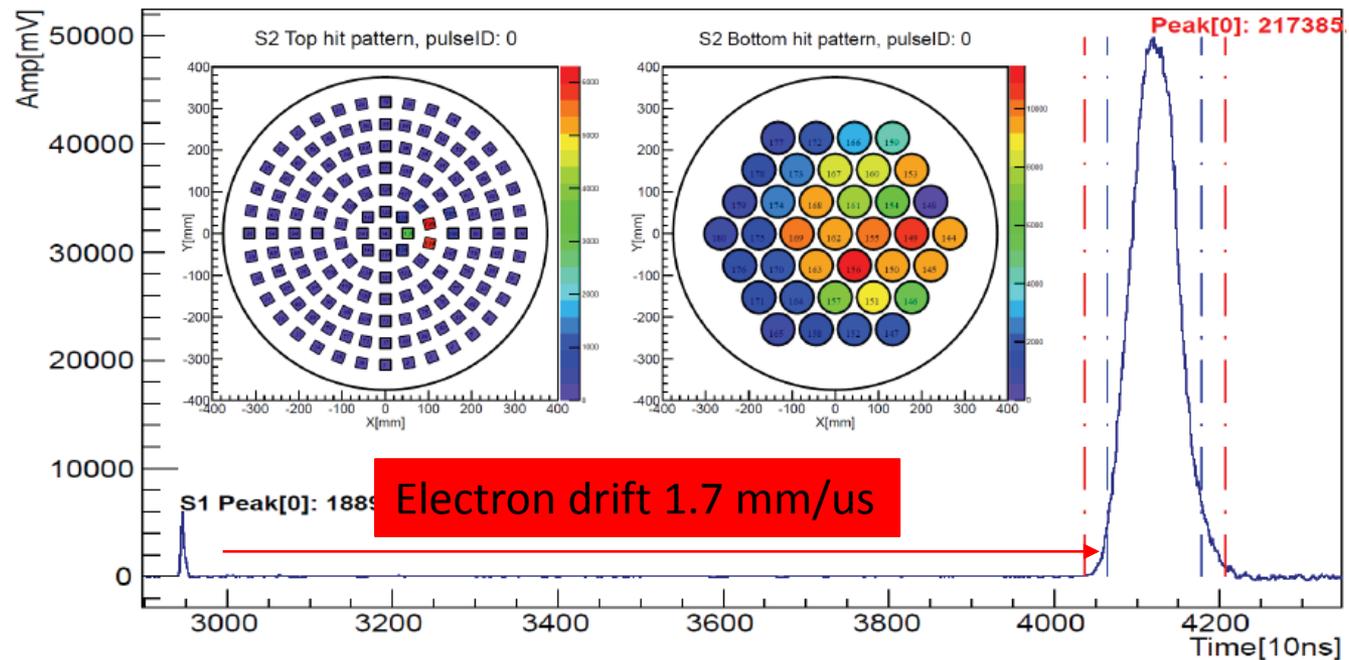
$$(S2/S1)_{NR} \ll (S2/S1)_{ER}$$



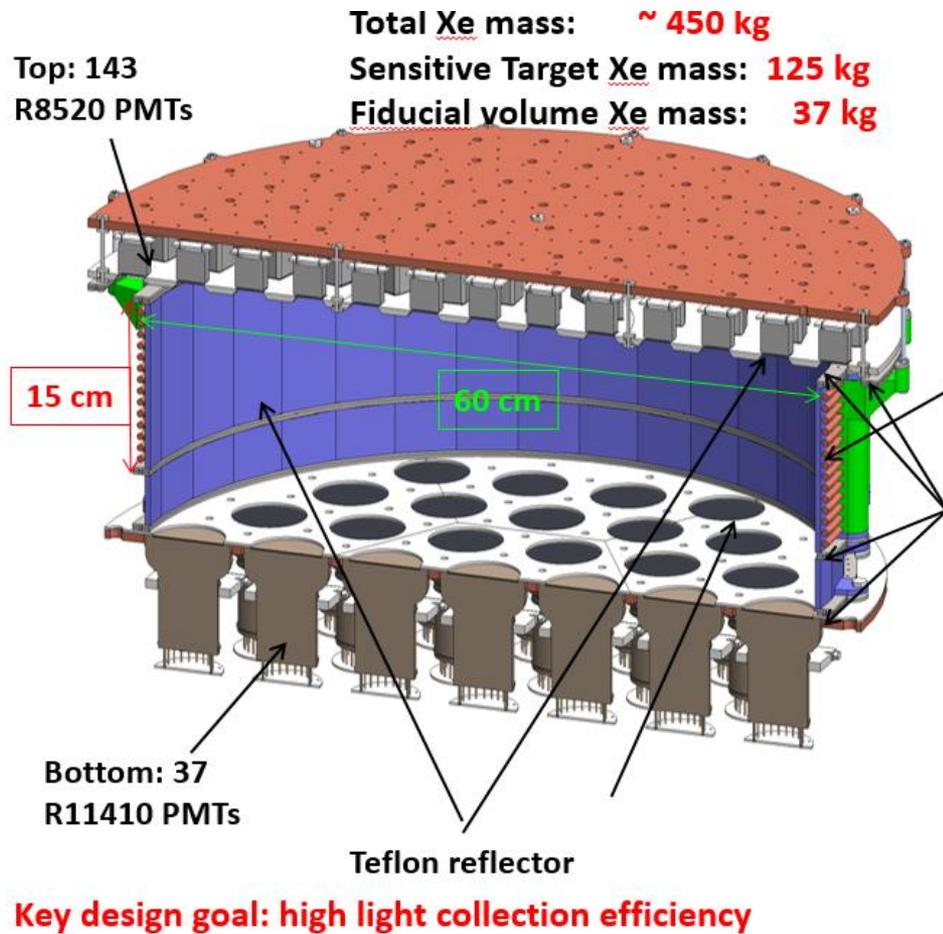
**Gamma background: electron recoil (ER)**

# An event

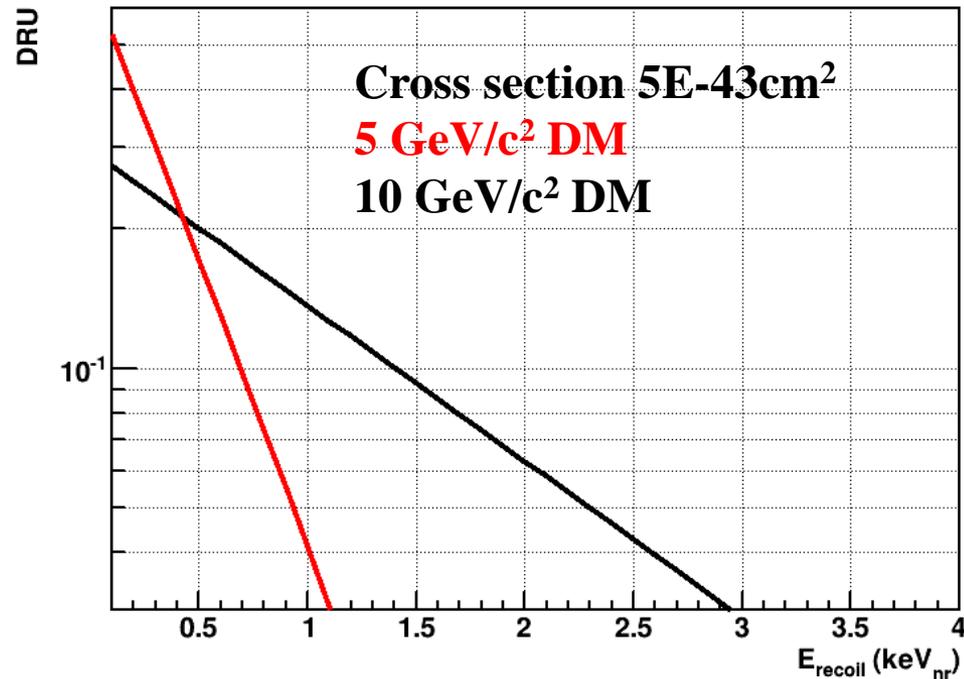
- **Horizontal position reconstructed from S2 hit pattern: either charge center or neural network method**
- **Vertical position reconstructed from S1-S2 separation**



# PandaX TPC

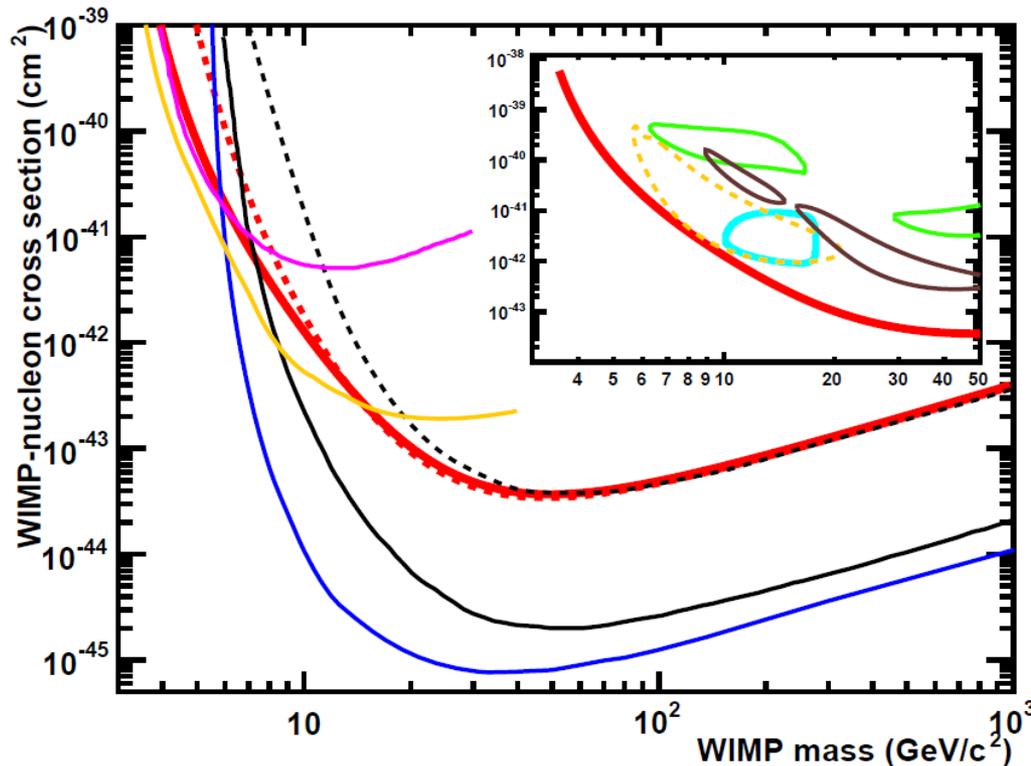


# Why more light?



- The lower mass of DM particle, the smaller recoil energy, the smaller amount of light
- Light yield is the key for low threshold to probe low mass DM

# PandaX-I first results: 17.4 day x 37 kg



Sci China-Phys Mech Astron, 2014, 57(11):  
2024-2030

- PandaX 37x17 kg-day, NEST
- - - PandaX 37x17 kg-day, Xenon100  $L_{\text{eff}}$
- - - XENON100 40x11 kg-day
- XENON100 34x225 kg-day
- LUX 118x85 kg-day (no LY below 3 keV<sub>nr</sub>)
- CDEX 2014
- SuperCDMS
- CoGENT 2014
- - - CDMS II-Si
- DAMA/LIBRA
- CRESST-II 2012

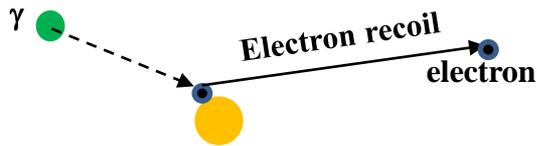
- **Our results disfavor again previously positive signals**
- **At low mass region, our results significantly better than XENON100 first results with similar exposure**

# Full dark matter run: May 26 to Oct. 16

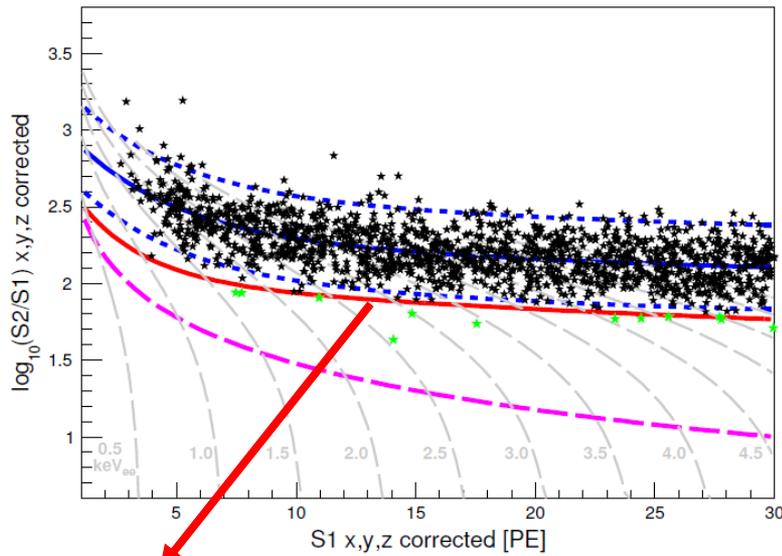
**arXiv:1505.00771, submitted to Phys. Rev. D**

- **80.1 live-day  $\times$  fiducial mass 54 kg (x7 exposure)**
- **FV and energy window defined **blindly** using background expectation!**
- **Calibrations with much larger statistics (ER/NR)**
- **Updated energy modeling at low recoil energy and improved treatment to low mass WIMPs**
- **Better understanding/modeling of background**
- **Likelihood approach to final results**

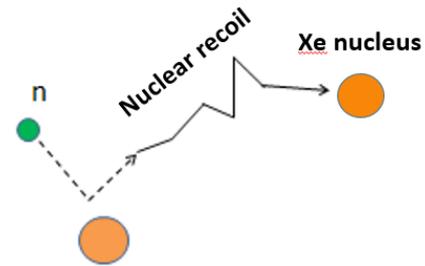
# ER/NR calibration



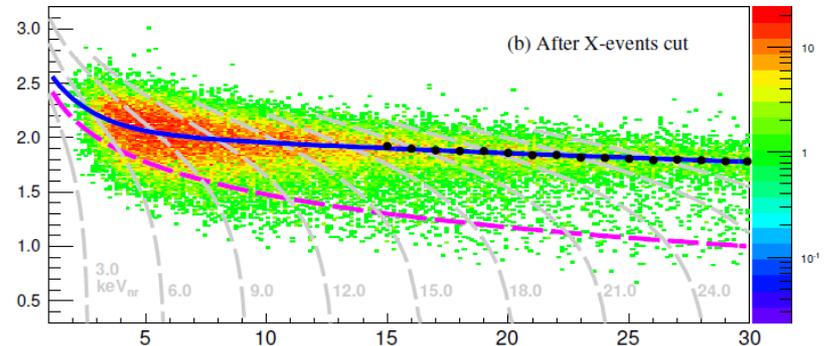
**Gamma events (electron recoil)**



**Median of NR (ER rejection 99.5%)**

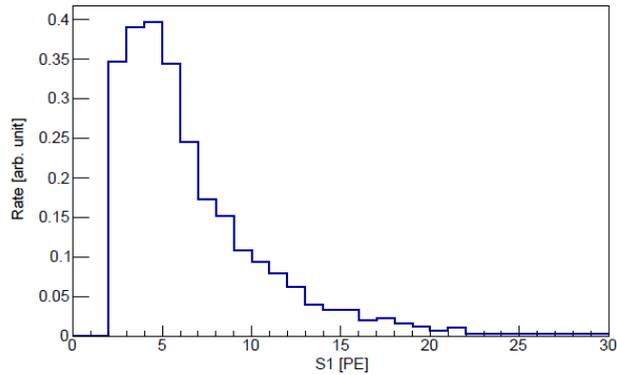


**Neutron events (NR signal)**

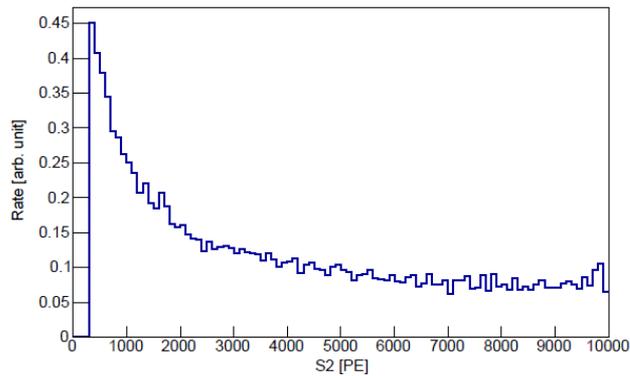


# Accidental background

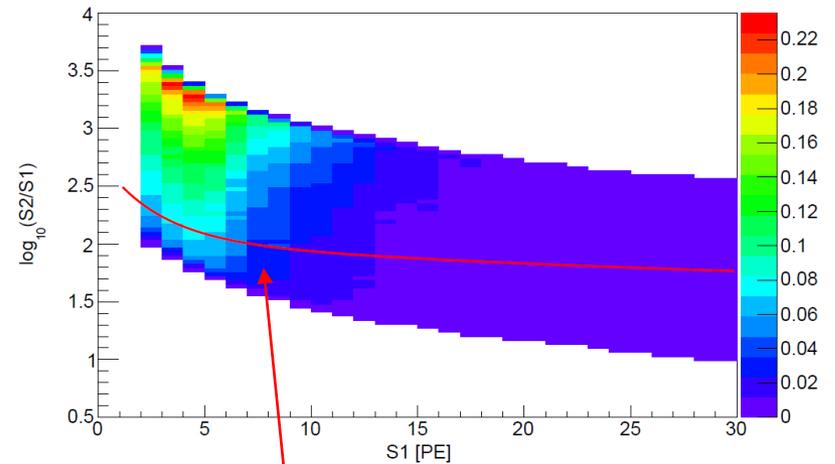
## Isolated S1 and S2 events



(a) Isolated S1

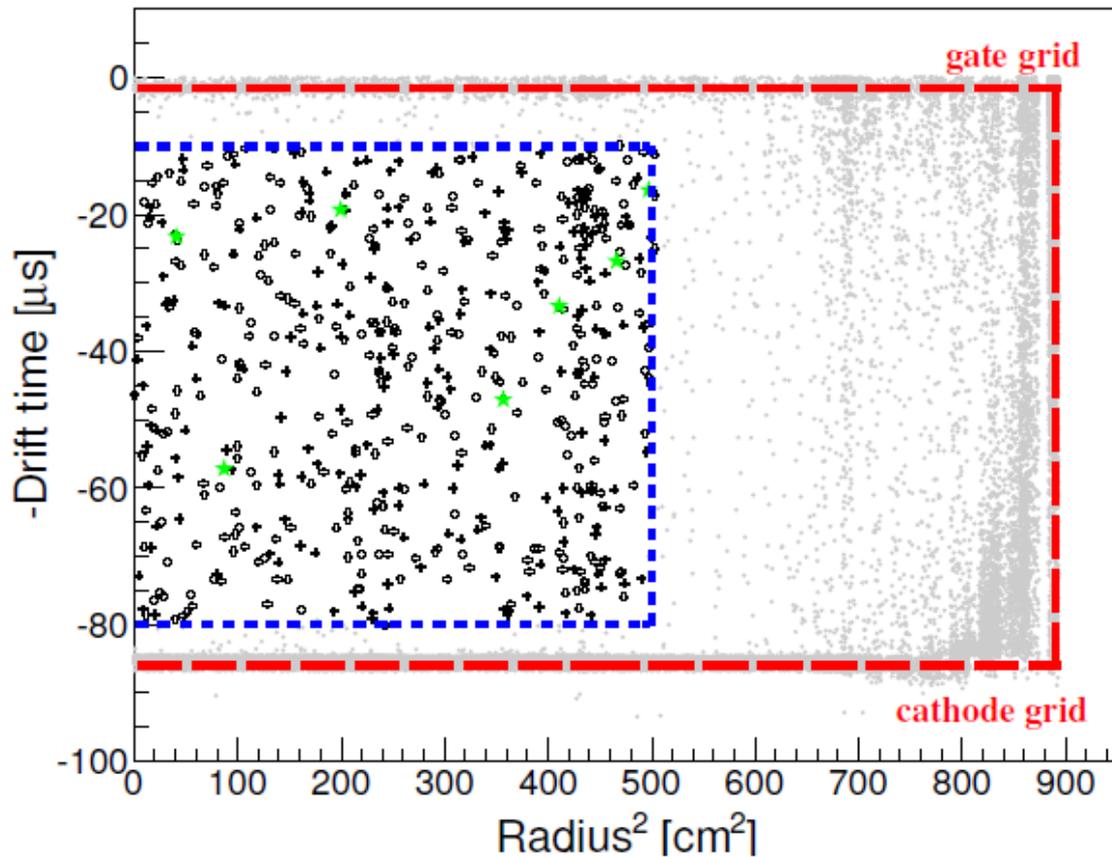


(b) Isolated S2

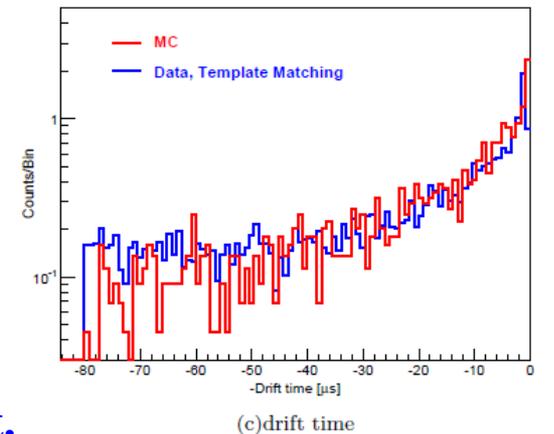
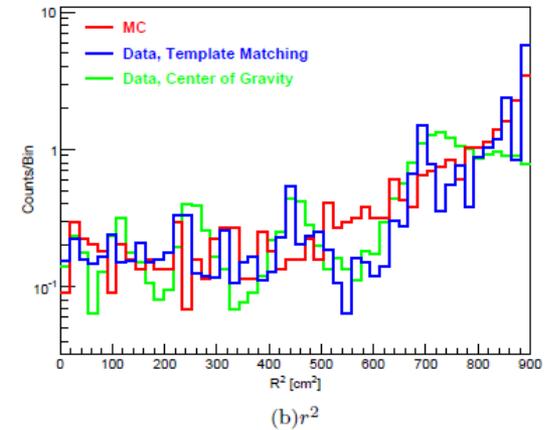


**Accidental distribution: some do leak below the NR median**

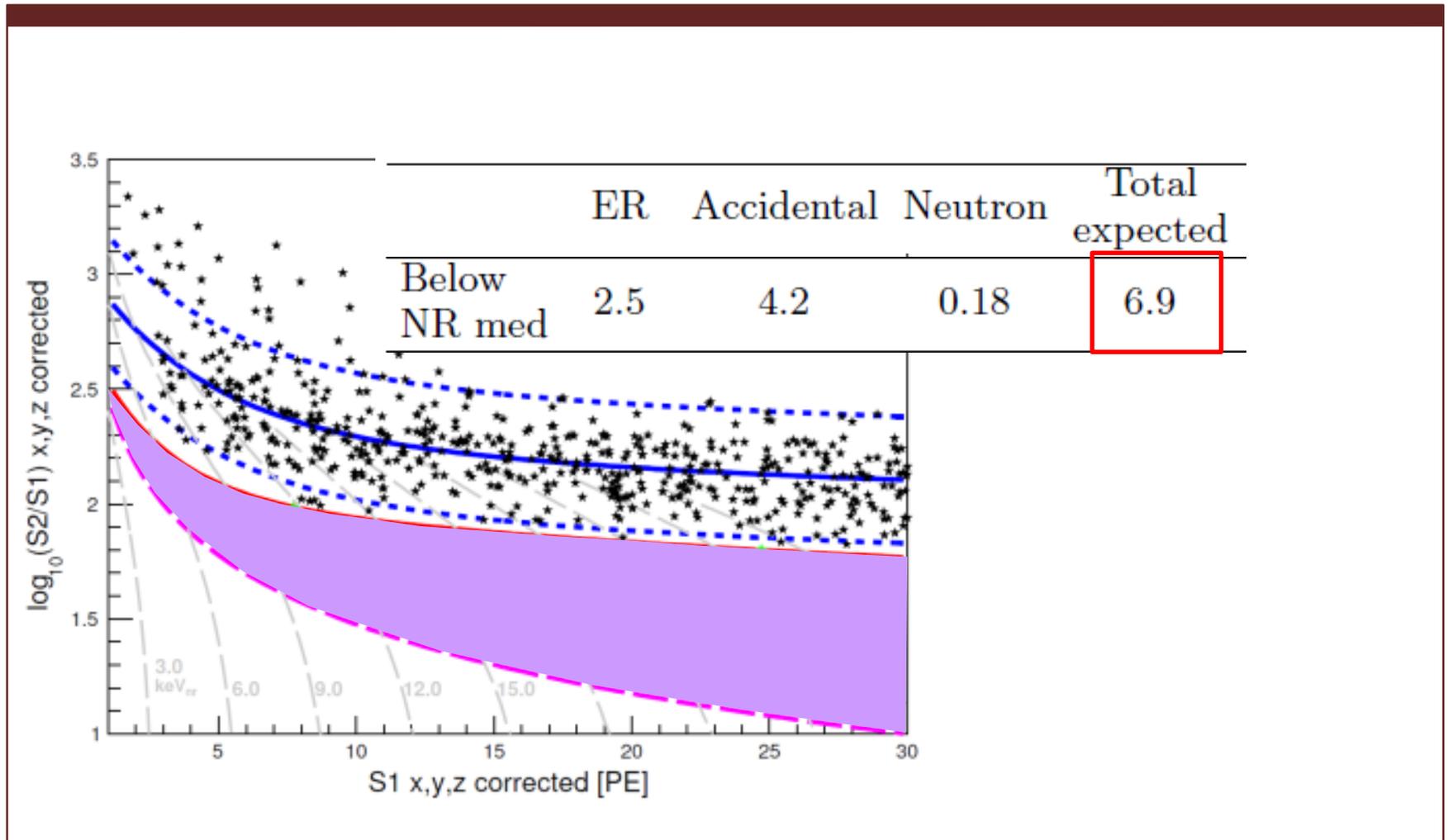
# Event vertex distributions



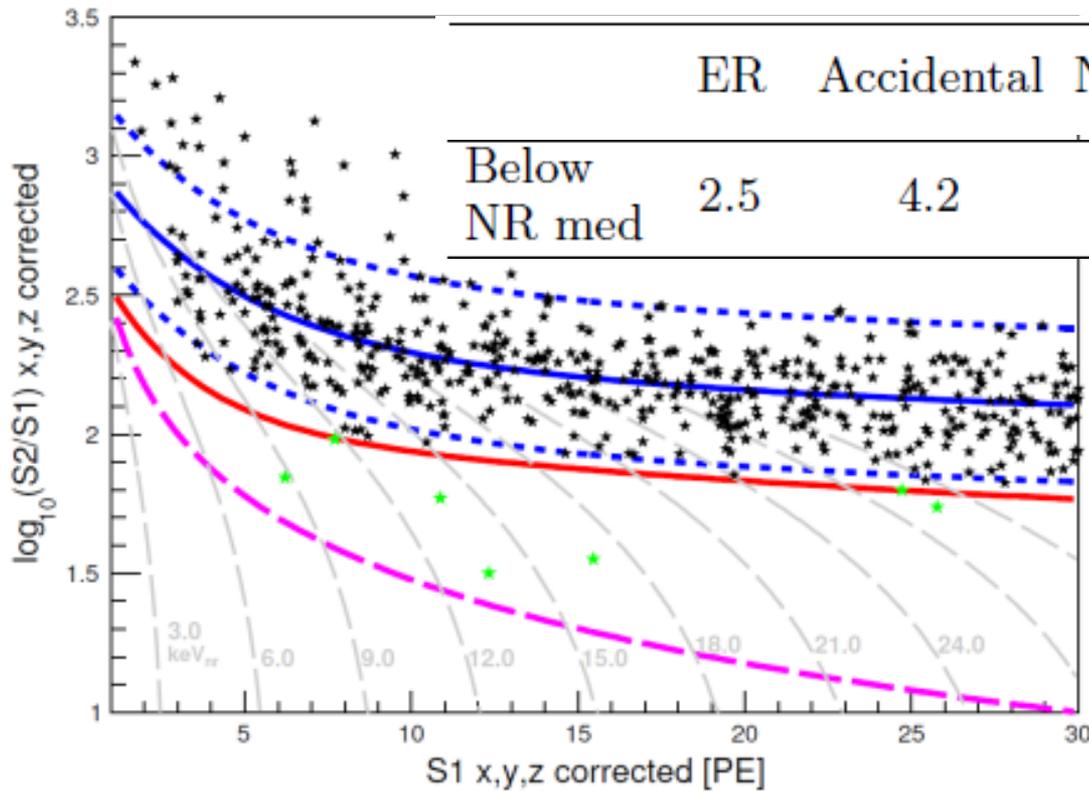
**PMT and inner vessel dominates the background budget.**



# Dark matter search data



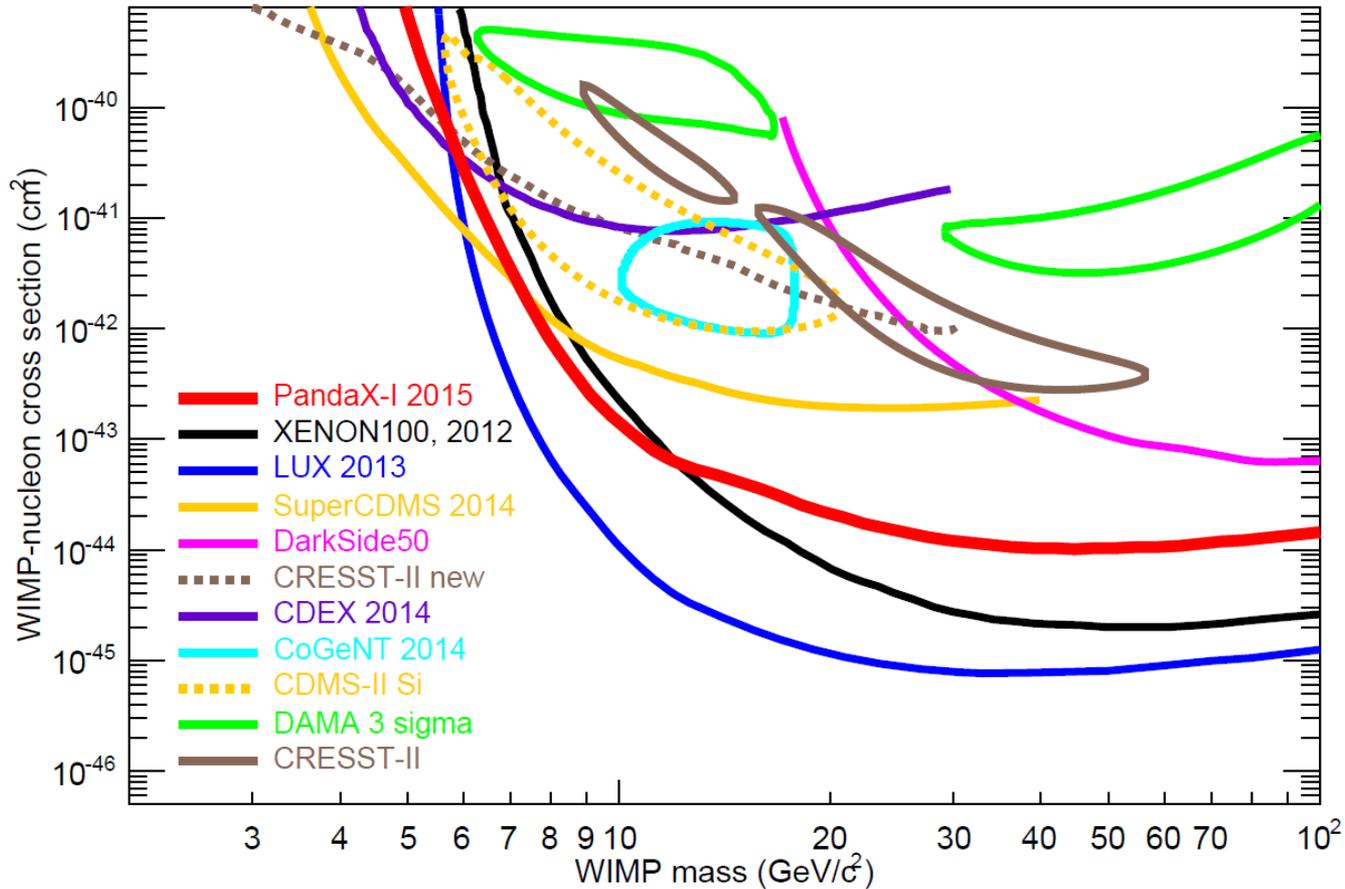
# Dark matter search data



	ER	Accidental	Neutron	Total expected	Total observed
Below NR med	2.5	4.2	0.18	6.9	7

**7 events found in the DM search region, however consistent with background expectation**

# DM limits



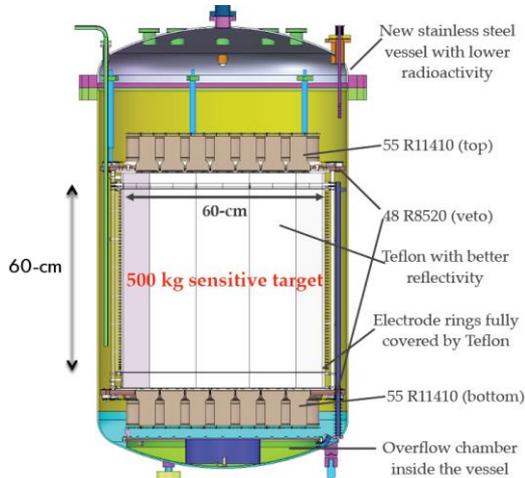
**Profile likelihood fit using DM and background distribution**

# Conclusions from PandaX-I

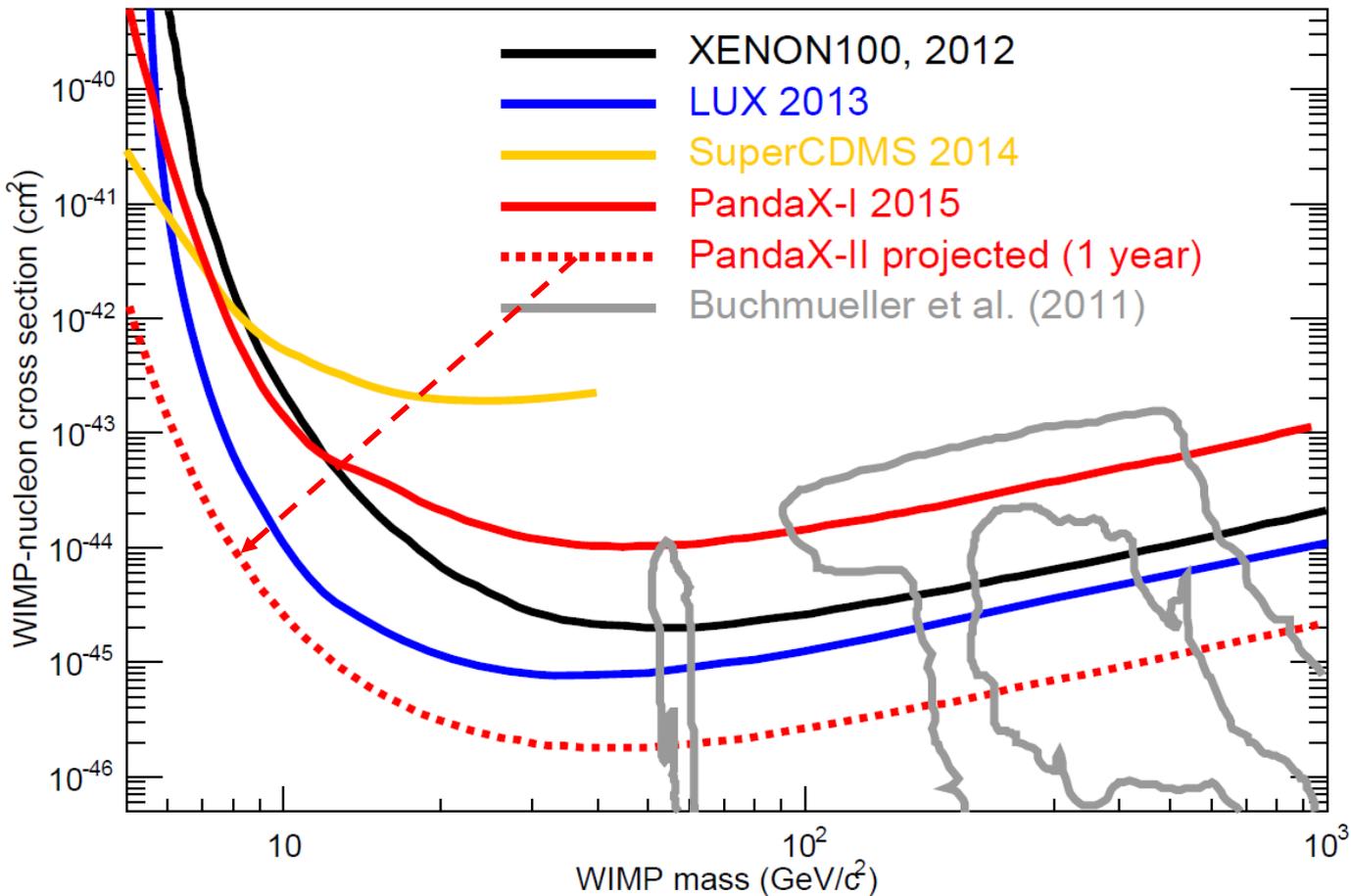
- **Full exposure results with a much more elaborated analysis confirmed the finding from the first results, **strongly disfavoring all positive WIMP claims****
- **Tighter bound than superCDMS above WIMP mass of 7 GeV/c<sup>2</sup>**
- **Best **reported** WIMP limits below 5.5 GeV/c<sup>2</sup> in xenon community**

# PandaX-II: 500 kg LXe target

- **Started construction June 2014**
- **Completed detector assembly in CJPL Mar 2015**
- **Presently under commissioning**
- **Expect to start dark matter data taking in 2015**
- **Expected running time for physics: 2 years**

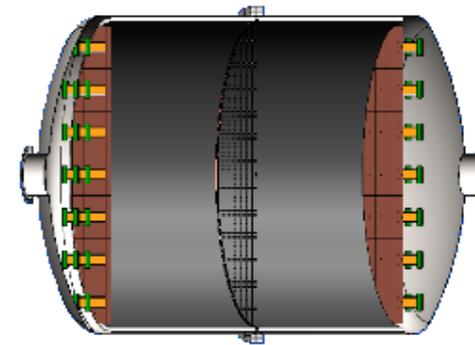


# PandaX-II: projected sensitivity

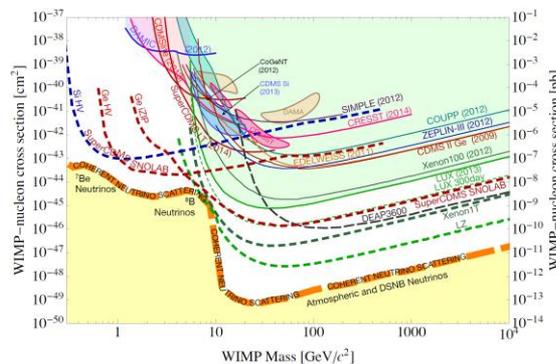


# PandaX next steps

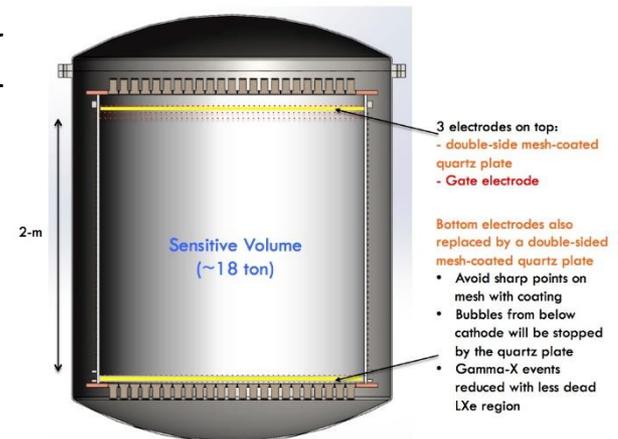
- **PandaX-III: High  $^{136}\text{Xe}$  Gas 0vDBD, 200 kg, modularized to 1-ton**



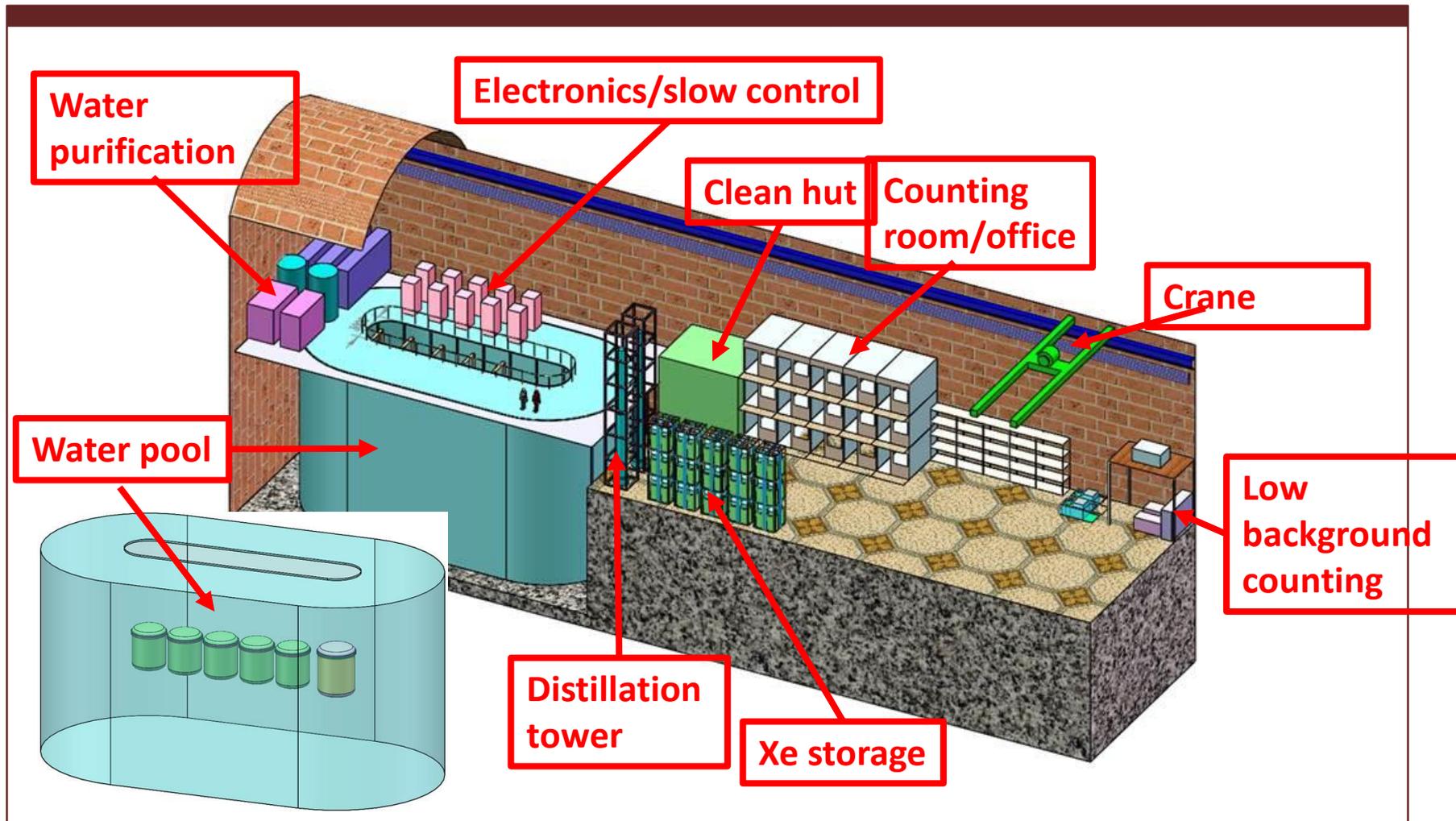
- **PandaX-IV: 20-ton LXe DM**



“Chase DM to  $\nu$ -floor”



# PandaX in CJPL-II



# Slides from Prof. Qian Yue, Tsinghua Univ.

## CDEX: China Dark matter EXperiment

Established in 2009.

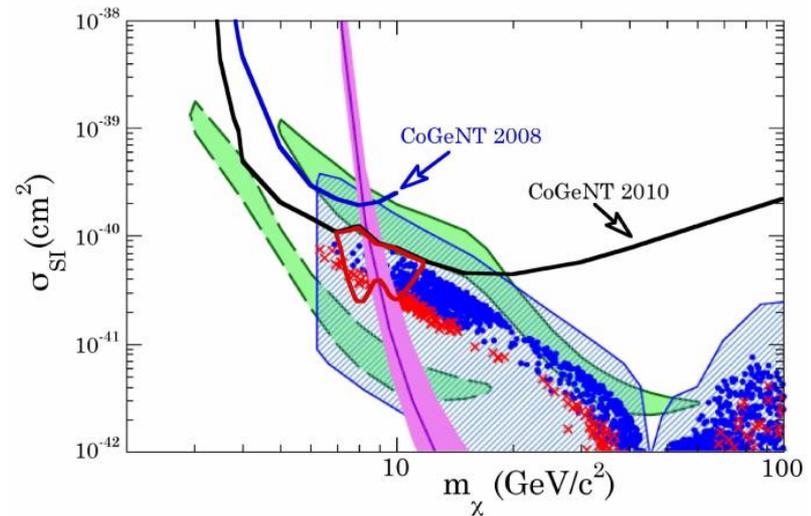
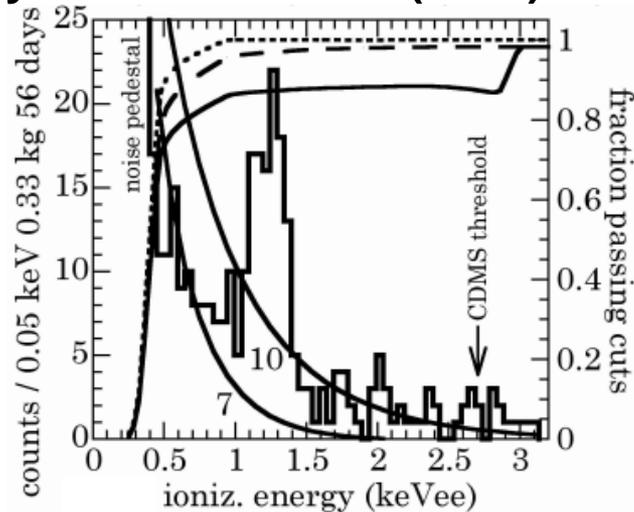
- Tsinghua University, THU
- Sichuan University, SCU
- Nankai University, NKU
- China Institute of Atomic Energy, CIAE
- Yalong River Hydropower Company, EHDC
- Collaborate with TEXONO and KIMS group.



2014年高能物理学会深地物理研讨会

# CoGEANT claim 2010

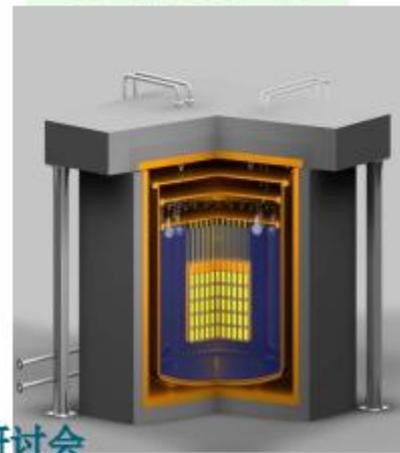
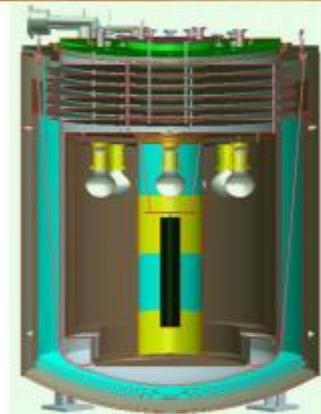
Phys. Rev. Lett. 106 (2011) 131301



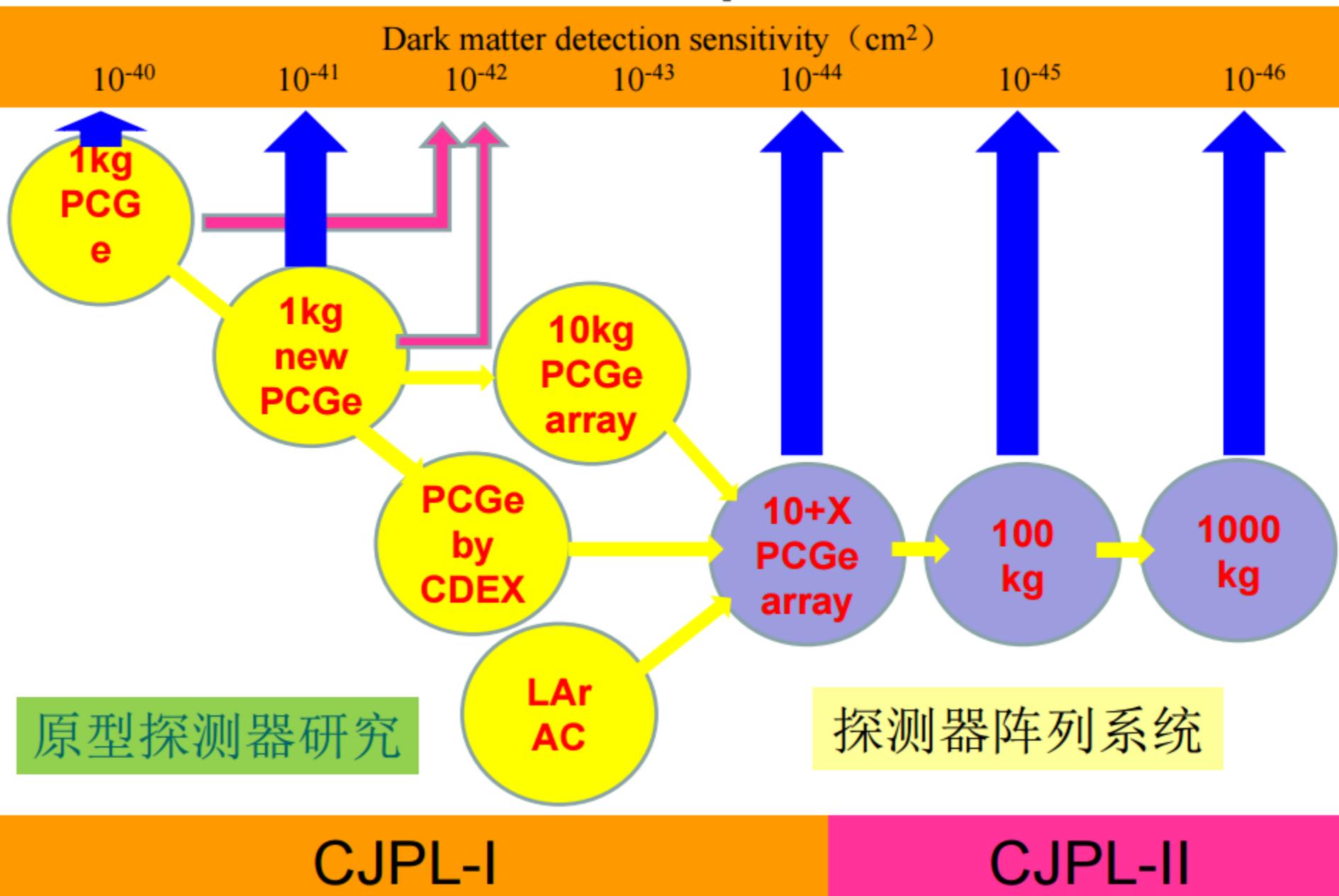
In conclusion, we presently lack a satisfactory explanation for the observed low-energy rise in a PPC spectrum devoid of most surface events. In view of its apparent agreement with existing WIMP models, a claim and a glimmer of dark matter detection in two other experiments, it is tempting to consider a cosmological origin. Prudence and past experience prompt us to continue

# CDEX development stages

- CDEX-1: Development of HPGe detector, its background understanding and the studies of its performances based on 1kg-scale-mass HPGe detector.
- CDEX-10: Performances of HPGe array detector system and its passive/active shielding systems.
- CDEX-10X: Fabrication of HPGe detector and Germanium crystal growth by CDEX.
- CDEX-1T: Multi-purpose experiment for dark matter and double beta decay.
- CDEX@CJPL



# CDEX plan



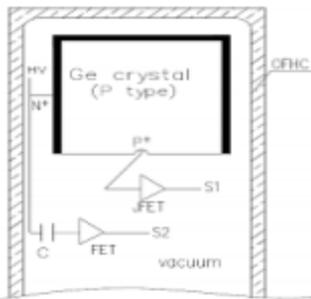
# CDEX-1 experiment

## 1. HPGe technology

- ✓ Designed the first one single module 1kg-scale p-type point-contact Ge detector (1kg-PPCGe) “prototype” C1A
- ✓ Improved the second 1kg-PPCGe C1B

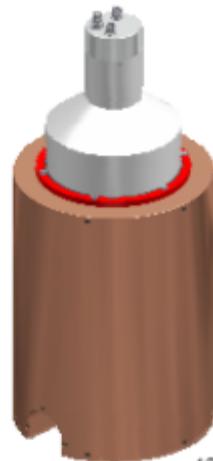
## 2. Active shielding technology: NaI(Tl) used as anti-Compton detector

- ✓ C1A 1kg-PPCGe run (2012-2013)
- ✓ C1A 1kg-PPCGe + NaI(Tl) run (Now)

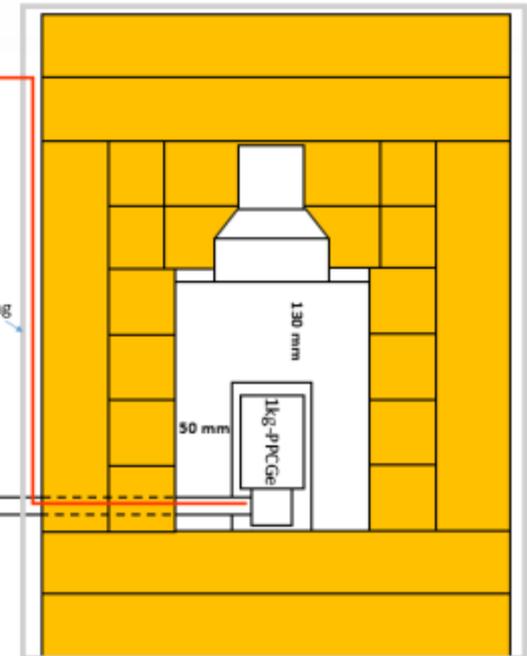


CJPL

1kg-PPCGe

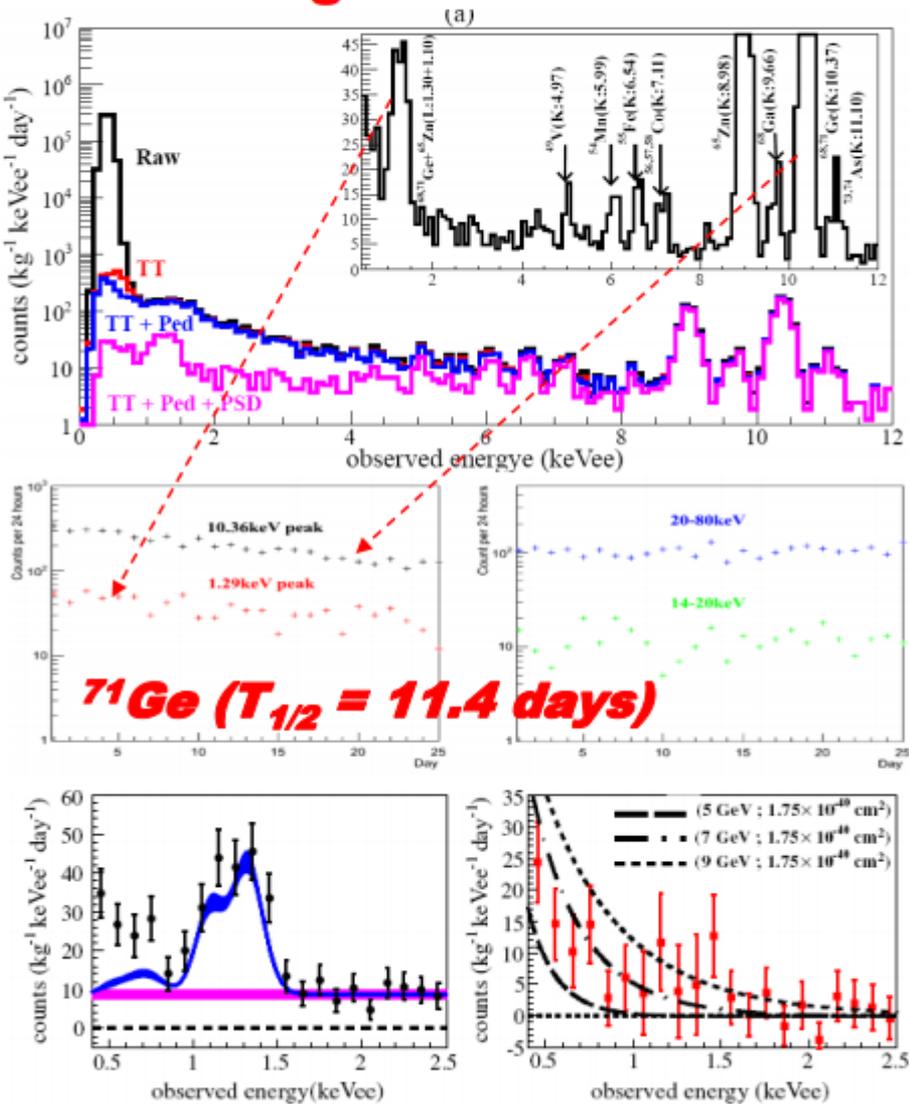


NaI(Tl)

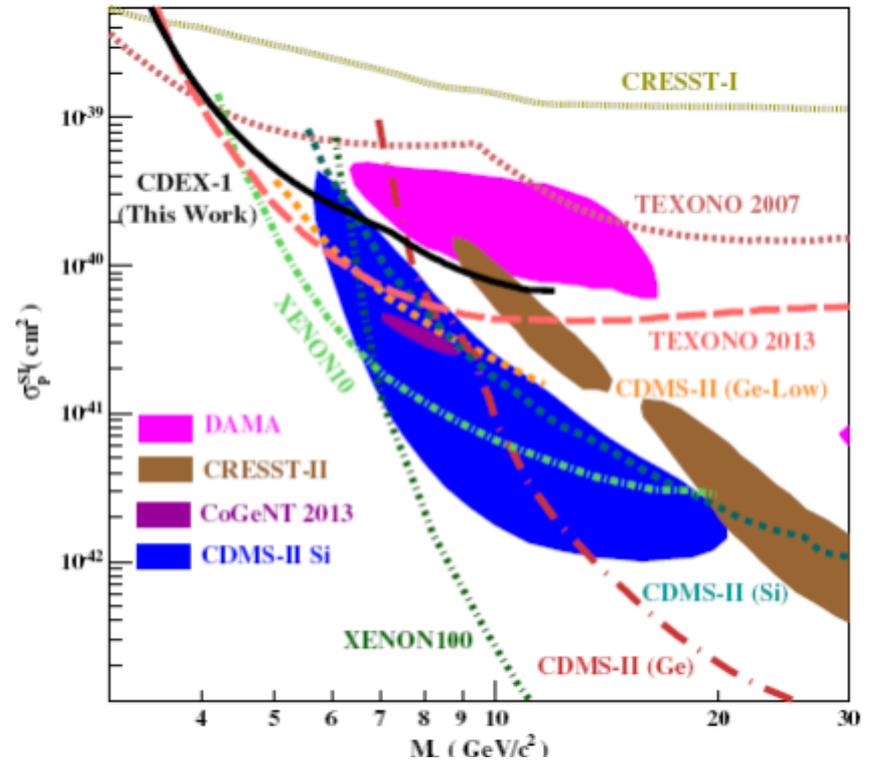


# CDEX-1 experiment

## C1A 1kg-PPCGe



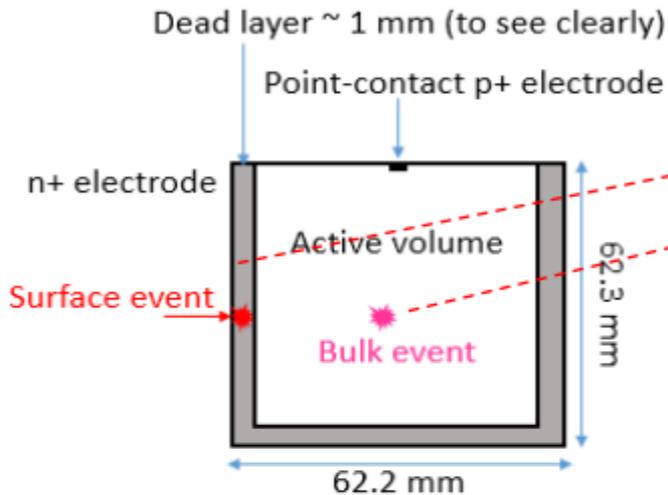
W. Zhao et al., Phys. Rev. D 88, 052004 (2013);



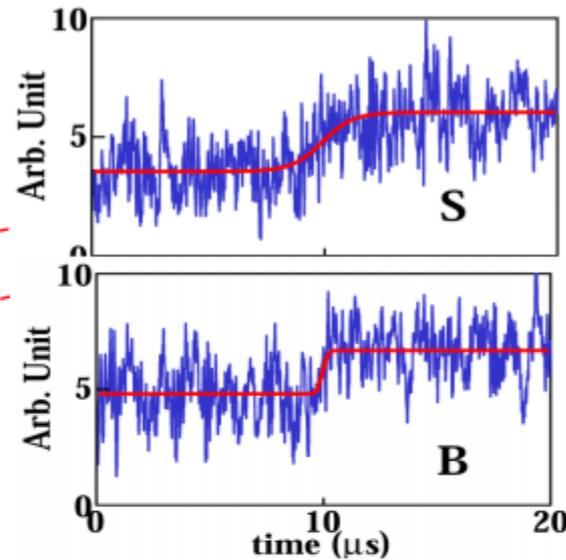
- The first dark matter physics results from mainland China
- The lowest energy threshold for PCGe in the world

✓ Energy threshold ~400eV! 201

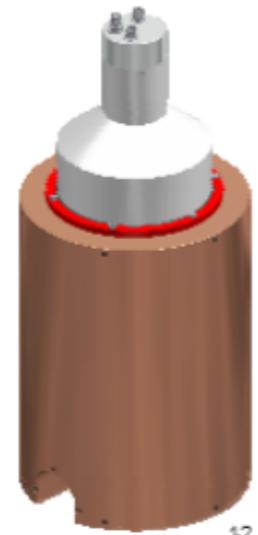
# CDEX-1 experiment from 2013



**pPCGe detector**



**Risetme  $\tau$**



**NaI(Tl) AC detector**

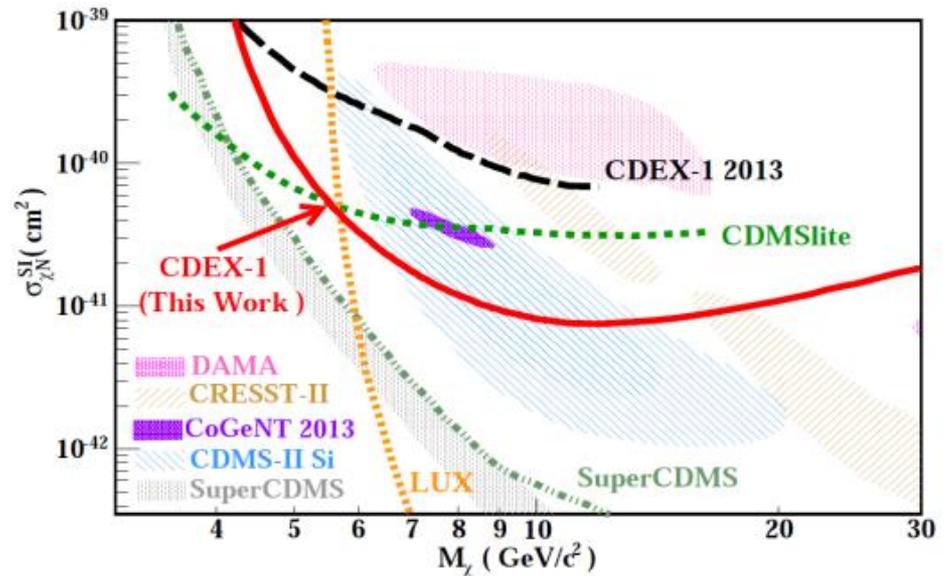
## **CDEX-1 upgrade in 2013:**

- **C1A 1kg-PPCGe + NaI(Tl)**
- **Bulk/Surface Discrimination**

# CDEX-1 2014 new results

## CDEX-1 physical results

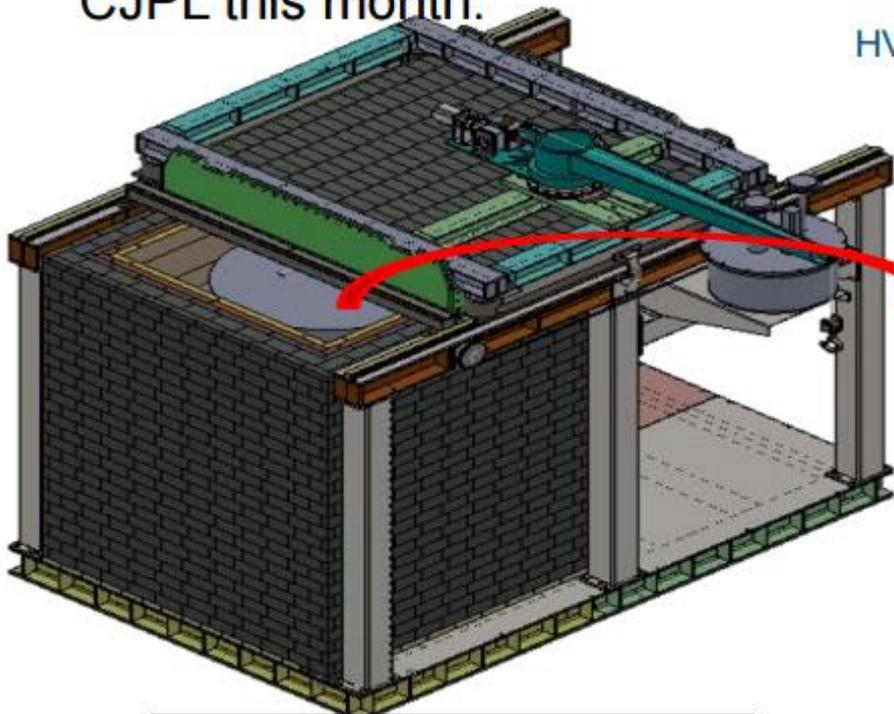
**Arxiv:1404.4946**  
**20141010 accepted by**  
**Physical review D**  
**(Rapid Communication)**



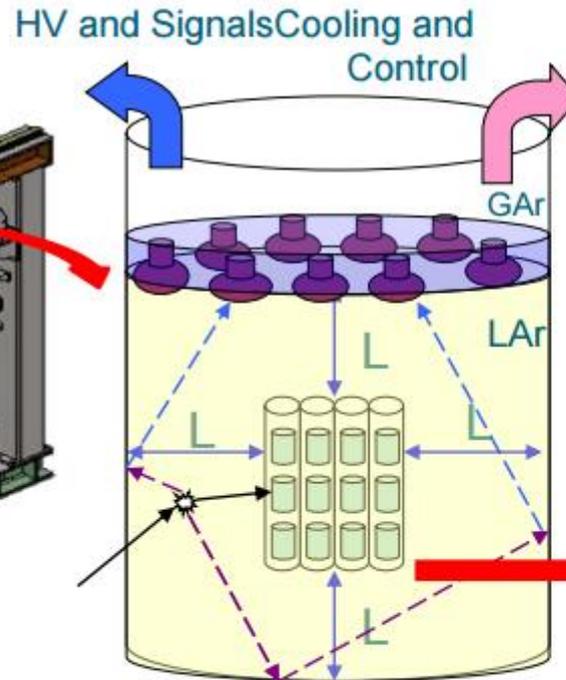
**Identical detector technology as CoGENT**

# CDEX-10 experiment

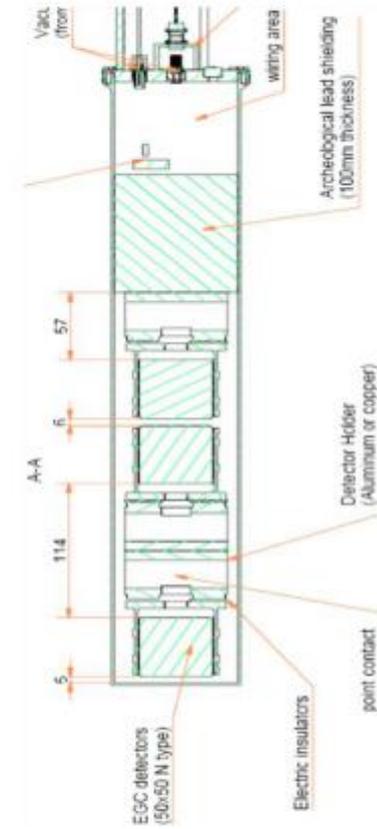
- The important stage towards tonne-scale Ge experiment!
- PCGe array and LAr passive shielding + active shielding.
- Finished ground testing of PCGe detector and test at CJPL this month.



**CDEX-10 experimental**



**10kg-PCGe +**



**3-PCGe elem**

# CDEX-10 高纯锗晶体阵列性能测试



# CDEX-1T –HPGe Detector



Vacuum  
Coating  
Machine



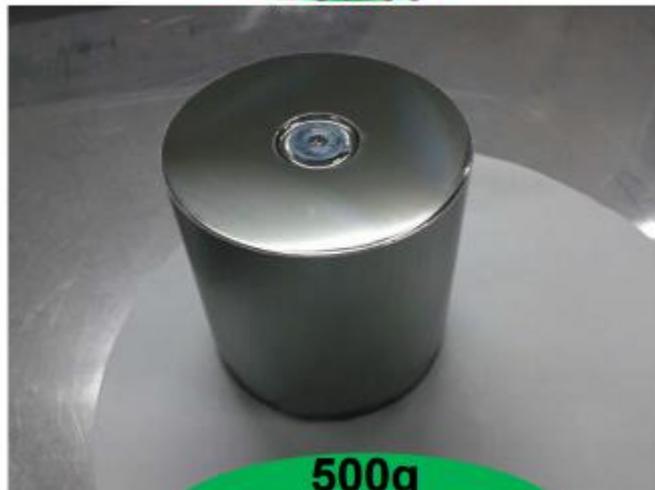
Magnetron  
Sputtering  
Device



Boron  
Implant  
Accelerator



10g Planar-  
Ge



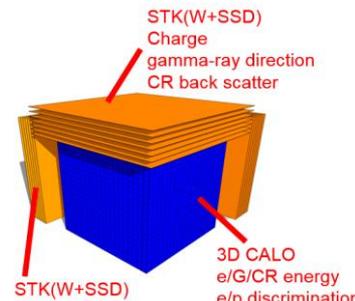
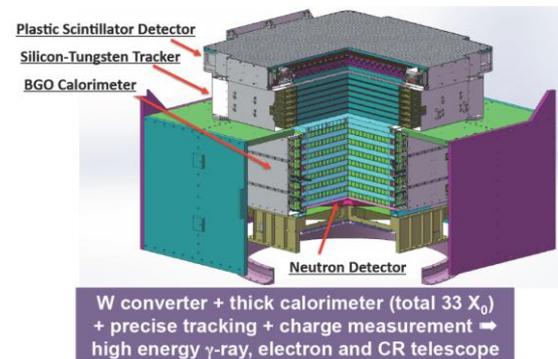
500g  
PGG  
(testing)



Front-  
electronics

# My big apologies to projects in China that I did not cover

- **Future Ar dark matter experiment in CJPL (IHEP, collaborating with DarkSide)**
- **Indirect dark matter search in space**
  - **DAMPE (launching 2015)**
  - **HERD in Chinese space station (2020-2021)**
- **LHC search, etc ...**



# Summary

- **In the past 5 years, China has developed a vibrant dark matter search community**
- **Direct detection experiments, PandaX and CDEX, have made steady progress in CJPL**
  - **PandaX-I (120 kg) has completed with results strongly disfavoring all positive WIMP claims, with good sensitivity to low mass WIMP**
  - **CDEX-1 unambiguously in conflict with CoGENT with better sensitivity at low mass**
- **PandaX-II and CDEX-10 underway, further upgrade lining up, and CJPL-II evacuation underway, stay tuned for future excitement!**

- **Thank you for your attention!**
- **Thanks CJPL and people working in the DM community in China, making all the progress possible!**
- **Thanks Prof. Qian Yue for the slides!**

