Dark Matter Search in China and Prospect

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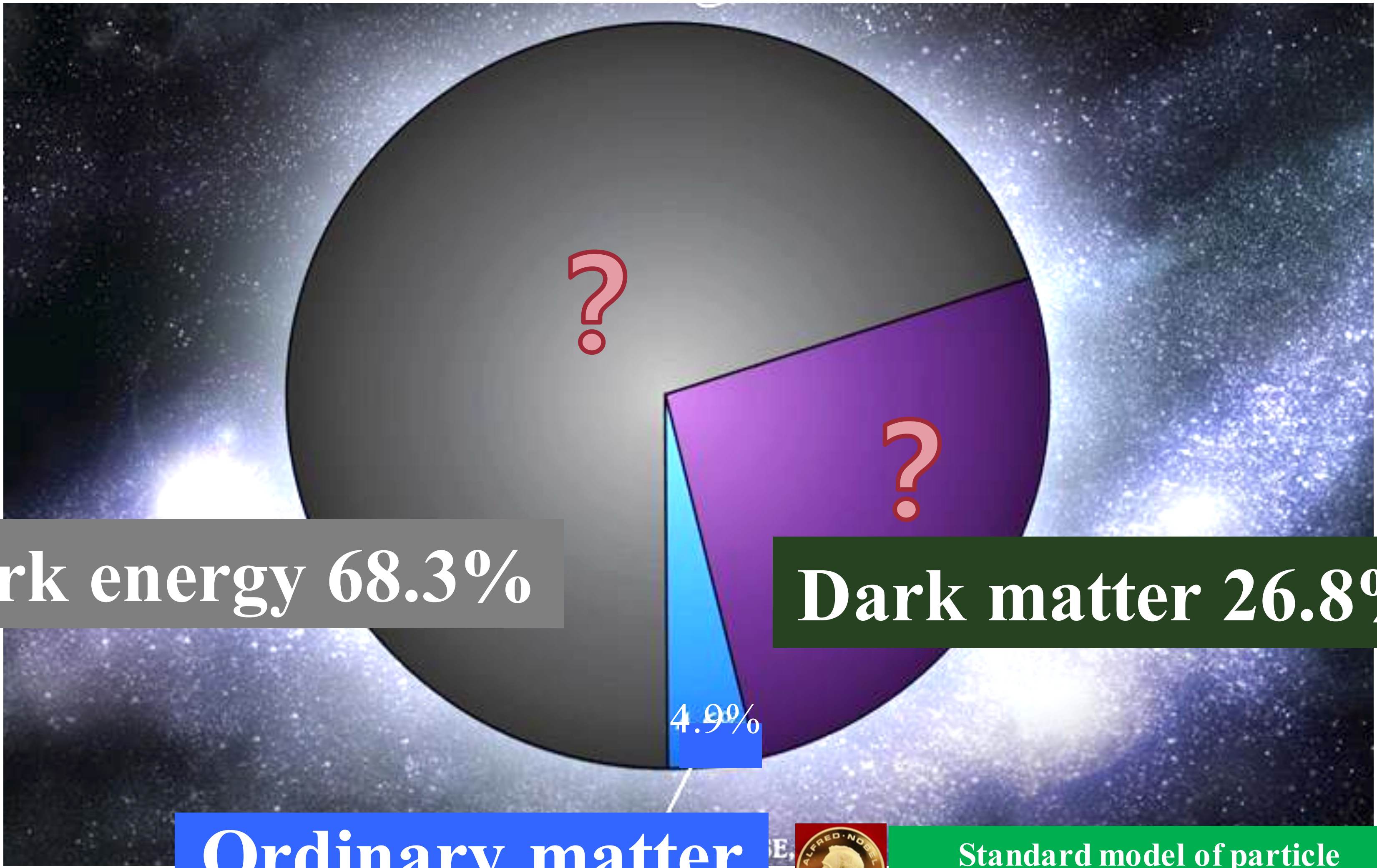
Shanghai Jiao Tong University

05NOV2016, Shanghia

Outline

1. Background
2. **PandaX**
   - PandaX-I,II,II,&IV
3. **CDEX** (China Dark Matter Exp.)
4. **DAMPE**(Dark Matter Particle Explorer)
5. **Exotic Bosons** searches by NMR
   - Axion/Dark Photon…
6. Summary

The Mass in Our Universe



Dark energy 68.3%

Dark matter 26.8%

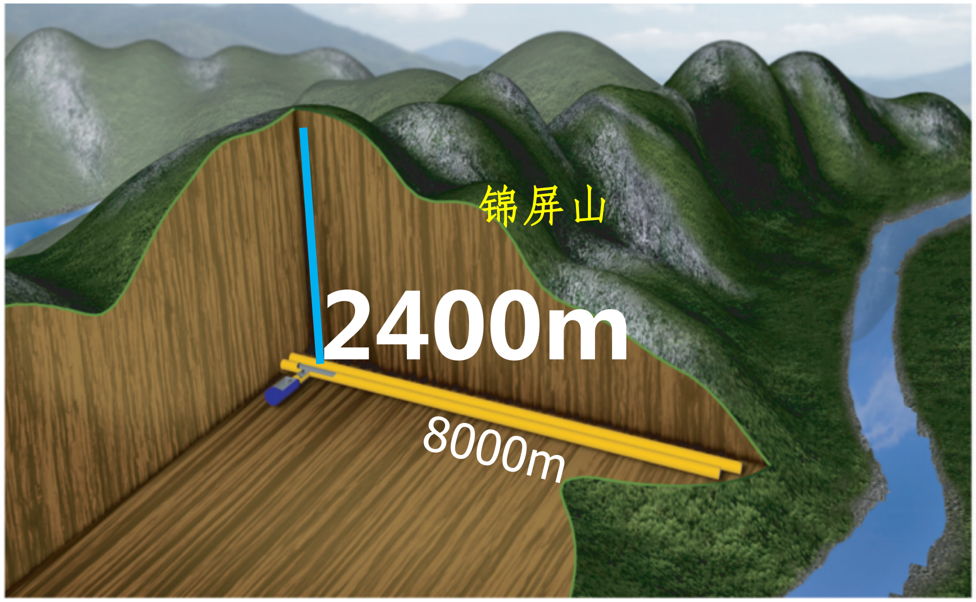
Ordinary matter

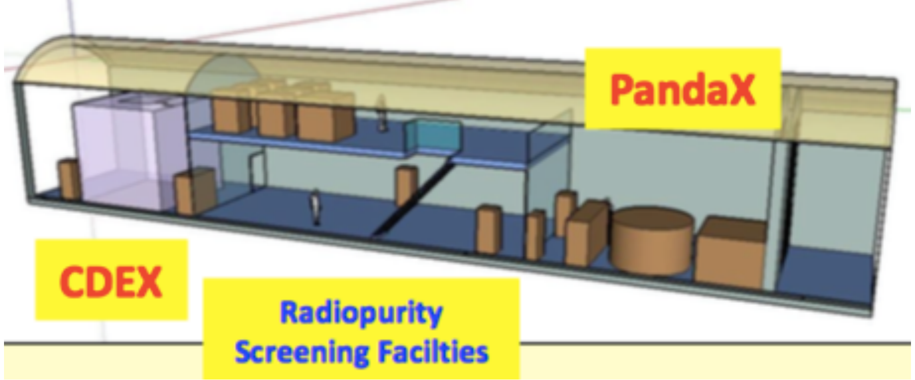
Standard model of particle physics, 16 times Nobel Prize

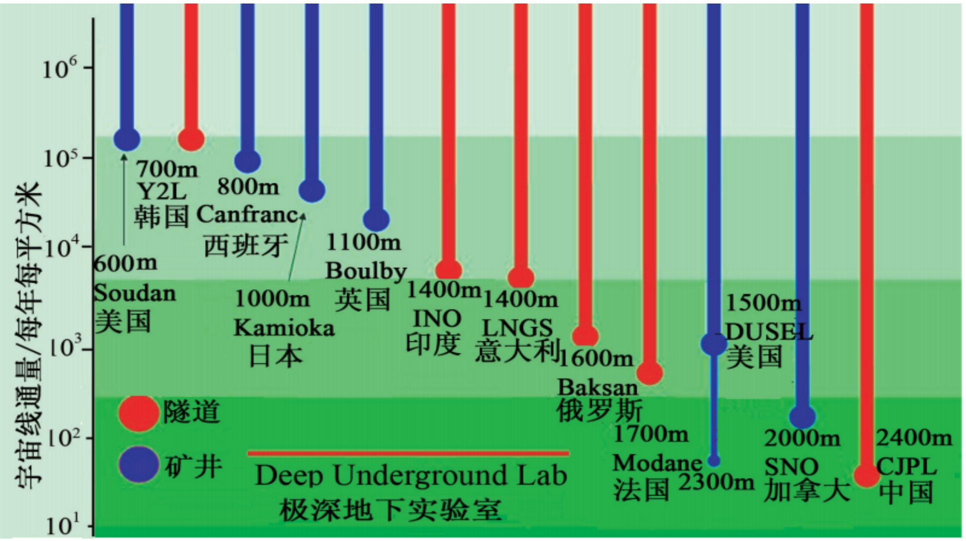
China JinPing Underground Laboratory

Deepest in the world (1μ/week/m²) and Horizontal access!

Zhongdian
中 甸
Xichang
西 昌


锦屏山
2400m
8000m


PandaX
CDEX
Radiopurity Screening Facilties

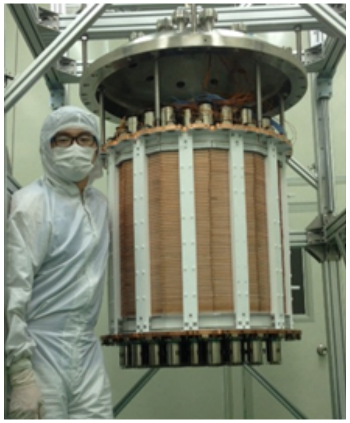


PandaX Experiment Timeline

PandaX＝Particle and Astrophysical Xenon Experiments

PandaX-I: 120 kg
DM experiment
2009-2014

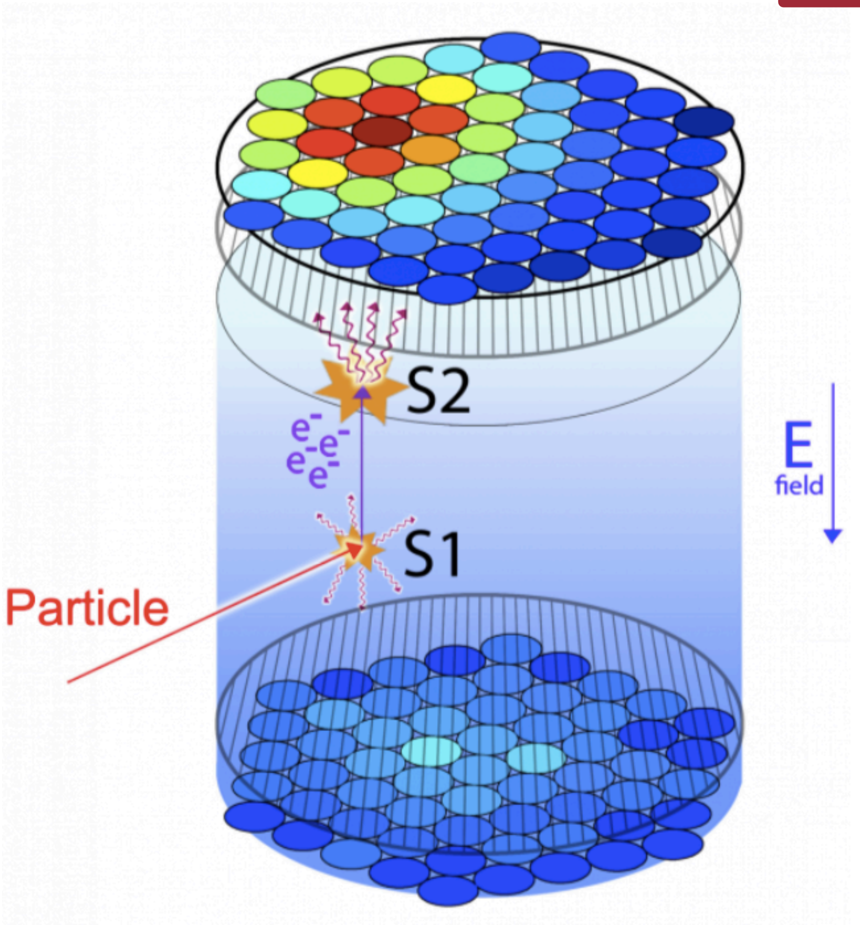
Phys. Rev. D **92**, 052004(2015)

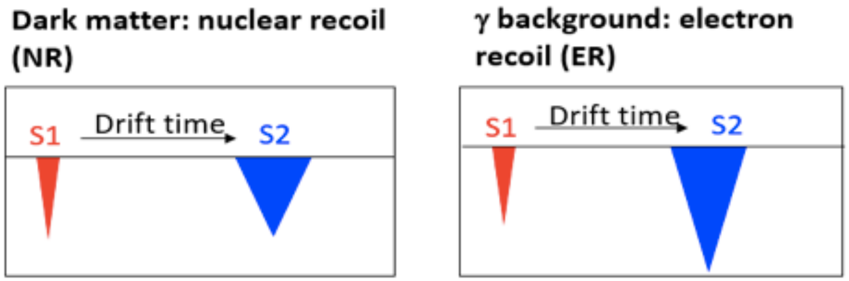


PandaX-II: 500 kg
DM experiment
2014-2017

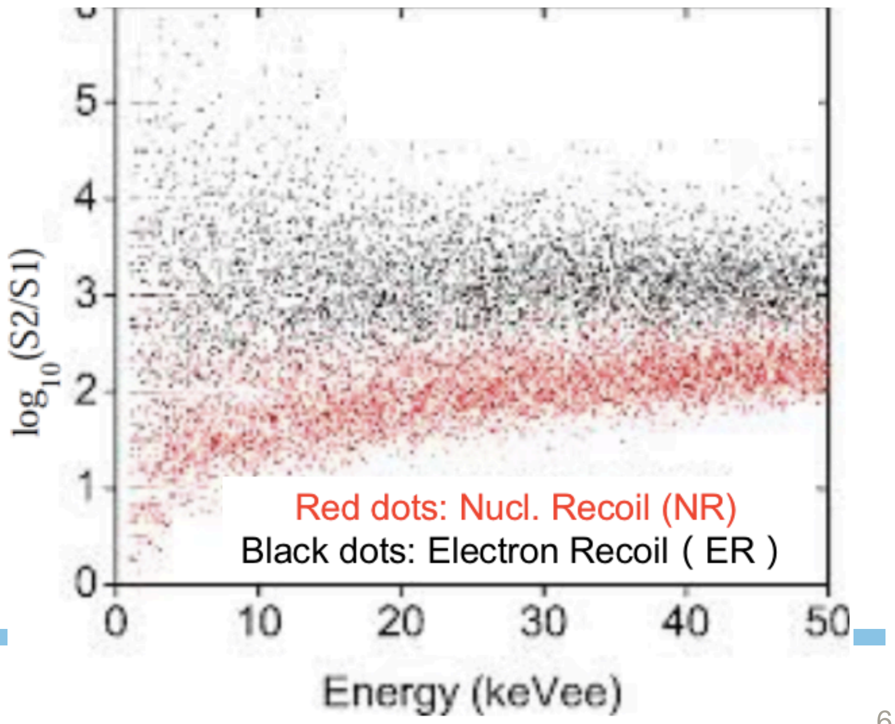
Dual phase xenon TPC

“Nuclear Recoil (NR)” and “Electron Recoil(ER)”


S2
e⁻ e⁻ e⁻ e⁻
S1
Particle
E
field


Dark matter: nuclear recoil (NR)
S1
Drift time
S2
γ background: electron recoil (ER)
S1
Drift time
S2

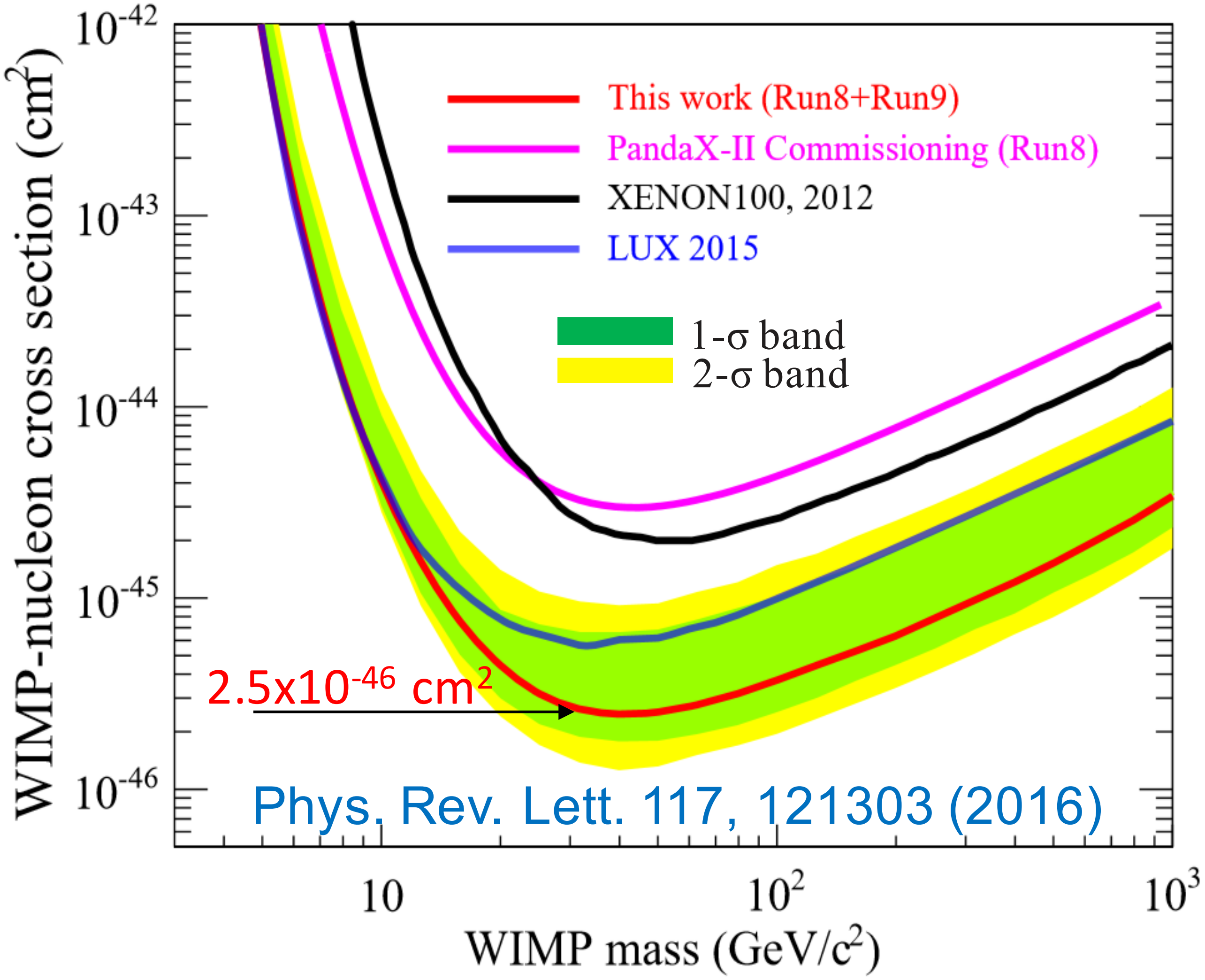
$(S2/S1)_{NR} << (S2/S1)_{ER}$



PandaX-II Running History

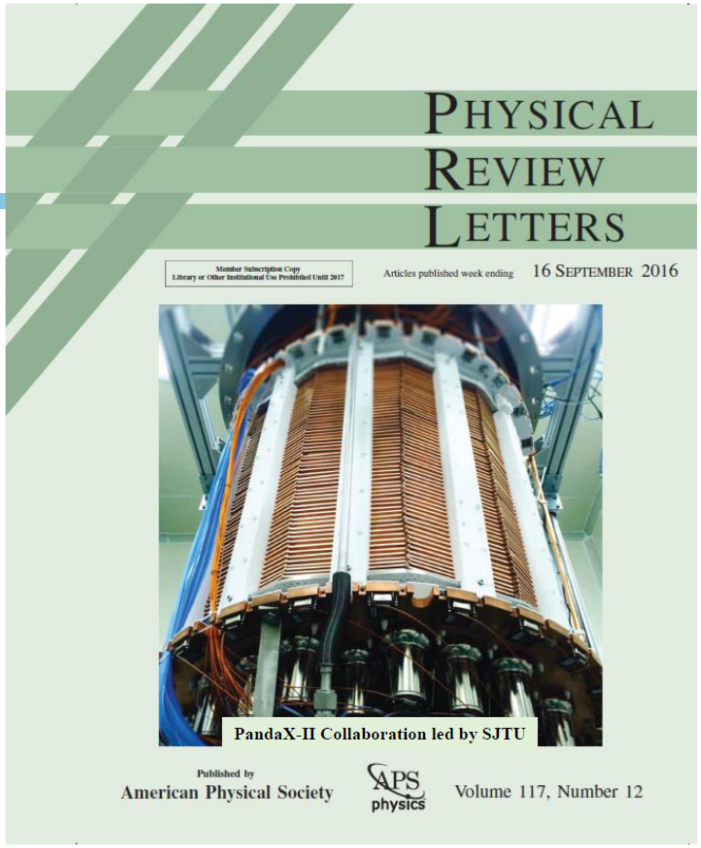
- **Enginnering Running**： from the beginning of 2015, Fix various problems
- **DM Running I(Run8)**： 2015.11. 22 – 12.14 (**19.1**days 306 kg， FV) with high Kr background (Phys. Rev. D. 39, 122009 (2016))
- **DM Runing II (Run9)**：Re-distillation to remove Kr, 2016.03.09 — 06.30 **(79.6 days)** PhysRevLett.117.121303
- **DM Running III**：Running Now!

Final results



2.5x10^{-46} cm^2

Phys. Rev. Lett. 117, 121303 (2016)



PHYSICAL REVIEW LETTERS

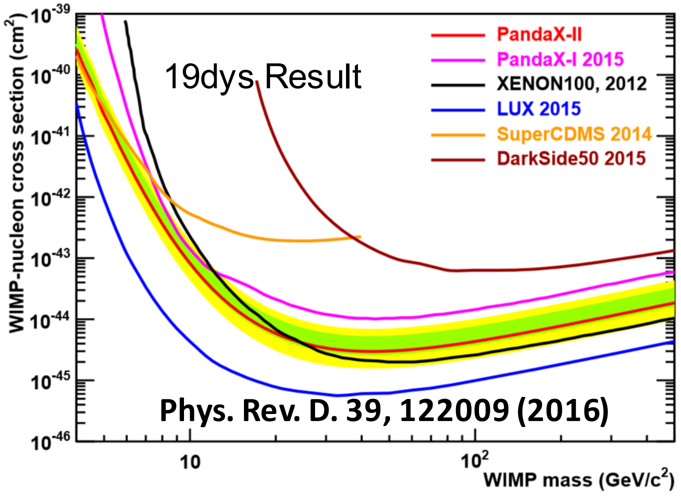
Articles published week ending 16 SEPTEMBER 2016

PandaX-II Collaboration led by SJTU

Published by American Physical Society

APS physics

Volume 117, Number 12



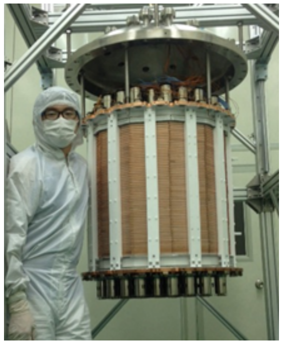
19dys Result

Phys. Rev. D. 39, 122009 (2016)

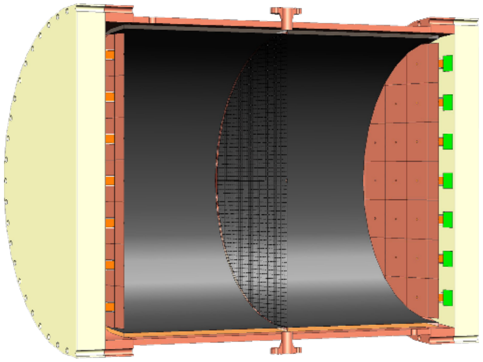
PandaX Upgrading

PandaX＝Particle and Astrophysical Xenon Experiments

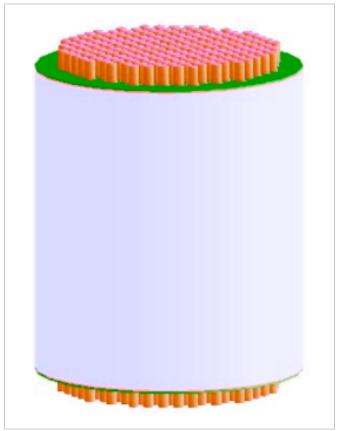
PandaX-I: 120 kg
DM experiment
2009-2014



PandaX-II: 500 kg
DM experiment
2014-2017

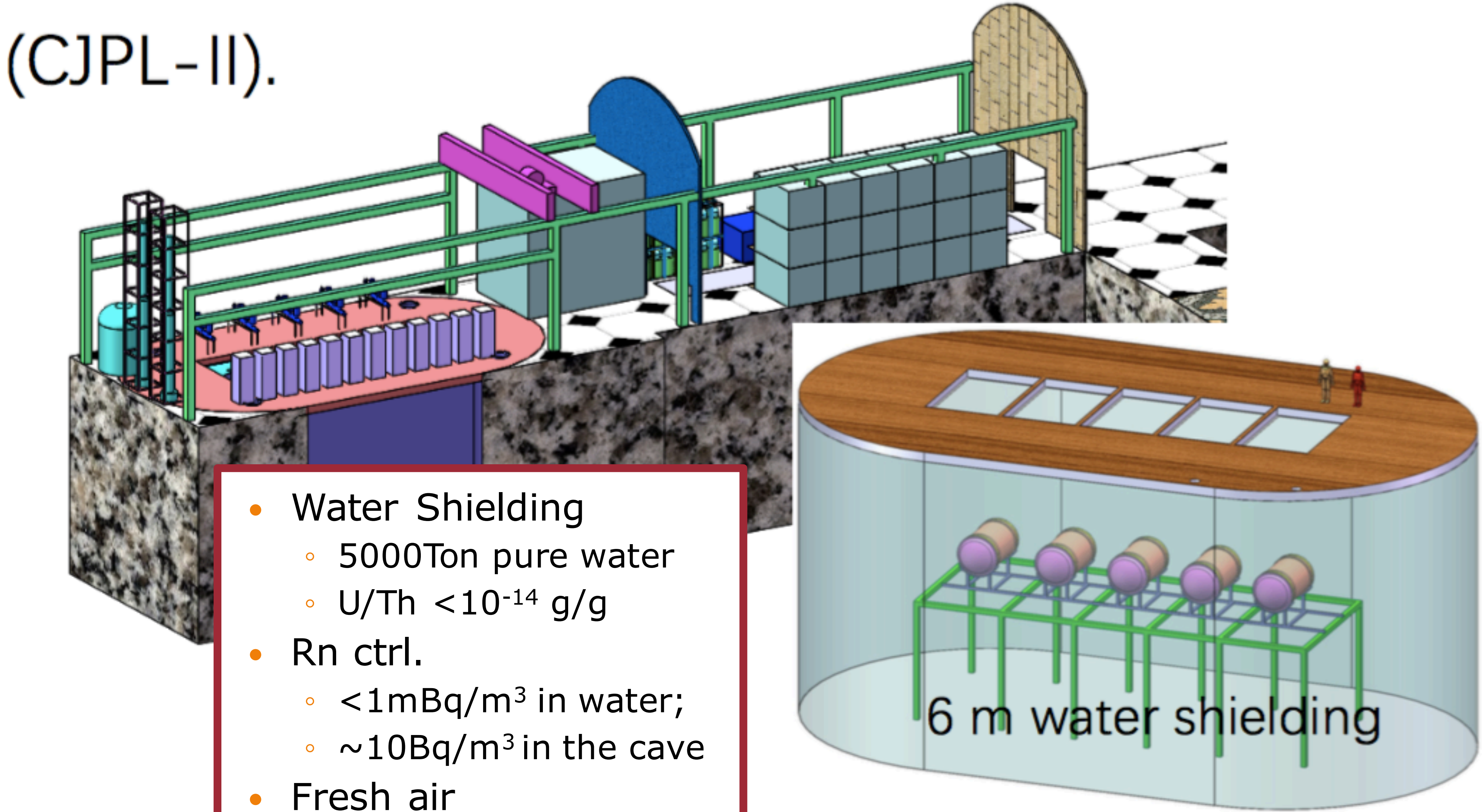


PandaX-III: 200 kg
to 1 ton ^{136}Xe
0vDBD experiment
2016-



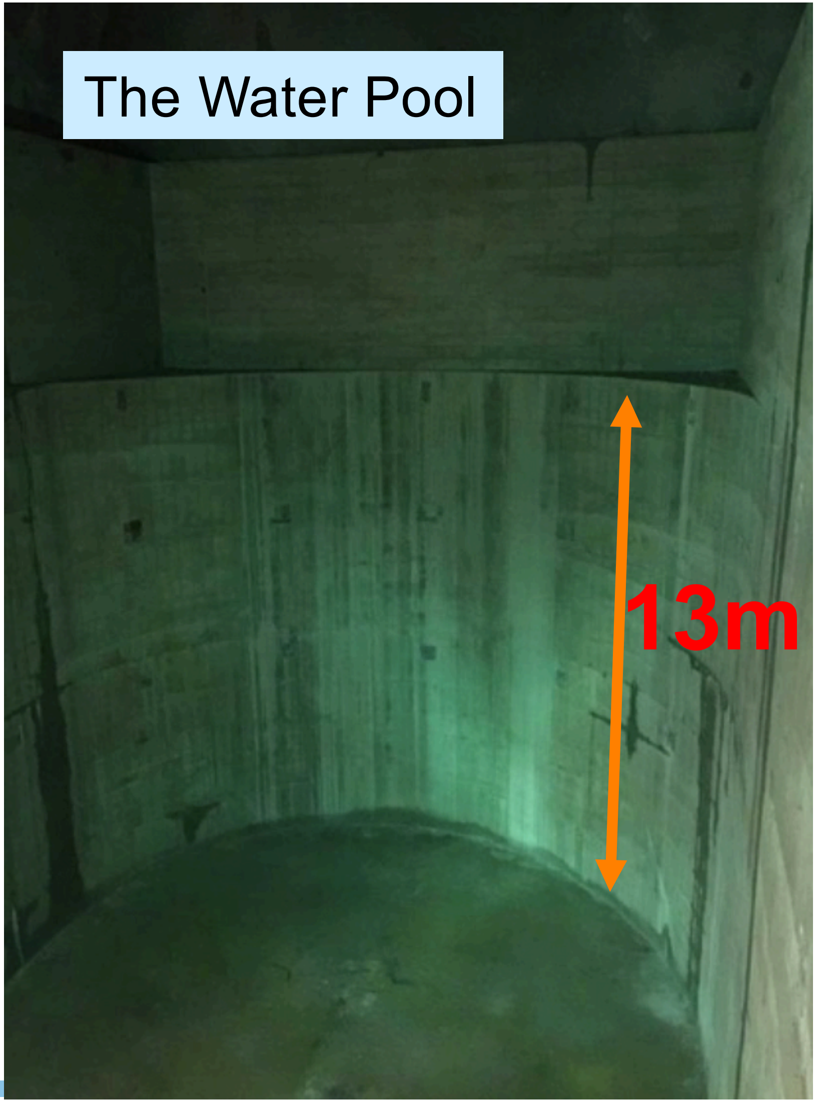
PandaX-xT:
multi-ton DM
experiment
2016-

PandaX Upgrading


(CJPL-II).
6 m water shielding

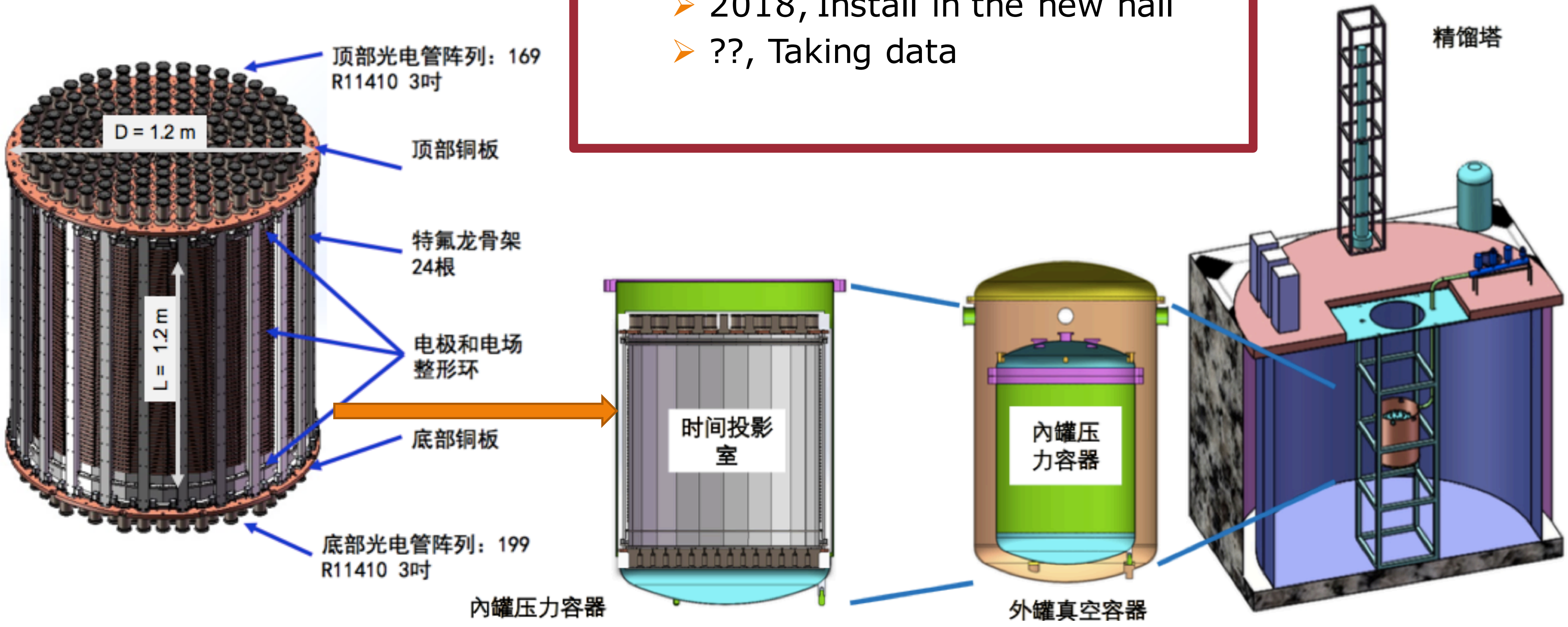
- Water Shielding
  - 5000Ton pure water
  - U/Th $<10^{-14}$ g/g
- Rn ctrl.
  - <1mBq/m^3 in water;
  - ~10Bq/m^3 in the cave
- Fresh air

The New Exp. Hall, updates


The Water Pool
13m

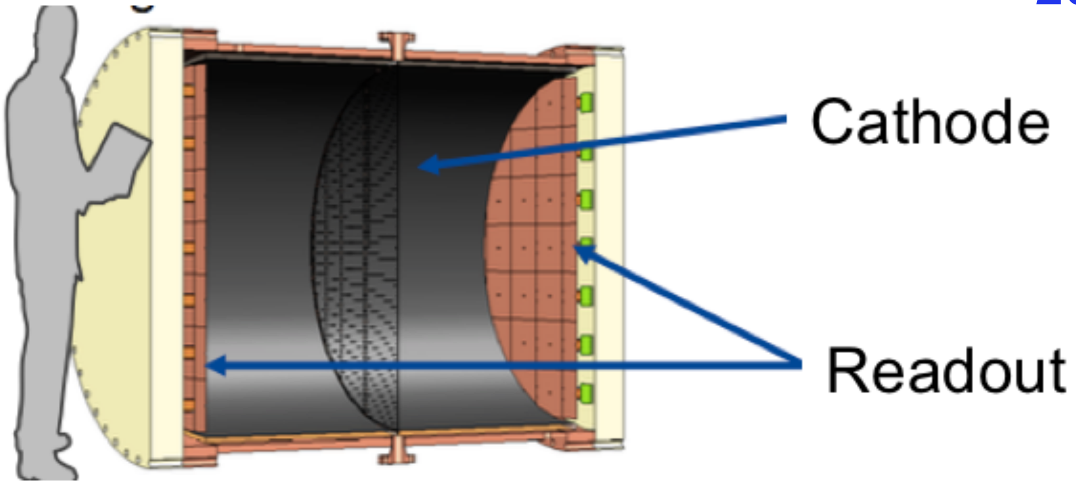
PandaX-IV: 4Ton DM

- 2016 , R&D
- Plan
  - 2018, Install in the new hall
  - ??, Taking data

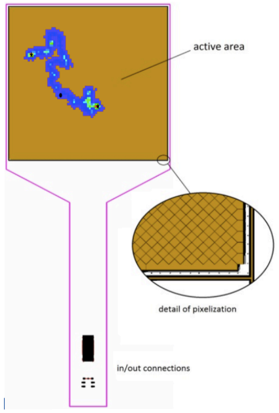

顶部光电管阵列：169
R11410 3吋
D = 1.2 m
顶部铜板
特氟龙骨架
24根
L = 1.2 m
电极和电场
整形环
底部铜板
底部光电管阵列：199
R11410 3吋
時间投影
室
內罐压力容器
內罐压
力容器
外罐真空容器
精馏塔

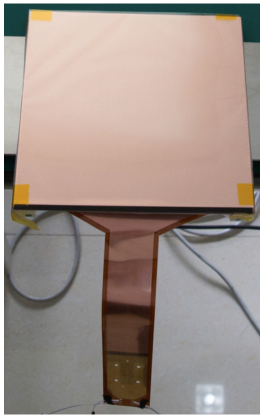
PandaX-III ^{136}Xe 0VBB (zero neutrino double beta decay)

200kg, TPC, double side reading:

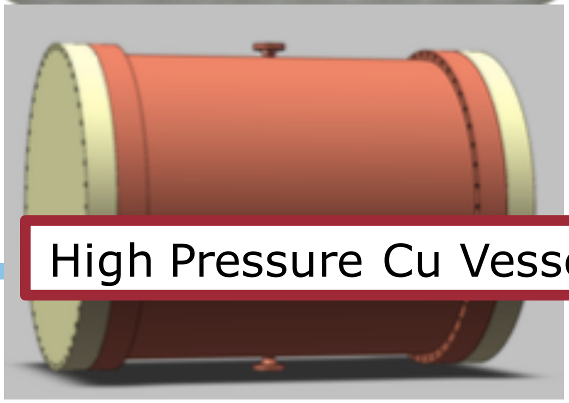

Cathode
Readout

- **3%** FWHM, Energy Resolution
- Position Sensitive
- Expect: $T_{1/2} > \mathbf{10^{26} y}$ (90%C.L.)
- Rescale


active area
detail of pixelization
in/out connections

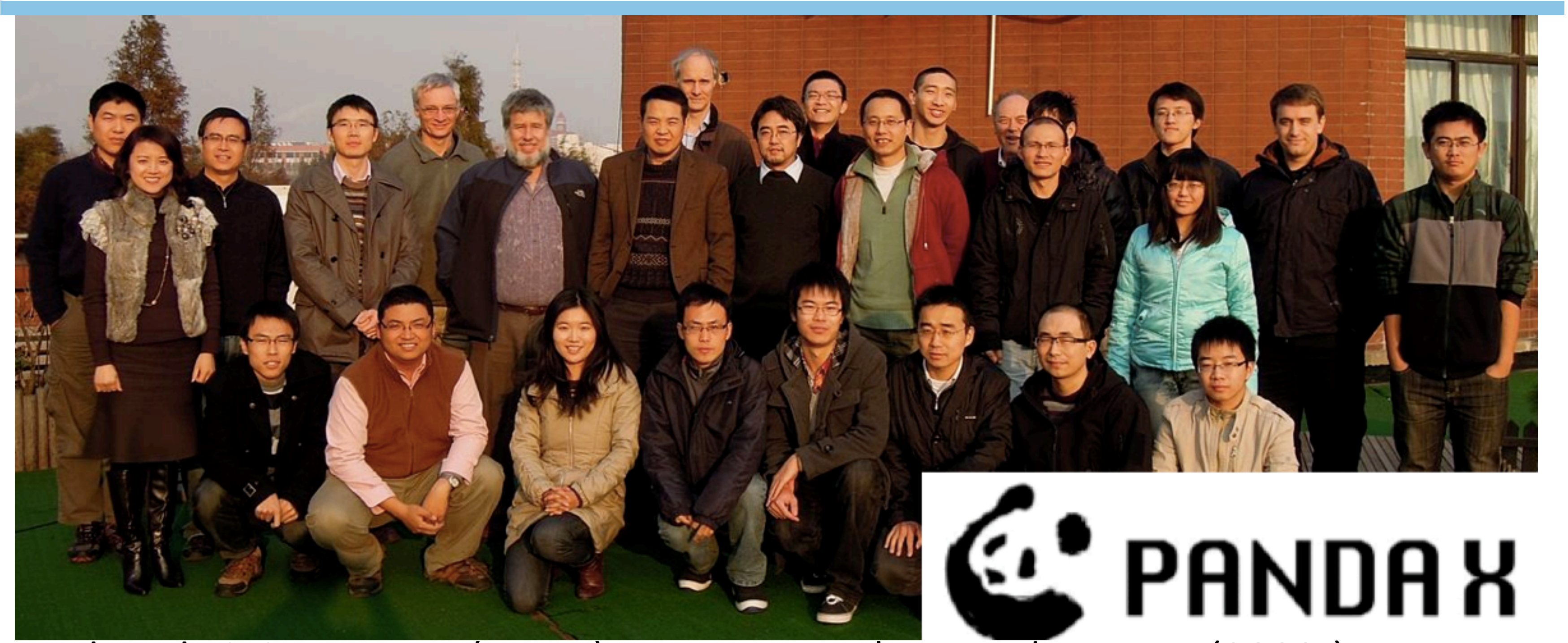


150Kg Xe136(90%)



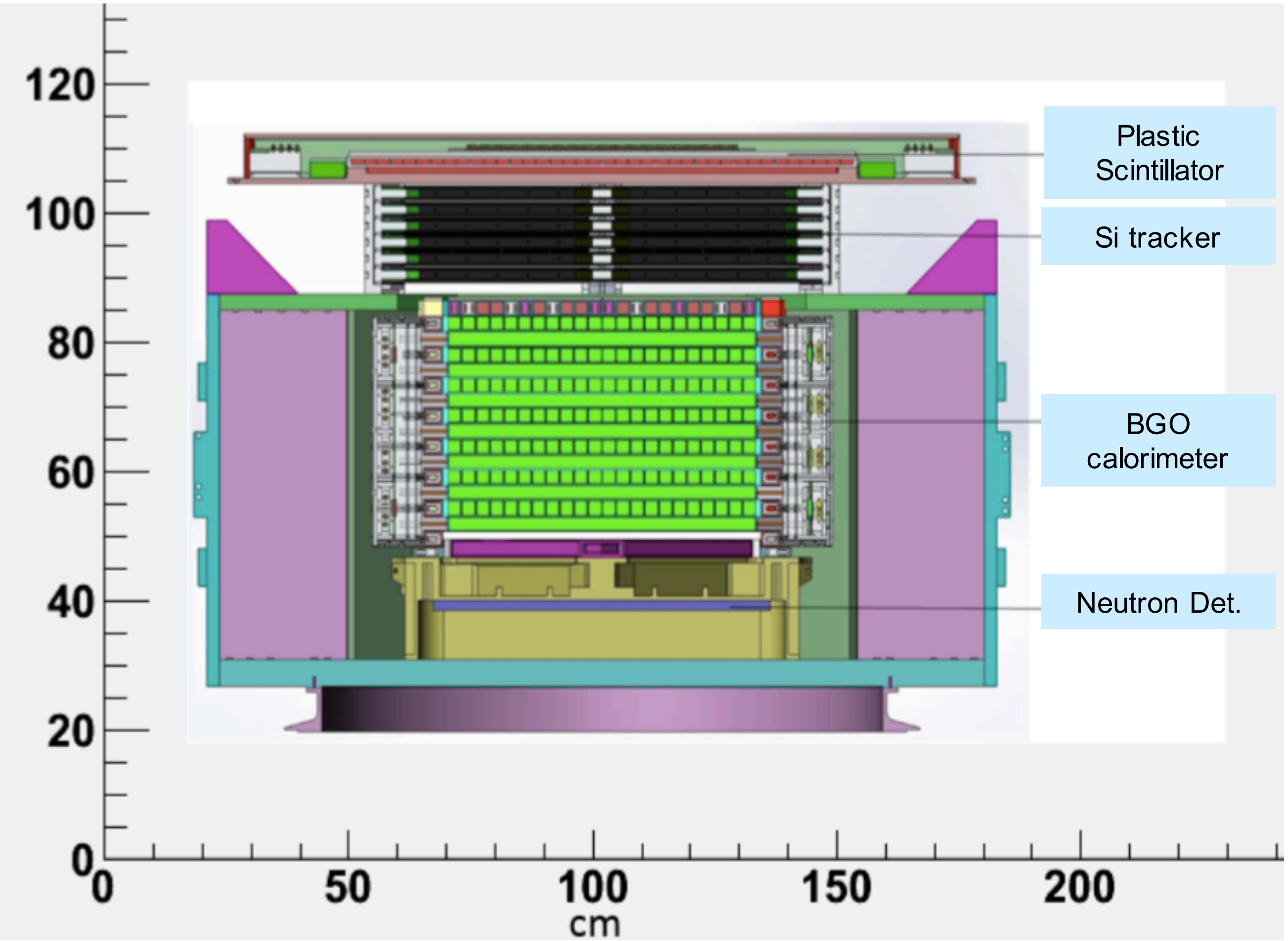
High Pressure Cu Vessel

PandaX Collaboration

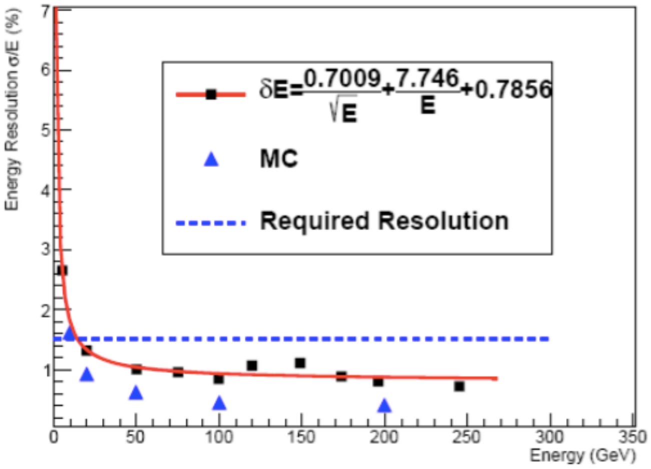


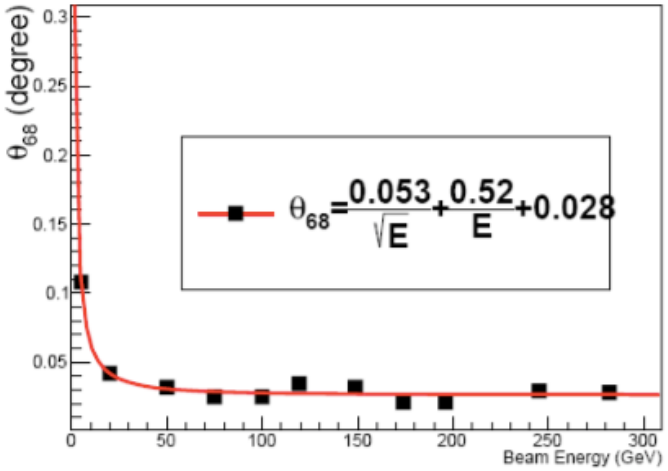
- 🇨🇳Shanghai Jiao Tong U (2009-)
- 🇨🇳Peking U (2009-)
- 🇨🇳Shandong U (2009-)
- 🇨🇳Shanghai Inst. App Phys, CAS (2009-)
- 🇨🇳U of Science & Tech. (2015-)
- 🇨🇳China Inst. of Atomic Energy (2015-)
- 🇨🇳Sun Yat-Sen U (2015-）
- 🇨🇳Yalong Hydropower (2009-)
- 🇺🇸U of Maryland (2009-)
- 🇺🇸U of Michigan (2011-2015)
- 🇫🇷Alt Eng. & Atom Eng. Comm. (2015-)
- 🇪🇸U of Zaragoza(2015-)
- 🇹🇭Suranaree U of Tech. (2015-)

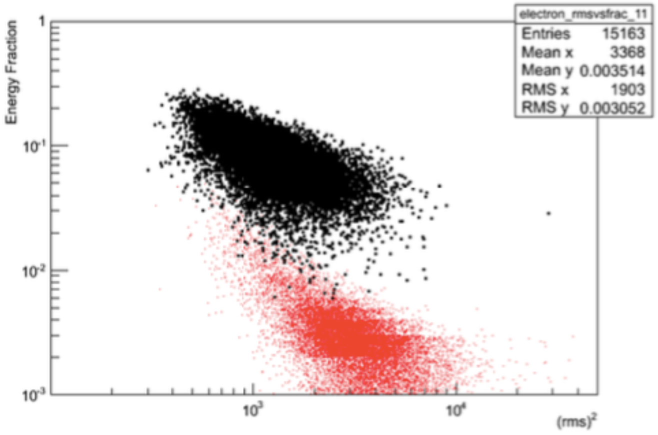
DAMPE: Dark Matter Particle Explorer



120
100
80
60
40
20
0
0
50
100
150
200
cm
Plastic Scintillator
Si tracker
BGO calorimeter
Neutron Det.







DAMPE（悟空：the Monkey King）

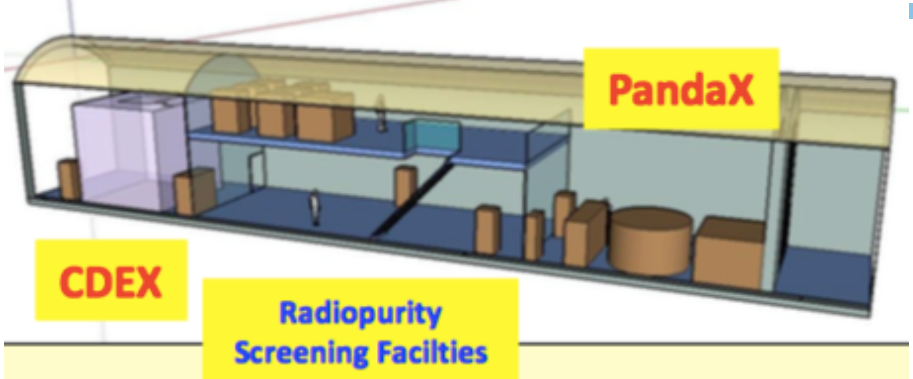
In orbit @ 17Dec2015

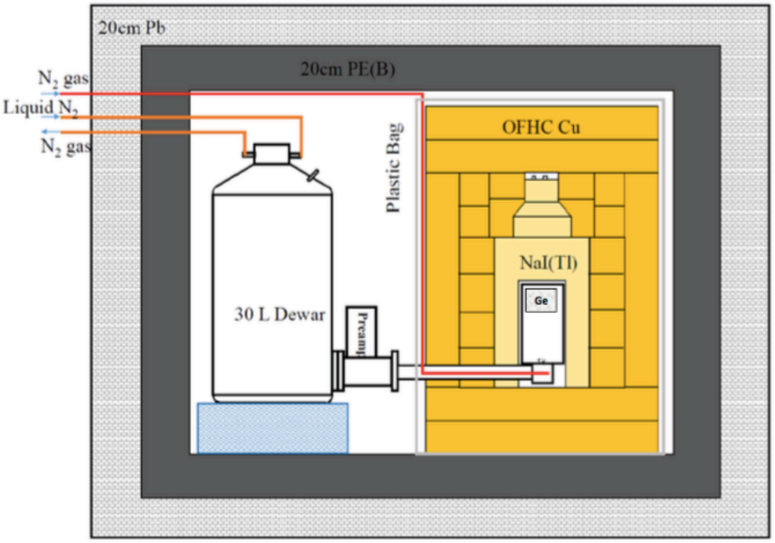
- **Altitude: 500km**
- **Inclination:97.4065**
- **Period: 90 min**
- **Orbit: sun-synchronous**

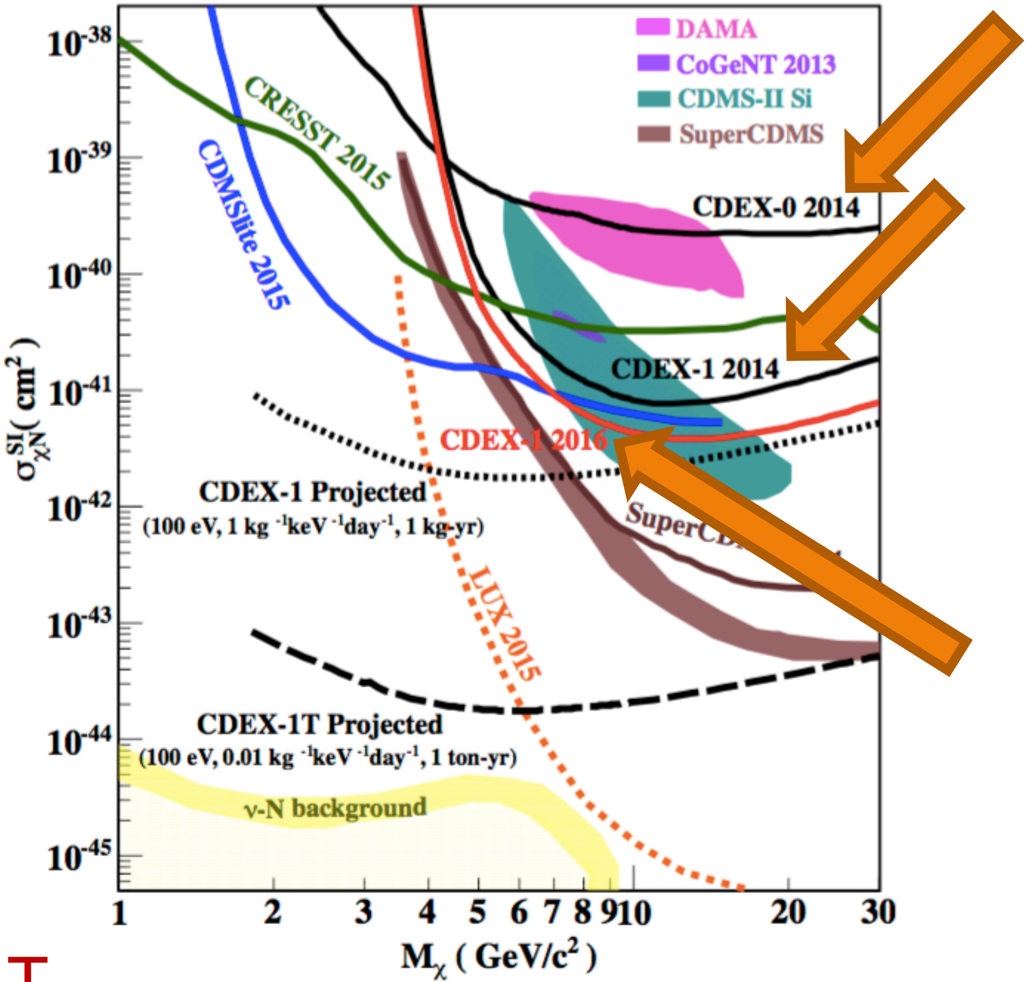
	DAMPE	AMS-02	Fermi LAT
e/γ Energy range (GeV)	5 - 10^4	0.1 - 10^3	0.02 - 300
e/γ Energy res.@100 GeV (%)	1.5	3	10
e/γ Angular res.@100 GeV (°)	0.1	0.3	0.1
e/p discrimination	10^5	10^5 - 10^6	10^3
Calorimeter thickness (X_0)	31	17	8.6
Geometrical accep. (m^2sr)	0.29	0.09	1

China Dark matter EXperiment

CDEX-0&1

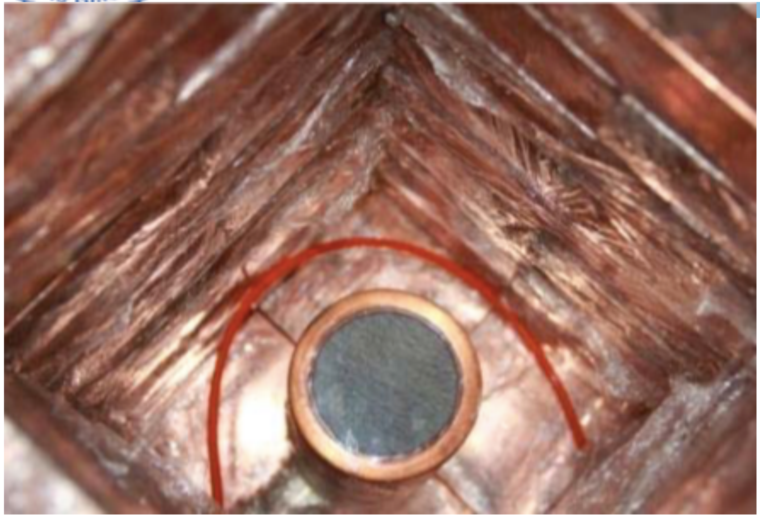

PandaX
CDEX
Radiopurity Screening Facilties

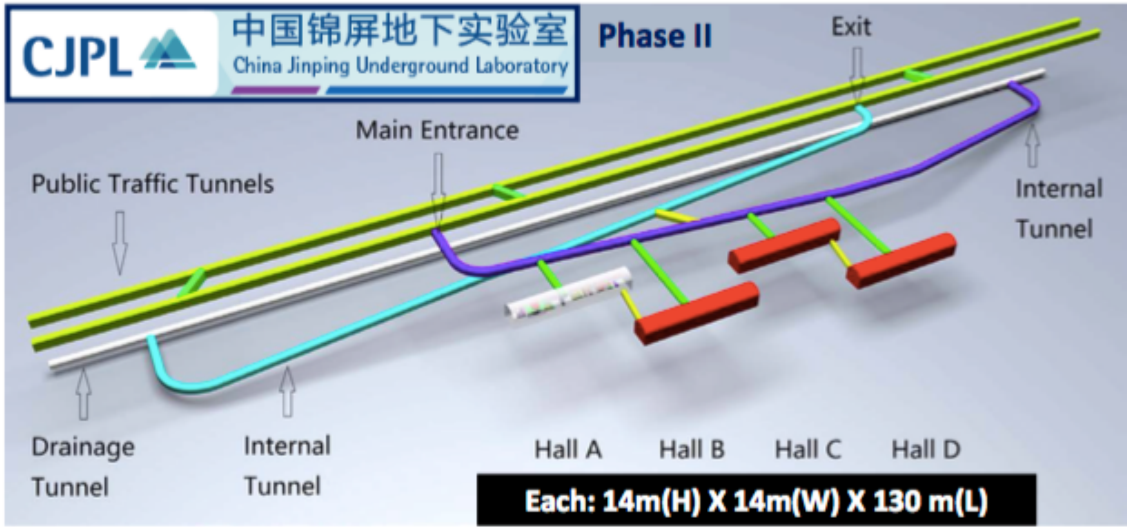

20cm Pb
20cm PE(B)
N_2 gas
Liquid N_2
N_2 gas
Plastic Bag
OFHC Cu
NaI(Tl)
Ge
30 L Dewar
Preamp

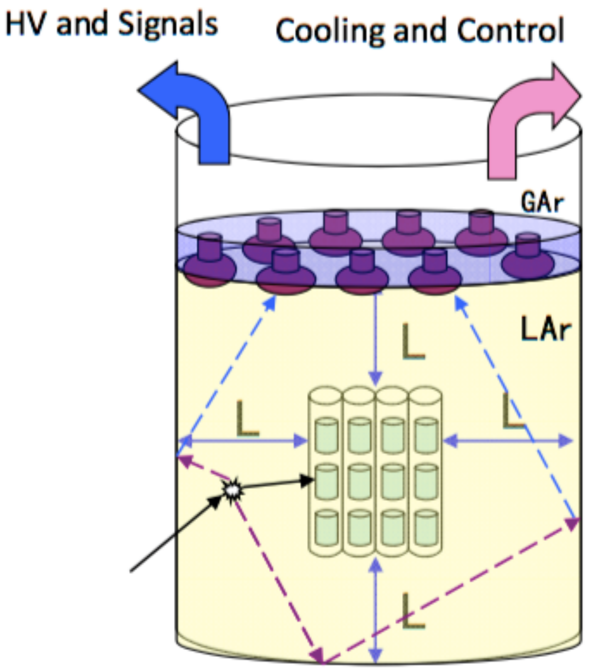


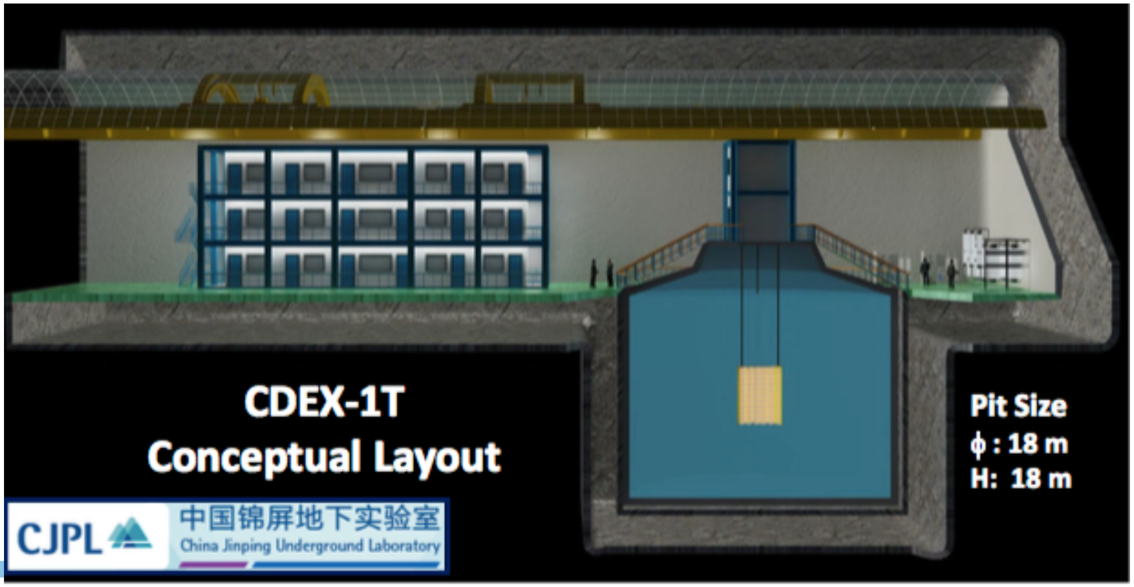
CDEX0(20g)➔1(1kg)➔10➔1T

CDEX-1,10,&1T




CJPL
中国锦屏地下实验室
China Jinping Underground Laboratory
Phase II
Exit
Main Entrance
Public Traffic Tunnels
Internal Tunnel
Drainage Tunnel
Internal Tunnel
Hall A
Hall B
Hall C
Hall D
Each: 14m(H) X 14m(W) X 130 m(L)

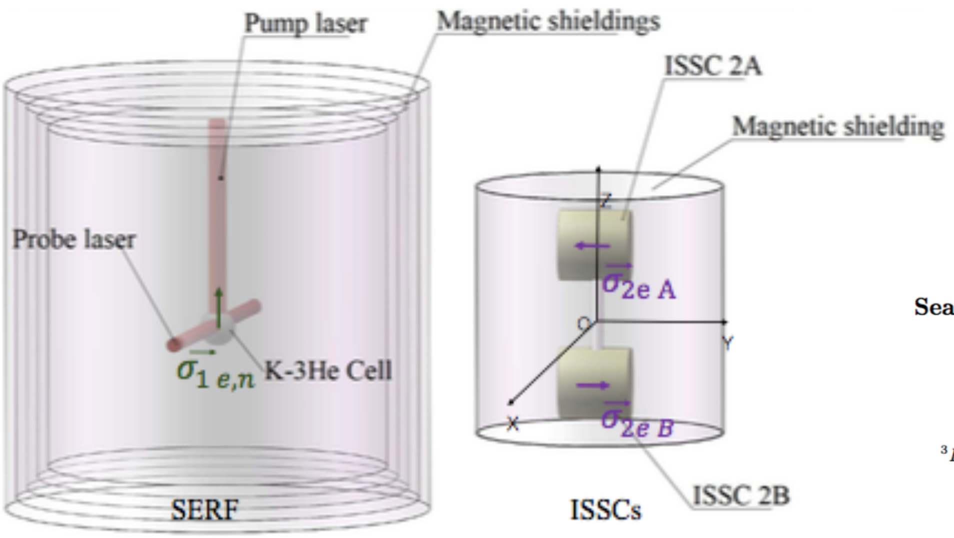

HV and Signals
Cooling and Control
GAr
LAr
L
L
L
L


CDEX-1T
Conceptual Layout
Pit Size
ϕ : 18 m
H: 18 m
CJPL
中国锦屏地下实验室
China Jinping Underground Laboratory

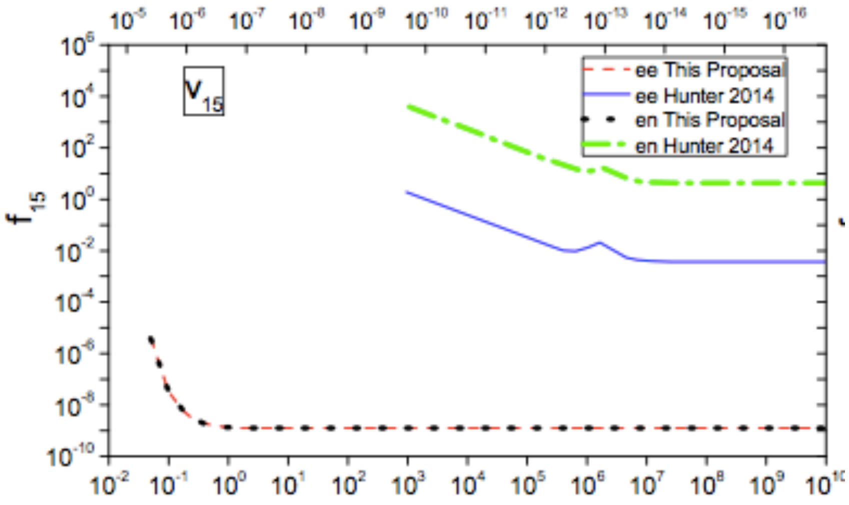
Exotic Bosons Searching

$$V_2 = \frac{f_2\hbar c}{4\pi}(\hat{\boldsymbol{\sigma}}_1\cdot\hat{\boldsymbol{\sigma}}_2)\left(\frac{1}{r}\right)e^{-r/\lambda}$$

$$B_{eff} = f_2\hbar c\,\hat{\boldsymbol{\sigma}}_2 e^{-r/\lambda}/(4\pi r)$$


Pump laser
Magnetic shieldings
ISSC 2A
Magnetic shielding
Probe laser
$\vec{\sigma}_{1\,e,n}$
K-3He Cell
Z
O
Y
X
$\vec{\sigma}_{2e\,A}$
$\vec{\sigma}_{2e\,B}$
SERF
ISSCs
ISSC 2B

H. Yan, G. Sun, S. Peng, et al., Phys. Rev. Lett. **115**, 182001 (2015).



Searching for New Spin-Dependent Interactions with SmCo$_5$ Spin Sources and a SERF Comagnetometer

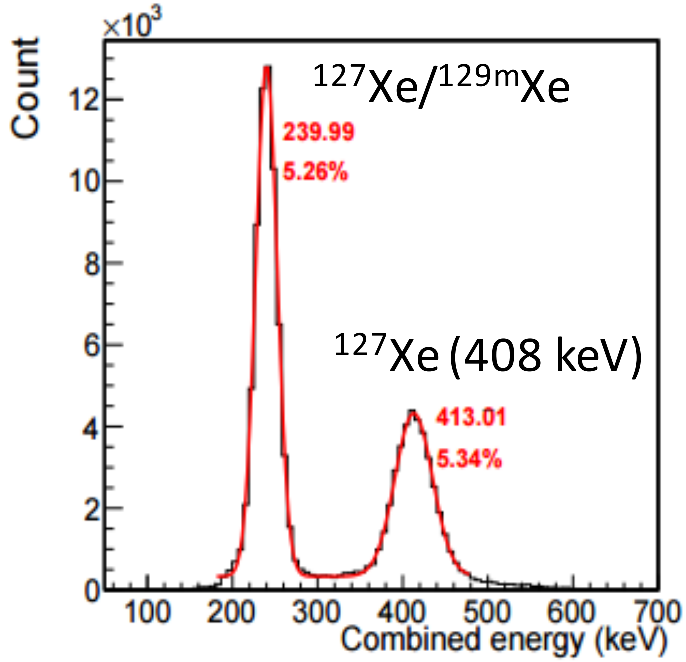
W. Ji,[1] C. B. Fu,[2,*] and H. Y. Gao[1,3,4,†]
[1] *Dept. of Phys., Tsinghua University, Beijing, 100084, China*
[2] *INPAC, Phys. & Astro. Dept., Shanghai Jiao Tong University, Shanghai, 200240, China*
[3] *Dept. of Phys., Duke University and Triangle Universities Nuclear Laboratory, Durham, NC 27708, U.S.A*
[4] *Duke Kunshan University, Kunshan, Jiangsu, 215316, China*
(Dated: November 1, 2016)

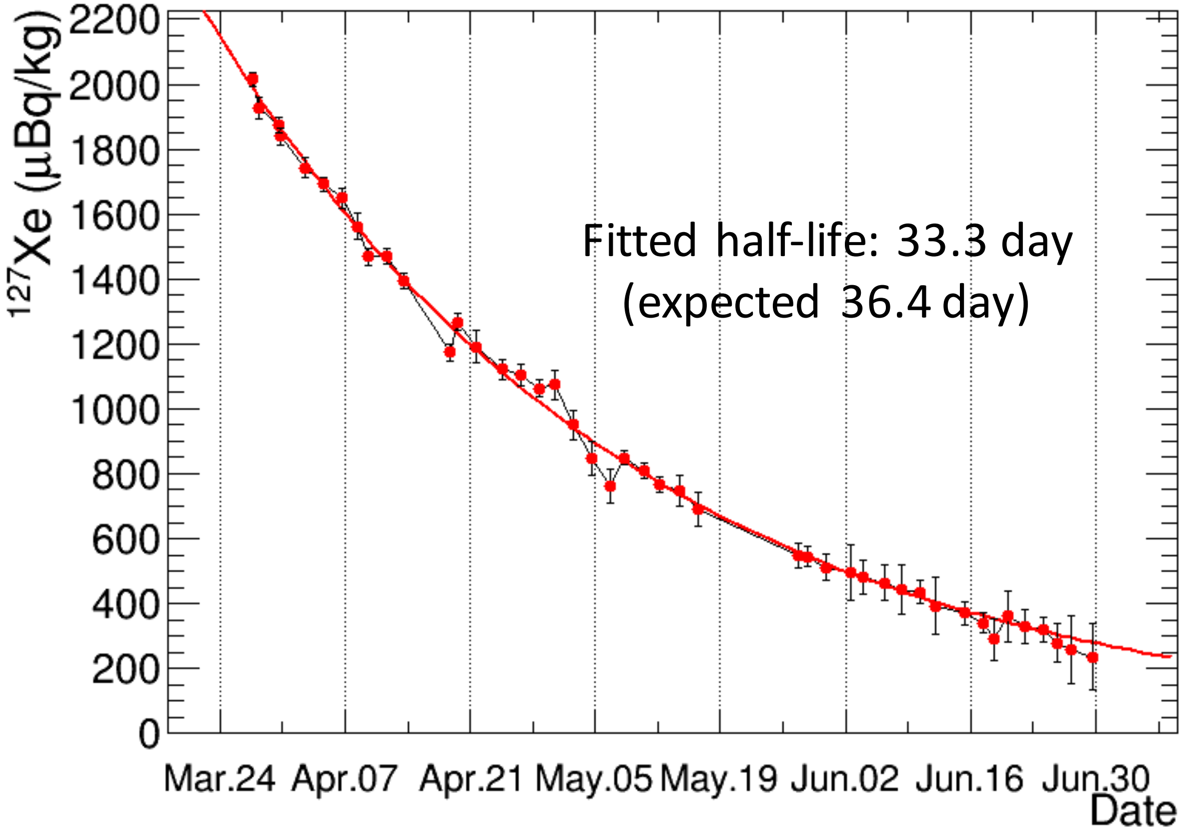
arXiv:1610.09483

Summary

- **PandaX-II** (500kg), the **Biggest Running Xe Detector** in the world;
- **PandaX-III&IV**, heading in the directions of DM&OVBB
- **CDEX**, the Ge-based Dark Metter Searching exp.
- **DAMPE**, indirect DM searching satellite.
- **Exotic Bosons** (including Axon-like) with **SERF** magnetometer.
- Forgive me, not intr. many important DM works in China!
  - Accelerator based DM searching
  - Argon-based DM searching
  - Theoretical Works.
  - …

^{127}Xe ^{128,129}Xe(γ, xn)^{127}Xe

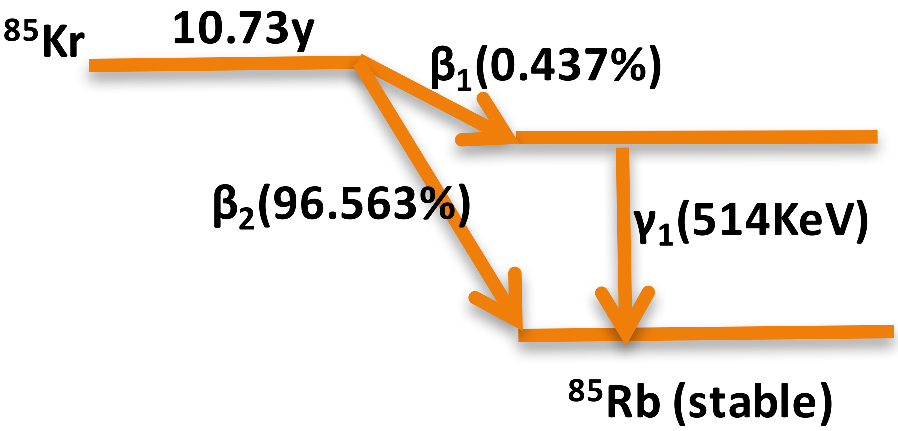




Average ^{127}Xe rate in the low energy DM search region (<10 keV) estimated to be **0.42±0.10 mDRU** (DRU = evt/kg/keV/day)

^{85}Kr

- Identified by delayed β–γ coincidence analysis
- **Uniform** distribution
- Significantly reduced after distillation



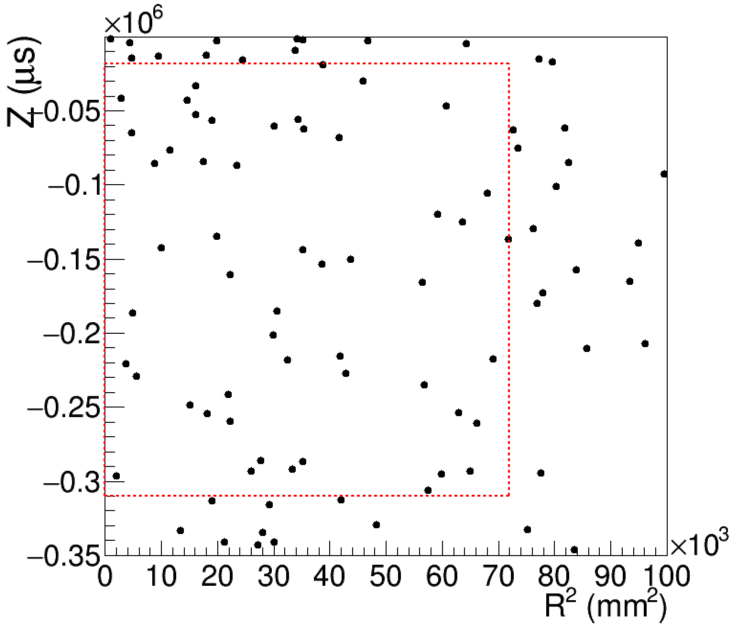
^{85}Kr 10.73y

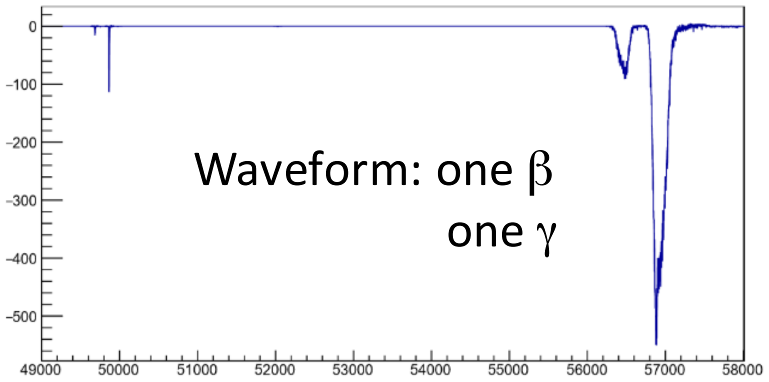
β_1(0.437%)

β_2(96.563%)

γ_1(514KeV)

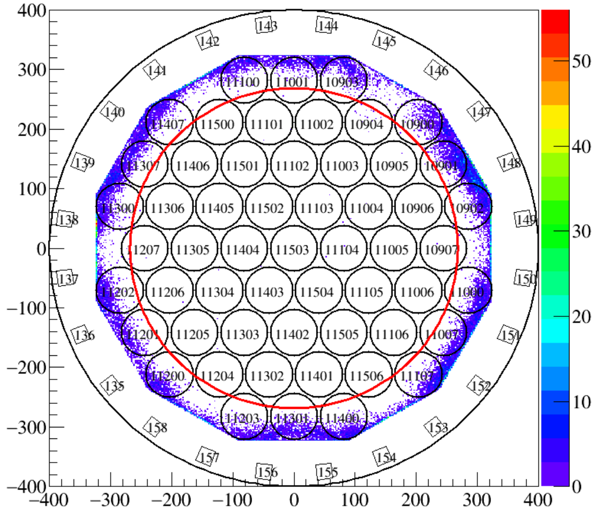
^{85}Rb (stable)

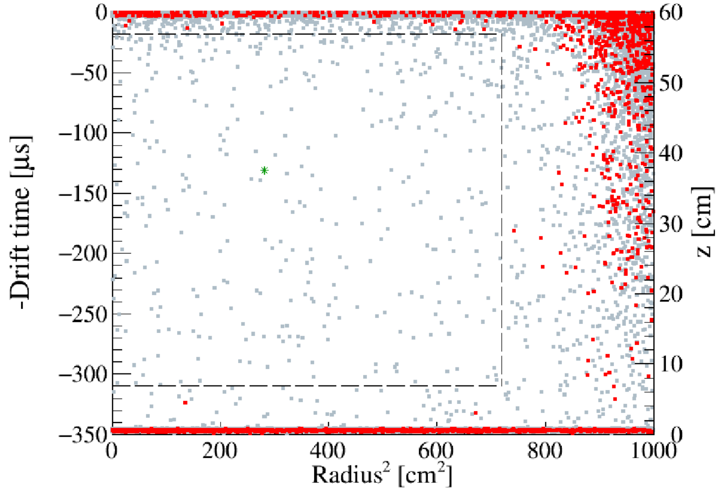


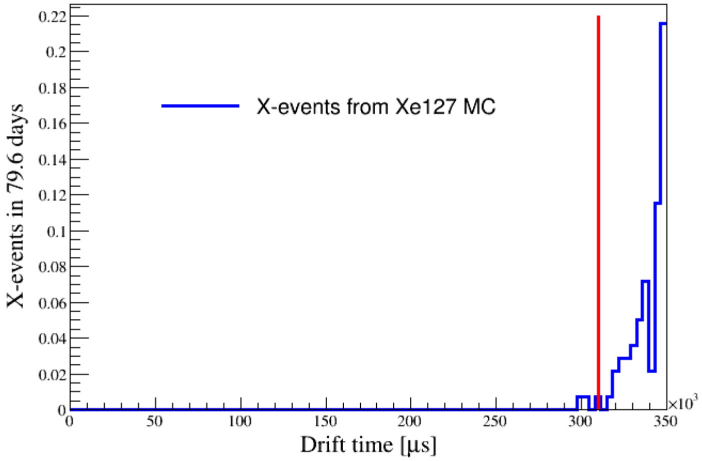


Waveform: one β
one γ

Final selection cuts

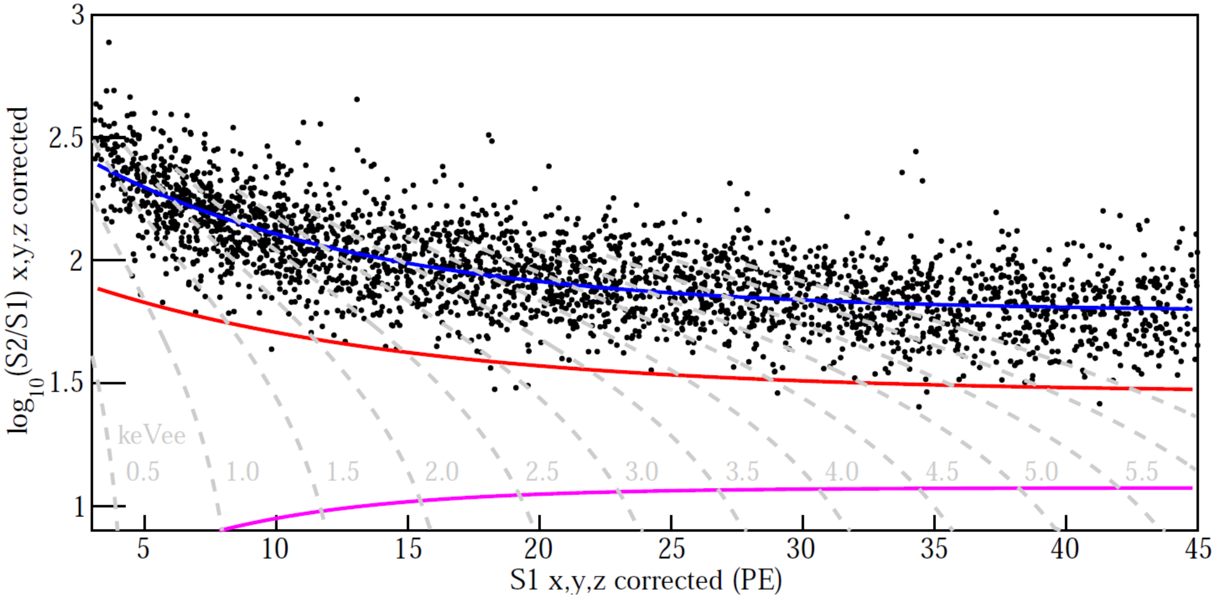


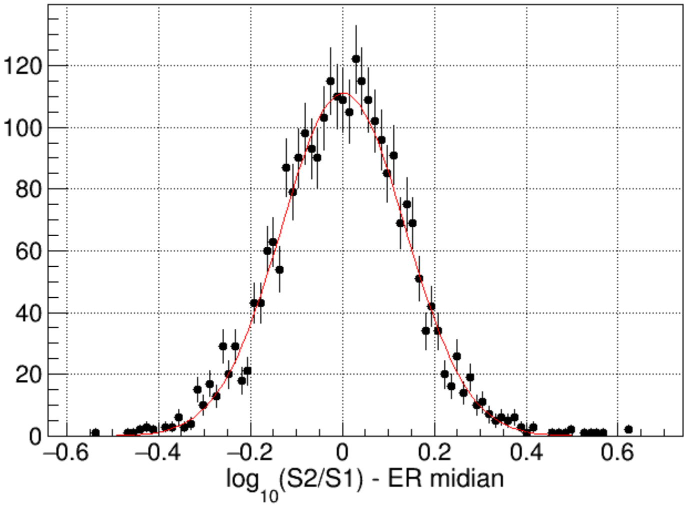


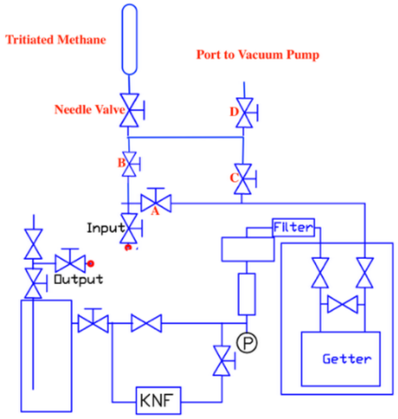


- □ 几何选取 (FV in Run 9 with 328.9 kg)
  - □ **Horizontal cut** determined by distribution of events with S1 between [45,200] PE and suppressed S2
  - □ **Vertical cut:** Upper boundary consistent with the previous analysis; Lower boundary determined by X-events from ^{127}Xe MC
- □ 噪声选取
  - □ **S1 cut:[3,45]** PE
  - □ **S2 cut[100raw, 10000]**PE

ER cal. w/ CH$_3$T β source







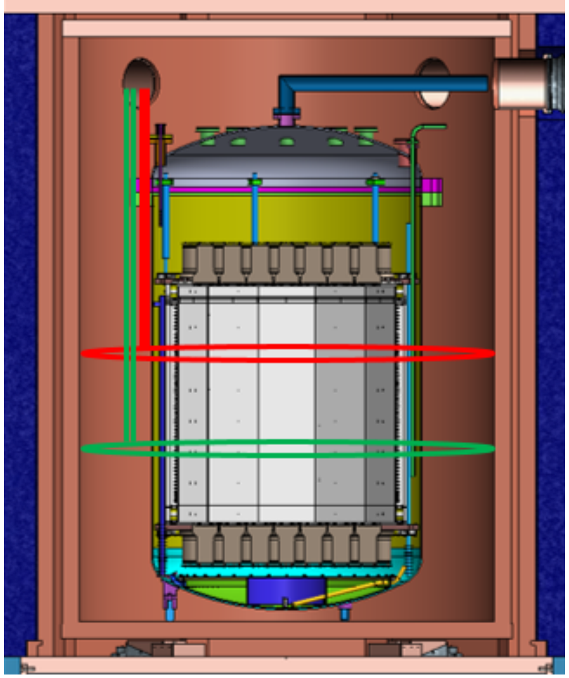
Tritiated Methane
Port to Vacuum Pump
Needle Valve
D
B
C
A
Input
Output
Filter
P
Getter
KNF

- 18.0 hours of tritium data taken, with ~2800 low energy ER events collected
- 9 events leaked below NR median, (0.32+/-0.11)%
- Consistent with Gaussian expectation

Radation Background

- ER background
  - ^{127}Xe (due to surface exposure of xenon during distillation)
  - ^{85}Kr (suppressed by a factor 10)
  - Others: U/Th/Rn…
- Accidental background (determined by data)

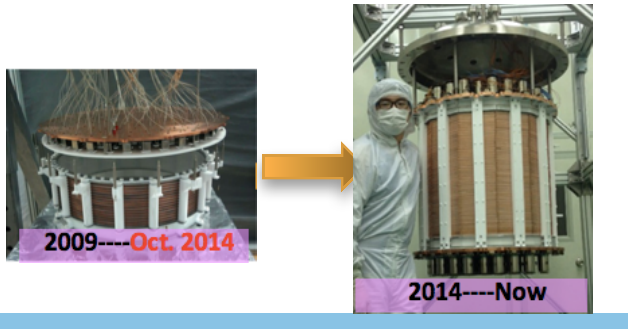
Calibration Program

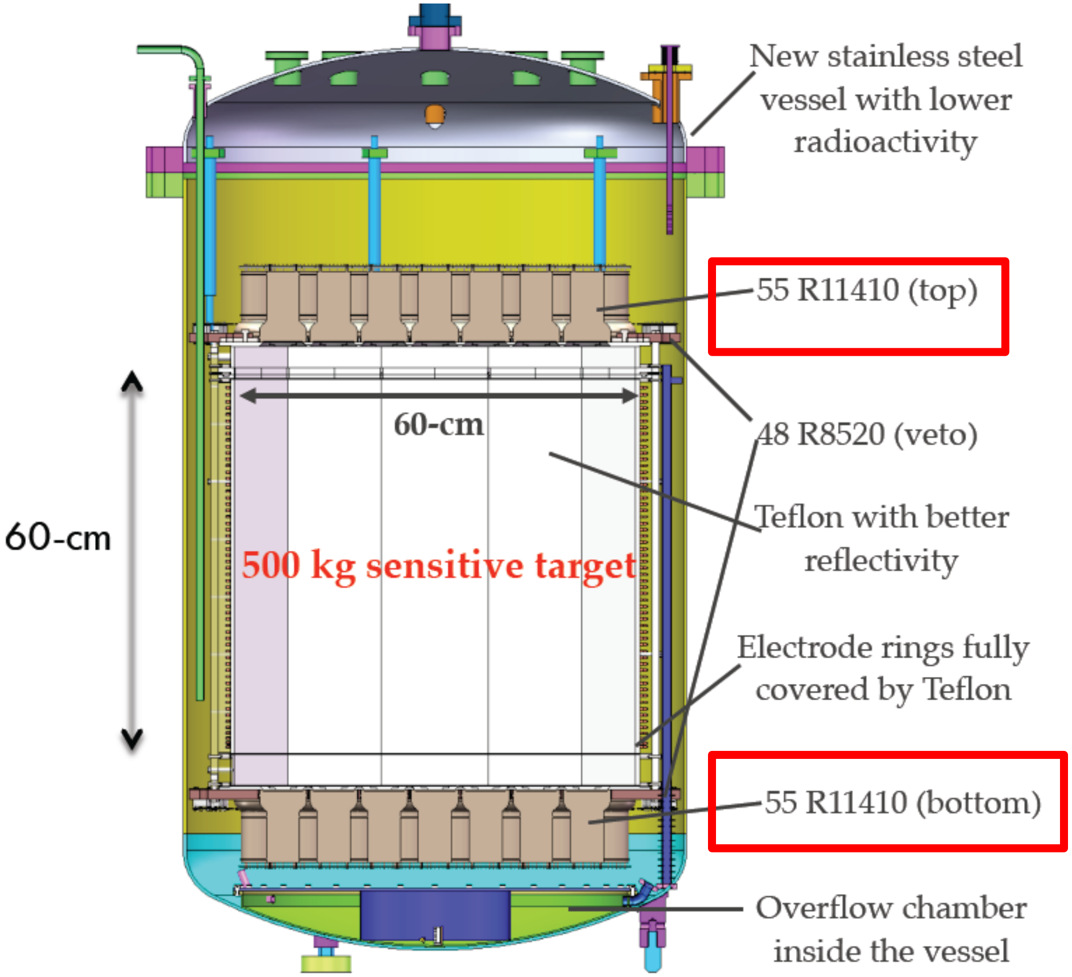


- **Energy**
- **Position**
- **Particle Id**

- **Electron Recoil (ER)**
  - **Internal/external ER** peaks:
    - Detector uniformity corrections
    - Light/charge collection parameters
  - **CH_3T** injection: tritium beta decays
    - Simulate ER background
- **Nuclear Recoil (NR)**
  - Low rate AmBe neutron source:
    - Simulate DM NR signal

PandaX-II

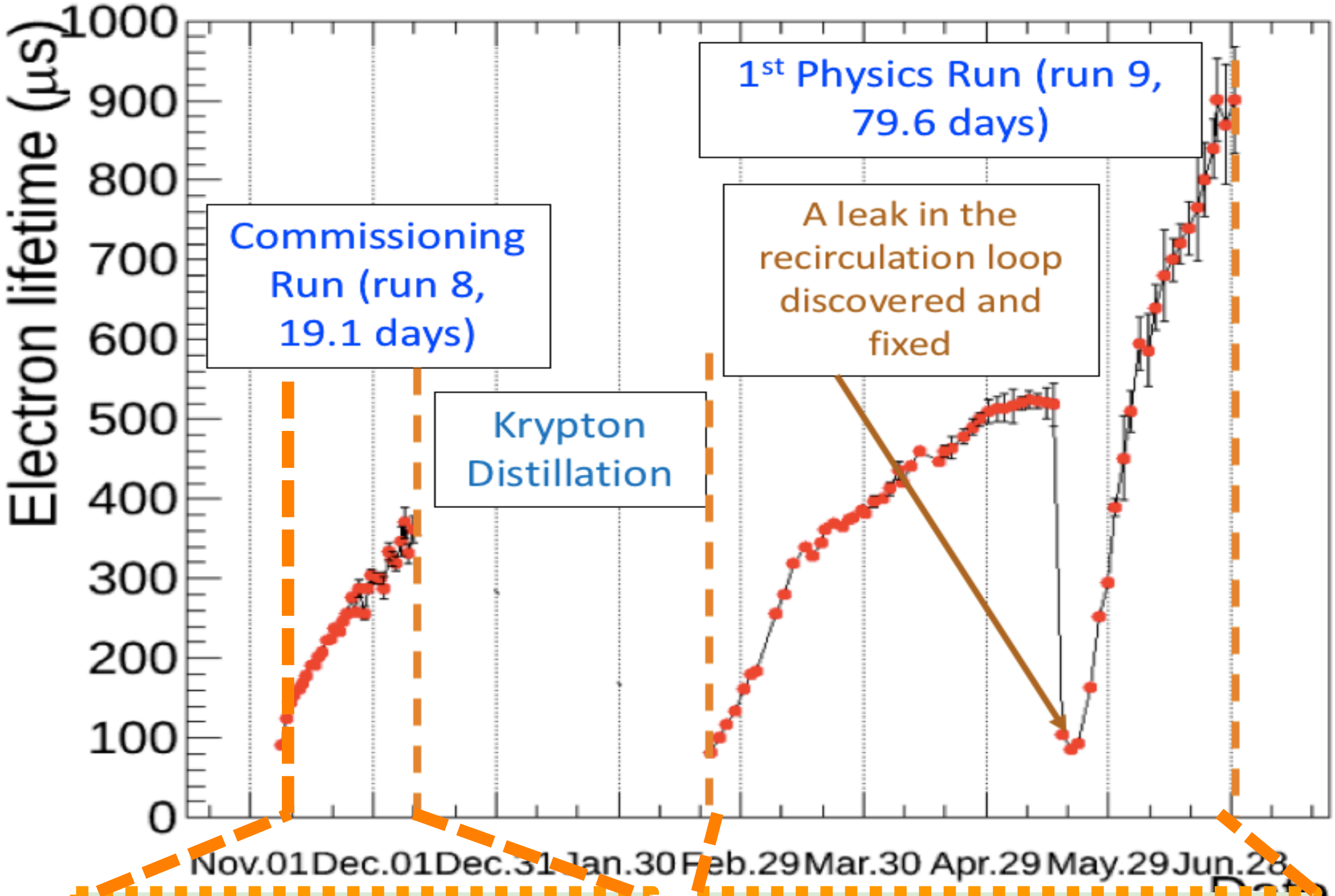

2009----Oct. 2014
2014----Now


60-cm
60-cm
500 kg sensitive target
New stainless steel vessel with lower radioactivity
55 R11410 (top)
48 R8520 (veto)
Teflon with better reflectivity
Electrode rings fully covered by Teflon
55 R11410 (bottom)
Overflow chamber inside the vessel

More than Large Volume

- **New IV: inner vessel with clean Low Rad. SS**
- **New PMTs: 55+55, 3” High Quam Eff., improved base design (±650V).**
- **New Veto PMTs in skin**
- **New OC: overflow chamber at Bottom, save Xe expensive Xenon**
- **Better Reflector: Improved Reflectivity**

Electron Lifetime



Commissioning Run (run 8, 19.1 days)

Krypton Distillation

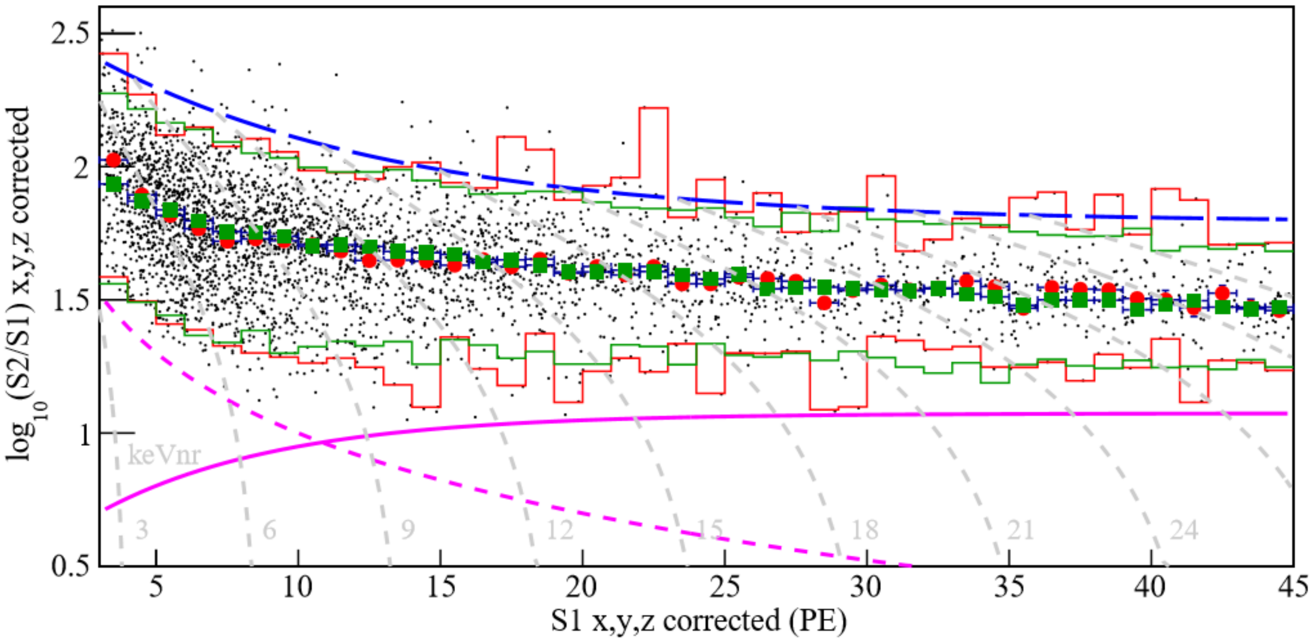
1st Physics Run (run 9, 79.6 days)

A leak in the recirculation loop discovered and fixed

2015.11.22---12.14

2016.03.09---06.30

Nuclear Recoil (NR) calibration



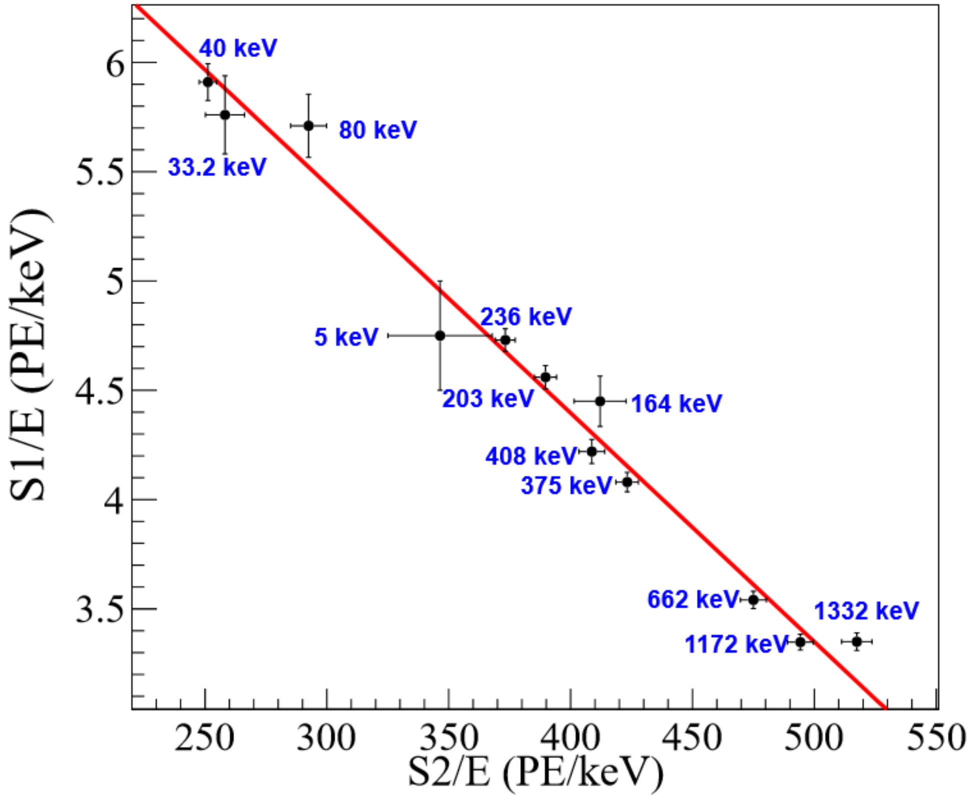
- 162.4 hours of **AmBe** data taken, with ~3400 low energy single scatter NR events collected
- NR median curve and NR detection efficiency determined

Extracting Det. Parameters

$$E_{ee} = W \times \left(\frac{S1}{\boxed{PDE}} + \frac{S2}{\boxed{EEE} \times \boxed{SEG}}\right)$$

W = 13.7 eV

- **PDE:** Photon Det Eff.
- **EEE:** Electron Extr. Eff.
- **SEG:** Single Electron Gain.



SEG → Determined by identifying Single Electron Events.

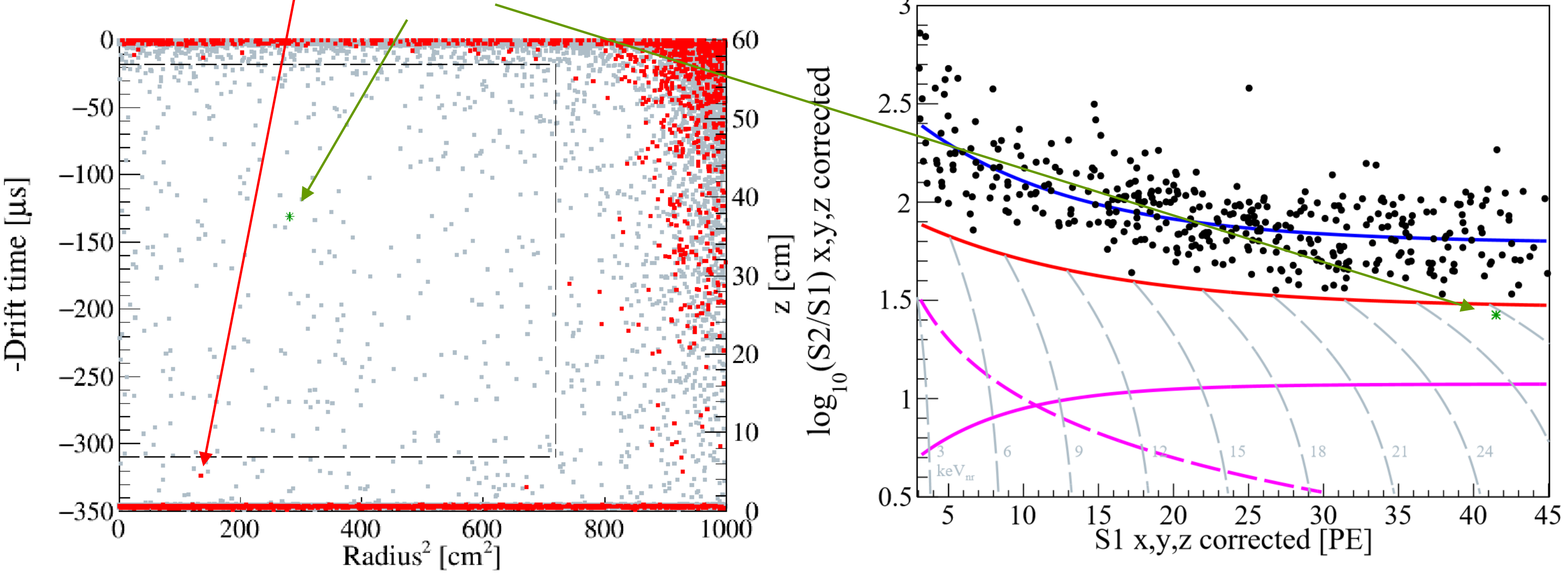
PDE/EEE → One Eq.; Two Variables

Final Candidates

Gray: all

Red: below NR median

Green: below NR median and in FV



Item	Run 8 (mDRU)	Run 9 (mDRU)
^{85}Kr	11.7	1.19
^{127}Xe	0	0.42
^{222}Rn	0.06	0.13
^{220}Rn	0.02	0.01
Detector material ER	0.20	0.20
Total	12.0	1.95

	ER	Accidental	Neutron	Total Expected	Total observed
Run 8	622.8	5.20	0.25	628±106	734
Below NR median	2.0	0.33	0.09	2.4±0.8	2
Run 9	377.9	14.0	0.91	393±46	389
Below NR median	1.2	0.84	0.35	2.4±0.7	1