Progress and Status of PandaX experiment in China Jinping Underground Lab

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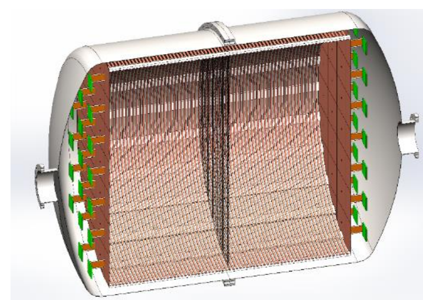
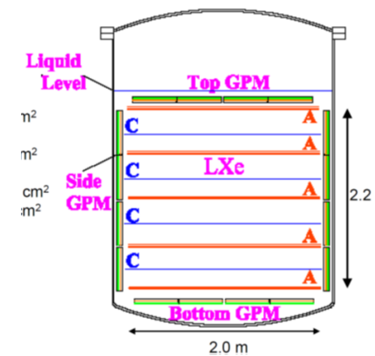
Outline

- PandaX & Jinping Lab
- PandaX-I: result of 120kg LXe DM search
- PandaX-II: status of 500kg LXe DM search
- PandaX-III: plan for ton scale Xe136 NLDBD
- The future: ultimate DM experiment

PandaX＝Particle and astrophysical Xenon Expts

粒子(无中微子双贝塔衰变)和天体物理(暗物质)氙探测实验





Stage I：
120kg LXe
DM Detector
2009-2014

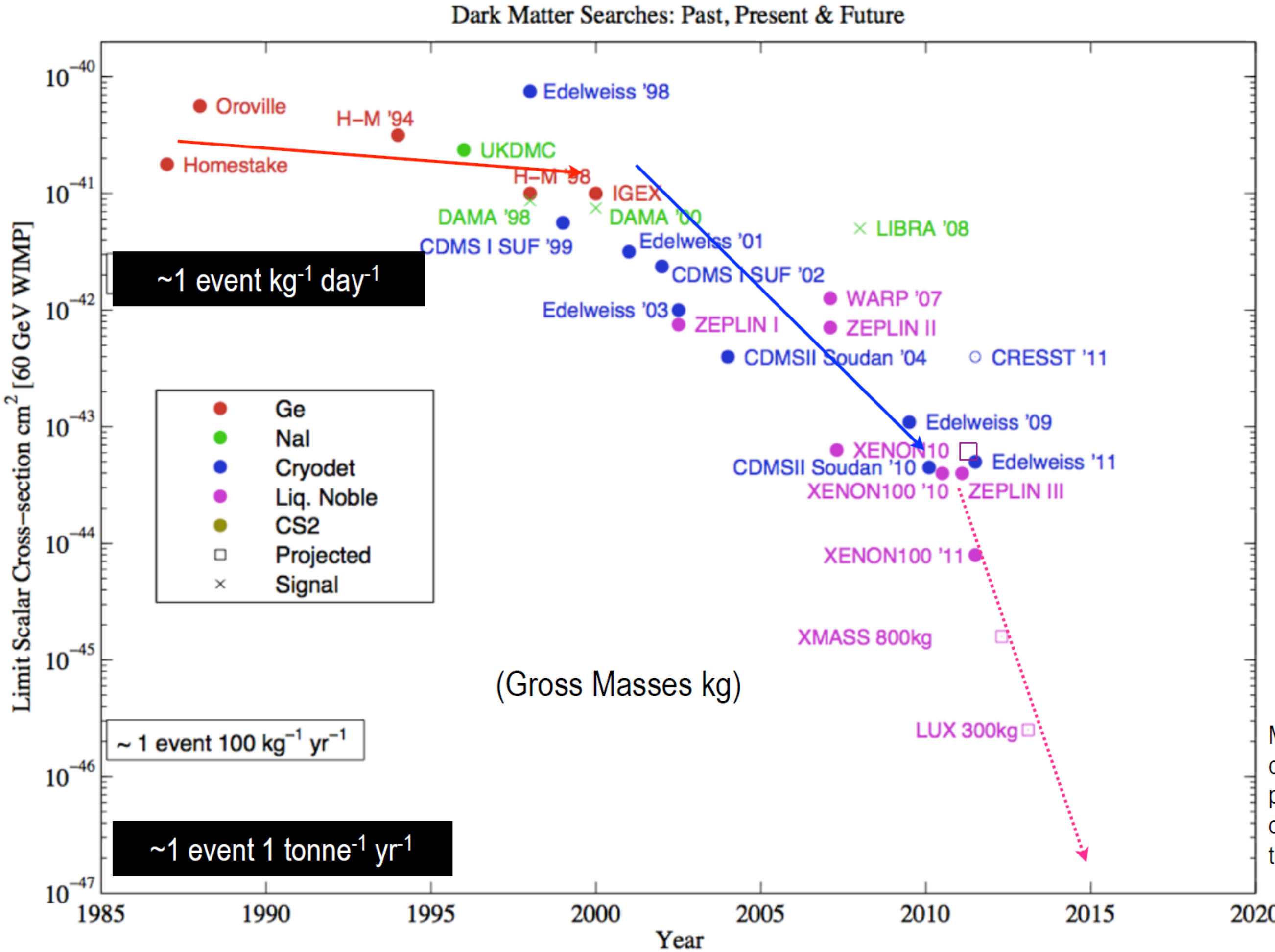
Stage II：
500kg LXe
DM Detector
2014-2016

Stage III：
200kg-1ton
Xe136 NLDBD
2016-2020

Stage IV：
20-30 ton
Lxe DM
2019-2025

DM Direct Search Progress Over Time (2012)

Plot does not track low mass WIMPs 10 GeV



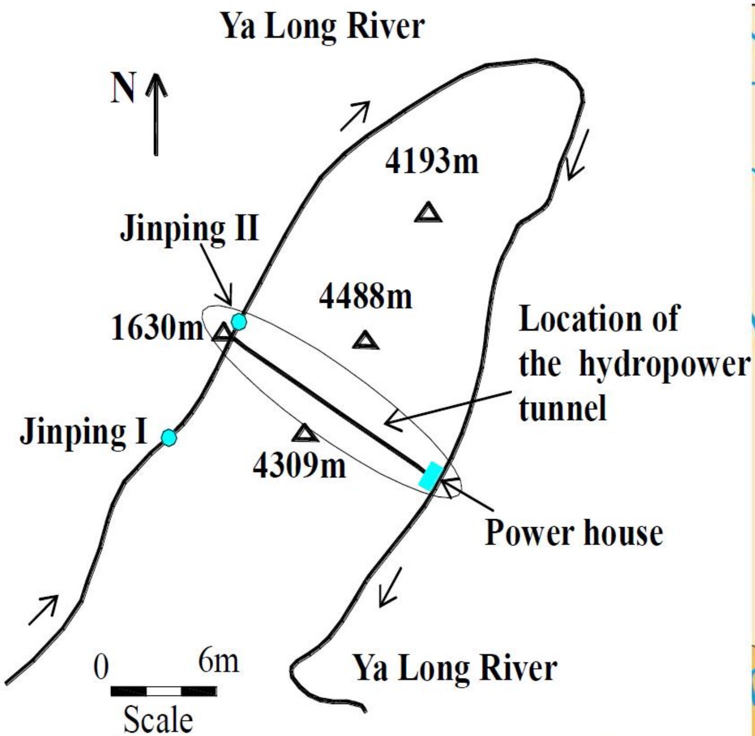
Many of current projections omitted fro this plot

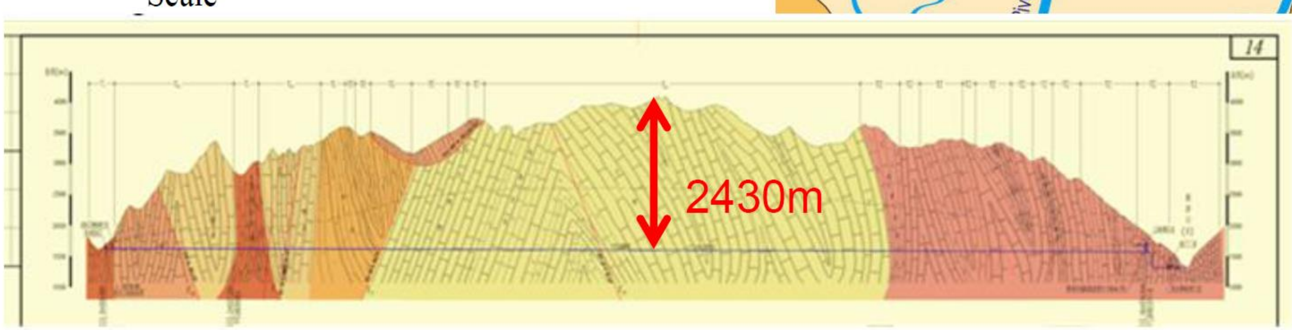
PandaX collaboration

Some of important questions related to CosPA

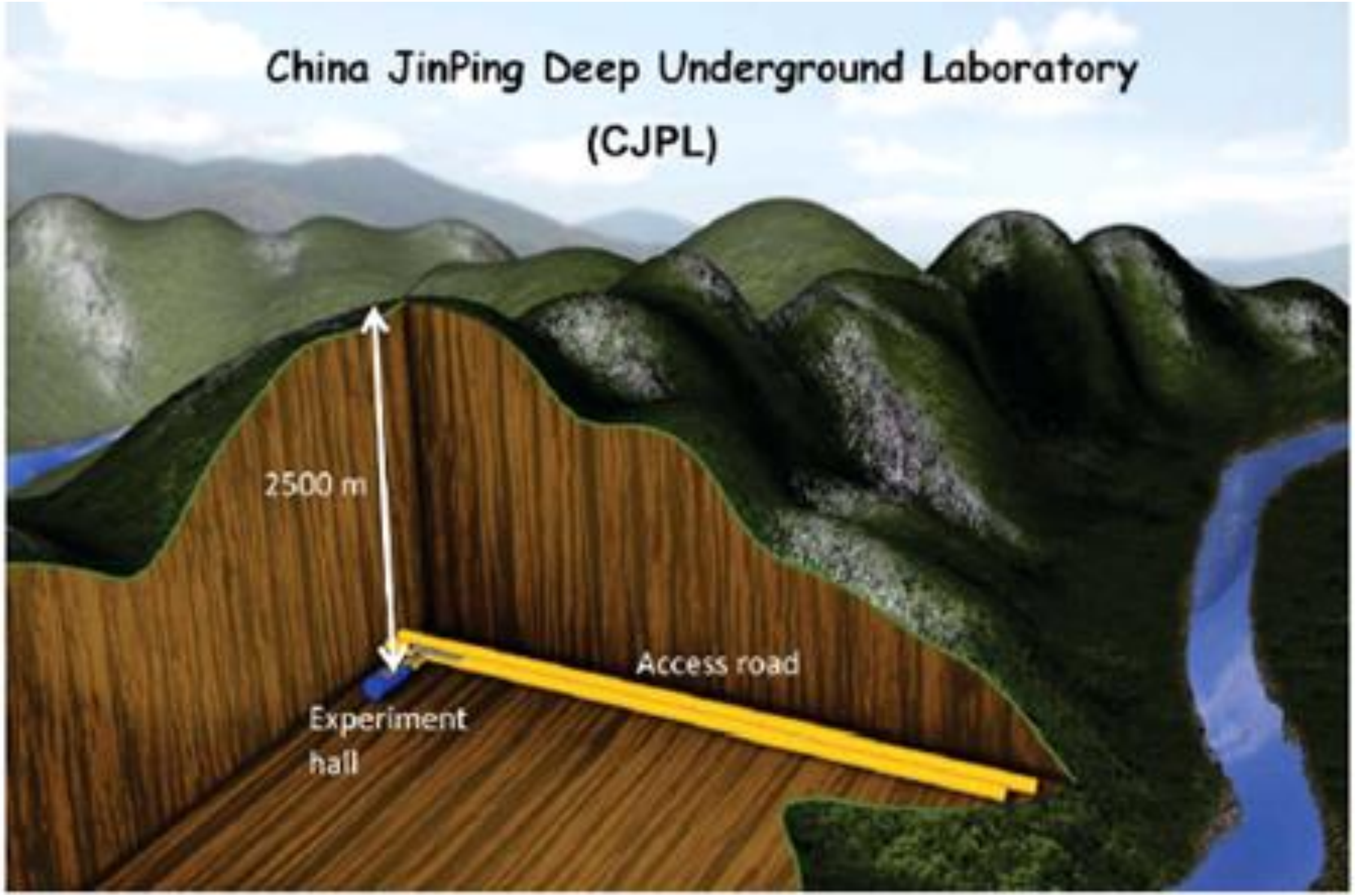
- What is dark matter?
  - Is there a WIMP component in Dark Matter?
  - Is the particle dark matter consistent with Astrophysical observation
- Is neutrino a Majorana particle?
  - Lepton number violation? Leptogenesis?
  - Supersymmetry?
  - Neutrino mass scale? cosmology
- …

China Jin-Ping underground Laboratory



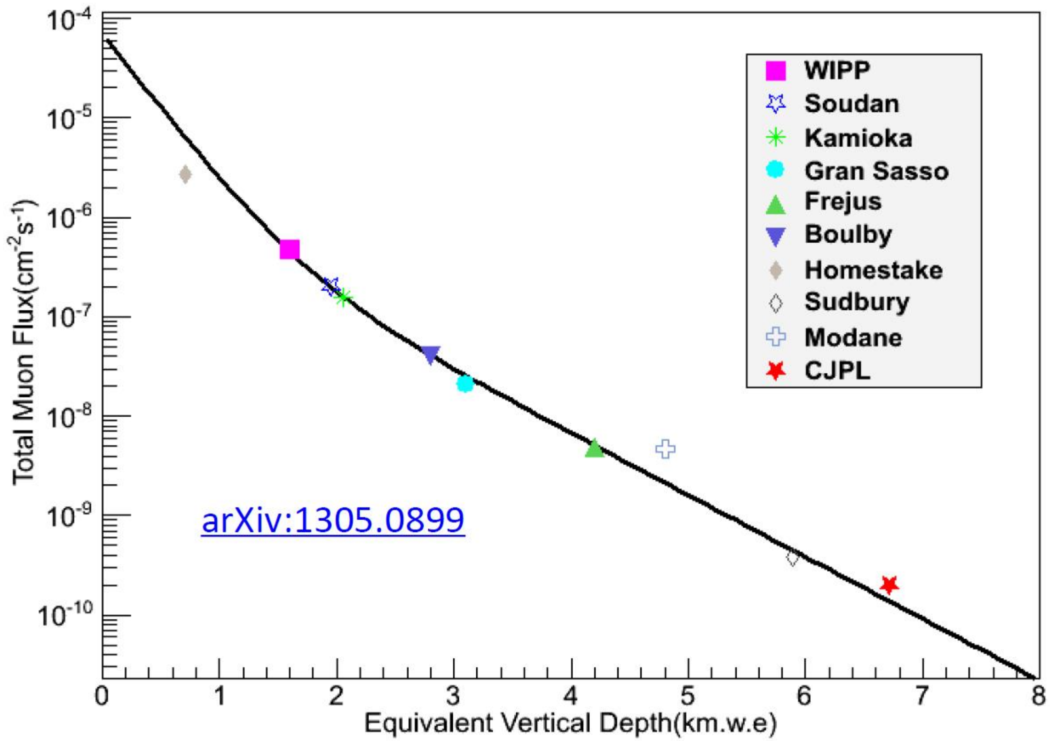


A deep underground lab?

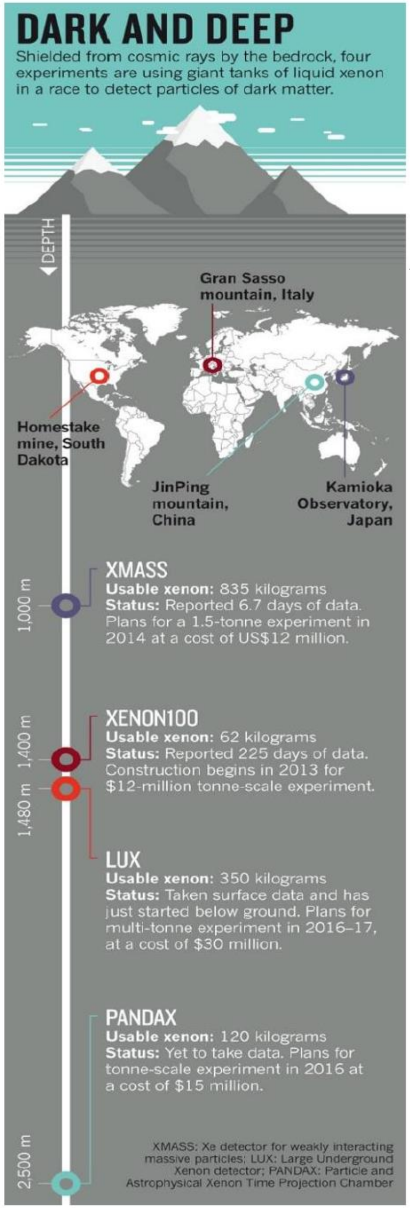


A small experimental hall

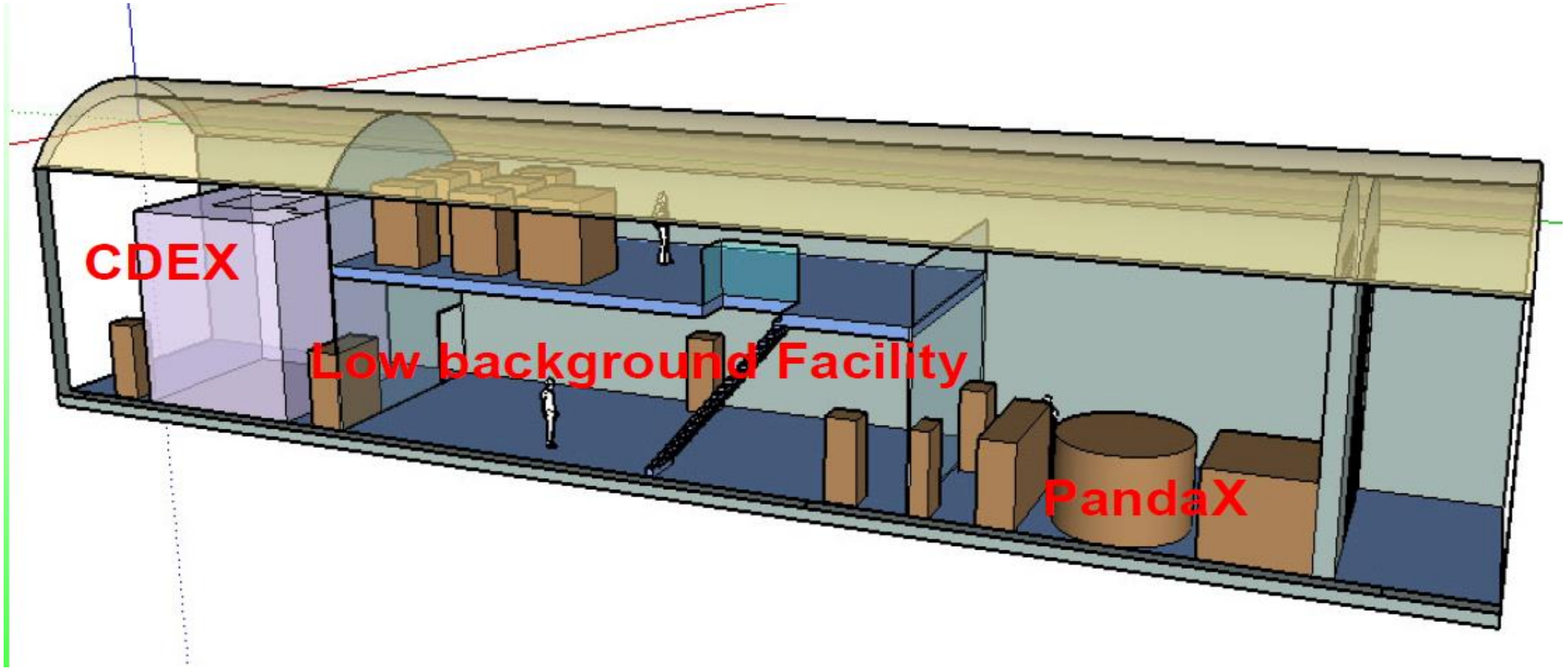
- In 2009, Tsinghua University and Yalong company decided to dig a small exp. hall for dark matter research
- The hall was excaved early 2010 with size $6x6x40m^3$.
- The hall can accommodate two experiments.



Depth	6800 mwe
Muon Flux	60 evn/m2/year
Rock	Marble
^{238}U	1.8 ± 0.2 Bq/kg
^{232}Th	<0.27 Bq/kg
^{40}K	<1.1 Bq/kg



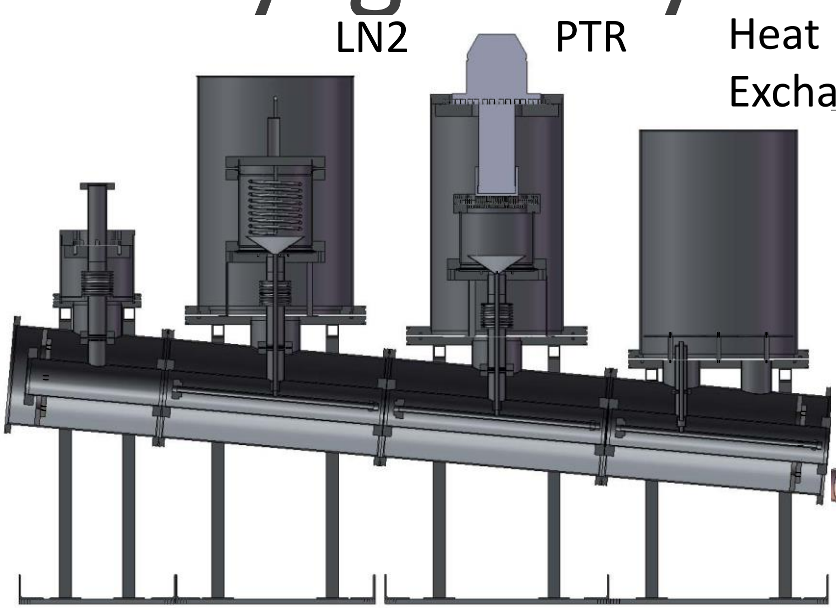
Layout of the exp in Jinping lab



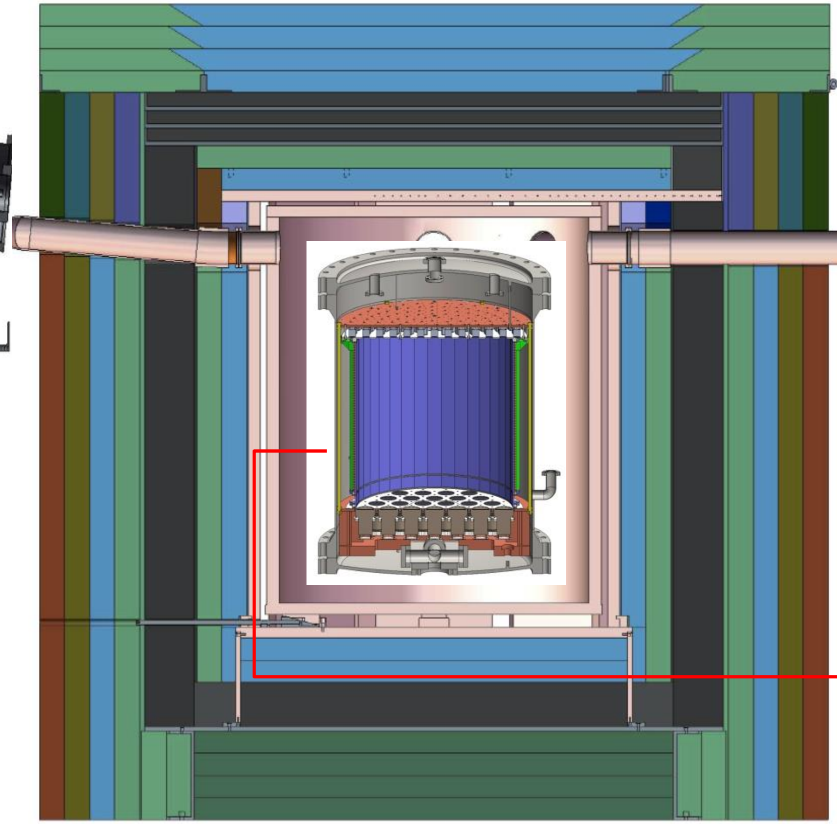
PandaX-I and result

PandaX-I 120 kg detector

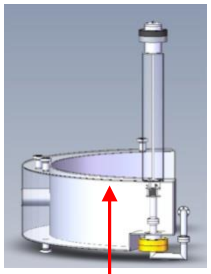
Cryogenic system



Cryogenic System



Overflow
+level
adjustment

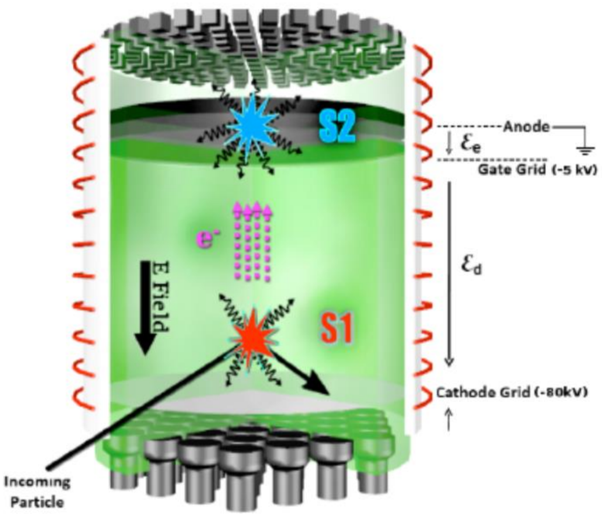


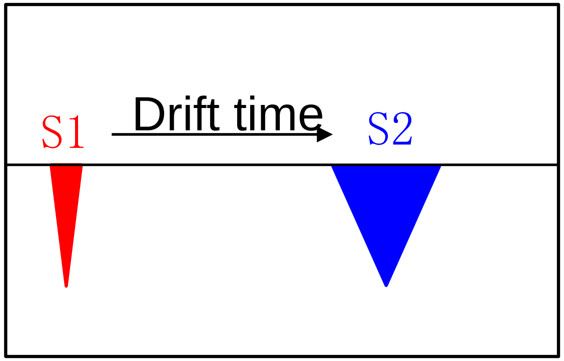
JINST 8 (2013) P01002

- All components of the cryogenic system are outside of shield
- Heat transport with flowing liquid Xe
- Modular design (upgradable to larger capacity)

Data-taking ceremony, March, 2014

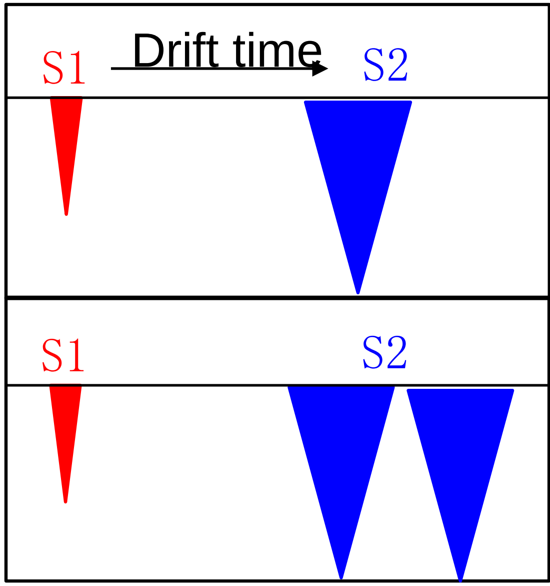
Dual phase xenon detector: charge and light detections





Dark matter: nuclear recoil (NR)

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



Gamma background: electron recoil (ER)

PandaX dark matter run: May 26 to Oct. 16, 2014

- **80.1 day of data**

Run type	DAQ Time (hr)	Live Time (hr)	Trigger Rate (Hz)
DM	2,158.32	1,923.11	3.58
^{252}Cf	95.32	94.05	17.95
^{60}Co	405.14	361.47	22.23

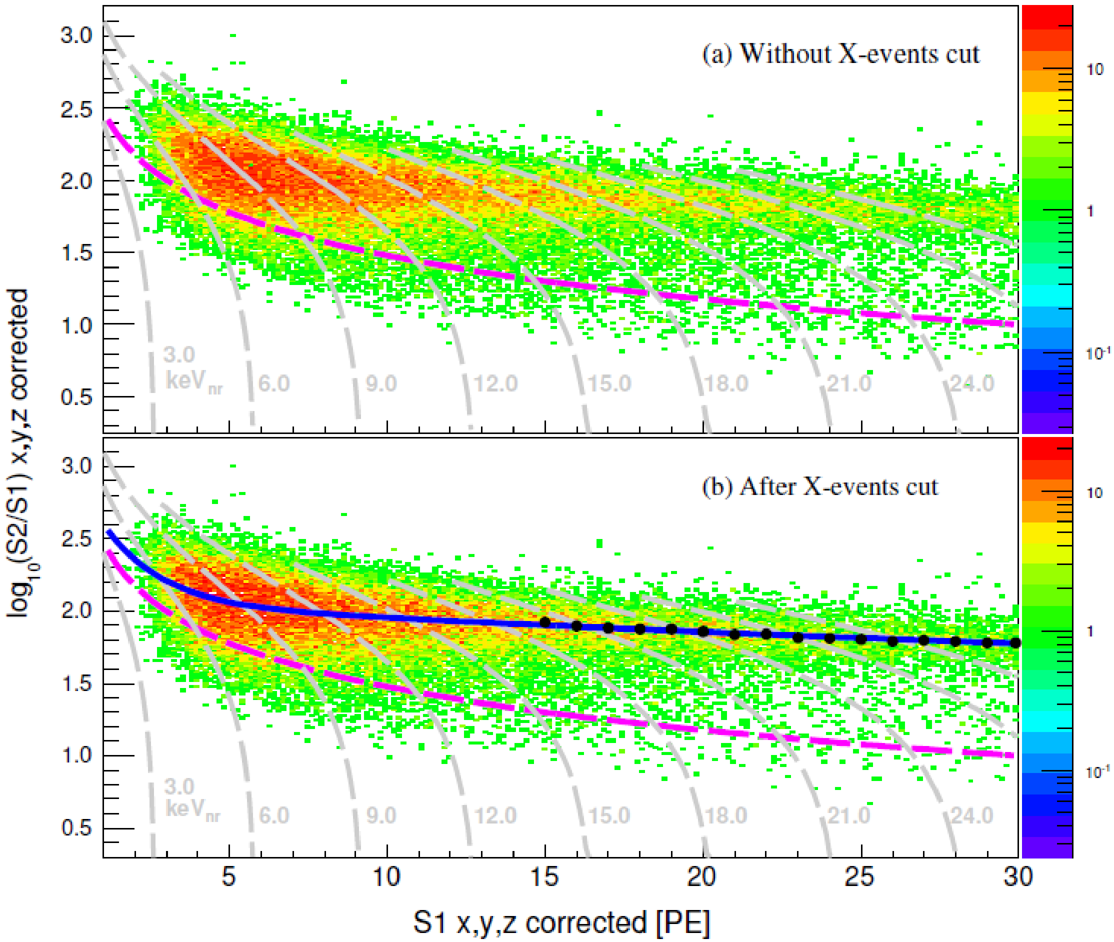
TABLE I: Summary of data taken during the entire PandaX-I running period.

- **Low-mass dark matter search results from full exposure of the PandaX-I experiment**

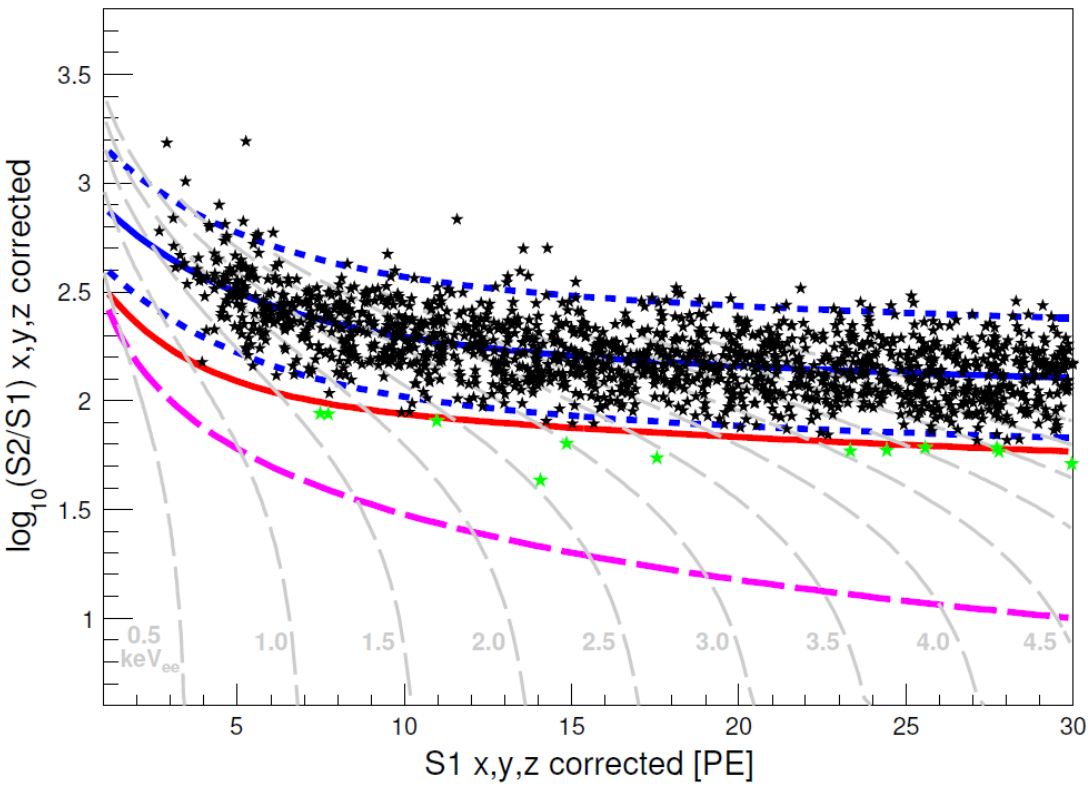
Xiang Xiao *et al.* (PandaX Collaboration)

Phys. Rev. D 92, 052004 – Published 15 September 2015

Neutron calibration



Gamma calibration



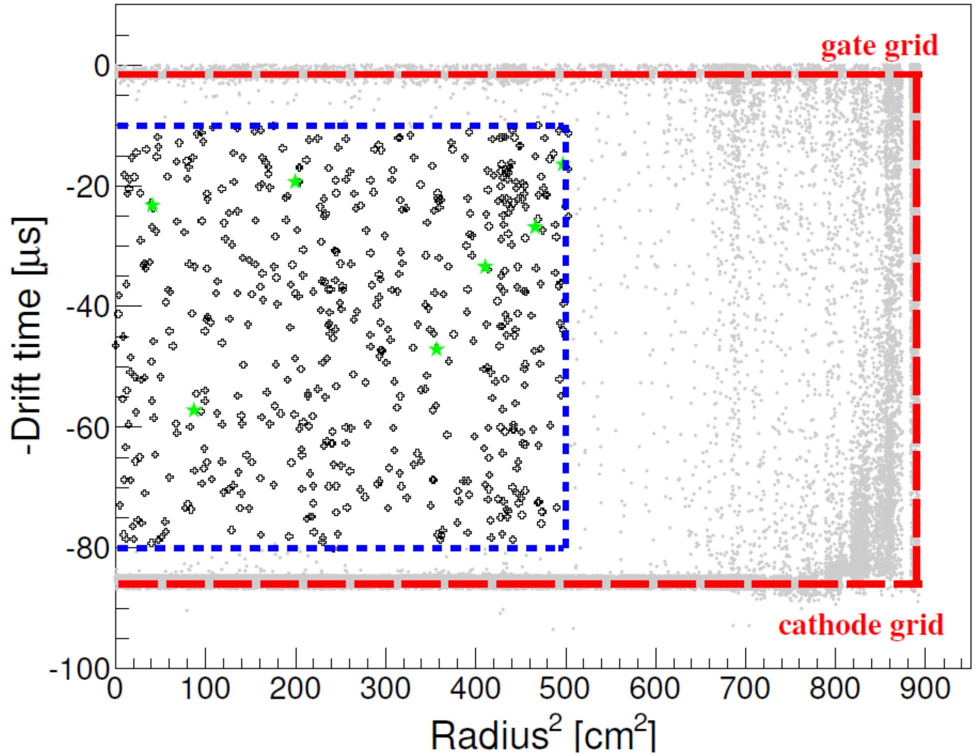
(a)ER band

Data reduction

Cut	# Events	Rate (Hz)
All triggers	24,762,972	3.58
Quality cut	6,127,280	0.88
Single-site cut	5,050,845	0.73
S1 range (2–30 PE)	62,872	9.08×10^{-3}
S2 range (300–10,000 PE)	44,171	6.38×10^{-3}
Fiducial volume	542	7.83×10^{-5}

TABLE III: The event rate of dark matter running after various cuts.

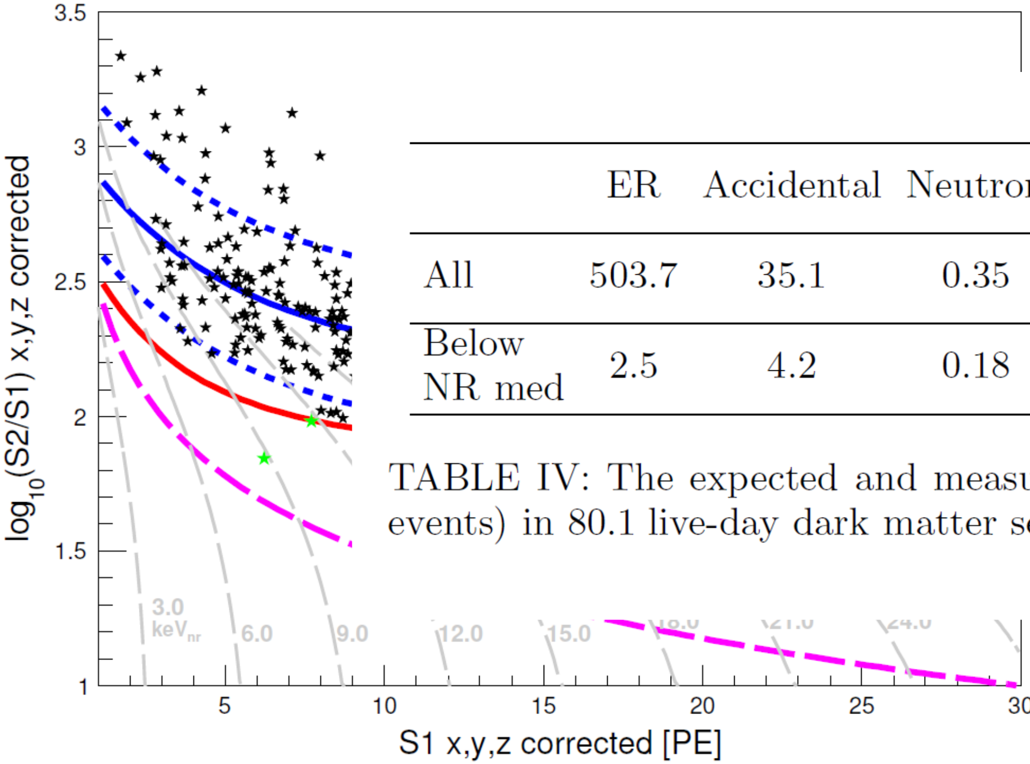
Vertex distribution



(a)drift time vs. r^2

- **Dominating background: PMTs and inner vessel**
- **Vertical asymmetric fiducial cut to balance the background from the top/bottom PMT array**
- **Radial direction cut to shield background from the vessel**
- **Very powerful self-shielding**

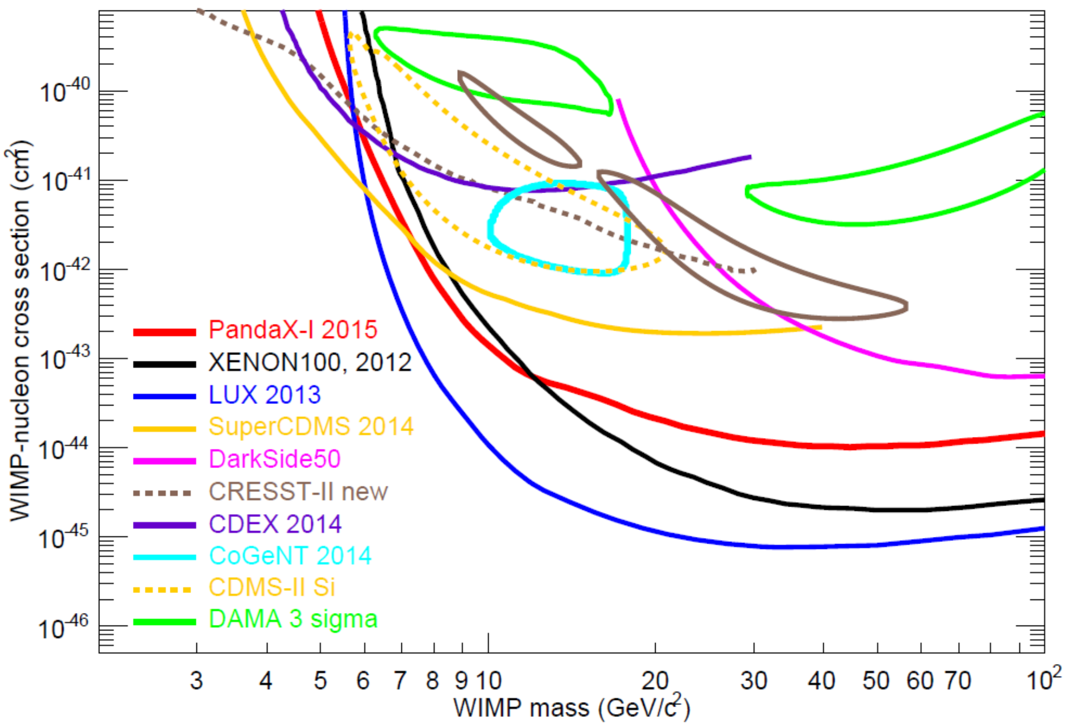
542 event distributions



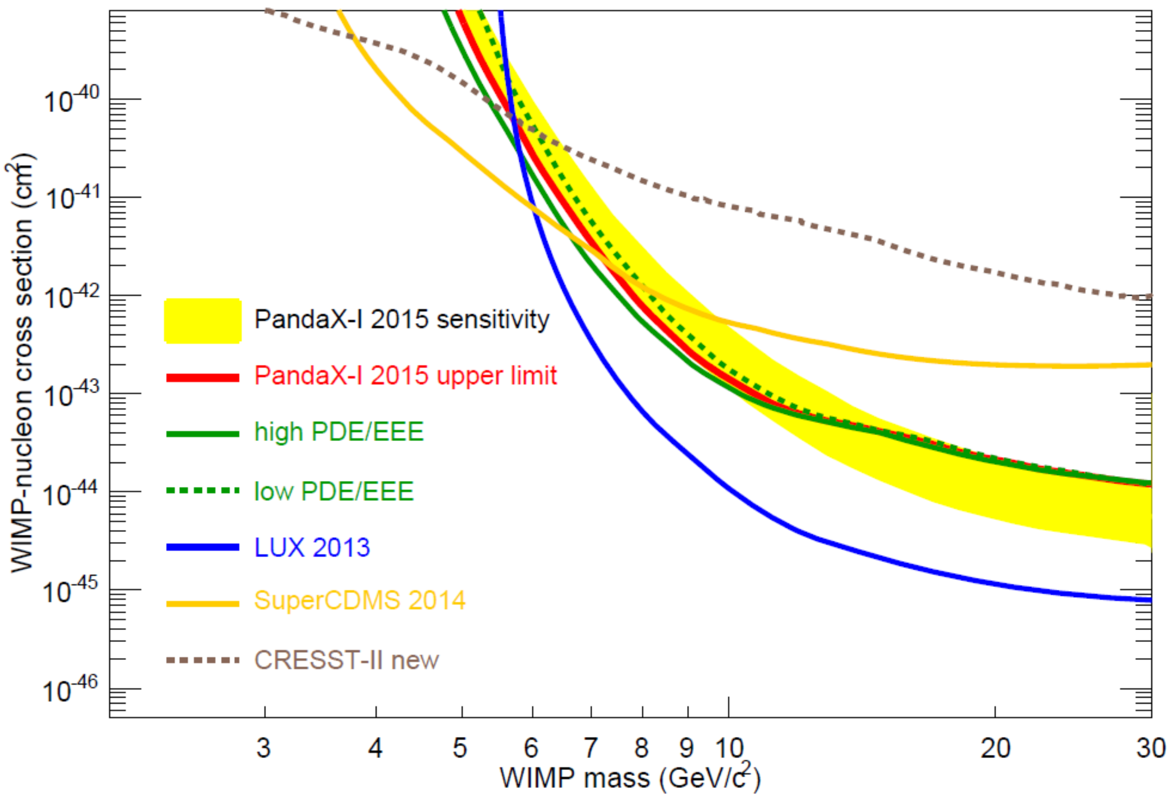
	ER	Accidental	Neutron	Total expected	Total observed
All	503.7	35.1	0.35	539.1	542
Below NR med	2.5	4.2	0.18	6.9	7

TABLE IV: The expected and measured events (in units of events) in 80.1 live-day dark matter search data.

Exclusion plot



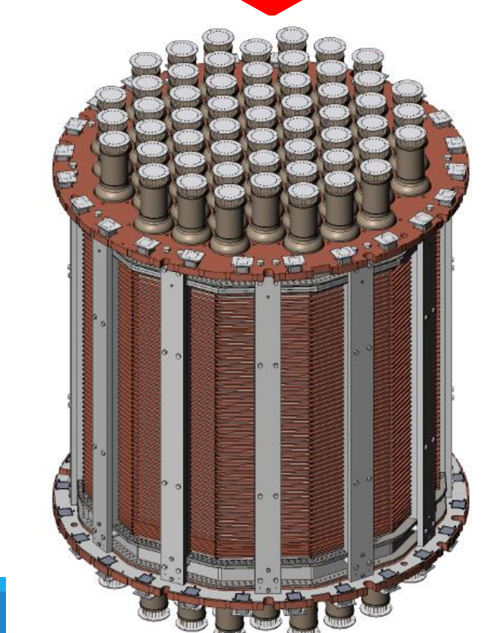
Sensitivity at low energy



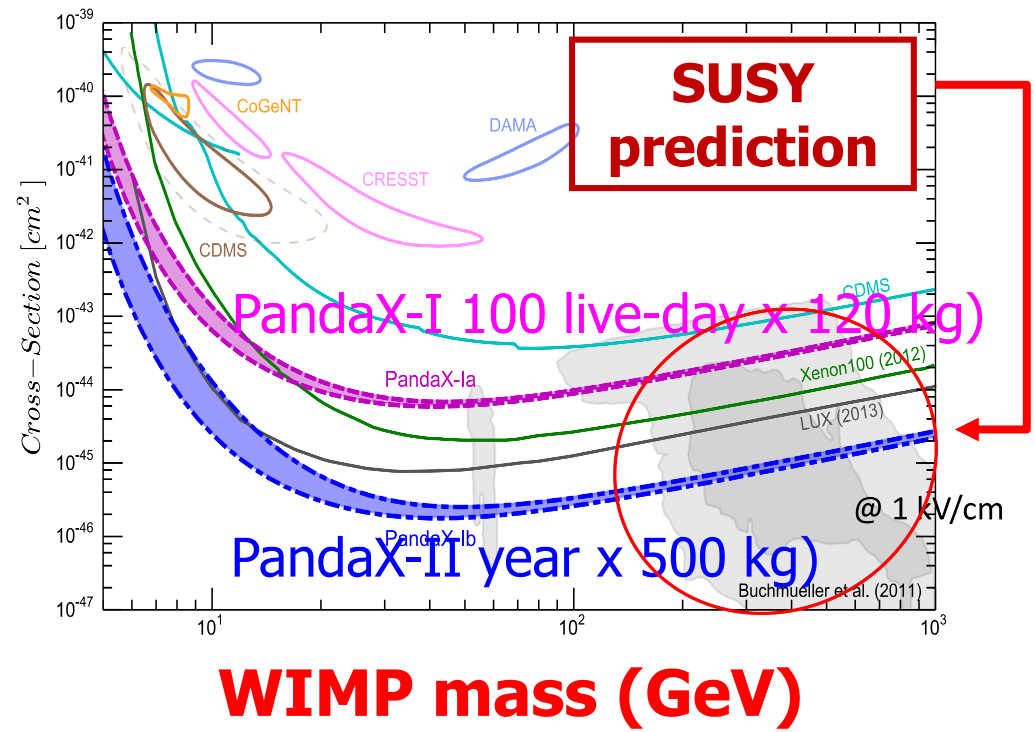
PandaX-II and Status

PandaX-I to PandaX-II Upgrade

120 kg



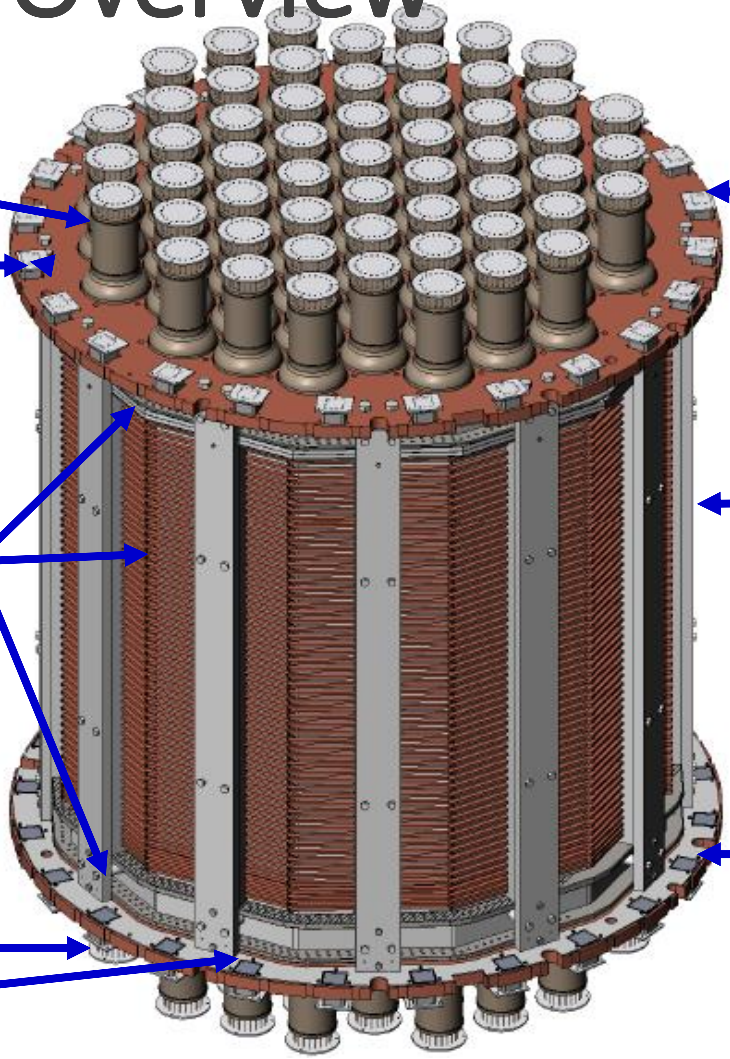
500 kg (cleaner vessel, more photocathode coverage, x4 larger TPC)



PandaX-II Overview

Top PMT Array： 55 R11410 3”+24 R8520 1”(veto)

Top Cu plate



Shaping rings and electrodes

Teflon ribs

Bottom PMT Array： 55 R11410 3”+24 R8520 1”(veto)

Bottom Cu plate

Planned improvements in PandaX-II

Background

- Replacing the SS vessel with one made with special 304 SS
- All 1.1-ton Xe with Kr level less than ppt
- Material surface treatment to minimize Rn

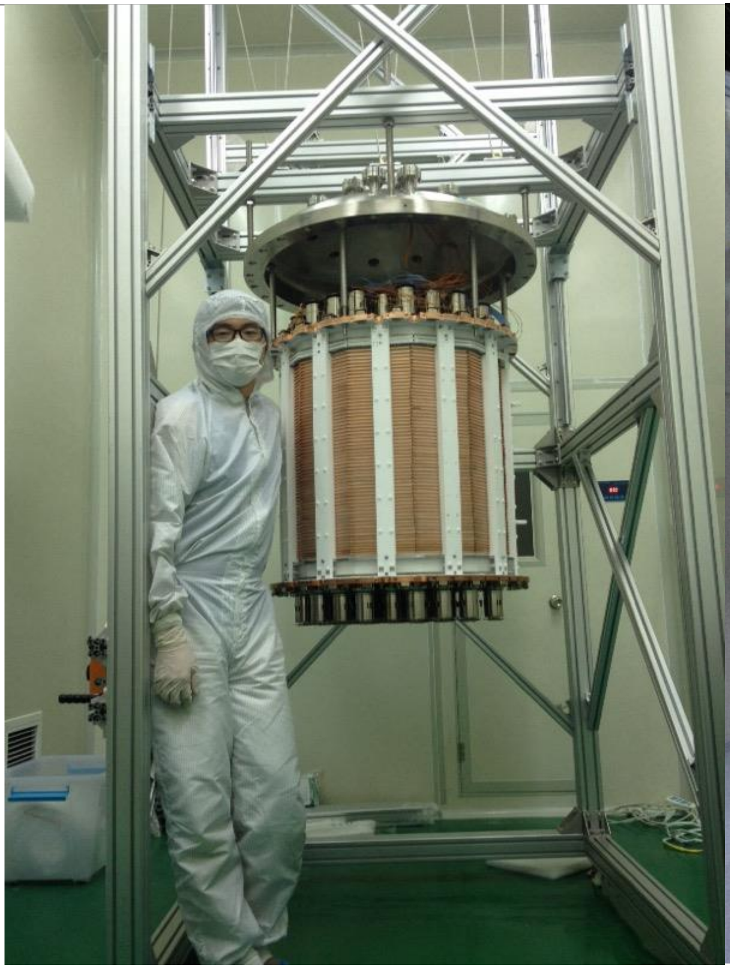
Performance

- Improved PMT base design to reduce HV relative to ground
- Increase circulation speed (parallel pumps/getters)
- Careful baking/flushing to reduce outgassing impurity
- Improvement to the cathode HV connection
- Two layer calibration system to allow calibrating multiple z location

PandaX II schedule

- Started construction in June 2014
- Start to commission in Feb. 2015
- Data taking in Dec. 2015
- First result by summer of 2016

500kg TPC in construction and Inner Vessel

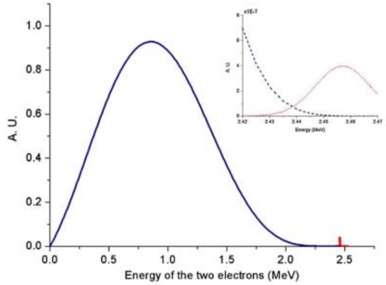


PandaX III:
High-pressure Xe136
0nuDBD experiment

Key requirements for discovering 0vDBD

1. Low radioactivity (more stringent requirement than for DM search)
2. Good energy resolution (sub% level)
3. Distinguishing Background from 0vDBD (Tracking, Cerenkov Radiation)
4. Scalability

   (price of isotope, exp expandability)

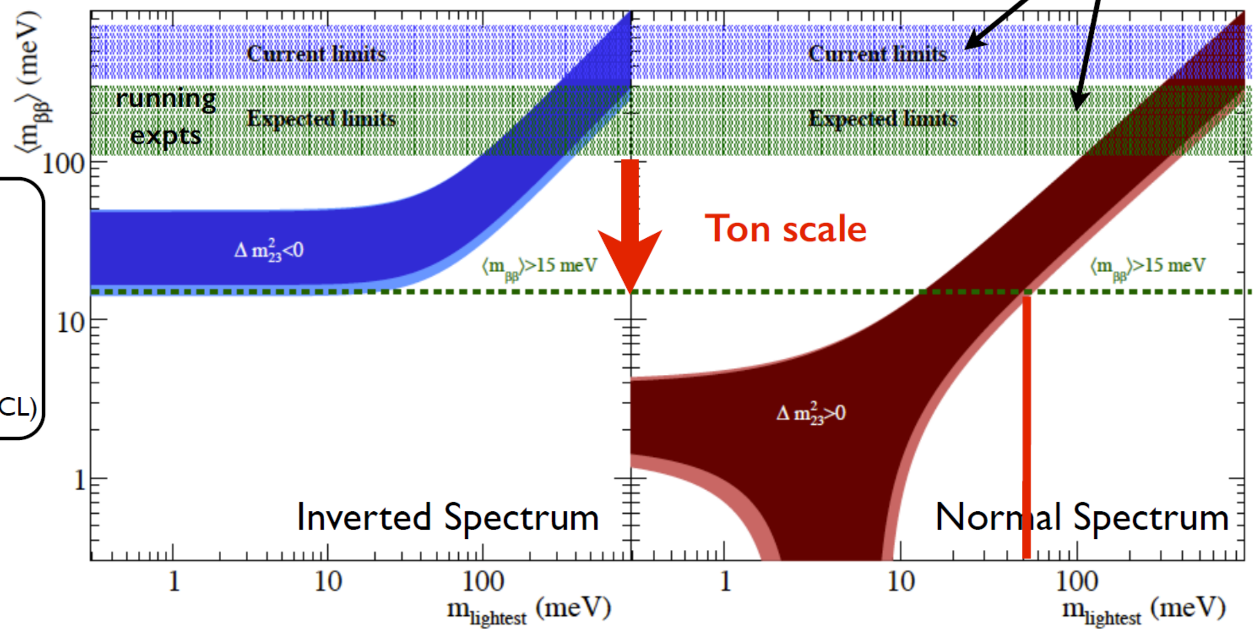


- Benchmark sensitivity for standard mechanism

Assume most "pessimistic" values for nuclear matrix elements

Dark bands: unknown phases

Light bands: uncertainty from oscillation parameters(90% CL)



- Ton-scale experiment will make a discovery if spectrum has
  1. inverted ordering *or*
  2. $m_{lightest}$ > 50 meV (irrespective of ordering)

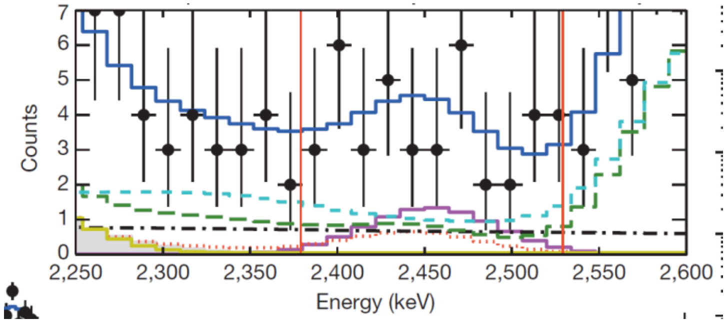
Front runners

Experiment	Isotope	Resolution (keV)	Efficiency	Phase	Mass (kg)	Exposure (kg·year)	Background rate (counts/(keV · kg · y))	Sensitivity (meV)
CUORE	^{130}Te	5	0.8	2015–2017 (I)	200	600	10^{-1}	140
				2018–2020 (II)	200	600	4×10^{-2}	85
EXO	^{136}Xe	100	0.7	2012–2014 (I)	160	480	7×10^{-3}	185
				(II) 2016–2020	160	800	5×10^{-3}	150
GERDA	^{76}Ge	5	0.8	2012–2014 (I)	18	54	10^{-2}	214
				2016–2020 (II)	35	175	10^{-3}	112
KamLAND-Zen	^{136}Xe	250	0.8	2013–2015 (I)	360	1440	10^{-3}	97
				2017–2020 (II)	35	2700	5×10^{-4}	60

Table 1.1: Proposals considered in the $m_{\beta\beta}$ sensitivity comparison. For each proposal, the isotope that will be used, together with estimates for detector performance parameters — FWHM energy resolution, detection efficiency and background rate per unit of energy, time and $\beta\beta$ isotope mass — are given. Two possible operation phases, with estimates for the detector mass and the background rate achieved, are given for each experiment.

A Front Runner: EXO200

- 200kg Liquid Xenon TPC, 2 years of running
- Superb control in radioactivity and energy resolution (3%)
- 39 events observed in 2σ region. 31 background events expected



EXO200: Nature 2014

New game: HP Gas Xe136 TPC

- possibly excellent energy resolution: intrinsic one is 0.3% FWHM (7.5 keV)
- Low-background, maybe can be as low as

10^{-3}count/keV kg yr

- Tracking capability
- Scalability (there is already 1 ton ^{136}Xe in the world)

Advantages of High Pressure Xe Gas

- Greater energy resolution

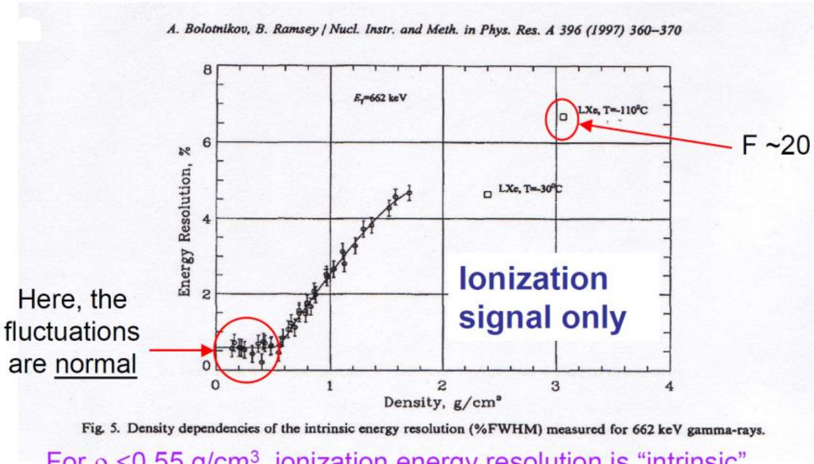
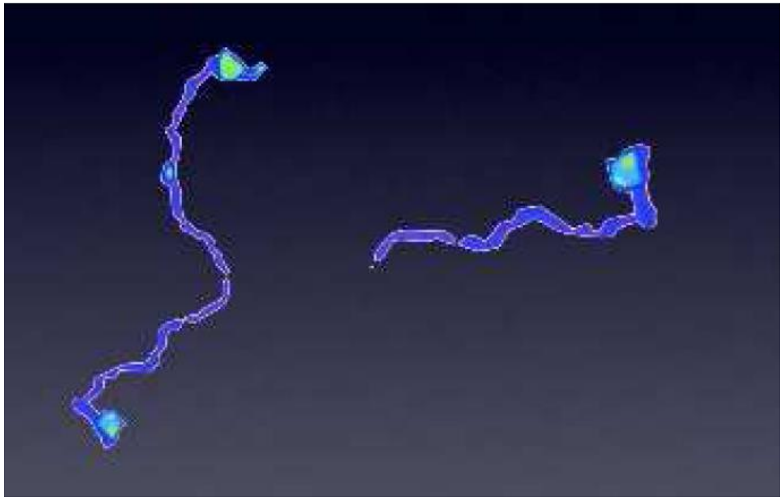


Fig. 5. Density dependencies of the intrinsic energy resolution (%FWHM) measured for 662 keV gamma-rays.

For ρ <0.55 g/cm^3, ionization energy resolution is "intrinsic"

- Tracking capability

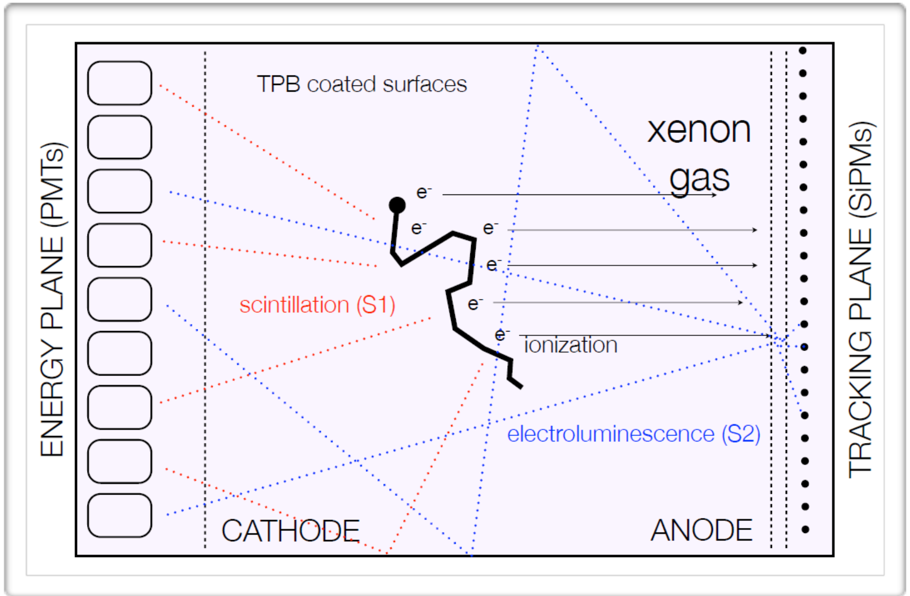


PandaX III: 200kg HP Xe TPC

- Develop a
  - high-energy resolution (0.5-3%FWHM)
  - low-background (10^{-3} c/keV kg yr)
  - large size (3-4m^3)
  - high-pressure (10-15bar)

  Xe136 gas TPC
- This is also the goal of the NEXT collaboration

What is NEXT?



EL mode is essential to get lineal gain, therefore avoiding avalanche fluctuations and fully exploiting the excellent Fano factor in gas

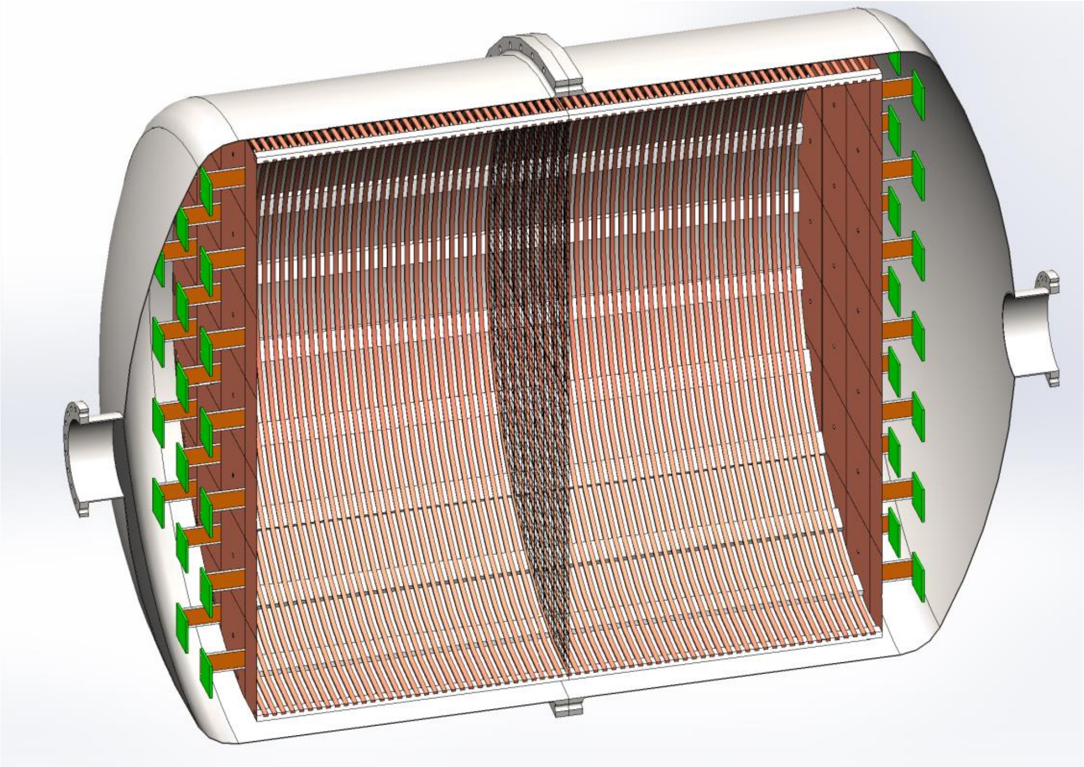
- It is a High Pressure Xenon (HPXe) TPC operating in EL mode.
- It is filled with 100 kg of Xenon enriched at 90% in Xe-136 (in stock) at a pressure of 15 bar.
- The event energy is integrated by a plane of radiopure PMTs located behind a transparent cathode (energy plane), which also provide t0.
- The event topology is reconstructed by a plane of radiopure silicon pixels (MPPCs) (tracking plane).

PandaX-III main differences

- Alternative Realization For Readout: symmetric charge readout
  - Stage1:MircoMegas, energy resolution 2-3% FWHM
  - Stage2:TopMetal (modified CMOS), energy resolution 0.5%
  - Benefits: radiopurity, scalability, and ultimate energy resolution, tracking
- Light readout? (optional)
- New type HP vessel
- 200kg modules for scalability to 1 ton
- Deepest underground lab (CJPL)

200kg HP Gas TPC

- Size: 1.5m in diameter, 2m long cylinder

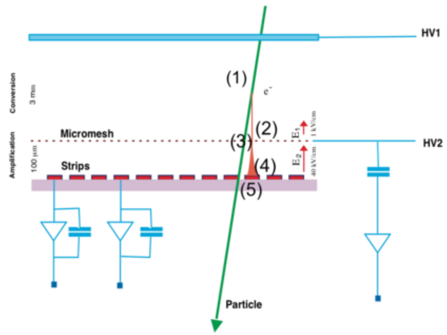


Xe136 0vDBD event

- Produce 2 electrons with total energy 2.458 MeV
- In Xe gas, it produces roughly 100K ionization electrons
- Track size in 10 bar gas, 30 cm
- Readout the total energy and the tracks.

Readout option 1: Micromegas

- Micromegas working principle: gas amplification through very thin layers 50μm



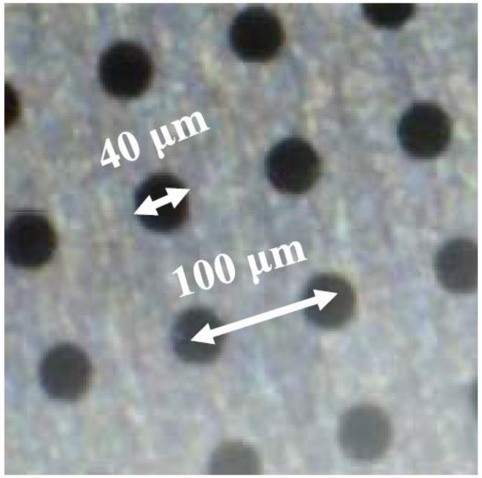
- MicroBulk technology, using lithographic tech to manufacture MM. Superb quality!

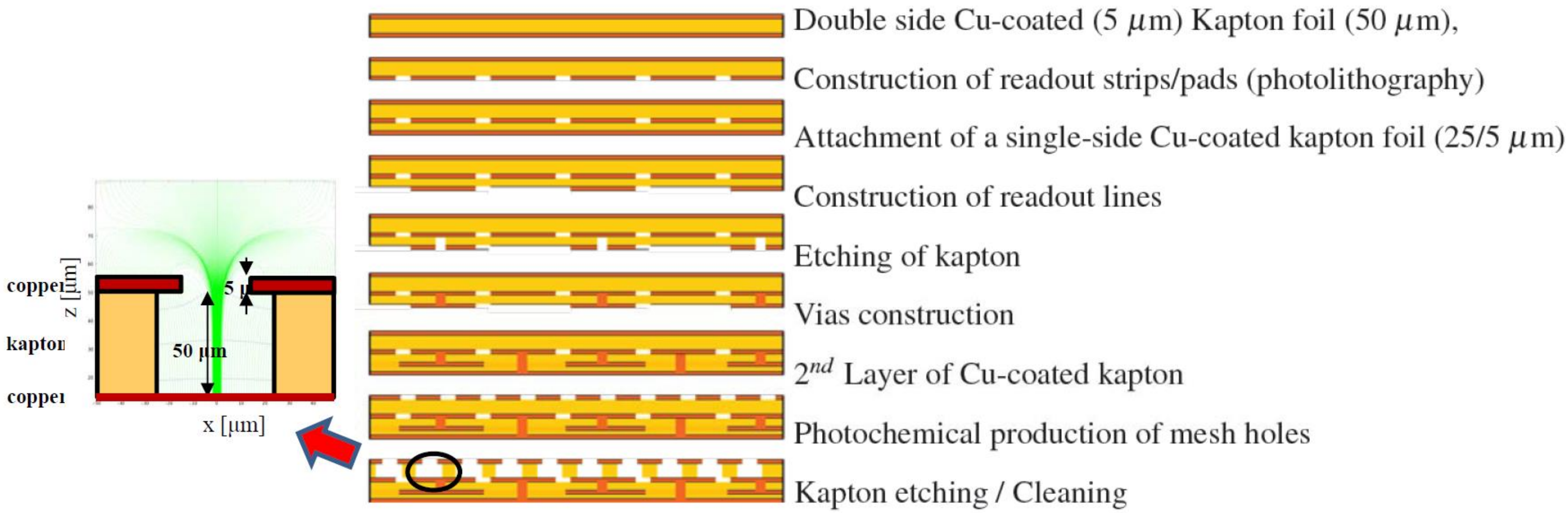
Micromegas readout

- **Microbulks Micromegas**
  - are made mostly of copper & kapton → potentially very radiopure
  - High gap homogeneity → very good energy resolutiosn

CERN workshop:
Rui de Oliveira et al

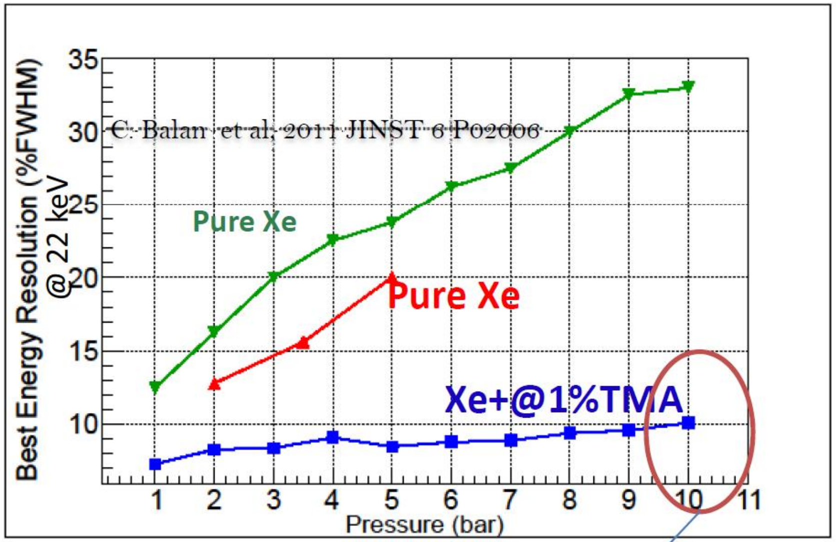
JINST 5(2010)P12001



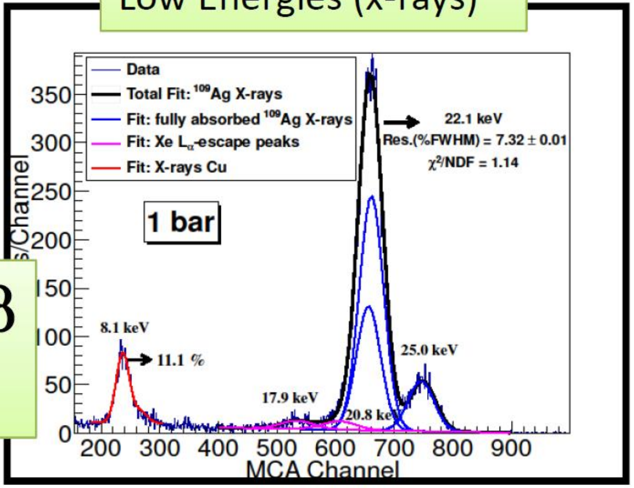


Energy resolution … in Xenon?

- Addition of TMA to Xe: perfect combination!
- higher gains, better E res, more stable operation

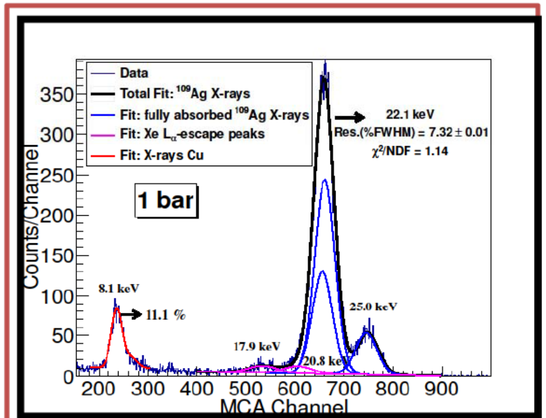


Small setup TREX-BB-0
Low Energies (x-rays)



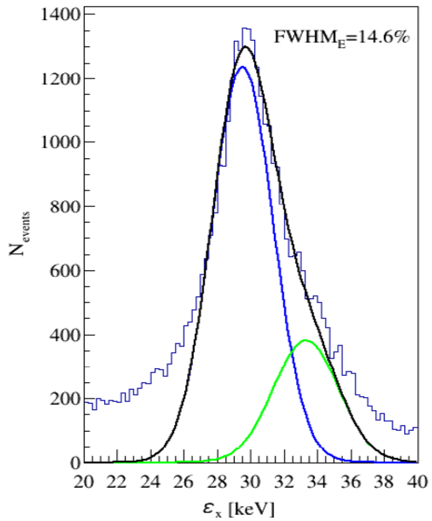
0.9% FWHM @ Qββ
10 bar

Energy resolution – real data



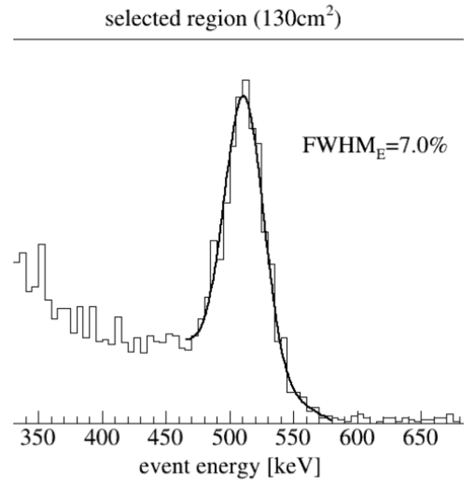
Small setup TREX-BB-0
Low Energies (x-rays)
~10% FWHM @ 22 keV

0.9% FWHM @
Qββ 10 bar



Large setup NEXT-MM
Low Energies
(isolated x-rays)
~15% FWHM @ 22 keV

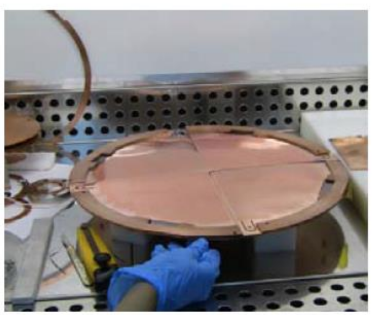
1.4% FWHM
@ Qββ 10 bar

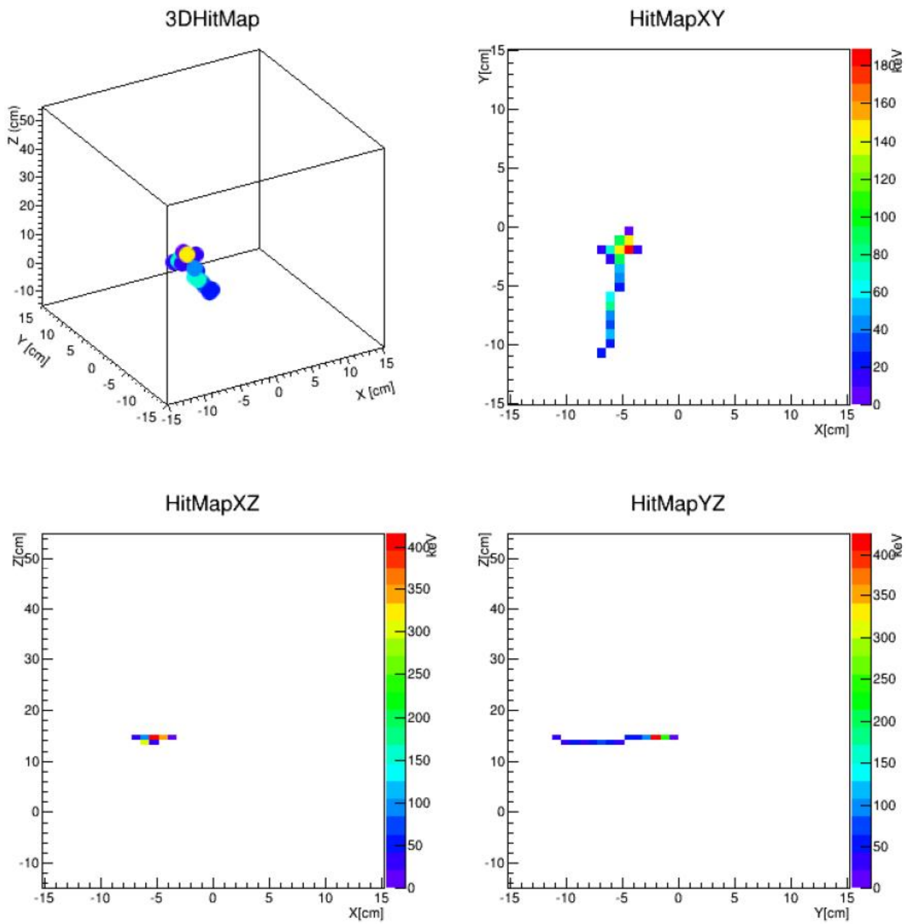


Large setup NEXT-MM
High energies (511 keV)
~7% FWHM @ 511 keV

3.1% FWHM
@ Qββ 10 bar

Real tracks in NEXT-MM @ UNIZAR



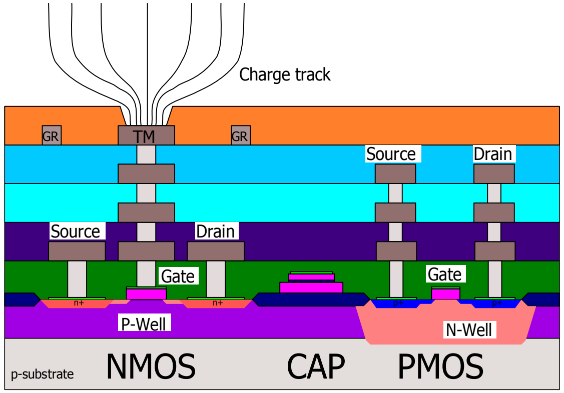


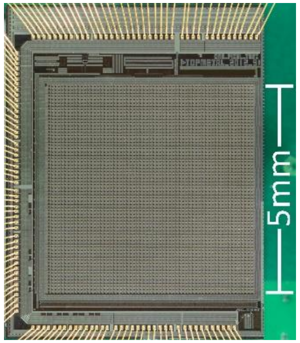
Energy
~1274 keV
(Na-22
photo peak)

“half a $2\nu\beta\beta$
event”

Alternative readout: Topmetal

- Direct pixel readout without gas amplification!
- 30 e noise level
- Superb radiopurity for FEE
- Game changer!
- Will developed by LBL/CCNU
- 0.3-0.5%FWHM??





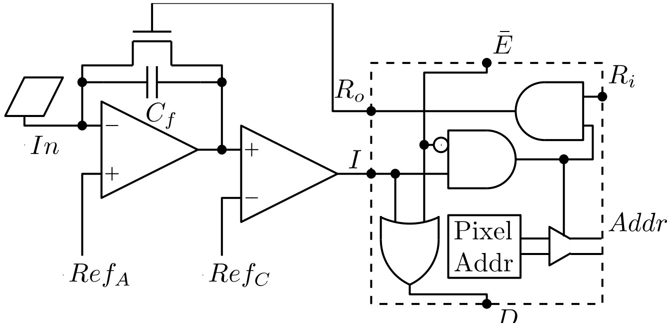
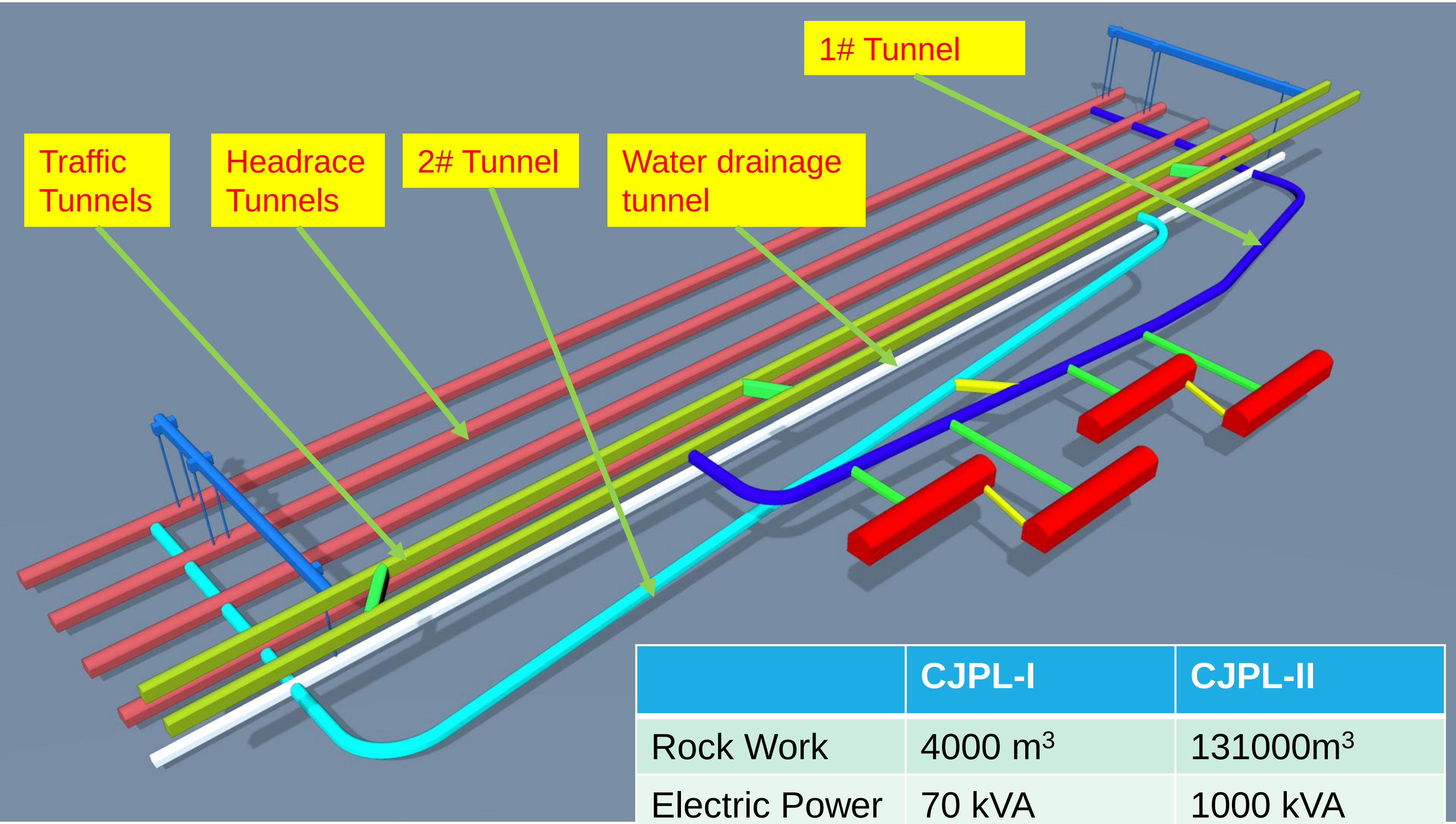


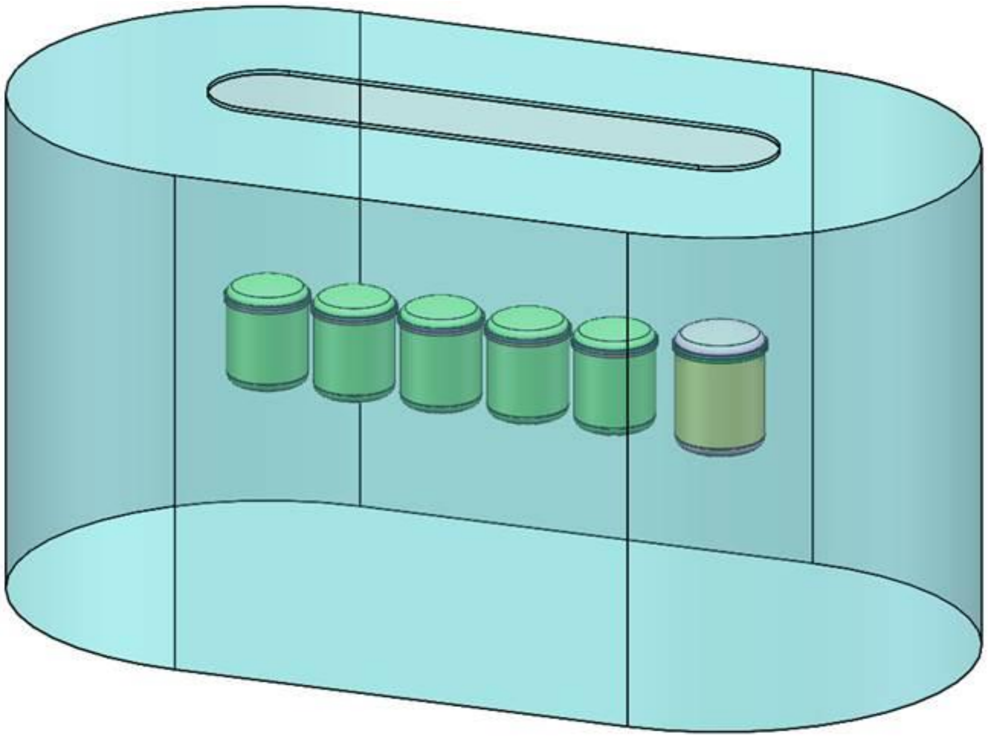
图 YM1

Preliminary Design of CJPL-II



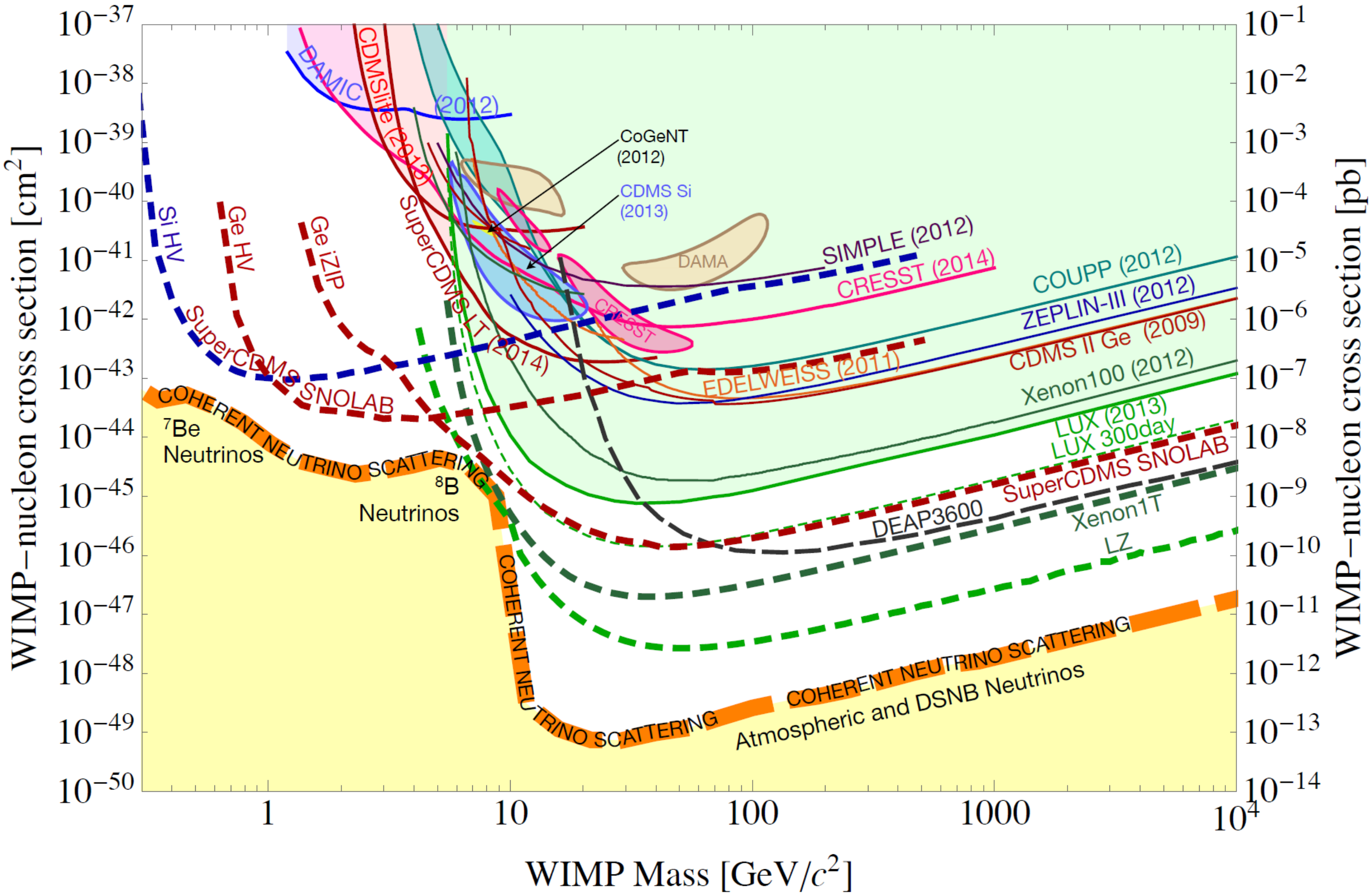
	CJPL-I	CJPL-II
Rock Work	4000 m^3	131000m^3
Electric Power	70 kVA	1000 kVA
Fresh Air	2400 m^3/h	40000 m^3/h

Water shield in jinping



Future: Ultimate dark matter experiment

暗物质直接探测路线图



WIMP−nucleon cross section [cm^2]
WIMP−nucleon cross section [pb]
WIMP Mass [GeV/c^2]
DAMIC (2012)
CDMSlite (2013)
CoGeNT (2012)
CDMS Si (2013)
DAMA
SIMPLE (2012)
CRESST (2014)
CRESST
COUPP (2012)
ZEPLIN-III (2012)
CDMS II Ge (2009)
EDELWEISS (2011)
Xenon100 (2012)
LUX (2013)
LUX 300day
SuperCDMS SNOLAB
DEAP3600
Xenon1T
LZ
SuperCDMS LT (2014)
Si HV
Ge HV
Ge iZIP
SuperCDMS SNOLAB
COHERENT NEUTRINO SCATTERING
^{7}Be Neutrinos
^{8}B Neutrinos
Atmospheric and DSNB Neutrinos

Ultimate dark matter experiment?

- 20-30 ton LXe
- 50-100 ton LAr (Darkside, 50kg)
- Europe: DARWIN group (Baudis)
- China Jinping lab, a joint effort by PandaX, LZ and XENONnT?
- Low mass: CDMS (US), CDEX (China),...

20-30 ton LXe experiment

- From this plot, a 20-30 ton LXe experiment is the ultimate direct DM search experiment for large mass WIMPs.
- This experiment needs
  - Deep overburden: Jinping
  - International collaborations, involving China, US and Europe?
  - New technology?

Two phases

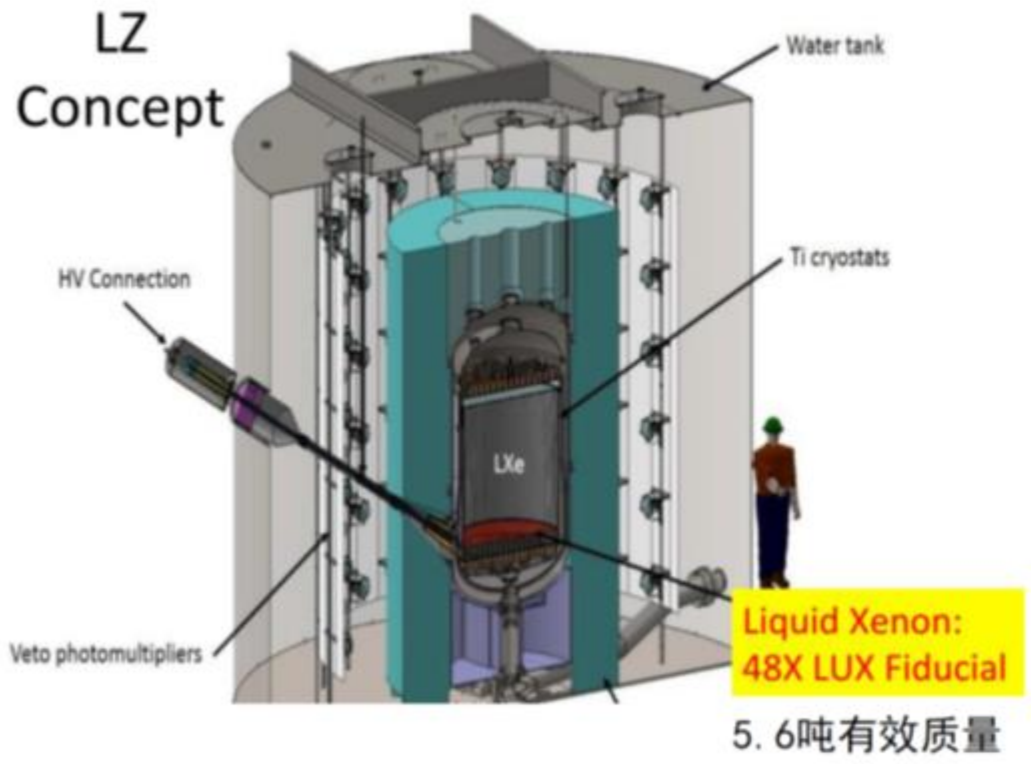
- R&D phase, in progress now: including
  - The traditional design
  - New design with single-phase
  - LZ experiment
- Construction phase

  2019-2021, data taking 2022-2025

LZ experiment

- LZ experiment in US is building a 10ton LXe experiment at SURF, Lead, SD.
- The experiment will start to run in 2018
- The PandaX collaboration has joined LZ as part of the R&D effort for the ultimate 20-30 ton LXe experiment.

LZ experiment



LZ sensitivity