The PandaX Experiment and the Results from the Full Exposure of PandaX-I

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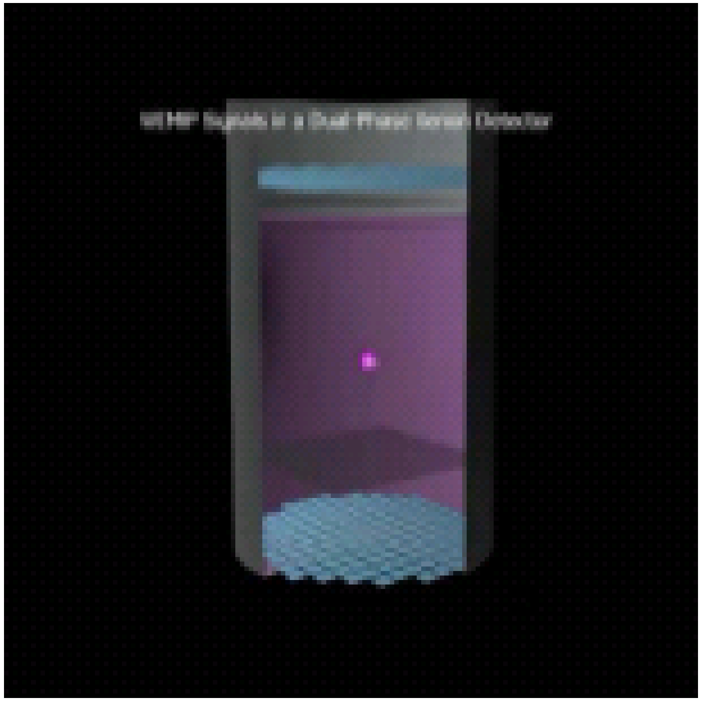
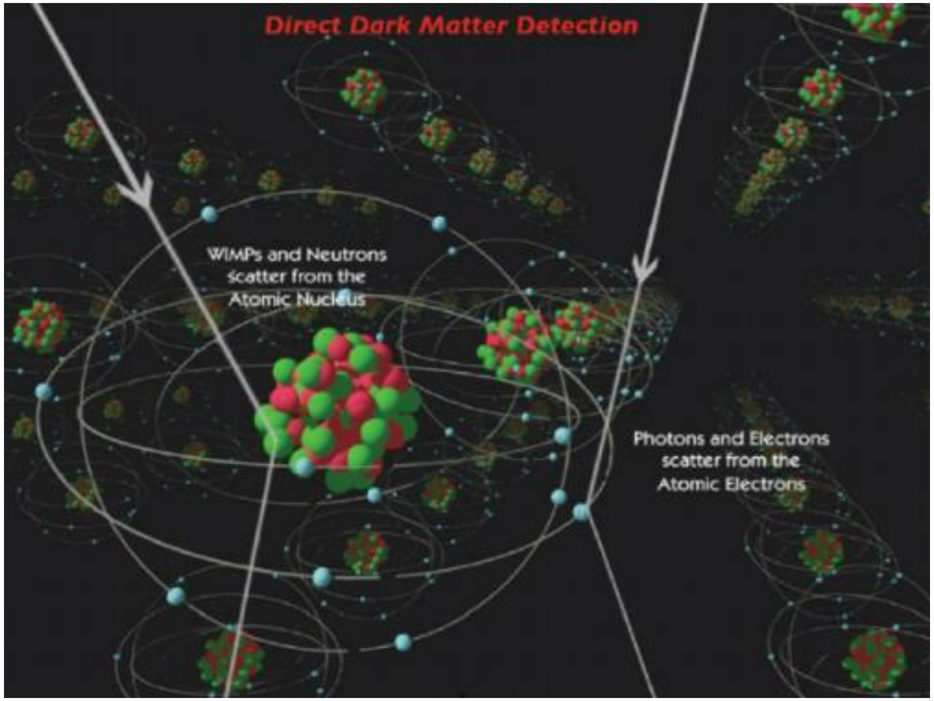
On Behalf of the PANDAX Collaboration

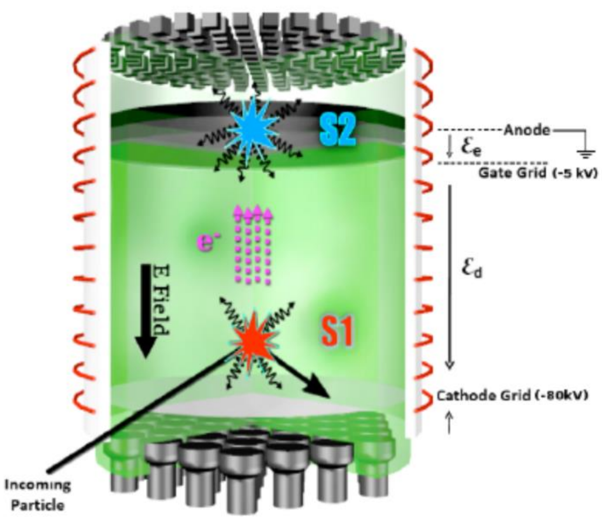
Dark matter: direct detection

- 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

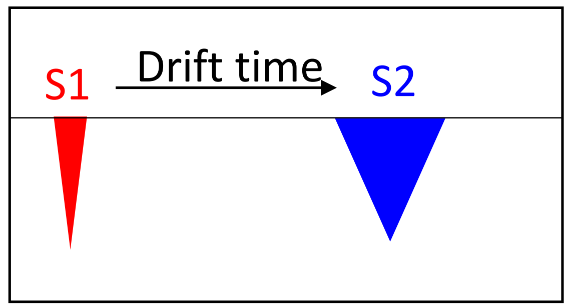




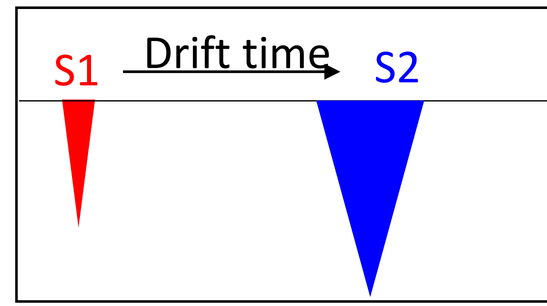
Dual phase xenon detector



Dark matter: nuclear recoil (NR)

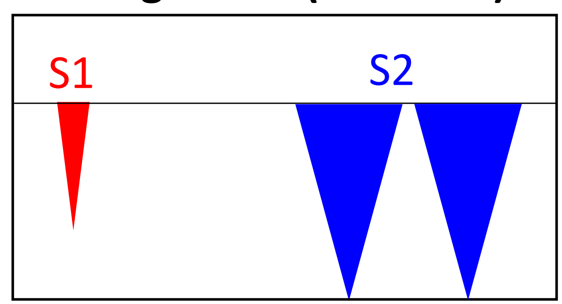


γ background: electron recoil (ER)



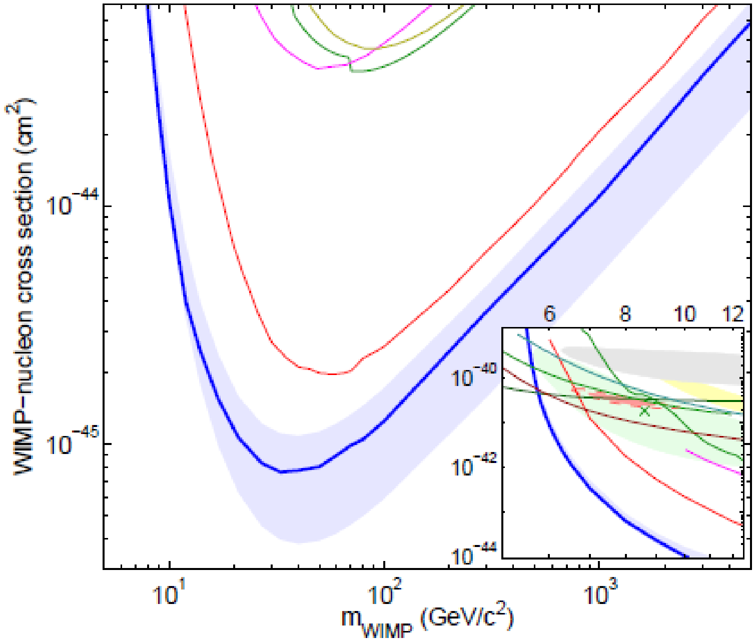
$$(S2/S1)_{NR} << (S2/S1)_{ER}$$

Multi-site scattering background (ER or NR)

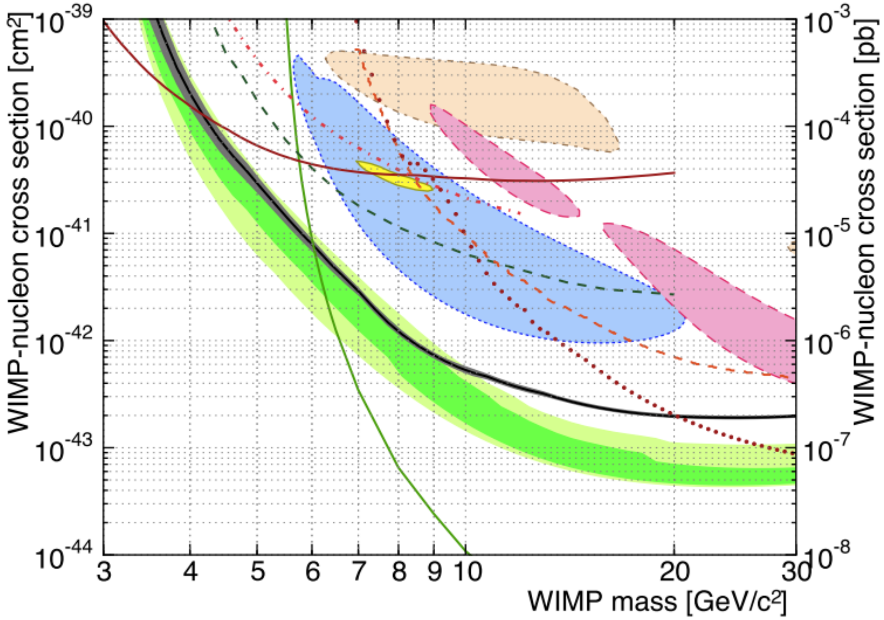


Direct detection: global situation

LUX 2013， PRL 112, 091303 (2014)



SuperCDMS, PRL 112, 241302 (2014)



- Many experiments utilizing different technologies
- Quite some contradictory claims
- Quite some high sensitivity null results
- Xenon experiments carve into the “mainstream” supersymmetry theory predictions, still say no

DM-rush in Jin-Ping, China (CJPL)

nature International weekly journal of science

Dark-matter hunt gets deep

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

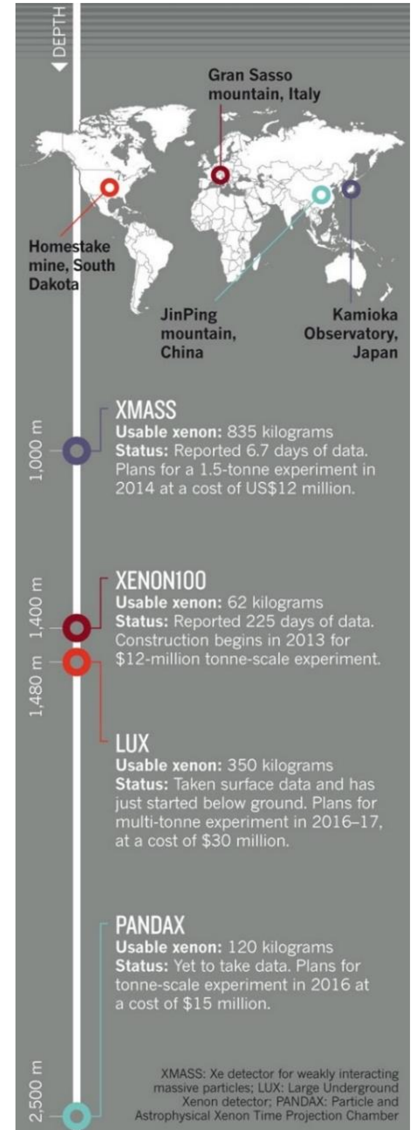
Eugenie Samuel Reich

20 February 2013 | Corrected: 21 February 2013

NATURE | NEWS

See also talks
Q. Yue, DM-A, Sep. 7
J. Li, DM-A, Sep. 9

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.



PandaX collaboration

~40 people

Started in 2009

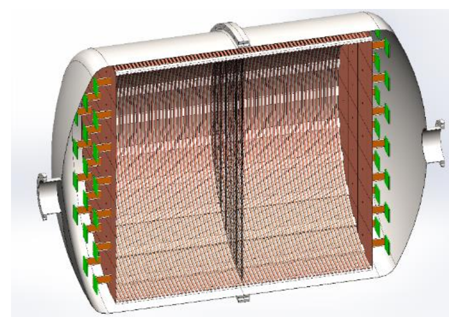
- Shanghai Jiao Tong University (2009-)
- Peking University (2009-)
- Shangdong University (2009-)
- Shanghai Institute of Applied Physics, CAS (2009-)
- University of Science & Technology (2015-)
- China Institute of Atomic Energy (2015-)
- Yalong Hydropower (2009-)
- University of Maryland (2009-)
- University of Michigan (2011-2015)

PandaX experiment

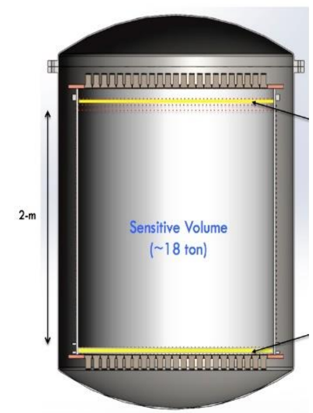
PandaX＝Particle and Astrophysical Xenon Experiments

Phase I: 120 kg DM
2009-2014

Phase II: 500 kg DM
2014-2017

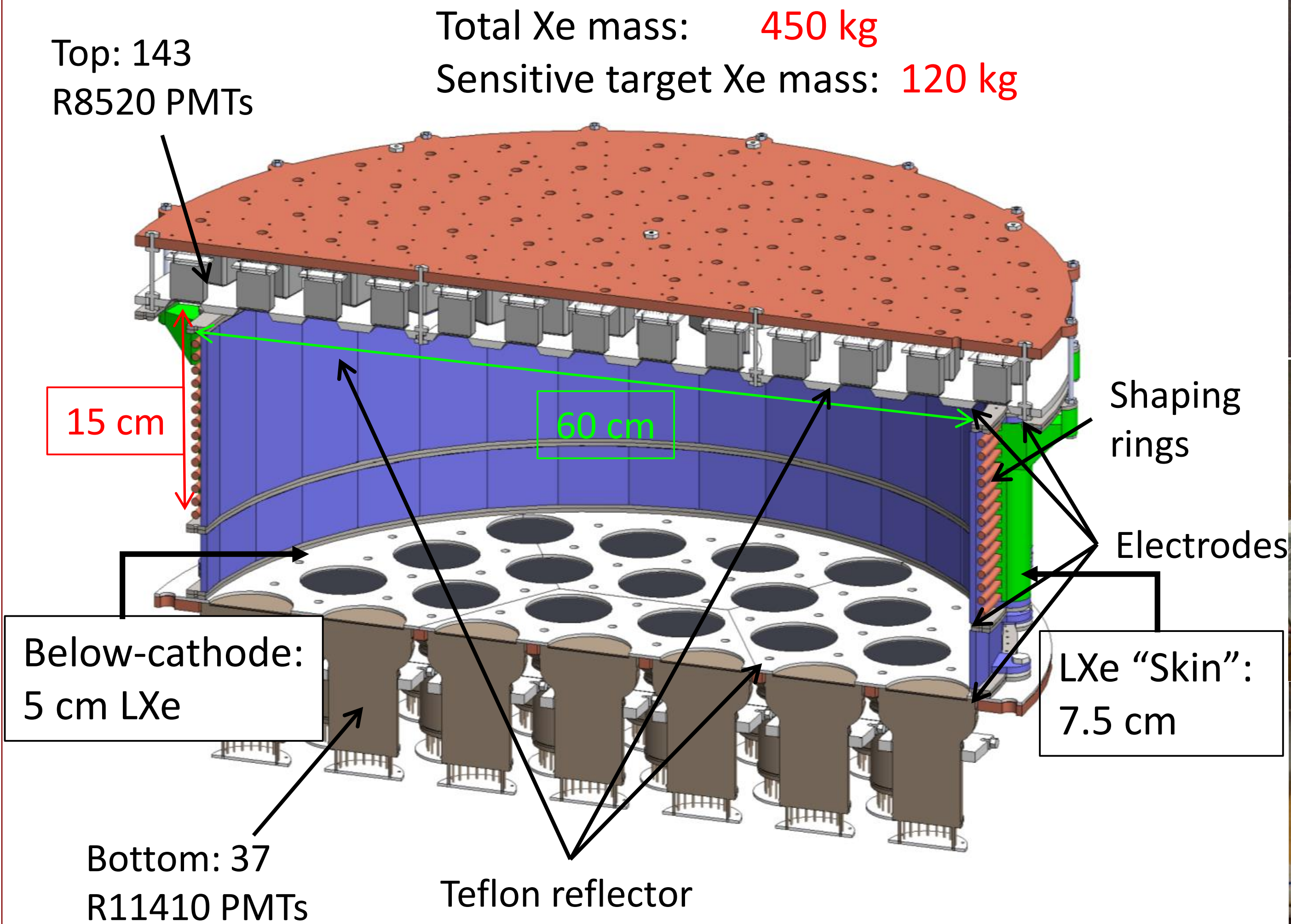


Phase III: 200 kg to 1 ton ^{136}Xe 0vDBD
2016-2020



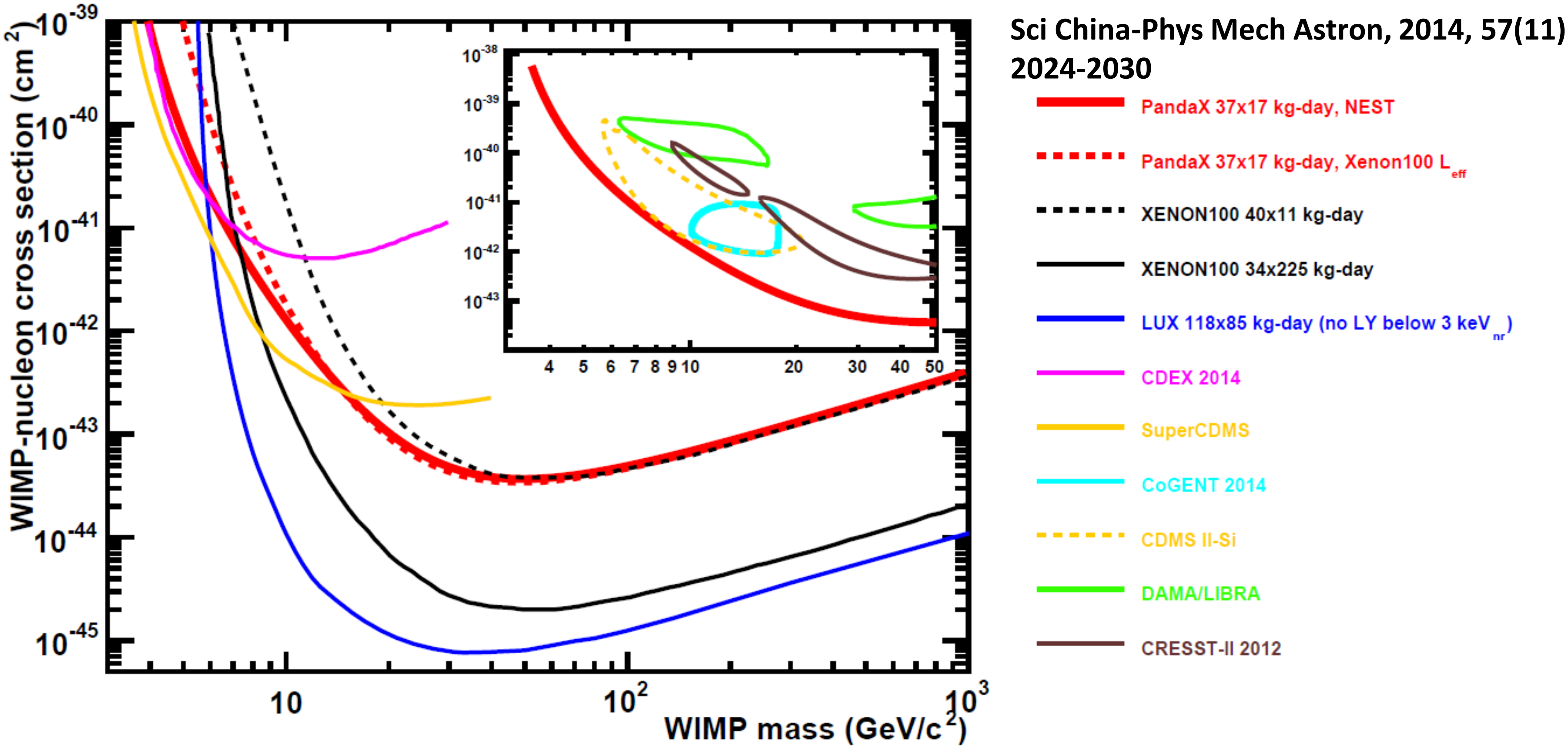
Phase IV: 20 ton DM
2020-2025

PandaX-I TPC



Key design goal: high light collection efficiency

PandaX-I first data: 34x17 kg-day



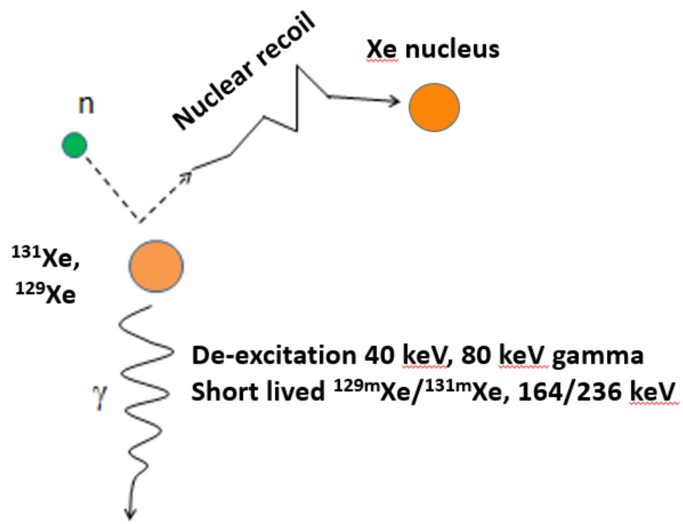
- Disfavor all previously positive signals
- At low mass region, our results more constraining than XENON100 first results with similar exposure

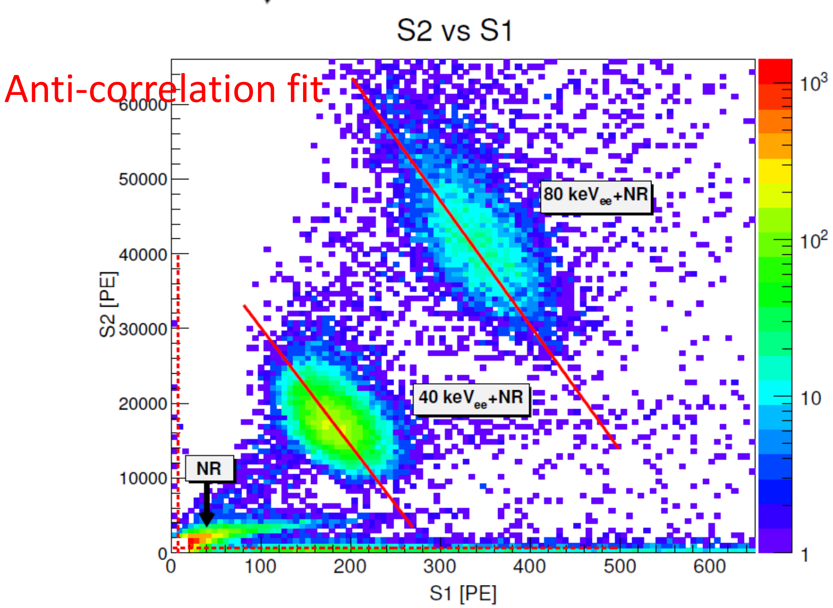
PandaX-I full exposure run

arXiv:1505.00771, accepted by Phys. Rev. D

- 80.1 live-day × fiducial mass 54 kg (x7 exposure)
- 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
- Blinded analysis: FV and energy acceptance defined blindly using FoM based on background expectation and exposure
- Likelihood approach to final results

Extracting detector parameters





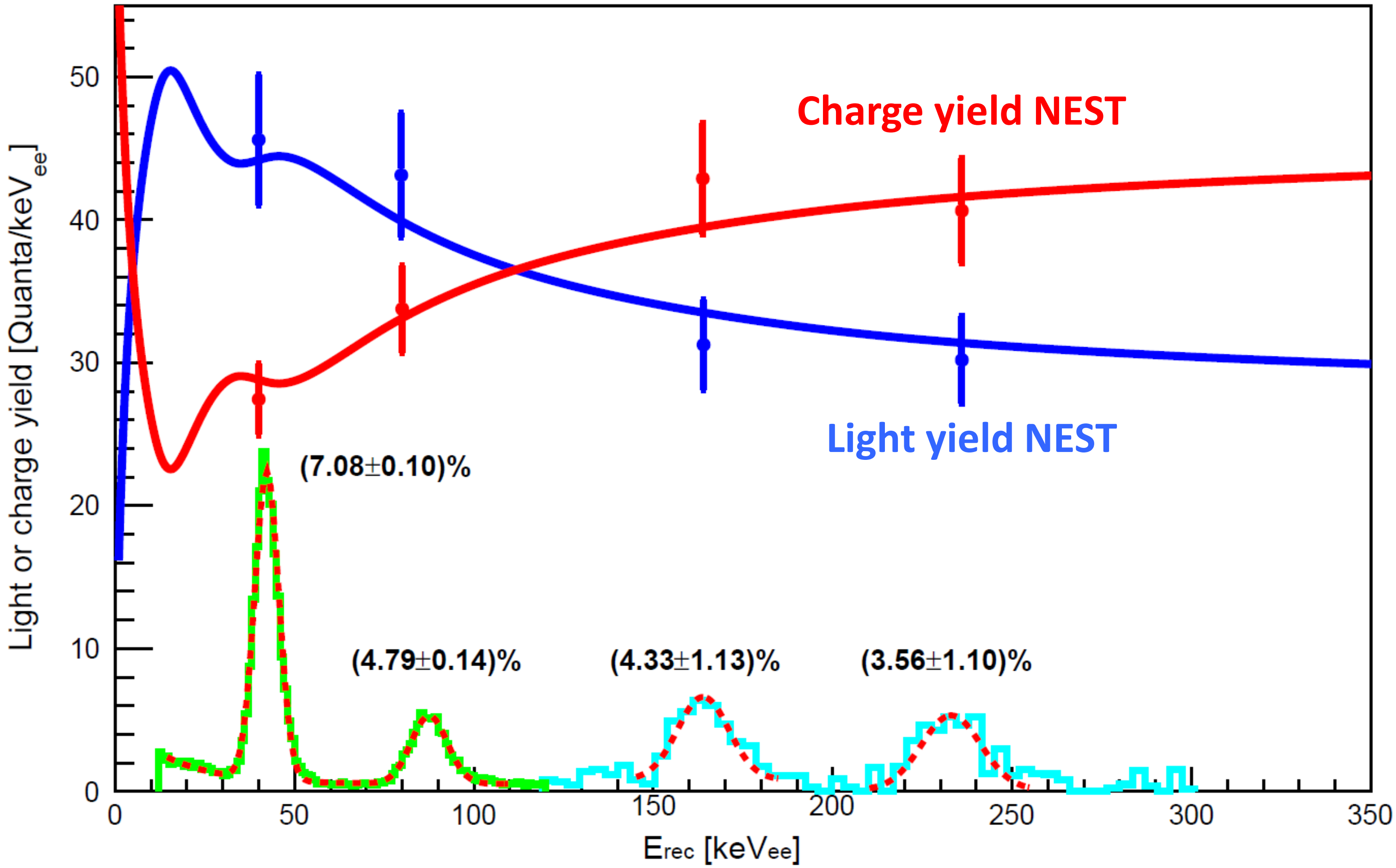
$$E_{ee}^{ce} = w\left(\frac{S1}{PDE} + \frac{S2}{\text{gas gain} \times EEE}\right)$$

W = 13.7 eV (NEST)

Photon detection efficiency (PDE):
9.55(1.0)%

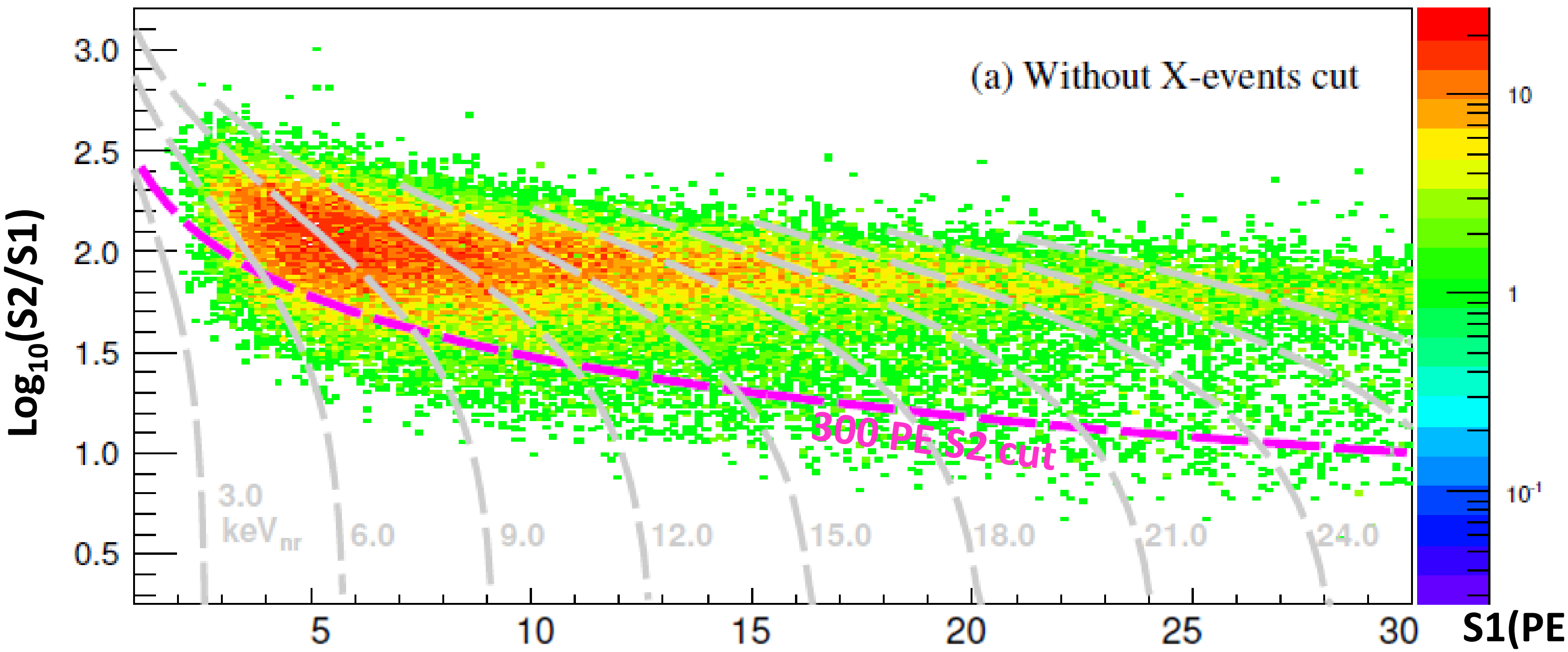
Electron extraction efficiency (EEE):
82.1(7.4)%

Comparison with NEST model

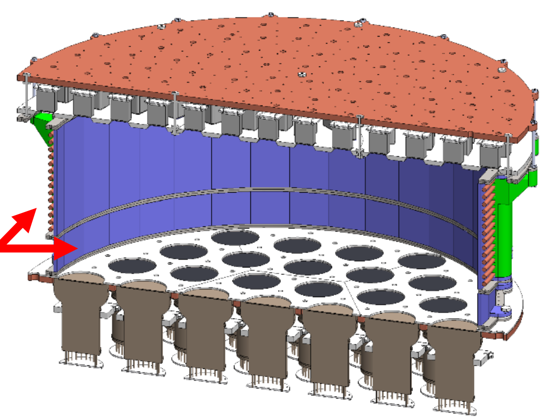


NEST prediction consistent with our measurement within uncertainty.

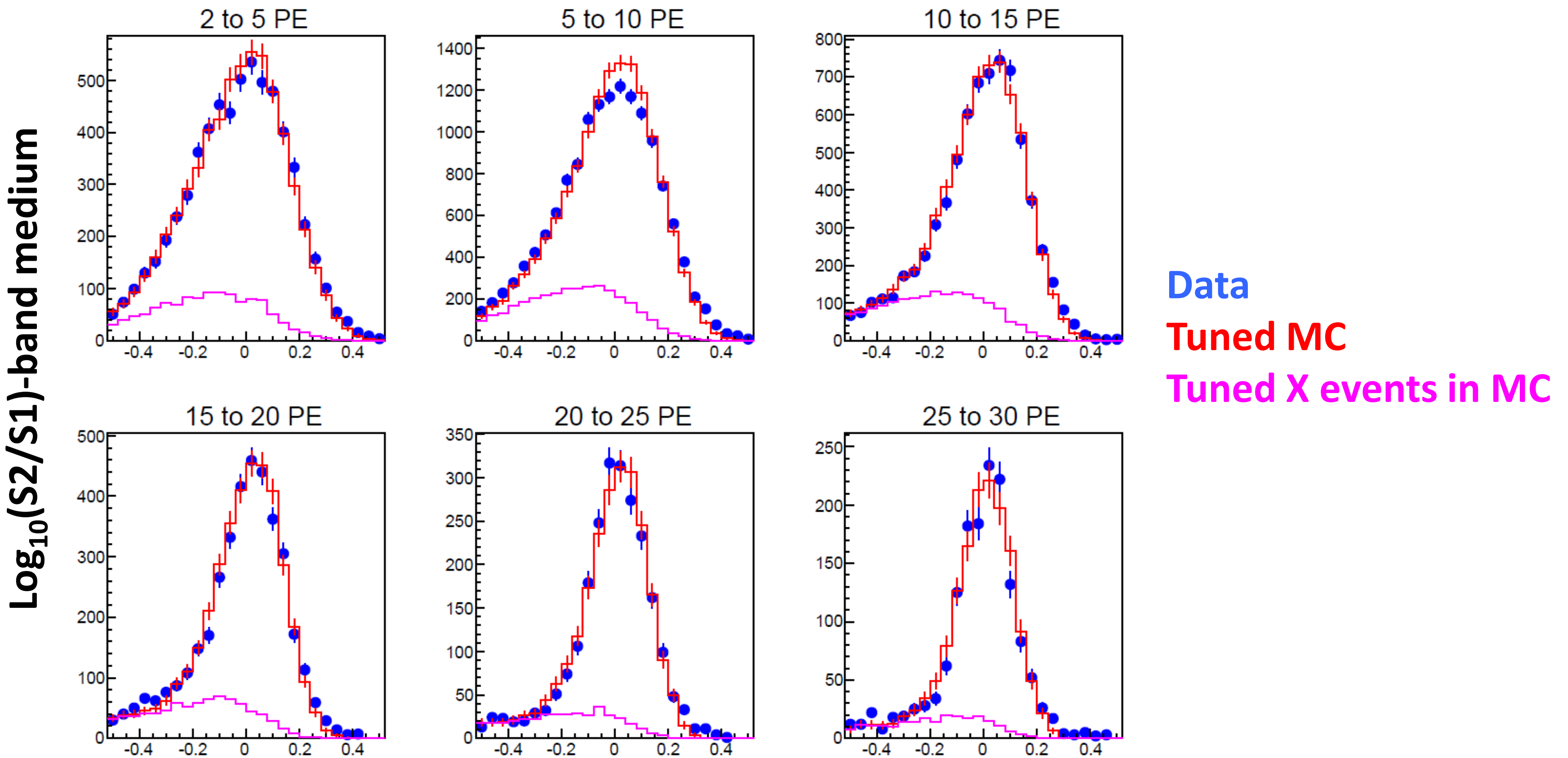
Nuclear recoil band



- Observe significant "single scatter" events with suppressed S2
- "X events" in the "chargeless" region
  - Below-cathode-events (5 cm of LXe)
  - Events with energy deposition in the skin (7.5 cm of LXe)

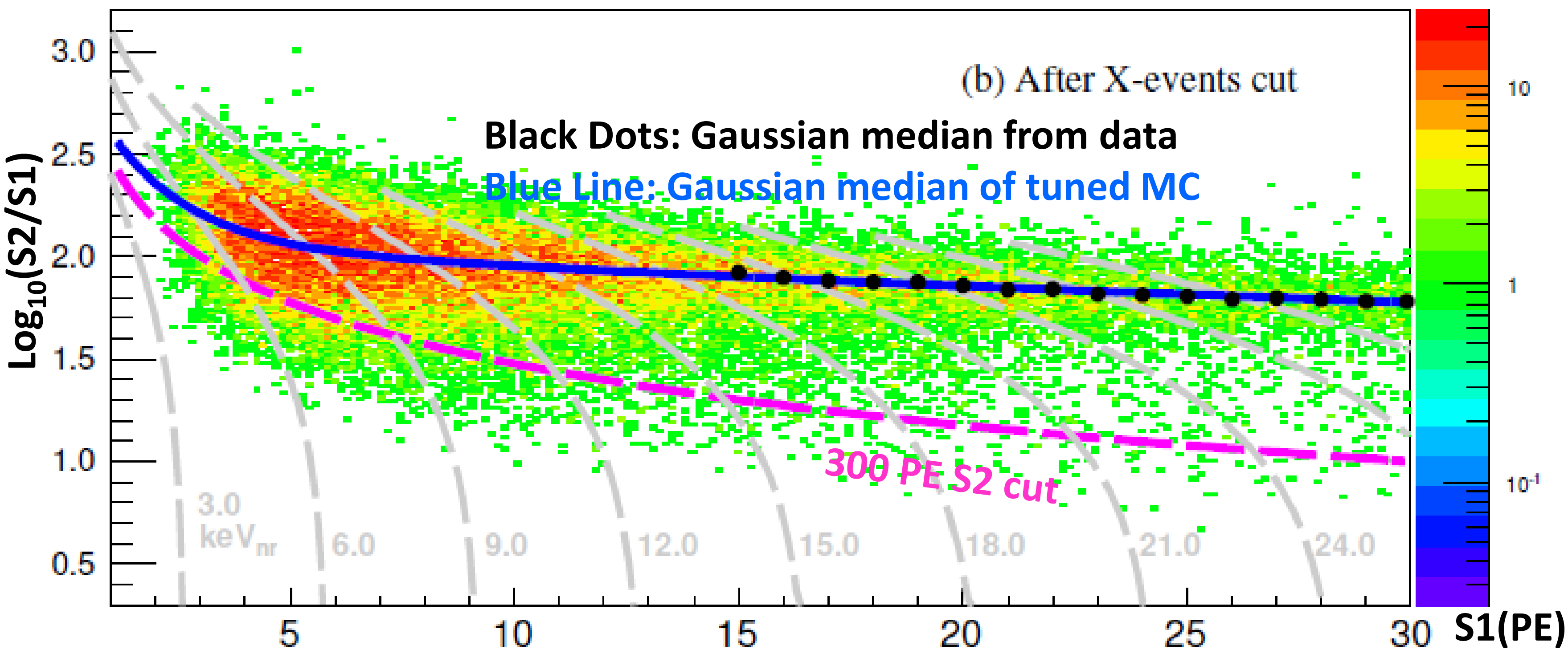


Nuclear recoil band: data vs MC



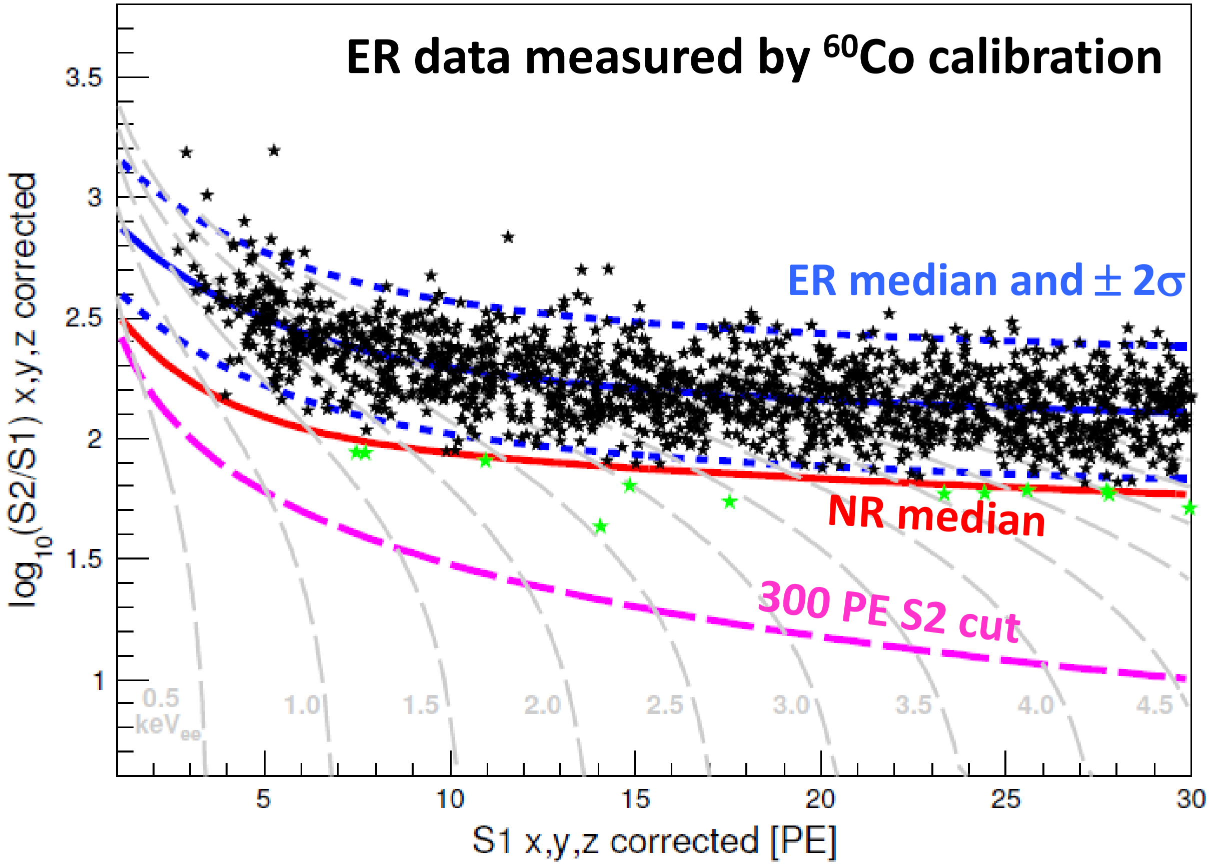
- Established quantitative understanding of the "X" event by Monte Carlo
- Tuned MC (efficiency applied) is able to reproduce the full NR distribution observed in the data

Nuclear recoil band AFTER cuts



- Developed charge pattern cuts which were effective suppressing the "X event"
- Data agrees with NEST

ER/NR discrimination power



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

Event type	# of events
Total	1520
Below NR median	12
Accidental	1.6

- "Leakage" = 10.4/1520=0.68(23)%
- Expected Gaussian: 0.5%

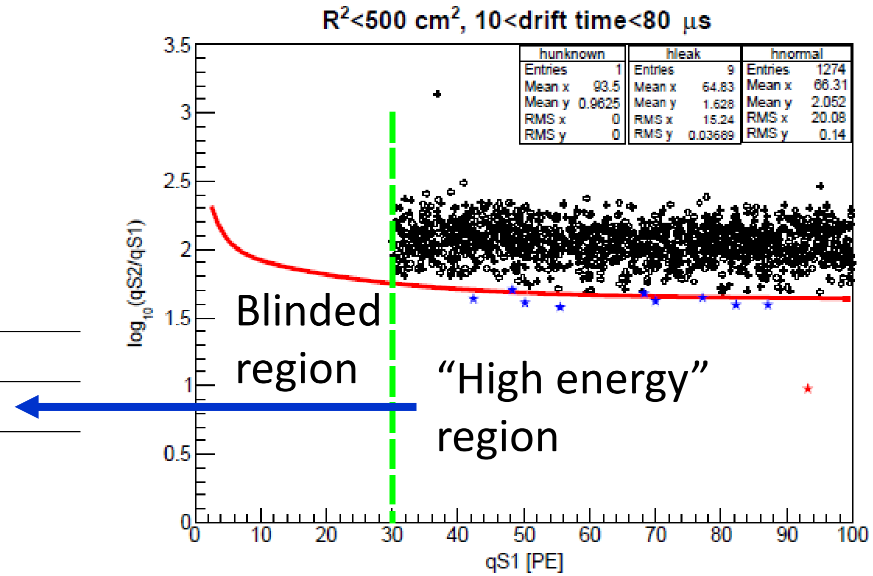
Backgrounds

- ER background (external/internal): data driven
- Accidental background: data driven
- Neutron background (NR): MC based/loosely bound by data

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

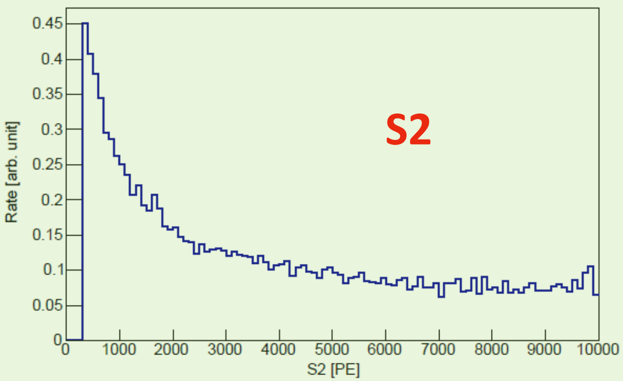
ER background

Source	background level (mDRU)
Top PMT array	4.7±2.3
Bottom PMT array	2.3 ±1.5
Inner vessel components	3.8 ±2.2
TPC components	1.9 ±0.9
^{85}Kr	2.6 ± 1.2
^{222}Rn & ^{220}Rn	0.5 ± 0.2
Outer vessel	0.9±0.6
Total expected	16.7±3.9
Total observed	23.6±3.5



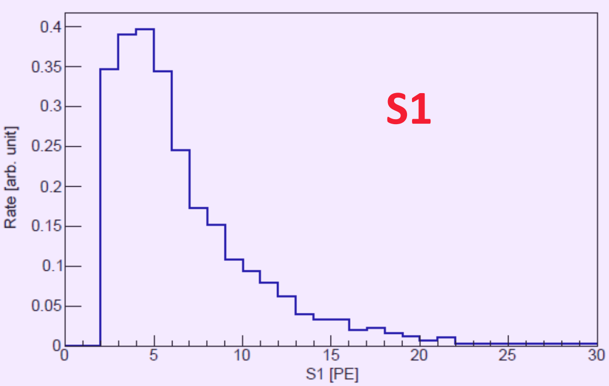
Accidental background

Isolated S1 and S2 events in random coincidence



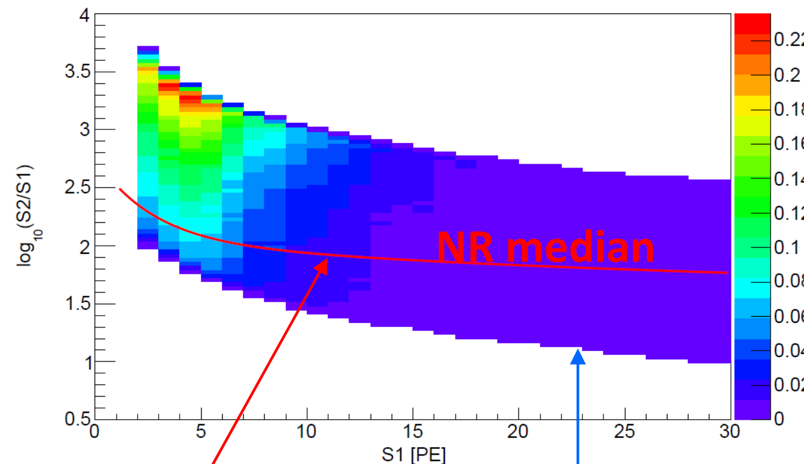
(b)Isolated S2

~240/day, physical low energy events depositing energy close to anode



(a)Isolated S1

~23 Hz, originated from electrodes, PMTs, and interactions in “chargeless regions”

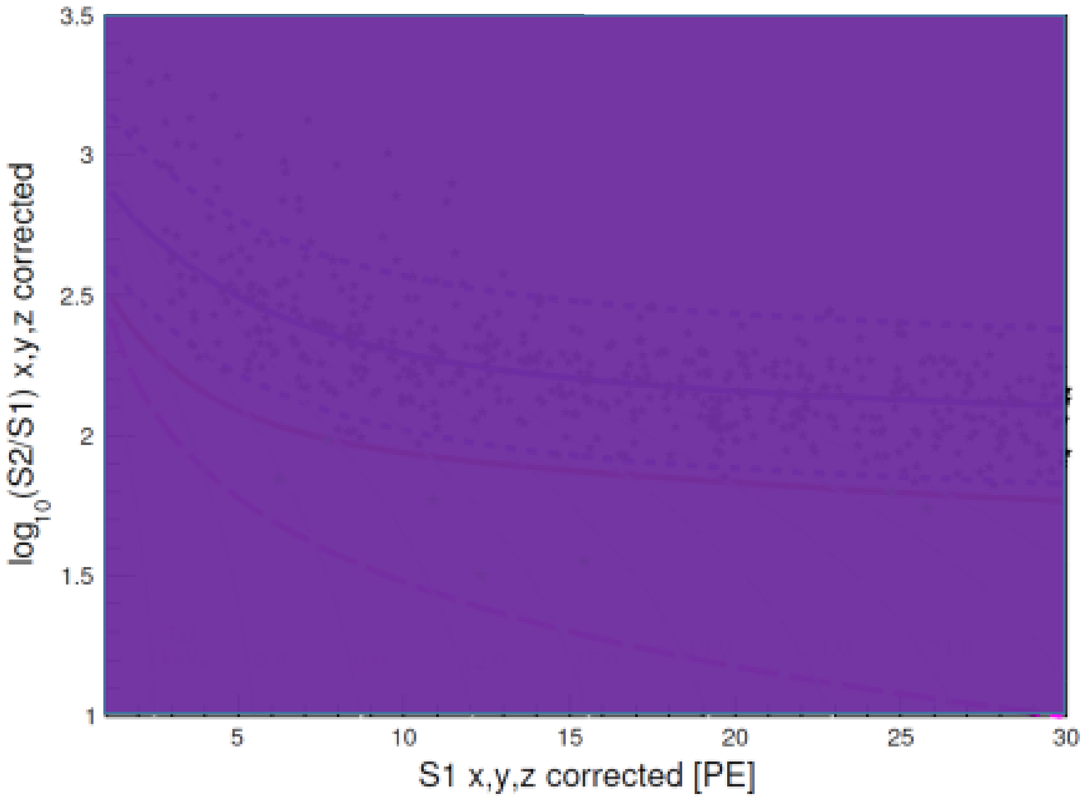


Accidental distribution: some do leak below the NR median

300 PE S2 cut to suppress accidental

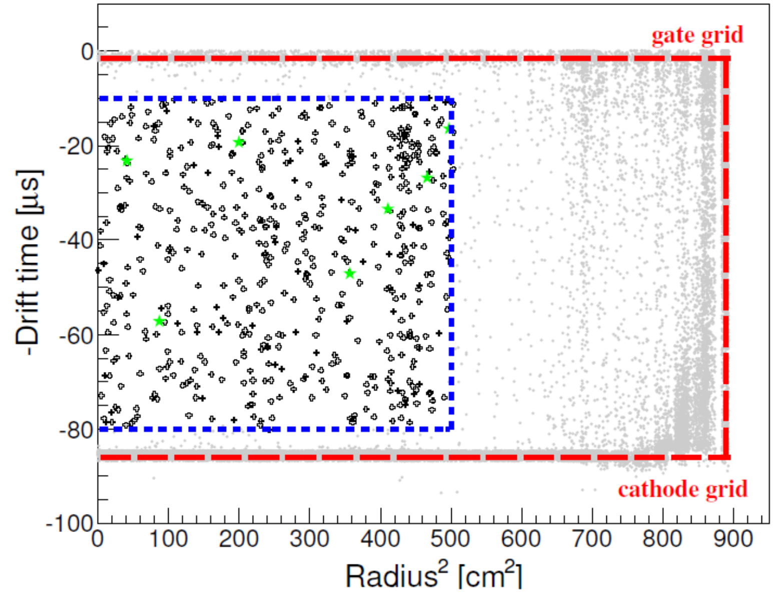
Blinded cut selection

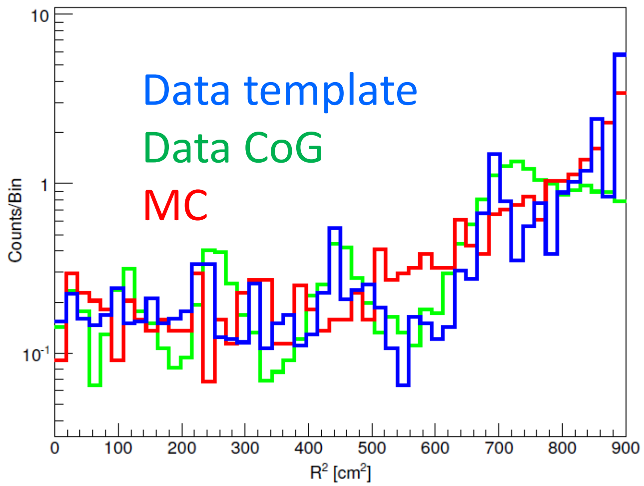
	ER	Accidental	Neutron	Total expected
All	503.7	35.1	0.35	539.1
Below NR med	2.5	4.2	0.18	6.9

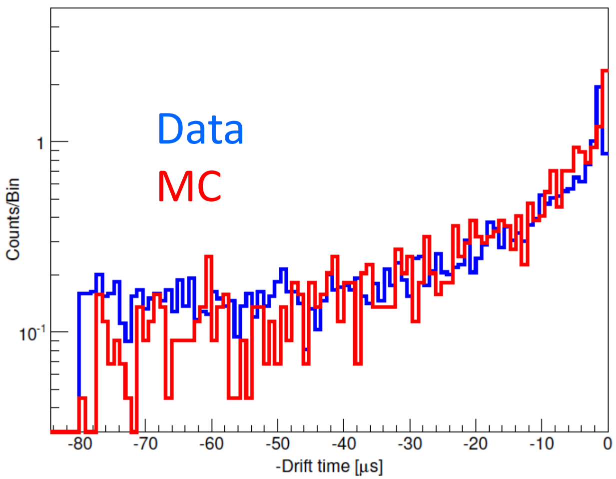


Fiducial volume and S1 cut determined blindly by maximizing the counting sensitivity based on the background expectation below the NR median

Unblinded vertex distribution



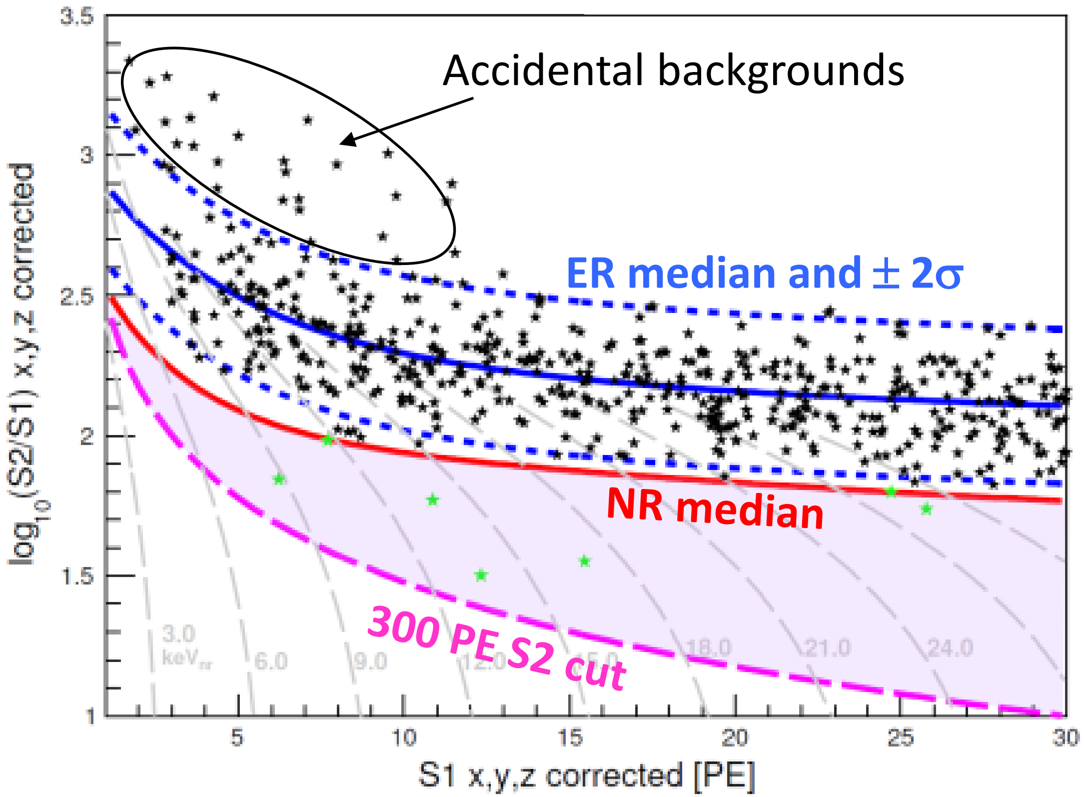




Data/MC agree well!

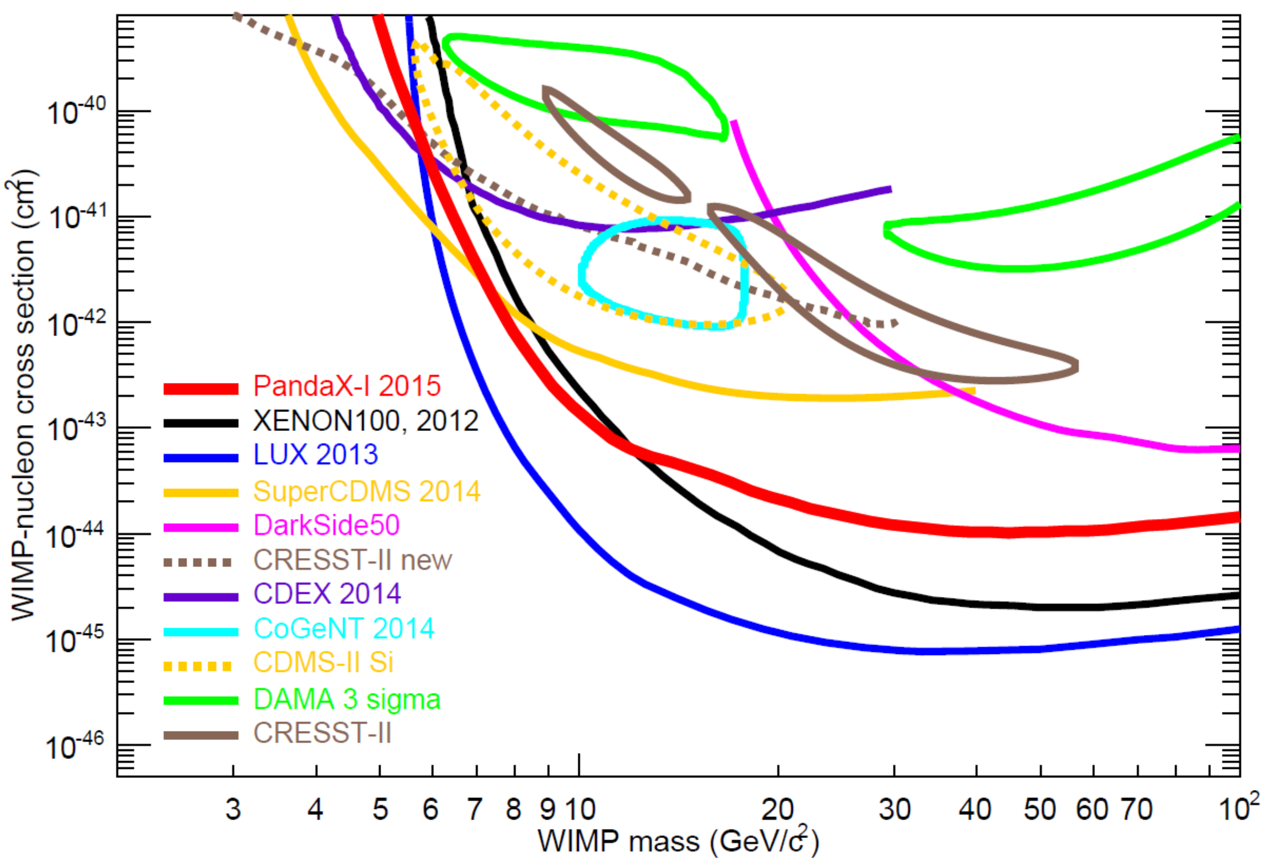
Search for dark matter!

	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



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

DM limits



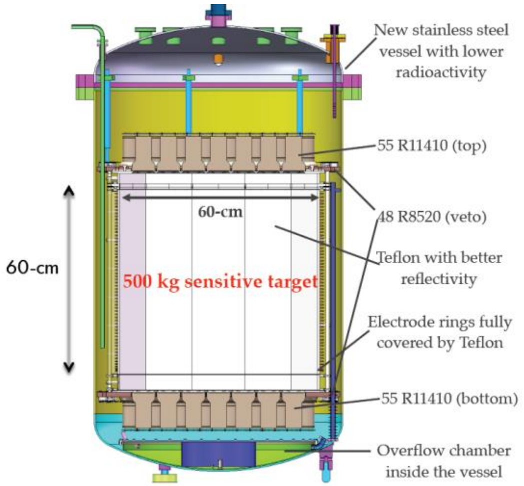
Profile likelihood fit using DM and background distribution.

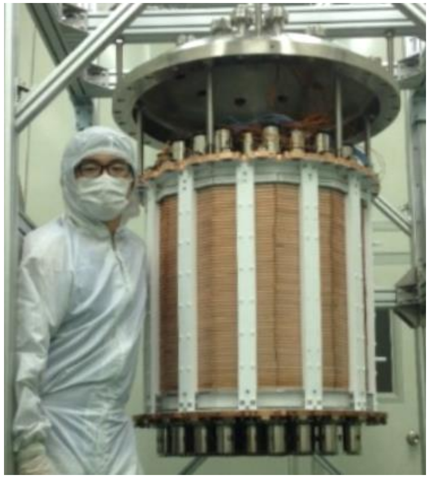
- **Full exposure results with an improved analysis confirmed the finding from the first results, disfavoring all positive WIMP claims**
- **Tighter bound than superCDMS above WIMP mass of 7 GeV/c^2**
- **Best reported* WIMP limits below 5.5 GeV/c^2 in xenon community**

**LUX chose a cutoff below 3 keV$_{nr}$, whereas we used the NEST model all the way.*

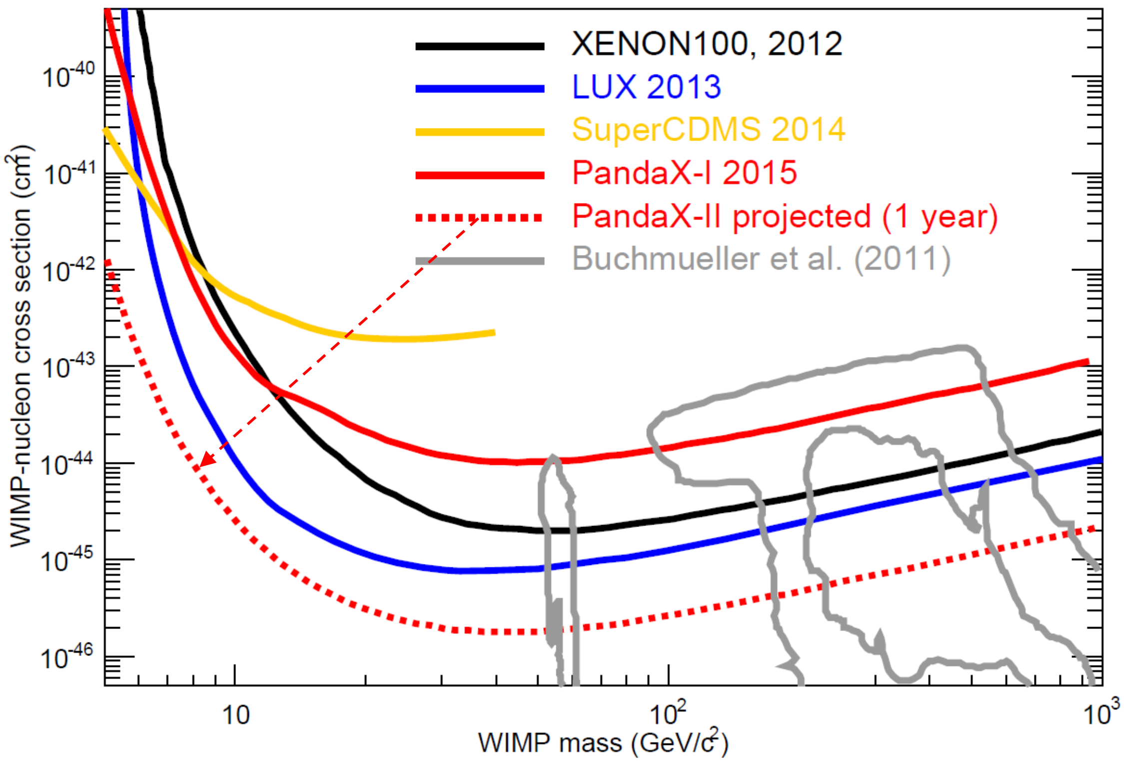
PandaX-II: 500 kg LXe target

- 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



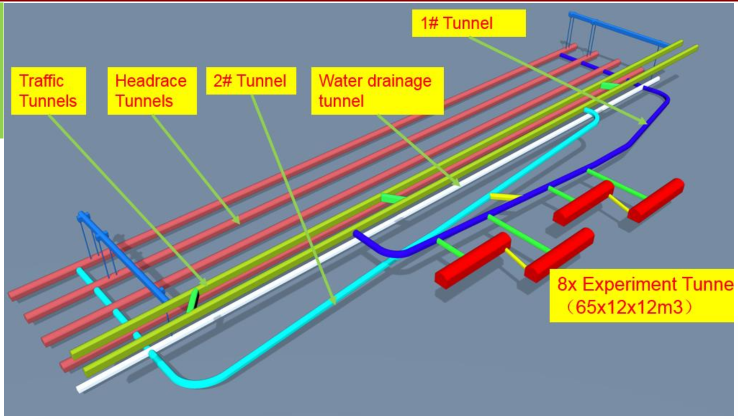
PandaX-II sensitivity assumes:

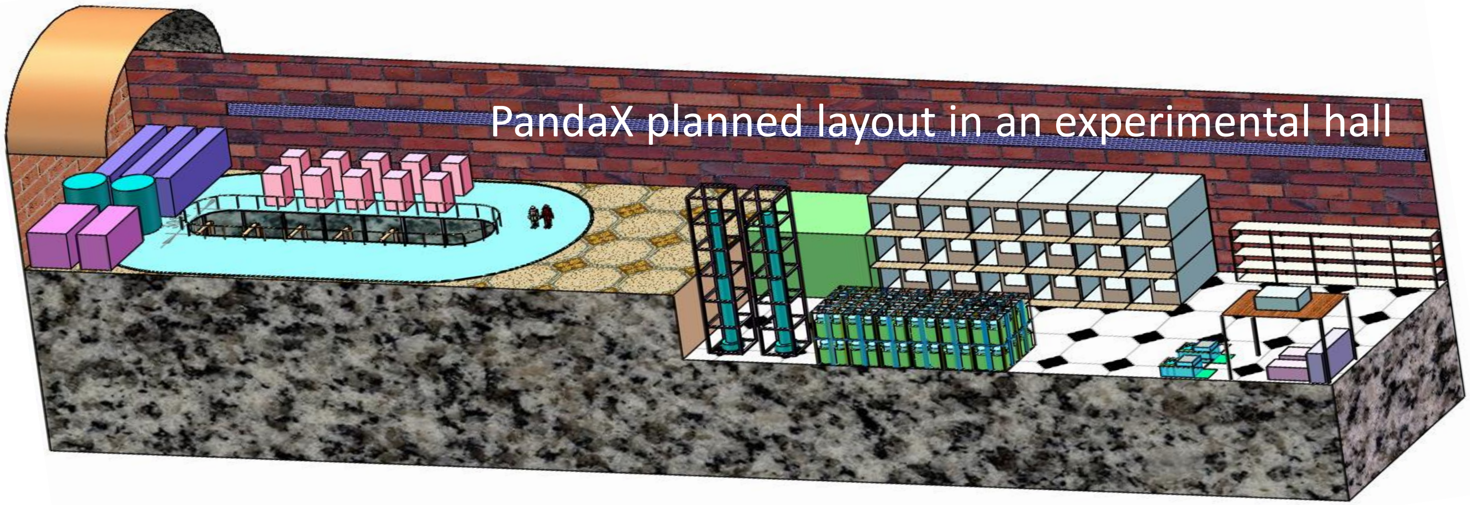
- 300 kg x 365 day
- 4.4 PE/keV$_{ee}$ (@122 keV)
- S1 range: [3, 47] PE
- ER rejection 99.75%
- NR acceptance 35%
- <3.7 background events

PandaX-II covers significant region in the SUSY WIMP parameter space.

PandaX future program in CJPL-II

See also talk
J. Li, DM-A, Sep. 9





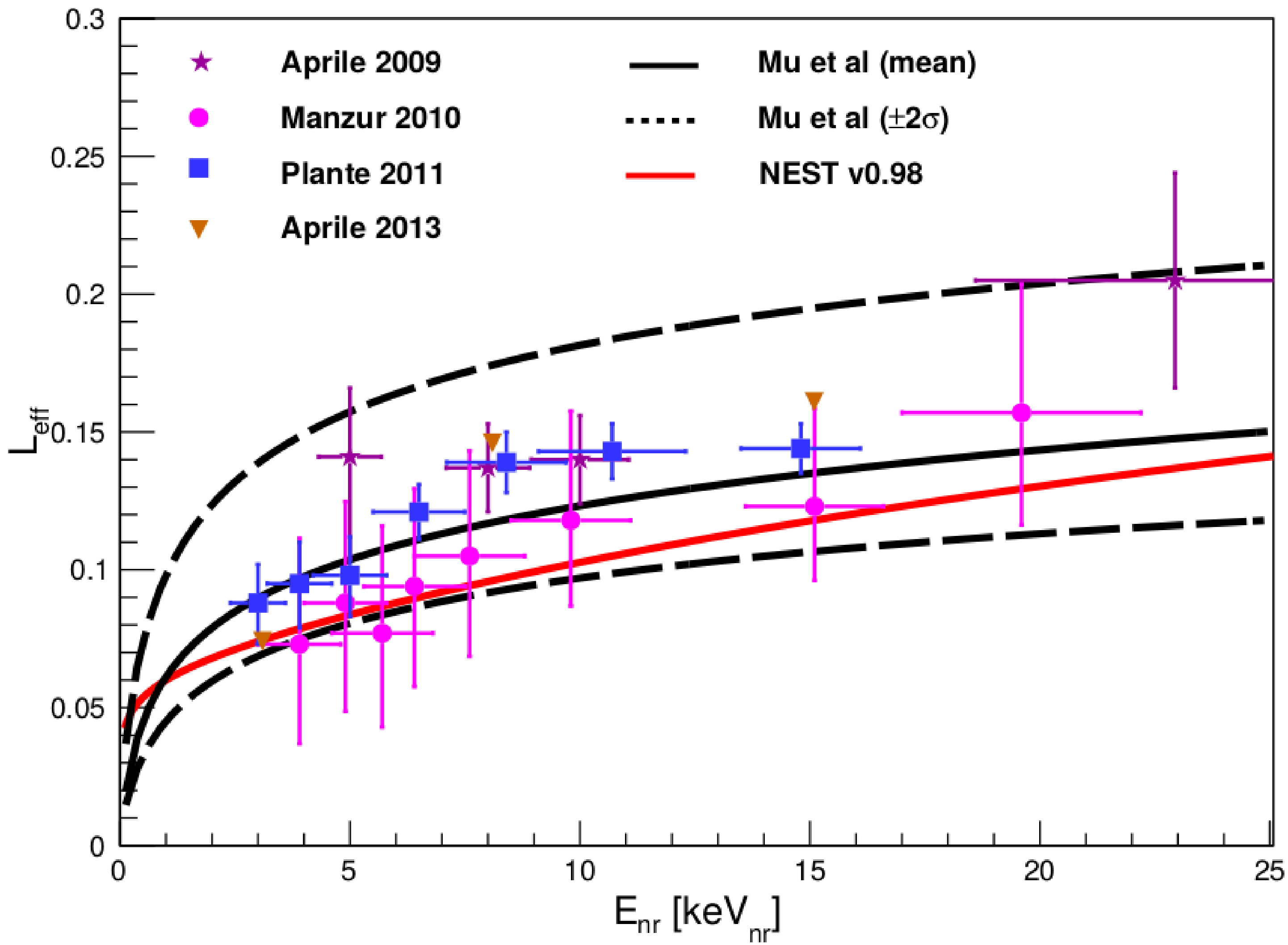
- CJPL-II expansion ongoing (civil ready 2016).
- Can host PandaX-III (DBD) and PandaX-IV (DM) in the same water pool.

Summary

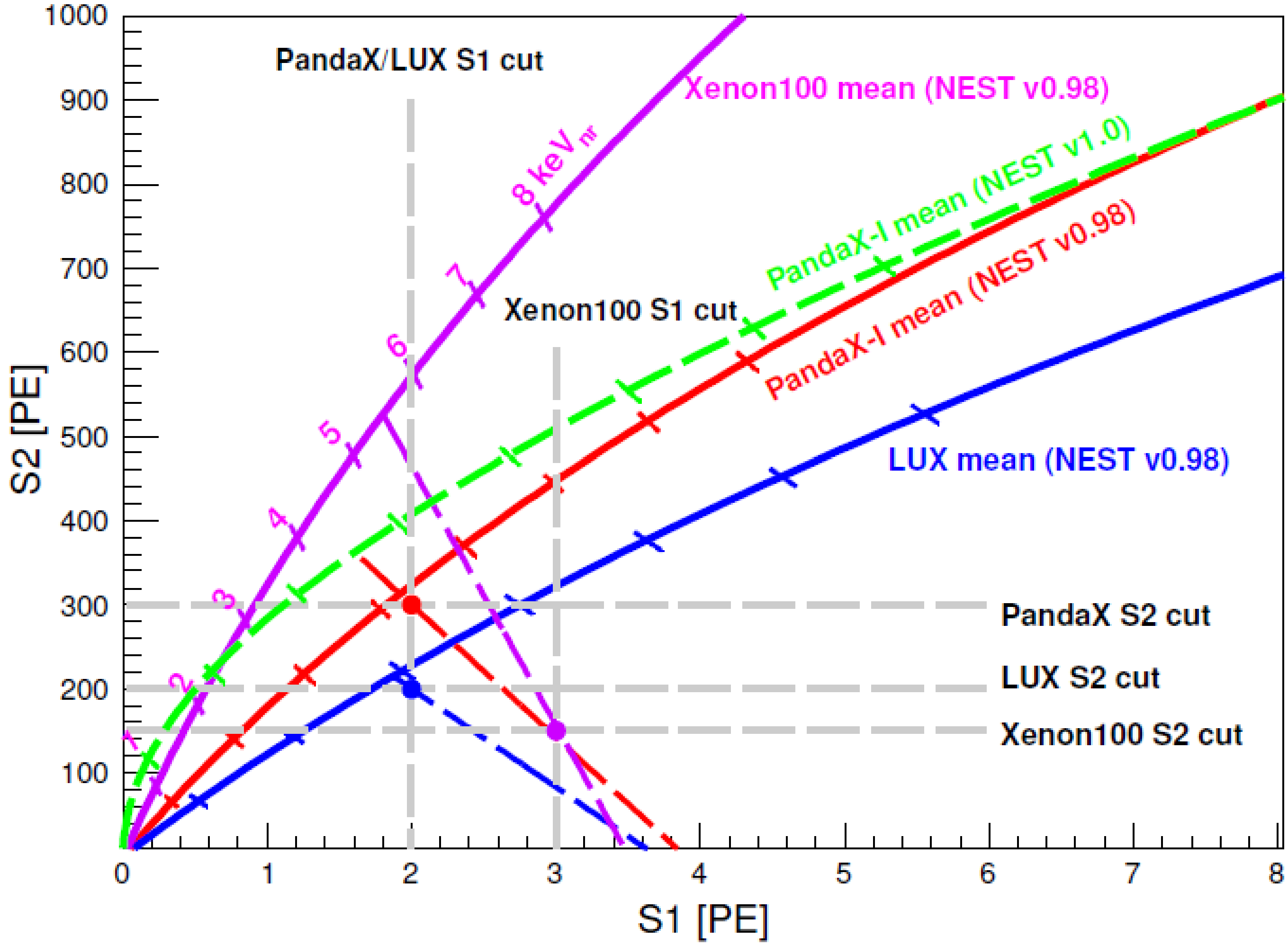
- **PandaX-I completed with 54.0 x 80.1 kg-day full exposure**
  - **Data disfavor previously reported signals from other experiments**
  - **Tighter bound than superCDMS above WIMP mass of 7 GeV/c^2**
  - **Best reported WIMP limits below 5.5 GeV/c^2 in xenon community**
- **Learn A LOT from PandaX-I experience**
- **PandaX-II being commissioned and future CJPL-II program - stay tuned for future excitement!**

Backups

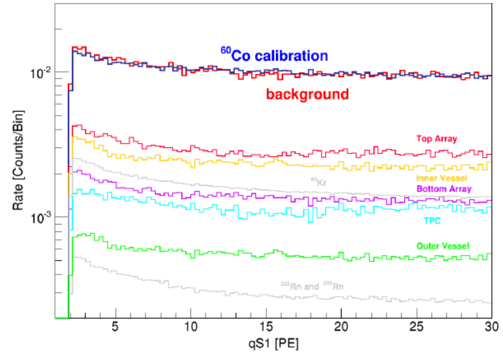
Low NR energy model



Comparison of analysis thresholds



Unbinned likelihood function

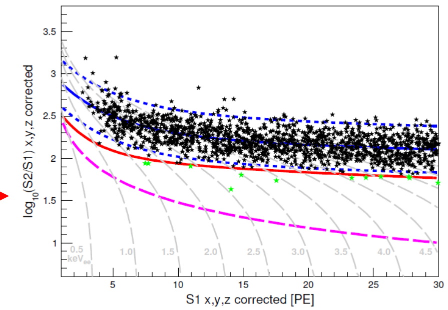


Expected shape of ER background same as that in ^{60}Co calibration!

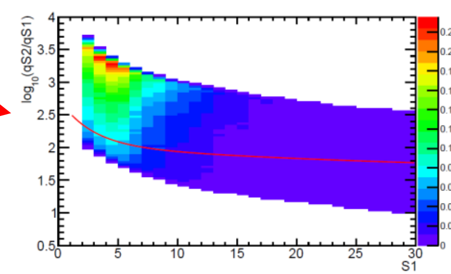
$$\mathcal{L} = Poiss(N_m|N_{exp})\times$$

$$\Pi_{i=1}^{i=N_m}[\frac{N_{DM}(1+\delta_{DM})P_{DM}(s_1^i,s_2^i)\epsilon_{NR}(s_1^i,s_2^i)}{N_{exp}}$$

$$+\frac{N_{ER}(1+\delta_{ER})P_{ER}(s_1^i,s_2^i)}{N_{exp}}$$



$$+\frac{N_{Acc}(1+\delta_{Acc})P_{Acc}(s_1^i,s_2^i)}{N_{exp}}$$



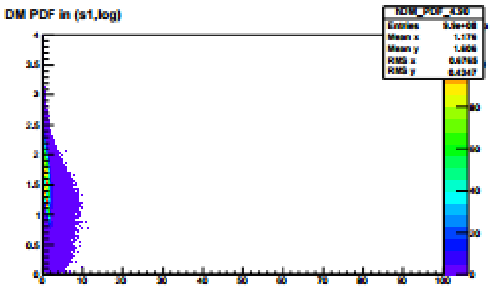
$$+\frac{N_{nbkg}(1+\delta_{nbkg})P_{nbkg}(s_1^i,s_2^i)\epsilon_{NR}(s_1^i,s_2^i)}{N_{exp}}]$$

$$\times G(\delta_{DM},0.2)G(\delta_{ER},0.15)G(\delta_{Acc},0.1)G(\delta_{nbkg},0.5)$$

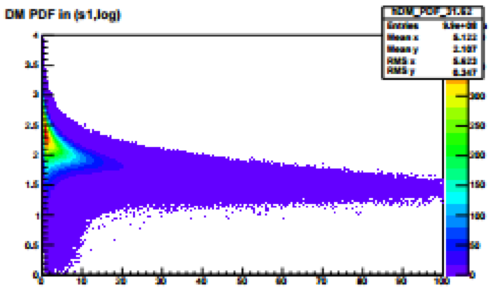
DM PDF

$$\Pi_{i=1}^{i=N_m}\left[\frac{N_{DM}(1+\delta_{DM})P_{DM}(\mathrm{S1}^i,\mathrm{S2}^i)\epsilon_{NR}(\mathrm{S1}^i,\mathrm{S2}^i)}{N_{exp}}\right.$$

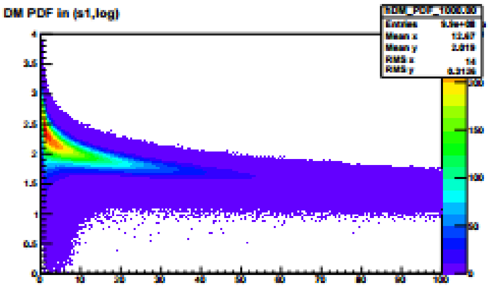
Average DM efficiency (WIMP mass dep) : $\langle\varepsilon_{\mathrm{DM}}\rangle = \int P_{\mathrm{DM}}(S1,S2)\varepsilon_{\mathrm{NR}}(S1,S2)dS1dS2$



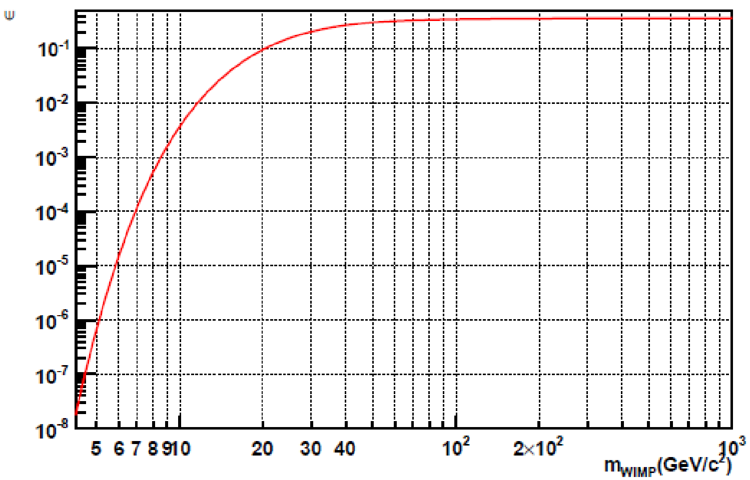
(a)4.9 GeV/c^2



(b)31.62 GeV/c^2



(c)1000 GeV/c^2



PandaX-I sensitivity