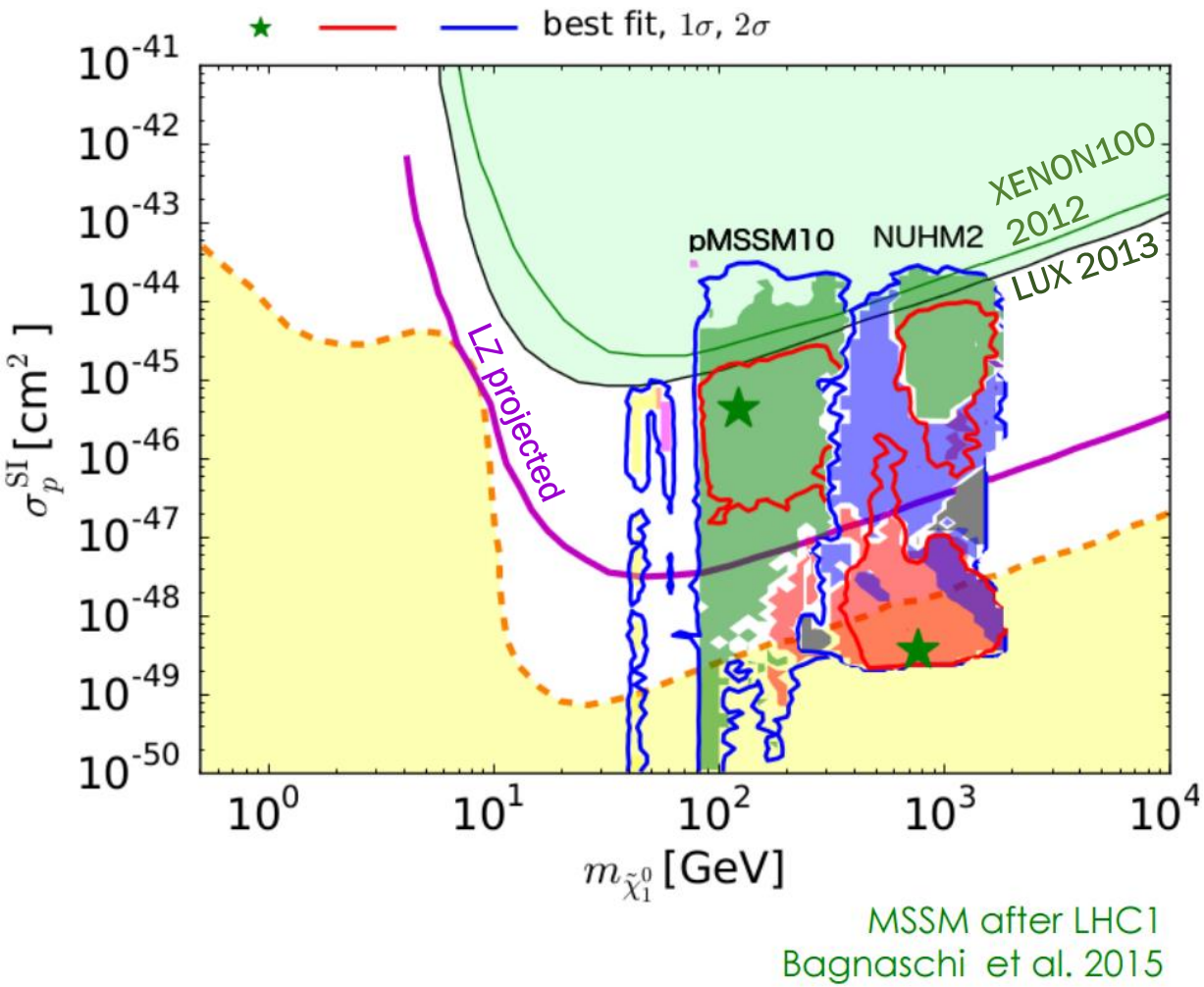
Recent Results from the PandaX-II Dark Matter Experiment

Jianglai Liu

Shanghai Jiao Tong University

On behalf of PANDA X Collaboration

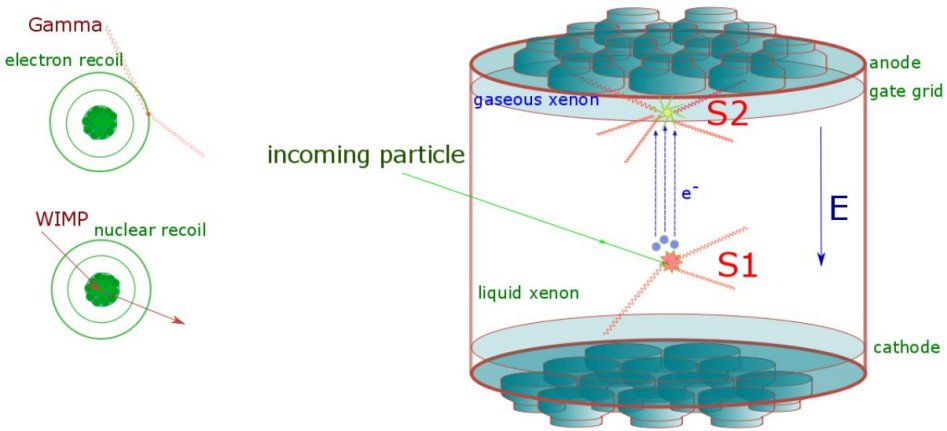
WIMP direct detection & LHC search

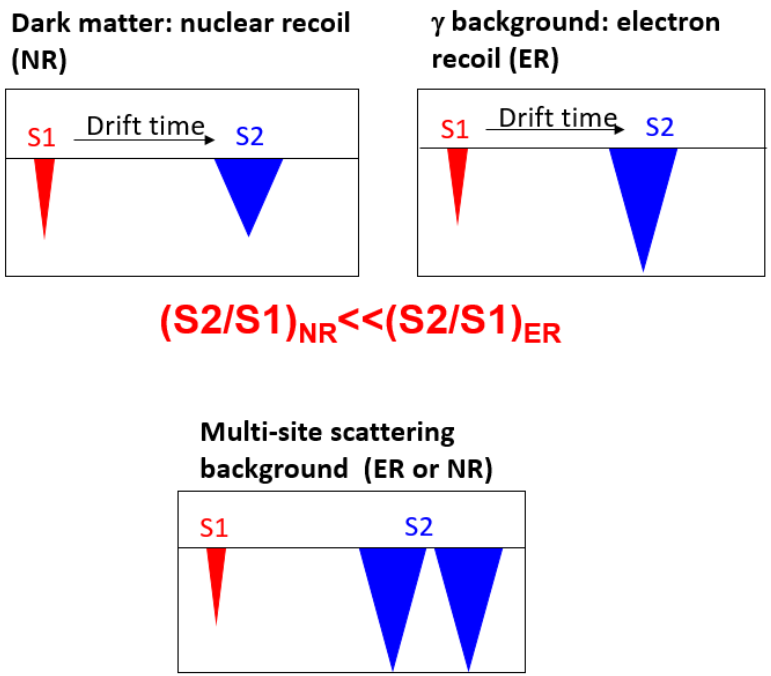


Excellent case for more sensitive DM detectors and complementarity between collider and direct searches!

Dual phase xenon TPC

DM direct detection: recoil of atomic nucleus in the detector (Goodman & Witten, 1985), <10 keV_{ee} energy

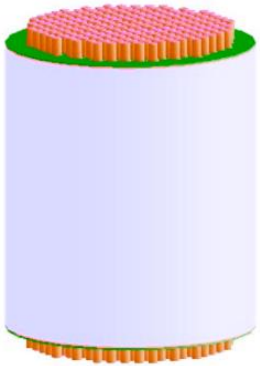




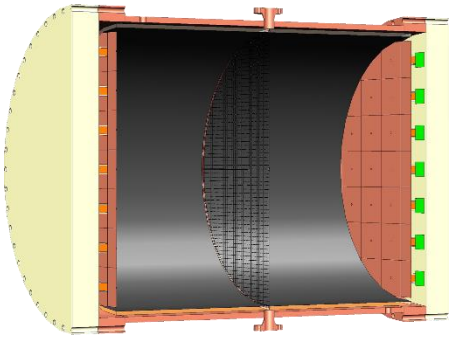
PandaX experiment

PandaX-I: 120 kg DM experiment 2009-2014

PandaX-II: 500 kg DM experiment 2014-2017



PandaX-xT: multi-ton (~4-T) DM experiment 2017- or 2018-

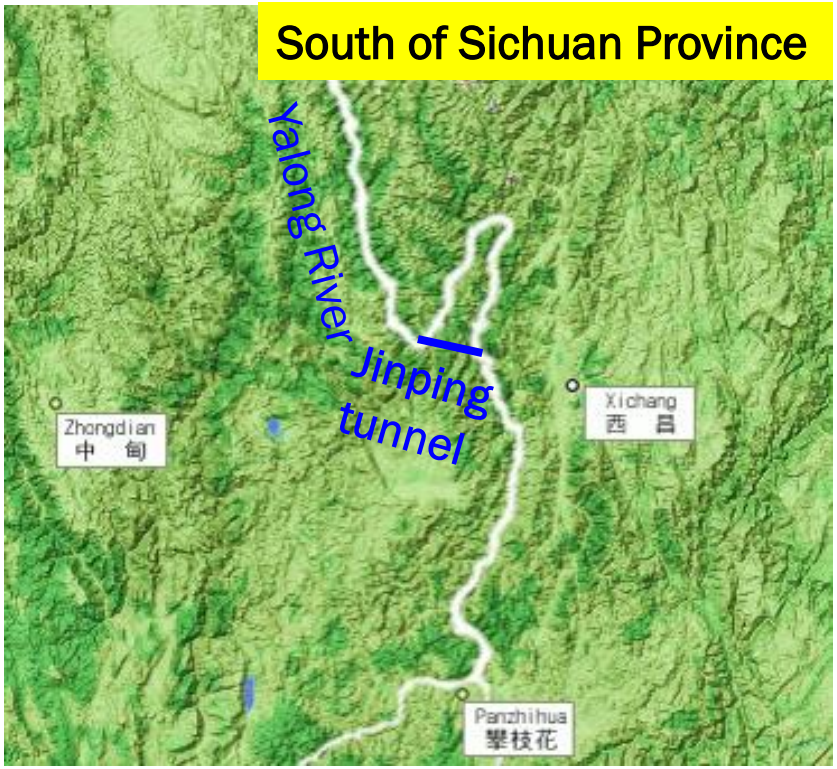


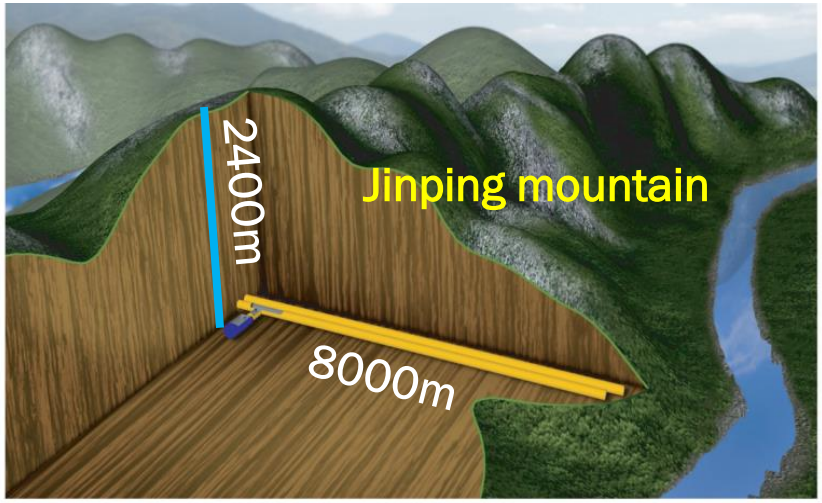
PandaX-III: 200 kg to 1 ton HP gas ^{136}Xe 0vDBD experiment 2016-

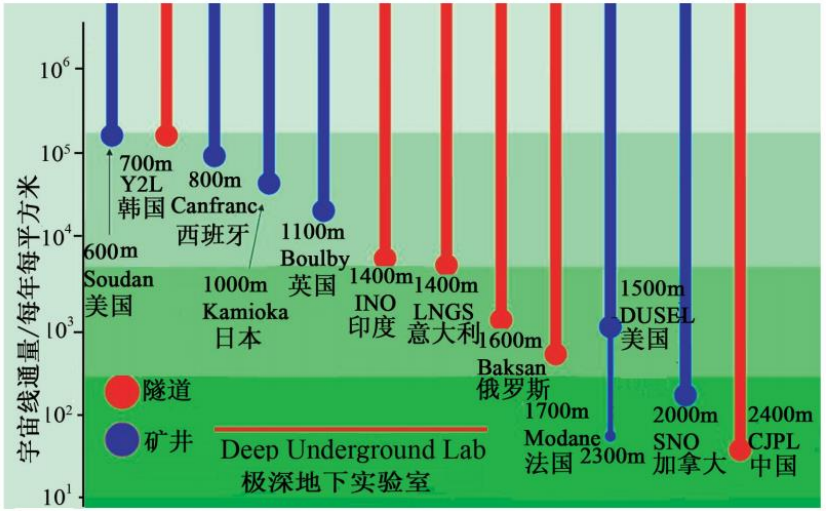
PANDA X = Particle and Astrophysical Xenon Experiments

China Jinping underground lab

Deepest in the world (1μ/week/m^2)
and Horizontal access!







PandaX collaboration

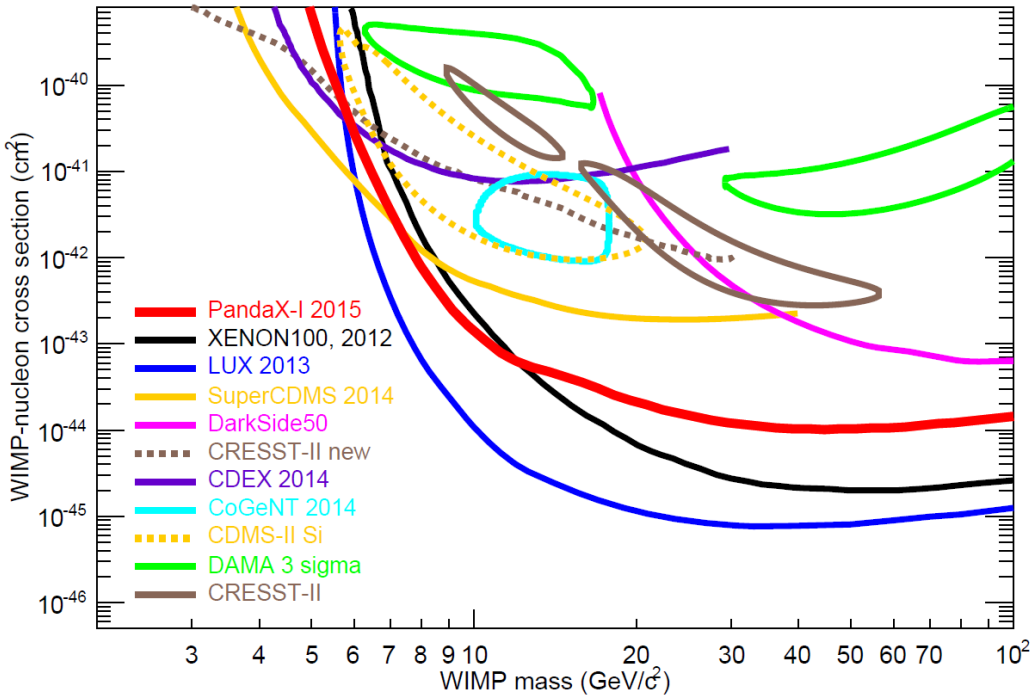
Started in 2009, ~50 people

- Shanghai Jiao Tong University (2009-)
- Peking University (2009-)
- Shandong University (2009-)
- Shanghai Institute of Applied Physics, CAS (2009-)
- University of Science & Technology of China (2015-)
- China Institute of Atomic Energy (2015-)
- Sun Yat-Sen University (2015-)
- Yalong Hydropower Company (2009-)
- University of Maryland (2009-)
- Alternative Energies & Atomic Energy Commission (2015-)
- University of Zaragoza (2015-)
- Suranaree University of Technology(2016-)

First delivery of PandaX equipment to Jinping

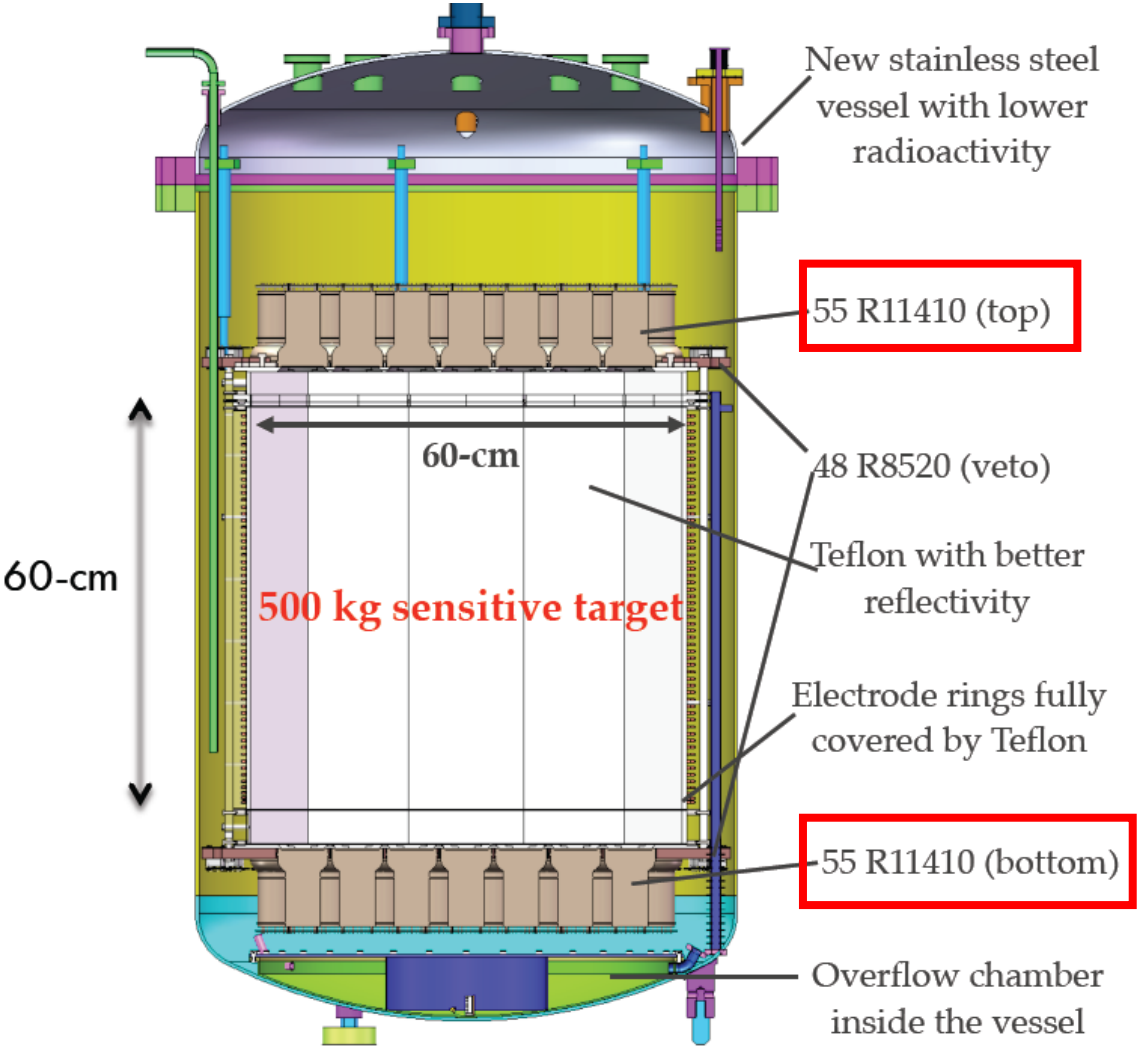
Results from PandaX-I

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



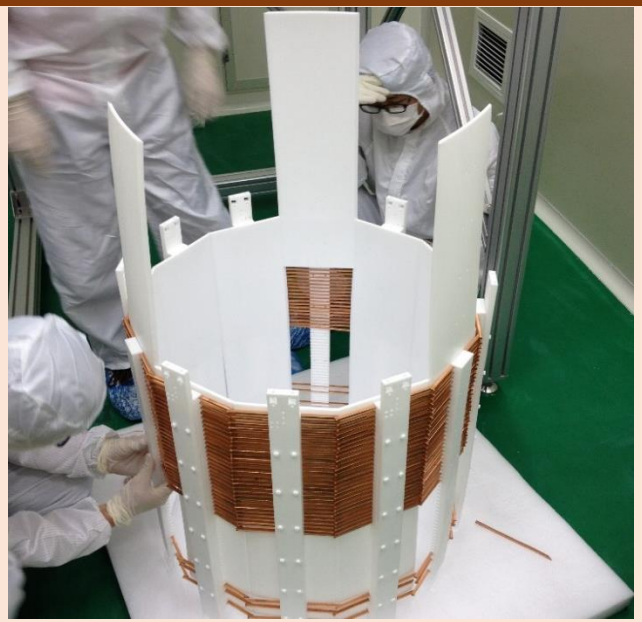
- Completed in Oct. 2014, with 54.0 x 80.1 kg-day exposure
- Data strongly disfavor all previously reported claims
- Competitive upper limit for low mass WIMP among xenon experiments

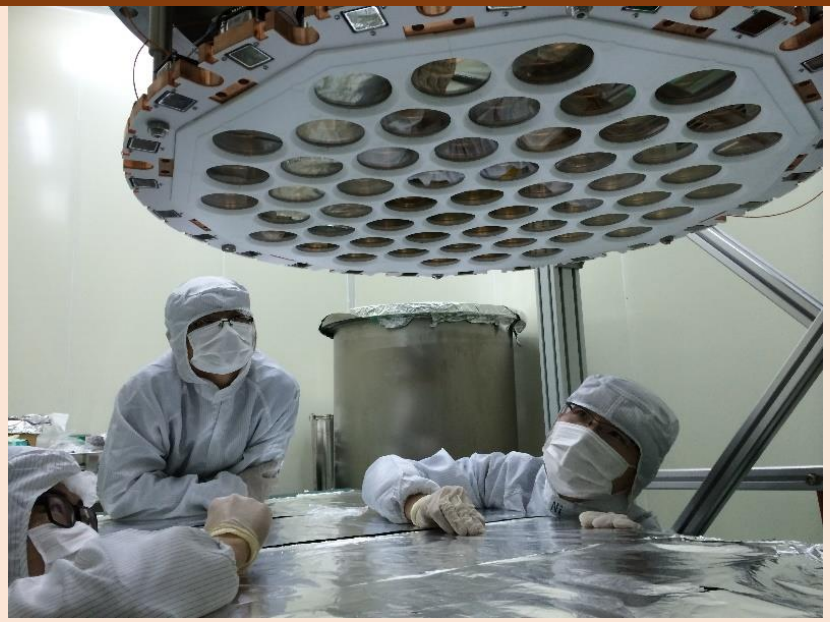
PandaX-II

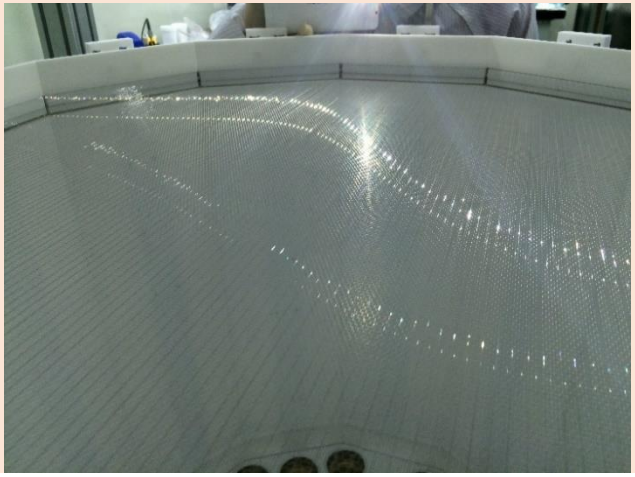


- New inner vessel with clean SS
- New and taller TPC
- More 3” PMTs and improved base design with split –ve and +ve HV
- New isolated skin veto region

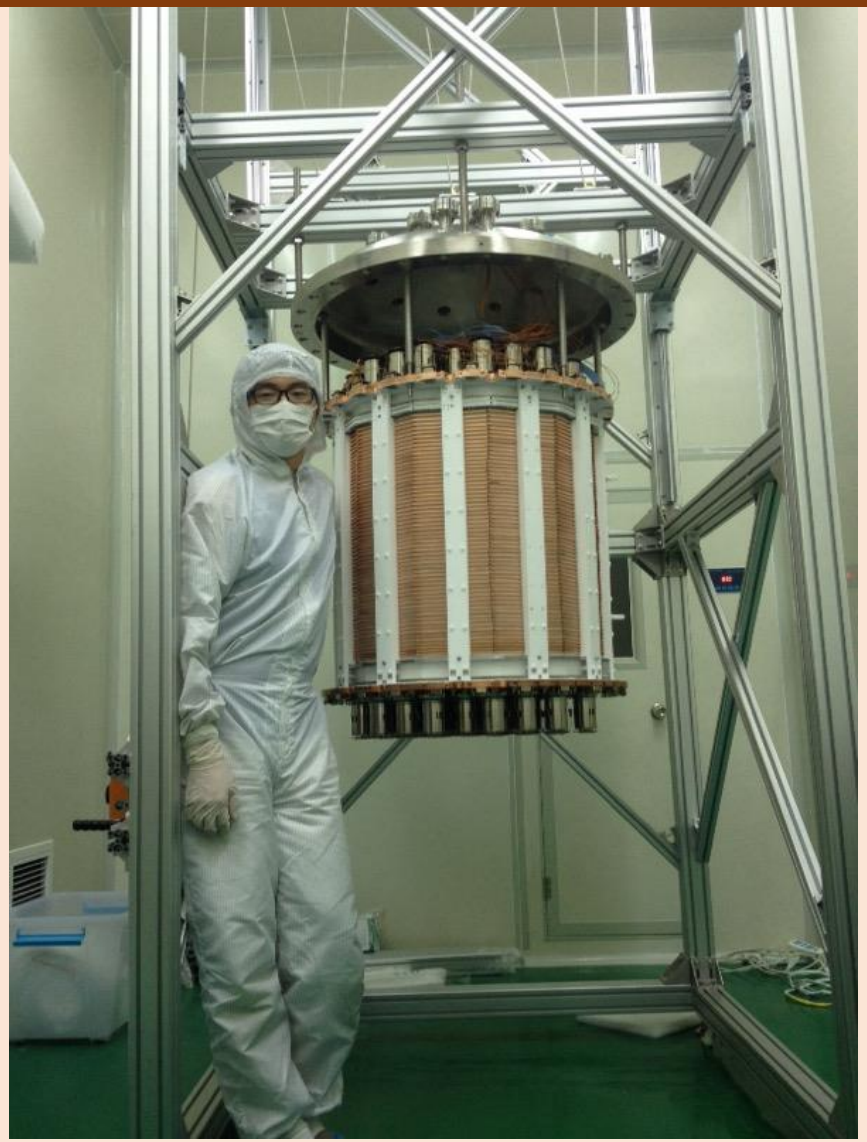
Detector construction

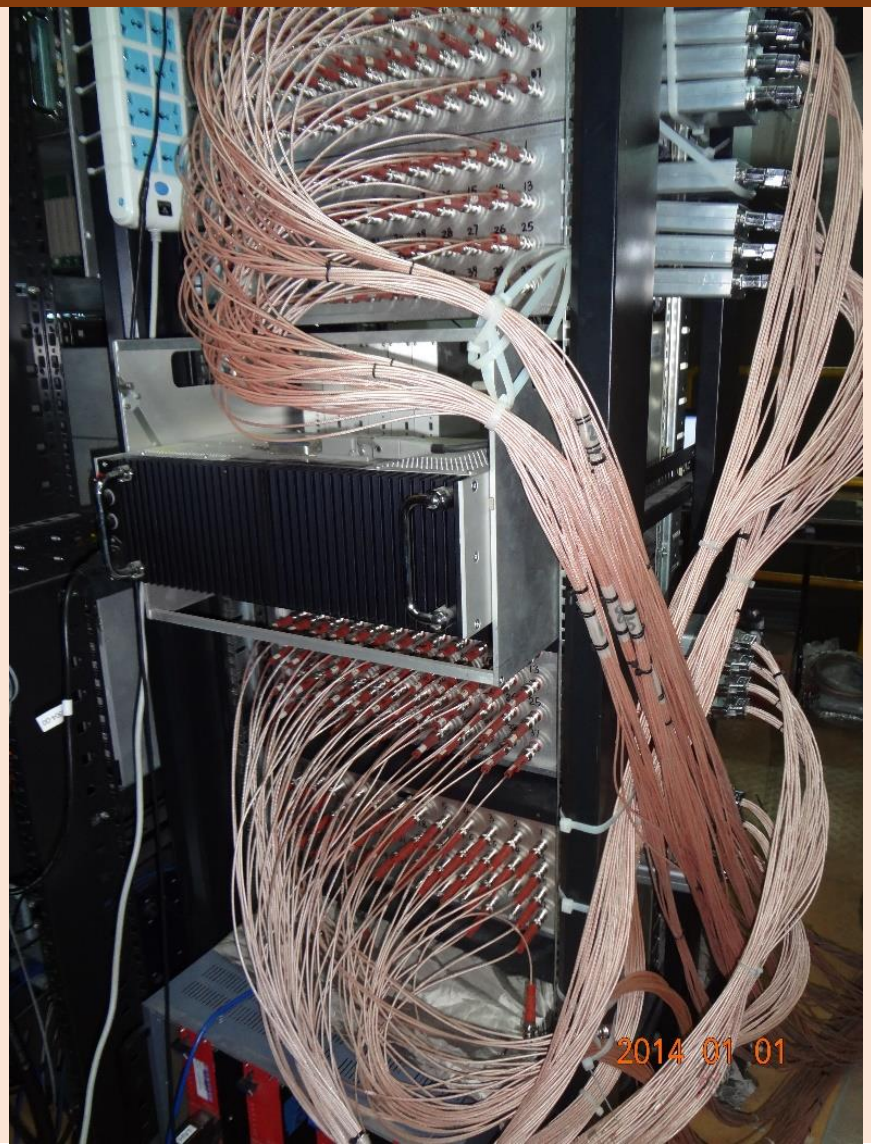




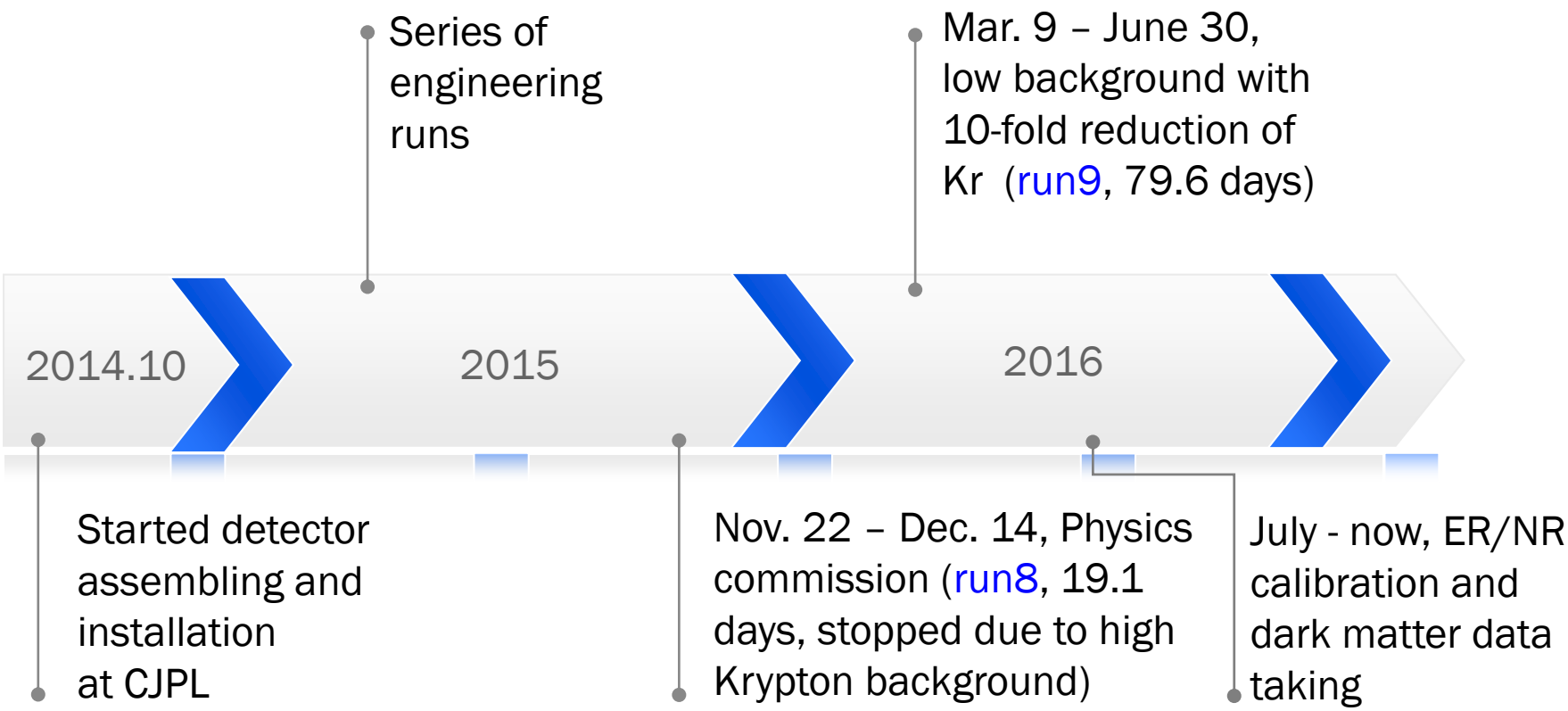


Putting all together





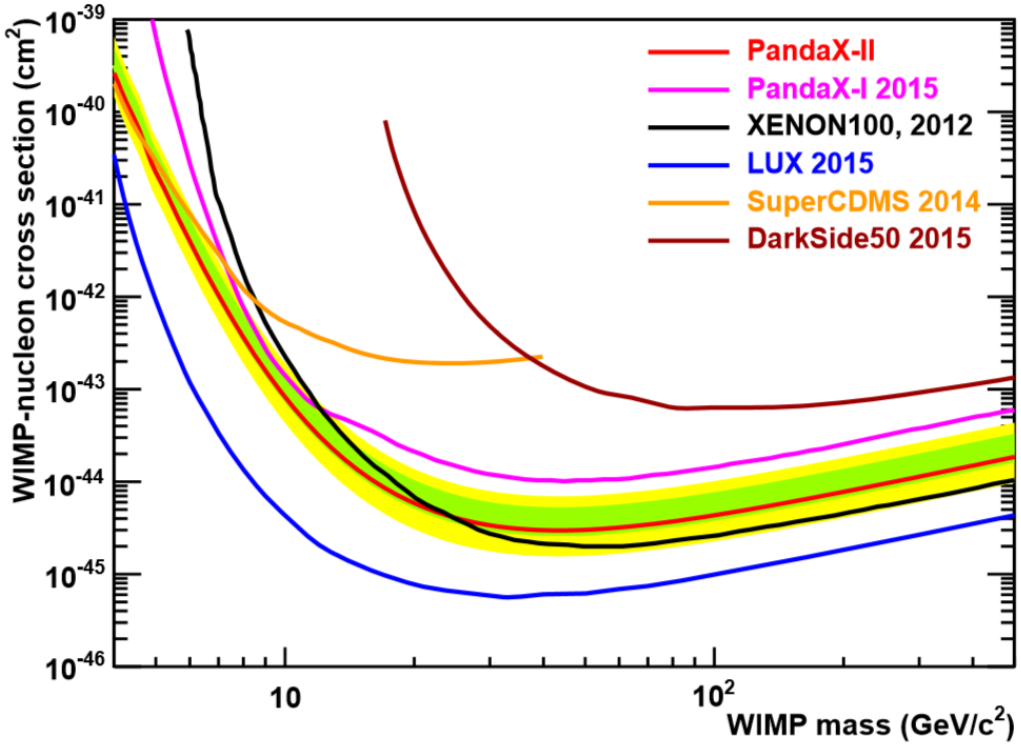
Run history



- Run8+run9=98.7 days, exposure:3.3×10^4 kg-day
- Largest dual phase xenon experiment producing science data

Results from PandaX-II run 8

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



306 x 19.1 kg-day

- Cut-and-count analysis with 2 candidates and 3.2(0.7) expected background
- Low mass region: competitive with SuperCDMS 2014
- High mass region: similar exclusion limit as XENON100 225-day

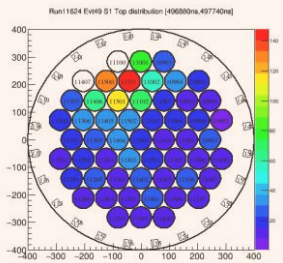
Major upgrades in run 9

Items	Status in Run 9
Krypton level	Reduced by x10
Exposure	Increased x4 (79.6 vs 19.1 day)
ER calibration	Using tritium calibration
NR calibration	Statistics x6
Analysis	Improved position reconstruction
Background	Accidental background suppressed more than x3 using BDT

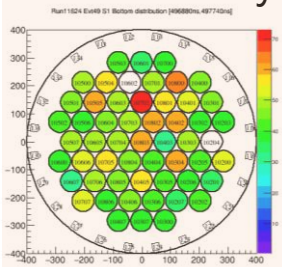
Typical single scattering event

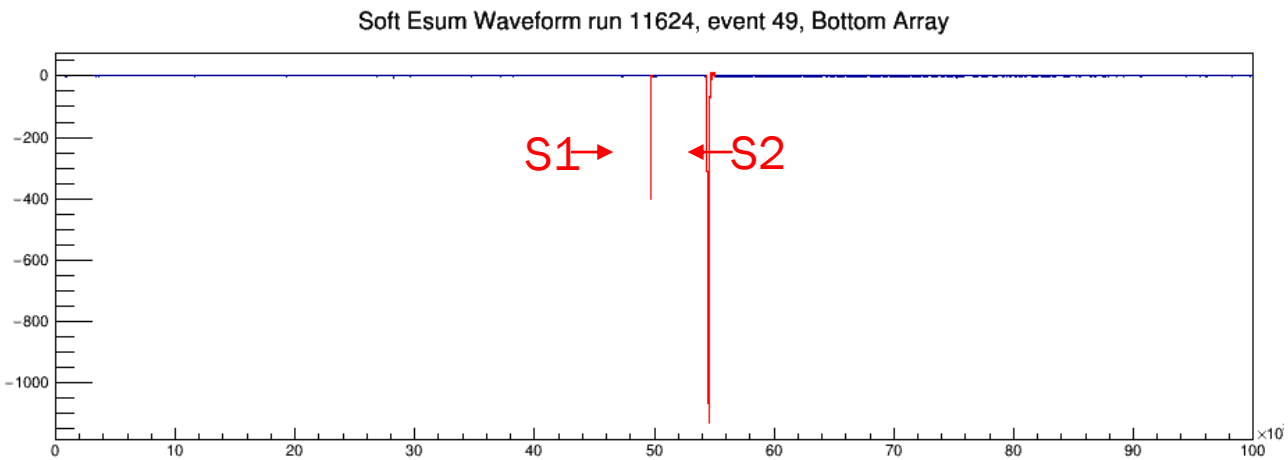
S1

Top Array

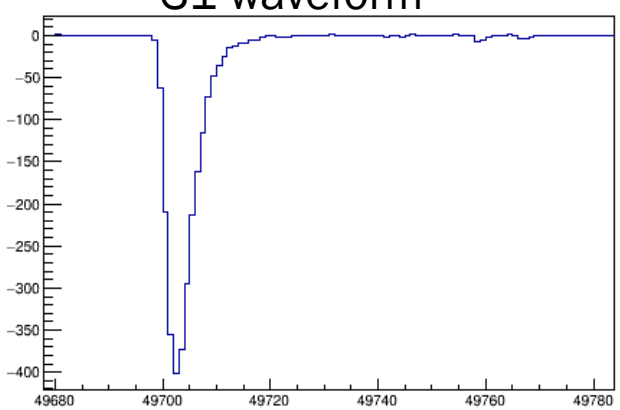


Bottom Array

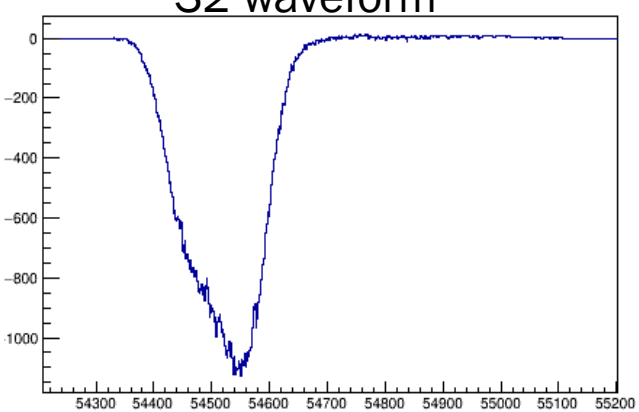




S1 waveform

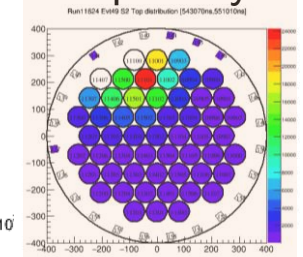


S2 waveform

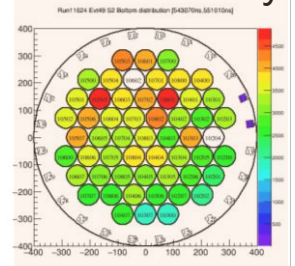


S2

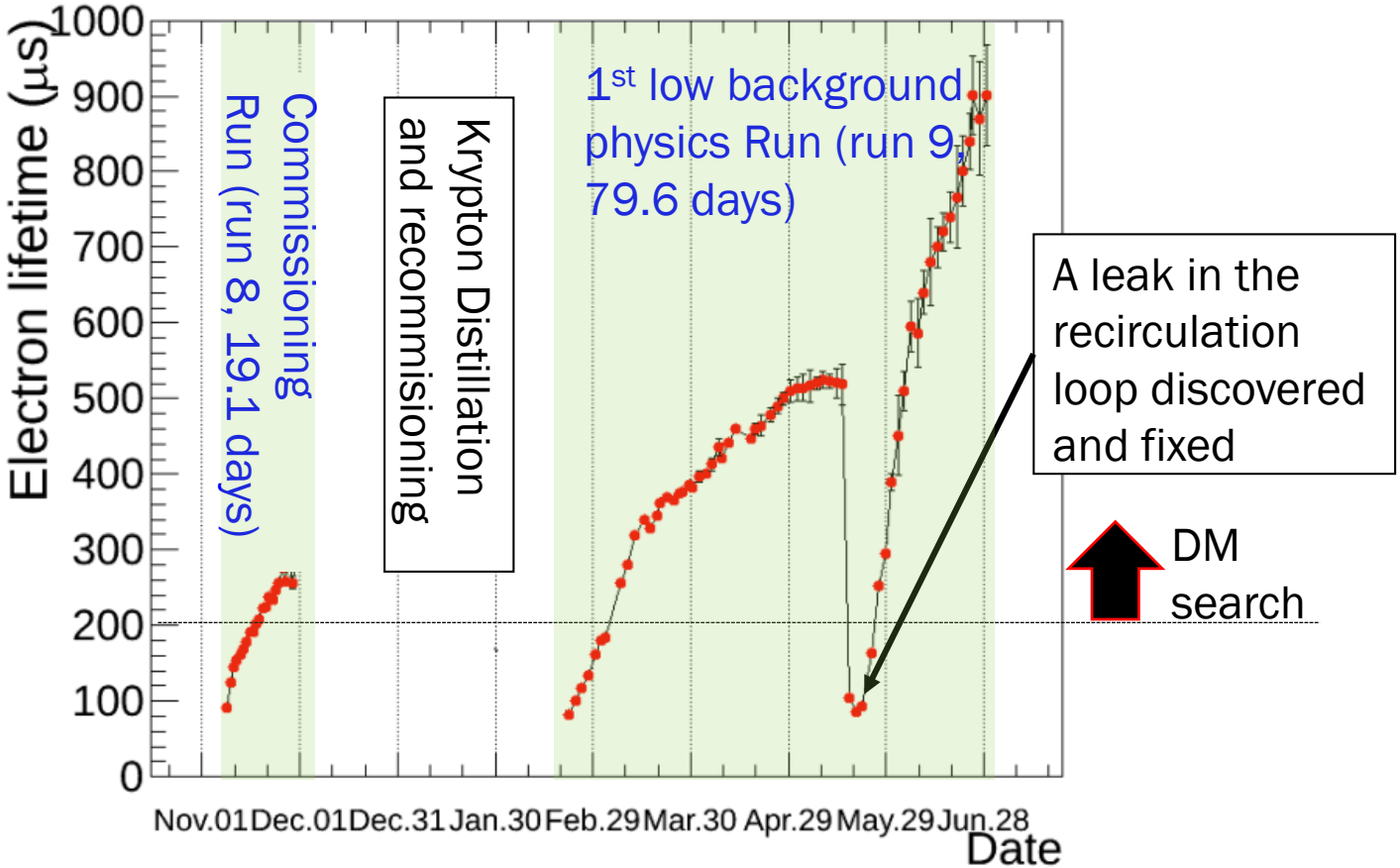
Top Array



Bottom Array

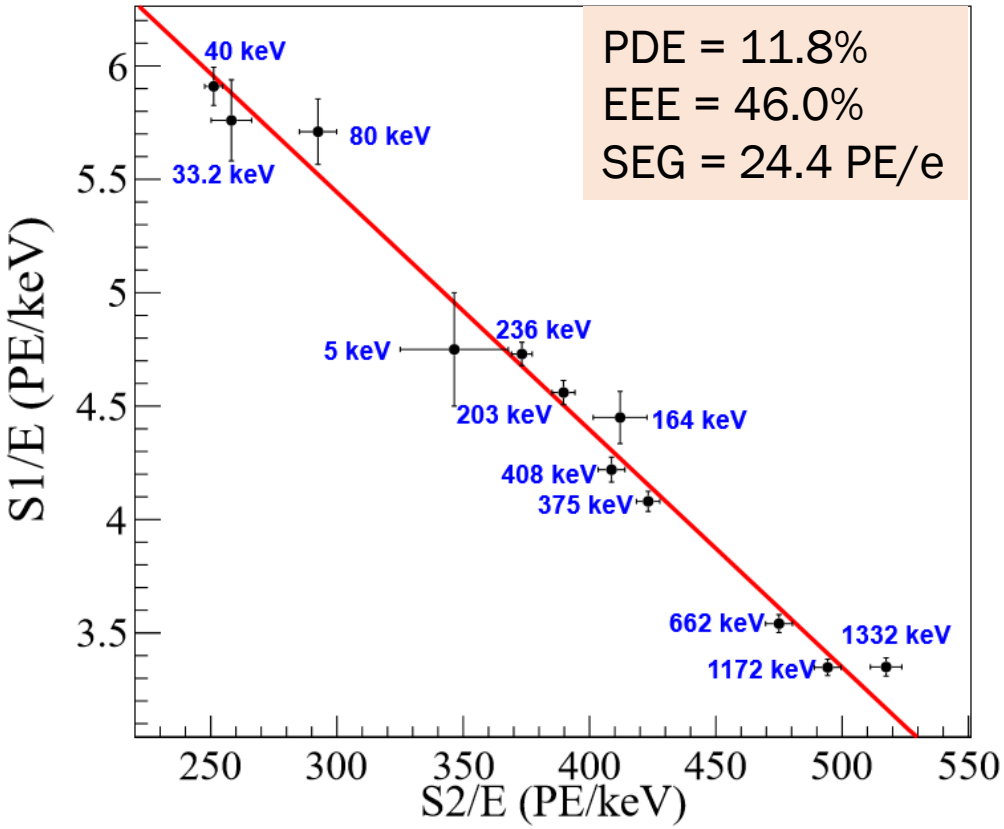


Electron lifetime evolution



- Dominated the uniformity correction (but well self-calibrated)
- Built into the DM and background signal model

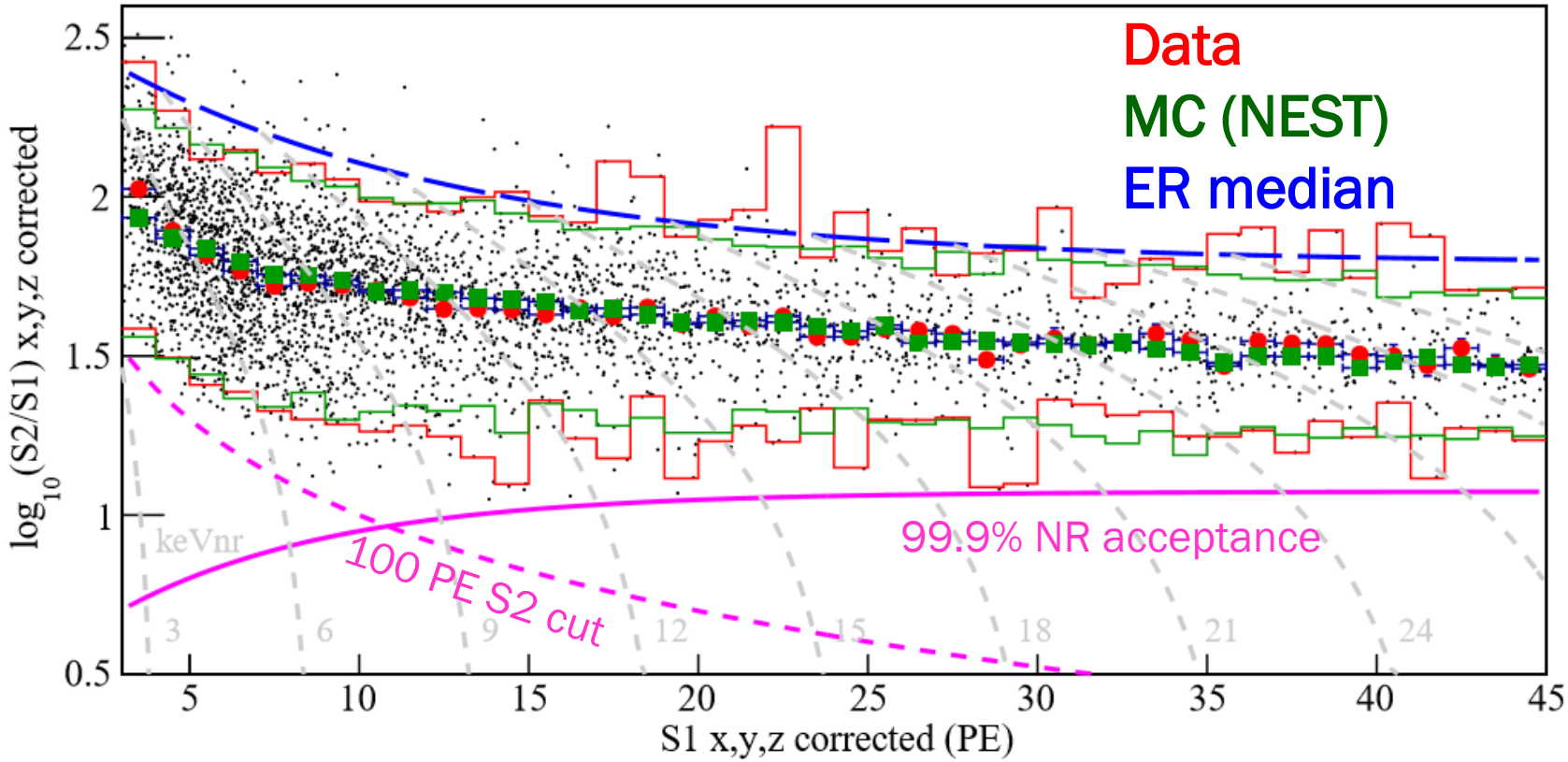
Extraction of detector parameters



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

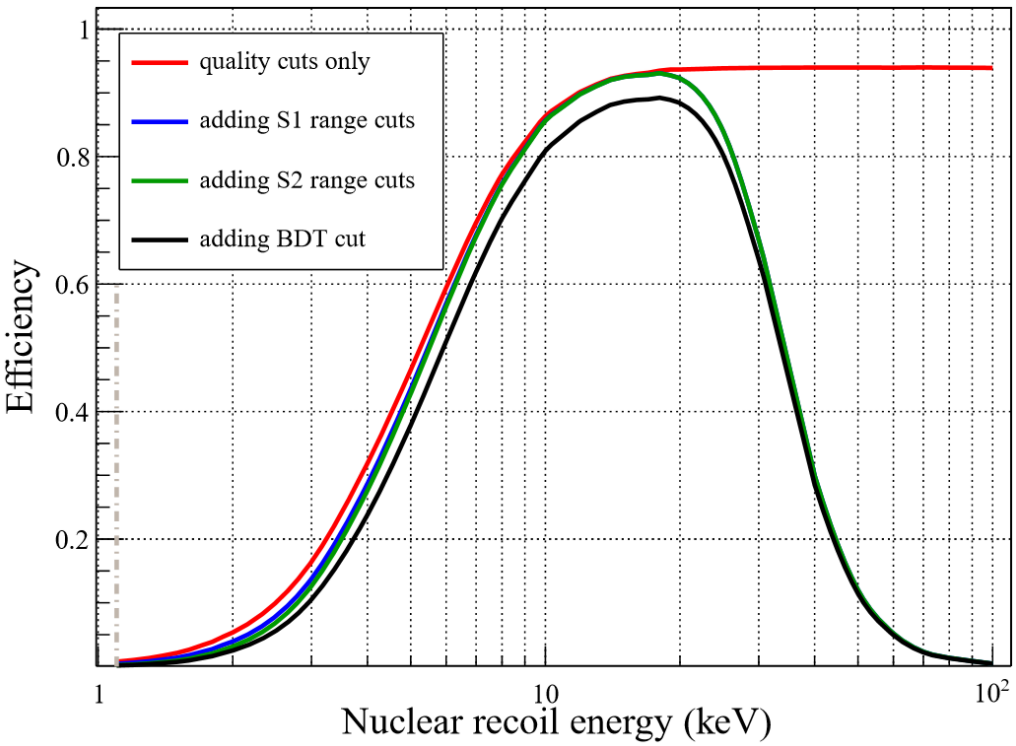
- Gaussian fits to all ER peaks in data
- Uncertainty on each data point estimated using energy nonlinearity
- Linear fit in S1/E vs S2/E to extract PDE and EEE

NR calibration



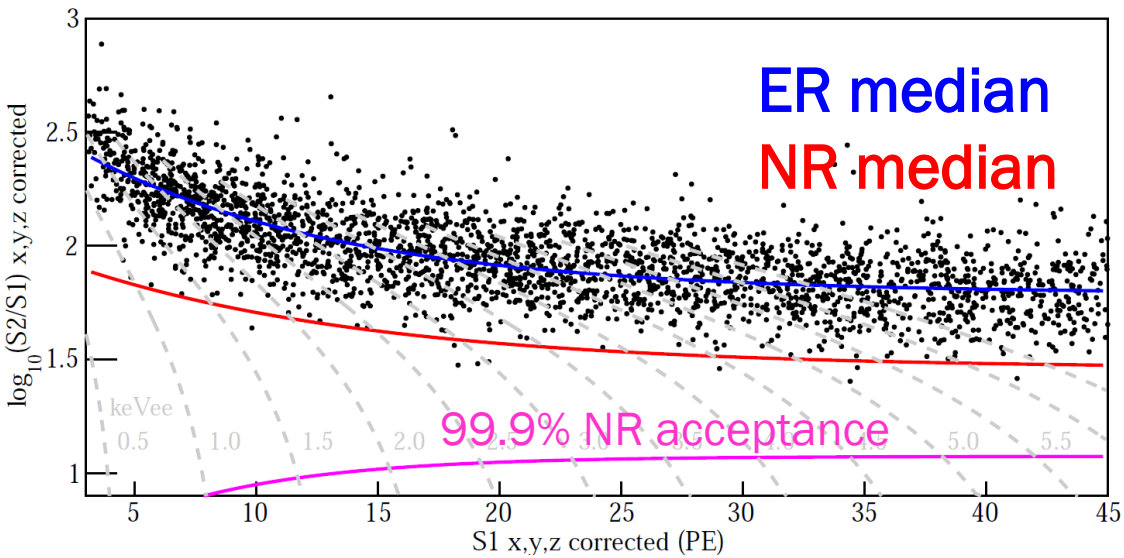
- 162.4 hours of AmBe data taken, with ~3400 low energy single scatter NR events collected
- NR median curve and width in agreement with NEST prediction

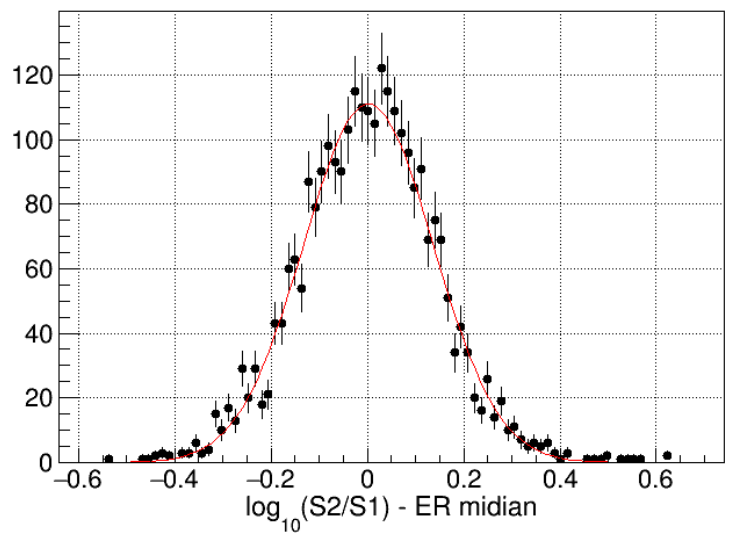
NR detection efficiency



- NR efficiency obtained by data/MC(NEST) ratio
- S1 [3,45] PE, S2 [100_{raw}, 10000_{corr}] PE
- Adopted 1.1 keV_{nr} threshold
- NR efficiency function agrees with that obtained in tritium ER calibration

ER calibration with CH_3T

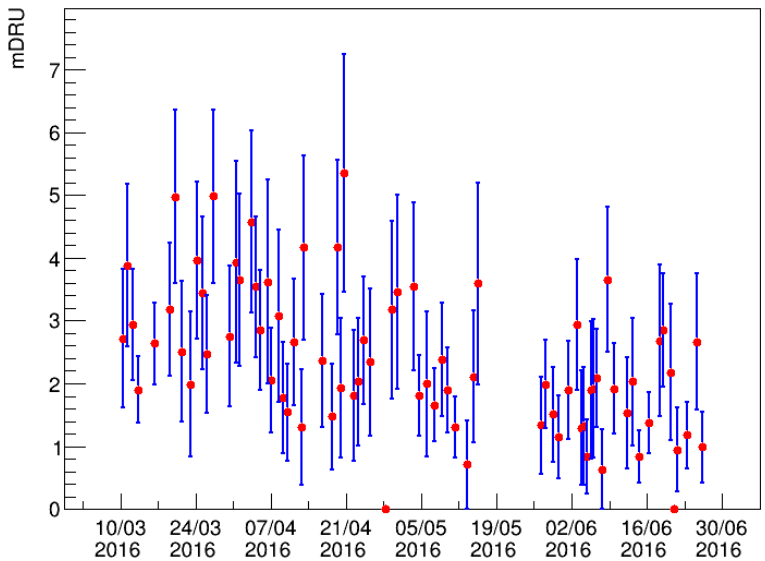




- 18.0 hours of tritium data taken, with ~2800 low energy ER events collected in the FV
- 9 events leaked below NR median, (0.32 ± 0.11)%
- Consistent with Gaussian expectation

Low energy rate in run 9

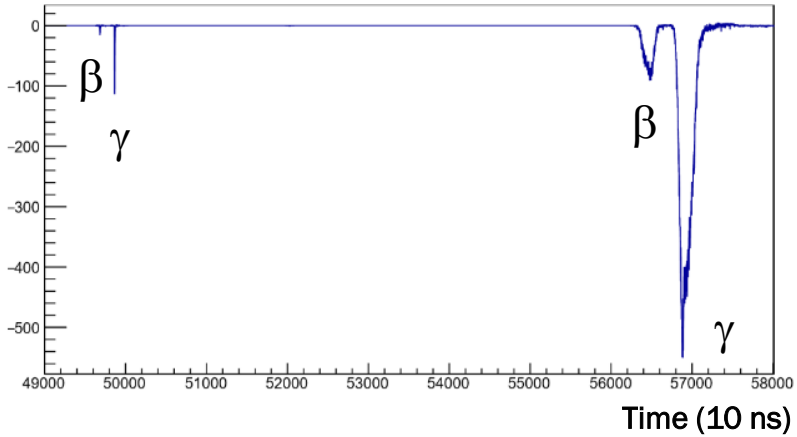
DRU = evt/kg/keV$_{ee}$/day

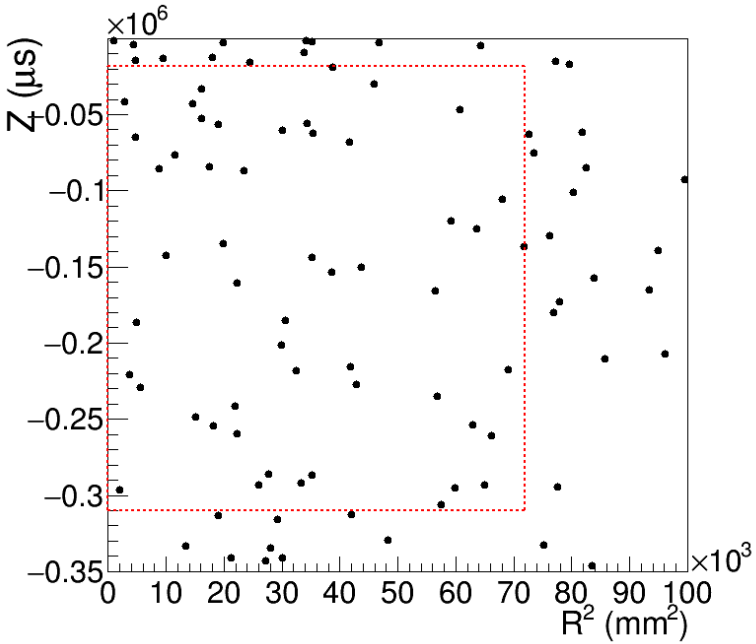


Item	Run 8 (mDRU)	Run 9 (mDRU)
^{85}Kr	11.7	1.19
^{127}Xe	0	0.42
^{222}Rn	0.06	0.13
^{220}Rn	0.02	0.01
Detector material ER	0.20	0.20
Total	12.0	1.95

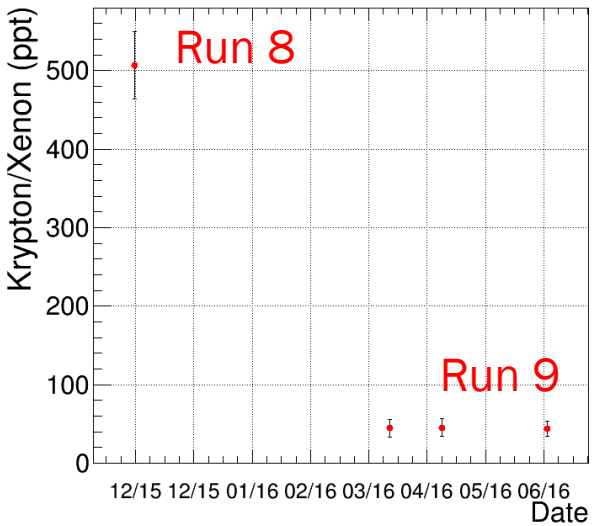
- Events selected in the FV with energy <10 keV$_{ee}$
- ~2 mDRU in the FV on average, lowest reported background level in dual phase xenon
- Decrease over time due to ^{127}Xe decay

^{85}Kr

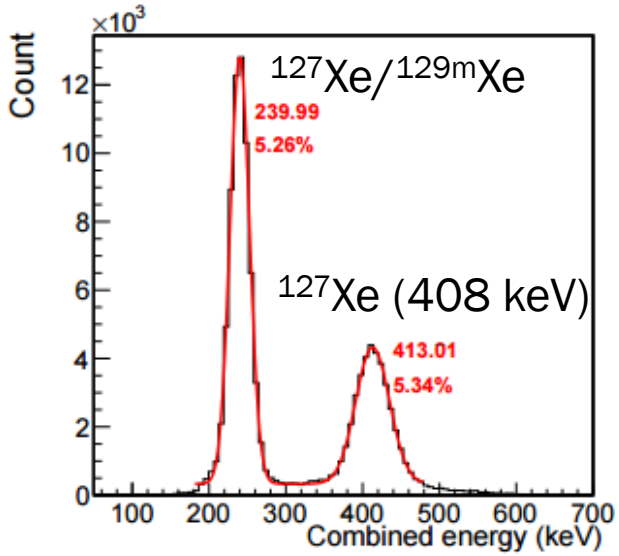


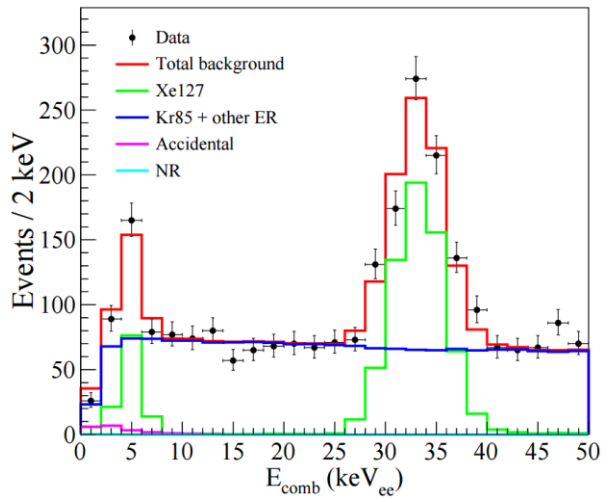


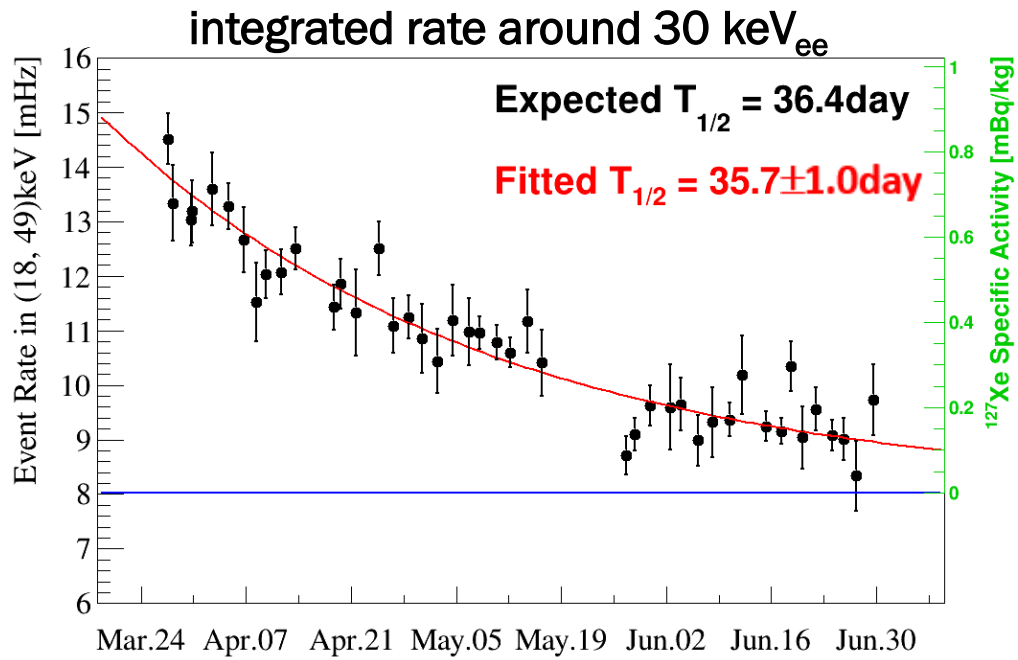
- 0.43% β decay with delayed ^{85m}Rb γ de-excitation
- Uniformly distributed
- Significantly reduced (x10) after the distillation



^{127}Xe

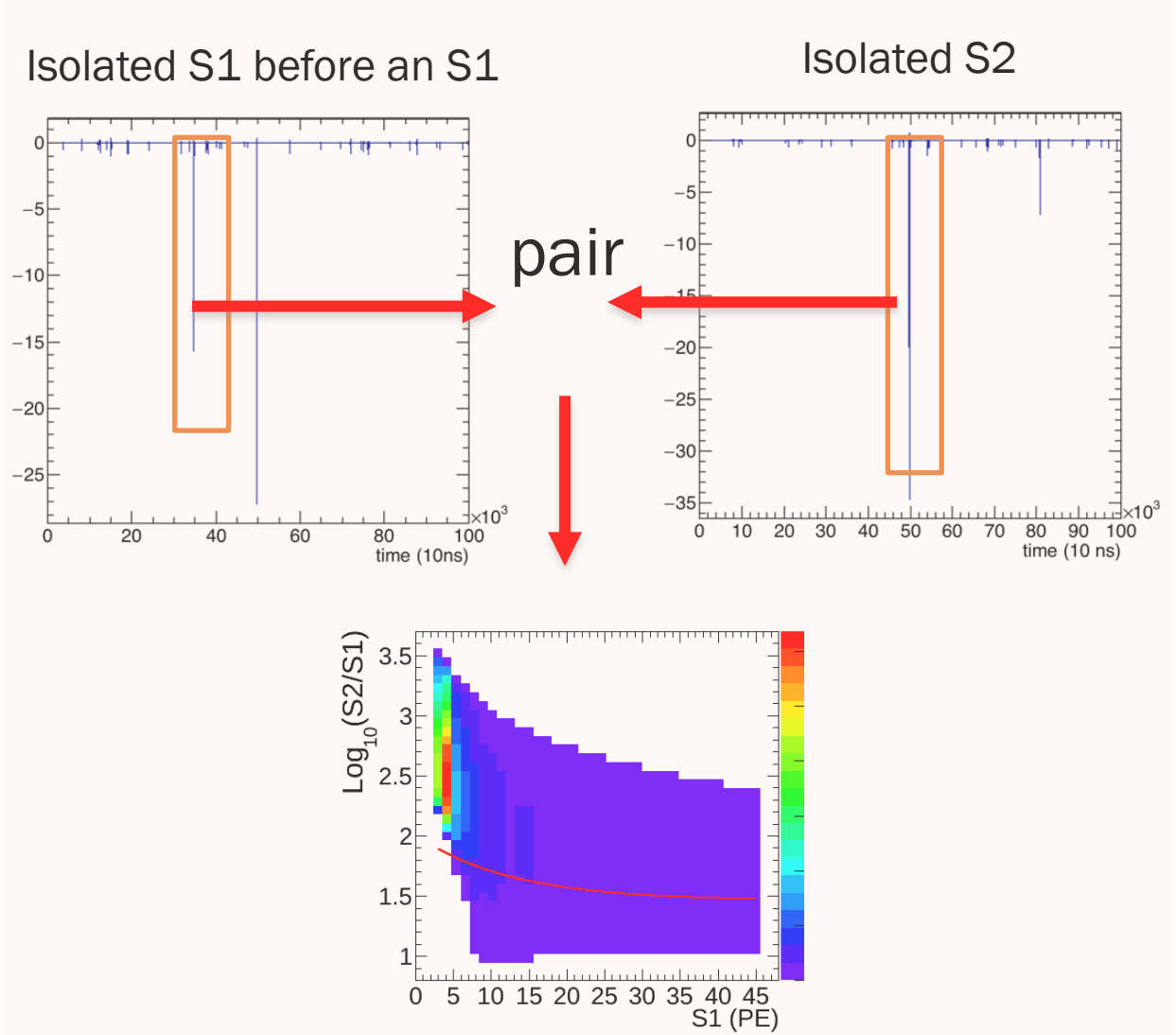






Average ^{127}Xe rate in the DM search region: 0.42±0.10 mDRU

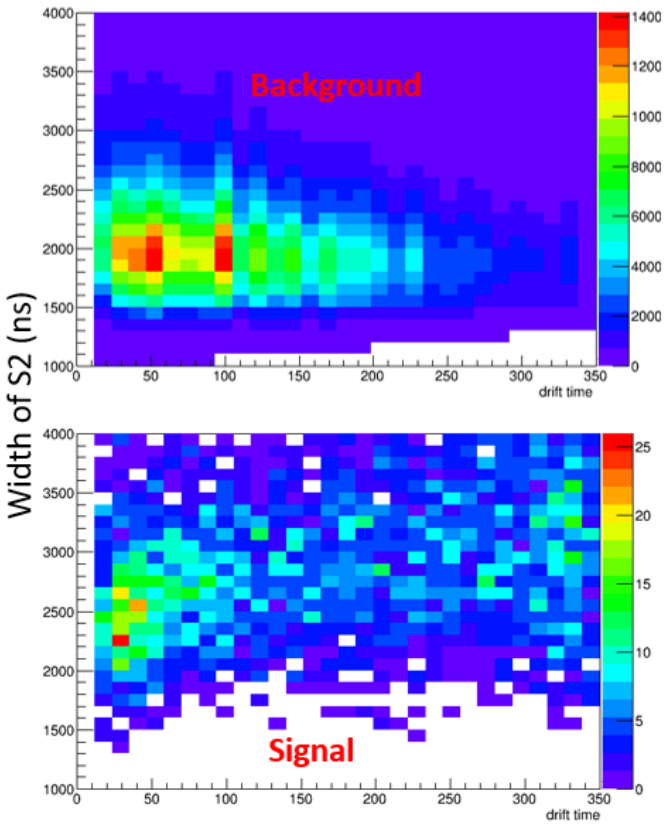
Accidental background



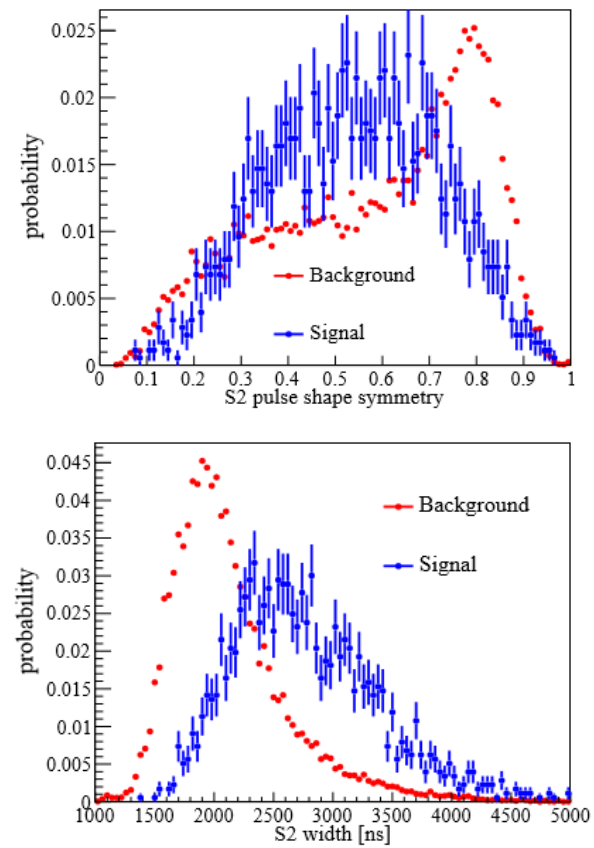
- Isolated S1 and S2 were selected and randomly paired to determine accidental distribution
- Further suppressed this background by x3 using boosted decision tree (BDT) technique

BDT discrimination power (examples)

- Accidental S1 and S2 lack intrinsic correlations

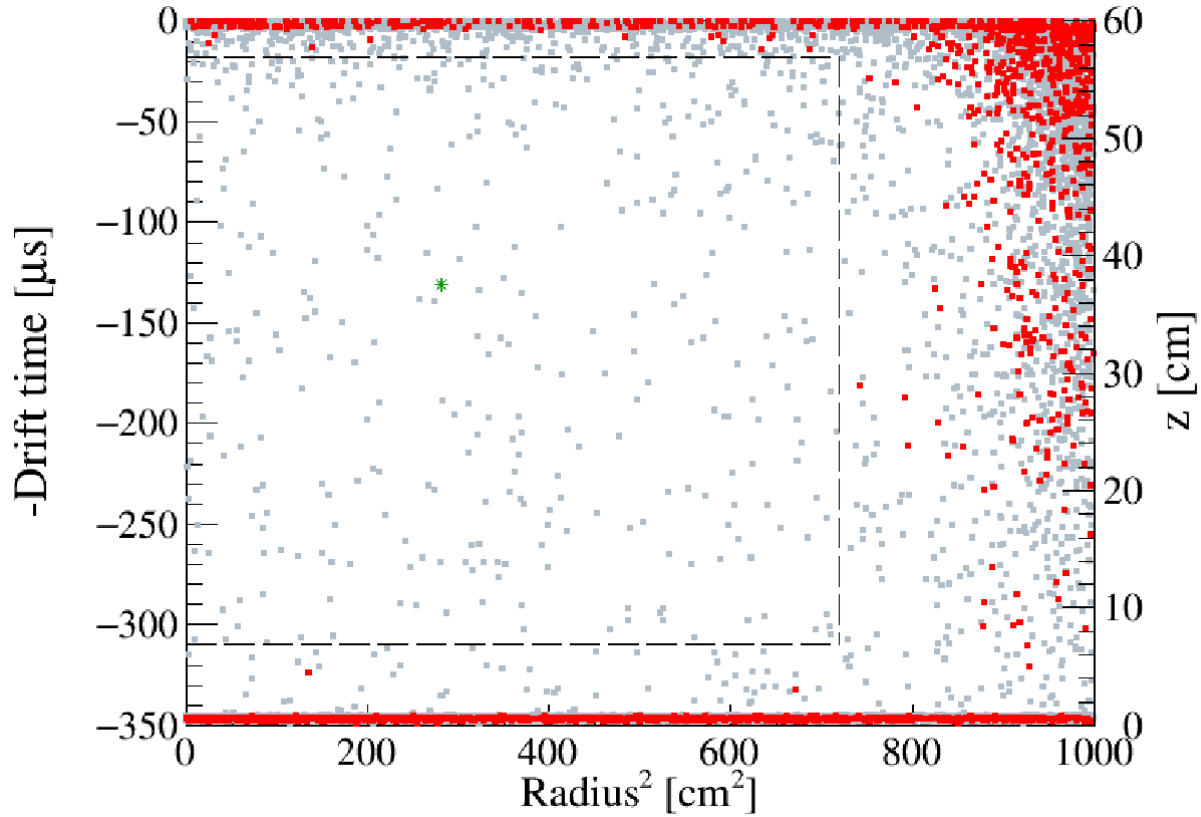


- Single S2 likely from gate and gas region (small width, large asymmetry)



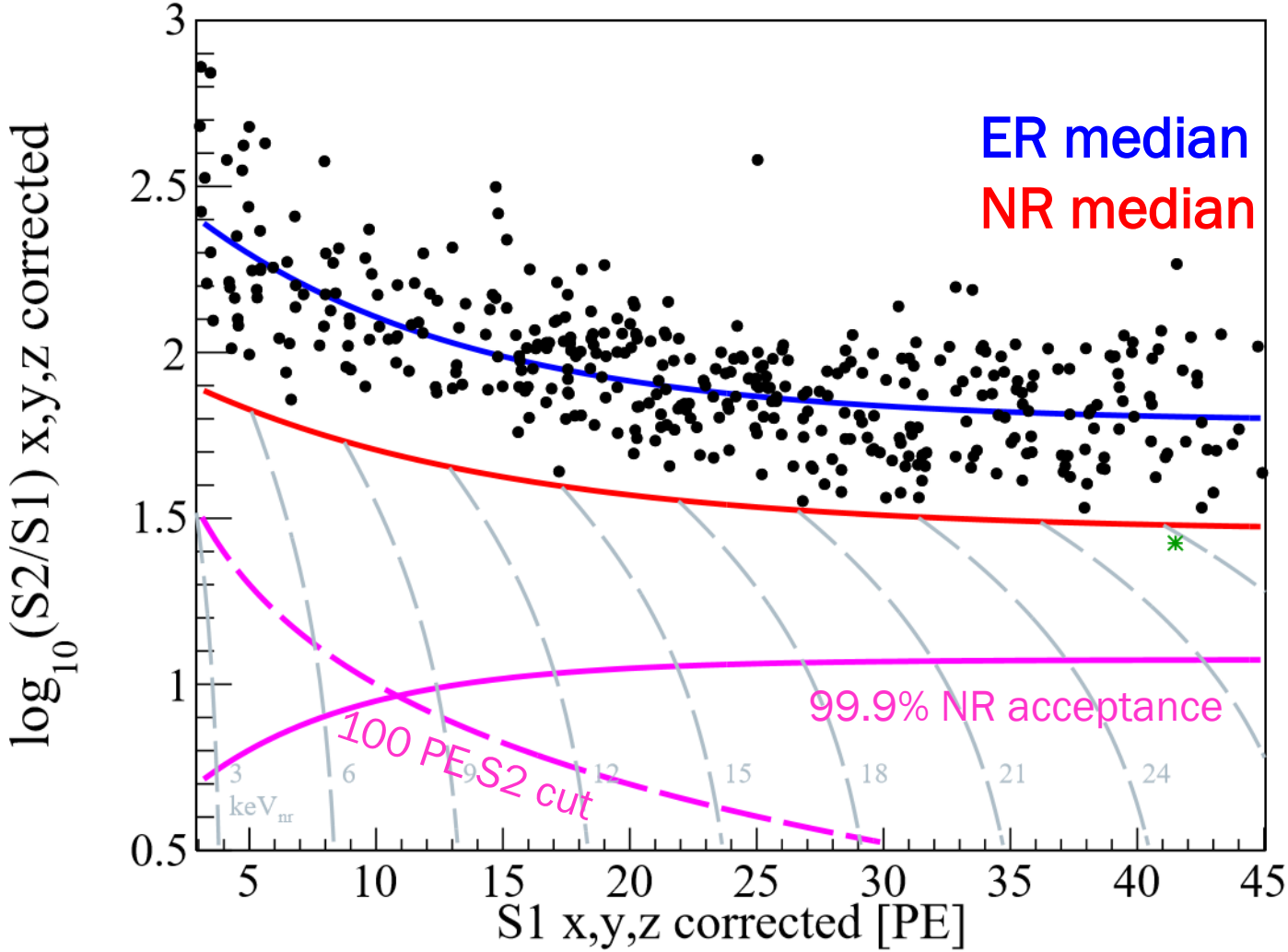
Final candidates (run 9)

Gray: all
Red: below NR median
Green: below NR median and in FV

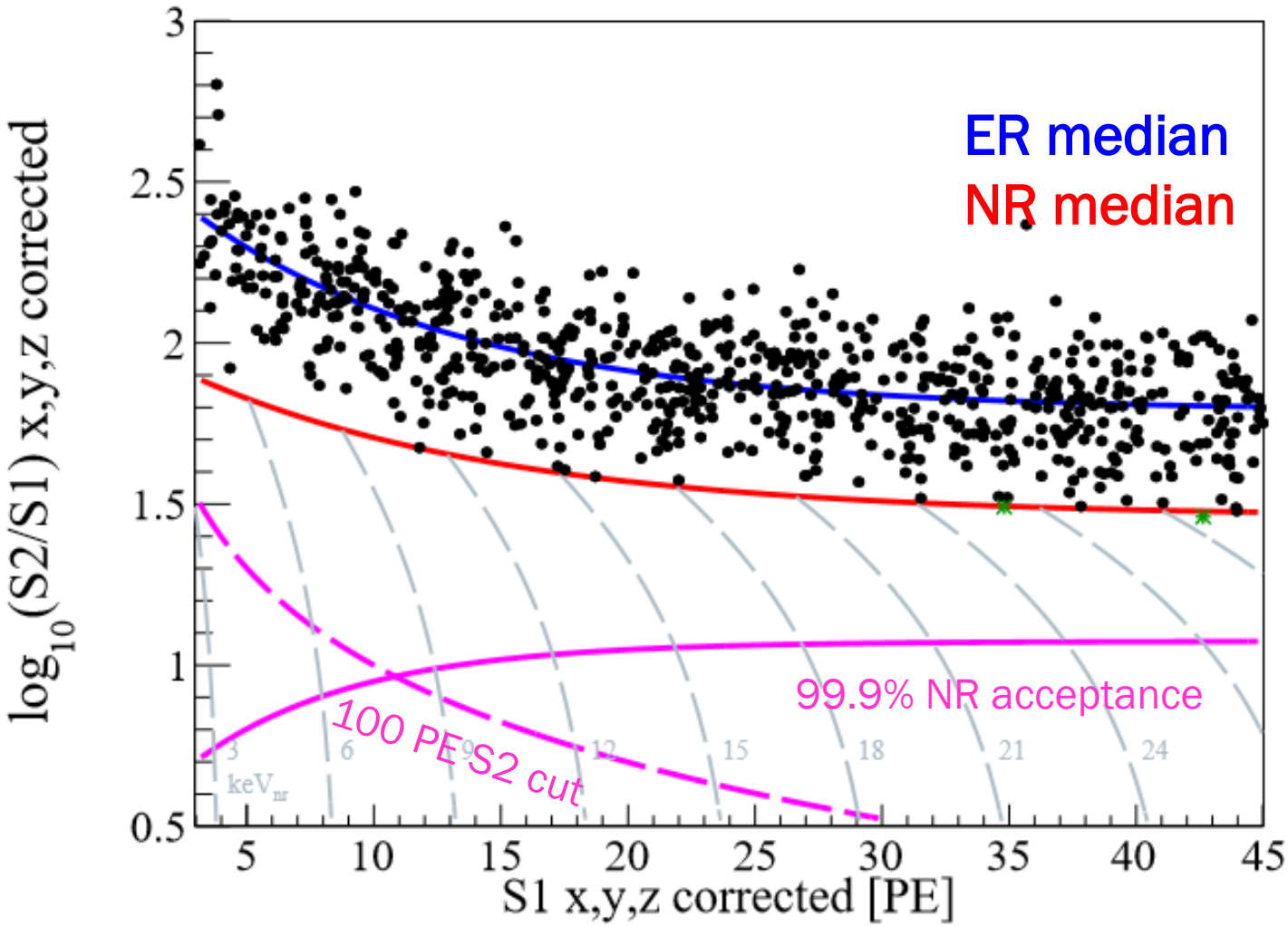


- 389 total candidates found in the FV (329 kg)
- 1 below NR median
- Outside FV, edge events more likely to lose electrons, leading to S2 suppression

Final candidates (run 9)



Final candidates (run 8)



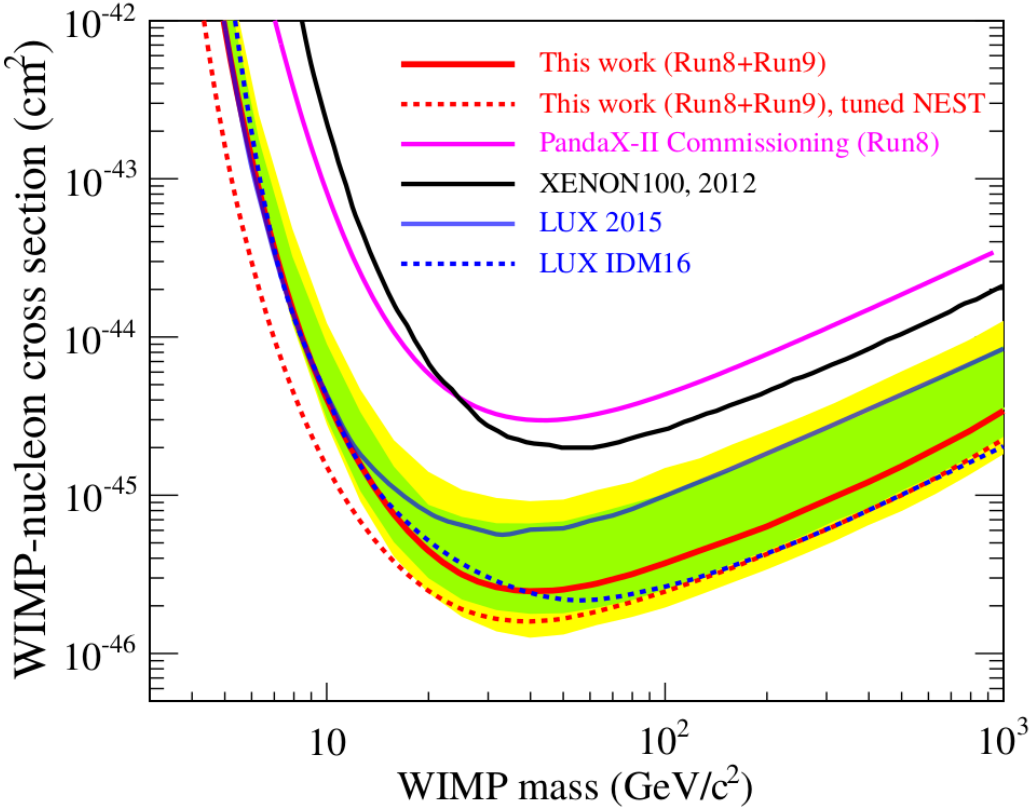
Summary of final candidates

	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

Total exposure: 33,000 kg-day

Cross section limit

90% limit (PLL, CL_s), SI isoscalar elastic DM-nucleon

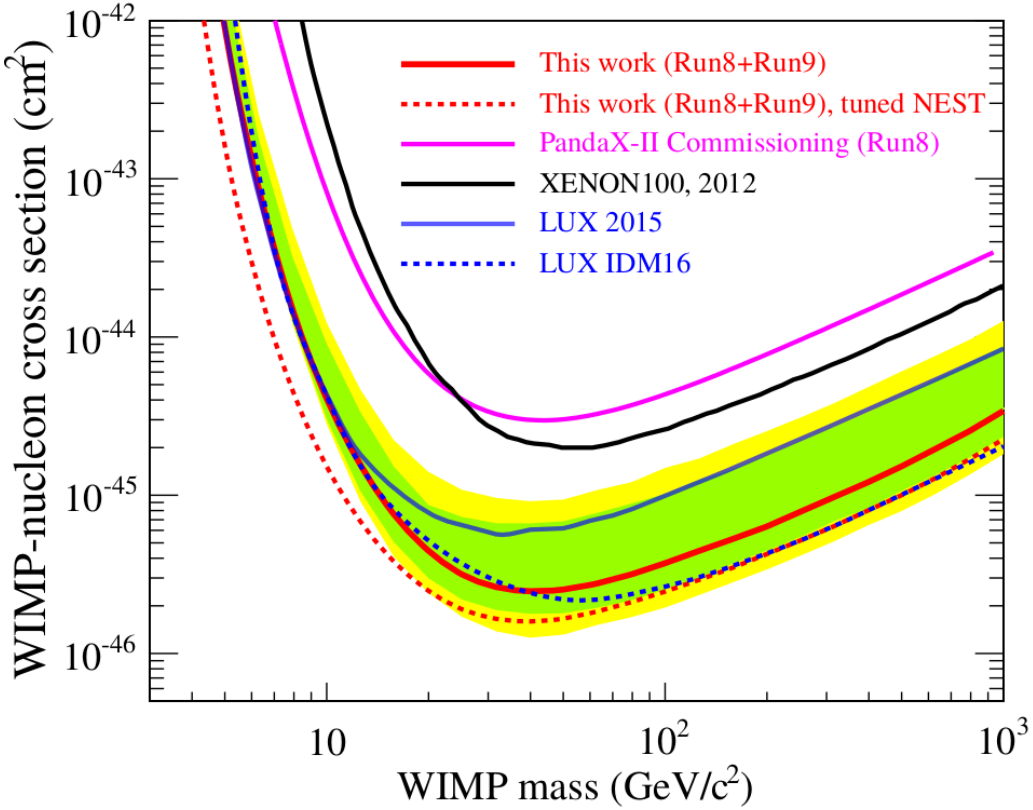


Released at IDM on July 21, arXiv:1607.07400 on July 26, accepted by PRL on Aug. 16

- Minimum exclusion: 2.5×10^{-46} cm^2 @ 40 GeV/c^2, improved x10 from run 8, >x2 from LUX 2015
- More constraining result could be obtained with a tuned NR model (in some aspects agreeing better with NR calibration). Conservatively used NEST model for official results

Cross section limit

90% limit (PLL, CL_s), SI isoscalar elastic DM-nucleon



Released at IDM on July 21, arXiv:1607.07400 on July 26, accepted by PRL on Aug. 16

- LUX 332-day results presented at IDM (arxiv:1608.07648) with similar exposure and limit (slightly more constraining than PandaX towards high mass)
- This is the first low background result from PandaX-II, a long life (~500 live-day) ahead of this!

Summary and outlook

PandaX-II has reached the forefront of the DM search!

- 79.6 live-day of dark matter data with much suppressed background (12⇒2 mDRU)
- In combination with commissioning run (19.1 day), ~33,000 kg-day exposure in total. No DM particles found
- The WIMP-nucleon elastic SI scattering cross sections are constrained to $<2.5\times10^{-46}$ cm^2 at 40 GeV/c^2. Other physics results (e.g. SD) expected soon
- Continue PandaX-II data taking till end of 2017
- In preparation for PandaX-xT and PandaX-III!

Improved position reconstruction

Major difficulties:

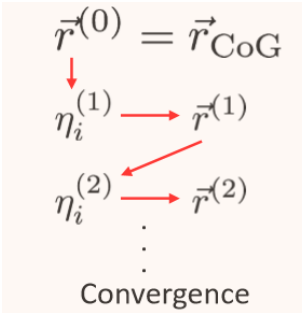
- 3” PMT: optimizing photon collection, but naively causing coarse quantization
- Complicated optics, particularly due to the photon reflections on the PTFE reflector

- Construct and fit photon acceptance function(PAF) for each PMT

$$\eta(r) = A \cdot \exp\left(-\frac{a \cdot \rho}{1+\rho^{1-\alpha}} - \frac{b}{1+\rho^{-\alpha}}\right), \quad \rho = \frac{r}{r_0}$$

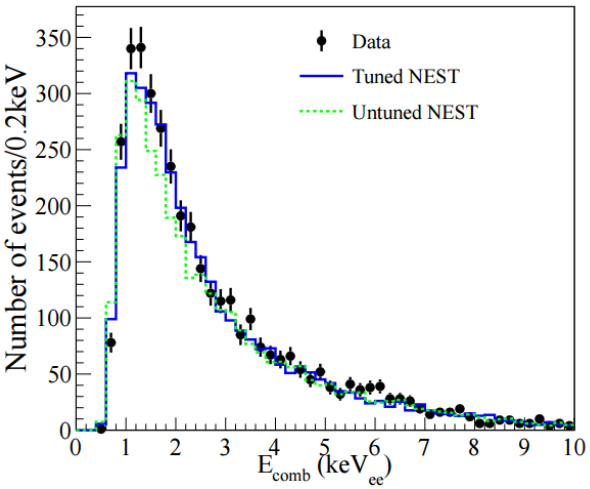
- Event-by-event max likelihood fit on charge pattern to reconstruct position

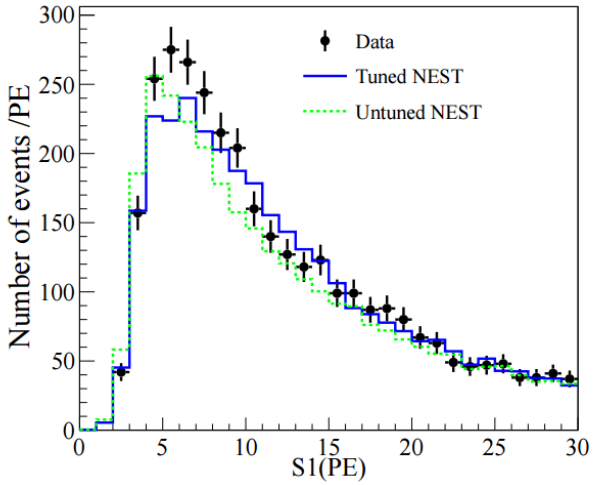
- Iterations to improve PAFs based on data

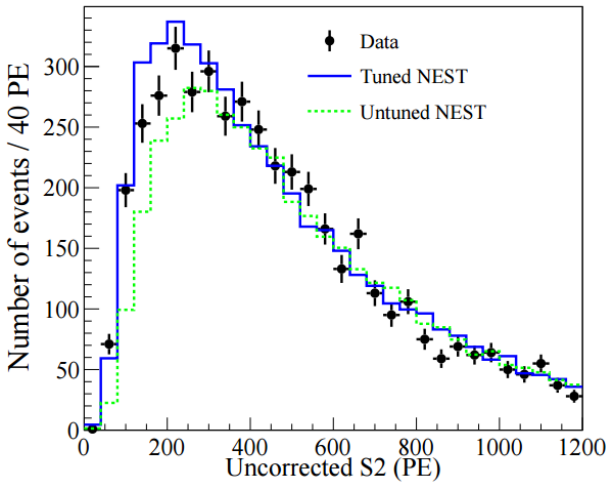


V. N. Solovov *et al*, *IEEE* doi: 10.1109/TNS.2012.2221742

NR data vs model comparison



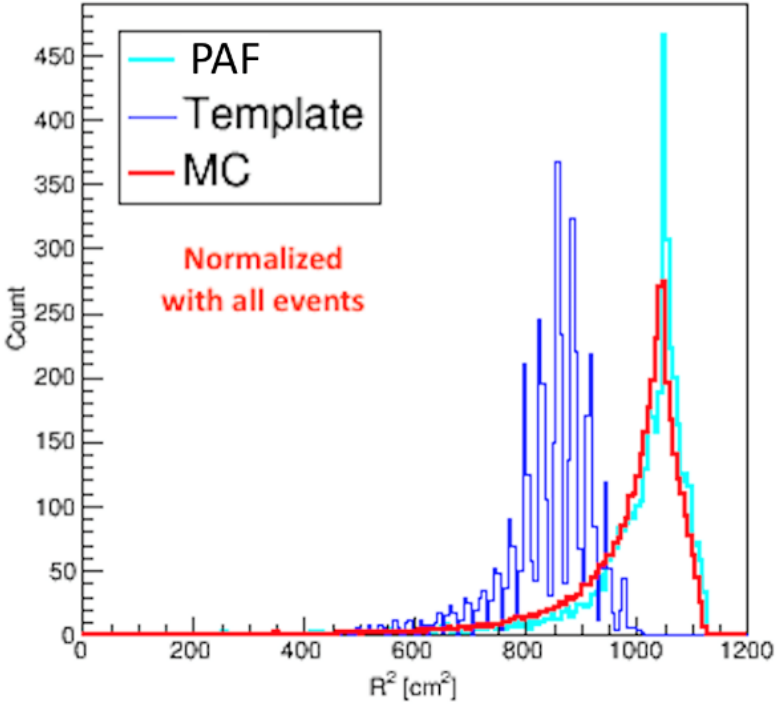




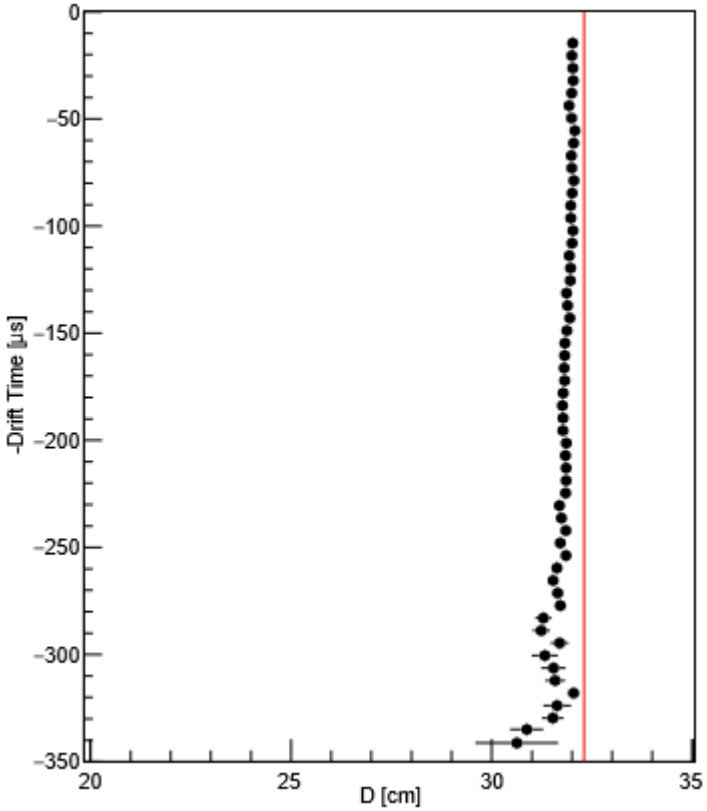
- Data and untuned NEST agree in the median and width of NR band
- Small discrepancy was observed in detailed shape for small S1 and S2. A tuned NEST model could improve this
- Detailed investigation is underway

Internal background distribution

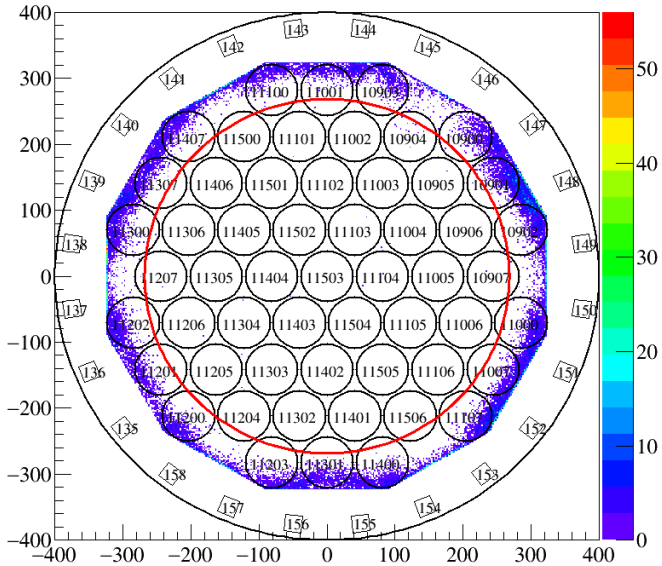
33.2keV from ^{127}Xe event R^2 distribution

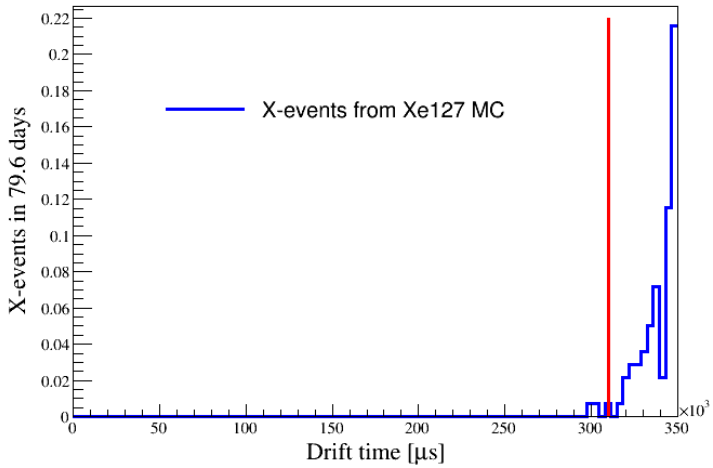


^{210}Po events from the PTFE wall



Final selection cuts





- 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 according to ^{127}Xe MC
- FV in Run 9 = 328.9 kg
- S1 cut:[3,45]PE & S2 cut: [100_{raw}, 10000_{corr}] PE, consistent with previous analysis