Dark matter results from first 98.7 days of data from the PandaX-II experiment

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On Behalf of the PANDAX Collaboration

PandaX collaboration

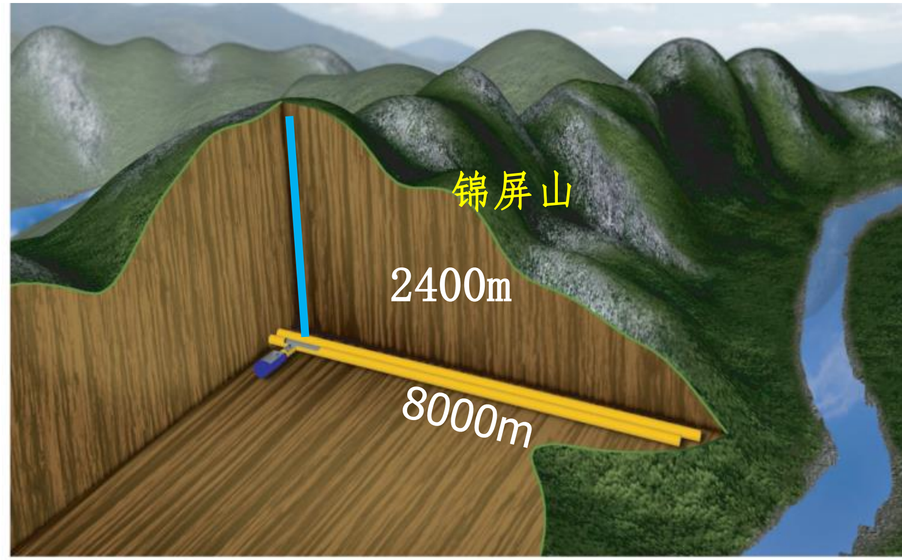
~50 people

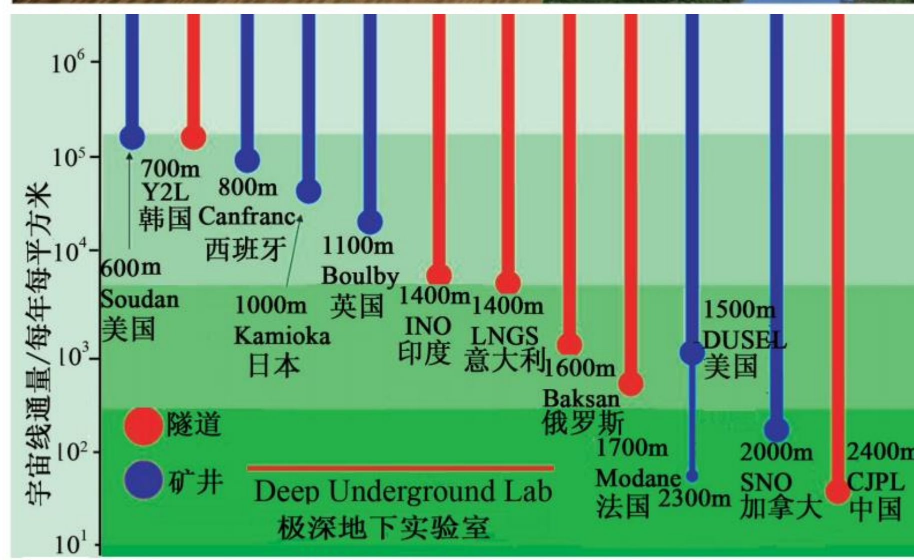
Started in 2009

- 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(2015-)

China Jinping Underground Laboratory

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

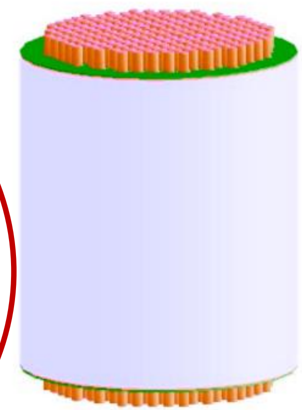




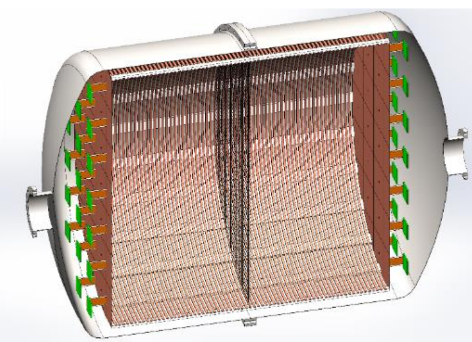
PandaX experiment

PandaX = Particle and Astrophysical Xenon Experiments

Phase I:
120 kg DM
2009-2014



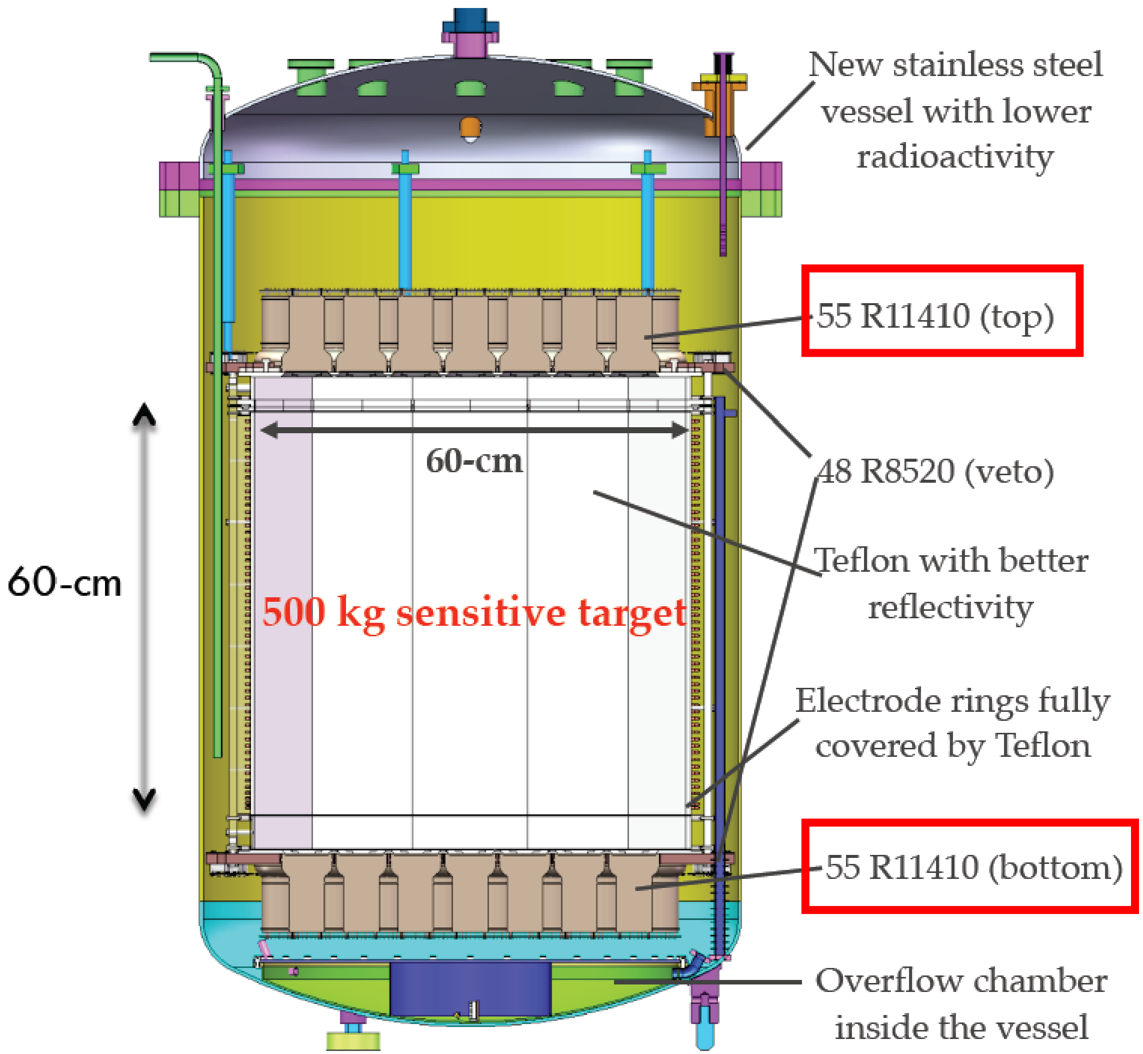
Phase II:
500 kg DM
2014-2017



PandaX-xT:
multi-ton DM
future

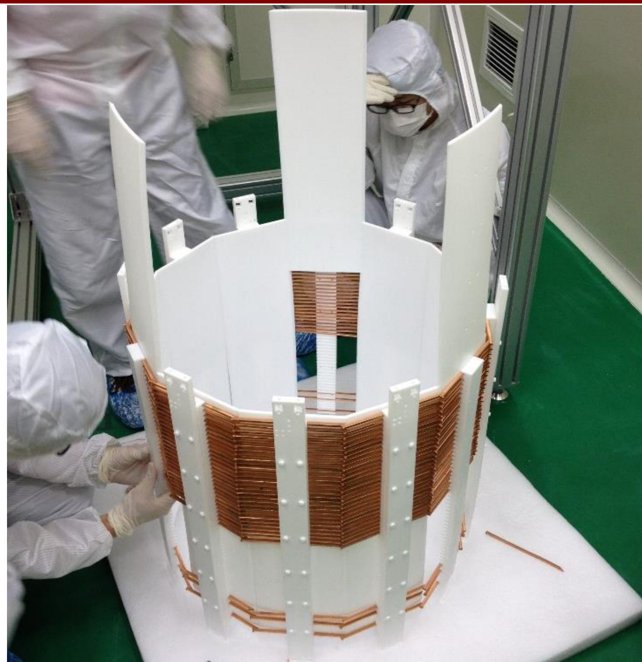
PandaX-III:
200 kg to 1 ton
^{136}Xe 0vDBD
future

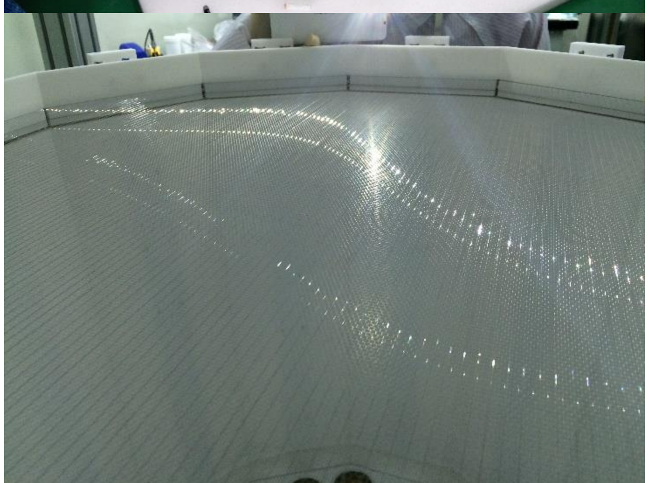
PandaX-II



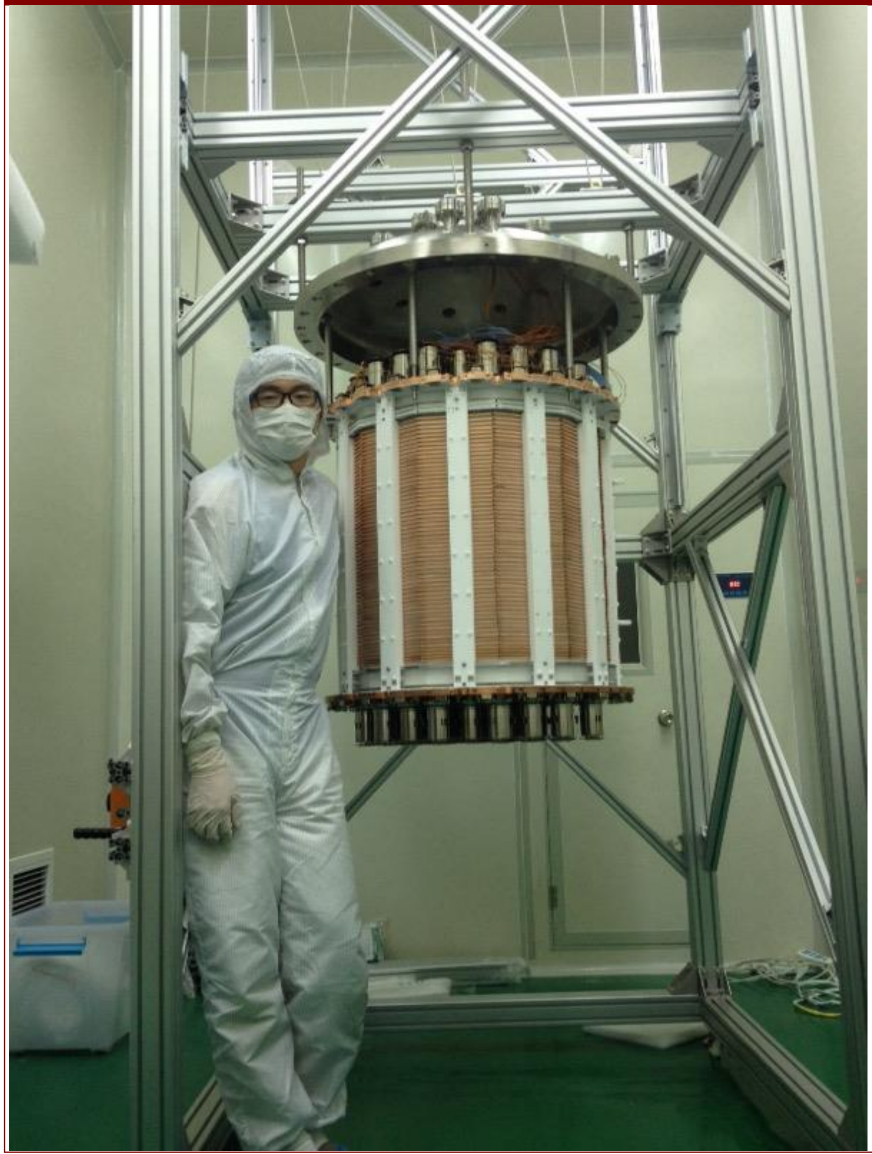
- New inner vessel with clean SS
- New and taller TPC with brand-new electrodes
- More 3” PMTs and improved base design
- New separate skin veto region

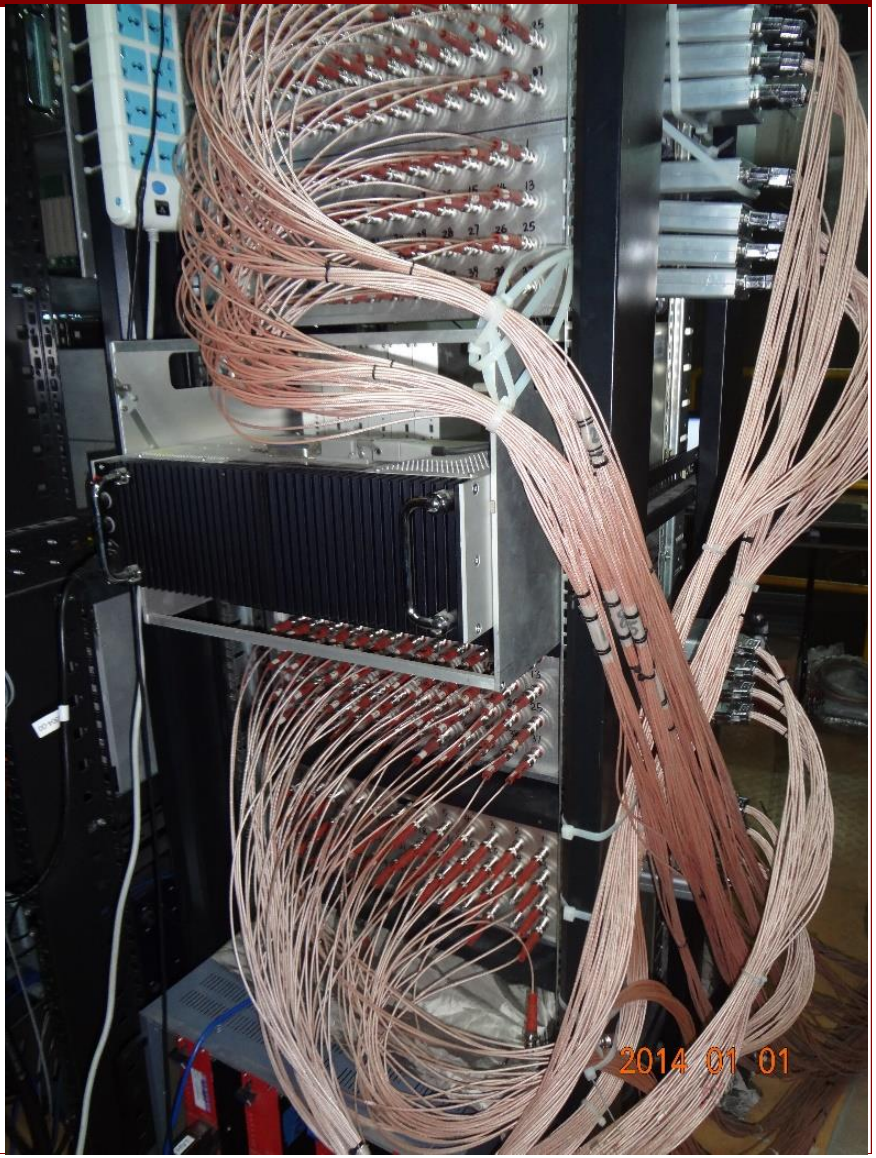
Assembling the detector





Assembling the detector





Run history

Series of Engineering runs

Distillation and re-started (Run9, 80 days)

Detector installation at CJPL

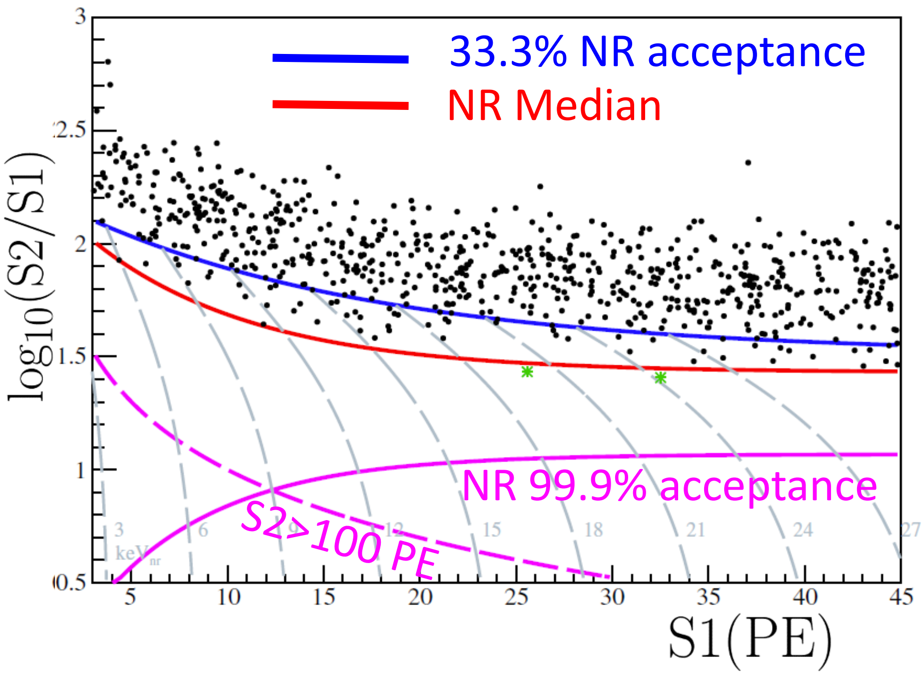
Nov 22 – Dec 14, Physics commission (Run8, 19 days, stopped due to high Krypton background)

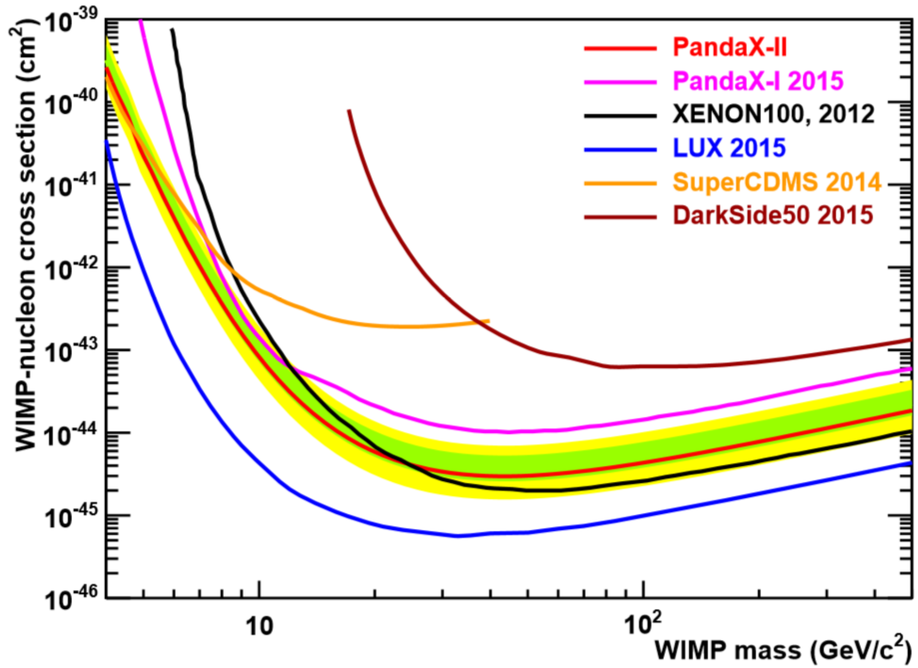
Phys. Rev. D. 39, 122009 (2016)

Run8+Run9=98.7 days
Exposure:3.3x10^4 kg-day

Results from PandaX-II Run 8 (19-day)

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

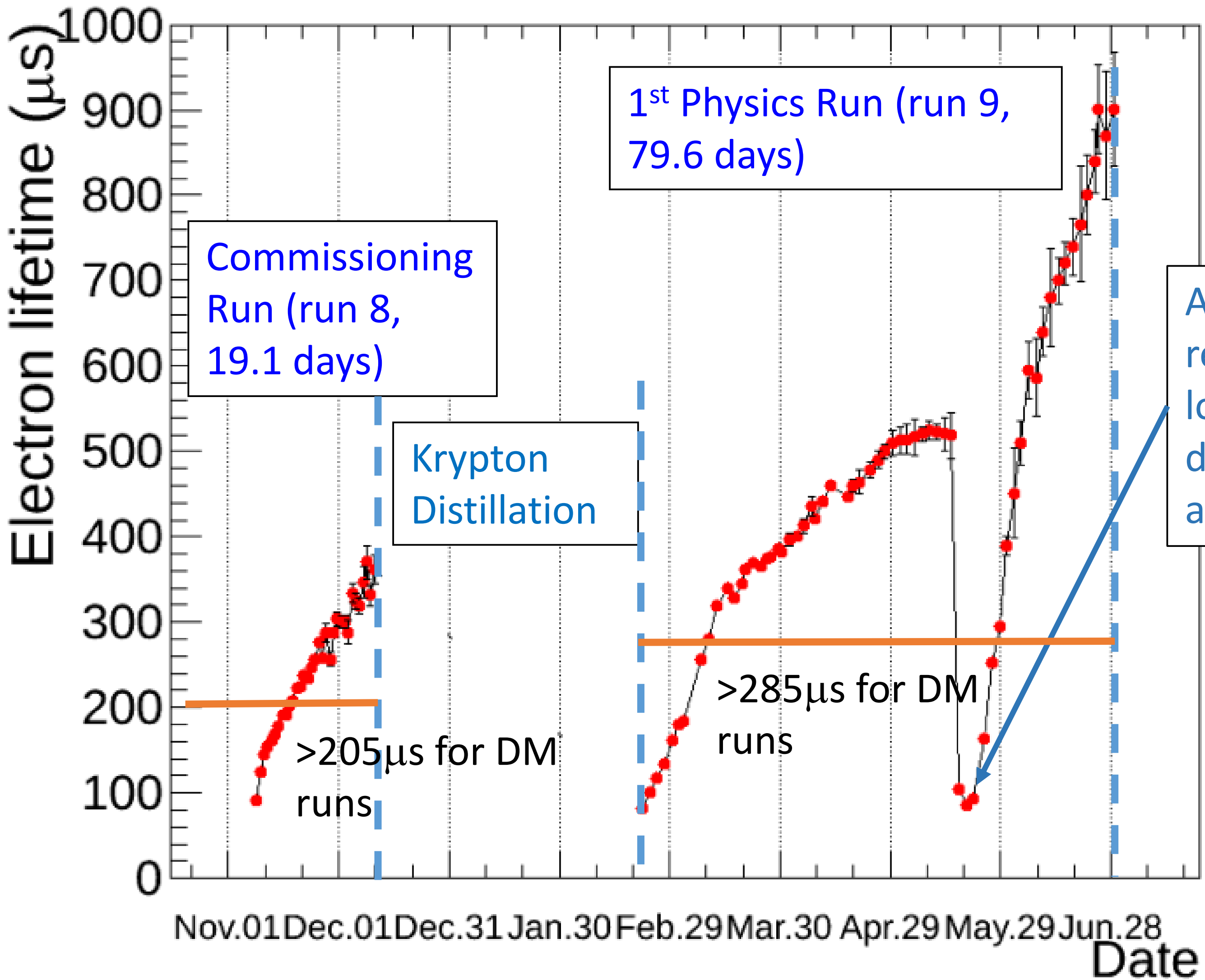




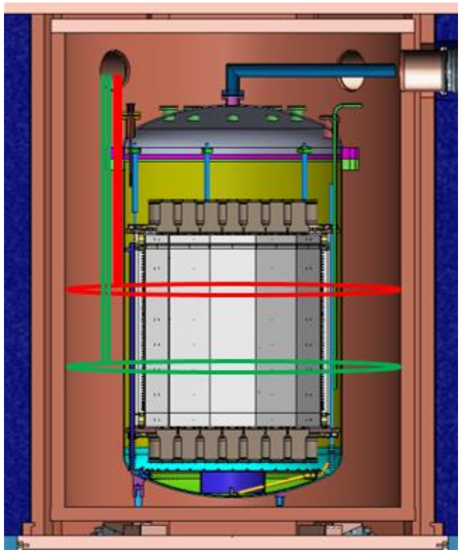
	ER	Accidental	Neutron	Total Expected	Total observed
All	611	5.9	0.13	617±104	728
Below NR median	2.5	0.7	0.06	3.2±0.71	2

Low mass: competitive with SuperCDMS;
High mass: similar results as XENON100 225-day

Electron lifetime evolution



Calibration program



- Internal/external ER peaks:
  - Detector uniformity corrections
  - Light/charge collection parameters

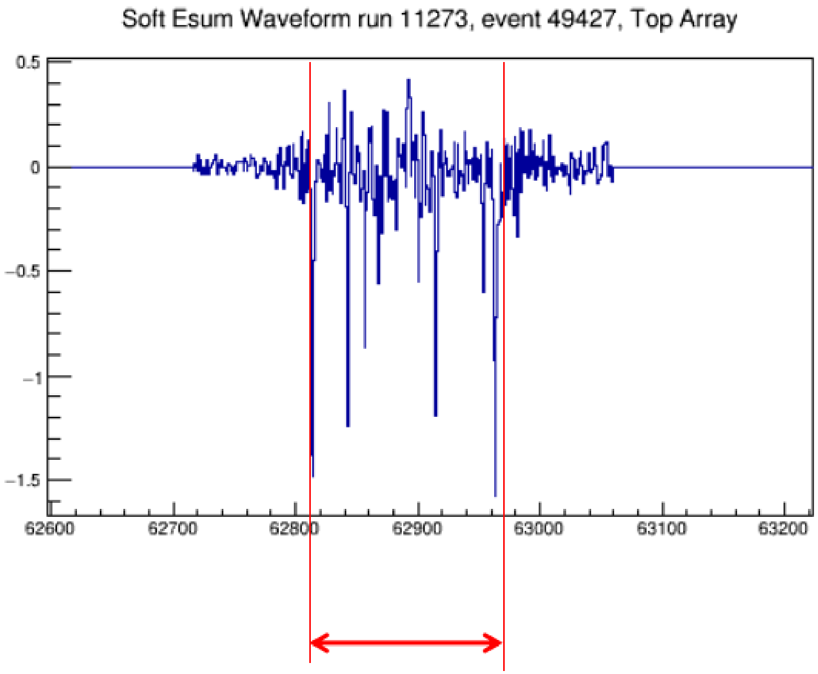
- Low rate AmBe neutron source:

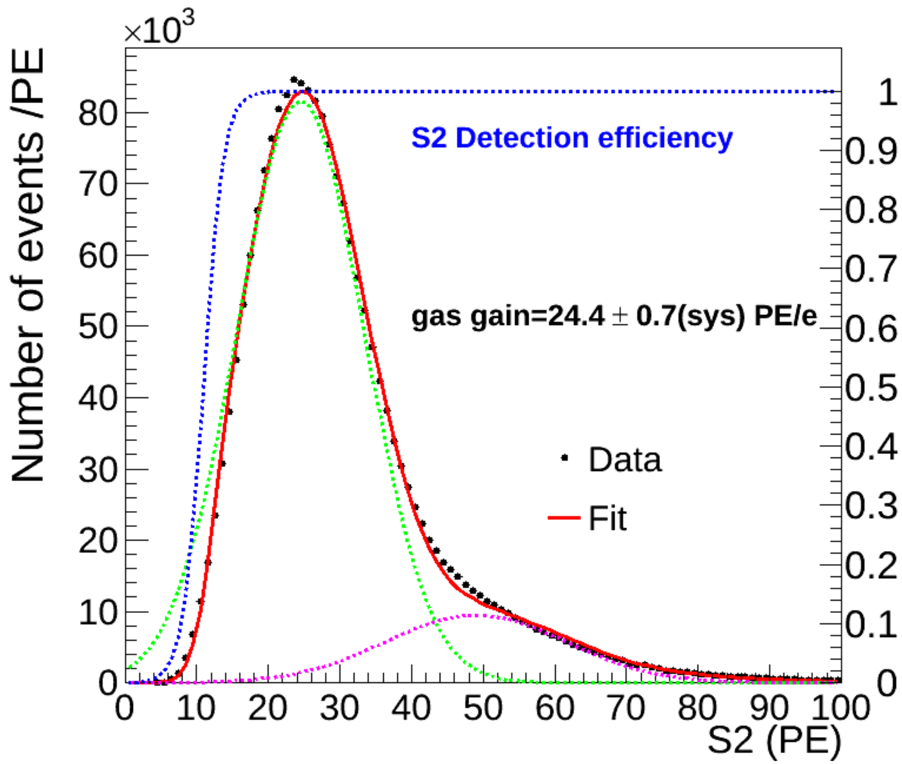
$\Rightarrow$ Simulate DM NR signal

- CH_3T injection: tritium beta decays

$\Rightarrow$ Simulate ER background

Single electron gain



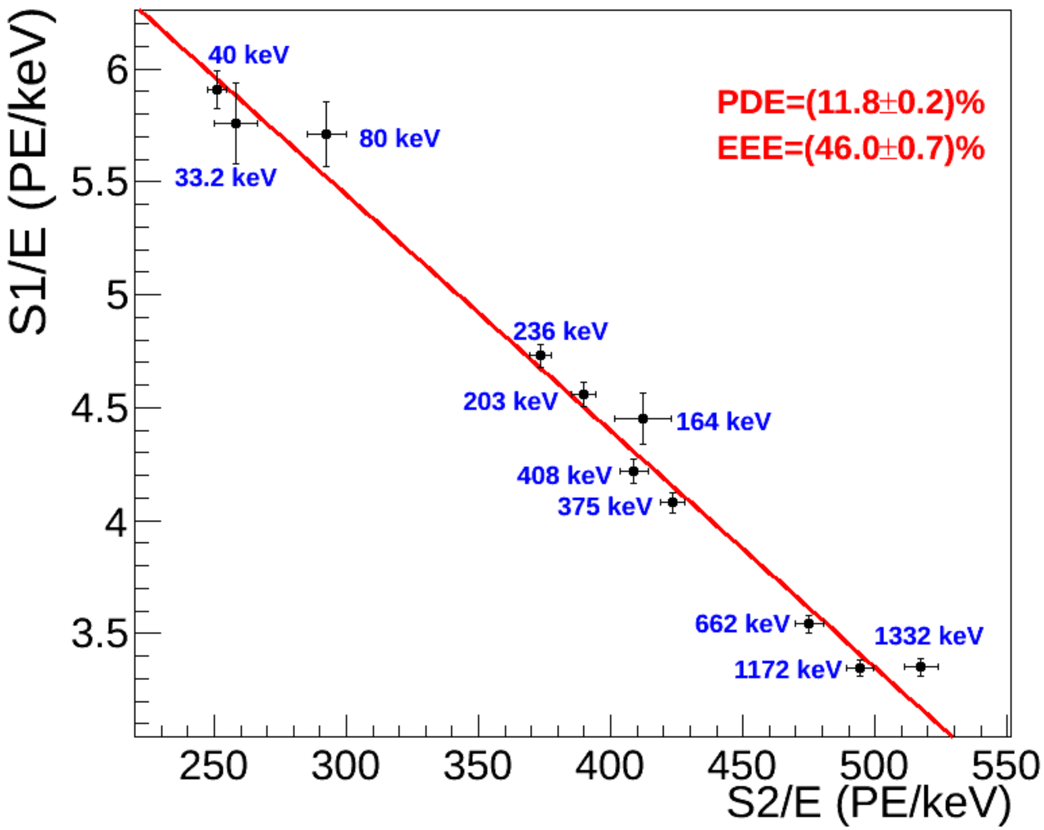


- Identify smallest S2 in the data
- Fitted with two Gaussians (with S2 rec. efficiency taken into account)
- SEG: 24.4± 0.7 PE/e

Extracting detector parameters

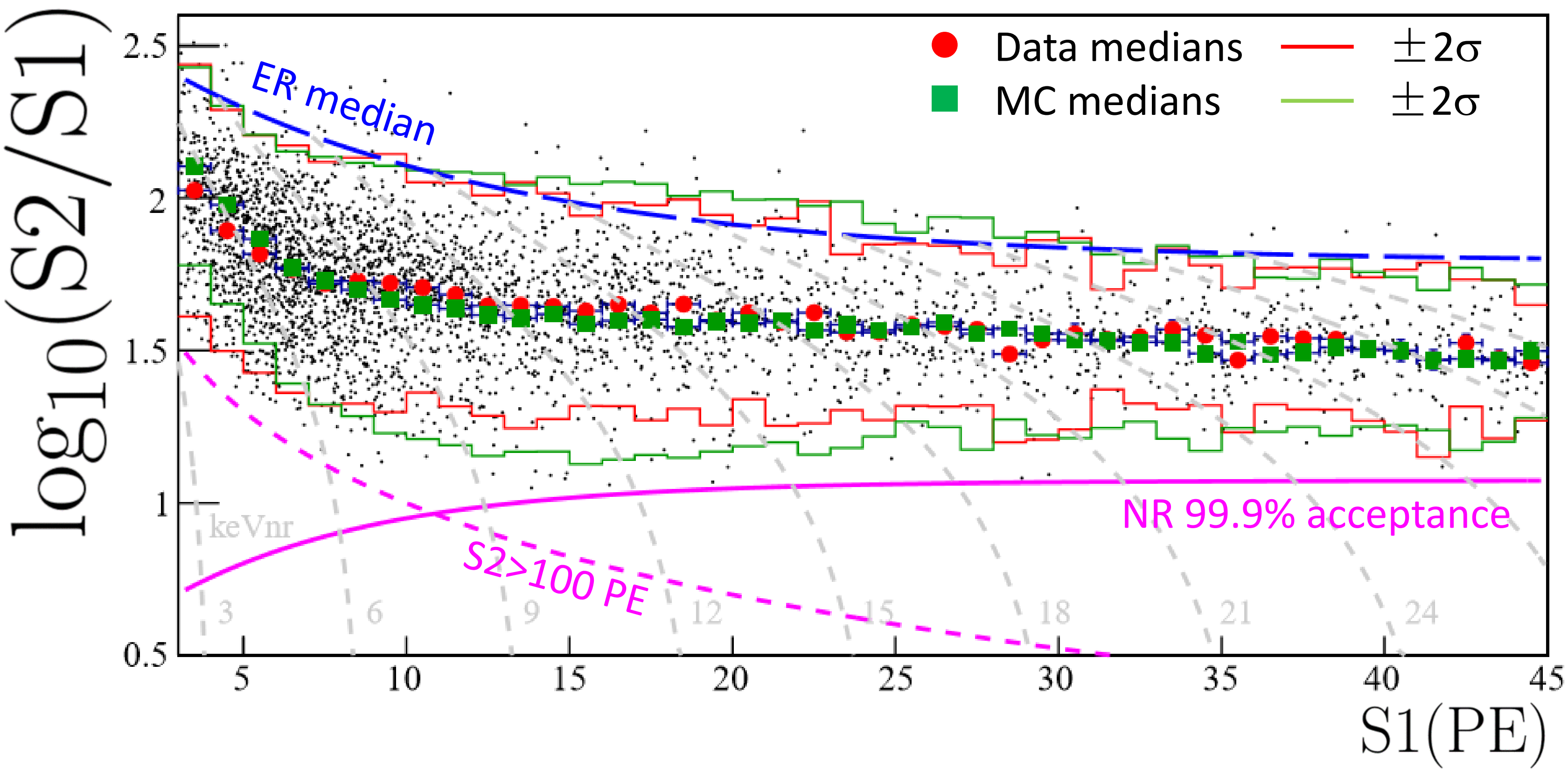
$$E_{ee} = W \times \left(\frac{S1}{\boxed{PDE}} + \frac{S2}{\boxed{EEE} \times \boxed{SEG}}\right)$$

W = 13.7 eV



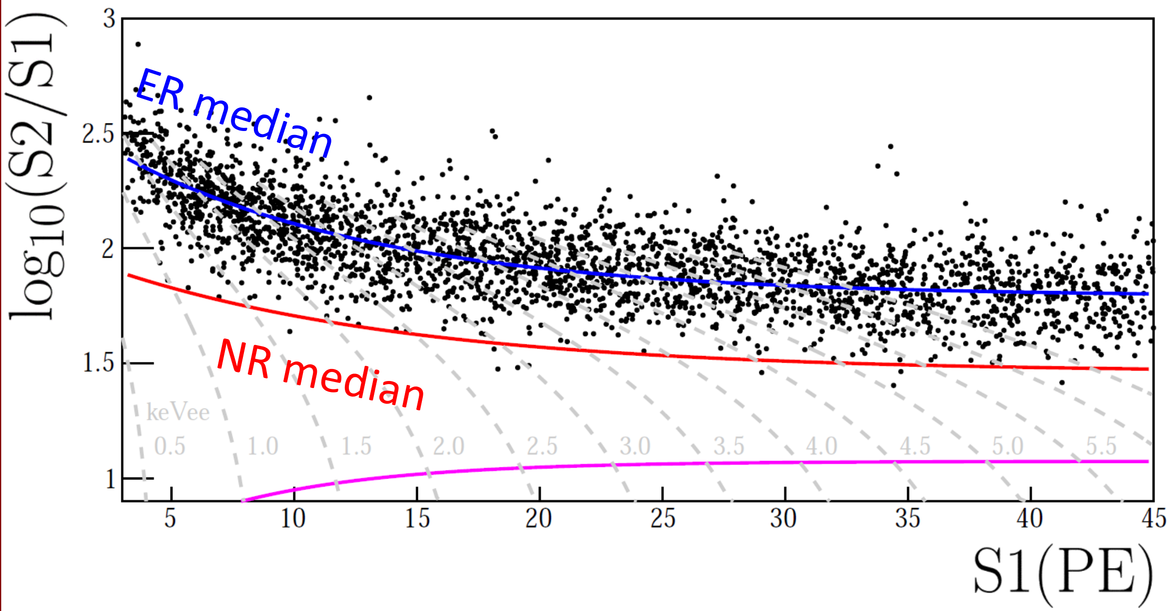
- Gaussian fits to all ER peaks in data
- Linear fit in S1/E vs S2/E to extract PDE and EEE

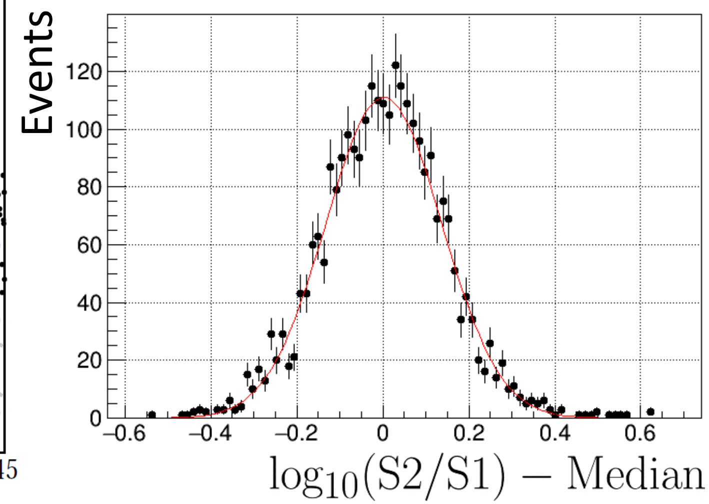
NR calibration

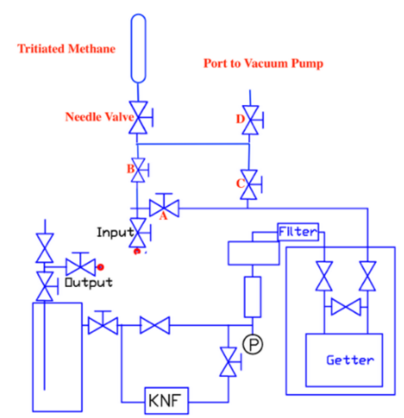


- 162.4 hours of AmBe data taken, with ~3400 low energy single scatter NR events collected
- NR median curve and NR detection efficiency determined

ER calibration with CH_3T







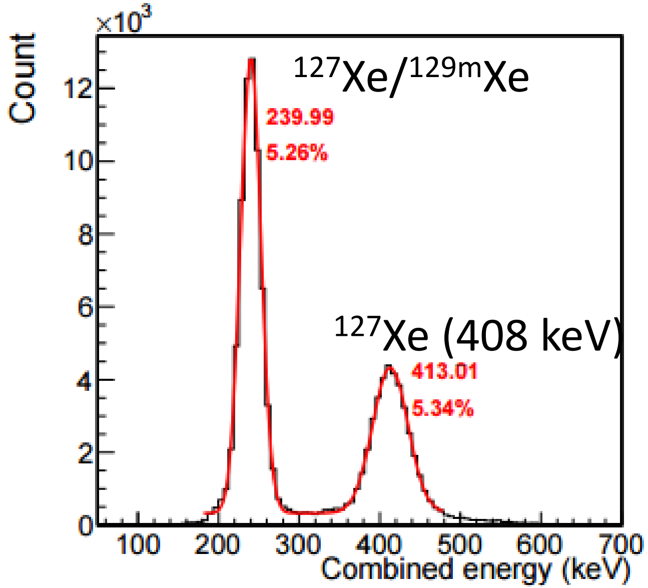
- 18.0 hours of tritium data taken, with ~2800 low energy ER events collected
- 9 events leaked below NR median, $(0.32 \pm 0.11)\%$
- Consistent with Gaussian expectation

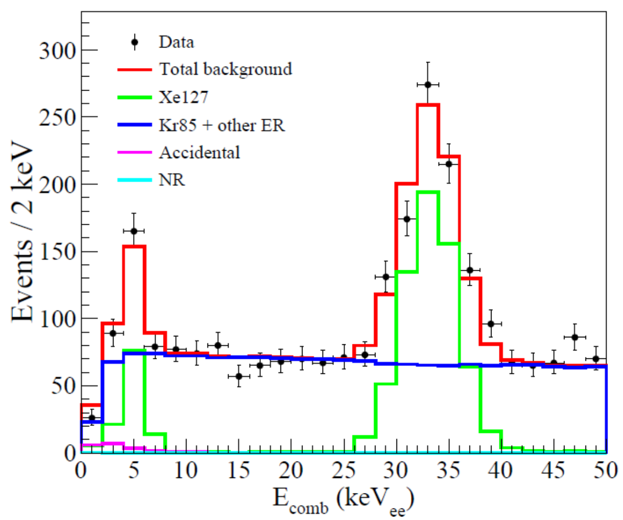
Background: Overview

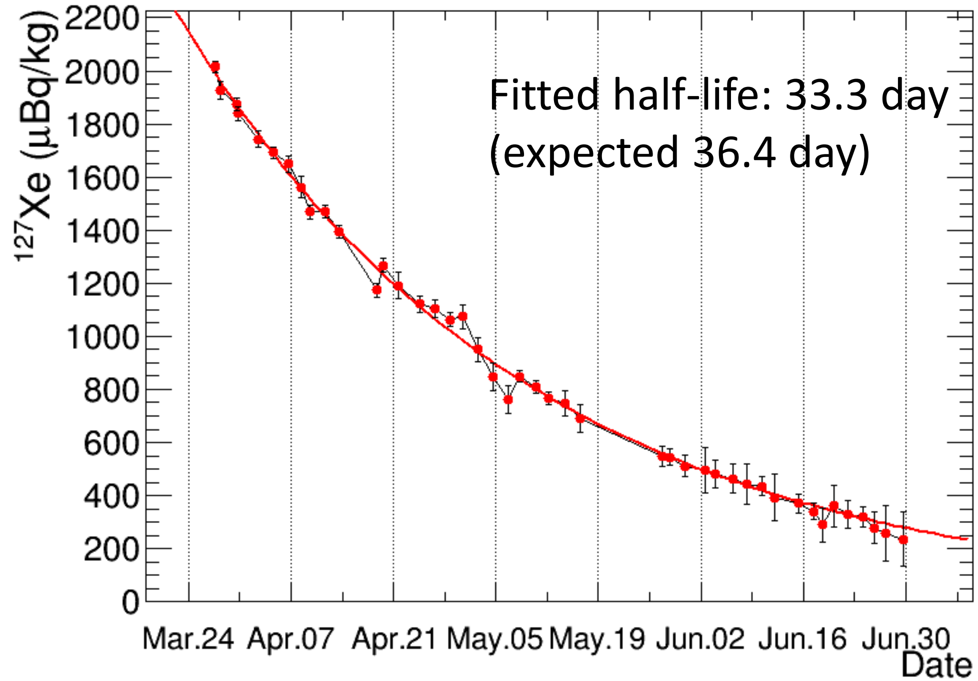
Like before, ER and accidental background identified in the data. Neutron background is from simulation.

- ER background
  - ^{127}Xe (due to surface exposure of xenon during distillation)
  - ^{85}Kr (suppressed by a factor 10)
  - Others
- Accidental background

^{127}Xe



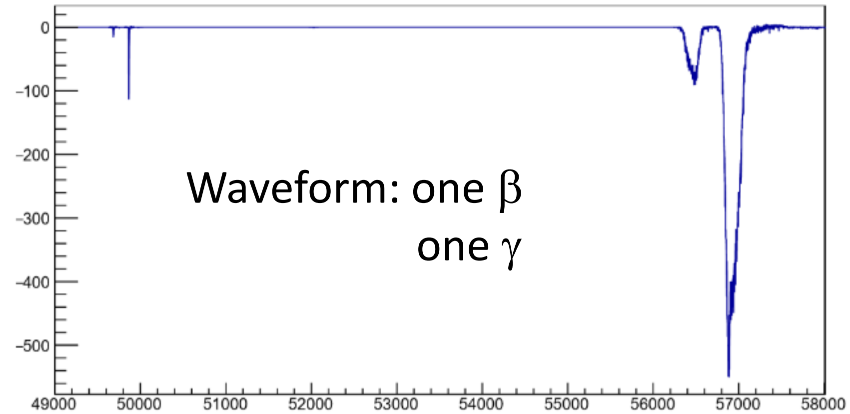


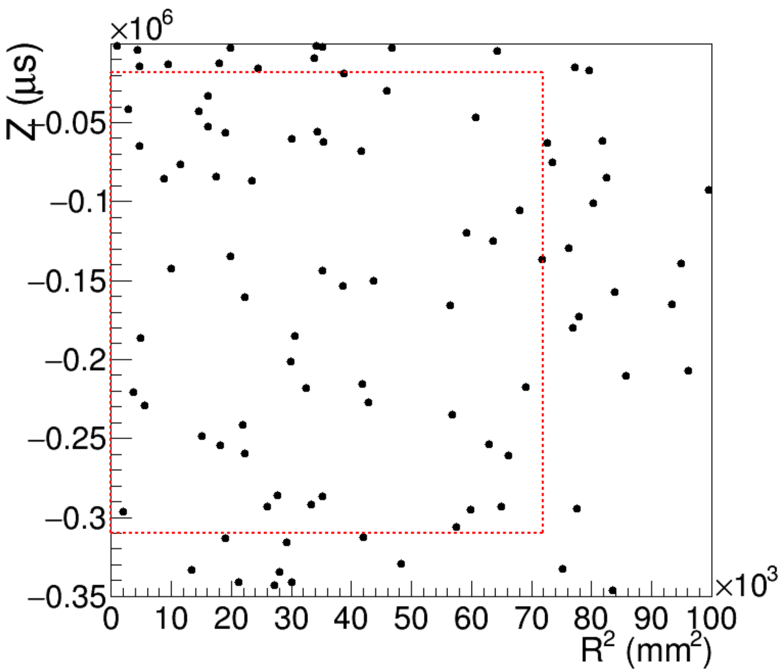


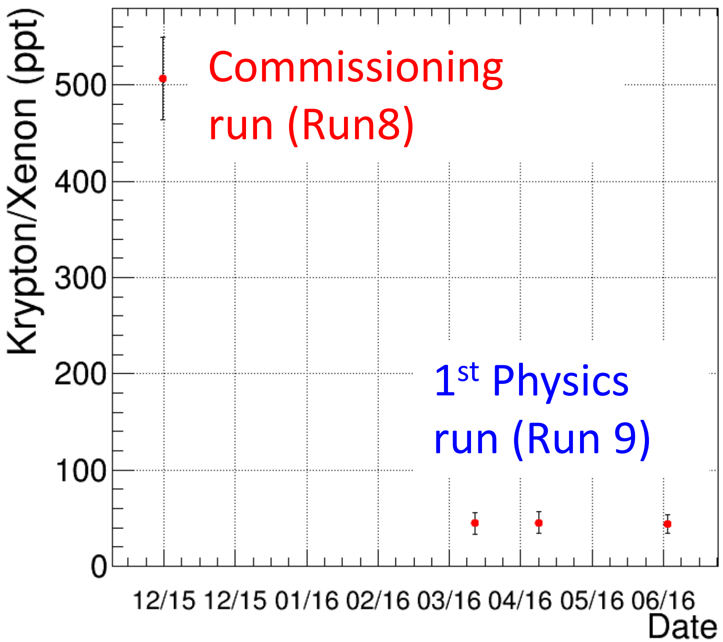
- ^{127}Xe evolution studied from the 408 keV (375+33.2 keV) peak
- ~0.4 mDRU for <10 KeV_{ee}, from low-energy fit

^{85}Kr

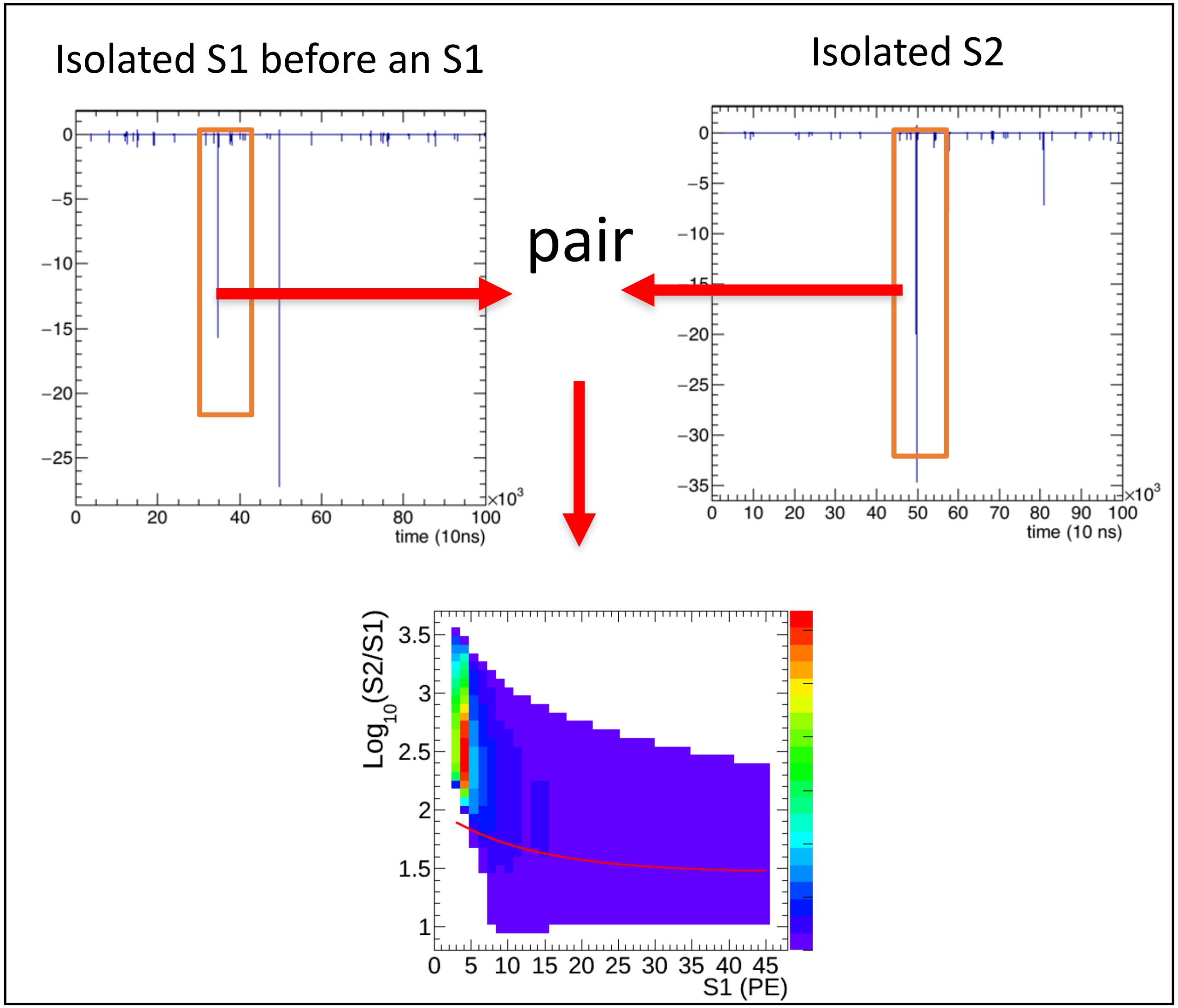
- Estimated from delayed β–γ coincidence analysis
- Uniformly distributed
- Significantly reduced after distillation





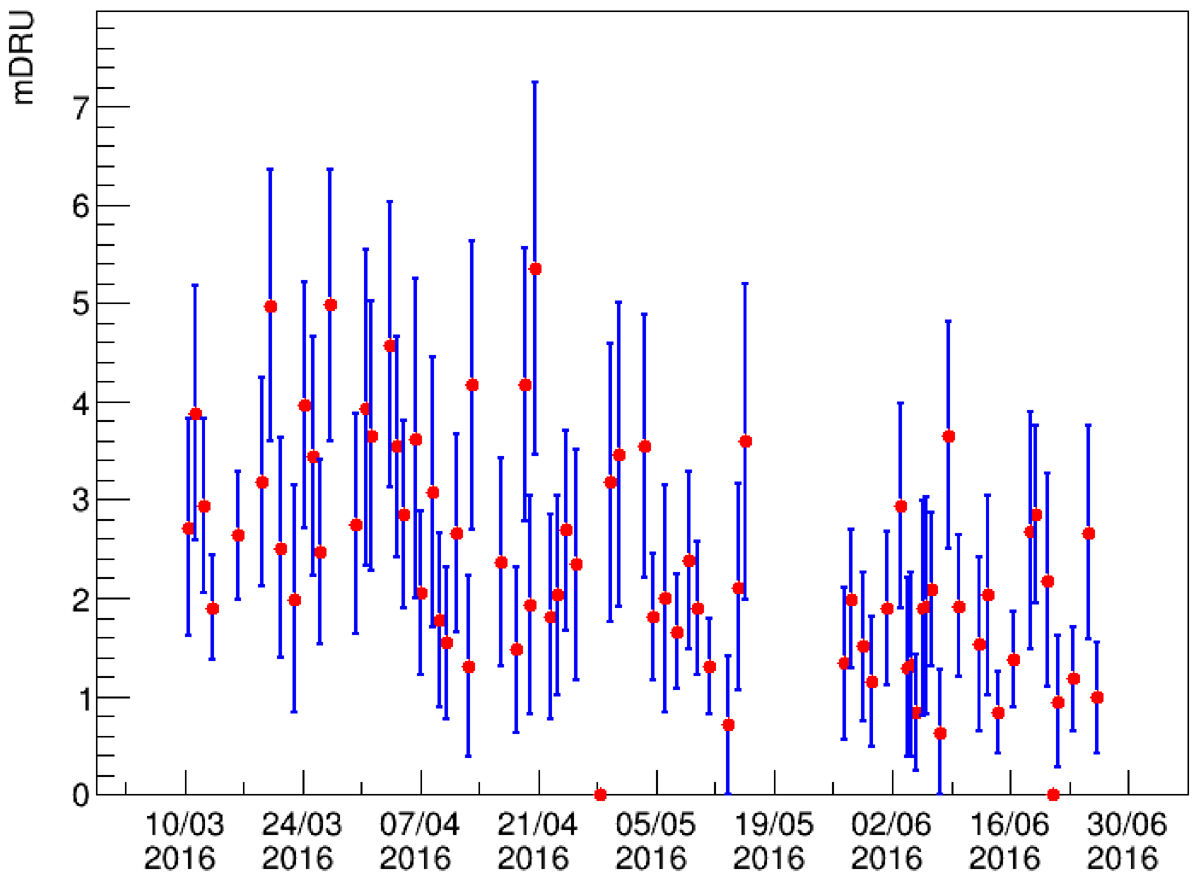


Accidental background



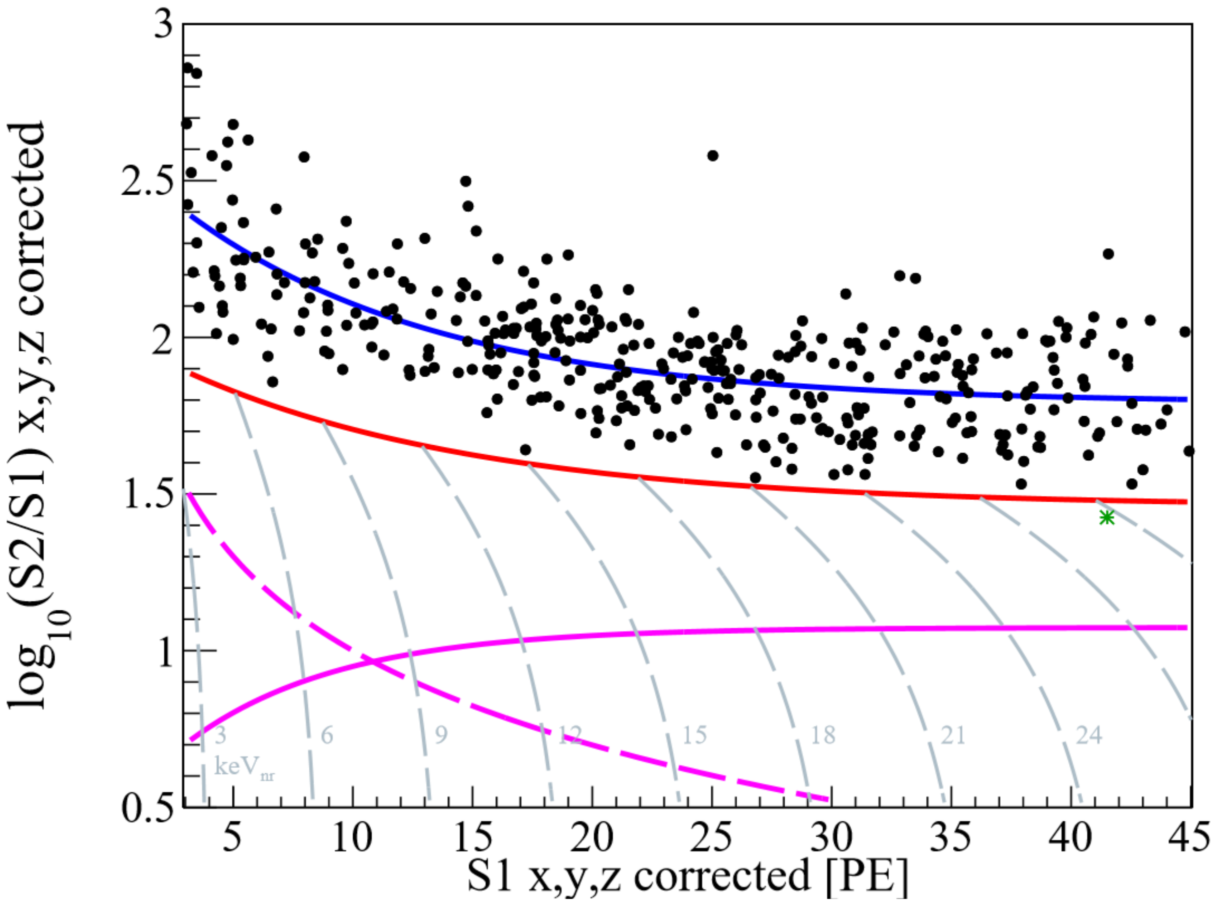
- Isolated S1 and S2 were selected and randomly paired to simulate accidental events
- Significantly reduced using a multivariate technique (BDT).
  - x3 rejection for background
  - 90% efficiency for signals

Low energy background in Run 9



- Events selected with energy <10 keV
- ~2 mDRU on average (15.3 mDRU in Run 8)
- Decrease over time due to ^{127}Xe decay

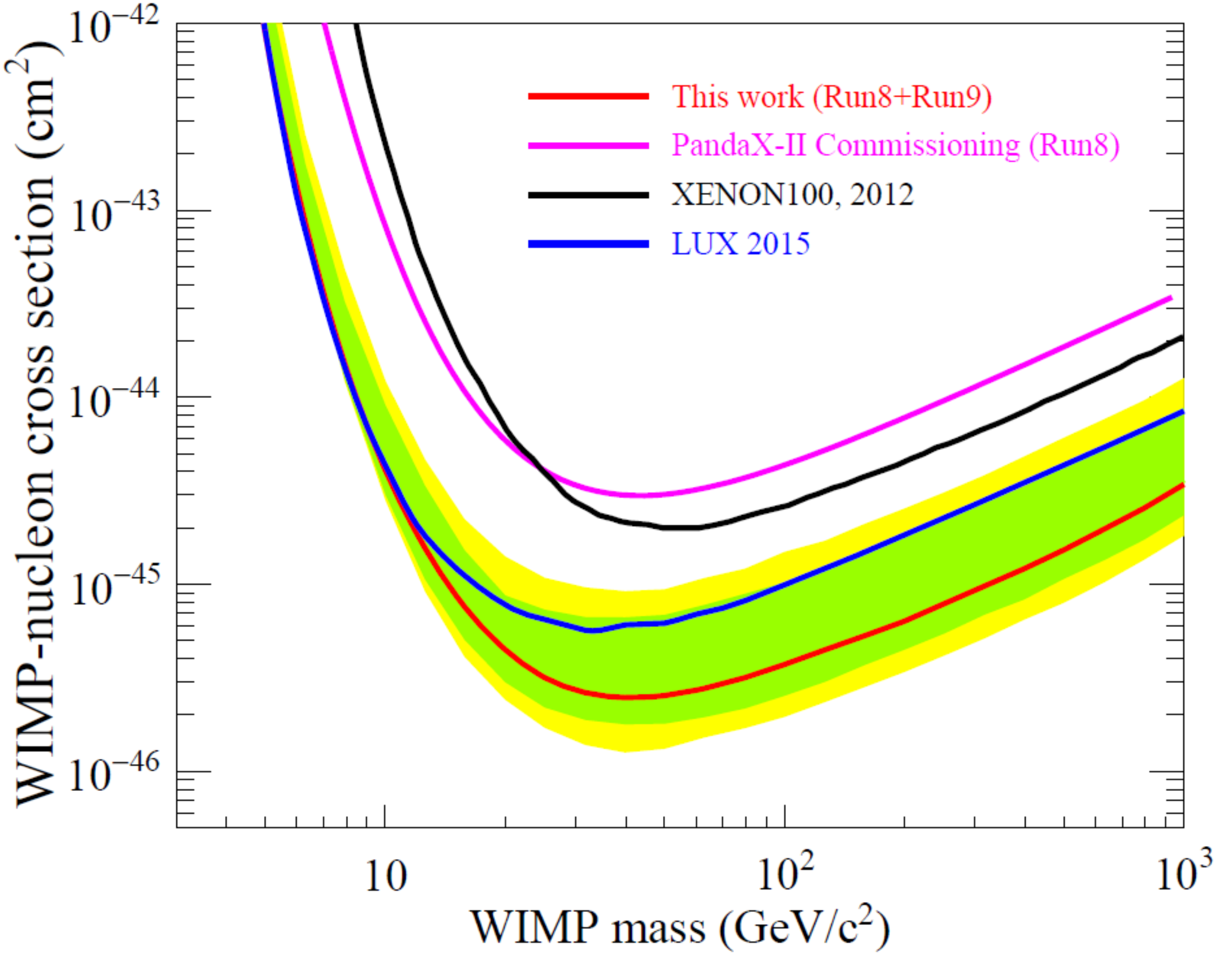
Final candidates



	ER	Accidental	Neutron	Total Expected	Total observed
Below NR median	1.2	0.84	0.35	2.4±0.7	1

Combined results

arXiv:1607.07400 Submitted to PRL



- Minimum upper limit for isoscalar SI elastic cross section reaches 2.5×10^{-46} cm^2 at 40 GeV.
- More than a factor of 2 improvement for high-mass DM compared to the LUX 2015 results

Summary and outlook

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

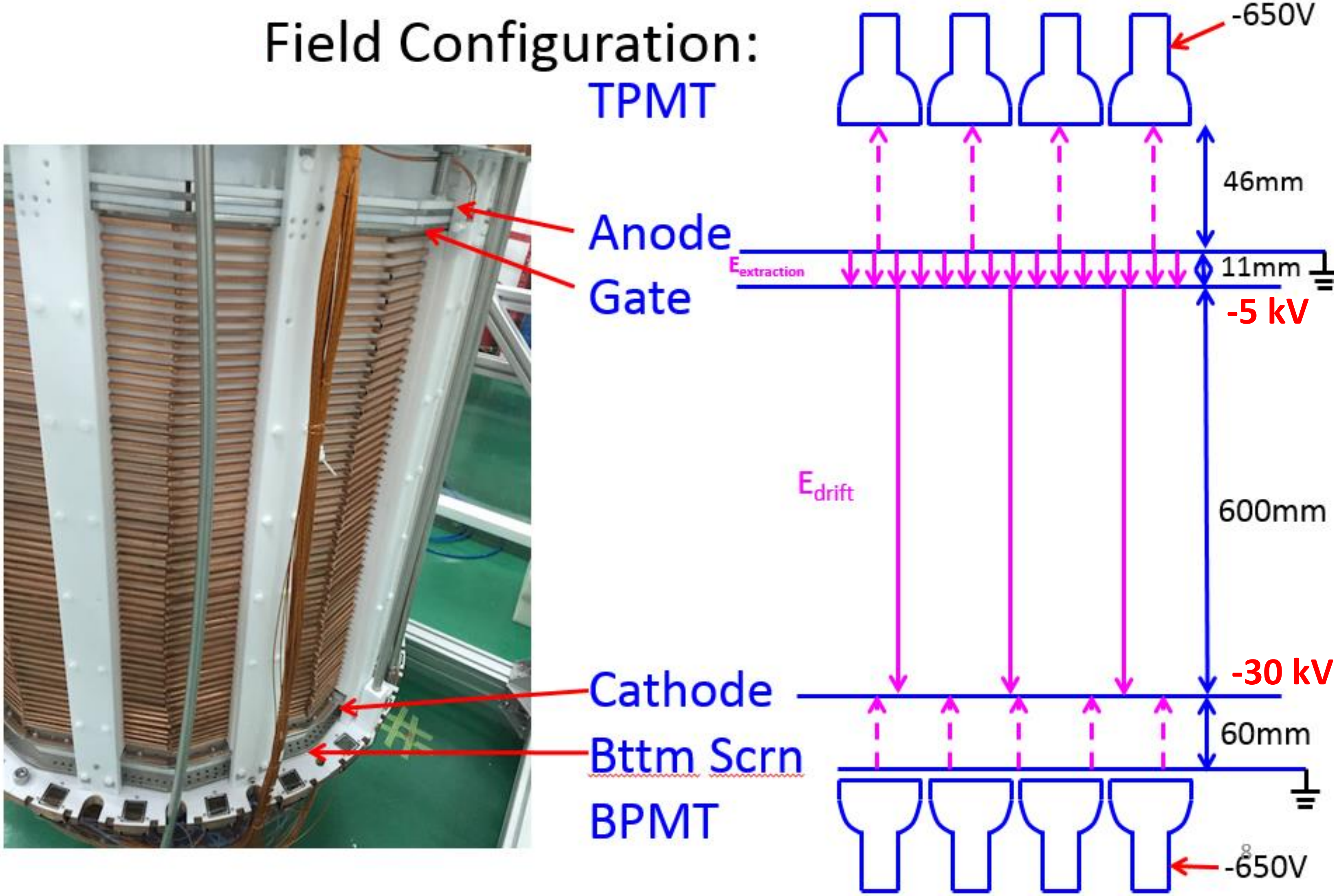
- 79.6 live-day of dark matter data with much suppressed background (15⇒2 mDRU)
- In combination with commissioning run (19.1 day), ~33,000 kg-day exposure in total. No DM signals are observed
- The WIMP-nucleon elastic scattering cross sections are constrained to 2.5×10^{-46} cm^2 at 40 GeV DM mass.
- Continue PandaX-II data taking till end of 2017. In preparation for PandaX-xT!

THANK YOU！

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	Now have tritium calibration
NR calibration	Statistics x6
Position reconstruction	Improved position reconstruction
Background	Accidental background suppressed more than x3 using BDT

Configuration of fields

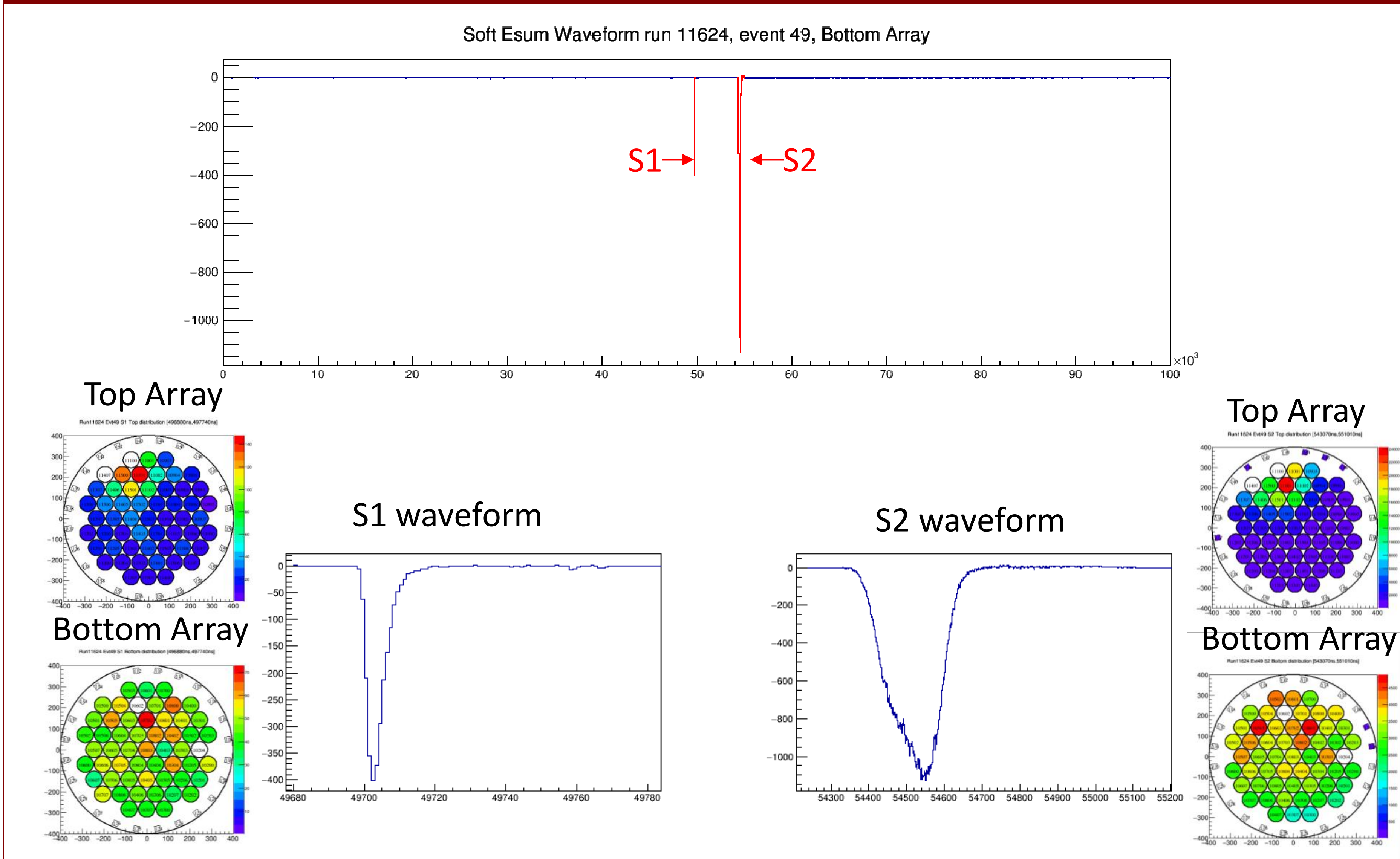


Data sets with different fields

Condition	live time (day)	E_{drift} (V/cm)	E_{extract} (kV/cm)
1	7.76	397.3	4.56
2	6.82	394.3	4.86
3	1.17	391.9	5.01
4	63.85	399.3	4.56

Mar. 9-Jun 30, in total 79.6 live-day of under slightly different conditions (optimization of drift and extraction fields).

Typical single scatter waveform



Improved position reconstruction

- Maximum Likelihood $$-\ln \tilde{L}(\vec{r}) = -\sum_i \frac{n_i}{\mathrm{qS2T}} \ln \frac{\eta_i(\vec{r})}{P(\vec{r})}$$
- Photon Acceptance Function(PAF) of Each PMT
- The iteration to determine the PAFs

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

$$\vec{r}^{(0)} = \vec{r}_{\mathrm{CoG}}$$

$$\downarrow$$

$$\eta_i^{(1)} \rightarrow \vec{r}^{(1)}$$

$$\swarrow$$

$$\eta_i^{(2)} \rightarrow \vec{r}^{(2)}$$

$$\vdots$$

Converge

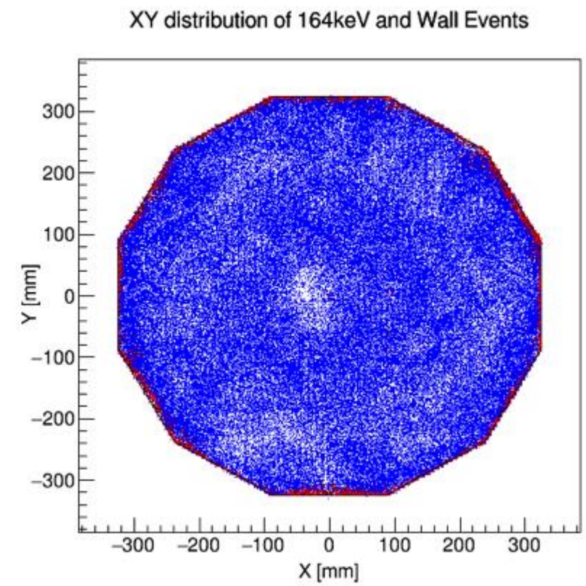
V. N. Solovov *et al*, *IEEE* doi: 10.1109/TNS.2012.2221742

- Big 3” PMT
- Big separations between PMTs
- Big gap between outermost PMTs and the physical boundary of TPC wall

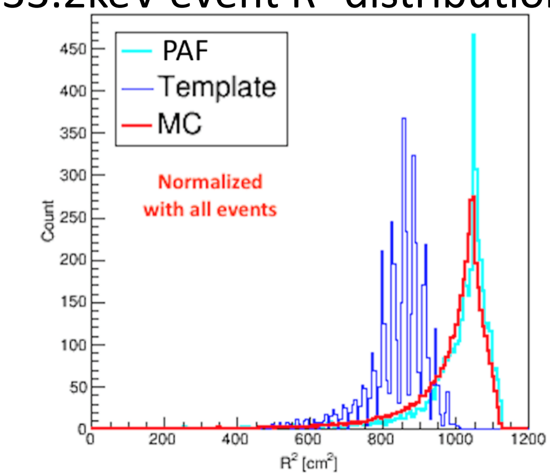
Have to abandon isotropic assumption of PAF of outside PMTs

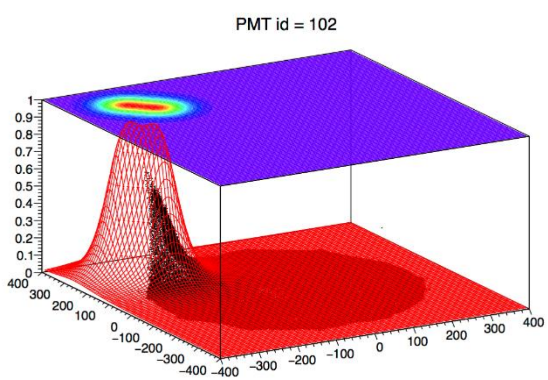
Reflection Component of the PAF

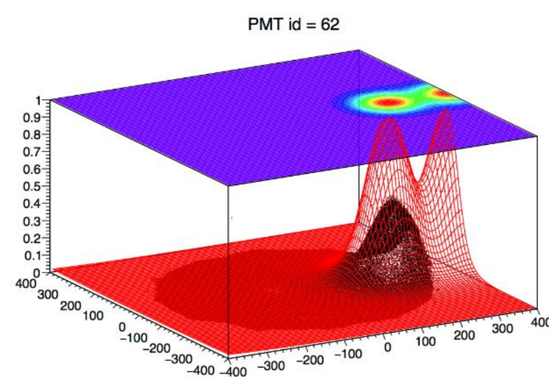
- For ^{210}Po events close to the top to be reconstructed onto the wall, reflection components were added into PAFs for peripheral PMTs



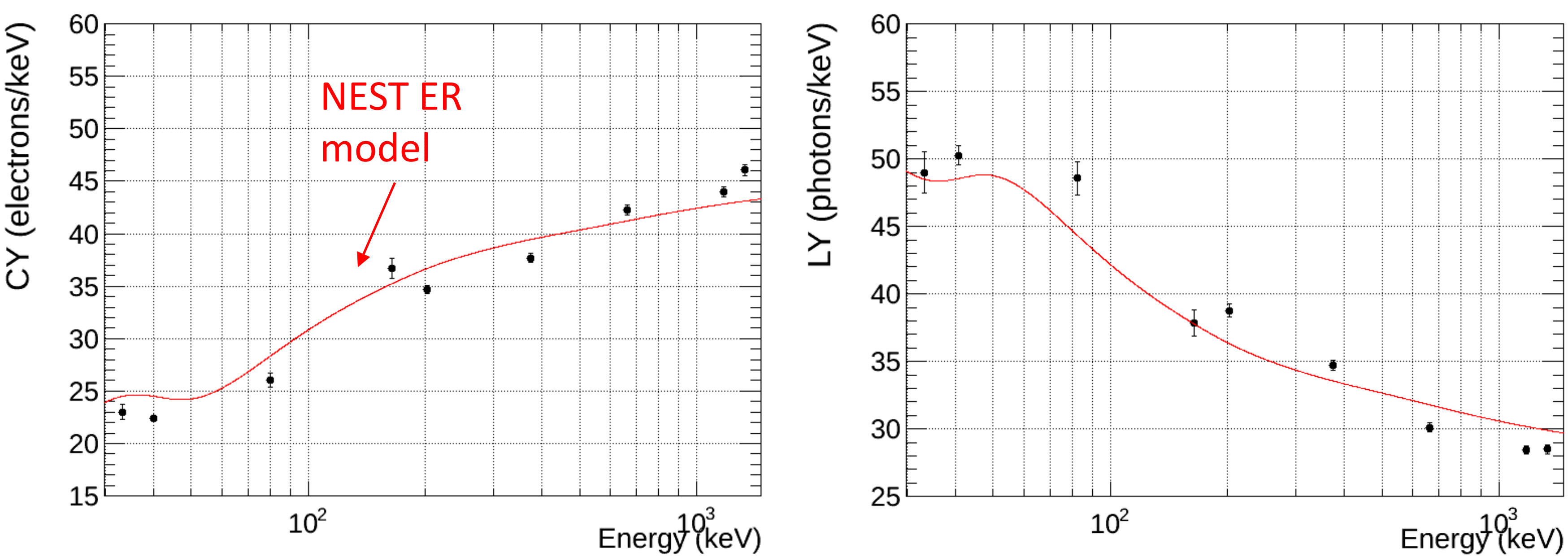
33.2keV event R^2 distribution





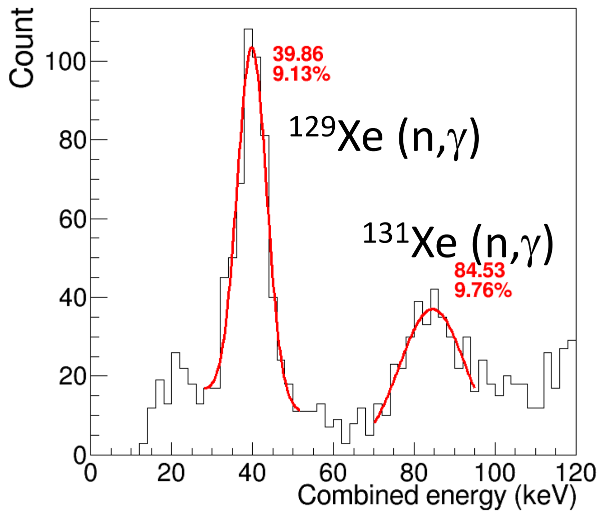


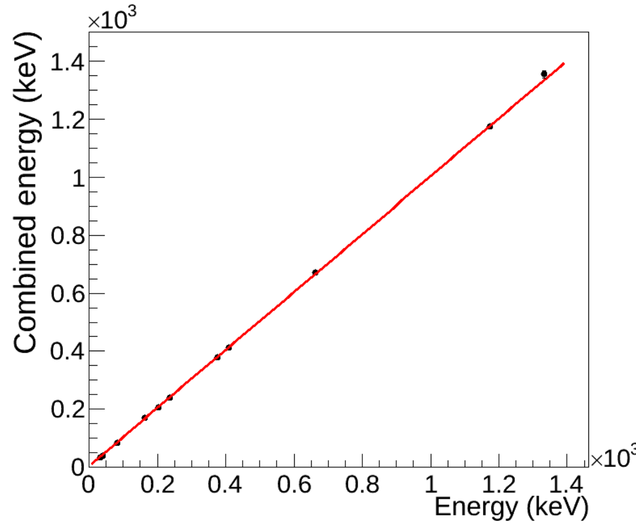
Comparison with NEST-0.99



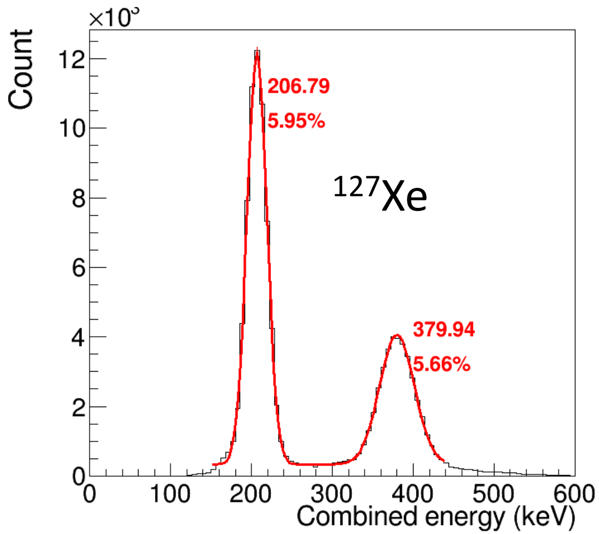
- Reasonable agreement observed between NEST ER model and values extracted from our data

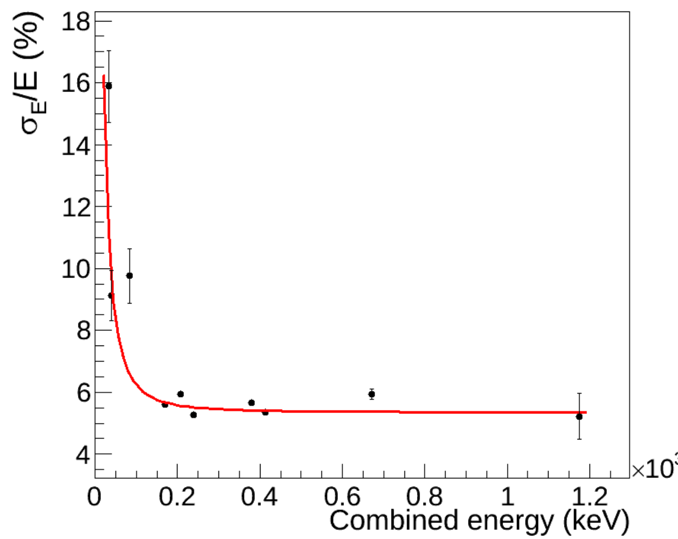
Energy nonlinearity and resolution





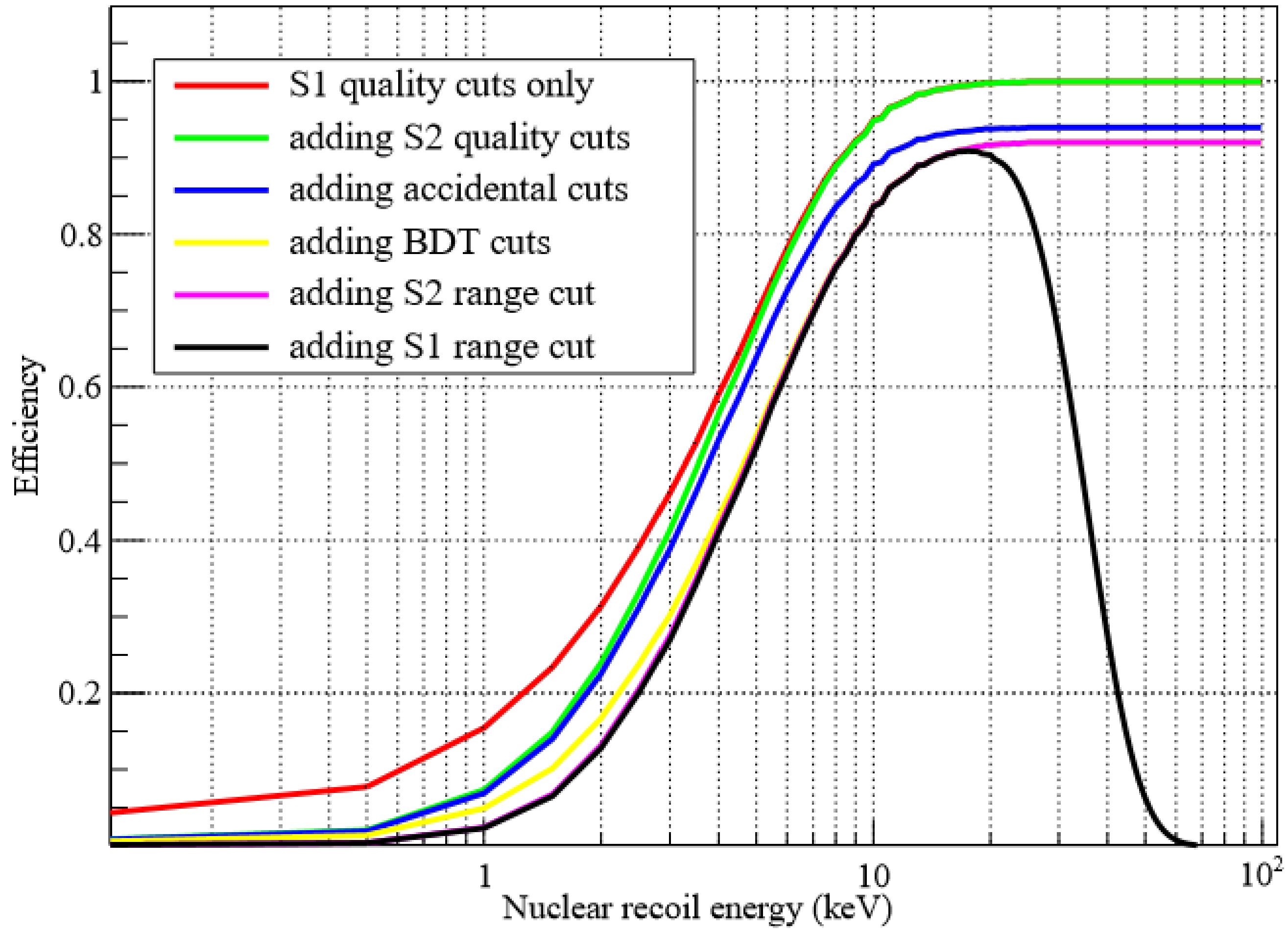
< 2% nonlinearity achieved for [33, 1332] keV





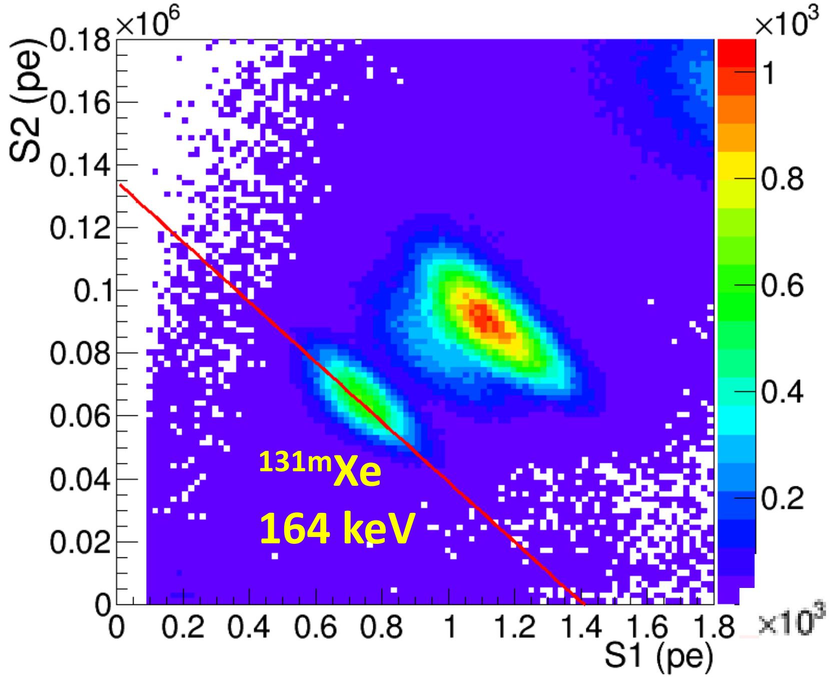
Resolution approaching 5% @ high energy

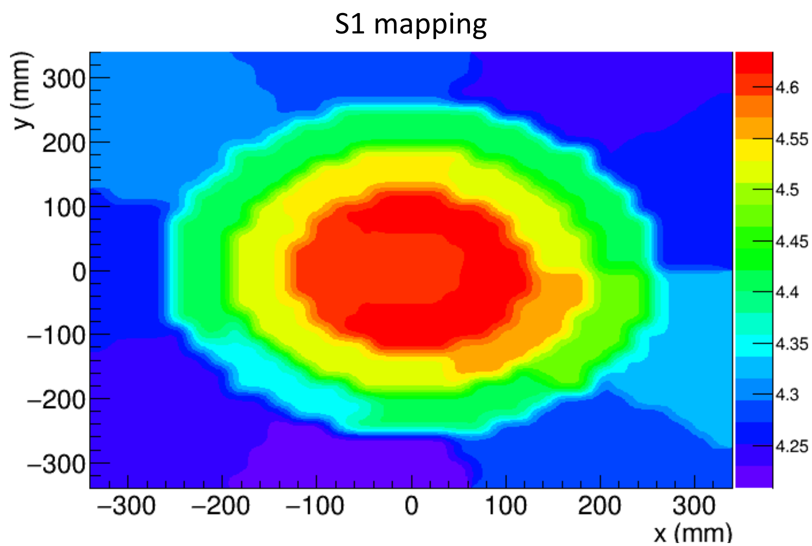
NR efficiency

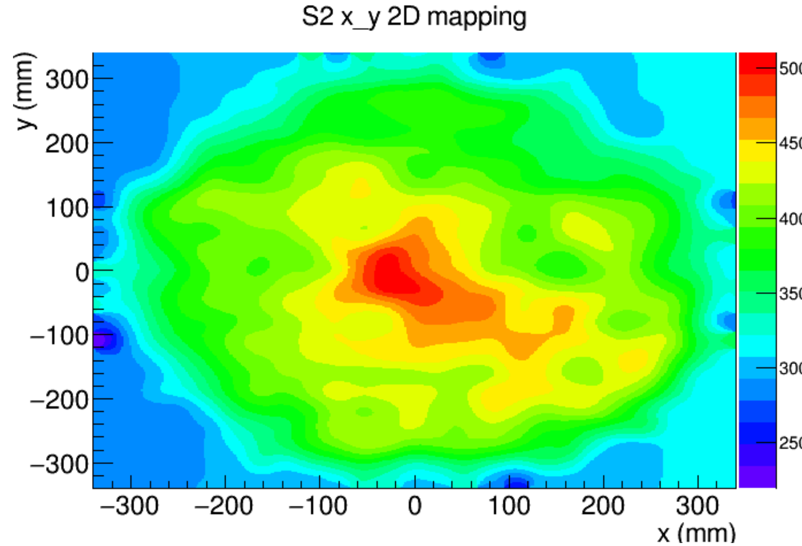


NR enegy >1.1 kev is imposed for DM simulation

Uniformity correction for S1 and S2





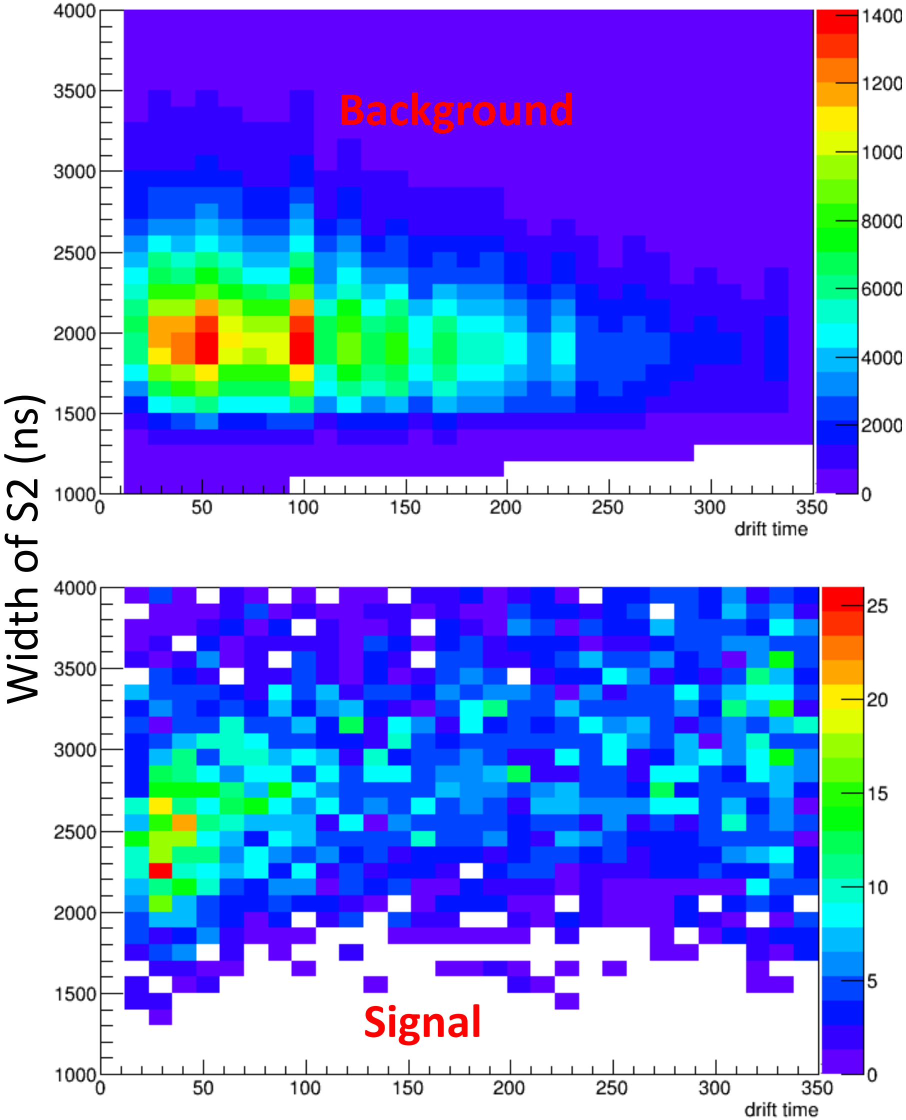


- LY: PE/keV @ 164 keV vs. horizontal position
- CY: PE/keV @ 164 keV vs horizontal position
- Vertical non-uniformity corrected by electron lifetime

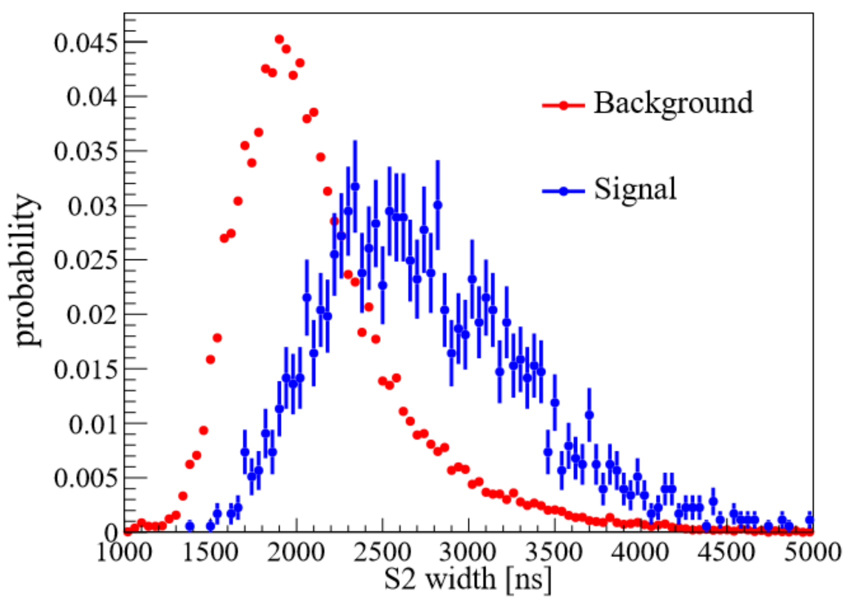
Boosted decision tree

- Seek additional suppression of accidental background using a multivariate approach (BDT)
- Training and test samples: randomly paired coincident events (background) and AmBe low energy events (signal)
- Variables:
  - S2 pulse shape asymmtry
  - S2 width
  - S2 charge top-bottom ratio
  - S1 charge top-bottom asymmtry
  - etc …

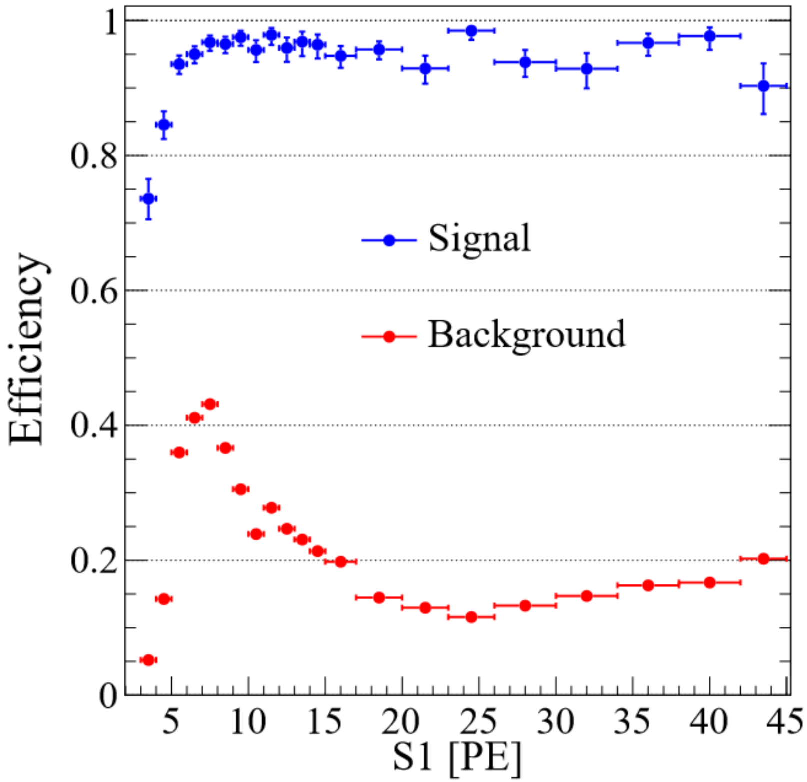
Example: S2 width vs drift time

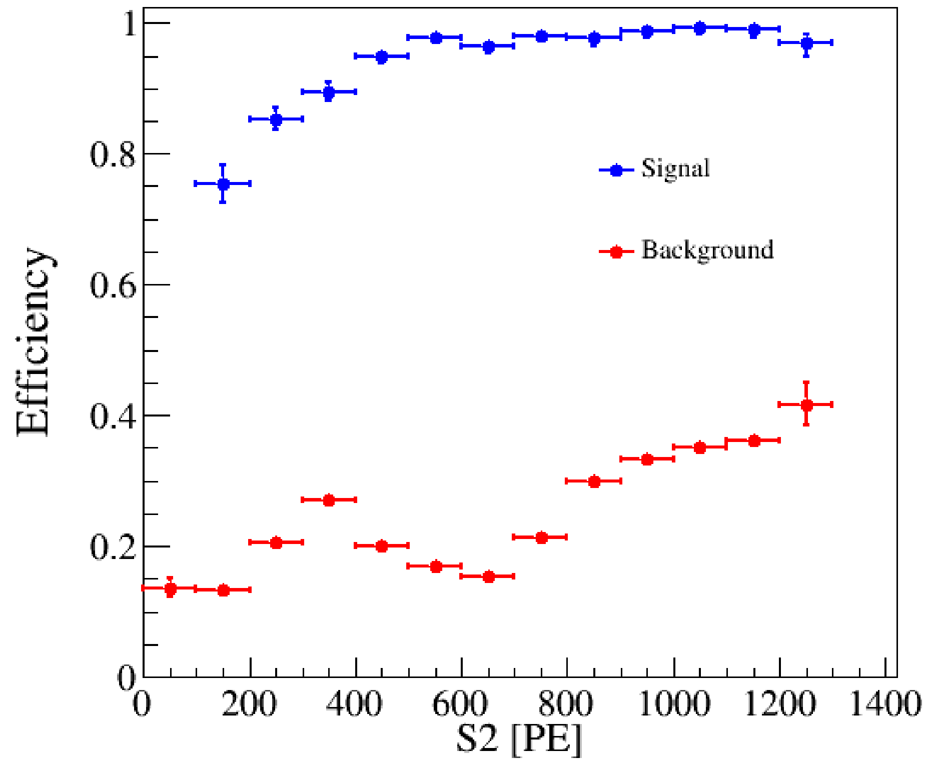


- Accidental S1 and S2 lack intrinsic correlations
- Single S2 likely originated from the gate grid (small width)



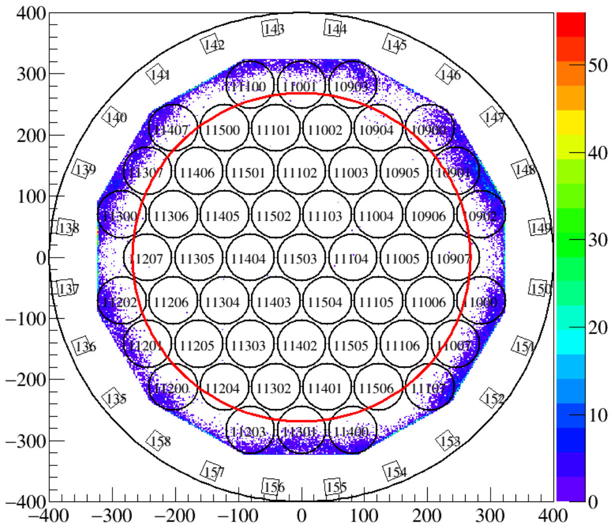
BDT cuts and efficiency

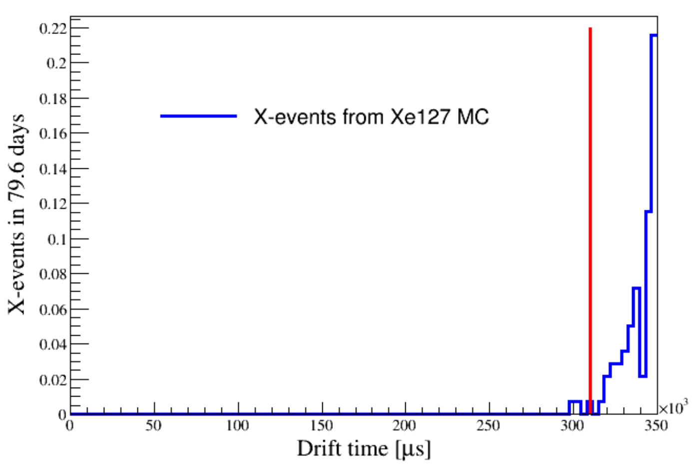




BDT removes the accidental events by more than a factor of 3, while maintaining an average 90% efficiency

Final selection cuts

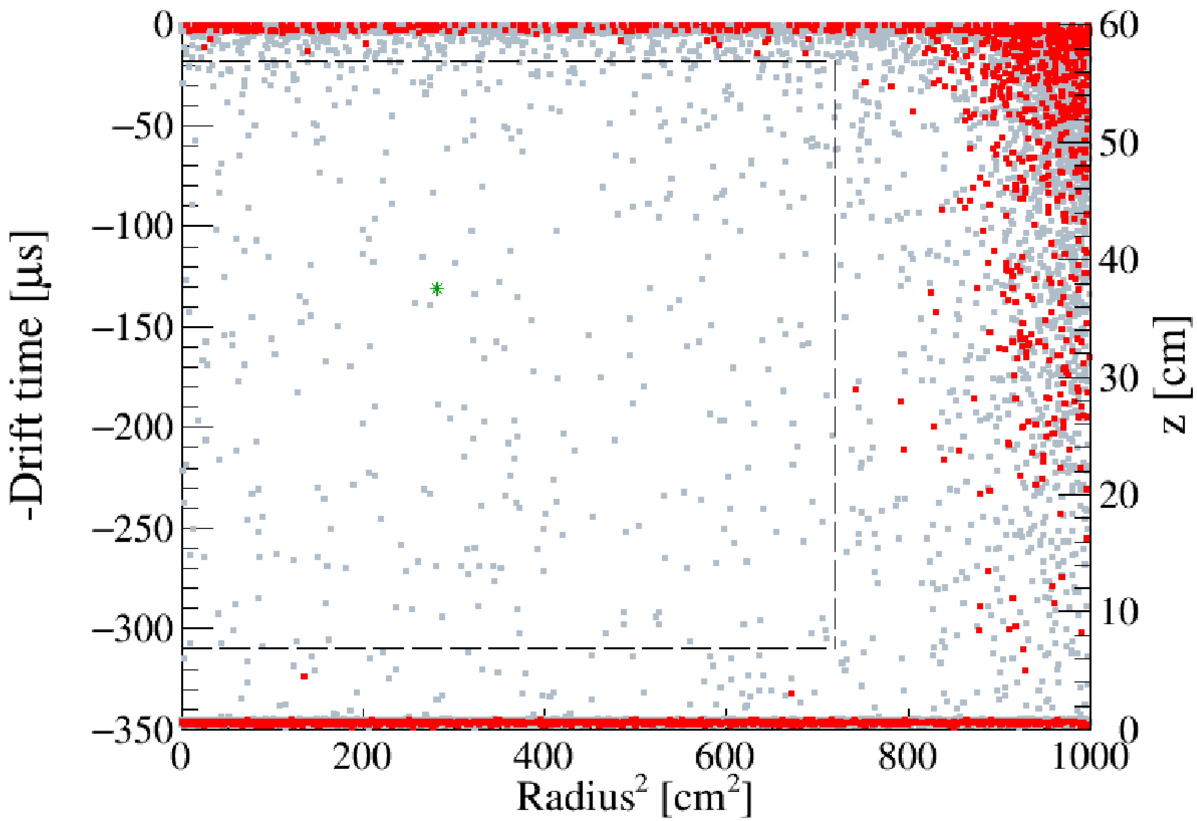




- Horizontal cut determined by distribution of events with S1 between [45,200] PE and suppressed S2
- Vertical cut: 18<drift time < 310 μs, Lower cut consistent with the run8 analysis; Tighter upper cut is to suppress below-cathode gamma deposit(gamma-X events) from ^{127}Xe
- FV in Run 9 with 328.9 kg
- S1 cut:[3,45]PE & S2 cut[100raw, 10000] PE: consistent with previous analysis

Final candidates

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



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

Summary of ER backgrounds

Item	Run 8 (mDRU)	Run 9 (mDRU)
Total	12.0	1.95
^{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

TABLE II: Summary of ER backgrounds from different components in Runs 8 and 9. The fractional uncertainties of ^{85}Kr, ^{127}Xe, ^{222}Rn and ^{220}Rn in Run 9 are 14%, 25%, 54%, and 55%, respectively. The fractional uncertainty due to detector materials is estimated to be 50% based on the systematic uncertainty of the absolute efficiency of the gamma counting station. Different from Ref. [5], values in the table are now folded with detection efficiency.