First Results from PandaX-4T

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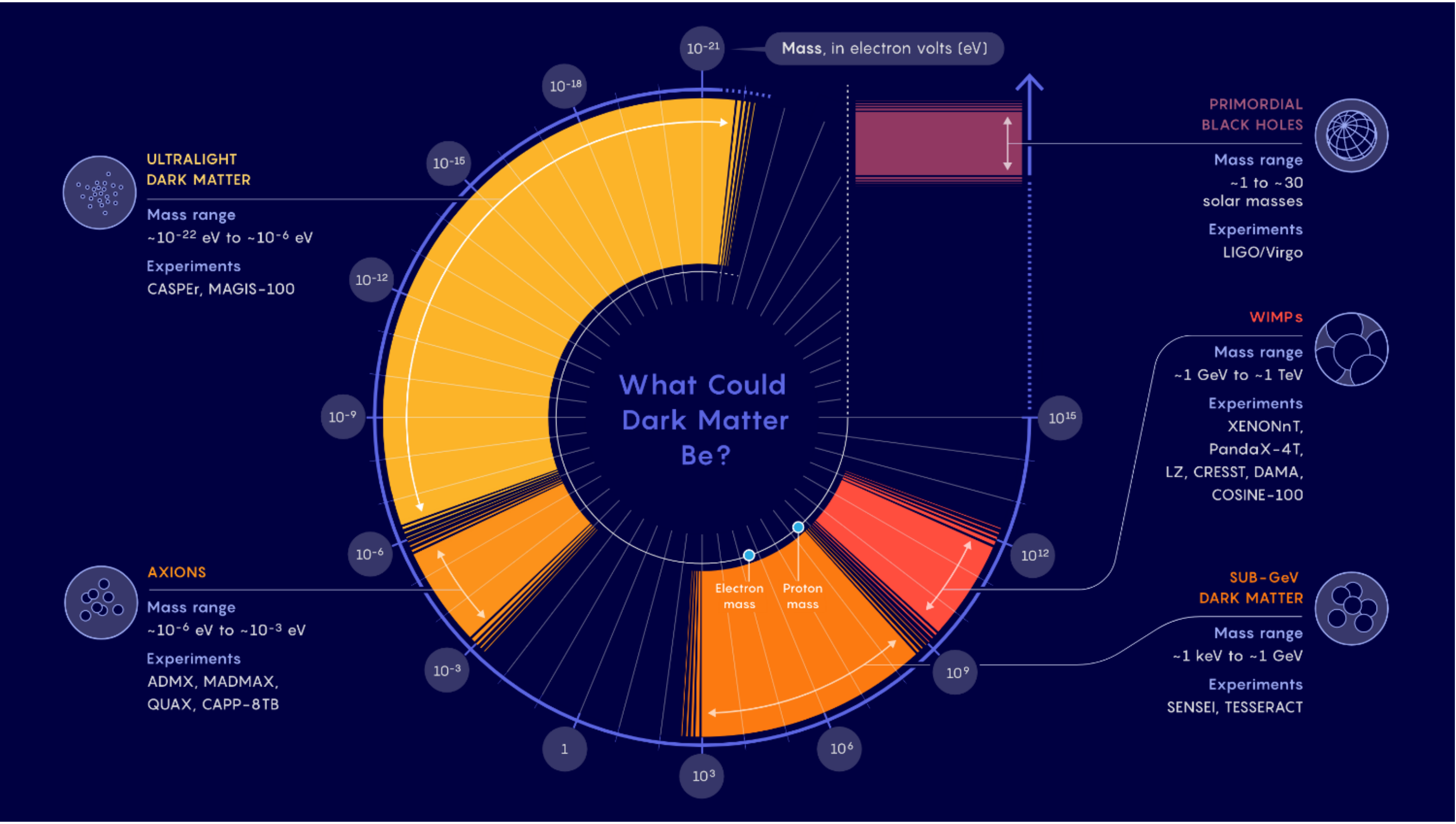
On behalf of the PandaX Collaboration

PANDAX
PARTICLE AND ASTROPHYSICAL XENON TPC

Dark matter: “too” many possibilities

PandaX



Samuel Velasco/Quanta Magazine

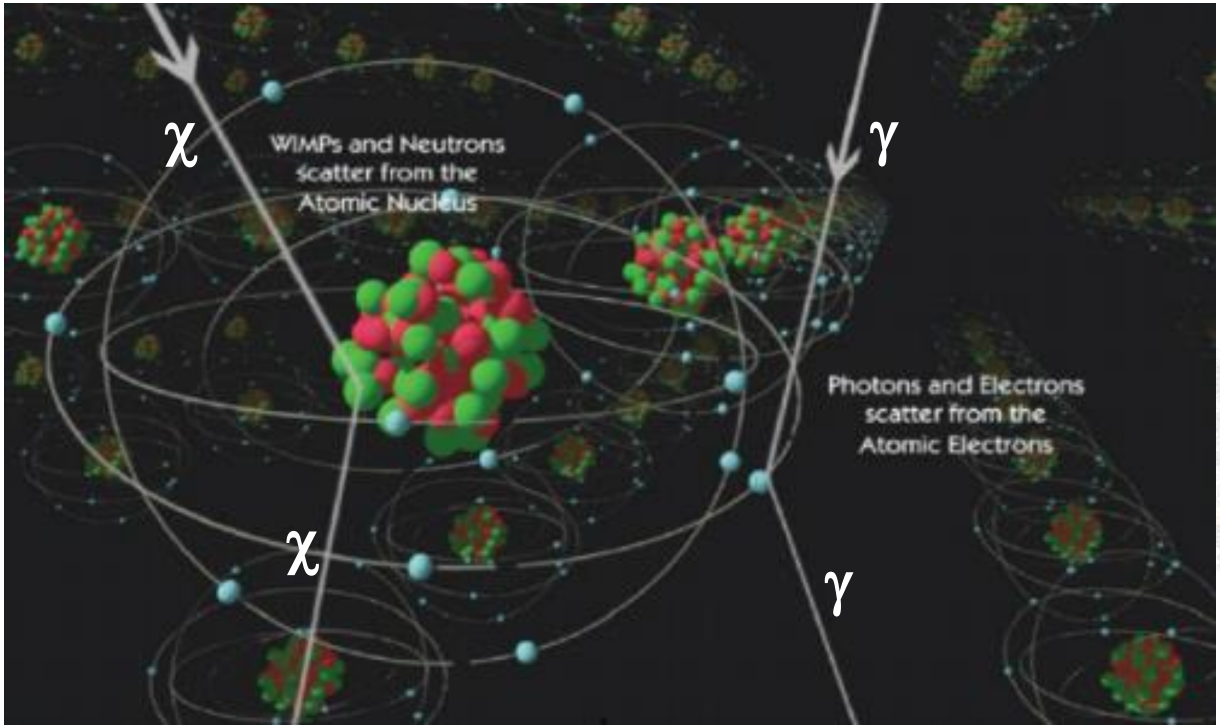
"Certain" dark matter candidates

PHYSICAL REVIEW D VOLUME 31, NUMBER 12 15 JUNE 1985

Detectability of certain dark-matter candidates

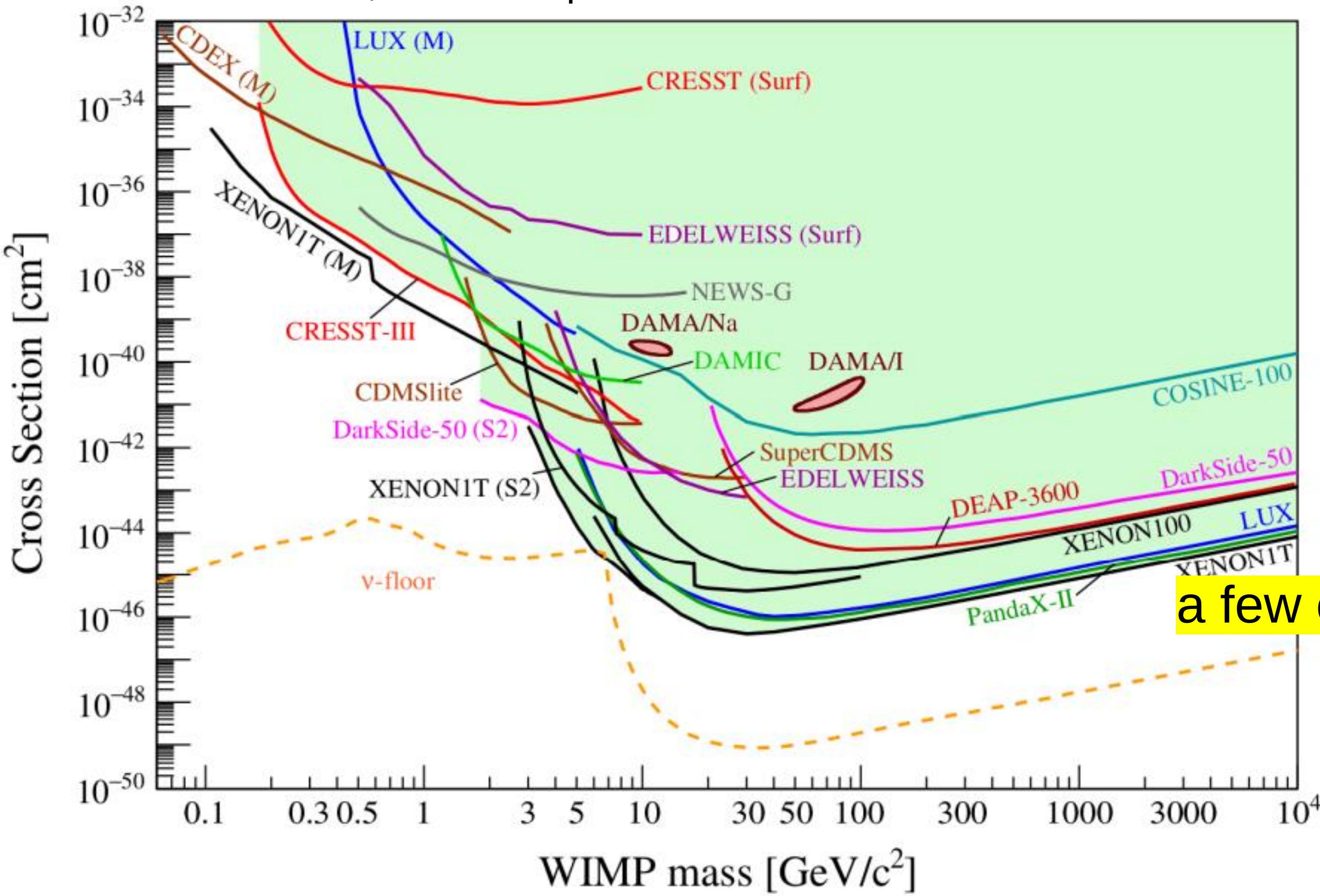
Mark W. Goodman and Edward Witten
Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08544
(Received 7 January 1985)

We consider the possibility that the neutral-current neutrino detector recently proposed by Drukier and Stodolsky could be used to detect some possible candidates for the dark matter in galactic halos. This may be feasible if the galactic halos are made of particles with coherent weak interactions and masses $1-10^6$ GeV; particles with spin-dependent interactions of typical weak strength and masses $1-10^2$ GeV; or strongly interacting particles of masses $1-10^{13}$ GeV.



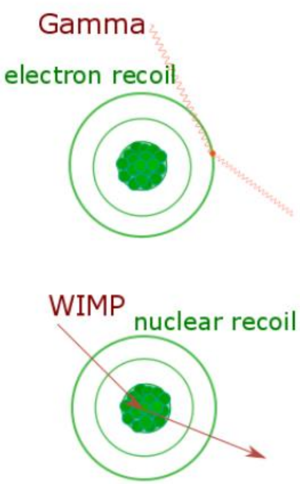
WIMP: hide and seek

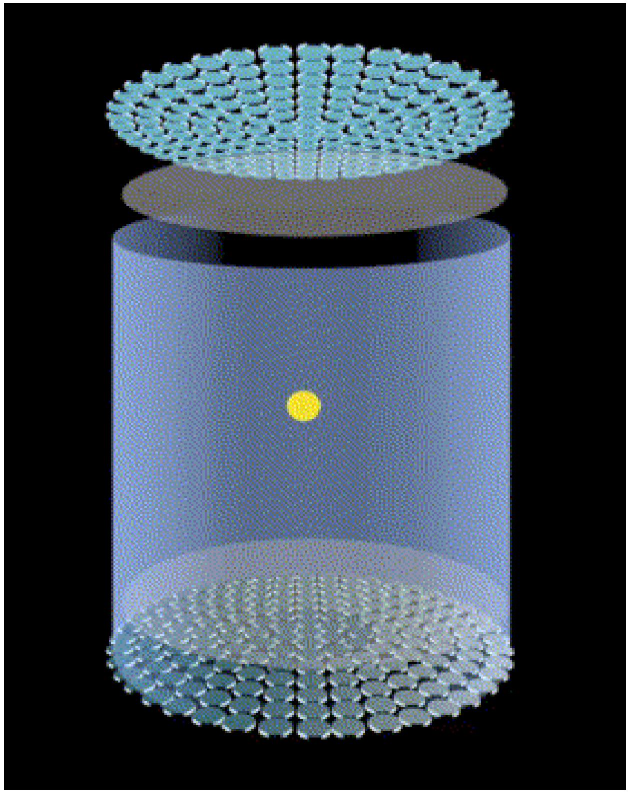
2104.07634, APPEC report on dark matter direct detection

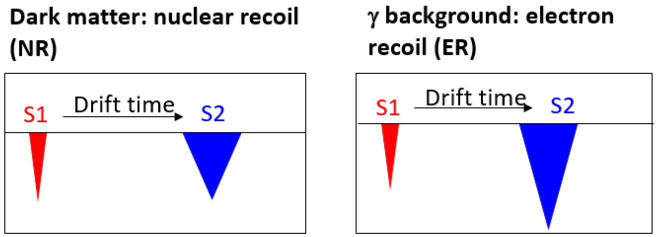


a few evts/t/y

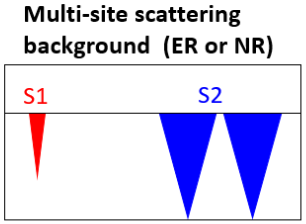
Dual phase xenon TPC







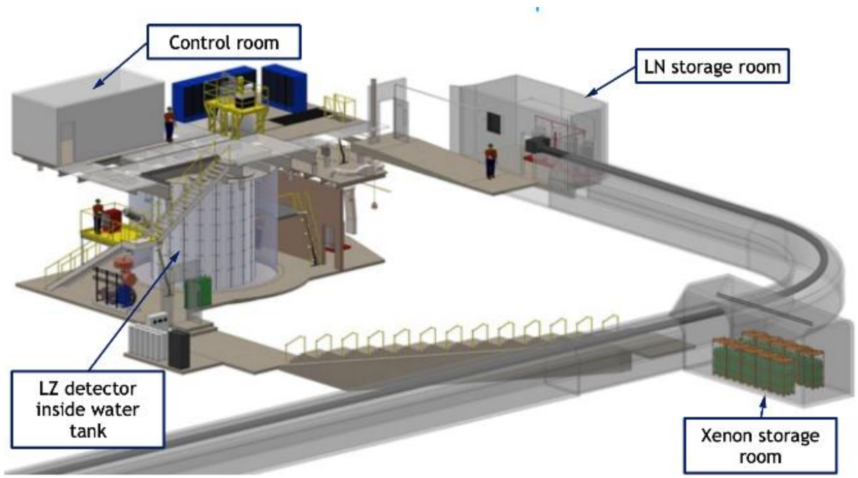
$(S2/S1)_{NR} << (S2/S1)_{ER}$

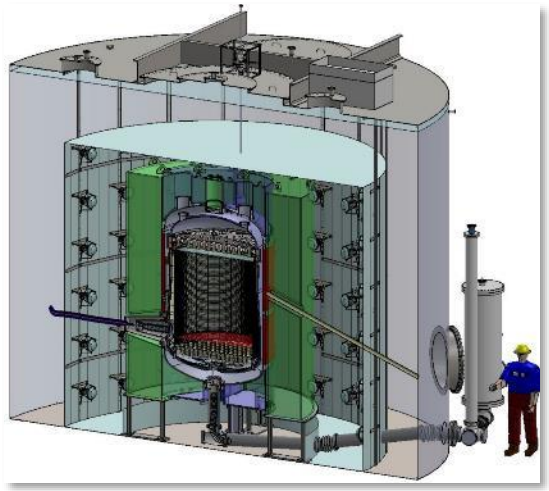


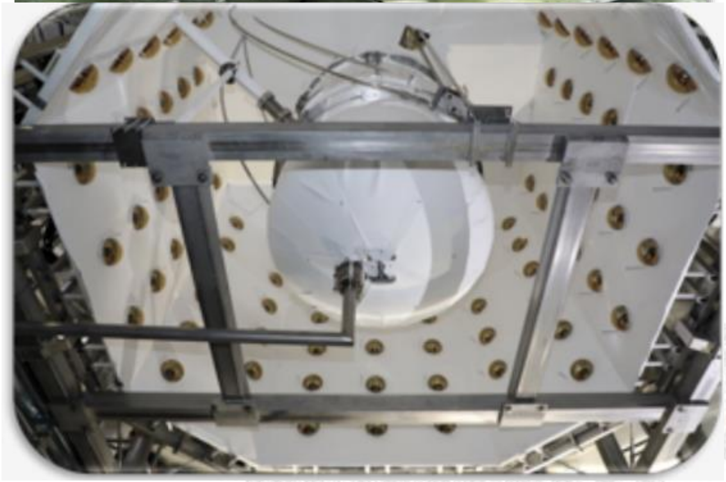
Detector capability:

- ❑ Large monolithic target
- ❑ 3D reconstruction and fiducialization
- ❑ Good ER/NR rejection
- ❑ Calorimeter capable of seeing a couple of photons/electrons

Multi-ton LXe Experiments



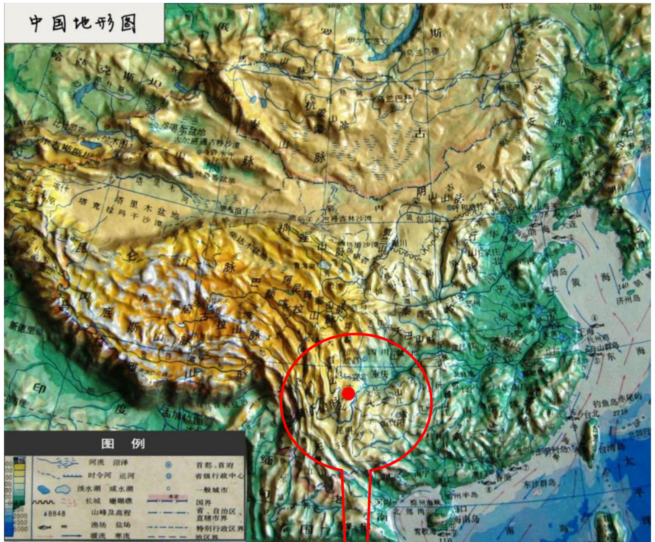


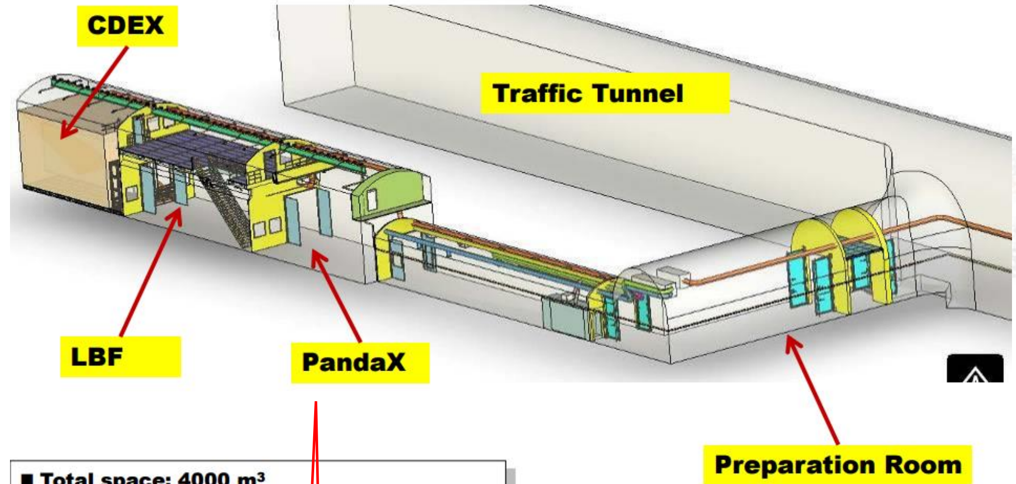


LZ, 7 ton,
Sanford Lab, US

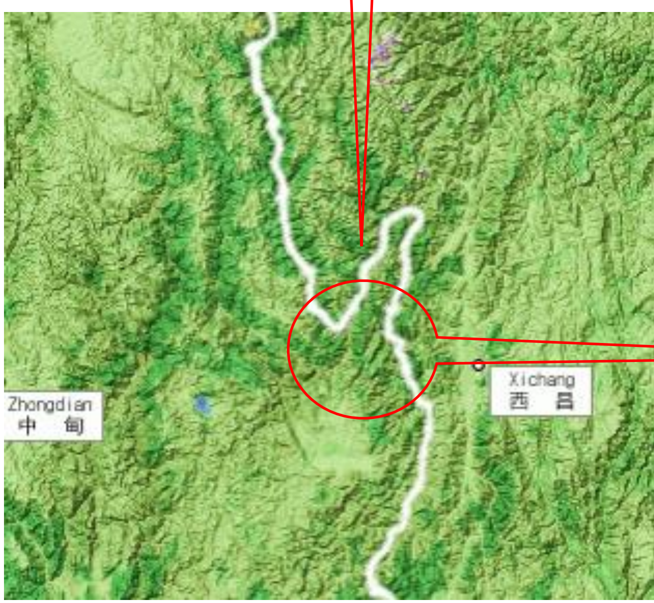
XENONnT, 6 ton
LNGS, Italy

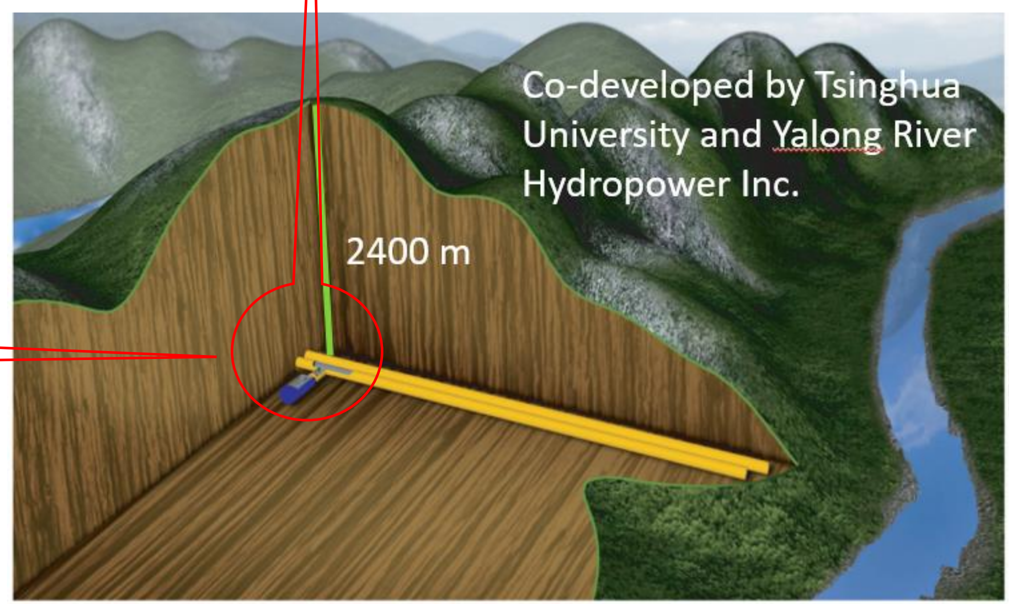
China Jinping underground Laboratory





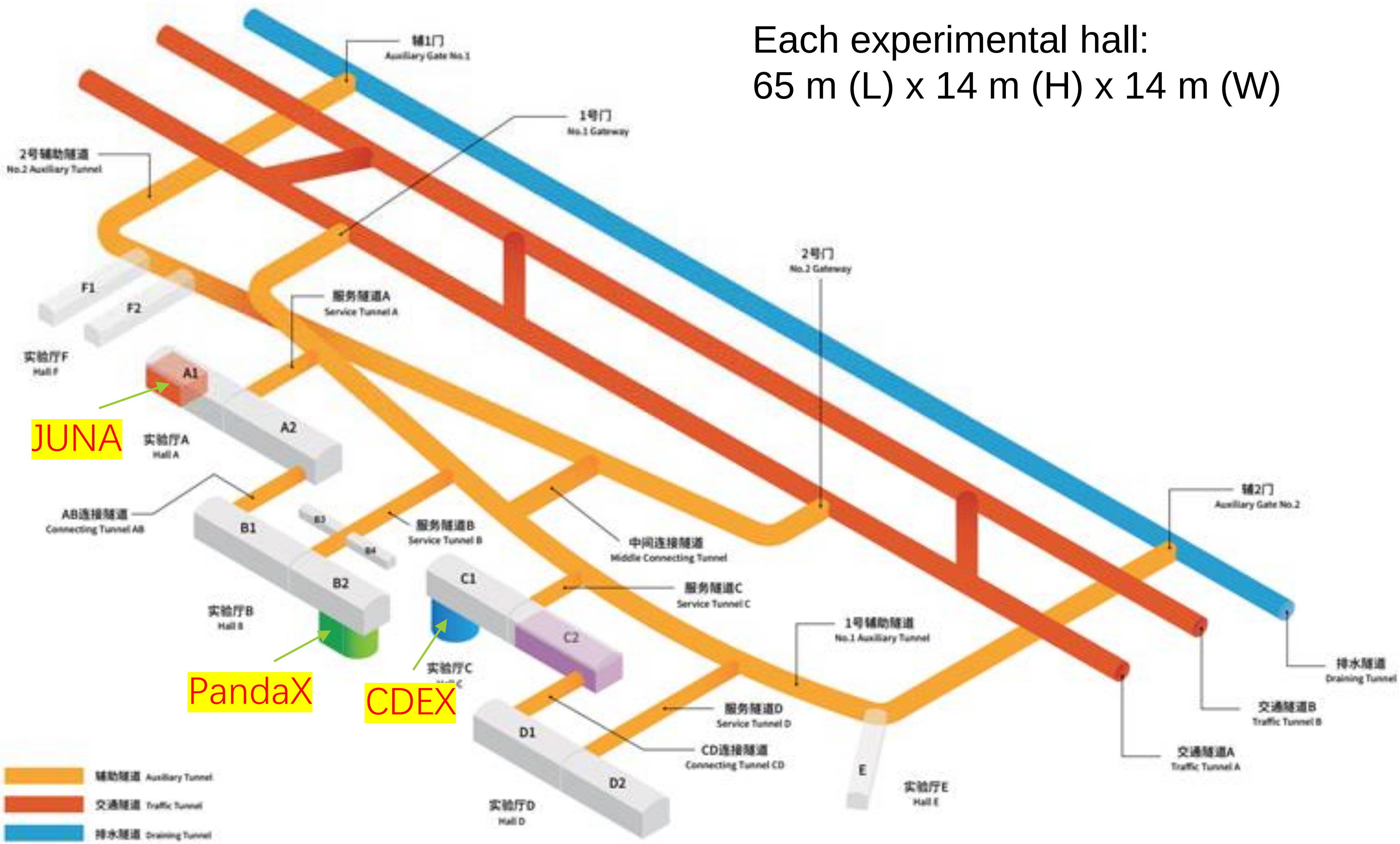
- Total space: 4000 m³
- Main Lab Space: 6.5(W) x 6.5(H) x 42(L)





CJPL-II

Each experimental hall:
65 m (L) x 14 m (H) x 14 m (W)



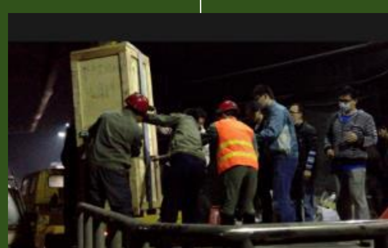
PandaX Experiments

Particle and Astrophysical Xenon Experiments

Collaboration formed

2009.3

2012.7



PandaX-I apparatus moved to Jinping

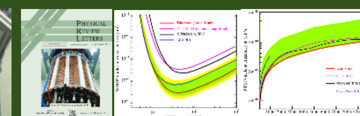
PandaX-I started

2014.3

2014.5-10

PandaX-I, 120 kg operation

PandaX-II, 580 kg operation



2016.7 -2019.7

2019.8-

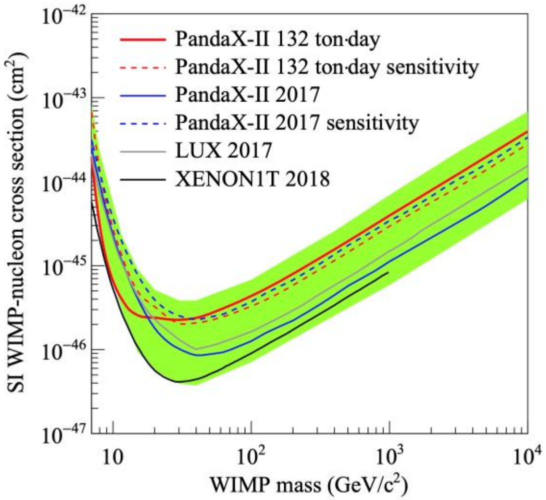
PandaX-4T moved to CJPL-II

PandaX Collaboration

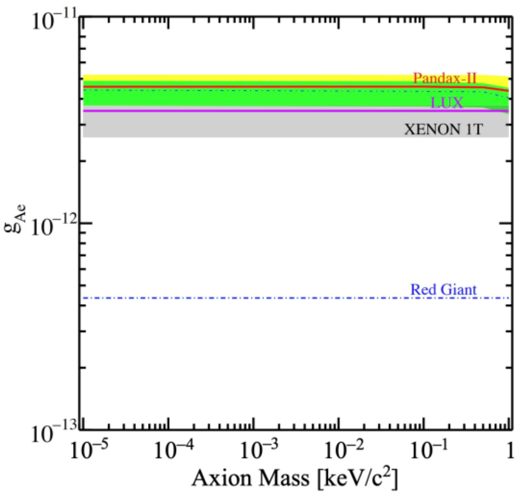
SINAP CNNC 雅砻江水电

Recent PandaX-II results

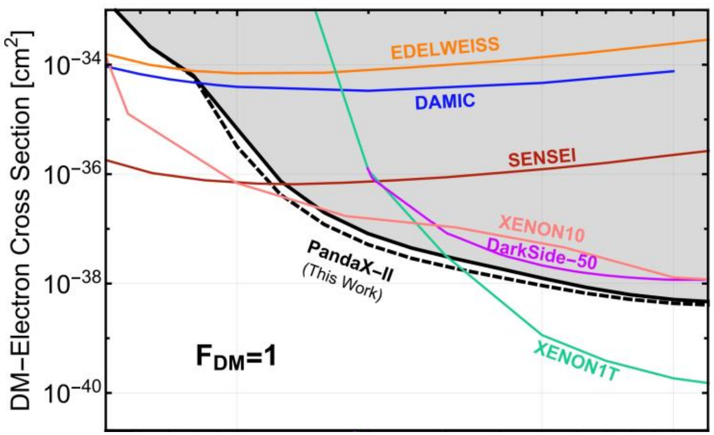
Finished total 132 ton-day exposure in 2019



Chin. Phys. C 44 125001

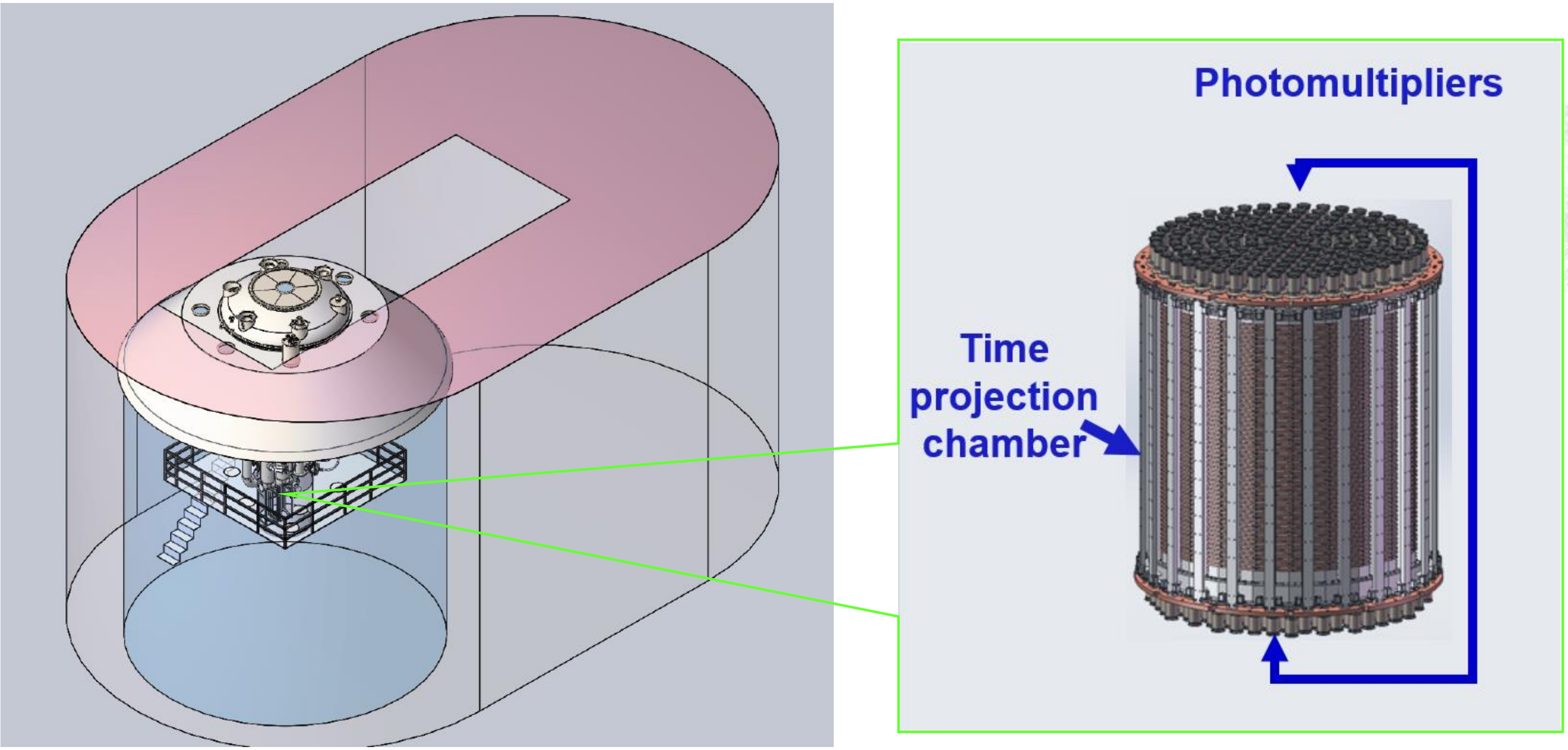


Chin. Phys. Lett. 38 011301



Phys. Rev. Lett. 126, 211803

PandaX-4T overview



- Ultrapure water shield: 13 m (H) x 10 m (D) ~ 900 m^3
- TPC: 1.2 m (H) x 1.2 m (D), 3.7-tonne of LXe
- 3-in PMTs: 169 top/199 bottom

PandaX-4T major milestones

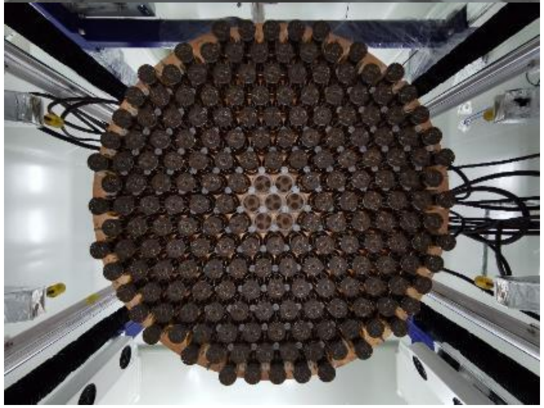
- Apr. 2, 2018, permission from CJPL management to start construction in B2 hall
- Aug. 19, 2019, infrastructure completed, detector installation in CJPL-II started
- Mar 6, 2020, offline distillation of xenon completed
- May 28, 2020, installation completed
- Nov. 28, 2020 – Apr. 16, 2021, commissioning run

Infrastructure construction photos

Infrastructure construction photos

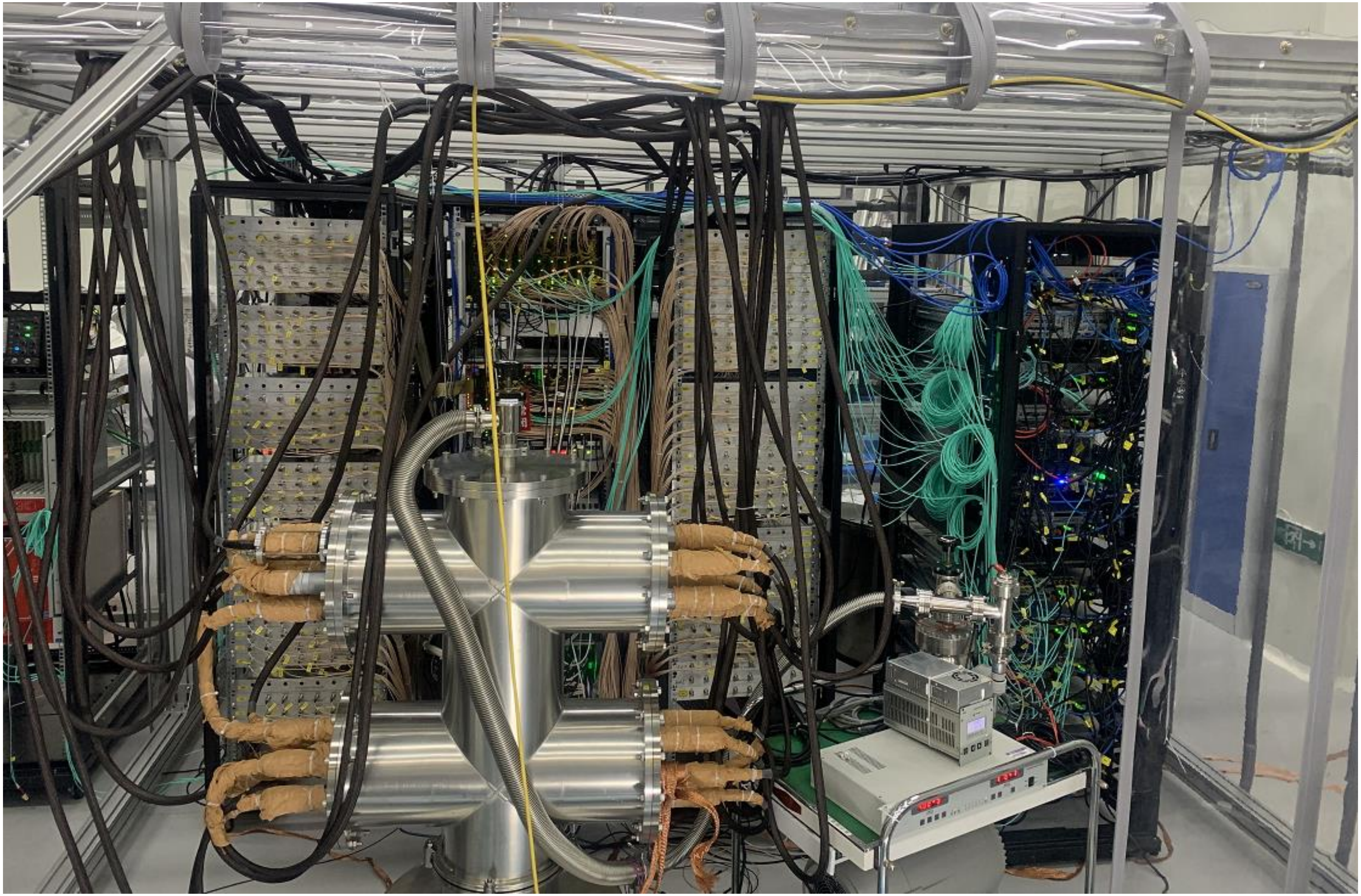
Gas, cryogenics, and distillation systems

TPC installation

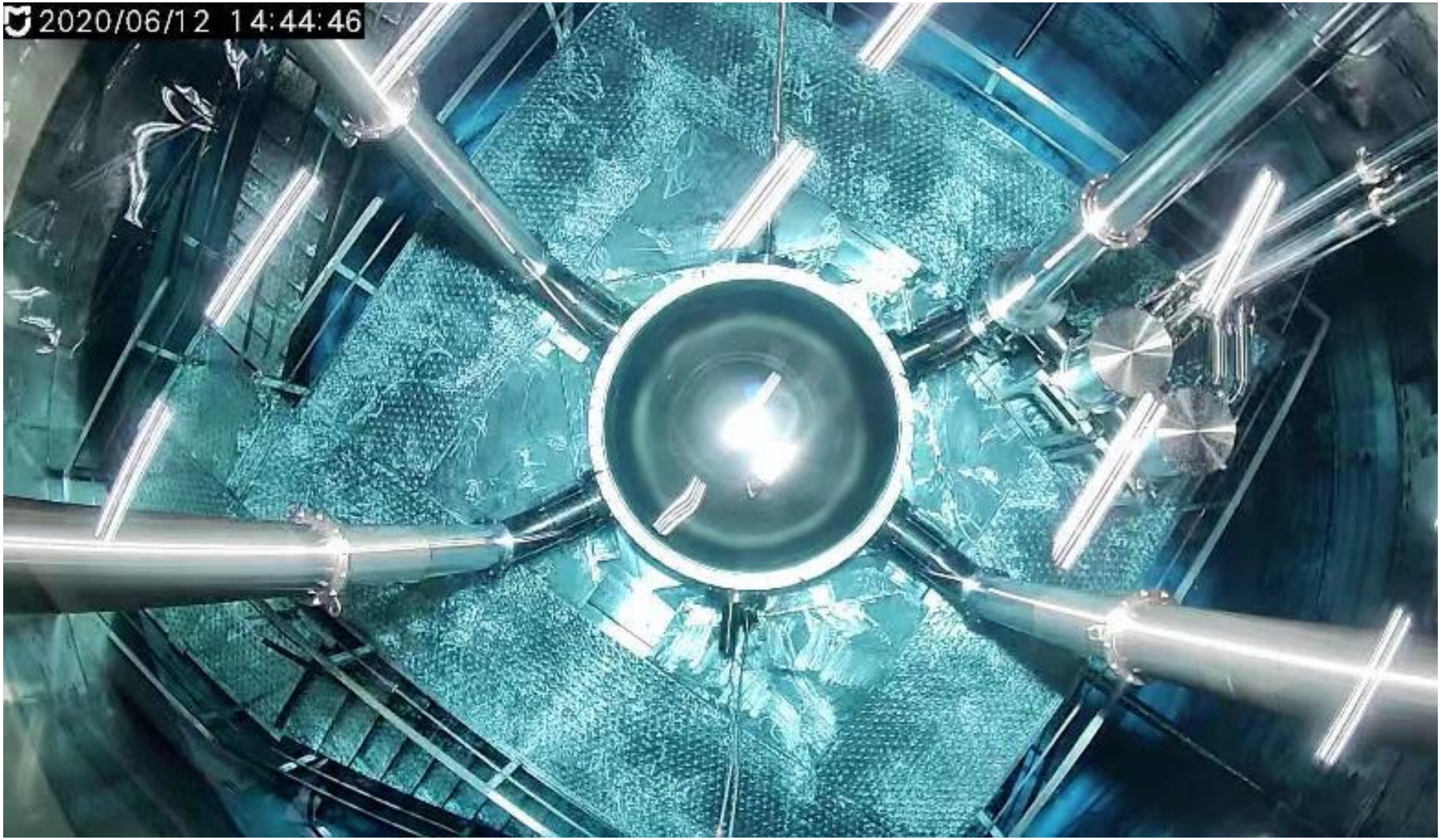


Instrumented clean room

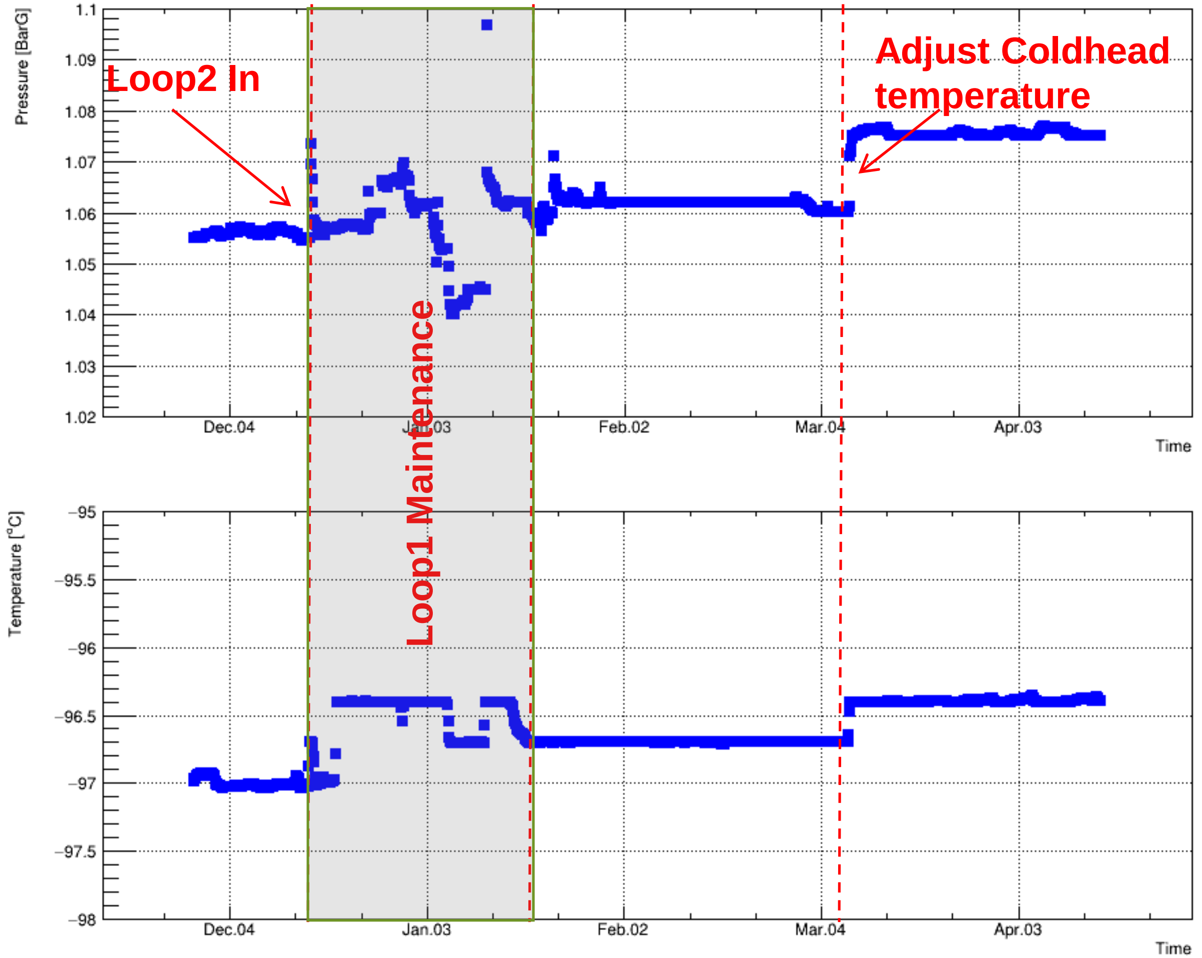
Electronics hut



Ultrapure water filling



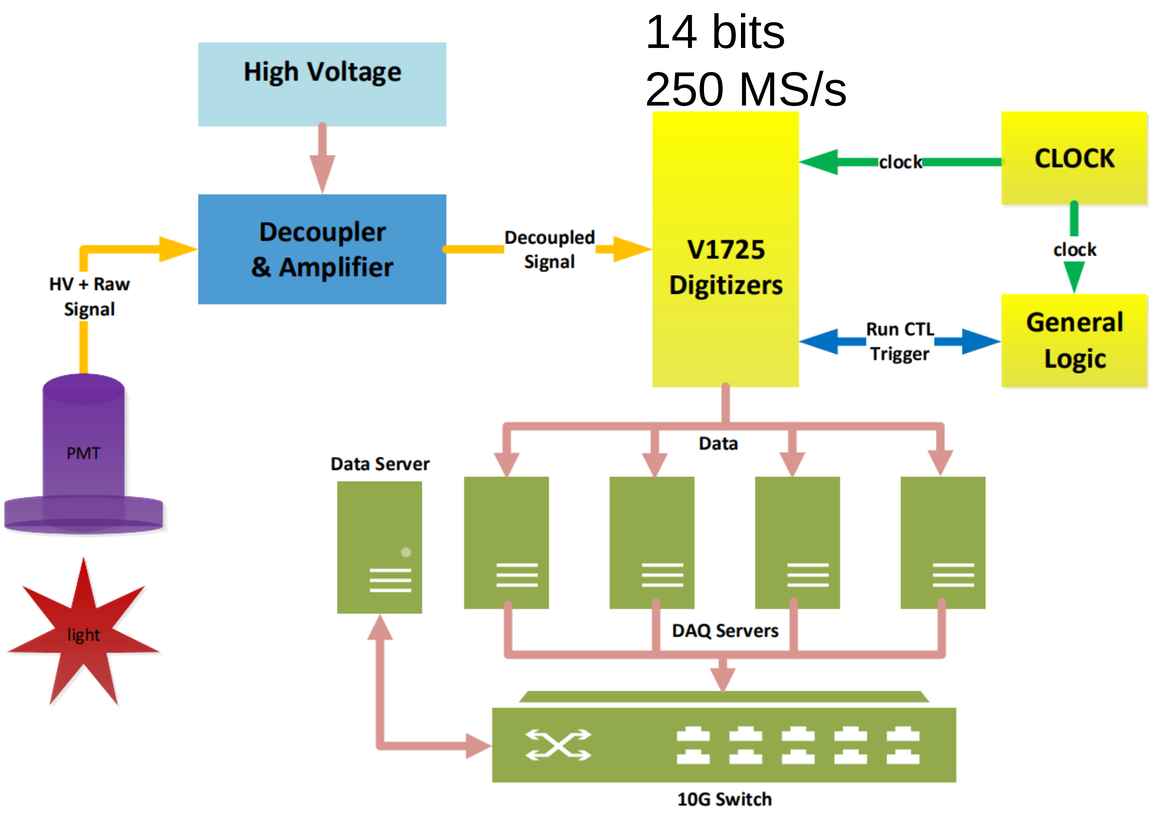
Cryogenics stability



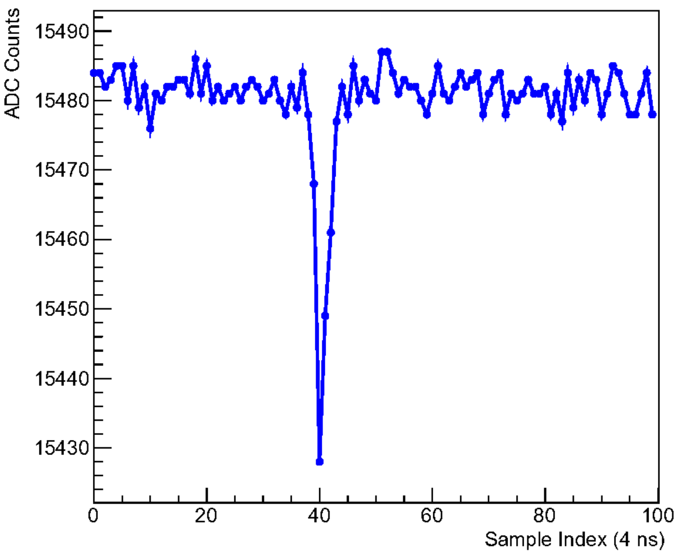
- In the stable running period, the P and T are stable within 0.5% and 0.1K, separately.

Parameters	Heating load (No purification)	Maximum Cooling Power	Purification flow rate	Outer Vacuum
Value	~50W	~580W	~110 SLPM (40 kg/h)	<2E-4Pa

Electronics and DAQ

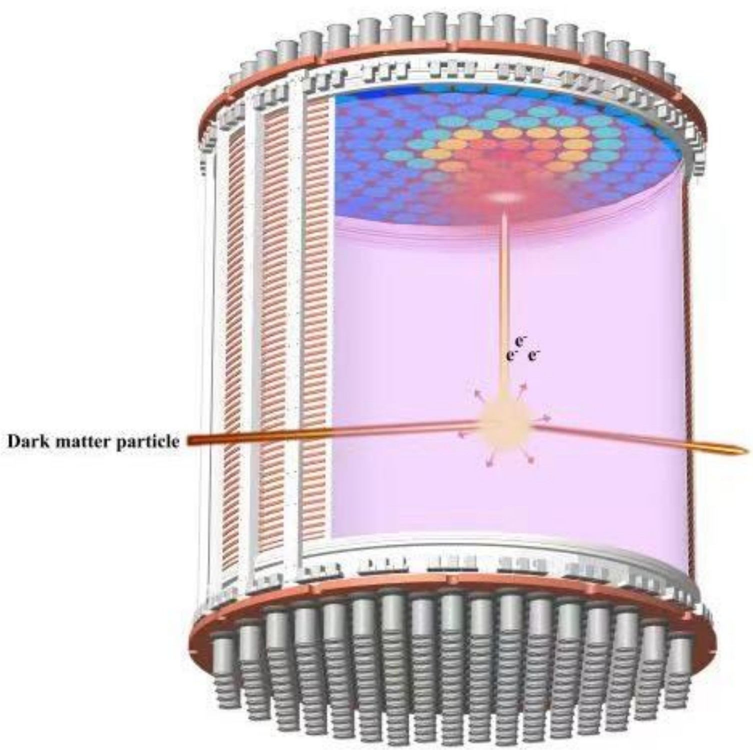


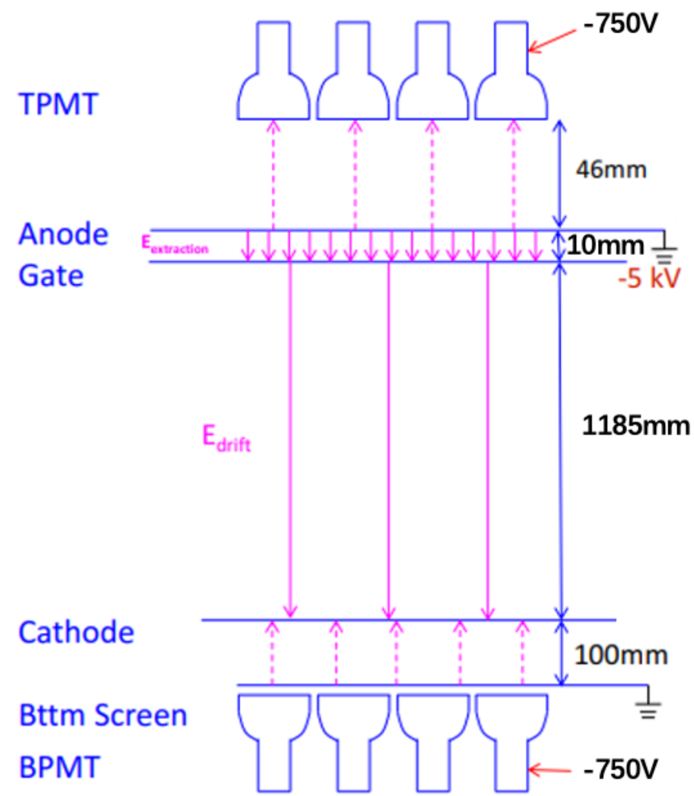
Typical single photon pulse



- ❑ Trigger-less mode: read out pulses above 20 ADC (~ 1/3 PE)
- ❑ Average single photon efficiency ~ 95%
- ❑ DAQ maximum bandwidth 450MB/s

TPC operation conditions

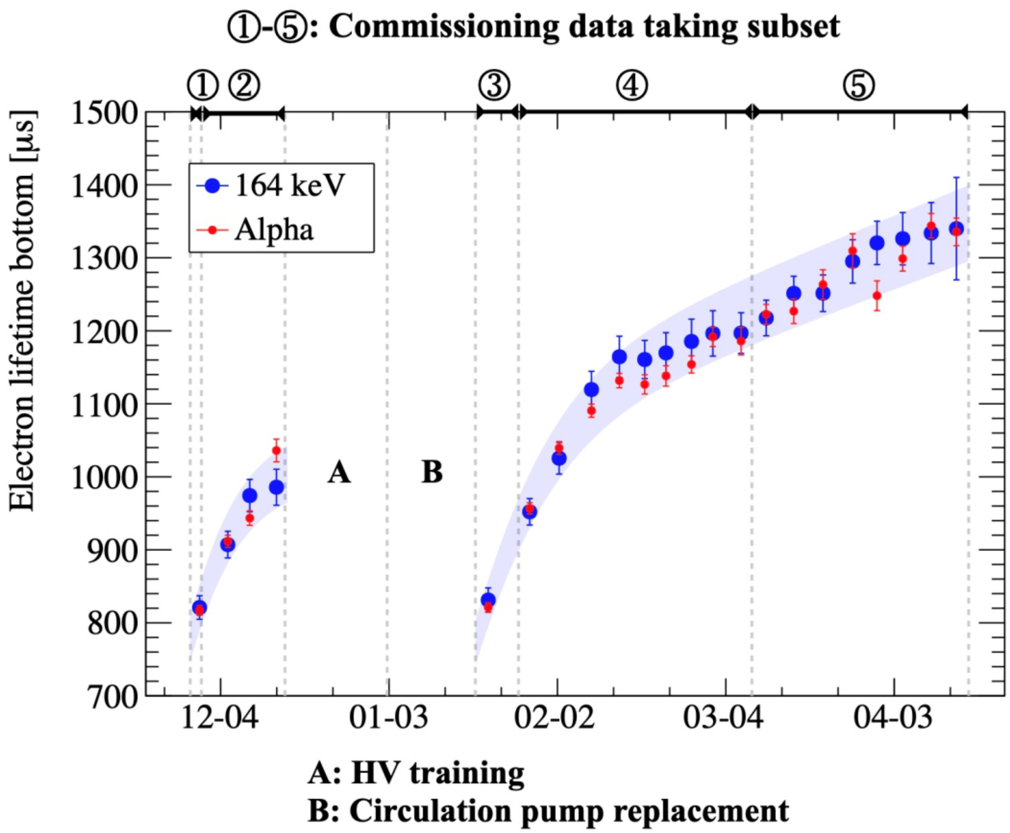




	Set1	Set2	Set3	Set4	Set5
Gate(kV)	-4.9		-5	-5	
Cathode (kV)	-20	-18.6	-18	-16	

During the run, HV set at a few different values to avoid excessive discharges.

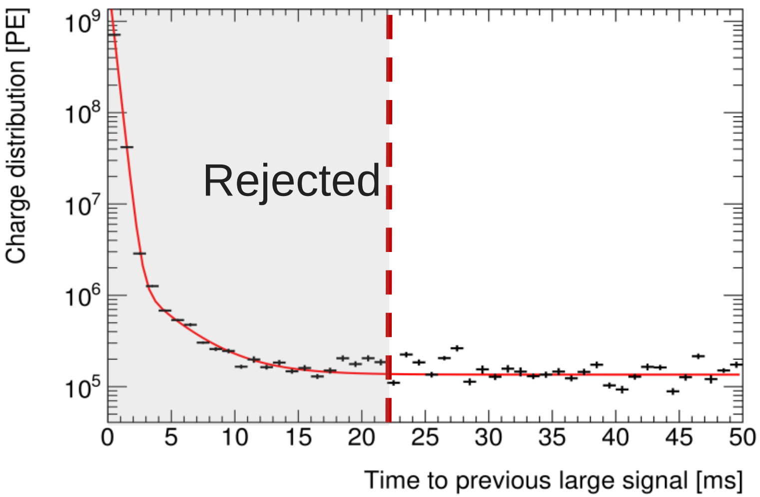
Data taking history



- ❑ Electron lifetime: *in situ* S2 vertical uniformity calibration
- ❑ Ref: the maximum drift time ~ 840 μs (field dependent)
- ❑ Stable data running period: 95.0 calendar days

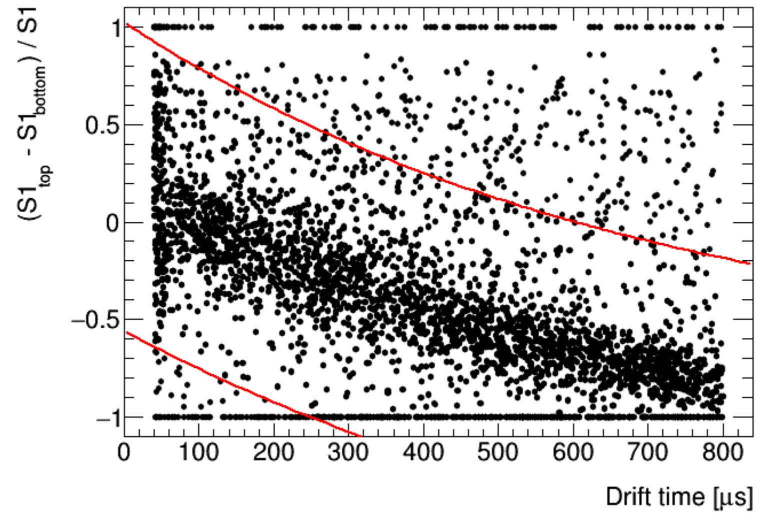
Lower level data selection cuts

Time to previous large signals

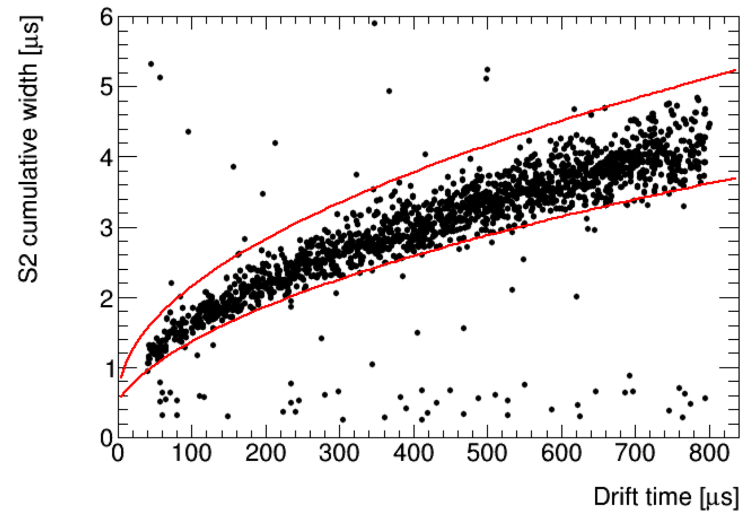


- ❑ Livetime fraction: 92.7%
- ❑ Rate excursion cuts: 97.7%

T-B asymmetry cut for S1



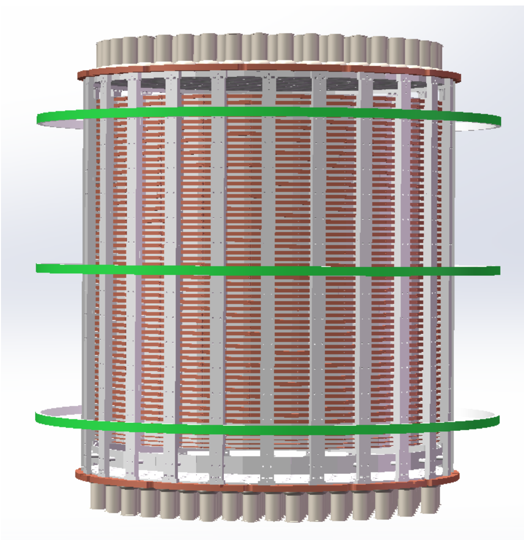
Diffusion cuts

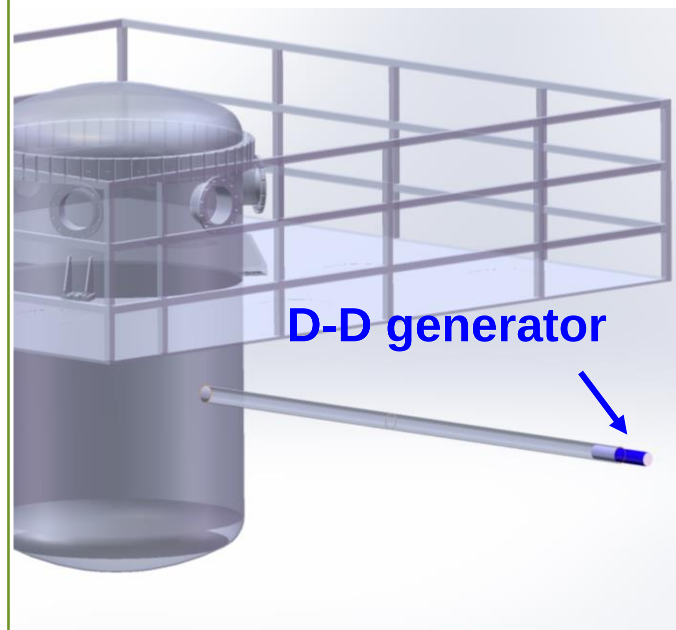


Calibration methods

Gaseous source injection panel

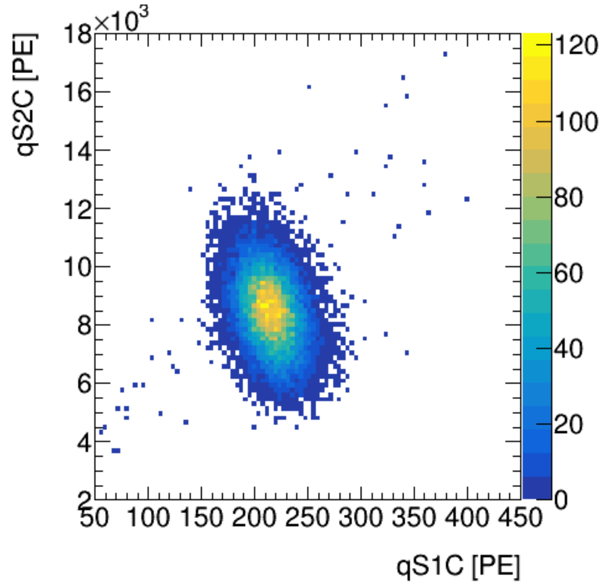
Calibration tubes

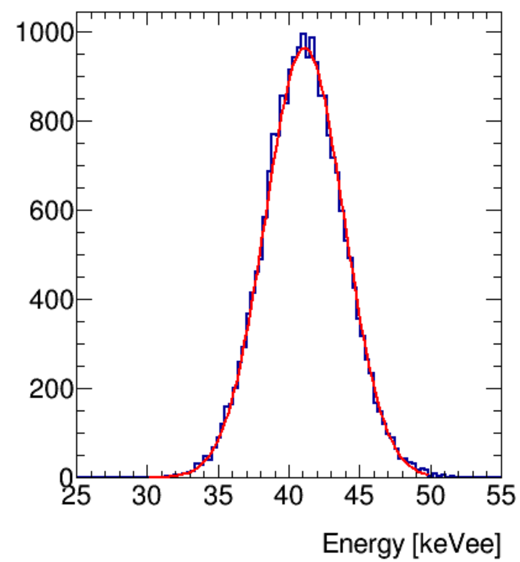




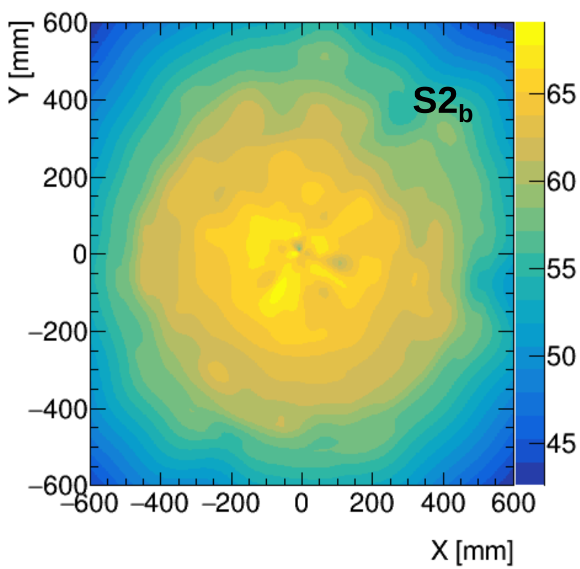
Calibration source	Position
^{83m}Kr/^{220}Rn	Injected from gas panel
^{241}Am-Be	Calibration tubes
D-D neutron	Beam pipe

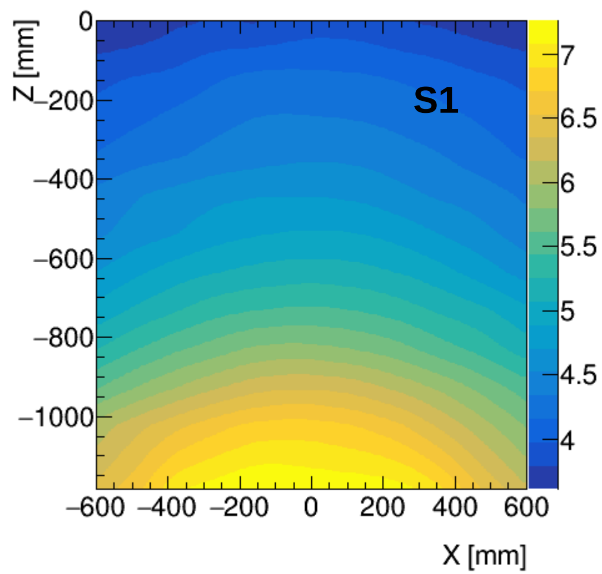
Uniformity correction with ^{83m}Kr (41.5 keV)





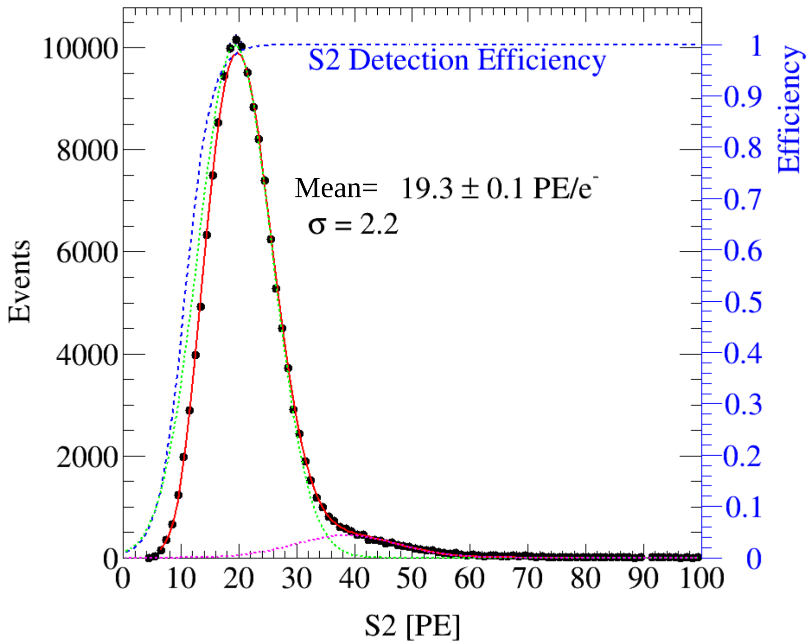
- Energy resolution @ 41.5 keV: 6.8%

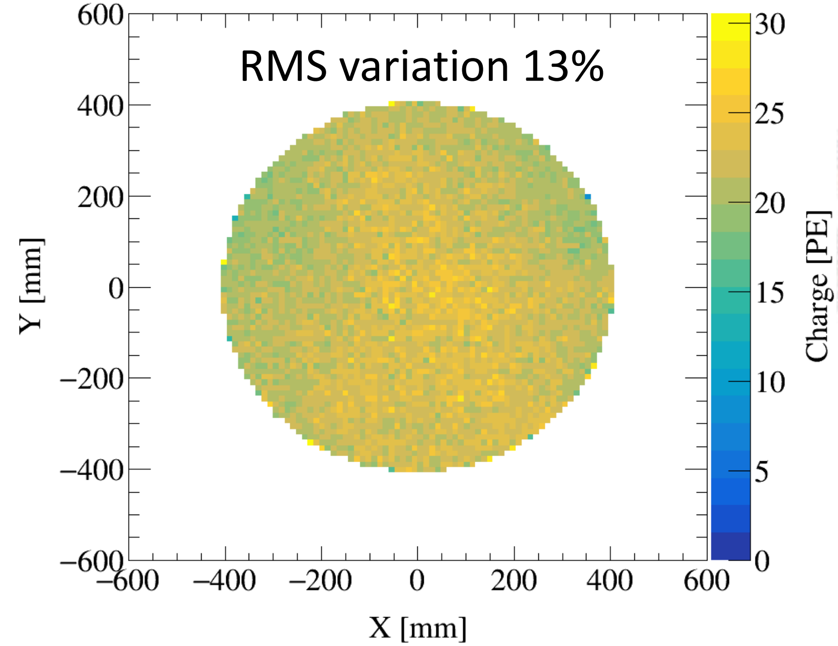


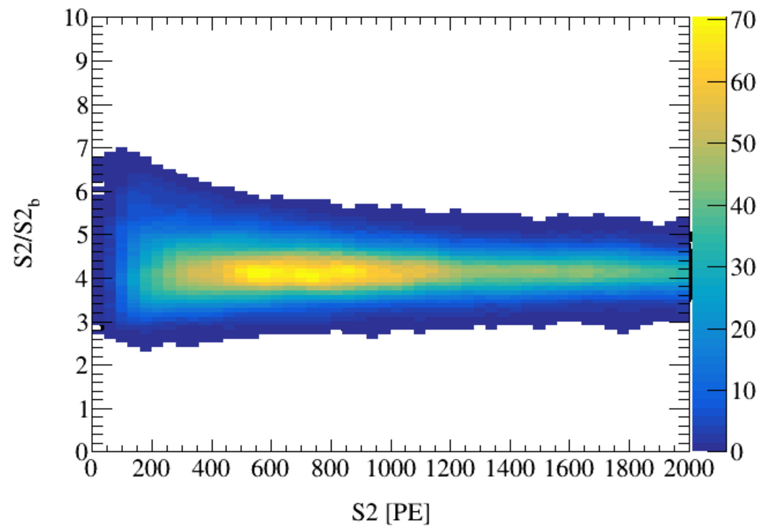


- S2$_b$ RMS in FV: 12%
- S1 RMS in FV: 20%

SEG and uniformity



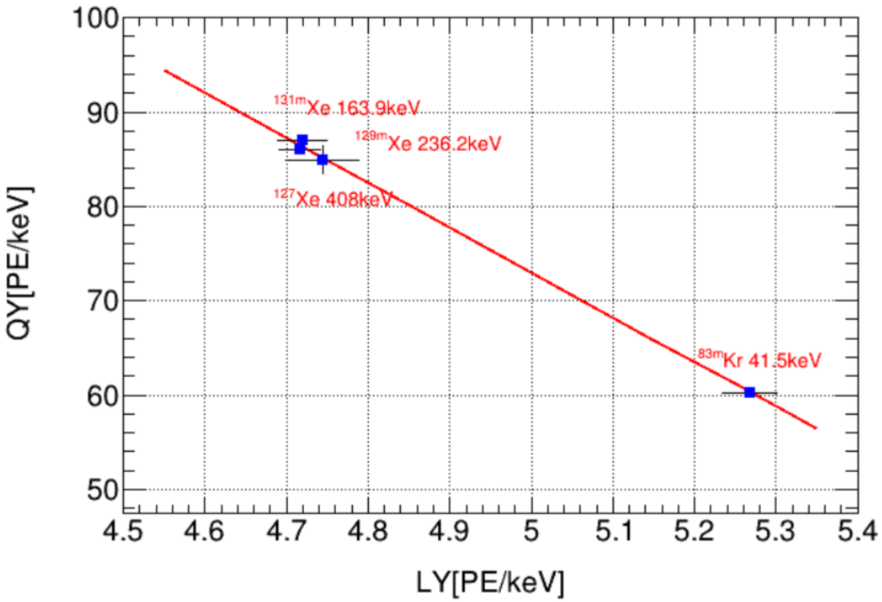


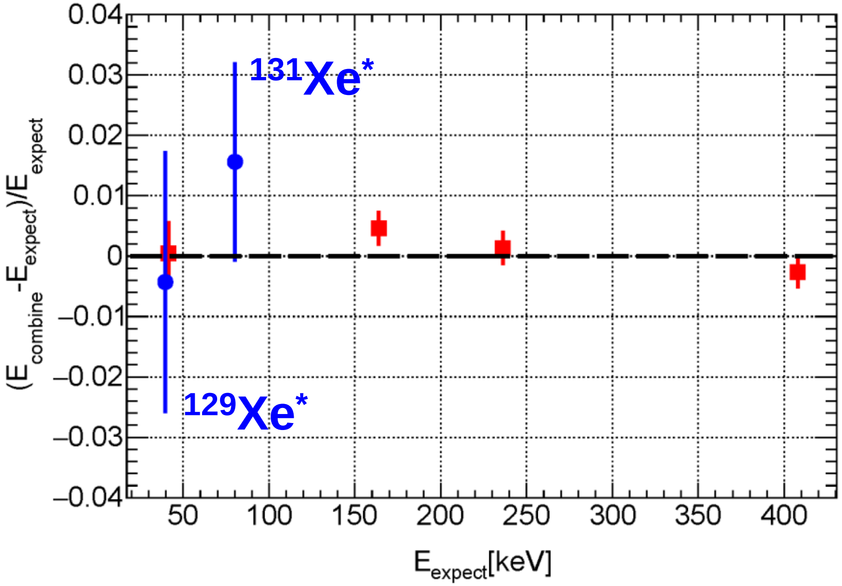


- ❑ S2/S2b ~ 4.2
- ❑ SEG = 4.6 ± 0.1 PE/e

Energy reconstruction

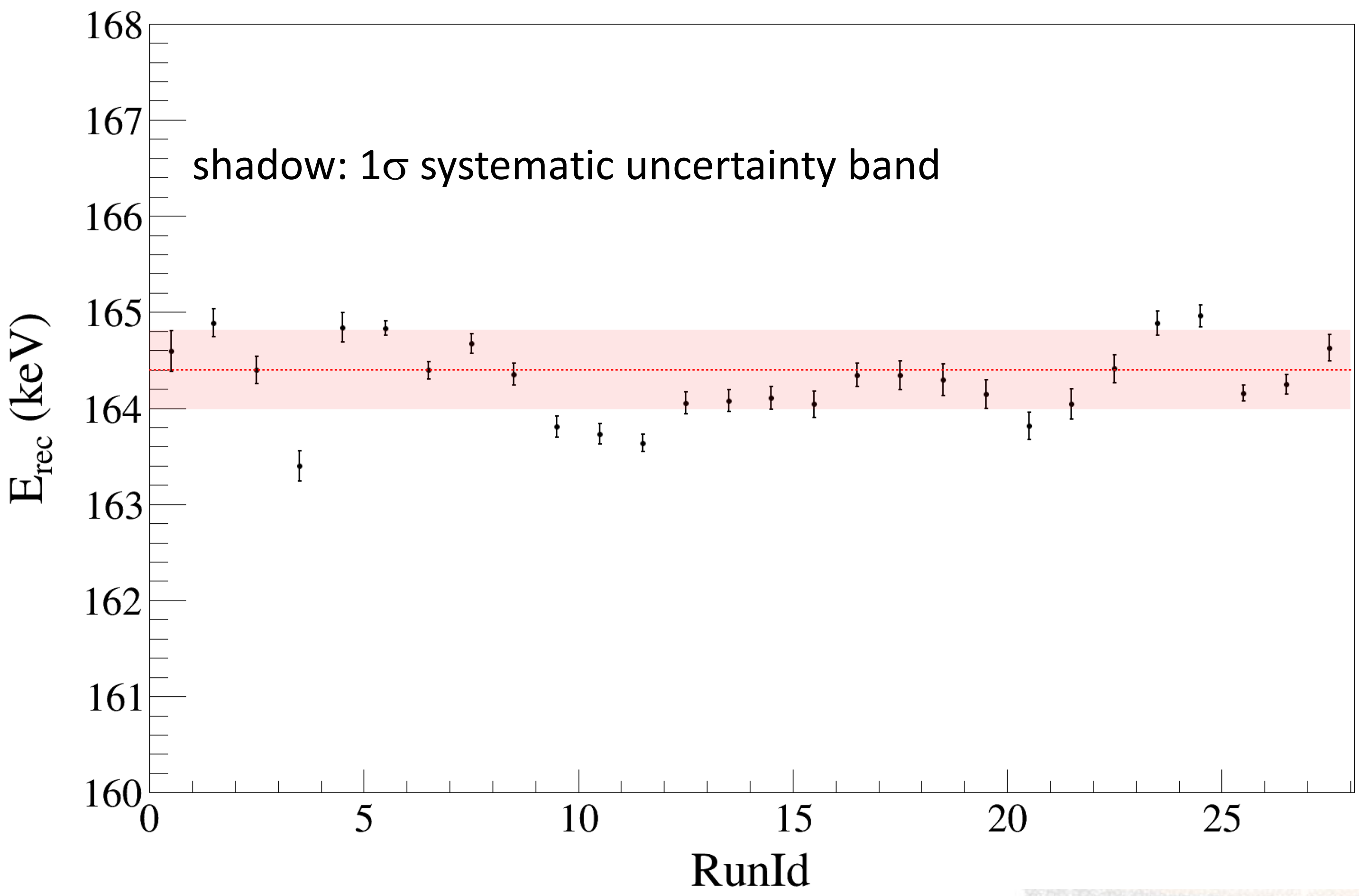
$$E = 13.7\mathrm{eV} \times \left(\frac{\mathrm{S1}}{\mathrm{PDE}} + \frac{\mathrm{S2_b}}{\mathrm{EEE} \times \mathrm{SEG}}\right)$$





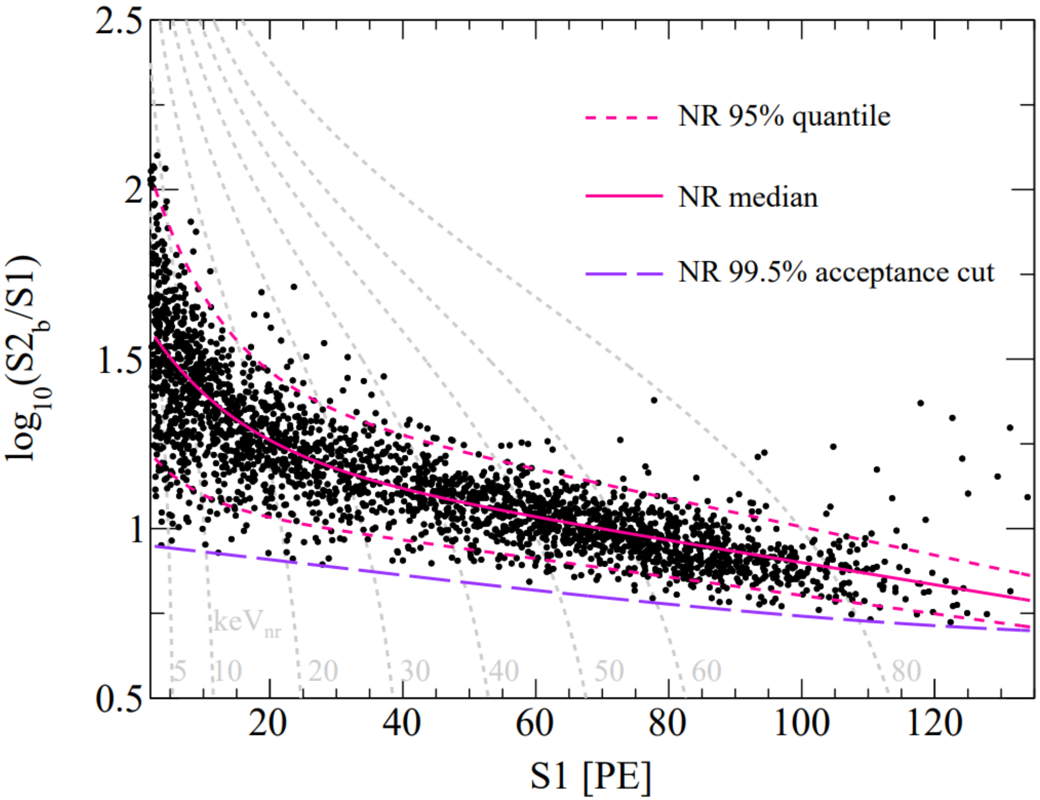
#Set	PDE [%]	EEE [%]	SEG [PE/e]
1-2	9.0±0.2	90.2±5.4	3.8±0.1
3-5	9.0±0.2	92.6±5.4	4.6±0.1

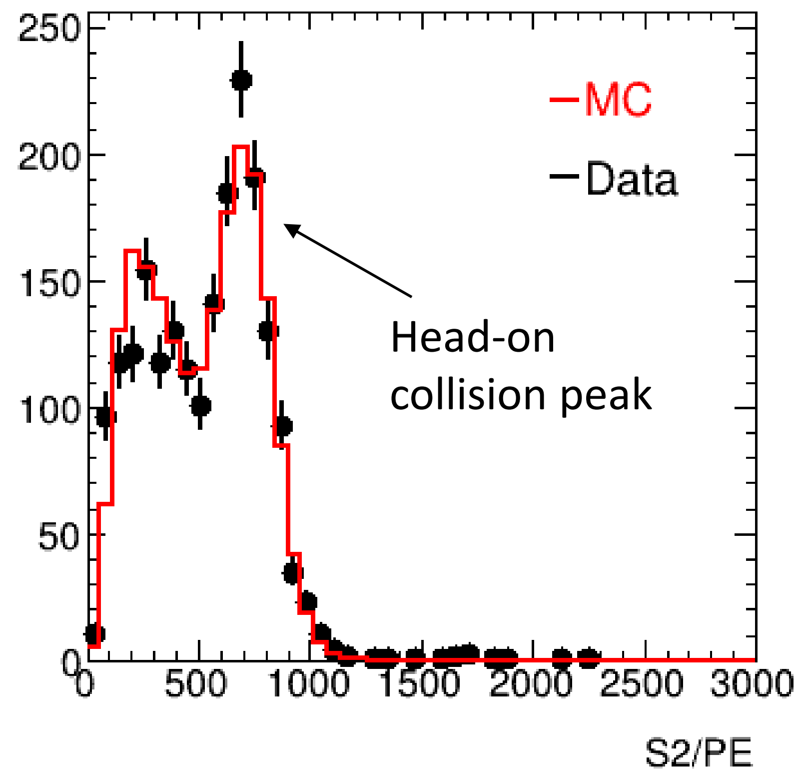
164 keV (^{131m}Xe) evolution



- Each data point represents about 4000 ^{131m}Xe events
- Systematic uncertainty ~ 0.3%

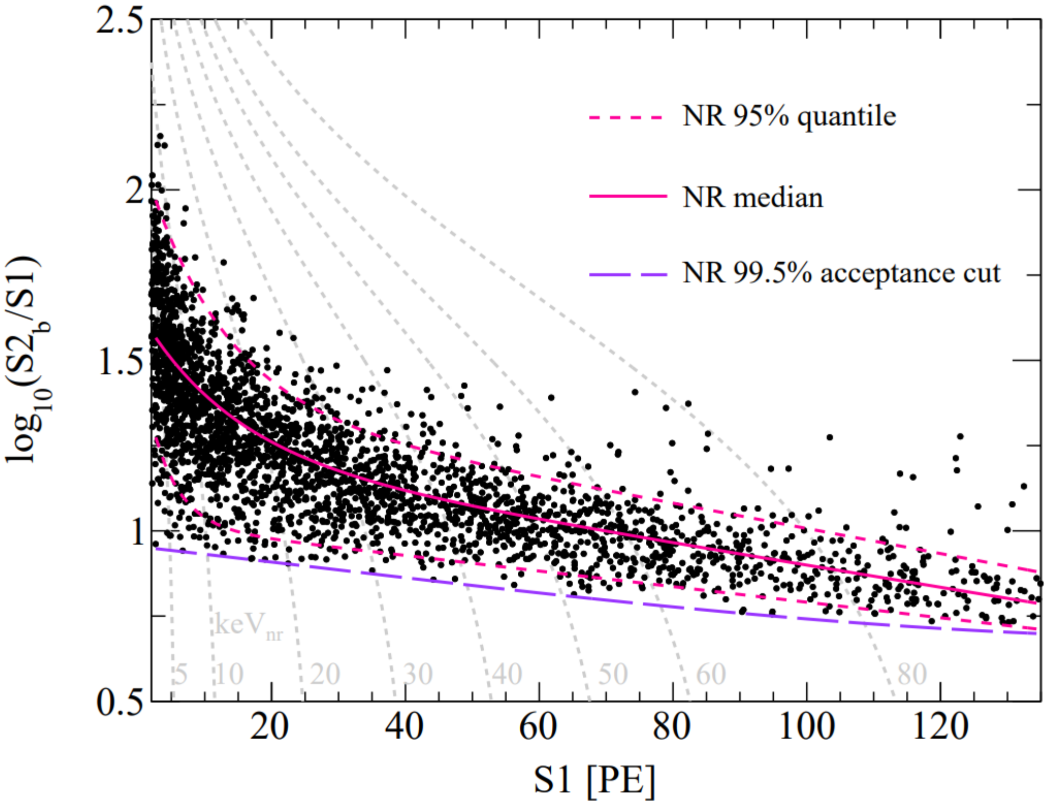
Nuclear recoil calibration with DD neutrons

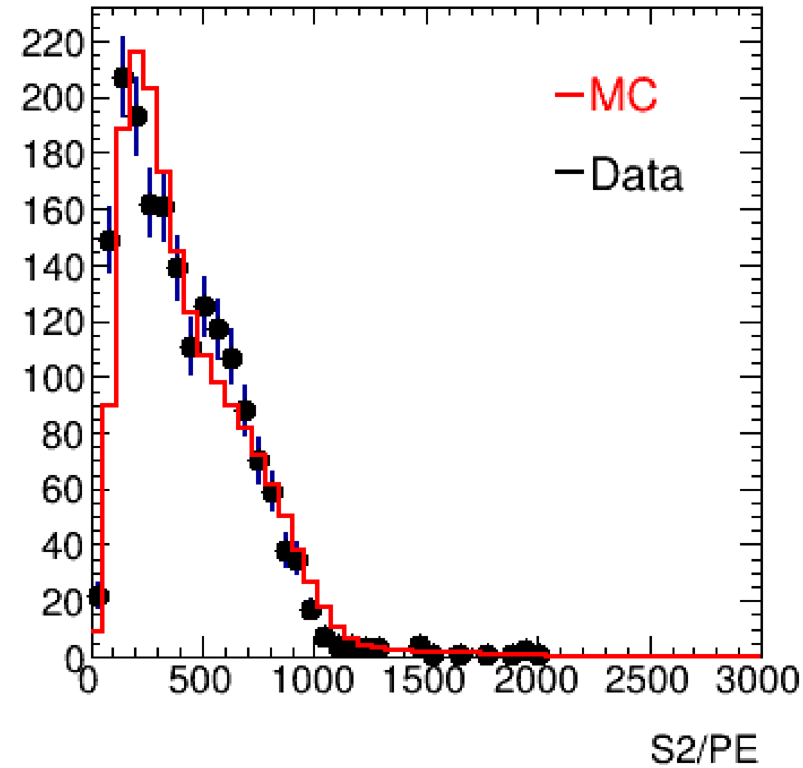




- Data used together with AmBe to tune the light, charge yield, as well as fluctuations in our signal model

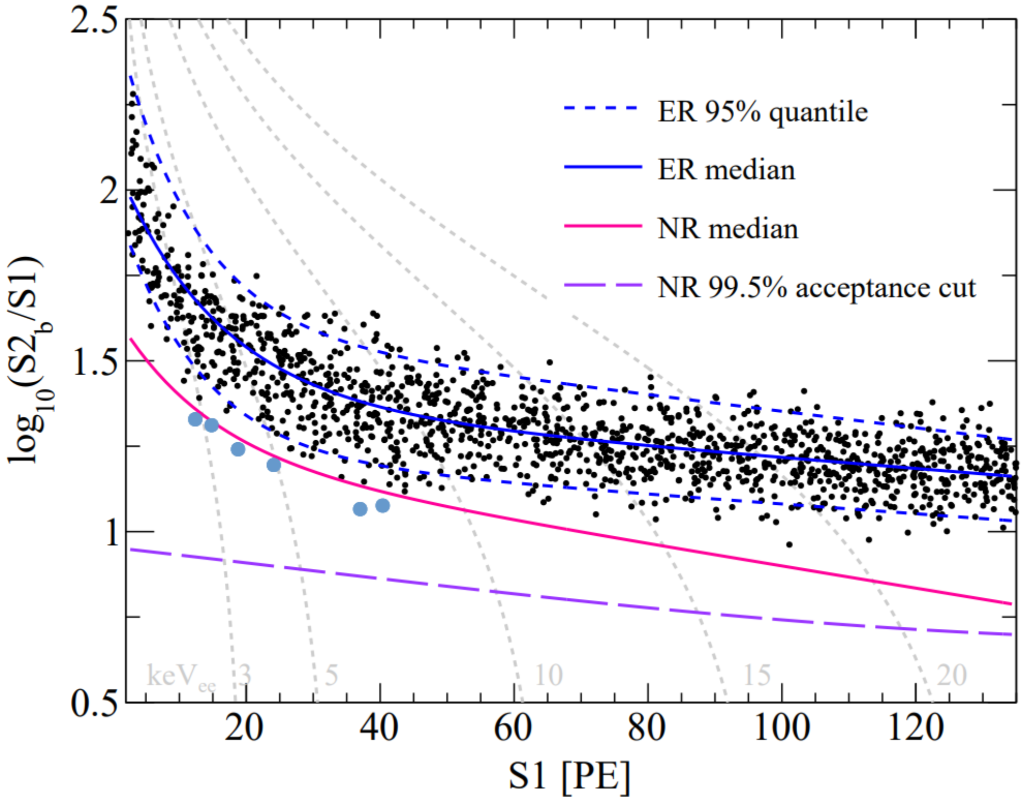
Nuclear recoil calibration with AmBe neutrons

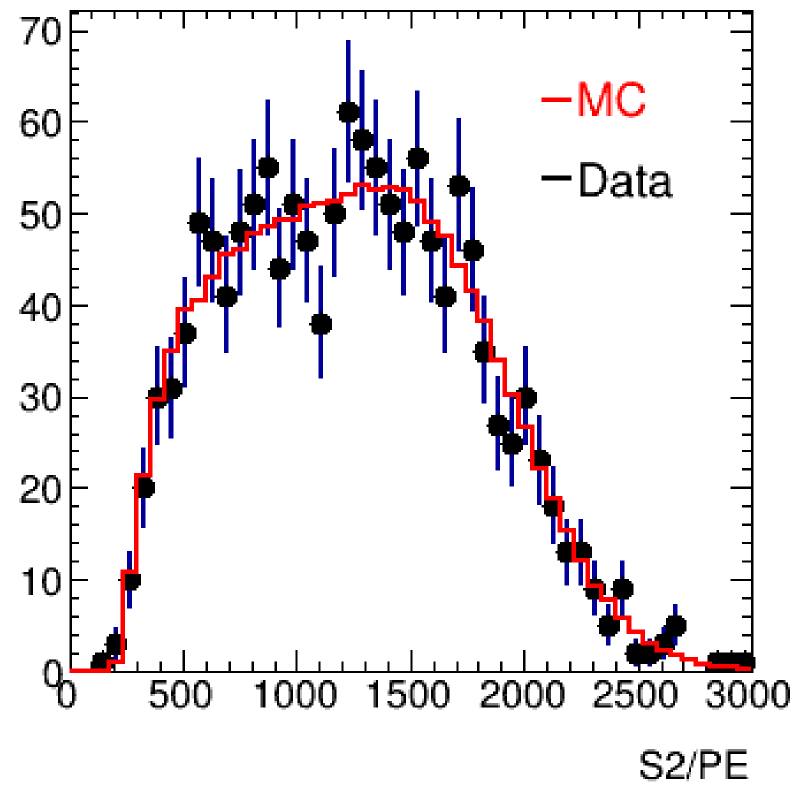




- Data used together with DD to tune the light, charge yield, as well as fluctuations in our signal model

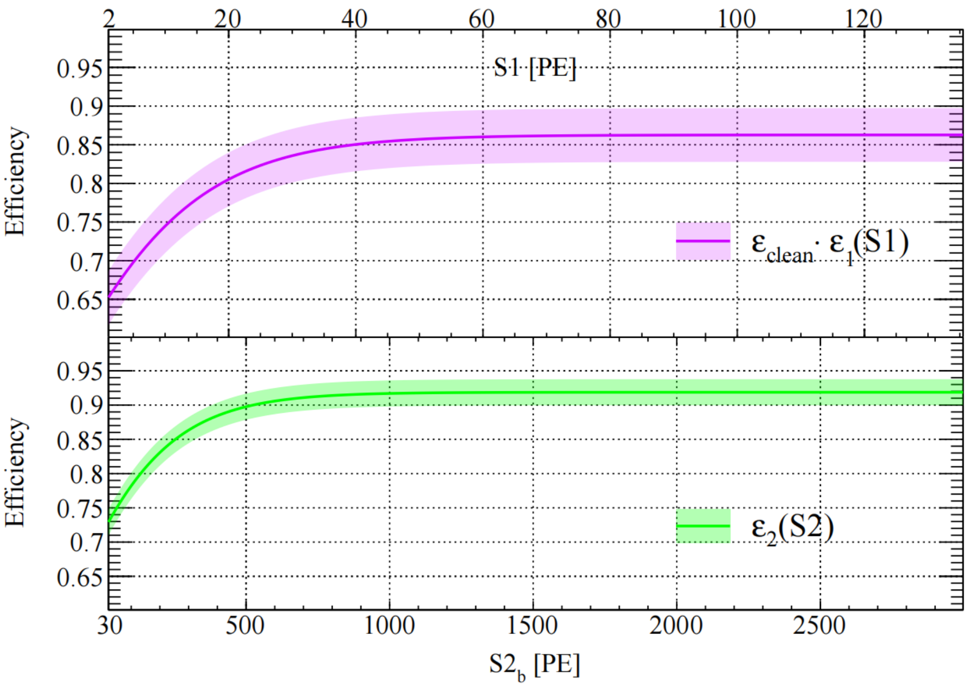
Electron recoil calibration with ^{220}Rn

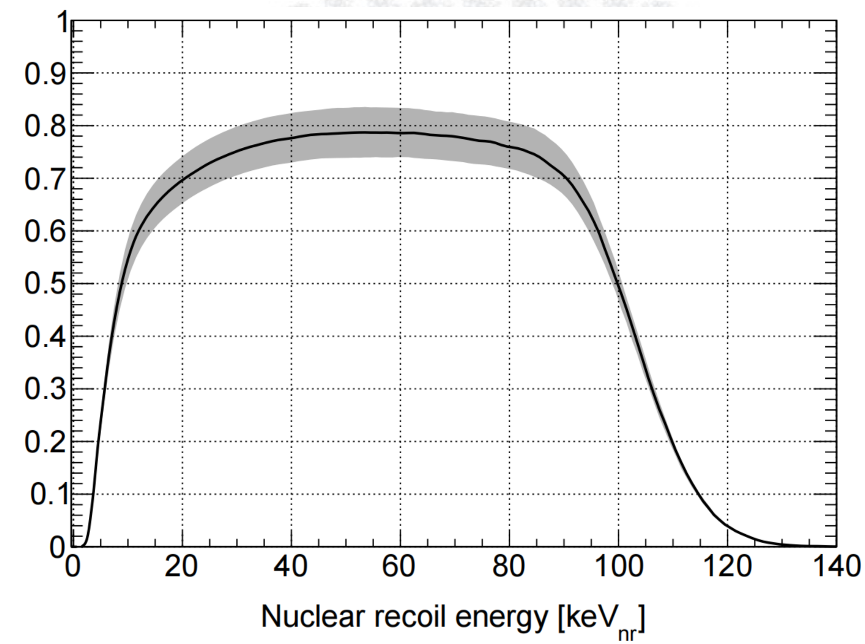




- ❑ Measured leak ratio (below NR median) = 6/1393 = 0.43%±0.18%
- ❑ Data and ER model agree well

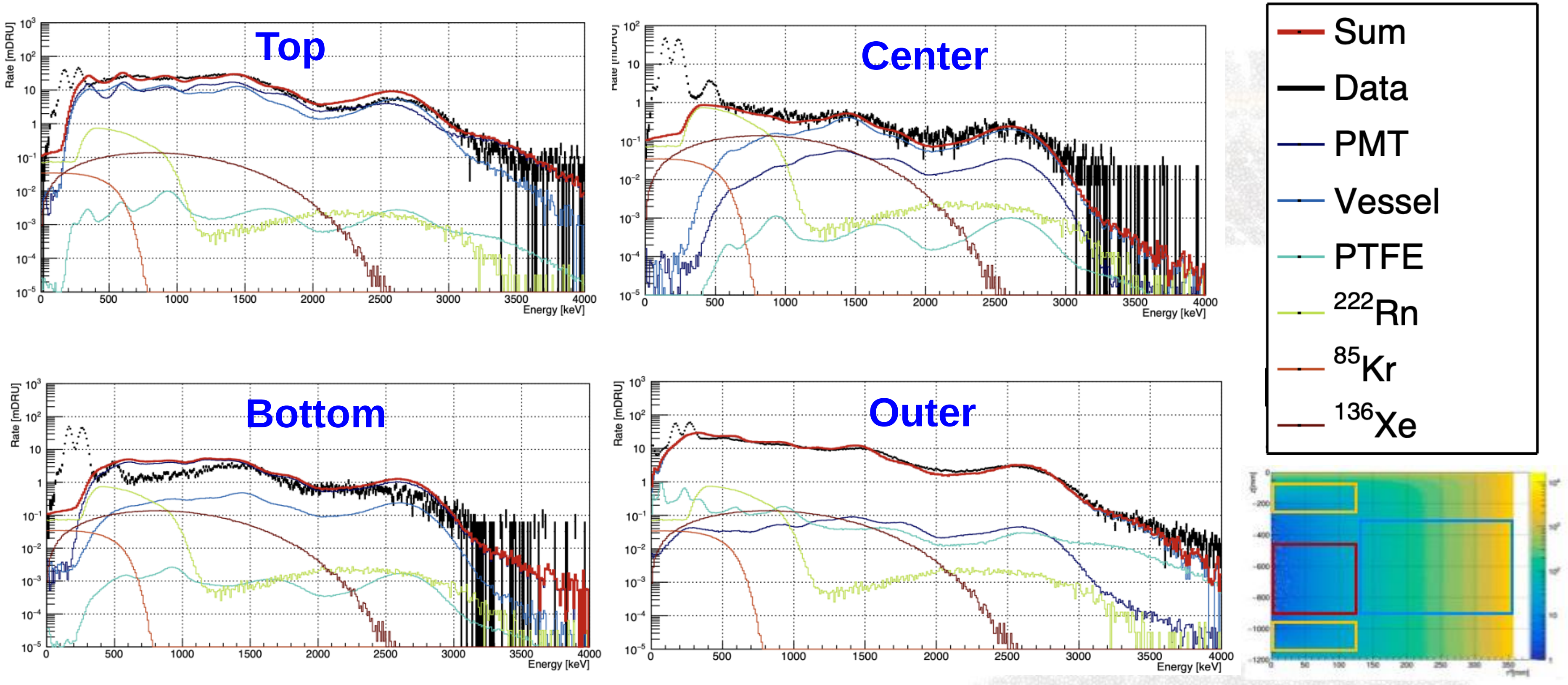
Efficiencies obtained from calibration data





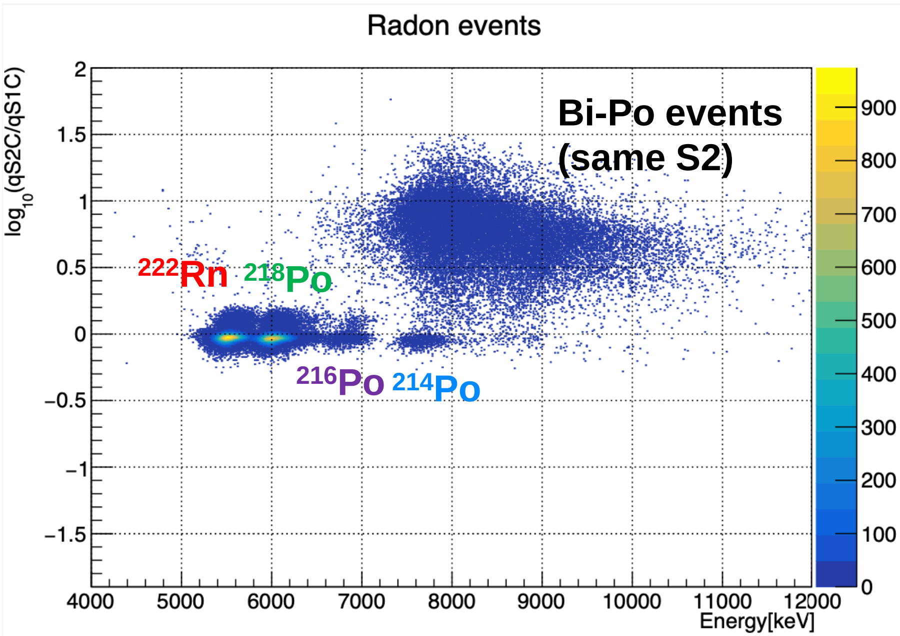
- Same S1 and S2 efficiency obtained from the ER and NR data
- Plateaued efficiency at 40 keV_{nr} ~78%.

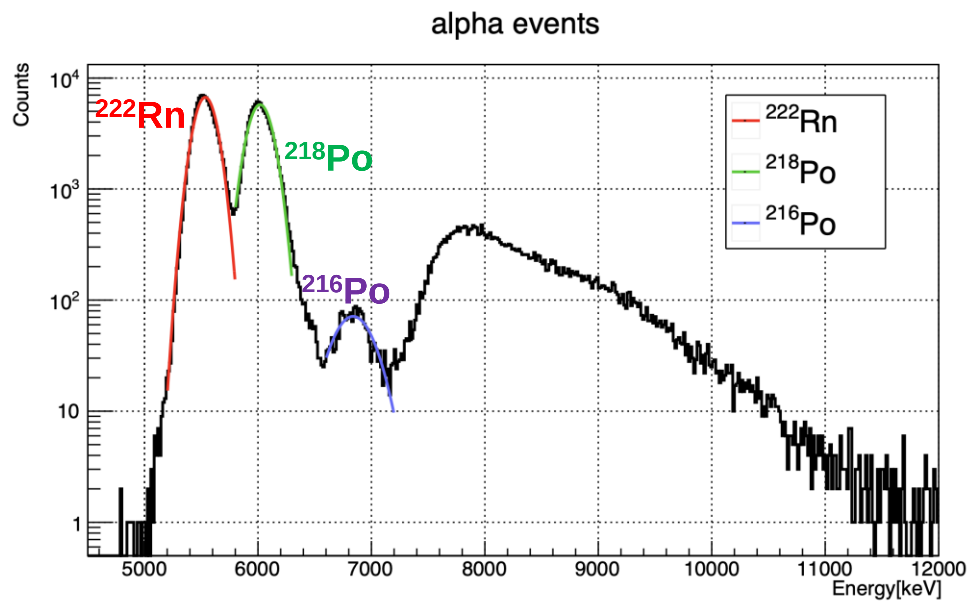
ER background from detector materials



- Overall agreement between data and MC (>1MeV): 14%
- Expected background: 33 ± 4 events

Rn background

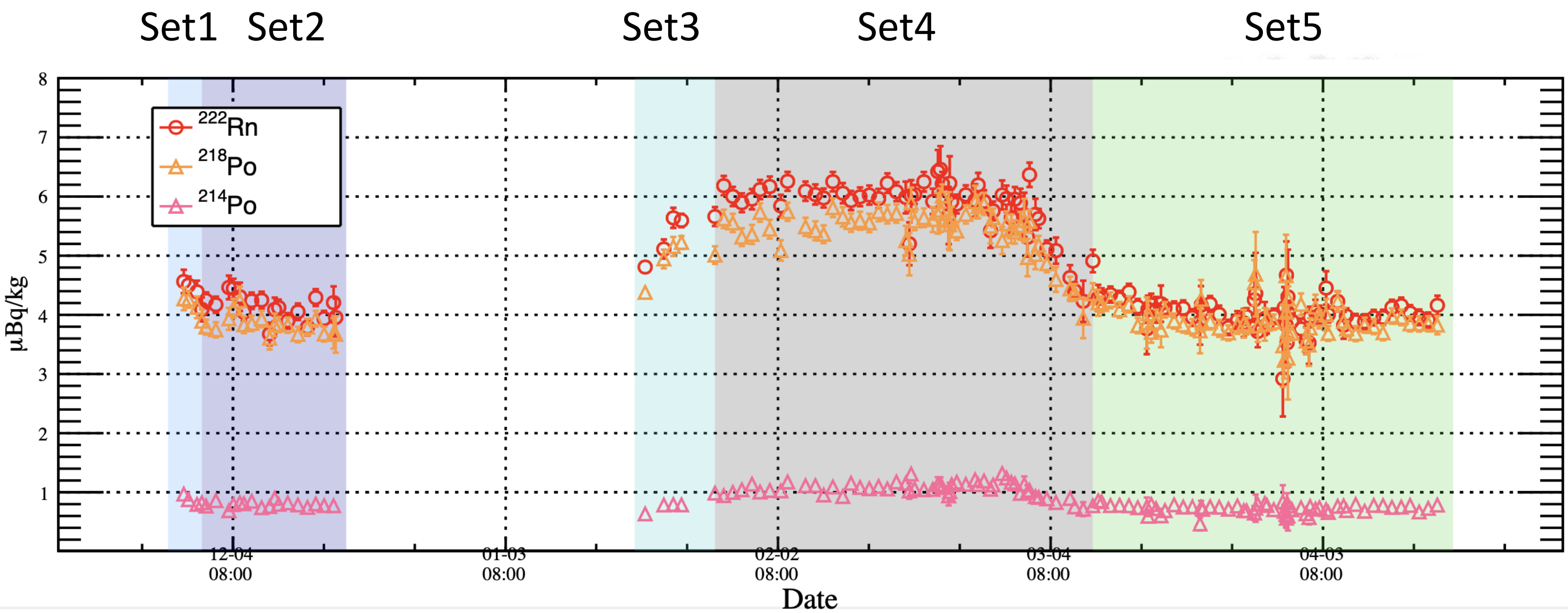




Rn background	Estimation method	Activity [μBq/kg]
^{222}Rn	^{222}Rn alpha	4.8 (0.1)
	^{218}Po alpha	4.5 (0.1)
	^{214}Bi-^{214}Po coincidence	0.87 (0.01)
^{220}Rn	^{220}Rn-^{216}Po coincidence	0.07 (0.01)

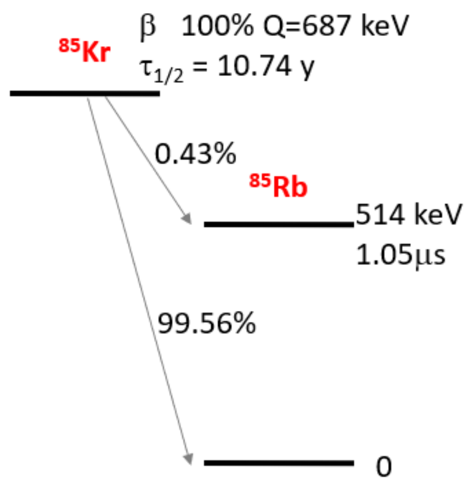
Improved 6 times from PandaX-II!

^{222}Rn level evolution

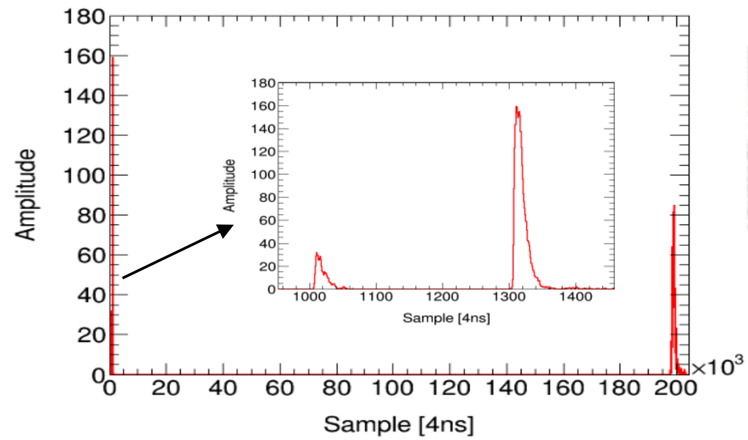


- Set 3→4: online Kr distillation (10 SLPM)
- Set 4→5: distillation off to reduce Rn emanation from the tower
- Low background directly extracted: 347 ± 190 events

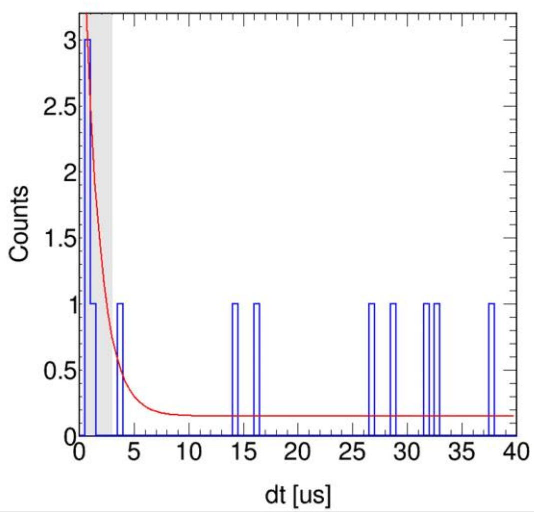
^{85}Kr



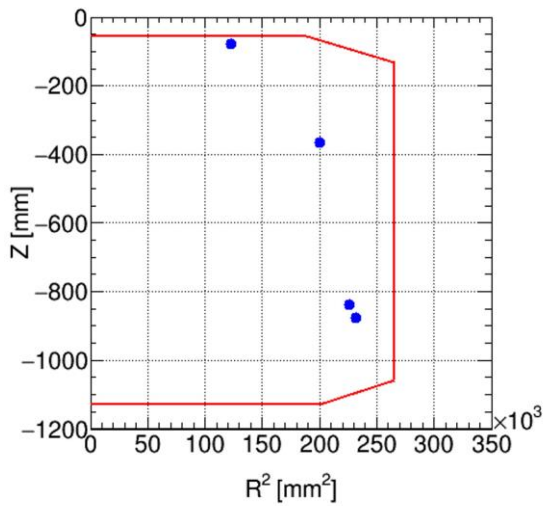
Waveform of ^{85}Kr's β-γ coincidence



Time separation between β-γ

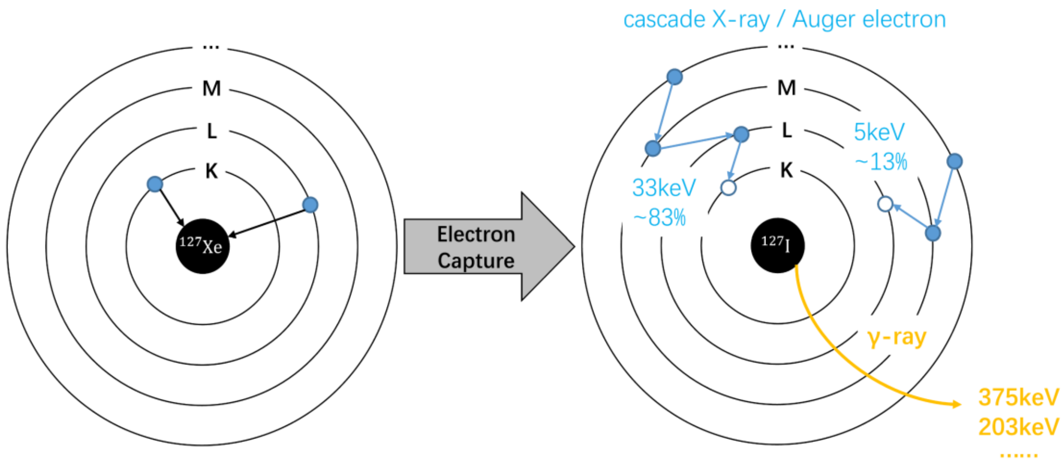


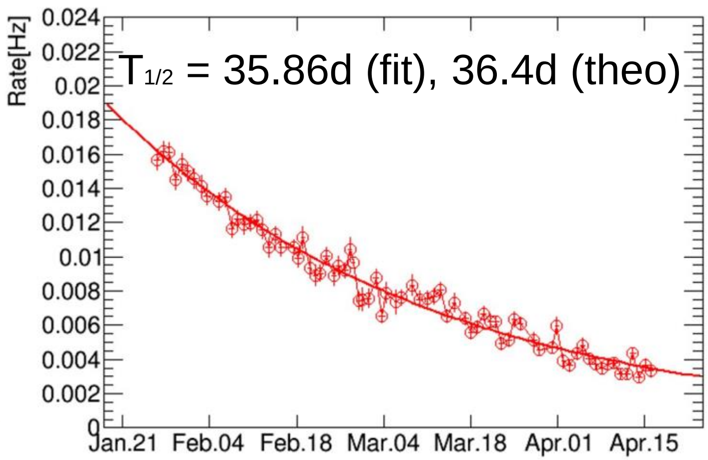
Vertex distribution of β-γ candidates

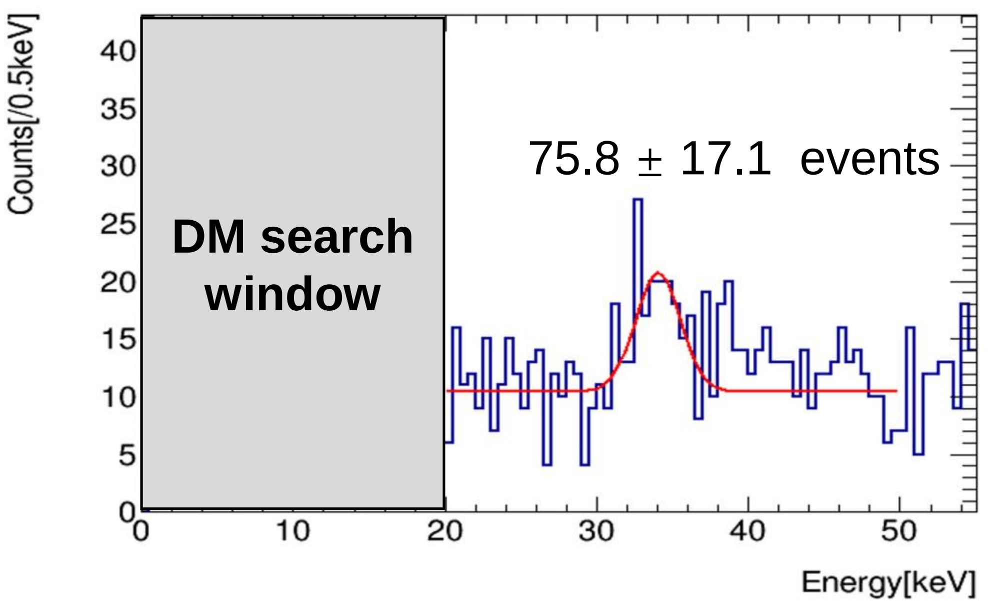


- ❑ Kr/Xe = 0.33(0.21) ppt (mol/mol), improved 20 times from PandaX-II!
- ❑ Beyond sensitivity of our Kr assay system
- ❑ Expected background: 53 ± 34 events

^{127}Xe (cosmogenically activated)

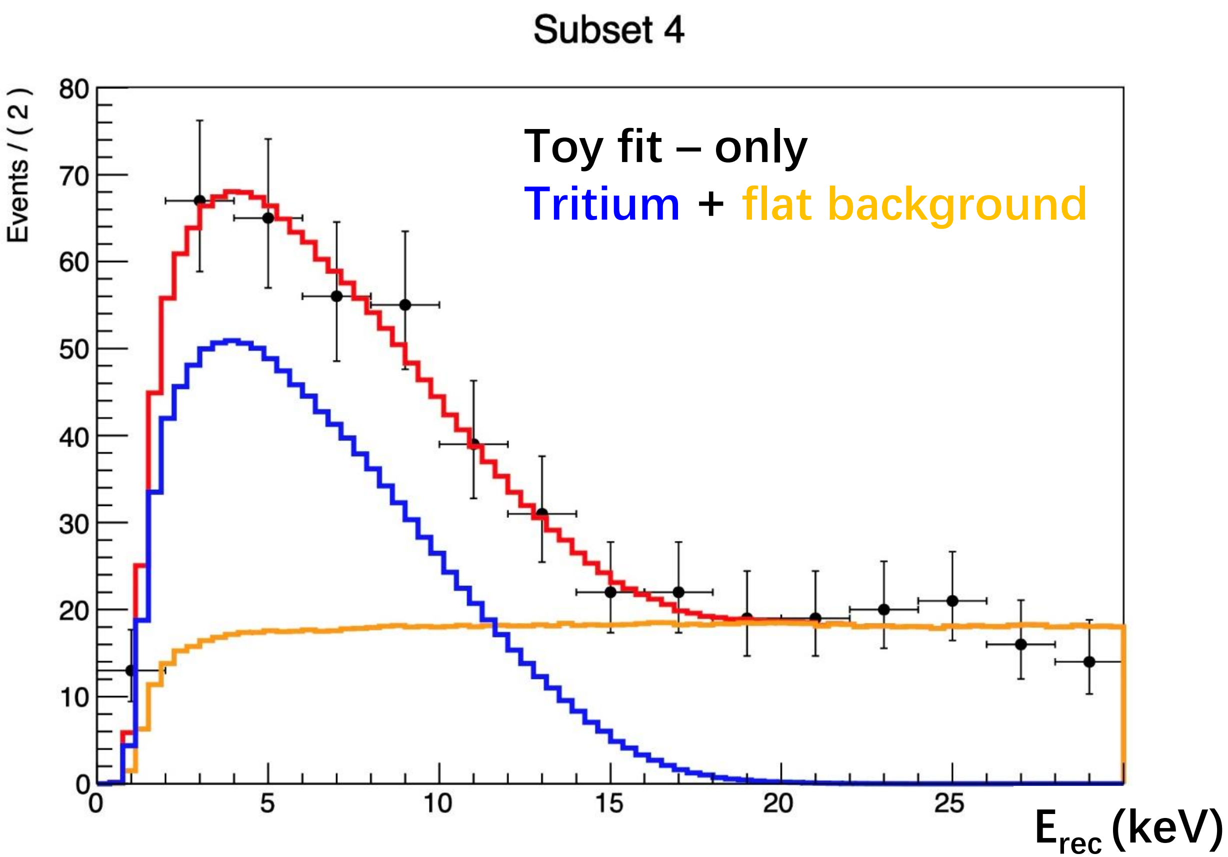






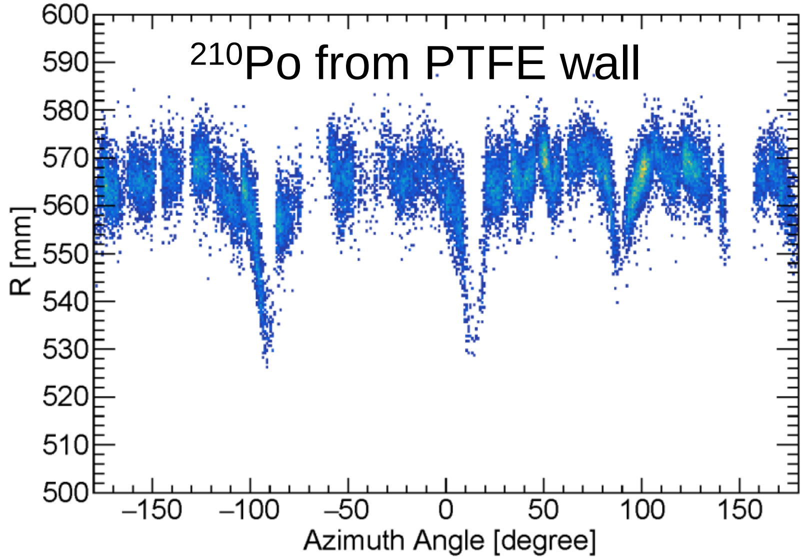
- Expected background (5 keV):
  9 ± 2 events

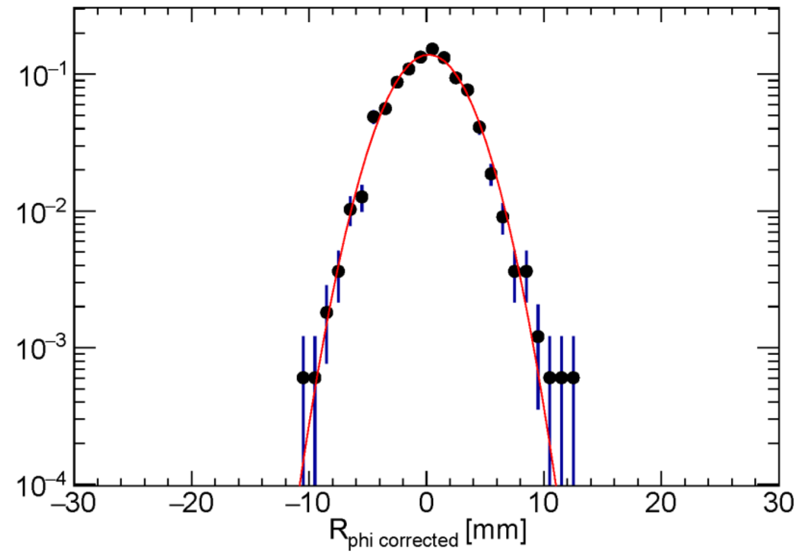
Tritium background

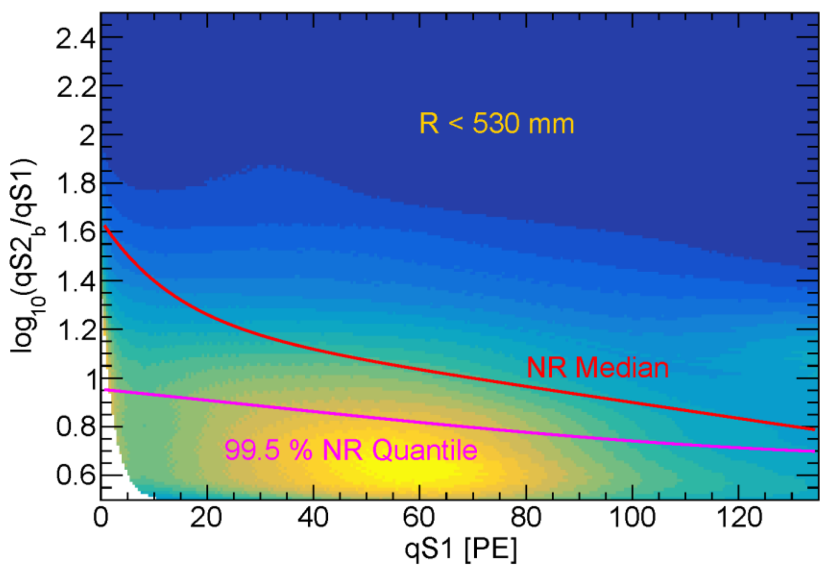


- ❑ Tritium spectrum identified in the data
- ❑ Likely originated from a tritium calibration at the end of PandaX-II
- ❑ Level floating in the final dark matter fit: ~ 5(0.3)x10^{-24} (mol/mol)

Surface background (Rn progenies)

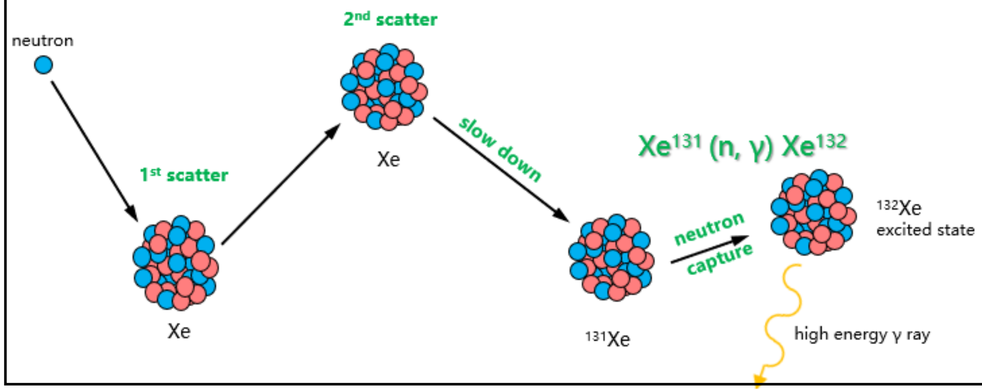




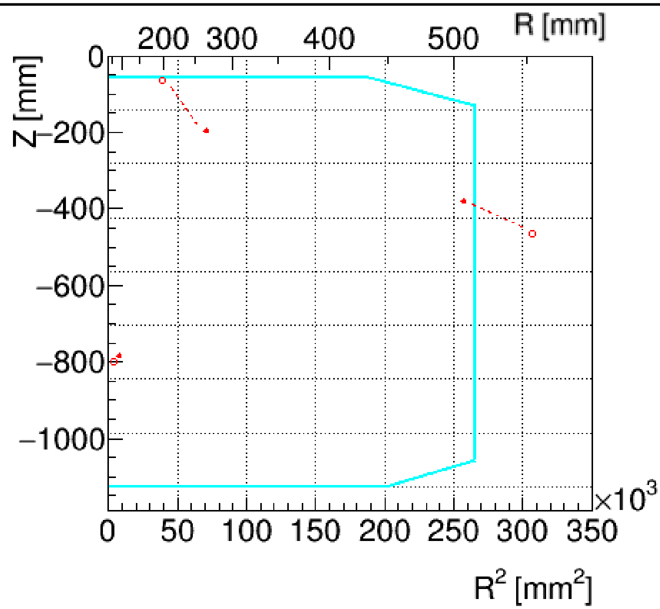


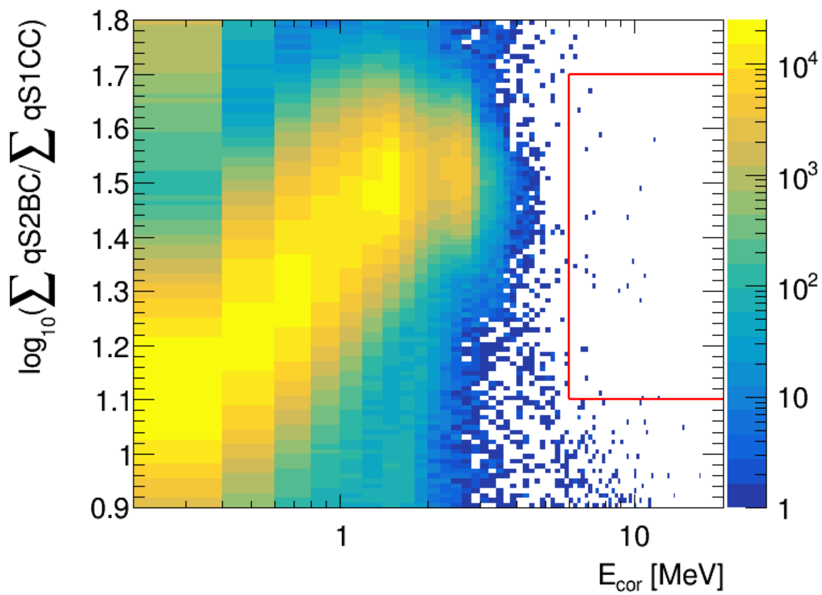
- Surface events with larger qS2 (better reconstruction) are more suppressed by radial cut.
- Expected background: 0.6 ± 0.2 events

Neutron background



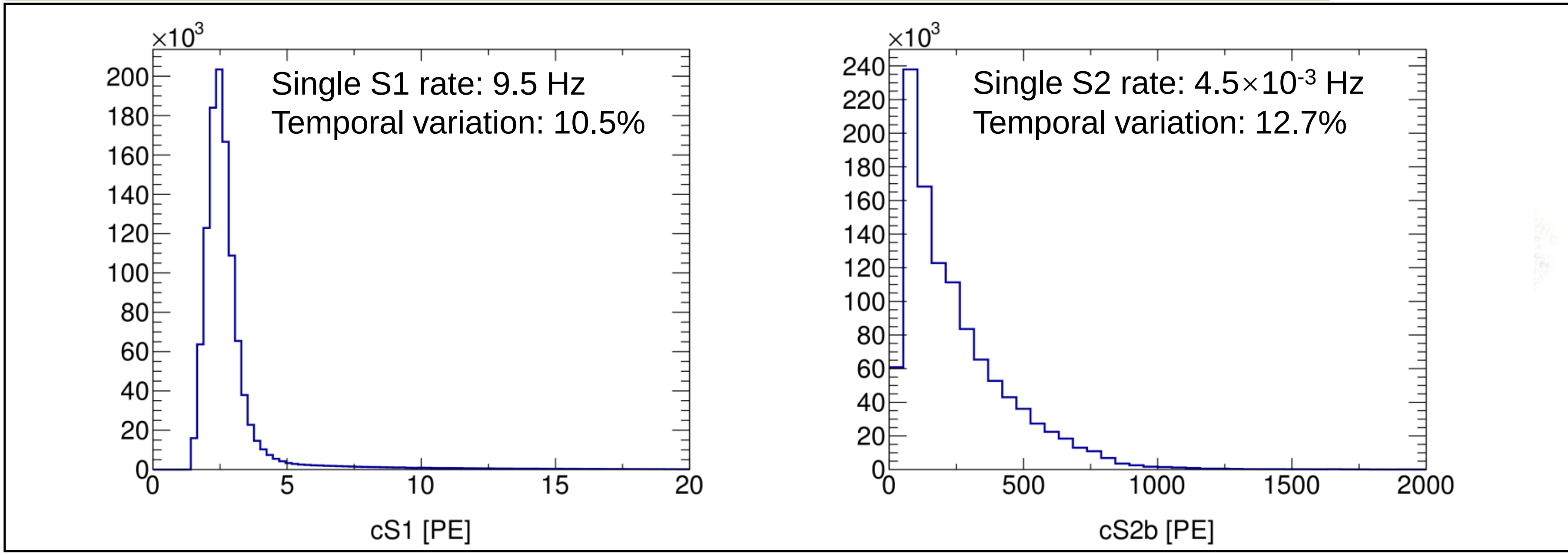
- Tags: multiscatters and captures
- Both process benchmarked by neutron source calibration

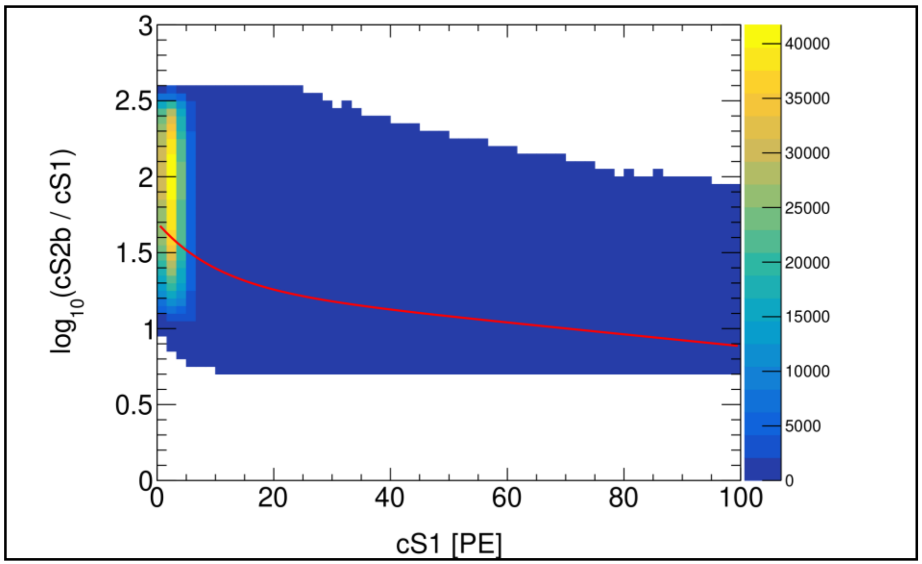




Neutron background: 1.3 ± 0.6 events, including 30% "neutron-X" events (E deposition in the below-cathode region)

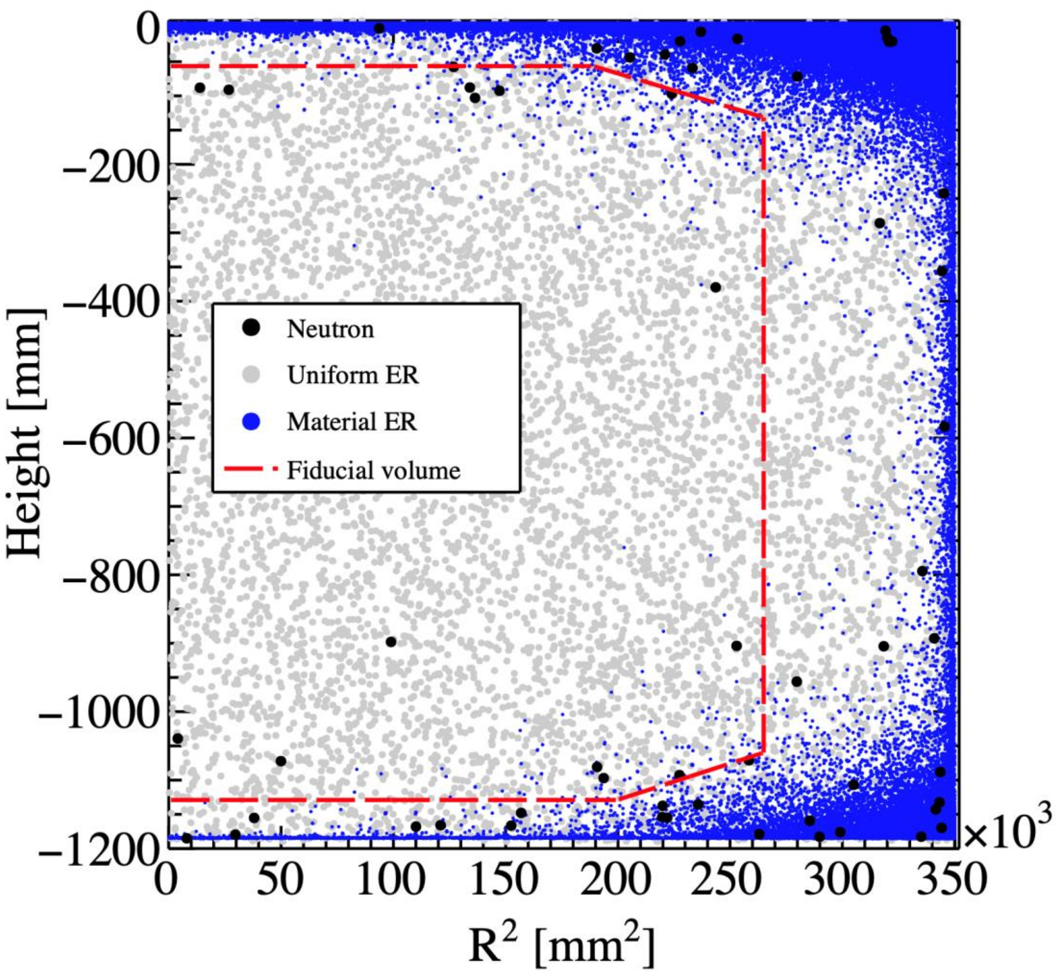
Accidental background





- Expected accidental background: 2.4 ± 0.5 events

FV determination



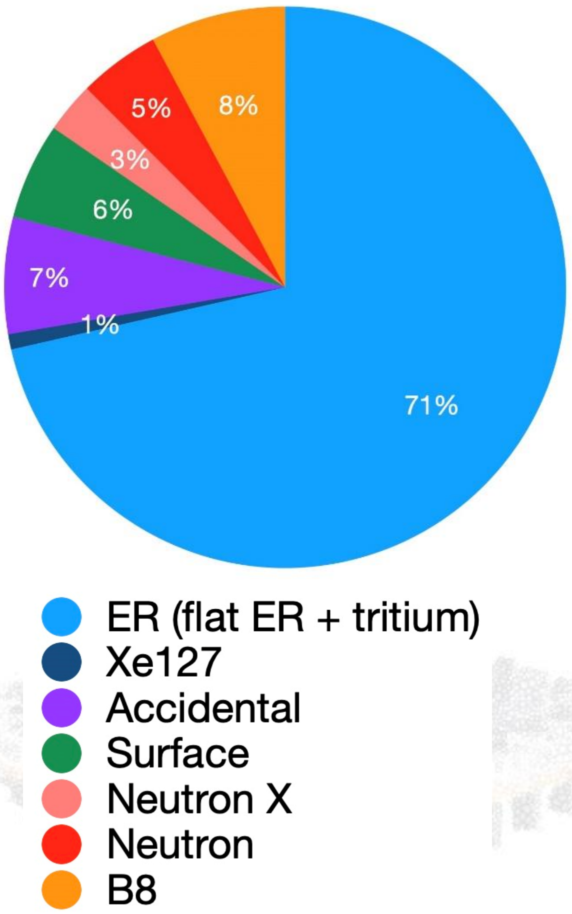
- Based on background simulation (10 t-year)
- Uniform ER (including tritium) normalization come from data
- Define FoM = sqrt(B)/M
- Best FV = 2.67 tonne
- FV cuts in the data maintaining the same FV (correcting for reconstruction bias)

Background composition

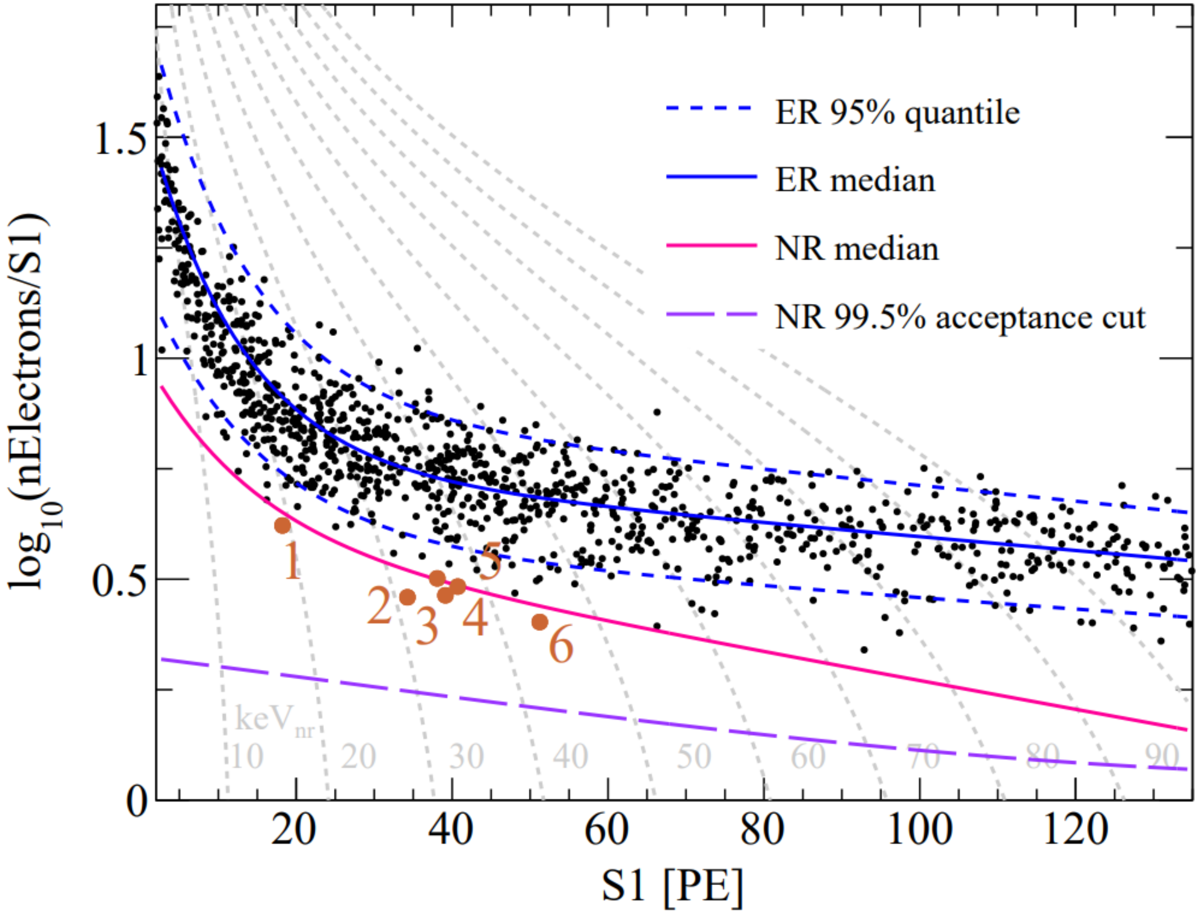
Component	Nominal (evts)
^{3}T (from fit to data)	527 (50)
Flat ER* (18-30keV side band)	492 (31)
Rn	347 (190)
Kr	53 (34)
Material	33 (4)
Xe127	9 (2)
Neutron	0.9 (0.4)
Neutron-X	0.4 (0.2)
Surface	0.6 (0.2)
Accidental	2.4 (0.5)
B8	0.8 (0.4)
Sum	1033 (59)

- Flat ER (Rn+Kr+Material) is determined from side band in DM data
- Background per unit target is improved from PandaX-II by 4 times (<10 keV)

Expected below-NR-median events: 10.3 (1.0) evts

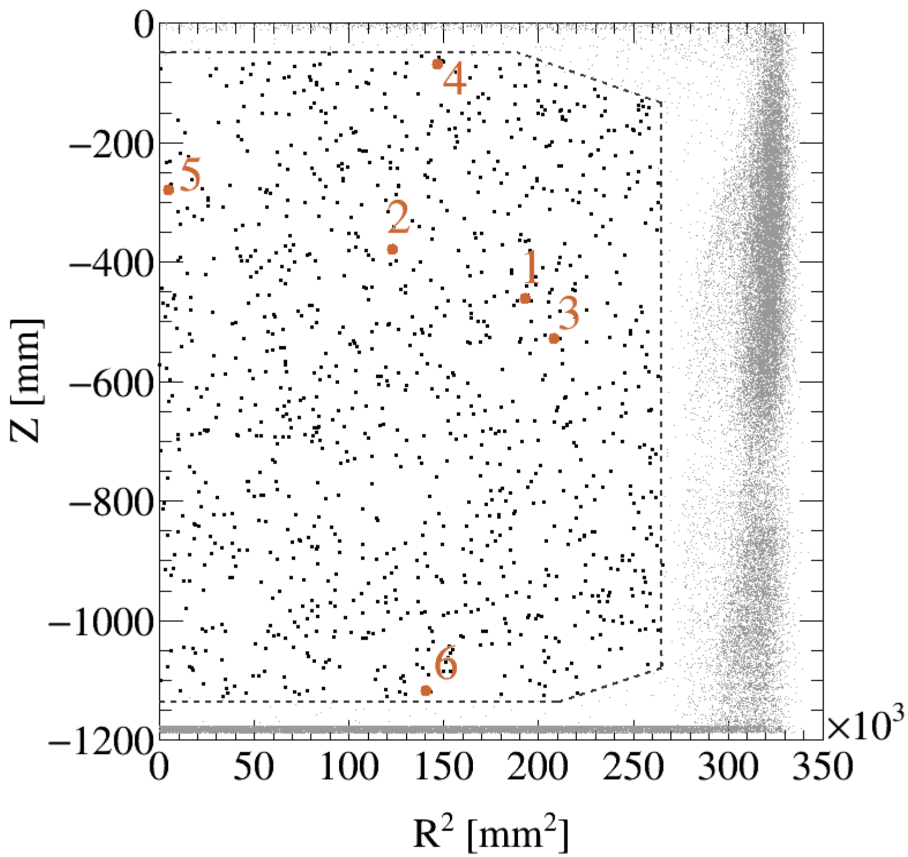


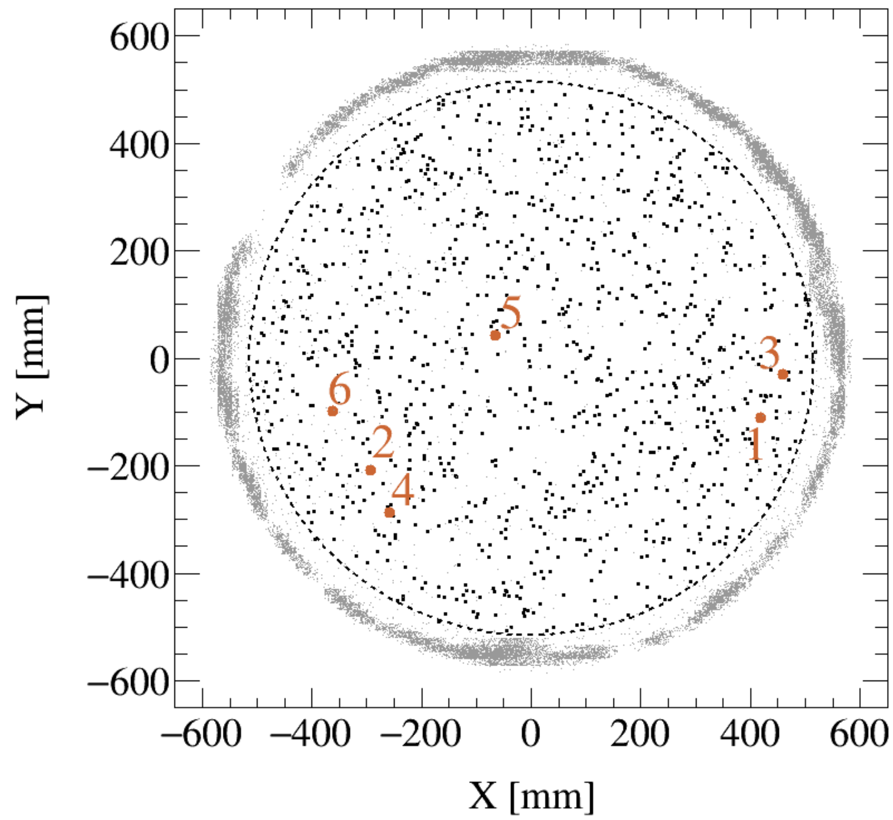
Dark matter candidates



- S1 = (2, 135) PE, $S2_{raw}$ > 80 PE, S2 < 20000
- In FV, 1058 candidates
- 6 below NR median line

Position distributions

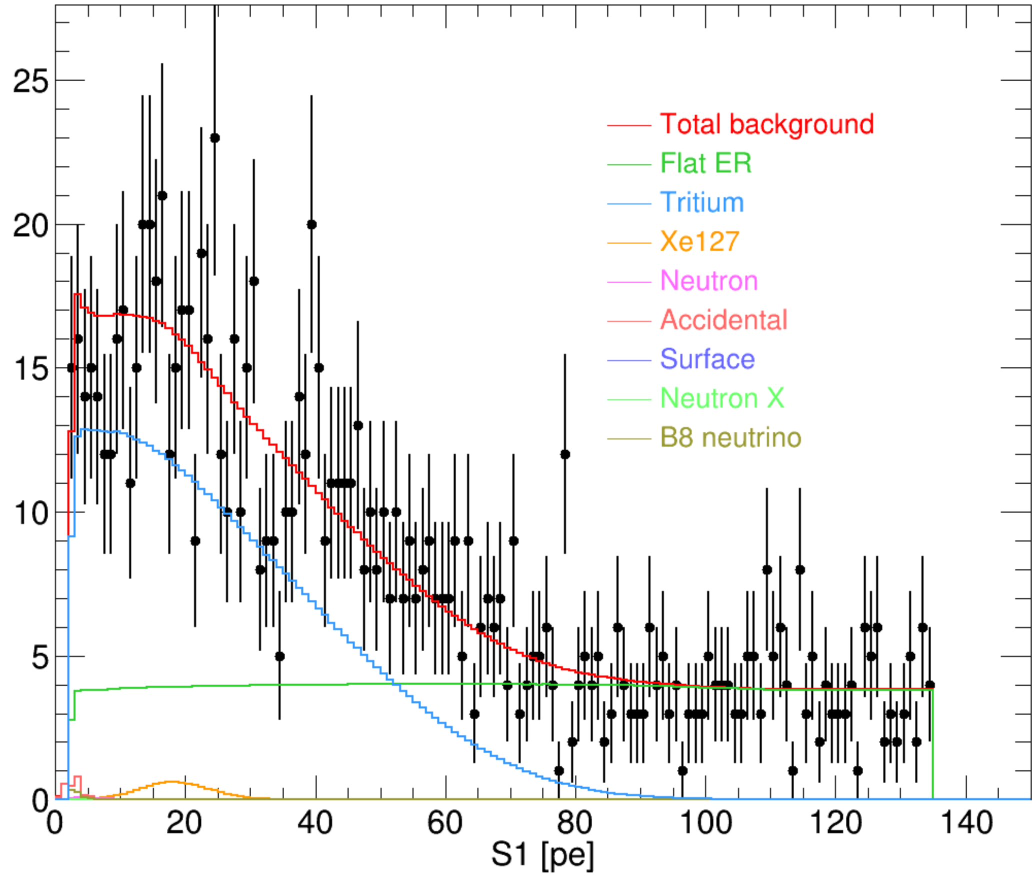




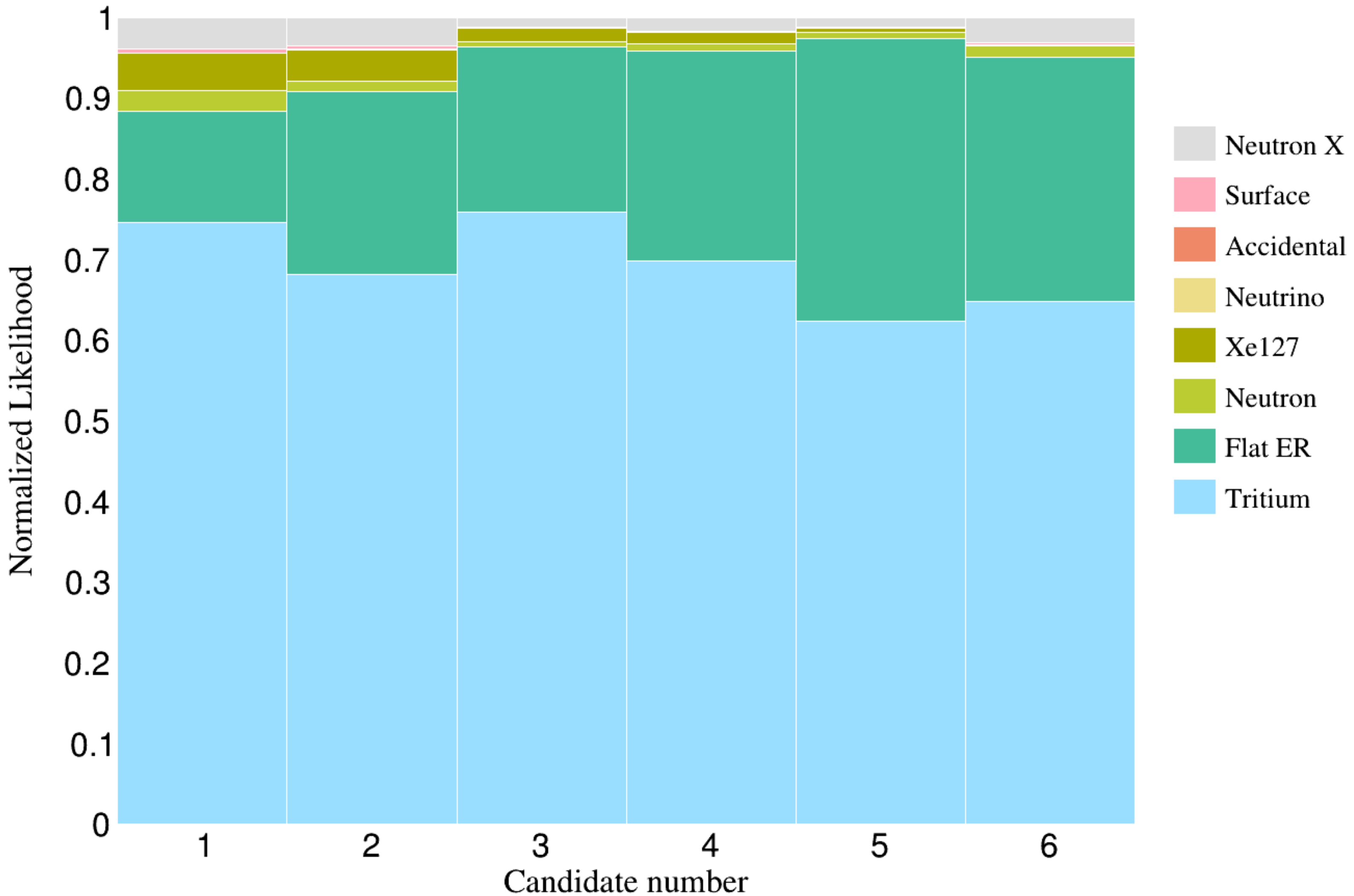
- Events uniformly distributed in the FV, expected if dominated by tritium and radon.

Spectral comparison

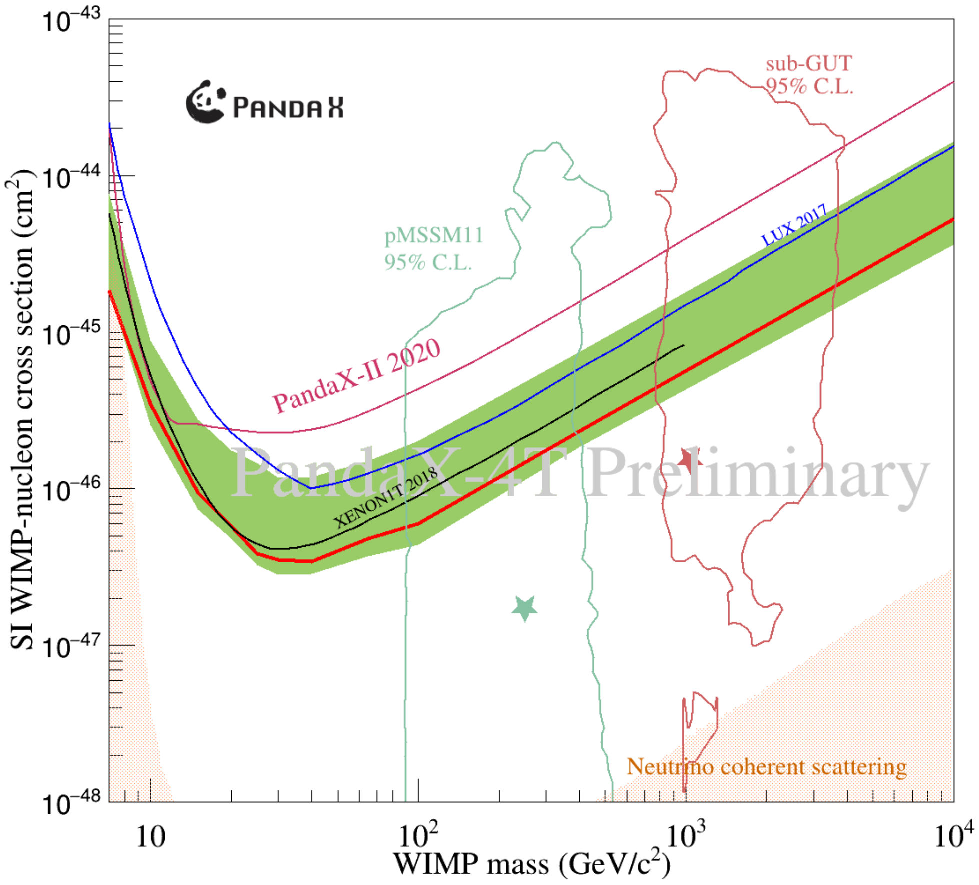
- Fit data with unbinned likelihood with all signal/background PDFs in ($S1$, $S2_b$)
- No excess found, background-only p-value 0.7
- Spectrum agrees with expected background



Likelihoods of the six below-NR events



WIMP-nucleon SI exclusion limits



SUSY benchmark contours (MasterCode)

EPJC 78, no.3, 256 (2018), EPJC 78, 158 (2018)

- Exposure: 0.63 tonne•year
- Sensitivity improved from PandaX-II final analysis by 2.8 times (40 GeV/c^2)
- Our limit is ~1.3 times stronger than XENON1T around 40 GeV/c^2
- Dived into previously unexplored territory!
- Approaching the "low E" neutrino floor

Conclusion and outlook

- PandaX-4T has completed its commissioning run
- With a 0.63 tonne•year exposure, PandaX-4T produced the strongest WIMP-nucleon interaction constraint (arXiv shortly)
- This demonstrates the physics potential of a highly sensitive multi-ton liquid xenon detector (dark matter, neutrinos, …)
- PandaX-4T is currently performing an offline tritium removal campaign, aiming to reduce the electron recoil background by at least two-fold
- In parallel, the collaboration is developing the plan for the next generation experiment at CJPL

Charge pattern of ^{83m}Kr event