First Science Results from the XENONnT Experiment

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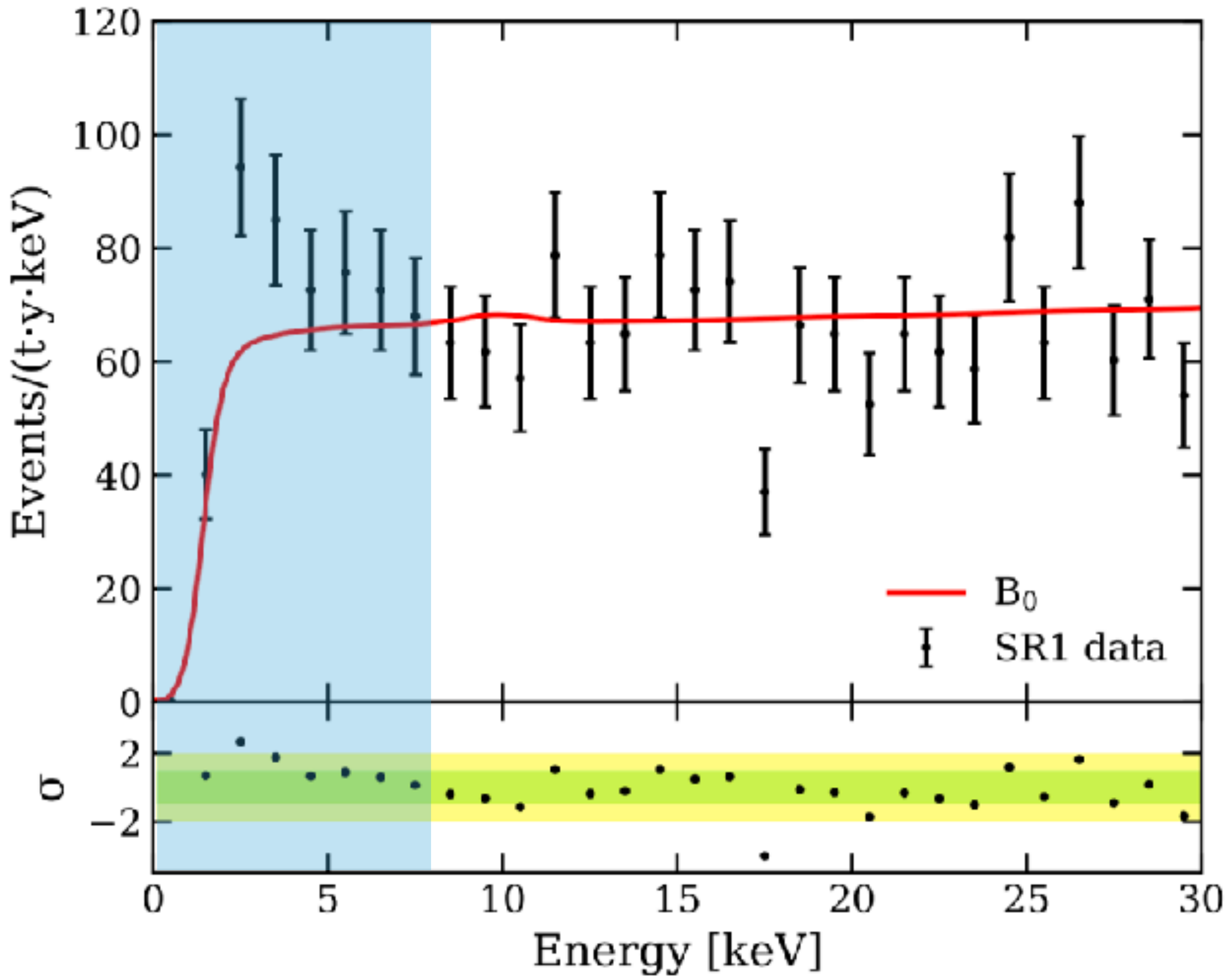
for the XENON collaboration @LIDINE2022

XENON Experiment

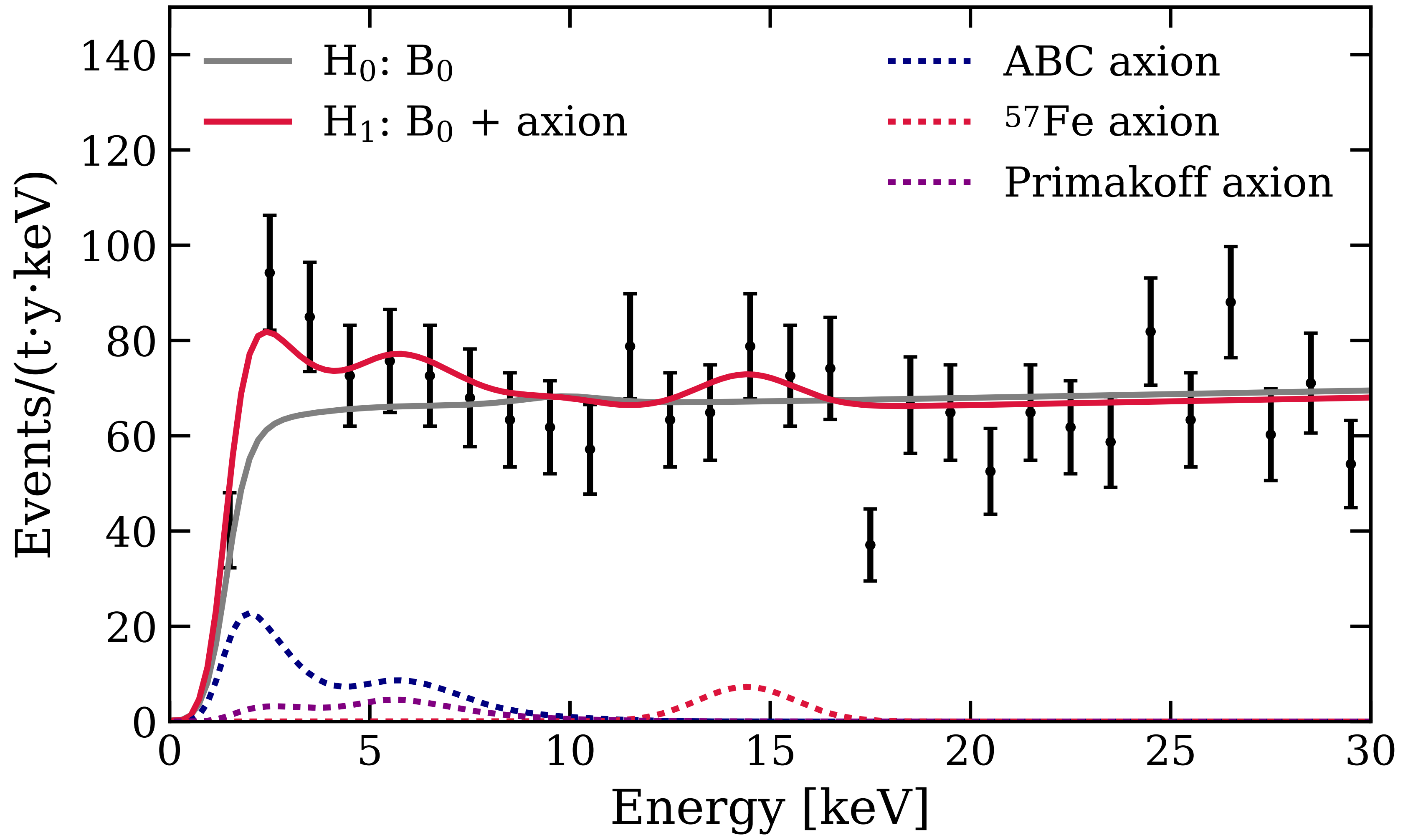
- XENONnT experiment at LNGS (Italy)
- 170 scientists, 27 institutions, 12 countries

Low-Energy Electronic Recoil Excess in XENON1T

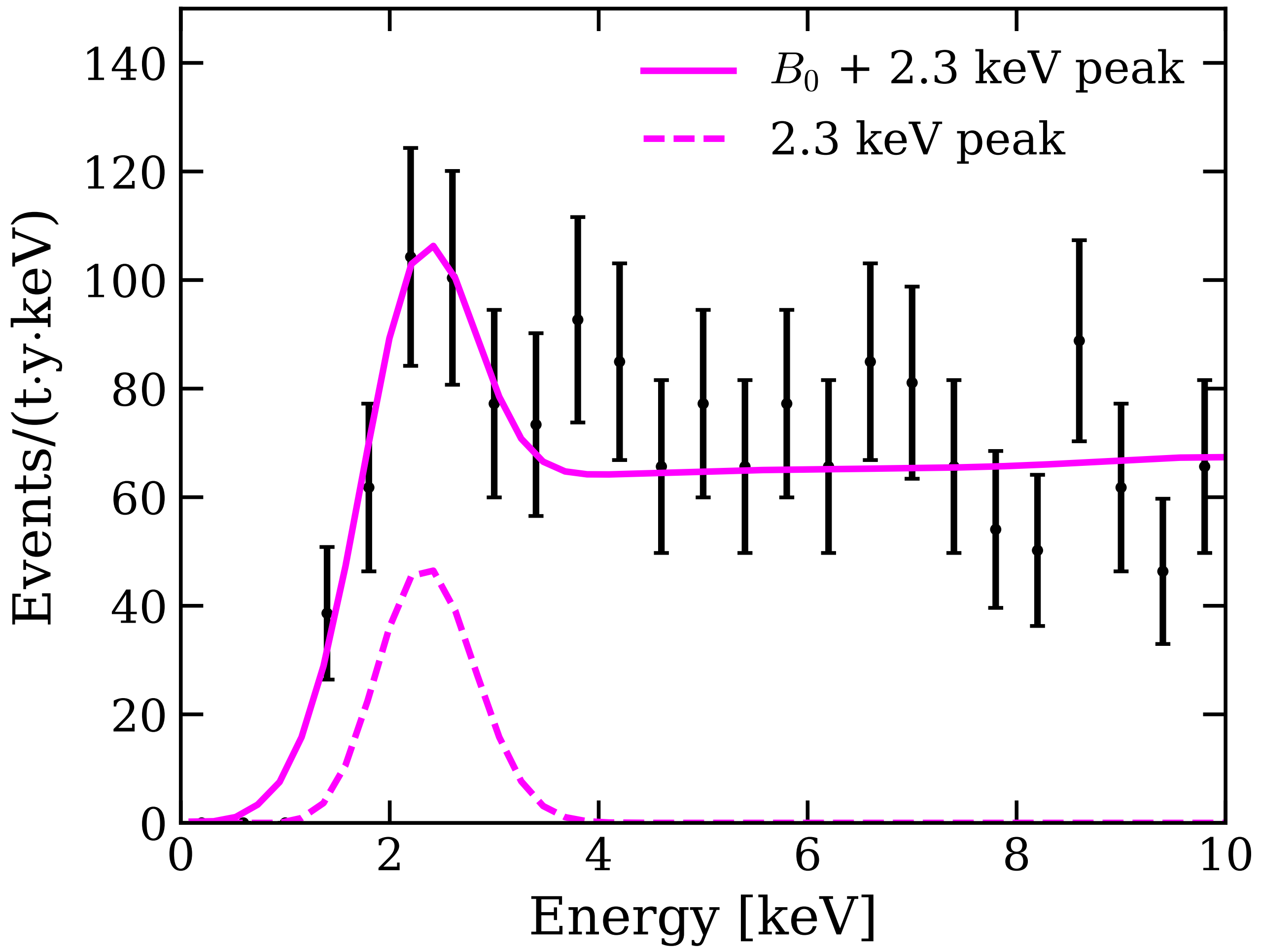


- XENON1T observed an excess near 2 keV (3.3σ)
- Excess compatible with solar axions, ALPs, dark photons, neutrino magnetic moment and many more
- However, it is also consistent with tritium (HT, HTO)
- Investigate this excess with the initial XENONnT data

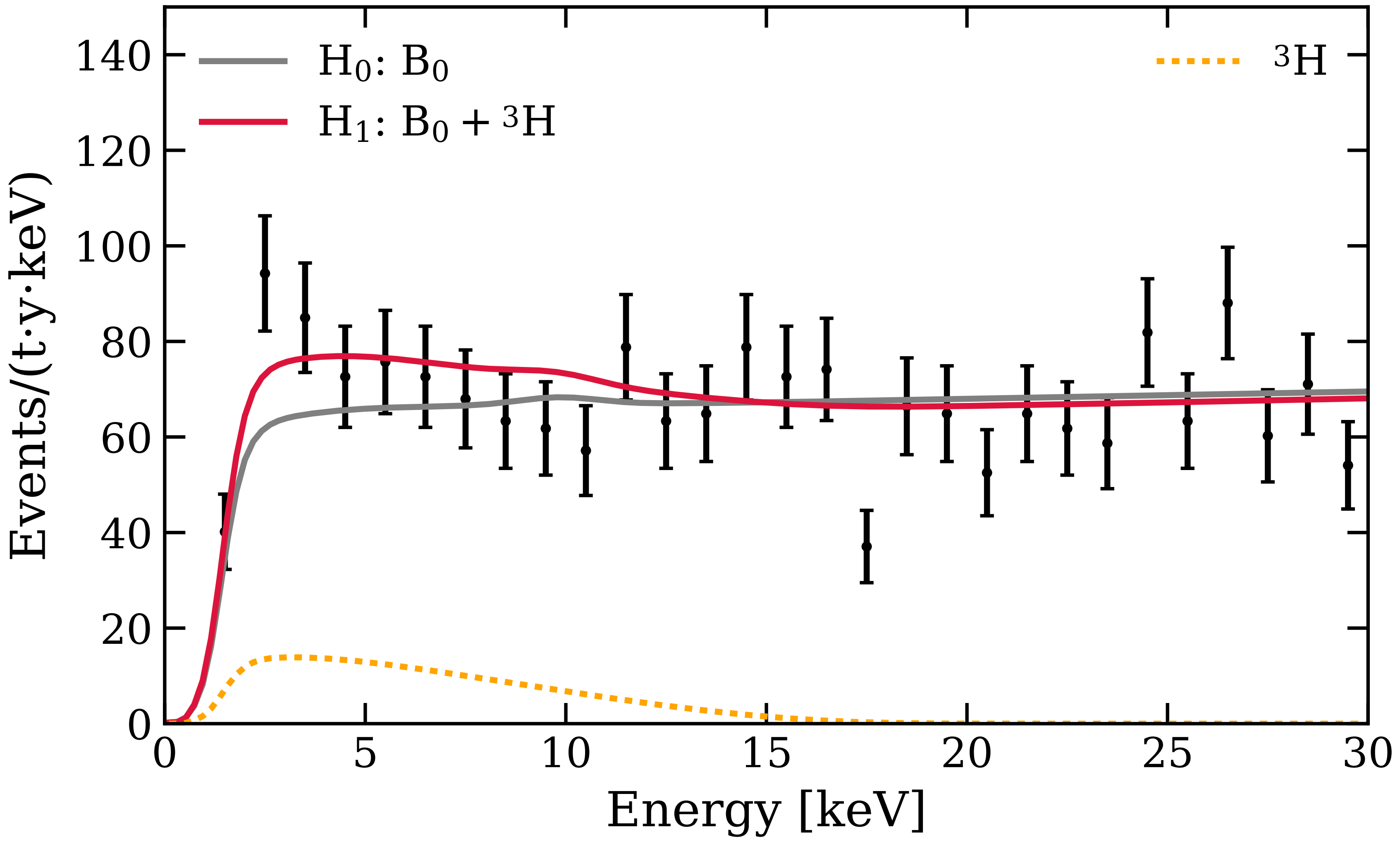
Solar-axion



ALPs/Dark Photon



Tritium

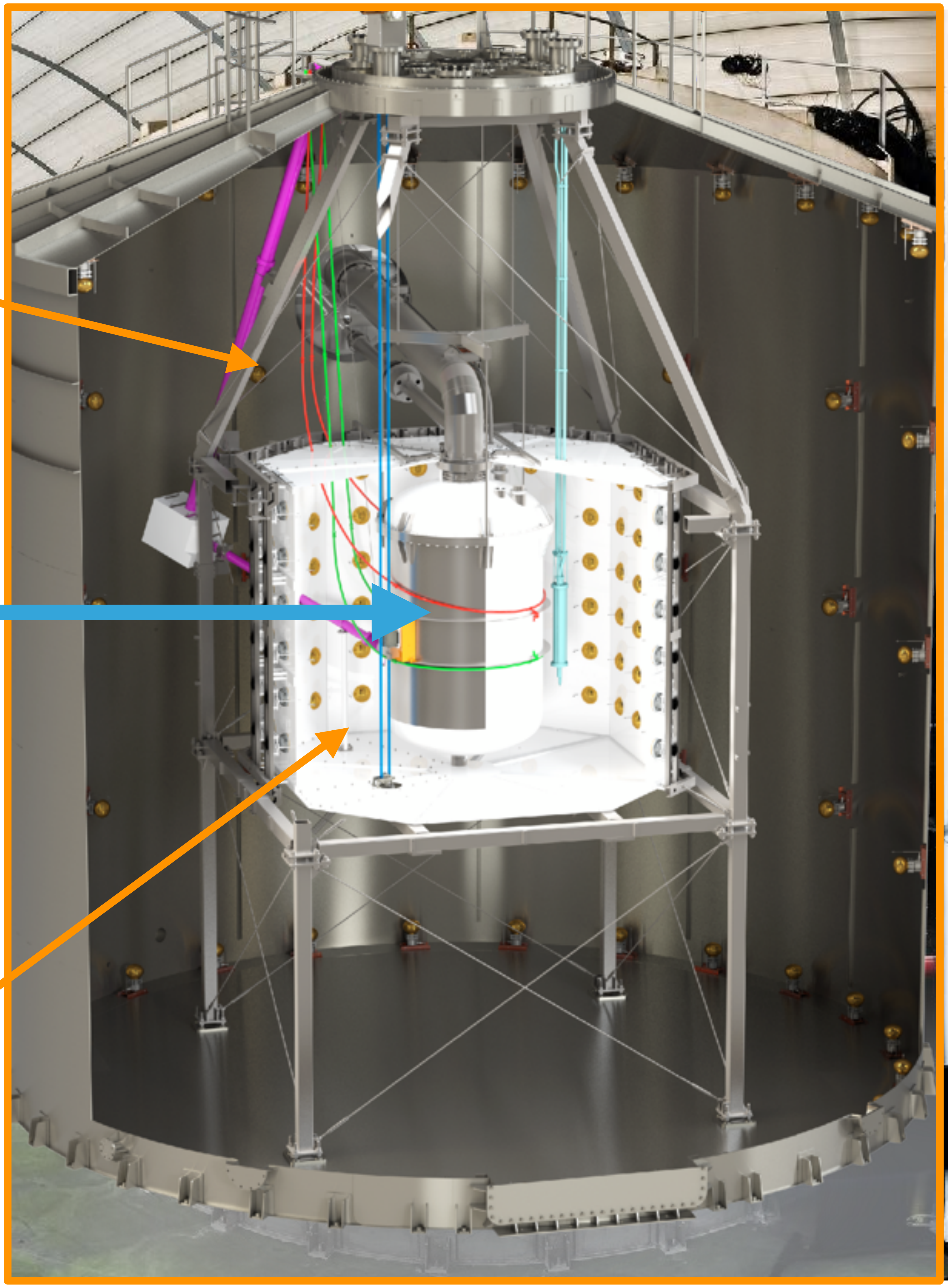


The XENONnT Detectors

New ER and NR calibration systems

Larger TPC with 3x active volume

Gd-loaded water Cherenkov neutron veto

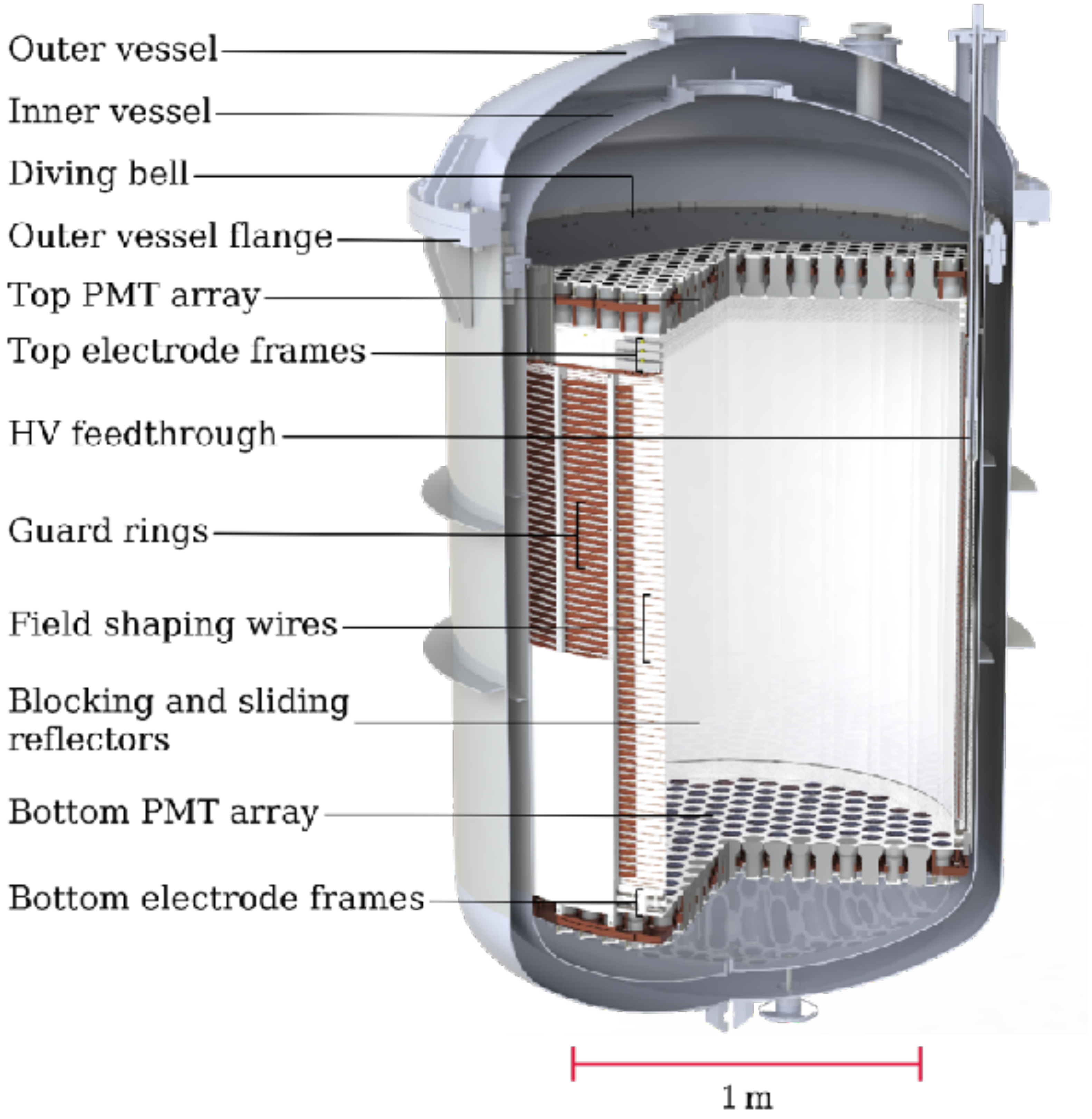


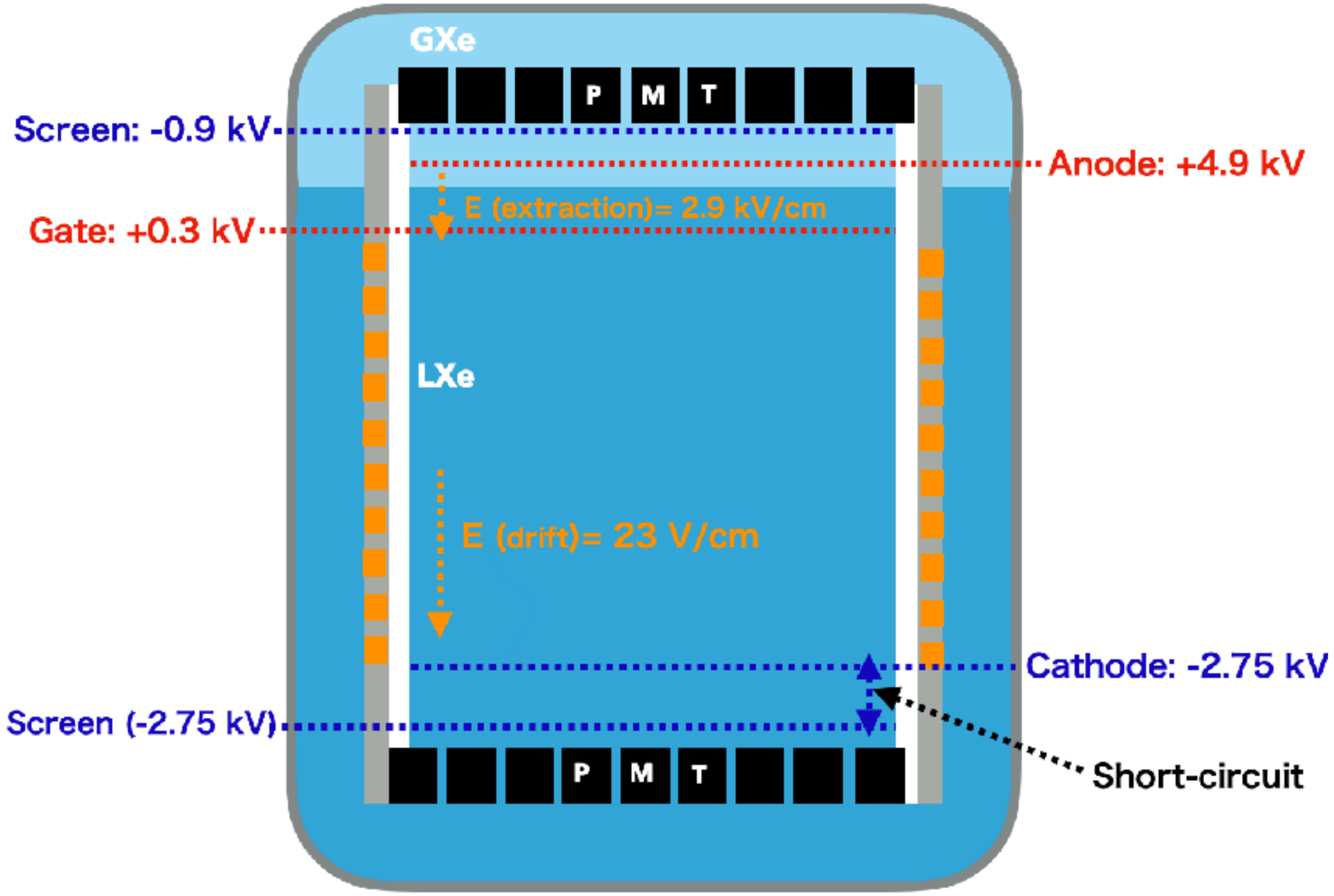
Radon distillation column

Upgraded DAQ with dedicated high-energy readout

Liquid xenon purification

TPC



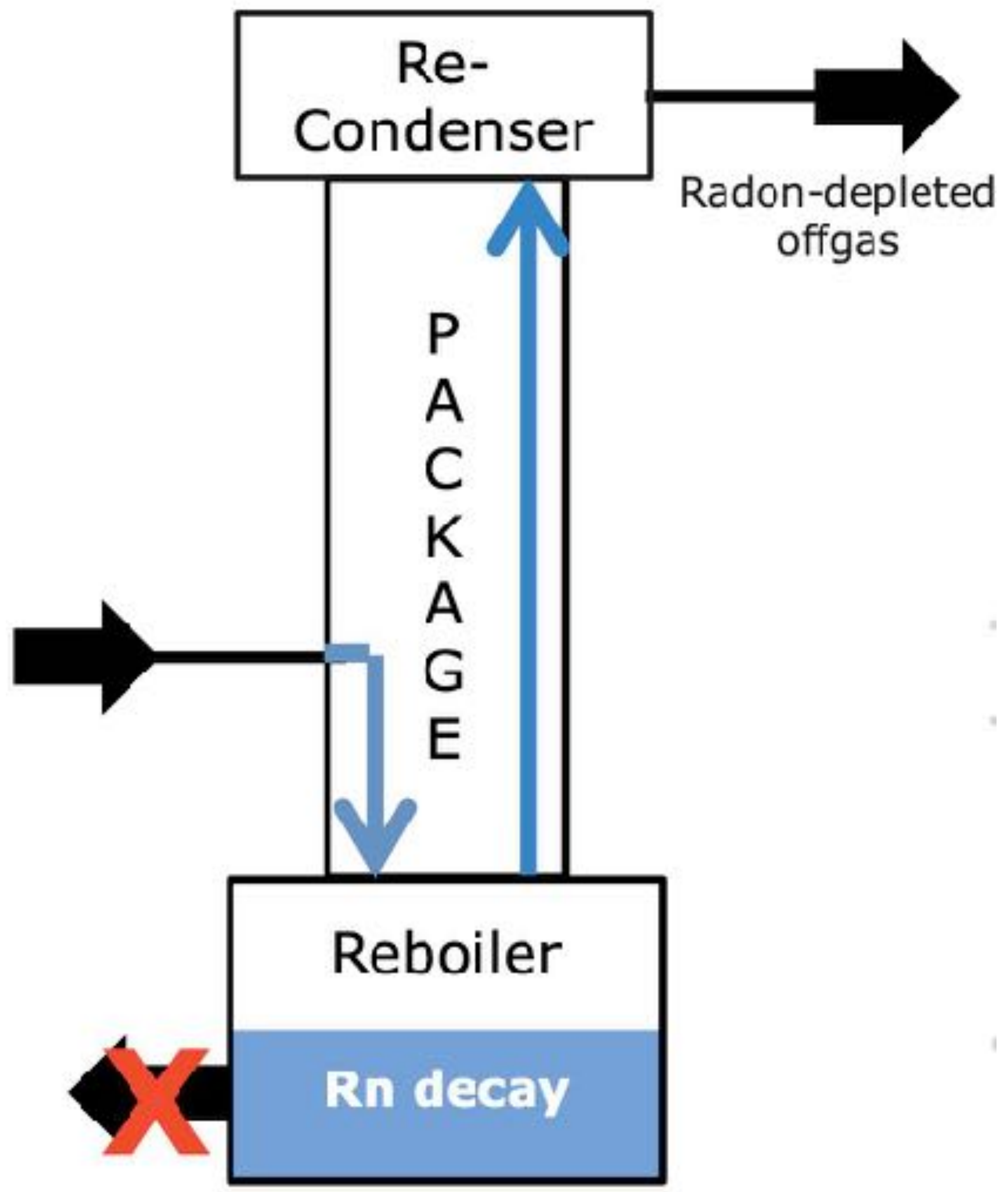


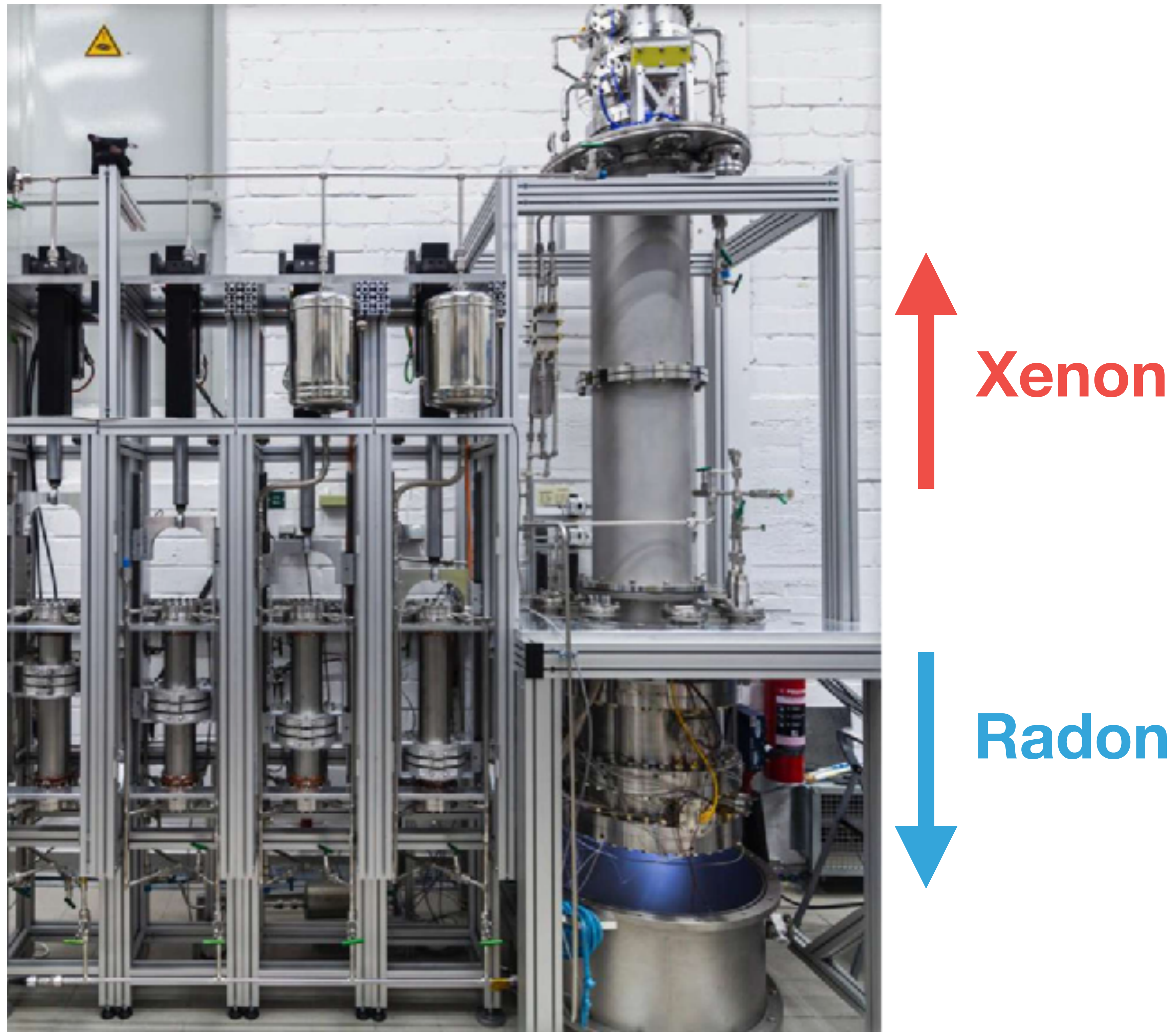
- 1.3 m diameter and 1.5 m height
- 5.9 t xenon instrumented, 8.5 t total xenon
- 5 electrodes and 2 sets of field shaping rings
- PTFE reflectors to maximize light collection efficiency (LCE ~ 36%)

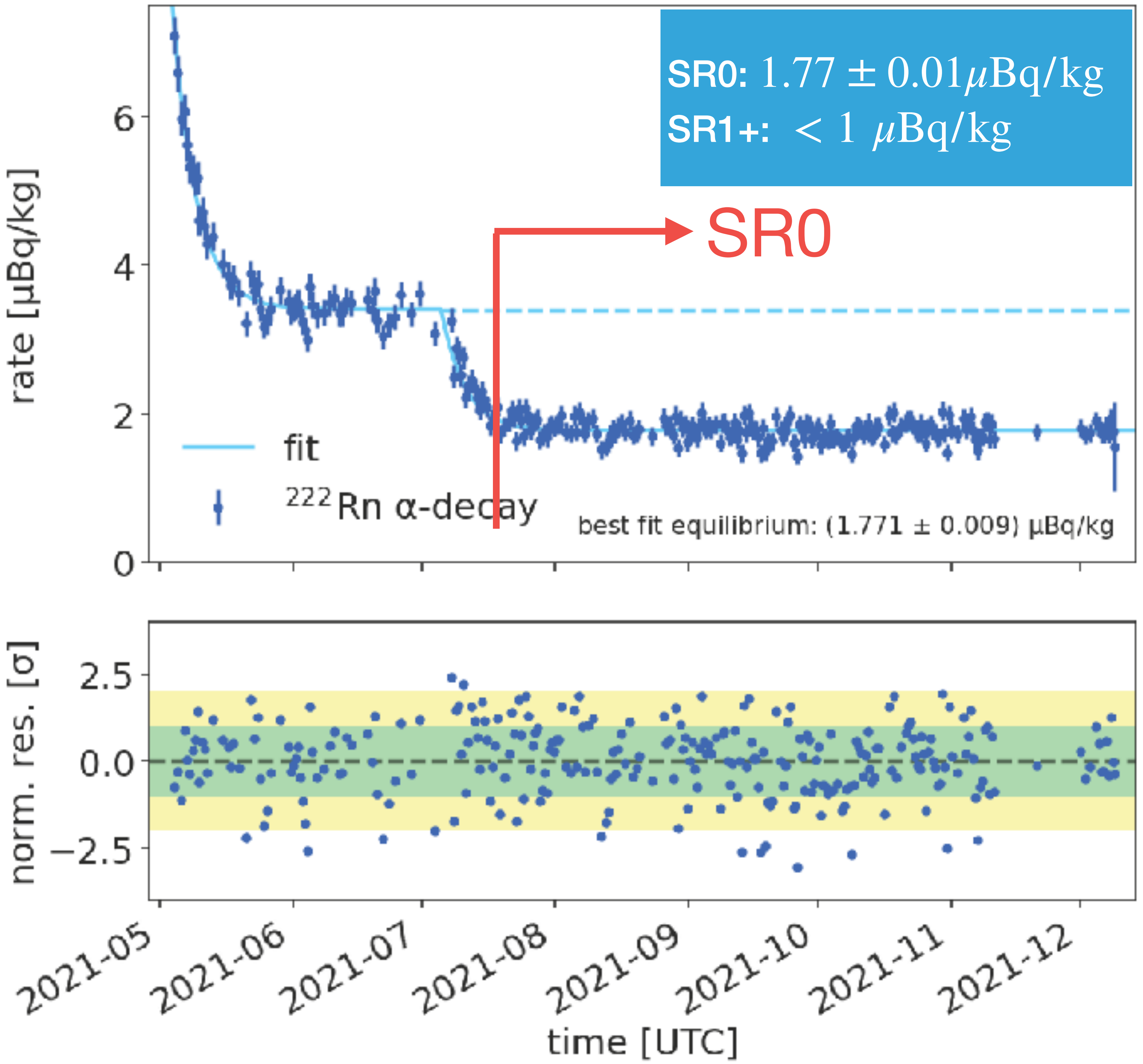
- 494 3” PMTs (R11410-21) in the top/bottom array (QE ~ 34%)
- Anode/Gate: SUS (216 μm), Cathode: SUS (304 μm)
- short-circuit between the cathode and bottom screen limited the cathode voltage to −2.75 kV

Radon Distillation

Eur. Phys. J. C 77, 275 (2017)
PTEP Vol 2022, Issue 5, May 2022
Eur. Phys. J. C 77, 358(2017)
M.Murra et al, arXiv:2205.11492

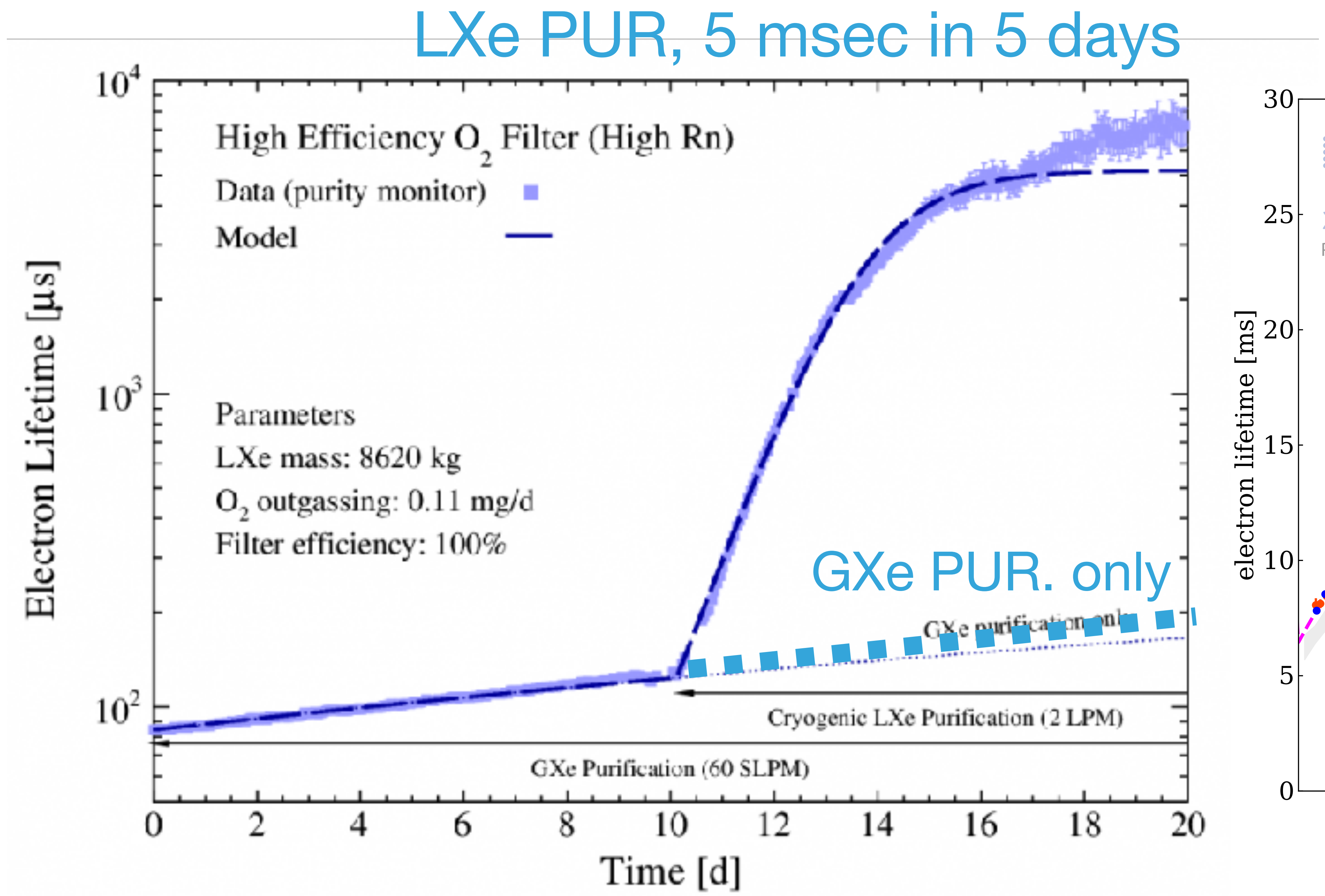


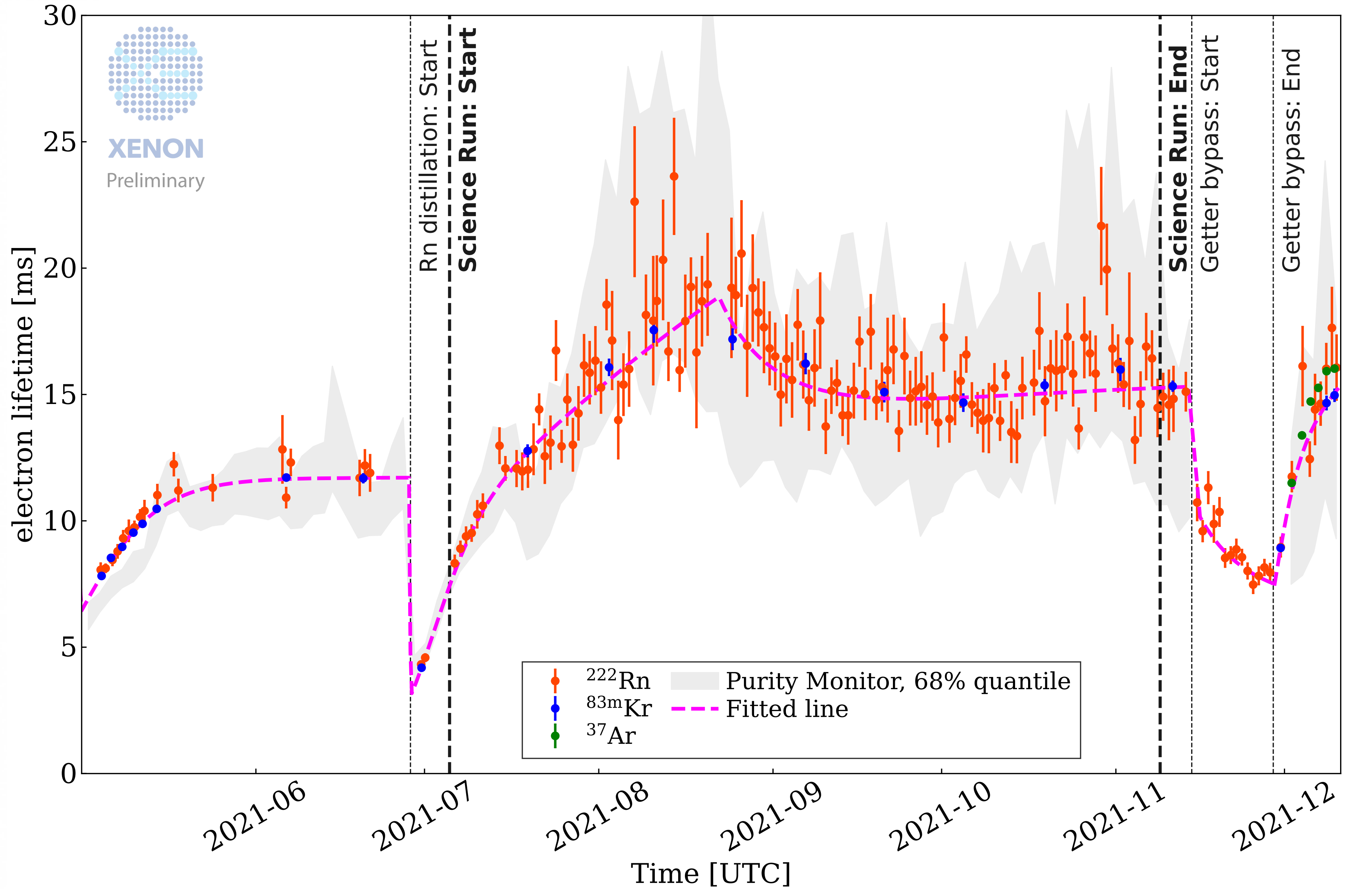




- Constant removal of emanating Rn using difference in vapor pressure (Rn atom accumulates into LXe more than GXe)
- Design: 1 μBq/kg ^{222}Rn level (XENON1T: 13 μBq/kg)
- Reached equilibrium concentration of 1.77 ± 0.01 μBq/kg by gas extraction only (~8 times less w.r.t. 1T)
- Reaching < 1 μBq/kg via liquid extraction in the following science runs

LXe Purification

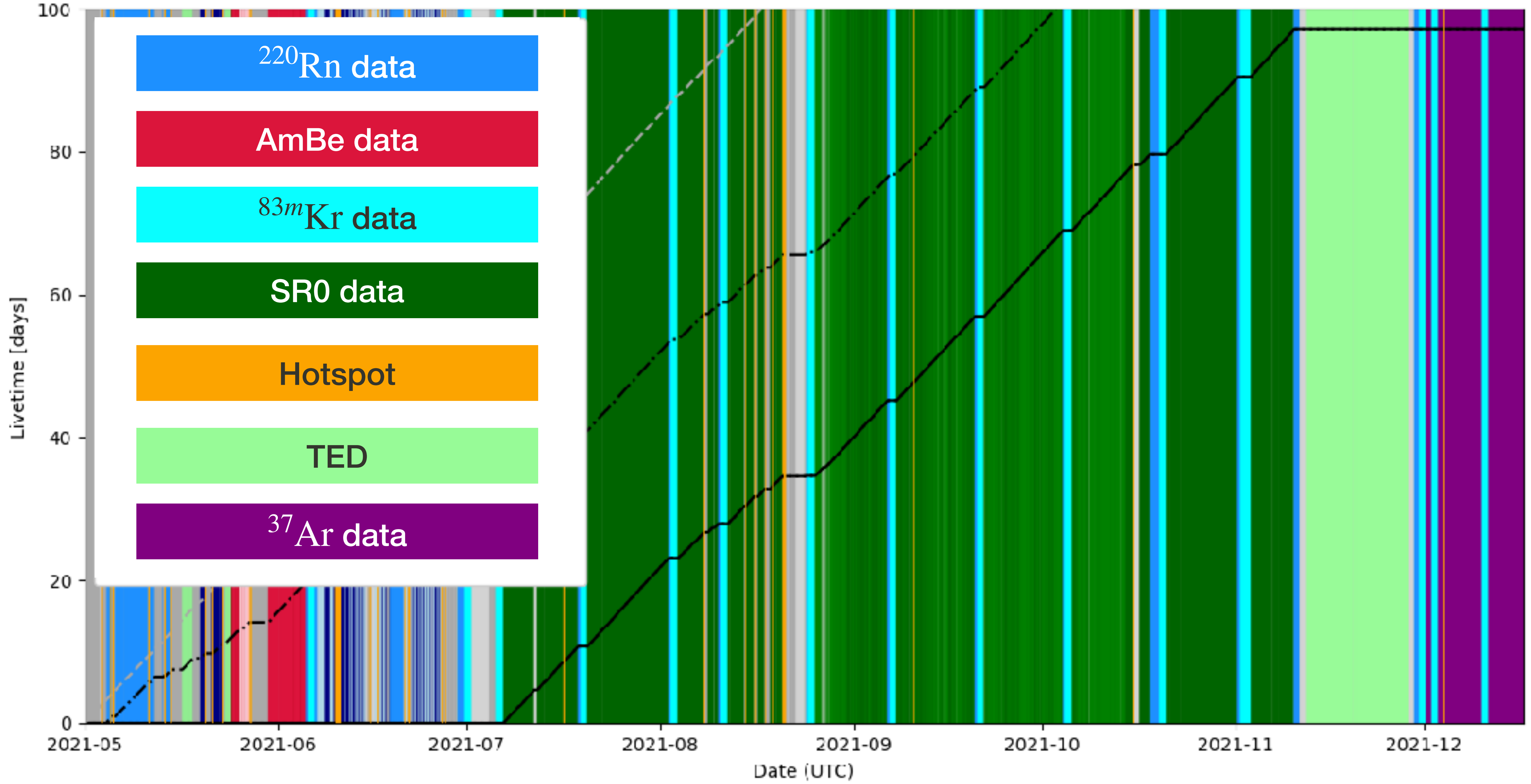


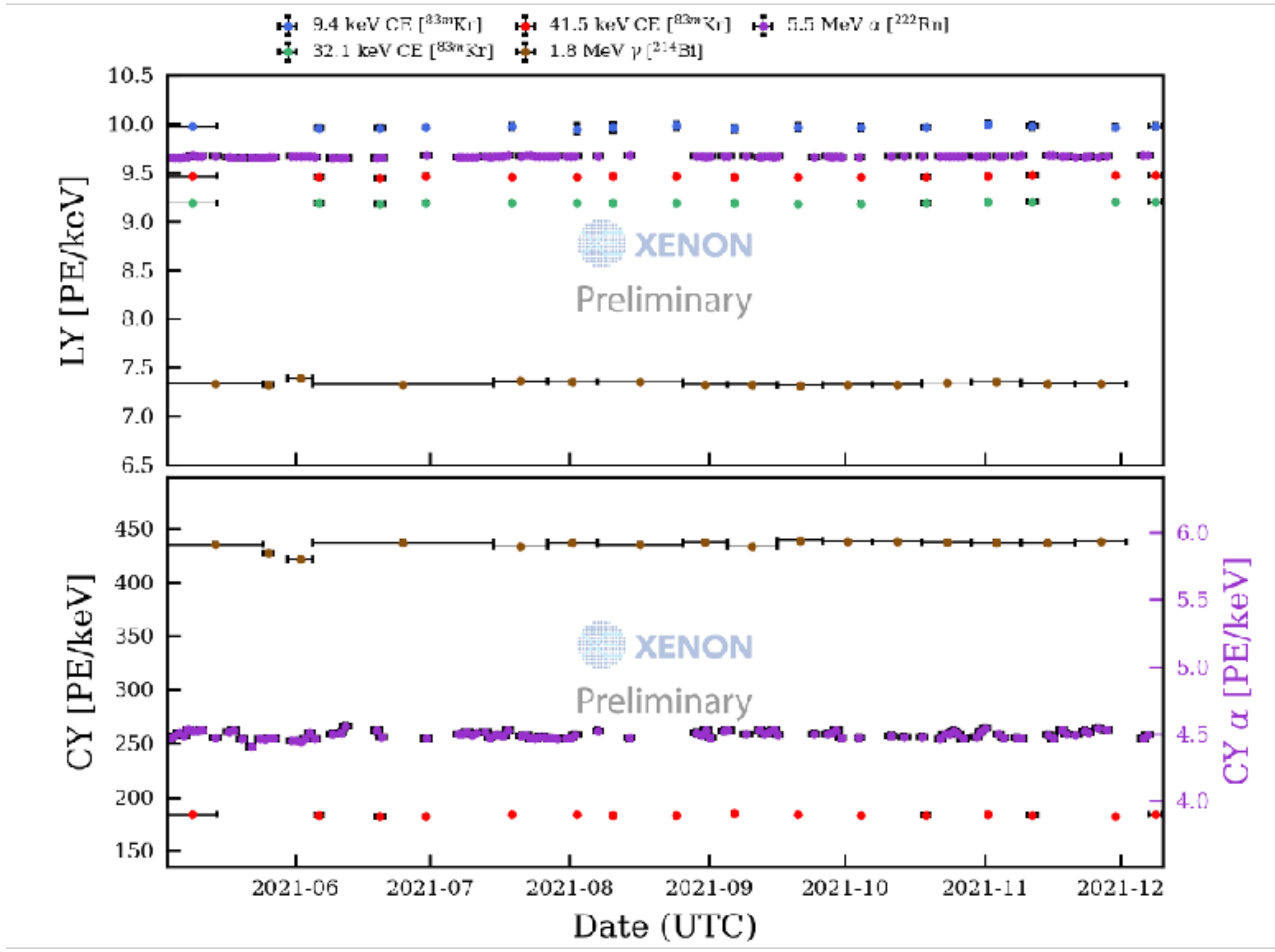


- Direct liquid circulation with cryogenic pump
  - 2 LPM (18h to exchange the entire volume of 8.5 ton)
- Multiple filters
  - Cu: High eff / high Rn (for fast purification)
  - Getter: Mid eff / low Rn (for science runs)

	Full TPC drift time	electron lifetime	electrons surviving a full drift length	O_2	Purification speed
XENON1T	0.67 ms	0.65 ms	30%	~ 1 ppb	0.65 ms in ~3months
XENONnT	2.2 ms	> 10 ms	> 90%	~ 0.02 ppb	5ms in ~5 days

First Science Run of XENONnT (SR0)



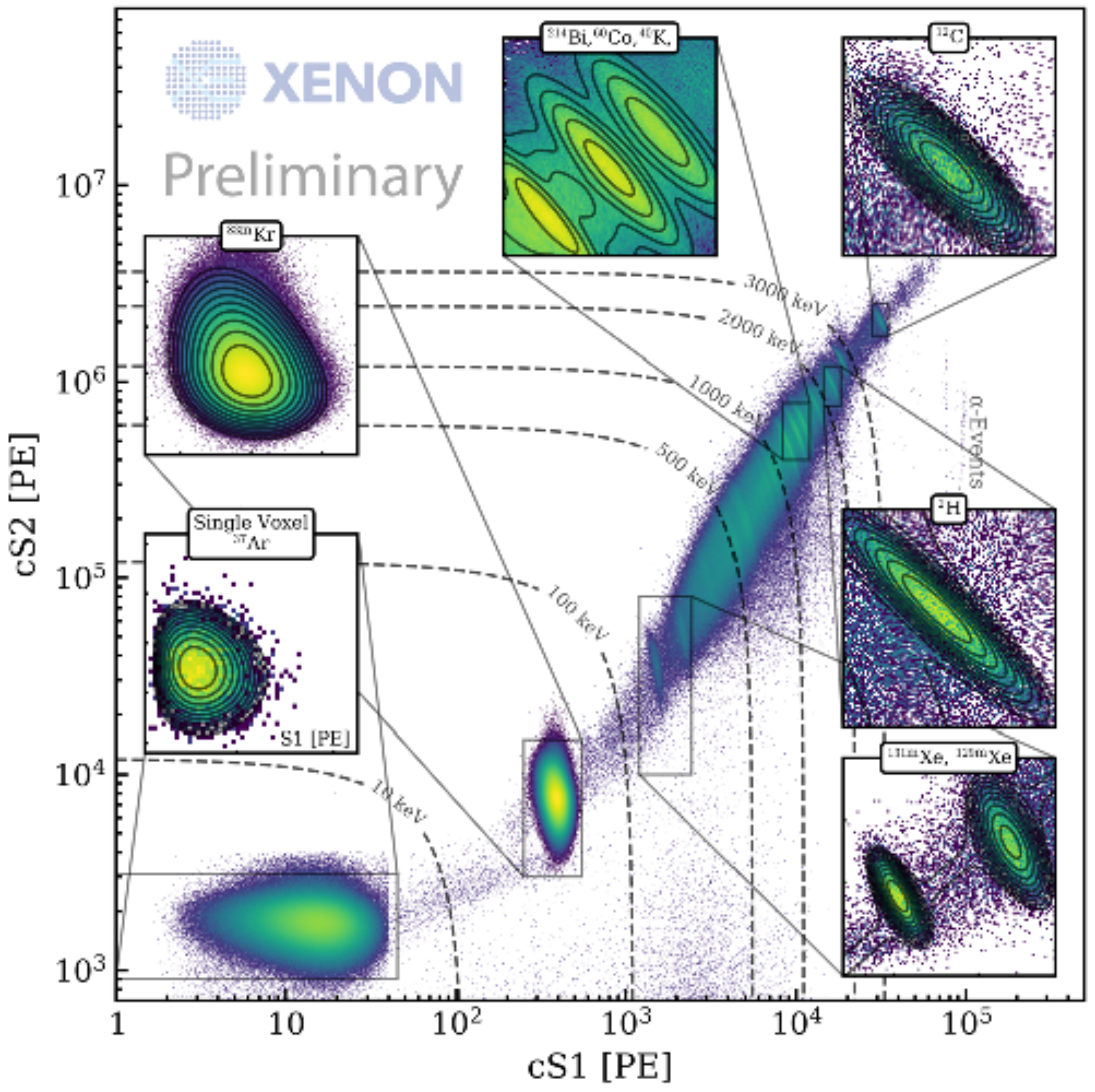


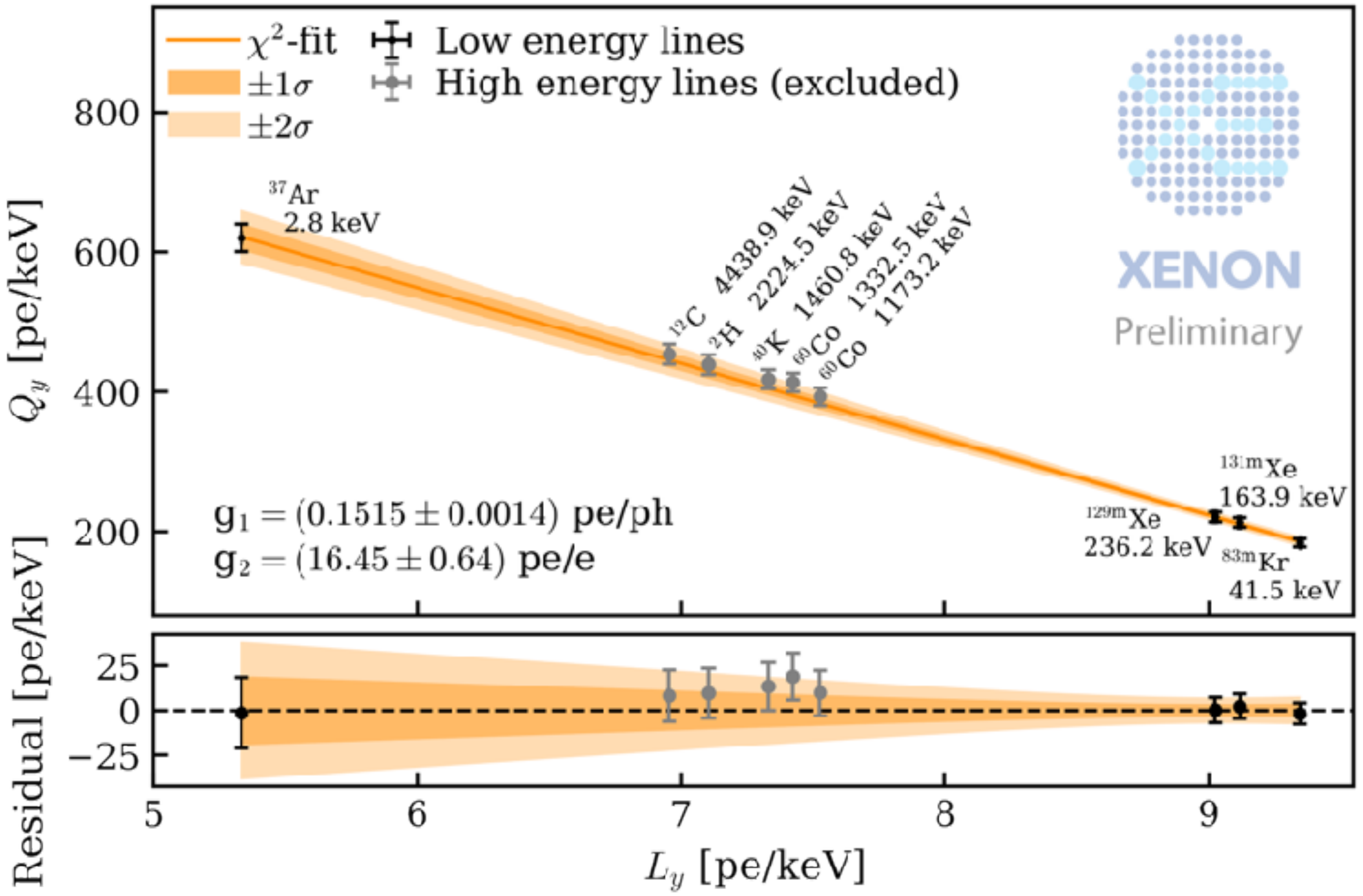
- Livetime: 97.1 days
- FV: (4.37 ± 0.14) tonnes
- Exposure: 1.16 t-yr
- Drift field: ~23 V/cm
- Extraction field: ~2.9 kV/cm
- Localized high single-electron emission occurring at random, anode ramped down
- e-lifetime: > 10 msecn
- 477/494 working PMTs (Gain stable < 3%)
- ER and NR blinded analysis
- Alphas from ^{222}Rn and gammas from materials used for monitoring light and charge yields. Fluctuations within 1% and 1.9% respectively

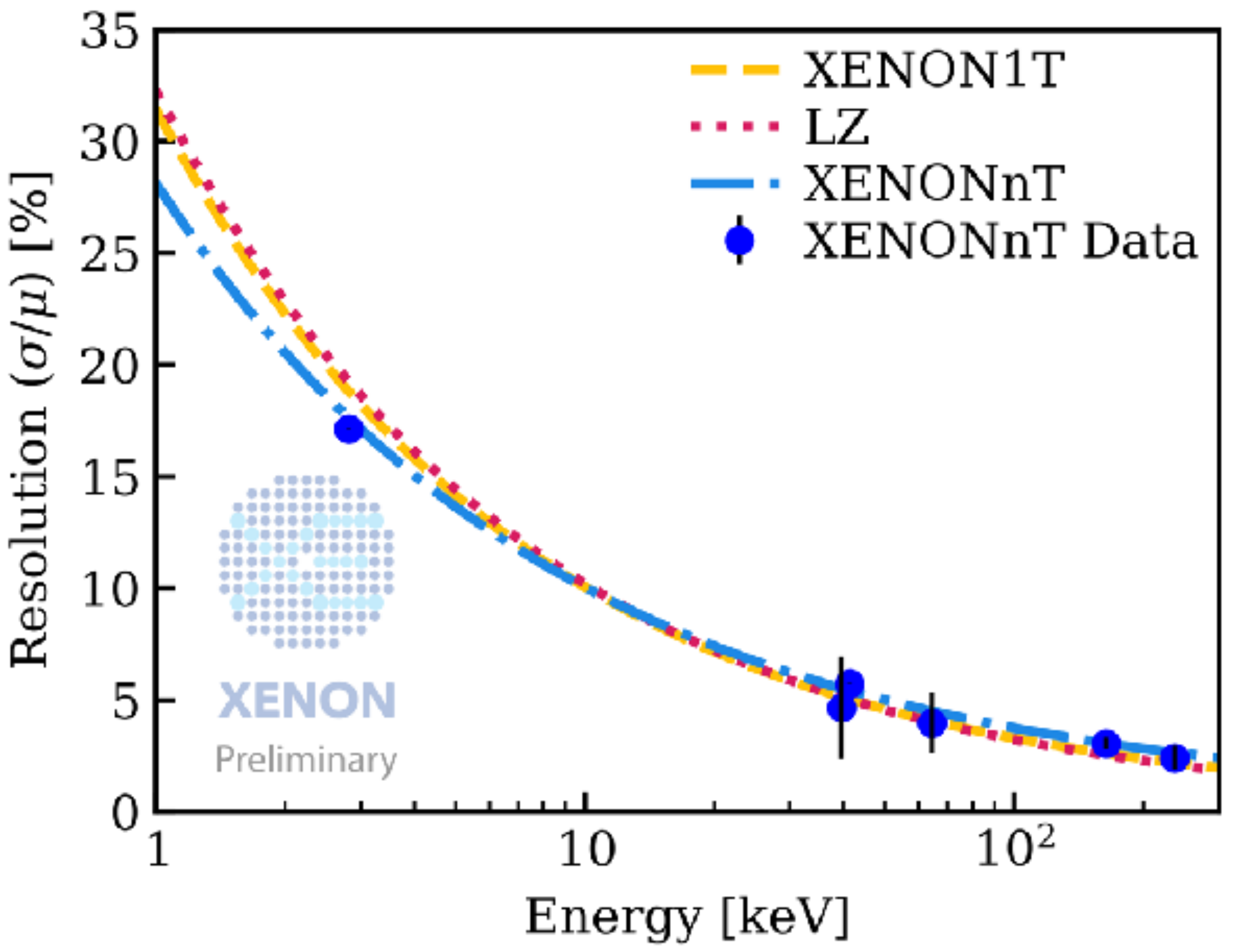
Energy Calibration

- Calibration sources: ^{37}Ar, ^{83m}Kr, ^{129m}Xe, and ^{131m}Xe
- Reconstruction has not been optimized for high-energy events (~ MeV)
- Energy resolution @ 2 keV ~ 17%

$$E = (n_{ph} + n_e) \cdot W = (\frac{cS1}{g1} + \frac{cS2}{g2}) \cdot 13.7(\mathrm{eV}) \rightarrow Q_y = -\frac{g2}{g1} \cdot L_y + \frac{g2}{W} \quad (Q_y = cS_2/E, \quad L_y = cS_1/E)$$







Data-Quality / Cuts

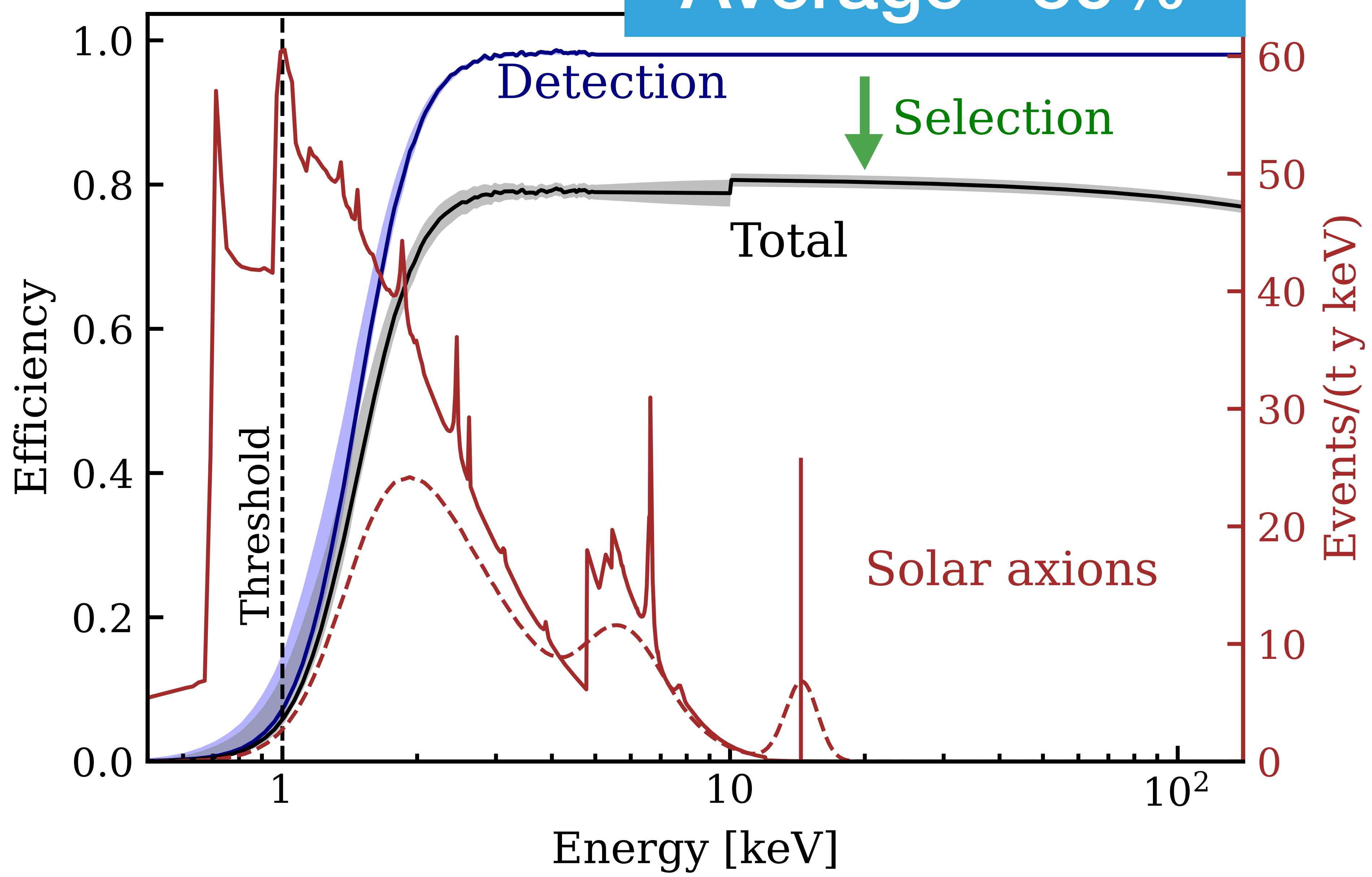
- Energy threshold is driven by 3-fold PMT-hits coincidence requirement in S1

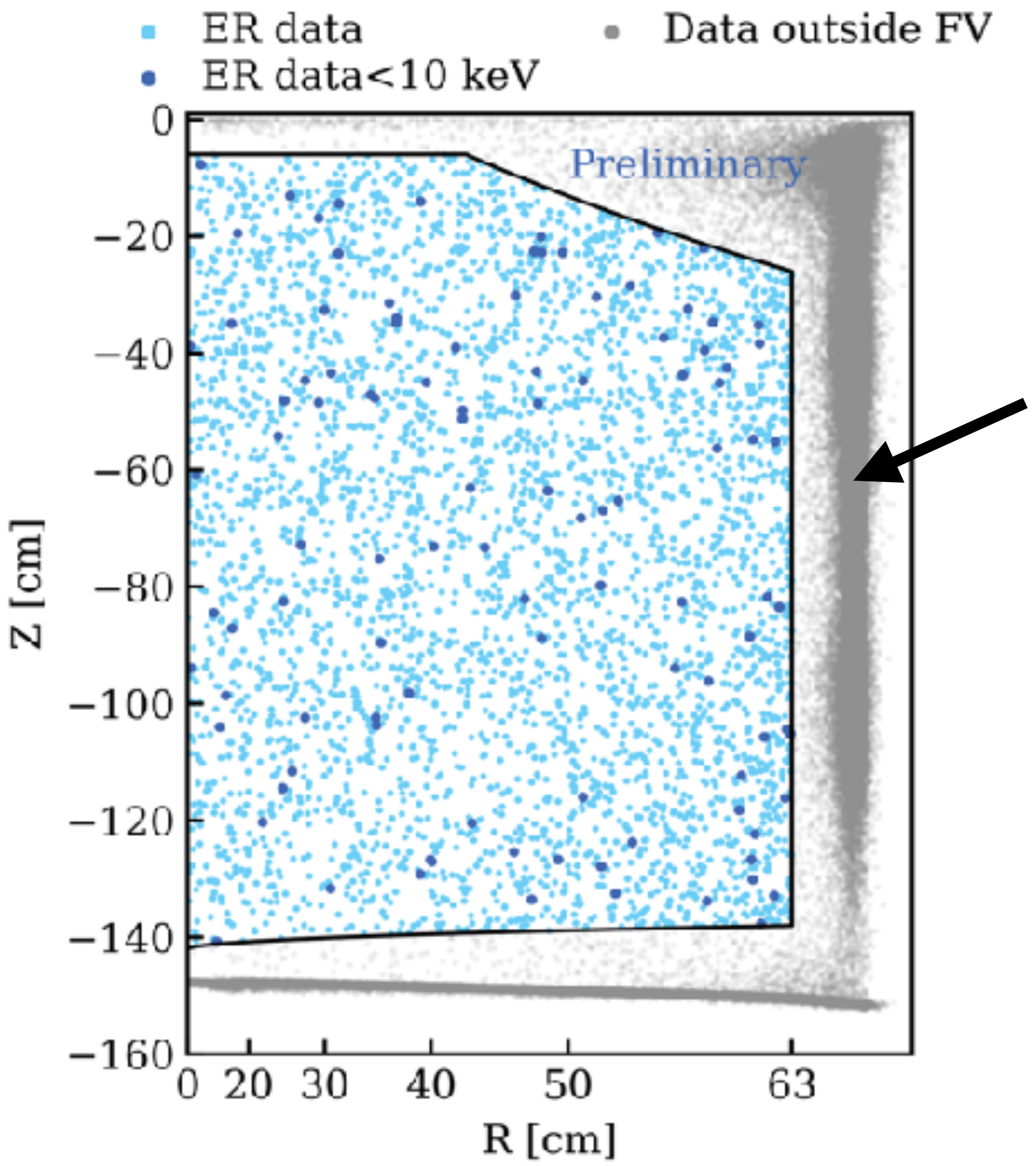
- Events required to pass a range of quality cuts:
  - S1 and S2 peak should each have patterns, top/bottom ratios etc. consistent with real events
  - An S2 width consistent with the expected diffusion
  - An S2 over 500 PE
  - Not within $< 300\ ns$ of a neutron veto event

- Fiducial volume cut selects a mass of (4.37 ± 0.14) tonnes with low backgrounds

→ 1.16 tonne – year (×2 larger FV w.r.t 1T)

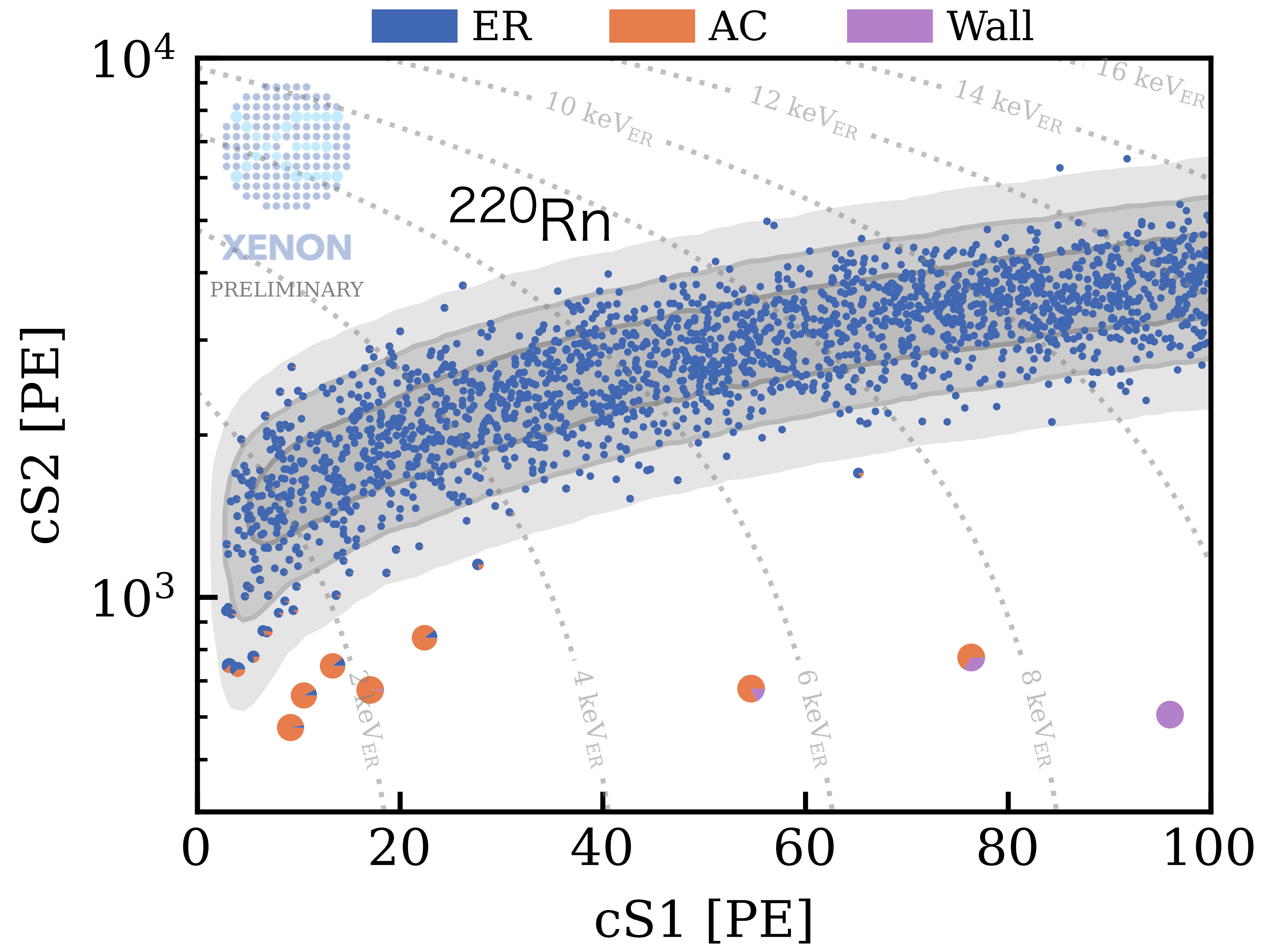
Average ~86%

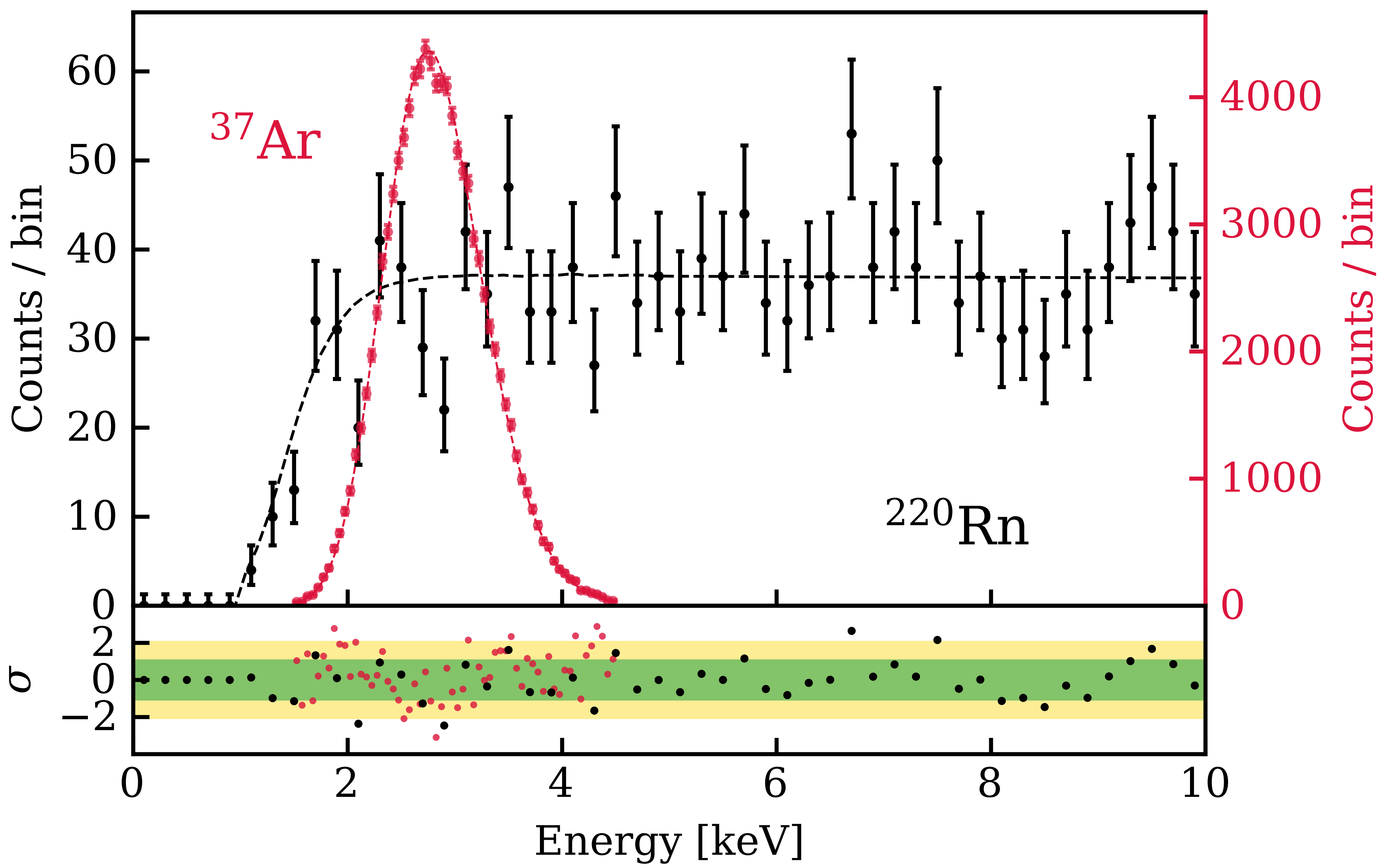




Material gamma BG

Low-Energy Calibration using ^{220}Rn and ^{37}Ar





- At low energy, we have two ER calibration sources:
  - ^{212}Pb from ^{220}Rn gives a roughly flat β-spectrum to estimate cut acceptances and also validates our threshold.
  - ^{37}Ar, which gives mono-energetic 2.82 keVpeak used to anchor the low-energy response and resolution models with high statistics

Good agreement between data and our models

Tritium

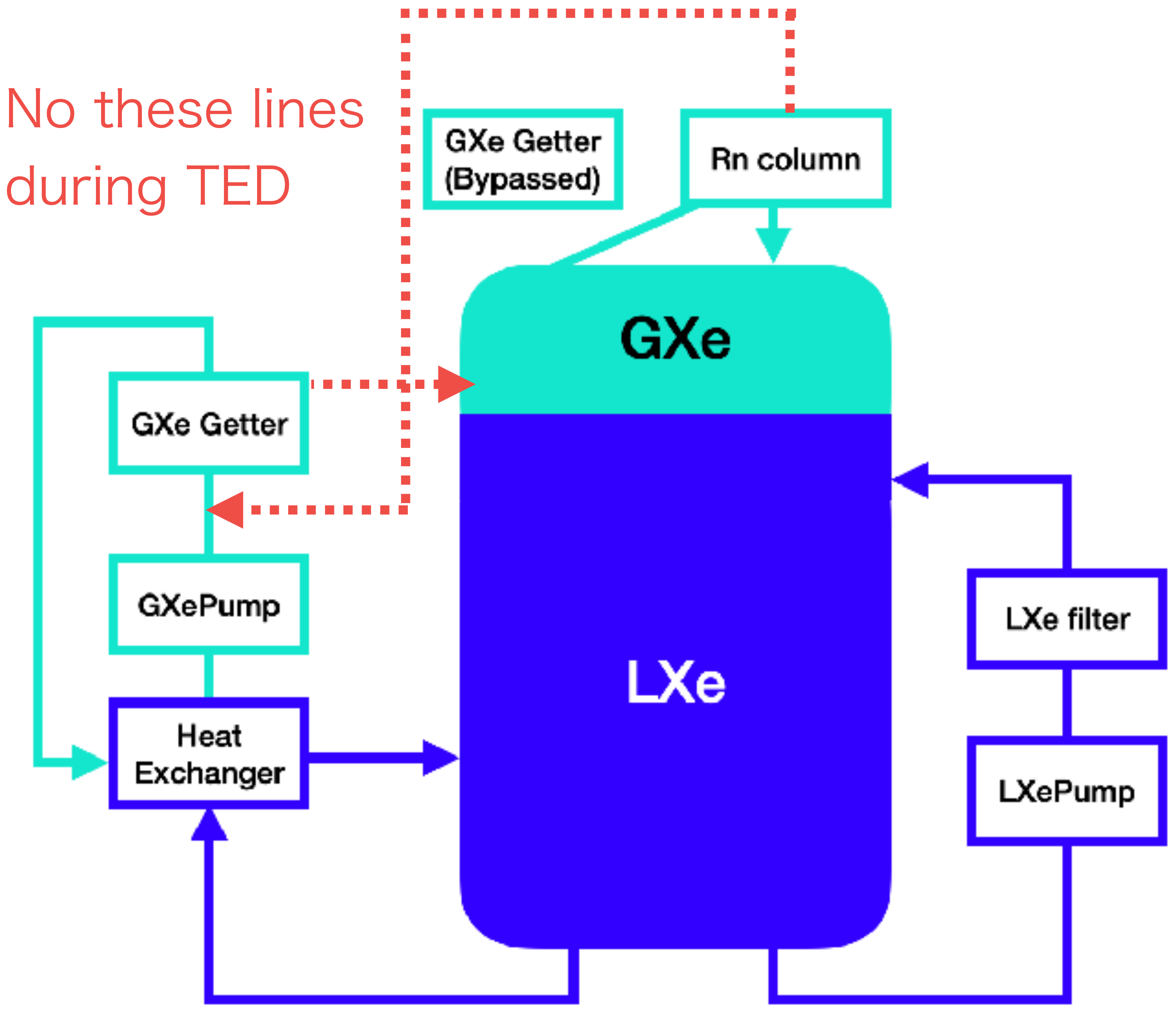
Significant efforts to reduce tritium

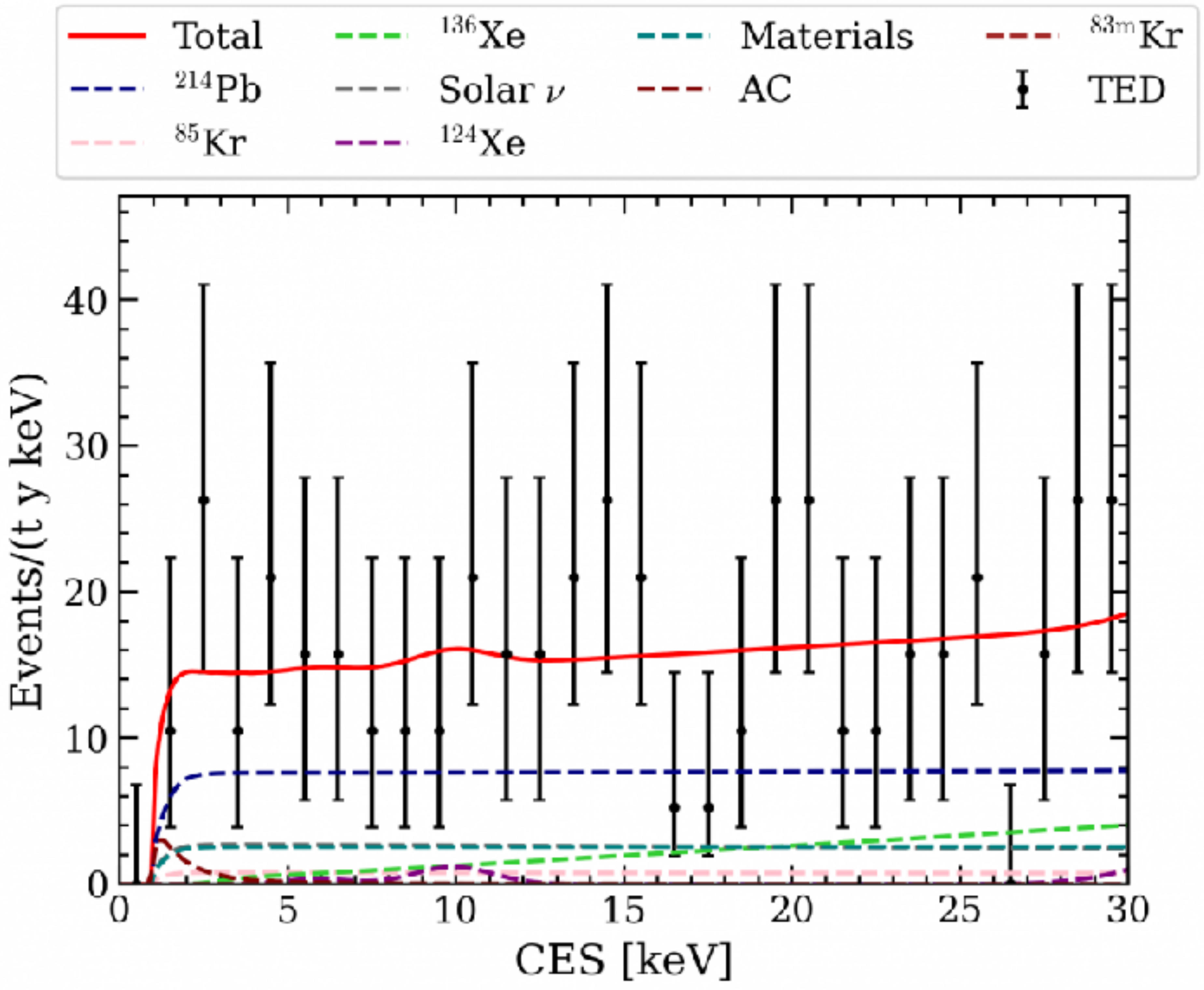
- 3 months of outgassing
- 3 weeks of GXe (warm) cleaning with hot getters
- GXe purified with Kr-removal system during its transfer into the gas storage system
- When filling to TPC, GXe purified with hot getters

Special data-taking mode:

- "tritium enhanced data" (TED) bypassing getters
- orders of magnitude in hydrogen level increase (conservative – at least 10x)
- 14.3 days of TED data

No these lines during TED

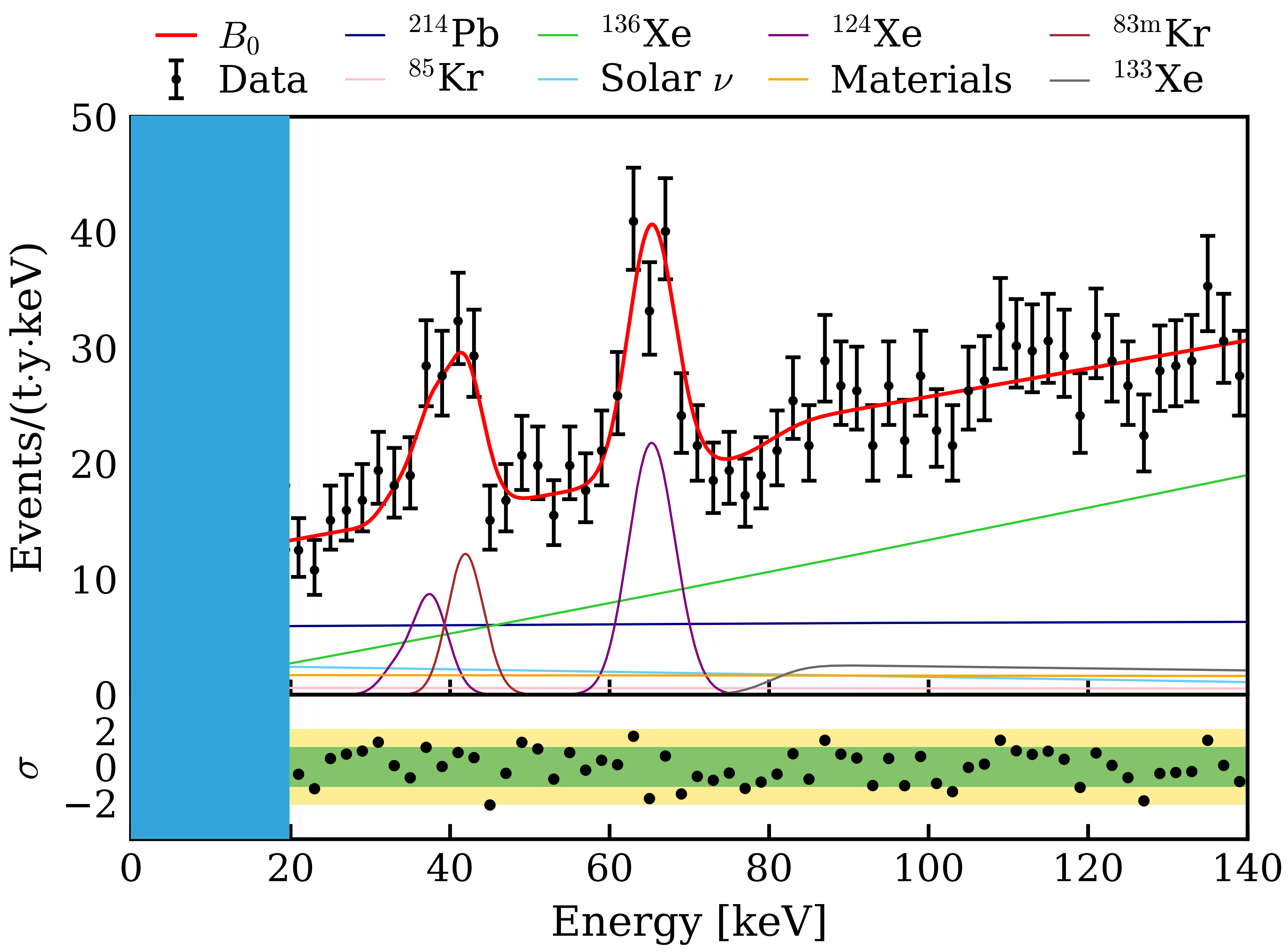




Results of blind TED analysis
→ No tritium excess
→ Tritium is not considered in the BG model

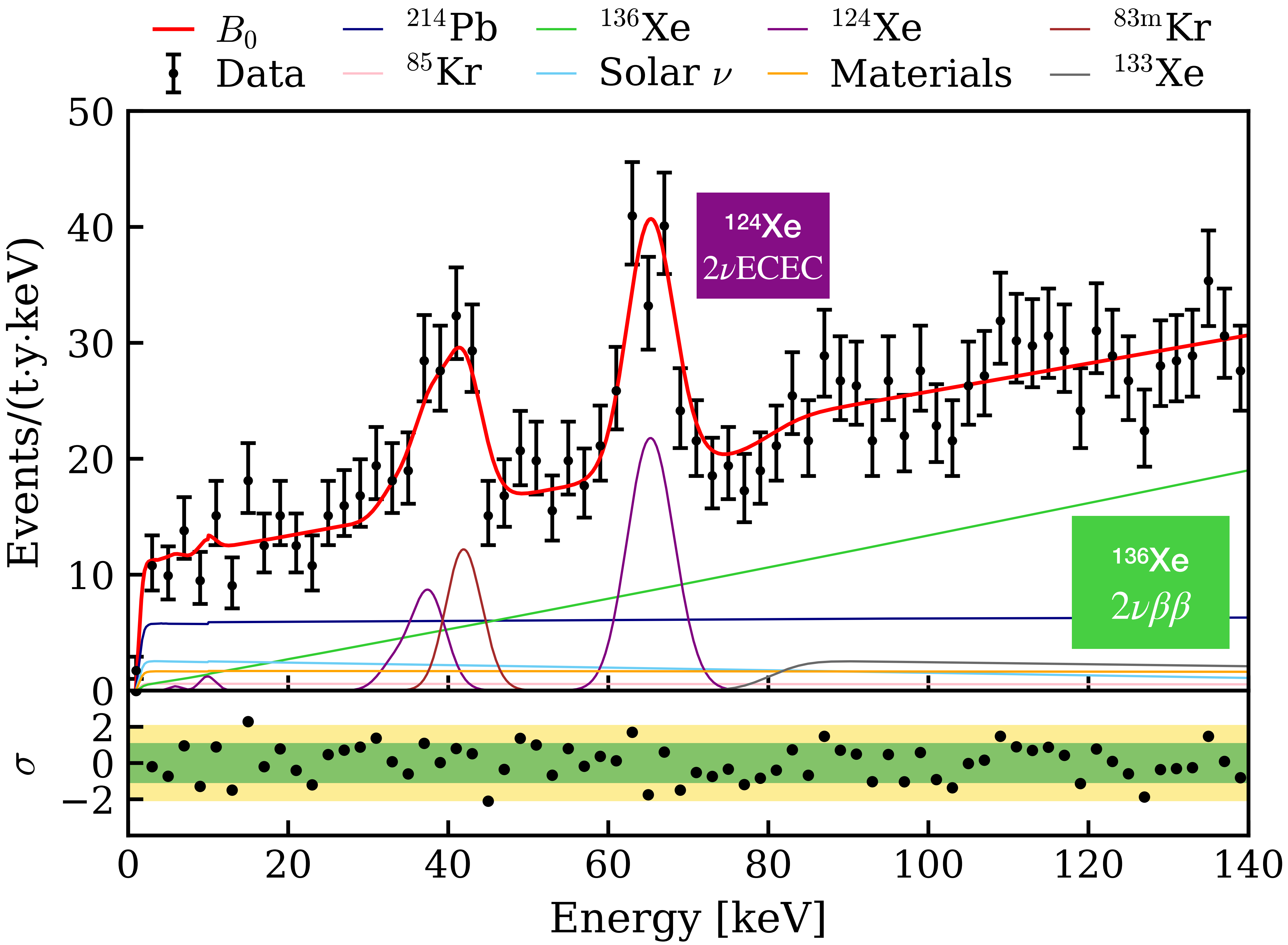
ER Backgrounds

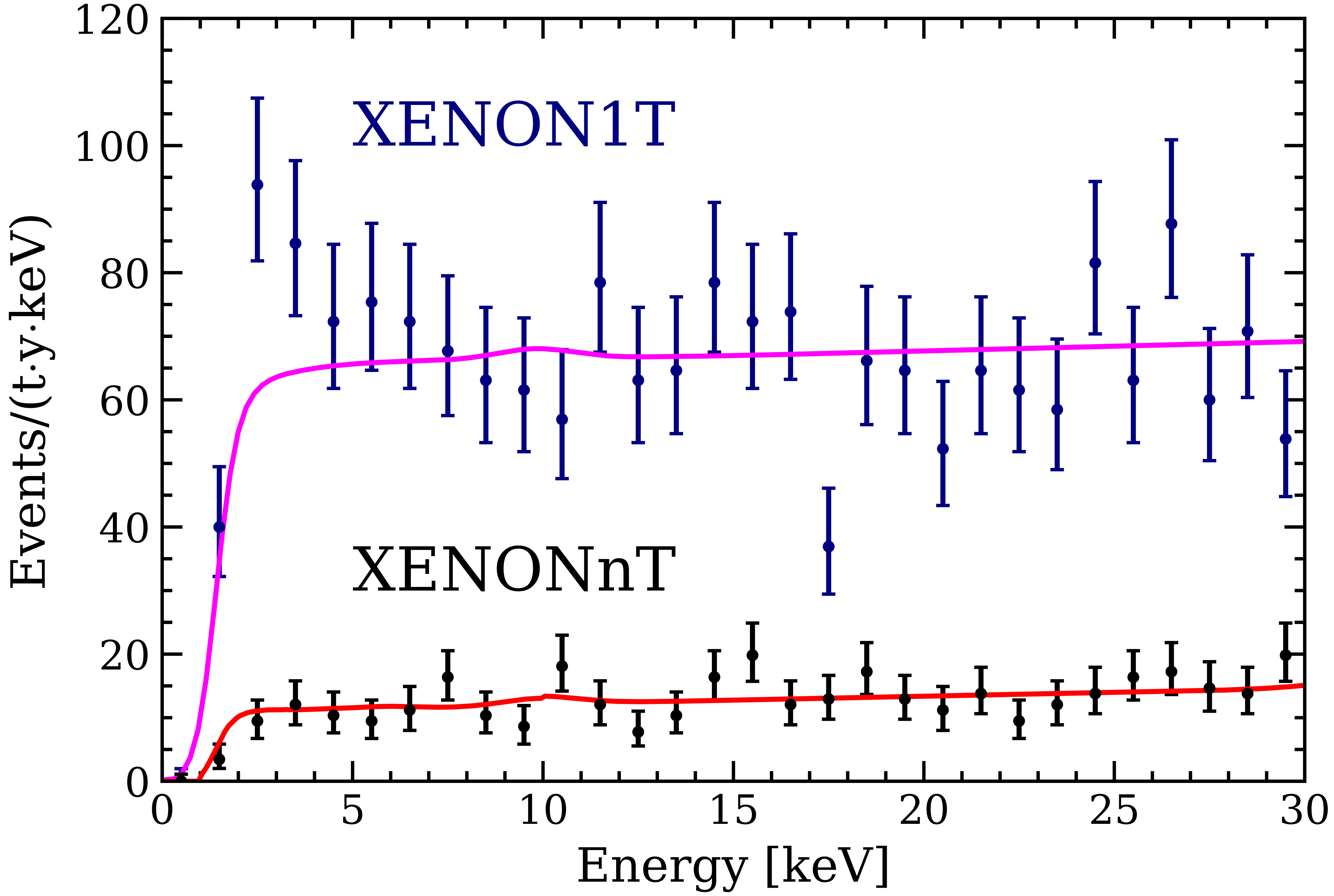
- Low-energy ER spectrum is dominated by ^{214}Pb, plus contributions for materials, ^{136}Xe and solar neutrinos.
- External constraints are included for
  - ^{85}Kr, 2×10^{-11} of (56 ± 36) ppq using RGMS
  - material gammas, (2.1 ± 0.4) events/(t × yr × keV) from GEANT4 and screening measurements
  - ^{136}Xe from RGA and $T_{1/2}$ measurements
  - solar neutrinos have a 10% rate uncertainty given the Borexino measurements of the flux.



	Number of events in ER band 1-140 keV	Expected < 10 keV
^{214}Pb	980 ± 120	56 ± 7
^{85}Kr	91 ± 58	5.8 ± 3.7
Materials	267 ± 51	16.2 ± 3.1
^{136}Xe	1523 ± 54	8.7 ± 0.3
Solar neutrino	298 ± 29	24.5 ± 2.4
^{124}Xe	256 ± 28	2.6 ± 0.3
Accidental coincidence	0.71 ± 0.03	0.71 ± 0.03
^{133}Xe	163 ± 63	0
^{83m}Kr	80 ± 16	0

ER Backgrounds after Unblinding





- Data agree with background only model in the whole energy range
- No Excess found
- Double weak processes from Xe124 and Xe136 start to dominate the background, and useful to validate our models
- Most likely the explanation of XENON1T excess is a small tritium contamination.

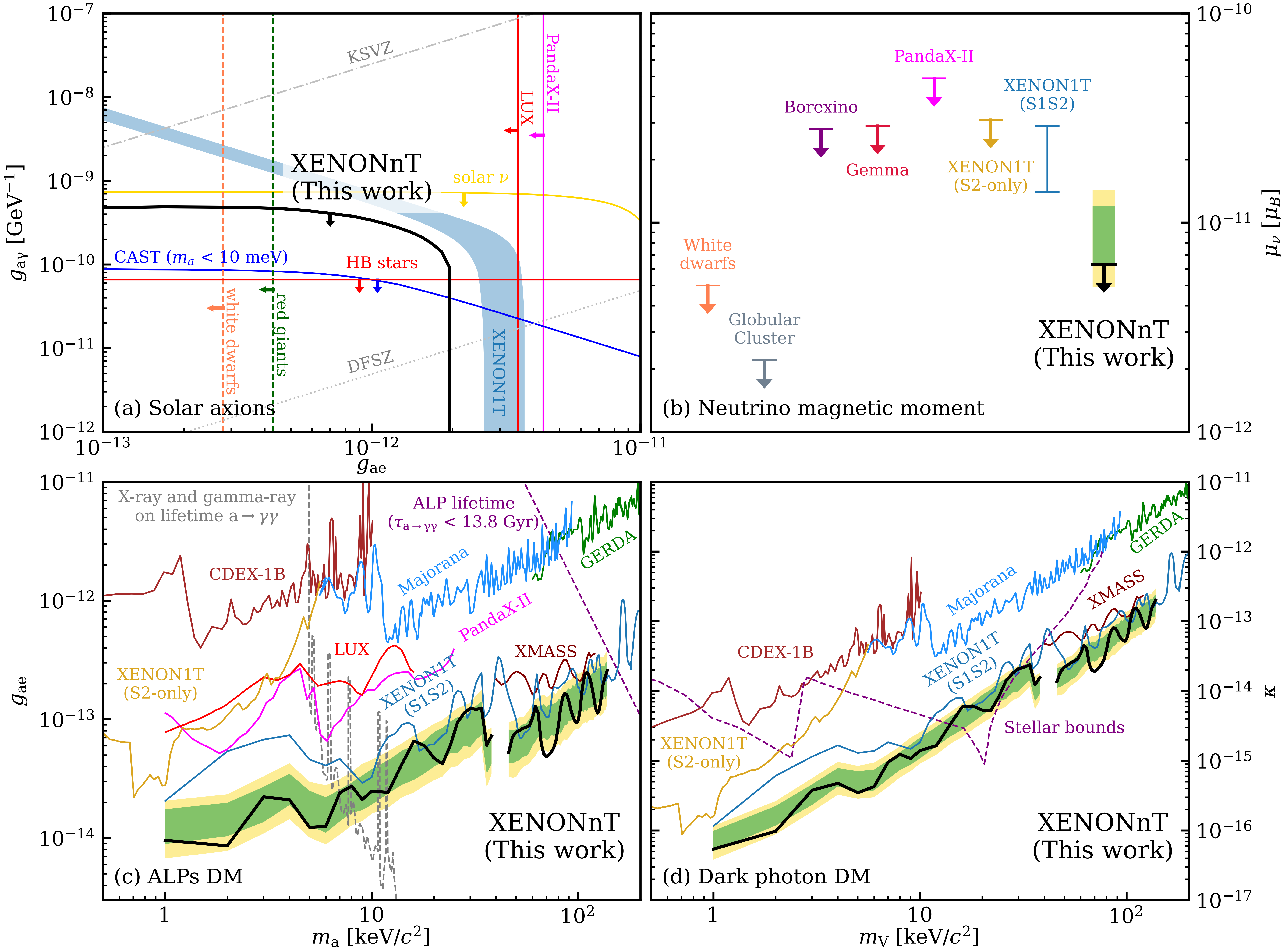
Constraints on BSM Physics

Solar-axion

Neutrino magnetic moment

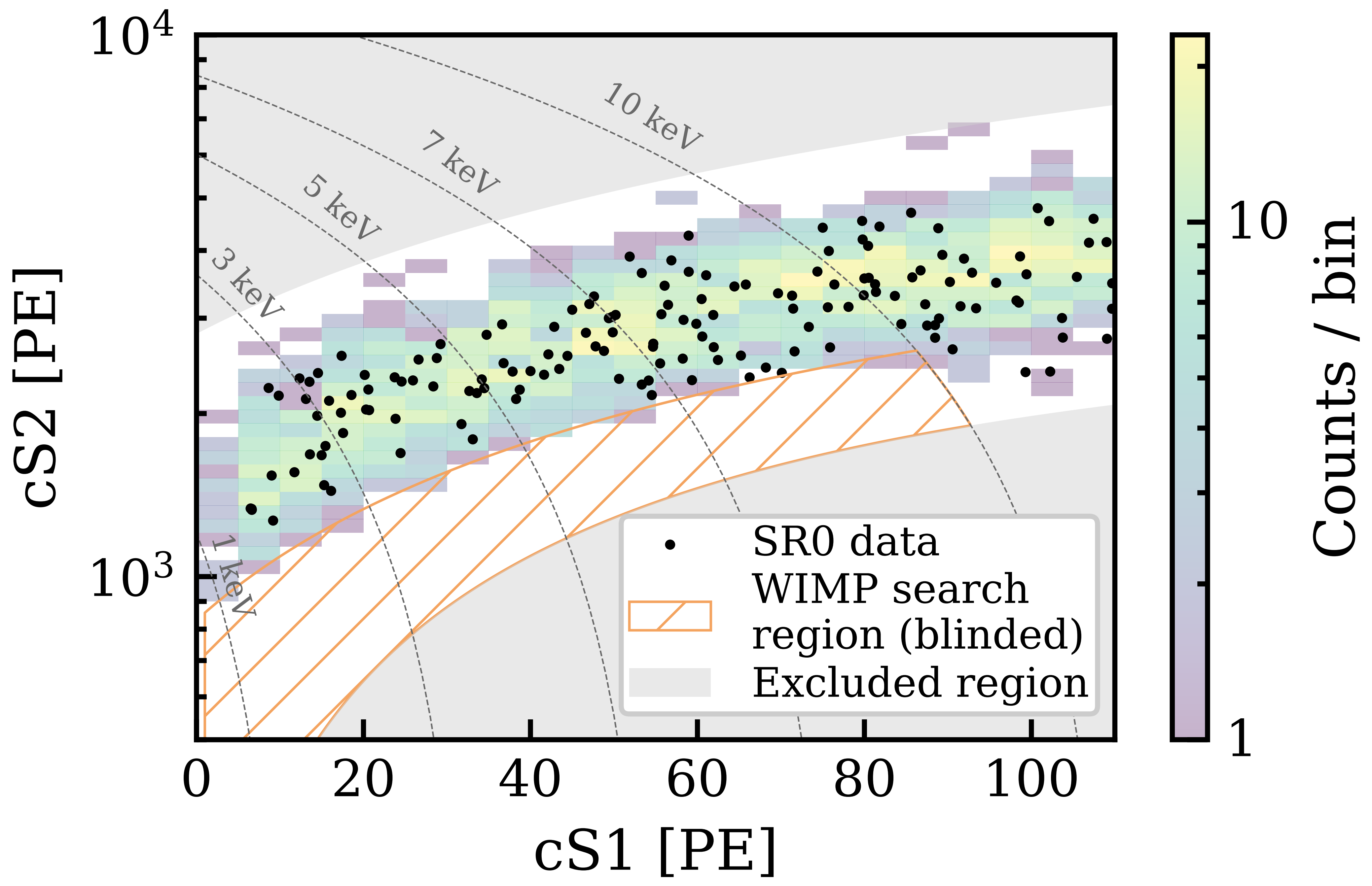
ALP

Dark Photon



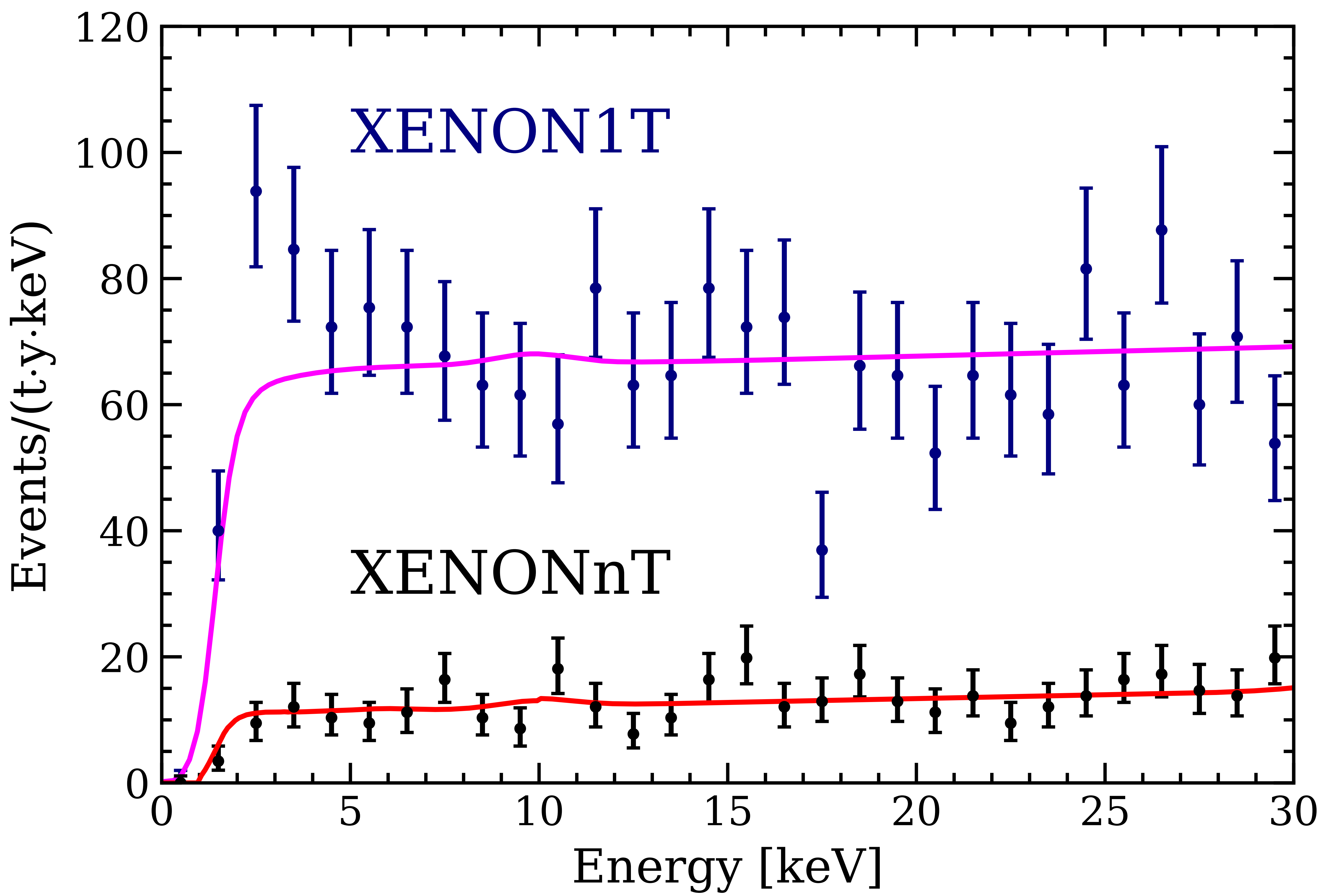
Summary / Prospect

- Successful construction and commissioning of XENONnT:
  - Lowest BG level ever achieved: $(16.1 \pm 0.3)\ \text{events}/(\text{t} \times \text{yr} \times \text{keV})$
- Fully blinded analysis of electron recoil data: No excess from 1 to 140 keV
- Incompatible to XENON1T excess
  - BSM models that explain the XENON1T excess are excluded
  - New world leading limits on solar-axions, ALPs and DPs as well as neutrino magnetic moment
- XENON1T excess is most likely due to the small tritium contamination
- NR WIMP unblinding is in progress
- Stay tuned, WIMPs search results to come!



Back Up

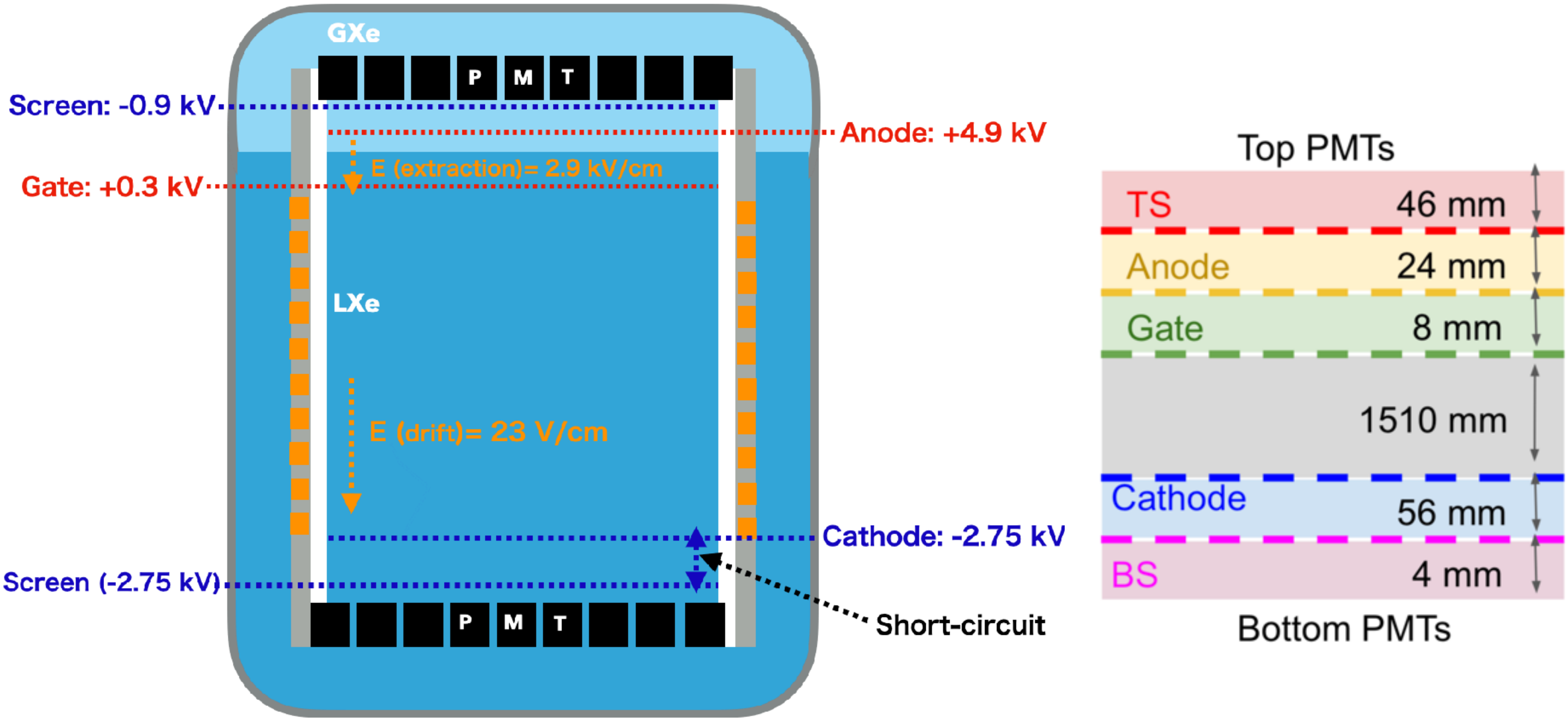
XENONnT vs XENON1T



Exposure: 1.16 tonne − years	$\sim \times 2$ **XENON1T ER search (0.65 tonne-years)**
Background rate: (16.1 ± 0.3) events/(t × yr × keV) **in 1-30 keV range**	$\sim \times 0.2$ **XENON1T**
Best-fit signal strength: 0	**XENONnT rejects a XENON1T-size peak at** 8.6σ
Exclusion of XENON1T excess $(2.3$ keV$)$ **peak.**	**Measurements incompatible at ~**4σ

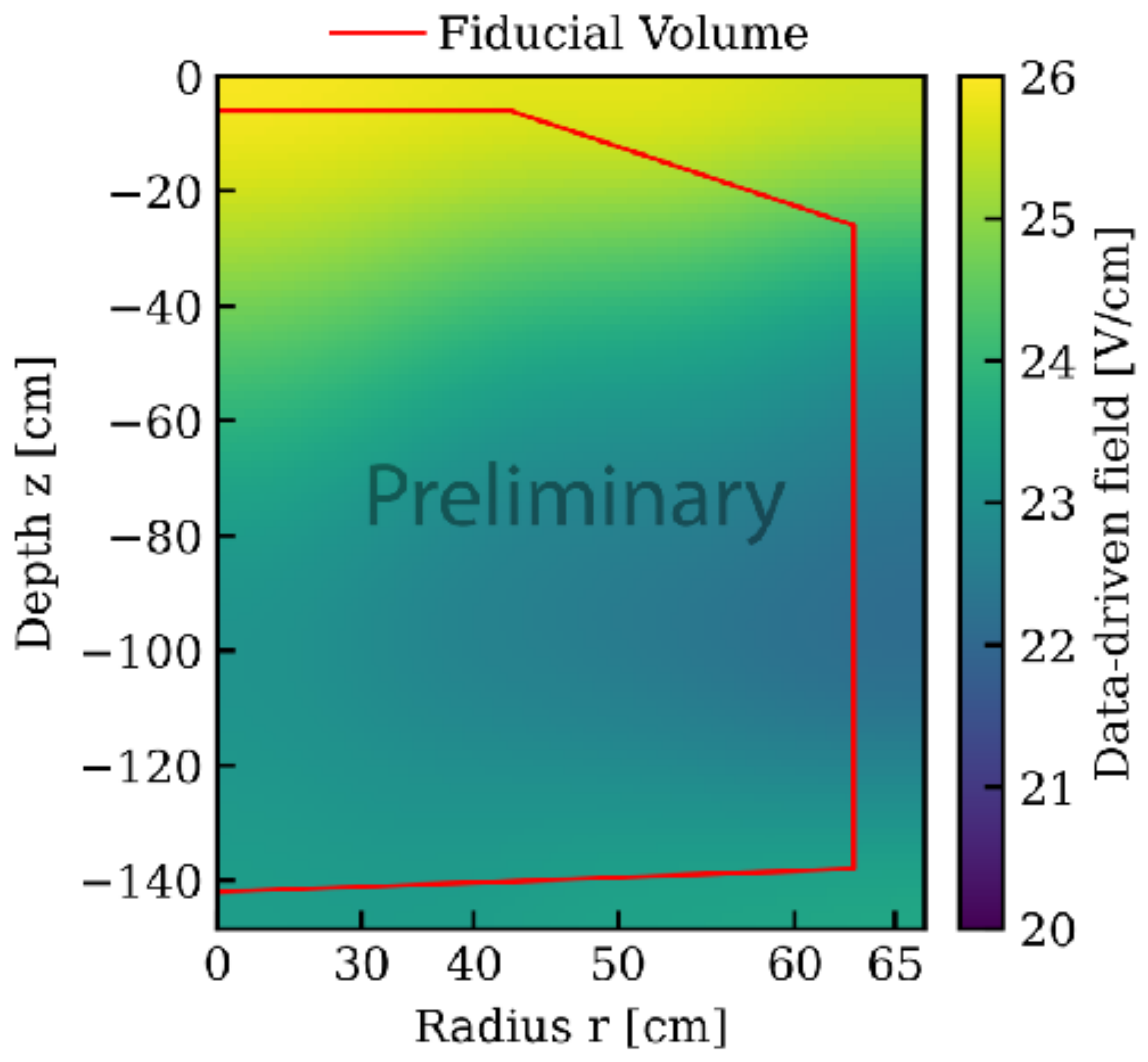
Most likely the explanation of XENON1T excess is a small tirtium contamination.
XENONnT, taking steps to reduce tritium outgassing sees no excess

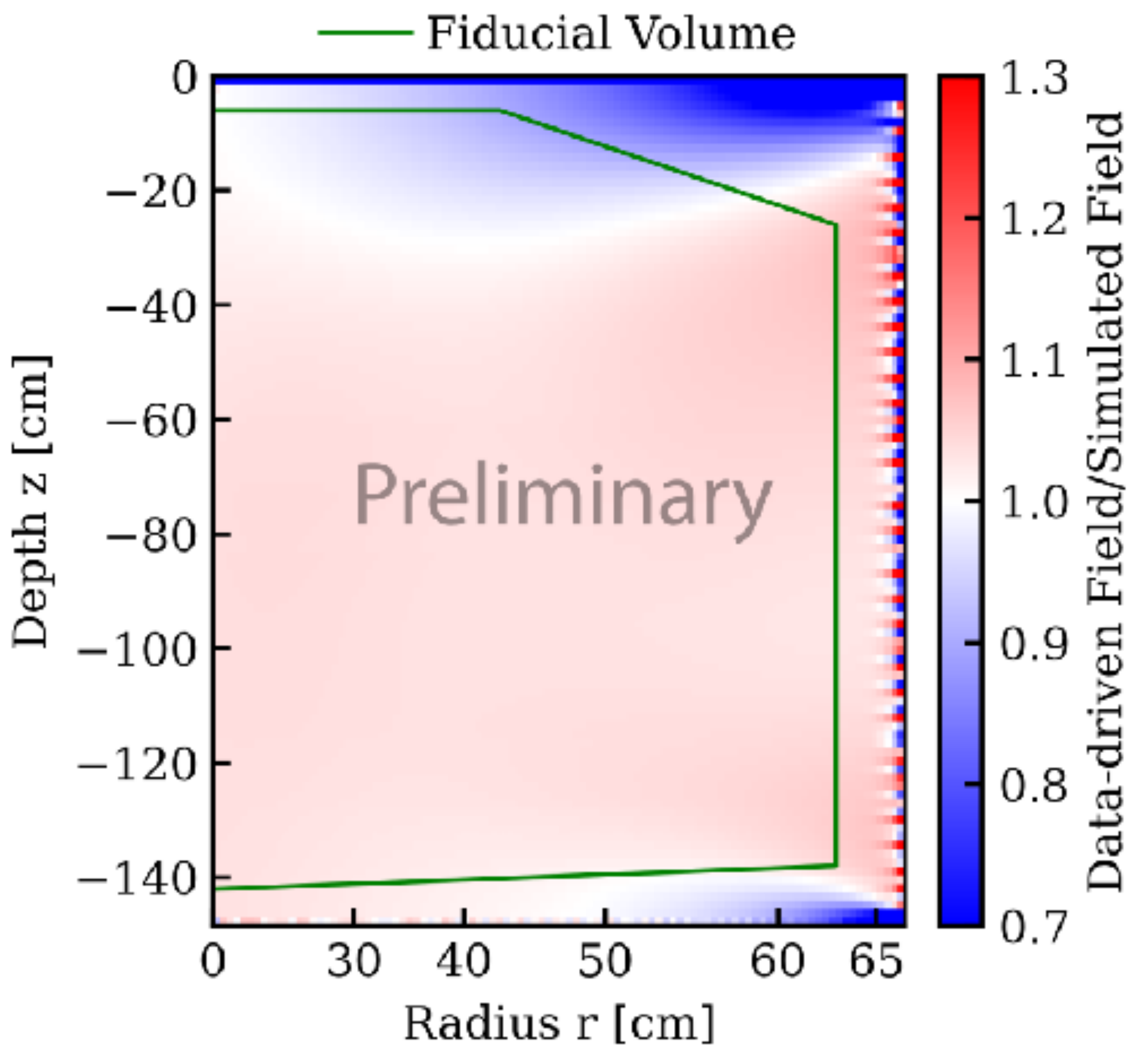
TPC


GXe
P M T
Screen: -0.9 kV
Anode: +4.9 kV
E (extraction)= 2.9 kV/cm
Gate: +0.3 kV
LXe
E (drift)= 23 V/cm
Cathode: -2.75 kV
Screen (-2.75 kV)
Short-circuit
P M T
Top PMTs
TS 46 mm
Anode 24 mm
Gate 8 mm
1510 mm
Cathode 56 mm
BS 4 mm
Bottom PMTs

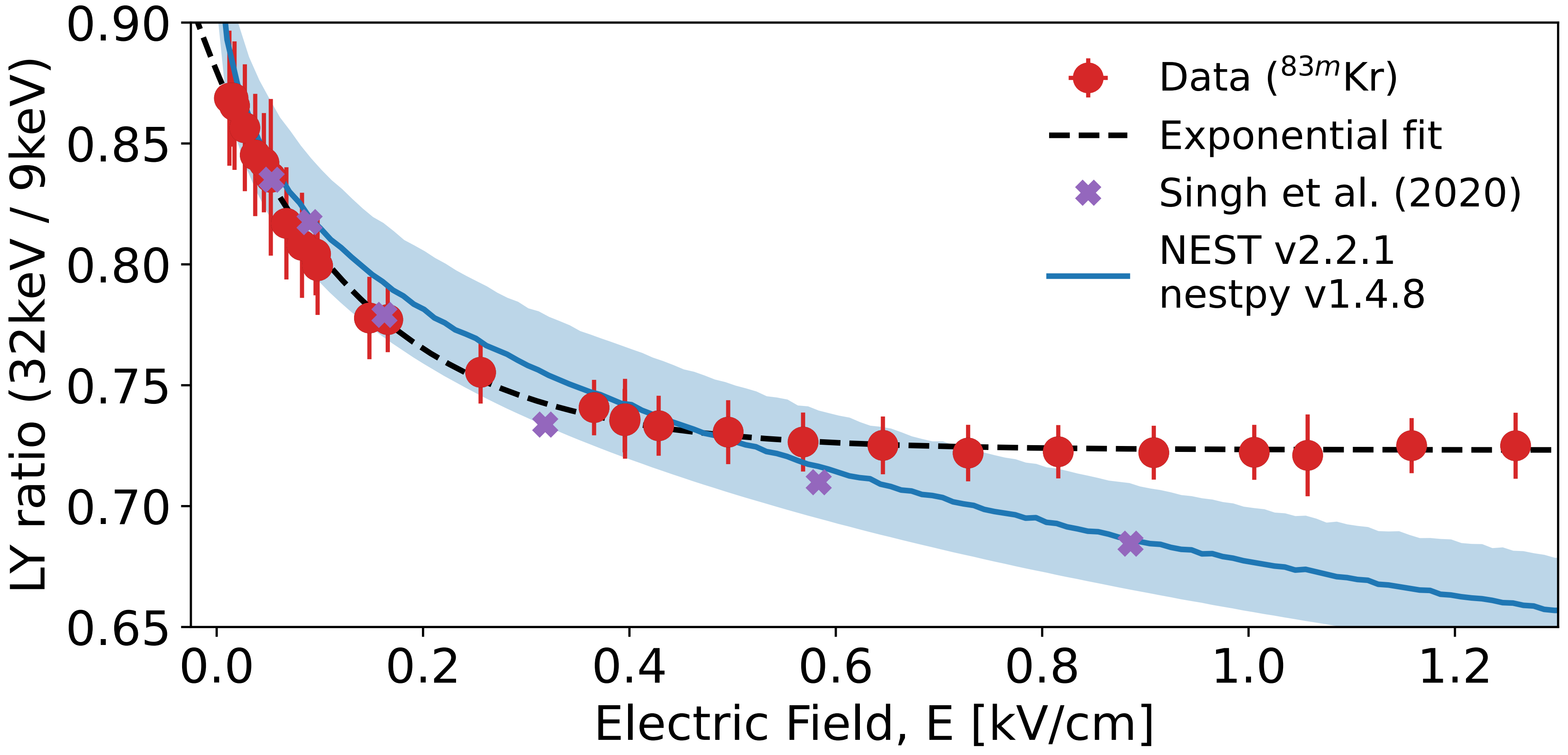
Drift Field Calibration

- Current drift field at ~23 V/cm
- Important to control field non-uniformities
- Calibration with ^{83m}Kr
  - two consecutive lines 32.1 and 9.4 keV
  - ratio of observed amplitudes → drift field sensitivity
  - tuning of COMSOL-based field simulation to current detector conditions
- Better than 10% match in fiducial volume for SR0

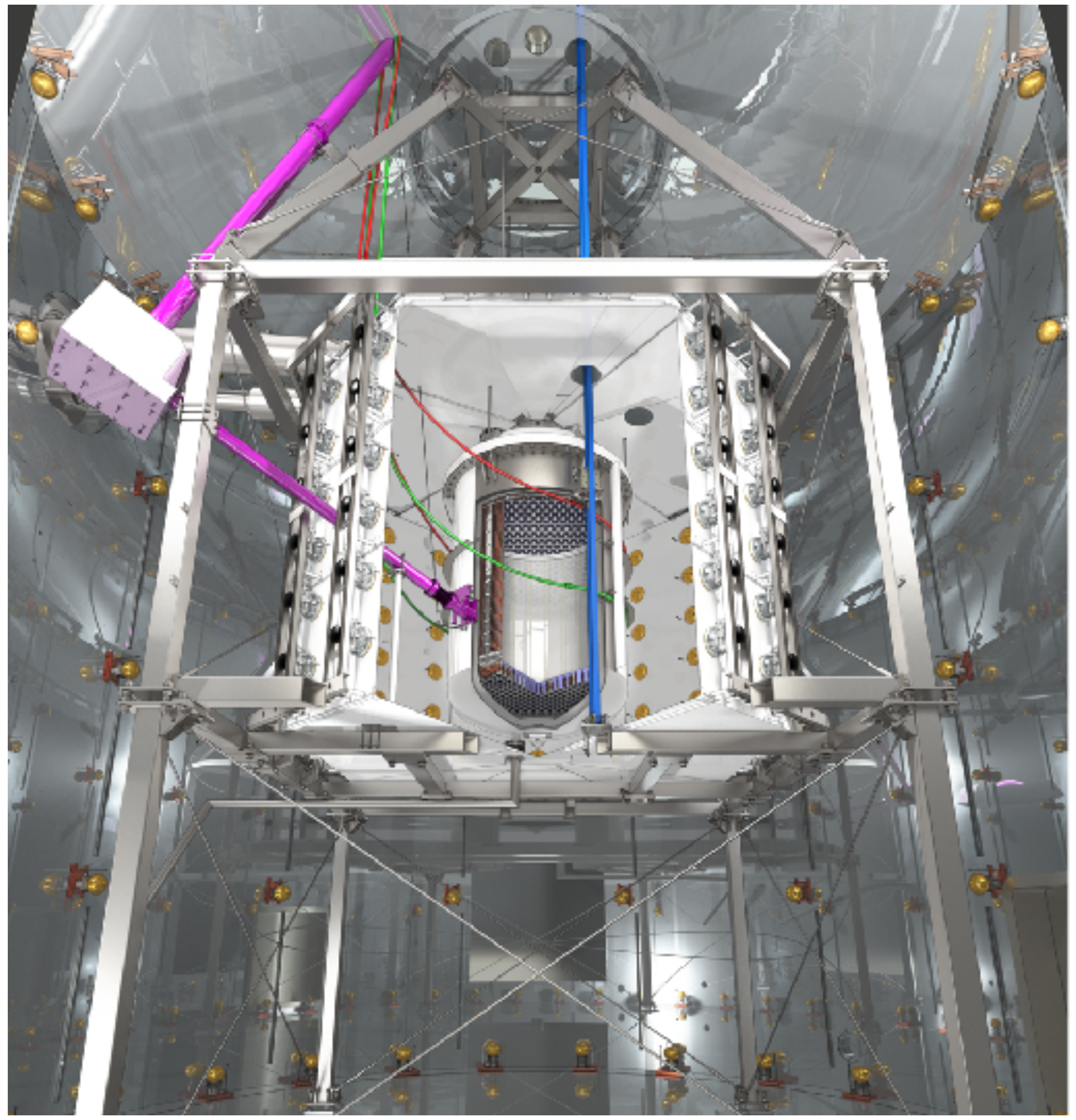


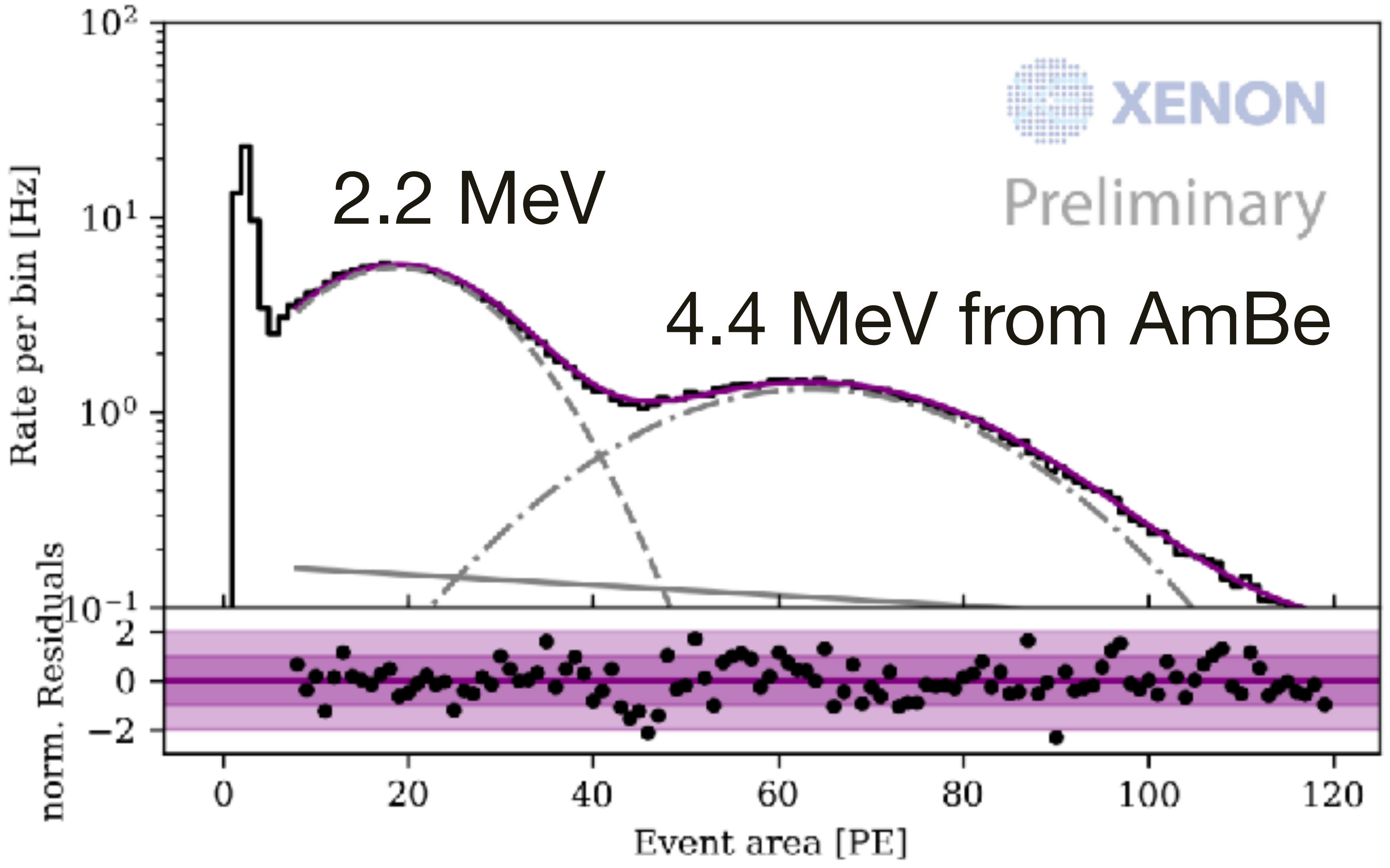


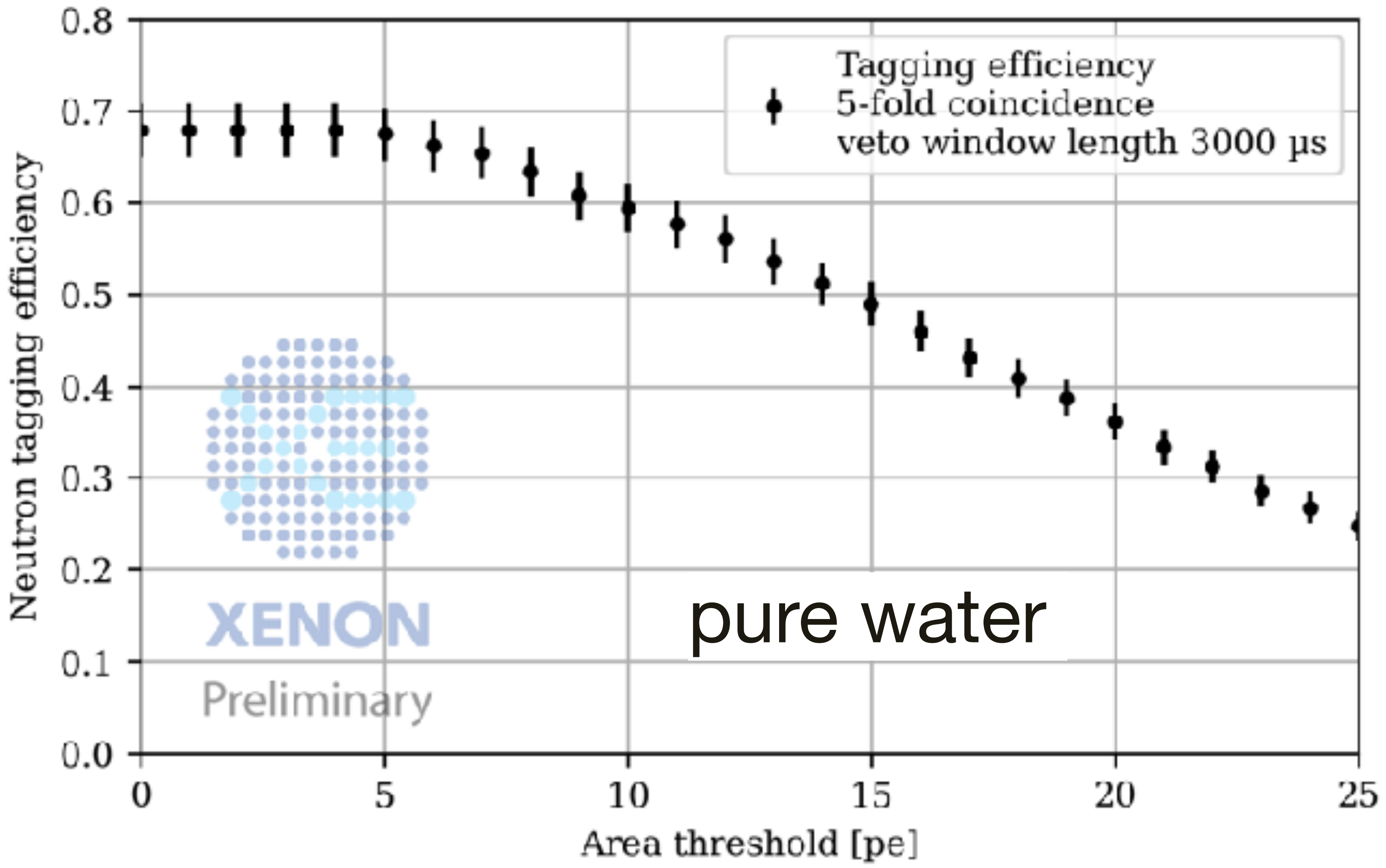
Eur. Phys. J. C 82, 361 (2022)



Neutron Veto







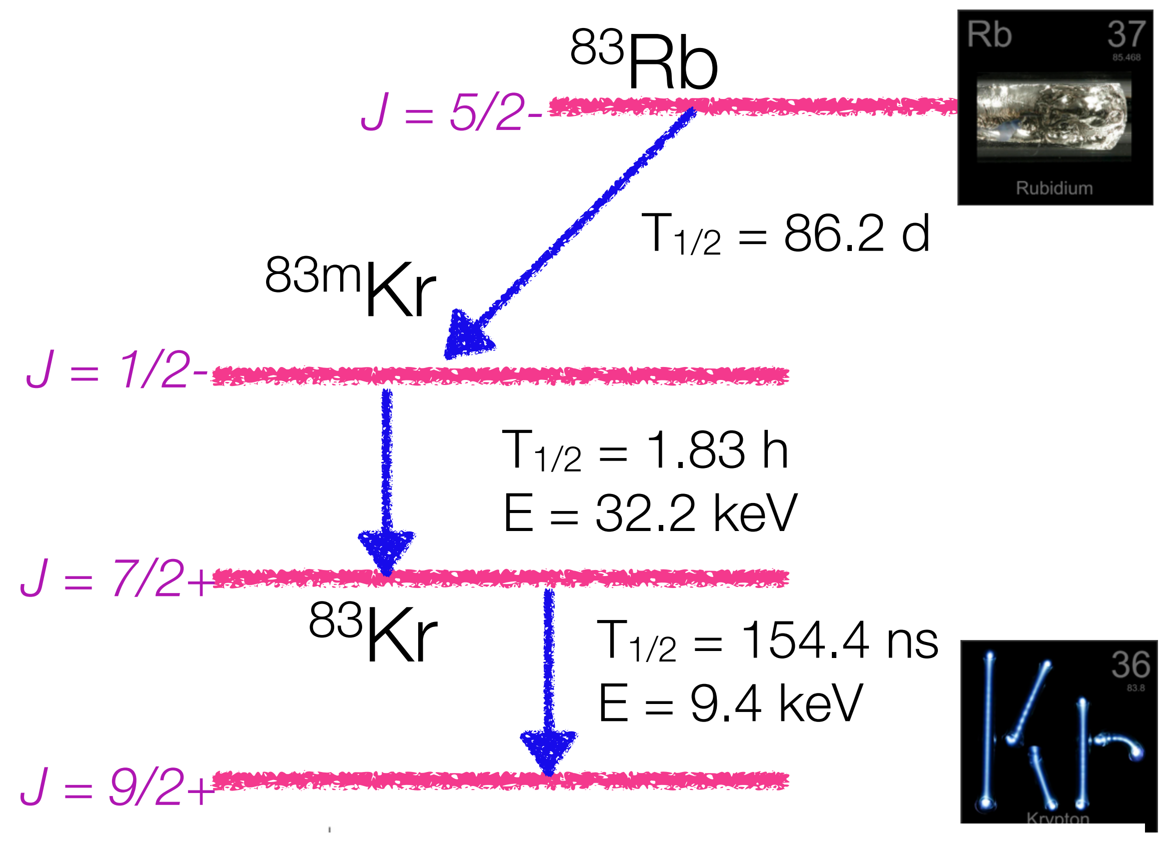
- Gd-Water Cherenkov detector (SuperK/EGADS technology)
- Neutrons are captured by Gd, then produce gammas with total energy of 8MeV
- Covering the entire detector wall with ePTFE with ~99% reflectivity

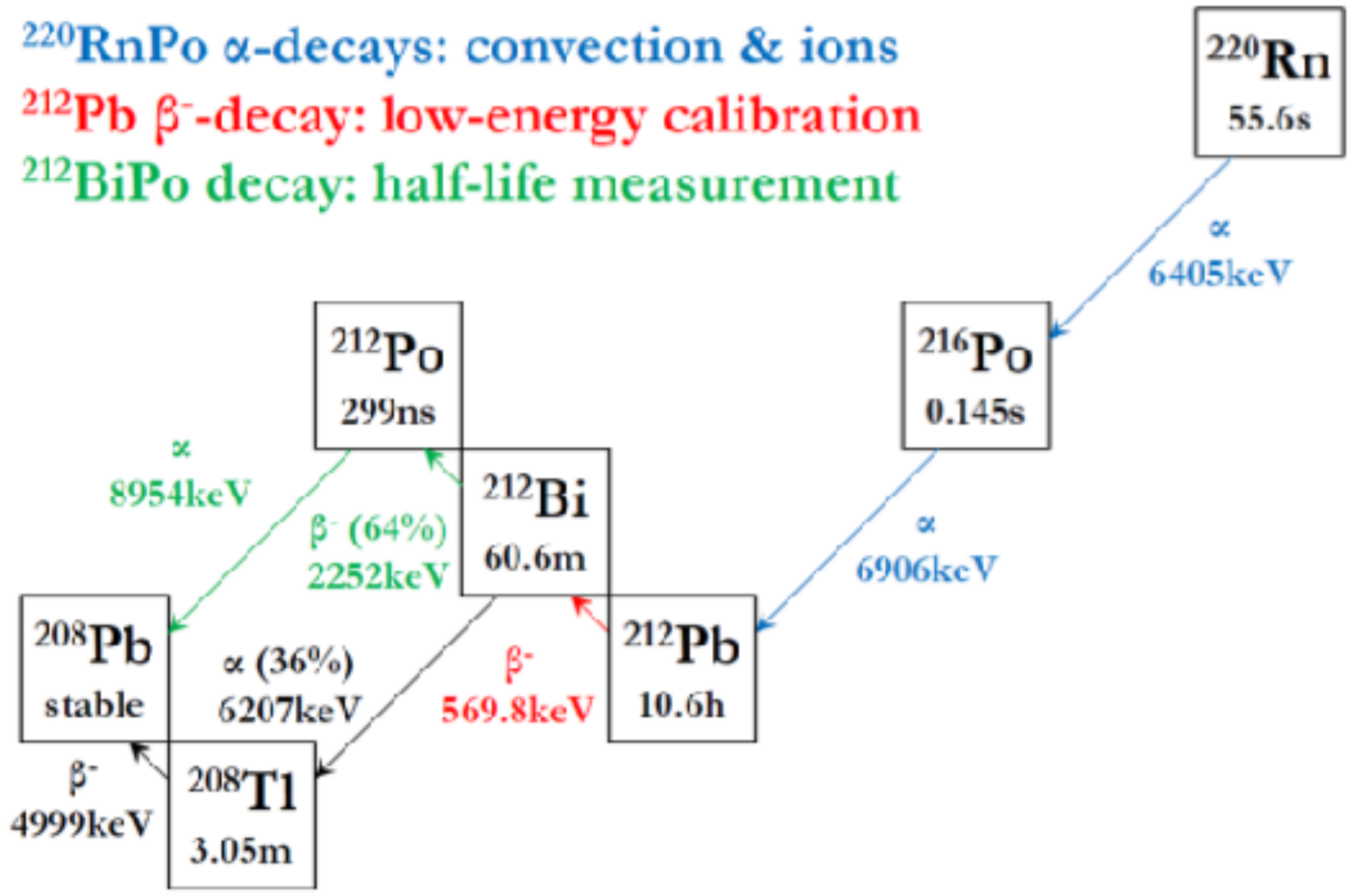
- Can reconstruct 2.2 MeV gamma
- 65% neutron tag. eff. In pure water (SR0)
- Future: ~87% tag. eff with Gd doping

Calibrations in XENONnT

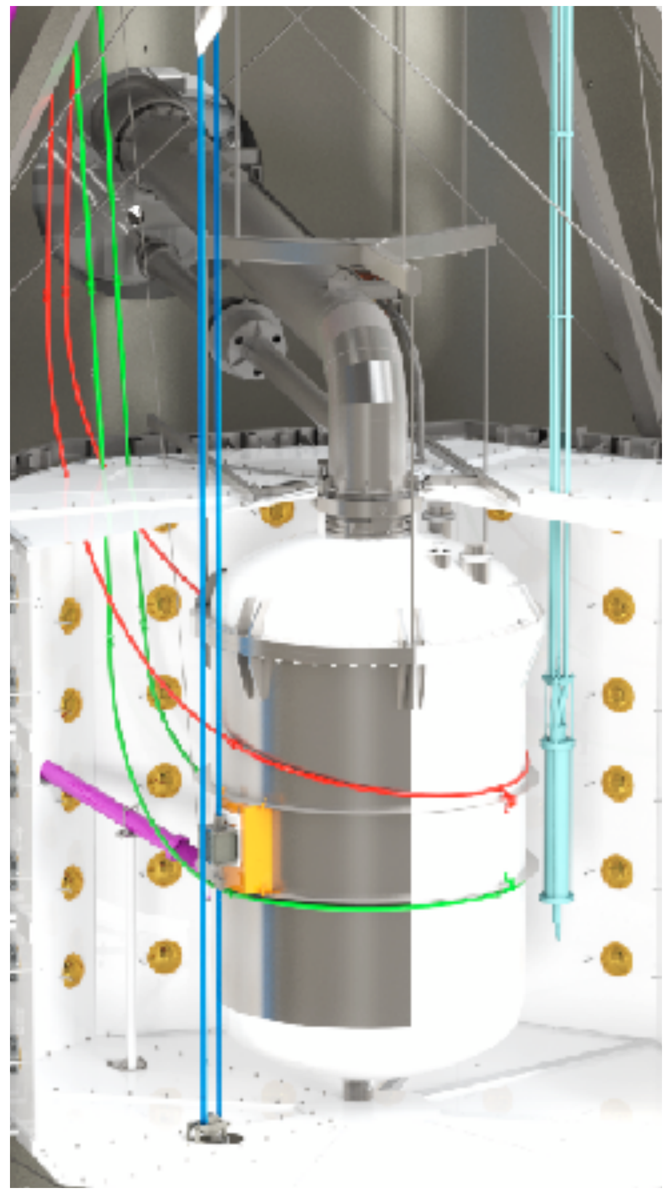
What do we calibrate:

- energy scale
- energy resolution
- detection and selection efficiency
- correction of detector response non-uniformities ($S1 \rightarrow cS1$, $S2 \rightarrow cS2$)





	Purpose	Decay mode	Particle, Energy	half-lifetime
^{83m}Kr	Uniformity, energy scale, etc	Internal Conversion	e, 32 keV / 9 keV	~1.8 h
^{220}Rn	Low-energy ER	β-decay	e, Q=570keV	~11h
^{37}Ar	Uniformity, energy scale, threshold	Electron capture	X-ray, 2.82 keV	Half-lifetime: ~35 days -> rejection: ~5 days with distillation
^{241}AmBe	Low-energy NR, high-energy gammas from activation	(α, n) reaction	n, O(1) MeV	Half-lifetime of ^{129m}Xe / ^{131m}Xe ~ 10 days

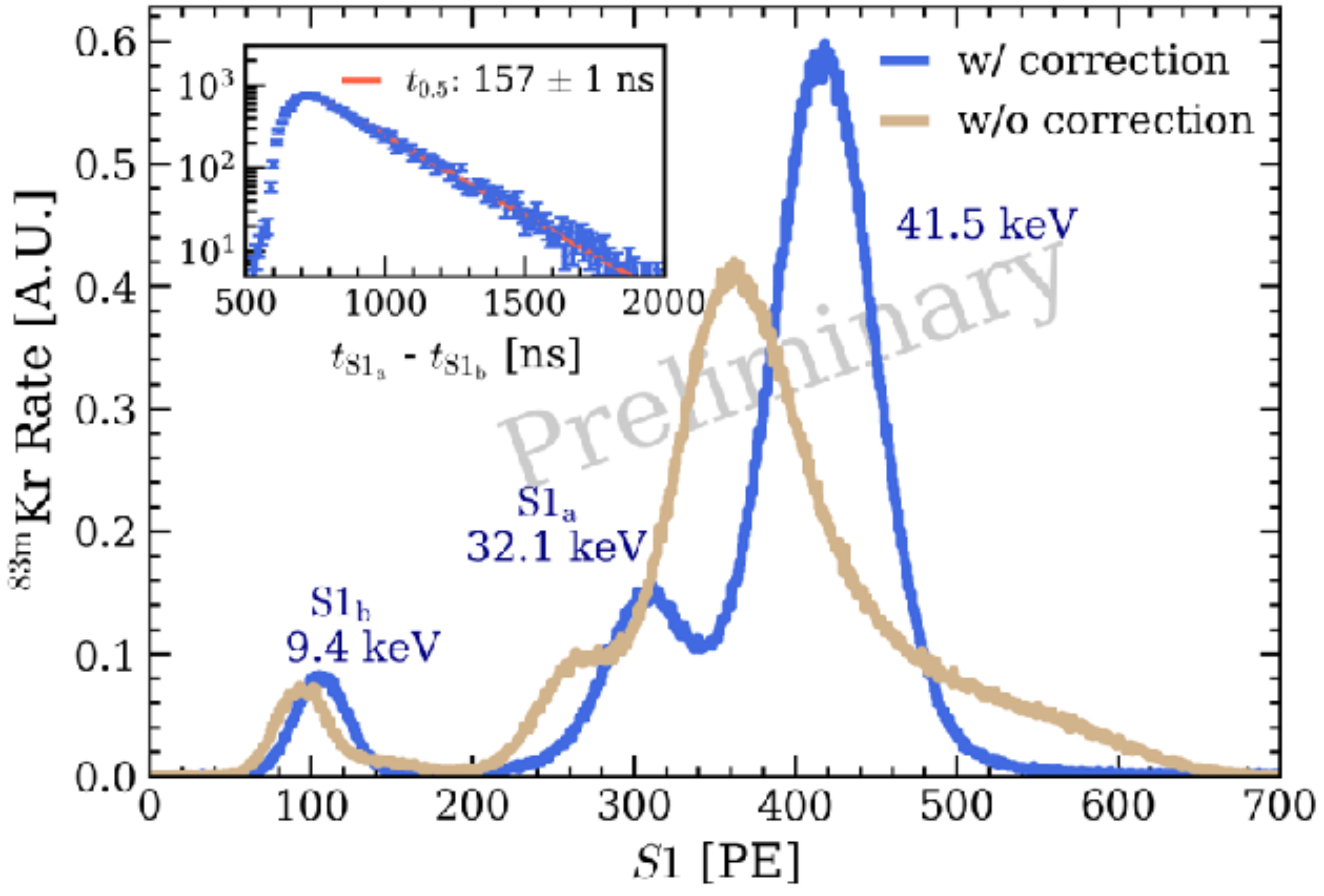


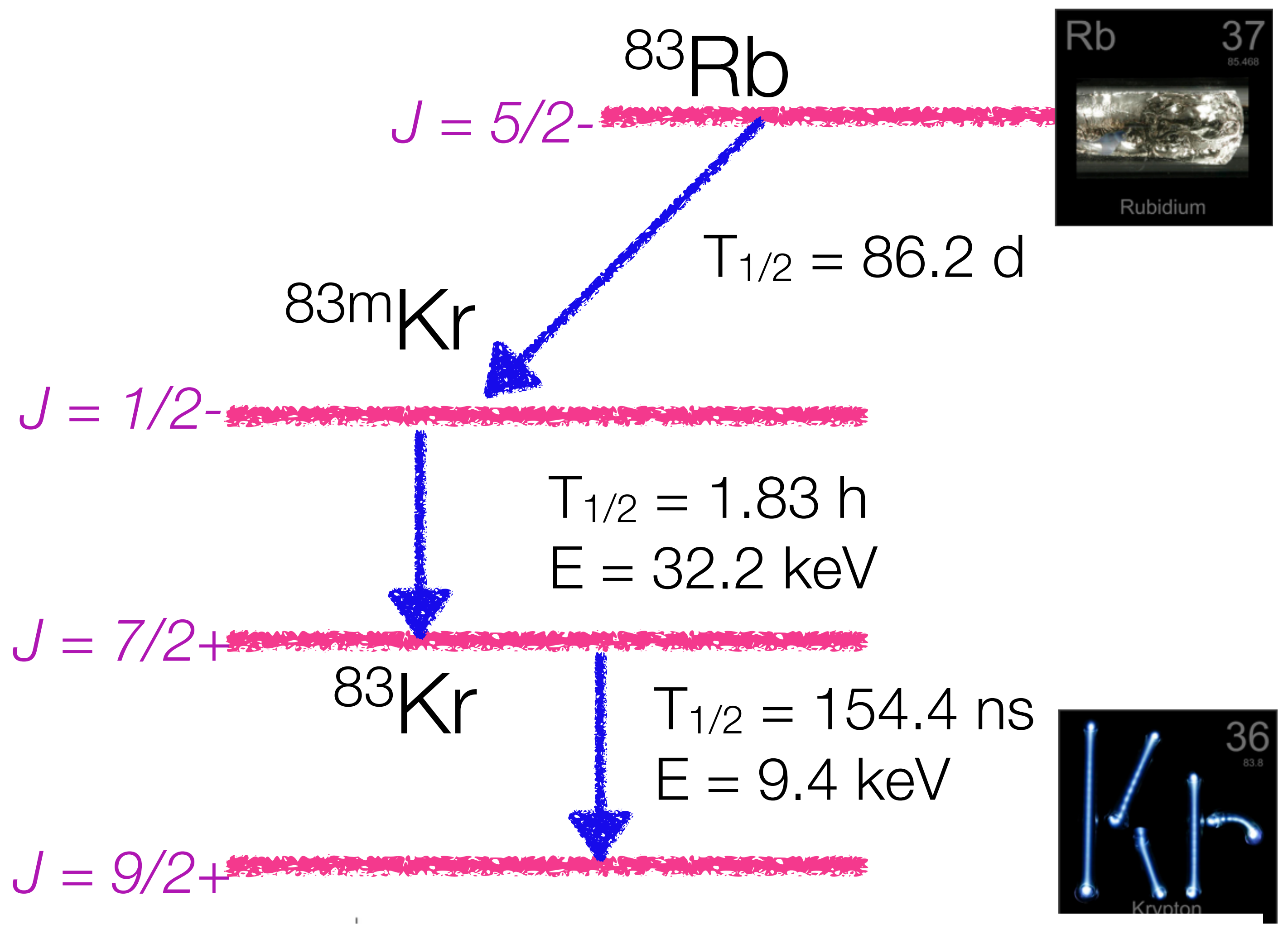
Corrections

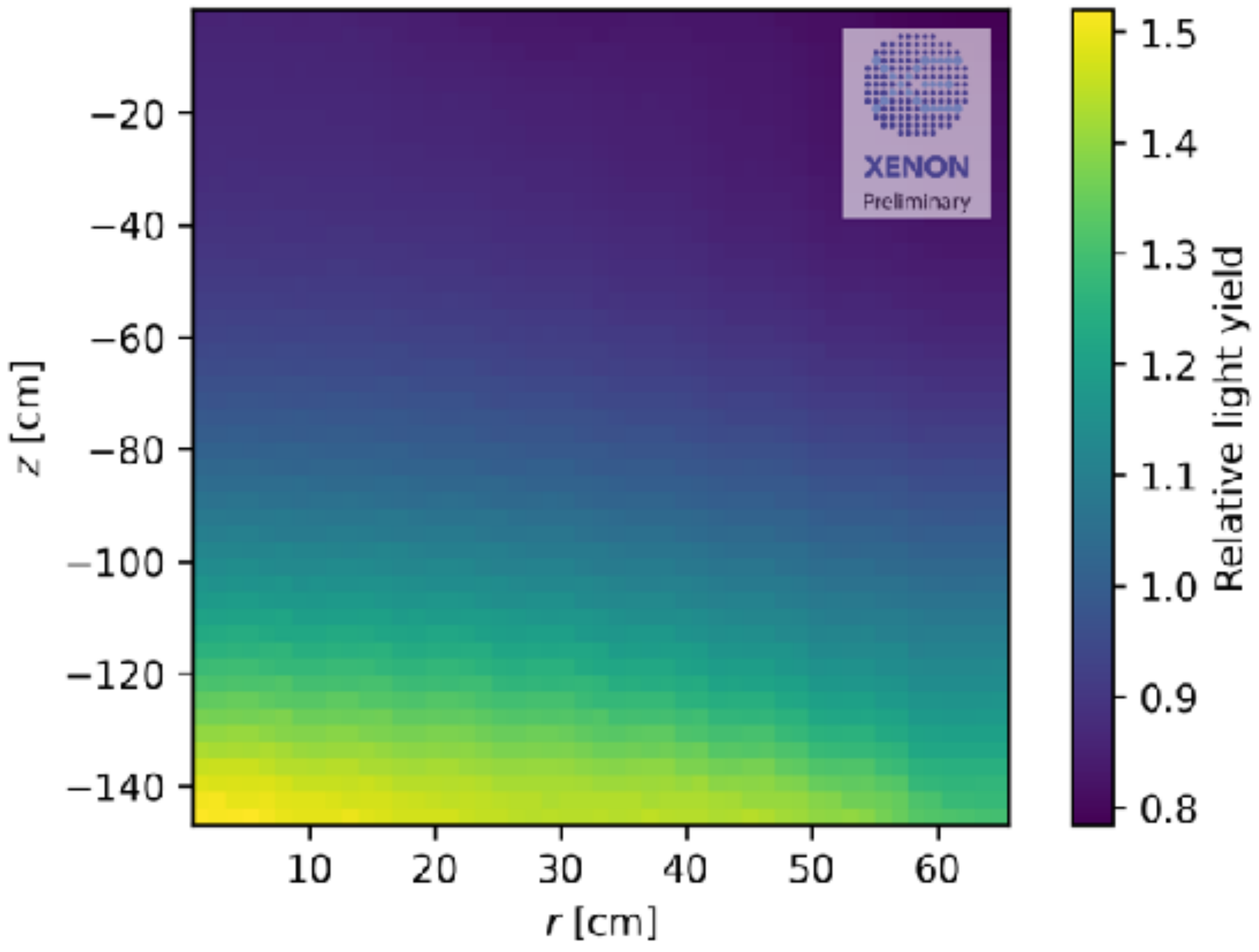
Spatial signal corrections with ^{83m}Kr source

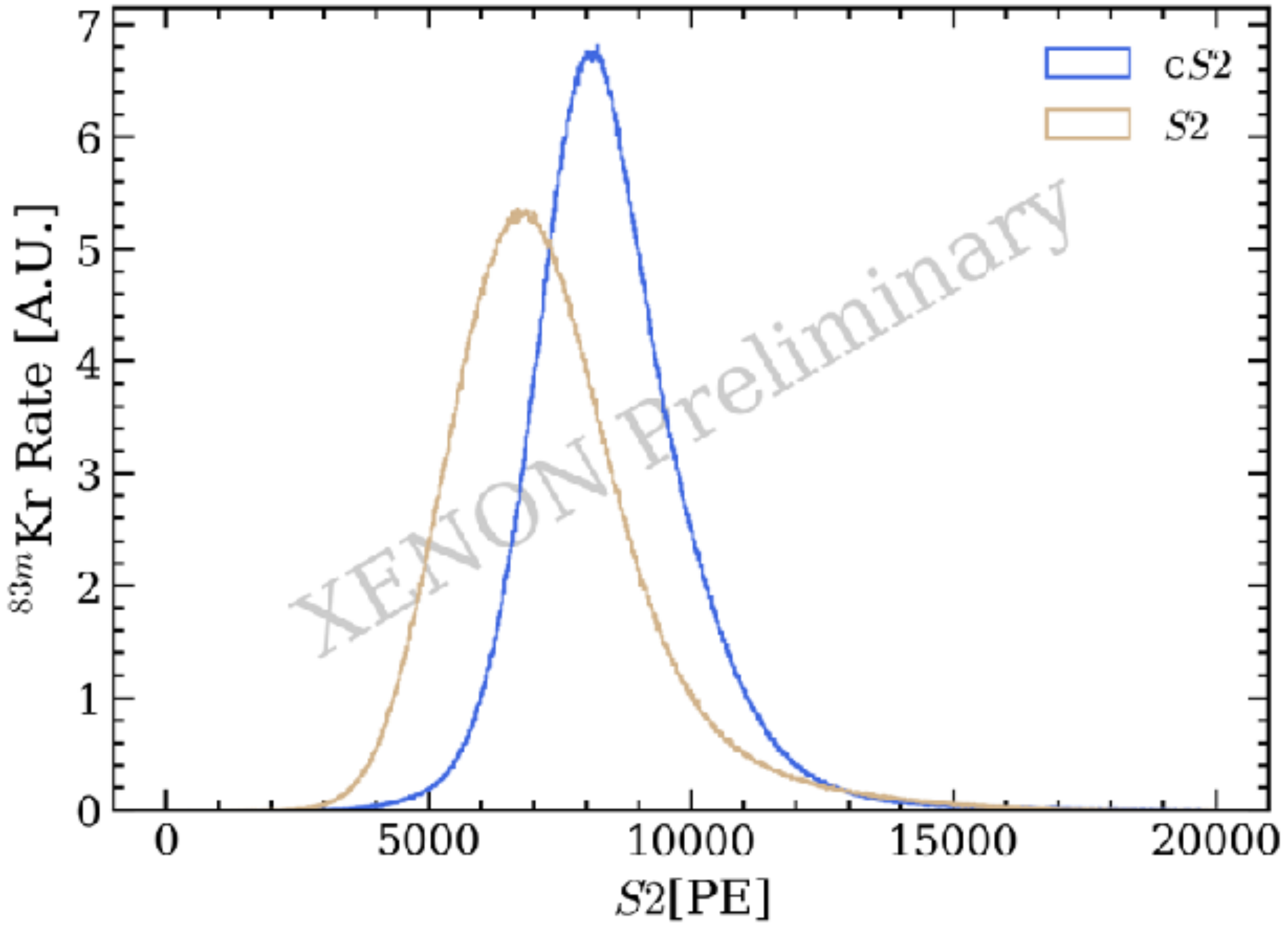
- Position dependent light collection efficiency
- Position dependent S2 amplification
- Electron lifetime correction

S1 → cS1, S2 → cS2

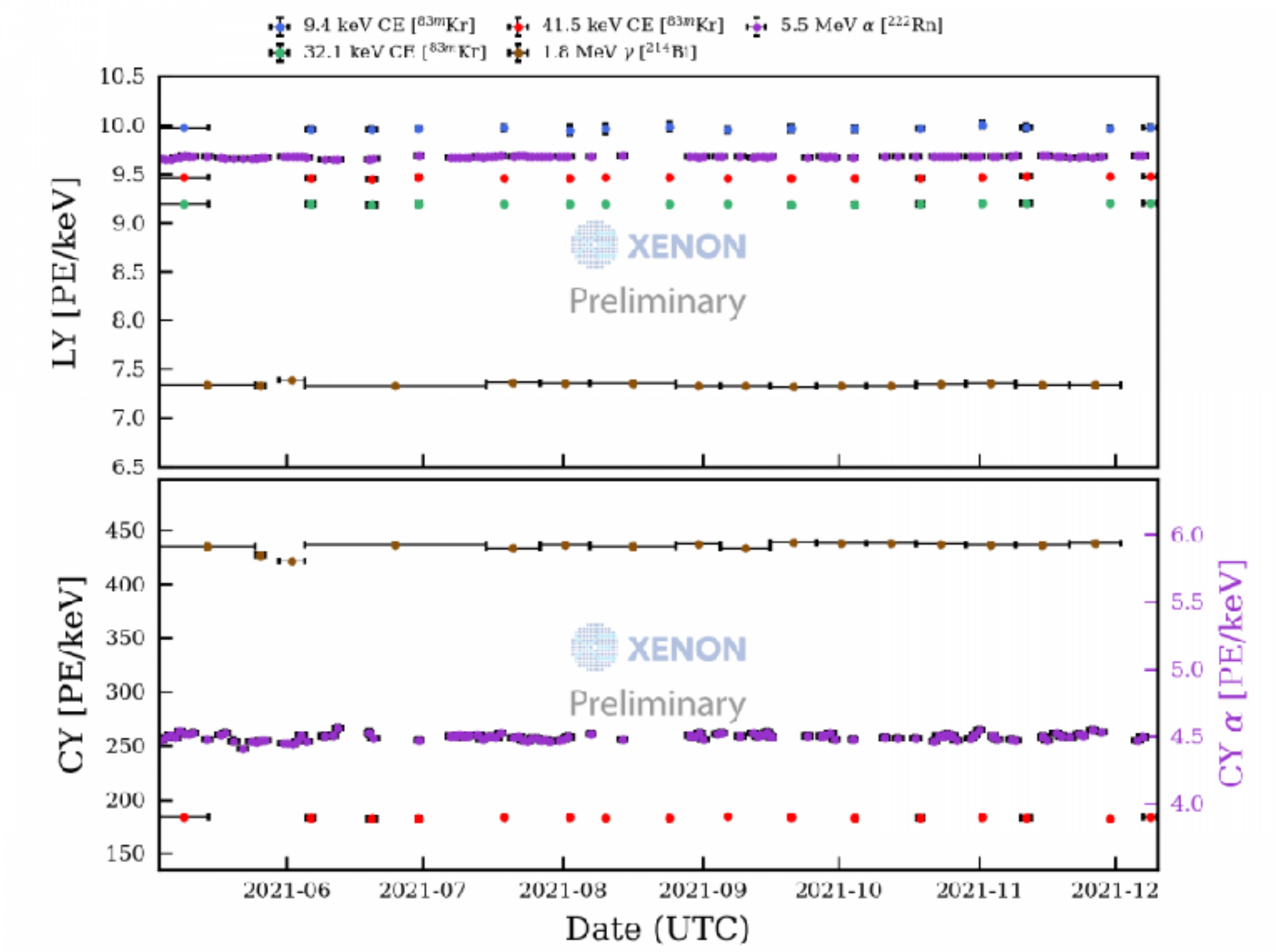


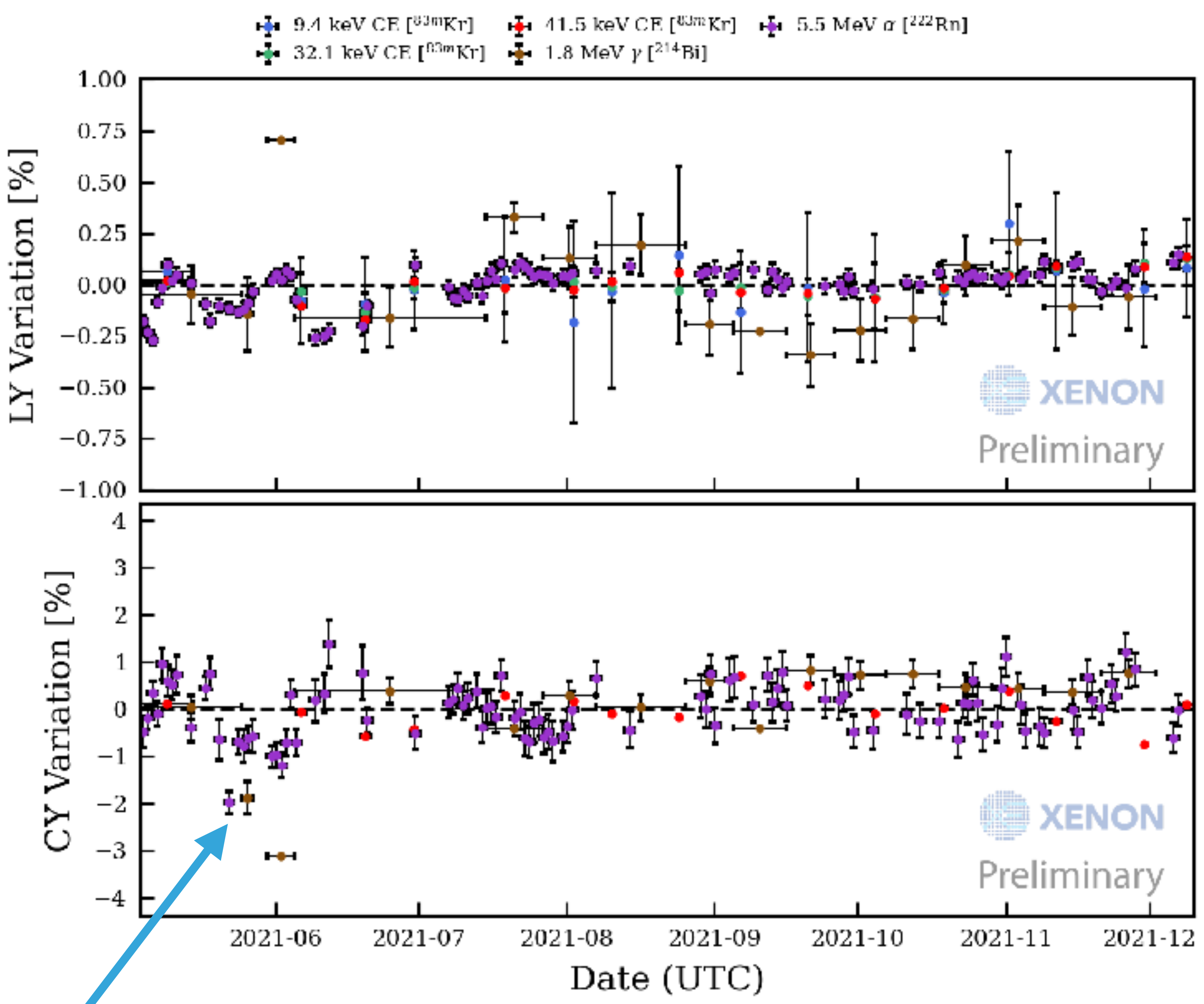






Detector Response Stability





- Continuous monitoring of detector stability:
  - regular bi-weekly ^{83m}Kr calibration
  - background sources
- Light yield stability < 1%
- Charge yield stability < 1.9%

- CY fluctuation in the end of May is due to the frequent anode ramp down/up, resulting in time- and spatial-dependent single-electron gain and electron extraction efficiency