XENON

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Electronic recoil channel in XENONnT: Results and perspective

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On behalf of the XENON Collaboration

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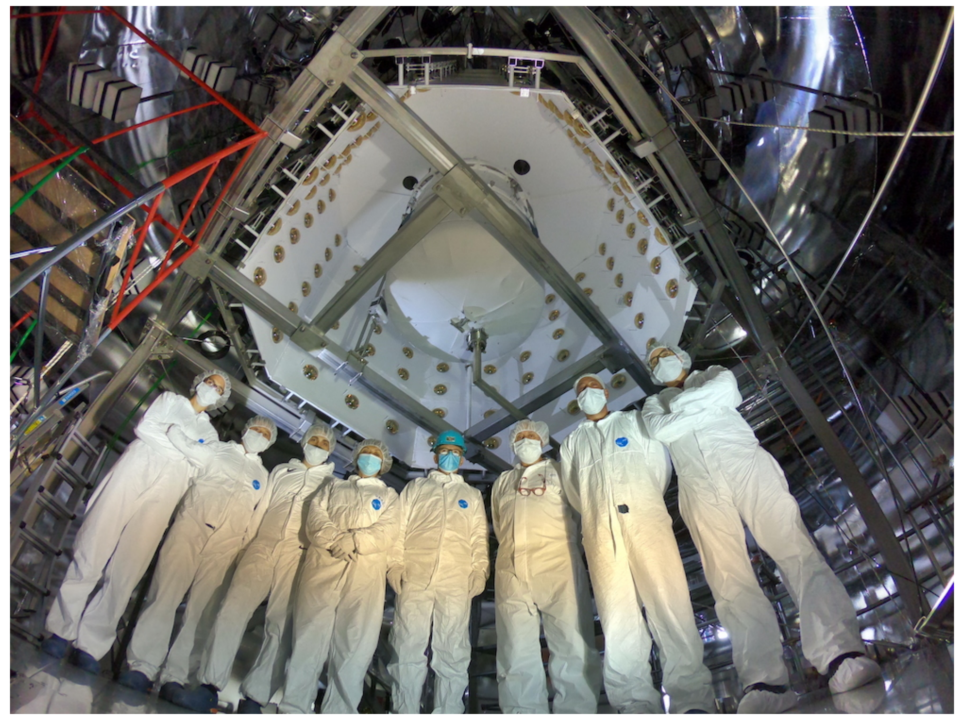
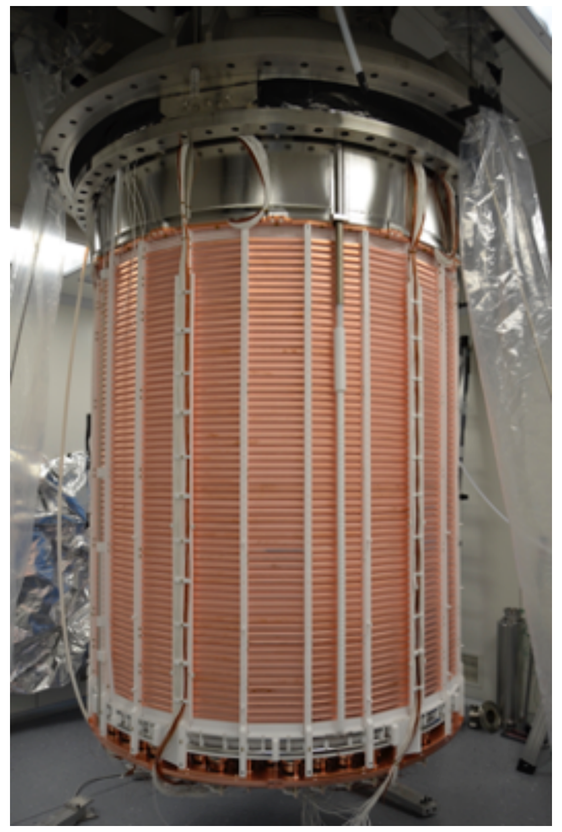
The XENONnT experiment

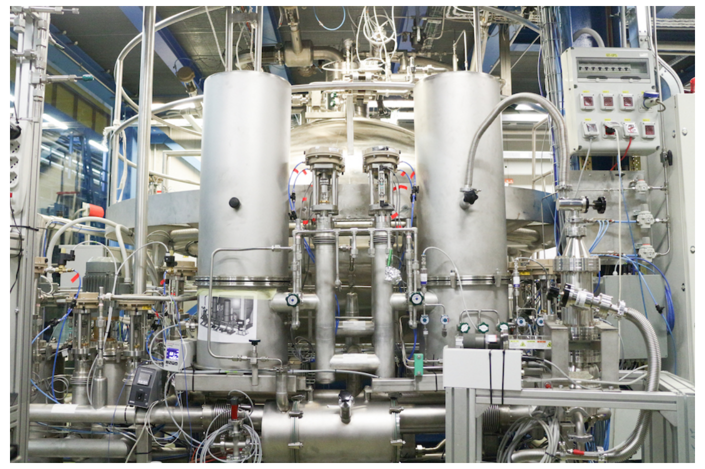


Neutron veto

Radon distillation column



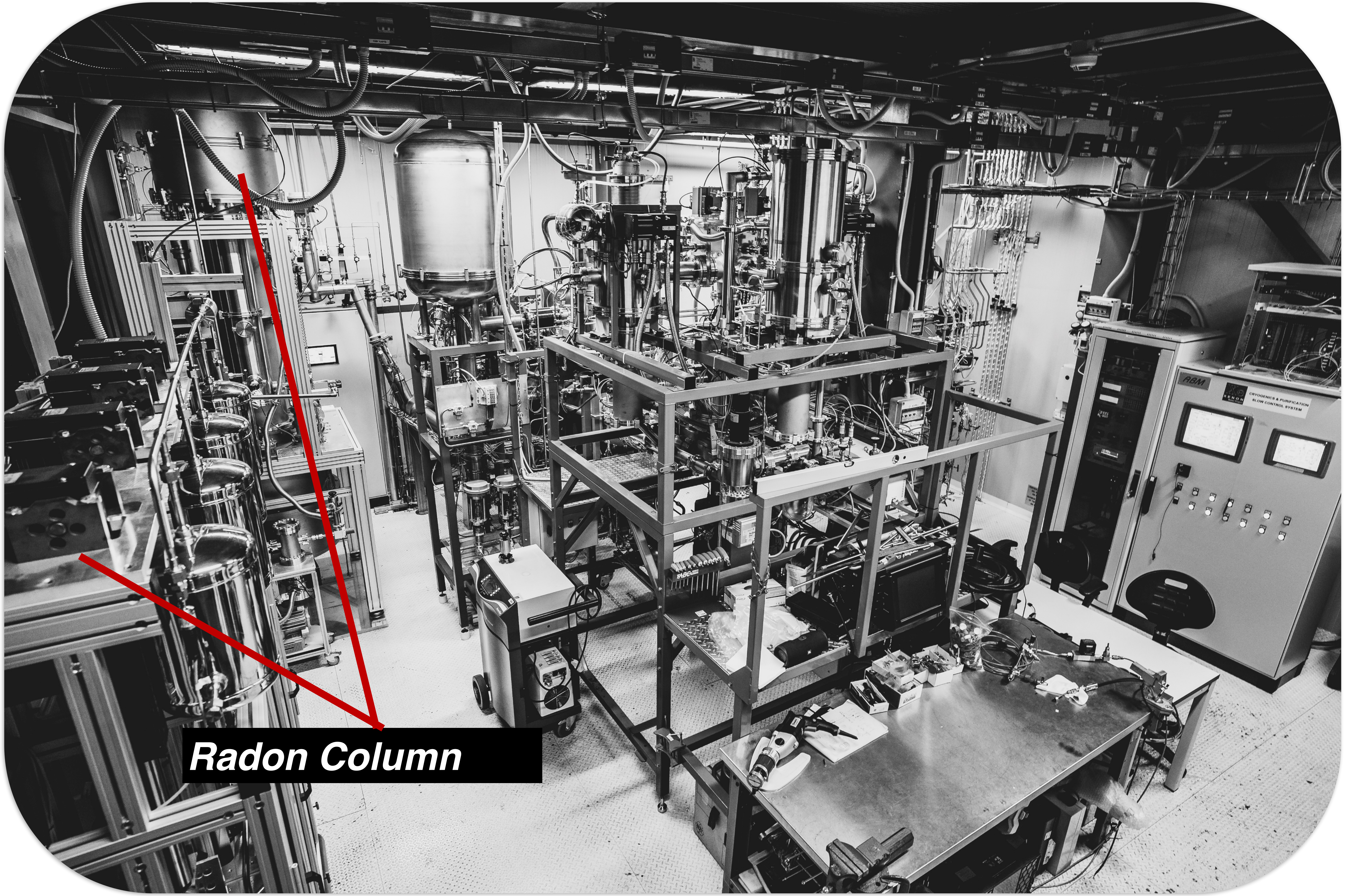
XENONnT TPC

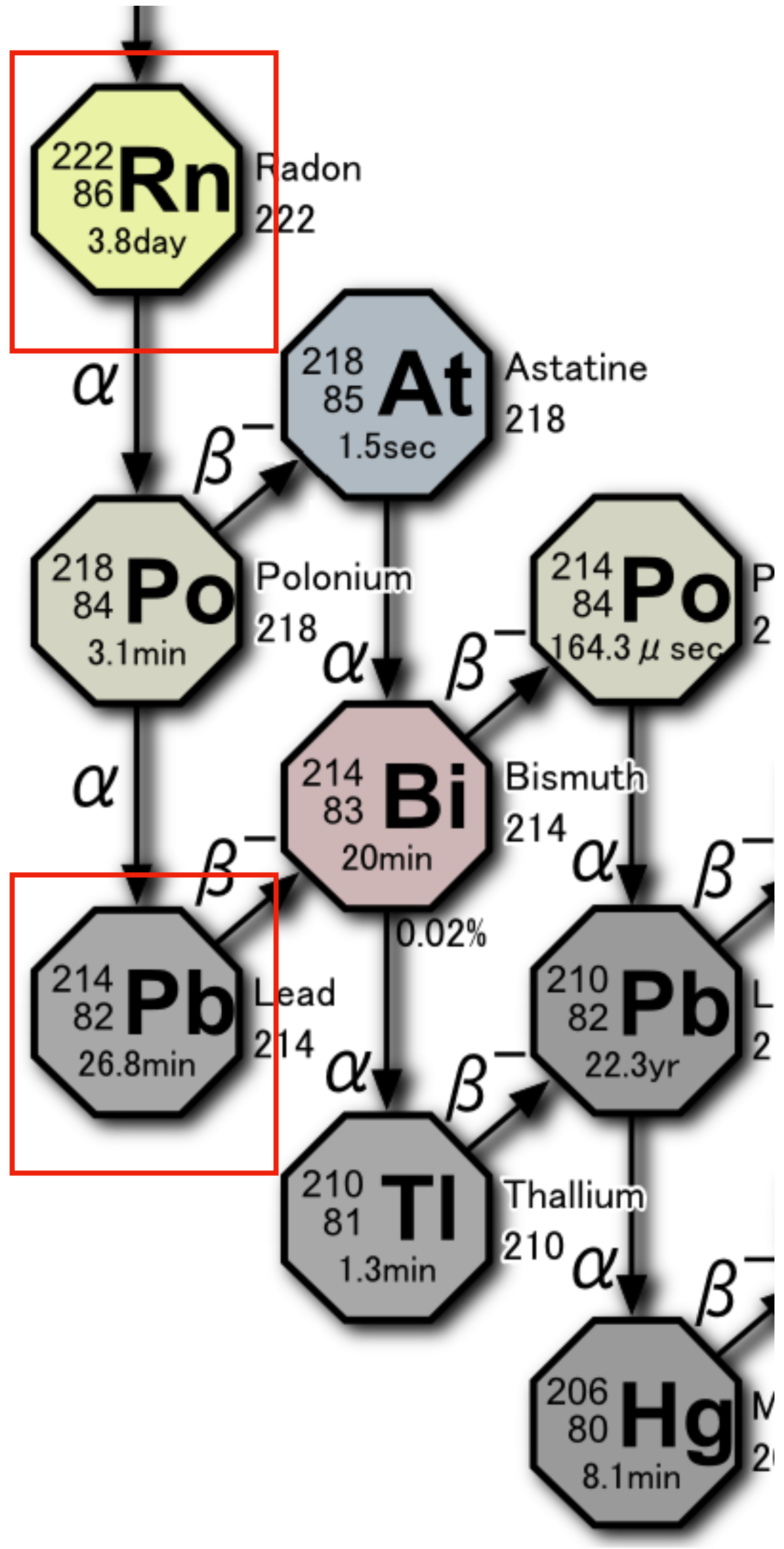


Liquid xenon purification system

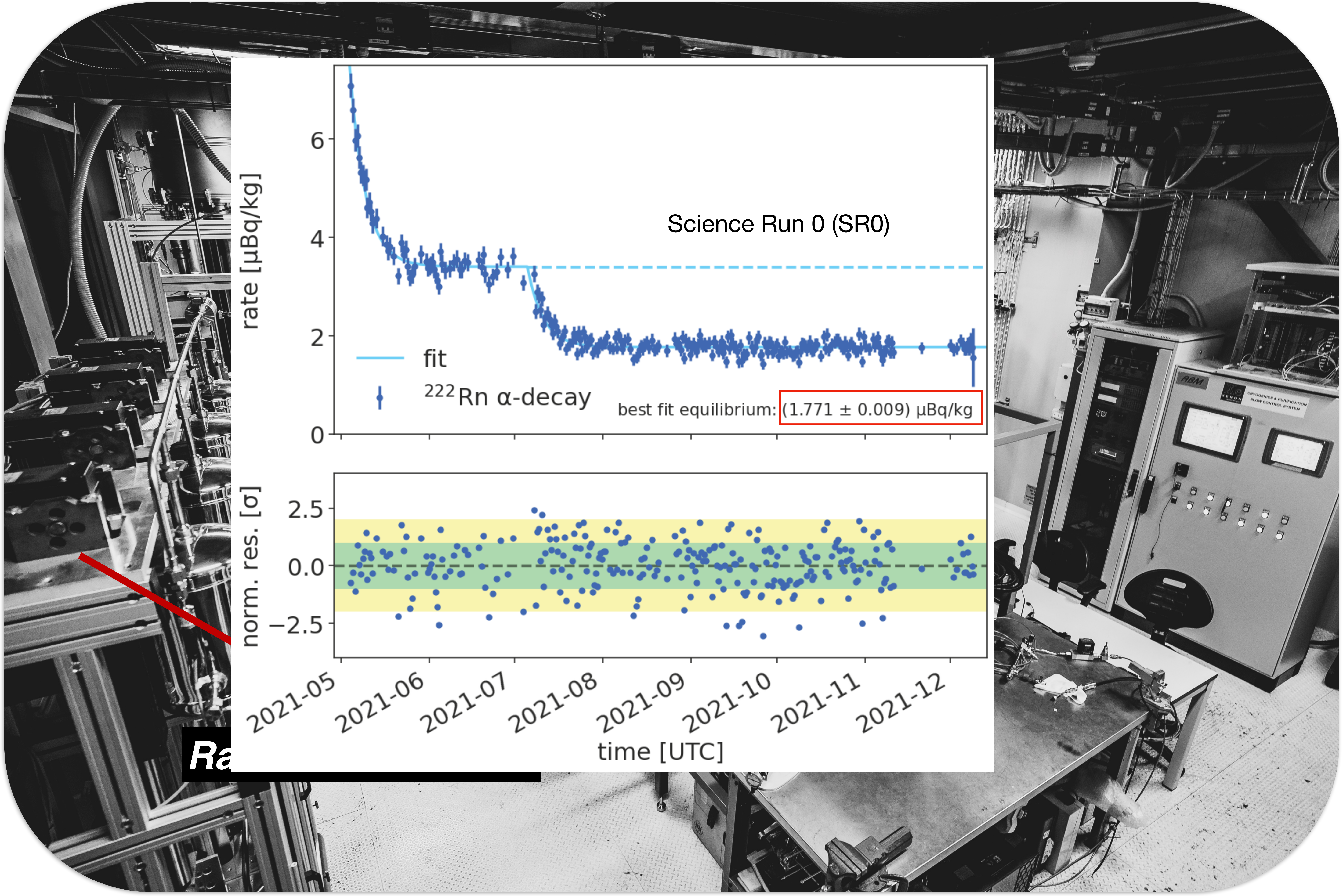
Krypton distillation column

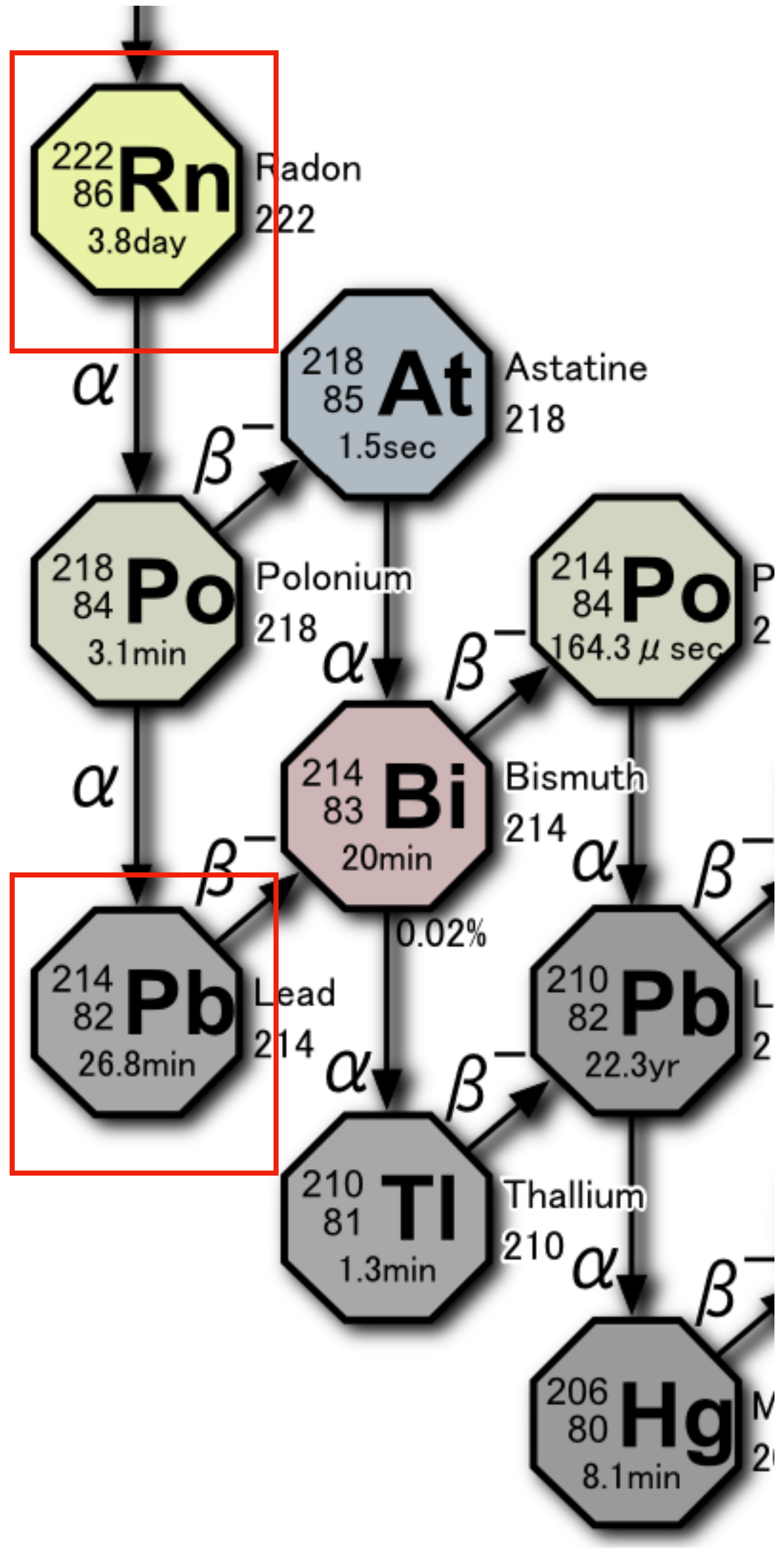
Radon distillation column



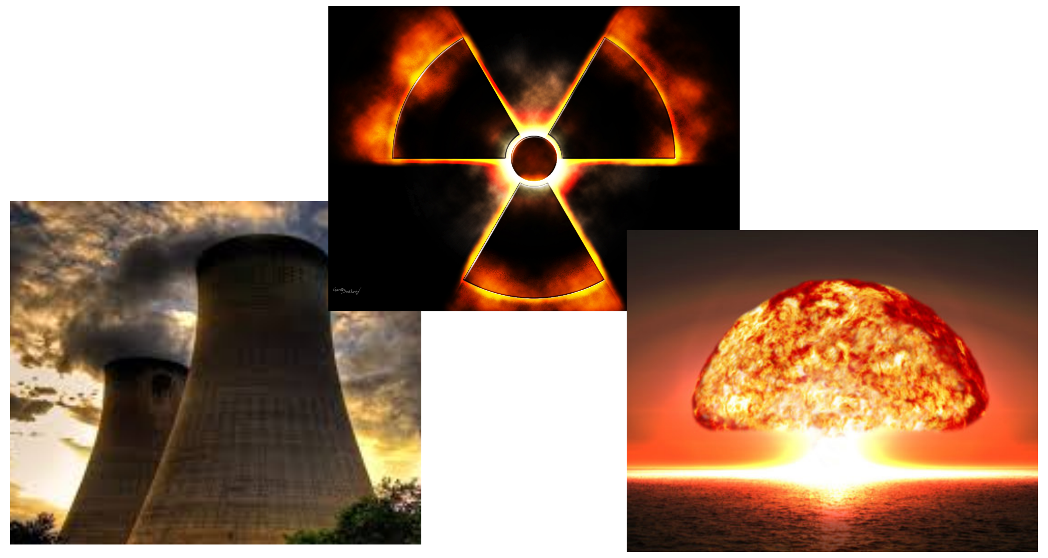


Radon distillation column

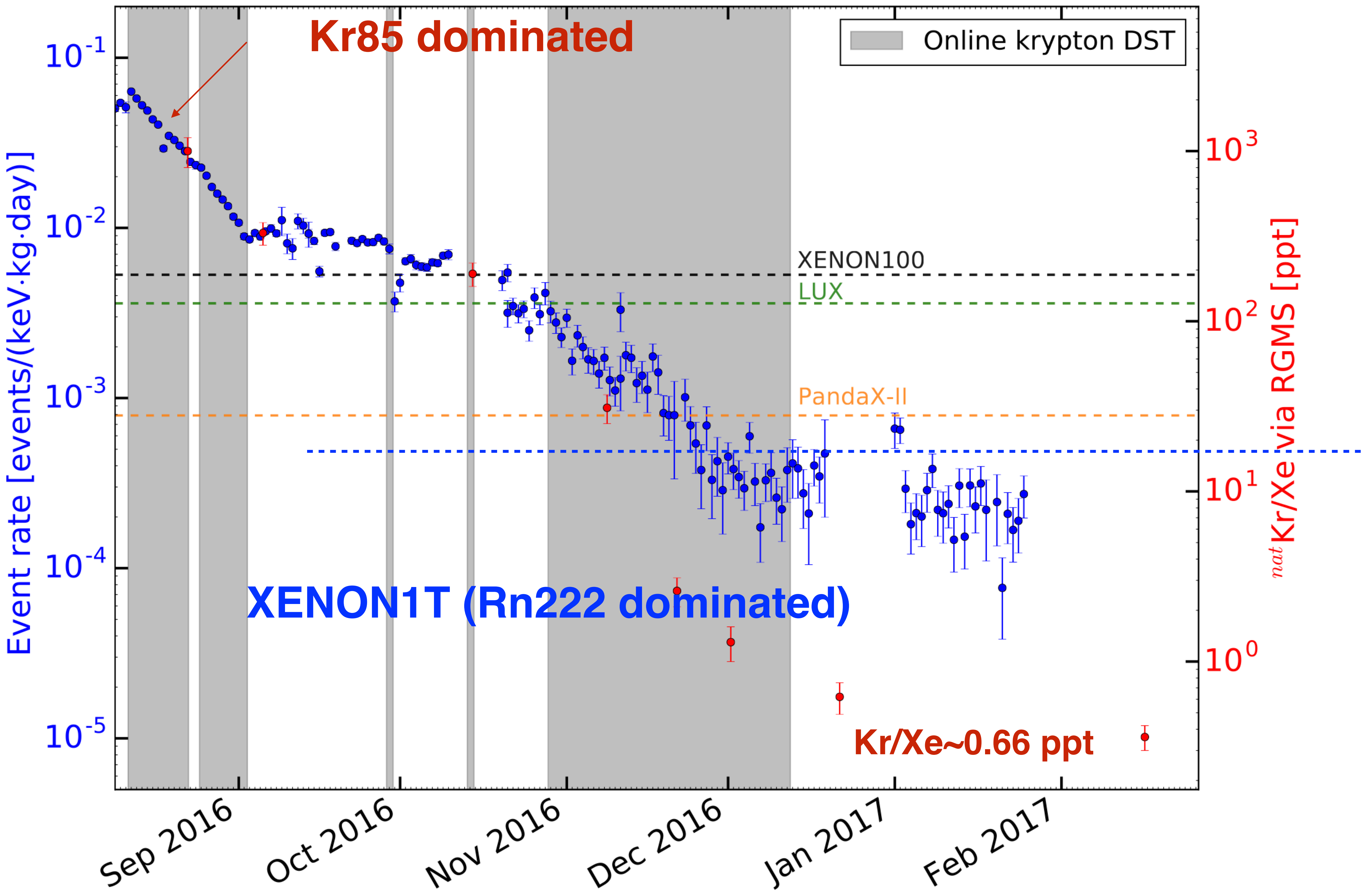




Krypton distillation column

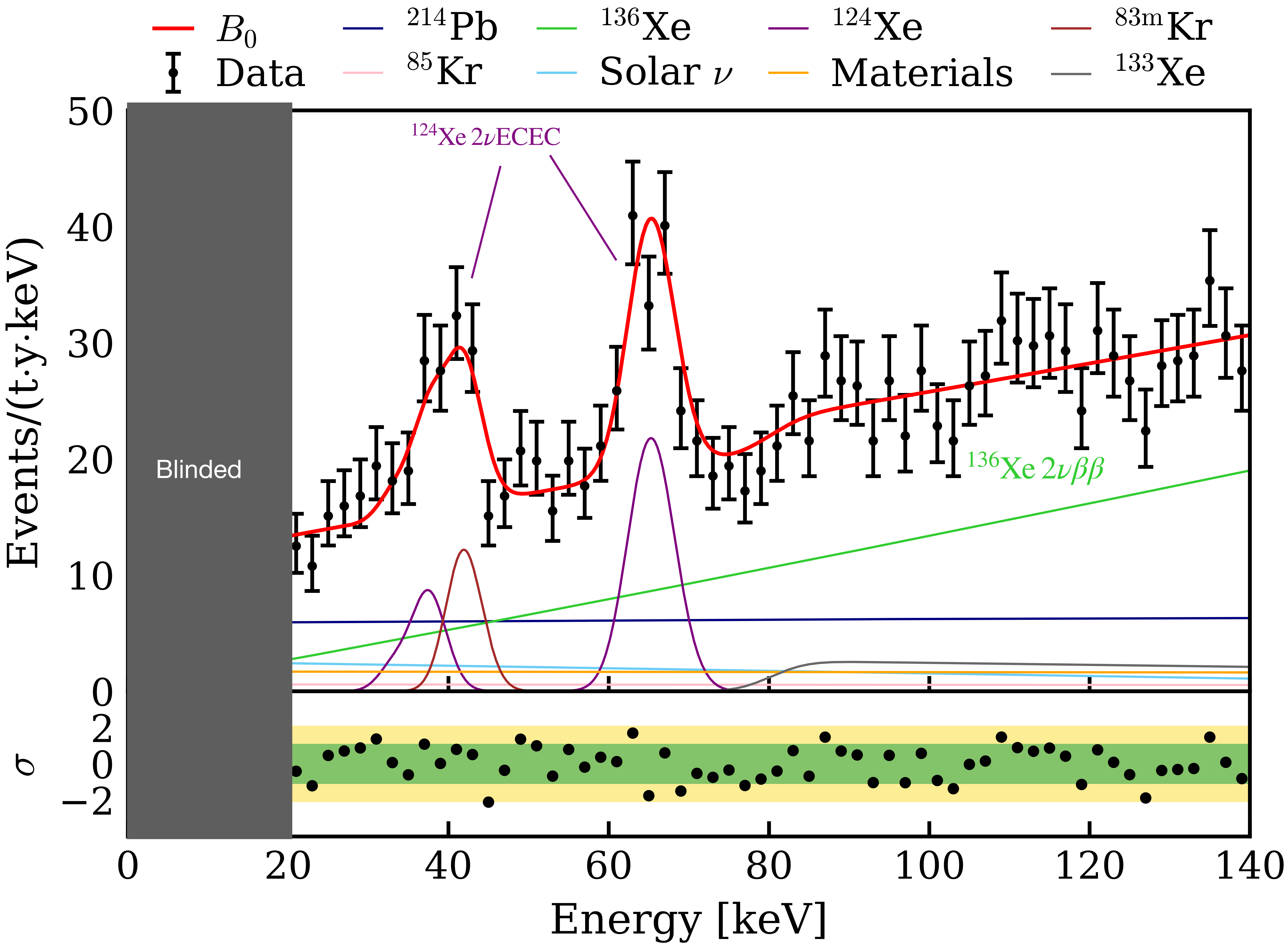


^{85}Kr

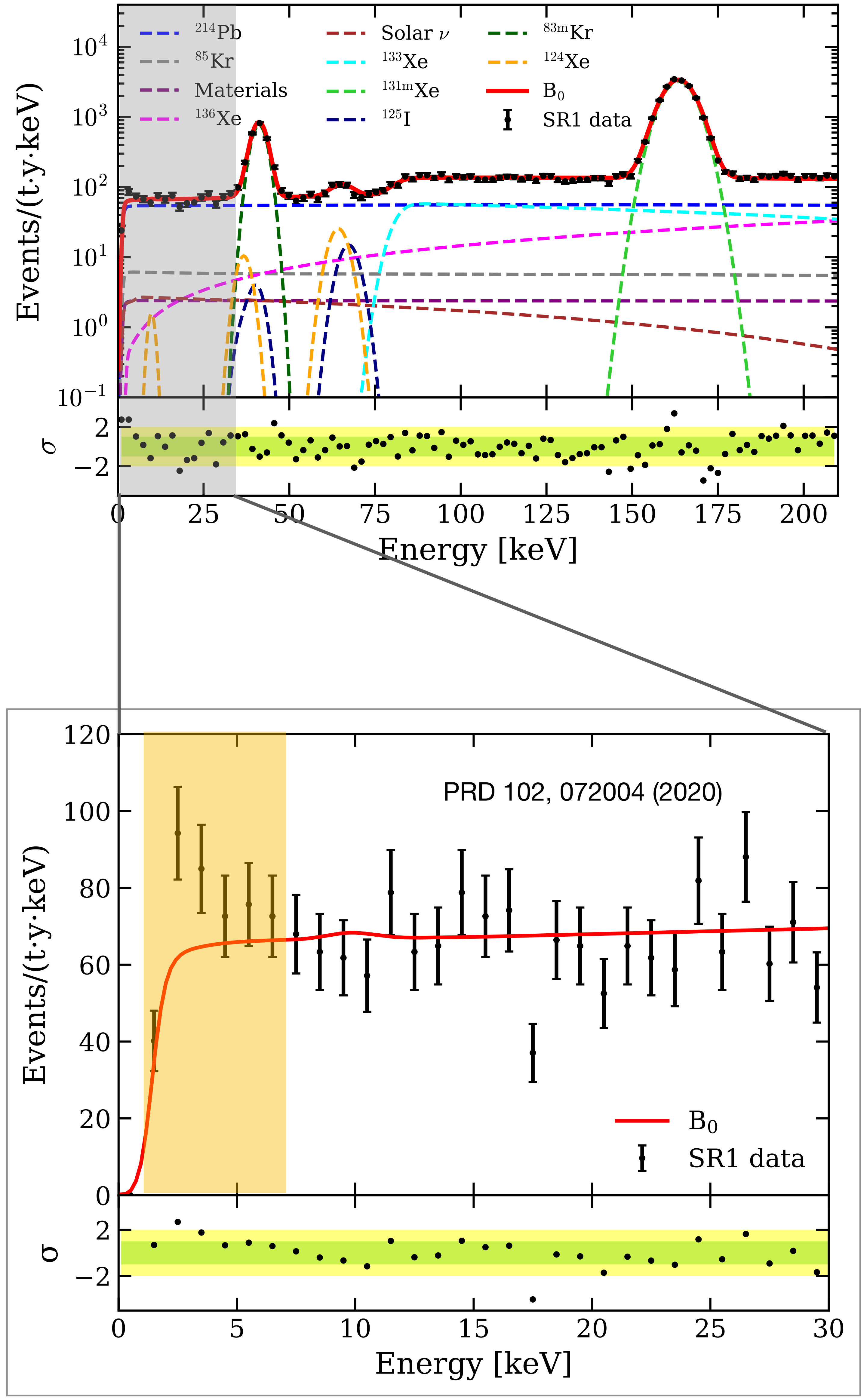


- Decrease krypton concentration by cryogenic distillation
- ^{nat}Kr: (56 ± 36) ppq (XENON1T SR1: (660 ± 110) ppq)

SR0 ER backgrounds



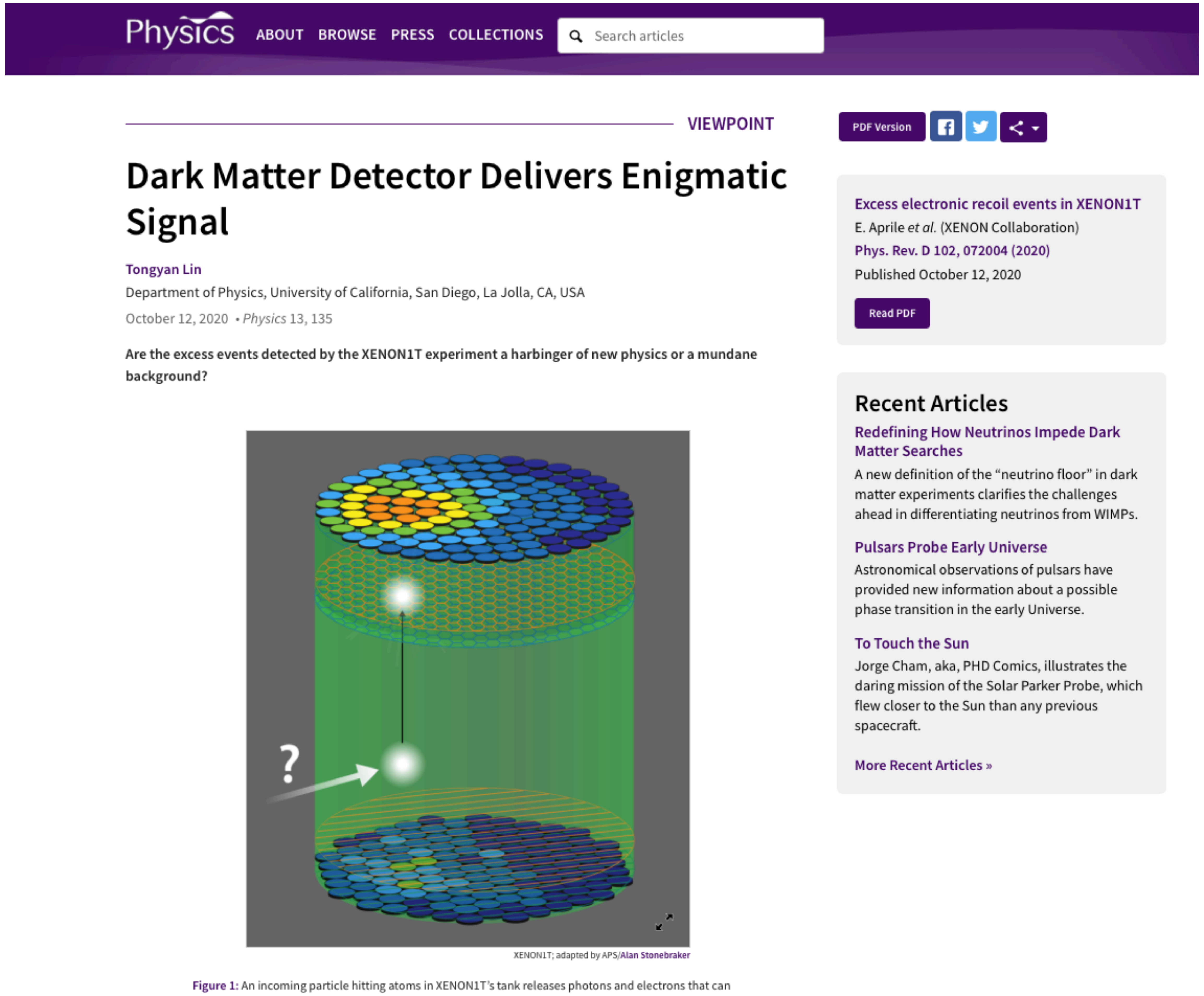
XENON1T Excess



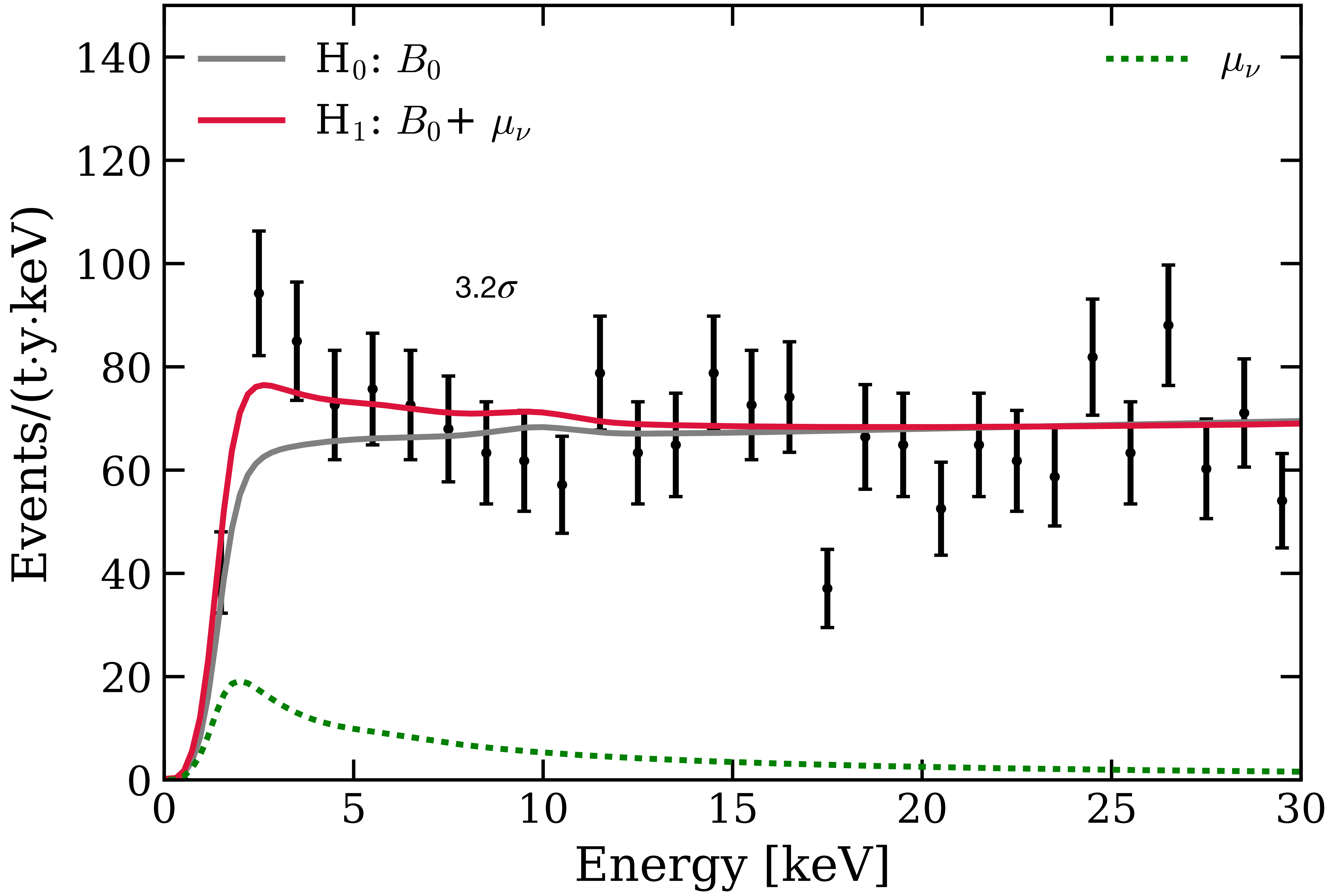
1—7 keV
(reference region)

Expected: 232
Observed: 285

3.3 σ
Poissonian fluctuation
(naive estimate;
main analysis uses
profile likelihood ratio)

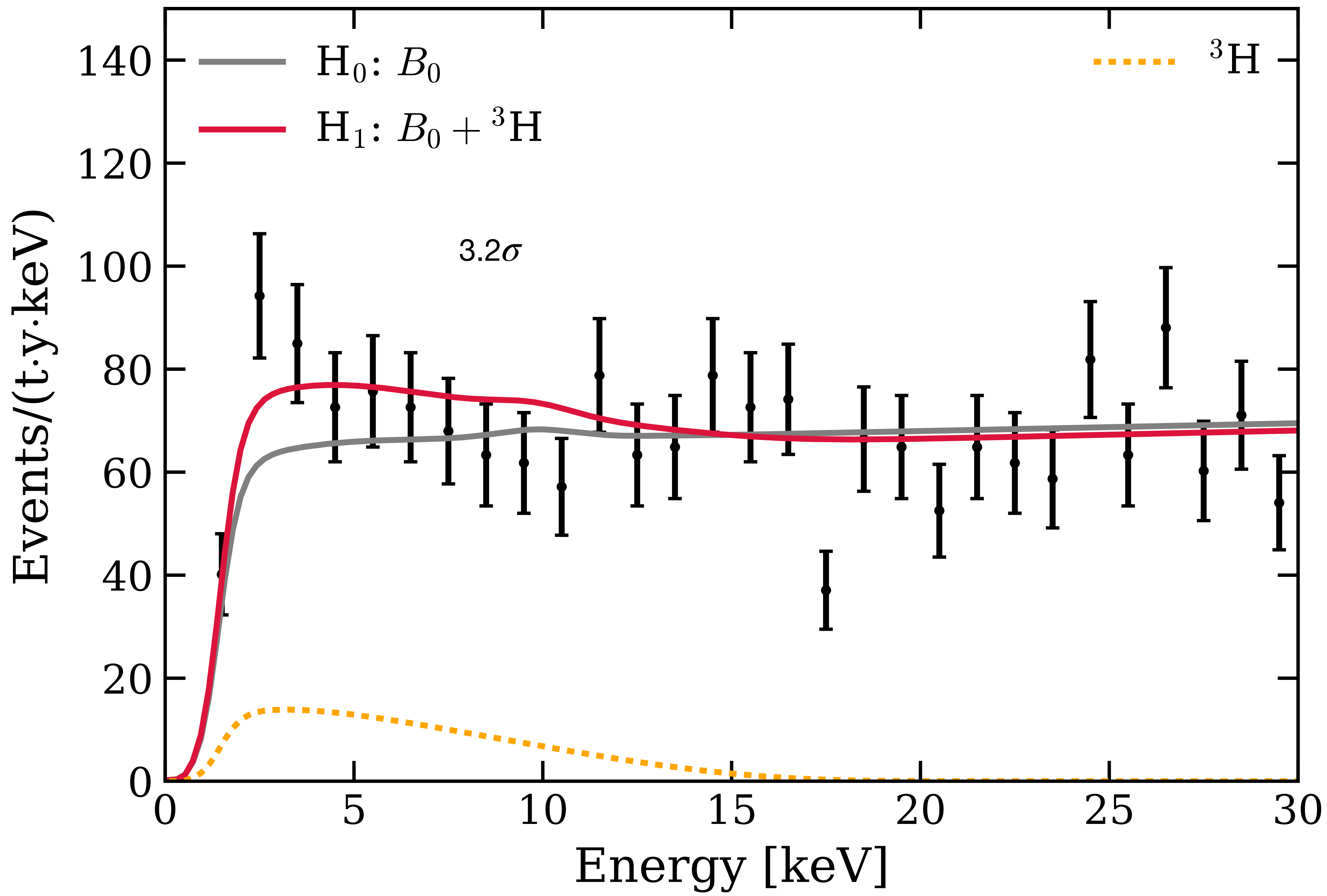


New physics or background?



Neutrino magnetic moment

Enhance solar pp neutrino elastic scattering with electrons

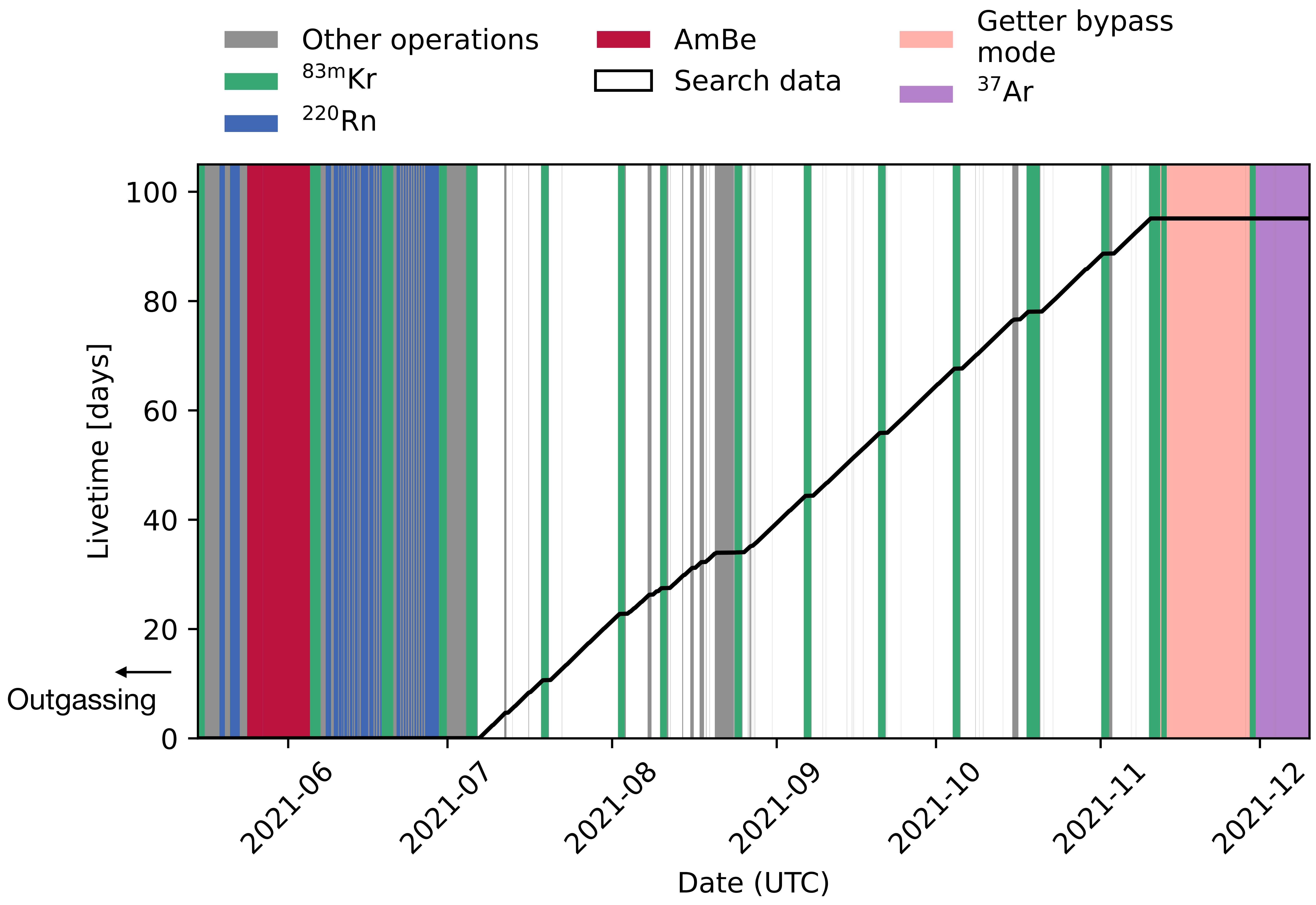


Tritium

- Can be introduced to an underground detector in the forms of HT and/or HTO
- No external constraint on the amount of tritium, in particular HT

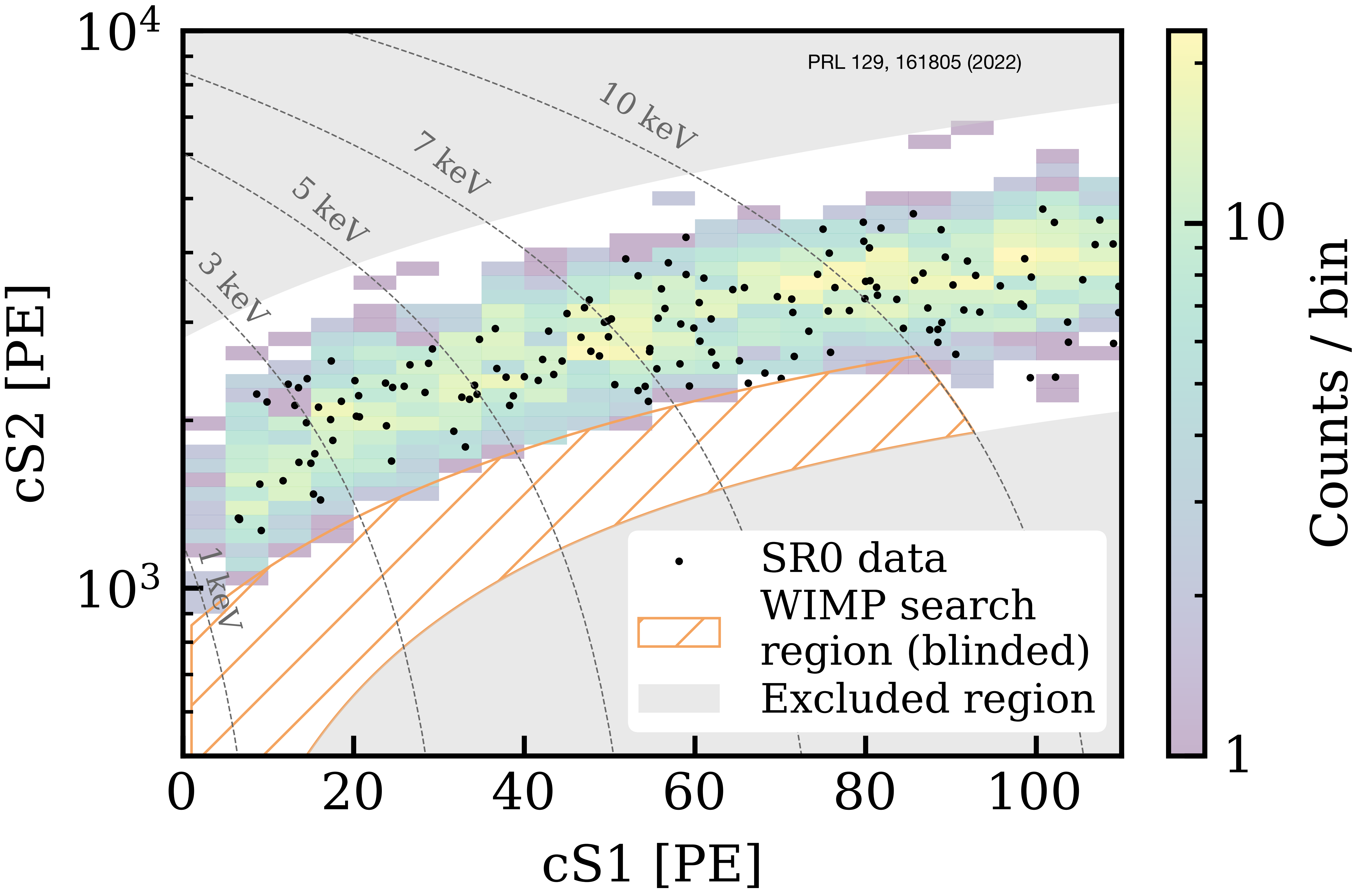
PRD 102, 072004 (2020)

XENONnT SR0



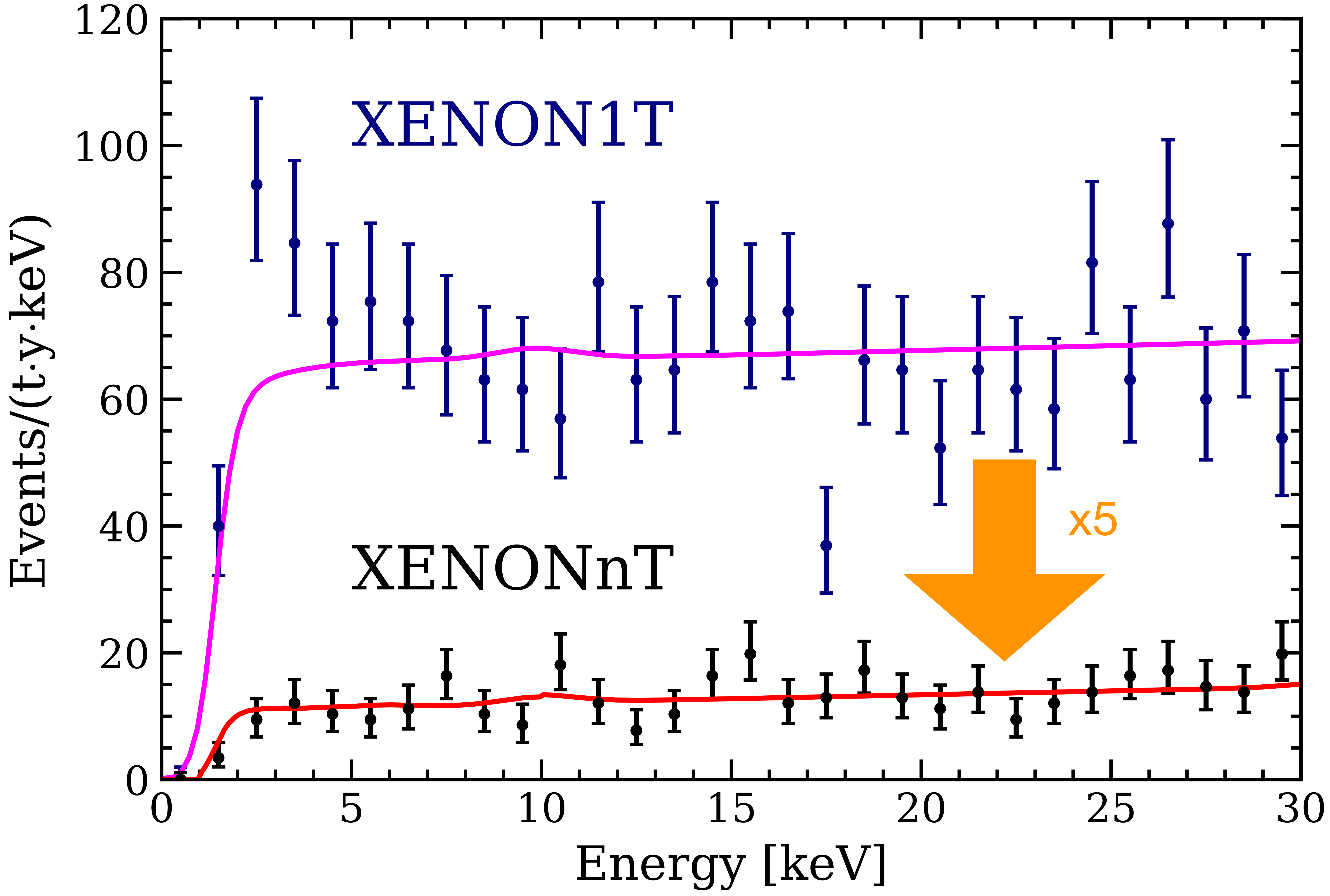
- The first science run length is defined to decipher the XENON1T excess
- Exposure: $(1.16 \pm 0.03)\,\mathrm{tonne} \cdot \mathrm{year}$
- TPC outgassed for ~3 months before filling GXe to reduce HTO/HT (~10 days in XENON1T)

Unblind SR0 ER Data



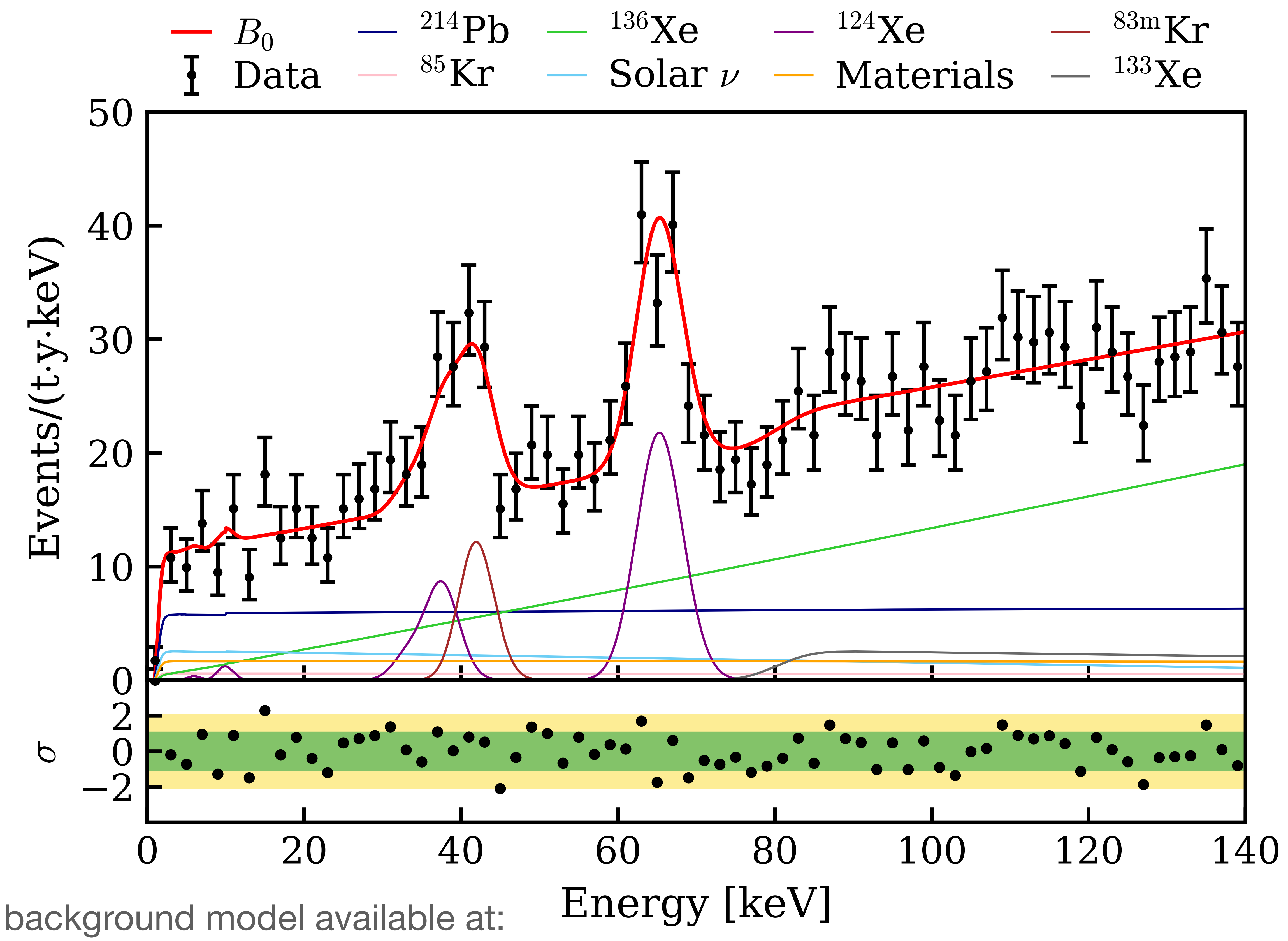
- Unblinded ER region only
- NR region (for WIMP search) was still blinded

XENONnT ER results



- No ER excess is found in XENONnT, which rejects new physics interpretations of the XENON1T excess.
- The XENON1T excess was likely to be caused by trace amount of tritium

XENONnT ER results



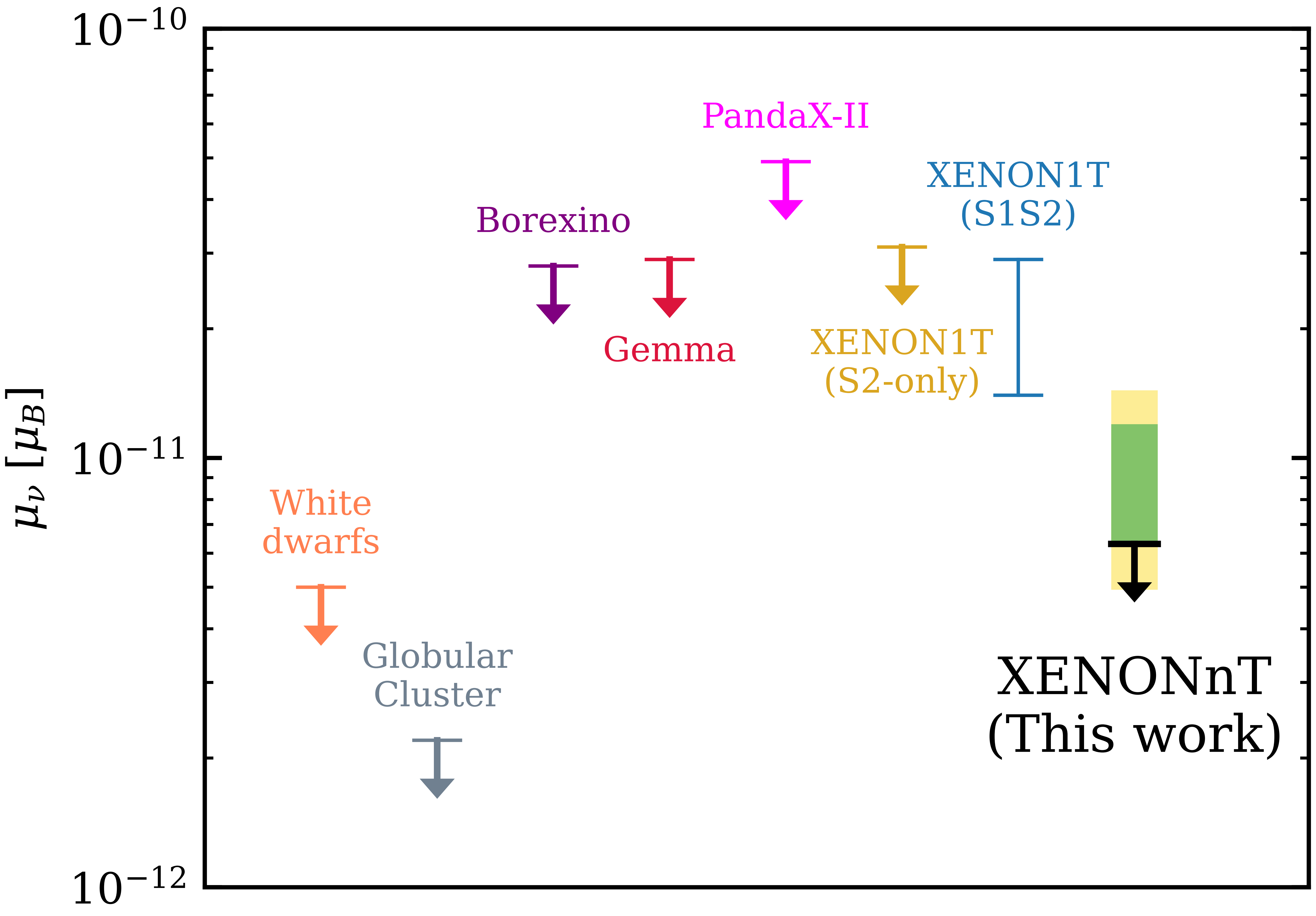
Data and background model available at:
https://zenodo.org/records/7992017

Best-fit values

	(1, 10) keV	(1, 140) keV
^{214}Pb (^{222}Rn)	55 ± 7	960 ± 120
^{85}Kr	6 ± 4	90 ± 60
Materials	16 ± 3	270 ± 50
^{136}Xe	8.8 ± 0.3	1550 ± 50
Solar pp neutrino	25 ± 2	300 ± 30
^{124}Xe	2.6 ± 0.3	250 ± 30
AC	0.70 ± 0.03	0.71 ± 0.03
^{133}Xe	-	150 ± 60
^{83m}Kr	-	80 ± 16

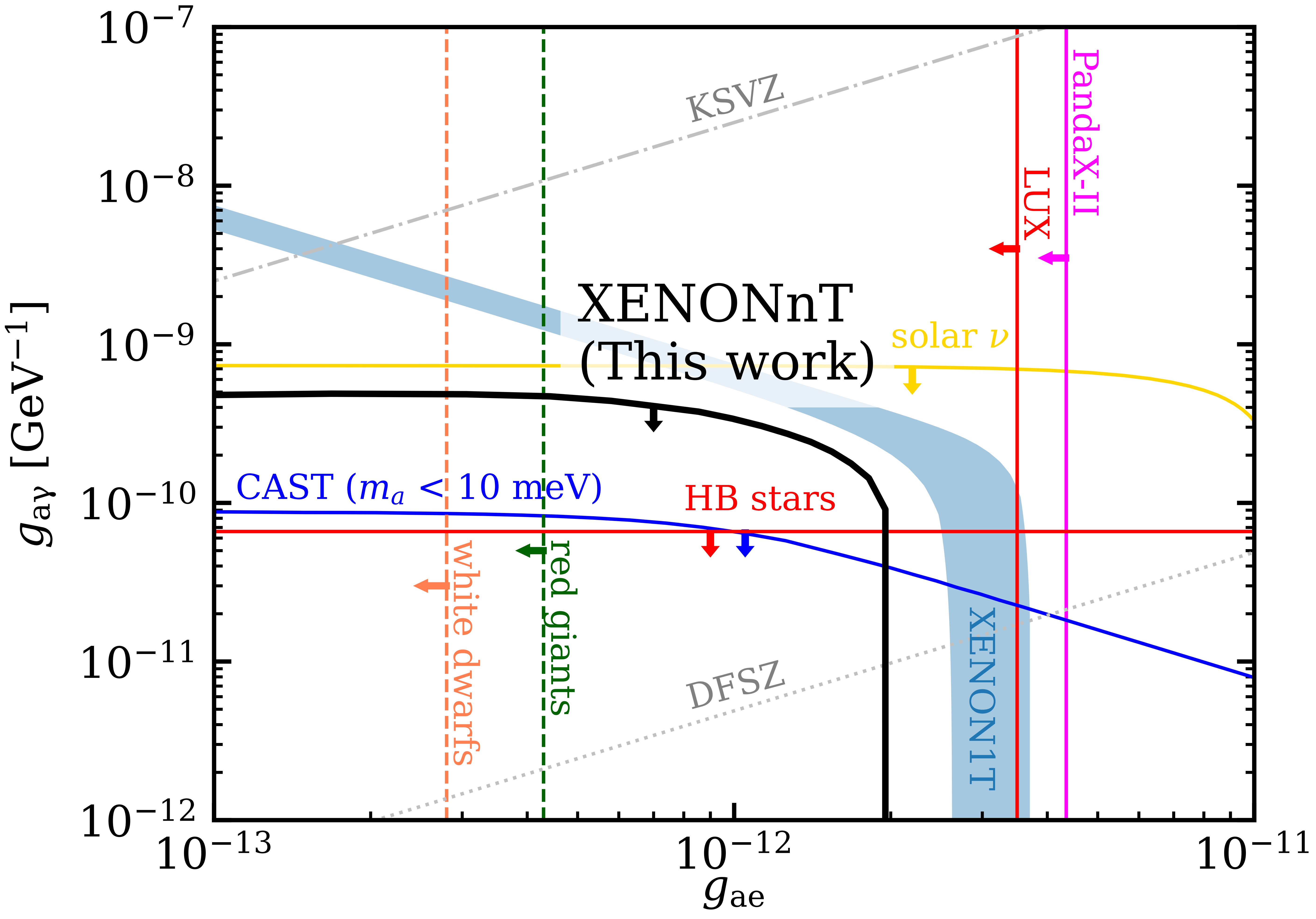
- The total ER rate below 30 keV is $(15.8 \pm 1.3_{\text{stat}})$ events/$(\text{t} \cdot \text{y} \cdot \text{keV})$
- ^{214}Pb best-fit value: $(1.31 \pm 0.17_{\text{stat}})\ \mu\text{Bq/kg}$
- Solar pp neutrino: the 2nd largest ER contribution below 10 keV in SR0

Neutrino magnetic moment



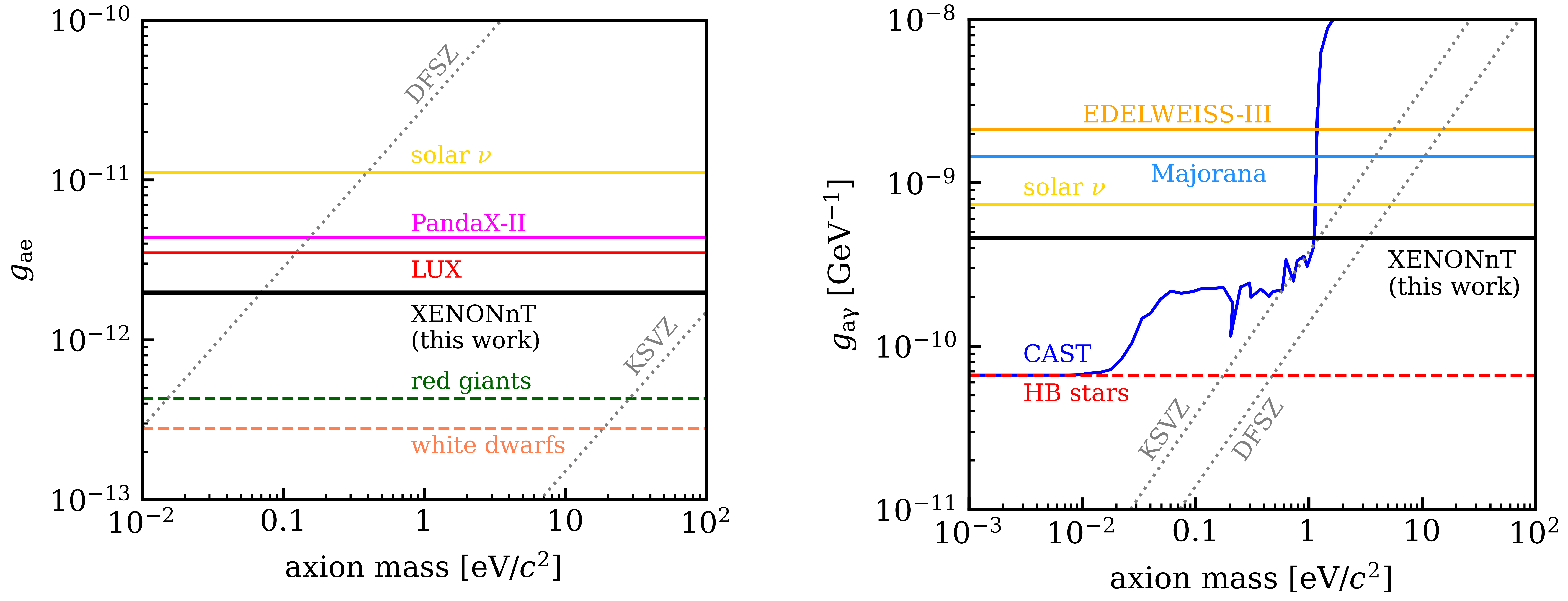
- Constrain the effective neutrino magnetic moment μ_ν^{eff} using solar neutrinos as LXe detectors are not sensitive to neutrino flavors
- XENONnT result: $\mu_\nu^{\mathrm{eff}} < 6.4 \times 10^{-12}\,\mu_{\mathrm{B}}$ (90% C.L.)

Solar axion Limit



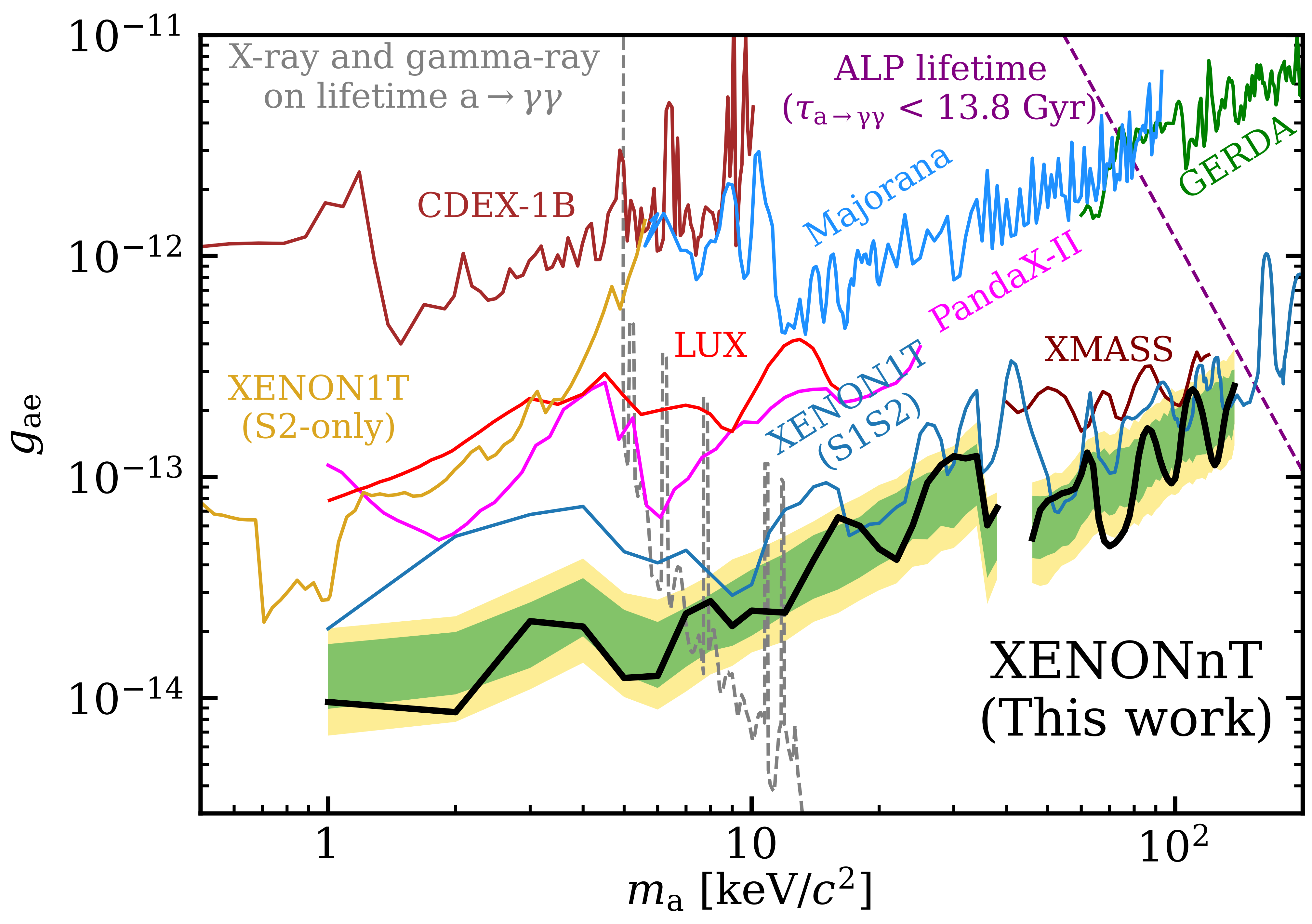
- Statistical inference is done in 3D space (g_{ae}, $g_{a\gamma}$, g_{an}^{eff})
- Projection to 2D space of g_{ae} and $g_{a\gamma}$ as they matter most for the low-energy region

Solar axion Limit

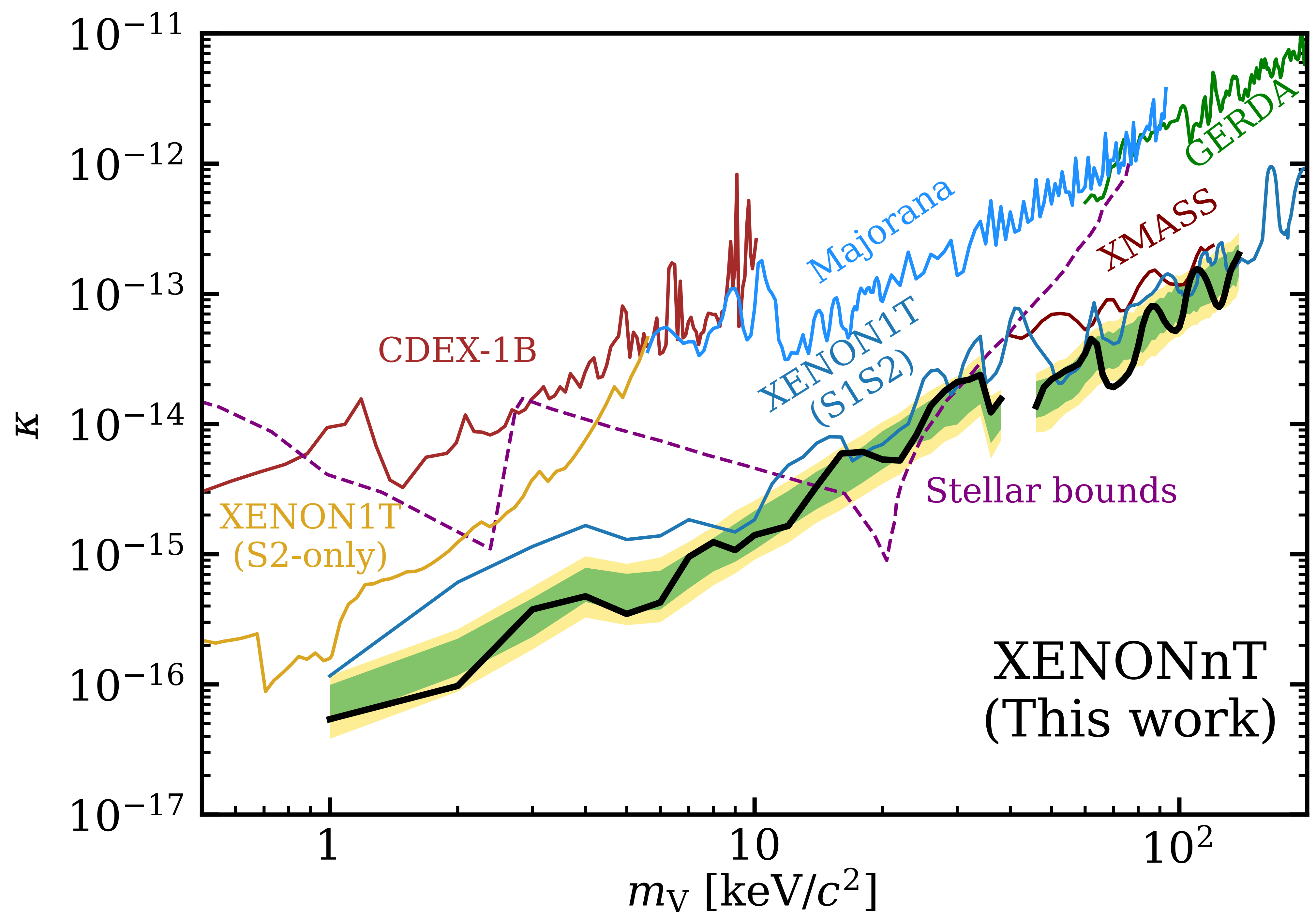


- Valid for axions with mass below 100 eV/c^2
- Best direct detection limit of g_{ae} for axion mass below 100 eV/c^2
- Best direct detection limit of $g_{a\gamma}$ for axion mass between 1 and 100 eV/c^2

Bosonic dark matter



ALPs

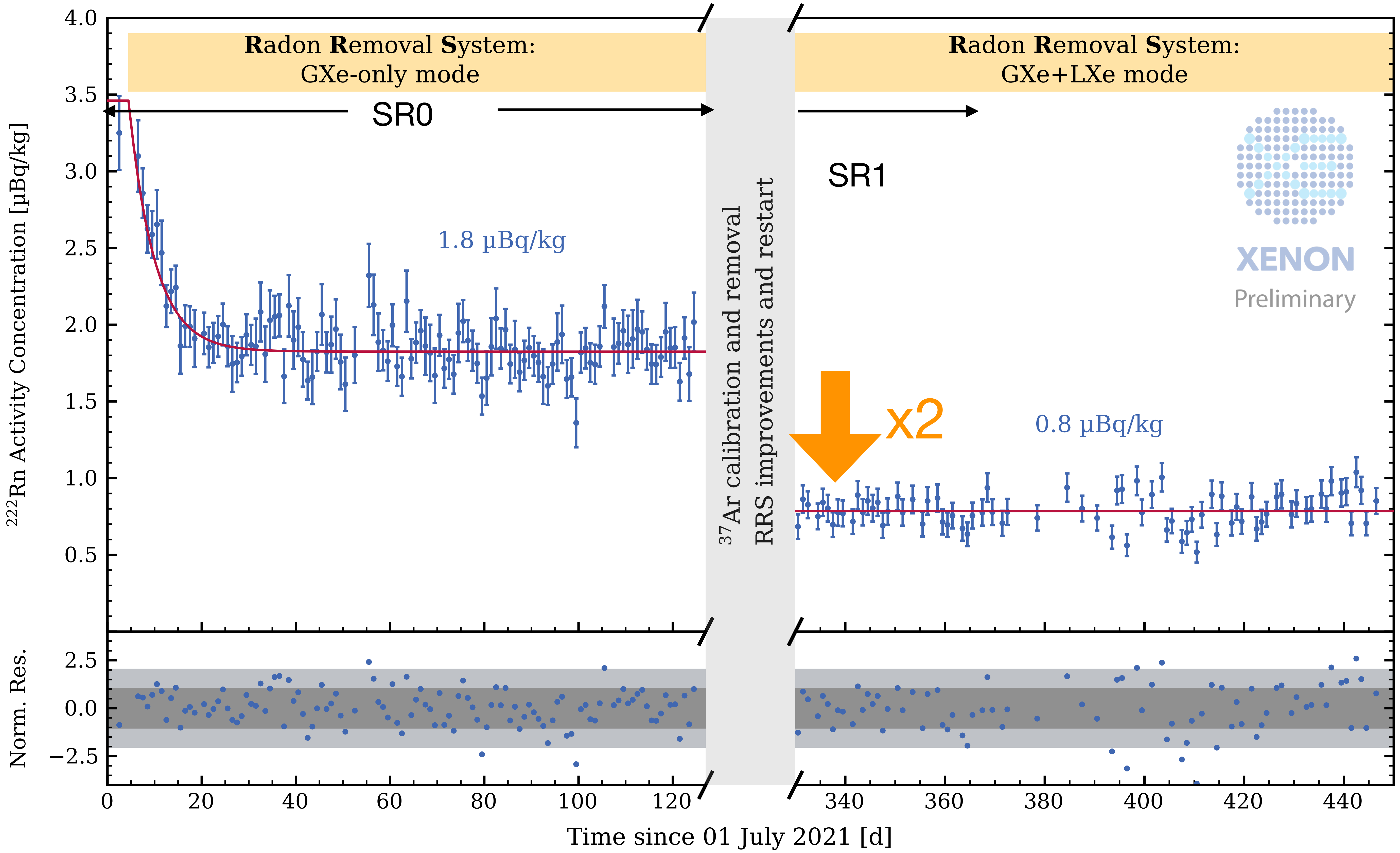


Dark photon

- Bosonic DM:
  - ALPs
  - Dark photons
- Competitive limits for mass in (1, 39) and (33, 140) keV/c^2
  - No limit/sensitivity between (39, 44) keV/c^2 because $^{83m}\mathrm{Kr}$ background rate is not constrained
  - The maximum local significance ~1.8 σ at ~109 keV

What is next?

Further reduction of ^{222}Rn



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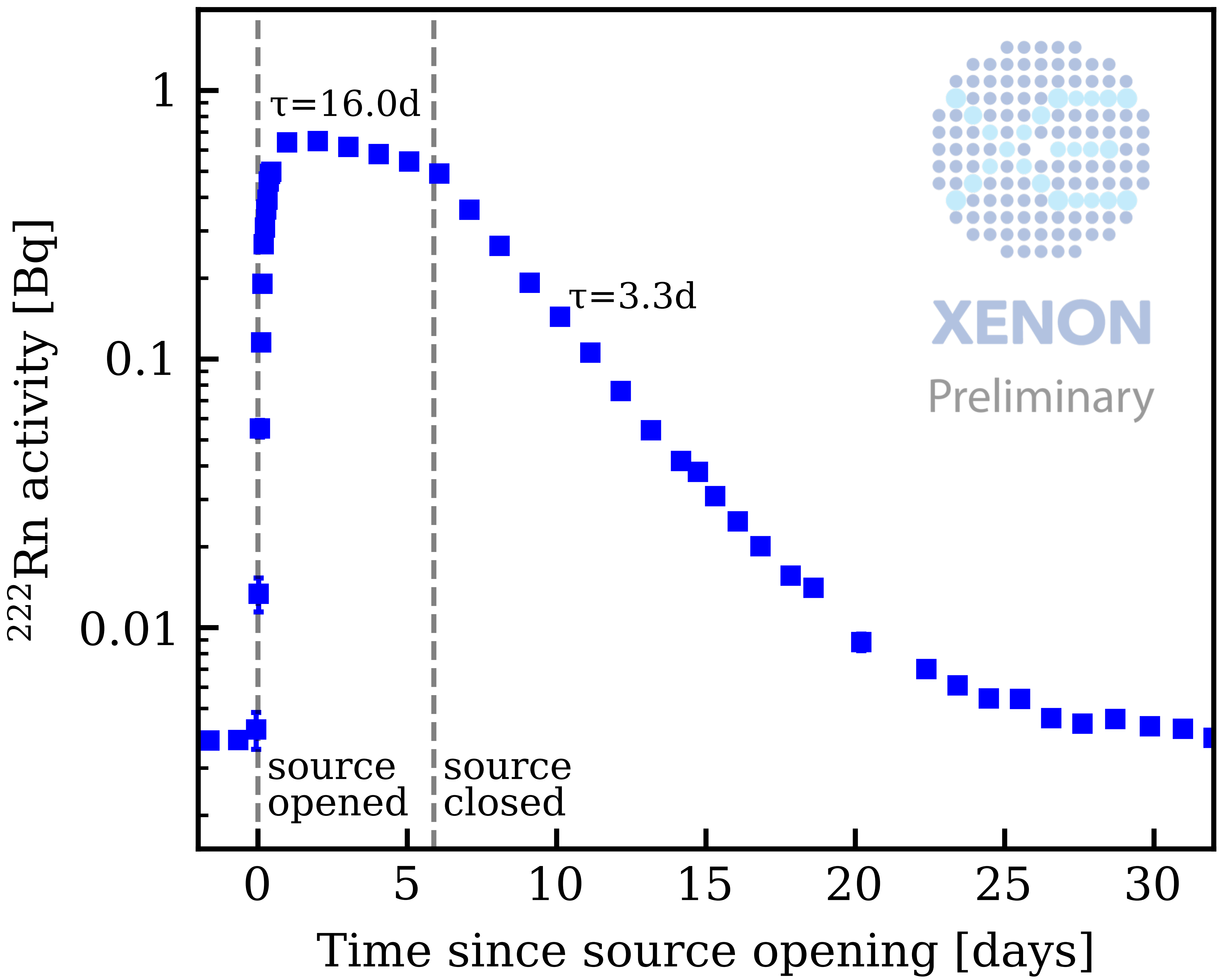
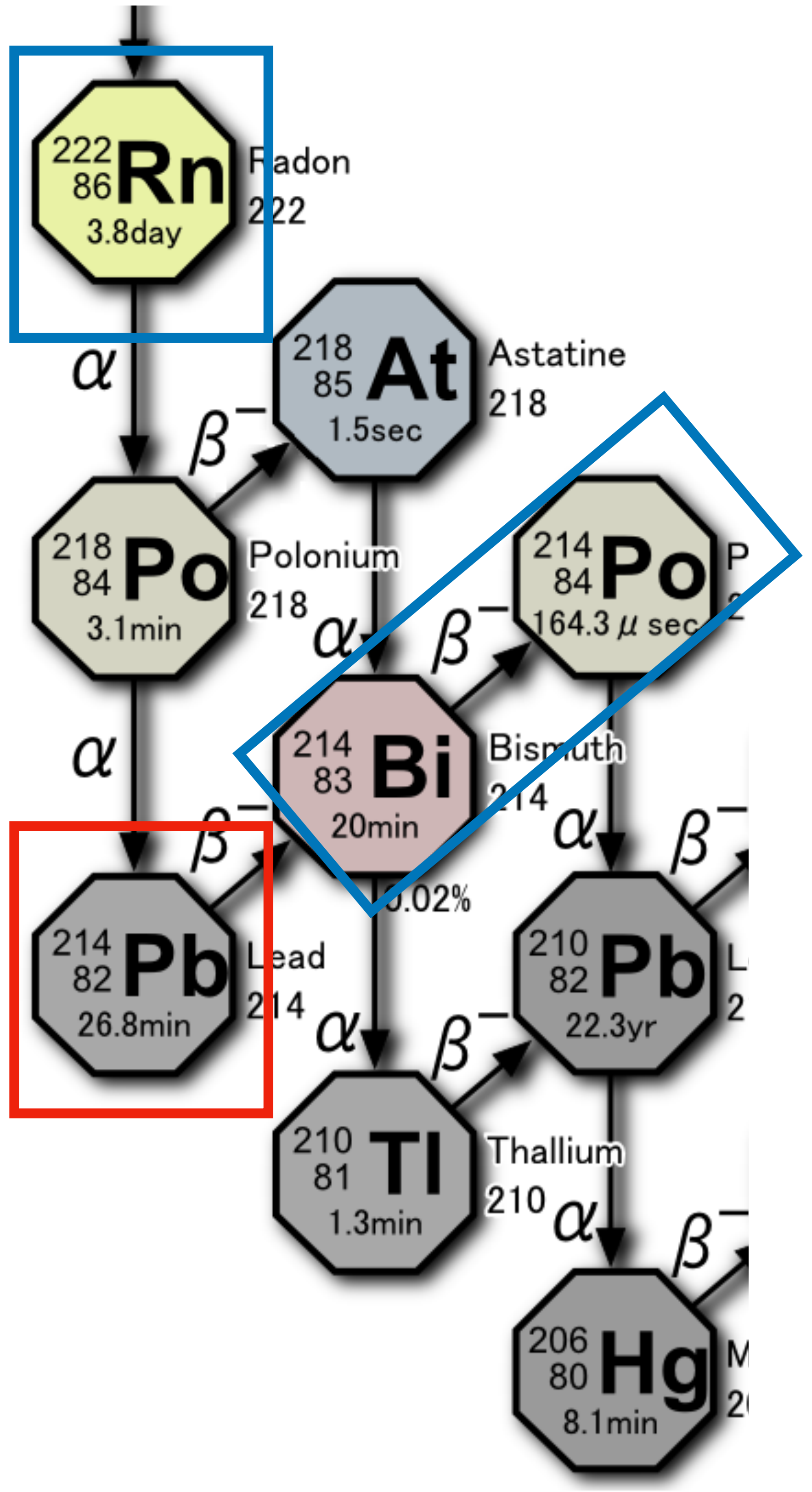
- ^{222}Rn was further reduced by a factor of 2 in the following science run
- The contribution of ^{222}Rn to ER events is at a similar level of elastic scattering between solar pp neutrinos and electrons

^{222}Rn calibration

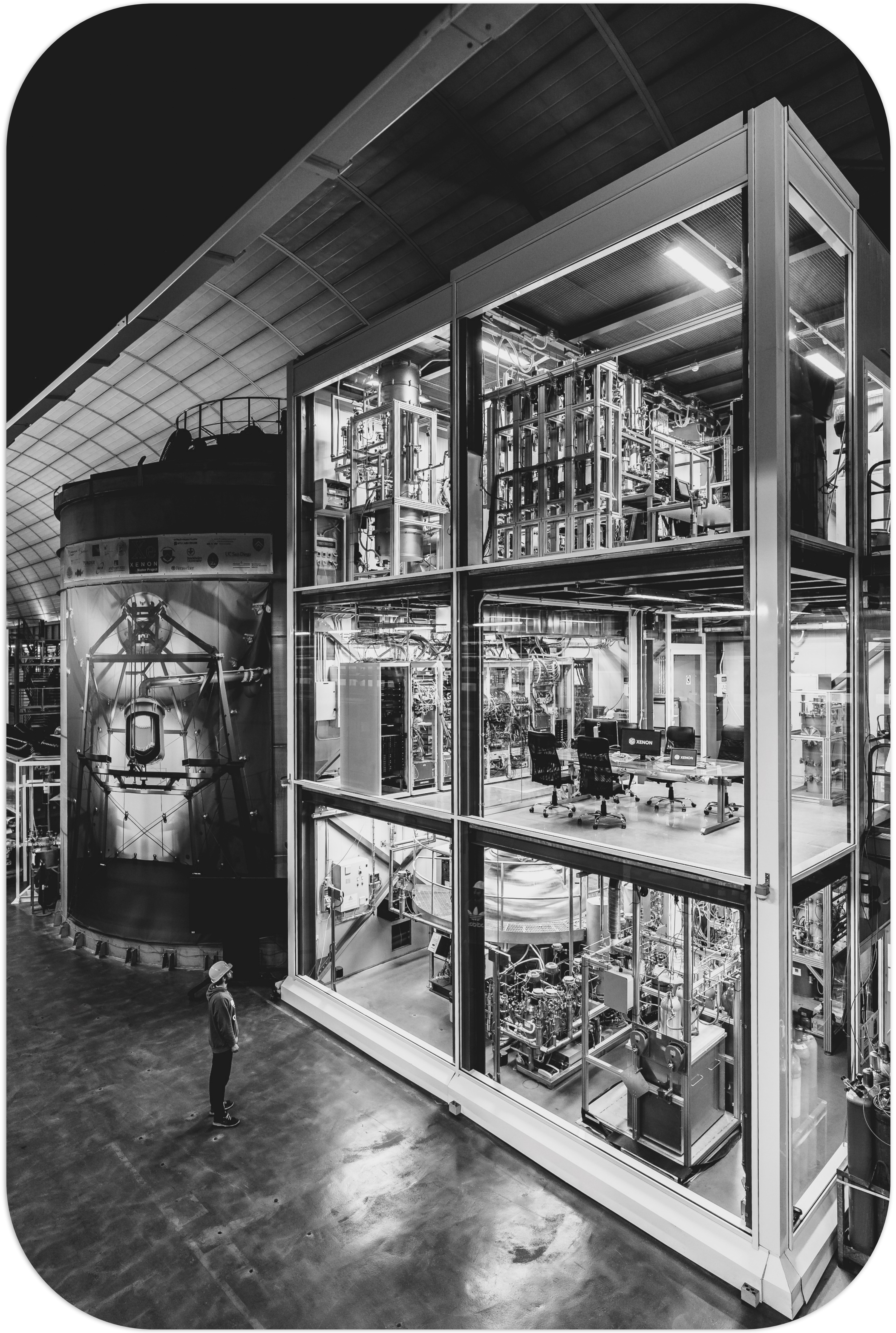




- ^{214}Pb best-fit value: $(1.31 \pm 0.17_{\text{stat}})\ \mu$Bq/kg
- Constrain the uncertainty of ^{214}Pb by constraining the ratios between ^{214}Pb and its daughters/parents

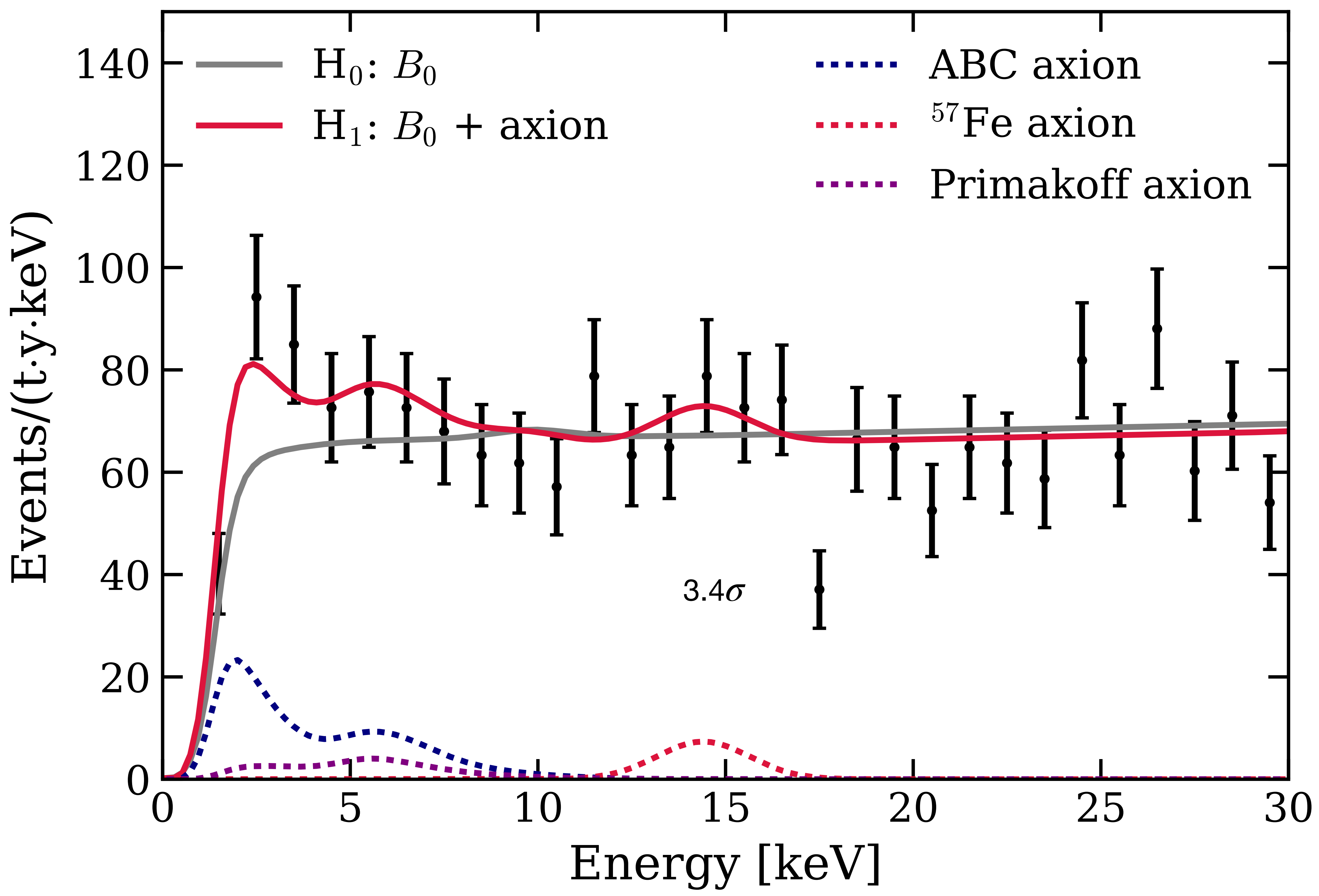
Summary & Outlook

- **SR0** - 1.16 t·yr exposure
- **Unprecedented low ER background** - 15.8 events/(t y keV)
- **Low ER results** PRL 129, 161805 (2022)
  - Deciphered XENON1T excess
  - Competitive limits on solar axions, bosonic dark matter
  - Best limit on neutrino magnetic moment $\mu_\nu < 6.4 \times 10^{-12}\,\mu_\mathrm{B}$
- **SR1**
  - Further reduction of $^{222}\mathrm{Rn}$ (< 1$\mu\mathrm{Bq/kg}$)
  - $^{222}\mathrm{Rn}$ calibration was performed to reduce $^{214}\mathrm{Pb}$ uncertainty
  - More topics
    - Solar pp neutrinos
    - …



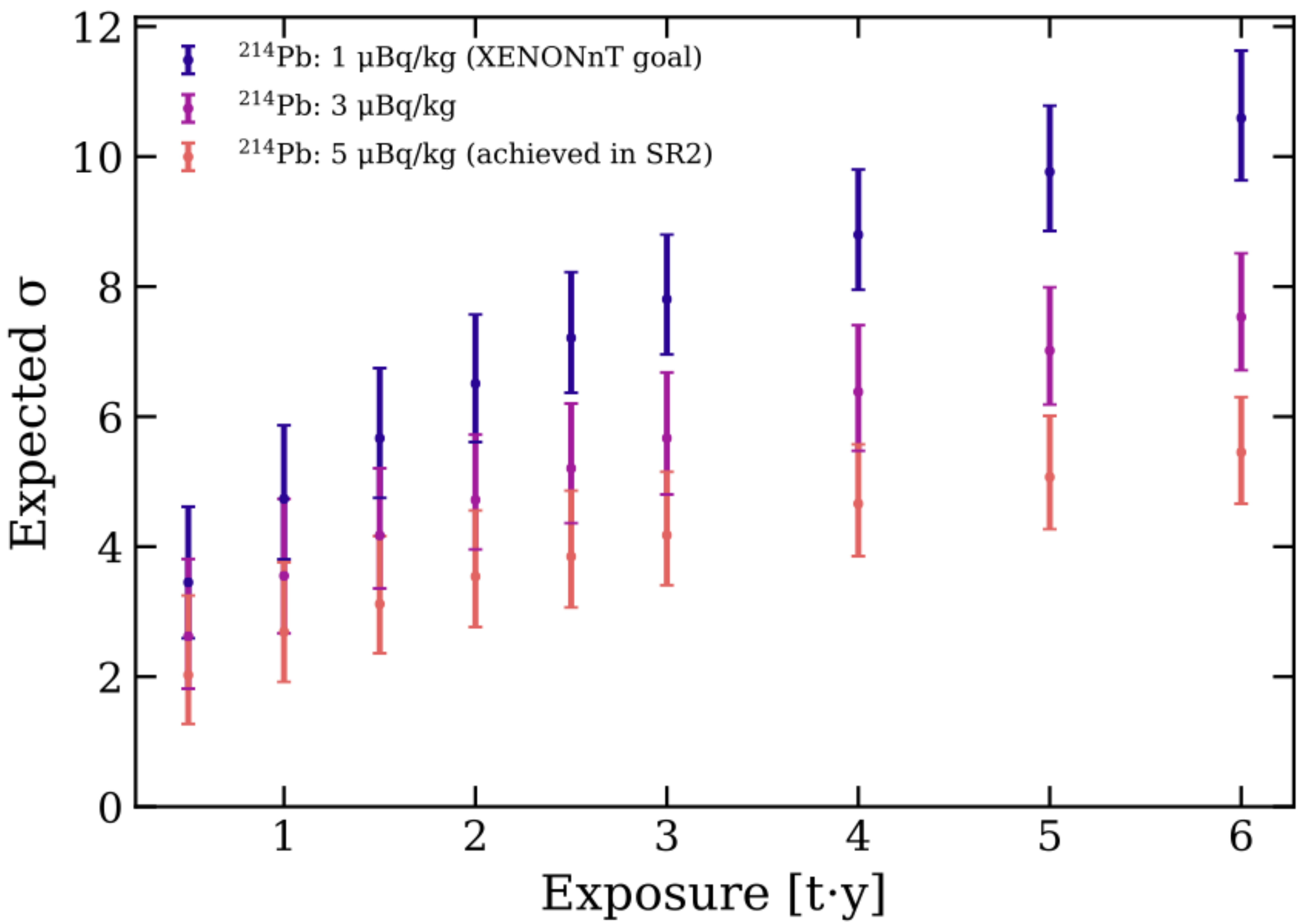
Back up

Solar axion hypothesis



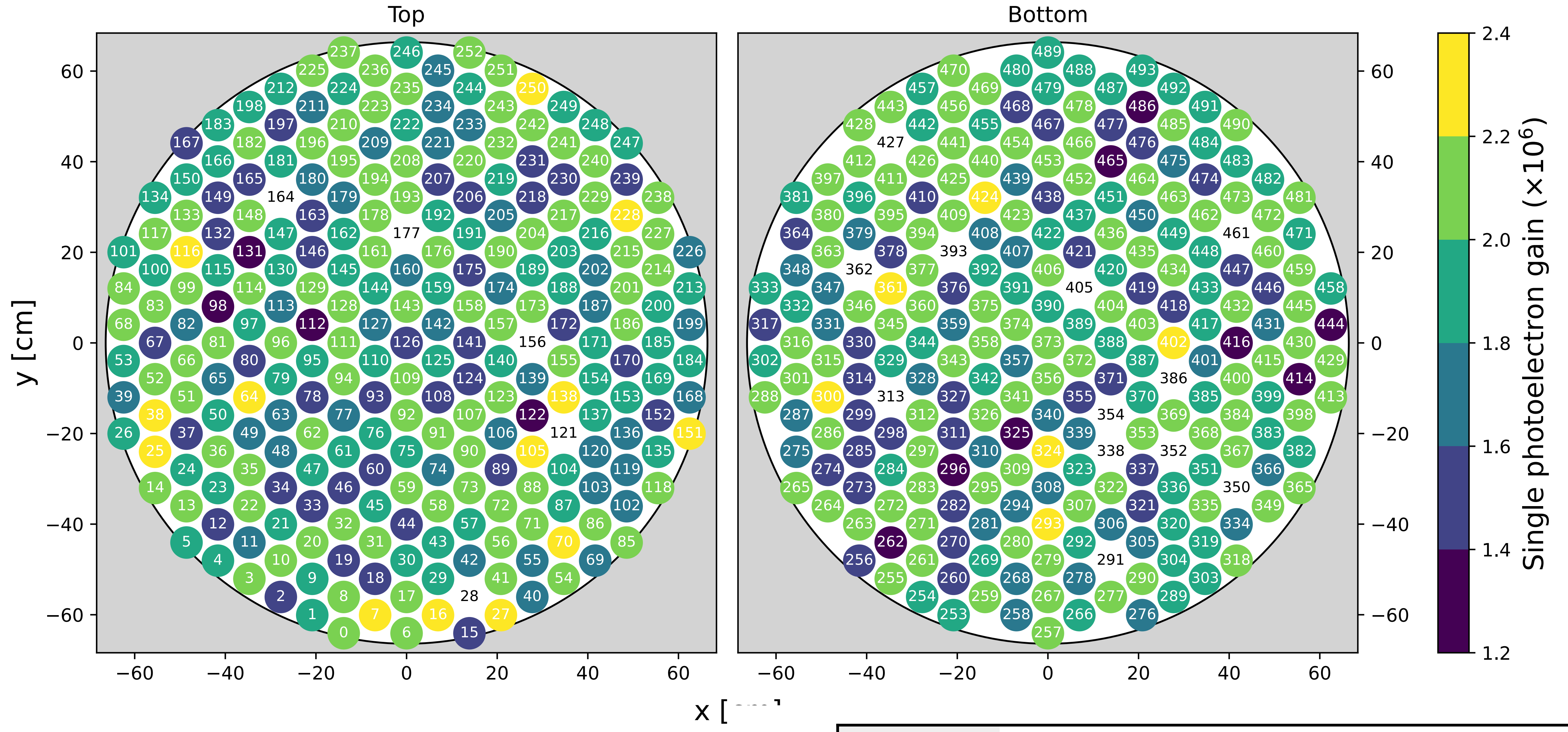
- Axions can be produced in the Sun via its couplings to electrons, photons, and nucleons
- Solar axions can be detected in LXe detectors via axio-electric effect and inverse Primakoff effect, which was not considered in XENON1T but is included in XENONnT
- Solar axion hypothesis is favored by XENON1T data at 3.4σ

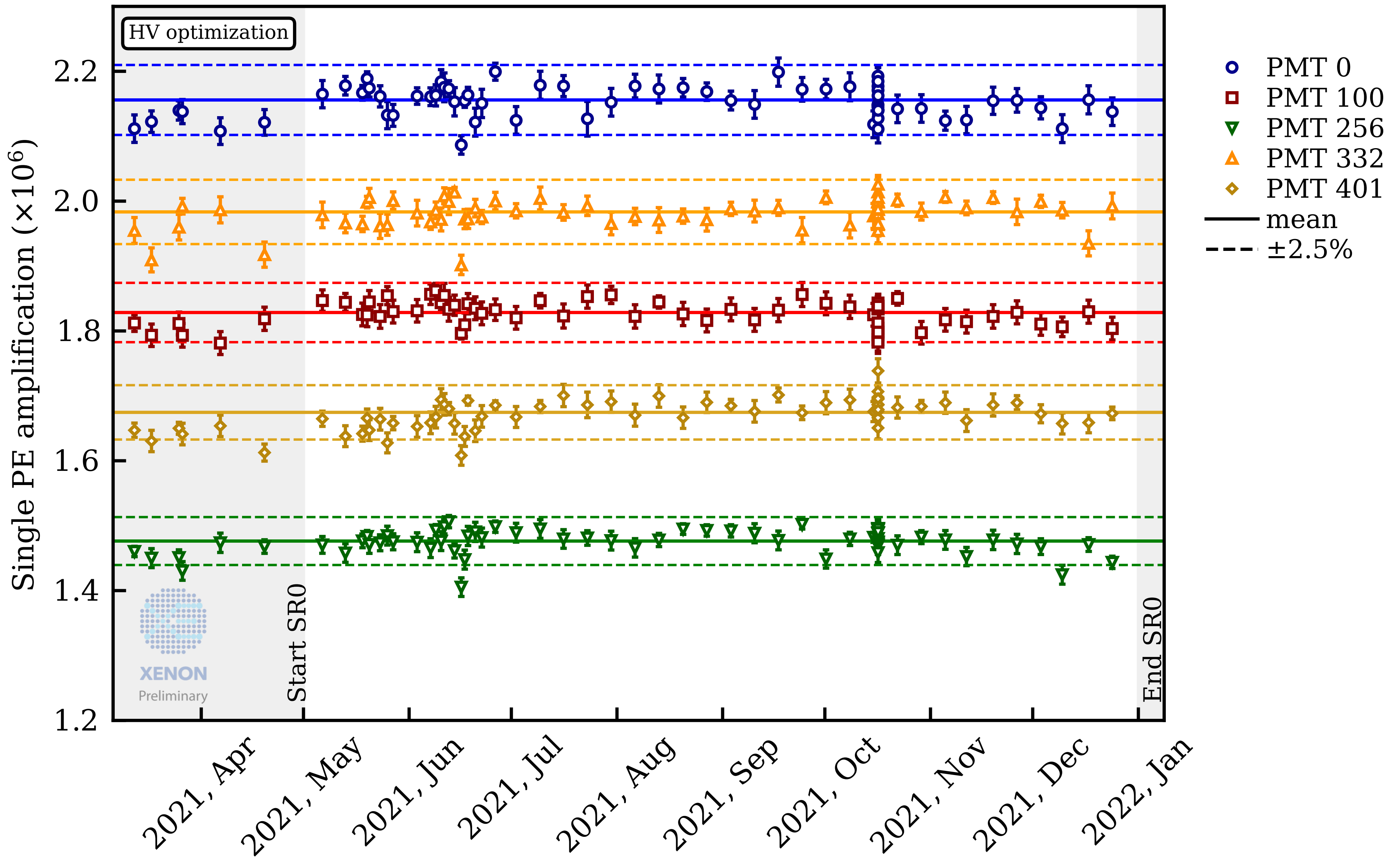
Expected discrimination power in XENONnT



XENONnT should be able to differentiate the excess with a few months of data

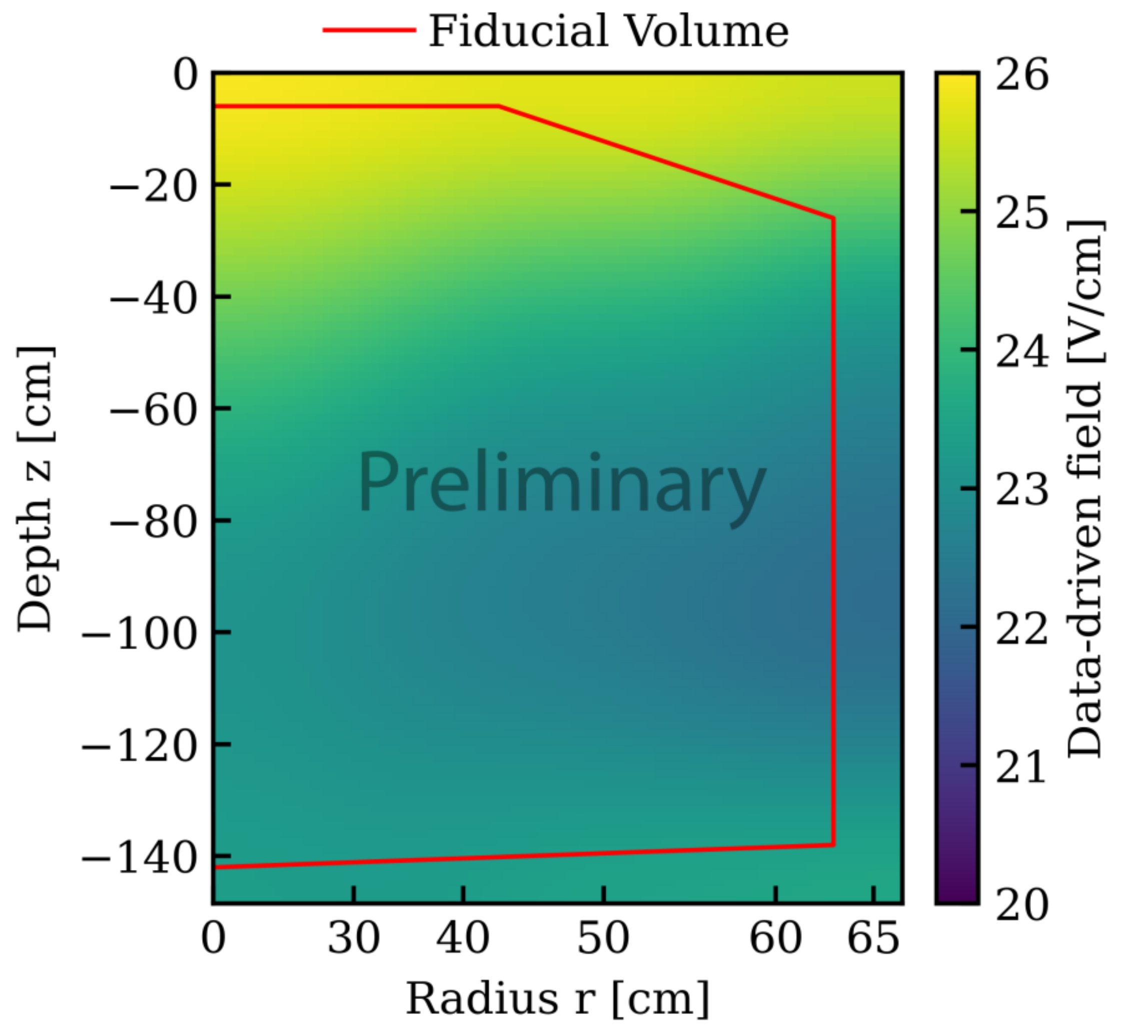
PMT calibration



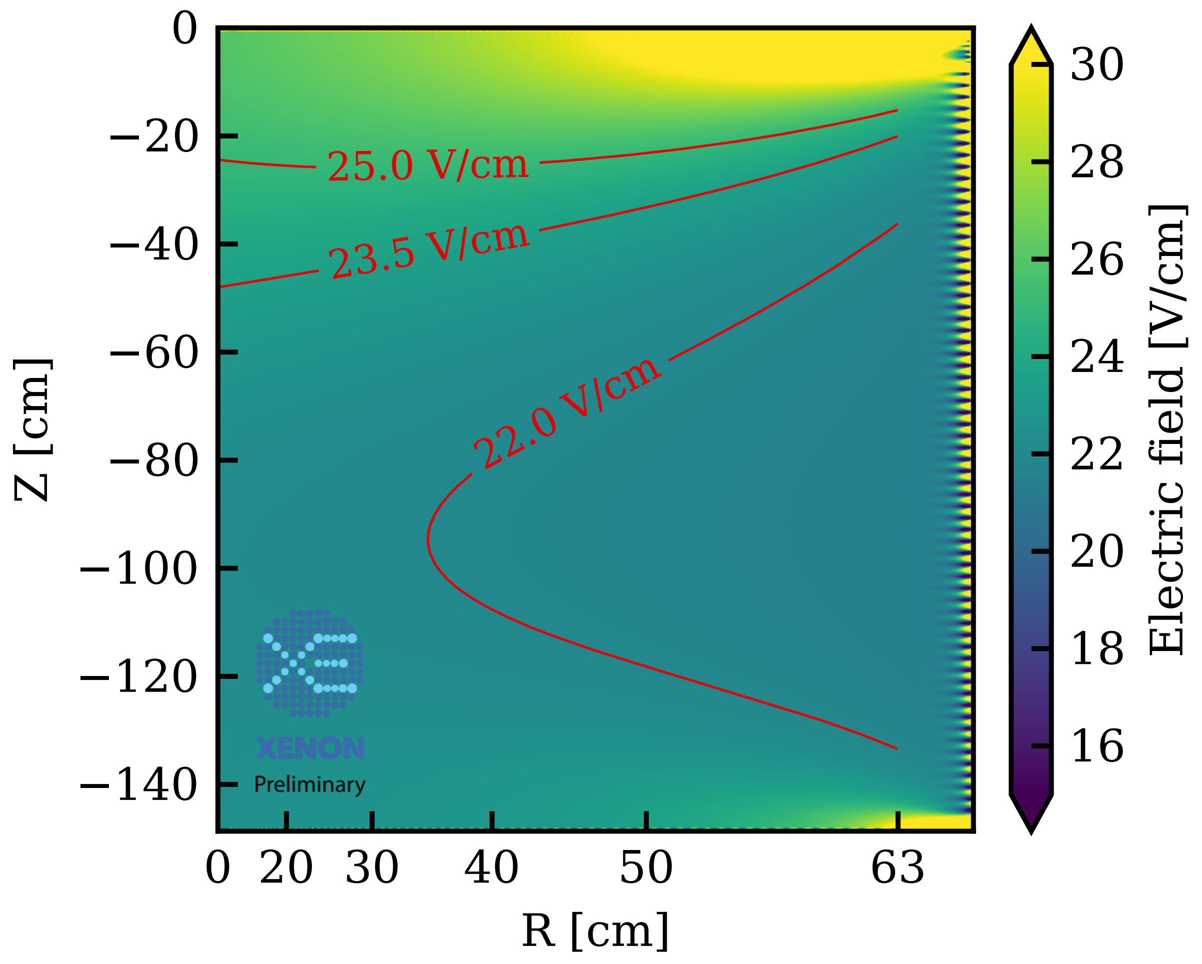


- Weekly PMT calibration using LED light
- 477/494 PMTs working
- Gain stability within 3%

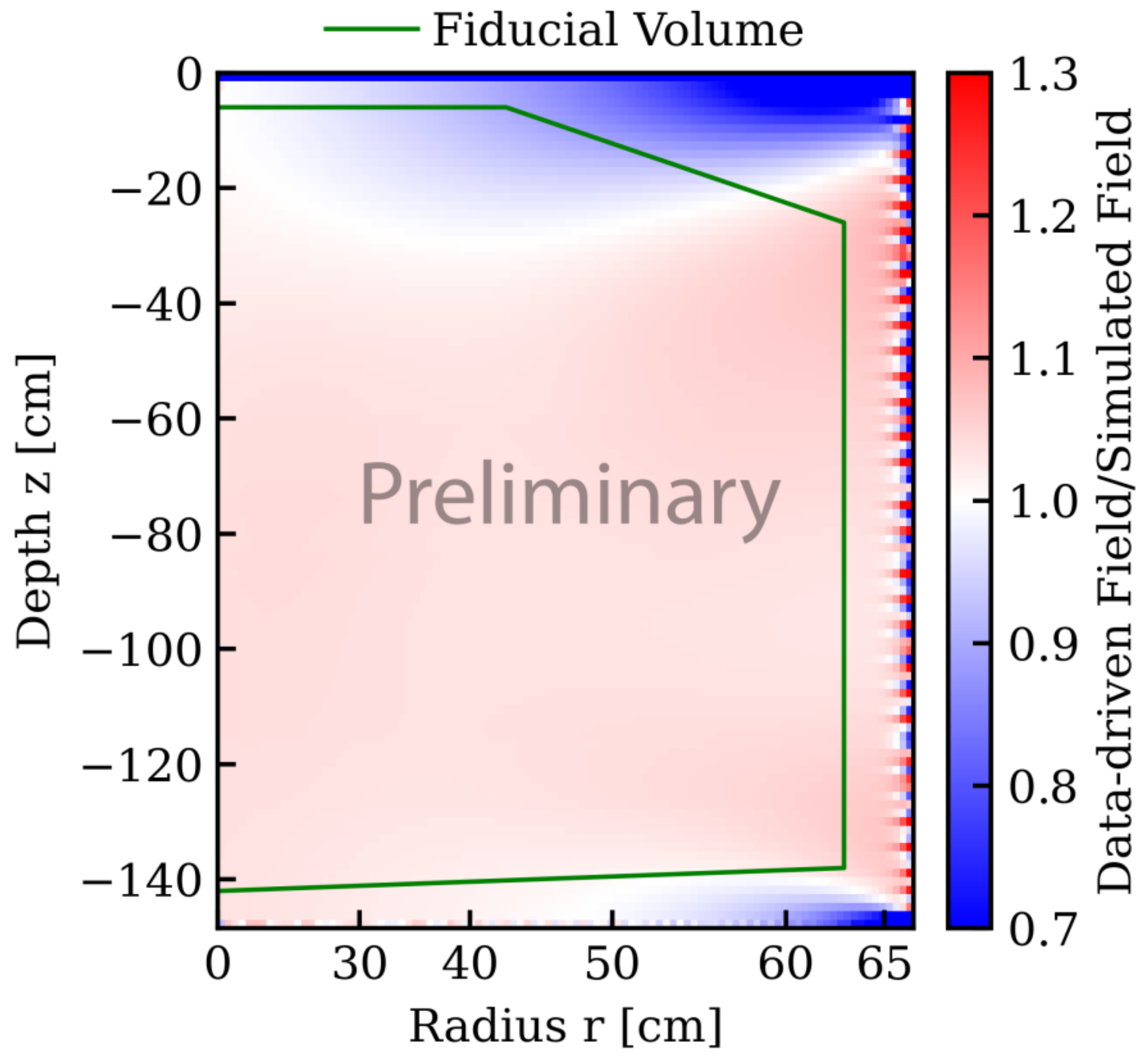
Drift field



Data-driven based on ratio of ^{83m}Kr S1a and S1b

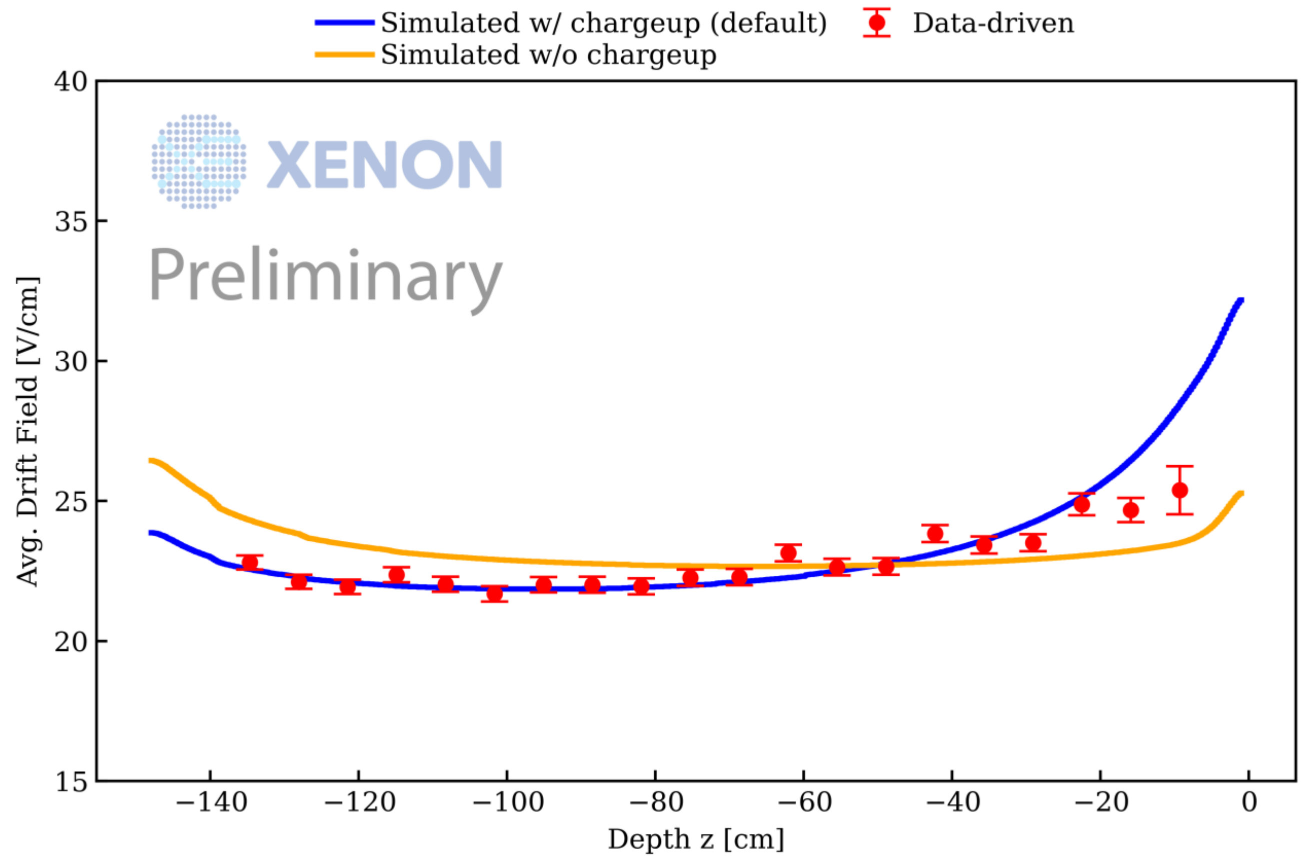


Simulation with charge-up the teflon surface



Data-driven and simulated maps agree well

Drift field: $23^{+5.5}_{-1.5}$ V/cm in the fiducial volume

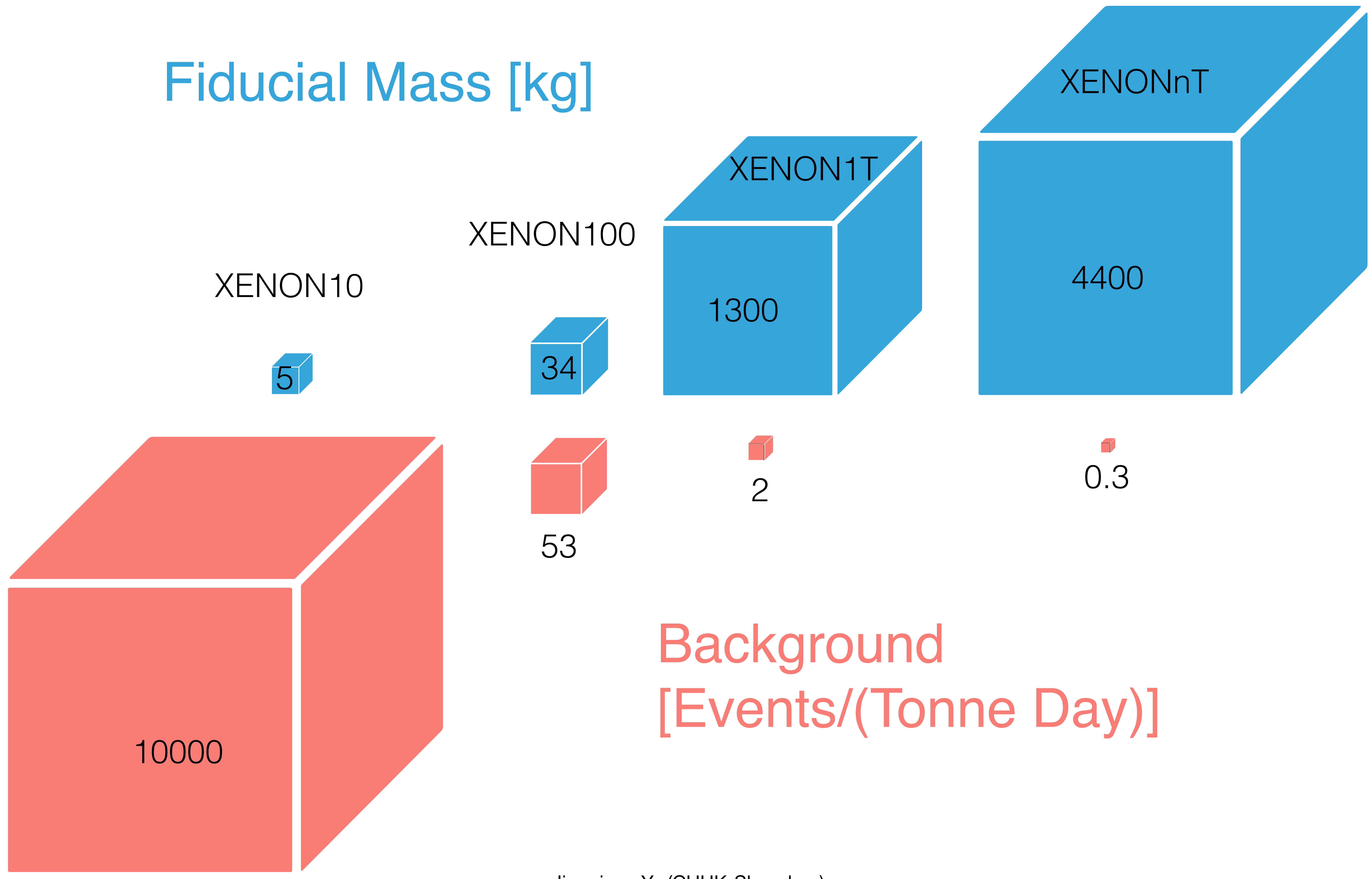


The evolution of XENON experiments

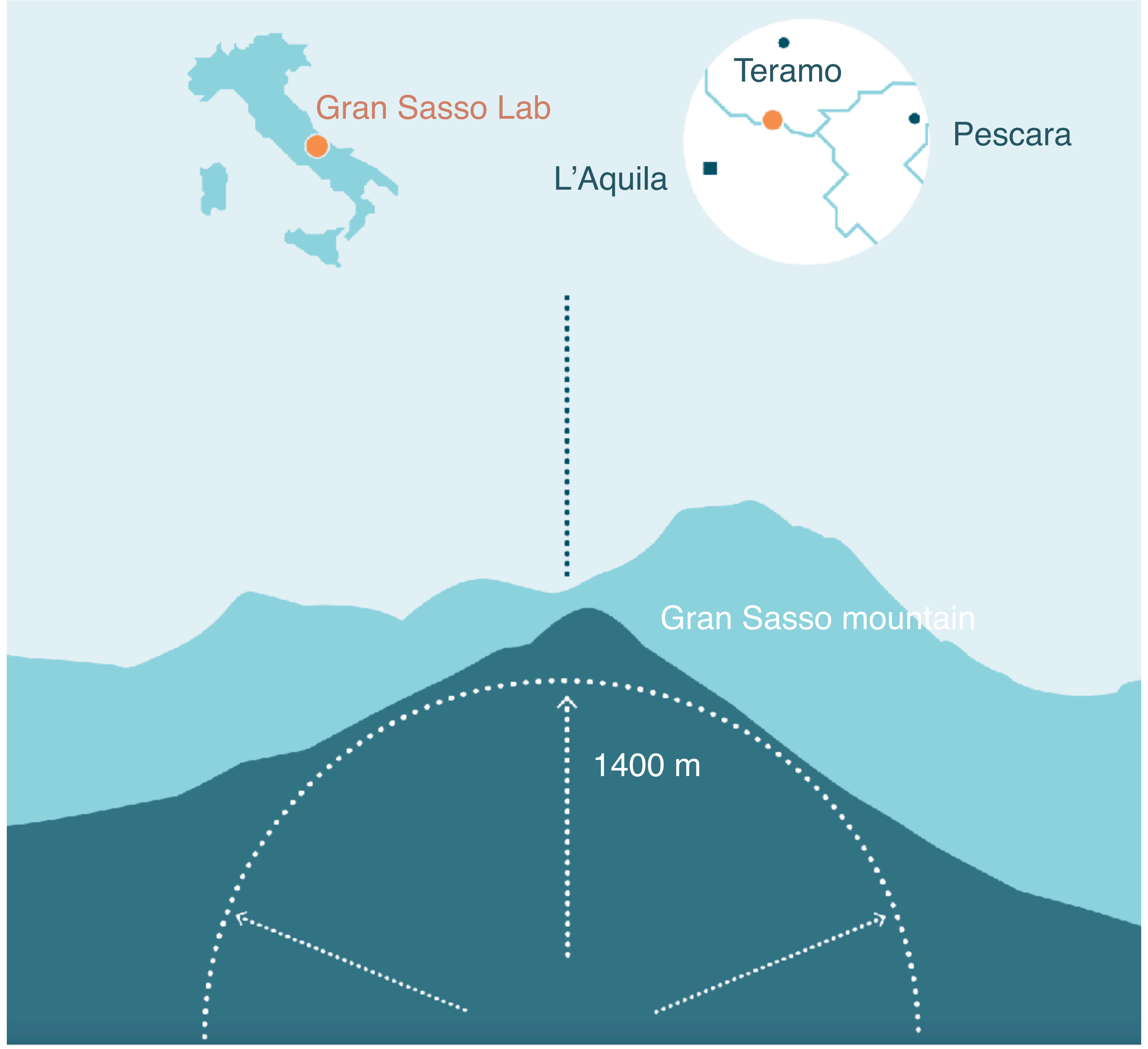


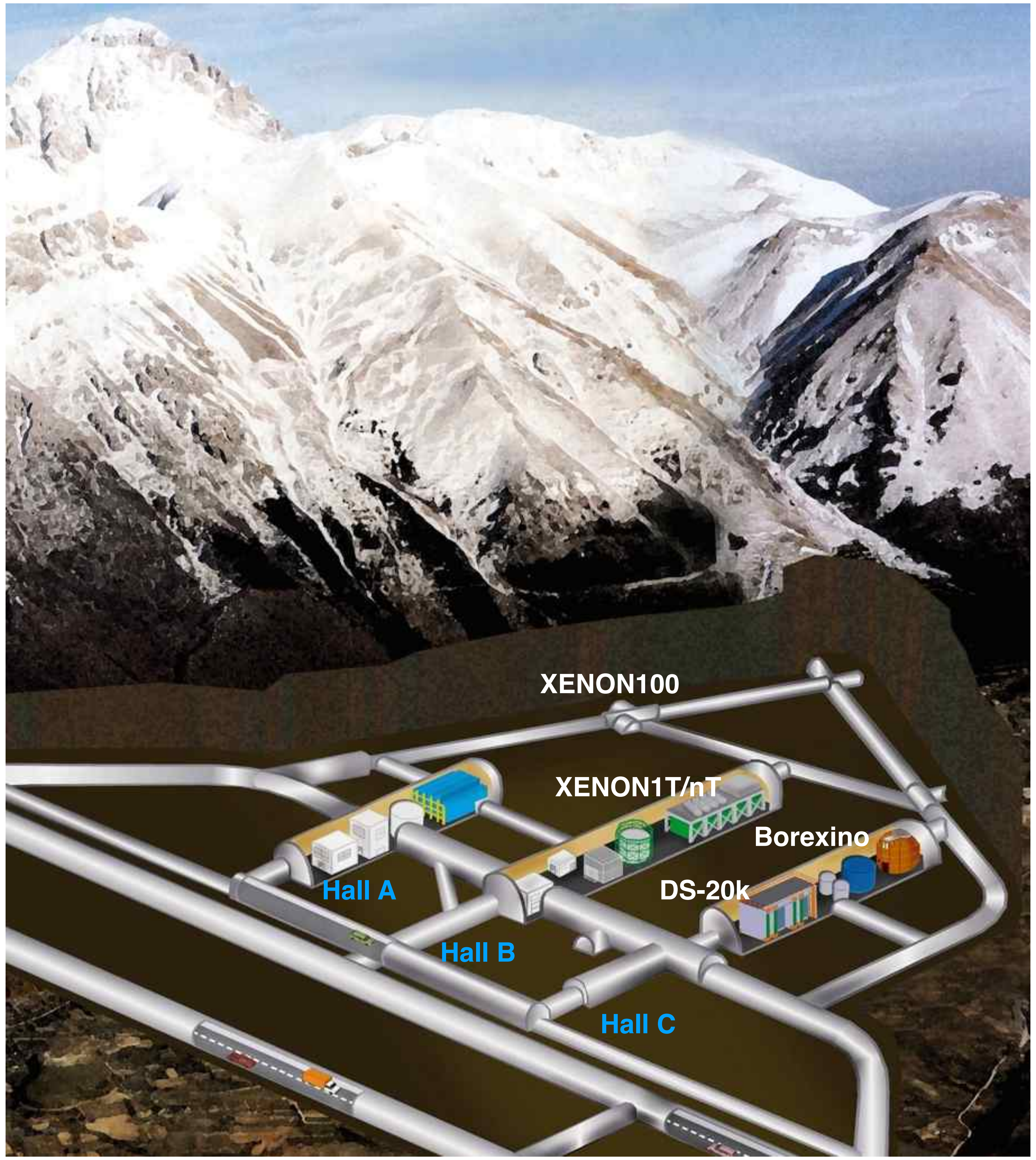

	XENON10	XENON100	XENON1T	XENONnT
Science data taking	2005-2007	2008-2016	2012-2018	2021-2025
Xe Target	14 kg	62 kg	2 t	5.9 t
Background	~2000000 ER events/(keV t y)	1800 ER events/(keV t y)	82 ER events/(keV t y)	15.8 ER events/(keV t y)
WIMP sensitivity	~10^{-43} cm^2	~10^{-45} cm^2	4 ×10^{-47} cm^2	~10^{-48} cm^2 (projected)

Fiducial mass and background



INFN Gran Sasso National Laboratory (LNGS)

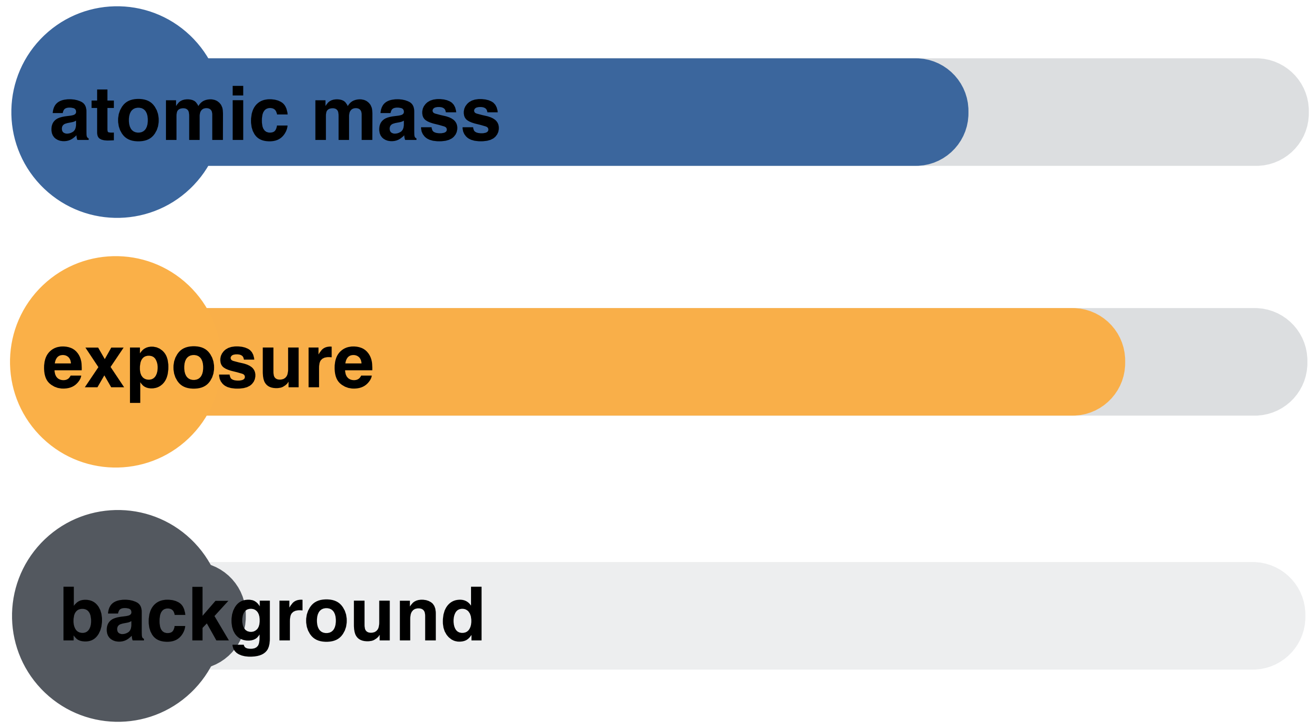




Why xenon?

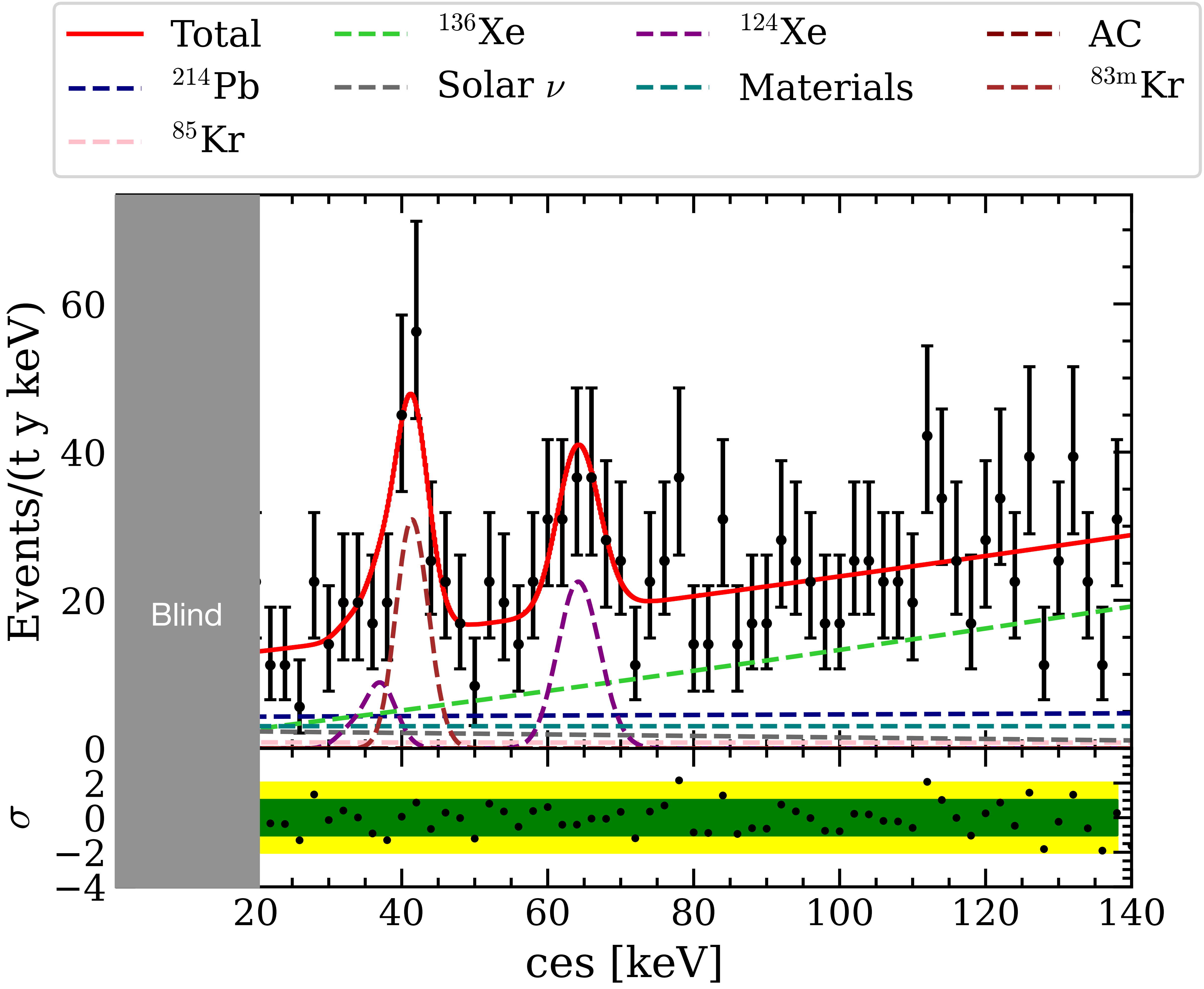
Selected Properties of Xe

Property	Value
Atomic Number (Z)	54
Atomic Weight (A)	131.30
Number of Electrons per Energy Level	2,8,18,18,8
Density (STP)	5.894 g/L
Boiling Point	−108.1 °C
Melting Point	−111.8 °C
Volume Ratio	519
Concentration in Air	0.0000087 % by volume



- Heavy
- Scalability & Stability
- Radiopurity

Tritium Enhanced Data (TED)



- Bypass the getter purifying the GXe volume to enhance H2/HT
- The enhancement factor is conservatively estimated to be 10, but can be much larger

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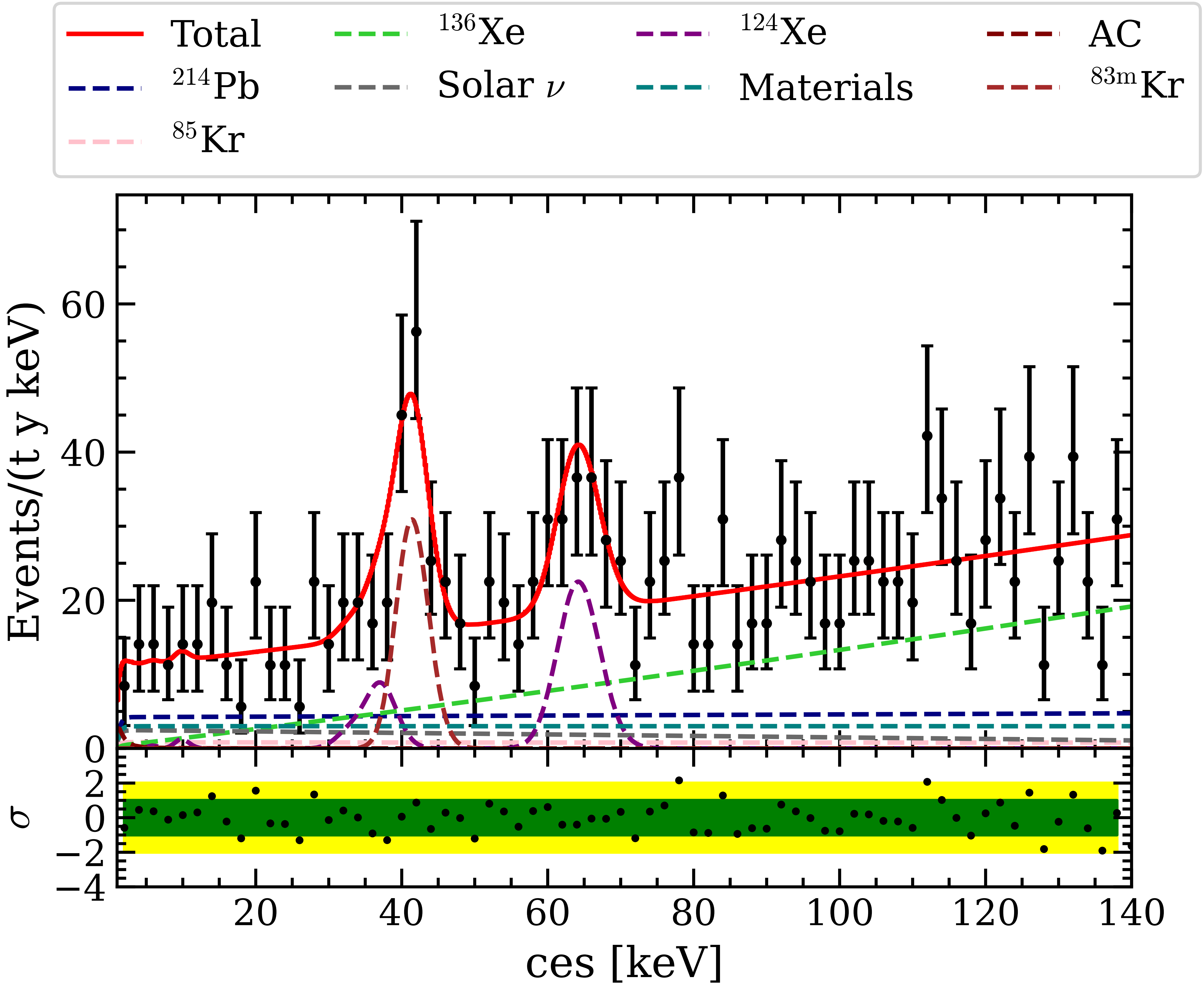
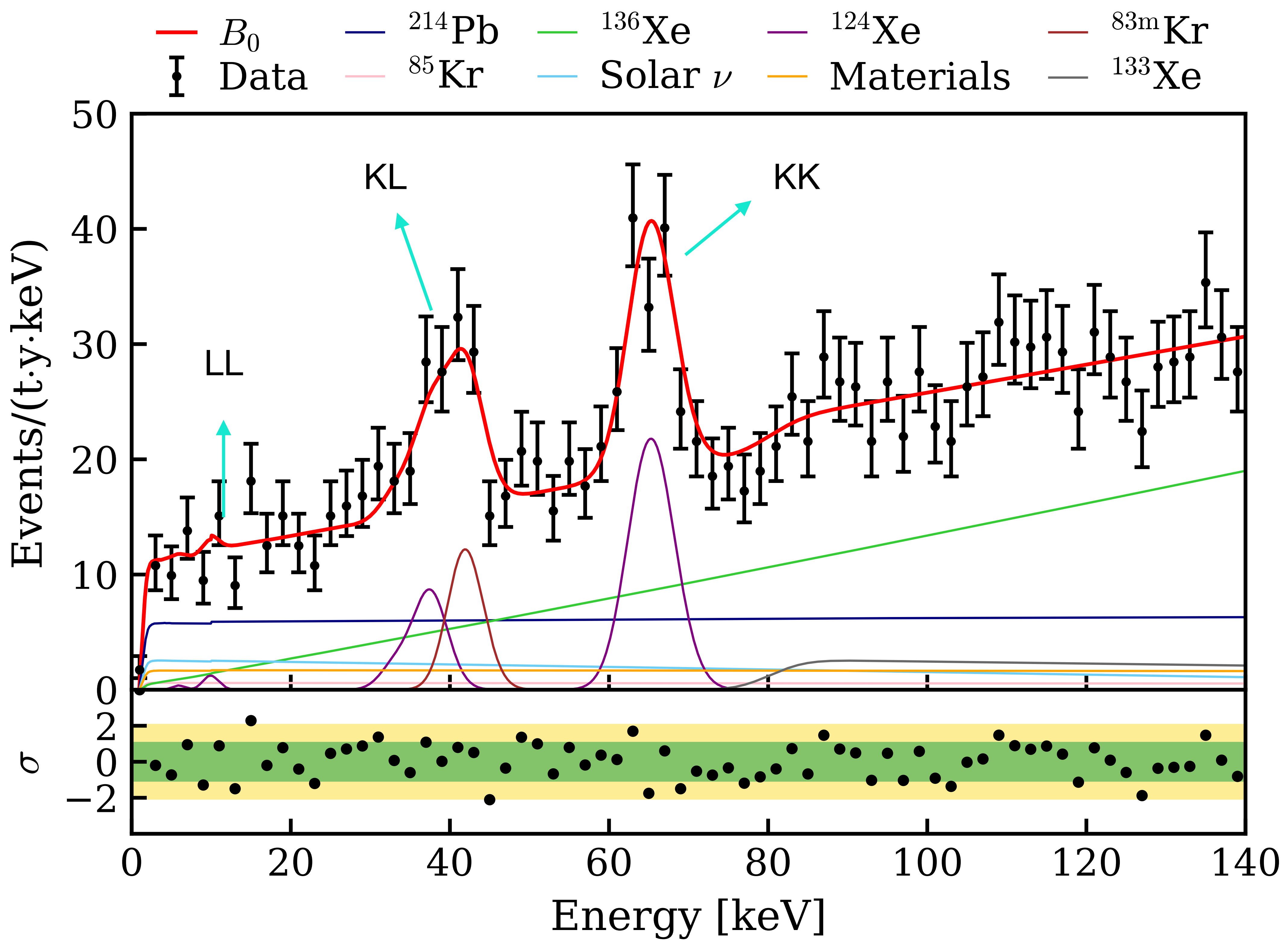
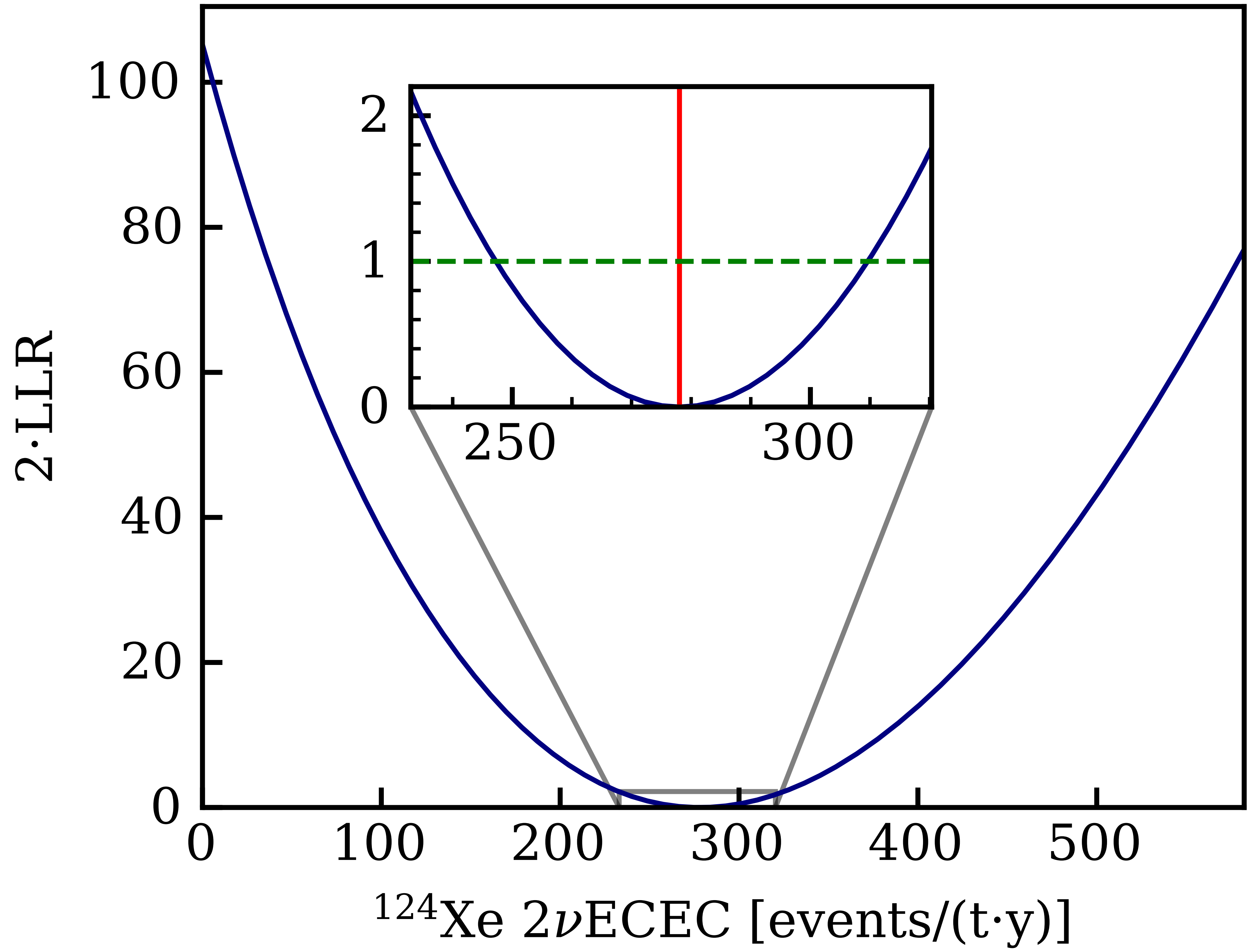


- Bypass the getter purifying the GXe volume to enhance H2/HT
- The enhancement factor is conservatively estimated to be 10, but can be much larger
- No excess is found in TED data after unblinding

$^{124}Xe\ 2\nu ECEC$





The measured half-life $T_{1/2}^{2\nu\mathrm{ECEC}} = (1.15 \pm 0.13_{\mathrm{stat}} \pm 0.14_{\mathrm{sys}}) \times 10^{22}$ yr with a significance of 10 σ

- Statistical uncertainty decreases to the same level as systematic uncertainty
- Consistent with the previous XENON1T result, $T_{1/2}^{2\nu\mathrm{ECEC}} = (1.1 \pm 0.2_{\mathrm{stat}} \pm 0.1_{\mathrm{sys}}) \times 10^{22}$ yr. XENON Collaboration, Phys. Rev. C 106, 024328 (2022)