Search for New Physics in Electronic Recoil Data from XENONnT

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Today's paper

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Editors' Suggestion

Search for New Physics in Electronic Recoil Data from XENONnT

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(XENON Collaboration)[††]

Abstract

The primary science goal of XENONnT:

Search for weakly interacting massive particles (WIMPs)

To reduce radon-induced backgrounds in liquid xenon detectors

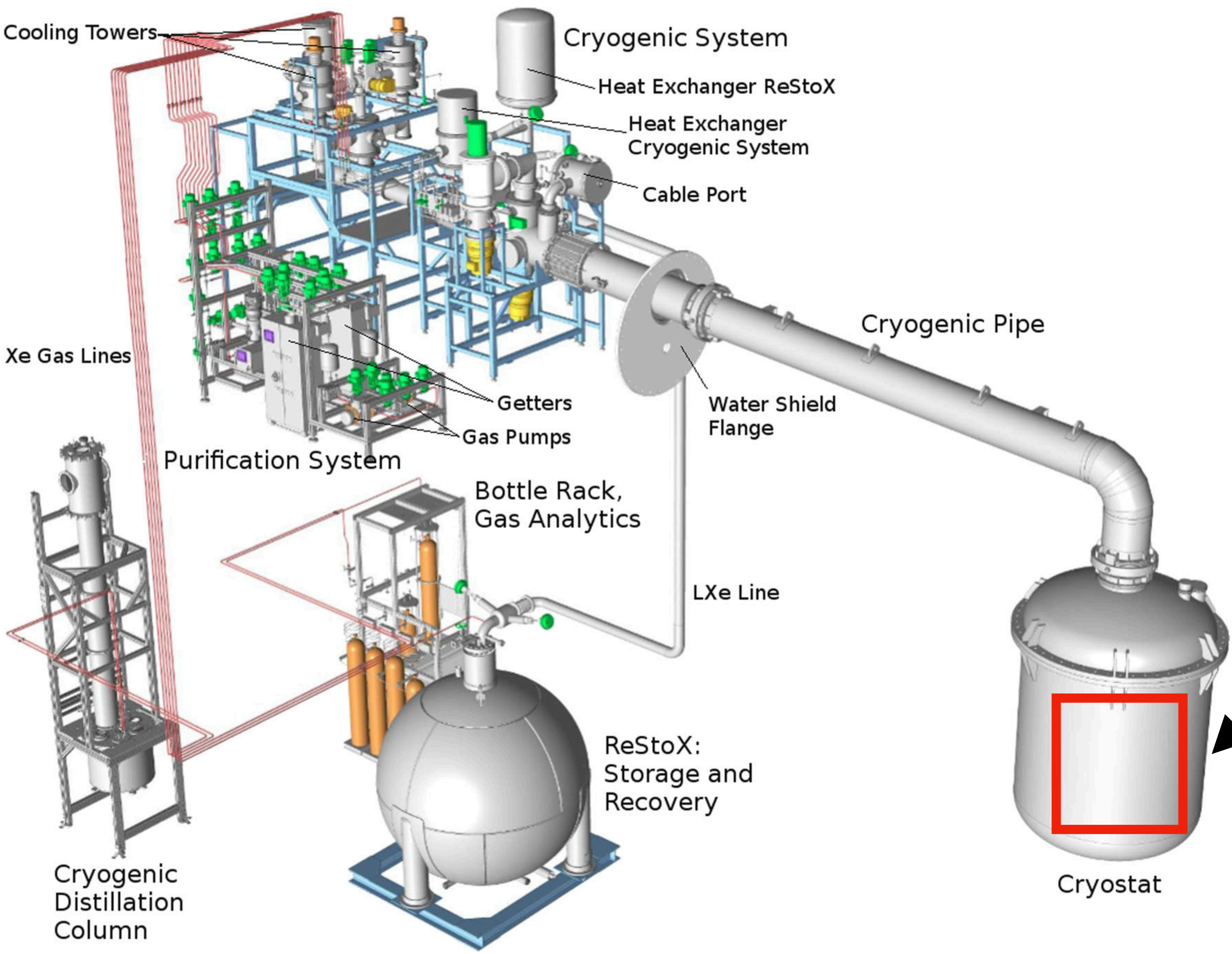
↓

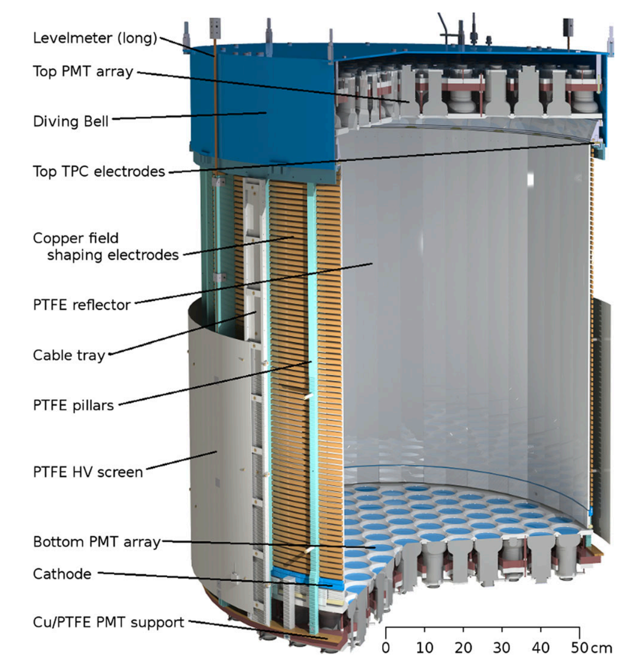
A high-flow radon removal system based on cryogenic

↓ data analysis

- No excess above background
- Set stringent new limits
  - solar axions
  - an enhanced neutrino magnetic moment
  - boson dark matter

XENON1T

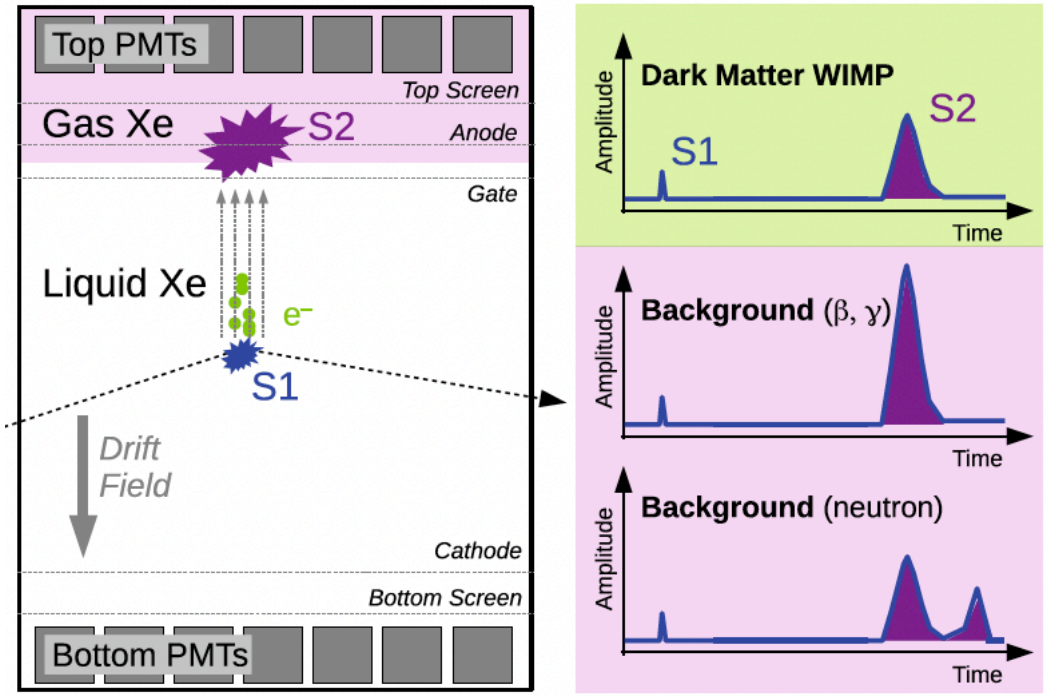




XENON1T TPC

https://link.springer.com/article/10.1140/epjc/s10052-017-5326-3

Working principle of a dual-phase LXe TPC



Particles catter off xenon nuclei (WIMPs or neutrons)

→ nuclear recoils

Particles interact with atomic electrons (γ rays and β electrons)

→ electronic recoils

The recoils excite and ionize the LXe

https://link.springer.com/article/10.1140/epjc/s10052-017-5326-3

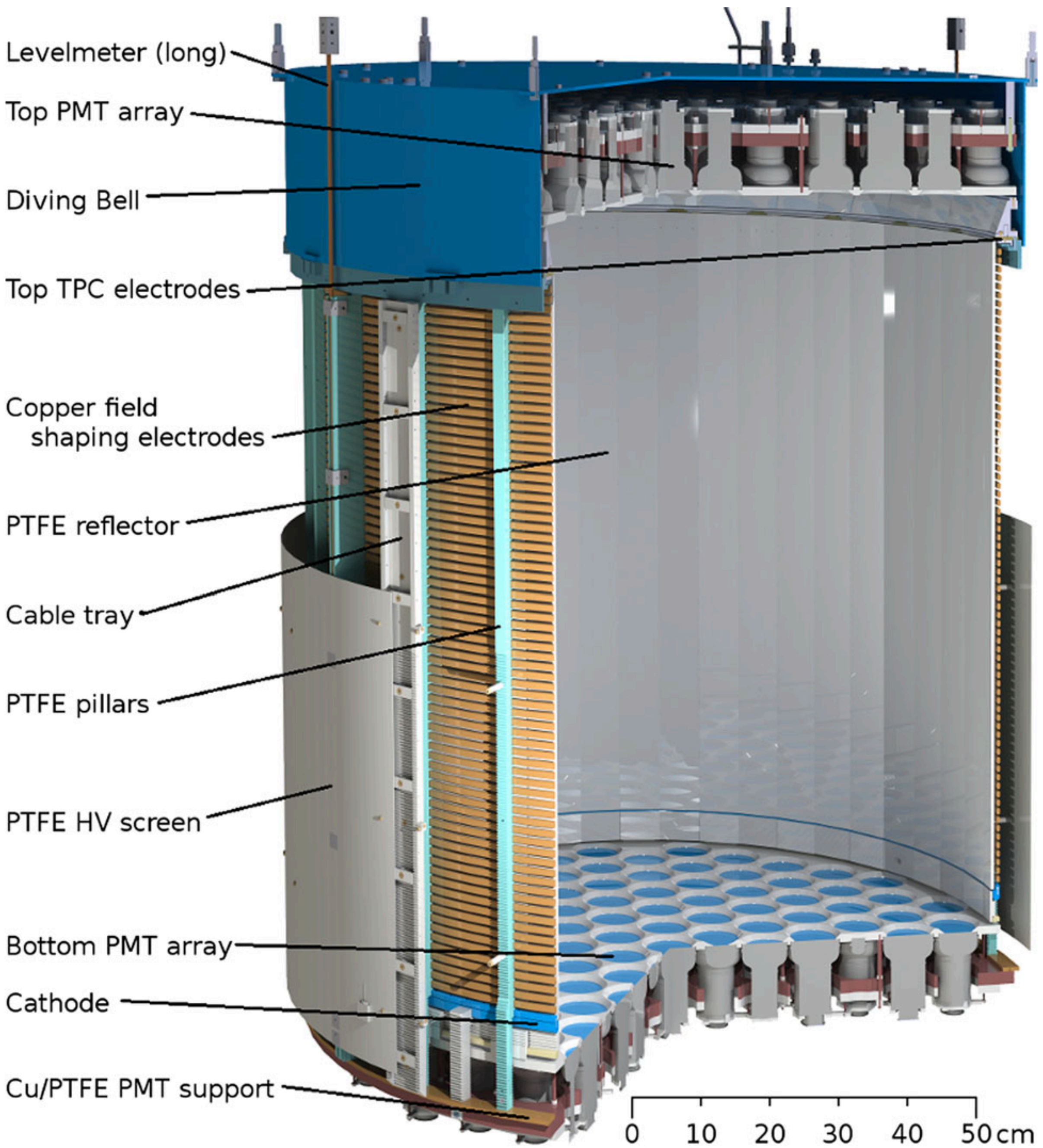
S1: scintillation photons

S2: secondary scintillation photons

The S1-S2 time difference

→ The ratio S2/S1 can be employed for electronic recoil background rejection

Illustration of a dual-phase LXe TPC



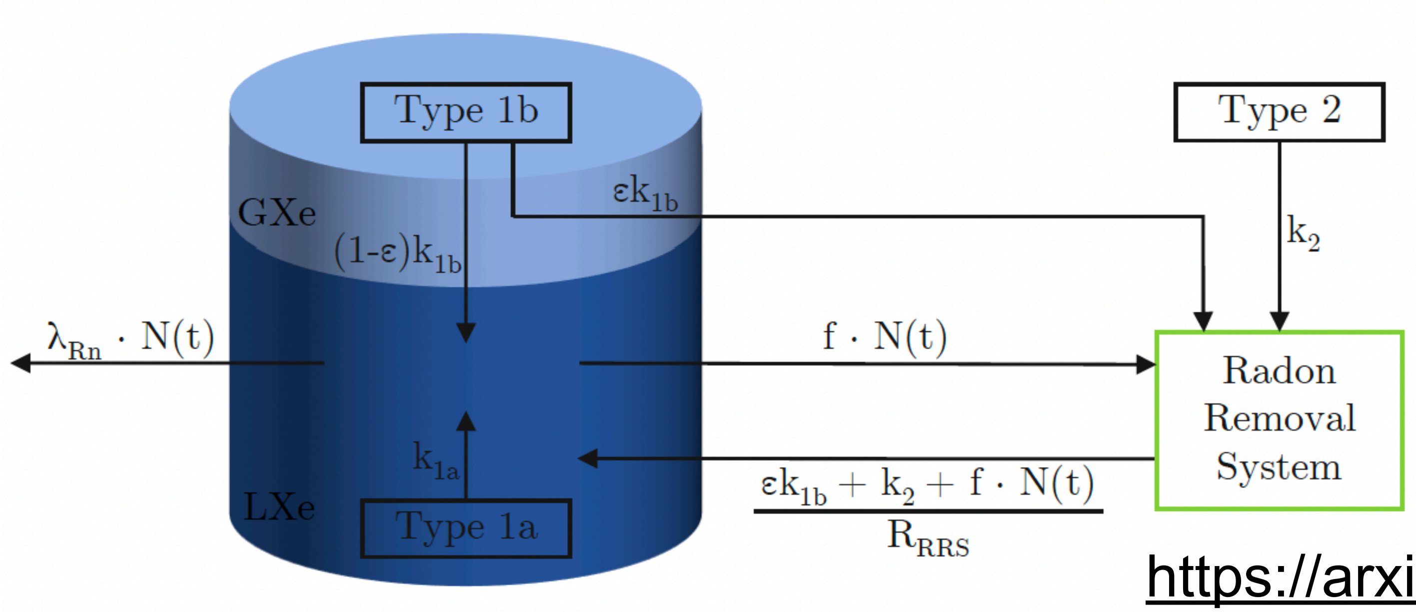
- an active LXe target of 2.0t
- built from materials selected for their low radioactivity
- enclosed by 24 interlocking and light-tight PTFE (polytetrafluoroethylene) panels

https://link.springer.com/article/10.1140/epjc/s10052-017-5326-3

Improvement from XENON1T

A high-flow radon removal system (RRS) based on cryogenic

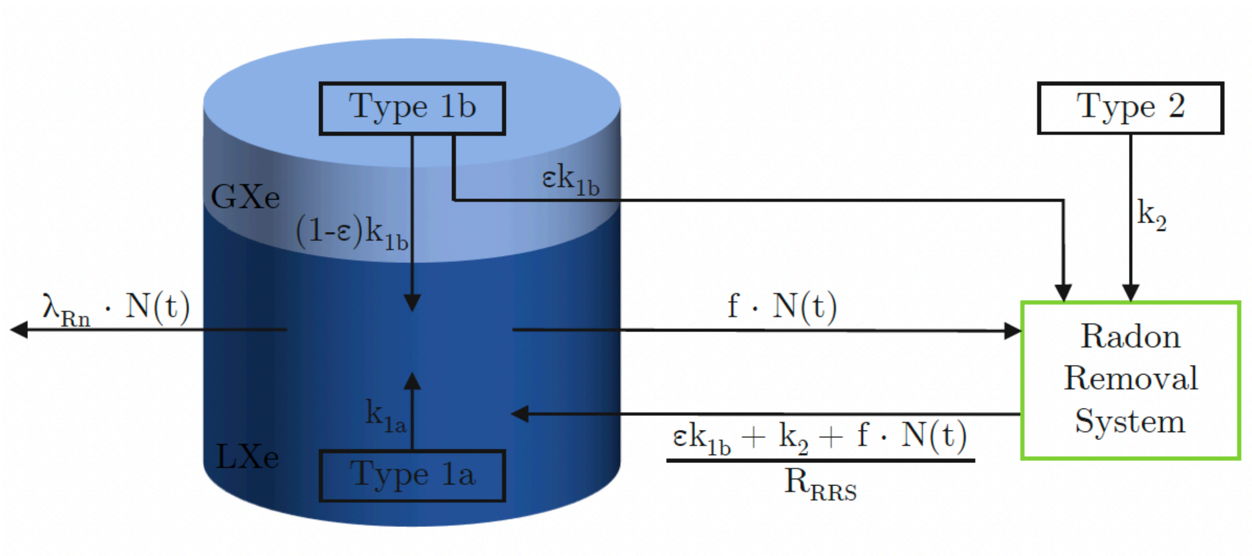
→ further reduce background



https://arxiv.org/abs/2205.11492

Radon removal system (RRS)

Radon removal system (RRS)



https://arxiv.org/abs/2205.11492

The change in the number of radon particles

$$\frac{dN(t)}{dt} = k_{1a} + (1-\epsilon)k_{1b} - \lambda_{\mathrm{Rn}} \cdot N(t) - f \cdot N(t) + \frac{k_2 + \epsilon k_{1b} + f \cdot N(t)}{R_{\mathrm{RRS}}}$$

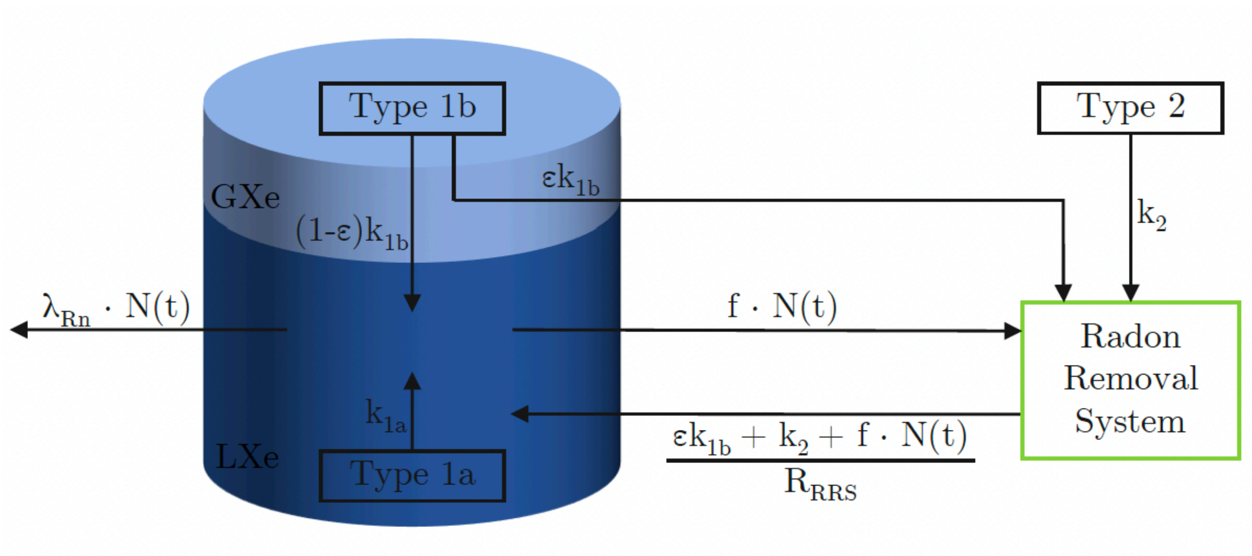
the decay of $^{222}\mathrm{Rn}$ the effective radon particle flux

$$\lambda_{\mathrm{Rn}} = 0.18[1/\mathrm{d}] \qquad f = \frac{F_{\mathrm{Xe}}}{m_{\mathrm{Xe}}} = \frac{1}{\tau_{\mathrm{ex}}}$$

ϵ: extraction efficiency τ_{ex}: the detector's Lee volume exchange time

$R_{\mathrm{RRS}} \equiv \frac{c_{\mathrm{F}}}{c_{\mathrm{D}}}$: RRS's reduction factor

Radon removal system (RRS)



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Starting condition $N(t=0) = N_0$ (N_0: the number of radon atoms before starting the removal)

$$N(t) = \frac{K}{\Lambda} + \left(N_0 - \frac{K}{\Lambda}\right) \cdot e^{-\Lambda \cdot t}$$

$$K = k_{1a} + (1-\epsilon)k_{1b} + \frac{k_2 + \epsilon k_{1b}}{R_{RRS}}$$

$$\Lambda = \lambda_{Rn} + f \cdot \left(1 - \frac{1}{R_{RRS}}\right)$$

Radon removal system (RRS)

In case a perfect RRS can fully remove radon

$$N_{\mathrm{equi}} \overset{t\to\infty}{=} \frac{K}{\Lambda} = \frac{k_{1\mathrm{a}} + (1-\epsilon)k_{1\mathrm{b}} + \frac{k_2 + \epsilon k_{1\mathrm{b}}}{R_{\mathrm{RRS}}}}{\lambda_{\mathrm{Rn}} + f\cdot\left(1 - \frac{1}{R_{\mathrm{RRS}}}\right)} \overset{R_{\mathrm{RRS}}\to\infty}{=} \frac{1}{\lambda_{\mathrm{Rn}} + f}\cdot\left(k_{1\mathrm{a}} + (1-\epsilon)k_{1\mathrm{b}}\right)$$

$N_{\mathrm{equi}}\left(R_{\mathrm{RRS}}, f, \epsilon\right)$

The reduction inside the detector's LXe volume

$$r\left(R_{\mathrm{RRS}}, f, \epsilon\right) = \frac{N_{\mathrm{equi}}\left(R_{\mathrm{RRS}} = 1, f, \epsilon\right)}{N_{\mathrm{equi}}\left(R_{\mathrm{RRS}}, f, \epsilon\right)}$$

$$r\left(R_{\mathrm{RRS}} \to \infty, f, \epsilon\right) = \frac{\lambda_{\mathrm{Rn}} + f}{\lambda_{\mathrm{Rn}}}\cdot\frac{k_{\mathrm{tot}}}{k_{1\mathrm{a}} + (1-\epsilon)k_{1\mathrm{b}}}$$

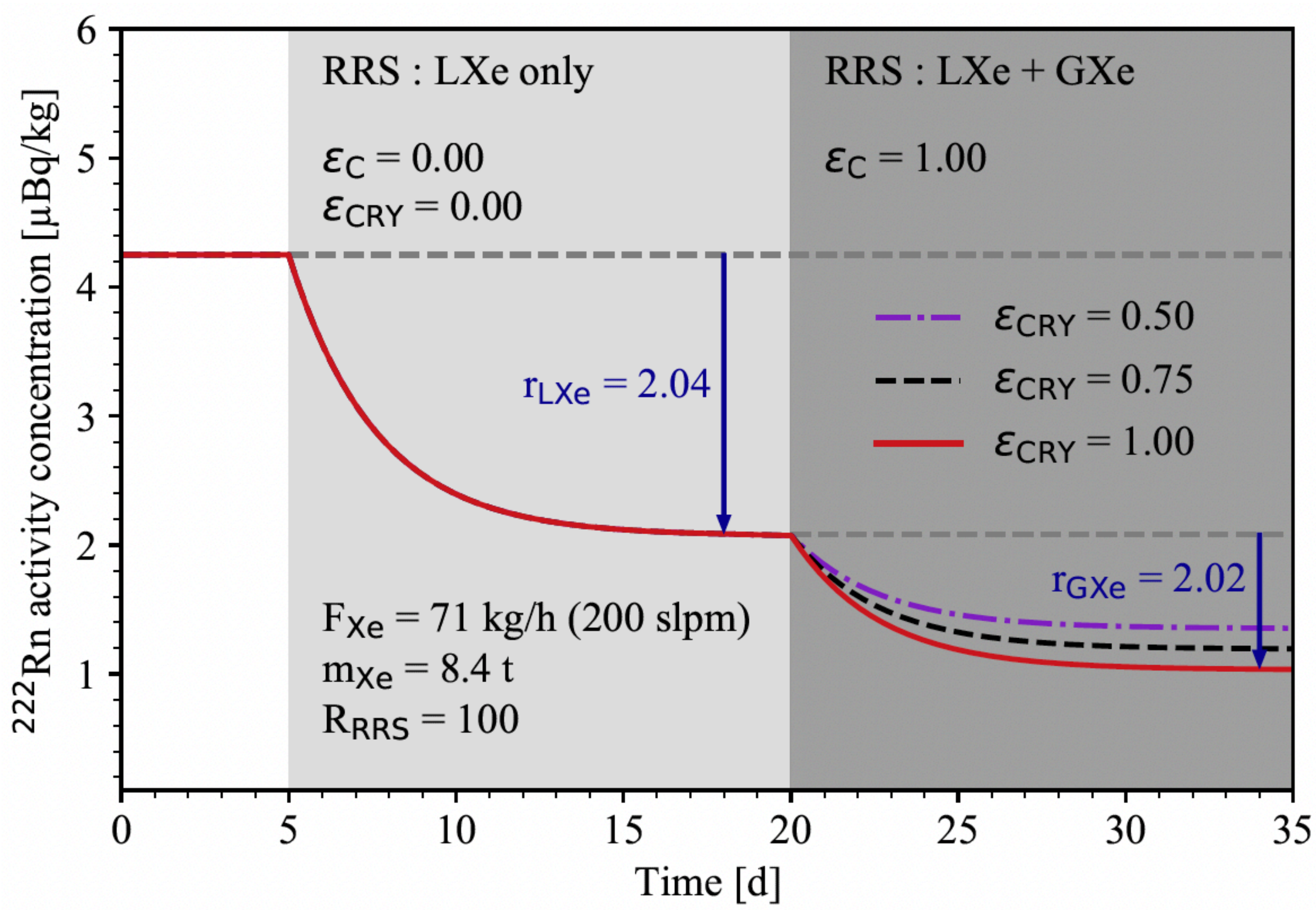
The combined LXe and GXe modes

The individual reduction capabilities

$$r_{\mathrm{LXe}} = r\left(R_{\mathrm{RRS}} \to \infty, f, \epsilon = 0\right) = \frac{\lambda_{\mathrm{Rn}} + f}{\lambda_{\mathrm{Rn}}}\cdot\frac{k_{\mathrm{tot}}}{k_{1\mathrm{a}} + k_{1\mathrm{b}}}$$

$$r_{\mathrm{GXe}} = r\left(R_{\mathrm{RRS}} \to \infty, f = 0, \epsilon\right) = \frac{k_{\mathrm{tot}}}{k_{1\mathrm{a}} + (1-\epsilon)k_{1\mathrm{b}}}$$

Radon removal system (RRS)

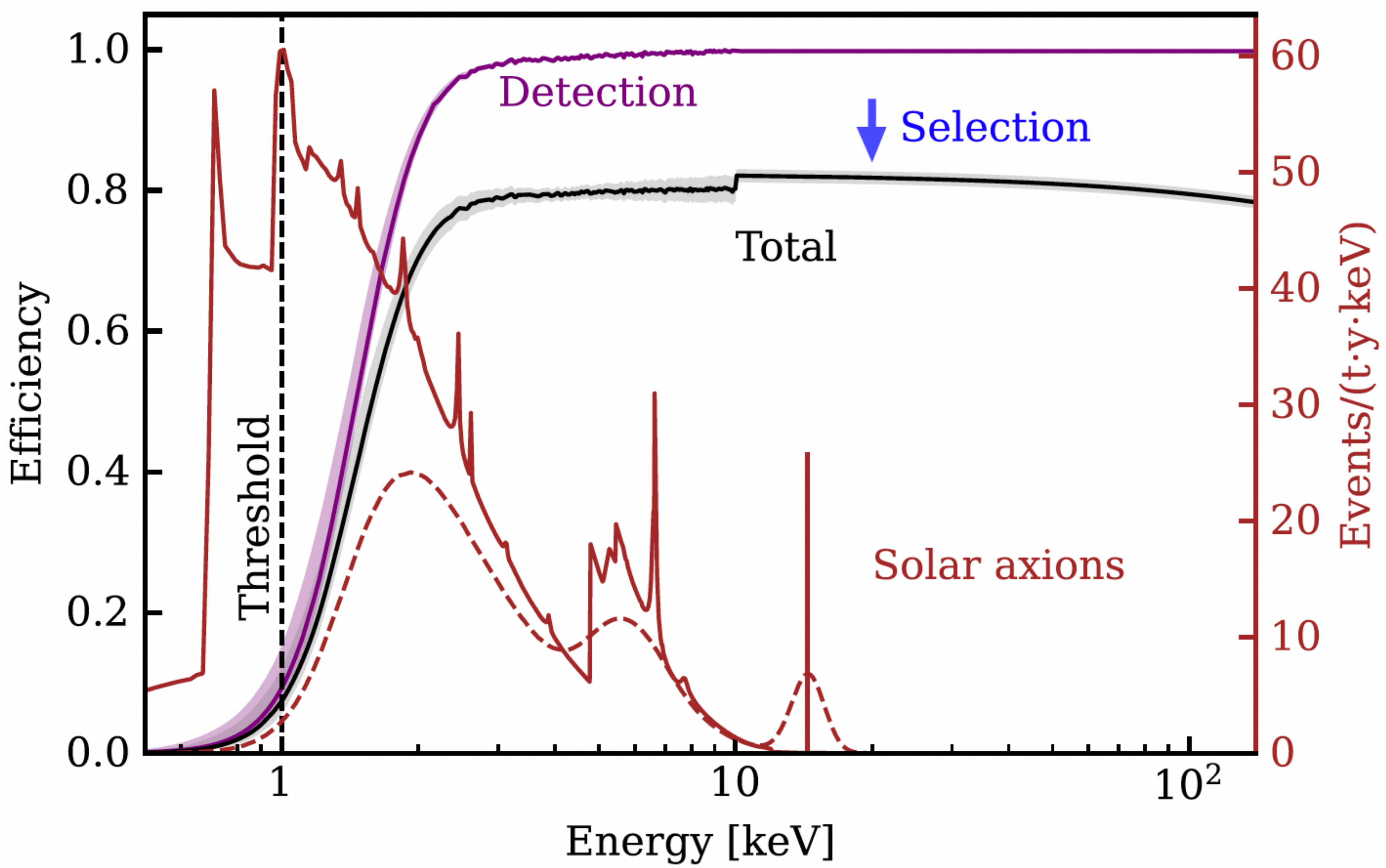


Expected radon reduction in XENONnT ($R_{RRS} \rightarrow \infty$)

↓

XENONnT can reach ^{222}Rn activity concentration of 1 μBq/kg

Efficiencies

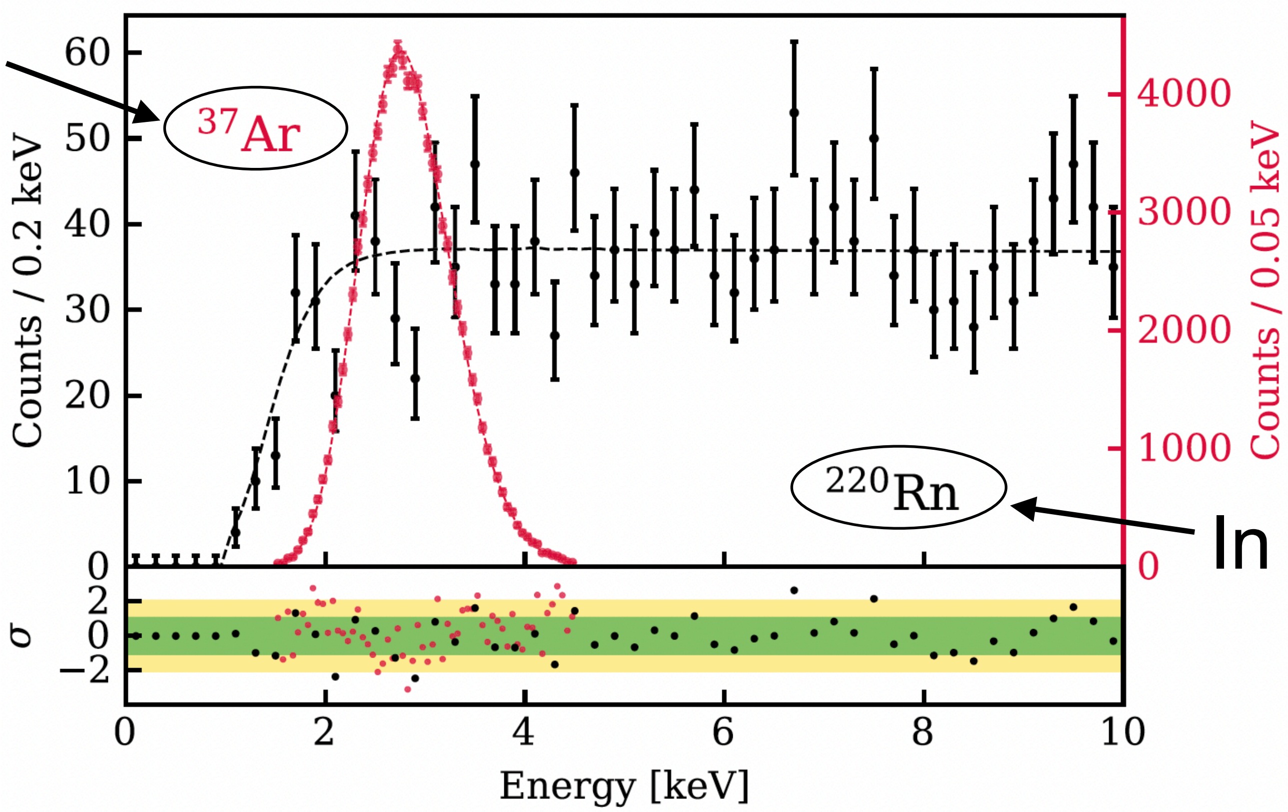


Efficiencies in reconstructed energy and the solar axion signal

Calibration data and models at low energy

consider ER interactions only

In December 2021



In June 2021

^{220}Rn → the energy threshold, selection efficiency, energy reconstruction

^{37}Ar → validate the energy reconstruction and skew-Gaussian smearing model

Background model B_0

Consider 9 components in the background model B_0

The dominant background at low energy → ^{214}Pb

The dominant component above 40 keV → ^{136}Xe

accidental coincidence → AC

Component	Constraint	Fit
^{214}Pb	(570, 1200)	960 ± 120
^{85}Kr	90 ± 60	90 ± 60
Materials	270 ± 50	270 ± 50
^{136}Xe	1560 ± 60	1550 ± 50
Solar neutrino	300 ± 30	300 ± 30
^{124}Xe	$\cdots$	250 ± 30
AC	0.70 ± 0.04	0.71 ± 0.03
^{133}Xe	$\cdots$	150 ± 60
^{83m}Kr	$\cdots$	80 ± 16

constraints between (39, 44) keV are excluded

Tritium hypothesis

Further the possibility of tritium as an explanation for the XENON1T excess
→ operated XENONnT in a different mode for 14.3 days after the SR0 data collected (SR0: from July 6, 2021 to November 10, 2021)

↓

Tritium dataset showed no evidence for a tritium like excess

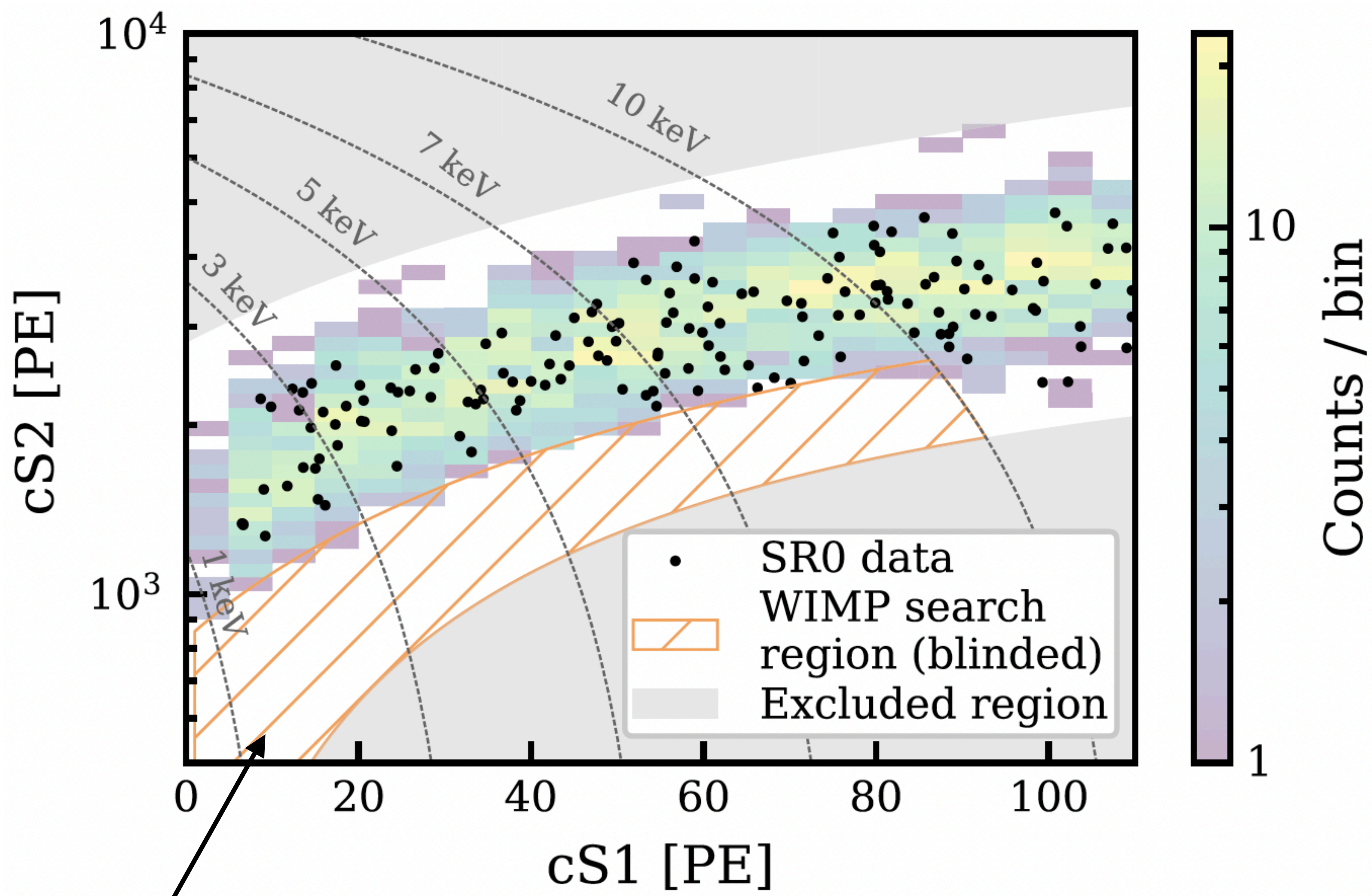
↓

Tritium is not included in the background model !

↓

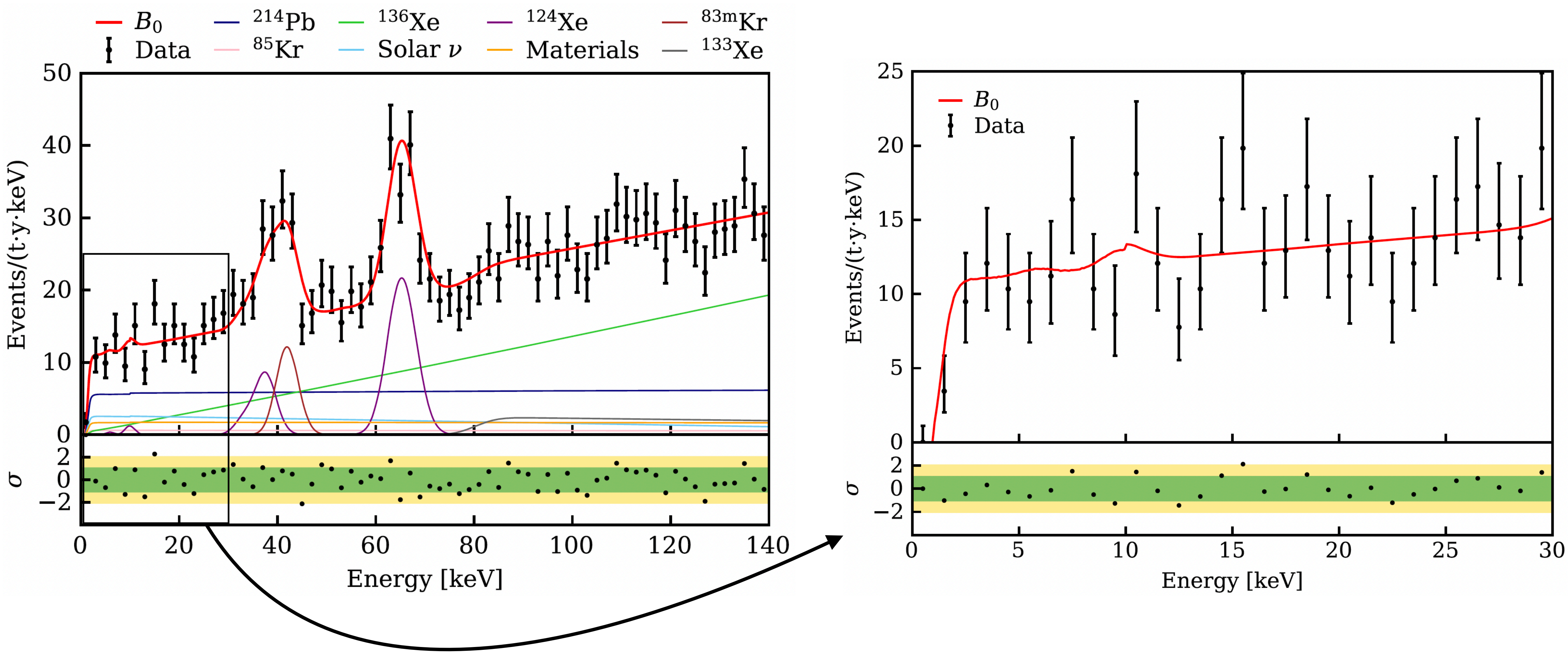
Tritium may be the cause of the excess observed in XENON1T

cS1-cS2 space



The WIMP search region is not used in this search

Fit to SR0 data using the B_0 model

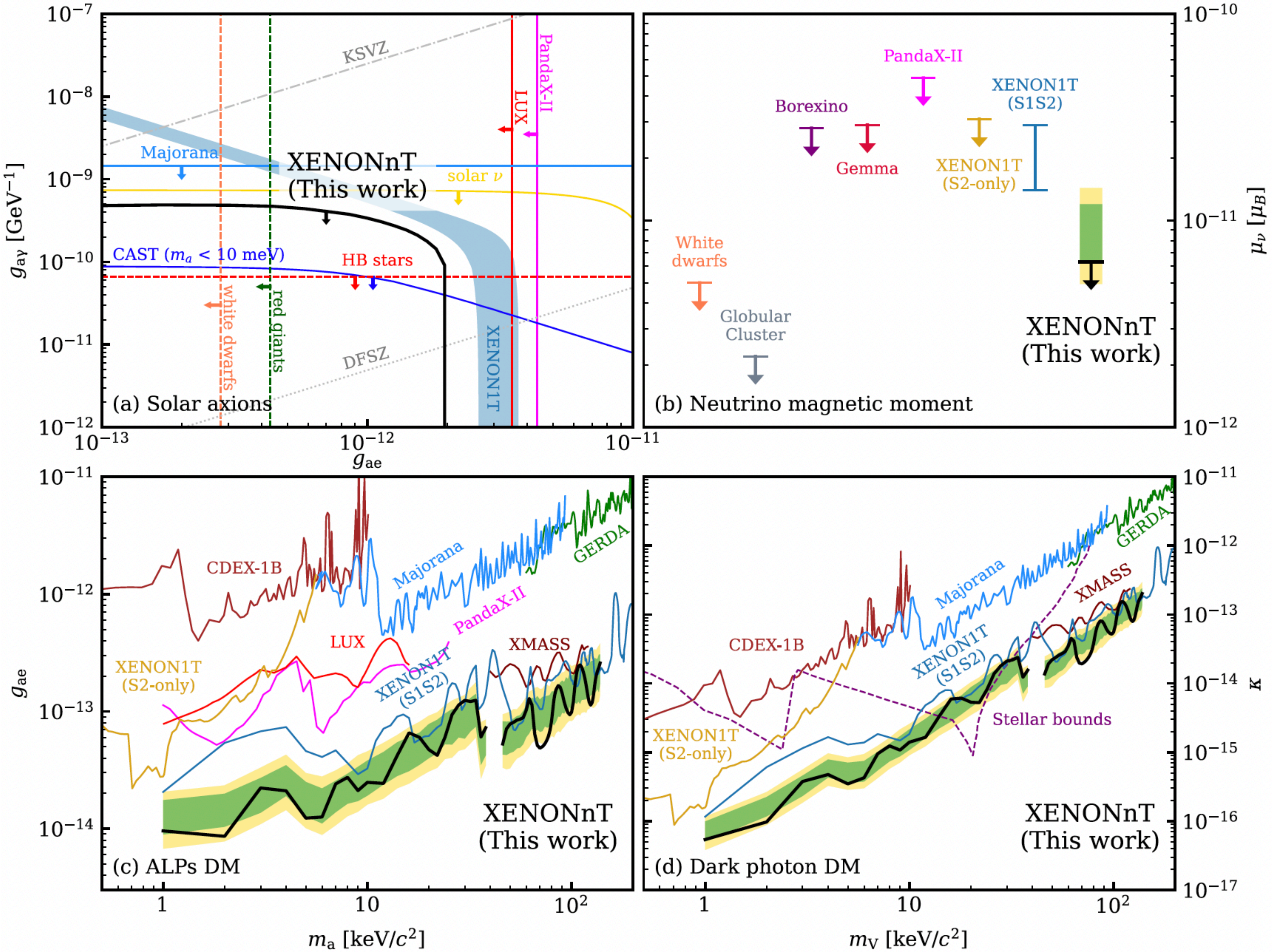


ER background rate within (1,30) keV → (15.8 ± 1.3)events/(ton×year×keV)

↓

The lowest background rate ever achieved !

90% C.L. upper limit



Summary

- The blind analysis shows no excess above the background.

→ Tritium may be the cause of the excess observed in XENON1T.

- The average ER background rate of (15.8 ± 1.3)events/(ton×year×keV) in the (1,30) keV energy region is the lowest ever achieved in a DM search experiment.