Searching for New Physics in the First XENONnT Data

Dr. Erwann Masson

LPNHE — Paris, France

GDR DUPhy — 19 October 2022

The XENON Collaboration

180+ scientists
27 institutes / 11 countries

XENON

Columbia | KIT | Nikhef | Muenster | Stockholm | Mainz | MPIK, Heidelberg | Freiburg | Zurich

Chicago

UCSD

Rice

Purdue

Tsinghua

Tokyo

Nagoya

Kobe

Subatech | Coimbra | LPNHE | Torino | Bologna | L'Aquila | LNGS | Napoli | Weizmann | NYUAD

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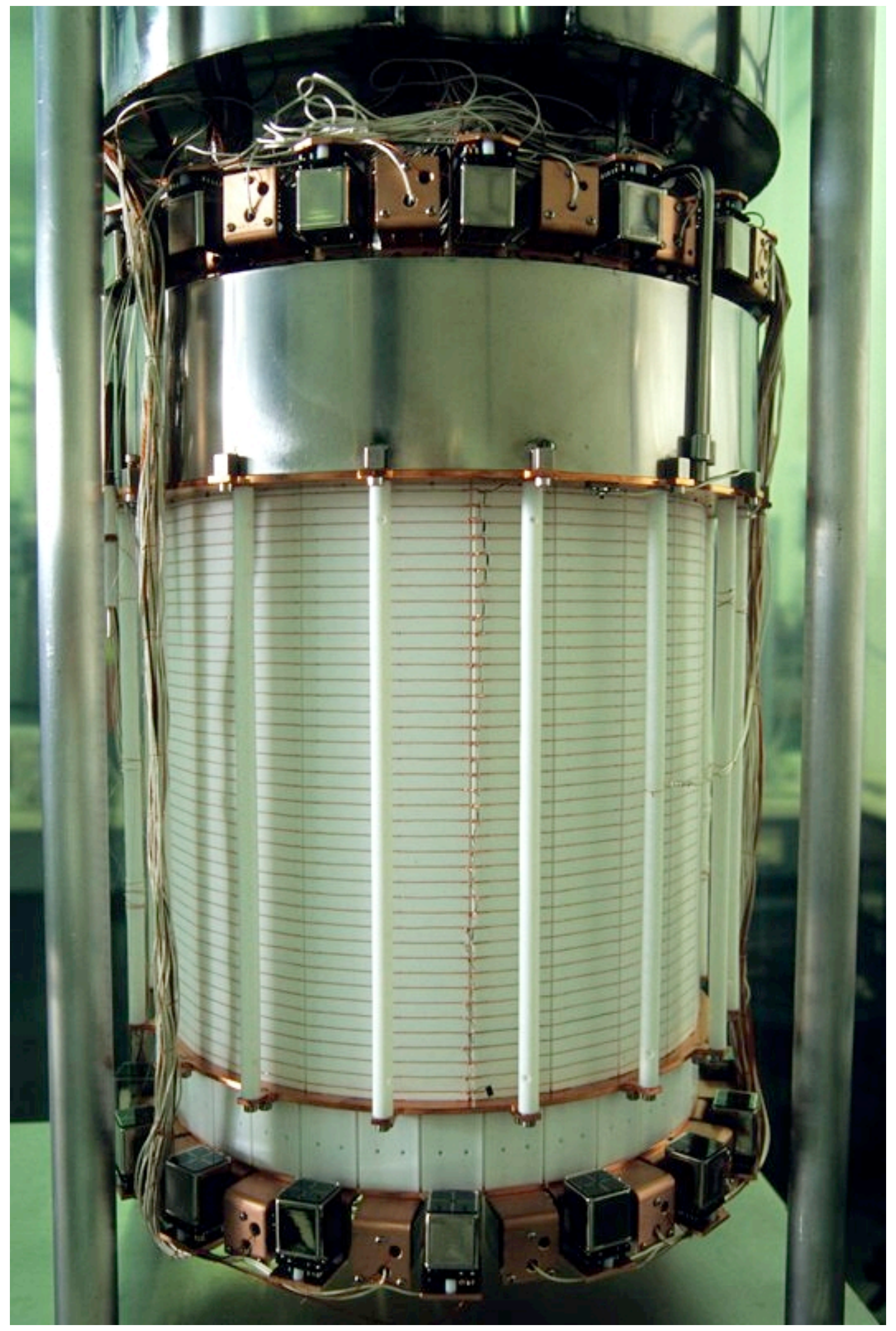
The XENON Program

PRL 100 (2008) 021303
PRD 94 (2016) 122001
PRL 121 (2018) 111302

XENON

XENON10
2005–2007

25 kg LXe
15 cm drift length
$\sigma_{SI} \sim 9 \times 10^{-44}$ cm^2
at 100 GeV/c^2 (2007)



XENON100
2009–2016

161 kg LXe
30 cm drift length
$\sigma_{SI} \sim 10^{-45}$ cm^2
at 50 GeV/c^2 (2016)

XENON1T
2016–2018

3.2 t LXe
1 m drift length
$\sigma_{SI} \sim 4 \times 10^{-47}$ cm^2
at 30 GeV/c^2 (2018)

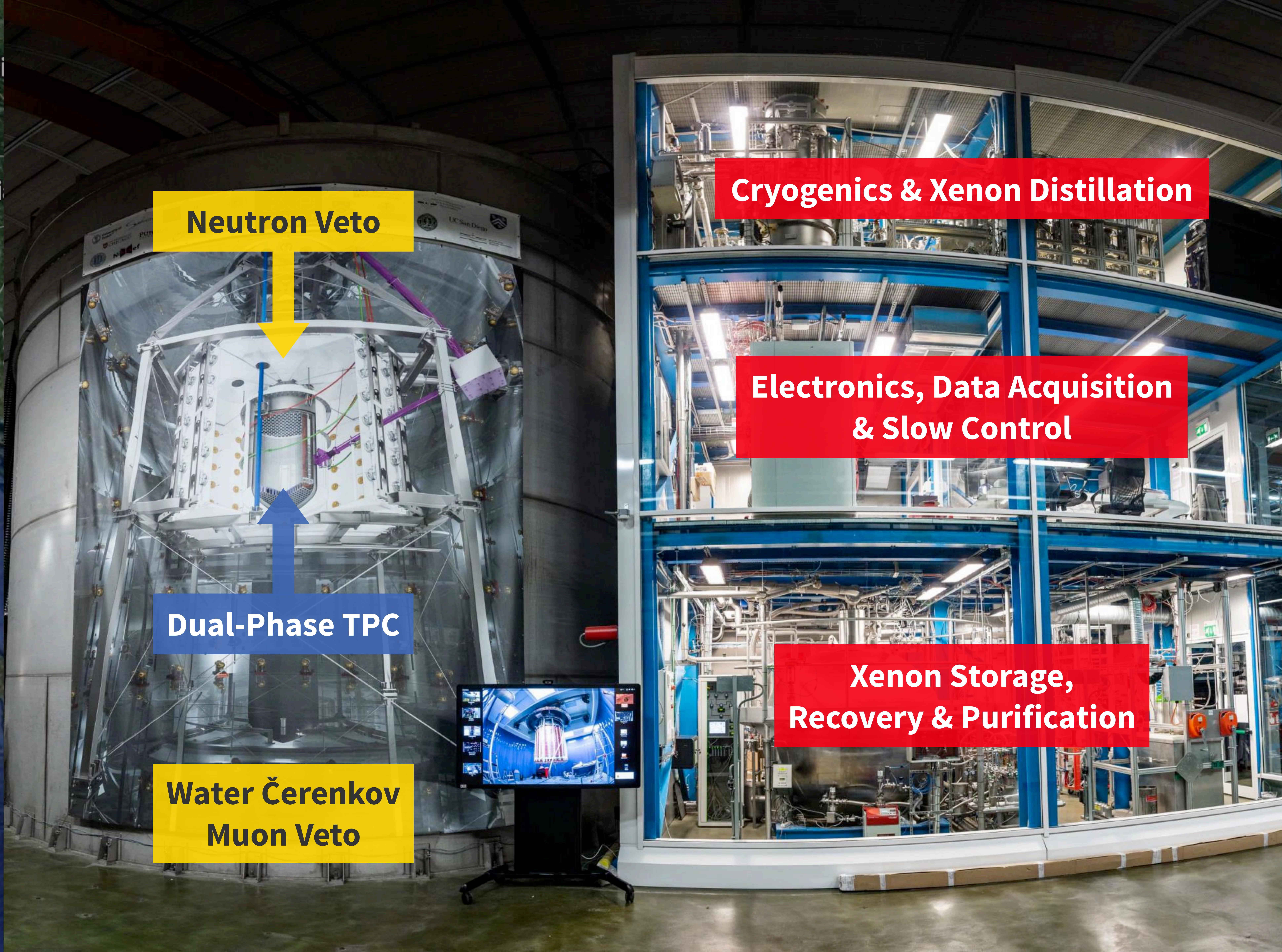
XENONnT
2020–2025

NOW

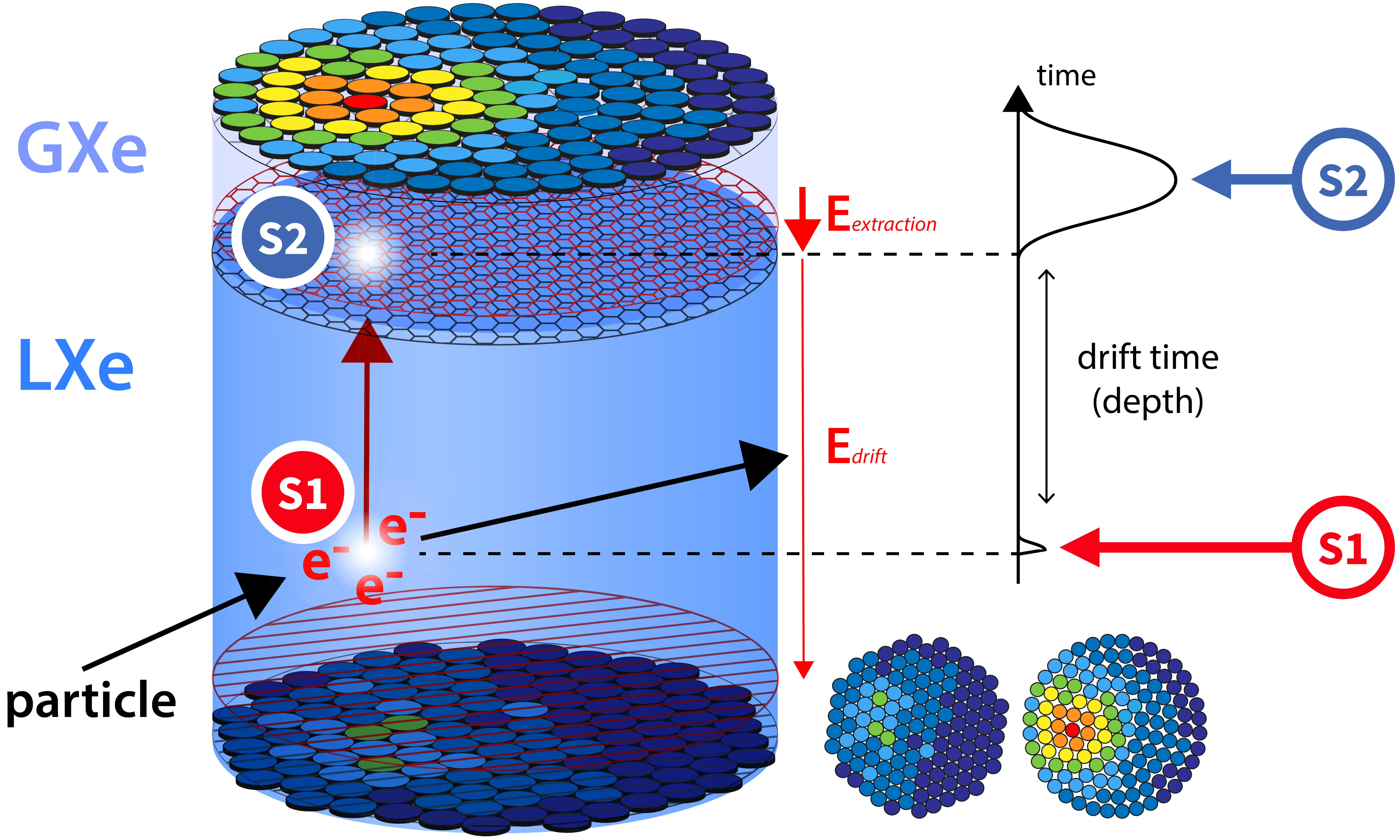
8.4 t LXe
1.5 m drift length
$\sigma_{SI} \sim 1.4 \times 10^{-48}$ **cm^2**
at 50 GeV/c^2 (20 t $\times$ yr)


Austria
Milan
Slovenia
Croatia
Italy
Rome
INFN
LNGS
XENON


Milan
Croatia
Italy
Rome
INFN
LNGS


Neutron Veto
Dual-Phase TPC
Water Čerenkov
Muon Veto
Cryogenics & Xenon Distillation
Electronics, Data Acquisition
& Slow Control
Xenon Storage,
Recovery & Purification

Detecting Particles with a TPC

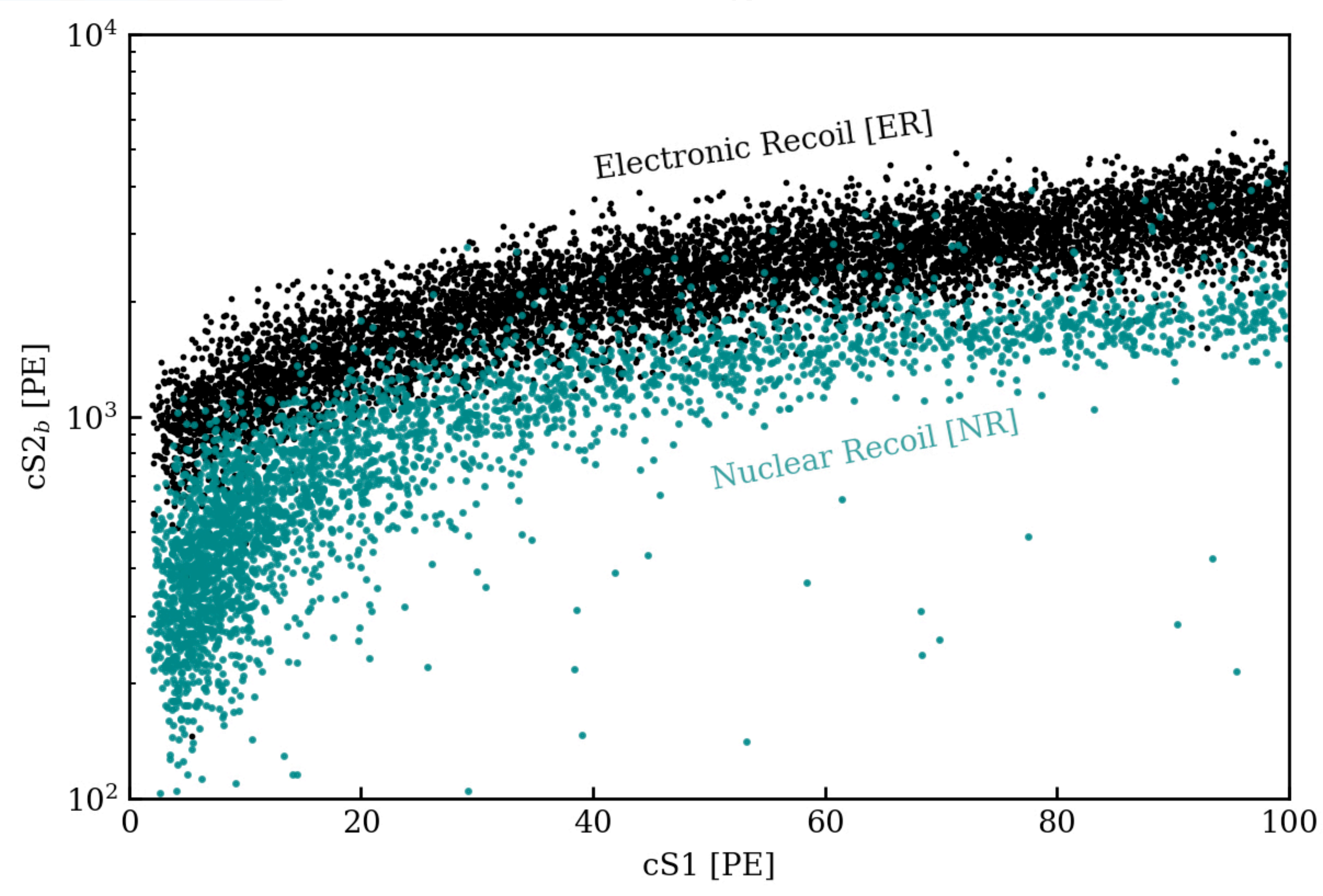


Detecting Particles with a TPC

Detecting Particles with a TPC

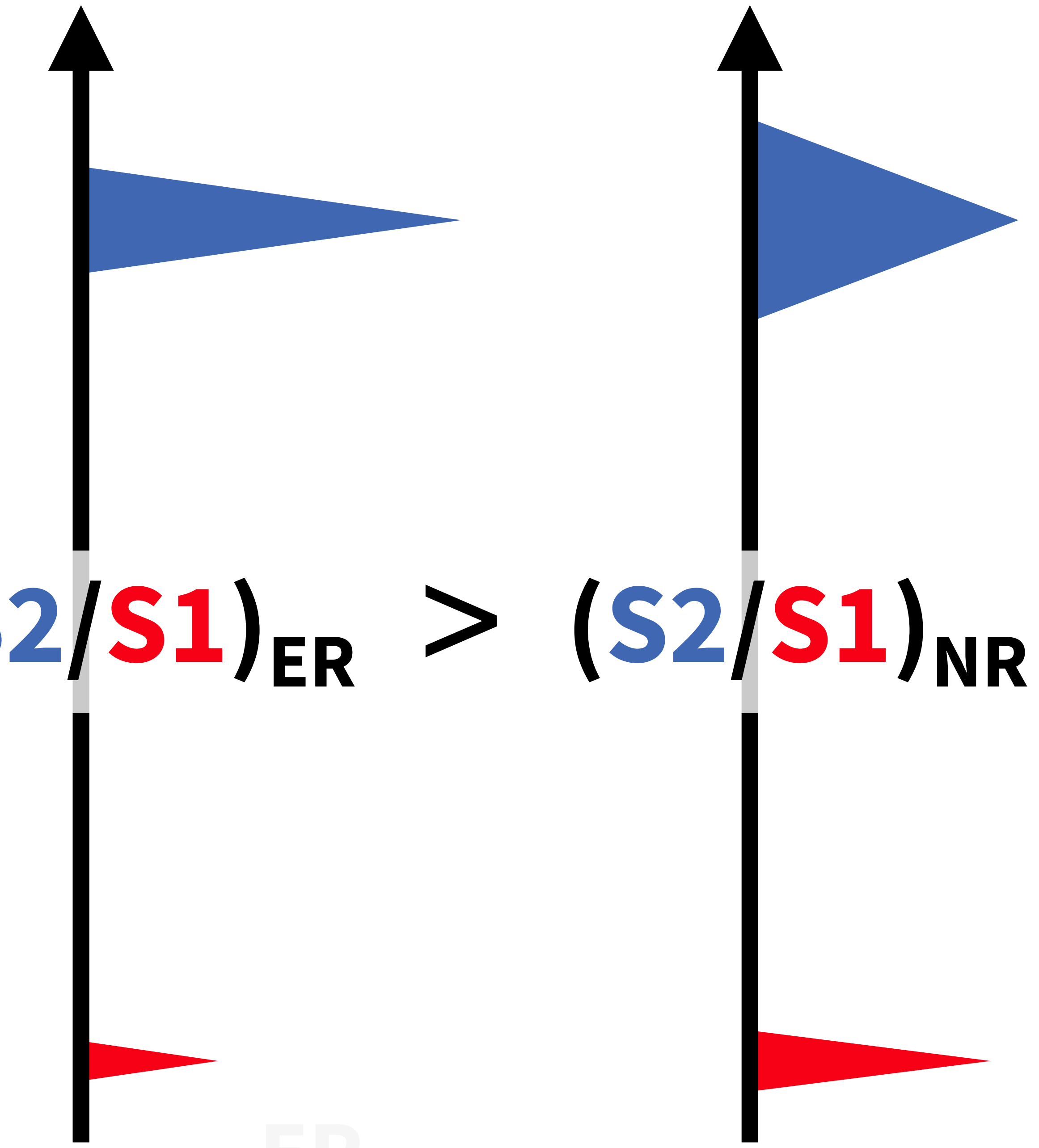
Leptophilic DM
Solar axions/ALPs
Double β decay

WIMP search
Solar neutrinos
Supernova neutrinos



Electronic Recoil (ER)

Nuclear Recoil (NR)

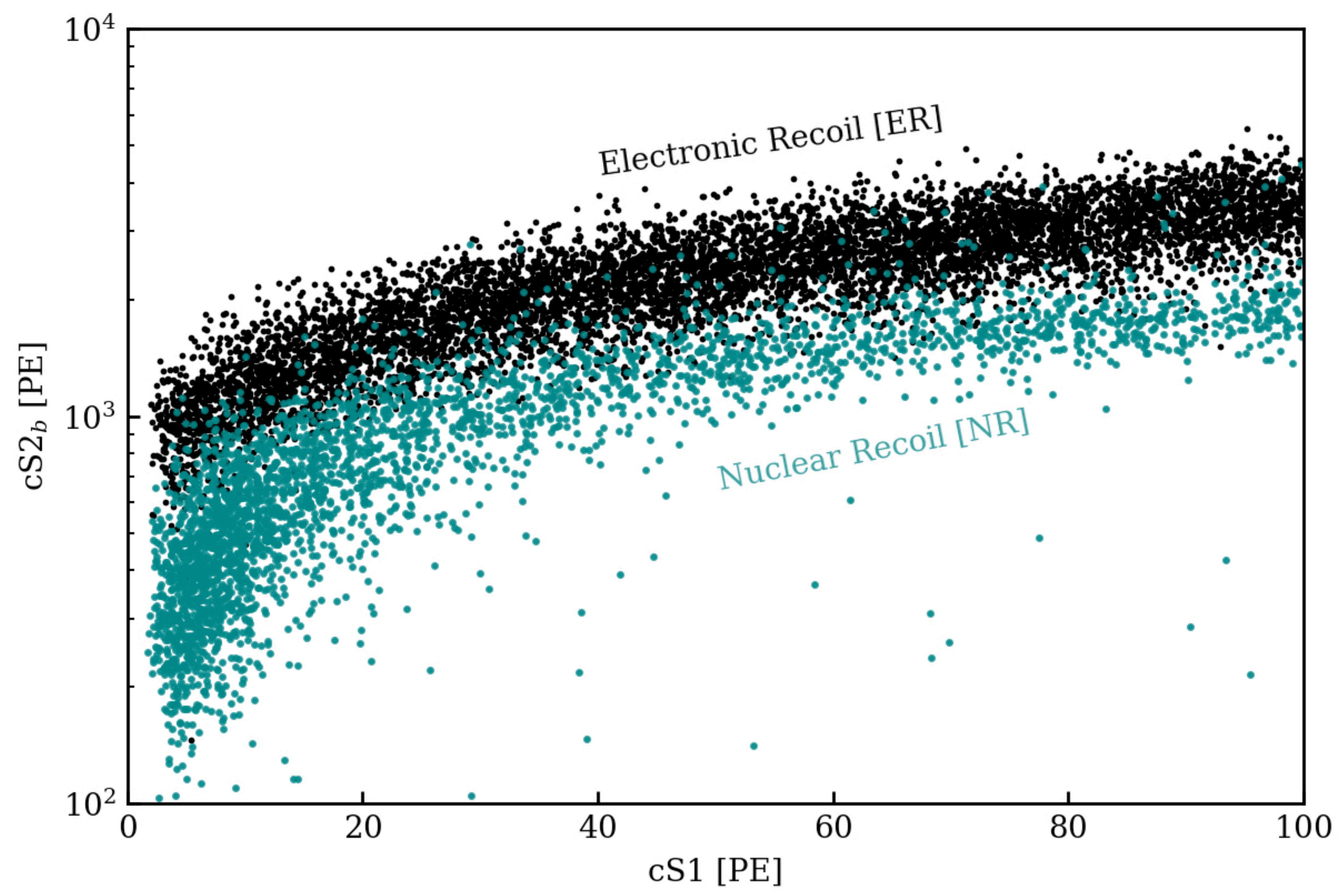


$(S2/S1)_{ER} > (S2/S1)_{NR}$

Detecting Particles with a TPC

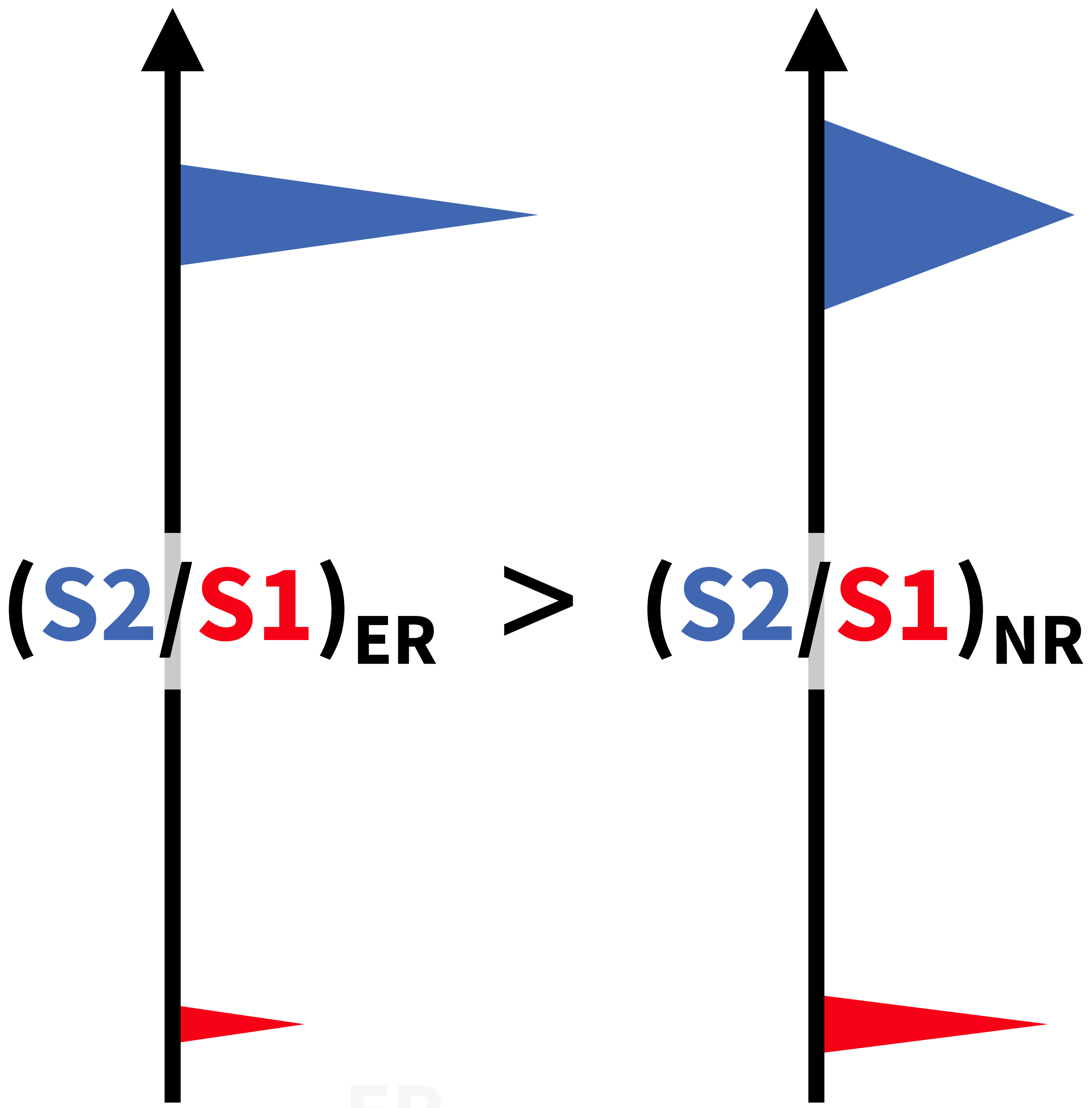
Leptophilic DM
Solar axions/ALPs
Double β decay

WIMP search
Solar neutrinos
Supernova neutrinos



Electronic Recoil (ER)

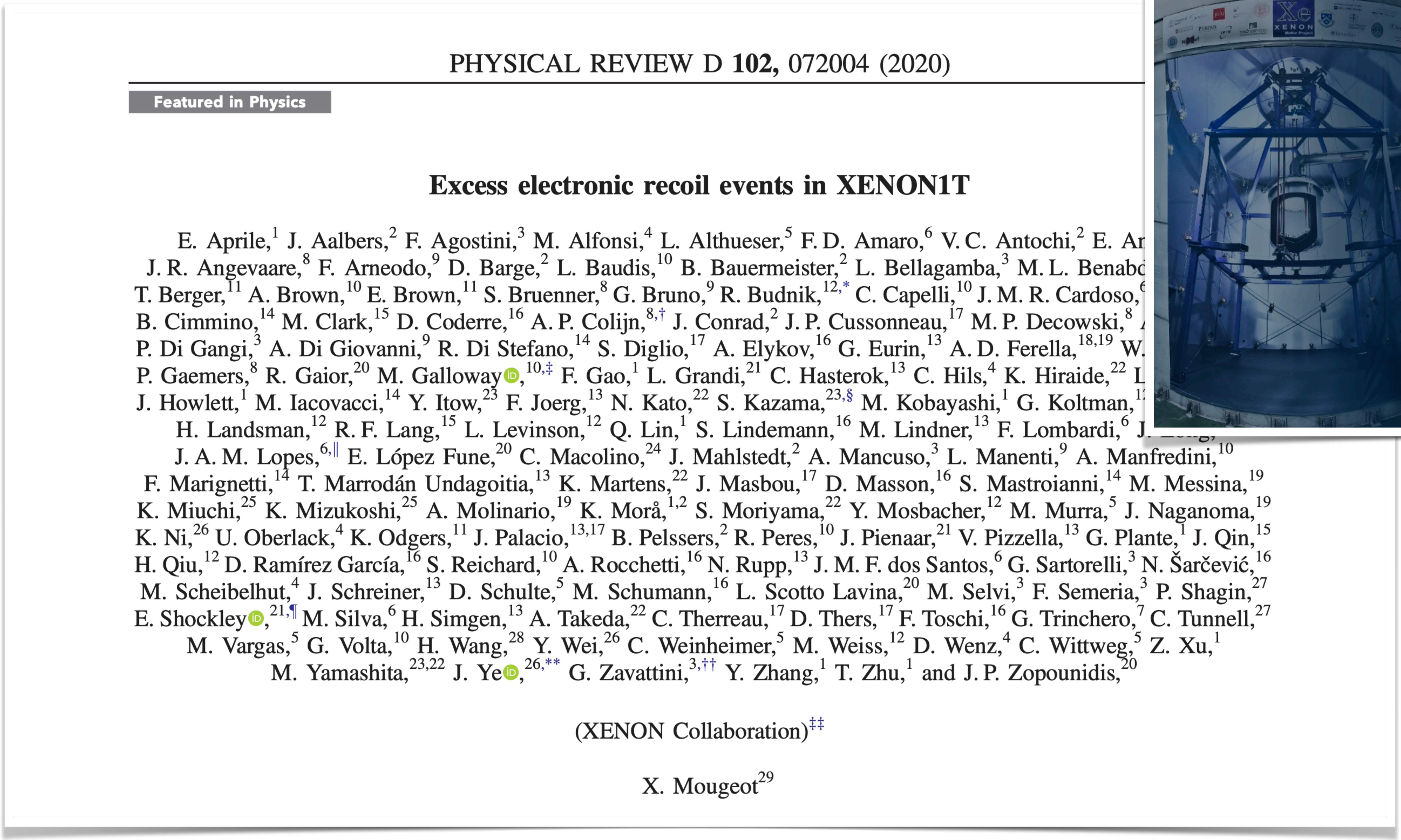
Nuclear Recoil (NR)



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

The Tale of
an Event Excess

An Unexpected Excess of Events



PHYSICAL REVIEW D **102,** 072004 (2020)

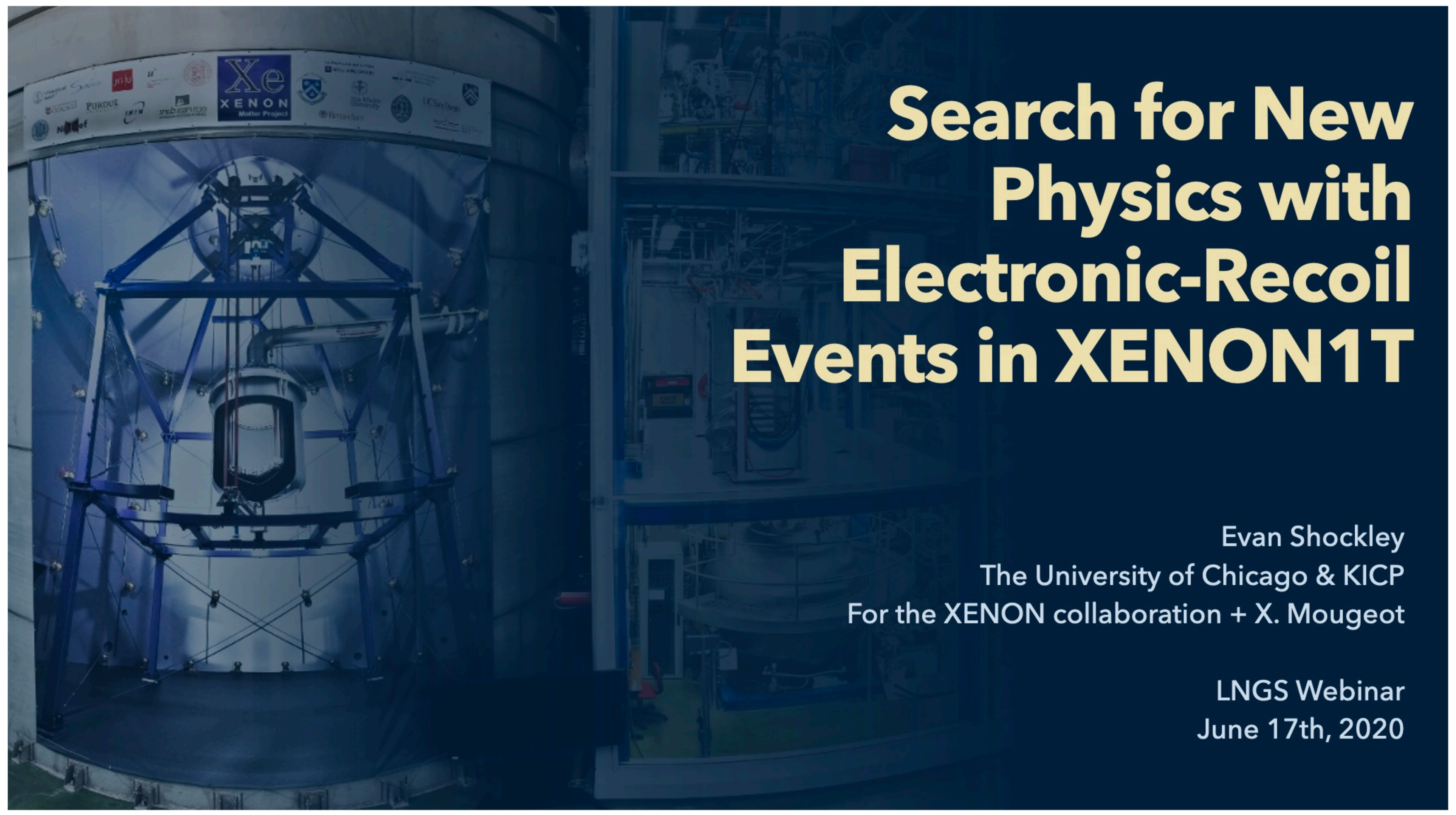
Featured in Physics

Excess electronic recoil events in XENON1T

E. Aprile,[1] J. Aalbers,[2] F. Agostini,[3] M. Alfonsi,[4] L. Althueser,[5] F. D. Amaro,[6] V. C. Antochi,[2] E. Ar
J. R. Angevaare,[8] F. Arneodo,[9] D. Barge,[2] L. Baudis,[10] B. Bauermeister,[2] L. Bellagamba,[3] M. L. Benabd
T. Berger,[11] A. Brown,[10] E. Brown,[11] S. Bruenner,[8] G. Bruno,[9] R. Budnik,[12,*] C. Capelli,[10] J. M. R. Cardoso,
B. Cimmino,[14] M. Clark,[15] D. Coderre,[16] A. P. Colijn,[8,†] J. Conrad,[2] J. P. Cussonneau,[17] M. P. Decowski,[8]
P. Di Gangi,[3] A. Di Giovanni,[9] R. Di Stefano,[14] S. Diglio,[17] A. Elykov,[16] G. Eurin,[13] A. D. Ferella,[18,19] W.
P. Gaemers,[8] R. Gaior,[20] M. Galloway,[10,‡] F. Gao,[1] L. Grandi,[21] C. Hasterok,[13] C. Hils,[4] K. Hiraide,[22] L
J. Howlett,[1] M. Iacovacci,[14] Y. Itow,[23] F. Joerg,[13] N. Kato,[22] S. Kazama,[23,§] M. Kobayashi,[1] G. Koltman,
H. Landsman,[12] R. F. Lang,[15] L. Levinson,[12] Q. Lin,[1] S. Lindemann,[16] M. Lindner,[13] F. Lombardi,[6] J.
J. A. M. Lopes,[6,∥] E. López Fune,[20] C. Macolino,[24] J. Mahlstedt,[2] A. Mancuso,[3] L. Manenti,[9] A. Manfredini,[10]
F. Marignetti,[14] T. Marrodán Undagoitia,[13] K. Martens,[22] J. Masbou,[17] D. Masson,[16] S. Mastroianni,[14] M. Messina,[19]
K. Miuchi,[25] K. Mizukoshi,[25] A. Molinario,[19] K. Morå,[1,2] S. Moriyama,[22] Y. Mosbacher,[12] M. Murra,[5] J. Naganoma,[19]
K. Ni,[26] U. Oberlack,[4] K. Odgers,[11] J. Palacio,[13,17] B. Pelssers,[2] R. Peres,[10] J. Pienaar,[21] V. Pizzella,[13] G. Plante,[1] J. Qin,[15]
H. Qiu,[12] D. Ramírez García,[16] S. Reichard,[10] A. Rocchetti,[16] N. Rupp,[13] J. M. F. dos Santos,[6] G. Sartorelli,[3] N. Šarčević,[16]
M. Scheibelhut,[4] J. Schreiner,[13] D. Schulte,[5] M. Schumann,[16] L. Scotto Lavina,[20] M. Selvi,[3] F. Semeria,[3] P. Shagin,[27]
E. Shockley,[21,¶] M. Silva,[6] H. Simgen,[13] A. Takeda,[22] C. Therreau,[17] D. Thers,[17] F. Toschi,[16] G. Trinchero,[7] C. Tunnell,[27]
M. Vargas,[5] G. Volta,[10] H. Wang,[28] Y. Wei,[26] C. Weinheimer,[5] M. Weiss,[12] D. Wenz,[4] C. Wittweg,[5] Z. Xu,[1]
M. Yamashita,[23,22] J. Ye,[26,**] G. Zavattini,[3,††] Y. Zhang,[1] T. Zhu,[1] and J. P. Zopounidis,[20]

(XENON Collaboration)[‡‡]

X. Mougeot[29]



Released on
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Science

Dark matter hunt yields unexplained signal

By Paul Rincon
Science editor, BBC News website

Le Monde

Consulter le journal

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SCIENCES • PHYSIQUE   Favoris

Physique des particules : des détections déroutantes en Italie

L'expérience Xenon1T, installée dans le laboratoire souterrain de Gran Sasso pour traquer la matière noire a enregistré un signal inattendu. S'agit-il d'une particule encore jamais observée ou d'une contamination du dispositif ?

Par Nathaniel Herzberg · Publié le 19 juin 2020 à 14h23 - Mis à jour le 22 juin 2020 à 15h59

Quanta magazine | Physics | Mathematics | Biology | Computer Science | All Articles

ABSTRACTIONS BLOG

Dark Matter Experiment Finds Unexplained Signal

11

Researchers say there are three possible explanations for the anomalous data. One is mundane. Two would revolutionize physics.

GLI ESPERIMENTI SOTTO IL GRAN SASSO

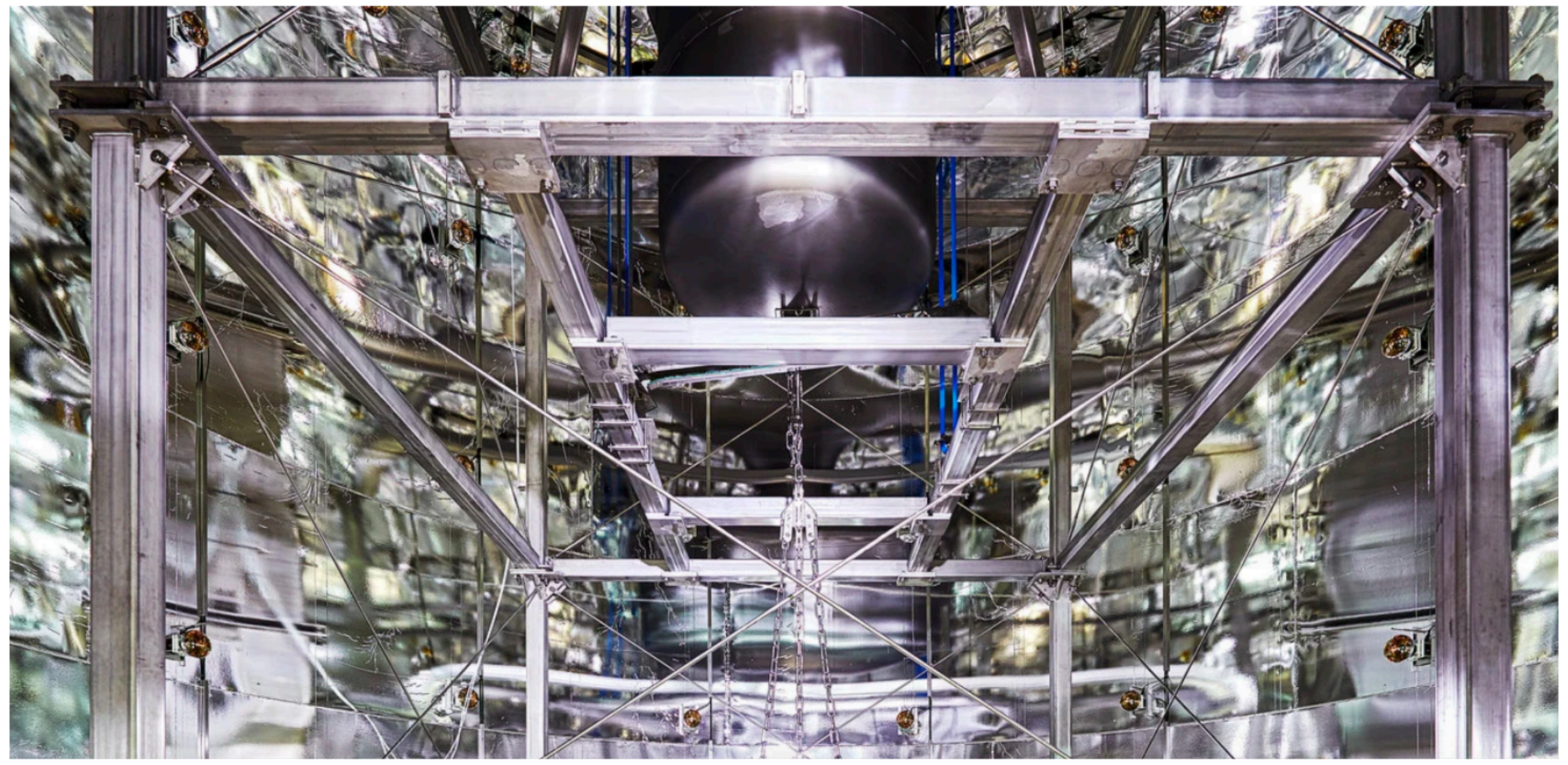
Laboratorio del Gran Sasso, registrati segnali anomali nella caccia alla materia oscura: sono gli assioni?

The New York Times

OUT THERE

Seeking Dark Matter, They Detected Another Mystery

Do signals from beneath an Italian mountain herald a revolution in physics?



759 | 68 | Share

JUNE 17, 2020

Observation of excess events in the XENON1T dark matter experiment

by Kavli Institute for the Physics and Mathematics of the Universe

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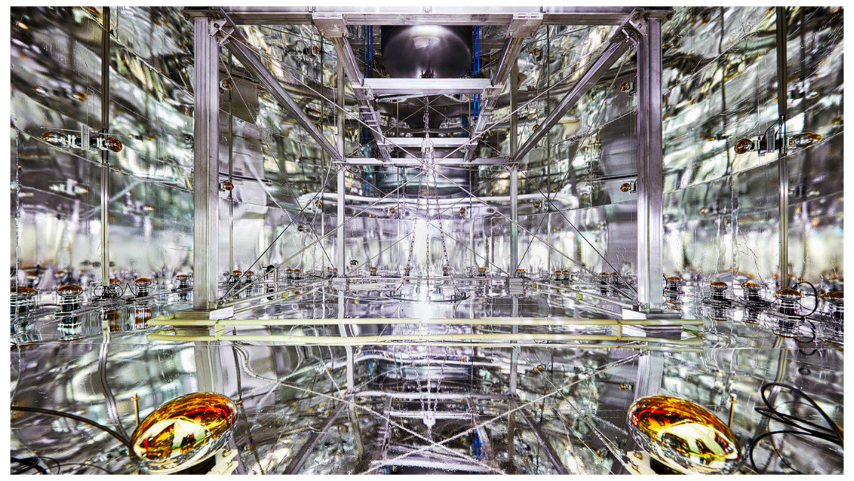

The XENON1T detector, which ran from 2016 to 2018, may have seen signs of exotic particles—or not. ENRICO SACCHETTI/SCIENCE SOURCE

Dark matter hunters' inconclusive signal grabs headlines

By Adrian Cho | Jun. 17, 2020 , 5:55 PM

Forbes

EDITORS' PICK | 5326 views | Jun 17, 2020, 10:00am EDT

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Ethan Siegel Senior Contributor
Starts With A Bang Contributor Group
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The Universe is out there, waiting for you to discover it.

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Exotic Dark Matter Detector Deep in an Italian Mountainside Picks Up Unexplained New Signal

TOPICS: Dark Matter | Particle Physics | Popular | University Of Chicago

BY MAGGIE HUDSON, UNIVERSITY OF CHICAGO | JUNE 18, 2020

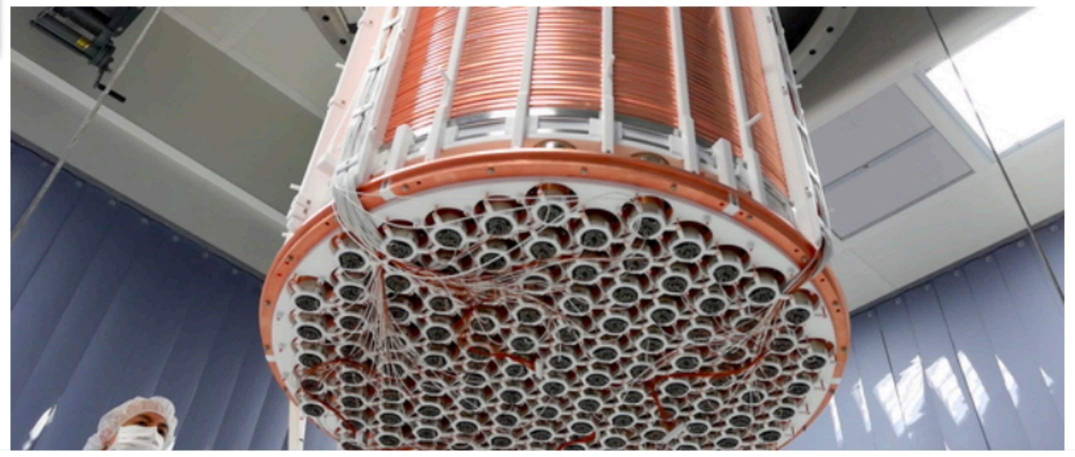
MENU | CERCA

Il Messaggero

Materia Oscura, mistero sui nuovi eventi scoperti nei laboratori del Gran Sasso

SCIENZA

Giovedì 18 Giugno 2020 di Enzo Vitale

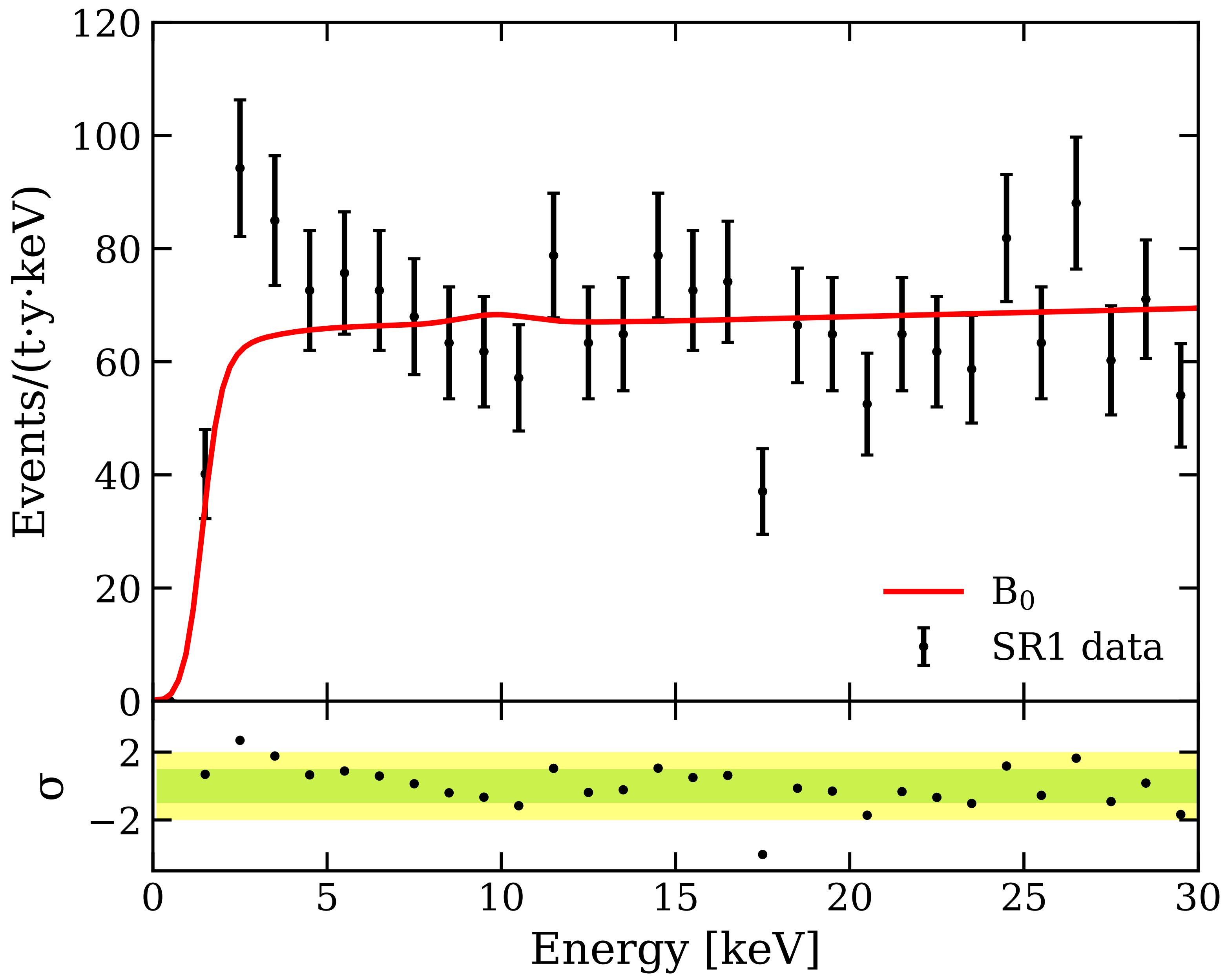


Ancora una volta la parola che più si accosta al termine Fisica è Italia. E seppur con la dovuta cautela gli scienziati vanno a passo di piombo, gli aventi accaduti nei **Laboratori del Gran Sasso** prefigurano scena

The XENON1T Excess

PRD 102 (2020) 072004

- **3.3σ excess in electronic recoil data near 2 keV** → compatible with new physics models (up to 3.4σ) or a tritium background (3.2σ)



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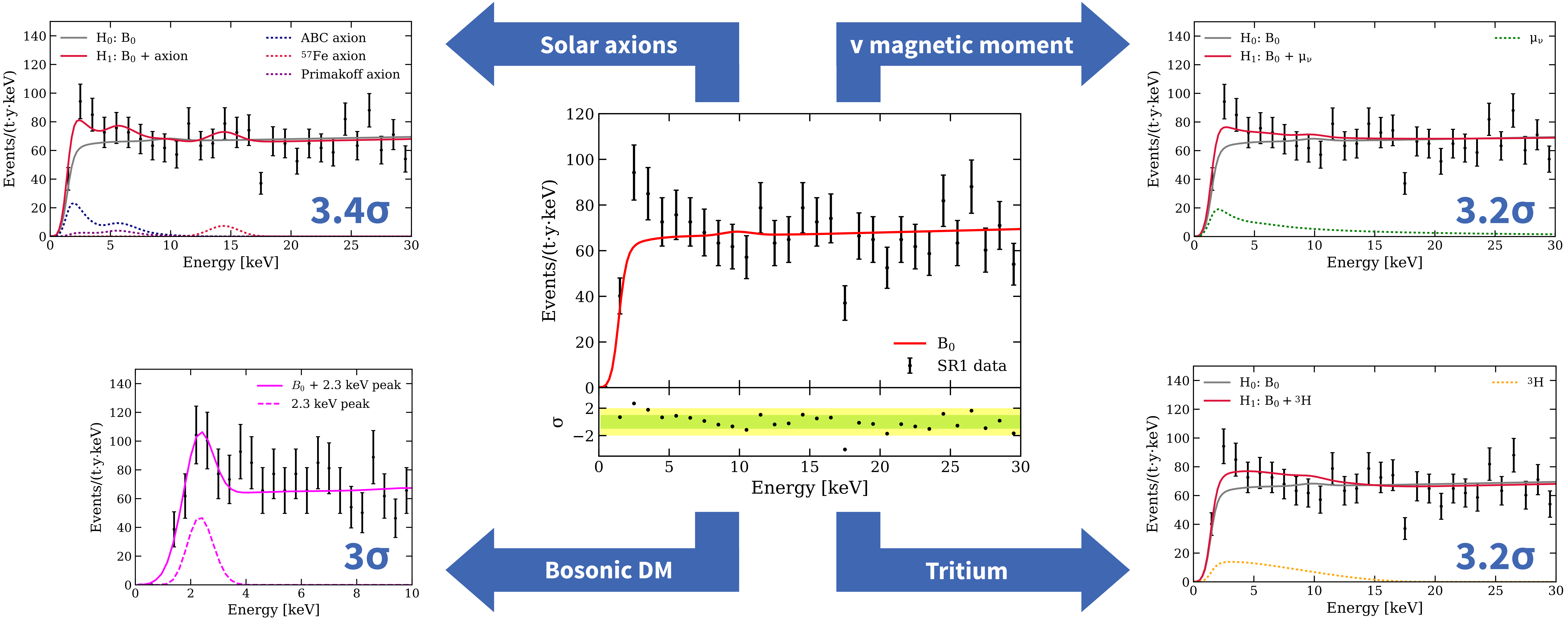

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PRD 102 (2020) 072004

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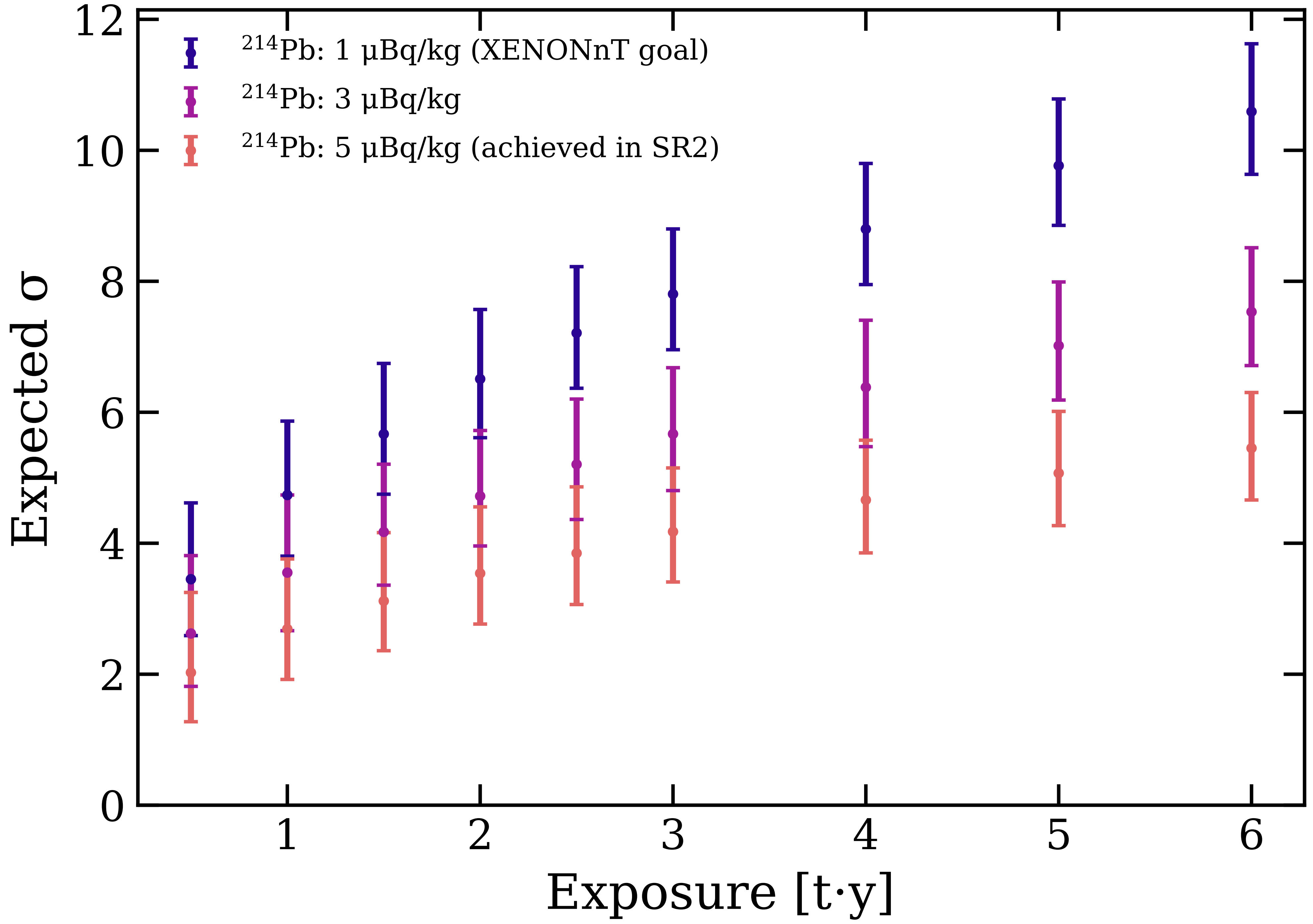
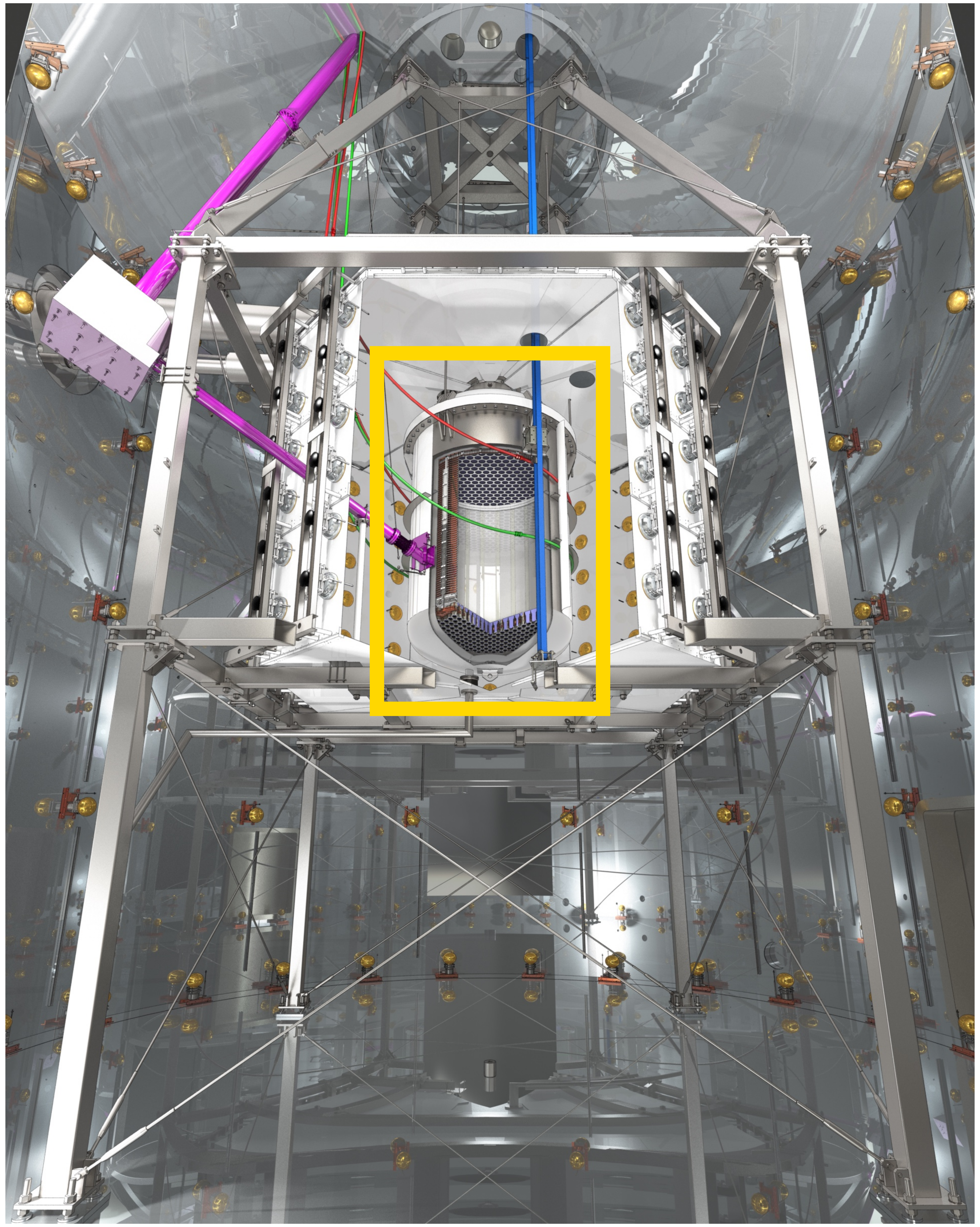
Low-energy ER excess axion–tritium discrimination

A few months



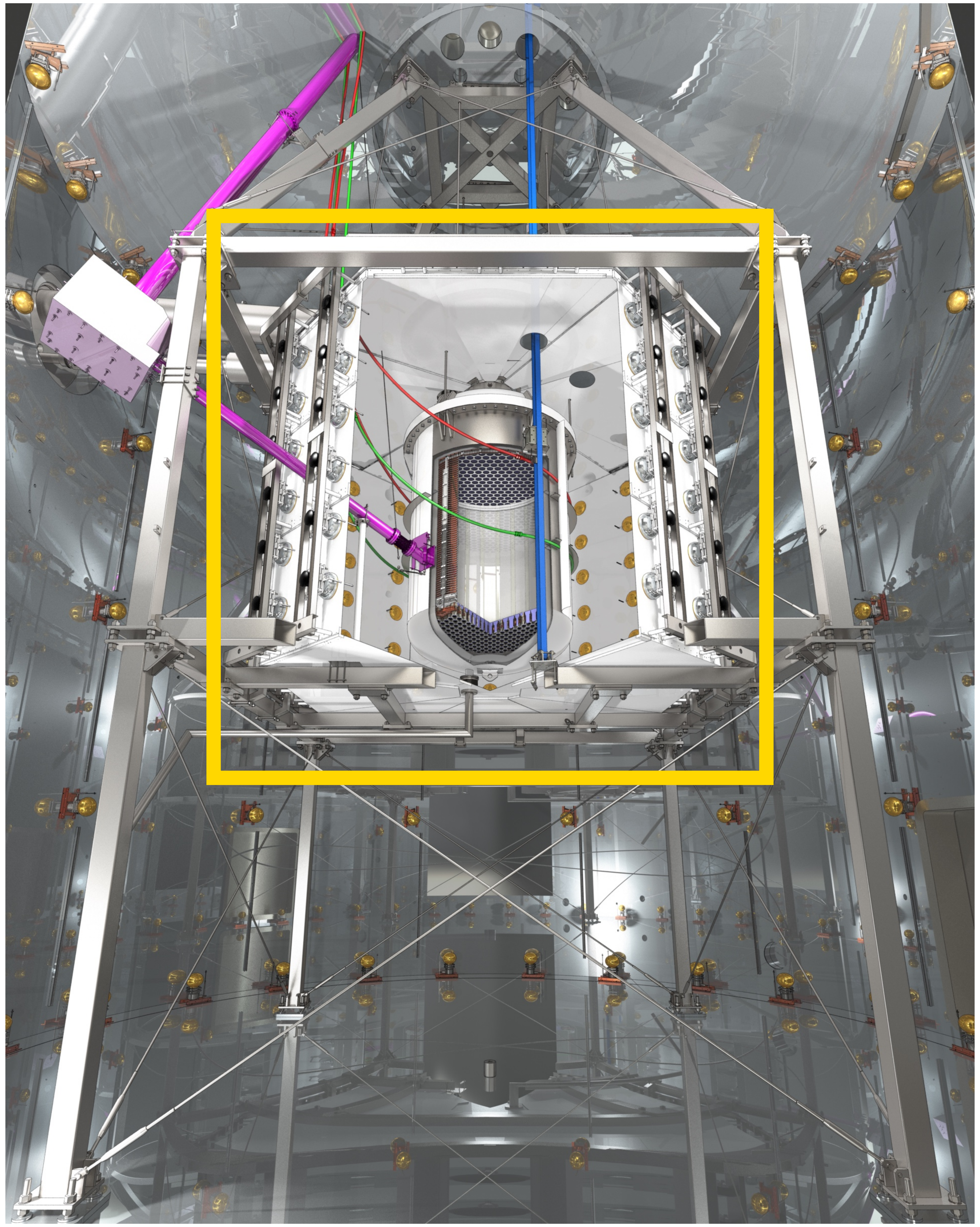
From 1T to nT

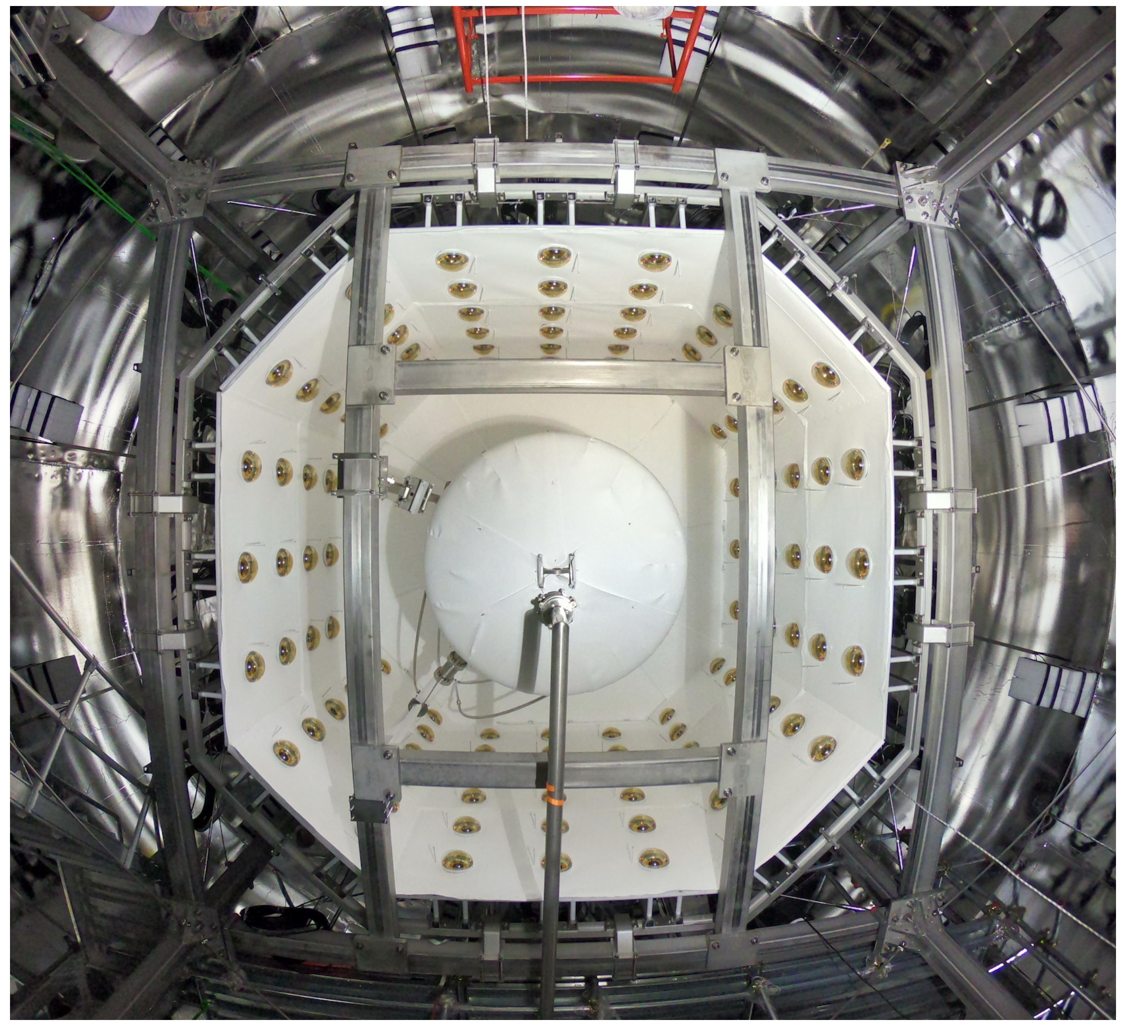
From 1T to nT—TPC Upgrade

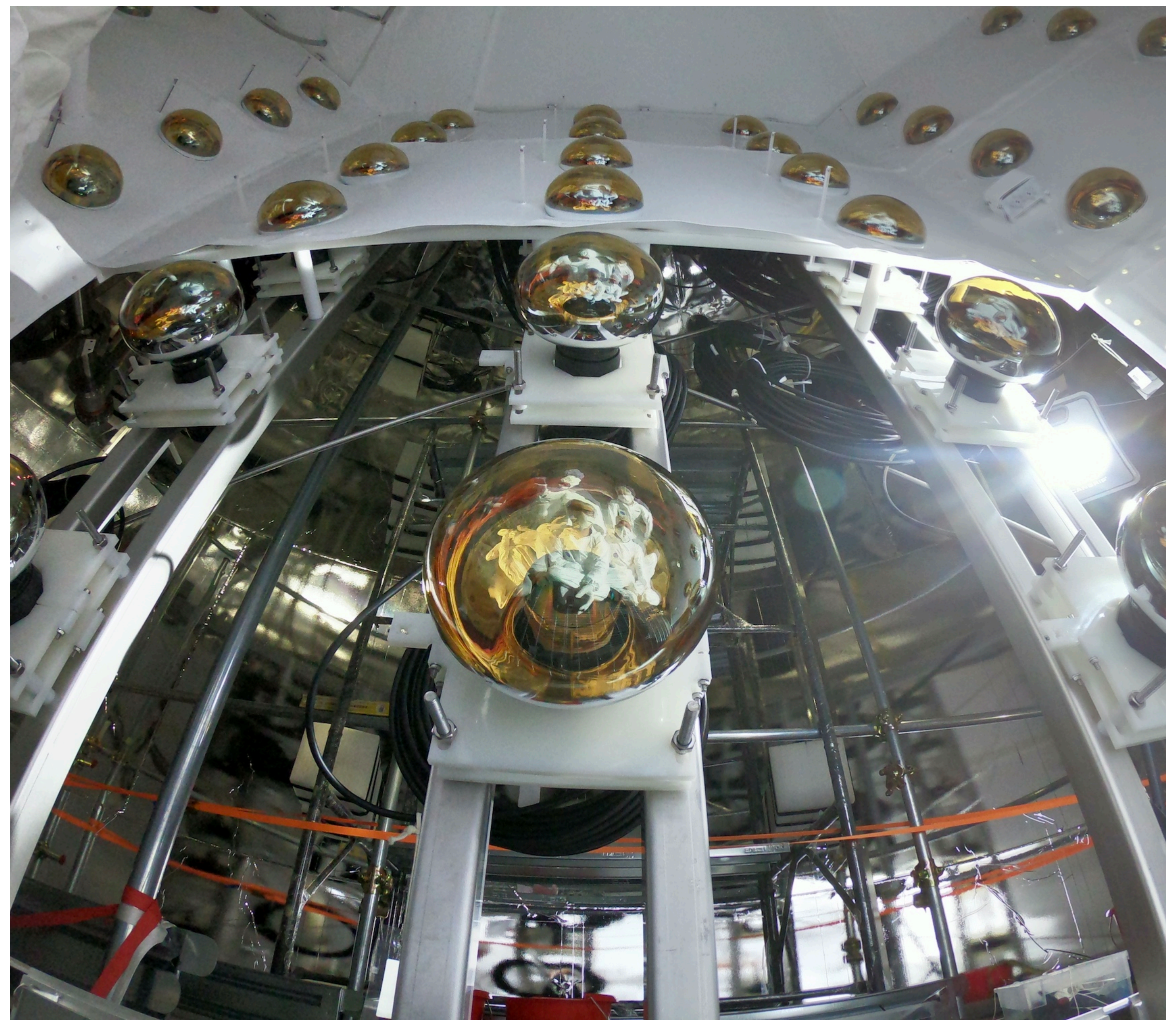


- **1.5× longer drift length** (1 m ➞ 1.5 m)
- **3× larger LXe active mass** in the TPC (2 t ➞ 5.9 t)
- **Twice as much PMTs** as in XENON1T (248 ➞ 494)

From 1T to nT—Neutron Veto

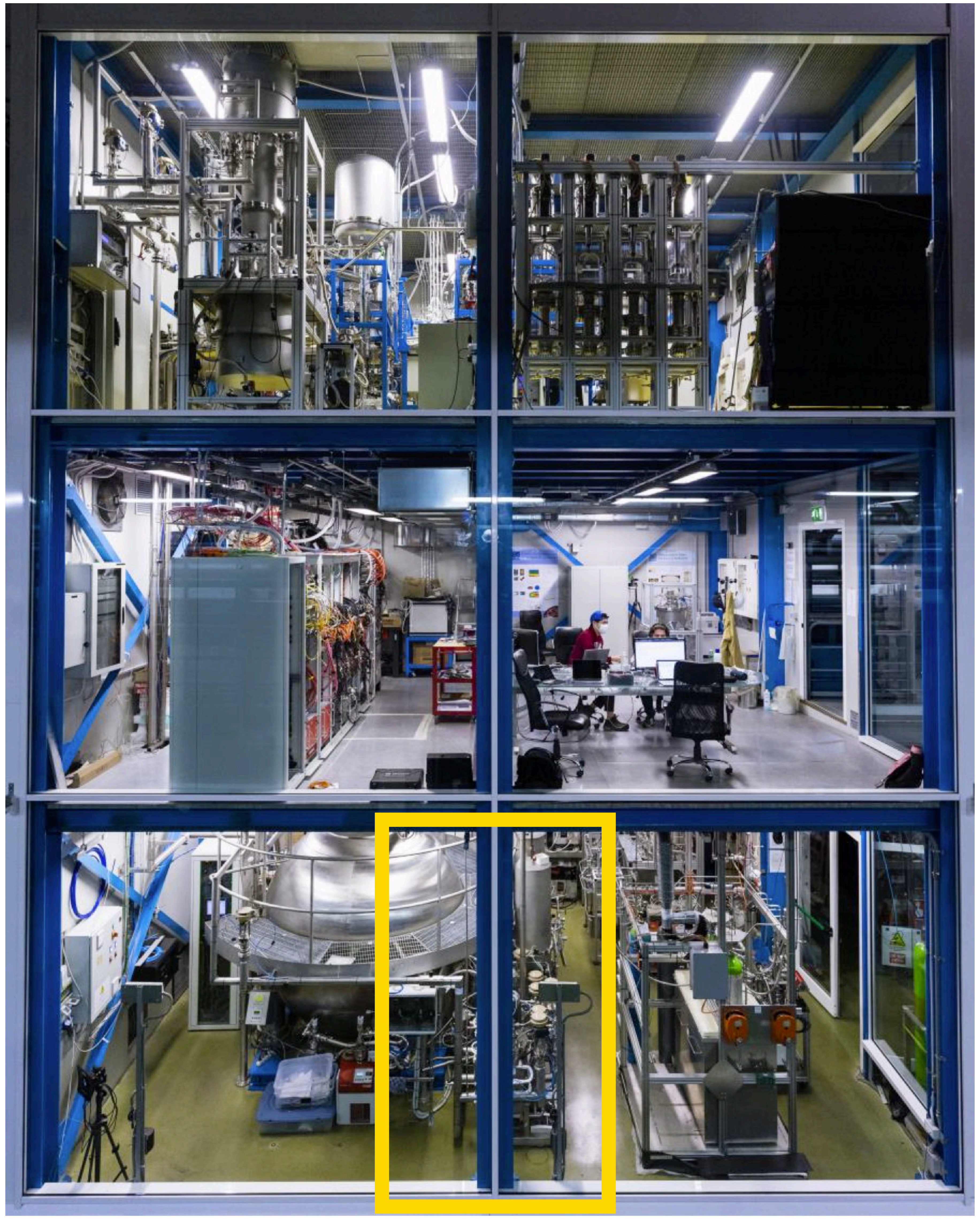


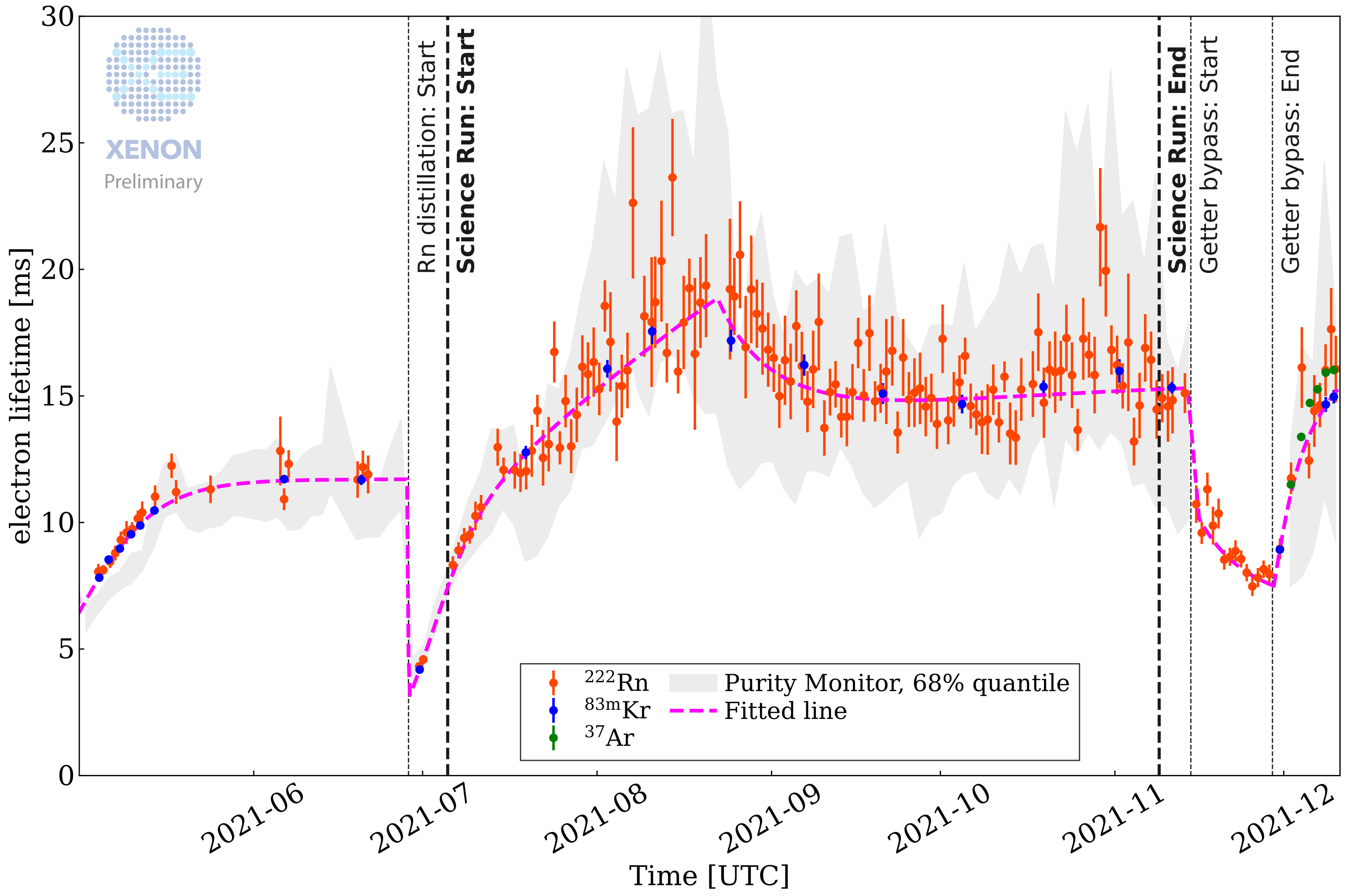




- Active neutron veto filled with **pure water** around the TPC, **Gd-doping planned**
- 120 PMTs + high-reflectivity walls to contain light → **Čerenkov detector** seeking neutron captures
- Crucial to **enhance the WIMP sensitivity** by tagging neutrons (68% efficiency now, 87% expected with Gd)

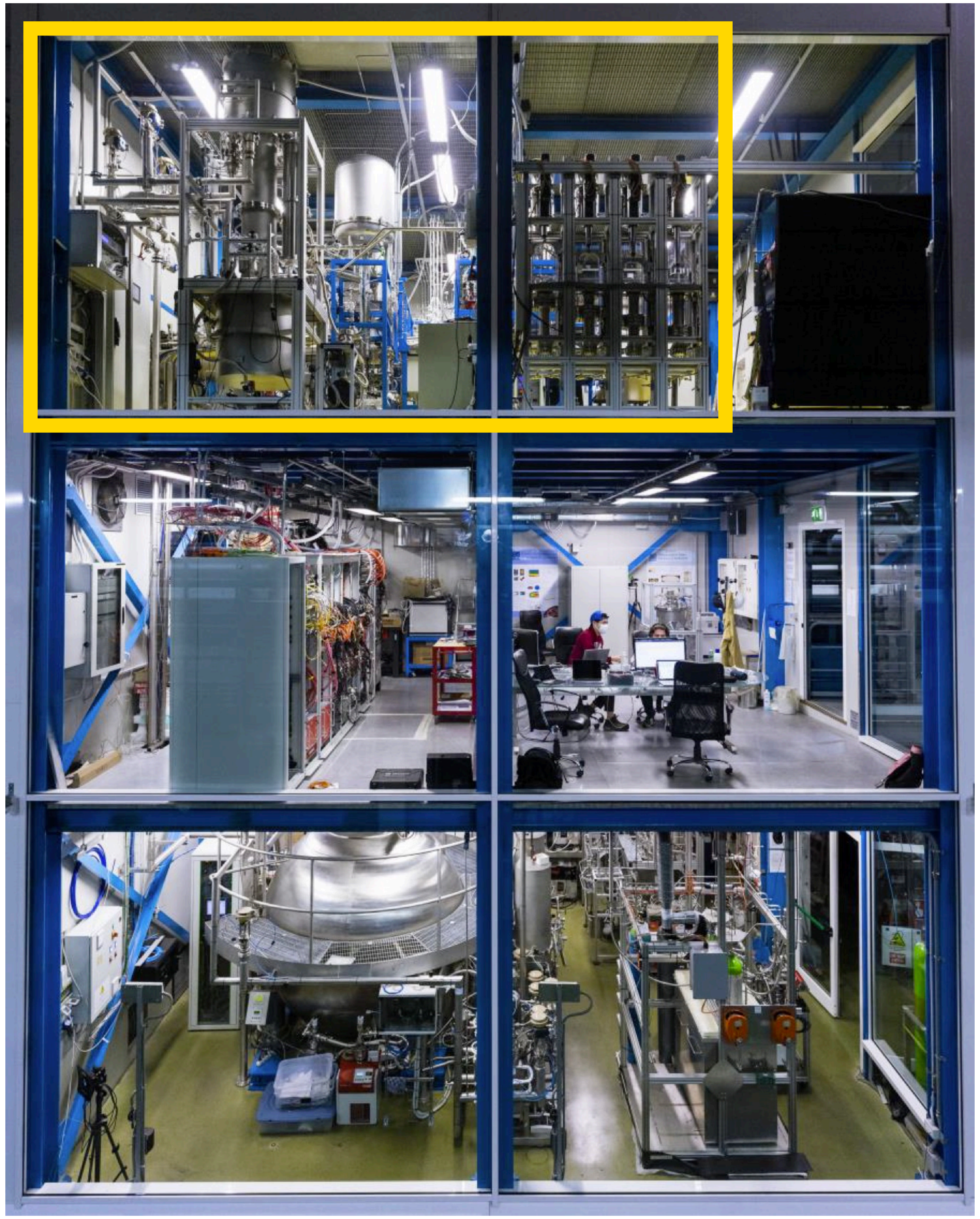
From 1T to nT—Purification Upgrade

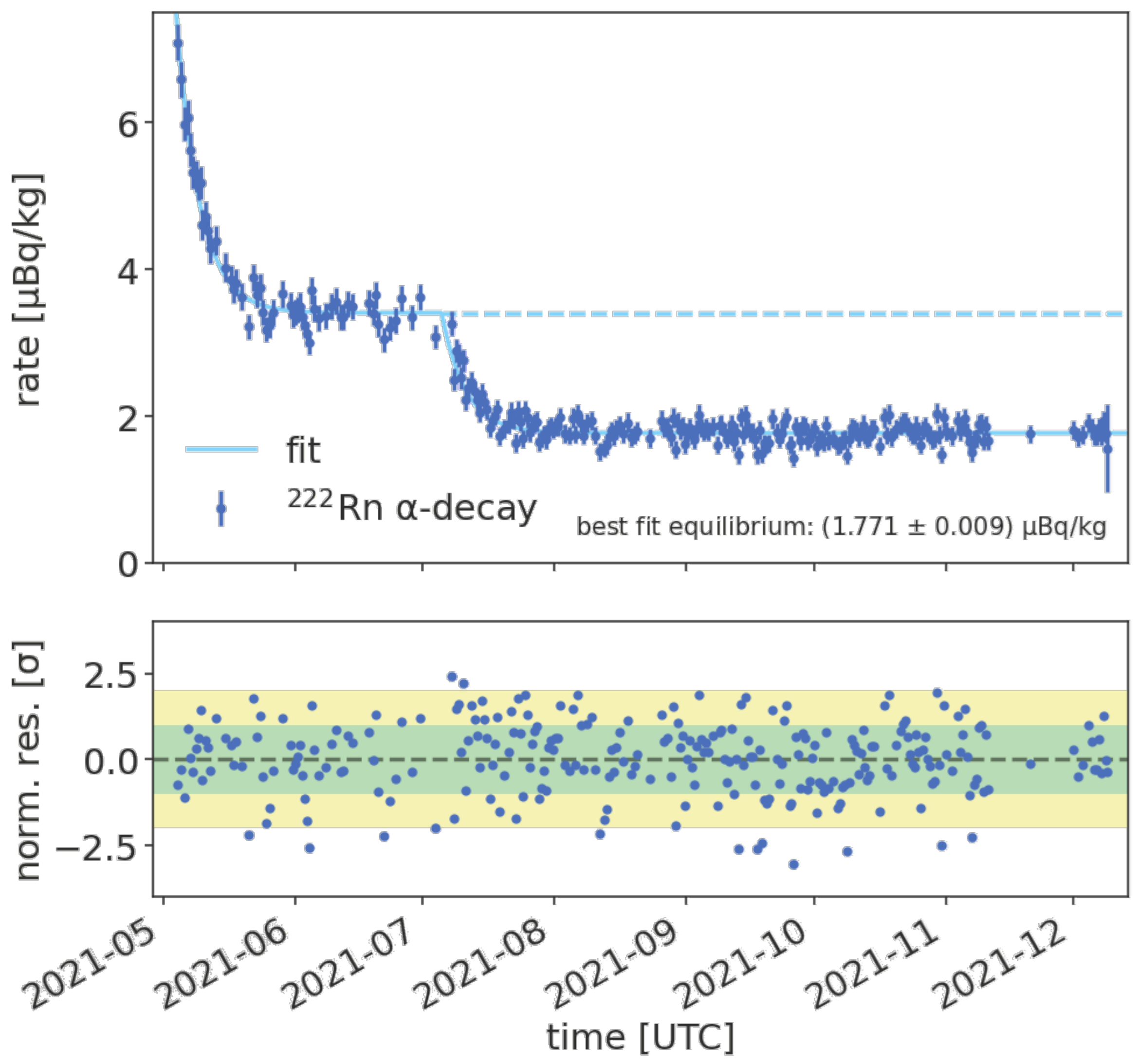




- **New liquid-phase purification technique** with low-radon O_2 filters [EPJC 82 860 (2022)]
- High-flux purification at 2 L/min LXe (≈ 350 kg/h)
  → **very high purity achieved within a week**
  (> 20× longer electron lifetime than XENON1T)

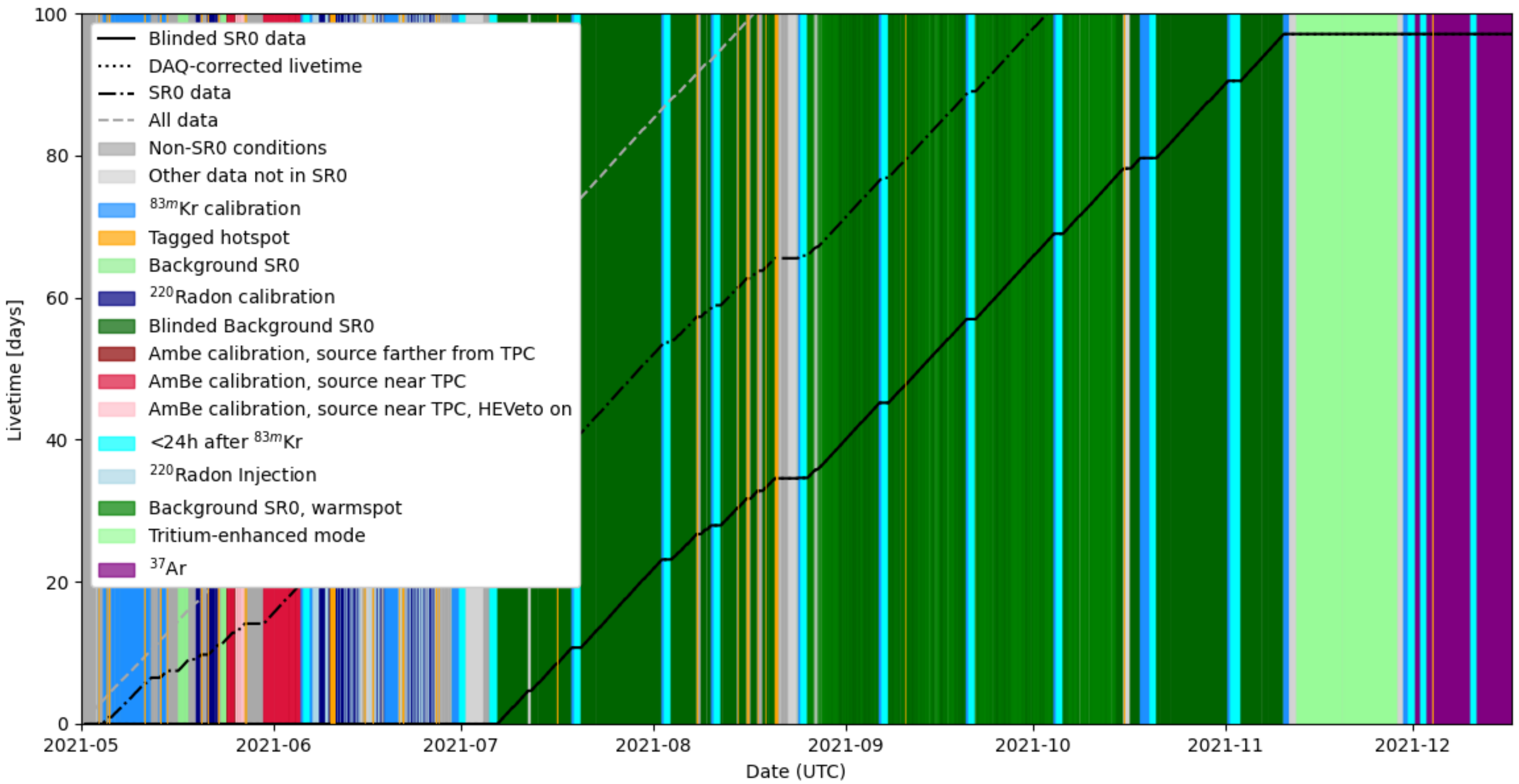
From 1T to nT—Radon Removal Upgrade

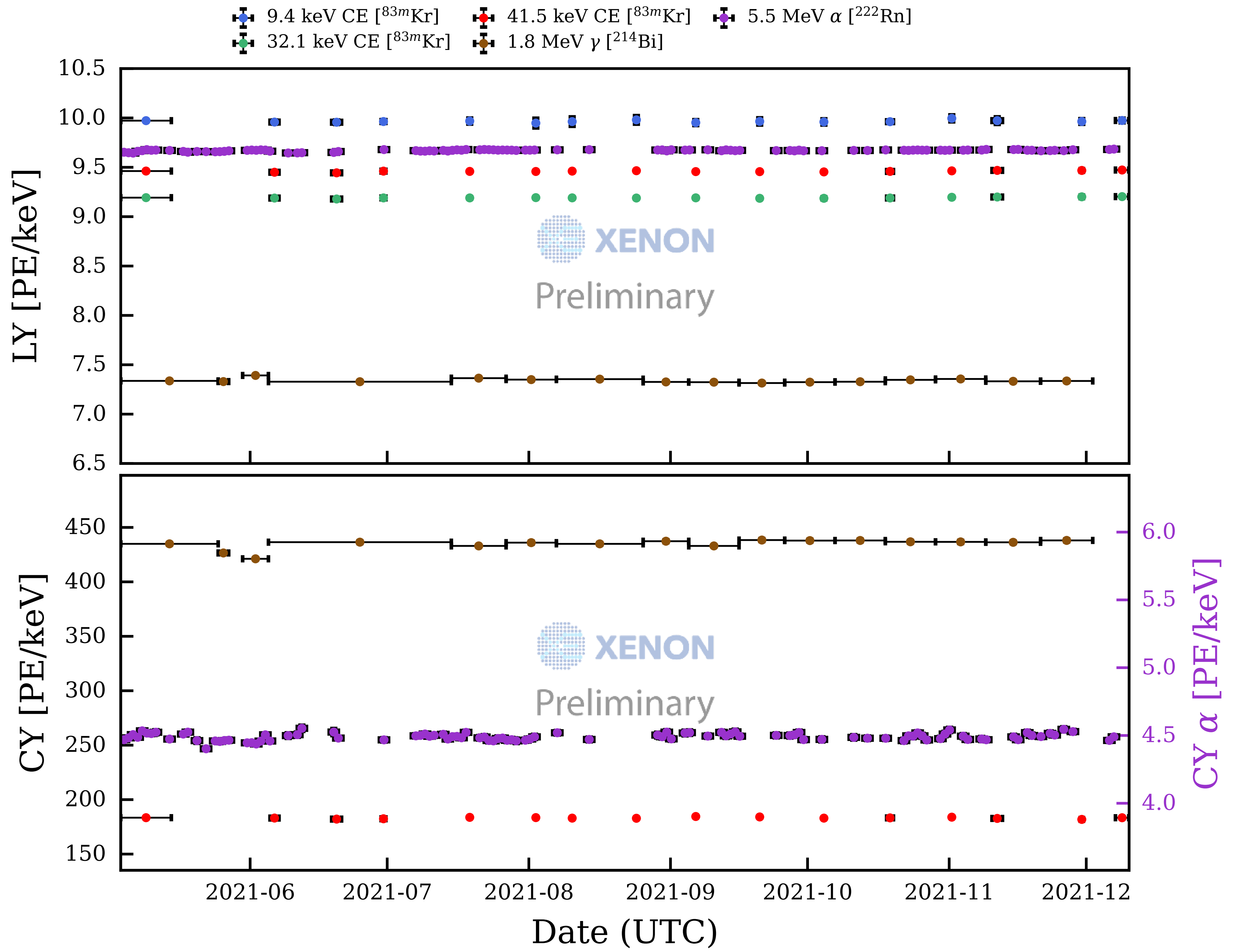




- **New distillation column** constantly removing ^{222}Rn (ER background) from xenon [arXiv:2205.11492]
- GXe-only mode during SR0 → ^{222}Rn reduction **down to 1.77 µBq/kg** (7× lower than XENON1T)
- Reaching goal of **< 1 µBq/kg** with LXe mode (next science runs)

XENONnT Science Run 0

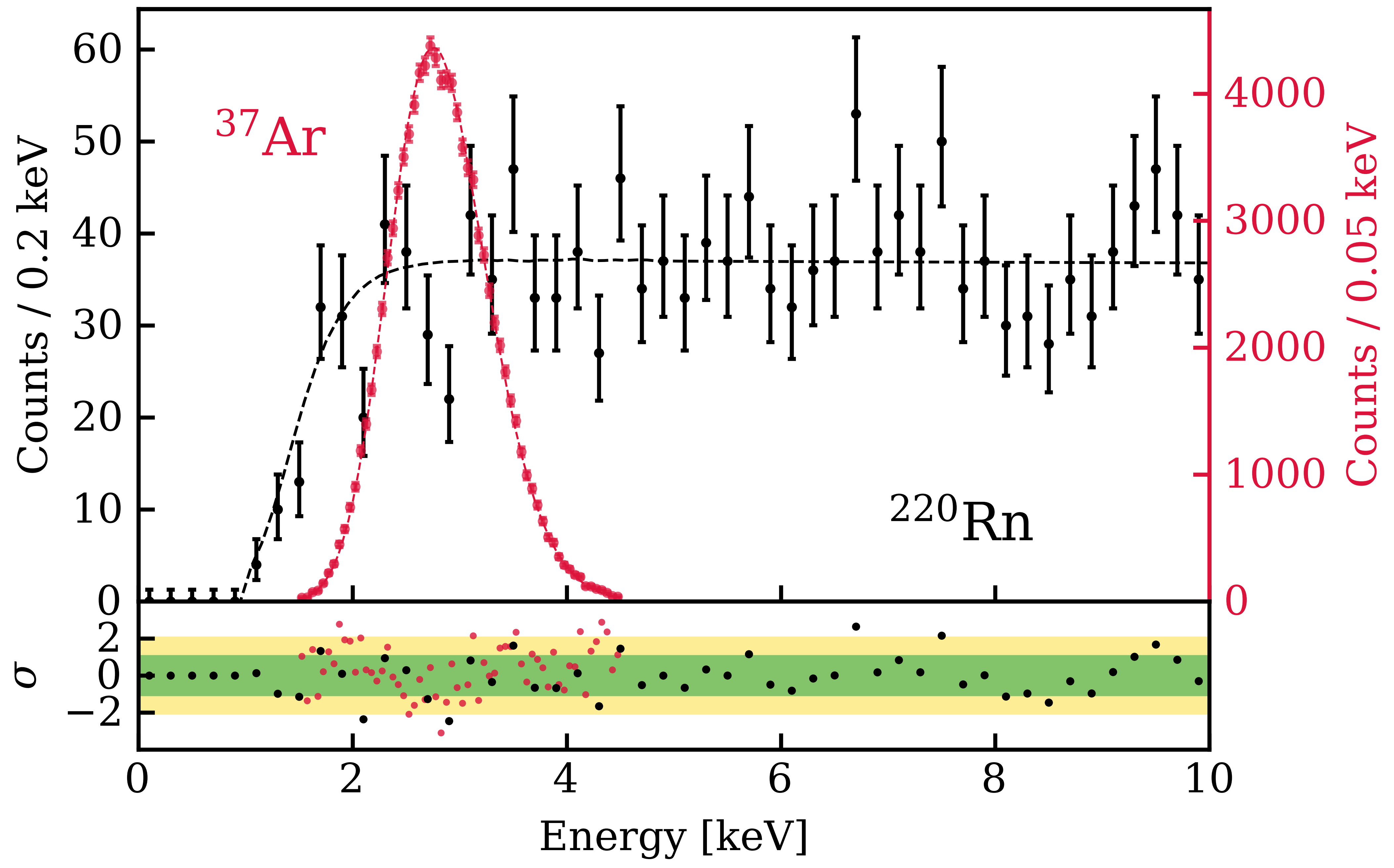


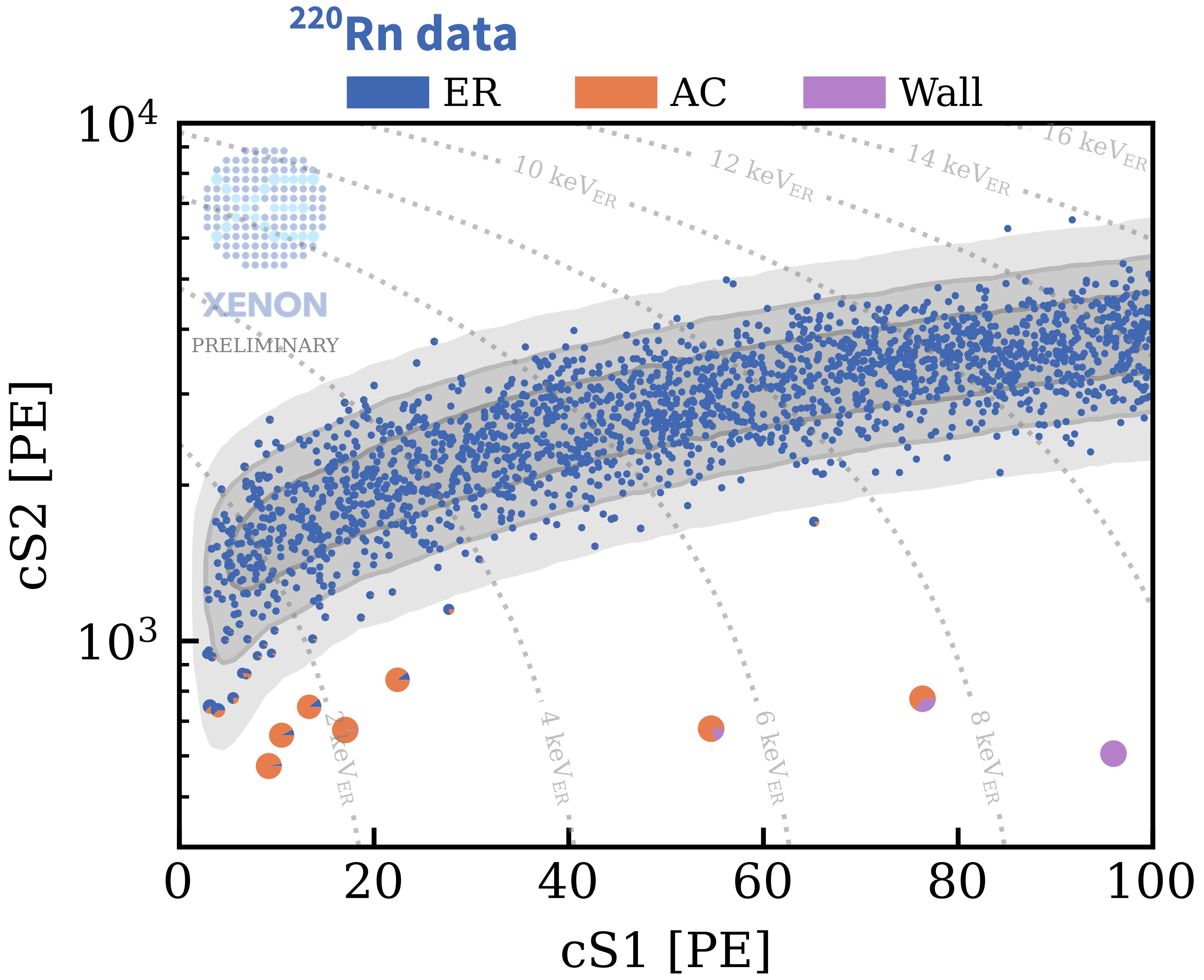


- Science Run 0 (SR0), 6 July–10 Nov. 2021 ⟶ **97.1 days of science livetime**
- **High stability overall** (light and charge yields ± 2%, PMT gain ± 3%), **monitored with regular calibrations** and remaining internal radioactivity (^{222}Rn α, materials γ)
- Intermittent, localised high single-electron emissions ⟶ **limited drift field (23 V/cm)**

Low-Energy ER Response

PRL 129 (2022) 161805





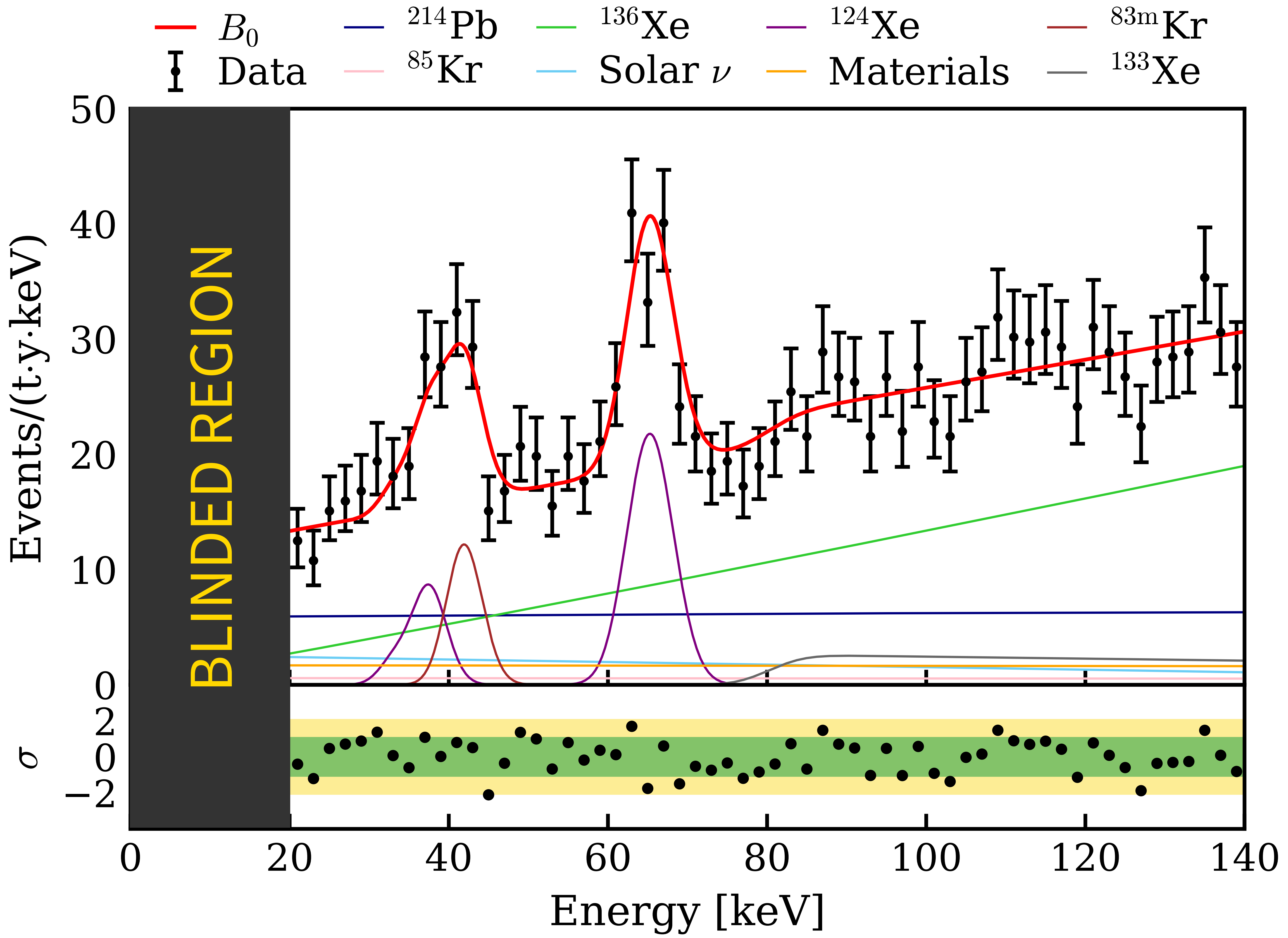
Two low-energy ER calibration sources to validate our procedures

- ^{37}Ar → 2.82 keV peak, **anchoring response model at low energy** with high statistic
- ^{212}Pb (from ^{220}Rn) → flat β spectrum, **estimating acceptance and validating threshold**

Low-Energy ER Background

PRL 129 (2022) 161805

- **Blind analysis** (energy region < 20 keV)
- Initial background estimates mainly based on **external measurements**



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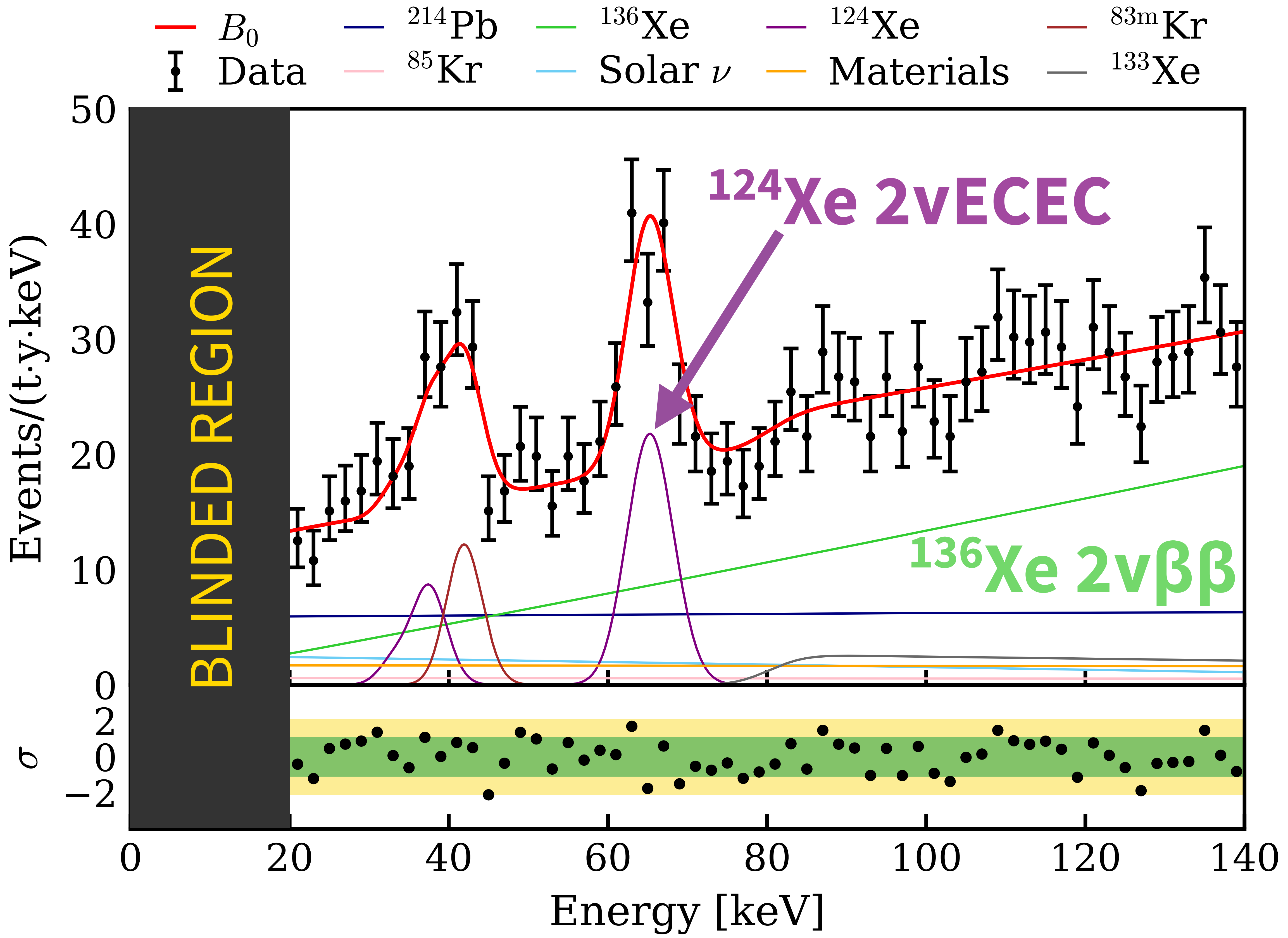
- Background starts to be **dominated by rare double-weak processes** (^{124}Xe 2νECEC, ^{136}Xe 2νββ)



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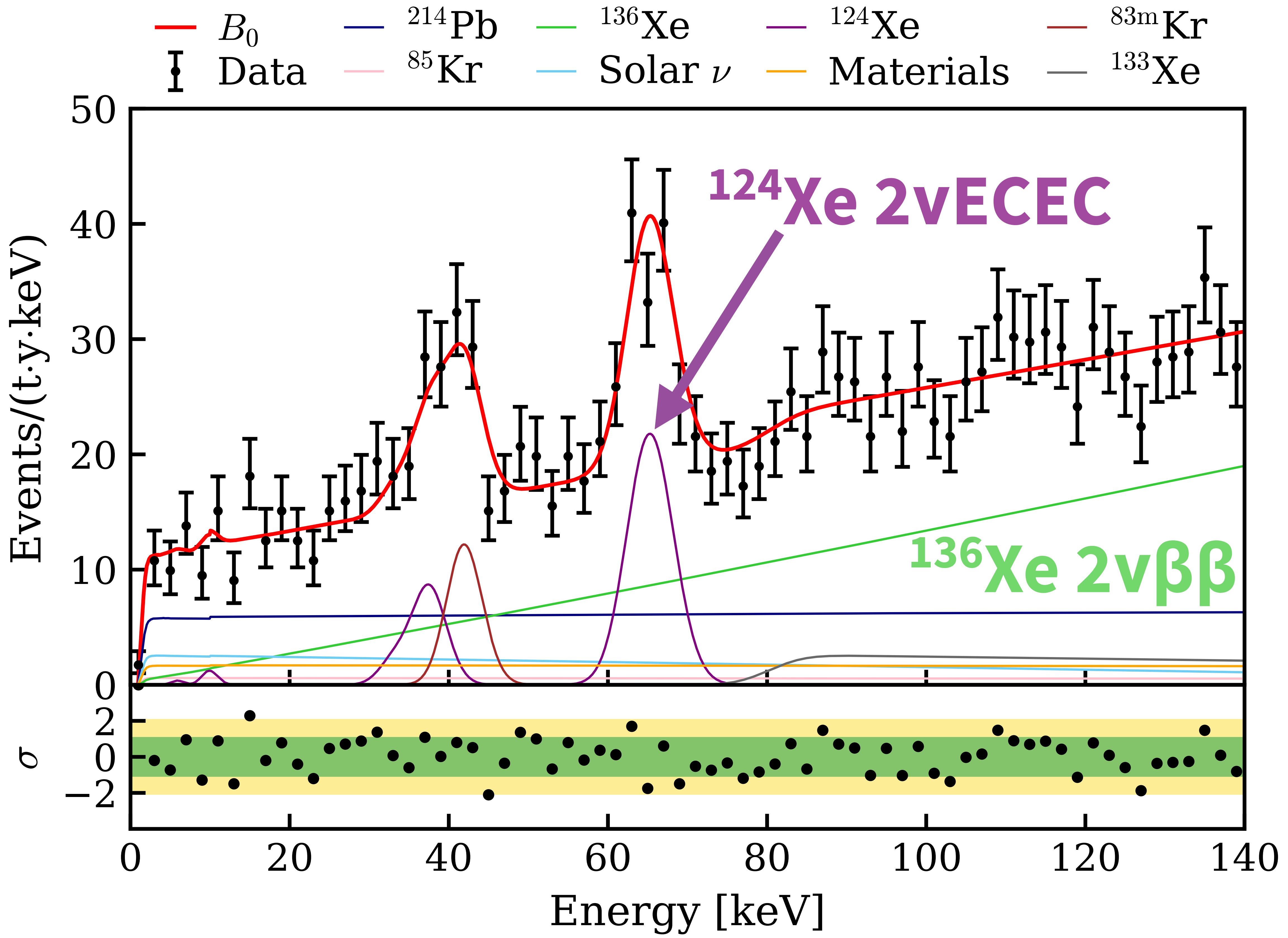
- **Excellent data-model agreement** over the whole energy range, even at low energy



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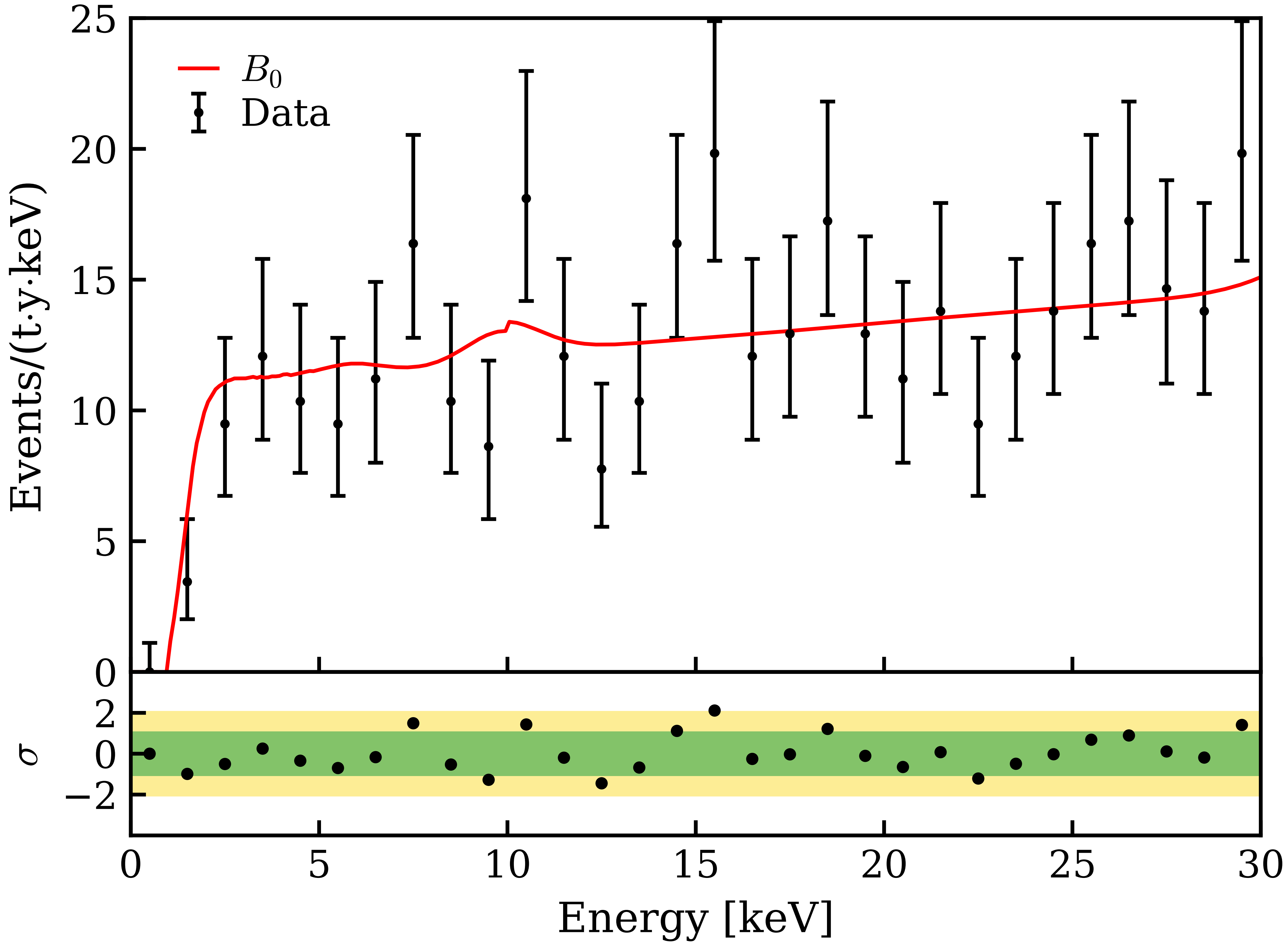
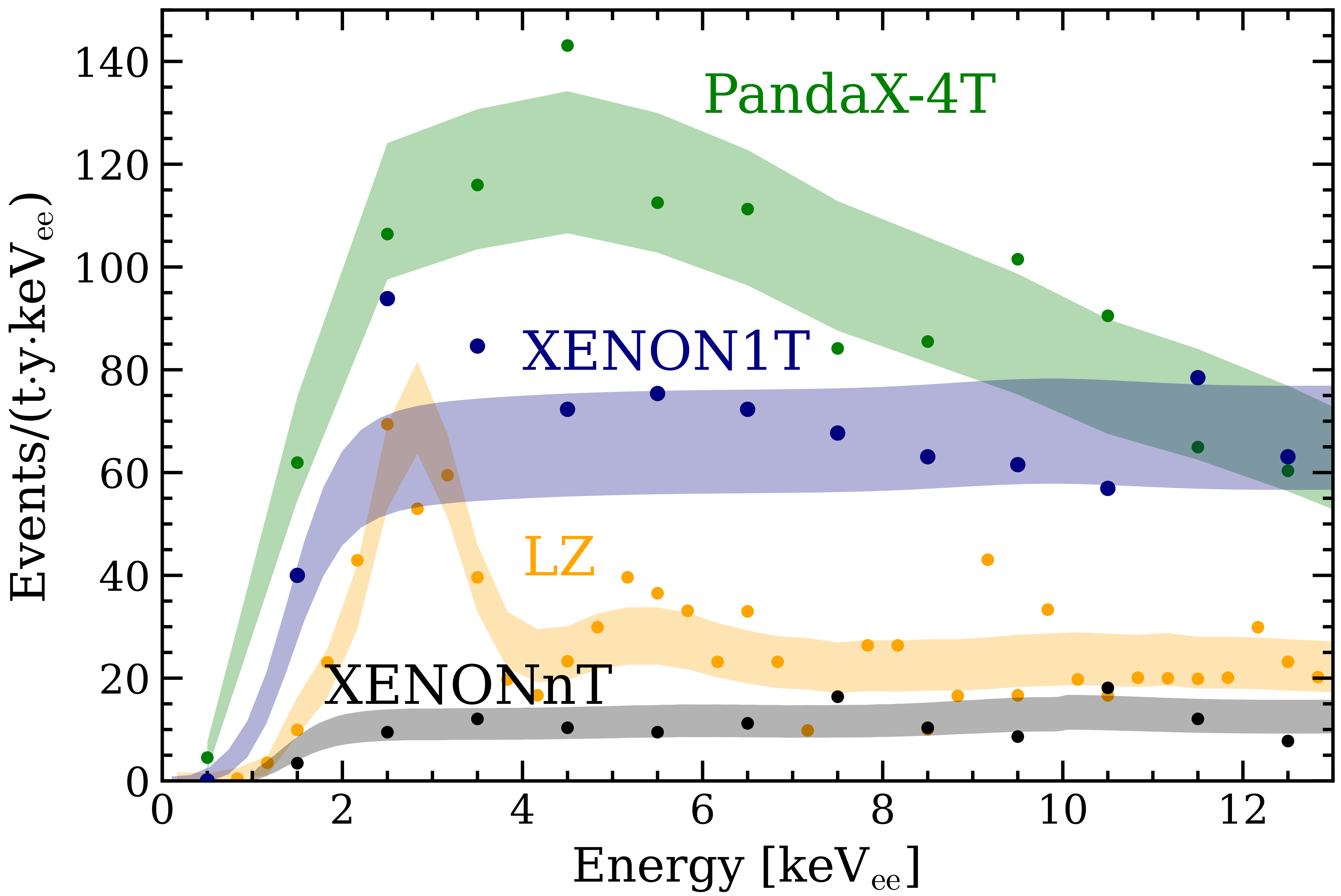


No excess observed

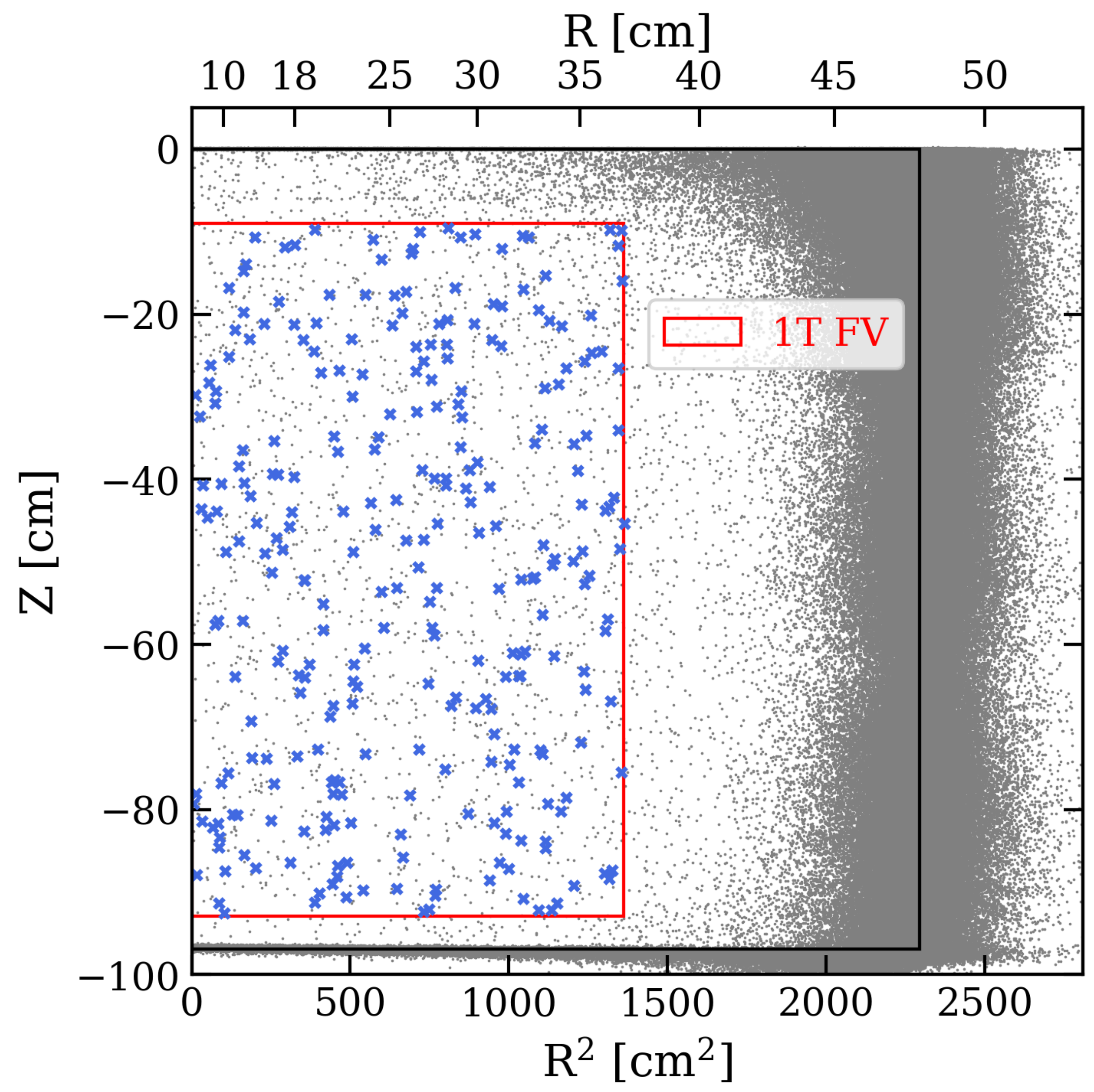
ER Background—XENONnT vs Others

PRL 129 (2022) 161805

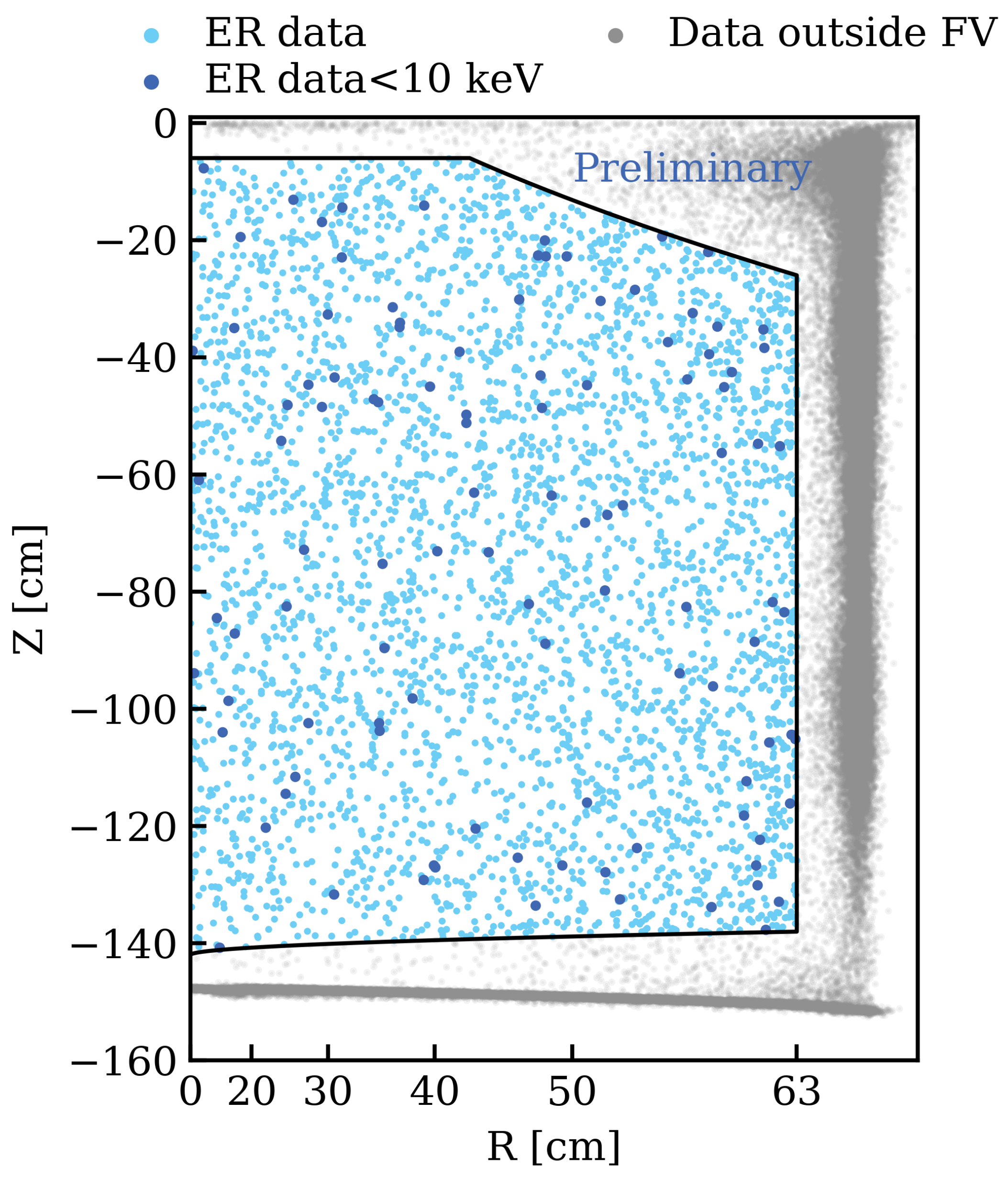
- **Outstanding 5× reduction** compared to XENON1T → (16.1 ± 1.3) events/(t × yr × keV)
- **XENON1T-like excess excluded at 8.6σ** → XENON1T excess likely caused by a small tritium contamination (further investigations underway), **not by BSM physics**



XENON1T (1.04 t fiducial volume)



XENONnT (4.37 t fiducial volume)



Searching for New Physics

PRL 129 (2022) 161805

No event excess ? Let's set new limits on some BSM models!

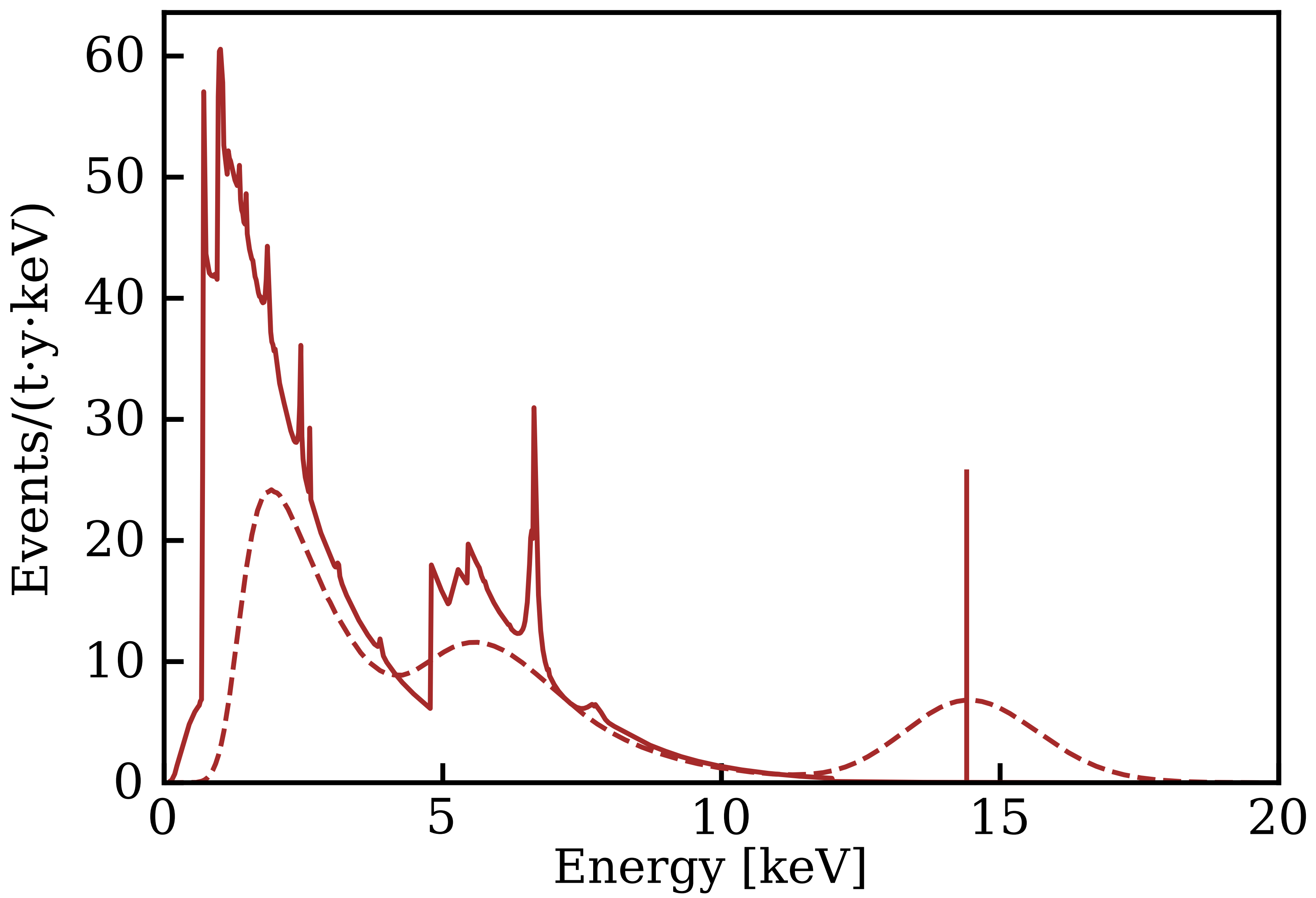
Searching for New Physics

PRL 129 (2022) 161805

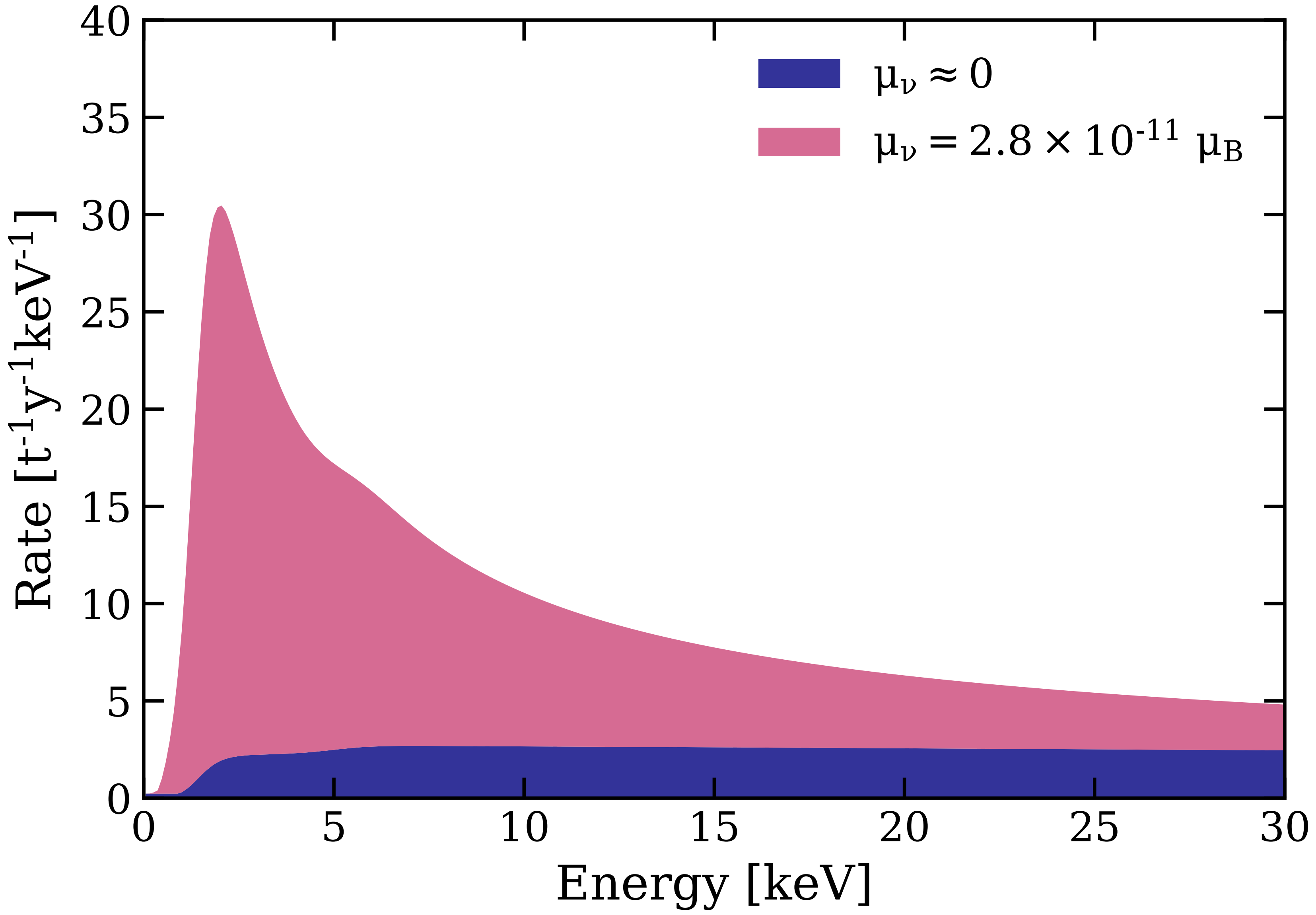
No event excess ? Let's set new limits on some BSM models!

- **Solar axions** (possible strong *CP* problem solution, would be produced in the Sun ~ keV)
- **Enhanced neutrino magnetic moment** (enhanced ν–e⁻ cross section at low energy)
- **Bosonic Dark Matter** (ALPs & dark photons, would produce monoenergetic peaks)

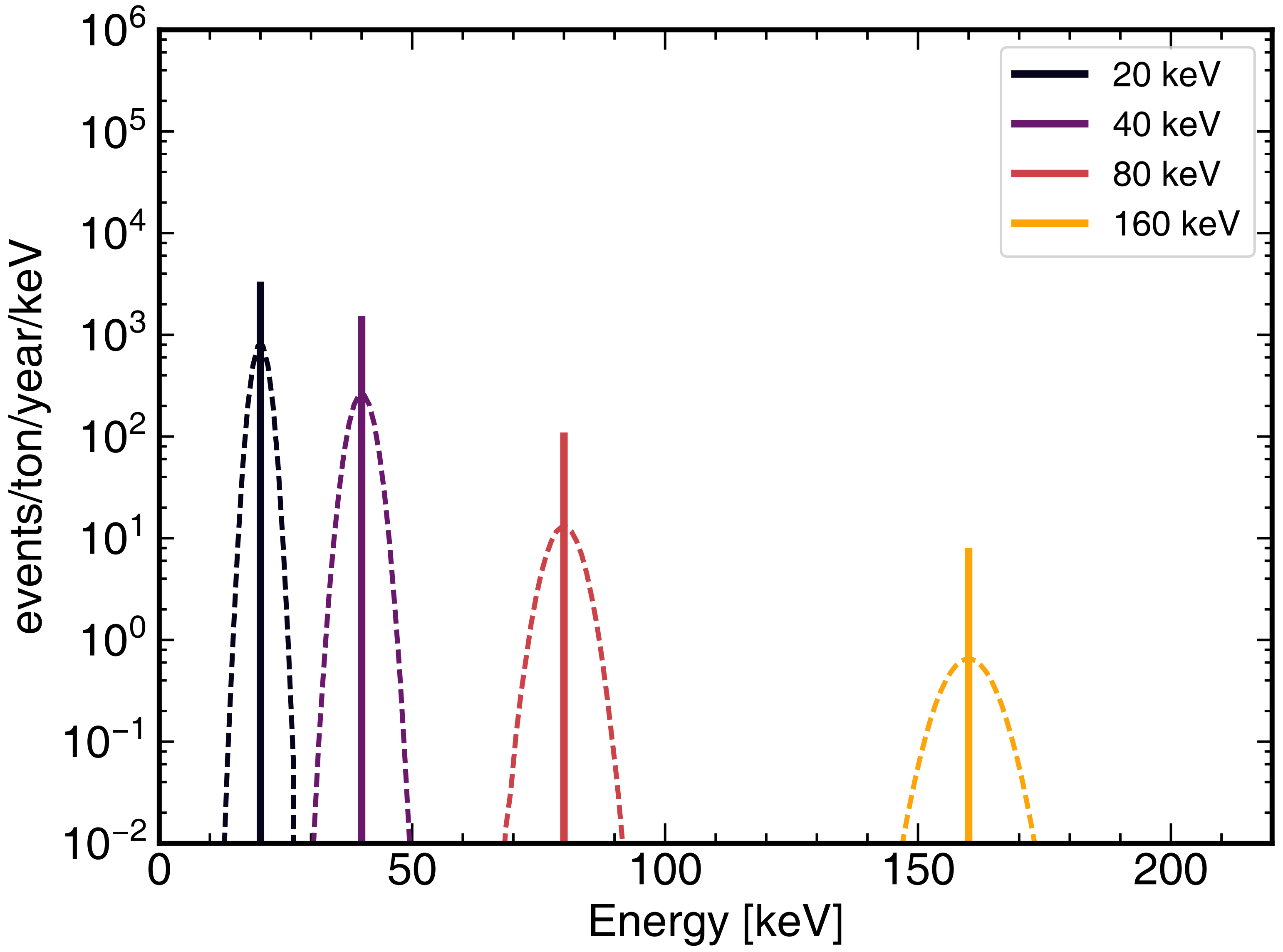
Solar axions



Enhanced μ_ν



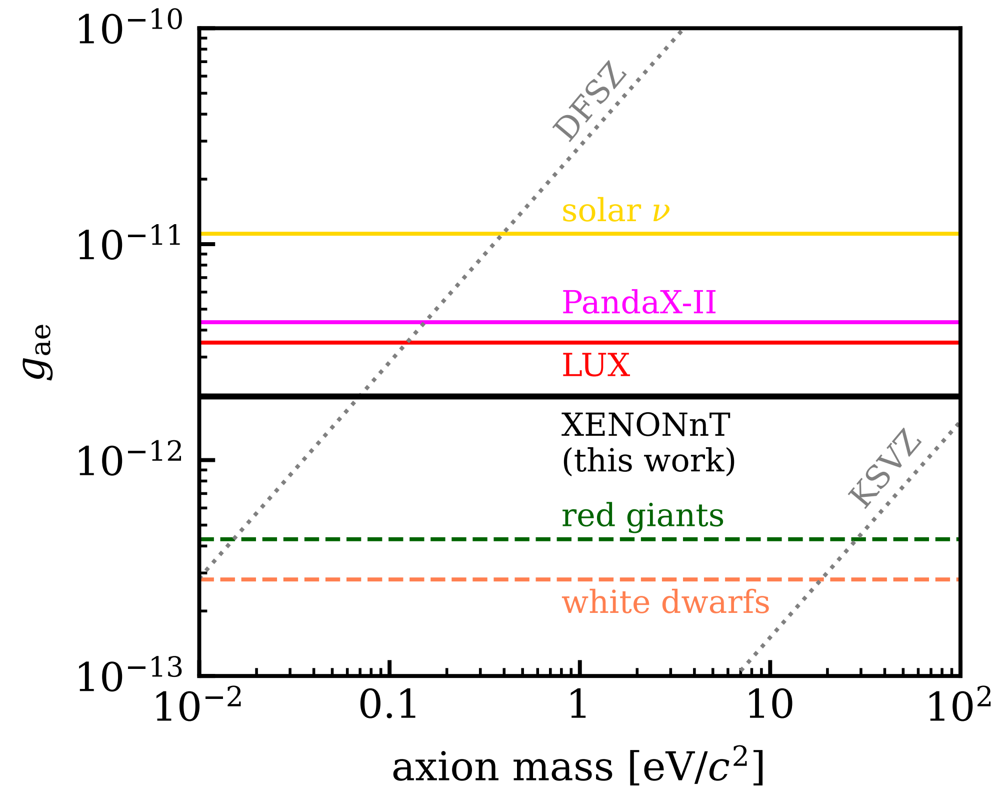
Bosonic Dark Matter

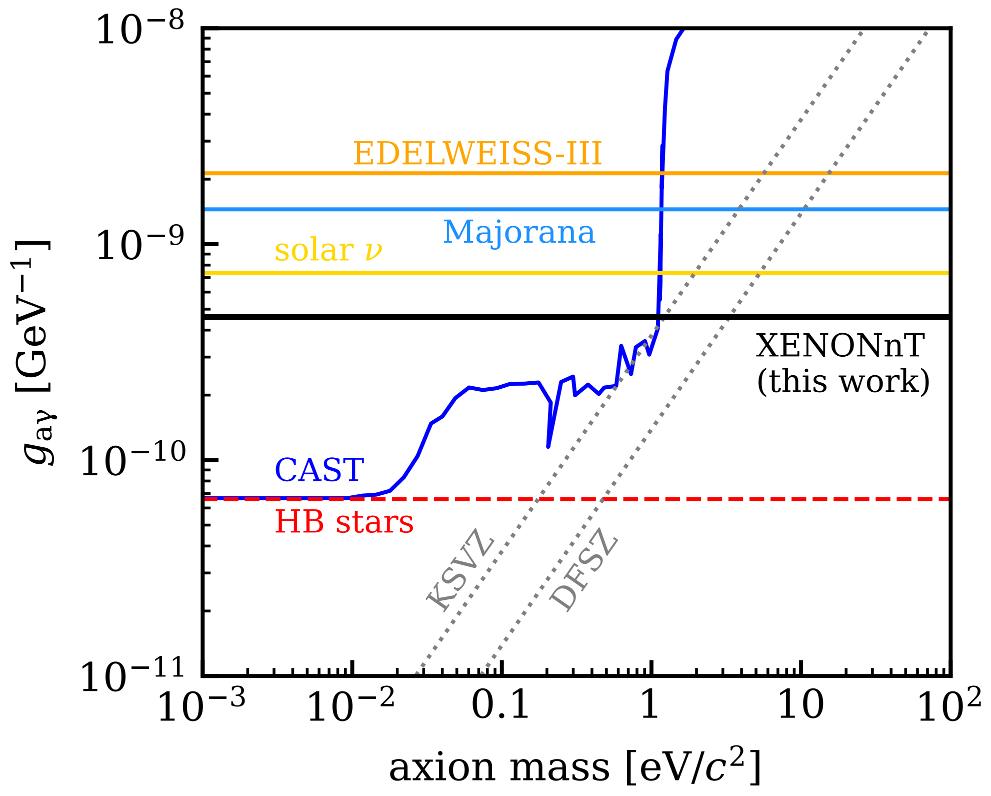


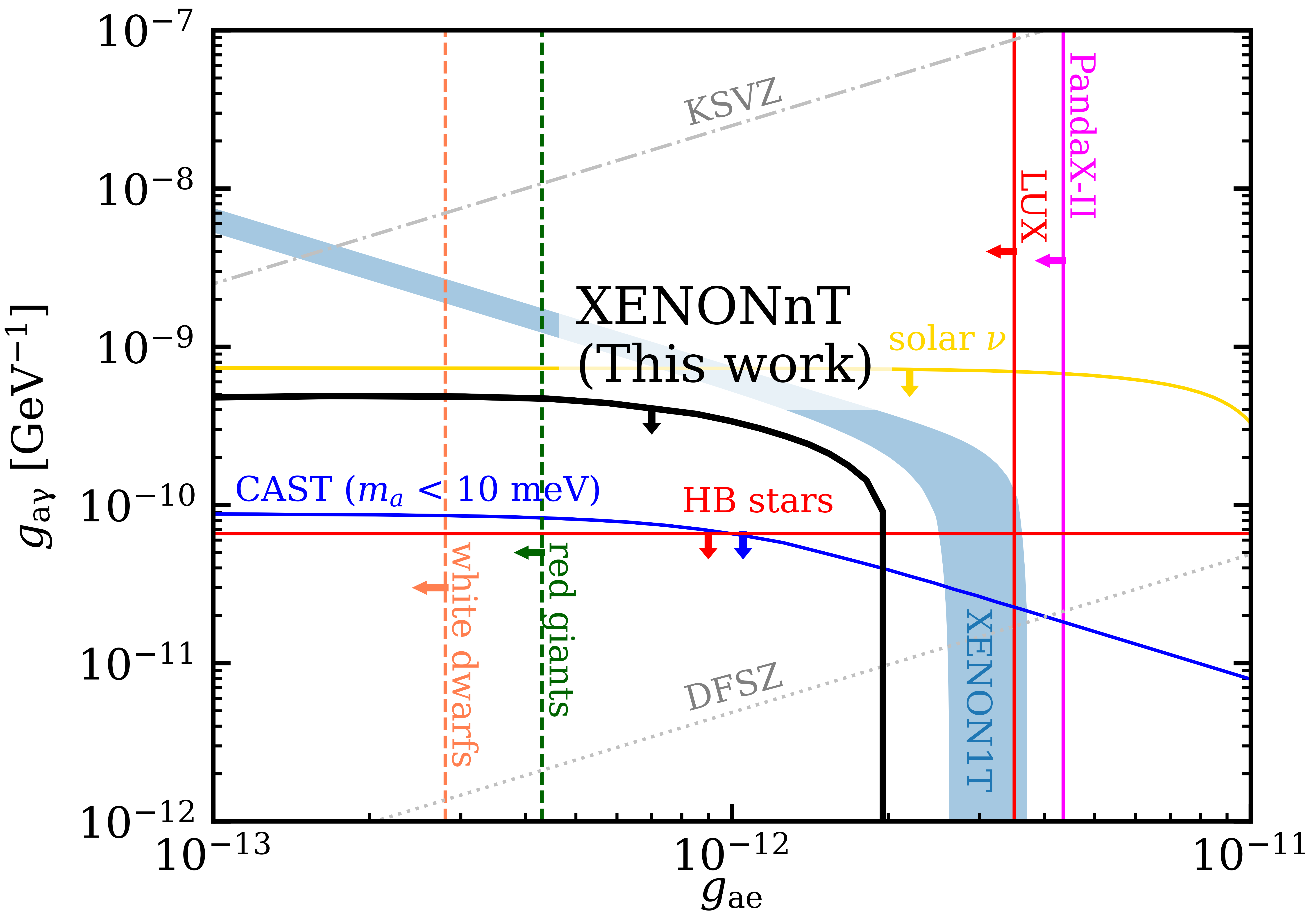
Results—Solar Axions

PRL 129 (2022) 161805

- Two potential detection channels
  a. **Axioelectric effect** (already in the XENON1T result)
  b. **Inverse Primakoff effect** (new in the XENONnT analysis)
- **Improved constraints** on axion-photon, axion-electron and axion-nucleon couplings





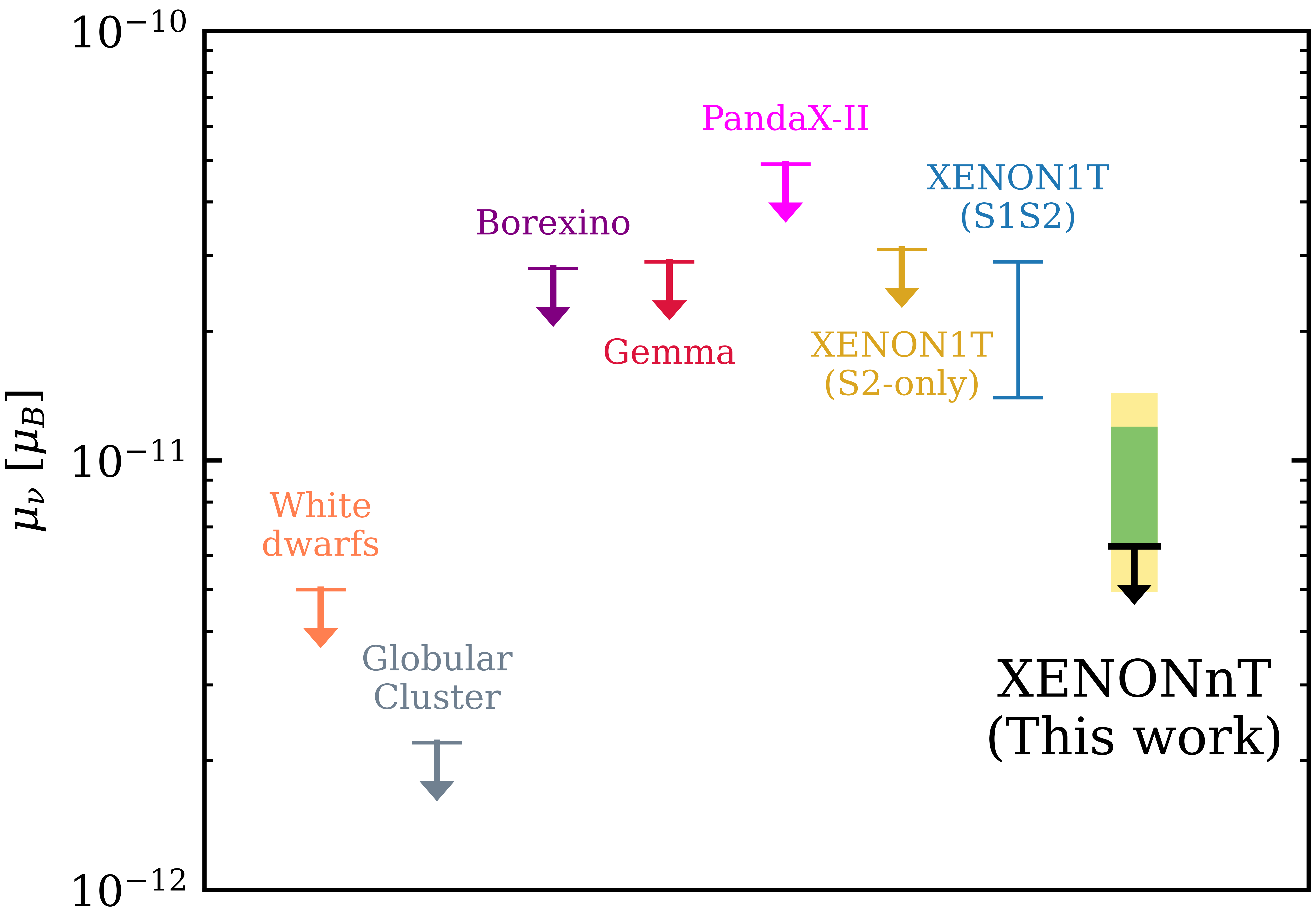


Results—Neutrino Magnetic Moment

PRL 129 (2022) 161805

- **Improved constraint** on the neutrino magnetic moment
  → $\mu_\nu < 6.3 \times 10^{-12}\, \mu_B$

The most stringent limit from any DM direct detection experiment so far!

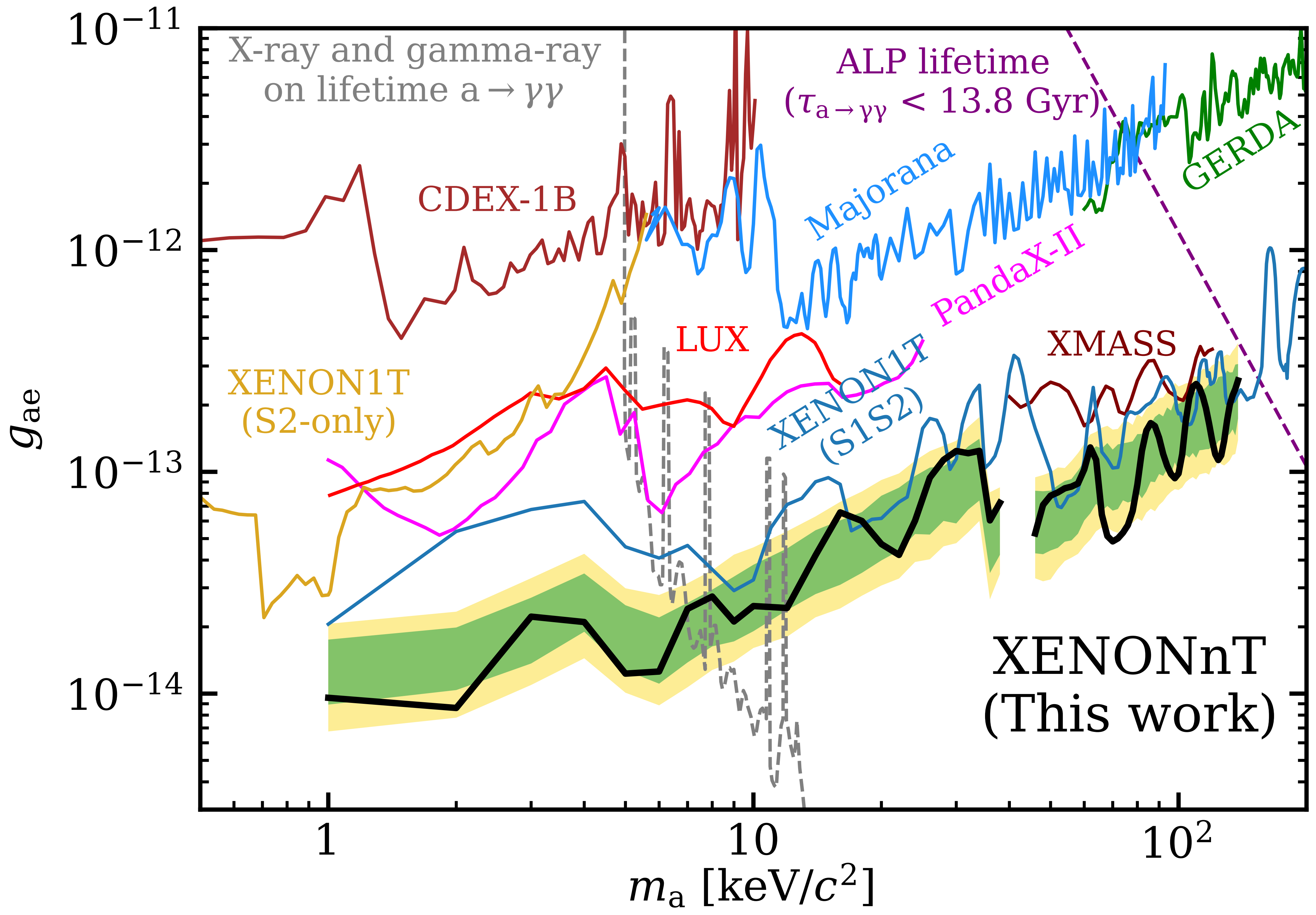


Results—Bosonic DM

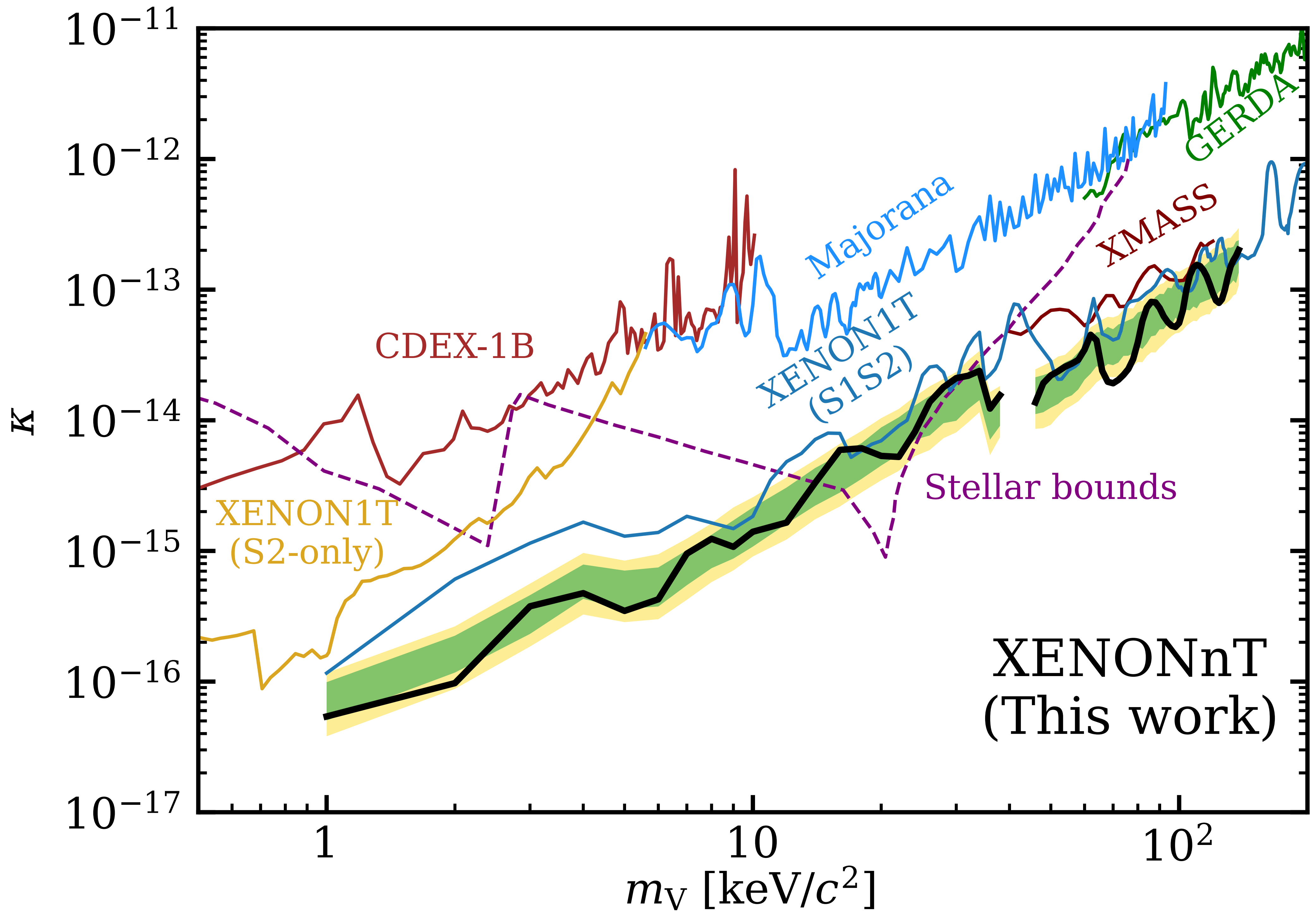
PRL 129 (2022) 161805

- **New stringent limits** over a large ALP and dark photon mass range (1–140 keV/c^2)
- No limit in 39–44 keV/c^2 due to the **unconstrained ^{83m}Kr background** trace amount

ALPs (Axion-Like Particles)



Dark photons



In Conclusion

@XENONexperiment

The XENONnT first science run (SR0) yielded its first results!

- **5× lower background than XENON1T**, very high xenon purity, great performance overall
- **No excess in low-energy ER data**, the XENON1T excess was not caused by BSM physics
- **New world-leading limits on the same models** (solar axions, neutrino μ_ν, bosonic DM)

In Conclusion

@XENONexperiment

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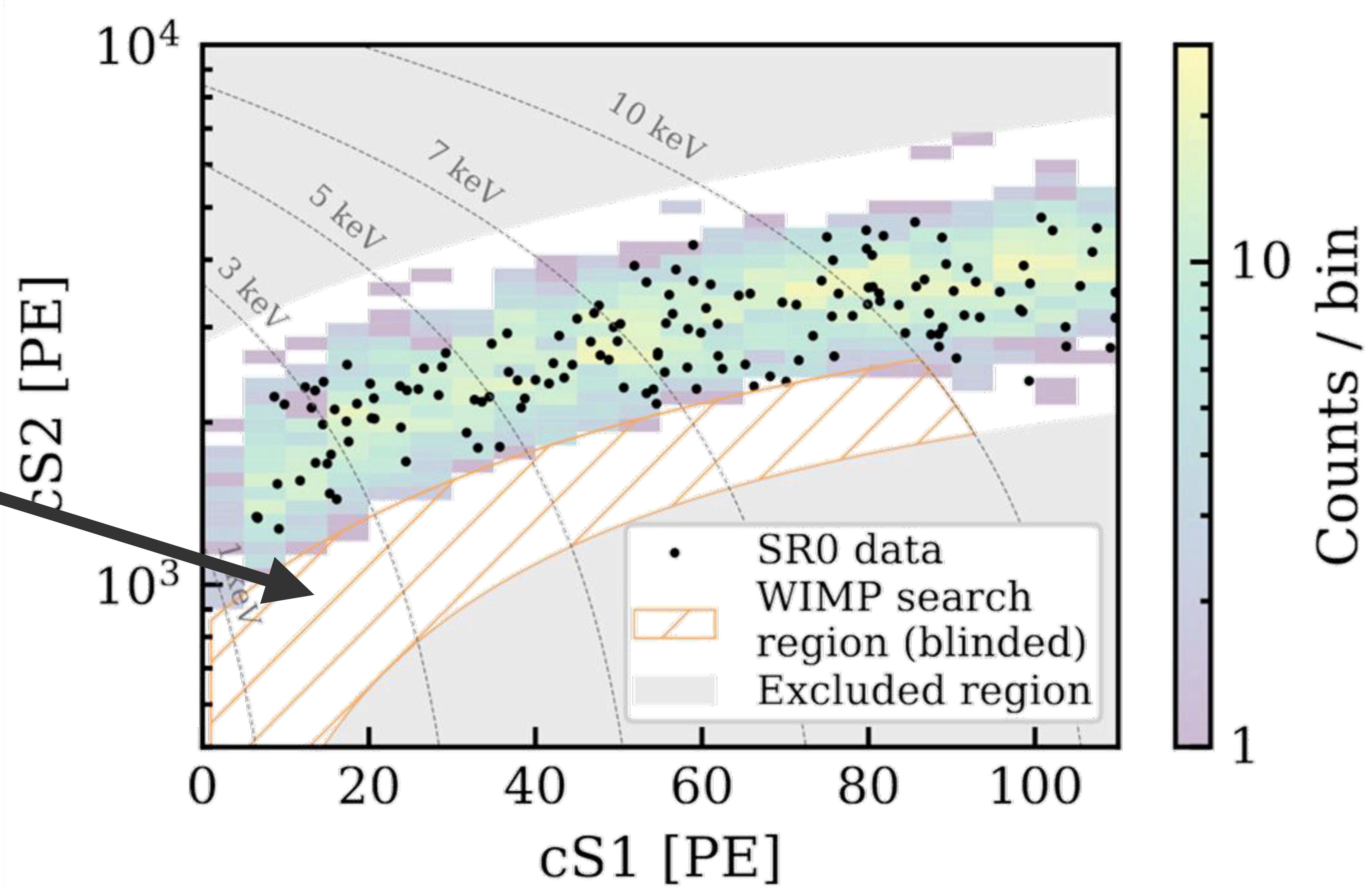
What's next?

- WIMP search analysis in progress → **Nuclear Recoil data soon to be unblinded**
- **Science Run 1 about to start** with twice as less radon and a better detector knowledge



What's Next Long Term?

World-leading DM direct search collaborations joining forces

Behold the XLZD Consortium!

@XLZDconsortium [arXiv:2203.02309] **Luca's talk, 16:30**

XENON	LUX-ZEPLIN	DARWIN
Currently operating with 8.5 tonnes of liquid Xenon at Gran Sasso in Italy	Currently operating with 10 tonnes of liquid Xenon at SURF in South Dakota	Leading many R&D projects designing a future 50 tonnes liquid Xenon detector

Merci de votre attention !

Dr. Erwann Masson

LPNHE — Paris, France

✉ erwann.masson@lpnhe.in2p3.fr

@DrErwannMasson

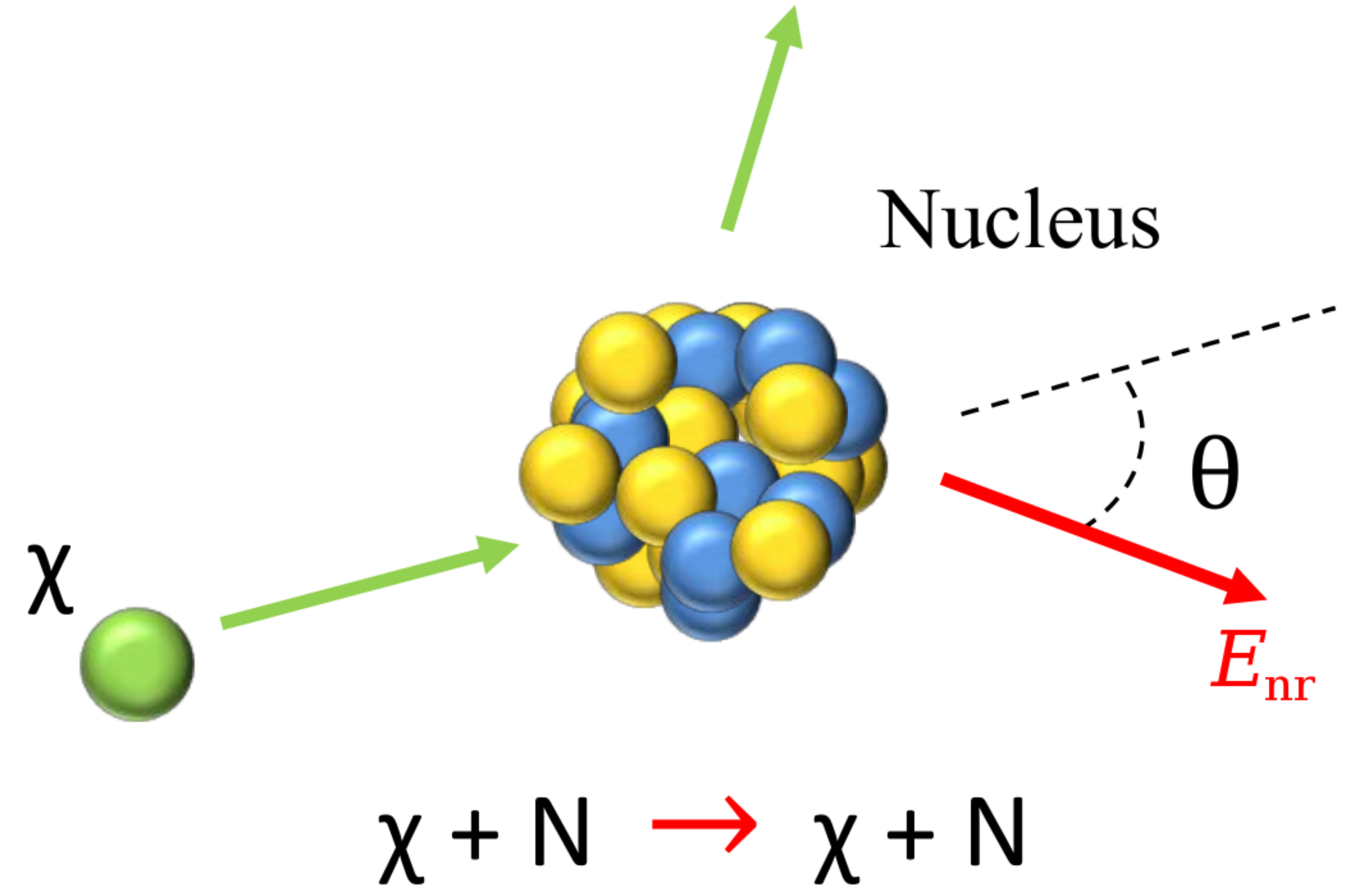
Additional slides

Dark Matter in a Nutshell

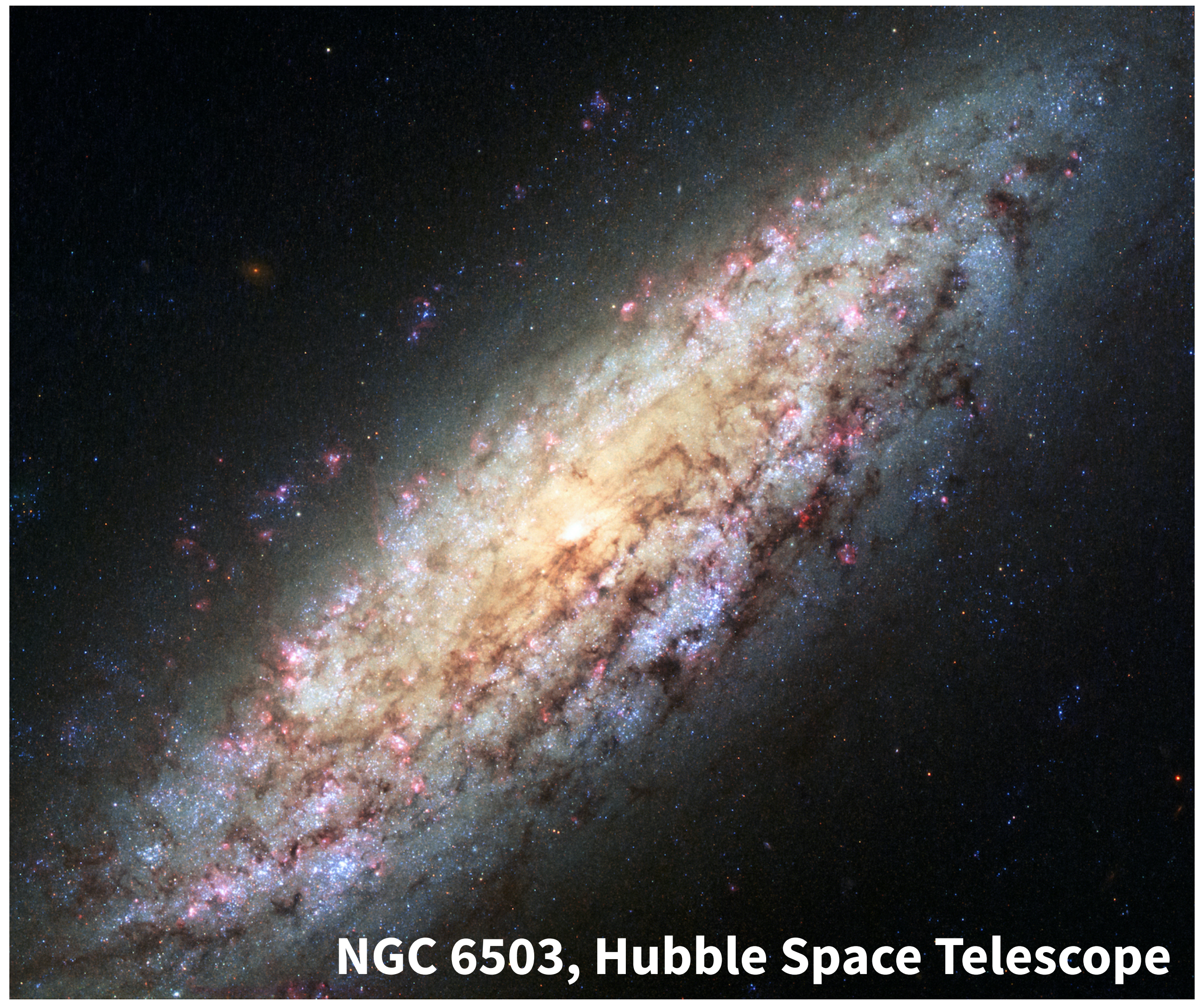
- A **non-luminous matter** is needed to explain what is observed in the Universe **at all scales**
- Standard cosmological model → **27%** of non-baryonic, non-relativistic, and almost non-interacting matter
- Most promising candidate in particle physics
  → **Weakly Interacting Massive Particles (WIMPs, χ)**

WIMP (expected) ID card

- High mass, $m_\chi \in$ GeV/c^2–TeV/c^2
- Low velocity, $v_0 \approx$ 220 km/s (locally)
- Very low interaction cross section, $\sigma_{int} \in 10^{-41}$–$10^{-48}$ cm^2
- Elastically scatters off atomic nuclei
  → Nuclear Recoils (NR) $\lesssim$ 100 keV

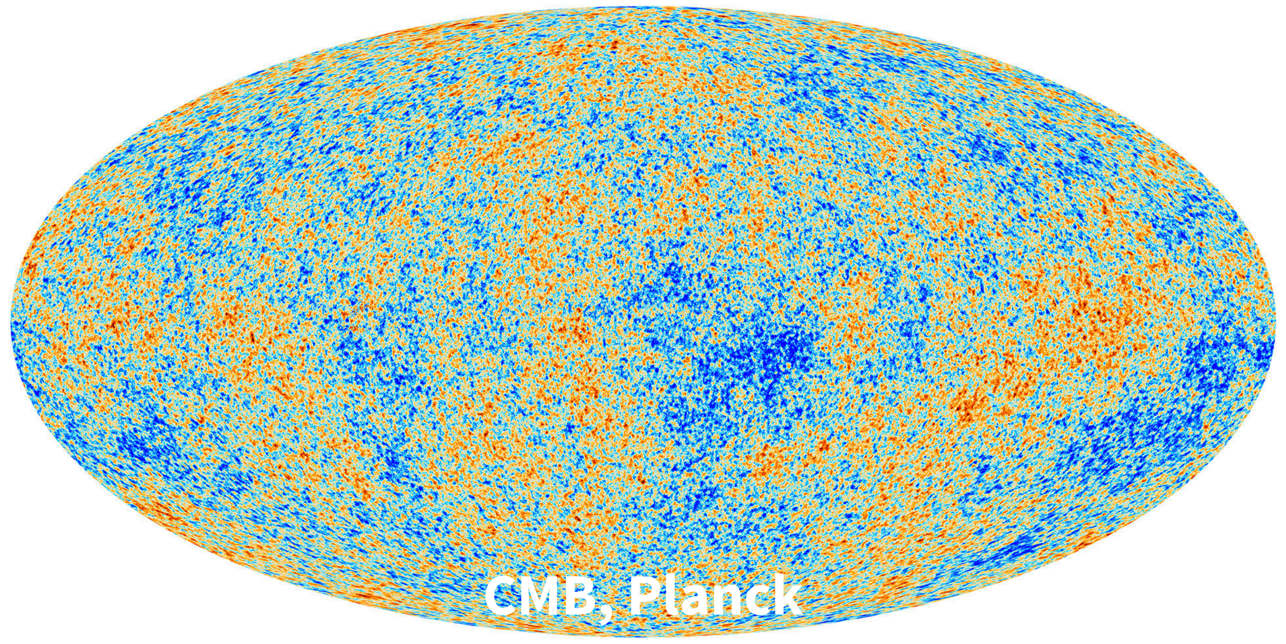


20–60 kpc



2–10 Mpc

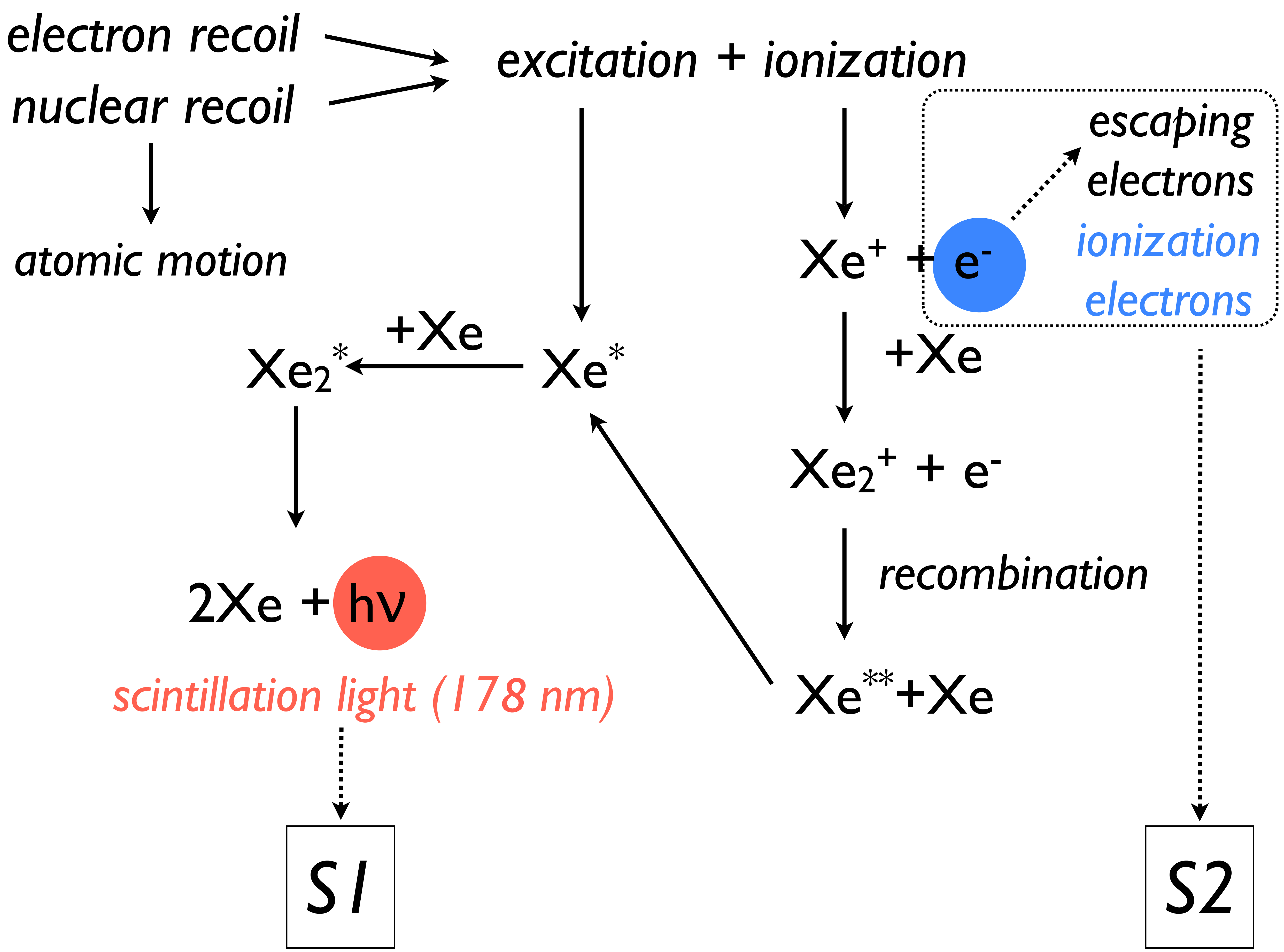
4 Gpc



Liquid Xenon as a Detection Medium

Liquid Xenon (LXe) ID card

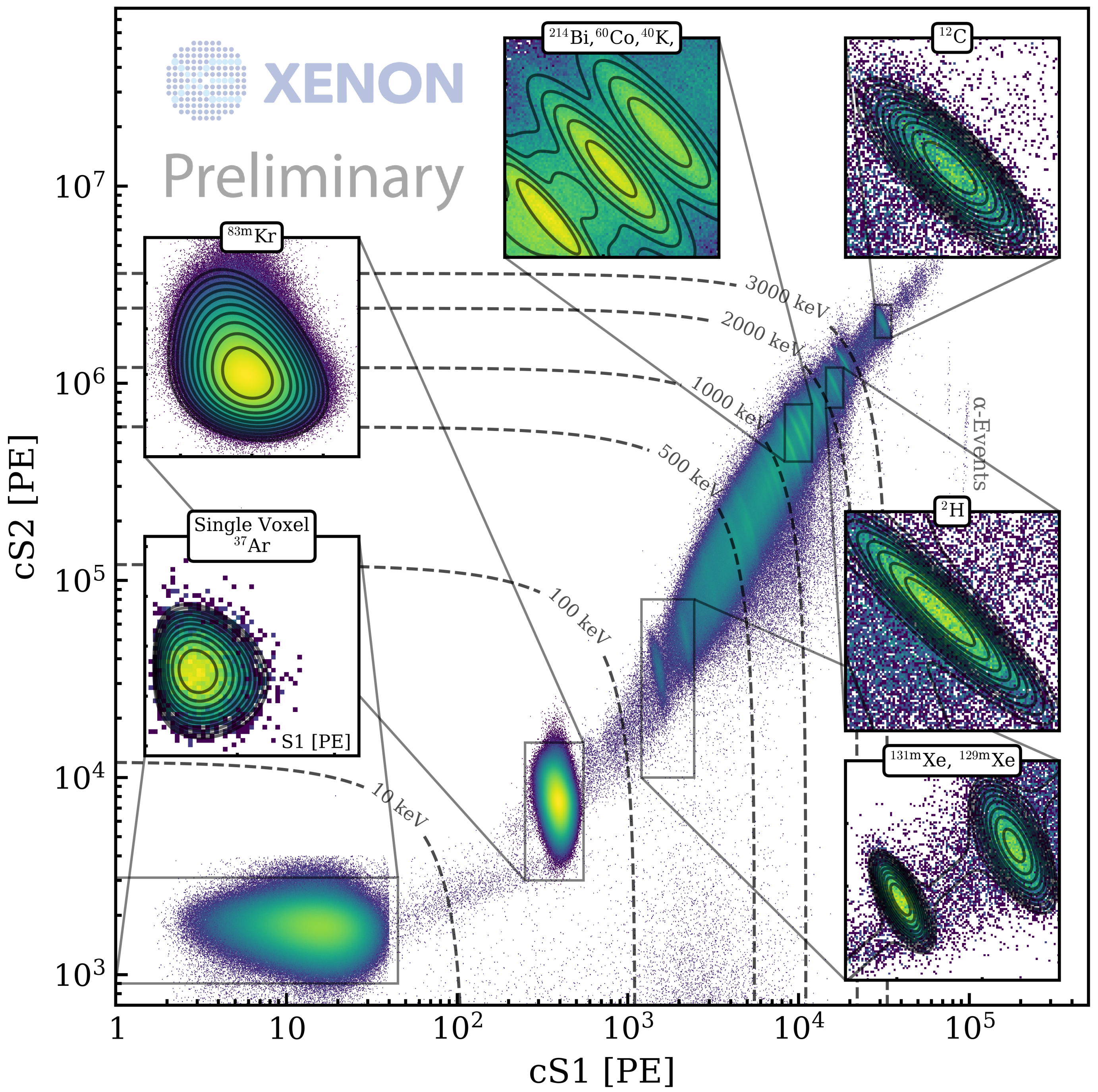
- High atomic number $Z = 54$
- High mass number, $\langle A \rangle = 131$
- High density at 177 K, $\langle \rho \rangle = 2.86\ \text{g/cm}^3$
- **No** long-lived radioisotopes in WIMP ROI
- Efficient **UV scintillator** (178 nm)



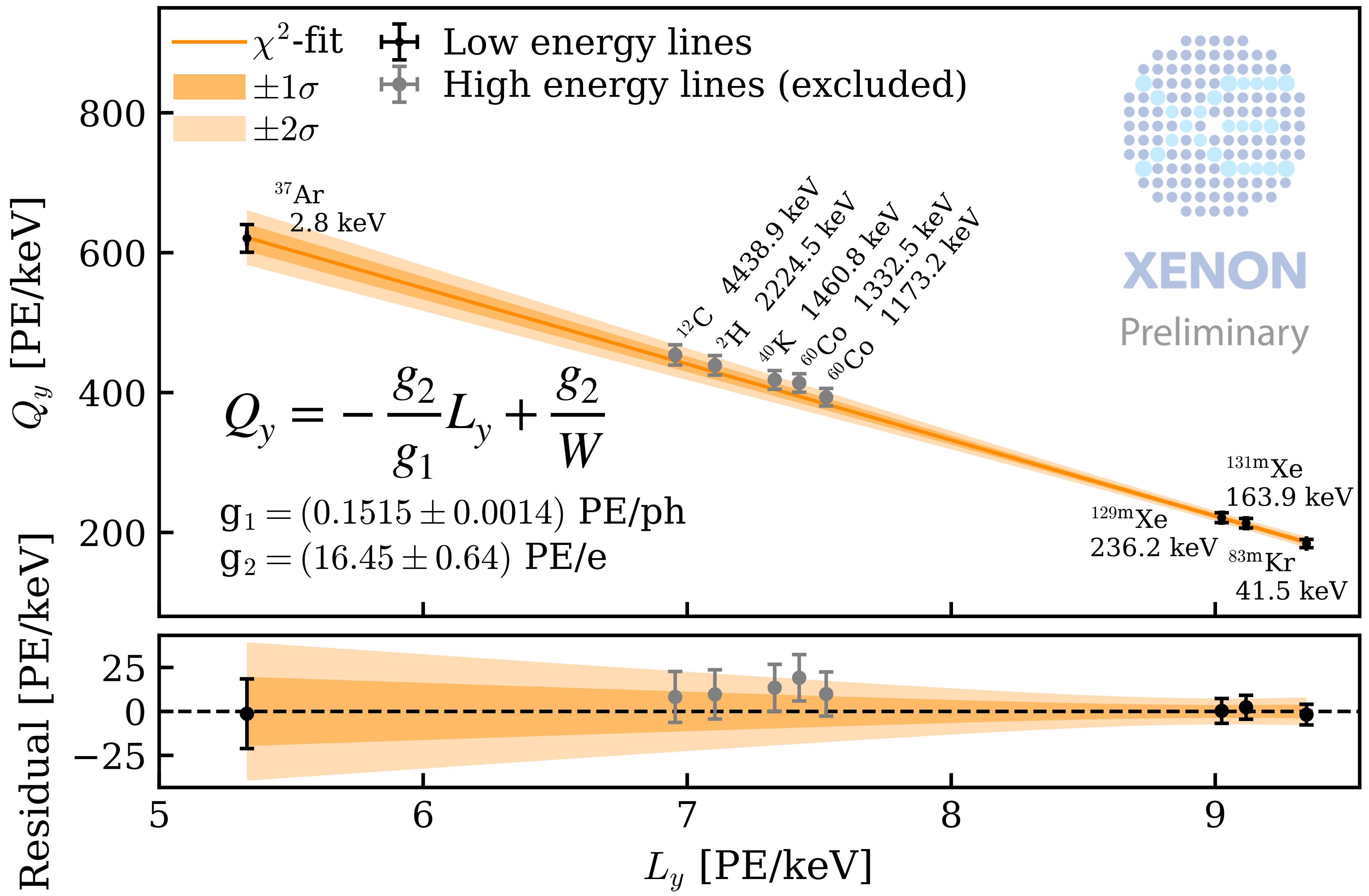
PRC 81 (2010) 025808

- **Maximised** interaction cross section ($\propto A^2$)
- High stopping power and **self-shielding**
- **Free** from harmful intrinsic background
- Powerful DM discrimination combining **scintillation and ionisation** properties
- **Scalable** → well suited to DM search and evolving projects like **XENON**

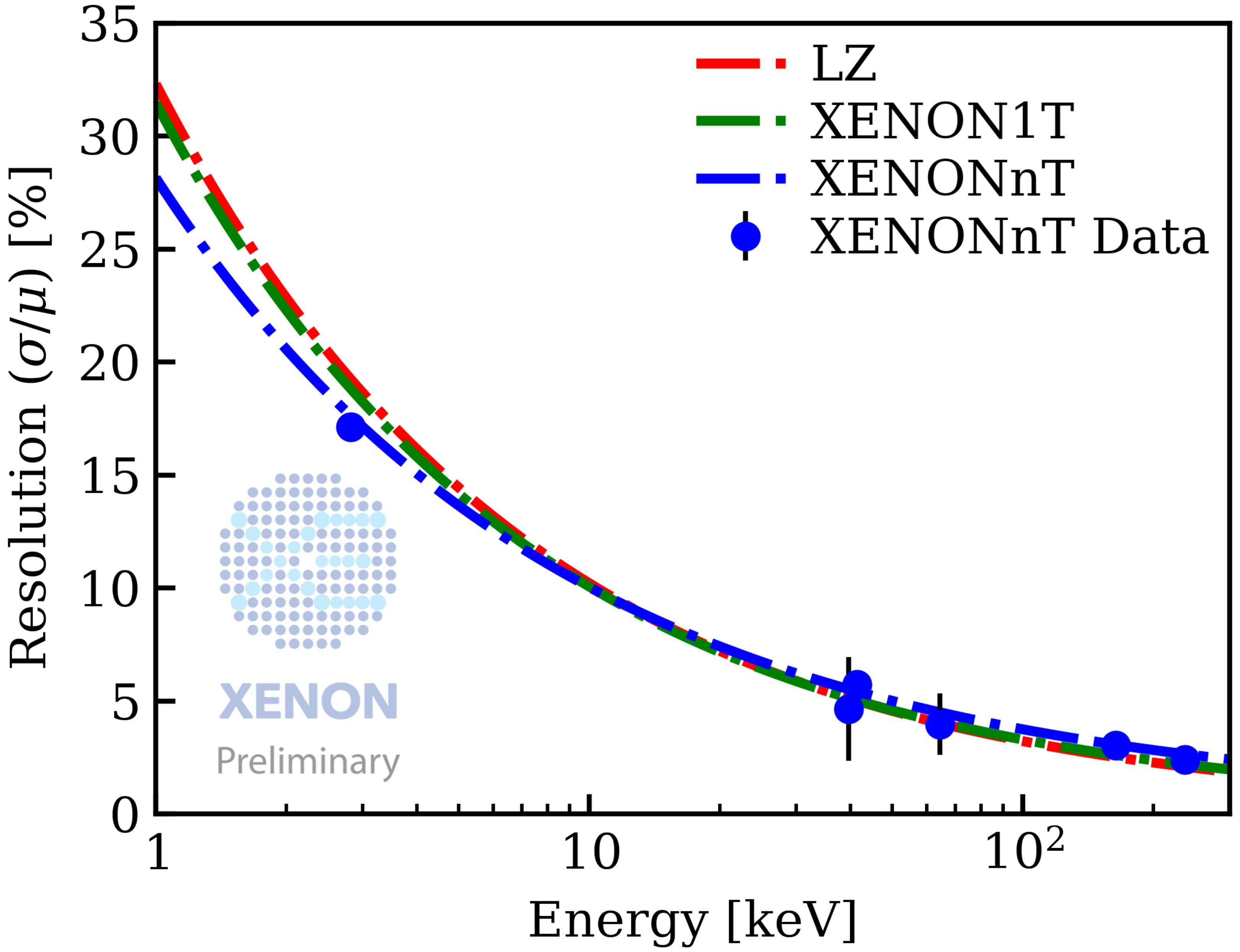
Reconstructing Energy

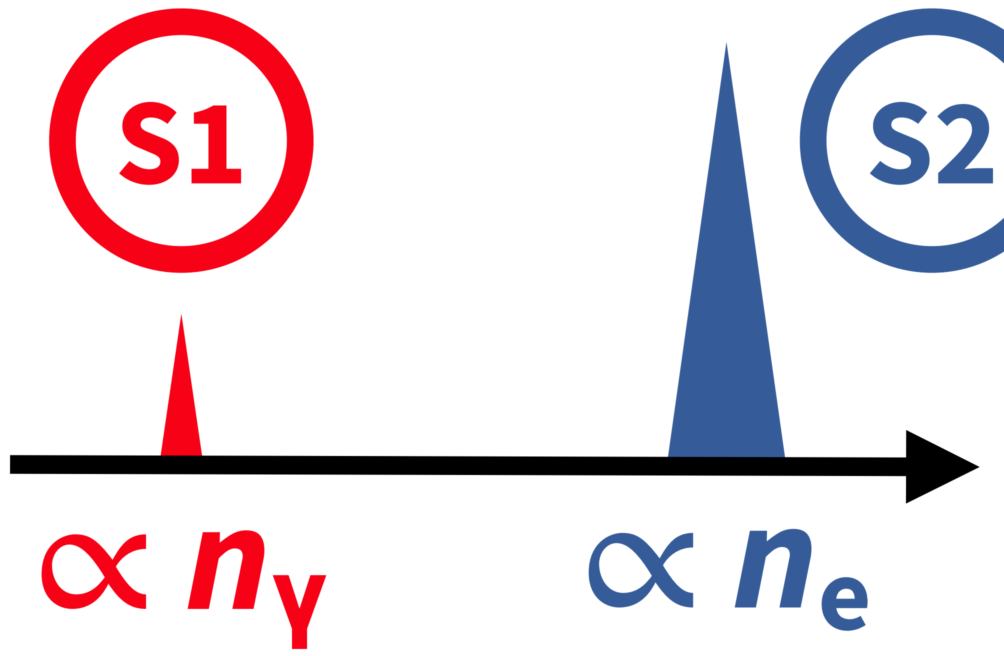


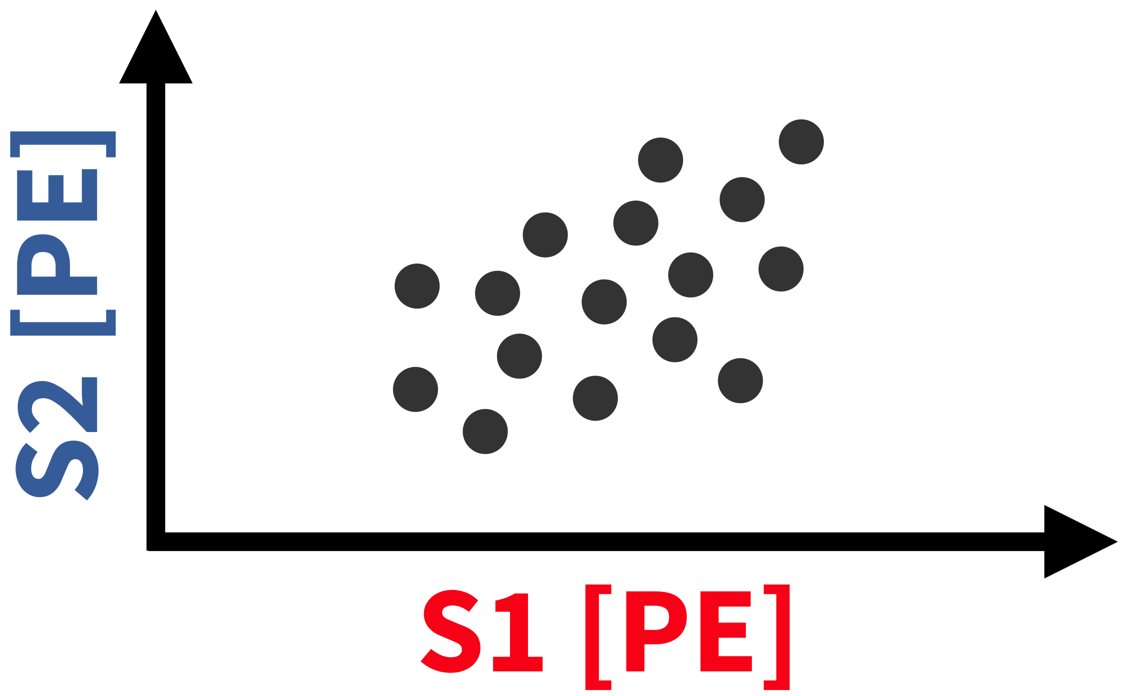
Low-energy focus (^{37}Ar, ^{83m}Kr, ^{131m}Xe, ^{129m}Xe)



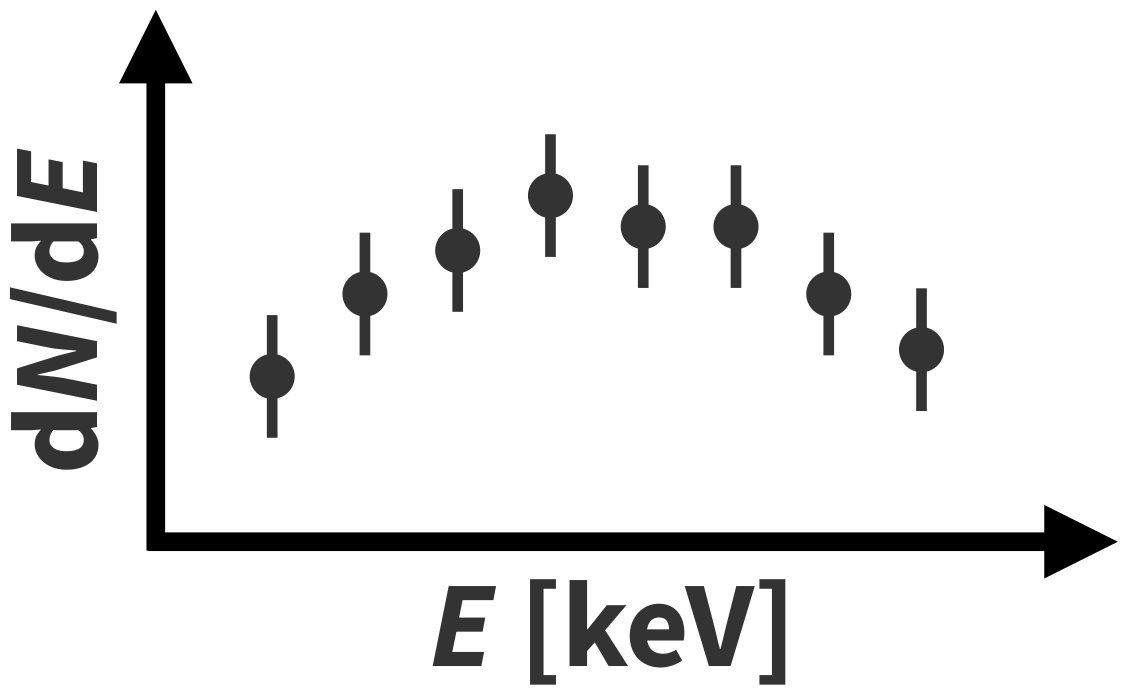
Optimised reconstruction **at low energy**



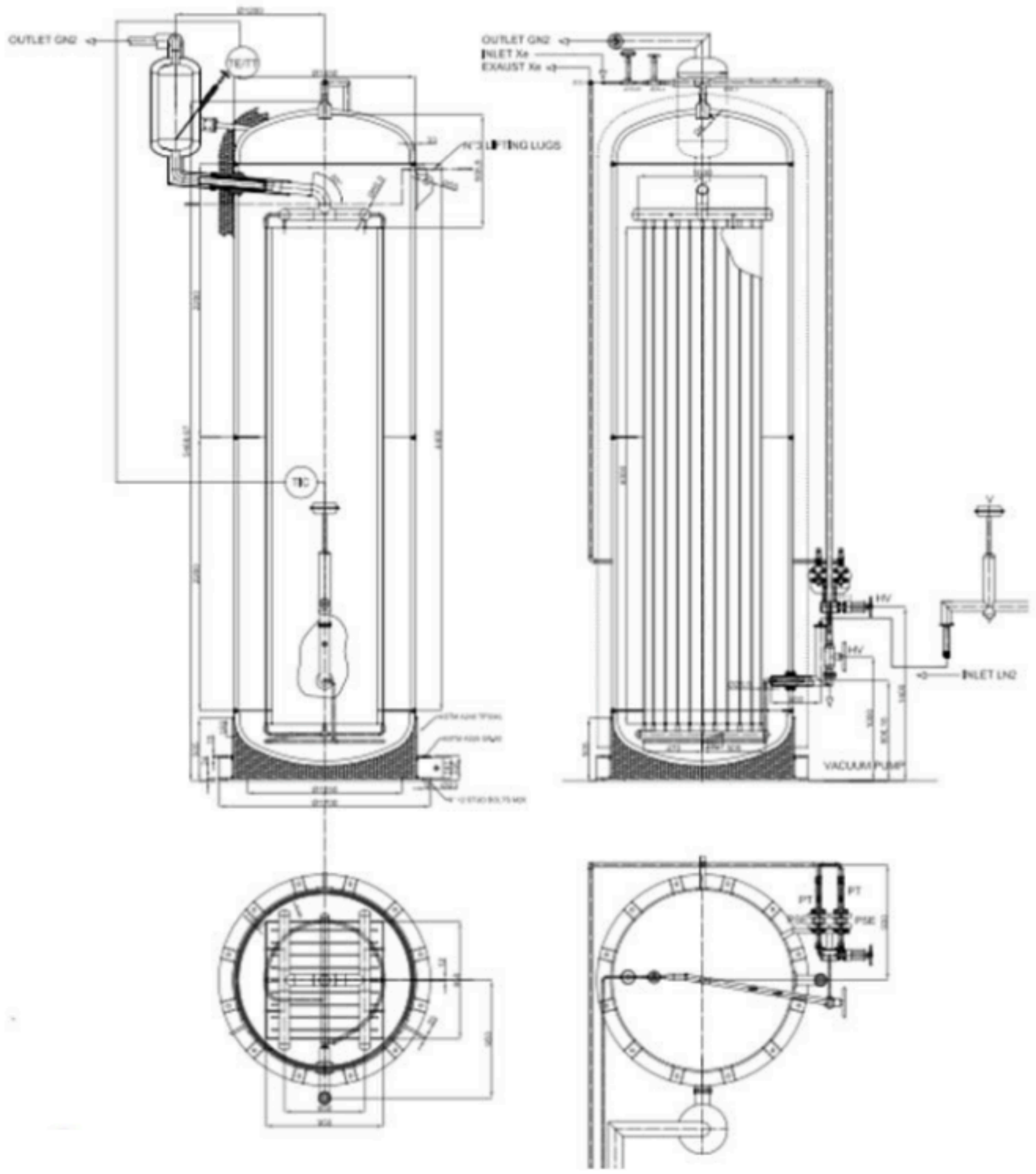


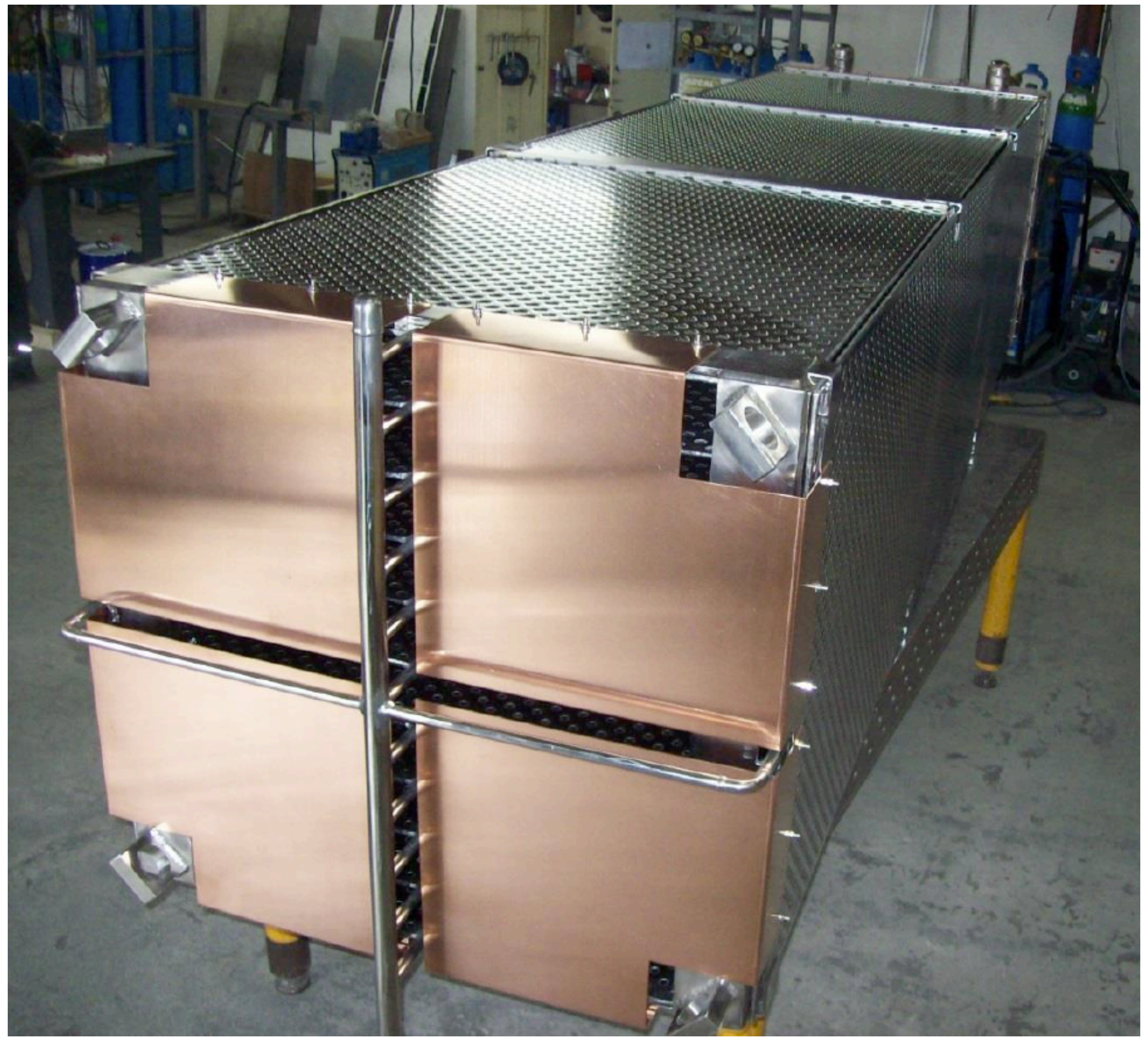


$$E = W\left(\frac{\mathrm{cS1}}{g_1} + \frac{\mathrm{cS2}}{g_2}\right)$$



Keeping 8 tonnes of LXe Safe (STORAGE)

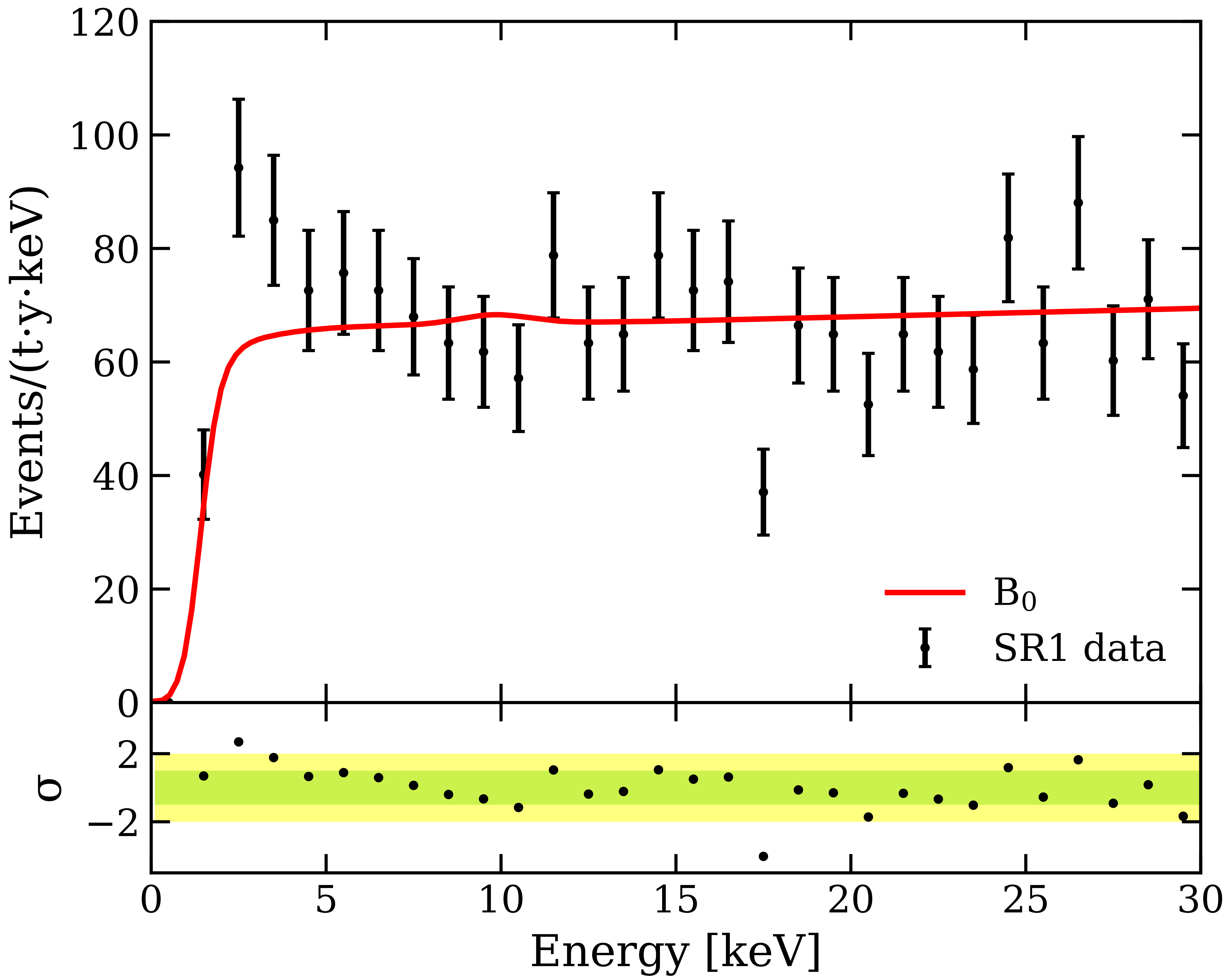




- ReStoX2 → **fast xenon recovery system** through xenon crystallisation (500 kg/h)
- ∼ 6 m high, **up to 10 t of xenon** cooled by liquid nitrogen (LN_2)
- Designed and funded by Subatech and LPNHE (+ LAL)
  → **100% French contribution**

The XENON1T Low-Energy ER Excess

PRD 102 (2020) 072004

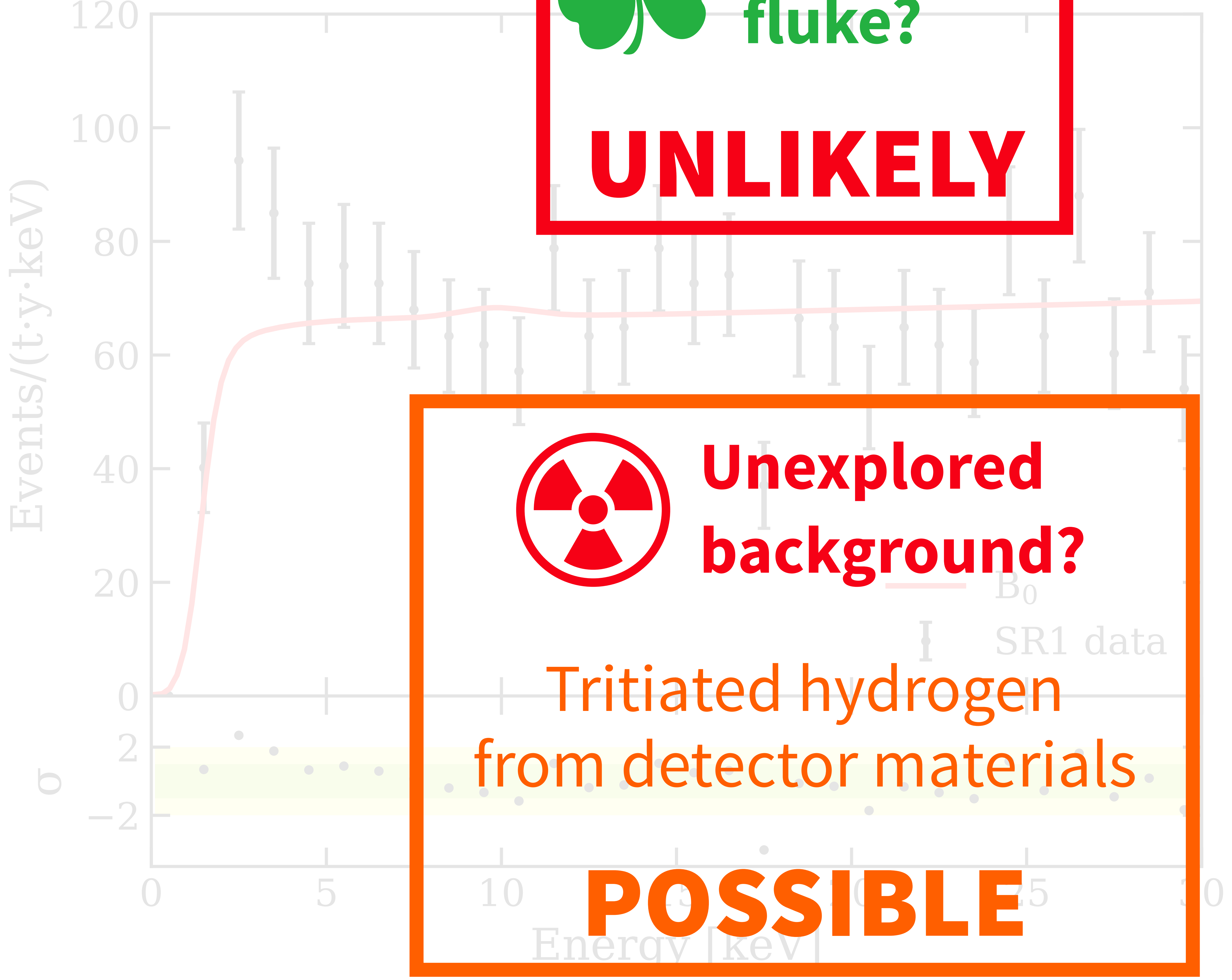


- Very good match between **electronic recoil data** and our comprehensive **background model** in 1–210 keV
- Lowest background rate ever achieved in 1–30 keV
  → **(76 ± 2) events/$(t \times yr \times keV)$**

Observed 285 events in 1–7 keV
Expected (232 ± 15) events
→ $\sim 3.3\sigma$ Poissonian fluctuation!

The XENON1T Low-Energy ER Excess

PRD 102 (2020) 072004



Statistical fluke?

UNLIKELY

Systematic effects?

UNLIKELY

Unexplored background?

Tritiated hydrogen from detector materials

POSSIBLE

New physics?

Solar axions

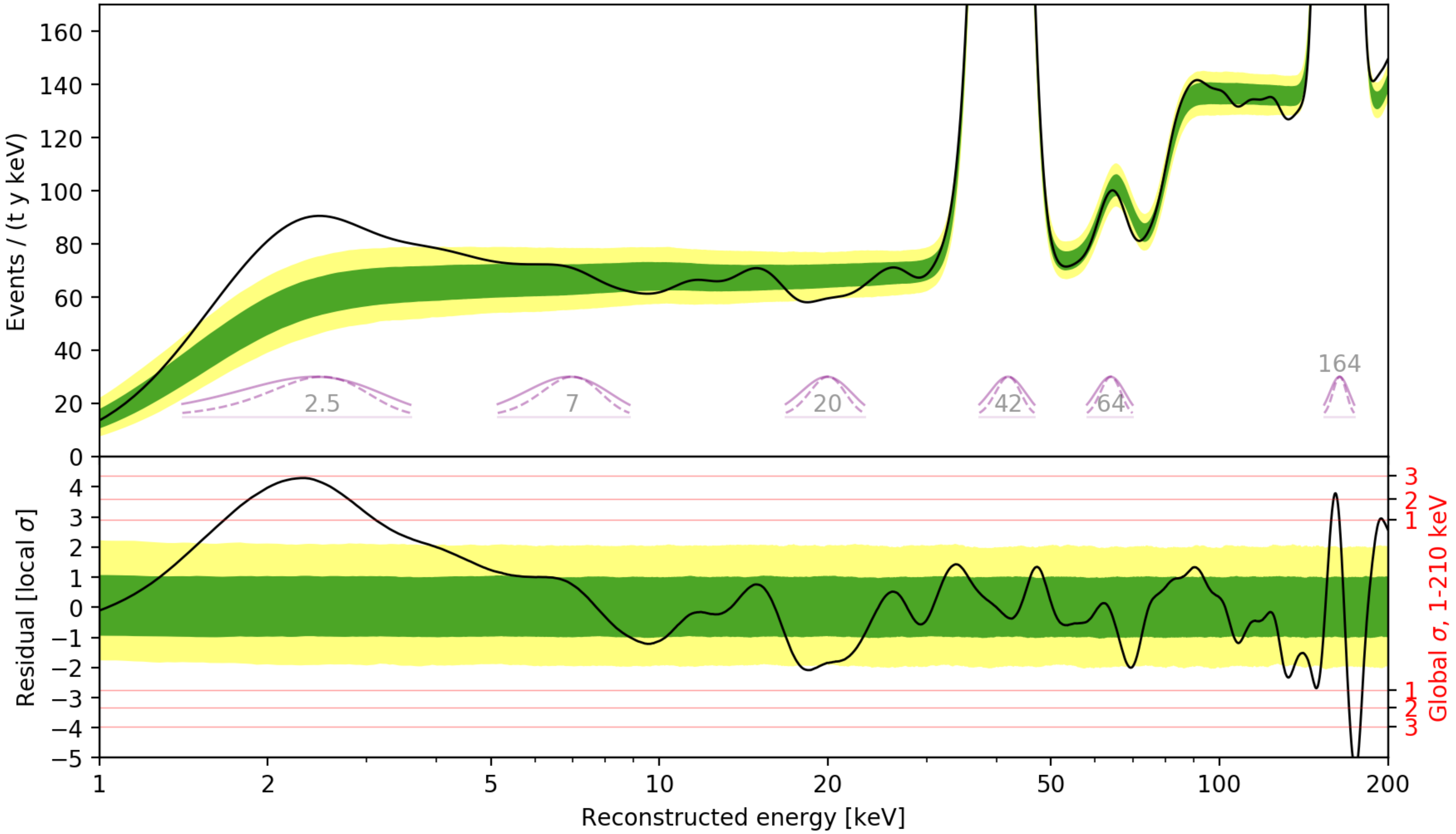
ν magnetic moment

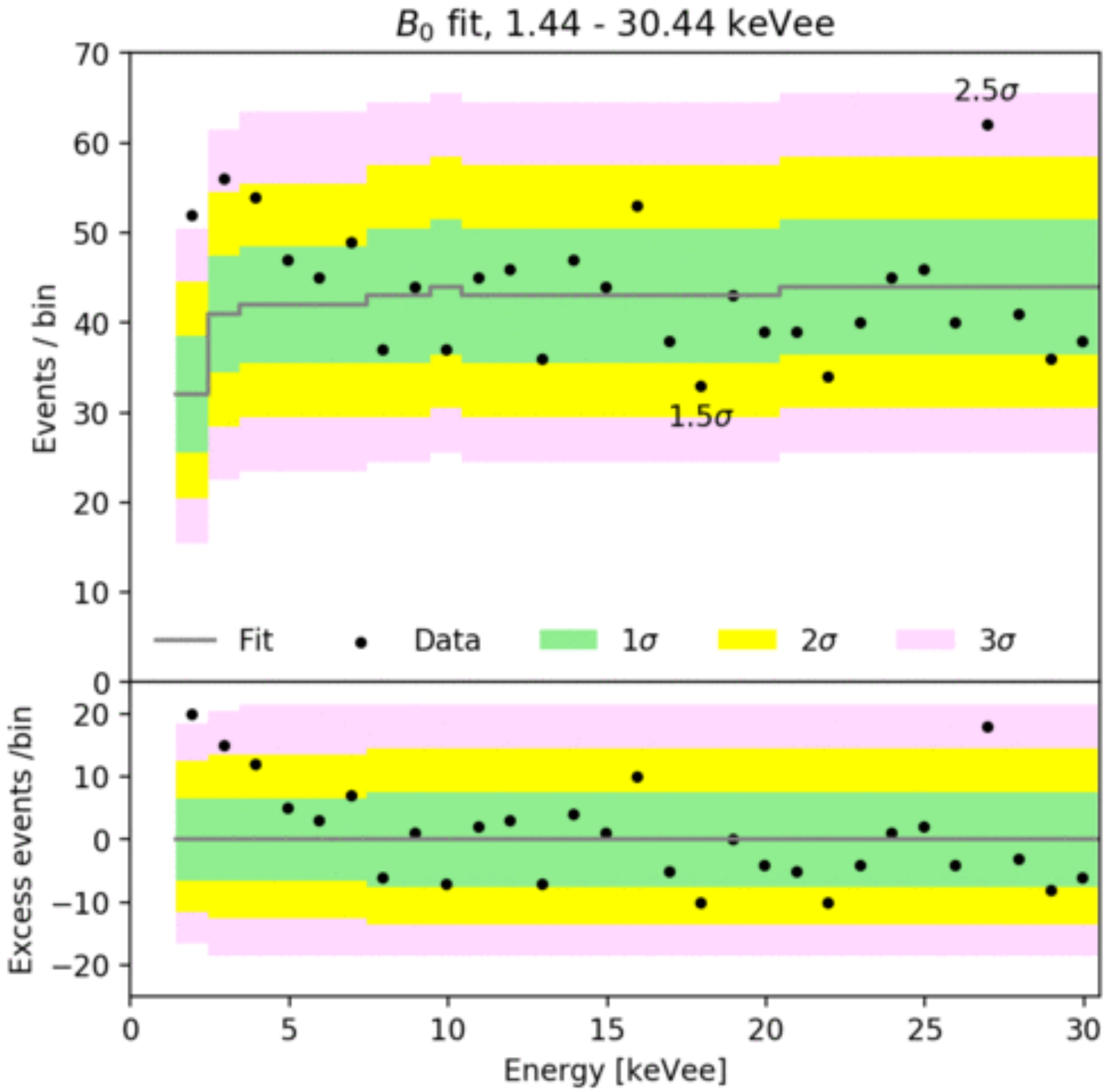
Bosonic DM

POSSIBLE

Statistical Fluke? ☘

PRD 102 (2020) 072004

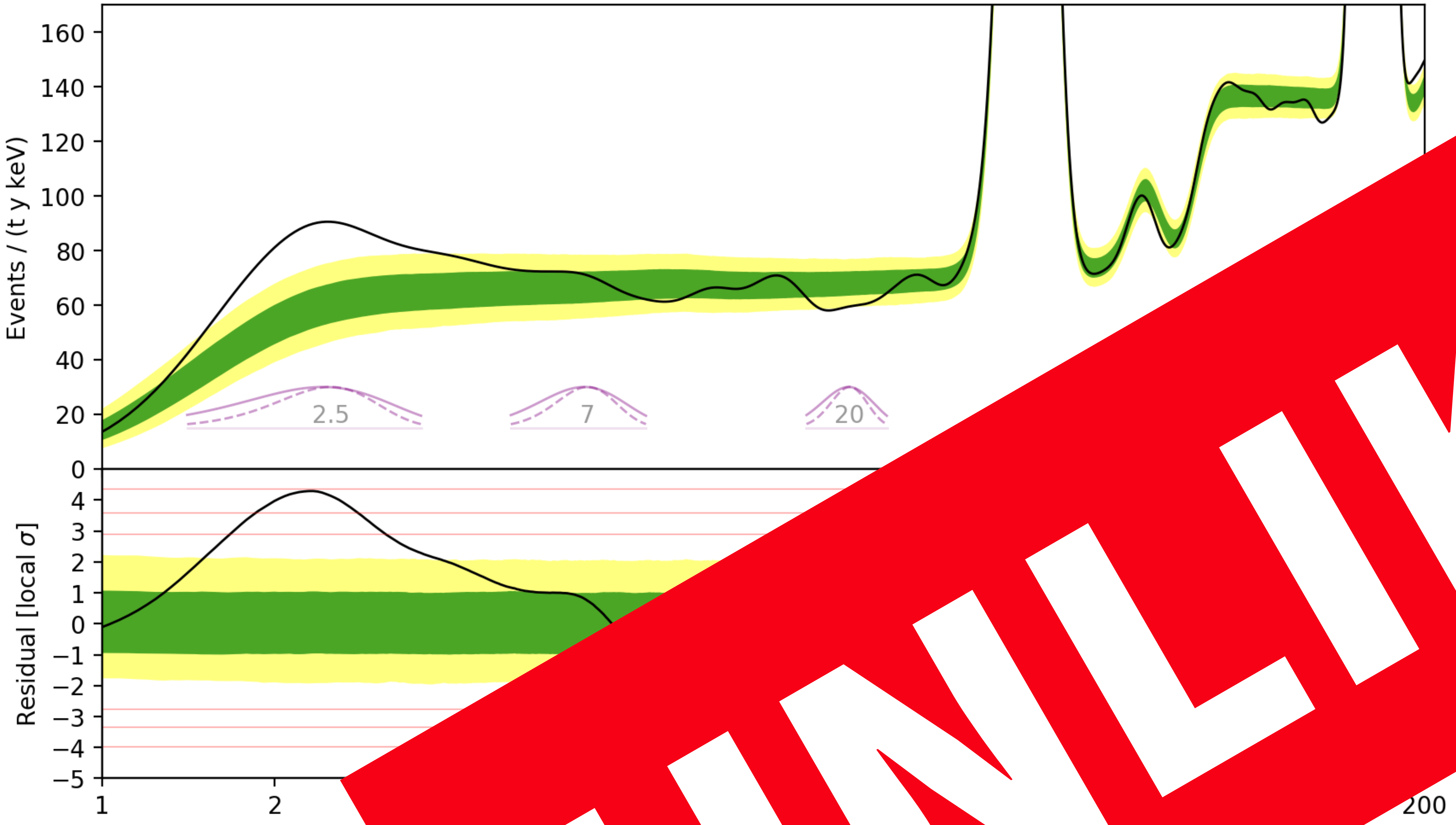


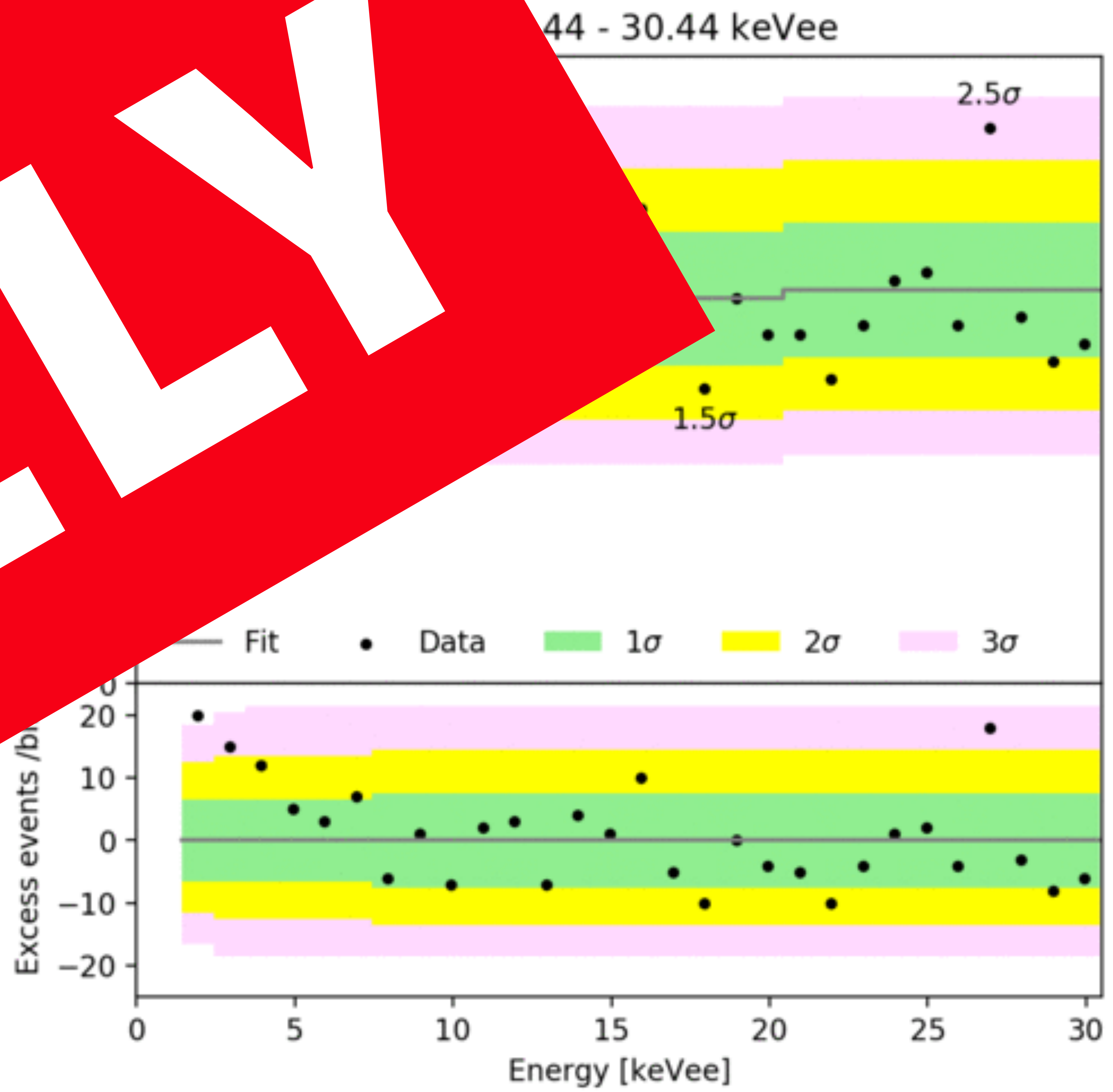


- KDE with energy resolution as width → **low-energy excess still significant**, the rest no
- Display binning change → bin width smaller than energy resolution, **low-energy excess robustly visible across several bins**, the rest no

Statistical Fluke? ☘

PRD 102 (2020) 072004





UNLIKELY

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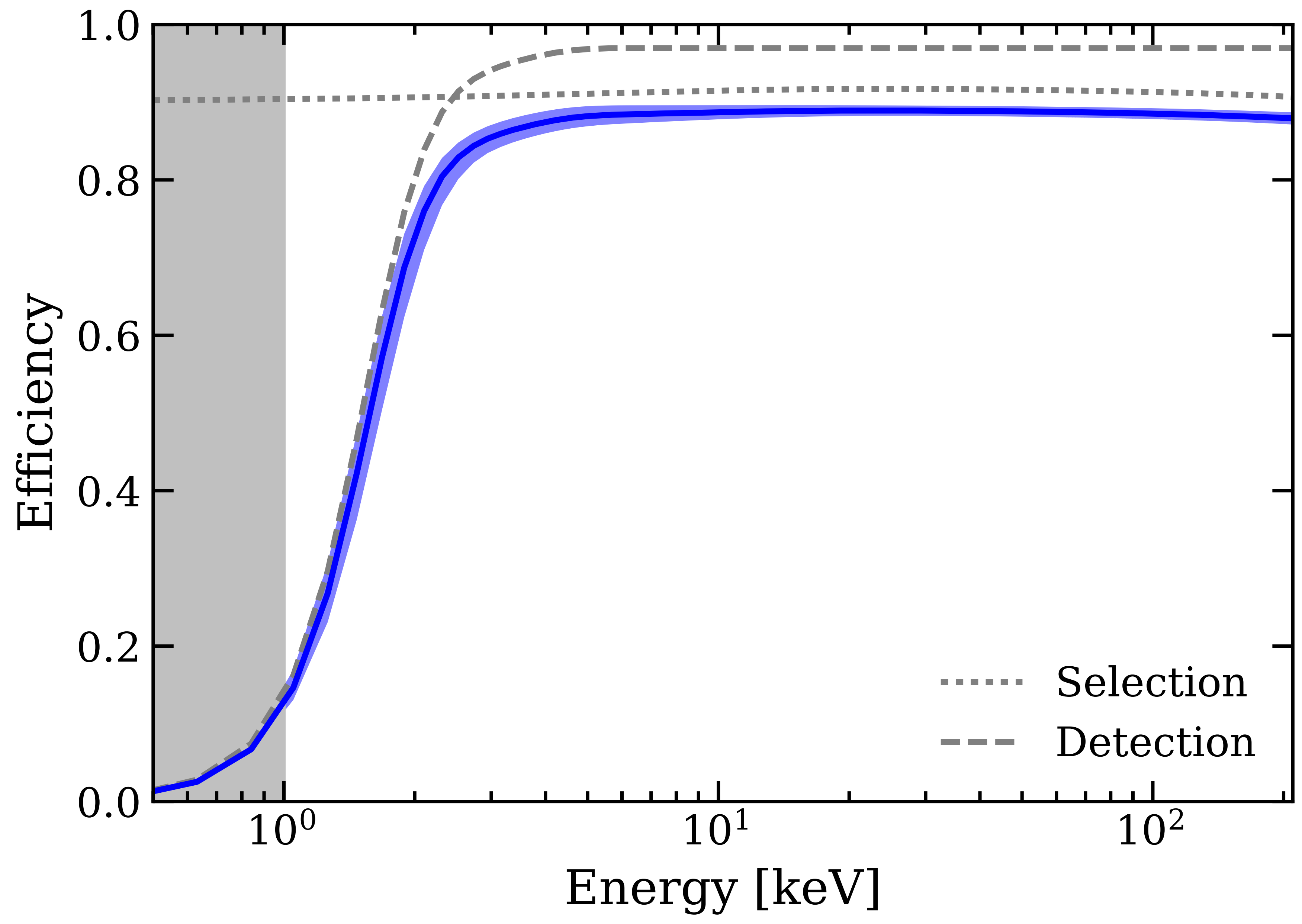
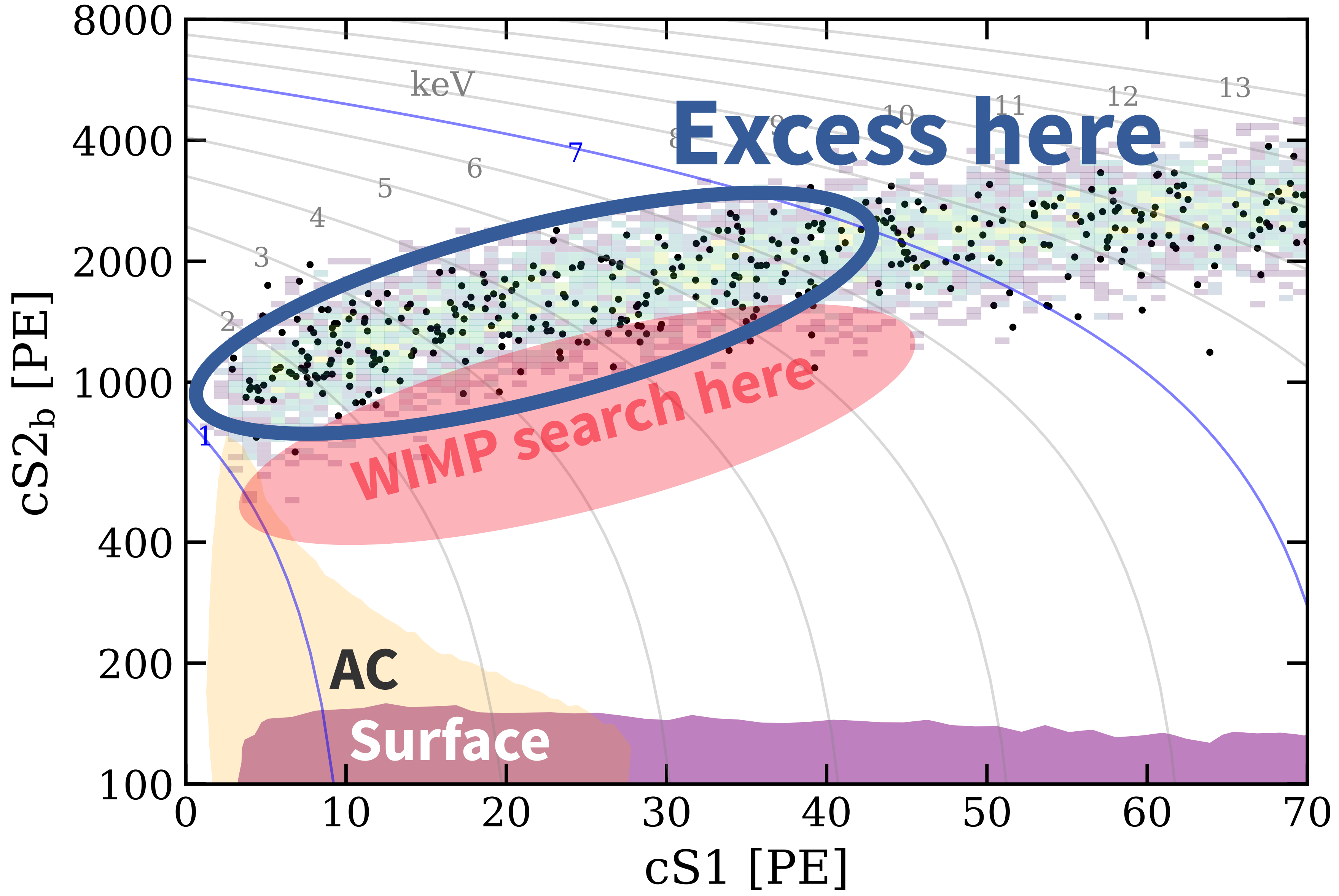
Systematic Effects?

- Excess close to but **not at the analysis threshold** (~ 85% detection efficiency at 2–3 keV)
- Still present if threshold is **doubled**

PRD 102 (2020) 072004



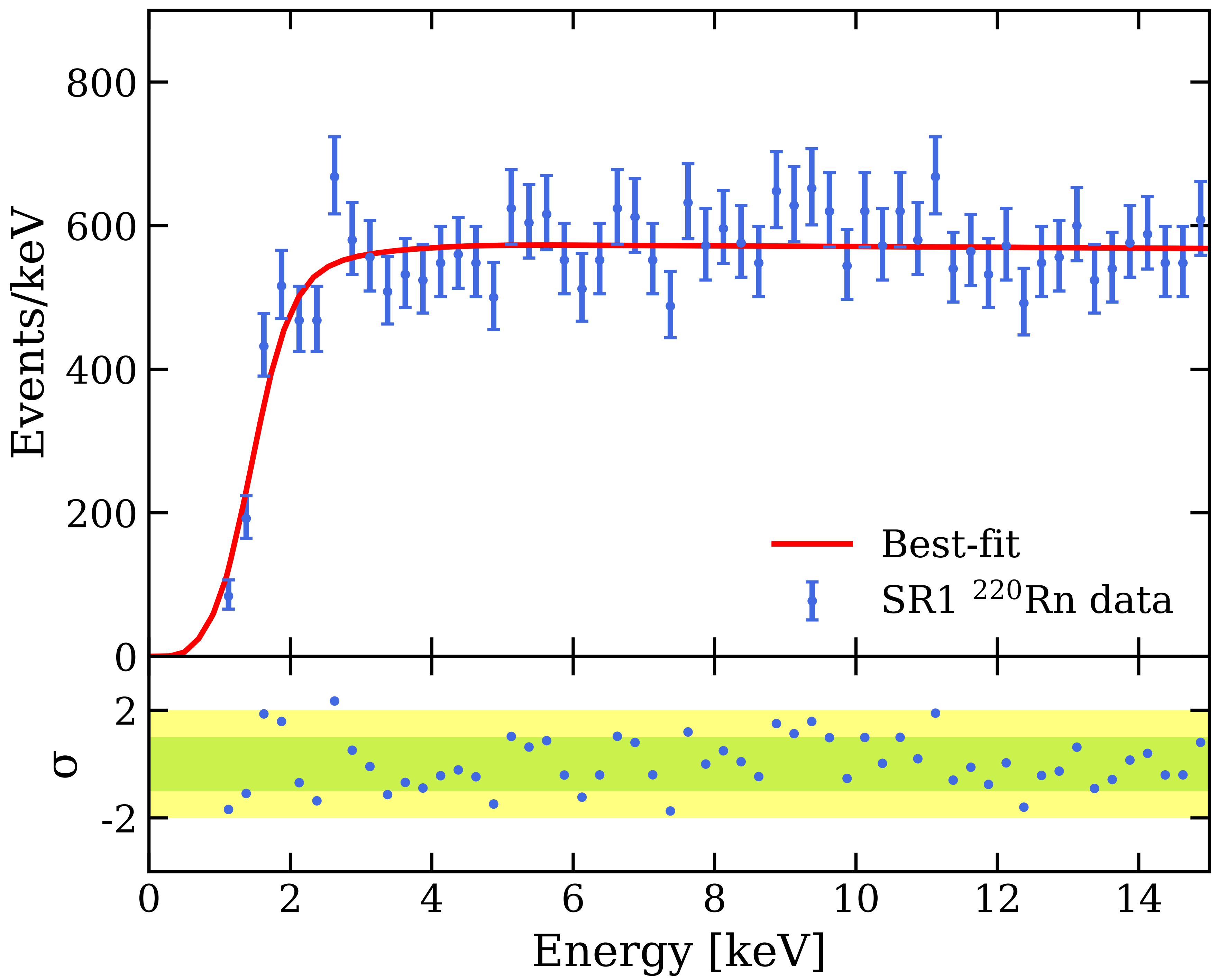


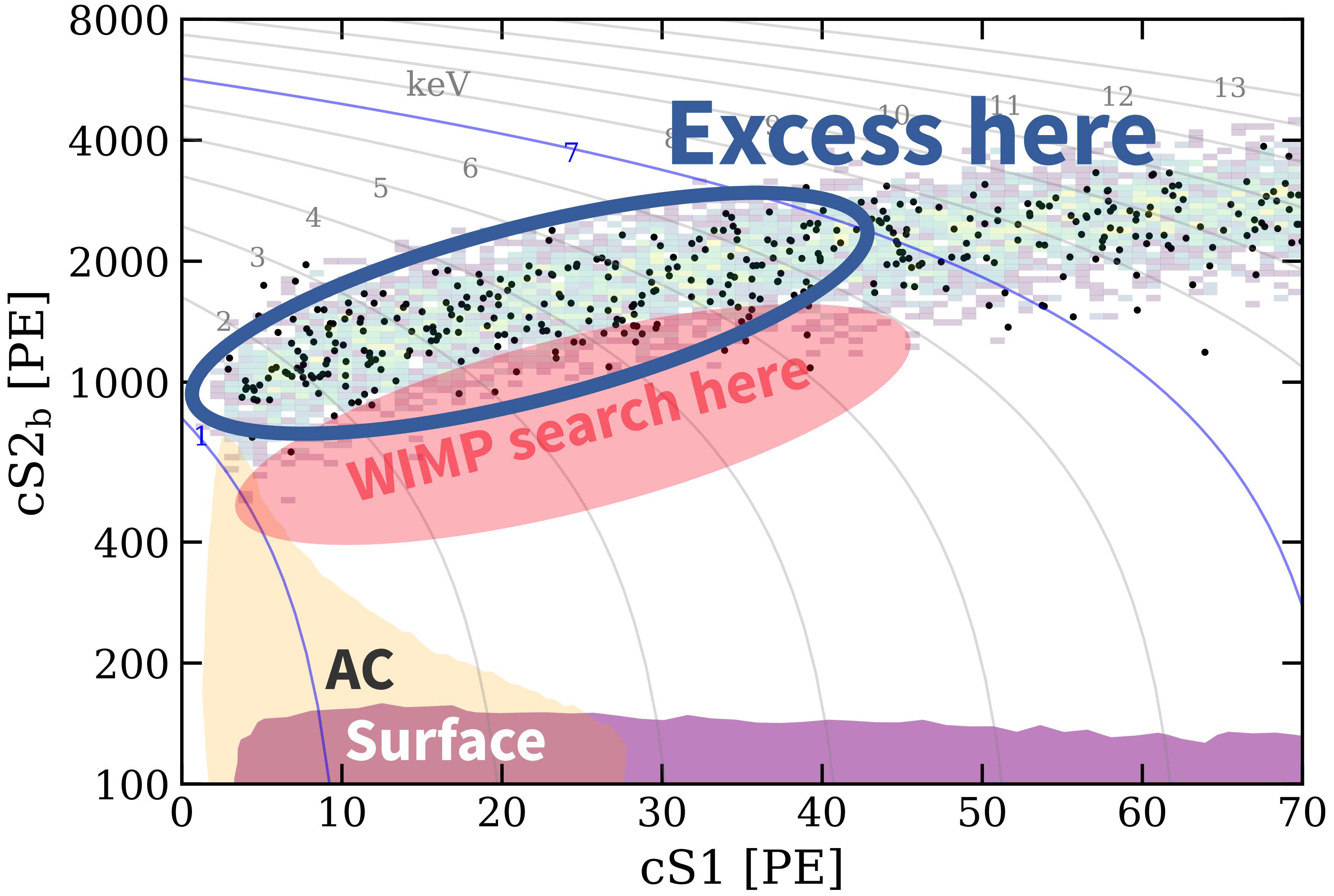
- Surface events ➞ **absent from the search region** thanks to fiducialisation
- Accidental Coincidences (AC events) ➞ **tightly constrained** and well-understood (S1, S2) signature

Systematic Effects? ⚖

PRD 102 (2020) 072004

- Excess close to but **not at the analysis threshold** (∼ 85% detection efficiency at 2–3 keV)
- Still present if threshold is **doubled**
- Efficiency verified with high-statistic ^{220}Rn calibration data → **background model validated**





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PRD 102 (2020) 072004

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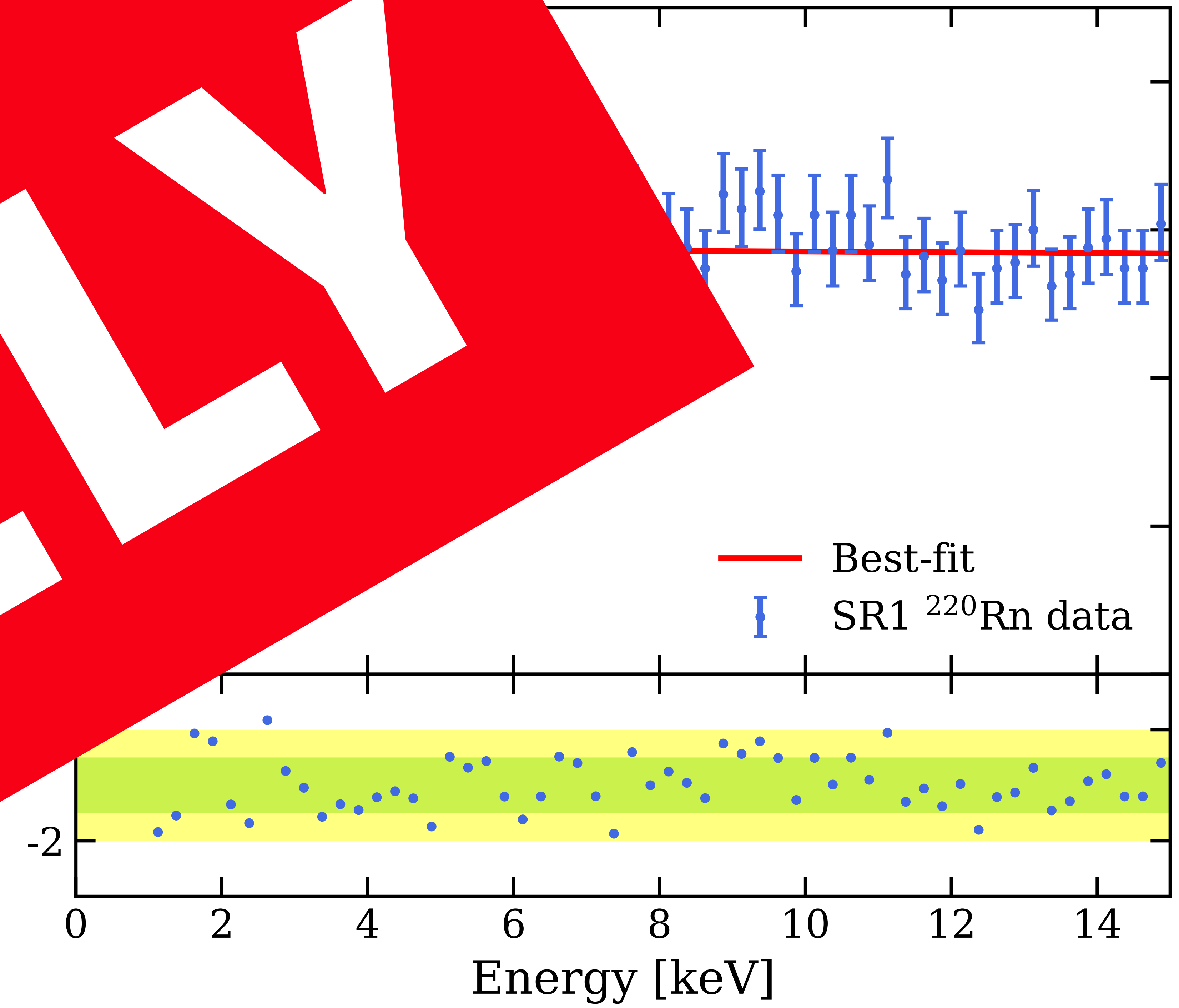

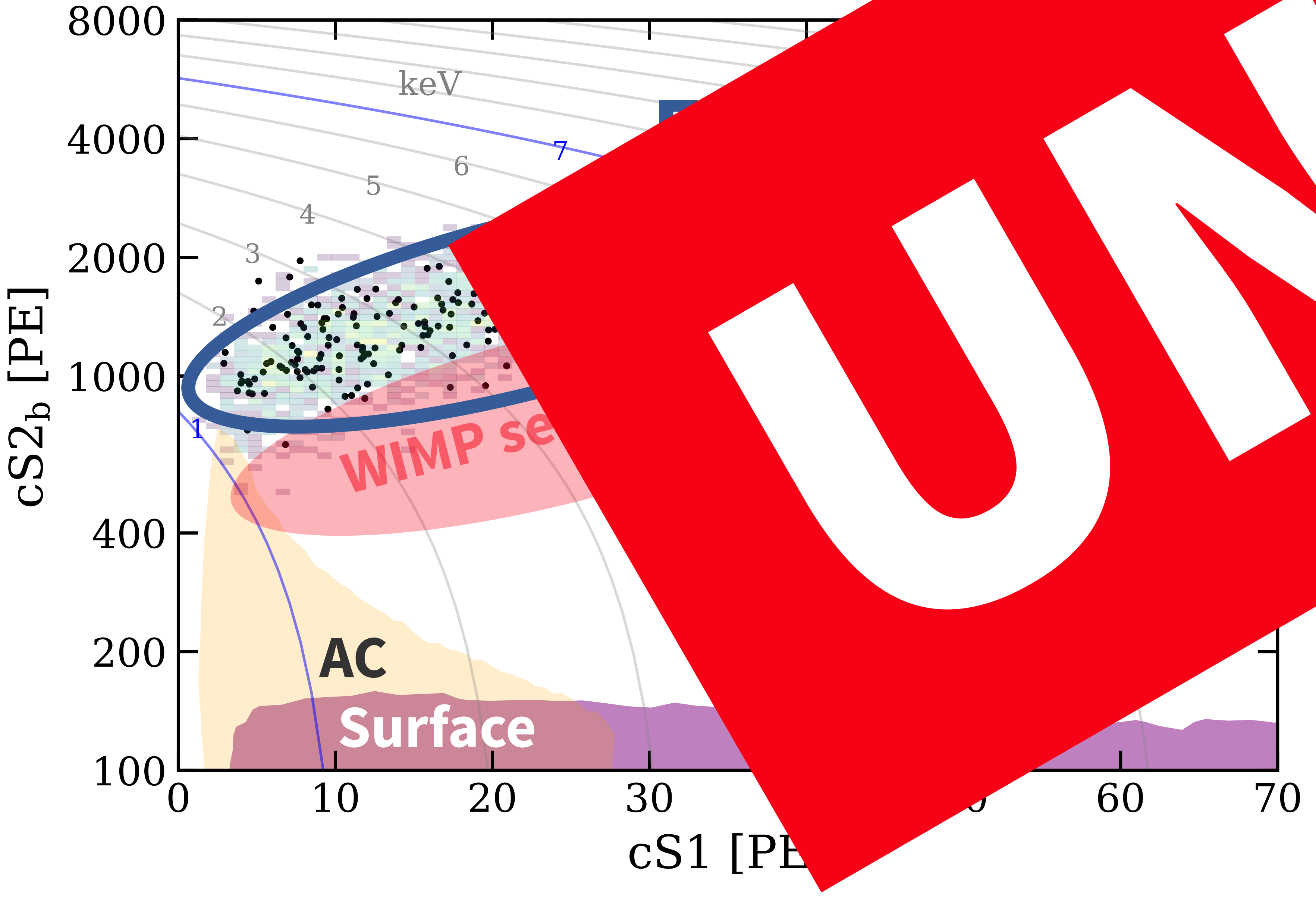

UNLIKELY

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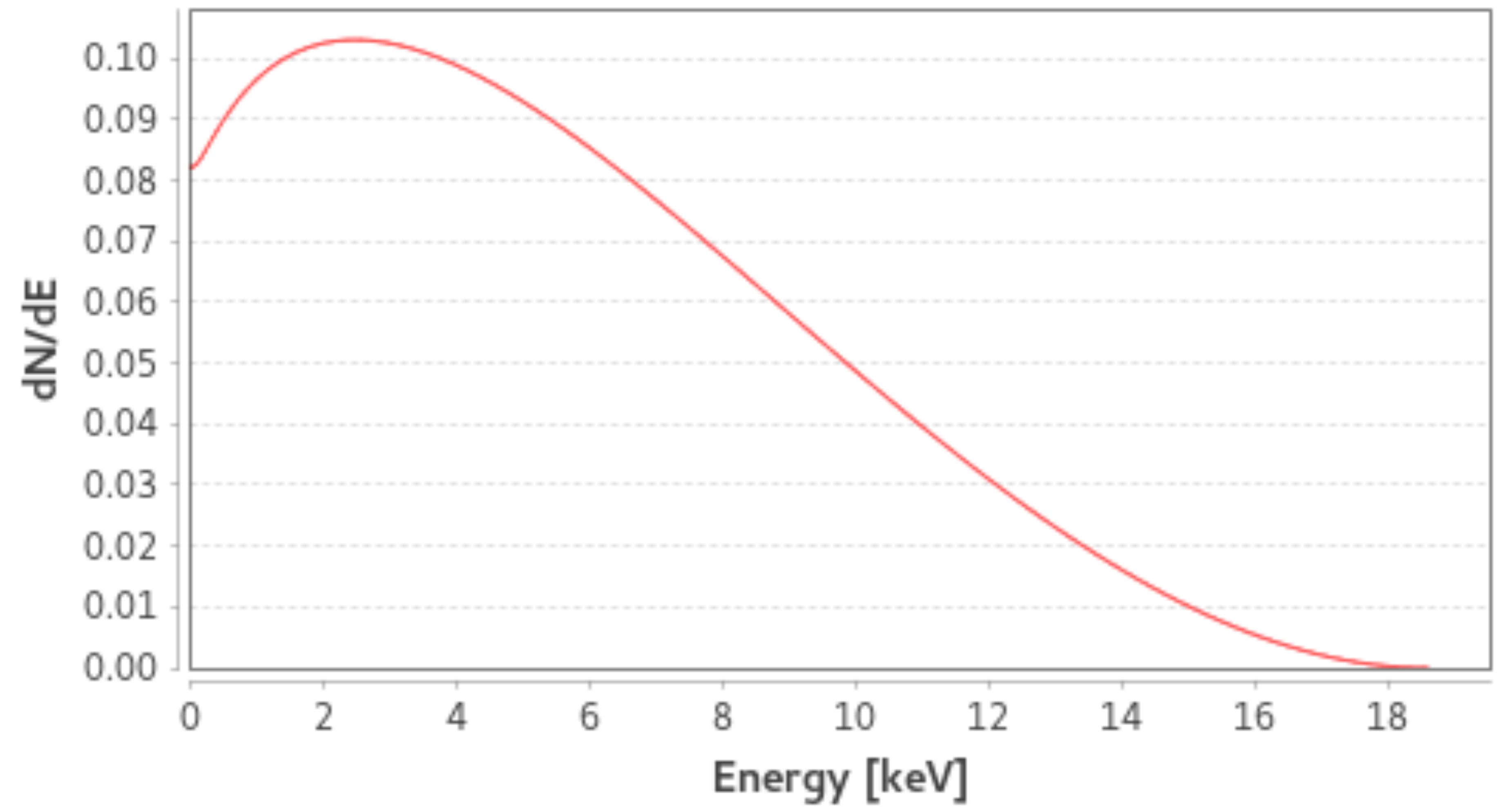
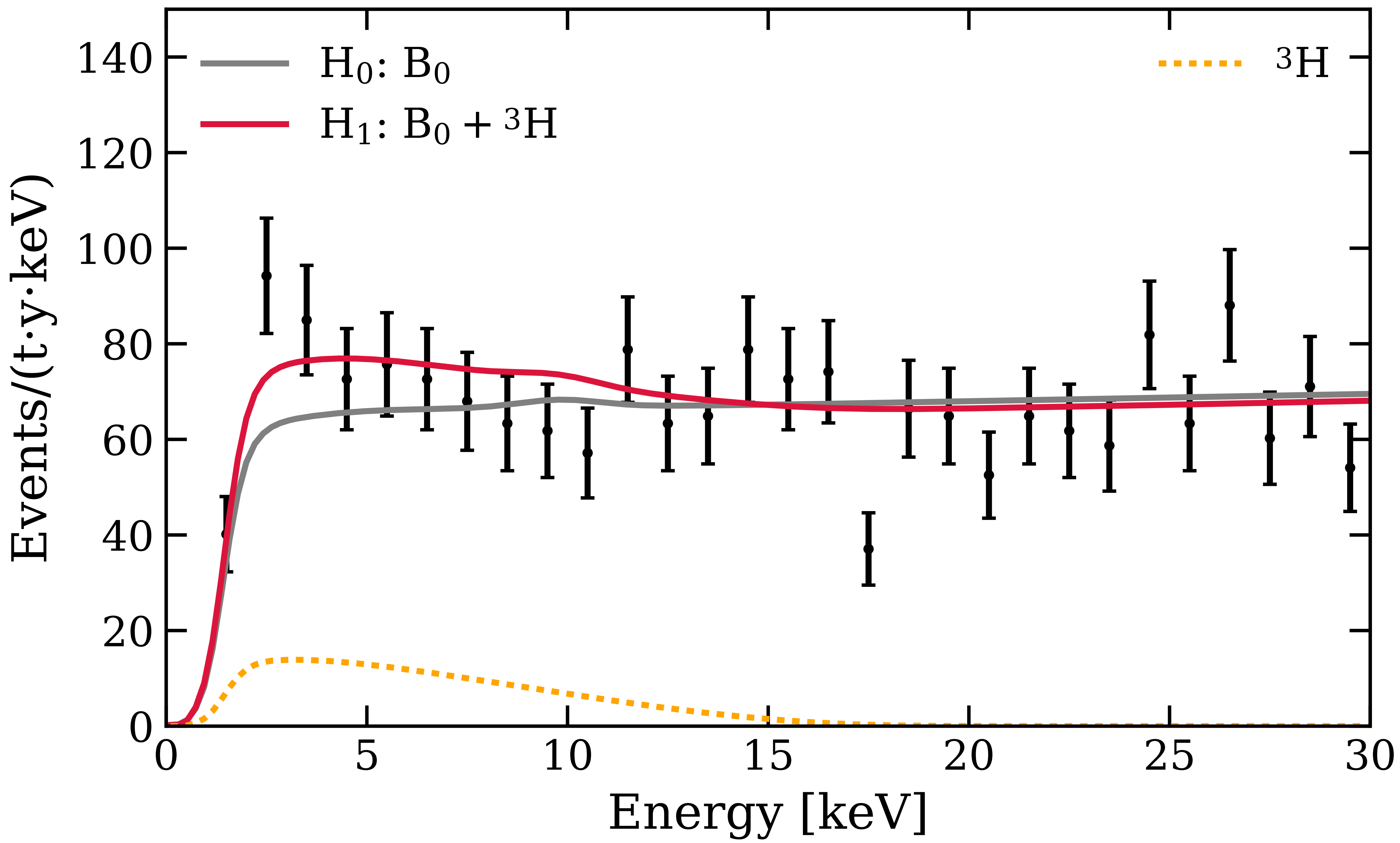
The Tritium Hypothesis

NDS 130 (2015) 1-20
PRD 102 (2020) 072004

- **Never observed before** as background in LXe TPCs
- β^- emitter → $Q_\beta = 18.6$ keV, $t_{1/2} = 12.3$ yr
- Cosmogenic activation? Atmospheric abundance?





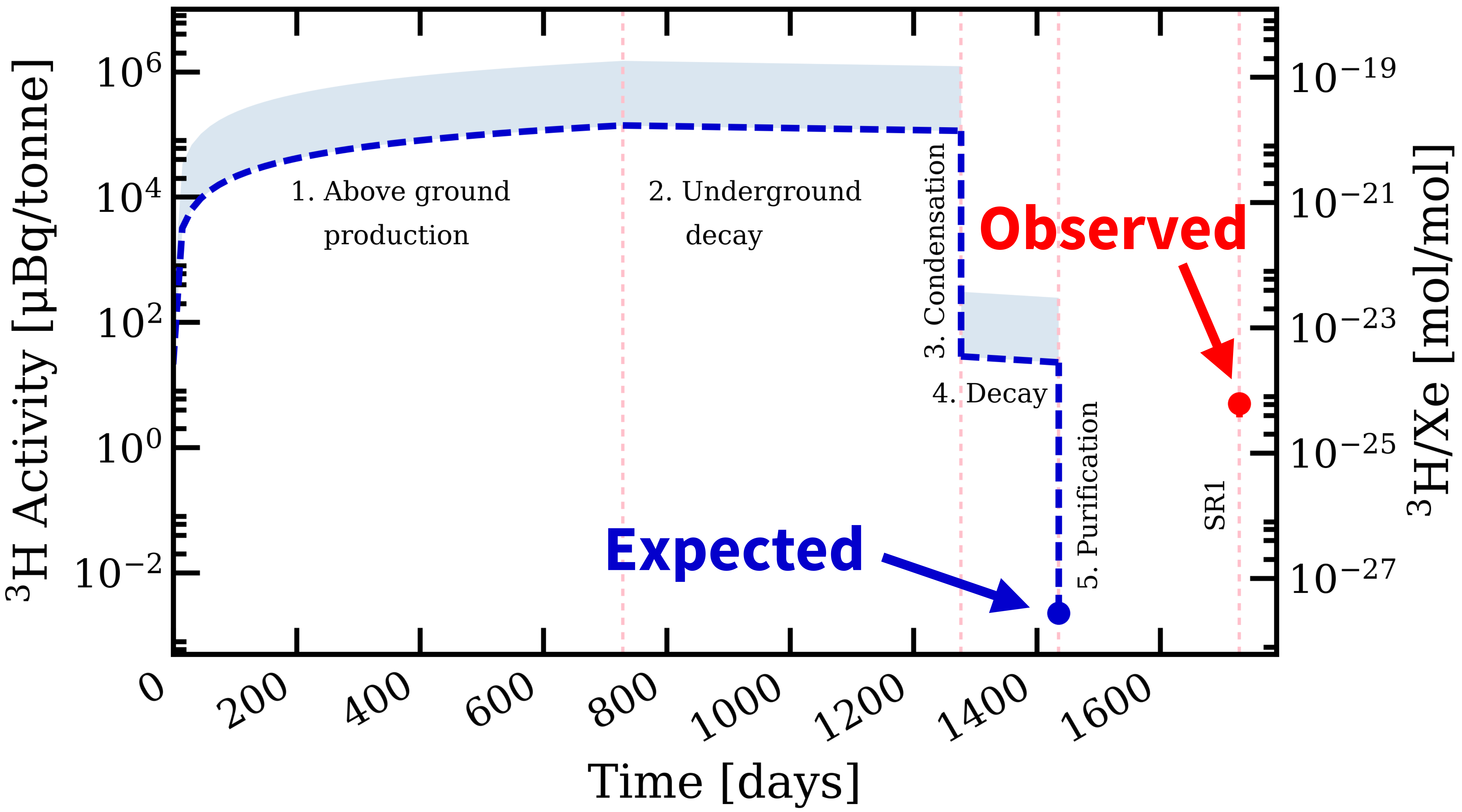
Tritium hypothesis favoured over B_0 at 3.2σ

- Fitted rate → (159 ± 51) events/(t × yr)
- $^3H/Xe = (6.2 \pm 2.0) \times 10^{-25}$ mol/mol
  → $\lesssim$ **3 tritium atoms/kg of xenon**

Tritium from the Cosmos?

PRD 102 (2020) 072004

1. Xenon gas storage above ground ➞ ~ 32 tritium atoms/(kg × d) ➞ **tritiated water (HTO)** with ~ 1 ppm water impurities
2. Xenon gas moved underground ➞ **tritium decay**, no more cosmogenic activation
3. Xenon filled into its cold storage vessel ➞ water condensation (including HTO) and "capture" by the vessel walls
   ➞ **× 4000 HTO reduction**
4. Further tritium decay
5. Purification and detector filling
   ➞ **99.99% water removal** (including HTO)



Tritium from the Cosmos?

PRD 102 (2020) 072004

UNLIKELY

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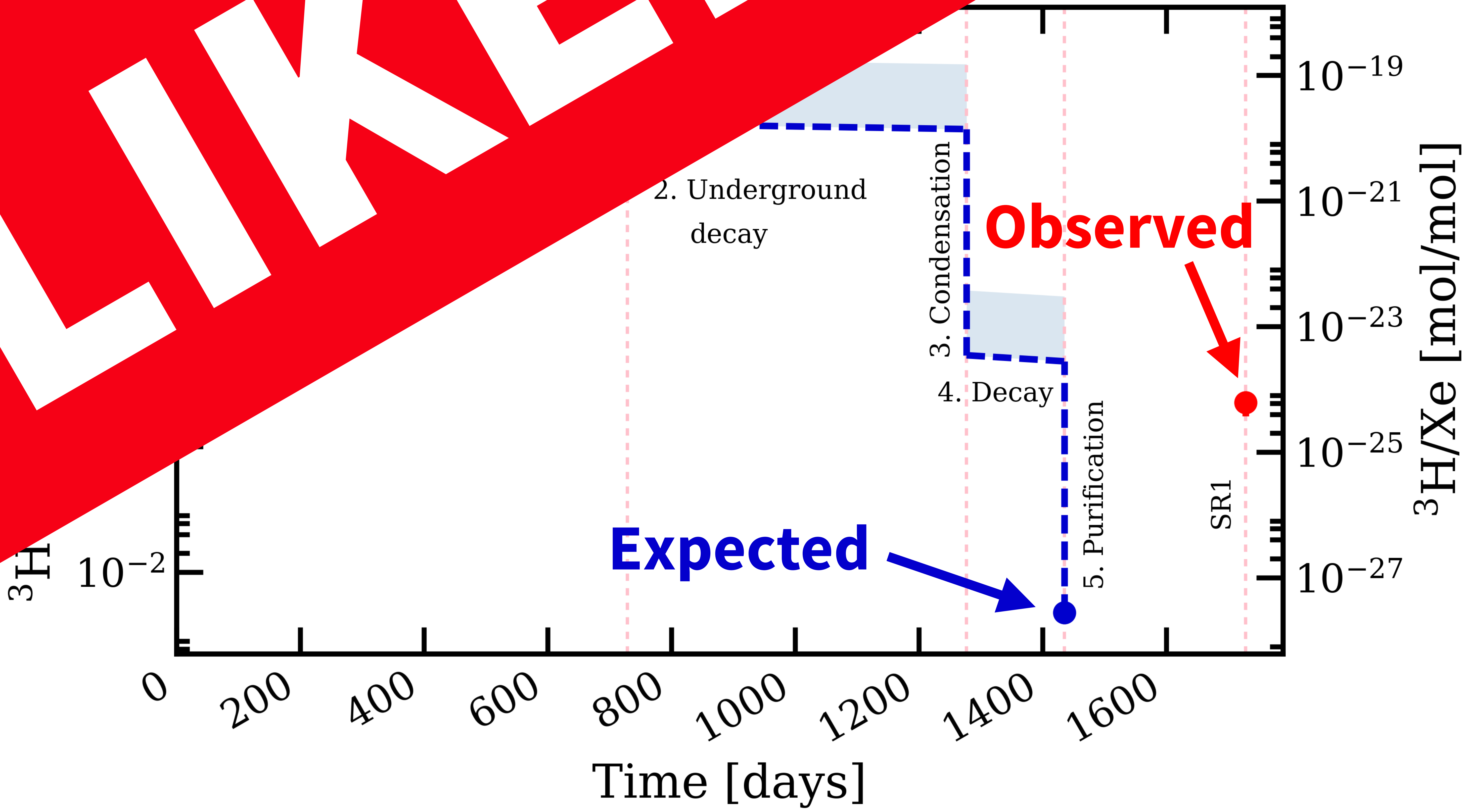
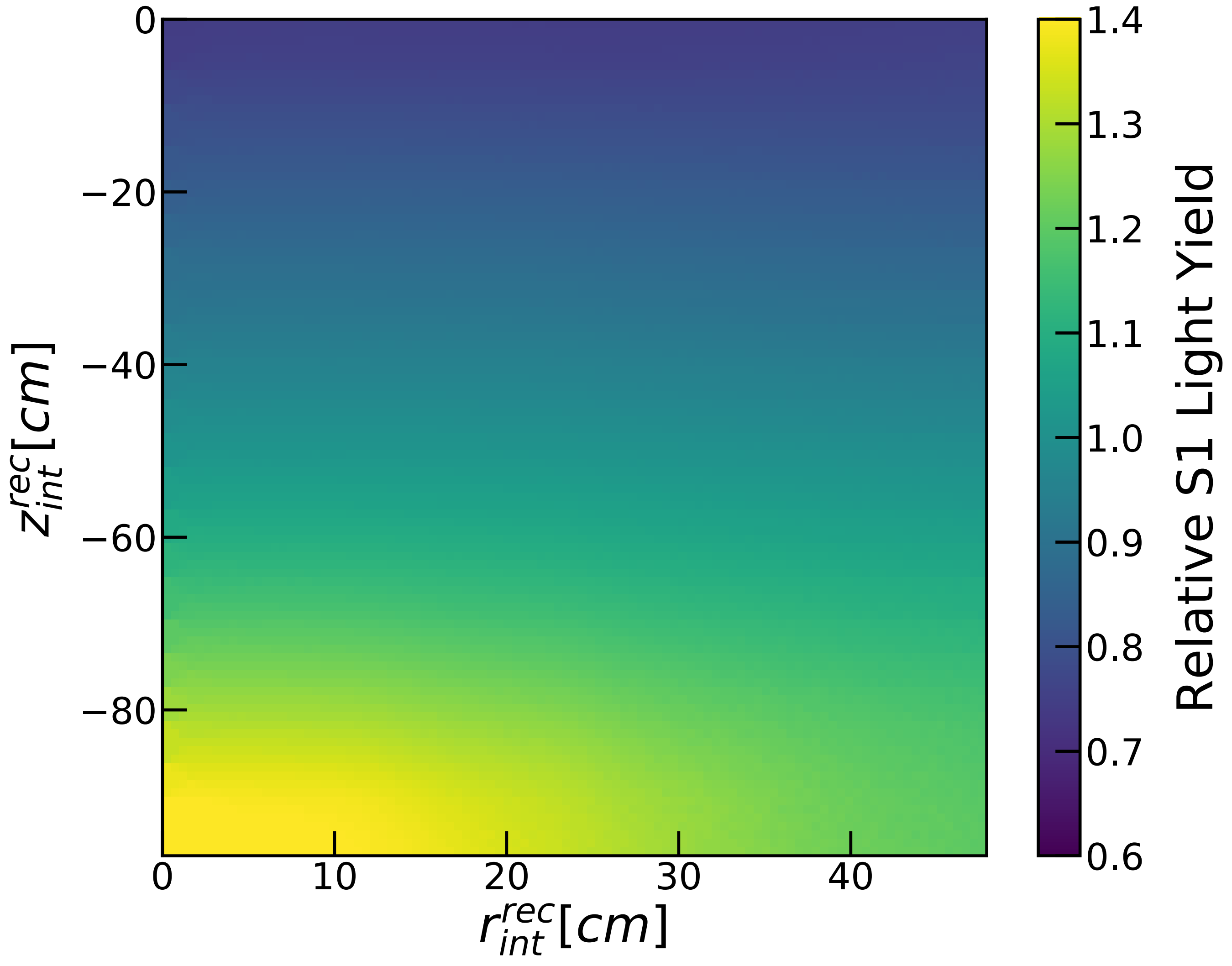


Tritium from the Atmosphere?

PRD 102 (2020) 072004

- Atmospheric abundance → tritium stored as **tritiated water (HTO) or hydrogen (HT)** in detector materials, then **emanating in xenon**
- $HTO/H_2O = (5\text{–}10) \times 10^{-18}$ mol/mol, **assuming** the same value for HT/H_2
  → $\mathbf{(H_2O + H_2)/Xe \gtrsim 30}$ **ppb** required to make up the tritium-fitted excess

Tritiated water (HTO)



Light yield measurement

↓

$H_2O/Xe = O(1)$ ppb

↓

$^3H/Xe \sim 10^{-26}$ mol/mol

Tritiated hydrogen (HT)

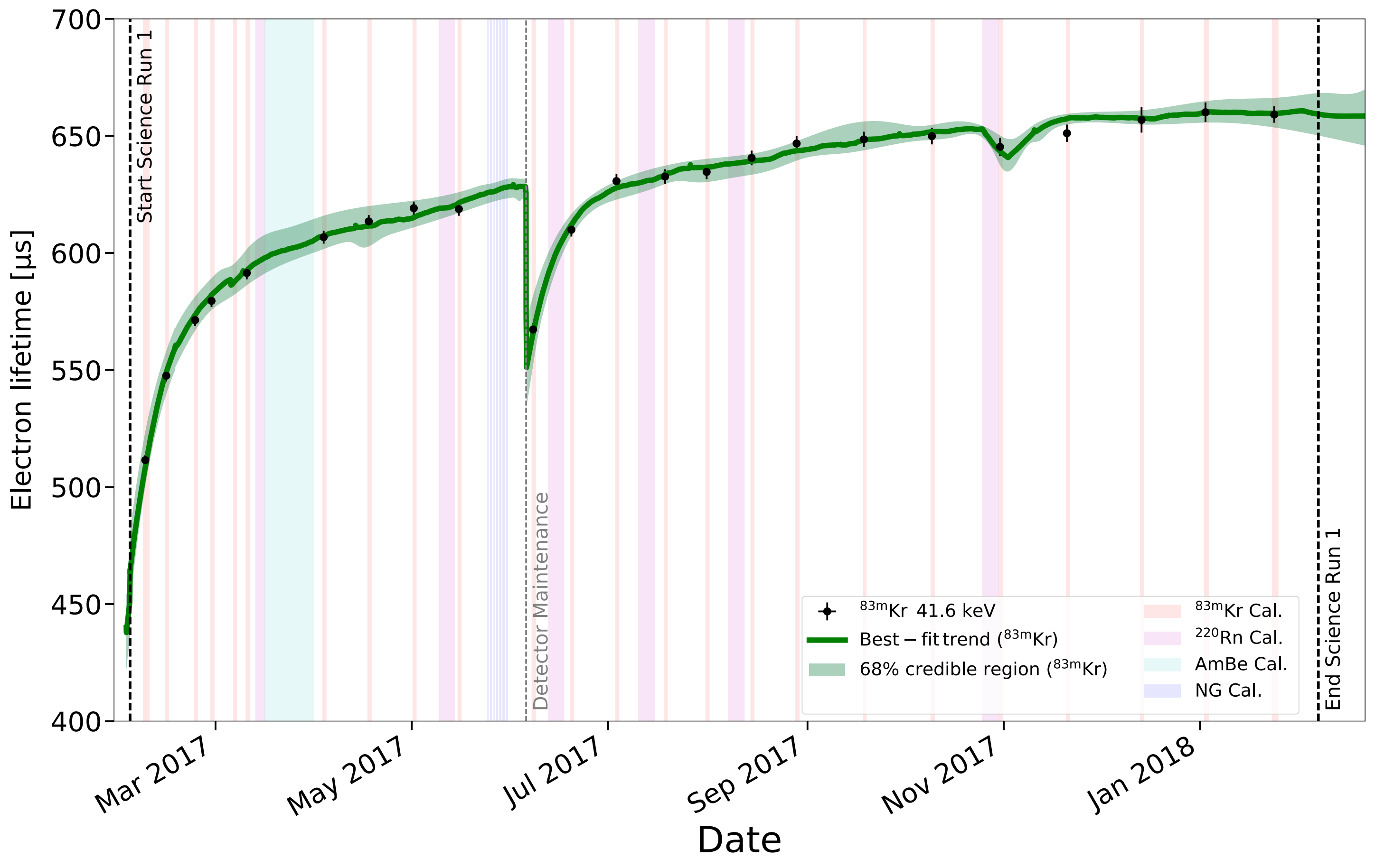
Electron lifetime measurement

↓

No H_2 measurement

O_2-eq./Xe < 1 ppb

↓



100 × more H_2 required to explain the excess

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PRD 102 (2020) 072004

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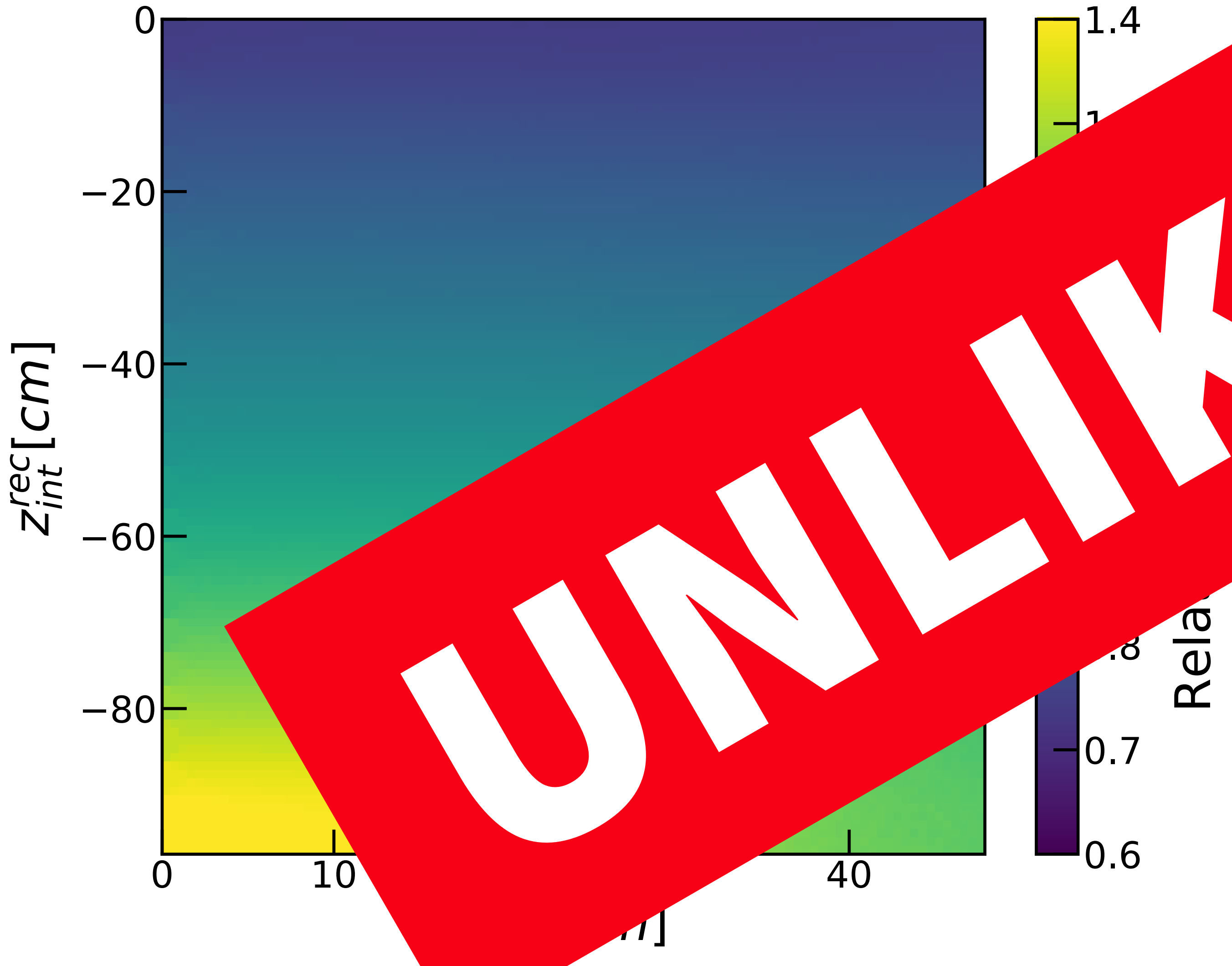
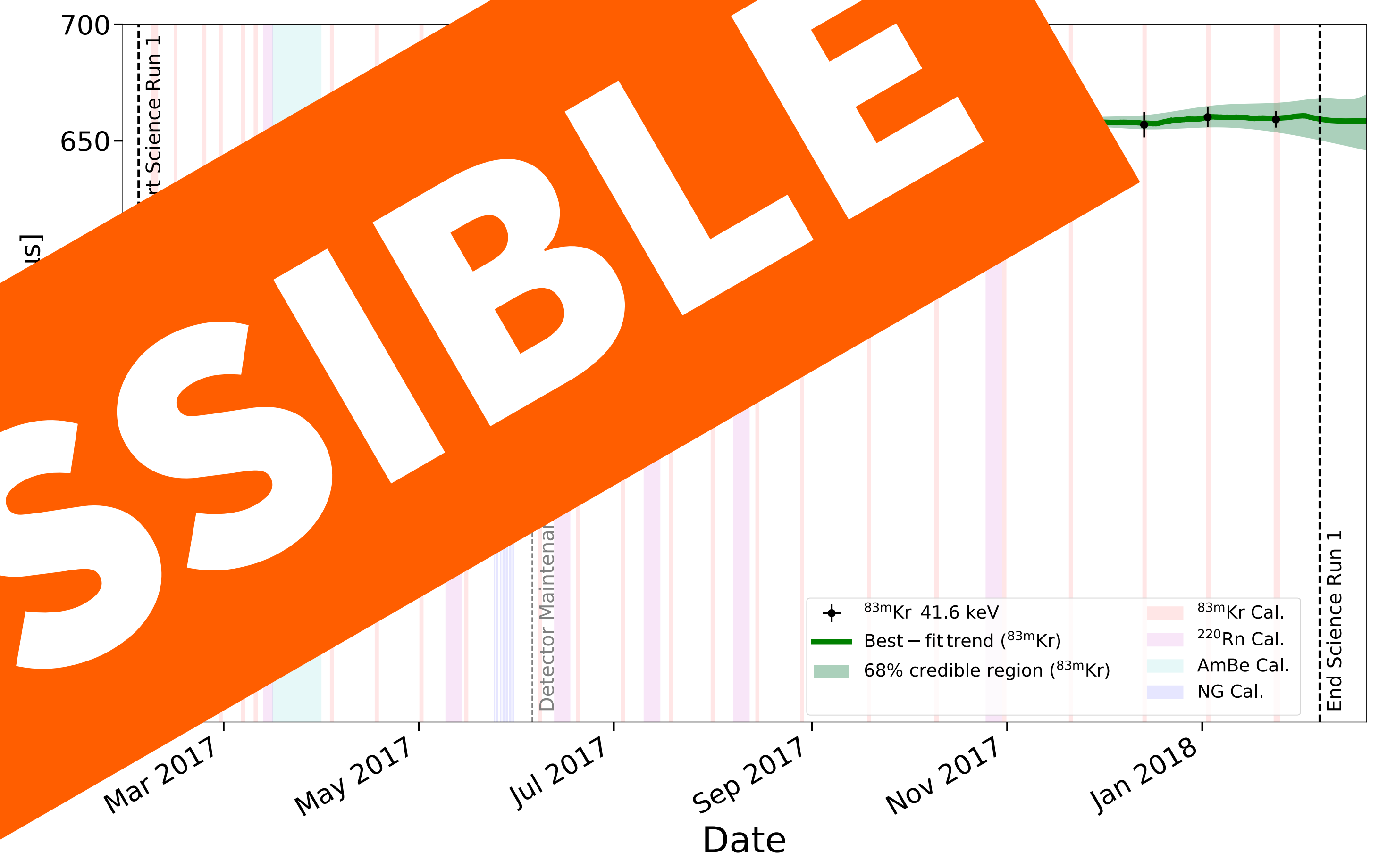


d
ent
↓
$H_2O/Xe = O(1)$ ppb
↓
$^3H/Xe \sim 10^{-26}$ mol/mol

UNLIKELY

Tritiated hydrogen (HT)

Electron lifetime measurement
↓
No H_2 measu
O_2-eq



100 × H_2 required to explain the excess

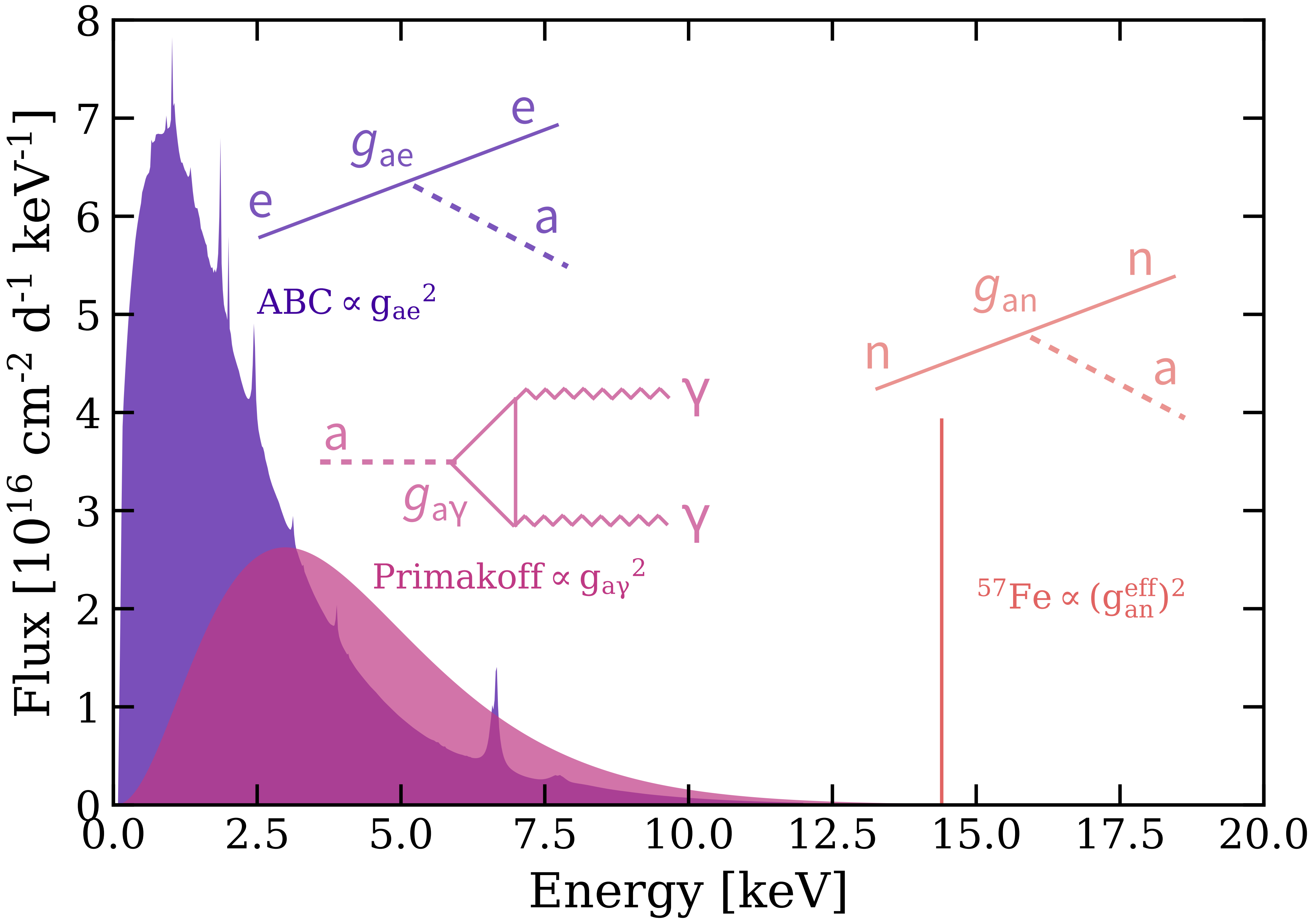
POSSIBLE

The Solar Axion Hypothesis

PRD 102 (2020) 072004

- Hypothetical particle suggested as a **QCD strong *CP* problem solution**
- Motivated **Dark Matter candidates** (≪ keV) or possibly **produced in the Sun** (∼ keV)

Atomic recombination and de-excitation, Bremsstrahlung and Compton (ABC) $\propto$ Axion-electron coupling $(g_{ae})^2$	Primakoff conversion of photons to axions $\propto$ Axion-photon coupling $(g_{a\gamma})^2$	A ^{57}Fe monoenergetic nuclear transition (14.4 keV) $\propto$ Effective axion-nucleon coupling $(g_{an}^{eff})^2$

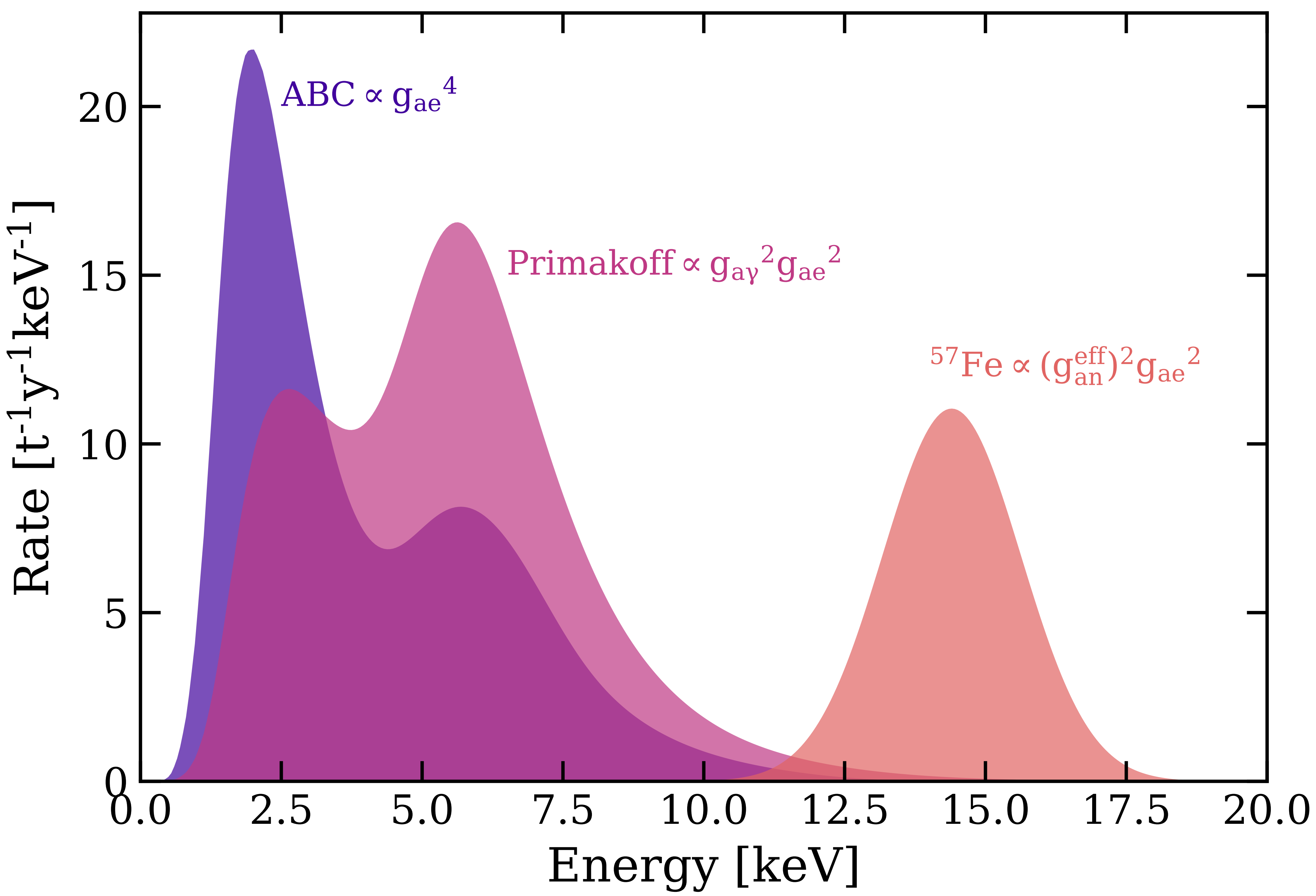


XENON

Detection via axioelectric effect $\propto (g_{ae})^2$

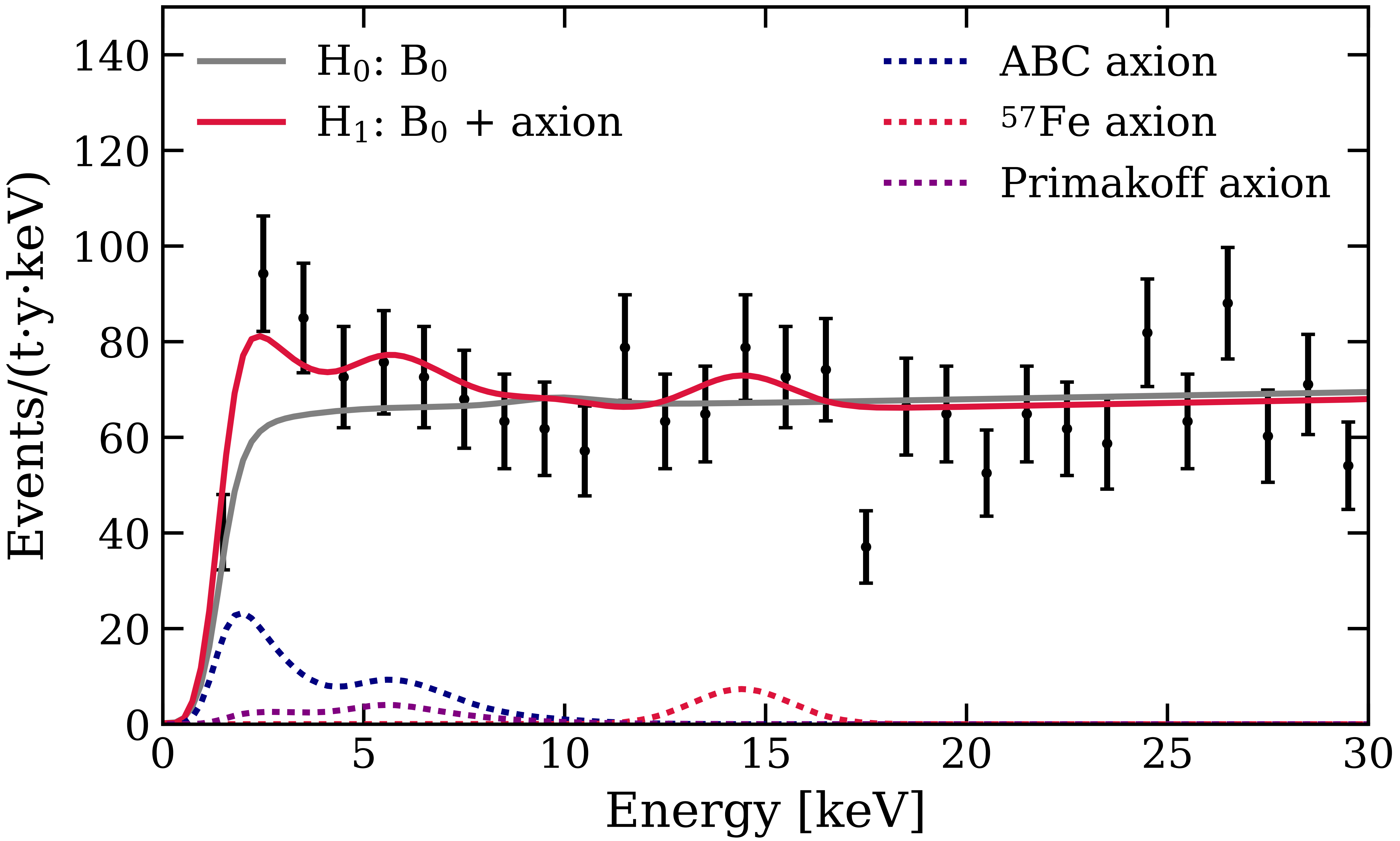
$\otimes$

Reconstruction effects



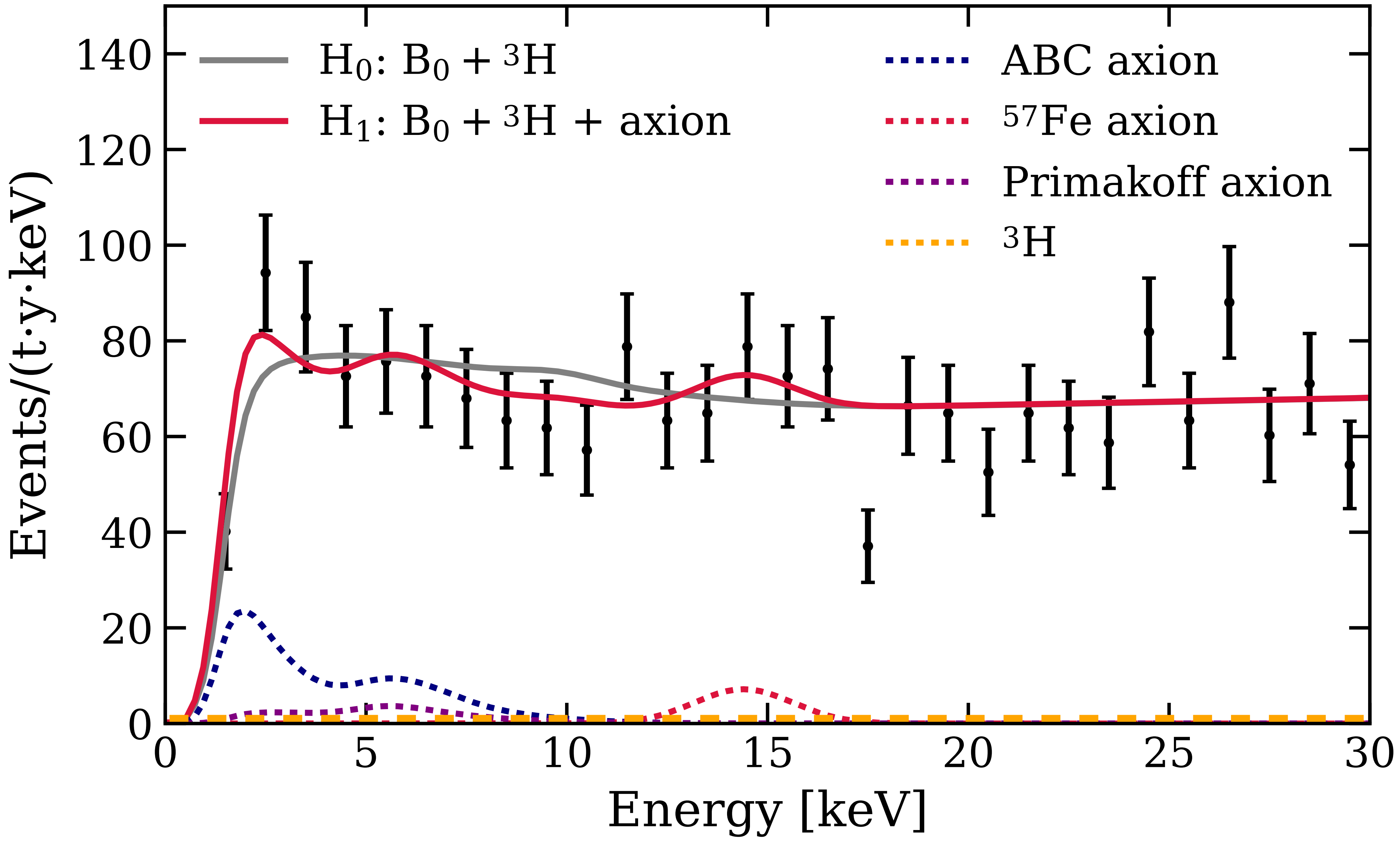
The Solar Axion Hypothesis

PRD 102 (2020) 072004



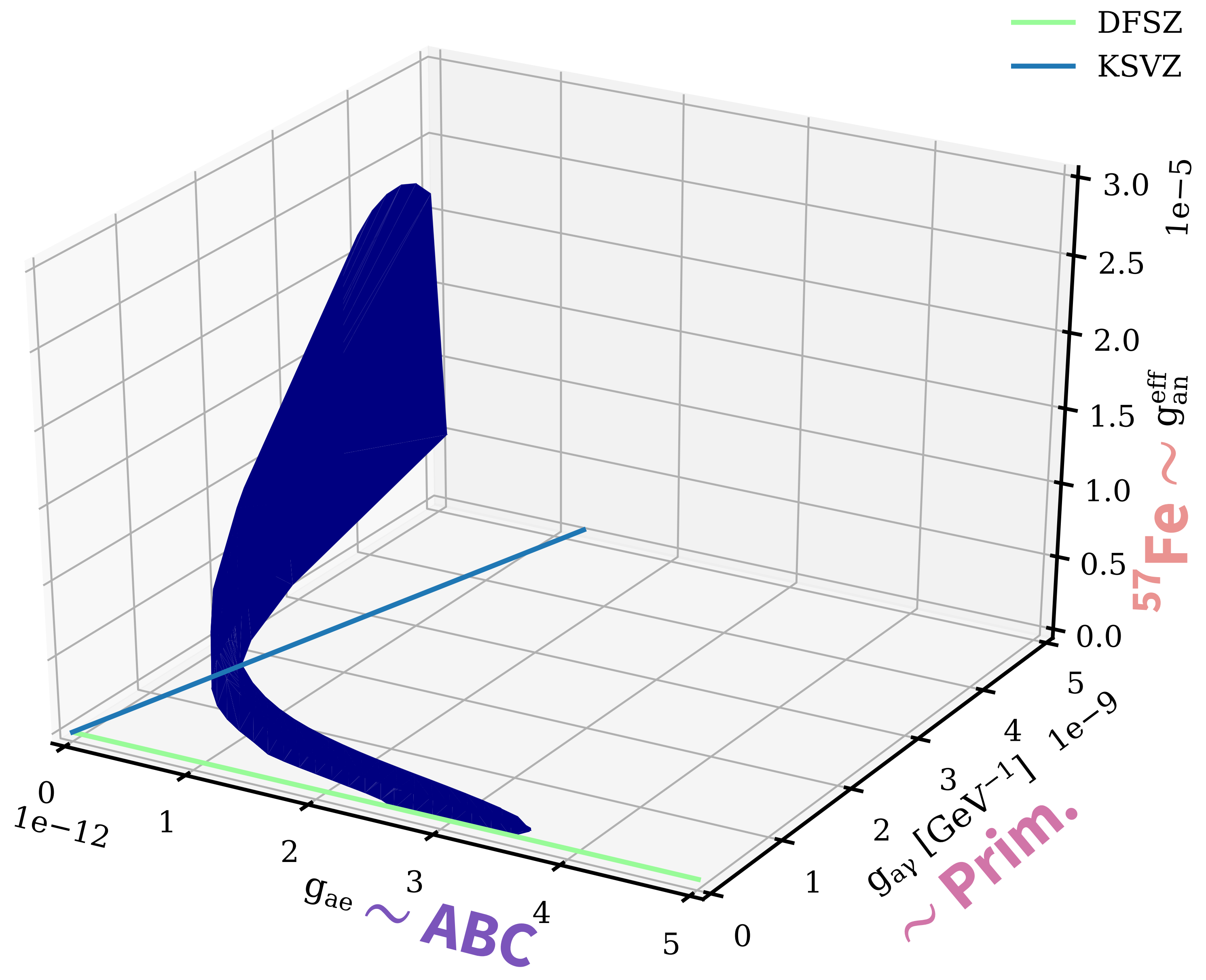
Axion hypothesis favoured over B_0 at 3.4σ

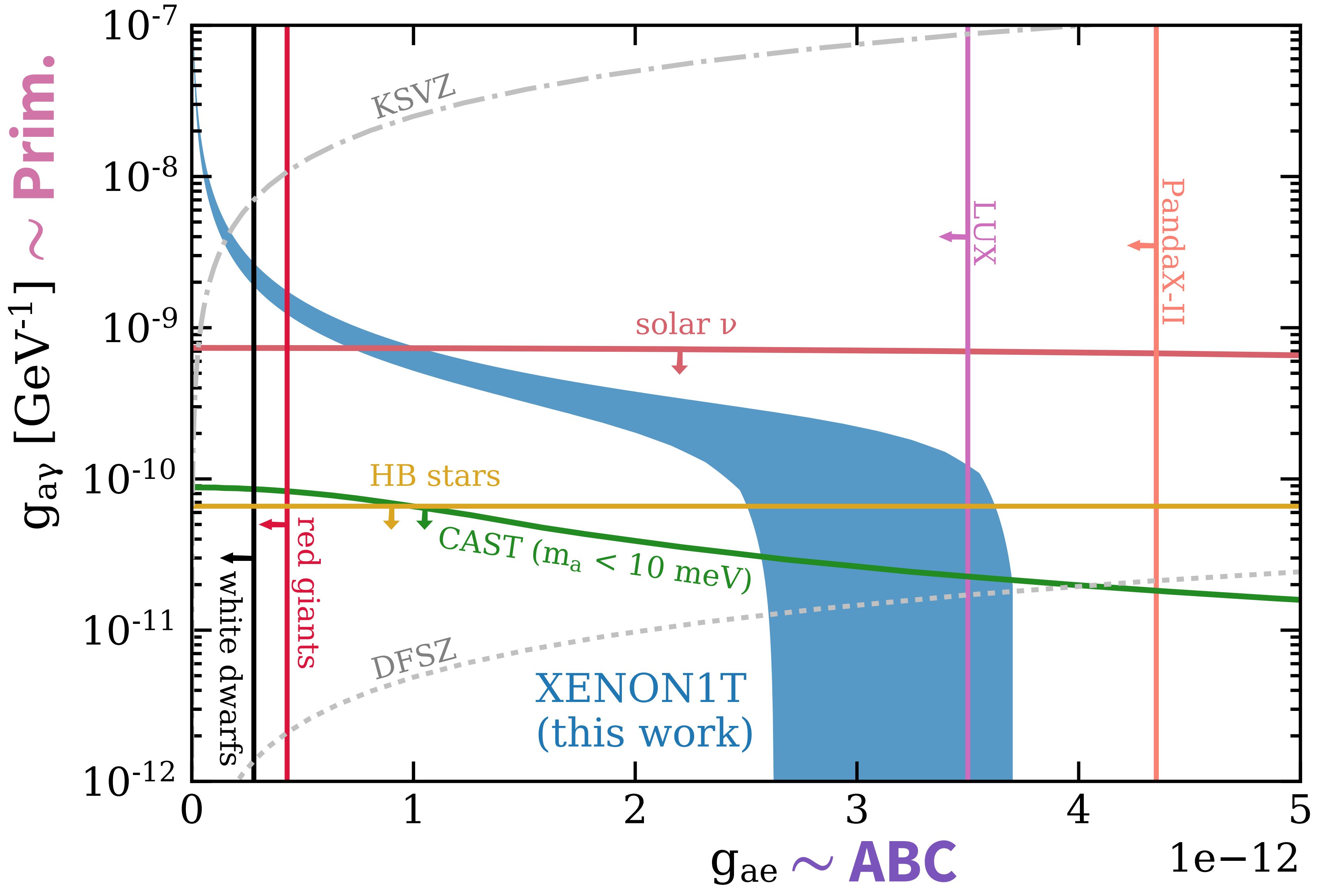
- Simultaneous search for **ABC**, **Primakoff** and **^{57}Fe** axions (unconstrained components in the fit)
- Axion hypothesis **still favoured over $B_0 + $ tritium** at 2.0σ

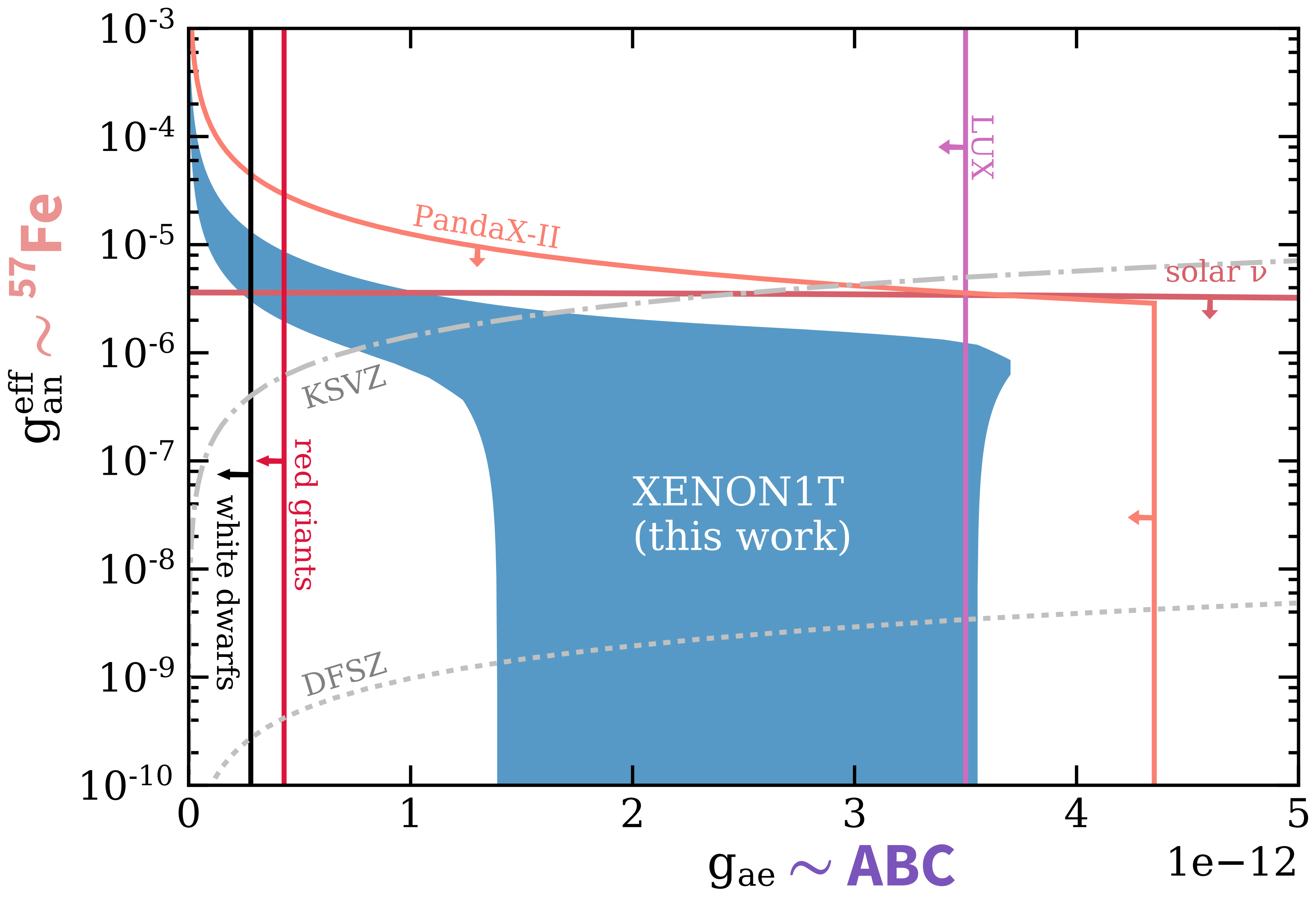


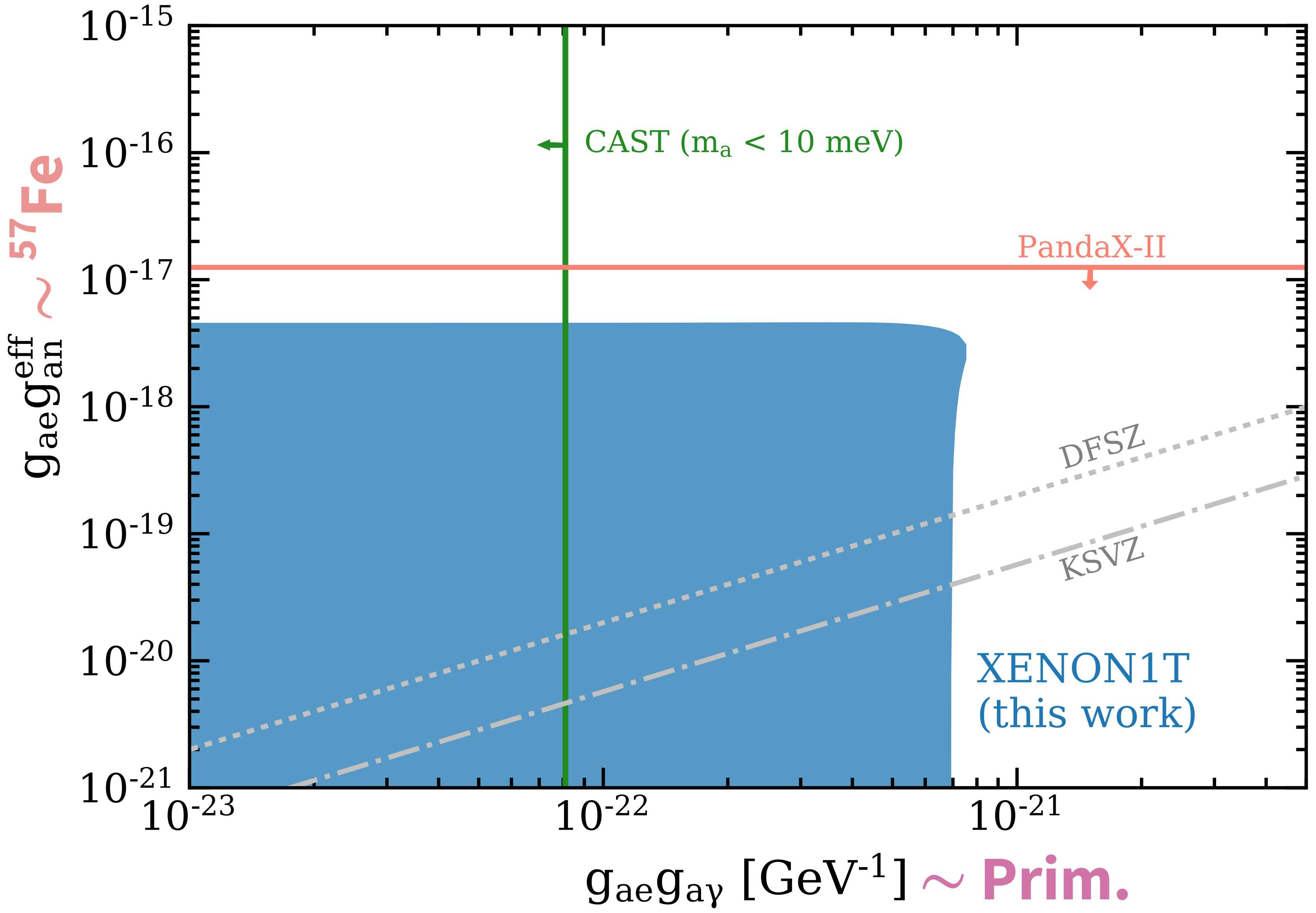
Solar Axion Results

PRD 102 (2020) 072004









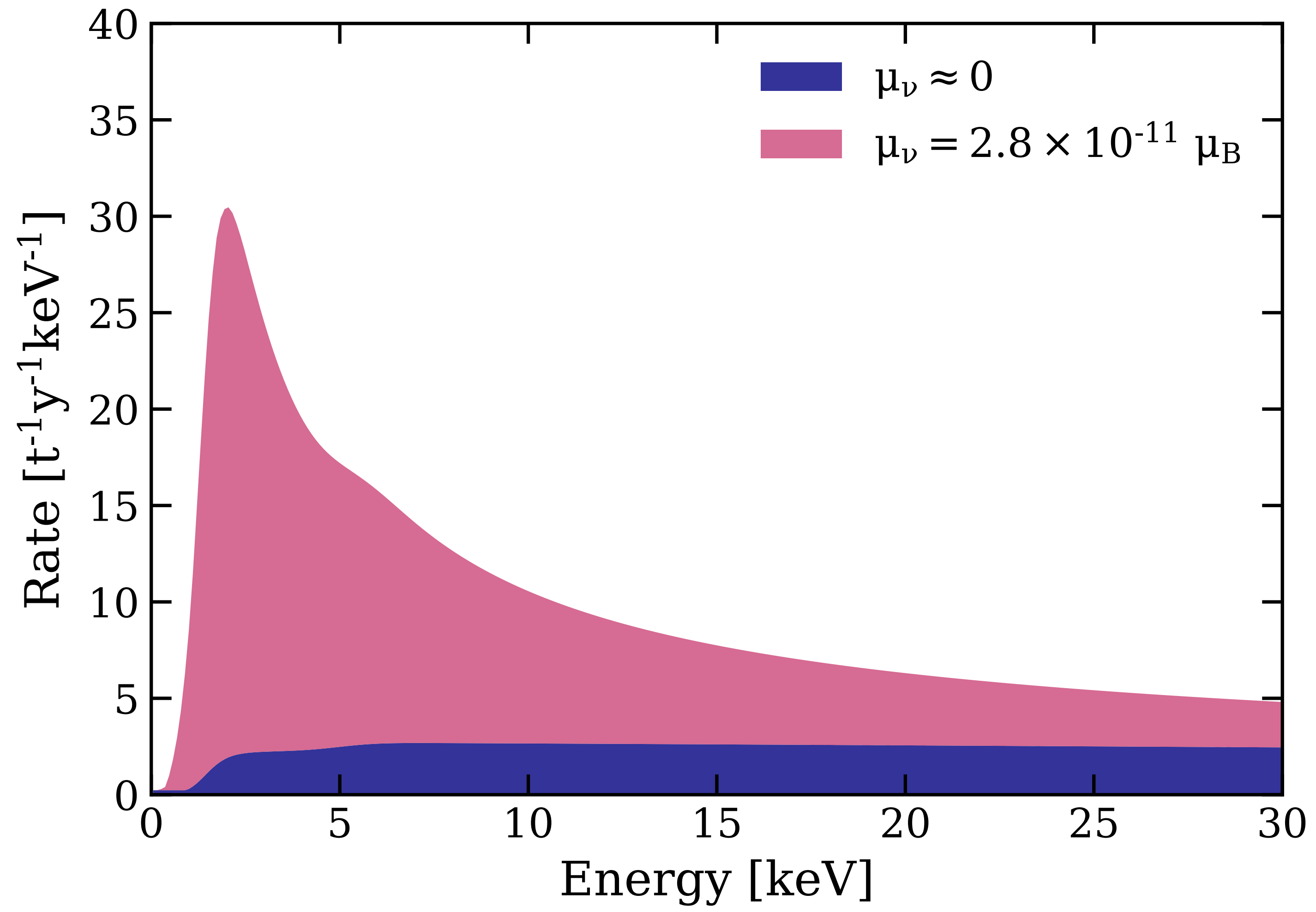
- 3D 90% C.L. volume g_{ae} vs. $g_{ae}\, g_{a\gamma}$ vs. $g_{ae}\, g_{an}^{eff}$
- Exclusion of $g_{ae} = 0$ **OR** $g_{ae}\, g_{a\gamma} = g_{ae}\, g_{an}^{eff} = 0$
- **Strong tension** with stellar cooling constraints

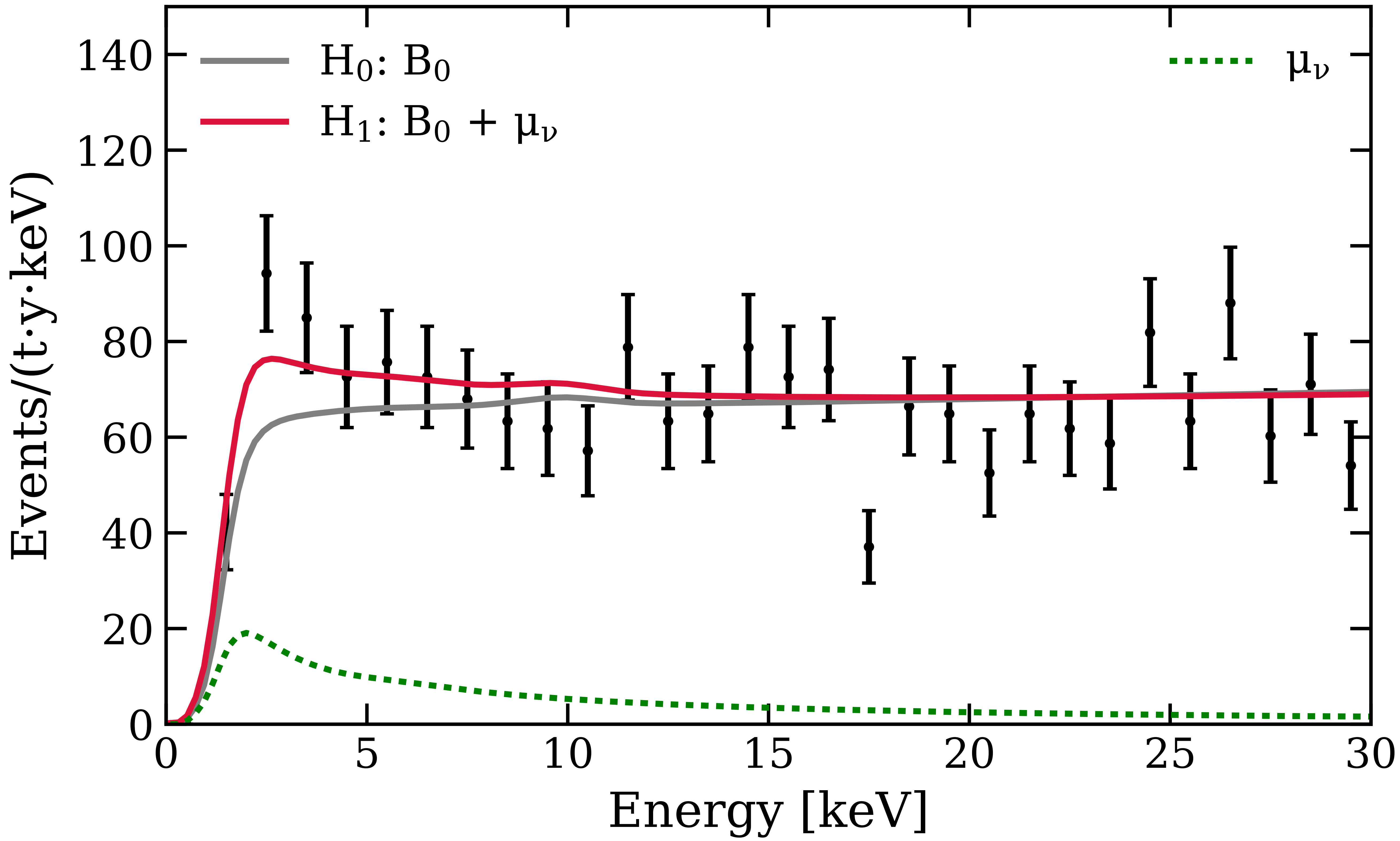
The ν Magnetic Moment Hypothesis

PRD 102 (2020) 072004

- SM extensions ➞ **magnetic moment μ_ν** enhancing ν–e⁻ cross section **at low energy**
- Cherry on top, $\mu_\nu \gtrsim 10^{-15}\,\mu_B$ ➞ neutrinos may be **Majorana** fermions

Neutrino magnetic moment hypothesis favoured over B_0 at **3.2σ**





The ν Magnetic Moment Hypothesis

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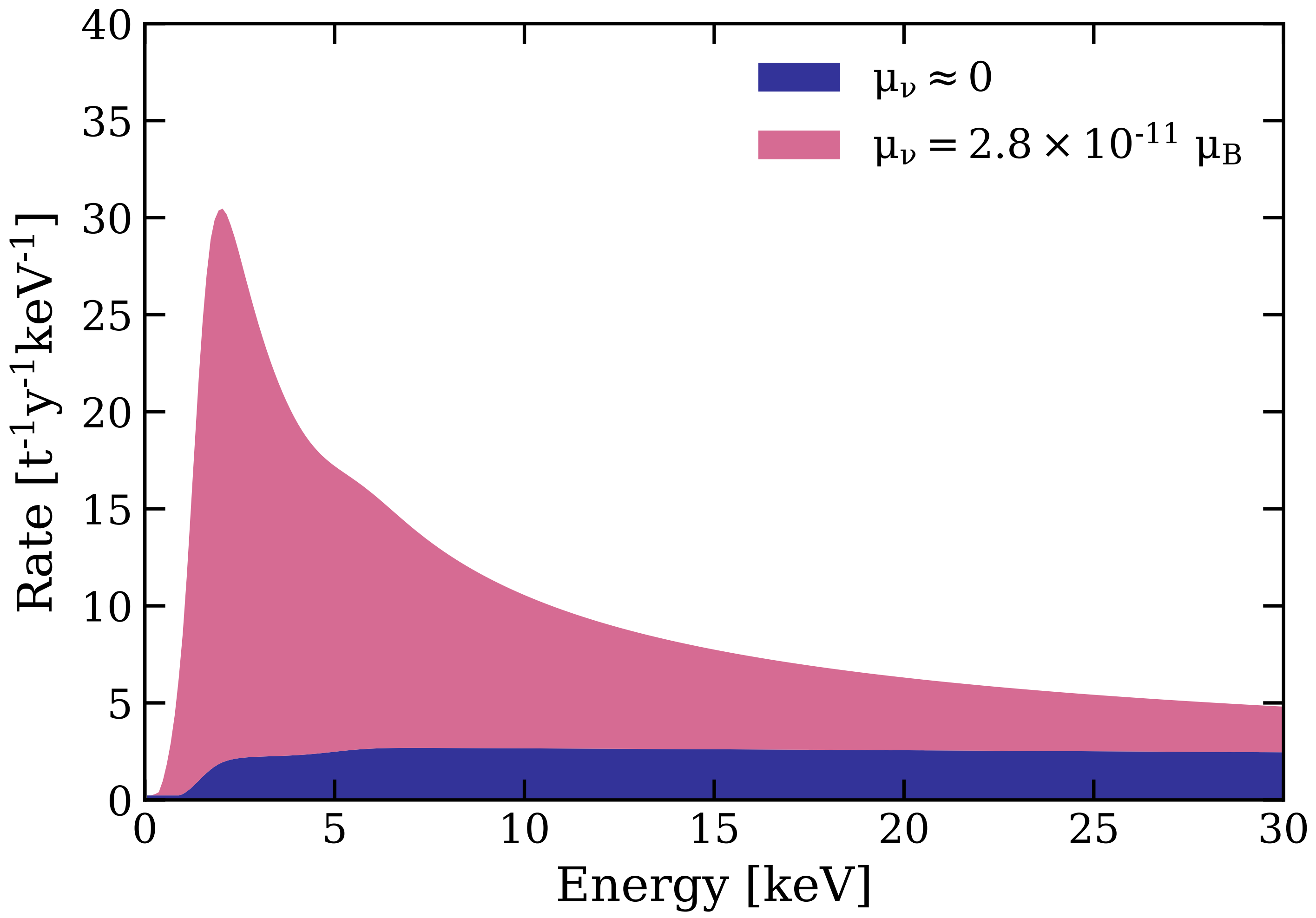
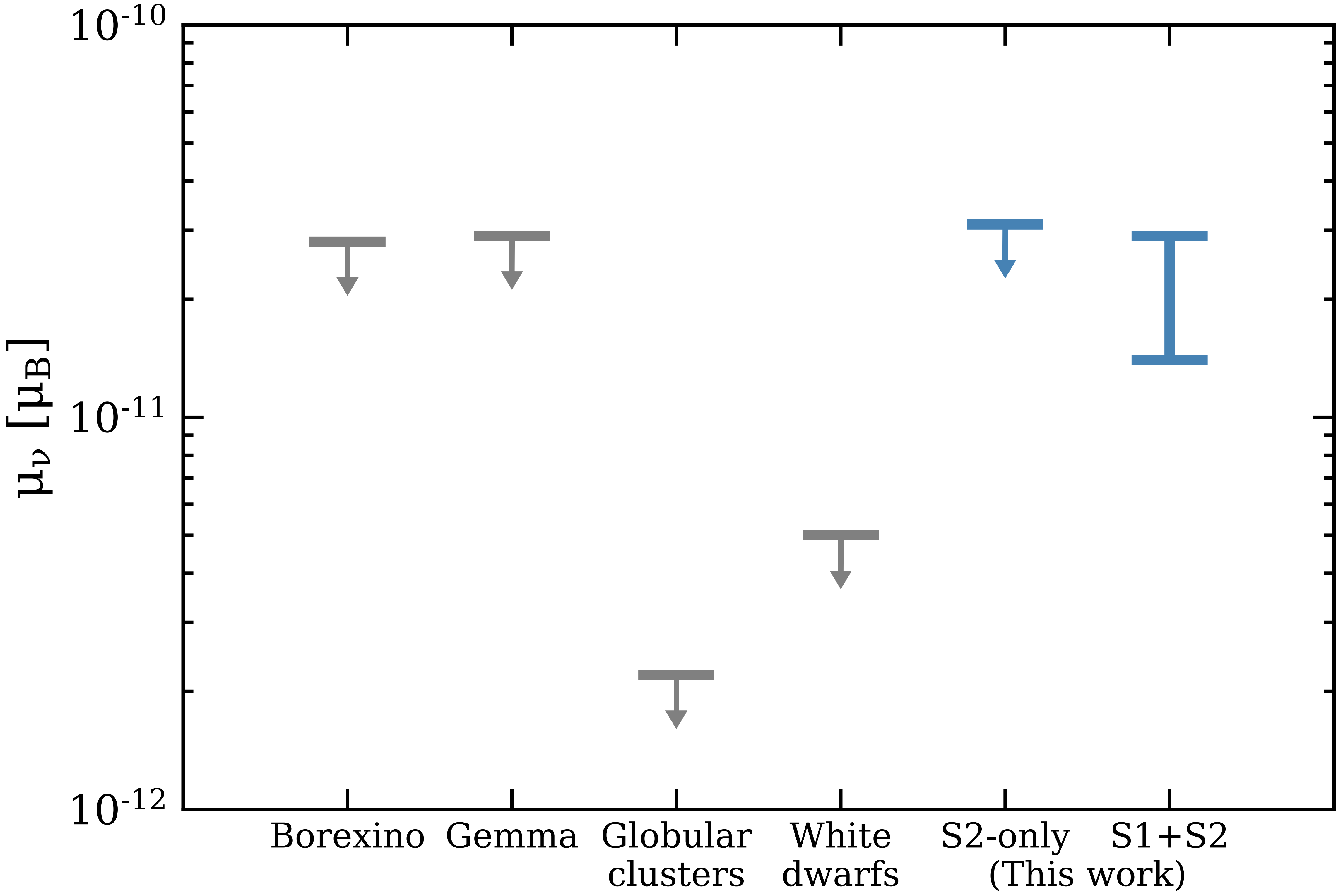
- SM extensions → **magnetic moment μ_ν** enhancing ν–e⁻ cross section **at low energy**
- Cherry on top, $\mu_\nu \gtrsim 10^{-15}\,\mu_B$ → neutrinos may be **Majorana** fermions
- **Strong tension** with astrophysical limits but consistent with comparable Borexino results

Neutrino magnetic moment hypothesis favoured over B_0 at **3.2σ**





The Bosonic Dark Matter Hypothesis

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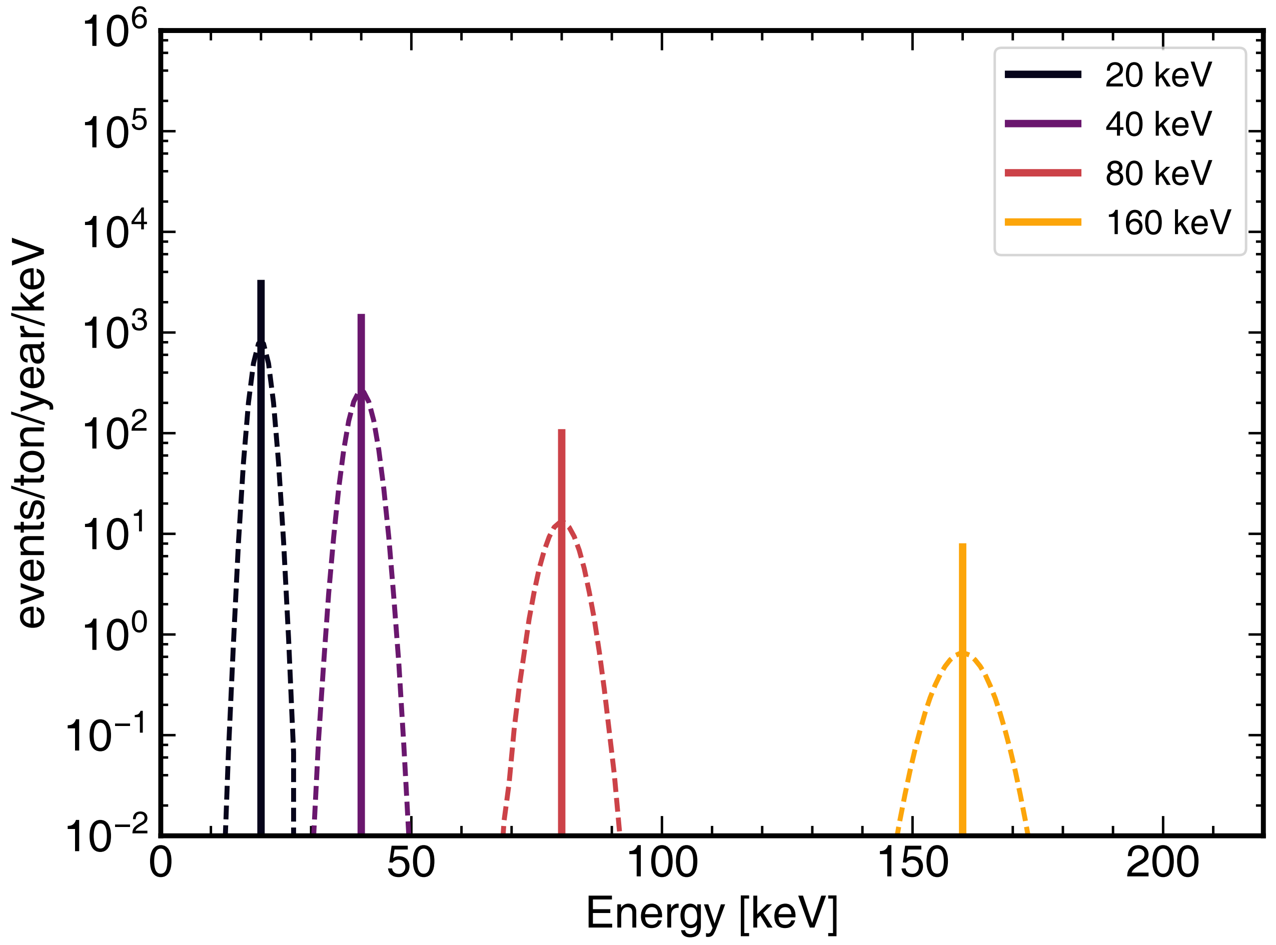
- Searching for two main components as **monoenergetic peaks**
  → **Axion-Like Particles** ≈ axions ($\propto (g_{ae})^2$) with higher masses
  → **Dark photons**, could couple with photons ($\propto \kappa^2$) and be absorbed by photoelectric effect



- Most significant at **(2.3 ± 0.2) keV/c²** (favoured at 3σ)
- No excess above 3σ → upper limits on g_{ae} and κ
- **Best limits overall**