Tsinghua University

Electronic Recoil Events in XENON1T

arXiv: 2006.09721

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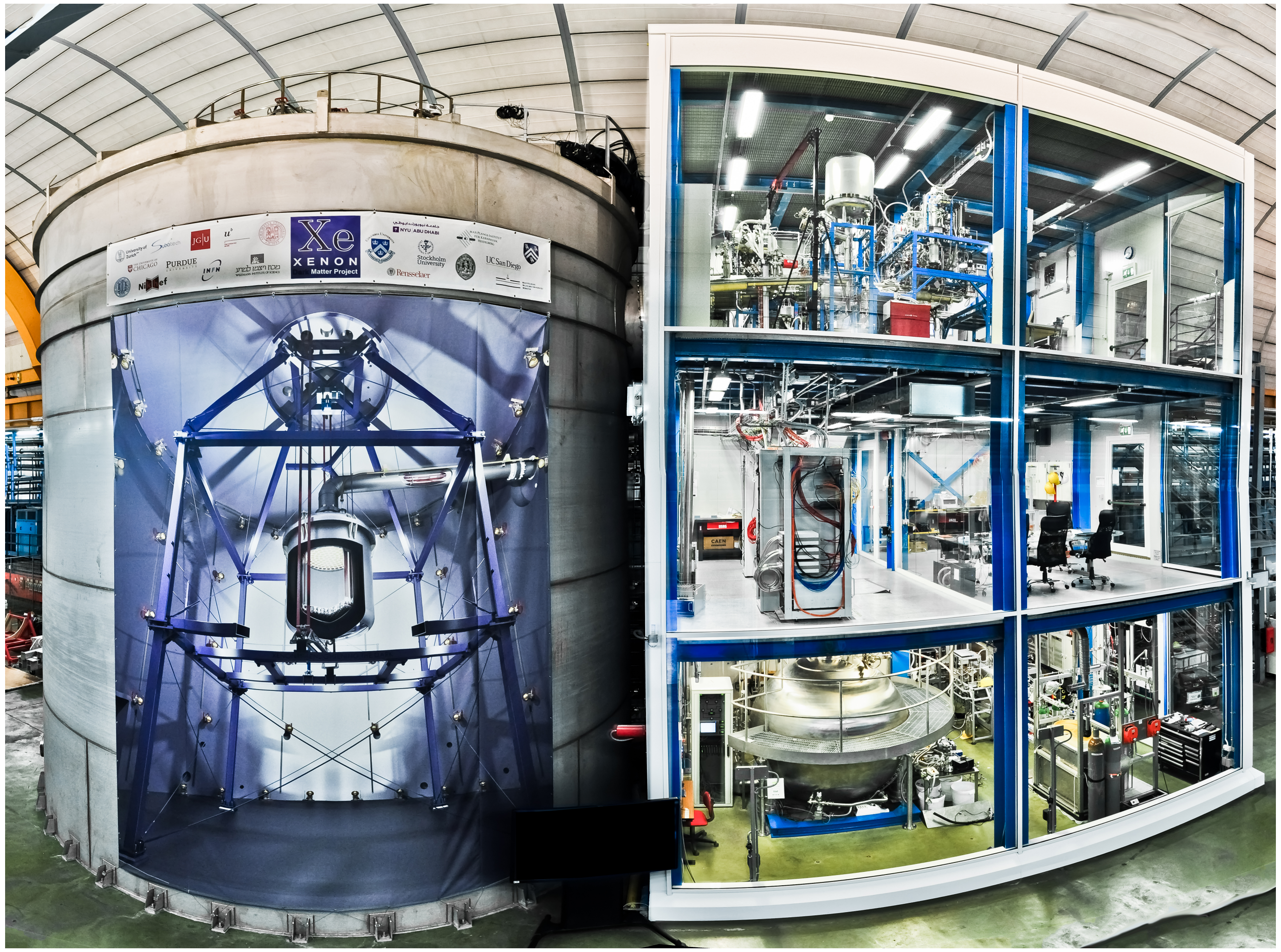
On behalf of the
XENON Collaboration
+ X. Mougeot

PKU, Beijing
Sep 26, 2020



The XENON Collaboration: ~170 scientists

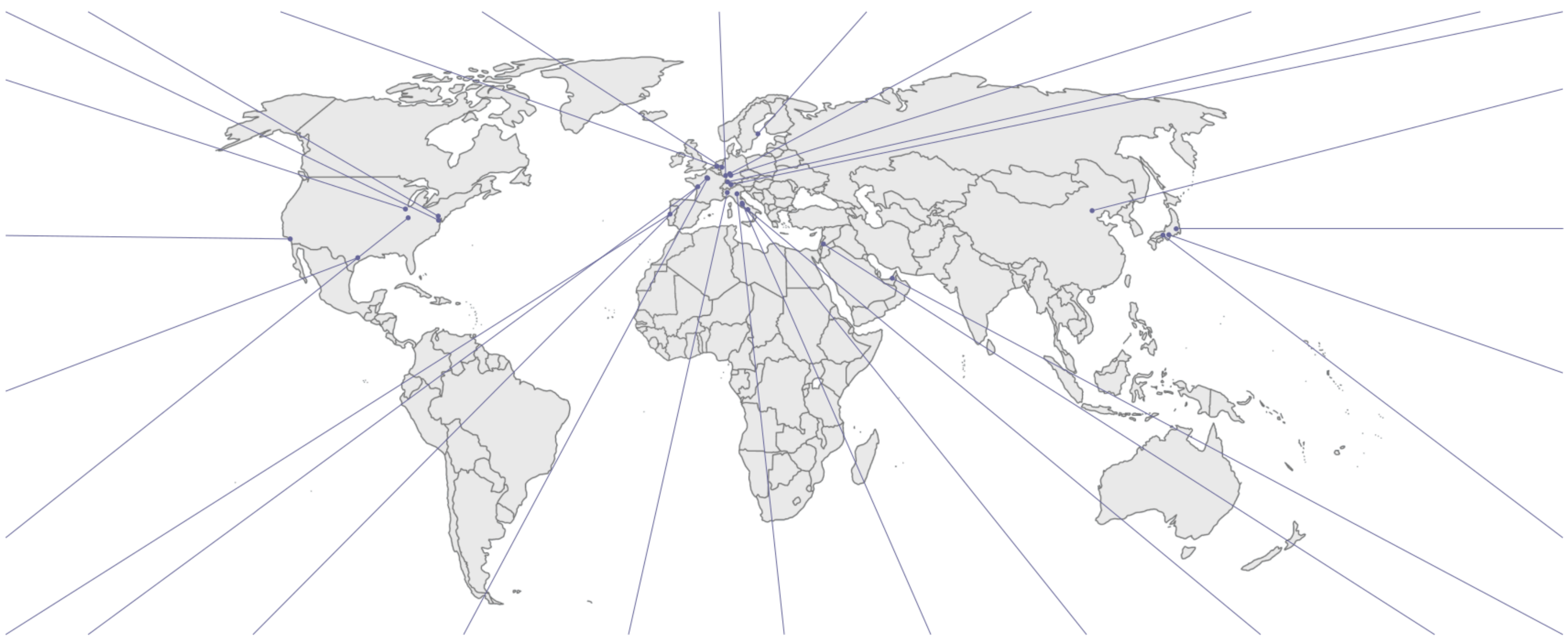
Columbia | RPI | Nikhef | Muenster | KIT | Stockholm | Mainz | MPIK, Heidelberg | Freiburg | Zurich

Chicago

UCSD

Rice

Purdue



Tsinghua

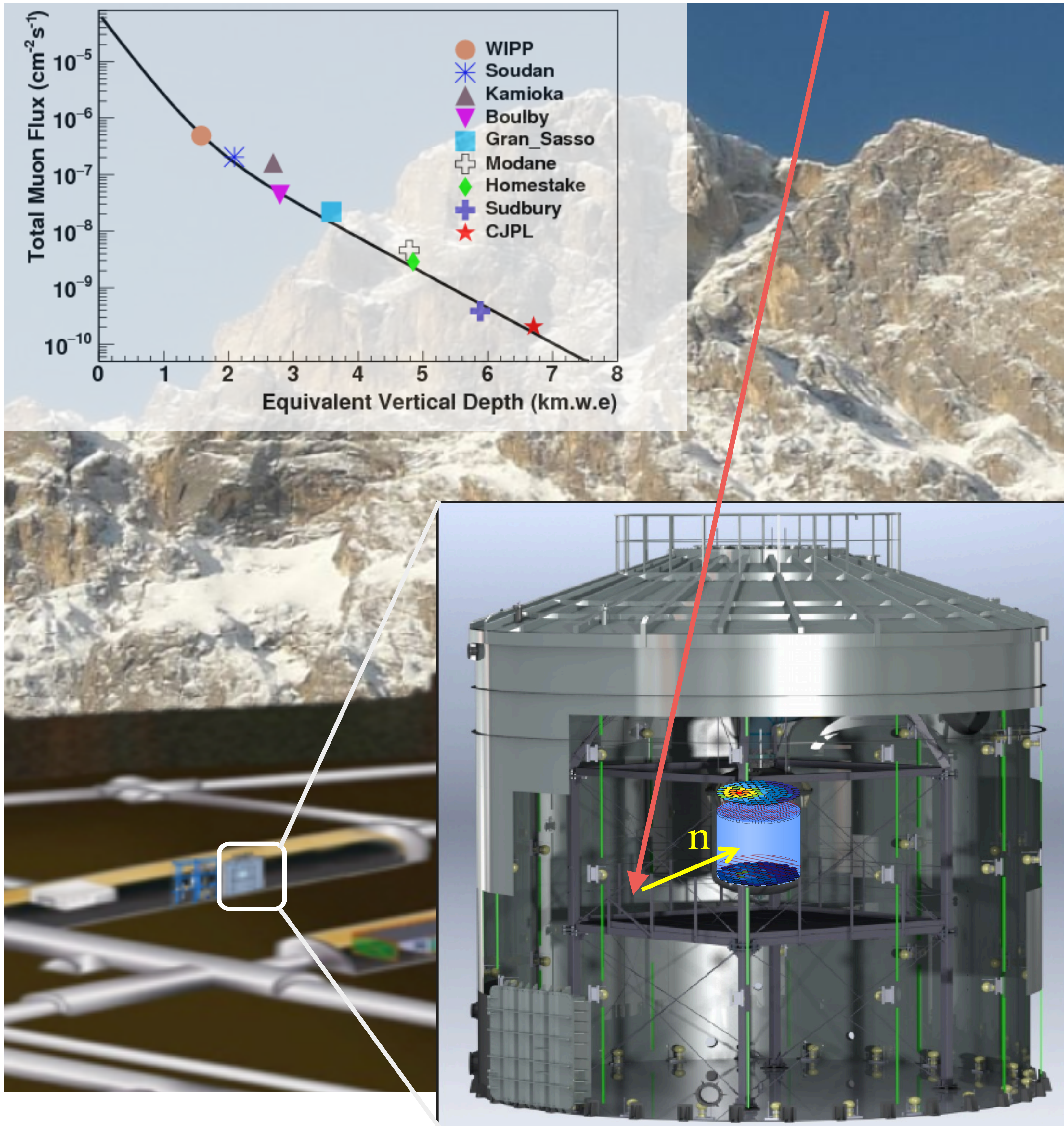
Tokyo

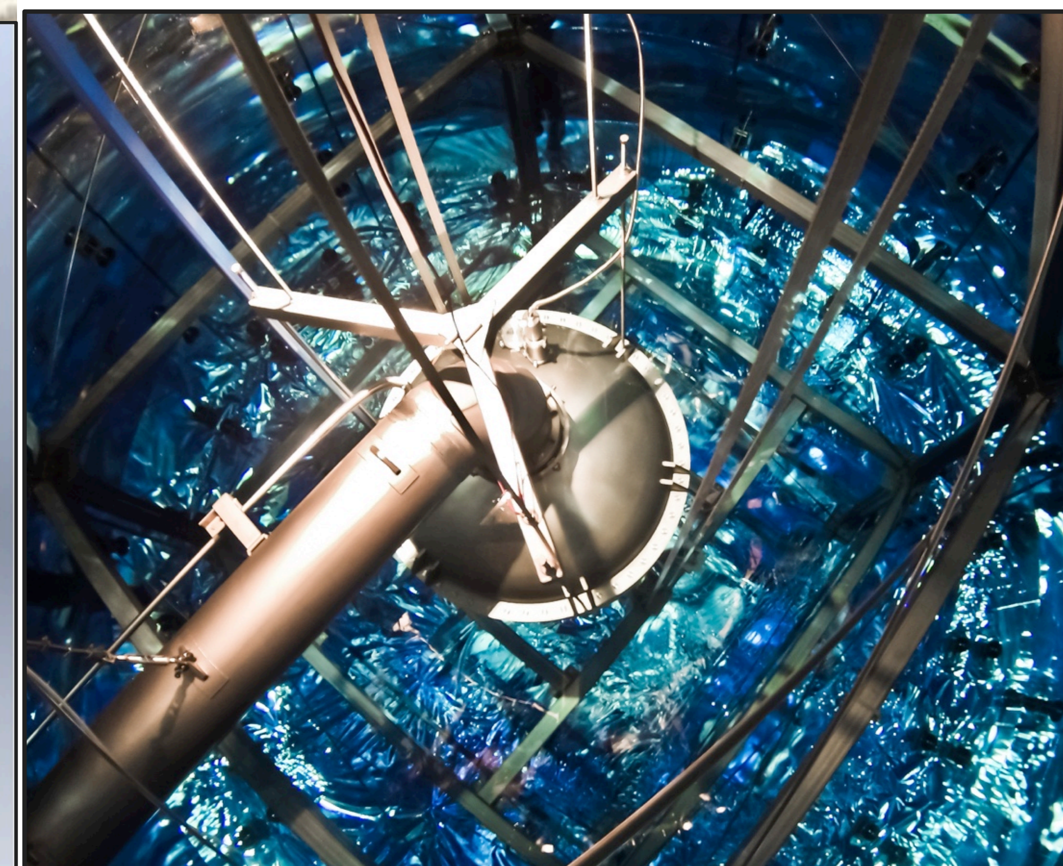
Nagoya

Kobe

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

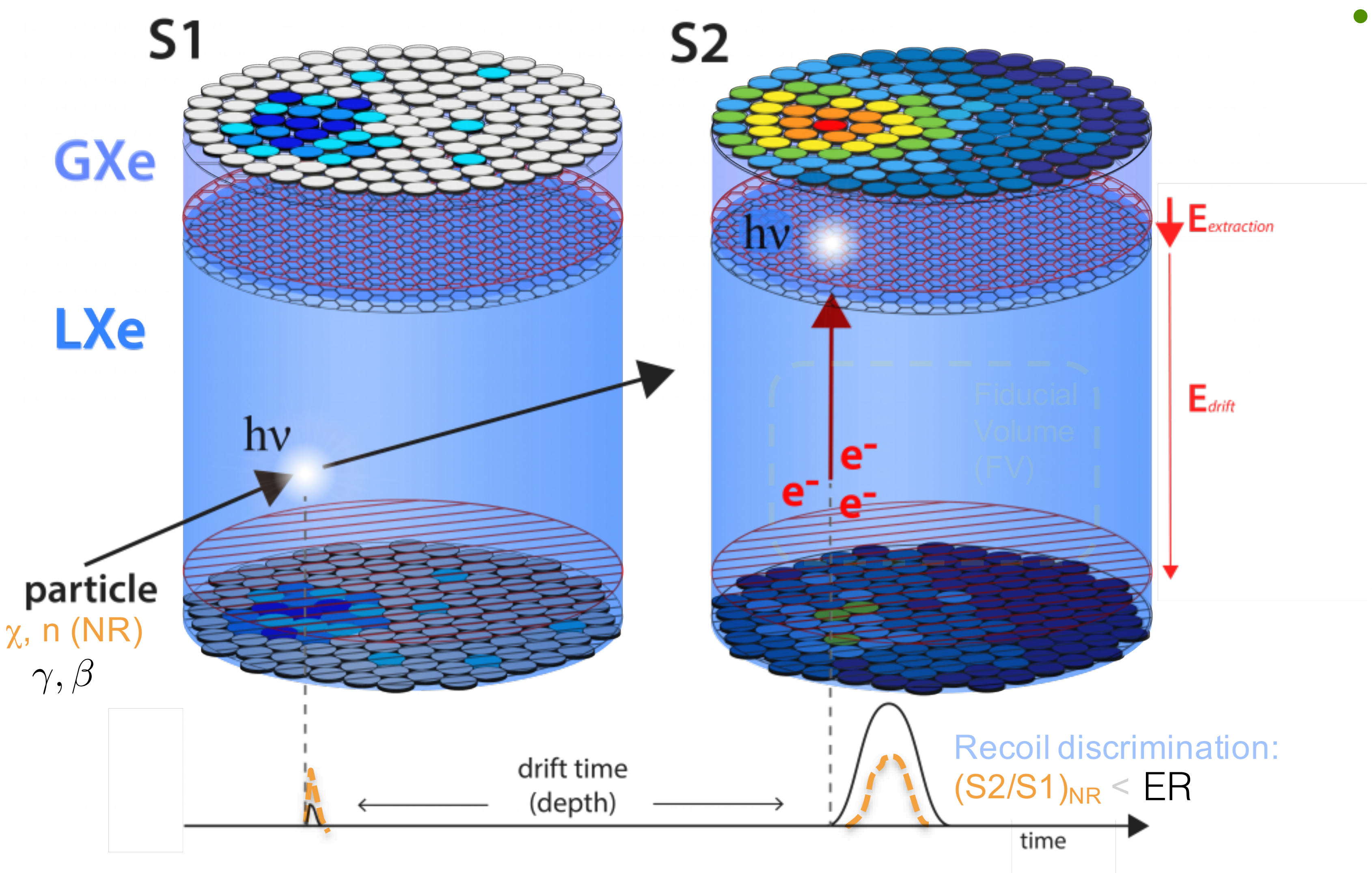
Gran Sasso —The XENON Shield



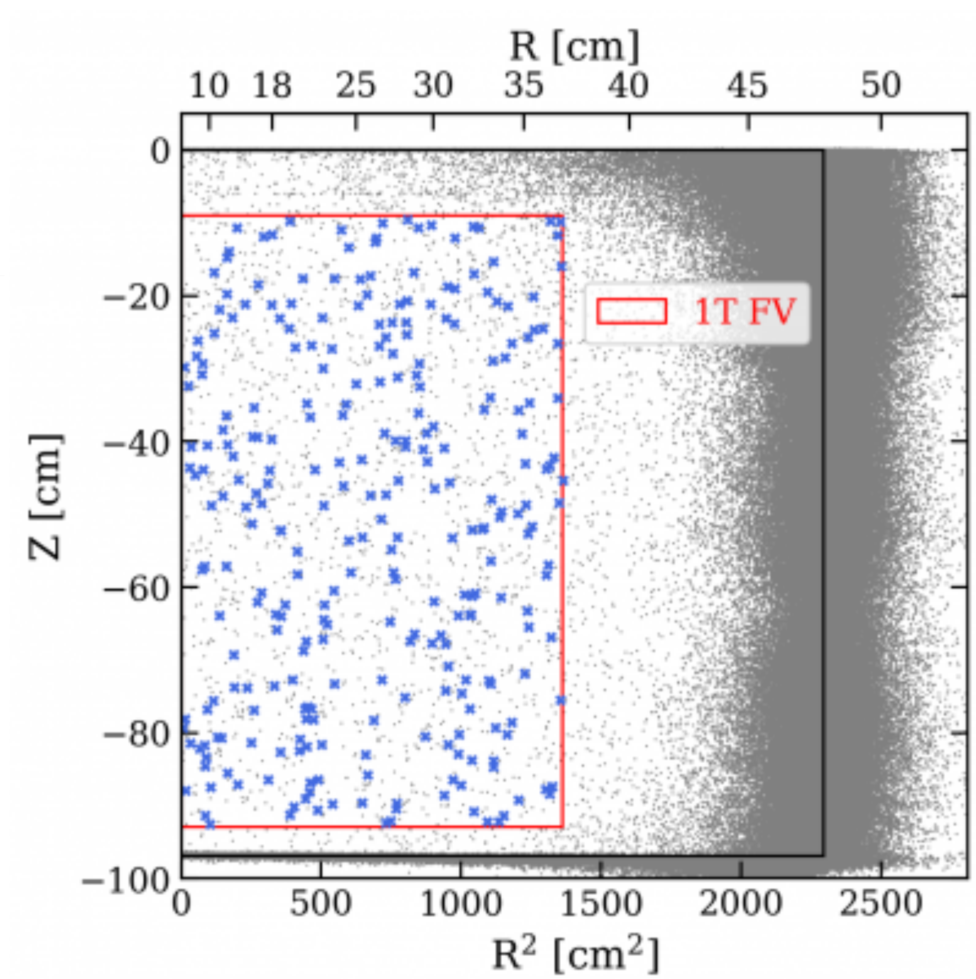


Two-phase Xe Time Projection Chamber

- **Scintillation light - S1**
- **Ionization electron -S2**



- two signals for each event:
  - 3D event imaging: x-y (S2) and z (drift time)
  - self-shielding, surface event rejection, single vs multiple scatter events



Two-phase Xe Time Projection Chamber

- **Scintillation light - S1**
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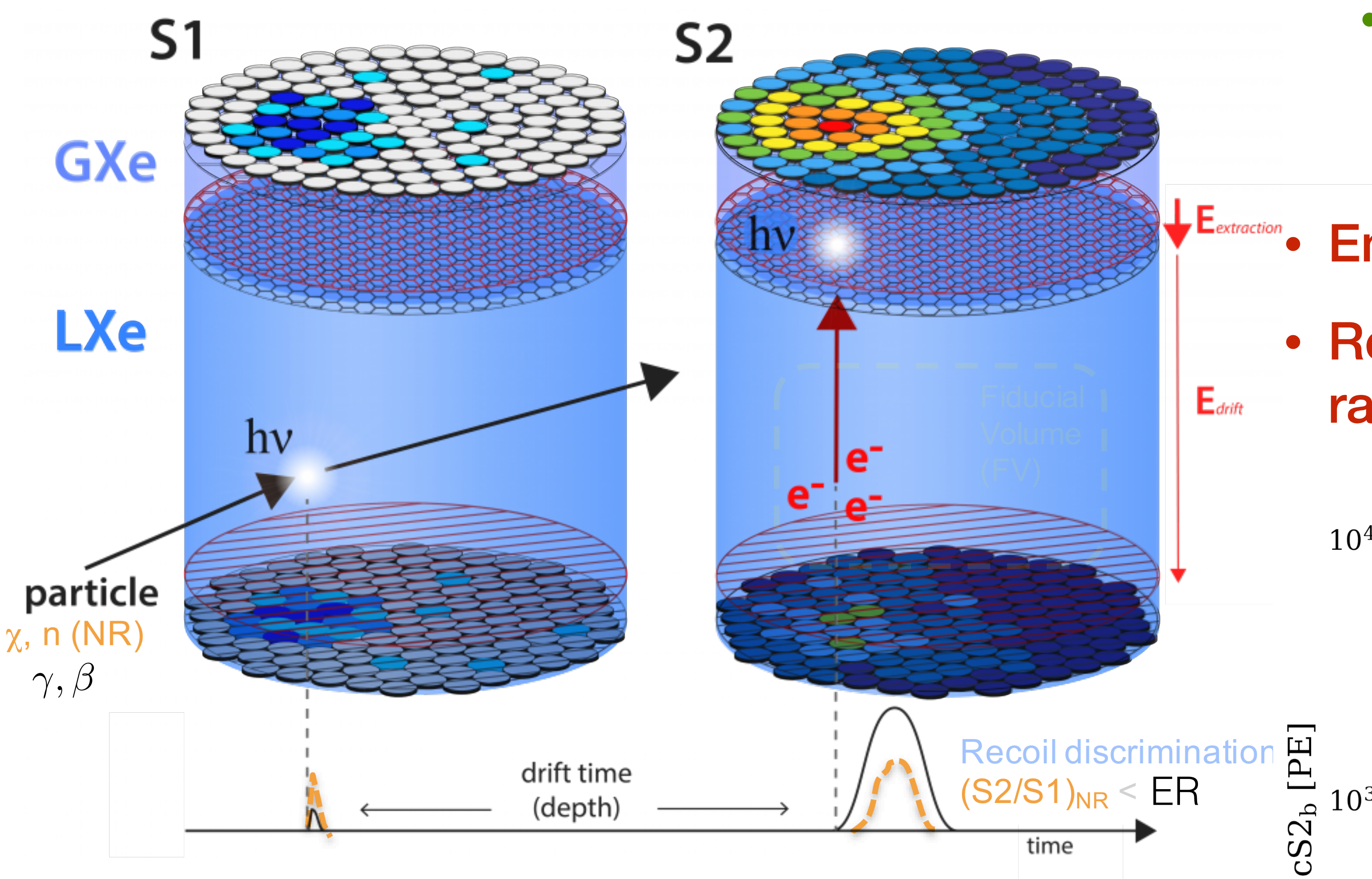
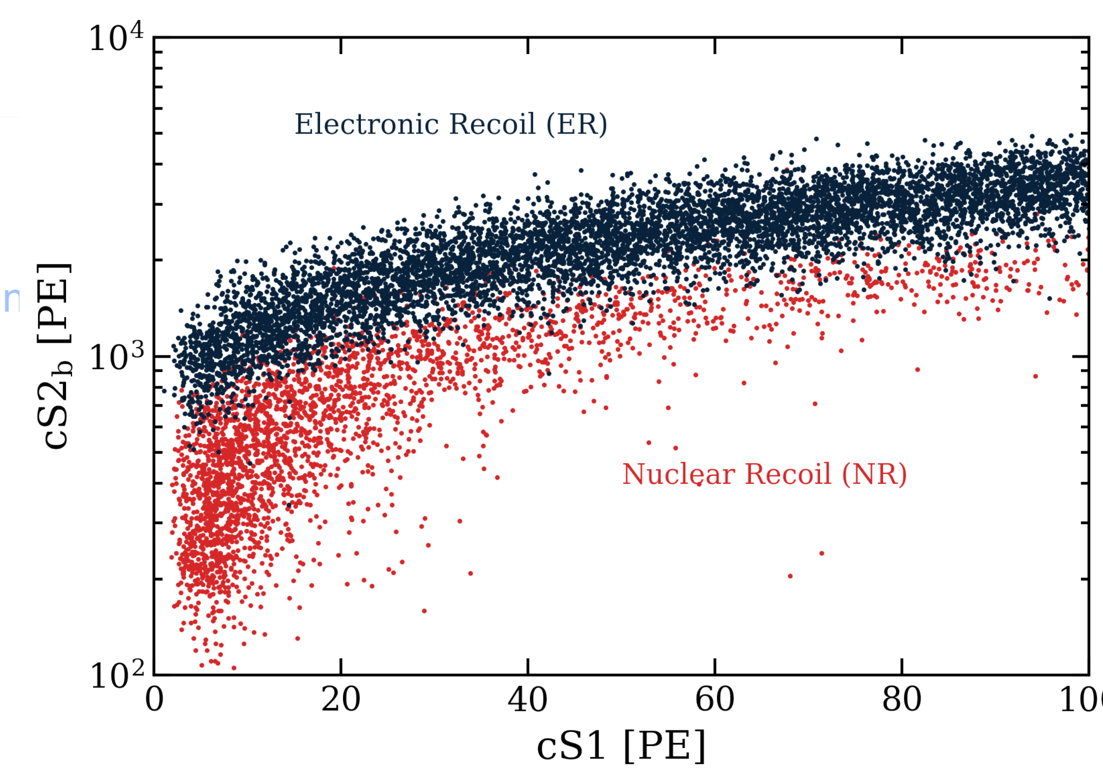
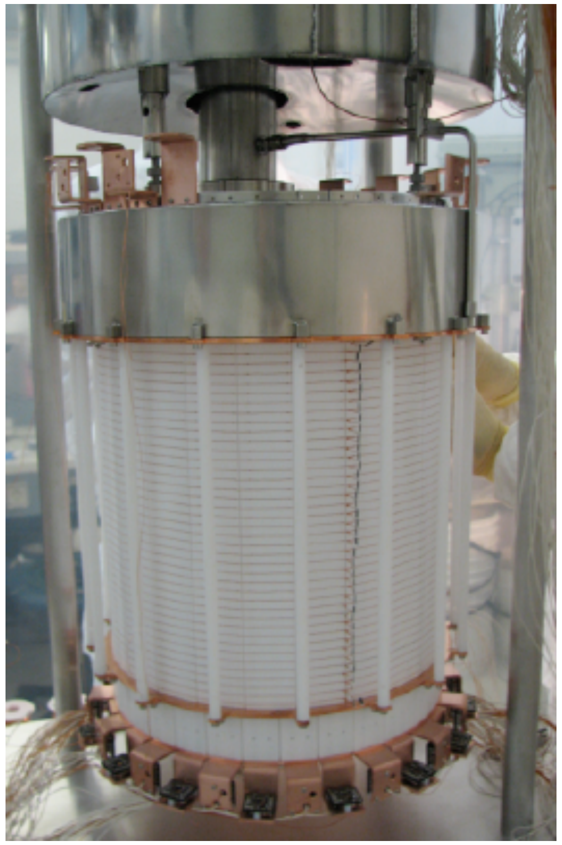
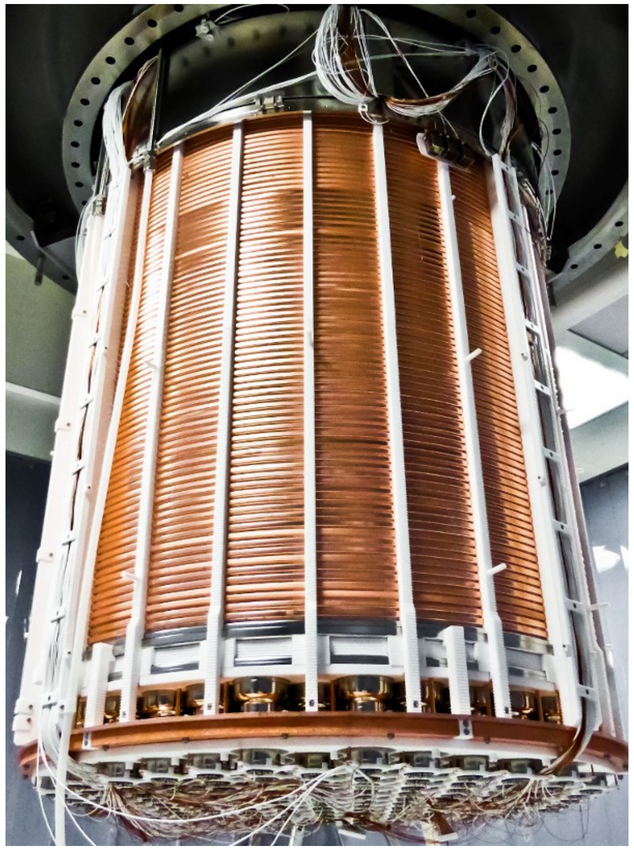


- two signals for each event:
  - 3D event imaging: x-y (S2) and z (drift time)
  - self-shielding, surface event rejection, single vs multiple scatter events
- Energy from S1 and S2 area
- Recoil type discrimination from ratio of charge (S2) to light (S1)



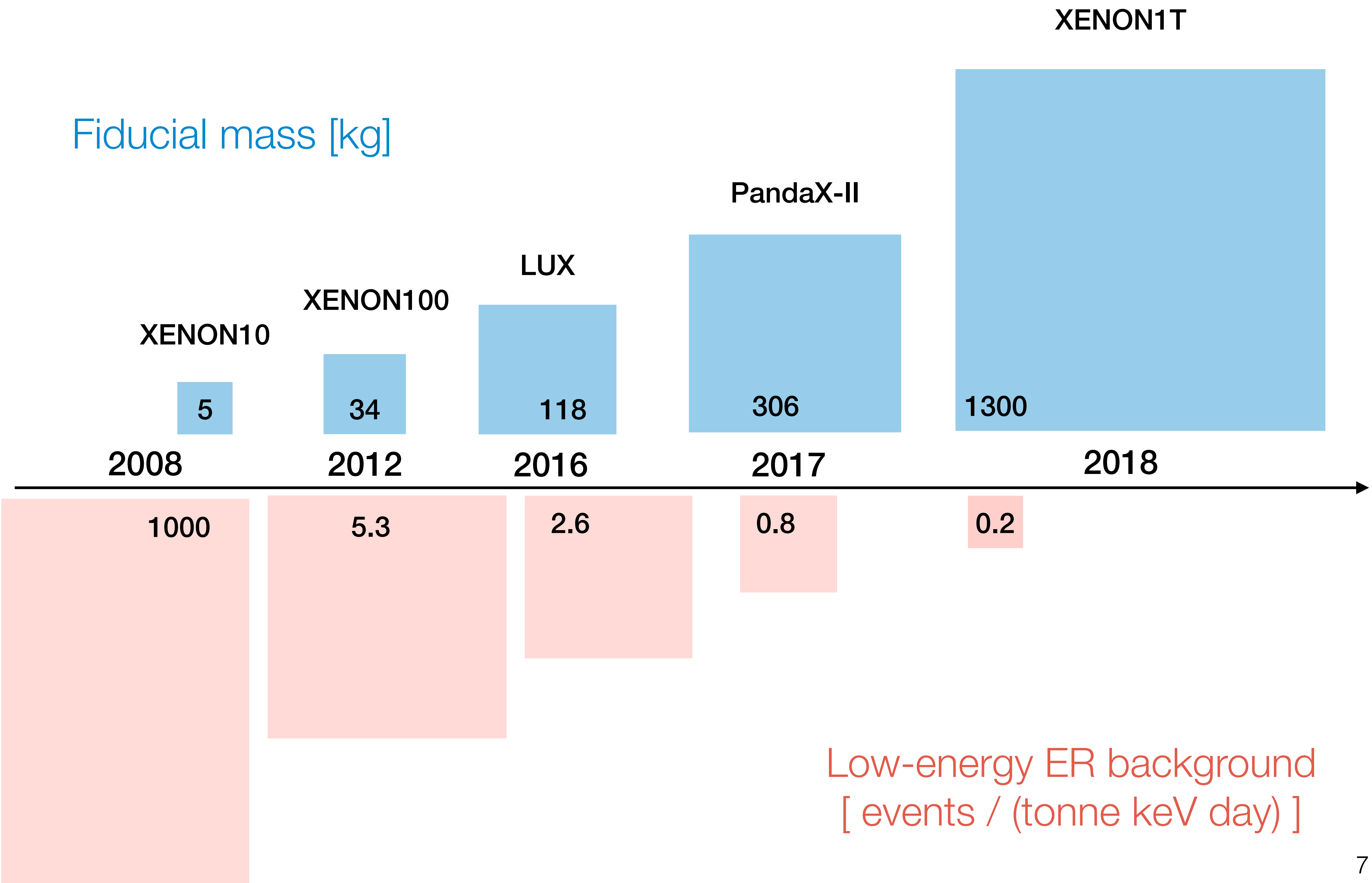
Development of XENON Program

XENON10	XENON100	XENON1T	XENONnT

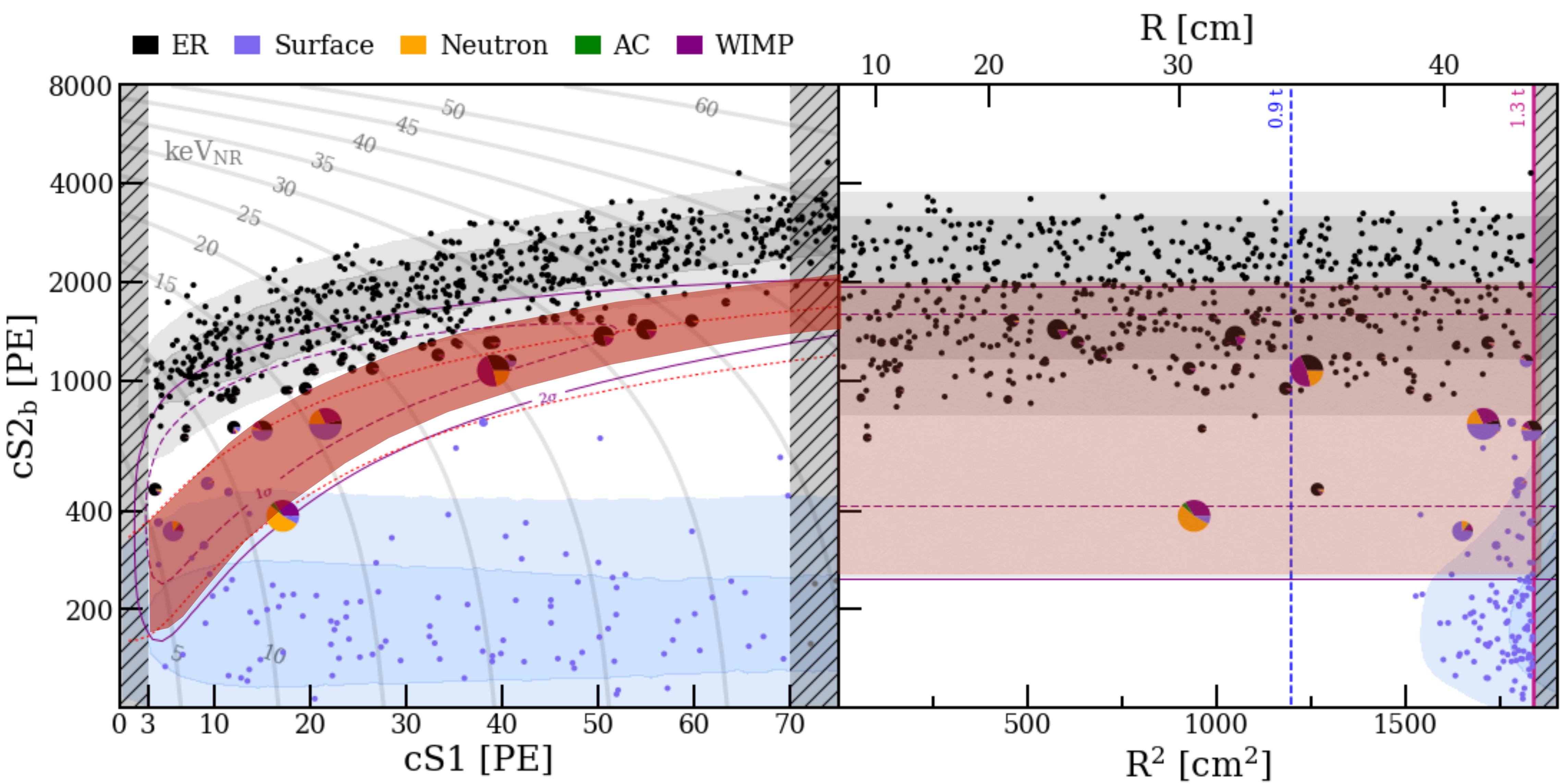

2005-2007	2008-2016	2012-2018	2019-202x
25 kg - 15cm drift	161 kg - 30 cm drift	3.2 ton - 1 m drift	8 ton - 1.5 m drift
$\sim 10^{-43}$ cm^2	$\sim 10^{-45}$ cm^2	$\sim 10^{-47}$ cm^2	$\sim 10^{-48}$ cm^2

Evolution of LXeTPCs as WIMP Detectors



XENON1T WIMPs Search - 2018

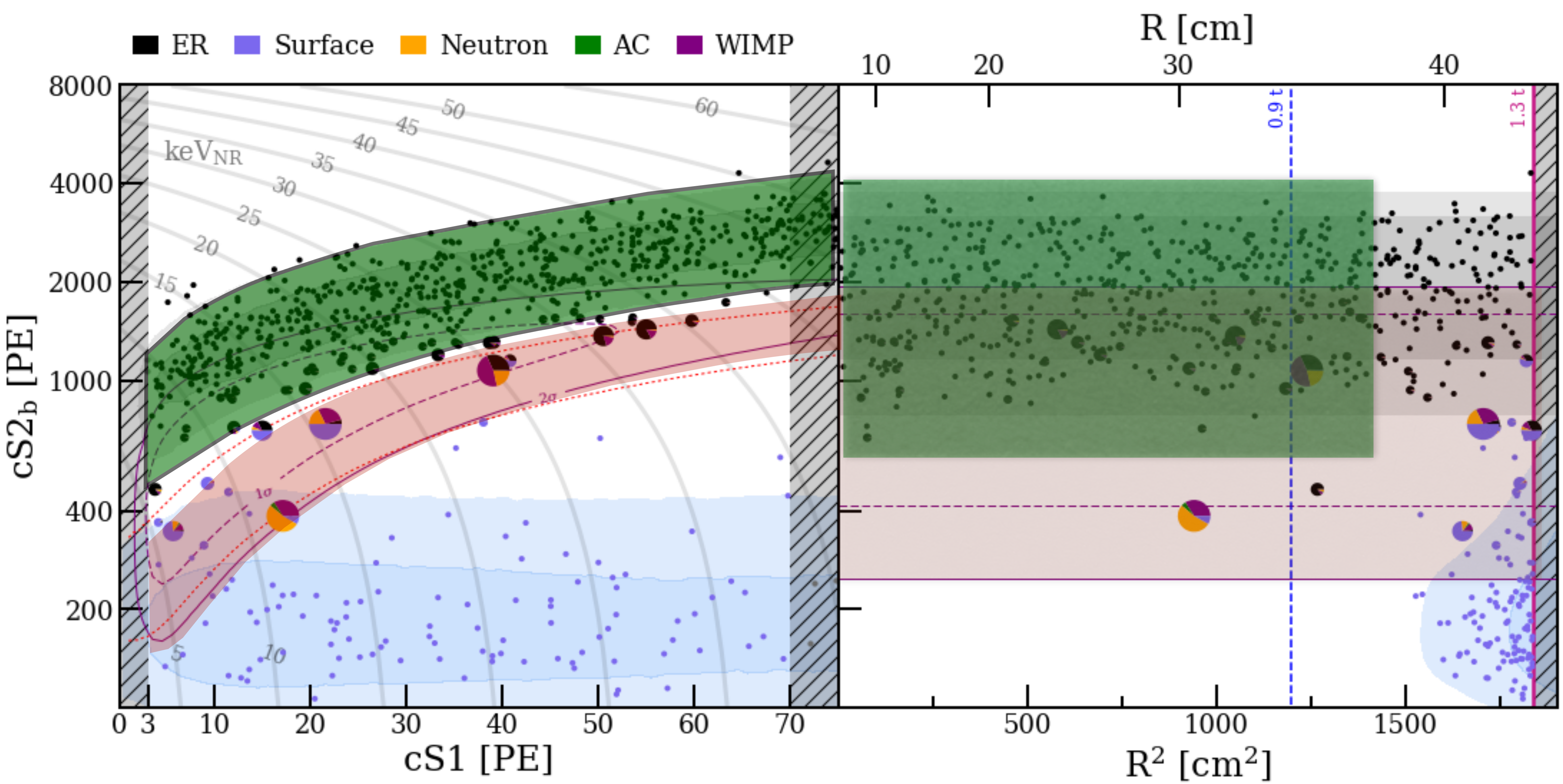
One ton-year of search for WIMPs induced nuclear recoils



Most stringent result on WIMP Dark Matter down to 3 GeV/c² masses [*PRL 121, 111302 + PRL 123, 251801*]

XENON1T Solar Axion Search - 2020

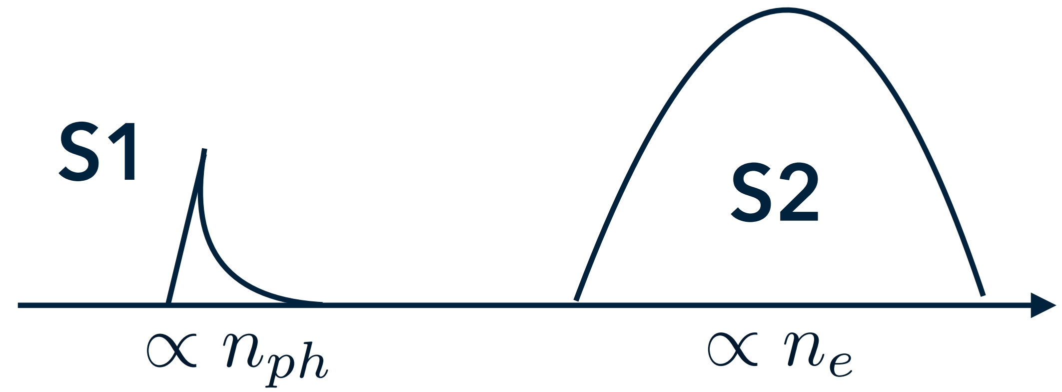
Reduced fiducial volume to search for ER signals



Adding additional volume is not as helpful, since we are limited by ER background

Energy Response in XENON1T

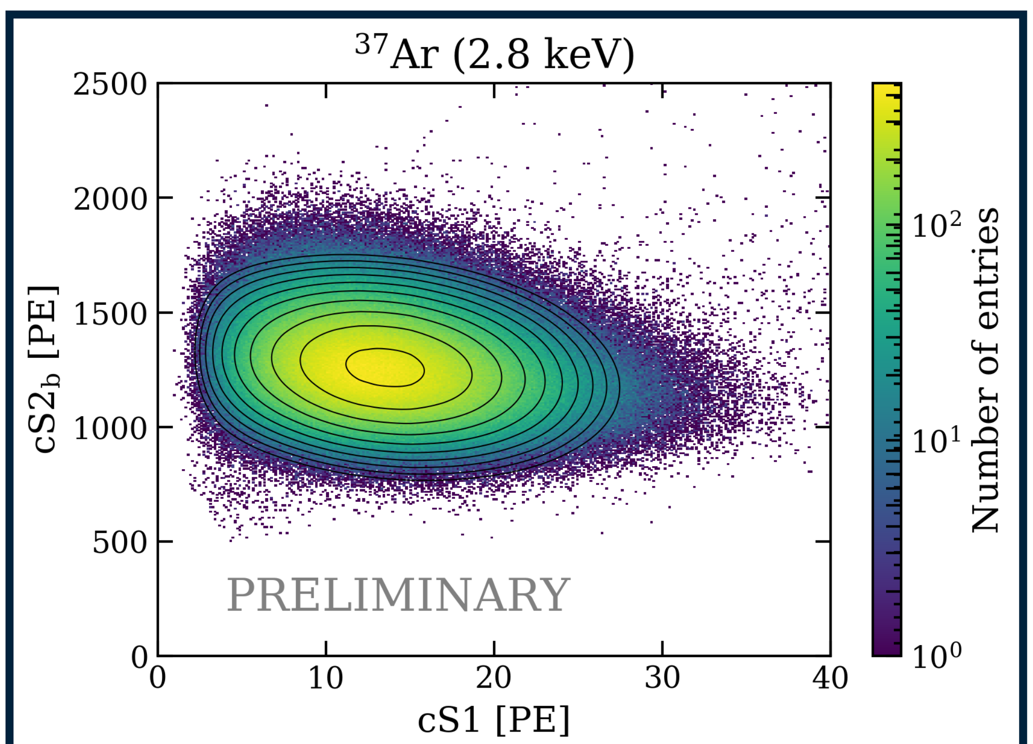
$$E = W(n_{ph} + n_e)$$

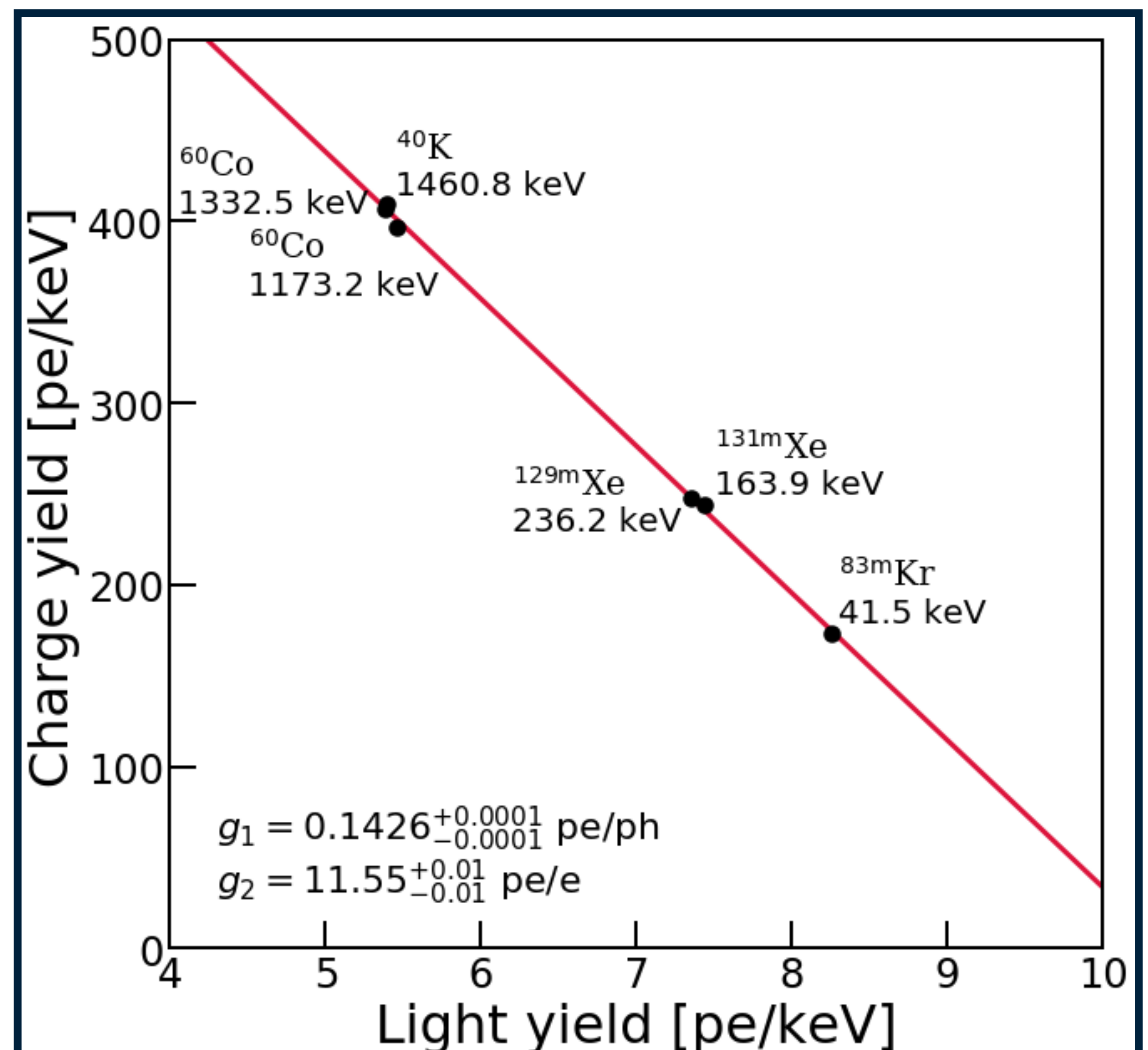


$$E = W\left(\frac{S1}{g_1} + \frac{S2}{g_2}\right)$$

$$\frac{S2}{E} = -\frac{g_2}{g_1}\frac{S1}{E} + \frac{g_2}{W}$$

g1 and g2: detector-specific gain **constants**



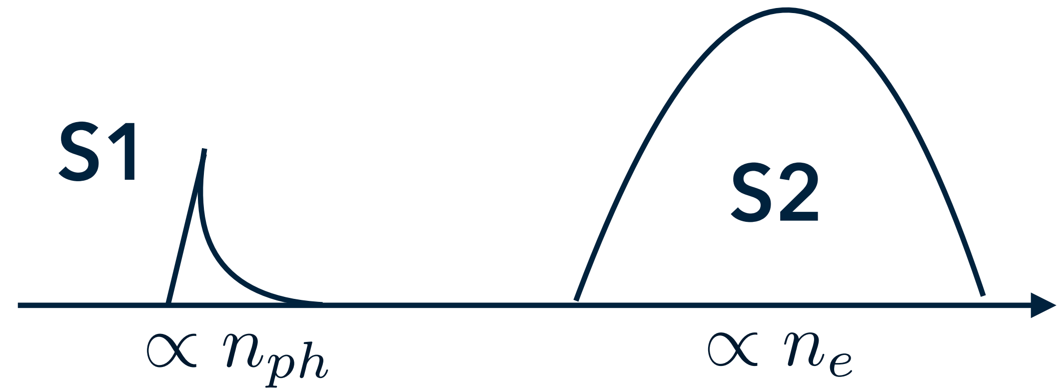


Calibration of XENON1T down to **2.8 keV**

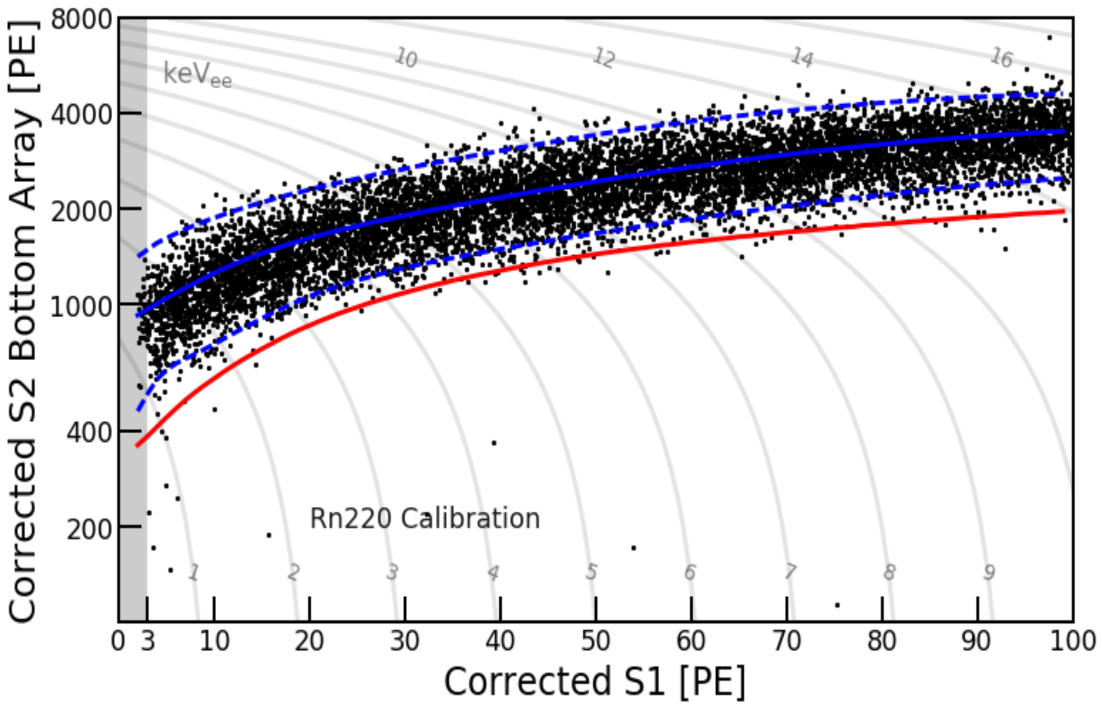
Energy as Analysis Space

$$E = W(n_{ph} + n_e)$$

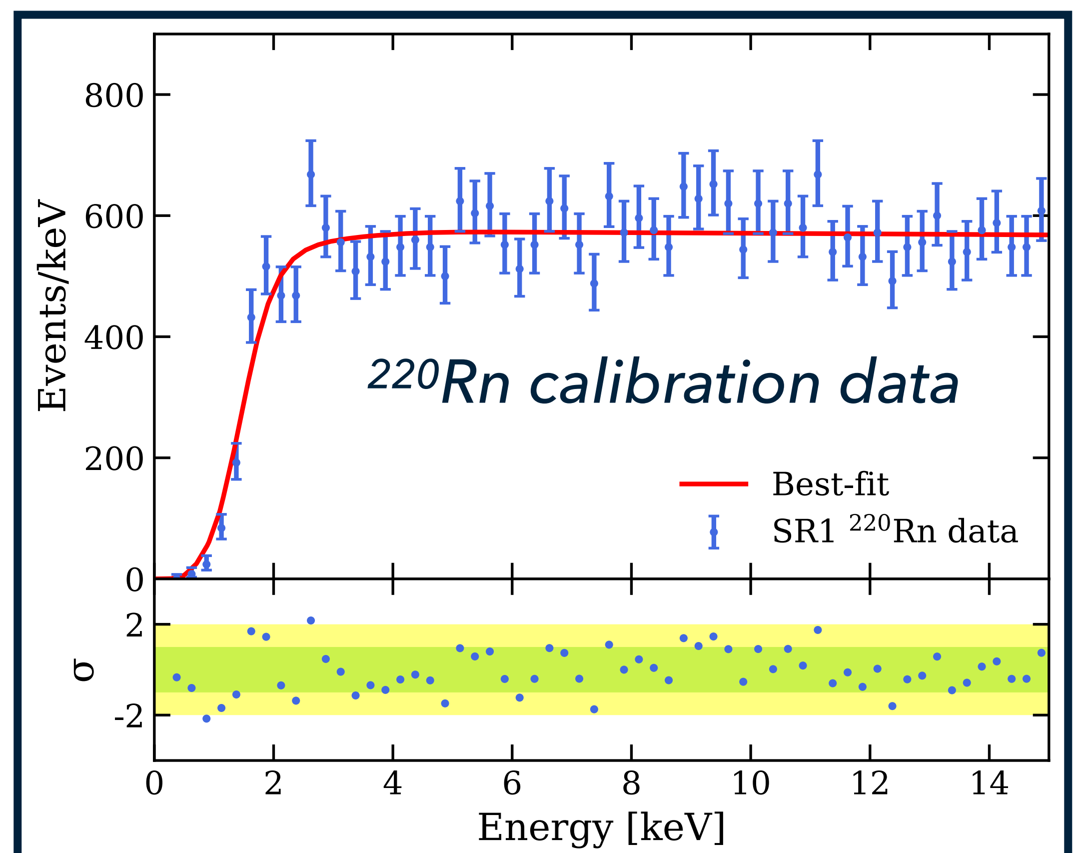
$$E = W\left(\frac{S1}{g_1} + \frac{S2}{g_2}\right)$$



$$\frac{S2}{E} = -\frac{g_2}{g_1}\frac{S1}{E} + \frac{g_2}{W}$$

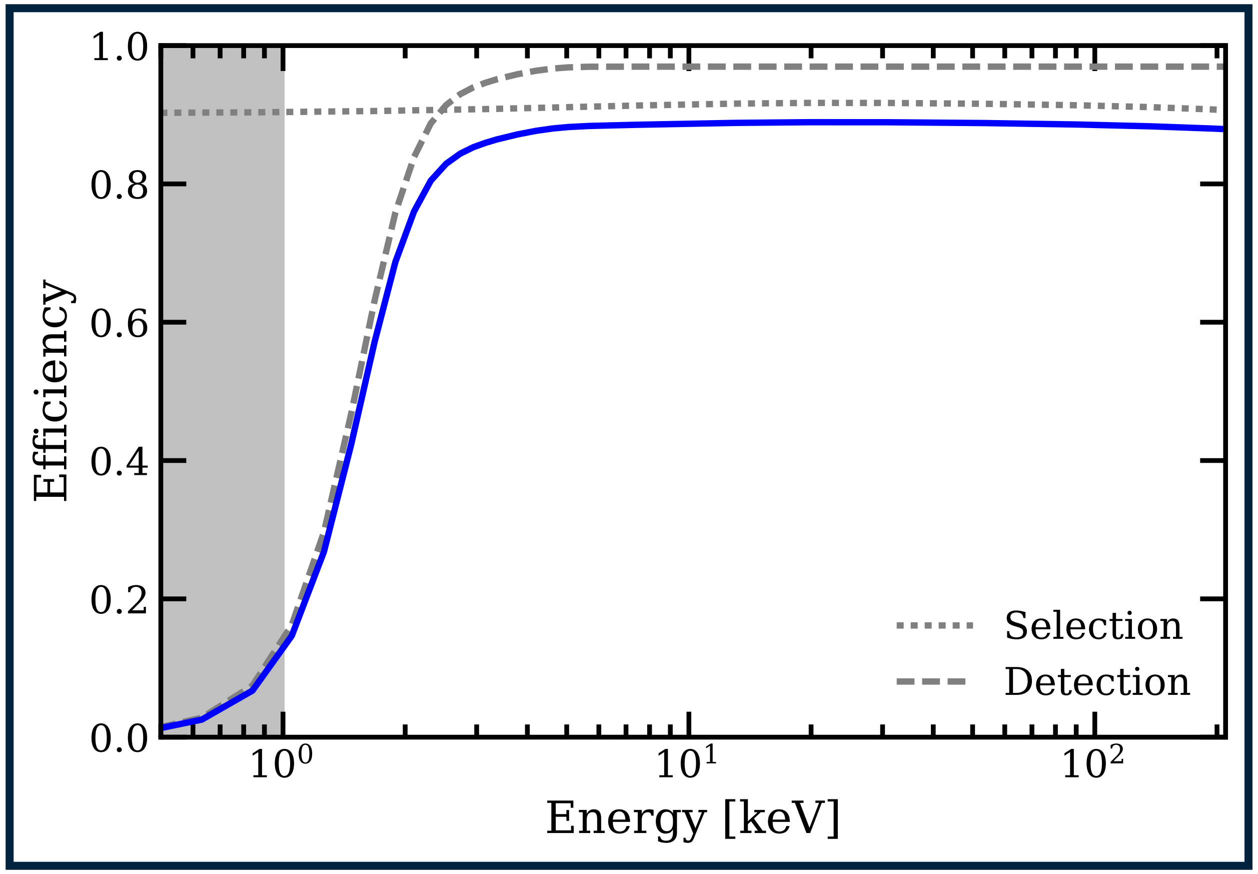


2-3D analysis w/ discrimination



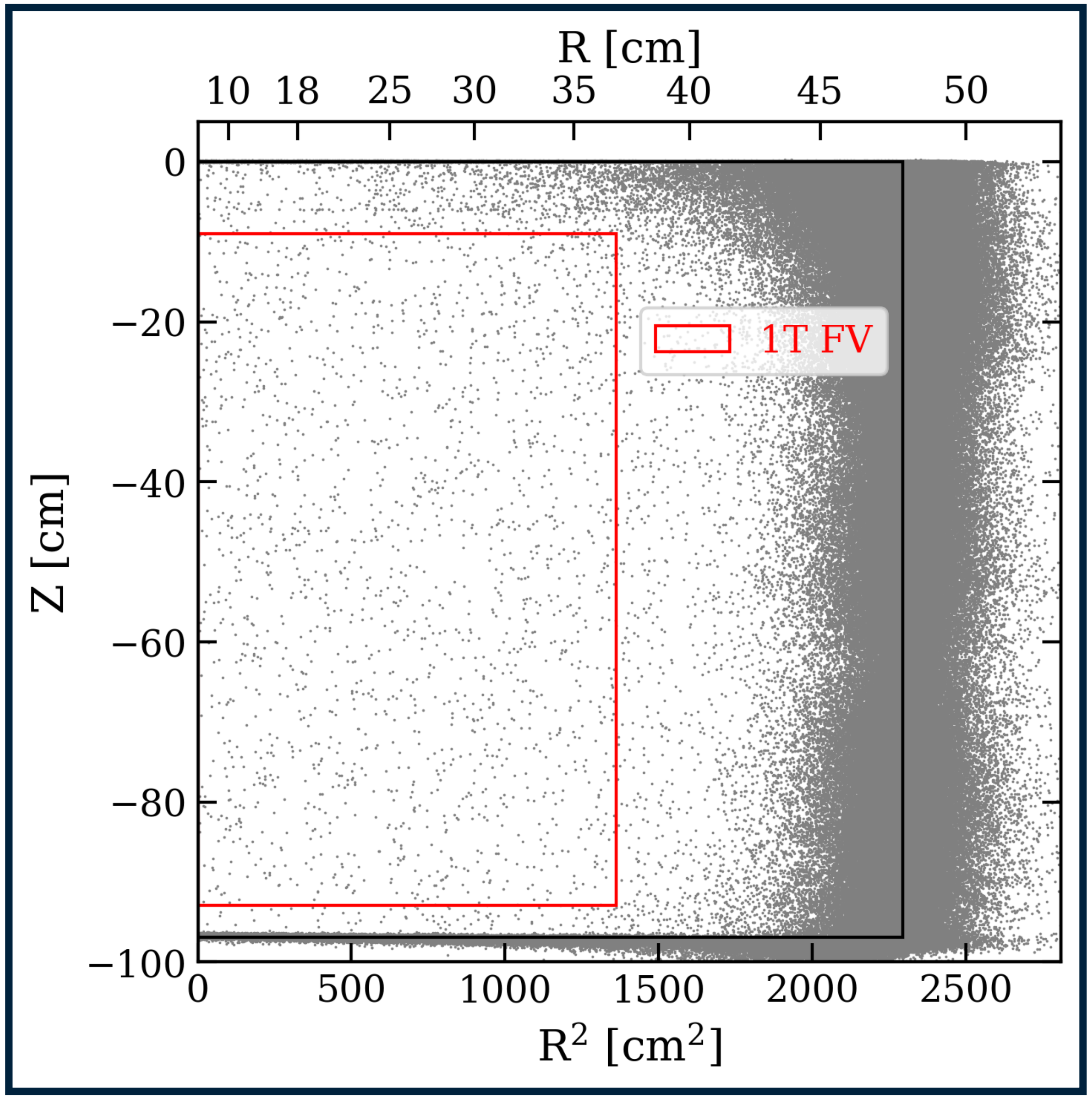
1D energy spectrum

Data Selection and Signal Efficiency



Similar selection criteria as WIMPs search in 2018

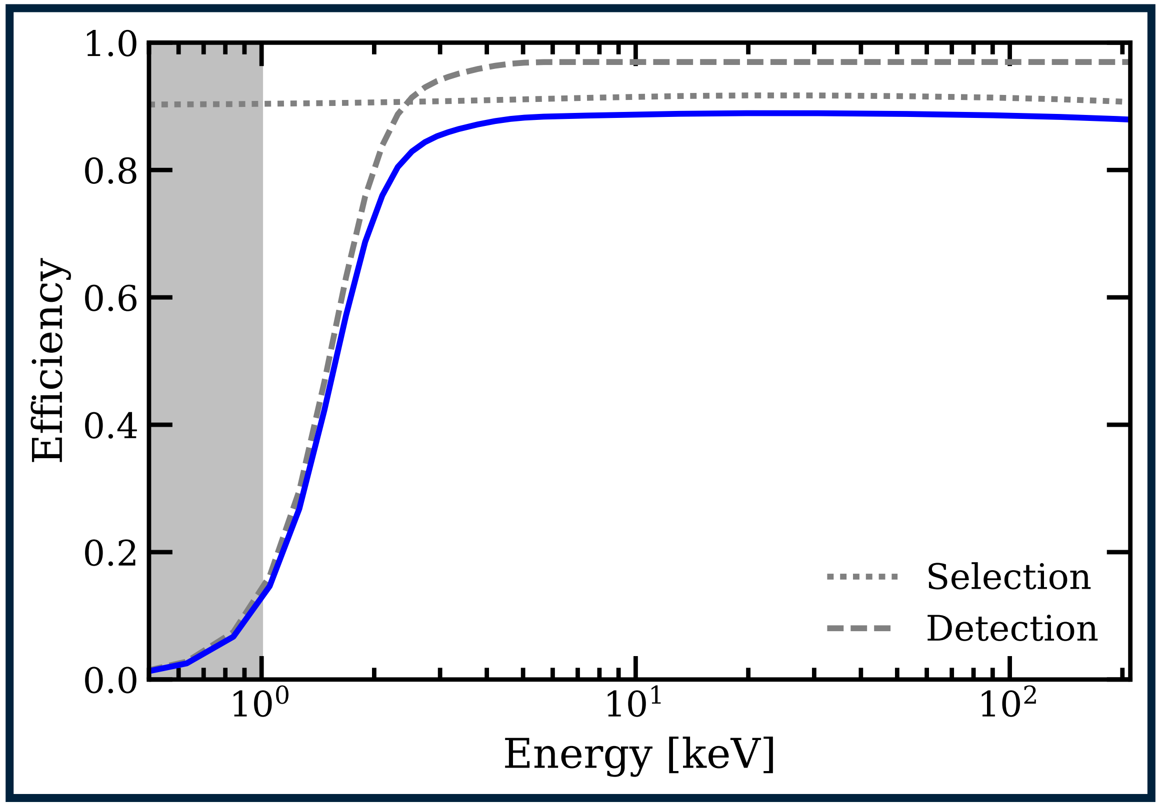
Reduced fiducial volume for ER search



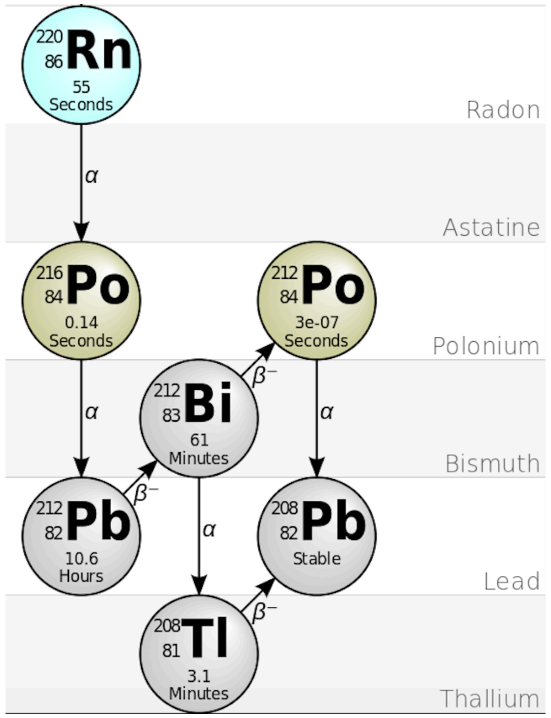
Higher S2 threshold to remove surface background and accidentals

High acceptance for ER energy > 2 keV

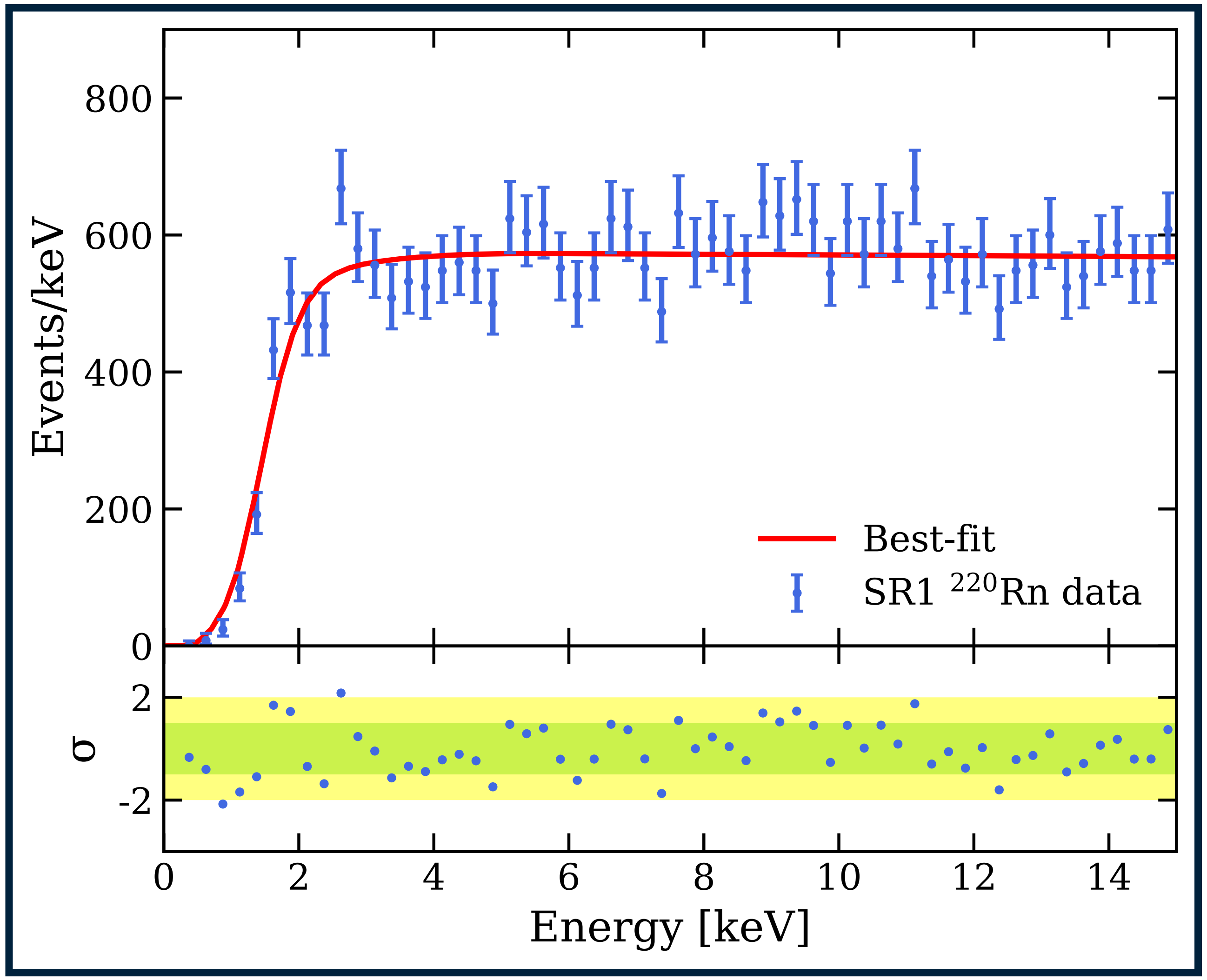
XENON1T’s Response to Betas



Decent matching between data and MC down to the energy threshold <~1keV !

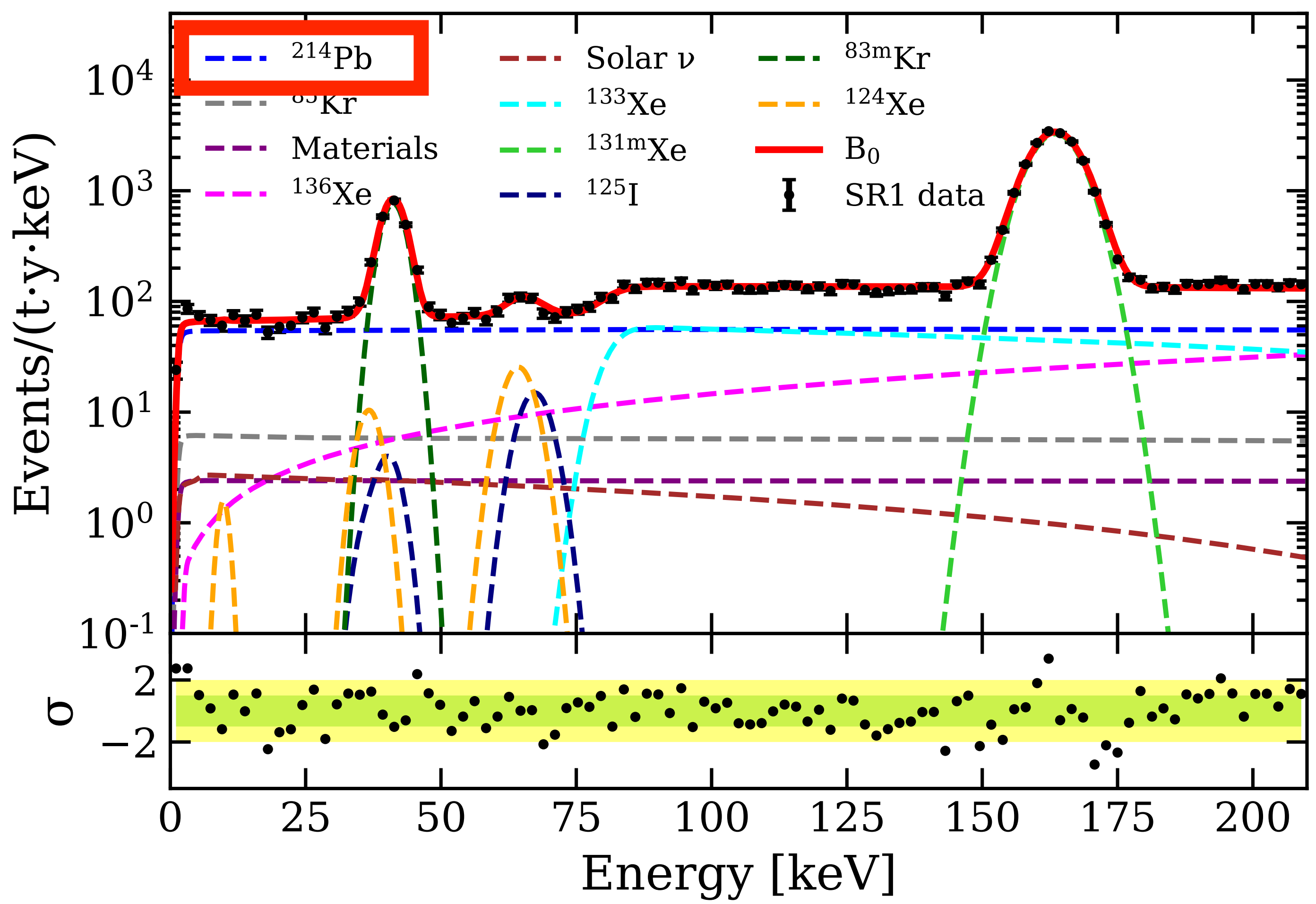


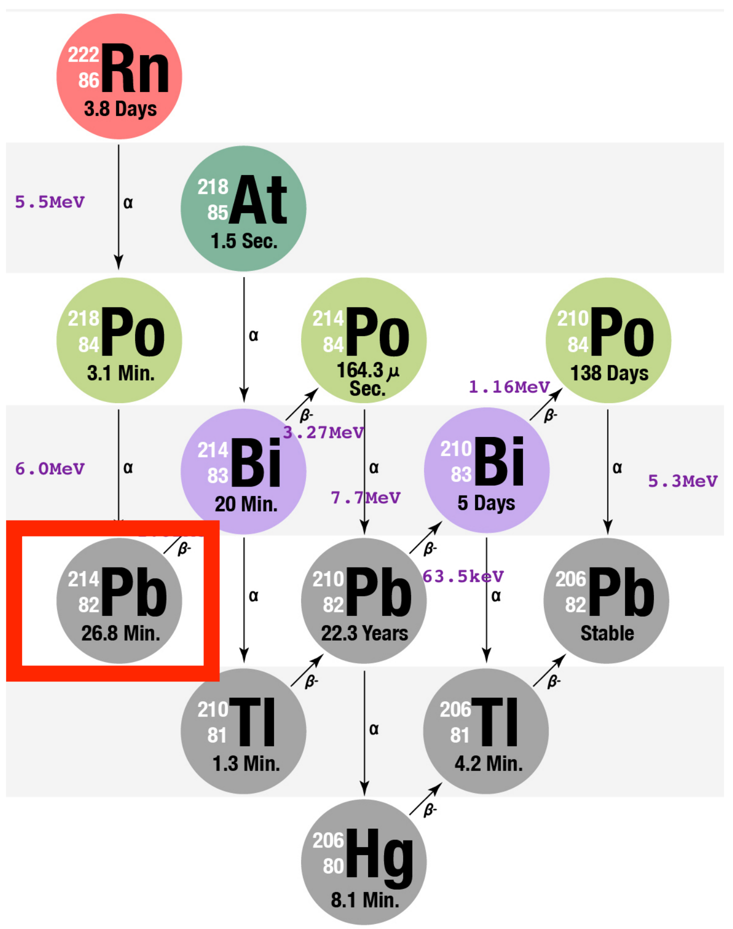
beta decay of Pb212 is used to calibrate detector’s response to ER background



The XENON1T ER Background

dominated by Pb214 betas



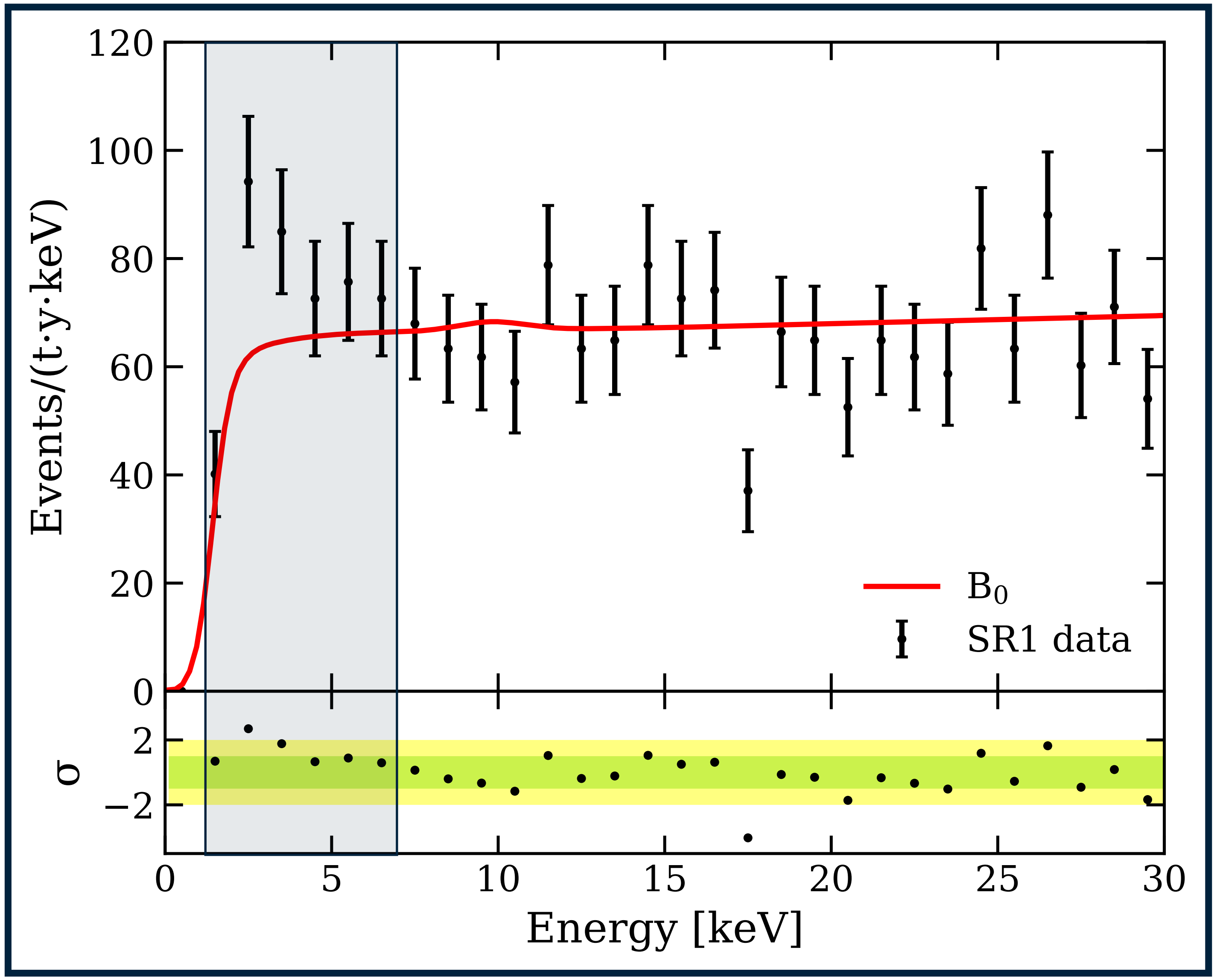


Decent matching across the whole energy range 1-210 keV

(76 +/- 2) events/(t·y·keV) in [1, 30] keV

Lowest background rate ever achieved in this energy range!

The Low Energy Excess



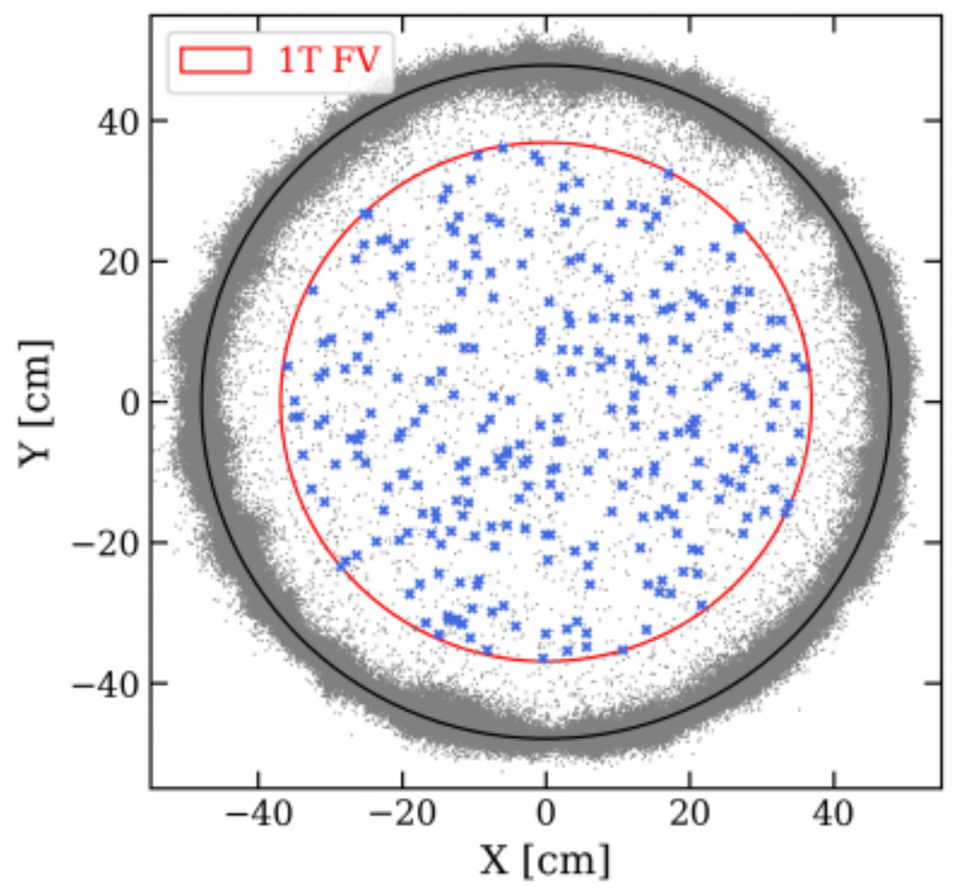
Excess between 1- 7 keV!

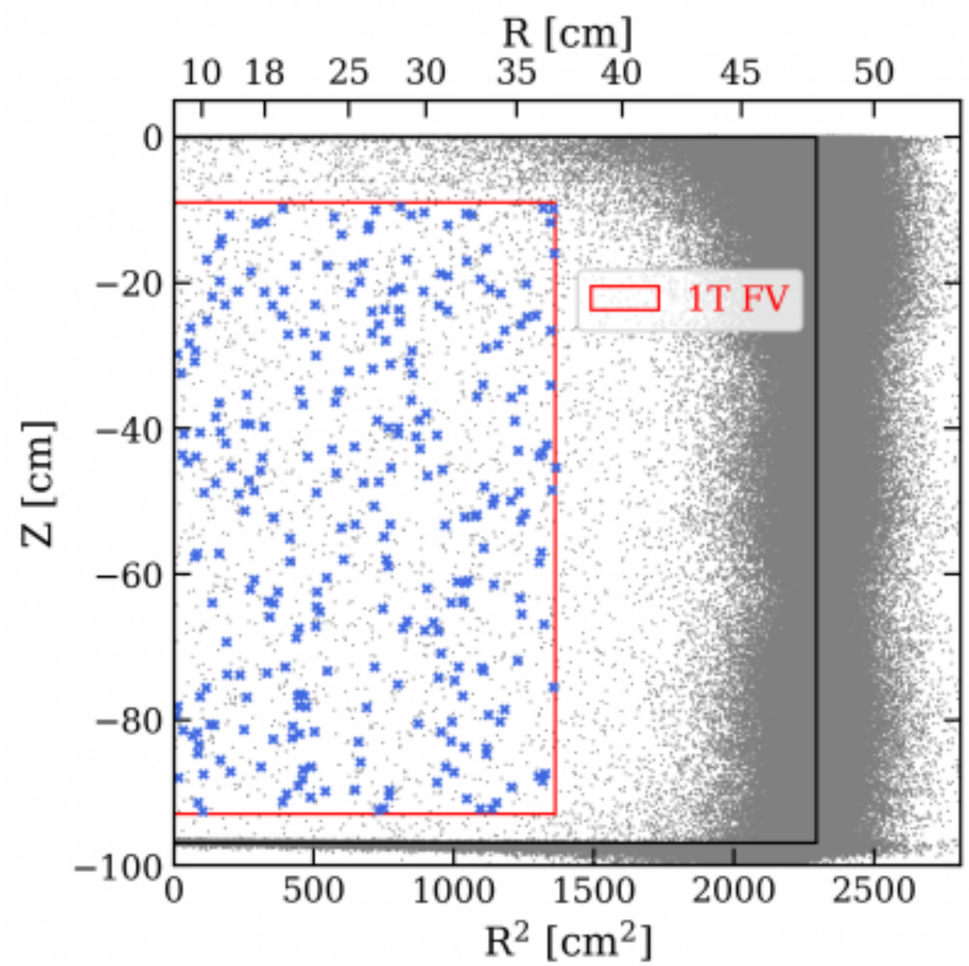
Expectation: 232±15

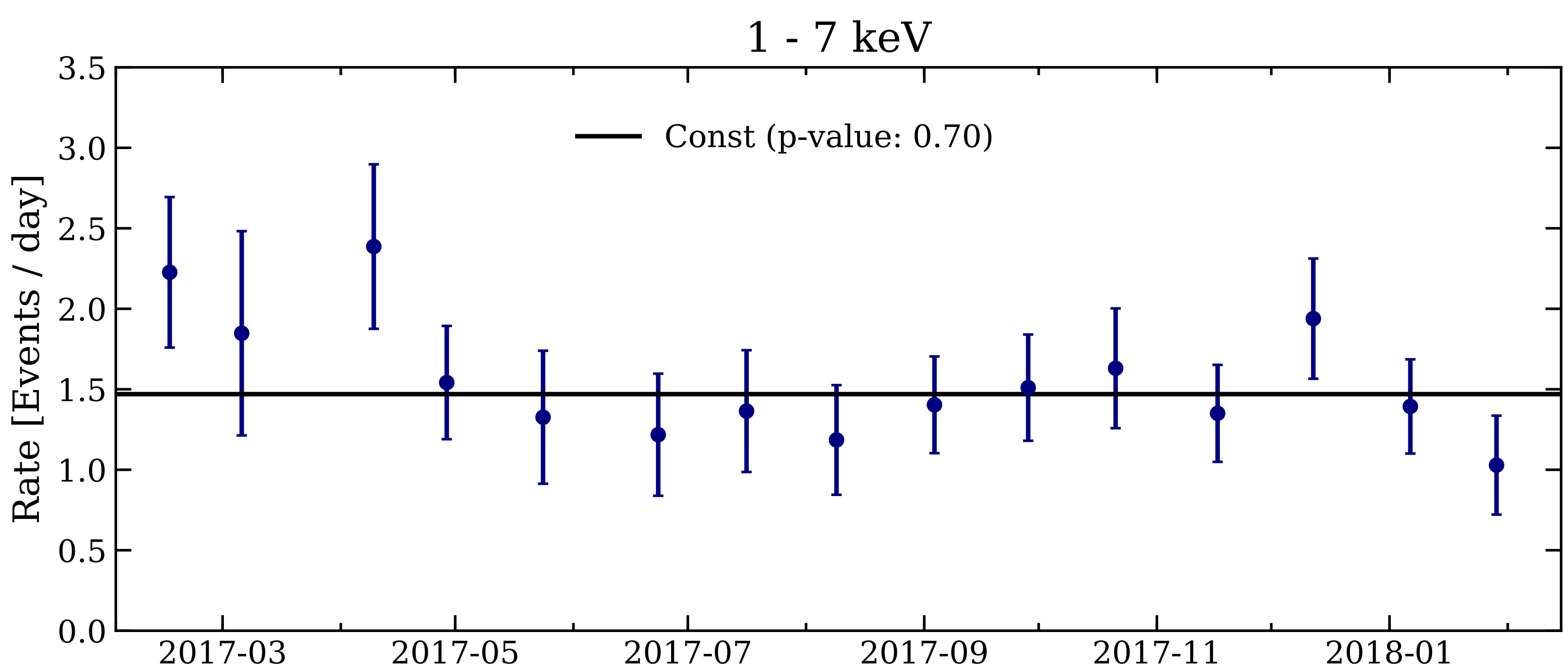
Observation: 285

Excess is most abundant between 2-3 keV

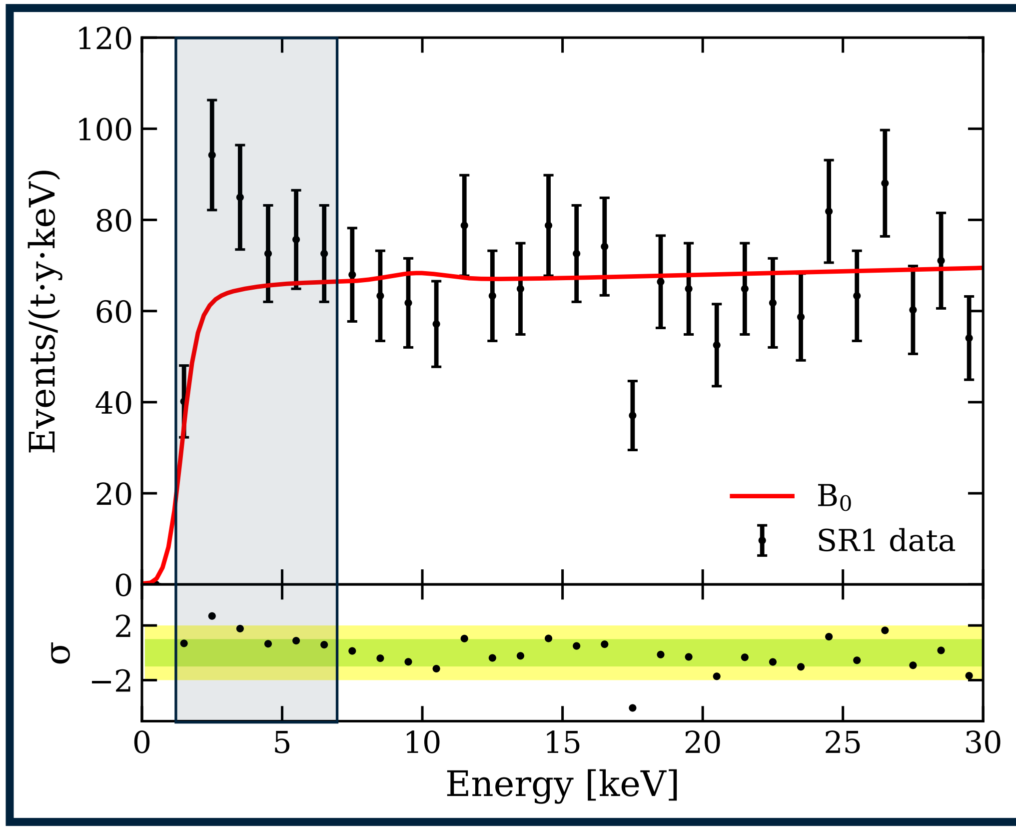
The Low Energy Excess



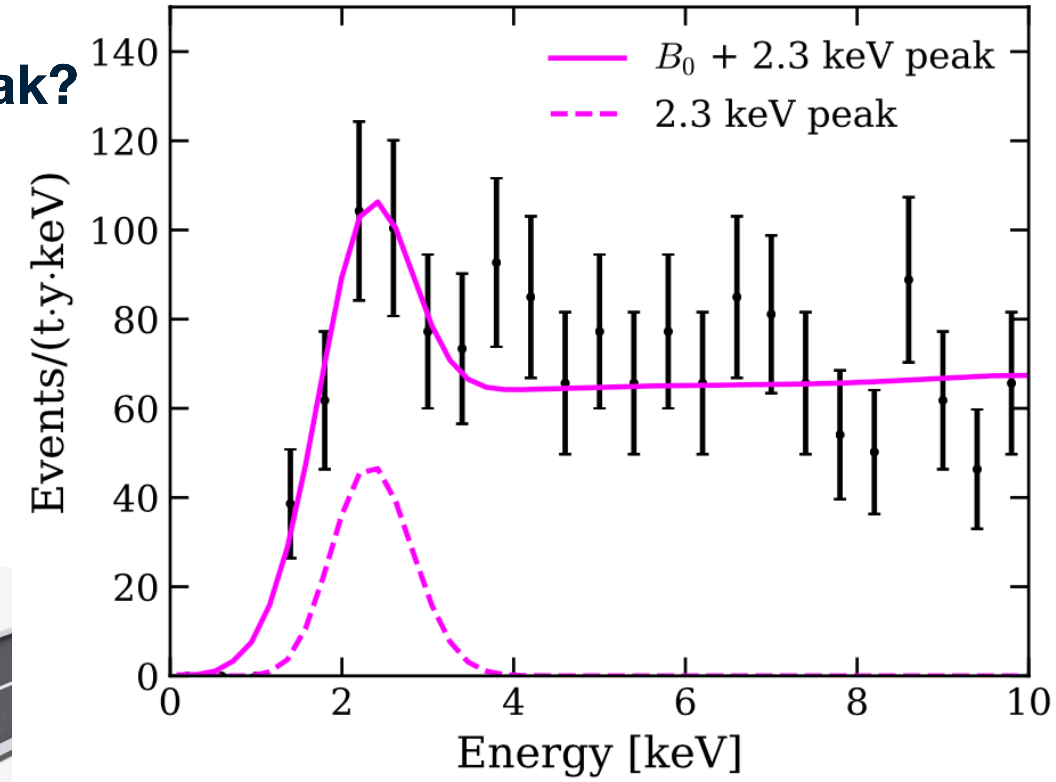




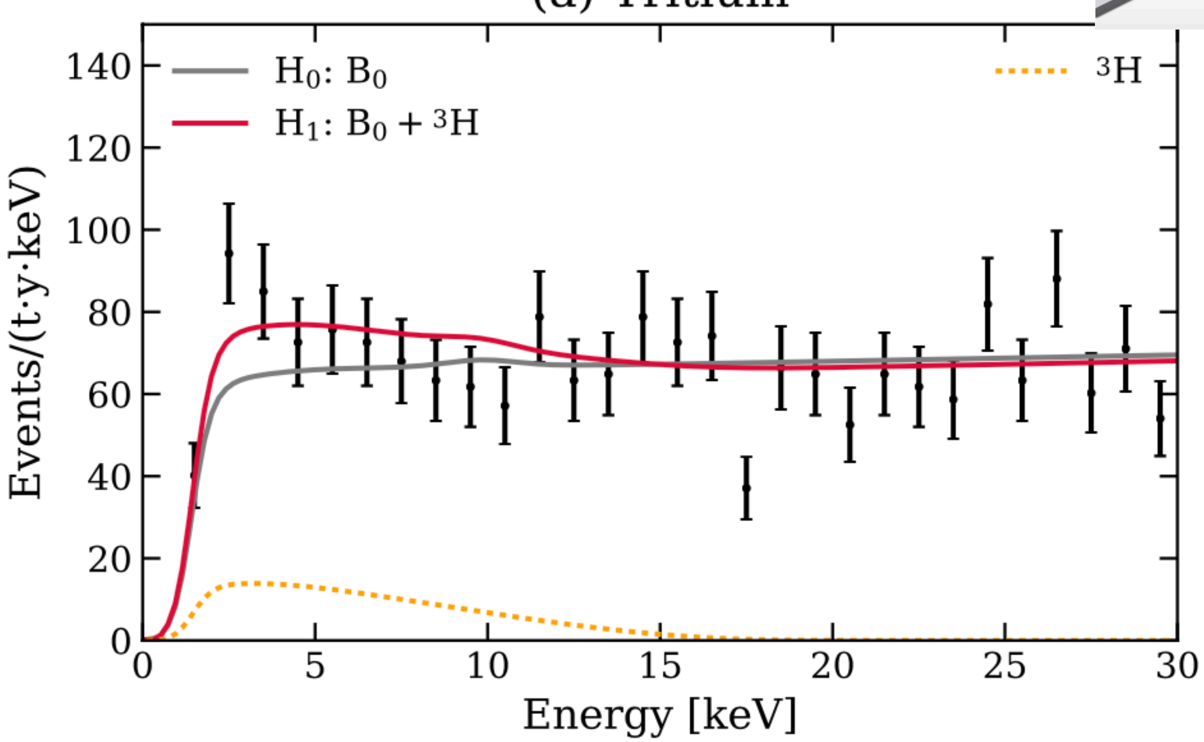
What caused the Excess?



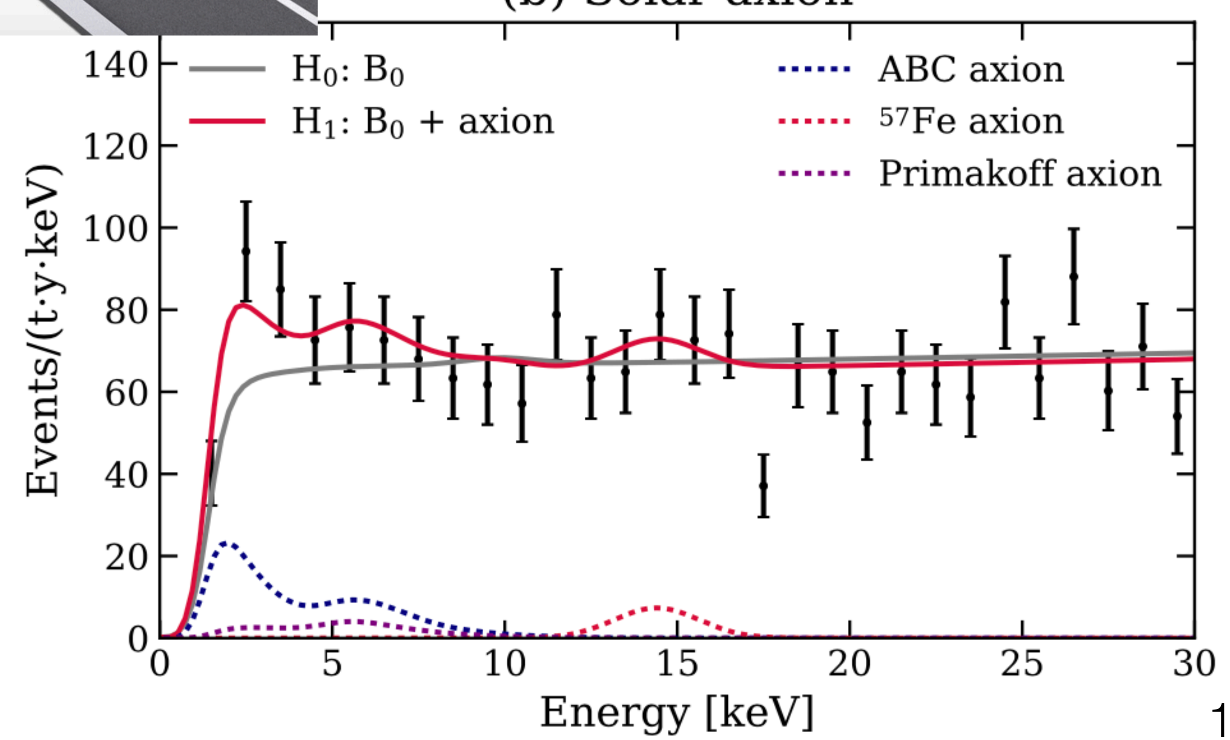
A Peak?



(a) Tritium

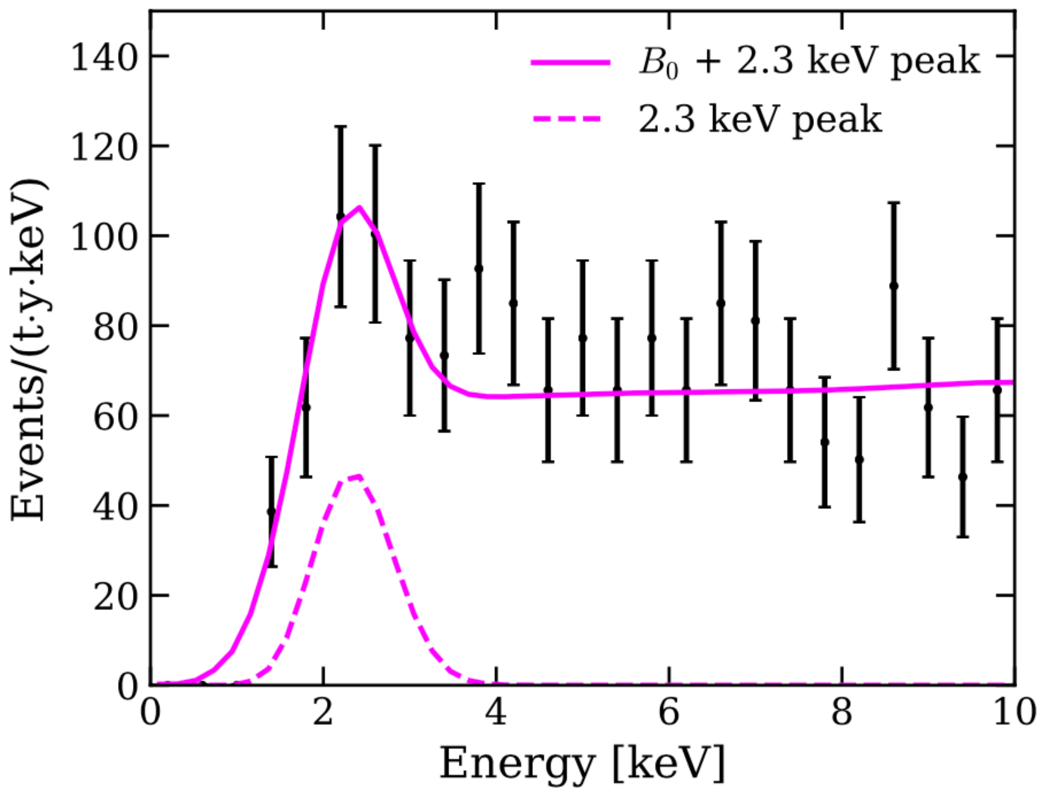


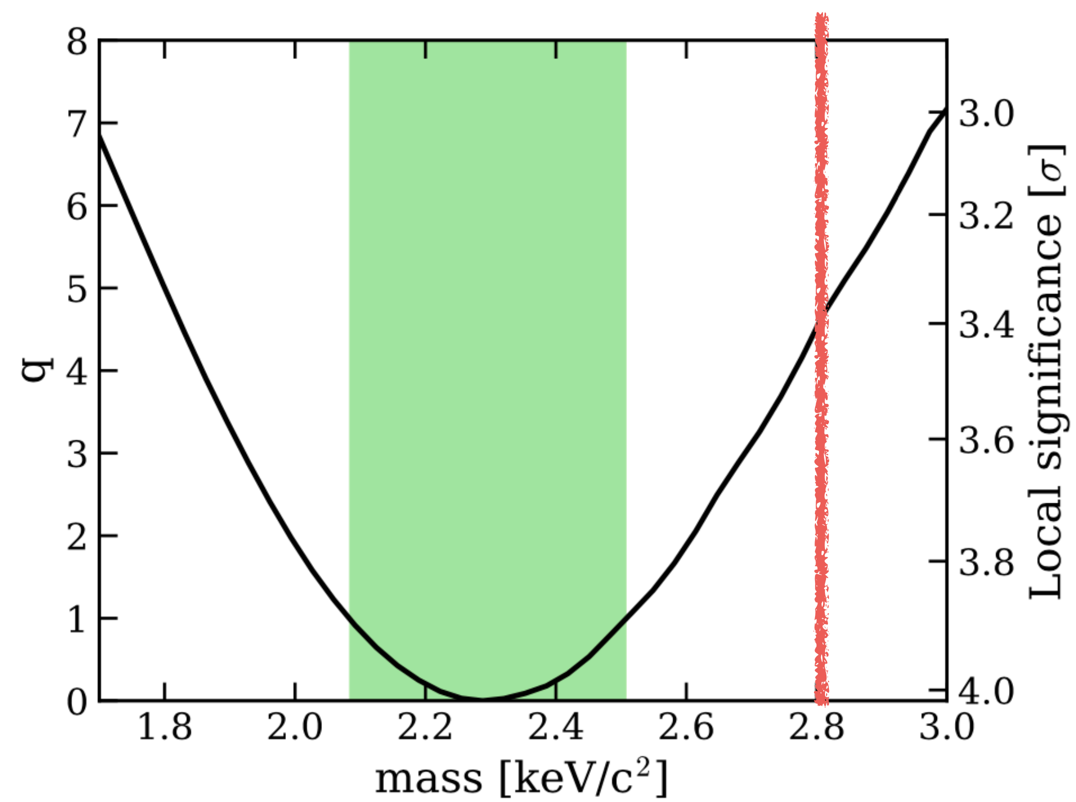
(b) Solar axion



Ar37

Short half life (35 days)





Best fit peak energy is 2.3 instead of 2.8 keV

Initial Ar37 contamination is gone:

1. **Quick decay**
2. **Online distillation**

What if they comes from air leaks?

1. **Initial leak before SR? Not consistent with temporal evolution**
2. **Constant leak over SR?**

Required leak >13 liter/y

Actual leak < 0.9 liter/y

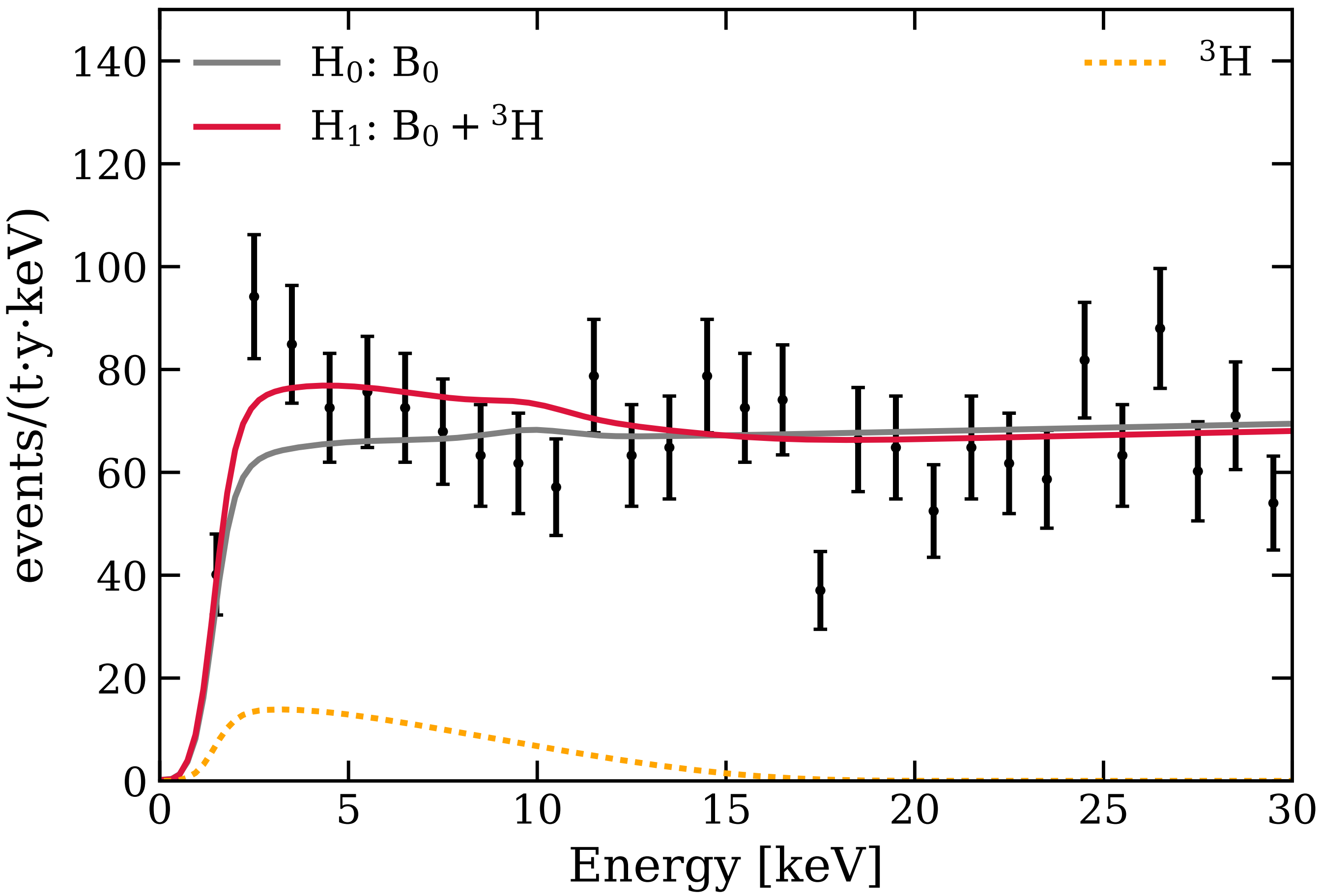
Conclusion: Ar37 hypothesis is OUT

Tritium

Tritium favored over background-only at 3.2σ

Low energy (Q-value 18.6keV)

Long half life (12.3 years)



Tritium Rate

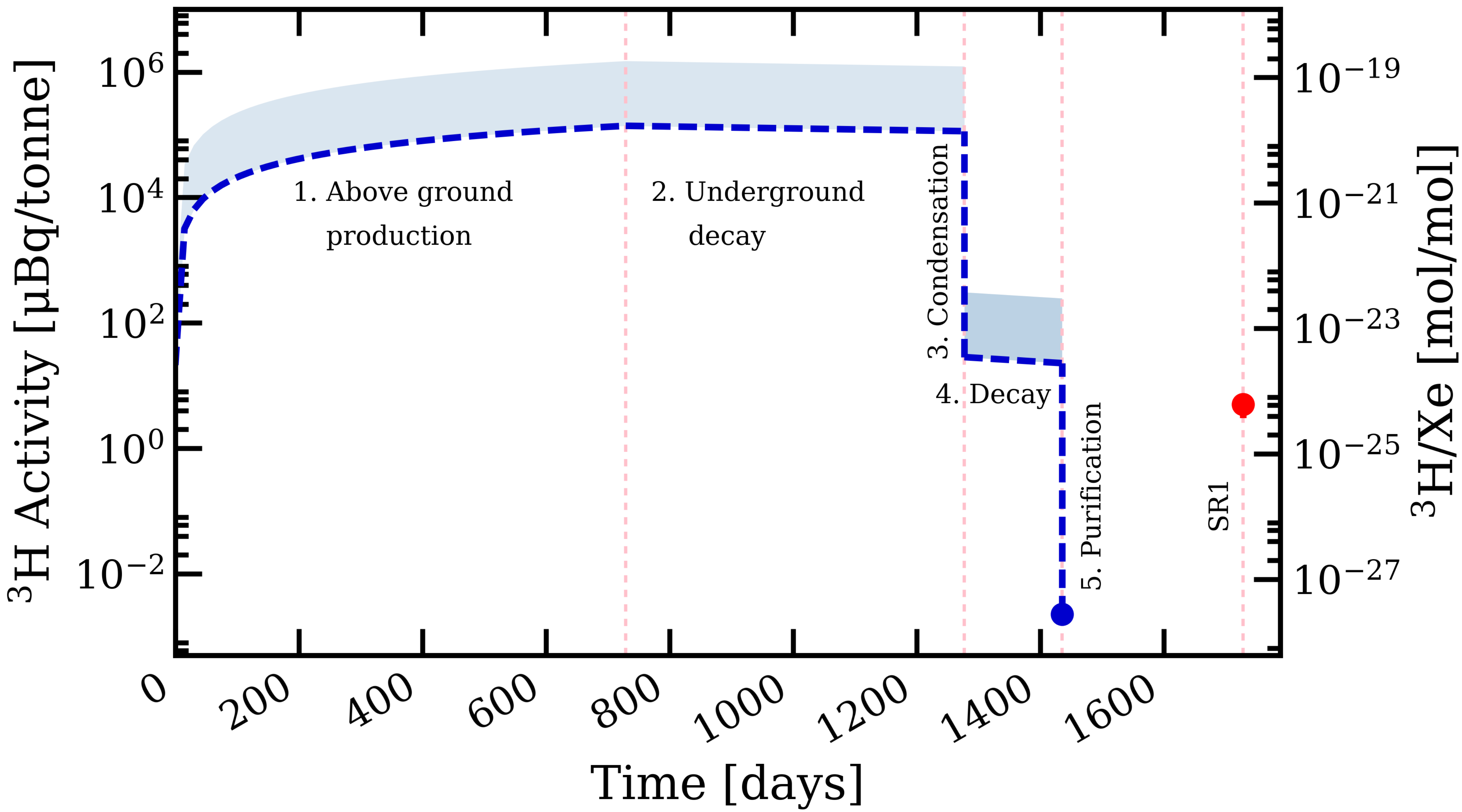
$$159 \pm 51 \, \text{events}/(\text{t} \cdot \text{y})$$

^3H:Xe concentration

$$6.2 \pm 2.0 \times 10^{-25} \ \text{mol}/\text{mol}$$

Reduction of Cosmogenic Tritium

Cosmogenic activation **Reduction due to xenon handling**



OUT

Natural Abundance in Material

Required tritium level: $\sim 10^{-24}\,\mathrm{mol/mol}$

T: H ratio: $\sim 10^{-17}\,\mathrm{mol/mol}$

Required concentration of H2O or H2 in Xe to explain the excess **~100 ppb**

H2O in XENON1T: O(1) ppb, otherwise can not detect light

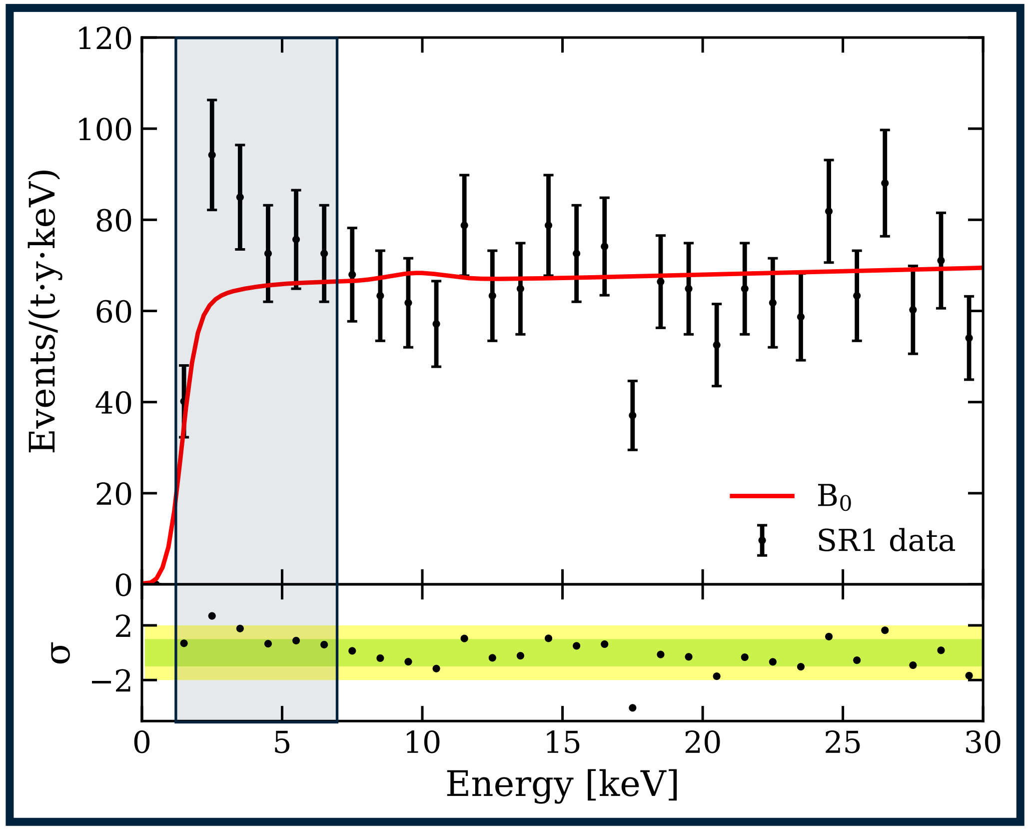
O2 in XENON1T: <1ppb, otherwise can not drift electrons

H2 ~100ppb? -> ~100x higher than O2?

How about other molecules?

Possible

Axion?



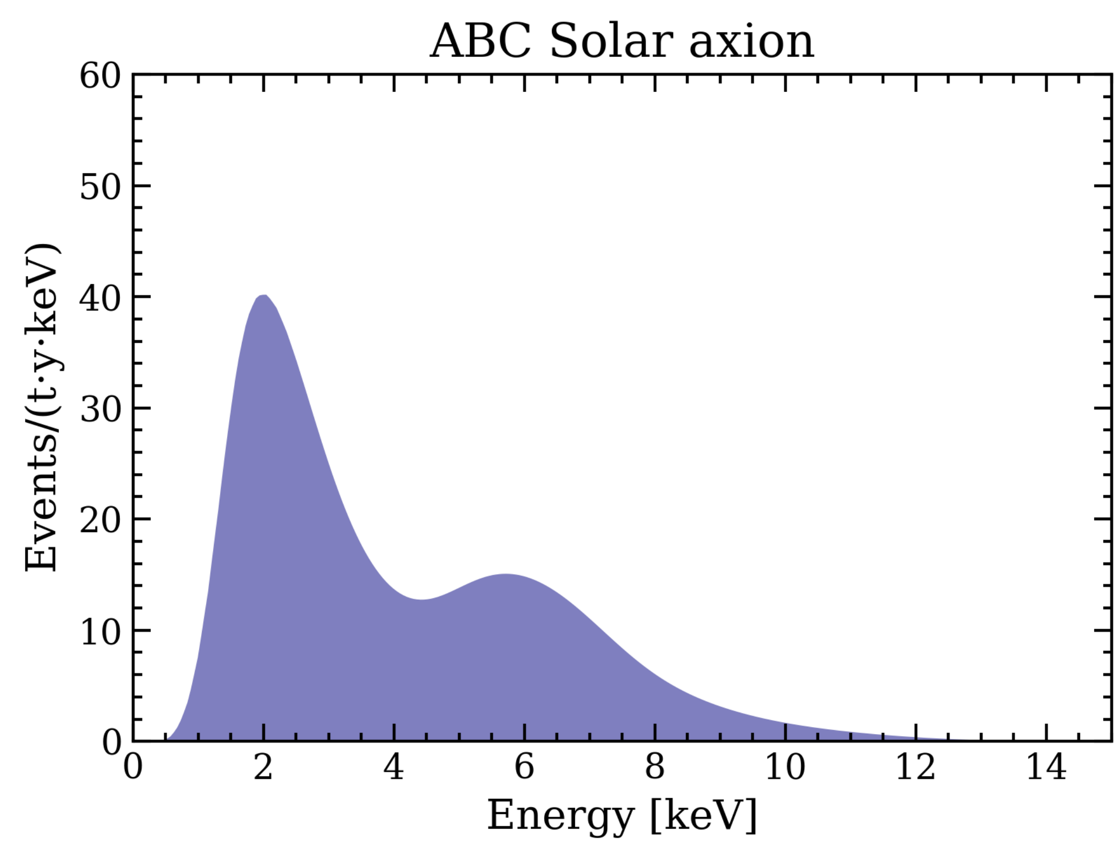
Why do we like Axions?

Solution to the "strong CP problem"

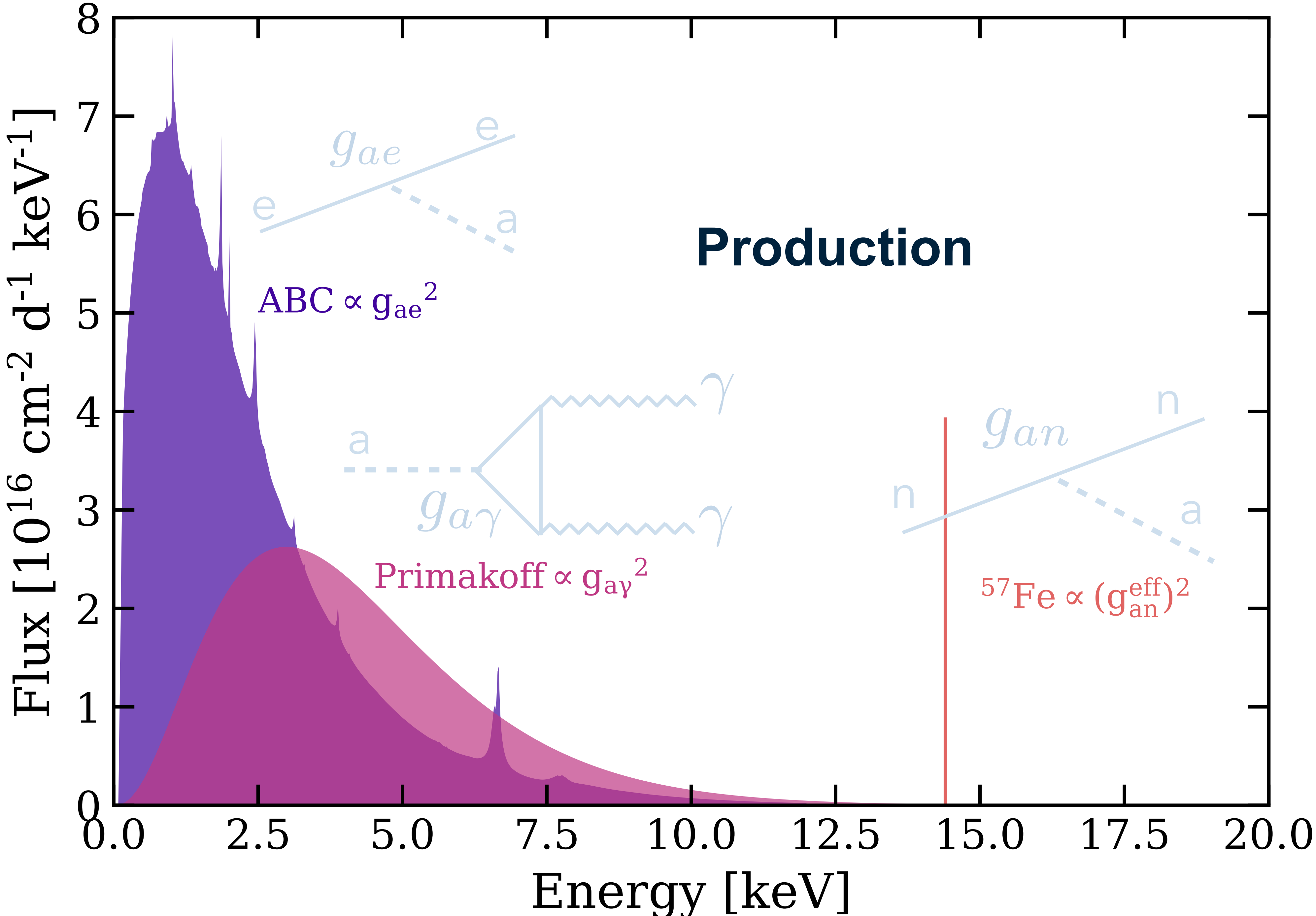
Natural candidates of the dark matter

Axions would also be produced in the Sun, with kinetic energies ~ keV

Detectable in Xe1T!



Production and Detection of Solar Axion

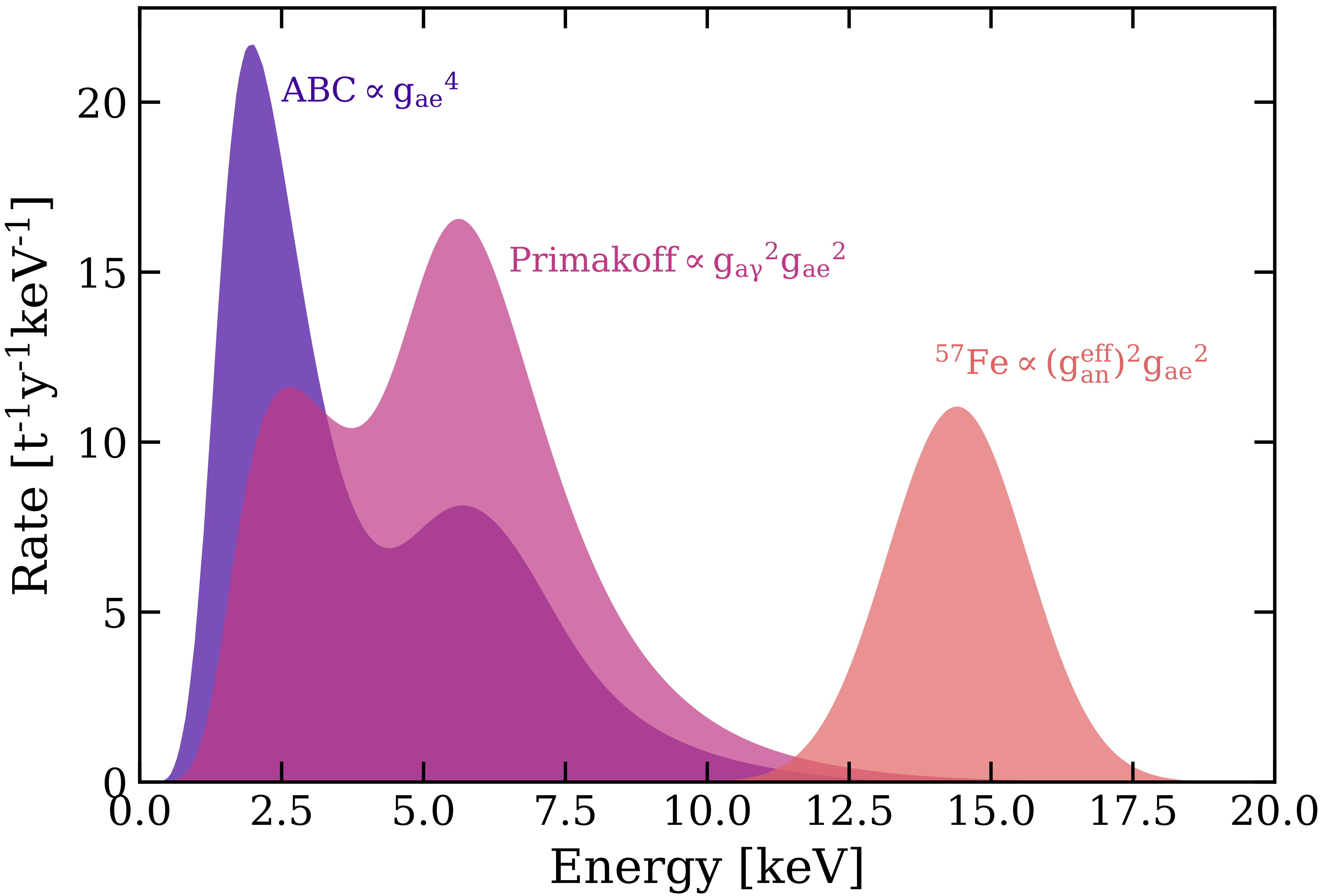


Axioelectric effect

Detection

$$\sigma_{ae} = \sigma_{pe} \frac{g_{ae}^2}{\beta} \frac{3E_a^2}{16\pi\alpha m_e^2} \left(1 - \frac{\beta^{2/3}}{3}\right)$$

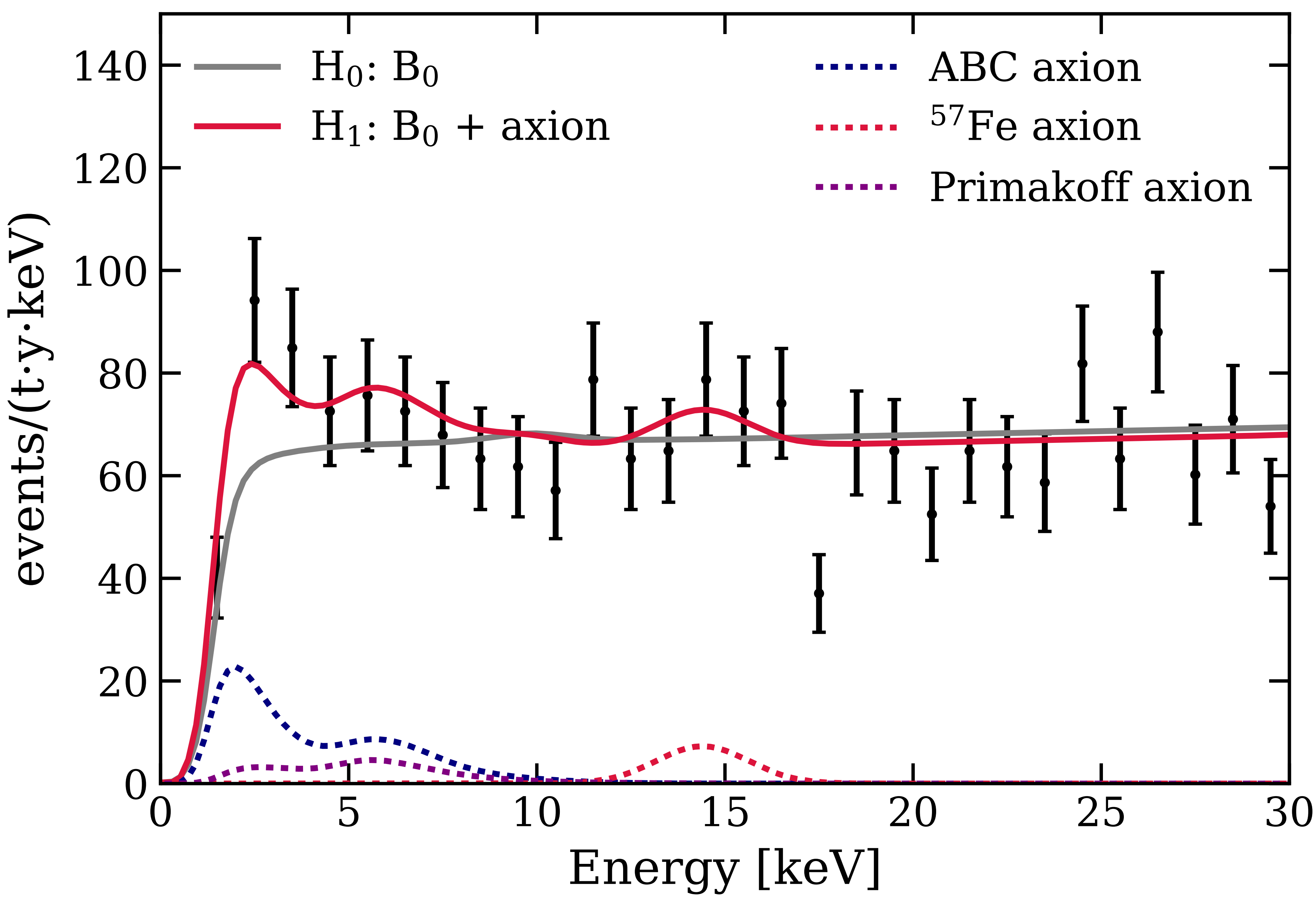
Including Detector Effects



Detection

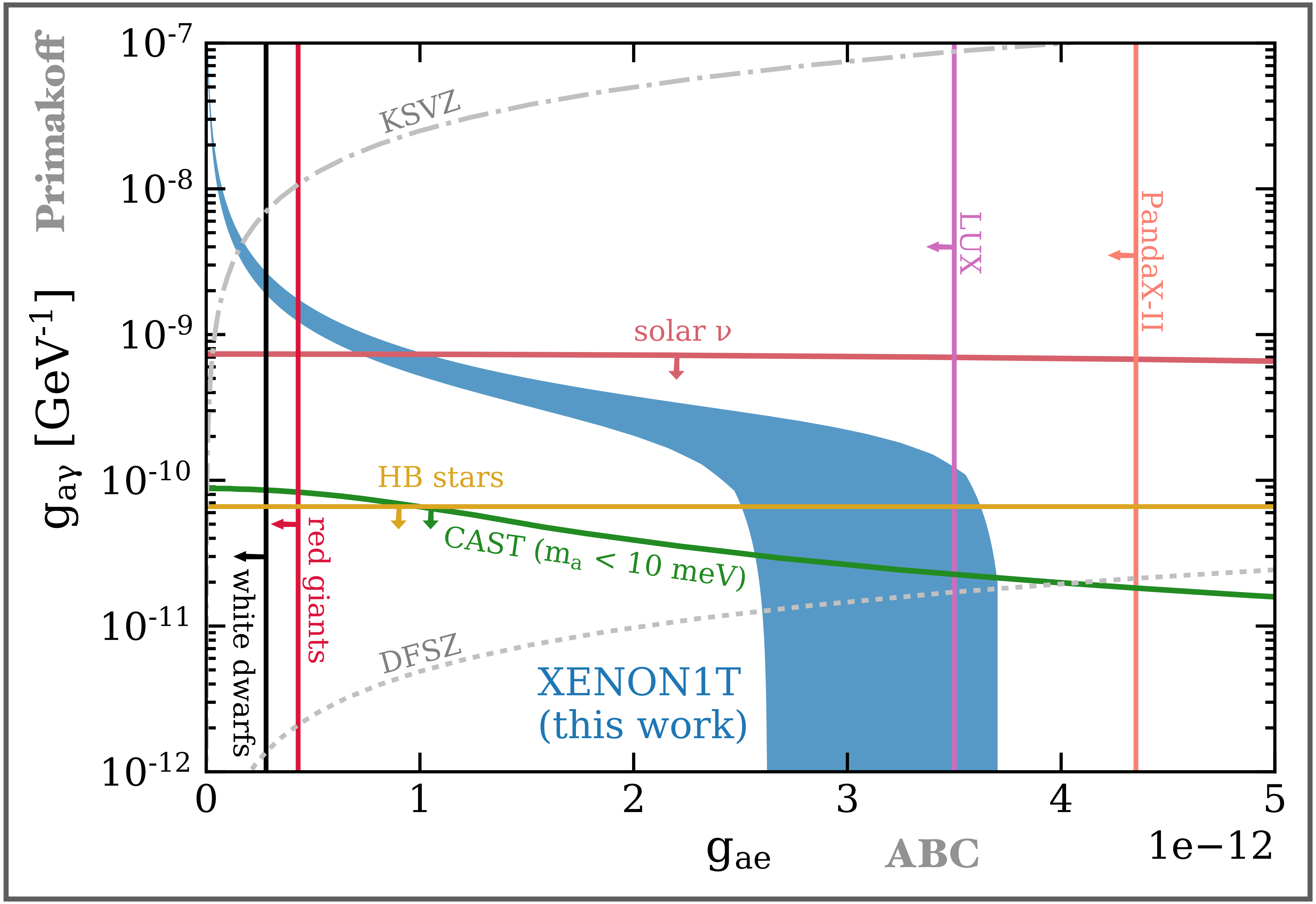
$$\sigma_{ae} = \sigma_{pe} \frac{g_{ae}^2}{\beta} \frac{3E_a^2}{16\pi\alpha m_e^2} \left(1 - \frac{\beta^{2/3}}{3}\right)$$

Fitting Axions to the Excess



Axion is favored over background-only at 3.4σ

Allowed Parameter Space



In tension with astrophysical constraints from stellar cooling

(arXiv 2003.01100)

Summary of the Excess

XENON1T observes ER excess events in 1-7 keV region

Potential sources:

Tiny amount of Ar37? NO

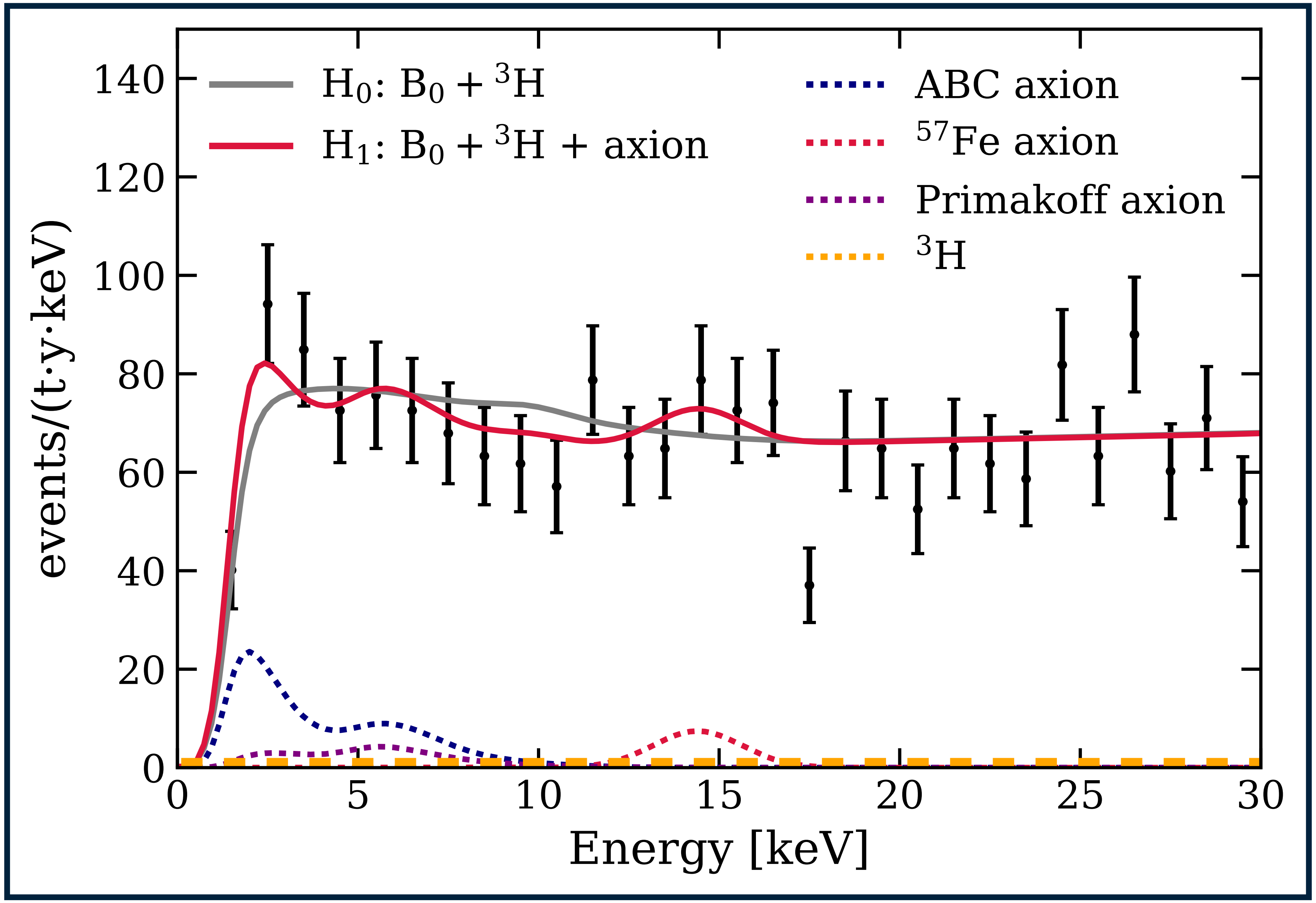
Tiny amount of tritium: 3.2 sigma, Possible

Solar Axions: 3.4 sigma

And many more…

What's Next? - XENON1T

Axion + ^{3}H favored over ^{3}H hypothesis at 2.0σ



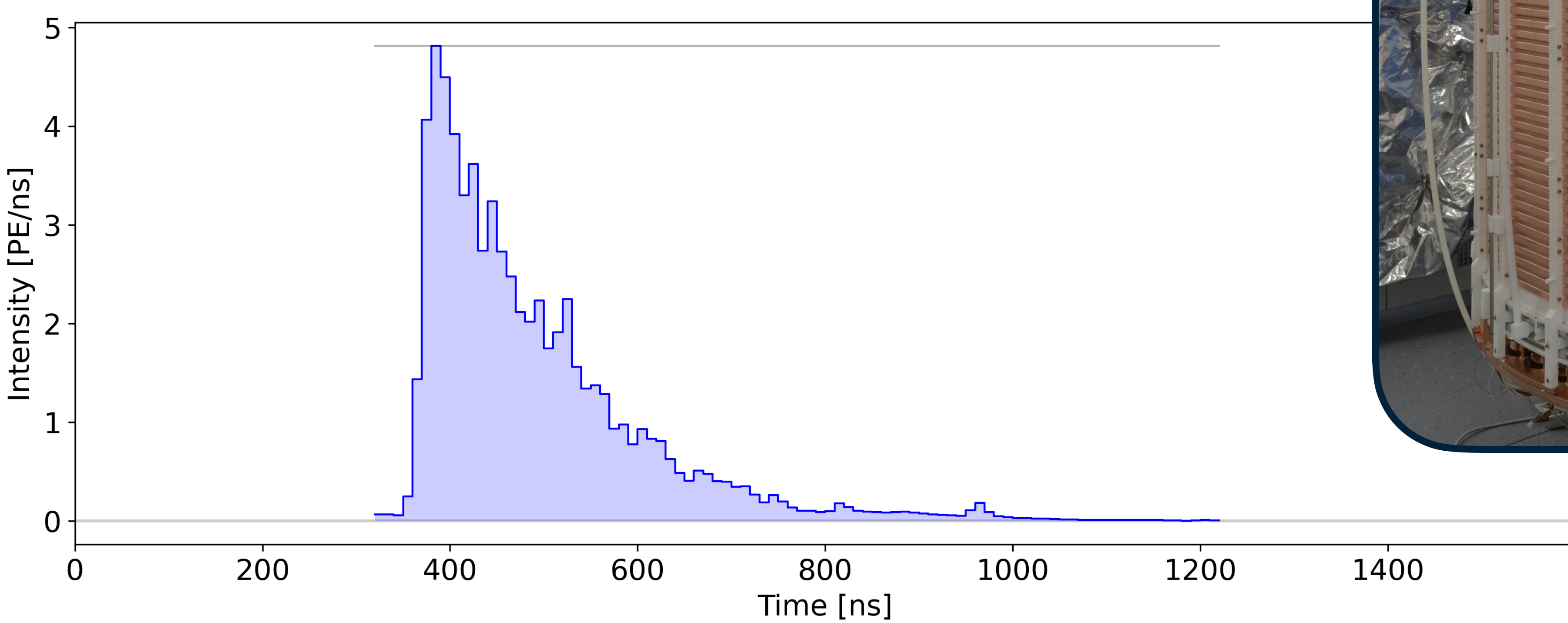
Can we distinguish the two hypothesis by additional checks?

What's Next? - XENONnT

~4 times larger fiducial mass

~1/6 background level

First light in gaseous xenon



It’s exciting to see what XENONnT orders for us

Thank you!