Search for Axions in the XENON Dark Matter Experiment

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On behalf of the XENON Collaboration

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The XENON Collaboration

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

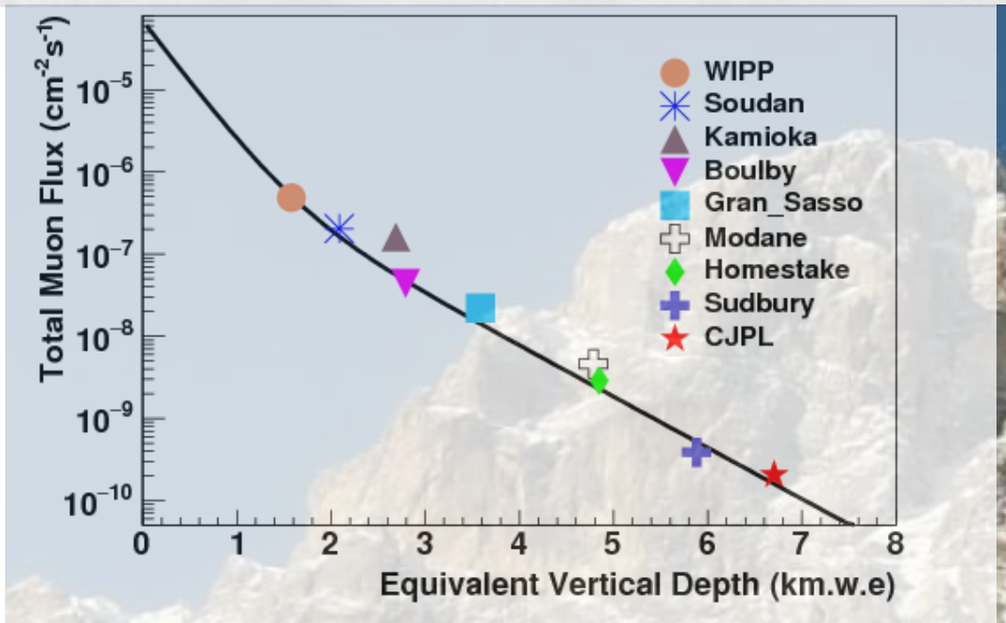
Chicago · UCSD · Rice · Purdue · Tsinghua · Tokyo · Nagoya · Kobe

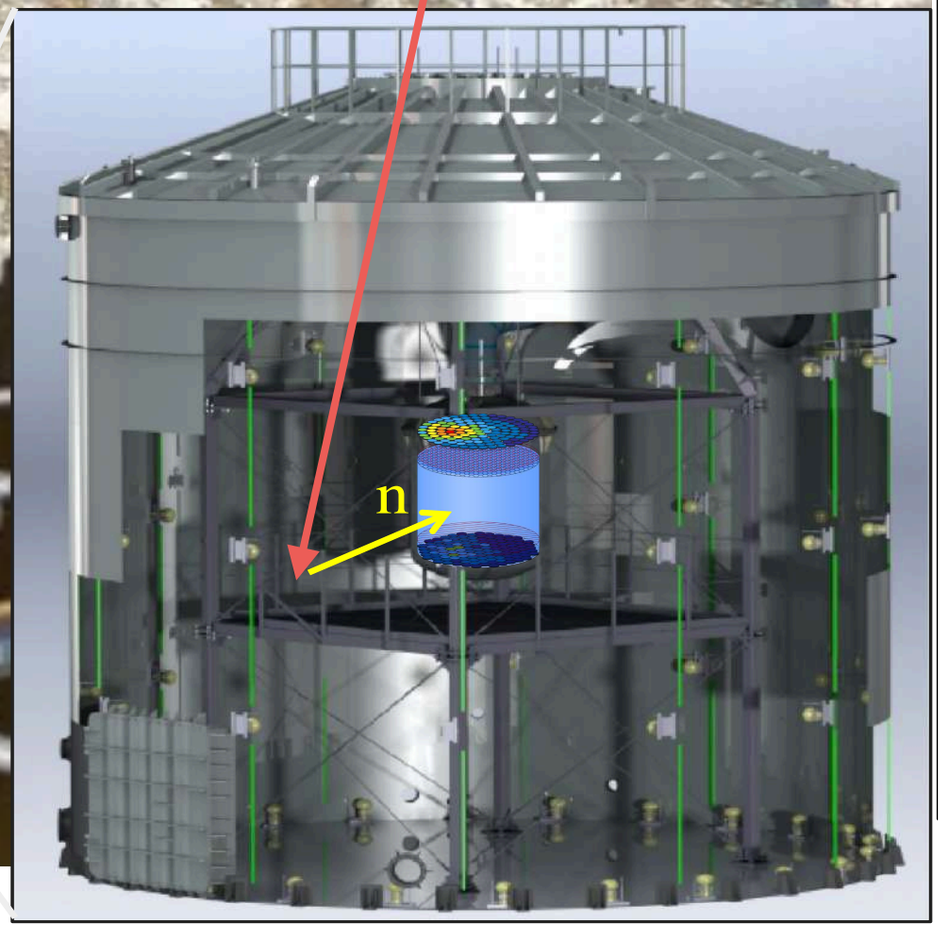
Subatech · Coimbra · LPNHE · Torino · Bologna · L'Aquila · LNGS · Napoli · Weizmann · NYUAD

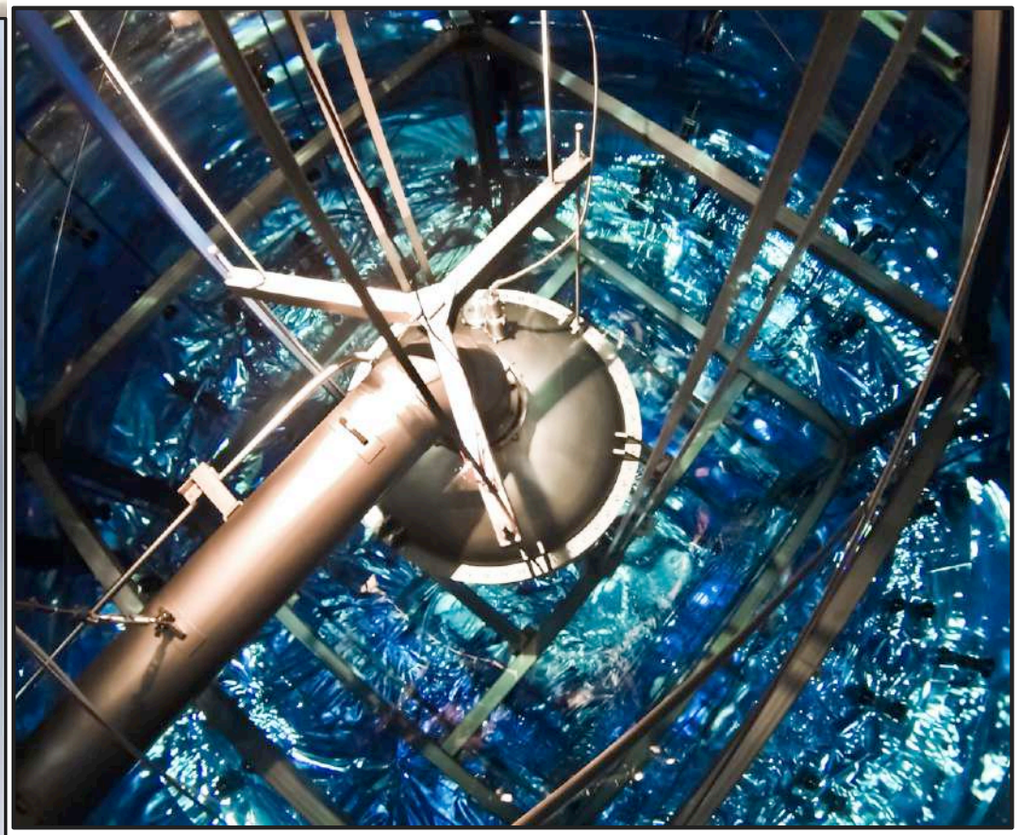
Development of XENON Program

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	8.6 ton - 1.5 m drift
~10^{-43} cm^2	~10^{-45} cm^2	~10^{-47} cm^2	~10^{-48} cm^2

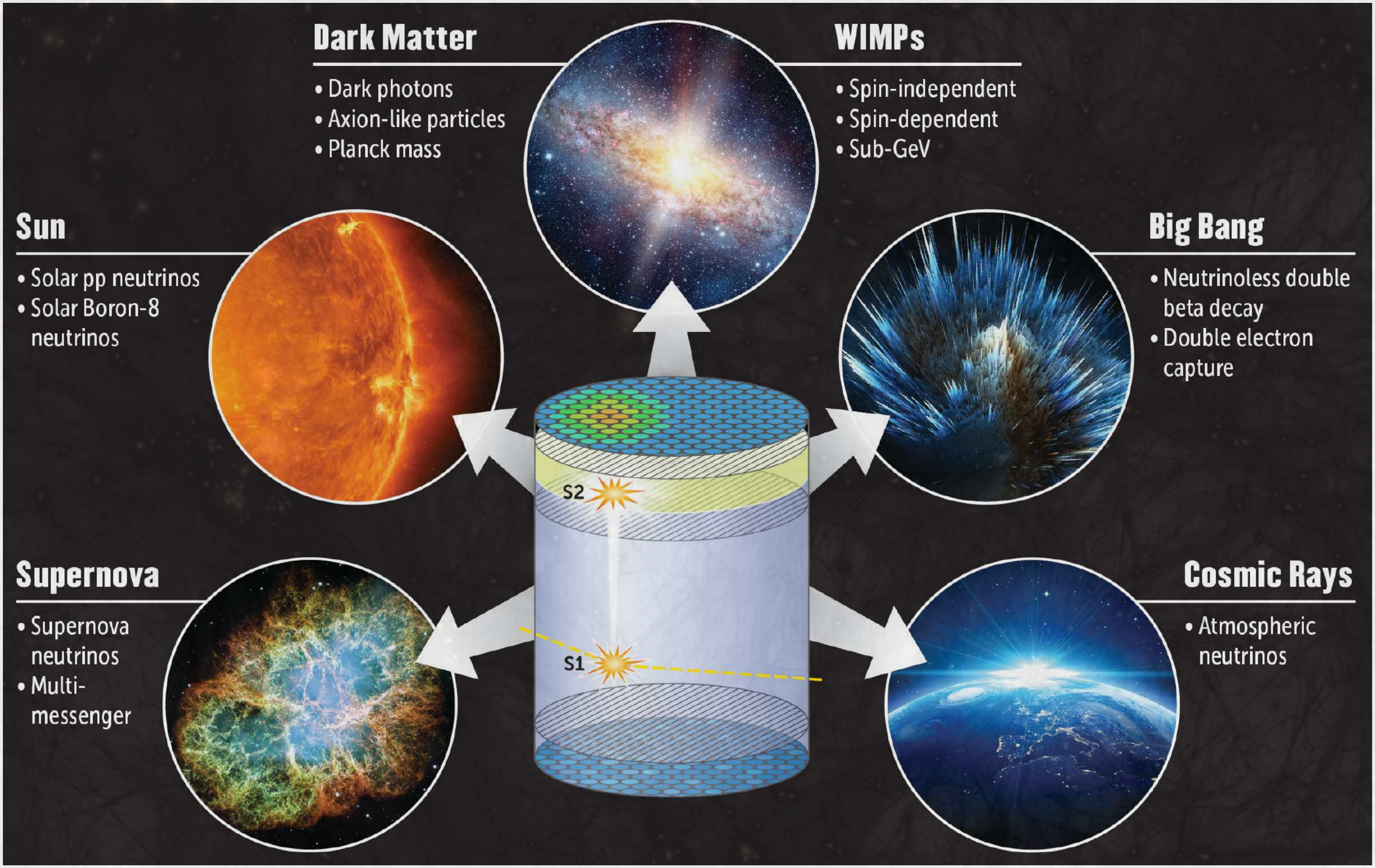
Gran Sasso: The XENON Shield





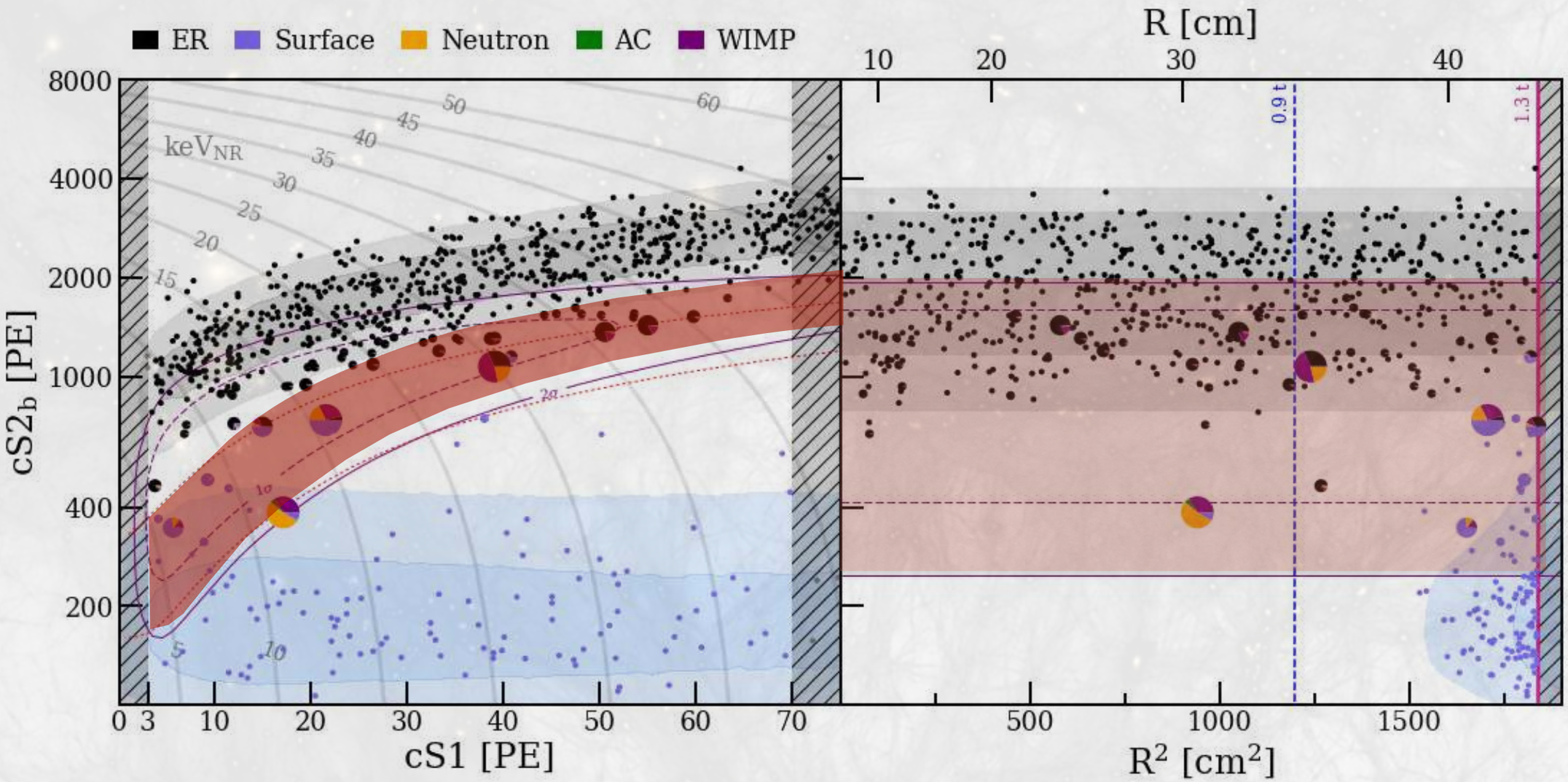


Physics in XENON



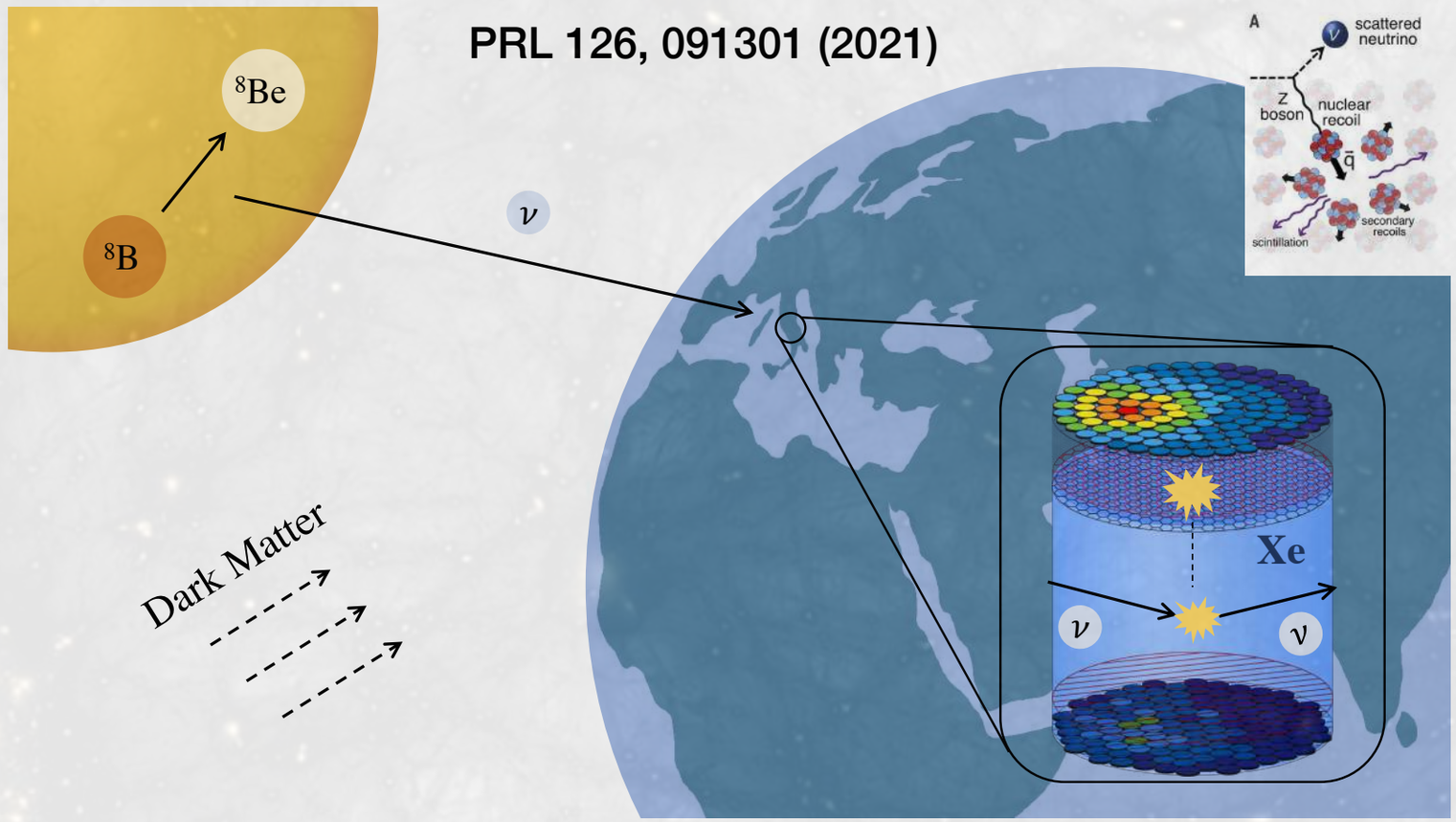
XENON1T WIMPs Search

One ton-year of search for WIMPs induced nuclear recoils



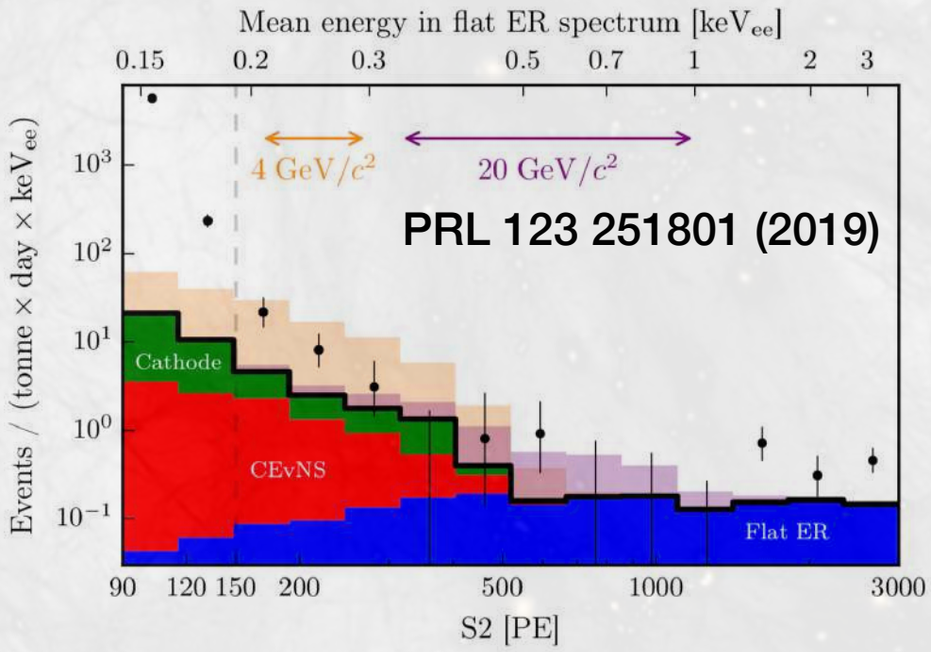
Most stringent result on WIMP Dark Matter down to 3 GeV/c² masses [*PRL 121, 111302 + PRL 123, 251801]*

Solar B8 “Neutrino Fog” in XENON1T



#1: “S2-only” approach

A limit setting analysis (expect 2.0±0.3 CEvNS)

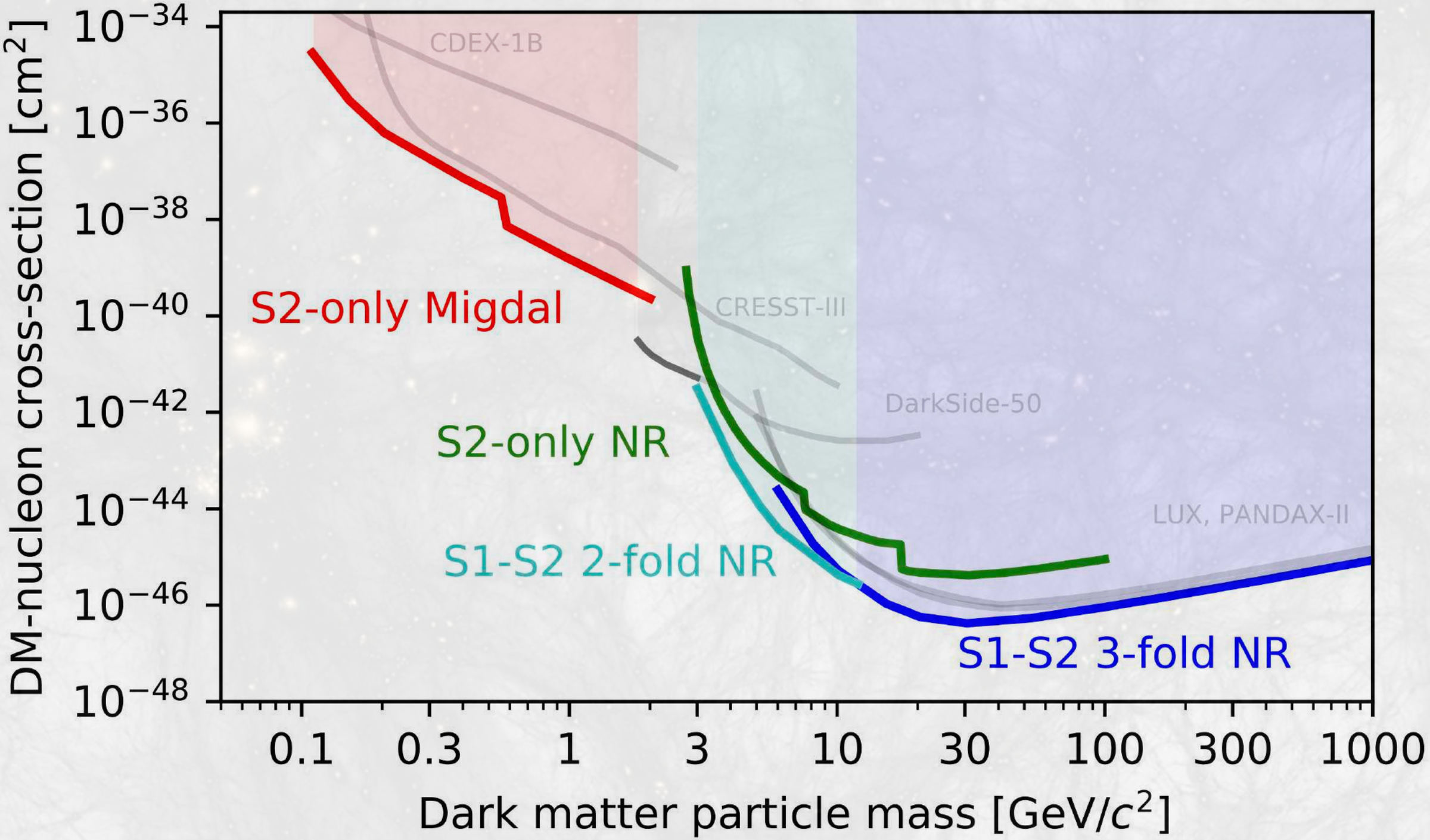


#2: lowering S1 & S2 together

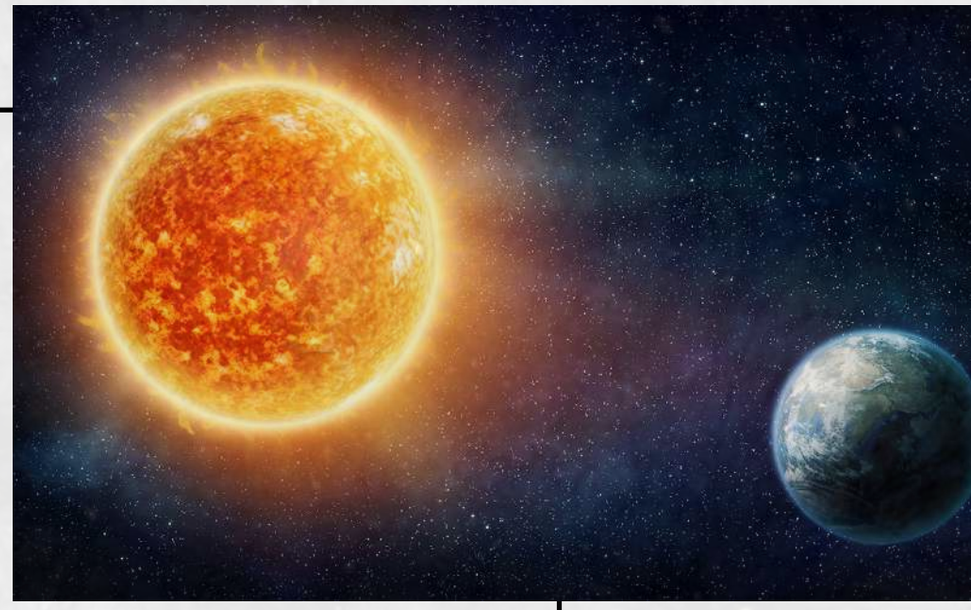
- S1: 2 or 3 photons
- S2: ~4 - 18 electrons

Source	Expectation
CEvNS	**2.25**
Accidental	5.14
ER	0.21
Radiogenic	0.03
Total	7.65

Constraints on Dark Matter Interactions



Production and Detection of Solar Axion



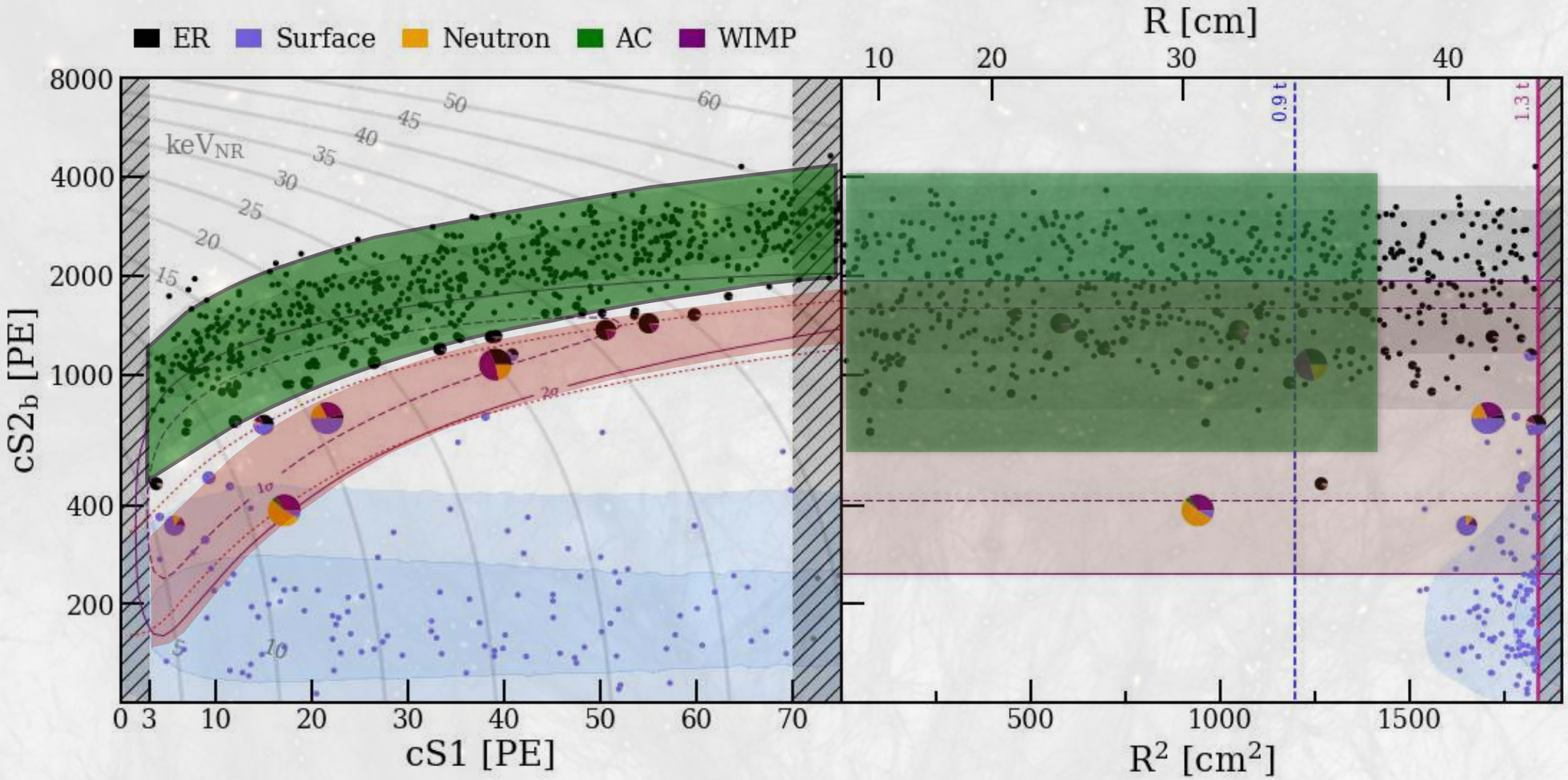
Axioelectric effect

Detection

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

XENON1T Solar Axion Search

Reduced fiducial volume to search for ER signals



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

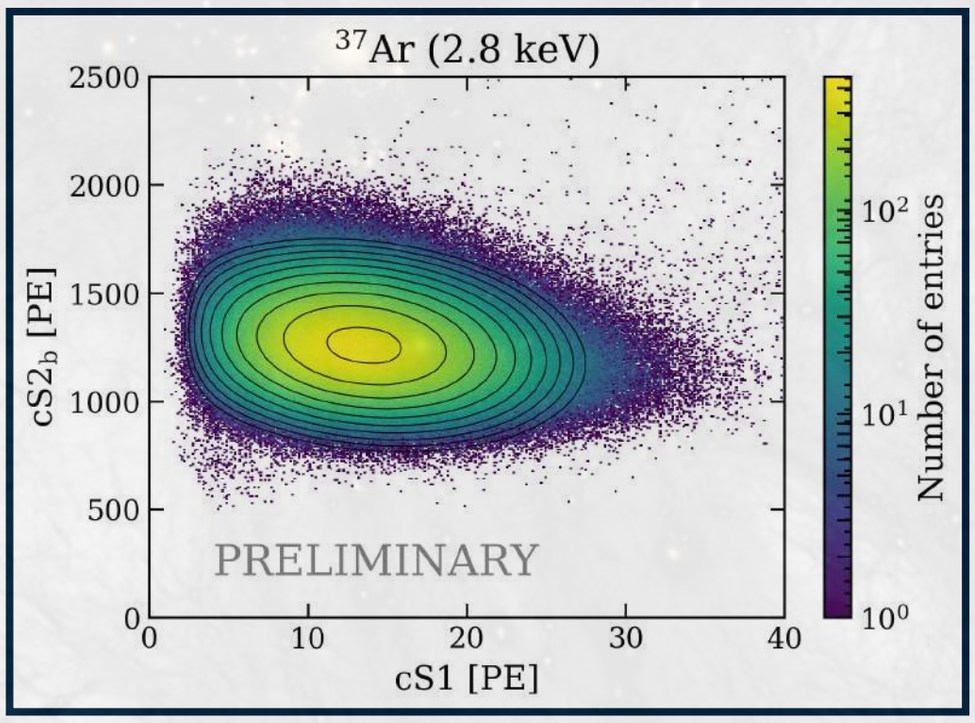
Energy Response in XENON1T

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

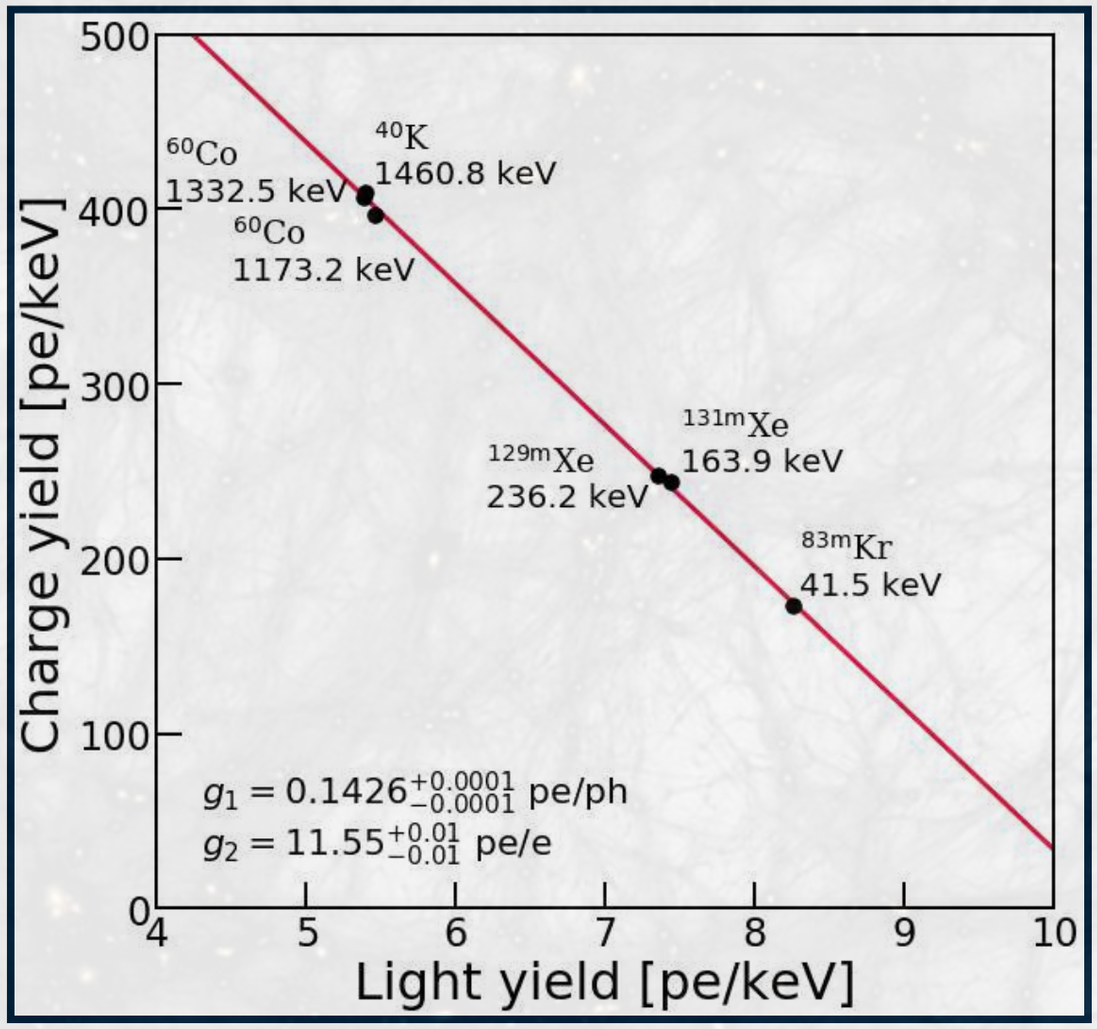
$$E = W\left(\frac{S1}{g_1} + \frac{S2}{g_2}\right)$$

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

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



Calibration of XENON1T down to **2.8 keV**

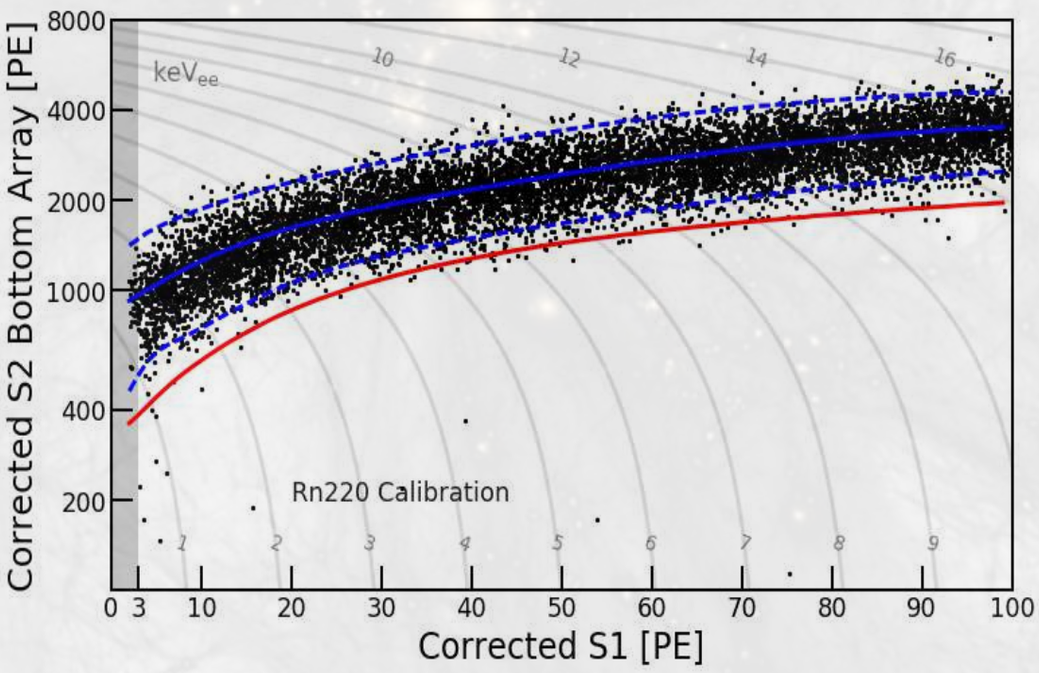


Energy as Analysis Space

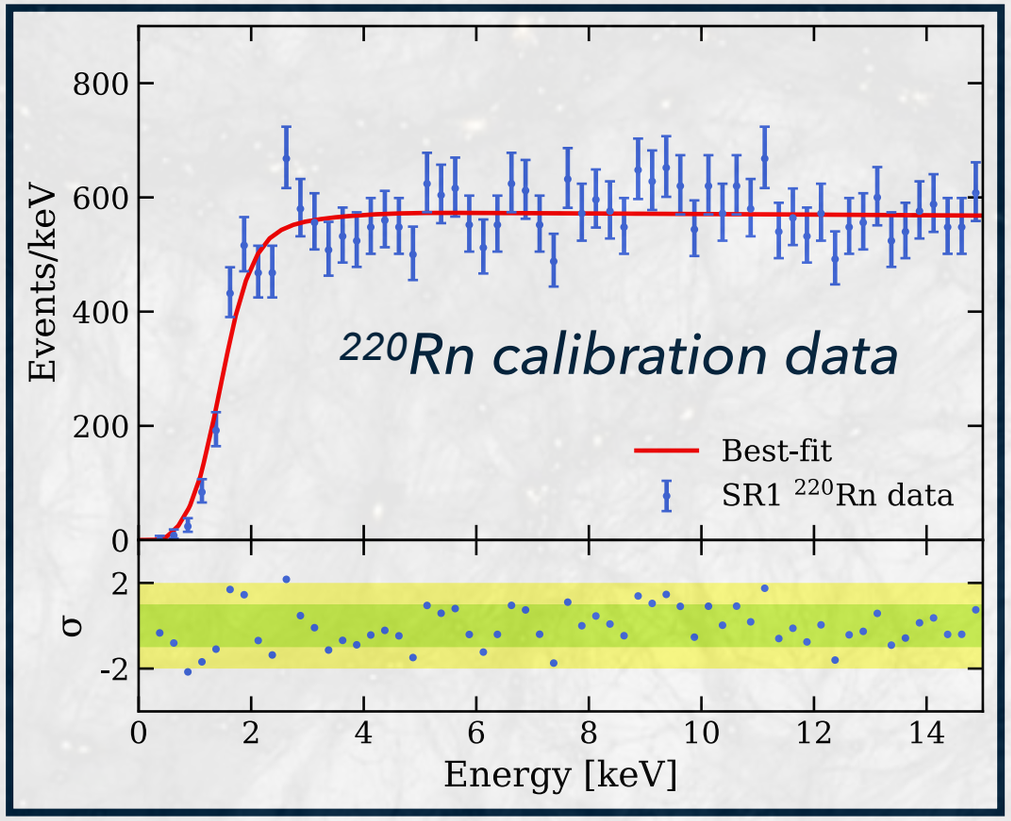
$$E = W(n_{ph} + n_e)$$

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

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

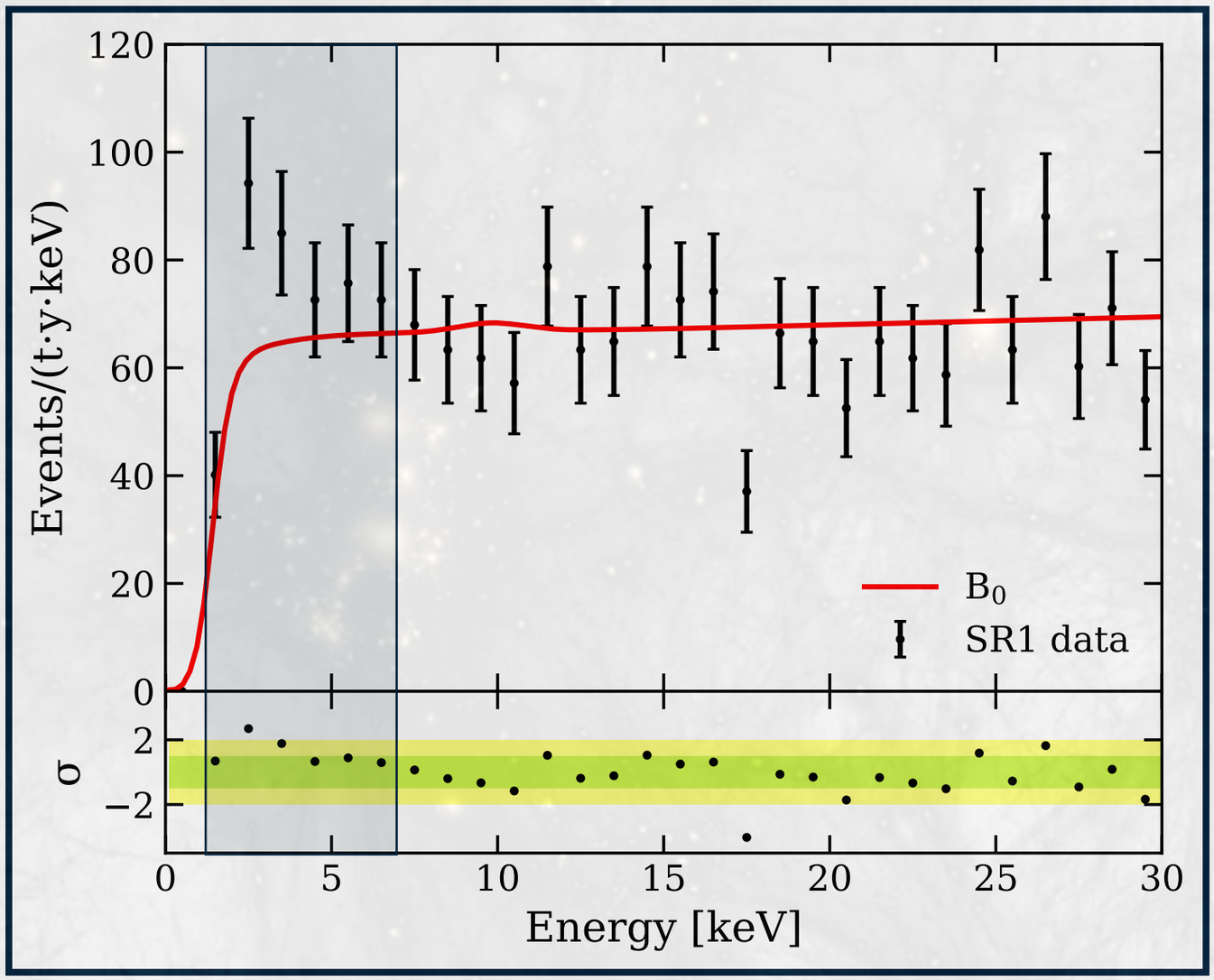


2-3D analysis w/ discrimination



1D energy spectrum

The Low Energy Excess



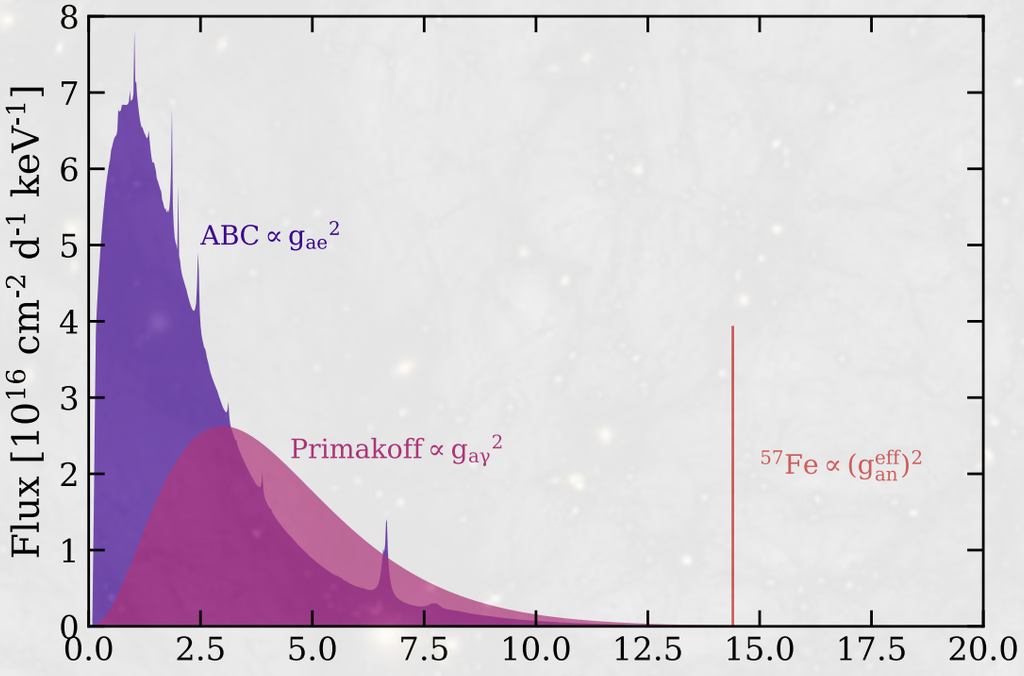
Excess between 1- 7 keV!

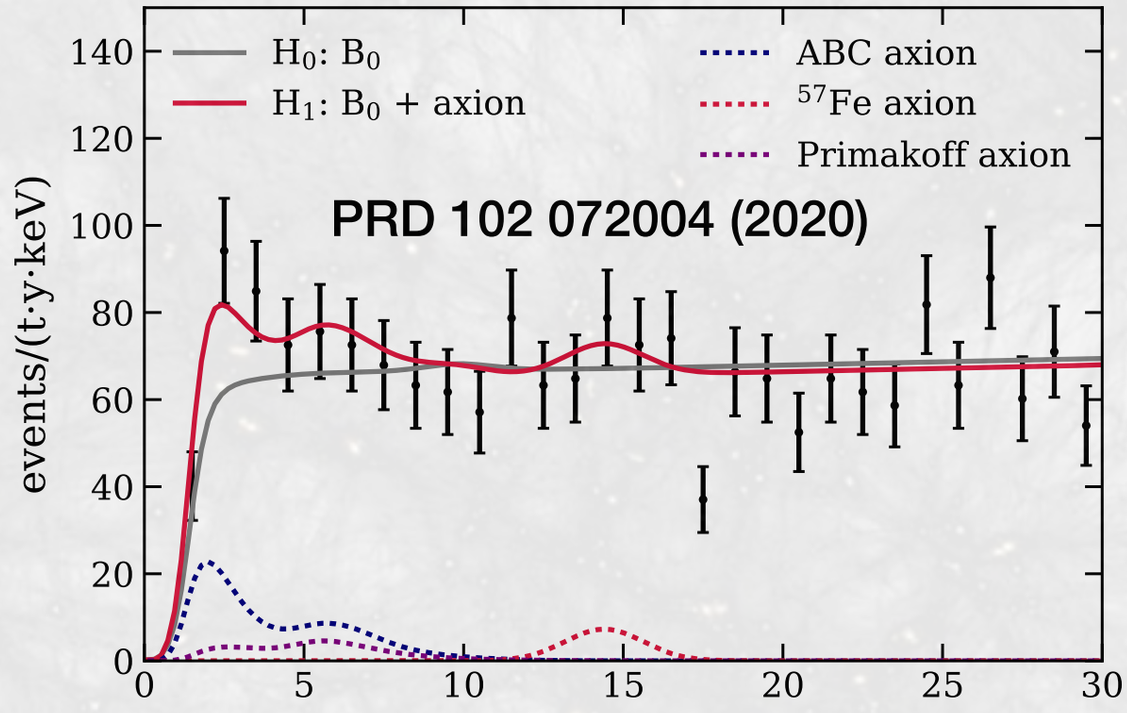
Expectation: 232±15

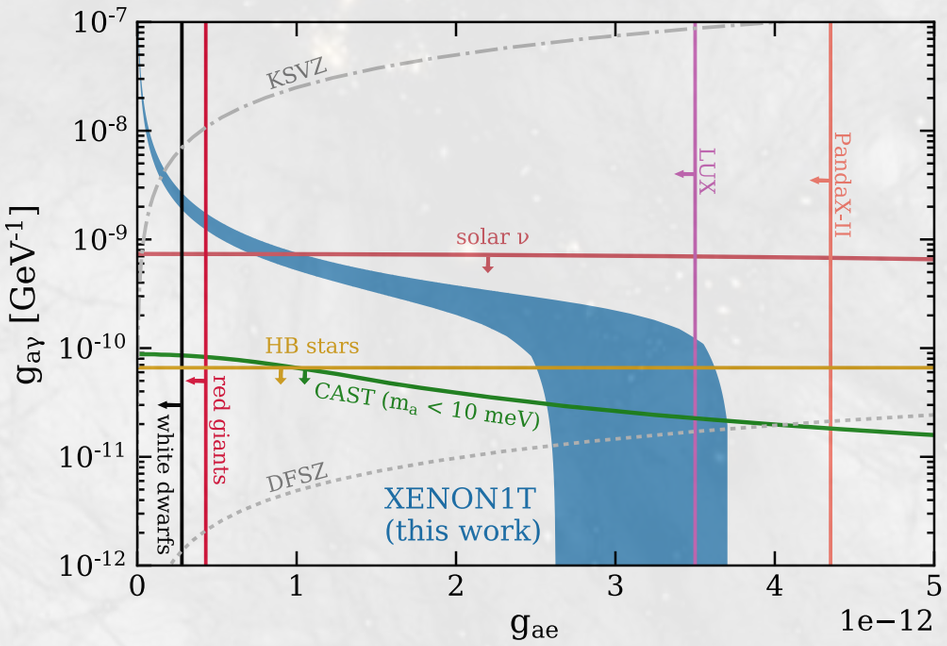
Observation: 285

Excess is most abundant between 2-3 keV

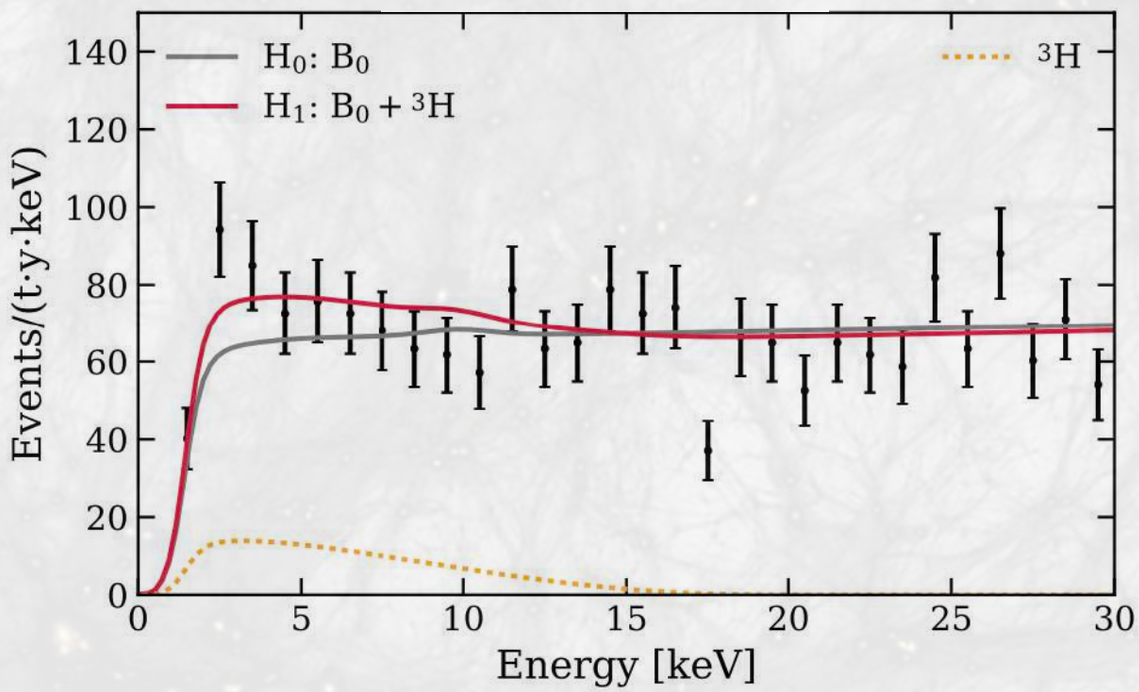
What Causes the Excess?







Tritium? Possible!



Axion explanation is in tension with stellar constraints

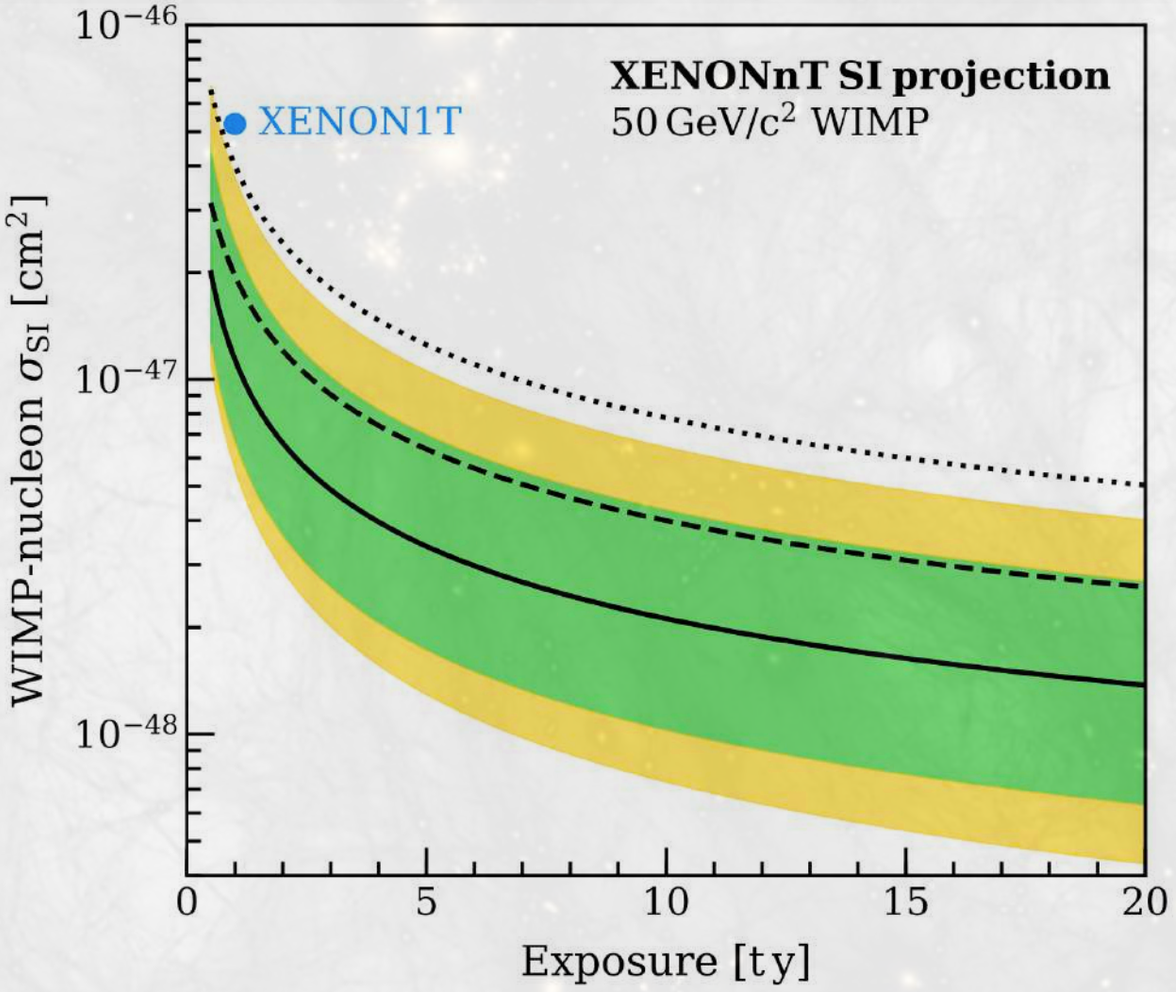
XENONnT: Currently running at Gran Sasso

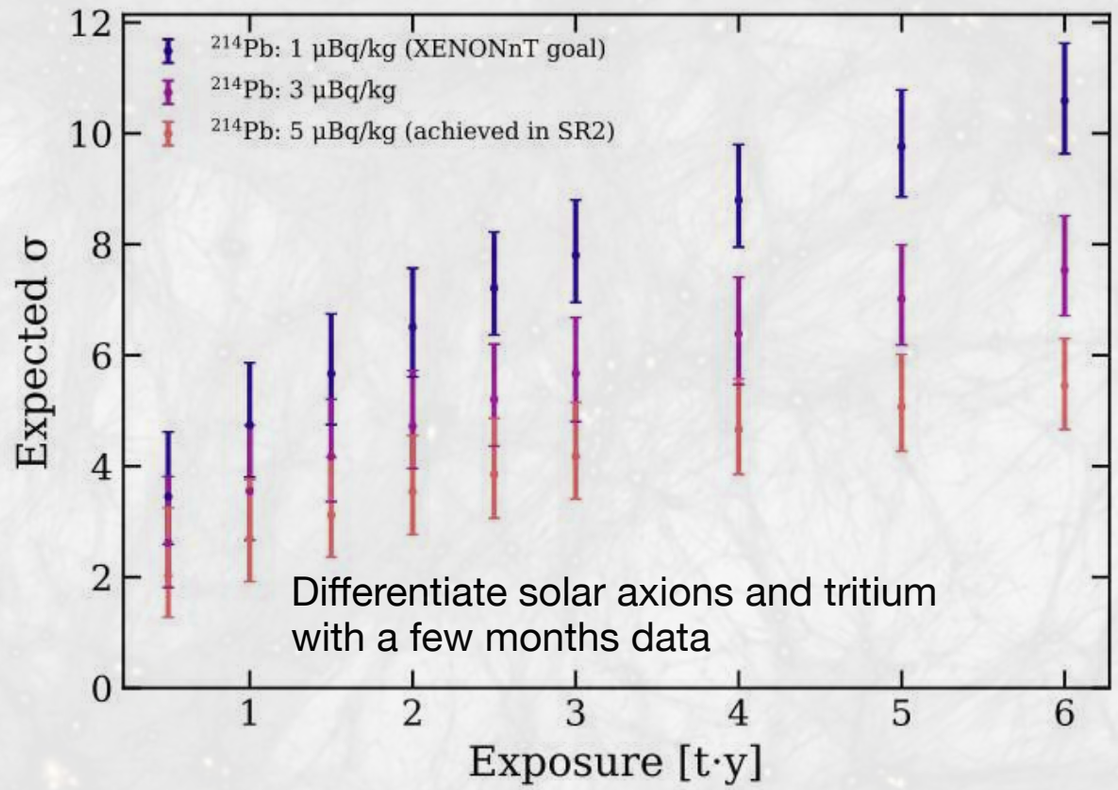
Goal: ~4.0 ton fiducial volume

~1/6 XENON1T ER background level

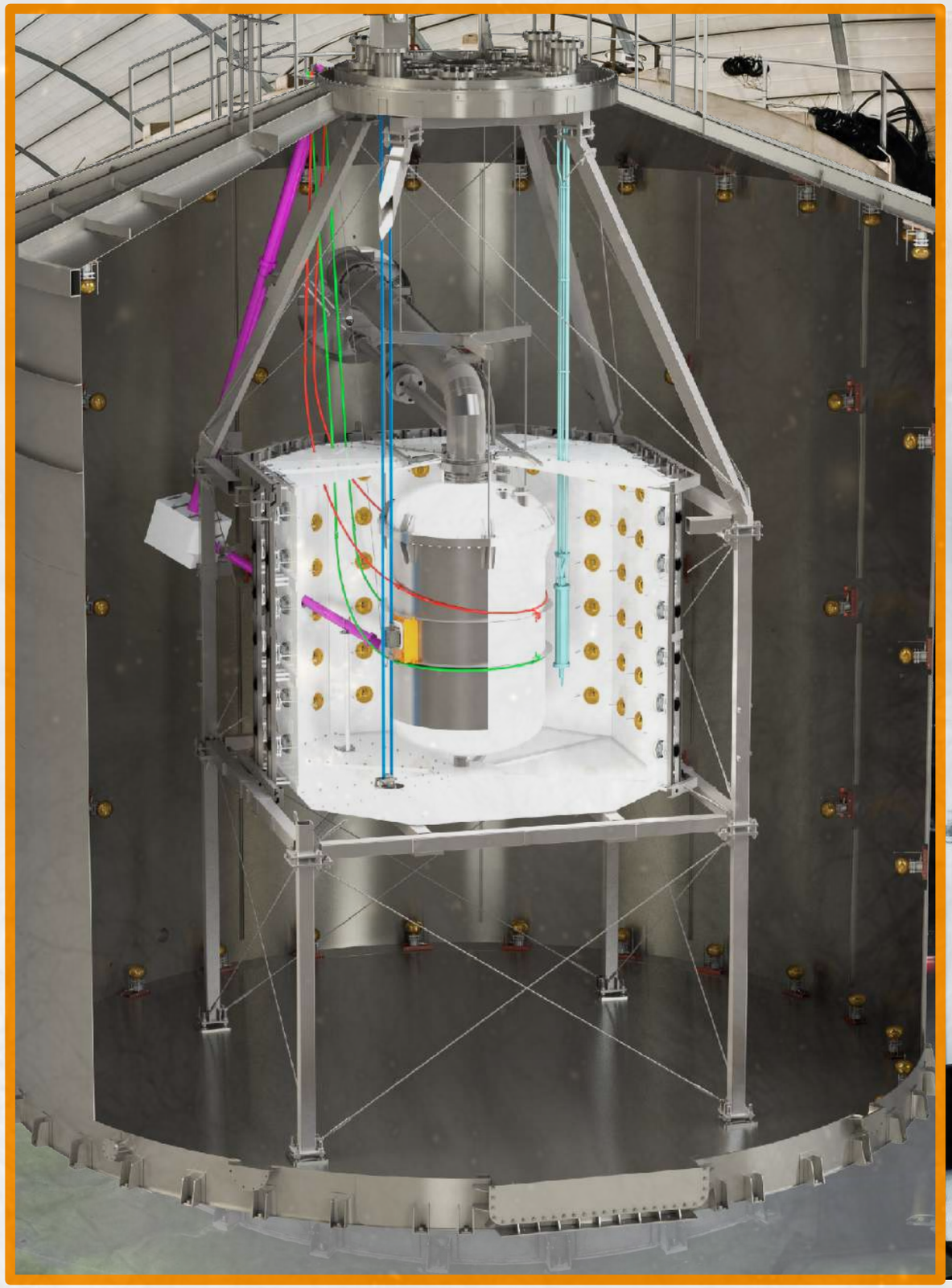
~1 neutron induced background in 20 ton-year exposure

JCAP 11 (2020) 031





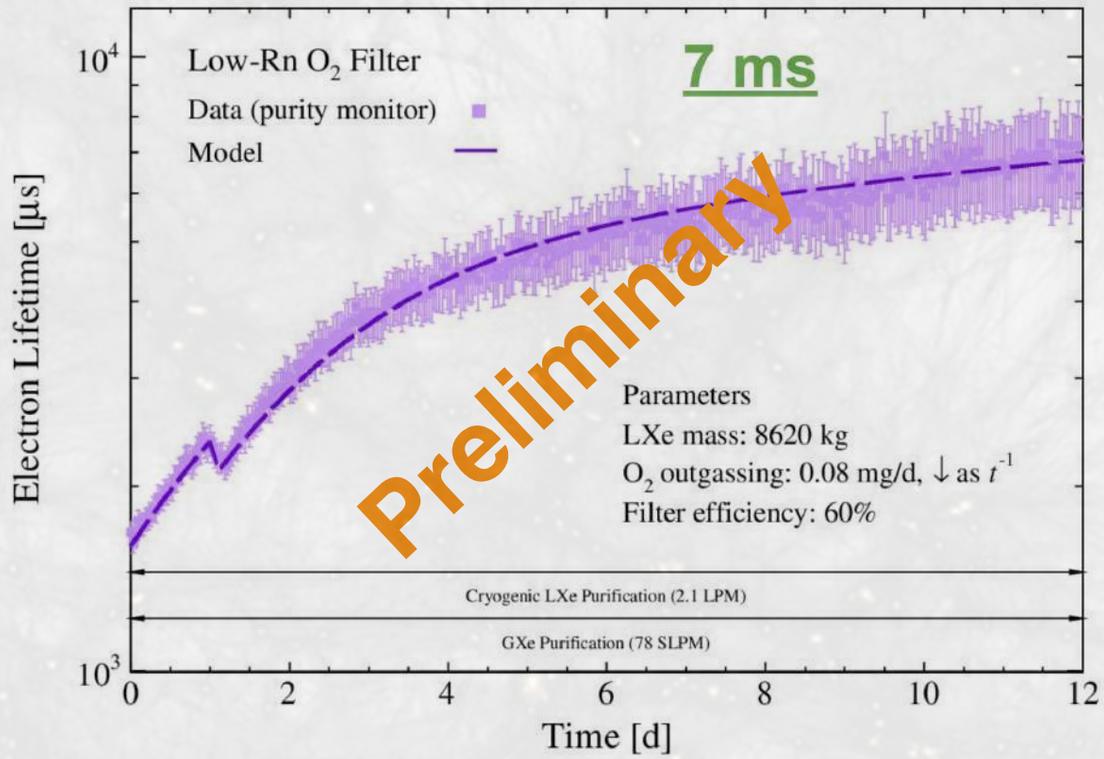
Upgrading to XENONnT

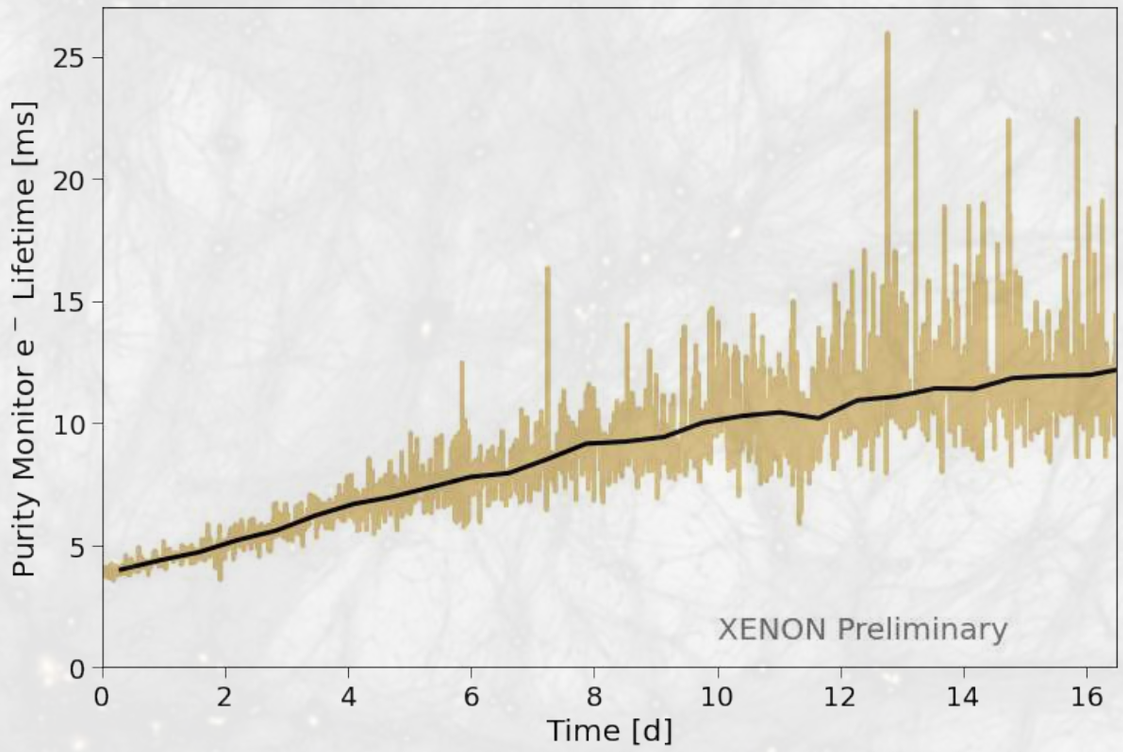


XENONnT Cryogenic Liquid Purification

Cryostat is filled with ~8.5t of LXe

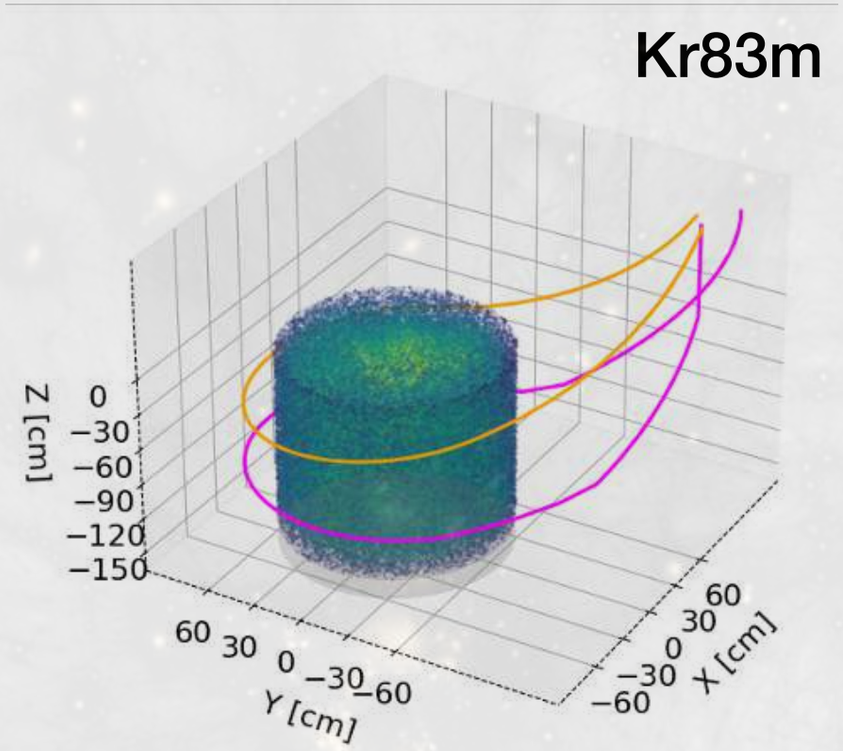
Exp	Max Drift [ms]	Electron lifetime [ms]	Cathode electron survival	Purification speed
XENON1T	0.73	0.65	30%	0.65ms in ~ 3 months
XENONnT	2.2	~10	>90%	5ms in ~5 days



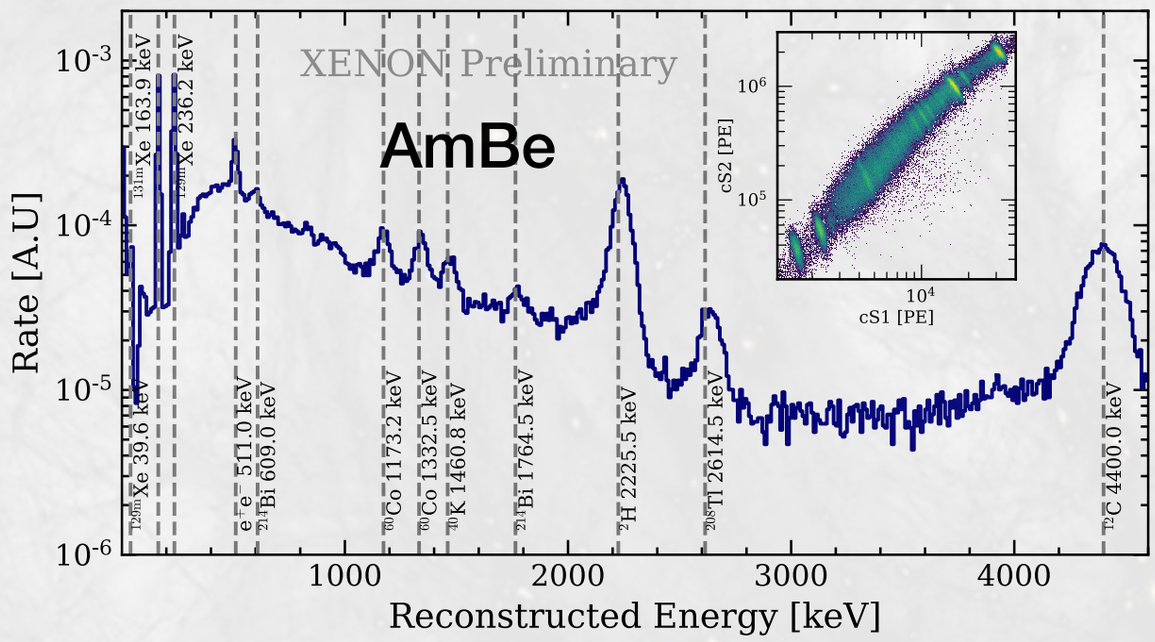


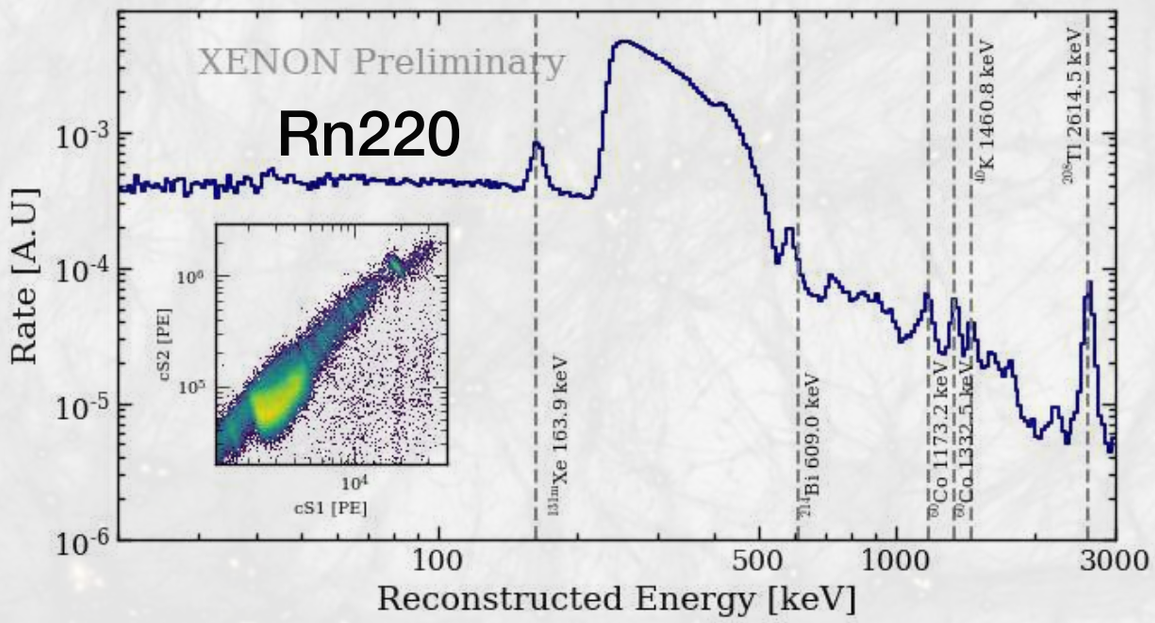
Calibrating XENONnT

- XENONnT's 5.9-ton LXe sensitive volume is calibrated from keV to MeV

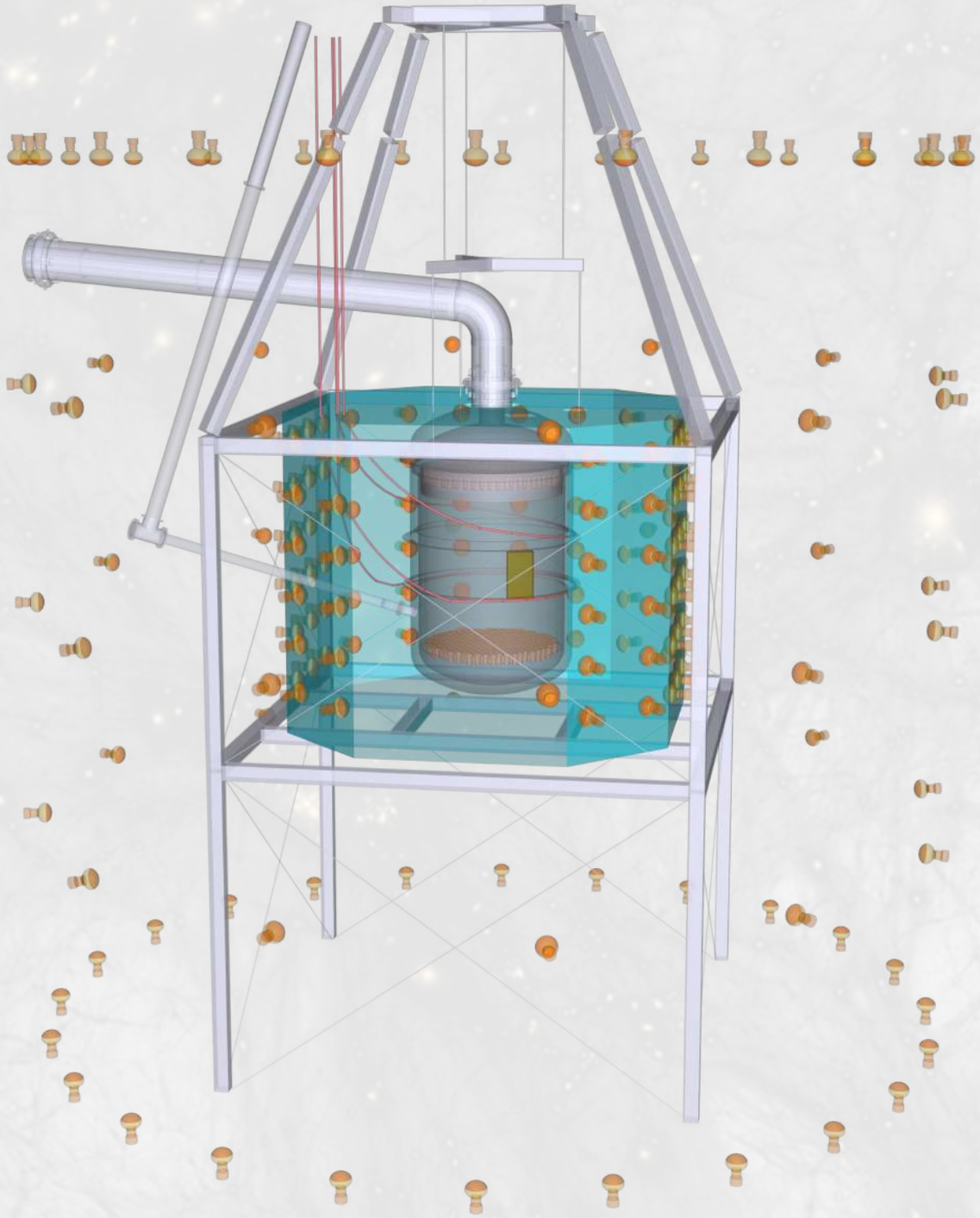


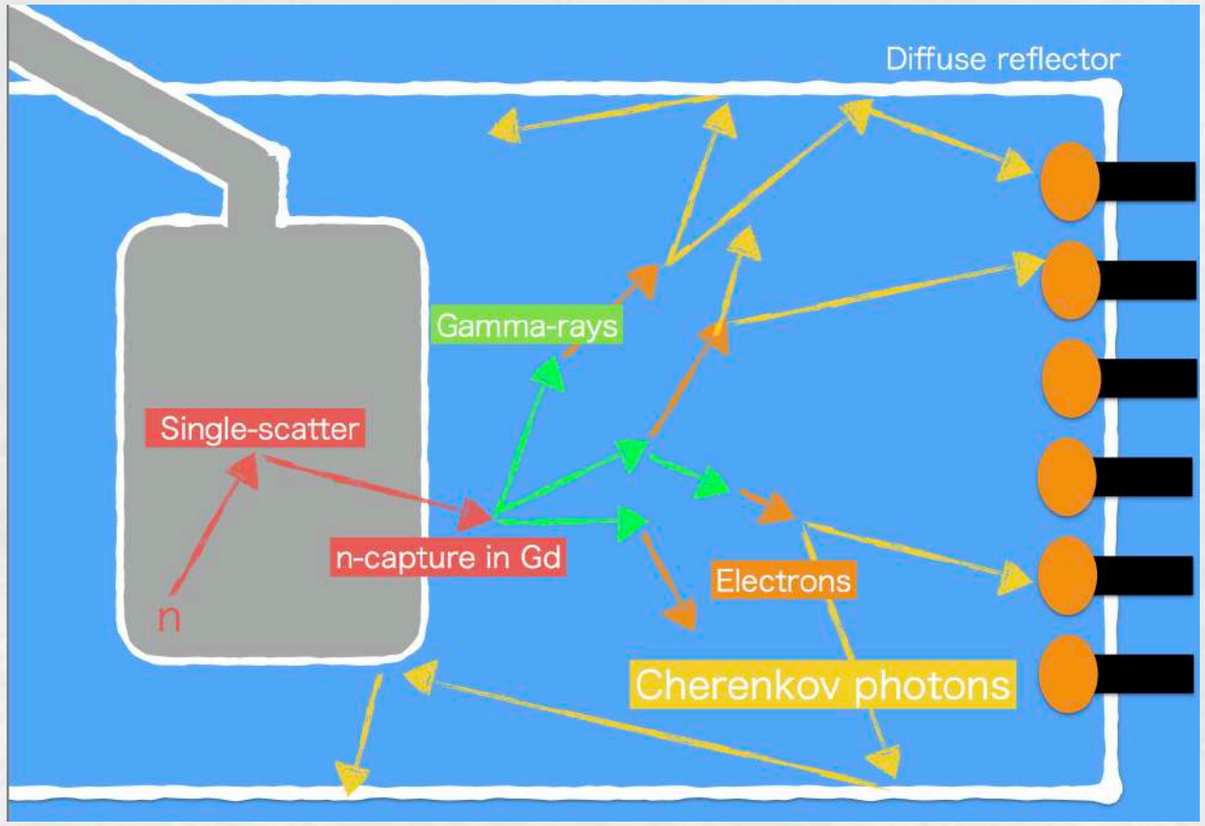
- XENONnT Calibration Campaign
  - Kr83m: uniformity, light/charge yield etc
  - Rn220: Low Energy ERs
  - AmBe: Low Energy NRs, high energy ERs
  - Other calibrations: PMTs etc





XENONnT Neutron Veto



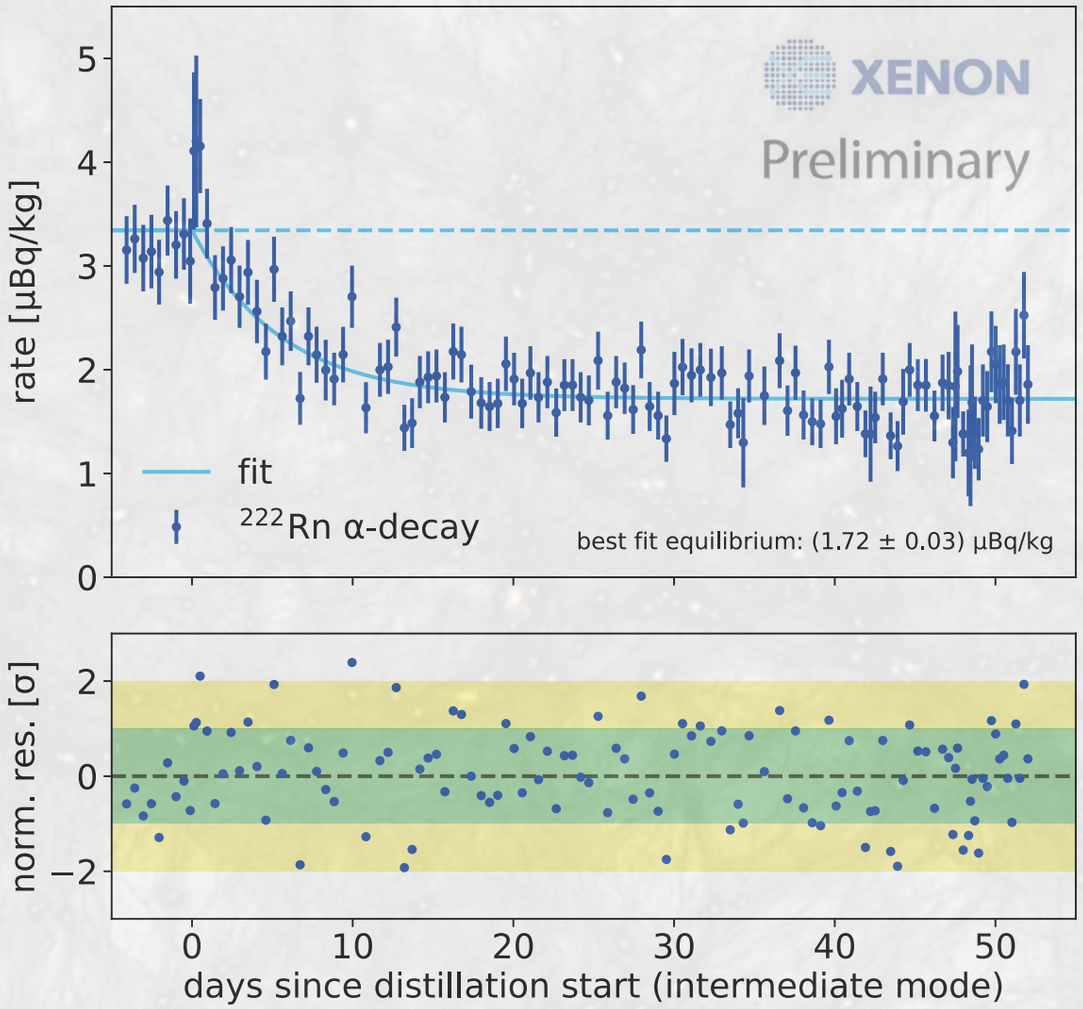


- Gd-Water Cherenkov veto detection (designed efficiency >85%)
- Neutron background reduced to < 1 events / (20 tonne year)

XENONnT Radon Distillation Column

Xenon

Radon



- Initial gas phase only distillation reduced the radon level to 1.7 μBq/kg
- Lowest radon level ever achieved in a LXeTPC

Summary

XENON1T: Still leading the search of many rare phenomena:

- WIMPs search & Solar B8 “Neutrino Fog”
- Solar Axions
- ……

XENONnT: running at Gran Sasso

- lower background
- larger exposure
- higher sensitivity

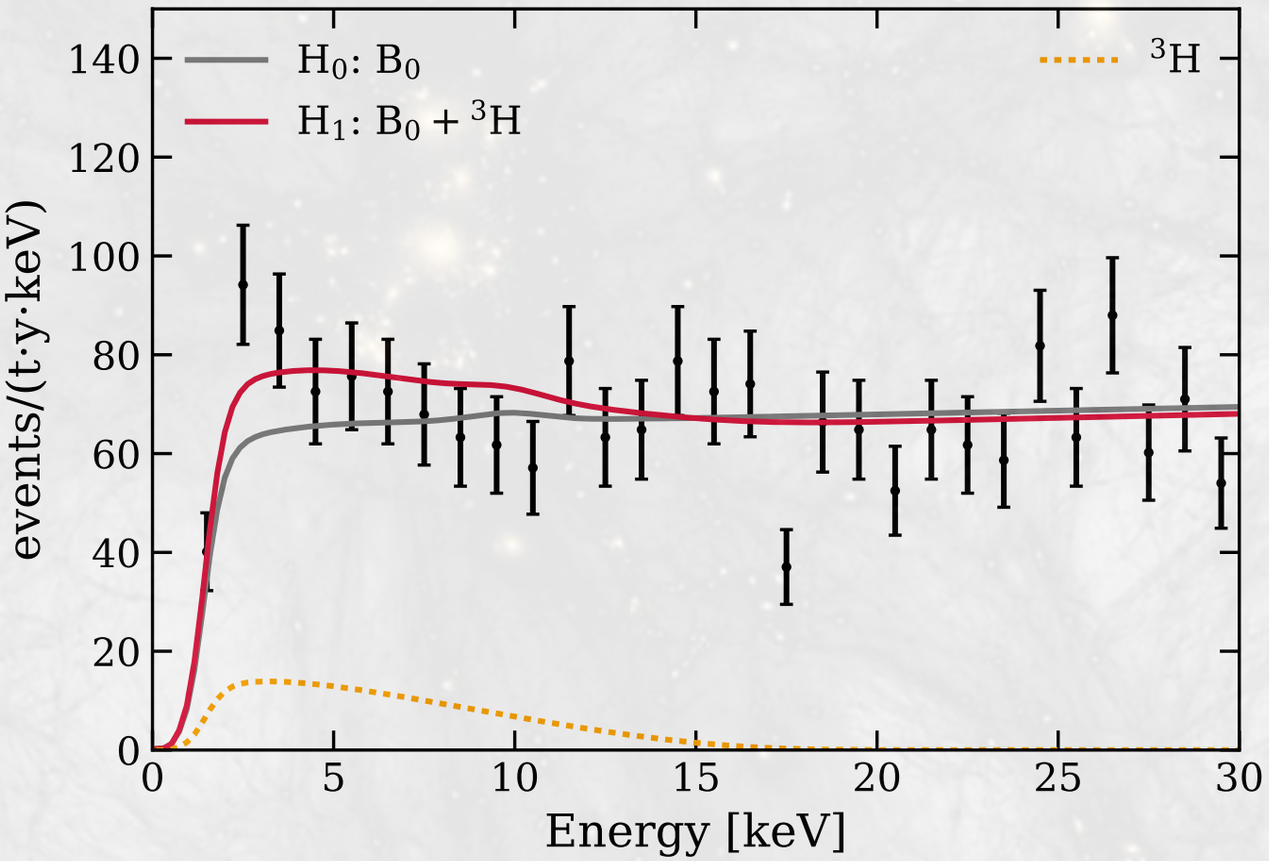
Addressing the low energy ER Excess soon!

Stay Tuned ：)

www.xenonexperiment.org
xe-pr@lngs.infn.it

Tritium

Tritium favored over background-only at 3.2σ



Low energy (Q-value 18.6keV)

Long half life (12.3 years)

Tritium Rate

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

^{3}H:Xe concentration

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