# First Results from XENONnT

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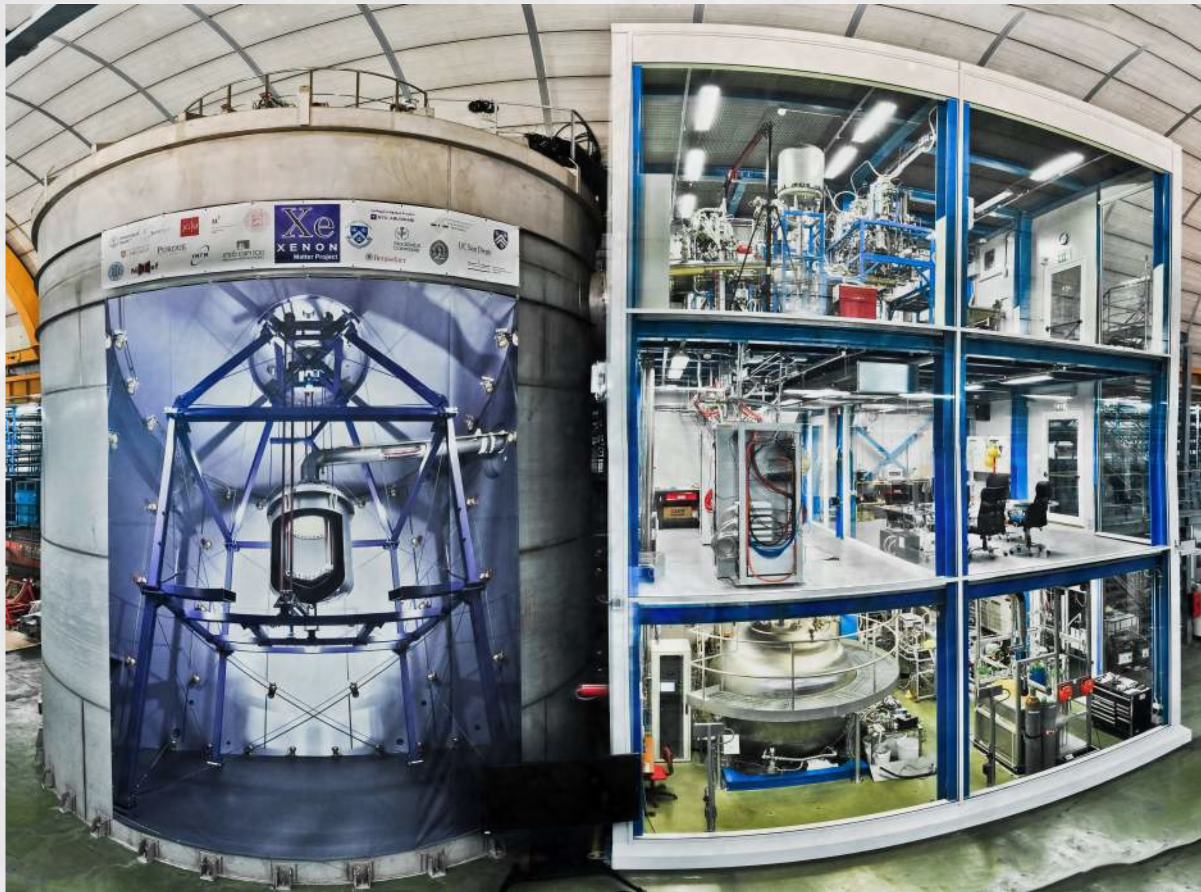
On behalf of the XENON Collaboration

第三届粒子物理前沿研讨会
中山大学
July 24, 2022



# The XENON Collaboration

Columbia KIT Nikhef Muenster Stockholm Mainz MPIK, Heidelberg Freiburg Zurich

Chicago

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Rice

Purdue

Tsinghua

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Nagoya

Kobe

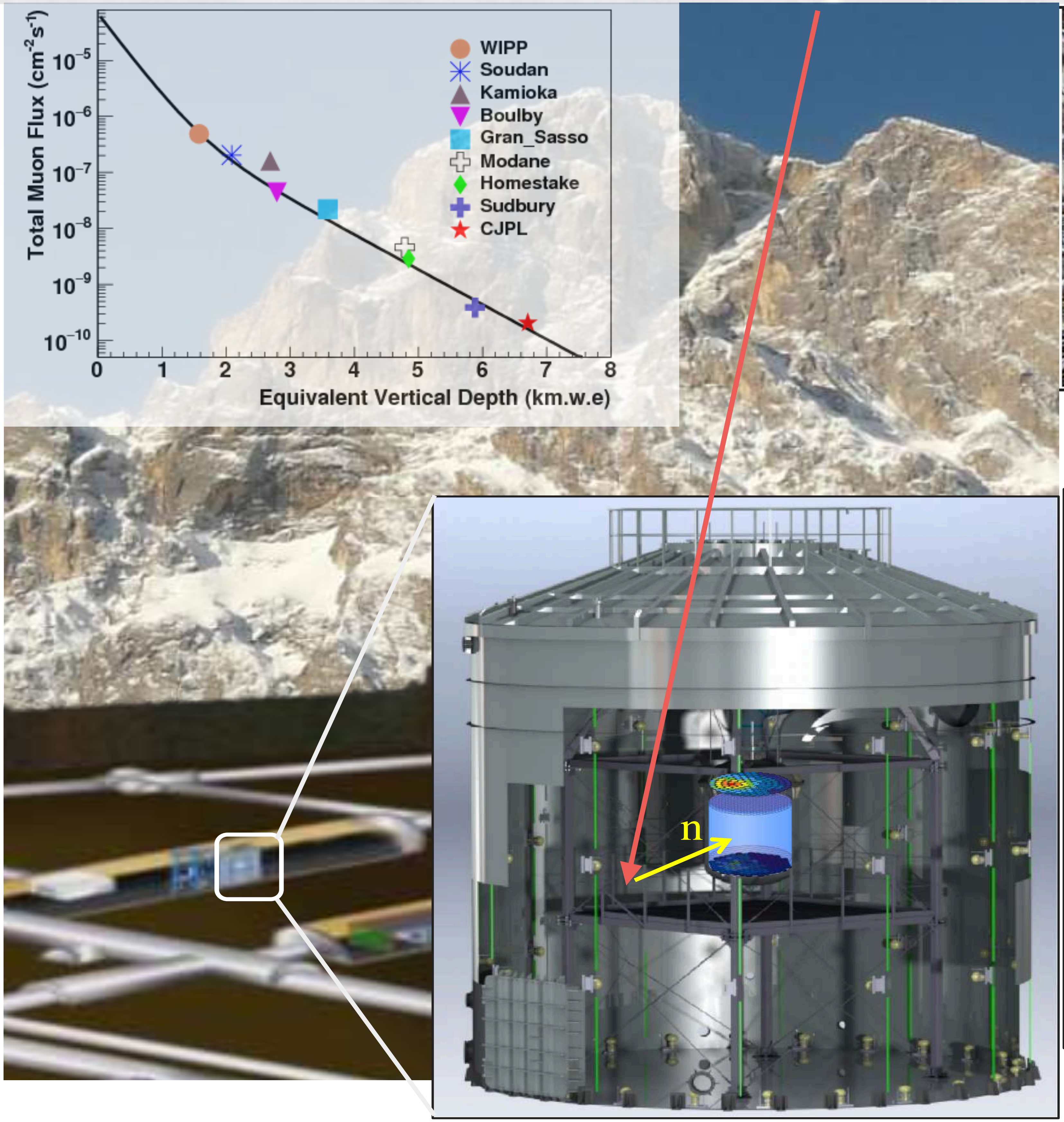
Subatech Coimbra LPNHE Torino Bologna L'Aquila LNGS Napoli Weizmann NYUAD

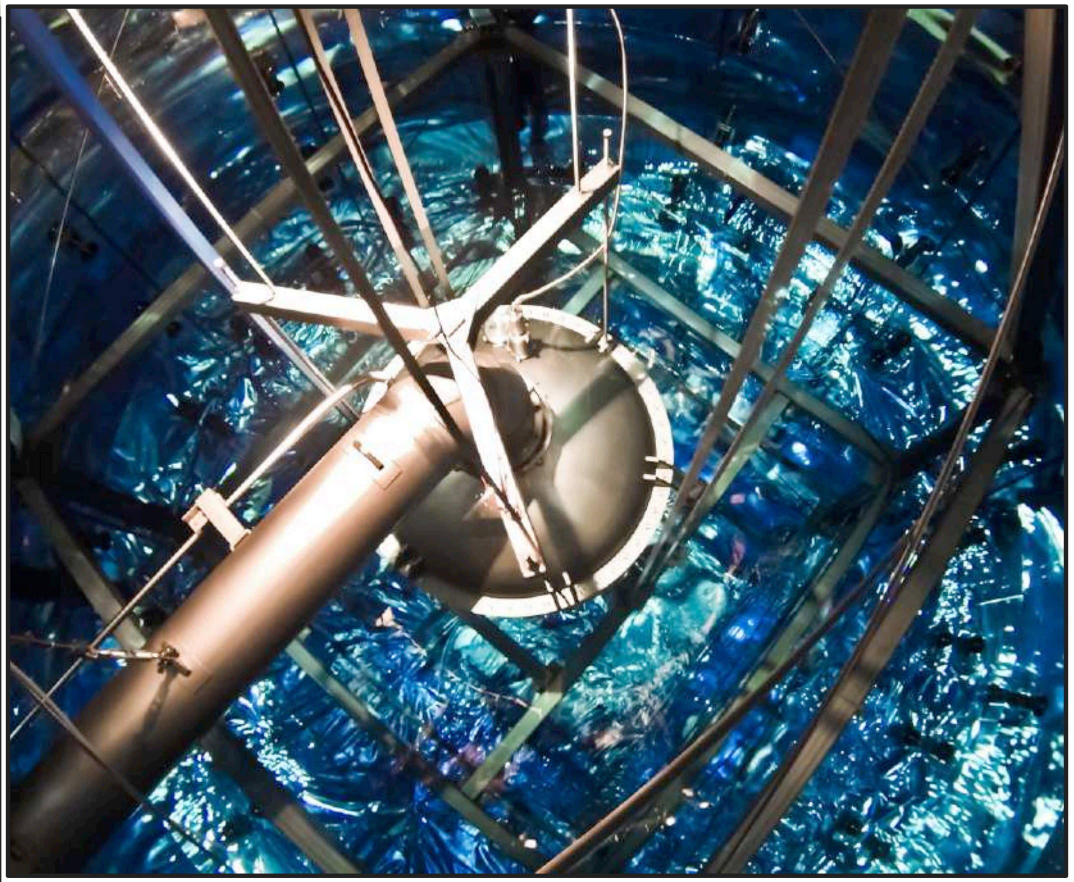
# Development of XENON Program




| XENON10 | XENON100 | XENON1T | XENONnT |
|---|---|---|---|
| 2005-2007 | 2008-2016 | 2012-2018 | 2019-202x |
| 14 kg - 15cm drift | 62 kg - 30 cm drift | 2 ton - 1 m drift | 6 ton - 1.5 m drift |
| $\sim 10^{-43}$ cm$^2$ | $\sim 10^{-45}$ cm$^2$ | $\sim 10^{-47}$ cm$^2$ | $\sim 10^{-48}$ cm$^2$ |

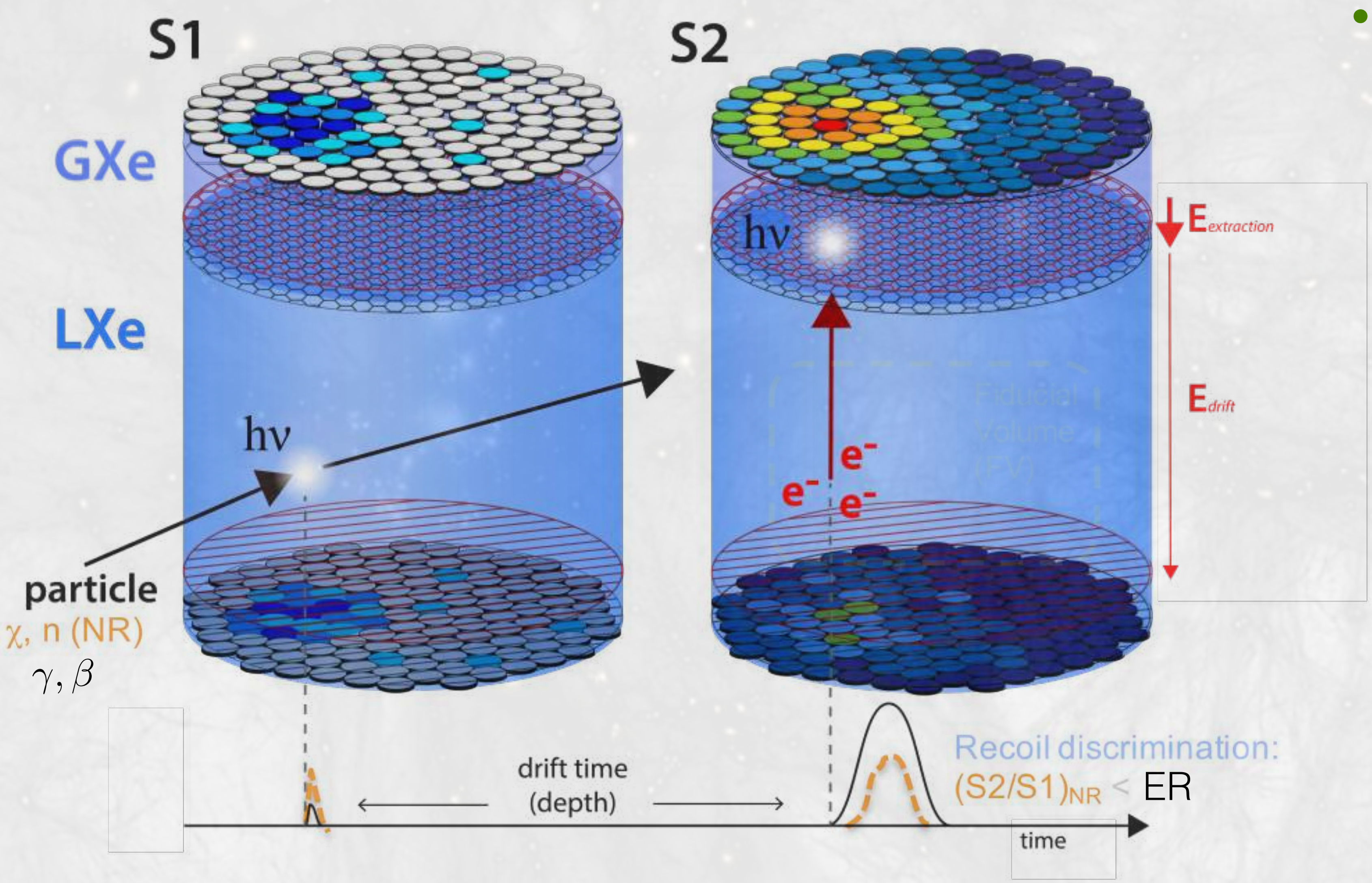
# Gran Sasso: The XENON Shield



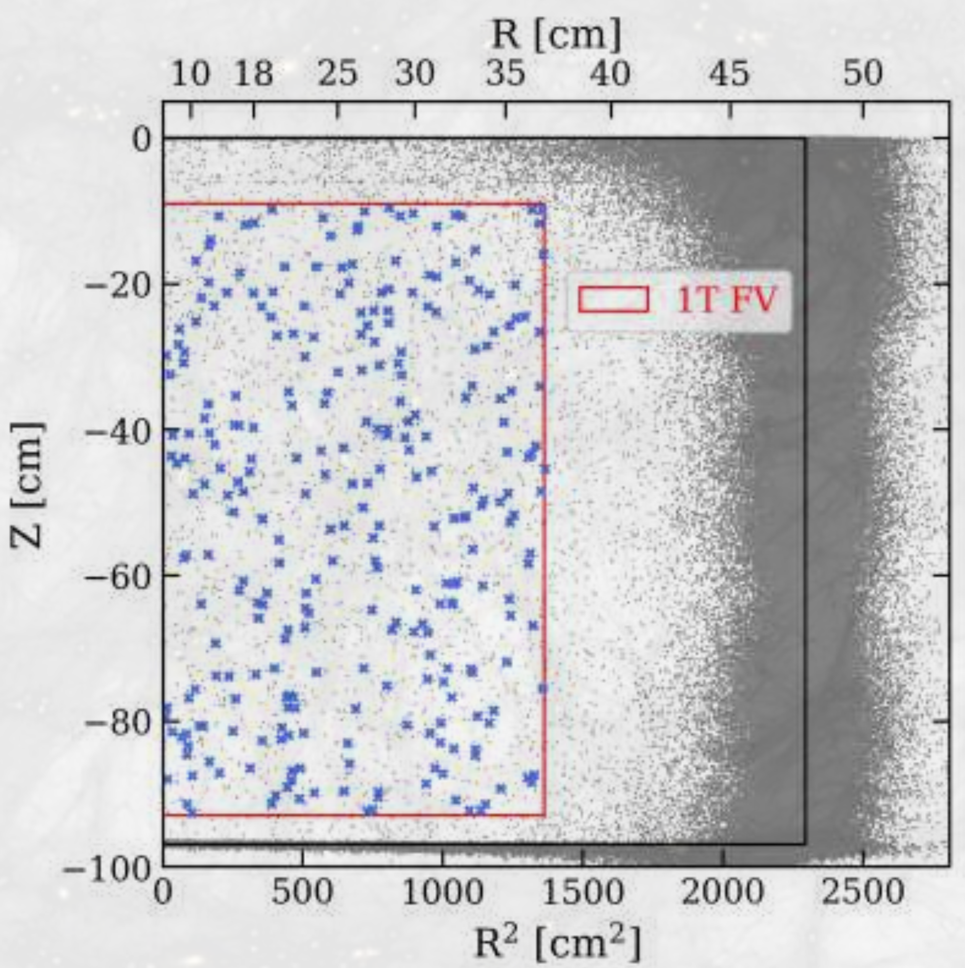



# Two-phase Xe Time Projection Chamber

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

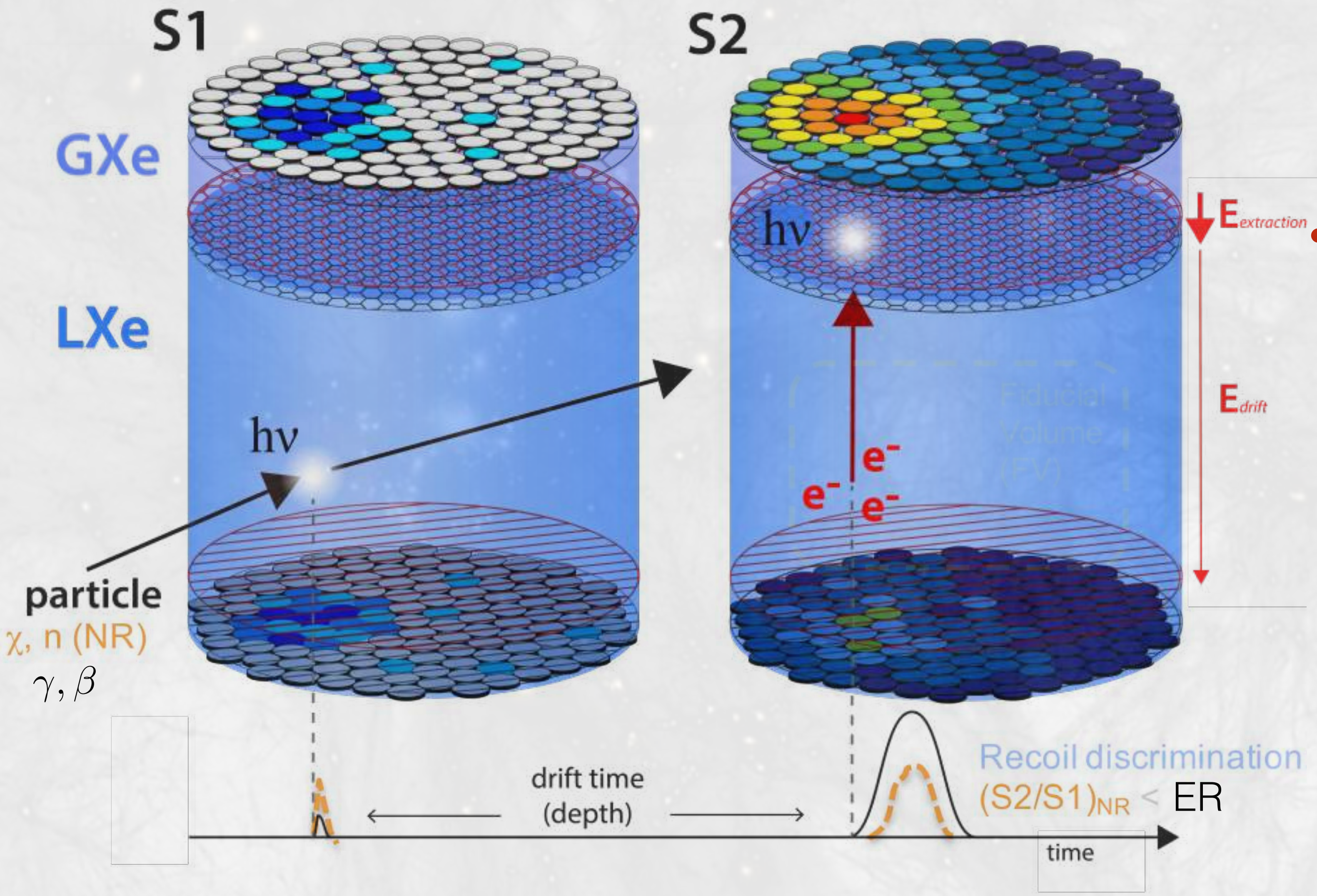



- two signals for each event:
  - 3D event imaging: x-y (S2) and z (drift time)
  - self-shielding, surface event rejection, single vs multiple scatter events

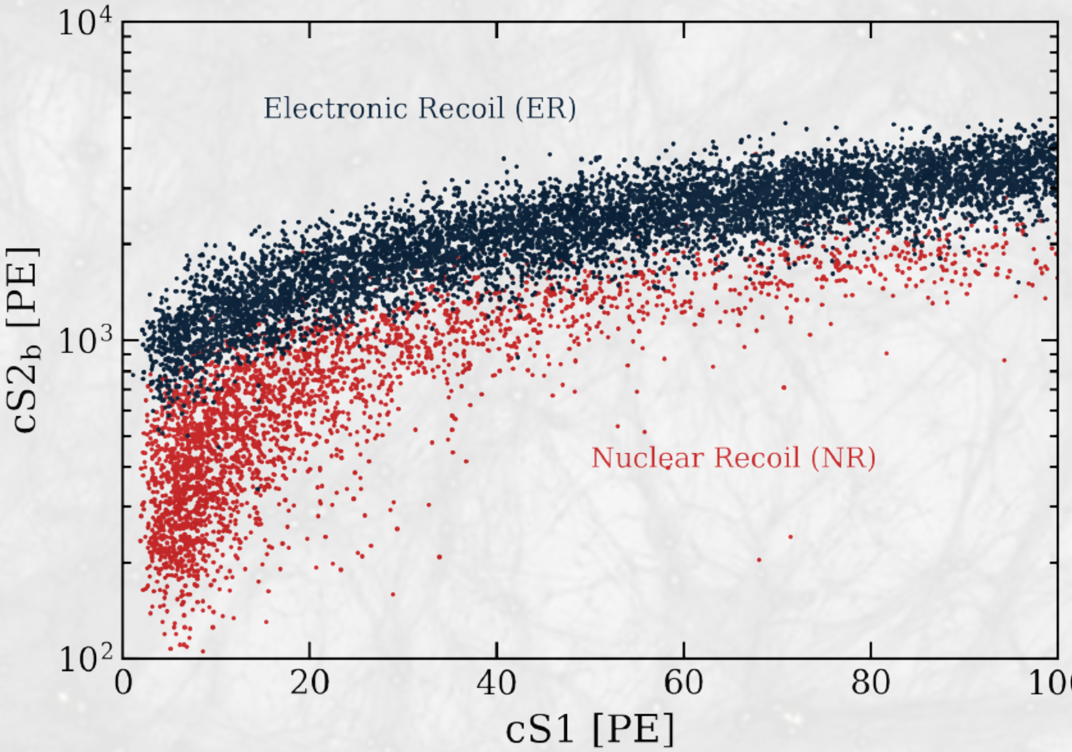


# Two-phase Xe Time Projection Chamber

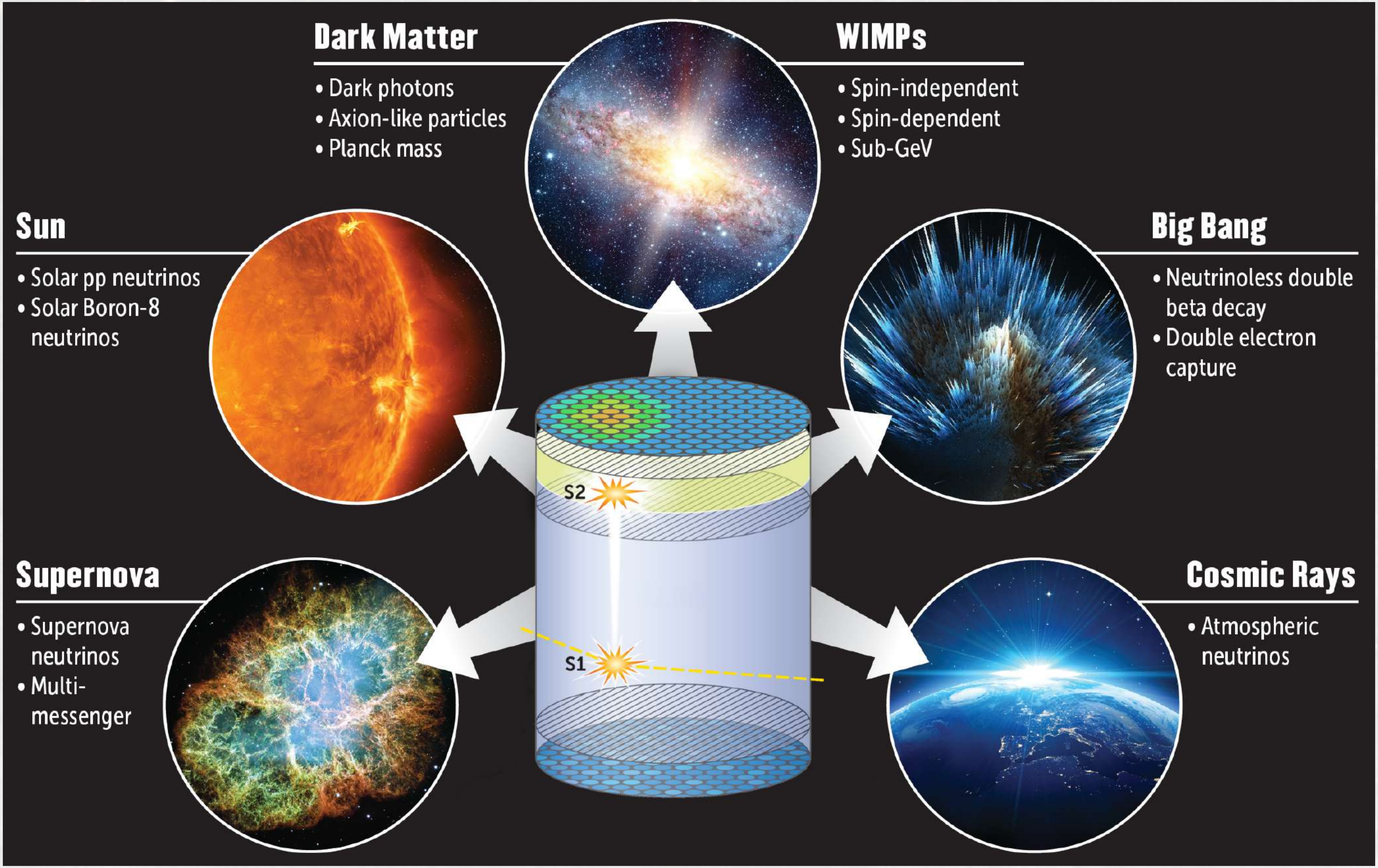
- Scintillation light - S1
- Ionization electron -S2




- 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
- Recoil type discrimination from ratio of charge (S2) to light (S1)



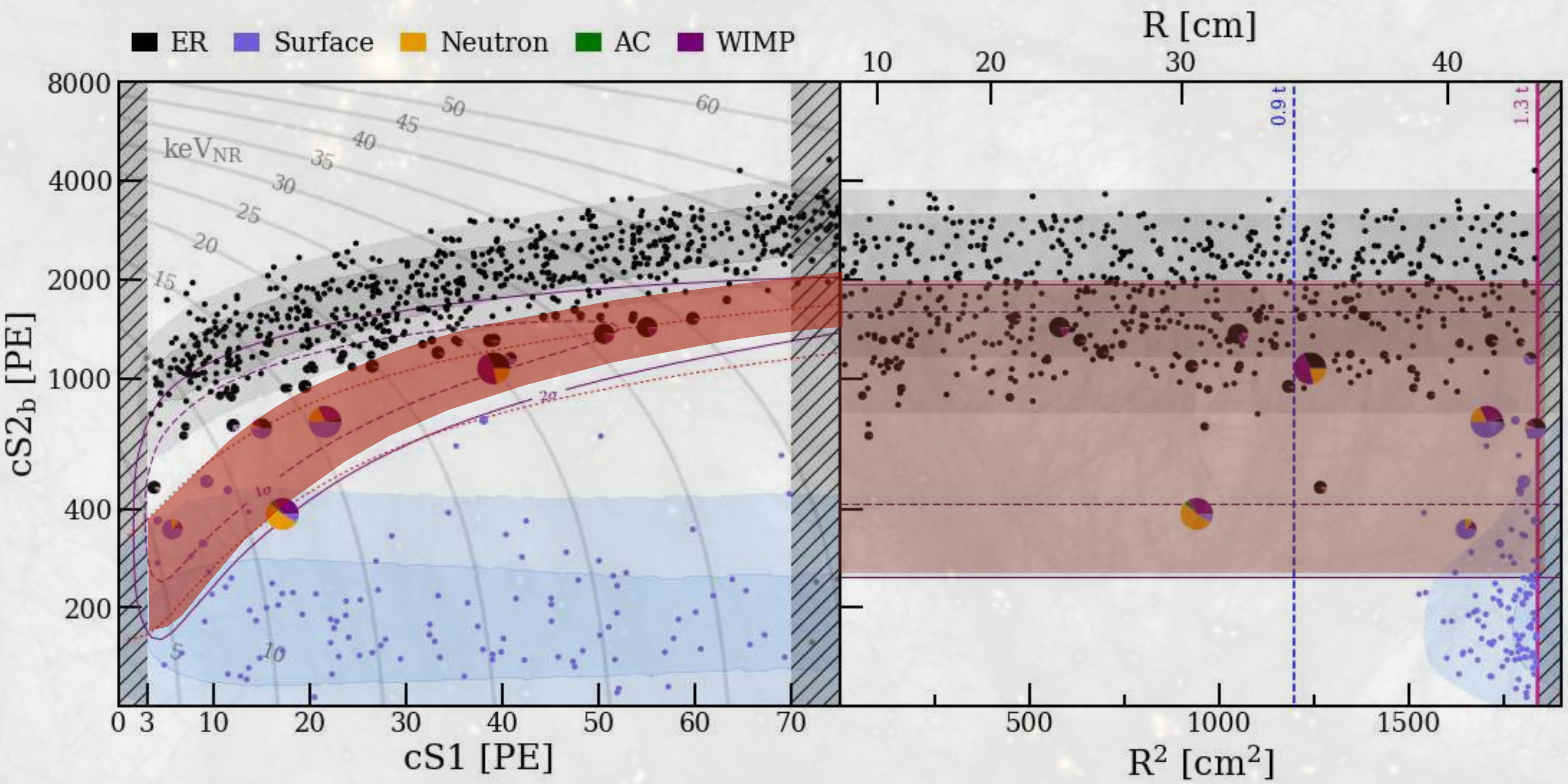
# Science in XENON



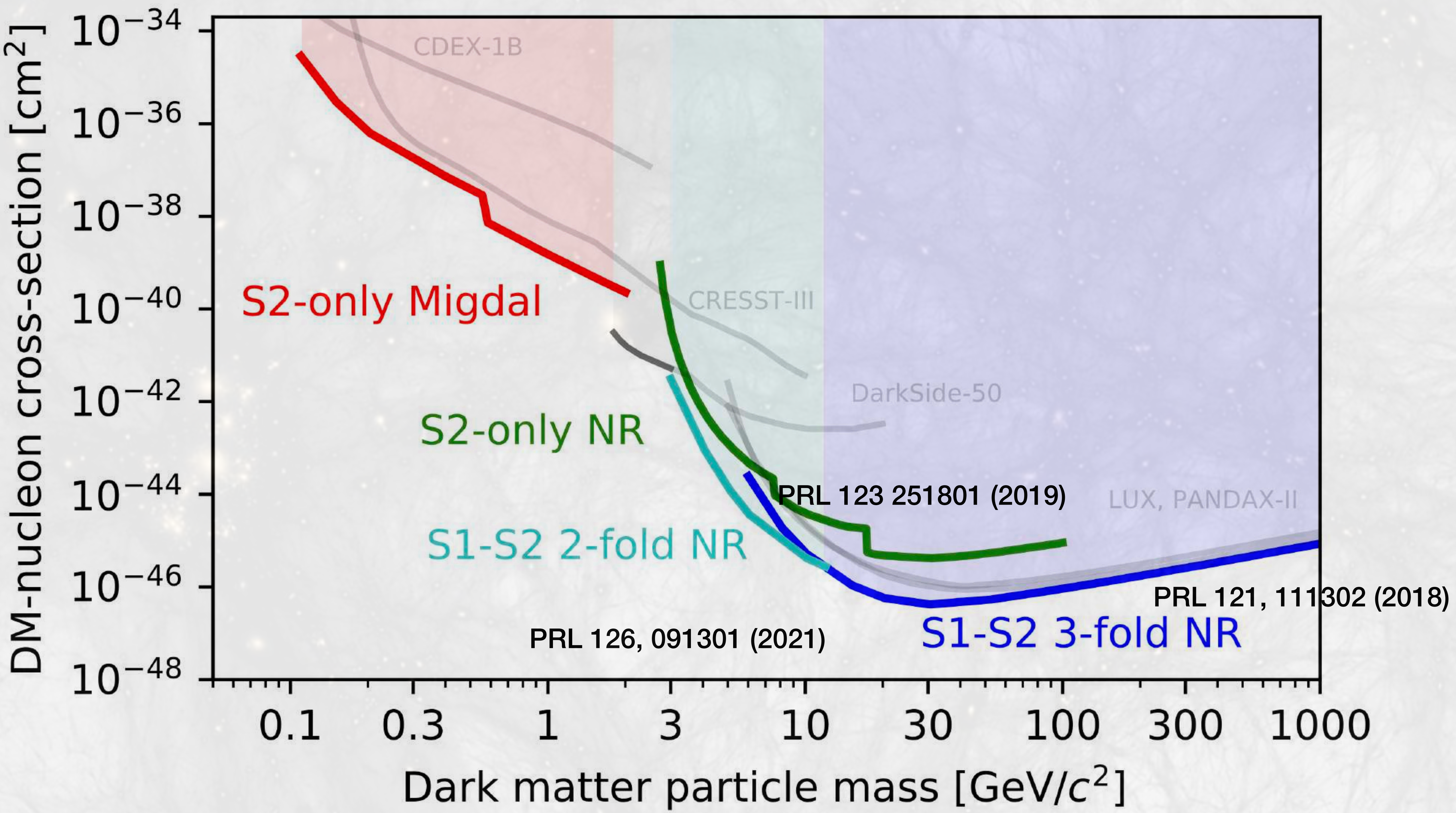
# XENON1T WIMPs Search

- World's most sensitive WIMPs search back then

| Source | 1.3 t | 1.3 t, NR Ref. | 0.9 t, NR Ref. |
|---|---|---|---|
| ER | 627 ± 18 | 1.6 ± 0.3 | 1.1 ± 0.2 |
| Radiogenic | 1.4 ± 0.7 | 0.8 ± 0.4 | 0.4 ± 0.2 |
| Accidental | 0.5 $^{+0.3}_{-0.0}$ | 0.10 $^{+0.06}_{-0.00}$ | 0.06 $^{+0.03}_{-0.00}$ |
| Surface | 106 ± 8 | 4.8 ± 0.4 | 0.02 |
| **Total** | 735 ± 20 | 7.4 ± 0.6 | 1.6 ± 0.3 |
| 200 GeV WIMP $\sigma_{SI}$ = 4.7 x $10^{-47}$ | 3.6 | 1.7 | 1.2 |
| **Data** | **739** | **14** | **2** |



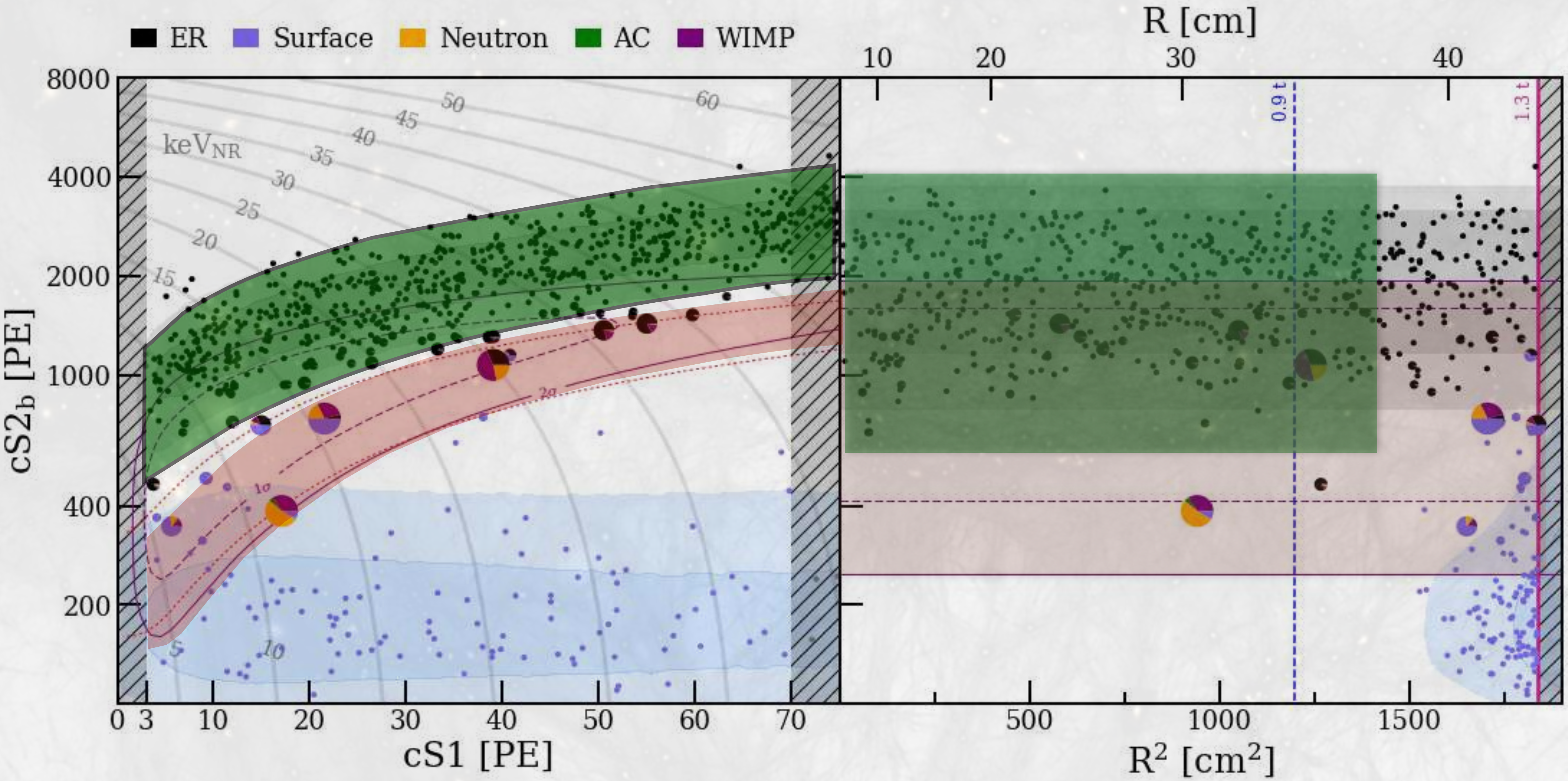
# XENON1T WIMPs Search




- WIMPs searches are optimized for different masses, touching the neutrino fog!

# XENON1T Solar Axion Search - 2020

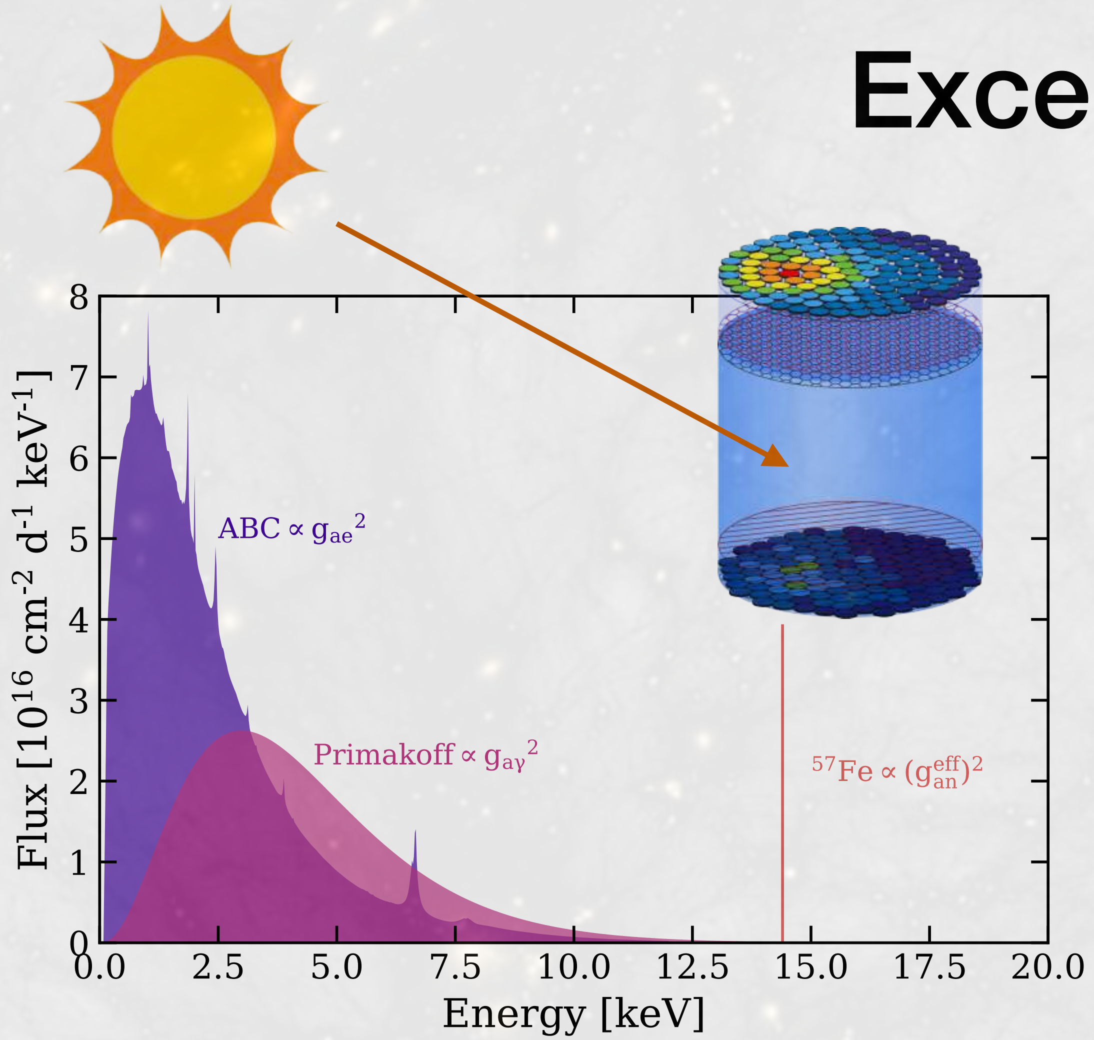
PRD 102 072004 (2020)

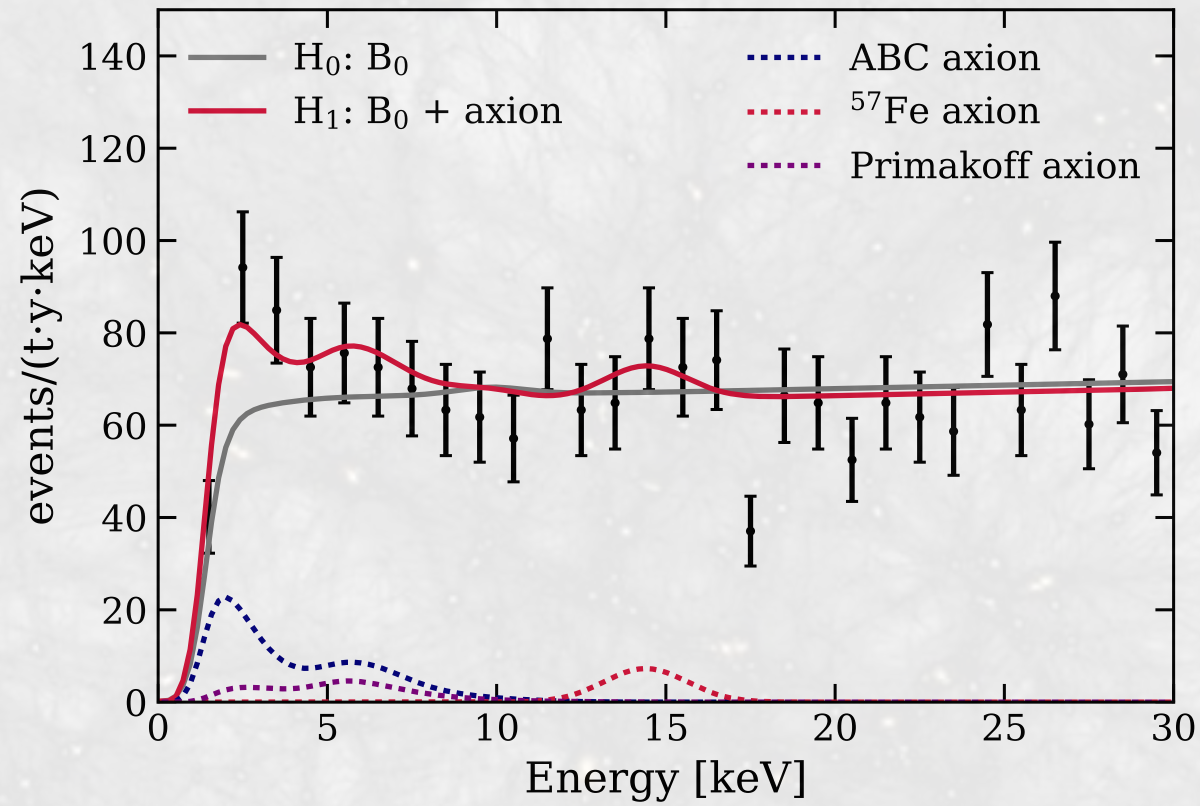


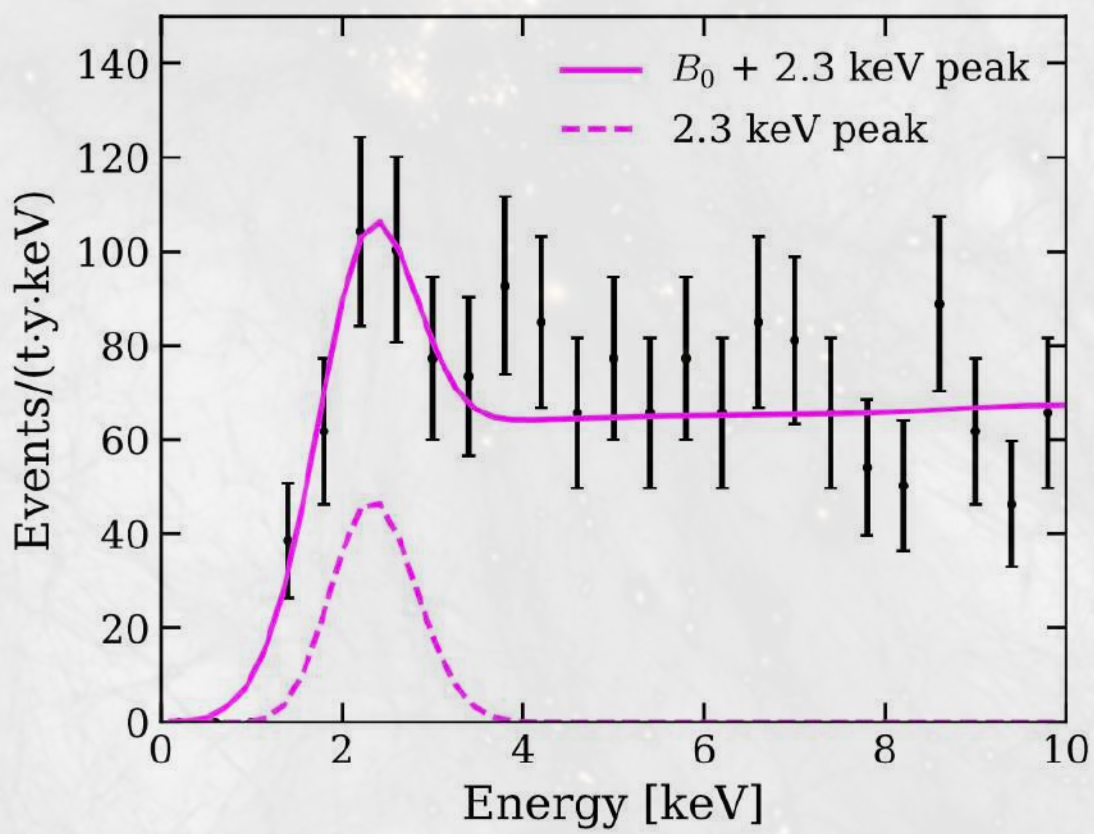

- XENON1T Excess in the Electronic Recoil (ER) Data!

# Excess ER Events

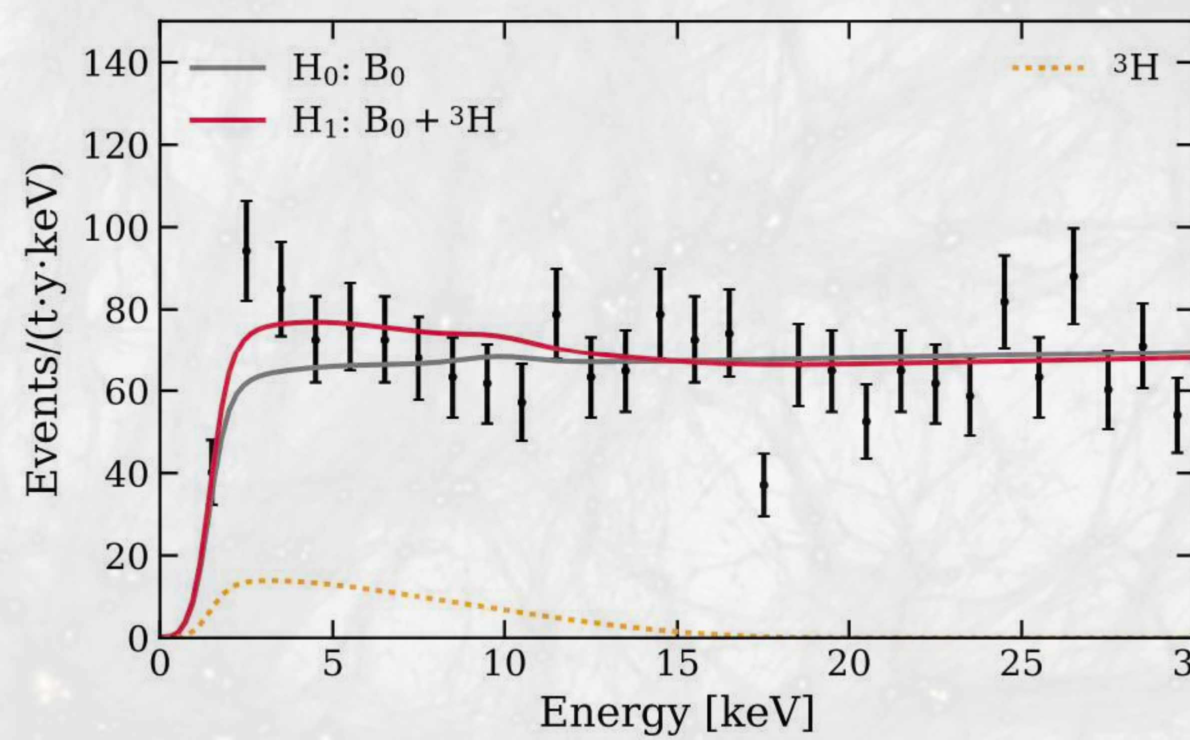
PRD 102 072004 (2020)



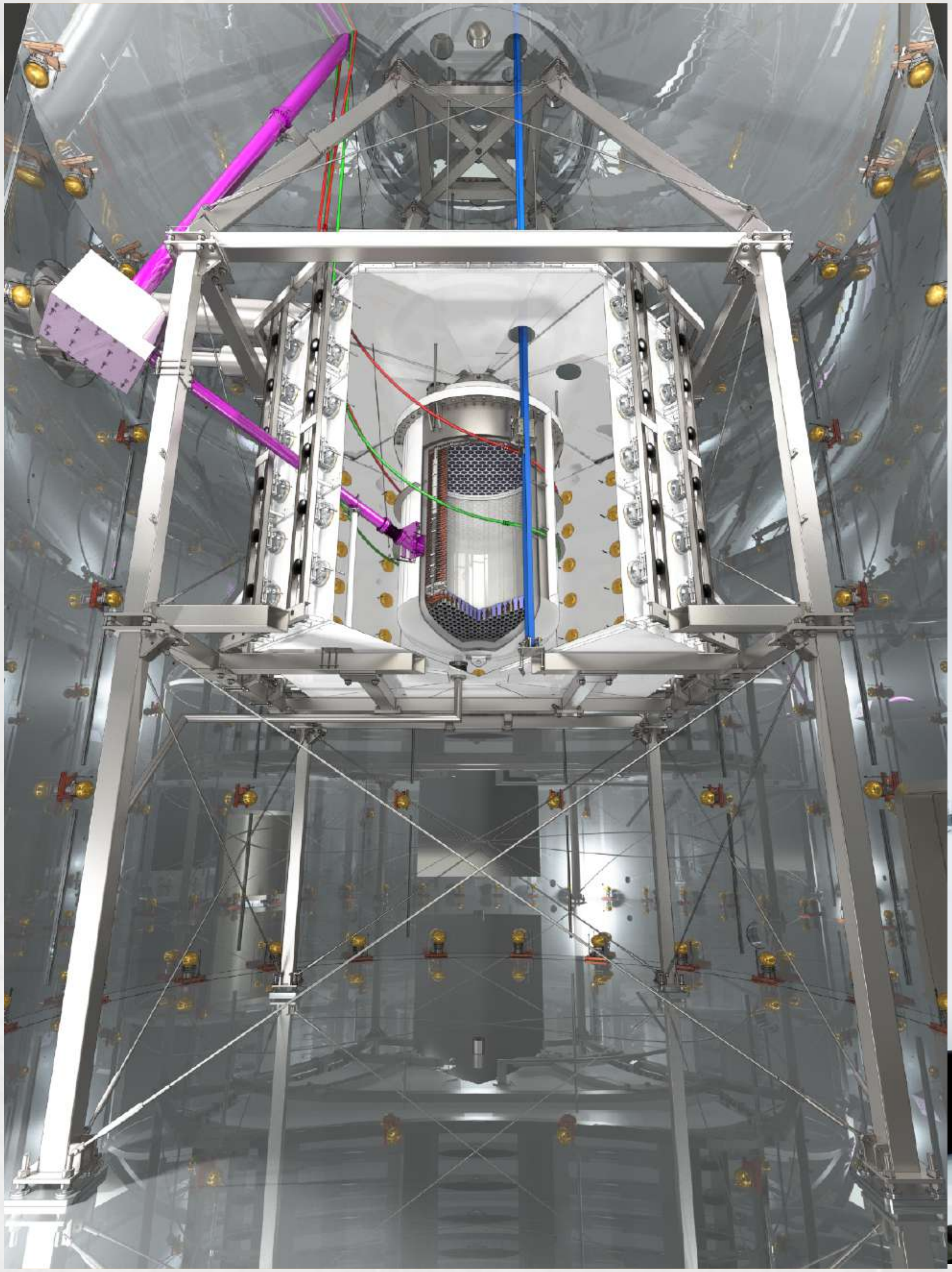



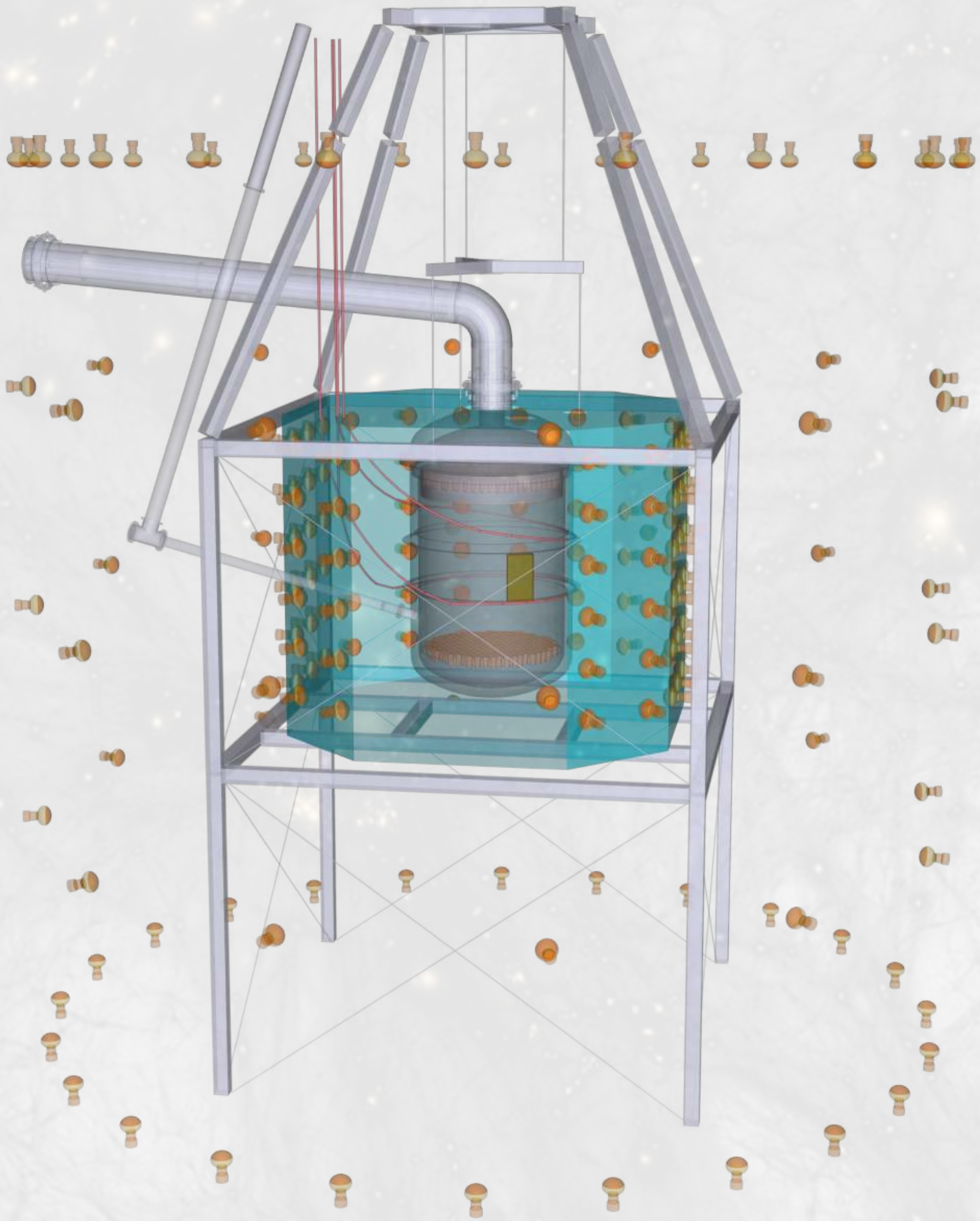

Tritium? Possible!

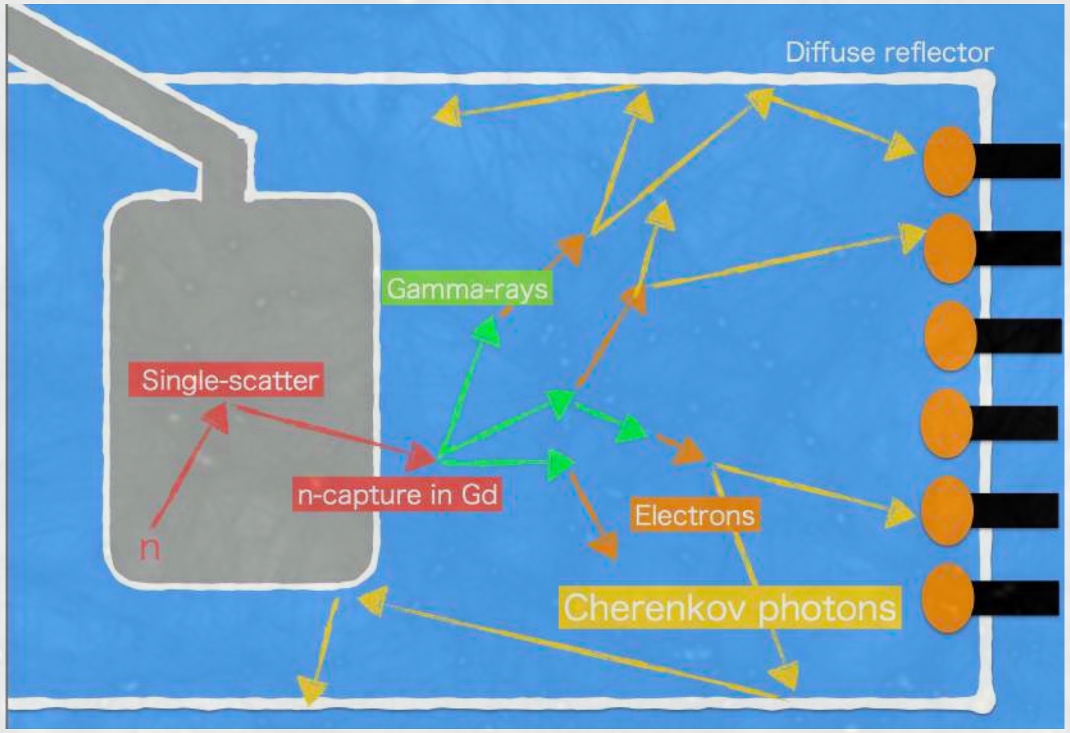


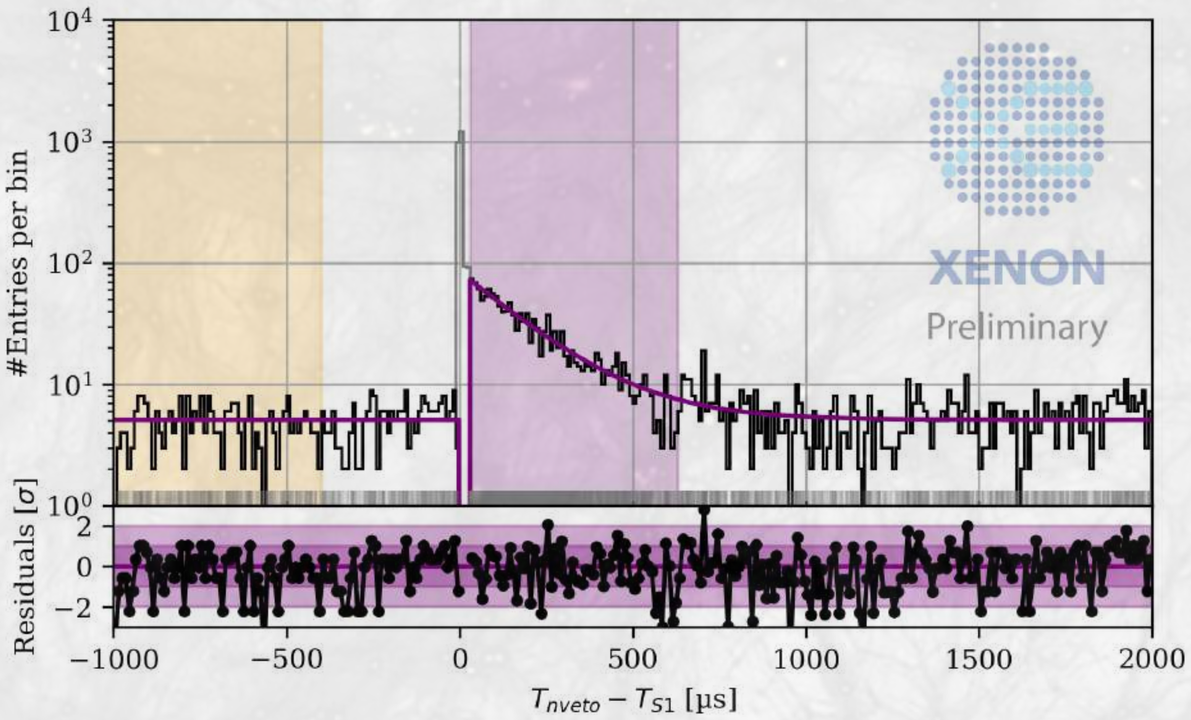
# Upgrading to XENONnT



# XENONnT Neutron Veto

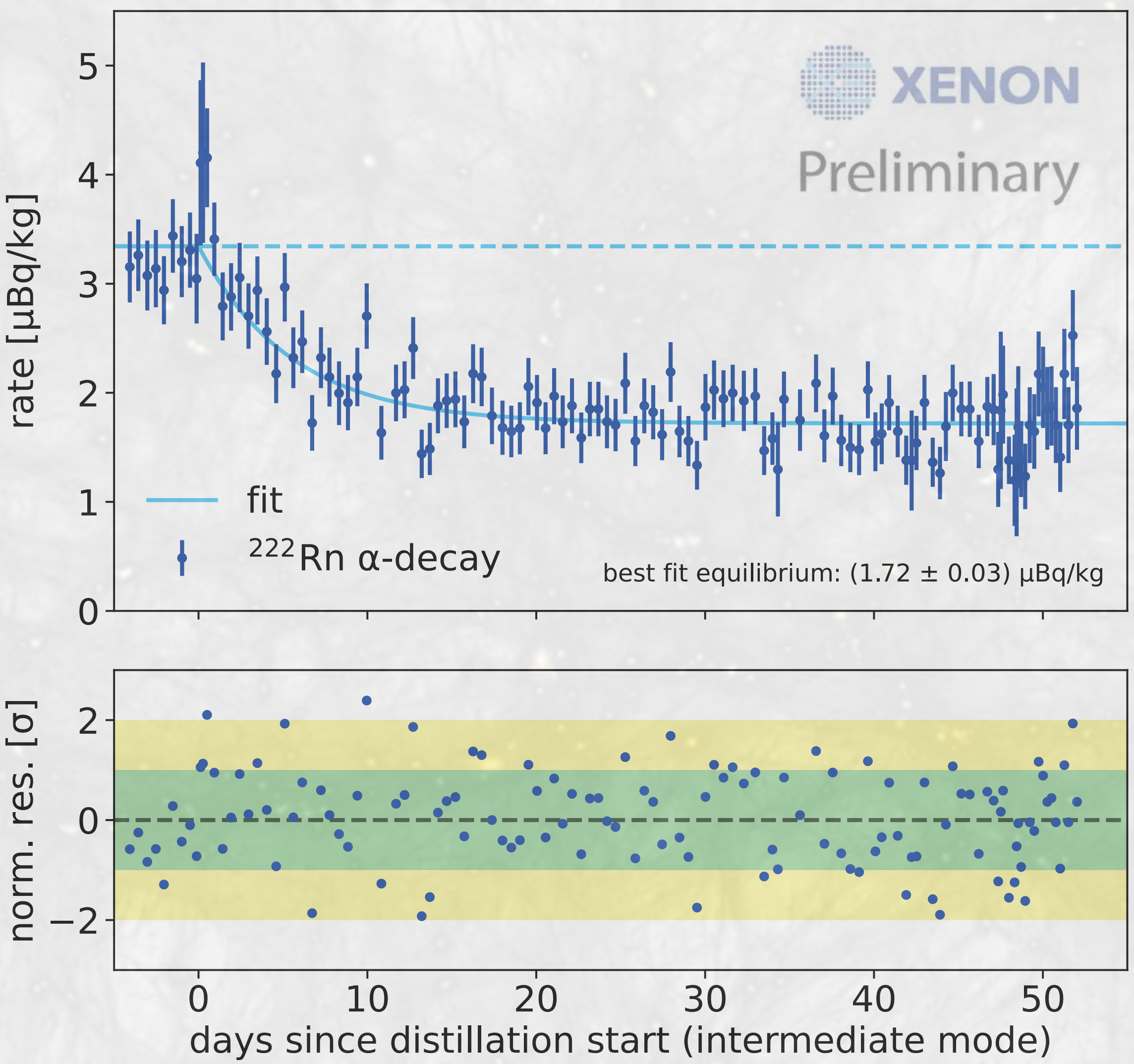





- SR0: Water only veto efficiency of 68%
- Design Goal: Gd-Water veto efficiency of >85%

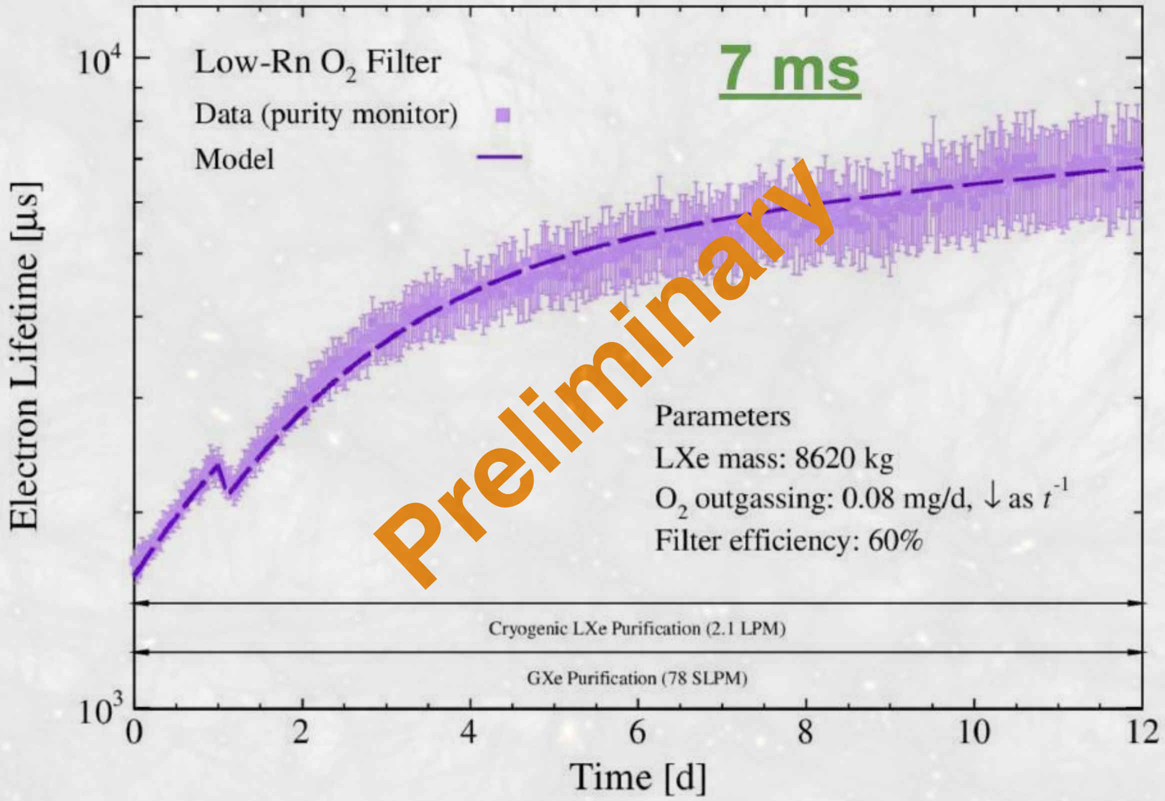
# XENONnT Radon Distillation Column

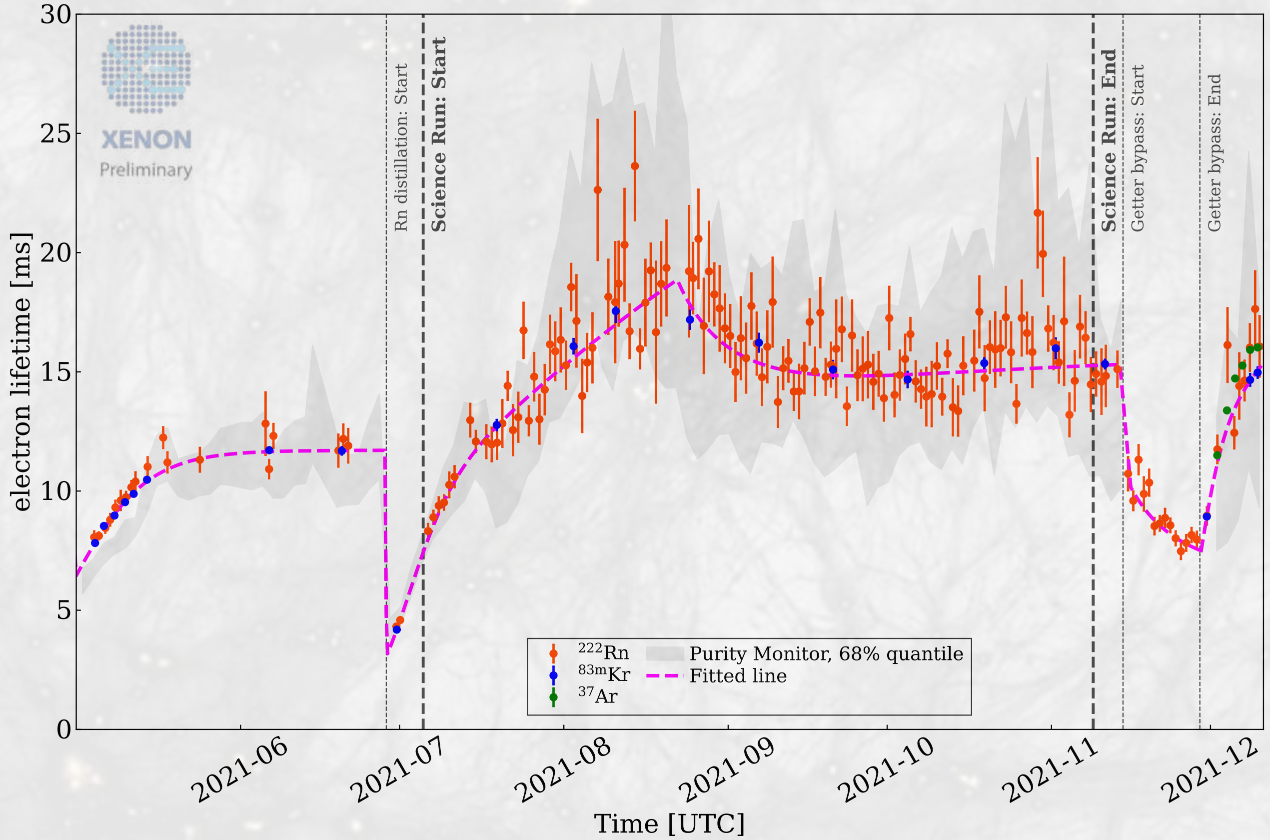

- Initial gas phase only distillation reduced the radon level to 1.7 μBq/kg
- Lowest radon level ever achieved in a LXeTPC
- Liquid phase distillation additionally reduced the radon level to <1 μBq/kg

# XENONnT Cryogenic Liquid Purification

Cryostat is filled with ~8.5t of LXe



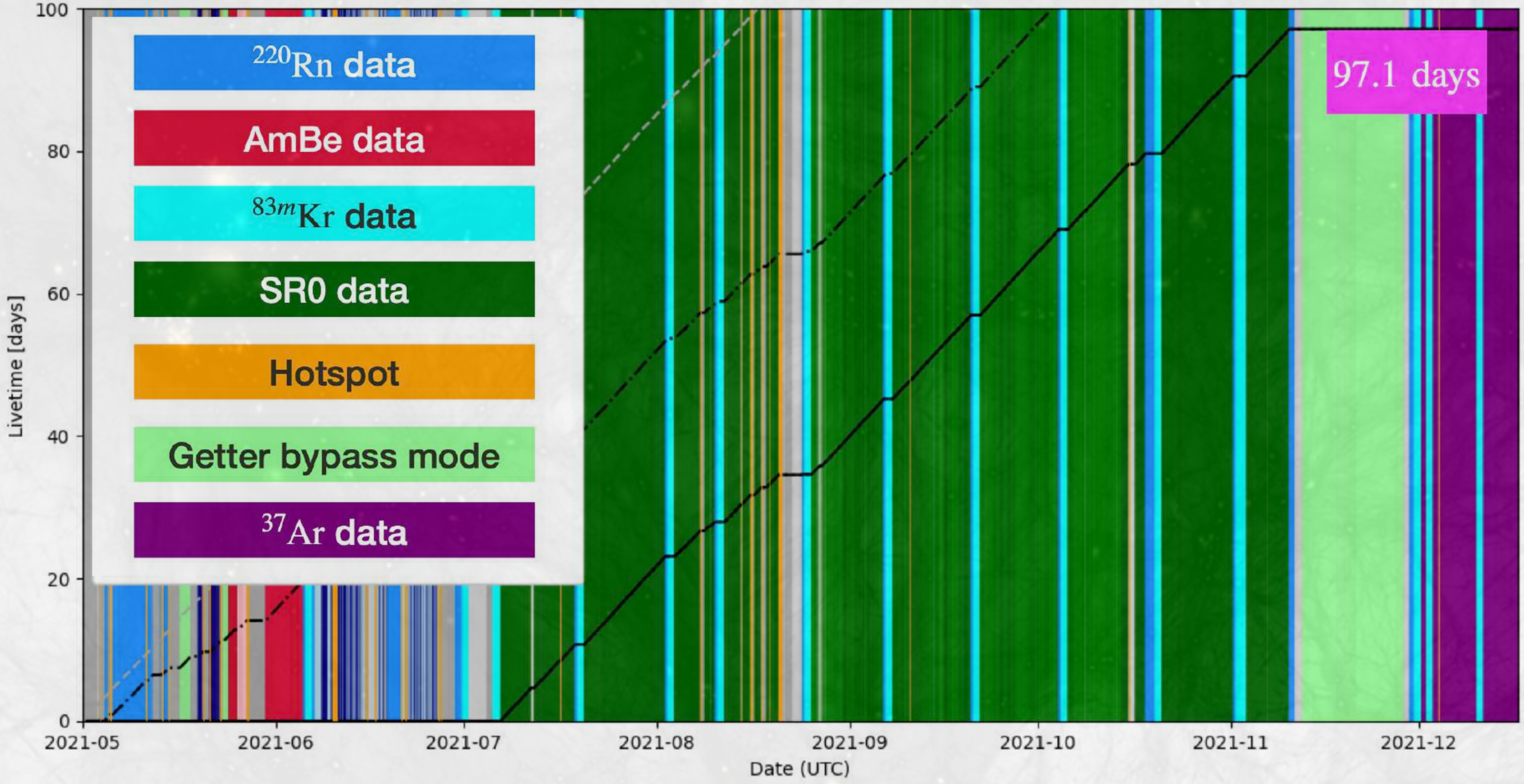

| Exp | Max Drift [ms] | Electron lifetime [ms] | Cathode electron survival | Purification speed |
|---|---|---|---|---|
| XENON1T | 0.73 | 0.65 | 30% | 0.65ms in ~ 3 months |
| XENONnT | 2.2 | ~10 | >90% | 5ms in ~5 days |



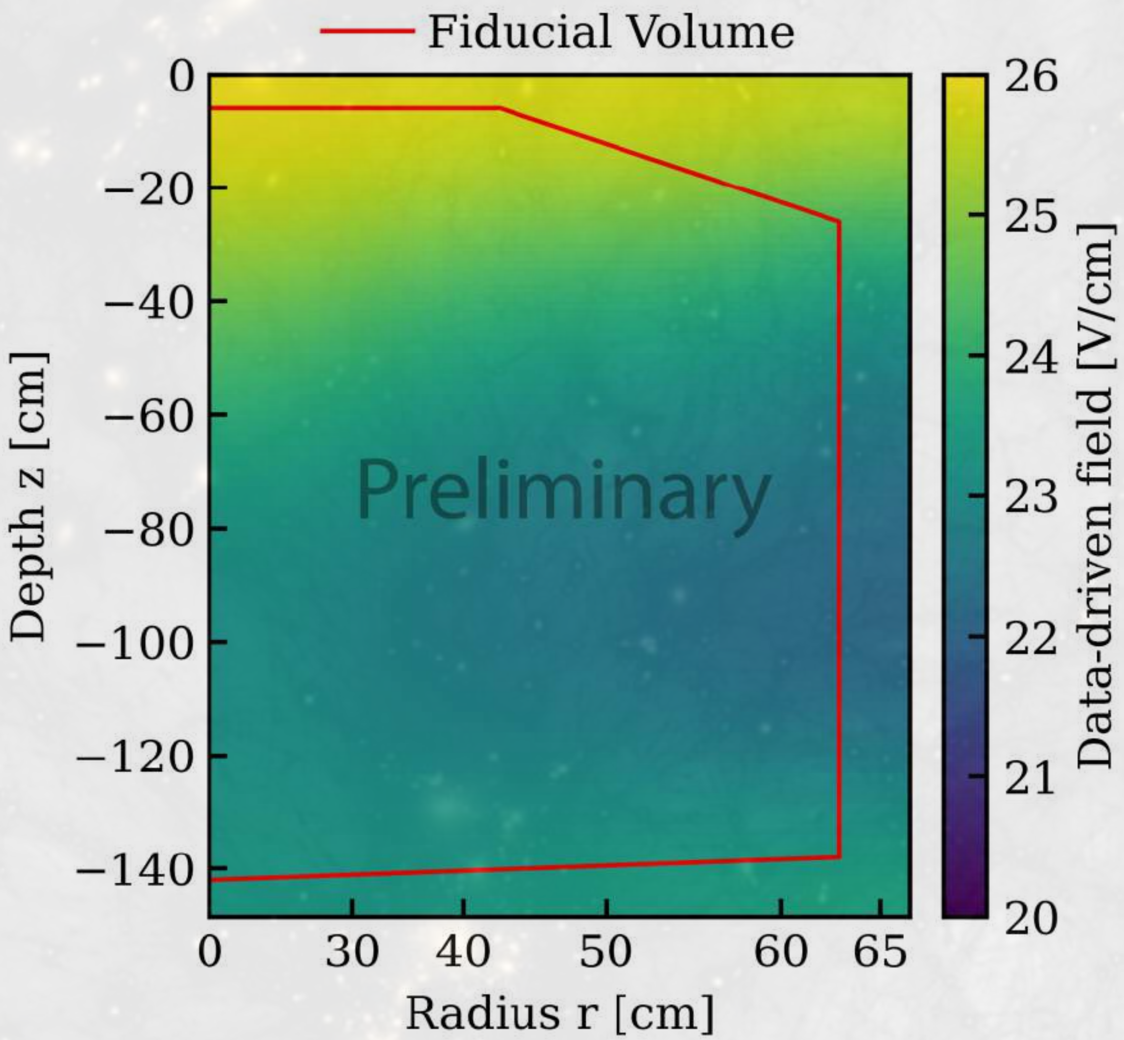
# XENONnT: First Data

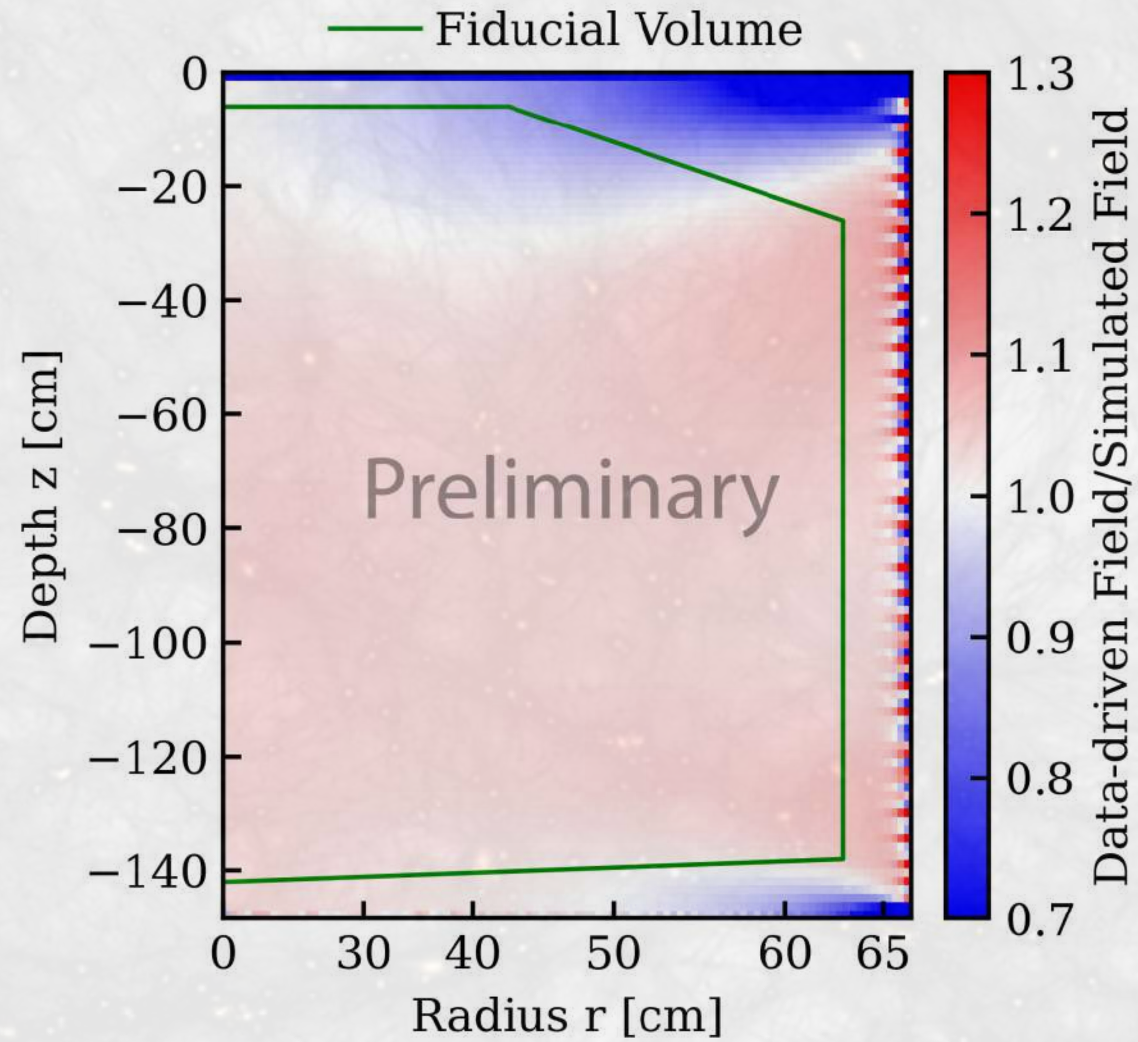
Primary Goals: Shedding light on the XENON1T ER Excess

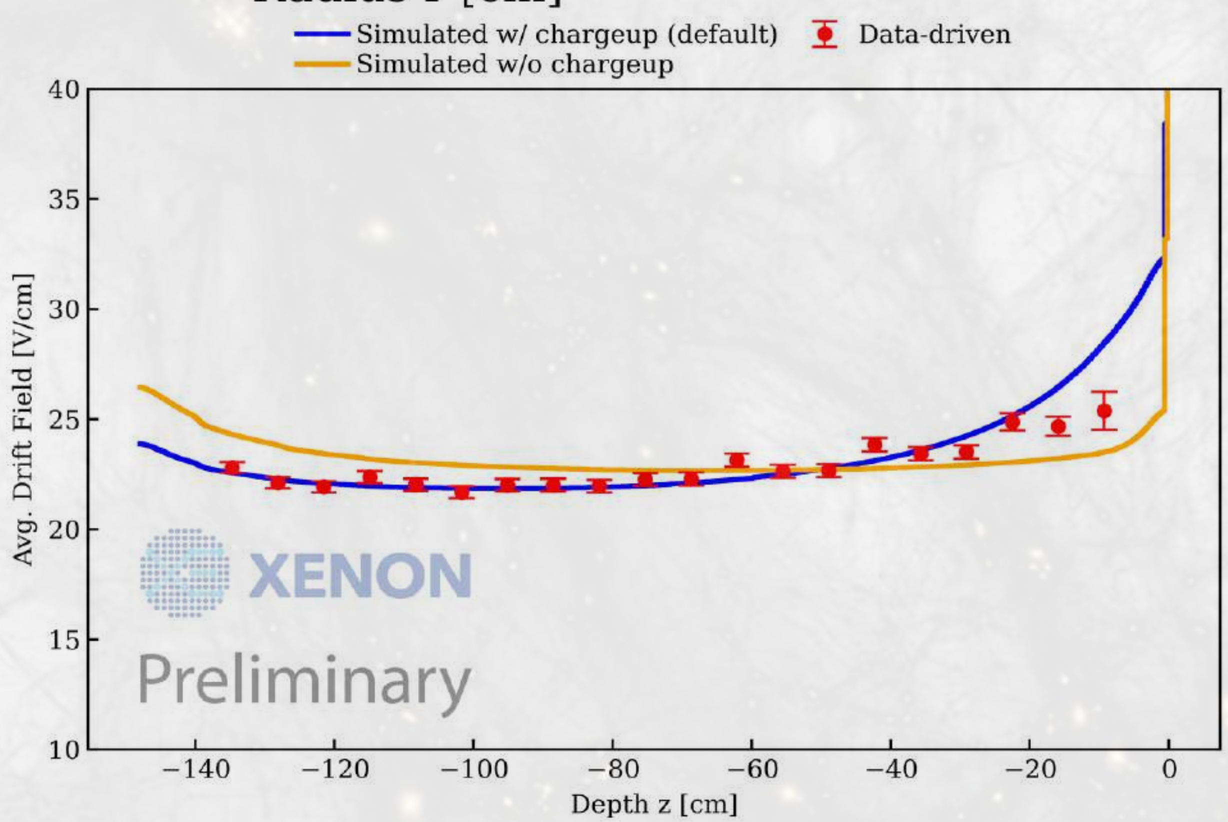
Improving sensitivity to WIMPs



# Drift Field in the TPC



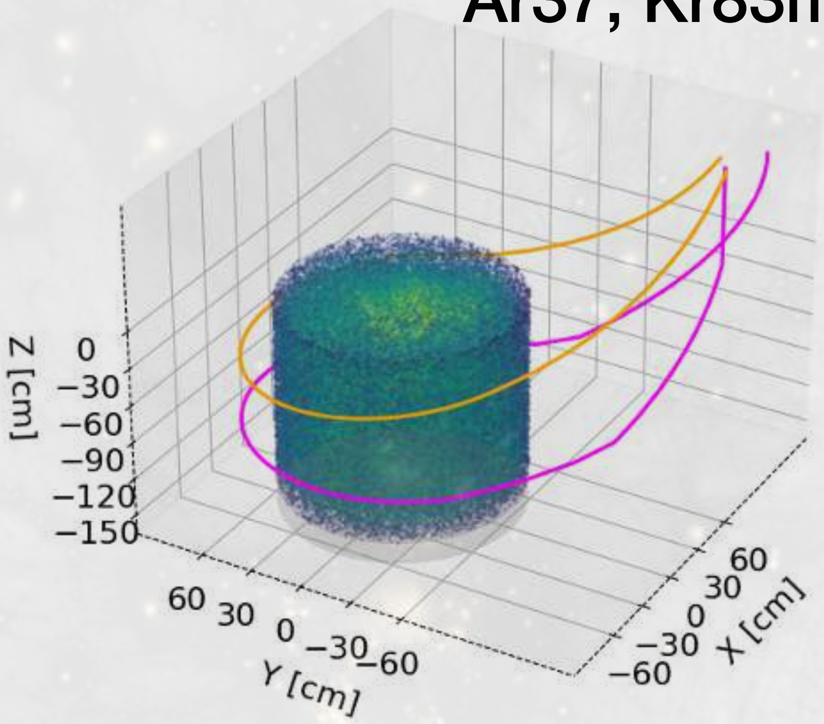

Low drift field introduces new challenges in signal identification and background suppression

Fiducial mass: 4.37±0.14 ton

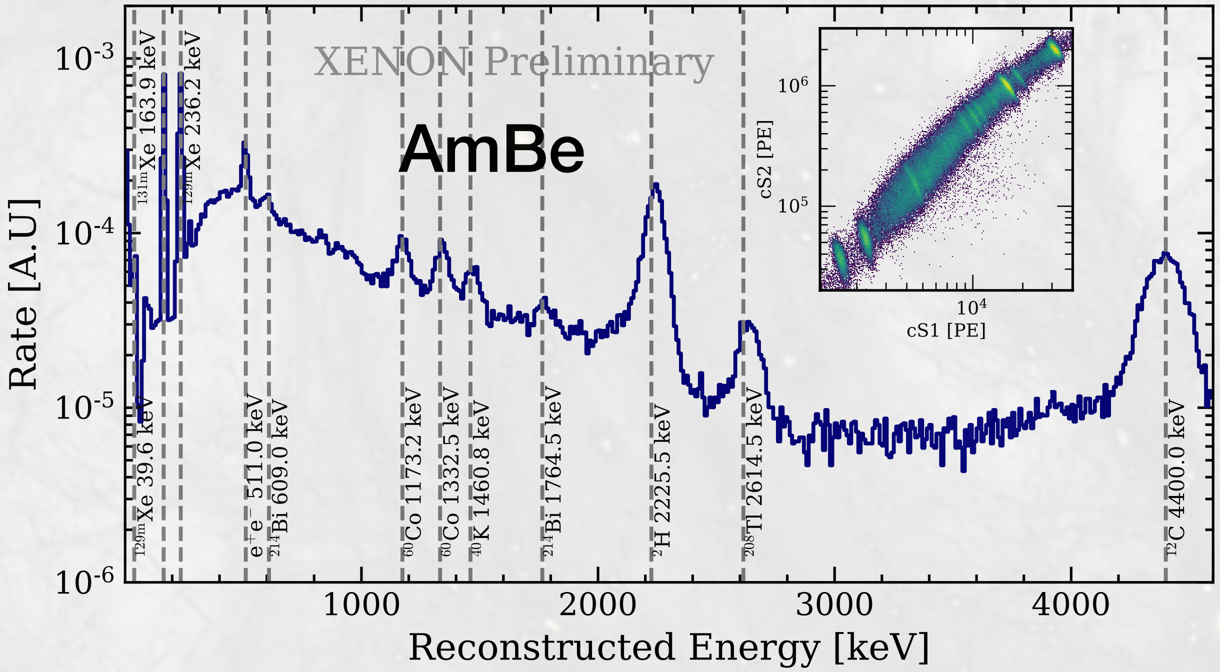
# Calibrations in XENONnT

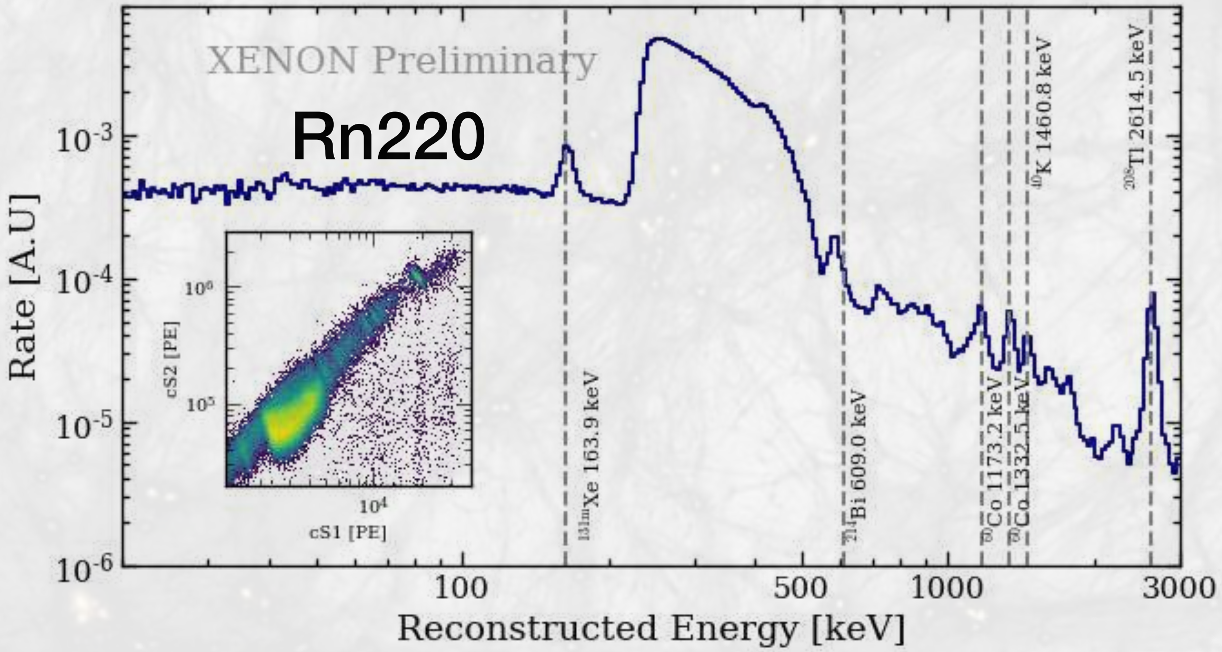
- XENONnT's 5.9-ton LXe sensitive volume is calibrated from keV to MeV

Ar37, Kr83m

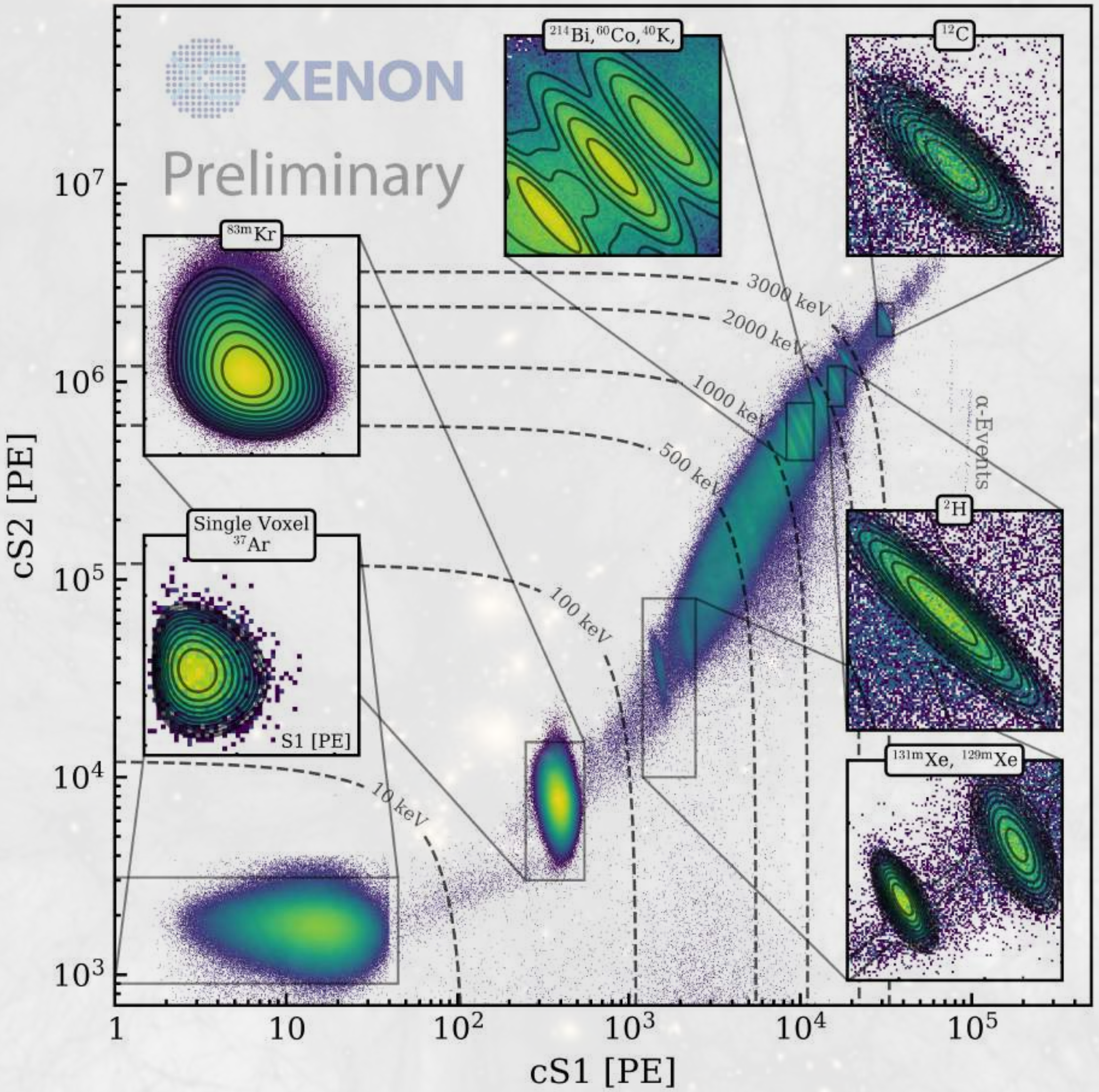



- Kr83m : uniformity, energy scale etc
- Rn220: Low Energy ERs
- AmBe: Low Energy NRs, high energy ERs
- Ar37: uniformity, energy scale, threshold

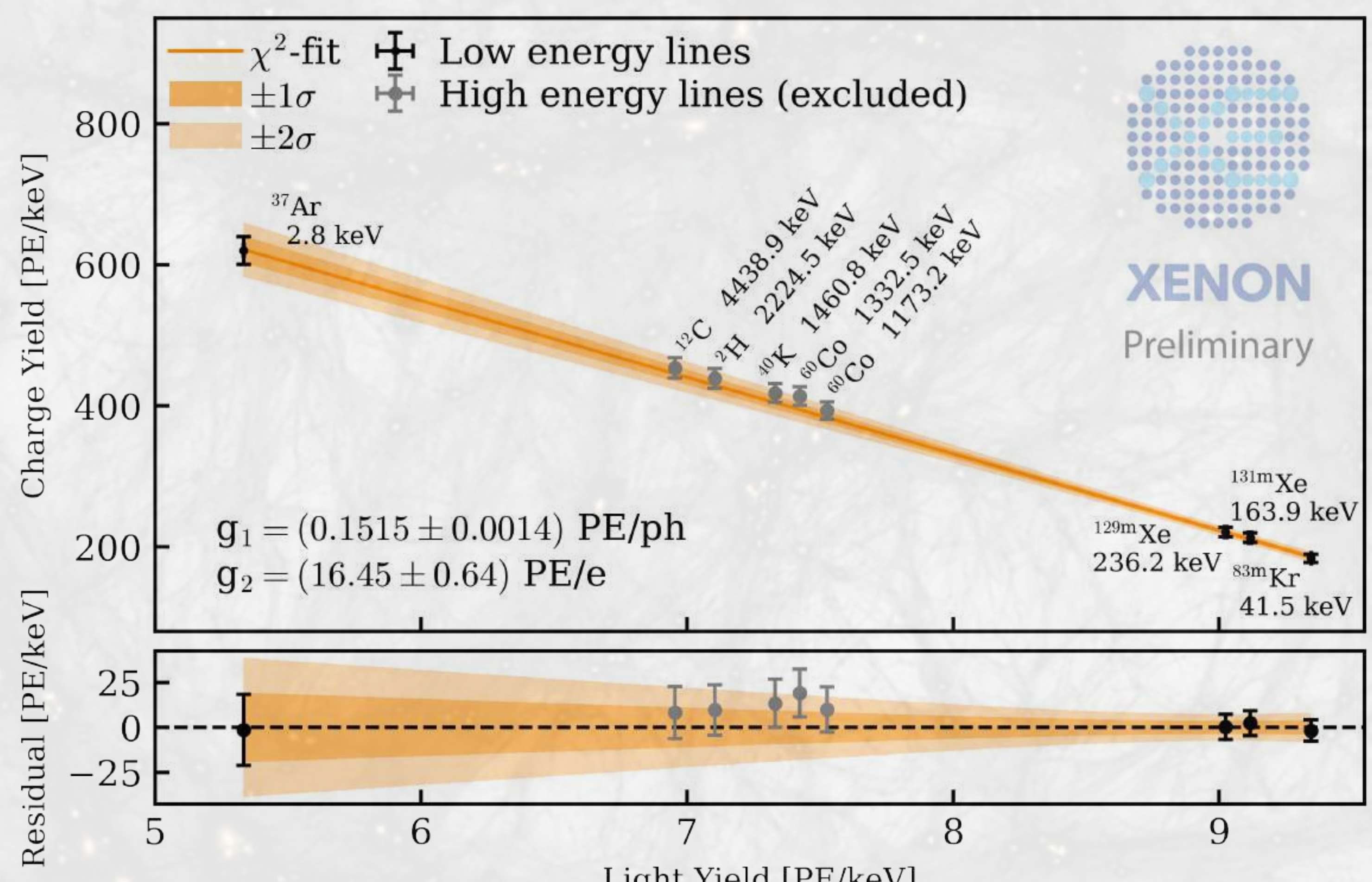


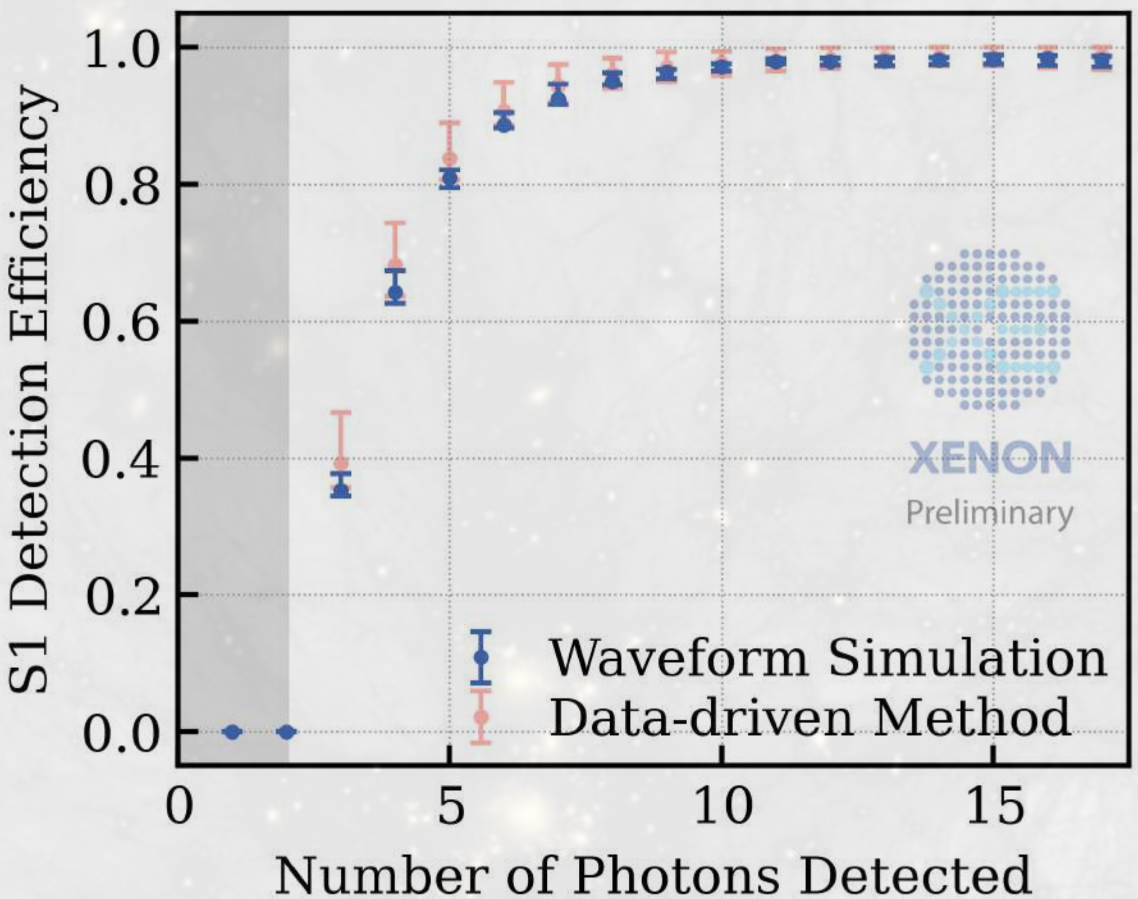
# Energy Calibrations




- Calibrations are done from keV to MeV
- Ar37, Kr83m, Xe131m, Xe129m are primarily used for low energy analysis



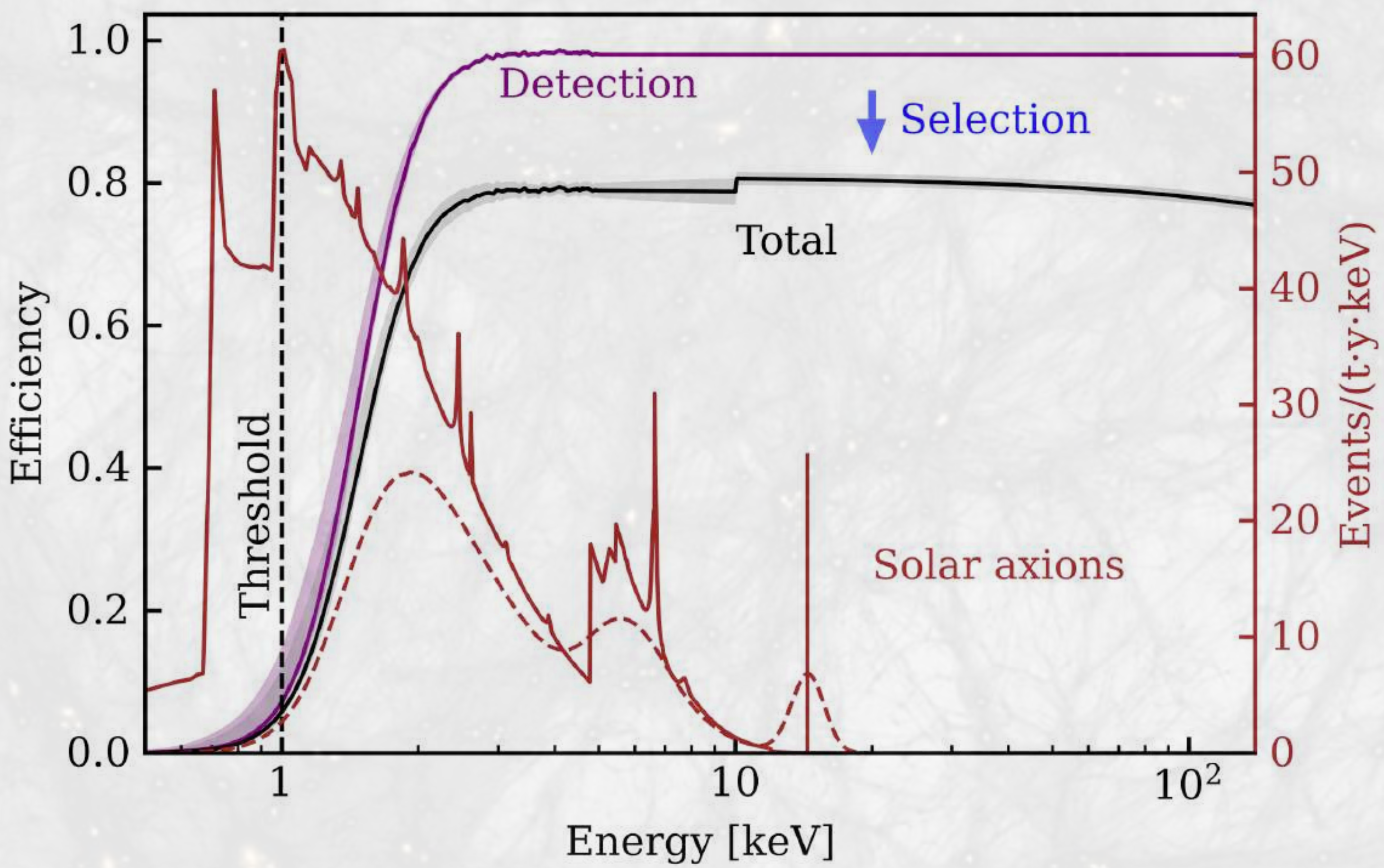
# Threshold and Acceptances



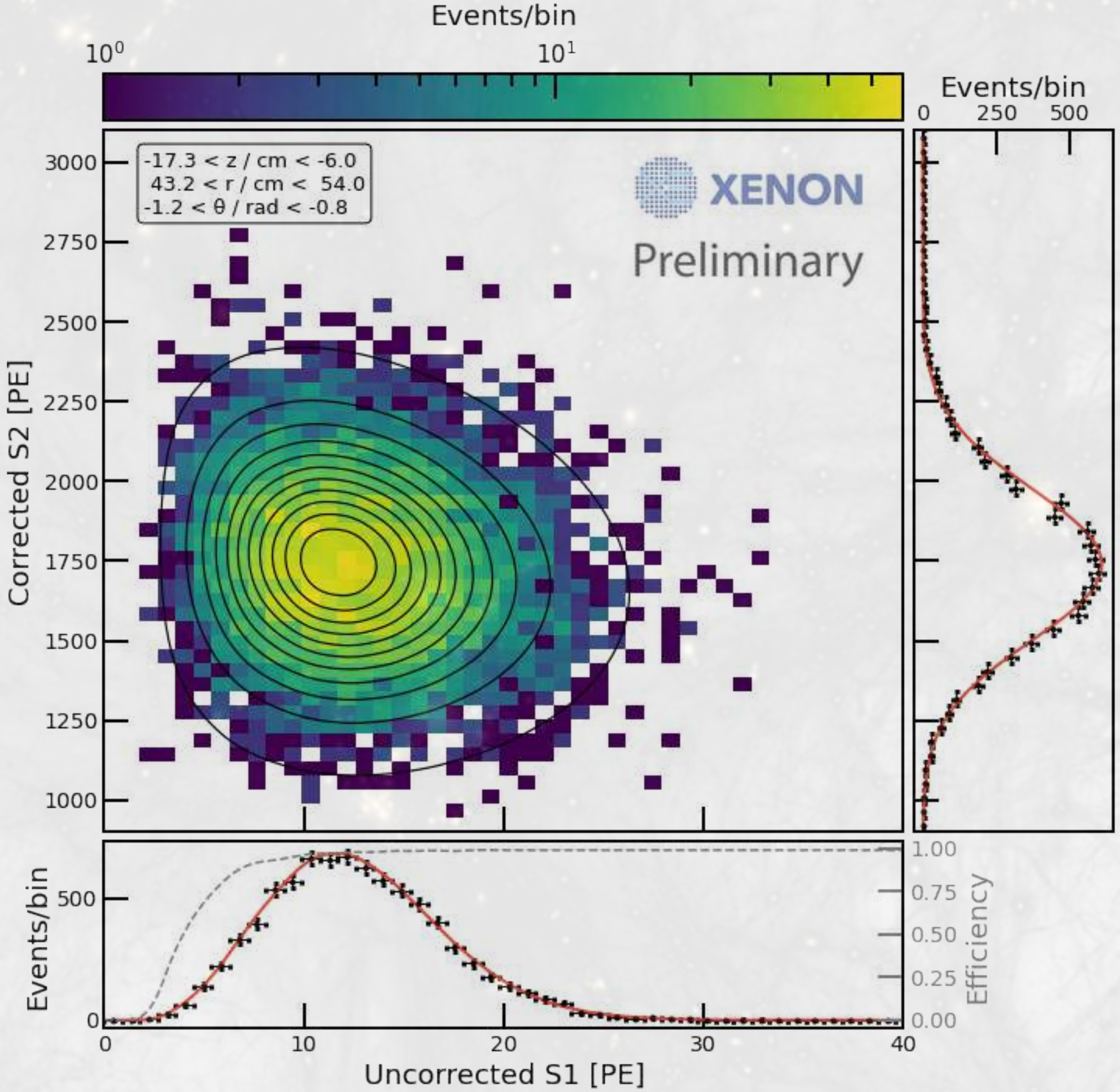

- Energy threshold is primarily driven by 3-fold coincidence in S1

- Analysis threshold of 1keV

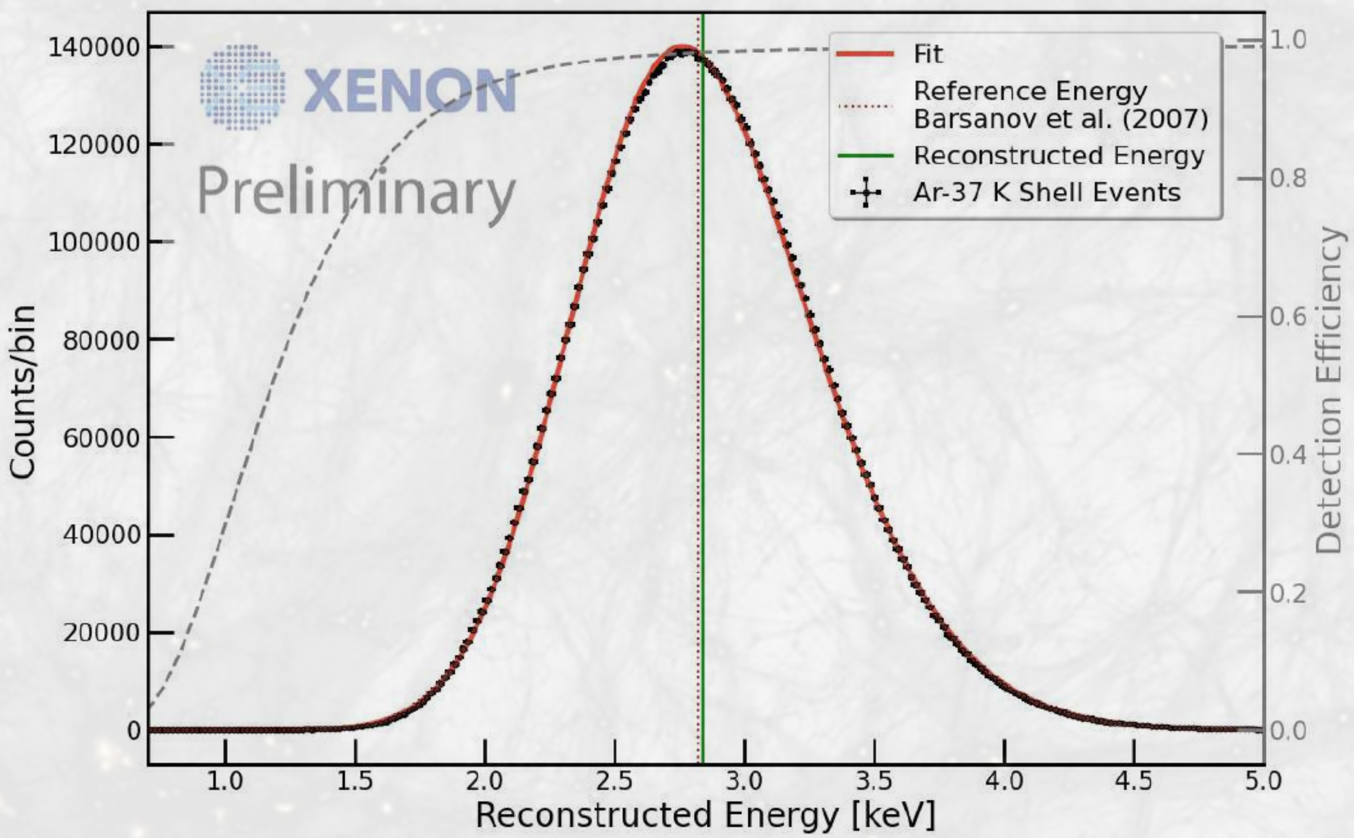
- Detection efficiency at 2keV is ~0.7



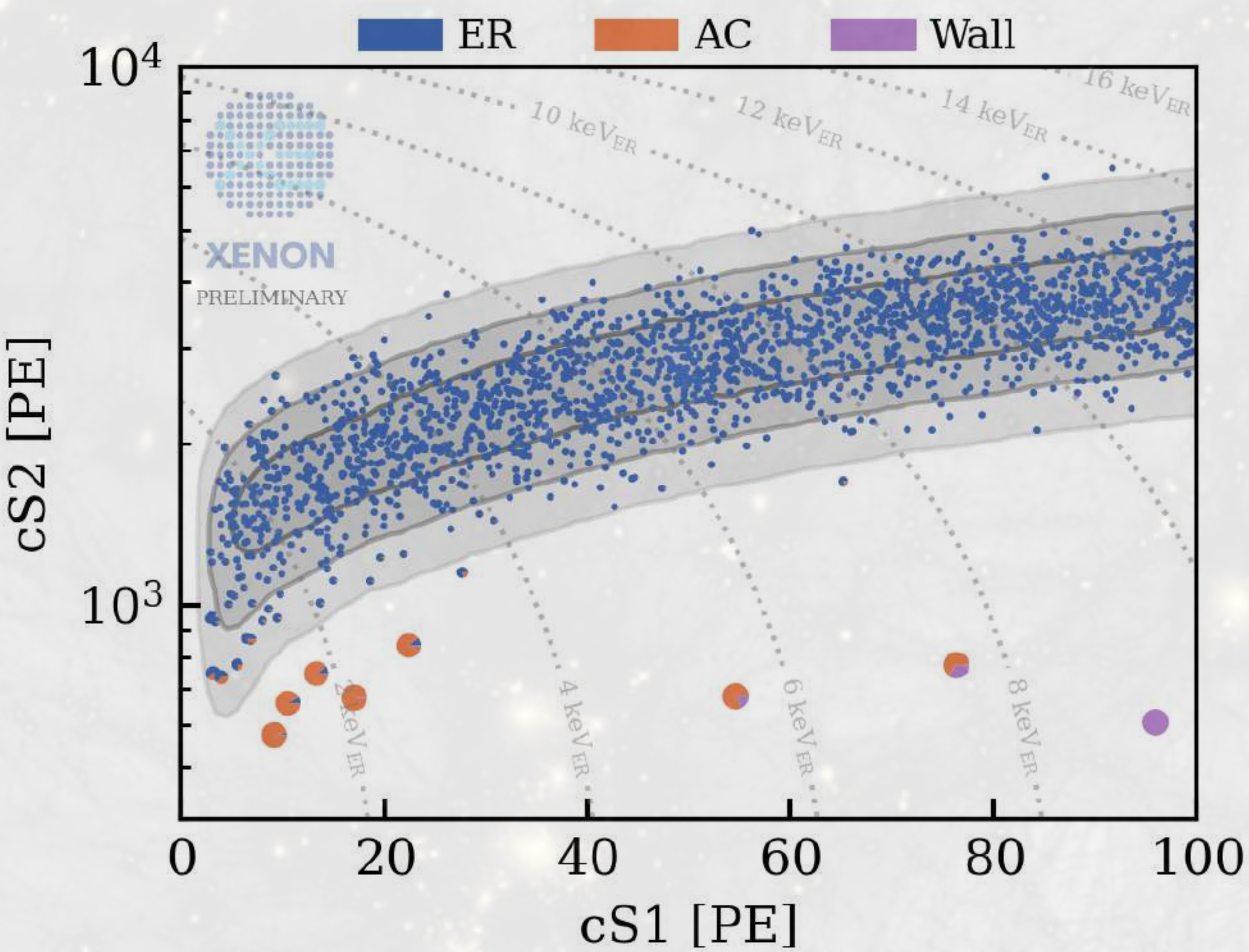
# A detailed look at Ar37 Calibration




- **Ar37: mono-energetic peak @ 2.8keV**
- **Modeled well with skewed Gaussian distribution in reconstructed energy**



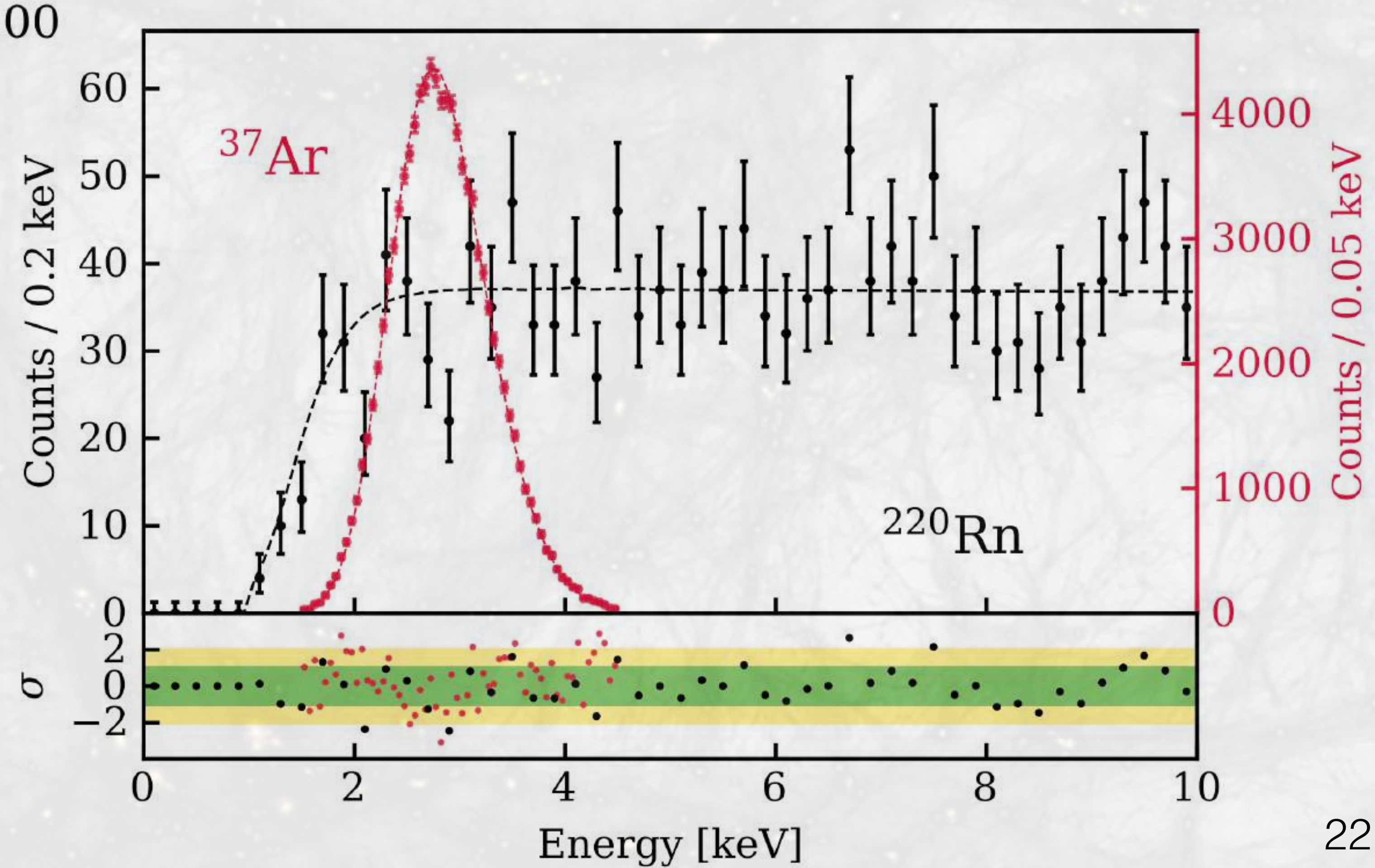
# A detailed look at Rn220 Calibration



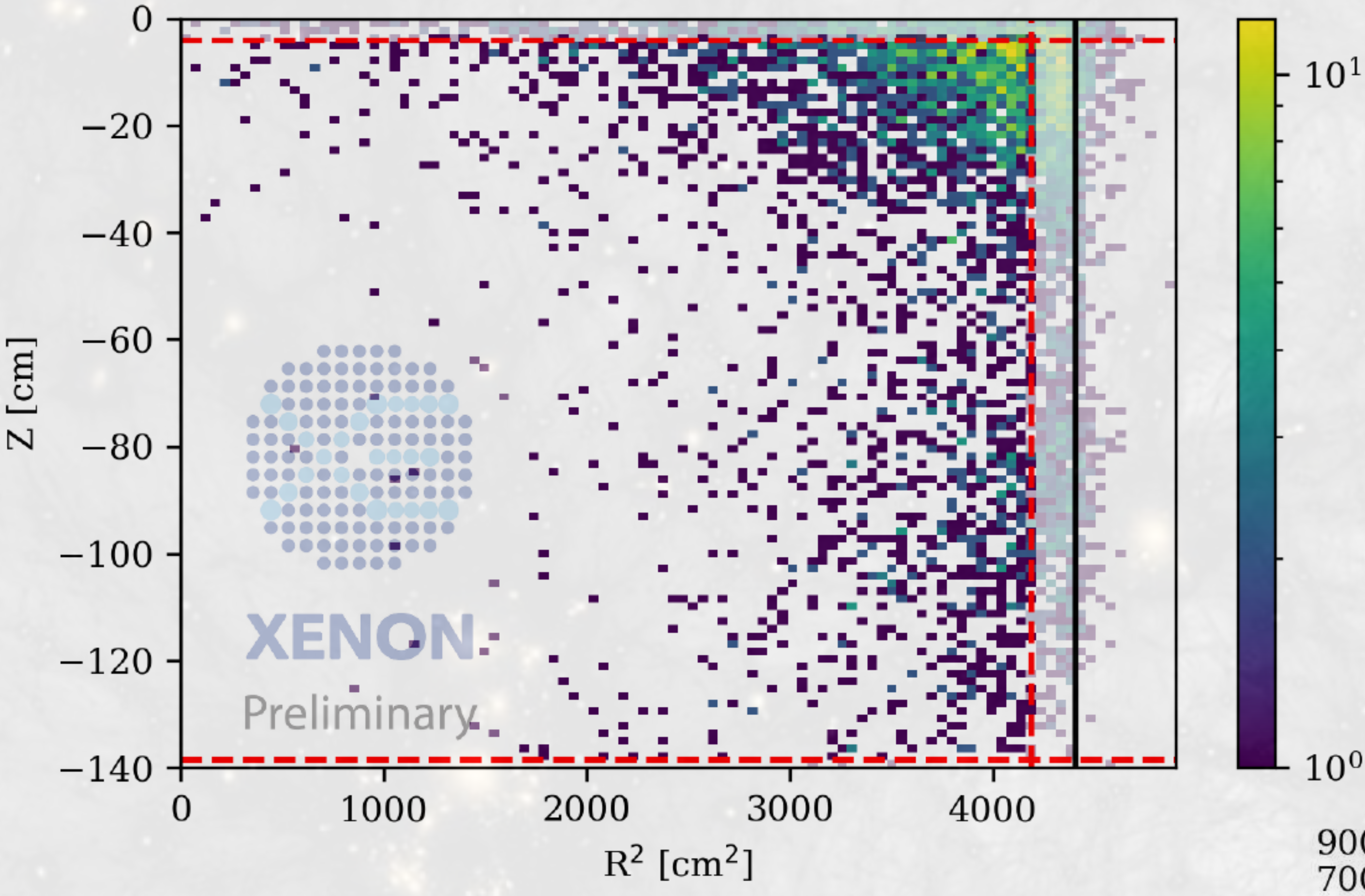

Rn220 calibration goals:

- Distribution in S1 and S2 (2-D) space for WIMPs search
- Distributions in energy (1D) space for ER analysis

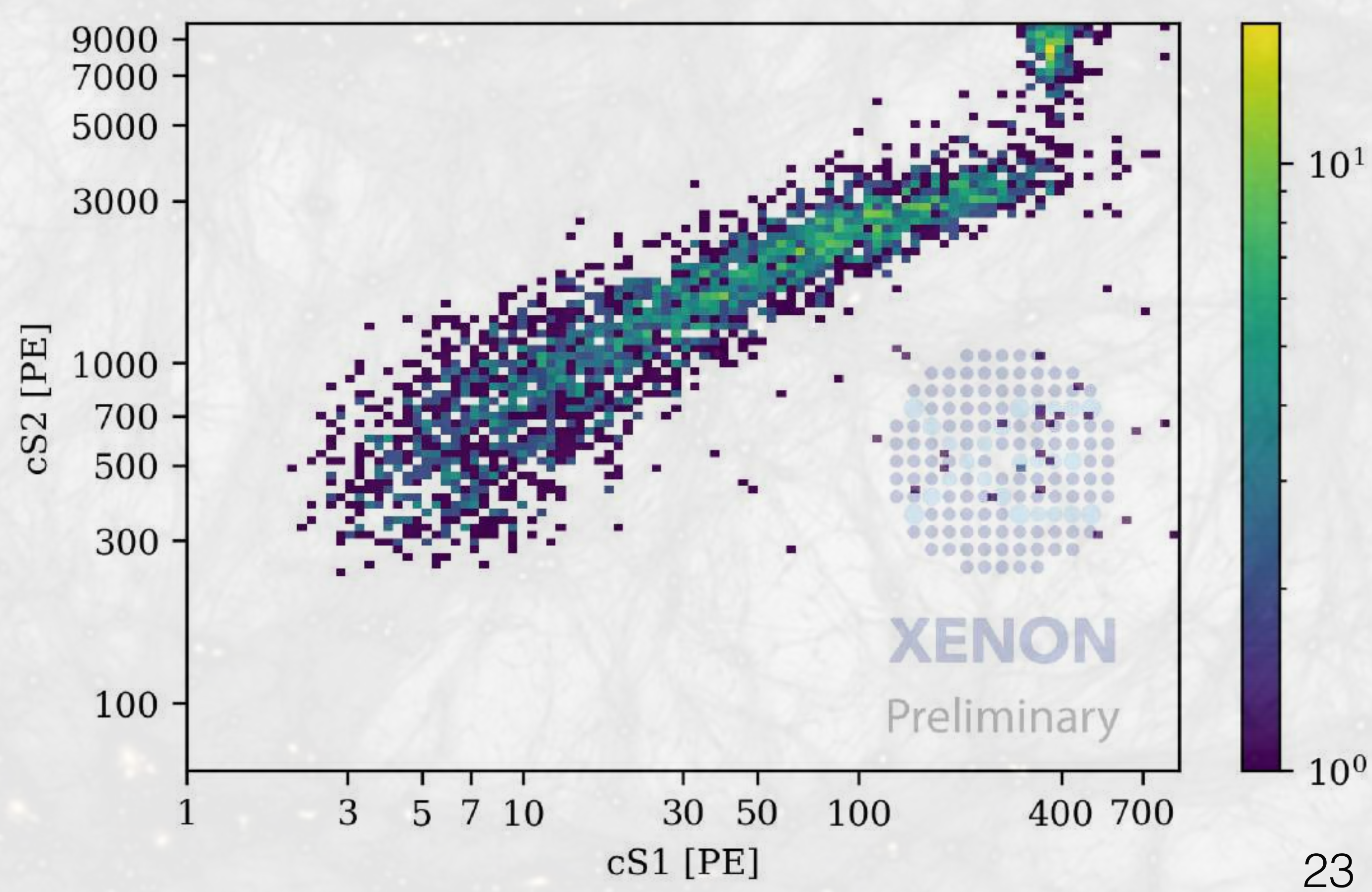
Decent agreement between data and models (Rn220 & Ar37)



# Nuclear Recoil Calibrations via AmBe

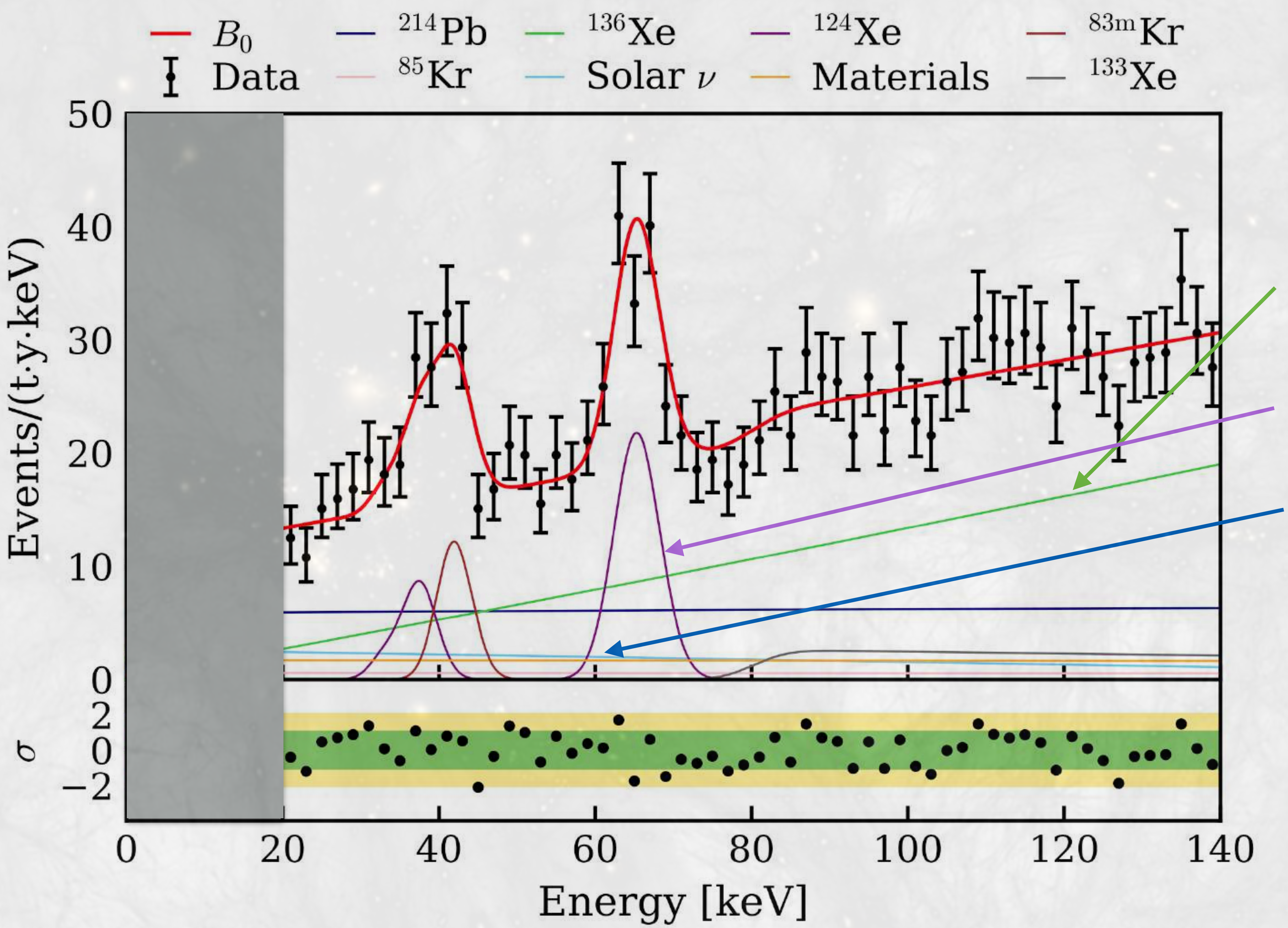



- AmBe source placed at 3 different locations to calibrate the detector
- Coincidence with neutron veto to suppress the accidental coincidence




- AmBe data is used to validate our nuclear recoil modeling

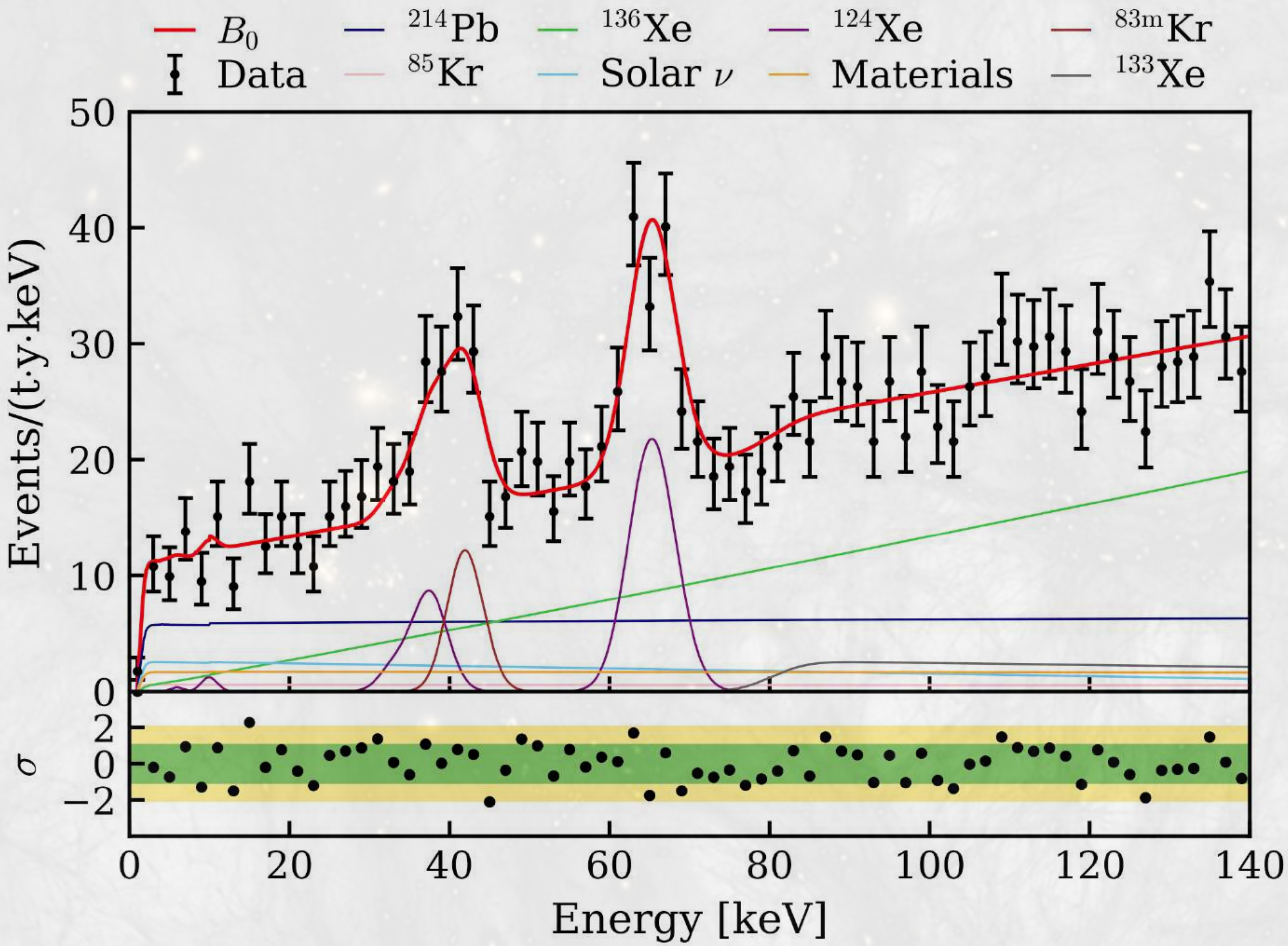
# ER Backgrounds




| | |
|---|---|
| Pb214 | 980±120 |
| Kr85 | 91±58 |
| Xe136 | 1523±54 |
| Xe124 | 256±28 |
| Solar pp-neutrino | 298±29 |
| Material | 267±51 |
| Xe133 | 163±63 |
| Kr83m | 80±16 |
| Accidental Coincidence | 0.71±0.03 |

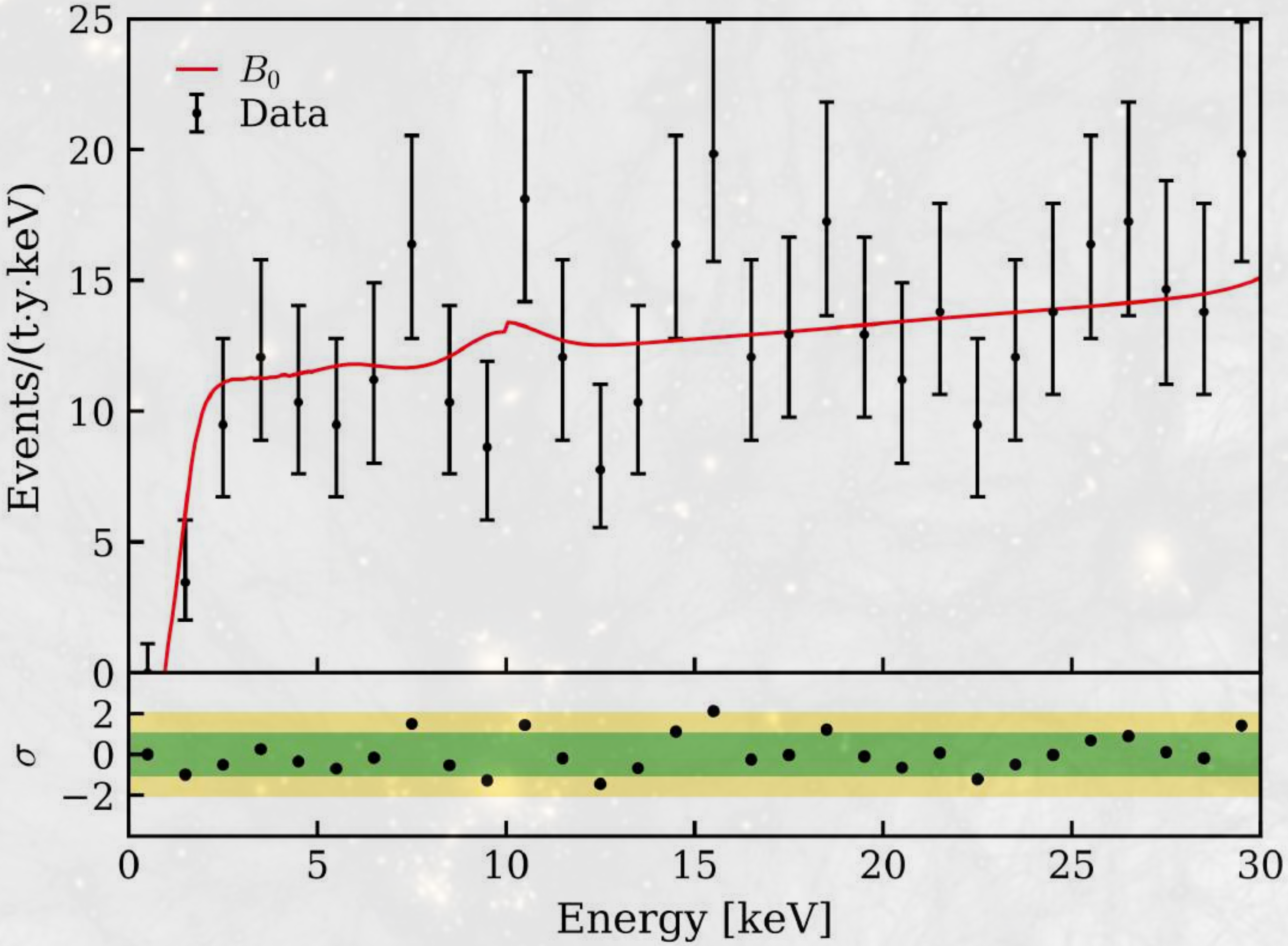
- ER data <20 keV is blinded before analysis is finalized

# ER Background after Unblinding




- Data agrees with background only model in the whole energy range
- Double weak processes from Xe124 and Xe136 start to dominate the background, and useful to validate our models
- No Excess is found in the low energy region!

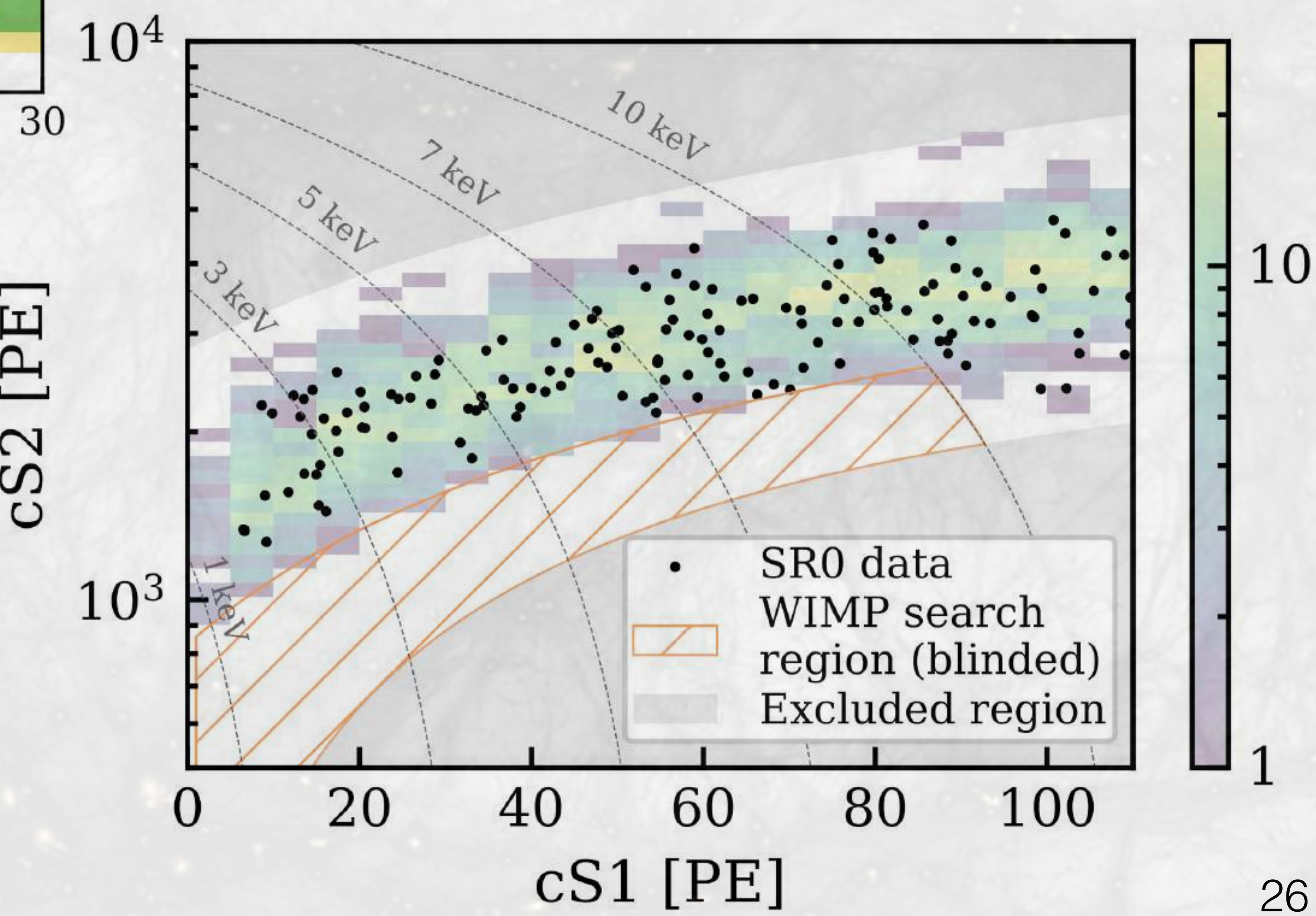
# Zoomed in look below 30 keV



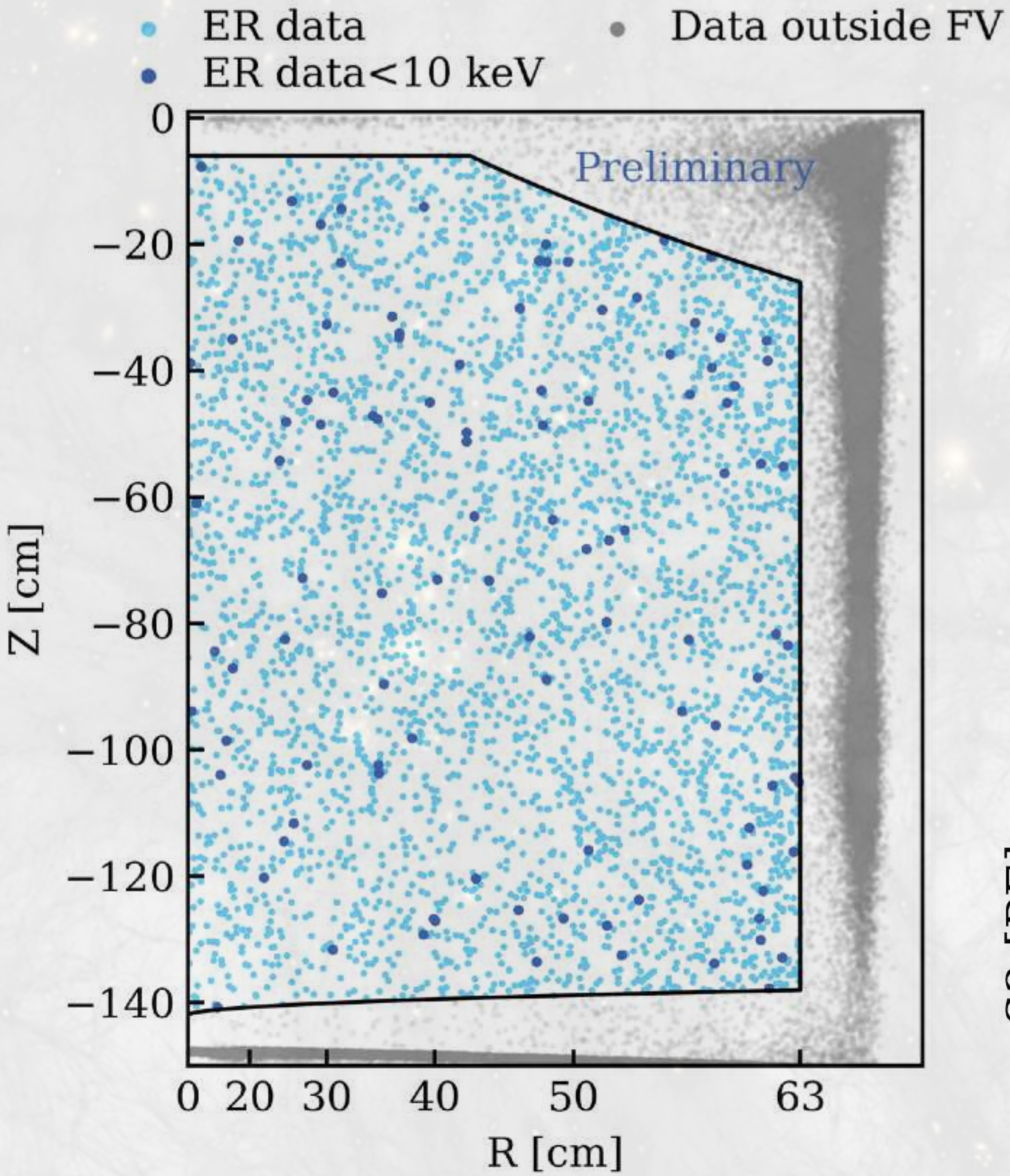

- Lowest background level is achieved:

$$(16.1 \pm 1.3)\,\text{events}/(\text{t} \cdot \text{y} \cdot \text{keV})$$

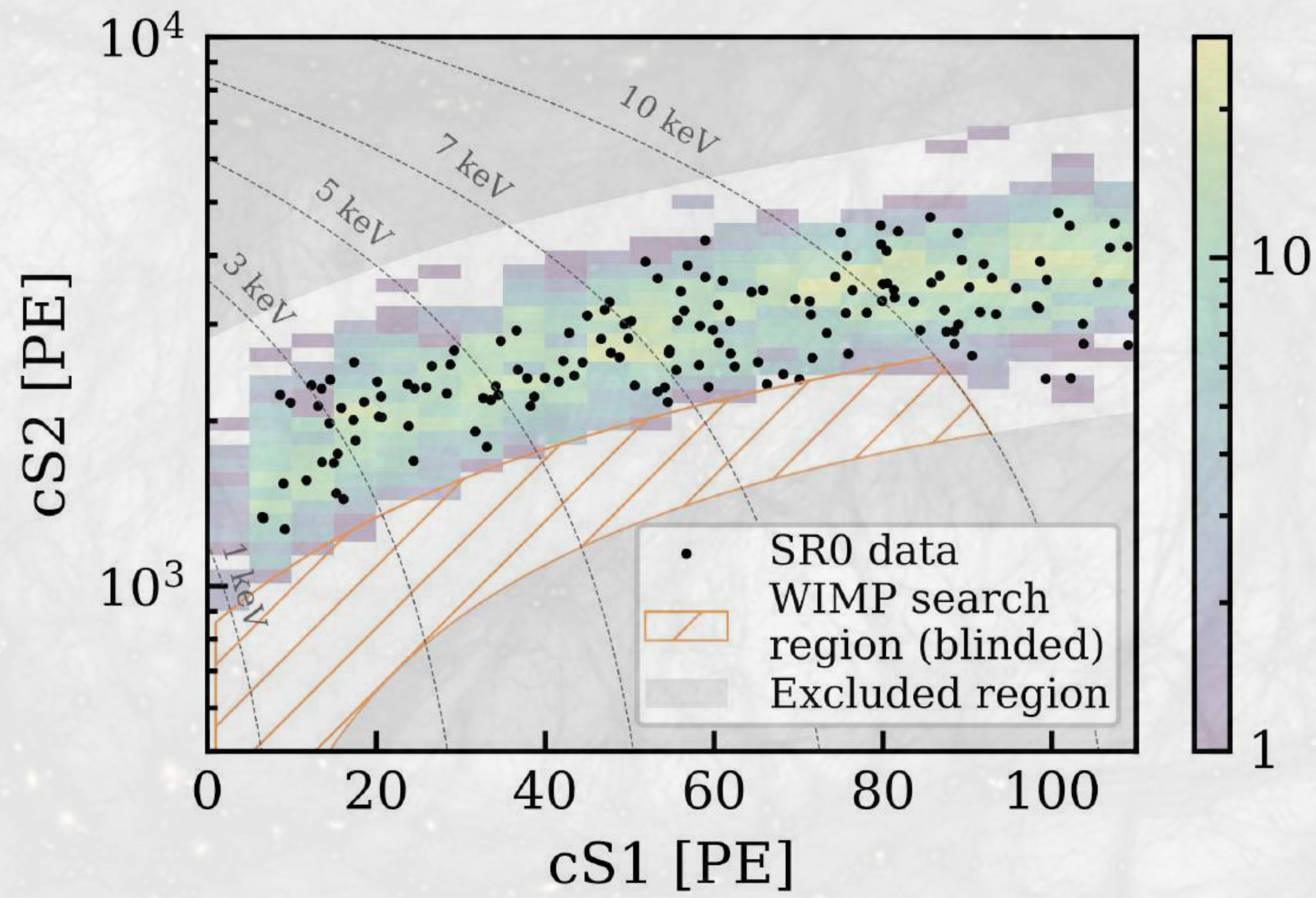
- NR search data being blinded while searching for ER signals



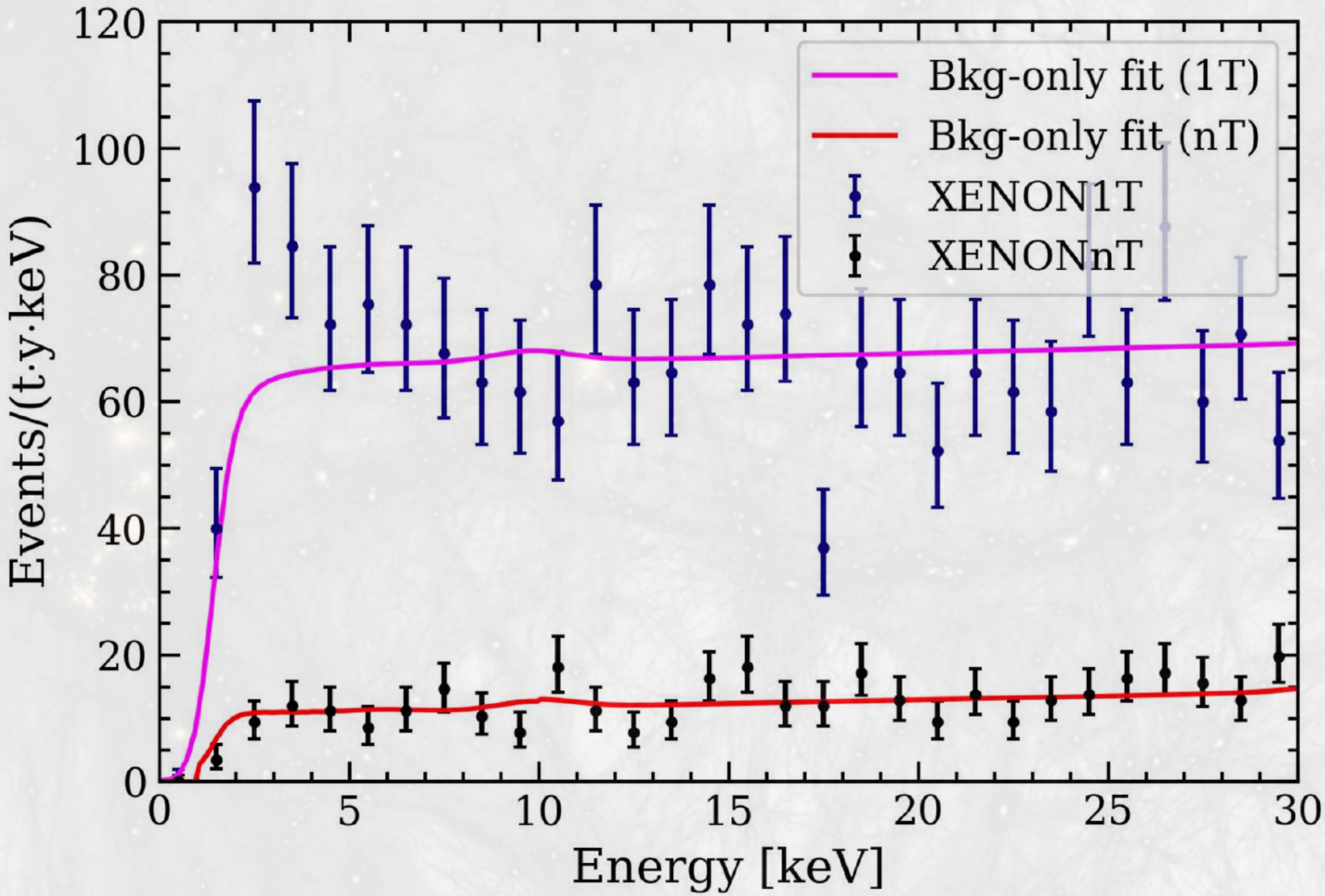
# Zoomed in look below 10 keV




- lowE Events are uniformly distributed across the TPC as expected

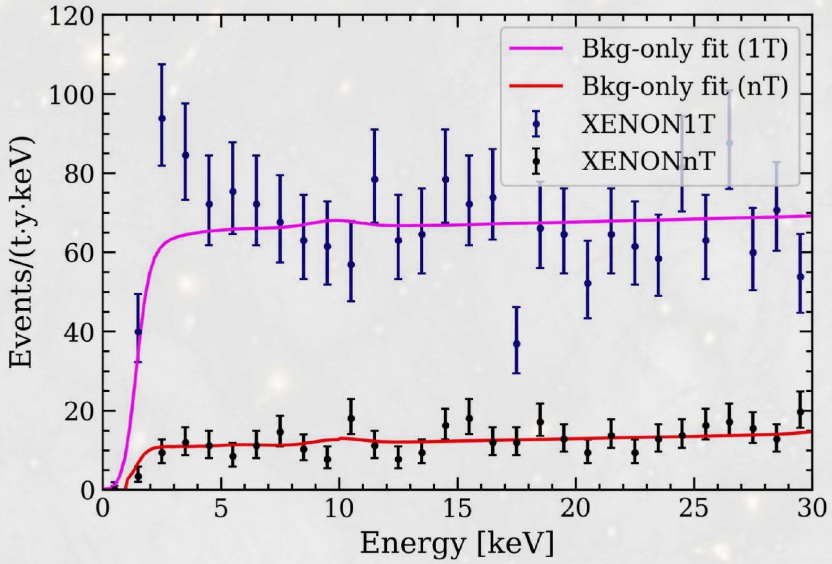


# Comparison with XENON1T

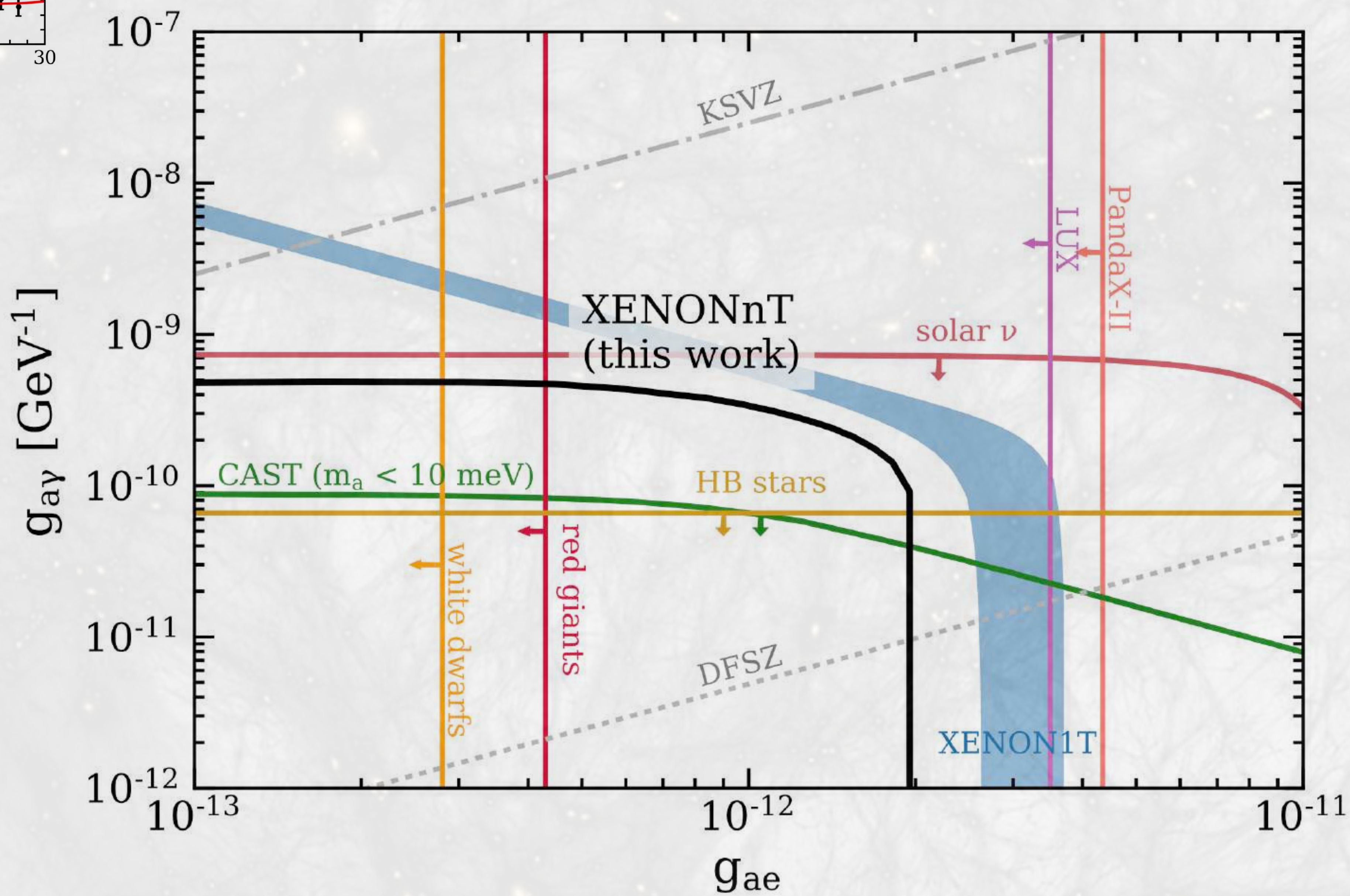



- **XENONnT ER background rate is 1/5 of that in XENON1T**

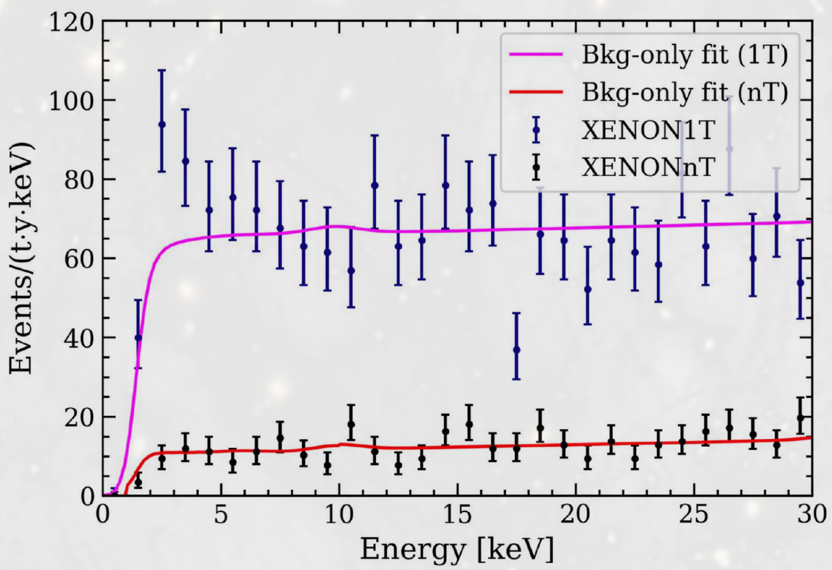
# Exclusion limits on Solar Axions



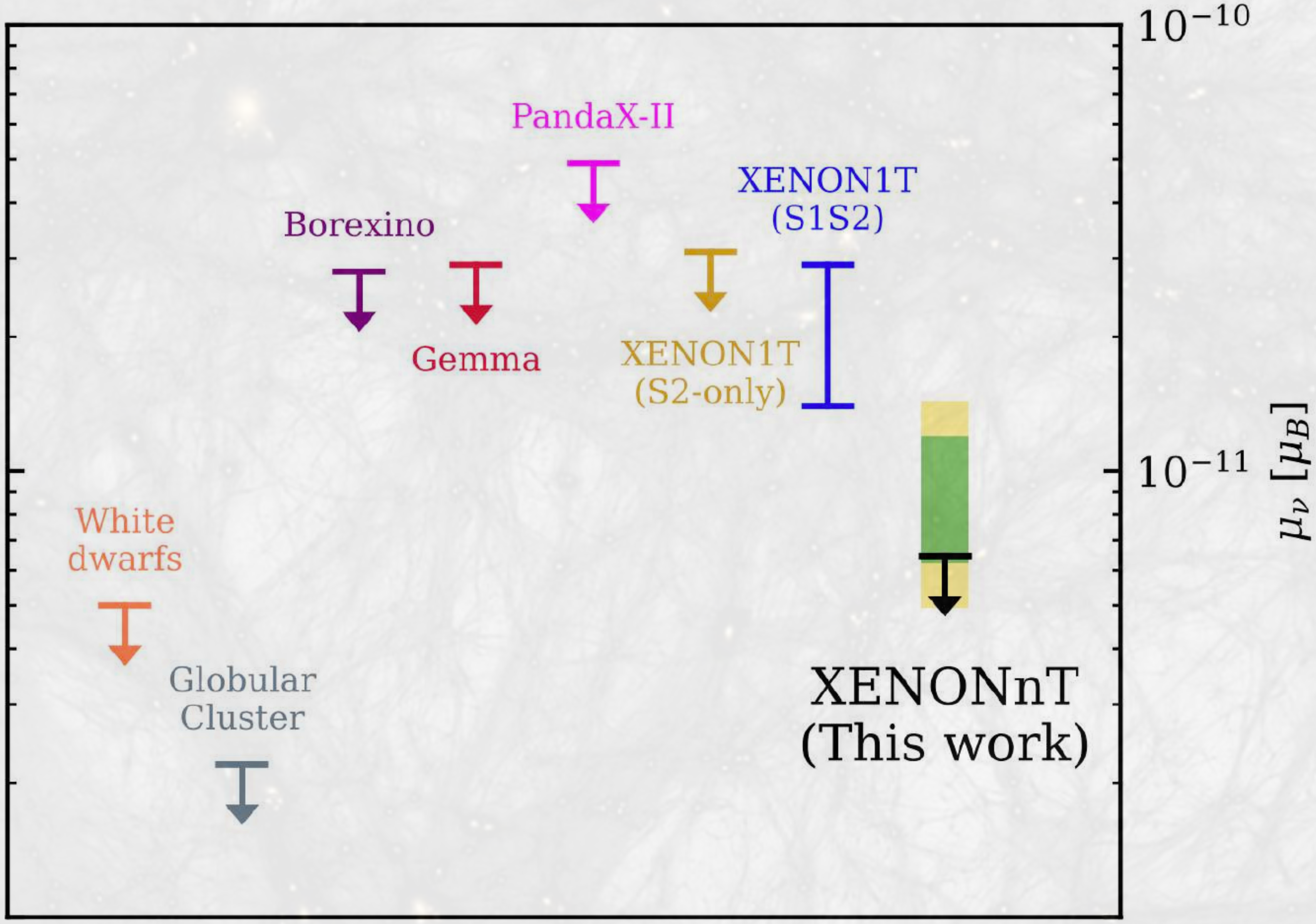

- XENON1T Excess, interpreted as being due to Solar Axion signals, is ruled out by XENONnT



# Exclusion limits on Neutrino Magnetic Moment

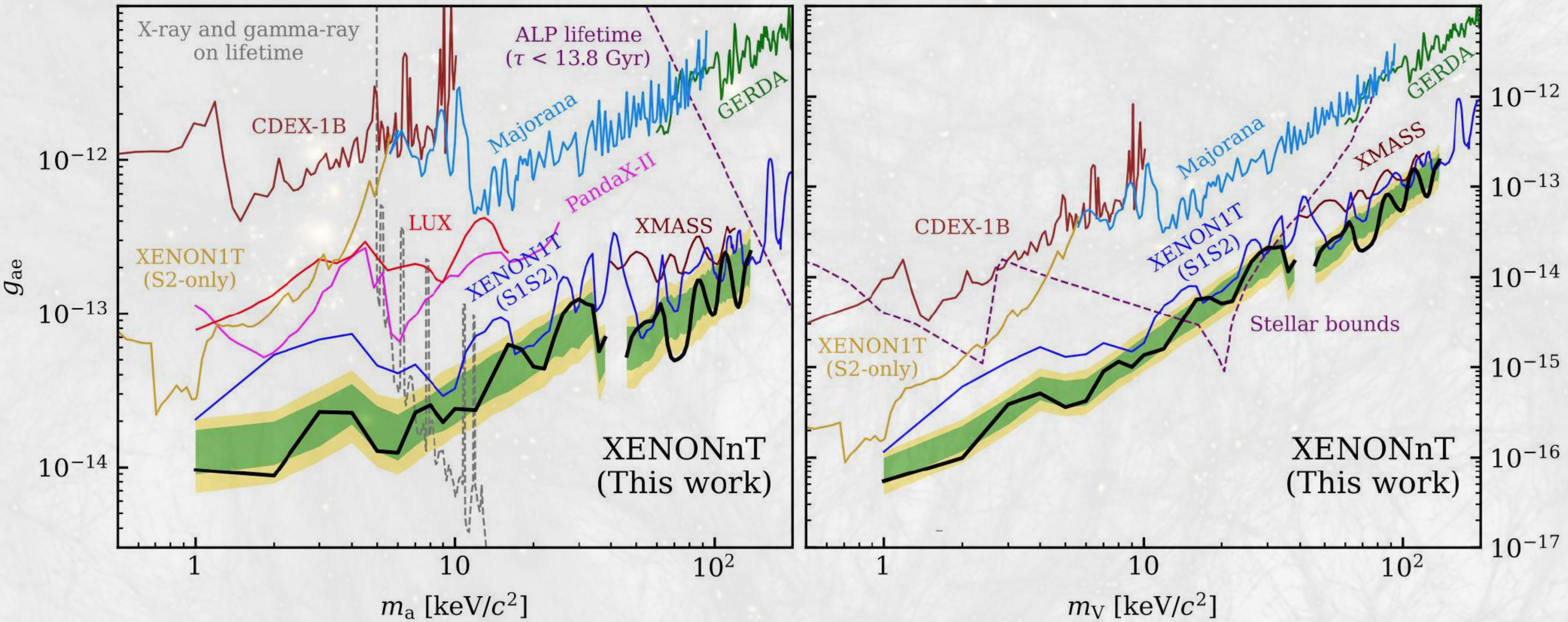



- **XENON1T Excess, interpreted as being due to Solar neutrino signals with an enhanced magnetic moment, is ruled out by XENONnT**



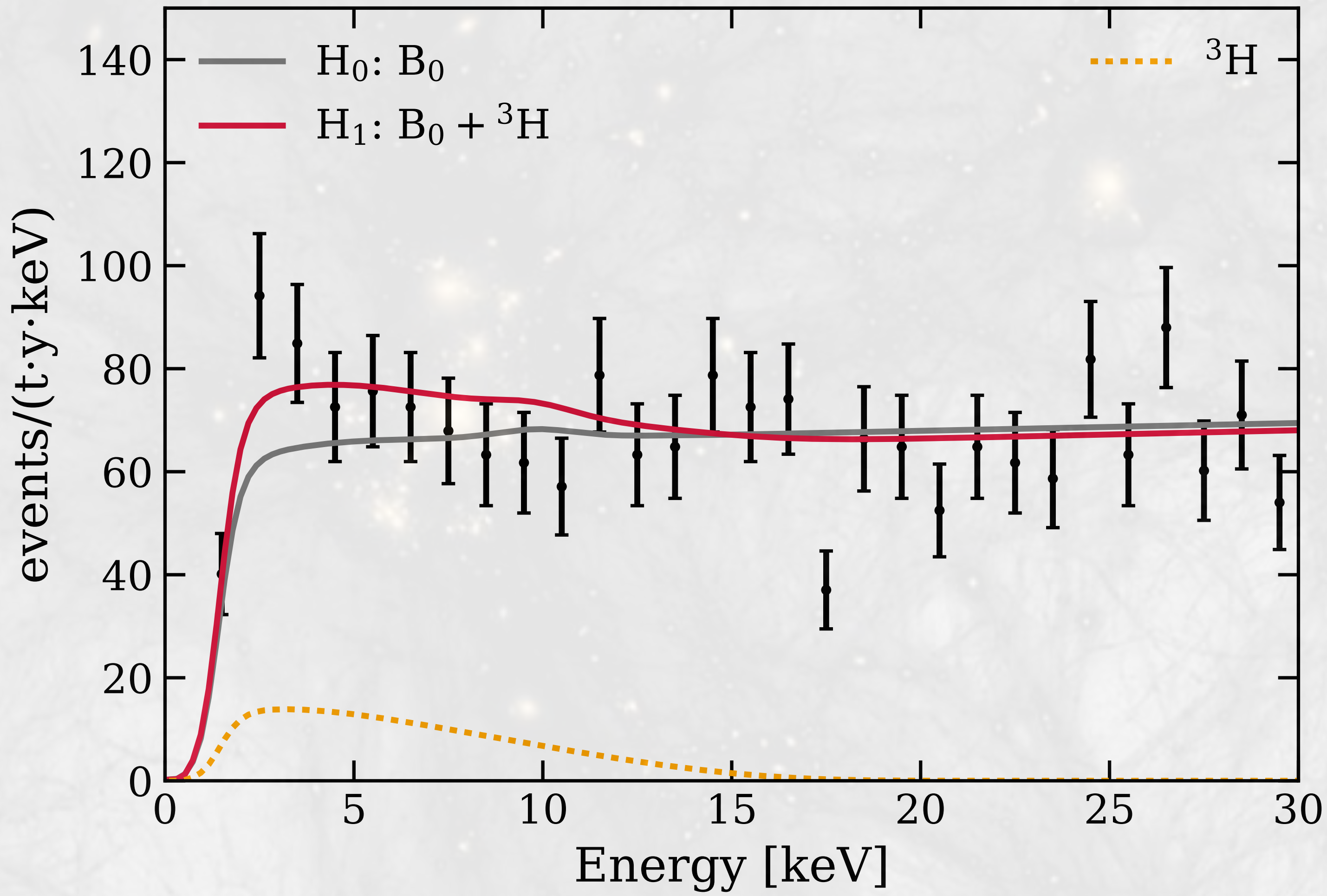
# Exclusion limits on ALPs and DPs

- XENON1T Excess, interpreted as being due to mono-energetic peaks from ALPs and DPs, are ruled out by XENONnT



# Tritium for the XENON1T Excess?

- **XENON1T Excess, interpreted as being due to tritium, is not seen by XENONnT**




Tritium Fit in XENON1T

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

XENONnT tritium control data

$$\leq 8.2\,\mathrm{events}/(\mathrm{t}\cdot\mathrm{y}),\,90\,\mathrm{C.\,L.}$$

XENONnT First Data:

$$\leq 14\,\mathrm{events}/(\mathrm{t}\cdot\mathrm{y}),\,90\,\mathrm{C.\,L.}$$

# Summary from XENONnT First Data

Key Numbers for XENONnT

- 5.9ton sensitive volume
- 1.16 ton-year of exposure in SR0
- >10ms electron lifetime
- 1.7 μBq/kg of Rn222 in LXe in SR0, and <1 μBq/kg in SR1

# Summary from XENONnT First Data

- No Excess is found from 1 to 140 keV
- Incompatible to XENON1T excess
  - Typical new physics models to explain the 1T Excess are excluded
  - New world leading limits on Solar Axions, ALPs and DPs as well as neutrino magnetic moment
- Tritium remains an explanation of the XENON1T excess, but is not seen in XENONnT

**Stay tuned, WIMPs search results to come!**