

# Towards an Era of Discovery: Status of the XENONnT Experiment

Dr. Erwann Masson

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cnrs

  
université  
PARIS-SACLAY

  
XENON

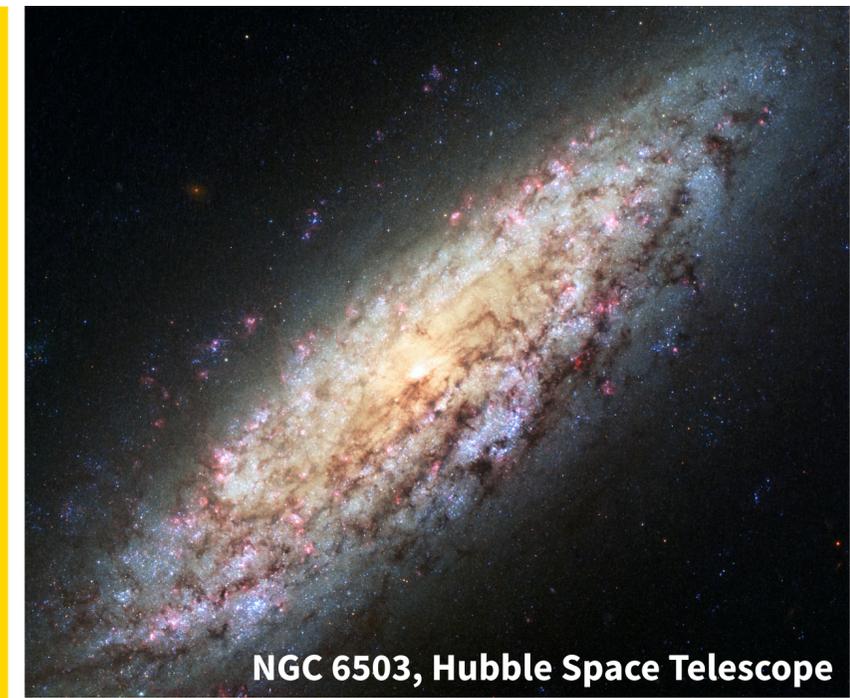
# On Dark Matter & Liquid Xenon

# Dark Matter in a nutshell

See Geneviève Bélanger's talk (WP1)

- ▶ A **non-luminous matter** is needed to explain what is observed in the Universe **at all scales** (1 pc  $\approx$  3.26 ly)
- ▶ Standard cosmological model  $\rightarrow$  **27%** of non-baryonic, non-relativistic, and almost non-interacting matter
- ▶ Most promising candidate in particle physics  
 $\rightarrow$  **Weakly Interacting Massive Particles (WIMPs,  $\chi$ )**

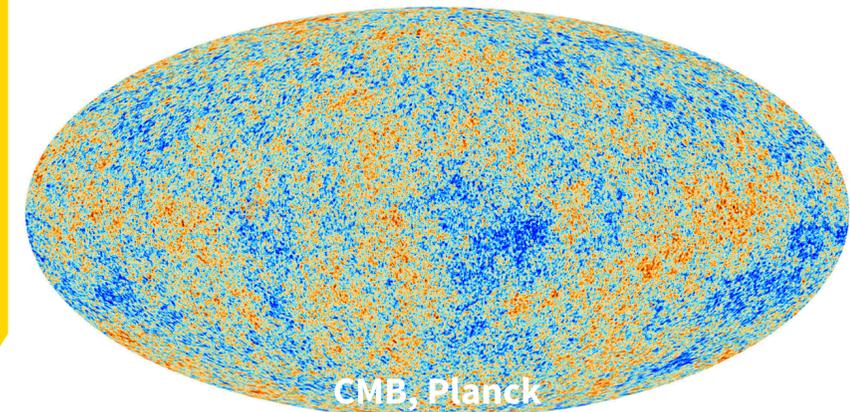
20–60 kpc



2–10 Mpc



4 Gpc



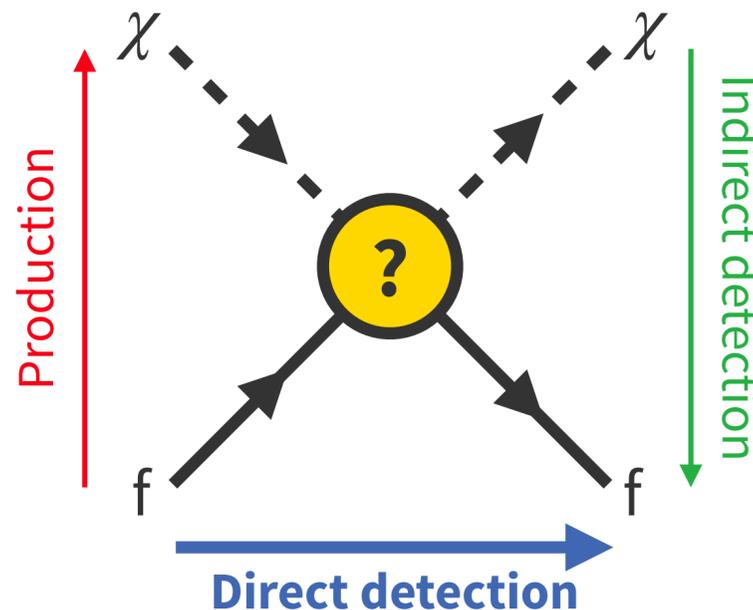
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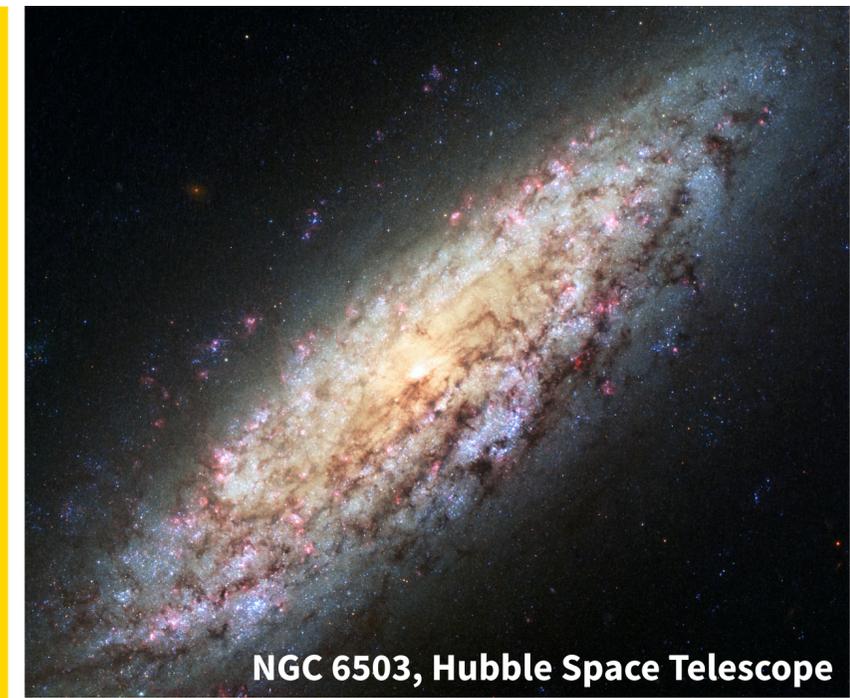
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- ▶ Most promising candidate in particle physics  
 $\rightarrow$  **Weakly Interacting Massive Particles (WIMPs,  $\chi$ )**

## WIMP (expected) ID card

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



20-60 kpc



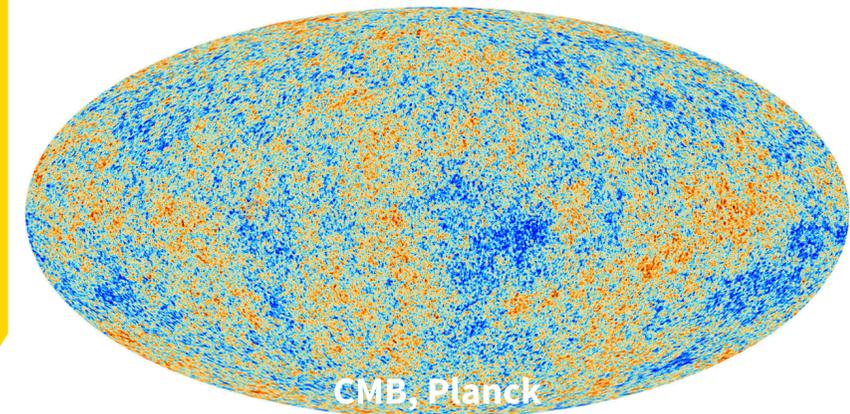
NGC 6503, Hubble Space Telescope

2-10 Mpc



Bullet Cluster, Chandra X-ray Observatory

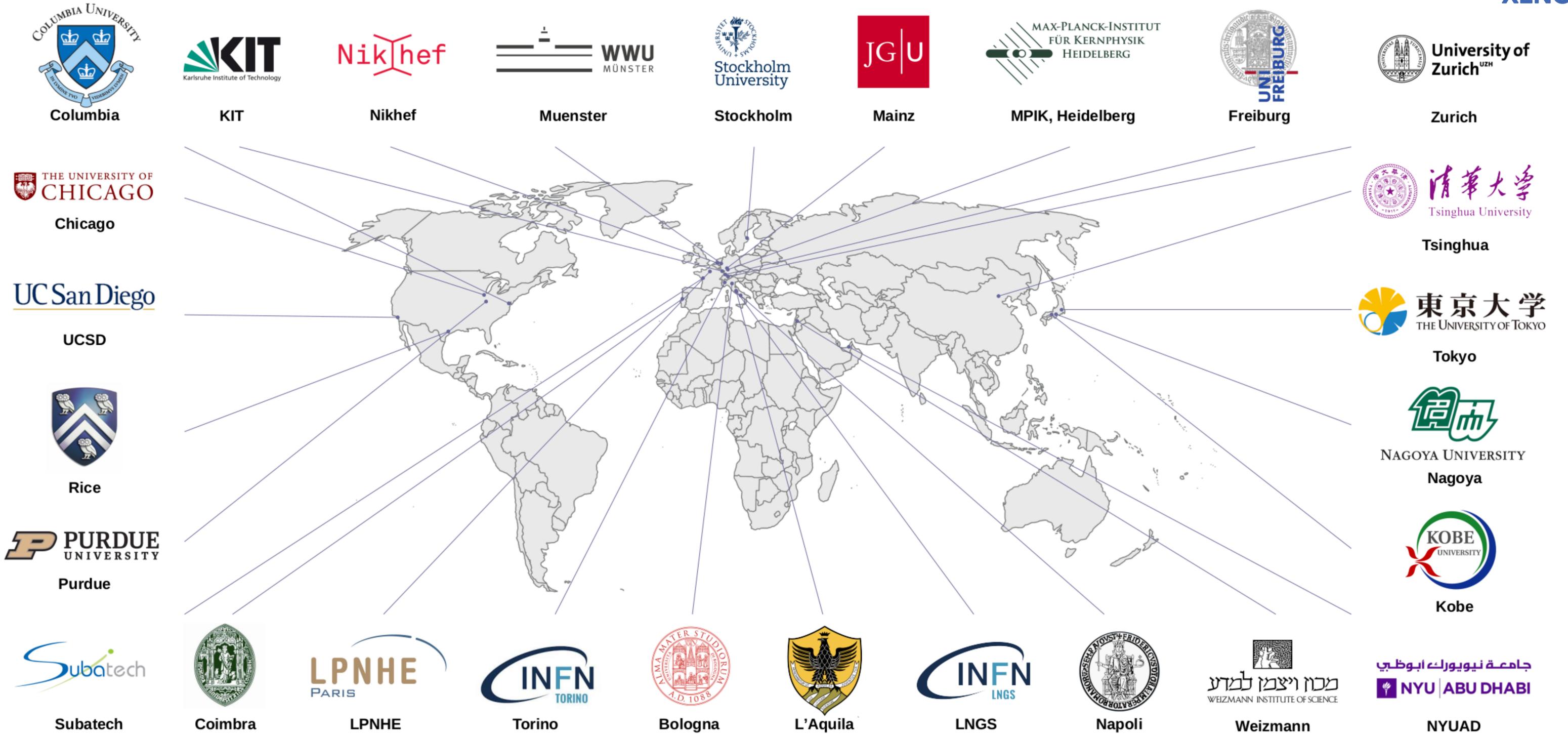
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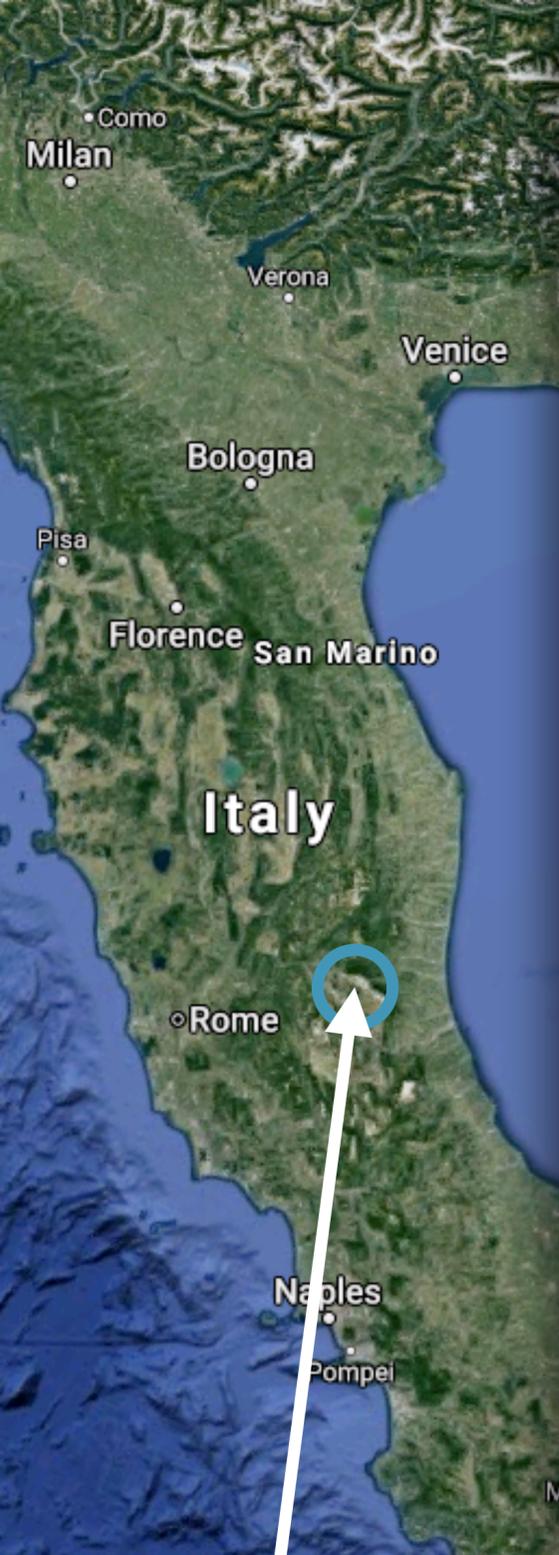


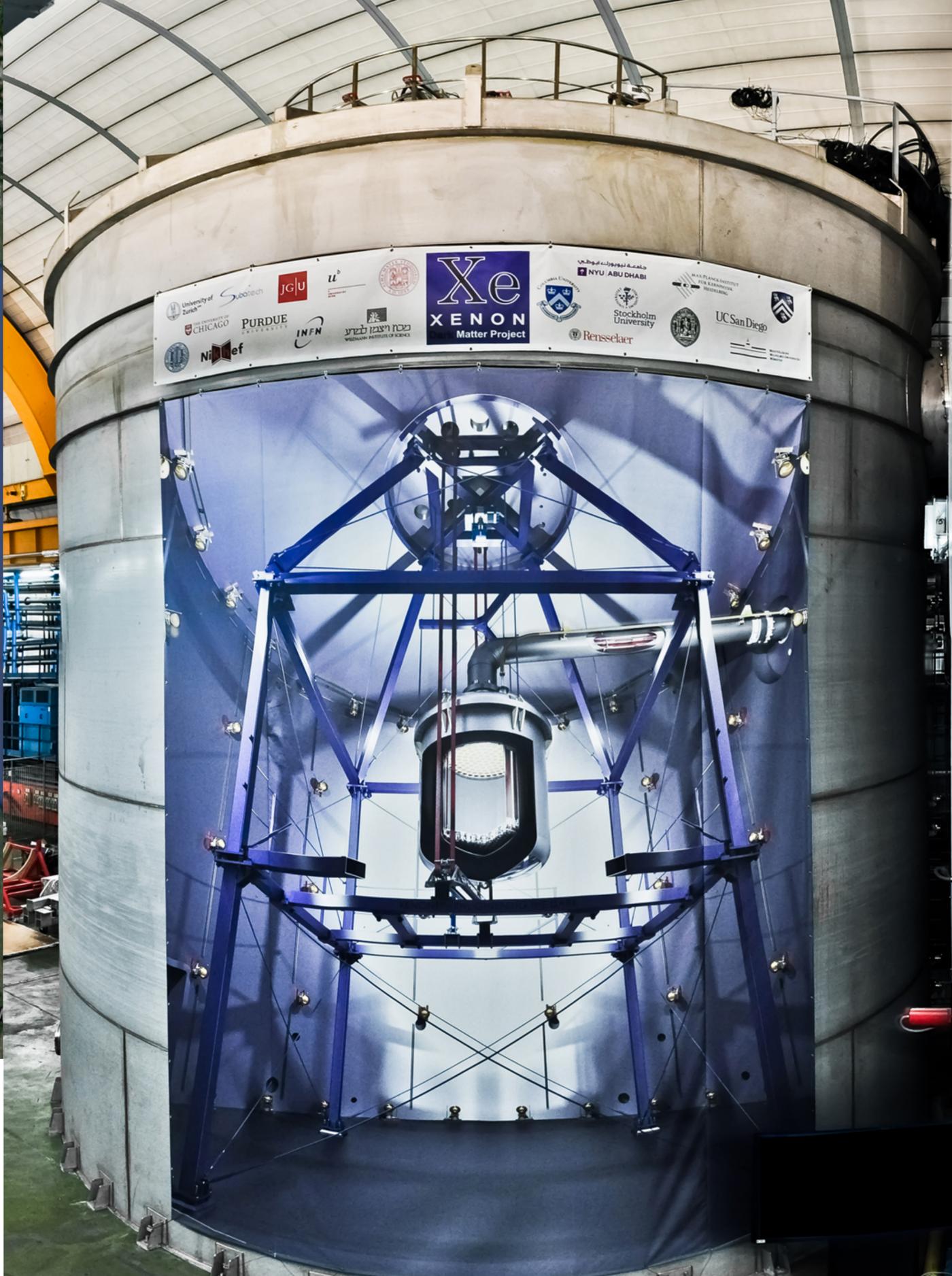
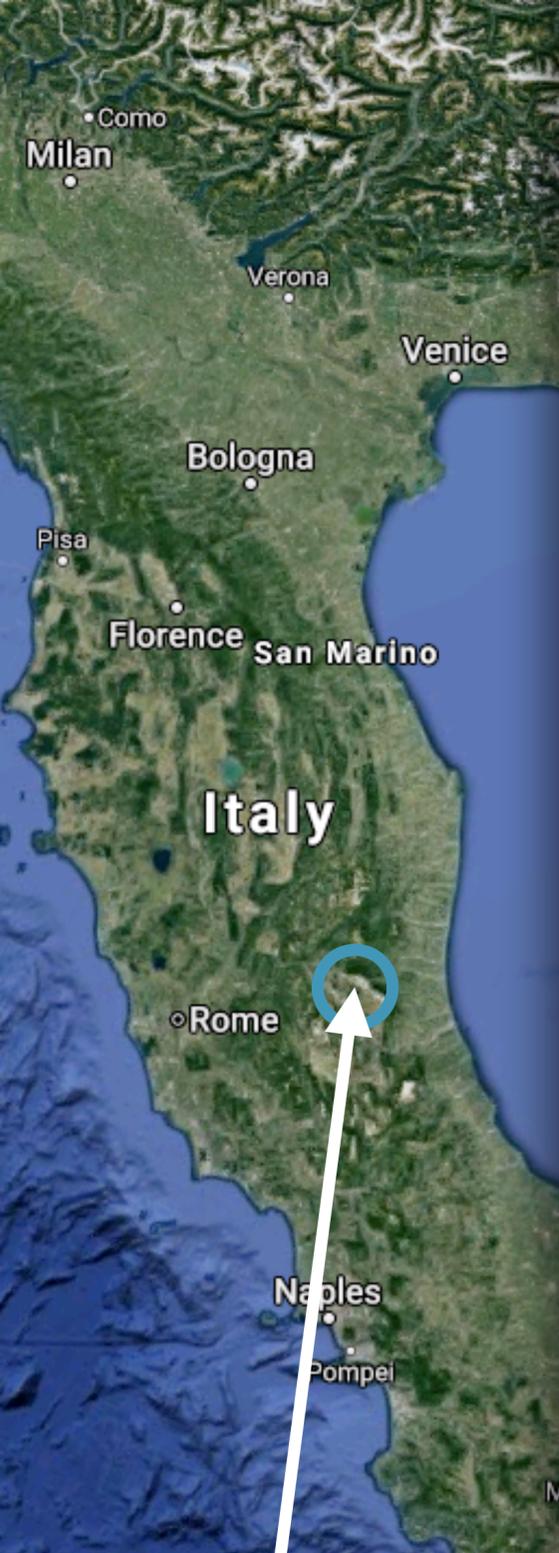
CMB, Planck

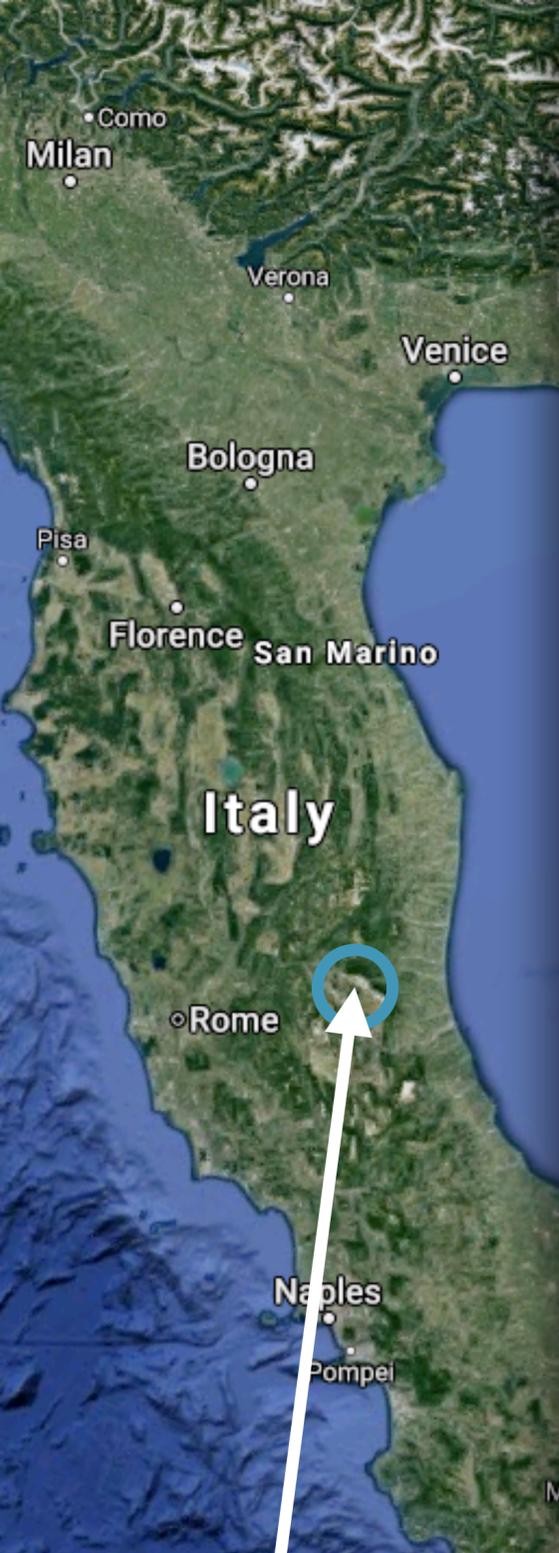
# The XENON Collaboration

170+ scientists  
27 institutes / 11 countries









University of Zurich JGU u Xe XENON Matter Project NYU ABU DHABI PURDUE UNIVERSITY INFN Stockholm University Rensselaer UC San Diego

Dual-Phase TPC

Water Čerenkov  
Muon Veto



Cryogenics & Xenon Purification

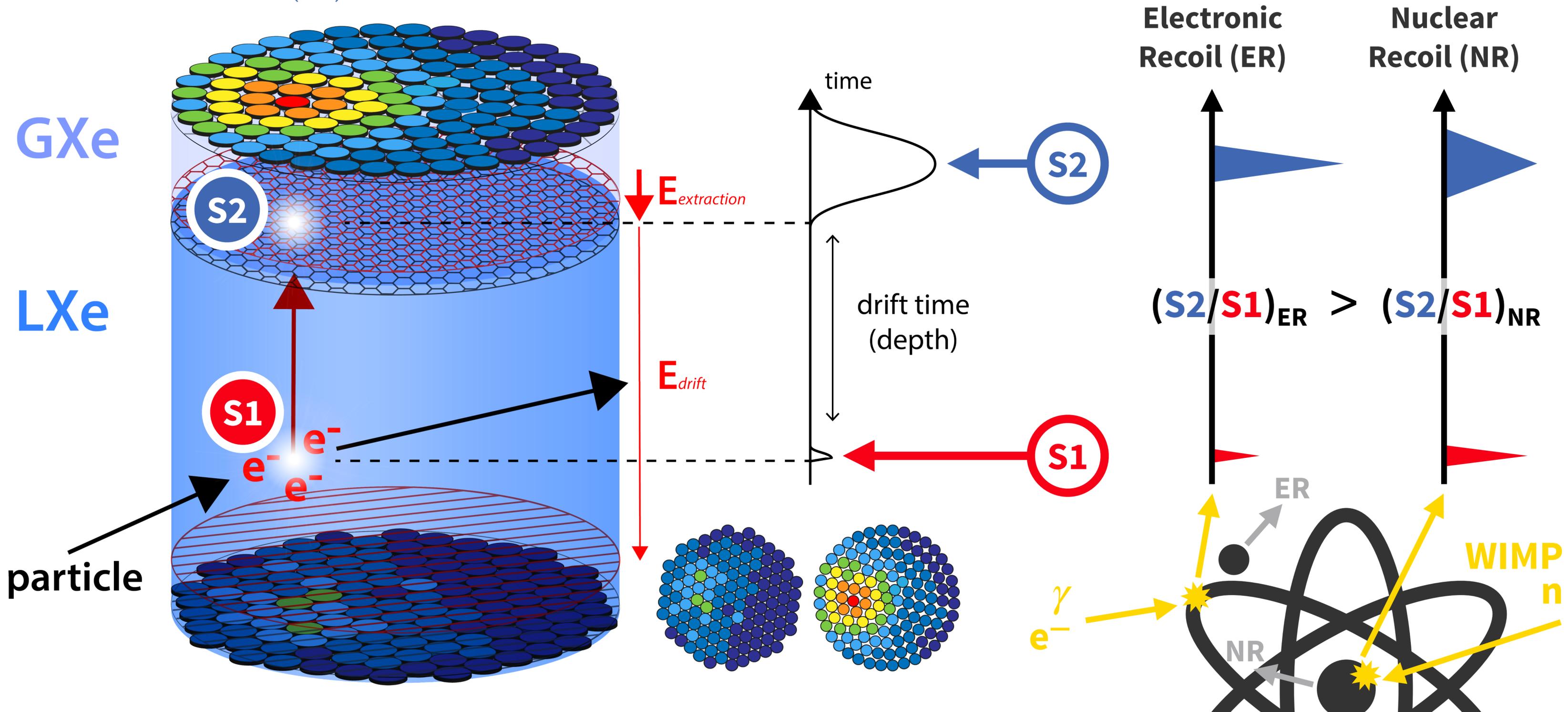
Electronics & Data Acquisition

Xenon Storage,  
Recovery & Distillation



# Detecting particles with a dual-phase TPC

See Maxime Pierre's talk (WP3)



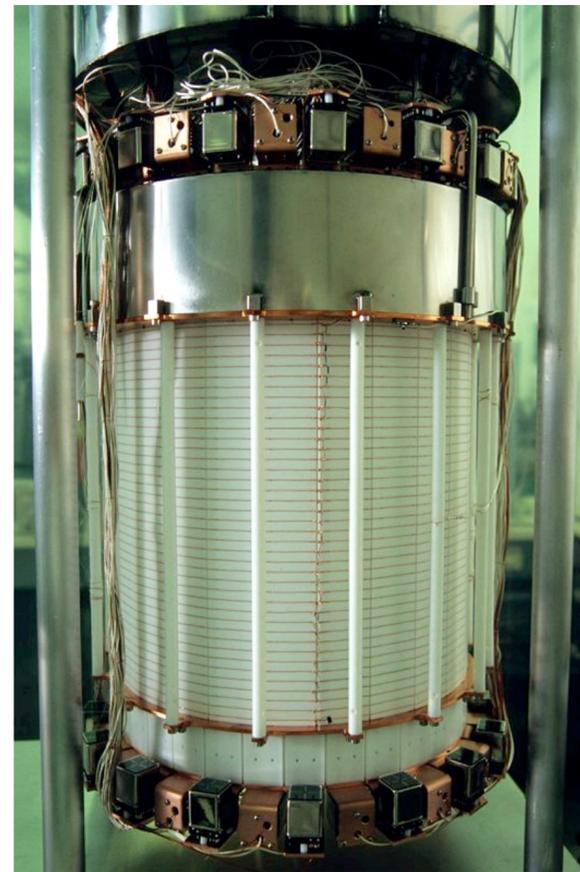
# The XENON program

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



**XENON10**  
2005–2007

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



**XENON100**  
2009–2016

161 kg LXe  
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**XENON1T**  
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**XENONnT**  
2020–2025

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

NOW

**What XENON1T**

**found so far**

## Light Dark Matter

PRL 123 (2019) 241803

PRL 123 (2019) 251801

## WIMP Dark Matter

PRL 121 (2018) 111302

PRD 103 (2021) 063028

## Bosonic Dark Matter

PRL 123 (2019) 251801

PRD 102 (2020) 072004

# What XENON1T

# found so far

## Solar Axions

PRD 102 (2020) 072004

## Neutrino Magnetic Moment

PRD 102 (2020) 072004

## Solar $^8\text{B}$ CEvNS

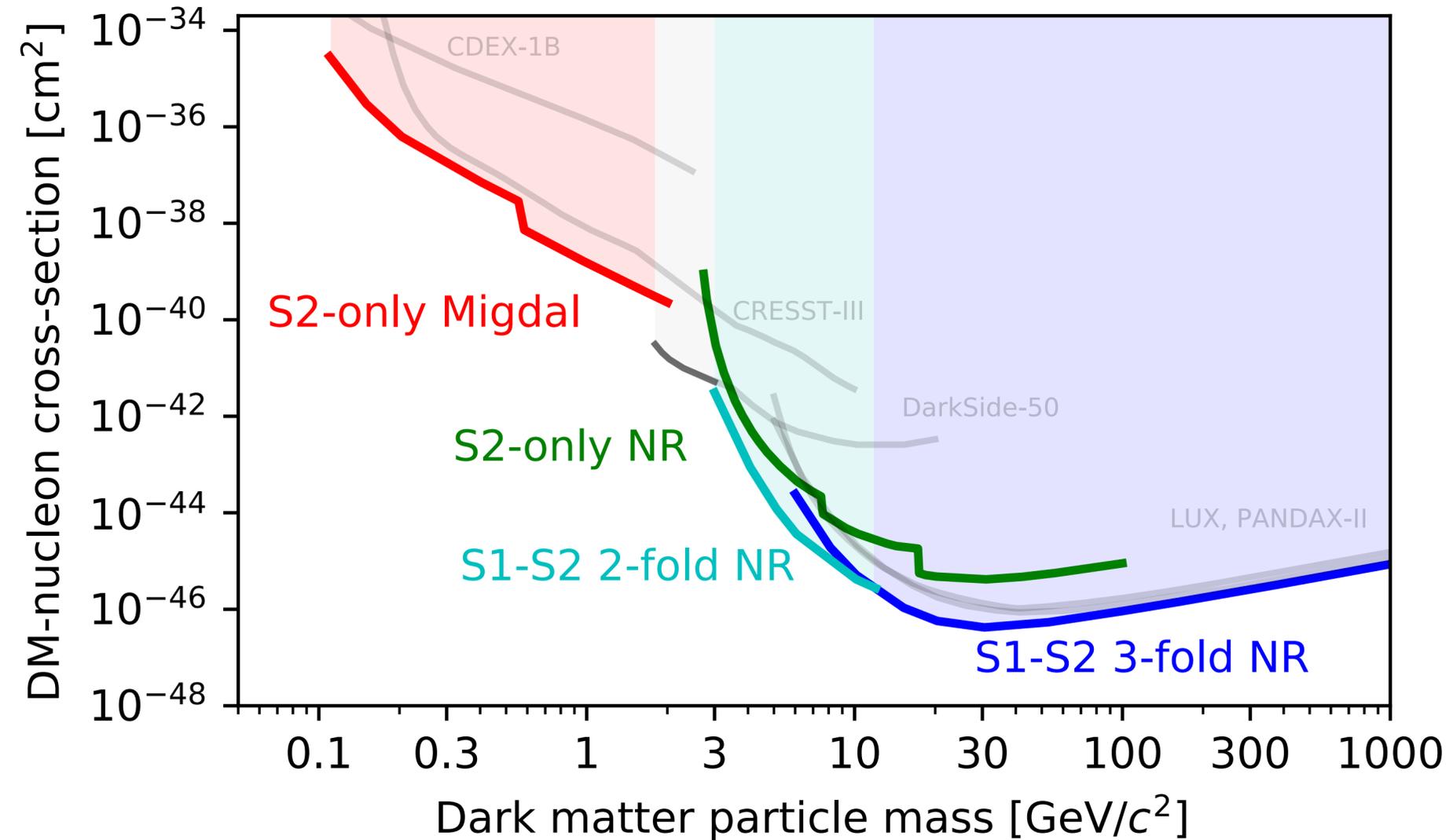
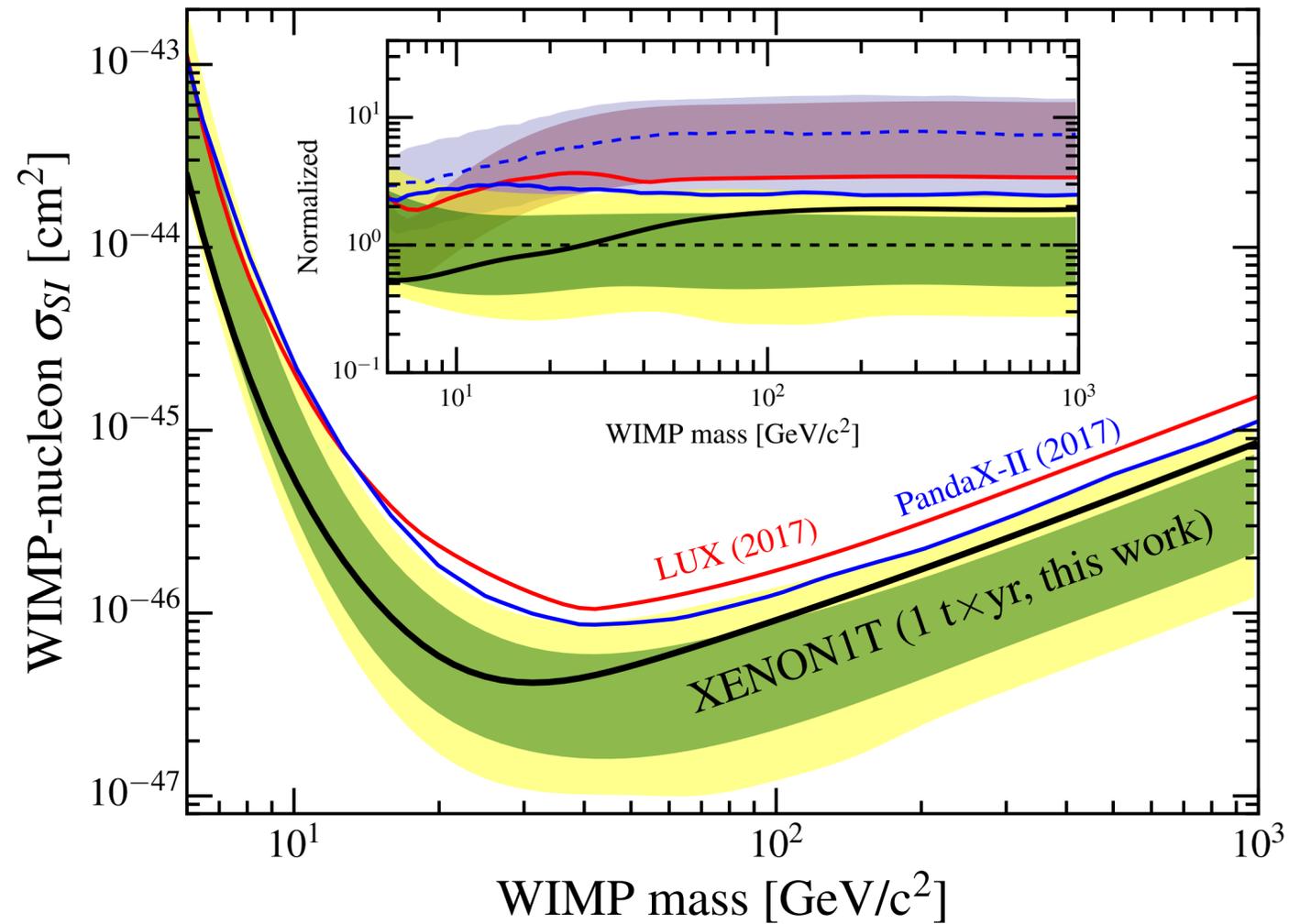
PRL 126 (2021) 091301

## 2 $\nu$ Double Electron Capture

Nature 568 (2019) 7753

# High-mass WIMP-nucleus interactions

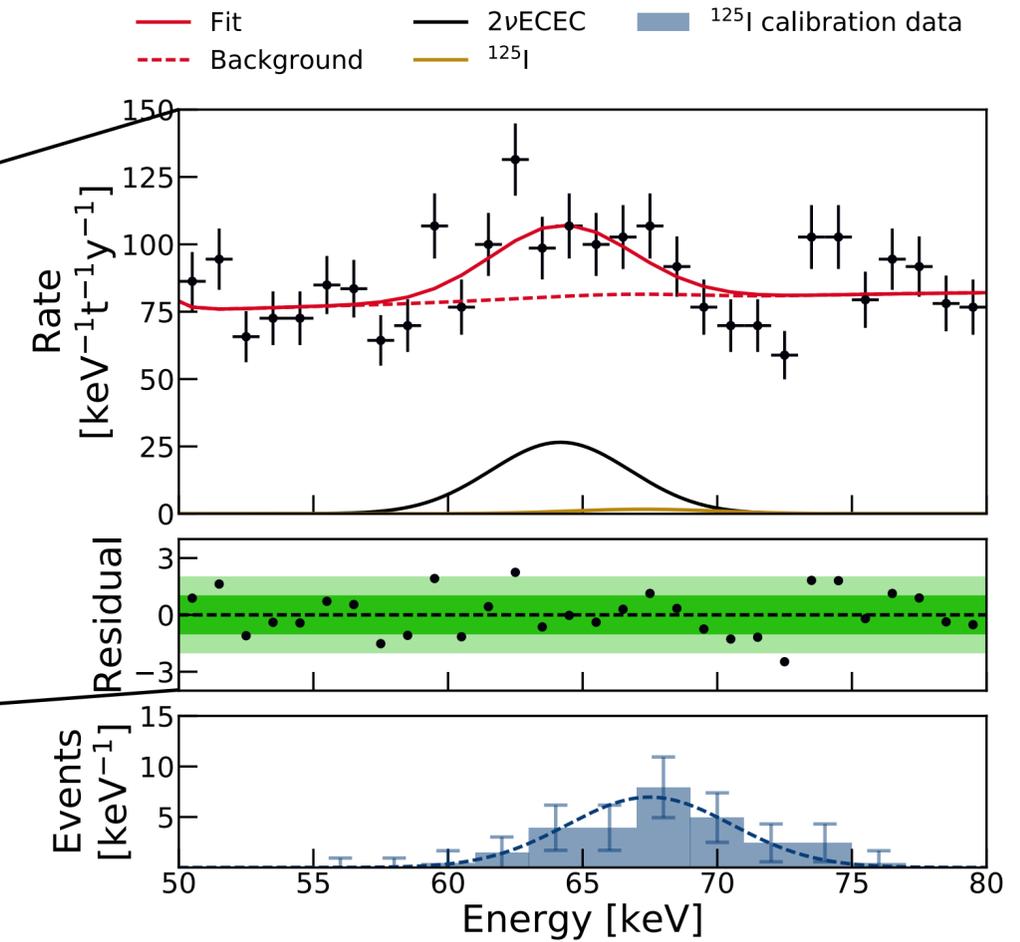
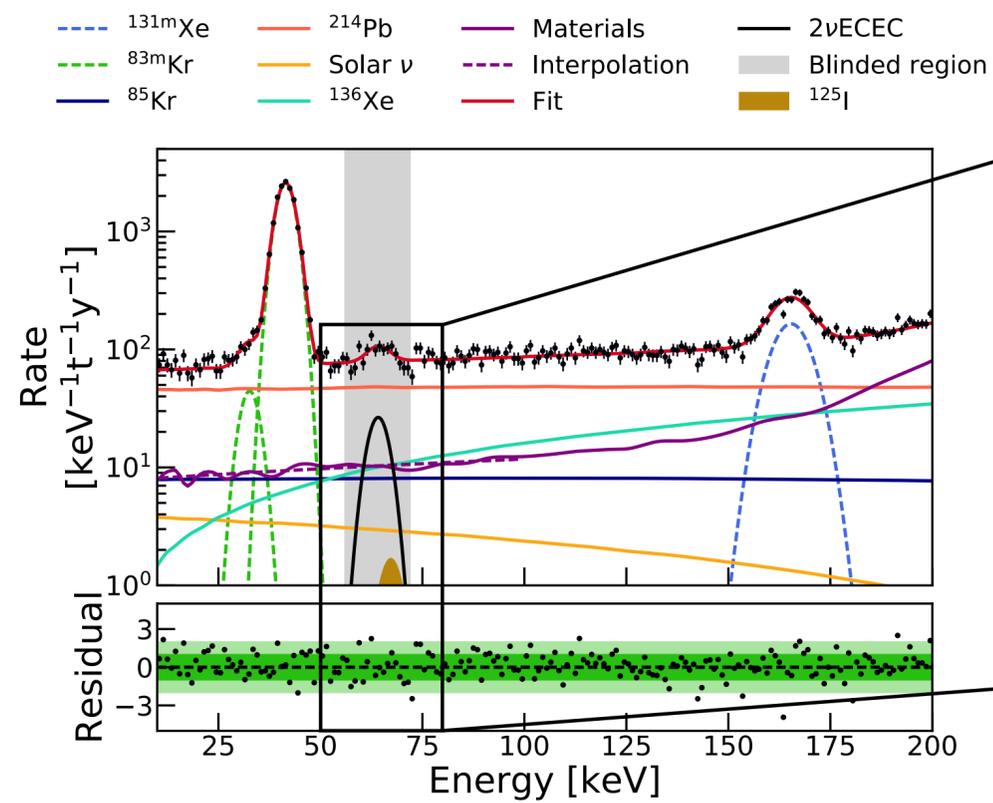
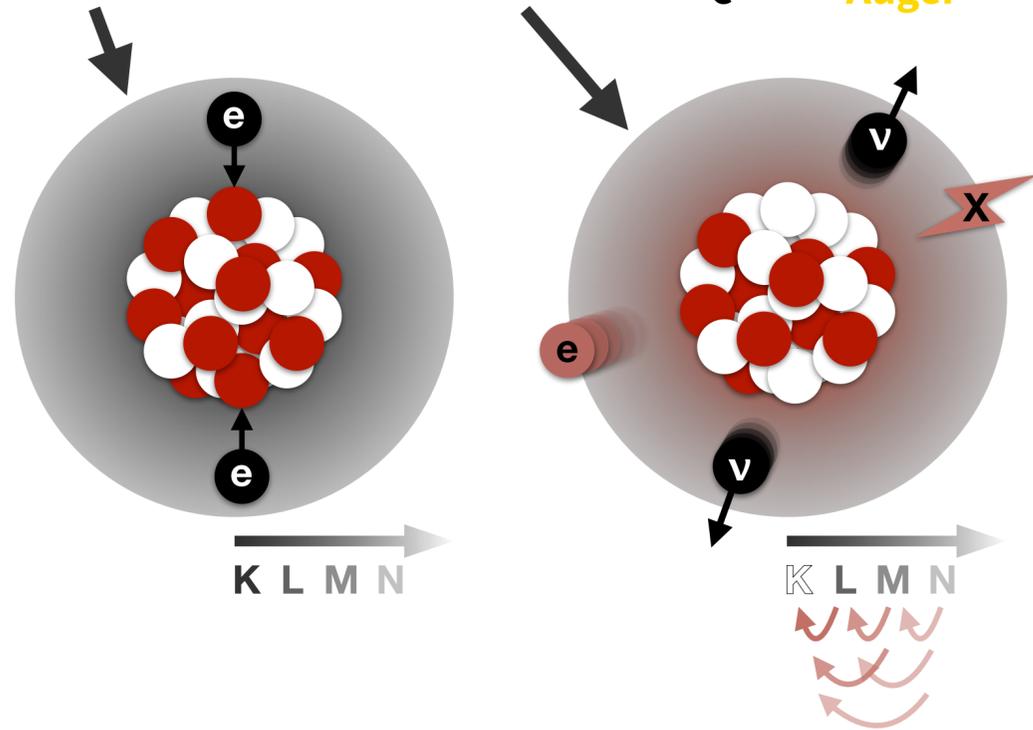
PRL 121 (2018) 111302  
EPJC 80 (2020) 785



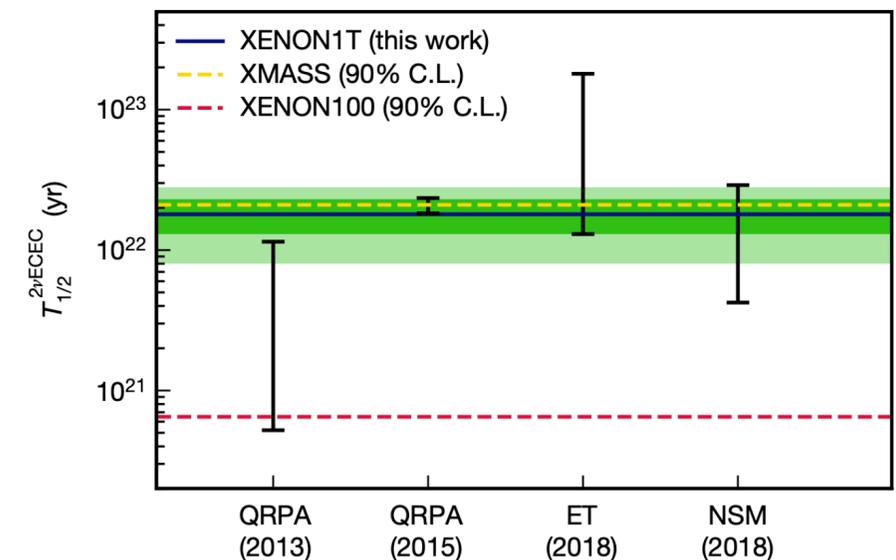
- ▶ To date, **strongest limit** to the WIMP-nucleon cross section for WIMPs **above 6 GeV/c<sup>2</sup>**
- ▶ Unprecedented minimum of  **$4.1 \times 10^{-47} \text{ cm}^2$**  at **30 GeV/c<sup>2</sup>** (90% C.L.)
- ▶ Leading (most of) the searched DM mass range

# 2ν Double Electron Capture in $^{124}\text{Xe}$

Nature 568 (2019) 7753

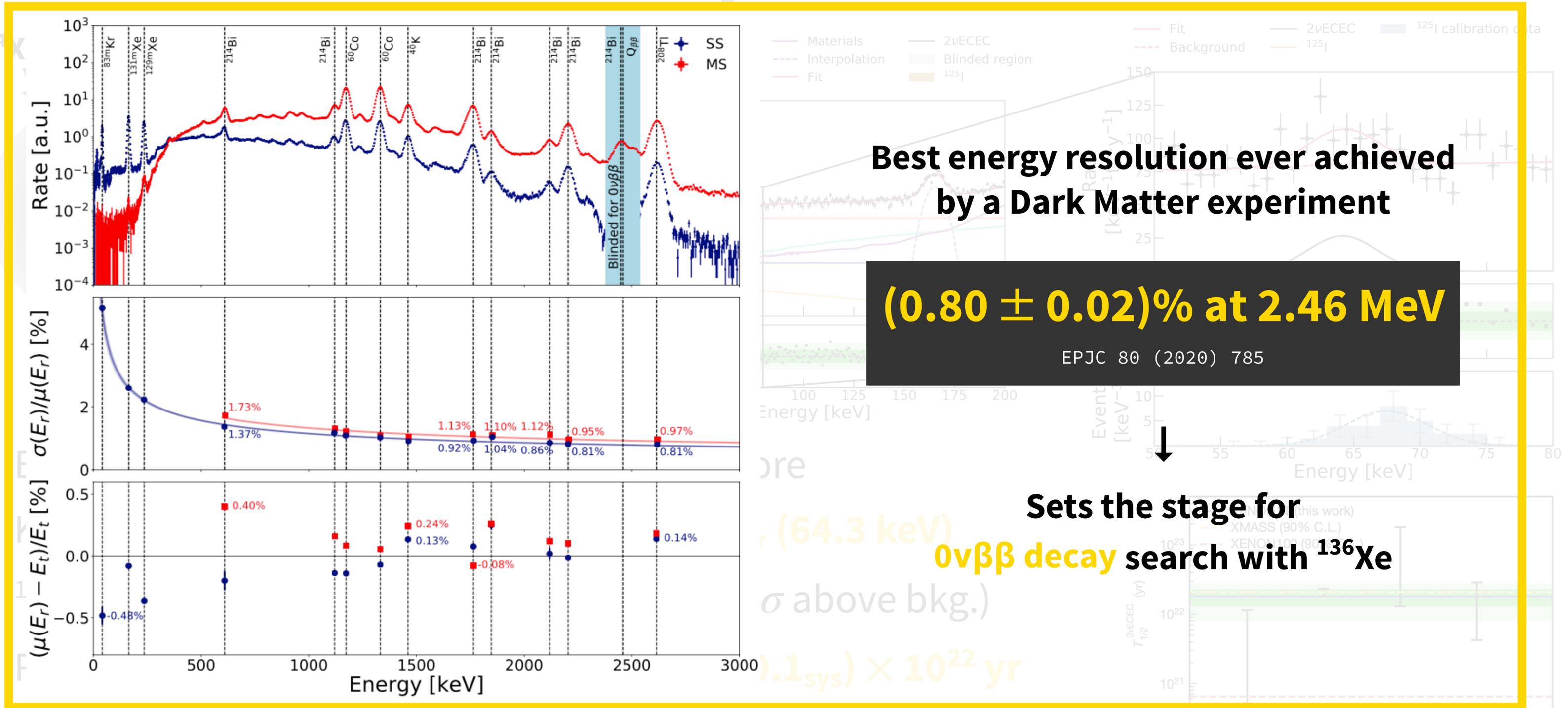


- ▶ Extremely rare process, never observed before
- ▶ K-shell electron capture → **X-rays and  $e_{\text{Auger}}$  (64.3 keV)**
- ▶  $^{124}\text{Xe} \sim 1 \text{ kg/t LXe} \rightarrow$  **126 2νDEC events** ( $4.4\sigma$  above bkg.)
- ▶ Resulting half-life →  **$T_{1/2} = (1.8 \pm 0.5_{\text{stat}} \pm 0.1_{\text{sys}}) \times 10^{22} \text{ yr}$**
- ▶ Unprecedented sensitivity to **rare decay searches**



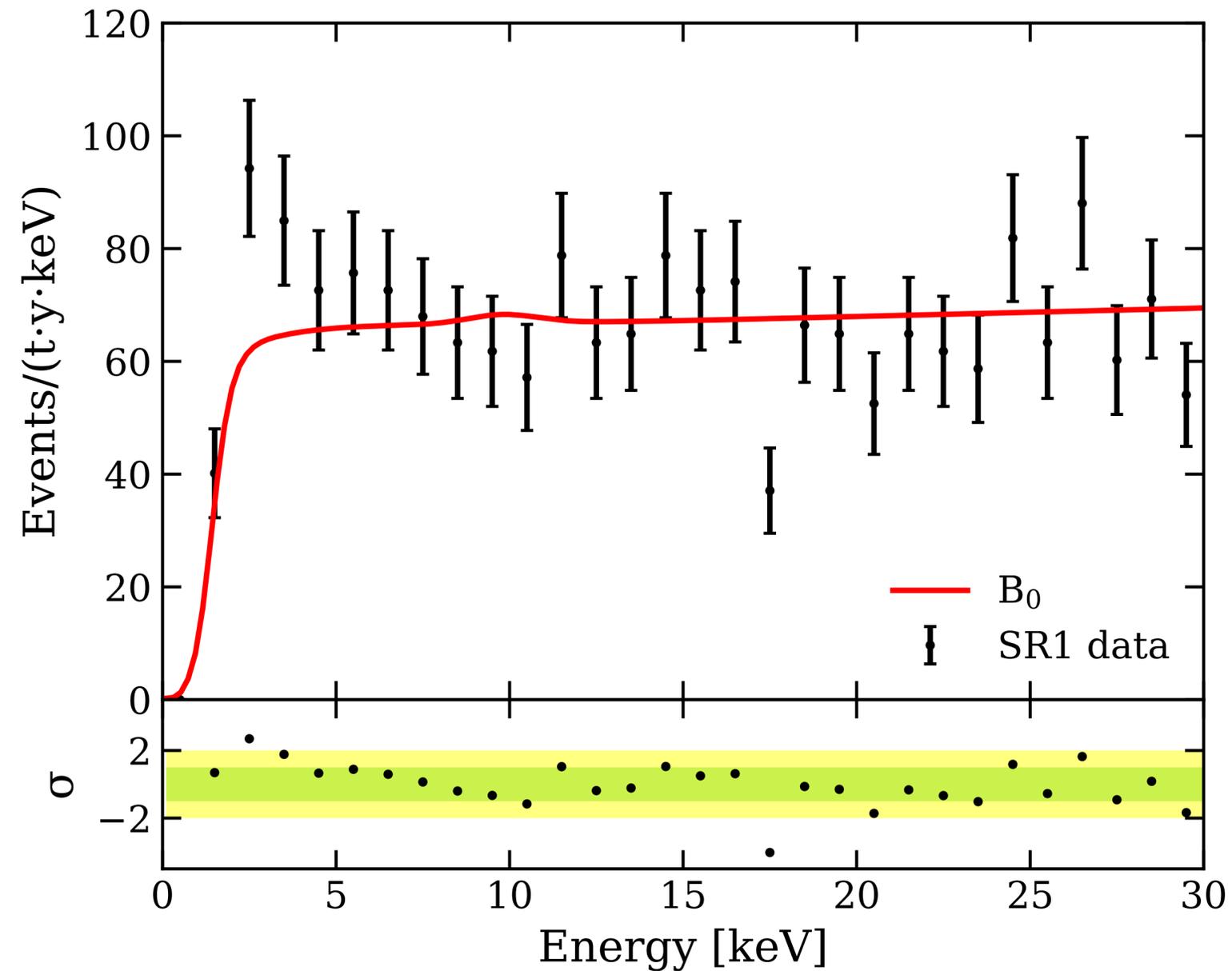
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Unprecedented sensitivity to rare decay searches

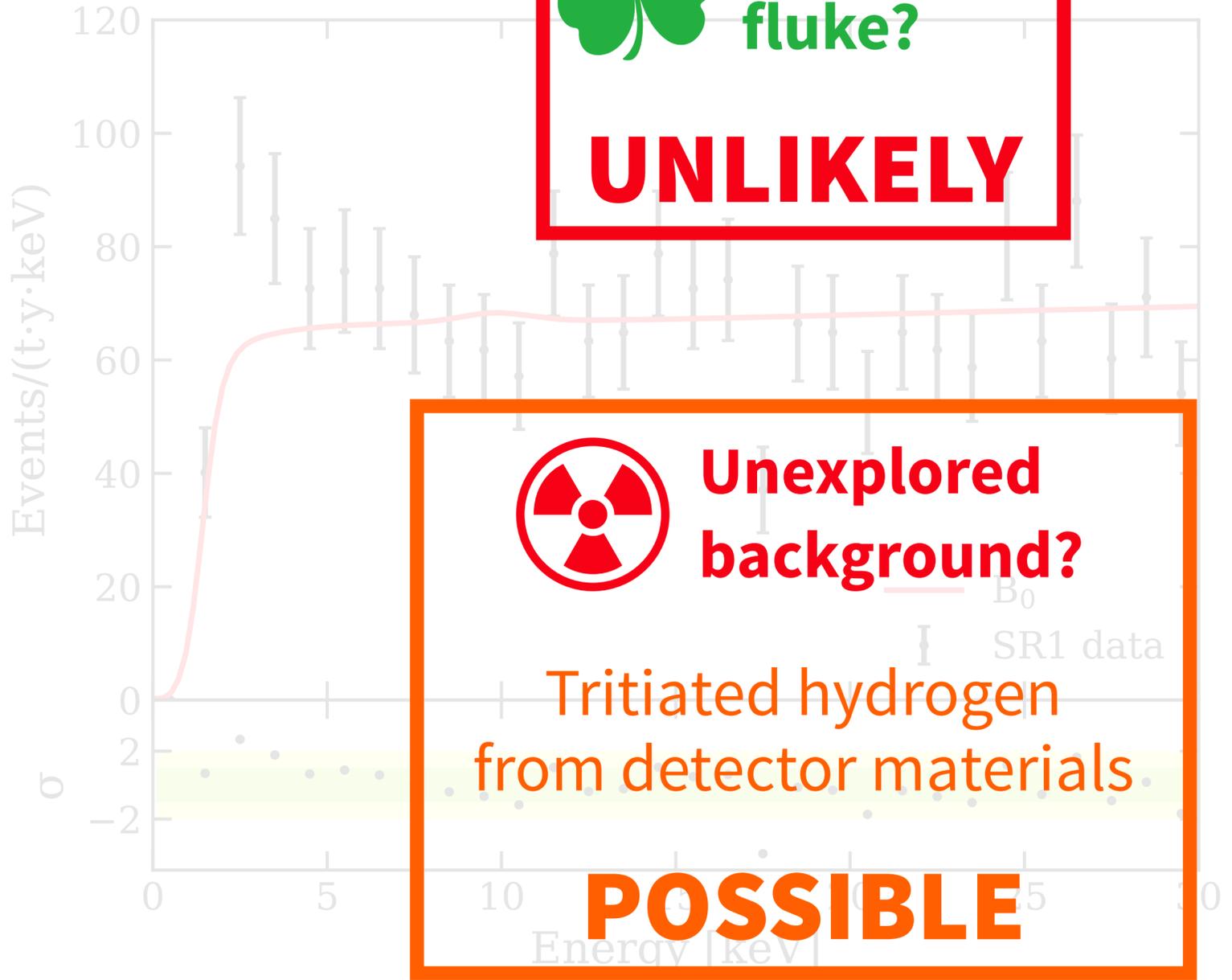
# The low-energy ER excess



- ▶ 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  
→  **$(76 \pm 2)$  events/(t × yr × keV)**

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

# The low-energy ER excess



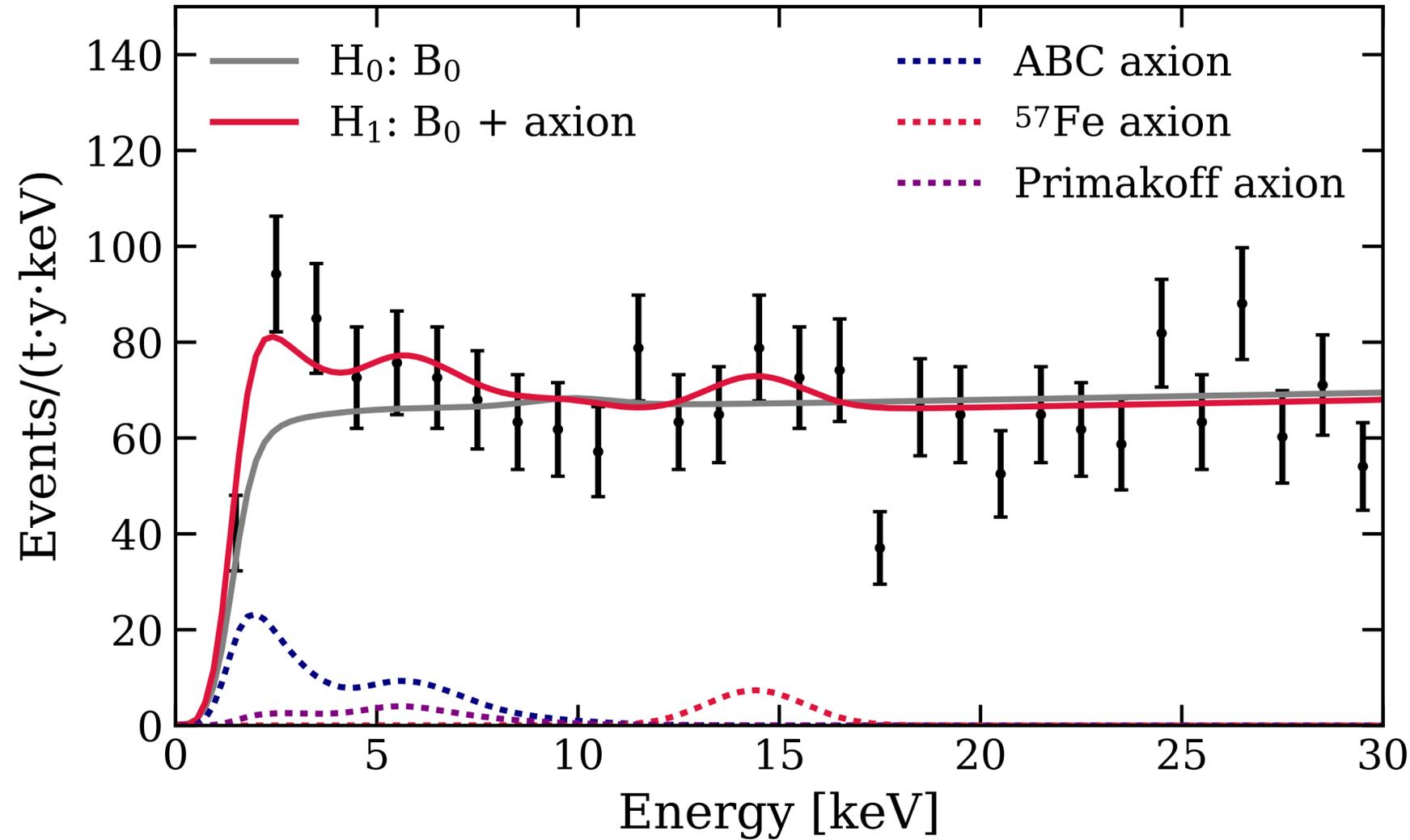
 **Systematic effects?**  
**UNLIKELY**

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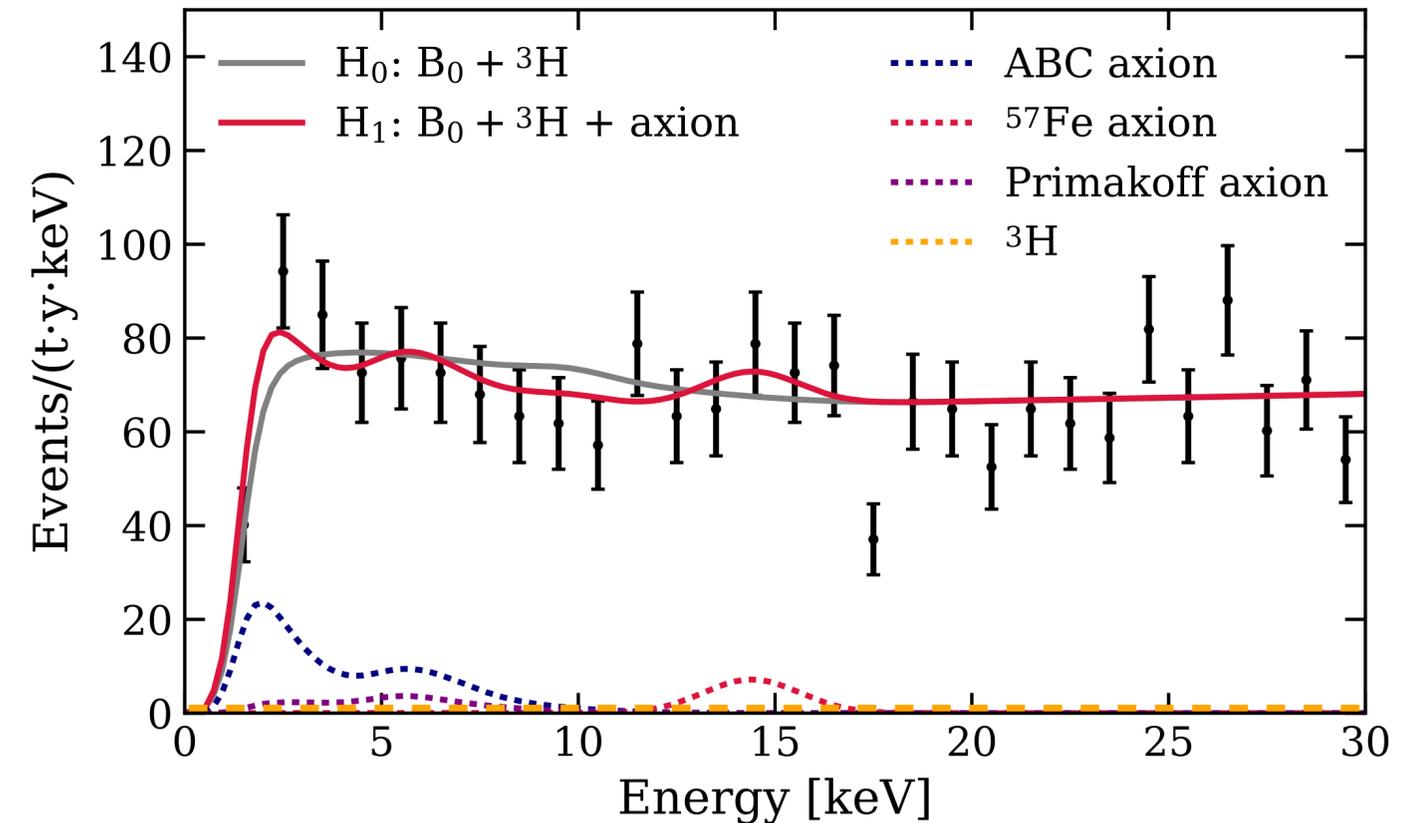
 **New physics?**  
Solar axions  
 $\nu$  magnetic moment  
Bosonic DM  
**POSSIBLE**

Observed 235 events in 1–7 keV  
Expected  $(232 \pm 15)$  events  
→  $\sim 3.3\sigma$  Poissonian fluctuation!

# The solar axion hypothesis



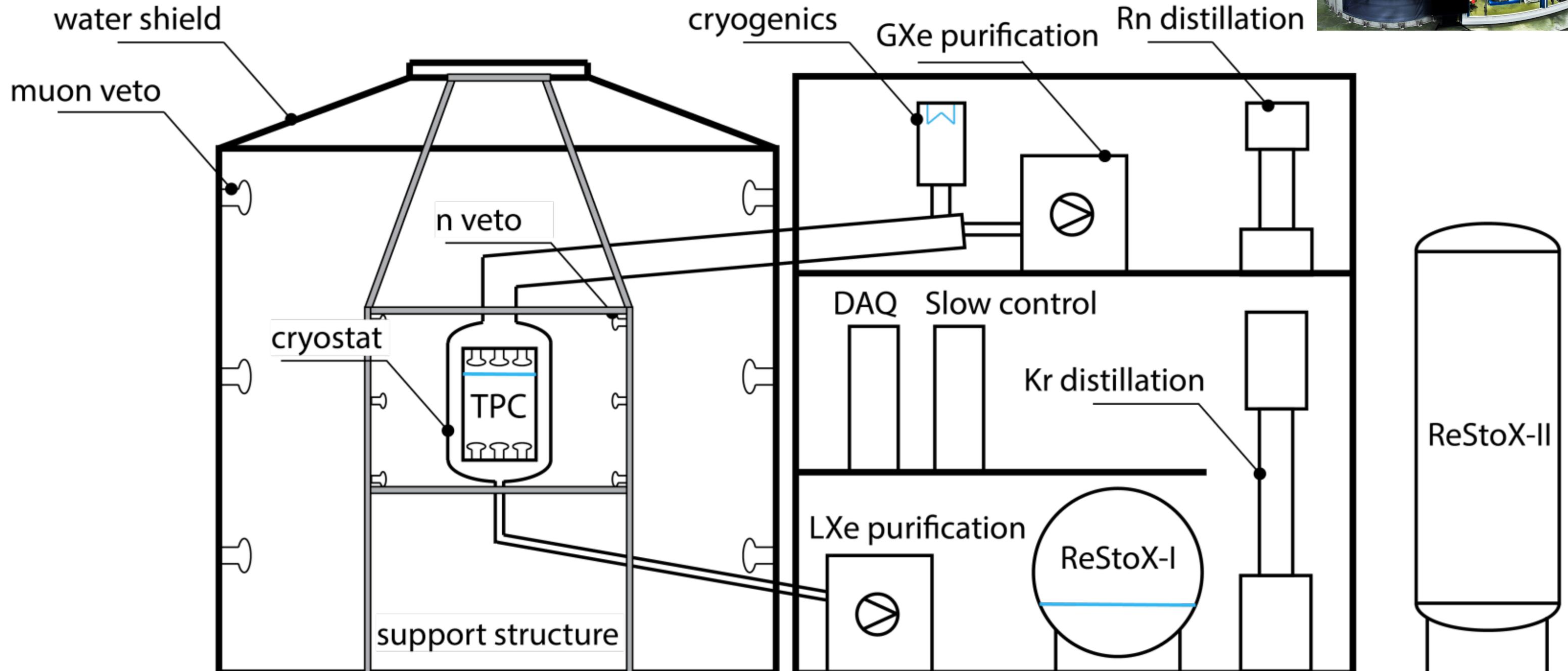
- ▶ Simultaneous search for **ABC**, **Primakoff** and  **$^{57}\text{Fe}$**  axions (unconstrained components in the fit)
- ▶ Axion hypothesis **still favoured over  $B_0 + \text{tritium}$**  at  $2.0\sigma$



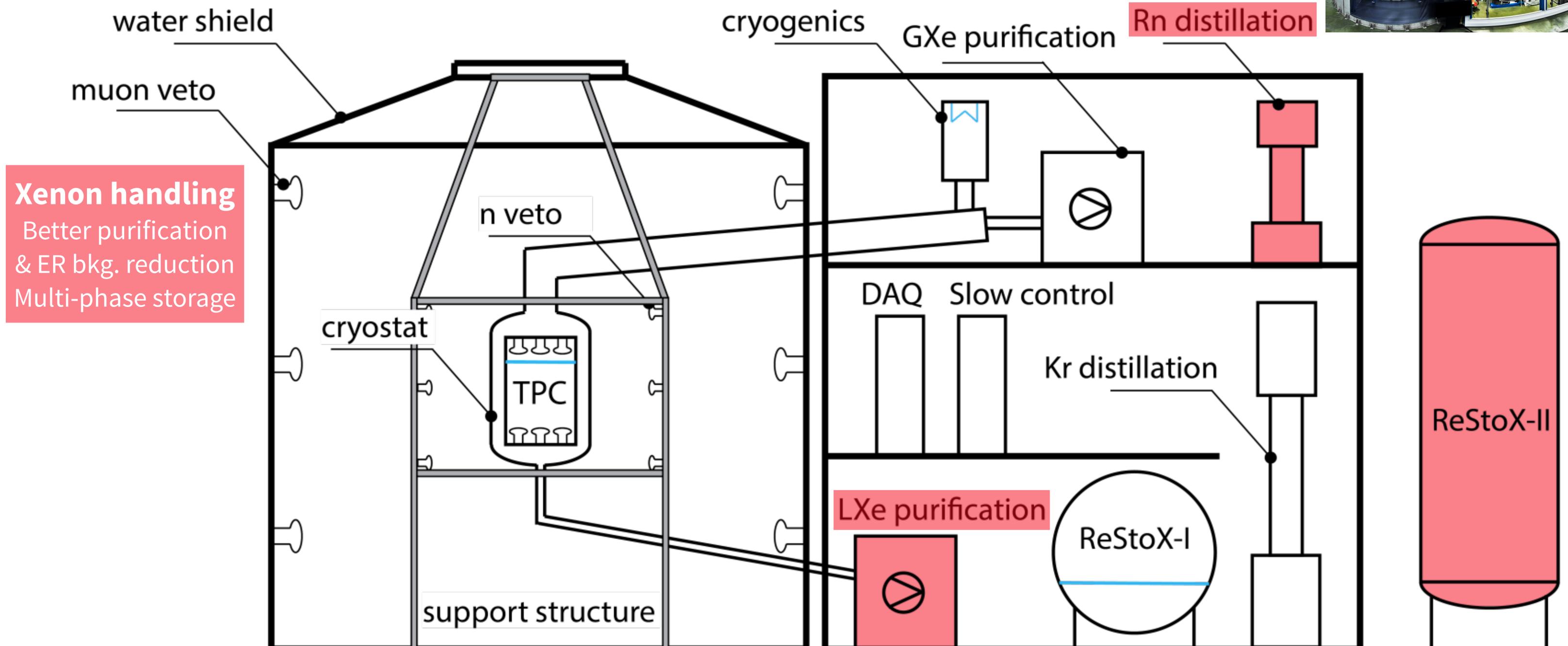
Axion hypothesis favoured over  $B_0$  at  **$3.4\sigma$**

**How is XENON  
now?**

# Meet XENONnT

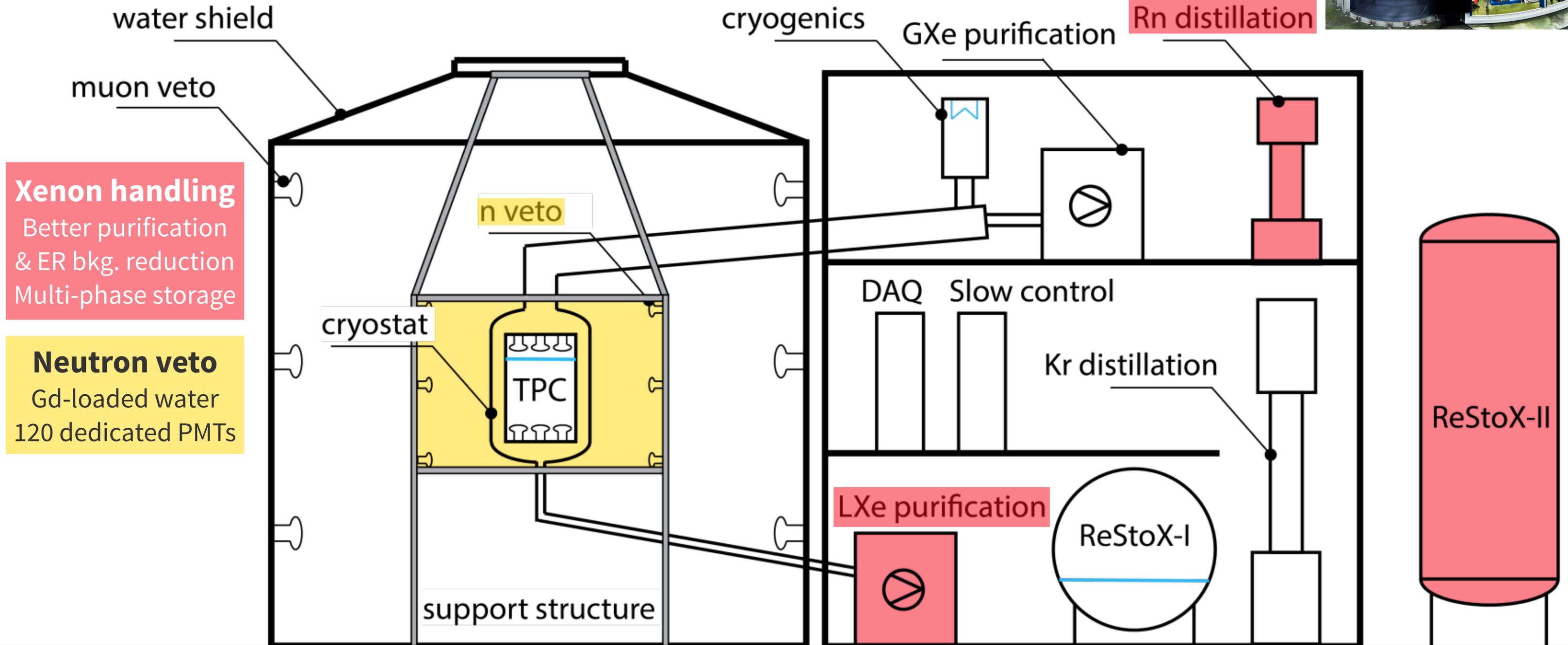


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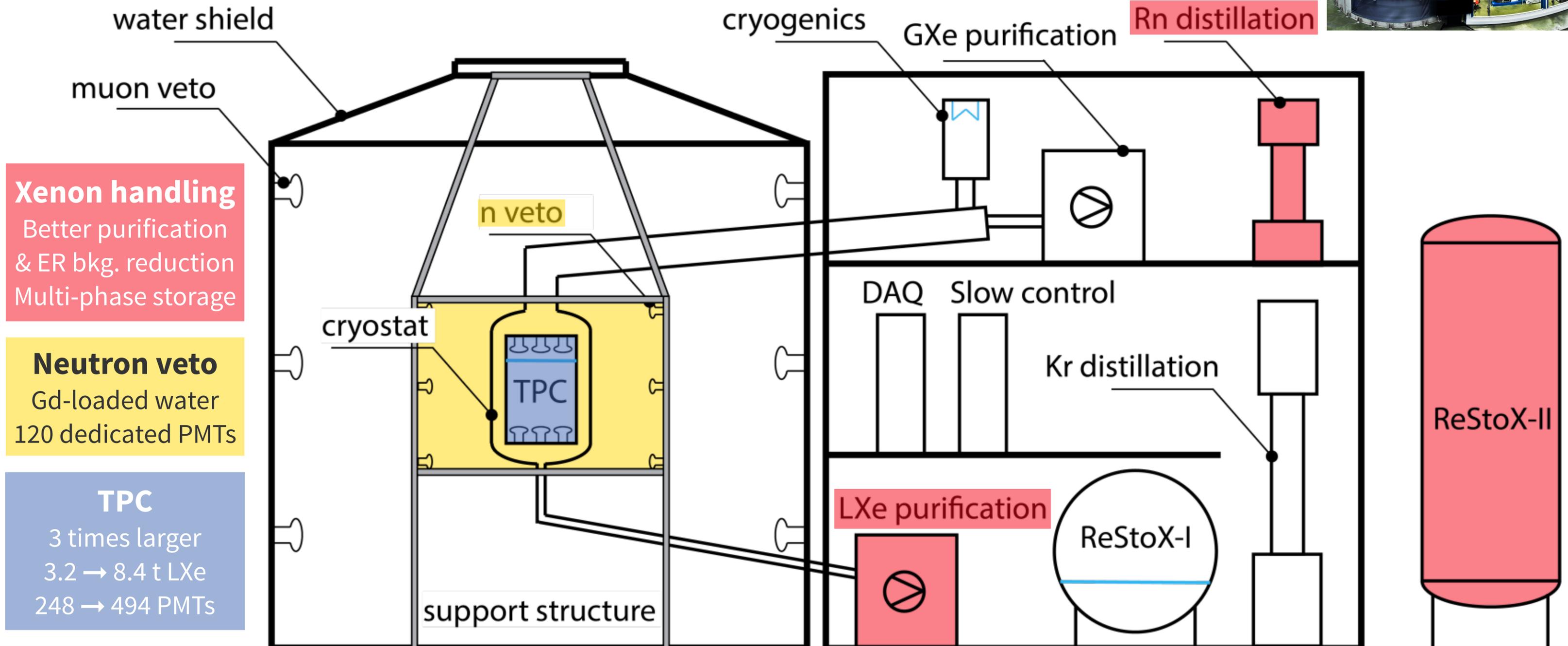


**Xenon handling**  
Better purification  
& ER bkg. reduction  
Multi-phase storage

# Meet XENONnT



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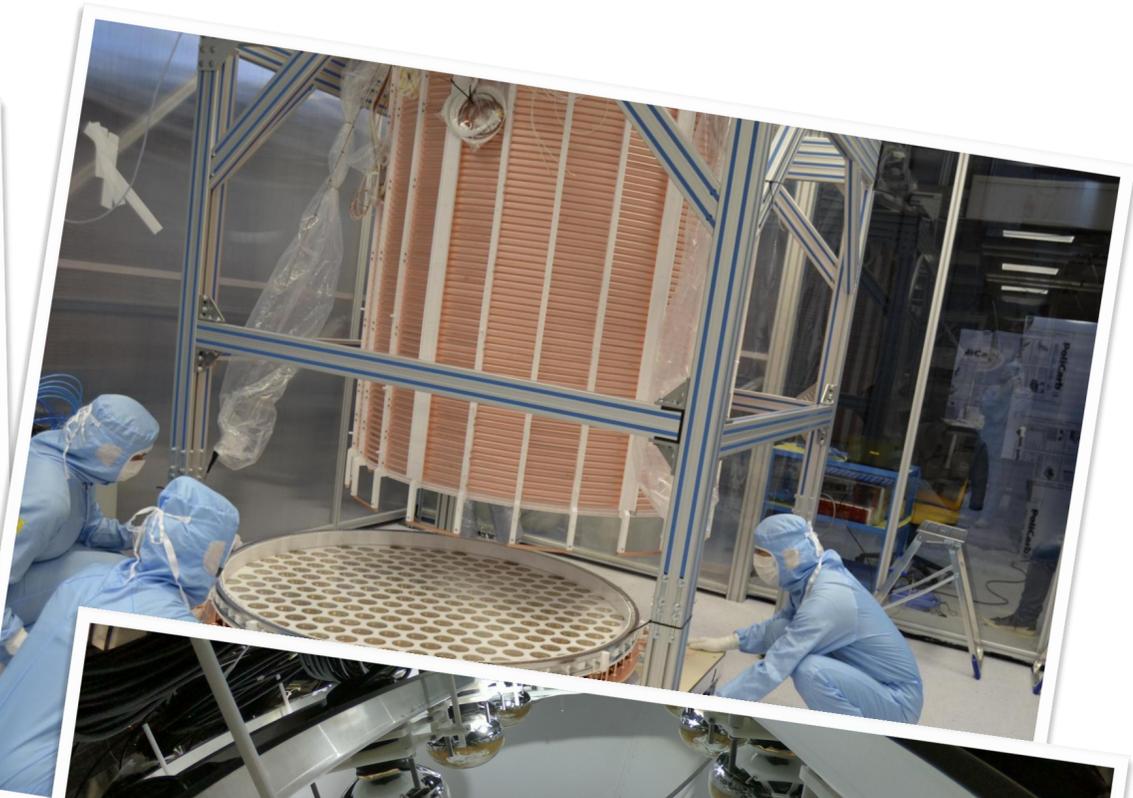
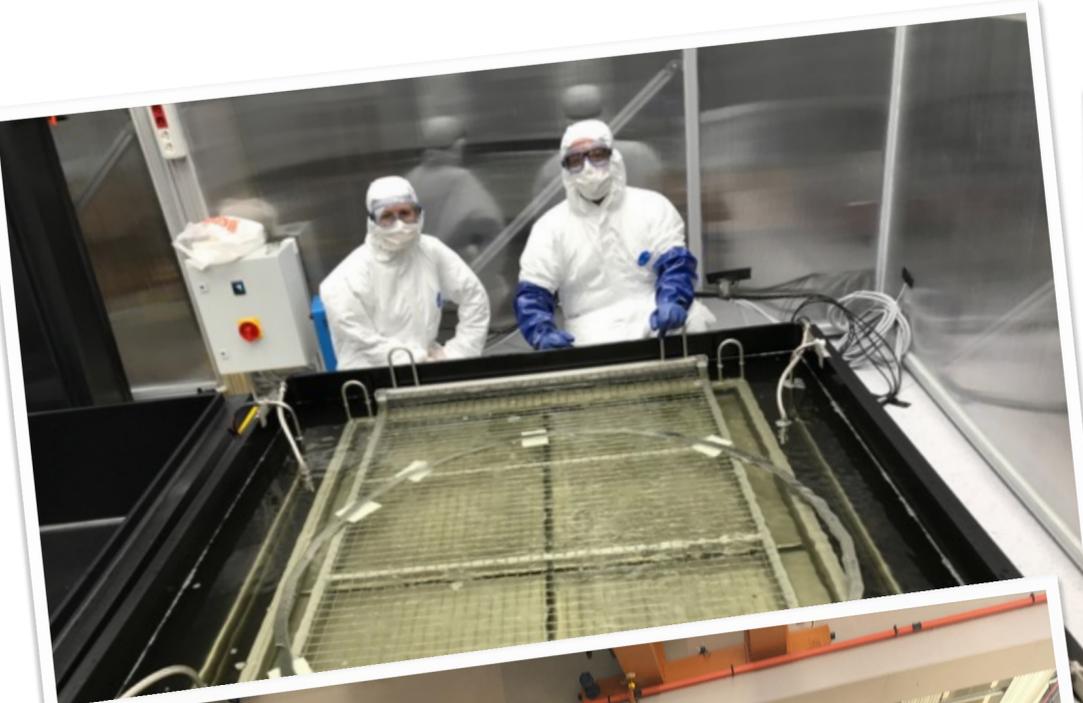


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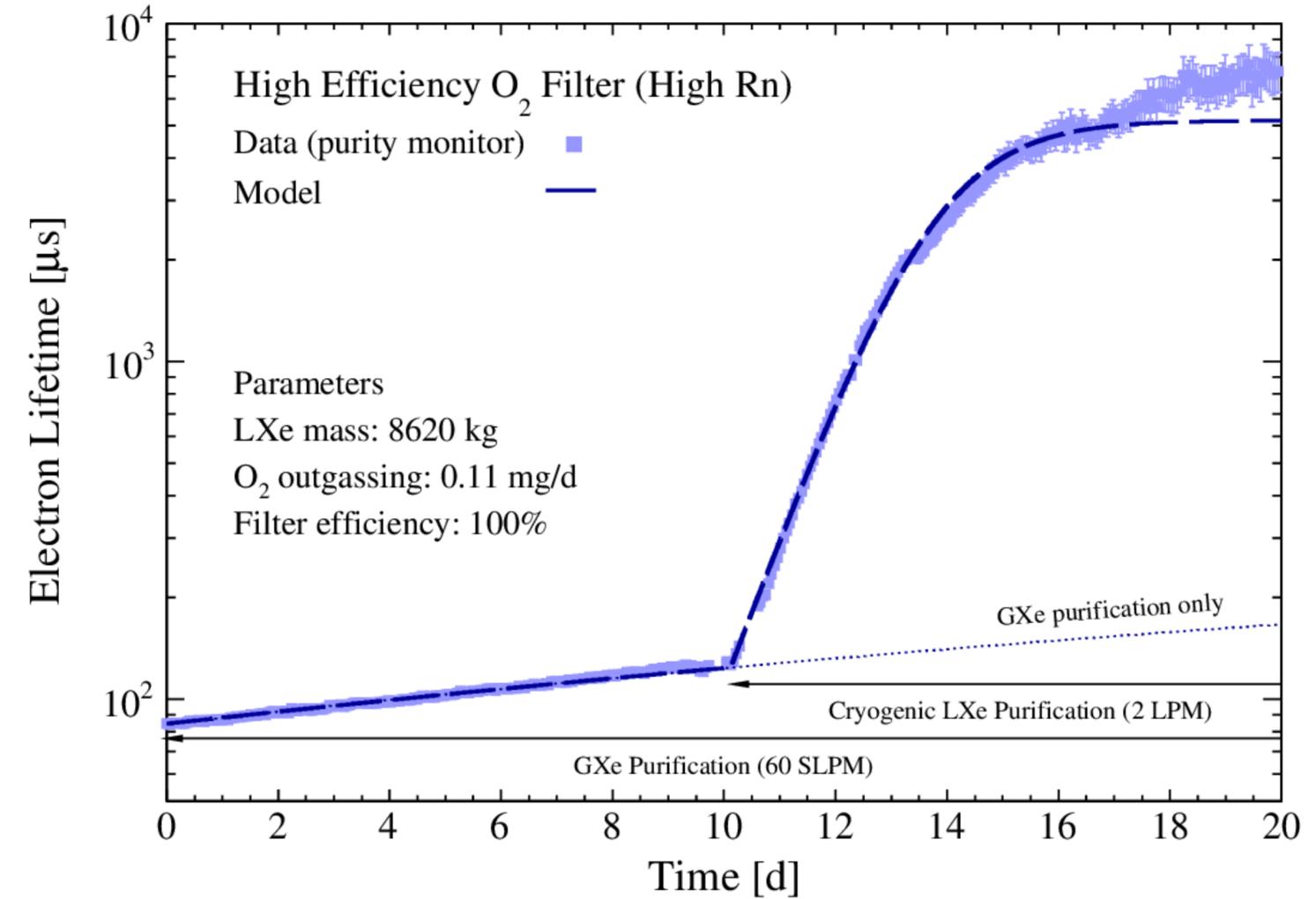
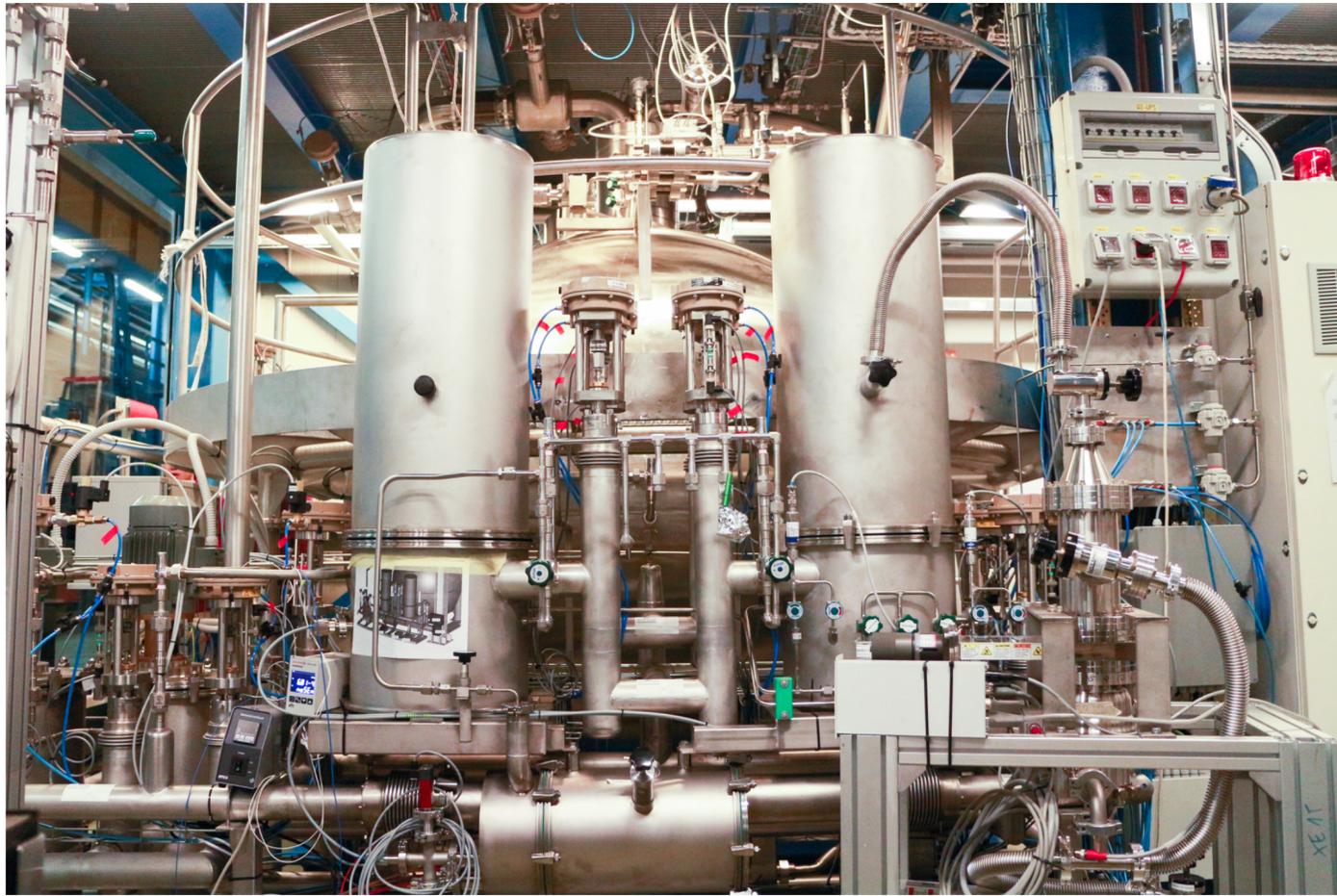
**Neutron veto**  
 Gd-loaded water  
 120 dedicated PMTs

**TPC**  
 3 times larger  
 3.2 → 8.4 t LXe  
 248 → 494 PMTs

# An outstanding dedication in COVID times

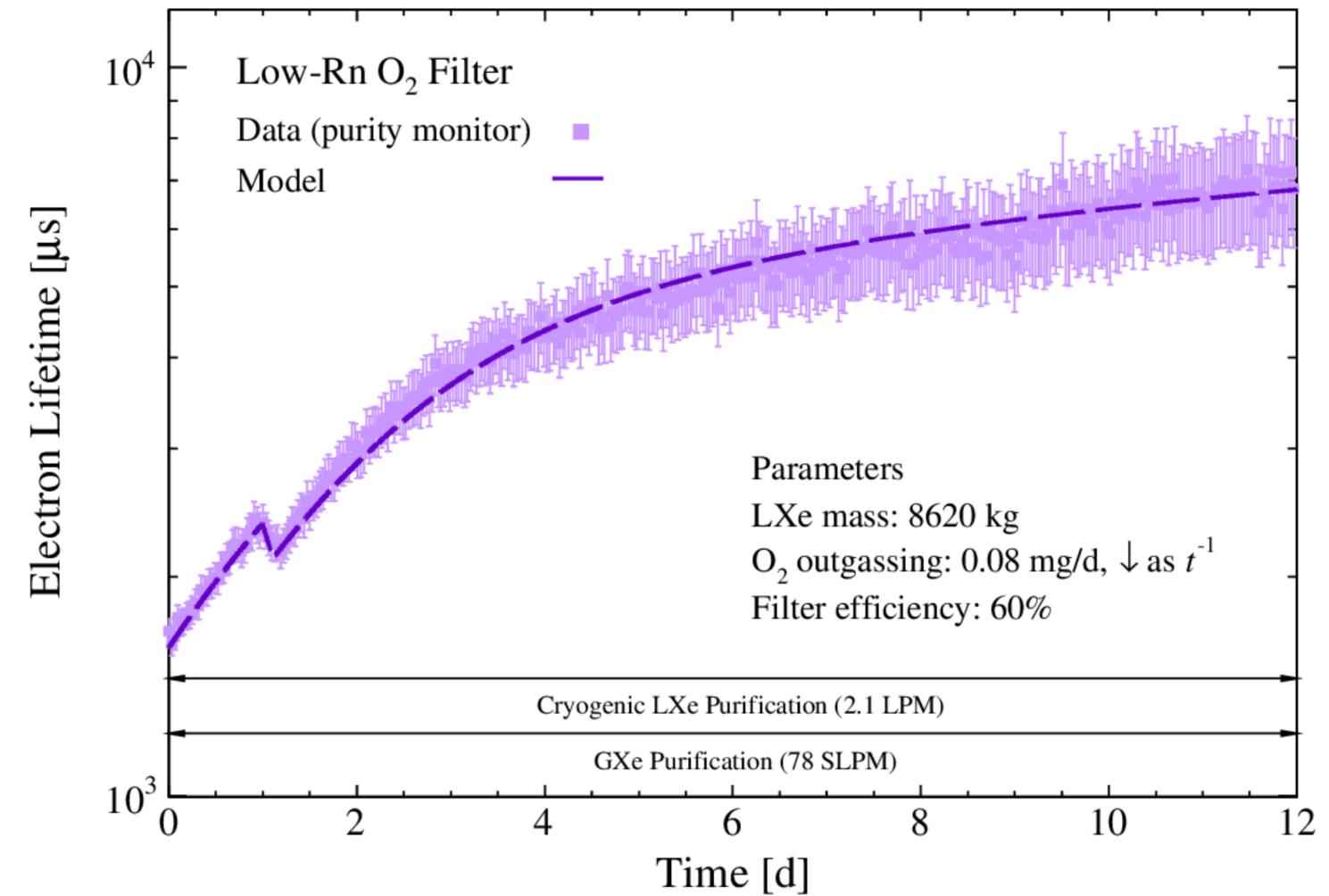
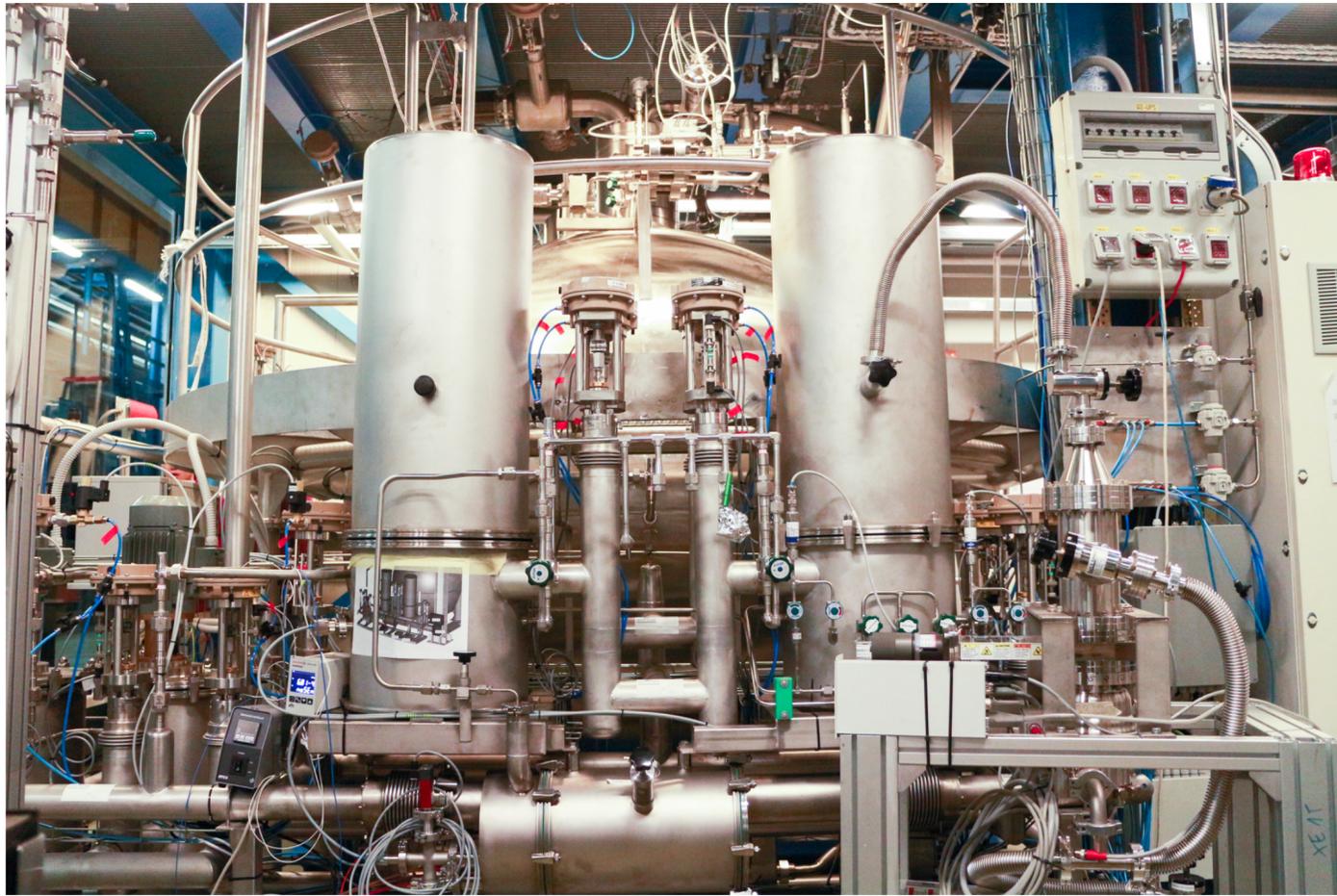


# Making the most of LXe (PURIFICATION)



- ▶ High-flux purification to **remove electronegative impurities** → 2 L/min LXe ( $\approx$  350 kg/h)
- ▶ High-efficiency O<sub>2</sub> filter → electron lifetime **from 100 μs to 5 ms within 5 days**

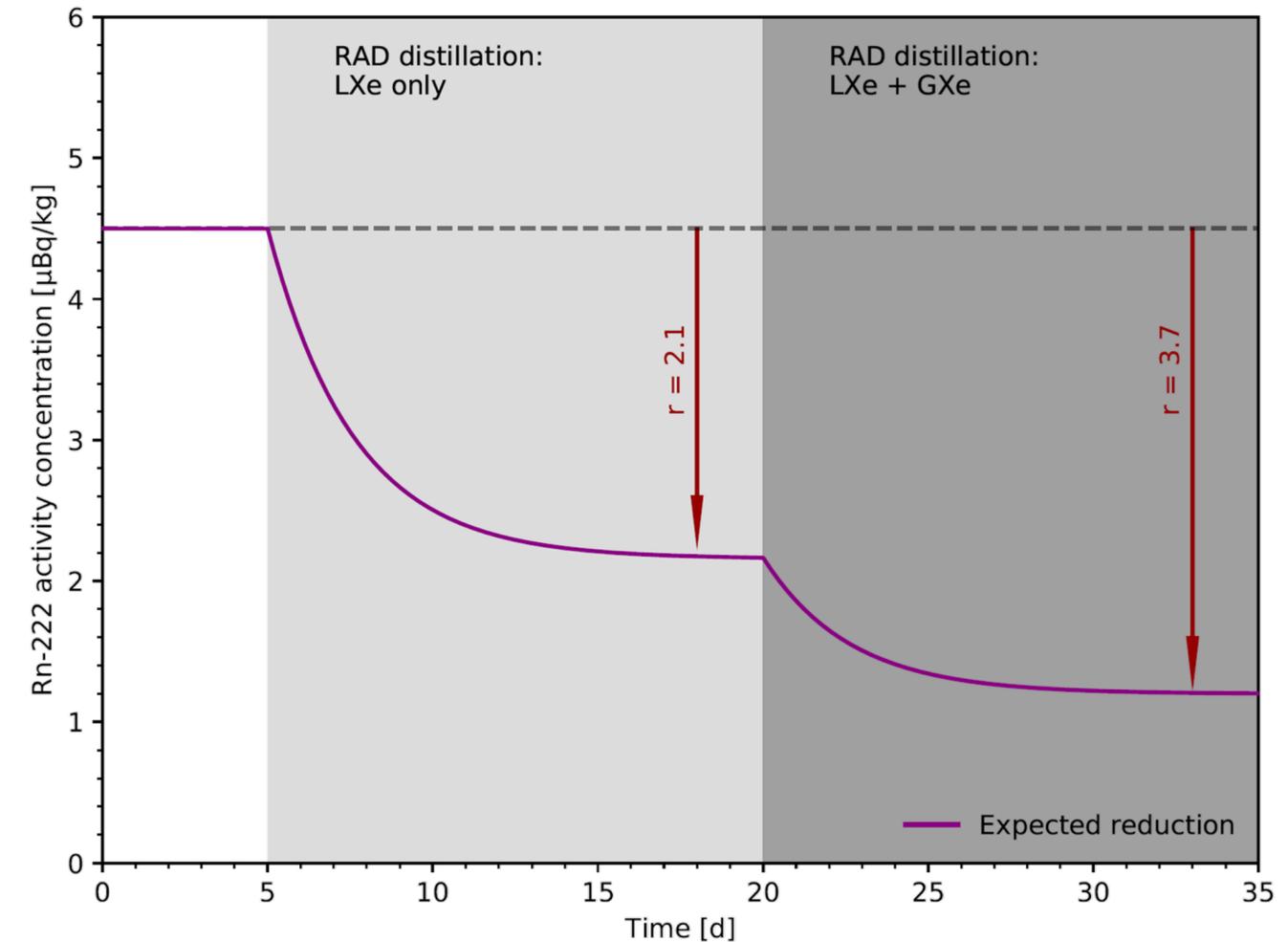
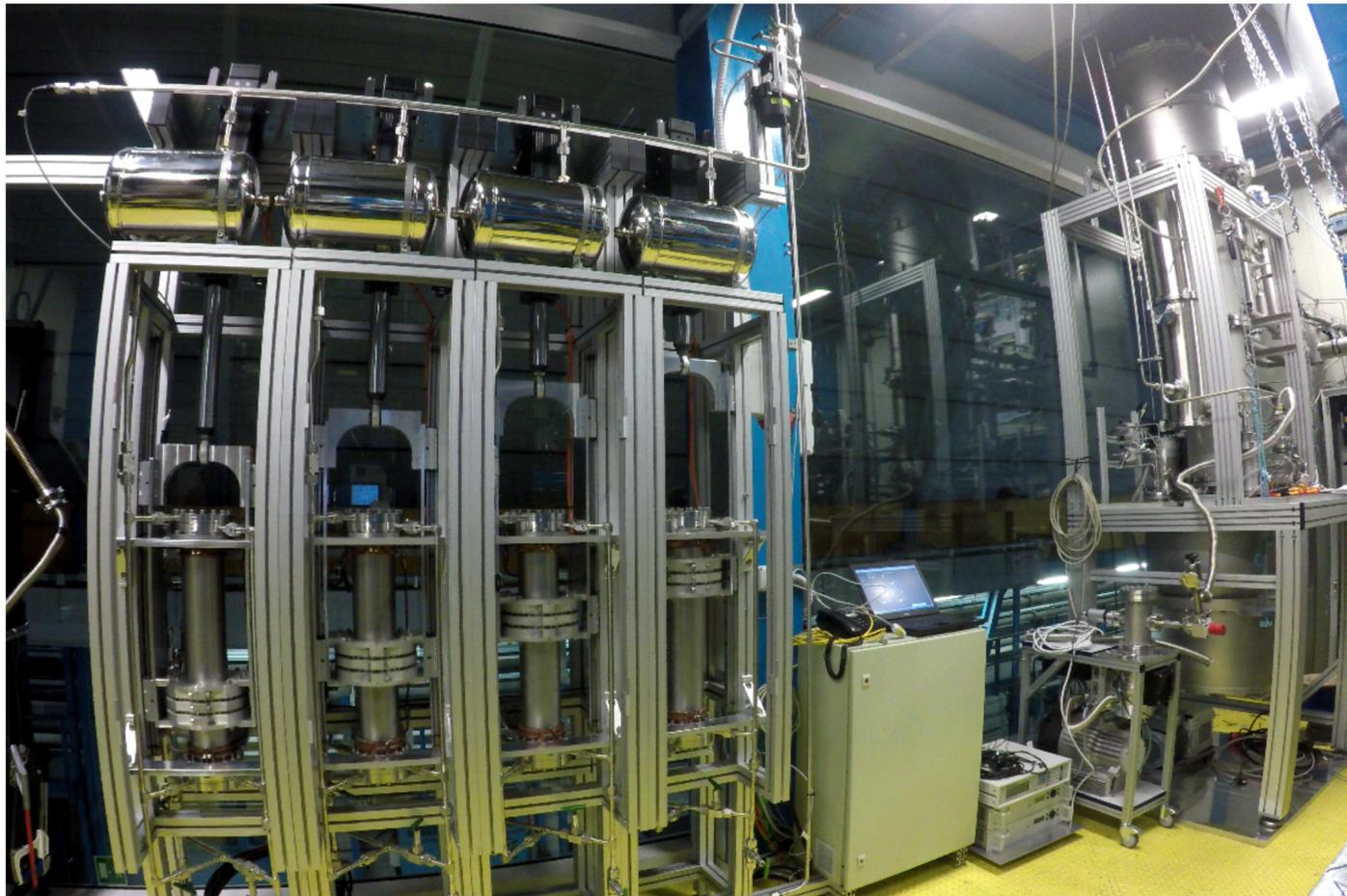
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- ▶ Low-Rn  $\text{O}_2$  filter  $\rightarrow$  electron lifetime  **$>$  7 ms in just a few days** (vs. 0.6 ms in XENON1T)

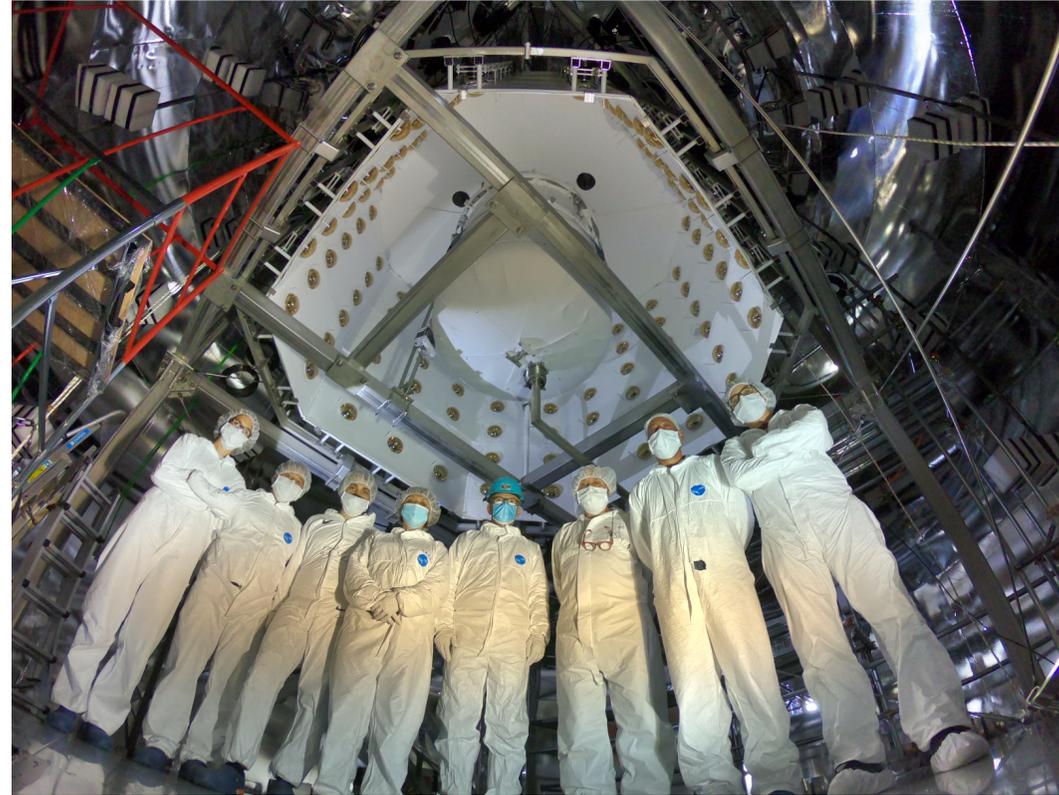
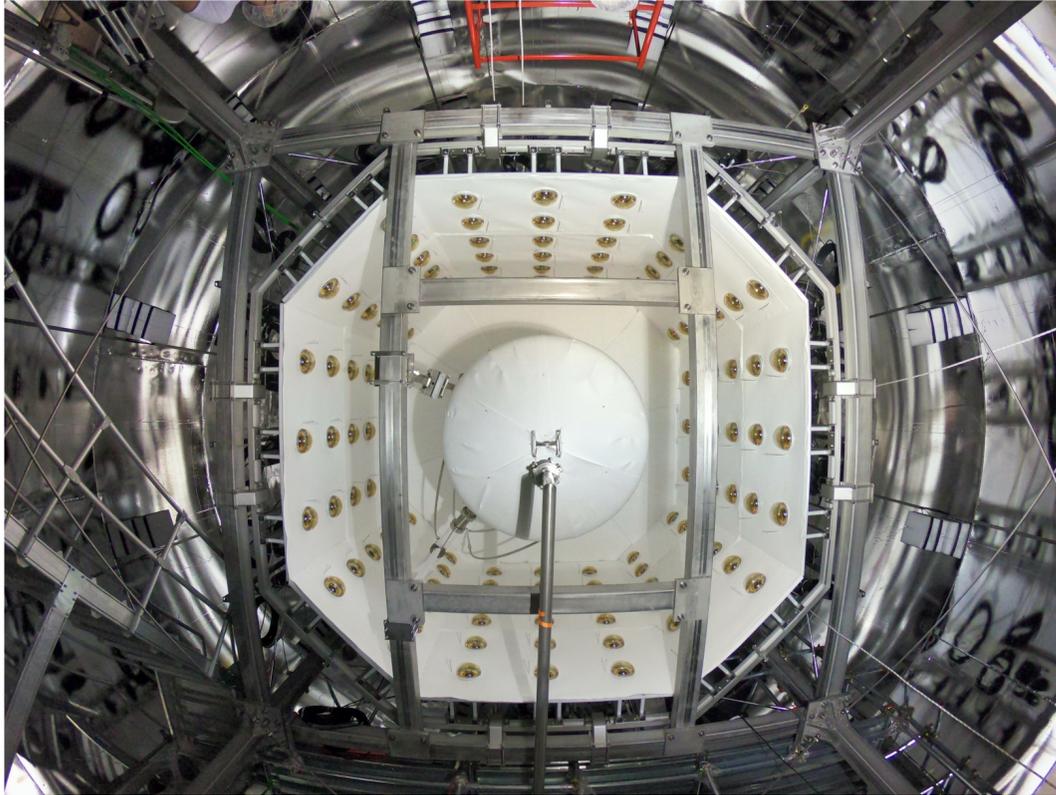
# Muting ER background (RADON REMOVAL)

EPJC 78 (2018) 604



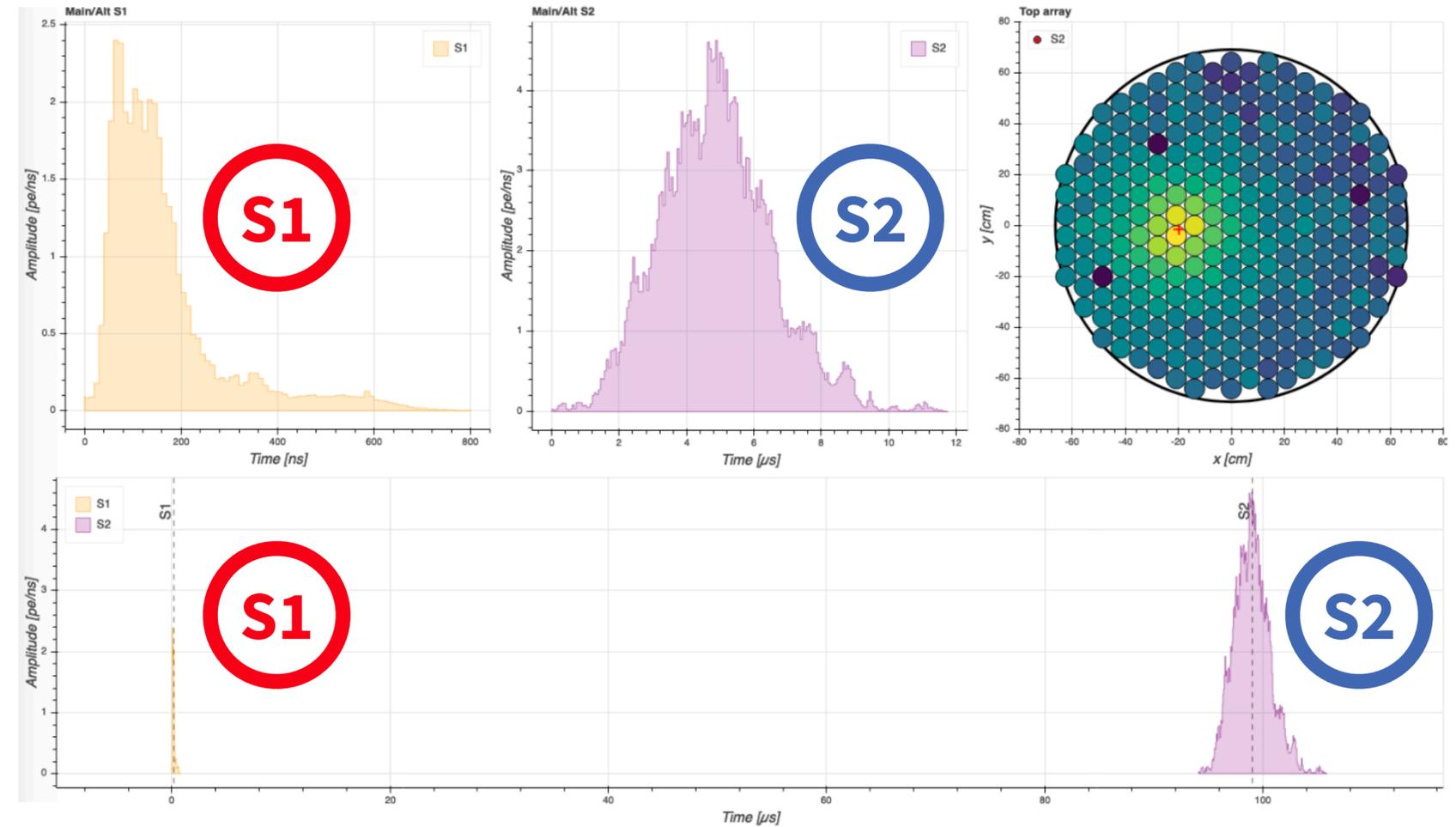
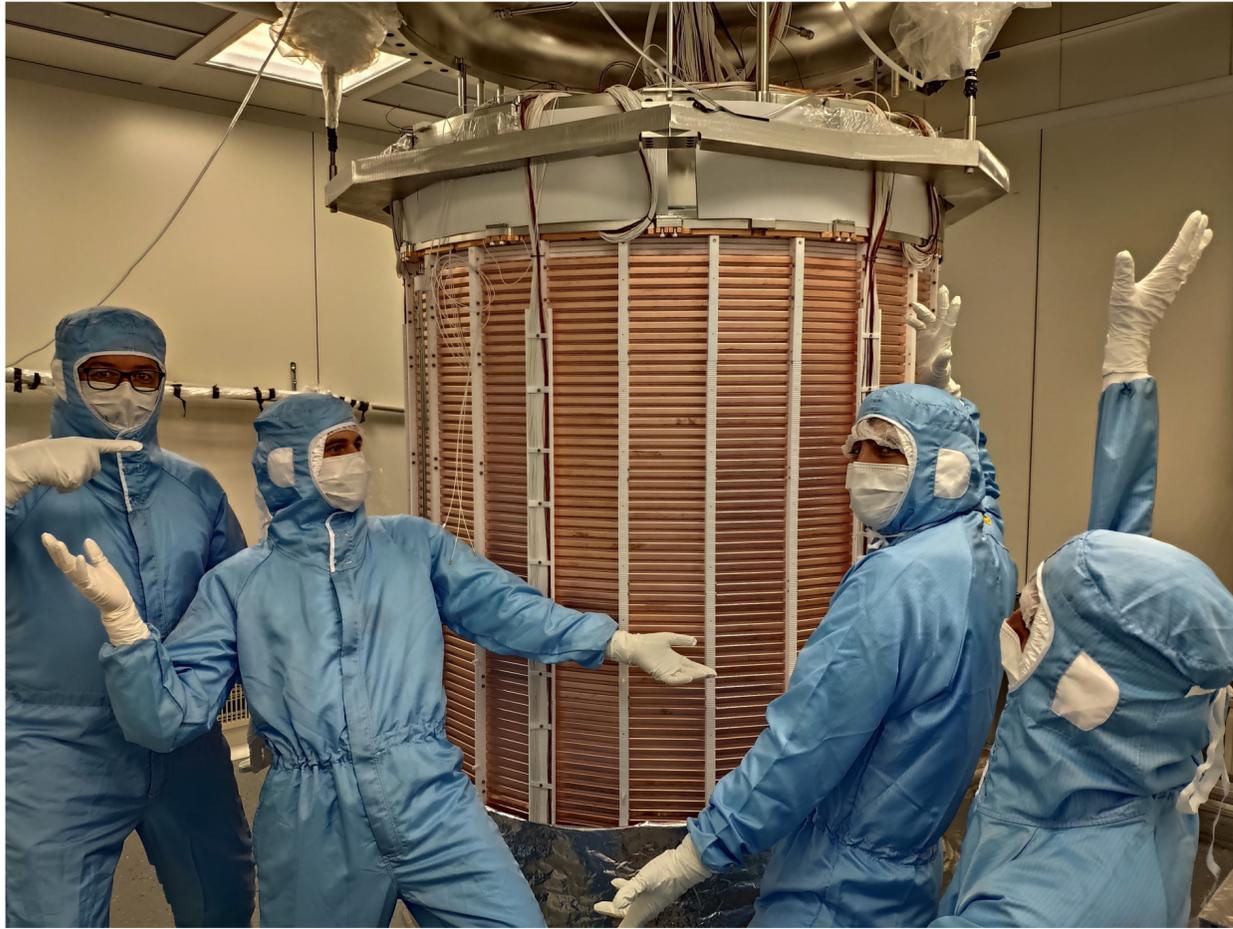
- ▶ Dedicated  **$^{222}\text{Rn}$  cryogenic distillation column**  $\rightarrow$  0.4 L/min LXe ( $\approx$  70 kg/h)
- ▶  $^{222}\text{Rn}$  reduction of **a factor 2** inside the TPC within 2 weeks
- ▶ Aiming for **a 1  $\mu\text{Bq/kg}$   $^{222}\text{Rn}$  level** (vs. 13  $\mu\text{Bq/kg}$  in XENON1T SR, 4.5  $\mu\text{Bq/kg}$  in R&D run)

# Taking a fresh look at neutrons (nVETO)



- ▶ Active neutron veto filled with **Gadolinium-doped water** surrounding the TPC
- ▶ 120 PMTs + high-reflectivity walls → **Čerenkov detector** seeking neutron captures
- ▶ 87% neutron tagging efficiency expected

# Better focusing on interactions (NEW TPC)

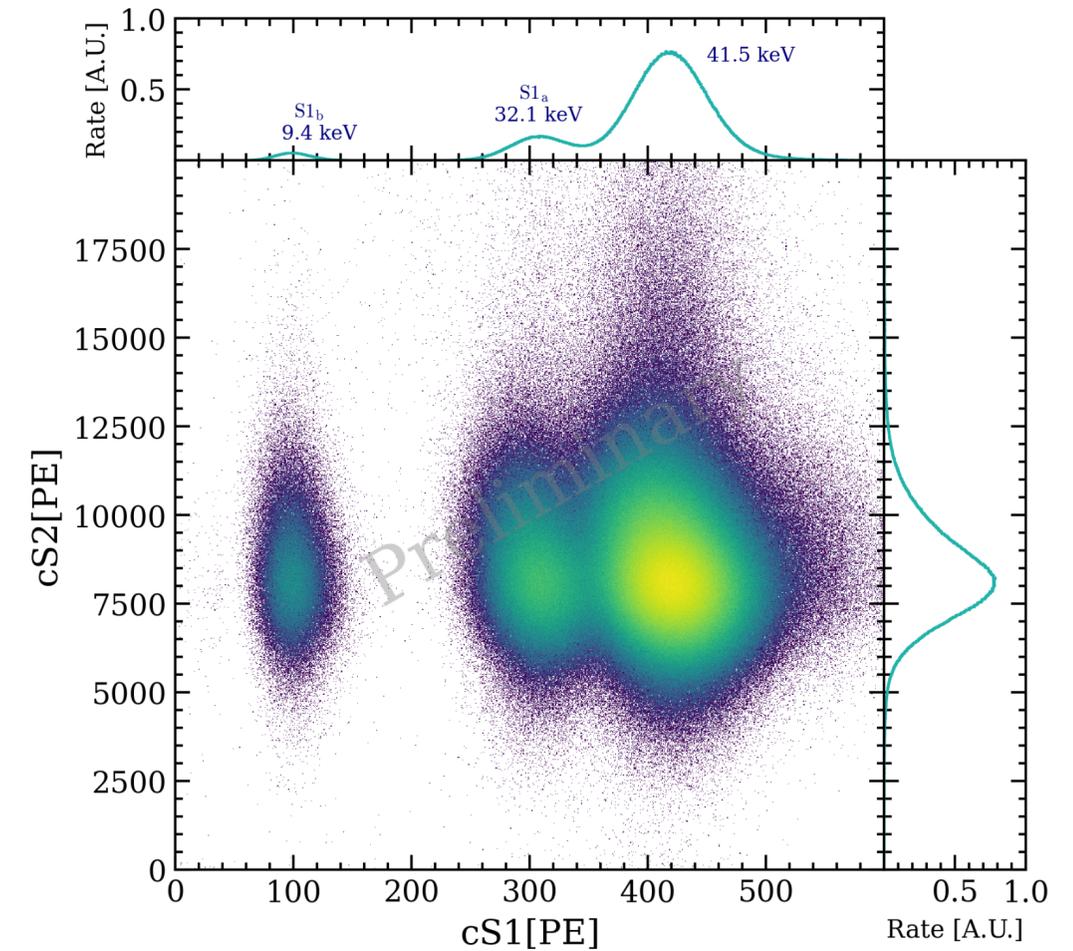


- ▶ 1.5 m tall, 1.3 m diameter → **3 times larger** than XENON1T TPC
- ▶ 3.2 t → 8.4 t LXe in the full system / **2 t → 5.9 t LXe target mass** inside the TPC
- ▶ 494 PMTs → **twice as much** as in XENON1T TPC (248 PMTs)

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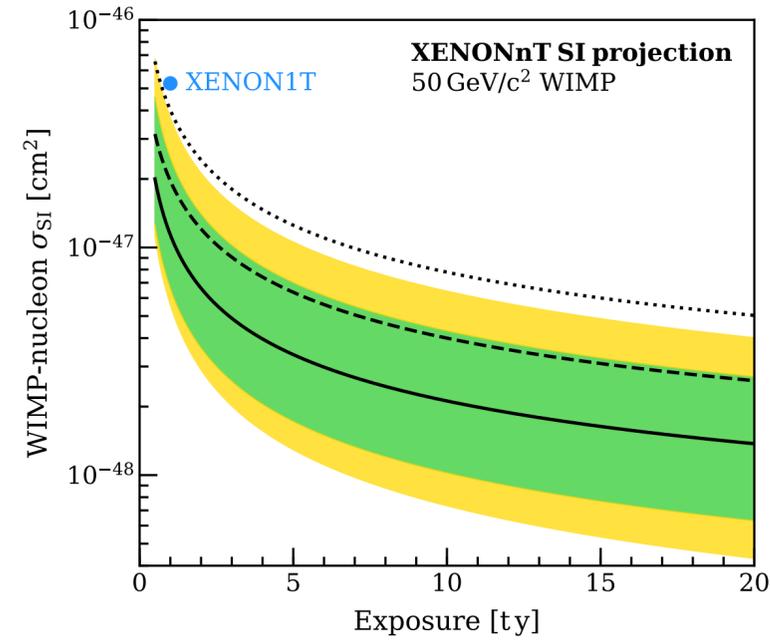
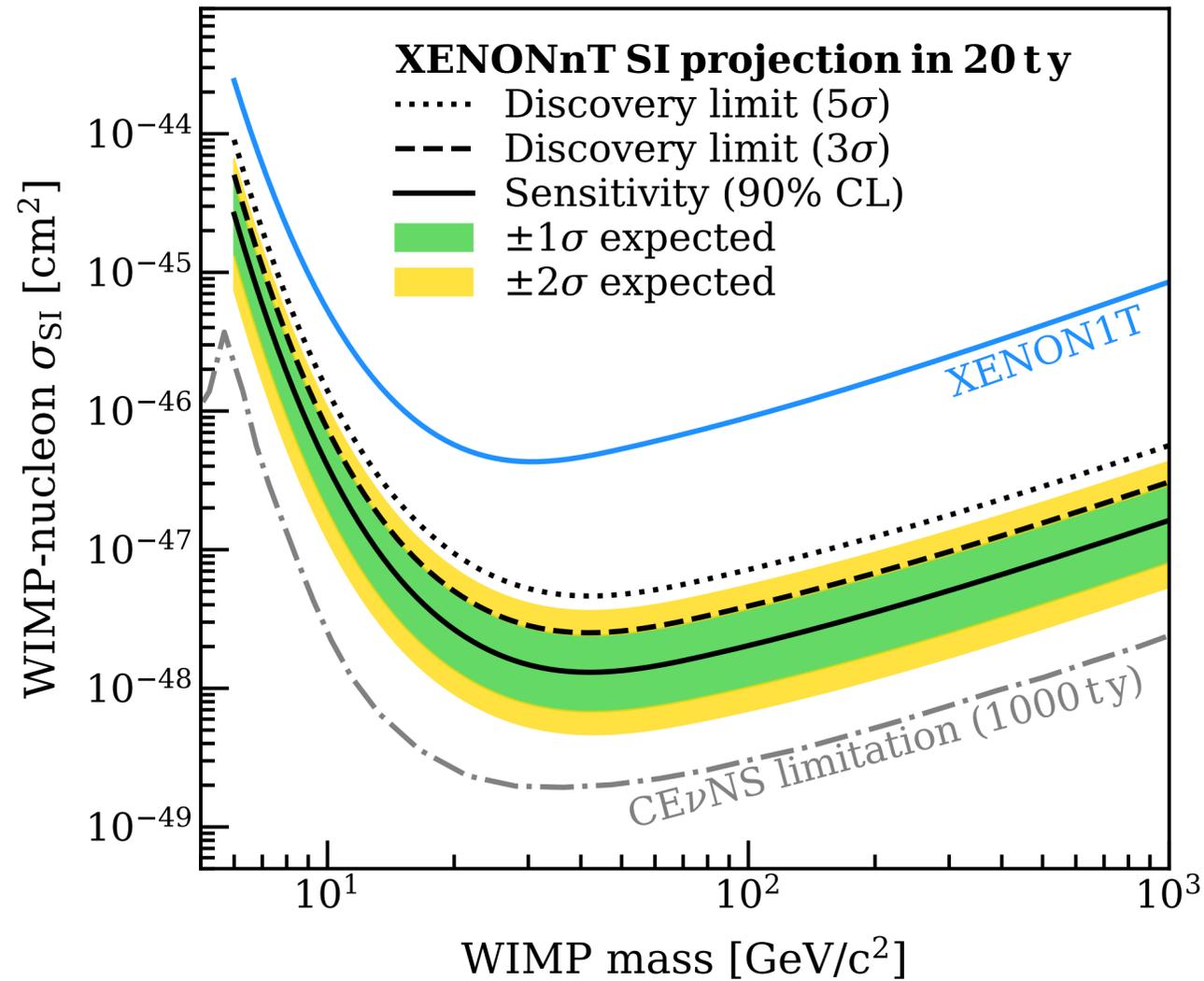


Successful  
low-energy  
reconstruction with  
 $^{83\text{m}}\text{Kr}$  calibration



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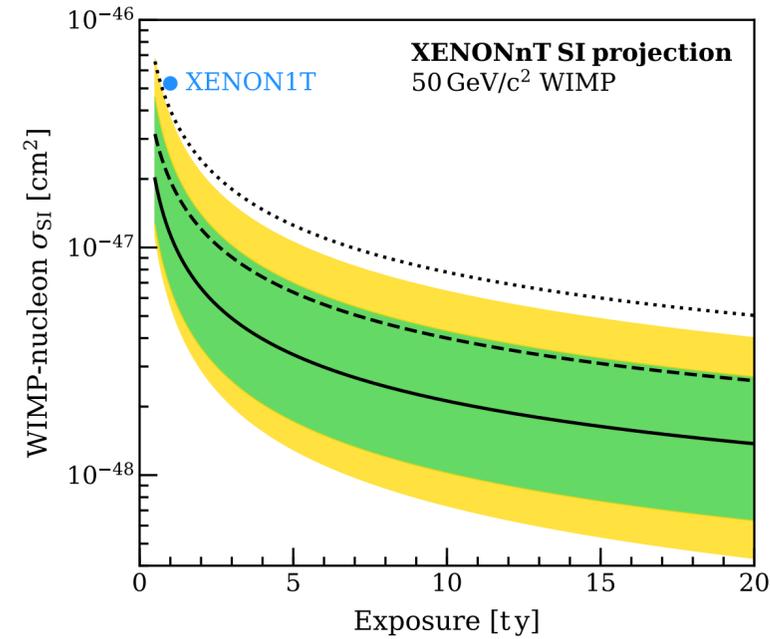
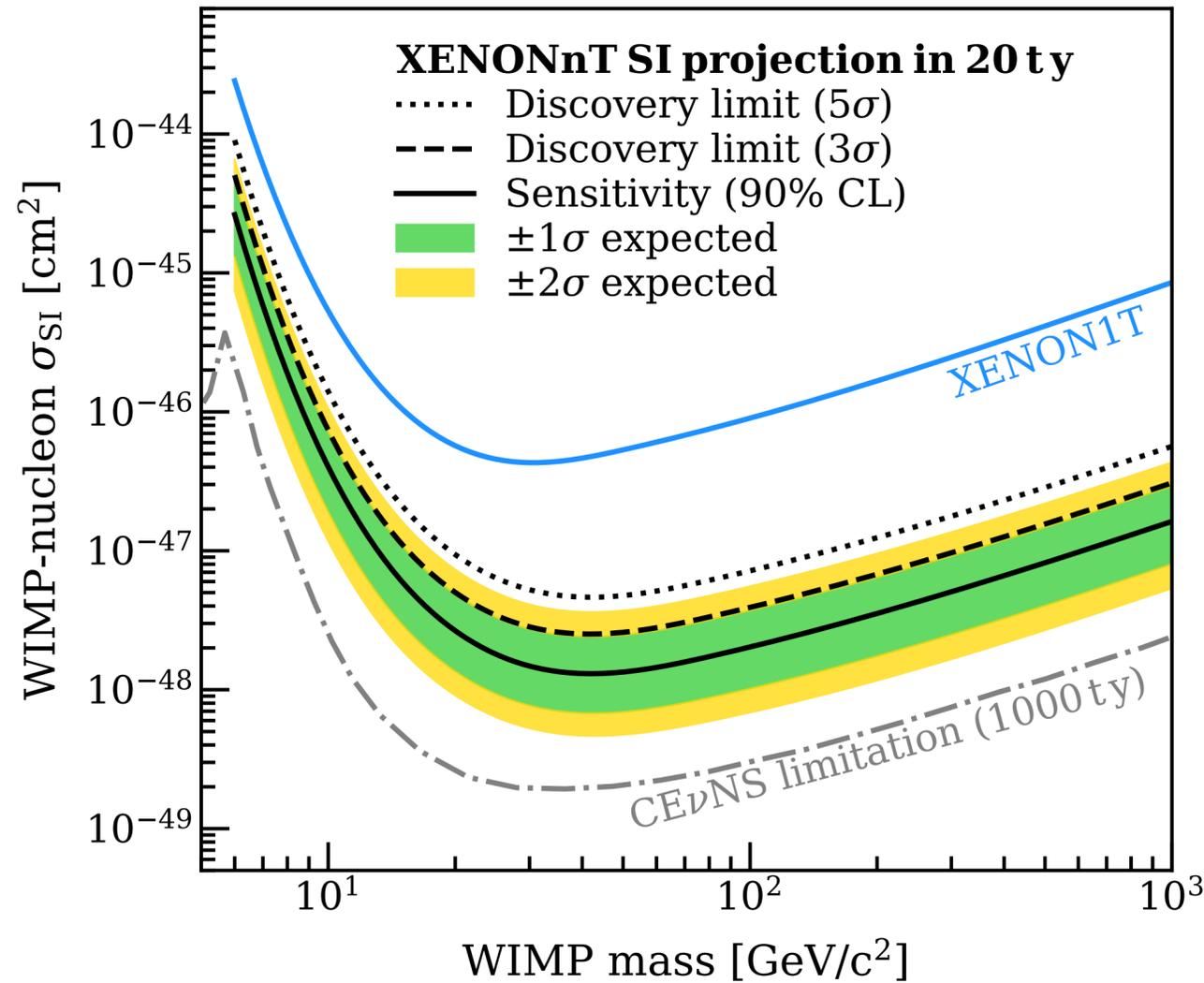
# XENONnT physics reach



Expected WIMP-nucleon cross section  
(20 t  $\times$  yr exposure goal)

$$\sigma_{SI} \sim 1.4 \times 10^{-48} \text{ cm}^2 \text{ at } 50 \text{ GeV}/c^2$$

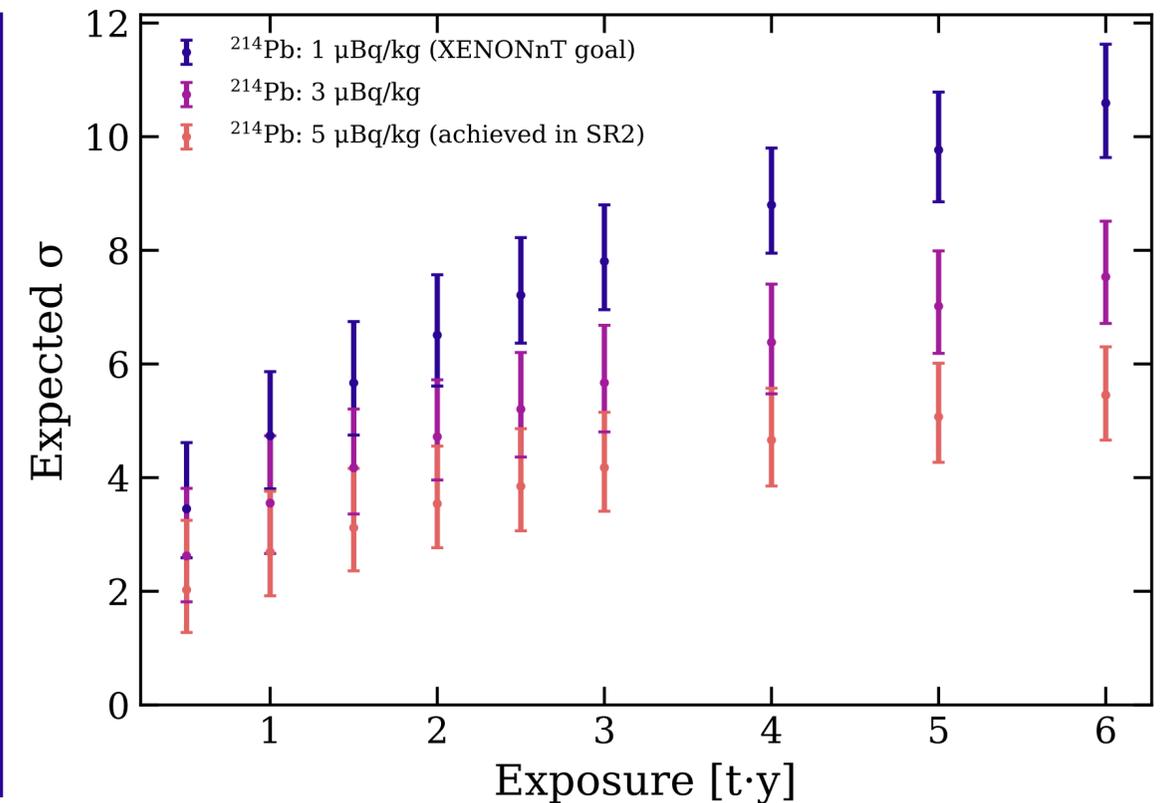
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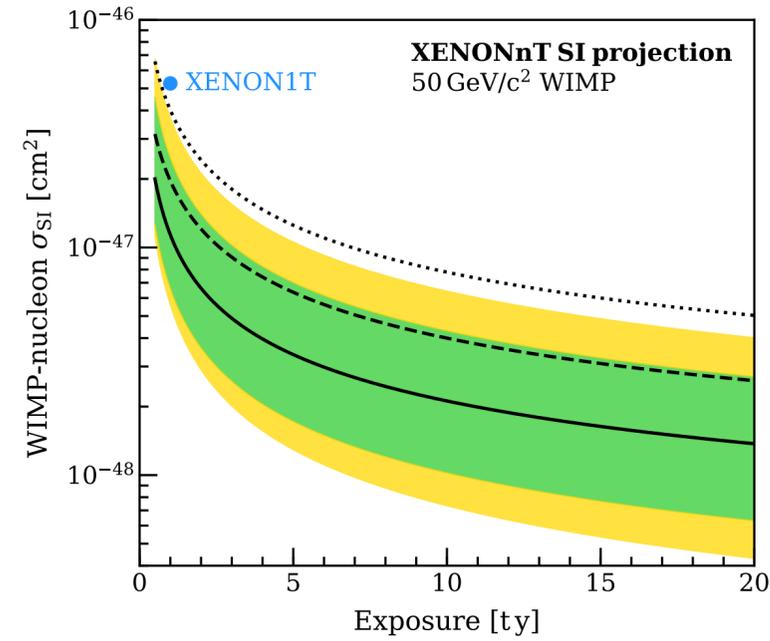
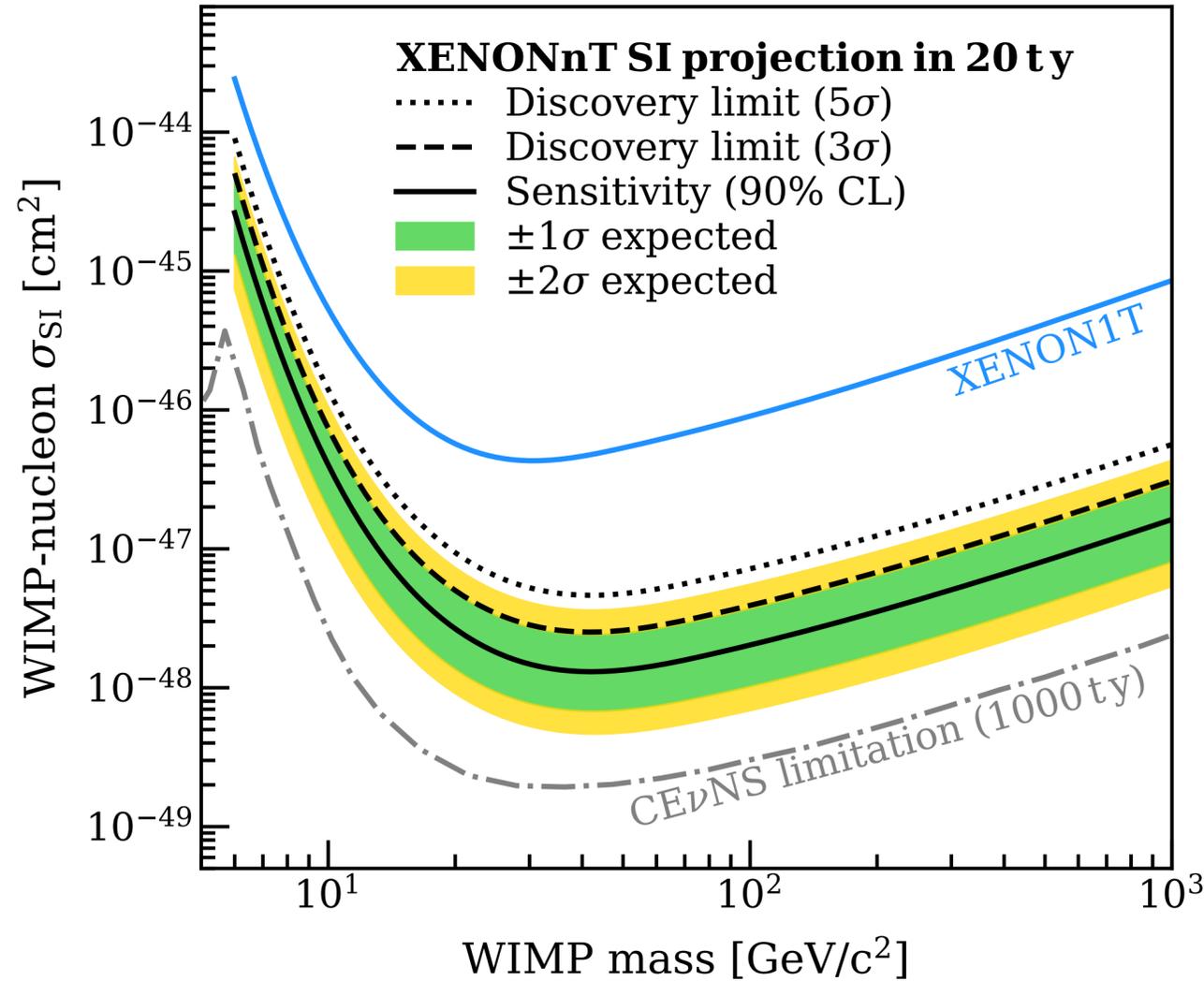
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Low-energy  
ER excess  
axion-tritium  
discrimination  
**A few  
months**



# XENONnT physics reach



**$0\nu\beta\beta$**     Supernova neutrinos  
 **$0\nu\text{DEC}$**

And so much more!

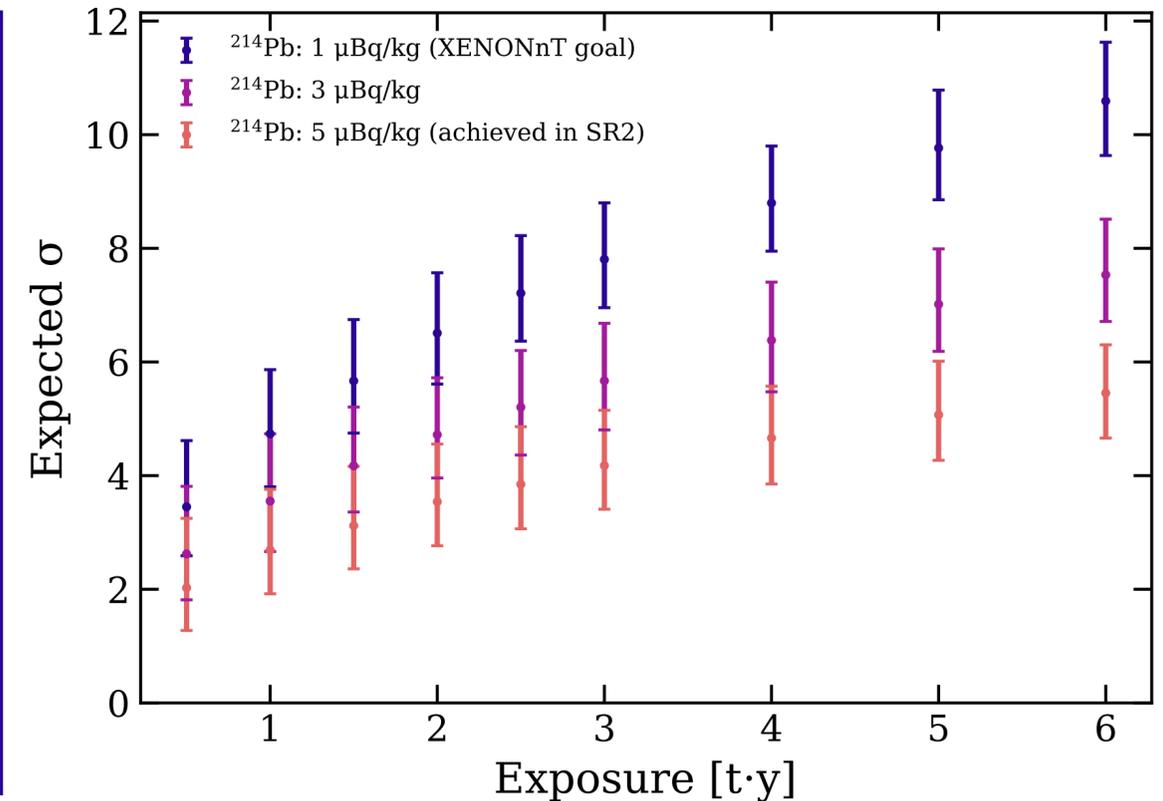
Solar  $^8\text{B}$     Dark Matter  
 CE $\nu$ NS    models

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Low-energy  
 ER excess  
 axion-tritium  
 discrimination

**A few  
 months**



# XENONnT physics reach

JCAP 11 (2020) 031



**@XENONexperiment**

# Merci pour votre attention!

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IJCLab — Orsay, France

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🐦 [@DrErwannMasson](https://twitter.com/DrErwannMasson)

  
Irène Joliot-Curie  
Laboratoire de Physique  
des 2 Infinis

  
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