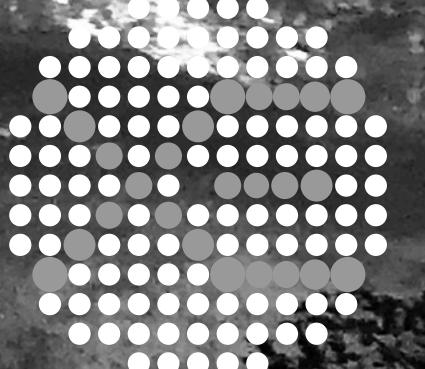


# Investing the Neutrino Sector: The XENON First Steps

Dr. Erwann Masson

LPNHE – Paris, France

IRN Terascale – 23 November 2021



XENON

# On Dark Matter & Liquid Xenon

# 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,  $\chi$ )**

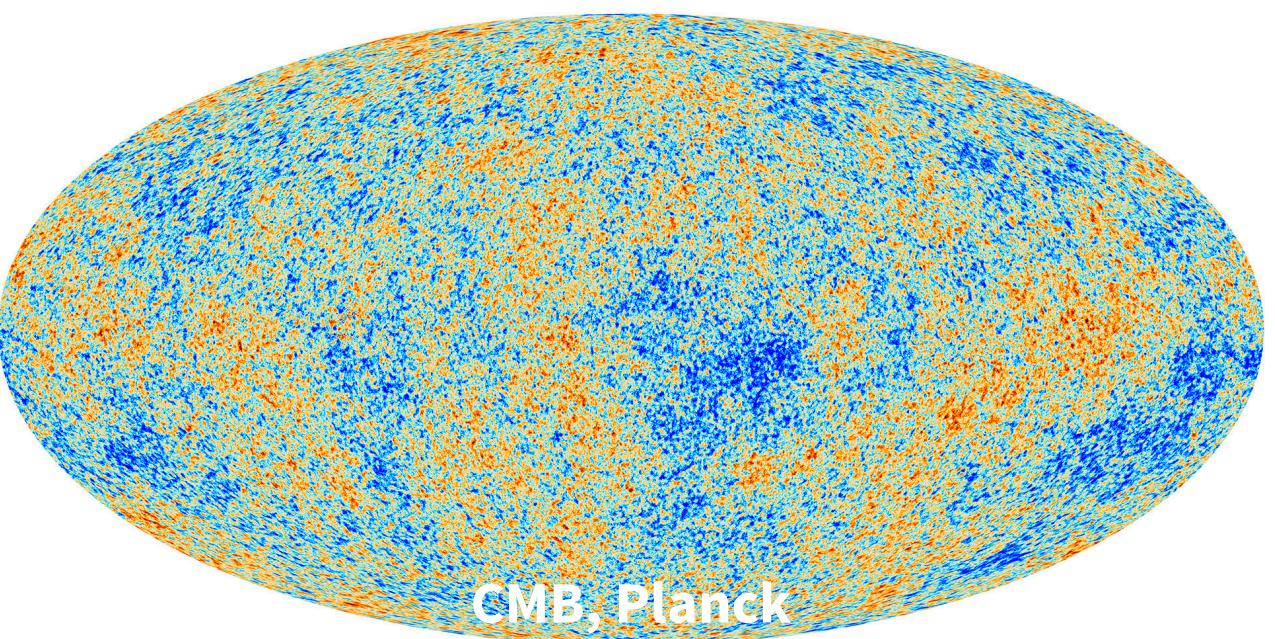
20-60 kpc



2-10 Mpc

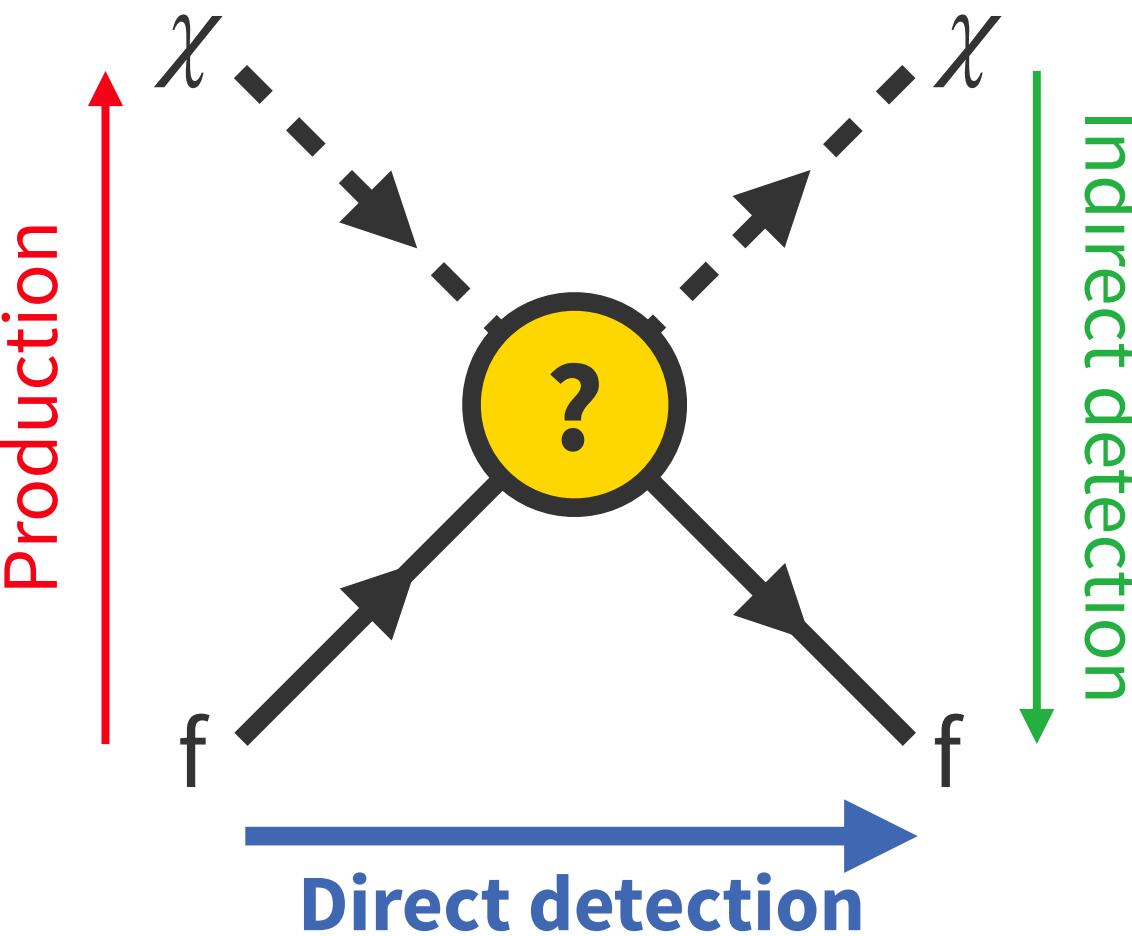
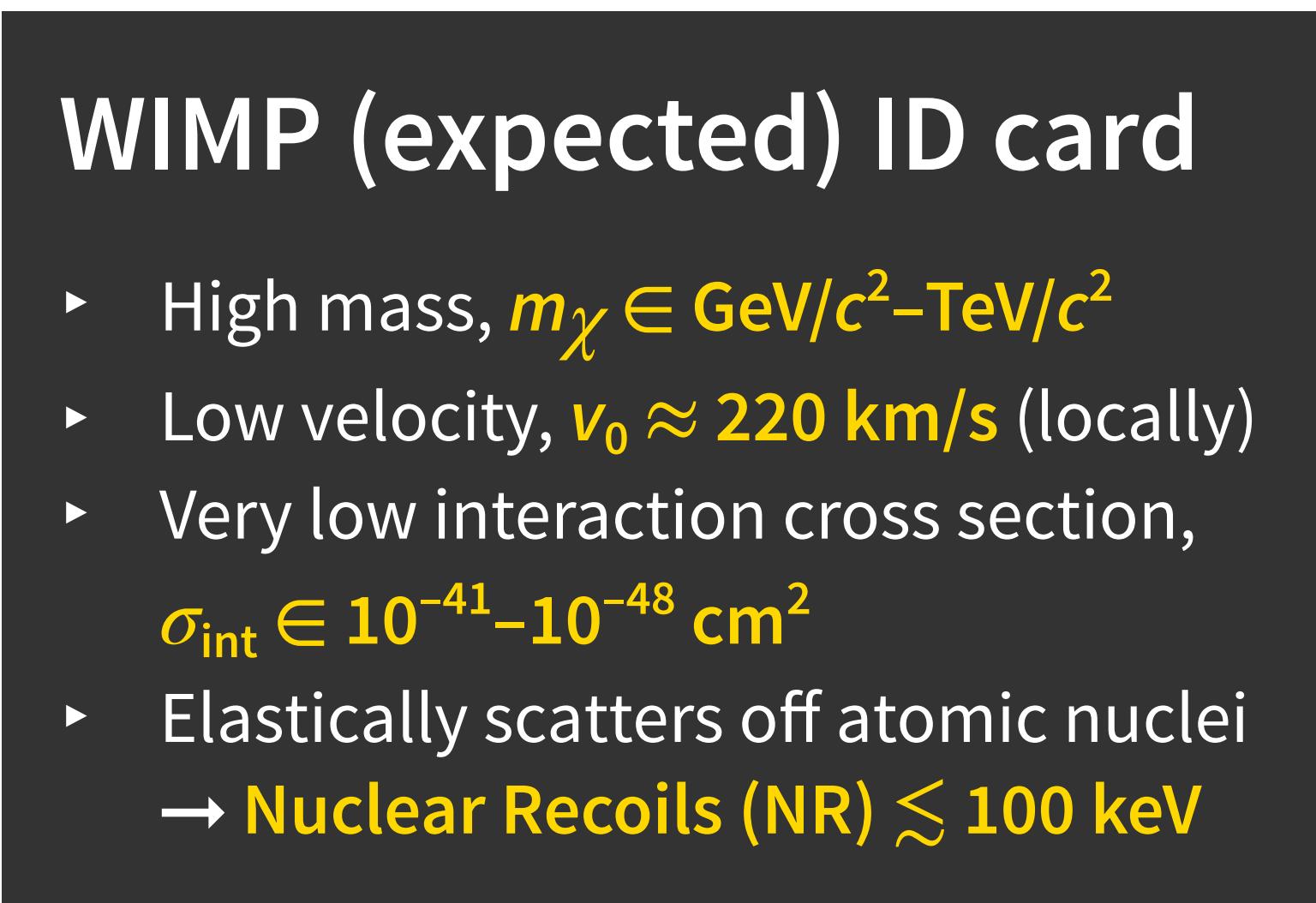


4 Gpc

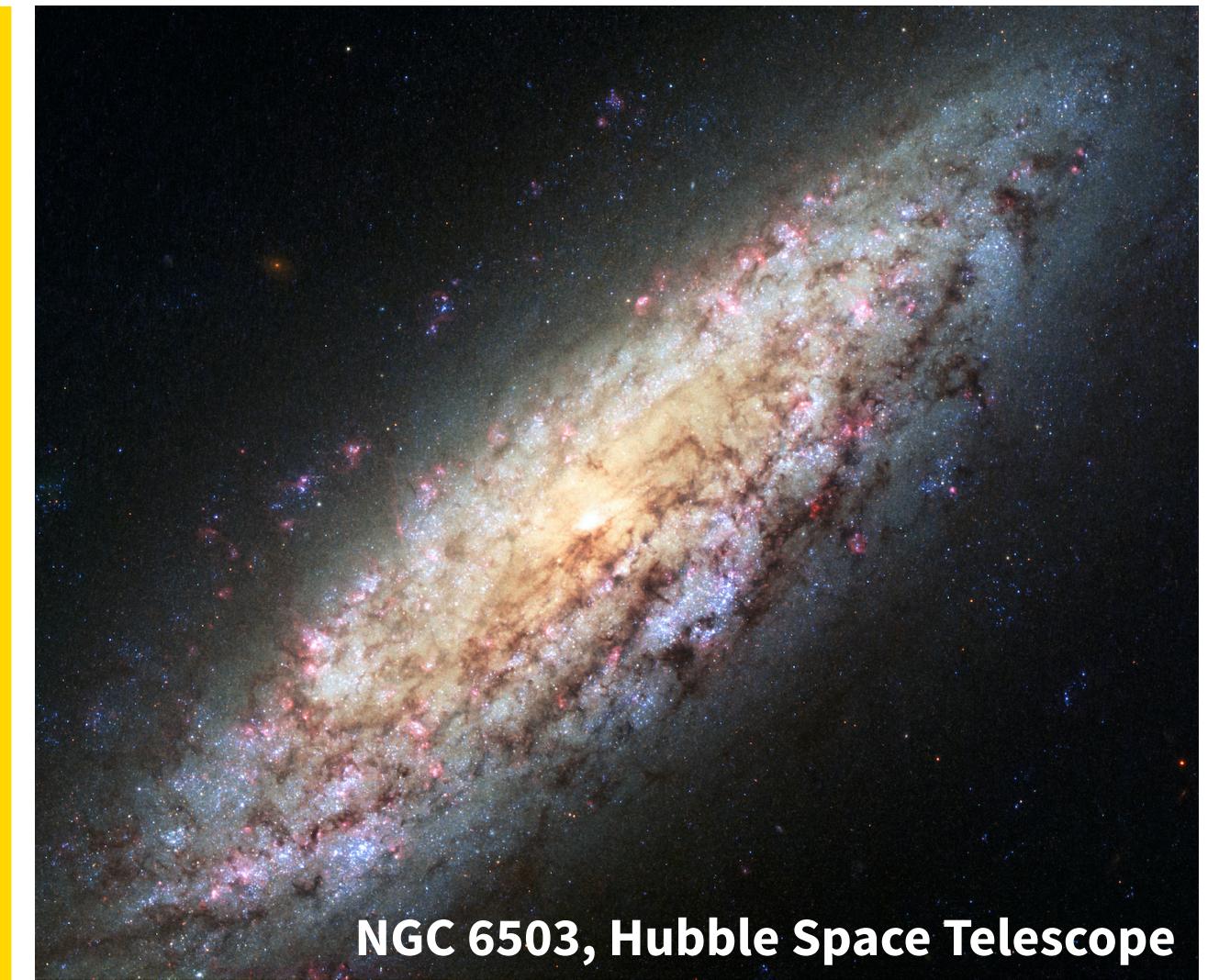


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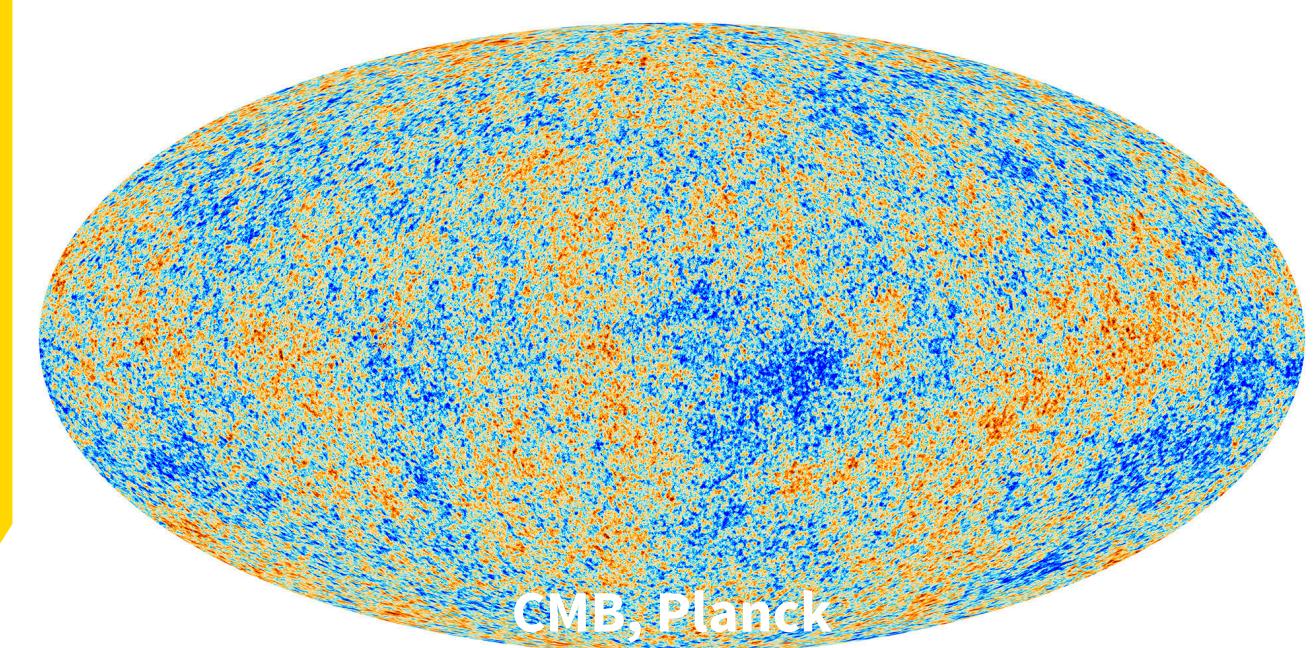
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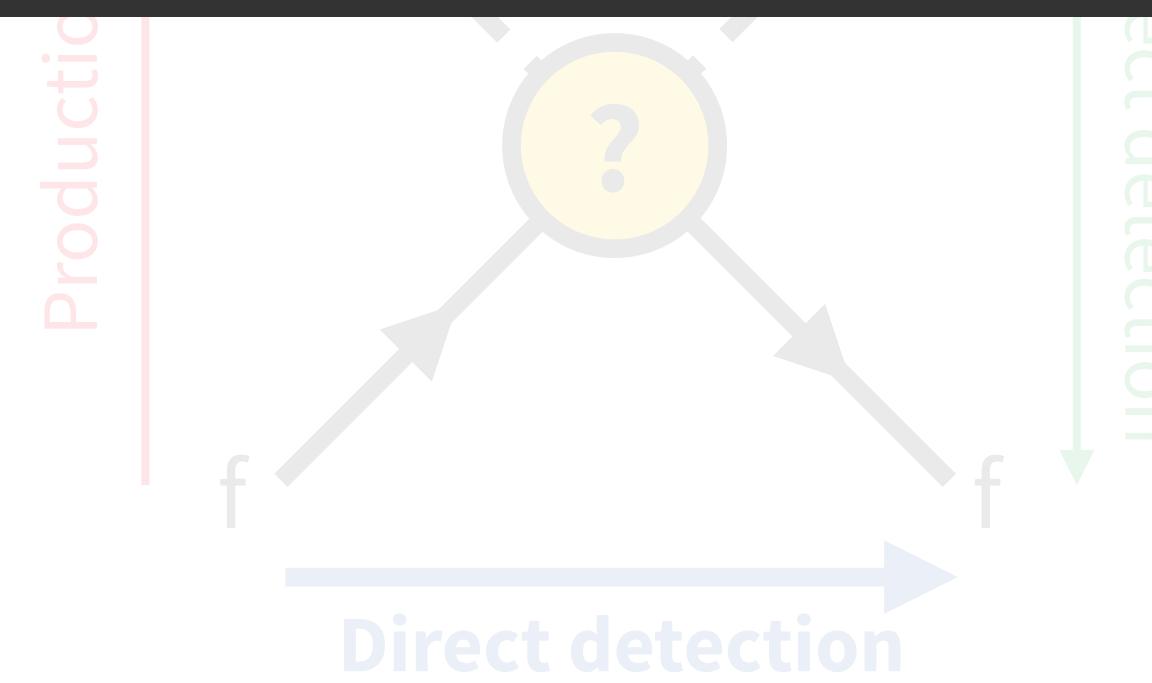
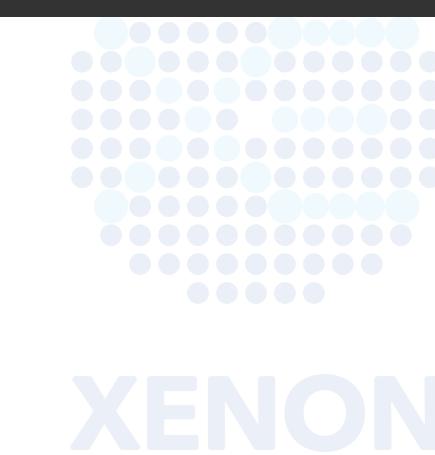
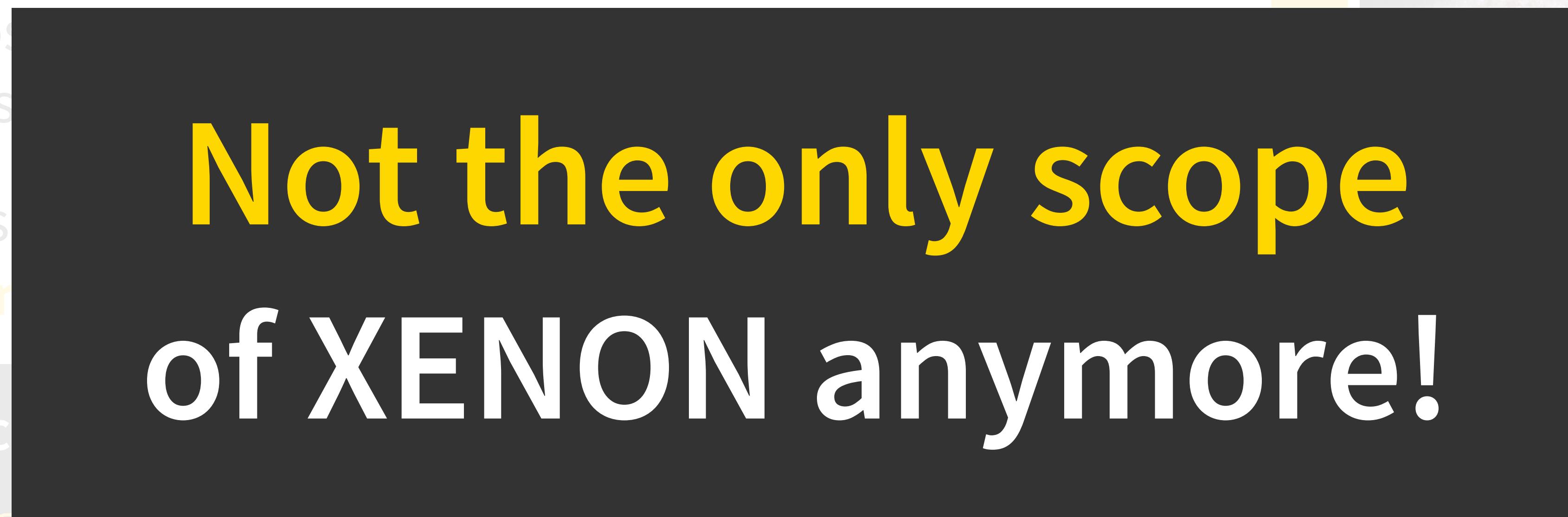
# Dark Matter in a nutshell

- A **non-luminous matter** is needed to explain what is observed in the Universe **at all scales**

- Standard cosmology  
non-relativistic
- Most promising  
→ **Weakly Interacting**

WIMP (expected)

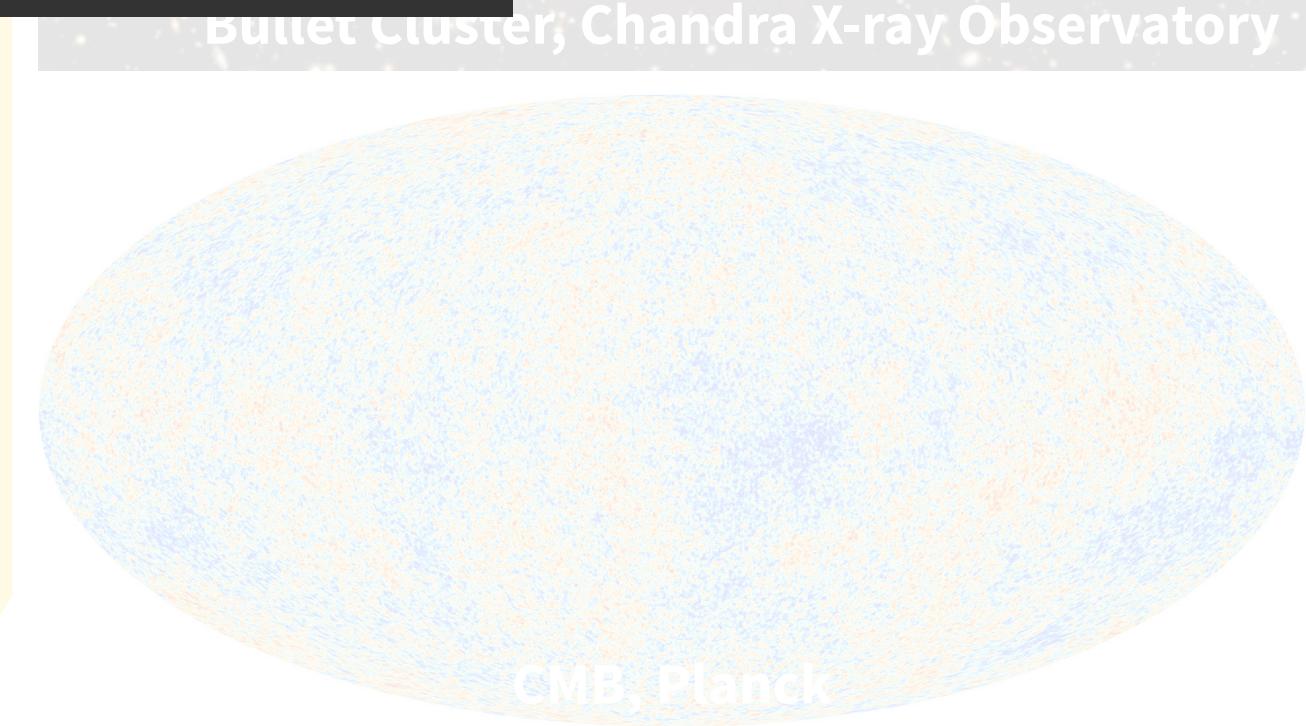
- High mass,  $m_\chi \in 10^6 \text{ eV/c} - 10^{12} \text{ eV/c}$
- Low velocity,  $v_0 \approx 220 \text{ km/s}$  (locally)
- Very low interaction cross section,  
 $\sigma_{\text{int}} \in 10^{-41} - 10^{-48} \text{ cm}^2$
- Elastically scatters off atomic nuclei  
→ **Nuclear Recoils (NR)  $\lesssim 100 \text{ keV}$**



20-60 kpc

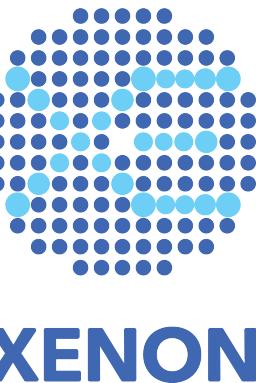
4 Gpc

6503, Hubble Space Telescope



# The XENON Collaboration

180+ scientists  
27 institutes / 11 countries



Columbia



KIT



Nikhef



Muenster



Stockholm



Mainz



Freiburg



Zurich



Chicago



UCSD



Rice



Purdue



Subatech



Coimbra



LPNHE



Torino



Bologna



L'Aquila



LNGS



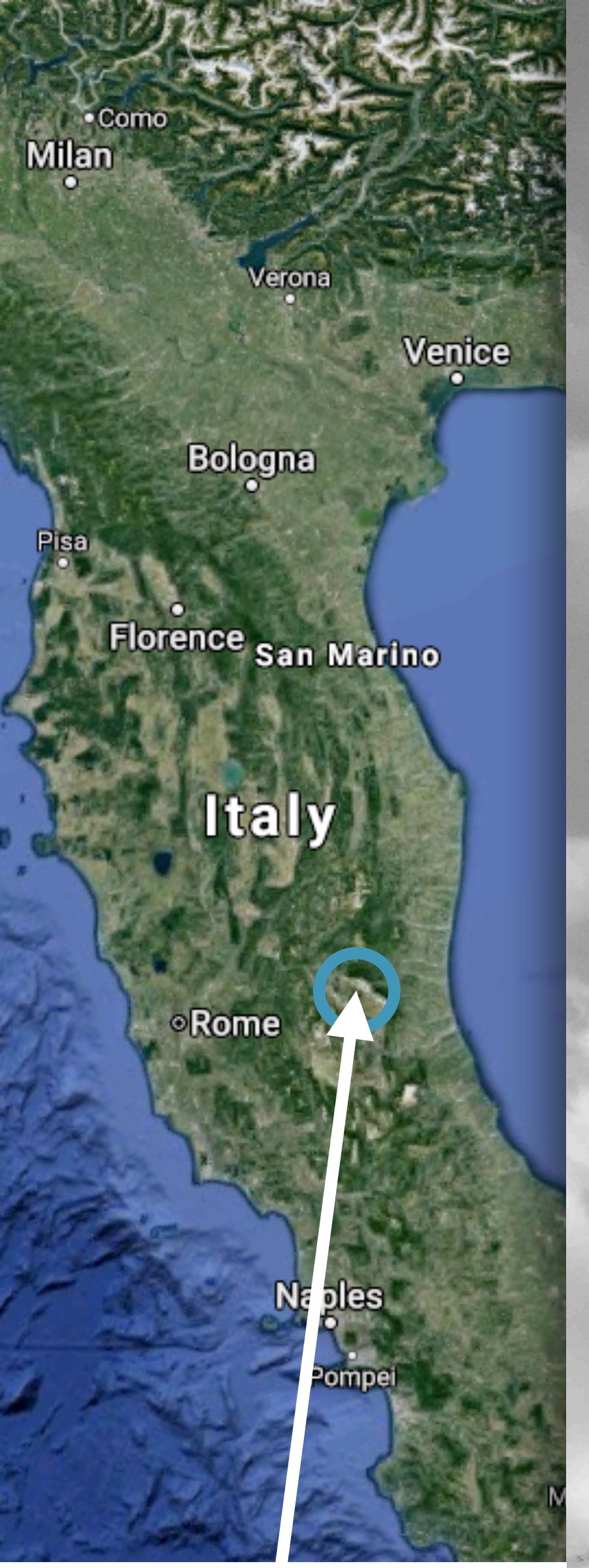
Napoli

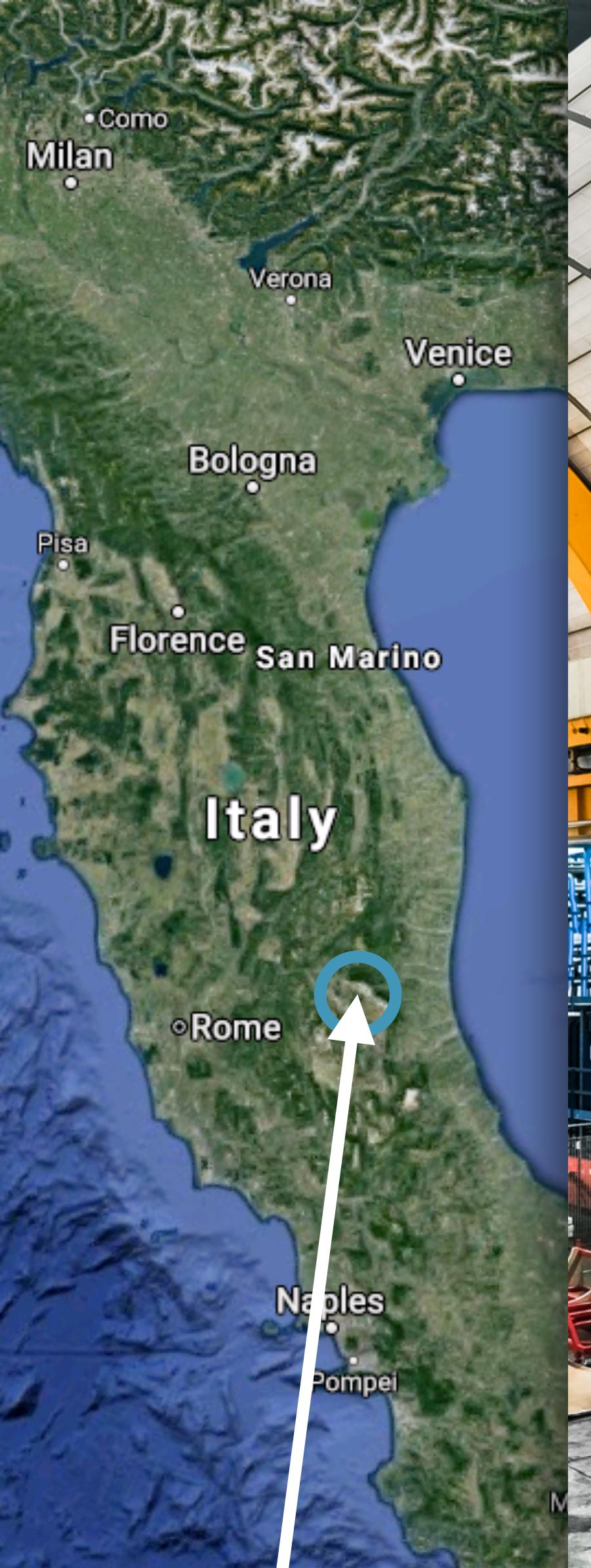


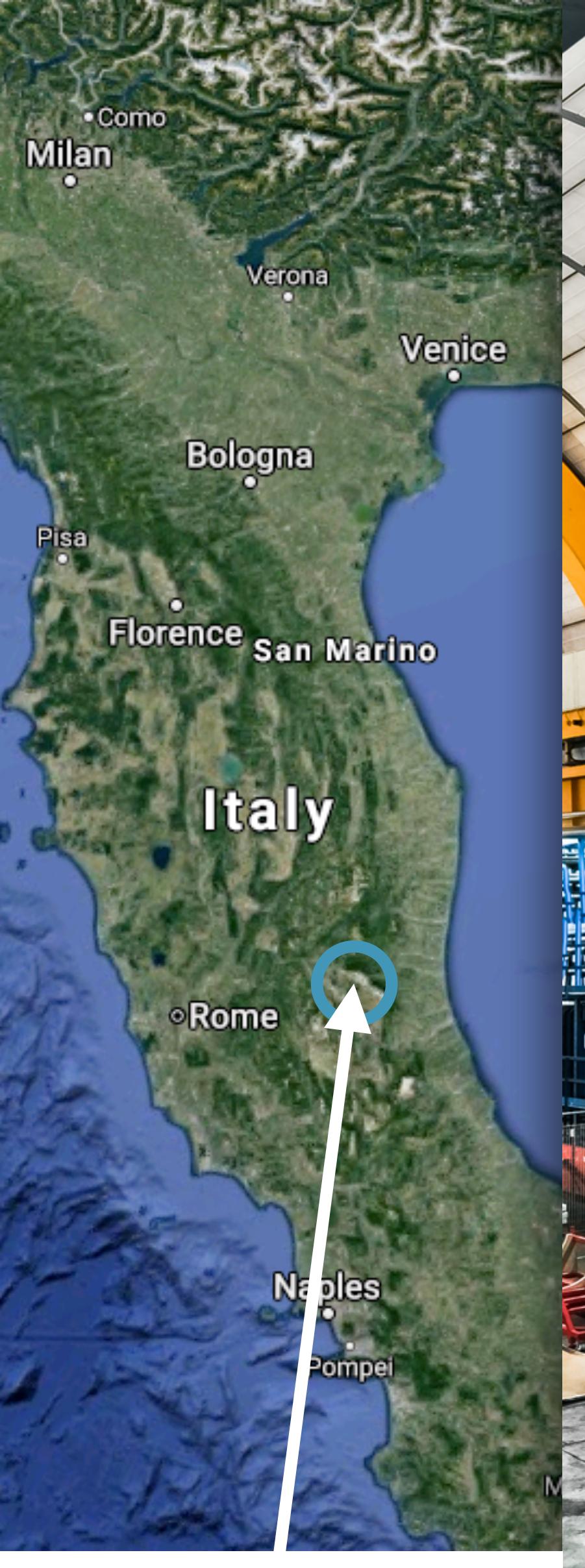
Weizmann



NYUAD







**INFN**  
LNGS



Dual-Phase TPC

Water Čerenkov  
Muon Veto

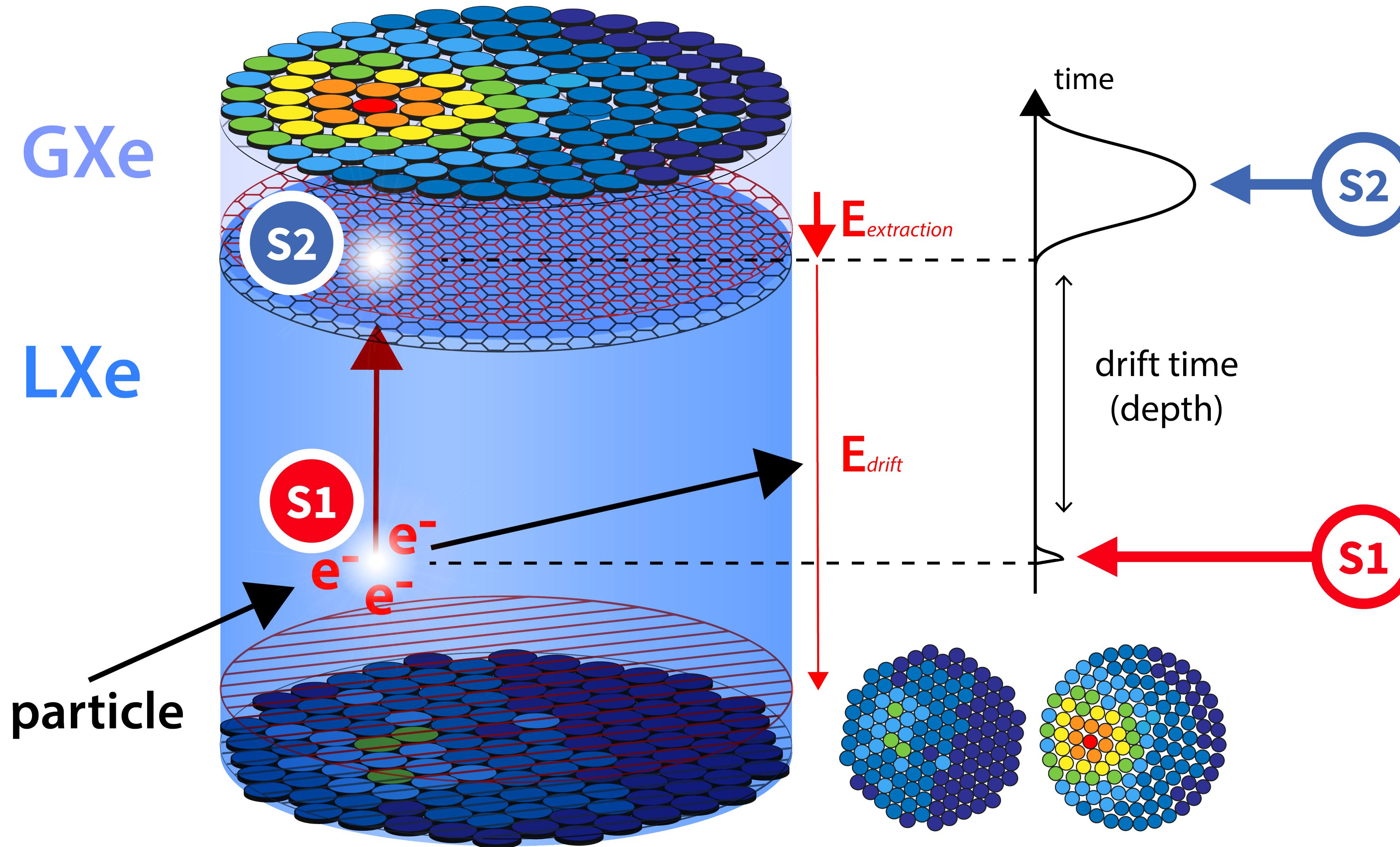


Cryogenics & Xenon Purification

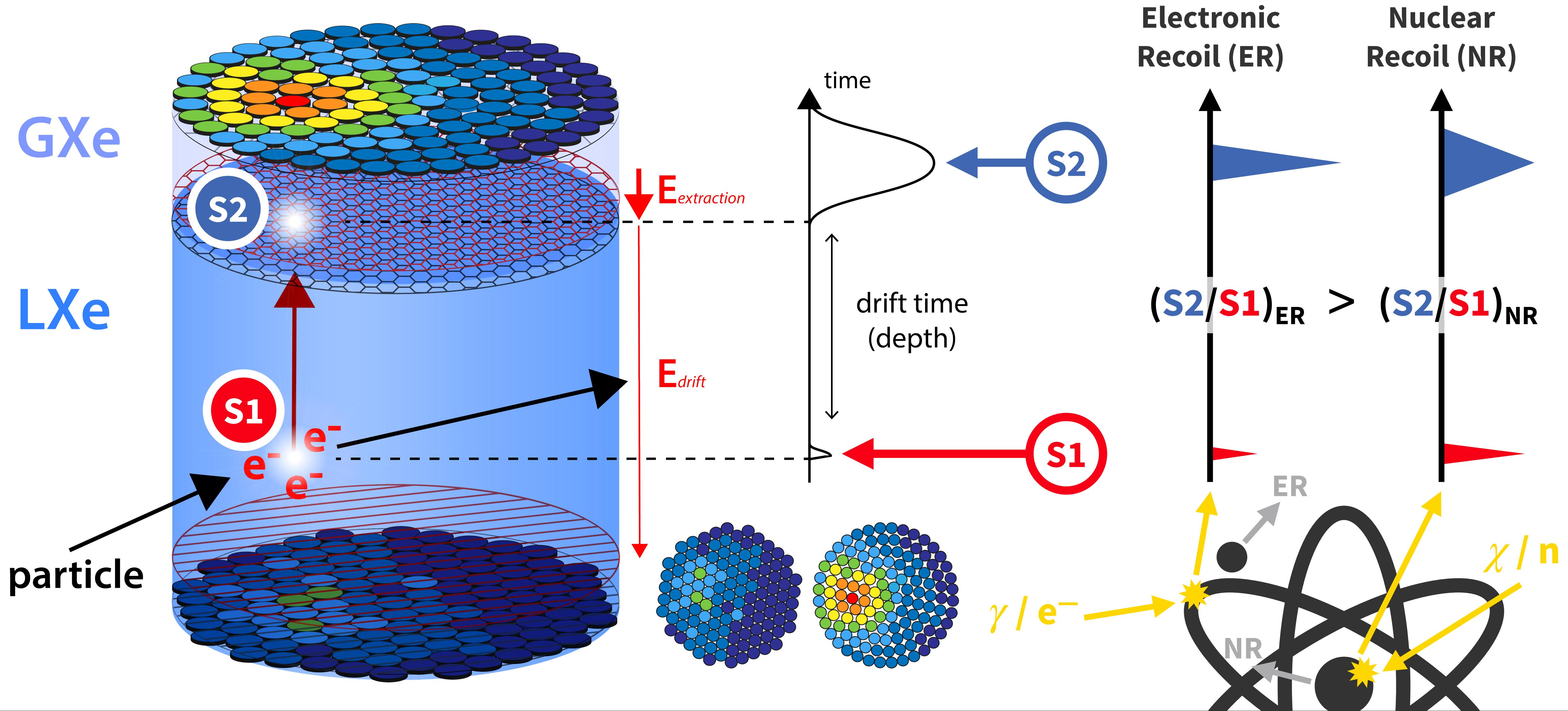
Electronics, Data Acquisition  
& Slow Control

Xenon Storage,  
Recovery & Distillation

# Detecting particles with a dual-phase TPC



# Detecting particles with a dual-phase TPC

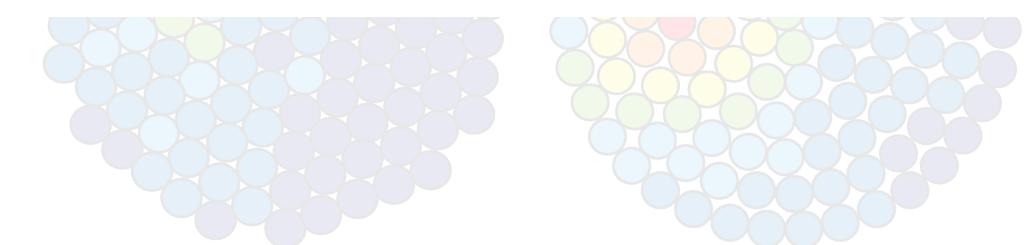
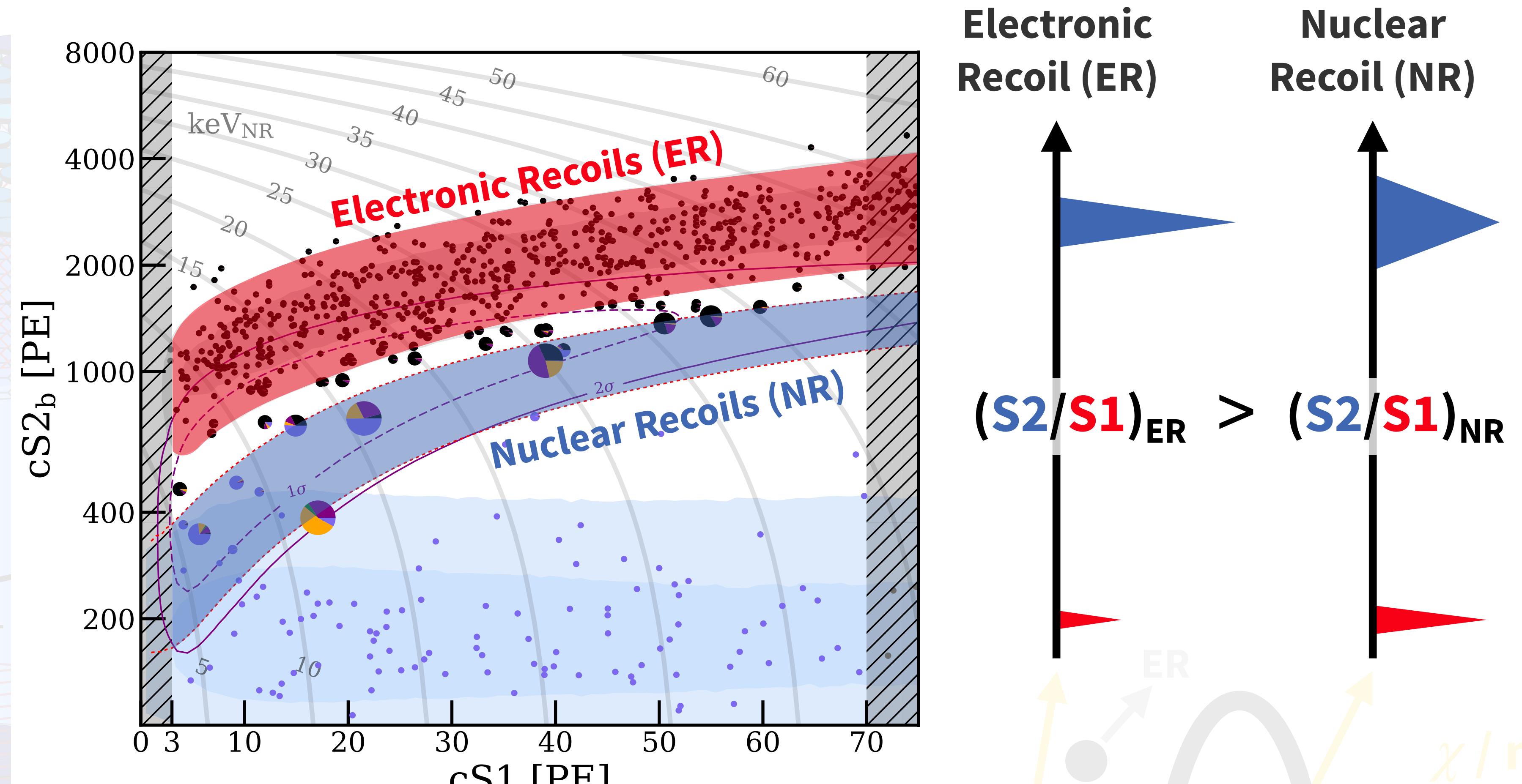
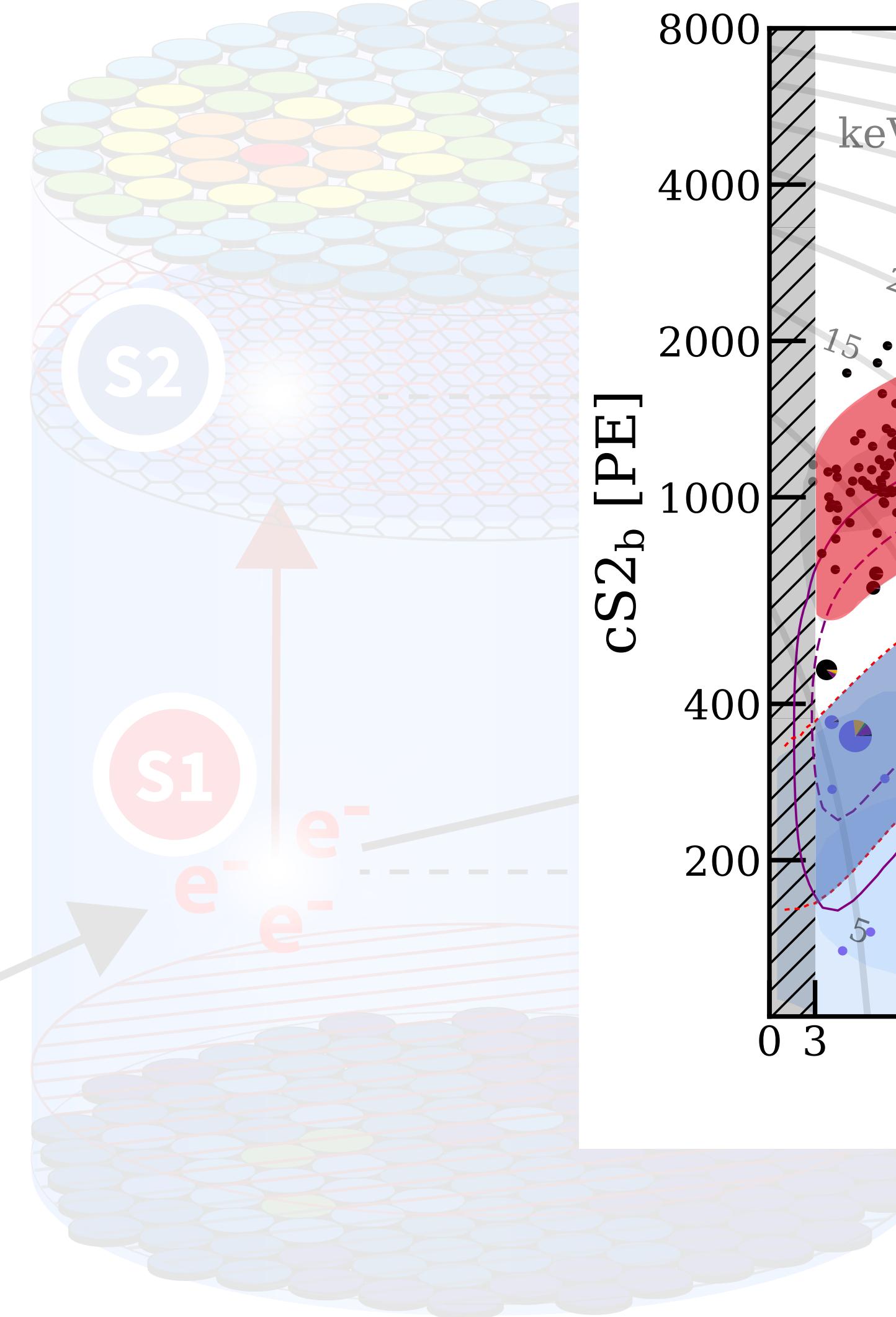


# Detecting particles with a dual-phase TPC

G<sub>Xe</sub>

L<sub>Xe</sub>

particle



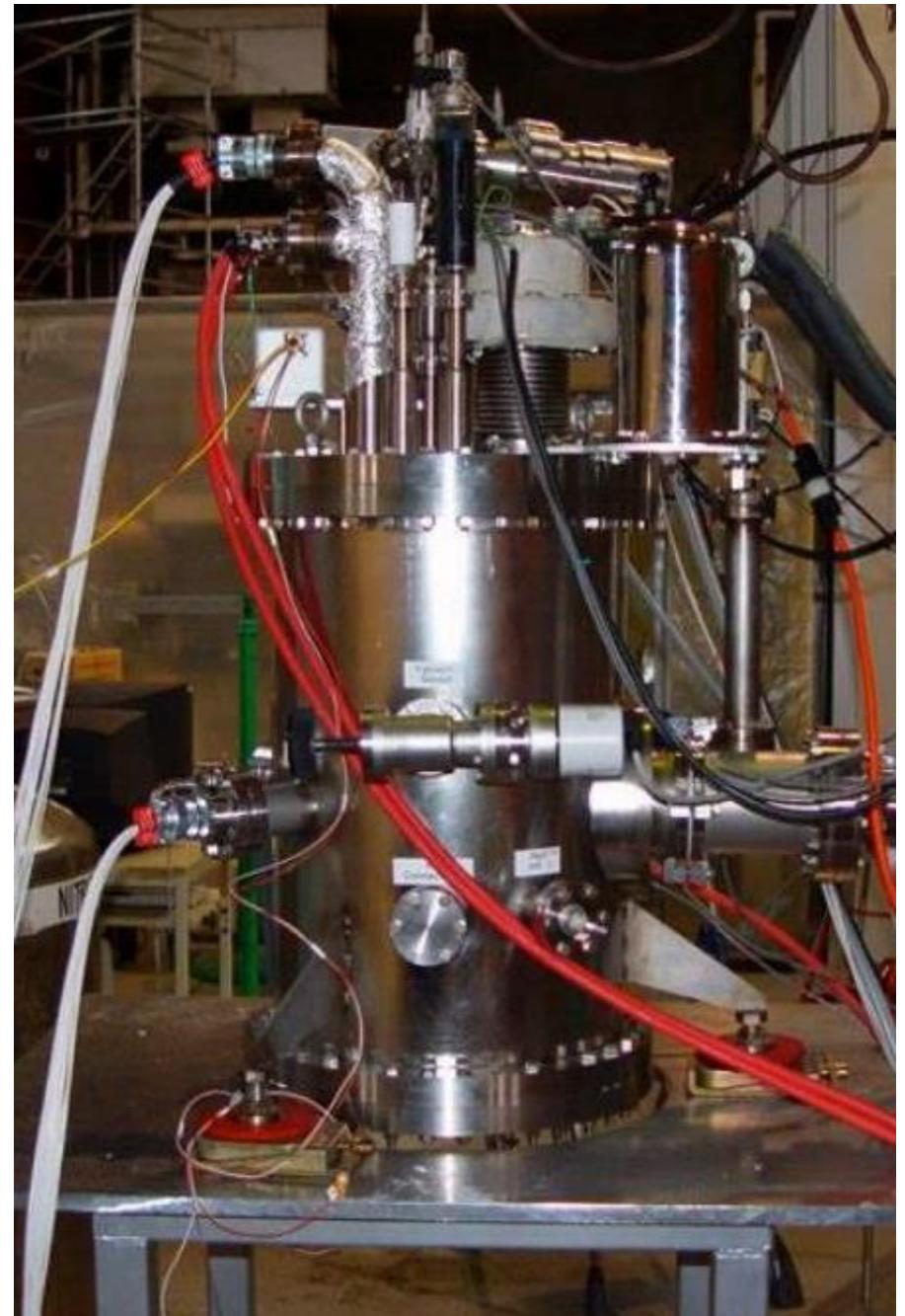
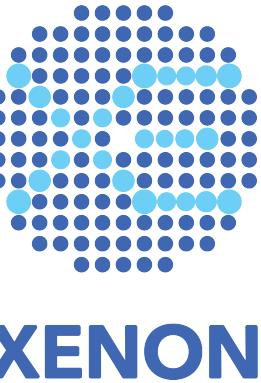
Electronic  
Recoil (ER)

Nuclear  
Recoil (NR)

$$(S_2/S_1)_{ER} > (S_2/S_1)_{NR}$$

# The XENON program

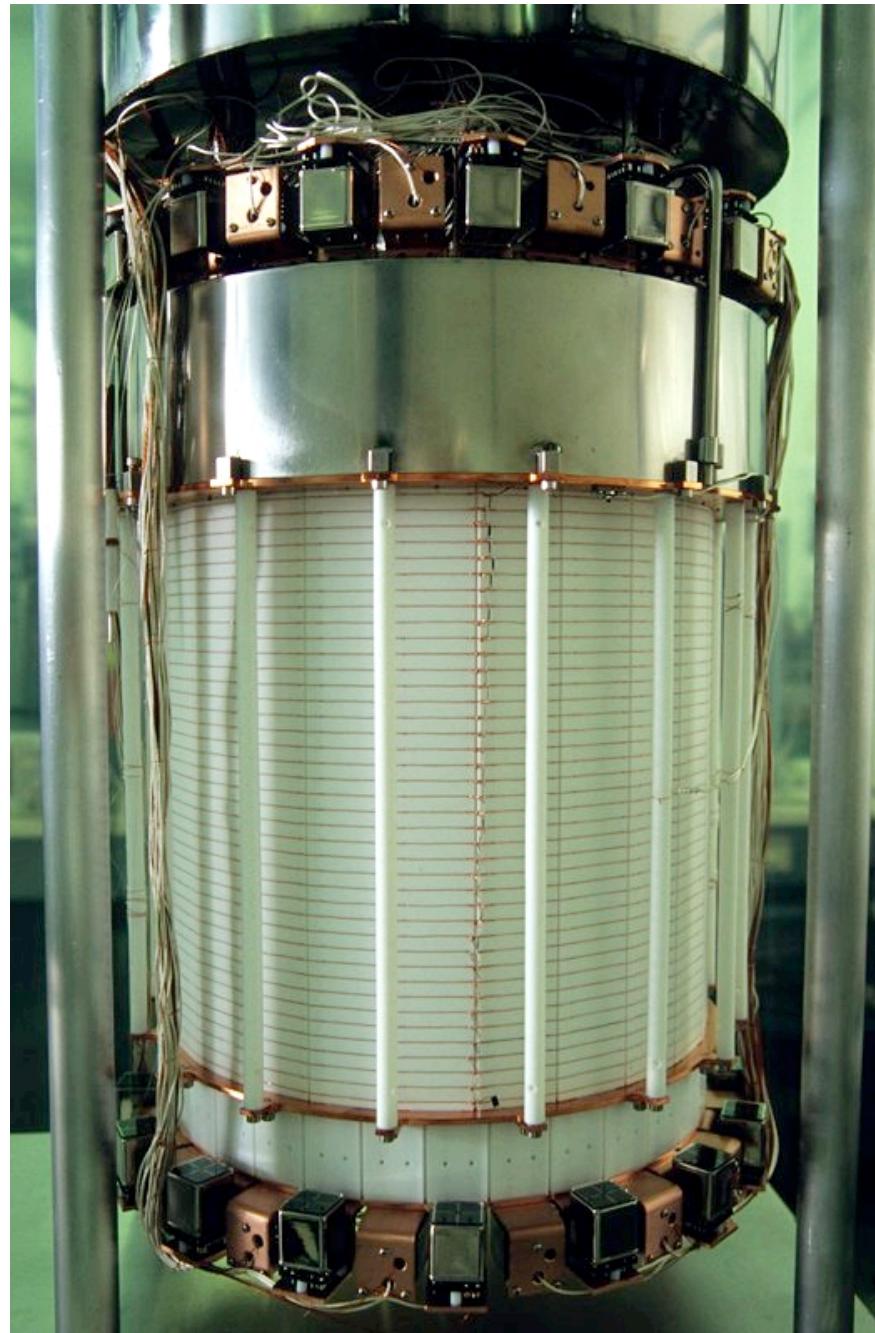
PRL 100 (2008) 021303  
PRD 94 (2016) 122001  
PRL 121 (2018) 111302



**XENON10**

2005–2007

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



**XENON100**

2009–2016

161 kg LXe  
30 cm drift length  
 $\sigma_{\text{SI}} \sim 10^{-45} \text{ cm}^2$   
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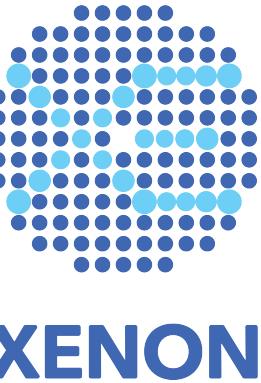
**XENON1T**

2016–2018

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

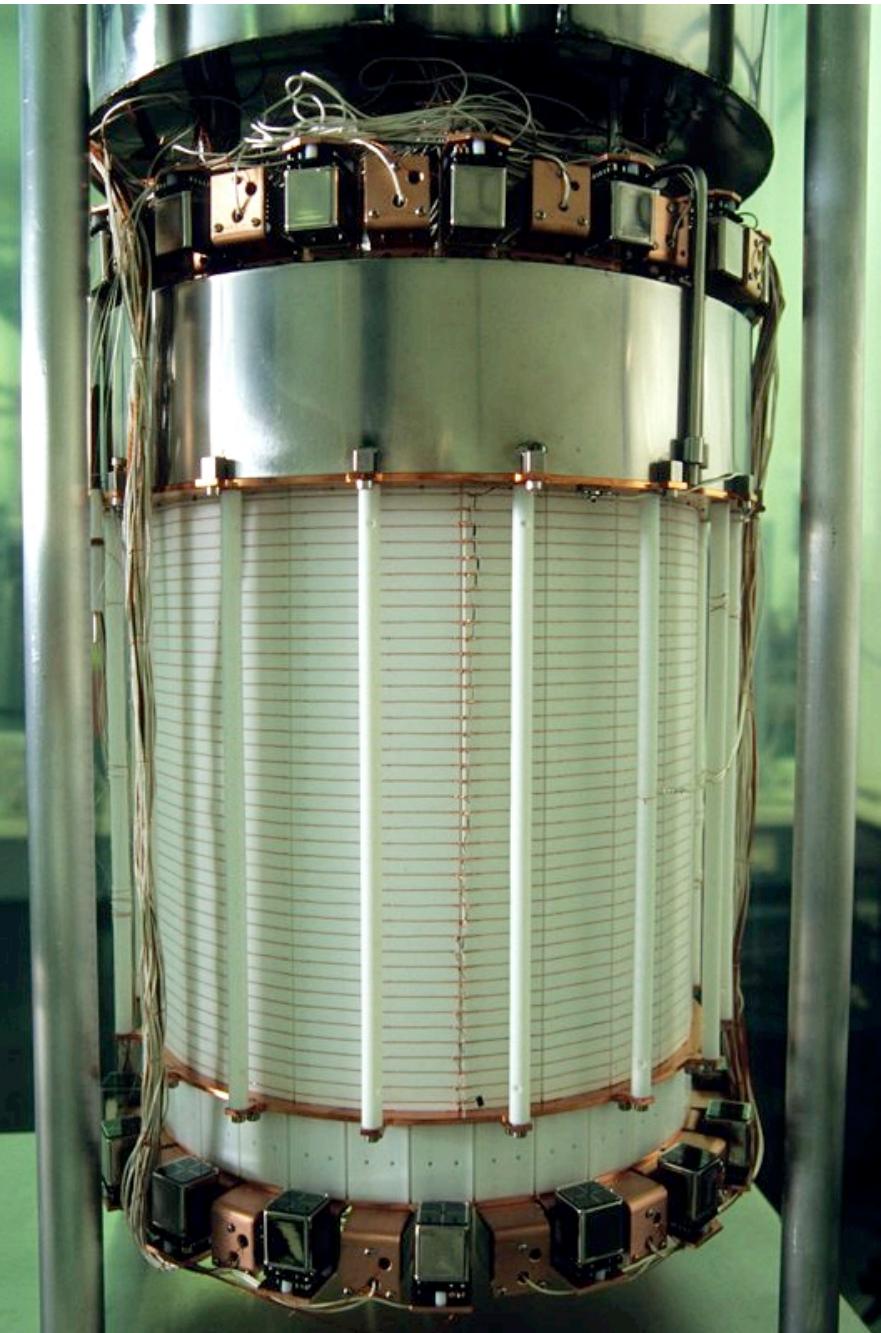
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**XENONnT**  
2020–2025

NOW

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

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

PRL 126 (2021) 091301

## 2 $\nu$ Double Electron Capture

Nature 568 (2019) 7753

## Solar Axions

PRD 102 (2020) 072004

## Neutrino Magnetic Moment

PRD 102 (2020) 072004

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PRL 126 (2021) 091301

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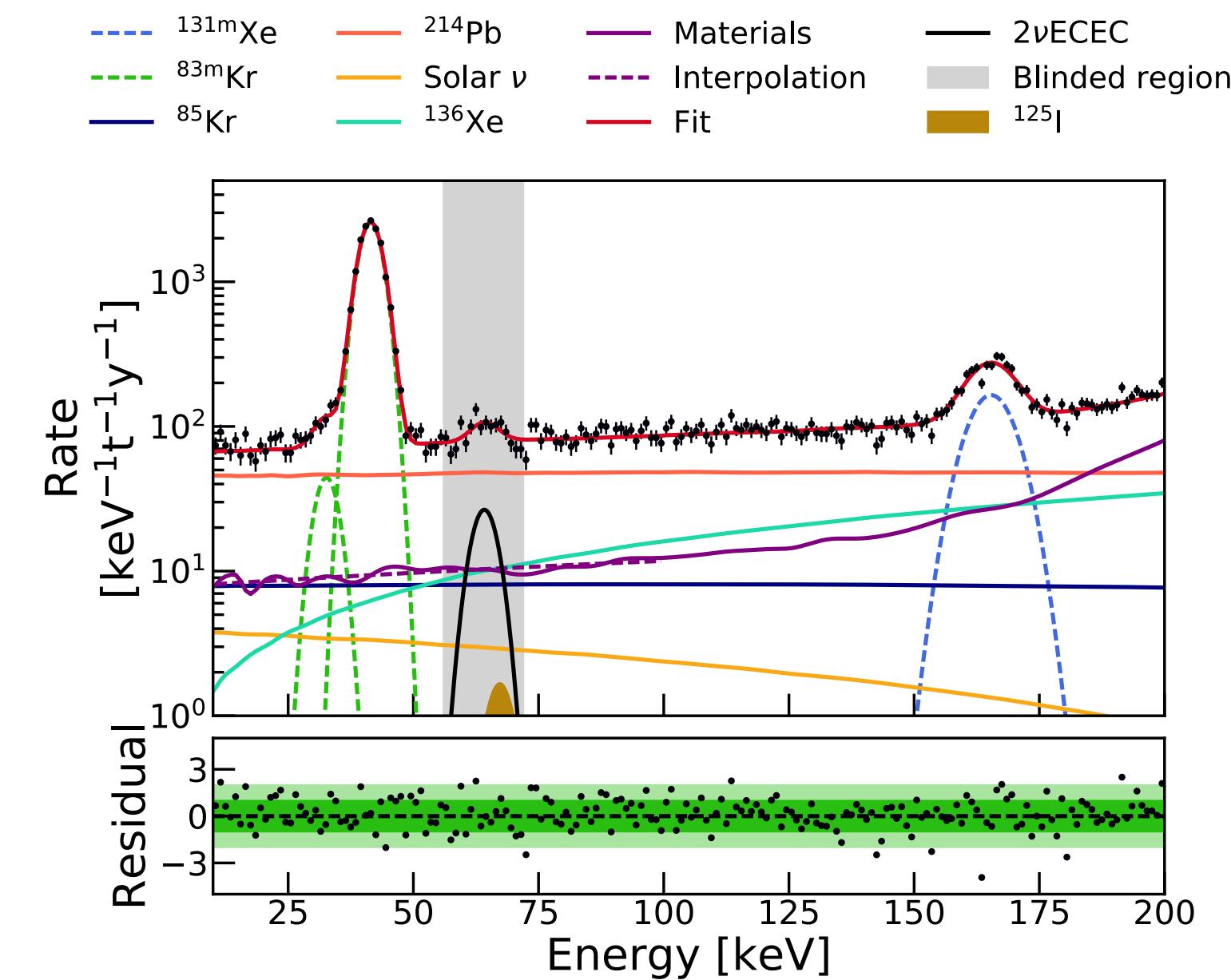
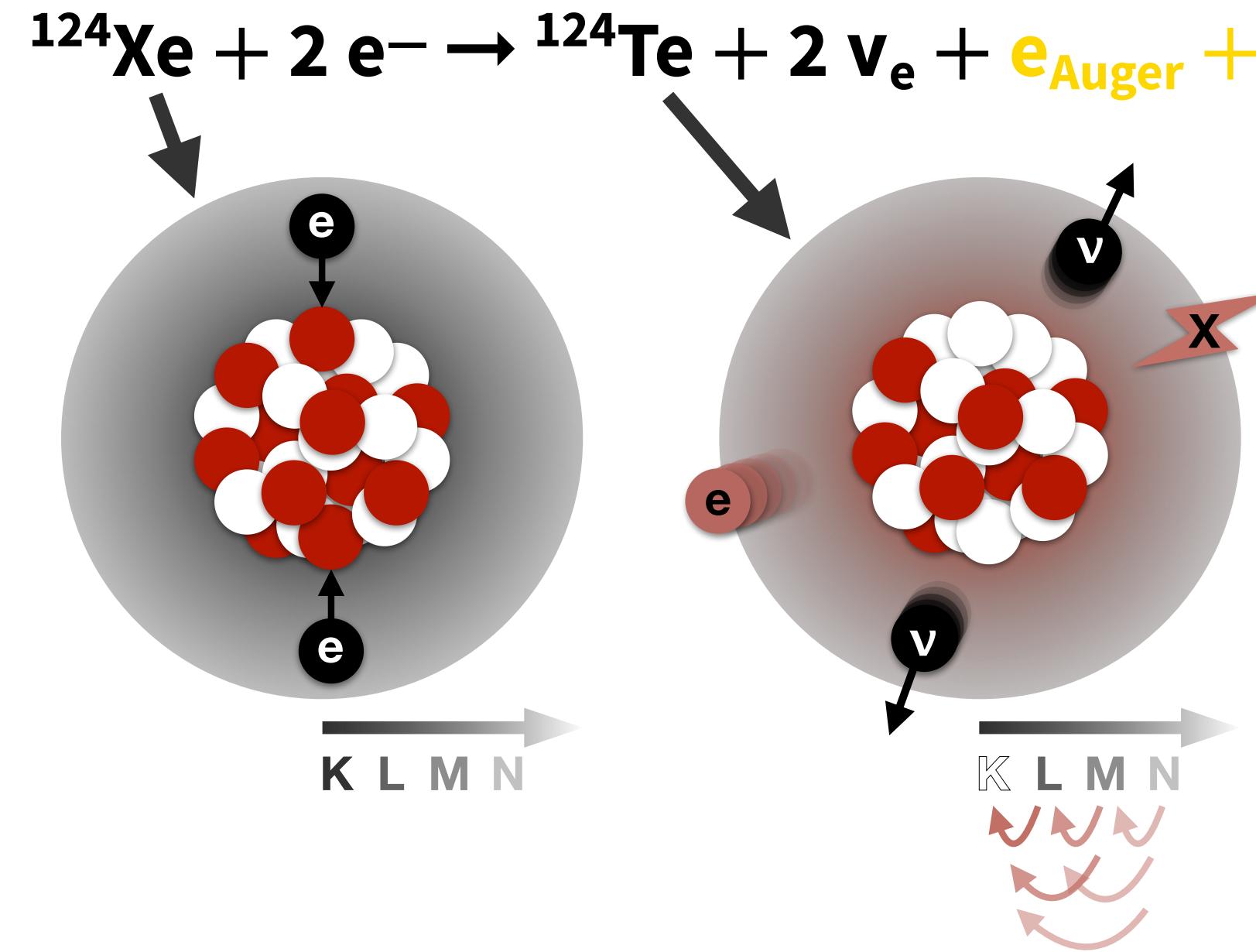
PRD 102 (2020) 072004

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PRD 102 (2020) 072004

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

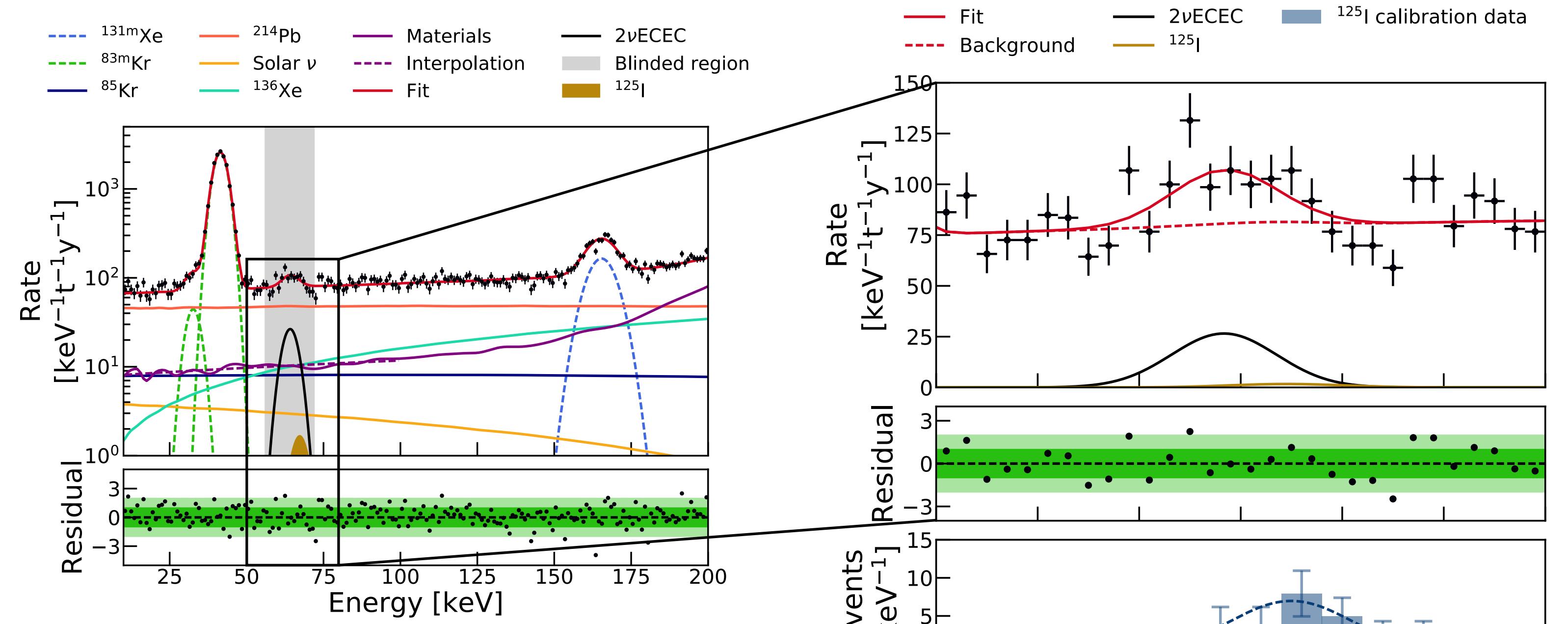
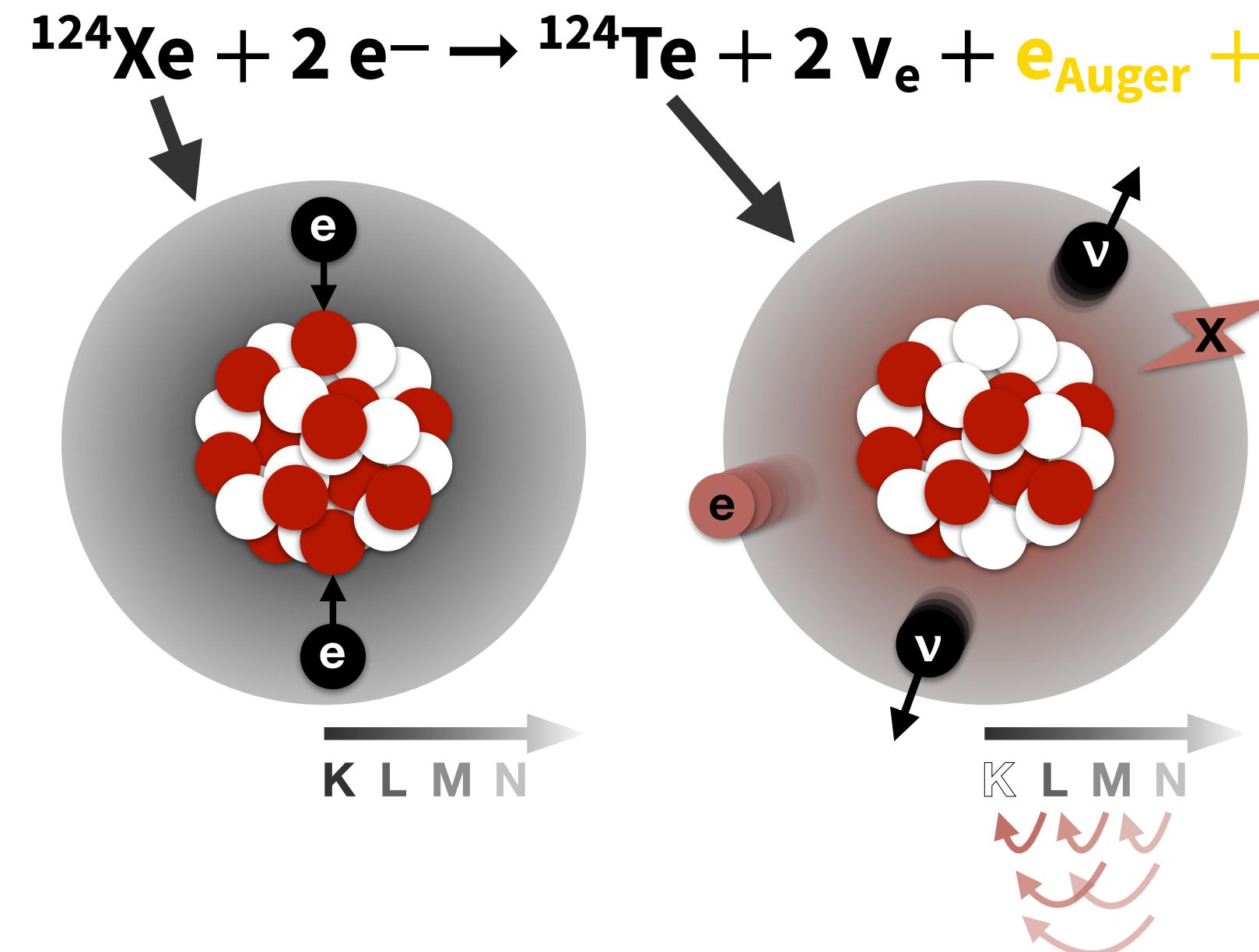
Nature 568 (2019) 7753



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- K-shell electron capture → **X-rays and  $\text{e}_{\text{Auger}}$  (64.3 keV)**

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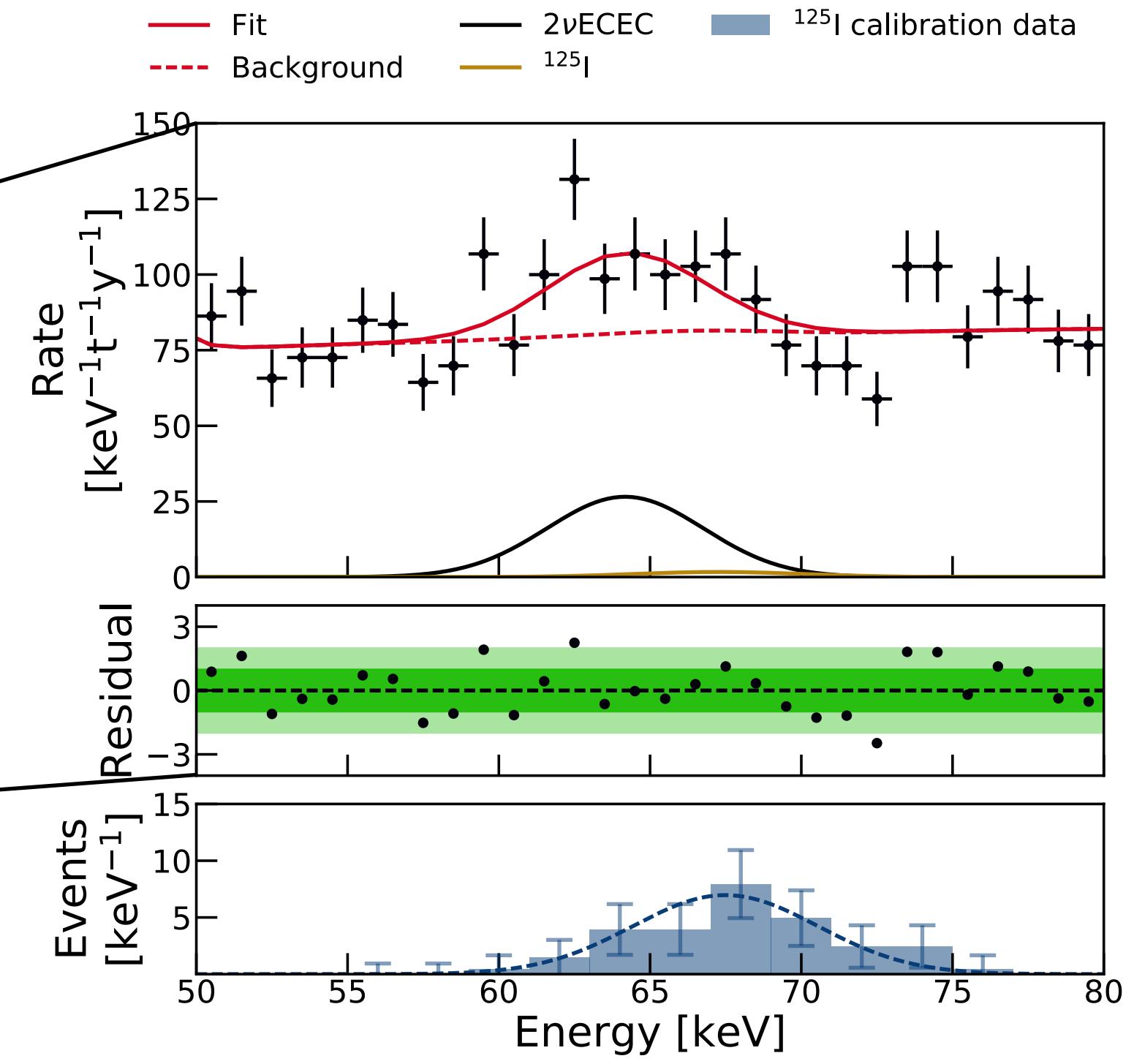
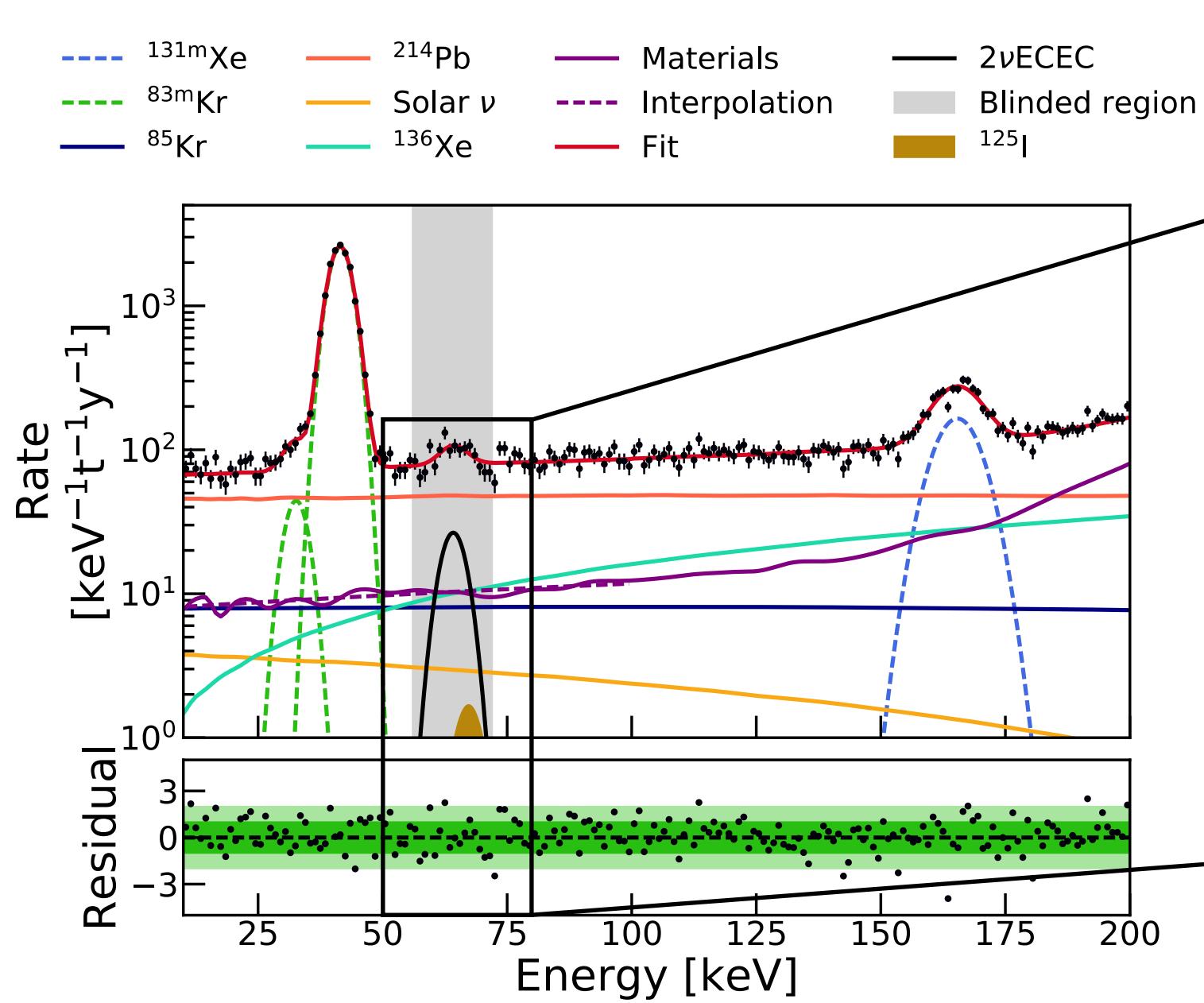
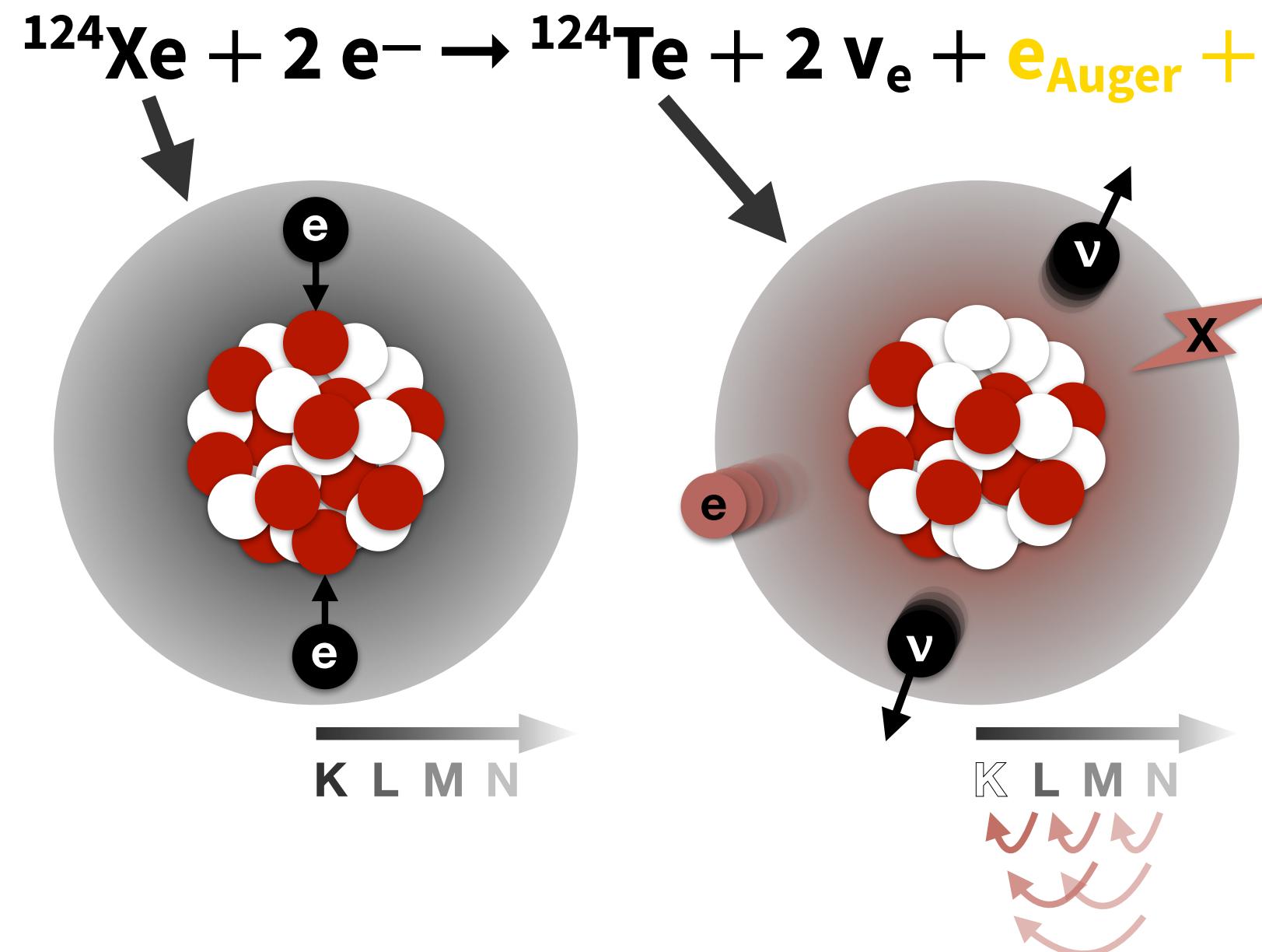
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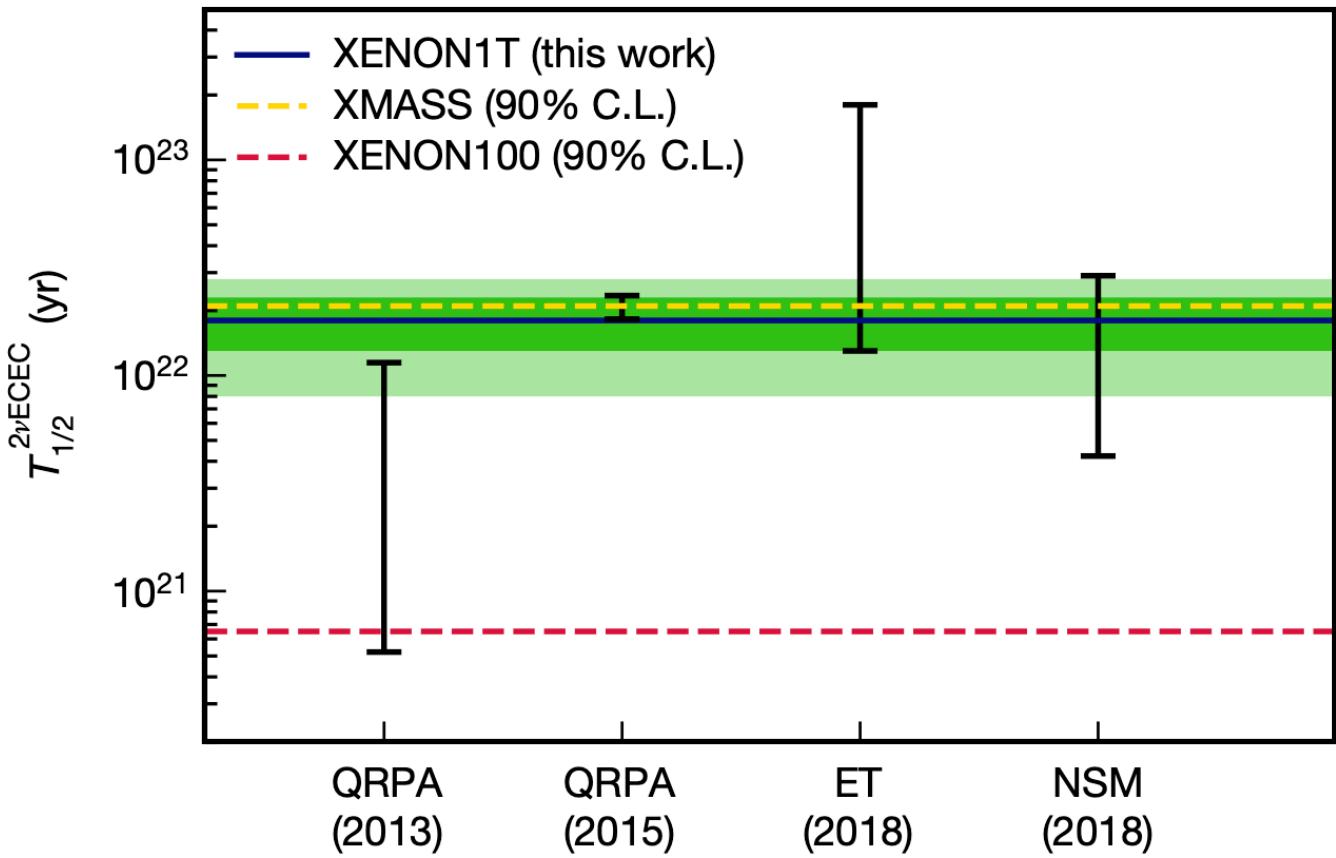
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- $^{124}\text{Xe} \sim 1 \text{ kg/t LXe} \rightarrow$  126 2vDEC events (4.4 $\sigma$  above bkg.)

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Nature 568 (2019) 7753

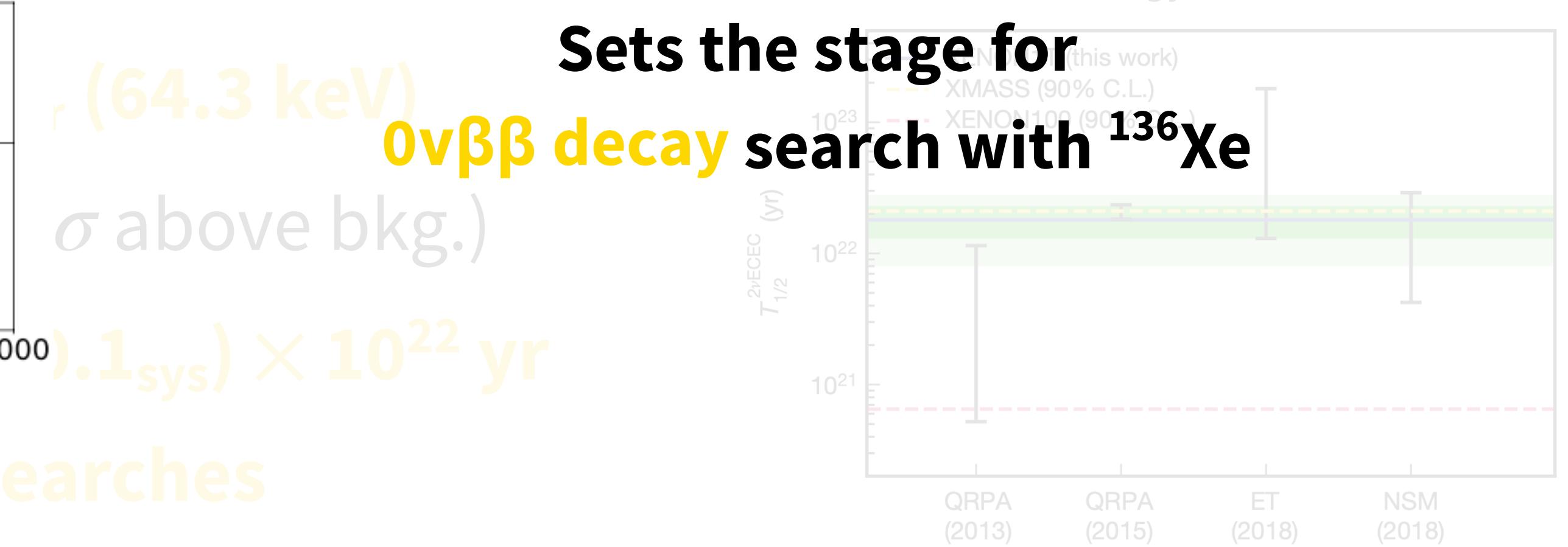
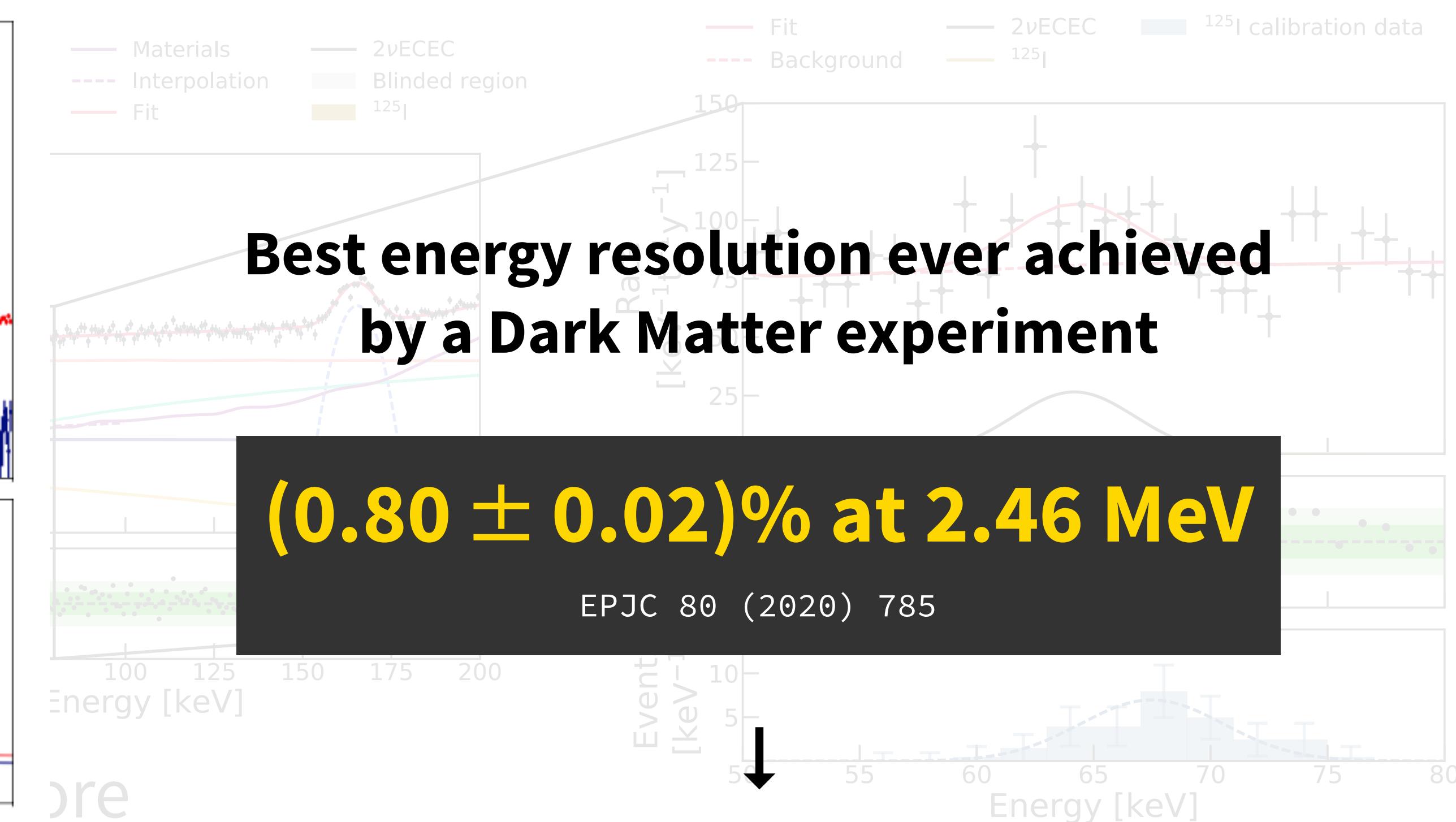
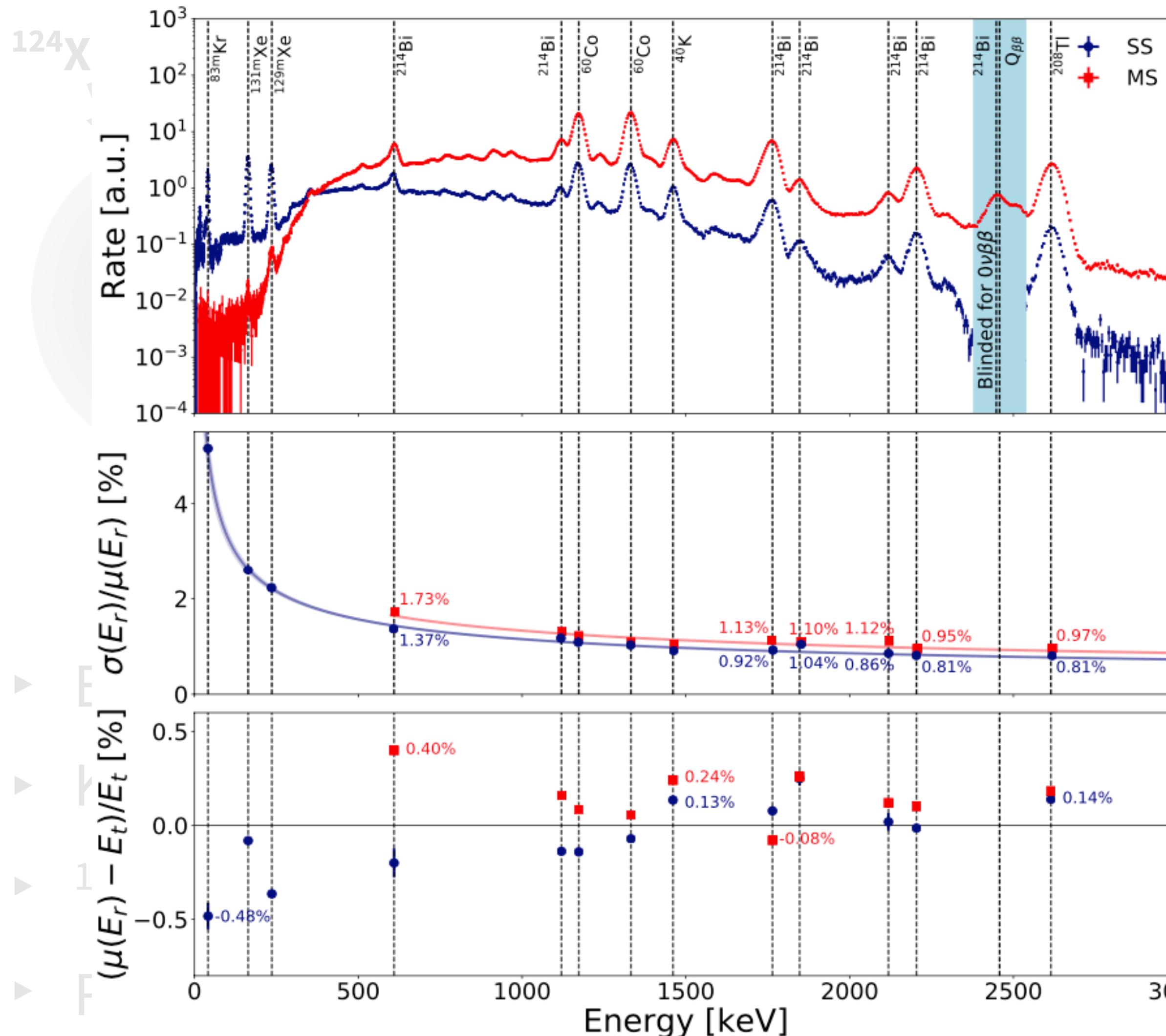


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- Resulting half-life →  $T_{1/2} = (1.8 \pm 0.5_{\text{stat}} \pm 0.1_{\text{sys}}) \times 10^{22} \text{ yr}$
- Unprecedented sensitivity to **rare decay searches**



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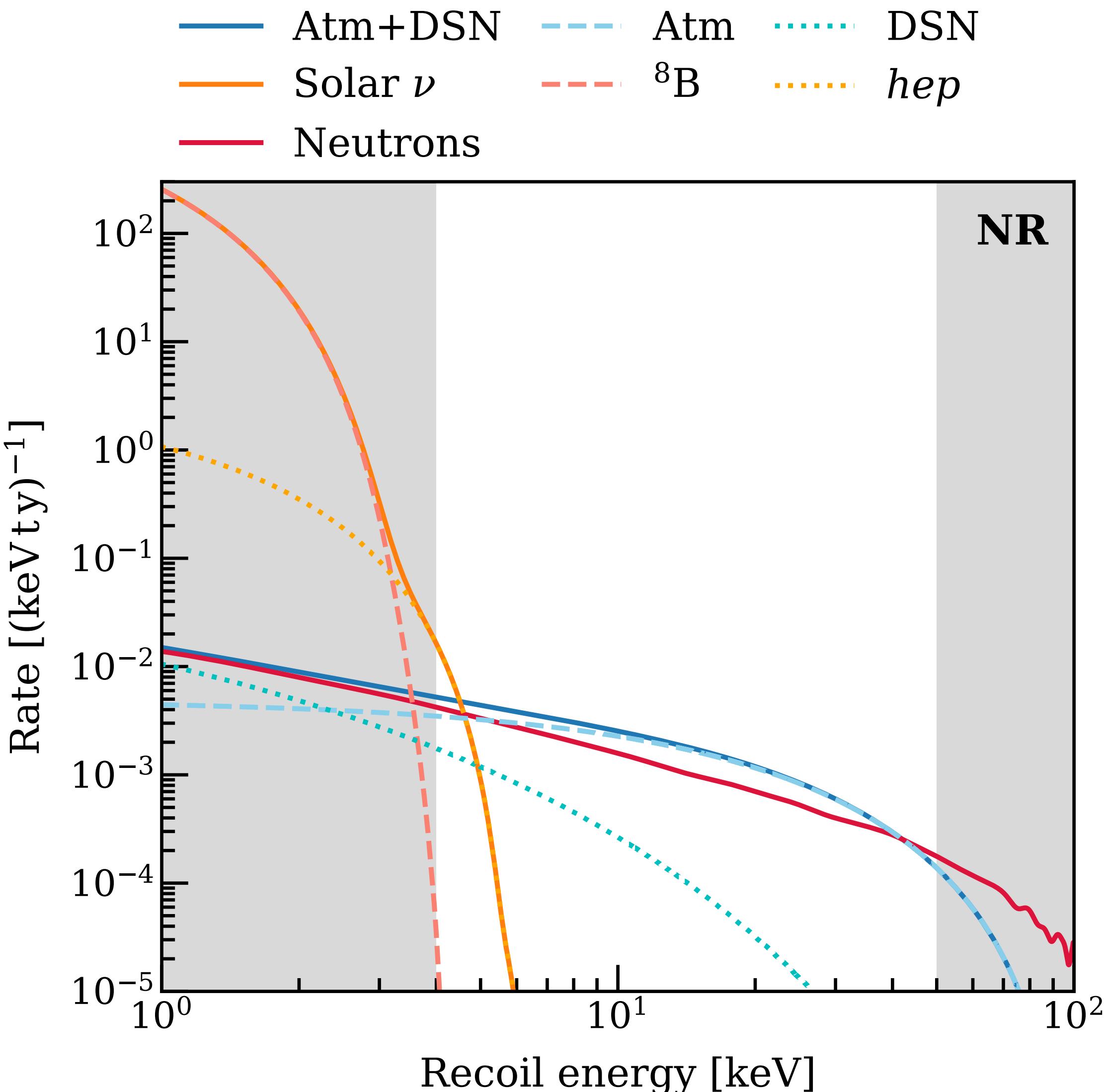
Nature 568 (2019) 7753



# The CEvNS process and XENON1T

JCAP 11 (2020) 031

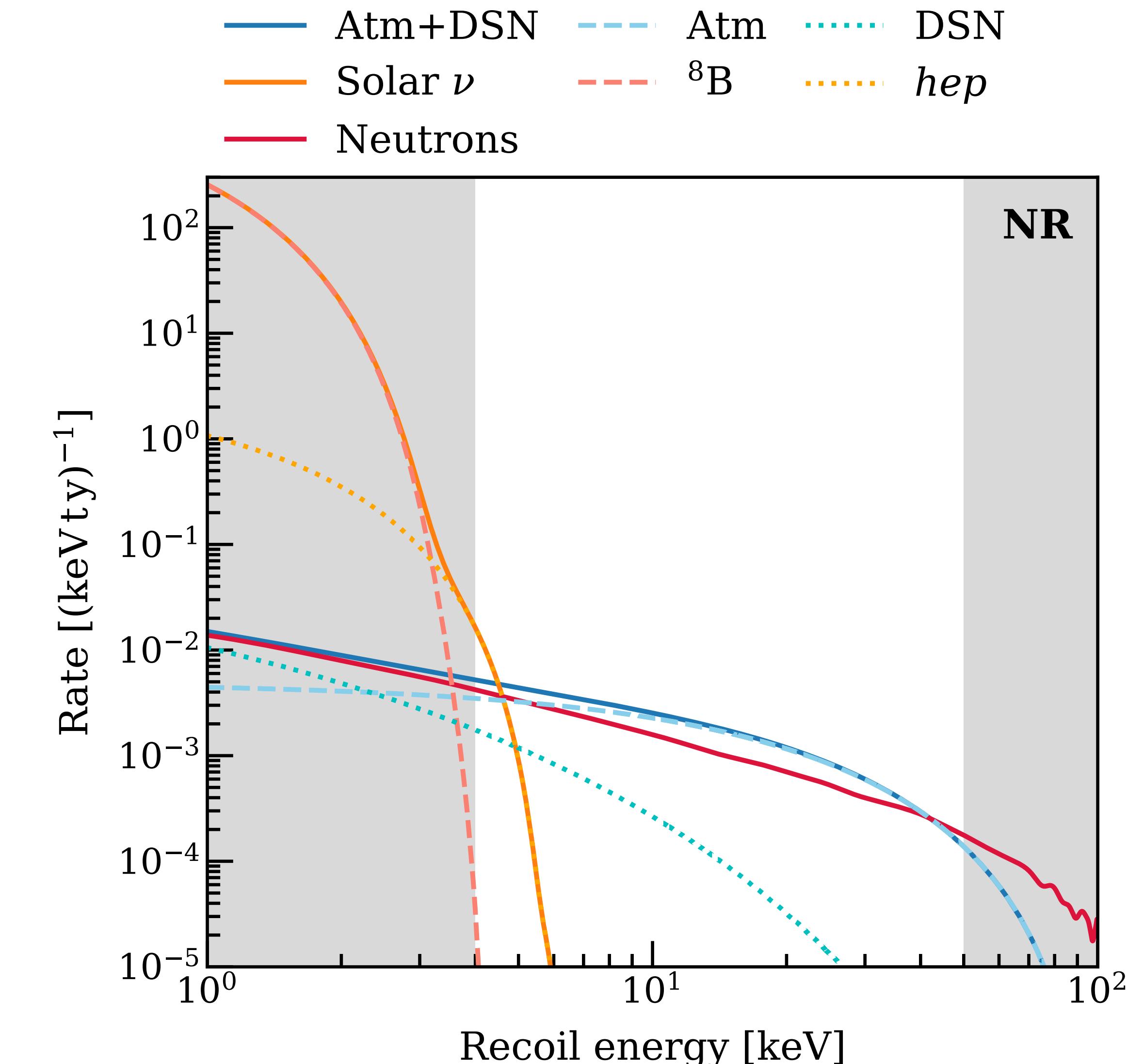
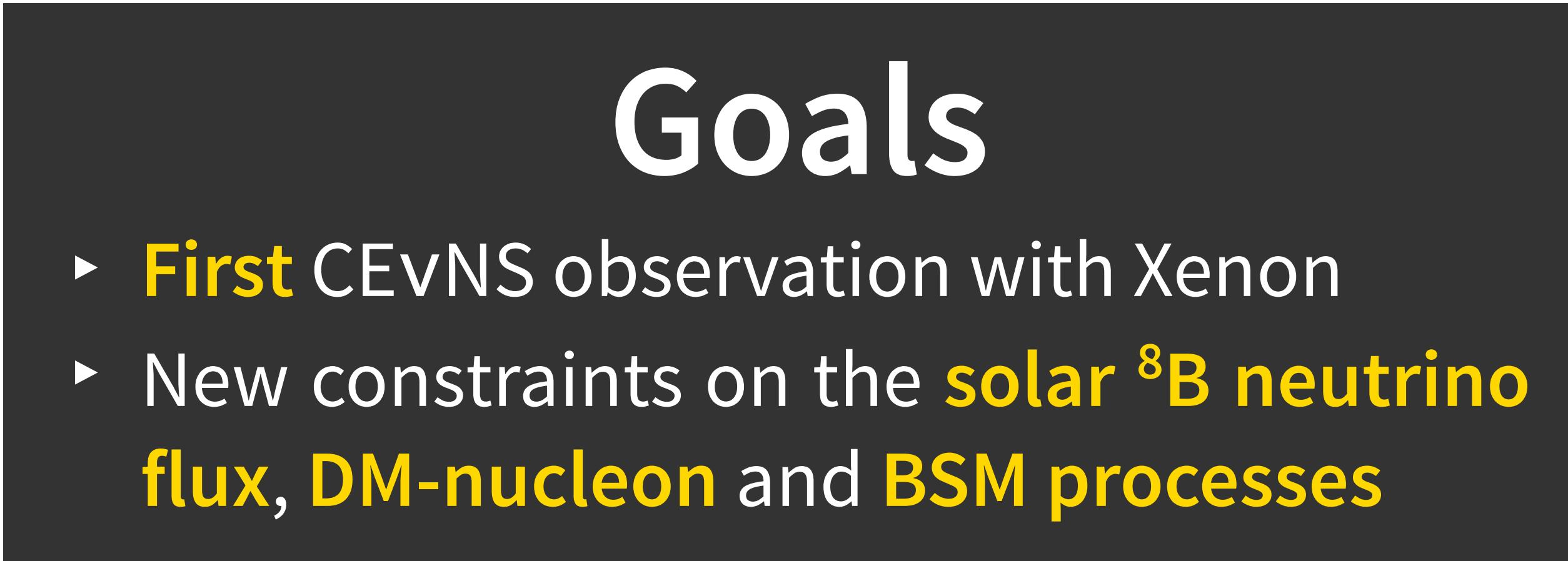
- ▶ Neutrinos elastically scatter off atomic nuclei  
→ **Nuclear Recoils (NR)** like WIMP-nuclei
- ▶ Sources → the Sun, atmospheric cosmic ray showers and supernovae
- ▶ Greatest contributor to CEvNS in LXe DM experiments → **solar  ${}^8\text{B}$**  ( $\rightarrow {}^8\text{Be}^* + \text{e}^+ + \nu_e$ )



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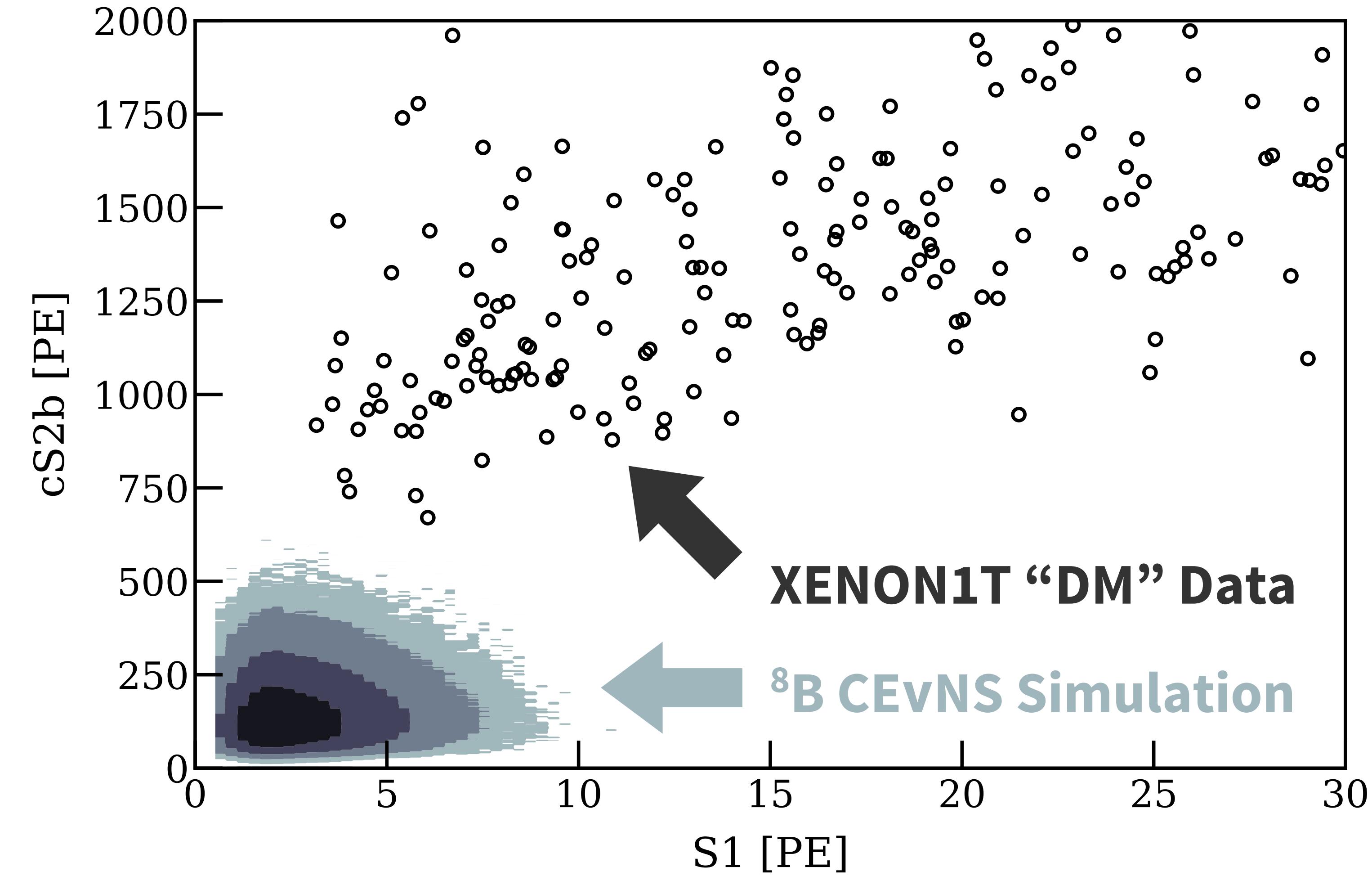
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# Turning a background into a signal

PRL 126 (2021) 091301

- ▶ Solar  ${}^8\text{B}$  CEvNS  $\sim 6 \text{ GeV}/c^2$  WIMPs **as a background** (“neutrino fog”)
- ▶  ${}^8\text{B}$  CEvNS signal expected **below the previous analysis threshold**  
→ lower the S1 and S2 thresholds



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3-fold → 2-fold  
PMT requirement

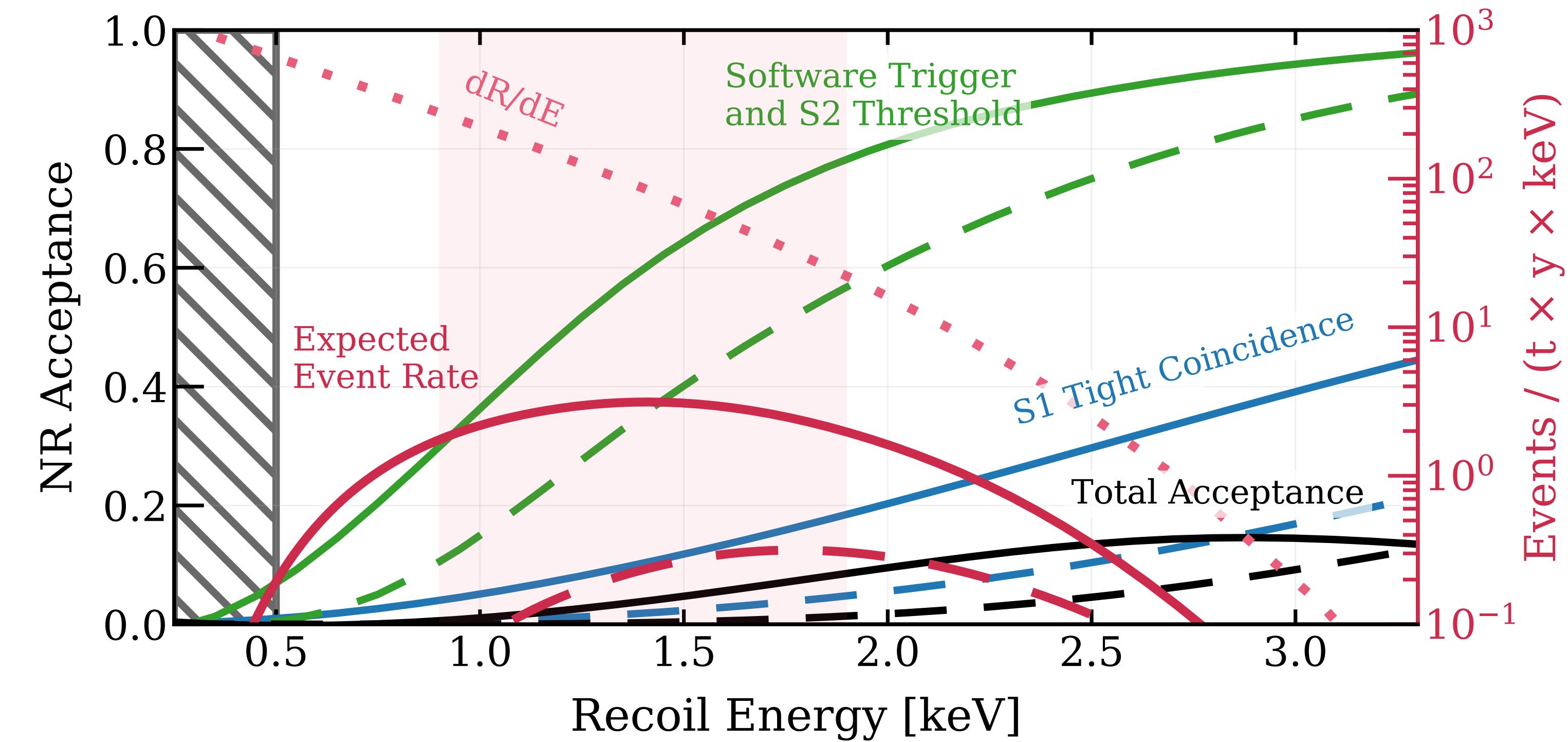


**CEvNS acceptance**  
 $1\% \rightarrow 5\%$

200 PE → 120 PE  
S2 area threshold



**CEvNS acceptance**  
**92% post-trigger**



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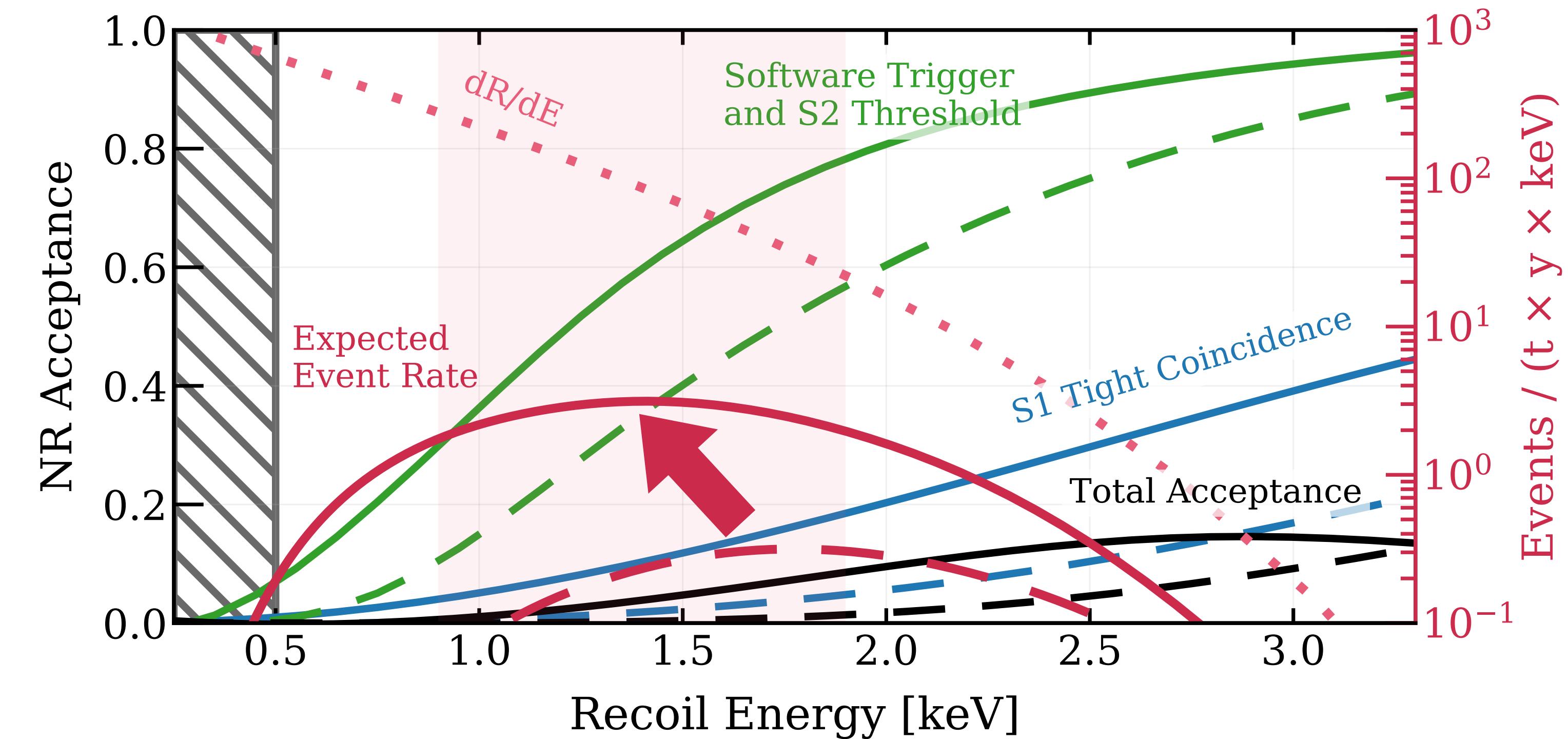


**1% → 5%**  
**CEvNS acceptance**

200 PE → 120 PE  
S2 area threshold



**92% post-trigger**  
**CEvNS acceptance**



Lowered XENON1T energy threshold  
(2.6 keV → 1.6 keV)  
→ 20-fold CEvNS signal increase expected

# Solar flux & detector constraints

PRL 126 (2021) 091301

Observed **6 events** in the ROI

Expected 2 CEvNS + 5 background events

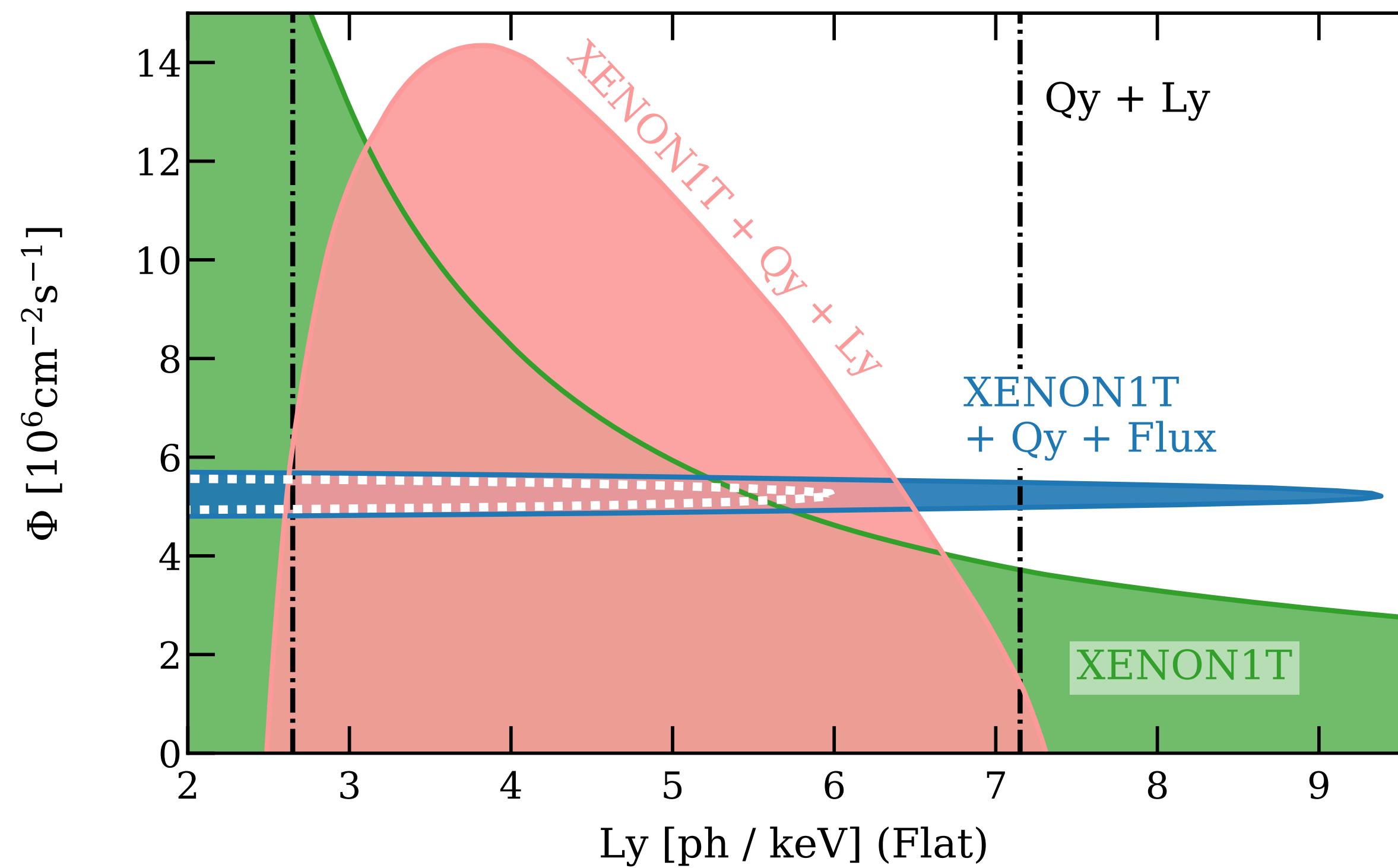
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- ▶ **Check constraint on  $\Phi$**  ( $< 14 \times 10^6 \text{ cm}^{-2} \text{s}^{-1}$ , measured elsewhere at  $5.3 \times 10^6 \text{ cm}^{-2} \text{s}^{-1}$ )

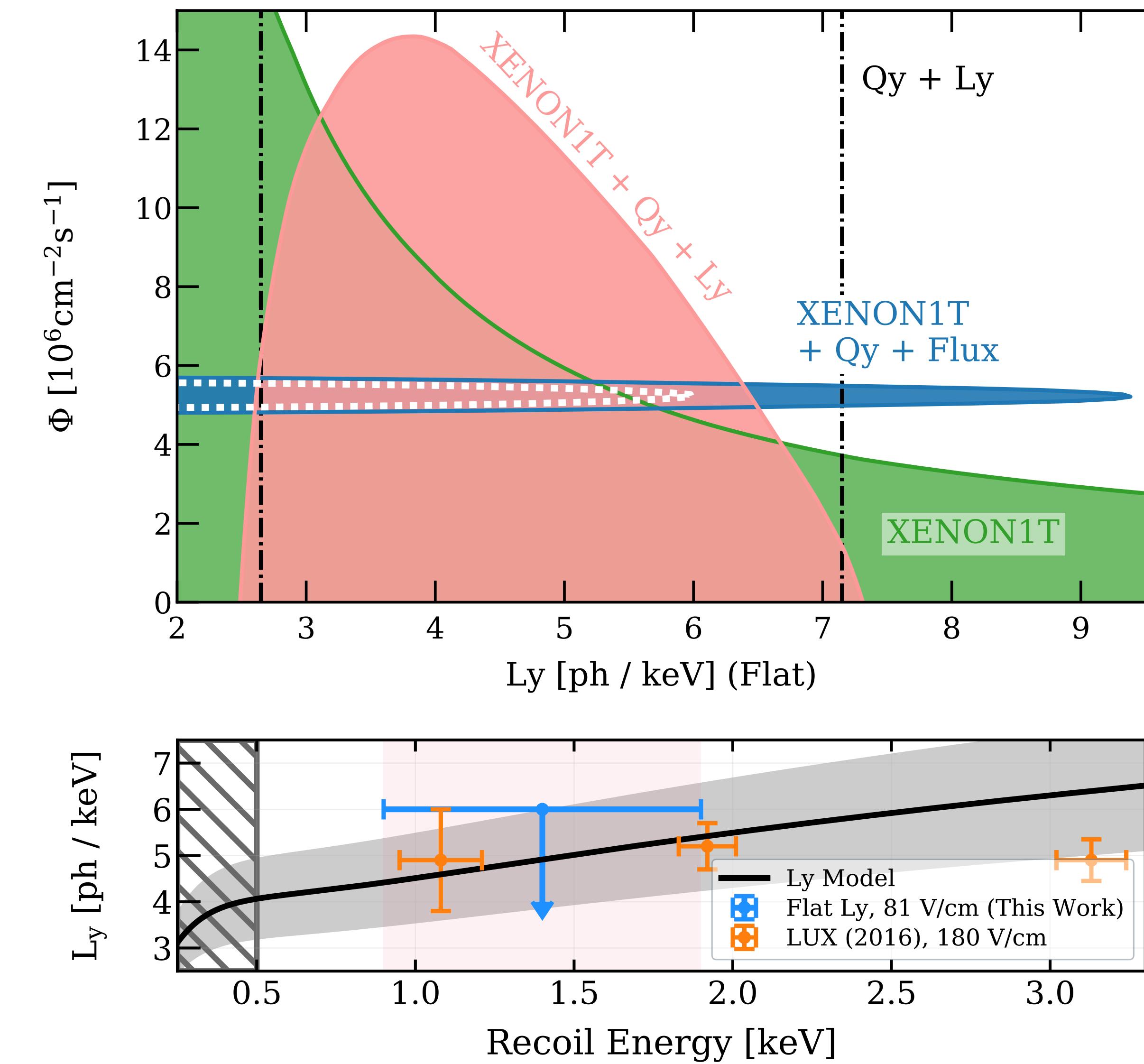


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- New constraint on  $L_y$**  from 1–2 keV recoils



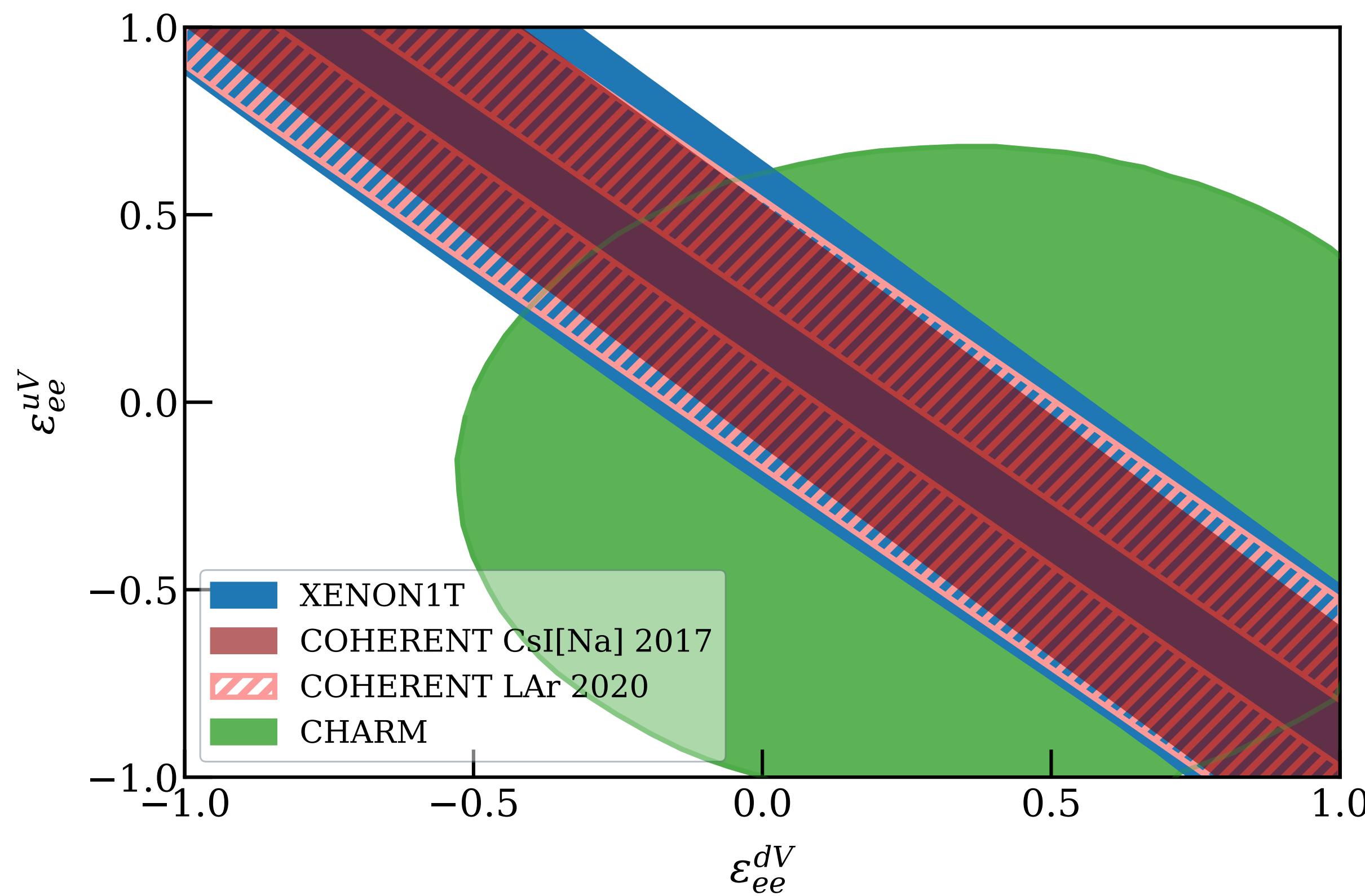
# BSM & Dark Matter constraints

PRL 126 (2021) 091301

- Constraining **non-standard neutrino-quark interactions** with modified CEvNS

$$\frac{dR_{CE\nu NS}}{dE} \propto \tilde{Q}_w^2(\varepsilon_{ee}^{uV}, \varepsilon_{ee}^{dV})$$

$\nearrow \searrow$   
 $0 \rightarrow$  Standard Model



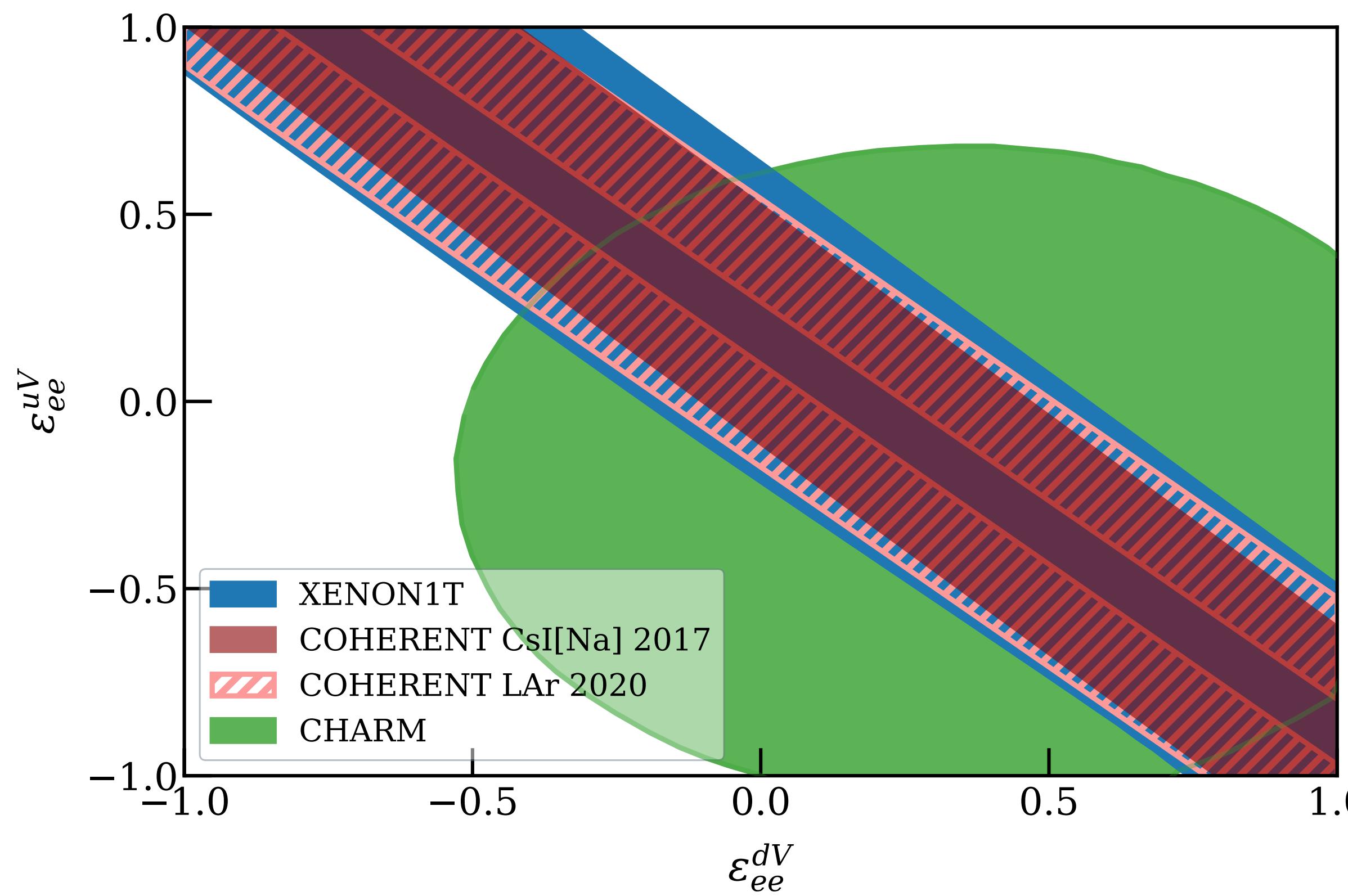
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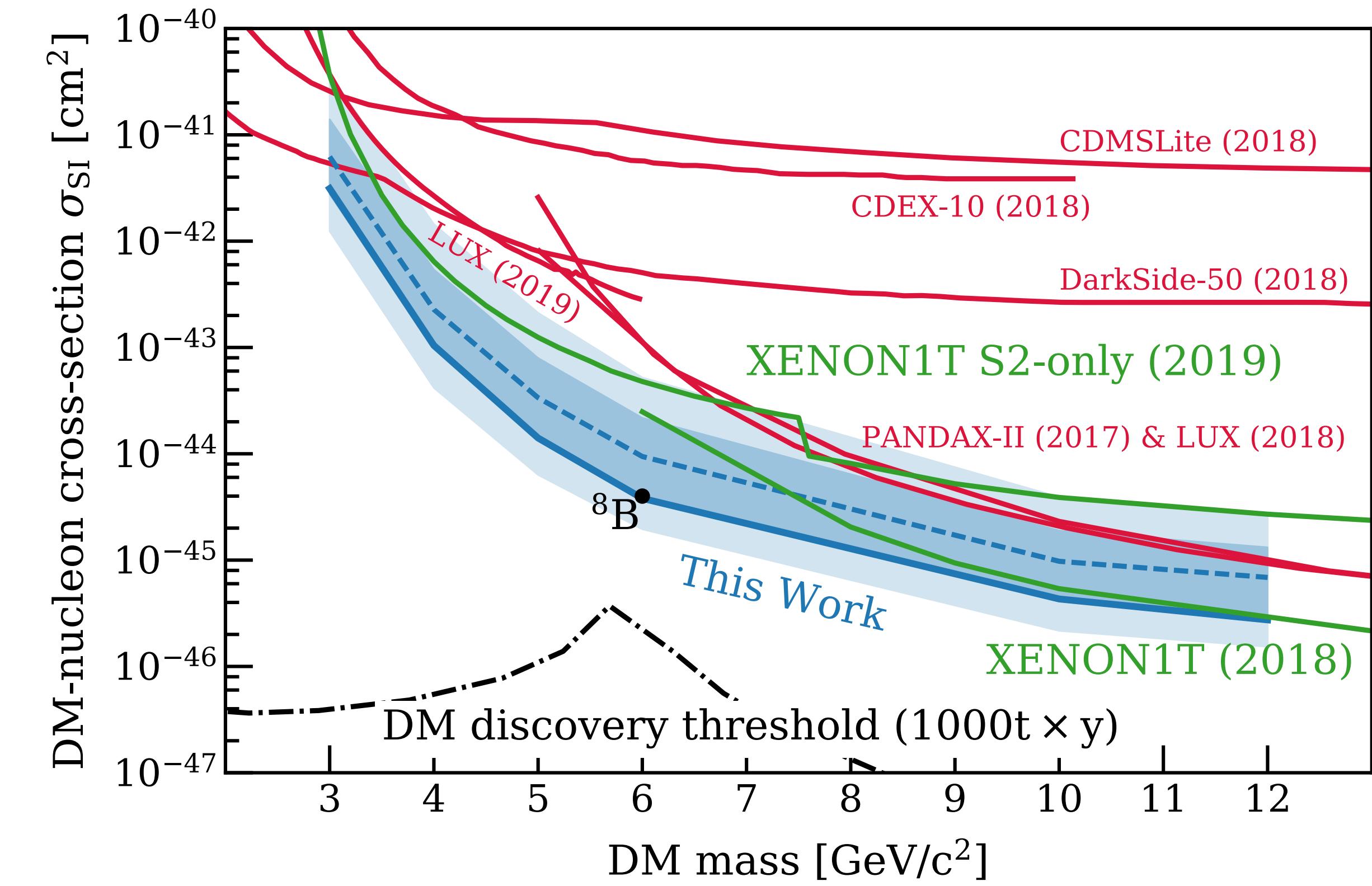
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- Considering  ${}^8B$  CEvNS as a background to DM-nucleon interaction search  
→ **improving upon previous limits** in the 3–11 GeV/c<sup>2</sup> DM mass range



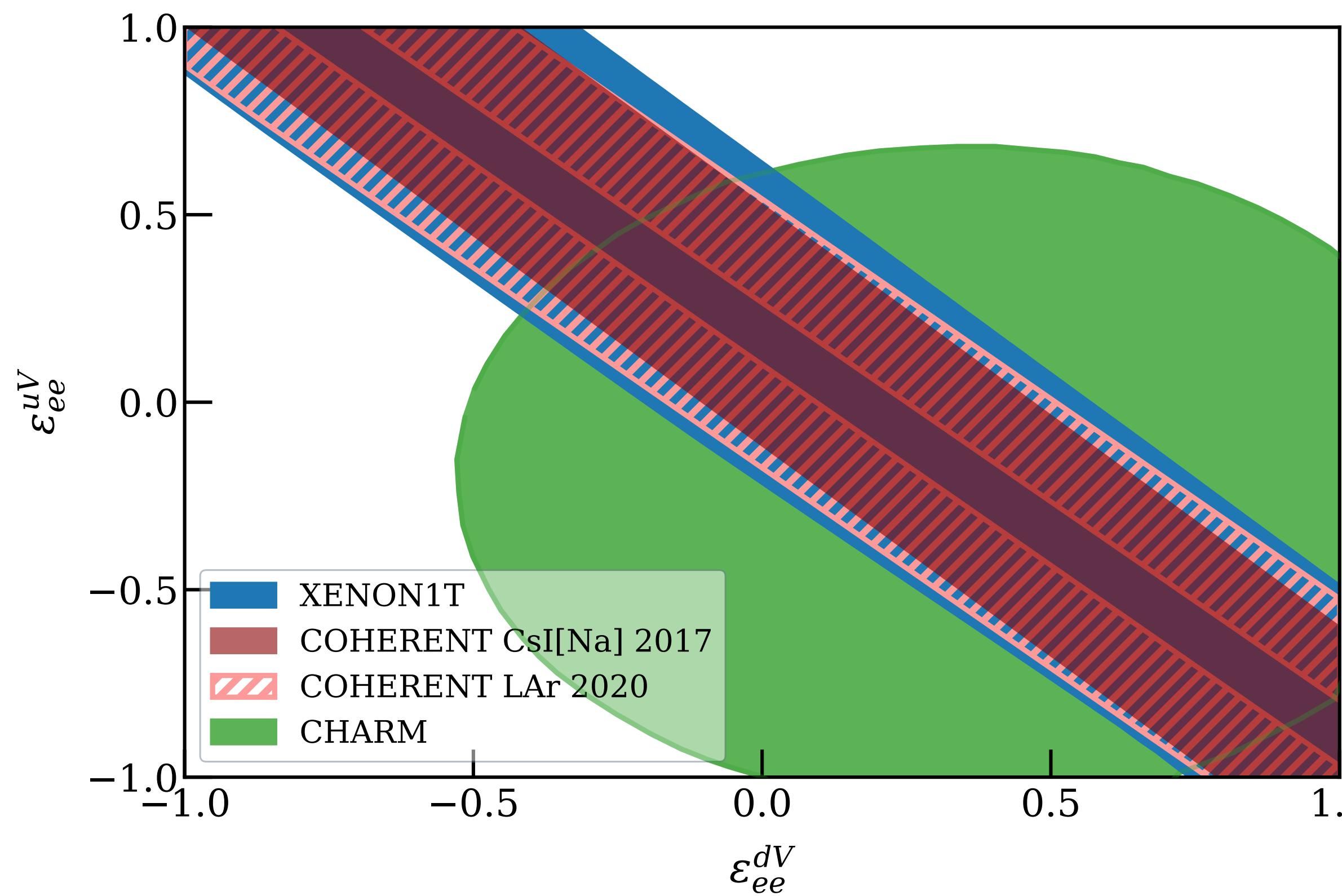
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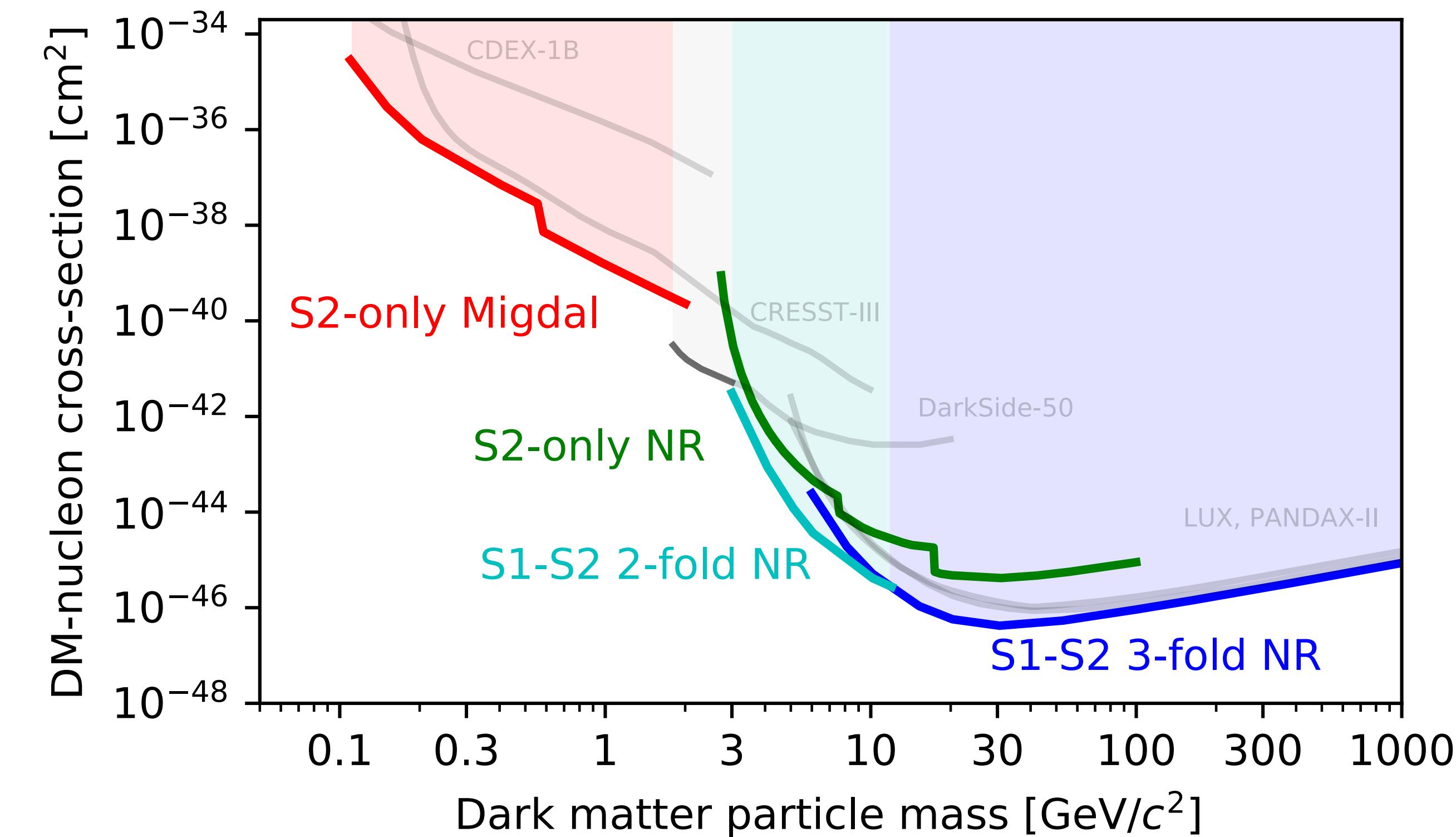
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$\begin{array}{c} \swarrow \\ 0 \end{array} \rightarrow$  Standard Model

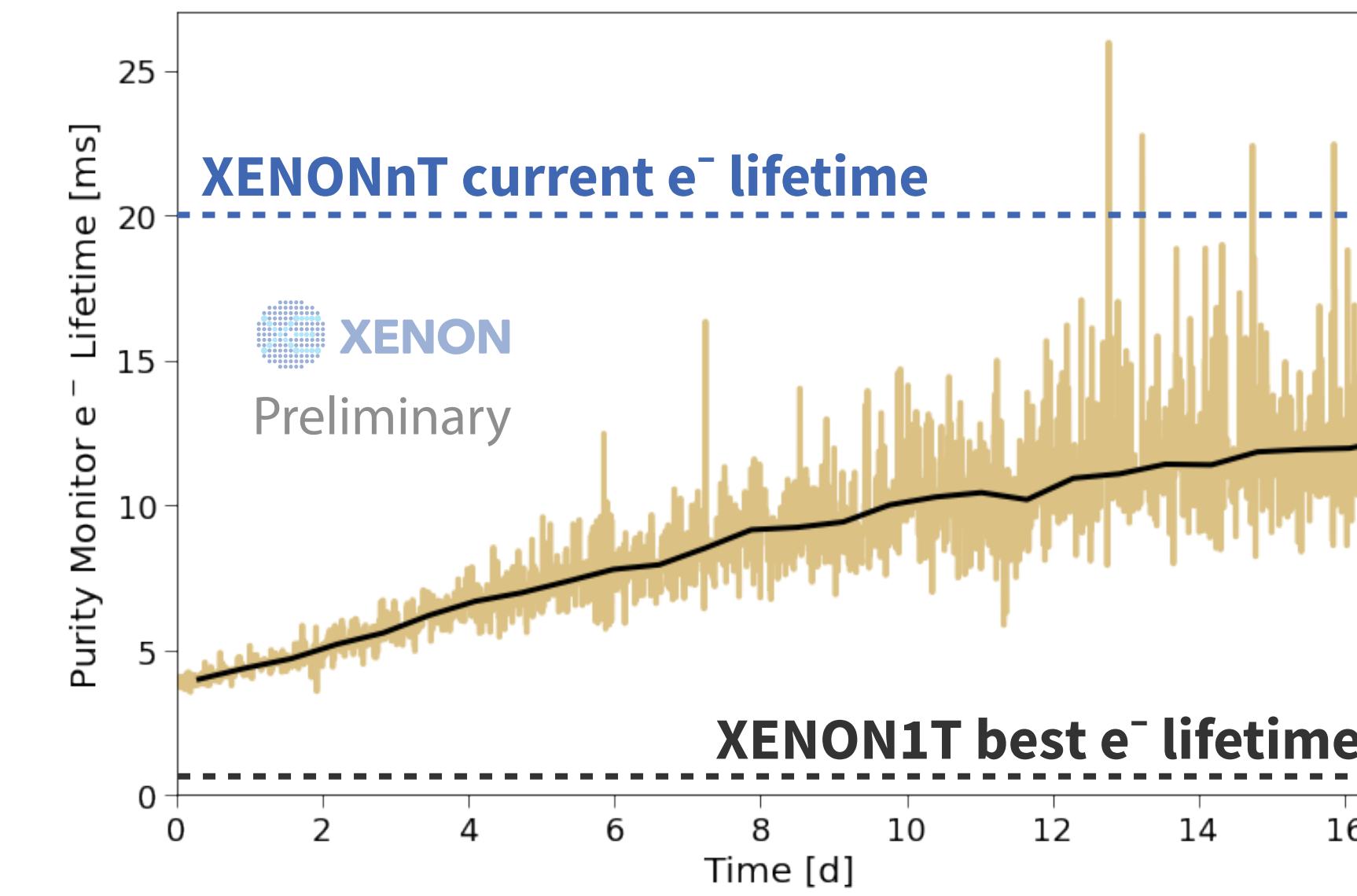
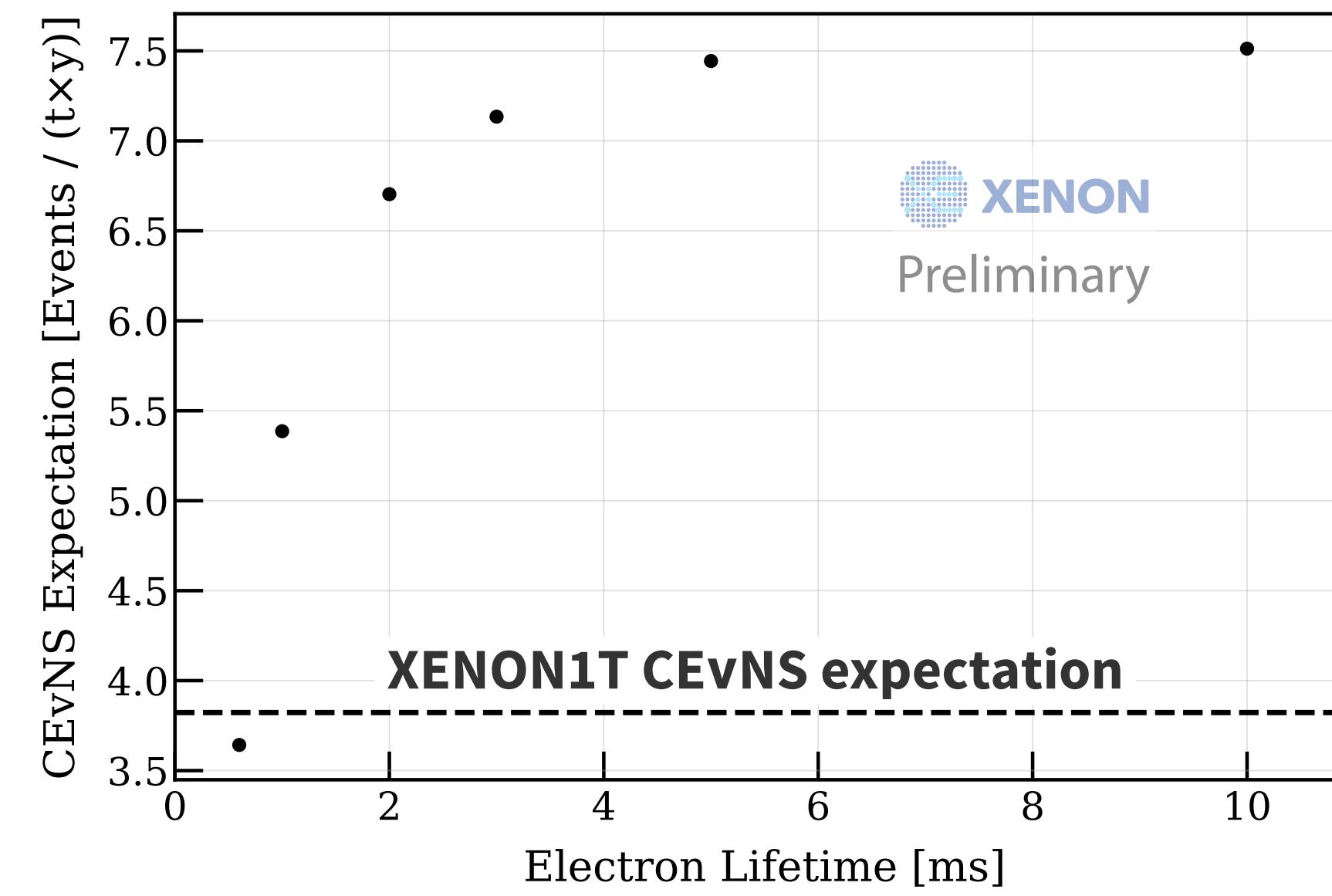


- Considering  ${}^8B$  CEvNS as a background to DM-nucleon interaction search  
→ **improving upon previous limits** in the 3–11 GeV/ $c^2$  DM mass range



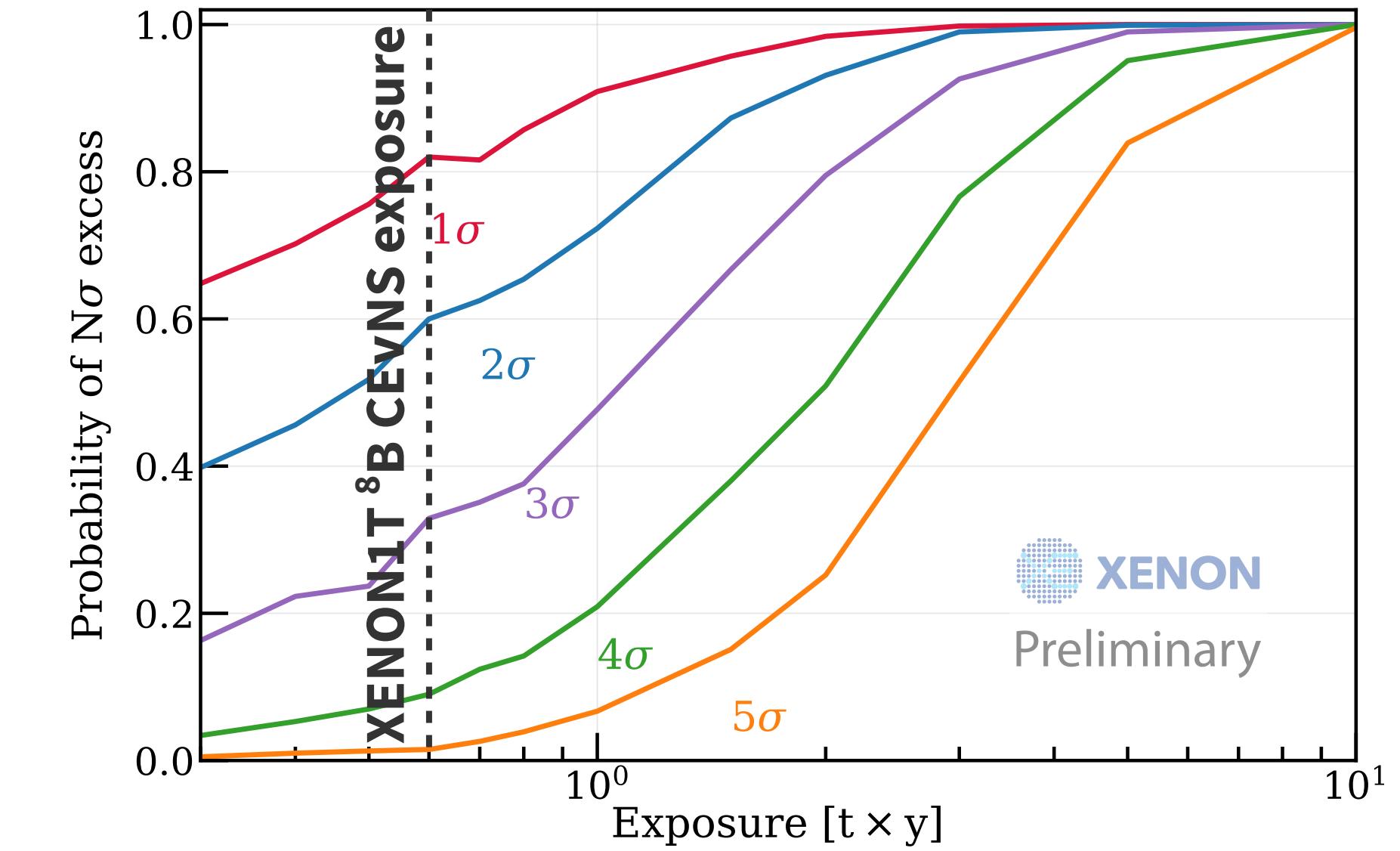
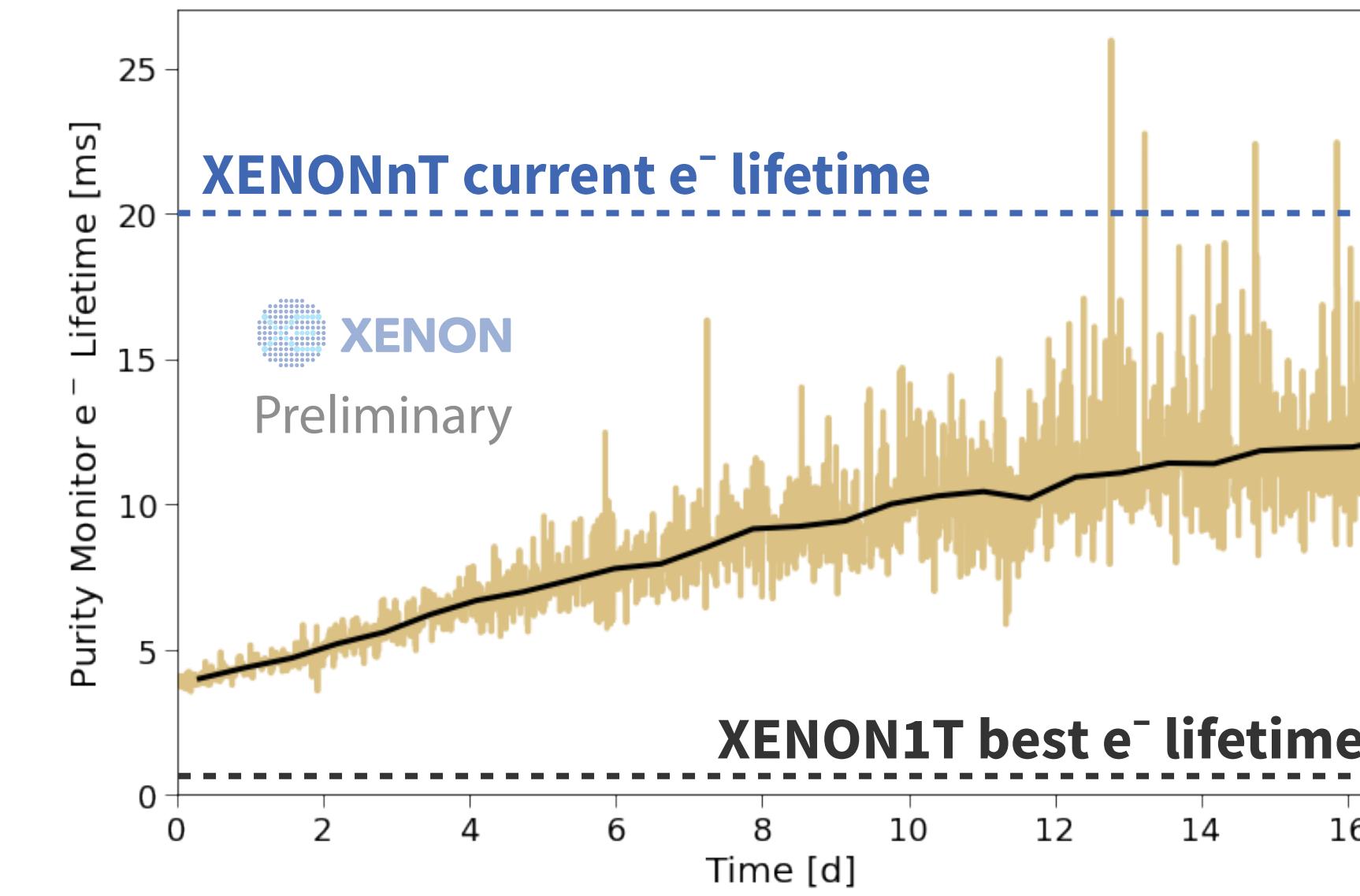
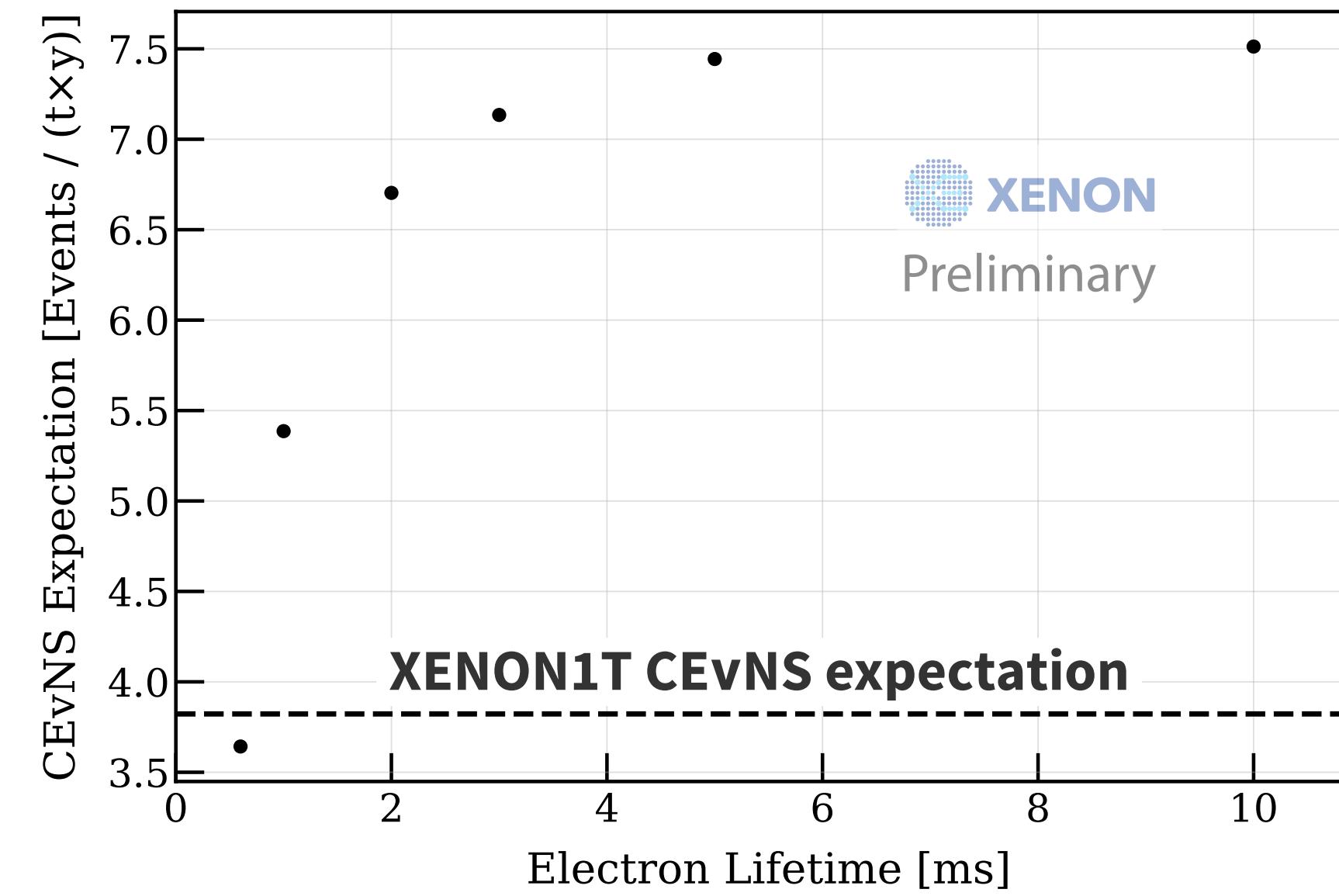
# Solar ${}^8\text{B}$ CEvNS prospects with XENONnT

Higher LXe purity



# Solar ${}^8\text{B}$ CEvNS prospects with XENONnT

Higher LXe purity

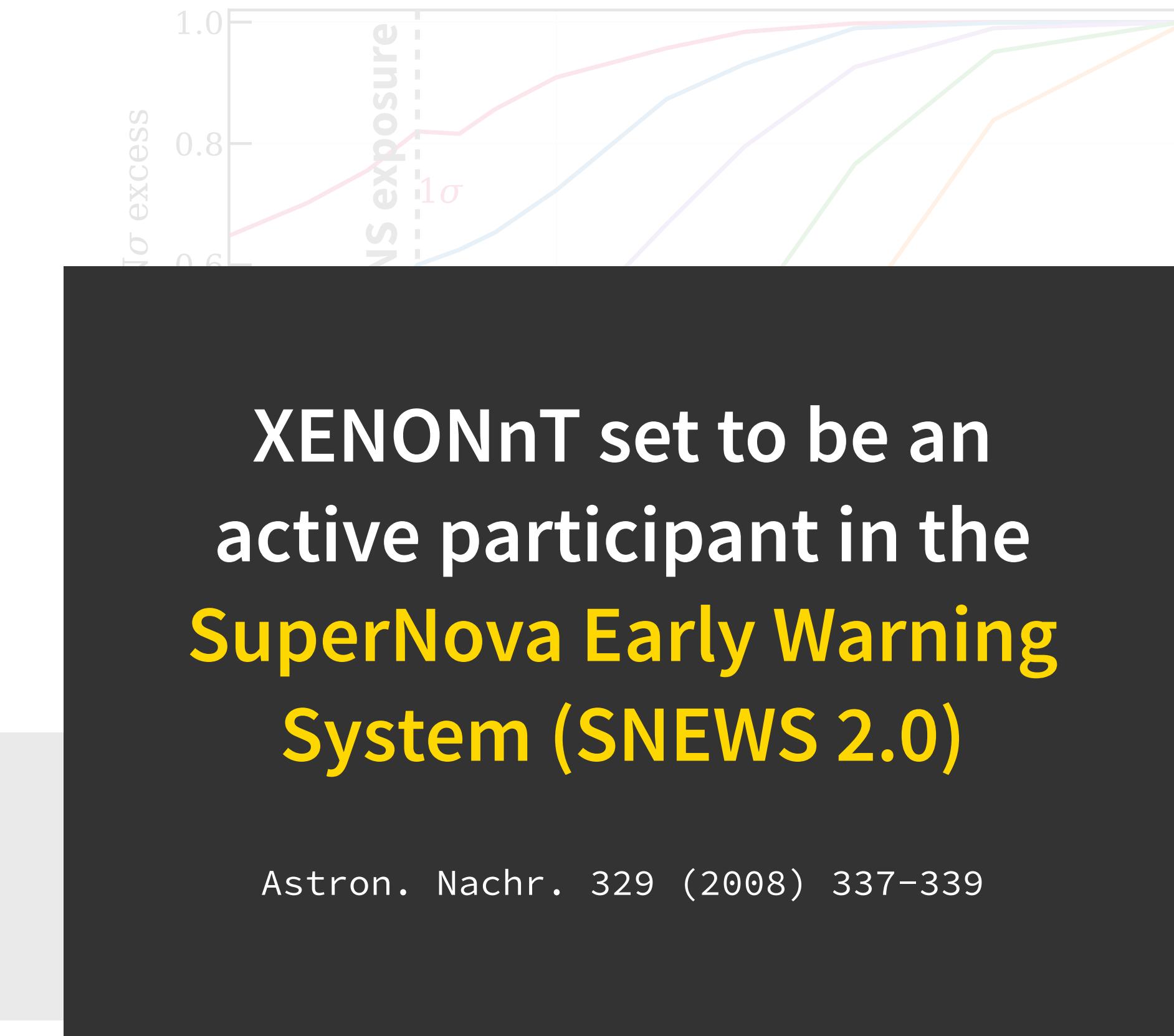
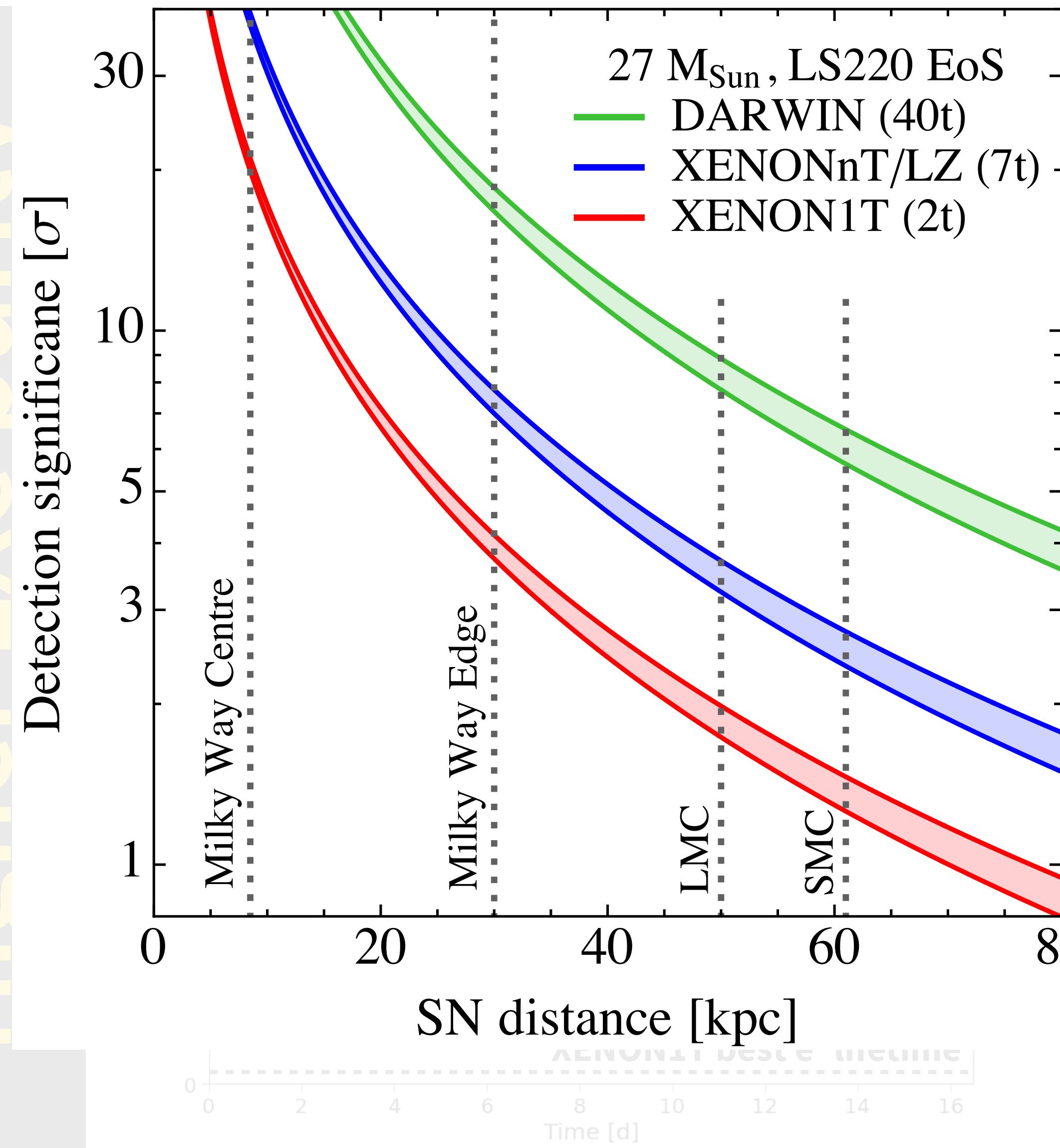


Larger exposure

And also a triggerless DAQ  
(permanently recording all signals)

# Solar $^{8}\text{B}$ CEvNS prospects with XENONnT

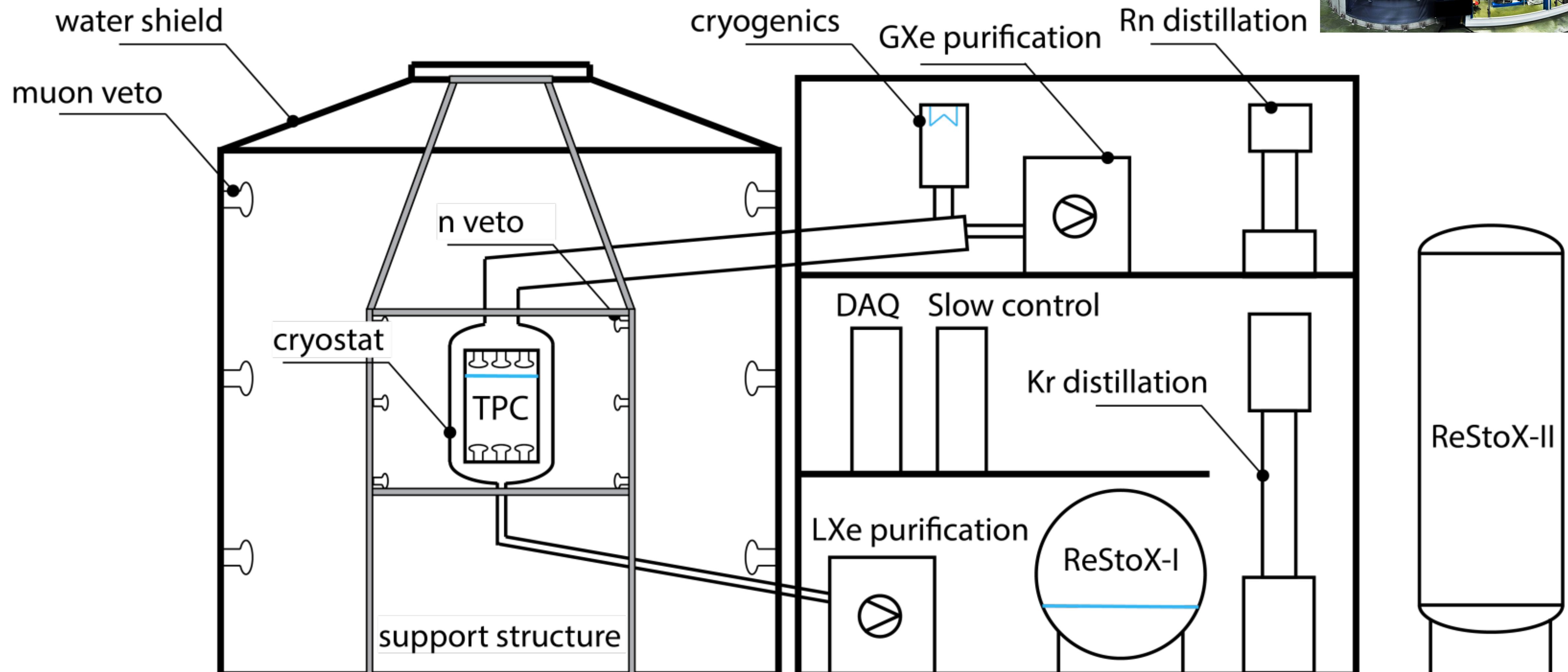
Higher L $\text{Xe}$  purity



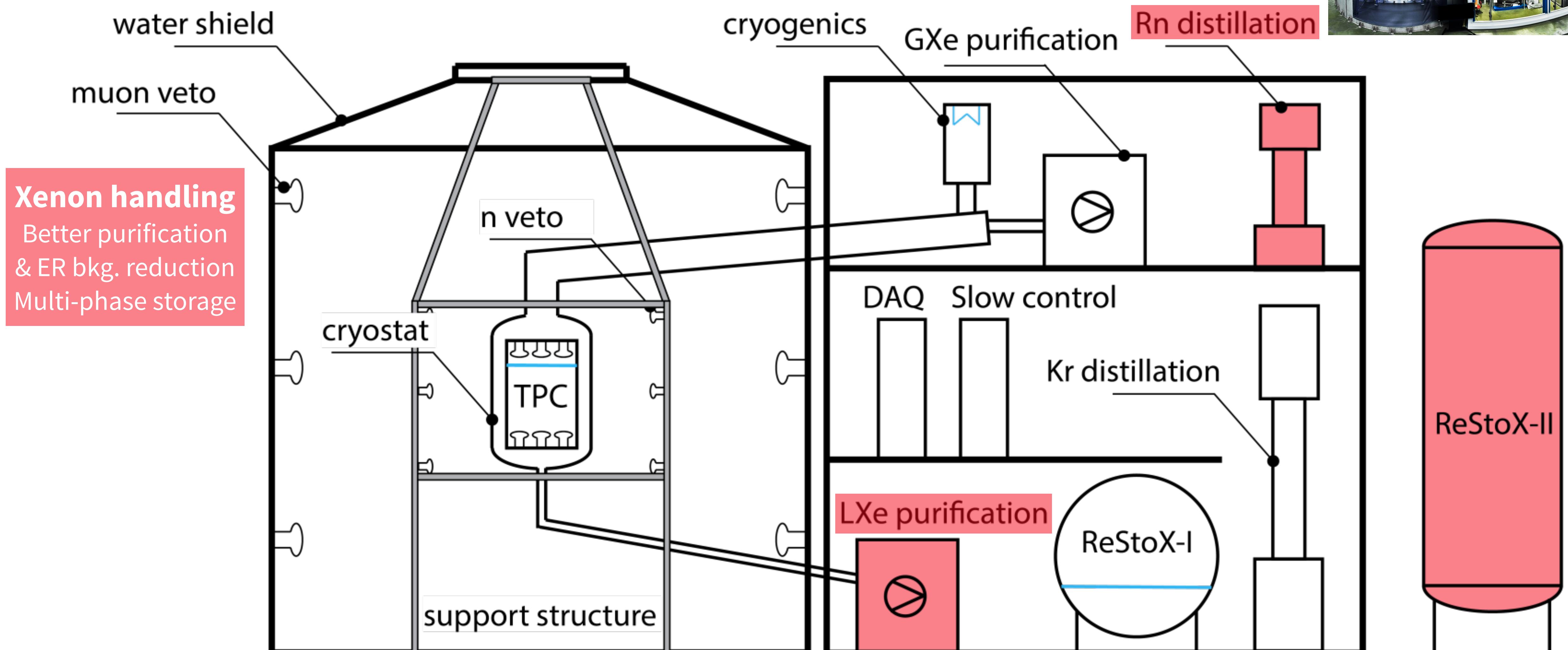
And also a triggerless DAQ  
(permanently recording all signals)

**From  $1\Gamma$  to  $n\Gamma$**

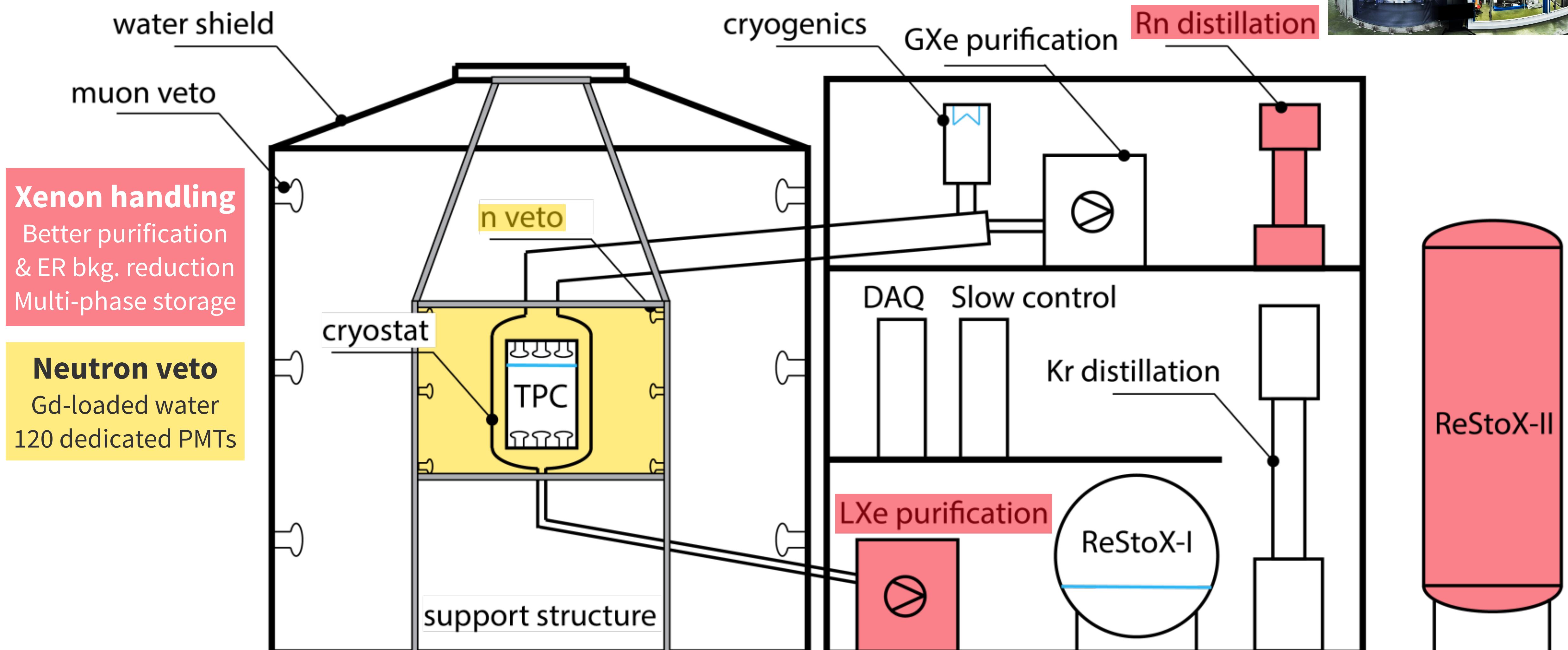
# Meet XENONnT



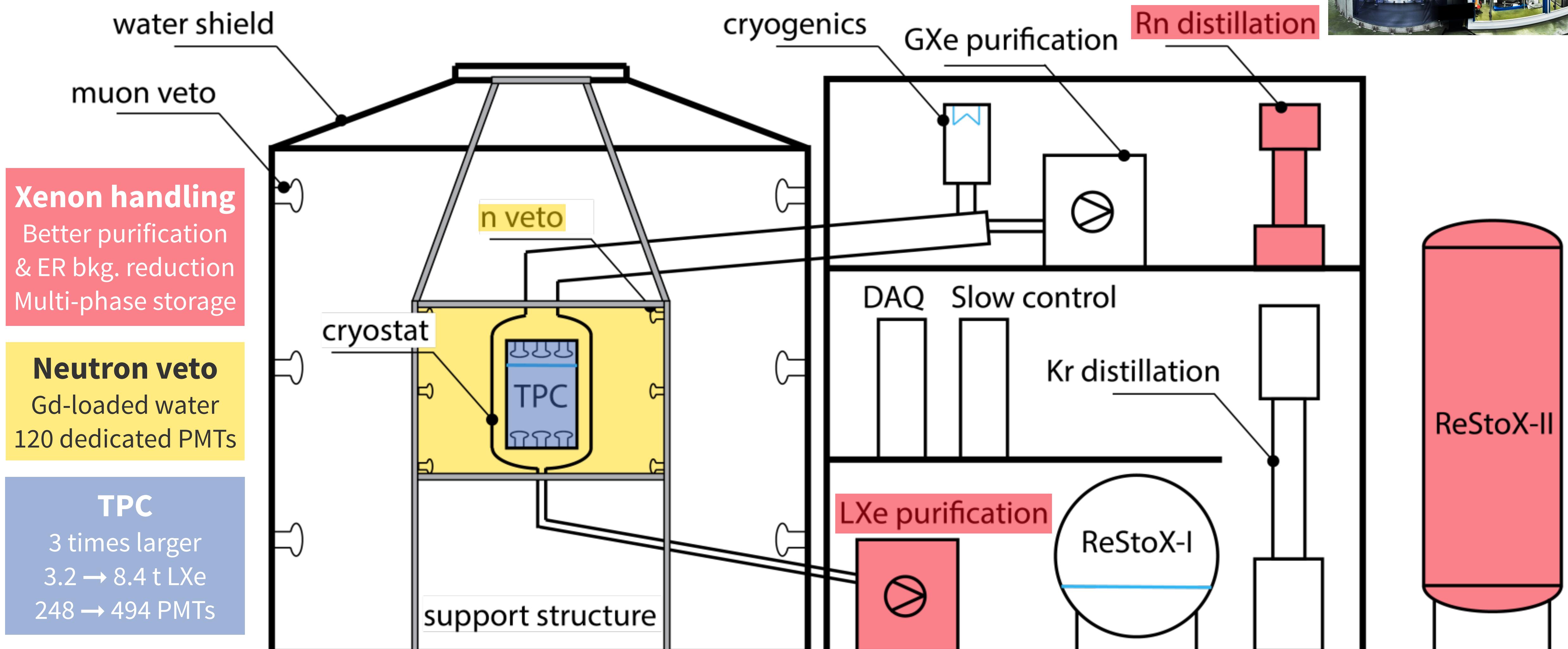
# Meet XENONnT



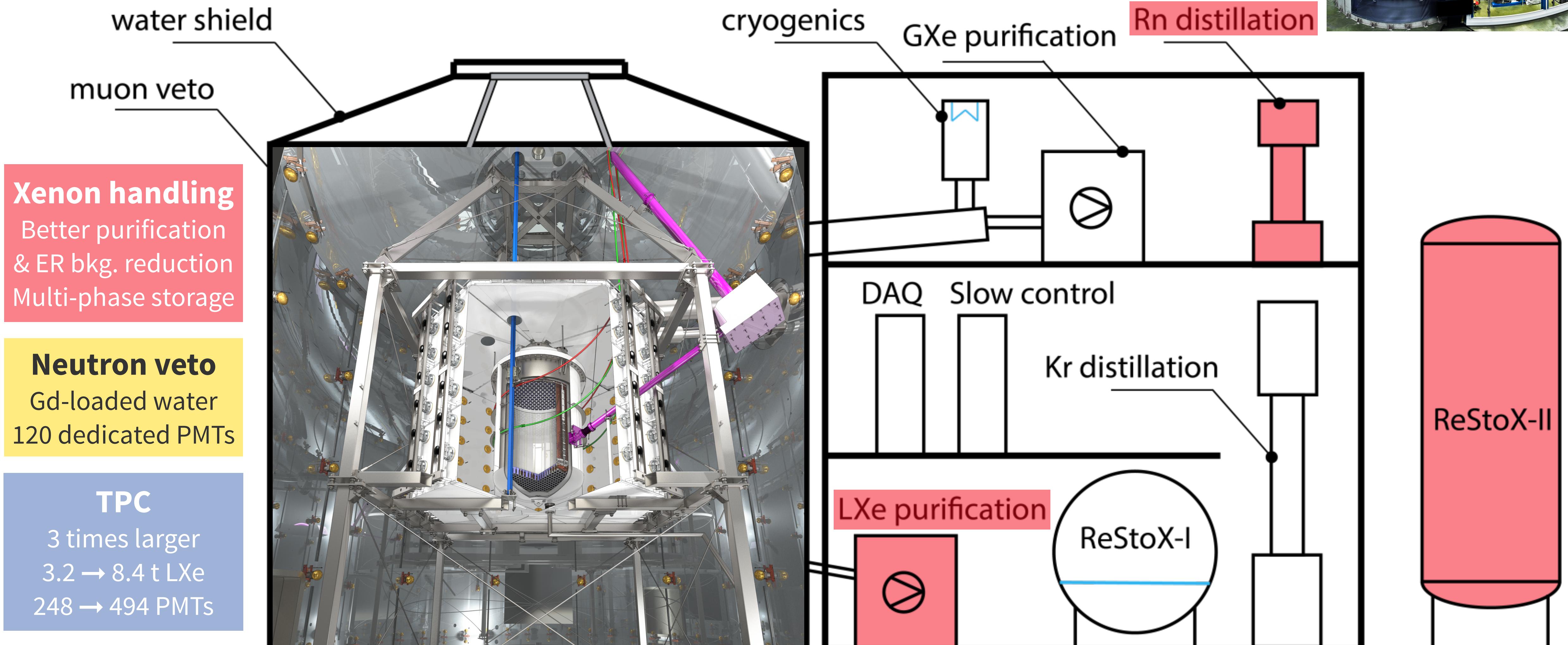
# Meet XENONnT



# Meet XENONnT



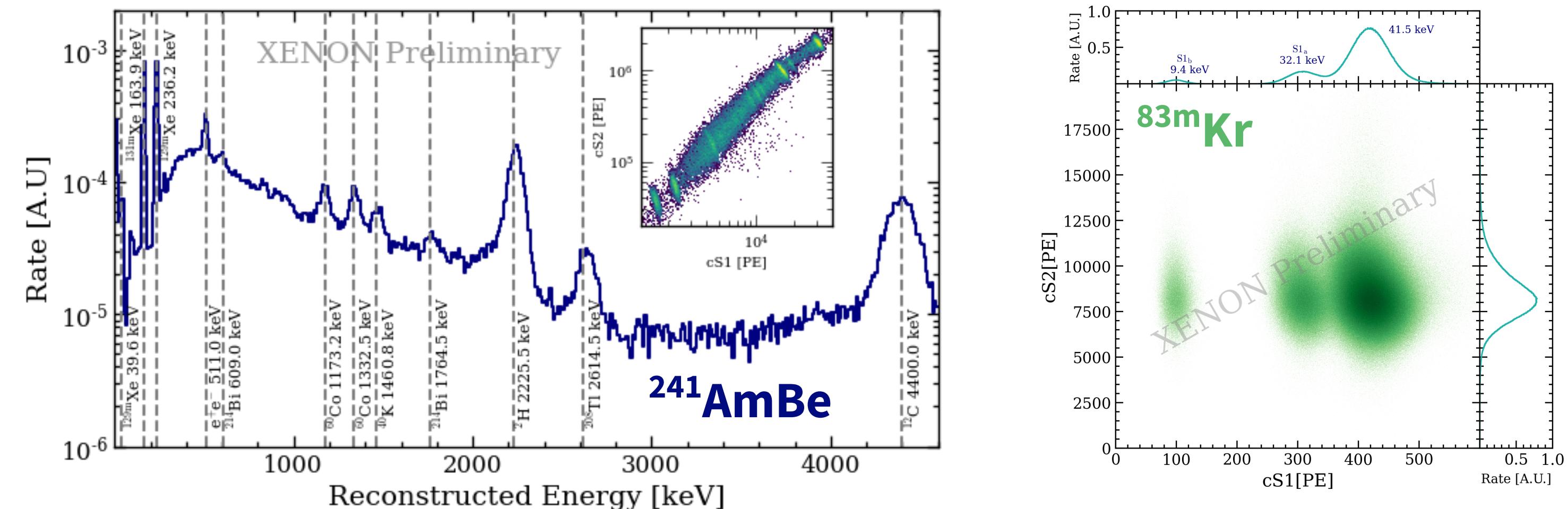
# Meet XENONnT



# Thanks to an outstanding dedication...



# ... XENONnT is alive!



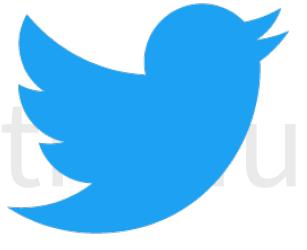
NR & ER responses successfully probed at various energies with  $^{83m}\text{Kr}$ ,  $^{220}\text{Rn}$  and  $^{241}\text{AmBe}$  sources

- 3.2 t → 8.4 t LXe in the full system / **2 t → 5.9 t LXe target mass** inside the TPC
- New **LXe purification** and  **$^{222}\text{Rn}$  reduction** units → greatly improving performance
- Active Čerenkov **neutron veto** → tagging and rejecting neutron captures

... XENONnT is alive!

# First science data Being taken now

energies with  $^{83m}\text{Kr}$ ,  $^{220}\text{Rn}$  and  $^{241}\text{AmBe}$  sources

- ▶ 3.2 t → 8.4 t LXe in the full system  **@XENONexperiment** inside the TPC
- ▶ New **LXe purification** and  **$^{222}\text{Rn reduction}$**  units → greatly improving performance
- ▶ Active Čerenkov **neutron veto** → tagging and rejecting neutron captures

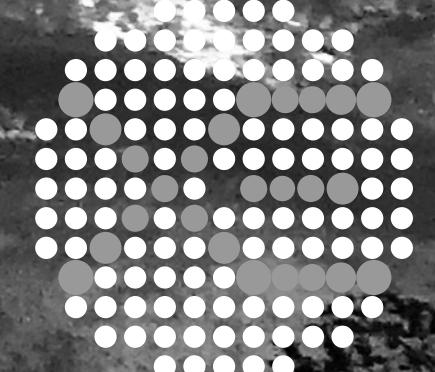
# Merci pour votre attention !

Dr. Erwann Masson

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🐦 @DrErwannMasson



XENON