XX International Workshop on Neutrino Telescopes

Monday, 23 October 2023 - Friday, 27 October 2023
Istituto Veneto di Scienze, Lettere ed Arti, Venice

Neutrinos in XENONnT dark matter experiment

Emanuele Angelino

on behalf of the XENON collaboration

UNIVERSITÀ DI TORINO

INFN TORINO

INAF ISTITUTO NAZIONALE DI ASTROFISICA OSSERVATORIO ASTROFISICO DI TORINO

XENON

The XENON project

Direct search for dark matter with **liquid xenon (LXe)** deep underground at the INFN **Laboratori Nazionali del Gran Sasso** (LNGS) in Italy

XENON10	XENON100	XENON1T	XENONnT
25 kg	**161 kg**	**3.2 t**	**8.5 t**
2005	2008	2016	2020

1.4 km rock/3600 m.w.e.

10^6 μ reduction factor

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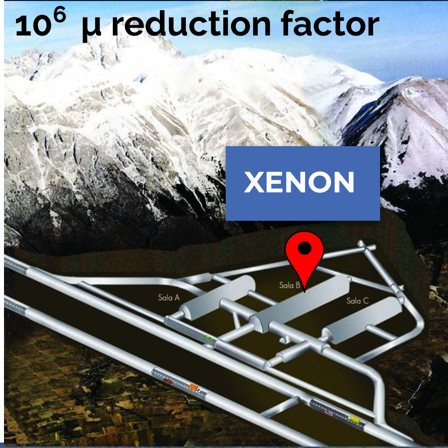

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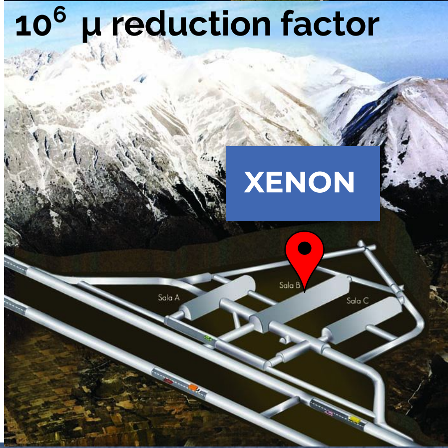
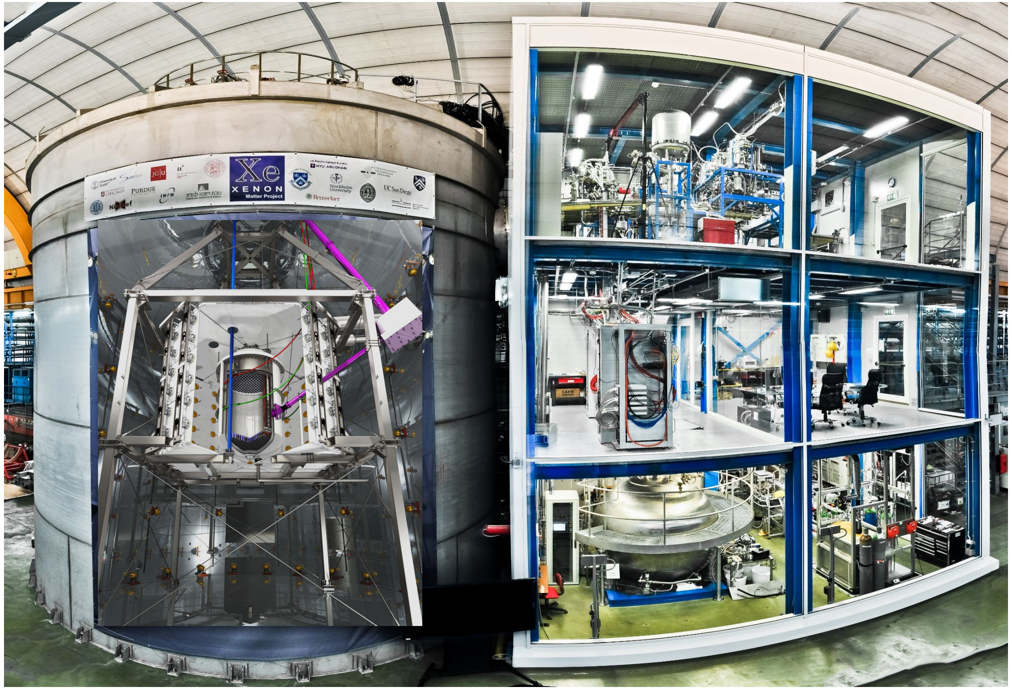


Dark matter searches require **extremely low background**

Many other physics channels can be investigated!

The XENONnT experiment

WATER TANK   SERVICE BUILDING



The XENONnT experiment

Dual-phase Xe TPC new

Drift length	**1.5 m**
Total mass	**8.5 t**
Active mass	**5.9 t**
Photosensors	**494 PMTs**

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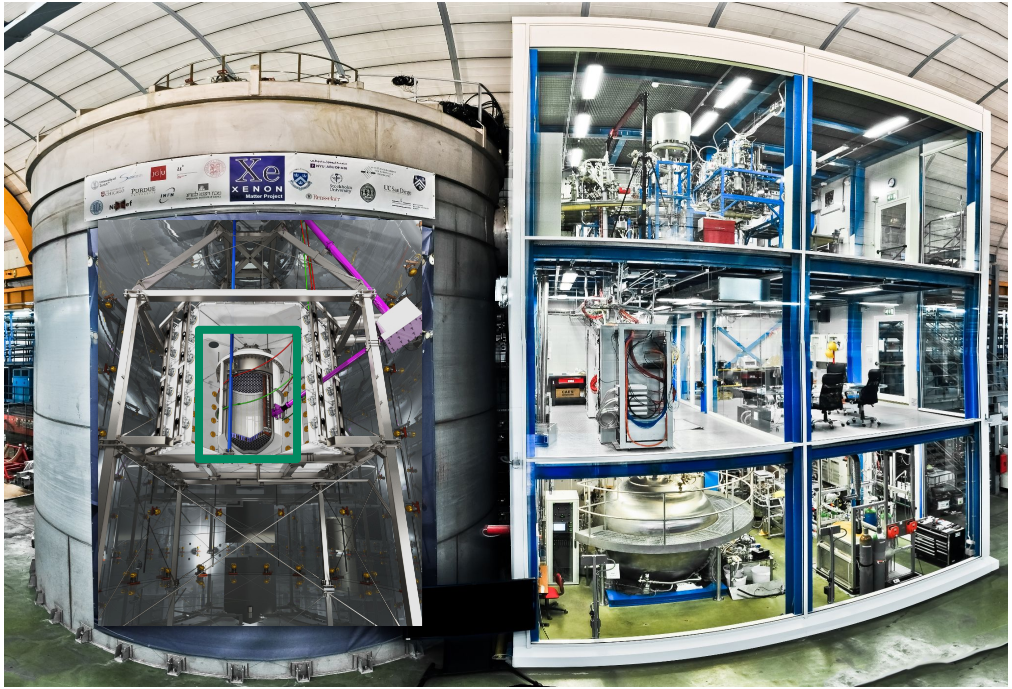

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Neutron veto
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Water **Cherenkov** detector ($33\ m^3$)

Neutron tagging efficiency: **53%**

Soon with **Gd-doped water** (expected **87%** efficiency)

Photosensors **120 PMTs**

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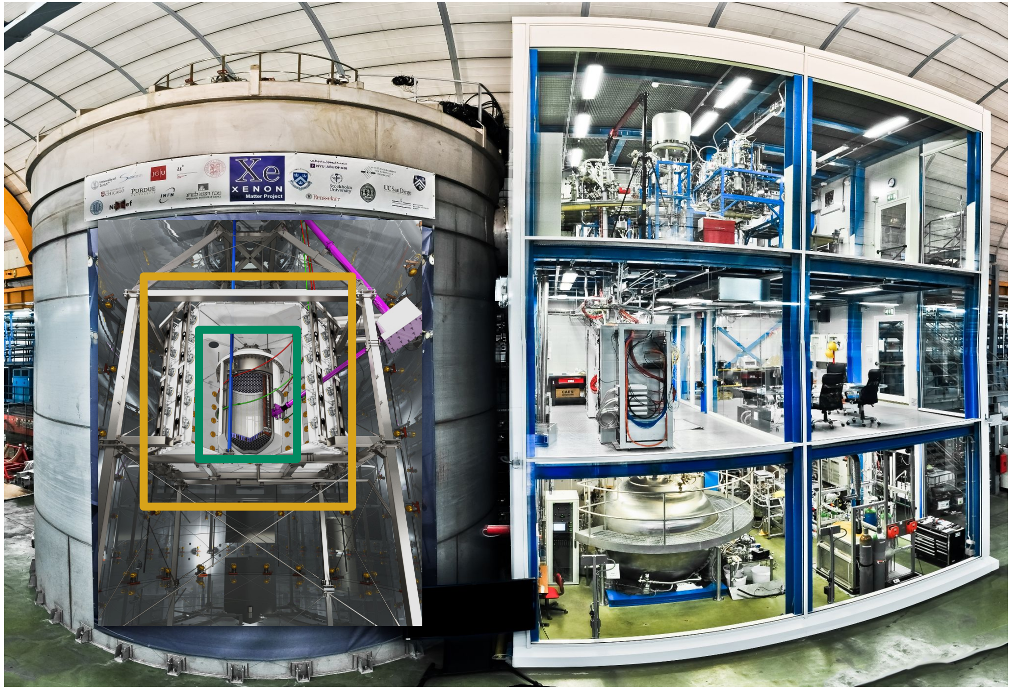

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700 t ultra-pure **water**
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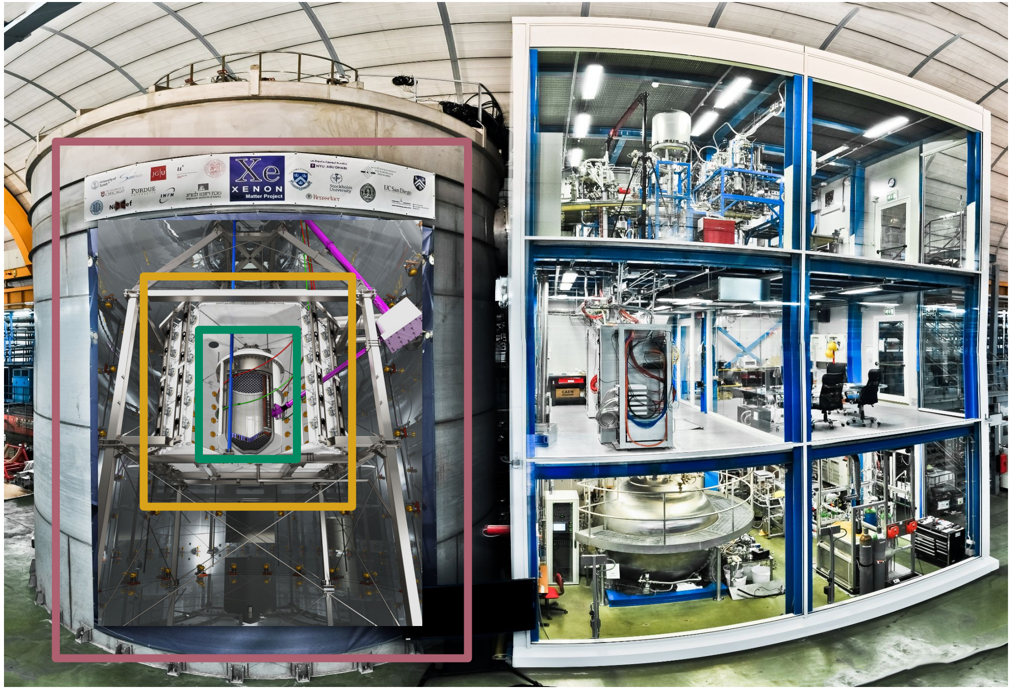

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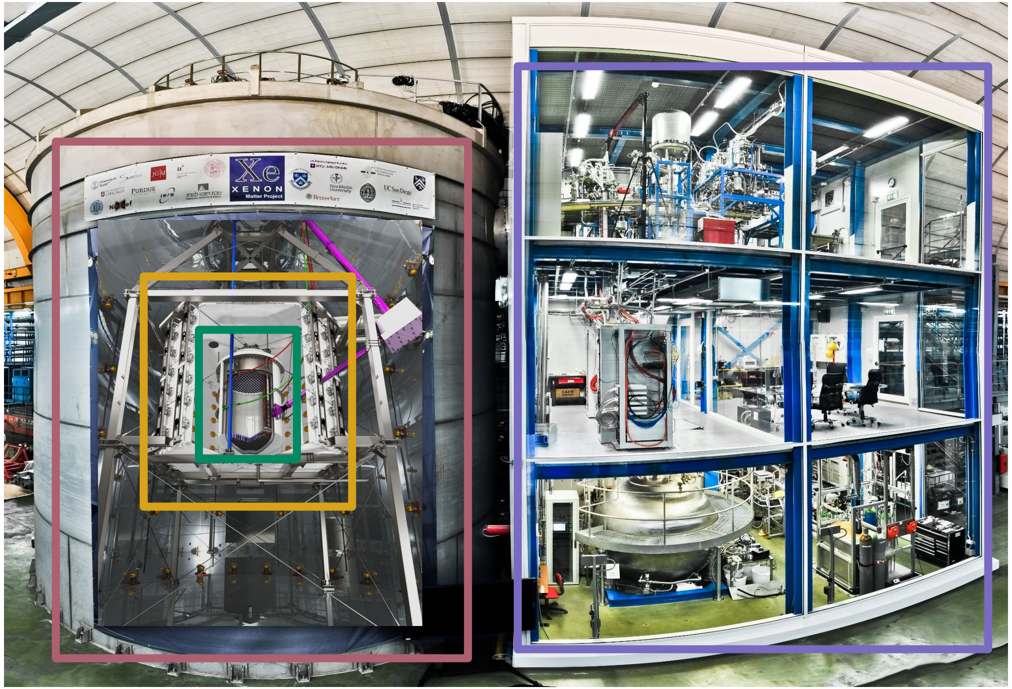


Cryogenics

GXe Purification
Calibration System

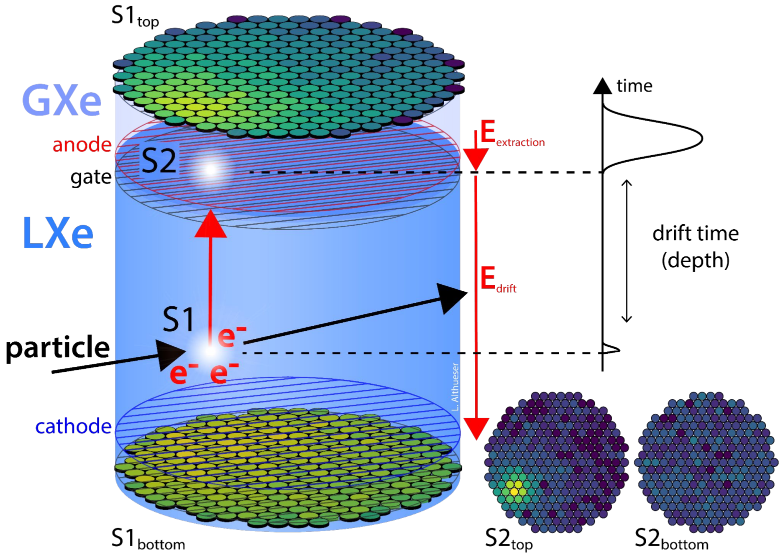
Electronics

Data Acquisition
Slow Control

Recovery & Purification

Kr Distillation Column
Rn Distillation Column new
LXe Storage
LXe Purification new

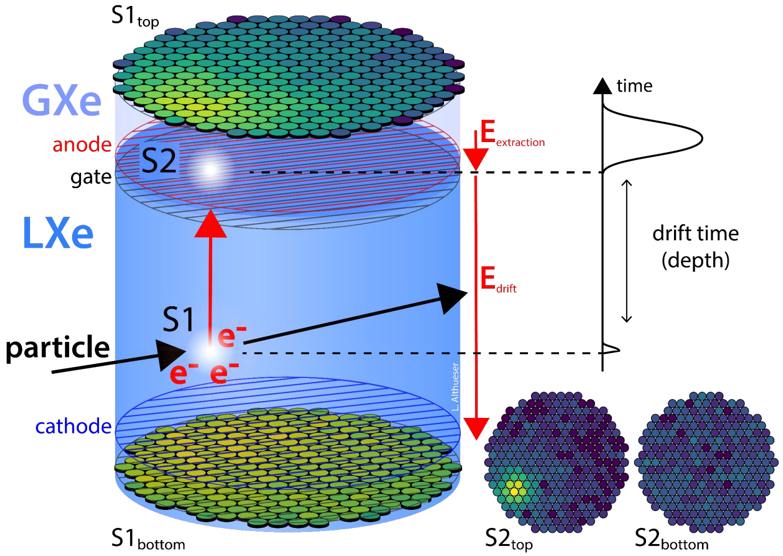
Dual-phase Time Projection Chamber



In **dual-phase** Time Projection Chamber (**TPC**) **scintillation** and **ionization** signals:

- **Prompt scintillation** light → **S1**
- **Secondary scintillation** proportional to **drifted electrons** → **S2**

Dual-phase Time Projection Chamber



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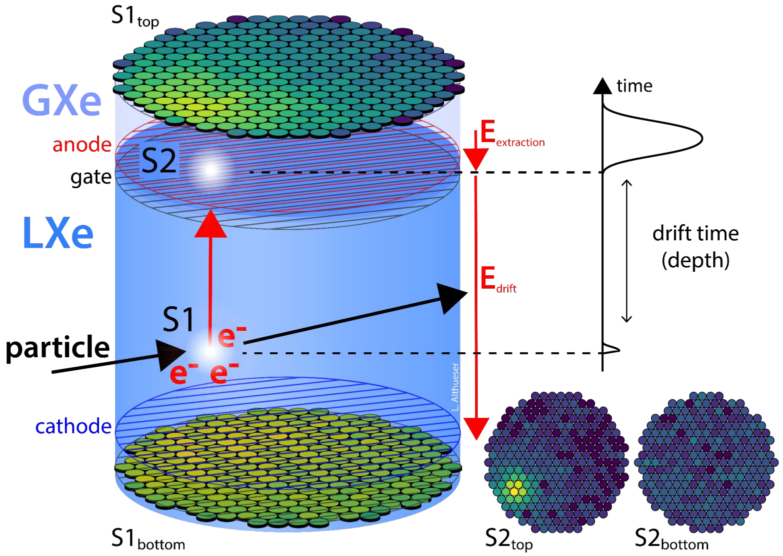
ENERGY RECONSTRUCTION
from **combining S1** and **S2** signals

3D POSITION RECONSTRUCTION
x-y from PMTs **light pattern**, **z** from **drift time**

RECOIL TYPE IDENTIFICATION
S2/S1 different for **Electronic Recoils** (**ER**) and **Nuclear Recoils** (**NR**), resulting in two bands

Dual-phase Time Projection Chamber



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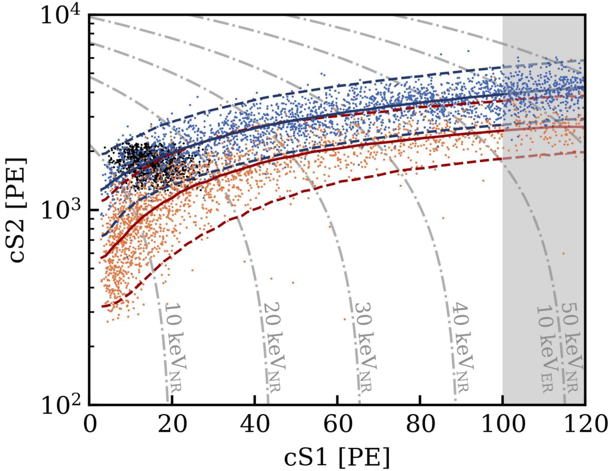
Electronic Recoils

Electrons, photons, neutrinos, (axions ...)

Nuclear Recoils

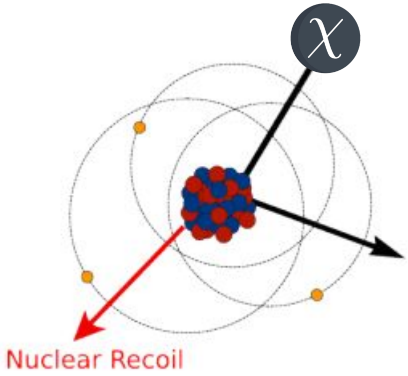
Neutrons, neutrinos via coherent scattering, (WIMPs ...)



Phys. Rev. Lett. 131, 041003, 2023

Dark matter and neutrino detection

WIMP dark matter is expected to induce **O(1)-O(10) keV NR scattering** off xenon atoms, as well as neutrons



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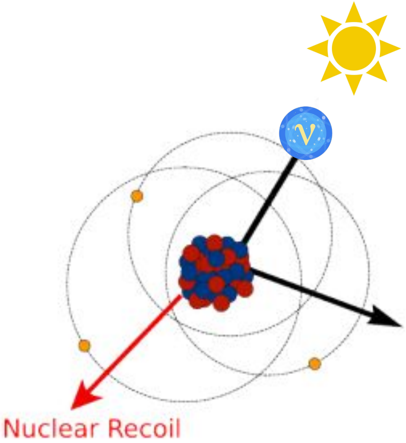
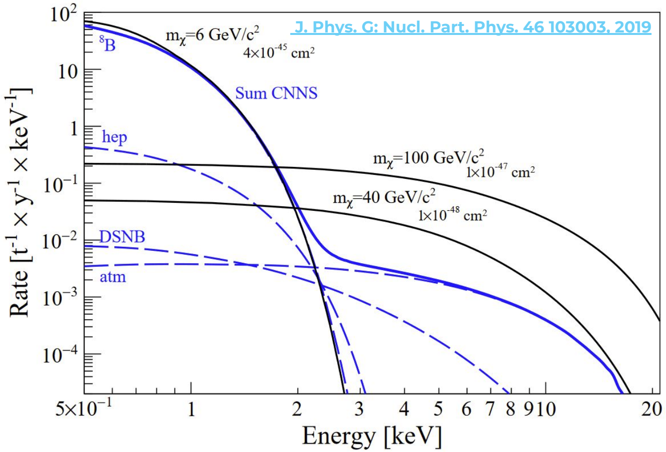
Coherent elastic neutrino nucleus scattering (**CEvNS**) has the **same** signature of **low mass** spin-independent **WIMP** interaction, producing low-energy **NRs** (via Z-exchange, ∝ $(A\text{-}Z)^2$)





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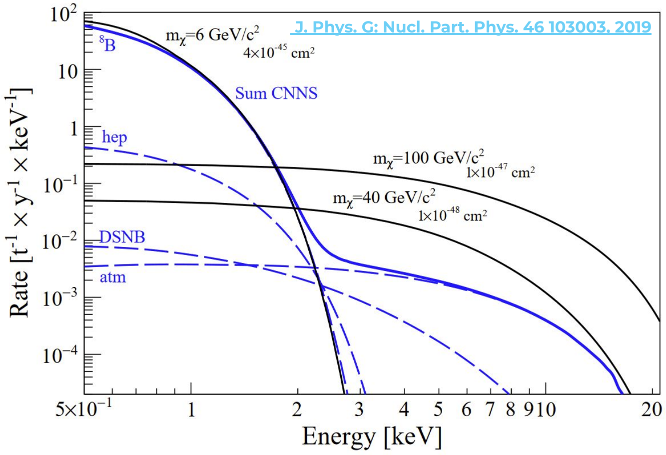
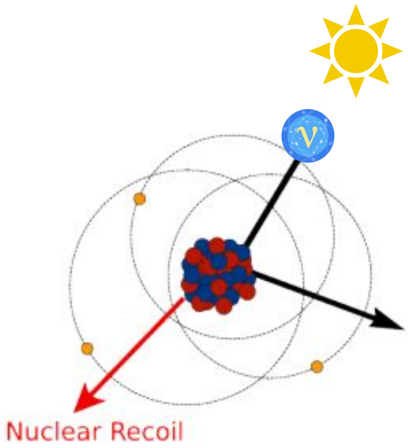
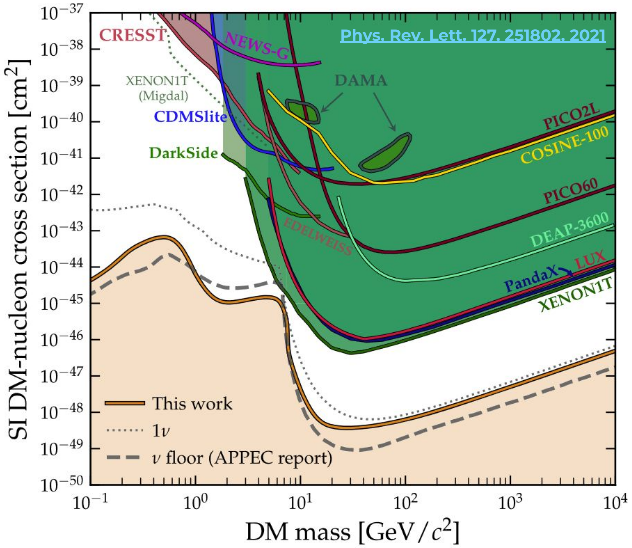




Current detectors are approaching the **neutrino "fog"**, where **distinction** between WIMPs and neutrinos is **challenging**

Neutrino "**floor**", indicated where DM experiment are inevitably limited by **irreducible background** from neutrinos



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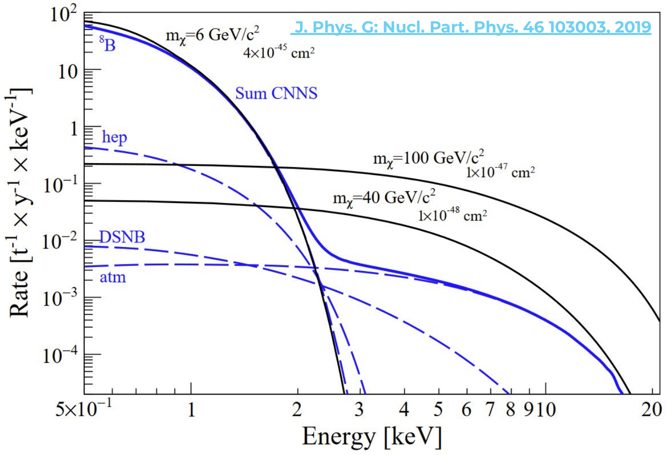

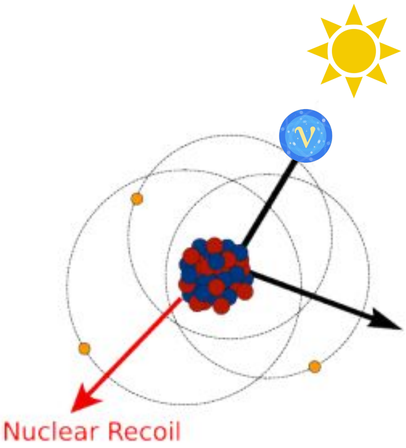

CEνNS process, first measured in **2017** by **COHERENT**, has **never** been observed for **solar neutrinos**

Solar ^{8}B, which is the **main** contributor, can be treated as a **signal** and **detected** in LXe **DM** experiment!

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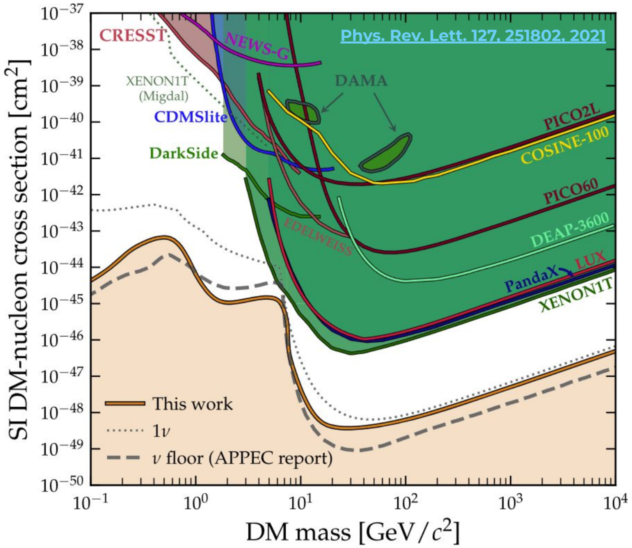
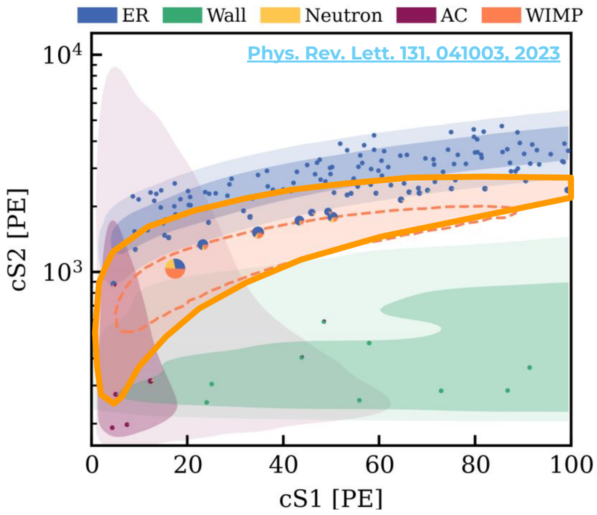


Nuclear Recoils in XENONnT SR0



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	ROI		Signal-like
ER	134	135^{+12}_{-11}	0.92 ± 0.08
Neutrons	$1.1^{+0.6}_{-0.5}$	1.1 ± 0.4	0.42 ± 0.16
CEνNS	0.23 ± 0.06	0.23 ± 0.06	0.022 ± 0.006
AC	4.3 ± 0.9	$4.4^{+0.9}_{-0.8}$	0.32 ± 0.06
Surface	14 ± 3	12 ± 2	0.35 ± 0.07
Total background	154	152 ± 12	$2.03^{+0.17}_{-0.15}$
WIMP	...	2.6	1.3
Observed	...	152	3

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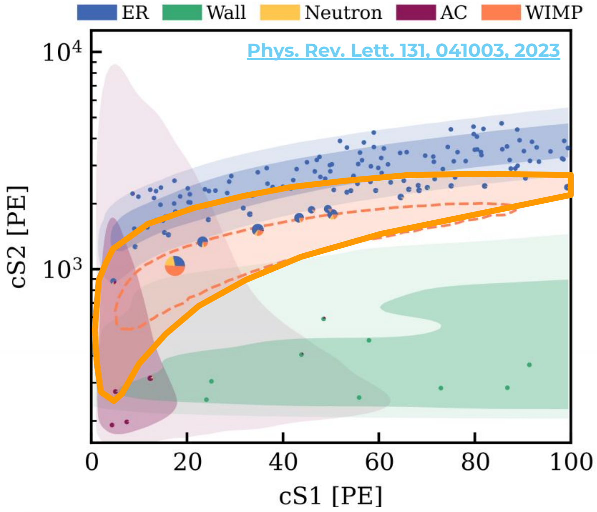

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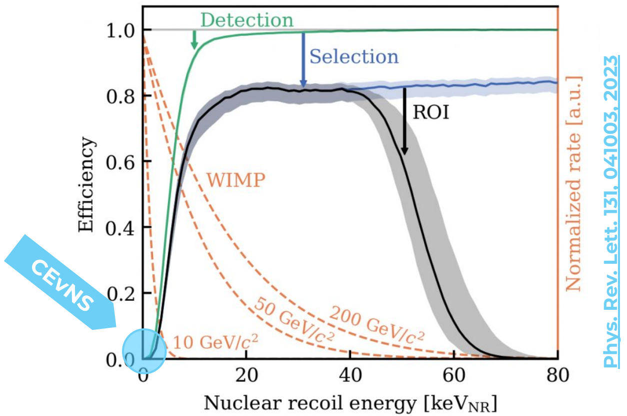
Expected **hundreds** of events from **CEvNS** in detector:

$$R = \phi(\nu) \times \sigma_\nu \times \text{exposure}$$
$$\simeq 600 \,\text{events}/(\text{tonne} \times \text{year})$$

but at extremely low energies.
Detection **efficiency** for **v** in **NR** search is around 0.04%, too **low** for **detection**



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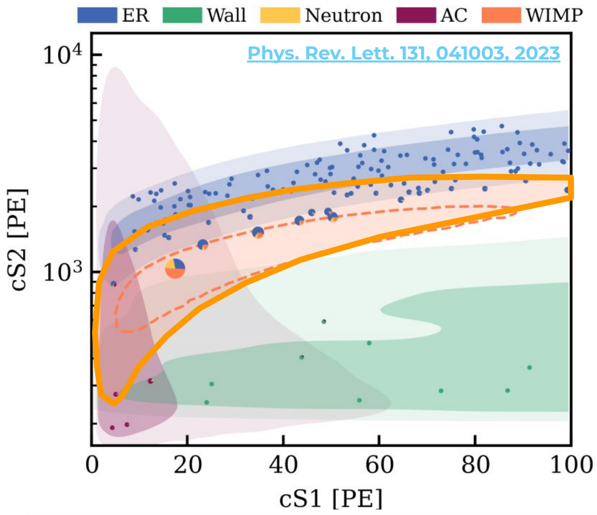

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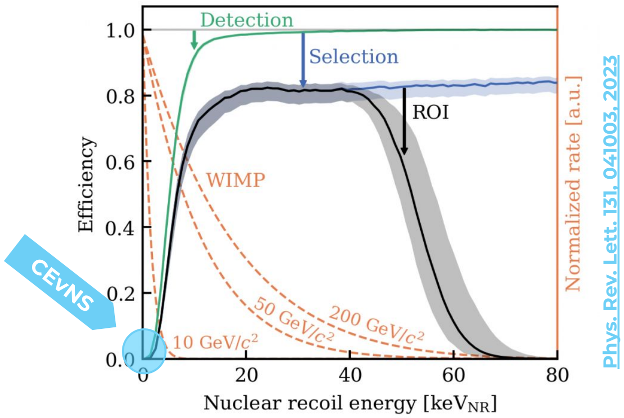
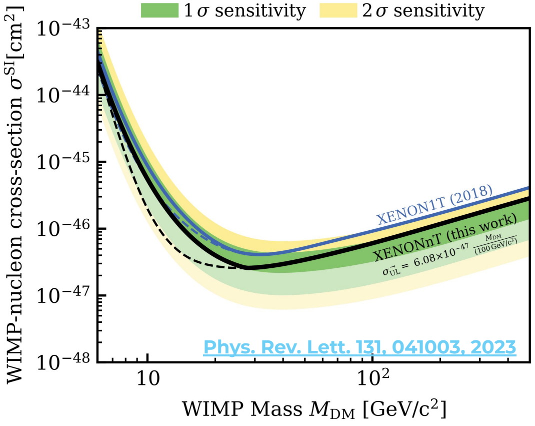
Blinded NR analysis with **4.2 t** fiducial mass and total **exposure** of **1.1 t × y** in **Science Run 0** (**SR0**)

No significant excess

Upper limit for **WIMP** interactions σ, minimum at **2.6 × 10^{-47} cm^2** at **28 GeV/c^2** (spin-independent)





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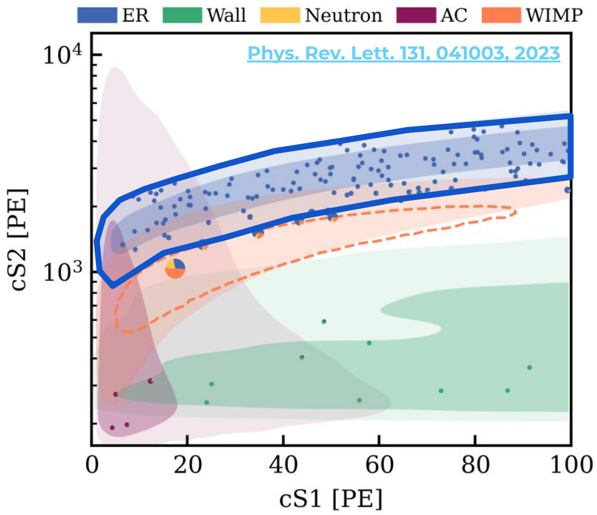

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^{214}Pb	(570, 1200)	960 ± 120
^{85}Kr	90 ± 60	90 ± 60
Materials	270 ± 50	270 ± 50
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Solar neutrino	300 ± 30	300 ± 30
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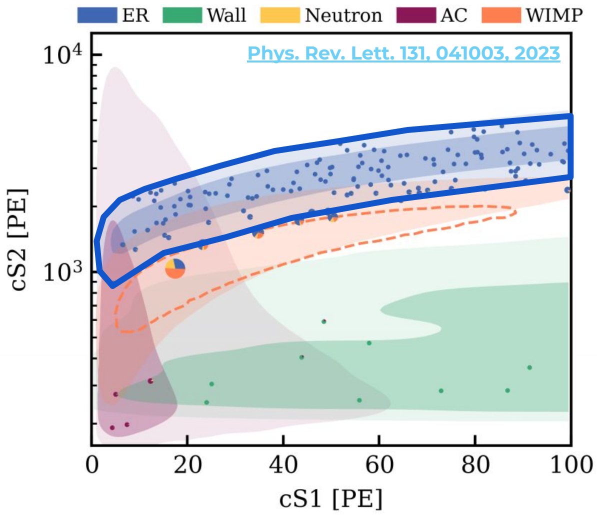

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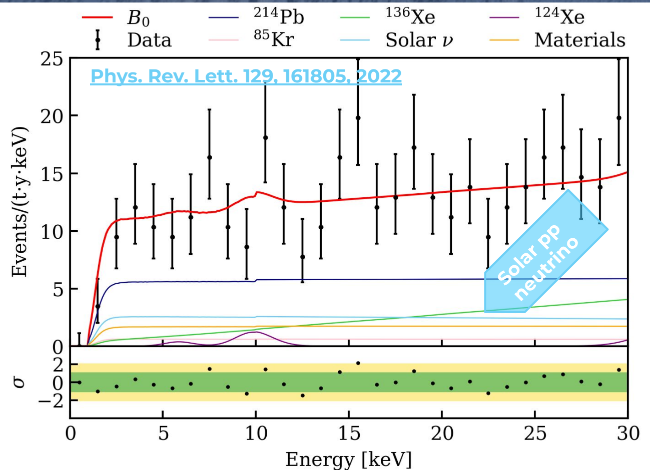

Lowest background rate ever achieved in this **energy range** thanks to radio-purity **screening** and **online** cryogenic **radon distillation** (16.1 ± 1.3 events / t × y × keV) in [1,30] keV

Solar neutrinos (**pp** reaction) elastic scattering off **e$^-$** of LXe

Magnetic moment of neutrino would cause **enhanced interaction** with **e$^-$**

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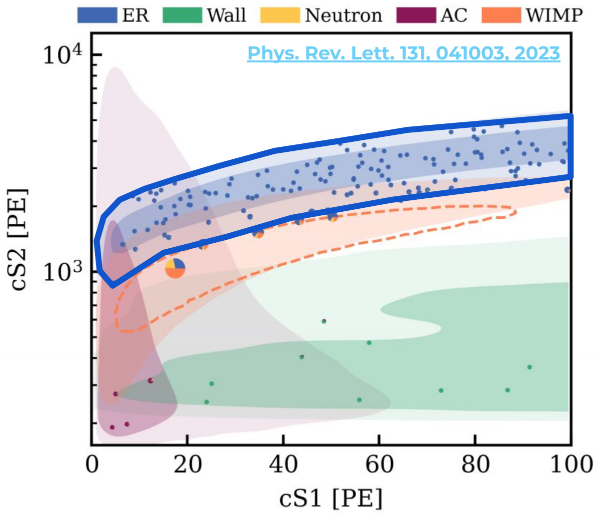

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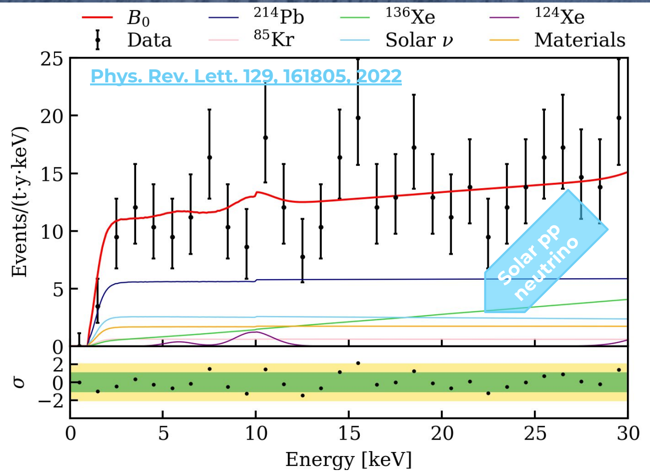

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Solar neutrinos (**pp** reaction) elastic scattering off **e$^-$** of LXe

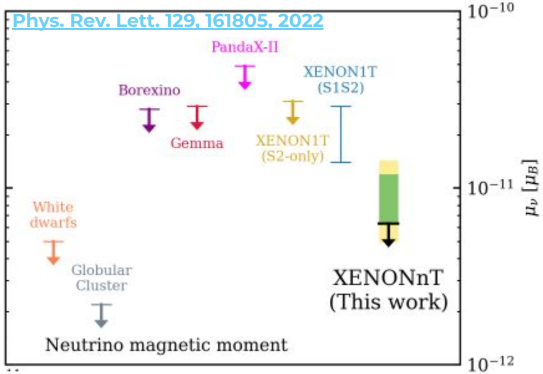
Magnetic moment of neutrino would cause **enhanced interaction** with **e$^-$**

Blinded ER analysis with **1.16 t × y** exposure (SR0)

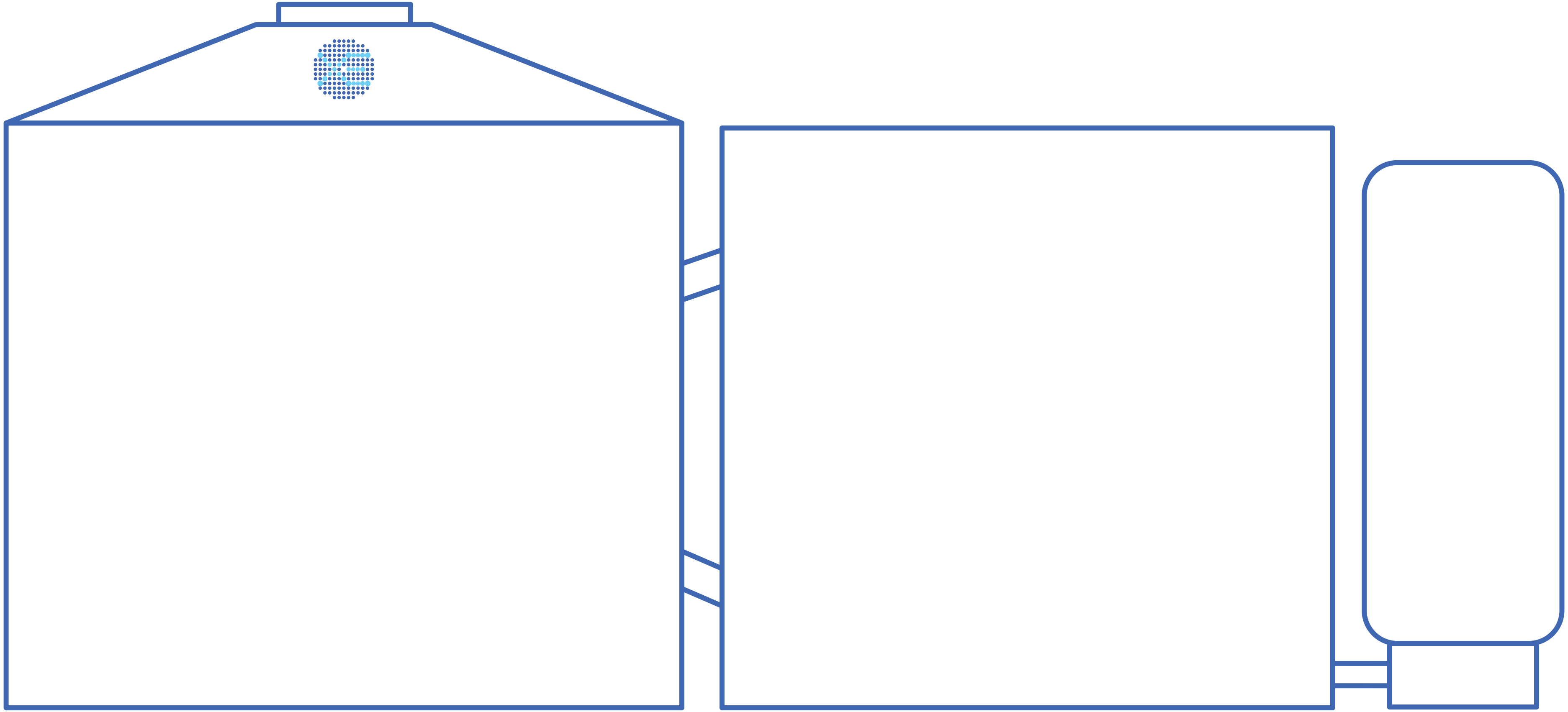
Strongest experimental limit to date, **competitive** to **indirect** searches, for magnetic moment

$$\mu_\nu < 6.3 \times 10^{-12} \mu_B$$

With **lower background, solar pp** neutrino interaction rate could be directly **measured**



Neutrino searches in XENON detectors



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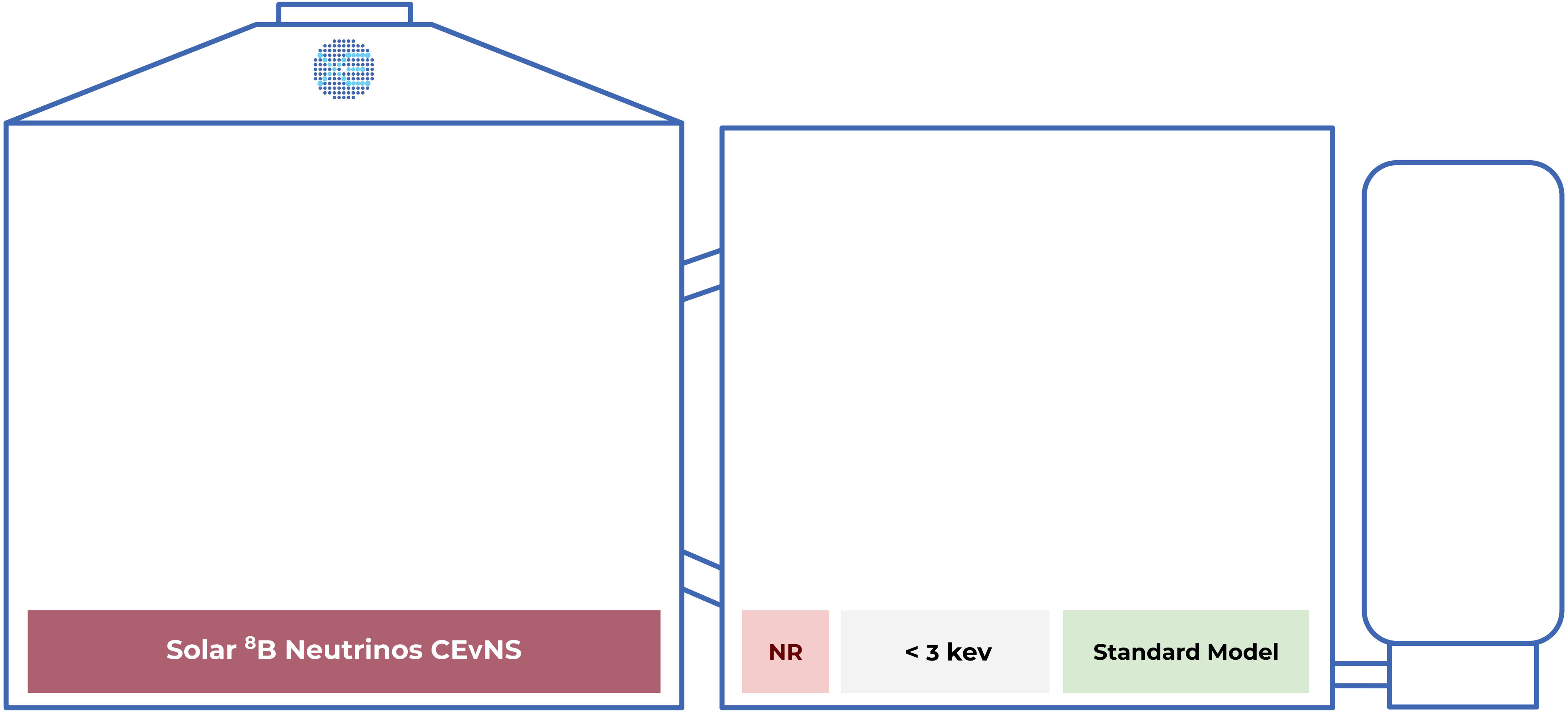

Neutrino searches in XENON detectors

Supernova (SN) Neutrinos	NR	< 10 keV	Standard Model
Solar ^{8}B Neutrinos CEvNS	NR	< 3 kev	Standard Model

Neutrino searches in XENON detectors

Solar pp Neutrinos Elastic Scattering	ER	O(1) keV - O(100) keV	Standard Model
Supernova (SN) Neutrinos	NR	< 10 keV	Standard Model
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Neutrino searches in XENON detectors

Solar pp Neutrinos with Enhanced Magnetic Moment	ER	O(1) keV - O(100) keV	Beyond Standard Model
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Neutrino searches in XENON detectors

2 Neutrinos Double Electron Capture (2νDEC) in ^{124}Xe	ER	64.3 keV	Standard Model
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Nature 568, 532–535, 2019

First observed in XENON1T

Longest half-life ever measured!

~ 10^{22} y

Neutrino searches in XENON detectors

Neutrinoless Double β decay ($0\nu\beta\beta$) in ^{136}Xe	ER	2458 keV	Beyond Standard Model
2 Neutrinos Double Electron Capture (2νDEC) in ^{124}Xe	ER	64.3 keV	Standard Model
Solar pp Neutrinos with Enhanced Magnetic Moment	ER	O(1) keV - O(100) keV	Beyond Standard Model
Solar pp Neutrinos Elastic Scattering	ER	O(1) keV - O(100) keV	Standard Model
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Nature 568, 532–535, 2019

First observed in XENON1T

Longest half-life ever measured!

~ 10^{22} y

Neutrino searches in XENON detectors

After the first **science run** (**SR0** with **~1 t×y**), **another science run** (**SR1**) has **started** to collect data, to obtain the **exposure** needed to perform **these searches** and **improve** obtained **limits**

Neutrinoless Double β decay ($0\nu\beta\beta$) in ^{136}Xe	ER	2458 keV	Beyond Standard Model
2 Neutrinos Double Electron Capture (2νDEC) in ^{124}Xe	ER	64.3 keV	Standard Model
Solar pp Neutrinos with Enhanced Magnetic Moment	ER	O(1) keV - O(100) keV	Beyond Standard Model
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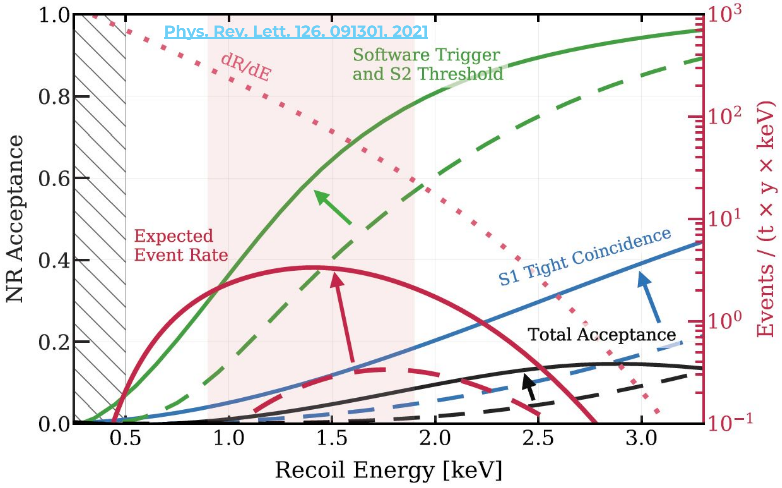
INCREASED DETECTION EFFICIENCY

S1 threshold: 3 → 2 PMTs coincidence

S2 threshold: 200 → 120 PE

Expected **total efficiency** for CEvNS around **1%**

Lower energy **threshold** → **Background rate** increased by **two orders** of magnitude



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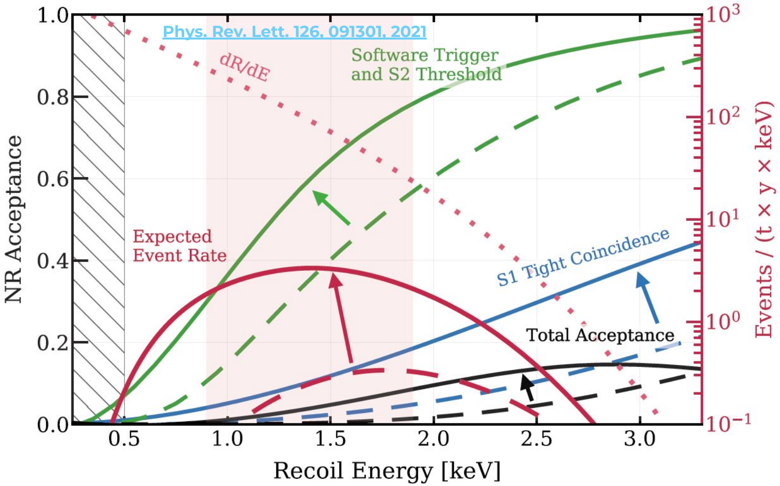


LOW-ENERGY BACKGROUND REDUCTION

Main background for **CEvNS** given by **Accidental Coincidences** (AC), resulting from random **pairing** of **isolated S1s** and **S2s**.

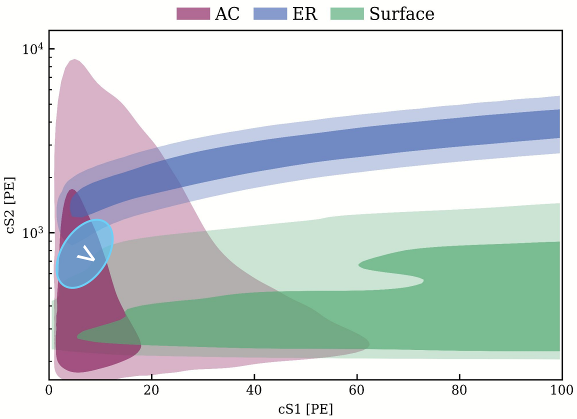
Various **mitigation** strategies: excluded events in **proximity** of **large peaks**, dedicated **selection** in **specific observables**, **machine learning** techniques and AC background modeling

Isolated **S1s**

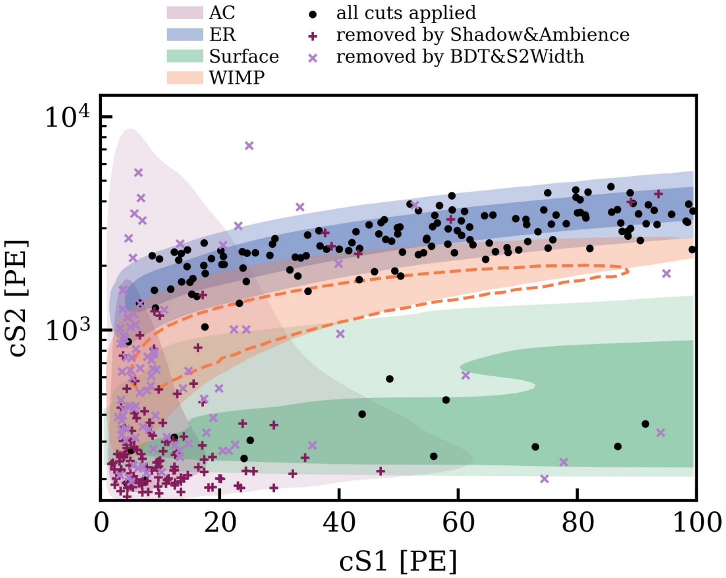
- → PMT **dark counts**
- → Misidentified **single electron**
- → Below-**cathode** and **surface** events

Isolated **S2s**

- → **Single electrons** from **delayed** extraction or **photo-ionization**
- → Misidentified PMT **afterpulses**



^{8}B neutrino discovery potential



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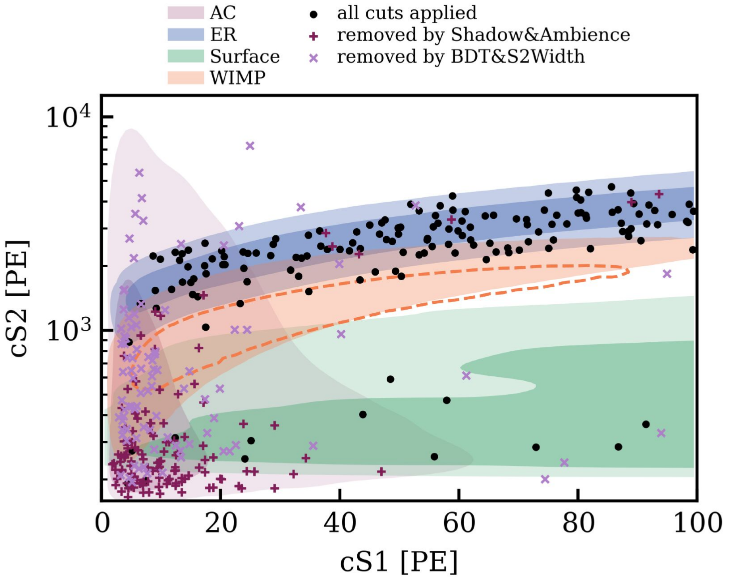

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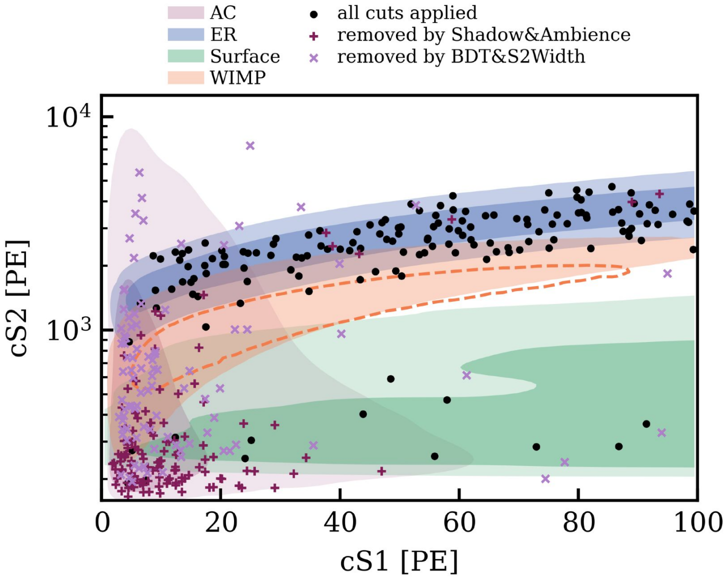

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Larger AC rate but improved **AC suppression** with new techniques

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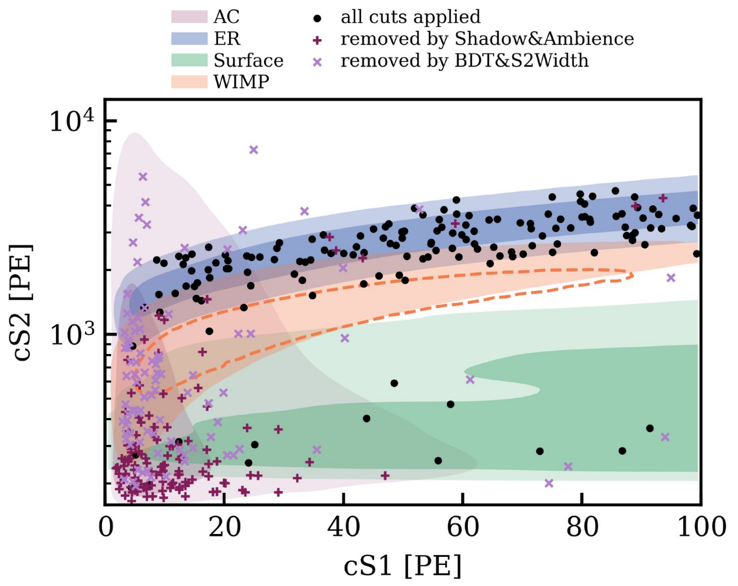

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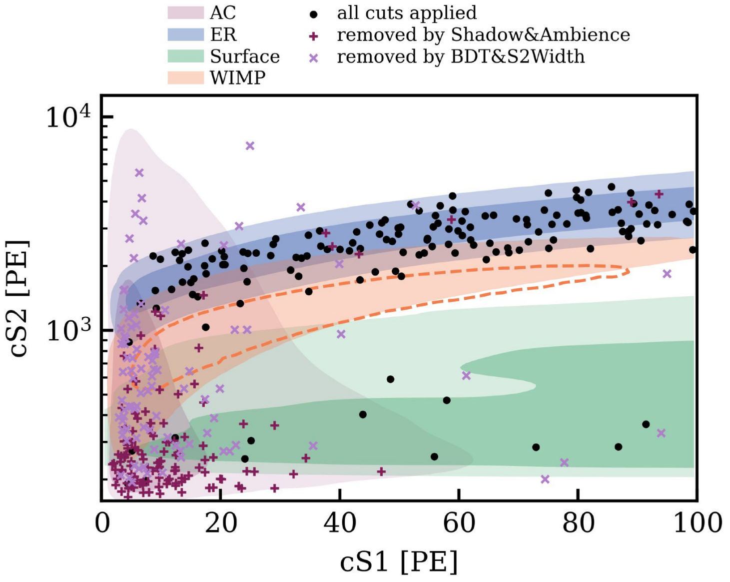

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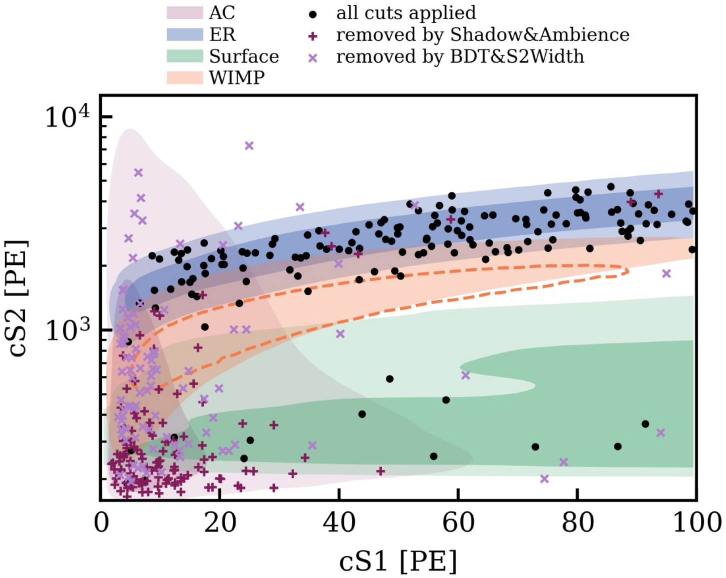

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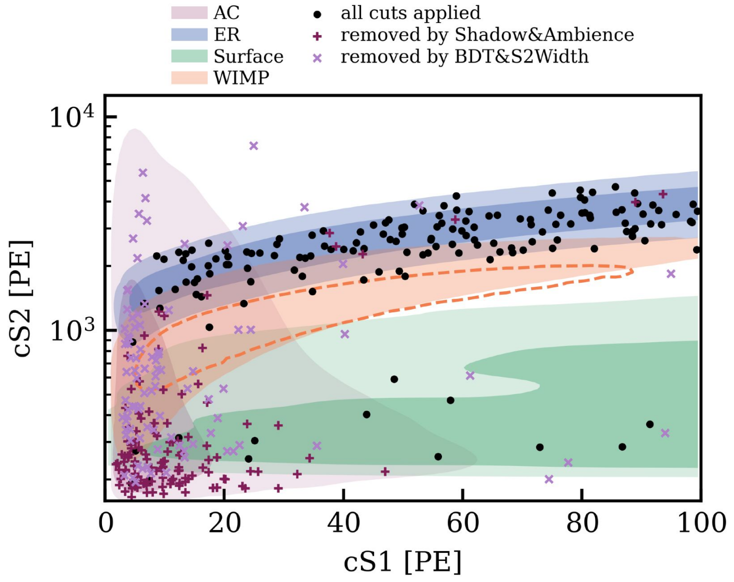

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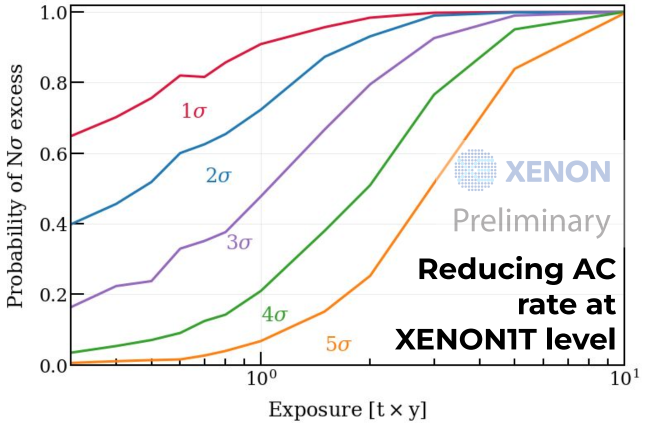

Reducing AC rate at XENON1T level

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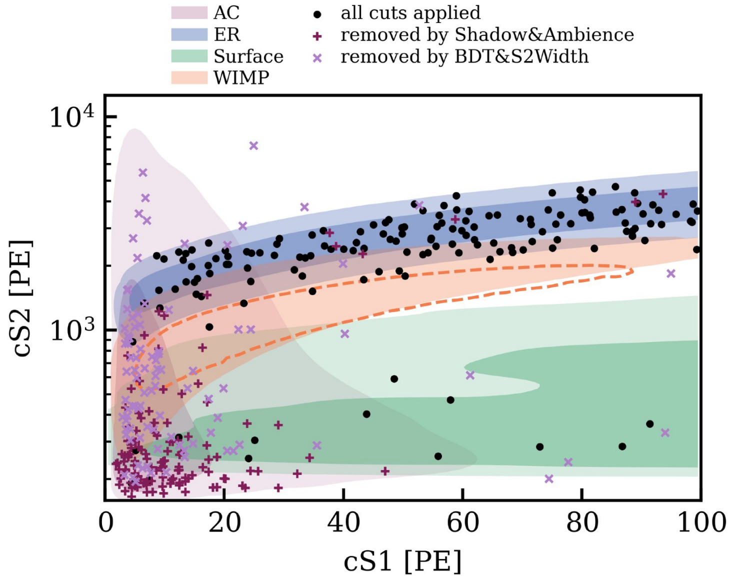

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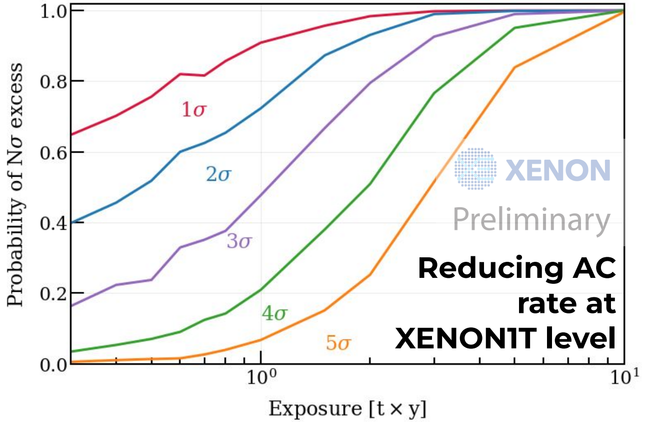


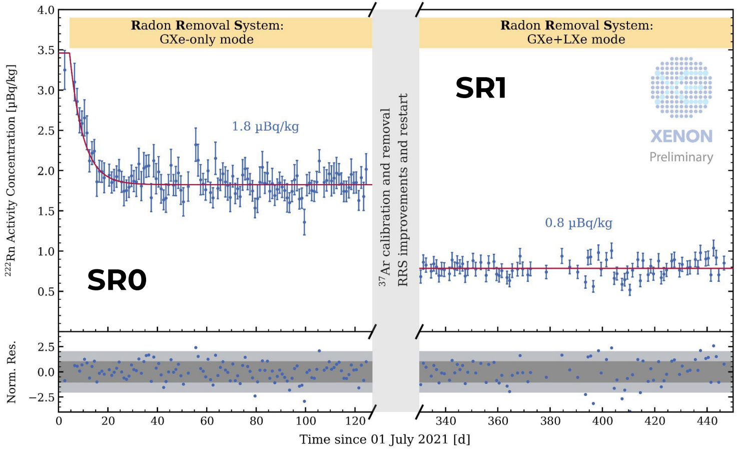
XENONnT will be more sensitive to solar ^{8}B neutrino and a first observation could be within reach

Solar pp neutrino elastic scattering

ELECTRONIC RECOILS SEARCH

Solar neutrinos **below 100 keV** (**pp** process) can be detected due to **elastic scattering** off **e$^-$** in LXe (charged and neutral current)

^{214}Pb (from **^{222}Rn**) is one **major background** in this region but improvements to **Radon Removal System** reduced it **below 1 uBq/kg** for the **next** science runs



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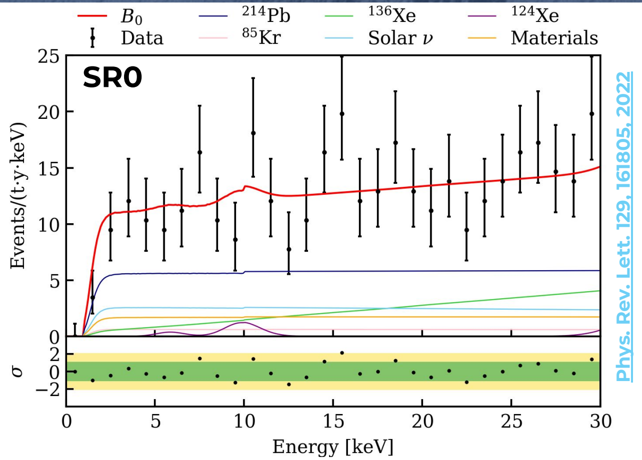
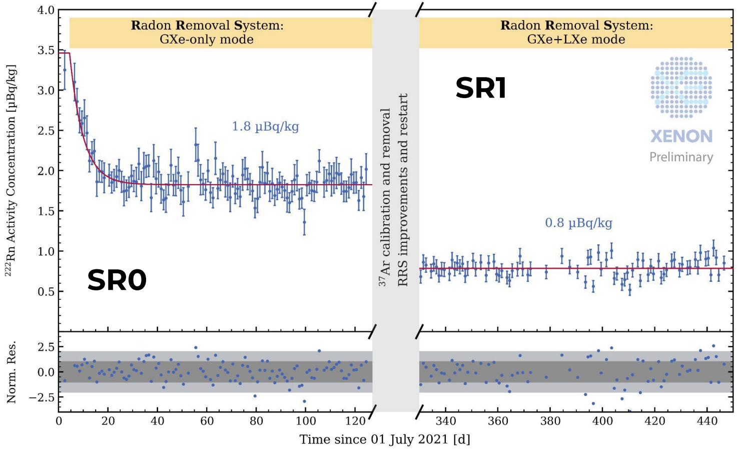
Not directly **measured yet** in SR0 but **constrained** component in the fit

First measurement in **[1, 200] keV possible if** even **lower** background is **reached**





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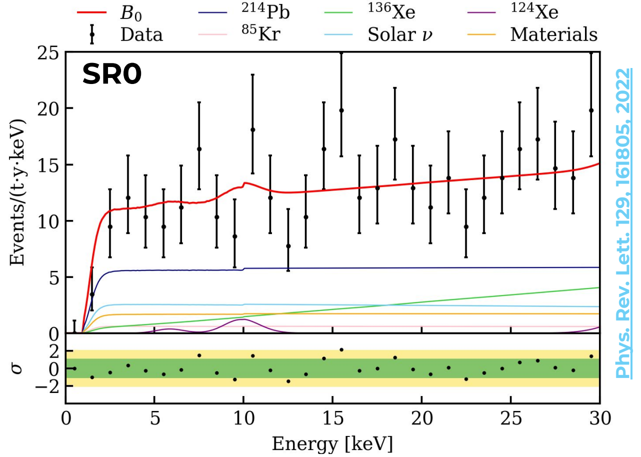
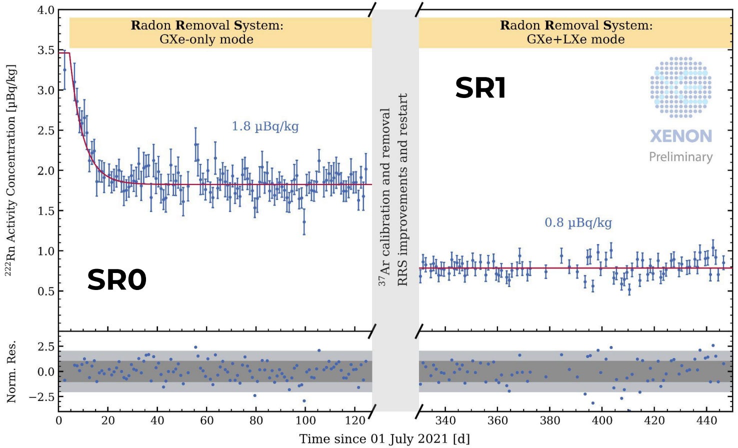
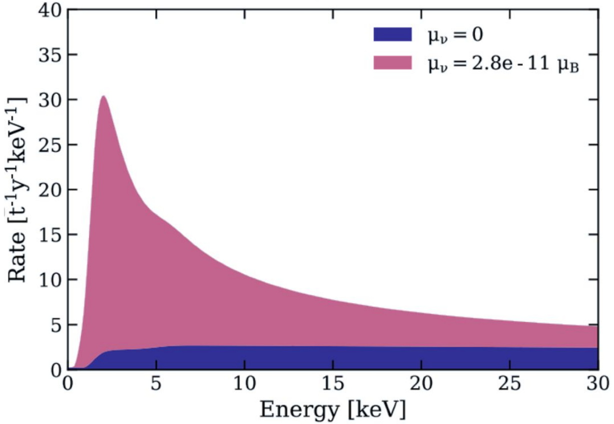




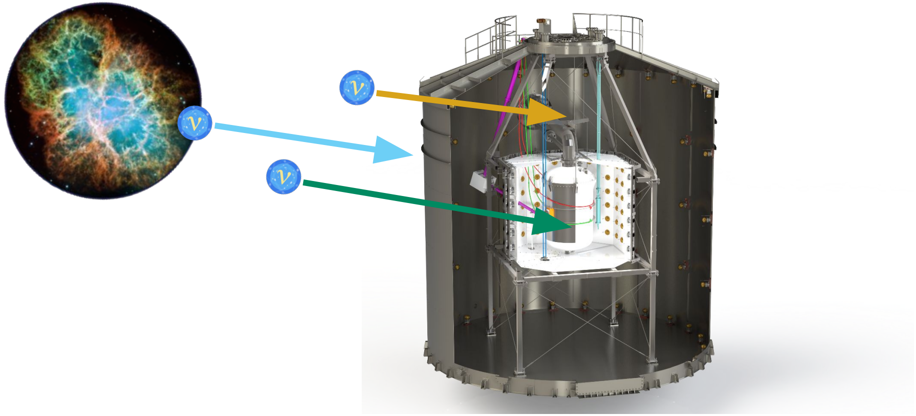
ENHANCED NEUTRINO MAGNETIC MOMENT

Non-standard magnetic moment would **increase cross-section** with electrons

Not observing an **excess** results in **upper limits** on **magnetic moment**



Supernova neutrino



SUPERNOVA NEUTRINO CHANNELS IN XENONnT

→ **TPC**, **6 t** of LXe

$\nu_{e,\,\mu,\,\tau}$, $\bar{\nu}_{e,\,\mu,\,\tau}$ via **CEvNS** (charged and other neutral current are subdominant)

~ **100 expected** events from supernova at 10 kpc

→ **MUON & NEUTRON VETO**, **700 t** ultra-pure water

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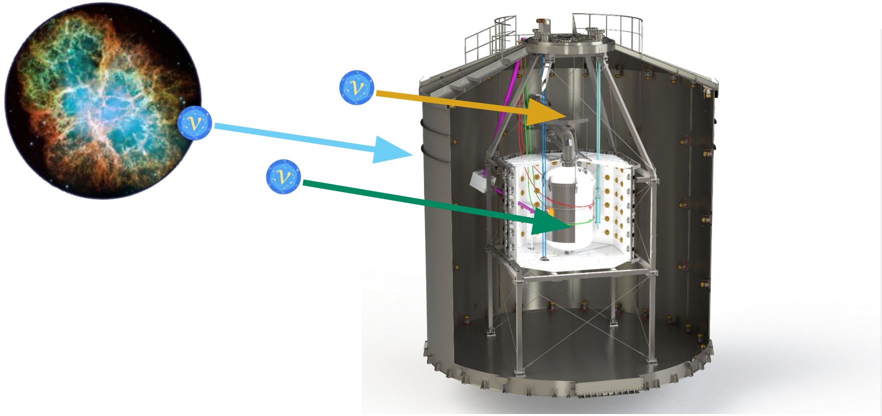

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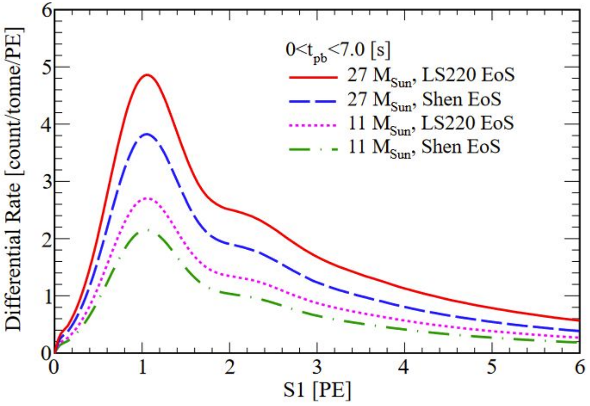
PREDICTIONS IN XENONnT

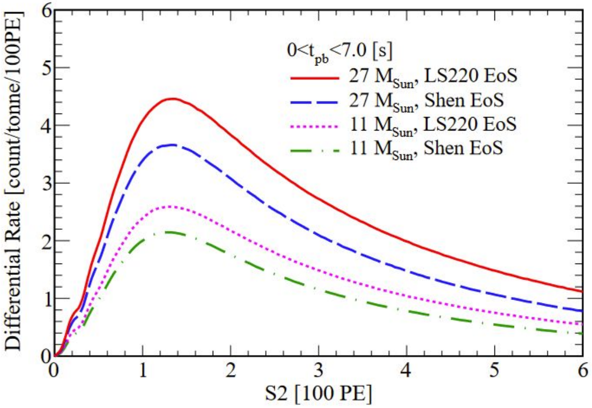
Neutrinos deposit around **O(1) keV** in LXe

Background stable in time, can be reduced with **specific selection** (similar to ^{8}B search)

Possible improvements using **coincident** signals from **vetoes**

Phys. Rev. D 94, 103009, 2016





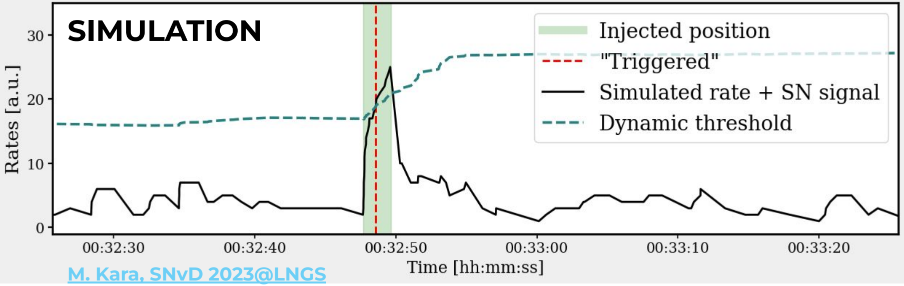
Supernova neutrino

SENSITIVITY PROJECTIONS

Cuts can **reduce background** down to **~3 Hz**, while **average signal** (SN at **10 kpc**) will results in **~45 events** in **~ 6 s** (~ 18 background events)

Triggerless DAQ allows **continuous** data taking and **increases** in **rate** with respect to a **dynamic threshold** can be monitored online

Considering signal evolution, time **window** can be **optimized**, resulting in ~8σ significance (10 kpc)



M. Kara, SNvD 2023@LNGS

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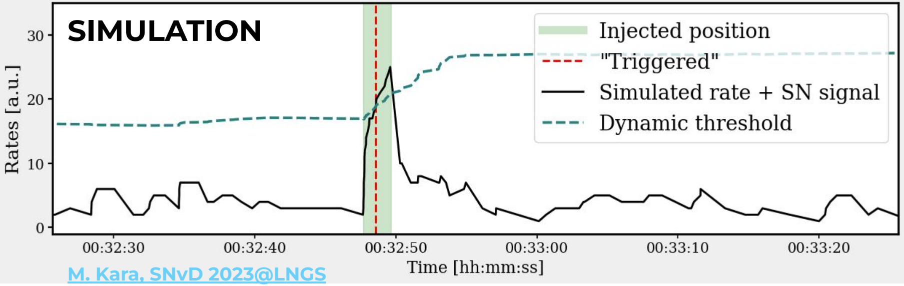

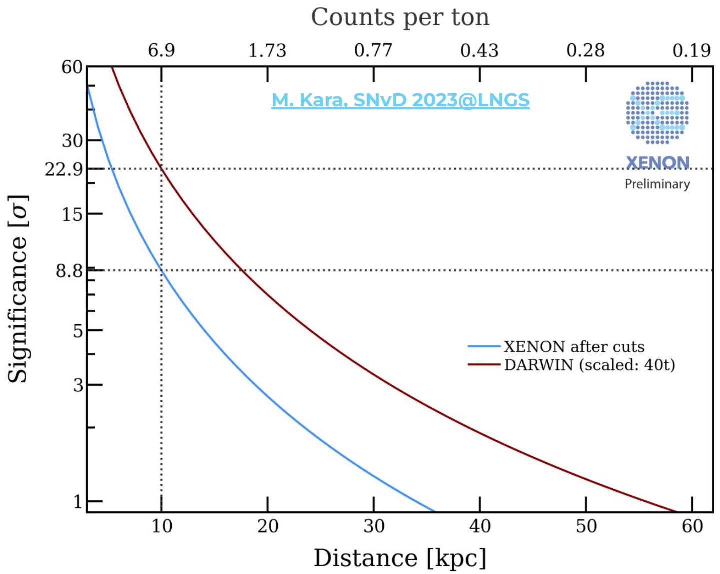

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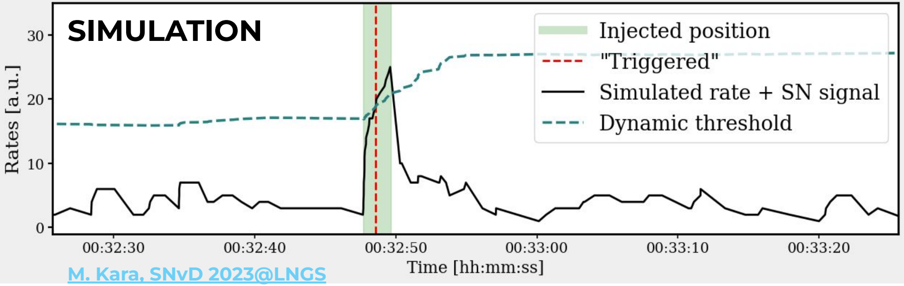

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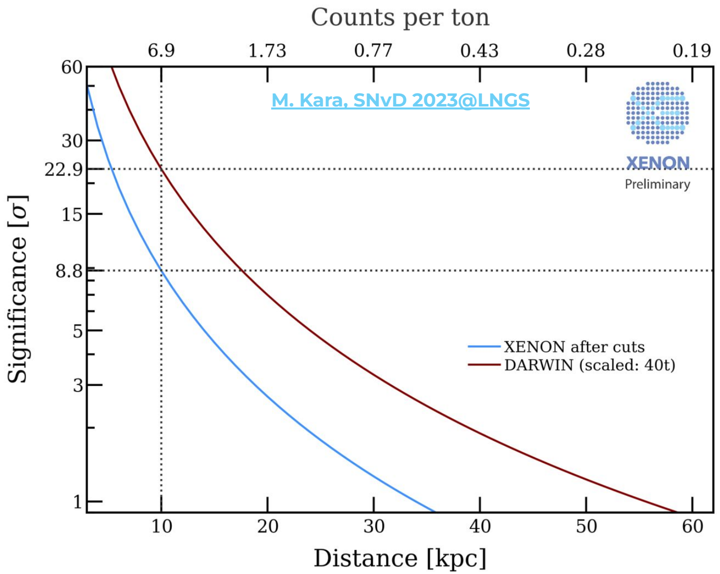


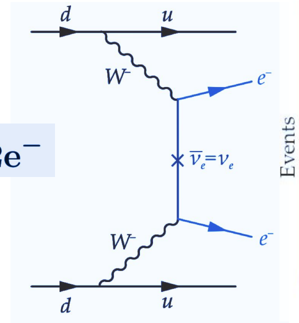
SNEWS INTEGRATION

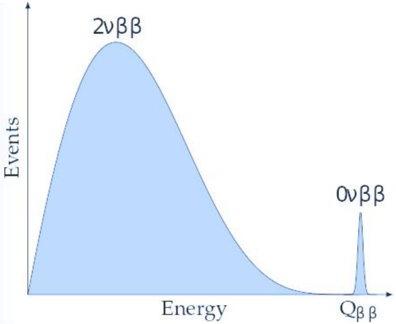
XENONnT is **ready** to join the **Supernova Early Warning System** (**SNEWS**)

It will **receive** incoming **alerts** to check data and **send** possible **supernova observations**

Neutrinoless double-beta decay in ^{136}Xe

$$^{136}\mathrm{Xe} \rightarrow {}^{136}\mathrm{Ba} + 2e^-$$





In XENONnT ^{124}**Xe** & ^{136}**Xe (0.1%** and **8.9% abundancy)** are **long-lived** isotope which produce detectable ER signals

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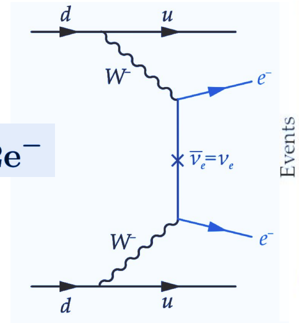

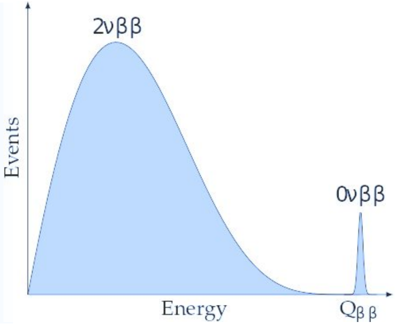

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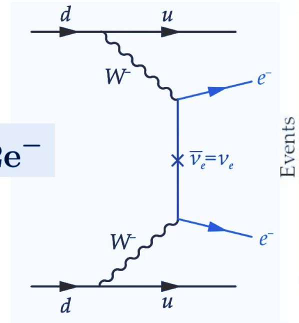
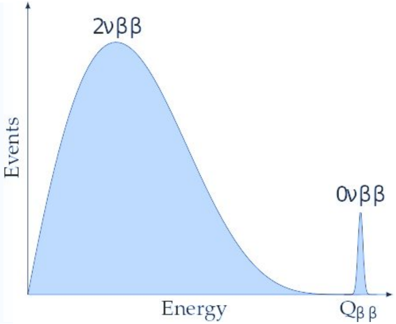
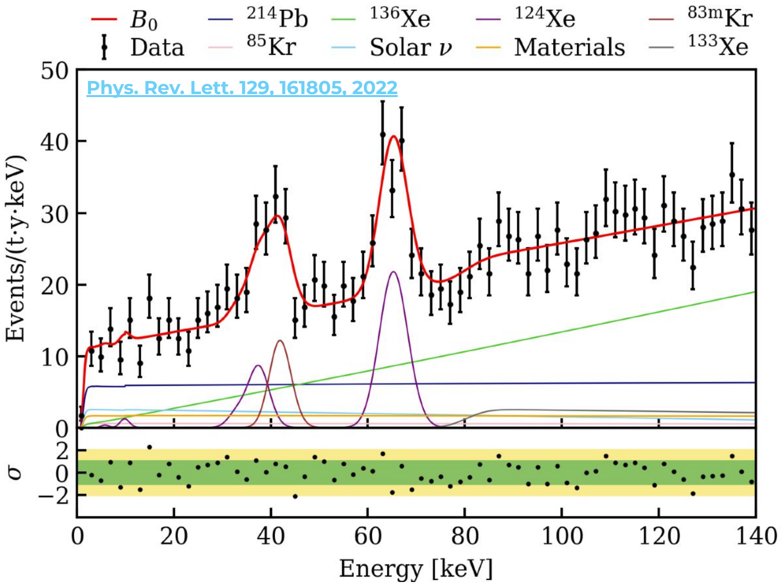




^{124}**Xe** & ^{136}**Xe** produce **single site ER** events due to **LXe high stopping power**

They became a major **background** for **electronic recoil** searches



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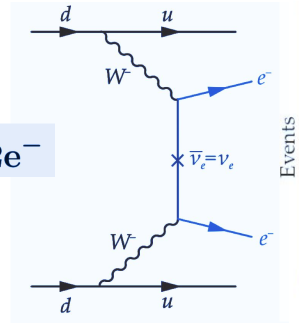
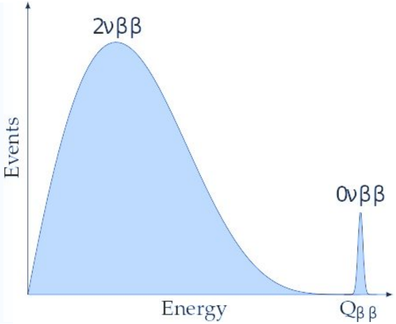




In XENONnT ^{124}**Xe** & ^{136}**Xe (0.1%** and **8.9% abundancy)** are **long-lived** isotope which produce detectable ER signals

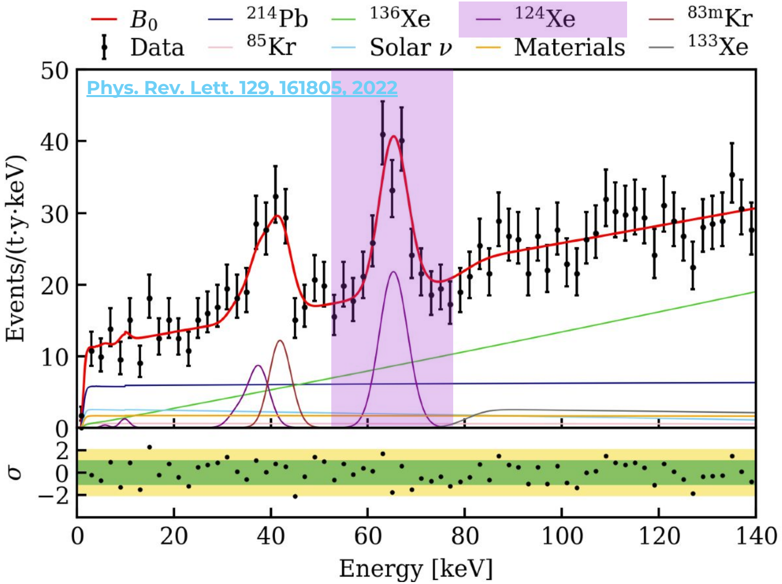
First **observation** of ^{124}**Xe 2νDEC** in **XENON1T** demonstrated **sensitivity** to **extremely rare events** and can be used to constrain **Nuclear Matrix Element (NME)** calculations

2νββ-decaying ^{136}**Xe isotope with** $Q_{\beta\beta}$ = (**2457.83** ± 0.37) **keV** is a good **candidate** for **0νββ**

0νββ would demonstrate the **violation** of **total lepton number** and a **nonzero Majorana component** of neutrino mass

^{124}**Xe** & ^{136}**Xe** produce **single site ER** events due to **LXe high stopping power**

They became a major **background** for **electronic recoil** searches



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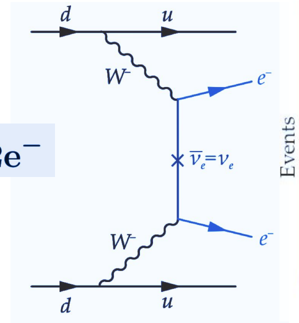

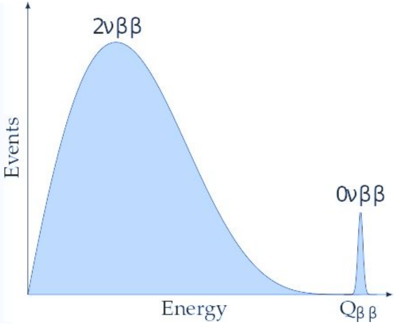

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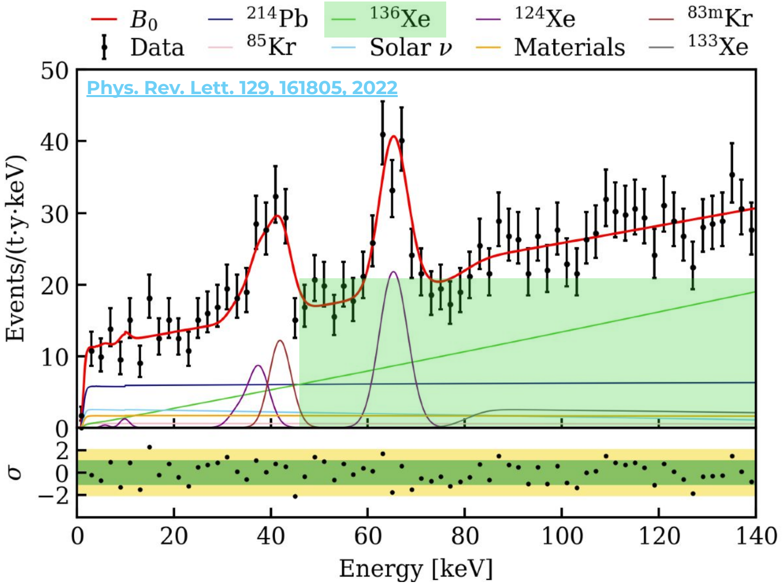

Neutrinoless double-beta decay in ^{136}Xe

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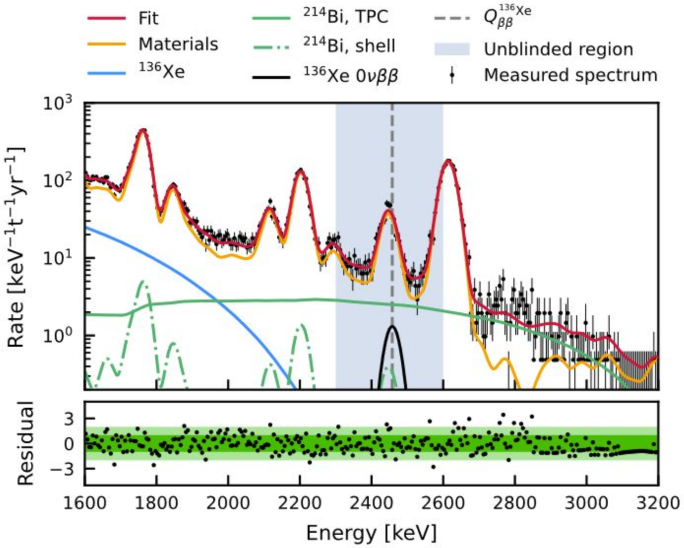
Dedicated treatment of signals for **saturation** effects in **digitizers** and **PMTs** at **MeV** energies



[Phys. Rev. C 106, 024328, 2022]

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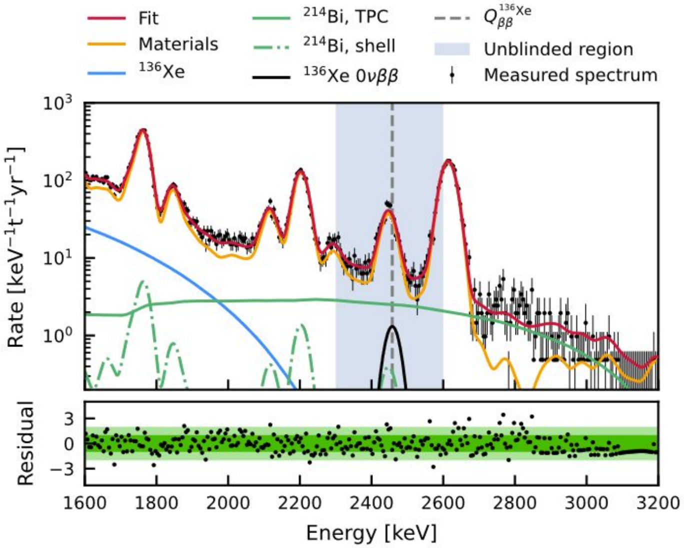

Phys. Rev. C 106, 024328, 2022

XENON1T RESULTS

$T^{0\nu\beta\beta}_{1/2}$ **> 1.2 × 10^{24} yr** with **tonne-scale** fiducial mass, resulting in isotope exposure of **36.16 kg** × yr

Best results for a **non enriched** target detector

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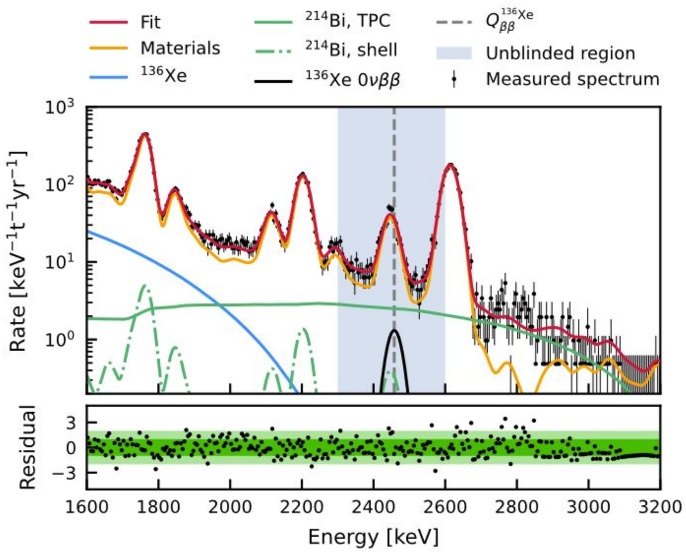

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Non-enriched target (dedicated experiments with 90% isotopic abundance)

Materials optimized for **DM search** (stainless steel cryostat)

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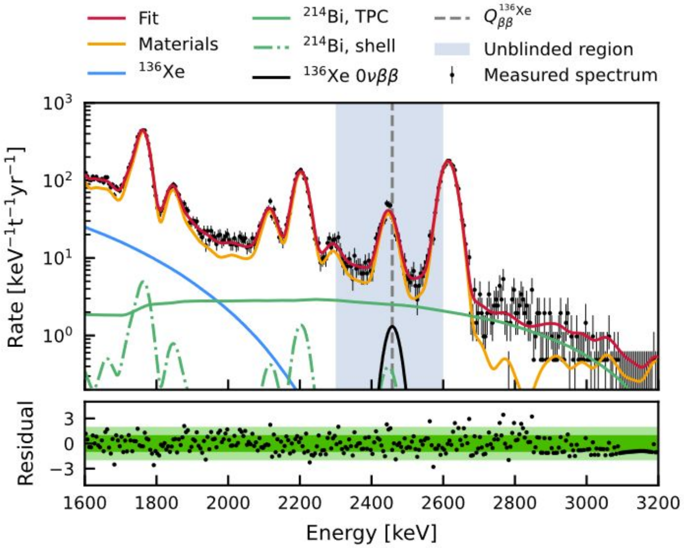

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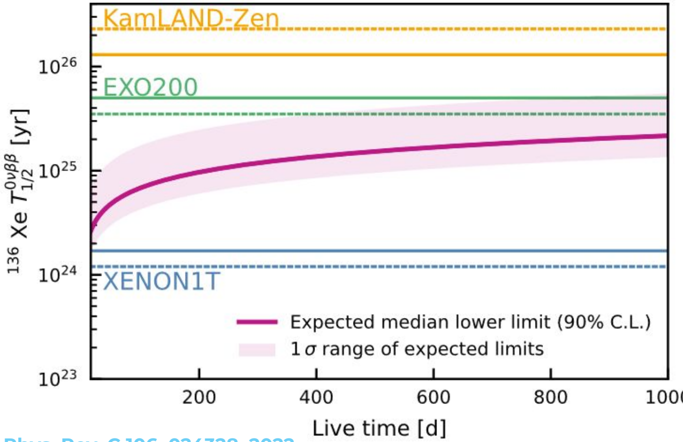
XENONnT SENSITIVITY PROJECTION

With **275** kg × yr exposure, expected upper limit of $T^{0\nu\beta\beta}_{1/2}$ **> 2.1 × 10^{25} yr**

Future xenon DM detector with **optimized** high-energy **backgrounds** and **larger exposure** can perform also 0νββ searches



Phys. Rev. C 106, 024328, 2022

Conclusions and future perspective

IN A NUTSHELL

XENONnT performed **blinded** searches of **electronic** and **nuclear recoils**, finding **no significant excess** in **SR0**

It achieved the **lowest ER background** in the field

Potential to search for different **rare processes** regarding **neutrino**, such as **SN neutrino** or **0νββ**

In particular, XENONnT is **currently sensitive** to **^{8}B solar neutrino**, which can be **detected** via **CEvNS**

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New science runs with **50% lower ^{222}Rn** (**ER background**)

Planned **neutron veto** with **Gd-loaded water** to reach **87% neutron** background **tagging efficiency**

Improved **WIMP limits** and **new analysis results** with much **more exposure**

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NEXT-GENERATION LXe EXPERIMENT

Dual-phase Xe TPC with **~50** t of **LXe**, from the **joint** efforts of **XENON**, **LZ** and **DARWIN** collaboration into the **XLZD consortium**

Multi-purpose observatory for **dark matter, neutrino** and **rare events**, probing **WIMPs** down to **neutrino floor**

J. Phys. G: Nucl. Part. Phys. 50 013001

XX International Workshop on Neutrino Telescopes

Thank you for your attention!

XENON OFFICIAL WEBSITE
www.xenonexperiment.org/

CONTACT XENON
xe-pr@lngs.infn.it

STAY TUNED!

XENONnT is going to take and analyze more science data!

facebook.com/XENONexperiment/

instagram.com/xenon_experiment/

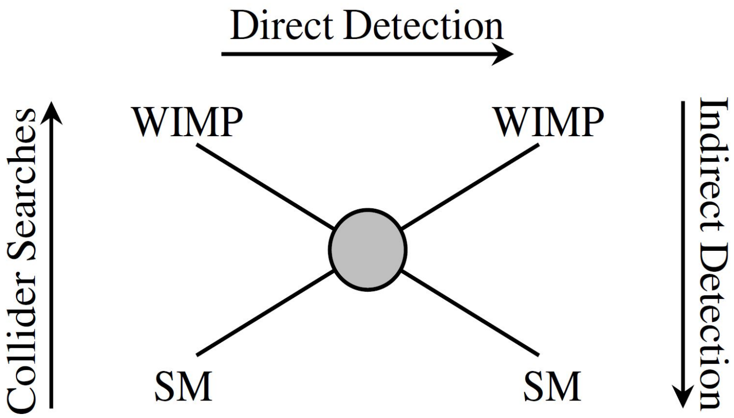
twitter.com/xenonexperiment


BACKUP

Direct detection of dark matter

EXPERIMENTAL SEARCH OF DM

- Production at **colliders**
- **Indirect** search from **annihilation** products
- <u>**Direct** detection of DM **scattering** off SM particles</u>

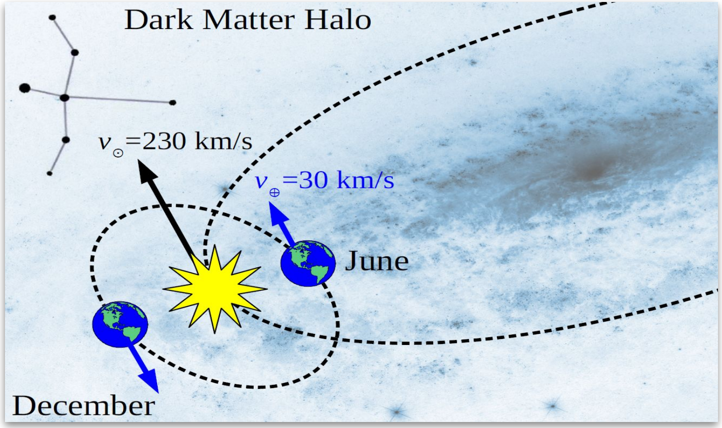


DETECTION OF DM HALO PARTICLES

Local dark matter **density** ρ_0 = **0.3 GeV/cm^3**

For WIMPs, with **mass = 100 GeV/c^2**:

- Density: 3000 particles / m^3
- Flux: **10^5** particles / (cm^2 s^{-1})



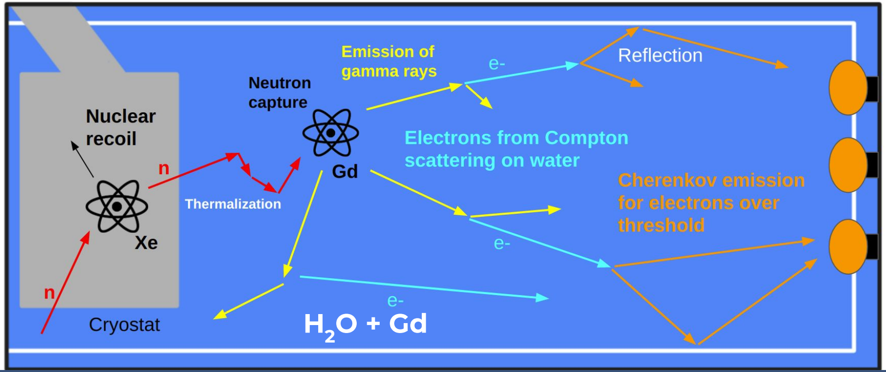
Neutron veto

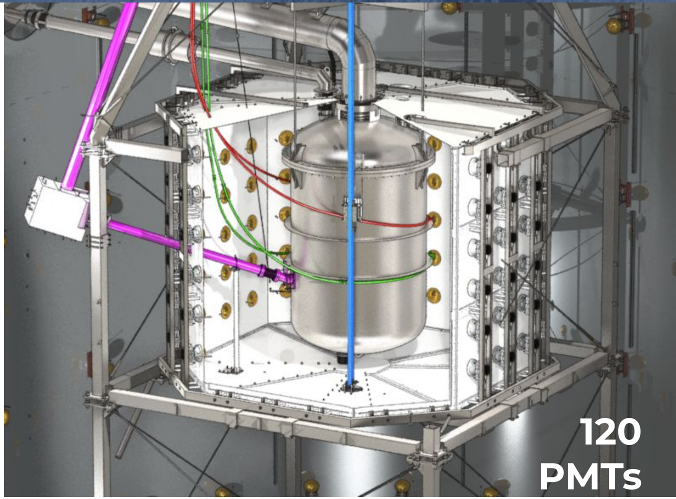
	Neutron capture cross-section	γ energy	Mean capture time
H	0.33 b	Single, 2.2 MeV	200 us
Gd	49000 b	3-4 γ, 8 MeV in total	30 us

In **demi-water** neutron **tagging efficiency ~ 53%** and livetime **reduction** of **1.6 %**

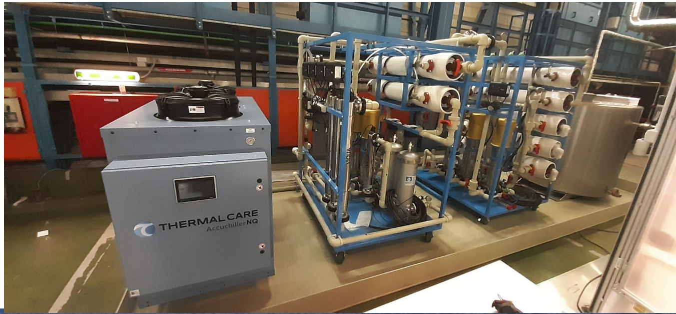
3 multiple scatter + **1 single** scatter tagged by neutron veto, resulting in **total neutron** expectation of $\mathbf{1.1_{-0.5}^{+0.6}}$ in ROI

Plan to dissolve **3.4 t** of Gd sulphate octahydrate $\mathbf{Gd_2(SO_4)_3 \cdot 8H_2O}$ to reach **0.2%** of **Gd** in **mass**





Gd-WATER PURIFICATION PLANT COMMISSIONING AT LNGS

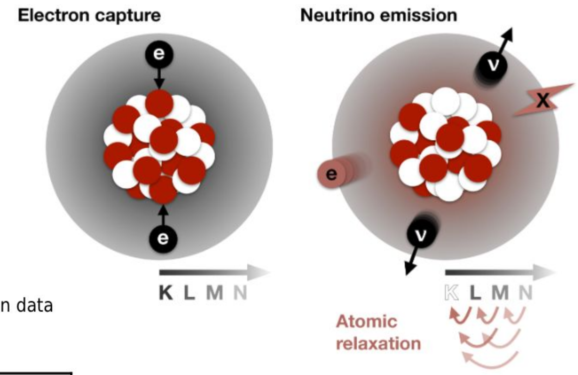


2ν Double-Electron Capture in ^{124}Xe

First **direct observation** of nuclear decay via **two-neutrino double electron capture (2VDEC)**:

$$^{124}\mathrm{Xe} \longrightarrow {}^{124}\mathrm{Te} + \nu_e + \nu_e$$

Expected signature: (**64.3** ± 0.6) **keV** monoenergetic **peak**

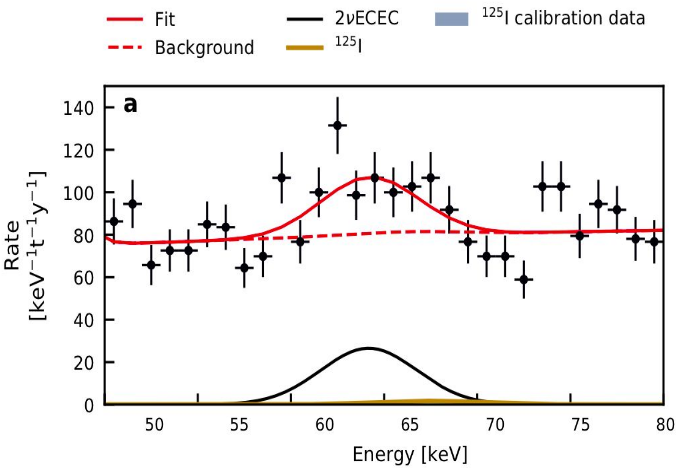


Observed peak of **126 ± 29 events** at (**64.2** ± 0.5) **keV**

4.4 σ discovery significance

Measured half-life: ($\mathbf{1.8} \pm 0.5_{stat} \pm 0.1_{sys}$) x $\mathbf{10^{22}}$ **yr**

~ $\mathbf{10^{12}}$ times **larger** than the age of the **Universe**

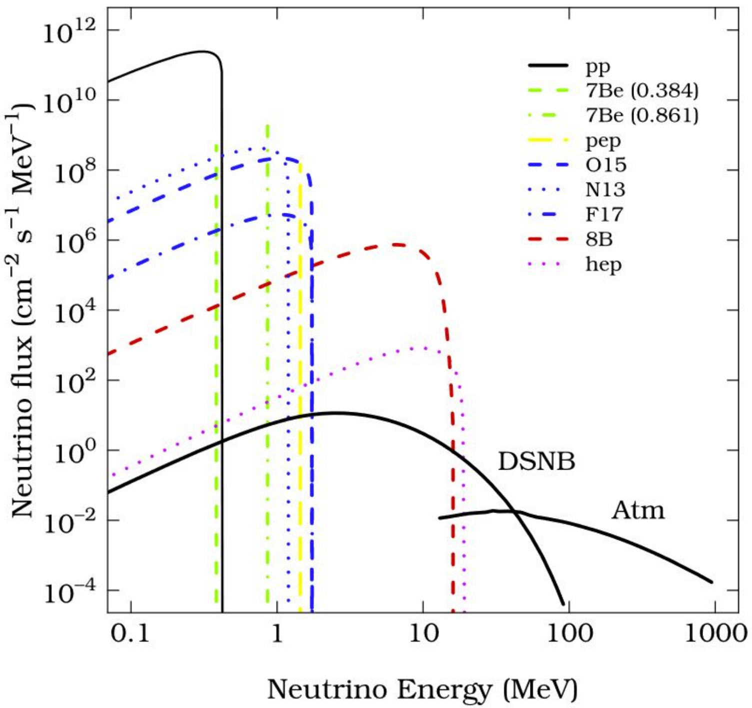


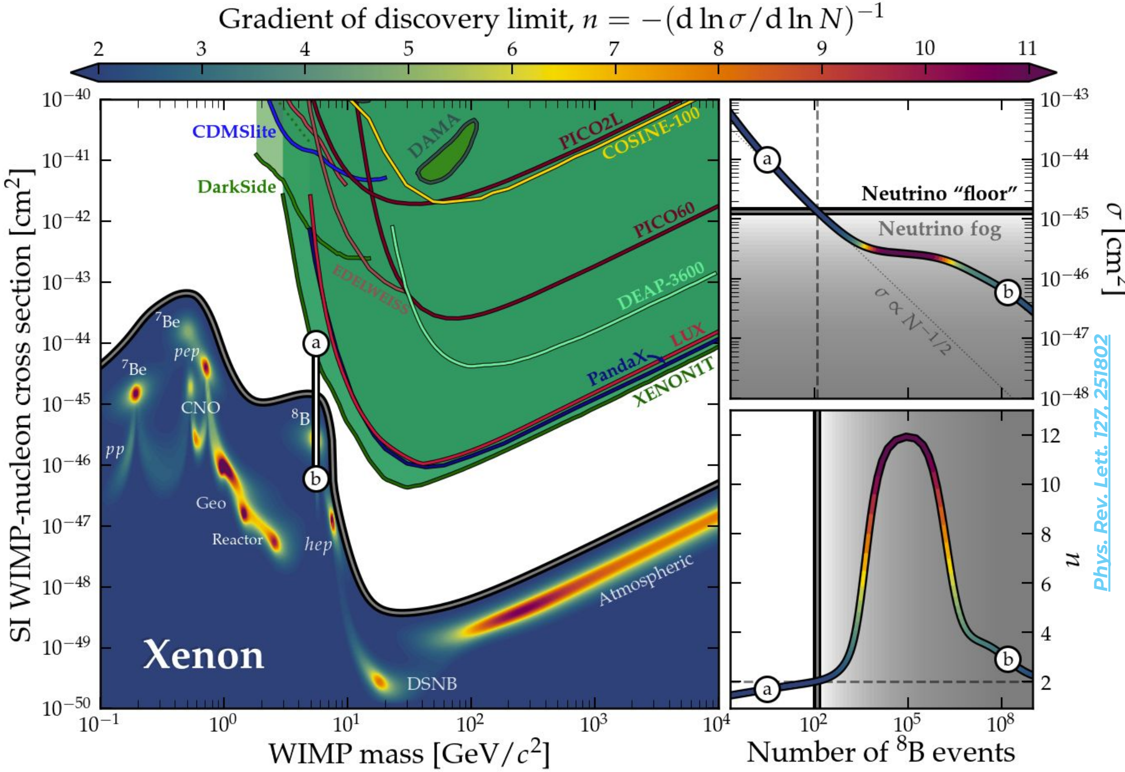
Nature 568, 532–535 (2019)

The rarest process ever directly observed!

Neutrino fog in LXe detectors

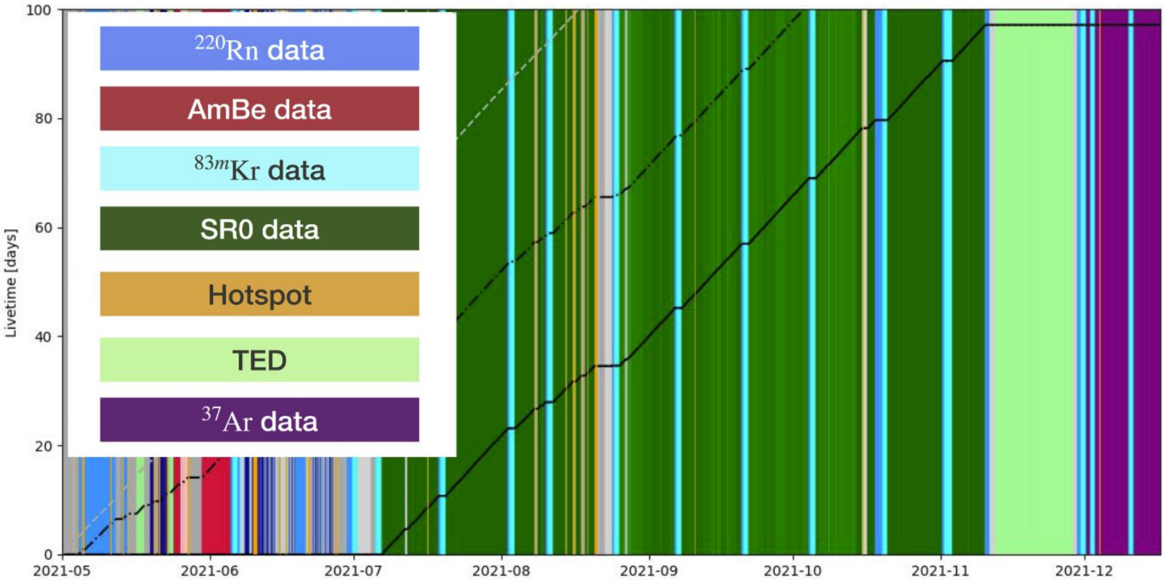
J. Phys. G: Nucl. Part. Phys. 50 013001





Phys. Rev. Lett. 127, 251802

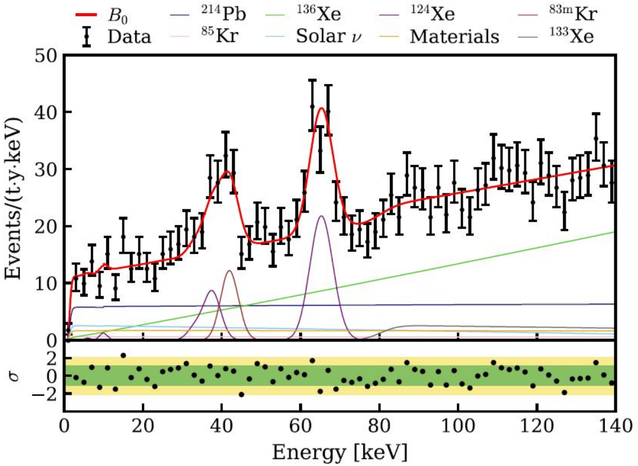
XENONnT Science Run 0

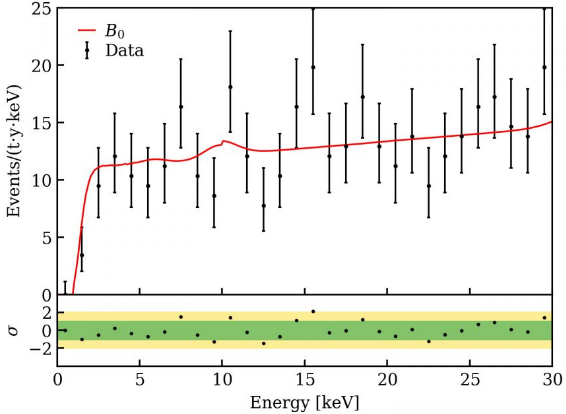


ER and NR blinded analyses

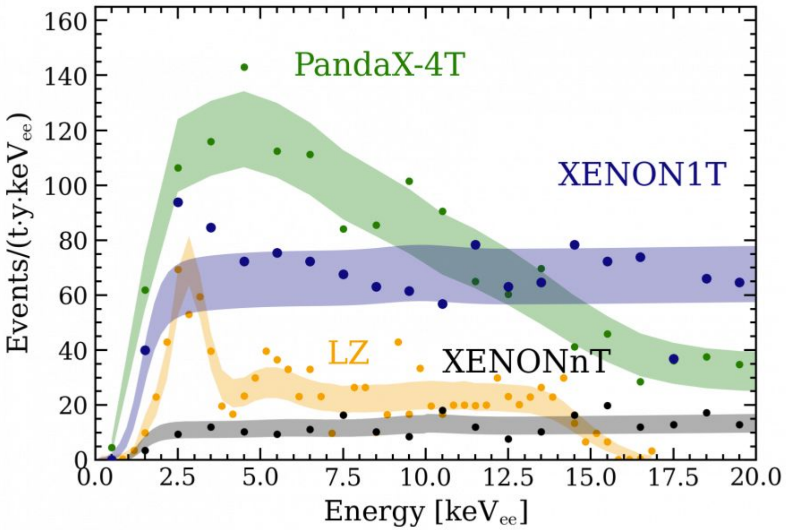
- **97.1 days** of **exposure** from **July 6th - Nov 11th 2021**
- **Radon** column operating in **gas-only** mode
- **477** out of **494 PMTs** operative, **gain stable** at **3%** level
- **Drift** field **23 V/cm** (cathode voltage **limited** to **–2.75 kV** due **short-circuit** with **bottom screen mesh**)
- **Extraction** field in LXe **2.9 kV/cm**
- **Localized** high **single-electron emission** (hotspot) occurring seemingly at random, anode ramped down

Background comparison in LXe experiment





Phys. Rev. Lett. 129, 161805



5x ER background **reduction** with respect to **XENON1T**

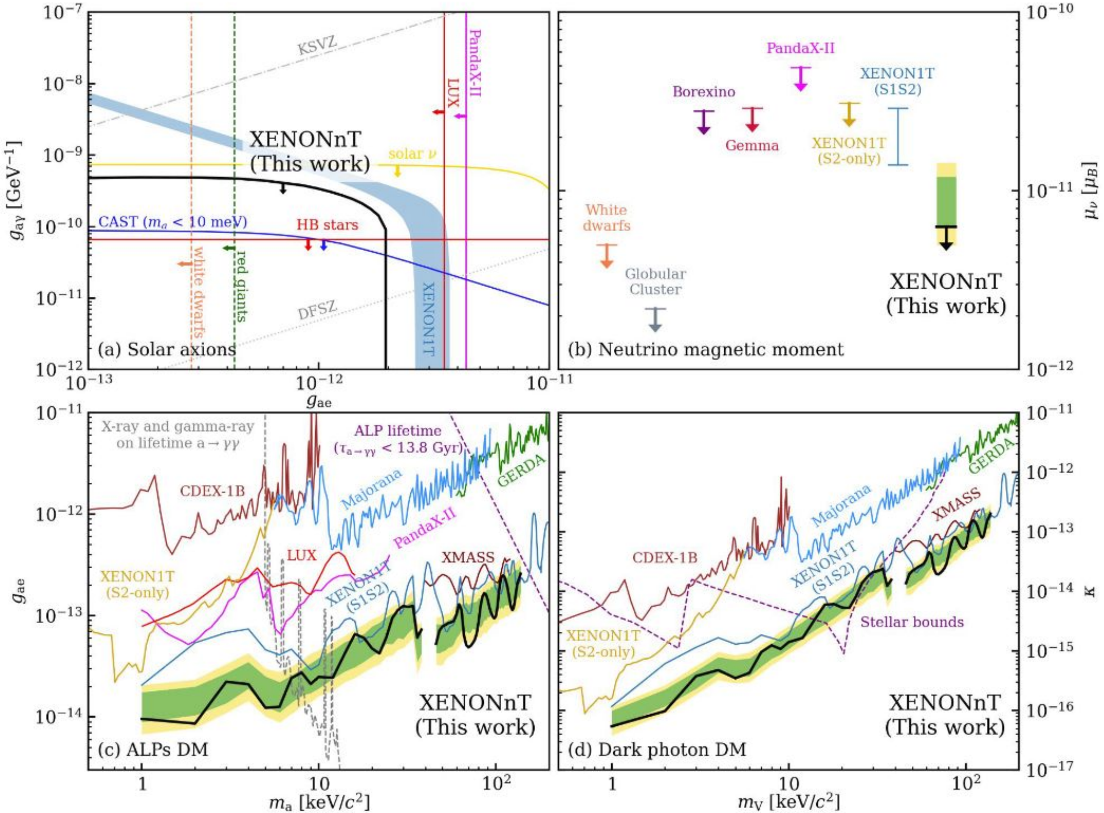
Dominated by beta-decays from ^{214}**Pb** a daughter of ^{222}**Rn**

Lowest background level **ever** achieved by a **dark matter** experiment: **(16.1 ± 0.3)** events/(t y keV)

8.6 σ exclusion on XENON1T **excess**

Other ER searches in XENONnT

Phys. Rev. Lett. 129, 161805



SOLAR AXIONS

Best limit from **dark matter** direct detection **experiments**

- Included **axio-electric** and **reverse Primakoff** effect
- Improved constraints on axion-**photon**, axion-**electron** and axion-**nucleon couplings**
- Upper **limit** on the ^{57}**Fe solar axion rate**

BOSONIC DARK MATTER

No peak-like signals. New limits on:

- Axion like particle dark matter
- Dark photon dark matter

WIMP search background model in SR0

Low ER background

- Dominated by beta-decays from ^{214}Pb a daughter of ^{222}**Rn**
- 16 events/(t*y*keV) in the [1, 30] keV range

Accidental background (AC)

- **Random pairing** of S1 and S2 lone signals
- **Suppressed** by a dedicated Gradient Boosted Decision Tree cut (GBDT), using S2 shape, R and Z information

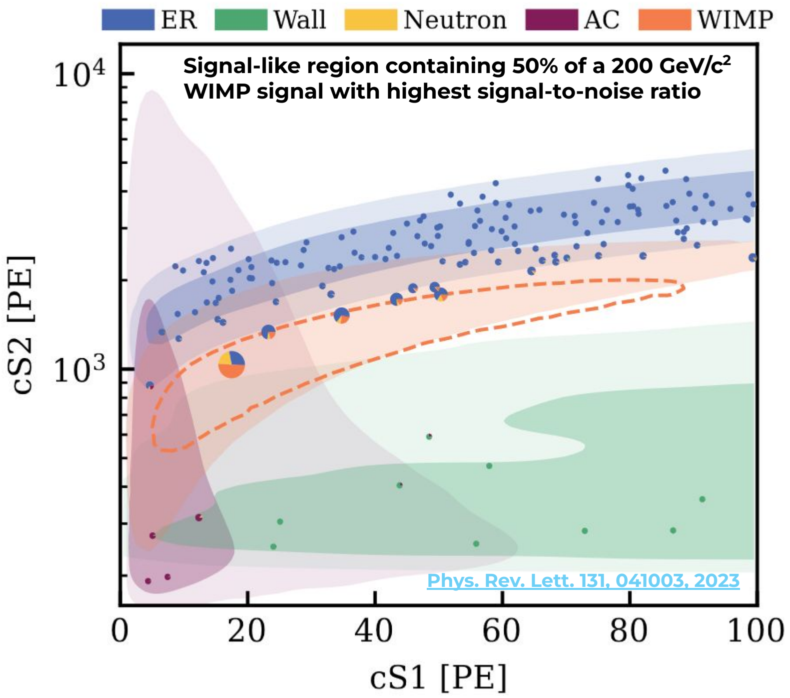
Surface background

- Due to ^{210}**Pb** plate out at TPC walls (beta-decay)
- Suppressed by R_{max} **< 61.35** cm of fiducial volume

NR background

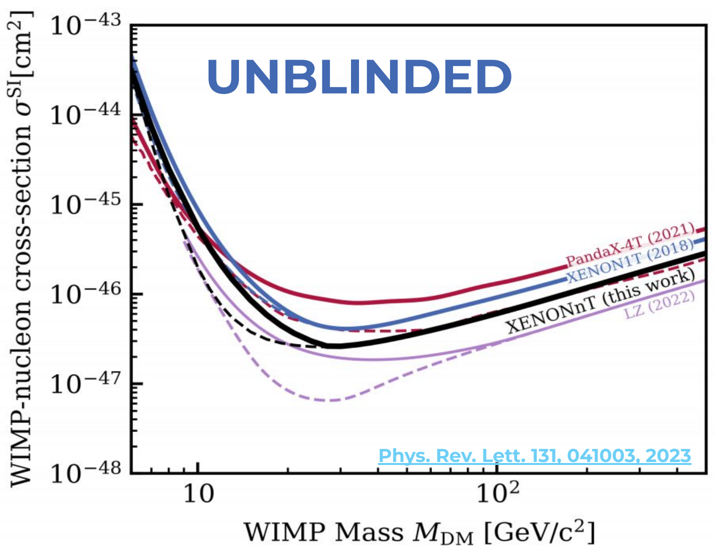
- Neutrons from spontaneous fission and (α,n) reactions
- CEvNS (coherent elastic neutrino-nucleus scattering)

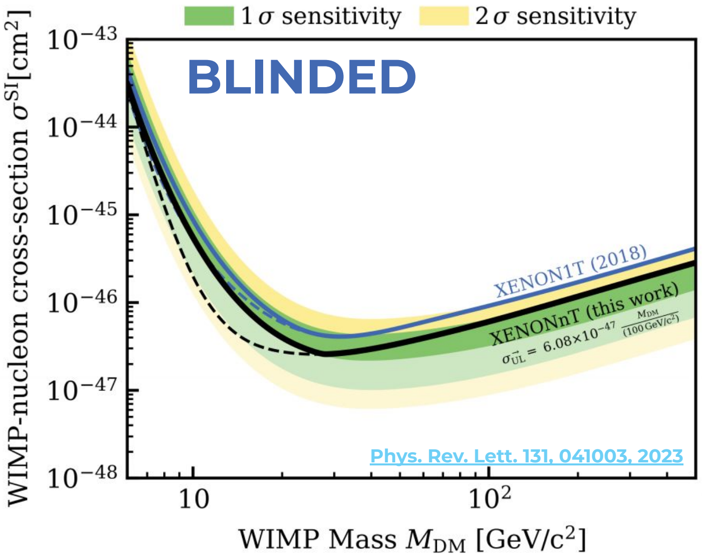
	Nominal	Best Fit	
	ROI		Signal-like
ER	134	135^{+12}_{-11}	$0.86^{+0.08}_{-0.07}$
Neutrons	$1.1^{+0.6}_{-0.5}$	1.1 ± 0.4	0.42 ± 0.17
CEνNS	0.23 ± 0.06	0.23 ± 0.06	0.022 ± 0.011
AC	4.3 ± 0.2	4.32 ± 0.15	0.366 ± 0.013
Surface	14 ± 3	12^{+0}_{-4}	$0.35^{+0.01}_{-0.11}$
Total Background	154	152 ± 12	2.0 ± 0.2
WIMP	-	2.6	1.3
Observed	-	152	3



Pie-chart representing **component fraction** of the **best-fit model** including a 200 GeV/c^2 **WIMP evaluated** at **event position**

Comparison with other NR searches





Log-Likelihood-ratio as test statistics, **median upper** limits at **90%** confidence, **p-values** of test statistic indicate **no significant excess** for all WIMP masses

Community had agreed on using **Power-Constraint Limit (PCL)** to avoid **too low exclusion** limits, but the PCL **critical threshold β_r** was defined on **discovery** power **instead** of **rejection** power

Typically **PCL** used to constrain the limit at **-1σ (β_r=0.16)** but it was show to be **pathological** for **downward fluctuations** and it was **raised** to be conservative to **0.5** (median), it need **to be further discussed** within the community

Purification and distillation

NEW!

RADON DISTILLATION COLUMN

^{222}Rn intrinsic background from **materials**

Dedicated system in addition to Kr column

Lowest level in LXe TPCs (~ μBq/Kg ^{222}Rn)

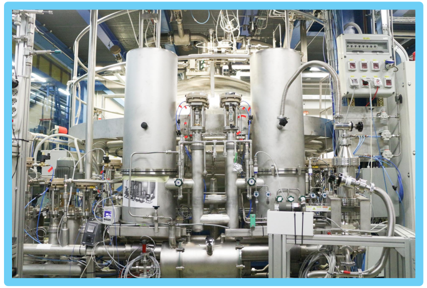
LIQUID Xe PURIFICATION

Removal of **electronegative impurities**

High-flux purification (350 kg/h)

High efficiency **O_2 filter**

Electron lifetime improved by factor 50



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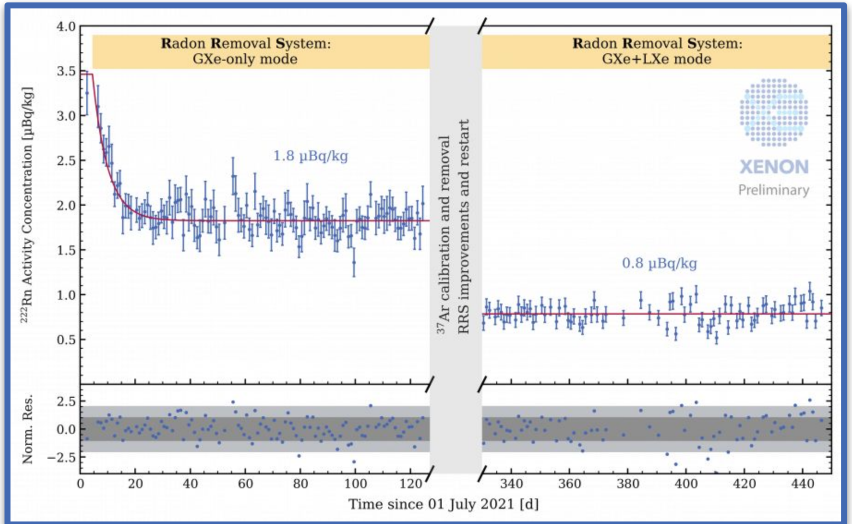
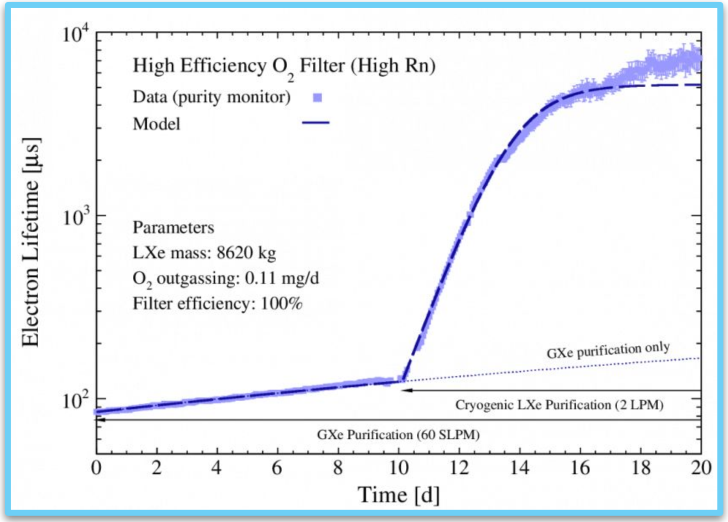




Calibration sources

PMTs

LEDs → Dark rate, gains, SPE acceptance

Material Radioactivity

^{214}Bi, ^{60}Co, ^{40}K → **High-energy** lines

External sources

^{241}AmBe → **Continuous** spectrum of **NRs**

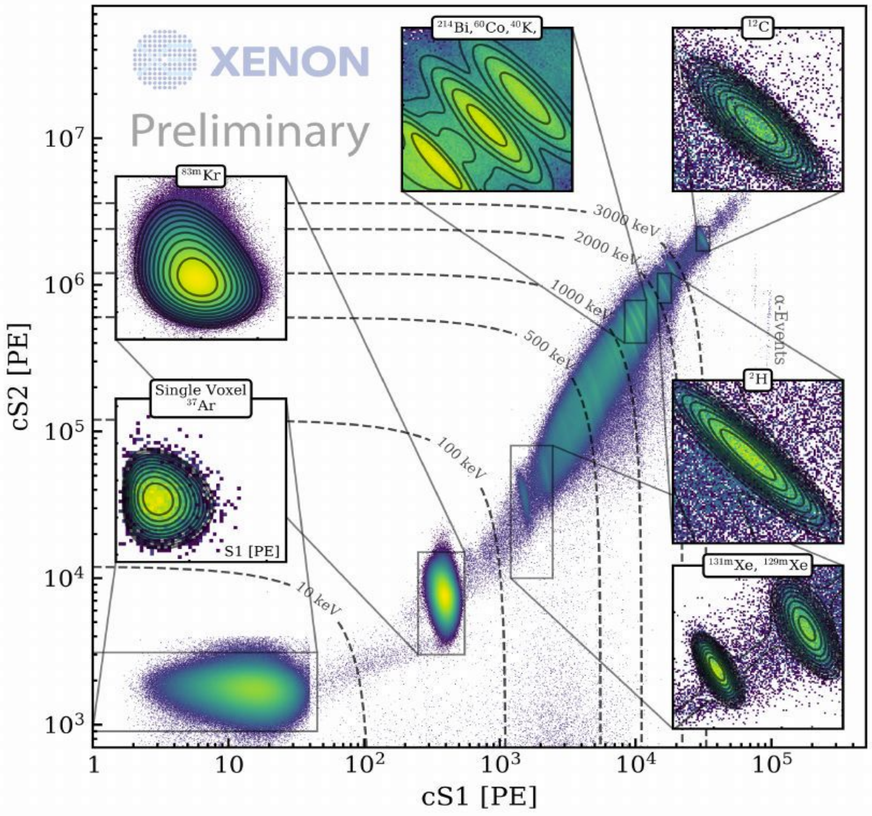
Internal Sources

^{131m}Xe, ^{129m}Xe → **Activated** during AmBe calibration, lines at **163.9 keV** and **236.2 keV** with half-lives of **11.8 days** and **8.9 days**

^{220}Rn → **Continuous** spectrum of **ERs** at low energy down to 1 keV

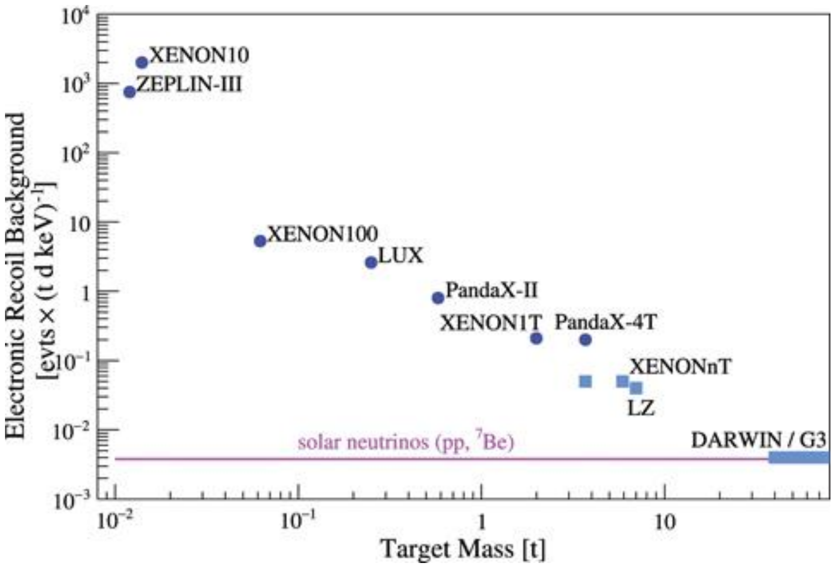
^{83m}Kr → **Two-transition** (**32.1 keV** and **9.4 keV**) decay resulting in 41.5 keV line

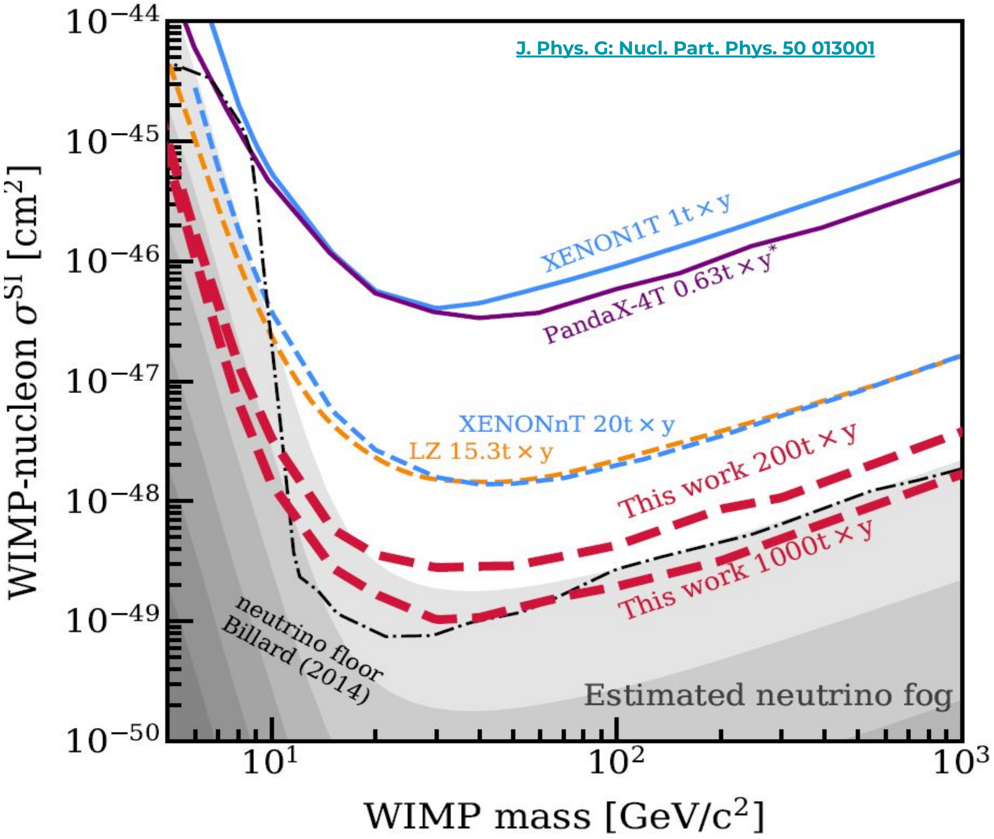
^{37}Ar → Monoenergetic source producing **2.82 keV** line **(K-shell)**



Next generation LXe experiment

Dual-phase Xe TPC with **~50** t of **LXe**, from the **joint** efforts of **XENON**, **LZ** and **DARWIN** collaboration into the **XLZD consortium**





Backup