Search for new physics with the XENONnT detector

R. Biondi on behalf of XENON Collaboration

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK HEIDELBERG

XENON

34th Rencontres de Blois - 16th May 2023

The XENON Collaboration

- 27 Institutions Worldwide
- More than 180 Scientists

Main goal:

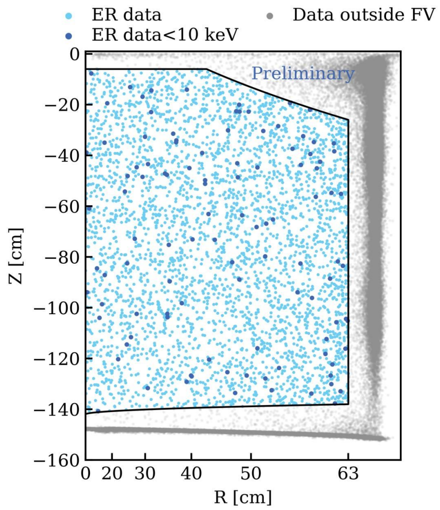
Detection of dark matter particles
with a liquid xenon TPC

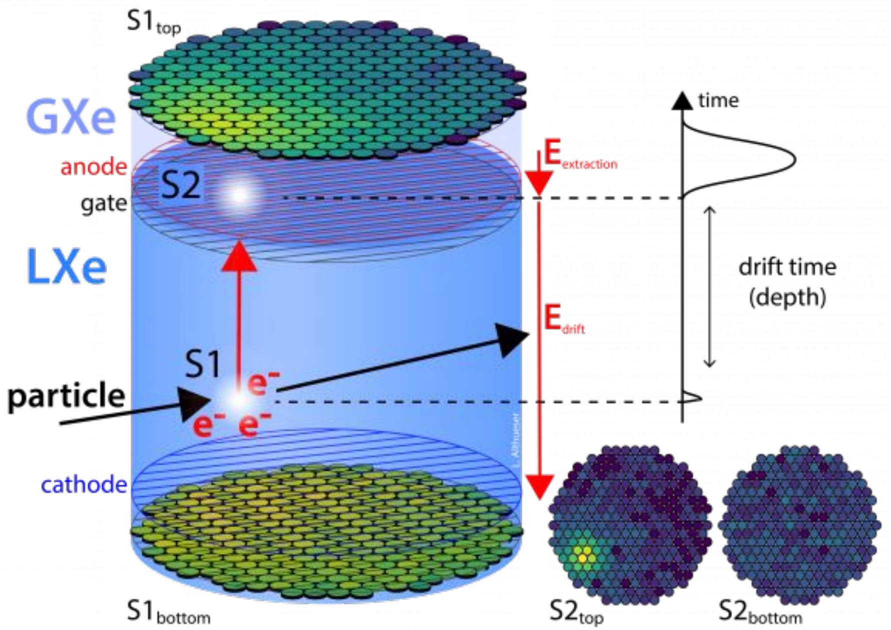
Last Collaboration Meeting in L'Aquila 1-3 February 2023

Xenonexperiment.org
Xenon_experiment
XENONexperiment
XENONexperiment

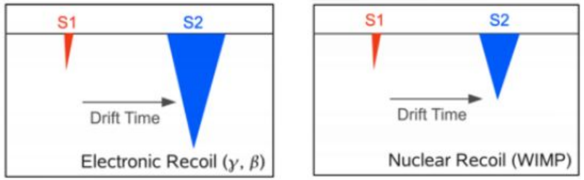
The TPC Detection Principle

- Dual-phase (liquid+gas)
- Energy reconstruction
- 3D event reconstruction
- Fiducialization
- Event discrimination

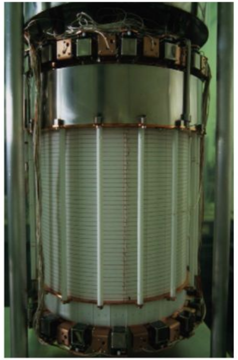
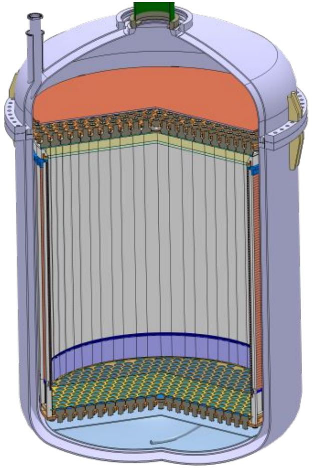




$$E = W\left(\frac{S_1}{g_1} + \frac{S_2}{g_2}\right)$$



Evolution of Xe-based DM detectors

	XENON10	XENON100	XENON1T	XENONnT	DARWIN - XLZD
Period	2005 - 2007	2008 - 2016	2012 - 2018	**2019 - 2025**	**2025 - ...**
Dimensions	15 x 20 cm	30 x 30 cm	1 x 1 m	**1.5 x 1.3 m**	**2.6 x 2.6 m**
Active mass	14 kg	62 kg	2 tons	**5.9 tons**	**40 tons**
Sensitivity	$\sim 10^{-43}$ cm^2	$\sim 10^{-45}$ cm^2	$\sim 10^{-47}$ cm^2	**$\sim 10^{-48}$ cm^2**	**$\sim 10^{-49}$ cm^2**

The XENON project at LNGS

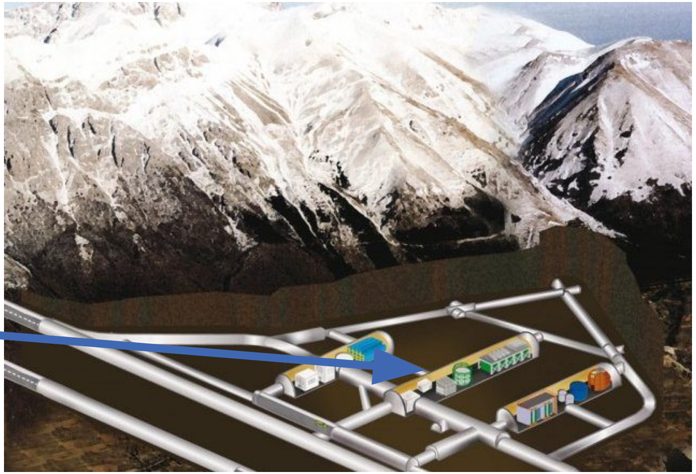
Laboratori Nazionali del Gran Sasso – INFN (Hall B)

1400 mt of rock: 3.800 m.w.e.

Muon flux ~ 1 m^{-2} h^{-1}

Suppression factor: 10^6

XENON1T



Low-ER excess in XENON1T

From: Phys. Rev. D 102, 072004

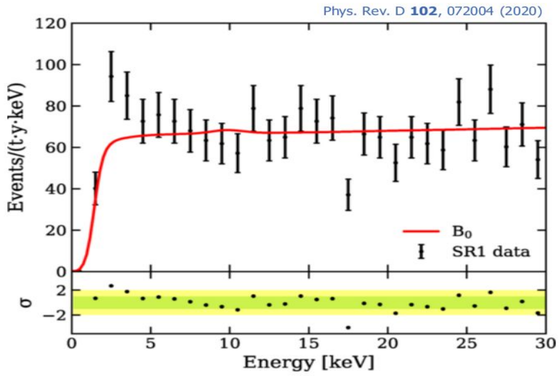
ER search in <30 keV range shown an excess of events over the expected background corresponding to a **3.3 σ fluctuation**

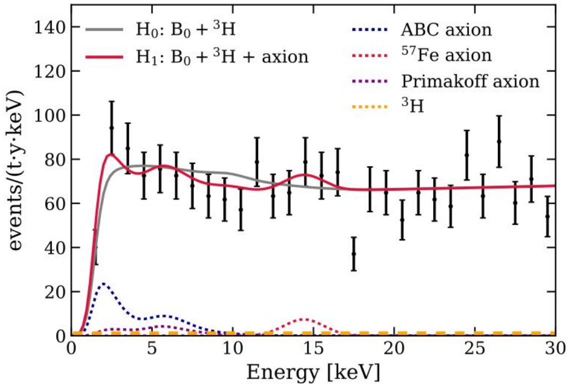
Hypothesis of ^{37}Ar leak is excluded:

- Removed by Kr distillation
- Limits on air leak from other contaminants (Kr, Rn)

Several hypothesis:

- Solar axions (3.4σ over bkg)
- Neutrino magnetic moment (3.2σ over bkg)
- Bosonic DM: ALPs, dark photons (3.0σ over bkg)
- β decay of Tritium
- New Physics?





XENONnT

Fast upgrade exploiting the infrastructures from XENON1T

Larger TPC

Neutron Veto

Material selection and cleaning

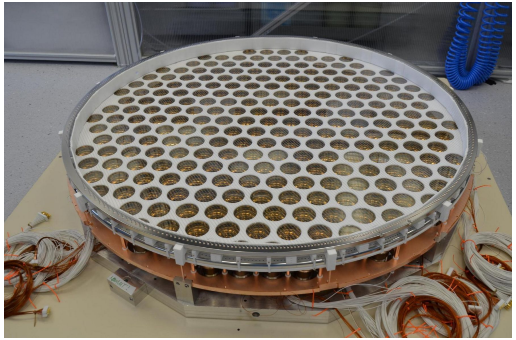
Rn distillation column

Rn-free pumps

Liquid-Xe Purification

New TPC

- Drift length 1.5 m (XENON1T had 1 m)
- Active **Xe mass 5.9 t** (2 t)
- Double the number of PMTs to 494
- Light detection efficiency: 36%
- Carefully **selected materials** to minimize background
- Field shaping rings with tunable potential

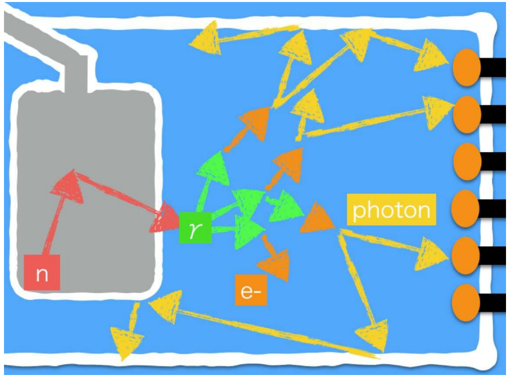


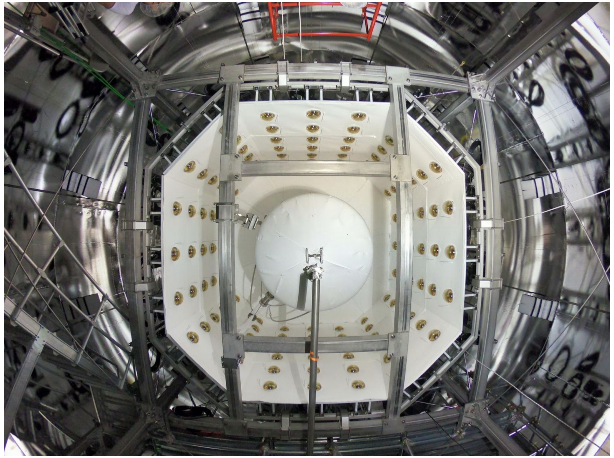
Commissioned in March 2020 during the lockdown due to COVID pandemic

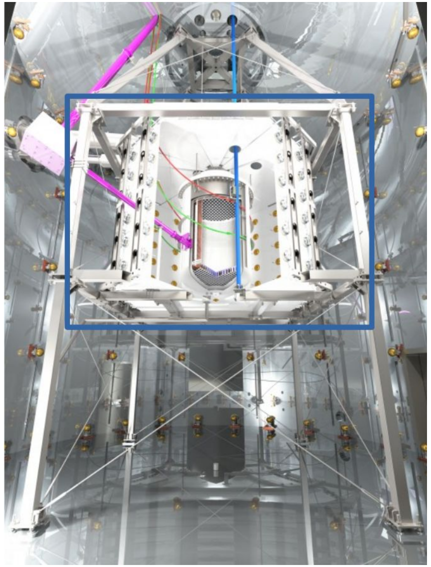
Neutron Veto

Water Cherenkov detector built around the cryostat with 120 PMTs inside an enclosure of reflective panels

To tag **neutrons events** which contribute to background in WIMP search







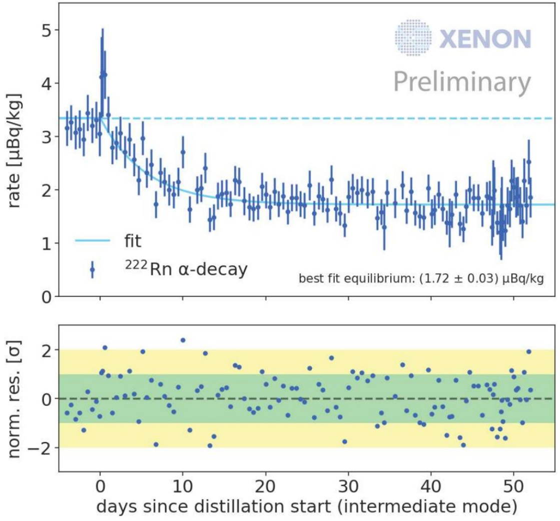
Running with pure water: **Measured tagging efficiency 68%**

It will be doped with Gd to increase performances (~87% efficiency predicted)

Rn Removal Column

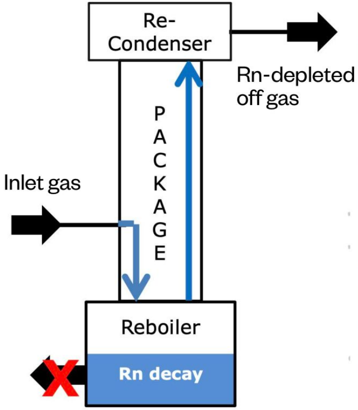
Low-ER search background comes mainly from β-decay of ^{214}Pb originating from ^{222}Rn accumulating into LXe and GXe, mitigated through careful material screening and selection.

Rn atoms are kept in the column and decay



1.7μBq/kg

(GXe-only mode)



Two operation modes: GXe and LXe:

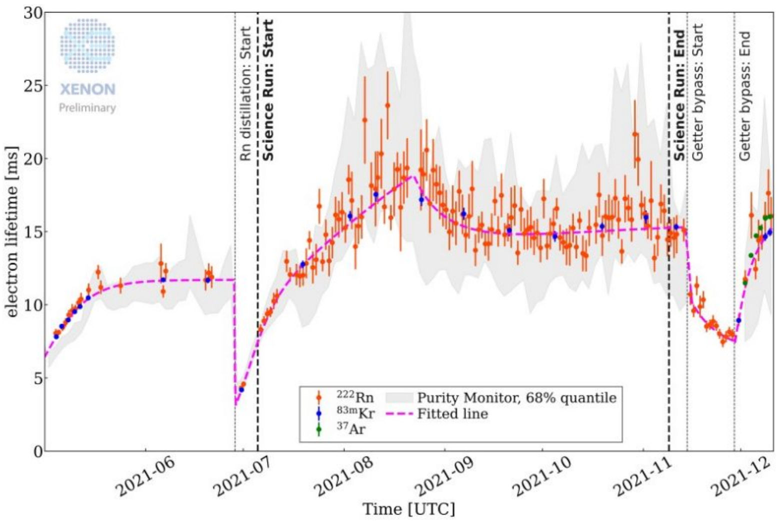
- GXe: Remove Rn emanated from signal cables, cryogenic pipe, …
- LXe: Remove Rn emanated from TPC body, PMT, …

Further x2 reduction achieved for new science run with GXe+LXe: **<1 μBq/kg**

Liquid Xe Purification System

Direct liquid circulation with cryogenic pump To purify faster the full inventory of LXe

- High flow: 2 liters LXe/min
- Replaceable filter units with low Rn emanation
- Online purity measurement by purity monitor

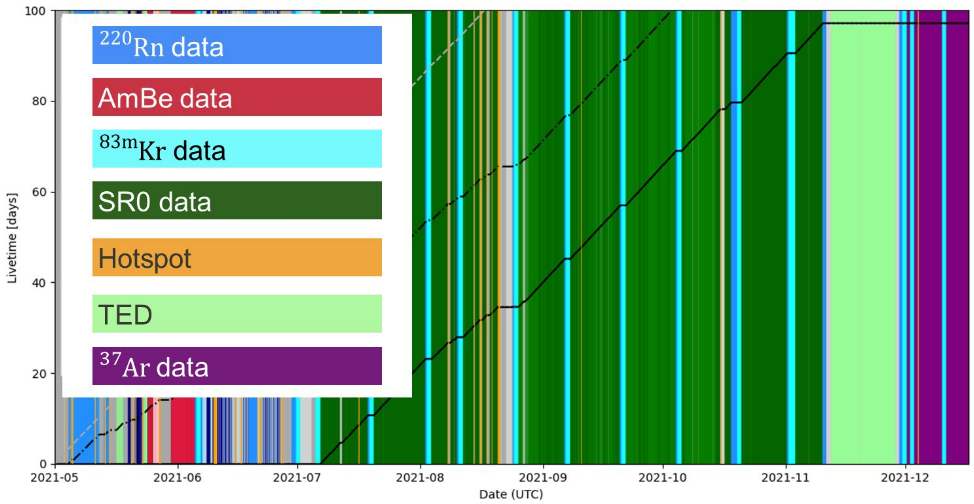


Achieved x10 better purity than XENON1T

Electron lifetime > 10 ms in science run

First Science Run - SR0

97.1 days livetime: July 6th - November 10th 2021



- All but 17 PMTs working
- Triggerless acquisition
- Online processing
- Gain: 2×10^6 stable at 3% level
- Drift field: 23 V/cm due to short circuit between cathode and bottom screen
- Extraction field: 2.9 kV/cm
- Extraction efficiency: ~53%
- Single Electron Gain: ~31 PE
- Internal calibration: ^{83m}Kr, ^{220}Rn, ^{37}Ar
- External calibration: AmBe
- Tritium Enhanced mode (TED)

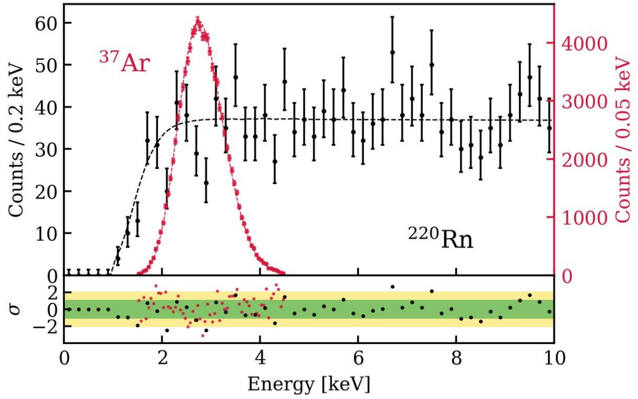
Main Goal:
Clarify the excess in LOW-ER from XENON1T

Occasional temporary ramp-downs of the anode, due to localized, high-rate, bursts of electrons (Hotspot).

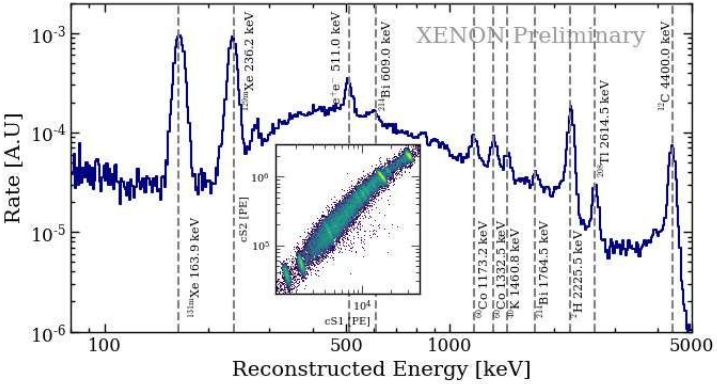
Calibration

Two **ER calibration** sources at low energies:

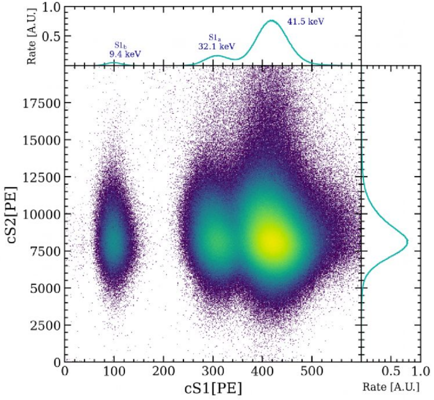
- **^{37}Ar:** mono-energetic peak at 2.82 keV, validates resolution model and energy reconstruction of peaks.
- **^{220}Rn:** its daughter ^{212}Pb provides a flat β-spectrum used to estimate cut acceptances and energy threshold



NR calibration with **AmBe** source:



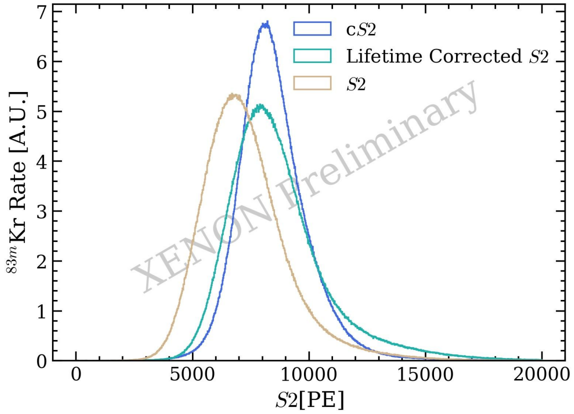
^{83m}Kr: bi-weekly calibrations: for corrections and e-lifetime

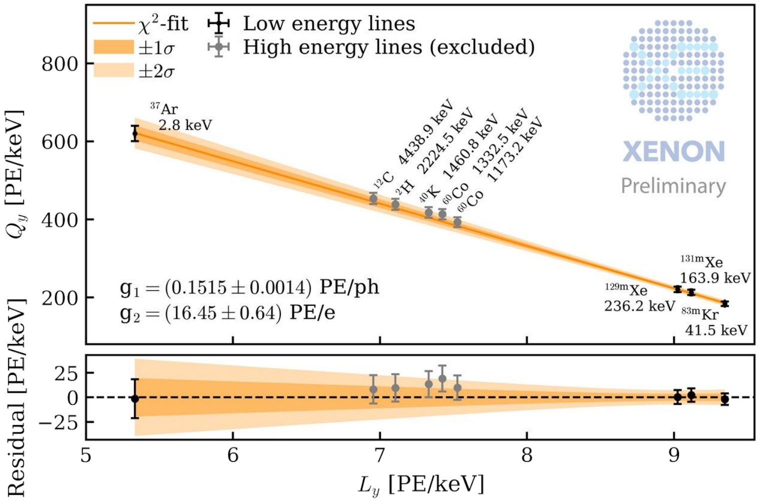


Corrections and Energy Reconstruction

S1 and S2 signals have to be corrected to take into account **position dependent response** of the detector, this is done via the periodical ^{83m}Kr calibration.

Corrected signals cS1 and cS2 are then used in the analysis





Energy reconstruction:

Using: ^{37}Ar, ^{83m}Kr, ^{131m}Xe, ^{129m}Xe calibration

$$E = 13.7\text{ eV}\left(\frac{cS1}{g_1} + \frac{cS2}{g_2}\right)$$

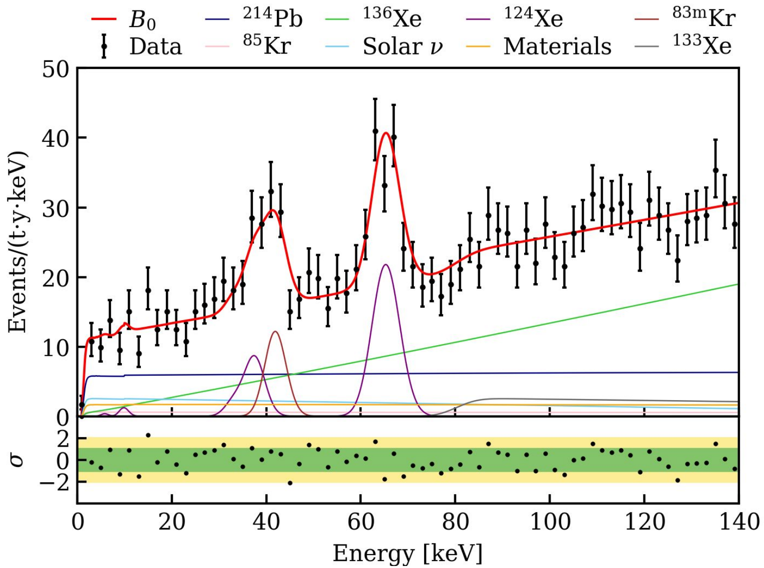
Low Energy ER Analysis

From: PRL 129, 161805 (2022)

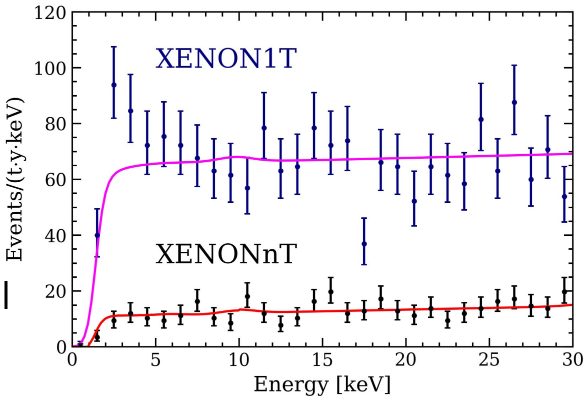
Full blind analysis

- Energy range: (1-140) keV
- Fiducial mass: (4.37±0.14) t
- Exposure: **1.16 tons years**

No excess observed



The excess observed in XENON1T could come from either tritium or statistical fluctuation



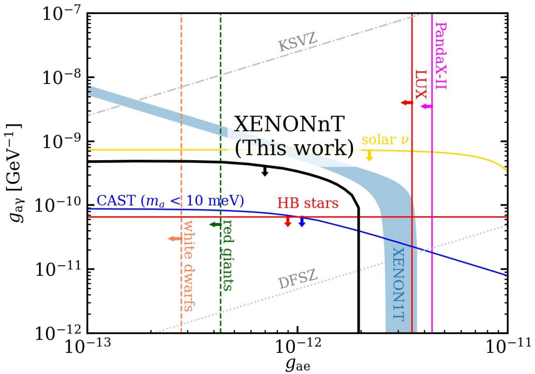
Background in (1,30) keV:

(15.2 ± 1.3 stat)events/(t*y*keV)

Factor ~5 reduction w.r.t. XENON1T

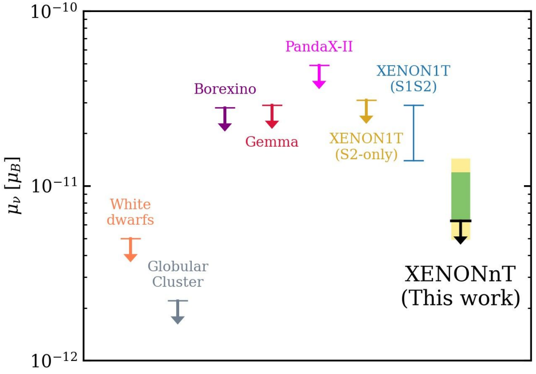
Limits on New Physics

Solar Axions



Limit on 14.4 keV peak for ^{57}Fe solar axions is < 20 events/(t*y)

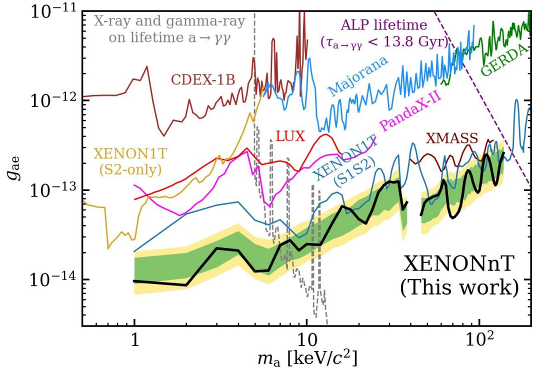
ν Magnetic Moment



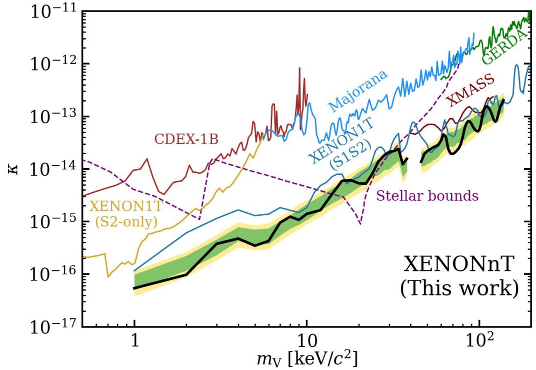
$\mu_\nu < 6.3\ 10^{-12}\ \mu_B$

The most stringent limit from direct detection experiment

Axion-like particles



Dark Photon



WIMPs search

From arXiv: 2303.14729

Background model:

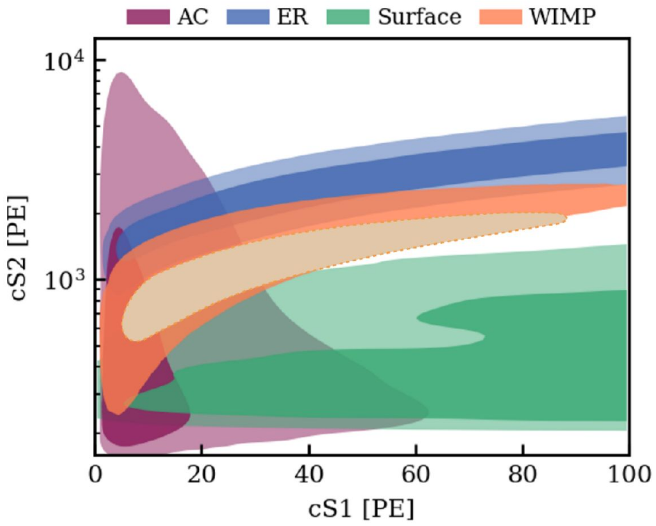
Electronic Recoil (ER): Mainly β decay of ^{214}Pb from ^{222}Rn

Accidental Coincidences (AC): random pairing of small S1 and S2 signals

Surface/Wall: ^{210}Pb plate-out on the PTFE wall of the TPC

Nuclear Recoil backgrounds (same shape as WIMP):

- CEvNS
- Neutrons



Signal-like region containing 50% of a 200GeV/c² WIMP signal with highest signal-to-noise ratio

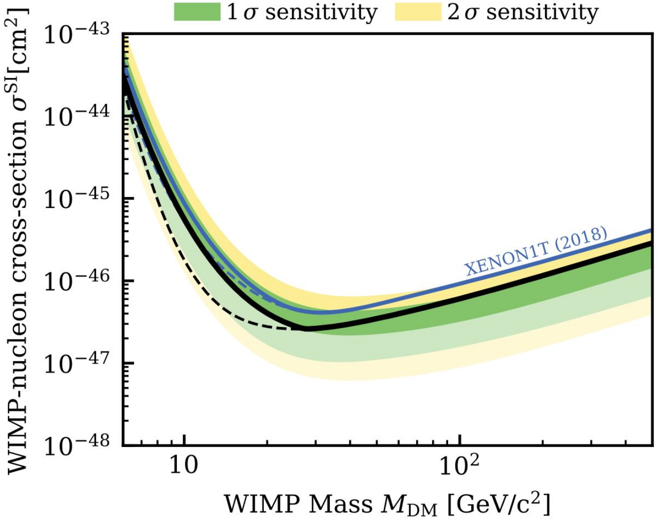
WIMPs Results

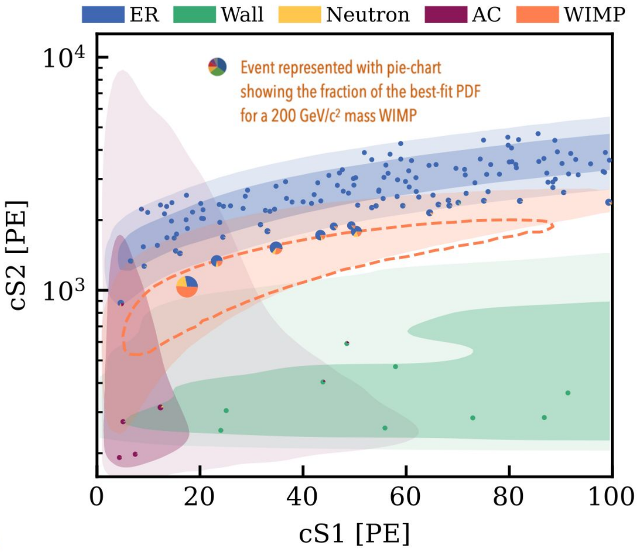
Full blind analysis

- Fiducial mass: (4.18±0.13) t (Same shape of ER, but smaller R < 61.35 cm)
- Exposure: **1.1 tons years**

No significant excess

XENONnT 90% C.L. Power-Constrained Limit To constrain large downwards fluctuations



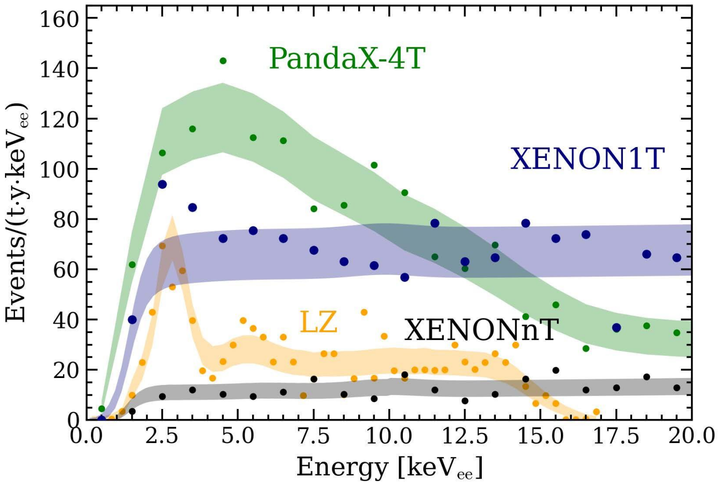


*Assuming a 200 GeV WIMP and a best-fit σ = 2.5 × 10^{-47} cm^2

Comparison with other LXe Experiments

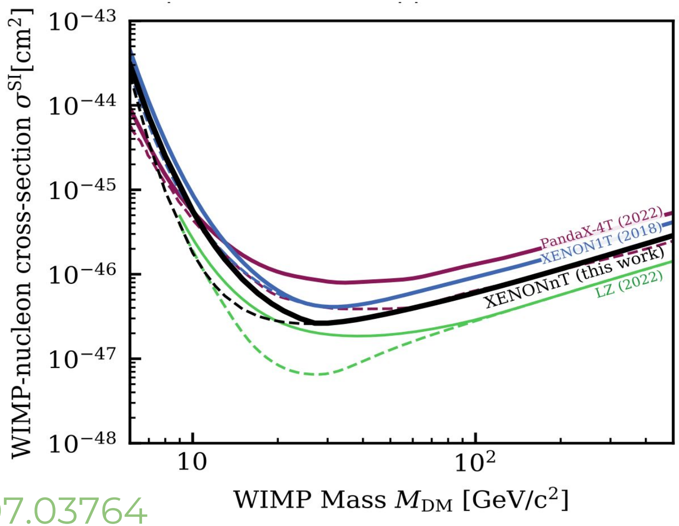
ER Background:

PandaX-4T PRL 129, 161804 (2022)
XENON1T PRD 102, 072004 (2020)
LZ arXiv:2207.03764
XENONnT PRL 129, 161805 (2022)



Spin-Independent WIMP-Nucleon cross section:

Same conservative power-constraint applied to results of other LXe experiments from non-blind analyses:



LZ, arXiv:2207.03764
XENON1T, PRL 121, 111302 (2018)
PandaX-4T, PRL 127, 261802 (2021)

Summary and Outlook

We performed a search for new physics exploiting **electronic and nuclear recoil data from XENONnT**

The average ER background rate of (15.8 ± 1.3 stat) events/(t·y·keV) in the (1, 30) keV energy region is the **lowest ever achieved in a DM search experiment**

Blind analysis shows **no excess above the background**, excluding BSM interpretations of the XENON1T excess.

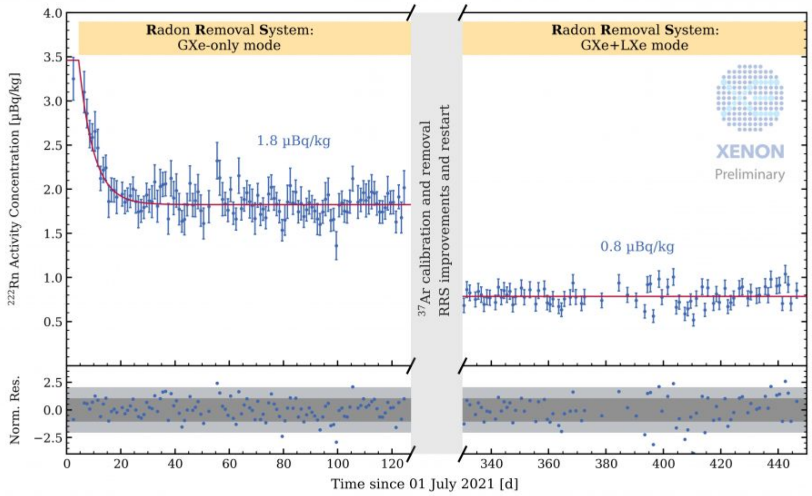
Best fit for WIMP search indicates **no significant excess** we therefore set a new limit for SI WIMP cross section:

$2.6 \cdot 10^{-47}$ cm^2 at 28 GeV/c^2 and 90% CL

Thank You!

What's next:

- Ongoing science run (SR1) with factor 2 lower radon level
- Addition of Gd salt to the Neutron veto



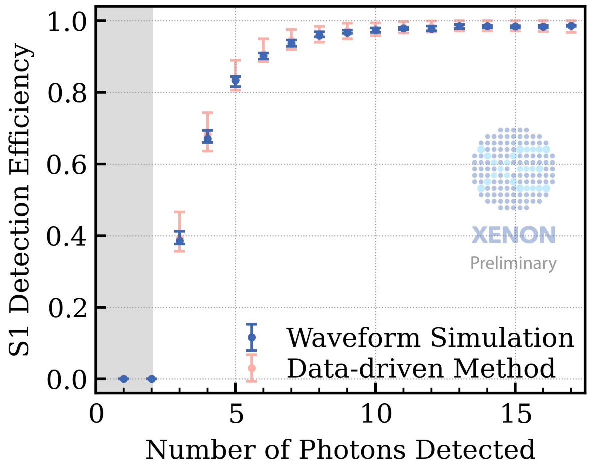
BACKUP

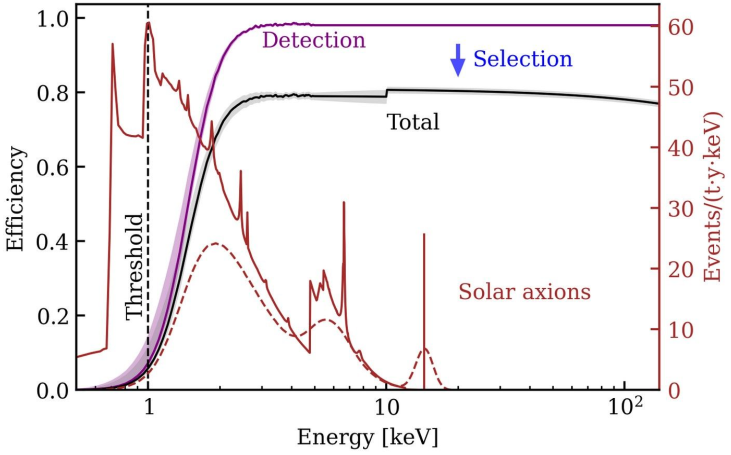
Efficiencies

Detection efficiency validated using **Monte Carlo** and **Data-Driven** methods

Good agreement between the two approaches

Total efficiency takes also **event-selection efficiency** into account



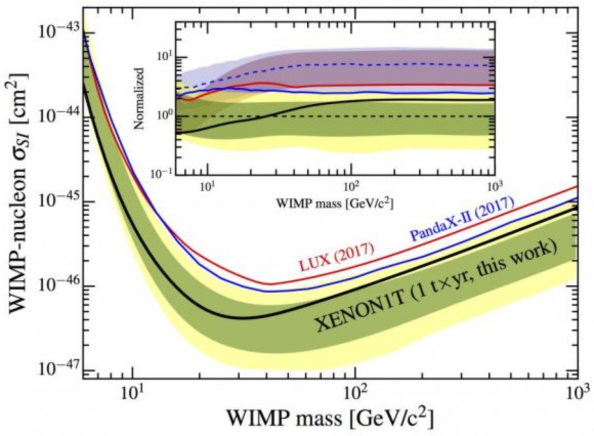


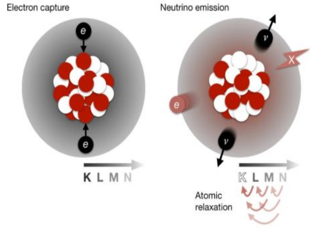
Results from XENON1T

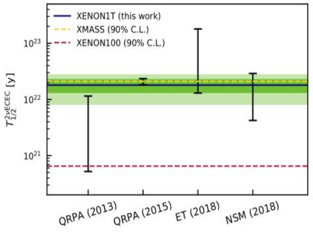
Upper Limit on WIMP-nucleon cross section:

4.1×10^{-47} cm^2 @ 30 GeV/c^2 (90% CL)

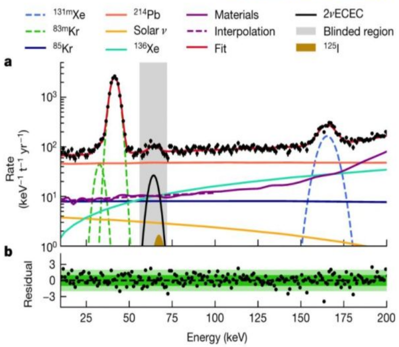
Phys. Rev. Lett. **121**, 111302 (2018)







Nature volume 568, 532–535(2019)



Half-life of **Double Electron Capture in ^{124}Xe**

Longest half-life ever observed:

1.8×10^{22} yr

(4.4σ Significance)

Tritium Enhanced Dataset (TED)

To Exclude presence of Tritium traces in the detector, XENONnT was operated **bypassing the GXe purification** for 14.3 days at the end of SR0

This would enhance the HT concentration in LXe by a factor 10-100

Data collected in this TED mode were **blinded**

After the unblinding, **no evidence was found for a tritium-like excess**

Tritium is therefore not included in the background model.