First results from the XENONnT Dark Matter Experiment

Valerio D'Andrea

INFN Sezione di Roma Tre

on behalf of the XENON Collaboration

La Thuile 2023 - Les Rencontres de Physique de la Vallée d'Aoste

March 5th - 11th, 2023

Outline

- Introduction
  - XENON Collaboration
  - Working Principle
  - XENON History
- XENONnT
  - Detector Upgrades
  - Purification Systems and Distillation Columns
- First Results from XENONnT

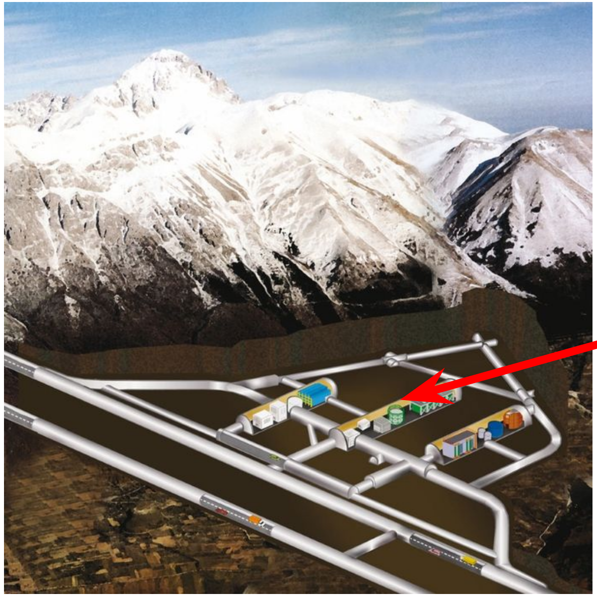
XENON Collaboration

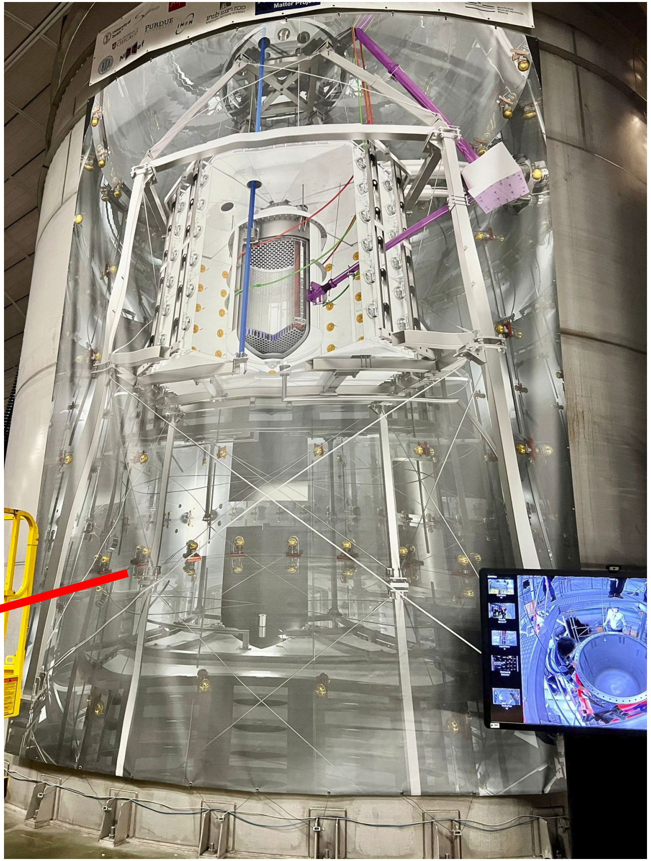
XENON Collaboration

XENON Location

INFN Laboratori Nazionali del Gran Sasso, L’Aquila, Italy

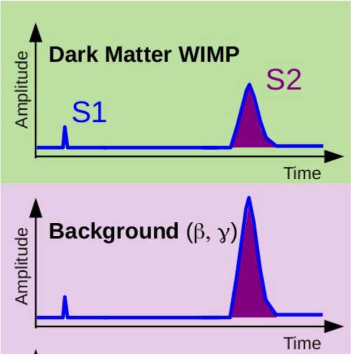
1300 m of rock → 3600 m.w.e.



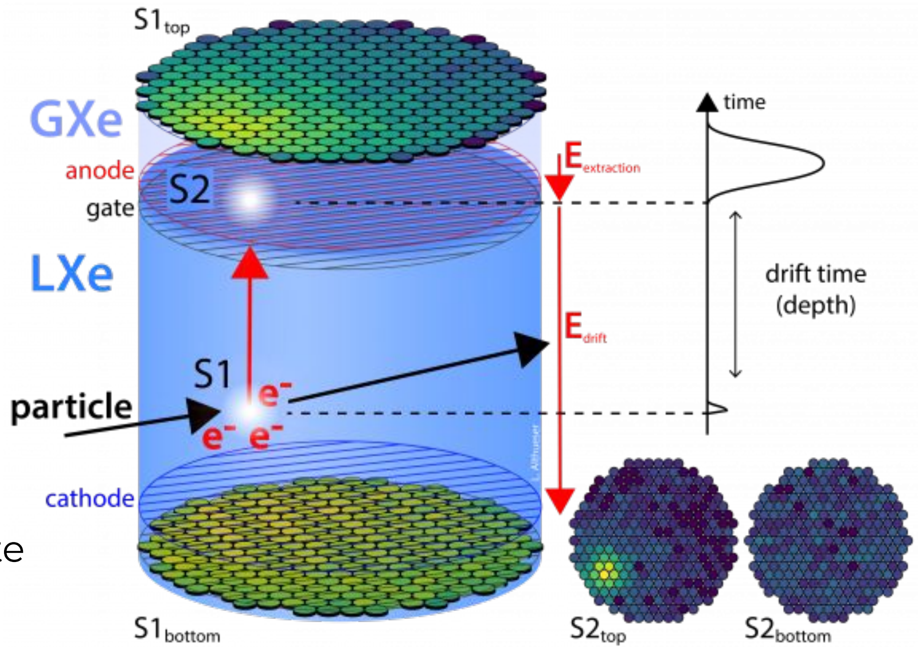


XENON Detector: Dual-Phase Xe TPC

- dual-phase Xenon (**LXe** + **GXe**)
- **prompt scintillation light S1 in LXe**
- **secondary-light signal S2 in GXe**
- **electrodes** to establish electric fields
- **3D event reconstruction**

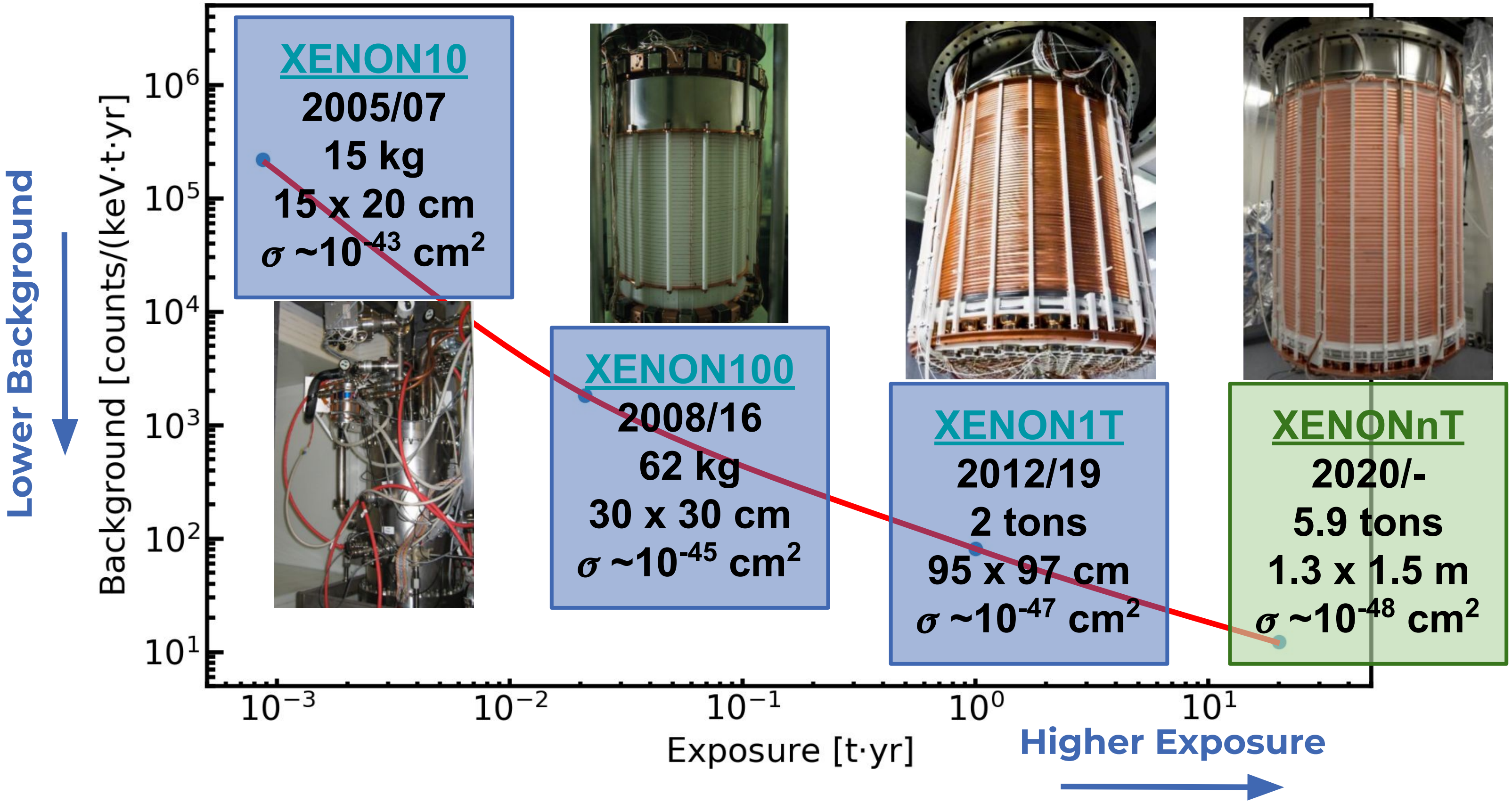


S2/S1 ratio to discriminate **electronic recoil (ER)** and **nuclear recoil (NR)**



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

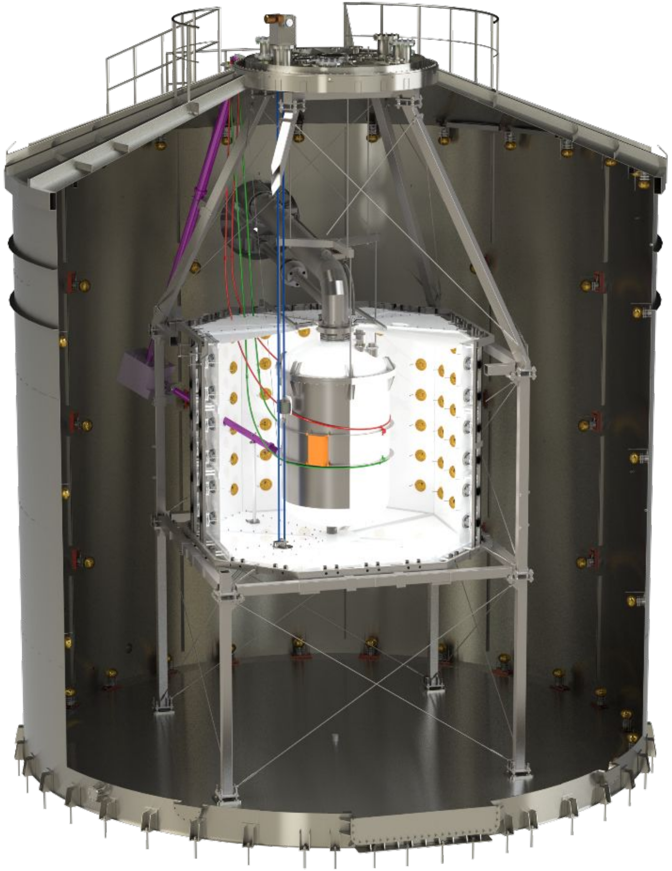
Evolution of XENON detectors



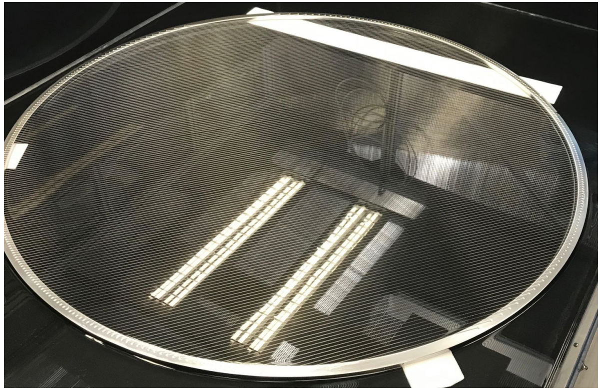
Low Background Techniques in XENON

- **Underground facility** at LNGS, muon flux 3.4 10^{-4} $m^{-2}s^{-1}$ JCAP 05 (2012) 015
- **LXe properties**: Radiopure & Self-shielding
- **Cherenkov muon veto** JINST 9, P11006
- **Online Krypton Distillation** PTEP 074 (2022) EPJC (2017) 77, 275
- **XENONnT Upgrades:**
  - **Strong material selection** EPJC (2022) 82, 599
  - **Improved Purification Systems** EPJC (2018) 78, 604 EPJC (2022) 82, 860
  - **NEW radon distillation column** EPJC (2022) 82, 110
  - **NEW neutron veto with Gd-loaded water**

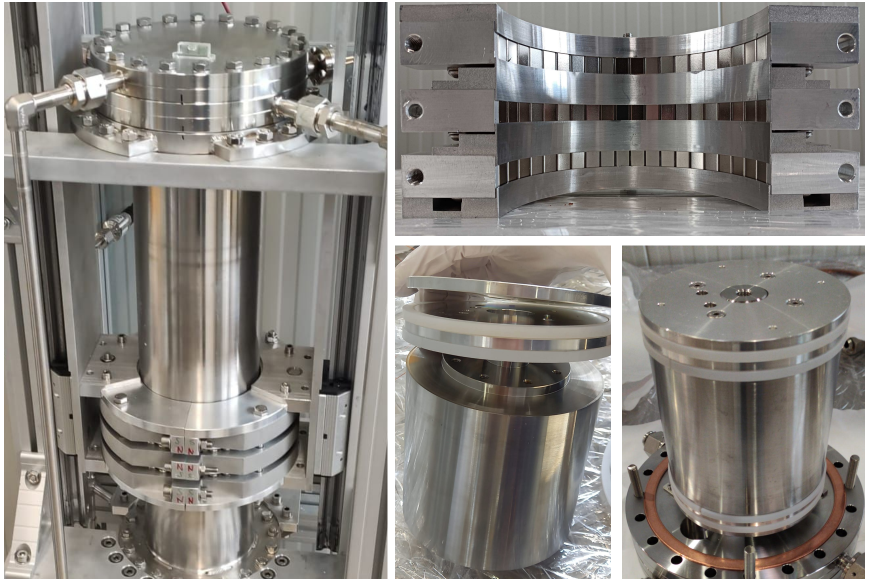
XENONnT

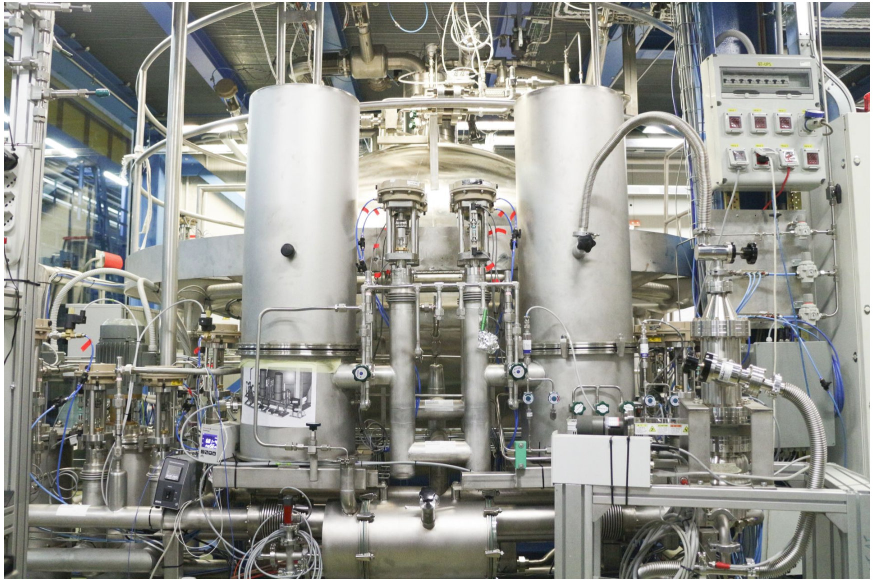


- Larger TPC (1.3 x 1.5 m) with active LXe mass 5.9 t
- TPC read by 494 PMTs
- Purifications Systems Improvement
- Radon distillation column
- New Neutron Veto (nVeto)



XENONnT GXe/LXe Purification Systems





- **improved GXe purification** with **magnetically coupled piston pumps**
- **only high-purity components** to guarantee **low Rn emanation**

EPJC (2018) 78, 604

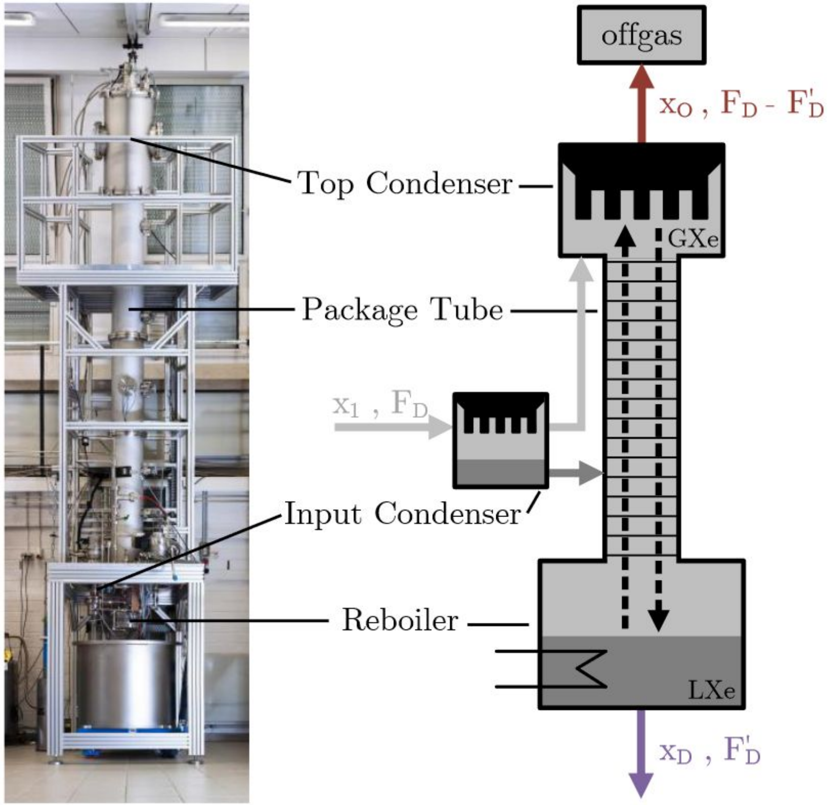
- **novel LXe purification** with ultra-low radon emanation O_2 filters
- **continuous monitor** of impurities, **electron lifetime > 10 ms (< 0.1 ppb)**

EPJC (2022) 82, 860

XENONnT Online Krypton Distillation Column

PTEP 074 (2022) EPJC (2017) 77, 275

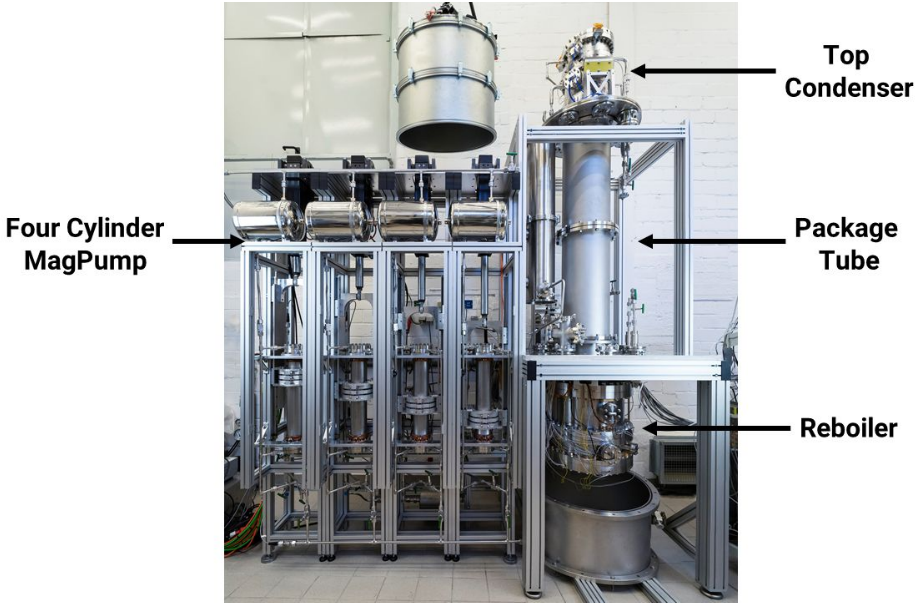
- **developed for XENON1T**
- system demonstrated a concentration level **< 50 ppq ^{nat}Kr/Xe**
- column also used to **reduce ^{37}Ar**
- technique based on the **higher vapor pressure** of Kr/Ar compared to Xe at -96 °C
- more volatile gases (Ar/Kr) enriched at **Top Condenser** and depleted in the **Reboiler**

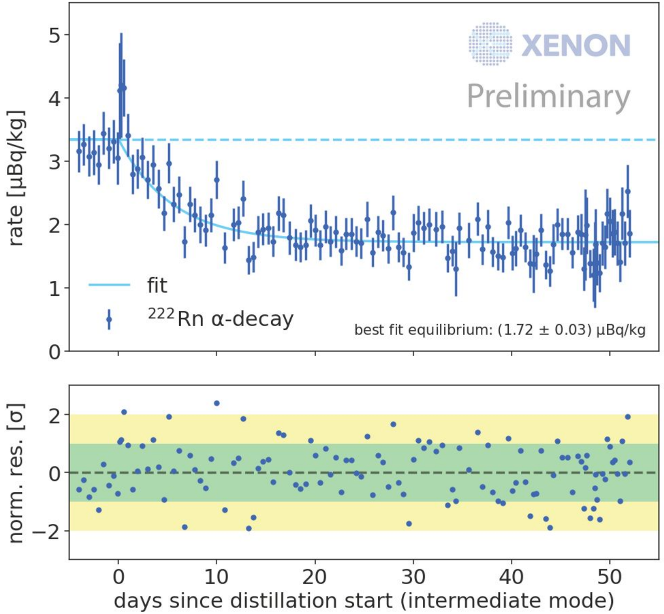


XENONnT Radon Distillation Column

EPJC (2022) 82, 1104

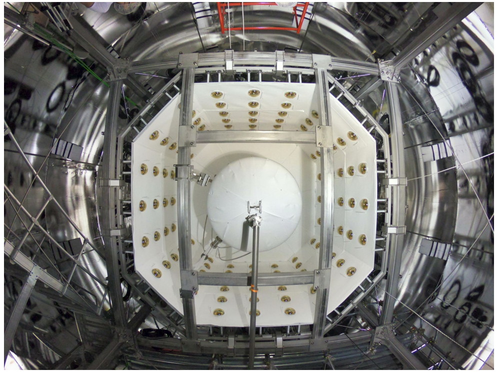
- **novel distillation column** to separate Rn from GXe due to lower vapor pressure
- **1.7 μBq/kg ^{222}Rn achieved** (factor of ~10 lower than XENON1T), expected further reduction to reach **XENONnT goal of 1 μBq/kg**

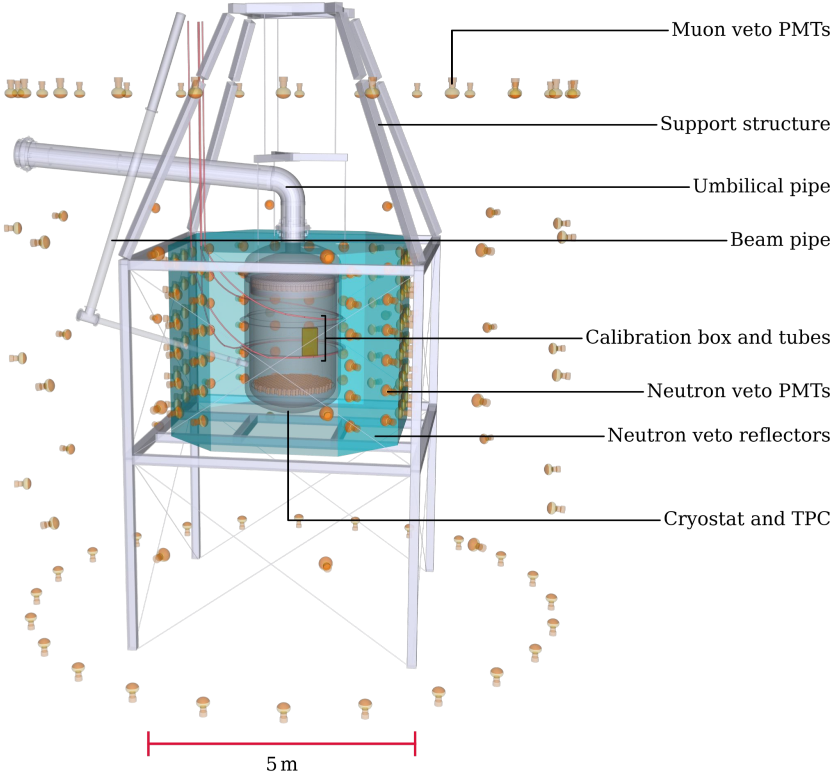




XENONnT Neutron Veto

- **nVeto** with Gd-doped water, high cross-section for thermal neutrons capture ($\sigma \sim 10^5$ b for ^{157}Gd)
- **volume of 33 m^3** around the cryostat instrumented with 120 low radioactivity PMTs
- **Gd-water purification system** to improve transparency for Cherenkov radiation
- **efficient neutron tag** of ~87% (so far nVeto with demi-water, 66% tagging efficiency)



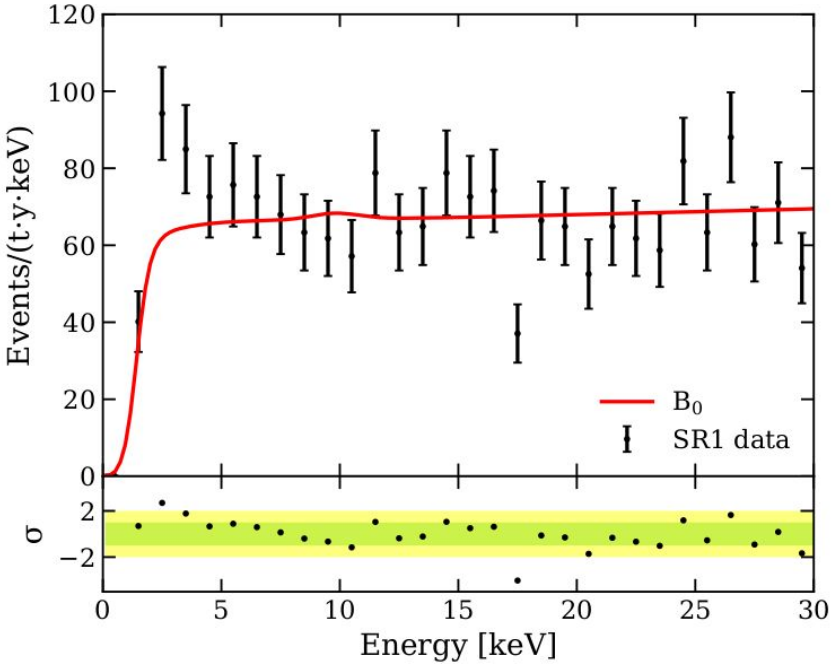


First Results from XENONnT

XENON1T Low-ER excess

PRD 102, 072004 (2020)

- **electron recoil** search < 30 keV
- **285 events** observed, 232 ± 15 expected (3.3σ fluctuation)
- compatible with beyond-SM (**solar axions, enhanced neutrino magnetic moment, ALPs, dark photons** ...)
- compatible with **^{3}H contamination** at 3.2 σ with concentration (6.2 ± 2.0) × 10−25 mol/mol

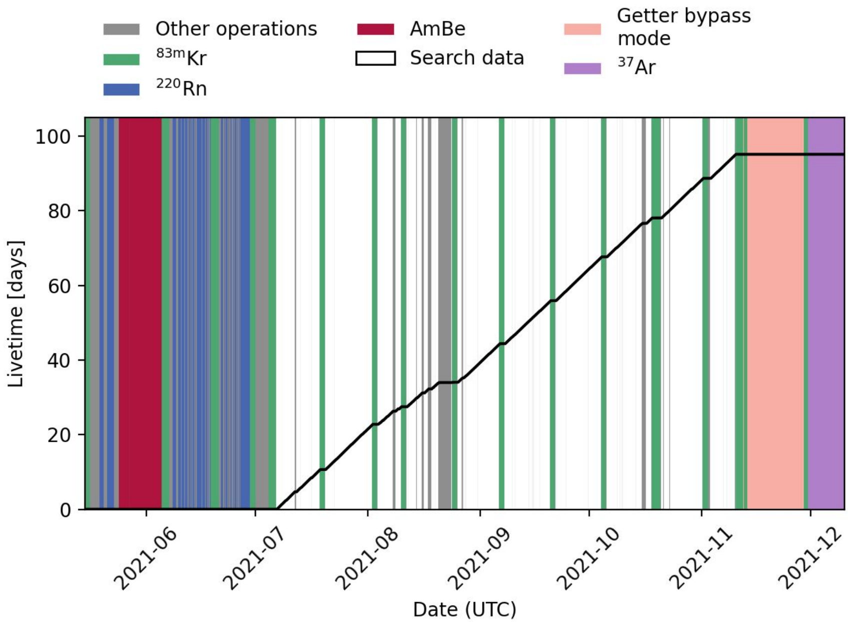


Addressing this question in next slides

XENONnT First Science Run

PRL 129, 161805 (2022)

Main Goal:
clarify the XENON1T Low-ER excess



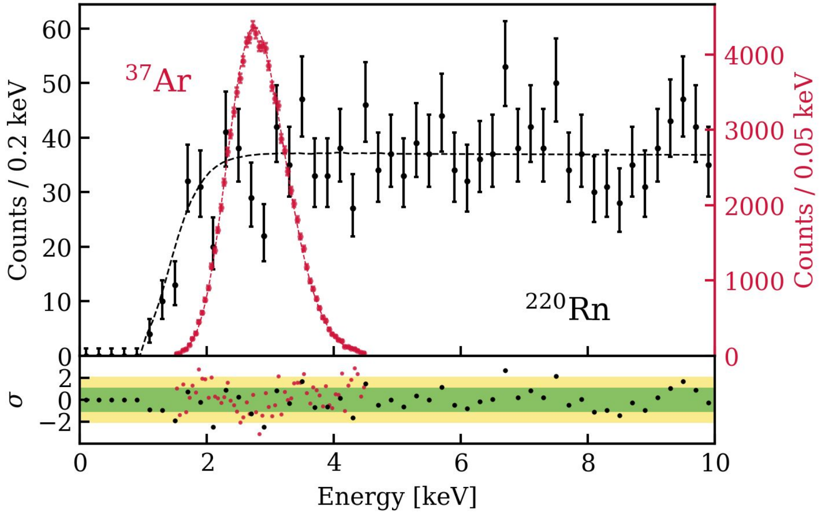
- **97.1 days of exposure from July 6th to Nov 11th 2021**
- **477 out of 494 PMTs** operative, gain stable at 3% level
- **Drift field 23 V/cm** (cathode voltage limited to –2.75 kV due short circuit between cathode and bottom screen)
- **Extraction field in LXe 2.9 kV/cm**
- Temporary anode ramp-downs due to localized high-rate single-electron emissions

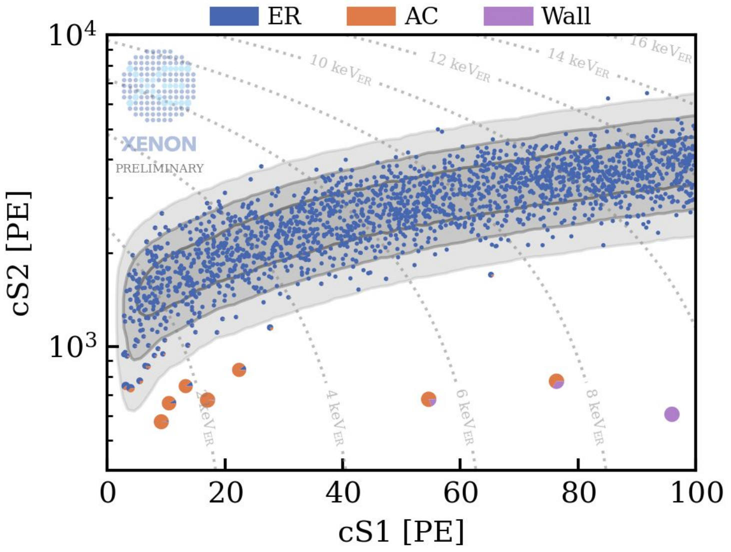
ER response characterization

[PRL 129, 161805 (2022)]

Two homogeneously-distributed ER calibration sources:

- **^{212}Pb from ^{220}Rn with a flat β-spectrum**, to estimate cut acceptances and energy threshold
- **^{37}Ar with a mono-energetic 2.82 keV peak**, validates resolution model and energy reconstruction of peaks

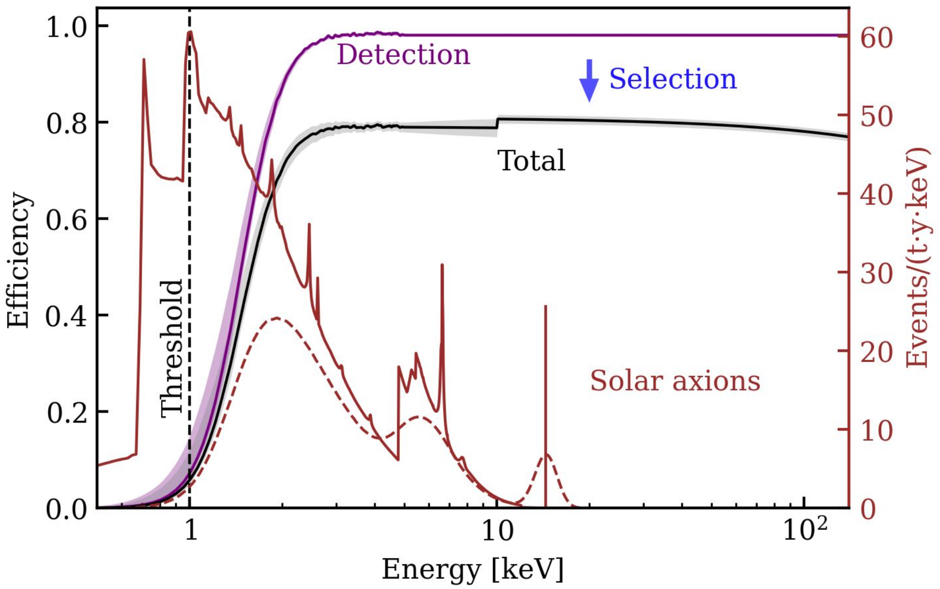




Detection and selection efficiencies

PRL 129, 161805 (2022)

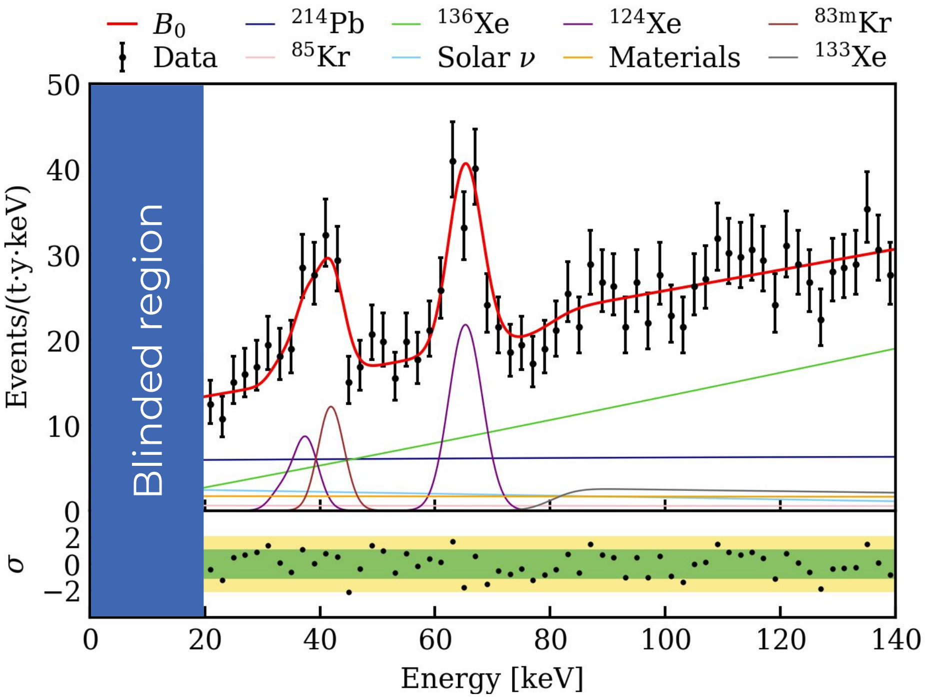
- **Detection efficiency** validated with data and waveform simulations
- Events required to pass quality cuts:
  - **S1 and S2 peaks** must have patterns, area ratios, ecc… consistent with real events
  - **S2 width** consistent with the expected diffusion (modeled with ^{83m}Kr data)
- Fiducial volume cut yields a mass of **(4.37 ± 0.14) tonnes**



Electronic Recoil background

PRL 129, 161805 (2022)

- ^{214}Pb **ultra-low activity of 1.3 μBq/kg**
- ^{85}Kr **ultra-low level of 56 ppq** $^{nat}Kr/Xe$
- subdominant background from **detector materials** EPJC (2022) 82, 599
- **Xe long-lived isotopes:** ββ decay of ^{136}Xe, ECEC in ^{124}Xe PRC 106, 024328 (2022)
- electron scattering of **solar neutrinos**
- ^{133}Xe by neutron activation from $^{241}AmBe$ and ^{83m}Kr from calibrations



Energy range (1, 140) keV, exposure 1.16 t y

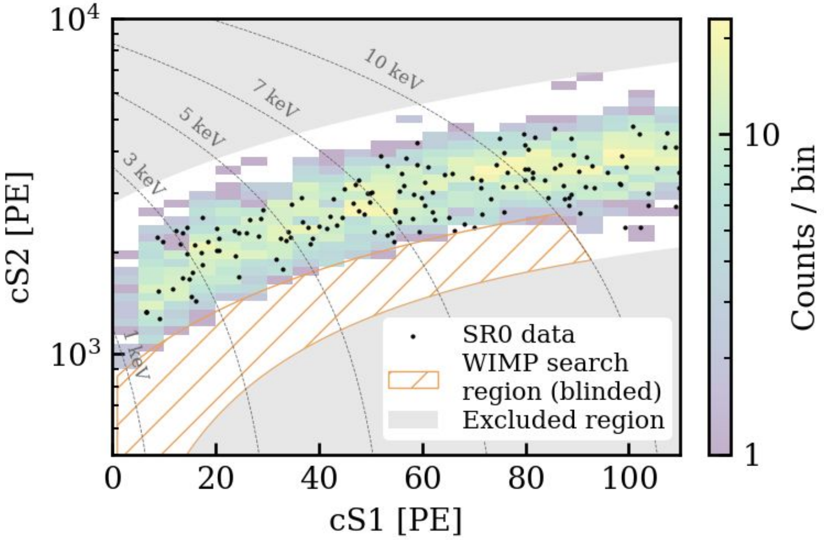
NR and ER data below 20 keV blinded

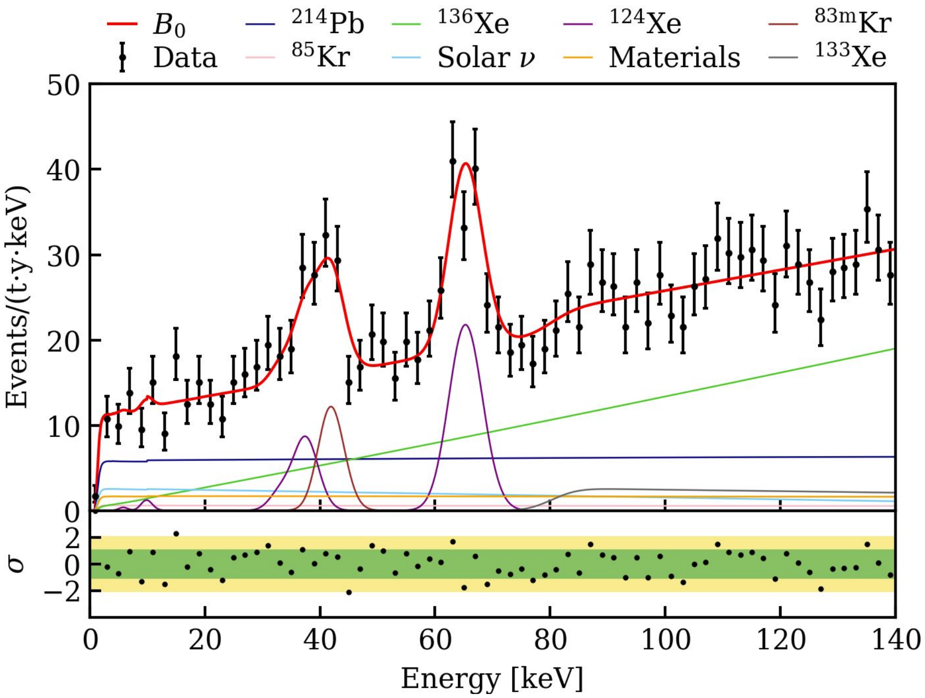
Unblinding of LowER Region

[PRL 129, 161805 (2022)](#)

No excess above the background is found

^{3}H contamination is the most plausible explanation for the XENON1T excess

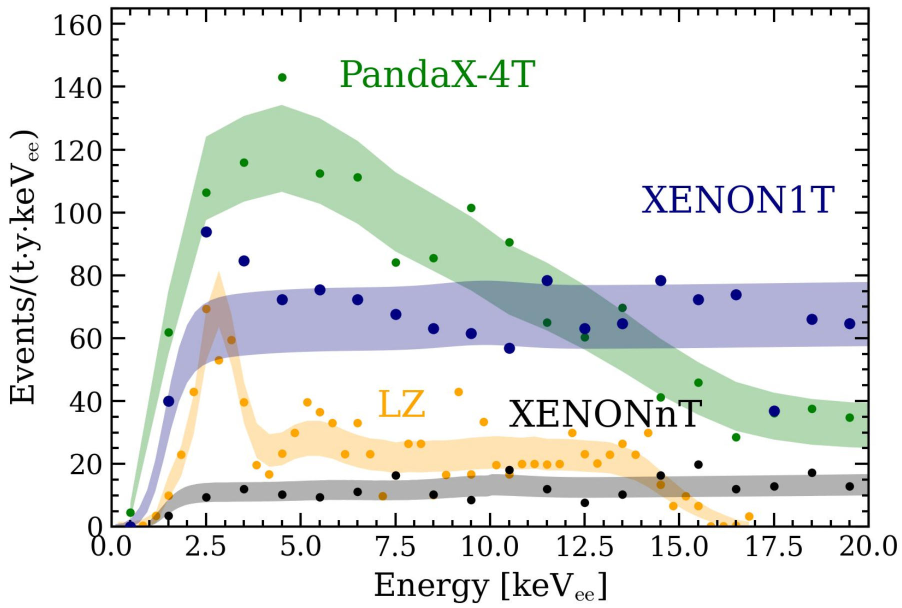




Spectral shape mostly dominated by two second-order weak processes (^{136}Xe and ^{124}Xe)

XENON1T vs XENONnT

- **Lowest ER background in XENONnT of 15.8 ev/(t y keV), factor 5 background reduction with respect to XENON1T**
- **No excess below 5 keV found: 8.6σ exclusion on XENON1T excess**

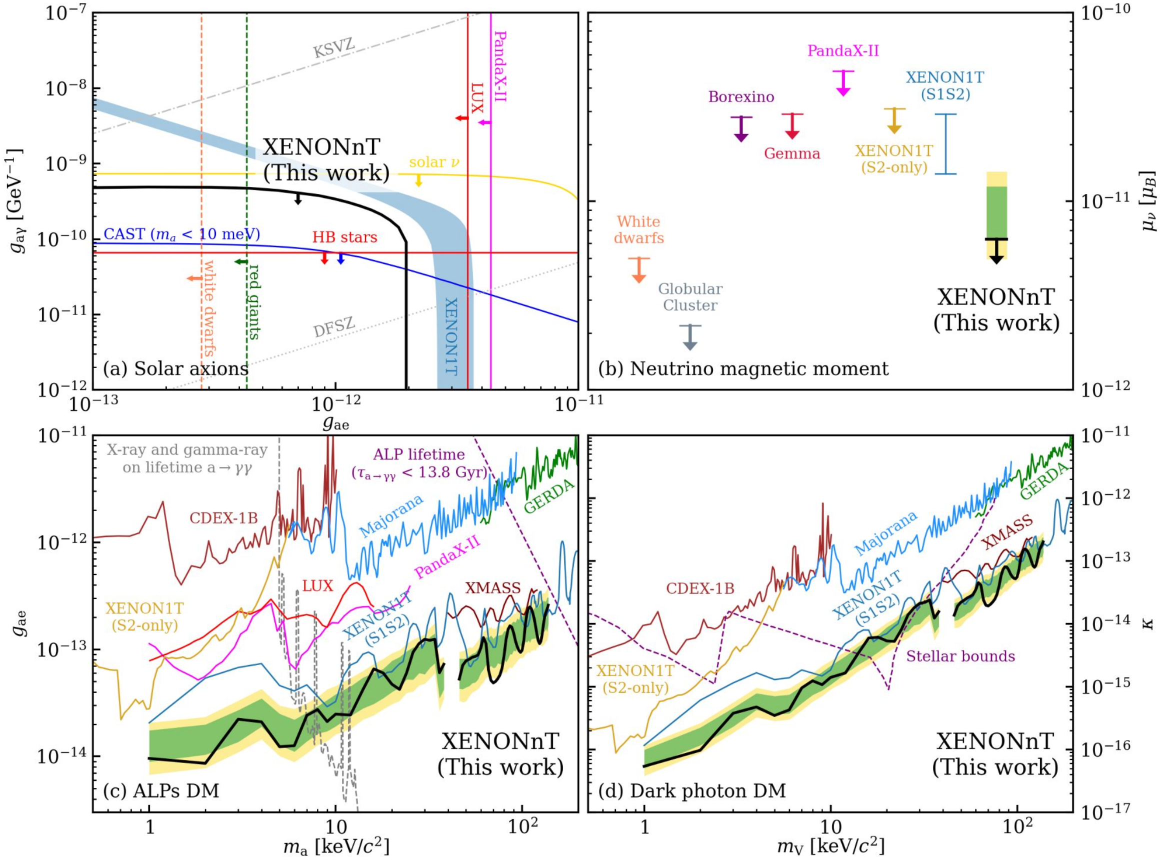


PandaX-4T PRL 129, 161804 (2022)
XENON1T PRD 102, 072004 (2020)
LZ arXiv:2207.03764
XENONnT PRL 129, 161805 (2022)

Limit on New Physics

Solar Axions

Neutrino Magnetic Moment



Axion-like particles

Dark Photons

Summary and Outlook

- Xe based dual-phase TPC is the **leading technology** for direct dark matter searches
- **XENONnT** has several improvements w.r.t. **XENON1T**: **strong material selection**, upgraded **GXe/LXe purification**, novel **Radon column** and **efficient neutron veto**
- **XENONnT was successfully commissioned and data taking is ongoing:**
    - **results from 1st science reported the lowest ER background ever achieved in DM experiments**
    - **no excess above the background, excluding BSM interpretations of the XENON1T excess**
    - **soon new results on WIMPs search**
- **XENON**, **LZ** and **DARWIN** collaborations are joining forces towards a **next-generation LXe observatory (XLZD)** for dark matter search and neutrino physics **white paper**

Home Dark Matter Our Detector ▾ Collaboration Science ▾ Media ▾ News

XENON Dark Matter Project

Direct Search for Dark Matter with Liquid Xenon Deep Underground at the INFN Laboratori Nazionali del Gran Sasso, Italy.

EXPLORE

Check our new website
xenonexperiment.org

Thanks you for the attention!

Follow us

@XENONexperiment

@xenonexperiment

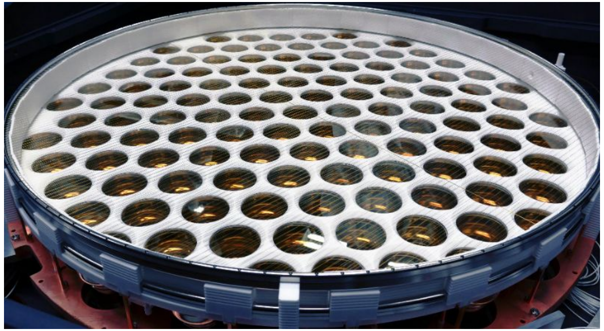
@xenon_experiment

BACKUP

XENON1T

EPJC (2017) 77, 881

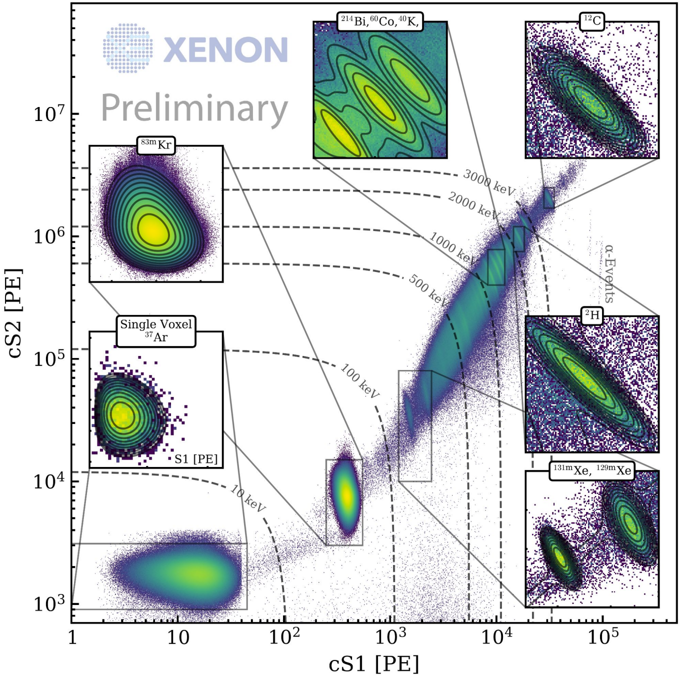
- **cylindric TPC** (97 x 96 cm)
- mass 3.2 t LXe (2.0 t active)
- **drift field** ~ 100 V/cm
- **248 3-inch PMTs**
- **X-Y reconstruction** via neural network
- **best energy resolution** ever in LXe TPC ~1.6% at 2.5 MeV and 6% at 40 keV



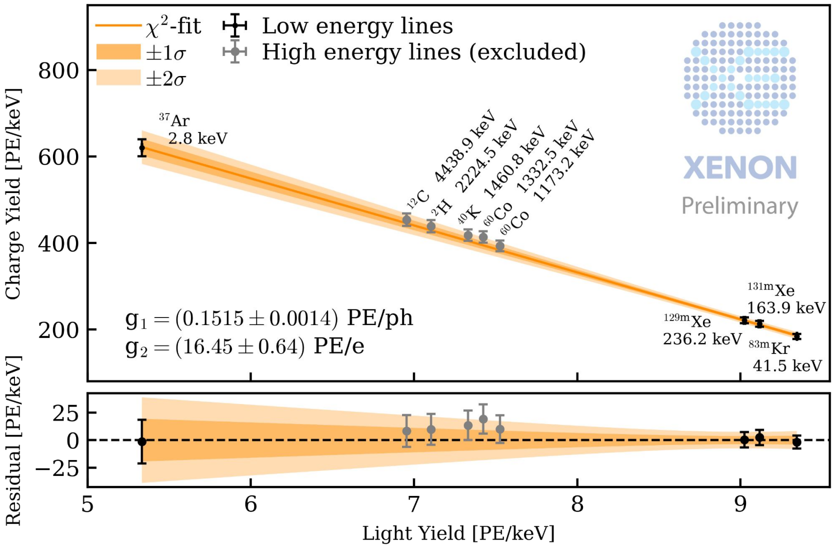
- water tank with **Cherenkov muon veto (mVeto)**
- novel cryogenics, Xe storage and purification systems, **most systems used also in XENONnT**

Energy Reconstruction

- Calibration using 4 low-energy peaks **^{37}Ar**, **^{83m}Kr**, **^{129m}Xe** and **^{131m}Xe**
- Observed 1-2% bias in reconstructed energy used as systematic uncertainty in modeling

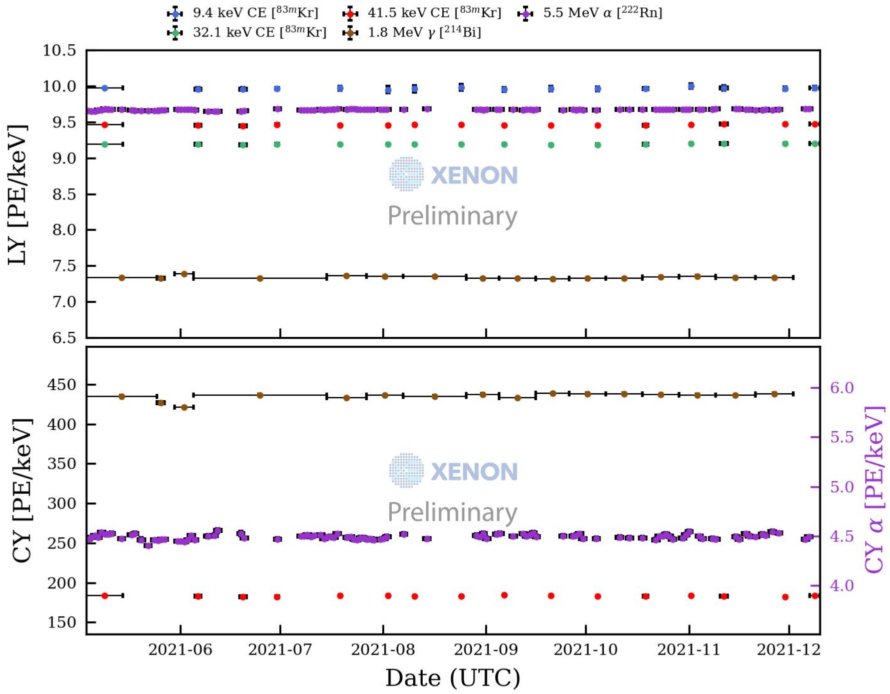


$$E = 13.7\text{eV}\left(\frac{cS1}{g_1} + \frac{cS2}{g_2}\right)$$



Detector response stability

Bi-weekly ^{83m}Kr, α's from ^{222}Rn and γ's from materials background used for monitoring light and charge yields

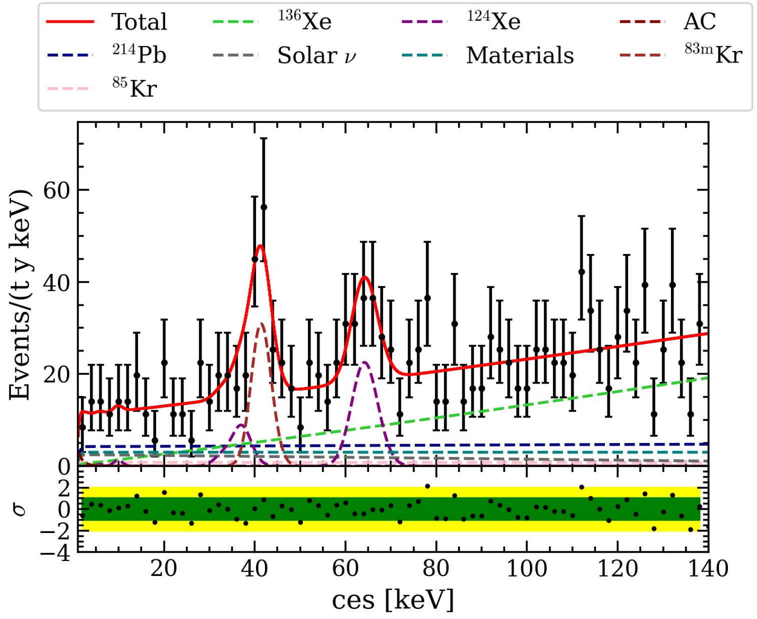


Δ*LY* = 1%

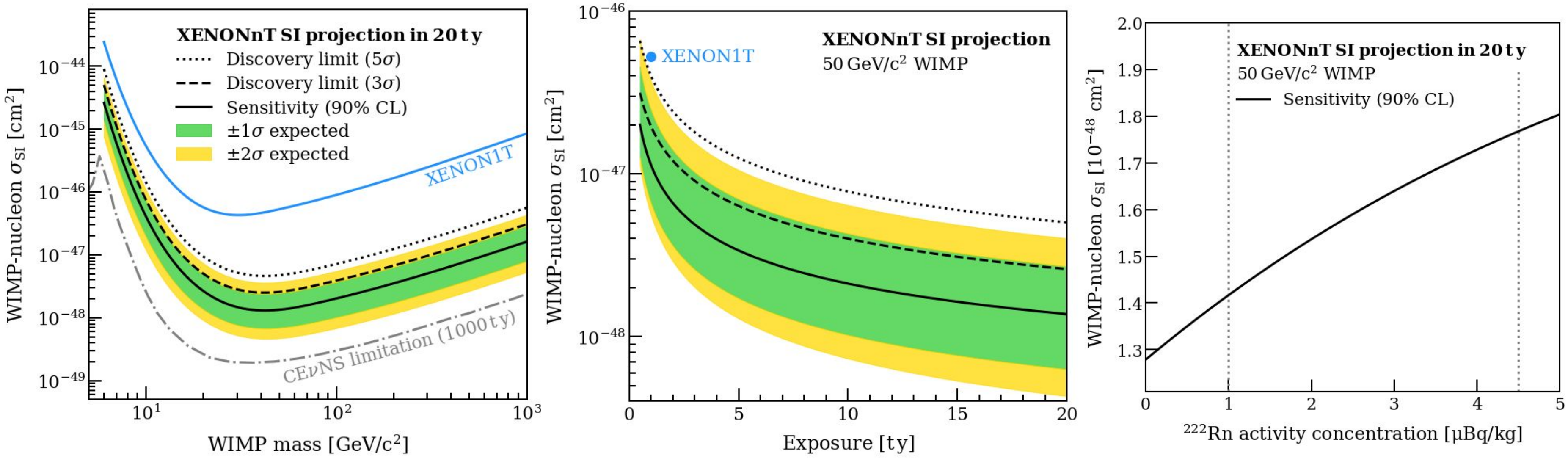
Δ*CY* = 1.9%

Tritium control

- Tritium (^3H) as possible explanation for the XENON1T excess
- Additional contamination control in XENONnT:
  - 3 months of detector outgassing
  - 3 weeks of GXe (warm) cleaning with hot getters
  - All Xe inventory circulated in advance through Kr-removal system
  - GXe purified with hot getters when filling the TPC
- 14.3 days of special data-taking mode after SR0:
  - "Tritium-enhanced" data (TED) bypassing getters
  - Conservative estimate for ^3H enhancement of at least x10
- Results of blind TED analysis: **no significant ^3H levels in SR0**

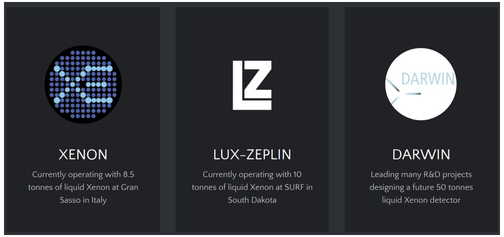


XENONnT Expected Sensitivity on WIMPs

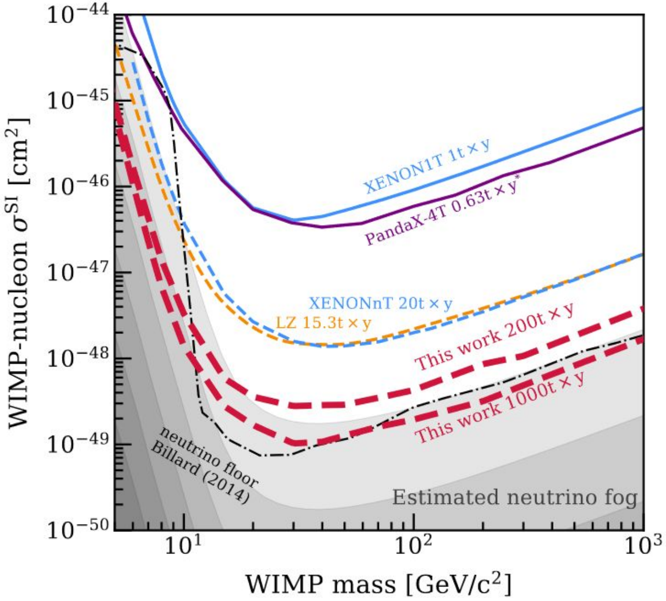


- focus on WIMP detection, with exposure of 20 t x yr sensitivity on spin-independent interaction of **1.4×10^{-48} cm^2 (90% CL)** with 50 GeV/c^2 mass [JCAP (2020) 11 031]
- reduction of ^{222}Rn background is crucial to increase the sensitivity

Next-generation Dark Matter experiment



Joining forces toward a next-generation liquid xenon observatory for dark matter and neutrino physics: XLZD
[J. Phys. G: Nucl. Part. Phys. 50 (2023) 013001]



- **Direct Dark Matter Search** expected sensitivity with 200 ton x yr **3×10^{-49} cm^2 @ 40 GeV/c^2**
- **Search for the neutrinoless double-beta decay** (^{136}Xe) with sensitivity of $T_{1/2}$~10^{27} yr (90% C.L.)
- **Solar Neutrinos:** precise measurements of pp and ^{7}Be fluxes (<1%) through elastic e-ν scattering
- **Observation of supernova** via CEvNS
- **New physics prospects:** solar axions, galactic axion-like particles and dark photons