# XENONnT Dark Matter Experiment
# Recent Status and Latest Results

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of XENON collaboration
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**DSU2022@Sydney**

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Bretagne-Pays de la Loire
École Mines-Télécom
cnrs
Nantes Université
XENON

# XENONnT Dark Matter Experiment
# Recent Status and Latest Results

XENONnT Upgrades

First Science Data

Probe of XENON1T Excess

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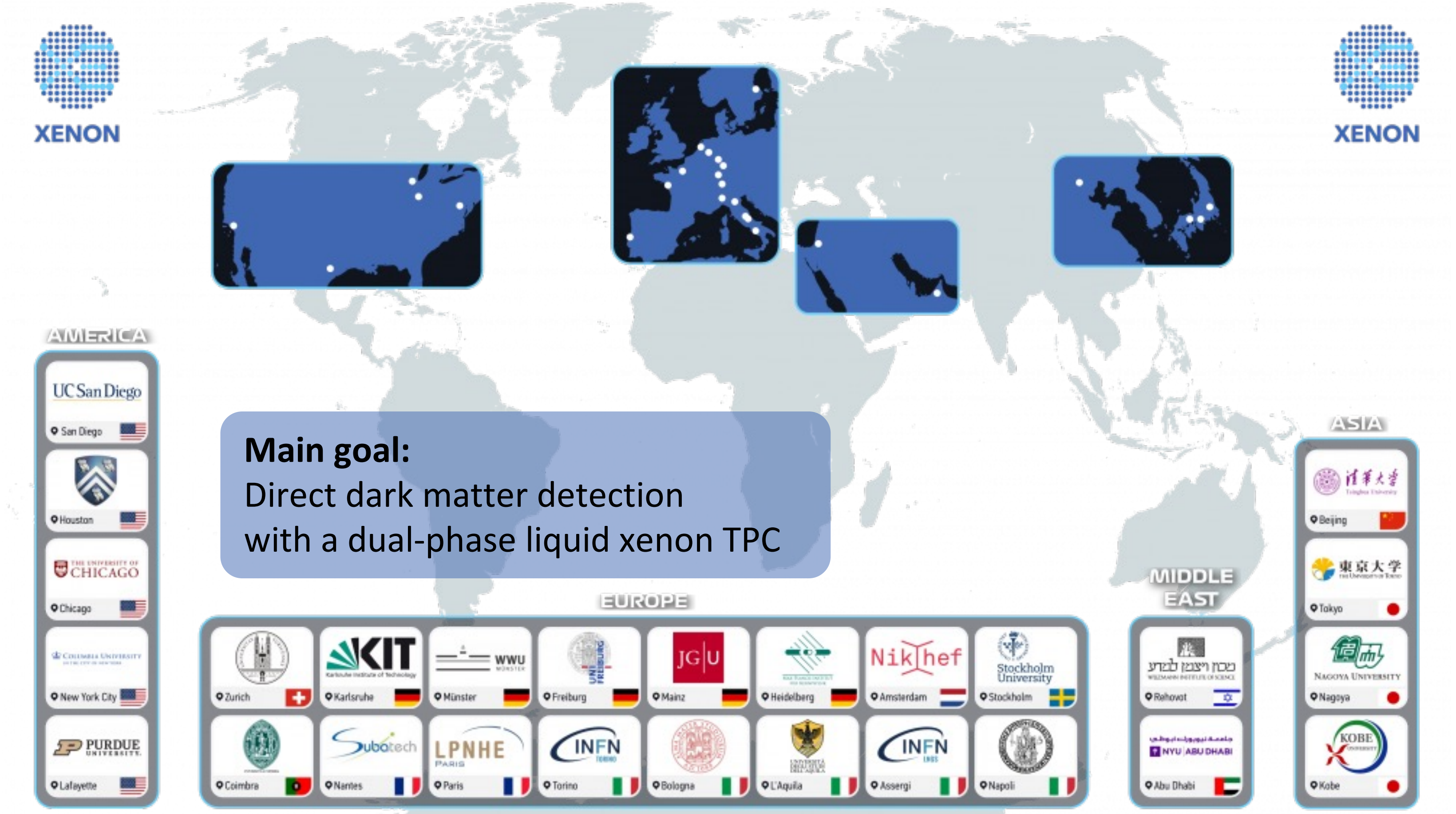
# XENON Collaboration

More than 180 scientists, 27 institutions, 12 countries

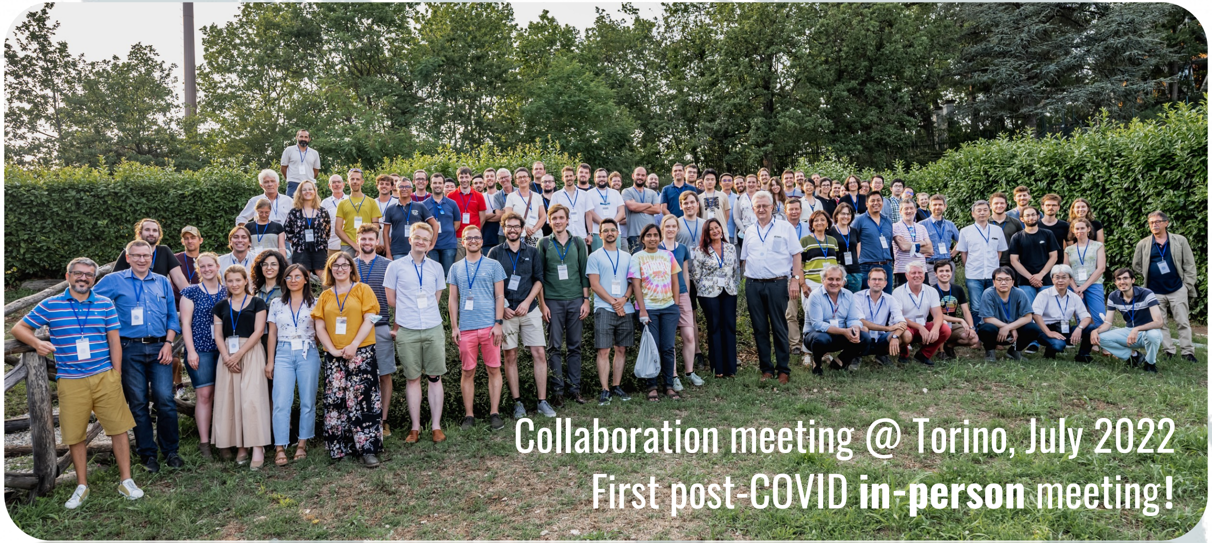



**Main goal:**
Direct dark matter detection
with a dual-phase liquid xenon TPC

# XENON Collaboration

More than 180 scientists, 27 institutions, 12 countries

XENON



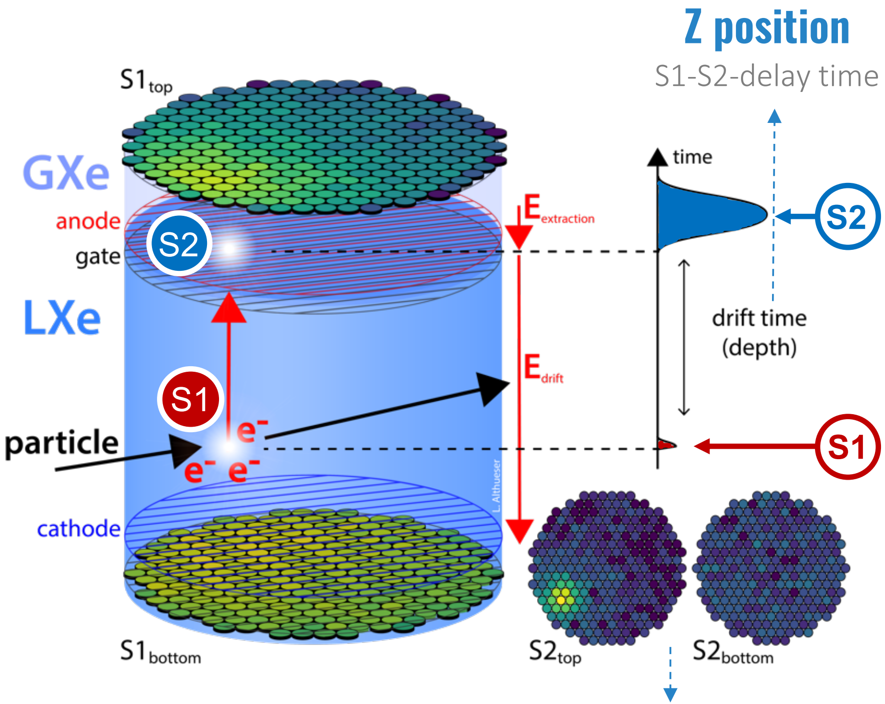

**AMERICA**
- UC San Diego — San Diego
- Houston
- The University of Chicago — Chicago
- Columbia University — New York City
- Purdue University — Lafayette

**EUROPE**
- Zurich
- KIT Karlsruhe Institute of Technology — Karlsruhe
- WWU Münster — Münster
- Uni Freiburg — Freiburg
- JGU — Mainz
- Heidelberg
- Nikhef — Amsterdam
- Stockholm University — Stockholm
- Coimbra
- Subatech — Nantes
- LPNHE Paris — Paris
- INFN Torino — Torino
- Bologna
- L'Aquila
- INFN LNGS — Assergi
- Napoli

**MIDDLE EAST**
- Weizmann Institute of Science — Rehovot
- NYU Abu Dhabi — Abu Dhabi

**ASIA**
- Tsinghua University — Beijing
- The University of Tokyo — Tokyo
- Nagoya University — Nagoya
- Kobe University — Kobe

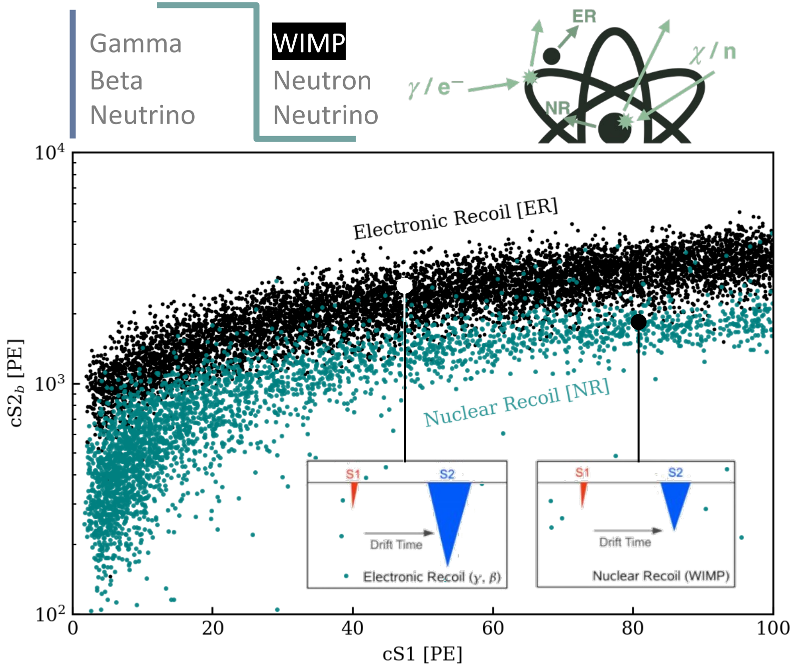
# Dual-phase XENON TPC




- **S1** prompt scintillation
- **S2** proportional to ionization

Combination of S1 and S2 signals allows for:

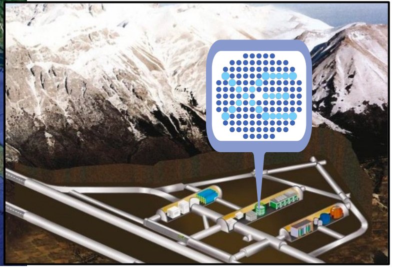
- 3D Position reconstruction
- Energy reconstruction
- ER/NR discrimination through S1/S2 ratio



# XENON Dark Matter Project

Dark matter direct detection experiments
Located in the Gran Sasso laboratories

Underground Laboratory
1400 m overburden (3600 m.w.e)


| | XENON10 | XENON100 | XENON1T | XENONnT | DARWIN | |
|---|---|---|---|---|---|---|
| Time | 2005 | 2008 | 2016 | 2021 | >2030 | |
| Active mass | 15 kg | 62 kg | 2.0 t | 5.9 t | *40 t | |
| Background | ~1000 | 5.3 | 0.2 | 0.04 | - | [t.day.keV]$^{-1}$ |
| Sensitivity | ~$10^{-44}$ | ~$10^{-45}$ | ~$10^{-47}$ | *~$10^{-48}$ | *~$10^{-49}$ | [cm$^2$] |
| | PAST | | | NOW | FUTURE | |

* → Projections

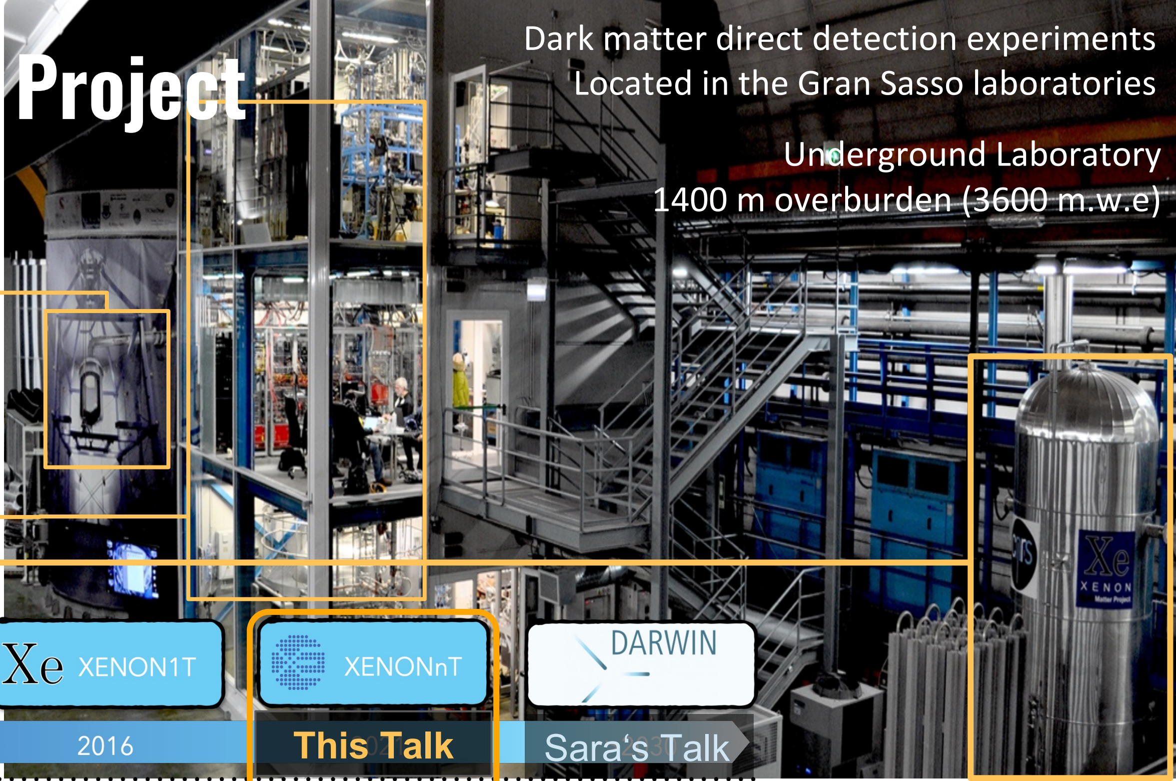
**Sensitivity Improvements**

# XENON Dark Matter Project

XENON

**From XENON1T to XENONnT**

- Larger TPC
- Neutron Veto
- Rn distillation
- Liquid purification
- DAQ & Slow Control
- ReStoX-II

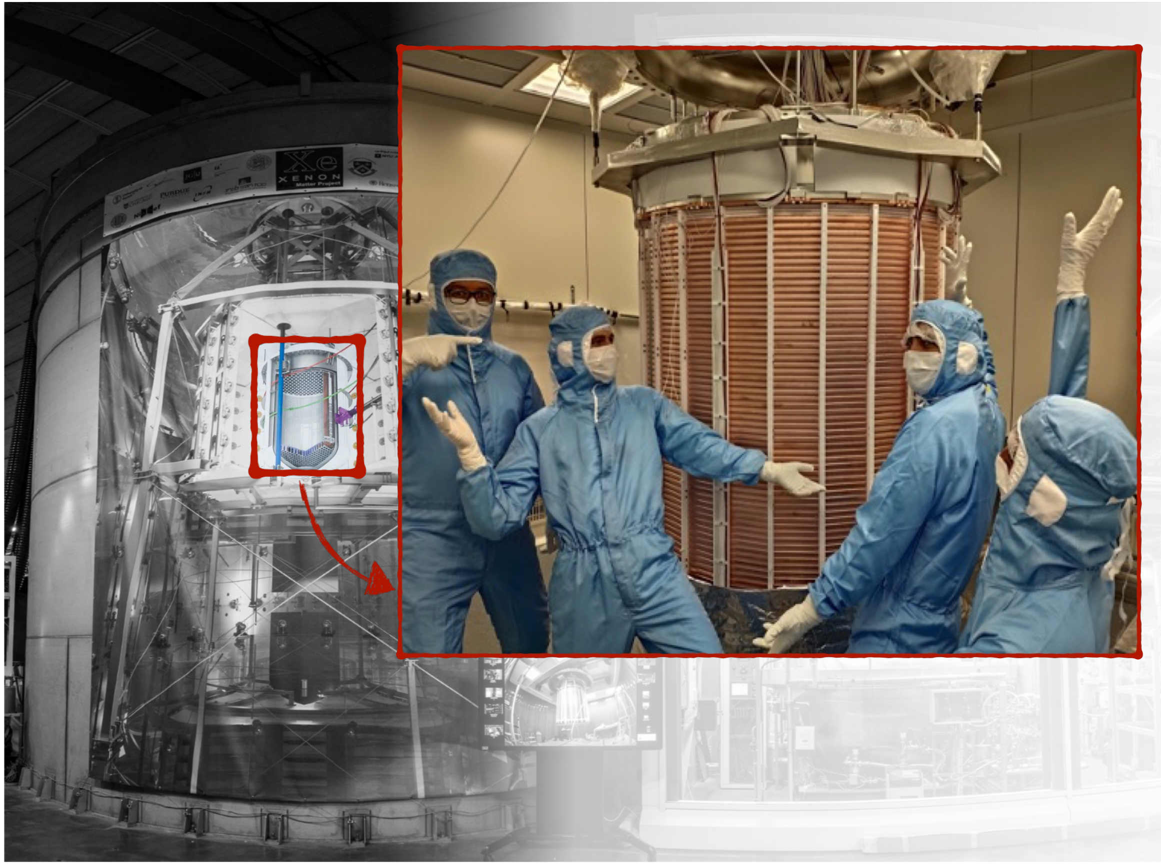



| | XENON10 | XENON100 | XENON1T | XENONnT | DARWIN |
|---|---|---|---|---|---|
| Time | 2005 | 2008 | 2016 | This Talk | Sara's Talk |
| Active mass | **15 kg** | **62 kg** | **2.0 t** | **5.9 t** | ***40 t** |
| Background | **~1000** | **5.3** | **0.2** | **0.04** | **-** [t.day.keV]$^{-1}$ |
| Sensitivity | **~$10^{-44}$** | **~$10^{-45}$** | **~$10^{-47}$** | ***~$10^{-48}$** | ***~$10^{-49}$** [cm$^2$] |
| | **PAST** | | | **NOW** | **FUTURE** |

* → Projections

**Sensitivity Improvements**

# From XENON1T to XENONnT – Larger TPC

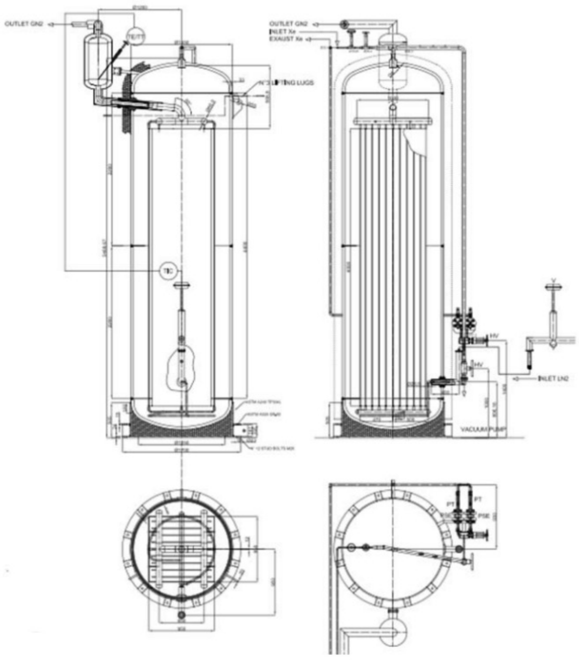


| 3.2t → 8.6t LXe | 2t → 5.9t LXe |
|---|---|
| **x2.5** | **x3** |
| **Total Masse** | **Active Volume** |

| 1m → 1.5m | 248 → 494 |
|---|---|
| **x1.5** | **x2** |
| **Drift Length** | **Num. of PMTs** |

Carefully selected materials to **minimize backgrounds** (Eur. Phys. J. C (2022) 82:599)

# From XENON1T to XENONnT – ReStoX-II



**Keep LXe Safe !**

**ReStoX-II**
→ **fast xenon recovery system** through xenon crystallisation (500 kg/h)

6 m high, **up to 10 t of xenon** cooled by liquid nitrogen (LN2)

Designed and funded by **Subatech** and **LPNHE** (+ LAL) → **100% French contribution**

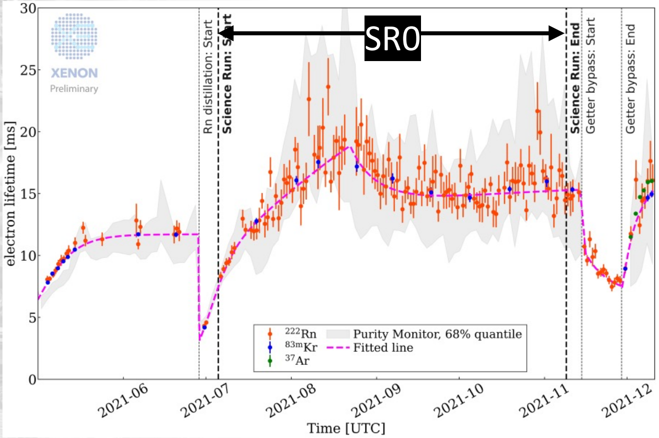
# From XENON1T to XENONnT - Liquid Xenon Purification

**New liquid xenon purification technique** with replaceable filter units + extremely low Rn emanation [EPJC 82 860 (2022)]

**High-flux purification at 2 L/min LXe**
⟹ reach very high purity in **< 1 week**
⟹ **18 h** to exchange the entire volume

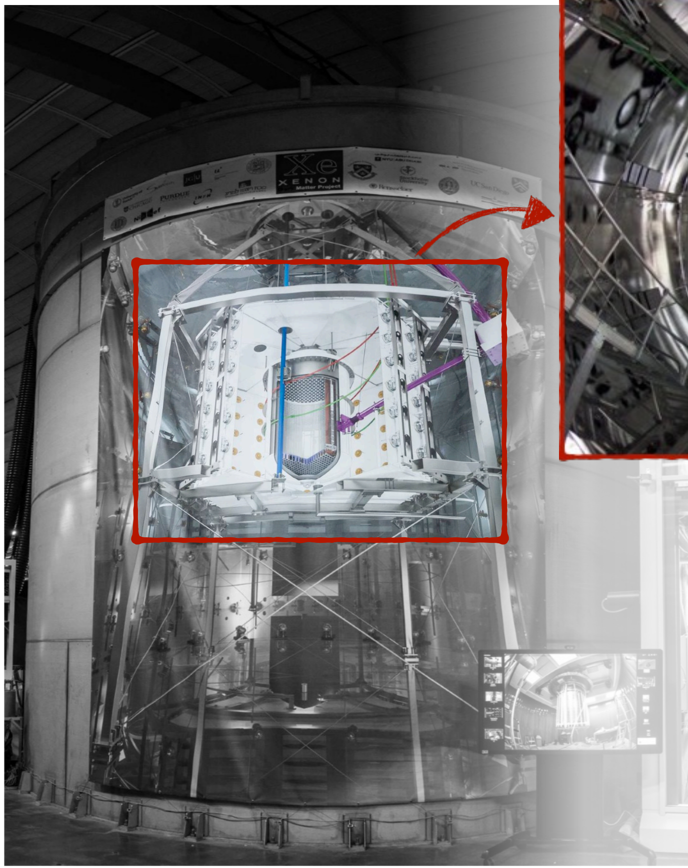
**Electron lifetime > 10 ms** in science run (~ 5x Max. drift time)

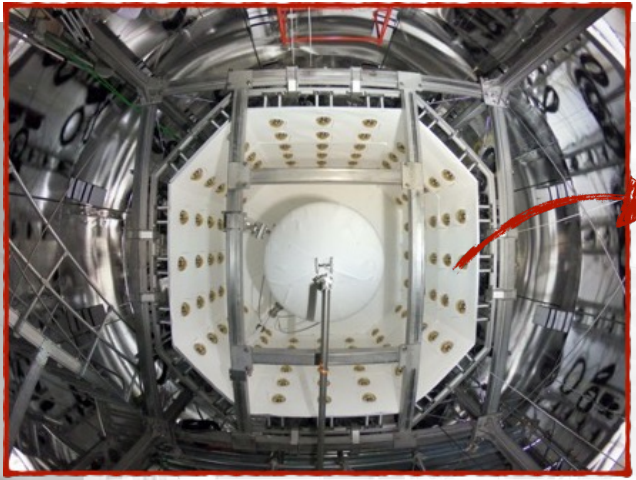
**Purity x10 than XENON1T**




| | Max. drift time | Electron lifetime | e– survival @ max. drift length |
|---|---|---|---|
| 1T | 0.67 ms | 0.65 ms | 30% |
| nT | 2.2 ms | > 10 ms | > 90% |

# From XENON1T to XENONnT - Neutron Veto



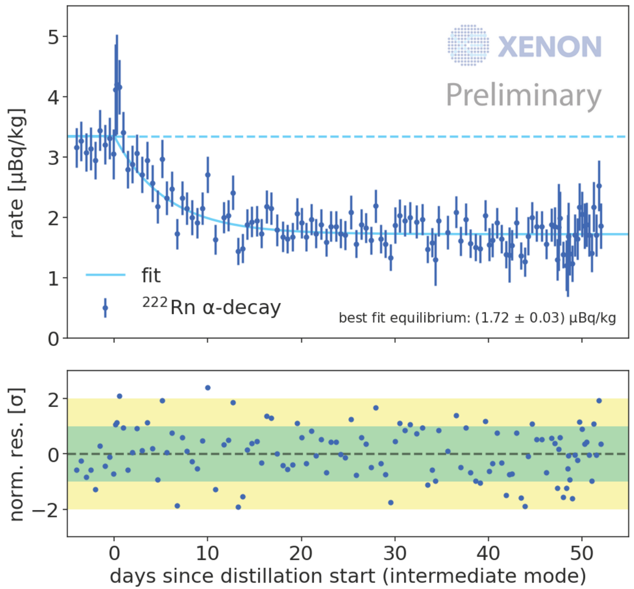



- Active neutron veto filled with **pure water** around the TPC
  **Gd-doping planned**

- 120 PMTs high-reflectivity walls to contain light
  → **Cherenkov detector** seeking neutron captures

- Crucial to **Enhance the WIMP Sensitivity** by tagging neutrons
  **68% efficiency now (pure water), 87% expected with Gd**

# From XENON1T to XENONnT - Radon Distillation Column




**Newly Rn distillation column** handles large Xe flows using Rn-free compressors and heat exchangers [arXiv:2205.11492]

**$^{222}$Rn reduction**

**x7**

**XENON1T [SR1]**

**$^{214}$Pb dominant in low energy** → originated from **$^{222}$Rn** in Xe

**GXe-only mode during SR0** → $^{222}$Rn reduction down to **1.7 µBq/kg**

Reaching goal of **1 µBq/kg** with **LXe mode** (next science runs)

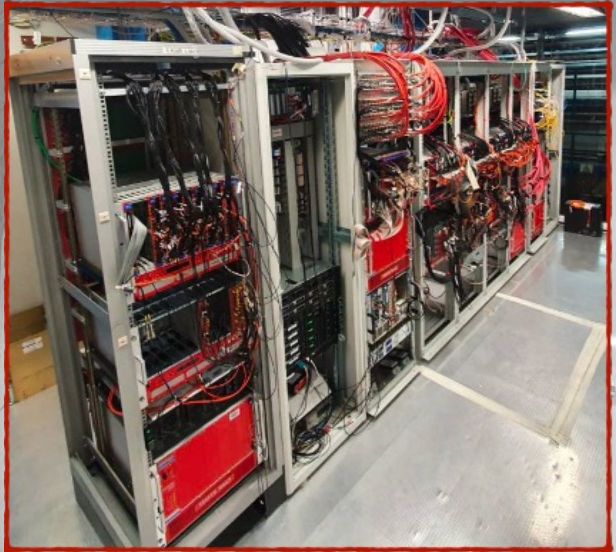
# From XENON1T to XENONnT - Data Acquisition BACK-UP

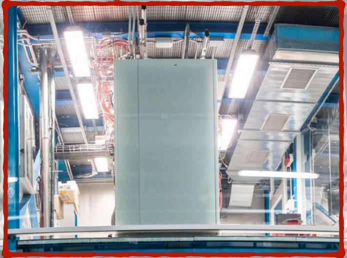


**Triggerless**: all data above per channel threshold stored long term

**Fully live processing**

**Open-source software**: strax + straxen (straxen@github)

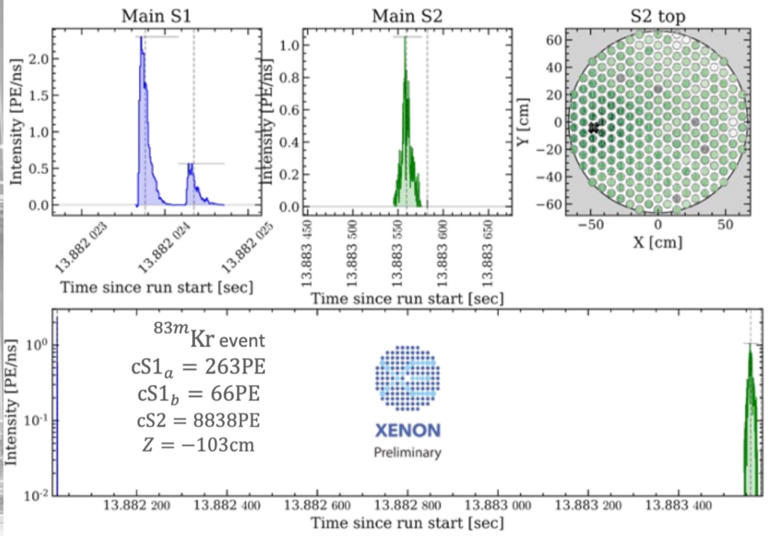




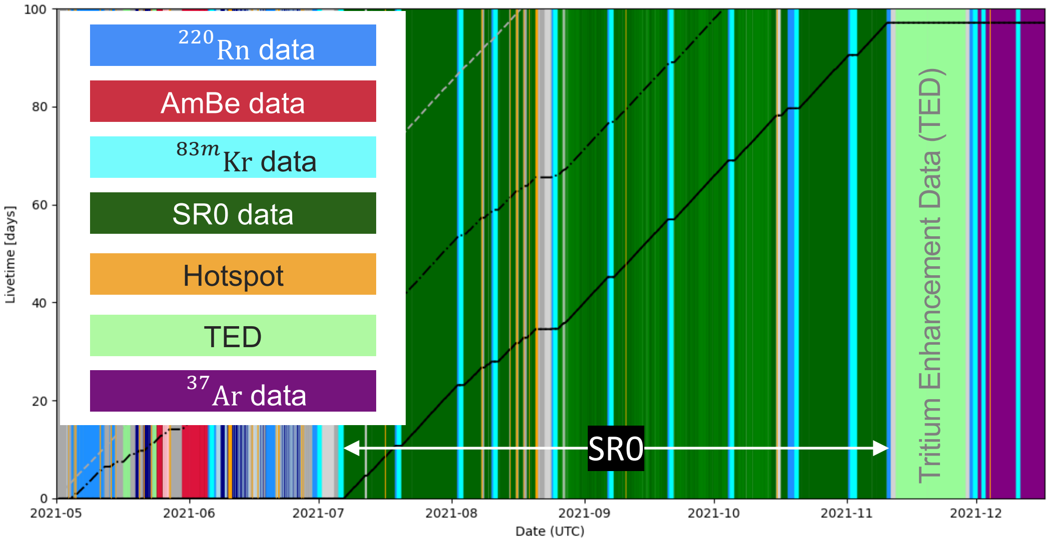
**Predecessors**

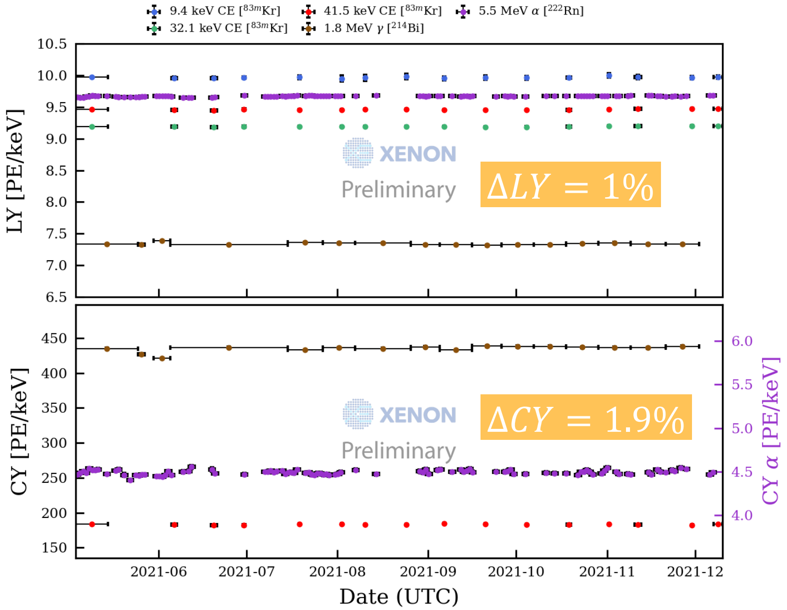
**x10$^2$**

**faster than 1T**



# First Science Run - XENONnT SR0



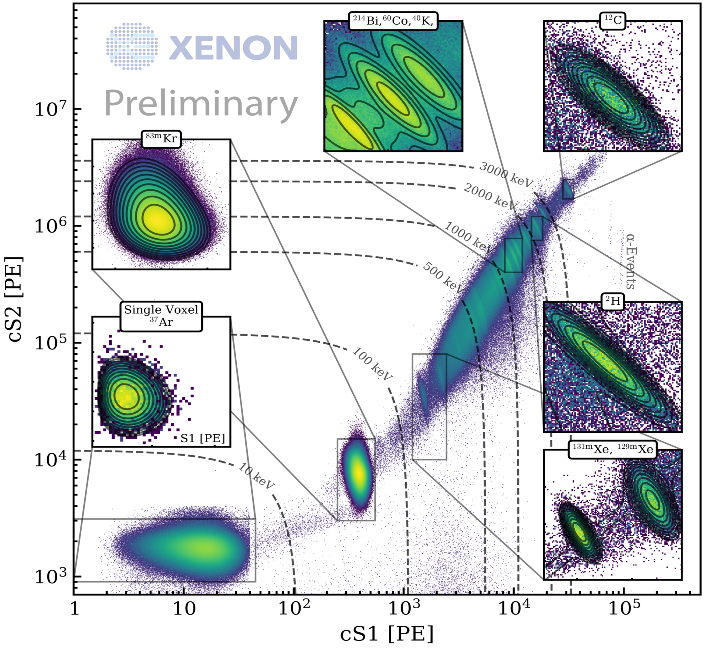



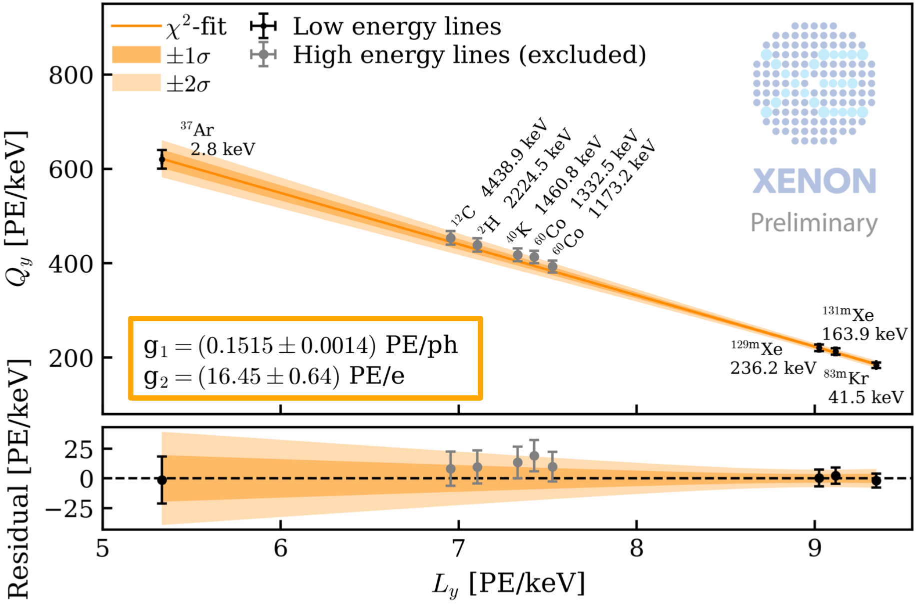

- **97.1 days of science livetime** from July 6th-Nov 11th 2021
- **Hot-spots**: localized, high-rate, bursts of electrons ➞Anode Ramp-down
- **High stability overall** (**light and charge yields ± 2%, PMT gain ± 3%**), **monitored with regular calibrations** (bi-weekly $^{83m}$Kr) and **remaining internal radioactivity** ($^{222}$Rn α, materials γ)

**ER and NR blinded analysis**

# Energy reconstruction

BACK-UP



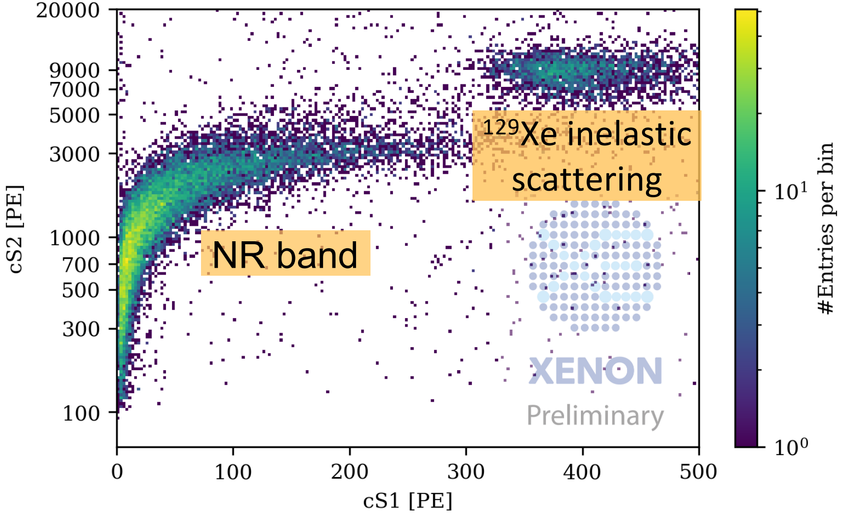

- Energy reconstruction: $E = W \cdot \left(\frac{cS1}{g1} + \frac{cS2}{g2}\right)$
- Four low-energy calibration points: **$^{37}$Ar, $^{83m}$Kr, $^{129m}$Xe and $^{131m}$Xe**
- Observed **1-2%** bias in reconstructed energy used as **systematic uncertainty** in modeling.

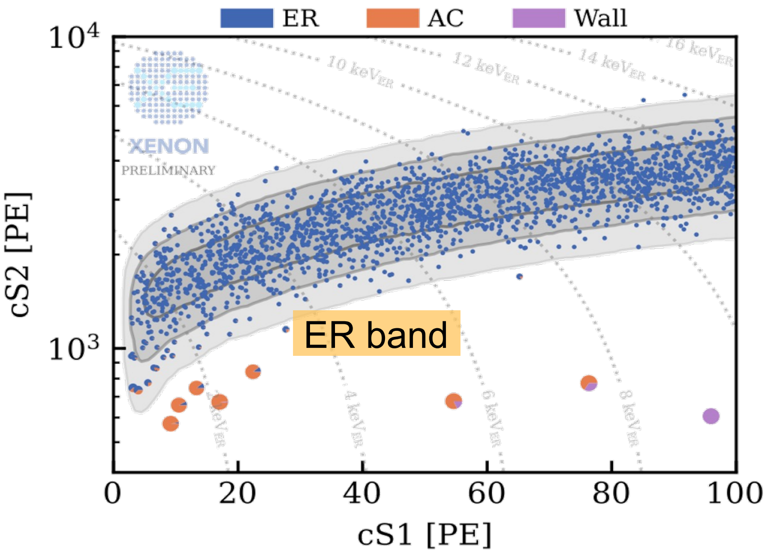
# Characterization of NR/ER Response

**NR calibration:** neutrons provided by **AmBe source**, deployed in the calibration tubes around the TPC

**ER calibration** at low energy:

- **$^{212}$Pb from $^{220}$Rn** ⟶ roughly flat $\beta$-spectrum, **estimating cut acceptances and validating threshold**
  Also used to define our **blinding region**, check **detector response**



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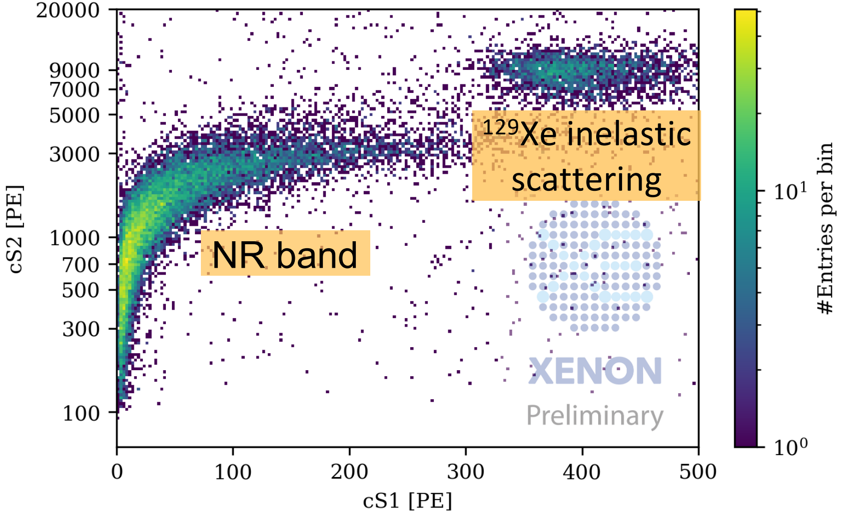
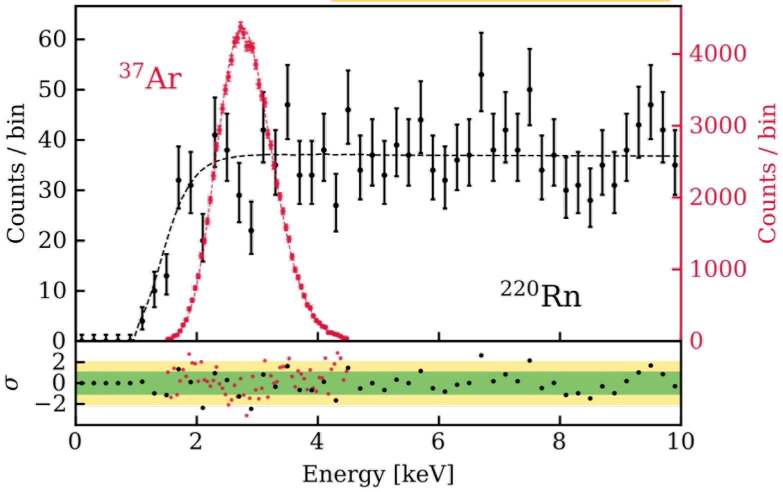
  Also used to define our **blinding region**, check **detector response**
- **$^{37}$Ar** ⟶ 2.82keV peak, **anchoring response model at low energy** with high statistic [arXiv:2211.14191]




Energy reconstruction

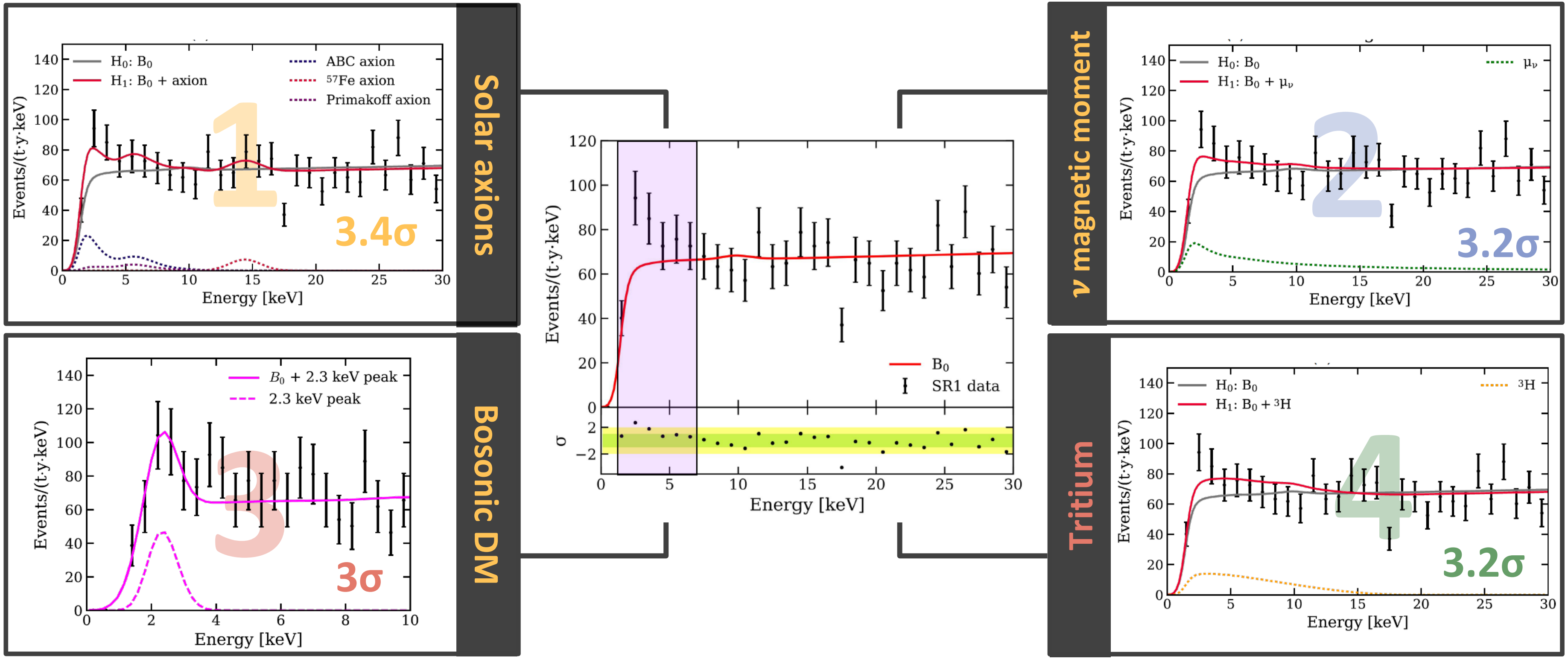


# The XENON1T LowER Excess

**~3σ excess fit in electronic recoil data at 2.3keV**

Phys. Rev. D 102, 072004 (2020)

➞ compatible with **new physics** models (up to 3.4σ) or a **tritium background** (3.2σ)



# XENONnT Low-Energy ER Spectrum

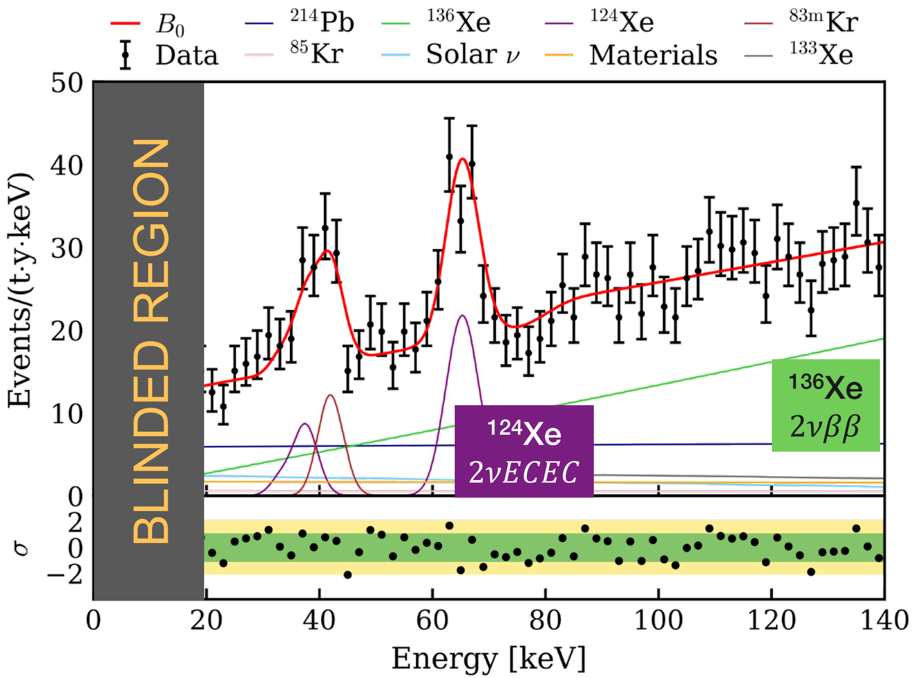
Energy range (1, 140) keV, exposure 1.16 ty

**Blind analysis** (energy region < 20 keV)

Initial background estimates based on
- **external measurements**
- data-driven accidental coincidence model
- Verification in side-band

**Double weak processes**
dominating the backgrounds

PRL 129 (2022) 161805



# XENONnT Low-Energy ER Spectrum

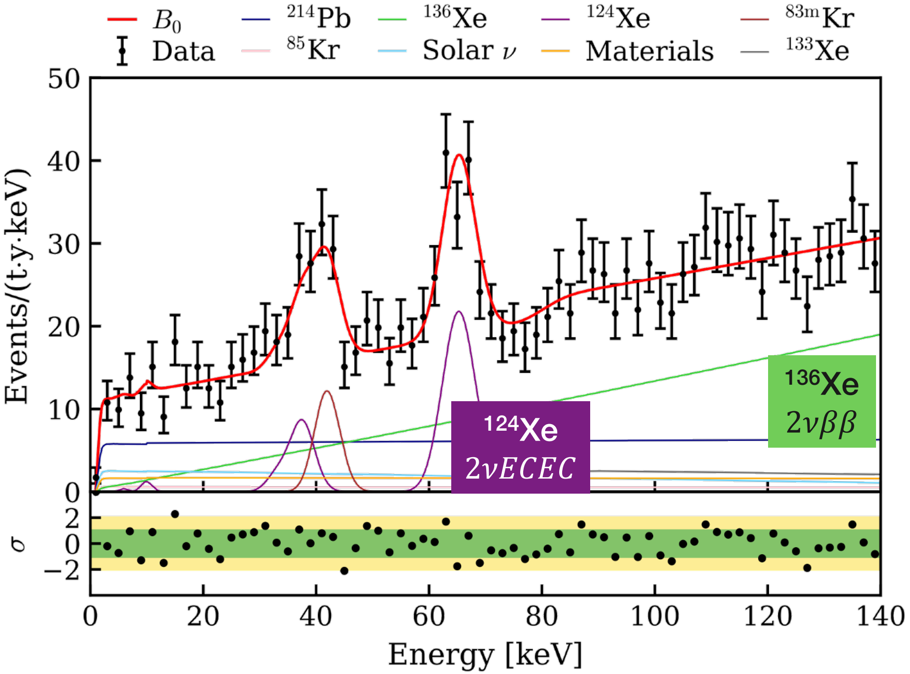
**Various stages of unblinding:** 10-20 keV side band, accidental coincidence, wall sample, full range

| Component | Constraint | Fit |
|---|---|---|
| $^{214}$Pb | (570, 1200) | 960 ± 120 |
| $^{85}$Kr | 90 ± 60 | 90 ± 60 |
| Materials | 270 ± 50 | 270 ± 50 |
| $^{136}$Xe | 1560 ± 60 | 1550 ± 50 |
| Solar neutrino | 300 ± 30 | 300 ± 30 |
| $^{124}$Xe | - | 250 ± 30 |
| AC | 0.70 ± 0.04 | 0.71 ± 0.03 |
| $^{133}$Xe | - | 150 ± 60 |
| $^{83m}$Kr | - | 80 ± 16 |

**Excellent data-model agreement** over the whole energy range, even at low energy

**No excess observed**

PRL 129 (2022) 161805

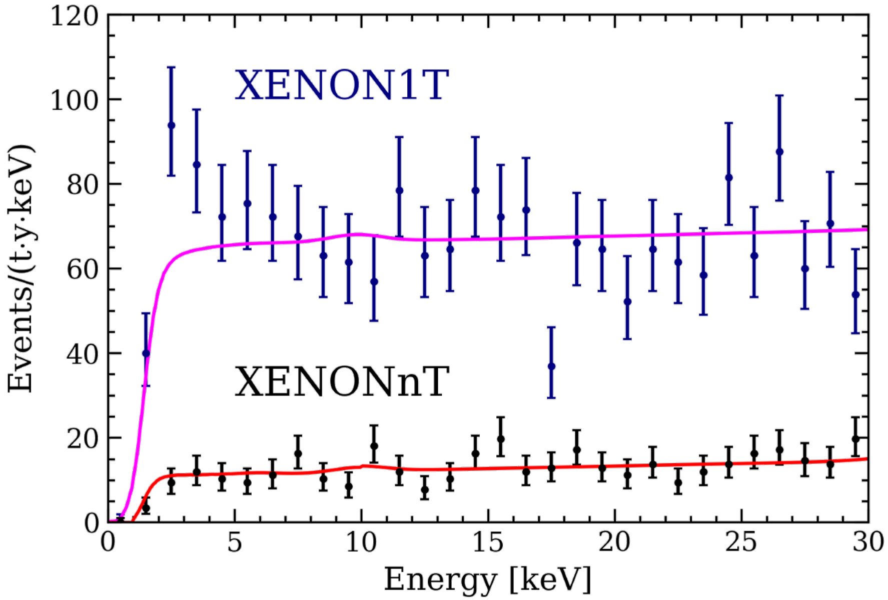


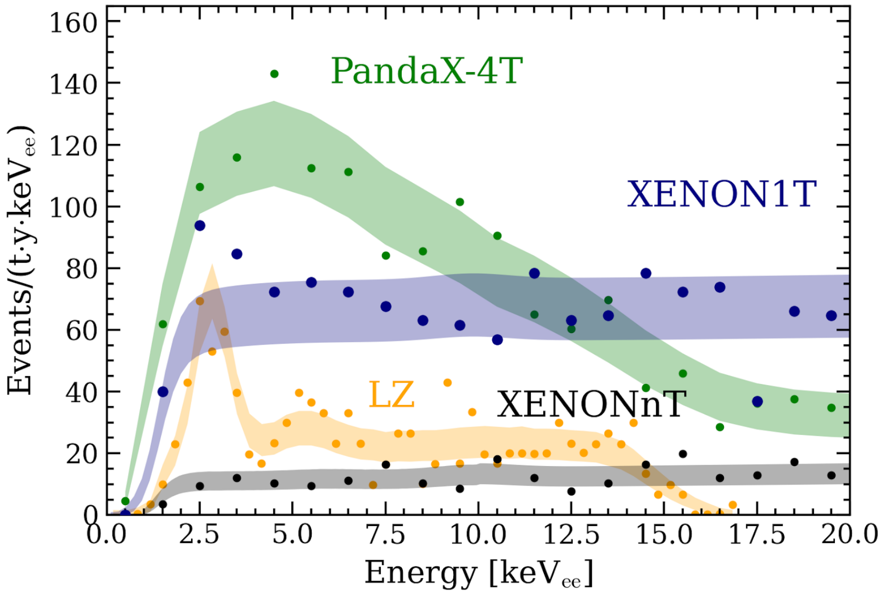
# XENON1T vs XENONnT

- **Outstanding 5× reduction** compared to XENON1T
  ➞ (16.1 ± 1.3) events/(t x yr x keV)

- **No excess below 5 keV** found: **8.6σ** exclusion on XENON1T excess
  ➞ XENON1T excess likely caused by a small **tritium contamination** (further investigations underway), **not by BSM physics**

PRL 129, 161804 (2022)
PRD 102, 072004 (2020)
arXiv:2207.03764
PRL 129, 161805 (2022)



# nT LowER Results – Limits on New Physics

PRL 129 (2022) 161805

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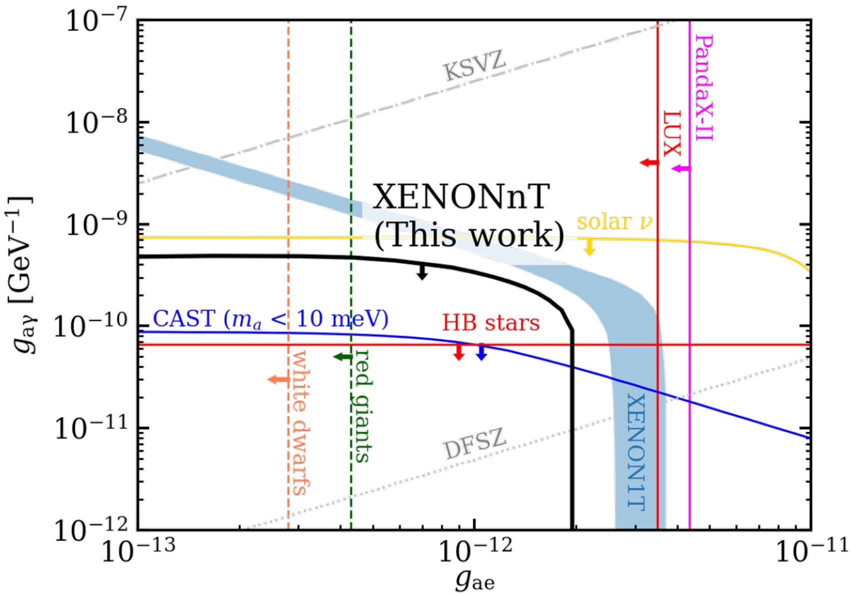
## Solar axions



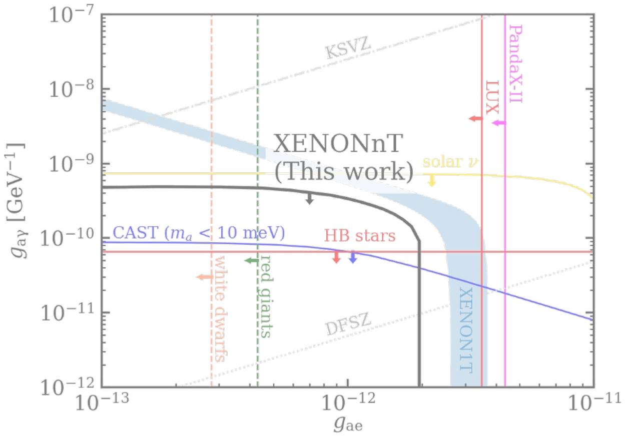

Set new limits on solar axions couplings $g_{ae}$ and $g_{a\gamma}$

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

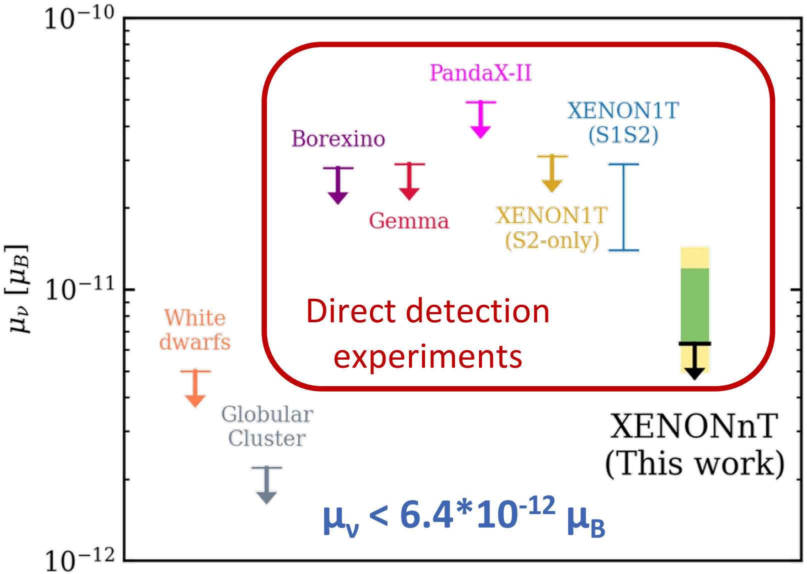
# nT LowER Results – Limits on New Physics

PRL 129 (2022) 161805

Solar axions




## ν magnetic moment



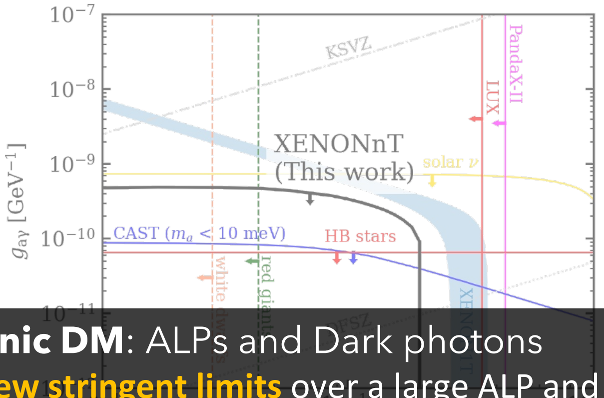

$\mu_\nu < 6.4 * 10^{-12}\ \mu_B$

**The most stringent limit in any direct detection experiment**

# nT LowER Results – Limits on New Physics

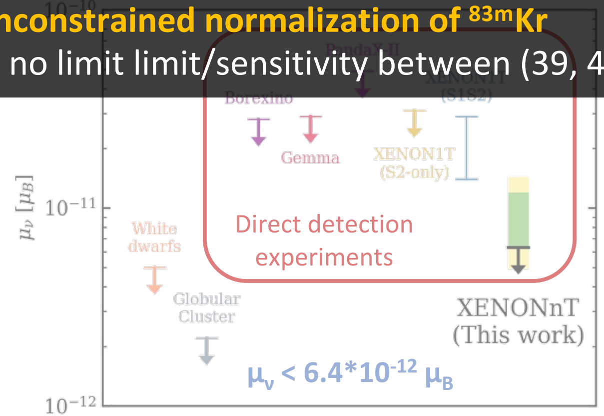
PRL 129 (2022) 161805

**Solar axions**

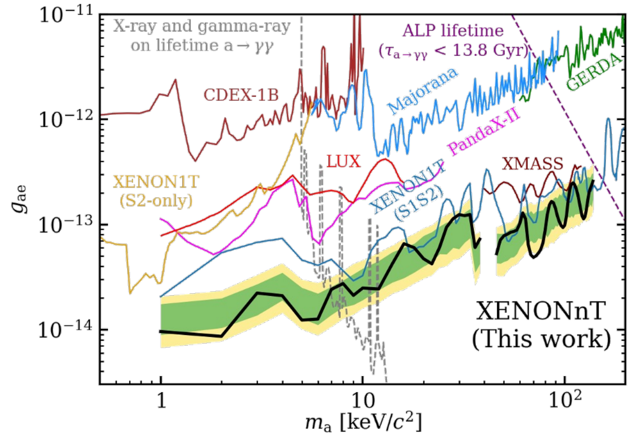



**Bosonic DM**: ALPs and Dark photons
- **New stringent limits** over a large ALP and dark photon mass range **(1–140 keV/c²)**
- **Unconstrained normalization of $^{83m}$Kr**
  → no limit limit/sensitivity between (39, 44) keV/c²

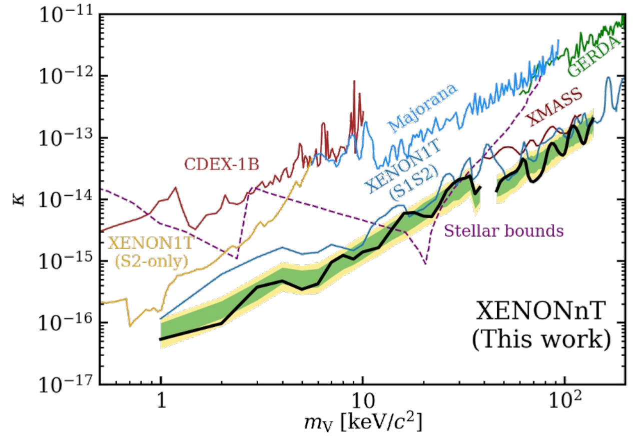
**ν magnetic moment**




**Axion-Like Particle**




**Dark photon**



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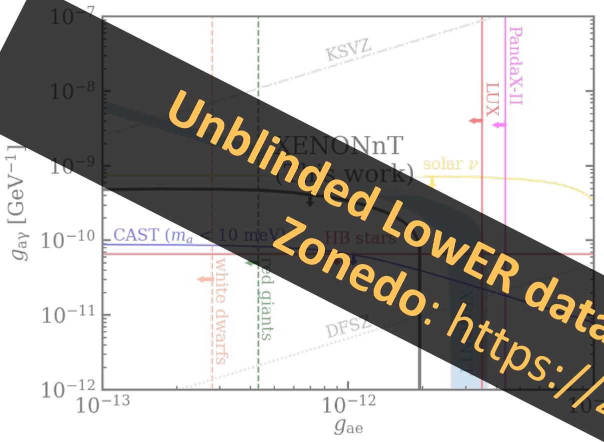
# nT LowER Results – Limits on New Physics

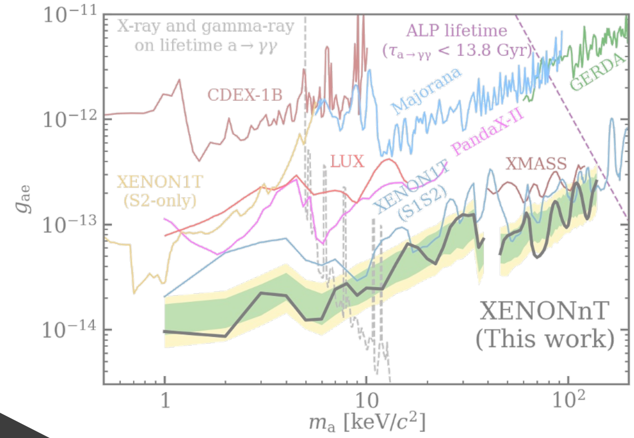
PRL 129 (2022) 161805

**Unblinded LowER data** as well as the **Limits** are available in **Zonedo**: https://zenodo.org/record/7311940

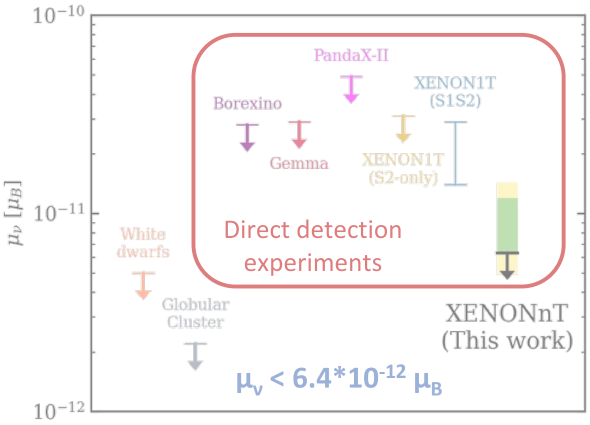
Solar axions




Axion-Like Particle

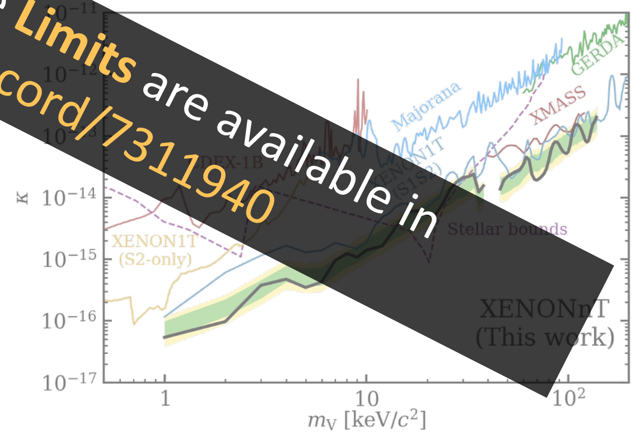



ν magnetic moment




$\mu_\nu < 6.4*10^{-12}\ \mu_B$

Dark photon



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# Summary

**XENONnT SR0**

- Electron lifetime of > 10 ms
- ~5× lower background w.r.t. 1T

**First results**

- Blinded electronic recoil (ER) search
- No excess observed -> limits on new physics (2207.11330)

**In progress**

- NR WIMP unblinding analysis
- SR1 with factor 2× lower radon

**Stay tuned, WIMPs search results to come!**

# Summary

# XLZD consortium

Joining forces toward a next-generation Dark Matter experiment (white paper: [arXiv:2203.02309](https://arxiv.org/abs/2203.02309))

xlzd.org

Sara's Talk

### XENON

Currently operating with 8.5 tonnes of liquid Xenon at Gran Sasso in Italy

### LUX-ZEPLIN

Currently operating with 10 tonnes of liquid Xenon at SURF in South Dakota

### DARWIN

Leading many R&D projects designing a future 50 tonnes liquid Xenon detector

xenonexperiment.org

xenon_experiment

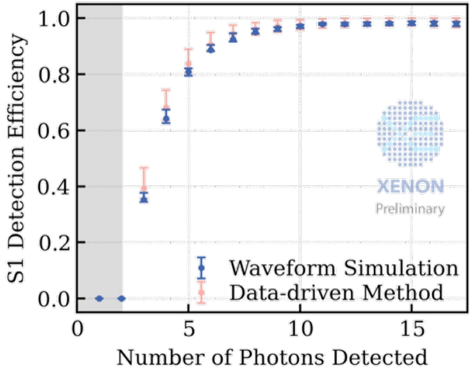
**Thank you!**

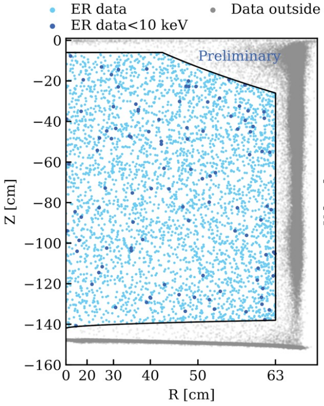
# Backup

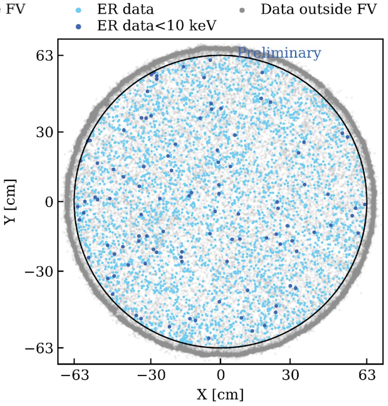
XENON

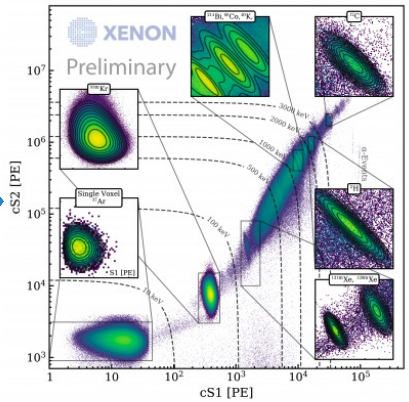
# SRO Analysis

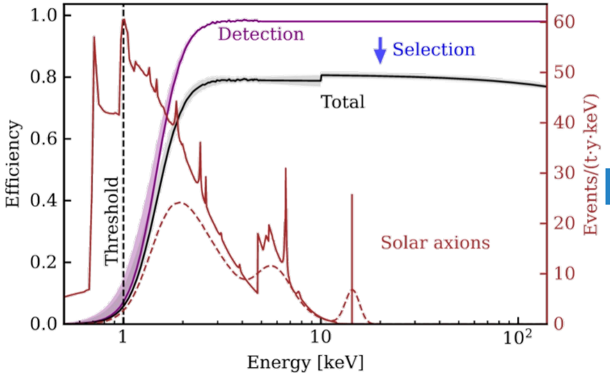
BACK-UP

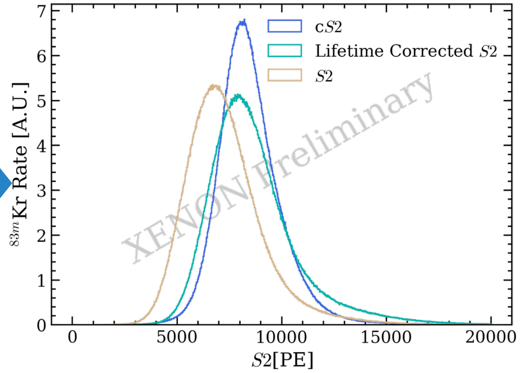


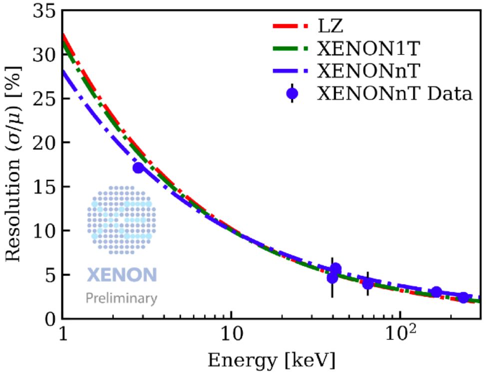



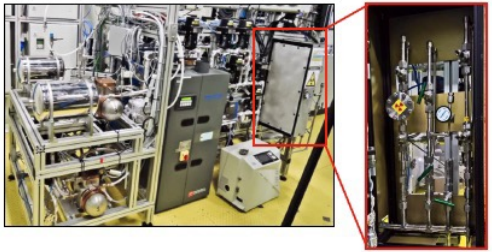



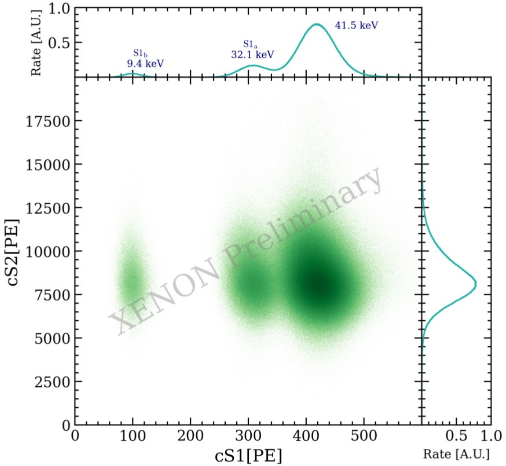



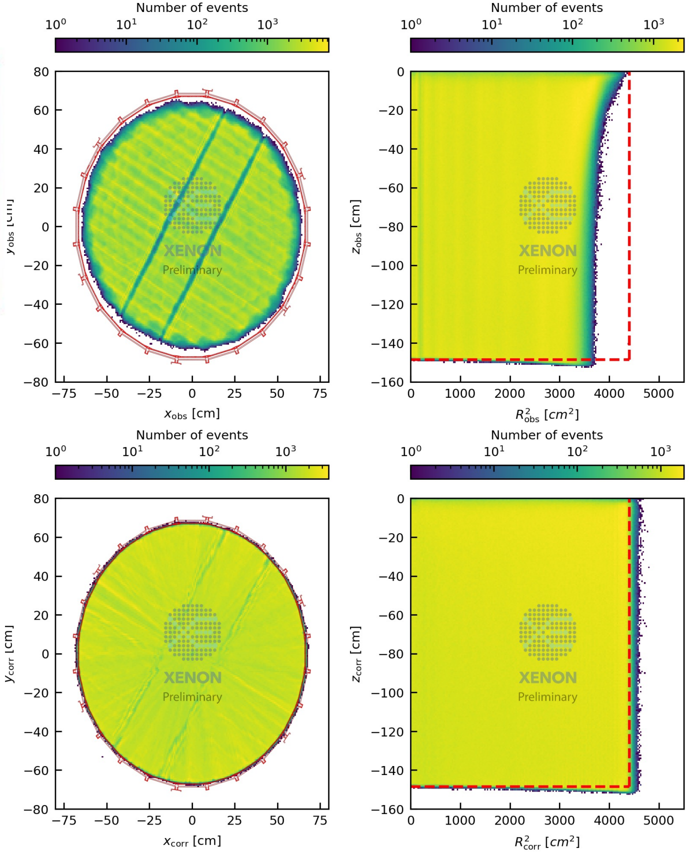

Average data-quality cut acceptance ~86 %

# $^{83m}$Kr Calibration

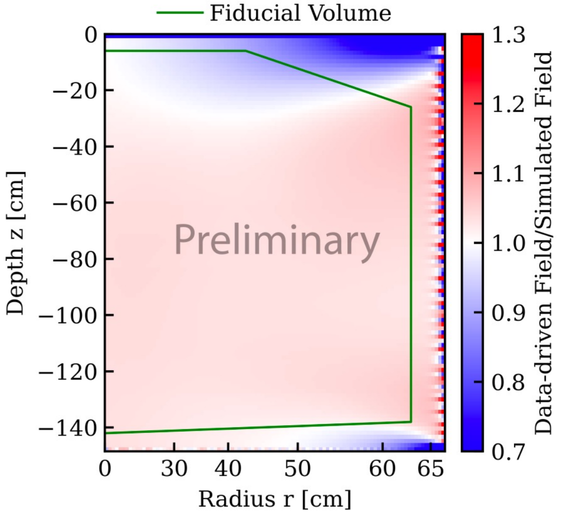






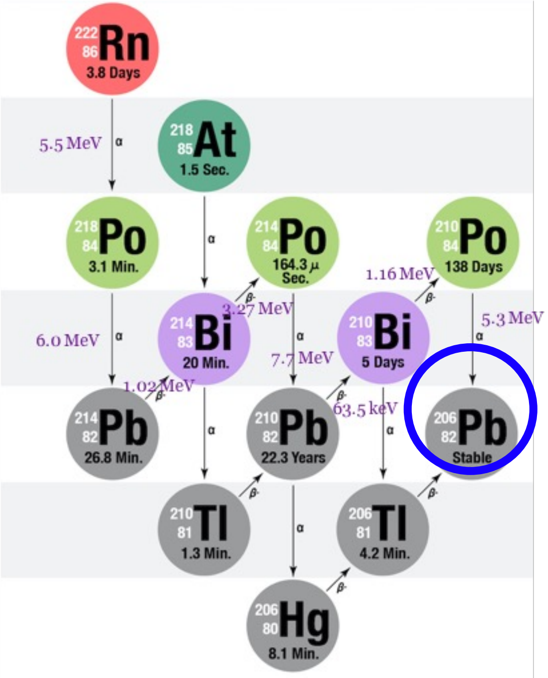



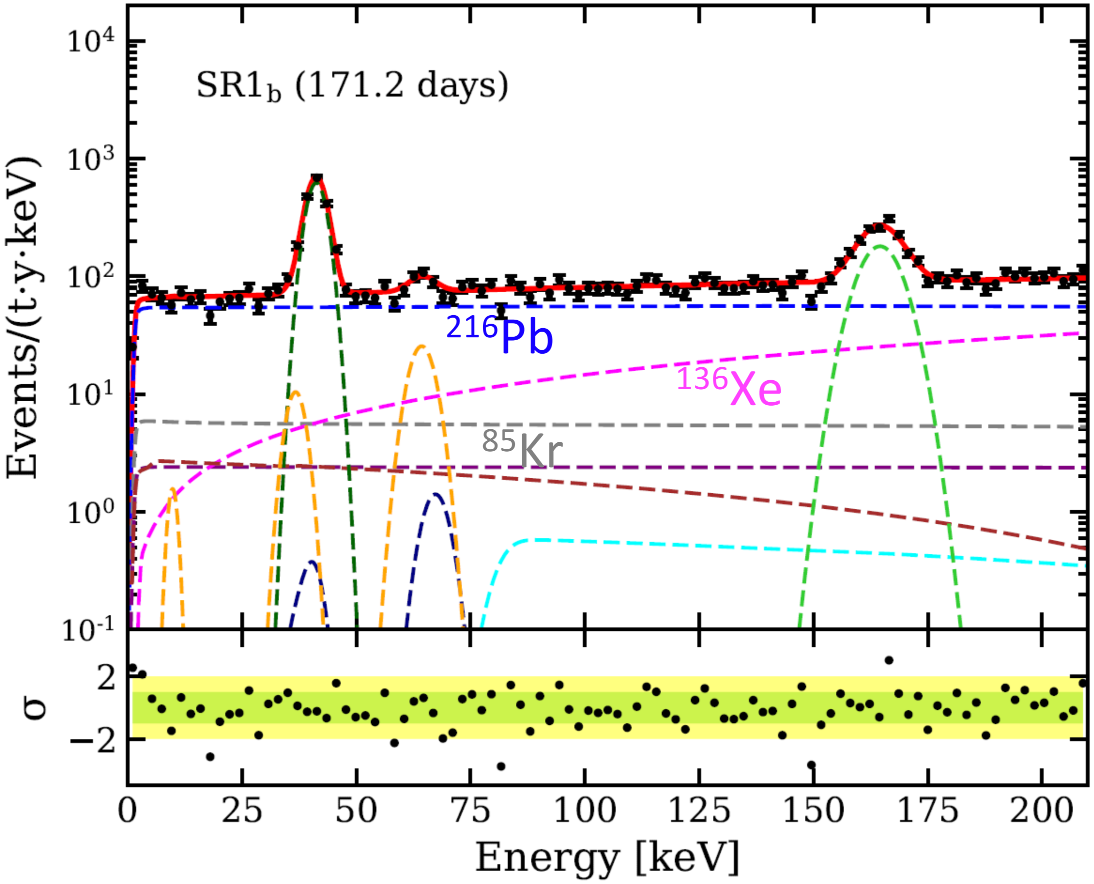

Detector uniformity and electric field validation



# ER Backgrounds in XENON1T

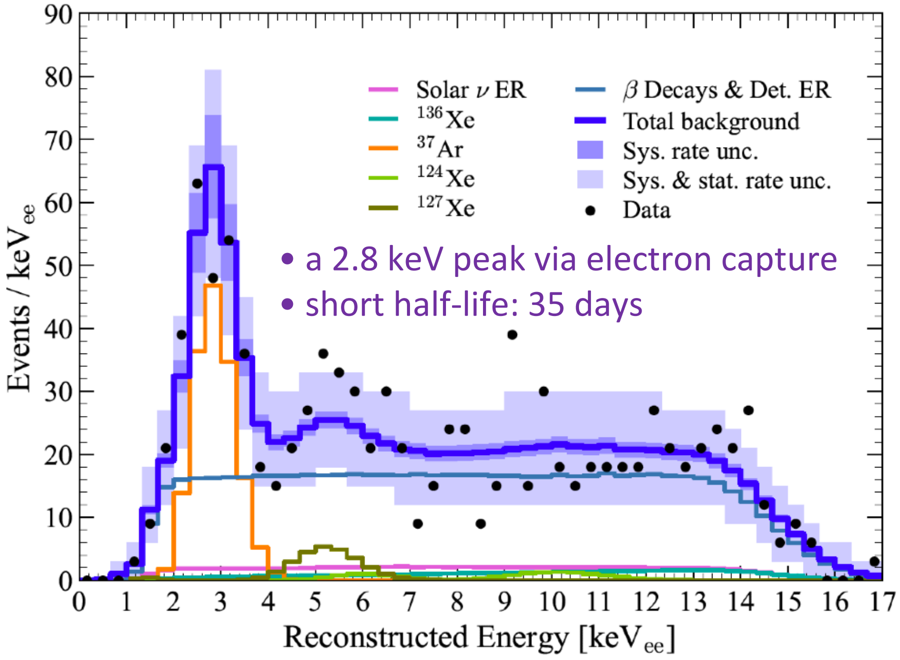
BACK-UP



# Why Not Include $^{37}Ar$ Background?






$^{37}Ar$ is observed in the LZ experiment due to cosmogenic activation during transportation above ground

### Why $^{37}Ar$ is not possible in XENONnT?

### Cosmogenic activation

• Xenon in the XENONnT detector has been underground for years

• Before taking SR0 data, the entire xenon inventory was cryogenically distilled by the Kr-removal system underground, which is also effective in removal.

XENON Collaboration, PTEP 2022, 053H01.

➡️ **Cosmogenic activation (or any initial presence of after distillation) is not possible**

### Leak

• 'leak' size is small using the conservative estimation of nat-Kr variation

• combined with the measured activity in the lab air, the amount 'leaked' into the detector is negligible

➡️ **leak during the SR0 operation is not possible**

# Tritium Control

BACK-UP

**Tritium ($^3H$) as possible explanation for the XENON1T excess**

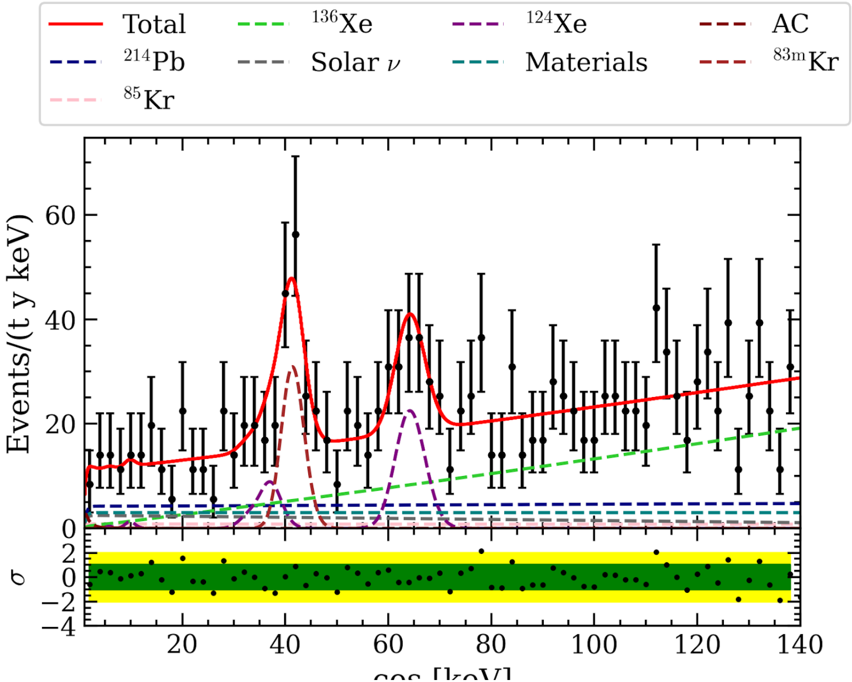
Additional contamination control in XENONnT:

- 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 WIMP Projection/Unblinding