University of Zurich[UZH]

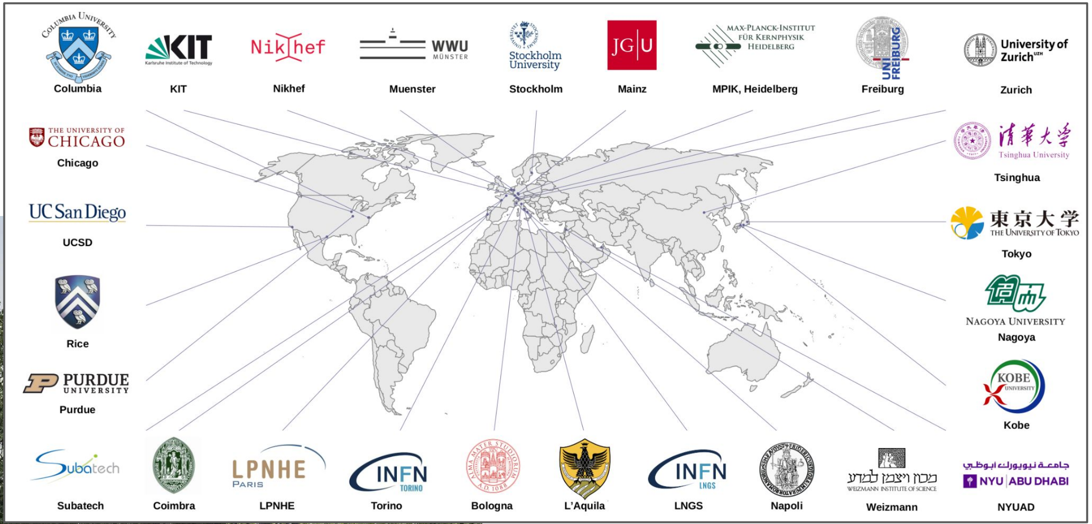
First XENONnT results on electronic recoil interactions

Diego Ramírez (UZH) on behalf of the XENON collaboration @ EDSU2022

November 10th 2022 | La Réunion, France

XENON Dark Matter Project

Dark matter direct detection experiment hosted at Laboratori Nazionali del Gran Sasso (LNGS)

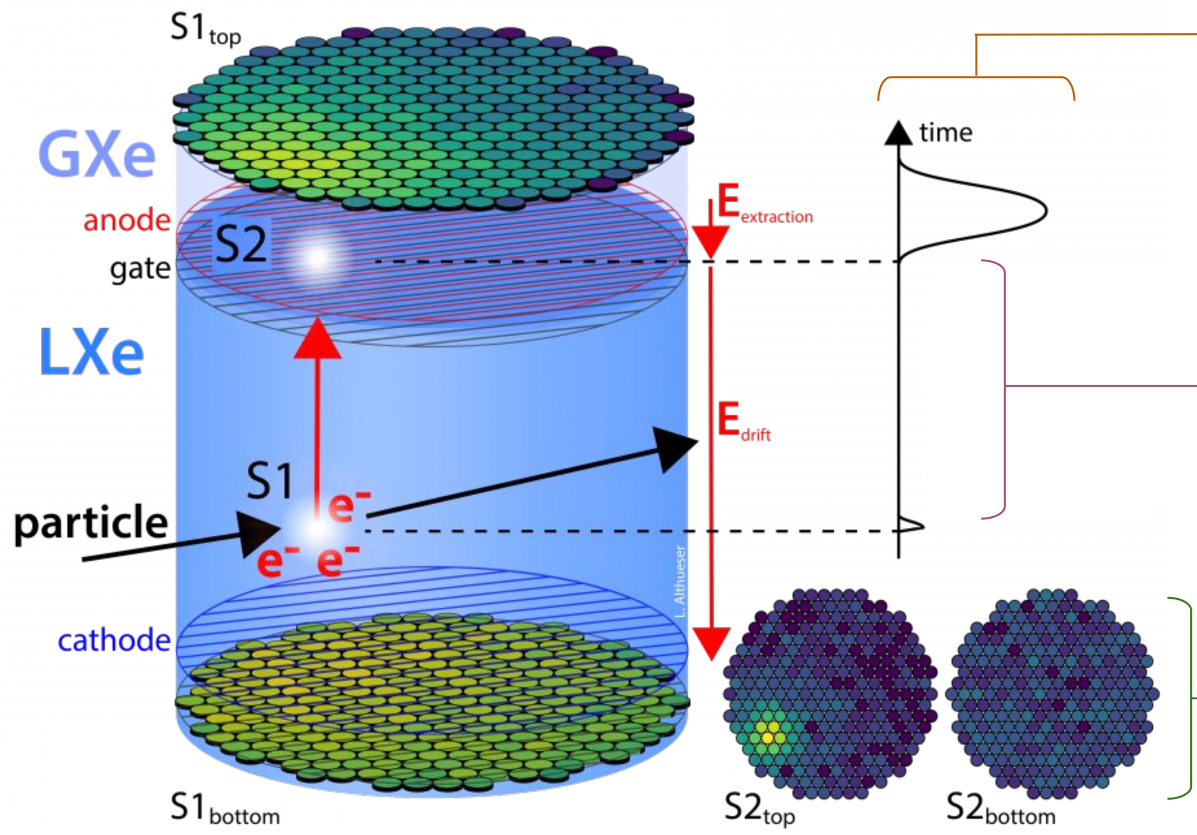


12 countries

27 institutions

~ 170 scientists

Xenon dual-phase time projection chamber

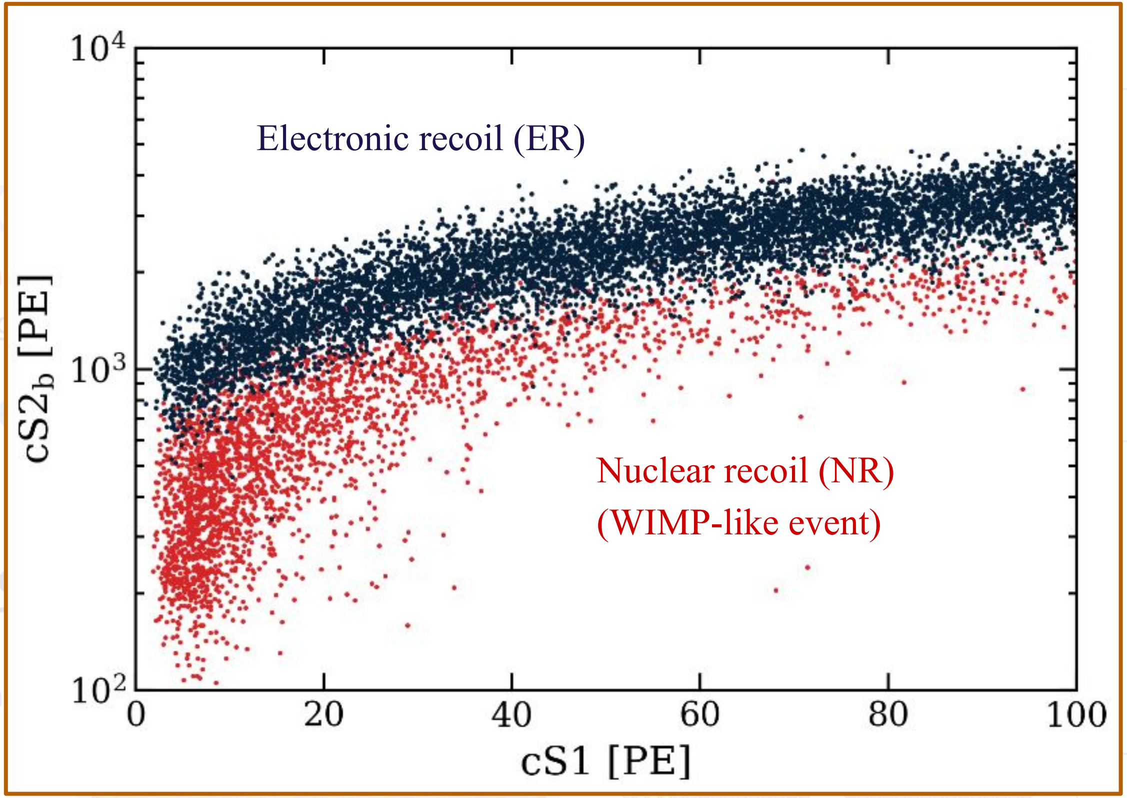


S2/S1 ratio
Signal discrimination

Electron drift time
Z position

S2 hit pattern
XY position

Detection principle



XENON1T calibration data

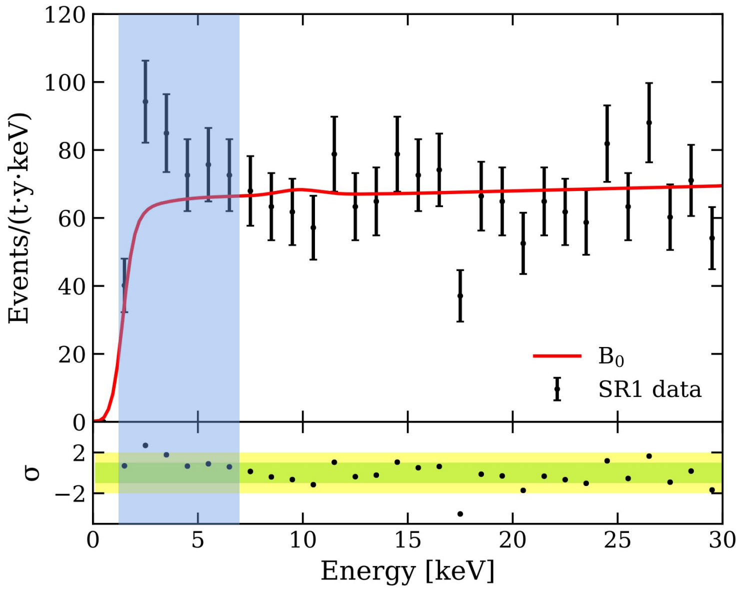
S2/S1 ratio
Signal discrimination

Electron drift time
Z position

S2 hit pattern
XY position

Low-energy ER excess in XENON1T

PRD 102, 072004 (2020)



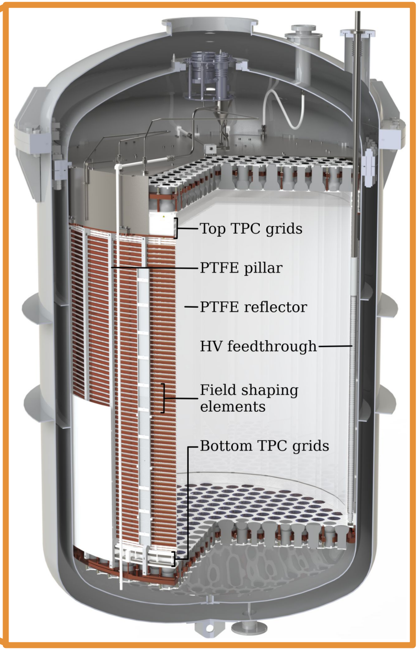
285 events observed vs. 232 ± 15 expected
3.3σ Poissonian fluctuation

- Compatible with various **beyond-SM** signatures (solar axions, ALPs, dark photons, enhanced neutrino magnetic moment, …)
- Consistent with **potential tritium (^{3}H) background**, but required contamination conflicts with observed target purity and transparency
- **^{37}Ar removed** by the online Kr distillation. Air leak at 13 l/y could explain excess, but upper limit is 0.9 l/y
- Addressing this question with first XENONnT science data

From XENON**1**T to XENON**n**T

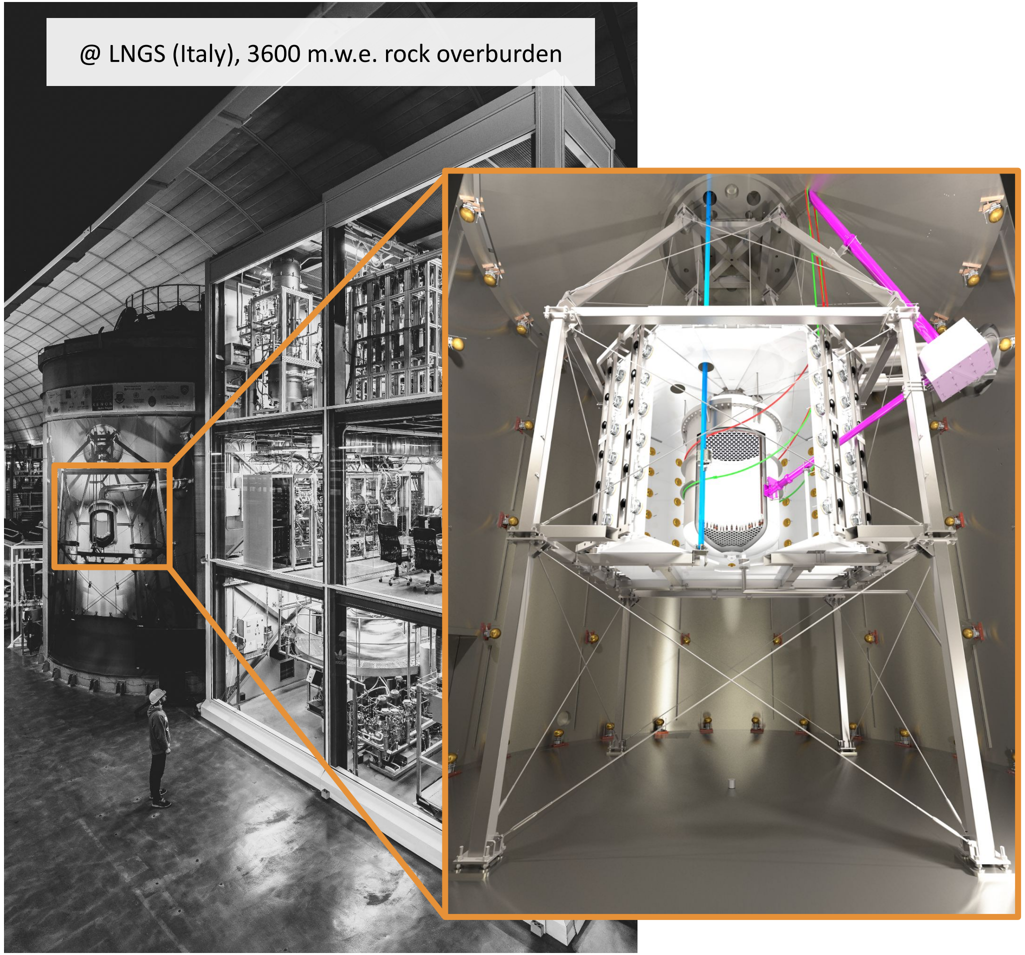
From XENON1T to XENONnT

Time projection chamber (TPC)



- 1.3 m (∅) × 1.5 m
- 8.5 t LXe in cryostat (2.5x XENON1T)
- 5.9 t LXe active (3x XENON1T)
- 494 3″ PMTs (2x XENON1T)
- Five electrodes made of SS wires
- Two sets of concentric field-shaping rings, tuneable potential for top one

From XENON1T to XENONnT



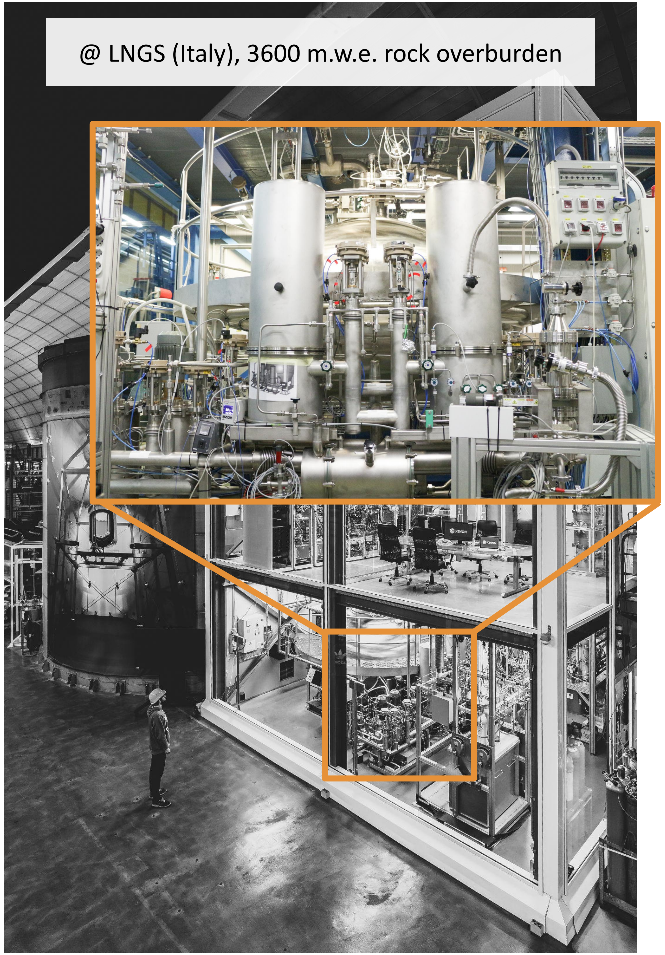
Neutron veto

- Cherenkov neutron veto inside inherited muon veto tank, 120 8″ PMTs facing the TPC
- Reflective ePTFE walls and ultra-pure water to minimize light absorption before detection
- Neutron tagging efficiency projected to 87% with (planned) Gd-doping, 68% with current pure water

JCAP 11 031 (2020)

- Using tagged calibration neutrons also to study the NR TPC response

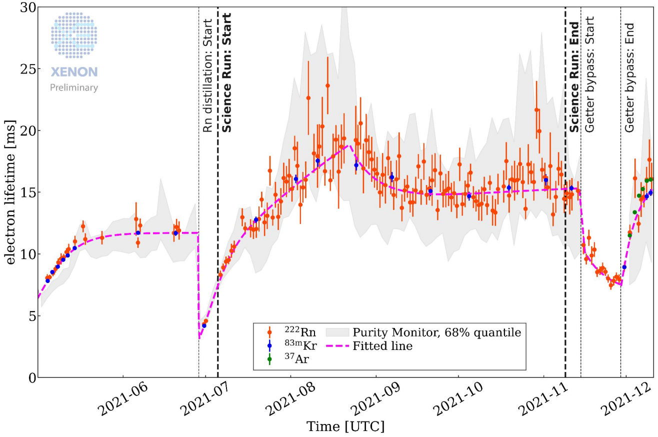
From XENON1T to XENONnT



Liquid xenon purification

Eur. Phys. J. C 82, 860 (2022)

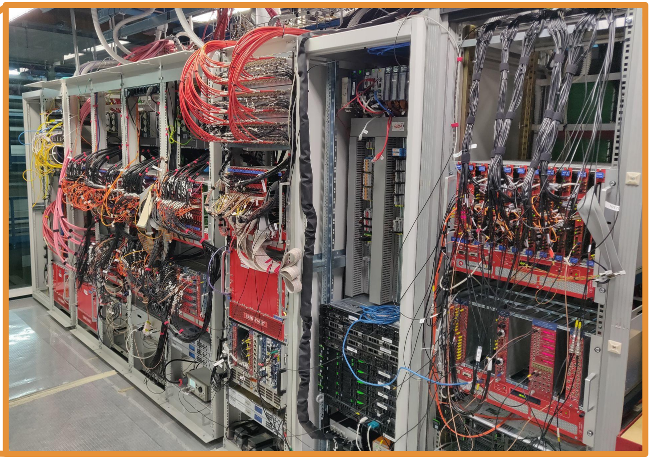
- LXe purity is crucial for electrons to survive until liquid-gas interface
- Novel liquid-phase purification with replaceable filter units, some with extremely low radon emanation (science run mode)
- 2 liters of LXe per minute: 18 h to recirculate entire inventory



	Max. TPC drift time	Electron lifetime	e⁻ survival @ max. drift length
1T	0.67 ms	0.65 ms	30%
nT	**2.2 ms**	**> 10 ms**	**> 90%**

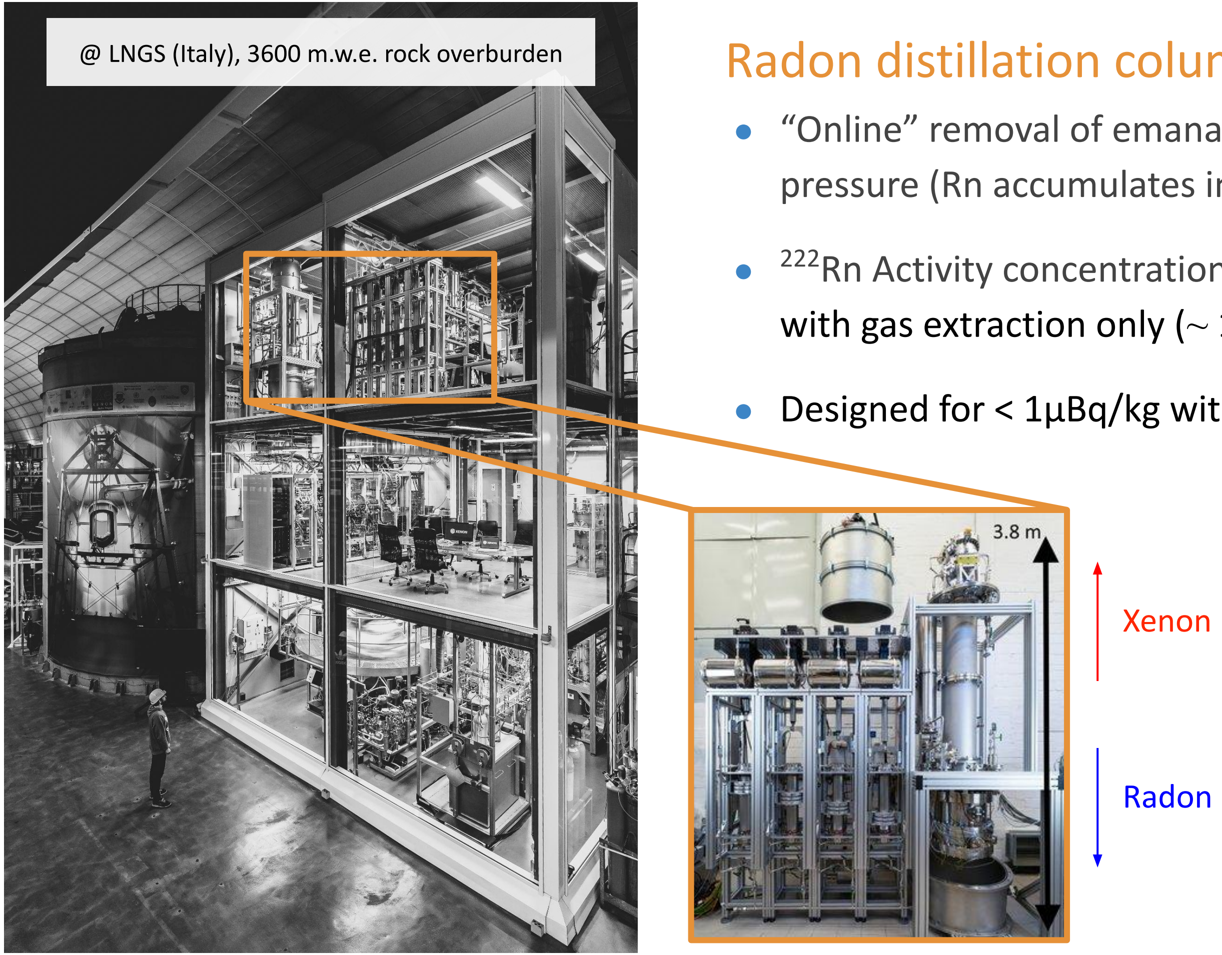
From XENON**1**T to XENON**n**T

Data acquisition



- Triggerless: all data above per-channel threshold stored long term
- Fully live processing
- Open source processing software: straxen@github

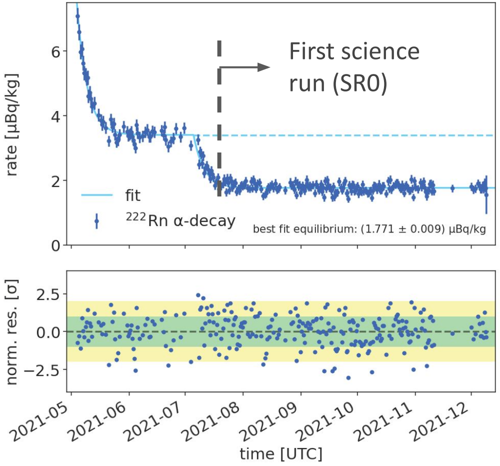
From XENON1T to XENONnT



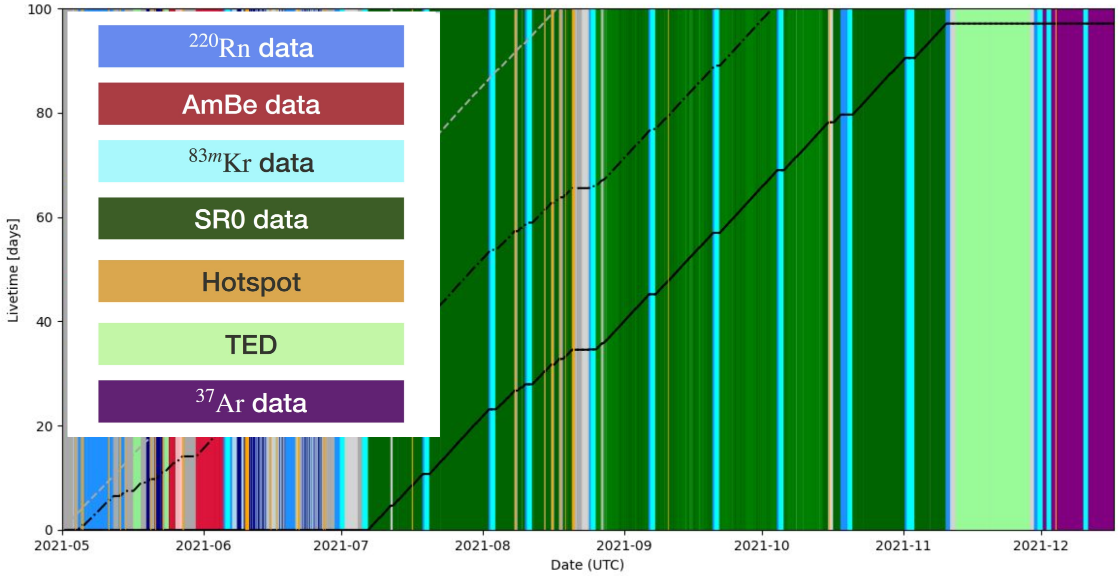
Radon distillation column

arXiv:2205.11492

- “Online” removal of emanating Rn using difference in vapor pressure (Rn accumulates into LXe more than GXe)
- ^{222}Rn Activity concentration equilibrium of 1.77 ± 0.01 µBq/kg with gas extraction only (~ 13 µBq/kg in XENON1T)
- Designed for < 1µBq/kg with gas+liquid extraction in future runs



First XENONnT science run (SR0)



ER and NR blinded analysis

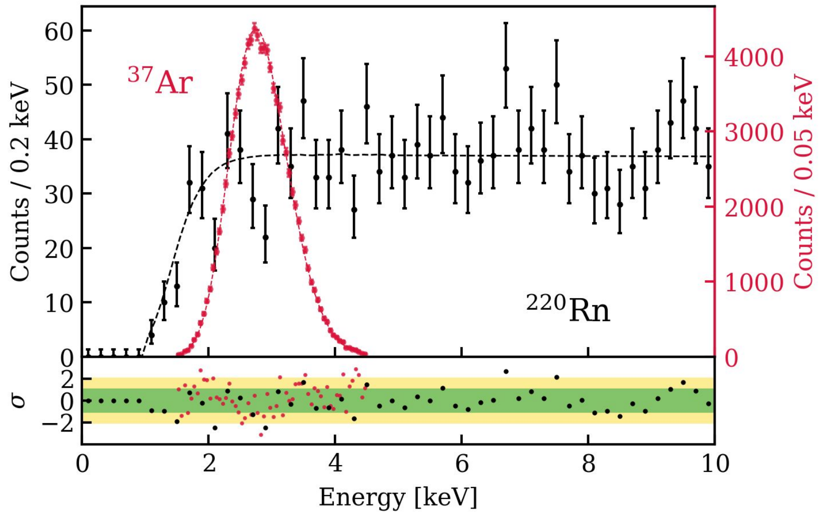
- **97.1 days of exposure** from July 6th - Nov 11th 2021
- Radon column operating in gas-only mode
- 477 out of 494 PMTs operative, gain stable at 3% level
- Drift field 23 V/cm (cathode voltage limited to –2.75 kV due short-circuit with bottom screen mesh)
- Extraction field in LXe 2.9 kV/cm
- Localized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

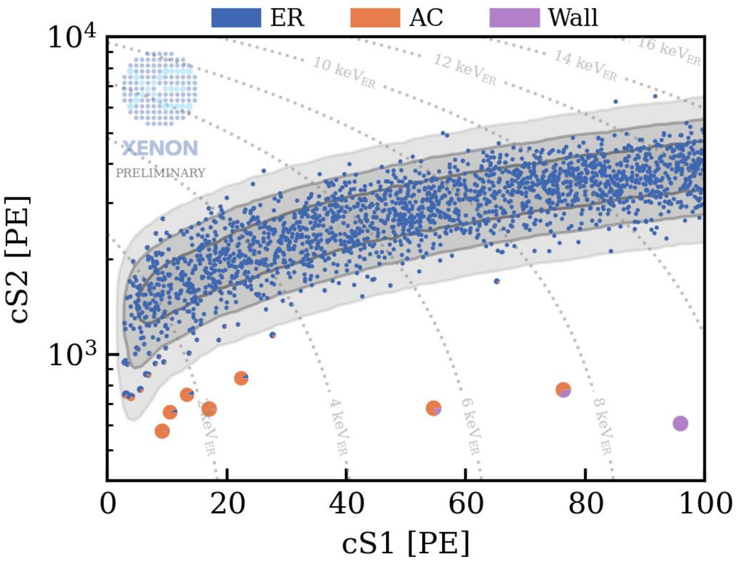
ER response characterization

Two homogeneously-distributed ER sources to derive response model and define blinding region:

- **^{212}Pb** from **^{220}Rn** gives a roughly flat β-spectrum, to estimate cut acceptances and energy threshold
- **^{37}Ar**, which gives a mono-energetic 2.82 keV peak, to model with high statistics low-energy response and resolution near detector energy threshold

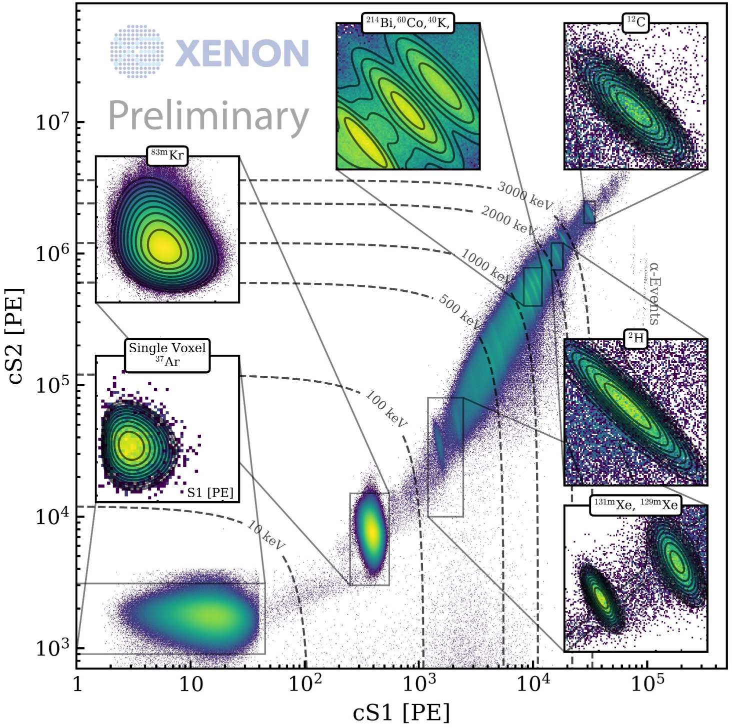
PRL 129, 161805 (2022)



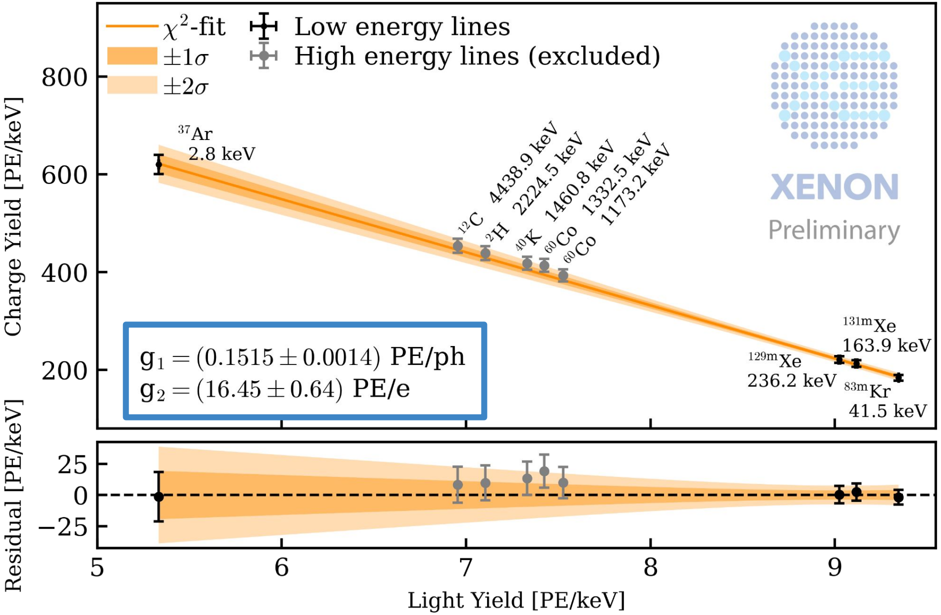


Energy reconstruction

- 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

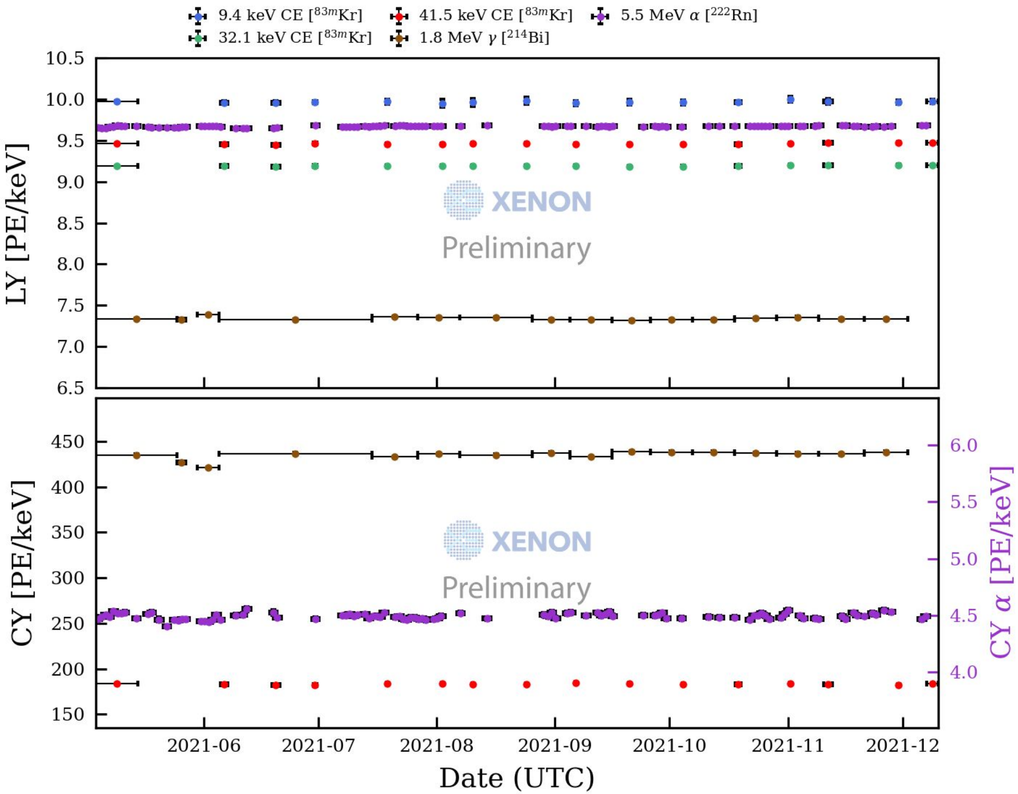


$$E = 13.7\text{eV}\left(\frac{cS1}{g_1} + \frac{cS2}{g_2}\right)$$



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



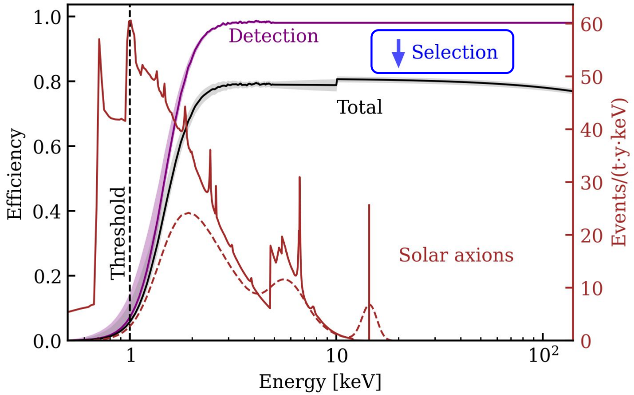
ΔLY = 1%

ΔCY = 1.9%

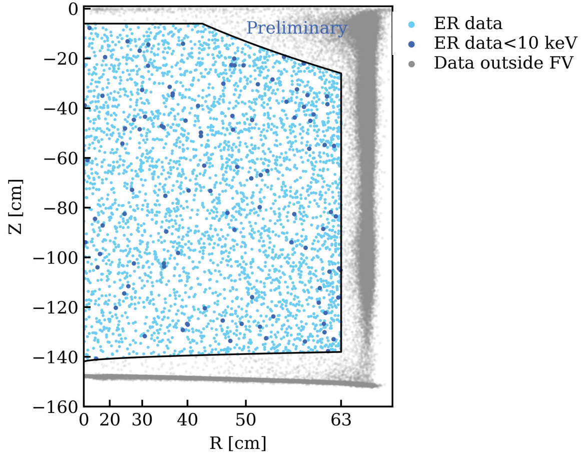
Detection and selection efficiencies

- Detection efficiency validated with data and waveform simulations (good agreement)
  - Dominated by 3-fold PMT coincidence requirement to identify an S1
- Events required to pass a range of data quality cuts
  - S1 and S2 peaks must have patterns, top/bottom area ratios etc. consistent with real events
  - S2 width consistent with the expected diffusion
  - S2 > 500 PE
  - Not within < 300 ns of a neutron veto event
- Fiducial volume cut optimization yields a mass of (4.37 ± 0.14) tonnes with low backgrounds

Average total cut acceptance ~ 86%



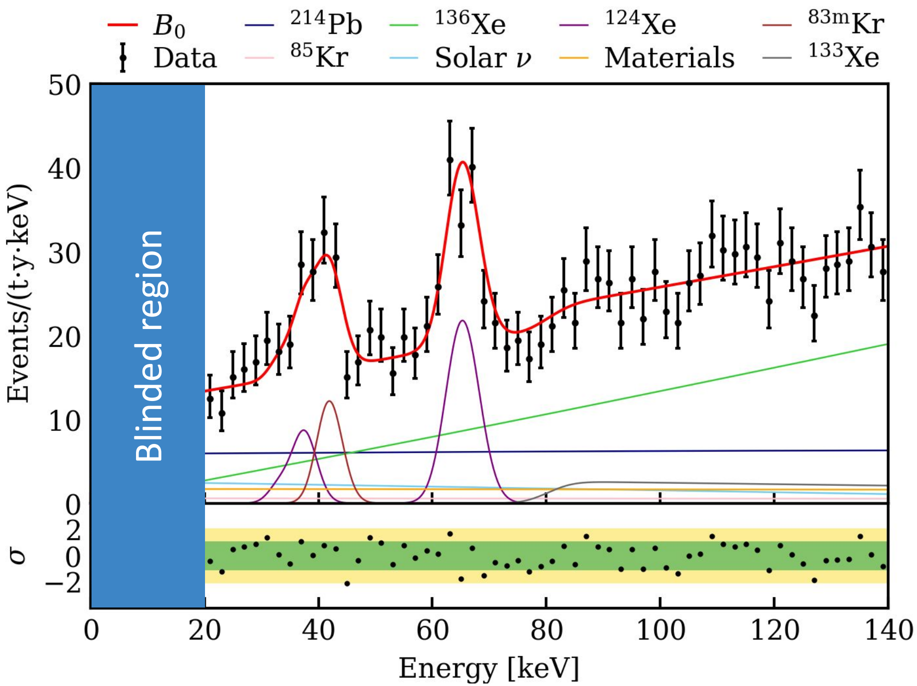
PRL 129, 161805 (2022)



Electronic recoil background model

- Energy range (1, 140) keV, exposure 1.16 t y
- NR and ER data below 20 keV blinded
- Background estimates:
  - Constraints by external measurements
  - Data-driven accidental coincidence model
  - Verification in side band before unblinding
  - Double weak processes 2νECEC (^{124}Xe) and 2νββ (^{136}Xe) dominate background
- Various unblinding stages:
  - (10, 20) keV sideband, accidental coincidence, wall sample, full range

PRL 129, 161805 (2022)

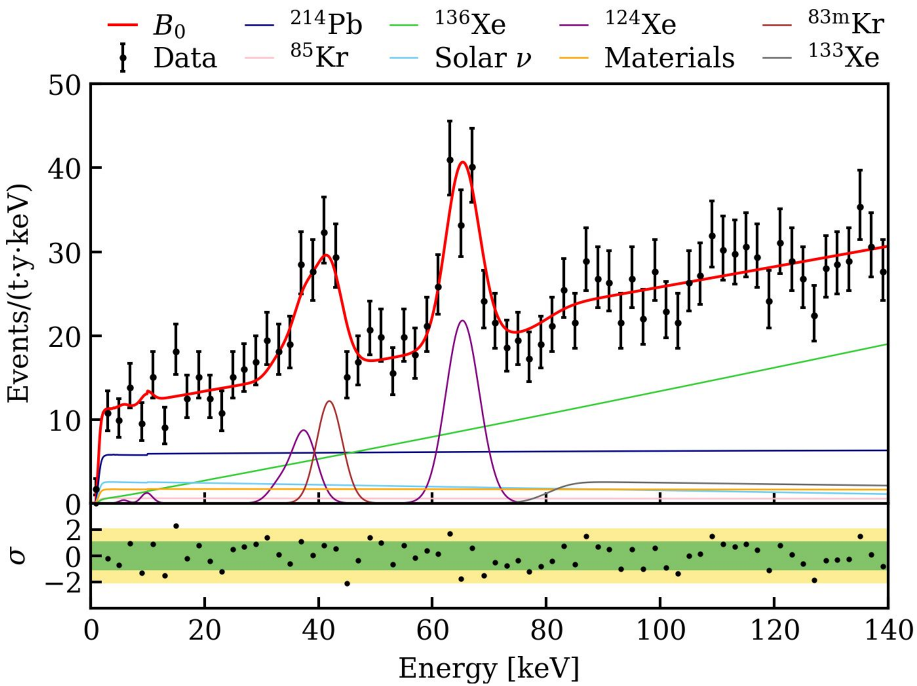


Electronic recoil unblinding

PRL 129, 161805 (2022)

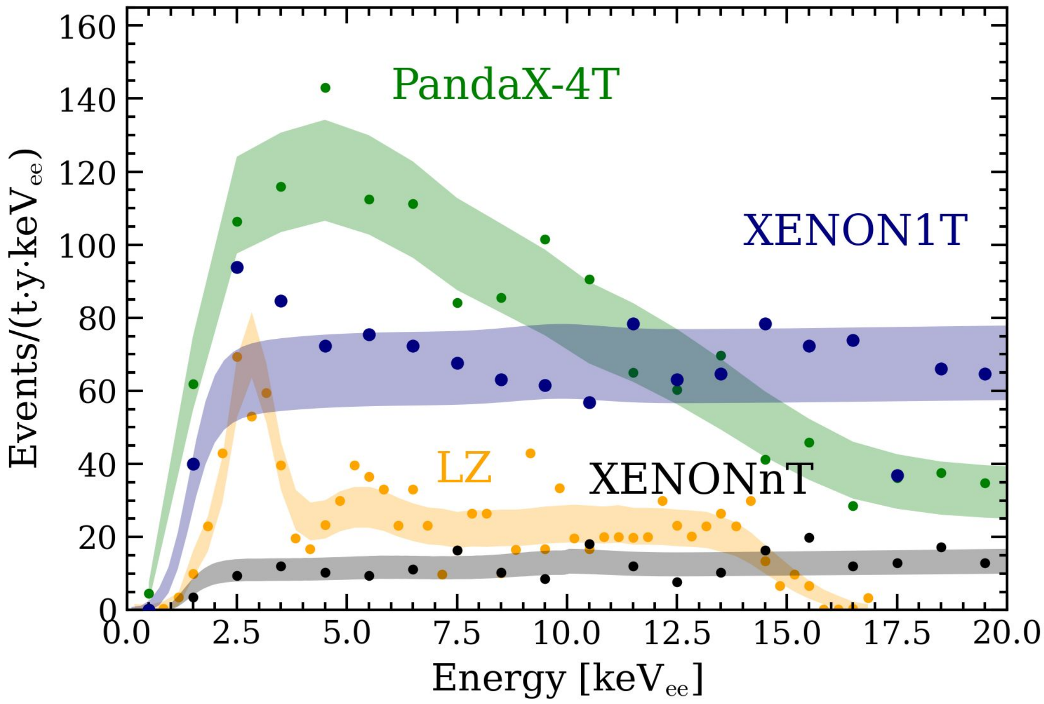
TABLE I. The background model B_0 with fit constraint and best-fit number of events for each component in (1, 140) keV.

Component	Constraint	Fit
^{214}Pb	(584, 1273)	980 ± 120
^{85}Kr	90 ± 59	91 ± 58
Materials	266 ± 51	267 ± 51
^{136}Xe	1537 ± 56	1523 ± 54
Solar neutrino	297 ± 30	298 ± 29
^{124}Xe	-	256 ± 28
AC	0.70 ± 0.04	0.71 ± 0.03
^{133}Xe	-	163 ± 63
^{83m}Kr	-	80 ± 16



- **No excess observed**
- **A small ^{3}H contamination is the most plausible explanation for the XENON1T excess**. Further time-stability studies in preparation

XENON1T vs. XENONnT

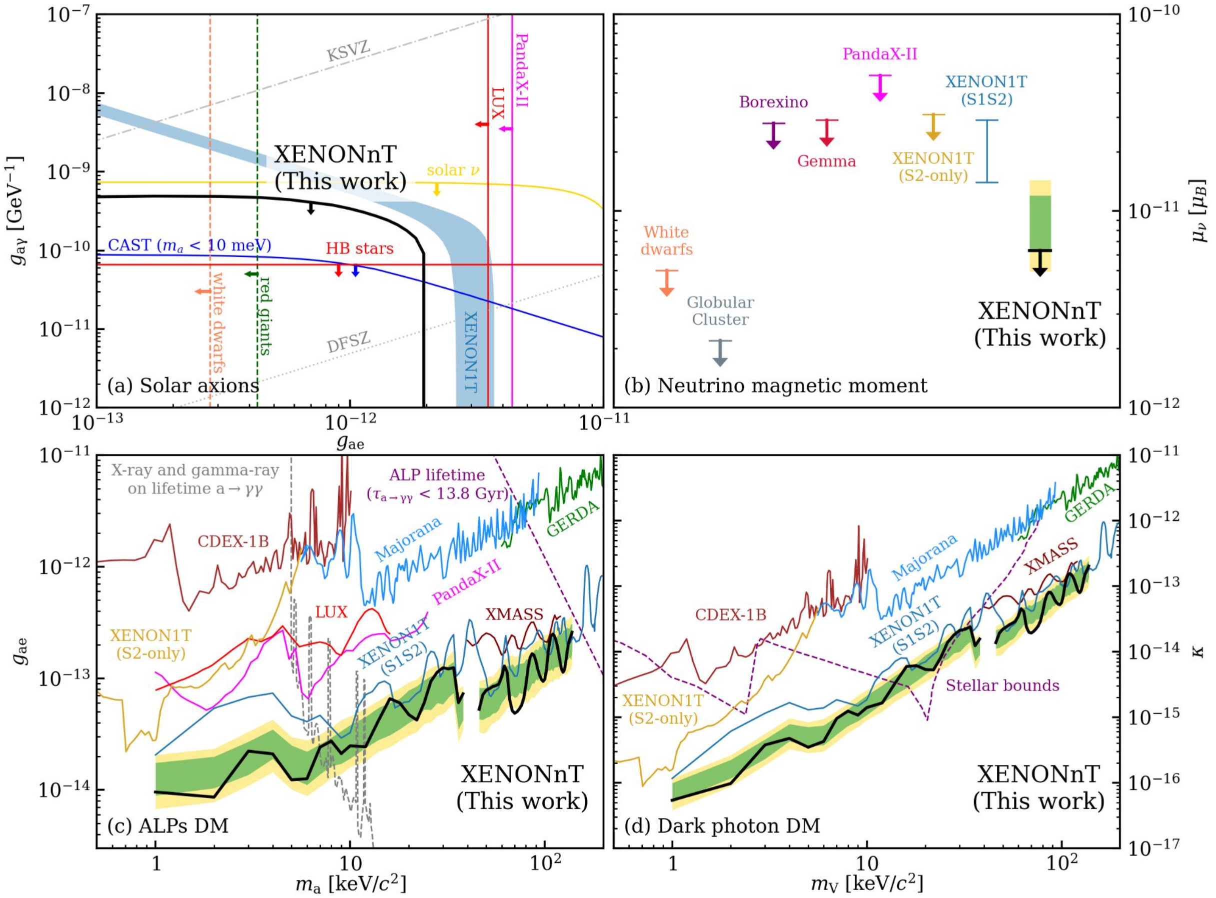


PRL 129, 161804 (2022)
PRD 102, 072004 (2020)
arXiv:2207.03764
PRL 129, 161805 (2022)

- Factor five background reduction with respect to XENON1T
- No excess below 5 keV found: 8.6σ exclusion on XENON1T excess

Constraints on BSM physics

PRL 129, 161805 (2022)



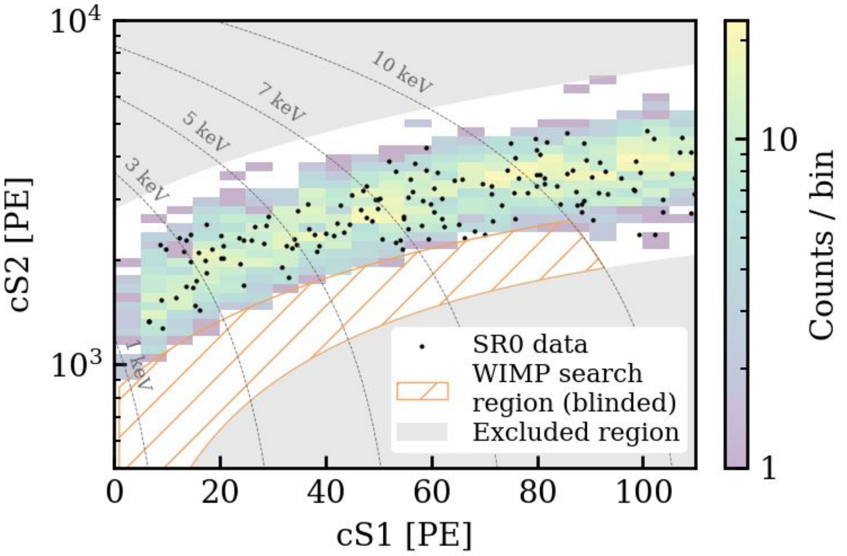
Summary

- Successful commissioning of new XENONnT subsystems
- Lowest background level ever achieved by a dark matter experiment: (16.1 ± 0.3) events/(t y keV)
- First results (SR0):
    - 97.1 d, for an exposure of ~ 1.16 t y
    - Fully blinded analysis of electronic recoil data
    - No excess observed: new limits on BSM physics
    - XENON1T excess most likely due to small ^{3}H contamination
- **NR WIMP unblinding in preparation. Stay tuned!**

xenonexperiment.org

xenon_experiment

xenonexperiment



Summary

XLZD meeting @ Karlsruhe, June 2022

xenonexperiment.org

xenon_experiment

xenonexperiment

xlzd.org

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

XLZD consortium

Joining forces towards a next-generation Dark Matter experiment

(white paper: arXiv:2203.02309)

Backup

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**