The XENONnT Experiment: Dark Matter and Beyond

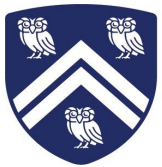
Shixiao Liang

On behalf of the XENON Collaboration

WIN2023

July 7th 2023

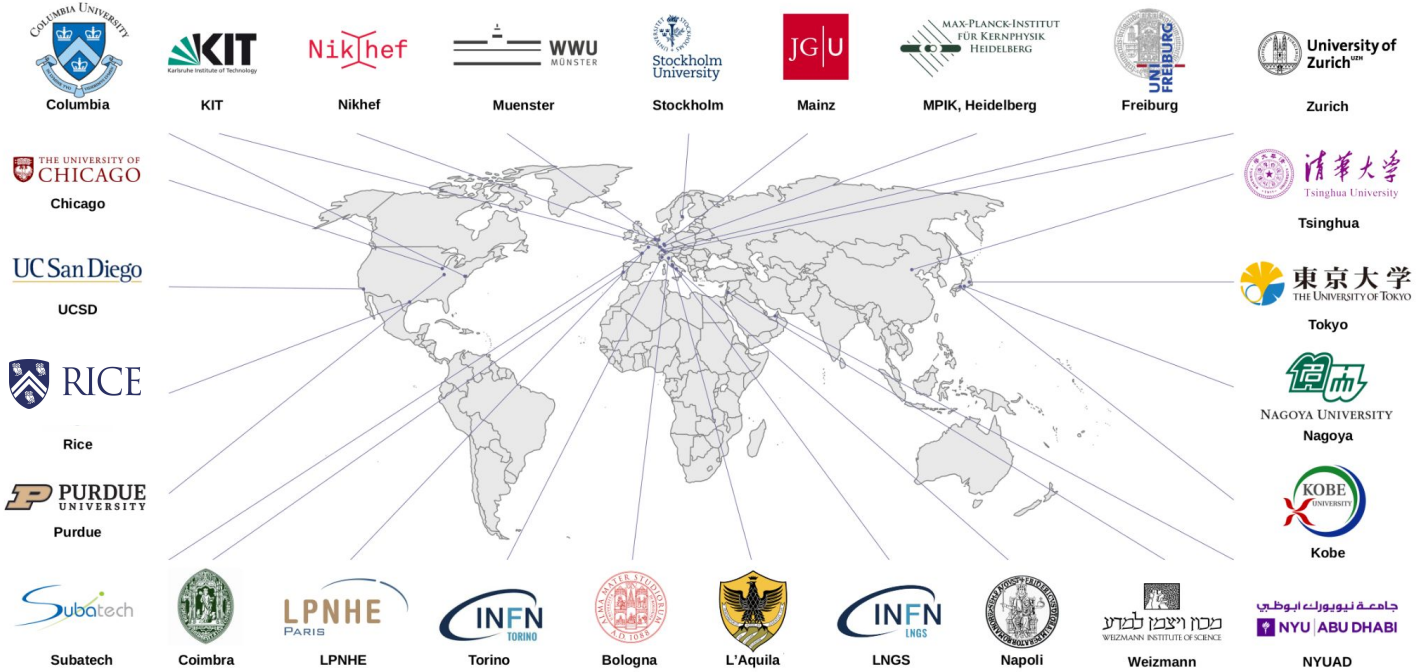
XENON



RICE

XENON Collaboration

27 institutes ~170 members



XENON Collaboration

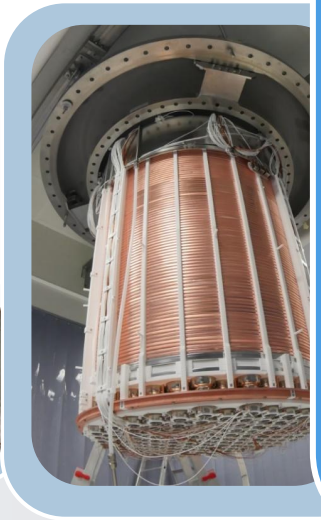
29 institutes ~170 members

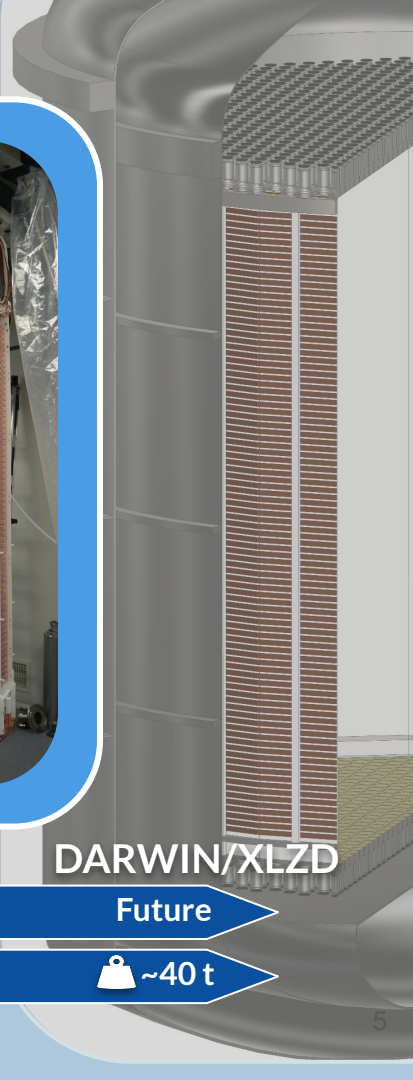
XENON Collaboration

Collaboration meeting at L'Aquila, Italy
February 1st-3rd 2023

XENON dark matter project

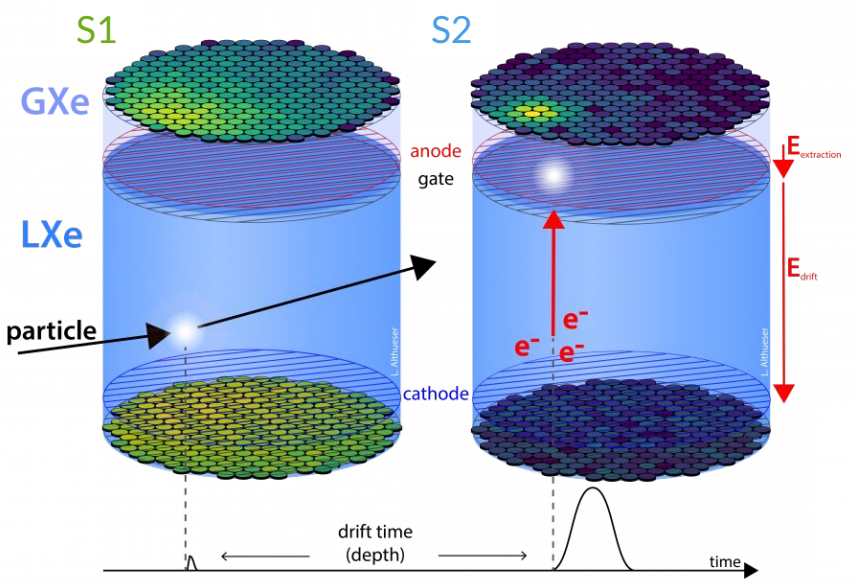
INFN
Laboratori Nazionali
del Gran Sasso



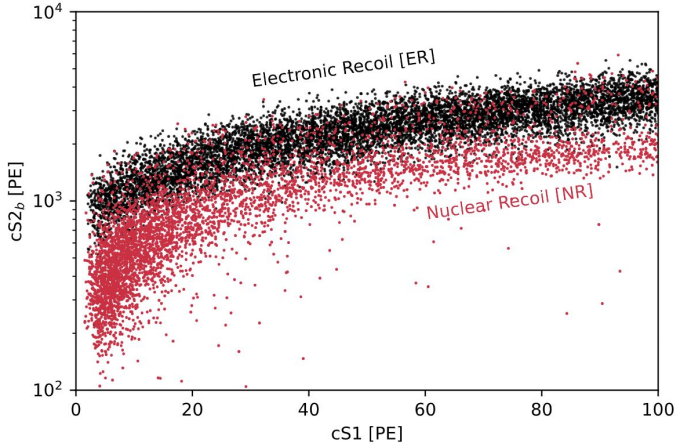


XENON10	XENON100	XENON1T	XENONnT	DARWIN/XLZD
2005 - 2007	2008 - 2016	2016 - 2019	2020 - Now	Future
14 kg	62 kg	2.0 t	5.9 t	~40 t

Dual-phase Xenon Time Projection Chamber



- Initial scintillation light: S1
- Proportional scintillation signal: S2
- Energy: S1 area, S2 area
- Interaction type: S2/S1 ratio (**ER**/**NR**)
- Position: Z (drift time), X-Y (S2 signal)



XENONnT Upgrades

Reusing XENON1T infrastructure

×3

Active Volume

1/6

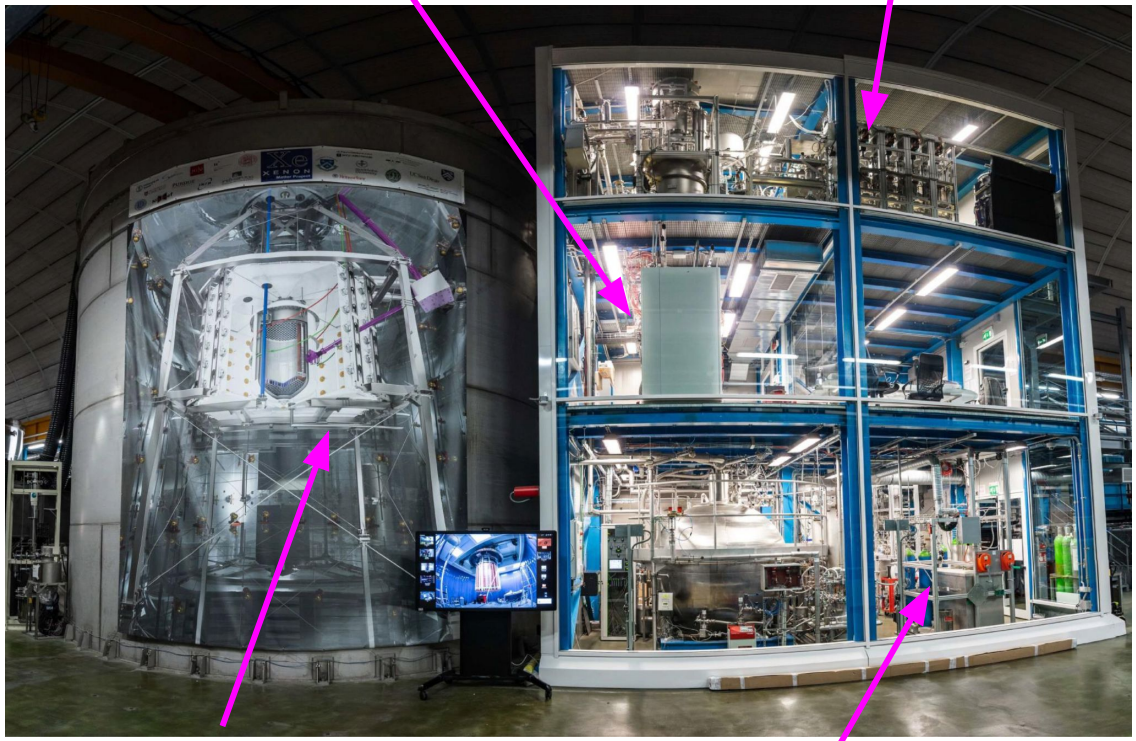
Backgrounds

Carefully selected materials
Eur. Phys. J. C **82**, 599 (2022)
arXiv:2112.05629

straxen
Streaming analysis for XENON(nT)
https://github.com/XENONnT/straxen

Triggerless data acquisition
Accepted by *JINST*
arXiv:2212.11032

Radon distillation system
Eur. Phys. J. C **82**, 1104 (2022)
arXiv:2205.11492

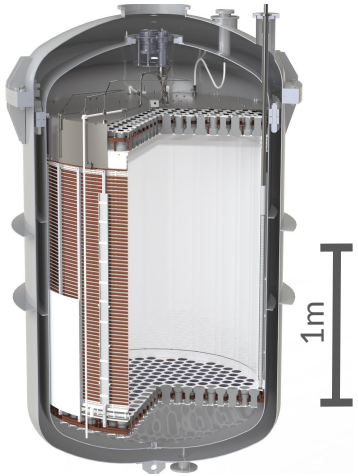


Neutron veto
JCAP 11 (2020) 031
arXiv:2007.08796

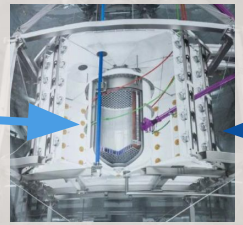
Liquid xenon purification system
Eur. Phys. J. C **82**, 860 (2022) arXiv:2205.07336

TPC & Neutron Veto

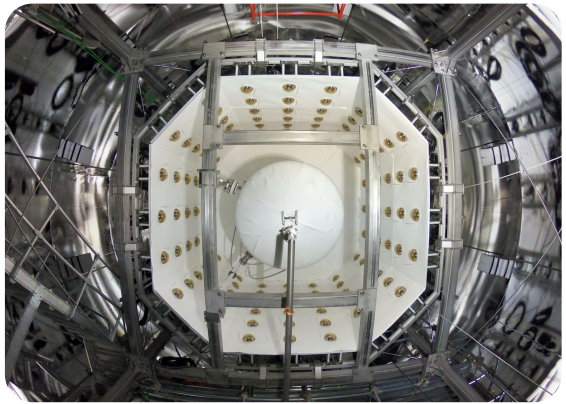
XENONnT TPC



- 8.5 t of LXe in cryostat, 5.9 t in TPC
- 494 × 3” PMTs
  (253 top array, 241 bottom array)
- 1.5m long, 1.3m in diameter



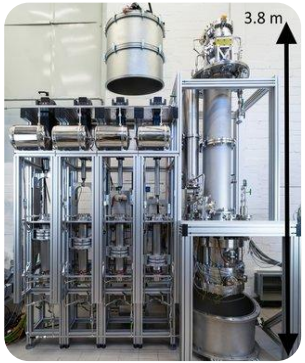
Neutron Veto



- Built inside Muon Veto
- 33 m^3 of volume, 120 × 8” PMTs
- 53% Neutron tagging efficiency in SR0 condition

JCAP 11 (2020) 031
arXiv:2007.08796

Xe Purification & Rn Removal



Radon Removal

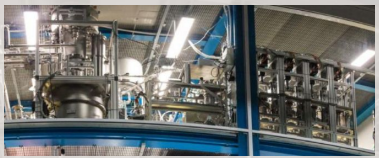
- ^{222}Rn mitigation - material selection & screening
- Radon removal via online cryogenic distillation
- Radon activity < 2 µBq/kg

Eur. Phys. J. C **82**, 1104 (2022)
arXiv:2205.11492

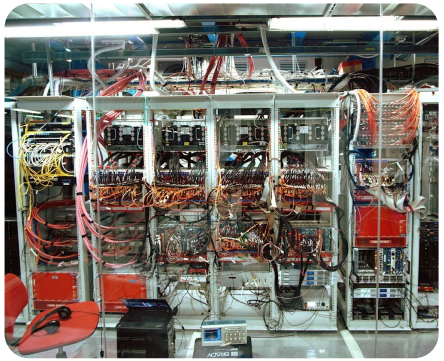
Liquid Xenon Purification

- Ultra-low radon emanation filters
- High LXe flow of 8.3 t / d
- Electron lifetime > 10 ms

Eur. Phys. J. C **82**, 860 (2022)
arXiv:2205.07336



DAQ & Softwares



Data Acquisition System

- Triggerless data acquisition
- Dual gain digitization for top array
- Online processing & live monitoring

Accepted by *JINST*
arXiv:2212.11032

Softwares

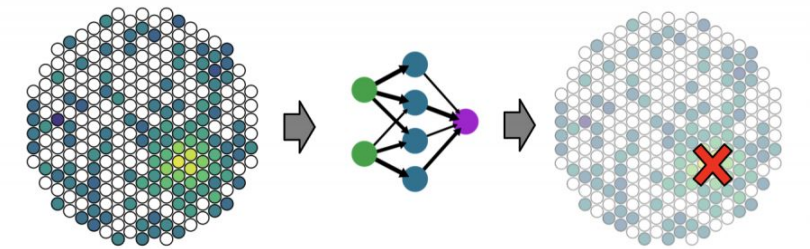
`straxen`
Streaming analysis for XENON(nT)
github.com/XENONnT/straxen

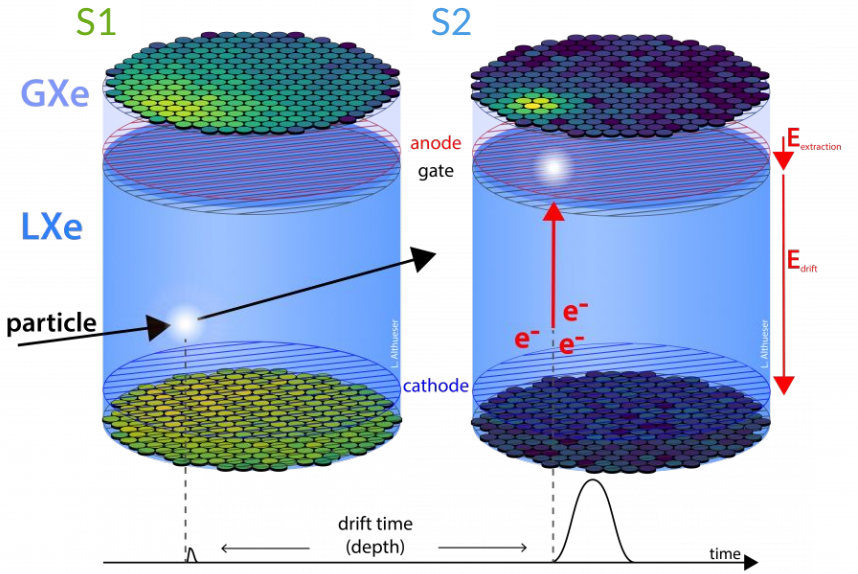
`XeDocs`
XENON metadata management tool
github.com/XENONnT/xedocs
zenodo.org/record/7945375

`WFSim`
The XENON waveform simulator
github.com/XENONnT/wfsim

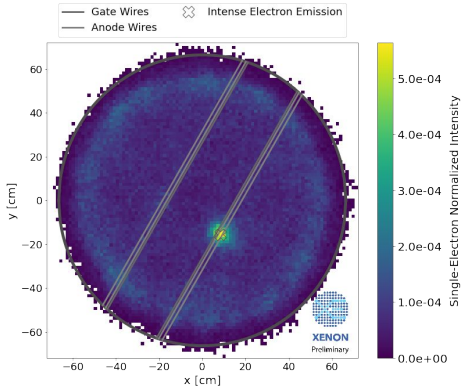
- Open source softwares
- Developed in Python
- No ROOT dependency

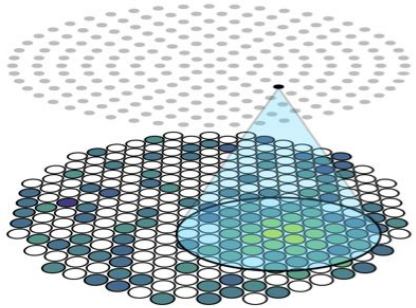
Data Processing with Neural Networks





- Reconstruct X-Y positions of S2 signals
- 3 models: Multilayer Perceptron (MLP),
  Graph Constrained Network (GCN),
  Convolutional Neural Network (CNN)
- Trained on simulated S2 signals
- Optimized for speed & run in real time for monitoring
- GCN: architecture designed for S2 position reconstruction





Front. Artif. Intell. **5** (2022) 832909
arXiv:2112.07995

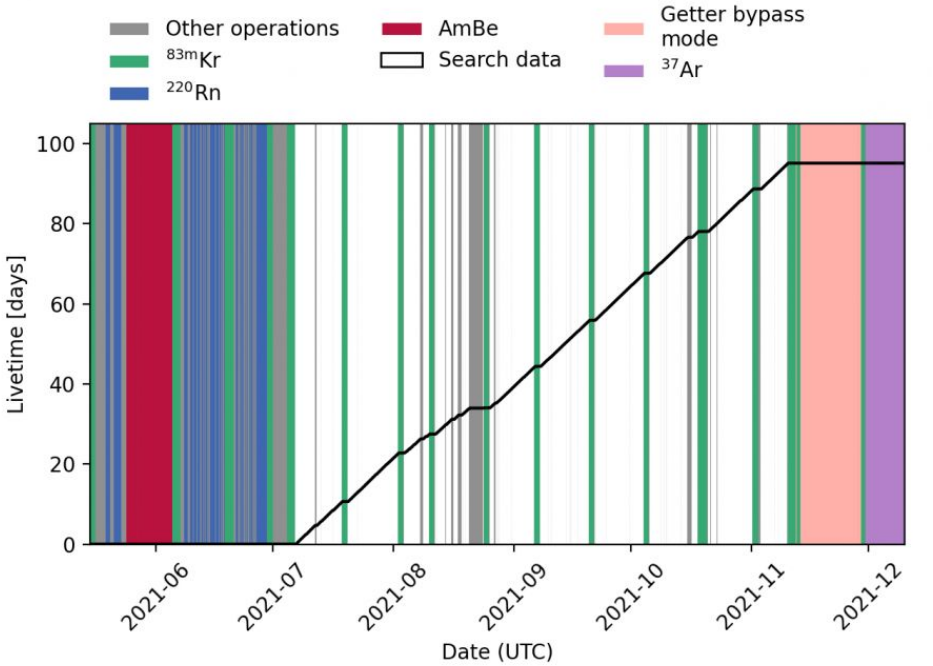
XENONnT Science Run 0

Data:

- 97.1 days of data taking:
  July 6th 2021 - Nov 10th 2021
- Low ER background
  15.8 ± 1.3 events /(keV × t × yr)
- Average electron lifetime > 10 ms

Analysis:

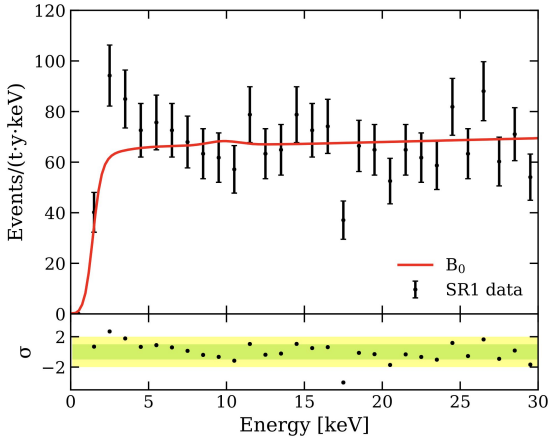
- Low energy electronic recoil
- WIMP dark matter search



XENON1T Electronic Recoil Excess

Phys. Rev. D **102**, 072004
arXiv:2006.09721

- Data excess background model in low energy electronic recoil region

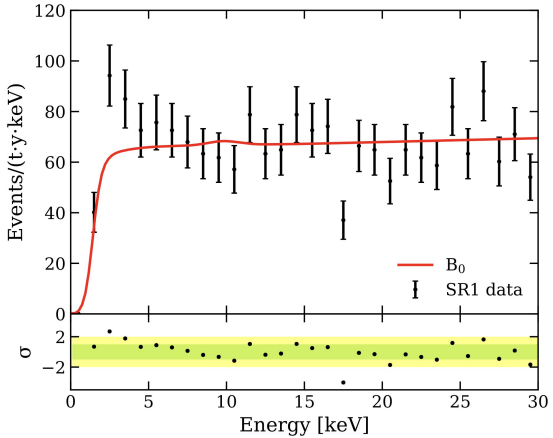


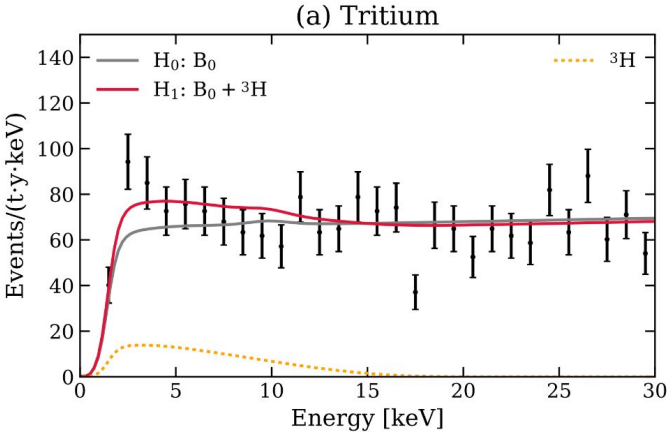
XENON1T Electronic Recoil Excess

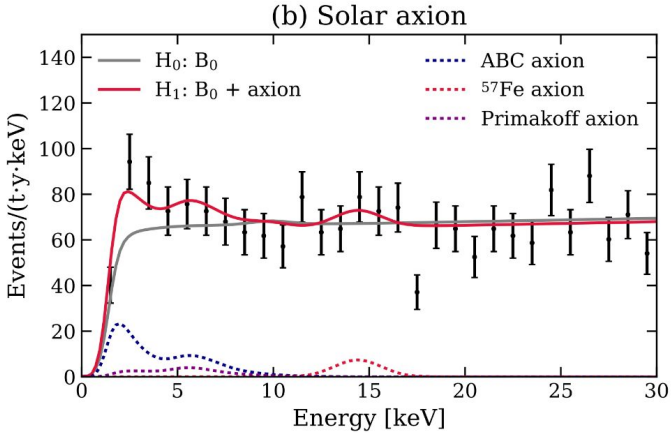
Phys. Rev. D **102**, 072004 (2020)
arXiv:2006.09721

- Data excess background model in low energy electronic recoil region

- Possible explanations:
  - tritium background
  - new physics







XENONnT LowER Result

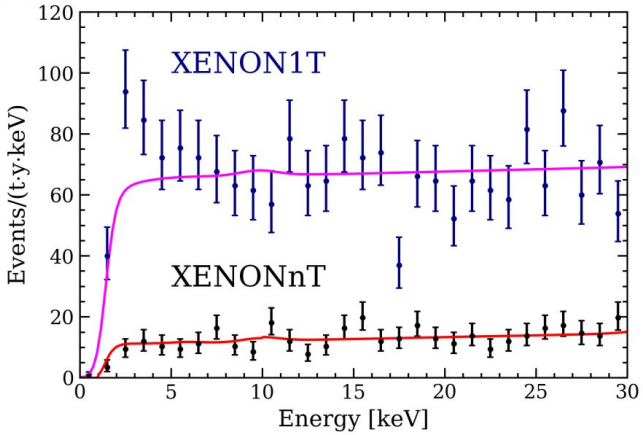
Phys. Rev. Lett **129**, 161805 (2022)
arXiv:2207.11330

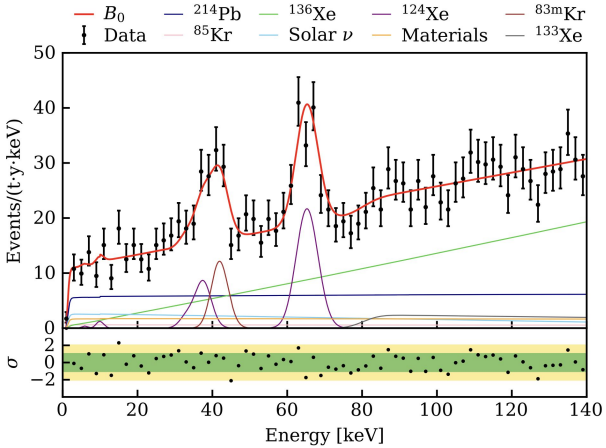
Data:

- 1.16 t × yr of exposure
- ~⅛ background level of XENON1T
- Spectrum shape dominated by double-weak decays

Result:

- Data agree with background-only model
- No excess
- XENON1T excess excluded by 4σ



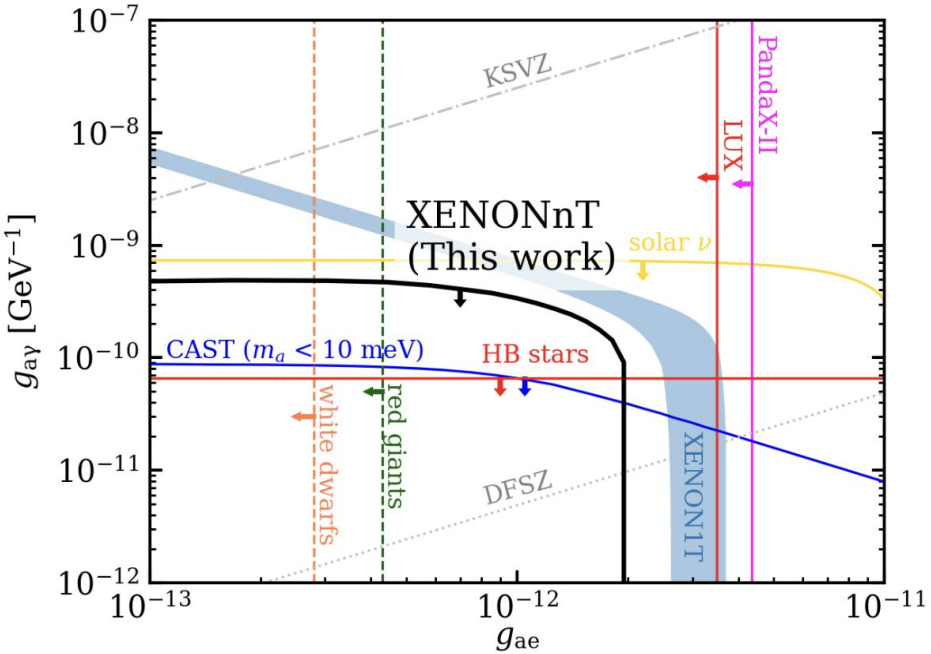


XENONnT LowER Result

Phys. Rev. Lett **129**, 161805 (2022)
arXiv:2207.11330

Constraint on new physics

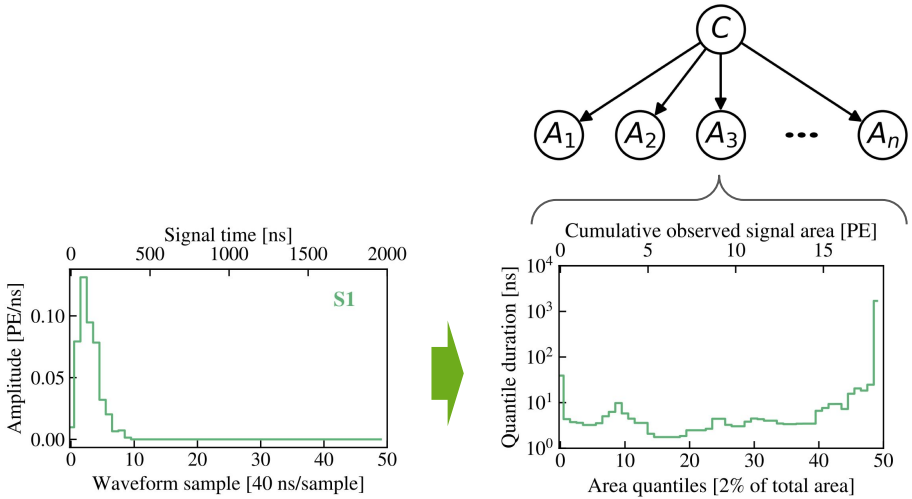
- Solar Axion
  - Best limit from dark matter direct detection experiment
- Other
  - Neutrino magnetic moment
  - Axion like particle dark matter
  - Dark photon dark matter

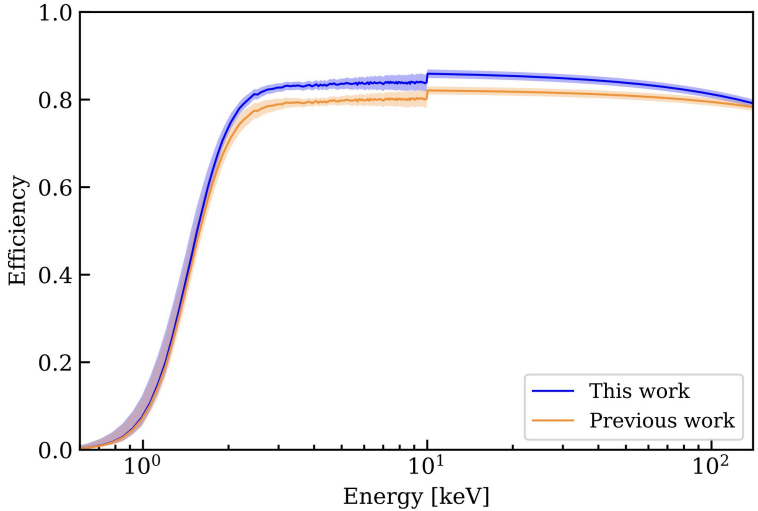


Bayesian Network Analysis

Accepted by *Phys. Rev. D*
arXiv:2304.05428

- Bayesian network trained on waveform attributes
- S1/S2 classification and event selection based on model output
- Effectiveness demonstrated using SR0 low ER data
- 3% increase in ER event selection efficiency
- Corroborates result of low ER analysis





Calibration & Efficiency

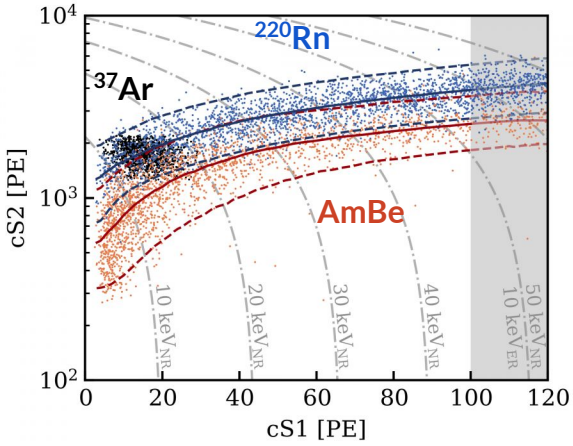
Accepted by *Phys. Rev. Lett*
arXiv:2303.14729

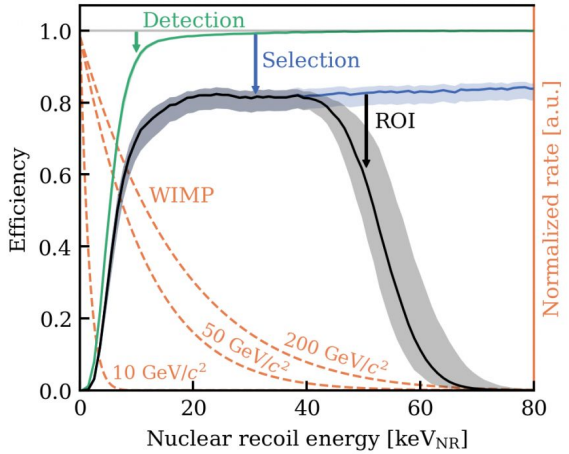
ER Calibration

- **^{220}Rn**
  - Approximately flat energy spectrum < 200 keV_{ER}
  - Used to validate cut acceptance
- **^{37}Ar** (2.8 keV_{ER} line)
  - Validate detector performance at low energies

NR Calibration

- external AmBe neutron source

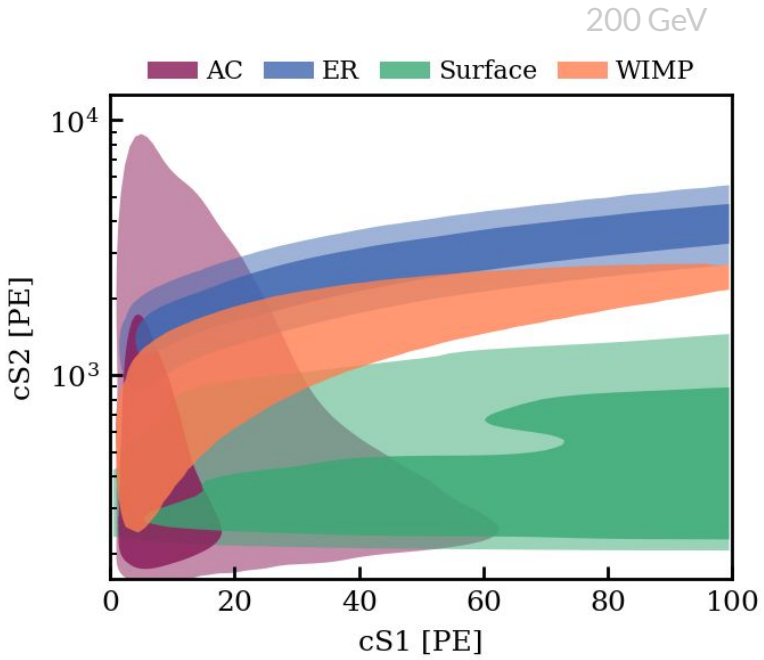




WIMP search backgrounds

Accepted by *Phys. Rev. Lett*
arXiv:2303.14729

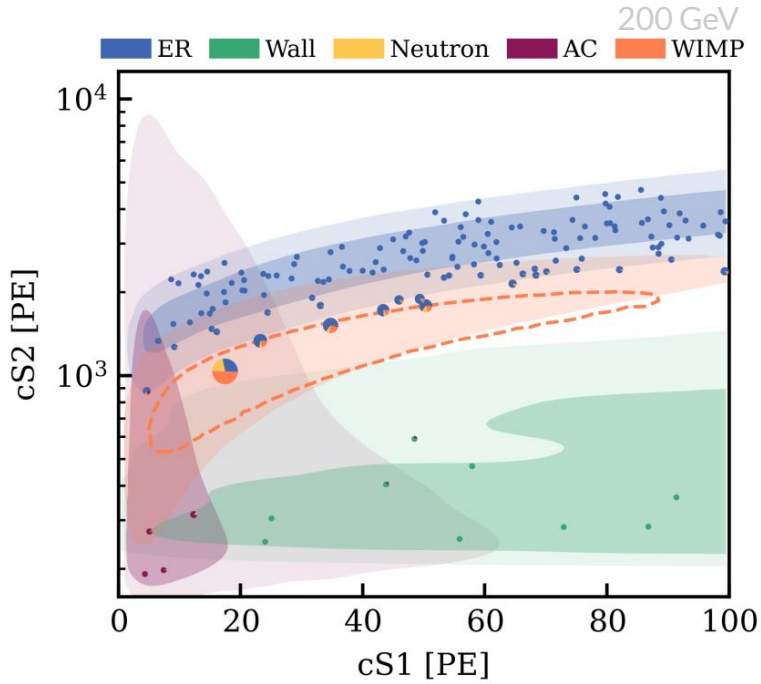
- **Electronic Recoil (ER):**
  - Dominated by beta decay of ^{214}Pb (daughter of ^{222}Rn)
  - ^{85}Kr background sub-dominant
- **Accidental Coincidences (AC):**
  - Random pairing of S1 & S2 signals
- **Surface:**
  - ^{210}Pb plate-out on PTFE walls of the TPC
- **Nuclear Recoil (NR):**
  - Radiogenic neutron rate prediction from Neutron Veto tagging
  - ^{8}B CEvNS constrained by flux



WIMP search result

Accepted by *Phys. Rev. Lett*
arXiv:2303.14729

	Expected	Best Fit
	ROI	
ER	134	135 (+12) (-11)
Neutrons	1.1 (+0.6) (-0.5)	1.1 ± 0.4
CEvNS	0.23 ± 0.06	0.23 ± 0.06
AC	4.3 ± 0.2	4.32 ± 0.15
Surface	14 ± 3	12 (+0) (-4)
Total	**154**	**152 ± 12**
WIMP (200 GeV)	-	2.6
Observed	-	**152**

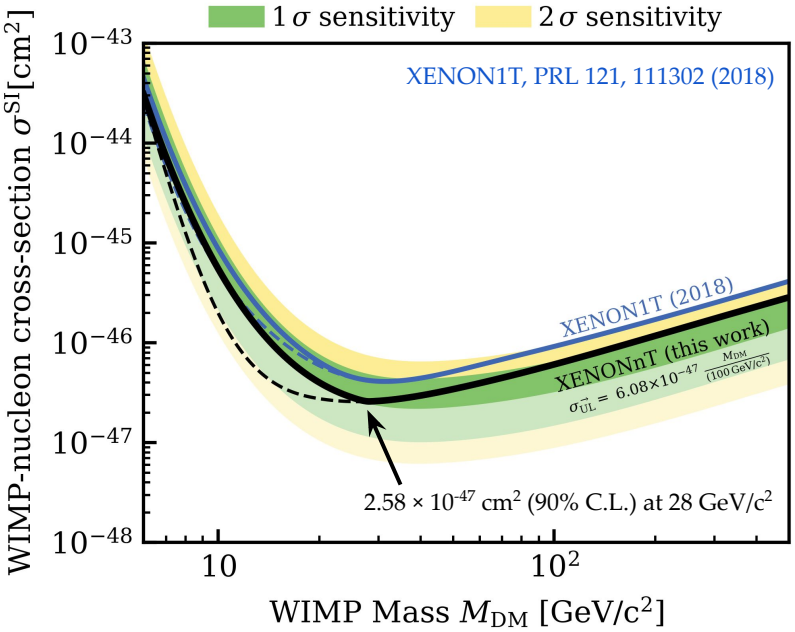


- 1.1 t × yr of exposure
- 152 events in ROI, 16 in blinded region
- **No significant excess**

Spin-independent limit

Accepted by *Phys. Rev. Lett*
arXiv:2303.14729

- XENONnT 90% C.L. Power-Constrained Limit (PCL)*
- **Minimum upper limit:** 2.58×10^{-47} cm^2 (90% C.L.) at 28 GeV/c^2
- 1.6× improvement from XENON1T with shorter life time



* arXiv:1105.3166, arXiv:2105.00599 with 50% [median] rejection power

Spin-independent limit

Accepted by *Phys. Rev. Lett*
arXiv:2303.14729

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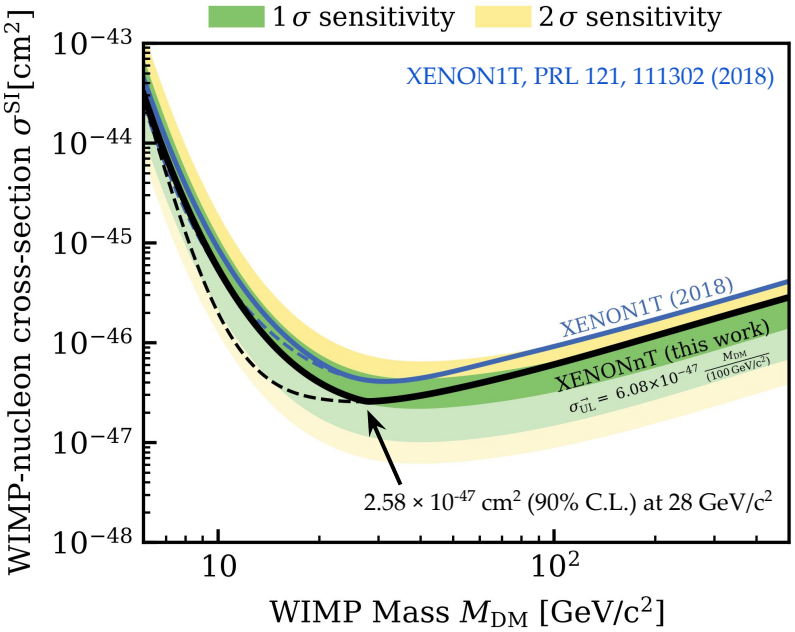
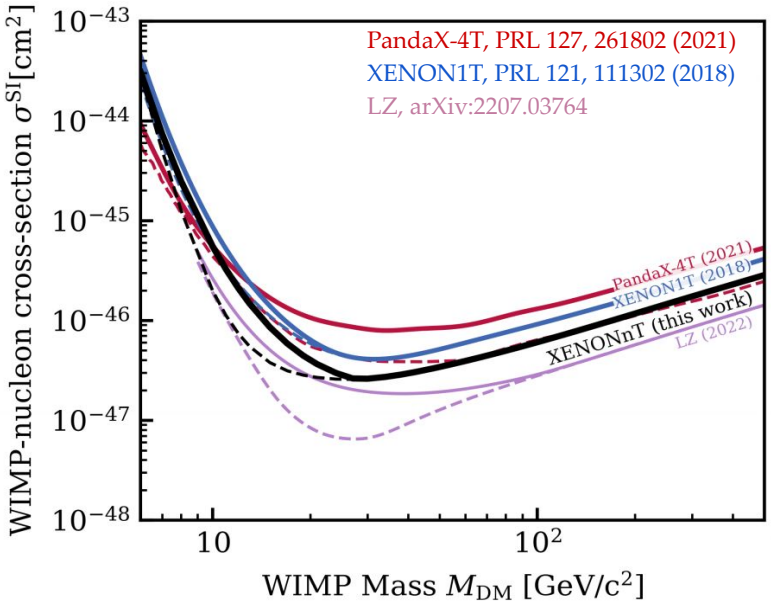
- **Minimum upper limit:** 2.58×10^{-47} cm^2 (90% C.L.) at 28 GeV/c^2
- 1.6× improvement from XENON1T with shorter life time

- Same PCL applied to results of other recent LXe experiments





* arXiv:1105.3166, arXiv:2105.00599 with 50% [median] rejection power

Summary

- **SR0** - 1.1 t × yr exposure in 2021
- **Low-energy ER background**

  15.8 ± 1.3 events /(keV × t × yr)
- **Low ER result** arXiv:2304.05428 PRL

  Excluded XENON1T result, limit on new physics
- **WIMP result** arXiv:2303.14729 PRL

  SI limit of 2.58 × 10^{-47} cm^2 (90% C.L.) at 28 GeV/c^2

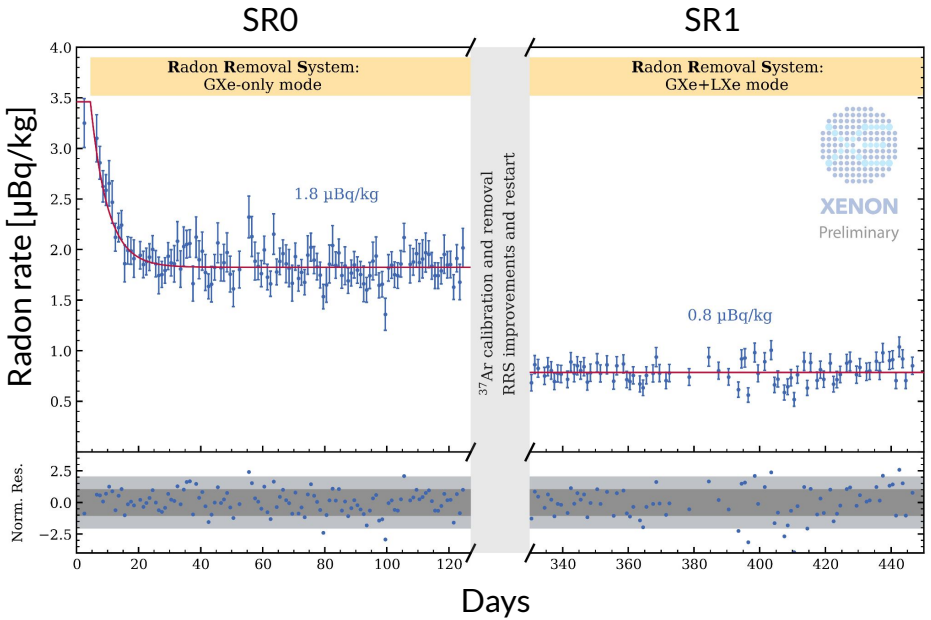
- **SR1** - data taking ongoing, further reduction of ^{222}Rn
- Upcoming works:

  Papers on detector design, LXe purification…

  Solar neutrino analyses: pp, ^{8}B CEvNS

  s2-only studies

  …



xenonexperiment.org

xenon_experiment

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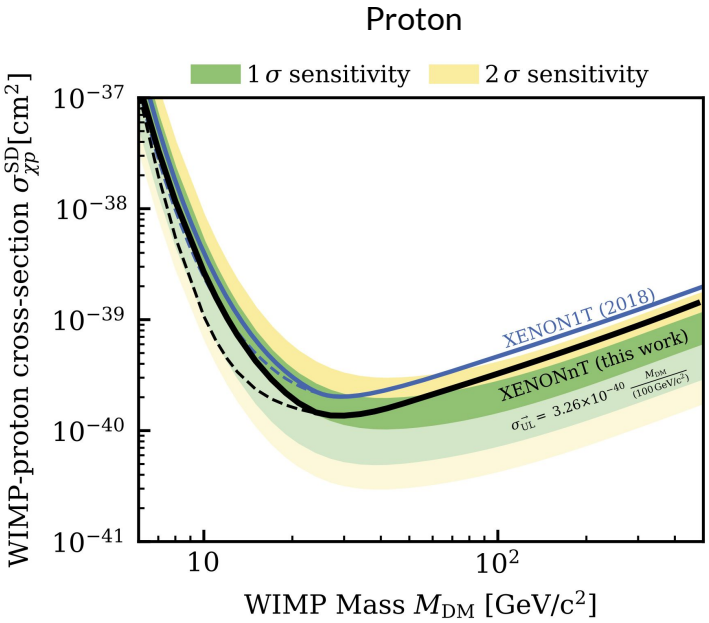
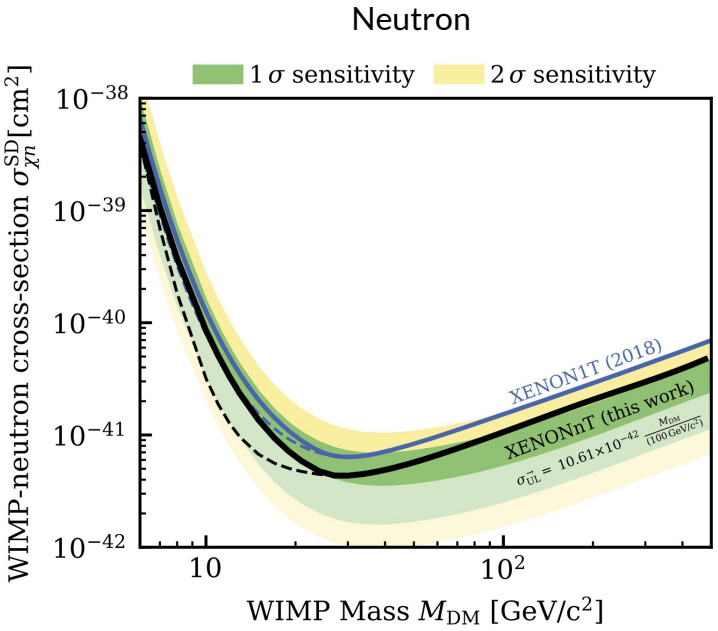
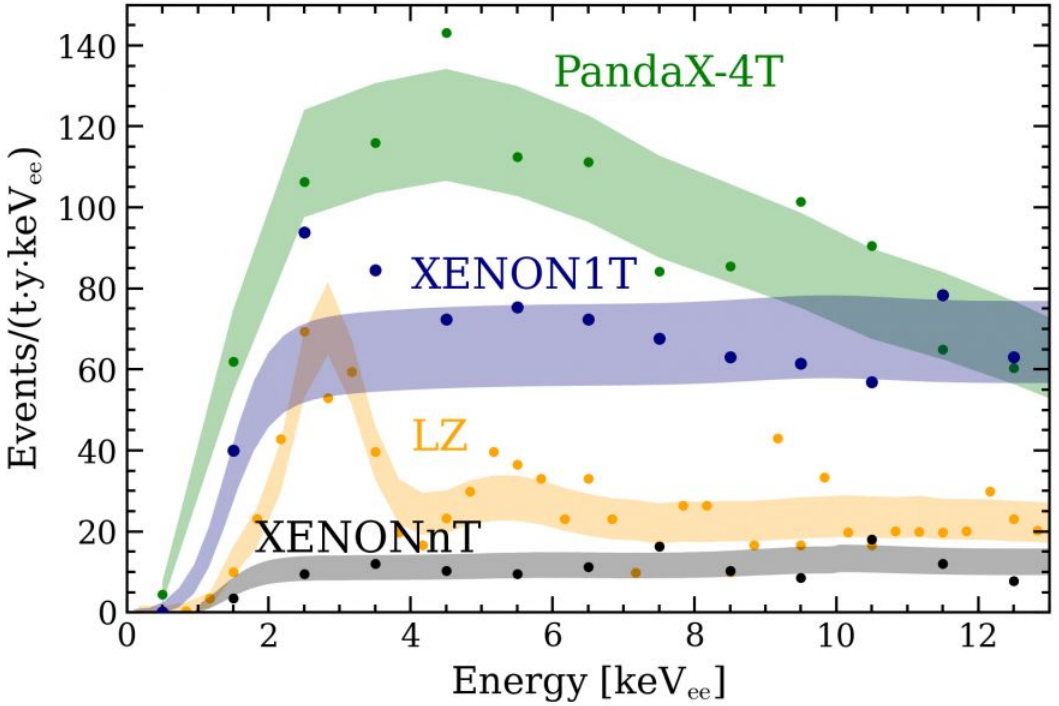
Backup - SD limit





Backup - Low ER background



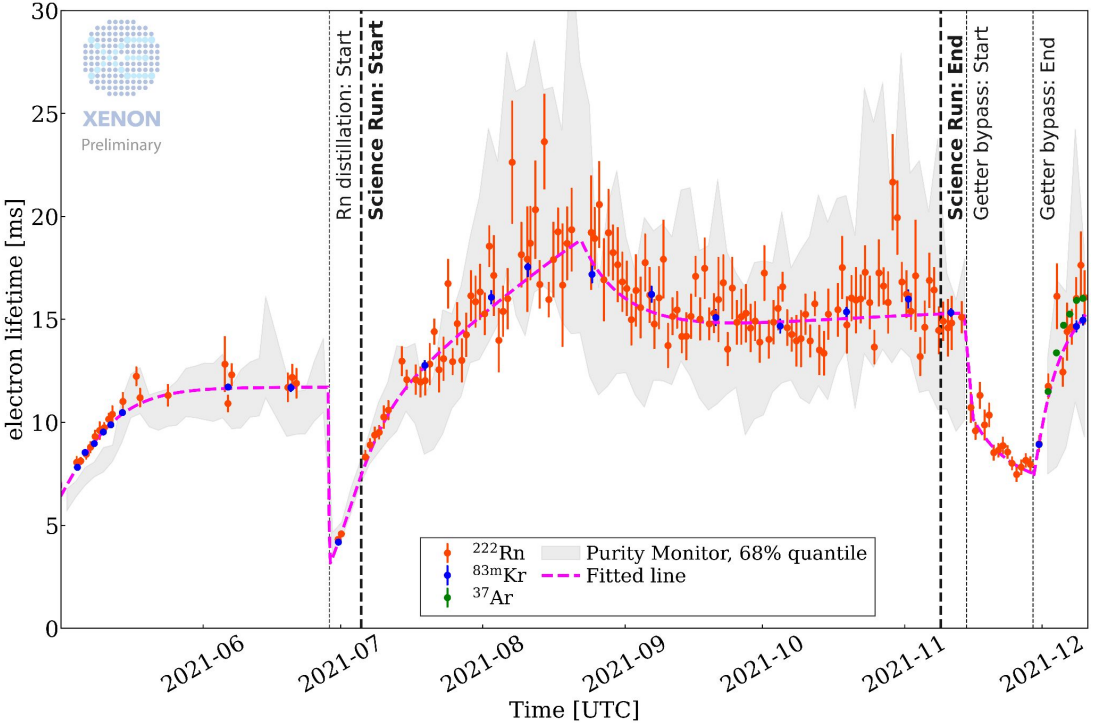
arXiv:2206.02339

arXiv:2006.09721

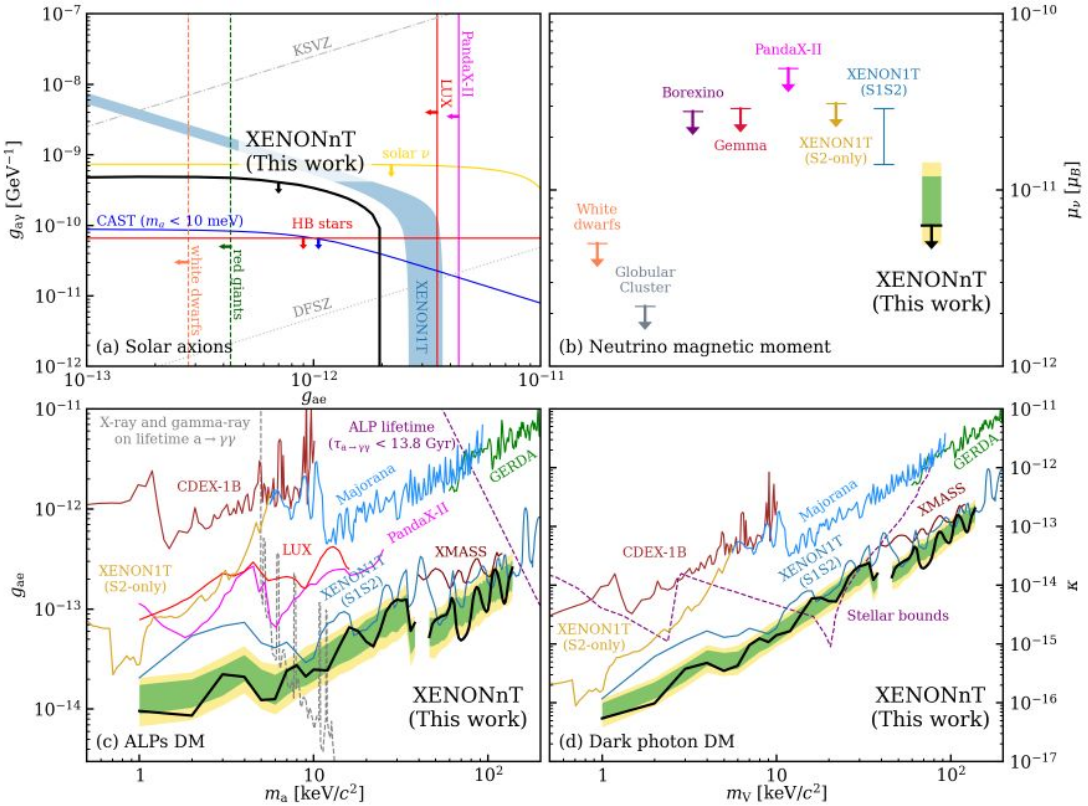
arXiv:2207.03764

arXiv:2207.11330

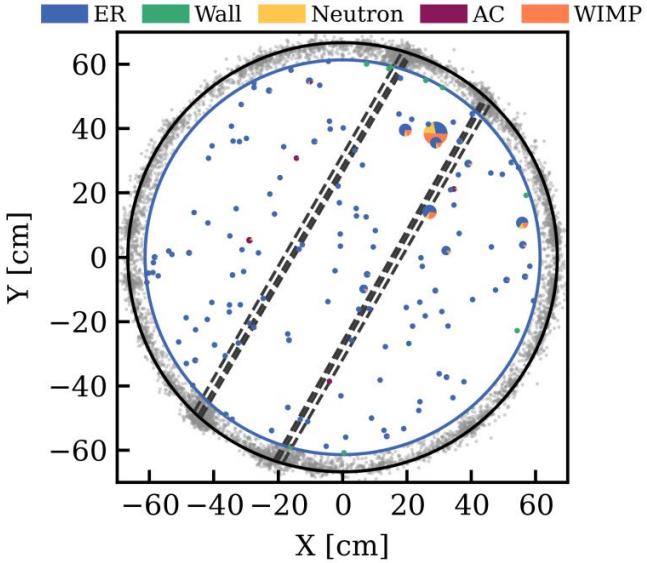
Backup - electron lifetime

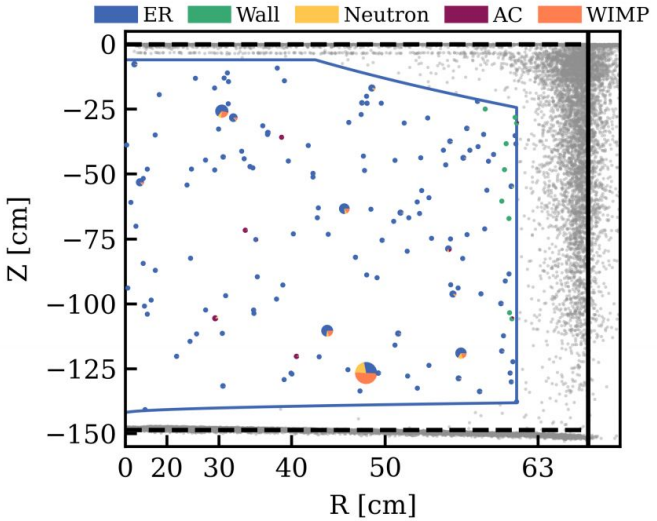


Backup - low ER new physics constraint



Backup - Event positions





Backup - peak classification