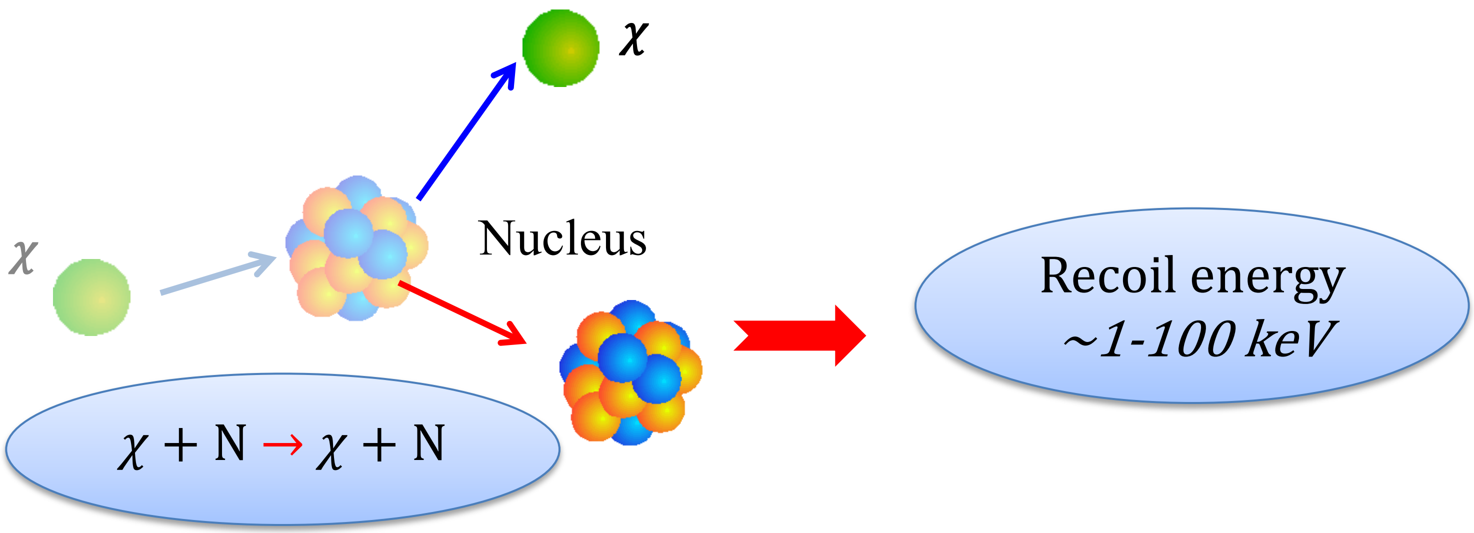
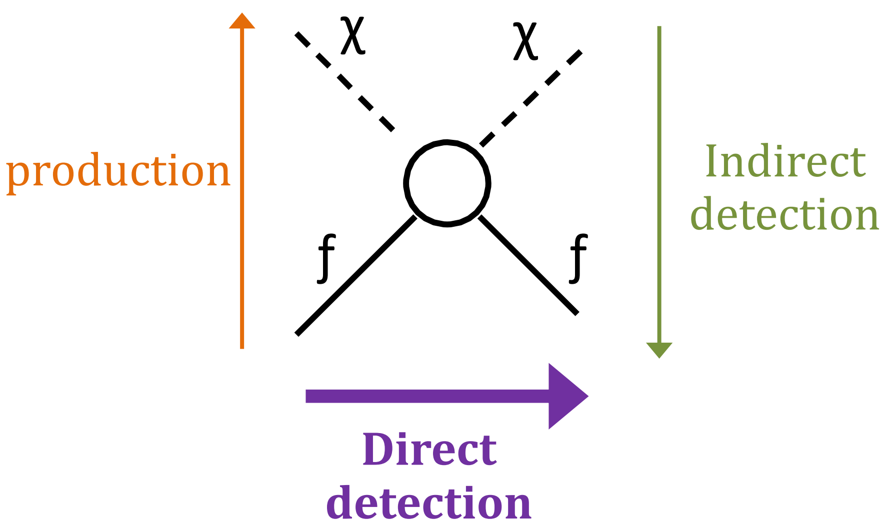
First WIMP Search Results from the XENONnT Experiment

Julien Masbou
on behalf of the XENON Collaboration
Subatech – Université de Nantes

WIMP direct detection principle

Nuclear Recoil (NR)





Electronic Recoil (ER)

γ and β particles interact with the atomic electrons
➔ Background in « standard WIMP analysis »

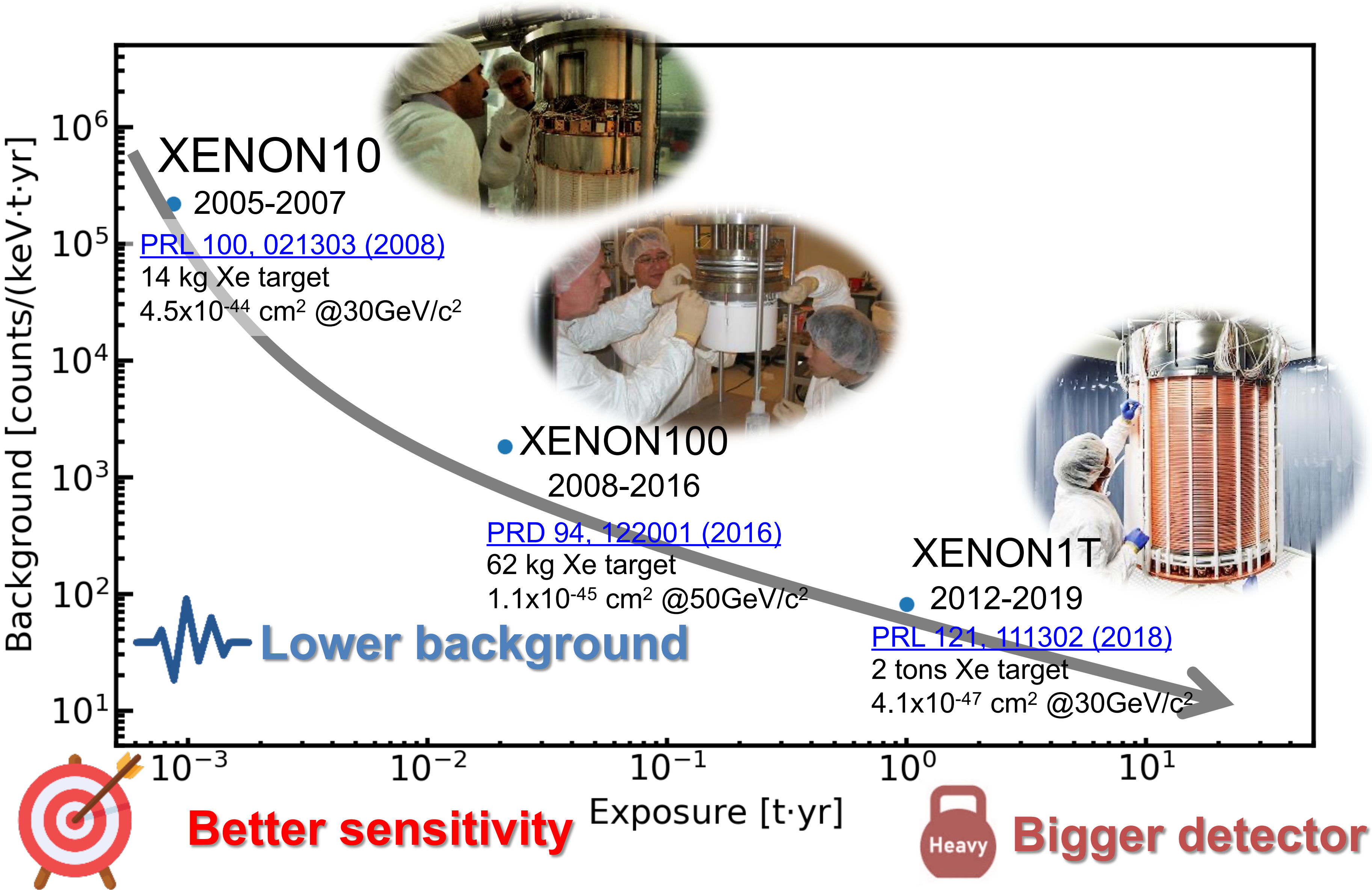
XENON Collaboration

~170 scientists

27 institutions

11 countries

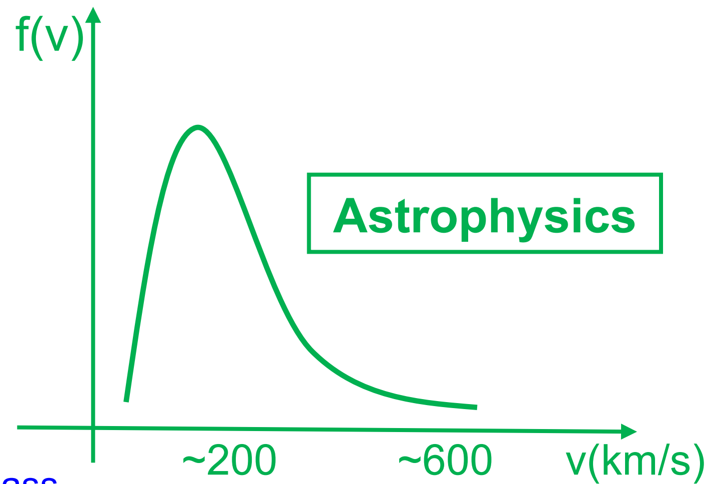
Phases of the XENON Program

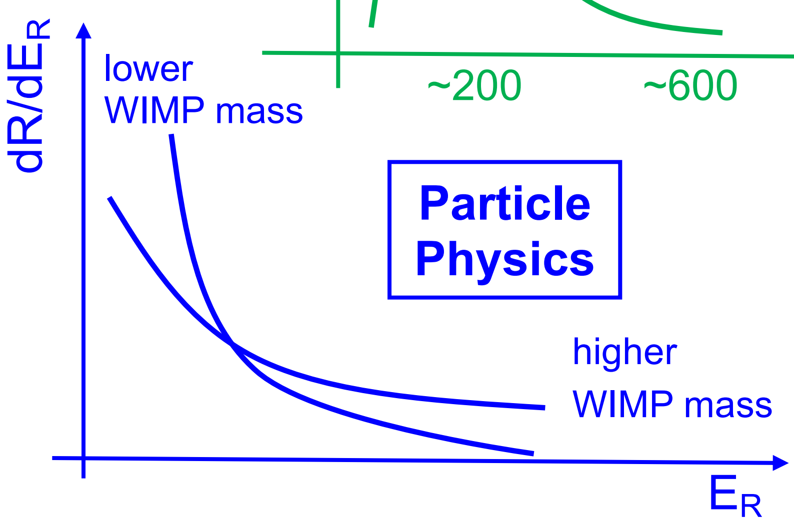


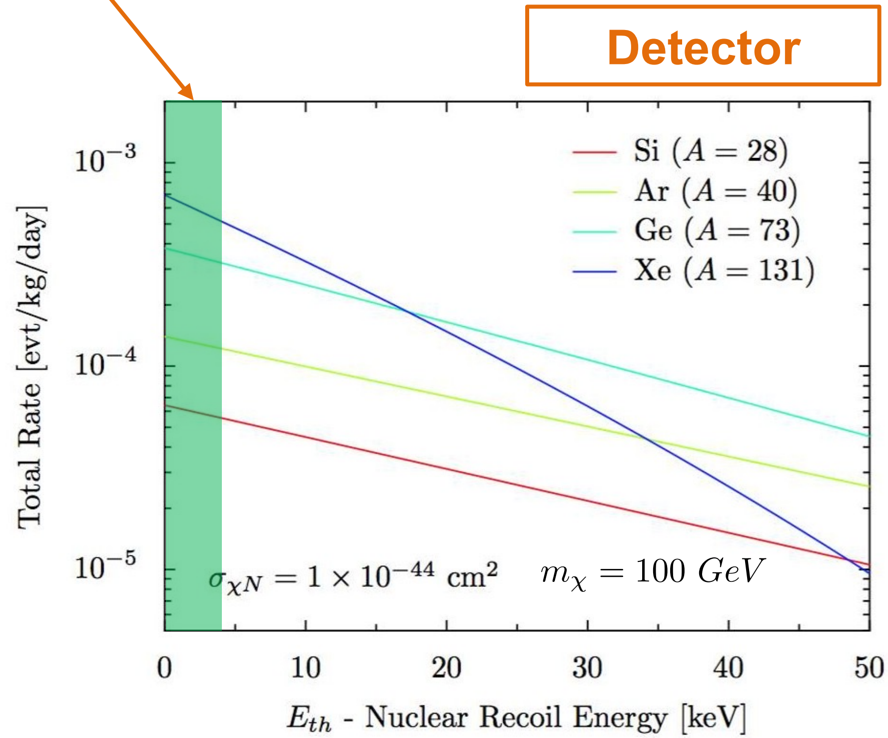
Expected rate for terrestrial detector

$$\frac{dR}{dE_R} = N_N \frac{\rho_\odot}{m_\chi} \int_{v_{min}}^{v_{max}} f(v)\, v \frac{d\sigma}{dE_R} dv$$

$$v_{min} = \sqrt{\frac{m_N E_{th}}{2\mu}}$$







Expected rate for terrestrial detector

We aim to measure:

$$\frac{dR}{dE_R} = N_N \frac{\rho_\odot}{m_\chi} \int_{v_{min}}^{v_{max}} f(v) v \frac{d\sigma}{dE_R} dv$$

with

$$\frac{d\sigma}{dE_R} = \frac{1}{E_{max}} \left(\sigma_{SI} F_{SI}^2 + \sigma_{SD} F_{SD}^2\right)$$

Spin-independent
scales like A^2

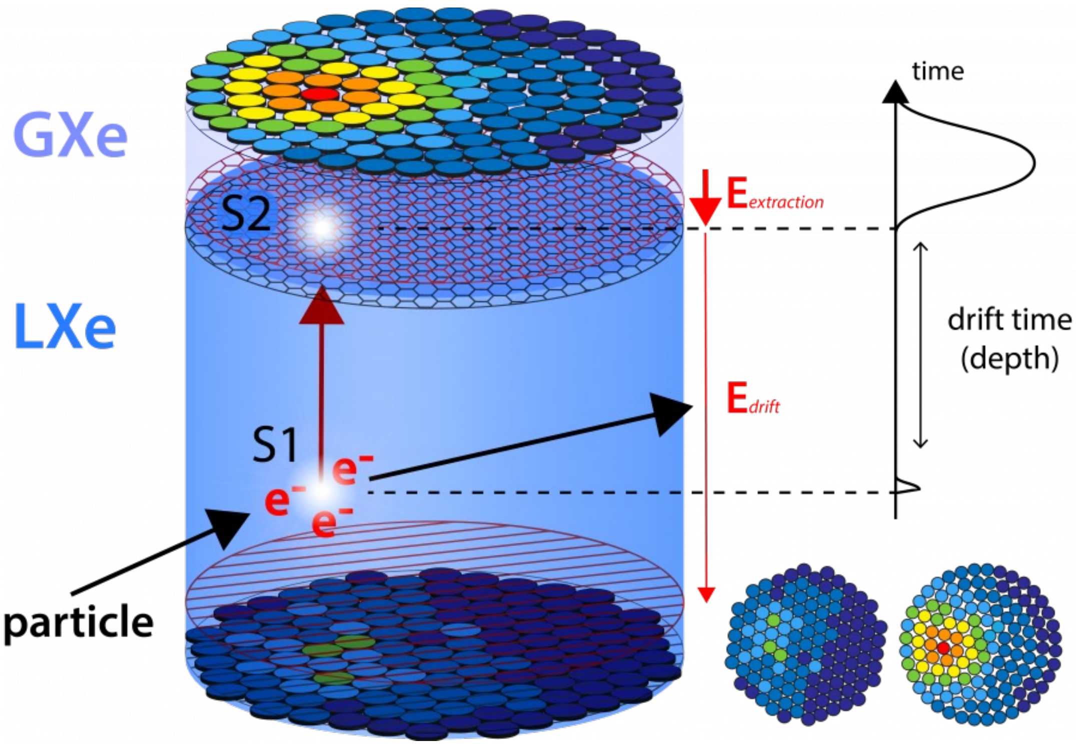
Spin-dependent
needs nuclei with non-zero spin

^{129}Xe (spin-1/2) , 26.4% n.a.

^{131}Xe (spin-3/2), 21.2% n.a.

Dual phase TPC: principle

TPC = Time Projection Chamber

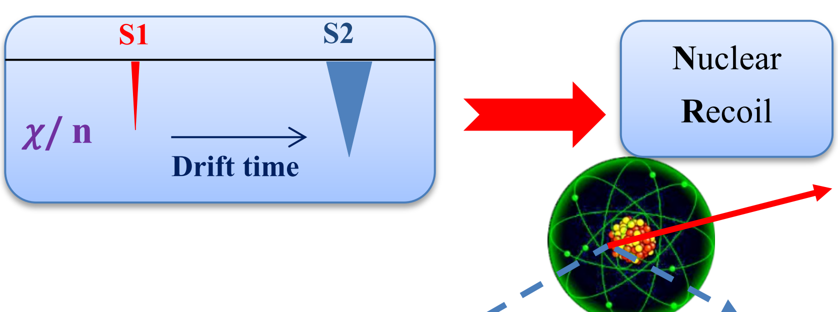


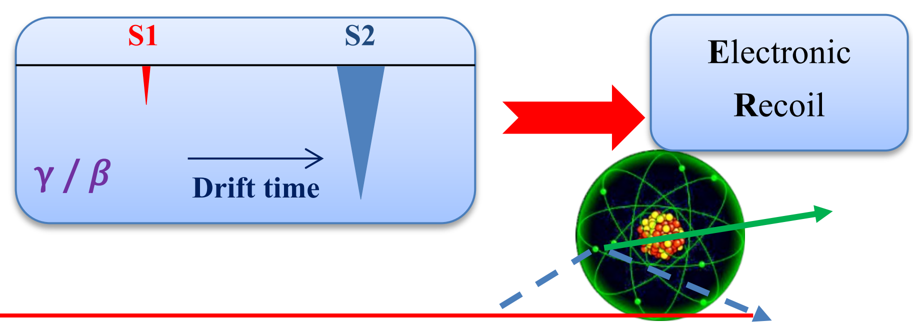
S1:
→ Photon (λ = 178 nm) from Scintillation process

S2:
→ Electrons drift
→ Extraction in gaseous phase
→ Proportional scintillation light

3D reconstruction :
→ X,Y from top array
→ Z from Drift time

$$(S2/S1)_{WIMP,n} < (S2/S1)_{\gamma,\beta}$$





From XENON1T to XENONnT

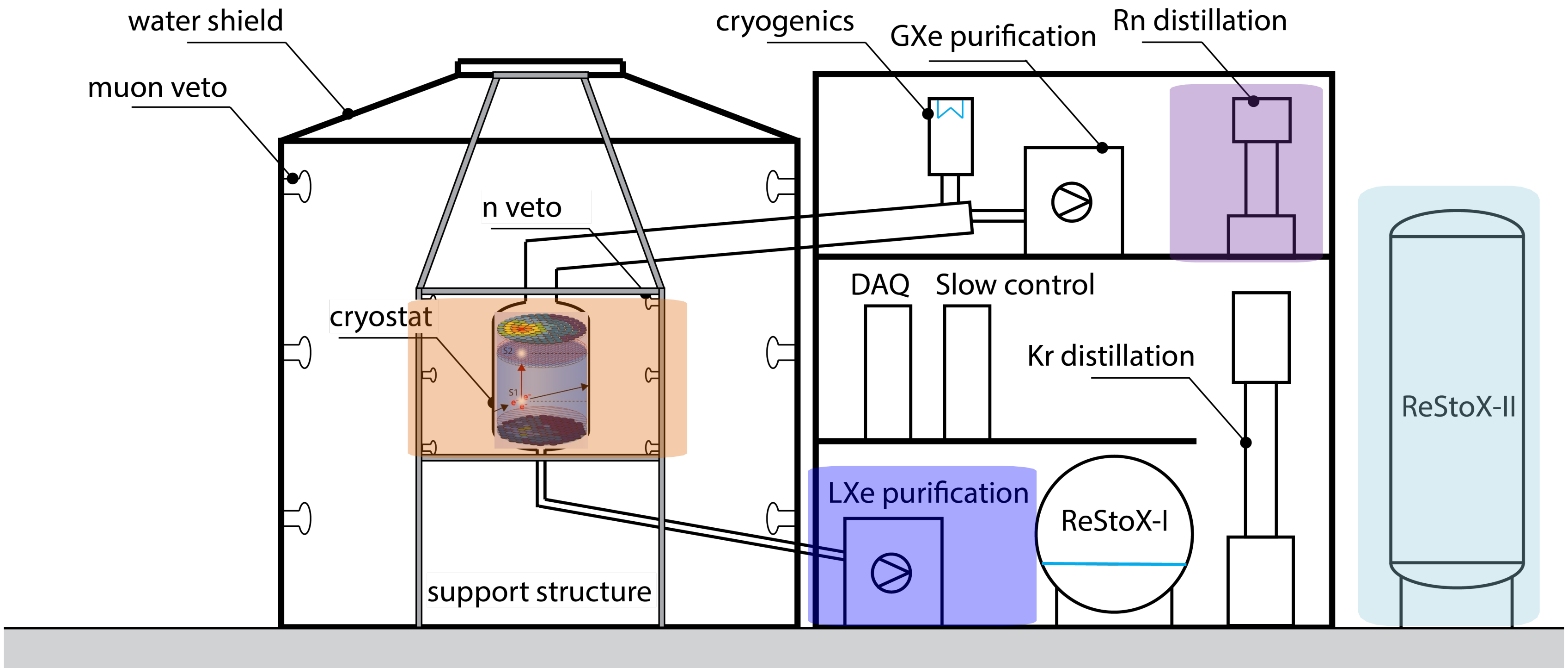
+ Reused much of the XENON1T infrastructure
+ Larger TPC: 2 t → 5.9 t LXe (active target)
+ Improved cleanliness and radiopurity
+ Liquid xenon purification system
+ Radon distillation system
+ Water Cherenkov neutron-veto
+ New calibration systems and techniques
+ Triggerless DAQ
+ 2nd Recovery & Storage system

XENON, arXiv:2112.05629

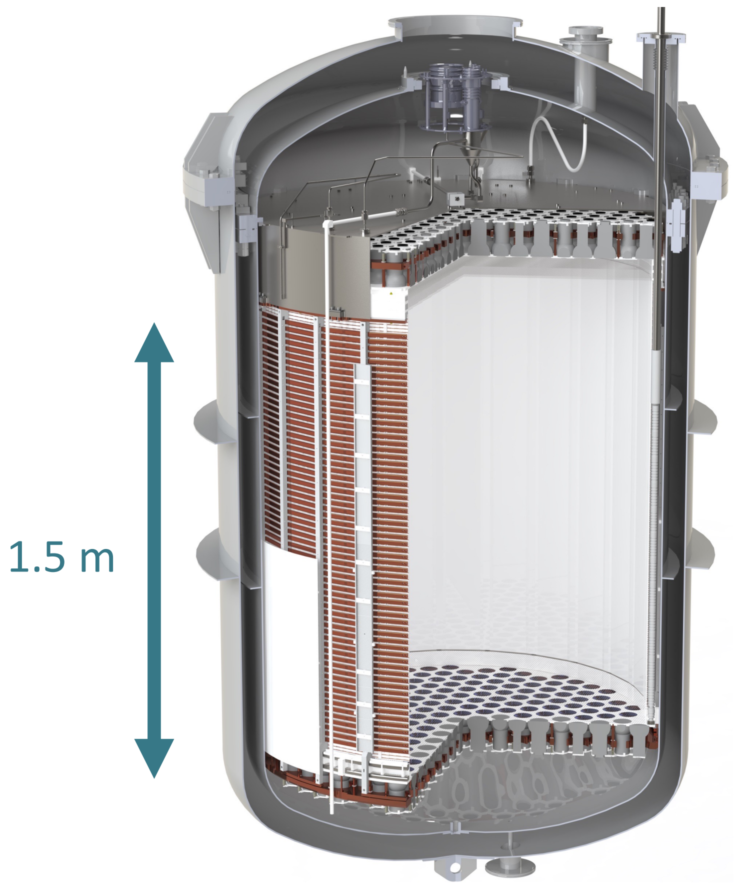
Plante et al, arXiv:2205.07336

Murra et al, arXiv:2205.11492

XENON, arXiv:2212.11032

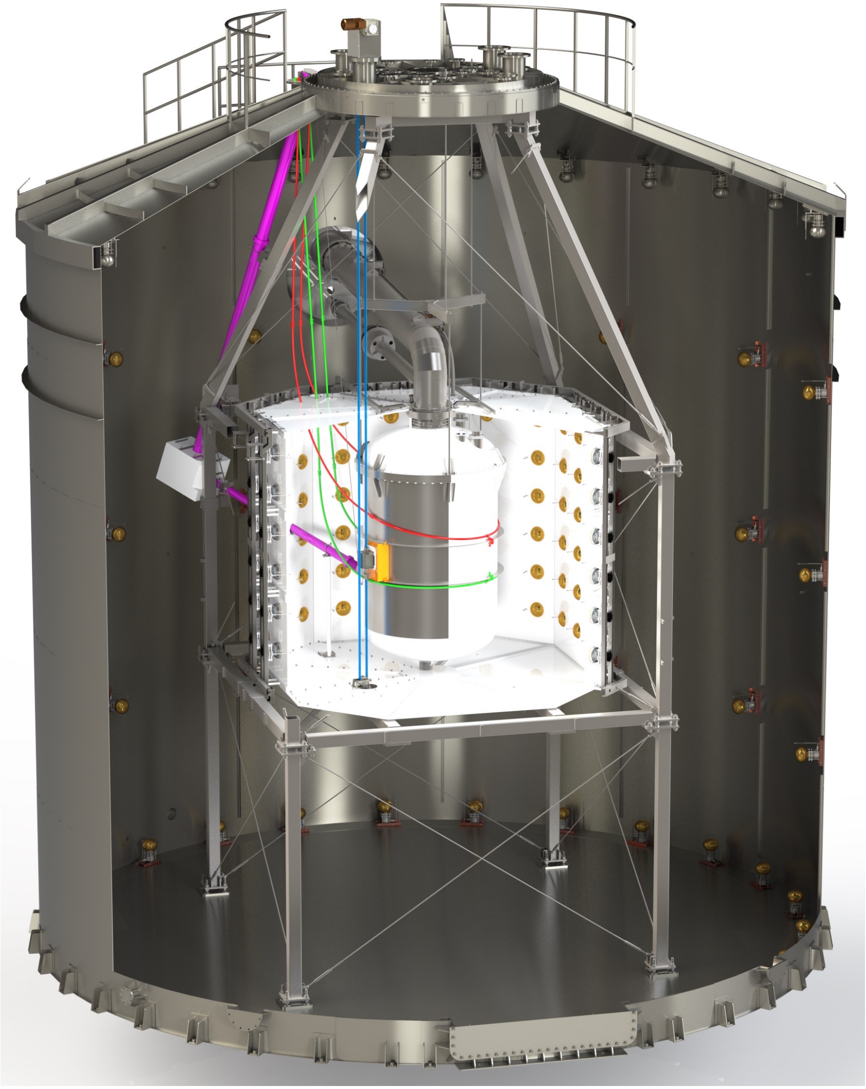


XENONnT Time Projection Chamber



- 8.5 t of LXe total, 5.9 t in target
- 494 3-inch Hamamatsu R11410-3 PMTs
- 3 electrodes for drift and extraction fields
- 2 additional electrodes for PMT shielding

XENONnT Time Projection Chamber

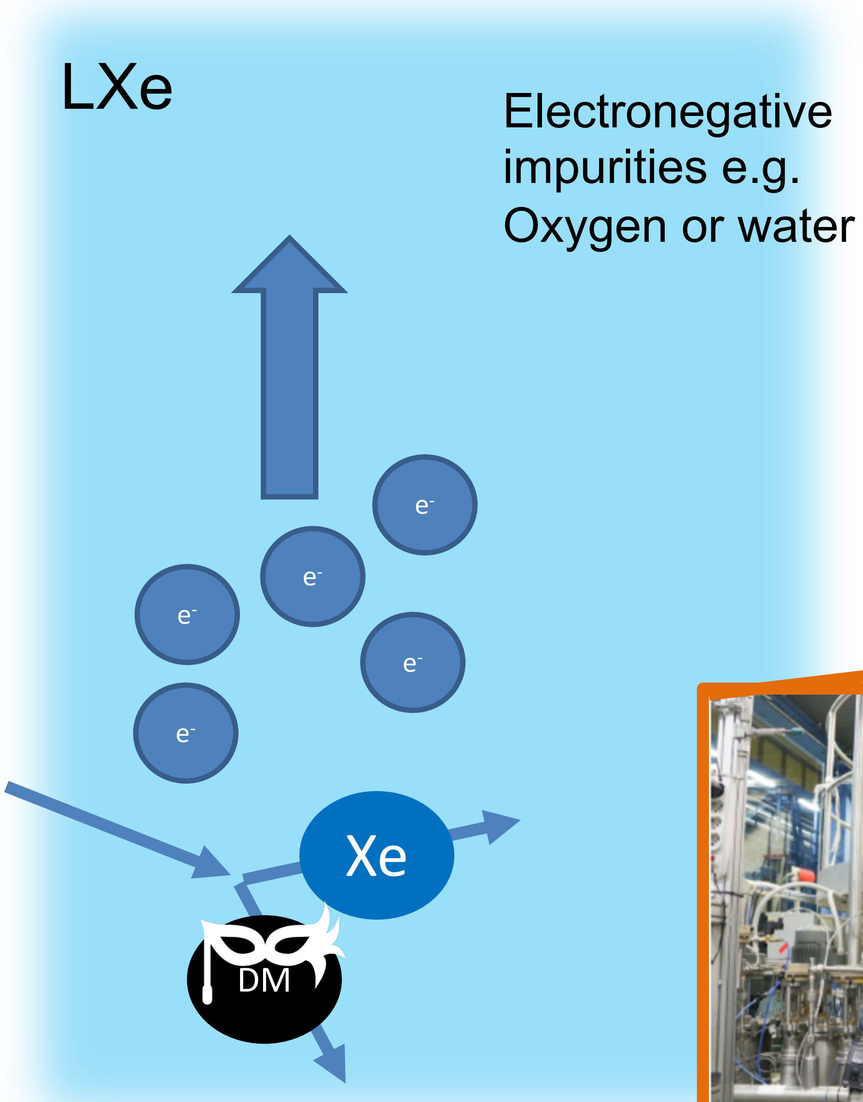


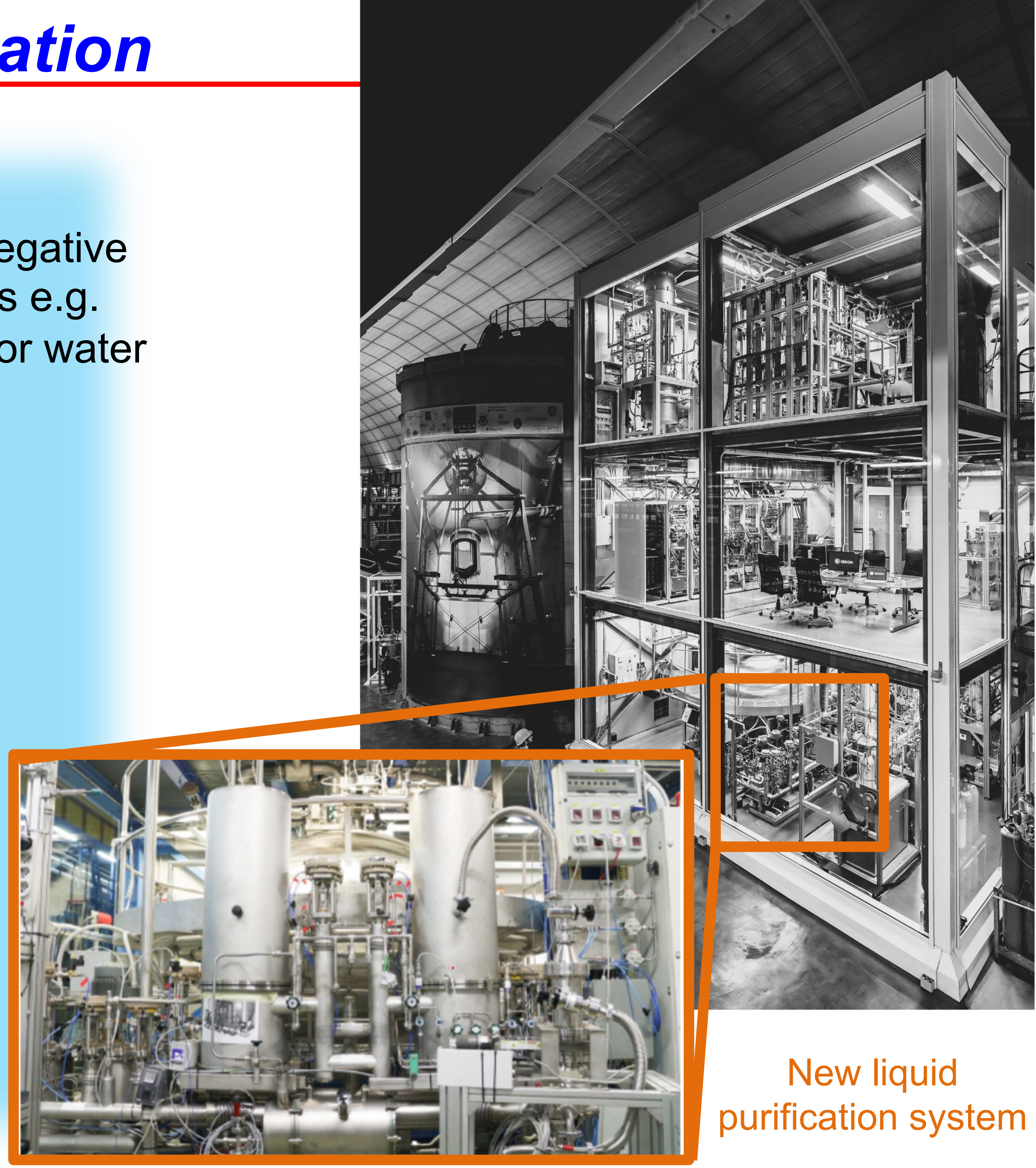
Calibration of detector response and efficiency:

- Internal sources:
  ^{37}Ar, ^{83m}Kr, ^{129m}Xe, ^{131m}Xe, ^{220}Rn

- External sources:
  AmBe, Th

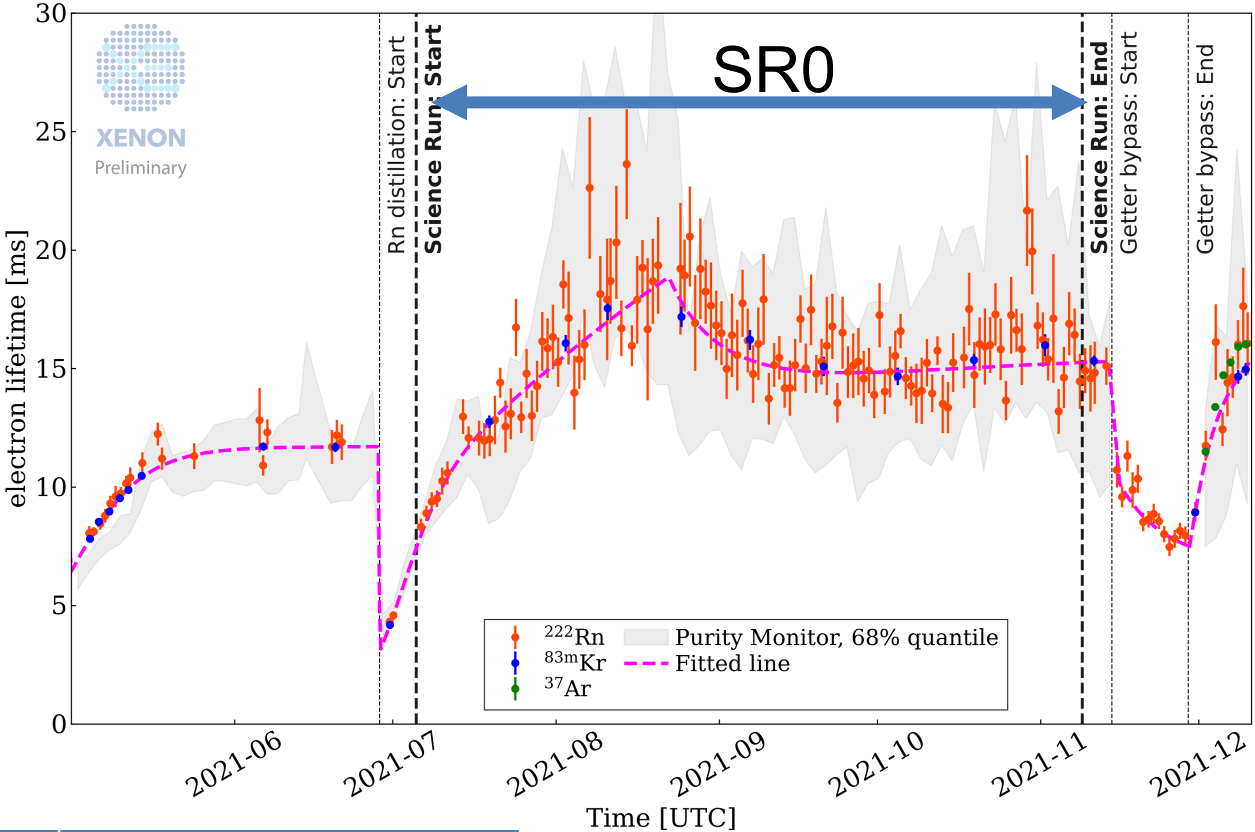
Liquid xenon purification





New liquid purification system

Liquid xenon purification



	Full drift time:	Electron lifetime:	Electron survival (@full drift length):
1T	0.67 ms	0.65 ms	30 %
nT	2.2 ms	**~15 ms**	**86 % @ 15 ms**

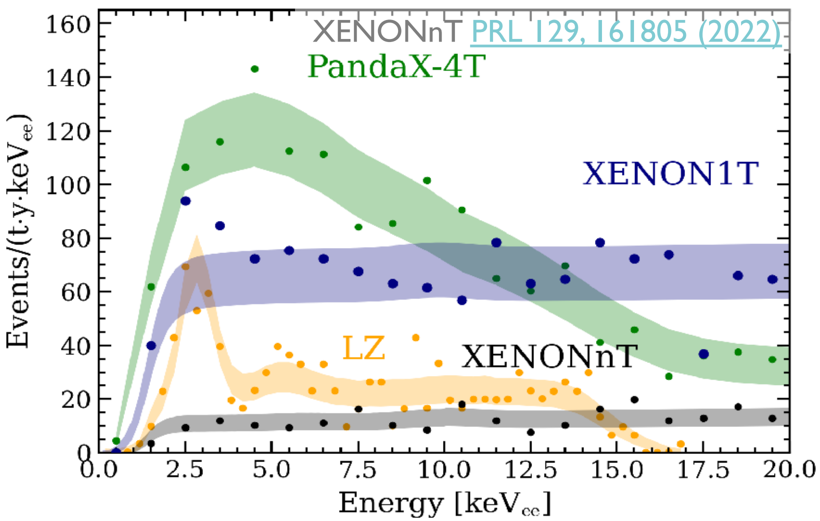
Background Mitigation

Background from intrinsic radioactive isotopes:

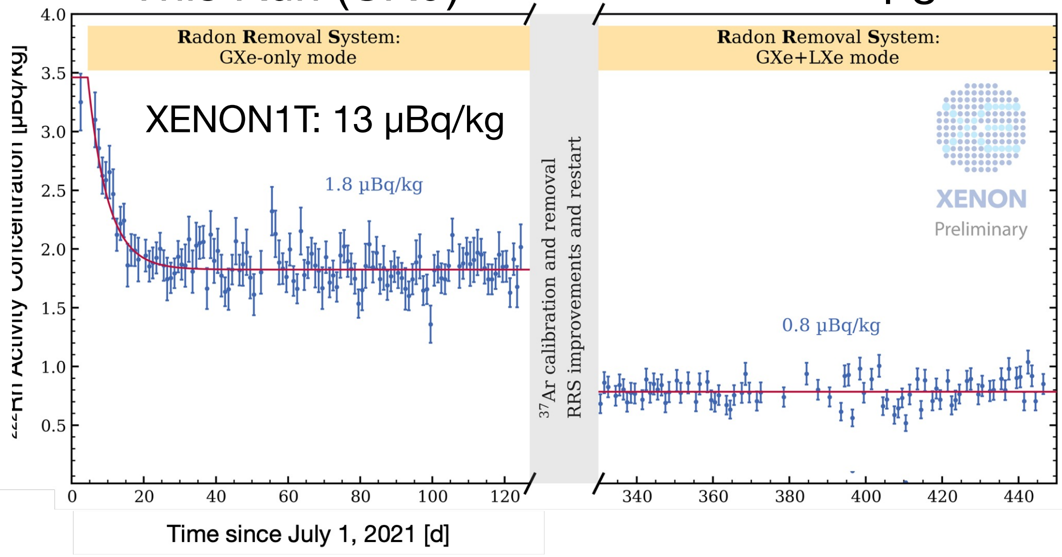
- ^{214}Pb (^{222}Rn daughter)
- ^{85}Kr

Careful screening, material selection and Continuous Radon Removal through distillation

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



This Run (SR0)
After recent upgrades

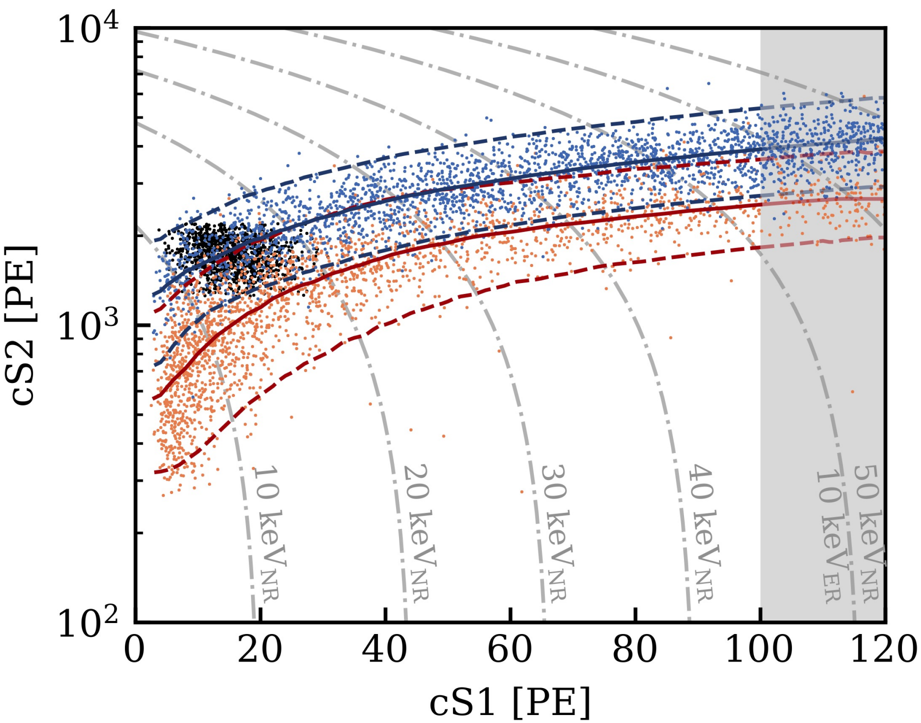


(15.8 ± 1.3) events / (keV × t × yr)

XENON, PRL 120, 161805 (2022)

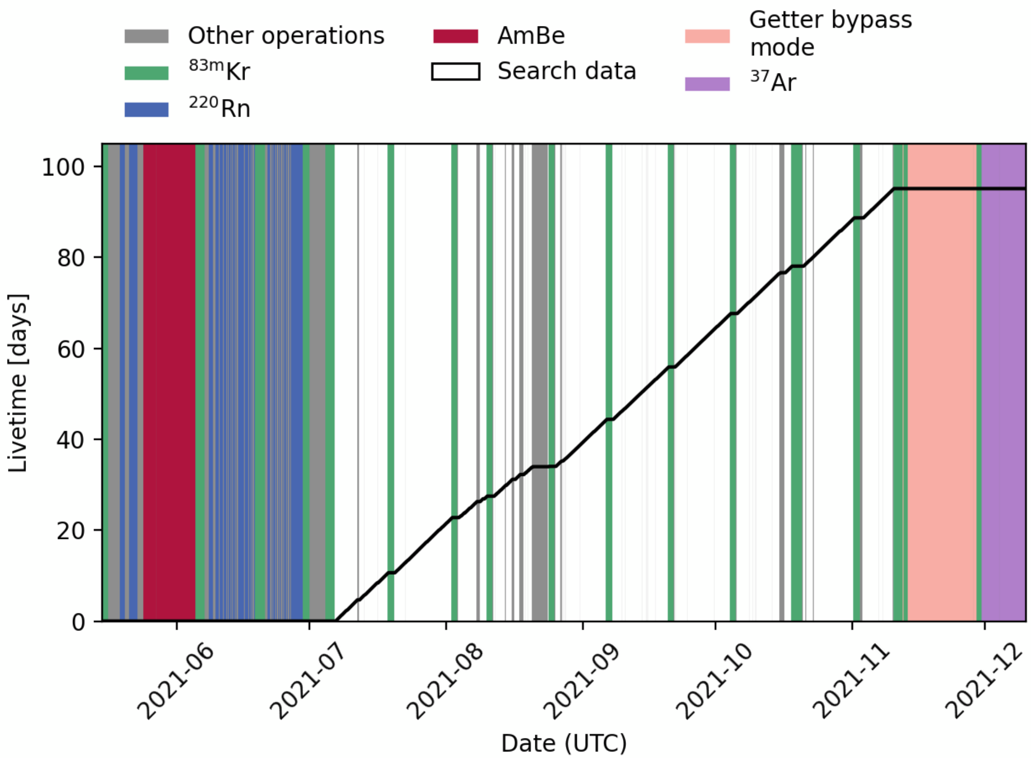
Background ~5x smaller than in XENON1T

Calibration of ER / NR Response



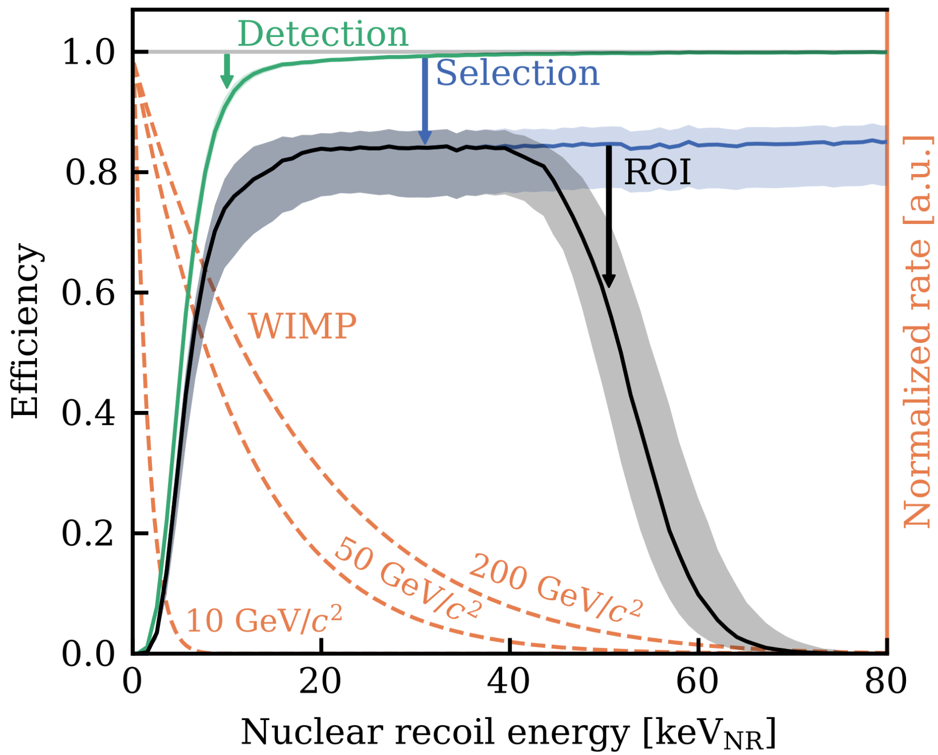
- **Calibration of ER** response using ^{220}Rn
  - Gives approximately flat energy spectrum
  - Used to validate cut acceptance
- Detector performance at low energy with ^{37}Ar
  - Mono-energetic line at 2.8 keV
  - High statistics
  - Removed via distillation column ($T_{1/2}$ = 35 d)
- **Calibration of NR** response with AmBe
- ER model based on combined fit
- Uncertainties propagated via Principal Component Analysis

Data Set: Science Run 0



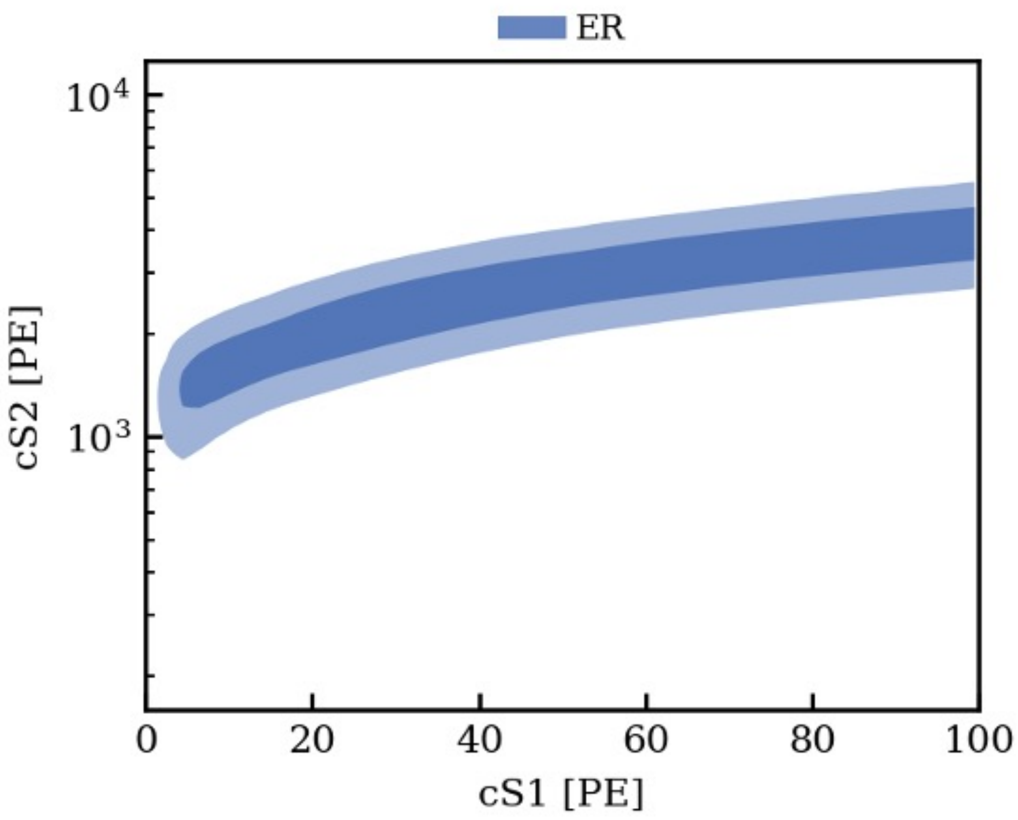
- SR0 Nuclear Recoil Search Data
- July 6 to Nov 10, 2021 (97.1 days)
- 95.1 days lifetime corrected
- (4.18 ± 0.13) tonne Fiducial Volume
- Exposure: **1.1 tonne x year**
- **Blind analysis**

Efficiency



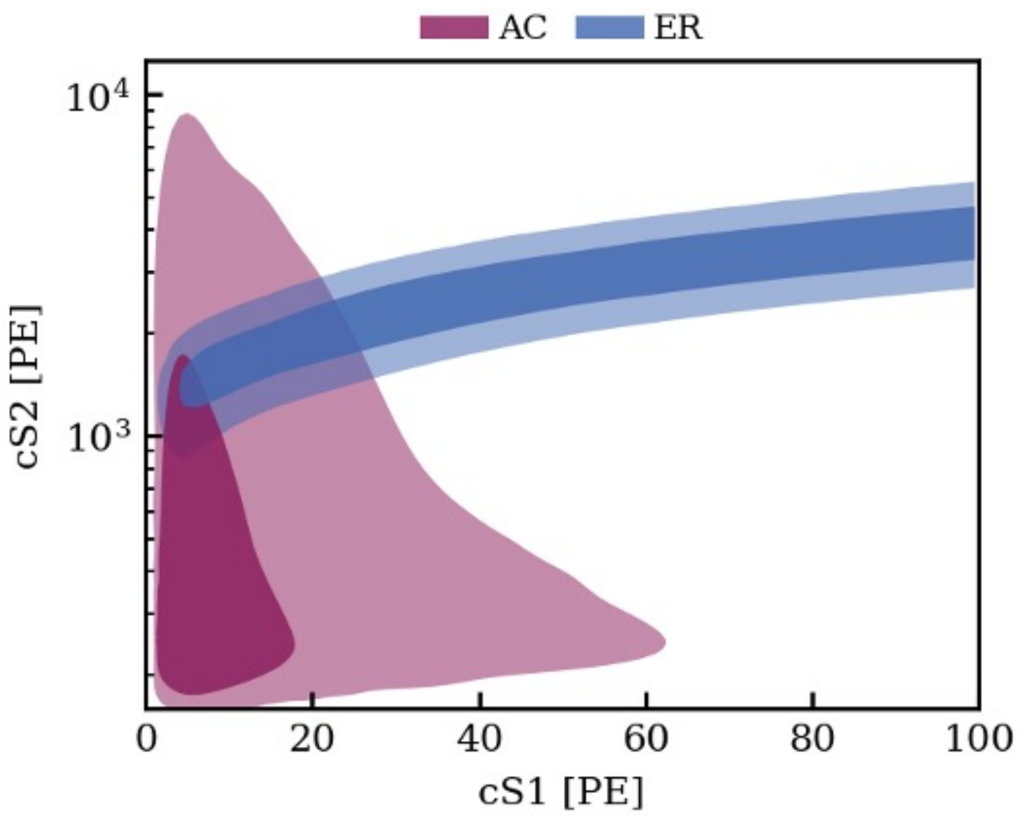
- Detection efficiency:
  - Threshold driven by 3-fold PMT coincidence for S1
  - Full waveform simulation
  - Data-driven methods from ^{83m}Kr and ^{37}Ar
- Data quality selection evaluated with calibration data
- ROI defined to fully contain WIMP spectra
  - cS1 [0 pe, 100 pe]
  - cS2 [$10^{2.1}$ pe, $10^{4.1}$ pe]
- Total acceptance > 10% for [3 keV$_{NR}$, 60 keV$_{NR}$]

Backgrounds



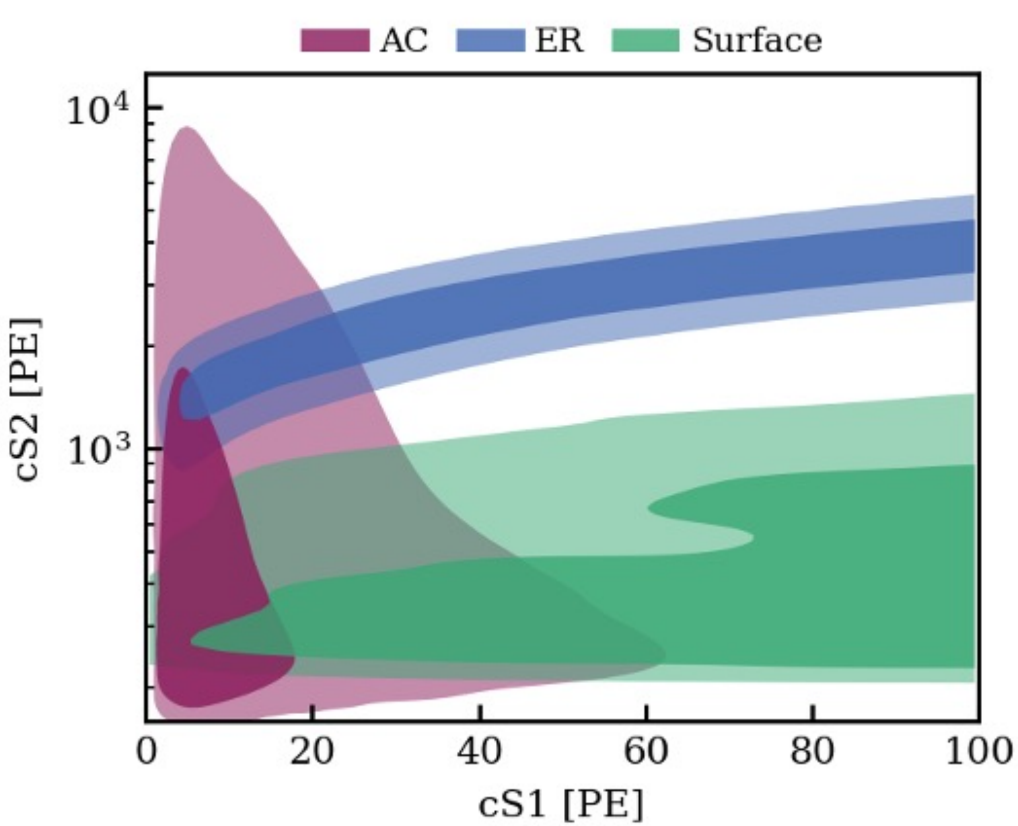
- Electronic Recoil (ER): Dominated by beta decay of ^{214}Pb from ^{222}Rn

Backgrounds



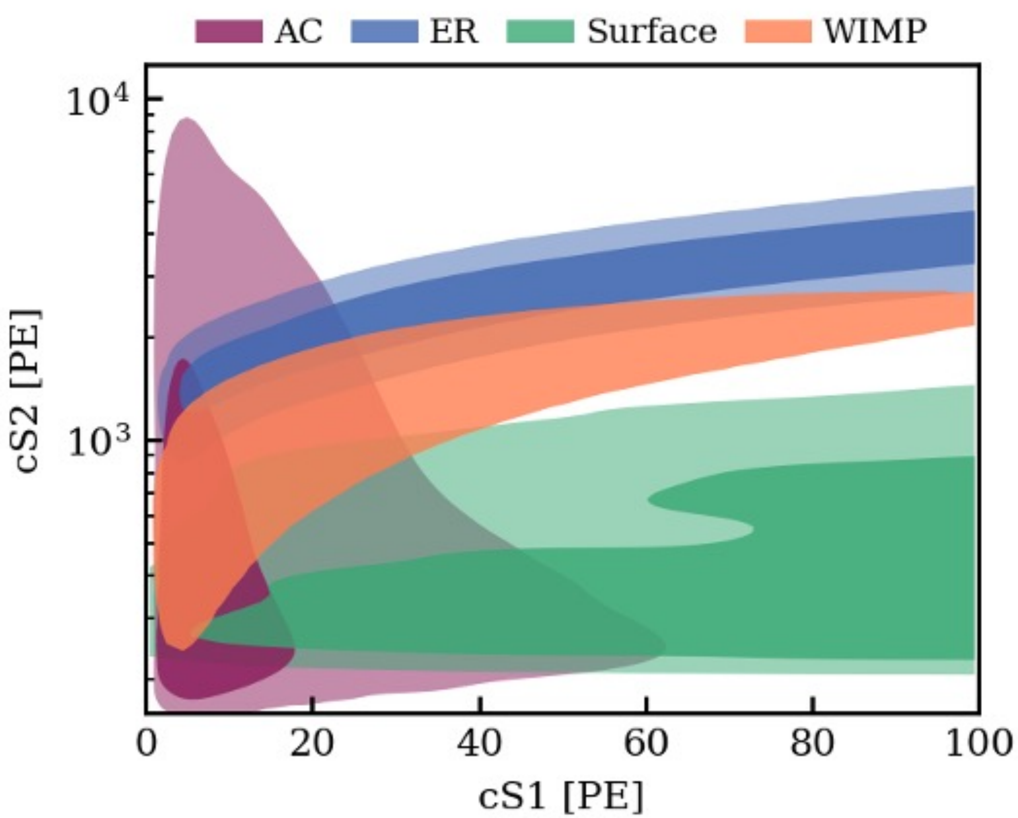
- Electronic Recoil (ER): Dominated by beta decay of ^{214}Pb from ^{222}Rn
- Accidental Coincidences (AC): random pairing of small S1 and S2 signals

Backgrounds



- Electronic Recoil (ER): Dominated by beta 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 → ^{210}Po α-decays

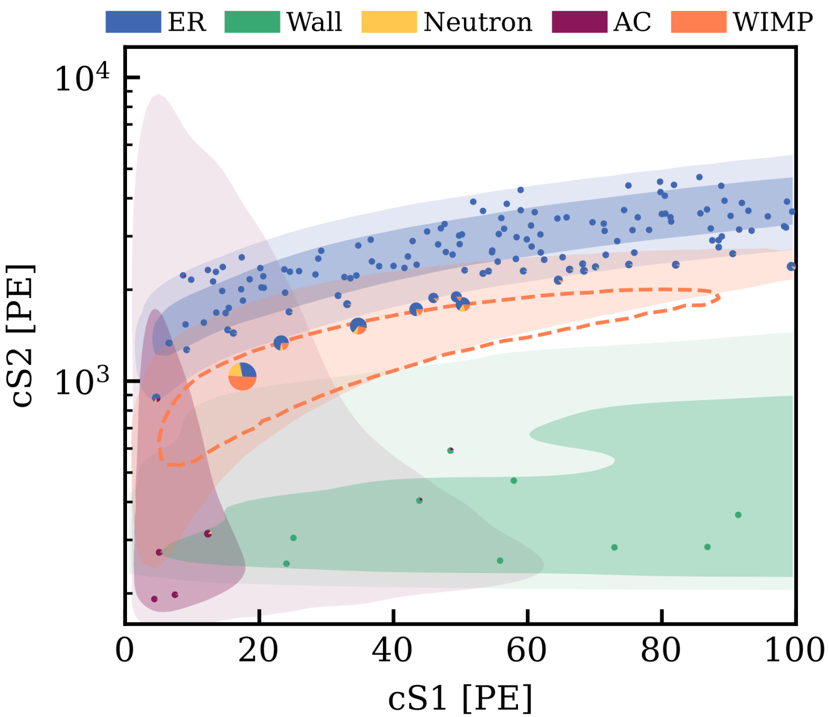
Backgrounds



- Electronic Recoil (ER): Dominated by beta 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 → ^{210}Po α-decays
- Nuclear Recoil backgrounds:
  - o CEvNS
  - o Neutrons

WIMP Results

	Expectation	Best Fit	
	ROI		Signal-like
ER	134	135^{+12}_{-11}	0.81 ± 0.07
Neutrons	$1.1^{+0.6}_{-0.5}$	1.1 ± 0.2	0.42 ± 0.10
CEvNS	0.23 ± 0.06	0.23 ± 0.06	0.022 ± 0.011
AC	4.3 ± 0.2	4.32 ± 0.15	0.363 ± 0.013
Wall	14 ± 3	12^{+0}_{-4}	$0.34^{+0.01}_{-0.11}$
Total	154	152 ± 12	$1.95^{+0.12}_{-0.16}$
WIMP		2.4*)	1.2*)
Observed		152	3



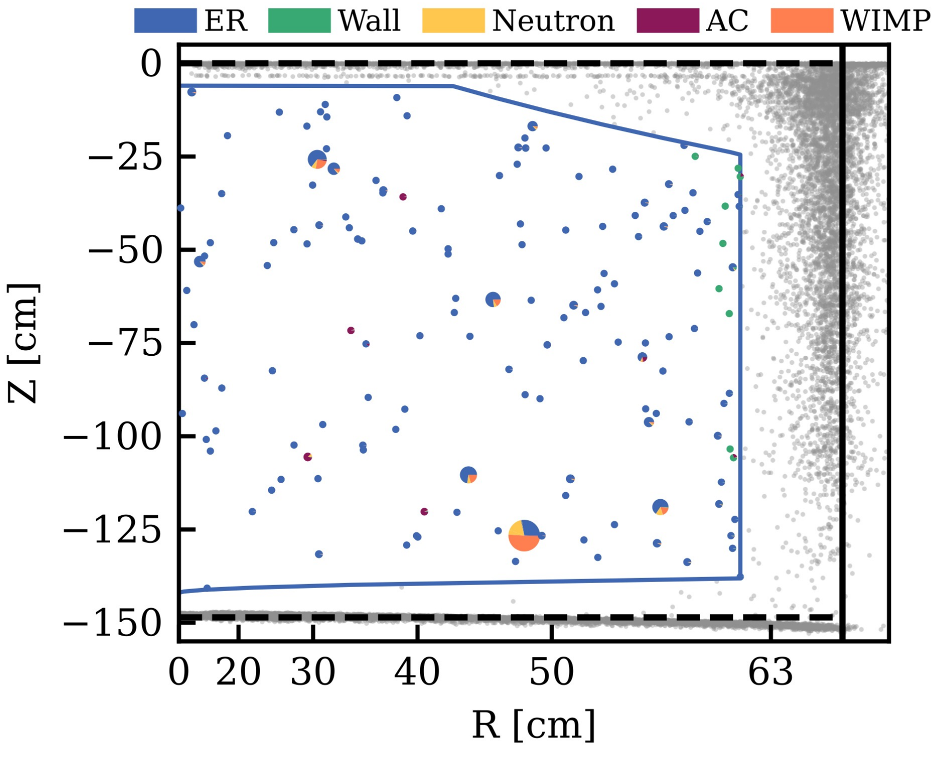
*) Assuming a 200 GeV WIMP and a best-fit σ = 2.5 × 10^{-47} cm^2

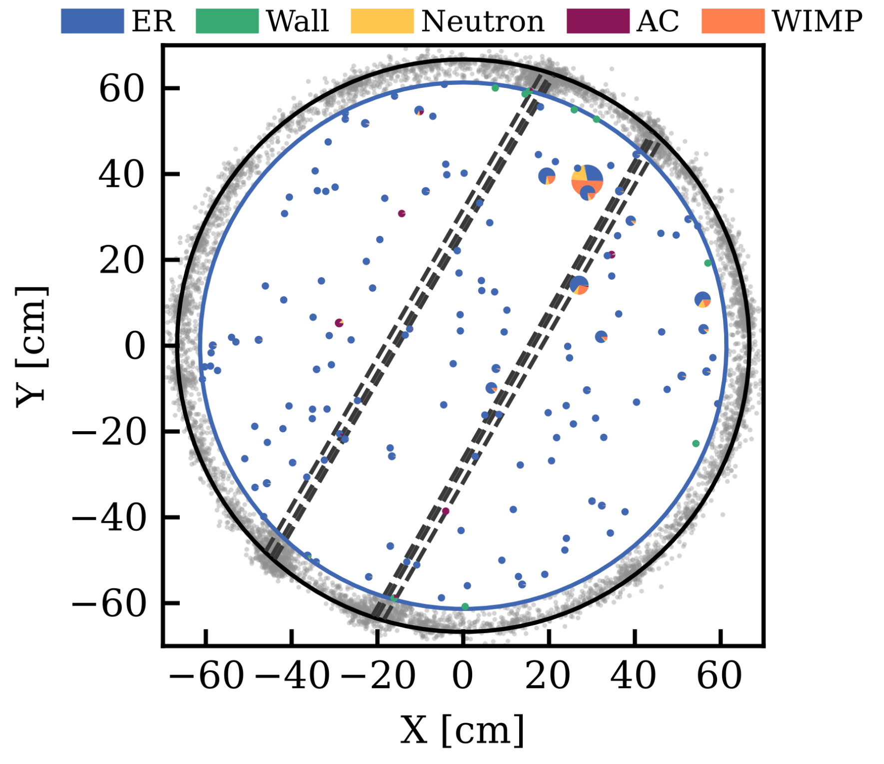
152 events in ROI, 16 in blinded region

Best fit indicates no significant excess

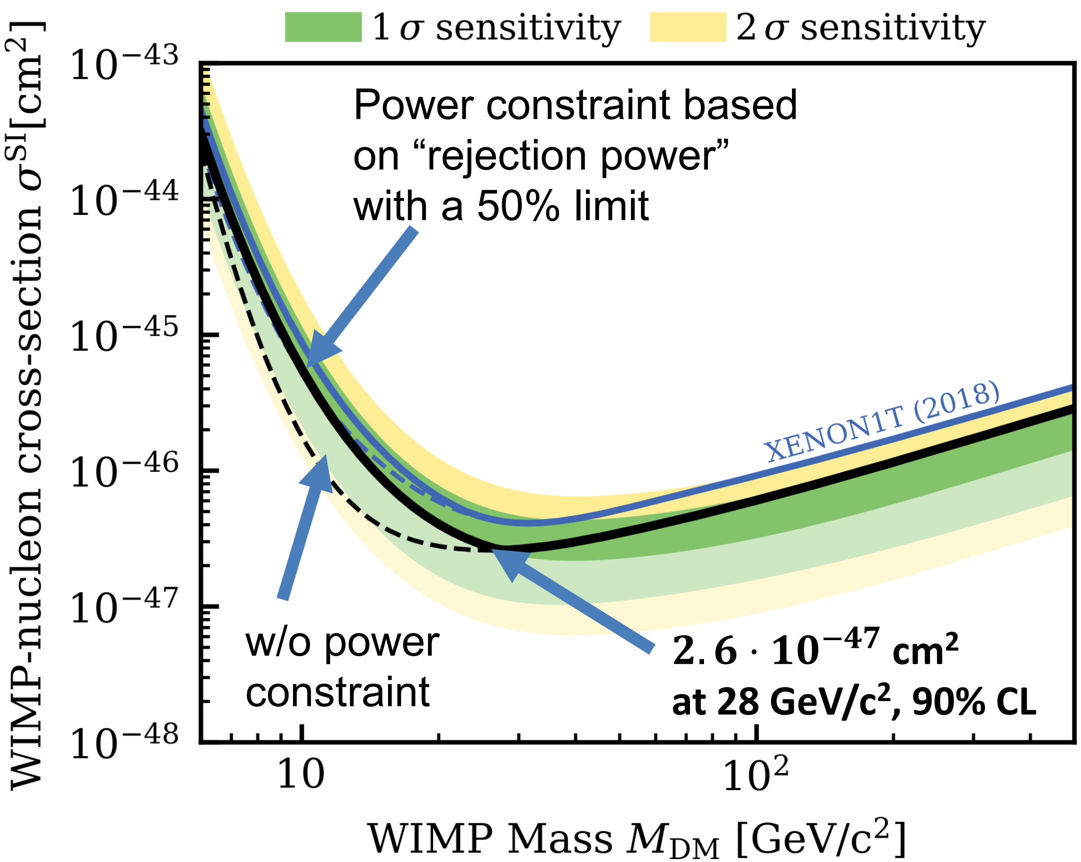
WIMP Results

- XY asymmetry in unblinded data
- Not observed in corrections, quality selection or calibration data





WIMP Spin-Independent Results



Blinded analyses

XENON, PRL 121, 111302 (2018)

XENONnT 90% C.L. Power-Constrained Limit*

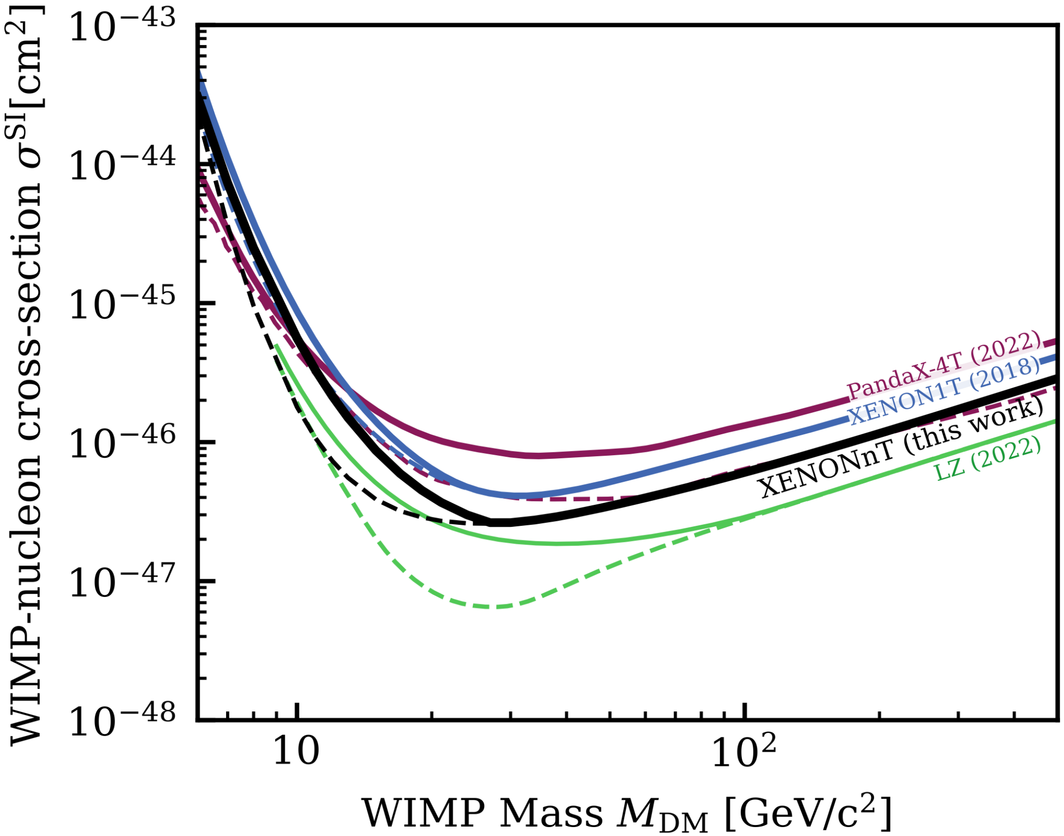
Sensitivity improvment of ~1.6

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

arXiv: 2303.14729

WIMP Spin-Independent Results

Unblinded analyses



PandaX-4T, PRL 127, 261802 (2021)

XENON, PRL 121, 111302 (2018)

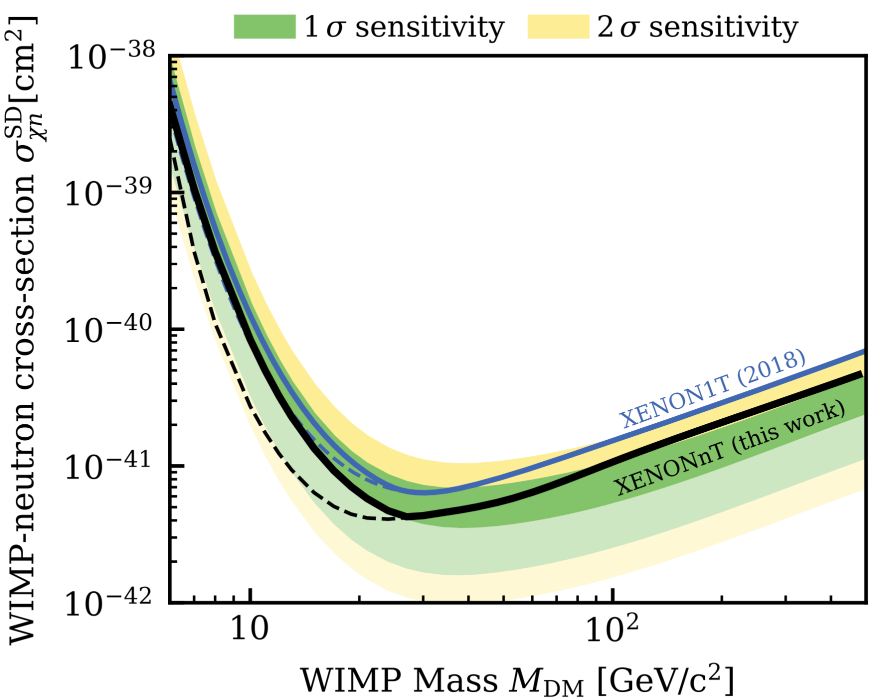
LZ, arXiv:2207.03764

arXiv: 2303.14729

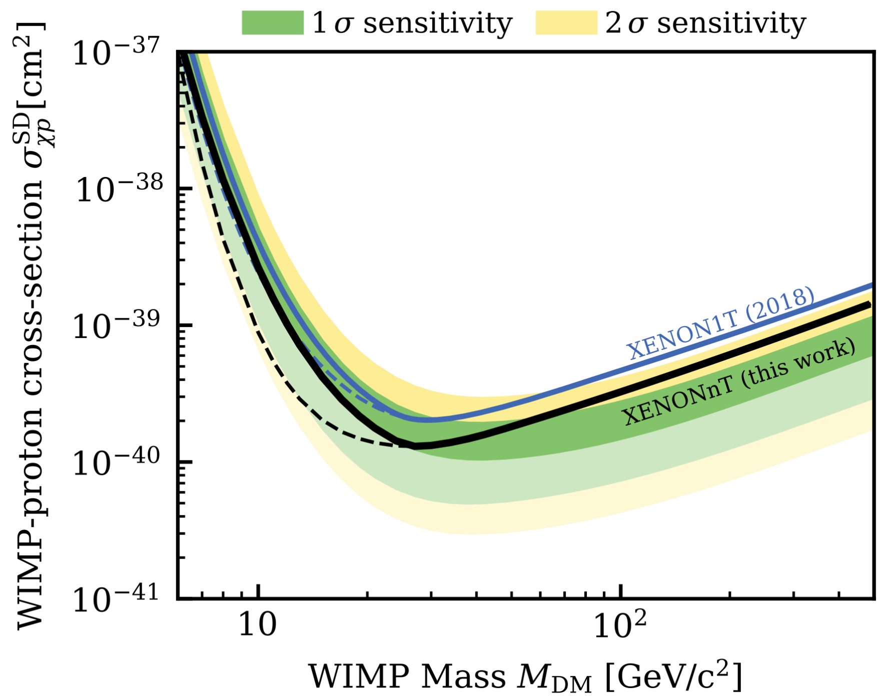
WIMP Spin-Dependent Results

Reinterpreting results as a purely spin-dependent coupling to ^{129}Xe and ^{131}Xe

WIMP - neutron coupling



WIMP - proton coupling



arXiv: 2303.14729

Conclusions

- Results from a blinded Dark Matter search with 1.1 tonne-year exposure
- Unprecedented low ER background rate of (15.8 ± 1.3) events / (keV $\times$ t $\times$ yr)
  - Further reduction with GXe + LXe radon distillation
- Spin-independent limit of 2.6×10^{-47} cm^2 (90% C.L.) at 28 GeV/c^2
- Data taking ongoing with improved ER background
- Neutron veto will be loaded with Gd-sulfate octahydrate to increase neutron detection efficiency

https://xenonexperiment.org

arXiv: 2303.14729