First WIMP dark matter search results from XENONnT

Zihao Xu
On behalf of the XENON collaboration
Columbia University, New York City
TAUP Aug 28th 2023, Vienna

Other XENON talks and posters

Parallel talks:

- **Radon emanation suppression by surface coating**, Hardy Simgen, 28 Aug 6:15 PM [2]
- **Search for solar ^{8}B neutrinos with XENONnT**, Christian Wittweg, 29 Aug 2:00 PM [1]
- **Exploring New Physics up to the MeV energy scale with XENONnT**, Maxime Pierre, 29 Aug 2:15 PM [1]
- **XENONnT experiment and Machine Learning**, Christopher Tunnel, 29 Aug 5:15 PM [2]

Posters:

- **Krypton Removal for the XENON Dark Matter Project**, Johanna Jakob
- **Searching for Heavy Dark Matter near the Planck Mass with XENON1T**, Shengchao Li
- **XENONnT Radon Removal System**, David Koke
- **The physics-driven surface background model for XENONnT**, Cecilia Ferrari
- **Ultra-clean four cylinder magnetically-coupled piston pump for noble gas experiments**, Andria Michael

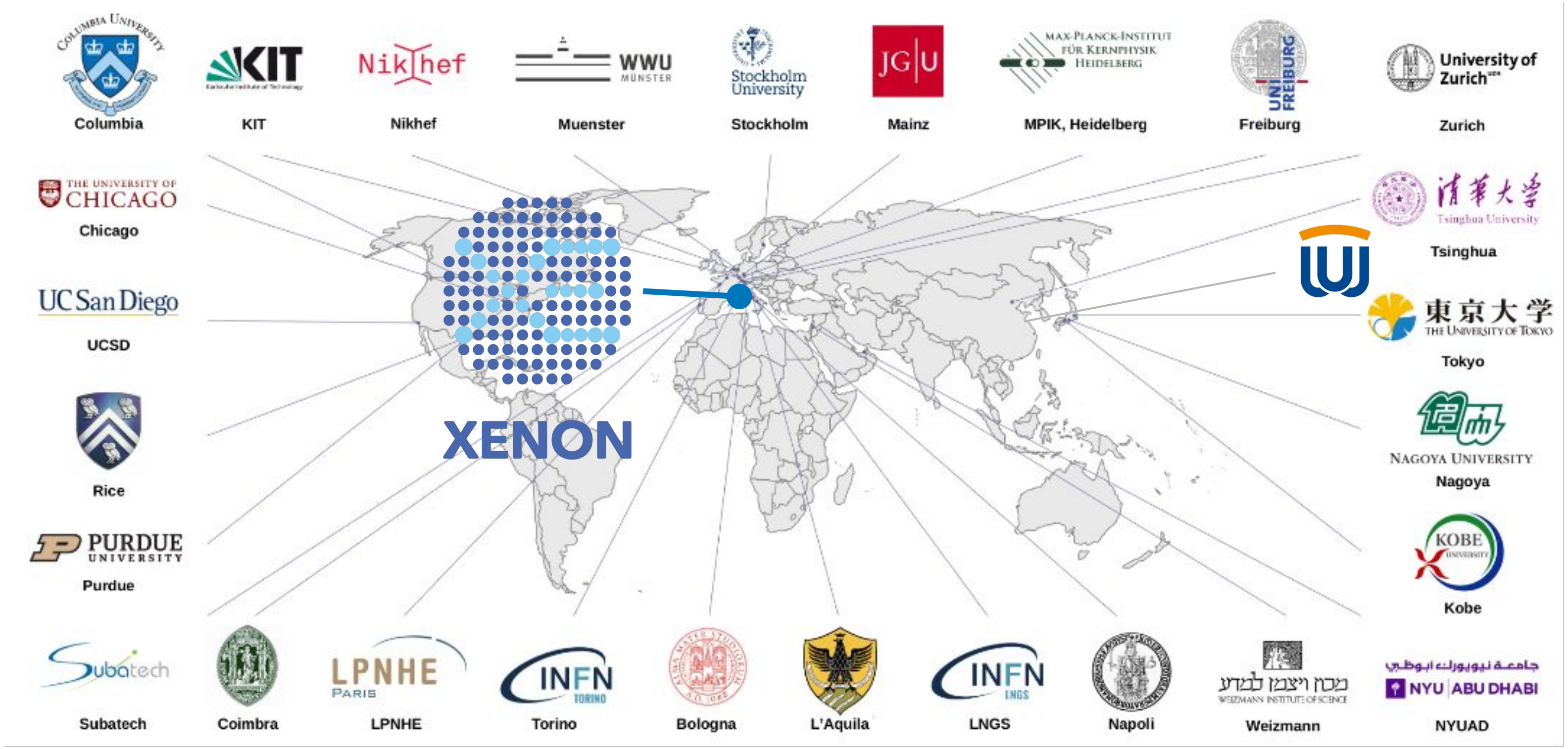
[1] Hörsaal 7 lecture hall

[2] BIG-Hörsaal lecture hall

XENON collaboration

~ 180 scientists

XENON collaboration



27 institutions

Dual-phase xenon TPC

Detection

S1: prompt scintillation in LXe

S2: proportional scintillation in GXe

Event reconstruction

Z: drift time × drift velocity

X, Y: from PMT pattern

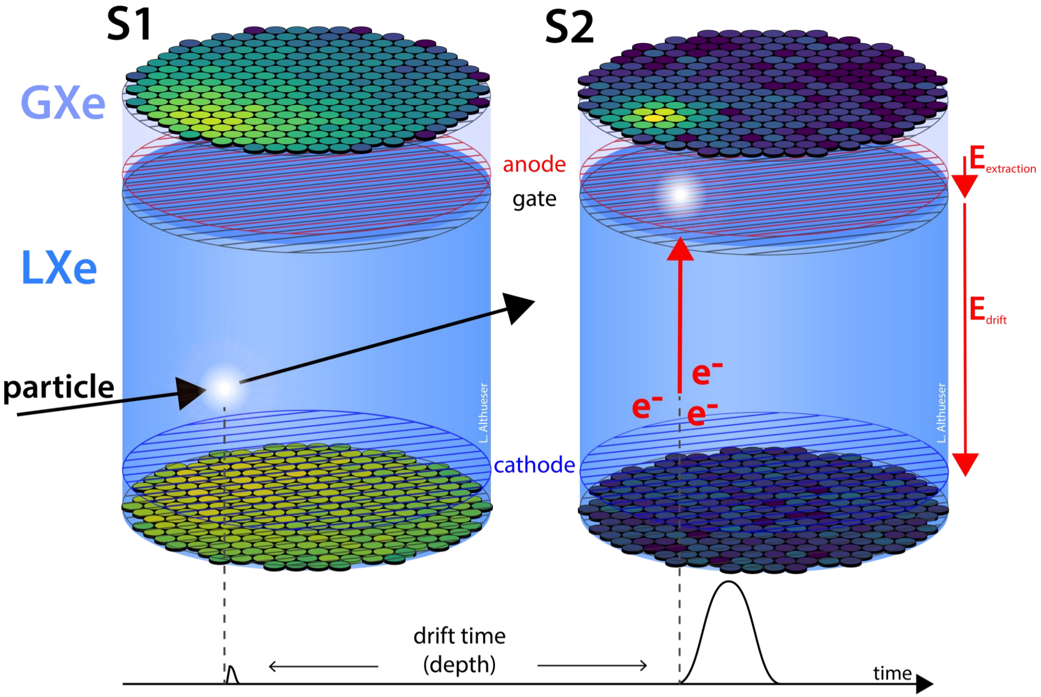
Combined energy scale: W (cS1 / g1 + cS2 / g2)

Particle discrimination

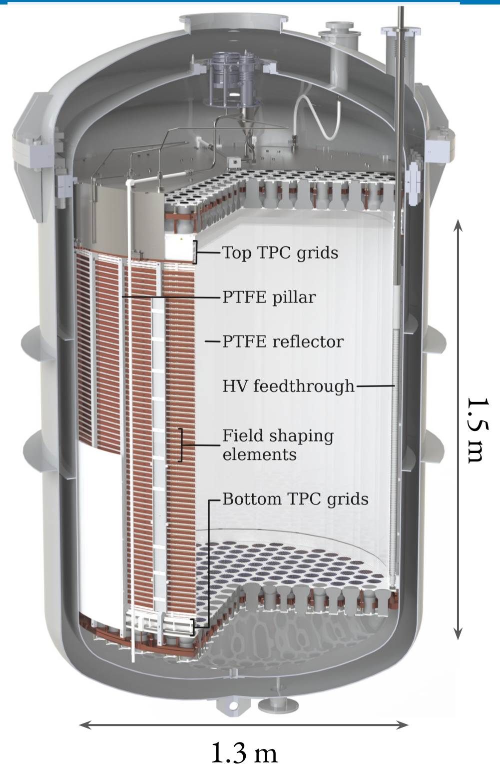
Electronic recoil (ER): beta, gamma

Nuclear recoil (NR): neutron, WIMP

In the WIMP search ROI, $(\mathbf{S2/S1})_{\mathbf{ER}} > (\mathbf{S2/S1})_{\mathbf{NR}}$



XENONnT at LNGS



XENONnT TPC

Xe target mass (×3 XENON1T)

~ 6 tonne in active volume

~ 4 tonne in SR0 WIMP fiducial volume

Electric fields

Drift field = 23 V/cm

Extraction field = 2.9 kV/cm

(extraction efficiency ~ 50%)

XENONnT upgrades

Neutron veto

Water Cherenkov neutron veto

~ 50% tagging efficiency with only 1.6% exposure loss

Radon column

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

Continuous distillation to remove ^{222}Rn

(dominant background from the daughter ^{214}Pb)

Lowest ^{222}Rn background ever: < **1 μBq/kg (SR1), 1.8 μBq/kg (SR0)**

LXe purification

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

High-flow purification to remove electro-negative impurities

~ 2 L/min flow (~ 18 h to exchange the full liquid xenon volume)

Electron lifetime **~ 15 ms** (only ~ 14% charge loss for a full drift length 1.5 m)

ER/NR Calibrations

^{220}Rn

- Uniform distribution in the TPC
- The beta decays from its daughter ^{212}Pb
- Has the same spectrum as the major ER background ^{214}Pb
- Use it to fit the ER response model

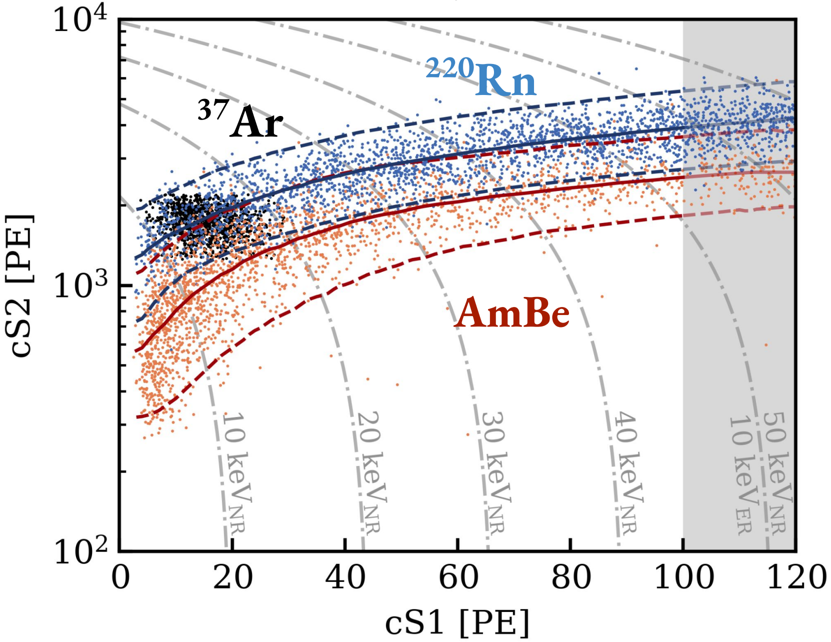
^{37}Ar

- Uniform distribution in the TPC
- Fully removed by distillation after the calibration [1]
- Use its 2.8 keV ER peak to validate low-energy ER response

^{241}AmBe

- Use it to fit the NR response model
- Select neutrons by tagging 4.4 MeV coincident gamma in neutron veto

Phys. Rev. Lett. **131**, 041003



[1] Progress of Theoretical and Experimental Physics, Volume 2022, Issue 5, May 2022, 053H01

Signal model

Phys. Rev. Lett. **131**, 041003

Detection efficiency

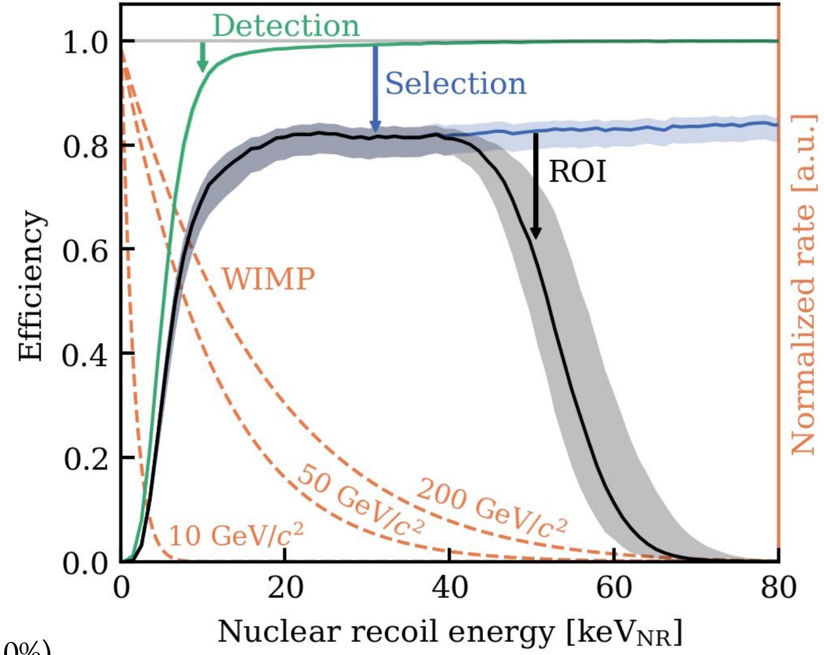
- Determined by S1 3-fold threshold
- Simulations and data-driven methods give consistent results

Selection acceptance

- Data quality and anti-AC (accidental coincidence) cuts
- Flat after 20 keV_{NR} ~ 80%

Region of interest

- cS1/PE $\in$ [0, 100]
- cS2/PE $\in$ $[10^{2.1}, 10^{4.1}]$
- $\Rightarrow$ Energy $\in$ [3.3, 60.5] keV_{NR} or [1.0, 14.0] keV_{ER} (efficiency > 10%)



Background models

Electronic recoils (ERs)

- Dominant background in WIMP search
- ~ 50% from ^{214}Pb, ~ 20% from solar neutrino, ~ 30% from (gamma from material + ^{85}Kr + ^{136}Xe)

Nuclear recoils (NRs)

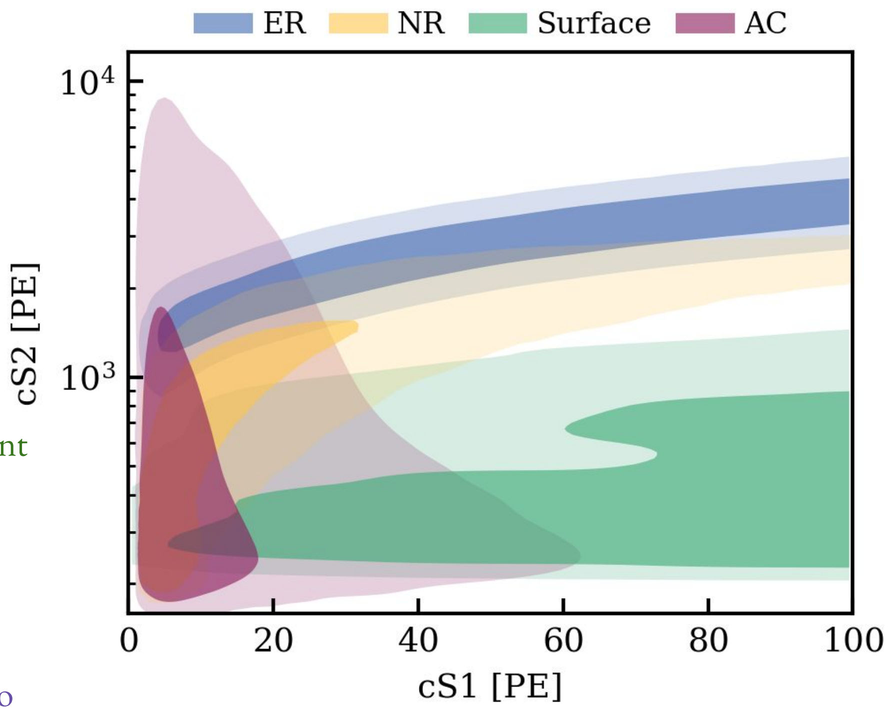
- Radiogenic neutrons not tagged by NV ~ 1.1 events
- NRs by neutrinos (CEνNS) ~ 0.2 event

Surface

- ^{210}Pb decays from ^{222}Rn decay chain at the wall with significant electron loss due to non-uniformity of drift field
- Mainly suppressed by fiducial volume selection

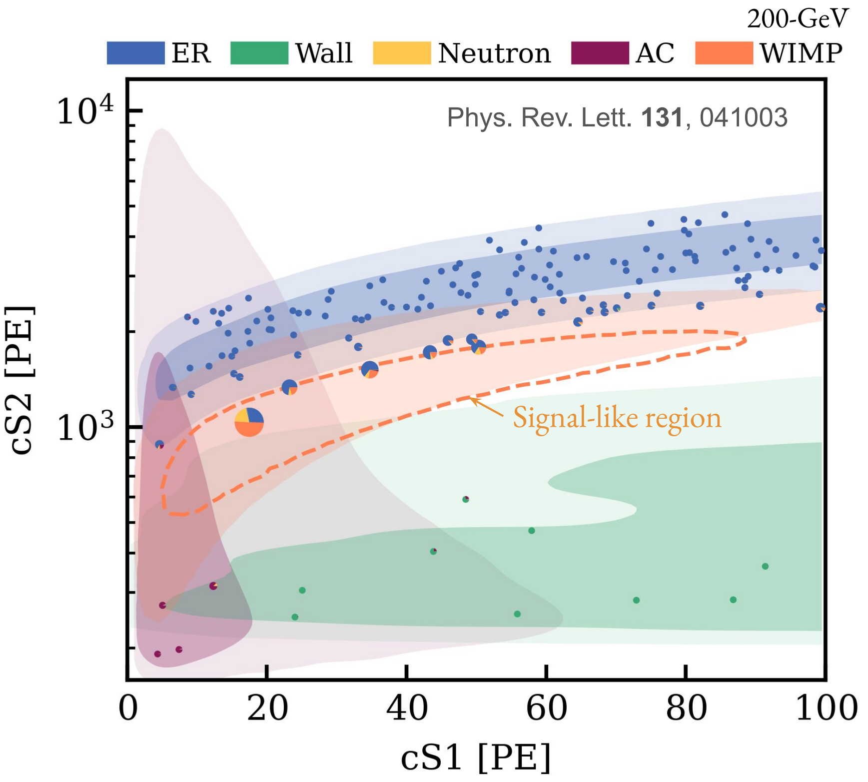
Accidental coincidence (AC)

- Events whose S1 S2 are not from the same physical events
- Use dedicated anti-AC cuts including machine-learning cut to suppress



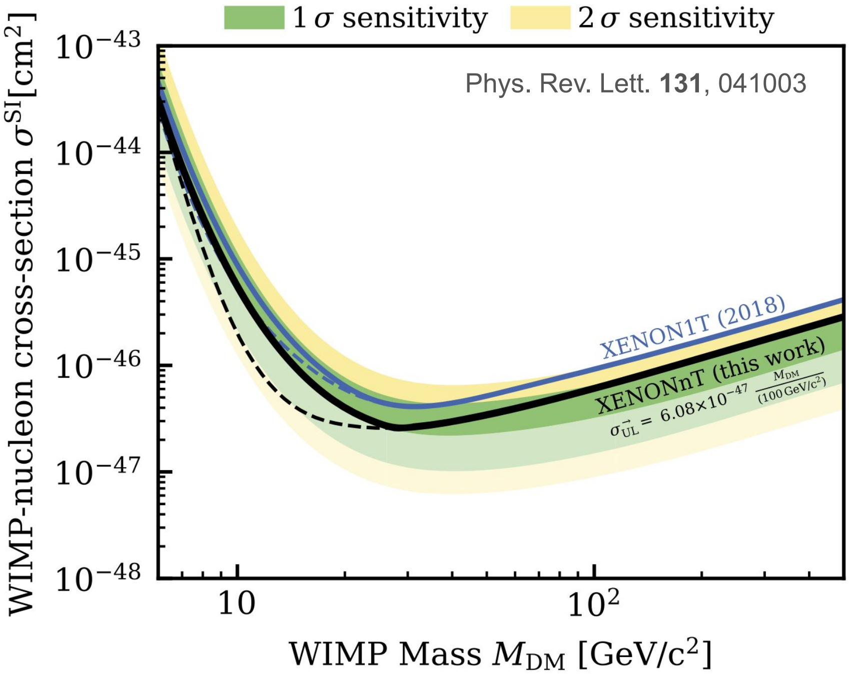
WIMP unblinding results

	Nominal	Best fit	
	ROI		Signal-like
ER	134	135^{+12}_{-11}	0.92 ± 0.08
Neutrons	$1.1^{+0.6}_{-0.5}$	1.1 ± 0.4	0.42 ± 0.16
CEνNS	0.23 ± 0.06	0.23 ± 0.06	0.022 ± 0.006
AC	4.3 ± 0.9	$4.4^{+0.9}_{-0.8}$	0.32 ± 0.06
Surface	14 ± 3	12 ± 2	0.35 ± 0.07
Total background	154	152 ± 12	$2.03^{+0.17}_{-0.15}$
WIMP	…	2.6	1.3
Observed	…	152	3



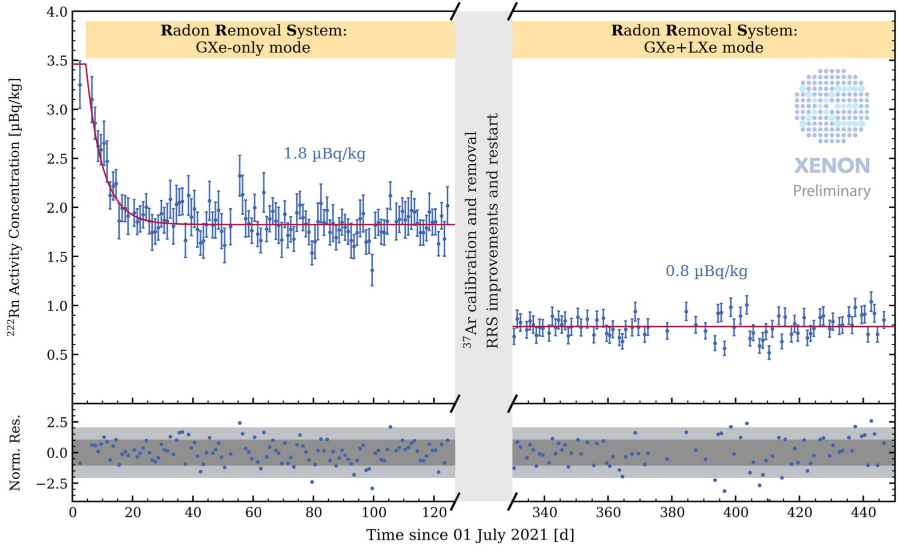
WIMP unblinding results

- No significant excess is observed
- Upper limit with 90% CL on spin-independent WIMP-nucleon cross section is shown
- Power constraint limit chops at median of sensitivity band
- Minimal upper limit is 2.58×10^{-47} cm^2 for 28 GeV / c^2 WIMP



Summary and outlook

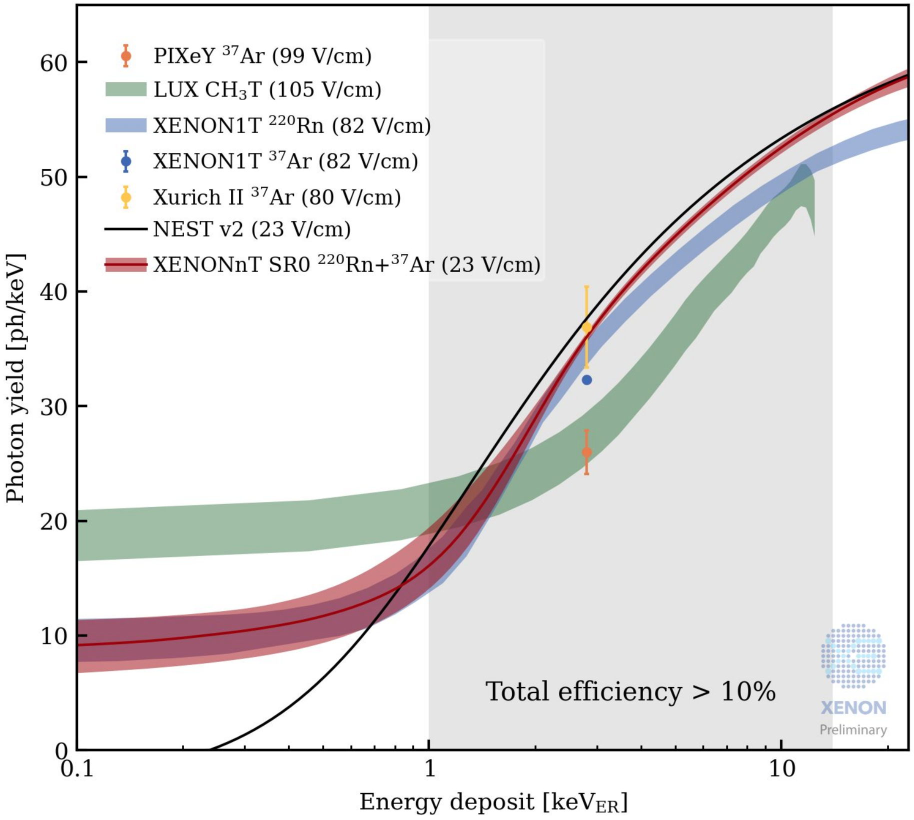
- Compared to XENON1T, XENONnT SR0 has
  - More xenon (SR0 exposure = 4.2 tonne ╳ 95 days ~ total XENON1T exposure)
  - Lowest ER background rate ever
  - Water Cherenkov neutron veto
  - Higher electron lifetime
- A blinded analysis shows no significant excess
- SR1 is ongoing, and has
  - Lower ^{214}Pb background rate (~ 50% SR0 level)
  - More exposure
  - Improved analysis techniques
- SR0+SR1 combined WIMP analysis is on the way
- SR1+ we will insert Gd into neutron veto to further improve tagging efficiency

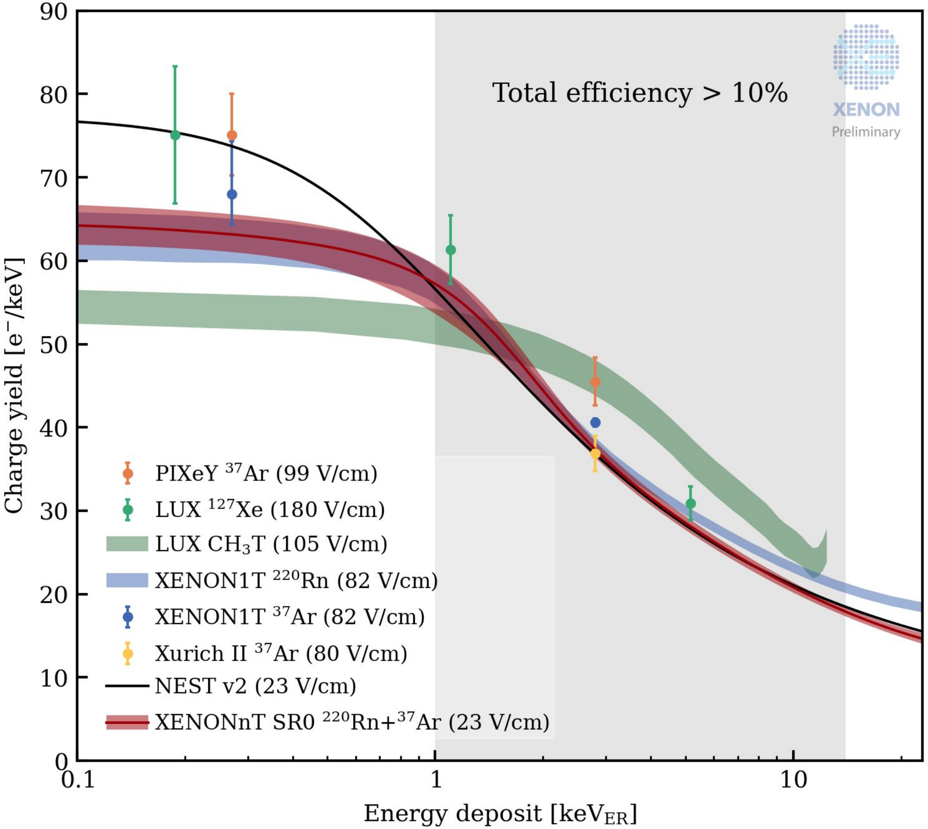


Thank you!

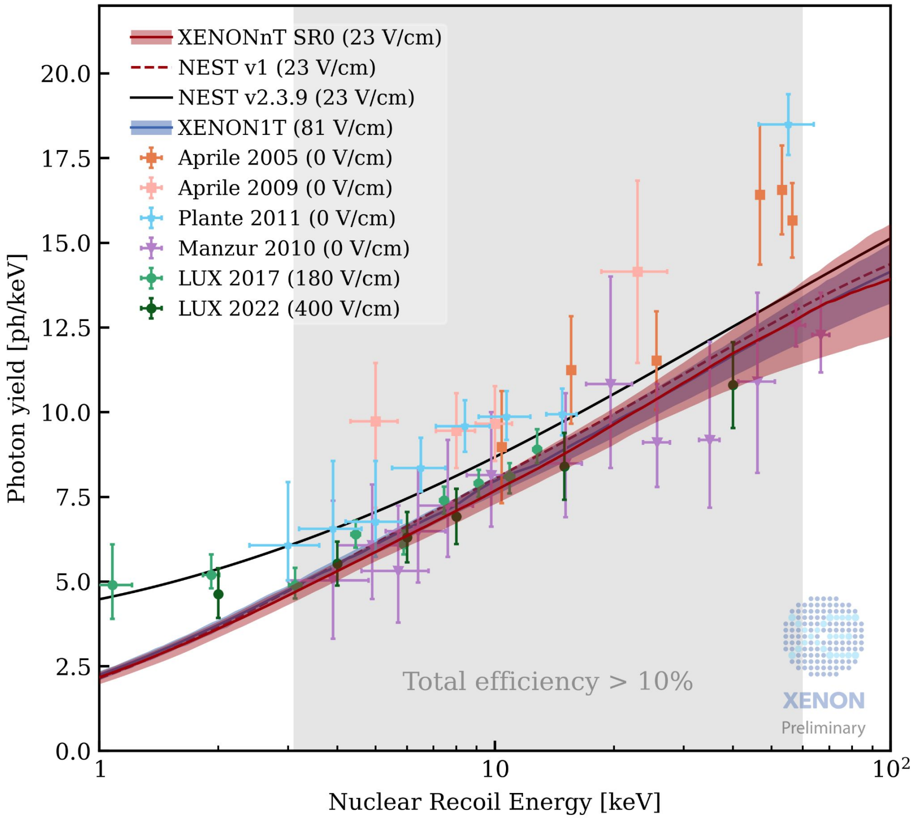
Zihao Xu
On behalf of the XENON collaboration
Columbia University, New York City
TAUP Aug 28th 2023, Vienna

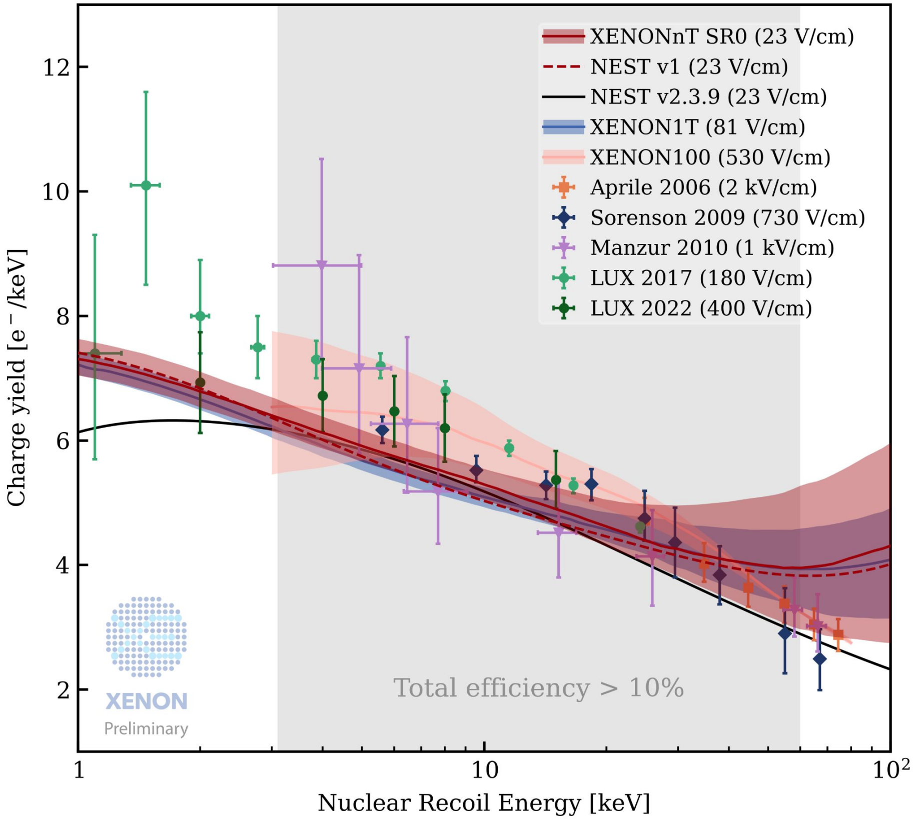
ER response

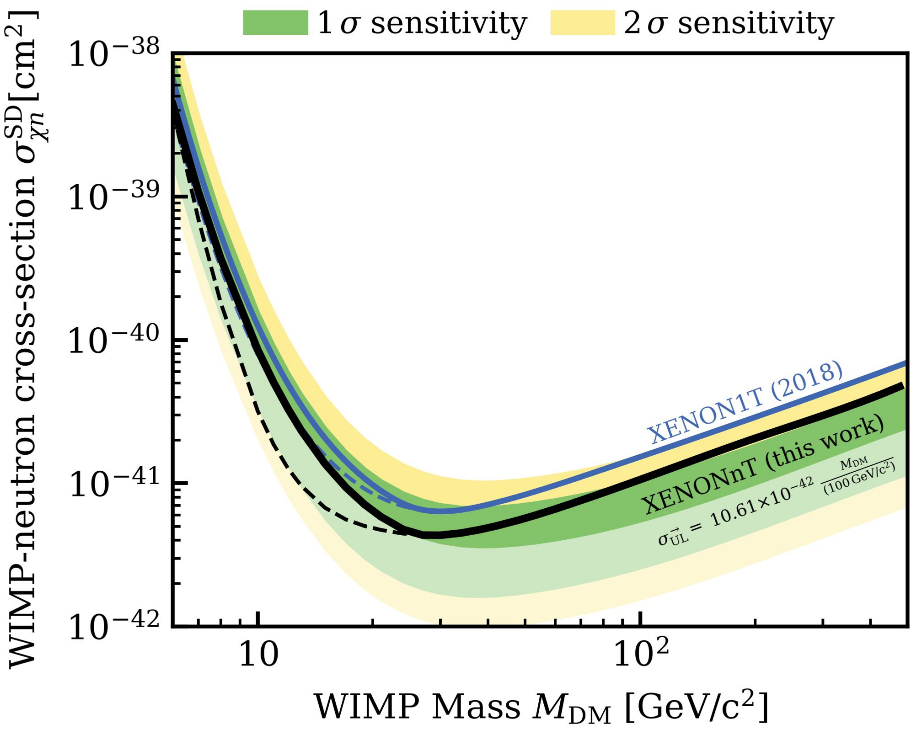

PIXeY ^{37}Ar (99 V/cm)
LUX CH_3T (105 V/cm)
XENON1T ^{220}Rn (82 V/cm)
XENON1T ^{37}Ar (82 V/cm)
Xurich II ^{37}Ar (80 V/cm)
NEST v2 (23 V/cm)
XENONnT SR0 ^{220}Rn+^{37}Ar (23 V/cm)
Total efficiency > 10%
XENON
Preliminary
Photon yield [ph/keV]
Energy deposit [keV_{ER}]

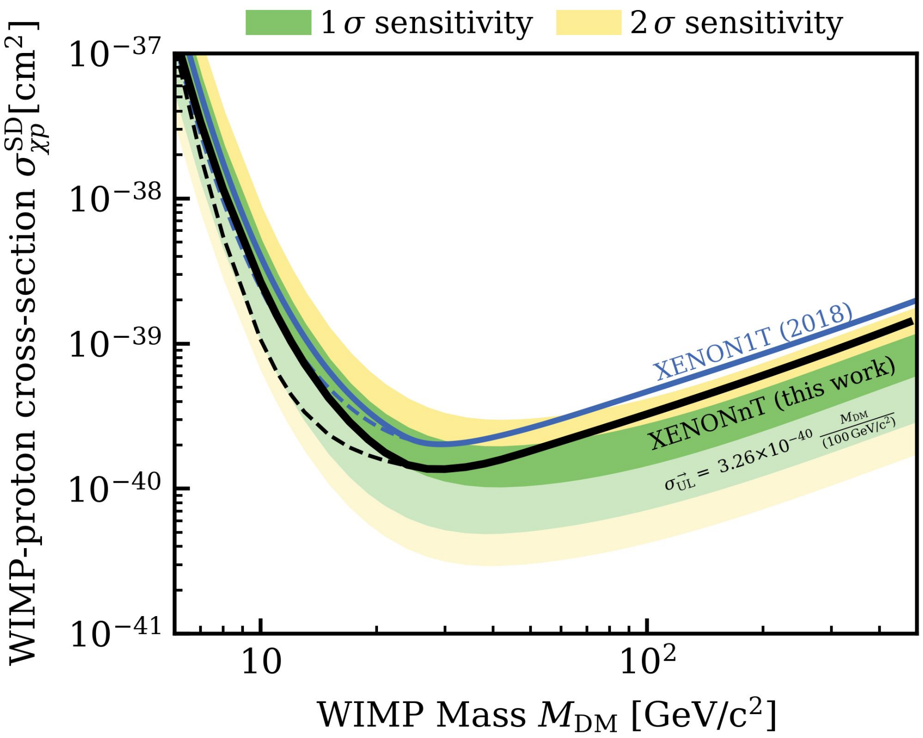

Total efficiency > 10%
XENON
Preliminary
PIXeY ^{37}Ar (99 V/cm)
LUX ^{127}Xe (180 V/cm)
LUX CH_3T (105 V/cm)
XENON1T ^{220}Rn (82 V/cm)
XENON1T ^{37}Ar (82 V/cm)
Xurich II ^{37}Ar (80 V/cm)
NEST v2 (23 V/cm)
XENONnT SR0 ^{220}Rn+^{37}Ar (23 V/cm)
Charge yield [e^-/keV]
Energy deposit [keV_{ER}]

NR response

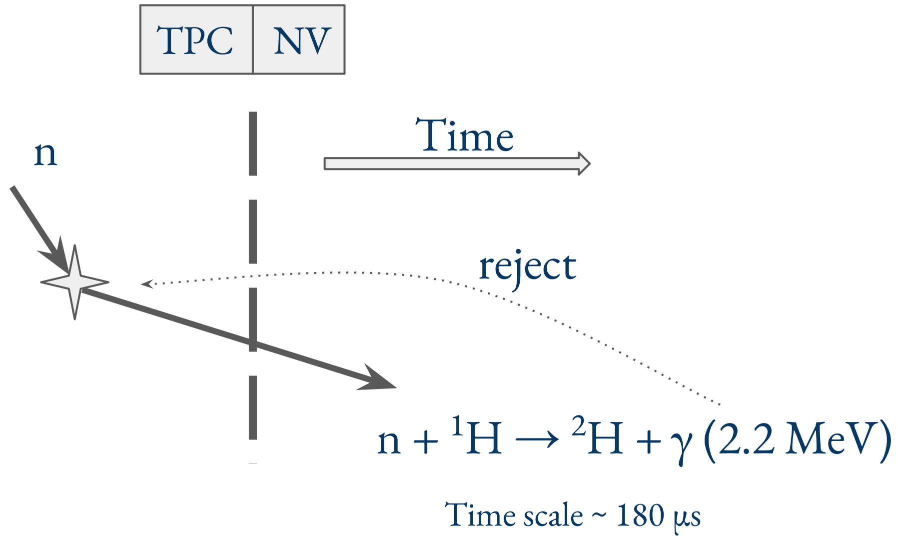

XENONnT SR0 (23 V/cm)
NEST v1 (23 V/cm)
NEST v2.3.9 (23 V/cm)
XENON1T (81 V/cm)
Aprile 2005 (0 V/cm)
Aprile 2009 (0 V/cm)
Plante 2011 (0 V/cm)
Manzur 2010 (0 V/cm)
LUX 2017 (180 V/cm)
LUX 2022 (400 V/cm)
Photon yield [ph/keV]
Nuclear Recoil Energy [keV]
Total efficiency > 10%
XENON
Preliminary


XENONnT SR0 (23 V/cm)
NEST v1 (23 V/cm)
NEST v2.3.9 (23 V/cm)
XENON1T (81 V/cm)
XENON100 (530 V/cm)
Aprile 2006 (2 kV/cm)
Sorenson 2009 (730 V/cm)
Manzur 2010 (1 kV/cm)
LUX 2017 (180 V/cm)
LUX 2022 (400 V/cm)
Charge yield [e⁻/keV]
Nuclear Recoil Energy [keV]
Total efficiency > 10%
XENON
Preliminary

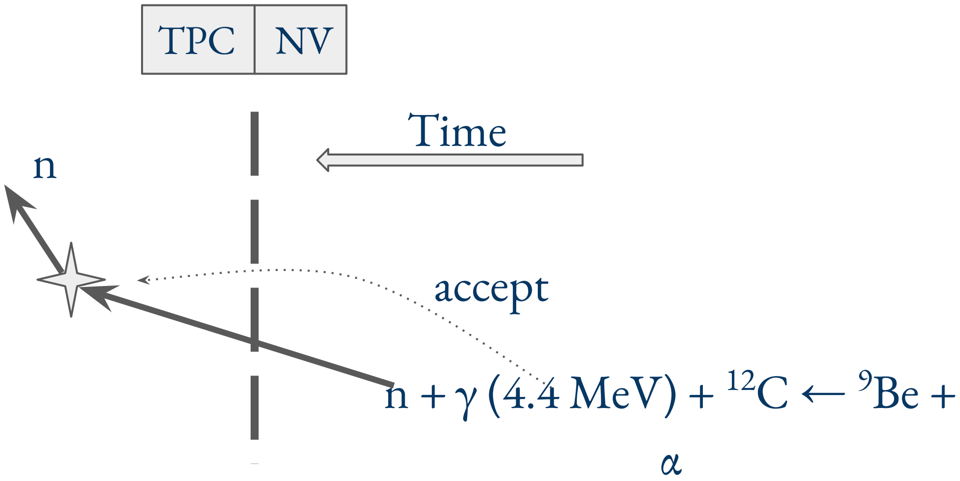

1 σ sensitivity
2 σ sensitivity
WIMP-neutron cross-section $\sigma^{SD}_{\chi n}$ [cm^2]
10^{-38}
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10
10^2
WIMP Mass M_{DM} [GeV/c^2]
XENON1T (2018)
XENONnT (this work)
$\sigma_{UL}^{\vec{}} = 10.61\times10^{-42}\ \frac{M_{DM}}{(100\,GeV/c^2)}$


1 σ sensitivity
2 σ sensitivity
WIMP-proton cross-section $\sigma^{SD}_{\chi p}$ [cm^2]
10^{-37}
10^{-38}
10^{-39}
10^{-40}
10^{-41}
10
10^2
WIMP Mass M_{DM} [GeV/c^2]
XENON1T (2018)
XENONnT (this work)
$\sigma_{UL}^{\vec{}} = 3.26\times10^{-40}\ \frac{M_{DM}}{(100\,GeV/c^2)}$

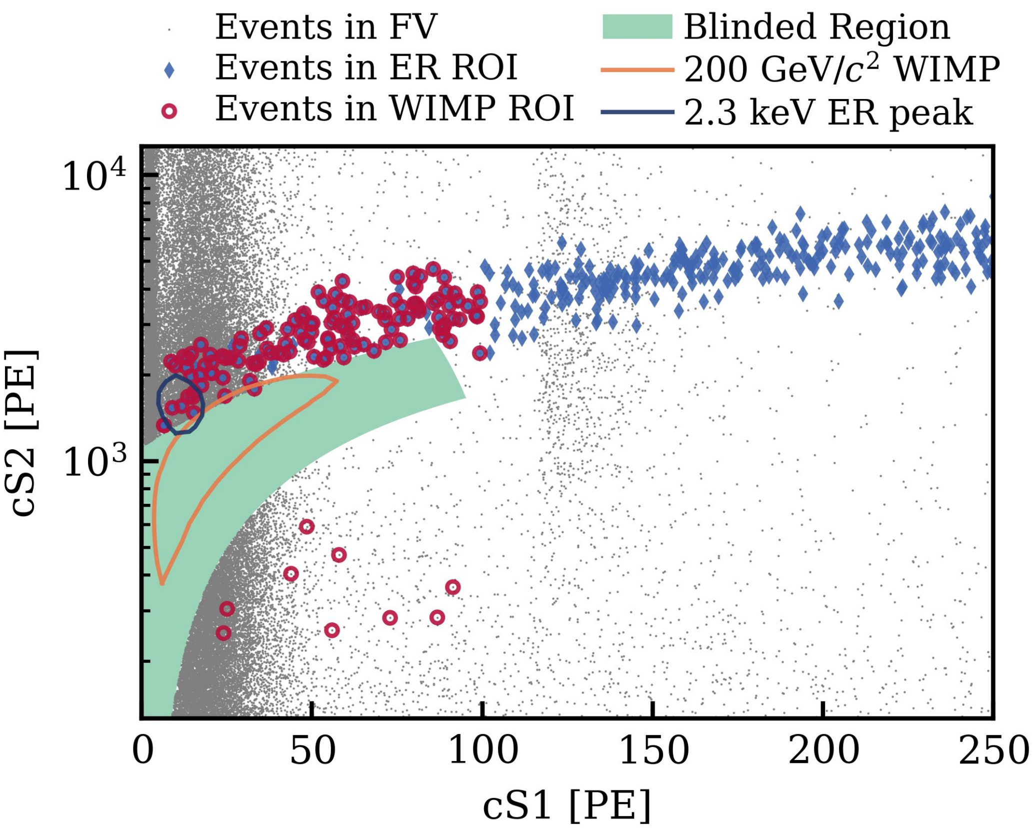
How neutron veto works



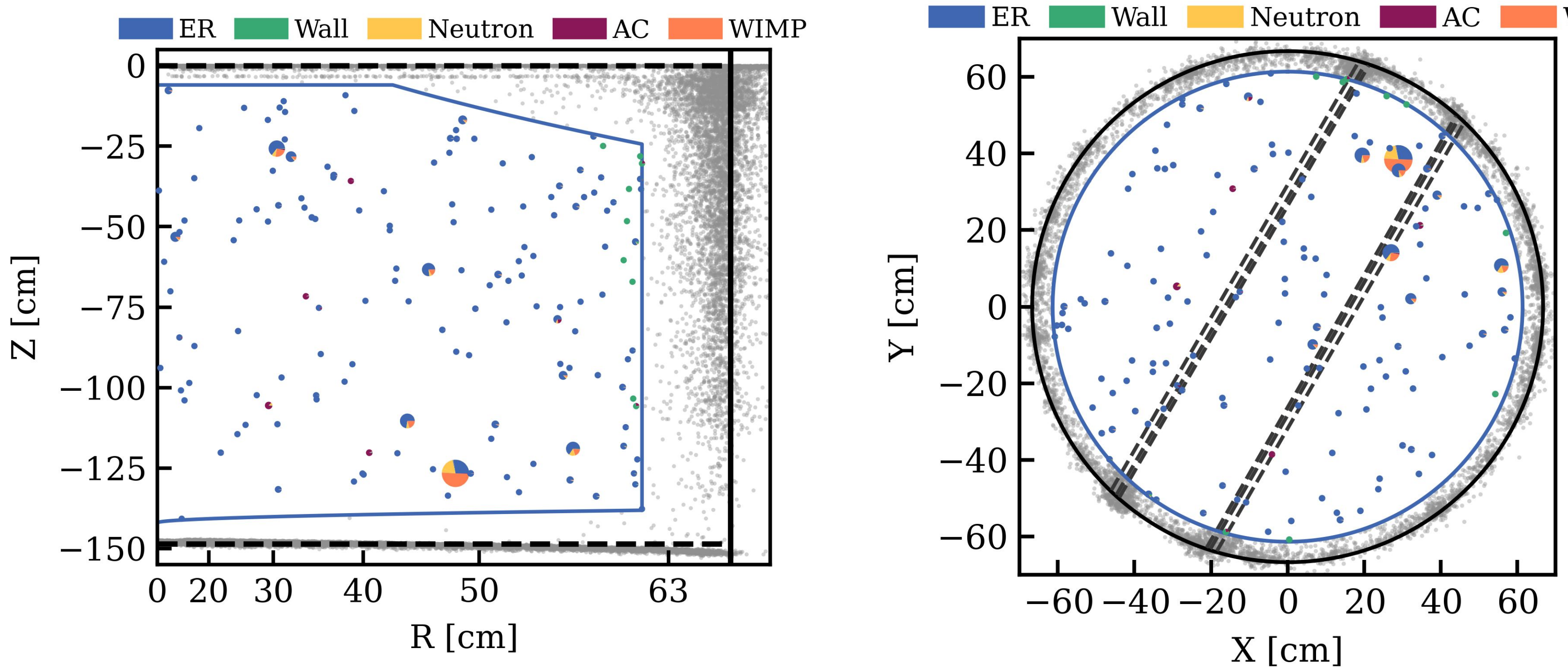
AmBe selection



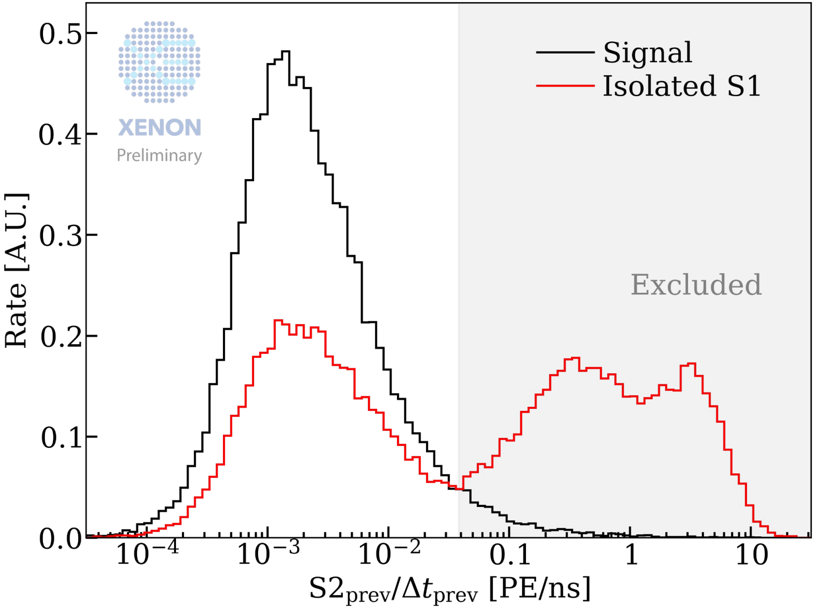
Unblinding strategy



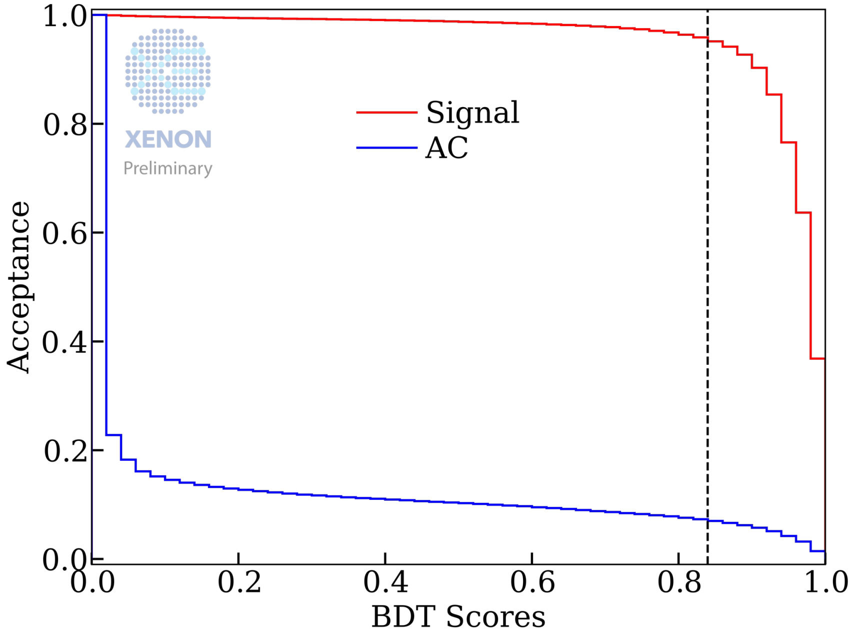
WIMP unblinding results



Anti-AC cuts



XENON
Preliminary
Signal
Isolated S1
Excluded
Rate [A.U.]
0.0
0.1
0.2
0.3
0.4
0.5
10^{-4}
10^{-3}
10^{-2}
0.1
1
10
$S2_{prev}/\Delta t_{prev}$ [PE/ns]



XENON
Preliminary
Signal
AC
Acceptance
0.0
0.2
0.4
0.6
0.8
1.0
BDT Scores

^{37}Ar removal