XENON collaboration

~160 scientists
27 institutions
Dual-phase Xenon TPC

Liquid Xenon
- High density, self-shielding
- Good scintillator
- No long-living radioactive isotope

Time Projection Chamber
- 3D position
- ER/NR discrimination
- Multiple scatter rejection
- Low energy threshold
- Scalable to multi-ton

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A. Molinario

PATRAS 2019
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Ideal for WIMP and rare processes search

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Timeline of the project

Active Mass (kg)

- 15 kg, XENON10
- 62 kg, XENON100
- 2 ton, XENON1T
- 5.9 ton, XENONnT

@ LNGS

Background in ROI (events/ton yr keV ee)

- XENON10: $\sigma_{SI} \sim 10^{-43}$ cm$^2$
- XENON100: $\sigma_{SI} \sim 10^{-45}$ cm$^2$
- XENON1T: $\sigma_{SI} \sim 10^{-47}$ cm$^2$
- XENONnT: $\sigma_{SI} \sim 10^{-48}$ cm$^2$

Years:
- 2005: XENON10, XENON100
- 2012: XENON1T
- 2020: XENONnT
Data taking

Monitoring the stability of the detector and PMTs

SR0 32 days
SR1 247 days

278.8 days
1 ton-year exposure

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Electronic recoil background

Initially Kr-dominated

Kr concentration reduced by distillation from 1 ppb to 0.7 ppt

SR1 ER background dominated by $^{222}$Rn (mainly $^{214}$Pb $\beta$-decay)

<table>
<thead>
<tr>
<th>Source</th>
<th>Fraction [%]</th>
<th>Mitigation strategy</th>
<th>ER background in the ROI</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{222}$Rn</td>
<td>85</td>
<td>S2/S1, material selection</td>
<td>$82^{+5}<em>{-3}$ (syst) ± 3 (stat) events/(ton yr keV$</em>{ee}$)</td>
</tr>
<tr>
<td>Solar $\nu$</td>
<td>5</td>
<td>S2/S1</td>
<td>Lowest ER background for a dark matter detector</td>
</tr>
<tr>
<td>$^{85}$Kr</td>
<td>4</td>
<td>S2/S1, distillation</td>
<td></td>
</tr>
<tr>
<td>Materials</td>
<td>4</td>
<td>S2/S1, material selection, fiduc.</td>
<td></td>
</tr>
<tr>
<td>$^{136}$Xe</td>
<td>1</td>
<td>S2/S1</td>
<td></td>
</tr>
</tbody>
</table>
Nuclear recoil background

**Source**

- Radiogenic neutrons (from materials)
- CEvNS (mainly $^8\text{B}$ solar $\nu$)
- Cosmogenic neutrons

**Mitigation strategy**

- Material selection, reject multiple scatter, fiducialization
- Muon Veto, reject multiple scatter, fiducialization

Dedicated search for multiple scatter events found 9 candidates with $(6.4 \pm 3.2)$ expected

Constrain the expected single-scatter neutron event rate
Other backgrounds

Accidental coincidences

Random pairing of lone S1 and S2

Background model derived from data and used in likelihood estimation

Surface events

$^{222}\text{Rn}$ progeny plate-out on the inner surface of PTFE panels

Charge loss which reduces S2 size

Events shifted in NR band

Data-driven background model
Background predictions

ROI corresponds in average to [4.9, 40.9] keV_{nr} ([1.4, 10.6] keV_{ee})

<table>
<thead>
<tr>
<th>Mass (ton)</th>
<th>1.3</th>
<th>1.3</th>
<th>0.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>(cS1, cS2_b)</td>
<td>Full</td>
<td>Reference</td>
<td>Reference</td>
</tr>
<tr>
<td>ER</td>
<td>627 ± 18</td>
<td>1.62 ± 0.30</td>
<td>1.12 ± 0.21</td>
</tr>
<tr>
<td>Neutron</td>
<td>1.43 ± 0.66</td>
<td>0.77 ± 0.35</td>
<td>0.41 ± 0.19</td>
</tr>
<tr>
<td>CEνNS</td>
<td>0.05 ± 0.01</td>
<td>0.03 ± 0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>AC</td>
<td>0.47 ± 0.27</td>
<td>0.10 ± 0.06</td>
<td>0.06 ± 0.03</td>
</tr>
<tr>
<td>Surface</td>
<td>106 ± 8</td>
<td>4.84 ± 0.40</td>
<td>0.02</td>
</tr>
<tr>
<td>Total BG</td>
<td>735 ± 20</td>
<td>7.36 ± 0.61</td>
<td>1.62 ± 0.28</td>
</tr>
</tbody>
</table>

NR reference region
50% NR acceptance with 99.75% ER rejection

Statistical inference in 1.3 t fiducial volume and full (S1, S2) space
SI-WIMP result

All selection criteria were defined before unblinding
Events that pass all cuts are shown. They are shown as pie charts representing the best-fit probabilities of the background and signal (200 GeV WIMP) components at each event.
SI-WIMP result

Performed unbinned profile likelihood, model uncertainties included as nuisance parameters.

Maximum radius of 1.3 t fiducial volume set by surface event contribution.
SI-WIMP result

\( \sigma_{SI} < 4.1 \times 10^{-47} \text{ cm}^2 \) (90% C.L.) @ 30 GeV/c^2

Median sensitivity 7 times better than previous experiments

No significant excess (>3\( \sigma \)) in the 1.3 tons fiducial volume at any WIMP mass

SD-WIMP result


Same event selection criteria for a SD search

Most stringent limit on WIMP-neutron scattering cross section

Exclude new parameter space in isoscalar theory with axial-vector mediator
WIMP-Pion coupling


Coupling of WIMP with virtual pion-current between two nucleons

Same falling exponential differential recoil spectrum as WIMP-nucleon interaction

Limit setting as in SI analysis
$^{124}\text{Xe}$ Double Electron Capture

$^{124}\text{Xe} + 2e^- \rightarrow ^{124}\text{Te} + 2\nu_e$

Detection of X-rays and Auger electrons
Total energy (64.3±0.6) keV

Background from $^{125}\text{I}$ produced by $^{124}\text{Xe}$ activation

Blinded [56-72] keV region
$^{124}$Xe Double Electron Capture

$^{124}$Xe + 2e$^- \rightarrow ^{124}$Te + 2ν$_e$

Detection of X-rays and Auger electrons
Total energy (64.3±0.6) keV

Detected peak at (64.2±0.5) keV with 4.4σ significance

Measured half-life of the process $T_{1/2} = (1.8 \pm 0.5_{\text{stat}} \pm 0.1_{\text{sys}}) \times 10^{22}$ y

\( ^{124}\text{Xe} \) Double Electron Capture

\[ ^{124}\text{Xe} + 2e^- \rightarrow ^{124}\text{Te} + 2\nu_e \]

Detection of X-rays and Auger electrons

Total energy (64.3 ± 0.6) keV

Dedicated talk by S. Lindemann on Friday at 12:25

124\text{Xe DEC} 125\text{I at 67.3 keV}

Detection of X-rays and Auger electrons

Total energy (64.2 ± 0.5) keV with 4.4σ significance

A half-life of the process \( T_{1/2} = (1.8 \pm 0.5_{\text{stat}} \pm 0.1_{\text{sys}}) \times 10^{22} \text{ y} \)

Ongoing analysis

S2-only analysis

WIMP search with Migdal effect

ALPs, Super WIMPs, Dark photons, Solar Axions

Annual modulation

0νββ of $^{136}$Xe

$^{37}$Ar calibration
Ongoing analysis

S2-only analysis

WIMP search with Migdal effect

Low energy Electronic Recoils

ALPs, Super WIMPs, Dark photons, Solar Axions

Annual modulation

$0\nu\beta\beta$ of $^{136}\text{Xe}$

$^{37}\text{Ar}$ calibration
Tests after SR1

Upgrade of purification system

New magnetic pump

Increased purification of gas flow

1 ms electron lifetime reached

Rn-removal

With new magnetic pump Radon reduced by 45%

Rn distillation tested, another 30% reduction

Factor 4 above XENONnT goal (1μBq/kg)

$^{37}$Ar calibration

Test of new calibration source for low energy ER (2.8 keV, 0.27 keV)
To increase sensitivity by one order of magnitude:

$$\sigma_{SI} \sim 10^{-48} \text{ cm}^2$$

Use most of XENON1T subsystem

increase fiducial mass by factor 4

reduce background by factor 10

Patricia Molinario

PATRAS 2019
New features XENONnT

**NEW TPC**

- 494 PMTs
- 1.5 m height
- 1.3 m diameter

**LXE PURIFICATION**

- Much faster purification speed
- Possible to purify the 8 t of Xe in a reasonable time

**RADON DISTILLATION COLUMN**

- Goal 1 μBq/kg Rn contamination
- Rn distillation already tested in XENON1T

**NEUTRON VETO**

- 0.2% Gd-doped water
- 120 additional PMTs around cryostat
Conclusions

XENON1T reached 1 ton-year exposure with the lowest ER background for a dark matter detector

Most stringent limit for WIMP-nucleon SI cross section was set for WIMP masses greater than 6 GeV/c²

First detection of double electron capture of $^{124}$Xe, longest half-life ever measured

Upgrade to XENONnT is ongoing, expected to start data taking by the end of 2019
Calibrations (1)
Calibrations (2)

Charge yield [pe/keV]

Light yield [pe/keV]

$g_1 = 0.1426 \pm 0.001$ pe/ph

$g_2 = 11.55 \pm 0.01$ pe/e

Energy resolution [%]

Energy [keV]

EXO Phase I

EXO Phase II

PandaX, 417 V/cm

Xenon100, 530 V/cm

LUX, 180 V/cm

XENON1T, 80 V/cm
Data – MC matching

![Graph showing data and Monte Carlo matching with various energy spectra and residual plots.](image-url)
SI-WIMP result
$0\nu\beta\beta$ decay

Sensitivity @ 90% CL [yr]

- Red: XENON1T 670kg FV, 28.3 cts/(keV t yr)
- Blue: XENONnT 2t FV, 1 cts/(keV t yr)
- Black: Darwin 6t FV, 3.1e-2 cts/(keV t yr)
- Purple: Inverted Hierarchy

Livetime [yr]

XENON Preliminary