The XENON collaboration

160 scientists
27 institutes
11 countries

Columbia
RPI
Nikhef
Muenster
Stockholm
Mainz
MPIK, Heidelberg
Freiburg
Zurich

Chicago
UCLA
UC San Diego
UCSD
Rice

Purdue
Coimbra
Subatech
LPNHE
LAL
Bologna
LNGS
Torino
Napoli
Weizmann

NYU
NYUAD
Evolution of the XENON TPCs

- **XENON10**: 15 kg
- **XENON100**: 161 kg
- **XENON1T**: 3.2 t
- **XENONnT**: 8.4 t
- **DARWIN**: 50 t

Timeline:
- 2005: XENON10
- 2007: XENON100
- 2009: XENON1T
- 2023: XENONnT
- 2025: DARWIN

**Dedicated talk on DARWIN by K. Thieme** here at 12:40
XENON1T at LNGS

- 700 t pure water
- 84 8-inch PMTs
- Cryostat
- TPC
- Cryogenics and purification
- DAQ and slow control
- Krypton distillation
- Xenon storage

Google street view: tinyurl.com/LNGStour
Dual-phase time projection chamber

Particle interacts in liquid xenon
- S1: prompt scintillation signal
- S2: electrons drifted to gas produce proportional scintillation signal

Position reconstruction
- \((x, y)\) from S2 pattern on top PMTs
- \(z\) (depth) from S1 – S2 delay

Particle type identification
- S2:S1 ratio different for electronic recoils (\(\beta, \gamma\)) and nuclear recoils (WIMP, n)
TPC in XENON1T

TPC

- Holding 2 t liquid xenon
- ~1 m diameter
- ~1 m length
- Highly reflective PTFE walls
- 74 copper field shaping rings
- Five high-transparency electrodes

Hamamatsu R11410-21 PMTs

- 248 3-inch PMTs in XENON1T
- Low radioactivity & VUV-sensitive
- QE ~ 35% at 175 nm

Calibration of ER / NR bands

220Rn injected into liquid xenon
Decays away in few days

212Pb β− decay:
continuous low E spectrum

Neutron generator

External sources mounted on belt system
D-D fusion generator

High neutron flux (2000 n/s)
Reduce calibration weeks → days compared to AmBe source

JINST 11:P04004 (2016)
ER backgrounds

4.1% Materials
- HPGe γ screening: material selection
- Suppressed by fiducialisation

1.4% $^{136}$Xe

85.4% $^{222}$Rn
- ~ 10 μBq/kg
- Control surface emanation
- Further reduction by online distillation (more later)

4.9% Solar ν

4.3% $^{85}$Kr
- Cryogenic distillation
- natKr (0.66 ± 0.11) ppt

Expectations in 1 t FV in [1, 12] keV

ER Rate
(82 ± 5) ev/(keV t y) in 1.3 t below 25 keVee

Lowest ER background ever achieved in DM detector

JCAP 04:027 (2016)
NR backgrounds

< 0.01 ev Cosmogenic n
- $\mu$-induced neutrons
- Rock overburden
- Muon veto

JINST 9:P11006 (2014)

0.02 ev CEvNS
- Coherent elastic neutrino-nucleus scattering of $^8$B solar $\nu$
- Irreducible, very low energy (< 1 keV)

JCAP 04:027 (2016)

0.6 ev Radiogenic n
- From ($a$, n) and spontaneous fission
- Material selection
- Mostly multiple scatter
- Fiducialisation

EPJ C 77:890 (2017)
Dark matter search results

- Results interpreted with **profile likelihood analysis**
- 4 dimensions:
  - **3 unbinned**: cS1, cS2\textsubscript{bottom}, R
  - **1 binned (binary)**: core 0.65 t volume with low radiogenic n rate

![Graph showing dark matter search results](image)

- **200 GeV WIMP signal 1\sigma and 2\sigma**
- **NR reference region**

Pie charts show relative contribution of each component to that event’s PDF

Large pie charts have more WIMP probability
Dark matter search results

- Results interpreted with **profile likelihood analysis**
- 4 dimensions:
  - **3 unbinned**: cS1, cS2_{bottom}, R
  - **1 binned (binary)**: core 0.65 t volume with low radiogenic n rate

![Graph showing dark matter search results](image)

- Core 0.65 t volume
- 1σ & 2σ of radiogenic neutron pdf
Limit on WIMP cross-section

Sensitivity

- 7-times improvement over previous-generation experiments

Limit

- Strongest exclusion limits for WIMPs above 6 GeV

Minimum

\( \sigma_{SI} < 4.1 \times 10^{-47} \text{ cm}^2 \) at 30 GeV

Spin-dependent scattering

- Same data and quality criteria as for SD analysis
- Most stringent limit for WIMP-neutron scattering
\[ ^{124}\text{Xe} + 2e^- \rightarrow ^{124}\text{Te} + 2\nu_e \quad (Q_{\text{DEC}} = 2857 \text{ keV}) \]

- Recoil energy of nucleus negligible
- Observe X-rays and Auger electrons
- Double K-shell capture \( \Rightarrow \) energy 64.3 keV
Energy scale calibration

Combined Energy Scale (CES):

\[ E = (N_{ph} + N_e) \times W \]
\[ E = \left( \frac{S1}{g_1} + \frac{S2}{g_2} \right) \times W \]

Average energy of one quantum in LXe: \( W = 13.7 \) eV

Excellent energy resolution
Improved at high energies using saturation corrections
2νECEC search results

Combined χ² fit in two volumes (inner & outer)

Best fit:
\[ N_{\text{DEC}} = 126 \]
\[ N_{\text{I-125}} = 9 \]

Important background \(^{125}\text{I}\)
Daughter of \(^{125}\text{Xe}\), which is produced during neutron calibrations
Cut acceptance $\sim 97\%$

$T_{1/2} = (1.8 \pm 0.5_{\text{stat}} \pm 0.1_{\text{sys}}) \times 10^{22}\,\text{yr}$

Longest directly measured half-life

4.4σ exclusion of null hypothesis
The future: XENONnT

**neutron veto**
- Inner region of existing muon veto
- optically separate
- 120 additional PMTs
- Gd in the water tank
- 0.5% $\text{Gd}_2(\text{SO}_4)_3$

**larger TPC**
- Total 8.4 t LXe
- 5.9 t in TPC
- ~ 4 t fiducial
- 248 → 494 PMTs

**222Rn distillation**
- Reduce radon from pipes, cables, cryogenic system
- New system, tested in XENON1T

**LXe purification**
- Faster xenon cleaning
- 5L/min LXe (2500 slpm)
- Now: 120 slpm
Summary

**XENON1T**

- First multi-ton scale LXe TPC
- Stable operation > 1 year
- More results on the way: low-mass WIMP, $0\nu\beta\beta$, solar axions, dark photons

**XENONnT**

- $4\times$–$5\times$ bigger fiducial mass
- $10\times$ better sensitivity
- Now being constructed in Gran Sasso

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Stay tuned for more exciting results

contact@xenon1t.org

www.xenon1t.org

@xenon1t