Upcoming Results from XENON1T

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Weizmann
NYU/Abu Dhabi
Tokyo
Nagoya
Kobe
Liquid Xenon as Dark Matter Target

WIMPs neutral, S-I coupling $\propto$ target atomic mass

→ xenon: A ~131

Require a low-background environment

→ very high purity xenon can be obtained
  - No naturally occurring radioactive isotopes (except $^{136}$Xe)
→ xenon has a high stopping power
  - self-shielding

LXe simultaneously target and detector

→ xenon liquid at a reasonably high temp. (-95C)
  - easily accessible to modern cryogenic systems
→ scintillation light @ 178nm

LXe TPCs are the most competitive WIMP detectors for a broad mass range
Stages of the XENON Project

XENON10
Time: Until 2007
Total: 25 kg
Target: 14 kg
Fiducial: 5.4 kg
Limit: $\sim10^{-43}$ cm$^2$

XENON100
Time: Until 2015
Total: 162 kg
Target: 62 kg
Fiducial: 48 kg
Limit: $\sim10^{-45}$ cm$^2$

XENON1T
Time: From 2016
Total: 3500 kg
Target: 2000 kg
Fiducial: $>1000$ kg
Sensitivity: $\sim10^{-47}$ cm$^2$

XENONnT
Time: From 2019
Total: 7500 kg
Target: 5900 kg
Fiducial: 4000 kg
Sensitivity: $\sim10^{-48}$ cm$^{-2}$
Recap: First XENON1T Results

- 34 live days dark matter exposure Oct 2016-Jan 2017
- No evidence of a signal → upper limit
- Additional 247 live days of data collected to date
  - the rest of this talk

278 days high quality data (livetime-corrected)
1 ton x year at estimated 1.3t fiducial volume

Science data spans more than one calendar year of stable operation!

Detector still collecting data today.
Dark Matter Detection with LXe TPCs

**Energy**
- S1 area
- S2 area

**Position**
- x-y (S2 signal)
- z (drift time)

**Interaction type**
- S2/S1 ratio (ER/NR)
See: github.com/XENON1T
>1 Year Stable Data-Taking

- Electronegative impurities absorb drift electrons
- Continuous purification during operation
- Monitor purity via ‘electron lifetime’
- Plateau shows stable equilibrium reached for this configuration

Light and charge yields stable throughout science run
- Rn222 background → exploit α-decay lines
- Kr83m calibration → 9, 32 keV conversion e-
- 129mXe, 131mXe → activation after n calibrations
Electronic Recoil Backgrounds

- Minimize leakage into cryo system (i.e., hermetically sealed pumps)
- Low radon emanation components
- Dedicated radon emanation measurements

- \( ^{85}\text{Kr} \)
  - \(^{85}\text{Kr}/^{\text{nat}}\text{Kr} \approx 2 \times 10^{-11} \)
  - \( \text{Kr/Xe} \approx 10^{-9} - 10^{-6} \) (commercial Xe)
  - Online distillation \(^{\text{nat}}\text{Kr}/\text{Xe} \approx 0.62 \text{ ppt} \)
  - Offline distillation \(^{\text{nat}}\text{Kr}/\text{Xe} < 48 \text{ ppq} \)

- \( ^{222}\text{Rn} \)
  - Minimize leakage into cryo system (i.e., hermetically sealed pumps)

\[ \begin{array}{|c|c|c|}
\hline
\text{Source} & \text{Count} \ [\text{t}^{-1}\text{y}^{-1}] & \text{Fraction} [\%] \\
\hline
\text{Materials} & 29 \pm 3 & 4.1 \\
\hline
^{222}\text{Rn} & 620 \pm 60 & 85.4 \\
\hline
^{85}\text{Kr} & 31 \pm 6 & 4.3 \\
\hline
\text{Solar neutrinos} & 36 \pm 1 & 4.9 \\
\hline
^{136}\text{Xe} & 9 \pm 4 & 1.4 \\
\hline
\text{Total} & 720 \pm 60 & \\
\hline
\end{array} \]

(2-12 keV search window, 1t FV, single scatters, before ER/NR discrimination)

→ All detector components screened for radiopurity using HPGe detectors (shown are some cable plugs)
Nuclear Recoil Backgrounds

Muon-induced Neutrons
- 3,600 m.w.e. rock overburden (1x10^6 attenuation of muon rate)
- 700 m^3 demineralized water surround detector
- Water Cherenkov Muon Veto provides additional reduction
- 0.012 events/t-ya expected BG

Radiogenic Neutrons
- (α, n) reactions from U- and Th- chains and spontaneous fission
- Mimic WIMP signal (many are single scatter, many penetrate into fiducial volume)
- Reduction via careful material selection and minimization of material budget
- O(1) event/t-ya expected

Coherent Neutrino Nucleus Scattering
- Irreducible background
- Larger at very low energies (1keV)
- Nearly no contribution above threshold of 5 keV
- 0.01 event/t-ya expected
Nuclear Recoil Backgrounds

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**XENONnT: Active neutron veto**
- 15 tons liquid scintillator (Gd-LAB) in acrylic vessels surrounding outer cryostat
- 120 Hamamatsu R5912Assy 8” PMTs
- For 4 ton inner volume expect 0.35 events/y with 75% neutron tagging
PTFE Surface Background

- S2 loses charge on the PTFE wall → ER events misreconstructed in signal region
- Suppressed via fiducial volume
- Data-driven model based on selected samples of surface events
Increasing the active volume

**Fiducial volume**: exploit LXe self-shielding by selecting only a low-activity inner volume to use for the WIMP search. Optimized on combined background models

- **First result**: 1-ton fiducial
- **This result**: expanded by several hundred kg!
  - Improvements to position reconstruction and field and teflon charge-up corrections
  - Additional spatial dimension in statistical interpretation

Further parameterize inner volume as function of $r$ to increase useful exposure volume:

- **Left**: largest fiducial volume, visible surface background
- **Right**: inner 1T volume, no surface background
Calibration and Background Data in the Search Region

2016 data re-analysis (32.13 d)  2017 data (246.74 d)

A blind analysis is the only way to perform this type of rare event search

- Signal region inaccessible to analysts until analysis fixed
- Prevents human bias

The data is also ‘salted’

- Fake signal events may or may not inhabit signal region
- Additional protection against bias in post-unblinding scrutinization of events

We’re unblinding this data very soon!
Parameterizing Signal and Background

- **WIMP signal, ER background, and NR background** models derived by fitting Monte Carlo simulations to calibration data.

- **Surface background, accidental coincidences** described by empirical models derived from data.

- All models derived in 3-dimensional space: (cs1, cs2, radius)
Upcoming Results

- Results interpreted with unbinned profile likelihood analysis in cs1, cs2, r space
- XENONnT to provide another order of magnitude boost to sensitivity

- For a WIMP-nucleon cross-section at the current best limit, this exposure has >50% chance at a 3-sigma excess
Conclusion/Outlook

- New results coming soon!
  - Twitter: https://twitter.com/xenon1t
  - Blog: https://www.xenon1t.org

- Our one ton-year exposure allows us to do rare event searches in other channels as well:
  - Low-mass WIMPs (S2-only)
  - ER searches (e.g. axions)
  - Annual modulation of ER rate
  - And more, stay tuned

- Our next upgrade, XENONnT is under construction and planned to start operation in 1.5 years
Extra: Combined S1+S2 Energy Reconstruction

Energy loss to *either* light or charge channel
→ S1/S2 anticorrelation

\[
\frac{S1}{E} = \frac{n_\gamma}{n_e + n_\gamma} \times \frac{g_1}{W} \\
\frac{S2}{E} = \frac{n_e}{n_e + n_\gamma} \times \frac{g_2}{W}
\]

“Doke plot” → linear fit to calibration isotopes

ROI for WIMP search up to ~30 keV

- Solve the above for E for combined energy reconstruction
- Excellent resolution across a broad energy range
**Extra: S1 Light Collection**

- **PTFE Lining**
  - High reflectivity
  - Low radioactive background
  - Covers entire inner volume

- **Highly sensitive light detection**
  - 248 Hamamatsu R11410-21 PMTs
  - Quantum efficiency: 35% @178nm
  - Operating gain $5 \times 10^6$ @ 1.5kV
  - Single photoelectron acceptances ~94%
  - Gains stable within 1-2%
  - Low background design

Near-transparent field grids
- Transparencies >90%
Light collection position dependent (solid angle)

However very well understood:
- Direct measurement with $^{83m}$Kr calibrations
- Agreement with optical Monte Carlo simulation

Light yield stability monitored throughout the science run with several sources:
- $^{222}$Rn daughters
- Activated Xe after neutron calibrations
- $^{83m}$Kr calibrations
**Extra: S2 Energy Reconstruction**

### Electron Lifetime
- Ionization e- absorbed by impurities
- Exponential loss w.r.t. drift time
- Monitoring with $^{222}$Rn alpha decays and $^{83m}$Kr calibrations

### Amplification correction
- x-y dependent amplification correction
- Driven by anode ‘sagging’ w.r.t. gate

### Charge yield
- Monitored with $^{222}$Rn progeny, activated Xe, $^{83m}$Kr
- Stable within a few percent
- Slight rise during science run probably driven by improving purity
“Lone” s1/s2 coincidences
- S1 from eg. below cathode
- S2 from eg. near field grids
- Can get fake events that populate signal region

Empirical model
- Select unpaired S1/S2 from data
- Randomly pair to form events
- Apply selection conditions from analysis
- Performance verified in $^{220}$Rn data and background sidebands
x-y reconstruction via **neural network**:  
- **Input**: charge/channel top array  
- **Training**: Monte Carlo simulation

**Position resolution** using $^{83\text{m}}\text{Kr}$  
- Two interactions (9, 31 keV), same x-y  
- Position resolution (1-2 cm)  
- PMT diameter (7.62 cm)

**Position corrections** using $^{83\text{m}}\text{Kr}$  
- Drift field distortion  
- Localized inhomogeneities from inactive PMTs  
- Data-derived correction verified by comparison to MC with several event sources

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Data | Neutron Generator Source | MC | (blinded) background data