Analysis of the XENON1T Dark Matter Experiment

Patrick de Perio
Columbia University
for the XENON Collaboration

ICRC 2017
Busan, South Korea
Searching for Dark Matter
XENON World

~130 scientists from 22 institutions

Laboratori Nazionali del Gran Sasso (LNGS), Italy

XENON1T (Hall B)
XENON1T Detector and Subsystems

See details in Elena Aprile’s highlight talk [DM060] tomorrow July 19 @ 10:30 am

1 m height, 3.2 t Xe TPC

Water Čerenkov active veto and passive shield
XENON1T Detector and Subsystems

See details in Elena Aprile’s highlight talk [DM060] tomorrow July 19 @ 10:30 am

First result, this talk

1 m height, 3.2 t Xe TPC

Water Čerenkov active veto and passive shield

Science run time (days)

Date
Detector Principles

Particle propagation → Energy deposit → Charge & scintillation (S1) emission → e^-

Charge drift

Extraction/proportional scintillation (S2)

Optical photon propagation

PMT/electronics response

Trigger & Reconstruction

Selection

Samples for statistical inference or models

Dual-phase liquid-gas xenon time projection chamber

G_Xe
L_Xe

S1
S2

Particle

Energy deposit

Charge & scintillation (S1) emission

Charge drift

Extraction/proportional scintillation (S2)

Optical photon propagation

PMT/electronics response

Trigger & Reconstruction

Selection

Samples for statistical inference or models

χ, n (NR)
γ, β (ER)

(S2/S1)_{NR} < (S2/S1)_{ER}

Charge

drift time (depth)

Time

Patrick de Perio (Columbia University)
Energy Sources

Real Data
- Particle propagation
- Energy deposit
- Charge & scintillation (S1) emission

Model
- Geant4 simulation / calculation

Extracted signals:
- Calibration: Kr83m (e^-), Rn220 (β), AmBe (n)
- Backgrounds: radioactivity in materials (e^-, γ, n), neutrinos (e^-, n), internal Rn222 (β)
- Signals: WIMPs

Calibration:
- Kr83m (e^-), Rn220 (β), AmBe (n)

Backgrounds:
- Radioactivity in materials (e^-, γ, n), neutrinos (e^-, n), internal Rn222 (β)

Signals:
- WIMPs
LXe Microphysics

- Parameterization of Xe ion and excimer generation and recombination (ala NEST)
- MC simulation of fluctuations at all stages
- Emission of photons (S1) and electrons

Real Data
- Particle propagation
- Energy deposit
- Charge & scintillation (S1) emission

Model
- Geant4 simulation / calculation
- LXe emission model

Real Data 

MC simulation of fluctuations at all stages

- Emission of photons (S1) and electrons

Charge 

Extraction/

- Photon yields
  - ± 1 σ region
  - Best-fit (mean of posteriors)
- Initial (NEST v0.98)

Recoil Energy [keV_{nr}]

Recoil Energy [keV_{ee}]

Light yield

AmBe nuclear recoils (NR)

L_y [photons/keV_{nr}]

Charge yield

Q_y [electrons/keV_{nr}]

Rn220 electronic recoils (ER)

L_y [photons/keV_{ee}]

Patrick de Perio (Columbia University)
Electron (e⁻) Drift

- Measured diffusion constant and drift velocity agree well with literature
- Evolution of LXe purity (e-lifetime) well described by physical model

\[ \sigma = \sqrt{\frac{2Dt}{v^2} + \sigma_0} \]

<table>
<thead>
<tr>
<th>Date</th>
<th>Deviation [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nov 19 2016</td>
<td></td>
</tr>
<tr>
<td>Nov 26 2016</td>
<td></td>
</tr>
<tr>
<td>Dec 03 2016</td>
<td></td>
</tr>
<tr>
<td>Dec 10 2016</td>
<td></td>
</tr>
<tr>
<td>Dec 17 2016</td>
<td></td>
</tr>
<tr>
<td>Dec 24 2016</td>
<td></td>
</tr>
<tr>
<td>Dec 31 2016</td>
<td></td>
</tr>
<tr>
<td>Jan 07 2017</td>
<td></td>
</tr>
<tr>
<td>Jan 14 2017</td>
<td></td>
</tr>
<tr>
<td>Jan 21 2017</td>
<td></td>
</tr>
</tbody>
</table>

RMS = 1.31%
e\textsuperscript{-} Extraction and Light

- Photon detection efficiency ($g_1$) and proportional scintillation amplification ($g_2$) from known mono-energetic lines
- Spatial dependence of light collection efficiency (LCE) from uniformly distributed Kr83m source

- Geant4 simulation / calculation
- LXe emission model
- e-lifetime and diffusion

- Real Data
  - Particle propagation
  - Energy deposit
  - Charge & scintillation (S1) emission

- Model
  - Extraction/ proportional scintillation (S2)
  - Optical photon propagation
  - PMT/ electronics response
  - Trigger & Reconstruction

- S1 & S2 LCE maps from sim and real data
- S1 \& S2 LCE Map Interpolation
- S2 light yield map (bottom)

Patrick de Perio (Columbia University)
Waveform Simulation

Several effects considered:
- baseline fluctuations,
- SPE shape, photoionization,
- PMT gains/QE/after-pulse/
dark counts/DPE...

Trigger & Reconstruction
- Selection
- Samples for statistical inference or models

Optical photon propagation

PMT/ electronics response

Extraction/ proportional scintillation (S2)

Charge

Simulation

AmBe data

S1 & S2 LCE maps from sim and real data

S1 & S2 bias and smearing from waveform simulator

Several effects considered:
- baseline fluctuations,
- SPE shape, photoionization,
- PMT gains/QE/after-pulse/
dark counts/DPE…

Patrick de Perio (Columbia University)

XENON1T Analysis @ ICRC2017
Calibration Fitting

- All parameters fitted in MCMC framework with no significant deviation from priors.
Background model

- ER and NR spectral shapes derived from models fitted to calibration data
- Other background expectations are data-driven, derived from control samples

- FV: 1.042 t
- 34.2 days

<table>
<thead>
<tr>
<th>Background &amp; Signal Rates</th>
<th>Total</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronic recoils (ER)</td>
<td>62 ± 8</td>
<td>0.26 (+0.11)(-0.07)</td>
</tr>
<tr>
<td>Radiogenic neutrons (n)</td>
<td>0.05 ± 0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>CNNS (ν)</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>Accidental coincidences (acc)</td>
<td>0.22 ± 0.01</td>
<td>0.06</td>
</tr>
<tr>
<td>Wall leakage (wall)</td>
<td>0.52 ± 0.32</td>
<td>0.01</td>
</tr>
<tr>
<td>Anomalous (anom)</td>
<td>0.09 (+0.12)(-0.06)</td>
<td>0.01 ± 0.01</td>
</tr>
<tr>
<td>Total background</td>
<td>63 ± 8</td>
<td>0.36 (+0.11)(-0.07)</td>
</tr>
</tbody>
</table>
Dark Matter Search

- Extended unbinned profile likelihood analysis
- Most significant ER & NR shape parameters included from cal. fits
- Normalization uncertainties for all components
XENON1T Analysis Summary

- Advanced modeling of detector integrated into analysis
- **First result paper** under peer review
- World’s best sensitivity and growing

See more details tomorrow @ 10:30 am (E. Aprile highlight talk [DM060])