THE XENON DARK MATTER PROGRAM - RESULTS, STATUS AND PROSPECTS

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On behalf of XENON collaboration
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THE XENON DARK MATTER PROGRAM @LNGS

2005-2007

XENON10
15 cm drift TPC - 25 kg

2007-2016

XENON100
30 cm drift TPC - 161 kg

2012-2022

XENON1T/XENONnT
96 cm drift TPC
~3.2 tonne (1T)
~8 tonne (~140cm) (nT)
Background reduction achieved:
- Location of the detector deep underground.
- Light/charge yield discrimination
- Fiducialization
- Material screening/purification
- Passive and active shielding
- Single scatter identification
XENON100 LEGACY

- Operational 2009-2016, 477 live days of dark matter data
  - Standard WIMP search (PRL 10,11,12,13)
  - Inelastic DM (PRD 2011)
  - Axions (PRD 2014)
  - Leptophillic/DAMA (Science 2015)
  - Annual modulation (PRL 2015)
  - Low mass WIMP search (arxiv 2016)

- A few result still in the pipeline, especially:
  - Standard WIMP search with full set of data
Amplitude and phase excludes DAMA (WIMP electron axial-vector coupling) at $4.8\sigma$

1 year period: weak signal in single and multiple scatter.

No signal observed for random period search.
STILL: FULL DM DATA SET

- 477 live-days analysis will allow large periods to be tested, plus a few improvements in analysis.

- Best fit 1 year period would increase $\sim 1\sigma$ in significance if real.

STAY TUNED!
EXCLUSION OF DAMA – INTEGRATED RATE

- DAMA due to WIMP electron (axial) couplings excluded @ 4.4σ (conservatively).

Science 349 6250 (2015)
LOW MASS WIMP SEARCH

- Ionization signal "S2"-only $\rightarrow$ threshold 0.7 keV
- No z-position and S2/S1 discrimination.

- Limit without background model.

- $m \sim 6$ GeV
XENON100 477 LIVE DAYS

<table>
<thead>
<tr>
<th>Properties</th>
<th>Run I</th>
<th>Run II</th>
<th>Run III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Live days</td>
<td>101</td>
<td>223</td>
<td>153</td>
</tr>
<tr>
<td>Fiducial mass [kg]</td>
<td>48</td>
<td>34</td>
<td>34</td>
</tr>
<tr>
<td>85KR [ppt]</td>
<td>360±70</td>
<td>19±4</td>
<td>6±1</td>
</tr>
<tr>
<td>Electron livetime [µs]</td>
<td>294</td>
<td>519</td>
<td>720</td>
</tr>
<tr>
<td>(&quot;purity&quot;)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bkg expected</td>
<td>3.8±0.5</td>
<td>1.7±0.4</td>
<td>1.0±0.2</td>
</tr>
<tr>
<td>Observed events</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

- Combined likelihood:

\[
\mathcal{L} = \mathcal{L}^I \times \mathcal{L}^II \times \mathcal{L}^III \times \mathcal{L}_3(t_{\text{eff}}) \times \mathcal{L}_4(t_{Q_y})
\]

Light (S1)- and charge (S2) yield uncertainties

- Improved S2 identification applying XENON1T reconstruction package, improved S2 energy threshold.

STAY TUNED!
XENON1T TPC

- 96 cm drift x 96 cm diameter TPC
- Filled since April 2016
- 3.2 tonne total mass, 2 tonne active mass
- 248 3” low background PMTS

Arxiv: 1609.01654
TPC COMMISSIONING

- Cryogenics: well behaved, stable pressure and temperature
- Both charge and light are detected throughout the whole TPC
- Electron lifetime (‘purity’) at a few 100 us and improving exponentially (drift through the total TPC ~560 us)

Taken without water shield, Not final performance
- TPC fully immersed in water since July 2016
- Background studies and calibration runs started
XENON1T BACKGROUND PREDICTION

GEANT4 simulations based on measurements (screening)
Post-rejection:

<table>
<thead>
<tr>
<th>Material</th>
<th>Rate</th>
</tr>
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<tbody>
<tr>
<td>ER</td>
<td>1.62 ev/1T/yr</td>
</tr>
<tr>
<td>NR</td>
<td>0.46 ev/1t/yr</td>
</tr>
<tr>
<td>Total</td>
<td>~2 ev/1t/yr</td>
</tr>
</tbody>
</table>

cf. WIMP rate ~2 evts/1t/yr (mass ~100 GeV, $\sigma \sim 10^{-47}$ cm$^2$)

Nuclear Recoil
- radiogenic
- cosmogenic
- neutrinos

Electromagnetic recoil
- 85Kr
- 222Rn
- materials
- 136Xe-2$\nu$2$\beta$
- $\nu$
20 live-days until XENON1T will be probing new parameter space

JCAP 1604 (2016) 027
XENONnT

- Larger TPC (target ~6t), additional PMTS, other systems (storage, cryogenics ..) will be ~reused

- 20 t yr exposure, reduced background \(\rightarrow\) go for \~1\ dex improvement

- Operation \~ 2018
SUMMARY

- Final XENON100 results about to be published.
- XENON1T (~ 2 tonne xenon TPC presently being commissioned.
- **Science run of XENON1T later this autumn.**
- XENON1T (~ 2018) probes favoured WIMP parameter space
- Gearing up for XENONnT → major parts of WIMP parameter space probed by early 2020’s
• Bonus slides
Post Discovery Complementarity

Roszkowski+ (2016)

250 GeV WIMP discovered by XENON1T

--- here for 25 GeV WIMP … but would look similar for ~1 TeV WIMP discovered at XENON1T (I believe)

Also branching fractions…..
LHC/DD COMPLEMENTARITY

Spin independent (Vector) 90% CL projected limits

$\sigma^0_{SI} \quad [cm^2]$

$m_{DM} \quad [GeV]$

HL-LHC14: $g_q = g_{DM} = 1.45$
HL-LHC14: $g_q = g_{DM} = 1.0$
HL-LHC14: $g_q = g_{DM} = 0.5$
HL-LHC14: $g_q = g_{DM} = 0.25$

SuperCDMS (GeV

XENONnt

DARWIN 200 t yr

coherent v scattering

Malik+, (2015)
XENON 1T-CRYOSTAT

- Double-vessel cryostat
- Inner vessel: 2 t TPC (3.2 t in total)
- Outer vessel: upgraded TPC
Continuous Gxe circulation and purification

Can be scaled up for faster circulation speed
Distillation column for 85Kr removal.

Requirement Kr/Xe < 0.2 ppt, achieved <0.048 ppt.

Fast: throughput 3kg/hour.
Based on two pulse tube refrigerators (PTRs)

Backed up by liquid nitrogen cooling (in case of power failure)
XENON 1T - STORAGE

- Double walled, high pressure, vacuum insulated, 2.1 m sphere, nitrogen cooled

- Store up to 7.6 t of Xe, recover Xe from the detector, within a few hours, in case of emergency