The XENON1T Experiment

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on behalf of the XENON Collaboration

13th Pisa Meeting on Advanced Detectors - May 29, 2015
XENON Program

**XENON10**
- **2005-2007**
- **25 kg**
- Achieved (2007) $\sigma_{SI} = 8.8 \times 10^{-44}$ cm$^2$

**XENON100**
- **2008-2015**
- **161 kg**
- Achieved (2011) $\sigma_{SI} = 7.0 \times 10^{-45}$ cm$^2$
- Achieved (2012) $\sigma_{SI} = 2.0 \times 10^{-45}$ cm$^2$

**XENON1T/XENONnT**
- **2012-2018 / ~2018-2022**
- **3300 kg / 7000 kg**
- Projected (2018) $\sigma_{SI} \sim 2 \times 10^{-47}$ cm$^2$
- Projected (2022) $\sigma_{SI} \sim 3 \times 10^{-48}$ cm$^2$
Why Xenon?

- Large mass number $A$ ($\sim 131$), expect high rate for SI interactions ($\sigma \sim A^2$) if energy threshold for nuclear recoils is low
- $\sim 50\%$ odd isotopes ($^{129}\text{Xe}$, $^{131}\text{Xe}$) for SD interactions
- No long-lived radioisotopes (with the exception of $^{136}\text{Xe}$, $T_{1/2} = 2.2 \times 10^{21}$ yr), Kr can be reduced to ppt levels
- High stopping power ($Z = 54$, $\rho = 3 \text{ g cm}^{-3}$), active volume is self shielding
- Efficient scintillator ($\sim 80\%$ light yield of NaI), fast response
- Scalable to large target masses
- Nuclear recoil discrimination with simultaneous measurement of scintillation and ionization
Dual Phase TPC Principle

- Bottom PMT array below cathode, fully immersed in LXe to efficiently detect scintillation signal (S1).
- Top PMTs in GXe to detect the proportional signal (S2).
- Distribution of the S2 signal on top PMTs gives $xy$ coordinates while drift time measurement provides $z$ coordinate of the event.
- Ratio of ionization and scintillation (S2/S1) allows discrimination between electron and nuclear recoils.
From XENON100 to XENON1T: A Few of the Challenges

<table>
<thead>
<tr>
<th></th>
<th>XENON100</th>
<th>XENON1T</th>
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</thead>
<tbody>
<tr>
<td>LXe Mass (kg)</td>
<td>161 kg</td>
<td>3300 kg</td>
</tr>
<tr>
<td>ER Bkgnd (evts/keV/kg/d)</td>
<td>$5 \times 10^{-3}$</td>
<td>$\sim 3 \times 10^{-5}$</td>
</tr>
<tr>
<td>Kr Concentration (ppt)</td>
<td>$19 \pm 4$</td>
<td>$&lt; 0.2$</td>
</tr>
<tr>
<td>Rn Concentration (µBq/kg)</td>
<td>$\sim 65$</td>
<td>$\sim 1$</td>
</tr>
<tr>
<td>Charge drift (cm)</td>
<td>30</td>
<td>100</td>
</tr>
<tr>
<td>Cathode HV (kV)</td>
<td>$-16$</td>
<td>$-50$ to $-100$</td>
</tr>
<tr>
<td>LXe Purification</td>
<td>Several Months</td>
<td>Few Months</td>
</tr>
<tr>
<td>Cryogenics</td>
<td>$\sim 1$ year run</td>
<td>$\sim 2+$ year run</td>
</tr>
<tr>
<td>Storage/Recovery</td>
<td>GXe</td>
<td>LXe</td>
</tr>
</tbody>
</table>

Guillaume Plante - XENON

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XENON1T: Water Cherenkov Muon Veto

- Water tank 10 m high and 9.6 m diameter
- Interior lined with 3M specular reflector foil
- Water tank construction completed 2013/12
- 84 high QE 8” Hamamatsu R5912 PMTs
- $\mu$-induced neutron background < 0.01 evt/yr
- Trigger efficiency > 99.5% for neutrons with $\mu$ in water tank, ~78% with $\mu$ outside
- Details in Aprile et al., JINST 9, P11006, 2014
XENON1T: Cryostat, TPC

- Double-wall vacuum insulated cryostat, constructed from selected low-activity stainless steel
- Outer vessel 2.4 m high, 1.6 m diameter, inner vessel ~2 m high, 1.1 m diameter
- 3.3 tons LXe, ~0.7 m$^3$ TPC, active target mass of 2 tons
- 248 3” PMTs Hamamatsu R11410-21, 36% average QE, < 1 mBq/PMT in U/Th
- Background ×100 lower than XENON100
- Custom low-activity high voltage feedthrough
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- Custom low-activity high voltage feedthrough
• Design based on experience acquired by operating XENON10, XENON100, and XENON1T Demonstrator

• Heat load below 50 W (without circulation)

• Redundant 200 W pulse tube refrigerators

• One PTR can be serviced while the other is in operation

• Backup liquid nitrogen cooling

• Circulation at \( \sim 100 \) slpm through heat exchangers
XENON1T: Xe Storage

- Double-wall, high-pressure (70 atm), vacuum insulated, LN2 cooled sphere
- Designed to store \(\sim 7.6\) tons of xenon, in liquid form at \(-100^\circ C\) or in gaseous form at room temperature
- Detector can be filled with liquid xenon directly instead of condensing xenon gas
- In case of emergency, liquid xenon from the detector can be recovered in a few hours
- Continuous GXe circulation at ~100 slpm
- Purification using high-flow heated getters
- Two parallel circulation pumps and purification circuits
- GXe purity in-situ analytics
- Continuous monitoring of impurity concentrations (e.g. H₂O)
Building custom designed cryogenic distillation column for Kr removal

XENON1T Kr/Xe concentration requirement is < 0.2 ppt, aim at < 0.1 ppt with the column

High throughput, 3 kg/hr at $10^4$ separation

3.5 tons in ~1.8 months (single pass)

Custom gas purity diagnostics (online, $^{83m}$Kr tracer, and offline, ATTA, RGMS, RGA + cold trap)
**XENON1T: Expected Backgrounds**

**ER background, before S2/S1 discrimination**

- Full MC simulation of the detector (TPC, PMTs, cryostat, water shield) with GEANT4 to predict ER background
- Neutrons from \((\alpha, n)\) calculated with SOURCES-4A
- Total ER background rate expected to be \(\sim 3 \times 10^{-5}\) evts/keVee/kg/day before S2/S1 discrimination

**Total Background in XENON1T**

- Single scatters, 1 ton fiducial volume, [2, 12] keVee, [5, 50] keVr, 99.75% S2/S1 discrimination, 40% NR acceptance

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<thead>
<tr>
<th>Source</th>
<th>Background (evts/yr)</th>
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<tbody>
<tr>
<td>ER from materials</td>
<td>0.06</td>
</tr>
<tr>
<td>(^{85})Kr (0.2 ppt (^{nat})Kr)</td>
<td>0.07</td>
</tr>
<tr>
<td>(^{222})Rn (1 (\mu)Bq/kg)</td>
<td>0.08</td>
</tr>
<tr>
<td>Solar neutrinos</td>
<td>0.08</td>
</tr>
<tr>
<td>(^{2}\nu\nu)</td>
<td>0.02</td>
</tr>
<tr>
<td>NR from materials</td>
<td>0.25</td>
</tr>
<tr>
<td>Total</td>
<td>0.56</td>
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</table>
• Spin-independent WIMP-nucleon interaction cross section sensitivity of $2 \times 10^{-47} \text{ cm}^2$ for WIMPs with a mass of 50 GeV/c$^2$. 
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XENONnT: Upgraded XENON1T Detector

- Rapid deployment possibility: no modifications to infrastructure required, only construction of a larger inner vessel and TPC
- Additional $\sim 200$ PMTs and DAQ electronics channels for the upgraded TPC
- Target mass of $\sim 6$ tons, sensitivity to spin-independent WIMP-nucleon elastic scattering cross sections of $3 \times 10^{-48}$ cm$^2$
• XENON1T under construction at LNGS, water tank, service building, cryostat support, cryostat, storage, cryogenics, and purification completed
• Integration of primary systems (cryostat, cryogenics, storage, purification) completed
• Primary systems currently under commissioning
• TPC assembly in summer 2015 at LNGS, installation in early fall
• Aiming at science run starting before the end of 2015!
• XENONnT, possibility of a rapid upgrade path included in the XENON1T design