The XENON Dark Matter project: from XENON100 to XENON1T

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XENON Dark Matter project

2005 – 2007
XENON10

\[ \sigma_{SI} < 8.8 \times 10^{-44} \text{ cm}^2 \]

2008 – today
XENON100

\[ \sigma_{SI} < 2 \times 10^{-45} \text{ cm}^2 \]

start in 2015
XENON1T

goal sensitivity \( \sigma_{SI} \sim 2 \times 10^{-47} \text{ cm}^2 \)
Liquid xenon as WIMP target

Weakly Interacting Massive Particles cause nuclear recoils

LXe: compact, uniform & pure, scalable & cost-effective target

- $A=131.3$, density 2.8kg/l (compact target)
- Even and odd isotopes
- Self shielding from high density & $Z=54$
- No long-lived radioactive isotopes
- High light & charge yields
Dual phase xenon TPC

- Prompt light (S1) collected by photodetectors arrays.
- Electrons drift to and cross liquid surface.
- In the gas phase charge is converted to proportional scintillation (S2).
- Time Projection Chamber: Z from S2 – S1 time delay.
- X-Y from S2 PMT pattern
- S2/S1 ratio: particle identification.
XENON100 detector

- 62 kg LXe, 30 cm drift TPC
- 99 kg LXe active veto around
- Hamamatsu R8520 (QE > 32% @ 175nm)
  - top array (98 PMTs)
  - bottom (80 PMTs)
  - veto (64 PMTs)
- Material screening for low radioactivity

Aprile et al., Astropart.Phys.35 (2011) 43
• Located at LNGS in Italy, under 1.4 km of rocks (3600 m water-equivalent)
• Cu/Pb/polyethylene/water shield
• Weekly calibrations with sources in a pipe winding around the detector:
  • Light yield, spatial corrections
  • Characterisation of nuclear/electronic recoils bands
Detector understanding

• Absolute matching between data & full MC for nuclear recoil calibration with AmBe neutron source (*Aprile et al., PRD 88 (2013) 012006*):
  • Source strength fixed to 160±4 n/s as measured by PTB Braunschweig
  • If free parameter, we find 159 n/s from the fit
  • Competitive measurement of Q_y for small recoils

• We understand the detector acceptance and low energy thresholds!
XENON100 WIMP search

- S.I. Limit 2012: $\sigma_{\text{SI}} < 2.0 \times 10^{-45} \text{ cm}^2$ @ 55 GeV/c$^2$ (90% CL)
  

- Spin-dependent results: world-best limit for neutron coupling,
  

* Updates from both experiments presented at IDM and PATRAS exclude their previous allowed regions
Use electronic recoil background to constrain searches for Axions and Axion-like Particles: these particles can couple with electrons, ionising atoms ("axio-electric" effect).

- Axion introduced to explain the unobserved CP violation in QCD, should be produced in the Sun (and converted back in the detector)
- Galactic Axion-like particles is an hypothesis for Cold Dark Matter alternative to WIMPs
Solar Axions

- XENON100 results improves the upper limit for the coupling to electrons of solar Axions (E. Aprile et al., arxiv:1404.1455):

\[ g_{Ae} < 7.7 \times 10^{-12} \text{ (90% CL)} \]
Galactic Axion-Like Particles

- XENON100 results provide a competitive upper limit for the coupling to electrons of galactic Axion-like Particles in a wide range of possible Axion masses (E. Aprile et al., arxiv:1404.1455)

\[ g_{Ae} < \sim 1 \times 10^{-12} \text{(90\% CL)} \]
XENON100 plans

• Additional 150 days of data taken in 2013, to be unblinded soon
• Annual modulation analysis on-going.

• 2014 data-taking focuses on calibration:
  • New AmBe calibration.
  • Low energy nuclear recoils from YBe mono-energetic neutron source.
  • Low energy electron recoils from $^{83m}$Kr gamma source diluted in the LXe.
XENON1T coming soon!

- Under construction in Hall B at LNGS
- Commissioning early 2015, goal sensitivity of \(2 \times 10^{-47} \text{ cm}^2\) after 2 years of data-taking
XENON1T detector

- 3.3 tons of LXe total
- 2 tons active volume (1 ton fiducial)
- 1 m drift TPC
  - Cathode voltage up to 100kV possible!
  - Custom-made feedthrough
  - Demonstrator in Columbia U.
- 248 3” Hamamatsu R11410-21 PMTS:
  - High QE 36% at 175nm
  - < 1 mBq/PMT from Hamamatsu
  - All screened
  - Tested & characterised in warm & cold environments, a subset in LXe
XENON1T detector
XENON1T detector
XENON1T detector
XENON1T detector
XENON1T detector
XENON1T water tank

- Detector in a 10m diameter water tank instrumented as Cherenkov active veto for muon-induced neutrons
XENON1T support systems
XENON1T support systems
What’s next? XENONnT!

• Already larger outer cryostat for an upgrade in 2018, reusing other systems
• Goal: 20 tons-years exposure, reach few $10^{-48}$ cm$^2$
• XENON100 detector largely contributed to the Dark Matter search, not only in the form of WIMPs.

• The detector and its systematics are well understood from many calibration measurements and consistency checks.

• Novel calibration techniques can be studied in XENON100, in view of the successor experiment XENON1T.

• XENON1T is well in the construction schedule, and it will start data-taking in 2015.

• The expected sensitivity is $2 \cdot 10^{-47} \text{ cm}^2$ within 2 years, and it is ready for an upgrade to achieve a sensitivity of few $10^{-48} \text{ cm}^2$. 
Backup slides
The Dark Matter puzzle

Subatomic constituent cannot be found in the Standard Model of Particle Physics.
18 evts/100-kg/year $E_{th} = 5$ keVnr

8 evts/100-kg/year $E_{th} = 15$ keVnr
Analysis highlights

- Blind analyses
- Full 3-D reconstruction (3mm X-Y, 0.3 mm Z resolution):
  - Rejection of multiple scatterings
  - Volume fiducialization
- Electron recoil rejection from S2/S1 ratio of 99.75% with a nuclear recoil acceptance of about 50%
Detector understanding

• Absolute matching between data & MC for nuclear recoil calibration with AmBe neutron source:
  • Source strength fixed to 160 n/s as measured by PTB
  • If free parameter, we find 159 n/s from the fit
• We understand the detector acceptance and low energy thresholds
• Measurement of $Q_y$ for small recoils

E. Aprile et al., PRD 88, 012006 (2013)
Spin-dependent couplings

- World-best limit for neutron coupling:
  \[ \sigma_n < 3.0 \times 10^{-40} \text{ cm}^2 \] @ 45 GeV/c² (90% CL)

\[ \begin{align*}
\text{Phys. Rev. Lett. 111, 021301 (2013)}
\end{align*} \]
XENON1T background

- Complete MC (GEANT4, SOURCES-4A) of the detector, information from material screening
- Estimate: < 0.5 events/ton/year