Status of the XENON100 experiment

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www.physik.uzh.ch/groups/groupbaudis/xenon/
1. Introduction

2. The XENON experiment

3. Detector calibration

4. First XENON100 results

5. Summary
Xenon as detection medium

Detection via scatter off nuclei

- Self-shielding → High stopping power
- 178 nm UV photons → No wavelength-shifter
- Simple cryogenics
  \( \sim 180 \, \text{K} = -93^\circ \)
- High atomic mass \( A \sim 131 \) → spin-indep. interactions
- \(^{129}\text{Xe}\) and \(^{131}\text{Xe}\) → spin-dep. interactions
Noble gas scintillation process

Nuclear recoil

Excitation: \( R^* \)

\[ R^* + R \rightarrow R_2^* \]

\[ R_2^* \rightarrow 2R + \text{hv} \]

Ionization: \( R^+ \) and \( e^- \)'s

\[ R^+ + R \rightarrow R_2^+ \]

\[ R_2^+ + e^- \rightarrow R^{**} + R \]

\[ R^{**} \rightarrow R^* + \text{heat} \]

\[ R^* + R \rightarrow R_2^* \]

\[ R_2^* \rightarrow 2R + \text{hv} \]

Singlet and triplet states:
- Singlet: 19 ns, 15 \( \mu \)s, Neon
- Triplet: 5 ns, 1.6 \( \mu \)s, Argon
- 3 ns, 25 ns, Xenon
Two phase noble gas TPC

- Scintillation signal (S1)
- Charges drift to the liquid-gas surface
- Proportional signal (S2)

Electron recombination is stronger for nuclear recoils

→ Electron- / nuclear recoil discrimination
XENON experiment

- **XENON10**: 15 kg active volume
  - Finished: No evidence for DM
    

- **XENON100**: 62 kg active volume
  - Currently running

- Laboratori Nazionali del Gran Sasso (Italy)
- ~ 3 650 m.w.e. shielding
XENON100 Collaboration

Columbia | Rice | UCLA | Zürich | Coimbra | LNGS | SJTU

Mainz | Bologna | Subatech | Münster | Nikhef | Heidelberg | Weizman

US, Switzerland, Portugal, Italy, China, Germany, Holland, France and Israel
XENON100 detector

- 30 cm drift length and 30 cm $\varnothing$
- 161 kg total (30-50 kg fiducial volume)
- $\sim 100x$ less background than XENON10
- Material screening and selection
- 242 low activity 1” PMTs (R8520)
- Cooling (PTR) outside the shield
- Active liquid xenon veto

1 inch PMTs

30 cm $\varnothing$ meshes
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30 cm $\varnothing$ meshes
Light and charge read out

- Bottom PMTs: high quantum efficiency (on average >30% @178 nm)

- 3 Dim. position reconstruction
  - XY from light pattern in the PMTs
  - Z from the drift time

- 3 mm resolution in XY and 2 mm in Z
Background prediction

Material screening underground with a 2.2 kg HP Ge detector

- Gamma background expected in WIMP search region:
  - $5 \cdot 10^{-3}$ evts/kg/keV/d (before S2/S1 discrimination)

- Neutron bg from simulations:
  - 2/3 from radioactivity and 1/3 muon-induced

- Removal of $^{85}$Kr: distillation column
  - Kr/Xe \sim ppm-ppb commercially available
  - Measurement in XENON100 after purification:
    - RUN07: \sim 150 ppt via delayed gamma-beta coincidence

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Measured background spectrum

- No tuning of the Monte Carlo
- The measured single scatter rate below 100 keVee is $10^{-2}$ evts/kg/keV/d without veto cut. Is reduced by 50% with veto cut!
- Factor 100 less than in XENON10 achieved!

→ currently optimizing the data/MC comparison
Background in the low energy range

→ Lowest ever measured background rate in a dark matter experiment
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Calibration with gamma sources

- Energy dependence of resolution in light ($S_1$), charge ($S_2$) and CES signals
- CES: combined energy scale using anticorrelation between $S_1$ and $S_2$ signals
**Neutron calibration**

- **Source:** *AmBe with 220n/s*
- **Determination of nuclear recoil band**
- **Further calibration lines from inelastic recoils in xenon**

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**Graphs:**

- Left graph: Neutrons with energy levels at 40 keV and 80 keV.
- Right graph: Various energy peaks at 40 keV, 80 keV, 164 keV, 236 keV with labels for different elements.

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Corrections on the S1 and S2 signals

- Data is corrected for:
  - S1 light collection
  - S2 XY-collection
  - Electron lifetime

- Sources used for corrections:
  - 40keV, inelastic line
  - $^{137}\text{Cs}$ (external)
  - 164 keV, activated xenon

→ Results from different sources compatible within few %
Electronic and nuclear recoil bands

- **Electronic recoil band**: defined with $^{60}$Co source
- **Nuclear recoil band**: defined with AmBe neutron source
- Discrimination better than 99% @ 50% nuclear recoil acceptance
Low energy calibration of xenon detectors

$^{83}\text{mKr}$ calibration source:
- EC decay-product of $^{83}\text{Rb}$
- Lines at 9.4 and 32.1 keV
- Uniform distribution

$^{83}\text{mKr}$ calibration planned in XENON100

Target mass: $\sim 0.1$ kg Xe
Volume: 3 cm drift length and 3.5 cm diameter
Two R9869 PMTs
6 pe/keV in double phase
→ at University of Zürich

Calibration of the nuclear recoil energy scale

- Nuclear recoil energy ($E_{nr}$):
  \[ E_{nr} = \frac{S_1}{L_y L_{eff}} \times \frac{S_e}{S_r} \]

  - $S_1$: measured signal in p.e.
  - $L_y$: LY for 122 keV $\gamma$ in p.e./keV
  - $S_e/S_r$: quenching for 122 keV $\gamma$/NR due to drift field

- Relative scintillation efficiency of NR to 122 keV $\gamma$ at 0-field
  \[ L_{eff} = q_{nucl} \times q_{el} \times q_{esc} \]

  - $q_{nucl}$: Linhard quenching
  - $q_{el}$: Electronic quenching
  - $q_{esc}$: Escape e$^-$'s at 0-field
Measuring the nuclear recoil scale

- Efforts within the collaboration to measure below 5 keV$_{nr}$

  → Columbia and Zürich chambers

  - First measurements done at Columbia!

  
  Discussions on Leff measurements:
  A. Manalaysay, arXiv:1007.3746
Overview of the data taking:

- Analysis of non-blinded data
- Main data sample (blinded) not yet analyzed!

- 11.17 life days
- Data selection based on stable conditions:
  - no activation
  - stable HV operation
  - low and constant Rn level

- Period:
  October-November 2009

- Cuts defined on calibration data: AmBe and $^{60}\text{Co}$
Cuts applied to the data

- **Signal/noise ratio cut**
- **Single S1 peak**: remove accidental coincidences
- **Single S2 peak**: select single scatter events
- **Remove events in gas phase**
- **Apply active veto cut**

- **Energy cut**: Select events with energies lower than $28\text{ keV}_{nr}$ (keV nuclear recoil equivalent)

**!! Self-shielding**: Most of the low energy events are located close to the edges of the detector

→ remaining events in fiducial volume: mostly intrinsic contamination
3-D position reconstruction:
- allows the selection of the inner part of the detector
  - events with energies below 28 keV

Current fiducial volume: cylindrical shape with 40 kg mass
→ will be further optimized
‘Background free’: in the 11.17 days after discrimination

Comparison to XENON10: for approximately the same exposure

→ much cleaner detector
Limit from non-blinded data analysis

- **Spin independent limit**: for standard halo parameters

- **Excellent sensitivity**: even for few days of data

  → Sensitivity to low WIMP masses depends on $L_{\text{eff}}$

- **Much more data recorded in blind mode**
  + analysis in the high nuclear-recoil energy region

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E. Aprile *et al.*, arXiv:1005.0380 accepted for publication in PRL
Future: XENON1T

- 1.2 ton fiducial mass (total of 2.4 ton LXe)
- Drift length = \( \sim 90 \) cm
- 100x background reduction
- Muon veto
- Copper/titanium cryostat
- New photo-detectors: QUPIDs

→ New collaborators
→ Currently working on MC simulations and design 
+ secure remaining funding

Timeline: 2010 - 2015
QUPIDS for light readout

- **QUartz Photon Intensifying Detector** (hybrid detector)
- Development by UCLA & Hamamatsu for LXe and LAr detectors

- Ultra-low radioactivity ($\sim 0.1$ mBq)
- High QE and high SPE resolution

- First test at UCLA
- QUPID working in LXe!
  $\rightarrow$ single electron response

K. Arisaka et al., Astroparticle Physics 31 (2009) 63
XENON1T @ LNGS (Hall B)
- 4 m water shield

XENON1T @ LSM
- solid shield (55cm poly, 20cm Pb, 15cm poly, 2cm ancient Pb, >99% muon veto)
XENON sensitivity

- XENON100 sensitivity for 6 000 kg days (200 d × 30 kg bg free)
- Capability to detect about 10 events for 100 GeV mass for a WIMP-nucleon cross section of $\sim 10^{-44}$ cm$^2$ within 2010
Liquid xenon is a promising detector material to discover dark matter

- Large nucleus ($A^2$ enhancement on $\sigma$)
- Dual-phase: particle discrimination and fiducialization
- Self-shielding (large detectors)

XENON100 is taking dark matter data

- Design low background level achieved!
- First non-blinded data analyzed
  - first results accepted for publication in PRL! arXiv:1005.0380
- New results coming ...

XENON1T currently under design