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. Highlights of run08

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7. 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

\[ M_\chi = 100 \text{ GeV}, \sigma_{\chi-p} = 10^{-45} \text{ cm}^2 \]
Noble gas scintillation process

Nuclear recoil

Ionization: $R^+$ and $e^-$'s

$R^+ + R \rightarrow R_2^+$

$R_2^+ + e^- \rightarrow R^{**} + R$

$R^{**} \rightarrow R^* + \text{heat}$

$R^* + R \rightarrow R_2^*$

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

Excitation: $R^*$

$R^* + R \rightarrow R_2^*$

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

Singlet: 19 ns, 5 ns, 3 ns

Triplet: 15 µs, 1.6 µs, 25 ns

Neon

Argon

Xenon
Two phase noble gas TPC

Electron recombination is stronger for nuclear recoils

→ Electron- / nuclear recoil discrimination

- Scintillation signal (S1)
- Charges drift to the liquid-gas surface
- Proportional signal (S2)
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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
US, Switzerland, Portugal, Italy, China, Germany, Holland, France and Israel
XENON100 detector

- 30 cm drift length and 30 cm Ø
- 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 Ø meshes
XENON100 detector

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1 inch PMTs
30 cm $\phi$ 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
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
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
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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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**Graphical Content:**

- **Chart 1:** Logarithmic plot of $\log_{10}(cS2/cS1)$ vs. $cS1$ [pe] showing peaks at 40 keV and 80 keV.
  - Note:Label: Neutrons

- **Chart 2:** Graph showing rate vs. energy with peaks at 40keV, 80keV, 110keV, 164keV, 236keV labeled with various isotopes of xenon.
  - Legend: Only Z cut, Z cut + R<120 mm

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**XENON100 experiment**

**München, 29/10/2010**
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
  - $^{137}$Cs (external)
  - 164 keV, activated xenon

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

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

- **$^{83m}Kr$** calibration source:
  - EC decay-product of $^{83}Rb$
  - Lines at 9.4 and 32.1 keV
  - Uniform distribution

- 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

$^{83m}Kr$ calibration planned in XENON100

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

- Columbia and Zürich chambers
- First measurements done at Columbia!

Discussions on $L_{eff}$ measurements:
A. Manalaysay, arXiv:1007.3746
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Overview of the data taking:

- Analysis of non-blinded data
- Main data sample still blinded

- 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 $^{60}$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

$\rightarrow$ 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_{nr}

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

- Excellent sensitivity: even for few days of data
- Sensitivity to low WIMP masses depends on $L_{\text{eff}}$

Spin independent limit: for standard halo parameters

Highlights of run08: Overview

Long data set being analyzed:

- New likelihood for anomalous pattern recognition
- New position reconstruction algorithms
- Improved corrections: XY and Z
- New analysis of sensitivity based on likelihood methods

→ preparing the unblinding for end of the year/beginning of next year
Highlights of run08: likelihood for anomalous patterns

Events leaking into the nuclear recoil band

Log Likelihood cut defined as 97.5% acceptance of the NR

- **Gamma-X events**: double scatters where one of them takes place in a charge insensitive region
 Highlights of run08: position reconstruction

SVM position reconstruction used for run07 analysis

Improved NN position reconstruction
Highlights of run08: new corrections

Run07 S2 XY correction determined with $^{137}\text{Cs}$ or 40 keV

Improved Run08 improved map, more statistics allow for finer binning
Future: XENON1T

- 1 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

Timeline: 2011 - 2014
Light readout

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

- Ultra-low radioactivity (∼ 0.1 mBq)
- High QE and high SPE resolution

Alternative solution
- Low radioactivity R11410 3” PMT
- High QE: > 34% at 175 nm
  → PMTs being currently tested at University of Zurich
**Status of location**

**XENON1T @ LNGS (Hall B)**
- 4 m water shield

**XENON1T @ LSM**
- solid shield (55cm poly, 20cm Pb, 15cm poly, 2cm ancient Pb, >99% muon veto)
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$^2$
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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 published, also arXiv:1005.0380
- Run08 data is being analyzed ($\sim 100$ days)
  - new results coming ...

XENON1T currently under design
- TDR submitted to Gran Sasso in October
Background in the low energy range

→ Lowest ever measured background rate in a dark matter experiment