Backgrounds and Sensitivity Expectations for XENON100

IDM08, Stockholm, August 19, 2008

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For the XENON100 Collaboration

LNGS collaboration meeting, Oct. 2007
The XENON Program

XENON R&D
ongoing

XENON10
2006-2007

XENON100
in progress

XENON1t
2009-2013
Reminder: Backgrounds in XENON10

- Dominated by contribution from detector materials:
- steel (~ 180 kg, $^{60}$Co), PMTs (89 R8520, U/Th/K/Co) and ceramic HV feed-throughs (U/Th/K)

2 cm radial cut (+ z-cut) → 5.4 kg LXe mass
⇒ background rate of 0.6 events/(kg d keV)

dru = events/(kg day keV)
The XENON100 Detector and Background Goals

- Factor ~100 reduction compared to XENON100:
  - 1 dru -> 10 mdru raw gamma BG

How?
- selection of ultra-low background materials for detector components and shields
- active LXe veto shield (100 kg) surrounding target on all sides
- reduce intrinsic $^{85}$Kr contamination to the required level (50 ppt)
- detector design: place cryogenics and feed-throughs outside the Pb/Poly shield
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- detector design: place cryogenics and feed-throughs outside the Pb/Poly shield
- improve shield by reducing poly activity with 5 cm of OFRP Cu

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Xenon100 Materials and Shields

- **Polish Lead:**
  - 15 cm, 27 t

- **French Lead:**
  - 5 cm, 6 t

- **Polyethylene:**
  - 20 cm, 2 t

- **Copper:**
  - 5 cm, 2 t

- **Cryostat (stainless steel)**
- **Bell (stainless steel)**
- **Veto PMTs and holders (Cu)**
- **TPC structure (PTFE)** (and PMTs inside)
- **LNGS student**
- **UZH postdoc**
- **Columbia student**

Support bars: stainless steel
Xenon100 Materials and Shields

- The shield is continuously flushed with N\textsubscript{2} to avoid events related to radon decays inside it
- The radon levels are continuously monitored (all written out to slow control)

![Image of radon detector (RAD7) and correlation graph between Rn concentration and DAQ rate.](image)

**Correlation between Rn values and DAQ rate**

Xenon100 BG rate, June 6-9, 2008

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XENON100 Material Screening

- Ultra-low background, 100 % efficient (2 kg) HPGe-spectrometer, operated at LNGS (plus detectors from LNGS screening facility)

- **Shield:** 5 cm of OFRP Cu (Norddeutsche Affinerie); 20 cm Pb (Plombum, inner 5 cm: 3 Bq/kg $^{210}$Pb), air-lock system and nitrogen purge against Rn, slow control for online monitoring of HV, N$_2$ flow rate, leakage current and LN level

- **Background spectrum:** < 1 event/(kg d keV) above 40 keV

- Screened all XENON100 detector/shield components for a complete BG model

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**Data:** stainless steel sample

**Background**
30 kg days (October 2007)
## XENON100 Material Screening

<table>
<thead>
<tr>
<th>Material*</th>
<th>$^{238}\text{U}$</th>
<th>$^{232}\text{Th}$</th>
<th>$^{40}\text{K}$</th>
<th>$^{60}\text{Co}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless Steel 1.5 mm (316Ti, Nironit; cryostat)</td>
<td>&lt;2 mBq/kg</td>
<td>&lt;2 mBq/kg</td>
<td>10.5 mBq/kg</td>
<td>8.5 mBq/kg</td>
</tr>
<tr>
<td>Stainless Steel 25 mm (316Ti, Nironit, cryostat)</td>
<td>&lt;1.3 mBq/kg</td>
<td>&lt;0.9 mBq/kg</td>
<td>&lt;7.1 mBq/kg</td>
<td>1.4 mBq/kg</td>
</tr>
<tr>
<td>PMTs (R8520-AL)</td>
<td>&lt;0.24 mBq/PMT</td>
<td>0.18 mBq/PMT</td>
<td>7.0 mBq/PMT</td>
<td>0.67 mBq/PMT</td>
</tr>
<tr>
<td>PMT Bases</td>
<td>0.16 mBq/pc</td>
<td>0.10 mBq/pc</td>
<td>&lt;0.16 mBq/pc</td>
<td>&lt;0.01 mBq/pc</td>
</tr>
<tr>
<td>Teflon (TPC)</td>
<td>&lt;0.3 mBq/kg</td>
<td>&lt;0.6 mBq/kg</td>
<td>&lt;2.3 mBq/kg</td>
<td>--</td>
</tr>
<tr>
<td>Poly I (shield)</td>
<td>&lt;3.8 mBq/kg</td>
<td>&lt;2.9 mBq/kg</td>
<td>&lt;5.88 mBq/kg</td>
<td>--</td>
</tr>
<tr>
<td>Poly II (shield)</td>
<td>2.43 mBq/kg</td>
<td>&lt;0.67 mBq/kg</td>
<td>&lt;4.66 mBq/kg</td>
<td>--</td>
</tr>
<tr>
<td>Polish Pb (outer shield)</td>
<td>&lt;5.7 mBq/kg</td>
<td>&lt;1.6 mBq/kg</td>
<td>14 mBq/kg</td>
<td>&lt;1.1 mBq/kg</td>
</tr>
<tr>
<td>French Pb (inner shield)</td>
<td>&lt;6.8 mBq/kg</td>
<td>&lt;3.9 mBq/kg</td>
<td>&lt;28 mBq/kg</td>
<td>&lt;0.9 mBq/kg</td>
</tr>
</tbody>
</table>

* only a selection is shown here, all PMTs are screened and show consistent values; also screened: copper, cables, screws, ...

** thanks also to Matthias Laubenstein (LNGS screening facility)

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## Gamma Background Predictions from MC Simulations

<table>
<thead>
<tr>
<th>Material</th>
<th>Rate [mdru]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless steel (cryostat, 65 kg)</td>
<td>2.01 ± 0.22</td>
</tr>
<tr>
<td>Teflon (TPC, 10.7 kg)</td>
<td>0.18 ± 0.02</td>
</tr>
<tr>
<td>PMTs (including bases, 242)</td>
<td>4.91 ± 0.60</td>
</tr>
<tr>
<td>Polyethylene (shield, 2t)</td>
<td>2.50 ± 0.29</td>
</tr>
<tr>
<td>Copper (shield, 2t)</td>
<td>0.026 ± 0.002</td>
</tr>
<tr>
<td>Total*</td>
<td>9.63 ± 0.70</td>
</tr>
</tbody>
</table>

*dominant background rate before S2/S1 discrimination in fiducial mass

dru = events/(kg day keV)
Gamma Background Predictions from MC Simulations

Total single scatters in fiducial volume

- total rate
- Stainless steel
- Teflon
- PMT
- Polyethylene

Count rate [events/(kg day keV)]

Energy [keV]

Average rate in 4.5-30 keV, Veto Threshold > 20 keV (DRU)

Radius [mm]

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Neutron Backgrounds: MC Simulations

- Internal neutron BG from detector materials + shield, from (α,n) and fission reactions
- Numbers based on detailed MC, with measured U/Th activities of all materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Total n-rate [yr⁻¹]</th>
<th>Single NR rate [μdru]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless steel</td>
<td>17.7</td>
<td>0.29</td>
</tr>
<tr>
<td>Teflon</td>
<td>28.0</td>
<td>0.58</td>
</tr>
<tr>
<td>PMTs</td>
<td>7.0</td>
<td>0.32</td>
</tr>
<tr>
<td>LXe</td>
<td>0.81</td>
<td>0.007</td>
</tr>
<tr>
<td>Copper</td>
<td>1.6</td>
<td>0.01</td>
</tr>
<tr>
<td>Poly shield</td>
<td>416.3</td>
<td>0.49</td>
</tr>
<tr>
<td>Polish Pb</td>
<td>5805.8</td>
<td></td>
</tr>
<tr>
<td>French Pb</td>
<td>416.3</td>
<td>0.38</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>~ 1.74</strong></td>
<td></td>
</tr>
</tbody>
</table>

=> ~ 0.6 single NRs/year in FV (~ 44% of events are singles)

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WIMP rate versus neutron background

- assumptions:
  - spin-independent WIMP-nucleon cross section: $2 \times 10^{-45}$ cm$^2$
  - local WIMP density: 0.3 GeV/cm$^3$
Preliminary Background from XENON100 Data

Data and Monte Carlo predictions are in good agreement for overall rate
Expected Sensitivity for WIMPs and SUSY Predictions

- **Spin-independent**
  - WIMP Mass [GeV/c^2]
  - Cross-section [cm^2] (normalised to nucleon)

- **Spin-dependent (pure n-couplings)**

  - Many SUSY models

XENON10 limit: PRL100, 021303 (2008)

XENON10 limit: arXiv:0805.2939 accepted in PRL08
Expected sensitivity for heavy Majorana Neutrinos

XENON100: expected number of events in $50 \text{ kg x 300 days}$

XENON10: expected number of events in $5.4 \text{ kg x 58.6 days}$

$\Rightarrow M_{\nu M} < 9.4 \text{ GeV and } > 2.2 \text{ TeV}$

arXiv: 0805.2939
accepted in PRL08
Expected Sensitivity for WIMPs and UED Predictions

\[ \Delta q_i = \Delta m / m_{\gamma_1} \]

**Spin-independent**

LHC reach in 4l+E\_T channel

**Spin-dependent**

WMAP5 region
(WIMPs make 100% of the dark matter)

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Conclusions and Outlook

• XENON100 is in commissioning phase at LNGS
  ➡ strong effort to reduce backgrounds by factor 100 compared to XENON10

• electromagnetic background: dominated by PMTs, stainless steel cryostat and poly shield
  ➡ room for improvement (lower-activity poly, Cu cryostat, lower BG PMTs)

• nuclear recoil background dominated by internal neutrons from material
  ➡ less than 1 single NR/year predicted for ~ 46 kg fiducial mass
  ➡ muon induced NR background under study (expected to be negligible)

• preliminary data from XENON100 => overall background as expected based on MCs
  • extrapolated sensitivity to WIMPs is ~ $2 \times 10^{-45}$ cm$^2$ for SI couplings for ~7 months exposure

• XENON100 has a fantastic discovery potential for dark matter particles of galactic origin
  and can test many theoretical models of particle physics beyond the Standard Model
End
Neutron background from the rock and concrete

U/Th activities taken from measurements of LNGS Hall A (similar to XENON10 location)

⇒ (5.0 ± 1.0) single nuclear recoils/year in 63 kg LXe
⇒ (2.5 ± 0.9) single nuclear recoils/year in 46 kg LXe

additional water/PE shield outside the Pb is being added to reduce this background component to negligible levels
Neutrons from Materials

- single nuclear recoils from neutrons generated by (alpha,n) and fission reactions in detector and shield materials
Next Step: XENON1t

- Studies in progress for 3 ton (1 ton fiducial) LXe detector
- Possible location: inside LVD SN neutrino detector at LNGS -> active veto for $\mu$-induced neutrons
- Gamma flux inside LVD structure: 10-20 times lower than in main halls (detailed mapping of gamma and neutron background in progress)