XENON Experiment
Development of Xe Dual Phase Prototype for Dark Matter Detection

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see information at
http://www.astro.columbia.edu/~lxexe/XENON/
http://particleastro.brown.edu/
XENON Dark Matter Collaboration

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Very Typical WIMP Signal

- Low Thresholds Vital

Graph shows integrated event rates for $E > E_r$ for Xe (green), Ge (red) and S (blue).

Large nuclei enhanced by nuclear coherence, however, in reality $\ll A^2$ ...

\[ \frac{dN}{dE_{r}} \]

Example cross-section shown is at current (90%) exclusion limits of existing experiments.

Xe WIMP rate for $E_r > 16$ keVr is

1. within factor 2 of maximum achievable rate ($E_r > 0$)
2. equivalent kg/kg to low threshold Ge detector
3. 5x better kg/kg than light nucleus (e.g. S in CS$_2$)

Graph: $m_W = 100$ GeV, $\sigma = 3.6 \times 10^{-42}$ cm$^2$
XENON Event Discrimination: Electron or Nuclear Recoil?

Within the xenon target:

- Neutrons, WIMPS => Nuclear recoils
  => Scintillation, little ionisation
- , e-, , (etc) => Electron recoils
  => Scintillation, substantial ionisation

Ionisation electrons are drifted by field $E_{GC}$ and extracted to the gas phase by field $E_{AG}$.

Due to increase in field $E_{AG}$ around anode wires electrons increase kinetic energy => proportional scintillation via collisions with gaseous Xe.

The result is a large proportional light signal, which gives event-by-event discrimination against background.
Addition of CsI Photocathode at base

A Tertiary signal can be generated from absorbing primary photons into CsI photocathode

- Efficiency very good
  - Geometry Solid Angle
  - In Liq (No TIF transmission loss)
  - CsI QE 30%

Note: 16 keV nuclear recoil:
  \( \approx 200 \) photons before applying efficiencies for geometry and PMT QE.

Also ionization signal
  \( \approx 7-20 \) electrons
  (assumes high field 8 kV/cm)
## SUMMARY OF PARAMETERS FROM EXISTING MEASUREMENTS

<table>
<thead>
<tr>
<th>Condition</th>
<th>Zero Field 0 V/cm</th>
<th>High Field 8 kV/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GAMMA EVENT - 1 keV electron equivalent energy</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UV Photons</td>
<td>60-75 UV</td>
<td>20-30 UV</td>
</tr>
<tr>
<td>Electrons+Ions</td>
<td>[60-75 elec]</td>
<td>50-60 elec</td>
</tr>
<tr>
<td><strong>NUCLEAR RECOIL EVENT - 1 keV recoil energy</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UV Photons</td>
<td>12-18 UV</td>
<td>11.6 UV</td>
</tr>
<tr>
<td>Electrons+Ions</td>
<td>[12-18 elec]</td>
<td>0.4-1.2 elec</td>
</tr>
<tr>
<td><strong>EFFECTIVE (NR/GAMMA) &quot;QUENCHING FACTOR&quot;</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UV Photons</td>
<td>20-25%</td>
<td>30-50%</td>
</tr>
<tr>
<td>Electrons+Ions</td>
<td>[20-25%]</td>
<td>0.8-2%</td>
</tr>
</tbody>
</table>

• Summary
  
  The ranges shown reflect spread in existing experimental measurements
  
  Note that the table considers signal from either 1 keV gamma or nuclear recoil event
  
  60 excitations / keV is equivalent to ~16 eV / excitation
  
  Zero field electron-ion #’s in [ ] are inferred, but are signal is not measured (extracted) directly
The XENON Experiment: Design Overview

- Dual Phase Liq/Gas Xe
- The XENON design is modular. Multiple 3D position sensitive LXeTPC modules, each with a 100 kg active Xe mass --> 1-tonne scale experiment.
- The 100 kg fiducial LXe volume of each module is shielded by additional 50 kg LXe. Active shield very effective for charged and neutral background rejection.

Currently - R&D towards 10 kg prototype.
Deployment goal: 100 kg
The Columbia LXeTPC - DM Prototype “0”

- **LXeGrit balloon telescope**
- 30 kg active Xe mass
- 20 x 20 cm² active area
- 8 cm drift with 4 kV/cm
- Charge and Light readout
- 128 wires/anodes ADC
- 4UV PMTs
XENON R&D Program

- Single Phase (Liq) + 2-10 cm Q drift (Qamp readout)
  - Testing different PMTs (Mech/QE/Elec)
  - Data for Light Collection Model
    (included Teflon reflectors)
    - Q drift good with teflon
  - Check Xe Contamination of components
  - DAQ Config.

- Dual phase, 1 cm Q drift (Prop scin readout)
  - PMT in gas
  - Study Electric Fields
  - Light Collection
  - Extra CsI Cathode

- Additionally
  - \( \approx 10 \text{ cm drift length measurements} \)
    - Demonstration of good electron drift with Teflon

- Also new setups being built at Brown, Princeton, Rice

- Construction of new Columbia 10 kg prototype underway
  - 7 PMTs
  - Pulse-tube cooled cryostat
Two Phase System (Columbia/ K. Ni)

$^{207}\text{Bi}$ Primary Scintillation

$^{207}\text{Bi}$ Proportional Light (Q)

Signal size increases by 6x after putting in Teflon
Single Phase

Just add Liq Xe & 662 keV ‘s
Xenon Purity

• Need to drift charge $>>1$ cm places most severe constraint on Xe purity
  
  Electronegative impurities $<1$ ppb level
  This is more stringent than levels required for observation of UV scintillation only

• Routinely achieving required levels
  
  Using SAES Getter (Also evaluating Ti arc getter)
  Chamber baked $\sim 70$ degC / pipes somewhat hotter

• Now evaluating contamination arising from various new components being introduced
  
  Steps to reduce contamination
  e.g. PMT bases -> Ceramic -> Kapton
  Cables replaced / PMT enclosures scrubbed
# Hamamatsu PMT Selection (Baseline design)

<table>
<thead>
<tr>
<th>Model</th>
<th>Photo (not same scales)</th>
<th>Dimension &amp; QE</th>
<th>Radioactive Background * [mBq/tube]</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>R6041</td>
<td></td>
<td>ø5 cm x 4 cm QE 5-8%</td>
<td>6000 mBq (Dominated by glass seal at base)</td>
<td>Specifically designed for ops in LiqXe TPC</td>
</tr>
<tr>
<td>R9288</td>
<td></td>
<td>ø5 cm x 4 cm QE 20%</td>
<td>150 mBq (Use of Kovar for most of base)</td>
<td>Evolution of 6041</td>
</tr>
<tr>
<td>R8520</td>
<td></td>
<td>(2.5 cm)² x 3.5 cm QE &gt;20%</td>
<td>15 mBq</td>
<td>Square/quad anode-good fill factor. Columbia tested at 150K/4 atm</td>
</tr>
<tr>
<td>R8778</td>
<td></td>
<td>ø5 cm x 12 cm QE 26%</td>
<td>31 mBq (expect further improvement)</td>
<td>Designed for XMASS. Columbia tested at 150K/4 atm</td>
</tr>
</tbody>
</table>

* 1 mBq/ø5cm project goal
Advanced readout schemes - Summary

- **Charge readout**
  - GEMs (Rice)
  - MWPC (Princeton)

- **Light detectors**
  - Burle MCP (Brown)
    - Constructed new cryogenic housing for MCPs
    - Expect first test in Liq Xe in Aug
  - Hamamatsu low-background PMTs
    - Quartz windows, limited ceramics
    - Backgrounds $\approx 10$ mBq/PMT - 1000 x better than standard.
  - LAAPD (Brown)
  - CsI (Columbia)

(A. Bondar et al., prepr. physics/0103082)
Removing Kr (+Ar) with chromatographic adsorption

- $^{85}$Kr in Xe
  - Xe Commercial grade 5-10 ppm Kr
  - Projection for $10^{-46}$ cm$^2$ sensitivity needs 100 ppt Kr
    - Goal 1 ppt possible
- Chromatographic separation:
  - Kr moves through column faster
  - Use He (or Ne) carrier gas
- Princeton Group

![Graph showing adsorption constant](image)

Graph showing Xe & Kr separation in 30 stage charcoal column

- Xe, cycle=0.1 tau
- Kr at 0.9 of cycle
- Kr at 0.95 of cycle

Position in column

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10 kg Dual Phase Prototype System

- Construction started of 10 kg dual phase system (assemble Aug ‘03)
- Temperature Control Using Pulse Tube Cooler
- Mechanical region for 7 x Ø5cm photodetectors - can accommodate different length PMTs discussed
- Fiducial / Drift Region ≥10 cm deep
- Note: Materials are not low background selected (this is next phase)
XENON Collaboration Summary

- Routinely Operating Two Xe Test Rigs at Columbia
  Additional rigs being constructed at Rice / Princeton / Brown

- Testing Components for 10 kg Prototype
  Baseline Design
    - Two phase demonstrated / necessary fields being studied
    - Collecting Data for Light Propagation Monte Carlos
    - PMT Selection - improvements in QE & radioactive backgrounds
    - Xe Purity - Q drift - routinely achieved (but often perturbed when inserting new components)

  Additional Technologies being investigated
    - Photodetectors / Alternative Q readout

- Building 10 kg Prototype
  Two phase with ≥7 PMTs and 10 cm drift
  Neutron measurement and gamma discrimination
  Test additional technologies/materials needed for low background version
Current & Next Generation Experiments & SUSY Theory Range

http://dmtools.brown.edu

Edelweiss (June 2003)
~0.25 event/kg/d

~1 event/kg/yr

~ 1 event/100 kg/yr