Measurement of low energy Electronic Recoil Response and Electronic/Nuclear Recoils Discrimination in XENON100

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Introduction

- Scintillation signal $S_1$
- Charge signal $S_2$
- Different $S_2/S_1$ for ER/NR

\[ g_1 = \frac{S_1}{N_{ph}}, \quad g_2 = \frac{S_2}{N_e} \]

- Primary scintillation gain $g_1$
- Secondary scintillation gain $g_2$
- $g_1$ is proportional to photon detection efficiency (PDE)
Calibration source & detector condition:
- CH$_3$T calibration (<18.6 keVee, ER)
- AmBe calibration (NR)
- 3 different drift and extraction fields

### Data Extraction

<table>
<thead>
<tr>
<th></th>
<th>Drift field(V/cm)</th>
<th>Extraction field(kV/cm)</th>
<th>Electron lifetime(us)</th>
<th>Max drift time(us)</th>
<th>Events in sub-FV($10^4$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH$_3$T</td>
<td>400</td>
<td>10.0</td>
<td>1470 ± 190</td>
<td>182</td>
<td>43.4</td>
</tr>
<tr>
<td>CH$_3$T</td>
<td>167</td>
<td>8.2</td>
<td>390 ± 160</td>
<td>202</td>
<td>11.9</td>
</tr>
<tr>
<td>CH$_3$T</td>
<td>100</td>
<td>8.2</td>
<td>590 ± 30</td>
<td>220</td>
<td>8.9</td>
</tr>
<tr>
<td>AmBe</td>
<td>400</td>
<td>10.0</td>
<td>1490 ± 100</td>
<td>182</td>
<td>3.5</td>
</tr>
<tr>
<td>AmBe</td>
<td>167</td>
<td>8.2</td>
<td>490 ± 130</td>
<td>202</td>
<td>3.6</td>
</tr>
<tr>
<td>AmBe</td>
<td>100</td>
<td>8.2</td>
<td>550 ± 60</td>
<td>220</td>
<td>6.5</td>
</tr>
</tbody>
</table>

To compare with different PDE:
- 7 sub-FVs (‘small detector’):
  - 50% quantile in $R^2$ direction, equal in drift time
  - Enough statistics in each sub-FV
  - Avoid strong field distortion in top and bottom region
- No position dependent correction of S1 and S2:
  - Small S1 and S2 variation in each sub-FV (6% for S1, 5% for S2)
  - PDE increases from top part to bottom part
Detector calibration \((g_1, g_2)\)

Calibration principle:
Doke method

\[ E = W \cdot \left( \frac{S_1}{g_1} + \frac{S_2}{g_2} \right), \quad W = 13.7\text{eV} \]

\[ \frac{S_2}{E} = -\frac{g_2}{g_1} \frac{S_1}{E} + \frac{g_2}{W} \]

**\(129\,^{m}Xe\)**
- \(E = 319.9\,\text{keV}\)
- \(S_2/E = 236.1\,\text{keV}\)

**\(131\,^{m}Xe\)**
- \(E = 163.9\,\text{keV}\)

**\(131\,^{m}Xe\)**
- \(E = 80.2\,\text{keV}\)

**\(83\,^{m}Kr\)**
- \(E = 41.5\,\text{keV}\)

\[ g_1 = (0.055 \pm 0.002) \, \text{PE/ph} \]
\[ g_2 = (8.09 \pm 0.39) \, \text{PE/e} \]
Detector calibration ($g_1$, $g_2$)

Calibration result:
- $g_1$ z dependence due to geometry effect
- $g_2$ z dependence due to electron lifetime
- $g_1$ is consistent under different drift fields
- $g_2$ increases with larger extraction field

$$
\begin{align*}
E_d &= 100 \text{ V/cm}, \ E_{ex} = 8.2 \text{ kV/cm} \\
E_d &= 167 \text{ V/cm}, \ E_{ex} = 8.2 \text{ kV/cm} \\
E_d &= 400 \text{ V/cm}, \ E_{ex} = 10.0 \text{ kV/cm}
\end{align*}
$$

![Graph showing $g_1$ and $g_2$ vs. FV number]
Simulation model

Excimer production
Binomial
$N_{ex} \sim B(N_q, \alpha/(1 + \alpha))$

Fano fluctuation
Gaussian
$N_q \sim N(E/W, \sqrt{FE/W})$
$F = 0.059$

Recombination fluctuation
Gaussian
$r \sim N(<r>, \Delta r)$

Recombination
Binomial
$\sim B(N_i, r)$

Photon detection
Poisson

Electron drift & extraction
Binomial
$\sim B(N_e, \varepsilon_d \cdot \varepsilon_{ex})$

$r$: recombination factor
$<r>$: average recombination fraction ($<r>$ is tuned)
$\Delta r$: recombination fluctuation ($\Delta r/<r>$ is tuned)
MC-data matching

Use Binned Maximum Likelihood Estimation (MLE) in Log10(S2/S1) vs S1 space to extract ER response
Light yield

- Lower light yield at higher drift field as expected
- Consistent with LUX measurement
- Light yield deviates from NEST at high energy, especially at high drift fields
Recombination fluctuation

No significant change observed between different drift fields

- d) 100 V/cm
- e) 167 V/cm
- f) 400 V/cm

Energy [keV]

Best estimation
±1σ fitting uncer.
Credible region
LUX @ 180 V/cm
ER/NR discrimination

- Normalize S1 to photons generated to compare ER leakage under different g1
- S2 is corrected for electron lifetime
ER/NR discrimination

ER leakage is smaller at larger $g_1$

![Graph showing ER leakages for different $g_1$ values.](image-url)
ER/NR discrimination for different $g_1$ and drift fields

- S1 range (100-400 photons), energy range (11-34 keVnr)
- ER leakage is smaller at larger $g_1$
- No significant difference for ER leakage between 100 V/cm and 400 V/cm drift field
Summary

• Light yield and recombination fluctuation for low energy under three drift field are measured
  • Light yield under 100 and 167 V/cm are consistent with LUX measurement

• ER leakage is smaller for larger photon detection efficiency

• No significant difference in ER leakage is observed between 100 V/cm and 400 V/cm drift field

• The paper will be available on arXiv next week
Back up

- Drift field increases:
  - ER/NR separation increases
  - ER band width increases
- \( g_1 \) increases:
  - ER/NR separation doesn’t change significantly
  - ER band width decreases
Recombination factor

\[
\langle r \rangle = \frac{n_{\gamma} n_{e}^2}{n_{\gamma e}}
\]

Energy [keV]

100 V/cm
167 V/cm
400 V/cm

Black: 180 V/cm
Blue: 105 V/cm

LUX Collaboration
arXiv: 1512.03133
**P-value**

- $0 < S_1 < 10$: $P$-value = 0.01
- $10 < S_1 < 20$: $P$-value = 0.16
- $20 < S_1 < 30$: $P$-value = 0.10
- $30 < S_1 < 40$: $P$-value = 0.37
- $40 < S_1 < 50$: $P$-value = 0.38