Low mass dark matter searches with sub-keV Germanium detectors

- **Experimental Programs**
  - TEXONO @ Kuo-Sheng Reactor Neutrino Laboratory (KSNL), Taiwan.
  - CDEX-1 @ China Jin-Ping Underground Laboratory (CJPL), China.

- **Point Contact Germanium Detectors**

- **Analysis: Bulk/Surface Event Selection**

- **Light WIMP Results**

Arun Kumar Soma
Institute of Physics, Academia Sinica
Taipei, Taiwan

H. B. Li et al., Astroparticle Physics 56, 1, 2014.
Experimental Configuration

- ~30 mwe overburden
- 28m away from the core

Kuo-Sheng Reactor Neutrino Laboratory

China Jin-Ping underground Laboratory (CJPL)

- ~2400m rock over burden
- Drive –in Tunnel access.
Sub-keV Sensitive Point Contact Germanium detectors

Baseline Design

Note: Outer cosmic-ray plastic scintillator is only for KSNL

p-PCGe detector
(1 kg Modular Mass)

Origin for Surface and bulk events

(n+ Surface Electrode
Dead Layer Thickness ~1 mm
Active Volume
p+ Point Contact
Bulk Event
Surface Event
(Partial Energy Deposit, Slow rise time)
Data Processing Towards Enhancement of Signal to Noise Ratio

Event Selection Criteria

- **Signal Inhibit events** are vetoed.
- **Events** uncorrelated with cosmic-ray and anti-Compton detector
- **Physics Vs Electronic noise: PSD & Timing**
  - Events with well behave pedestal and pedestal tail.
  - Events with linear voltage and charge deposition.
- **Surface – Bulk events**: Fast Amplifier Pulse.

**Pre-Amplifier Output**

**Shaping Amplifier Output (@ 6μs)**
Bulk and Surface Events Identification in p-PCGe

Timing Amplifier Output

Savitzky - Golay Filter

\[ \frac{1}{2} A_0 \times \tanh \left( \frac{t - t_0}{\tau} \right) + P_0 \]

Thickness of Dead Layer = 1.16 ± 0.09 mm

(\(^{133}\text{Ba}\) source) Ref: NIMA 701 176 (2013)
Bulk and Surface Events Selection Efficiency Measurement

\[
B = \epsilon_{BS} \cdot B_0 + (1 - \lambda_{BS}) \cdot S_0 \\
S = (1 - \epsilon_{BS}) \cdot B_0 + \lambda_{BS} \cdot S_0 \\
B_0 + S_0 = B + S.
\]

\[
B_0 = \frac{\lambda_{BS} \cdot B - (1 - \lambda_{BS}) \cdot S}{(\epsilon_{BS} + \lambda_{BS} - 1)} \\
S_0 = \frac{\epsilon_{BS} \cdot S - (1 - \epsilon_{BS}) \cdot B}{(\epsilon_{BS} + \lambda_{BS} - 1)}
\]

To obtain \((\epsilon_{BS}, \lambda_{BS})\) requires at least two measurements of \((B, S)\) where \((B_0, S_0)\) are known.

**Approach**

- **Very Surface Rich events with \(\gamma\)-ray sources** \((^{241}\text{Am})\); \(B_0\) from MC.
- **Surface Rich events with \(\gamma\)-ray sources** \((^{137}\text{Cs})\); \(B_0\) from MC.
- Cs and Am represents two extreme cases of \(\gamma\)-background.
- **Bulk Rich Cosmic-ray induced high energy neutrons**;
  - \(B_0\) from n-PCGe detector (**no anomalous Surface-Bulk events**).
- CDEX-1 employs \(^{60}\text{Co}\) instead of cosmic ray neutron.
BS Efficiency Measurement: Solving Coupled Equations

Bulk-rich comic induced high energy neutrons determines: $\varepsilon_{BS}$

Surface-rich ($^{241}\text{Am}$) determines $\lambda_{BS}$
BS Efficiency Measurement: Solving Coupled Equations

Cross-Check
Consistent with flat MC expectation

Anti-Compton tagged spectrum
Bulk and Surface Events Selection Systematic Error

Total Error = \( \frac{\text{Stats. Error of } (B, S)}{\varepsilon_{BS} + \lambda_{BS} - 1} \otimes (\Delta\lambda_{BS}, \Delta\varepsilon_{BS}) \otimes \text{Sys. Error} \)

- Stats. Error significant because of \((\varepsilon_{BS} + \lambda_{BS} - 1)\).
- Among the Sys. Err. the dominant contribution comes from difference in calibration and background.
- \(< 33\%\) of total errors, (6\% Increase in total error).

<table>
<thead>
<tr>
<th>Energy (keVee)</th>
<th>0.50 – 0.55</th>
<th>0.95 – 1.00</th>
<th>1.90- 1.95</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate and Errors (cpkkd)</td>
<td>10.6 ± 5.3</td>
<td>9.8 ± 2.4</td>
<td>6.1 ± 1.6</td>
</tr>
<tr>
<td>Statistic Error</td>
<td>90%</td>
<td>95%</td>
<td>98%</td>
</tr>
<tr>
<td>(\Delta\lambda, \Delta\varepsilon) contribution</td>
<td>24 %</td>
<td>6.3%</td>
<td>3%</td>
</tr>
<tr>
<td>Systematic from (\varepsilon, \lambda)</td>
<td>37%</td>
<td>31%</td>
<td>18%</td>
</tr>
<tr>
<td>Choice of (\tau_0)</td>
<td>11%</td>
<td>25%</td>
<td>9%</td>
</tr>
<tr>
<td>Fiducial Mass</td>
<td>3%</td>
<td>6%</td>
<td>6%</td>
</tr>
<tr>
<td>Normalization Range</td>
<td>12%</td>
<td>10%</td>
<td>7%</td>
</tr>
<tr>
<td>Normalization Scale</td>
<td>8%</td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td>Choice of discarded region</td>
<td>5%</td>
<td>1%</td>
<td>0.1%</td>
</tr>
<tr>
<td>Source of Calibration</td>
<td>33 %</td>
<td>16%</td>
<td>14%</td>
</tr>
</tbody>
</table>

- Analysis Threshold of 500 eV\text{ee}
- Fiducial Mass: 0.84 kg
- Data Size: 39.5 kg-days

- Flat background Subtraction
- QF by TRIM Software
- Standard Cosmological parameters

Residual Background Error in 500–800 eV\text{ee} is: 1.29 cpkd
CDEX-1 Result on Light WIMP

Analysis Threshold of 475 eVee; Fiducial Mass: 0.92 kg; Data Size: 53.9 kg-days

<table>
<thead>
<tr>
<th>Features</th>
<th>TEXONO (surface)</th>
<th>CDEX-1 (underground)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intensity of Ga X-ray (cpkd)</td>
<td>46</td>
<td>14</td>
</tr>
<tr>
<td>Bkg @ 2keVee (cpkkd)</td>
<td>3.9</td>
<td>3.8</td>
</tr>
<tr>
<td>Residual Bkg error @ Thrs. -800 eVee cpkd</td>
<td>1.29</td>
<td>0.64</td>
</tr>
<tr>
<td>$\chi N$ sensitivity at 8 GeV</td>
<td>An improvement by factor of 6</td>
<td></td>
</tr>
</tbody>
</table>
✓ A systematic surface/bulk effect analysis on p-PCGe has been performed by devising new calibration schemes.

✓ CDEX -1 results are consistent with the understood sub-keV background model. The excess sub-keV background at TEXONO is not WIMP induced and its origin is intensively pursued.

✓ R & D efforts at TEXONO is towards achieving the goal of ~O(100 ev) threshold detector for the observation of neutrino-nucleus coherent scattering at reactor.

✓ CDEX1 → CDEX10 → CDEX 1Ton at CJPL towards light WIMP searches (and double beta decay studies).

Thank You