Summary of Low Background / Low Threshold Detectors

Conveners: Juan Estrada and Noah Kurinsky

Phil Barbeau 3/22/2021
Priority Research Directions

• #5: Develop new modalities for signal detection

• #6: Improve understanding of detector microphysics and characterizations

• #14: Advance the state of the art in low-threshold Quantum Calorimeters

My apologies if I missed any that apply

One of they drivers in the related fields is the energy resolution and threshold.

There is an increasing emphasis on background reduction, particularly those caused by instrumentation.

Fundamentally a technology driven field.
Low Threshold SuperCDMS (motivated by CEvNS and light WIMPs)

HVeV Single electron phonon mediated detectors

- Developed in Blas Cabrera group at SU
- Use 1 cm$^2$ 0.4 cm thick Si: $\sim 1$ g
- Use CDMS QET design $T_c \sim 35$ mK
- CDMS HV technology @ 160 Volts.
- Monochromatic Laser light: 640 nm
- Achieved $\sim 0.1$ e-h pair resolution.
- Clear single electron resolution!

M. K. Romani et al., Appl. Phys. Lett. 112, 043501 (2018);
https://doi.org/10.1063/1.5010699
Low Threshold SuperCDMS (motivated by CEvNS and light WIMPs)

Andrew Jastram

25mm Diameter (4mm thick) Inner Detector
Low Threshold SuperCDMS (motivated by CEvNS and light WIMPs)

Rupak Mahapatra

Hybrid HV Detector Principle

Main idea: Monolithic detector with a low voltage (LV) and high voltage (HV) sides: LV to measure primary phonons like ZIP and HV to measure NTL phonons. Minimize HV to LV NTL phonon pollution using geometric suppression at the neck

NTL Phonons

Electron Recoil (ER) 1σ ER band Nuclear Recoil (NR) 1σ NR band

$E_R$ in keV_{ee}
Skipper CCDs: CONNIE’s non-destructive, multiple charge measurements

Reactor OFF low energy spectrum after selection cuts

- Event selection criteria using the reactor OFF data:
  - Reject noise events: energy core > 0.045 eVee.
  - Reject LLE events and optimally size of events < 0.95 pixels.
- After this selection we can open.
NEWS-G: New Low Energy Calibration Facility

Jean-Francois Caron

2019 Results

Lessons: need to reduce smearing from:
- LiF target itself (~1 μm)
- cooling system (~cm H₂O, Al)
- detection of reflected neutrons

Inconclusive results with:
- angular distribution of neutrons
- neutron spectrum

Neutron Production Threshold

\[ f(x) = \frac{A}{\sigma} \text{erfc} \left( \frac{X-x}{\sigma} \right) \]

- Test 1: \(A = 25.2 \pm 0.4\)
- Test 2: \(\mu = -1.8562 \pm 0.0005\) MeV
- Test 3: \(\sigma = 0.0137 \pm 0.0006\) MeV

Effective width and offset of proton beam
Low Work Function Semiconductors: improve threshold and resolutions

David Winn

<table>
<thead>
<tr>
<th>Z</th>
<th>ρ (g/cc)</th>
<th>E_gap (eV)</th>
<th>E_pair</th>
<th>μ_eV / μ_hole cm²/V/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ge</td>
<td>32</td>
<td>5.3</td>
<td>0.7</td>
<td>2.98</td>
</tr>
<tr>
<td>Si</td>
<td>14</td>
<td>2.3</td>
<td>1.1</td>
<td>3.6</td>
</tr>
<tr>
<td>GaAs</td>
<td>31,33</td>
<td>5.3</td>
<td>1.4</td>
<td>4.4</td>
</tr>
<tr>
<td>Cs₃Sb (S-11)</td>
<td>55,51</td>
<td>4.6</td>
<td>1.6</td>
<td>2.0</td>
</tr>
<tr>
<td>Ag-O-Cs (S-1)</td>
<td>55,47,8</td>
<td>7.1</td>
<td>&lt;0.3</td>
<td>0.4-0.7</td>
</tr>
</tbody>
</table>

Summary:

- Low Workfunction Semiconductors normally used as photocathodes: potential as low energy calorimetric diode or drifted ionization detectors.

- Cs₃Sb has potential to be a room temperature alternative to Si diodes or even Si APD. A “Cs₃SbPM” alternative to SiPM would not need much cooling in many applications.

- Cs₃Sb and Ag-O-Cs have potential to be higher rate detectors than Si due to the high mobility and nearly equal electron and hole mobilities.

- Ag-O-Cs may offer sub-eV energy deposition detection.

- Cs₃Sb and Ag-O-Cs - in thin film photocathodes - are radiation resistant.
**Xe (Ar) detectors – trace impurities photo-synthesis reactors**

- Impurities in liquid gases can make molecular aggregates and radicals that are not existing in gas phase.
- Molecules which will react in exothermal reaction in gas can form a low energy hydrogen bond - form a stable complex with excessive chemical energy.*
- **Our hypothesis:** in liquid Xe (Ar) impurities and radicals can form metastable clusters with chemical energy to release several electrons and photons (nano-explosives).

*“Spectroscopy of molecules and molecular complexes dissolved in liquid gases: Structure and reactivity”, published in Russian Chemical Reviews, 57 (8), 1988
NEXT: Background reduction by tagging daughter Ba daughter

"BOLD" concept with fully active cathode, SiPM-based tracking and Energy Barrel Detector

Barium Tagging Detector (BTD)  Energy Barrel Detector (Optical Fibers)

Ba$^{2+}$ e$^-$ e$^-$ e$^-$

Cathode (0V)  EL (+HV)

LASER  CCD
Cosmogenic Activation Measurements for Active Detector Materials

Richard Saldanha

LANSCE ICE-HOUSE Neutron Beam

Los Alamos Neutron Science Center (LANSCE) Weapons Neutron Research (WNR) Facility has a neutron beam (4FP30R ICE-HOUSE II) that is very similar in spectral shape to the cosmic ray spectrum.

The good agreement in spectral shape between 10–500 MeV allows for low-uncertainty extrapolations to cosmic ray activation rates.

The neutron flux is roughly $5 \times 10^8$ times larger than the sea-level cosmic neutron flux.

1 second on beam
~ 16 years on the surface
Ultra-Low Background Surface Contamination from Dust (Dedicated Testing Facility at PNNL)

Material selection: a critical challenging task

- Radiopurity requirements
  - $\mu$Bq/kg range or lower

- Extensive assay campaigns
  - Selection of the most-radiopure materials

- Ultrasensitive analytical techniques

- Ultraclean analytical procedures and material handling

For reference:
1 ppt Th = 4.1 $\mu$Bq $^{232}$Th/kg
1 ppt U = 12.4 $\mu$Bq $^{238}$U/kg
1 ppb $^{40}$K = 30.5 $\mu$Bq $^{40}$K/kg

Low Background 3D Printed Materials

Isaac Arnquis

3D Printing ULTEM – Complex Part (Spring Clip)

Spring Clip
(designed for ULB proportional counter)
- Printed on rafts for support during AM

Two different types of ULTEM (polyetherimide) were explored. Cleaned filaments and cleaned parts.
PPS is not clean (not shown): ~300-700 ppt Th, U

ULTEM 1010 looks to be the cleanest finished part yet, which agrees with previous data