Single Molecule Fluorescent Imaging & Neutrinoless Double Beta Decay

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Background Impact

Presence of background in the ROI severely impacts the sensitivity

Plot from Jason Detweiler
The Problem

- Background gammas entering the detector can mimic signal events
- No one has been able to reduce background to a negligible level

Limit on the Radiative Neutrinoless Double Electron Capture of $^{36}Ar$ from GERDA Phase I
GERDA Collaboration (M. Agostini (Gran Sasso) et al.). May 5, 2016. 7 pp.
Published in Eur.Phys.J. C76 (2016) no.12, 652

http://www.physik.uzh.ch/groups/groupbaudis/gerda/
Barium Tagging

In pure xenon barium is only produced by double beta decay
How does it work?

Molecules become fluorescence after capturing Ba++. Various molecules exist for fluorescence detection.
TIRF

External optical elements

- Laser
- Beam splitter
- Long-pass filter
- Spectrophotometer

Optical fiber

Fluorescence sensing electrode

- E-Field
- Ba^{2+}
- Light-guiding sensor
- Mirror
- Cathode

Color Key:
- Incident excitation light
- Emitted fluorescent light
- Unchelated sensing compound
- Ba^{2+} chelated sensing compound
Road Map

• Test in aqueous solution
• Measure barium mobility in xenon gas
  – Select Ba++ beam
• Test fluorescence in dry gaseous xenon
  – Test ensembles of barium ions
  – Test single ion sensitivity
Aqueous solution
Aqueous solution

Fluo-3

\[ \frac{F_{\text{max}}}{F_{\text{min}}} = 17.4 \]

Fluo-4

\[ \frac{F_{\text{max}}}{F_{\text{min}}} = 85.22 \]
Barium ion mobility in xenon gas
Barium ion mobility in xenon gas
Summary

• HPGXe TPC with internal real-time fluorescent tagging of barium daughter at room temperature may offer a new way to eliminate gamma ray backgrounds in NLDBD search
Summary

- HPGXe TPC with internal real-time fluorescent tagging of barium daughter at room temperature may offer a new way to eliminate gamma ray backgrounds in NLDBD search
- Initial steps have been completed at UT Arlington
Thank You
Apparatus
Measurements

Fluo-3

\[
\frac{F_{\text{max}}}{F_{\text{min}}} = 254.77
\]

Fluo-4

\[
\frac{F_{\text{max}}}{F_{\text{min}}} = 291.83
\]
• Evanescence excitation of molecules
What is SMFI?

Marko Kaksonen, Christopher P Toret, and David G Drubin. “Harnessing actin dynamics for clathrin-mediated endocytosis”. In: Nature Reviews Molecular Cell Biology 7.6 (June 2006), pp. 404–414. ISSN: 1471-0072. URL: http://dx.doi.org/10.1038/nrm1940.

How does it work?

The plug and play of chemistry

Frank Foss at UTA specializes in bonding these molecules
Sample preparation

- Buffer solution
- Moderates the H+ OH-
- Keeps the pH stable when adding chemicals to the solution
- Fluo is slightly acidic when reconstituted
- The dication solution is slightly acidic

\[ Ba(ClO_4)_2 \rightarrow Ba^{++} + 2(ClO_4)^- \]
Sample preparation

- Most dyes have $k_d$ in the nM range
- Fluo-4 $k_d$ is 325 nM
- The low $k_d$ makes SMFI extremely sensitive to ions

http://www.embl.de/eamnet/html/calcium/quantifying2.htm
**Sample preparation**

- Although trace amounts of dications they can still produce a large signal

<table>
<thead>
<tr>
<th>Cation traces</th>
<th>Amount (µg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag</td>
<td>≤0.001</td>
</tr>
<tr>
<td>Al</td>
<td>≤0.1</td>
</tr>
<tr>
<td>As</td>
<td>≤0.01</td>
</tr>
<tr>
<td>Au</td>
<td>≤0.005</td>
</tr>
<tr>
<td>B</td>
<td>≤0.1</td>
</tr>
<tr>
<td>Ba</td>
<td>≤0.005</td>
</tr>
<tr>
<td>Be</td>
<td>≤0.005</td>
</tr>
<tr>
<td>Bi</td>
<td>≤0.001</td>
</tr>
<tr>
<td>Ca</td>
<td>≤0.2</td>
</tr>
<tr>
<td>Cd</td>
<td>≤0.001</td>
</tr>
<tr>
<td>Ce</td>
<td>≤0.001</td>
</tr>
</tbody>
</table>

5nM

Sigma aldrich

Calcium Sponge™ S consists of the Ca\(^{2+}\)-selective BAPTA chelator coupled to a polymer matrix. Polycations including Ca\(^{2+}\) and Zn\(^{2+}\) can be selective removed from aqueous solutions simply by stirring a solution with the water-insoluble Calcium Sponge S polymer.
Measurements

Single Molecule Fluorescence Imaging as a Technique for Barium Tagging in Neutrinoless Double Beta Decay

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How to test in HPGXe?
How to test in HPGXe?

- Ion source assembled and currently being tested
- Spark voltage controls the amount of ions
How to test in HPGXe?

- Have optimized the protocol for plating barium onto copper rods
- EDX spectra of the surface shows an increase in barium and decrease in copper
How to test in HPGXe?
How to test in HPGXe?

- Gates have been constructed
How to test in HPGXe?
How to test in HPGXe?

Gas system pre assembly
How to test in HPGXe?

- Controlled by one NI card
- Low noise pre-amp
- Ability to chop the beam
How to test in HPGXe?

Transmitter board

• Allow us to send pulses to 12kV electronics safely

Receiver board

• Provide pre amplification with low noise

Amplifier board
213 V/cm applied field with 320 V ring to ring in main field cage. 600 V spark potential stepped down in 100 V steps over mini-field-cage.
Axial (Z) Field Residual \((fraction \ of \ applied \ field)\)

Radial (R) Field Residual \((fraction \ of \ applied \ field)\)