Optimizing the Design of a Highly-Segmented Neutron Detector with Geant4
D.P. Scriven\textsuperscript{1,2}, G. Christian\textsuperscript{1,2}

Motivation

- Detecting neutrons in the 1-30 MeV range has a wide range of applications to basic nuclear science and national security.
- Many materials are toxic or volatile liquids, and many solid scintillators don’t compete.
- Goal: To design an ultra-segmented detector and utilizes a new fast, bright, plastic scintillator, para-terphenyl.
  - 27,000 y/MeVee, 3.7 ns decay time
  - The highly segmented bright scintillator gives high-resolution timing and position measurements as well as acceptable pulse shape discrimination.
- In this work we present results from initial simulations using Geant4 to characterize and guide the design process of this instrument.

Investigation

- Geant4 has been used to assemble an array 1 m x 1 m x 10 cm, of cubic p-terphenyl crystals.
- Segmented in x, y, and z, each segment acts as a 3D pixel (a voxel).
- Interested in how different voxel sizes effect measurements of the detector across a range of timing resolutions and initial neutron energy, values are shown in Table 1.
- $\sigma = 200$ ps (FWHM of 471 ps) is assumed a reasonable timing resolution, and is used for data presented in this work.
- Code was modified to use MENTATE-R scattering models.
  - Low energy neutron behavior must be modelled correctly.
  - The models in MENTATE-R more accurately reproduced scattering cross sections and angular distributions for $^{1}$H and $^{12}$C, from 1 – 300 MeV.

Results

- Shown in Fig. 1, measured kinetic energies are calculated from TOF and were in good agreement with source energies.
- Our greatest interest is in the spatial resolution of the detector.
- To quantify spatial resolution, two measurements are made:
  - The emitted angle minus the known source angle
  - Triggered voxel location minus real hit location within a crystal
- An analysis routine was created to fit and measure full width half maxima of each measurement. Above are results of this routine.

<table>
<thead>
<tr>
<th>$T_{\text{initial}}$ (MeV)</th>
<th>1</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voxel Size (mm)</td>
<td>5</td>
<td>10</td>
<td>20</td>
<td>30</td>
<td>50</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>$\tau$ Timing (ps)</td>
<td>0</td>
<td>100</td>
<td>200</td>
<td>500</td>
<td>1000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1) Initial neutron kinetic energies, voxel sizes, and $\tau$ timing resolution tested in this work.

Conclusion

Measurements from these Geant4 simulations indicate that voxel sizes below 20 mm begin to give diminishing returns, and yield sub – 1° difference in angle measurement. These results are currently being used to guide the design of prototypes under construction at Texas A&M University in collaboration with Washington University in St. Louis. For more information on detector design, construction, and prototyping, see poster 14-LENS. More simulations are in progress at Texas A&M to study how the detector will perform with invariant mass measurements. We also plan to incorporate light transport, as this array will utilize a light piping system.