Optimizing the Design of a Highly-Segmented Neutron Detector with Geant4

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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 γ/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.

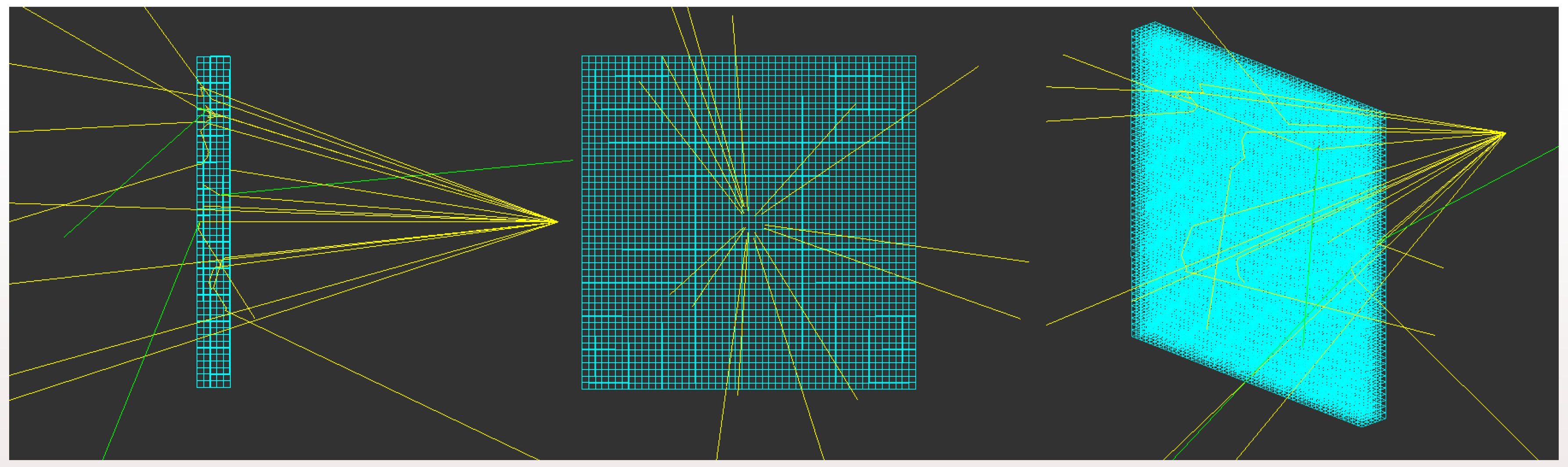

Fig.1) An image from Geant4 of a 1x1x0.1 m array of 2 cm/side voxels. A conic source of neutrons (yellow) is emitted 1 m from the array with Compton scattered gammas (green).

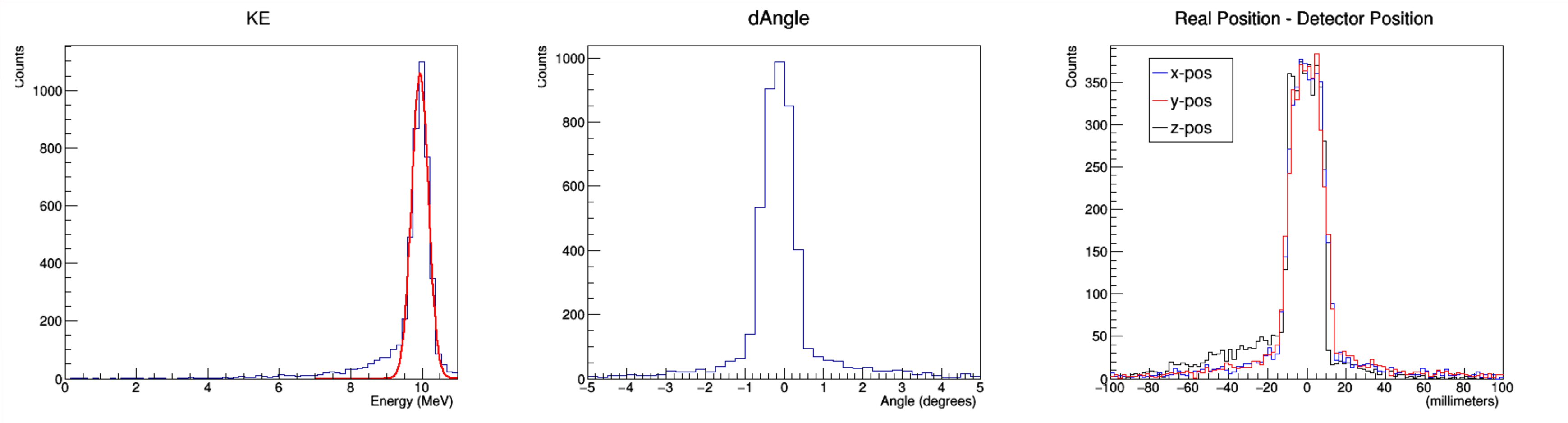

Fig. 2) Measurements for 20 mm voxels with 10 MeV source energy. Left: Measured neutron kinetic energies. Center: the difference in measured vs emitted angle. Right: Difference in crystal location vs real hit location.

Investigation

- Geant4 has been used to assemble an array $1m\ x\ 1m\ x\ 10\ cm$, 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, used values are shown in Table 1.
- σ = 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 *MENATE_R* scattering models.
  - Low energy neutron behavior must be modelled correctly.
  - The models in *MENATE_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.

$T_{n,initial}$ (*MeV*)	1	5	10	15	20	25	30
Voxel Size (*mm*)	5	10	20	30	50	100	
1σ Timing (*ps*)	0	100	200	500	1000		

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

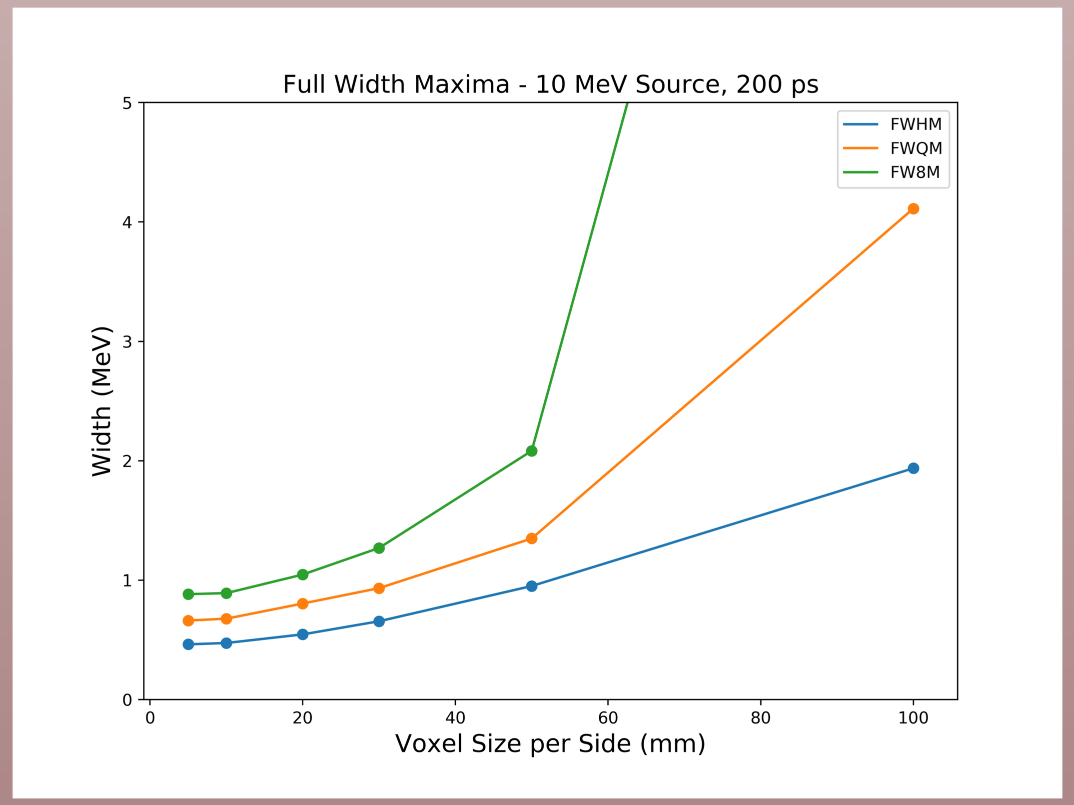

Fig. 5) The emitted source kinetic energy vs the measured kinetic energy fit results (as shown in Fig. 2) for different source energies and voxel sizes.

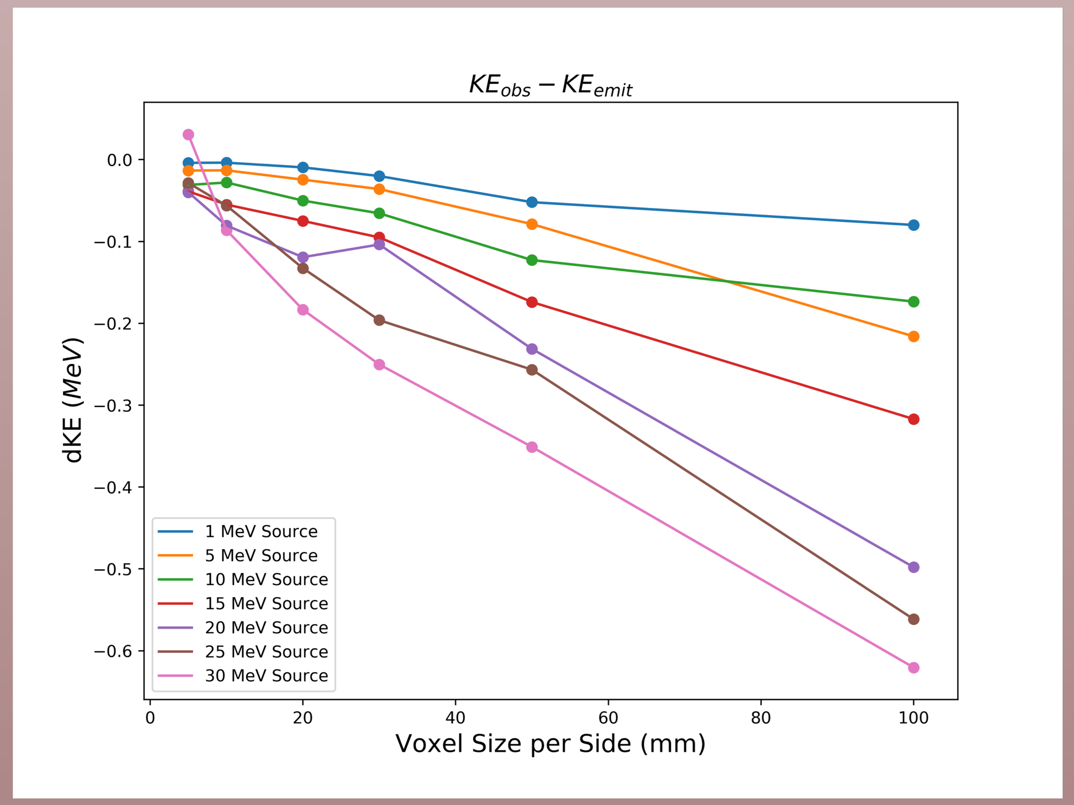

Fig. 4) The FWHM of KE for various voxel sizes with a source energy of 10 MeV. This result is representative of all simulations for the 1 – 30 MeV energy source neutrons.

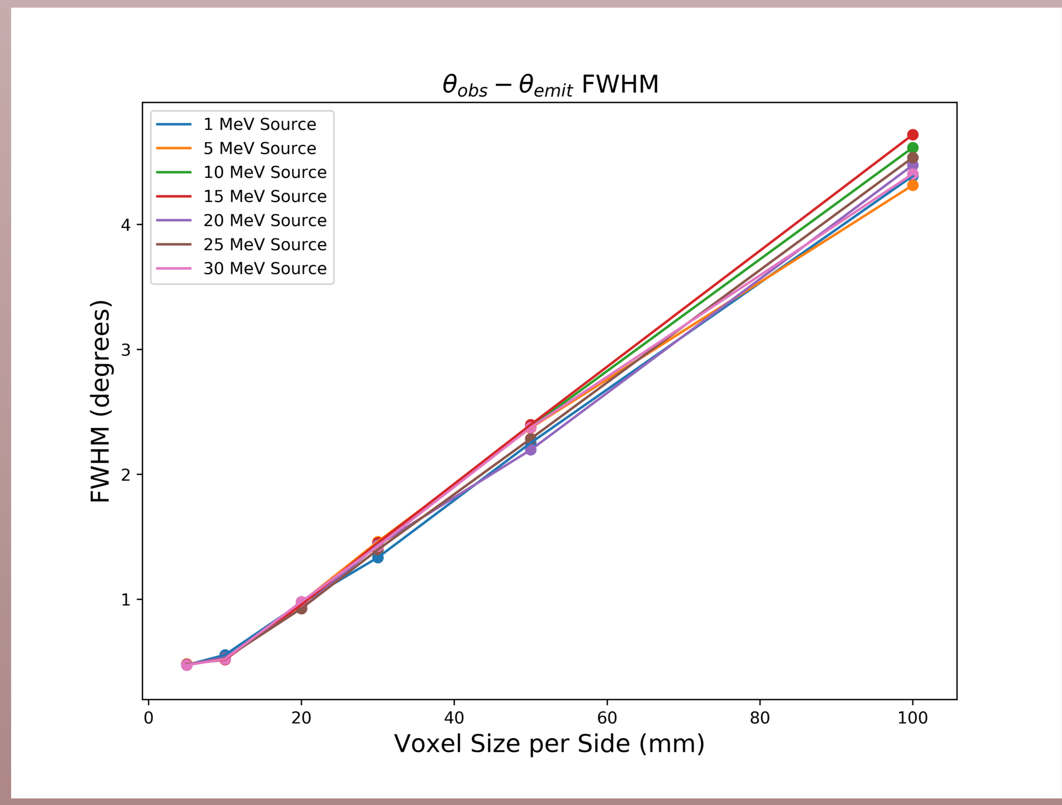

Fig. 3) The FWHM of the difference in observed angle vs emitted source angle for various voxel sizes and energies.

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.

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