Particle Detection utilizing Modified Bandgap Reference Circuit Design

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Particle Detectors: DET 3C

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Project Objectives

- Utilize transient signatures in a solid-state detector as a new mechanism of particle detection
- Novel approach: record fluctuations in Schottky barrier height of a gallium nitride (GaN) Schottky diode to identify particle events
  - Circuit design: modified bandgap reference circuit that outputs voltage proportional to GaN Schottky barrier height, related to the work function by:

$$\Phi_B = \phi - \chi$$

- Hypothesize that the signature of the fluctuations will be different for different types of particles
  - Focus on neutron detection, with comparison to alpha particles

W. Hunt. Towards a New Particle Detector Utilizing Ultra Wide Bandgap Materials.
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H. Palm, M. Arbes, and M. Schulz. Phys. Rev. Lett. **71** (14), 2224. 1993. https://doi.org/10.1103/PhysRevLett.71.2224

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Bandgap Reference (BGR) Circuit

- Goal of bandgap reference circuit: analog circuit whose voltage output equals that of the bandgap energy of the semiconductor being used
- Output of typical semiconductor devices is heavily temperature-dependent
- Bandgap reference adds components with equal but opposite temperature coefficients
- BGR circuit produces a fixed output voltage independent of temperature variations, supply variations, and loading
- Our bandgap reference circuit design provides an output voltage proportional to the work function of GaN, which serves as a fixed baseline for observing output fluctuations due to particle events
  - Temperature independence important to lend confidence that fluctuations observed are *not* due to temperature variations and ensures functionality in different environments

R.J. Widlar. IEEE J. Solid-State Circuits. **6**(1), 2-7. 1971. https://doi.org/10.1109/JSSC.1971.1050151.

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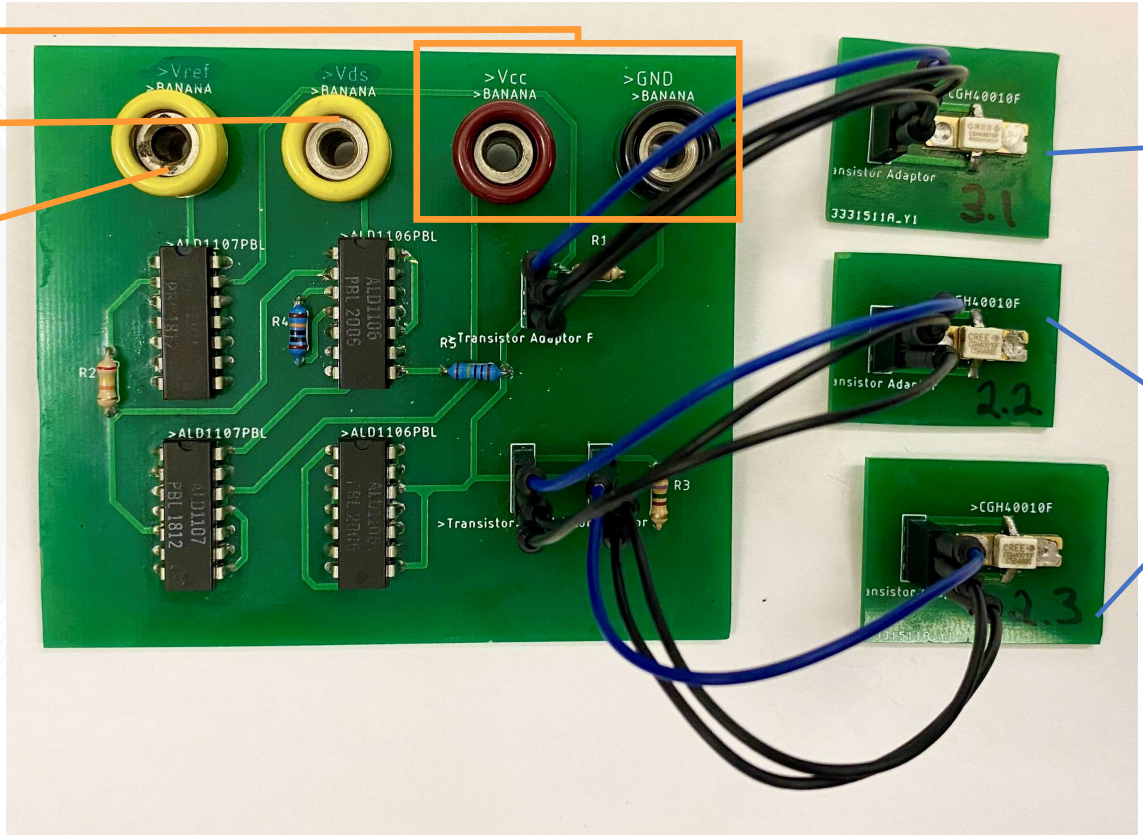
Work Function Reference Prototype

Power supply

Reference voltage

Voltage drop across irradiated diode



Transistor/Schottky diode exposed to radiation

Reference transistors/Schottky diodes

PCB manufactured by JLC PCB

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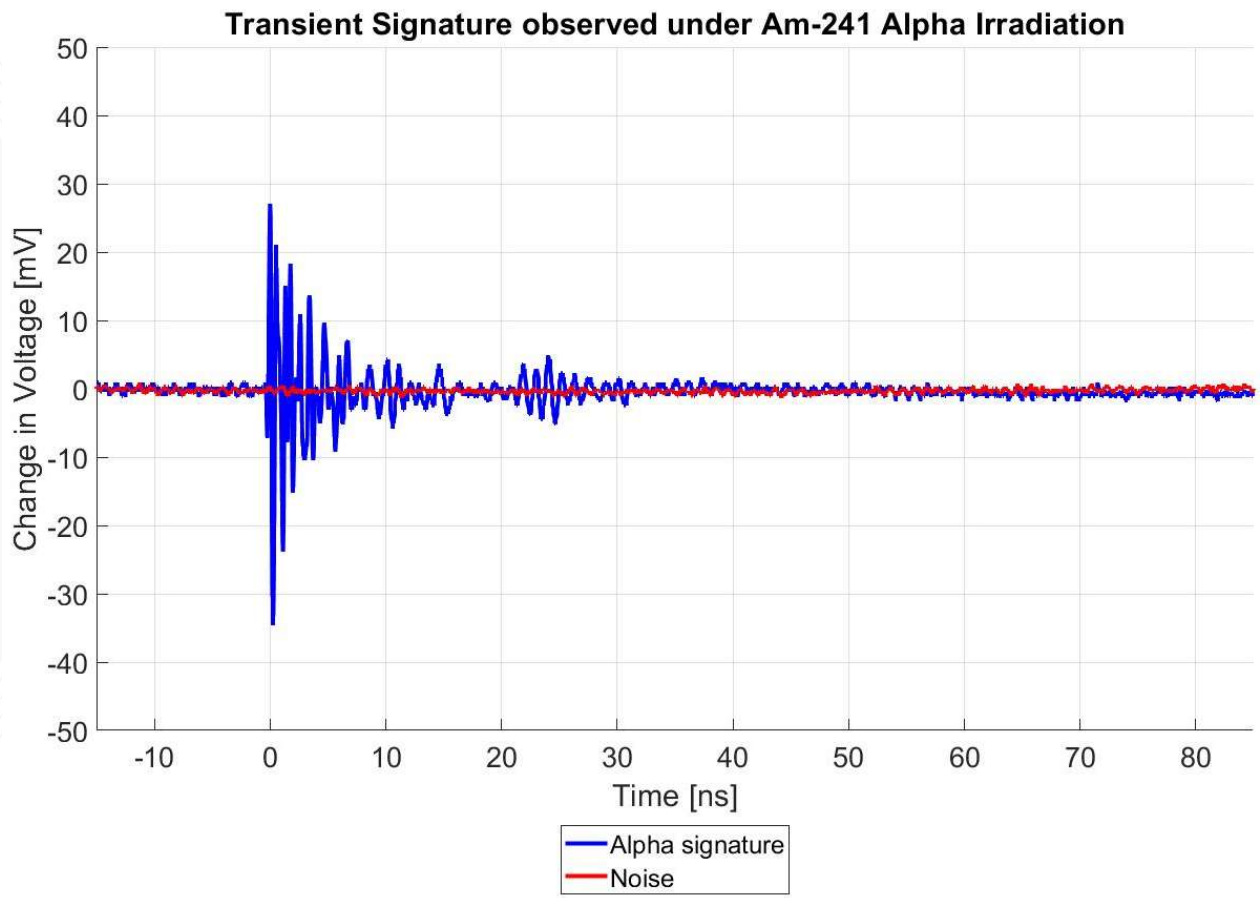
Alpha Irradiation



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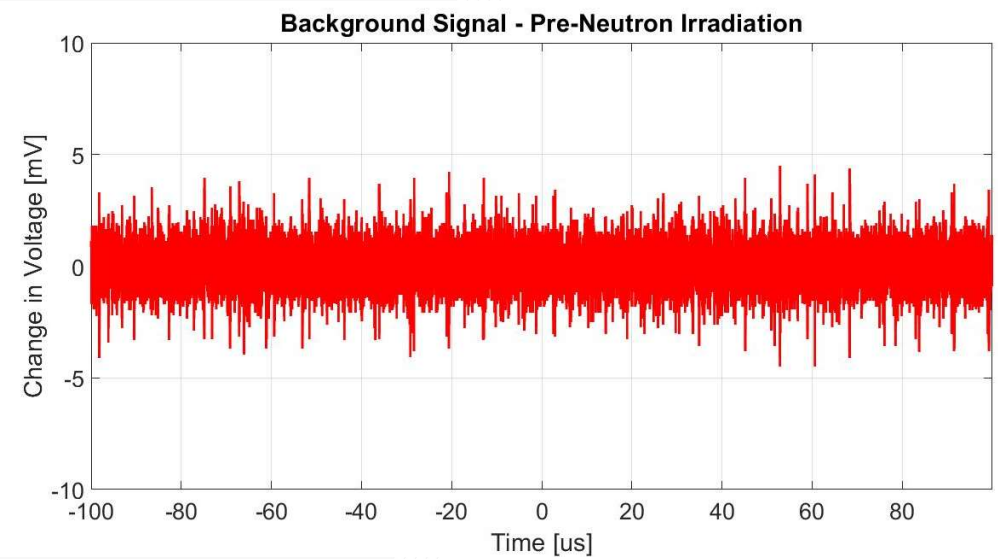
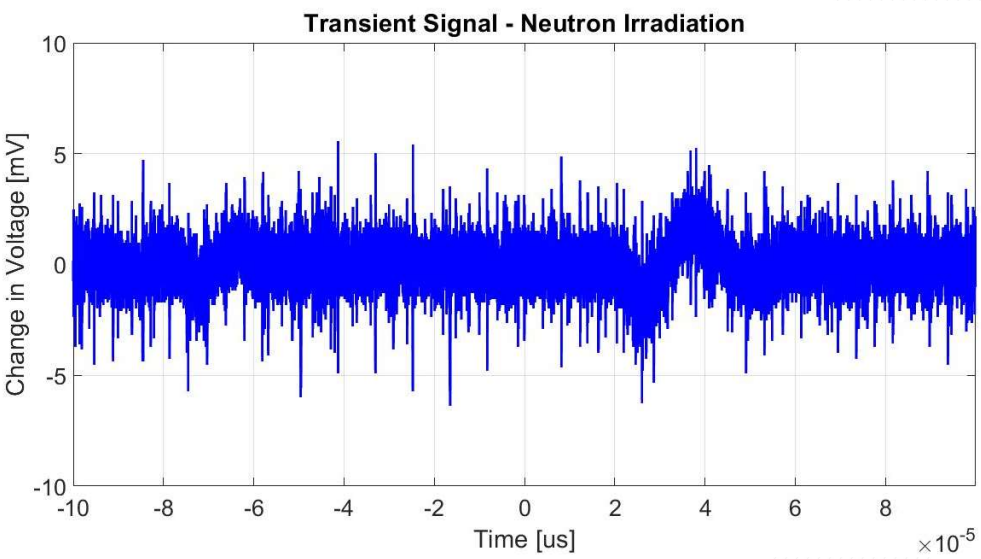
Neutron Irradiation– Cf-252





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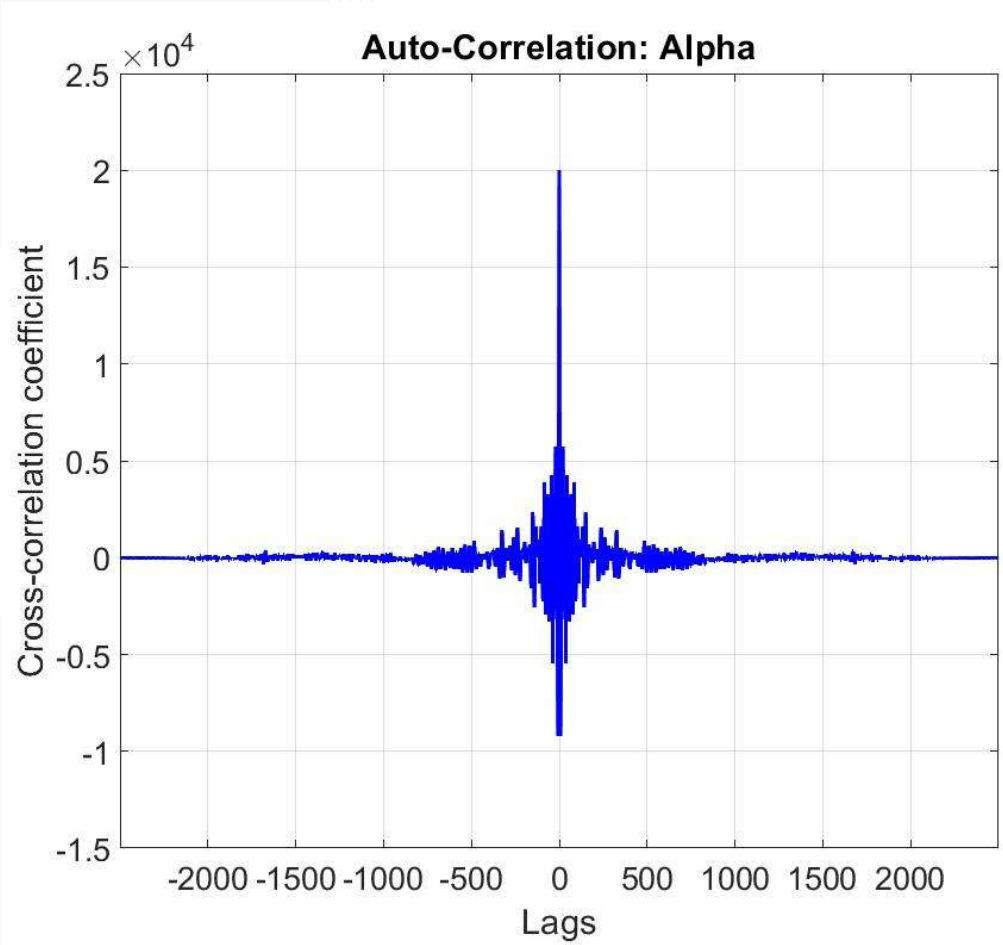
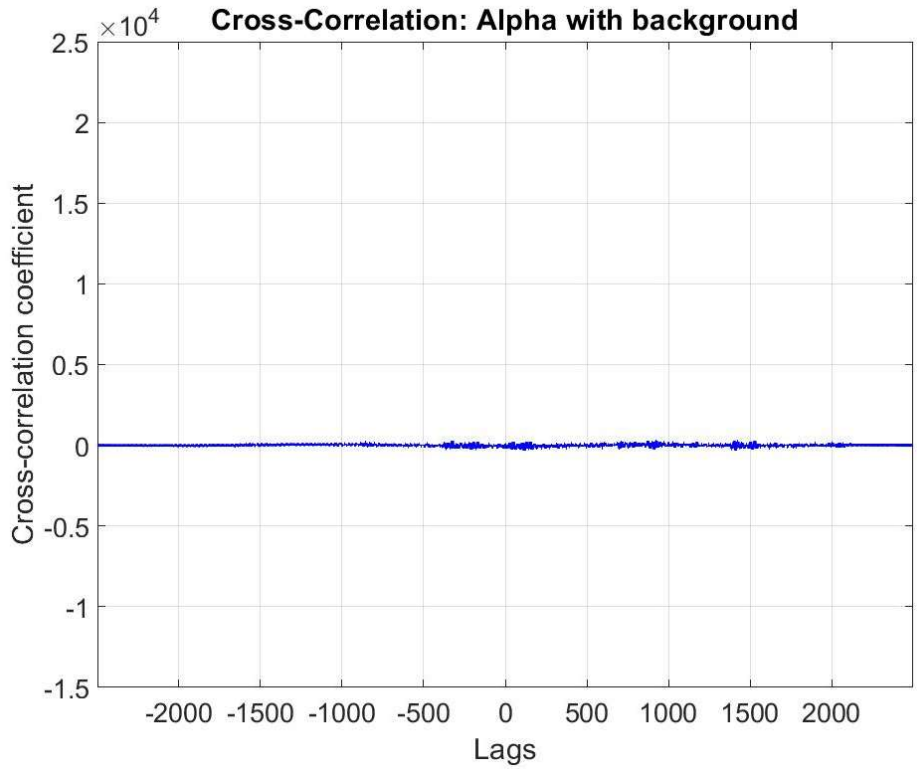
Correlation of Alpha Signals





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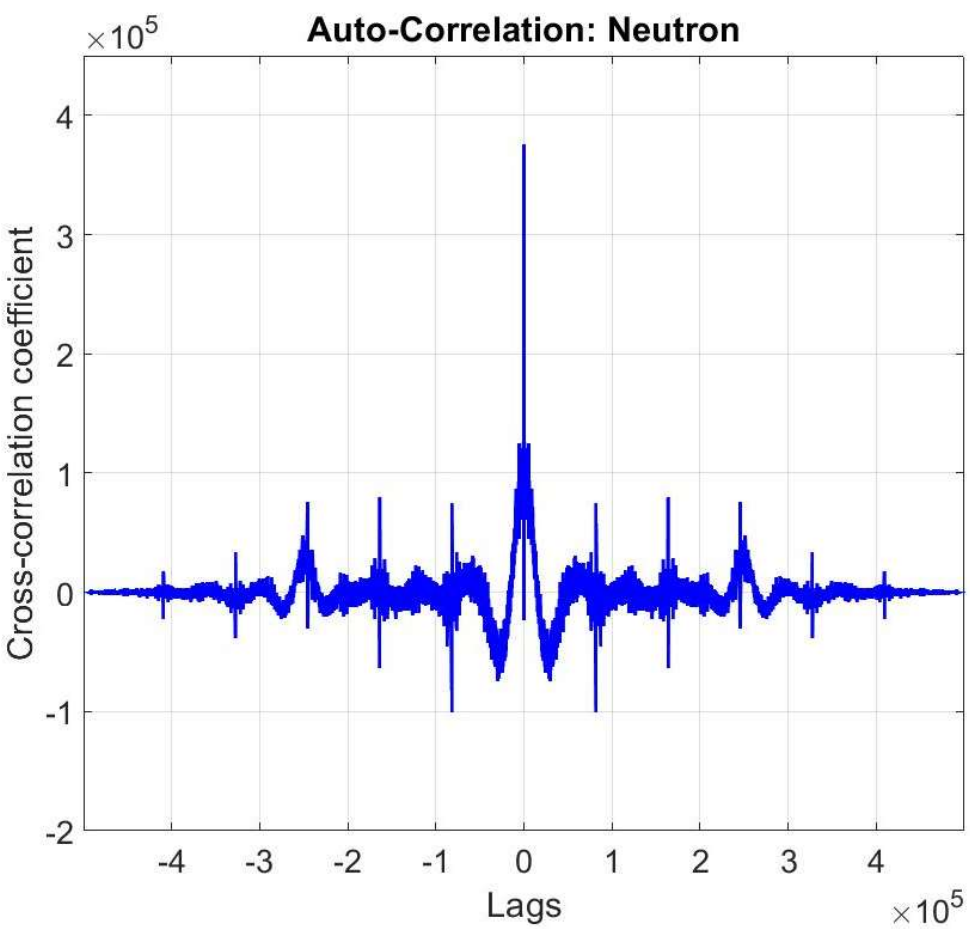
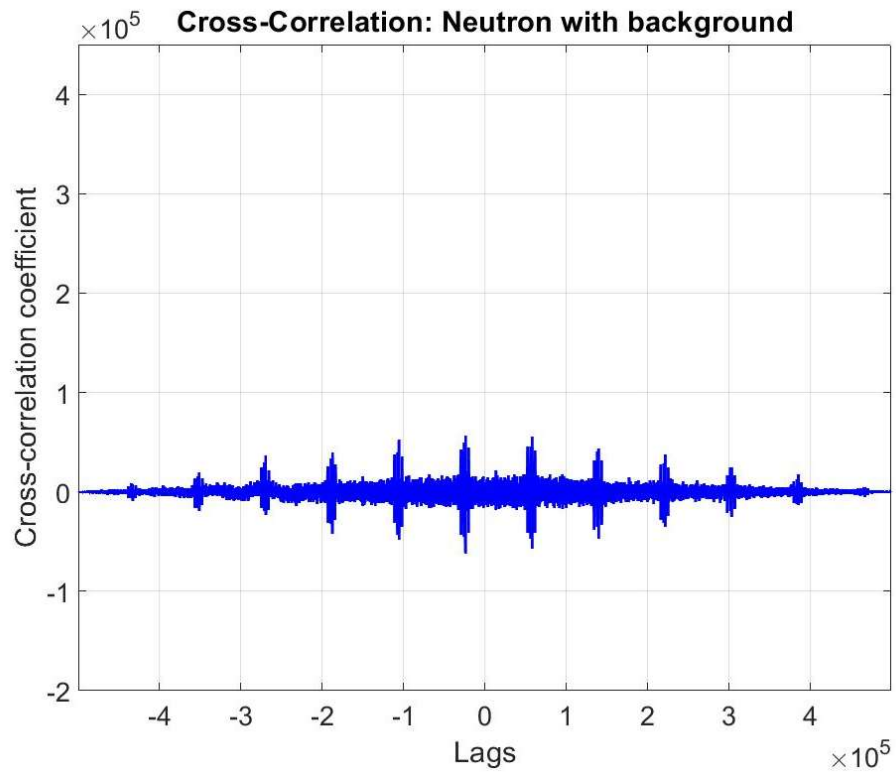
Correlation of Neutron Signals





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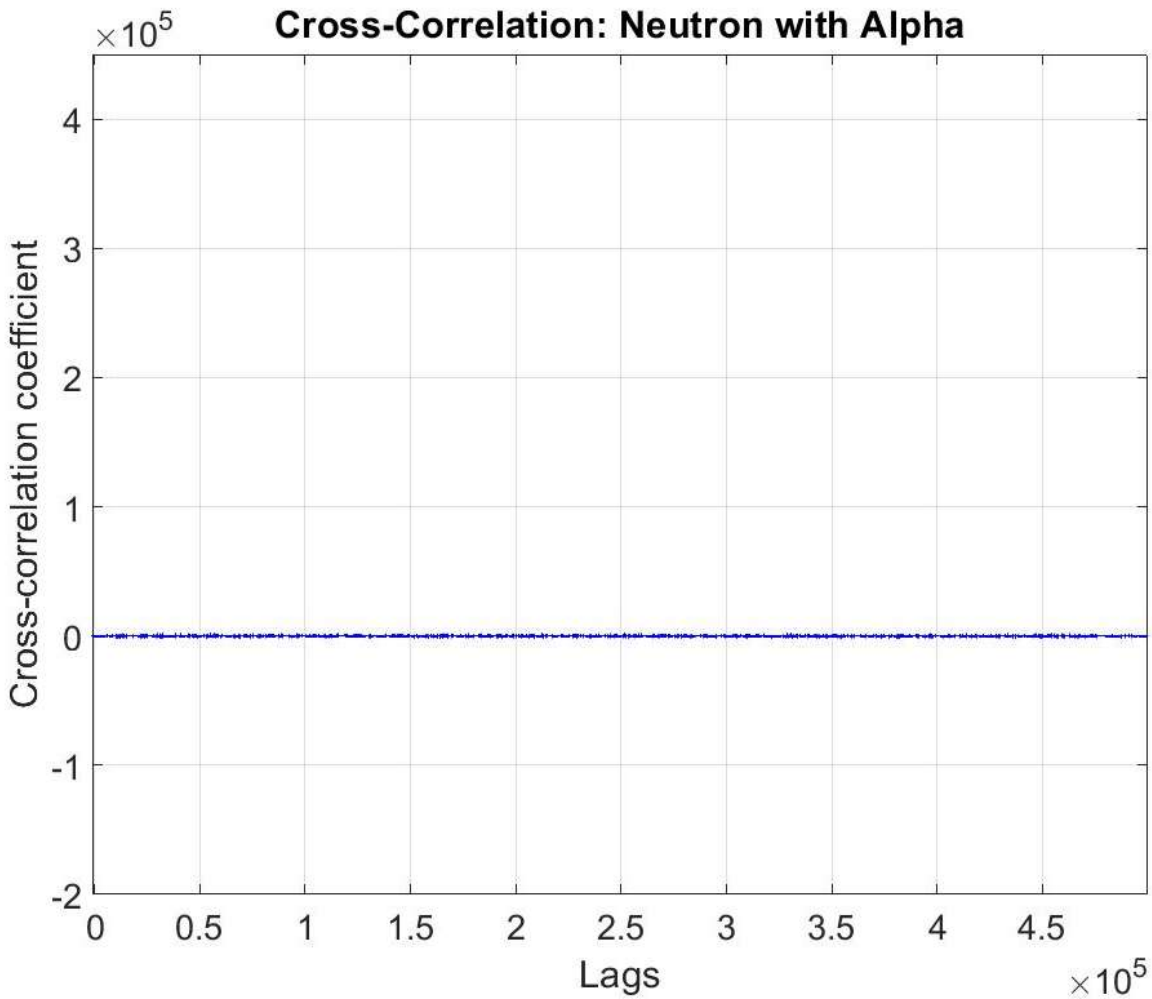
Cross-Correlation of Alpha and Neutron Signals (both with source)



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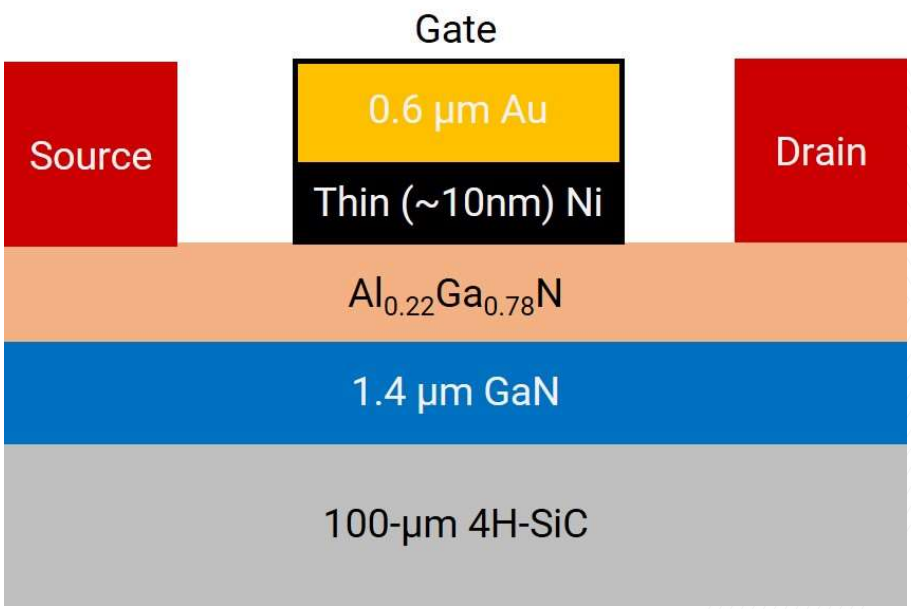
Geant4 Simulation Methodology

- Build the Cree CGH40010F device in Geant4, with all GaN sections as physical and logical volumes to enable tracking in those areas
- Establish a neutron source at 1 cm from the top face, with energy characteristics to match the Cf-252 source
- Establish an alpha source at 1 cm from the top face, with energy characteristics to match the Am-241 source
- Run simulations, storing energy deposition and particle track information for analysis



CGH40010 GaN device structure information from Ryan Baker of Wolfspeed, a Cree Company

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Summary

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- Designed a work function reference circuit that uses GaN semiconductor devices as a detector for neutrons and alpha particles
- Produced and fabricated a second prototype circuit board of the WFR circuit
- Irradiation testing of the fabricated prototypes indicates
  - Output is low-noise under non-irradiative conditions
  - Transient signatures are observable
  - Difference in transients observed for neutron and alpha irradiation
- Upcoming Work
  - Additional neutron irradiation experiments with PuBe
  - Complete fabrication of GaN device in Geant4 software to model the physics interactions occurring

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Conclusions

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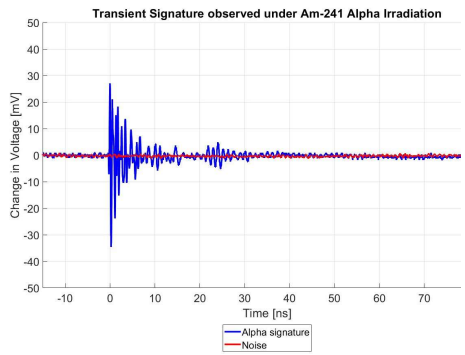
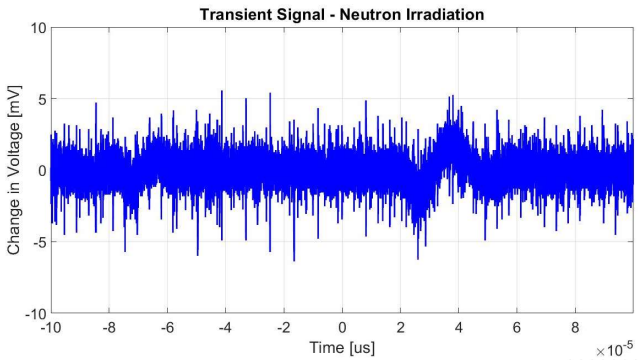
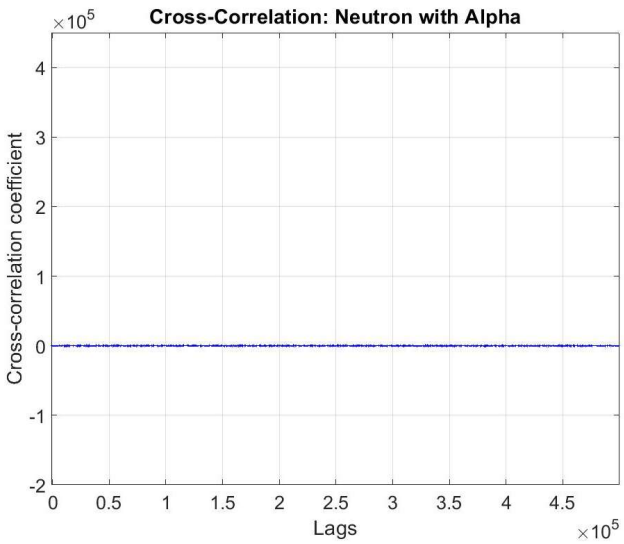
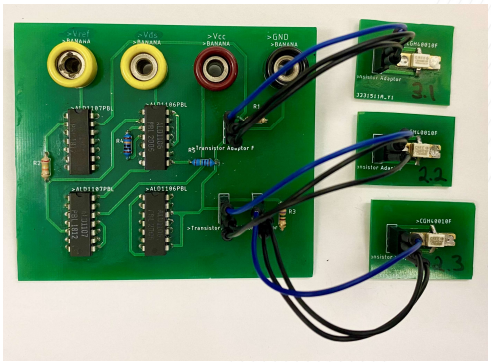
- Designed a work function reference circuit that uses GaN semiconductor devices as a detector for neutrons
- Assembled a prototype circuit of the WFR circuit after fabrication of PCB
- Irradiation testing of the fabricated PCB indicates
  - Output is low-noise under non-irradiative conditions
  - Transient signatures are observable
  - Difference in transients observed for neutron and alpha irradiation









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