Simulation studies of a MPGD-based Neutron Beam Monitoring system for ESS

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Abstract

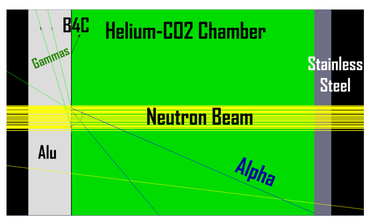
In modern neutron facilities such as the European Spallation Source (ESS), accurate beam monitoring is critical for ensuring robust diagnostics and data reliability. In this work, a Geant4-based simulation has been developed to support the design and optimization of ESS beam monitors, focusing on MPGDs with a B_4C conversion layer. The detector's response was evaluated by modeling energy deposition from neutron products in the drift gap for multiple gas mixtures and geometries. A systematic study of the B_4C layer thickness was performed to evaluate neutron interaction efficiency under monoenergetic and uniform neutron spectra. Additionally spatial resolution was investigated using a simplified strip readout model, giving insight into how various detector parameters affect spatial resolution. Finally, dosimetry simulations were carried out using a simplified model of the electronics geometry to estimate the energy deposition in the electronic systems.

Detector Response

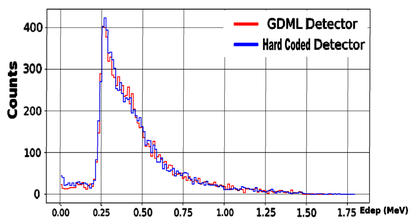
Detector Concept Micromegas based detector with B_4C converter layer. Neutrons undergo $^{10}B(n,\alpha)^7Li$ reactions, producing charged particles that ionize the gas inside the drift gap. Produced electrons then drift to the micromesh where gas amplification occurs. Amplified charge is collected on a segmented strip anode for position-resolved energy readout.

Goals

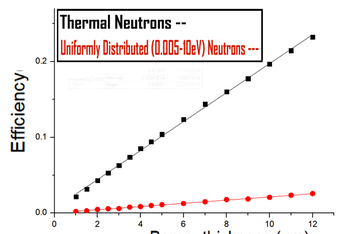
- Compare GDML based geometry with hard coded geometry in Geant4.
- Study energy deposition in the drift gap to estimate neutron response.
- Study effects of B_4C converter thickness.
- Estimate spatial resolution.



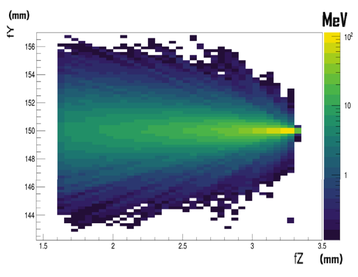
$^{10}B(n,\alpha)Li$ interaction and the Drift Gap



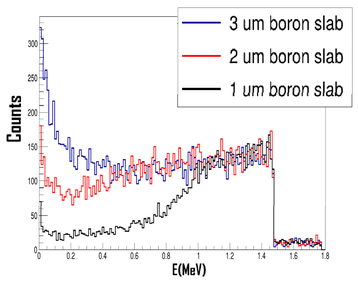
Alpha Edep: GDML vs Hard-Coded Geometry



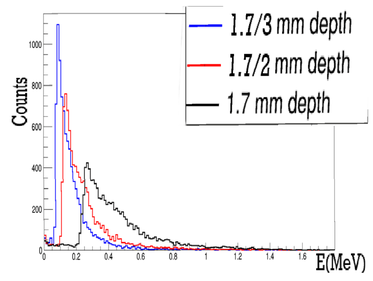
$^{10}B(n,\alpha)$ efficiency vs thickness



Alpha spatial energy deposition in drift gap



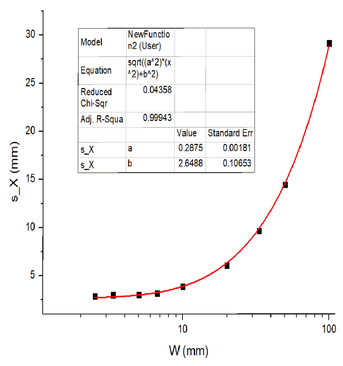
Emergent Alpha Energy vs B_4C Thickness



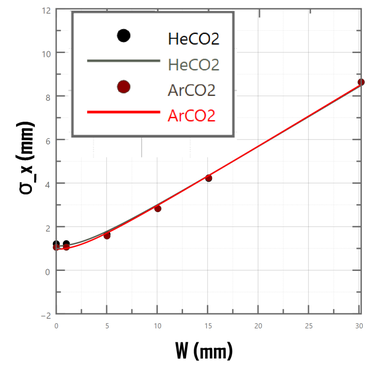
Alpha Energy Deposition vs Drift Gap

Spatial Resolution

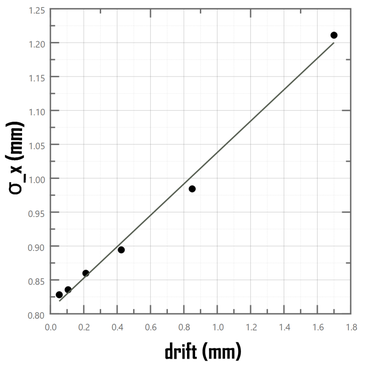
- Detector segmented into virtual strip readout regions of width W(mm).
- Position reconstructed using centroid method from deposited energy.



Spatial Resolution vs Strip Width W



$HeCO_2/ArCO_2$ Spatial Resolution vs Strip Width W



Spatial Resolution vs drift gap size

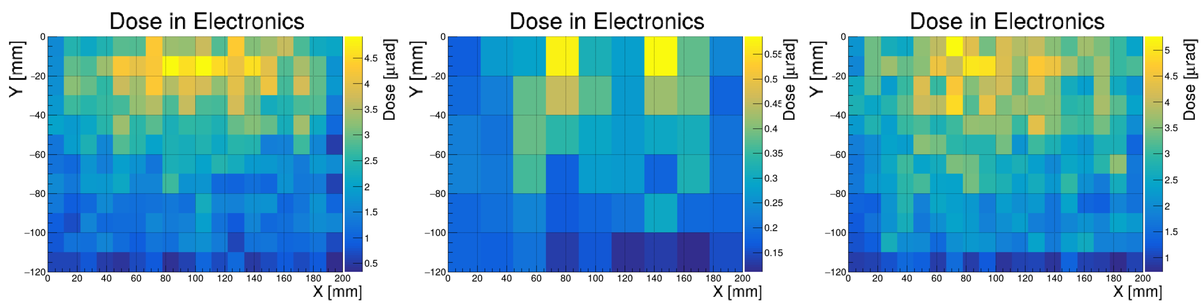
Key Results

- GDML geometry validated against hard-coded implementation.
- $^{10}B(n,\alpha)^7Li$ efficiency scales linearly with B_4C thickness.
- Spatial resolution improves with finer strip width.
- Gas mixture doesn't significantly affect resolution performance.
- Resolution degrades with increasing drift gap size.

Dose Calculation Studies

Objective: Determine the optimal placement of front-end electronics to minimize radiation-induced damage and improve detector lifetime using a Geant4 simulation.

Simulation Evolution (Geant4)



1. Single Slab
Fast but unrealistic sim

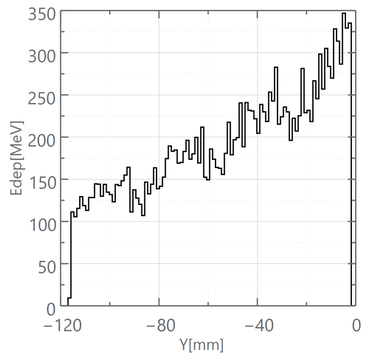
2. Segmented
54 regions, low statistics

3. Stripe Method
Realistic and high statistics

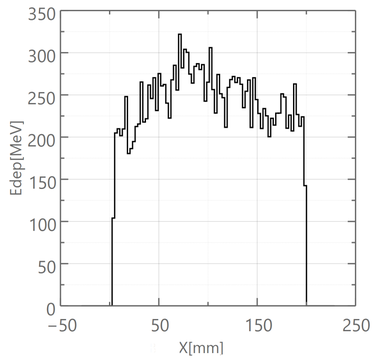
Simulation Strategy

- Initial slab geometry revealed reduced dose near detector corners.
- Segmented studies provided a more realistic simulation but required long simulation times.
- Final stripe geometry provided realistic full-detector coverage with improved computational efficiency.

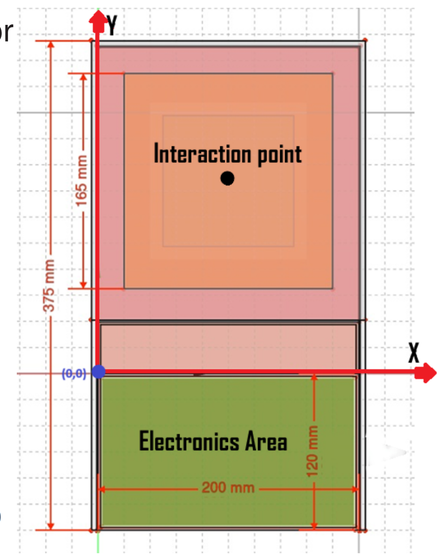
Stripe Method Results



Dose decreases toward lower Y positions

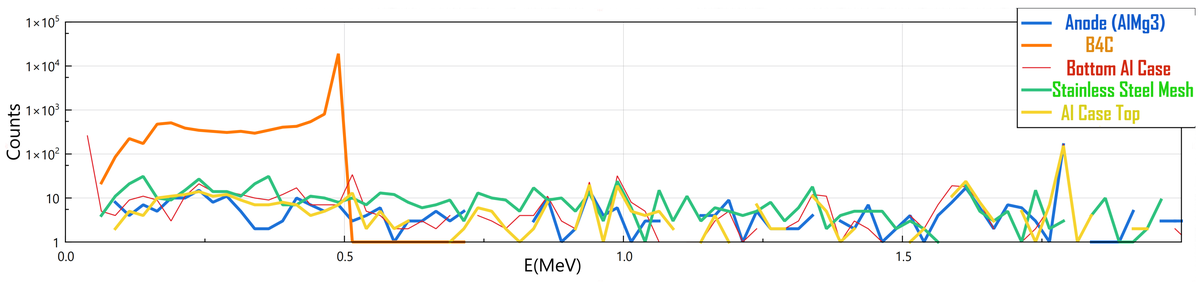


Lower X-edge regions are favored



Detector Geometry

Secondary Gamma Production



Secondary γ-ray interaction Energy spectrum grouped by detector volume

Key Findings

- Radiation dose varies significantly across the electronics area.
- Secondary γ rays produced by neutron interactions dominate the deposited dose.
- Region close to the interaction point is identified as the worst location for electronics
- Gammas are produced primarily by the B_4C volume.

Summary and Outlook

- A comprehensive Geant4 simulation framework has been developed for optimizing MPGD-based neutron beam monitors at ESS.
- B_4C converter thickness studies demonstrate linear efficiency scaling for $^{10}B(n,\alpha)^7Li$.
- Spatial resolution analysis using centroid reconstruction shows any dependence of the detector performance on gas mixture and drift gap size.
- Dose calculation studies identified that electronics should be positioned as far as possible from detectors active region, minimizing induced dose.

- Future work: experimental validation with prototype detectors, integration of realistic electronics response, and implementation at ESS.

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- **[4] CDT** – CASCADE Detector Technologies GmbH

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MORE INFORMATION

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