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EUROPEAN
SPALLATION
SOURCE

Advancing Beam Diagnostics on ESS Neutron Beamlines: Simulation and Validation of Ionization Chamber Monitors

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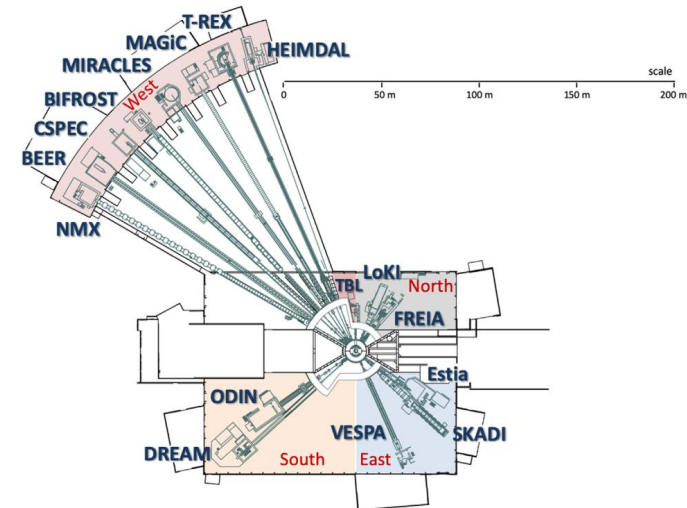
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The European Spallation Source

- Located in Lund, Sweden, currently under construction
- Set to begin its scientific program in 2027.
- Next-generation neutron scattering facility.
- Proton pulses of 2 GeV and 2.86 ms in length, with a repetition rate of 14 Hz impinging on a tungsten target.
- Designed to provide the world's highest brightness of cold and thermal neutrons.
- Will host 22 neutron beam instruments for research in physics, materials science, chemistry, biology, and engineering.

Motivation:

Due to the demanding performance requirements of the ESS, precise beam monitoring is essential. For this purpose, **Ionization Chamber Beam Monitors (I-BMs)**, a commercial beam monitor, were developed as an in-kind contribution to be deployed along the neutron beamlines.



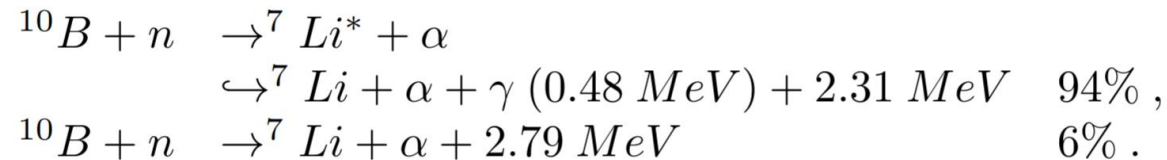
The Ionization chamber Beam Monitor (I-BM)

Design of the I-BM:

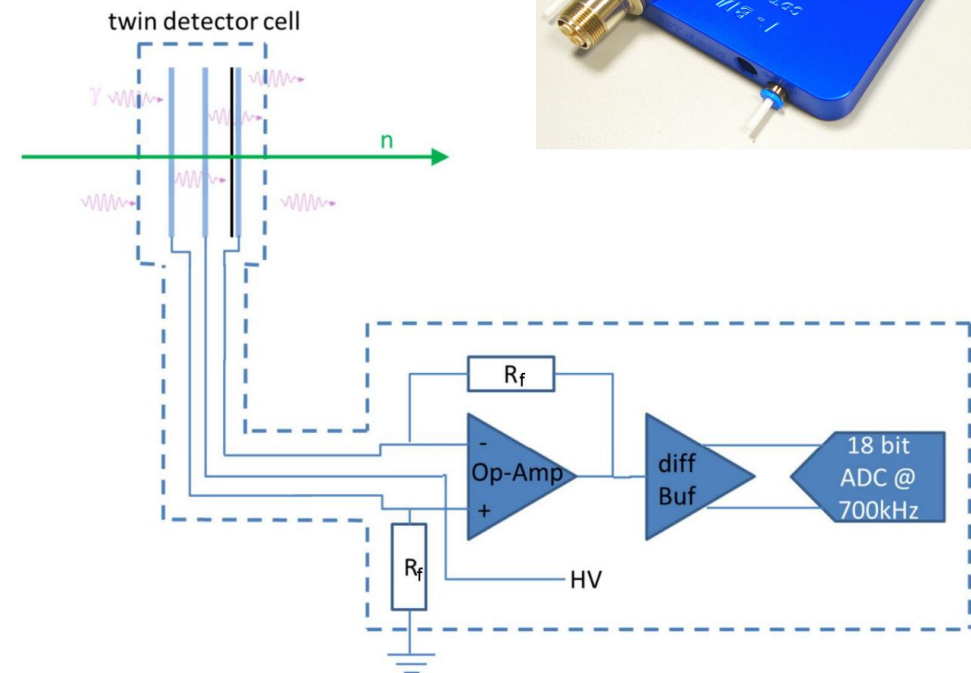
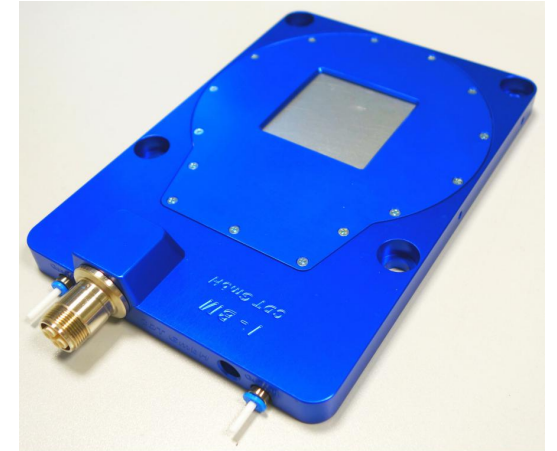
- Ionization chamber
- Three parallel aluminum plates
- Two separate gas volumes
- Enriched B₄C converter layer

Principle of operation:

- Neutron interaction in conversion layer via:



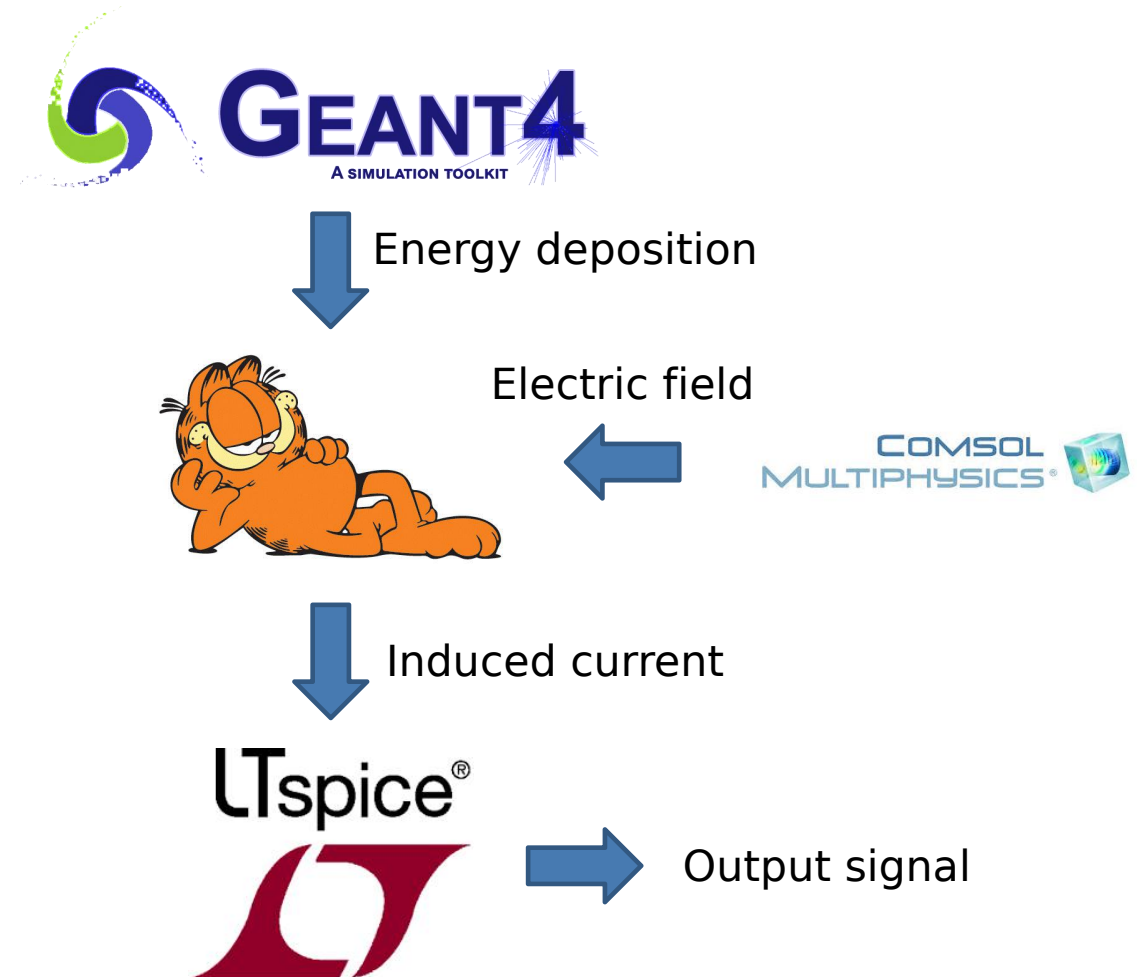
- Ionizations in gas from reaction products
- Electron - ion pairs drift due to the electric field
- Induced signal is fed into the front-end electronics
- Gamma-ray background subtraction capability



Simulation Workflow

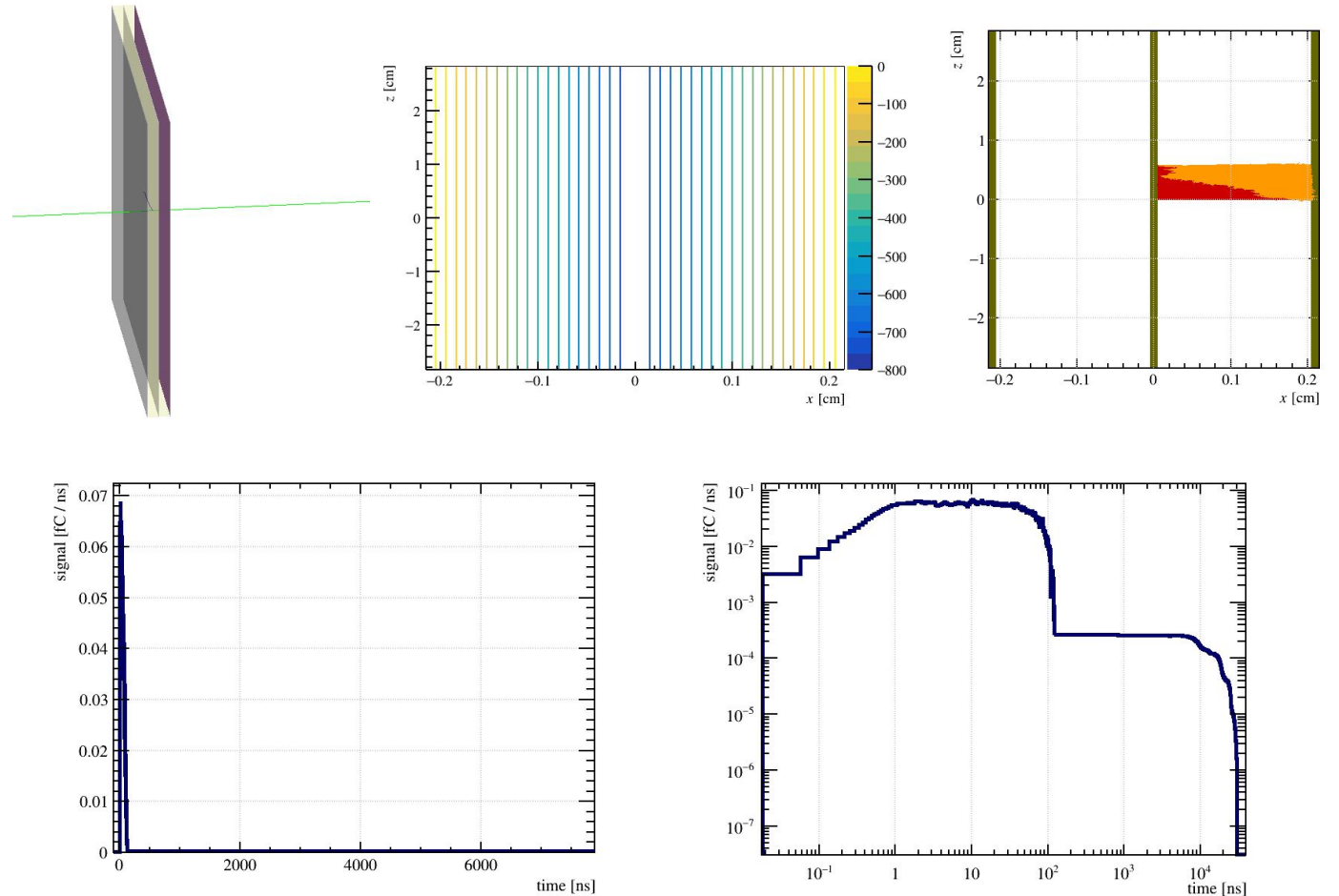
In order to simulate the complete chain of the output signal formation, four simulation tools are used:

- **Geant4:** Neutron interactions with conversion layer, energy deposition of ions in gas volume.
- **COMSOL:** Calculation of the applied electric field.
- **Garfield++:** Modeling the drift of the electron-ion pairs and induced signal calculation.
- **LTspice:** Emulation of I-BM's front-end electronics and calculation of output signal.



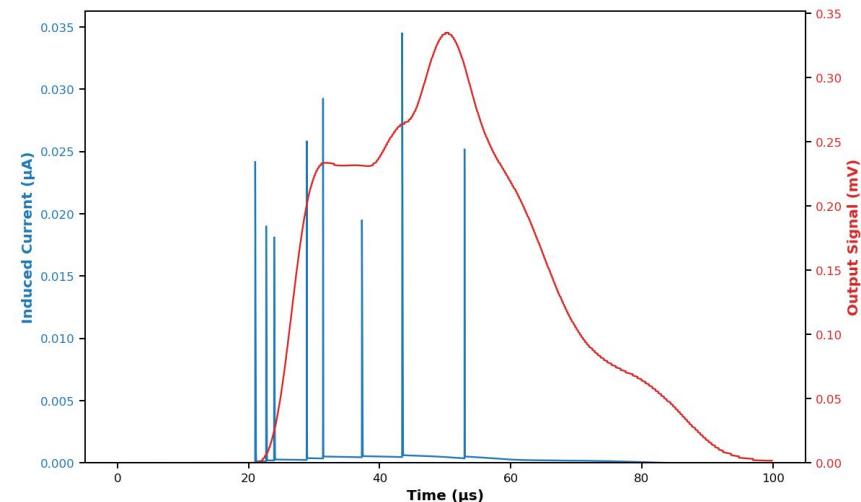
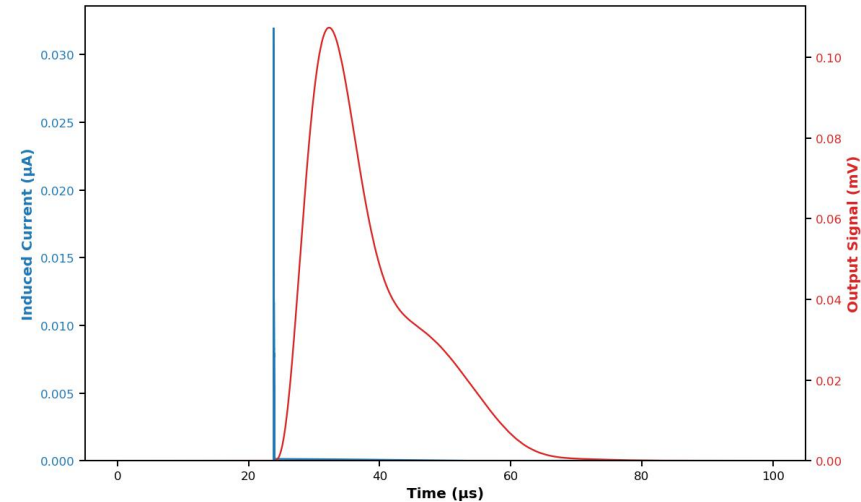
Geant4 and Garfield++ Models

- Active volume: 3 Al plates (100 μm), 2 gas gaps (2 mm, Ar), ^{10}B -enriched B_4C layer (120 nm)
- Neutron tracks (green) and interaction products (blue) simulated in Geant4
- Electric field computed in COMSOL and imported into Garfield++
- Electron-ion pair creation from Geant4 energy deposition, mapped into Garfield++
- Charge drift simulation performed in Garfield++
- Induced signal shows expected behavior: fast electron spike and long ion tail



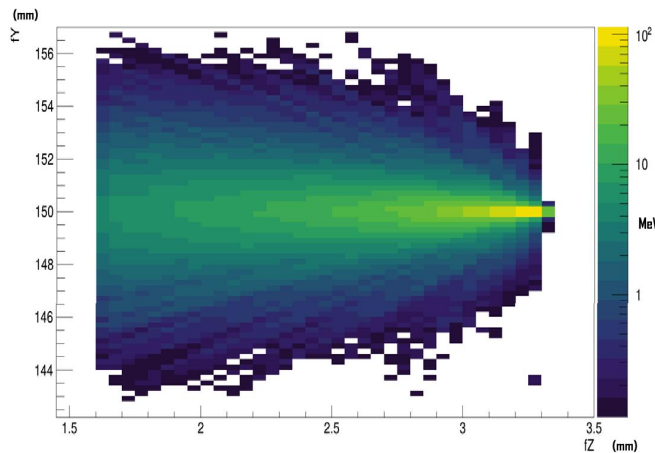
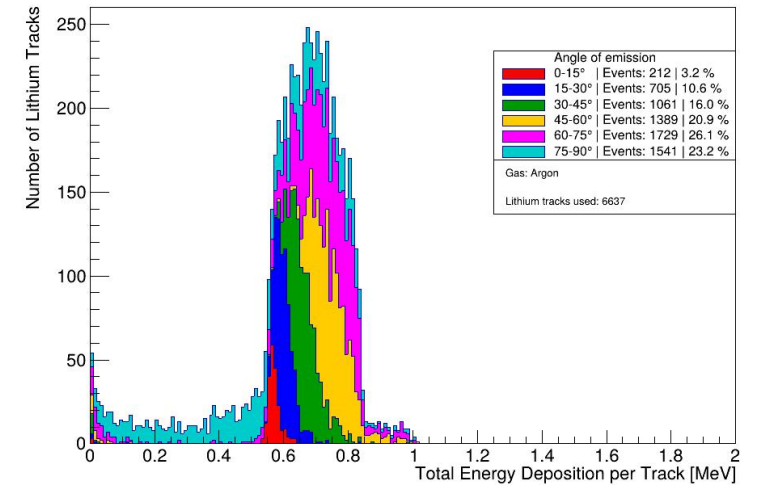
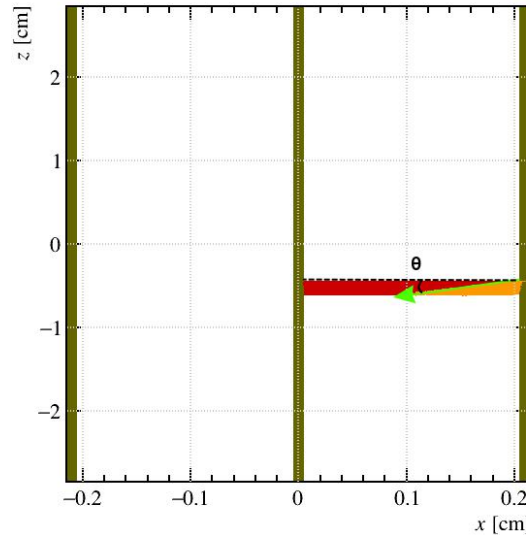
Output signal using LTspice

- The last part of the simulation chain is the conversion of the induced current to the output signal coming from the front-end electronics of the I-BM.
- After emulating the electronics using LTspice, the induced current from Garfield++ is “passed” through the electronics to calculate the output signal.
- Examples of a single neutron event (top figure) and of a multiple neutron event resulted from a thermal neutron bunch (bottom figure).



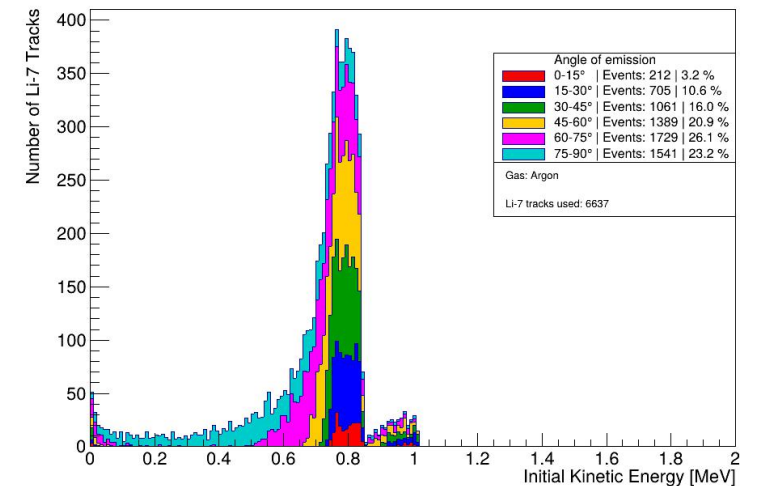
Energy Deposition of ions inside the gas volume

- Energy deposition strongly depends on ion emission angle from the conversion layer.
- At angles near 90°, energy deposition is minimal due to increased ion energy loss within the conversion layer.
- Also observed by [Alexandros Gardikiotis](#) studying a different neutron monitor using B₄C conversion layer.



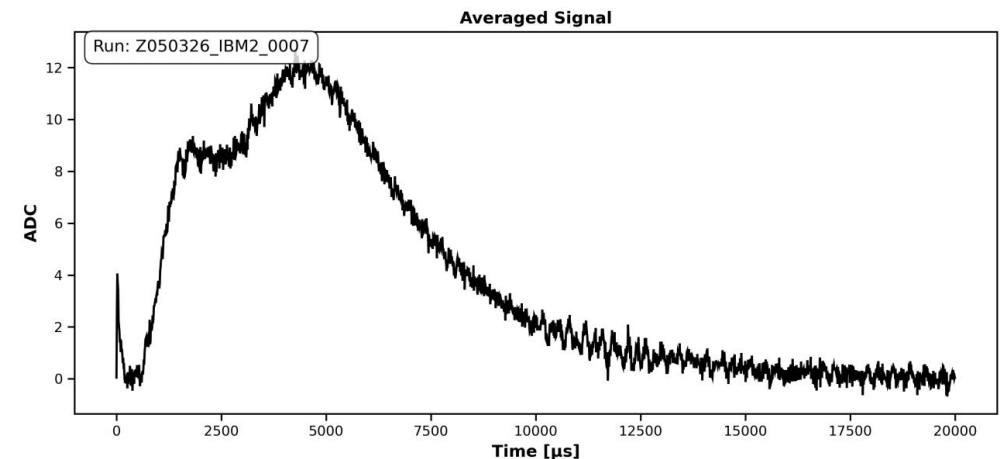
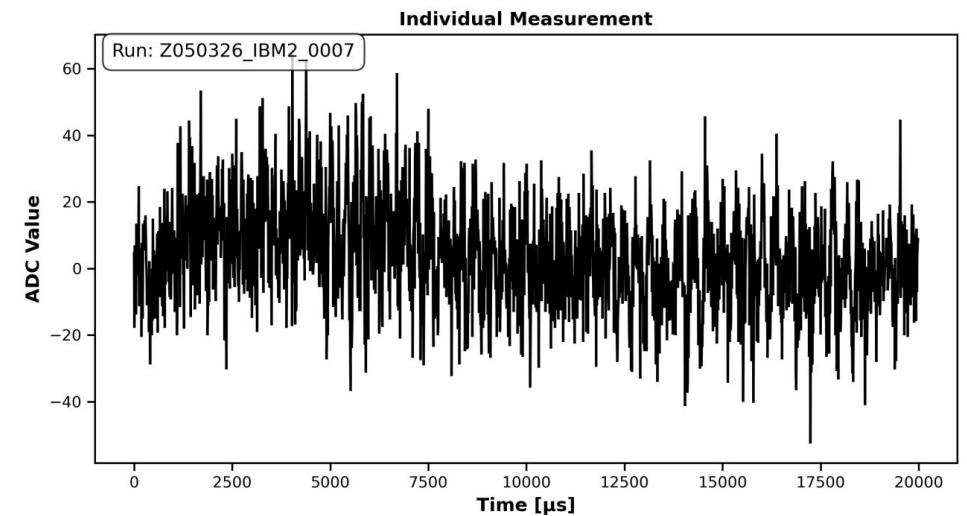
From poster:
“Simulation studies of a MPGD based Neutron Beam Monitoring system for ESS”

More information during the poster session.



Experimental Measurements

- Data using two I-BM detectors were acquired in the ISIS Neutron and Muon Source (UK), in the EMMA beamline.
- A trigger system operating together with a chopper along the beamline was employed to split the neutron beam into pulses within the recorded timeframes.
- The output of the front-end electronics is in the form of ADC values, 1 ADC increment being equivalent to $31.25 \mu\text{V}$.
- By averaging over the timeframes, the averaged signal of the recorded data is produced.

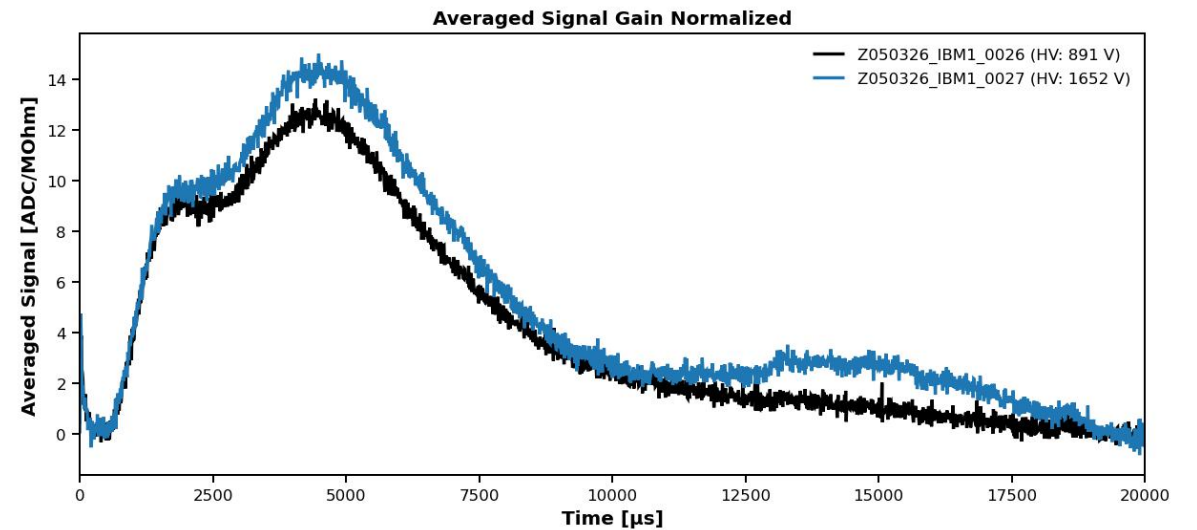


Experimental Measurements

- Different sets of operating parameters were used for the runs, in order to investigate how these parameters affect the I-BM's performance.

Run	Duration	HV (V)	Chopper Frequency (Hz)	Gas Mixture	Cable Configuration	Beam Status
IBM1_0026	60	891	50	Air	SN39+SN37	Beam On
IBM1_0027	60	1652	50	Air	SN39+SN37	Beam On
IBM1_0029	60	1652	50	Ar/CO ₂ (80/20)	SN39+SN37	Beam On
IBM2_0004	60	874	50	Ar/CO ₂ (80/20)	SN41+SNX	Beam On
IBM2_0006	60	874	50	Ar/CO ₂ (80/20)	SN41+SNX+SN38	Beam On
IBM2_0007	60	874	50	Ar/CO ₂ (80/20)	SN41+SNX+SN38	Beam On
IBM2_0008	60	874	50	Ar/CO ₂ (80/20)	SN41+SNX+SN38	Baseline

- As an example we see how the HV value affects the averaged signal.



Conclusions and Ongoing Work

Conclusions:

- A simulation framework for the ESS I-BM is under development, covering the full signal formation chain from neutron interaction to readout electronics.
- It enables systematic studies of detector response under different conditions.
- Experimental data are used as a benchmark and to compare with the simulation results.

Ongoing work:

- Additional studies (neutron energy, converter thickness, gas conditions)
- Towards full automation of the simulation framework
- Expand studies to MPGD based monitors to be used in the ESS

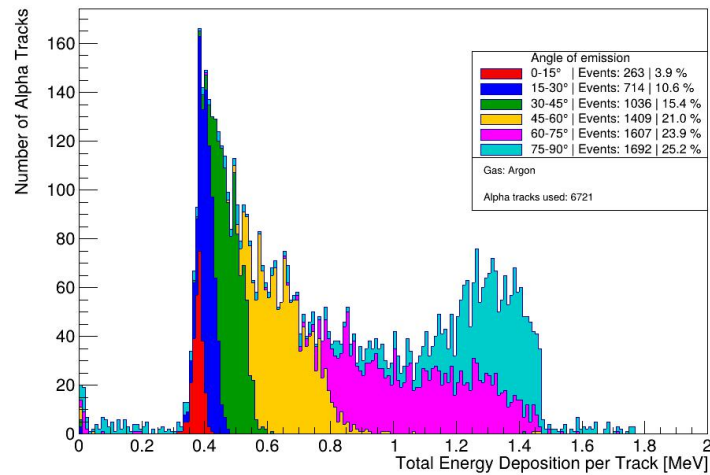
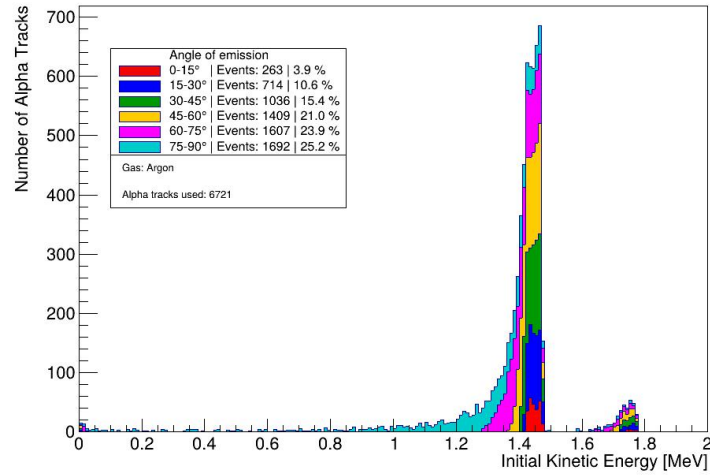
Goal: accurate reproduction of detector behaviour and use of the framework for detector optimization

References

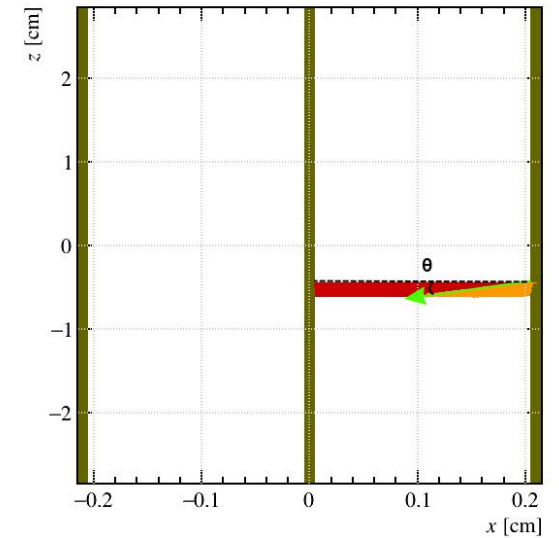
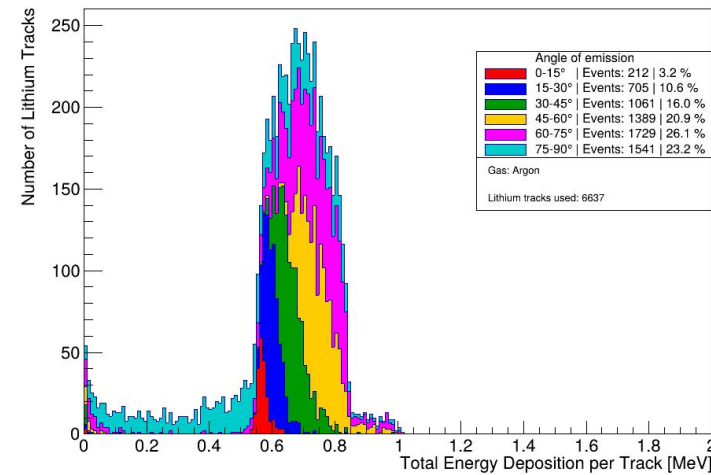
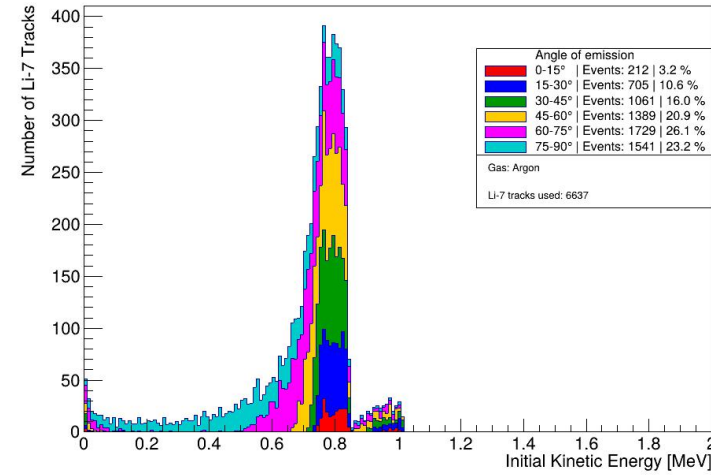
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- [2] R. Garoby et al., "The European Spallation Source Design," Physica Scripta, vol. 93, no. 1, Art. no. 014001, Dec. 2017, doi: 10.1088/1402-4896/aa9bff.
- [3] Ionization Chamber Neutron Beam Monitor (I-BM) Operating Manual, CDT CASCADE Detector Technologies GmbH, Heidelberg, Germany, Jul. 11, 2024.
- [4] C. Cazzaniga, D. Raspino, G. J. Sykora, and C. D. Frost, "Dosimetry of thermal neutron beamlines at a pulsed spallation source for application to the irradiation of microelectronics," IEEE Trans. Nucl. Sci., vol. 68, no. 5, pp. 921-927, May 2021, doi: 10.1109/TNS.2021.3064681.

Backup - Energy deposition of ions

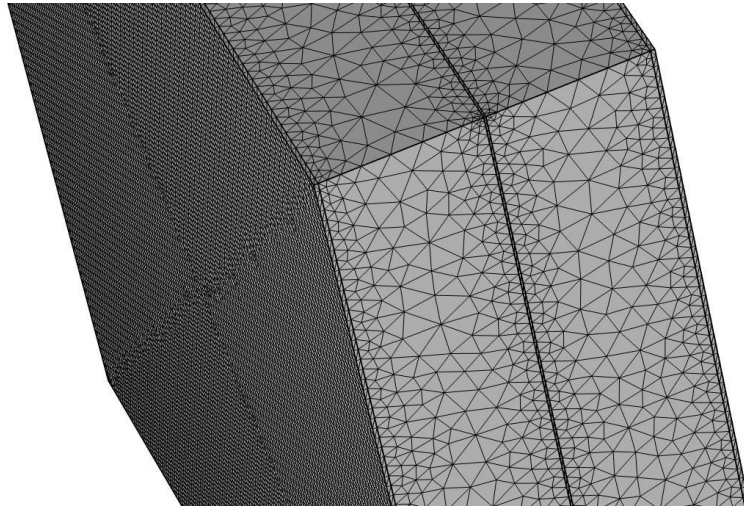
Alphas



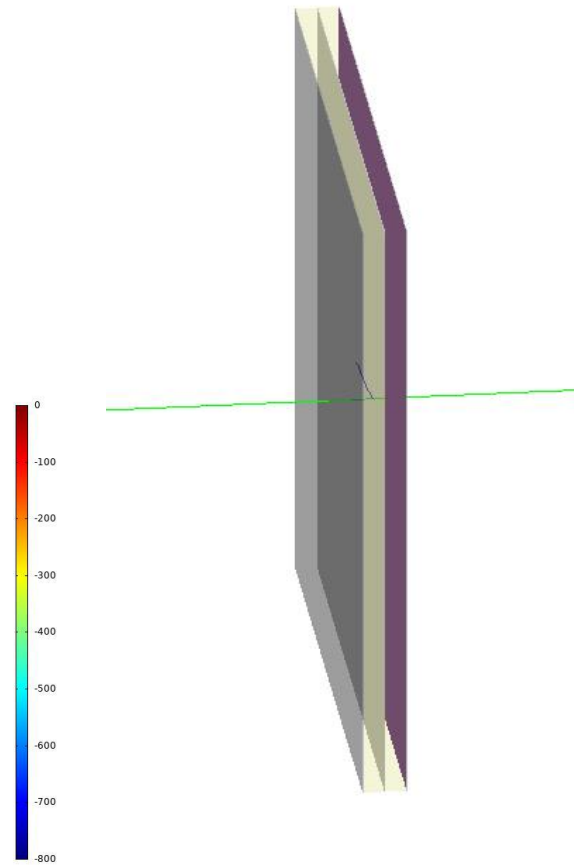
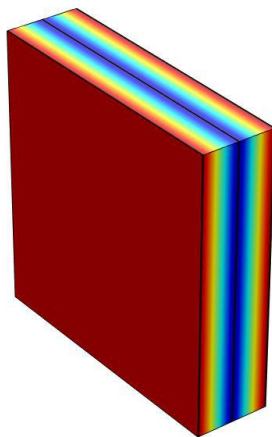
Lithium 7 ions



Simulation Plots

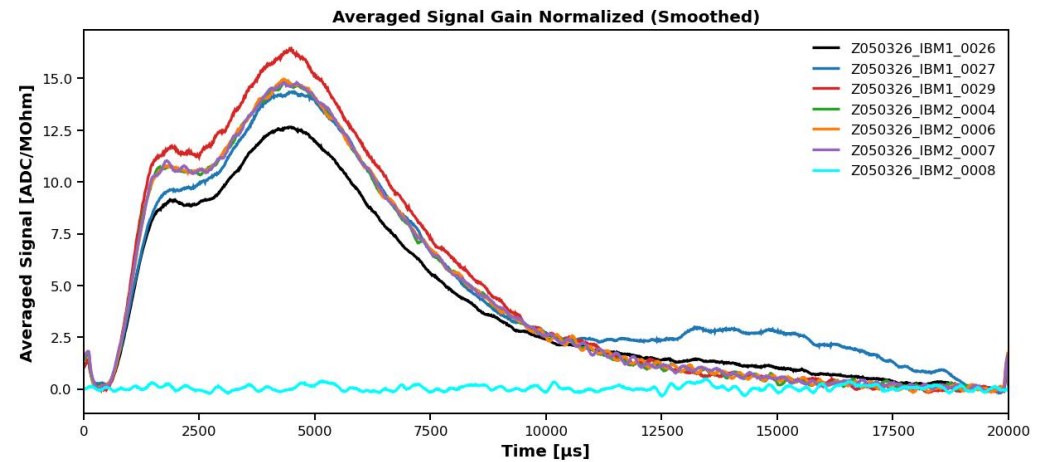
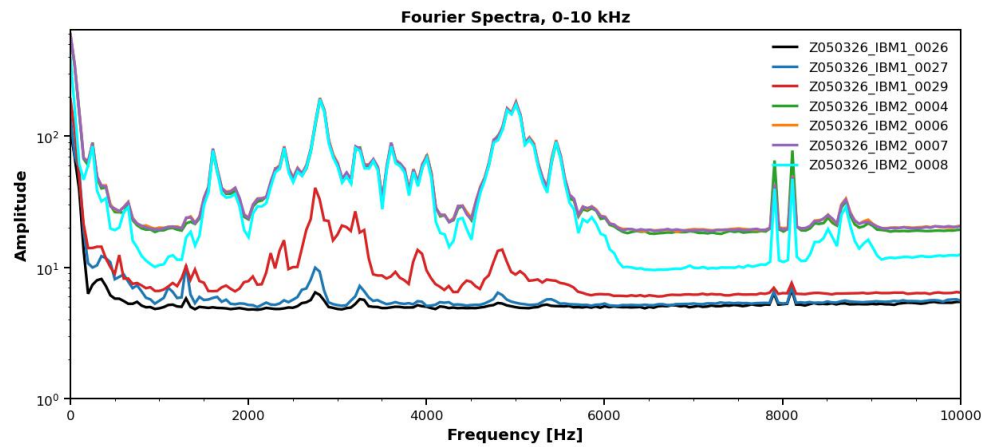
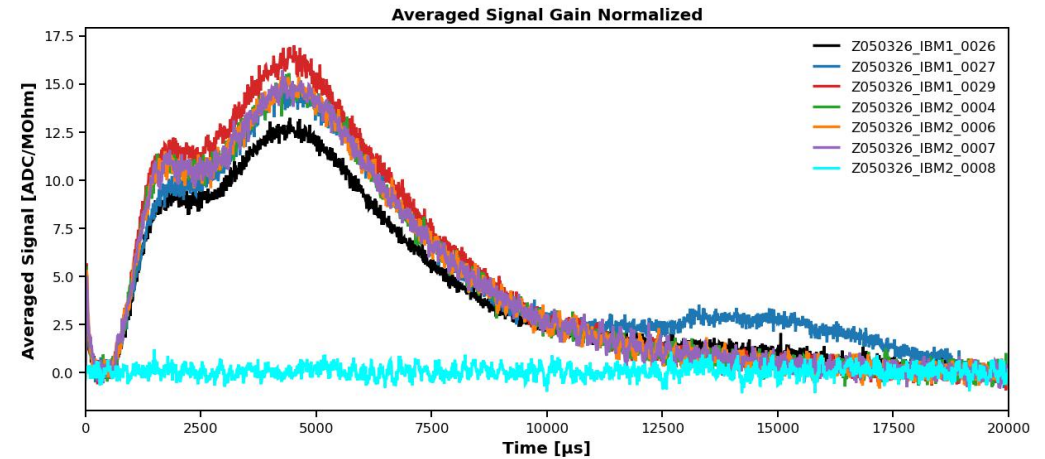


Surface: Electric potential (V)



Backup - ISIS EMMA beamline measurements

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