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Development of a Multi-layer Boron-coated GEM detector for slow neutron detection at spallation sources

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INTRODUCTION

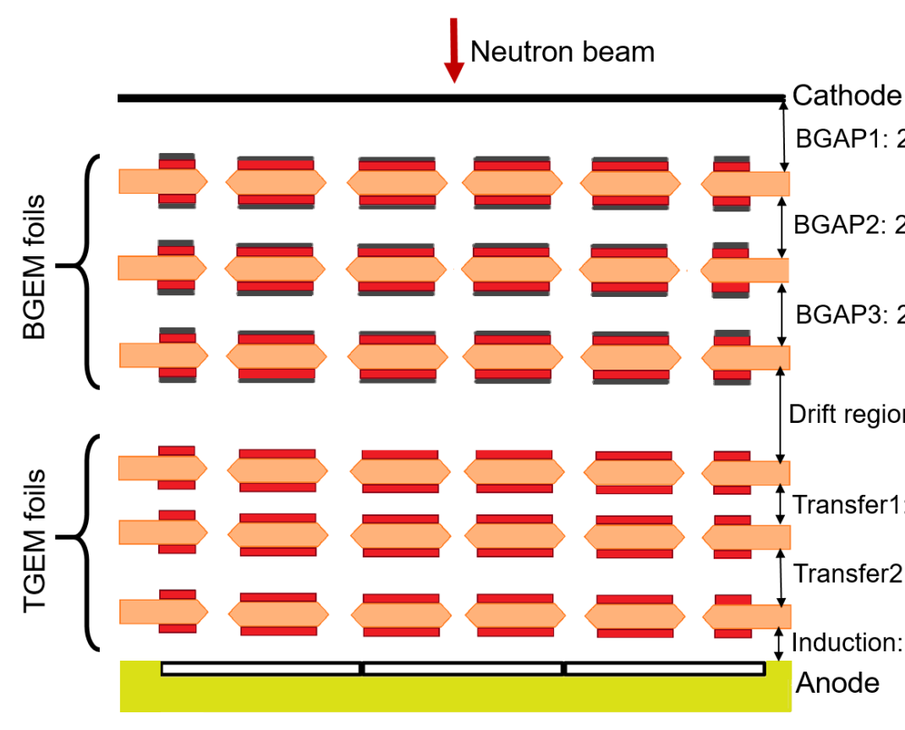
Experiments at neutron spallation sources require detectors with specific features such as high spatial resolution and high detection efficiency. The most common neutron detector is based on ^{3}He, but the recent ^{3}He shortage needs a new kind of detector with comparable performance.

GEM detectors [1] can be easily converted into thermal neutron detectors via suitable **neutron "converters"**. Moreover, coupling a GEM detector with a custom digital readout, high rates are sustained avoiding dead time and pile-up phenomena. This system makes GEM detectors very attractive for facilities where a high neutron flux rate is expected, such as the European Spallation Source (ESS).

[1] F. Sauli, "The gas electron multiplier (GEM): Operating principles and applications, Nucl. Instrum. 294 Methods. Phys. Res. A 805, 2, 2016

THE MBGEM DETECTORS

- The novelty of MBGEM [2] is the **neutron converter**: **a boron-coated GEM (BGEM) foil** made of 50 μm thick kapton layer, sandwiched between 5 μm thick copper layers and 1 μm thick $^{10}B_4C$ layers.
- The detector has been designed with two possible configurations either with three or six BGEM foils coupled with a standard triple GEM.



- Gas mixture: $ArCO_2CF_4$ (45%-15%-10%).

Figure 1. MBGEM detector scheme.

[2] A. Muraro et Al., "MBGEM: a stack of borated GEM detector for high efficiency thermal neutron detection", Eur. Phys. J. Plus (2021) 136:742

MEASUREMENTS at LENA TRIGA Mk II REACTOR

- Two different configurations of the MBGEM detector have been assembled: three (3-MBGEM) or six (6-MBGEM) foils respectively.
- Use of a padded anode of 256 pads (6x6 mm^2) allowing **imaging capabilities.**

Figure 2. 3-MBGEM detector at TRIGA Mark II reactor in Pavia.

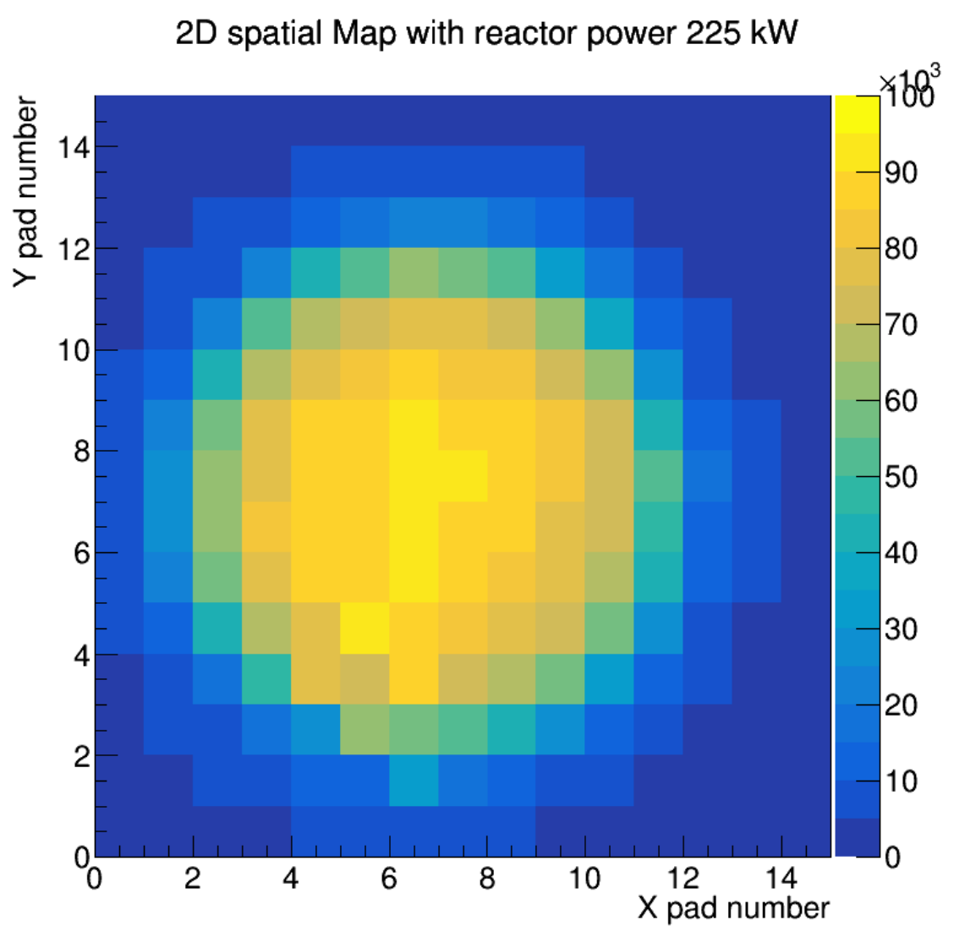


Figure3. 2D spatial map of the neutron beam performed with 3-MBGEM detector

- BGAPS (gas layer between BGEM foils): 2 mm.
- Use of **GEMINI digital electronic readout**.
- The detection efficiency scales as expected with the number of powered-on BGEM layers.
- Counting rate scales as expected with the reactor power.

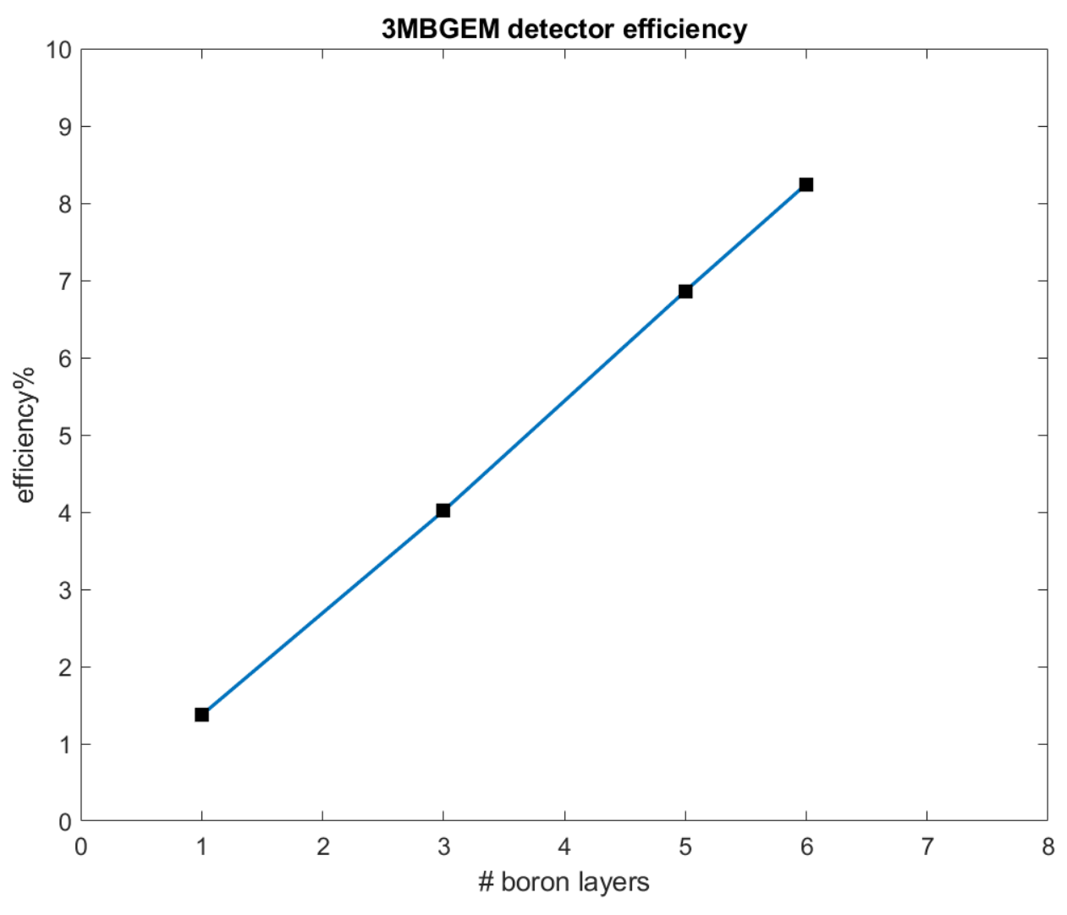


Figure4. 3MBGEM detection efficiency estimated with comparison with a calibrated ^{3}He tube.

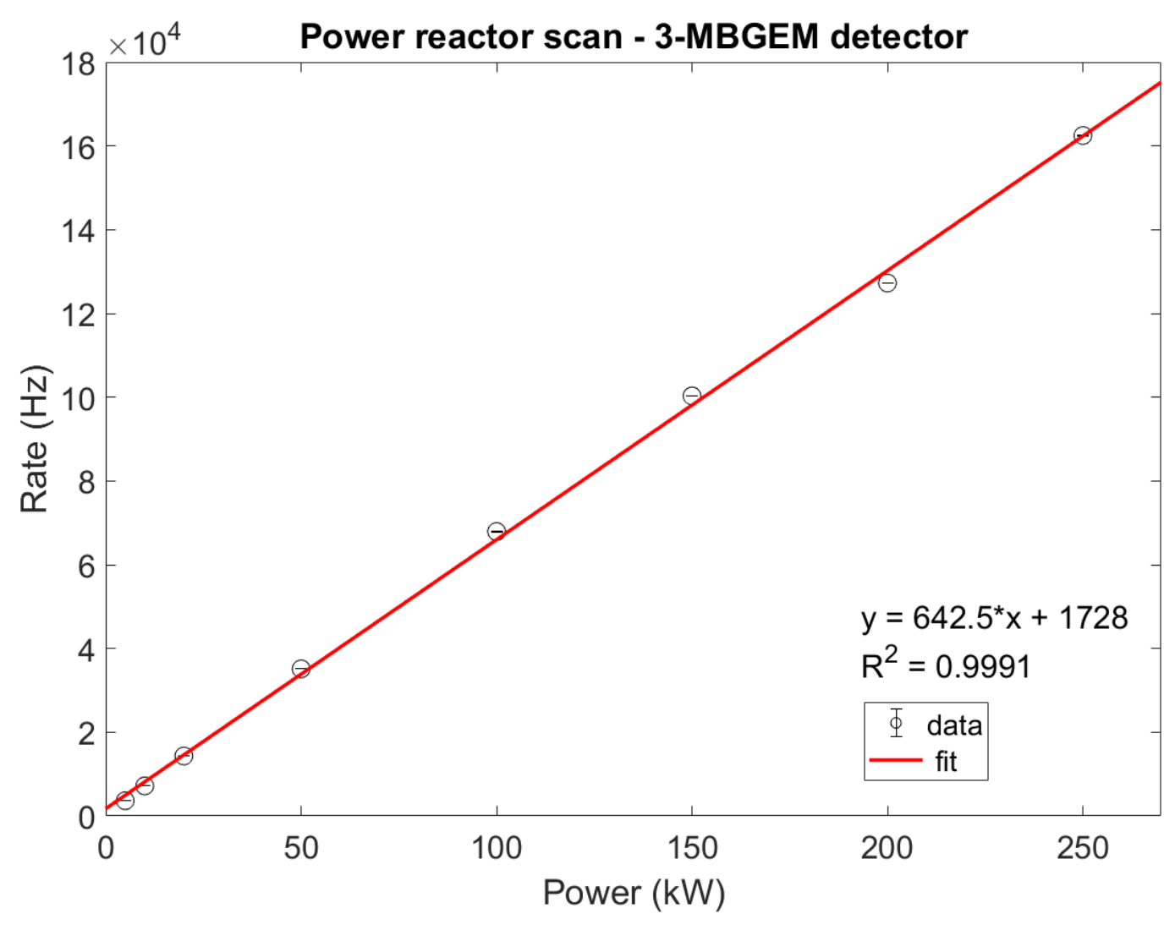


Figure5. The counting rate scales linearly with the reactor power up to 250 kW.

SIMULATIONS

- Use of GEANT4 software.
- $1 * 10^6$ neutron beam at 25 meV.
- Alpha and lithium produced via the nuclear reaction $n + ^{10}B \rightarrow \alpha + ^7Li$.
- Use of different thicknesses (1mm to 5mm) of the gas layers (BGAPS).
- Energy deposition by α and ^{7}Li depends on gas thickness; however, **the total number of counts is almost independent**: thin gas layers can be exploited.

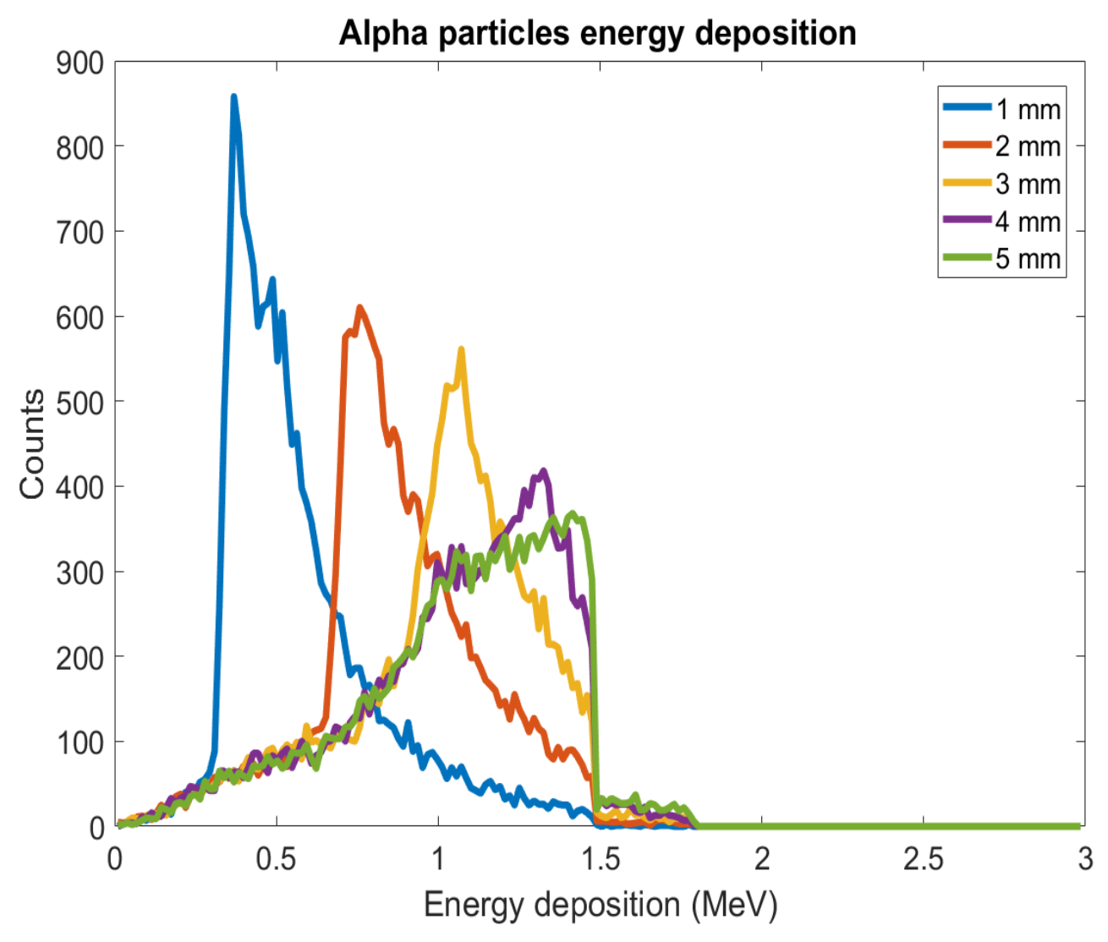


Figure6. Alpha energy deposition in the BGAP1 for different BGAP1 thickness

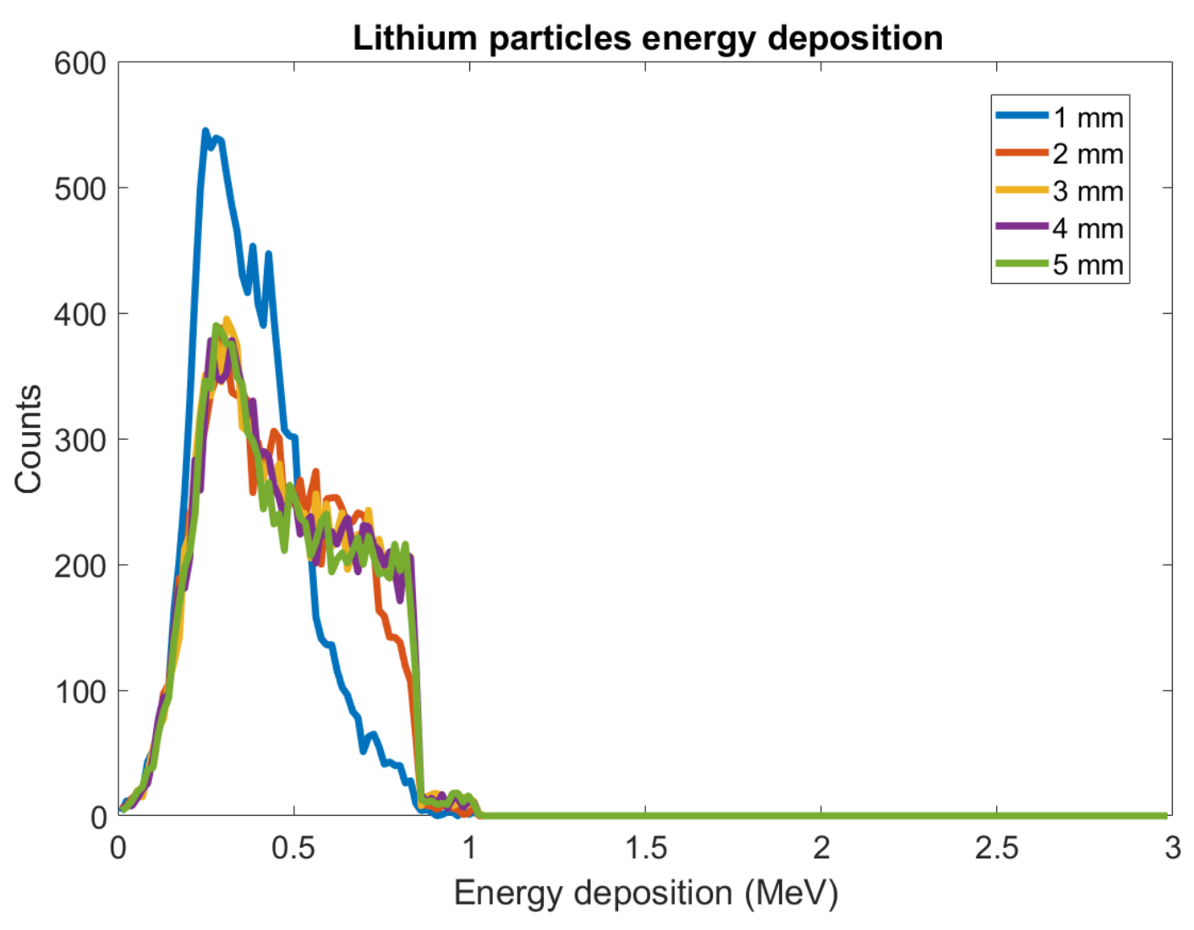


Figure7. Lithium energy deposition in the BGAP1 for different BGAP1 thickness

- Gamma-rays (478 keV and 1 MeV) deposit a much lower energy in the detector: they can be easily discriminated through a suitable LLD.
- A boron thickness around 1 μm is a suitable choice to reach a good detection efficiency.

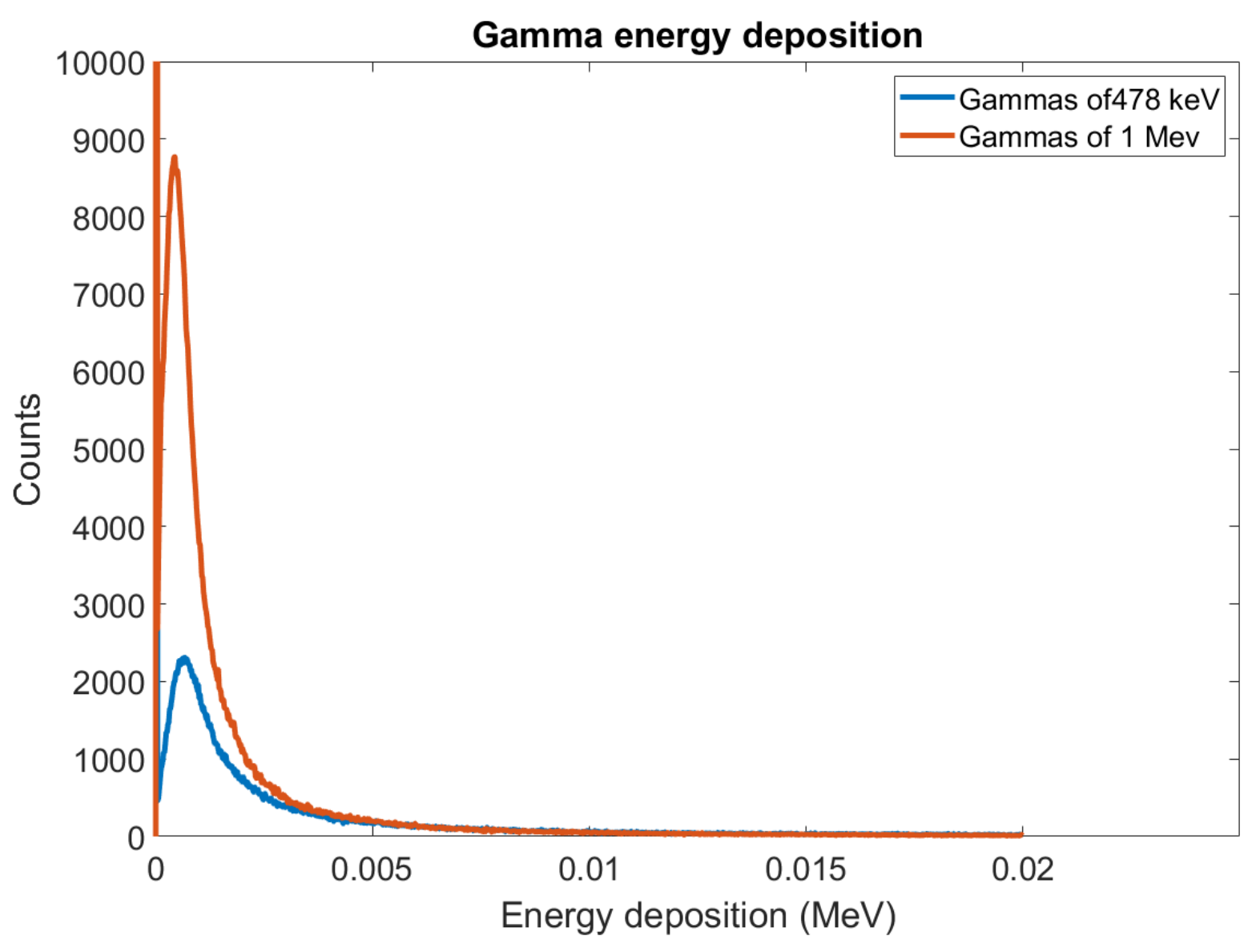


Figure8. Gamma-ray energy deposition in the MBGEM detector with six BGEM foils with BGAPS of 2 mm

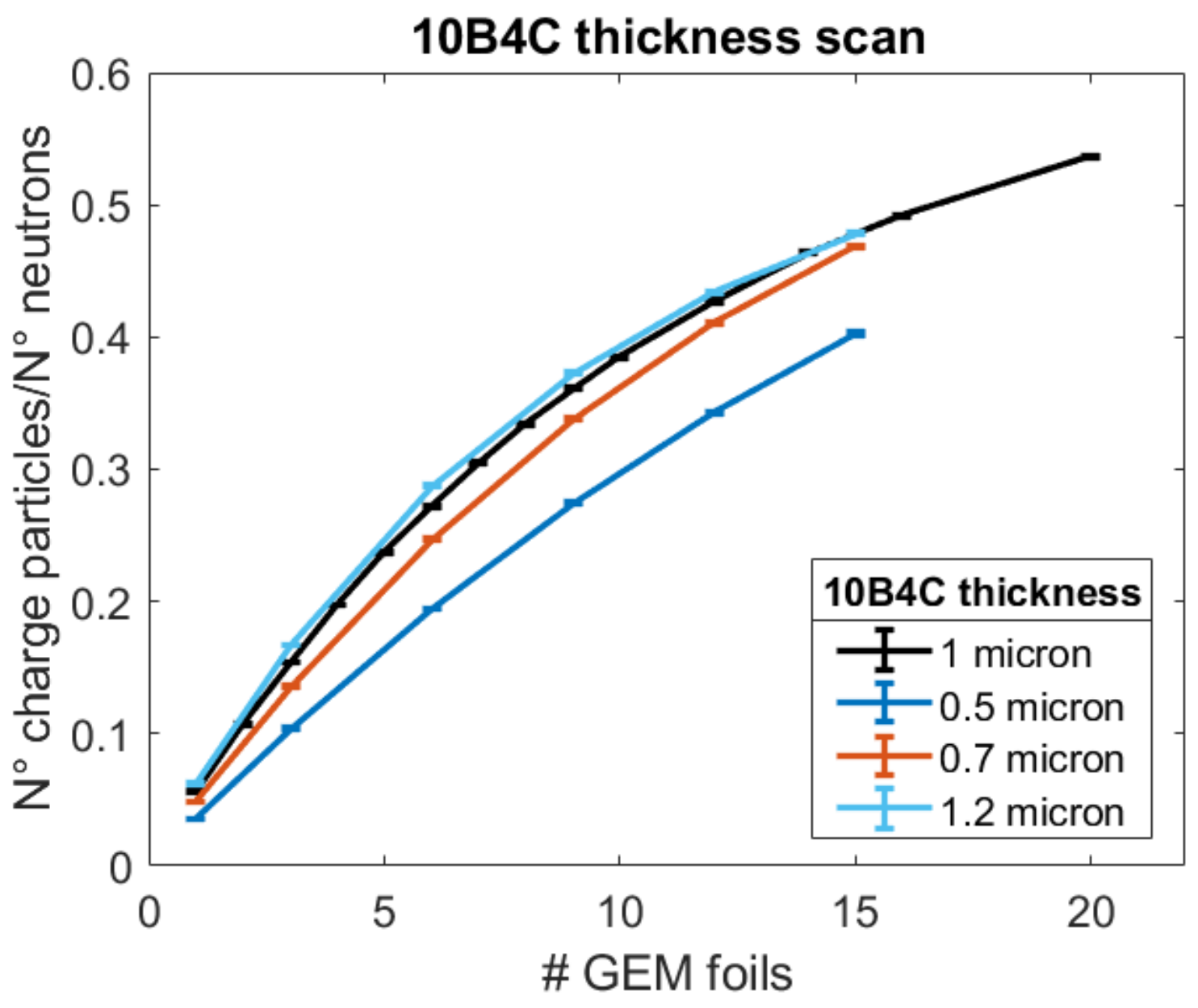


Figure9. Scan of different boron thickness with a BGAP of 2 mm.

- The detection efficiency increases with the increase of the layer number and it is higher for neutrons with low energy (5 meV) than neutrons with high energy (50 meV). This different behaviour is due to the ^{10}B neutron cross section.

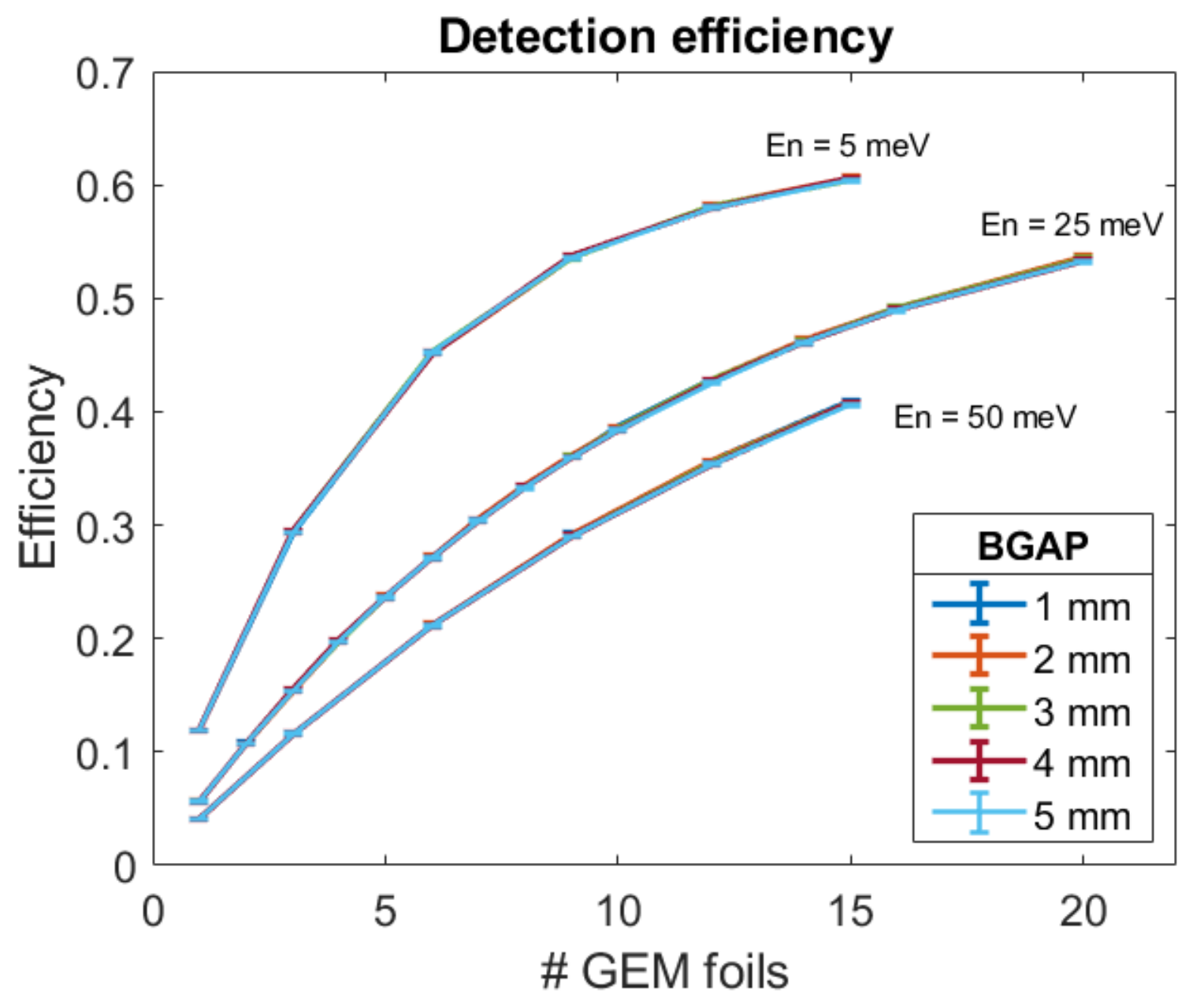


Figure10. Counts due to the alpha and lithium, which deposit their energy inside the gas. Charged particles are considered if they deposit an energy over 150 keV.

CONCLUSIONS

- The measurements at LENA of these prototypes had provided good results confirming the GEANT4 simulations.
- The simulations of the particle energy deposition suggest the possibility to build a new detector with **6 GEM foils**.
- The detector will be tested at the **ISIS neutron source** on the VESUVIO beamline and used as **transmission monitor**, in order to perform experiments aimed at determining overall neutron cross sections of samples in the energy range 0,1 meV-10 eV.

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