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GEANT4 simulation results of the interaction between a thermal neutron beam and a single boron-GEM foil

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Summary. — Since 2010, the *ensuremath*^{3}He crisis has brought the necessity to develop new thermal neutron detectors as an alternative of the tubes based on ^{3}He. A good candidate can be represented by Gas Electron Multiplier (GEM) detector, which can detect neutrons if coupled with a suitable neutron converter. This work presents the numerical simulations performed with the GEANT4 toolkit, where the interaction of a thermal neutron beam with the single innovative boron GEM (BGEM) foil has been studied.

1. – Introduction

The recent ^{3}He shortage has required the development of new neutron detectors as an alternative due to the ^{3}He crisis.

Several detectors have been studies, but a good choice is represented by Gas Electron Multiplier (GEM) detectors [1]. The main component of the GEM detector is represented by the GEM foil, 50 μm of an insulating layer (kapton) covered on both sides with a conductive layer (5 μm of copper); then, the foil is micro-perforated with high density (50–100 holes/mm^2). GEM detectors distinguish themselves from other gas detectors thanks to their capability to sustain high rates (MHz/mm); they have good spatial (μm) and time (ns) resolution, and they can be built with different shapes and cover large areas [2].

Since they can only track charged particles, the neutron detection is possible coupling the GEM detector with a suitable converter, in particular with boron, where the neutrons are converted via the nuclear reaction ^{10}B(n,α)^{7}Li.

A recent GEM detector optimised for thermal neutron detection is the Multi-layer (MBGEM) Boron-GEM detector [3].

The device has been realised with three innovative boron-GEM (BGEM) foils, a GEM foil covered on both side with a boron layer.

TABLE I. – *GEM foil parameters fixed during the simulations.*

Parameter	Value
Gas mixture	Ar-CO_2 70%–30%
Kapton layer thickness	50 μm
Copper layer thickness	5 μm
boron layer	$^{10}B_4C$
GEM foils active area	10×10 cm^2

This paper reports the numerical simulation performed with the GEANT4 toolkit [4], where the interaction of a thermal neutron beam and a single BGEM foil has been studied. These simulations are necessary to fix the final GEM geometry configuration, such as the distance between each foil and the boron thickness and they are the first step toward the next simulations aimed to study the stack of several BGEM foils.

2. – Simulations and results

Geant4 is a software based on C++ programming language, thus the main parameters of the simulations are implemented in the mandatory classes. The GEM geometry has been determine with the class *DetectorConstruction* and the fixed parameters are reported inside table I. For all simulations reported in this paper, the neutron energy has been fixed at 25 meV and 10^6 neutrons have been generated. The simulations have been performed at first for the region on the left of the GEM foil, following the neutron beam direction as reported in fig. 1, and then they have been repeated for the second region, on the right of the second copper layer.

The scheme of the GEM foil is shown in fig. 1. The studied parameters with the simulations for the two separate region are

- The energy threshold.
- The Ar-CO_2 layer thickness.
- The $^{10}B_4C$ layer thickness.

Figure 2 show the total counts due to the α and lithium particle contributions aimed to fix an energy threshold in order to discriminate the counts due to presence of the background. The gas layer thickness has been varied from 0.5 up to 5 mm and different

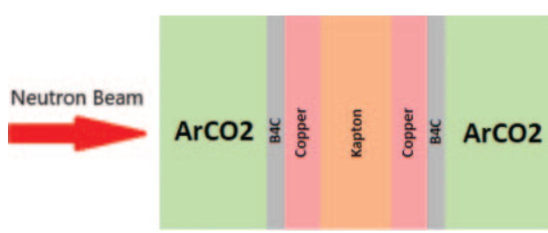
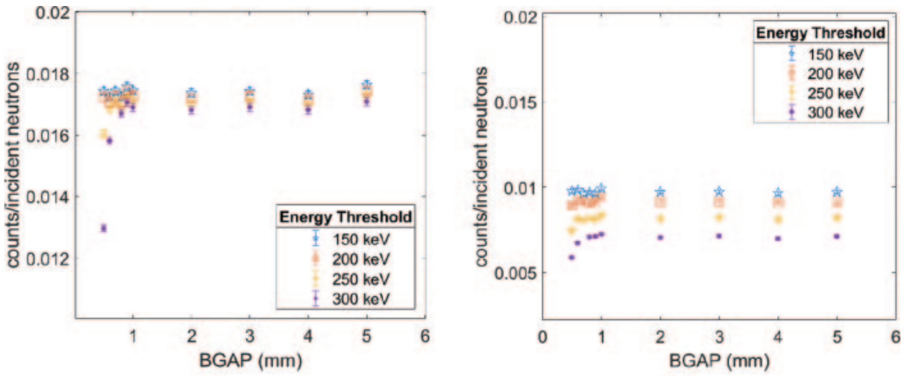


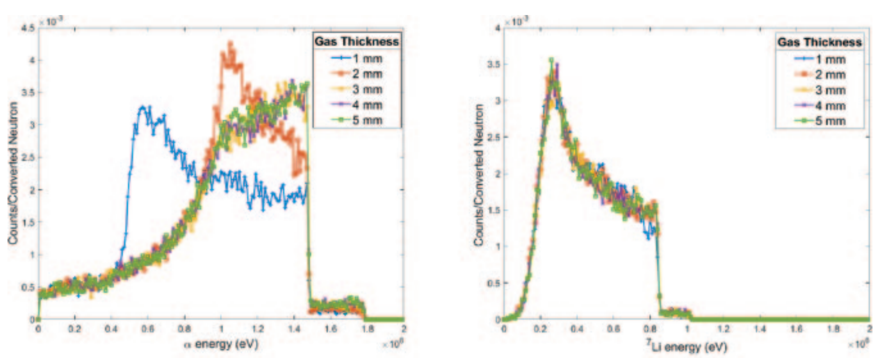
Fig. 1. – Scheme of GEM foils structure. The relative parameters are reported inside table I.



(a) (b)

Fig. 2. – Study of the count number variation for α (a) and lithium (b) with the increase of the energy threshold for different gas layer thicknesses.

energy thresholds have been set. In fact, events have been considered only if the energy released from α and lithium particles is higher than 150 keV, 200 keV, 250 keV and 300 keV. Until 1 mm, the events are lost since the gas layer is thin and the charged particles travel releasing their energy until they reach the end of the Ar-CO_2 layer. This effect is visible in fig. 3(a), where the energy released for different gas layer thicknesses is reported. Considering the energy released from α particles in 1 mm of Ar-CO_2, most of the energy of the α particles are concentrated around 0.5 MeV. These charged particles are emitted perpendicular to the boron layer toward the Ar-CO_2 layer, thus they cannot release their entire energy before the end of the gas layer. Only the α particles emitted with an angle different from 90° can release more energy than 0.5 MeV. Therefore, gas layer values less than 1 mm does not allow to release sufficient energy if the energy threshold increase. For this reason, only simulations starting from 1 mm gas layer have been considered and the energy threshold set for all the simulations is 200 keV, in order to represent the real case, where the gamma background lays below this energy and it is usually discriminates with a suitable threshold set to the electronic readout.



(a) (b)

Fig. 3. – α (a) and lithium (b) particles energy deposition with the variation of the Ar-CO_2 layer. These two graphs have been obtained fixing the $^{10}B_4C$ layer at 1 μm.

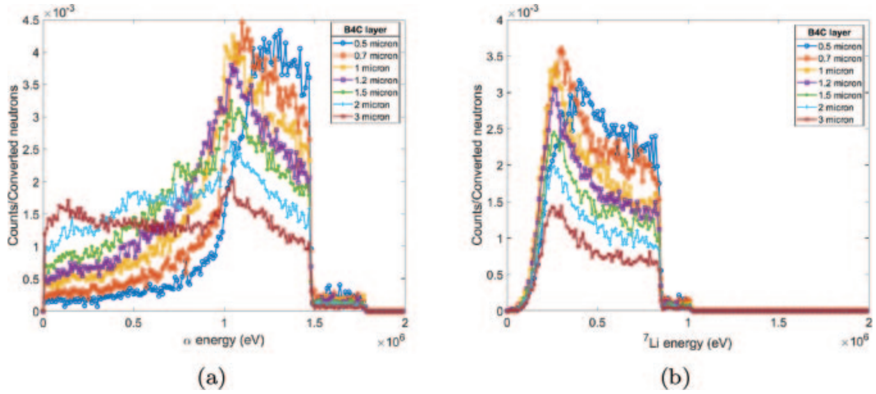


Fig. 4. – α (a) and lithium (b) particles energy deposition with the variation of the $^{10}B_4C$ layer thickness with the Ar-CO_2 layer fixed at 2 mm.

The study of the gas layer thickness has been conducted considering the energy released from the α and lithium particles varying the gas layer from 1 mm up to 5 mm. The events have been considered only if the energy released inside the gas layer is more than 200 keV. The graphs reported inside fig. 3 show the released energy from the charged particles with 1 μm of $^{10}B_4C$ layer. Increasing the gas layer thickness, the deposited α energy peak shifts from the left side toward the right side of the graph, which indicates that α particles have more space to travel and loose their entire energy. Lithium particles are less energetic than α, thus they need less gas thickness to deposit completely their energy and each gas layer provides the same spectrum shape.

Then, the same simulations have been repeated for different $^{10}B_4C$ layers (0.5, 0.7, 1, 1.2, 1.5, 2, 3 μm) and each obtained graph highlights that from 2 mm the α particles release most of their energy from 1 MeV, which is a good value to ionise the Ar-CO_2 gas mixture, thus a thickness of 2 mm has been fixed to study the $^{10}B_4C$ layers.

The last parameter studied with the simulations is the $^{10}B_4C$ layer thickness, which is the neutron conversion region. Since the α and the lithium particles are emitted back to back, only one of them (or neither) can be detected. Their range inside the $^{10}B_4C$ layer is around 3 μm for α and 1.5 μm for lithium particles, thus a $^{10}B_4C$ layer too thin reduces the probability of the neutron interaction with the layer, while a $^{10}B_4C$ layer too thick absorbs all the produced charged particles; for both cases the events are lost.

The $^{10}B_4C$ thickness has been varied from 0.5 up to 3 μm and the released energy from the charged particles has been plotted. The graphs 4 report the energy released from the α and lithium particles for different $^{10}B_4C$ thickness normalised for the number of the neutron converted inside the boron layer. Increasing the $^{10}B_4C$ thicknesses, only the charged particles produced near the Ar-CO_2 gas layer can enter inside the gas region and most of the particles loose most of their energy inside the boron layer. From the graphs, a $^{10}B_4C$ layer of maximum 1 μm thick can be chosen.

All the simulations have been repeated also for the second boron layer and no significant differences in the obtained graphs have been observed.

3. – Conclusions

This work presents the simulations performed with the GEANT4 toolkit to simulate the BGEM foil response after the interaction with a thermal neutron beam.

The Ar-CO_2 gas and $^{10}B_4C$ layers have been studied in order to find their optimum values and a Ar-CO_2 gas layer of 2 mm and a $^{10}B_4C$ layer maximum 1 μm have been found for both region.

Future simulations are aimed to determine optimum value of the $^{10}B_4C$ layer thickness at the increase of the number of the BGEM foils, in order to study how the detection efficiency can increase combining these two parameters.

All these simulations will be necessary to build up the first prototype of a GEM detector with a series of a BGEM foils with an active area of 10×10 cm^2.

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