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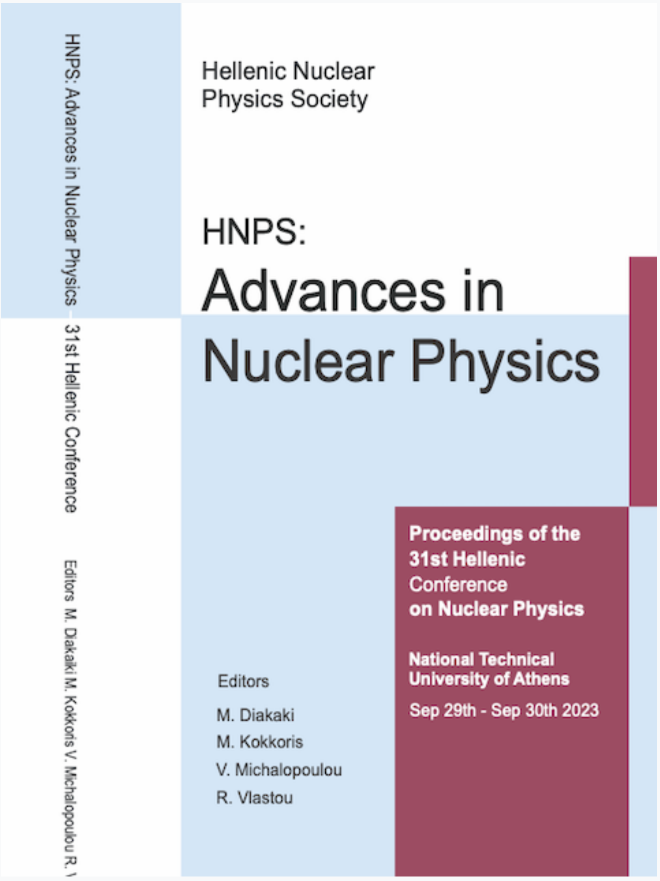

A study on the wall effect of the Spherical Proportional Counter for long-range particle detection

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A study on the wall effect of the Spherical Proportional Counter for long-range particle detection

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Abstract The Spherical Proportional Counter is a large-volume gaseous detector that finds application in many fields, like α, β, γ radiation detection, neutrino detection and Dark Matter research. When a reaction happens close to the detector wall it is possible for the produced particles to hit the wall and lose energy. This is known as the wall effect and it leads to wrong calculations of the incident particle energy. It depends on the particles' range and the detector characteristics, such as its size and the gas pressure. In this work, a study has been done in order to quantify the wall effect for the SPC, for any application. We used neutron beams, which cover the total volume of the sphere and interact with the gas nuclei, giving several reactions. The presented data derive from simulations on GEANT4 and are in agreement with the experimental data from neutron beams of the TANDEM Accelerator Laboratory, NCSR Demokritos.

Keywords Spherical Proportional Counter, wall effect, neutron detection, GEANT4

INTRODUCTION

The spherical proportional counter

The spherical proportional counter [1] is a gaseous detector, with the ability to be manufactured having either a large or a small volume and it is used in a wide range of applications. It consists of a spherical metallic shell with 2.5mm thickness and 30cm in diameter, which can be filled with gas mixtures at different pressures. The vessel is grounded and acts as the cathode of the system, while the anode consists of a small metallic sphere that is placed in the center of the hollowed vessel. The anode is supported by a metallic wire through which the high voltage is applied.

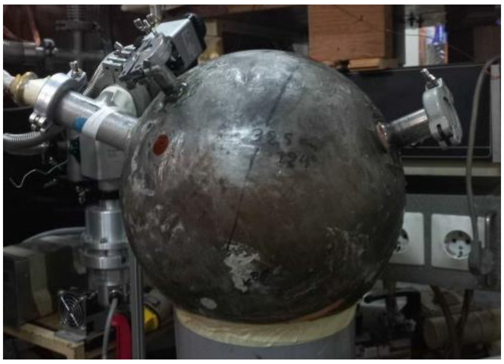

Figure 1. *The spherical proportional counter at Aristotle University of Thessaloniki*

The electric field is highly inhomogeneous along a radius and is inversely proportional to r^2. The difference in the intensity of the field divides the detector in two volumes, the drift and amplification region. When an energetic particle enters the detector, ionizations are produced and as the electrons drift towards the anode, at a distance of a few mm an avalanche is produced, inducing a signal.

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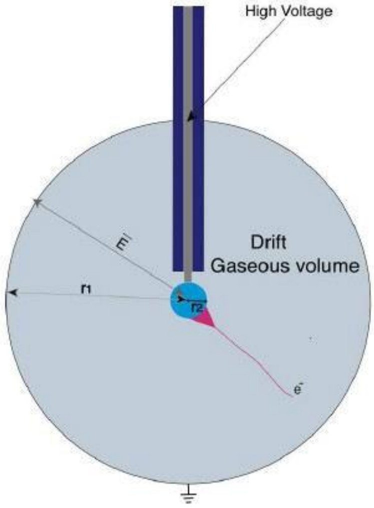

Figure 2. *Schematic of the spherical proportional counter [1]*

The detector response depends on the interacting particles, the gas mixture and the detector size. The large dimensions required to prevent the recoil from reaching the detector walls, also known as the wall effect, reduce the efficiency of the detector.

EXPERIMENTAL DETAILS

The wall effect

To detect an interacting particle that enters the detector, and especially to measure its energy, it is important for the produced particles to deposit all their energy inside the sensitive volume of the detector. When the detector that is used is small or the particles have a long range, if the reaction happens close to the vessel wall it is possible for one or more of the produced particles to hit the wall and lose part of their energy [2]. This phenomenon is called the wall effect, it appears in all detectors and depends on the size of the detector, the pressure in which it operates, but also on the range of the produced particles. It is important to take the wall effect into consideration when analyzing data, since it can lead to wrong conclusions.

The detection reactions

To measure and quantify the wall effect of the spherical proportional counter in our study, we exploit the neutron reactions in nitrogen gas and specifically the (n,p) and (n,α) reactions.

$$N^{14} + n \rightarrow C^{14} + p + 625.9 \ keV \quad (1)$$

$$N^{14} + n \rightarrow B^{11} + a - 158 \, keV \quad (2)$$

The first process has significant cross-section for thermal neutrons and fast neutrons with energies up to 20 MeV, while the latter has large cross-section for fast neutrons with energies above 2 MeV. It can be seen in Figure 4 that nitrogen gas appears to be inferior to other gases for neutron detectors however this cross section disadvantage can be covered by its large atomic number which results in reduced wall effect [4]. Also practical reasons, such as the fact that He gas is expensive and BF3 gas is very toxic, makes nitrogen gas an ideal alternative.

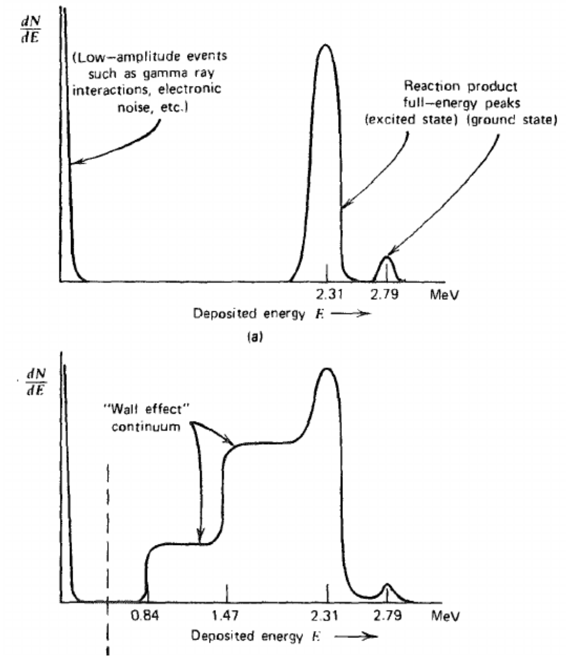

Figure 3. *The wall effect in a BF_3 cylindrical counter. Top: Full energy deposition peaks, Bottom: Energy deposition peaks for wall effect events [3].*

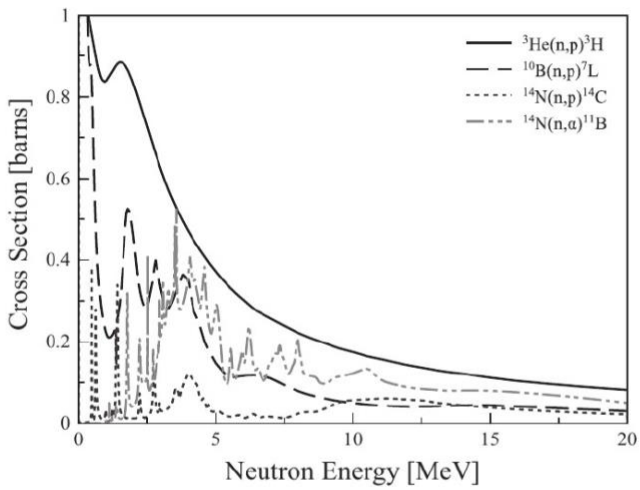

Figure 4. *Cross sections for neutron reactions in different gases [5]*

The simulation

To measure the wall effect from the neutron reactions, the Monte-Carlo based simulation framework Geant4 was used [6]. The simulation was built based on the "Hadr06" example from the provided files, with some modifications to create the exact geometry and gas mixture as in the spherical proportional counter.

The detector's diameter was fixed at 30 cm, with an iron shell of thickness 2.5 mm and measurements were taken for nitrogen gas at 4 different pressures (1 bar, 5 bar, 10 bar, 15 bar). For the study fast neutron beams with energies from 2 MeV up to 15 MeV were used. The simulated beams consisted of $5x10^6$ neutrons parallelly incident on the detector and they were emitted from a disk with the same diameter as the SPC placed at a small distance outside from it.

The data were analyzed using a python code, through which first the total number of (n,p) and (n,α) reactions are counted and then the percentage of produced particles that hit the wall is also calculated. These events are registered as lost due to wall effect and then the ratio of normal energy deposition events and wall effect events can be calculated.

RESULTS AND DISCUSSION

Results for 1 bar

For the (n,p) reactions, since the range of the protons in comparison to the detector's diameter is very large, most of the produced particles hit the wall and the percentage of events lost due to wall effect is very high. Even for low energy fast neutrons, it is not useful to study such a detector since the majority of events do not leave all their energy inside the sensitive volume thus they can not be studied correctly and would lead to wrong calculations and results.

In the case of (n,α) reactions it can be observed that as the incident neutron energy increases, the wall effect events also increase in an exponential way, with the percentage still being too high to take into consideration in an experiment.

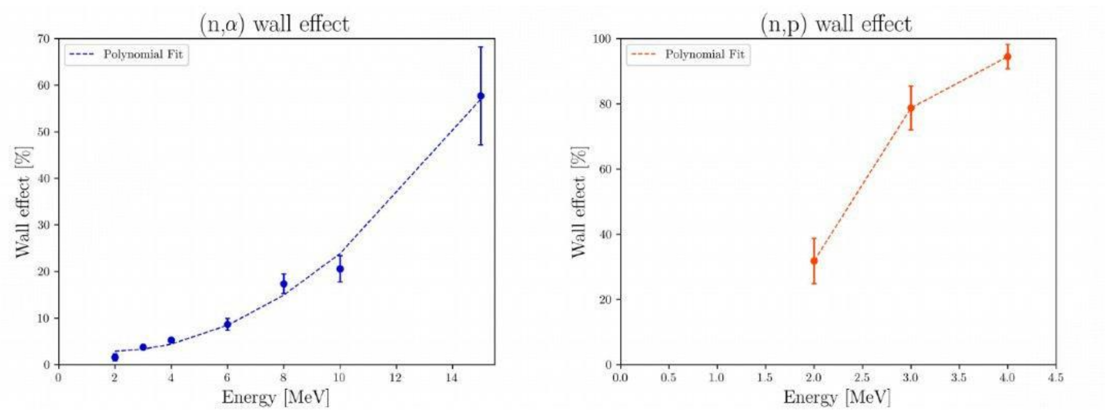

Figure 5. *Evolution of the wall effect with the incident neutron energy for 1 bar nitrogen gas*

Results for 5 bar

For operation at 5 bar the exponential growth of the wall effect is highly suppressed for both neutron interactions. Taking into consideration the (n,α) reactions, for 15 MeV neutrons it can be observed that increasing the pressure from 1 to 5 bar, leads to a 70% decrease in the events lost from wall effect.

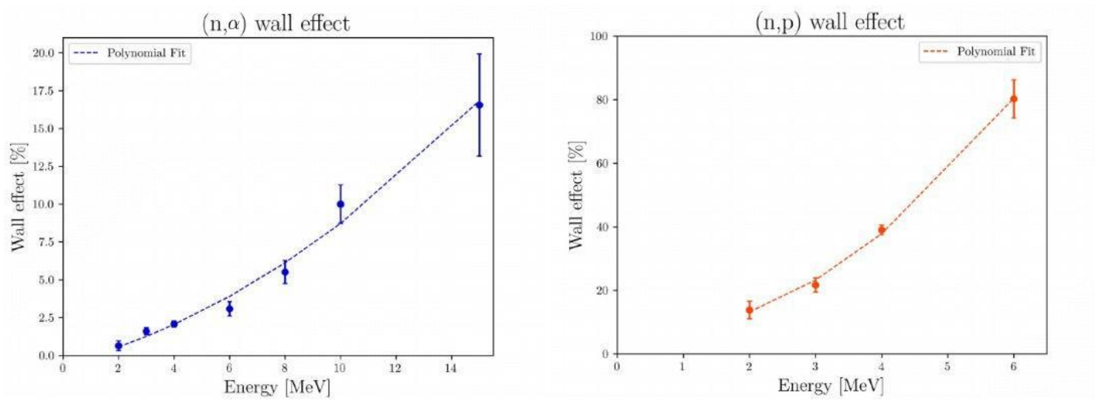

Figure 6. *Evolution of the wall effect with the incident neutron energy for 5bar nitrogen gas*

Results for 10 bar

For operation at 10bar, the majority of the alpha particles that are produced interact inside the gas without hitting the vessel walls, which results in a very low percentage of wall effect events. In order to study the wall effect in such a case a very large flux of neutrons would be needed which would not be practical, so the study continues with the observation of (n,p) reactions. As expected, for the protons as well as the alphas, the wall effect increases exponentially with the incident neutron energy.

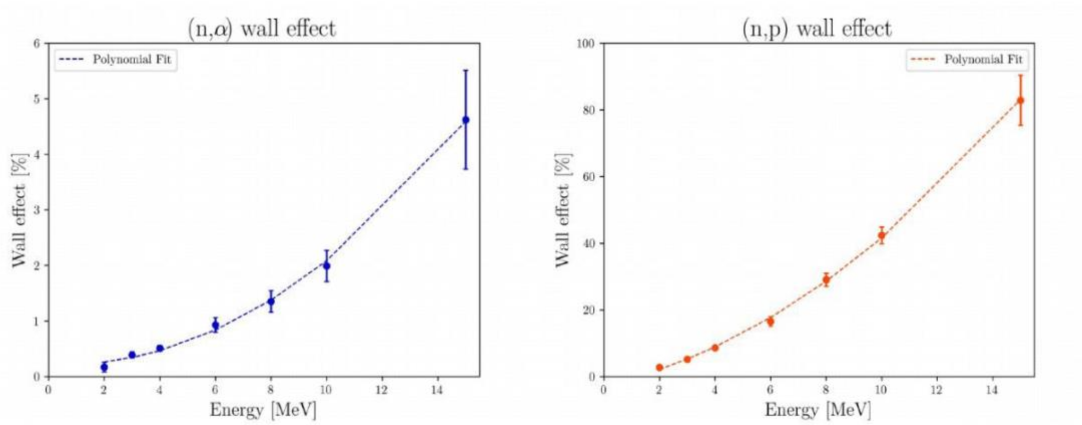

Figure 7. *Evolution of the wall effect with the incident neutron energy for 10bar nitrogen gas*

Results for 15 bar

At the highest studied pressure of 15 bar, the wall effect in (n,α) reactions can be considered negligible and for the (n,p) reactions, in continuation of what was observed for the alphas, as the neutron energy increases, the wall effect also grows, while it decreases when the gas pressure becomes greater.

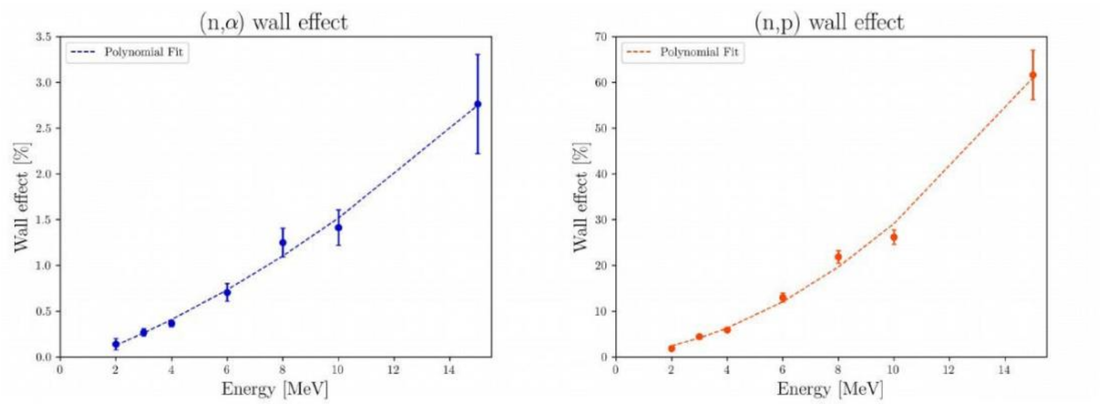

Figure 8. *Evolution of the wall effect with the incident neutron energy for 15 bar nitrogen gas*

Wall effect and particle range

An interesting point to study is how the percentage of the particles lost from wall effect is affected by their range. In order to do this the data for the range of protons and alphas were taken from the PSTAR and ASTAR programs of National Institute of Standards and Technology. For the lower pressures (1 bar, 5 bar) the wall effect behavior of the alpha particles was taken into consideration while for the higher pressures (10 bar, 15 bar) the results from the protons were used. In all of the cases studied, regardless of the particle or the gas pressure, the dependence of the wall effect percentage and the particle range was found to be linear.

This fact can be applied for other particles inside the SPC, where knowing the range at a specific gas pressure, the events that will be lost due to wall effect can be calculated and the appropriate corrections can be made in the data.

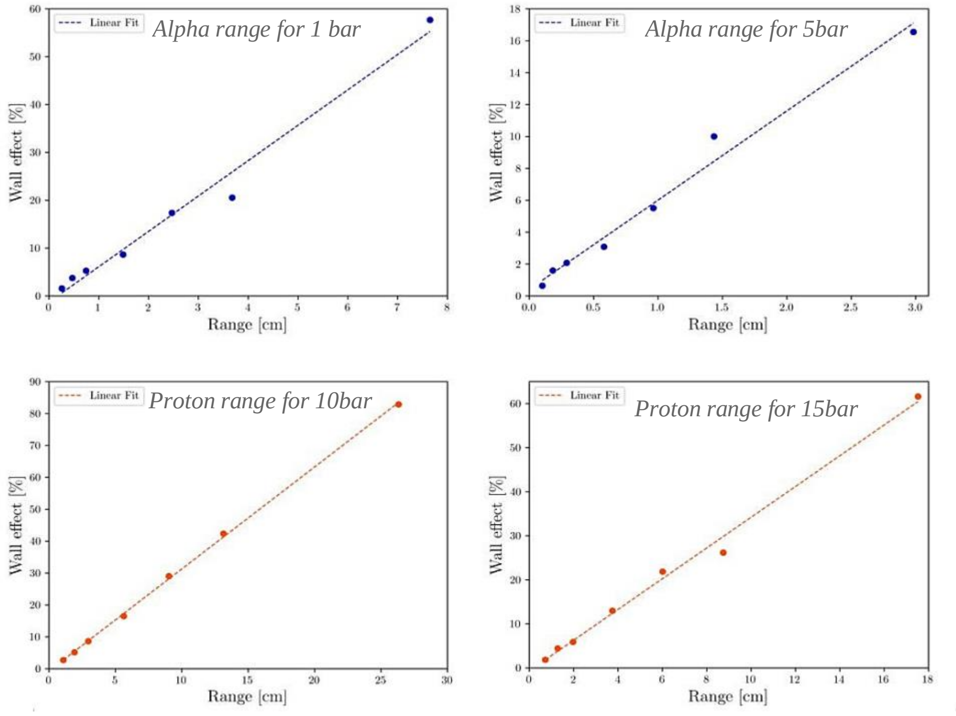

Figure 10. *Wall effect and particle range dependence*

CONCLUSIONS

Having quantified the wall effect for nitrogen gas of different pressures in the spherical proportional counter, leads to the conclusion that the detector can be used for spectroscopy of different paricles (i.e alphas, gammas, electrons). Also the fact that the detector can be operated at high pressures, suppressing the wall effect, makes it a great alternative for the previously used cylindrical counters BF_3, H_3.

Acknowledgments

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