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nRPC simulation with TOPAS

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Abstract. Neutron detectors are commonly made with ^{3}He, a gas that is now difficult to obtain. Resistive Plate Chambers (RPCs) present a realistic alternative as neutron detectors. The goal of this internship was to study the efficiency of an RPC for detecting neutrons. This was done by implementing an RPC using the TOPAS simulation framework. Furthermore, the results were compared with previous ones obtained with ANTS2.

Keywords: neutron, RPC, detector, TOPAS.

1 Introduction

1.1 Neutron detectors

The process of detecting a neutron requires indirect methods since neutrons have no electrical charge [1]. As a result, they cannot directly produce ionization in a detector and, therefore, cannot be detected.
Consequently, neutron detectors must rely upon a conversion process where a neutron interacts with a nucleus to produce a charged particle. These charged particles are then directly detected and, from them, deduced the presence of neutrons [2].
These types of reactions are mainly efficient for low-energy neutrons. The problem with high-energy neutrons is their small cross-sections for the conversion reaction, making it very unlikely. Due to this, it is necessary to slow the neutrons down in order to increase the probability of interaction.

1.2 Resistive Plate Chambers

Resistive Plate Chambers (RPCs) are gaseous detectors currently widely used in several areas of physics. Compared to others, some of the advantages of these detectors are their simple structure, low price and good spatial resolution [3]. Moreover, as their configuration is layered, the detector becomes more flexible.
Usually, RPCs have two electrode plates, anode and cathode, made of resistive material. As shown in figure 1, there is a thin layer of gas, called a gas gap, between plates. When a charged particle goes through the detector, it ionizes the gas molecules and creates electron-ion pairs, that propagate in the gas reaching the anode and cathode, making it possible to detect an electric signal.

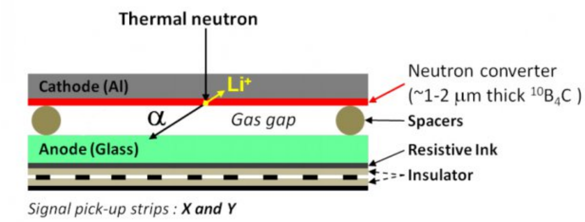

Figure 1. Schematic view of a nRPC detector. In addition, the process for the detection of neutrons in the converter ($^{10}B_4C$, red line) through the ^{10}B(n,a)^{7}Li reaction is shown.

1.2.1 Resistive Plate Chambers for neutrons

Resistive Plate Chambers for neutrons, also known as nRPCs, are an adaptation from the conventional RPCs. Since neutrons are uncharged particles, ionization does not occur when they travel through a medium. Consequently, it is crucial to implement neutron converters, such as a layer of ^{10}B, so that the RPC acknowledges the neutrons' presence.
These converters capture neutrons and emit charged particles through a neutron capture reaction that the RPC detects. When using ^{10}B in the converter the reaction that occurs in this layer is the following:

$$^{10}B{+}n\rightarrow\,^{7}Li\,(0.84\,MeV){+}^{4}He\,(1.47\,MeV){+}\gamma\,(0.48\,MeV)\qquad(94\%)$$

$$^{10}B+n\rightarrow\,^{7}Li\,(1.02\,MeV)+\,^{4}He\,(1.78\,MeV)\qquad(6\%)$$

As mentioned before, the converter layer is so thin that the charged particles reach the gas gap and ionize it [4]. Because of the conservation of momentum, the two charged particles move in opposite directions, and only one goes in the direction of the gas. Furthermore, since these particles have different masses, their kinetic energy needs to compensate so that the momentum is conserved.

2 Simulations with TOPAS

TOPAS is an advanced Monte Carlo simulation code that extends the Geant4 Simulation Toolkit [5].

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2.1 Materials

In order to simulate an nRPC with TOPAS, we needed to define each layer of the detector. Since each detector layer has a different material, we had to declare them. It is important to mention that all materials' definition was written from scratch, including the isotopes of each element used in the simulation, because some materials did not have the natural isotope composition.
Even though, there are a some examples of such definitions on the TOPAS user guide, we were asked to include our simulation code as an example.
Below we include a part of the code used to define the materials.

```
### Boron ###
d:Ma/Boron/Density = 2.3 g/cm3
sv:Ma/Boron/Components = 1 "Boron"
uv:Ma/Boron/Fractions = 1 1.

s:El/MyBoron/Symbol              = "MyBoron"
sv:El/MyBoron/IsotopeNames       = 2 "B10" "B11"
uv:El/MyBoron/IsotopeAbundances = 2 97.06 2.94

### 10 Boron ###
i:Is/B10/Z = 5
i:Is/B10/N = 10
d:Is/B10/A = 10.01 g/mole

### 11 Boron ###
i:Is/B11/Z = 5
i:Is/B11/N = 11
d:Is/B11/A = 11.01 g/mole

b:Ma/B4C/NormalizeFractions = "True"
d:Ma/B4C/Density = 2.242 g/cm3
sv:Ma/B4C/Components = 5 "Boron" "Carbon"
"Hydrogen" "Oxygen" "Nitrogen"
uv:Ma/B4C/Fractions = 5 81.7 17. 0.7 0.4 0.2
```

2.2 Geometry

Another aspect we had to define was the geometry of the simulation. Due to the shape of the detector, all the layers were defined as boxes.
As an example of the code used to define the geometry, up next part of the code related to the definition of the PickUp0 layer is shown. Figure 2 shows a double gap nRPC implemented in TOPAS.

```
#Pickup0#
s:Ge/Pickup0/Type      = "TsBox"
s:Ge/Pickup0/Parent    = "World"
s:Ge/Pickup0/Material = "Copper"
d:Ge/Pickup0/HLX       = Ge/RPC/HalfSide cm
d:Ge/Pickup0/HLY       = Ge/RPC/HalfSide cm
d:Ge/Pickup0/HLZ       = 0.0001 cm
d:Ge/Pickup0/TransX    = 0. cm
d:Ge/Pickup0/TransY    = 0. cm
d:Ge/Pickup0/TransZ    = Ge/RPC/Offsetz + 0.088 cm
d:Ge/Pickup0/RotX      = 0. deg
d:Ge/Pickup0/RotY      = 0. deg
d:Ge/Pickup0/RotZ      = 0. deg
i:Sc/Pickup0/XBins = 100
i:Sc/Pickup0/YBins = 100
i:Sc/Pickup0/ZBins = 100
s:Ge/Pickup0/Color     = "white"
```

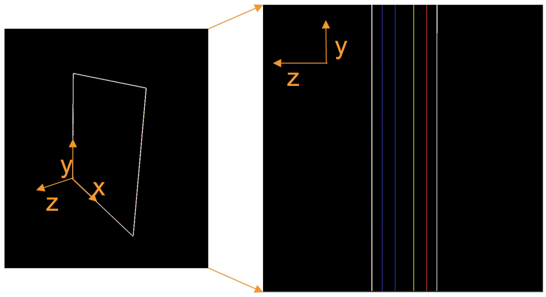

Figure 2. Simulation of a double nRPC detector with TOPAS. In the figure on the right, the layers from left to right are: PickUp0 (white), Glass0 (red), GasGap0 (orange), Converter0 (yellow), Cathode (green), Converter1 (lightblue), GasGap1 (blue), Glass1 (purple), PickUp1 (white). Some layers are not visible due to their width.

2.3 Source

It is important to refer that in order to maximize the efficiency of the simulations, a pencil beam source was used. This type of source is characterized by being a collimated beam. In this project we simulated neutrons with seven energies between 2.5×10^{-8} and 2.5×10−2 eV, increasing the energy of the neutrons each time by an order of magnitude.

```
### Particle source ###
s:So/NeutronSource/Type = "Beam"
s:So/NeutronSource/Component = "BeamPosition"
s:So/NeutronSource/BeamParticle = "neutron"
d:So/NeutronSource/BeamEnergy = 0.025 eV
u:So/NeutronSource/BeamEnergySpread = 0.
s:So/NeutronSource/BeamPositionDistribution = "Flat"
s:So/NeutronSource/BeamPositionCutoffShape = "Ellipse"
d:So/NeutronSource/BeamPositionCutoffX = 0.5 mm
d:So/NeutronSource/BeamPositionCutoffY = 0.5 mm
d:So/NeutronSource/BeamPositionSpreadX = 0.3 mm
d:So/NeutronSource/BeamPositionSpreadY = 0.3 mm
s:So/NeutronSource/BeamAngularDistribution = "Flat"
d:So/NeutronSource/BeamAngularCutoffX = 0.1 deg
d:So/NeutronSource/BeamAngularCutoffY = 0.1 deg
d:So/NeutronSource/BeamAngularSpreadX = 0.0032 rad
d:So/NeutronSource/BeamAngularSpreadY = 0.0032 rad
i:So/NeutronSource/NumberOfHistoriesInRun = 1000
```

2.4 Scorer

After defining the geometry, the materials, and the particle source, the program runs the simulation and tracks the neutrons along the geometry.
With the scorers available in TOPAS, we can study the detector's efficiency. According to our goals we used the

Phase Space scorer to count the number of charged particles that reached the gas gap. Phase Space refers to the technique of saving or replaying a set of particles crossing a given surface. It saves data to n-tuple format, rather than storing accumulated overall data.
In figure 3 is an example of a simulation made using TOPAS.

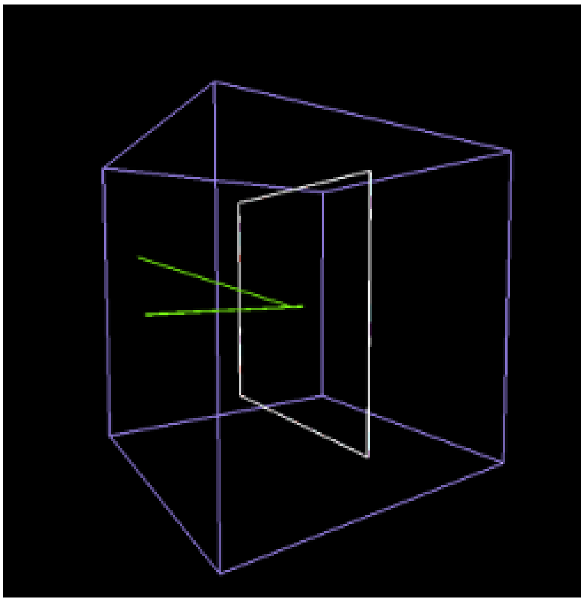

Figure 3. A simulation for ten events using a beam with thermal neutrons. In green is represented the gamma rays, a product of the neutron conversion reaction.

3 Results and Conclusions

Firstly, with all the data obtained from TOPAS simulations, we created a python code to calculate the efficiency of an nRPC detector in vacuum. Then we plotted the results, as shown in figure 4. This plot shows the efficiency of detection as a function of the neutrons' energy. The energies simulated were from 2.5×10^{-8} to 2.5×10−2 eV and are presented in a logarithmic scale. As shown in figure 4, the maximum efficiency was reached at 2.5×10^{-6} eV. Regarding thermal neutrons,2.5×10^{-2} eV, the efficiency is 4%.

Secondly, we compared the results obtained with TOPAS with the ones obtained with ANTS2. ANTS2 is a simulation and experimental data processing package for detectors [6]. Figure 5 shows the plot of both data. As one can see, the both plots overlap to almost every point studied. We believe that the difference that occurs for the first point is related to the physic's list considered in both of the simulations programmes.

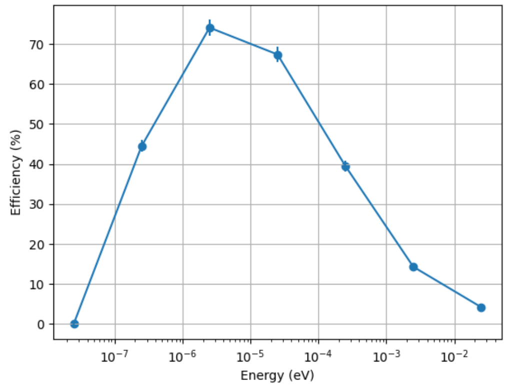

Figure 4. The efficiency of detection as a function of the neutron's energy. The solid line is provided to guide the eye through the points.

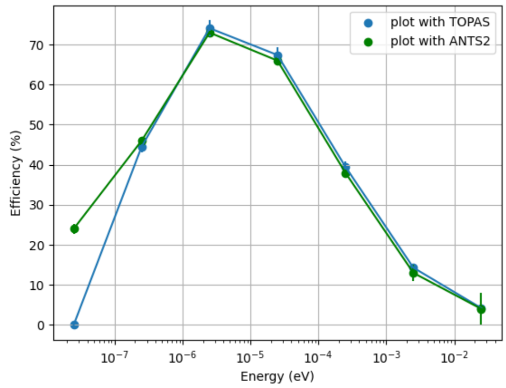

Figure 5. Neutron efficiency detection using the TOPAS simulation (blue) and the ANTS2 code (green).

4 Further work

In the future, more simulations could be done in order to study the efficiency of nRPCs. For instance, we could simulate a stack of nRPCs, simulate fast neutrons with a paraffin moderator and an nRPC detector with different configurations.

Acknowledgements

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