Monte-Carlo simulation of the experiment Sitrineo

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https://github.com/Cyrjl/Project-5-Monte-Carlo-Simulation

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Report

1.1 Introduction

1.1.1 Inspiration from a real experiment

The main purpose of this project is to create a simplified Monte-Carlo simulation. The one presented in this report is based on a real experiment : "Silicon Tracker International Education Objectives" (SiTrInEO). The purpose of this experiment is to measure the deviation angle of a charged particle travelling through a magnetic field, from which it is possible to recover the momentum of the particle knowing its charge, as well as the zone and the intensity of the applied magnetic field.

The system is composed of a particle gun and two pairs of silicon detectors. Both pairs are separated by a zone subjected to a magnetic field orthogonal to the particles trajectories. It is known from the equation of motion that a charged particle moving through a magnetic field has a circular trajectory. This type of simulation can be important for studying the feasibility of a project, comparing it to a theoretical model, or correcting data.

1.1.2 What has been simulated

In order to begin the project, trajectories of charged particles has been simulated, without taking into account the effects of the detectors on the particles kinematics, which are mainly a scattering effect and the energy loss of particles going through a medium with a stopping power.

Once the trajectories are correctly simulated, one added the scattering effect of the detectors and the energy loss of the particle, as well as the fact that particles must lose enough energy in a detector to trigger it, allowing a measurement.

Then the first spectrum can be simulated for particles of different momenta in order to see the impact of the multiple scattering and energy loss. An opening angle for the particles has been implemented to see if these have an influence or not.

1.2 Methods

1.2.1 Assumptions

For the sake of simplicity the simulation has been done in a two dimensional plan in which particles are moving and the magnetic field is orthogonal to that plan. The effect of the atmosphere is supposed negligible and doesn't affect the particles. Particles are considered points like. The experiment has been done with electrons but can be used with other particles' characteristics.

1.2.2 Trajectories

The initial idea was to use the Euler method to obtain the trajectories of particles, especially in the magnetic field region. Unfortunately this method sometimes gives odd results and it takes a lot of time to reconstruct spectra for a lot of particles using the Euler method. It is possible to solve analytically the equation of motion in a magnetic field, so the equation of motion have been used. It has two major advantages : the trajectories are exact and there are no errors, as it was the case with the previous method. The second important advantage is the gain of time for the simulation to run over a large number of events for the reconstruction of spectra. For the sake of simplicity, particles that are going backward after their interaction with the magnetic field and do not reach the last pair of detectors, are killed.

1.2.3 Code structure

Concerning the code structures, four classes have been created. The first class is used to define mathematical and physical quantities and constants. The second class "Detector" is used to create the four detectors and define important quantities such as their thickness, the mean excitation energy, the energy threshold to create a hole-electron pair (necessary to trigger the detector) and many others. The third class is dedicated to the magnetic field (region, intensity,...). The last class is about particles. This last class allow the creation of particles, with a chosen mass, momentum, charge, opening angle and, if the user wants, the effect of the multiple scattering and the energy loss.

More details about the particle class

Among the four classes, the one about particles contains some essentials functions for the simulation to run. The most important are explained here. The function that makes the particles move without a magnetic field is "move without field" and makes the particles move by a small step in time with a constant speed in a given direction. For the motion in the magnetic field, one use the "move with field" function, which makes the particles move again in a small time interval and also changes the speed vector of particles. The function "traj" computes the whole trajectory of particles, from the particle gun to behind the last detector. A function "detection check" is also created, to check if the particle has lost enough energy in the four detectors to be properly detected. To scatter the particles and update their energies when they go through a detector, two more functions have been created : "scatter" and "depot impulsion", which respectively rotates the speed vector and updates the particles properties after a loss of energy.

It is also possible to set a seed to always have the same scattering effect or energy loss for particles, to study the effect of the scattering or the energy loss properly, without both of them acting on the same time on particles.

1.3 Results

1.3.1 Trajectories of particles, with or without multiple scattering and energy loss

In this first part, electrons have been considered with a momentum of 2 MeV/c. A first reconstruction of the momentum has been done, which is close to 2 MeV/c. To see the results, have a look at figure 1.1, on which the detectors are represented by red lines.

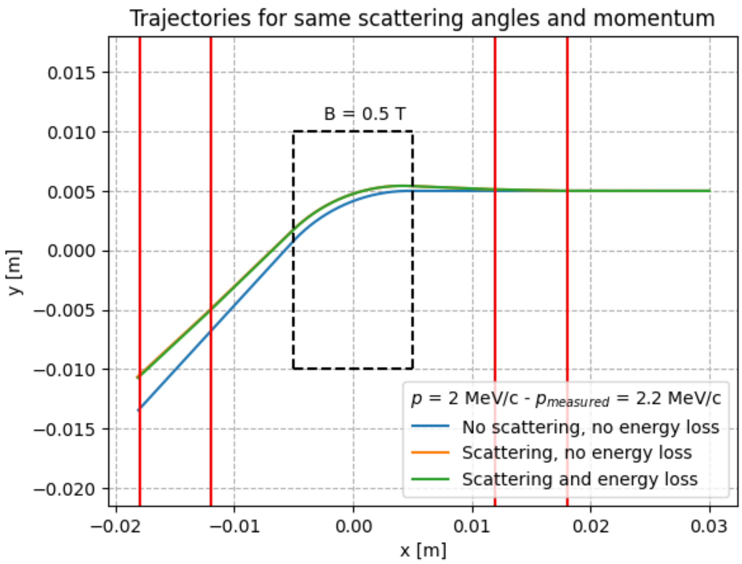

FIGURE 1.1 – First results

It is important to see that the reconstruction of momentum seems to work with a 10% accuracy and that the multiple scattering effect is the most important aspect in the variation of the trajectory, compared to the ideal trajectory.

1.3.2 Limits of reconstruction

To test the limit of the experiment, trajectories have been simulated for different momenta of electrons. The idea is to show that one value of the magnetic field doesn't allow the reconstruction of momenta which are too low because they simply don't cross the magnetic field. See figure 1.2 for a visual representation. The trajectories which are cut are assigned to particles that never reach the second pair of detectors because they turn around and leave the magnetic field by the same plane they went in. It seems (for electrons) that only momenta above approximately 1.5 MeV/c can be reconstructed. In fact it doesn't exist a precise lower value under which a momentum can not be reconstructed for two reasons. First, the trajectory depends on the mass of the particles, so for other particles the radius of curvature would be bigger or smaller. The second reason is that the scattering in the first pair of detectors has an influence if whether or not the particle reach the second pair of detector. Indeed, the angle of the particle entering the magnetic field may help the particle or not to cross the magnetic field.

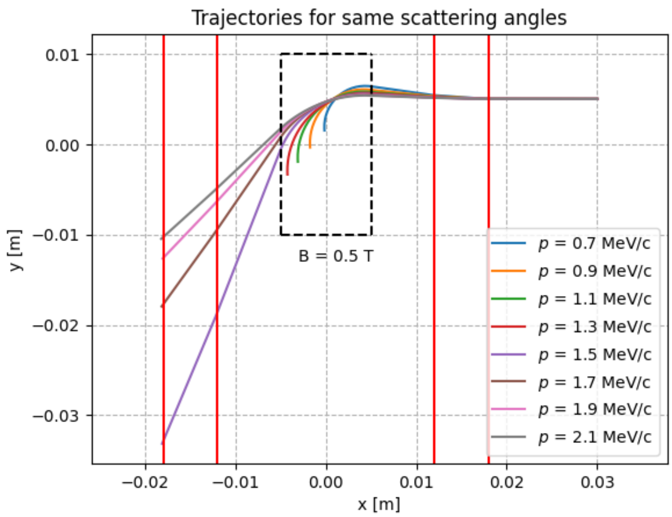

FIGURE 1.2 – Limit of reconstruction for low momenta

Another limit of the experiment is the efficiency of the detectors. In order to be detected in one detector, a particle must create at least a hundred pairs of hole-electrons by giving a fraction of their energy. The energy needed to create a pair of hole-electron is $w = 3.6$ eV. Particles with low energies may therefore have less chances to be detected because they have less energy to provide. The fraction of detected electrons as a function of the electrons momenta has been plotted in figure 1.3.

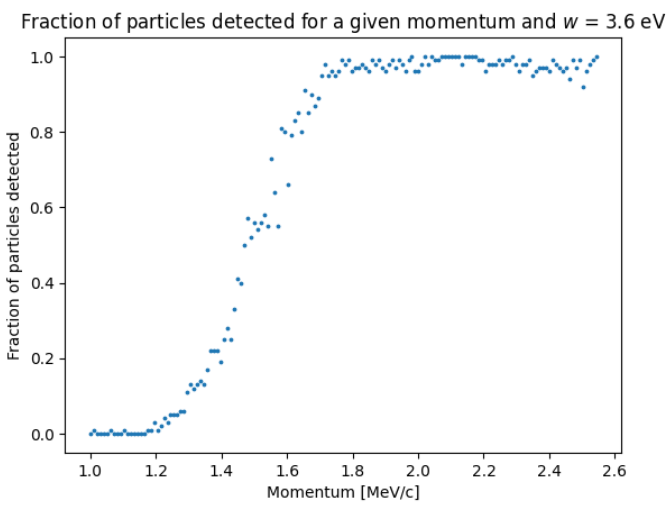

FIGURE 1.3 – Limit of reconstruction about thresholds

One can see that there is a region for electrons from 1.2 MeV/c to 1.8 MeV/c in which the fraction of detected electrons is an increasing function of the momentum, before it reaches a saturation value of full detection (or close to full detection).

1.3.3 Spectrum example for a Dirac distribution

Spectra for different momenta distribution have also been simulated for 1000 events. In the figure 1.4 one can see the measurements expected for momenta between 2 and 10 MeV/c.

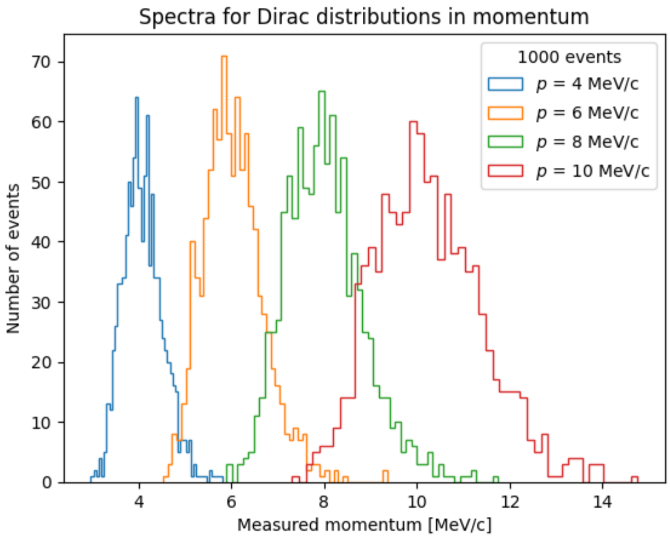

FIGURE 1.4 – Momenta reconstruction for Dirac distributions

One notice that the higher the momentum, the higher the width of the curves : high momentum measurements seem to have higher uncertainties.

1.4 Conclusion

Throughout the simulation, we tried to approach a realistic model by taking into account the effects related to the instruments. The effects due to scattering and energy loss are non-negligible and significantly alter the trajectories. However, we restricted ourselves to an experiment on negatively charged electrons. The simulation would have been very different for positively charged protons, which are heavier than electrons. Anyway the simulation can be adapted for any type of particles, so that any user can feel free to test it for other charged particles. Moreover, we could study this phenomenon in a less favorable environment and observe differences.