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UNIVERSITÉ DE STRASBOURG

RAPPORT

Project Report

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GitHub link :

https://github.com/sacharejai/M1-Project-MC-simulation.git

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1 Background

Cosmic radiation is a stream of particles that propagates through space and is generated by extraterrestrial sources, such as supernovas and black holes. The detection of these particles is an important area of research in particle physics, as it provides a better understanding of the composition of the universe and the physical processes that take place in it. In this project, we have developed a Monte Carlo simulation program for the detection of cosmic particles using detectors.

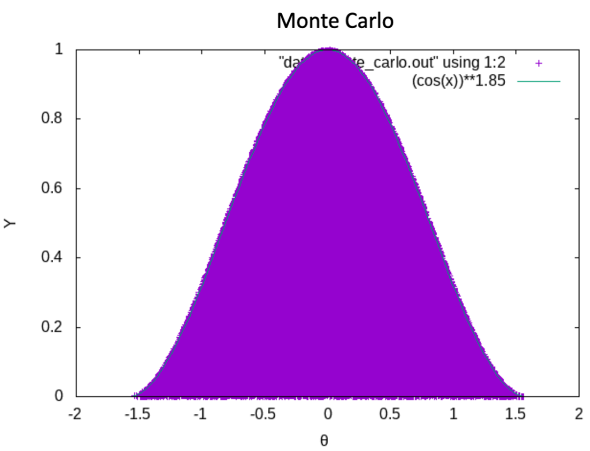
2 Objectives

The objective of this project was to develop a Monte Carlo simulation program for the detection of cosmic particles using detectors. This program was to simulate the passage of cosmic particles through detectors, as well as the response of these detectors to the particles.

3 Methods of resolution and results

The Monte Carlo simulation program was developed using the Python programming language. The program uses the Monte Carlo method to simulate the passage of cosmic particles through detectors. The simulation consists of three main steps : generation of cosmic particles, simulation of their passage through the detectors and measurement of the detector response to the particles.

In the first step, the code developed for this project uses object-oriented programming to represent the particles and detectors. Each particle is represented by a class that stores its properties, such as its position, velocity, energy, and type. The detectors are also represented by classes that store their properties, such as their size, position and sensitivity. Cosmic particles are generated using a probability distribution based on the experimental data. This probability distribution is used to simulate the energy, position and direction distribution of cosmic particles.



In our Monte Carlo simulation, we have taken into account the zenith angle distribution of cosmic particles, which follows a law in cosine power 1,85. This law describes the angular distribution of muons, which are charged particles produced by the interaction of cosmic rays with the Earth's atmosphere. This angular distribution is important to take into account for the measurement of the particle momentum, because it affects the probability of detection of the particles by the detectors, and it favors small angles.

More precisely, the particle angle distribution describes the probability of finding a particle at a given angle with respect to the direction of arrival of cosmic particles. This distribution is characterized by a parameter called spectral index, which depends on the nature of the particles and the energy of the cosmic rays. In our simulation, we used the spectral index corresponding to cosmic muons, which is equal to 1,85.

Taking into account the angle distribution of the particles in our simulation allows us to obtain more accurate results on the measurement of the particle momentum. Indeed, the angular distribution affects the probability of detection of the particles by the detectors, which can have an impact on the accuracy of the pulse measurement. In addition, the angular distribution can also affect the spatial resolution of the detectors, which can impact the accuracy of the particle position measurement.

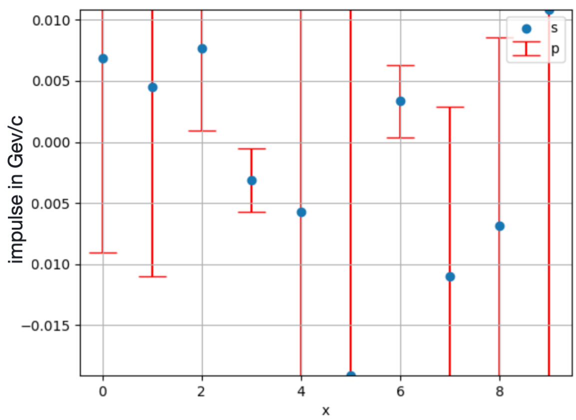
The particle angle distribution is an important feature to consider in the Monte Carlo simulation of cosmic particle detection. This distribution helps to understand the probability of particle detection by the detectors and to optimize the detector design to minimize the sources of error in the particle momentum measurement.

In the second step, the simulation of particle passage through the detectors is performed using particle-matter interaction models. These models simulate the interaction of the particles with the atoms of the material in the detectors, which can lead to the production of secondary particles. The simulation also takes into account the properties of the detectors, such as density and layer thickness.

In the third step, the response of the detectors to the particles is measured using the signals produced by the detectors. These signals can be used to reconstruct the properties of the particles. The final goal of the simulation developed in this project is to create an impulse spectrometer, which allows to measure the impulse of cosmic particles. Indeed, the deflection of charged particles in a magnetic field between the different detectors is used to find the value of their impulse from the angle of deflection. Thus, the Monte Carlo program allows to simulate the passage of particles through the magnetic field and to estimate their impulse from their trajectory.

The impulse is an important physical quantity in particle physics because it is related to the energy and mass of the particles. By measuring the momentum of cosmic particles, it is possible to determine their kinetic energy and mass, which can provide information about their origin and nature. The pulse spectrometer is therefore a valuable tool for the study of cosmic particles.

The Monte Carlo program developed in this project allows to accurately simulate the passage of cosmic particles through detectors and their deflection in a magnetic field. This simulation can be used to optimize the design of detectors and pulse spectrometers, as well as to interpret experimental results. In addition, the simulation can be used to study the effects of varying different parameters such as the energy and mass of cosmic particles on their momentum measurements.



In our Monte Carlo simulation, we studied the influence of the entry angle of the particles in our detectors as well as the induced angle on our detectors. The angle of entry of the particles into the detectors depends on the direction of arrival of the cosmic particles, which can vary depending on the position and orientation of the detector with respect to the direction of the cosmic particle flow.

We have found that the angle at which particles enter the detectors can affect the accuracy of the pulse measurement. Indeed, when particles enter the detectors with a large angle, their trajectory can be significantly deviated, which can affect their momentum measurement. In addition, the entry angle can also affect the spatial resolution of the detectors, which can impact the accuracy of the particle position measurement.

We also studied the induced angle on our detectors, i.e. the angle of deflection of the charged particles in the magnetic field generated by the detectors themselves. We found that this angle can vary depending on the configuration of the detectors and the position of the particles, which can have an impact on the accuracy of the pulse measurement.

Thus the study of the influence of the angle of entry of the particles into the detectors and the induced angle on the detectors is important to understand the sources of uncertainty in the measurement of the cosmic particle pulse. This study allows to optimize the design of the detectors and to minimize the sources of error in the measurement of the pulse.

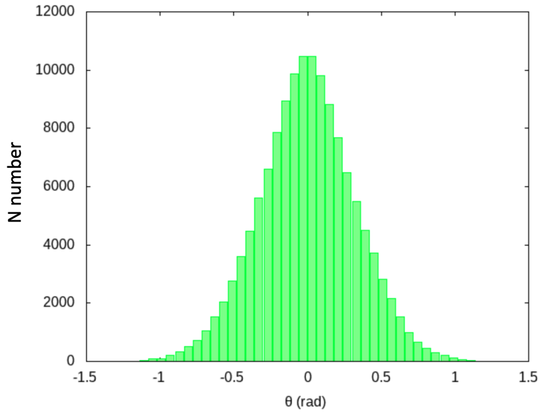


FIGURE 1 – zenithal angle of 0°

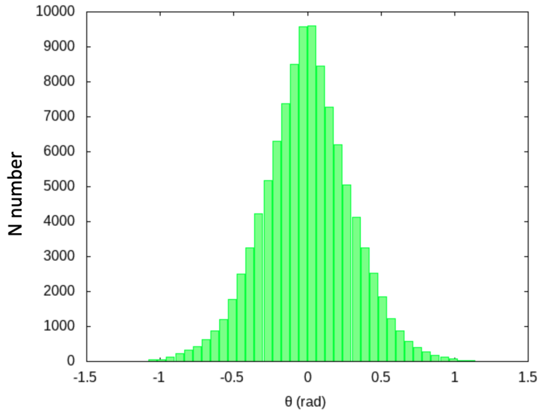
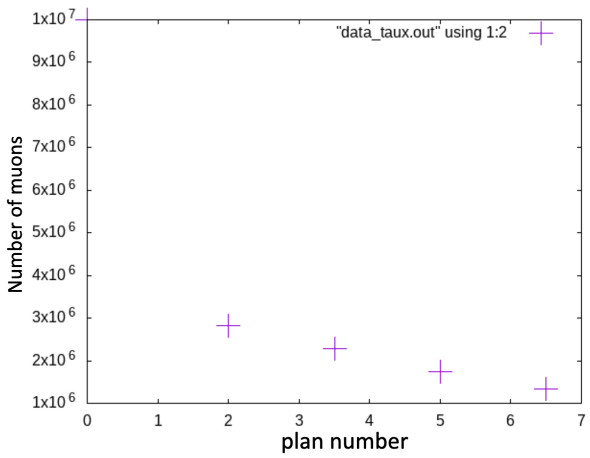


FIGURE 2 – zenithal angle of 45°

In addition, the study of the count rate as a function of the number of detectors, the distance between them and the angle of entry of the particles is important to understand the performance of the detector and to optimize its design.



The count rate is defined as the number of particles detected per unit time. This rate depends on the number of detectors, their size, shape, relative position and the distance between them. In general, a larger number of detectors increases the count rate, but also the complexity of the measurement. The distance between detectors affects the spatial and temporal resolution of the measurement.

The angle of entry of the particles also affects the count rate. Indeed, particles arriving perpendicular to the detectors have a higher probability of being detected than those arriving at an oblique angle.

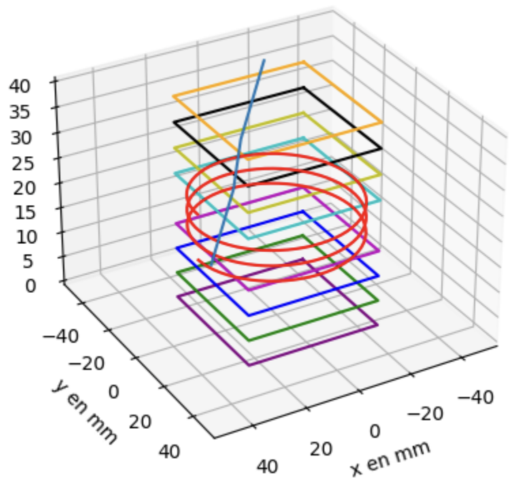
In our simulation, we studied the impact of these parameters on the count rate. We found that the number of detectors and their relative position had a strong influence on the count rate. An increase in the number of detectors increases the count rate, but also requires more computing power. We also found that the distance between detectors affects the spatial and temporal resolution of the measurement.

Finally, the angle of entry of the particles also affects the count rate. We observed that particles arriving perpendicular to the detectors have a higher detection probability than those arriving with an oblique angle of incidence. We therefore optimized the position of the detectors to maximize the count rate for particles arriving perpendicular to the detectors.

In conclusion, the study of the count rate as a function of the number of detectors, the distance between them, and the angle of entry of the particles is important for understanding the performance of the detector and for optimizing its design. This study allows us to understand the limits of our detector and to optimize it for future measurements.

We have also represented in 3 dimensions our system. To represent the trajectory of the particles and detectors in 3D, we used a three-dimensional linearization method. This method is necessary because the trajectory of the particles is not linear due to the deviation in the magnetic field.

We used a three-dimensional Cartesian coordinate system to represent the position of each particle at each detector. We also represented the magnetic coil in the coordinate system.

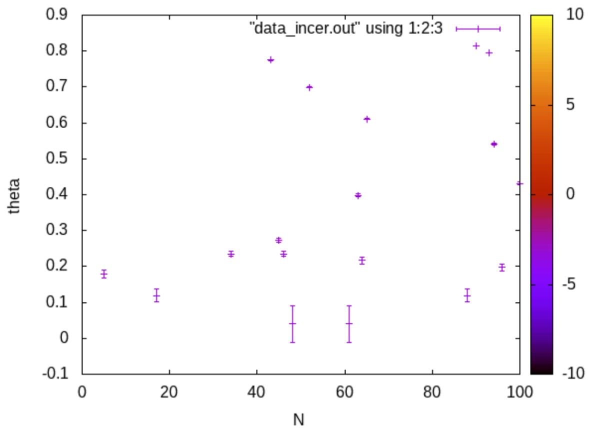


To represent the trajectory of the particles, we have, from the hits on our detectors, used a linearization method to represent this trajectory in 3D in a continuous way.

We also represented the position of the detectors in the three dimensional Cartesian coordinate system. For each detected particle, we recorded the position of the particle at the time of detection and the position of the corresponding detector.

Finally, we represented the magnetic coil in the three-dimensional Cartesian coordinate system using the actual dimensions of the coil.

The 3D representation of the particle and detector trajectory is important because it allows us to visualize the simulation results in a clear and concise manner. This representation also allows us to detect possible errors in the simulation and to correct them.



To evaluate the uncertainty on the angles and impulses of the particles, we used the uncertainty propagation formula. This formula allows to calculate the uncertainty on a quantity that depends on several measured variables. In our case, the uncertainty on the deflection angle and on the impulse depend on the uncertainties on the position measurements of the particles and the detectors, as well as on the magnetic field measurements.

We used statistical techniques to estimate the uncertainties in the position measurements and in the magnetic field measurements. Then, we propagated these uncertainties to calculate the uncertainty in the angles and pulses.The uncertainty propagation formula allows us to account for experimental errors in our calculation and provide accurate results with an estimate of the associated uncertainty.

It is important to note that the uncertainty in the measurements has a direct influence on the final uncertainty in the angles and impulses. Therefore, it is important to minimize measurement errors as much as possible in order to obtain accurate and reliable results.

4 Conclusion

In this project, we have developed a Monte Carlo simulation program for the detection of cosmic particles using detectors. The program uses the Monte Carlo method to simulate the passage of particles through detectors, as well as the response of detectors to particles. More precisely, the program simulates the passage of particles through a magnetic field and estimates their momentum from their trajectory. The resulting pulse spectrometer can be used to study the properties of cosmic particles and their origin. The simulation results showed that the program was able to accurately simulate the passage of cosmic particles through detectors and the response of the detectors to the particles. This program can be used in many applications in particle physics.

5 Perspectives

This Monte Carlo simulation program for cosmic particle detection can be enhanced by adding models of additional physical processes, such as secondary particle production in detectors. In addition, the program can be used to simulate more complex experimental setups, such as array detectors or Earth-orbiting experiments.