Simulation of a first case study for magnetic field imaging with the Magic-μ technique

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1. Introduction

Our group has introduced a new application for cosmic ray muons "imaging a magnetic field" by investigating the deflection of cosmic muons due to the Lorentz force in a magnetic field. The project is called **Magic-μ**, an acronym for MAGnetic field Imaging by Cosmic-ray MUons.

In this study, a feasibility study for the Magic-μ technique was carried out by simulating the measurement of cosmic muons traversing a magnetic field generated by a permanent magnet present in our group. The maximum magnetic flux density for this magnet is about 0.2 T in the center and decreases towards the edges.

2. Methodology

We used the three-dimensional finite element solution package AMaze and the Monte Carlo code PHITS (Particle and Heavy-Ion Transport code System) in this study. The distribution of magnetic flux densities for 3 dimensions in a $40\,cm \times 40\,cm \times 40\,cm$ voxelized region around the magnet was calculated in AMaze and the output was converted into a format readable by PHITS.

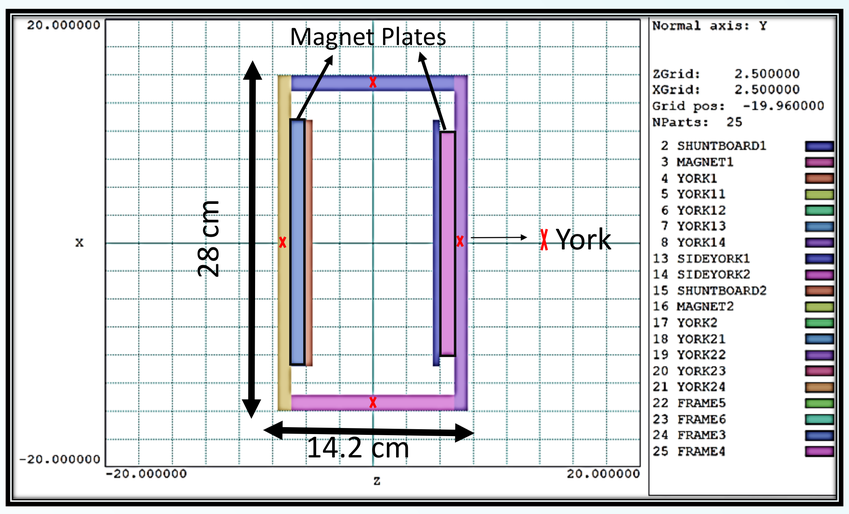


Figure. 1. Magnet and defined voxels in AMaze

The cosmic ray muons were generated as a hemisphere with a radius of 560 cm using the model PARMA implemented in PHITS. To observe the influence of the magnet, we placed a lead block 5 meters above the plastic scintillator detectors. This simulation corresponds to a real measurement of 152 hours and the statistical uncertainty was less than 1% in the region of interest. The simulation was performed in three stages:

Open sky: Only mu-PSDs
Background: Mu-PSDs and lead block
Foreground: Lead block and magnet.

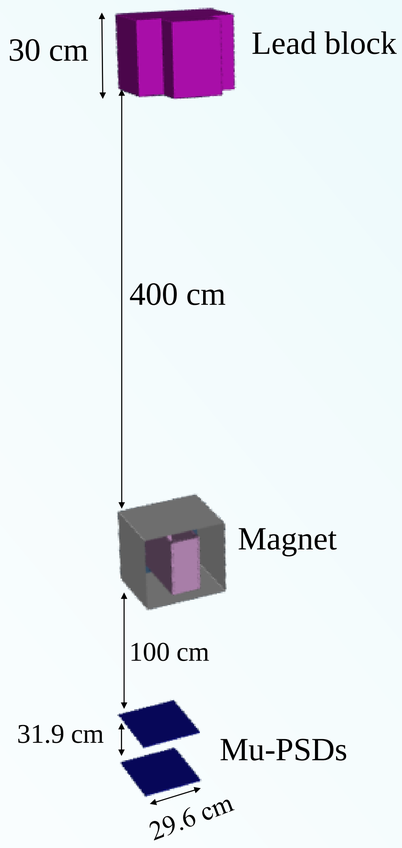


Figure. 2 Geometry in PHITS (by PHIG3D)

3. Results and Discussion

To evaluate the defined magnetic field region and the conversion of AMaze to PHITS, we used a surface source and low-energy muons. As shown in Figure 3, the deflection of the muons is proportional to the magnitude of the magnetic field flux density in the defined voxels. The empty area in the magnetic field region corresponds to the iron plates of the magnet

The information about the position, direction and energy of the muons hitting the first mu-PSD was recorded and analyzed using ROOT to create the counting rate maps (muography images of the lead block). Figure 4 shows the vector plots corresponding to the displacement of muons in the upper and lower mu-PSDs where the axes $\Delta\mathbf{X}$ and $\Delta\mathbf{Y}$ show the difference in the number of pixels for mu-PSD 1 and mu-PSD-2 in the x and y directions ($\Delta\mathbf{X} = \Delta\mathbf{Y} = 0$ shows the vertical muons).

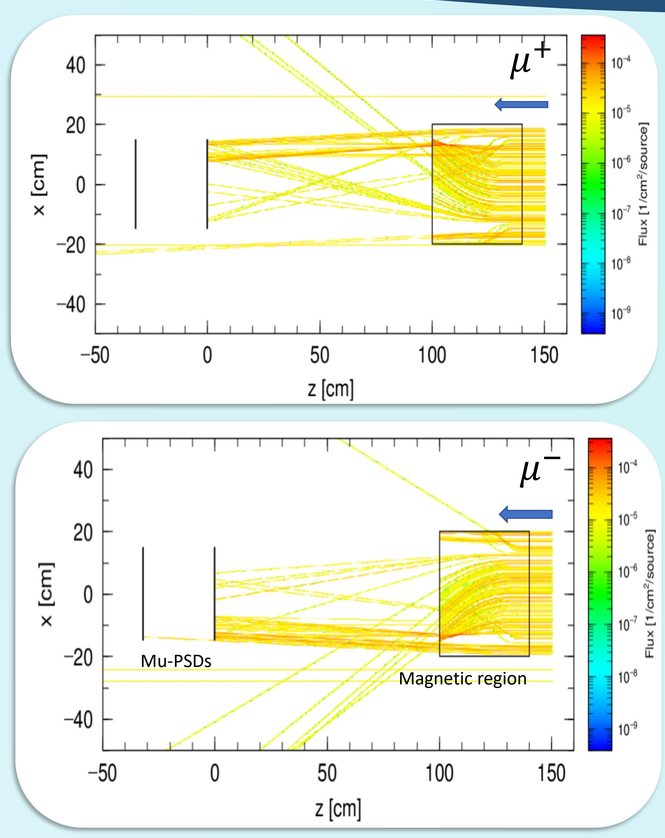


Figure. 3 The trajectories muons traversing a magnet

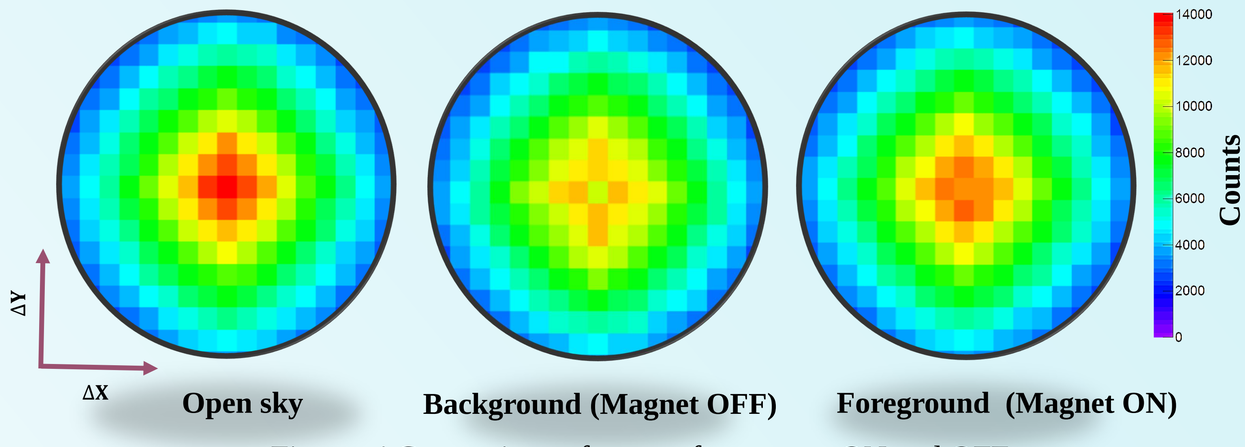
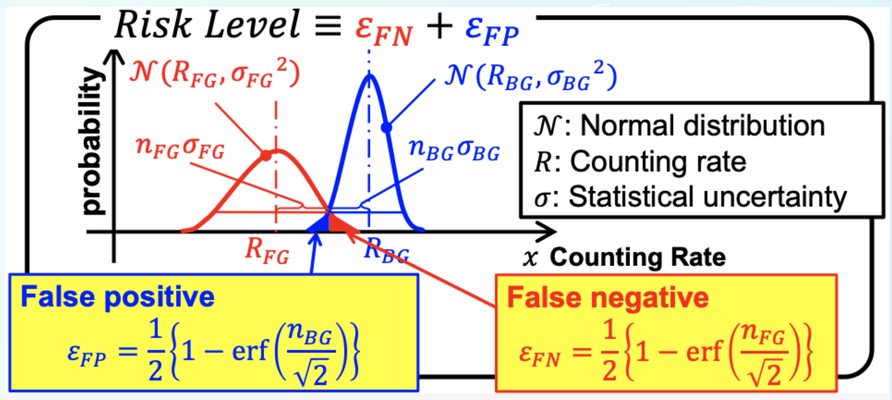
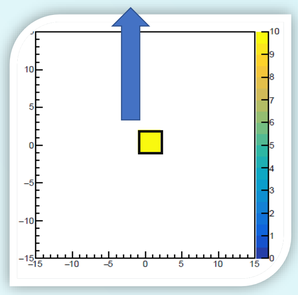


Figure. 4 Comparison of counts for magnet ON and OFF

The statistical significance between BG (no magnetic field) and FG was analyzed with a risk level of 5% to determine the magnetic field region.



Detected magnetic field region



4. Conclusion and future work

For a feasibility study of the proposed magnetic field muography technique, a simulation study was carried out by AMaze and PHITS. The results showed that this magnet will affect counting rate maps and can distort the muography image of the lead block. The simulation results are promising for the newly proposed application of cosmic muons; magnetic field imaging.

In the next step, we will perform a measurement test and develop an analysis method to estimate the presence of the magnetic field and its strength. Also, we aim to develop a new approach based on sandwiching the magnet between mu-PSDs.

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GHENT 24-26 NOV. Muographers 2021