Communication On A Vertical Axis Using Cosmic Ray Muons

CommunicaTED

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1. Introduction

Communication is a key part of our daily life. Moreover, in certain situations, we need it more than anything else. This is where muons come in handy.

Cosmic ray muons enable many means of wireless communication, especially in environments where traditional electromagnetic signals are not sufficient. Our project proposes a telecommunication system that works by changing the natural flux of atmospheric muons for data transmission.

Using a magnetic field to modulate muon trajectories and a dedicated detector to capture these variations, we encode binary information. At the end of this process, we will have transmitted signals through obstructions such as solid rock and water.

Because of the limited space in the CERN test area, our values will differentiate from the real-world. We have provided a Python script that gives us the calculations for any value that can be used in real-world applications. It can be found on page 7.

2. Why we want to go to CERN

We are a team of high school students from Turkey gathered by a passion for physics and curiosity. We aim to contribute to society by filling in gaps, enhancing current systems, and utilizing our knowledge across a variety of fields. That's why CERN is more than a destination for us. Our project aims to provide communication using cosmic ray-induced muons from the atmosphere. However, since the natural muon flux is irregular and uncontrollable, we need a controlled muon beam, a beamline, to make precise measurements and obtain experimental data. The beamline at CERN will provide us with well-characterized muon beams in a specific energy range, allowing us to perform our experiment in a healthy way.

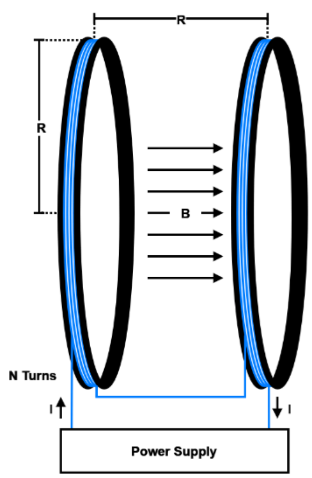
3. **Experiment and methodology**

3.1 Theoretical background

We are using muons because of their unique properties that make them ideal for our study.

- They have a relatively long lifetime (~2.2 microseconds), which allows them to travel significant distances.
- Due to their high mass (~200 times that of an electron) they can penetrate solid obstructions more than other charged particles. [2]
- Muons are the most abundant charged particles at sea level due to cosmic ray interactions with the atmosphere. This makes them easily available for our communication setup. [2]

A Helmholtz Coil is a device that produces a region of nearly uniform magnetic field. It consists of two electromagnets on the same axis carrying an equal electric current in the same direction. Helmholtz Coils do not only create magnetic fields, but also cancel external magnetic fields, such as the Earth's magnetic field.
A pair consists of two identical circular magnetic coils that are placed symmetrically along a common axis. The separation length between them is equal to the radius of a single coil. (h=r)



$$B = \frac{0.899176*10^{-6}*N*I}{r}$$

*B is the magnetic field in Tesla, N is the number of turns in each coil. I is the current through each coil and r is the radius of each coil, as well as the distance between the two coils. [1]

Our coil design features a radius of 15 cm, with 1000 turns per coil, and a current of 20 amperes is applied through each coil. That gives us a magnetic field equal to 0.119893T

$$\frac{0.899176*10^{-6}*20*1000}{0.15} = 0.119890T$$

As is typical for any wire carrying a current, a certain amount of heat is inevitably generated by our coils

Because the coils are going to be turned on and off repeatedly and rapidly, we wanted to make sure that this heat would not pose any issues for the setup. Here are the calculations of how much heat is generated per second and the temperature change of the coil.

We first calculated the power dissipated by the resistor.

$P = I^2R \qquad R = \frac{\rho_0 L}{A} \qquad$ so, $\qquad P = \frac{I^2\rho_0 L}{A}$

Then, we calculated the change in temperature in respect to heat dissipation.

$Q = mc\Delta T \qquad m = dLA \qquad$ so, $\qquad Q = dLAc\Delta T$

And we know that $P = \frac{Q}{t}$ so it can be re-written as $P = \frac{dLAc\Delta T}{t}$

Then we set two equations equal to each other, both yielding P.

$\frac{dLAc\Delta T}{t} = \frac{I^2\rho_0 L}{A}$ so, the temperature change is equal to $\Delta T = \frac{I^2\rho_0}{A^2cd}$

These are the values in our setup:

$\Delta T = \frac{20^2 * 1.68 * 10^{-8}}{(645 * 10^{-9})^2 * 386 * 8960}$ = 4.67C°/sec

If the heat dissipation of the coils is taken into account, temperature change decreases to ~2 C° per sec - a value which is not going to cause issues since the coils are activated for a relatively short amount of time. Additionally, an air-cooling setup will be used to keep the coils as cooler as possible.

3.2 Experimental Setup

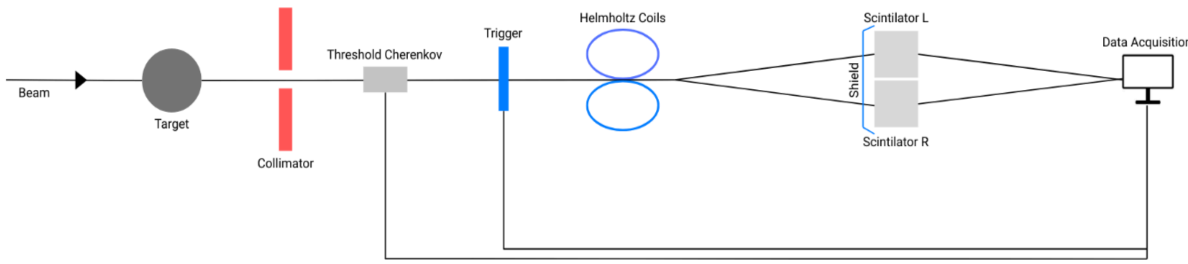


Figure 2: Schematic layout of the proposed experimental setup

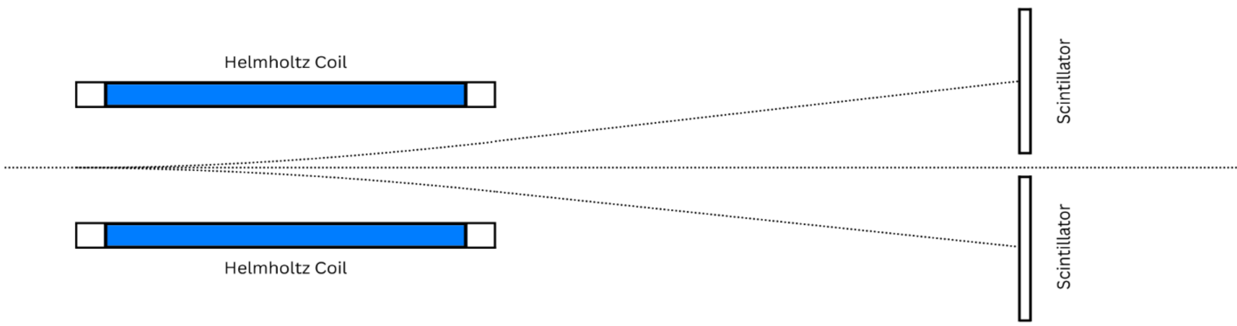


Figure 3: Trajectory of the muons before, inside and after the magnetic field.

In the figure above, muons are deflected from their trajectory by Helmholtz Coils. After exiting the magnetic field (30cm long) the muons travel an additional 4 meters before hitting the scintillators. (See figure 4)

Stated above, the magnetic field is equal to 0.119890T. We can find the cyclotron radius with:

$$R = \frac{mv}{q\beta} = \frac{p}{q\beta}$$

In our experiment muons with a momentum of 4 GeV/c are used. However, the beam at CERN has a momentum spread of ±15%.* But for now, calculations will be based on 4 GeV.

Since, 1 GeV/c = 5.344286×10^{-19} kg*m/s , the muons have a momentum that is equal to $21.37*10^{-19}$ kg*m/s.

*See Figure 5 for the momentum distribution histogram.

q is equal to $\pm 1.6*10^{-19}$C for muons.

$$\frac{21.37714*10^{-19}}{1.6*10^{-19}*0.119890} = 111.4414m = R$$

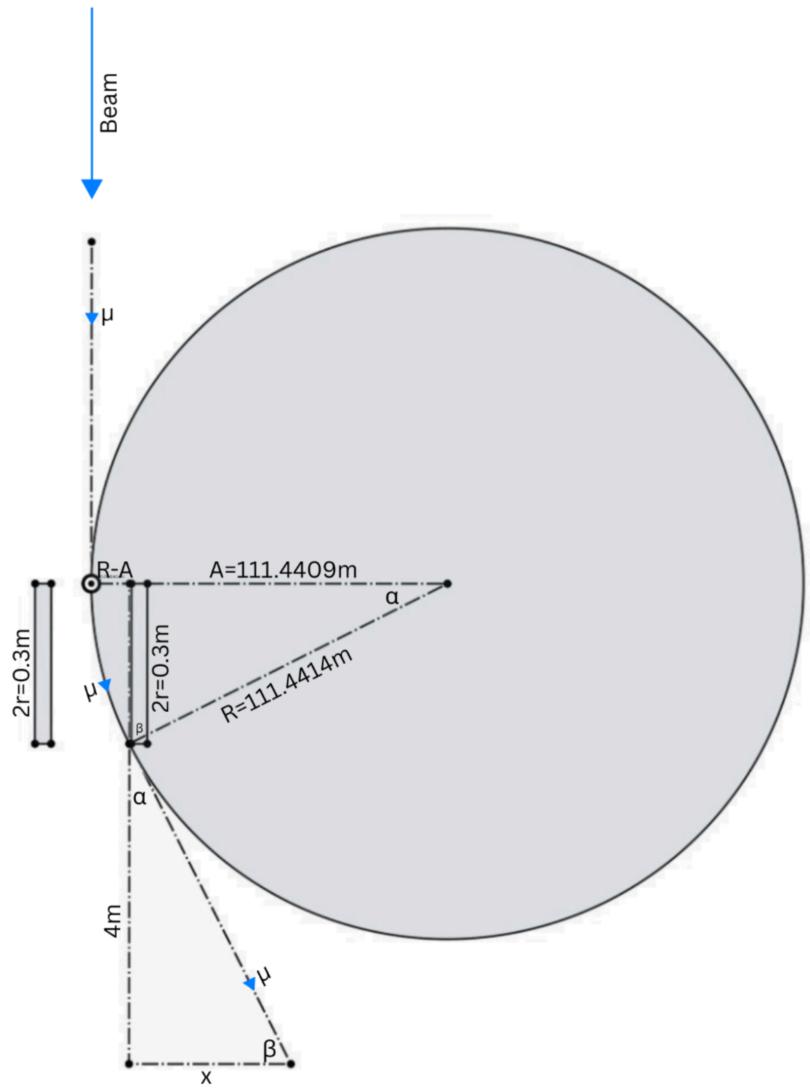


Figure 4: Cyclotron motion radius(R), Δx, 2r and A

$$\frac{\sqrt{(R^2-(2r)^2)}}{4} = \frac{2r}{x}$$

Since R = 111.4414 and r = 0.15m this equation of similar triangles gives us an x value of 1.076cm. In addition to that, we found that R-A is 0.4mm. Thus, 1.076cm + 0.04cm means a 1.106cm total deflection.

This means that the muons are deviated by 1.106cm over a 4m long path.

$$\frac{\sqrt{12,419.185-0.09}}{4} = \frac{0.3}{x}$$

As we stated above, the muons won't exactly have a momentum of 4 GeV/c at CERN. There is a ±15% spread. So, we calculated the deflection in respect to the distribution of momentum.

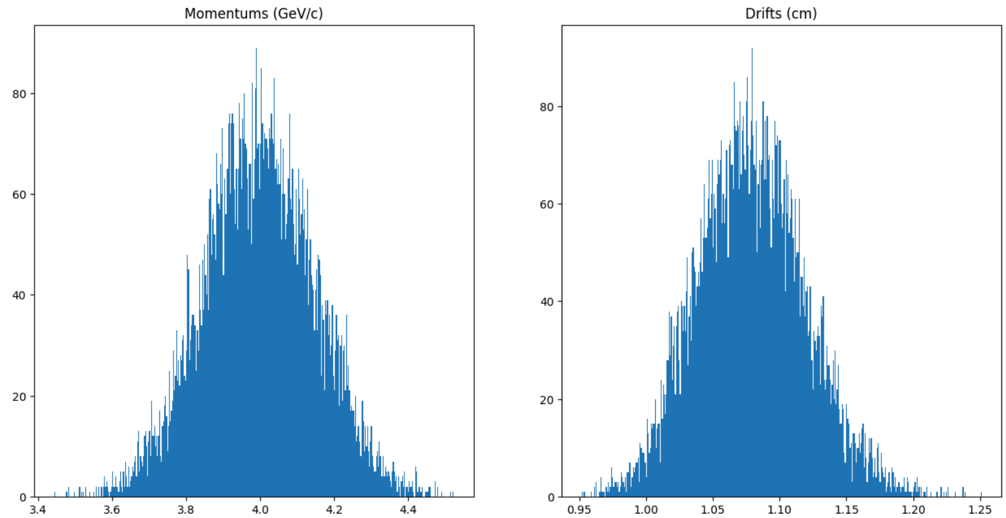


Figure 5: Histogram of the drifts in respect to momentum distribution

Then, a readout system is made using scintillators. 2 scintillators, one for positive and one for negative charged muons. By turning the coils on, the muons will be sent to the scintillators. And when the coils stay off, there won't be any digital output because the muons will pass right next to the scintillators. This therefore creates a binary readout system.

In our real-world setup, muons will be used. But the beam we get at CERN has some hadron contamination. So, to ensure an accurate readout, non-muon particles will be vetoed. This is done by using a trigger and a shield setup.

The trigger system will utilize signals from both the Threshold Cherenkov and the scintillators. To ensure that we only get a readout from muons, the system is going to be configured to have the Threshold Cherenkov signal when particles other than muons, such as pions and kaons pass through. If the Threshold Cherenkov activates, the data from the scintillators will be ignored to prevent false signals coming from other particles. For instance, we can create a Morse code-like system depending on whether we keep the coil open for a long or short duration.

We have written a Python script that calculates the Δx for any set of parameters we provide.

```
import math

def getDrift():
    d = 4                                           #Vertical length of the muon trajectory
    I = 20                           #Current
    r = 0.15                         #Coil radius
    N = 1000                         #Number of turns
    k = 8.99176e-7                   #Constant that is used for the coil T calculation
    T = (I*N*k)/r                    #Equation for the magnetic field
    p = 4                                           #Momentum
    R = (p*5.344285)/(1.6*T)  #Cyclotron motion radius
    A = math.sqrt(R*R-4*r*r)  #Calculation of the other right side of the inner triangle
    X=d*2*r/A                        #Δx in cm
    return 100 * X
```

4. What we hope to take away

- A working proof-of-concept demonstration of a muon-based wireless communication system
- Assessment of real-world feasibility in various environmental conditions
- Practical insights into particle physics and detector technology
- Broader inspiration and experience to carry this project beyond the lab

5. Acknowledgement

We want to give our sincere thanks to Bora Isildak and Eda Erdogan for their guidance throughout the preparation of this experiment. Also, to our physics teacher, Burcu Karabacak for introducing us to this competition.

6. References

[2] https://pmc.ncbi.nlm.nih.gov/

[1] https://www.e-magnetica.pl/doku.php/calculator/helmholtz_coil

[1] https://notblackmagic.com/bitsnpieces/helmholtz-coil/