Communication On A Vertical Axis Using Cosmic Ray Muons

Communica**TED**

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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 will give us the calculations for any value that can be used in real-world applications.

2. Why we want to go to CERN

We are senior high school students from Turkey who came together for our love of physics. We were all thrilled by this gathering, thinking about what we could achieve.
Motivated by curiosity and a love of learning, we want to improve society by filling in gaps, enhancing current systems, and utilizing our knowledge—particularly in physics—across a variety of fields. And to do this, we first need to test our setup at CERN and improve it accordingly with the results. We would like to sincerely thank CERN for making our dream possible.

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. [4]
- 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)**

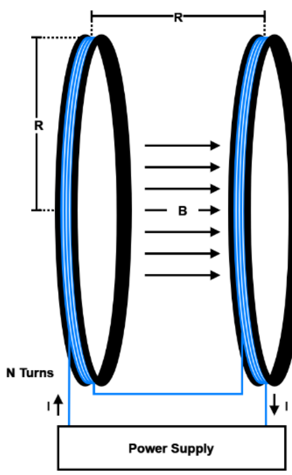

Figure 1: Close-up figure of the Helmholtz Coils in our setup.

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

*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 coils' radius' will be 15cm and the current going through them will be 20 amp. The number of turns per coil will be 1000 in our setup. That will give us a magnetic field equal to **0.119893T**

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

Like every wire carrying a current, our coils will inevitably generate a certain amount of heat.

We wanted to make sure that this heat will not cause problems for us. Because we will be turning it on and off repeatedly and rapidly. So here are the calculations of how much heat it will generate 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.

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

The values in our experiment will be:

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

4.67C°/sec won't create a problem for us because we will keep the coils on for a relatively short amount of time. But just to make sure, we may use an air-cooling setup to keep the coils cool.

3.2 Experimental Setup

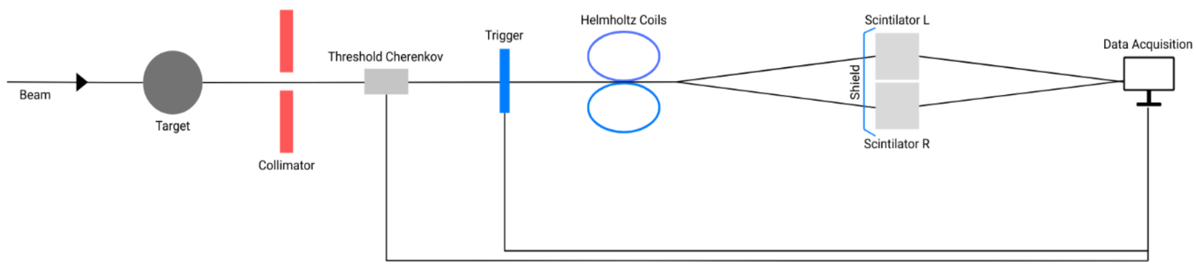

Figure 2: Schematic layout of the proposed experimental setup

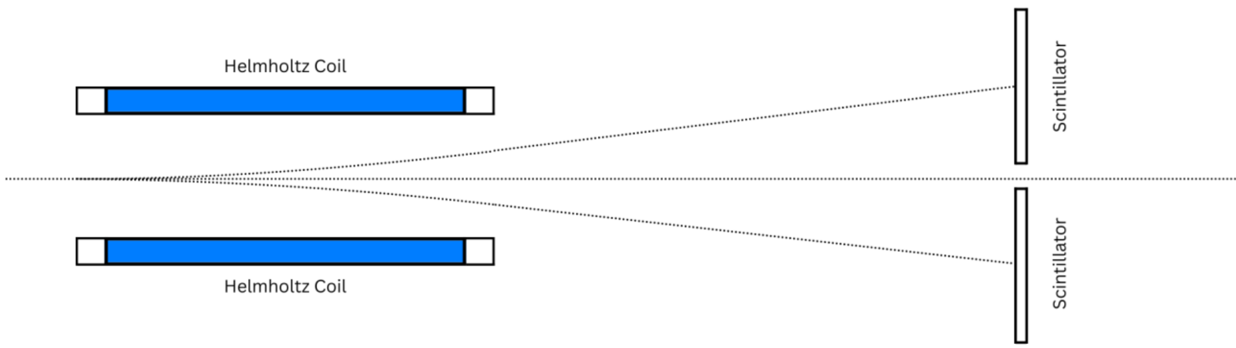

Figure 3: Trajectory of the muons before, inside and after the magnetic field.

In the figure above, Helmholtz coils deflect muons from their trajectory. After exiting the magnetic field (30cm long) the muons travel an additional 4 meters before hitting the scintillators. (Fig)

Stated above, we will use a magnetic field that is equal to 0.119890T. We can find the cyclotron radius with the equation below:

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

We will conduct this experiment with 4 GeV/c muons with a momentum spread of around ±15%. But for now, we will only take 4GeV. Since, 1 GeV/c = 5.344286×10^{-19} kg*m/s$_{(SI)}$ [3], our muons will have a momentum of $21.37*10^{-19}$ kg*m/s. *Fig. 5 for the momentum distribution and the drifts alongside them.

q will be $\pm1.6*10^{-19}$C for our muons.

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

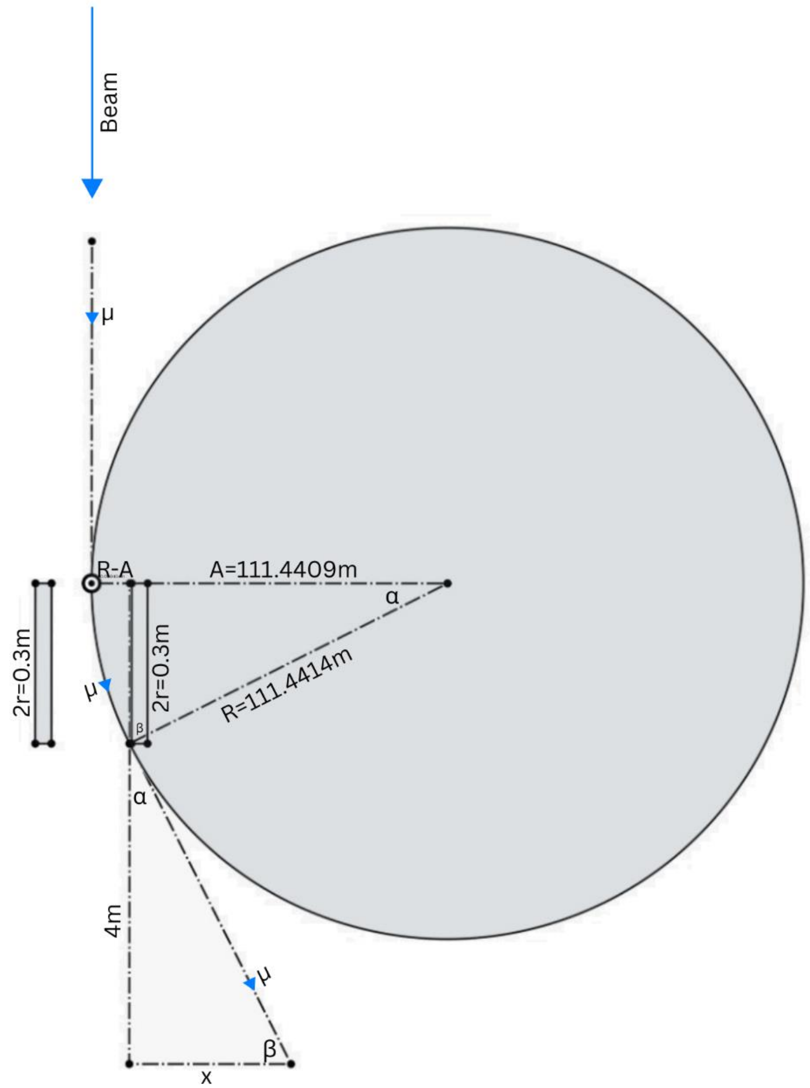

Figure 4: Cyclotron motion radius(R), Δx, 2r and A

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

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

This means that our muons will deviate their trajectory by **1.106cm** over a 4m long path.

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

However, the muons won't exactly have a 4 GeV/c momentum. There will be a ±15% spread. So, we calculated the deflection in respect to the distribution of momentum. (Fig 5.)

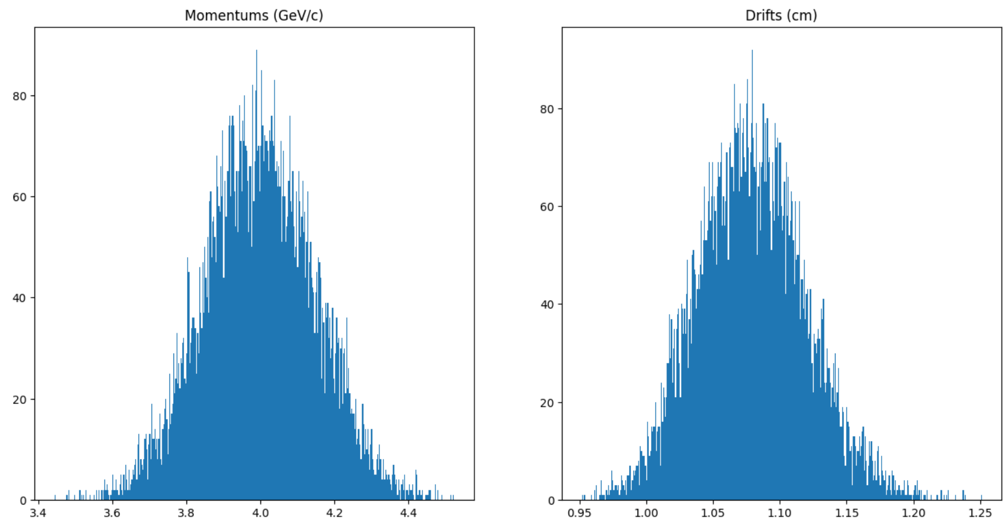

Figure 5: Histogram of the drifts in respect to momentum distribution

Then, we plan to make a readout system using scintillators. There will be 2, one for positive and one for negative charged muons. By turning the coils on, we will send the muons 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. We therefore create a binary readout system.

In our real-world setup, we will use muons. But the beam we get at CERN will have some hadron contamination. So, to make sure we get an accurate readout, we will veto the non-muon particles. We will achieve this 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, we will configure the Cherenkov detector to signal when particles other than muons, such as pions and kaons pass through. If the Cherenkov detector activates, we will ignore the data from the scintillators 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

- Proof-of-concept demonstration of a muon-based wireless communication system.
- Assessment of real-world feasibility in various environmental conditions.

5. References

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

[4] https://www.wikipedia.org/

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

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

[3] https://www.translatorscafe.com/unit-converter/lv-LV/momentum/47-1/gigaelectronvolt%20of%20momentum-kilogram-meter%20per%20second/

6. Acknowledgement

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