Journal of Physics: Conference Series

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To cite this article: K N Herrera-Guzman *et al* 2017 *J. Phys.: Conf. Ser.* **912** 012037

IOP Conf. Series: Journal of Physics: Conf. Series **912** (2017) 012037 doi:10.1088/1742-6596/912/1/012037

Design and construction of a uniform magnetic field generator for a 32 channel cosmic ray detector.

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Abstract. The trajectory of a particle can be measured if some points of its track are known. This is applied to any kind of particle, including cosmic rays. We have designed and built a device for this purpose. We present the design, construction and characterization of a uniform magnetic field generator system in a finite volume. An array of Cerenkov detectors will be placed inside of it for determining the cosmic rays charge and to reconstruct their trajectories.

1. Introduction

Charged cosmic rays at sea level are mostly muons [1]. The main goal of this work is to build a base to place a particle detector inside the magnetic field. It is very important that both materials, of the detector and base, do not distort the magnetic field. We built a system, with the requirements described above, for an arrangement of detectors of 8 in X 8 in X 8 in.

2. Analytic description

Cosmic Rays are very energetic, therefore it is necessary to consider a relativistic its deflection due to the presence of a magnetic field. We start with the Lorentz's principle [2] and the second Newton's principle with the relativistic correction,

$$\frac{d\vec{p}}{dt} = q\vec{v}x\vec{B}, \tag{1}$$

where $p = \gamma m v$ is the relativistic momentum, γ is the Lorentz factor, $\vec{v}$ and m are the velocity and the mass of the particle respectively.

In this case, $\vec{B} = (0, B, 0)$ and $\vec{v} = (v_x, 0, v_z)$ where $\alpha = \frac{\gamma m}{qB}$ and solving (1):

$$x = \alpha\left[Asen\left(\frac{t}{\alpha}\right) - Bcos\left(\frac{t}{\alpha}\right)\right] + K \tag{2}$$
$$z = -\alpha\left[Acos\left(\frac{t}{\alpha}\right) + Bsen\left(\frac{t}{\alpha}\right)\right] + C$$

and

$$v_x = Acos\left(\frac{t}{\alpha}\right) + Bsen\left(\frac{t}{\alpha}\right) \tag{3}$$
$$v_z = Asen\left(\frac{t}{\alpha}\right) - Bcos\left(\frac{t}{\alpha}\right)$$

Applying the initial conditions $x = 0$, $z = z_0$ and $v_x = 0$, $v_z = v_{z0}$ in $t = 0$ to (2) and (3) the solution is

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$$x = \alpha\, v_{z0} cos\left(\frac{t}{\alpha}\right) - \alpha\, v_{z0} \tag{5}$$

and

$$z = \alpha\, v_{z0} sen\left(\frac{t}{\alpha}\right) + z_0. \tag{6}$$

3. Design

The prototype design consists of Helmholtz coils with 210 turns and a ferric nucleus. Both coils are joined by ferric bars to close the magnetic field. An aluminum base, which will be used to place detectors inside the magnetic field, was designed too. Figure 1 shows a drawing of the coils and the aluminum base.

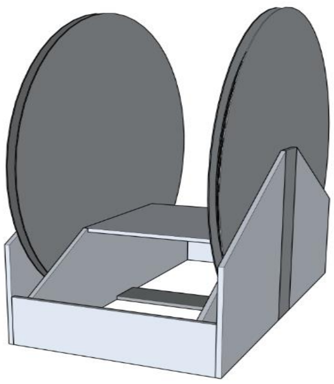

Figure 1. System perspective view.

Because this prototype is supposed to hold the electronic cards, few aluminum plates must be added. Those extra aluminum plates, and their location inside the coils, are shown in Figure 2.

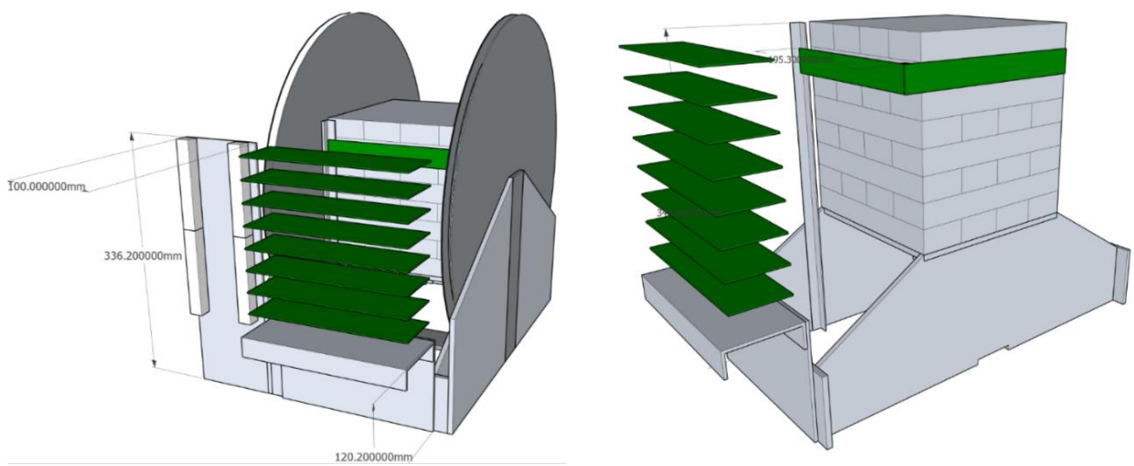

Figure 2. Aluminum pieces added to hold all electronic components.

4. Construction

All pieces were joined together with nuts, bolts and aluminum angles when necessary. Steel plates were glued together to form bars, resulting two bars of 27.5 cm X 5.0 cm X 0.6 cm and one of 23.4 cm X 5.0 cm X 0.6 cm (for future references this pieces are called L and K pieces respectively). Drilled discs form

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2 reels, each one containing two 23.4 cm radio discs and eleven 21.4 cm radio discs. The discs were glued together by the perimeter.
The steel reels were winded with 210 turns each with 19 AWG wire. Then, the reels were painted red color and the L and K pieces matte matt black color. Figure 3 shows the assembled system with and without electric connection.

a) **b)**

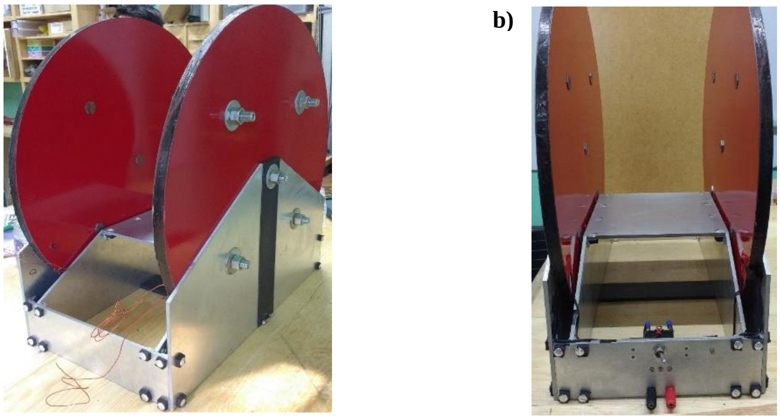

Figure 3. Assembled system a) without and b) with electric connection.

In order to map the magnetic field, a MakeBlock XY Plotter was adapted [3]. A graduated acrylic tube was used instead of a pencil. With this, it was possible to map the magnetic field in a volume of 20.00±0.05 X 19.00±0.05 X 20.0±0.1 cm in *x*, *y*, *z* directions respectively. Inside the acrylic tube, a Vernier VGM was placed. Figure 4 shows the measurement system on the prototype mentioned above. Each surface is mapped in 20 lines from left to right; each line is made of points 20. The volume mapped is made of 20 flat surfaces 1 cm apart.

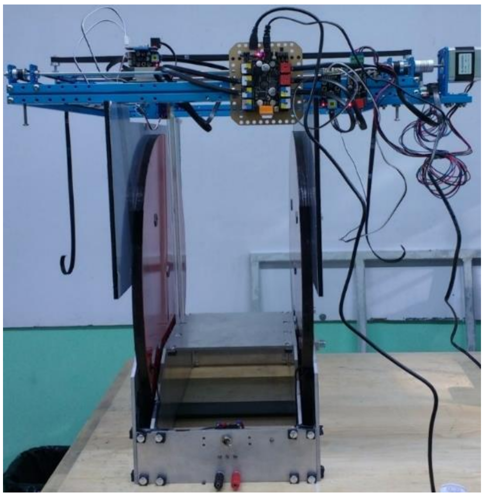

Figure 4. Magnetic field measurement system on the prototype.

5. Results
A model of the coils was simulated in Poisson Superfish [4]. Figure 5 shows the generated graph by Poisson Superfish.

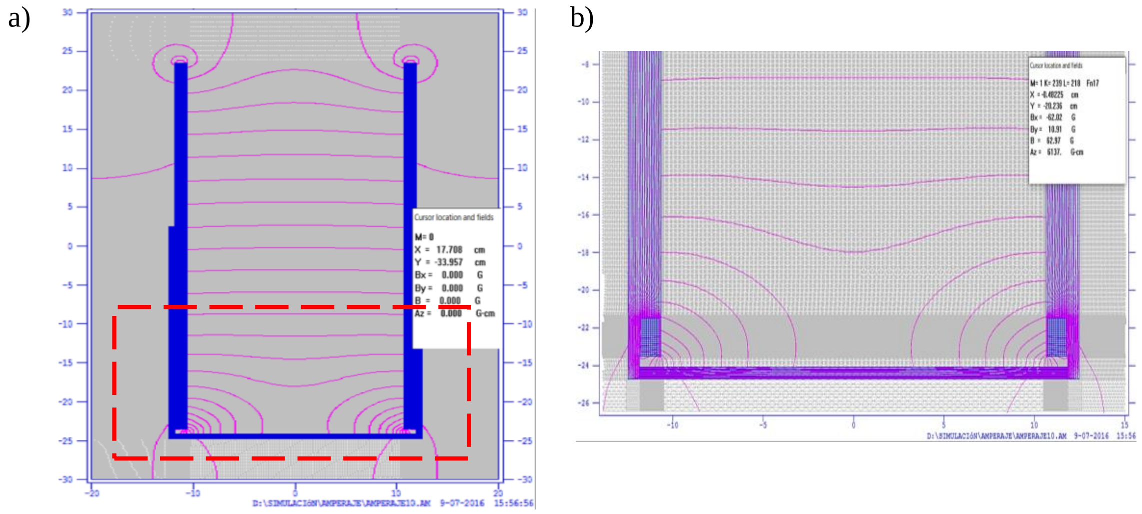

Figure 5. a) Magnetic field lines simulated and b) zoom of the simulated lines inside the red rectangle.

Equations (5) and (6) have to be solved to find the maximum and minimum particle energy in which the incident particle will be deflected in the desired way.
To solve this equations it is necessary to give B, m, q y z_0 values, those are the magnetic field generated by the coils, the muon mass, the muon charge and the point in which the particle enters in the magnetic field. Those values are: $B = 29.44$ mT (Poisson Superfish for a 20 Amperes), $m = 1.08838x10^{-28}$ kg, $z_0 = 23.52$ cm and $q = \pm 1.0602x10^{-19}$ C. Defining $\beta = \frac{m}{qB}$ we have:

$$x = \frac{\pm\beta xc}{\sqrt{c^2 - {v_{z0}}^2}} \cdot v_{z0}\left[cos\left(\frac{\sqrt{c^2 - {v_{z0}}^2}}{\beta xc} \cdot t\right) \mp 1\right], \tag{7}$$

$$z = \frac{\pm\beta xc}{\sqrt{c^2 - {v_{z0}}^2}} \cdot v_{z0}\left[sen\left(\frac{\sqrt{c^2 - {v_{z0}}^2}}{\beta xc} \cdot t\right) \mp 0.2352\right].$$

Lower bound; case in which the particle leaves the array of detectors before crossing its half:

$$x = \pm 0.1016 \text{ m}, \quad z = 0.0254 \text{ m}.$$

Upper bound; case in which the particle leaves the array of detectors without a detectable deflection (the width of one detector is 5.08 cm):

$$x = \pm 0.0508 \text{ m}, \quad z = -0.1016 \text{ m}.$$

The energy bounds found are:

$$E_{max} = 106.31 \text{ MeV}, \quad E_{min} = 105.85 \text{ MeV},$$

which were calculated with $E^2 = \gamma^2 m^2 c^2 + m^2 c^4$.
Table 1 shows the initial and final current and temperatures in which the measurements took place for some planes.

Table 1. Values of current and temperature between each plane was mapped.

Plane number	I_i (A)	I_f (A)	T_i $(°C)$	T_f $(°C)$
0	4.77	4.69	72.5	77.0
10	4.66	4.66	80.3	80.2
20	4.70	4.69	77.0	78.5

Figure 6 shows the graphs of some planes of the magnetic field generated by the coils. Figure 6.4 shows the maximum and minimum value obtained for each plane.

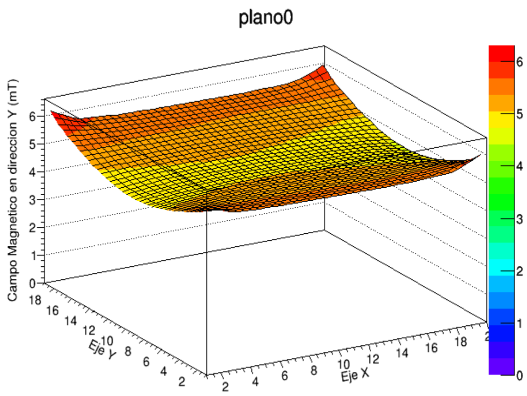

Figure 6.1. Magnetic field map in plane 0.

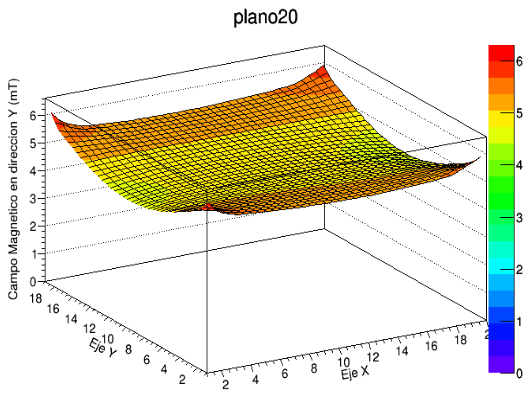

Figure 6.2. Magnetic field map in plane 20.

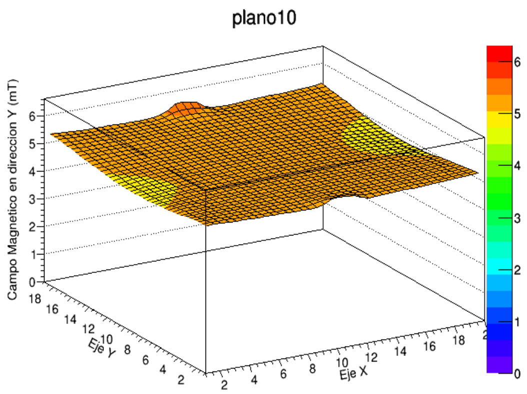

Figure 6.3. Magnetic field map in plane 10.

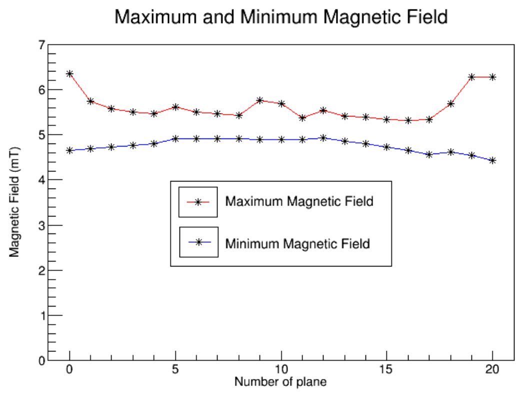

Figure 6.4. Maximum and minimum values of the magnetic field.

6. Conclusions

We simulated the magnetic field as a function of electric current; we have measured the magnetic field as a function of the applied electric current. Incident cosmic particles with energy between E_{max}=106.31 MeV and E_{min}=105.86 MeV must be detected by this spectrometer. Loss of energy from particles passing through the detectors is not considered. Magnetic field percent variation decreases as the sensor approaches to the axis of the coils and increases as they move away from it. Also it is observed that this variation increases faster in the upper planes than in the lower planes.

From figure 6.4 can be seen that the magnetic field uniformity is higher at the center planes and that the maximum difference is rapidly decreasing at the top and bottom planes.

Aknowledgments

CONACYT Project 223179, CB-2013-01 and UGTO Project.

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