LIP-STUDENTS-24-08

Testing new detectors with muography

Francisco Silva[1,a] and Yanhan Zhou[2,b]

[1] *Instituto Superior Técnico, Lisboa, Portugal*
[2] *Faculdade de Ciências, Lisboa, Portugal*

Project supervisor: Sofia Andringa *November 5, 2024*

Abstract. This paper aims to study the behavior of the sRPC muon telescope that is now operating at CERN to estimate the muon flux around the SND@LHC experiment. We started by selecting quality data, then we utilized the muography technique to analyze the detector's performance. By examining data collected from the detector in Coimbra, we sought to understand how the detector's behavior during a short period.

KEYWORDS: Muography, LHC, Coimbra, sRPC

1 Introduction

1.1 Muons and Muography

A *muon* is a heavy charged particle. The fact that it is heavy makes it so it tends to move in straight lines, which are very easy to map. The use of muons to image the interior of structures and objects is referred to as *muography*. Muography has been used in several projects, such as the mapping of the interior of pyramids.

In our project, since we know where our detector was placed, muography allows us to see if the data it is recording makes sense.

1.2 The sRPC muon telescope

The sRPC muon telescope we studied is currently at CERN, however, the majority of the data we analyzed was from its time in Coimbra University's Physics Department. The detector consists of 4 planes, each with 16 strips. The planes will determine the z coordinate, and the strips will determine the x coordinate (Figure 1). The y coordinate will be calculated indirectly by this formula:

$$y = \frac{TF - TB}{2} \times v \tag{1}$$

With:

- TF : Arrival time of the signal at the front end of the strip;
- TB : Arrival time of the signal at the back end of the strip;
- $v \approx 165.5$ (mm/ns) : propagation velocity of the signal;

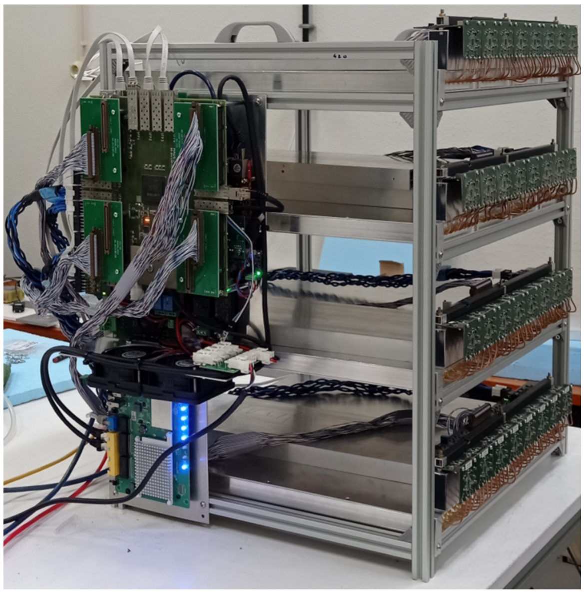


Figure 1: The sRPC Telescope on a work table in Coimbra

The detector has two triggers, the Muon Trigger and the Random Trigger. The Muon Trigger, activates when there are at least 3 registered hits across 3 different planes, in a short time-frame. The Random trigger activates in random bursts and serves mostly as a measurement of noise in the detector.

Most of our analysis was done looking at the Muon trigger, seeing as the Random trigger's main purpose is to measure noise.

Further information regarding the telescope can be found in [1].

1.3 Initial analysis

Our dataset contains 1 hour, 33 minutes, and 14 seconds of data collected in the 19th of October 2023 in the LIP detector laboratory in Coimbra. Initially we looked at data such as the number of hits (muons) per plane. We started by characterizing the full data set, looking for example at the total number of hits collected in each plane during the full period of data, shown in Figure 2. We also looked at

[a]e-mail: francisco.tomas.da.silva@tecnico.ulisboa.pt
[b]e-mail: fc58286@alunos.ciencias.ulisboa.pt

the total number of hits collected in each strip during the full period of data, as shown in Figure 3.

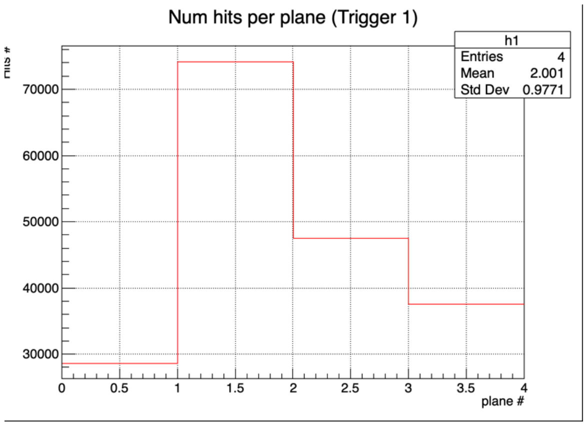


Figure 2: Total number of hits (in all the events detected with the muon trigger) detected by each plane.

The fact that plane 2 has more than double the amount of the hits as plane 1 can be partially explained with noise and the geometry of the detector. However it might have to do with different physical properties of the 2nd plane, which makes it more prone to "*streamer*" effects. A streamer is when 1 muon hit ends up spreading across neighbouring strips, making 1 muon appear multiple times in the data.

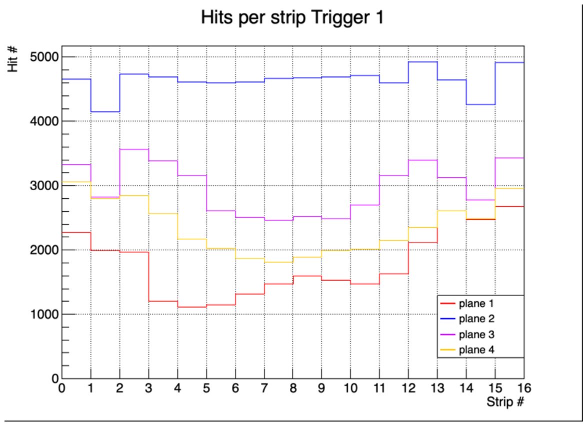


Figure 3: Number of hits per strip (Muon Trigger)

We also observed discrepancies between the strips.

1.4 Time & Charge distributions

Many plots were done regarding the time distributions, to better understand their behaviour (Fig 4 & 5).

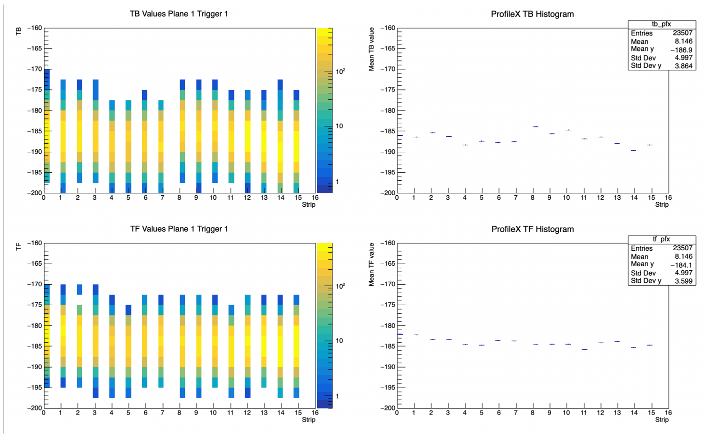


Figure 4: TB & TF values (Muon Trigger)

The time distributions appeared to be almost aligned across the different strips, however by using offsets, we could center every distribution to zero. Fortunately, another colleague at LIP, Tristan Barlerin, had already calculated the offsets and was kind enough to share them with us. [2]

Regarding the charge distributions (Figure 5) by looking at the distributions on all planes, we developed cuts for QF and QB (charge in front end and back end of the detector, respectively).

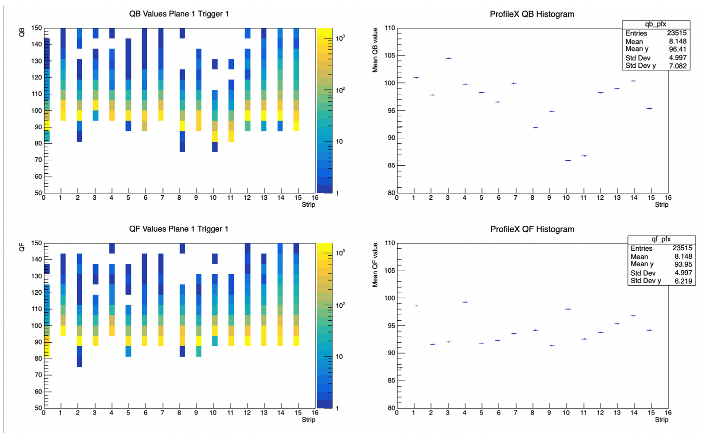


Figure 5: QB & QF values (Muon Trigger)

The cuts we used for each hit detected by the Muon Trigger were:

- $-200 \leq TB \leq -160$ (ns)
- $-200 \leq TF \leq -160$ (ns)
- $-3 \leq \frac{TB-TF}{2} \leq 2$ (ns)
- $50 \leq QB \leq 150$ (Arbitrary Units)
- $50 \leq QF \leq 150$ (Arbitrary Units)

2 Road to Muography

2.1 Reconstructing muons

At the beginning, we only used events in which two or more planes had exactly one hit per plane, because

	1 hit events	Total events
Plane 1	4549	9504
Plane 2	2089	14441
Plane 3	2994	12372
Plane 4	3244	10940

Table 1: Number of single hit events and total events

this required no additional processing to calculate the position of the incoming muon. Table 1 shows the number of single-hit events and the total number of events for each plane. Since most of the registered events have multiple hits in each plane, these events must be used, otherwise, very little data will be available. To account for the multiple hits, we calculated their mean position and then checked whether the difference between the original position of each hit and the mean position exceeded the limits defined below. Figure 6 shows absolute value for the difference between each hit position and the mean position in x, given by strip number (on the left), and y, given in ns (on the right). Note that for now y-axis is just the time difference ($\frac{TF-TB}{2}$). In the following subsections the y-axis will be the position, by applying equation 1.
By analyzing the histograms (figure 6), we decided that differences in position up to 1 strip and 0.1 ns are acceptable (these limits ensure that at least half of the data falls within the range, although they may be adjusted depending on further analysis methods) - and those values will be used as limits. If some hits are out of limit, these hits will be deleted and the mean position will be recalculated using the remaining hits. This process will be repeated until all hits are within our defined limits.

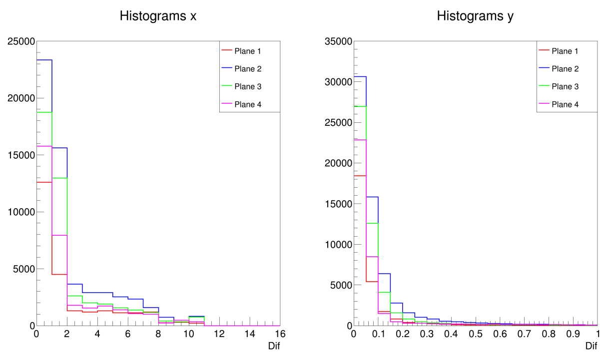
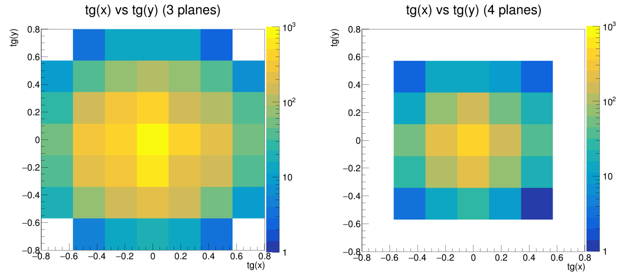


Figure 6: Difference between mean position and hits position (absolute value), before merging all hits

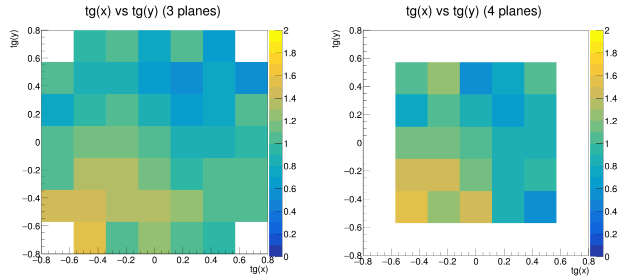
2.2 Direction Maps

Merging all hits in the same plane, we can recover many valid events, as shown in table 1 (for each plane). The mean points in the two outer plains are then used to predict a muon straight line trajectory and the points it must have crossed in the inner planes. These predicted points



(a) 3 Planes (b) 4 Planes

Figure 7: Direction maps using different activated plane



(a) 3 Planes (b) 4 Planes

Figure 8: Muography using different activated plane

are then compared to the detected points in each plane. Unfortunately, we did not have much time to analyze our data with other limits.
If the real position in the inner plane is within limits, this event of data will be used to calculate the tangent (direction) of the muon's trajectory. The directions are simply calculated by: $tan(x) = \Delta x/\Delta z$ and $tan(y) = \Delta y/\Delta z$, where Δx and Δy are the difference between the muon's positions in the two outer plane, in axes x and y respectively, Δz is height between the outer planes.
We created two separate direction maps, as shown in figure 7. Map (b) uses events where all four planes are activated, and all four points align with a muon trajectory. Map (a) includes events where only three planes are used to construct the muon line. This could occur if the muon is far from vertical and misses one of the outer planes, or if one of the planes failed to register the muon correctly. The direction maps display the quantity of incoming muons as a function of direction.

2.3 Normalization

After obtaining the direction map (figure 7), it seems almost symmetrical, making it hard to tell which direction had more incoming muons. To solve this, we decided to normalize the map.
Since the muon flux doesn't depend on azimuthal angle φ, we can rotate our map at any angle and this will not change the symmetry of the muon flux. The process used

for the normalization of the direction map is: rotate the original map 90 degrees 4 times to create 4 symmetrical maps, then sum them all together and divide by 4 to obtain map of the mean. By diving the original direction map by the mean map, we finally get the muography. The results are shown in figure 8.

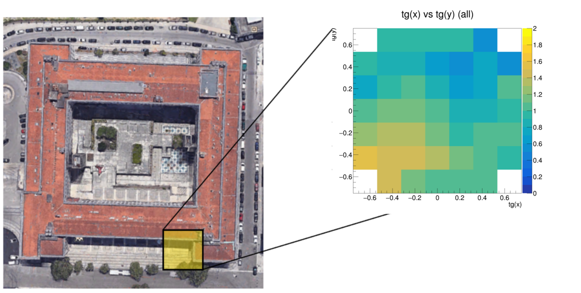


Figure 9: Localization of the muon telescope, adapted from [3]

3 Results and Discussion

As we mentioned, it is quite difficult to obtain useful information from direction maps. The way to interpret the normalization (muography) is every bin on the map is compared with mean of all 4 symmetrical position, that can show us for same polar angle, which direction, in terms of azimuthal angle, has more (or less) number of muons. That is also why the bin at center of map is always 1.
Regarding our final result, we first need to point out that the detector was placed under the physics department of university of Coimbra, it is shown in the figure 9. We can observe that the lower-left area of the muography (note that the muography shown in figure 8 is different than the muography in figure 9, the latter is sum of those two maps) shows more muons reaching the detector and for top-right area of the muography the situation is the opposite. That is because top-right area was covered by the building of the physics department, blocking most of the incoming muons. For lower-left, there is just an open space, allowing for more muons to be detected.
Also the telescope is symmetric, except for small detector effects that we may be sensitive to. In particular, the detection efficiency may vary along each plane which can lead to more muons being reconstructed in one direction than in other.

4 Next Steps

We have applied the muography technique to the data collected by the sRPC muon telescope during its time in Coimbra. However this data set corresponded to only 1.5 hour of exposure. A natural next step would be to see how the muography evolved over time, maybe even making an animation.

Another aspect we have yet to study, is the relationship between charge and efficiency, which could possibly yield interesting results.
Finally, we should compare the muography results once we have applied corrections to the efficiency.

5 Conclusion

Our study succeeded as a first step in the use muography to better understand the detector.
The behaviours of the sRPC detector are partially understood, but there are still issues that require further research. Once the next steps have been taken, we will hopefully better understand the detector.

Acknowledgements

We would like to thank our supervisor Sofia Andringa, for the valuable input throughout the entirety of the internship. We also want to express our gratitude to people of the SND@LHC group, for their selfless help.

References

[1] A. Mendonça, *Tracking muons in CERN's Large Hadron Collider*, Bachelor's thesis, IST (2024)

[2] T. Barlerin, LIP-STUDENTS-24-00, LIP Summer Internship (2024)

[3] Loumu project website, https://pages.lip.pt/loumu/telescopio/