NOVA SCHOOL OF
SCIENCE & TECHNOLOGY

Muography in Archeology

LIP SUMMER INTERNSHIP 2026 FINAL WORKSHOP

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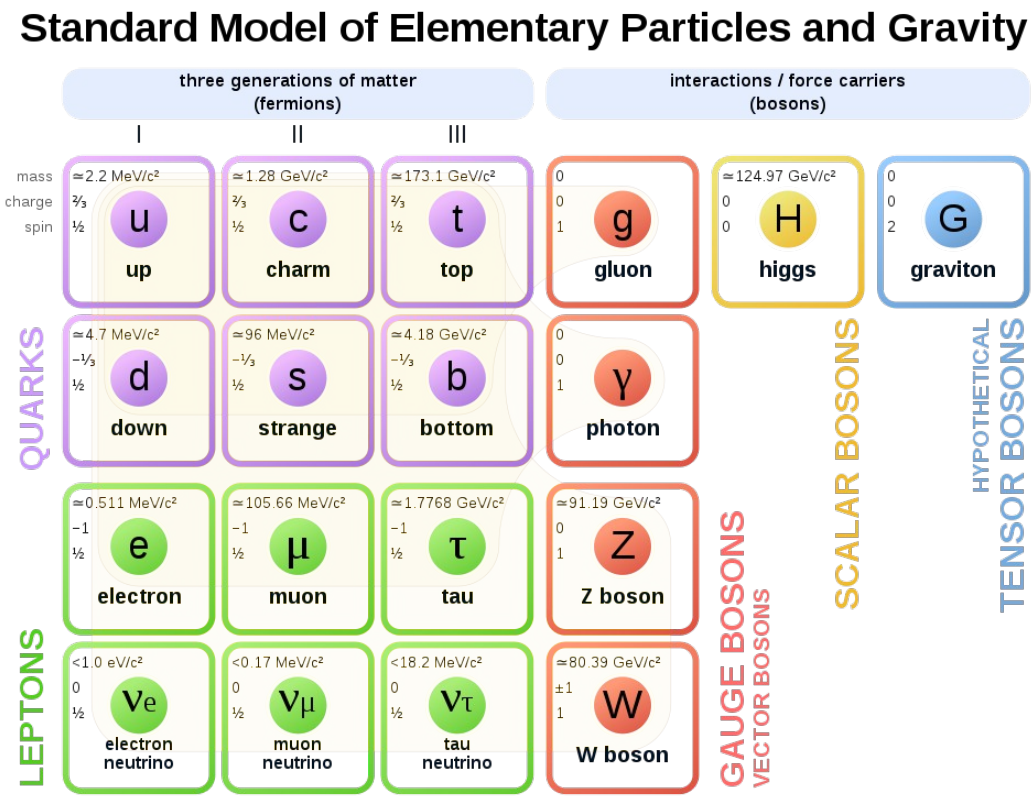
Muons

- Elementary particle 206x heavier than electrons

- Lose energy much slower than electrons

- Travel mostly in a straight line



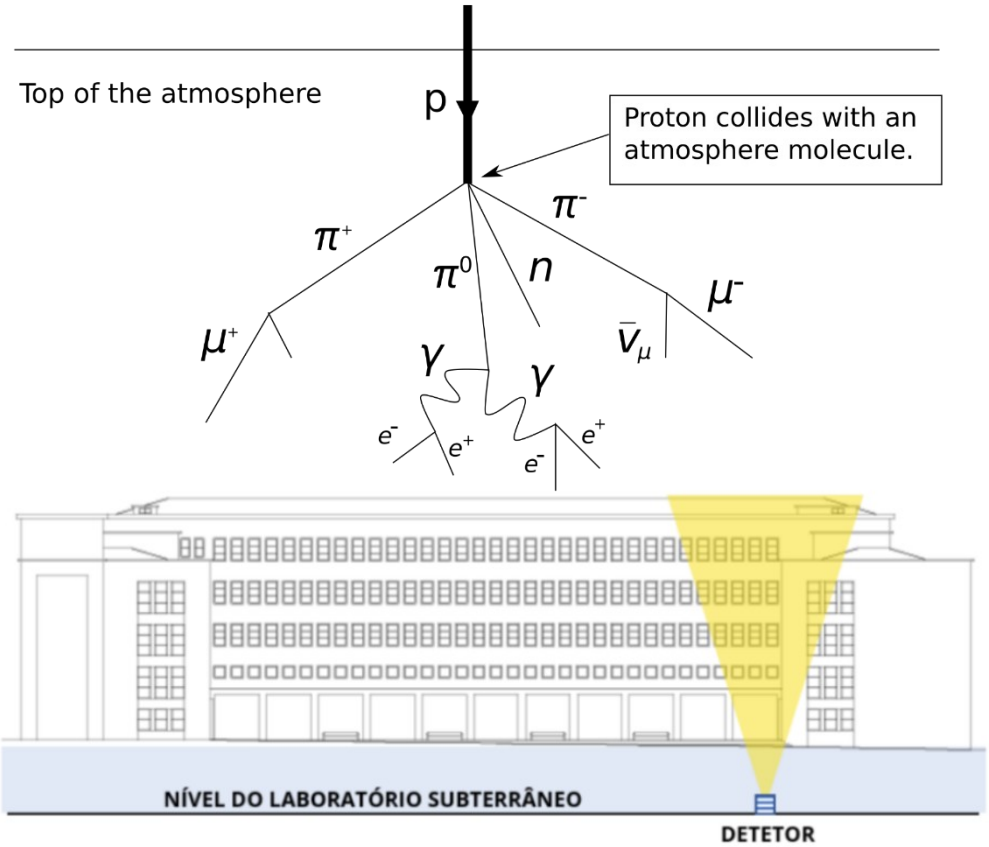
Muography

- Works similarly to a radiography

- Atmospheric muons travel through dense materials to reach the detector

- Differences in detectable flux due to material density

- Used in imaging of: Pyramids, Vul canoes, Mines



The sRPC Detector

A sealed Resistive Plate Chamber works by holding two plates at a very high potential difference, such that an energetic particle can initiate an avalanche.

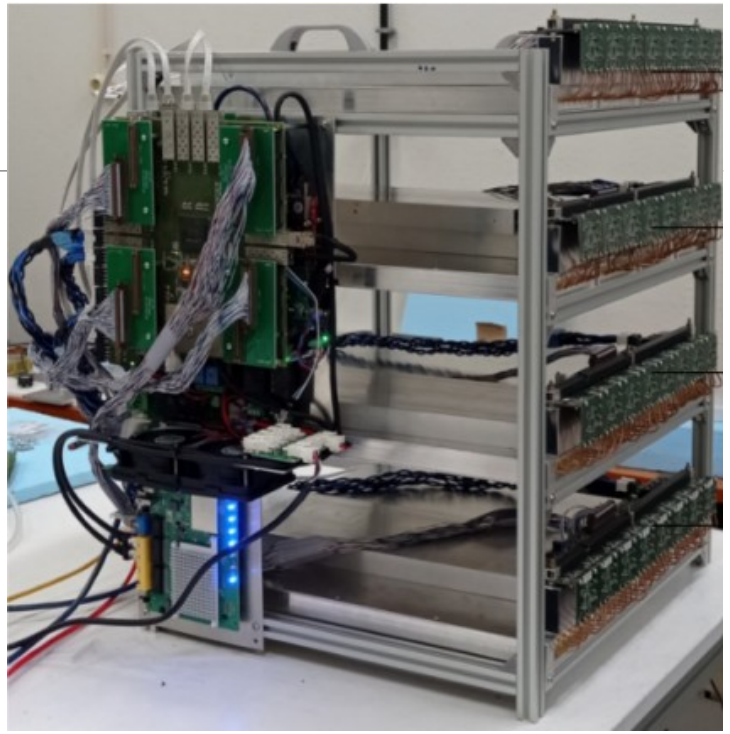
- Four Planes

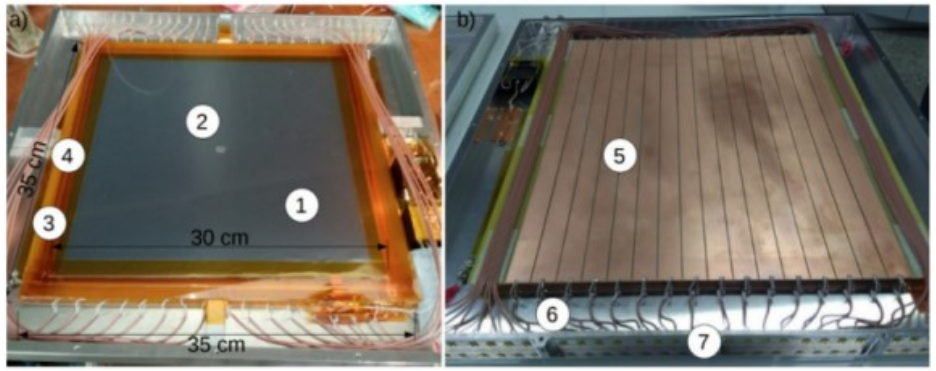
- 16 Strips determine X coordinate

- 2 Scintillators at each end of a strip give the charge and time which determine the Y coordinate

- Only records data if atleast 3 planes are hit

- The data was gathered in the basement of the university of Coimbra, for a month



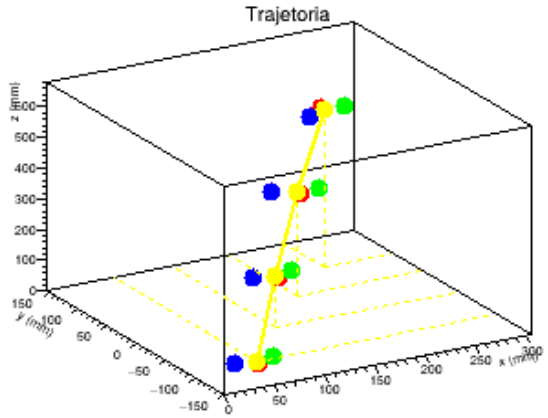


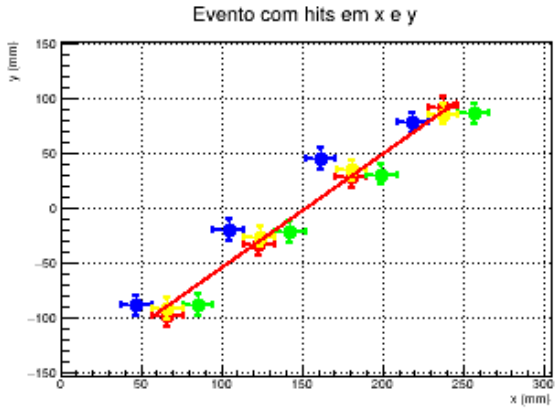
Reconstructing a Muon

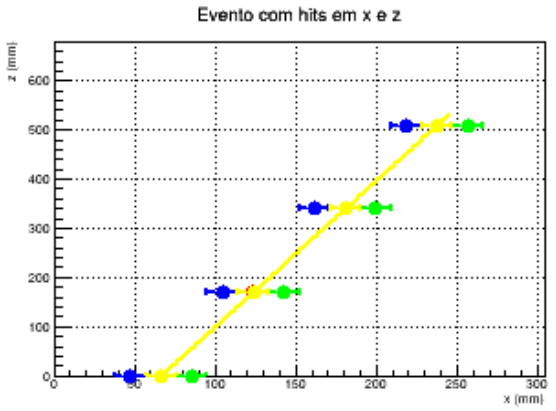
- From the sRPC we can get the position of the muon for each plane

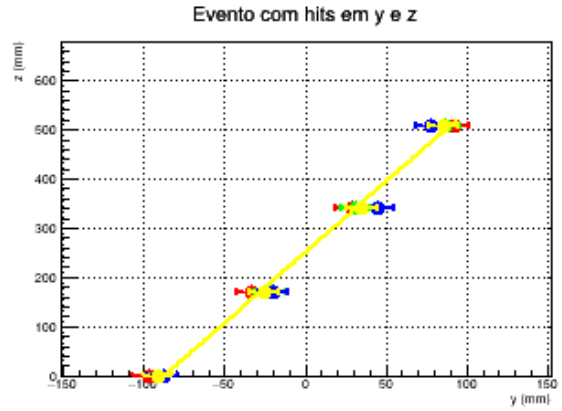
- For a given plane there can be many hits

- Averaged the points closest to the best hit, with the charge as a weight and then fitted the points in x(z) and y(z)







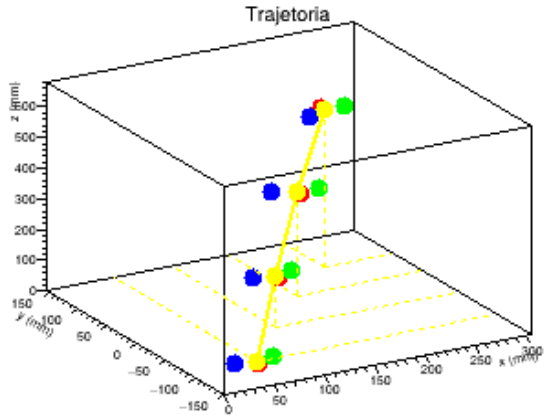


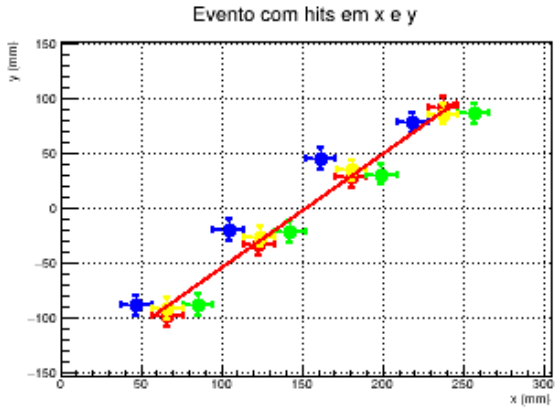
Reconstructing a Muon

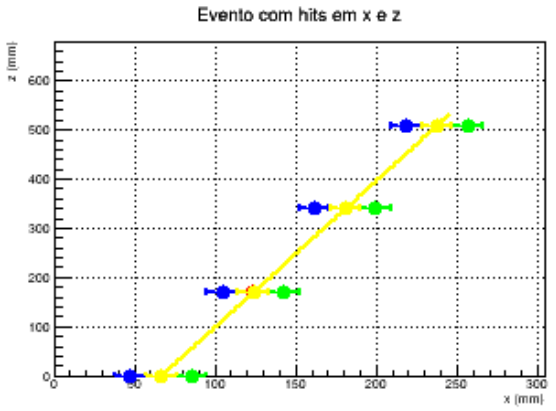
- Red points are highest charge, blue 2nd, green 3rd and yellow is the weighted average

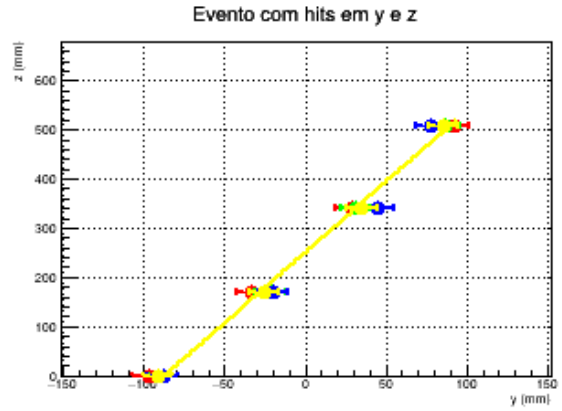
- The yellow lines are the fit, the red line is constructed from the two fits as a means of confirmation

- Typically detection with only 3 planes imply muons with a steeper angle whilst those with 4 planes are more vertical





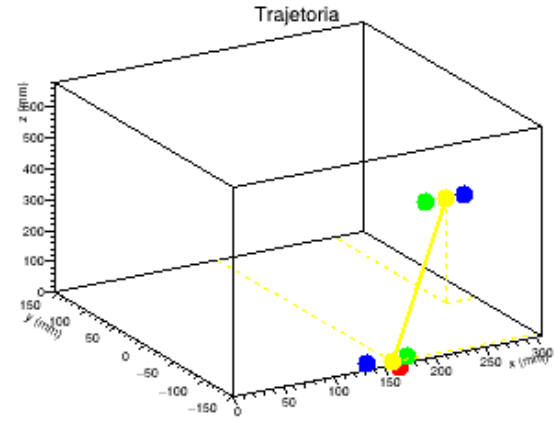


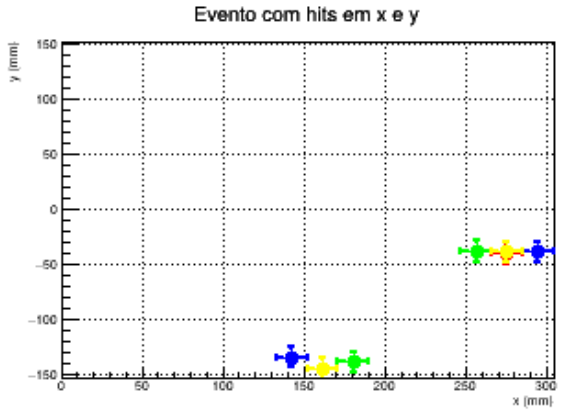


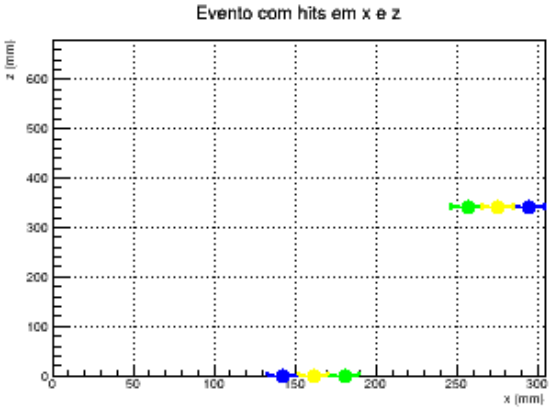
Imperfections

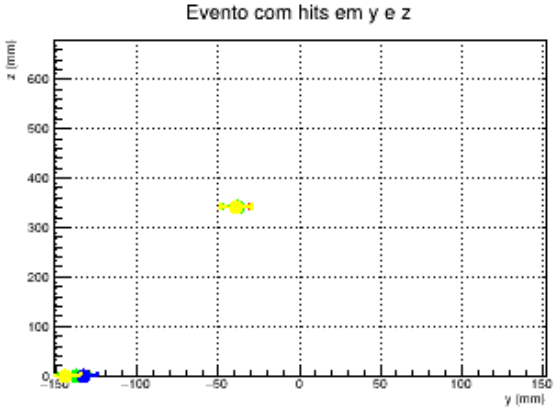
Unfortunately the detector isn't perfect which leads us into 3 cases where this method cant reconstruct a muon

- An event gets triggered even though we only record two planes









Imperfections

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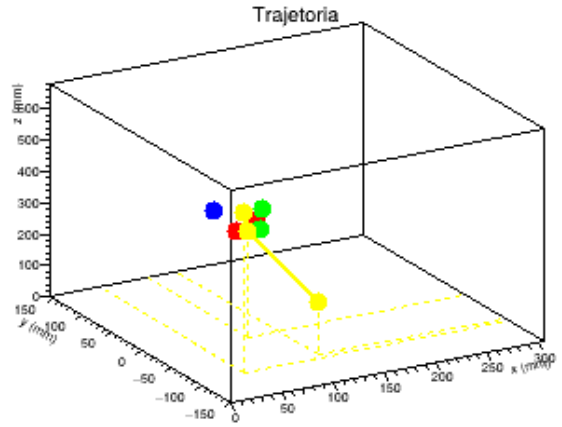
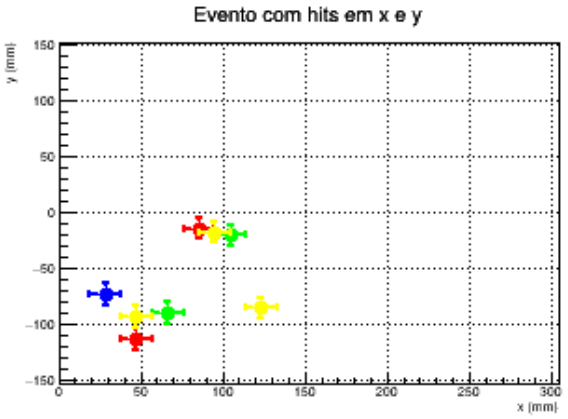
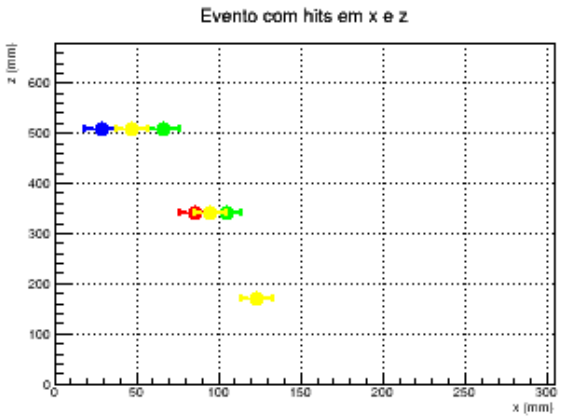
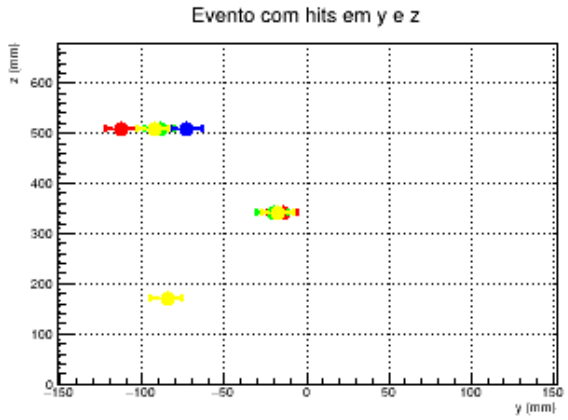
- The fit is not appropriate





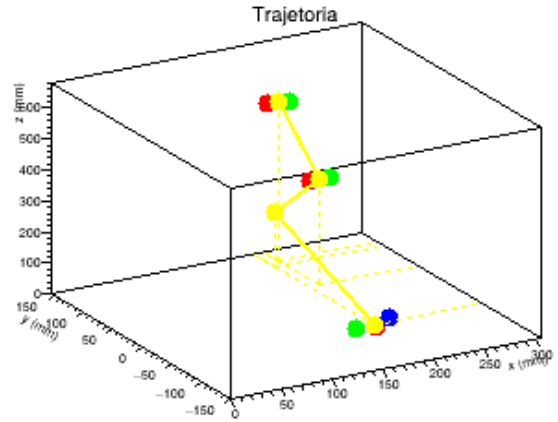


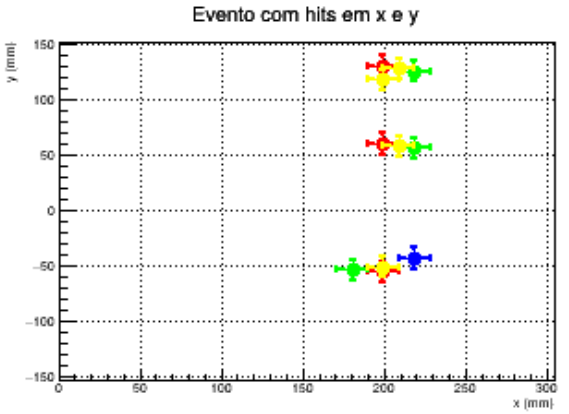


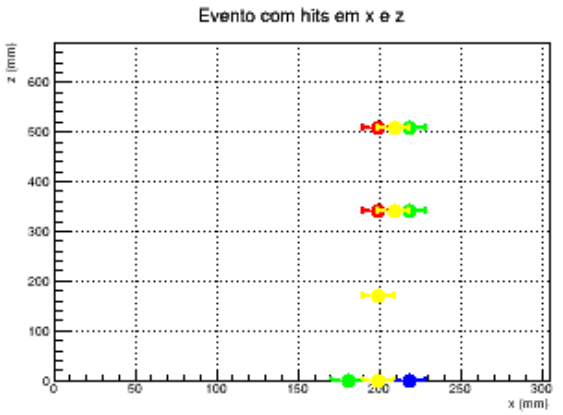
Imperfections

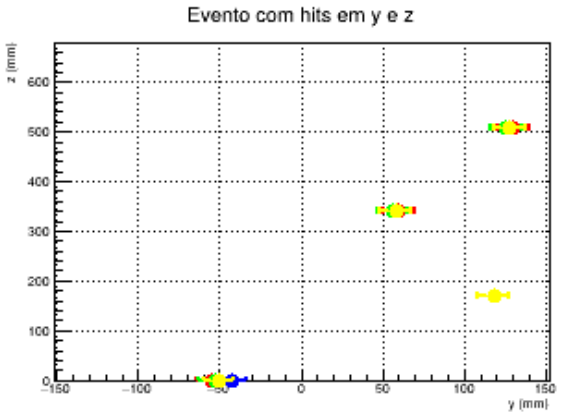
Unfortunately the detector isn't perfect which leads us into 3 cases where this method cant reconstruct a muon

- A single plane has an abnormal hit

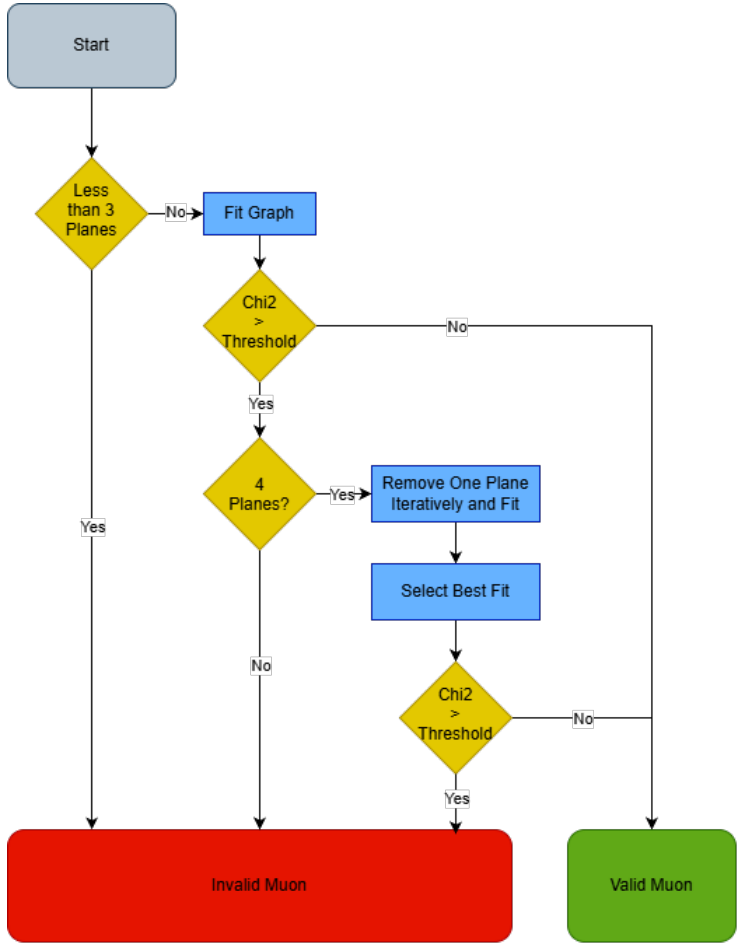


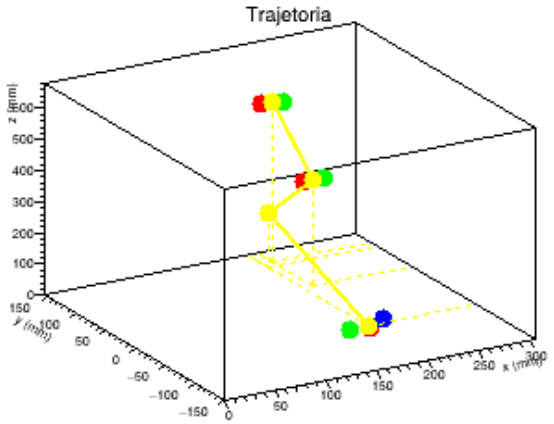


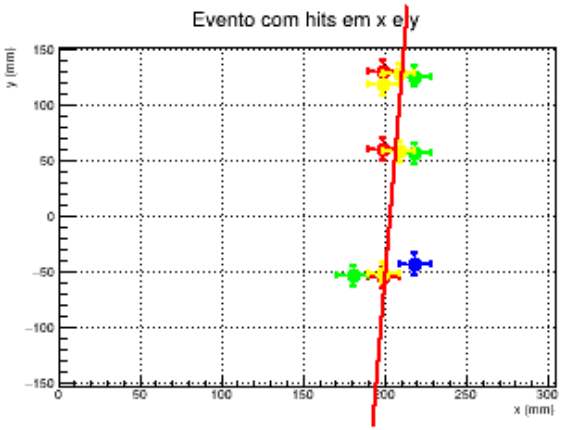


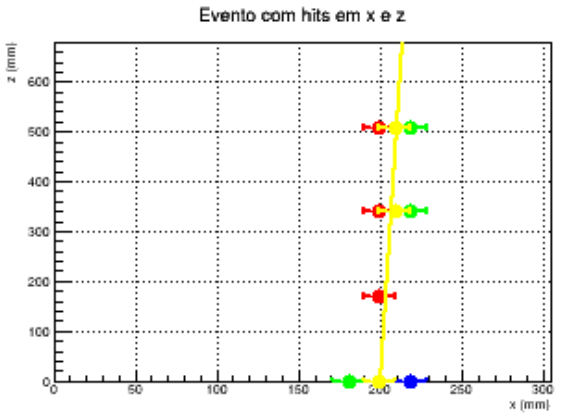


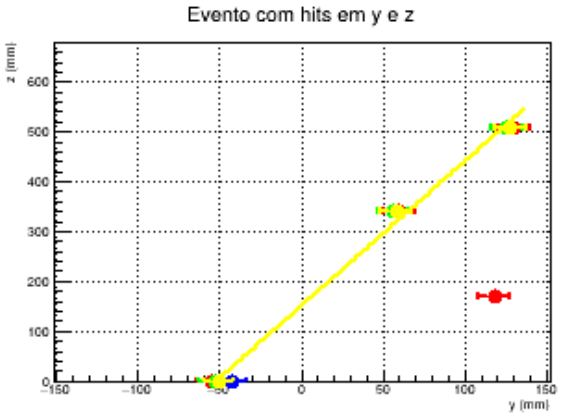
Correcting


Start
Less than 3 Planes
No
Fit Graph
Chi2 > Threshold
No
Yes
4 Planes?
Yes
Remove One Plane Iteratively and Fit
Select Best Fit
Chi2 > Threshold
No
Yes
No
Yes
Invalid Muon
Valid Muon


Trajetoria


Evento com hits em x e y
y (mm)
x (mm)


Evento com hits em x e z
z (mm)
x (mm)


Evento com hits em y e z
z (mm)
y (mm)

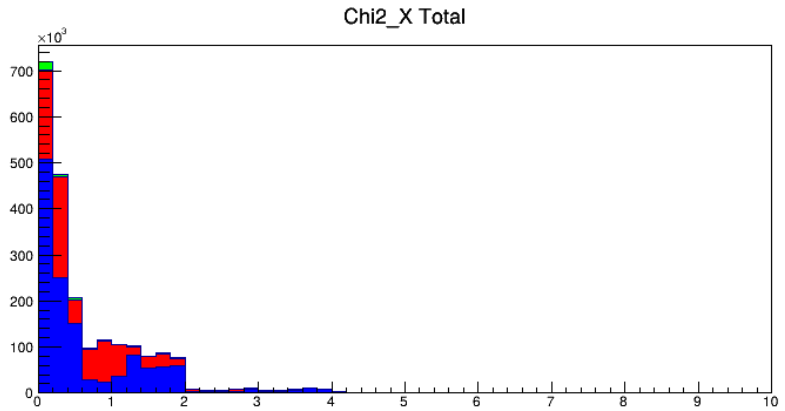
Verifying the fit

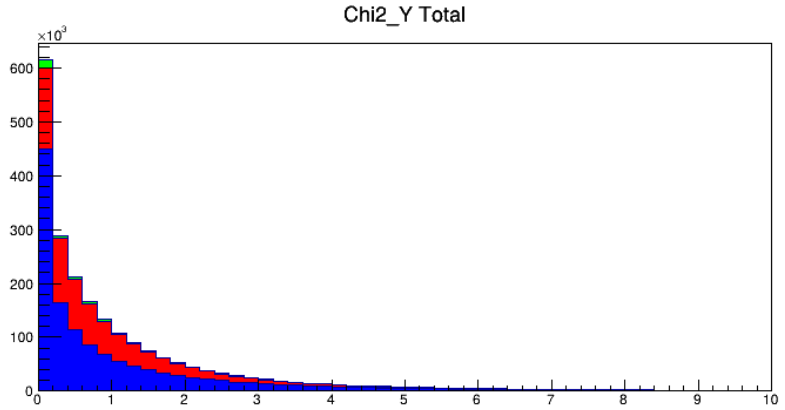
We use the Chi2 of the fit divided by the degrees of freedom as a means to filter out bad muons and to exclude planes, if necessary

From the graph we can tell that the x(z) chi2 is discrete due to strips

While the y(z) chi2 is a smooth distribution

In blue are the muons with only 3 planes, the red are 4 planes and the green 4 planes in which we discarded



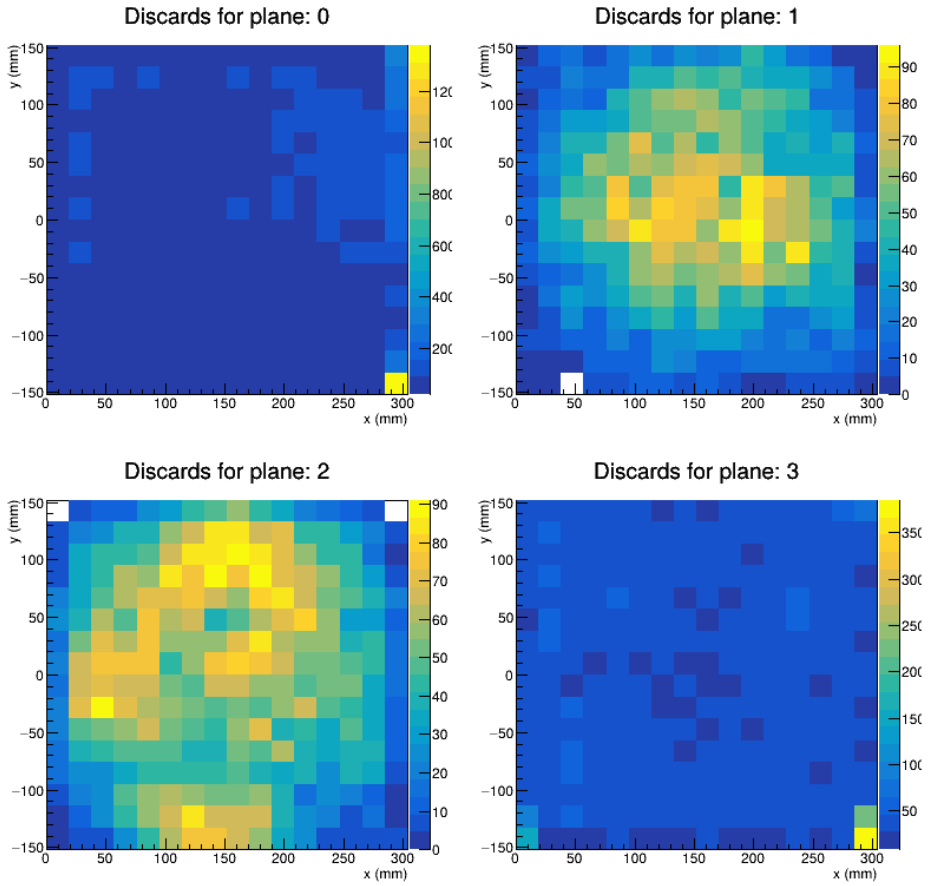


Discards

The points that were discarded from the fit were saved

We looked for a pattern within the points that were discarded to identify faults with the detector

By looking at the scale, we can see that plane 0 and 3 are more likely to have an erroneous detection, yet are more uniform when compared with planes 1 and 2



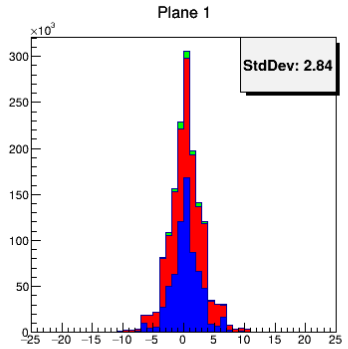
Characterizing the detector

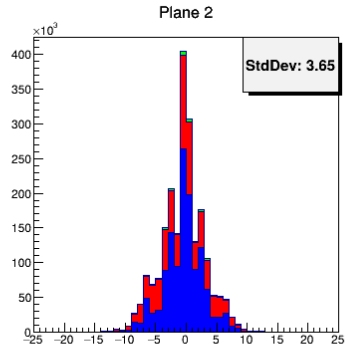
By checking the residuals we can verify that the detector is well aligned and identify the resolution of the detector

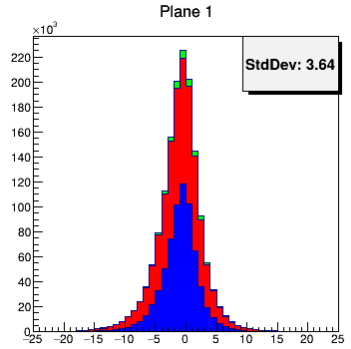
The residuals in x are discrete due to the stips, while the residuals in y are a smooth gaussian

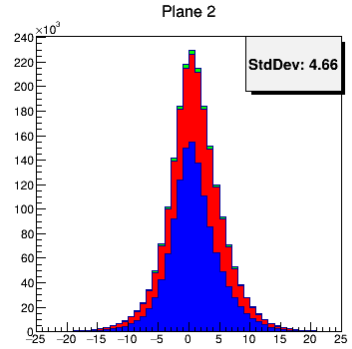
By fitting a gaussian we can find that the sensitivity in x is higher than y

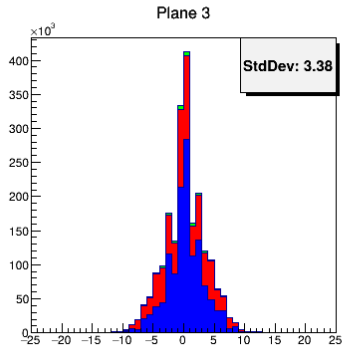
In blue are the muons with only 3 planes, the red are 4 planes and the green are 4 planes in which we discarded

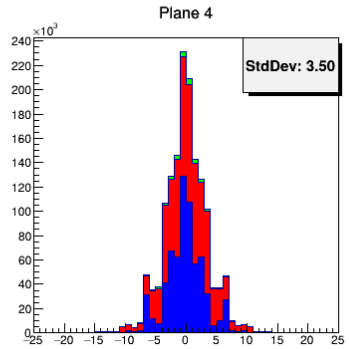


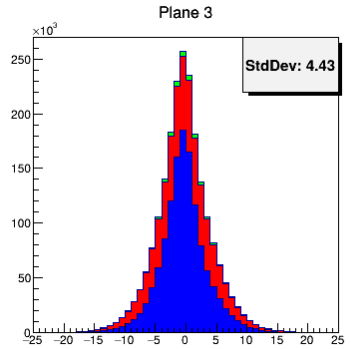


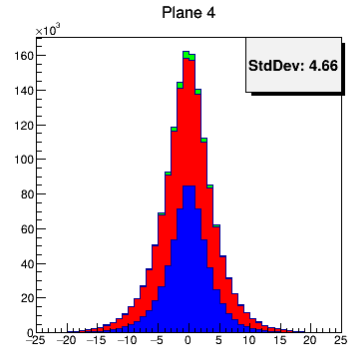








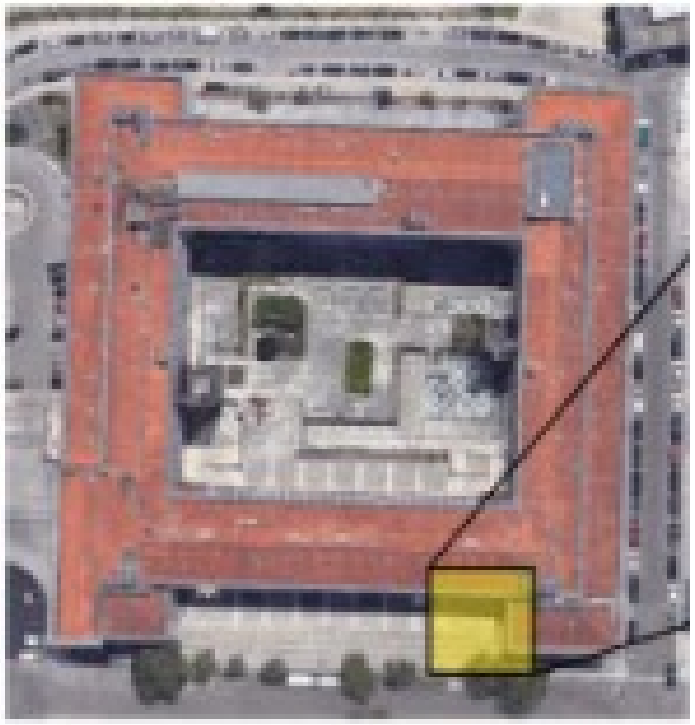


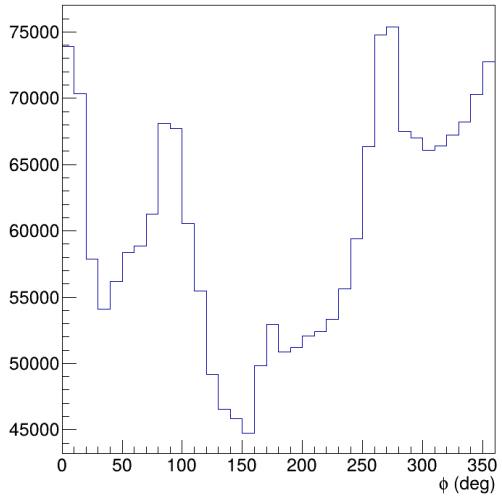


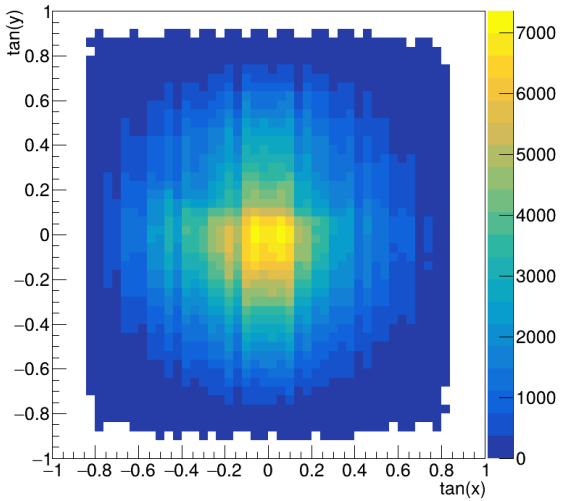
Performing a Muography

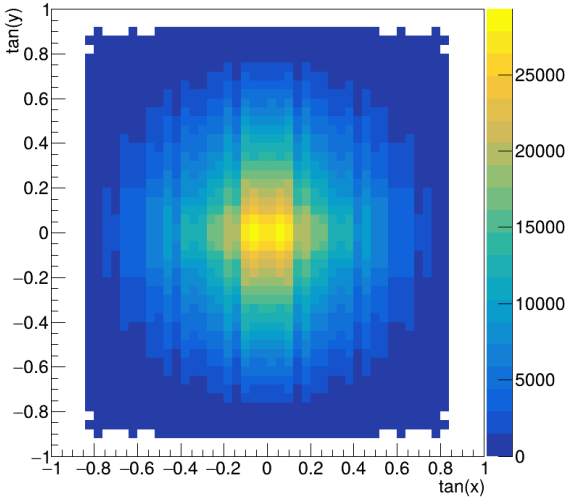
By taking the recorded flux and rotating multiple times by 90º we can get an expected spectrum

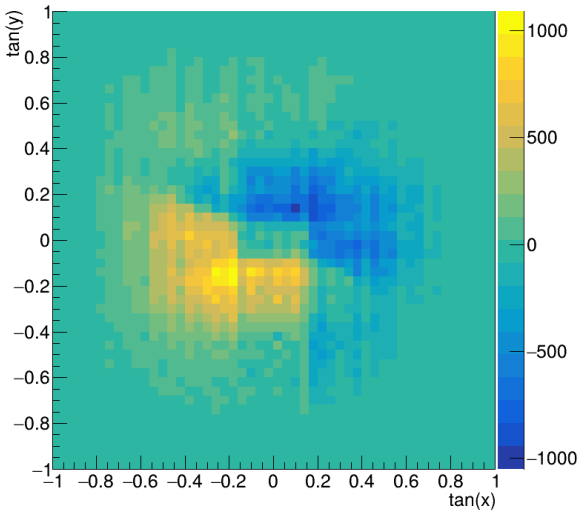
The difference between the two will highlight the difference in density of the material the muon went through











Future Work

Collapse the symmetric spectrum map into a curve and fit that to use as a model

Understand the patterns in the discard histograms

Identify the peak in phi graph

Image roman ruins in the Aljustrel mine