Muon Tomography at TRAGALDABAS

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Introduction

Tomography

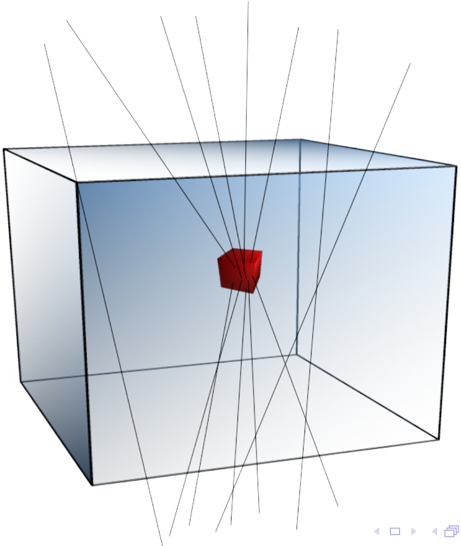
- Multiple scattering simulations.
- Reconstruction using POCA.

Tracking

- TimTrack algorithm implementation.
- Cascade identification method.

All of this using the EnsarRoot code, based on FairRoot framework.

Tomography

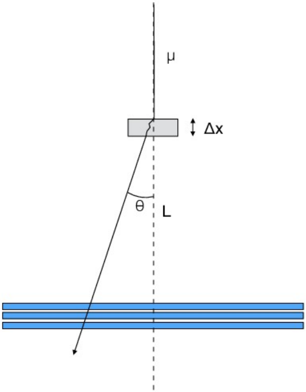


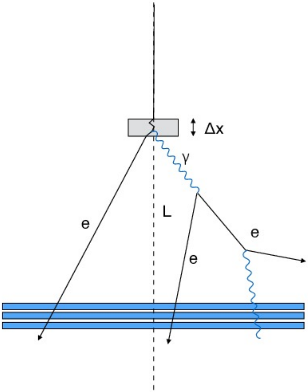
Multiple scattering

We simulated the behaviour of muons,electrons,and photons interacting to different materials with different widths at different kinetic energies.

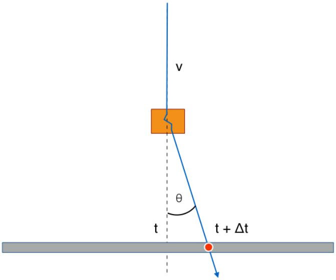
Parameters

- Materials: Lead, Iron, Uranium, Tungsten
- Widths: 1, 5, 10 and 20 cm
- Energies: From 0.1 up to 32 GeV


μ
Δx
θ
L

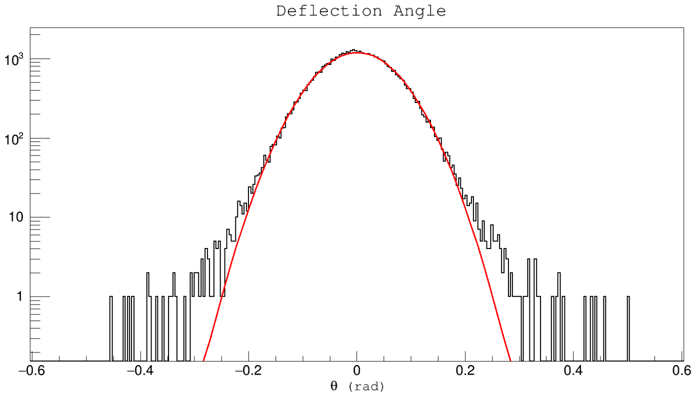

Δx
γ
L
e
e
e

Multiple scattering observables

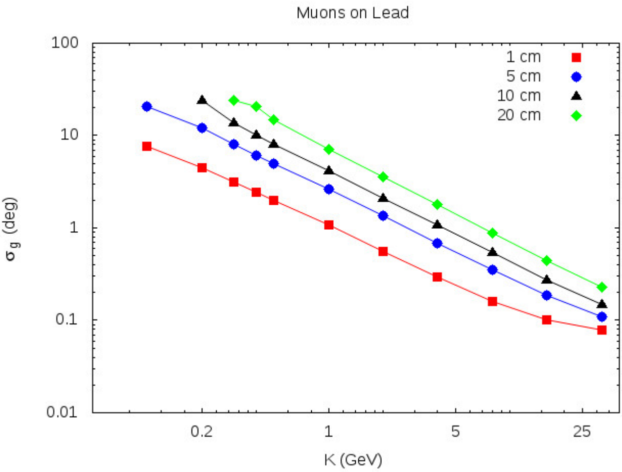


1. In our MC simulations we fired 10^6 muons.
2. We studied the θ angle that can be considered as Gaussian in the central region.
3. Time delay Δt.
4. Angular density $d(\theta)$.

Some results



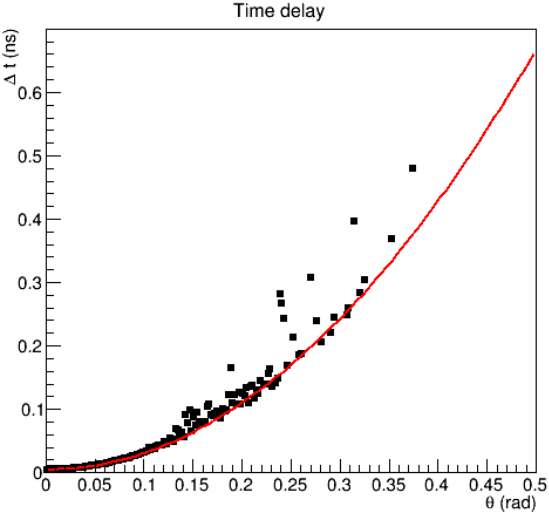
We plotted the sigma of the Gaussian fit around the central region (1.5σ)



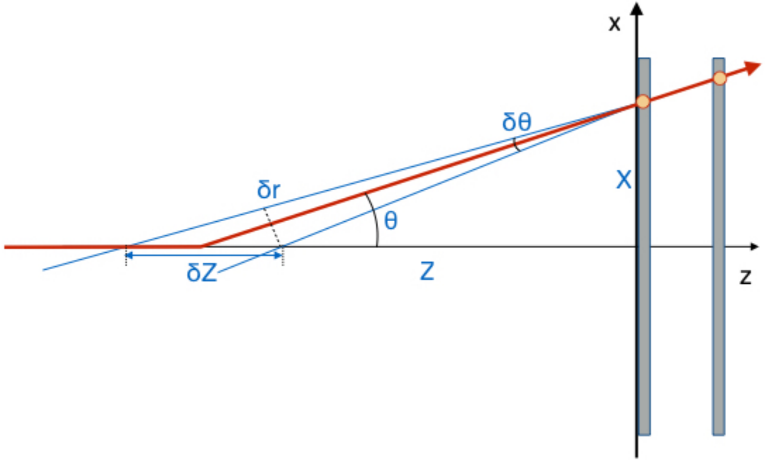
The time delay can be calculated as:

$$\Delta t = \frac{L}{v}\left(\frac{1}{\cos\theta - 1}\right) \approx \frac{L}{v} \cdot \theta^2 + \dots$$

- The time delay has a parabolic behaviour for small angles.
- This information, together with the deflection angle, can be used as a constraint.


Time delay
Δ t (ns)
0
0.1
0.2
0.3
0.4
0.5
0.6
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
θ (rad)

The angular density can be used to estimate the size of the sample space in order to obtain some spacial resolution:



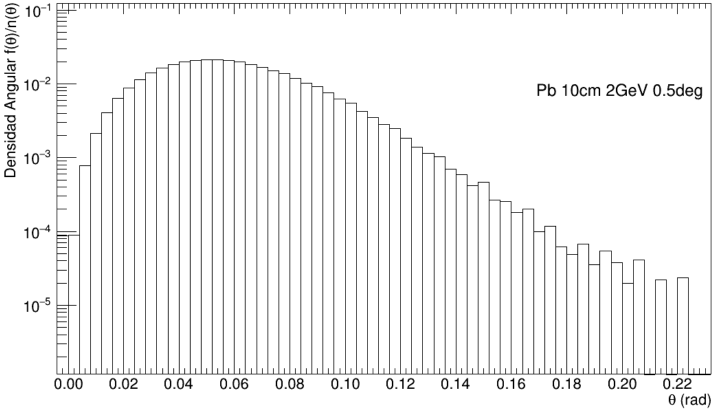
Assuming $\delta\theta << \theta$ we obtain

$$n(\theta) = \delta\theta^2 \left(1 + \frac{1}{\theta^2}\right)\left(\frac{L}{\delta Z}\right)^2$$

- This is a estimation of the number of muons that we need to obtain a certain δZ.
- The more angle, the less number of muons.
- Since we know the angular dispersion $f(\theta)$ it can be weighted with the number $n(\theta)$, obtaining the angular density:

$$d(\theta) = \frac{f(\theta)}{n(\theta)}$$

The position of the optimum value does not deppend on the angular resolution



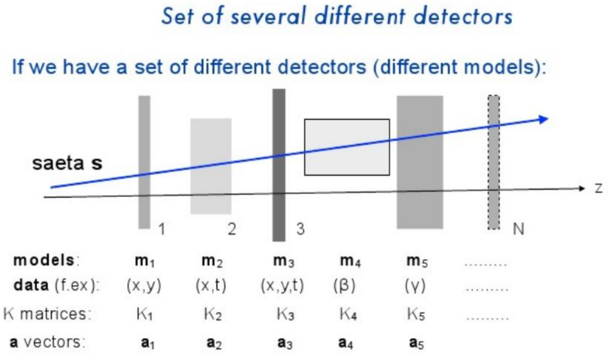
Tim Track method

- The aim of the Tim Track method is to take experimental data d, together with a model that describes them, $m(s)$, and then obtain the values of the parameters that provide the best fit to the data.
- The parameters form a vector called saeta:

$$s = (X_0, X_0', Y_0, Y_0', T_0, S)$$

- The parameters have the complete information about the propagation of the particle.

- Tim Track is based on the least squares method, therefore it can be completely described by *matrices*.
- There is only one equation to solve, the sea equation: $s = \mathcal{E} \cdot a$ (where $\mathcal{E} = K^{-1}$)
- It is general in the sense that it works for a set of different detectors.



Example

Let's consider a linear model $m(s)$ for our data $d = (x, y, t)$:

$$\begin{aligned} x &= X_0 + X' \cdot z \\ y &= Y_0 + Y' \cdot z \\ t &= T_0 + S \cdot z \end{aligned}$$

Of course, we can consider a non-linear model:

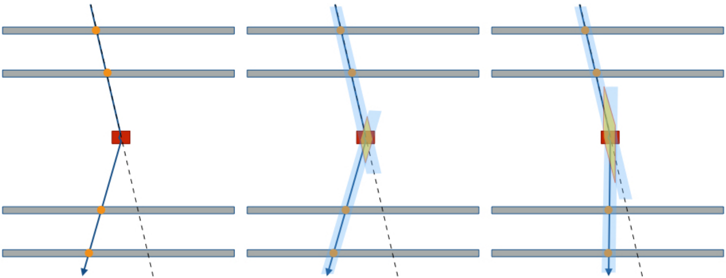
$$\begin{aligned} x &= X_0 + X' \cdot z \\ y &= Y_0 + Y' \cdot z \\ t &= T_0 + S \cdot z\sqrt{1 + X'^2 + Y'^2} \end{aligned}$$

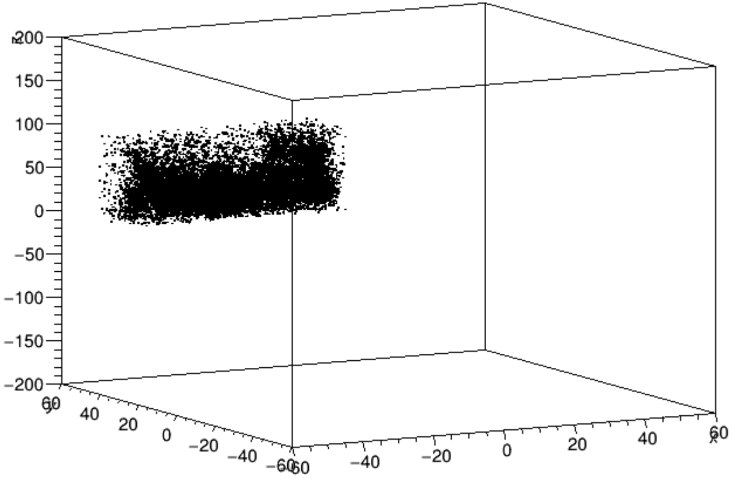
...funny, but we need to solve it by iteration.

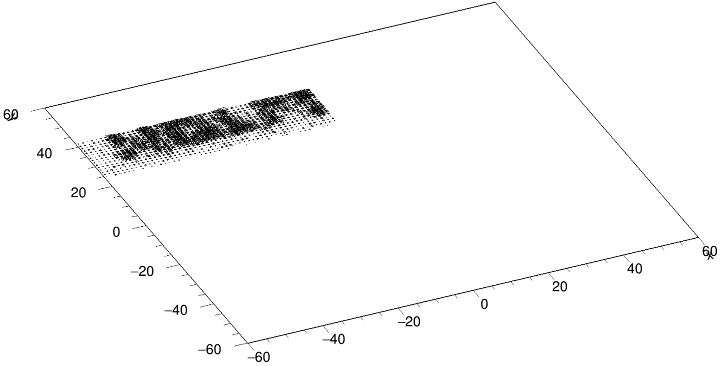
The POCA algorithm

How does it work...

1. We calculate two saetas.
2. With the saetas, we propagate two straight lines.
3. We find the Point Of Closest Approach for each line.
4. The vertex of interaction is given.




200
150
100
50
0
−50
−100
−150
−200
z
60
40
20
0
−20
−40
−60
y
−60
−40
−20
0
20
40
60
x


60
40
20
0
−20
−40
−60
−60
−40
−20
0
20
40
60

Tracking method for TRAGALDABAS: topology

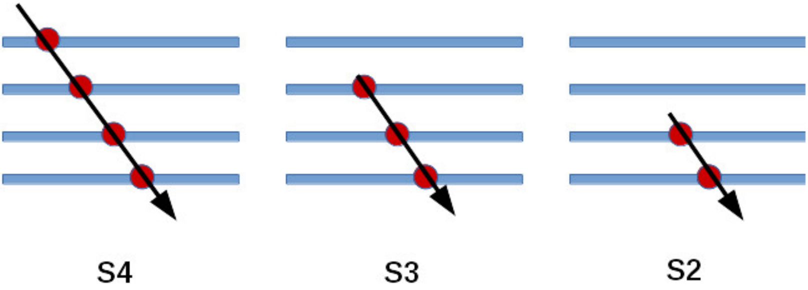
We propose a tracking method based on the Tim Track algorithm.

Definitions:

- $S2$, $S3$, $S4$: Saetas between 2, 3 or 4 planes.
- $V2$, $V3$, $V4$: Vertices. The number indicates the maximum number of hits in the largest branch.
- $C2$, $C3$, $C4$: Kinks. The number indicates the maximum number of hits in the largest branch.

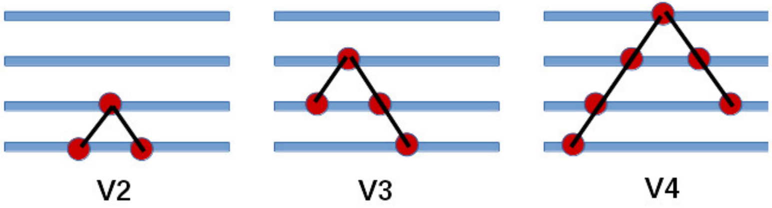
Saetas Sn

If we have four planes:

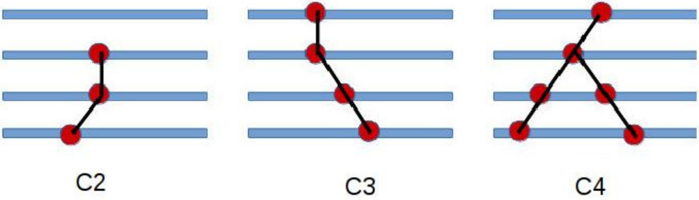


Vertices *Vn*

We can find different combinations:



Kink Cn



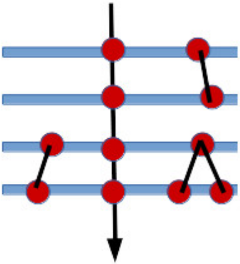
The topology of the cascade can be codified using the number of elements present:

Nomenclature

$$\begin{matrix} s_4 & s_3 & s_2 \\ v_4 & v_3 & v_2 \\ c_4 & c_3 & c_2 \end{matrix}$$

Let's see an example.

Example of codification



This cascade is codified as:

01	00	02
00	00	01
00	00	00

Summary of the codification method

- The codification indicates the number of elements present in the cascade.
- It provides an idea about its topology.
- We only consider 99 tracks per event.
- It can be found several cascades with the same topology.

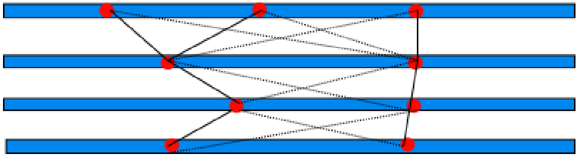
Tracking method: compatibility

How do we determine the different elements in a cascade?

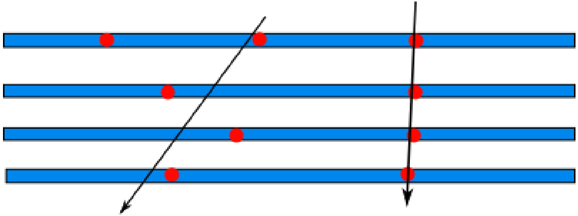
Compatibility

- We start by storing the information of all the hits registered during one event.
- Then, we construct the saetas $S2$ between two planes.
- We discard trajectories that are not consistent with the speed of light.
- After the first discrimination we proceed with $S3$ and $S4$.

We form all possible $S2$:

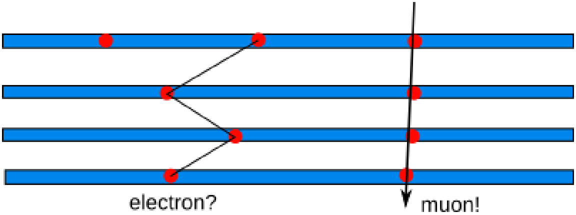


After that, we discard the $S2$ that are not compatible with c (dashed lines). Then we form the $S3$ and $S4$ with the remaining hits:



Is it possible to identify particles?

- We could use the χ^2 from the linear fit to guess what kind of particle interacts with our detector.



A not so good value of χ^2 could indicate us that the particle is an electron.

Summary and conclusions

1. The multiple scattering information, together with the TimTrack method provide a powerful tool to be used in muon tomography.
2. The POCA algorithm seems to be a good starting point to form images.
3. We need to improve the TimTrack method using a non linear model with vertex-constraints. This method could be much better than the POCA algorithm.
4. We also need to design a mechanism to filter our images.
5. The tracking method should be tested using real data from TRAGALDABAS.