Design and simulation of a Muon Tomographer

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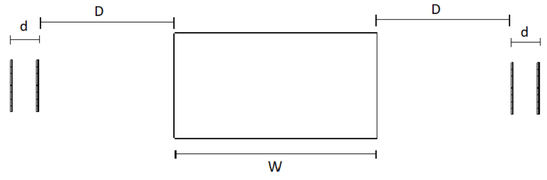
Goals

- Implement a GEANT4 [1] simulation of a prototype muon tomographer based on new and cost-affordable technology [2] (plastic scintillators and silicon photomultipliers) [2].
- Discriminate materials (e.g. air, H_2O, Al, concrete, Fe, Pb) by measuring the absorption and scattering angle after passing an object.
- Optimize the geometry and angular resolution of experimental setup.

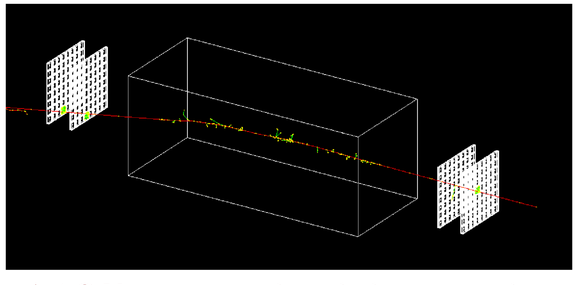
Detector design

Tomographer: two detectors each made of two planes. The detectors are placed before and after the analyzed object. Each plane is an array of 8×8 detection units (plastic scintillator $5 \times 5 \times 1$ cm^3 + SiPM 6×6 mm^2). Active area: 0.16 m^2. Each sensor is isolated inside an aluminum case to reach a better accuracy.



Geometrical parameters to optimize.

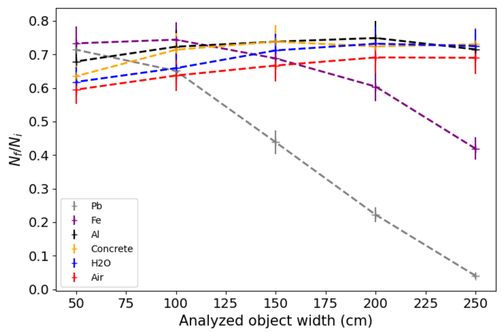
GEANT4 Simulation



A 4 GeV muon event through the tomographer. Red lines: muons + electrons, green: photons.

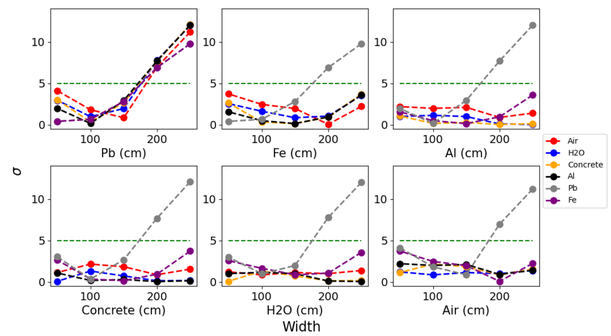
Absorption

We used the ratio between the incoming muons $N_i(\phi, \theta)$ and those that have traversed the structure $N_f(\phi, \theta)$ measured with the detectors.



Ratio between counts before N_i and after N_f the object versus its width.

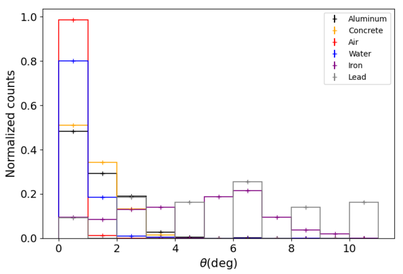
We can differentiate Pb and Fe for certain widths. Al, concrete, water and air ratios are compatible within the statistical error.



Number of σs versus the width for each material compared. Green line: 5σ.

Scattering Angle

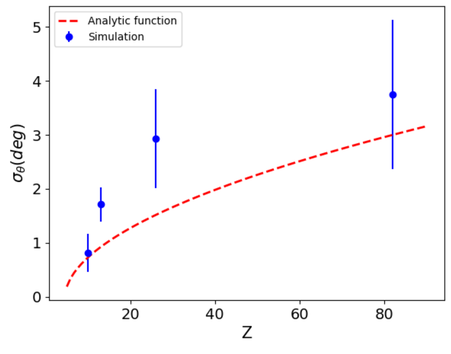
We identified the muon hit positions by the emitted scintillation photons in each plane, calculated a vector that joins both sensors and used a vector before and another after the block.
The distribution of the lighter materials are centered close to zero degrees.



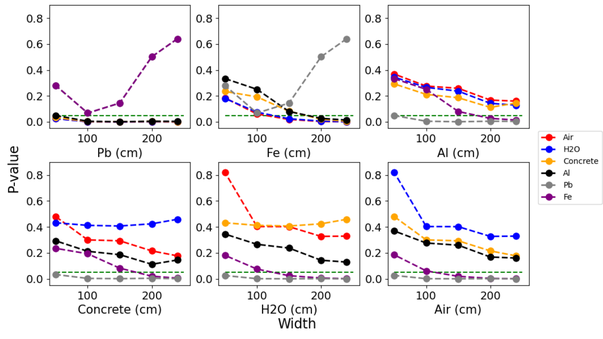
Scattering angle distribution for different materials.

Results

Best geometrical parameters to differentiate materials $d = 20$ cm and $D = 100$ for the absorption method.
We can identify Pb at 5 σ when $W = 150cm$ and Fe for $W = 250cm$.
P-value between angular distributions of Pb and Al is 0.005, but for Pb and Fe 0.502.
Exposure time needed: 3 hours for 1000 events at 1 ° of angular resolution for $D = 280$ cm.



Mean scattering angle for the analytic function (red) and σ of the Gaussian fit to the simulated scattering angle distribution (blue).



P-value from the comparison between scattering angle distributions. Green line: p-value = 0.05.

References

[1] S. Agostinelli and et. al.
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[2] S. N. Axani and et. al.
The CosmicWatch Desktop Muon Detector: a self-contained, pocket sized particle detector.
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[3] L. Bonechi and et. al.
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