Fast Simulation and Design of Muon Scattering Tomography System

Jiahui Chen[1,2], Huiling Li[2], LI, Yiyue Li[2]

[1]University of JiNan,

[2]Shandong Institute of advanced technology,[3]Shandong University

1. Background

Muon scattering tomography (MST) using cosmic ray muons of strong penetrating power as probes, is a non-destructive technique explored recently to image dense objects, such as nuclear materials.

In this work, a toy Monte Carlo tool is developed to simulate multiple scattering process of muons and spatial resolution of tracking detectors in MST system efficiently. The trackers of the MST system are to be built with plastic scintillating fibers, of which the track angular resolution is obtained from Kalman Filter algorithm. The well-known point of closest approach (PoCA) is applied to evaluate imaging performance of the MST system for different materials.

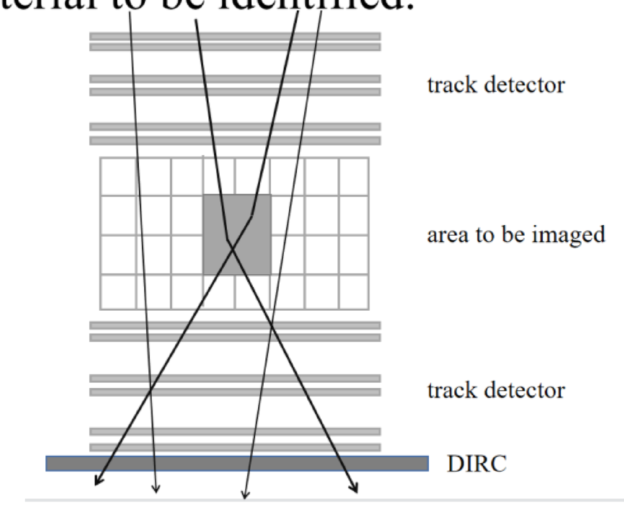
2. Theory

When cosmic ray muon passes through the track detector with plastic scintillating fibers , motion direction is deflected with multiple scattering. The nonprojected deflection angular distributions are given approximately by

$$\frac{1}{2\pi\theta_0^2}\exp\left(-\frac{\theta}{2\theta_0^2}\right)d\Omega$$

2. Theory

PoCA algorithm uses the track detector to obtain the angle deflection of muon passing through the material to be identified.



Angle deflection helps to calculate the scattering density, which is related to the atomic number of the material. The scattering density is defined as

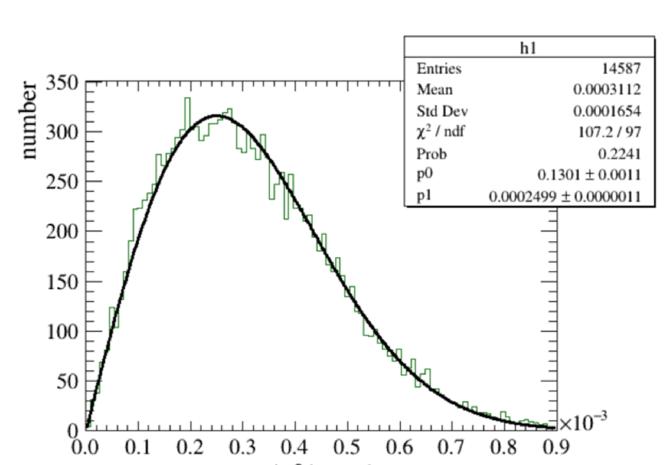
$$\lambda = \left(\frac{13.6}{cp_0}\right)^2\frac{1}{X_0}$$

p_0 is established as a nominal muon momentum. X_0 is radiation length of material.

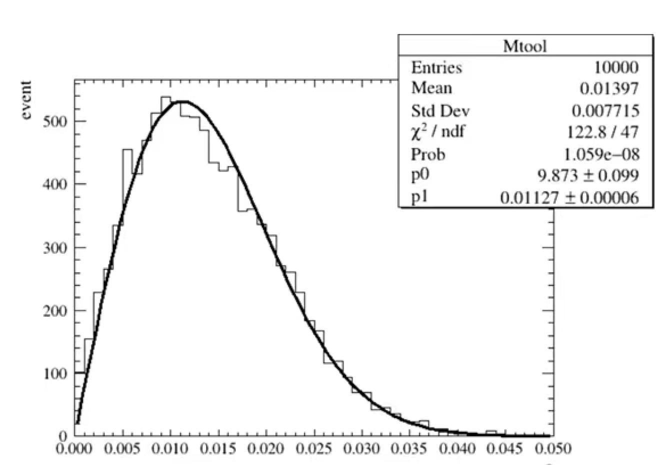
3.Result

1.Simulation

Direction deflection distribution of muon passing through track detector is shown in (a). The track detector is a plastic flash optical fiber detector. Detector thickness is 0.1 cm. Radiation length of detector is $42cm$ and multiple scattering angle is $2.439\times10^{-4}rad$.



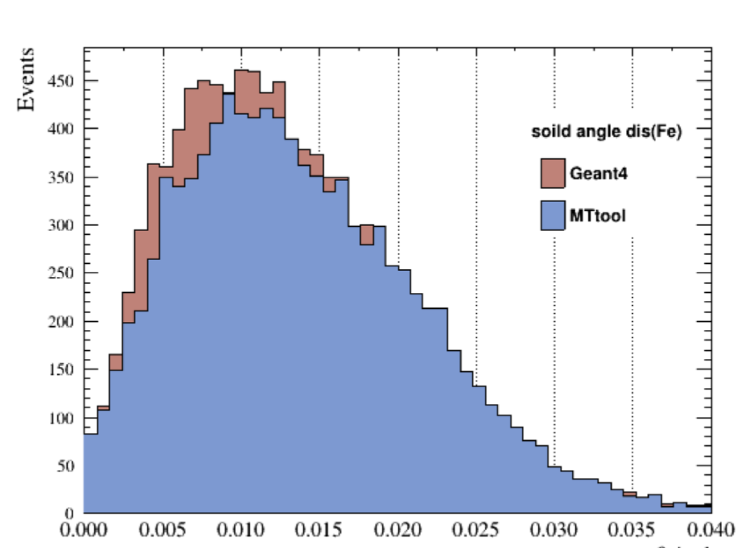
(a)



(b)

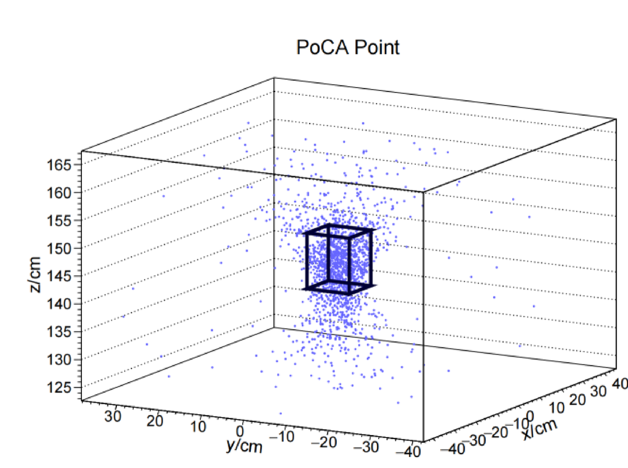
Direction deflection distribution of muon passing through track detector iron block($10\times10\times10cm^3$) is shown in (b).

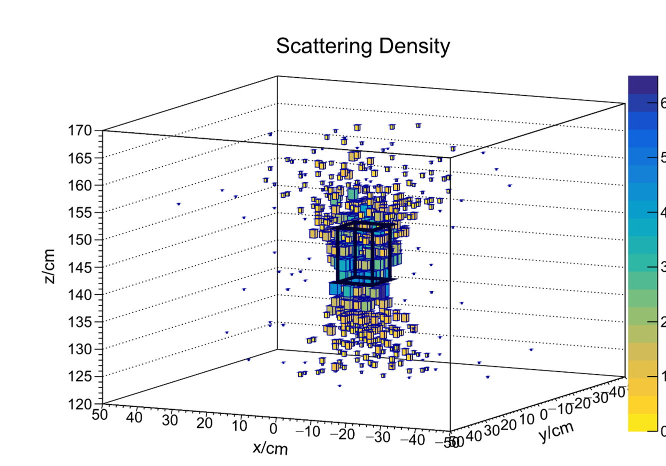
The deflection angle distribution simulated by the fast simulation tool is similar to simulation of GEANT4.



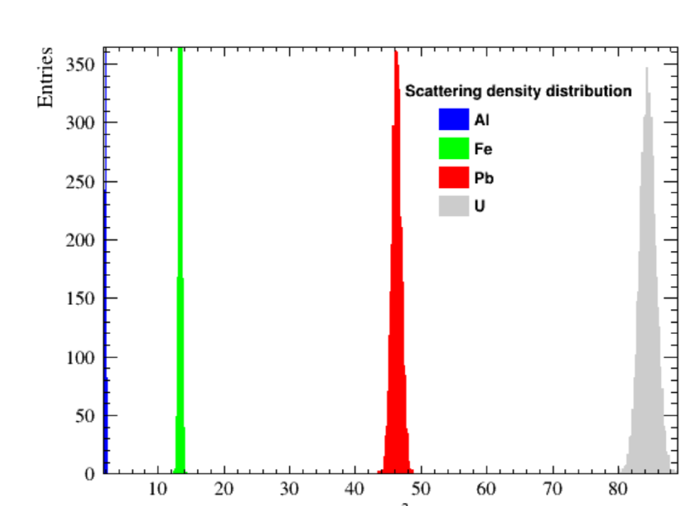
2. Muon Tomography

PoCA algorithm is used to identify the iron block. The incident and outgoing information of muon is obtained by using the simulated data. The distribution of poca points and scattering density can be calculated from the muon track information.





1000000 muons which were simulated by this fast tool were used to identify Al, Fe, Pb and U cube. Scattering density estimates were calculated for each cube, and this experiment was repeated 5,000 times. For a given cube, estimation of scattering density is underlying approximately Gaussian scattering distribution. The scattering density distribution illustrates the separability of these materials



4. Conclusion and Outlook

This fast full-chain simulation tool can preliminarily simulate cosmic ray muon tracks and identify different materials. It can be used as a tool to realize muon scattering tomography.

In the future, this tool can be used to explore the influence of detector spatial resolution and layout on imaging performance. To improve MST identification ability on dense materials, a Cherenkov detector will be introduced to measure muon momentum which is advanced to the accuracy of PoCA algorithm imaging.

Reference

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