**Improvement of Material Discrimination Using Muon Momenta in MST**

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**Abstract**

- Muons deviate while traversing through the matter due to multiple Coulomb scattering (mcs). Muon Scattering Tomography (MST) exploits the mcs phenomenon for imaging target materials.
- Interesting applications: Imaging cargo-containers, monitoring nuclear waste containers, identifying fissile materials, etc.
- MST simulations have been performed with GEANT4, reconstructed images have been analyzed with t-test and Pattern Recognition Method (PRM).
- An analytical method has been followed to predict incoming momenta of muons and improve the imaging with MST.

**MST Principle**

The deviation angle projected on a plane passing through the incoming muon direction has a distribution which is approximately Gaussian for particles of the same momentum, with zero mean and a root-mean-square (σ) according to the formula:

\[
\frac{dN}{d\theta} = \frac{1}{\sqrt{2\pi}\sigma^2} e^{-\frac{\theta^2}{2\sigma^2}}
\]

\(X_0 = \frac{716.4A}{\rho Z(Z+1)n^{2/3}}\)

\(p = \text{Momentum} \quad X = \text{Radiation Length} \quad A = \text{Atomic Mass} \quad Z = \text{Atomic Number} \quad \rho = \text{Density}\)

**Effect of Momentum**

- Cosmic-ray muon momenta distribution peaks around 3-4 GeV.
- Momentum of incoming muon affects mcs significantly.
- The weighting parameter S depends on scattering angles \(\theta\), true value of momentum \(p\).
- Nominal weighting momentum: \(p_0\)
- Number of entries to the pixels: \(r\)
- Without any momenta information

\[S = \sum_{k=1}^{n} \theta_k \frac{p_k}{p_0}\]

\[S = \sum_{k=1}^{n} t_k \frac{p_k}{p_0}\]

\[S = \sum_{k=1}^{n} \rho_k \frac{p_k}{p_0}\]

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Several techniques to obtain \(p_0\):
- Time of Flight information.
- Spectrometer with alternate layers of known target.
- An alternate approach has been considered, where with min. Scattering threshold momenta range is obtained.
- For 10 mrad threshold the range is between 0-3000 MeV. For Random value of \(p_0\) generated from fitted function.
- For events < 10 mrad, \(p_0\) values are used to generate the S-map.
- A range-fit approach with scattering angle and \(\rho^2\) fit of the track with incoming muon momentum is underway.

**Summary**

- MST simulation has been done in GEANT4 to discriminate high-Z materials.
- PRM has been used to learn from known samples of given size and to recognize targets in unknown region of interest.
- The discrimination has also been done based on a t-test.
- Cosmic-ray muon momentum has been studied to improve imaging results. A minimum scattering threshold is applied to reduce background noise.
- An analytical fit-based approach has been followed to estimate muon momenta.
- The obtained results have been compared with images with true momenta, improvement needed to reconstruction muon momenta.
- Work is going on to exploit the scattering angle vs. momentum range relationship to improve results.

**Acknowledgement**

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**References**


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**MST Setup in GEANT4**

(a) GEANT4 Simulation setup for material discrimination with 6 detectors (b) The setup with a slowing slab of concrete and additional detection layer

![MST Setup in GEANT4](image)

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