Simulations and Track Reconstruction for Muon Tomography using Resistive Plate Chambers

R. Sehgal[1,*], V. K. S. Kashyap[1], S. T. Sehgal[1], A. Bhattacharyya[1], P. Kanavi[2], I. Kanungo[3], V. Singh[3], G. Kekre[3], A. Jindal[4], A. Jain[4], L. M. Pant[1] & Alok Saxena[1]
[1]*Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085, INDIA,*
[2]*PG Department of Physics, Basaveshwar Science College,Bagalkot, Karnataka,*
[3]*Department of Physics, Indian Institute of Technology, Roorkee, Uttarakhand,*
[4]*Amity Institute of Applied Science, Amity University, Noida,*
** email: sc.ramansehgal@gmail.com*

Introduction : Highly penetrating cosmic ray muons shower the Earth at the rate of 10,000 m^{-2} min^{-1} at sea level. The mean energy of muons at sea level is about 3–4 GeV, sufficient to penetrate several meters of rock(Avg ρ ≈ 2.6). Due to their highly penetrating characteristics, they can be used for radiographic imaging of dense material. Using this freely available particle to detect the high Z material is very useful for homeland security application related to Shielded Nuclear Materials (SNMs). In this paper we will show the result of Geant4 [1] simulations to differentiate between different Z material using cosmic muons of 2 GeV. We present here, how Resistive Plate Chambers (RPCs), can be used to generate the muon tracks.

Principle of Muon Tomography : Cosmic ray muon tomography is based on the interaction of charged particles with matter by multiple coulomb scattering. The width of distribution is approximated as

$$\sigma_\Theta = \frac{13.6MeV}{\beta cp}\sqrt{\frac{L}{X_0}}\left[1 + 0.038 ln\left(\frac{L}{X_0}\right)\right]$$

where ***p*** is particle momentum in MeV/c and ***βc*** is its velocity and X_0 is radiation length. The radiation length decrease as atomic number Z increases and Θ_0 increases accordingly. By tracking the scattering angles of individual muon, the scattering material can be mapped, and different Z materials (Al, Fe, Pb etc) can be distinguished.

Monte Carlo Simulations: In order to study the effect on muon scattering angle for different materials, we did Geant4 simulations using cosmic muons of 2 GeV and embedding a scattering volume of 10 cm x 10 cm x 10 cm of Al, Fe and Pb blocks. The scattering angle of muons from different materials largely depend on the atomic number Z. Fig.1, below shows the simulated scattering angle distribution for different materials for 10^5 events.

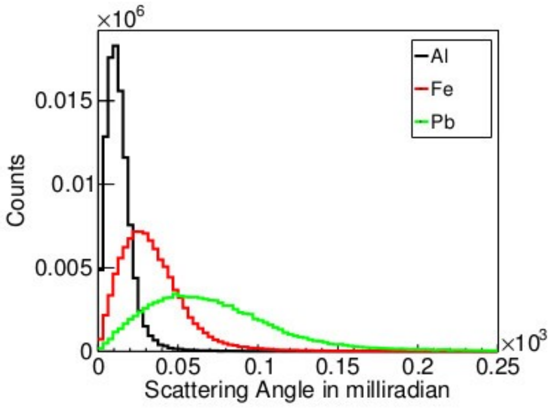

Fig. 1 : Scattering angle distribution for different materials

Fig. 2, below shows the standard deviation of scattering angle as the function of thickness for different materials (Al, Fe and Pb). These two figures clearly indicate the possibility to distinguish between high Z material by observing the scattering angle distribution.

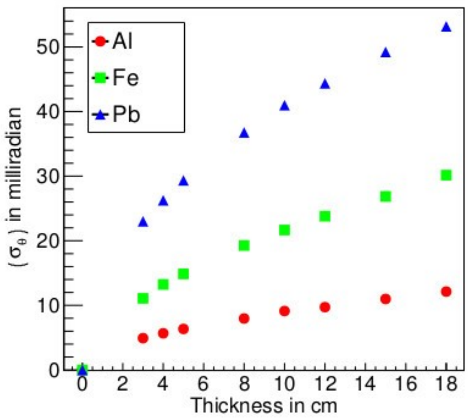

Fig. 2 : Standard deviation of scattering angle from materials of different thickness

Image Reconstruction : Muon tomography involves a very different image reconstruction technique. Conventional tomography techniques uses concept of absorption of man made penetrating radiation to reconstruct the image. In contrast, muon tomography relies on the production of muons by cosmic rays without any human intervention. Instead of absorption it relies on the extent of deflection in matter in the process of multiple Coulomb Scattering. Here image reconstruction depends on the measurement of incoming and outgoing tracks for individual muons. Various reconstruction algorithm like Point of Closest Approach (POCA), Expectation Maximization (EM)[2] exists, which takes the incoming and outgoing track information and tries to reconstruct the 3D image. So the first step in the image reconstruction process is to get the muon tracks, hence we need a position sensitive muon detector. We have used glass Resistive Plate Chambers for detecting the cosmic muon.

Track Reconstruction with RPCs : For large area coverages, to start with, two glass RPCs (1m x1m), separated by a distance of 1.2 metres, were employed in the cosmic hodoscope at NPD-BARC for detecting the cosmic muons through X,Y coordinated in each RPC. RPCs are highly efficient muon detectors and provide a fast timing signal [3]. Each RPC is having two readout planes, each having 32 strips made from Cu clad G-10 sheets [4], which are orthogonal to each other. So when a muon passes through the RPC , we get signal in readout strips in X and Y plane, which will finally be mapped to XY coordinates and Z position corresponds to the location of detector in vertical direction. For signal processing CMS RPC based electronics was employed which were fed to CAEN TDCs via twisted pair cables. So overall we get a 3D point in coordinate space with origin at the centre of cosmic hodoscope [5], which is required to generate the muon track. These muon tracks will be used as input for image reconstruction process. When a muon passes through the detector, more than one strip can fire in each plane. In that case selecting a correct coordinate in each plane needs intelligent algorithm. So as a first step towards track reconstruction we are considering only those events where only one strip fires in each plane in both the detectors. Hence we get one pixel in each detector, and the center of these pixels gives the required track. Fig. 3, below show the tracks generated using cosmic muons detected in RPCs, which are validated with a signal from the scintillator paddles at the top and bottom of the cosmic hodoscope covering the two RPCs (RPC1 & RPC2).

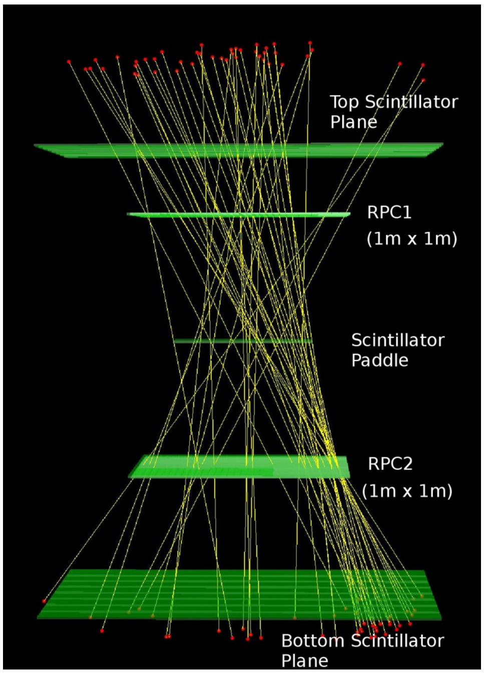

Fig. 3 : Validated muon tracks using RPCs in the cosmic hodoscope

Outlook : Muon tomography is very promising technique for the detection of high Z materials. We plan to have 3 RPCs for identifying the incoming muon track and 3 RPCs for identifying the scattered muon track with suitable scaterrers (Al, Fe and Pb) in between. Work is also in progress on development and optimization of reconstruction algorithms to identify the scatterring object under test.

References :

[1] http://geant4.cern.ch/
[2] L.J. Schultz, et al.,IEEE trans. on image process. Vol. 16, Aug 2007, p. 1985-1993
[3] G.Battistoni et al., NIMA 202, 459 (1982)
[4] S. T. Sehgal et al., Proceedings of the DAE Symp. on Nucl. Phys. 59, 922 (2014)
[5]C Yadav et al, Proceedings of the DAE Symp. on Nucl. Phys. 56, 1066 (2011)