Simulations and detector development for Muon Tomography with RPCs for identifying high Z materials

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Every minute the earth is bombarded with, about 10,000 muons on every square meter of area. This has been found as a promising way [1] to use this natural source of radiation to detect terrorist attempts to smuggle uranium or plutonium into the country. The technique also detects lead and tungsten, which could be used to shield the gamma rays emitted by nuclear materials - or other radioactive materials - in order to elude detection. This new technique uses the fact that muons are more strongly deflected, or scattered, by nuclear or gamma-ray-shielding materials than they are by materials such as plastic, glass, and aluminum. The muon tomography scanner plots the incoming muons' initial trajectories, then registers all outgoing muons on the opposite side and correlates them to the first measurements. The muon scan takes about a minute and poses no health hazard. The advantages of the technique are that it is passive, does not deliver any radiation dose above background, selective to high-Z dense materials, and is suitable for large amount of shielding.

With the above objectivity in mind, a new programme of Muon Tomography of high Z materials using RPC as the active detector element, has been proposed in the 12th plan which also provided linkages with our existing projects of assembling and characterizing of muon detectors such as RPCs for the CMS experiment [2], in which they are employed in the muon stations of the calorimeter and are crucial for providing the high level muon trigger and identifying the bunch crossing in LHC, with efficiency greater than 95% and excellent time resolution (~ 2 ns) .

It is planned to construct 1 m x 1 m RPCs using glass gas-gaps. The glass gas-gap (1m x 1m) coated with graphite (resistivity ~ 100's of kΩ /) have recently arrived in the lab., and their performance is under test, the results of which shall be discussed during the symposium. Fig. 1 shows a typical glass gas-gap kept on a transportation trolley. These gas-gaps along with gas flow pipes and read out planes shall be configured into RPCs. Six such RPCs shall be employed for the muon tomography project. Three of the top RPC layers will detect the path of the incoming muon and the remaining three at the bottom will detect the scattered muon. The scatterer (Al, Fe, Pb/U) shall be placed in between, in the newly commissioned cosmic rack. If required, double gas-gaps may be employed to enhance the signal quality, which may then need about 12 of glass gas-gaps forming six double layered RPCs. 32 channels, Cu read outs strips with a width of 28 mm at a pitch of 2 mm covering an active area of 1m x 1m, have also been designed and fabricated. These read out strips shall be capacitively coupled on the outside of the glass gas-gaps, on either side to provide a positive and negative signal, depending on the configuration of the applied HV. Each RPC will thus have 64 read out channels (32 each in X and Y). For six such RPCs we will have a total of 384 channels of electronics to be configured which will be read through VME based DAQ having 3 x 128 channel multihit TDCs with a resolution of 25 ps. The trigger for such events will be provided by the existing cosmic hodoscope consisting of plastic scintillators kept at top and bottom in the cosmic rack, separated by a distance of 2100 cm.

Fig 2, shows the initial simulations done with GEANT4 [2] for normal incident cosmic muons of 1 GeV, passing through three different scattering media, from left to right, viz. Iron, Lead and Uranium. The scattering objects were modeled as 10cm x 10cm x 10cm solid blocks. Each of RPC detectors is taken to be consisting of a gas gap formed by two 2 mm thick glass sheets separated by 2 mm of spacers, inside which the ionizing gas medium, R134a ($C_2H_2F_4$)

was chosen at atmospheric pressure, the conditions at which RPCs are normally operated.

Fig. 1 A typical glass gas-gap (1m x 1m) with graphite coating to be configured into an RPC for muon tomography

The distance between each RPC is kept at 30 cm, as has been designed in the existing cosmic rack in the lab. As the muons pass through the high Z scattering medium, they get deflected from their incident trajectory due to multiple Coulomb scattering. The angular scattering distribution of the muons can be approximated as Gaussian [3] :

$$f_\theta(\theta) \cong \frac{1}{\sqrt{2\pi}\sigma_\theta}\exp\left(-\frac{\theta^2}{2\sigma_\theta{}^2}\right)$$

with zero mean and standard deviation given by,

$$\sigma_\theta \cong \frac{15}{\beta cp}\sqrt{\frac{L}{L_{rad}}}$$

where, L is the depth of the material and L_{rad} is the radiation length of the material. In Fig. 2, the first three RPCs would be employed to track the incoming muon and the bottom three RPCs will track the scattered muon. These simulations will be subsequently generalized incorporating the angular distribution if the incident muons and their energy spectrum. The simulated tracks (the x, y, z coordinates) on each RPC detector will then be modulated by the detector position resolution. The data thus obtained will then be used to reconstruct the image back by using the point of closest approach (POCA) algorithm. The simulations clearly reveal the potential of these measurements, where the scattering material can be easily identified depending on its "Z".

The advantage with such a system is that it can be configured to larger areas with a reasonable cost, has ability to run for years without maintenance and can be operated in an open environment with non expert operators.

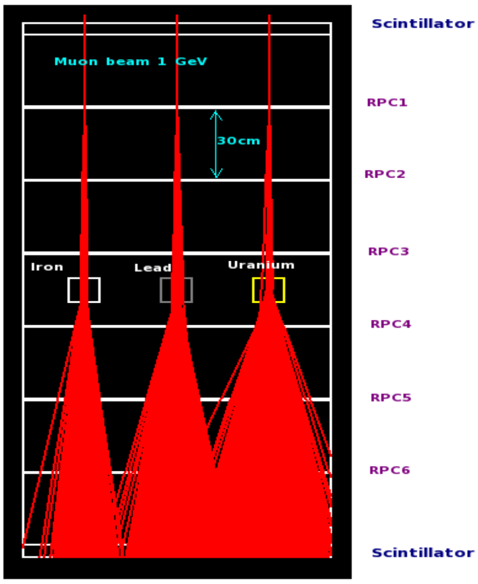

Fig. 2 GEANT-4 simulations of the Muon Tomography system for a normal incident monoenergetic stream of muons

References

[1] Borozdin, K. N., Hogan, G. E., Morris, et al., Nature, **422,** 277 (2003).

[2] http://geant4.cern.ch/

[3] L.J. Schultz, et al., Nucl. Instr. and Meth. A 519, 2004, p. 687