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A simulation tool for MRPC telescopes of the EEE project

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ABSTRACT: The Extreme Energy Events (EEE) Project is mainly devoted to the study of the secondary cosmic ray radiation by using muon tracker telescopes made of three Multigap Resistive Plate Chambers (MRPC). The experiment consists of a network of MRPC telescopes mainly distributed throughout Italy, hosted in different building structures pertaining to high schools, universities and research centers. Therefore, the possibility to take into account the effects of these structures on collected data is important to carry on the large physics programme of the project. A simulation tool, based on GEANT4 by using GEMC framework, has been implemented to take into account the muons interaction with EEE telescopes and to estimate the effects of the structures surrounding the experimental apparata on data. Dedicated event generator producing realistic muon distribution, detailed geometry and microscopic behavior of MRPCs have been included to produce experimental-like data. The comparison between simulated and experimental data, and the estimation of detector resolutions will be presented and discussed.

KEYWORDS: Only keywords from JINST's keywords list please

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Contents

1 Introduction

The EEE experiment[1] is a project with educational and research purposes of the *"Museo Storico della Fisica e Centro Studi e Ricerche Enrico Fermi"*[2] in collaboration with *"Istituto Nazionale di Fisica Nucleare"* (INFN) [3], and *"Ministero dell'Università, dell'Istruzione e della Ricerca"* (MIUR) and CERN[4]. The experiment consists of a network of MPRC-based telescopes, located mainly in Italian High Schools, at CERN and in some INFN sections, covering an area of about 0.3×10^6 km^2. The experiment, after 5 runs of data tacking, collected more than 100 billion of candidate muon tracks offering a large scientific programme: extensive air shower investigation via coincidence between different telescope [5, 6], the investigation of Forbush decrease[7], monitoring of long-term stability of civil structures [8] etc. To fully understand the data we need a precise knowledge of the effect on the measurements of the different structures holding the detectors, and of the different working setup. For these reasons, we implemented a simulation tool, by using the GEMC (GEant4 MonteCarlo) framework, in order to be able to describe the behaviour of a single telescope to estimate angular and absolute efficiency, and the absolute single muon rates.

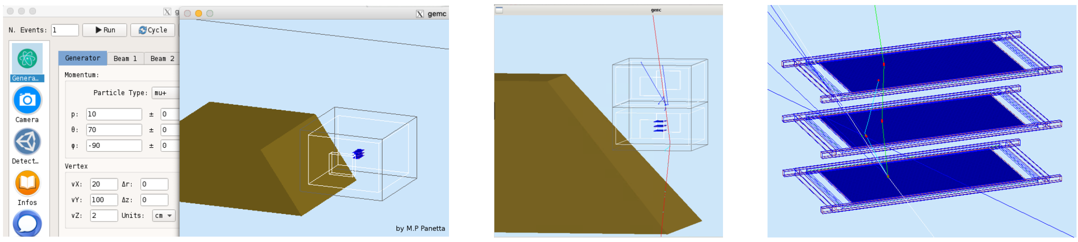
In the present paper, we describe the simulation tool and show some interesting results obtained with the simulated data like the reproduction of the experimental condition of a telescope working in a laboratory with a singular structure and position of the building, the estimation of the detector efficiency and the effect of the material surrounding the telescope on the ability of the detector to measure the right direction of muons; the comparison with the experimental and simulated polar angle distribution will be also presented and discussed.

2 The EEE Detectors

EEE telescope consists of three Multigap Resistive Plate Chambers (MRPCs) with a 80×160 cm^2 active area, assembled - in the most common configuration - in a three MRPC stack with 50 cm distance between chambers. Each chamber is segmented by 24 copper strips (180 cm × 2.5 cm spaced by 7 mm), which collect the charge signals produced in the gas (mixture of $C_2F_4H_2$ (98%) and SF_6 (2%)) of the chamber by the crossing of charged particles. The chamber configuration provides us two coordinates for each hit: one is given by the coordinate of the strip or, in the case of contiguous strips, by averaging their positions, while the other one is obtained by the time difference of the signals at the opposite edges of the strip (measured using TDCs with 100ps resolution). Details on the detector see Ref. [9] and reference therein.

3 The Simulation Tool

This simulation tool is based on the GEMC [10] framework providing user-defined geometry and hit description. Detector and building structures are implemented by using the standard GEANT volume description. The program handles multiple input/output format and provides a graphical interface to visualize the detector and the hits in active and passive volumes (see figure 1).



N. Events: 1

Momentum:

Particle Type: mu+

p: 10 ± 0

θ: 70 ± 0

φ: -90 ± 0

Vertex

vX: 20 Δr: 0

vY: 100 Δz: 0

vZ: 2 Units: cm

Figure 1. GEMC graphical interface (left panel); details of a muon interaction with the structure of two rooms (box of 30 cm thick concrete) and the detector (center panel), and a detail of the telescope (right panel).

GEMC supports the use of external event generator, with data in lund format, and it is provided with an internal event generator based on the model described in Ref.[11] to generate the single-muon distribution. The used parametrization is able to well reproduce the existing measurements [11]. The absolute muon flux normalization, used in the simulation, is the one reported in the PDG [12] (1.06 cm^{-2} min^{-1}).

The MRPC response was parametrized basing on the measured performance of the chambers [9]. In particular, the algorithm mimicking the avalanche propagation in the gas is effectively described by a cone with vertex generated in the upper layer interaction point of the chamber and developping downwards to the bottom one. The room hosting the detector is parameterized by a customizable box of concrete, of course more complicated geometries are customizable too, as one can see in left and central panel of figure 1.

The information generated by GEMC and necessary to reconstruct the muon track is: the total number of hits for each chamber (at least one); the coordinates of the strips giving signals; the signal time from the generation point to the edges of the chamber. By using this information the reconstruction program is able to write data in the experimental format.The comparison between the reconstructed and the generated events shows good agreement proving the correct operation of the reconstruction algorithms. The reconstruction code efficiency is found higher than 99%.

4 Simulation results

In this section we report a study on the validation of the simulation by comparing the simulated polar angle distribution corrected by the experimental efficiency and the experimental one, and two investigations about the effects of the material surrounding the telescope on the collected data.

4.1 Experimental-Simulated Data Comparison

In order to compare the simulated and experimental data, the detector efficiency has to be carefully estimated. Therefore, we choose a telescope selected for its stable working condition and negligible shielding of the hosting room (telescope TORI-03 located in a high school in Turin) to calculate the efficiency and to compare the simulated polar angle distribution and the experimental one. The efficiency of the telescope is performed by mapping each chamber in 24×20 sectors (X×Y directions), and then by estimating for each bidimensional interval the tracking efficiency and the counting efficiency, assuming no correlation between the two quantities.

We define the tracking efficiency as the ratio between the map of the missing hits (geometrical position with no hit, determined by using the information hit from the other two chambers) and the map of the good hits (each hit of the chambers is very close to the reconstructed track).

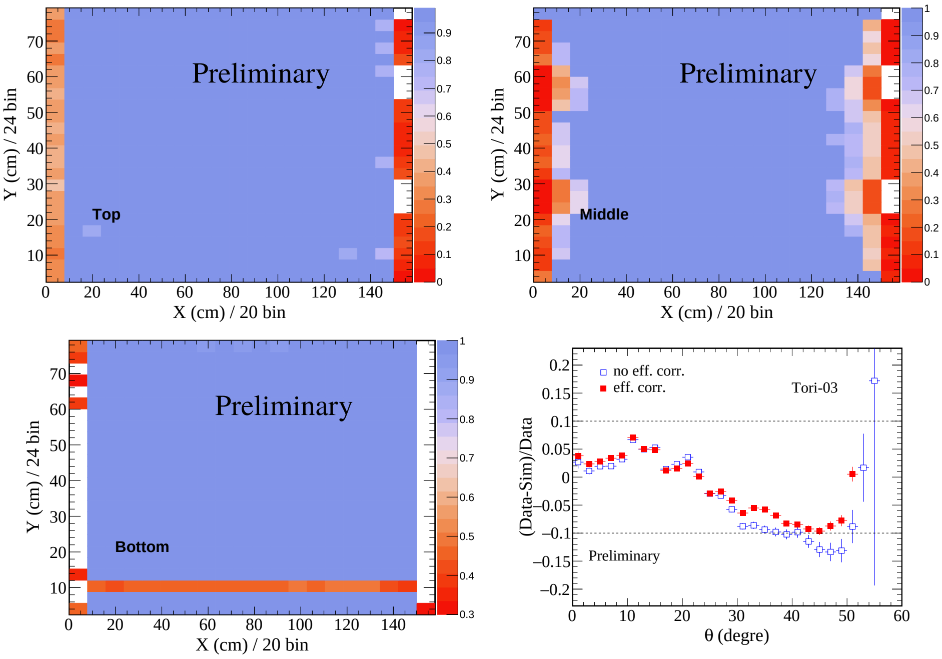


Figure 2. Global efficiency map for top, middle and bottom chamber of TORI-03 telescope (top-left, top-right and bottom-left respectively. Bottom-right panel the experimental-simulation data ratio normalized to experimental data of the polar angle distribution, without (empty circles) and (full circles) with efficiency correction.

The counting efficiency is obtained by mapping each chamber with the same binning used for the tracking efficiency, by filling these 2D histograms with all hits without any condition, and after correcting the distributions for geometric acceptance by normalizing each bin to average maximum rate.

The global efficiency map, for each chamber, is obtained as the product of the tracking and counting efficiency maps of the same chamber. Details about the procedure to measure the detector efficiency are reported in Ref. [13].

The global efficiencies of the three chambers of the TORI-03 telescope are reported in figure 2 (top panels, and bottom-left panel) and these maps are used to correct the polar angle distribution of simulated events. The efficiency maps are also able to reveal the inefficiency in small spotted regions in (see top-left panel of Fig. 2), at border of the chamber where lack of gas is possible (see top-right panel of Fig. 2) and the one of a strip (see bottom-left panel of Fig. 2).

In figure 2 bottom-right panel, the ratio between experimental and simulated polar angle distribution with and without efficiency correction is reported. The efficiency corrections derived from data are able to improve the experimental-simulation agreement within 10% in the whole polar angle acceptance of the EEE telescope. The improvement of the experimental-simulation agreement at large angle proves the procedure reliability in the estimation of the telescope efficiency by using the experimental data.

4.2 Macroscopic muon absorption

By analysing the data collected by the telescope located in the Department of Physics of the University of Genoa we found an asymmetry on the counting rate between the muons coming from the valley side (N_{ϕ^+} - $0° < \phi \leq 180°$) and the ones form the mountain side (N_{ϕ^-}- $0° < \phi \leq -180°$) in the azimuthal angle distribution at polar angle $35° < \theta < 45°$. This effect is due to the radiation absorption of the mountain located at one side of the build hosting the telescope.

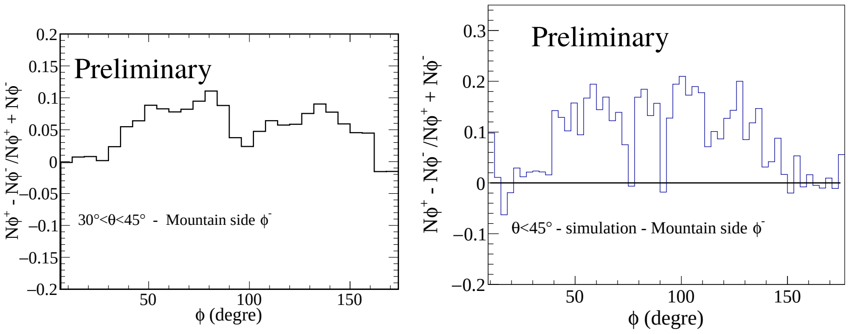


Figure 3. The azimuthal counting asymmetry for the experimental data (right panel), for a simulated data sample with a parametrized mountain in the ϕ^- side (right panel)

The distribution obtained by analysing a simulated data sample by parametrizing the mountain by placing a box of iron at a ϕ^- side of the telescope (in the same reference system of the experiment) shows an asymmetry similar to the experimental one. Of course in this attempt we use a crude parametrization of the mountain and this explains the slight difference with experimental asymmetry.

Such a qualitative study proves the simulation ability of reproducing realistic experimental condition of data taking.

4.3 Detector resolution estimation

The resolution of the muon polar angle and the hit position on the middle chamber (X and Y coordinate, where X is parallel to the strips, Y orthogonal) of the detector are estimated by analysing a simulated data sample generated with the telescope in a space containing just air and by using only muons with high energy (higher than 10 GeV). We use high energy muons to perform this estimation to make also negligible the effects of the air medium on the particle direction. We use as an estimator of the resolution the standard deviation of the distributions obtained as the difference of generated and reconstructed events.

We found a polar angle resolution lower than 1 degree, and a spatial resolution $\sigma_{\Delta X} = 1.64$ cm and $\sigma_{\Delta Y} = 1.07$ cm. These results are very promising in comparison with the experimental resolution estimation reported in Ref. [9], where the Collaboration found $\sigma_{\Delta X} = 1.47 \pm 0.23$ cm and $\sigma_{\Delta Y} = 0.92 \pm 0.02$ cm for the X and Y position, respectively. This result proves once again the potentiality of this tool for the understanding of the detector.

5 Conclusion

We presented a simulation tool to describe the EEE experiment MRPC telescope [1, 2] based on GEMC framework[10]. The event generator is implemented by using an improved version of the Gaisser parametrization of cosmic muon flux as a function of muon energy and momentum[11]. We presented a procedure to estimate the efficiency of telescope derived directly from data and we proved its reliability by comparing experimental and simulated data. Moreover, this tool is able to describe the single telescope behaviour reproducing an important quantity such as the muon polar angle direction with a precision of 10% in the whole detector acceptance. We qualitatively reproduced the behaviour of a telescope working in a building with a singular structure lying on the side of a mountain, showing the potentiality of the simulation tool. The estimation of the detector resolution with the simulation has been performed showing a good agreement with the experimental determination reported in Ref. [9].

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