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Measurement of the East-West Effect of the Cosmic Muon Flux Using a Compact Telescope Based on Resistive-Plate-Chamber Technology

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We describe the design, construction, and operation of a compact cosmic-ray (CR) telescope of the TRASGO (TRAck reconStructinG bOx) type, consisting of four resistive plate chambers (RPCs), located in Puebla City, Mexico, at latitude/longitude of 18° 59’ 56” N/98° 11’ 41” W. and 2100 m a.s.l. This telescope allows the detection of isolated muons with good angular resolution through the application of quality cuts on the TDC signals. We also describe the implementation of a webpage with an event display that shows the hits on each of the 4 planes and the reconstructed trajectories of isolated muons. These clean events were used to measure the azimuthal distributions of the muons crossing the detector for various cuts at the zenith angle. We report on the measurement of the East-West asymmetry in the flux of secondary cosmic-ray muons and compare our results with detailed simulations based on the CORSIKA software. Finally, we discuss the use of this type of small detector in education and outreach activities to measure several properties of secondary cosmic-ray muons.

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1. Introduction

In the early 1930's, during a series of experiments in the American continent conducted by A. H. Compton and his collaborators, the intensity of cosmic radiation was measured. A clear reduction of the intensity between 40° N and 40° S was observed, reaching a minimum close to the Equator. These results suggested that cosmic radiation consists of charged particles deflected by the Earth's magnetic field [1], and not photons alone as had been previously hypothesized by Millikan [2]. The work of J. Clay and H. P. Berlage also reported a decrease in radiation at sea level when moving toward equatorial latitudes [3], supporting Compton's findings. A theoretically approach was then developed by Lemaitre and Vallarta [4], who pointed out that if cosmic radiation were a mixture of charged particles-at least electrons and protons-the measured intensity coming from the East or West should depend on the particle's charge. In particular, if the radiation were proton-like, an excess of cosmic radiation intensity would be expected from the West rather than the East. Prof. Vallarta persuaded Prof. Compton to perform new measurements in Mexico to test these predictions. Experiments conducted in the mountains around Mexico City revealed an excess of about 10 % in intensity coming from the West, confirming that cosmic radiation consisted mainly of protons [5]. Between 1943 and 1946, two further experimental runs were carried out in Mexico City using the first Mexican cosmic-ray detector, based on a rotating rail system of Geiger counters. These measurements yielded results consistent with those obtained by Compton a decade earlier [6].

In this work, we report updated measurements of the East-West asymmetry obtained with a compact telescope based on resistive plate chamber (RPC) technology, located in Puebla City, Mexico.

2. MACARIO detector

MACARIO is a miniature TRASGO (TRAck reconStructinG bOx) type detector [7, 8], which consists of four planes of RPCs, each ∼ 30 x 30 cm^2 in size, separated by ∼ 13 cm between planes. Each plane has four copper strips as signal collectors, three of them of width 63 mm and the fourth 98 mm wide. The planes are arranged so that in one plane the wider strip is located on the far left, and in the next plane on the far right side, thereby covering the gaps between strips of the next plane with the above plane, optimizing the spatial resolution of the central zone of the detector; see Figure 1 (left panel). Each RPC is made by a polypropylene box with three glass plates of ∼ 2 mm and two gas gaps of ∼ 1 mm filled with Freon R134a supplied by feedthroughs, the outer surfaces of the glass are covered by a semiconductive paint for the high voltage (HV) distribution. The entire system is electromagnetically insulated inside an aluminum box, which also provides mechanical stability.

The signals are produced by the charge induced in the copper strips when secondary cosmic rays as muons ionize the gas inside the RPCs by passing through the planes of the detector. These signals are processed by Front-End Electronics (FEE) adapted from the HADES experiment [9], and sent to a TRB3sc [10] which serves as the DAQ system. The detector has an environmental sensor to monitor pressure, temperature and relative humidity, which helps correlate these parameters with the detector rate in a long time scales (several days or weeks). The results presented were obtained

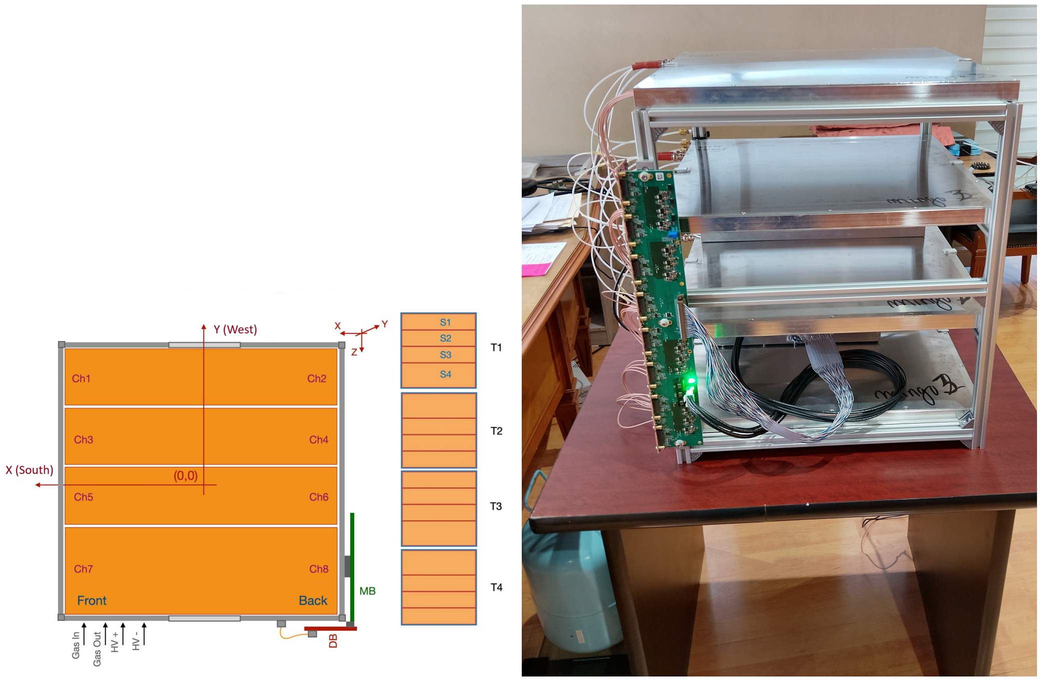

Figure 1: Coordinate system and orientation of Macario detector (left panel). Macario detector layout (right panel).

with an HV of ~ 4.8 kV per gap, which was determined as the optimal operating voltage. Figure 1 (right panel) shows a photograph of the Macario detector.

The electronics of MACARIO can be configured to set different types of trigger coincidences between planes, making it possible to distinguish clear muon tracks. The DAQ can process more than one million events per day, giving enough statistics to make studies related to low-energy cosmic rays, seasonal variation, atmospheric weather or solar activity. The results published by the first miniTRASGO detector demonstrating some of these capabilities can be found in [11].

3. Event display for reconstruction of tracks

In order to analyse the data generated by MACARIO, a graphical approach was taken by implementing a webpage[1] that allow us to analyse the data in an intuitive way and helps to teach the students the flow of information data to follow with this kind of detectors. Figure 2 shows the menu of the event display, which provides a brief story of cosmic rays, common applications for RPC detectors, and a description of the MACARIO detector; then the selection of a data file can be done, followed by histogram analysis of different channels, scatter plots to find correlations, the procedure for calibration of the channels, the possibility to simulate the signals and compare with data, a tri-dimensional reconstruction of the track (Figure 3, left panel) based on least squared method by considering the position along the strip, a summary of the event (reconstructed track) analysed, the angular distributions generated for the data file (Figure 3, right panel), and finally an option under development to make muography studies. At each stage, different quality cuts and parameters can

[1] https://ciiec.buap.mx/Macario/

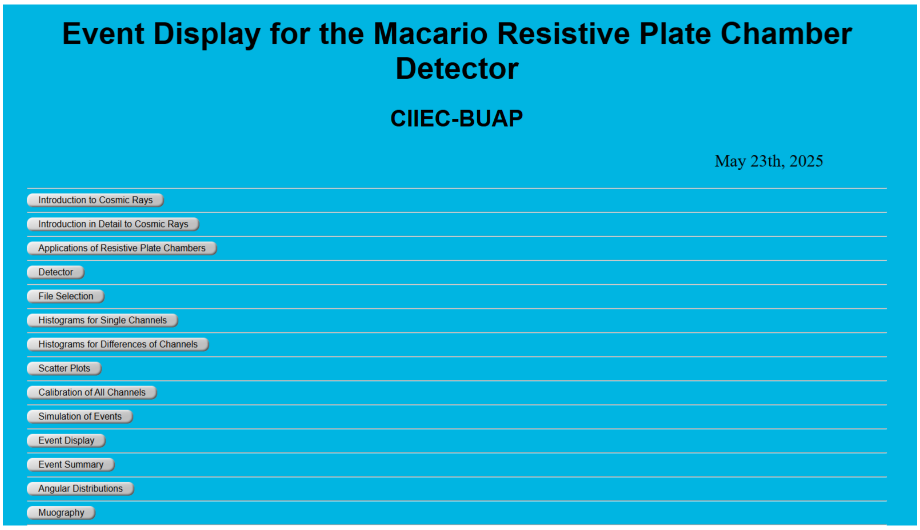

Figure 2: Menu for the event display of MACARIO detector implemented as a webpage.

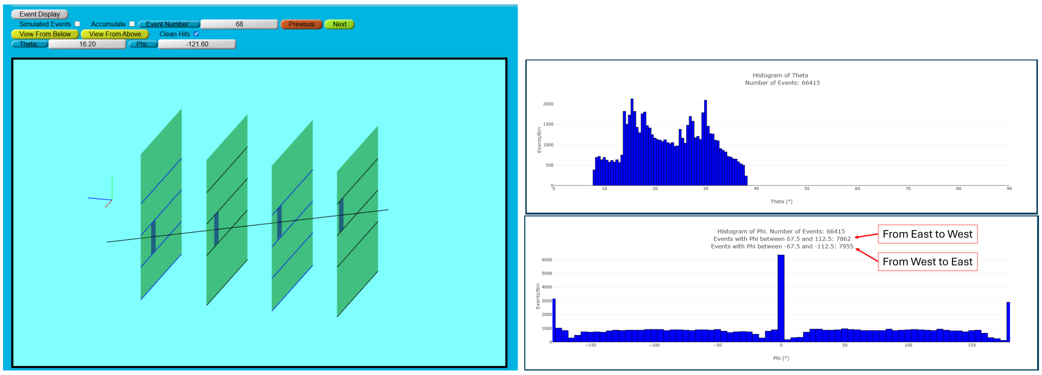

Figure 3: Reconstructed track of a clean muon passing through the 4 planes of MACARIO detector (left panel). Sample of angular distributions of reconstructed tracks (right panel).

be applied to find clean muon tracks or study events with different topologies, for example, one hit in one plane and two or more hits on different planes (possibility of electromagnetic cascade candidates).

4. East-West asymmetry measured by MACARIO

After a proper data reduction with quality cuts, about half a million clear muon track events were analysed. To study the East-West asymmetry, the azimutal arrival directions of the reconstructed events were separated by octants, this means the East (West) direction corresponds to events within an angular range of 45°. The results comparing the flux of secondary particles produced by primary cosmic rays coming from East and West can be reported as the asymmetry factor [6, 12], expressed as:

$$R = 2 \cdot (I_{West} - I_{East})/(I_{West} + I_{East}) \tag{1}$$

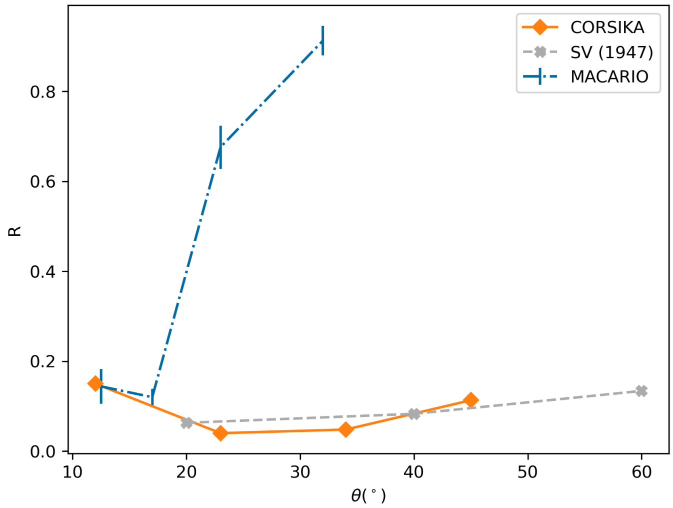

Figure 4: East-West asymmetry factor as dependent of zenith angle measured by MACARIO detector and comparison with CORSIKA simulations.

where I_{West} is the flux of particles coming from the West direction and I_{East} is the flux coming from the East. Figure 4 shows the asymmetry factor R as dependent of zenith angle, where can be seen a good agreement with the simulations predictions (see next section) for low zenith angles ($\theta < 18°$). For higher zenith angles, the asymmetry factor grows rapidly compared with the trend for low zenith angles and can be explained by an excess of particles hitting the detector coming from the West direction due to a window and walls effects of the building where the detector is located.

5. CORSIKA simulations

The simulations were performed employing the CORSIKA software [13]. Proton was selected as primary and 250'000 showers were generated per run; the energy of the primary was fixed as: 10, 100, 400 and 1000 GeV, zenith angles of 12, 23, 34 and 45°, an observation level of 2100 masl and magnetic field components of $B_x = 27.08\ \mu T$ and $B_z = 28.64\ \mu T$, corresponding to a geographical location of 18° 59' 56" N and 98° 11' 41" W. The hadronic energy interaction codes used were FLUKA for low-energy [14] and QGSJET II-04 [15] for high-energy.

The results showed that for low energy primaries (10 and 100 GeV) there is not an East-West asymmetry due to geomagnetic cut-off rigidity that prevents most of the secondary particles from reaching the observation level. On the other hand, for high energy primaries (1000 GeV) the asymmetry is also absent because the secondaries are energetic enough to be deviated by the Earth's magnetic field. In case of the primaries with 400 GeV, there is a noticeable East-West asymmetry and the results are presented as the asymmetry factor calculated from equation 1 on Figure 4, there is a good agreement with predictions and measurements for low zenith angles; for higher zenith angles the measurements obtained by S. Vallarta and col. [6], are included to show the agreement with the trending obtained by the simulations predictions. These results validate the simulations and the software CORSIKA to make such predictions.

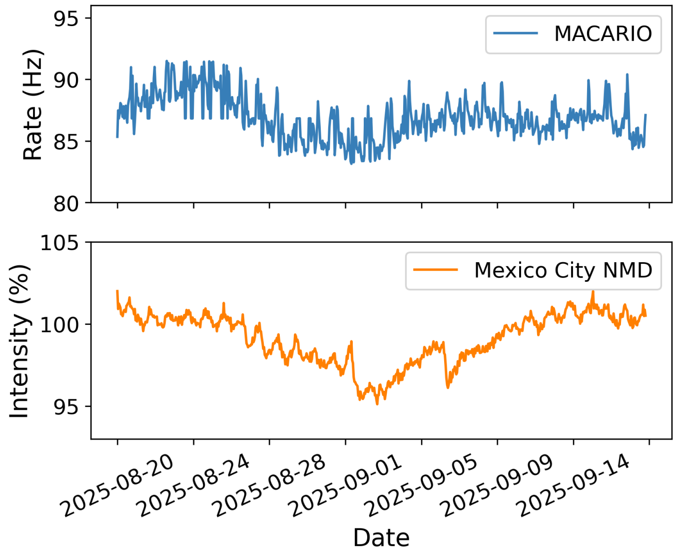

Figure 5: FD produced at the beginning of September 2025 recorded by the Mexico City Neutron Monitor and the recorded candidate by MACARIO. In both figures the resolution corresponds to one hour.

6. Forbush decrease candidate

Galactic cosmic rays (GCRs) experience variations due to solar wind disturbances such as interplanetary coronal mass ejections (ICMEs) and their shocks. ICMEs screen and compress the magnetosphere, leading to a reduction of GCRs intensity and generating geomagnetic storms. The fast reductions of GCRs intensity are known as Forbush decreases (FD) in honour of his discoverer S. Forbush in 1937 [16], FDs have an onset time of hours to days and a relatively slow recovery to normal values of about days to weeks. The magnitude of the FD depends on several factors including velocity of the ICME, size, and state of the magnetosphere, among others; depending on the magnitude of the FD it is expected that there is a reduction in the amplitude of GCRs intensity of several percent to 20 % or more [17].

At the beginning of September 2025, a small FD was detected by the Mexico City neutron monitor[2], leading to a reduction of about 5 % of cosmic rays intensity; around the same time, the MACARIO detector recorded a reduction in the number of events per second, showing a similar trending, which suggests the detection of this FD. Figure 5, shows a preliminary study of the rate recorded by MACARIO with one hour resolution, corrected by temperature of the laboratory and pressure; the data from the Mexico City neutron monitor is included to compare the relative intensity and date of the event. The detection of such an event opens up the possibilities to study some phenomena that modify the space weather and atmospheric properties with a compact telescope as MACARIO.

[2] http://132.248.105.25/index.php

7. Summary and outlook

The MACARIO detector is a compact muon telescope with the capabilities to study the flux of low energy cosmic rays and is based on present technology such as the one used for instrumentation on bigger particle physics projects. This kind of detector is particularly useful for training students who are starting to get involved in astroparticle and particle physics, which allows them to familiarise and gain experience in the high energy physics area. In this work, an event display webpage based was presented which contains useful information for data analysis of miniTRASGO detectors. The implementation of this resource allows to non-specialised persons to interact and learn about cosmic rays physics, RPCs detectors, and data analysis. This approach enables the possibility of making outreach activities or educational programmes, including the mobility of the detector to different sites because of its compact size. Finally, the results of the cosmic ray East-West asymmetry in Puebla, Mexico were made, along with detailed simulations employing the CORSIKA software, obtaining a good agreement with predictions and measurements for low zenith angles ($\theta < 18°$), for higher zenith angles the discrepancy between measurements and predictions can be explained due to building effects. This asymmetry is a fundamental phenomenon that happens in every place in the world but depends on the latitude and altitude, so these parameters should be taken into account when making measurements or predictions of this effect. In a future, it is planned to move the detector to a location where the building effects can be minimised and record new measurements in order to confirm the predictions in a wide range of zenith angles.

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References

[1] A.H. Compton, *Variation of the Cosmic Rays with Latitude*, *Physical Review* **41** (1932) 111.

[2] R.A. Millikan and G.H. Cameron, *A More Accurate and More Extended Cosmic-ray Ionization-Depth Curve, and the Present Evidence for Atom-Building*, *Physical Review* **37** (1931) 235.

[3] J. Clay and H.P. Berlage, *Variation der Ultrastrahlung mit der geographischen Breite und dem Erdmagnetismus*, *Naturwissenschaften* **20** (1932) 687.

[4] G. Lemaitre and M.S. Vallarta, *On Compton's latitude effect of cosmic radiation*, *Physical Review* **43** (1933) 87.

[5] J. Pérez-Peraza, *Reminiscences of cosmic ray research in Mexico*, *Advances in Space Research* **44** (2009) 1215.

[6] M.S. Vallarta, M.L. Perusquía and J. de Oyarzábal, *The Determination of the Sign and the Energy Spectrum of Primary Cosmic Radiation*, *Physical Review* **71** (1947) 393.

[7] D. Belver, P. Cabanelas, D. Domínguez, J.A. Garzón, G. Kornakov and M.F. Morales, *TRASGO: A proposal for a timing RPCs based detector for analyzing cosmic ray air showers*, *Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* **661** (2012) 163.

[8] J.A. Garzón, *TRASGOS: Towards a New Standard for the Regular Measurement of Cosmic Rays*, *Physics of Atomic Nuclei* **83** (2020) 453.

[9] D. Belver, P. Cabanelas, E. Castro, J.A. Garzón, A. Gil, D. Gonzalez-Diaz et al., *Performance of the low-jitter high-gain/bandwidth front-end electronics of the HADES tRPC wall*, *IEEE Transactions on Nuclear Science* **57** (2010) 2848.

[10] A. Neiser, J. Adamczewski-Musch, M. Hoek, W. Koenig, G. Korcyl, S. Linev et al., *TRB3: A 264 channel high precision TDC platform and its applications*, *Journal of Instrumentation* **8** (2013) .

[11] C. Soneira-Landín, A. Blanco, L.M. Fraile, J.A. Garzón, G. Kornakov, L. Lopes et al., *miniTRASGO: A compact RPC tracker for cosmic ray studies*, *Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* **1077** (2025) 170511.

[12] F. Riggi, D. Bonanno, G. Gallo, P. La Rocca, F. Longhitano, D. Lo Presti et al., *Investigation of the cosmic ray angular distribution and the East–West effect near the top of Etna volcano with the MEV telescope*, *European Physical Journal Plus* **135** (2020) 1.

[13] D. Heck, J. Knapp, J.N. Capdevielle, G. Schatz and T. Thouw, *CORSIKA: a Monte Carlo code to simulate extensive air showers.* (1998).

[14] A. Ferrari, P.R. Sala, A. Fassò and J. Ranft, *FLUKA: A multi-particle transport code (program version 2005)*, CERN Yellow Reports: Monographs, CERN, Geneva (2005), 10.5170/CERN-2005-010.

[15] S. Ostapchenko, *Monte carlo treatment of hadronic interactions in enhanced pomeron scheme: Qgsjet-ii model*, *Phys. Rev. D* **83** (2011) 014018.

[16] S.E. Forbush, *On the effects in cosmic-ray intensity observed during the recent magnetic storm*, *Cosmic Rays, the Sun and Geomagnetism: The Works of Scott E. Forbush* (2013) 117.

[17] I. Angelov, E. Malamova and J. Stamenov, *The Forbush decrease after the GLE on 13 December 2006 detected by the muon telescope at BEO - Moussala*, *Advances in Space Research* **43** (2009) 504.