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The East-West asymmetry of single muons at Campinas

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Summary. — The EASCAMP experiment, one of the few situated in the Southern Hemisphere, operating at the State University of Campinas, UNICAMP, Brazil, detected for two years single muons in the low energetic range. The primary cosmic rays that produce these muons have a geomagnetic vertical cut-off of 10.6 GV. We studied the azimuthal distribution of three million single muons obtaining an East-West asymmetry of $A_{\rm EW} = (8.91 \pm 0.04)\%$. Another analysis concerned with the atmospheric muons propagation index is performed comparing the experimental zenith angular distribution and a simulated isotropic cosmic rays distribution.

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1. – Introduction

The central module of the EASCAMP Extensive Air Shower experiment, located at the State University of Campinas, Brazil, detected routinely muons from August 1998 to June 2000. The experimental array is placed at 22° 54′ and 47° 05′ W, at 624 meters above sea level (940 g/cm^2) [1].

Since EASCAMP is situated near the geomagnetic equator the terrestrial magnetic field strongly affects the primary cosmic rays flux. The calculated vertical geomagnetic cut-off resulted to be about 10.6 GV for the two acquisition years, corresponding to 15° south geomagnetic latitude. Considering that near the geomagnetic equator there is a zone, known as "penumbra", where the majority of particle trajectories are prohibited, we estimated the effective vertical threshold rigidity around 11.6 GV [2].

We studied the azimuthal distribution of the recorded single muons to determine the amplitude of the East-West asymmetry induced by the earth's magnetic field. Since the majority of the primary cosmic rays are protons, according to the Störmer theory, we expected an excess of primary cosmic rays in the West incident geomagnetic direction and a lack in the East [3]. This azimuthal angular dependence is then reflected in the secondary muon flux.

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2. – Experimental array

The central detector has almost a cubical geometry: 4.36 m (width) $\times$ 4.07 m (length) $\times$ 3.22 m (height). It consists of 4 planes, separated one meter from each other and composed by 128 streamer tubes and 128 aluminium strips arranged orthogonally on the streamer chambers and receive induced signals from streamer discharges [4]. The dimensions of the single tubes and strips are, respectively, 3 cm $\times$ 3 cm $\times$ 436 cm and 3 cm $\times$ 0.004 cm $\times$ 407 cm.

These detectors provide two (tubes and strips) coordinates for the muon tracking reconstruction, while the height is achieved by the plane. The obtained zenith angular resolution for isolated tracks is 1.2° [5].

The limited streamer operation conditions are obtained with 5700 volts and fluxed gas mixture of Argon/CO_2/Isobutan with 2.5/88/9.5 corresponding percentages. This gas mixture presented low efficiency (75%) but is not flammable and has low cost.

The data acquisition system is implemented with CAEN-SGS equipment [6]. The electronic signals are read by SGS-Thomson electronic cards and sent to the Splitter Board CAEN SY190 unit. From here a trigger for single muon requiring at least one hit in three planes for each of the two projections (wires and strips) filters the signals. In case of trigger the electronic signals are directed to the Streamer Tube Acquisition System (Model C187-CAEN), which provided raw-data event hit position. The event time, measured by a Global Position System (GPS) receiver, of 0.5 seconds precision, and the barometric pressure, measured by an Analog Barometer transducer (Model PTB 100A of VAISALA of 0.1 mbar of resolution) are also recorded.

Taking into account the slowness of some acquisition system electronic components we introduced into the system one component (*Dual Timer*) that closed the acquisition for 57.8 μs, defining one dead time, and left the active acquisition time for 500 ns. The reconstructed single-muons counting rate was 0.83 Hz. Considering also the acceptance, efficiencies of trigger and event reconstruction, and measurements done by one streamer chamber shielded with layers of lead [7] only 0.3% of muons was sampled.

The raw data are decoded by one appropriate program written in FORTRAN. In fig. 1 we show the single-muons tracks reconstructed in the two projections: ZX using the electronic signals from the anode wires and ZY using signals from the strips. The minimal required tracking condition was at least three aligned points in each projection. Events with more than 60 hits per plane were excluded as noise.

3. – Data analyses

The total number of single muons observed by the EASCAMP central module over the two years was 9.4 million. For the East-West asymmetry study we selected initially 5.6 million events requiring good experimental conditions and acquisition uniformity: all four planes in operation, good stability of the rate of events, no hardware problems and no excessive electronic noise.

3˙1. *The East-West asymmetry.* – The second data selection requirement implemented was to eliminate any azimuthal asymmetry dependence caused by the rectangular geometry of the EASCAMP central module: we used for the analysis only the particle tracks that traversed the two basis of an imaginary cylinder centered on the module. The zenith angle range selected was $5° < \theta < 45°$. The total number of trajectories that satisfied these criteria was reduced to 3.0×10^6.

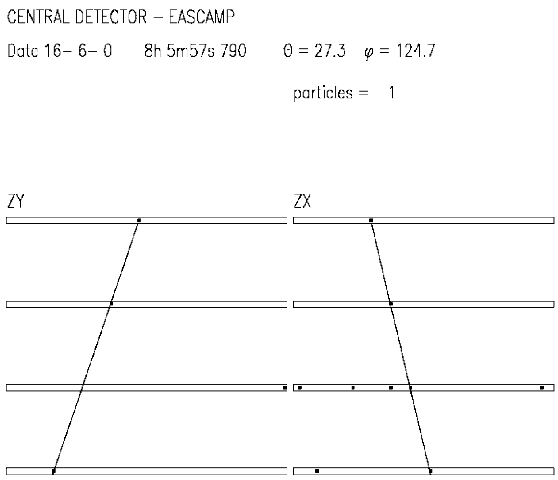

Fig. 1. – Display of the two projections of a single-muon event.

In fig. 2 we present the azimuthal anisotropy achieved, confirming the presence of the geomagnetic effect, that results in the data lack in the East incident directions and excess in the West region. We measured the azimuthal asymmetry amplitude A_{EW} as

$$A_{\mathrm{EW}} = \frac{N_{\mu\mathrm{WEST}} - N_{\mu\mathrm{EAST}}}{N_{\mu\mathrm{WEST}} + N_{\mu\mathrm{EAST}}} \cdot 2 = (8.91 \pm 0.04)\% \,, \tag{1}$$

where $N_{\mu\mathrm{WEST}}$ indicates the West incident muons counting and $N_{\mu\mathrm{EAST}}$ is the analogous for the East direction. Our result was compared with the same effect recently measured by Tokiwa *et al.* [8], who observed a muon flux azimuthal dependence fluctuation of

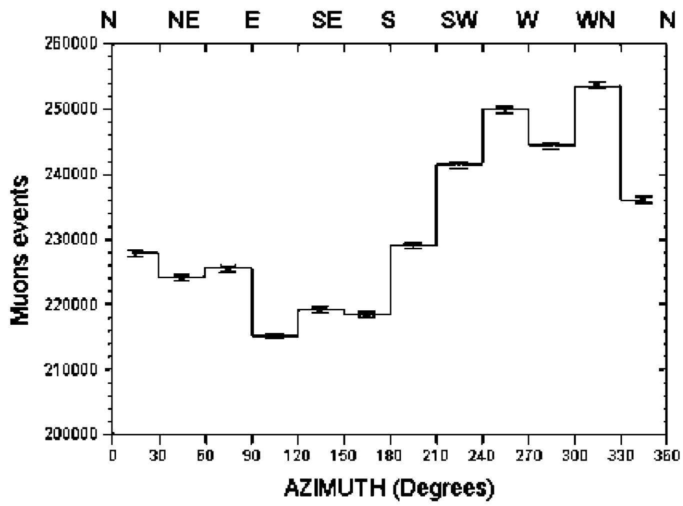

Fig. 2. – Azimuth angular dependence of 3.0×10^6 single muons.

13%. The accordance is good if we take into account the differences between the two experiments (muon zenith angle and momentum).

3˙2. *The propagation index.* – Another study performed with the EASCAMP central module was the zenithal angular dependence of the atmospheric muon intensity, which can be expressed as [9]

$$I(\theta) = I(0)\cos^n\theta\,, \tag{2}$$

where n is known as the propagation index. We found this index value comparing the experimental zenithal angular distribution with a simulated distribution obtained for an isotropic primary radiation flux.

First we defined the geometrical sensitivity (G.S.) of the central module as [10]

$$\mathrm{G.S.}(\alpha,\theta)\mathrm{d}\alpha\mathrm{d}\theta = D(\alpha,\theta)\sin\theta\mathrm{d}\theta\mathrm{d}\alpha\,, \tag{3}$$

where α, θ are the azimuth and zenith angles of the particle incident direction, respectively and $D(\alpha,\theta)$ is the detector directional response function. In the ideal case of an isotropic flux, the geometrical sensitivity, integrated over all azimuth angles, corresponds to the particles zenithal angular distribution. For a rectangular detector, $D(\alpha,\theta)$ assumes the following simple expression [11]:

$$D(\alpha,\theta) = \cos\theta(X - |Z\tan\theta\cos\alpha|)(Y - |Z\tan\theta\sin\alpha|)\,,$$

where X, Y and Z are the detector dimensions.

We defined also the radiation sensitivity (R.S.) as

$$\mathrm{R.S.}(\theta) = \mathrm{G.S.}(\theta)\cos^n\theta\,, \tag{4}$$

where the term $\cos^n\theta$ denotes the attenuation of the muon flux in the atmosphere, and n is known as the muons propagation index.

We determined the muons propagation index by a least-squares fit of the experimental zenithal angular distribution of all the 9.4 million single-muon events to the radiation sensitivity expression. We obtained $n = (1.7 \pm 0.1)$ with $\chi^2/\mathrm{d.o.f.} = 0.99$.

In the low-energy range the mean index value for muons of few GeV observed at sea level resulted to be $n = 1.85 \pm 0.10$ [9], in good agreement with our results.

4. – Conclusions

We studied single muons collected by a South Hemisphere experiment, located at the State University of Campinas that uses streamer tubes and strips for muons tracking. The apparatus operated for two years, almost continuously, and collected a total of 9.4×10^6 single-muon events.

We performed two analyses: measurement of the East-West effect and determination of the muons zenithal angular dependence, obtaining the following results:

– $A_{\mathrm{EW}} = (8.91 \pm 0.04)\%$ for the West-East asymmetry,

– $n = 1.7 \pm 0.1$ for the muon atmospheric propagation index.

All values of the analyses agree with the results of other experiments giving us confidence of good operating conditions of our experiment. We think that our apparatus will contribute with useful information to the study of geomagnetic effects on muon fluxes in atmosphere.

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