Search for cosmic-ray anisotropies using nuclear emulsions

D. Cottrell, J. Anselmo, and T. Robinson
Physics Department, San Diego State University, San Diego, California 92182
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Directions of fast particles from nuclear interactions were measured in nuclear emulsion fixed in celestial coordinates with a 1° accuracy. The purpose was to determine any anisotropy and to determine the existence of a neutral particle of high cross section. Neither were found.

This is the first report of an experiment designed to determine the distribution, with respect to the stars, of fast particles related to nuclear interactions. This search was carried out with a rotating nuclear emulsion stack which was stationary with respect to celestial coordinates.

The search for cosmic-ray sources or "hot spots" in the sky has been carried out by many groups. Most have found little anisotropy, usually a first or second harmonic which is no more than a few hundredths of a percent of the average intensity.

There have, however, been occasional hints at new particles in the cosmic radiation, such as the *U* particle proposed by Callan and Glashow,[1] some of which if they were to exist may be neutral.[2] These neutral particles would be unaffected by the galactic magnetic field and would come directly from their point of origin. One would hope to see the particles produced by the interaction of these neutral particles. There are a few groups who have found significant differences from isotropy by using narrow-angle muon telescopes.[3-5] These anisotropies, however, have not remained fixed; they have disappeared within two years. Such observations may be due to streaming of primary cosmic rays along magnetic flux tubes within our galaxy.[6] It is suspected that the disappearance of these sources is thought to be caused by the passage of the earth from the appropriate flux tube, or perhaps by the disruption of the field locally produced by the expansion of the solar cavity during sun spot maximum.[6] Still other groups of experimenters have found anisotropies in the direction of muon-rich showers,[7] or of neutral-particle-induced muons.[2]

This experiment is based on the hypothesis that particles associated with anisotropies might stand out more clearly from the background if the resolution of directions could be improved (we claim an over-all accuracy of one degree). Further, we believe that the particles associated with anisotropies might possibly stand out more clearly from the background in terms of the product of flux and cross section if these particles have a cross section intermediate between electromagnetic and hadronic.

For example, an isotropic flux of cosmic-ray muons with a cross section of 2 μb/nucleon could be mixed with an anisotropic flux of particles having a cross section of 100 μb/nucleon. Were such particles to constitute only 0.2% of the flux, they would still represent 10% of the nuclear interactions.

Although speculative, such a particle, in this case neutral, may already have been seen by Cowan.[2] Such a particle would also have the appealing feature of perhaps explaining the anomalously high frequency of stopping particles at great depths.[8]

Although the earlier research just cited suggests support for our hypothesis, this experiment has produced no compelling evidence to further support the hypothesis.

THE APPARATUS

Stacks of Ilford G-5 electron-sensitive emulsion were prepared by casting pellicles, 600 μm thick, from melted gel. When dried, after two days, these were stripped, cut, and stacked.[9] The prepared stacks were then placed in a box of 1-in.-thick iron shielding. This box was fixed to a shaft which was held parallel to the earth's axis, and which rotated once every 23 h 56 min (see Fig. 1). As a result of this rotation, one edge of the box remained fixed on the point in the sky corresponding to zero-zero celestial coordinates. An automatically activated emergency power supply was devised to prevent power failure to the clock drive.

The entire apparatus was placed in a chest-type freezer maintained at $-17\,^{\circ}$C to decrease the rate of track fading during the exposure. All of the above preparation, exposure, and subsequent processing was done in the basement of the building to decrease the soft component of the cosmic radiation.

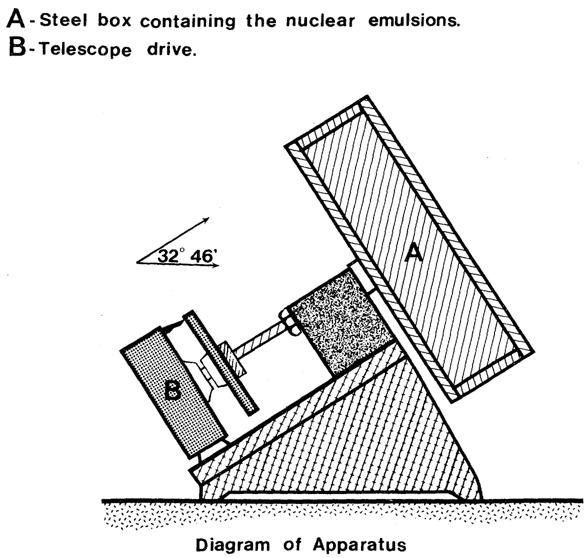

FIG. 1. Shielded box *A* containing nuclear emulsion is turned by telescope drive *B*, fixing orientation with respect to celestial coordinates.

THE SCANNING

The scannable nuclear emulsion consisted of two stacks of twelve plates each. They were manufactured simultaneously and exposed for six and twelve months respectively before processing. The central portion of each plate was systematically scanned under 100 power for nuclear interactions producing stars with long black prongs. Each star was then examined under higher power to determine the number, if any, of minimum ionizing tracks associated with the star. The tracks are the basis of assigning direction. The direction of the light tracks relative to the stack, and therefore relative to the celestial coordinates, was measured with great precision on a Koristka measuring microscope.

Each star was classified according to type of interaction, and when possible, incident directions were determined for the cosmic-ray particle producing each star.

DISCUSSION

The 14.57 cm^3 of scanned emulsion represents an exposure of 4.76×10^9 g sec. Within this scanned volume, 708 interactions of all kinds were found. This represents a frequency of interactions of 1.48×10^{-7} interactions per g sec of nuclear emulsion. Assignable directions for the incident particles were found for 179 of the 708 stars. These are plotted in Fig. 2. It is readily apparent from the plotting of these directions that there is no pronounced clustering.

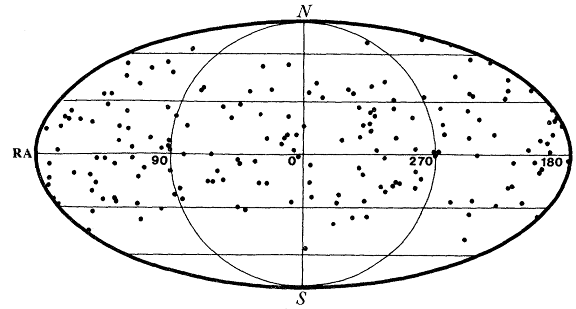

FIG. 2. Mollweide projection showing right ascension and declination of minimum-ionizing tracks associated with nuclear emulsion.

Figure 2 does, however, show a deficiency of data points near the north celestial pole. This is due to a scanning bias. The orientation of the plates was such that tracks caused by particles coming from the vicinity of the north celestial pole were vertical in the pellicles. It is very difficult to see a track orientated perpendicular to the field of view of a microscope especially if the star is near the upper surface of the pellicle. (This problem would be alleviated by a different stack orientation.)

The problems of scanning bias also apply to the south celestial pole, which is blocked from the apparatus by the earth. The most southerly point of the horizon at San Diego generates a circle at declination − 57° 14′. No interaction directions were found to come within that circle. Near this declination the density of interaction directions is depleted by the combined effect of horizon and absorption by the atmosphere.

These data were reduced to Fourier harmonics by grouping all points in Fig. 2 into 30-degree

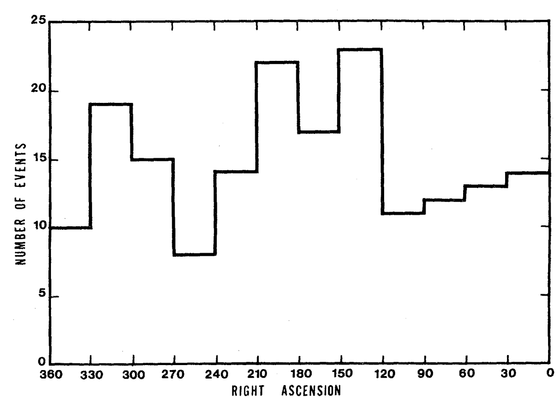

FIG. 3. The tracks of Fig. 2 are grouped in 30° bins. The first harmonic has a maximum at 13 h 22 min of right ascension.

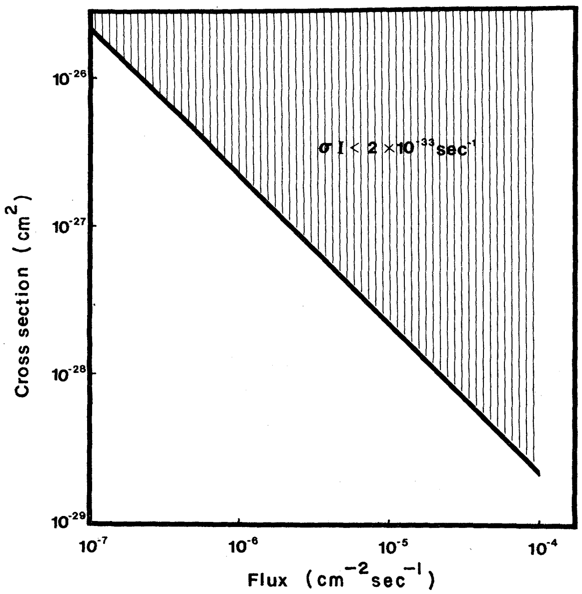

FIG. 4. The upper limit of the product of cross section and flux of particles coming from a point source established by this experiment is 2×10^{-33} sec^{-1} to 1% confidence.

bins (Fig. 3). The first harmonic has an amplitude of 18%; it is centered at 13 h 22 min and has no statistical significance.

We had hypothesized that a particle of high cross section might be associated with an anisotropy. A tight grouping of four particles within a circle of 5° has only a 1% possibility of chance occurrence, and would have been considered a possible source. Had there been such a cluster of four it would have corresponded to a point source of particles having a flux cross-section product of 2×10^{-33} particles per nucleon second. There is no such cluster of four. On the basis of this observation, we can depict an allowed region on a plot of cross section against flux (Fig. 4). There may be a small flux of new particles in the cosmic radiation and there may even be one associated with point sources. But if they exist they are not detectable at ground level with our equipment.

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