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A measurement of secondary muon angular distributions

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Abstract. Project GRAND is an array of proportional wire chambers composed of 64 stations with each station containing eight proportional wire planes and a 50 mm steel plate. The proportional wire planes together with the steel absorber allow a measurement of the angle and identity of single muon tracks. Of the two data-taking triggers, one is for single tracks. Since the rate of single muon tracks at sea level above the muon energy threshold of the experiment (0.1 GeV) is substantial, good statistics are available by accumulating several years of data. A map in sidereal right ascension and declination is obtained as well as one in a sun-centered coordinate system in order to study the sidereal and solar effects separately.

1 Introduction

Project GRAND is an extensive air shower array which detects secondary muons. Project GRAND's ability to identify the direction of origin for a muon track at a precise time allows for the creation of a map in right ascension and declination. This paper updates previous work: Poirier et al. (1999), Fields et al. (1997), and references therein.

2 Experimental Array

Project GRAND is a proportional wire chamber array located at $86°$W and $42°$N. The array has 64 stations, each containing four pairs of orthogonal proportional wire chamber (PWC) planes. The four pairs of planes are located above each other with a separation of 200 mm. Each plane contains 80 cells with a total active area of 1.25 m^2 achieving a resolution of $0.26°$, on average, in the projected planes. Above the bottom pair of planes is a 50 mm thick steel plate. Electrons interact with the plate and shower, scatter, or stop 96% of the time while the muons pass through unaffected 96% of the time. The 64 stations record a total of approximately

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2000 muons per second. The data on the muons from the 64 stations are read in parallel into a central data acquisition system at 12 MHz. The events are sent to eight separate CPUs in sequence for analysis in order to reduce the computer dead time. On a new event, the master CPU searches for a slave CPU not currently busy analyzing a previous event. Once information on 900 muons has been collected in a single CPU's memory buffer, the data from the buffer are written out to magnetic tape in a single record. A radio receiver tuned to WWVB in Boulder, Colorado provides time information with millisecond precision. As an additional back-up time reference, a one MHz crystal is also used. Information stored on magnetic tape includes the beginning and ending time of each record and the angle of the track in both the north/south and east/west planes.

3 Data Analysis

The data collected are used to generate files containing information on the number of muons originating from each $1° \times 1°$ of right ascension and declination during a complete sidereal day onto a 360×110 storage grid. ¿From January 1997 through December 2000, 1052 data files were collected containing information on a total of 110 billion muons. In order to eliminate possible spurious variations in counting rate caused by experimental problems (such as a station being offline for repair), a smoothness test is imposed on the data files of each day.

First, the number of muons detected is summed over all declinations for each degree of right ascension and the average and standard deviations of the values calculated. If the standard deviation/average ratio is greater than 2.9%, then that day's data file is not used. There were 635 data files containing information on 99 billion muons passed the smoothness test. Although Project GRAND has an average muon angular resolution of $0.26°$, the secondary muons themselves have a birth-angle relative to the primary and are further scattered and deflected as they traverse the atmosphere. This de-
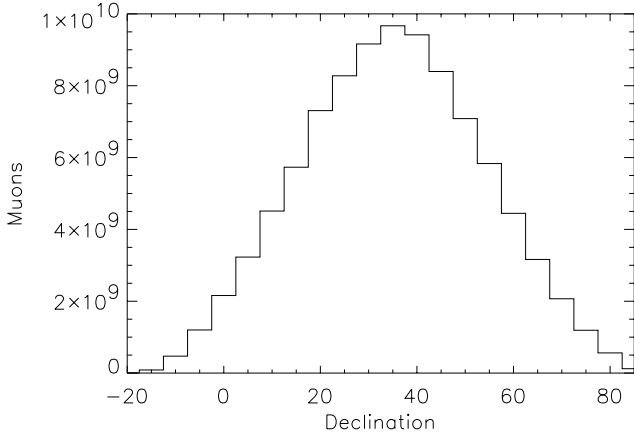
Fig. 1. A plot of counts vs. declination. There is a rapid variation caused by angles away from zenith traversing much larger thicknesses of air.
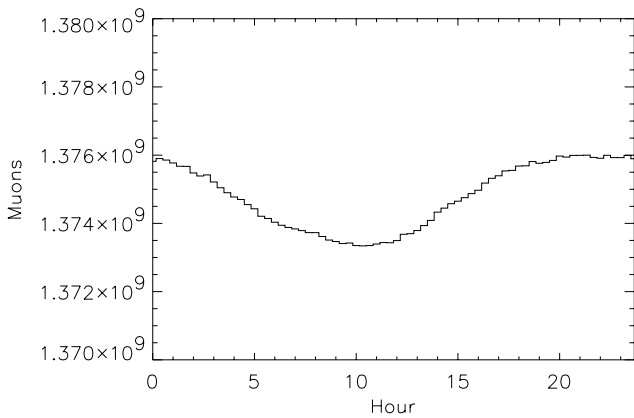

Fig. 2. A plot of counts vs. right ascension in five degree bins. The dependence is very smooth (notice the surpressed zero).
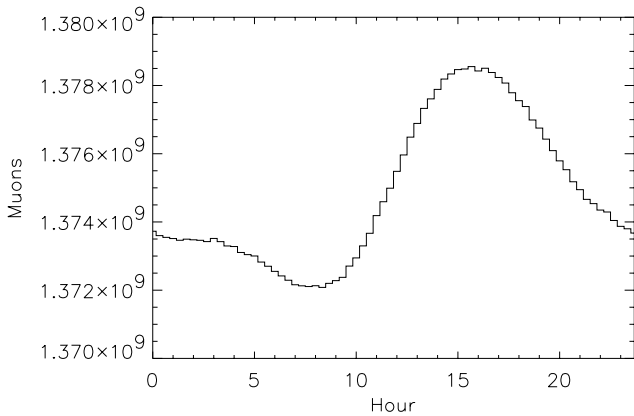

Fig. 3. A plot of counts versus solar hour-of-day). The dependence is quite smooth (notice the surpressed zero).

grades the resolution for the primary to about $\pm 3°$ depending on energy (Fassò and Poirier, 2001). The muon information is summed into $5°$ pixels. Figure 1 shows the number of counts per five degrees of declination. The counting rate has a steep dependence on declination because of the much greater acceptance near GRAND's zenith angle ($42°$). Figure 2 shows the number of counts per 5 degrees of right ascension. The number of counts per degree of right ascension is quite smooth; the greatest difference shown is only $\pm 8 \times 10^{-4}$ of the average number of counts.

The pixels were then normalized using equation (1),

$$Diff = \frac{N(\alpha, \delta) - \langle N(\delta) \rangle}{\sqrt{\langle N(\delta) \rangle}} \tag{1}$$

where $N(\alpha, \delta)$ is the number of counts in a given cell and $\langle N(\delta) \rangle$ is the average number of counts for that declination averaged over all α; the denominator is the statistical error in this quantity. This ratio is the number of standard deviations which this cell varies from its average.

In order to generate a contour map of declination vs. solar time, the individual data files are shifted by an amount which depends on the number of days past September 23 (the day the sun is at 12 hr of right ascension). Data from September 23 is not shifted while data from later in the year is shifted earlier by 0.9856 times the number of days after September 23 (shifted later for earlier days). The summed contour map generated using these shifted values also uses the normalization of Equation 1; Fig. 3 is the projection in half-hour increments of a solar day.

4   Conclusions

The $360°$ by $110°$ map of right ascension vs. declination is shown in Figure 4 as contours of a given deviation from average in units of standard deviations (smoothed). The highest deviations are $\geq 10\sigma$. The contour map of declination vs. solar time is shown in Figure 5. The greatest deviations in this map are $\geq 30\sigma$. The highest counting rate occurs near 16 hours. Since the map in solar coordinates has the larger variations, then perhaps the sidereal variations are caused by a solar-linked effect. All variations are small compared to the average number of 62.5 million muons in a $5°$ by $5°$ cell, but because of the high statistics obtained, the errors are small even relative to the size of, for example, the $\pm 8 \times 10^{-4}$ variations in Figure 2.

References

A. Fassò and J. Poirier, Phys. Rev. D **63**, 036002, 2001.

Fields, B. et al., in Proceedings of the 25th International Cosmic Ray Conference **6**, 365, 1997.

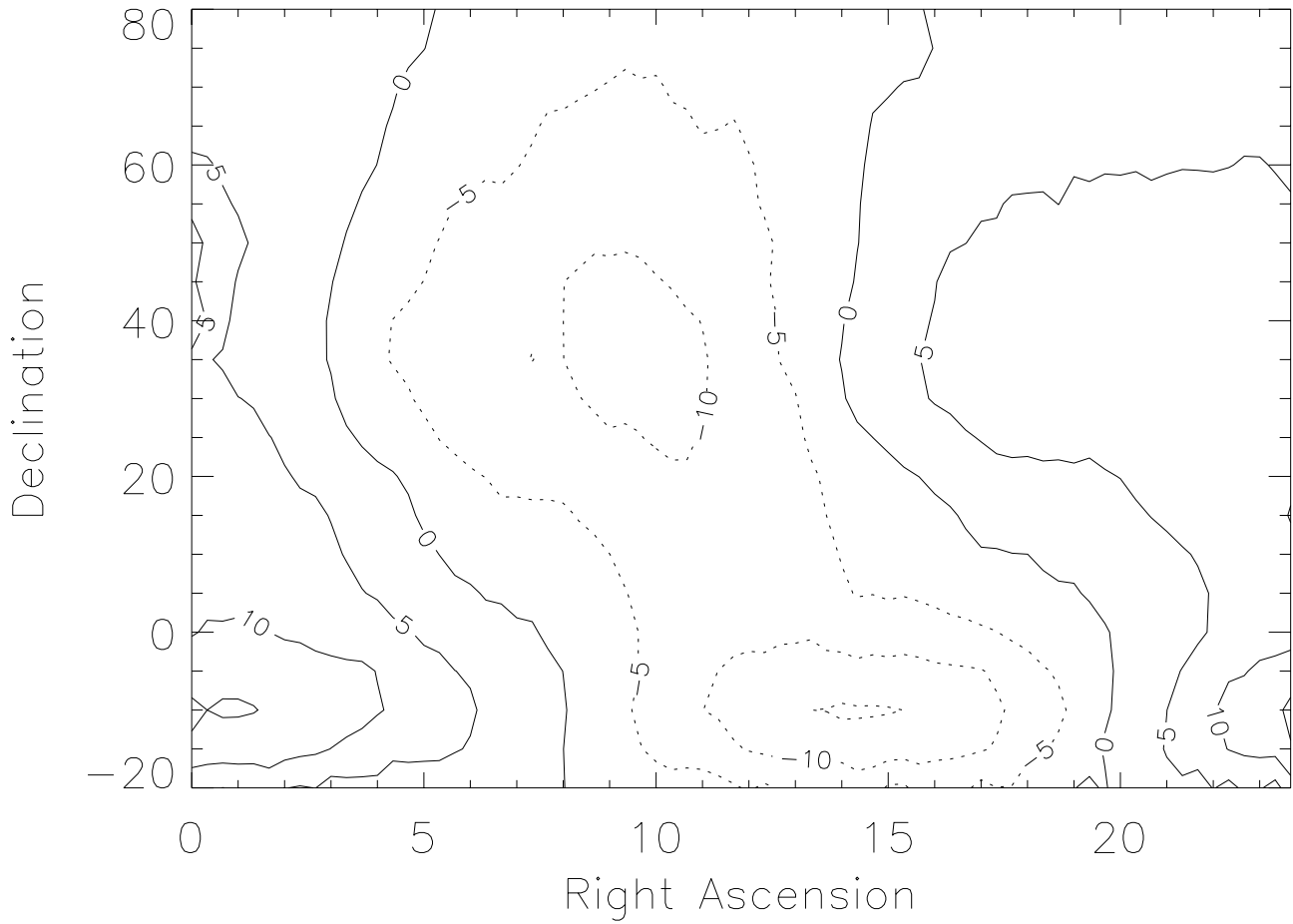Poirier, J. et al., in Proceedings of the 26th International Cosmic Ray Conference **2**, 64, 1999.

Fig. 4. Deviations from average muon angular distribution. The contours are the number of standard deviations from average. The abscissa is in right ascension of a sidereal day. Dashed curves are negative deviations (below average); solid curves are above average muon rate.
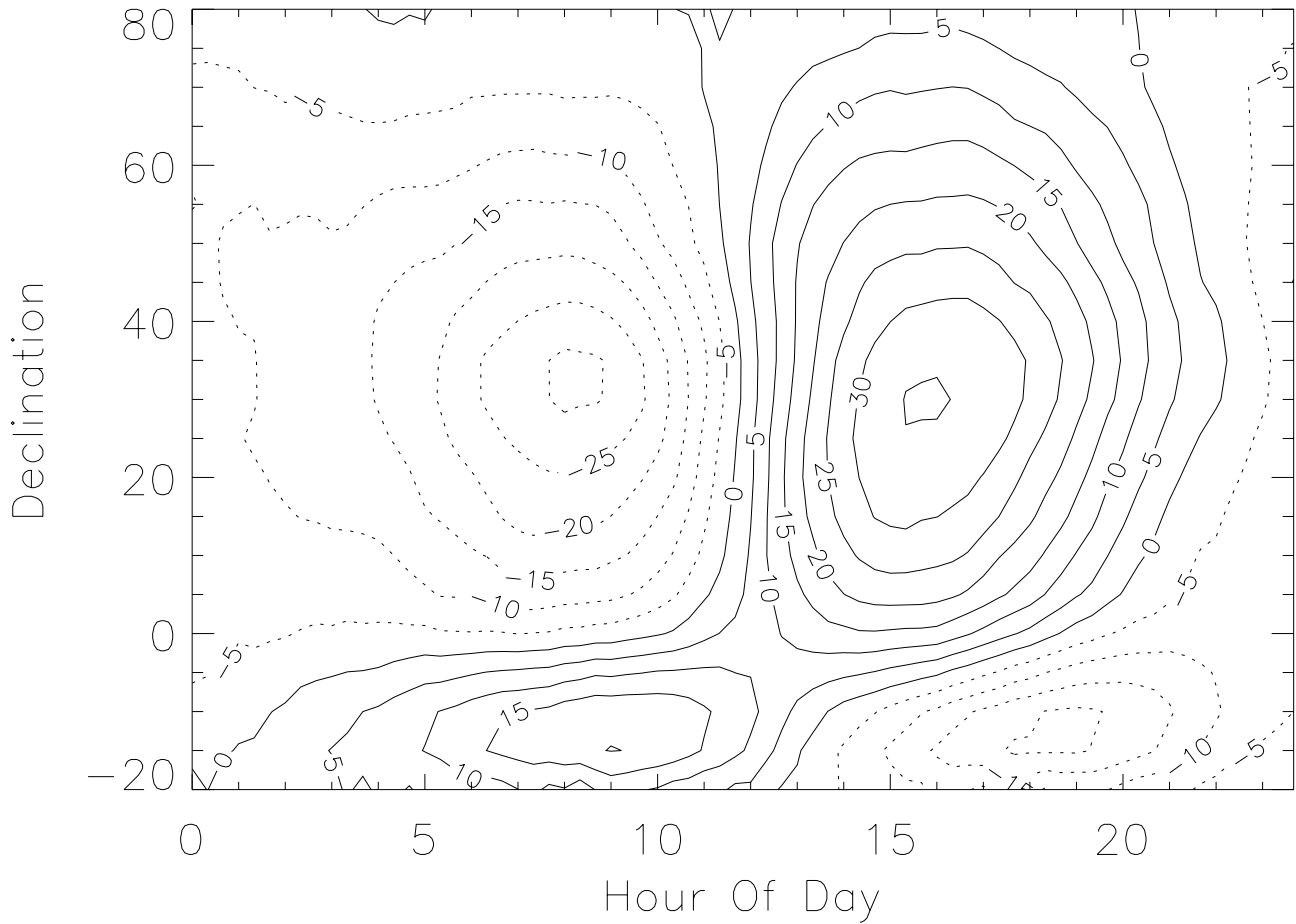
Fig. 5. Deviations from average muon angular distribution. The contours are the number of standard deviations from average. The abscissa is in hour of solar day (EST). Dashed curves are negative deviations (below average); solid curves are above average muon rate.