A Measurement of Secondary Muon Angular Distribution with High Statistics

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Abstract: Project GRAND is an array of proportional wire chamber stations which detects secondary muons produced by hadronic primaries. The geometrical arrangement of these proportional wire chambers allows for the determination of the angle of the incident muons to better than 0.5 degrees on a projected plane. The ground-level muon counting rate and mean incident angle are examined over five years in order to construct a high statistic map of muon flux in celestial (right ascension, declination) coordinates and in solar coordinates (solar hour of day EST and declination).

Keywords:muons,angular,distribution

1 Introduction

Project GRAND is a distributed array which detects and identifies secondary muons. The angle of each incident muon is determined with a resolution of better than 0.5 degree, in each of two projected planes. This, along with accurate information on the arrival time of the muon, allows for the creation of a map of muon counting rates in right ascension and declination. Data are collected over five years and used in the construction of such an angular map. The data are then re-plotted in declination vs solar hour of day in order to highlight possible solar daily variations in counting rate. This paper updates previous work: [1,2], and references therein.

2 Experimental Array

Project GRAND is an array of 64 proportional wire chamber stations located at 86o west longitude and 42o north latitude. Each station contains four pairs of orthogonal proportional wire chamber (PWC) planes. The four pairs of planes are vertically sepa-rated by 200 mm and stacked above one another. Each plane contains 80 cells, has an effective detec-tion area of 1.29 m2, and achieves a resolution of less than 0.5 degree in a projected plane. There is a 50 mm thick steel plate above the bottom pair of planes. This steel plate allows GRAND to differentiate be-tween muons and electrons. Electrons will shower, scatter, or be stopped by the plate 96% of the time while muons will pass through the plate unaffected 96% of the time. The array records approximately 1700 muons per second. Time information with mil-lisecond precision is obtained from a radio receiver tuned to WWVB in Boulder, CO. A one MHz crys-tal clock is used as a backup time reference in case the WWVB signal is lost. The data are stored in records of 900 muons each. The start and end times of these records are recorded as well as the incident angle of each muon in both the north-up and east-up planes. Further information on Project GRAND's experimental array can be found in [3].

3 Data Analysis

Five years of data collected from May 27, 2006 to May 27, 2011 are used to generate files containing information on the number of muons originating from each 1^{o} x 1^{o} of right ascension (1^{o} - 360^{o}) and declination (-20^{o} - 90^{o}) during a complete sidereal day into a 360 x 110 grid. During the time of the survey, 1750 days worth of data files were collected with a total of 242 billion muons. In order to eliminate false variations in counting rate caused by experimental problems (such as a station being offline for repair or a rapid change in humidity within a particular station), a smoothness test is imposed on each day's worth of data.

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 ratio of (standard deviation / average) is greater than 2.9%, then that day's data are not used. There were 1462 complete sidereal days containing 203 billion muons which passed this test. While GRAND has a resolution of less than one degree on a projected plane, the muons themselves have a birth-angle relative to the primary and are further scattered and deflected as they travel through the atmosphere. This degrades the effective resolution to approximately +/- 3 degrees depending on energy [4]. Therefore, the muon information is summed into 5 degree square pixels. The number of counts per degree of right ascension is very smooth. The greatest difference from minimum to maximum is only 0.26%. The counting rate, however, has a steep dependence on declination due to GRAND's higher acceptance near its zenith angle (42 degrees declination). In order to correct for this dependence on declination, the pixels were normalized using the following equation:

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

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 right ascension (α). The denominator represents the statistical error for the counts in that cell. This ratio is, then, the number of standard deviations which this cell varies from the average.

In order to generate a contour map of declination vs. solar time, the individual data files were shifted by an amount proportional to the number of days past September 23rd (the day the sun is at 12 hr of right ascension). Data from September 23rd are not shifted while data from later in the year are shifted earlier by (360 / 365.254) times the number of days after September 23rd. Data are shifted later by the same amount for earlier days. The summed contour map generated using these shifted values also uses the normalization of the above equation.

4 Conclusions

The 360° by 110° map of right ascension vs. declination is shown as contours of a given deviation from average in units of standard deviation (smoothed). The contour map of declination vs. solar time is shown. All variations are small compared to the average of 128.4 million muons in a 5° x 5° cell, but due to the large statistics, these variations are large compared to the small statistical errors.

5 Acknowledgment

Thanks to the Center for Research Computing for providing the on-campus data backup system that contributed to the 24/7 continuous operation and security of the data. Project GRAND was constructed with assistance from the National Science Foundation and is operated by gifts from The University of Notre Dame and private individuals.

6 Reference

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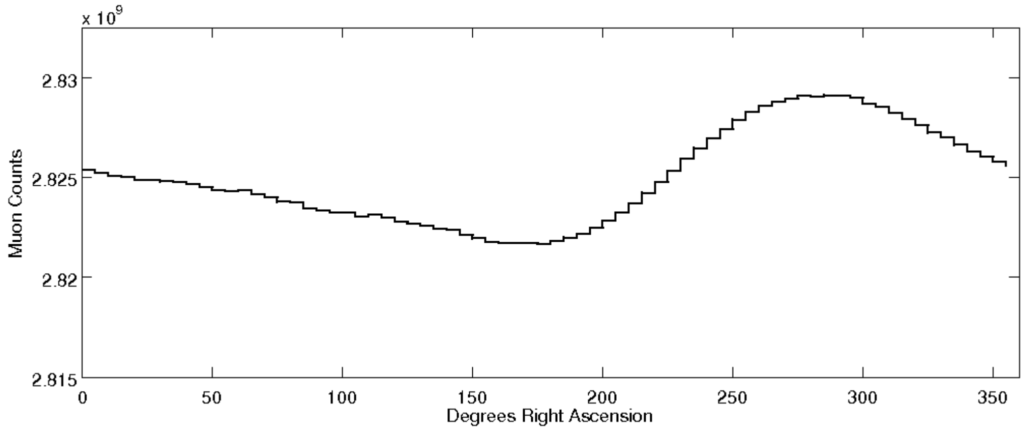

Figure 1. A plot of muon counts vs. right ascension in five degree bins. The dependence is very smooth (notice the suppressed zero).

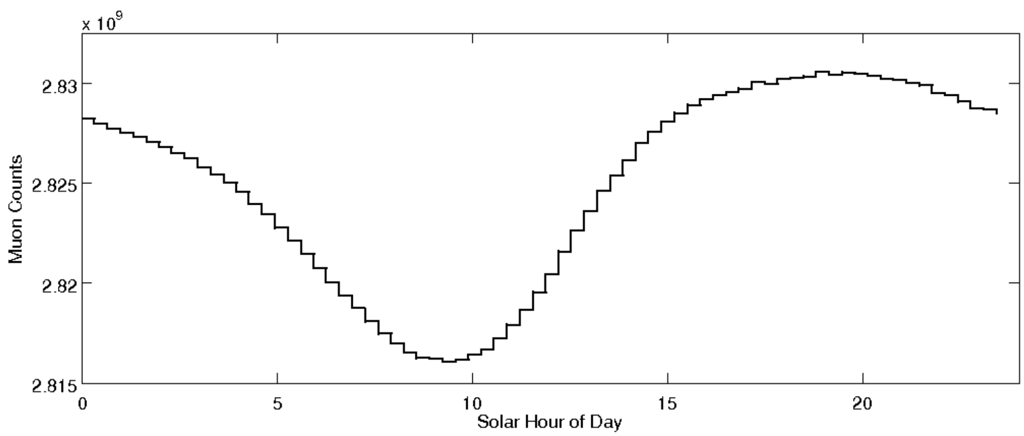

Figure 2. A plot of muon counts versus solar hour-of-day (EST). The dependence is quite smooth (notice the suppressed zero).

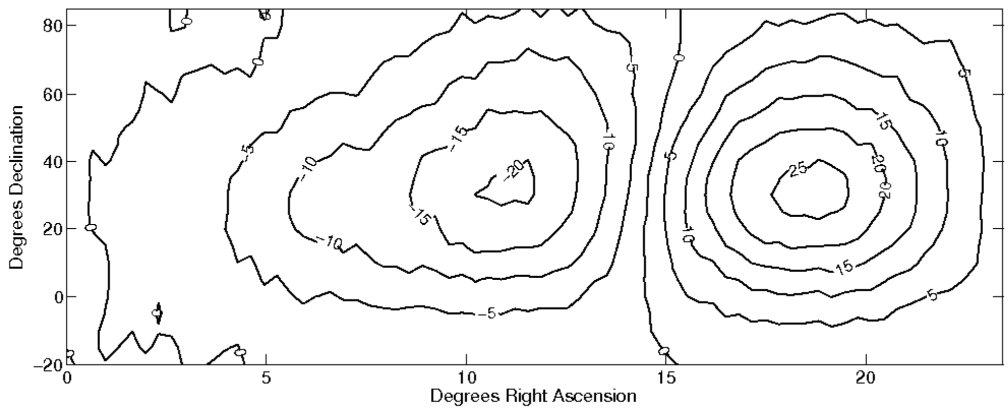

Figure 3. Sidereal day variations showing statistical deviations from average muon angular distribution. The contours are the number of standard deviations from average. The abscissa is in right ascension of a sidereal day.

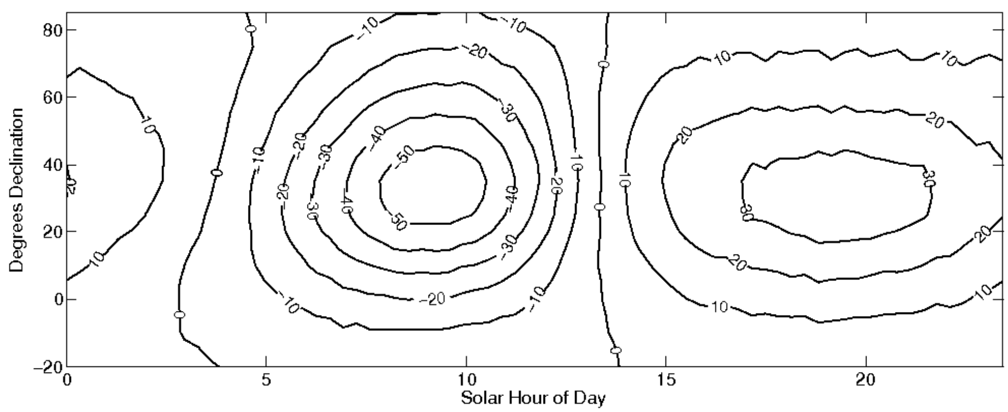

Figure 4. Solar day variations showing statistical deviations from average muon angular distribution. The contours are the number of standard deviations from average. The abscissa is in hour of solar day (EST).