Status report on project GRAND

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Abstract: GRAND is an array of position sensitive proportional wire chambers (PWCs) located at 86.2° W, 41.7° N at an elevation of 220 m adjacent to the campus of the University of Notre Dame with 82 square meters of total muon detector area. The geometry of the PWCs allows the angles of the charged secondary muon tracks to be measured to +/- 0.3 deg in each of two orthogonal planes. Muons are 99% differentiated from electrons by means of a 51 mm steel plate in each detector.

The muon detector array: GRAND

Project GRAND is an extensive air shower array of proportional wire chambers located at 41.7° N and 86.2° W at an elevation of 220 m above sea level and has been in operation with the construction of the complete 64 stations since 1995 (see Figure 1). Each of its 64 stations has an active detector area of 1.29 m² (for a total active detector area of 82 m²). The entire experiment is laid out in an 8 x 8 grid over a 100 m x 100 m field. Each detector station is a muon detector over its entire active area; the total area of the 64 muon detectors is available to gather statistics on ground level muons, which are precisely identified and their angles measured. Each detector station has eight planes of proportional wire chambers (PWCs) placed in a horizontal plane arranged vertically above each other with four planes measuring angles in the east-up plane and four in the north-up plane. Each plane has 80 individual wire cells. The number of cells and the geometrical arrangement of the planes combine to give GRAND an average angular resolution of +/- 0.26° for incident muons in both the east-up and north-up projected planes. Muons are differentiated from electrons by a 0.7 ton, 51 mm thick steel plate located above the bottom pair of planes. The minimum kinetic energy of muons which can traverse this steel plate vertically is 0.1 GeV increasing by 1/cos(theta) where theta is the angle by which the muon is inclined away from vertical. The detector's sensitivity to low muon energies increases its muon data collection rate and makes it a good match to the lower energy physics of solar phenomena. For electron secondaries, 96% of them stop, deflect, or shower in the steel plate. The signature of a muon is that it passes through the steel undeflected; 96% of the muons satisfy these criteria. The remaining 4% of the muons either stop or create delta rays which can produce a second hit in the two planes below the steel and thus mimic an electron. Since single tracks at ground level are predominately muons, the residual electron contamination in the muon-filtered data is about 1%. Two individual triggers simultaneously take data for: 1) single muons (single tracks of identified muons) at ~2000 Hz and 2) extensive air showers (multiple stations hit in coincidence) at a rate of ~1 Hz. The single track muon data are sensitive to primary energies >10 GeV with a median value of 56 GeV for vertical tracks. The coincidence trigger is sensitive to primary energies >100 TeV. We concentrate in this paper on the power of GRAND as a muon detector.

Project GRAND has demonstrated the ability to detect significant rises in ground level muon flux associated with solar flares [1,2] as well as the suppression in ground level muons associated with a Forbush decrease [3]. Project GRAND has also observed the daily variations in cosmic rays related to the interplanetary magnetic field (see Figure 2).

Since each plane has 80 signal wires, GRAND has the possibility of a large number of directional channels. These channels can be combined in such a way as to achieve good statistics per channel as well as maintain a high angular resolution. One such proposed method would combine the data into 15 x 15 = 225 directional channels each with a counting rate of approximately 30,000 muons / hour. This particular arrangement makes our data more easily compared to that of other muon detectors, but the fact that we start with angular data of 158 x 158 ~25,000 directional channels means that we can combine these narrow channels in various ways to match other muon detector's channel-widths thus making the data easier to compare as well as increasing the statistics in each of these wider angular channels. Data from Project GRAND can be automatically pressure corrected: $N=N_0\exp[1.2(P-P_0)/P_0]$ where N is the corrected rate, N_0 is the measured muon rate, P is the measured air pressure at that time, and P_0 is a reference pressure. These corrected muon rates can be made available in real time from pressure data which are locally measured and recorded.

Figure 2 shows these counting rate bins of one hour. It also shows a small daily variation which has been enhanced by showing only the top portion of the data. Even though the effect is small (deviations of about +/- 0.7%), the statistics of the muon counting rate makes these deviations significant. These deviations from a uniform muon secondary counting rate from cosmic ray primaries are presumably due to the quiet sun's Interplanetary Magnetic Field (IMF) on the galactic cosmic rays as observed by the secondary muons at ground level. Since these effects are distributed over a substantial portion of the IMF between the sun and the Earth, they have the potential of allowing us to study, on a daily basis, these effects of the solar wind and the IMF for a quiet sun in the absence of coronal mass ejections (CMEs). As we gain more information and understanding of these diurnal variations, they can be applied to forecasting the effects of CMEs arriving at the Earth from the sun. To the extent that the effect is due to the interplanetary magnetic field of the sun, a field which is not static and varies with time, a careful study of these variations with good statistics in the muon counting rate could give us a handle on these effects. It may be possible to get additional information by utilizing the angular data of the muons in addition to their absolute counting rate. Added details and publications for Project GRAND are available at: http://www.nd.edu/~grand.

Forbush decrease of 29 October 2003

As an example of muon data on a Forbush decrease (FD), GRAND's muon data rate for October 29 and 30, 2003 is shown in the upper part of Figure 3. Additional data following the FD show that it takes about nine days to recover to its original counting rate. In order to ensure that the data reflect only physical variations, a cut was performed to select only the best stations for analysis for this event. Angular muon information was also obtained from October 29 to October 30. The average angle in the east-up direction and the north-up direction was calculated. The average angle in the north-up direction is shown in the lower portion of Figure 3. Since an FD is caused by the large coronal ejection which deflects incoming particles when it impacts the Earth, it should be expected that this would cause a deficiency in particles from a particular direction. In the data for the October 29, 2003 event, there is indeed a deficiency in southward originating particles occurring near the time of the sudden decrease.

Worldwide muon coverage

A single ground-based muon detector can only view a portion of the sky and, therefore, not always be in a good position on the Earth to collect data relevant to solar activity at a given time. A sufficiently dispersed worldwide network of muon detectors can monitor all regions of the sky at any given time and therefore be able to provide valuable information throughout the course of a solar storm. GRAND represents a muon station in North America with that capability and, together with stations in Japan, Brazil, Tasmania, Kuwait, and Germany, could make an important contribution to these muon detector stations distributed around the world.

Education, archives, and outreach

Six Notre Dame undergraduate students have participated in research with GRAND and have written three theses. During the summers, undergraduate students from other universities are involved in an REU program, high school students in the REHS program, and high school teachers in the RET program. Their enthusiasm and quick assimilation to the basic analyses tools demonstrate the intuitive nature of the data from these PWC detectors and proves their capability to provide a good learning experience for budding scientists. The archiving of the data on accessible massive disk storage with the collaboration of Prof. D. Thain in the Engineering Department makes the data available to us as well as the high school students and teachers who have worked on the project to be able to do their own research on the data, which they helped collect.

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Figure 1: An aerial view of Project GRAND's muon detector stations.

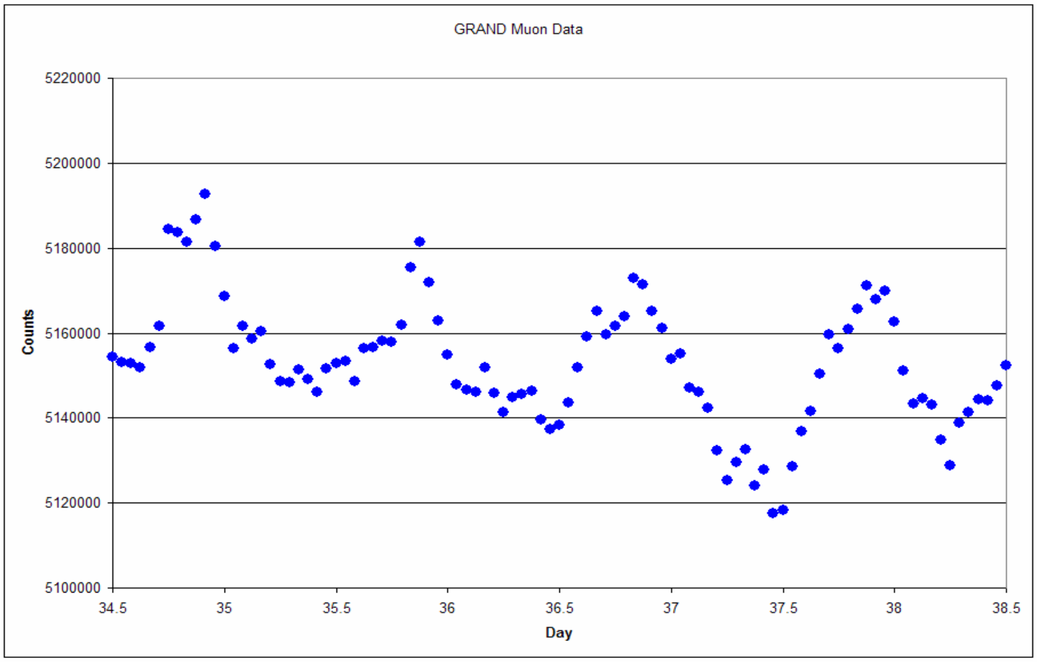

Figure 2: GRAND’s pressure corrected counting rate versus time (EST). Notice the diurnal daily variations which have been enhanced by the suppressed zero. These data will soon be available in real time.

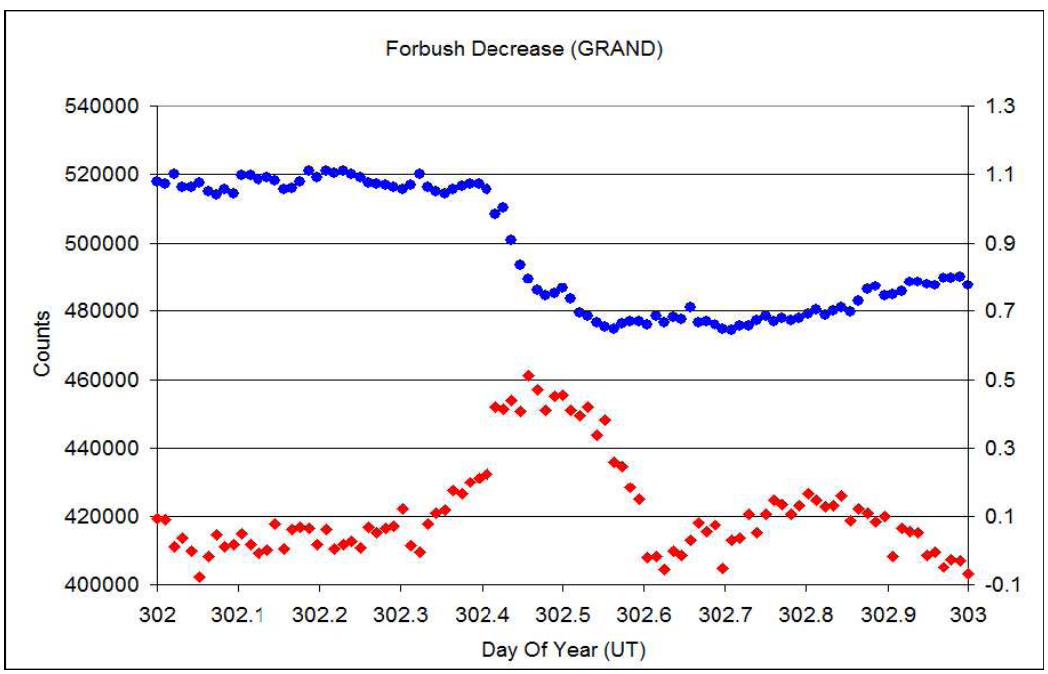

Figure 3: This plot shows GRAND's counting rate (circles, top points, left scale) as well as the mean angle of incoming muons in the north-up projected plane (diamonds, bottom points, right scale). Notice the shift in the angle of origin for particles during the time of the Forbush decrease.

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