# 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 deg W, 41.7 deg N at an elevation of 220 m located near the University of Notre Dame. The 64 detector stations have a total of 82 sq-m of muon detector area. The geometry of the PWC detector stations (four stacked pairs of x and y planes) allows the measurement of charged particle tracks in two orthogonal planes to within less than 0.5 degrees, on average. Muons are 99% differentiated from electrons by means of a 51 mm thick steel plate above the last pair of x and y planes. An overview of the operation of Project GRAND is given.

**Keywords:** muons, detector, array

## 1 Introduction

Project GRAND is a muon array of 64 detector stations near the University of Notre Dame and is located at 86.2 deg W and 41.7 deg N 220 m above sea level [1-4]. The detectors consist of proportional wire chambers (PWCs) manufactured with a winding machine and glass frames making them cost effective and provide precision results. Each gas detector enclosure has an x and a y plane of 80 cells. Four of these boxes are arranged vertically above each other with a 5 cm thick steel plate above the bottom pair which allows muon/electron differentiation to 96% efficiency; given the 4:1 muon:electron ratio at ground level, the muon candidates are therefore 99% pure. The measurement of each incident angle is determined with good resolution (less than 0.5 deg in each of the two perpendicular planes). If needed, the arrival time of the muon is recorded to an absolute precision within milliseconds. The data, initially recorded on internal disk storage, are backed up to an external disk each hour and to a second remote backup disk with a two-hour delay. Data have been collected and archived since 2005 on disk storage and from 1990 on 8 mm magnetic tapes. There is a plan to transcribe these early data on tapes to disk for easier subsequent analyses. The muon array has a second trigger which selects extensive air shower events of muons and electrons; the two types of data are collected at the same time and stored separately. This paper updates a previous status report: Poirier et al. (2007) and references therein. A website contains additional information: www.nd.edu/~grand.

## 2 Experimental array

Project GRAND is an array of 64 proportional wire chamber stations dispersed in an area of 100 m x 100 m in an 8 x 8 grid pattern. The 200 mm of vertical separation between the planes with a PWC cell width of 14 mm gives good angular resolution for each track in two orthogonal planes (x=east-up, y=north-up). The effective muon detector area of a station is 1.29 sq-m for a total muon collection area of 82 sq-m. The array records about 1700 muons/sec (a single-track trigger). The single-track muon data are compacted in real time by recording only the wire numbers of complete tracks (a single x and y hit in every plane). In 1990 this compaction required eight 'fast' computers working in parallel; now it is easily performed with but a single computer. Each muon's time is determined to within a few milliseconds, absolute, by means of a WWVB radio receiver. A quartz crystal clock is used as a backup clock in cases of poor radio reception from WWVB; it can be calibrated absolutely using the concurrent radio data before and after the outage. The experiment also runs with a trigger for extensive air showers (a multiple-track trigger) at a rate of about one Hz.

## 3 Geographical location

For cosmic ray physics associated with solar effects it is important to have muon detectors located at different longitude so that, as the earth rotates, the effect of the sun is visible to at least one detector at any time since solar activity occurs randomly. Figure 1 shows the locations of cosmic ray muon detectors which are now active. The locations of the circles give the longitude and latitude of the muon detector; the area of the circle is proportional to the area of the detector and hence its counting rate.

## 4 Upgrades

Uptime has been enhanced by going from tape to disk data storage, backing up data, using uninterruptable power supplies, and a new software program which enables a replacement external disk to be installed without stopping the data acquisition. A better operating efficiency for the detectors can be achieved by: A) addressing gas leaks in the system that transports the Ar/$CO_2$ gas mixture to the detectors and in the detectors themselves. This includes >300 m of underground tubing and their compression fittings. The low flow rate of the gas mixture and the extended distances for the leaks to occur make finding the leaks difficult. Several new leak-finding techniques will be utilized. B) Humidity in the hut (a 3.4 m x 3.4 m structure housing the PWC detectors) impregnates the Styrofoam insulator between ground and high voltage causing added HV current in the hut's isolation resistor producing a voltage drop to the detector thus lowering its efficiency. If the dehumidifier in the hut has to work too hard in the summer, it raises the temperature in the hut and trips off the dehumidifier so the hut does not overheat. Different methods to seal the Styrofoam against the absorption of water are being examined which would then eliminate the need for the dehumidifier thus solving two problems at once.

The Center for Research Computing (CRC, at Notre Dame) has engineered and provided an archival data storage device capable of storing up to 7 TB of data. Currently it stores data from 2005 to the present (with a two-hour delay). Prior data from 1990 to 2005 are archived on 8 mm magnetic tape. Copying these data on tape to disk storage will begin soon so all of GRAND's archived data, from 1990 to the present, will be online and hence available for presentation on its website for easy viewing and digital transference on request.

## 5 Education and outreach

GRAND's muon array is ideal for student participation and collaborative work. Since ~1989, there have been one to three REU (Research Experiences for Undergraduates) students working on Project GRAND for 10 weeks during the summer months; for the past eight years, two REHS (Research Experiences for High School students), and one to two RET (Research Experiences for Teachers); these "RE" programs are sponsored by the National Science Foundation [8]. For the past four years there have been two to three Notre Dame undergraduate students working on GRAND during the two semesters of the academic school year. It takes the REU students about two hours each week at the experiment changing gas tanks and recording various operating parameters to determine if everything is working properly. These students then spend most of their time analyzing data to extract physics, utilizing and writing the programs to do this work. Conversely the REHS students spend most of their time at the experiment locating and addressing various problems while spending one day a week on campus looking at and analyzing the data.

There have been three undergraduate theses, one master's thesis in Electrical Engineering, and two doctoral theses in Physics utilizing GRAND. Two high school teachers have worked on the experiment's physical structures. There has been a one-hour luncheon lecture on GRAND each summer to all the REU and RET students. At the beginning of each summer session, Calvin Swartzendruber, who has worked as an RET teacher for eight years, gives the entire incoming Notre-Dame class of REHS students an introductory talk on-site at GRAND to explain the detector and its capabilities.

An REU student, Rachel Bergen, wrote the first version of Project GRAND's website. This website presents data and pictures on the project (introduction, the detector array, detector modules, trailer, data acquisition system, in-depth description, publications, vital statistics, recent progress). The website can be found online at http://www.nd.edu/~grand. Calvin Swartzendruber has instituted a valuable addition to this website, "Live Data and Statistics" showing the operation of GRAND for various periods of time: 15 months, 5 weeks, 9 days, or 1.5 days (the latter showing up to the last 10 minutes of real time, invaluable for diagnostic work). Prof. Doug Thain from Notre Dame's Department of Electrical Engineering and two of his graduate students instituted another website; with the help of CRC it has now been converted to: https://grandbackup.phys.nd.edu. By logging on to this website and clicking "Dayfiles", one can select the total muon rate for selected periods of time from late 2005 until the present, with or without corrections for air pressure. In addition, a single hut's data can be displayed or all 64 huts at once, individually displayed. The data are displayed visually, making it easy to analyze from a remote site; these data can also be obtained digitally from the website. GRAND's cosmic ray data of muon rates, are easy to visualize and analyze, thus making it a natural vehicle for an outreach program.

## 6 Ground level enhancement January 2005

GRAND has previously published data on the 20 January 2005 GLE [5] which has been used in analyzing the multiple-component structure of this solar event [6]. Since the timing is important in this analysis, these data was reanalyzed in smaller time bins. Each muon is tagged with a time referenced to WWVB, the radio time standard of the U.S. In Figure 2 these data are displayed in 15-second wide bins; smaller time bins become more dominated by statistical errors. The FWHM width of these data for this GLE is three minutes. These data have been statistically enhanced by selecting angles near vertical [5]. This enhancement is possibly due to the lower than average energy of the solar protons and/or their preferred direction.

## 7 Forbush decrease of October 2003

The decrease in total muon counting rate at GRAND for October 29 and 30, 2003 is shown in Figure 3 [7] which shows ~8% rapid decrease in counting rate with the beginning of the more leisurely subsequent rise. The figure below this shows the mean *angle* of the muons during this same time frame. The upper, diamond points are the mean muon angle (in degrees) projected to the north-up plane; the lower, square points are the same for angles projected to the east-up plane. Although the angular change is very small (0.5 degree for the upper, north-up plane, points and somewhat smaller for the lower, east-up, points), it is obtained by averaging the angles of ~0.5 million muon angles making even this tiny effect statistically significant. It is also correlated with the rapid decrease in the counting rate of the muons; the time position of the mid-down point in muon rate is closely associated with the mid-up point in the muon angle. This is possibly the first direct proof that the decrease in cosmic rays is due to the charged cosmic rays being deflected in angle by the magnetic fields contained in a coronal mass ejection as it nears the earth.

## 8 Acknowledgments

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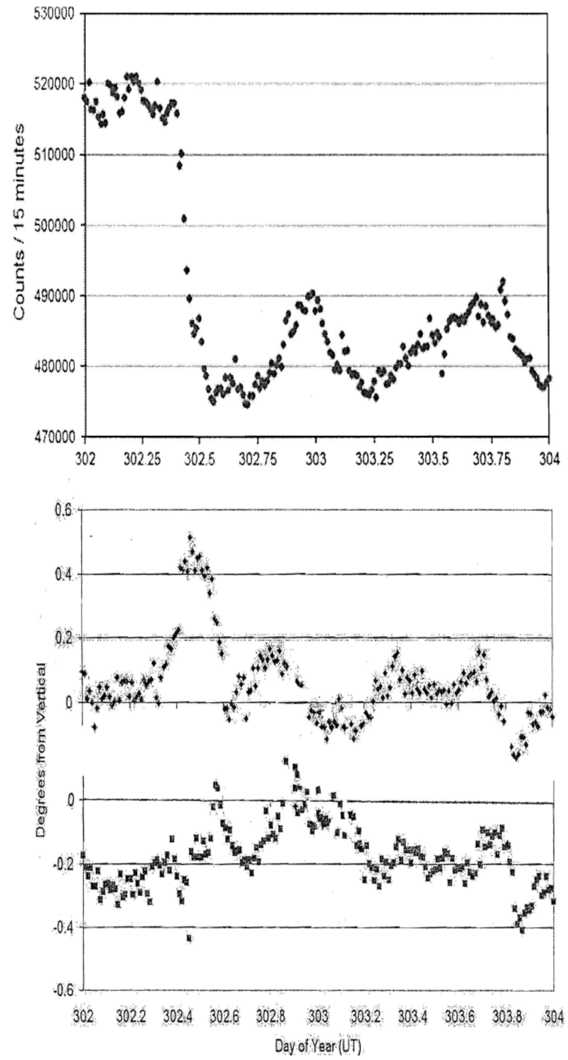
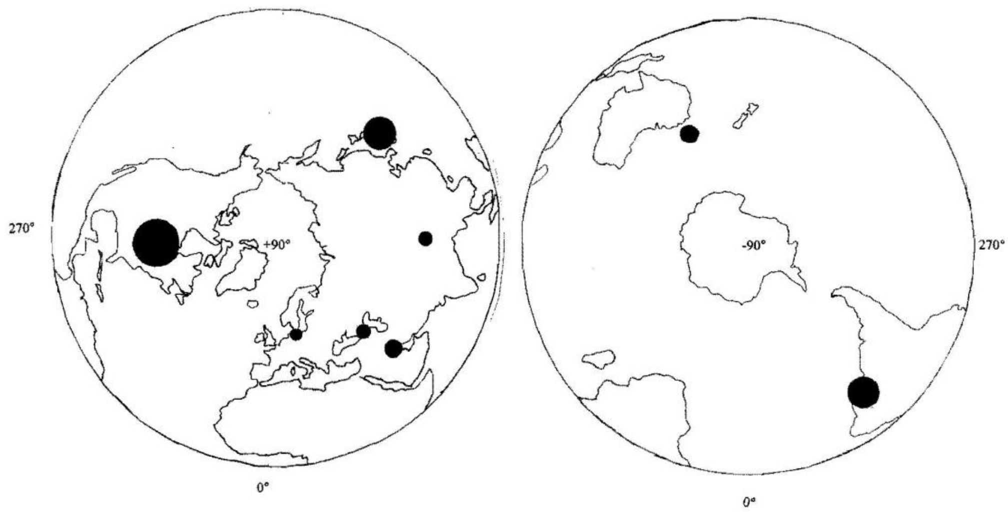



Figure 3.
*Upper figure:* shows GRAND's counting rate for the October 29, 2003 Forbush decrease from day-of-year 302 to 304. GRAND's total counting rate dropped by 8%.
*Lower two figures:* show the mean angle of muons for the same period of time. Diamonds (upper points) show the mean angle in the north-up projected plane with vertical muons = 0 degrees. There is a 0.5 deg change in the mean direction in the north-up plane during the time of the Forbush decrease, indicative of a deficiency in the south caused by the deflection of the cosmic rays by the coronal mass ejection's magnetic field. Squares (lower points) show the mean angle of muons in the east-up projected plane.




Northern Hemisphere Southern Hemisphere

Figure 1: Map of cosmic ray muon detector locations around the world. Circles indicate geographical positions within the earth's equator); angular position from 0-deg (bottom) represents the detector's longitude; latitude is represented by the linear distance from the equator toward the center which is the North Pole at +90 deg (Northern Hemisphere), or the South Pole at -90 deg (Southern Hemisphere). The area of the muon detector is represented by the area of the circle and is proportional to their counting rates. Northern hemisphere detectors are in order of longitude: Germany (Europe), Kuwait (Persian Gulf), Armenia (Middle East), Beijing (China), Nagoya (Japan), and GRAND (North America); Southern hemisphere, right figure: Hobart (Tasmania) and San Martinho (South America). Uniform worldwide coverage allows the sun to be seen 24 hours a day.

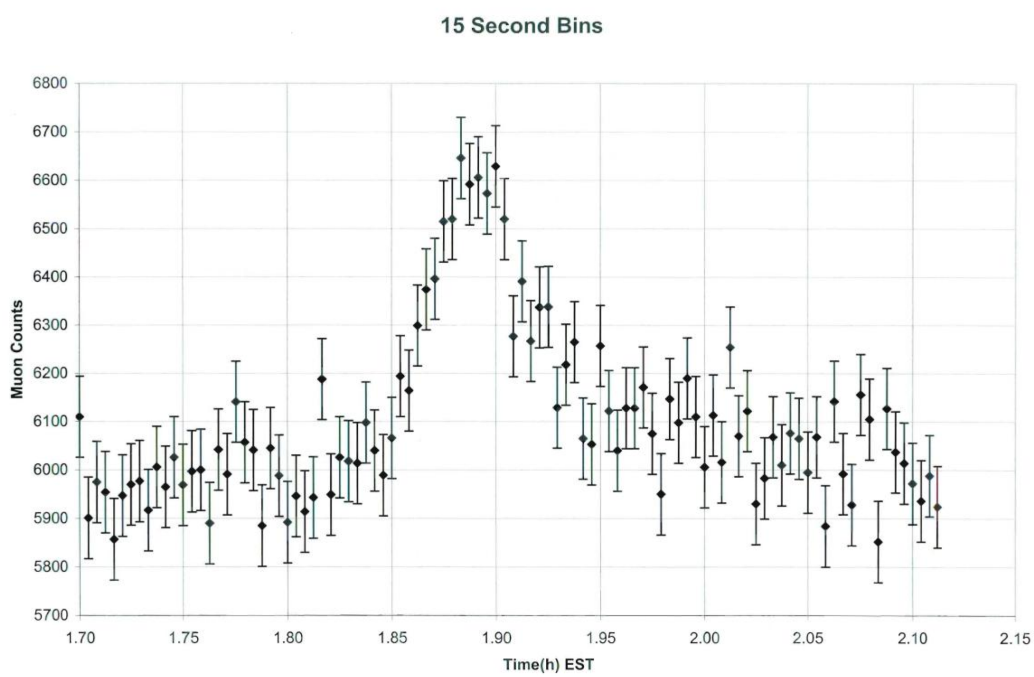



Figure 2. GRAND's muon data in EST (UT-5) showing the time details of the GLE of 20 January 2005 in 15-second wide time bins. The data are for muon angles near vertical [see 5] which yield a better signal/background ratio.