A Small Geiger Counter Array

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The Balloon Assisted Stratospheric Experiments (BASE) program at DePauw University has flown Geiger counters on more than forty flights since November 2006. Currently, three RM-60 Geiger counters from Aware Electronics are used in the array. The signal from each counter is fed to a 555 based one-shot circuit to produce a clean pulse. The pulse outputs are processed by an array of Basic STAMP microprocessors from Parallax Corporation. Data is stored in the non-volatile memory of each STAMP microprocessor.

I. Introduction

Geiger counters are simple devices that produce an electrical pulse whenever energetic particles ionize the gas inside the tube. It is possible to produce portable Geiger counters that are suitable for use in high altitude balloon experiments that are carried aloft by latex weather balloons. During our first flights we flew modified PASCO student Geiger Counters. These counters required significant modifications and it was difficult to keep the actual Geiger tube stable during the chaotic portions of the descent on many flights. Subsequently we moved to using the AWARE Electronics RM-60 Geiger counter that is very rugged and easily modified for remote data collection.

Our system is based on recording counts for either 30 or 60 seconds and recording the count totals into non-volatile memory on single board microprocessors. To keep the system simple, we decided to use the Basic Stamp Homework Boards from Parallax.com. These boards have a small bread board section on which we constructed the 555-based one-shot circuit. These boards have sufficient memory to allow storage of 960 values, where each value is stored in two bytes. On some flights a single board processed signals from two Geiger counters in a coincidence array with a data storage limit of 360 sets of values, for a total data collection time of about 5 hours.

The array has successfully detected the Pfotzer Maximum.[4] The seasonal variation of this maximum has been investigated. Additionally, the array has provided evidence of the zone in the stratosphere where energetic particles are produced. The behavior of Geiger counters in the presence of lead shielding is described. Preliminary efforts to use the array to investigate electromagnetic showers in lead, as originally studied by Rossi[5], are shared.

II. Geiger Counter Arrays

We have flown two different arrays of Geiger counters. The Geiger tubes that we use are approximately 2 centimeters in diameter and about 5 centimeters long. An RM-60 is a rectangular package approximately 10 centimeters long, 8 centimeters wide, and 4 centimeters tall. The earliest flights flew pairs of counters.[6] During the last few years we have begun to fly arrays with three Geiger counters.[7] The dual counter arrays can be oriented horizontally or vertically as shown in Fig. 1. The three Geiger array may be arranged orthogonally as shown in Fig. 2[8] or in a triangular arrangement, corresponding to Rossi's configuration, as seen in Fig. 3.[9] The orthogonal arrangement in Fig. 2 allows us to collect our dual axis coincidence data with just three Geiger counters.

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[4] Gaisser, Thomas K., **Cosmic Rays and Particle Physics,** p. 44, Cambridge University Press, 1990.
[5] Rossi, Bruno Benedetto. **High-energy Particles** New York: Prentice-Hall, 1952.
[6] BASE Flights 2-24 used dual counter arrays
[7] BASE Flights 28-56 used three counter arrays
[8] Flown on flights 28-49.
[9] Flown on flight 50-56.

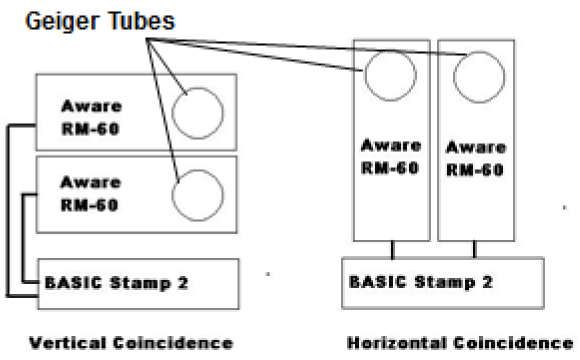

Figure 1. Dual Geiger Counter Arrays *Block diagrams of dual Geiger counter arrays*

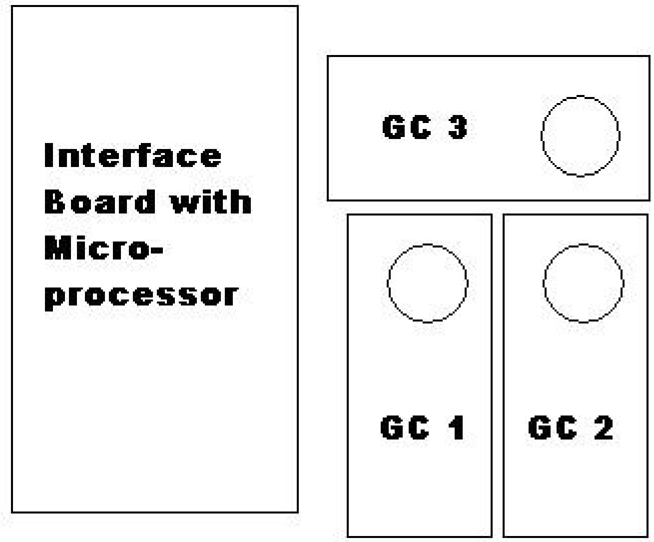

Figure 2. Orthogonal Three Geiger Counter Array *Block diagram of three Geiger counters in an orthogonal array. Horizontal coincidences measured by GC1 and GC2. Vertical coincidences measured with GC2 and GC2.*

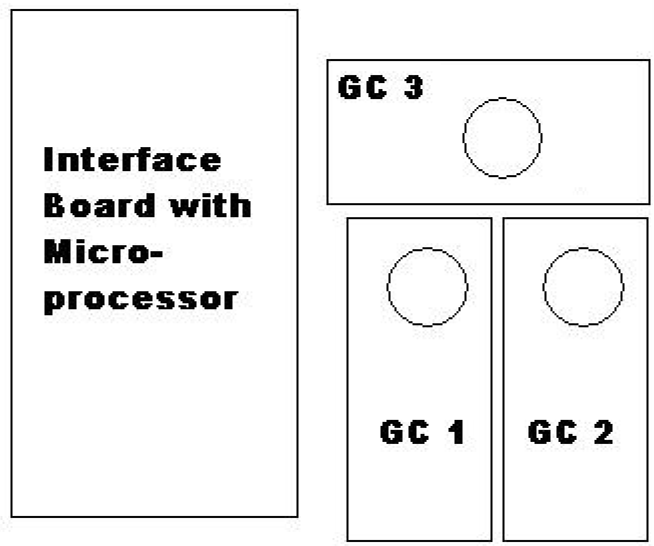

Figure 3. Triple Geiger Counter Array for studying showers. *Block diagram of three Geiger counters in non-orthogonal alignment.*

III. Geiger Counter Signal Processing

The Geiger counters produce a voltage spike whenever the gas inside the tube is ionized by an energetic particle. To insure accurate counting of the spikes a simple one-shot circuit is used with the 555 integrated circuit (see Fig. 4). The output line from the timing circuit serves as the input to the BASIC programs that collect the data and record the number of counts from a single Geiger tube or the number of coincidences of counts from multiple tubes. A coincidence occurs whenever two or three Geiger counters ionize at the same time. Since the Geiger tubes are very close to each other, the transit time between tubes for a single energetic particle is negligible. The RC time constant must be kept shorter than the counting period to avoid extra counts. If the time constant is too long, then it is possible that a single event could be counted more than once. The timing becomes a more important issue for the coincidence counters. Obviously long time constants could produce false coincidence signals since the two Geiger counters may not have triggered at the same moment, but the 555 circuits could show both counters as having fired at the same time.

The BASIC Stamp does not have an internal clock and the determination of the timing period was done experimentally. The complexity of the instructions in the program affects the timing of the circuit.

The challenges of determining the counting period for each software program has inspired us to consider an alternative data collection system using a microprocessor with an independent clock. Preliminary work to convert to a PicAxe microprocessor with an independent crystal clock has begun.

IV. Flight Data

The simplest experiment that we conduct is to add the total Geiger counts from all counters during a flight. A set of typical data is shown in Fig. 5. The increase in counts per minute is significant anud the data clearly show that the total counts per minute decreases at the highest altitudes.

Fig. 6 shows the values of the altitude at which the count rate is maximum for flights throughout the year. The abundance of data in June and July is attributed to the work of other DePauw students during the summer as part of the Science Research Fellows program. The scarcity of flights in January, February and December are related to the cold winter weather and the strong tropospheric and stratospheric jet streams that are generally aligned. The wind speeds may exceed 200 kilometers/hour. Flight paths can exceed 500 kilometers. If we cannot put a tracking and recovery vehicle downrange from the launch site, it may be difficult to stay in contact with the flight string. BASE 19, whose data is shown in Fig. 5, lost radio contact with the ground crew, but was recovered six weeks later with the data safely stored onboard the microprocessors. Although there is no indication of a seasonal variation in the Pfotzer maximum, many more flights need to be completed, particularly in the fall, winter, and early spring months.

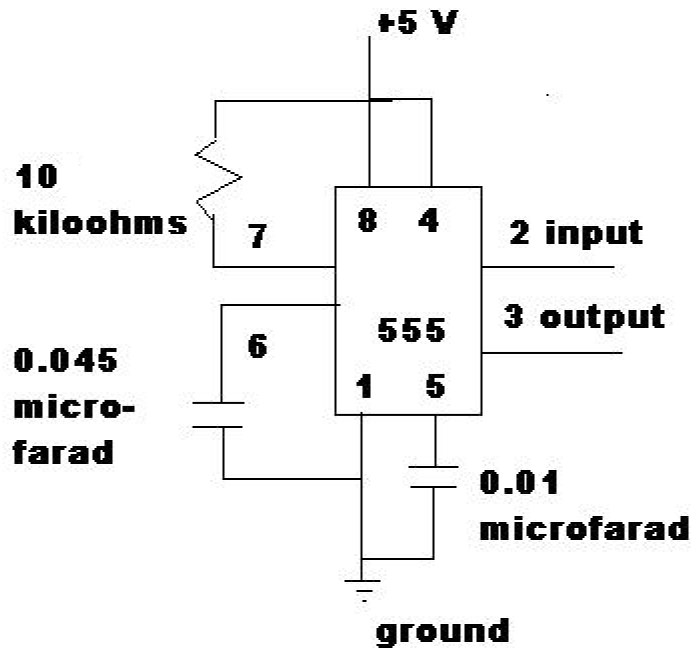

Figure 4. 555 One-Shot Timing Circuit *Schematic diagram of 555 timing circuit. Input from Geiger counter goes into pin 2 and output to counting program comes out on pin 3. The RC time constant is determined by the resistor on pin 7 and the capacitor on pin 6.*

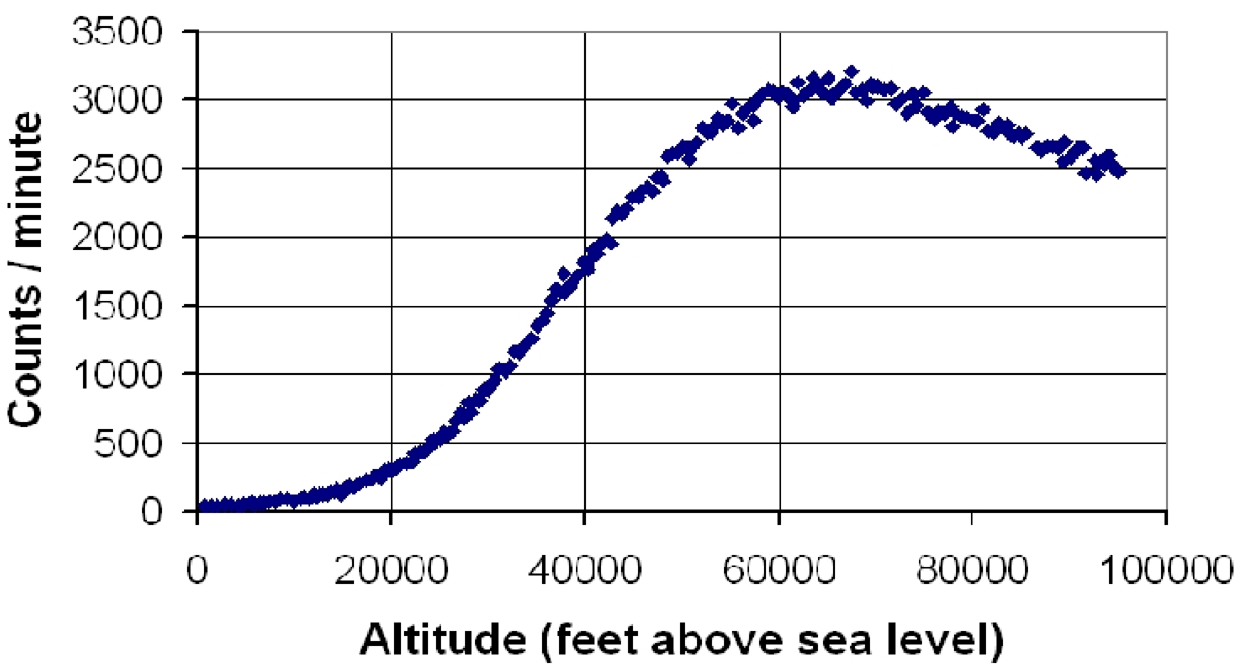

Figure 5. Geiger counts versus altitude *Data from BASE 19 flight showing total Geiger counts versus alitude. The peak count rate occurs at an altitude between 60,000 and 70,000 feet. This peak is known as the Pfotzer Maximum.*

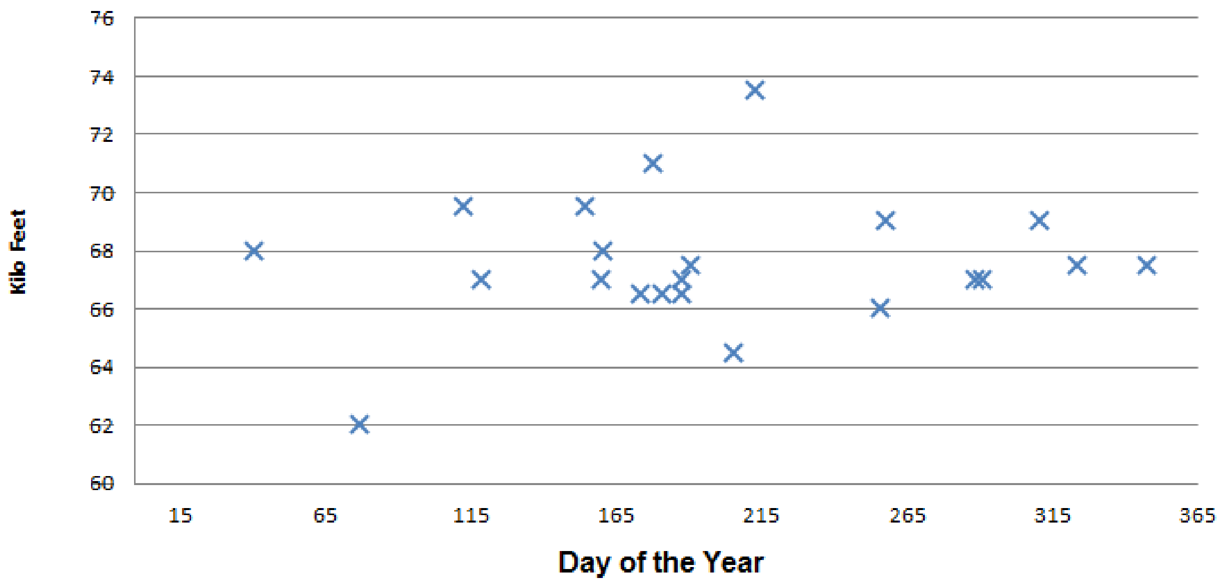

Figure 6. Pfotzer Maximum Altitude throughout the year *The data shows the altitude of the Pfotzmer Maximum for several flights. Day 15 is January 15, There have been few flights during the winter because of the long flight paths that occur with the strong stratospheric jet stream during that time of the year.*

We have also obtained very consistent results with our dual coincidence Geiger counter arrays. Fig. 7 shows sets of vertical and horizontal coincidences from a flight. The data for this chart was created by averaging the counts per minute for five consecutive minutes and plotting the resultant average with error bars of +/- one standard deviation at the altitude of the flight string in the middle minute of the averaged values. Most of the error bars are smaller

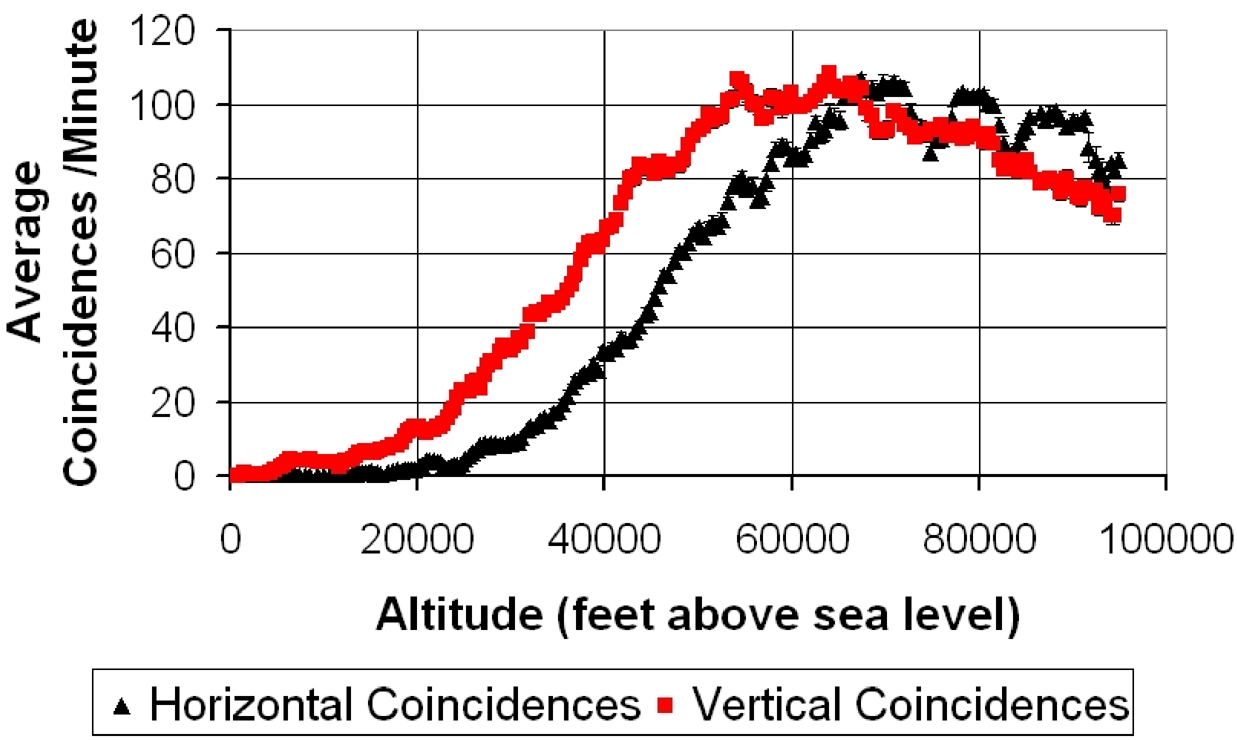

Figure 7. Dual Geiger counter coincidences as a function of altitude from a typical flight. *The coincidence data in average counts/minute shows a similar trend to the single Geiger counter data in Fig. 5. Note that the horizontal coincidences occur less frequently until the Geiger counters reach the portion of the stratosphere where the Pfotzer maximum occurs.*

than the symbols. The plot shows that the number of each type of coincidence is much larger in the stratosphere than on the surface. On the ground vertical coincidences are ten times more likely than horizontal coincidences. As is seen in Fig. 7 the horizontal coincidences become as frequent as the vertical coincidences in the lower stratosphere. The simplest explanation is that the energetic particles that cause the coincidences travel in all directions from their production point in the atmosphere. When the Geiger counters are near or in the production zone of these particles, the coincidence rates are essentially the same. The relative abundance of vertical coincidences at the surface supports the idea that horizontally traveling energetic particles fail to make it from the production zone to the Geiger counters since the path length that these horizontal particles travel is so long. Fig. 7 also shows a slight tendency for the horizontal coincidences to exceed the vertical coincidences at the highest altitudes. More data must be collected to confirm this distinction.

During the spring and summer of 2010, DePauw students investigated the impact on lead shielding on the count rates recorded by single Geiger counters. We expected that the lead would decrease the number of counts recorded by the Geiger counters. More lead would result in even fewer counts. The students hoped to find the amount of lead that would effectively eliminate the Geiger counts. It was anticipated that more lead would be needed to stop the counts in the stratosphere, where there are more energetic particles. The initial arrangement of lead shielding is shown in Fig. 8 where the entire RM-60 Geiger counter wrapped in lead sheet. Since we always fly FAA exempt flights, we must keep the weight of a single payload pod below 2.7 kilograms. This restriction limited the total thickness of the lead sheet to surround the box to 4.1 millimeters. To reduce the total weight while increasing the amount of lead surrounding the Geiger tube, the clips securing the tube to the circuit board were removed and the tube was rotated 90 degrees. A hole was drilled in the upper cover of the RM-60 box to hold the lead around the tube that no longer fit inside the original container. A picture of this modified Geiger counter is seen in Fig. 9.

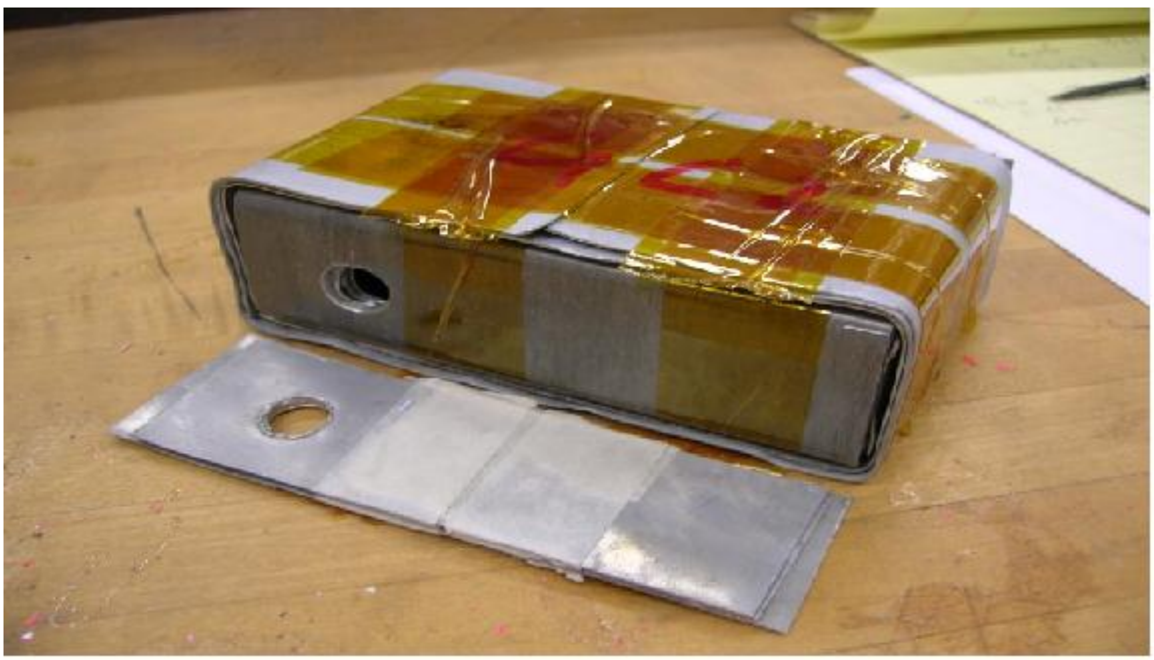

Figure 8. Lead sheet enclosing the entire RM-60 Geiger counter. *In 2010, DePauw students began a study of the effect of shielding the Geiger counter with lead.*

Tests on the ground showed a decrease in the count rate as the amount of lead shielding the tube was increased. However the results from our balloon flights were quite different. Fig. 10 shows the data from BASE 42 where three Geiger counters were flown. This plot shows the count rate versus time. The counters were started before the launch. For clarity the first 60 minutes of the count record are not shown. The "M" shape in the data results from the flight string passing through the Pfotzer maximum at the first peak of the "M". The burst occurs at the low point in the top of the "M", and the second peak happens as the flight string falls down toward the earth. The asymmetry of the two humps of the "M" is explained by the slow ascent on a filled balloon and a rapid descent after the balloon

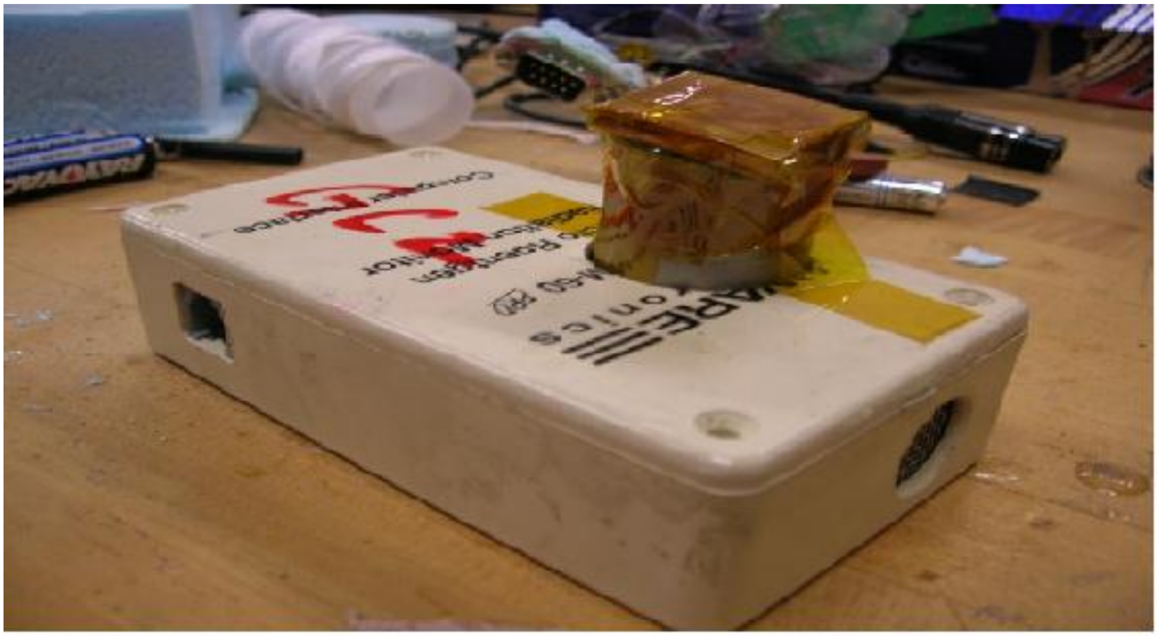

Figure 9. Modified RM-60 Geiger counter with lead shield *The tube is rotated 90 degrees and the lead wraps only around the tube.*

bursts. Eventually the parachute begins to slow the descent and the lower legs of the "M" are similar. The more significant result shown in Fig. 10 is that when at altitude the counts actually increased as the amount of lead increased.

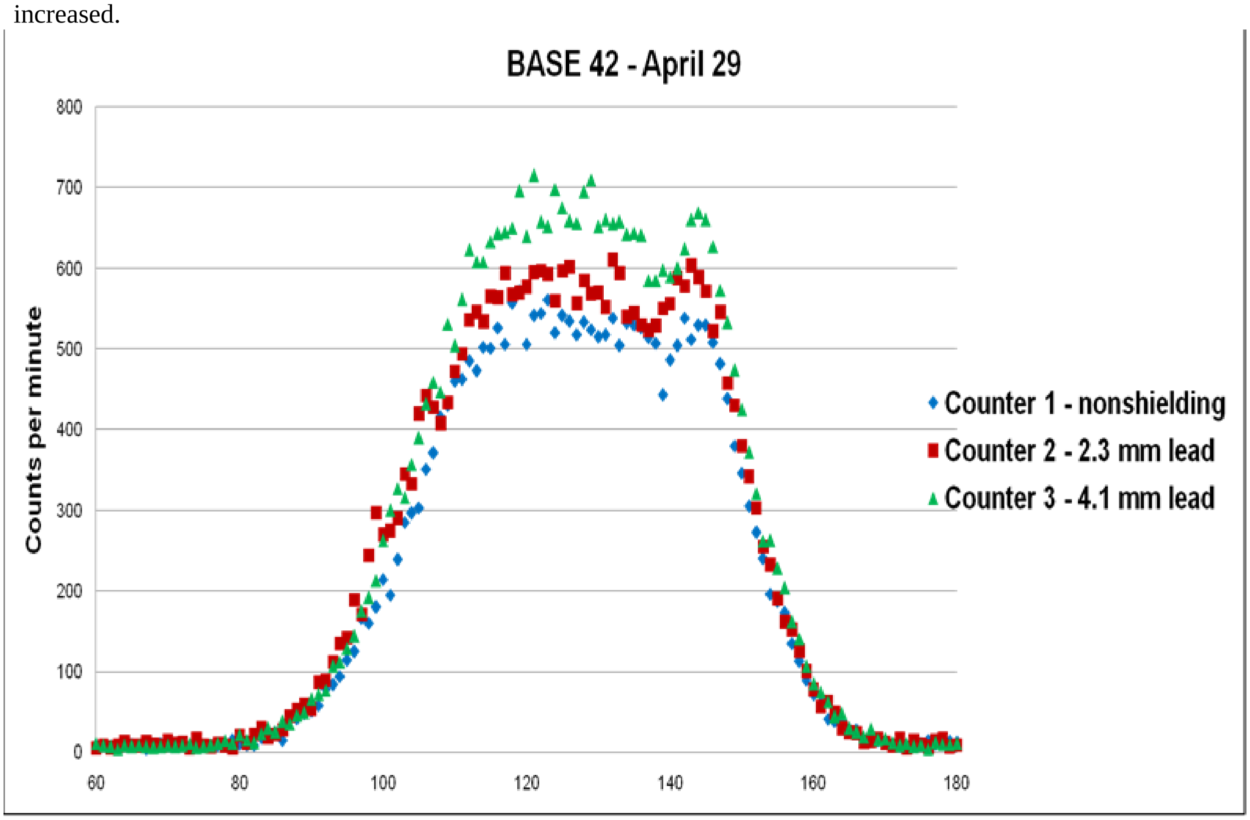

Figure 10. Counts per minute versus time (in minutes) for lead shielded Geiger counters. *Launch occurred at minute 60 with the burst just before minute 140. Note the much higher count rate for the thickest lead shield during the time that the Geiger counters were in the stratosphere.*

These results arise from electromagnetic showers that are produced in the lead by the atmospherically produced energetic particles. Bruno Rossi conducted a ground based study with larger Geiger tubes that showed this same effect.

In the Fall of 2010, a new array of three non-orthogonal tubes was assembled. Rossi's results showed a maximum triple coincidence rate when the lead thickness was between 1 centimeter and 2 centimeters. Our ground tests show a similar trend, however our total counts are much smaller since we have smaller Geiger tubes. To compensate for smaller tubes, we have increased our data collection time. The typical counting period is 7.5 minutes for a total record time of 120 hours. The initial flight tests suffered from an array of unrelated mishaps that have delayed our data collection efforts. It is anticipated that we will gather a comprehensive set of flight data for lead coincidences this summer.

V. Conclusion

Geiger counter arrays are simple to use in small weather balloon carried flight strings to investigate the nature of energetic particles in the stratosphere. We anticipate the continued development of our arrays as our studies progress.

Acknowledgments

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