A SEARCH FOR HEAVY LONG LIVED PARTICLES IN HIGH ENERGY COSMIC RAYS

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ABSTRACT

We present the results of an experimental search for energetic particles which arrive at sea level delayed with respect to the shower front, with an order of magnitude greater exposure than previous experiments. The experiment was sensitive to showers from cosmic rays between 10^5 and 10^7 GeV per nucleus. No evidence for the existence of heavy long lived particles in air showers was found. We set an upper limit to the flux of these particles at the 90% confidence level of 1.4×10^{-12} $cm^{-2}sr^{-1}s^{-1}$.

1. Introduction. The experimental search for heavy long lived particles such as heavy leptons, heavy quark matter, super-symmetric particles and magnetic monopoles is of great current interest. The cosmic ray beam may provide particles with sufficiently high energy to produce such objects by their interactions in the atmosphere. It is also possible that the cosmic ray beam may contain heavy stable particles of very large mass ($\geq 10^3$ GeV) as a minor component. Heavy cosmic rays, such as these would have escaped detection in searches for ultra heavy nuclei if they had a small net charge.

Several cosmic ray experiments have been carried out to search for such particles. The technique used is to detect energetic hadrons delayed with respect to the fast electrons ($\beta = 1$) in the air shower.[1-3] In the delayed particle experiments a search is made for the presence of a substantial signal in scintillation counters placed inside a calorimeter which is delayed with respect to the shower front by a time interval in the range 20 ns $< \tau <$ 200 ns. We have carried out a new experiment at sea level to search for delayed large calorimeter signals with a total exposure factor ~20 times greater than previous experiments.

2. Experimental Technique and Data Sample. (A) The arrangement: A set of 12 unshielded counters was used to sample shower particles and determine the times of arrival of the shower front. Eight of the shower counters were of 0.36 m^2 each and had a thickness of 7 cms of liquid scintillant. The counters are labelled S_1 through S_8 in figure 1 which shows a plan view of the experimental layout.[5,6] The remaining four counters, labelled A_1 through A_4 were placed directly over four calorimeters which sampled the hadrons in the shower. These counters were 0.64 m^2 in area and had 1.25 cm thickness of NE(102) scintillators. The apparatus was located in College Park, MD, at sea level. Counters were placed in the calorimeter at several depths to sample hadronic cascades. The longitudinal depth in radiation lengths of the counters for the two configurations is given in Table 1. We note three features of the design: (1) The top absorber consisting of 2" of Pb and 6" of Fe has sufficient number

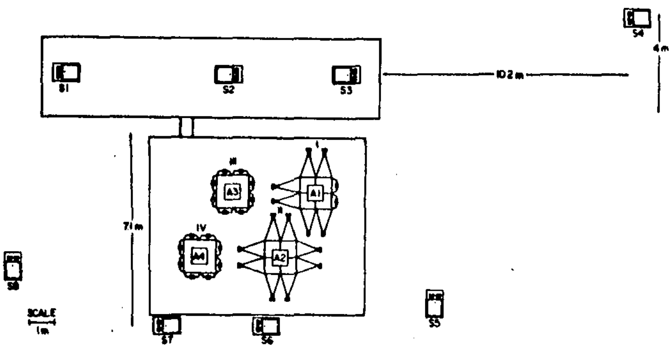

Figure 1: Experimental layout

Table 1

Calorimeter Profiles

Counter	Material	Size	Depth(in radaition lengths) Calorimeters I,II,III	IV
A	Ne 114	22" x 44" x 1/2"	0	0
T	Ne 102	24" x 24" x 1/2"	-	17.7
B	Ne 114	24" x 24" x 1/2"	17.7	17.7
C	Ne 114	24" x 24" x 1/2"	19.9	17.9
E	Ne 114	22" x 44" x 1/2"	37.2	35.1
D	Liquid Scintillator	24" x 24" x 1/2"	37.2	35.1

of radiation lengths to absorb the electromagnetic component of the air shower so that the B counters will not be triggered by the shower front. (2) The absorber in the first layer extends 25.4 cm beyond the B and C counters in all lateral directions so that EM component from side showers won't trigger them and (3) that each detector layer is divided into four quadrants in order to allow a measurement of the lateral spread of the hadronic cascades. (B) The trigger: The experiment was triggered when two conditions were satisfied: (1) The sum of the signals from the B and C counters in at least one of the calorimeters exceeded 70 equivalent particle levels and (2) there was a signal in two A counters in "coincidence" with the B + C pulse. In order to study delayed hadrons near cores of air showers further off line cuts were made. These required that the average signal in the A counters corresponded to eight particles or a density of 13.6 ptls/m^2 and a signal in B + C counters of one calorimeter was greater than 75 particles. At least two A's were required to have this density. (C) The data: In 9266 hours, 179,102 events triggered the array. Of these events, 29,182 passed the off line cuts. For each event we calculated the time difference between the arrival times of B and/or C counters from that of the A counter immediately above the calorimeter associated with the B and/or C counter. Most of the hadrons arrive in time with the shower. Two percent of the events have at least one counter delayed by greater than 20 ns. The majority of these events have S $\leq$ 20 equivalent particles.

The 72 large signal, large delay (called LSLD) events can be divided into three classes: (1) Single Counter Delays (SCD): large signal in a single counter with little or no energy deposited in neighboring counters separated by as little as 1gm/cm^2. (2) Single Quadrant Delays (SQD): large signal in one B or C counter with delay, with other B or C counters also delayed in the same quadrant. (3) Multiple Quadrant Delays (MQD): a large signal delayed counter and at least one counter in another quadrant delayed. Among these events, the most promising candidates for the presence of an energetic delayed hadron are those where some penetration by the cascade is evident. There were 27 events of this type.

3. Simulation of the Experiment and Analysis. In order to determine the significance of these 27 events (whether they might indicate the presence of an unusual particle as discussed in the introduction), a four dimensional Monte-Carlo simulation of the atmospheric cascades was carried out. These calculations used a particle production model which was based upon Fermilab, CERN.ISR and SPS-$\bar{P}$P collider data, an increasing cross section for hadron-air inelastic processes and a superposition model for primary nuclei other than protons. The program records the energy, position and arrival time for those hadrons which cross the detector altitude. Each π^0 is decayed into 2γs and the electromagnetic cascade of each γ-ray is calculated in approximation B and its contribution to shower density at the location of each hadron is obtained using a modified Nishumara-Kamata-Greisen lateral distribution.[6]

In simulating the actual trigger, the response of the calorimeter counters to hadrons, muons and electrons incident upon the calorimeter was simulated.

To determine response at low energies we exposed a prototype calorimeter to low energy (1 to 10 GeV/c π and p) hadron beams at the AGS test beam in order to study fluctuations in cascade development. We were able to measure fluctuations in the observed pulse height in the calorimeter counters at different depths to 10^{-4} to 10^{-5} level.[7] At higher energies we used data obtained at Fermilab[8] in a calorimeter with counters at depths similar to our B and C counters. A detailed Monte-Carlo simulation of hadronic cascades was done using the Oak Ridge code of T. Gabriel[9] to understand the observed fluctuations and to provide "Monte Carlo data" to use in our simulations at energies where no actual experimental data was available.

These measurements and calculations show that low energy hadrons which can arrive delayed, occasionally give a much larger than average energy deposit in the detector counters giving rise to abnormally large signals. Our calibration and subsequent calculations showed that 7 percent of 3.5 GeV hadrons give a signal greater than 20 equivalent particles while 0.2 percent give a signal greater than 50 equivalent particles.[7,9]

The Monte Carlo program was run on a set of incoming primaries of different nuclear species and picked according to energy spectra (typically $E^{-2.6}$) based upon different models.[10]

4. Discussion and Conclusions. We have carried out simulations for the distribution of pulse heights for delayed events generated by proton and iron primaries. The predicted distributions are shown in figure 2. We note that the distribution shape is essentially the same for the two species. Therefore the flux limit derived below is independent of the nature of the primary.

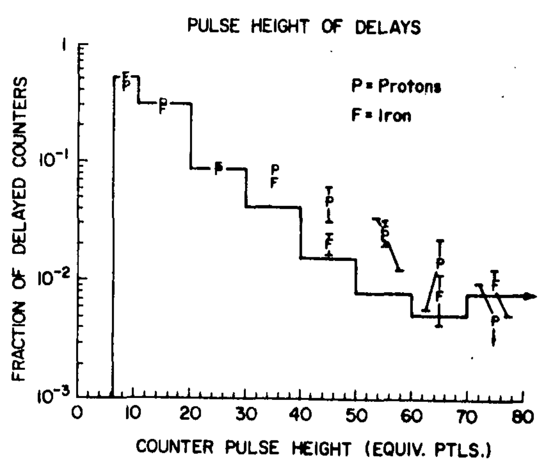

Figure 2: Predicted and measured (solid line) signal distributions for delayed events

We have compared the data with the signals predicted for a composition obtained from a rigidity confinement model of cosmic ray propagation.[11,16] The observed distribution can be accounted for both qualitatively and quantitively without the need for the presence of either new particles or processes. In Table 2 is shown the relative fraction of large signal events in each of the three categories. Good agreement is seen.

Table 2

Comparison of Observed and Simulated Delayed Events

Event Type	Fraction(%) Data	Simulated
Single Counter (SCD)	56 ± 9	41 ± 9
Single Quadrant (SQD)	24 ± 6	31 ± 8
Multiple Counter (MCD)	20 ± 5	28 ± 8

We calculate the upper limit to the flux of "Massive Long Lived" particles, ϕ, from the observation in Section 2 that no events of the SQD or MQD type were seen to penetrate into the D counters giving a pulse height larger than one particle (see Table 2). From our Monte Carlo we can estimate that 54 percent of all signals generated by 20 GeV incident hadrons should give ≥ 2 particle signal in D if they generate 20 particle signal in B + C. Therefore since none were observed we estimate at the 90 percent confidence level that we have a flux of less than 2.3/0.54 particles in 9266 hours with an area solid angle factor of 9.4 m^2sr, $\phi \leq 1.4 \times 10^{-12} cm^{-2} sr^{-1} s^{-1}$.

We remark that the large signal delayed events seen in a recent experiment reported by a Japanese group[11] and all other previous experiments can be explained in terms of fluctuations in cascades from low energy delayed hadrons in air showers.

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