Energetic delayed hadrons in large air showers observed at 5200m above sea level

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ABSTRACT

Energetic delayed hadrons in air showers with electron sizes in the range $10^{6.0}$ to $10^{9.0}$ have been studied by observing the delayed bursts produced in the shield of nine $4m^2$ scintillation detectors in the Chacaltaya air-shower array. The frequency of such delayed bursts is presented as a function of electron size, core distance and secθ.

1. Introduction

The Bolivian Air Shower Joint Experiment (BASJE) group carried out a series of measurements of the arrival time distributions both of muons in air showers with primary energies above 10^{17}eV and of atmospheric Cerenkov light from air showers with primary energies from 5×10^{15}eV to 2×10^{17}eV in the Chacaltaya air-shower array ($550gcm^{-2}$ atmospheric depth, 5200m above sea level). On the basis of these measurements, we concluded that the longitudinal developments both of muons and of electrons at the early stages are consistent with those expected from very high multiplicity models of particle interactions(1)(2). This conclusion is supported by measurements of the arrival time distributions of muons and of atmospheric Cerenkov light in the Akeno air-shower array ($930gcm^{-2}$ atmospheric depth, 900m above sea level) by the Tokyo Institute of Technology group using the almost same apparatus as used in the Chacaltaya array(3)(4).

Furthermore, high-energy delayed hadrons in air showers have been studied in the Chacaltaya array to examine whether the character of the multiple production of nucleons and anti-nucleons in high-energy interactions is also consistent with this conclusion, and to obtain an information on unknown heavy particles which may be produced in high-energy interactions. These delayed hadrons were observed as delayed bursts produced in the shield of nine $4m^2$ scintillation detectors in the Chacaltaya array.

In this report frequencies and delay time spectra of these delayed bursts are presented for air showers with electron sizes in the range $10^{6.0}$ to $10^{9.0}$.

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2. Experimental

The observation started in May 1982. The shield of detector is composed of 231gcm^{-2} of galena (PbS ore), 132gcm^{-2} of concrete and 23gcm^{-2} of lead. The signal from a 5in fast photomultiplier (Philips XP2040) in each detector was fed to an adding circuit. This combined signal was stored in a 100MHz storage oscilloscope (Tektronix 466) by local trigger signal generated when at least 7.0 particles passed through an unshielded 0.83m^2 detector just above the central 4m^2 shielded detector (this trigger level was changed to 3.0 particles from October 1982) and at least 3.5 particles passed through five shielded detectors out of nine. When this local trigger signal coincided with a master signal from the array, which observed an air shower with electron size above $10^{6.0}$, the stored signal was photographed. The time response of the whole system was 4.5ns in rise time between 10% and 90% of the signal and 12ns in full width at half maximum (FWHM).

3. Analysis

About 12,400 showers with electron sizes (N_e) above $10^{6.0}$ and secθ (θ: zenith angle) from 1.0 to 1.8 were observed until October 1983.

The delayed burst produced by a high energy hadron was picked up primarily when the burst was recognized as a separate delayed peak in the signal. Moreover, in order to avoid a contamination of apparent delayed signals due to fluctuation in the arrival times of muons, following criteria were requested for further screening:

(1) The burst size (n_b) is larger than 15 particles.

(2) The value of FWHM of the delayed signal is shorter than 20ns.

Since the number of particles was measured simultaneously using a 16in photomultiplier (DuMont K1328) in each 4m^2 scintillation detectors, the signal was accepted as the delayed burst finally when the number of particles contained in the separate delayed peak was equal to the number of particles of burst recognized from the pattern of the numbers of particles measured in nine detectors within the uncertainty. The delay time of the burst was measured from the particle front in the photograph.

The distribution of sizes of bursts produced by hadrons with energies E (GeV) were already calculated for the BASJE shielded detector(5) (6). And the average n_b is given by E/1.0GeV.

The delayed bursts were classified by N_e, secθ and core distance (R) into bins whose ranges were 0.5 in $\lg N_e$, 0.2 in secθ and 50m in R, respectively.

4. Results

Since the frequency of bursts is almost independent of secθ from 1.0 to 1.8, the results are presented by combining all of data in each bins of secθ. Figure 1 shows an example of delay time spectra of the bursts. The frequency decreases monotonously with delay time. In figure 2 the frequencies of delayed bursts are presented against electron sizes in three bins of core distances. As is seen in the figure, the frequency increases monotonously with electron size except for bursts with n_b larger than 15 in air showers with N_e larger than 10^8 in figure 2(a) and 2(b), where the first peak in the signal arising from muons is high and the tail obscured the delayed peak arising from the burst. The frequencies shown in the figure were compared with those estimated from the calculations on delayed nucleons and anti-nucleons made by Grieder(7) with a rising cross section of hadrons and an increasing multiplicity of nucleons and anti-nucleons. In the present estimation, the fluctuation in sizes of bursts from hadrons with a given energy was taken into account by referring to the calculation made by Rappaport(5). The frequencies of delayed bursts observed in the present experiment are higher than those estimated at electron sizes larger than 10^7, and the dependence on N_e is steeper than that estimated. At present, the dependence of multiplicity of nucleons and anti-nucleons on energy is being examined to explain the frequencies of observed delayed bursts.

Figure 3 shows a diplot of the burst sizes and the delay times of all delayed bursts in the present observation. Seven delayed bursts with n_b larger than fifty particles and the delay times longer than 50ns were found. Whether these bursts with large sizes and delay times are reasonably explained as arising from nucleons and anti-nucleons is an important problem and is being carefully examined.

References

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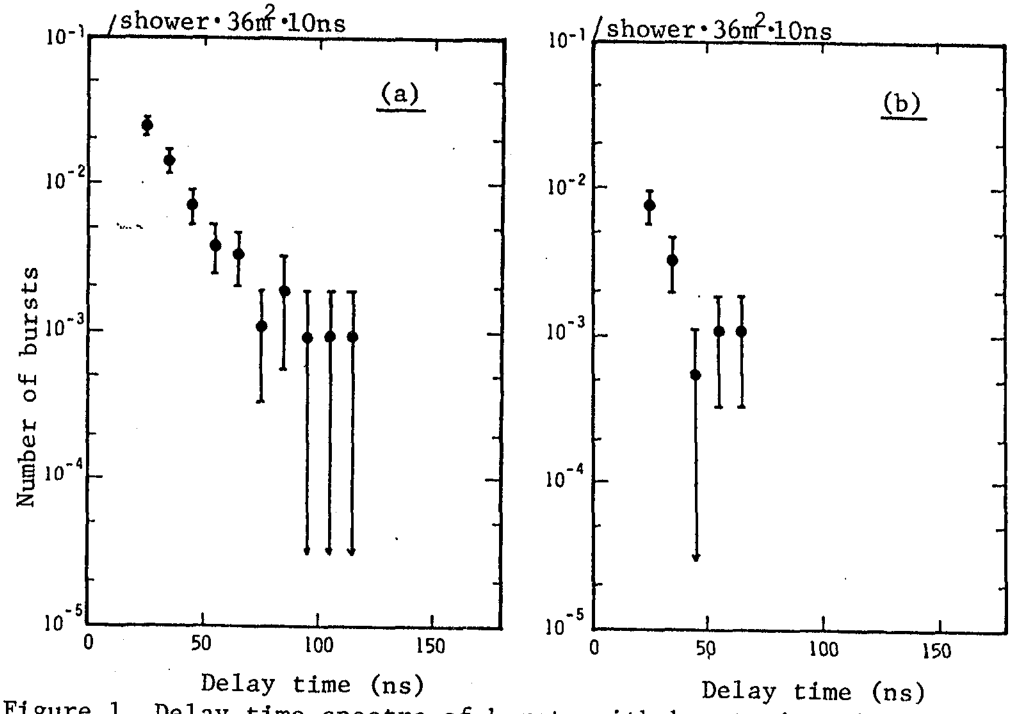

Figure 1. Delay time spectra of bursts with burst sizes larger than 15 in (a) and larger than 30 in (b) for air showers with electron sizes from $10^{7.0}$ to $10^{7.5}$ and core distances from 50m to 100m.

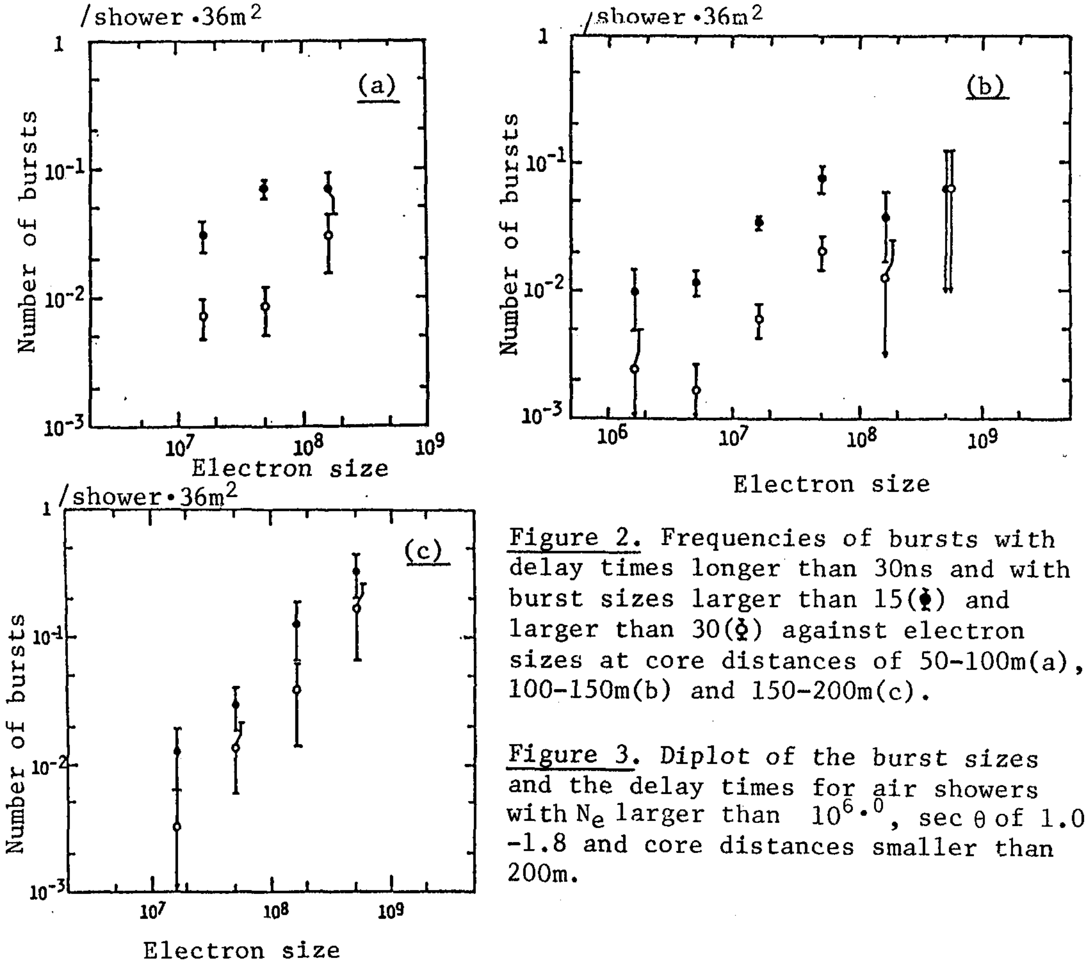

Figure 2. Frequencies of bursts with delay times longer than 30ns and with burst sizes larger than 15(●) and larger than 30(○) against electron sizes at core distances of 50-100m(a), 100-150m(b) and 150-200m(c).

Figure 3. Diplot of the burst sizes and the delay times for air showers with N_e larger than $10^{6.0}$, sec θ of 1.0 -1.8 and core distances smaller than 200m.

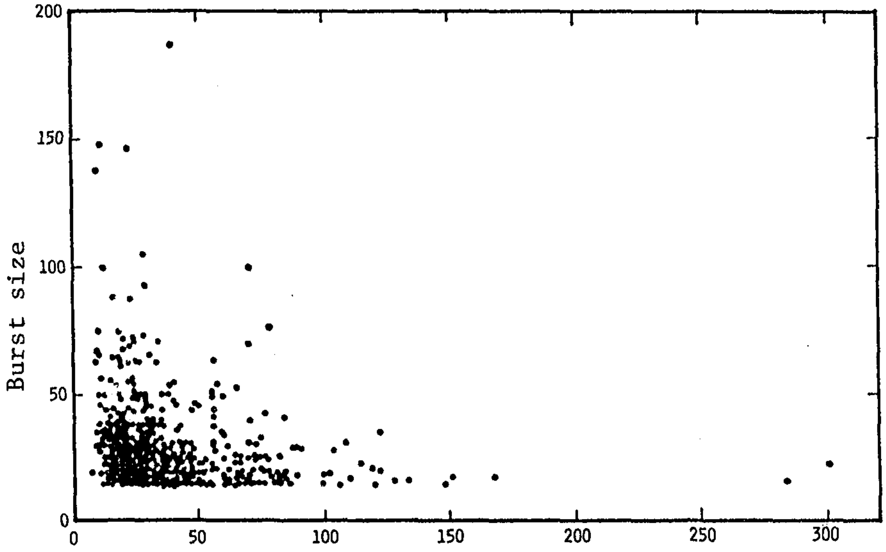

Figure 3. Delay time (ns)