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# Search for heavy mass particles in extensive air showers

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**Abstract.** A large multiplate cloud chamber with fast timing scintillators inside is being operated with the extensive air shower array at Ootacamund to further elucidate the time structure of high energy hadrons in air showers. The major interest in the present investigation is to understand the nature of the large delay (> 20 ns) high energy (> 40 GeV) events that appeared as strong candidates for heavy mass particles in an earlier experiment carried out with a total absorption spectrometer. Two events observed during one year's operation of the experiment are discussed.

**Keywords.** New particles; hadrons in extensive air showers.

## 1. Introduction

In a previous experiment (Tonwar *et al* 1971 *a*) carried out in our mountain laboratory at Ootacamund in Southern India at an altitude of 2200 meters above m.s. l on the time structure of hadrons in extensive air showers an interesting phenomenon was observed. Several events were recorded where in association with air showers of size $10^5$–$10^6$ particles, there was relatively large (> 40 GeV) energy release inside the well shielded sections of a total absorption spectrometer and the energy release was delayed relative to the air shower front by more than 20 ns. The expected minimum delay for 40 GeV hadrons, produced very high up in the atmosphere, say 10 kms, in the very first interaction of the air shower primary proton or nucleus is only 10 ns if the hadron is a nucleon. For lighter hadrons like pions or kaons the expected delay $\delta t$ is much less since $\delta t$ is proportional to the square of the mass ($m$) of the hadrons for a given energy ($E$);

$$\delta t \sim \frac{h}{2c} \cdot \frac{m^2}{E^2} \sim 1600 \cdot \frac{m^2}{E^2} \text{ ns/km}$$

$h$ is the height of the point of production of the hadron above the observational level and $c$ is the velocity of light. The observed frequency of the delayed high energy events was very much higher than expected from simulations of extensive air showers (Tonwar *et al* 1971 *b*, 1971 *c*) incorporating all the known sources of possible fluctuations.

These interesting events could therefore be interpreted as evidence for production of massive ($\gtrsim 10$ GeV/$c^2$) interacting particles in ultra high energy interactions.

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† Now deceased.

A serious drawback of the data obtained in this experiment was the lack of visual information on the nature of these events. In the absence of visual information it is not possible to rule out an alternative though highly improbable interpretation that each of these events is due to the arrival of a group of lower energy hadrons over the area of the spectrometer. Since the question of the existence of massive hadrons is obviously of great importance it was thought desirable to repeat the experiment using a large multiplate cloud chamber in place of the total absorption spectrometer. In this paper we present preliminary results obtained from this experiment.

## 2. Experimental details

The experimental arrangement is shown in figure 1. The large multiplate cloud chamber (2 m $\times$ 1·5 m $\times$ 1 m) contains 17 iron plates each 1·9 cms. (14 g.cm$^{-2}$) thick. The chamber is shielded on the top by 105 g.cm$^{-2}$ of iron. A plastic scintillator of size 60 $\times$ 60 $\times$ 10 cm$^3$ is placed on the top of the iron shielding above the chamber. This scintillator is viewed by a fast (RCA 6810 A) photomultiplier. The detector, CHO, is used to detect and time the arrival of air shower front, mostly electrons. Two plastic scintillators, each 60$\times$60 $\times$ 10 cm$^3$, enclosed inside a large (180 $\times$ 80 $\times$ 10 cm$^3$) aluminium box as shown in figure 2, are located inside the chamber below the 11th plate, that is under 154 g.cm$^{-2}$ of iron. Each of these two scintillators is viewed by two fast photomultipliers mounted in contact with one edge of the scintillator as shown in figure 2. These two detectors $C_L$ and $C_R$, detect and time the arrival of a hadron which produces a cascade inside the chamber. There are two liquid scintillators, each 80 $\times$ 75 $\times$ 10 cm$^3$, located below the chamber.

Each is viewed by a fast photomultiplier. These two detectors, $B_L$ and $B_R$ also time the hadron whenever the cascade has enough energy and proper direction to penetrate all the chamber plates downstream up to these detectors. The arrival time difference or the 'delay' between the signal from any of the timing detectors and the signal from CHO is measured in units of 7 ns. The accuracy of this measurement as obtained from the width of the distribution of the delay between two timing detectors looking at the same particles is 6 ns.

The air shower array (Tonwar *et al* 1971 *a*) provides data on the parameters of the showers associated with the hadron seen in the cloud chamber. The energy of the hadron is determined by measuring the track length integral and using the conversion factors obtained from Monte Carlo simulations (Vatcha *et al* 1972). It has been estimated that due to the fluctuations in the development of the cascade the track length integral and therefore the measured energy of the cascade has an uncertainty (standard deviation) of $\sim$ 40%. However, this estimate of the error is applicable only to the hadron initiated cascades. For photon-initiated cascades the error is only about 10%.

The cloud chamber is triggered and photographed when three selection criteria are satisfied. These are: (i) detection of an air shower as indicated by a time coincidence between the signals above a preset threshold of three particles in CHO and one of the particle density detectors of the air shower array. (ii) detection of a cascade in the cloud chamber as indicated by a signal above a preset threshold of 3 particles from either $C_L$ or $C_R$, and (iii) minimum time delay between the signals from CHO and $C_L$ or $C_R$ of 20 ns. This trigger also causes the recording of signals from all the density detectors, the time interval between CHO and $B_L$ and $B_R$, local time, shower identification number, etc. on paper tape in suitably coded form.

## 3. Results and discussion

In an effective operation time of 2800 hrs during 1972–73, a total of 2319 cloud chamber pictures have been taken which satisfied the selection criteria mentioned earlier. For most of these events the air shower parameters like the shower size, core location, etc., have been obtained after analysing the shower data. The cloud chamber pictures have been scanned for cascades which satisfy the geometrical requirement that the axis of the cascade should pass through the detector $C_L$ or $C_R$. The energies of such cascades have been determined using the method mentioned earlier.

In this data two clean events have been found whose energies have been measured to be more than 20 GeV. The first event, shown in figure 3, is a typical hadron cascade with observable heavy prongs and penetrating secondaries. The cascade passes through $C_R$ which recorded a large pulse delayed by 41 ns relative to the shower particle signal from CHO. The detector $B_R$ did not record any delayed signal; this was understandable since the cascade missed the detector. The energy of this cascade is determined to be 110 GeV assuming the cascade has been initiated by a hadron. If the cascade were due to an electron or a photon its energy would still be greater than 36 GeV. The associated shower had a size of $1 \cdot 7 \times 10^5$ particles and the shower axis was located at 4·6 m from the chamber.

The second event, shown in figure 4, shows a cascade initiated in the shielding material above the chamber. This cascade shows a saturated tube-like structure with no observable slow hadrons. However, the cascade is more elongated than the one expected for an average electron photon cascade of measured energy of 28 GeV. If one assumes that the cascade is initiated by a hadron the energy of the hadron is estimated as 80 GeV. The cascade passes through $C_R$ which has timed it as delayed by 25 ns relative to the air shower front. The cascade is completely absorbed before it reaches $B_R$. The size of the accompanying shower is $9 \times 10^4$ particles and its axis is located at a distance of 8 meters from the chamber.

These two events have characteristics similar to those observed for the delayed energetic events in the earlier spectrometer experiment. It may also be mentioned here that like the spectrometer events these two events also cannot be easily accounted in terms of chance coincidences. In an operation time of 2800 hrs only 0·1 event was expected due to a chance coincidence of a normal hadron event in $C_L$ or $C_R$ and a random noise pulse in CHO that was preceded by 100 ns or less relative to the pulse from $C_L$ or $C_R$. The possibility that the high energy hadron cascades seen in the chamber pictures for these two events are due to hadrons unrelated to the observed air showers and the signals from $C_L$ or $C_R$, has also been considered. However, in view of the similar 'age' of the tracks seen for particles of the high energy cascades and for particles of other low energy cascades seen in these two pictures, this interpretation of these two events as due to unrelated hadrons can be considered as highly unlikely.

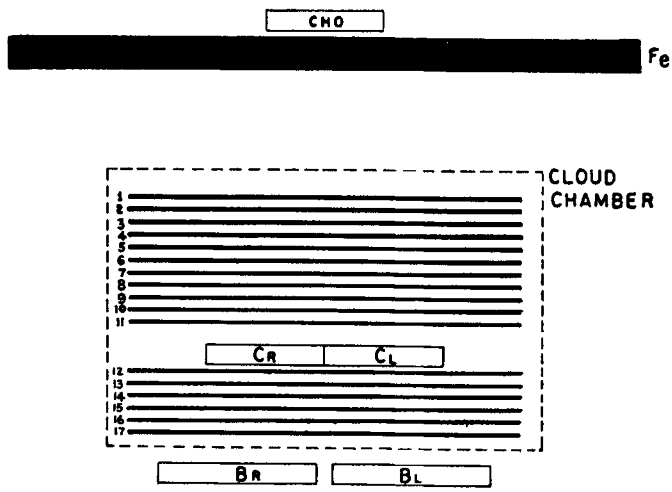



**Figure 1.** A schematic diagram of the cloud chamber-timing detector system.

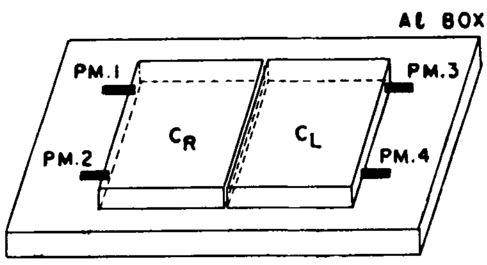
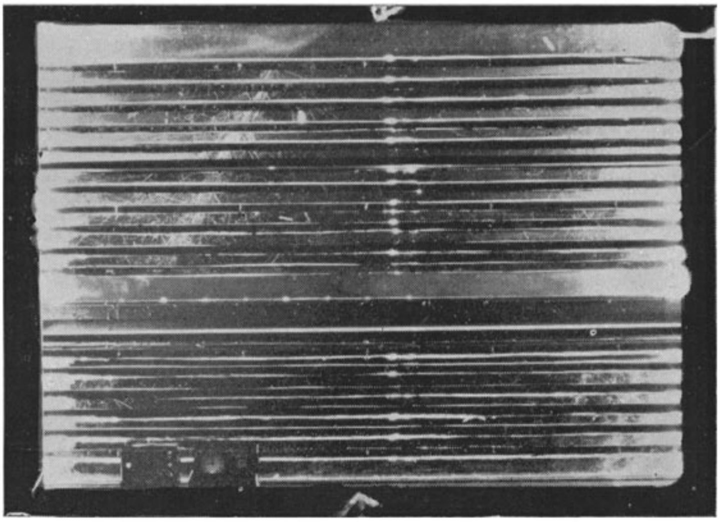
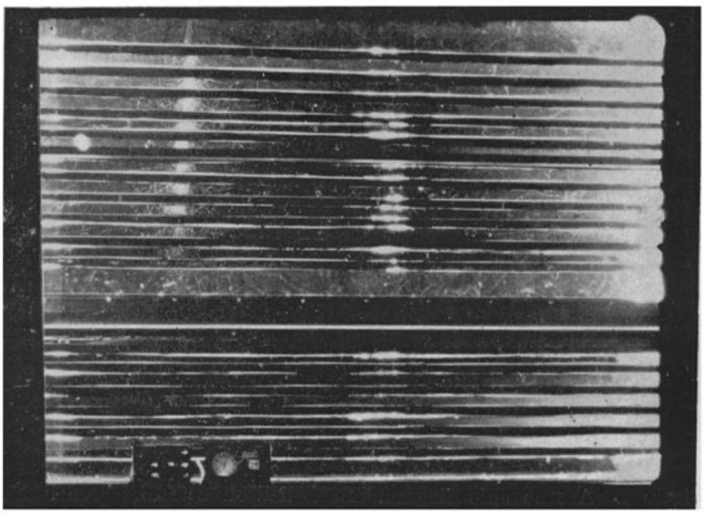



**Figure 2.** A schematic diagram of the hadron detectors used inside the cloud chamber.



(3)



(4)

**Figure 3.** Cloud chamber picture for delayed energetic event number 1.
**Figure 4.** Cloud chamber picture for delayed energetic event number 2.

The flux of these type of events can be computed from the observed rate of 2 events in 2800 hrs and the known geometrical aperture ($0 \cdot 2\ m^2\ sr$) of the detector-chamber plate assembly as $\sim 10^{-10}\ cm^{-2}.sec^{-1}.sr^{-1}$. This value is considerably smaller than the value of $10^{-9}\ cm^{-2}.sec^{-1}.sr^{-1}$ obtained in the spectrometer experiment. However, it must be pointed out that a comparison of the fluxes observed in the two experiments is not really possible for various reasons connected with the instrumentation used in the present experiment. The detector assembly in the present experiment is not optimised for selecting all the hadrons with energies greater than 20 GeV interacting anywhere in the given geometrical aperture. Also the scintillators used inside the chamber have rather short light attenuation lengths and due to edge viewing have a severe problem of thresholds being different at different points of incidence of cascades on the scintillators. It may be emphasized that the basic aim of the present experiment was not to measure fluxes under similar conditions as in the earlier spectrometer experiment but rather to study visually the details of the delayed events particularly about the reliability of the energy determination for the delayed events.

## 4. Conclusions

From the results and discussion presented here, it is clear that there are high energy hadron events in air showers which arrive considerably delayed relative to the shower front. These events are difficult to understand in terms of production of known hadrons. However statistics are poor and the instrumentation used to study these events needs to be improved. We feel that much mores ophisticated experiments are needed to give further details about the nature of such events. In particular the cascades should be timed at closer interval to rule out chance coincidences of even very small probabilities and should be studied in detail for energy estimation using visual detectors like the one used in the present experiment.

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