A FACILITY FOR INVESTIGATION OF MULTIPLE HADRONS AT COSMIC-RAY ENERGIES

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ABSTRACT

An experimental arrangement for studying multiple hadrons produced in high-energy hadron—nucleus interactions is under construction at the university of Turku. The method of investigation is based on the detection of hadrons arriving simultaneously at sea level over an area of a few square metres. The apparatus consists of a hadron spectrometer with position-sensitive detectors in connection with a small air shower array. The position resolution using streamer tube detectors will be about 10 mm. Energy spectra of hadrons or groups of simultaneous hadrons produced at primary energies below 10^{16} eV can be measured in the energy range 1-2000 GeV.

1. Introduction

Measurements of the exact shape of cosmic-ray hadron spectra give information on the properties of high-energy hadron—nucleus interactions. Recently, energy spectra of charged and neutral hadrons were measured at sea level in the range 0.05-1000 GeV /1/. Particularly interesting is the spectrum of pions, because the few previous measurements made at sea level have given contradictory results /2,3,4/. Nieminen et al. /1/ estimated pion spectrum assuming an identical shape of neutron and proton spectra above 5 GeV and a proton-to-neutron ratio of 1.05. Even then, above 50 GeV only upper bound was obtained for pion spectrum. This was due to simultaneous incidence of multiple hadrons, not necessarily pions.

Incidence of several simultaneous hadrons in sea-level detectors was earlier studied theoretically /5/. It was shown that the frequency of occurrence of multiple hadron events is noticeable above total hadron energies of about 100 GeV increasing with energy and is strongly dependent on the detector area. The role of multiple hadrons in the interpretation of air shower results was recently discussed by Sreekantan et al. /6/. At high energies the air shower results were found to be severely distorted if these events were not properly taken into account. The present report concerns an experimental arrangement for studying multiple hadron production.

2. Hadron spectrometer

Front view of the hadron spectrometer used in the experiment is shown in figure 1. Central part of the spectrometer is a double neutron monitor. Effective depth of the lead target in each monitor is 270 gcm^{-2}. Evaporation neutrons produced in hadron—lead-nucleus collisions are detected with 16 BF_3-counters with an average efficiency of 12.5 % /7/. In addition to the double neutron monitor, five liquid scintillation counters ($100\times100\times6.7$ cm^3), viewed from two sides by photomultipliers, are used to measure the energy of electromagnetic cascades produced in the spectrometer. The thicknesses of the four iron absorbers shown in fig. 1 are 1.2 cm, 5 cm, 10 cm, and 10 cm, starting from the top. The total depth of lead and iron in the spectrometer is 4.5 interaction mean free paths of hadrons. The measurement of energy of incident hadrons is based on recording the multiplicities of neutrons produced in each monitor and on the pulse heights observed in the liquid scintillators due to electromagnetic cascades. The spectrometer can be used in the energy range 1-2000 GeV.

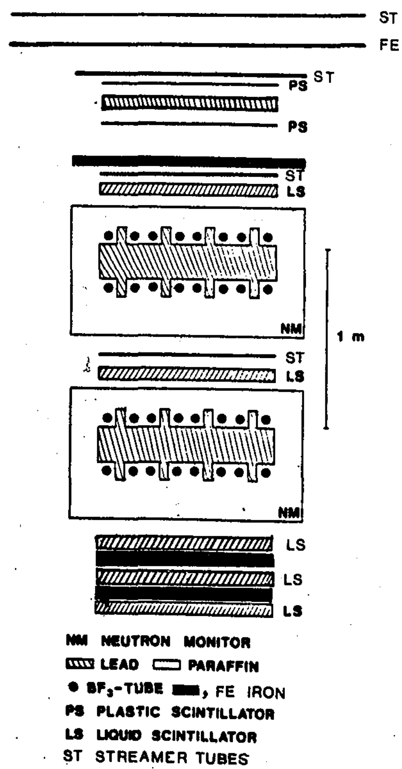

Fig. 1. Front view of the hadron spectrometer.

3. Position-sensitive detectors

Three layers of streamer tubes at the top of the spectrometer (fig. 1) are used to determine the number of simultaneously incident charged hadrons. The uppermost tube layer is unshielded while the other two are shielded against low-energy electrons by lead and/or iron layers. The active areas of these three detectors are 4.0, 1.7, and 1.0 m^2. The streamer tubes are of the same type as those of the Mont Blanc detector described by Iarocci /8/. The basic element is an 8-cell plastic profile coated with graphite. The dimensions of a cell are 0.9×0.9×120 cm^3. The diameter of the Be-Cu anode wires is 100 μm and the gas filling is a mixture of 75 % isobutane and 25 % argon. Two-dimensional read-out from each three tube planes by perpendicular induction strips enables the determination of positions and number of incident particles. To solve mirror ambiguities, the induction strips of successive tube planes are rotated by 45° with respect to each other. By using digital read-out, the position resolution will be about 10 mm. In addition, the angle of incidence of particles can be measured with an accuracy of about 2 degrees. The read-out electronics are based on commercial Camac system. A special circuit has been designed, which triggers the read-out in case a selected number (≥ 2) of charged particles traverses the sreamer tube layers.

A fourth layer of streamer tubes is installed between the two neutron monitors (fig. 1). This detector enables measurement of positions of showers produced in hadron cascades in the upper monitor. Thus, also the number of neutral hadrons incident on the spectrometer and interacting in the lead target can be determined.

4. Air shower array

The air shower array which will be constructed in connection with the hadron spectrometer is shown in figure 2. The shower parameters to be measured are core position, size, and arrival direction of a shower. The principal idea is to study hadrons near the shower core. The core position is determined using the method proposed by Bergamasco et al. /9/. This method enables the signals from the core detectors to be used as a master trigger for the other instruments in case the core falls in an appropriate distance (≲20 m) from the hadron spectrometer. There are in total four core detectors consisting of two plastic scintillators placed one on top of the other and separated by a lead layer with thickness of 5 cm. An example of such a detector are the two plastic scintillators at the top of the spectrometer (fig. 1). The measurement of the core position is based on the relative pulse heights observed in the two scintillators. Near the core the number of high-energy electrons undergoing multiplication in the lead is high.

Four liquid scintillators (DD in fig. 2) are used to measure the density of shower electrons and accordingly to estimate the shower size by using a theoretical lateral distribution function. Four plastic scintillators (FT in fig. 2) are equipped with fast photomultipliers. With these detectors the arrival times of the shower front in each peripheral timing detector are measured with respect to the central detector. The arrival direction of the shower is then estimated using plane approximation of the shower front.

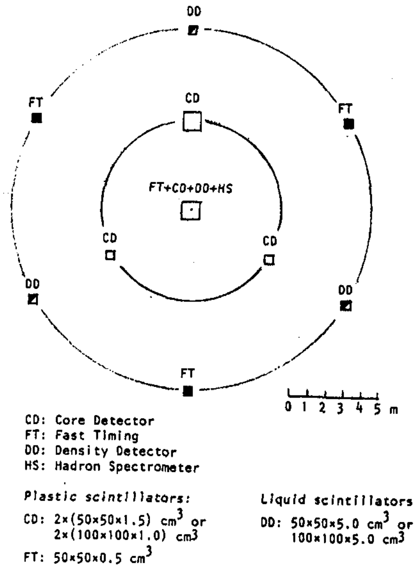

Fig. 2. Air shower array.

Electronic system used to measure all the pulse heights and time differences is based on Camac equipment. Microcomputers are used to read the data and store it on floppy disks. Hadron cascade model of Lumme et al. /10/ is being extended to include electromagnetic component in order to calculate response of the array as well as the accuracy of shower size, core position and arrival time measurements.

5. Discussion

Assuming that multiple cosmic-ray hadrons arriving simultaneously at sea level are produced in the last collision of a high-energy hadron in the atmosphere, the height of production will be a few hundred metres and particles detected over an area of 1 m^2 at sea level are emitted into very narrow cone (≲1 mrad). The higher is the collision point in the atmosphere, the narrower is the emission cone. Accordingly, such events of multiparticle production are detected, where the relative transverse momentum of the particles is very small. Using the experimental arrangement described above, intensities and energy spectra of groups with various numbers of hadrons can be studied. Restricting to single particles, the exact shape of energy spectra of cosmic-ray hadrons (e.g. pions) can be measured. Investigation of lateral distribution of particles produced in the same collision and emitted into a narrow cone is also possible, fixing the center of the group to the position of the most energetic particle. This can be estimated by determining the number of charged particles in hadron cascades observed under the first neutron monitor using analog read-out of the streamer tubes or possibly simply by observing the physical size of the clusters produced by the developing cascades.

Multiple high-energy hadrons observed without accompanying air showers are thought to be produced in diffractive excitation processes. In these processes the primary particle retains most of its energy thus preventing the development of a shower. Recently, however, a model of coherent production of hadrons with small transverse momentum from nuclear targets was advocated by Berlad and Dar /11/. The mechanism was attributed to the decay of resonances produced in Coulomb excitation. By measuring intensities of groups of simultaneous hadrons, energy dependence of cross sections of coherent production can be studied and their possible contribution to the rising total cross section estimated. Even the relative contribution of single and double diffractive excitation can be studied on the basis of observed single and double clusters of particles.

Multiple hadrons have been earlier investigated in air showers /6/ and at very high energies (> 1 TeV) by several groups using emulsion chambers. In the present experiment occurrence of multiple hadron events is studied both in air showers and without accompanying air shower. Furthermore, also low-energy (≃1 GeV) hadrons are taken into account. Primary energy range covered by the experiment is from 1 TeV upto about 10000 TeV. Properties of multiple production in air showers are of great importance and could explain, at least in part, for example the observed increase of transverse momentum with energy.

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