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INVESTIGATIONS OF THE CHARACTERISTICS OF THE DELPHI HADRON CALORIMETER PROTOTYPE

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1. Introduction

The main purpose of the performed research was to investigate the characteristics of the DELPHI hadron calorimeter prototype in various modes of operation of its detectors and to compare two versions of readout electronics. As shown in Refs. [1,2], the main reason of the failures of the plastic streamer tubes with a resistive cathode, which are used for the DELPHI hadron calorimeter [3], is the development of a self-sustained dark current. The appearance of this current is due to the Malter effect on a graphite cathode arising from a high current streamer discharge.

For increasing the tube reliability, we suggest to reduce the gas gain up to a value corresponding to the region of a saturated avalanche mode and to use more sensitive electronics.

We have investigated the dependence of the energy resolution of the calorimeter on gas amplification and studied the signal-to-noise ratio. This is important if the use of the calorimeter is required for muon trigger.

2. Experimental set-up

The investigations have been carried out using the hadron calorimeter prototype 1x1 m^2 in size (Fig. 1). The prototype is analogous to that of the DELPHI hadron calorimeter module [3]. Each of the plastic tubes, which the device is supplied with, consists of eight 9x9 mm^2 gaseous detectors 1 m in length with a resistive cathode in one gas volume. A Cu-Be 80 mm wire was used as an anode. As compared with other detectors of such a type, the resistivity of the graphite cathode was lowered up to a value of 10

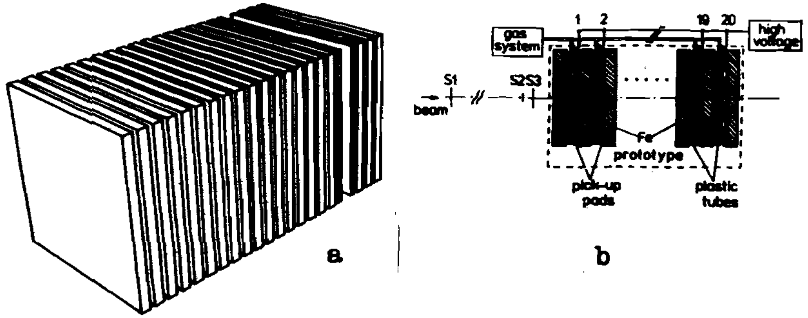


Fig. 1. a) General view of the hadron calorimeter prototype
b) experimental set-up.

kOhm/square. It should be noticed that an analogous method for improving detector reliability was also employed in the UA1 detector for the upgraded muon system (the cathode resistivity is about 2 kOhm/square [4]). Signal read-out from the DELPHI hadron calorimeter prototype was performed by the pick-up electrodes, which were subdivided into sixteen 25x25 cm^2 pads. To transmit a signal from the pick-up pads to the electronics input, we used flat and ribbon cables of the same type and lengths as in the real DELPHI hadron calorimeter. Because of the low resistivity of the graphite cathode, we used coverless tubes. This allowed one to avoid the effect of electrostatic screening of the pick-up electrodes. The signals from 5 sequential pads, connected to a tower, were read out by one electronic channel as in the DELPHI hadron calorimeter. An argon-isobutane (1:3) gas mixture was used.

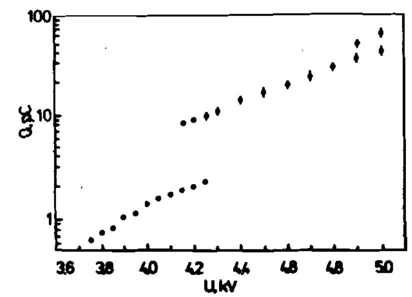
The hadron calorimeter prototype characteristics in various modes of tube operation were investigated both on a proton beam with a momentum of 6 GeV/c of the Dubna synchrophasotron and on cosmic rays. In the experiment LeCroy 2249 ADCs were used, which allowed one to register signals over a wide range of amplitudes. In addition, the ADCs, specially elaborated at IHEP(Serpukhov) for the DELPHI hadron calorimeter [5], were used.

3. Characteristics of the hadron calorimeter in various modes of detector operation

The dependence of the most probable amplitude of an anode signal from the tube, placed in front of the calorimeter, on the anode voltage is presented in Fig. 2. The single rate curve of this tube at a 10 pC threshold is shown in Fig. 3. The self-quenching streamer mode corresponds to the plateau of this curve.

A calorimeter response to 6 GeV/c protons versus high voltage is depicted in Fig. 4. The total signal from all the anode wires is taken as a response. The absence of a sharp

Fig. 2. The most probable amplitude of a signal from the anode wire of the plastic tube as a function of voltage.



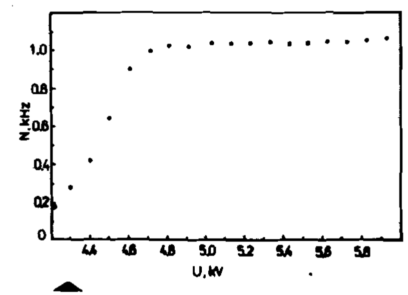
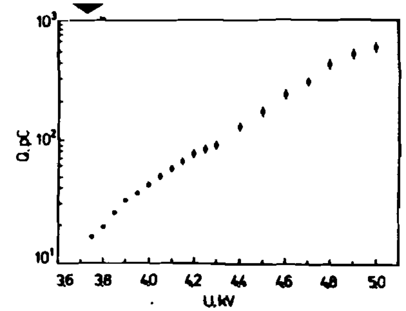


Fig. 3. Single rate curve of a detector of the hadron calorimeter prototype.

Fig. 4. Sum of signals from the anode wires as a function of voltage.



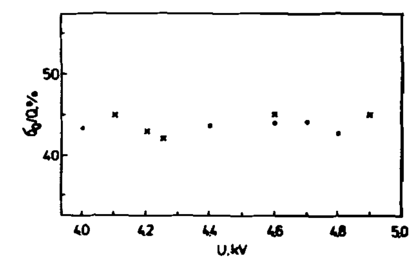


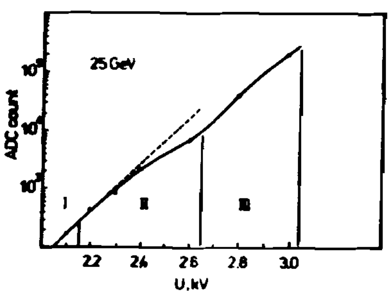
Fig. 5. Energy resolution of the device as a function of voltage: points-a signal from the anode wires, crosses-a signal from the towers.

transition between the proportional and streamer regimes is due to heavy-ionizing "soft" particles in a nuclear cascade, for which the streamer discharge begins at a lower anode voltage than for particles with minimum ionization.

The hadron calorimeter energy resolution versus high voltage is shown in Fig. 5. One can see that the resolution is nearly constant for a wide interval of anode voltage. At a voltage of 4.0 kV the response of the calorimeter decreases more than by a factor of 10 as compared with the one in the regime offered in [6]. In this paper it has been proposed to use the detectors of the DELPHI hadron calorimeter in the regime providing a 50 pC signal amplitude from an anode from the particle with minimum ionization. Of course, the transition to lower amplitudes increases significantly the stability and reliability of the calorimeter performance. At the same time the energy resolution of the calorimeter does not get worse.

Similar results obtained in Ref. [7] are shown in Figs. 6 and 7, where the hadron calorimeter response to hadrons and the energy resolution of this device are depicted as a function of voltage. One can see from Fig. 7 that the best resolution is obtained when the detectors operate in the saturated proportional mode.

Fig. 6. Response of the hadron calorimeter as a function of voltage (Ref. [7]): I-proportional mode, II-saturated proportional mode, III- self-quenching streamer mode.



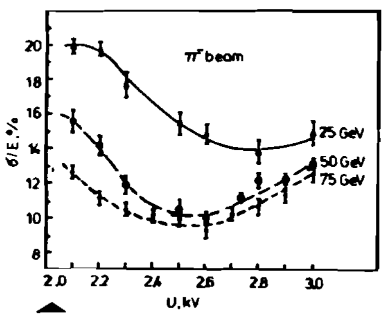


Fig. 7. Energy resolution as a function of voltage (Ref [7]).

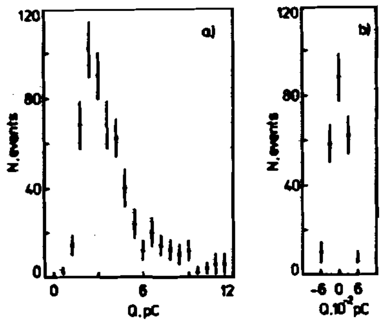
The analysis of the results in Fig. 4 shows that at the point offered by us (4.0 kV) the calorimeter response is about 3 times lower than the one on the streamer regime boundary (4.3 kV). An analogous transition in Fig. 6 to the signals, which are 3 times lower than in the streamer mode beginning, leads to a voltage of 2.5 kV. This value is within the region, which is an optimum in resolution of the hadron calorimeter for energies of 50-75 GeV (Fig. 7). For soft hadrons, a fraction of which will be suppresing at LEP energies [8], the transition from the optimum point does not lead to a drastic aggravation of the hadron calorimeter resolution (Figs. 5, 7). (According to the evaluation of Ref. [8], the mean hadron momentum from Z^0-decay is about 2.7 GeV/c).

4. Use of the hadron calorimeter signal for producing the muon trigger

To secure the performance of the hadron calorimeter at a relatively low gas amplification in the detectors, the electronics, having a sensibility of 0.03 pC/channel, has been suggested in Ref. [5]. The operation of some samples of new cards (64 channels) was studied for the calorimeter prototype working in the regime of cosmic muon registration. In this case it was arranged with a vertical axis. The anode voltage, corresponding to the most probable tower signal of 3 pC from one relativistic particle, was chosen for the investigations. Remind that the tower sums up signals from 5 planes of the detectors.

The spectrum of signals from cosmic muons from an individual tower is shown in Fig. 8(a). The distribution of zero counts of the electronics (pedestal), characterizing the noises of the electronic tract, is depicted in Fig. 8(b) for comparison. The standard deviation of this distribution is about 0.03 pC. Therefore, in spite of the high sensibility of the electronics the cross-talks on the signal tract are negligible, and they cannot affect the hadron calorimeter operation.

Fig. 8.a) Spectrum of signals from cosmic muons from a single tower,
b) distribution of electronics zero counts.



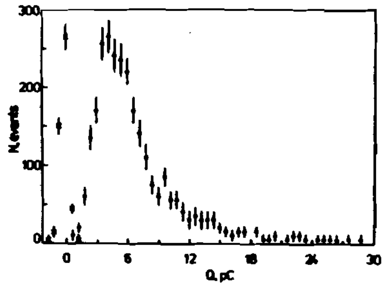
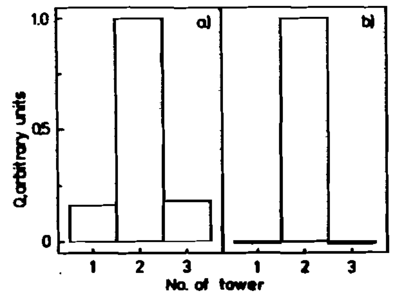


Fig. 9. Spectrum of signals from cosmic muons from a supertower: points-signal, crosses-pedestal.

Fig. 9 shows the spectrum of signals from a supertower (the sum of signals from 16 neighbouring towers), which allows one to draw a conclusion of the possibility to use the hadron calorimeter operating in the saturated proportional mode and supplied with the suggested electronics for producing the muon trigger. The amplitudes of the signals are somewhat larger than in Fig. 8 This can be due to the availability (in Fig. 8) of the events, in which the muon does not pass through the whole thickness of the tower, and to the existence of charge cross-talk because of the high resistivity of the tube cathode (Fig. 10). For 4 supertowers of the prototype the analysis of the signals, which are analogous to those in Fig. 9, allows one to draw a conclusion of purity and efficiency of the muon trigger produced by the hadron calorimeter operating in the offered regime and provided with the new electronics. Figure 11 depicts the curves characterizing the efficiency of the muon trigger produced when the signals from two or three supertowers exceed the threshold expressed in terms of standard deviations of the noise signal. In this figure the numbers of accidental triggers are shown as a function of the threshold value. One can see that the trigger is distinguished by a high efficiency and a small number of accidental coincidences when the threshold value is equal to 3-4 standard deviations of the noise distribution.

Fig. 10. Cross-talks of the charge: a) signals from the towers, the pads of which are placed along the tube; b) signals from the towers, the pads of which are across the tube. The muon track passes through the second tower.



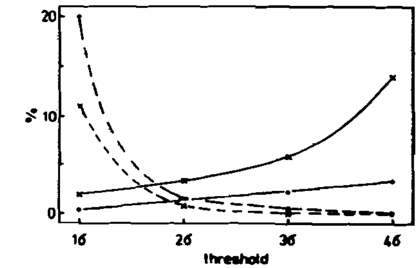
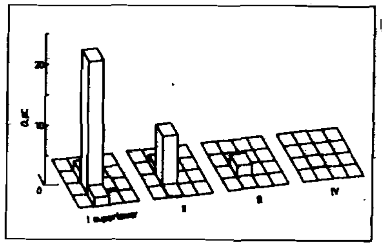


Fig. 11. Curves characterizing the efficiency of the muon trigger produced when the signals from two or three supertowers exceed the threshold expressed in terms of standard deviations of the noise signal: full lines-inefficiency of the trigger (relative to the external trigger), dotted lines- relative number of accidental triggers; points-data for two supertowers, crosses- for three supertowers.

5. Development of the nuclear-electromagnetic cascade in the matter of the calorimeter

The topology of a typical event of shower development in the calorimeter for a 6 GeV/c proton is shown in Fig. 12. The amplitudes of tower signals are presented by vertical columns. From this figure one can obtain information on the longitudinal development of a cascade. Signals from the anode wires provide more detailed information concerning the shape of the shower longitudinal profile (Fig. 13). For a more minute investigation of the features of the calorimeter operation, nuclear showers were simulated in the detector with the help of several programs. The shape of the shower longitudinal profile obtained by the DELSIM[9] program is depicted by the curve (Fig. 13). One can see a good agreement between the experimental and simulated data. Some shower samples simulated by the GHEISHA[10] program are presented in Fig. 14.

Fig. 12. Topology of a typical event of a shower in the hadron calorimeter prototype.



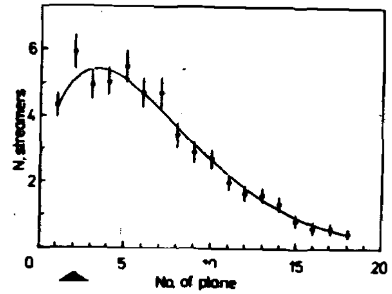
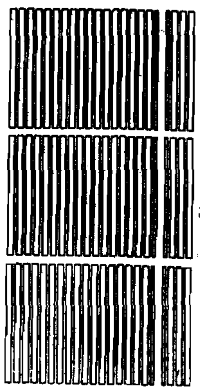


Fig. 13. Longitudinal profile of a shower in the hadron calorimeter prototype (information from the anode wires). The curve presents the results of simulation by the DELSIM program.

Fig. 14. Two-dimensional pictures of showers in the DELPHI hadron calorimeter prototype. The results have been obtained by the GHEISHA program.



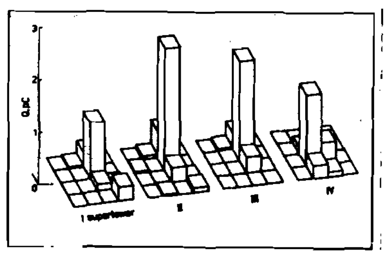


Fig. 15. Topology of a typical event of the cosmic muon passage through the device.

Figure 15 depicts a picture which results from the passage of cosmic muons through the device. The features of the topology of a muon event allow one to work out additional selection criteria of such events and to reconstruct the characteristics of particles passing through the calorimeter. It is clear that muon events make it possible to calibrate and to test the device.

6. Electromagnetic calorimeter

In the DELPHI detector an electromagnetic calorimeter will be disposed in front of the hadron one. This will result in a complication of the procedure of particle energy reconstruction as in some part of events a shower will begin in the electromagnetic calorimeter.

We have simulated a real situation by placing a scintillating crystal CsJ in front of the calorimeter across the beam path. The diameter of the crystal was 200 mm and its thickness along the beam 300 mm (17 radiation lengths). It was viewed by a photomultiplier of the type FEU 49.

The procedure of hadron energy reconstruction was executed by means of combining responses of the two calorimeters according to the expression:

$$E_h = K_{em}A_{em} + K_hA_h, \qquad (1)$$

where K_{em} and K_h are the coefficients of translation from ADC counts to hadron energy, A_{em} and A_h are the responses

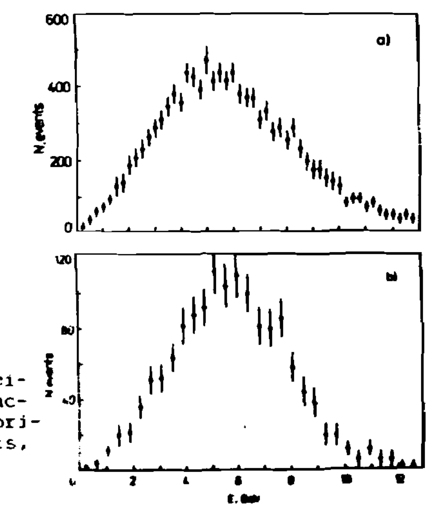


Fig. 16. Energy spectra of incident 6 GeV/c protons reconstructed from responses of the calorimeters: a) experimental results, b) simulated data.

of the two calorimeters in ADC counts. The spectrum of energies of incident protons reconstructed with the aid of expression (1) is shown in Fig. 16 a). The obtained resolution is about 43%. The spectrum in Fig. 16 b) has been obtained for simulated events. It characterizes the resolution of the system, consisting of the electromagnetic and hadron calorimeters, without taking apparatus effects into account. The standard deviation of this distribution divided by its mean value is about 36%.

Because of the spread of the shower beginning through the thickness of the calorimeters and different substances of the devices, simple summation of signals results in a distorted energy value [11]. The deviation from linearity in the data in Fig. 17, showing the energy released in the electromagnetic calorimeter as a function of the hadron calorimeter response, illustrates this statement. At present we are working out the procedure which will permit one to take into account a more precise dependence between signals from the electromagnetic and hadron calorimeters. This can result in an improvement of the energy resolution.

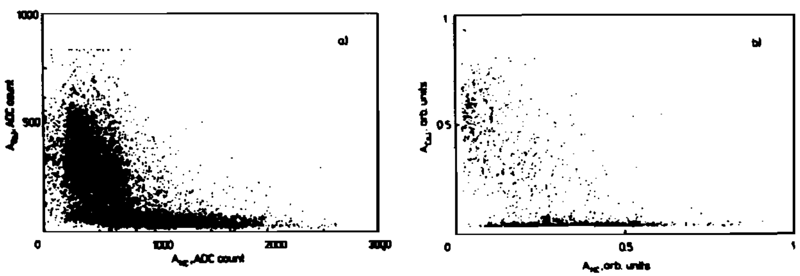


Fig. 17. Signal from the CsJ crystal as a function of the hadron calorimeter response: a) experimental results, b) data simulated by the GHEISHA program.

7. Conclusions

The presented data obtained from the DELPHI hadron calorimeter prototype allow one to conclude that the transition to the saturated proportional mode of detector operation and the use of more sensitive electronics do not make worse the main characteristics of the hadron calorimeter, and reliability of its operation will be essentially increased. The results show evidence for a good possibility of selection of muon tracks in the hadron calorimeter and their use for triggering.

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