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MONTE-CARLO SIMULATION FOR THE SHOWERS IN THE DELPHI (LEP) HADRON CALORIMETER

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INTRODUCTION

The modern theory and existent experimental data about the electromagnetic and hadron shower formation in calorimeters are described in the detailed recent reviews[1]. In this paper properties of a hadron calorimeter with streamer tubes as sensitive elements are considered, because a calorimeter of this type is under construction for DELPHI[2]. 5 cm thick layers of an iron yoke of the superconductive solenoid creating a magnetic field of 1.2 tesla will be used in this calorimeter as an absorber. Plastic streamer tubes[3] with cathode read-out performing in the self-quenching streamer mode[4] will be used as a detector. In this mode no formation of additional streamers on an anode wire piece is possible, if there already exists a streamer in this region. This phenomenon is known as the dead zone effect, and was observed in studies of both the streamer tubes[3] and drift chambers[4]. The dead zome value estimated in streamer tubes by different methods varies from 1.7 to 4.5 mm[3]. Investigation of the hadron calorimeter characteristics depending on the dead zone value, taking into account the strength and direction of the magnetic field is the aim of the present paper.

In the presented calculation the TATINA[5] package was utilized as the main tool for generating hadronic showers in the 23 modules that constitute the bulk of the calorimeter with 1x1 m^2 cross section. Each module includes 5 cm of iron absorber; 0.1 cm of plastic (the front tube wall); 1 cm of argon (the gas filling of the tubes with a cross section of 1x1 cm^2); 0.35 cm of plastic (the back tube wall, the read-out pads and the wall of the air pressure bag); and, at last, 0.65 cm of air.

The hadron beam was assumed to consist of π^+ mesons with energies of 5, 10, 20 or 40 GeV, travelling along the Z-axis. The sensitive planes of streamer tubes were taken to be parallel to the xy-plane, the tubes were directed along the y-axis. The results were obtained for a zero magnetic field, and for three homogeneous field values: $H_x = 10$ kgauss, $H_y = H_z = 0$; $H_y = 10$ kG, $H_x = H_z = 0$ and $H_z = 10$ kG, $H_x = H_y = 0$. In the zero-order approximation the last two situations correspond to the barrel part of the hadron calorimeter DELPHI (H_y = 10 kG), and to the end cap (H_z = 10 kG), respectively.

Before starting the discussion on the influence of the dead zone effect on the hadron calorimeter response it is necessary to note that the details of the streamer formation process in the streamer tubes still remain inclear. Therefore a simple model of this process was adopted as in paper [6]. For each counter the effective projection of track segments onto the anode wire, i.e., the projections corresponding to the segments of the tracks (hits) within the counter volume, were determined for all the tracks traversing the counter. It was also assumed that the energy deposition has no influence on the streamer formation. The number of streamers within each counter is determined by the number, sizes, and mutual disposition of the track projections on the anode wire. The distance between adjacent streamers for each track projections cannot be less than the dead zone length DZ, and so the total number of streamers in the counters is simply the total number of dead zones that can be packed into the full track projection length, taking into account its position on the wire. The size of the dead zone is determined by several factors, such as the gas mixture in the tubes, the gas pressure, the high voltage on the anode wire, etc. Here the interval DZ was taken as a parameter varying from 3 to 7 mm. A reasonable value for the DZ interval is 3-4 mm [3].

RESULTS

In Table 1 some parameters of showers are listed both for the hit mode and for the streamer one with DZ = 3 mm: N_{ev} is the number of generated showers, $N_{hits/ev}$ ($N_{str/ev}$) is the average number of hits (streamers) registered in the calorimeter per shower, σ_{hits}/N_{hits} (σ_{str}/N_{str}) represents a quantity that characterizes the energy resolution for the sampling under consideration.

In Fig.1 the energy dependence of the calorimeter response for different magnetic fields is presented in units of hits. The energy dependence turns out to be linear. In the presence of a magnetic field all track lengths are extended. This may be the reason for the obtained increase in the number of hits, which amounts to about 25%. A clear dependence of the hit response on the orientation of the magnetic field is not evident.

In Figs.2a-2b the energy dependence of the calorimeter response is shown to vary with the orientation of the homogeneous magnetic field vector, and with the dead zone interval DZ which was taken as a parameter. To make comparison easier the energy dependence is also given in terms of the hit response. A more or less universal behaviour of the calorimeter response as a function of the dead zone interval can be seen:

$$N_{str/ev}(DZ=3):N_{str/ev}(DZ=5):N_{str/ev}(DZ=7) = 1.30:1.15:1.0 \quad (1)$$

Table 1. The calorimeter response and energy resolution (%) in the hit and streamer modes

	$H=0$			$H_x=10$ kG, $H_y=H_z=0$			$H_y=10$ kG, $H_x=H_z=0$			$H_z=10$ kG, $H_x=H_y=0$		
E, GeV	N_{ev}	$N_{hits/ev}$ $N_{str/ev}$	σ_{hits}/N_{hits} σ_{str}/N_{str}	N_{ev}	$N_{hits/ev}$ $N_{str/ev}$	σ_{hits}/N_{hits} σ_{str}/N_{str}	N_{ev}	$N_{hits/ev}$ $N_{str/ev}$	σ_{hits}/N_{hits} σ_{str}/N_{str}	N_{ev}	$N_{hits/ev}$ $N_{str/ev}$	σ_{hits}/N_{hits} σ_{str}/N_{str}
5	2000	31.2±0.4 35.8±0.5	27.6±1.9 39.4±5.3	1000	36.5±0.4 45.0±0.8	29.9±2.8 55.8±13.9	1000	35.5±0.3 45.0±0.7	29.3±1.4 46.4±4.7	1129	35.7±0.3 403.±0.4	28.0±0.8 33.5±1.3
10	1733	69.2±0.9 75.8±0.9	23.7±1.1 29.8±1.1	464	81.1±1.0 97.6±1.7	24.7±4.0 37.8±4.1	477	82.6±1.0 91.8±1.2	25.8±4.2 29.7±3.5	1180	79.4±0.8 89.2±1.0	26.7±4.0 31.4±3.0
20	1206	139.2±1.0 138.8±2.9	22.2±3.1 26.3±3.8	429	166.2±1.7 186.5±2.3	19.7±2.3 26.4±3.8	365	173.0±2.8 172.5±2.8	28.3±4.7 28.5±4.3	860	162.5±0.9 160.5±0.9	17.0±5.6 18.0±5.9
40	1243	278.6±5.2 261.4±4.6	18.3±2.8 21.8±2.4	289	334.5±4.1 346.8±4.8	20.3±2.7 23.0±2.3	608	344.8±2.8 327.2±2.8	19.6±3.4 20.9±3.4	326	343.0±3.5 296.0±3.3	16.0±0.7 17.0±0.7

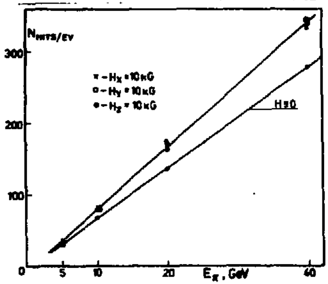

Fig.1. The calorimeter response in the hit mode versus the energy, value and direction of the magnetic field.

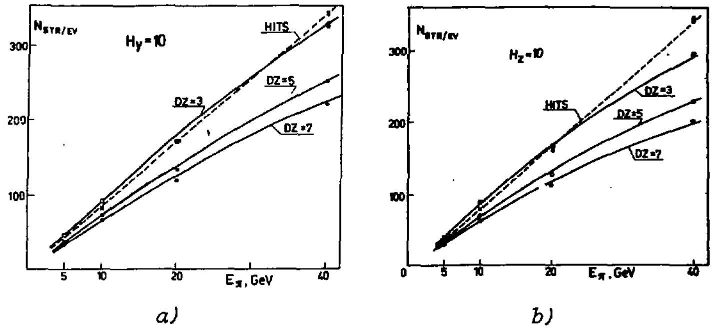

Fig.2. The energy dependence variation of the calorimeter response for different dead zone effective values: (a) $H_y = 10$ *kG; (b)* $H_z = 10$ *kG.*

In the streamer mode the effect of saturation is evident as the energy increases, while such an effect is absent in the hit-mode. This saturation effect is most pronounced in the presence of a longitudinal magnetic field, $H_z = 10$ kG, which acts as a focusing system on charged particles in the shower; owing to this phenomenon the overlapping effect of track projections is extremely essential and must be taken into account.

In Fig.3 the energy dependence of the calorimeter response for different magnetic fields is presented; the dead zone interval is set equal to DZ = 3 mm. As in the case of the hit response (Fig.1), the magnetic field must lead to an increase of the hadron calorimeter response. But, contrary to the number of hits, the enhancement of the number of streamers varies with the magnetic field orientation. The increase is the highest when the field is transversal, $H_x = 10$ kG, $H_y = H_z = 0$, since it makes the shower particles turn and move along the axis of the streamer tubes, which are directed along the y-axis, thus increasing the projection of all track segments on the anode wires and, consequently, the number of streamers. It seems appropriate here to note that the average momentum of charged particles born in the shower and passing through the tubes is not small (Table 2). The curvature radius of most tracks is much greater than the transversal size of streamer tubes. Because of this in the case of $H_y = 10$ kG, $H_x = H_z = 0$ the increase in the number of streamers is connected with the increase in the number of tubes being crossed by tracks when the magnetic field is directed along the tubes and comparable with the effect in the hit mode. The increase of the number

Fig.3. The calorimeter response in the streamer mode (DZ = 3 mm) versus the energy, value and direction of the magnitude field.

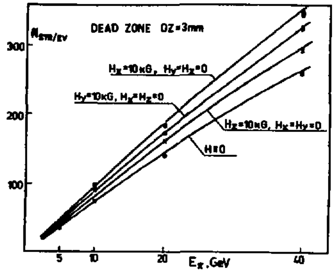

Table 2

The average momentum of charged particles in a hadron shower (20% accuracy)

H,kG	H = 0		H_x=10		H_y=10		H_z=10	
E , GeV	5	40	5	40	5	40	5	40
$P_{e^\pm}$,MeV/c	17.2	16	12.9	12.1	12.2	12.6	13.2	12.8
$P_{\pi^\pm}$,MeV/c	1920	1440	1820	1510	1690	1540	1850	1510
P_μ ,MeV/c	940	840	840	840	840	840	840	840

of streamers is the smallest in the longitudinal field H_z = = 10 kG, $H_x = H_y = 0$, owing to the focusing action of such field.

It is interesting, as one passes from the hit mode to the streamer mode, to compare such shower characteristics as the transversal and longitudinal sizes of showers. In Figs.4 and 5 examples are presented of the energy dependences in the field H_y = 10 kG of the values $\bar{r}$ and $\bar{z}$ which represent the average transversal and longitudinal sizes of showers respectively. An excess of about 20% is clearly visible in the transversal size of the shower measured in the streamer mode over the size corresponding to the hit one. This is connected with a decrease of the relative contribution of the region in the vicinity of the shower axis due to enhanced overlapping of the tracks. No such difference can be seen in the $\bar{z}$ behaviour under the same condition. Similar dependences were observed for these values in the cases $H = 0$ and $|H|$ = 10 kG with other orientation. Dependence of parameters $\bar{r}$ and $\bar{z}$ on strength and direction of the magnetic field in the streamer mode is shown in Figs.6,7. As one should expect the largest transversal shower size is obtained in transversal magnetic fields, and the

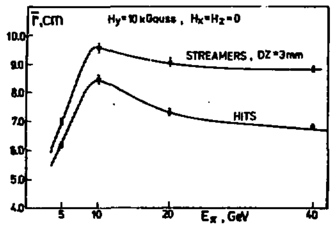

Fig.4. The average transversal size of the shower versus the energy at different registration modes.

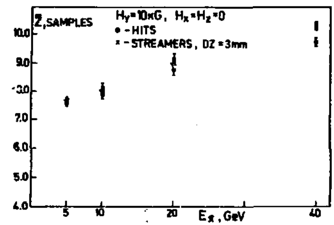

Fig.5. The average longitudinal size of the shower versus the energy at different registration modes.

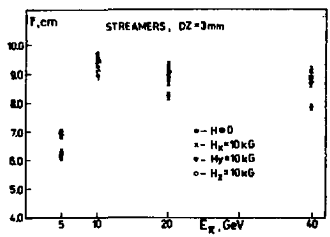

Fig.6. The average transversal size of the hadron shower versus the energy at different values and directions of the magnetic field.

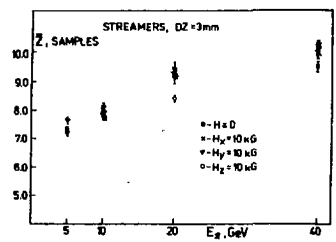

Fig.7. The average longitudinal size of the hadron shower versus the energy at different values and directions of the magnetic field.

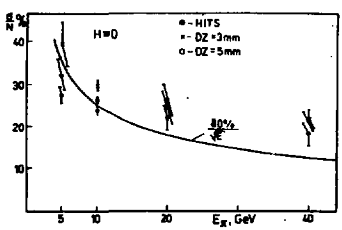

Fig.8. The energy resolution of the hadron calorimeter at different registration modes.

smallest one is obtained in the case of a longitudinal field (focusing). No clear dependence on the magnetic field is obtained for the longitudinal size of a shower.

In Fig.8 the energy dependence of the calorimeter resolution is presented for the hit and streamer modes. As an example, the results of simulation are given for the case of $H = 0$, but the same behaviour takes place for the energy resolution in the presence of a magnetic field. In the streamer mode the resolution becomes worse compared with hit mode especially at a low energy. This is due to an additional source of fluctuations connected with the accidental character of the streamer formation on track segments.

From the existent theoretical concepts about hadron shower formation in the sampling calorimeter the energy resolution dependence is described by the following formula /1/

$$\frac{\sigma_E}{E} = [(\frac{50\%}{\sqrt{E(Gev)}})^2 + (R'\sqrt{\frac{4t}{3E(Gev)}})^2]^{1/2} \simeq \frac{80\%}{\sqrt{E}}, \qquad (2)$$

here $R' = 30\text{–}40\%$, $t = x/X_0$ is the thickness of an iron layer in units of radiation lengths X_0. Formula (2) was obtained assuming the statistical independence of counts in different layers of the calorimeter detector. The first term is connected with fluctuation of the undetectable part of the hadron energy and the second one represents fluctuation of the energy dissipated in ionizations. The energy resolution curve according to (2) is presented in Fig.8. Correlation of counts in different tube layers during the shower formation process axisting in both modes (hit and streamer), as well as count losses owing to track overlapping (saturation effect in the calorimeter response) lead to noticeable deviation from dependence (2), and this deviation increases with energy.

CONCLUSION

The hadron calorimeter response and its other properties depend appreciably on the mode (hit or streamer) of shower registration. In the streamer mode the significant dependence of shower parameters on the magnitude and orientation of the magnetic field vector is observed. Because of this it may be necessary to calibrate the prototype of the DELPHI hadron calorimeter in a magnetic field. Description of the experimental data obtained in this way with simulation programs will give a possibility of better understanding the processes in the hadron calorimeter. This is necessary for adequate interpretation of information from a hadron calorimeter like DELPHI.

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