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MEASUREMENT OF THE RESOLUTION OF A COMBINED HODOSCOPE CALORIMETER AT 18 GeV AND 38 GeV

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ABSTRACT

The energy and space resolution of a combined detector consisting of the Cerenkov photon calorimeter GAMS-2000 and the modular hadron calorimeter MHC-100 has been studied at 18.5 GeV and 38 GeV incident pion energies at the IHEP accelerator. The energy resolution of the combined setup is substancially improved by applying a correction based on the analysis of the lateral development of hadron showers in GAMS and MHC. It is shown that the parameters of the correction depend only weakly on the hadron energy. The influence of the gap between both photon and hadron calorimeters on the combined detector characteristics is of lesser importance with increasing energy.

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1. INTRODUCTION

The characteristics of a combined detector consisting of an electromagnetic lead-glass calorimeter [1] and a modular hadron calorimeter (iron-scintillator sandwiches) [2] have been studied at 200 GeV [3]. In the present paper are presented similar measurements that have been performed at lower energies in order to study the energy dependence of the parameters in the algorithm proposed in [3] for the addition of the signals of hadrons in the two calorimeters.

2. EXPERIMENTAL SETUP

The measurements have been performed in a negative particle beam extracted from the 70 GeV IHEP accelerator. Particle coordinates were measured with hodoscopes to a precision of 1 mm. The particles were identified by two Cerenkov threshold counters.

The combined detector consists of the multiphoton spectrometer GAMS-2000 [4] followed by the modular hadron calorimeter MHC-100 [5].

GAMS-2000 is a matrix of 32 x 48 counters made of TF1 lead glass. Each cell is 38 x 38 mm^2 wide and 45 cm long. 60 % of the incident pions interact in the lead glass which is about one nuclear absorption length long. All hadrons are totally absorbed in MHC-100 which is an assembly of 9 x 11 modules 20 x 20 cm^2 each.

The minimum distance between the end face of the lead-glass radiators and the front end of the hadron modules is 50 cm. It may be increased up to 150 cm.

3. ENERGY RESOLUTION

Measurements have been made with 18.5 GeV/c and 38 GeV/c negative pions incident on the combined detector. Both calorimeters have been calibrated with muons and electrons [4,5].

The measurement accuracy in MHC-100 of the energy of pions which do not interact in GAMS (40%) is not impaired by the presence of GAMS. The resolution in this case is $\sigma_E/E = 0.02 + 0.54/\sqrt{E}$ (GeV) [2,5]. For the other 60% it is necessary to take into account the distribution of energy released in both calorimeters. To first approximation, a linear expression may be used for adding the signals of MHC (A_H) and GAMS (A_G) [3,6] :

$$A^{\circ}_{tot} = a^{\circ}_H A_H + a^{\circ}_G A_G \qquad (1)$$

The coefficients in formula (1) are determined by a minimization of the combined detector energy resolution.

Fig. 1 shows the distributions of A°_{tot}. Fig. 2 represents the energy dependence of the coefficients a°_H and a°_G. The energy resolution of the combined detector determined through relation (1) is definitely worse than that of the hadron calorimeter alone. The difference increases when energy decreases (cf table).

Formula (1) is a crude approximation. It does not take into account the non-linearity which occurs when the energy release in GAMS is large. In order to correct A_{tot} for this effect, it was proposed to take into account the lateral development of the showers in GAMS and MHC, characterised by their rms dispersion $\sqrt{D_G}$ and $\sqrt{D_H}$, respectively : $A^c_{H,G} = A_{H,G}(1 + b_{H,G}\sqrt{D_{H,G}})$ [3]. A linear expression is again used for the summation of the signals :

$$A^c_{tot} = a_H A^c_H + a_G A^c_G \qquad (2)$$

i.e.

$$A^c_{tot} = a_H A_H + a_G A_G + d_H A_H \sqrt{D_H} + d_G A_G \sqrt{D_G} \qquad (3)$$

When evaluated in this way, the energy resolution of the combined detector is nearly equal to that of the hadron calorimeter alone (cf table).

Two of the four parameters of formula (3) are almost energy independent (fig. 3). For the present detectors they may be taken as constant : $a_H = 2.0$ and $a_G = 0.32$, so that formula (3) now reduces to

$$A^c_{tot} = 2.0 \;\; A_H(1 + d'_H \sqrt{D_H}) + 0.32 \;\; A_G(1 + d'_G \sqrt{D_G}) \qquad (4)$$

which has only two energy dependent parameters. The resulting resolution is only slightly worse than that of the hadron calorimeter alone (cf table).

Fig. 4 shows that d'_H depends weakly on energy and that d'_G varies significantly only below 40 GeV. If d'_H is also taken constant (0.25), only one parameter is left (d''_G), which is practically constant above 40 GeV (fig. 4). In this case the accuracy is intermediate between that obtained with (1) and (4) (cf table and fig. 1).

4. SPATIAL RESOLUTION

The coordinates of the impact of hadrons in the combined detector are defined through the center of gravity of the showers in both GAMS and MHC with subsequent corrections for systematic shifts [2,3,5,7]. Fig. 6 shows the spatial resolution of GAMS-2000 and of MHC-100 as a function of the energy sharing between both calorimeters ($\propto = a^\circ_G A_G / A^\circ_{tot}$) Hadron coordinates are better measured with the information obtained from GAMS. MHC helps to improve the spatial resolution for hadrons that have lost little energy in GAMS and which are incident near the boundaries of the MHC modules. The same results are obtained at 18.5 GeV/c.

The accuracy of coordinate measurement of hadrons in the combined detector may be expressed as :

$$\sigma_x \approx \begin{cases} 40/\sqrt{E(\mathrm{GeV})}\ \mathrm{mm} & \text{for } \alpha \gtrsim 0.3 \\ 70/\sqrt{E(\mathrm{GeV})}\ \mathrm{mm} & \text{for } \alpha \lesssim 0.3 \end{cases} \qquad (5)$$

5 . EFFECT OF THE GAP BETWEEN GAMS AND MHC

The characteristics of the combined detector have been measured for different distances ℓ between the two calorimeters. The width of hadronic showers in MHC increases with ℓ (fig. 6 and 7) and the spatial reconstruction accuracy is consequently getting worse in MHC.

The hadron shower becomes narrower in MHC with increasing energy making the effect of the gap less important (fig. 8). The energy resolution only weakly depends on ℓ for $\ell \lesssim 1$ m.

6 . CONCLUSION

Algorithms for the summation of energies released by hadrons in an electromagnetic Cerenkov calorimeter followed by a modular hadron calorimeter have been studied. The energy resolution achieved with these algorithms is close to that of the hadron calorimeter alone. All characteristics of the combined detector improve with growing energy.

The data obtained between 20 GeV and 200 GeV may be reliably extrapolated into the TeV region. Such a detector might be used to record tens of gammas and hadrons simultaneously at UNK energies [8]. Energies may be measured with a precision of a few percent and coordinates up to a few millimeters.

The present work concludes a series of studies aimed at solving instrumental problems linked with the possible use of a large combined calorimeter at high energy accelerators, in particular in experiments at the 3 TeV UNK [8].

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TABLE

Energy resolution σ_E/E (%).

Hadron energy (GeV)		18.5	38	200 [3]
MHC alone		15	11	6.8
MHC + GAMS	with (1)	29 (35)*	17 (20)	8.4 (9.3)
	with (4)(d'_H fixed)	20.5 (23.5)	14.2 (16)	7.9 (8.5)
	with (4)	19.5 (22)	13.9 (15.5)	7.4 (7.8)
	with (3)	18 (21)	13.5 (15)	6.9 (7.0)

*) In parenthesis : values for hadron showers that start in GAMS.

FIGURE CAPTIONS

Fig. 1 Sum of GAMS-2000 and MHC-100 signal for 38 GeV pions. Thin histogram : pions traverse GAMS without interaction; thick histogram : addition of GAMS and MHC signals with formula [4] ($d'_H = 0.25$); dashed curve : idem with linear approximation (1).

Fig. 2 Energy dependence of the coefficients of the linear approximation (1). The points at the highest energy in this figure and the following ones are based on the data measured at 200 GeV [3]. Both GAMS and MHC signals are normalized to $\overline{A}_\mu$, the mean energy released by a traversing muon.

Fig. 3 Energy dependence of the coefficients of formula (3). $\sqrt{D_H}$ and $\sqrt{D_G}$ are measured in units of the calorimeters cell width (20 cm for MHC and 38 mm for GAMS).

Fig. 4 Idem for d'_H, d'_G and d''_G (see text).

Fig. 5 Hadron spatial accuracy determined by the signals in GAMS (full line for hadrons going through the center of the cell, dashed line for hadrons on the sides of the cell) and in MHC (for different distances x in cm from the center of the cell).

Fig. 6 Variation of the hadron shower half-width ($\sqrt{D_H}$) in MHC with the distance (ℓ) between the two calorimeters. Arrows indicate the shower half-width without the presence of GAMS for three energies, expressed in GeV.

Fig. 7 Fraction A_1/A_H of the shower energy released in a MHC cell which is laying on the beam axis as a function of ℓ. The arrows show this fraction in the absence of GAMS.

Fig. 8 Energy dependence of the shower width in MHC. The curve with black points is for MHC alone. Other curves are for two distances between the calorimeters of the combined detector : 50 cm and 100 cm, respectively

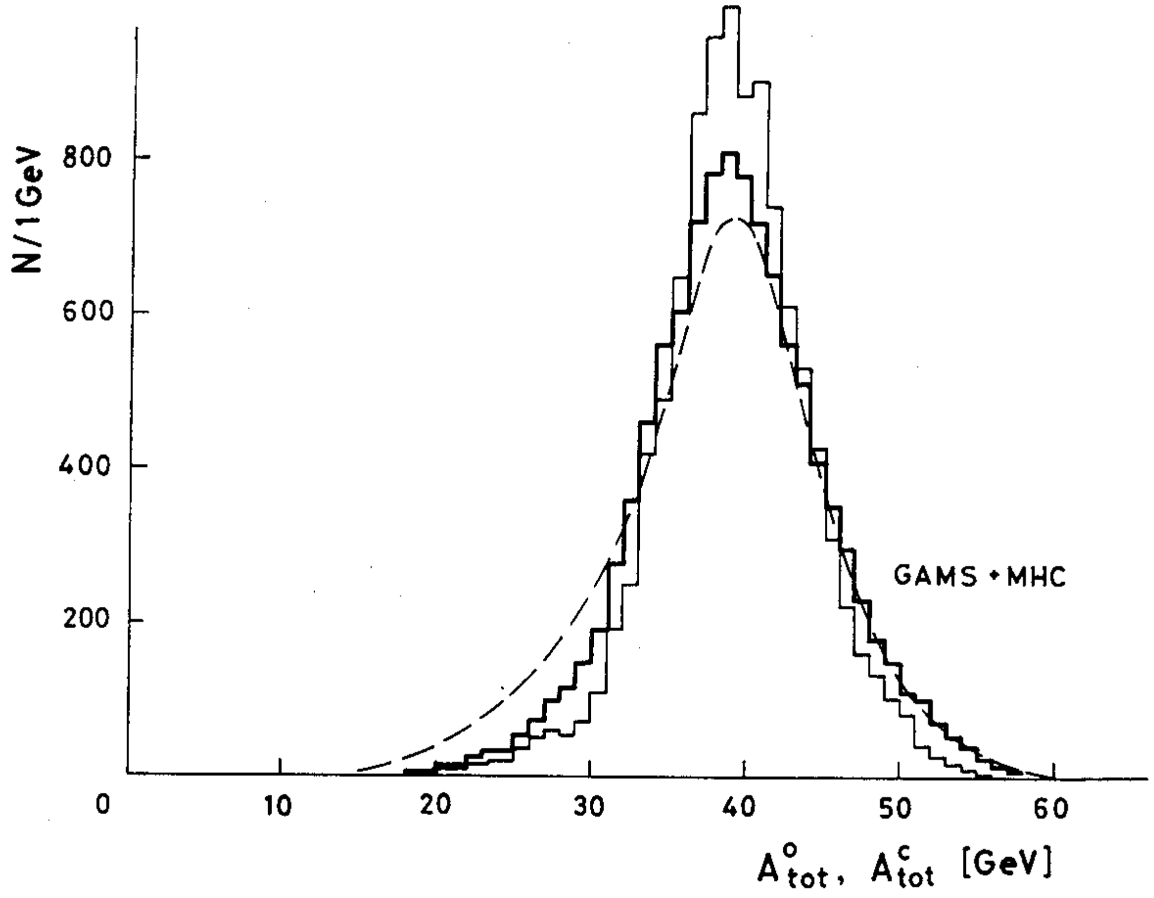

N/1GeV
800
600
400
200
0
10
20
30
40
50
60
GAMS + MHC
A^{o}_{tot}, A^{c}_{tot} [GeV]

FIG. 1

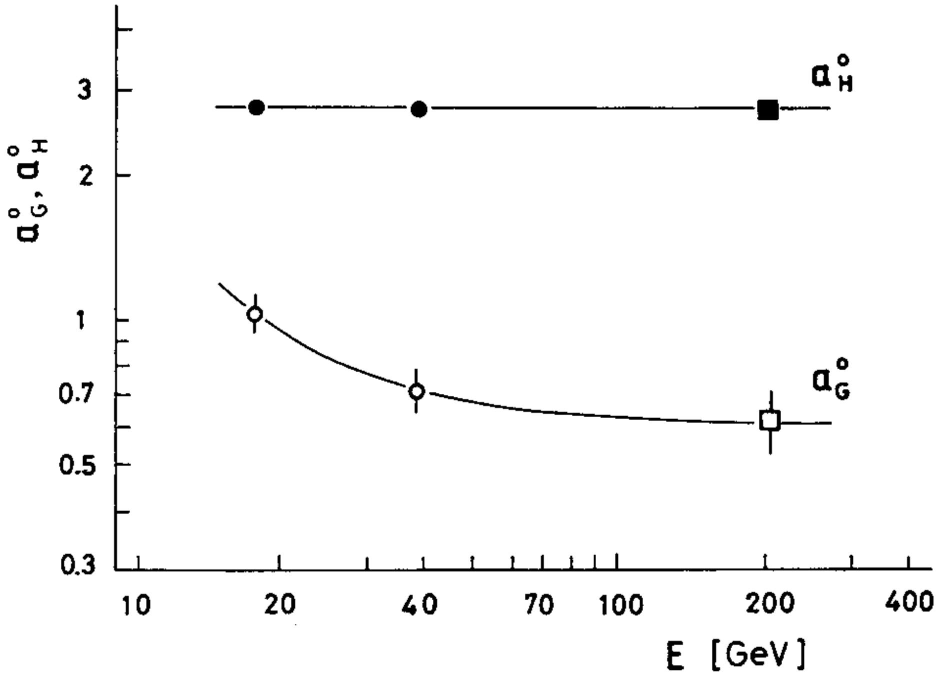


FIG. 2

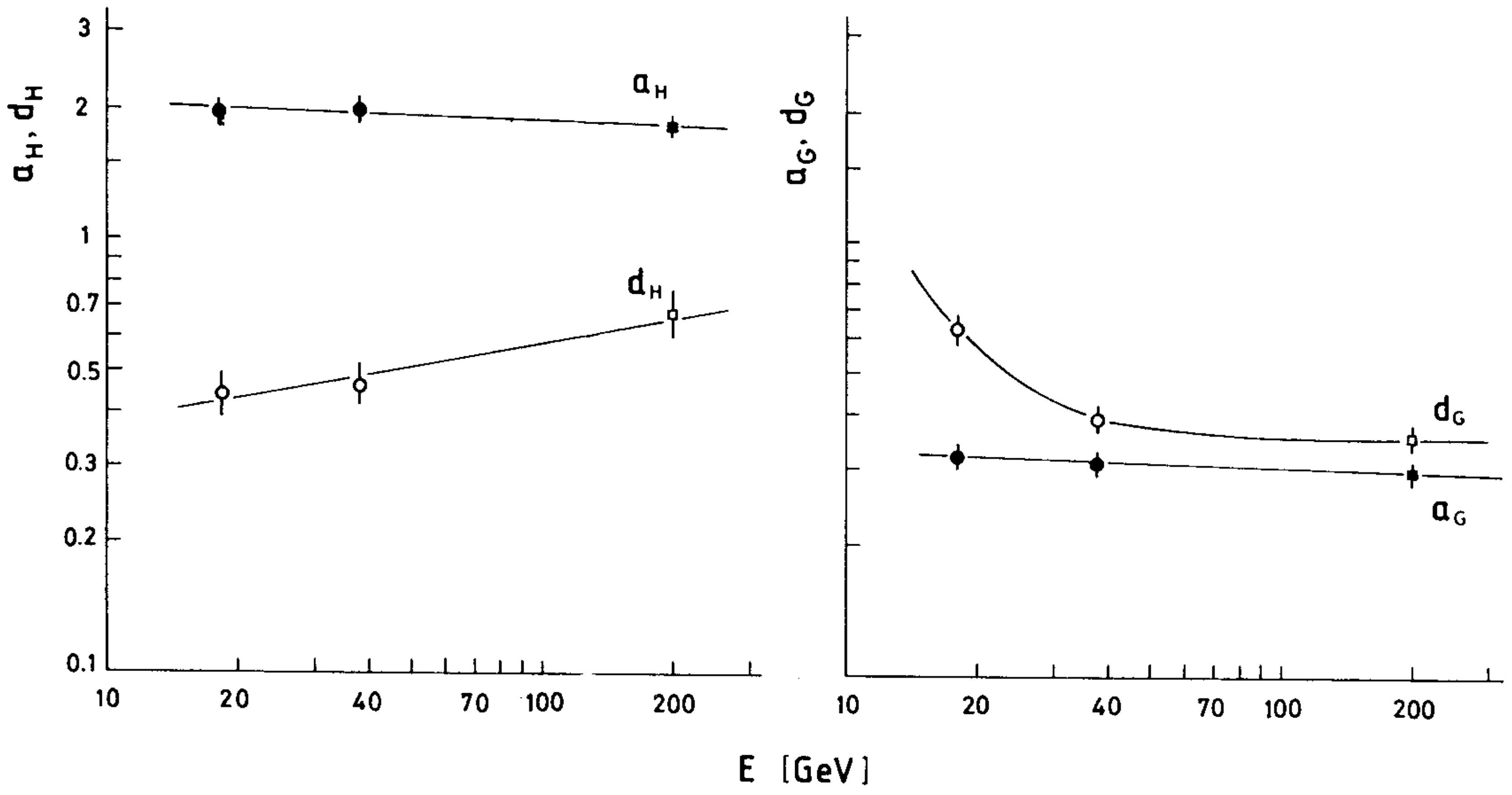

a_H, d_H
3
2
1
0.7
0.5
0.3
0.2
0.1
a_H
d_H
10
20
40
70
100
200
a_G, d_G
d_G
a_G
10
20
40
70
100
200
E [GeV]

FIG. 3

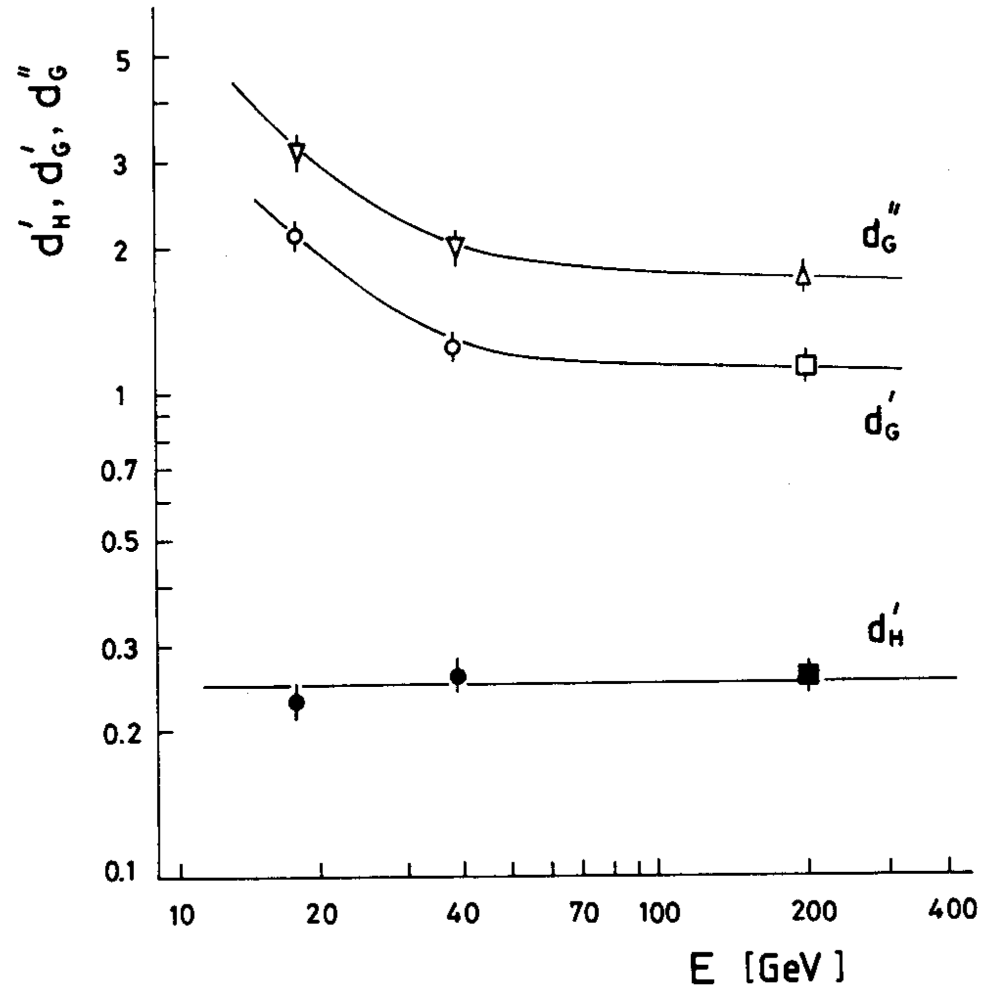
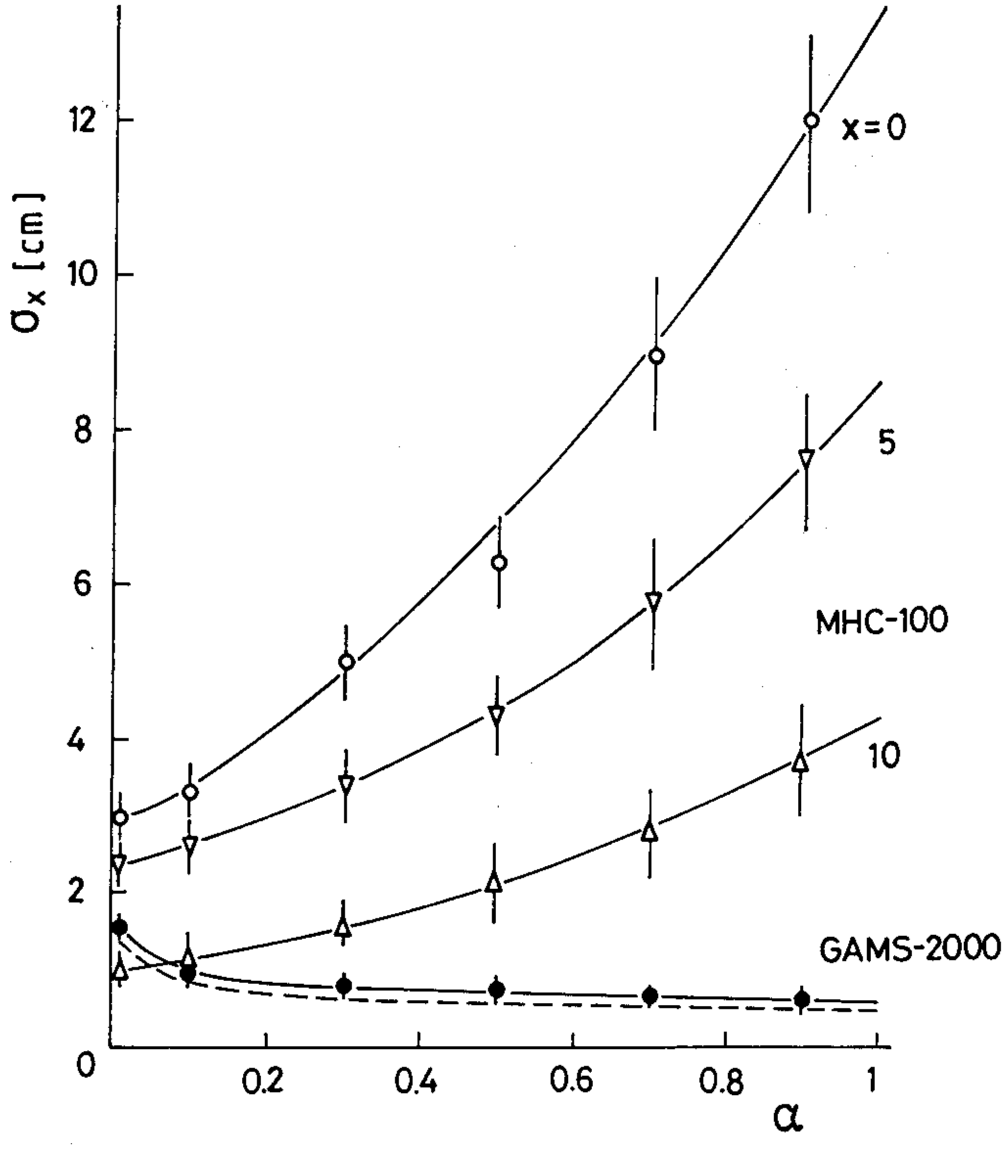
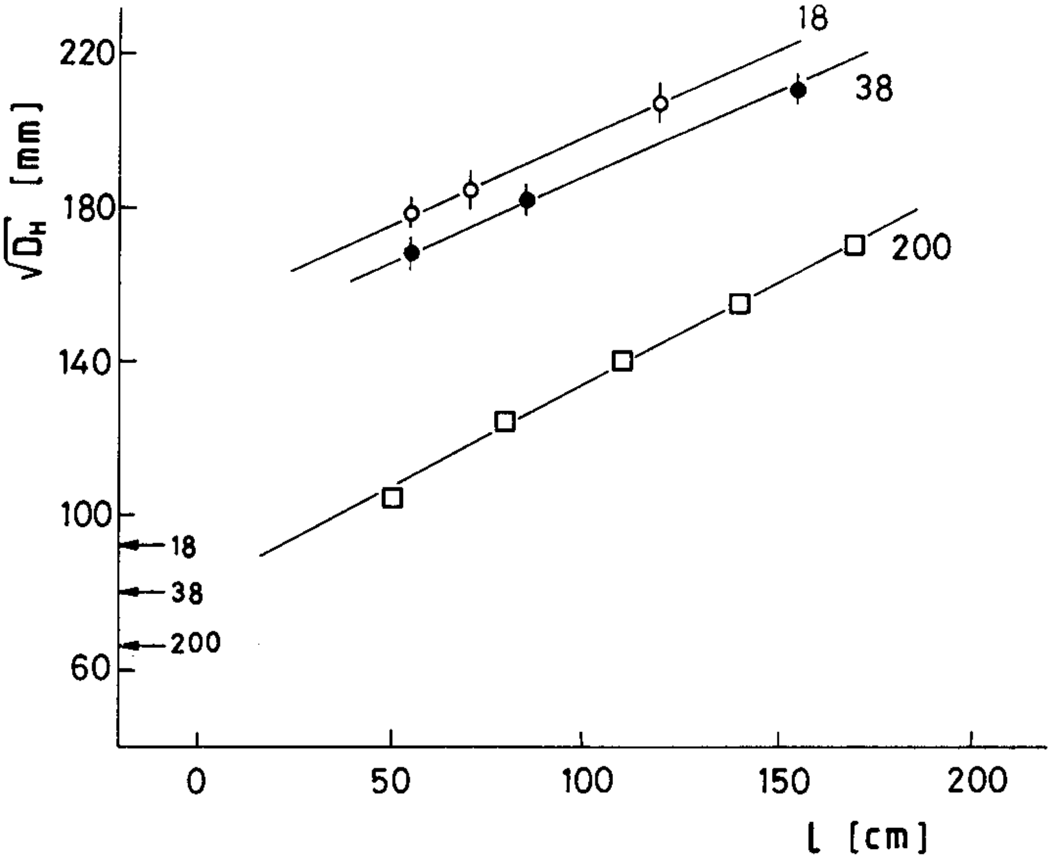


FIG. 4



σ_x [cm]
12
10
8
6
4
2
0
0.2
0.4
0.6
0.8
1
α
x = 0
5
MHC-100
10
GAMS-2000

FIG. 5



$\sqrt{D_H}$ [mm]
220
180
140
100
60
18
38
200
0
50
100
150
200
l [cm]
18
38
200

FIG. 6

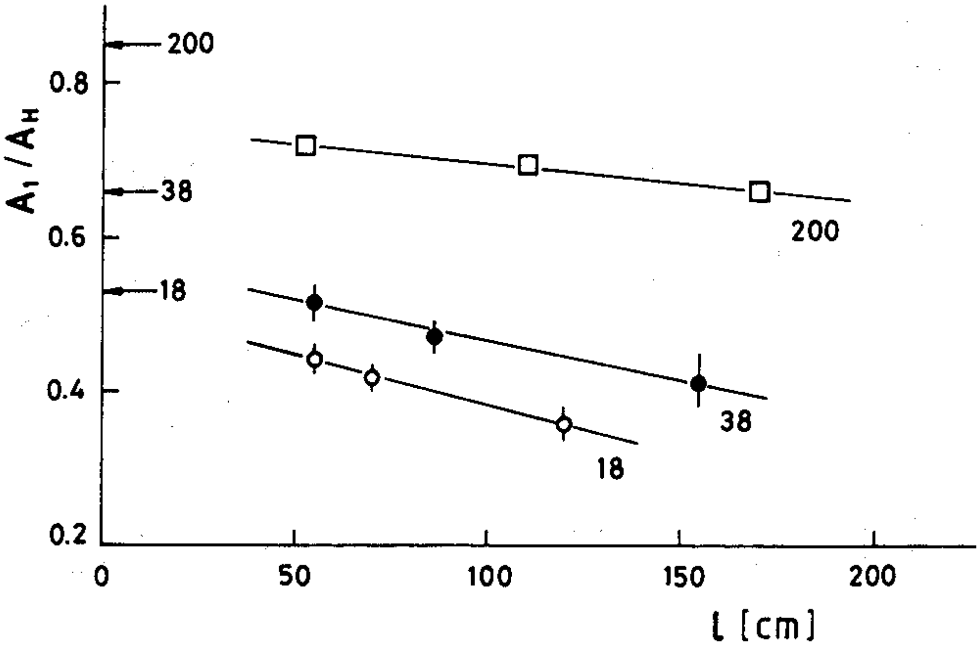


FIG. 7

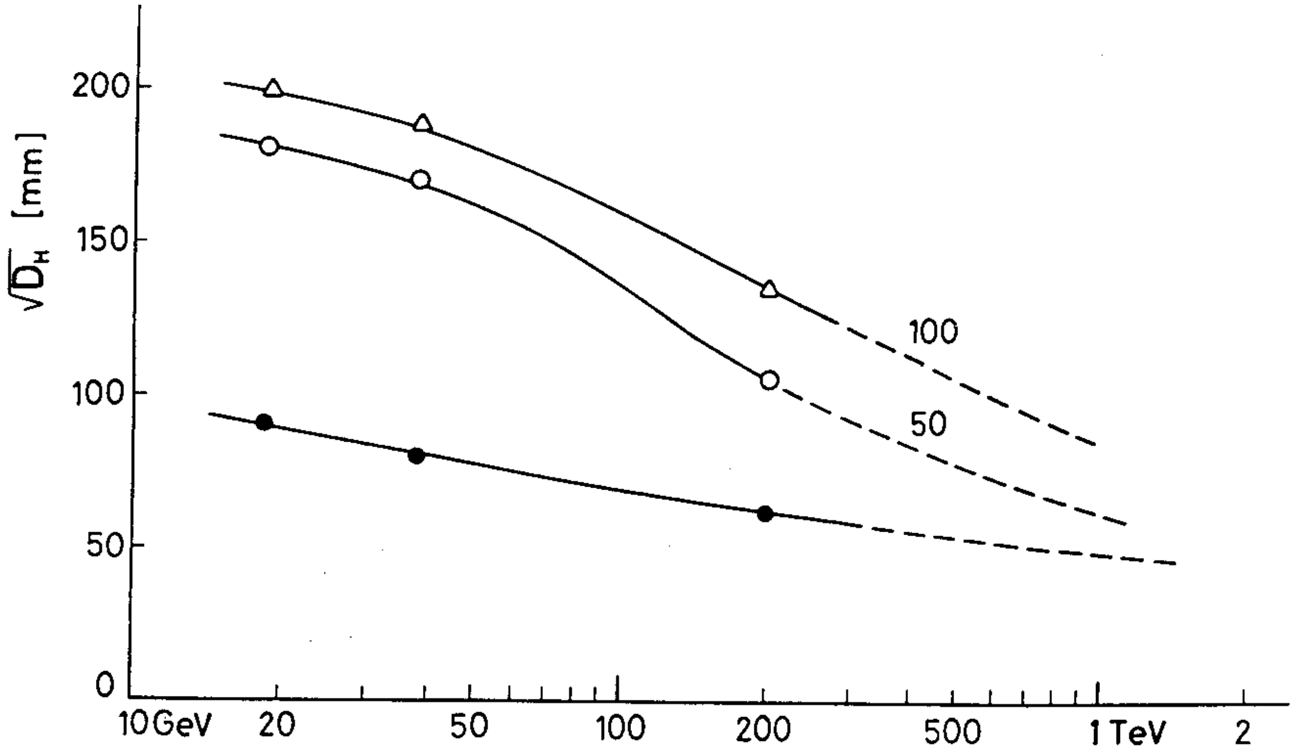


FIG. 8