EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/86-150
October 7th,1986

MODULAR HADRON CALORIMETER

IHEP[1] - IISN[2] - LAPP[3] Collaboration
(Joint CERN-IHEP experiment)

F. Binon[2*], C. Bricman[2*], V.M. Buyanov[1], V.S. Datsko[1], J. Dufournaud[3],
P. Duteil[4], M. Gouanère[3], V.A. Kachanov[1], D.B. Kakauridze[1], G.V. Khaustov[1],
J.P. Lagnaux[2*], V.G. Lapshin[1], D. Michotte[2*], Yu.V. Mikhailov[1], Th. Mouthuy[2],
V.F. Obraztsov[1], J.P. Peigneux[3], A. Possoz[5], V.V. Potapov[1],
Yu.D. Prokoshkin[1], V.I. Rykalin[1], P.M. Shagin[1], A.V. Shtannikov[1],
D. Sillou[3], A.V. Singovsky[1], J.P. Stroot[2*] and V.P. Sugonyaev[1].

ABSTRACT

A large cellular hadron calorimeter consisting of independent modular total absorption counters (iron-scintillator sandwiches) is described. Scintillation light is collected using light guides with a wavelength shifter. The characteristics of the detector have been studied in a 200 GeV hadron beam. The detector makes it possible to measure simultaneously the energy and coordinates of several particles.

(Submitted to Nuclear Instruments and Methods)

---

1) Institute for High Energy Physics, Serpukhov, USSR.
2) Institut Interuniversitaire des Sciences Nucléaires, Belgium.
3) Laboratoire d'Annecy de Physique des Particules, France.
4) CERN, Geneva, Switzerland.
5) University of Louvain La Neuve, Belgium; now at Enrico Fermi Institute, University of Chicago, USA.
*) Mailing address: CERN, EP Division, CH-1211 Geneva 23, Switzerland.

1. INTRODUCTION

In recent years the use of hadron calorimeters with a cellular structure has become widespread in high-energy experiments ; the scintillation light is collected in these calorimeters by light guides loaded with a wavelength shifter [1-8]. These detectors have distinct advantages when compared to planar type calorimeters for recording events with large particle multiplicity. The measurement of the shower space distribution makes it possible to determine with high accuracy not only the energy but also the coordinates of the hadron producing the shower [2,9,10]. The use of light guides with a wavelength shifter makes it much easier to construct the cells and makes it possible to design large-scale calorimeters with an aperture of several square meters.

In this paper, the modular hadron calorimeter MHC-200 built for the NA-12 experiment at CERN and its calibration procedures are described. This 50-ton cellular-type detector is installed in the H8 beam channel of the 450 GeV SPS immediately behind the hodoscope multiphoton spectrometer GAMS-4000 [11]. It is designed both for measuring the energy and coordinates of hadrons*) and for improving the separation of photons and hadrons. The detector aperture is some 7 m^2. It contains 240 total absorption counters of the sandwich type (iron-scintillator). The modularity makes it possible to change the calorimeter configuration to suit the requirements of the experiment.

2. CALORIMETER DESIGN

The MHC-200 calorimeter takes the form of a matrix of 13 x 13 modules, arranged on a mobile platform. Two types of modules are used in the detector. The basic modules (144 of them) are sandwich counters with 20 x 20 cm^2 transverse dimensions. The centre of the calorimeter has an hole with the dimensions of a basic module (20 x 20 cm^2) through which passes the high intensity beam. It is surrounded by 24 modules with the same external dimensions, but which contain four 10 x 10 cm^2 sandwich counters which allow to cope with the larger intensity of secondary particles near the beam axis.

---

*) The joint operation of these two calorimeters as a combined hadron detector is described in another article [12].

The design of the basic module is shown in figure 1. The total absorption counter consists of thirty-six 25 mm thick steel plates, interleaved with 5 mm thick scintillator sheets. The overall thickness of the counter is 5 nuclear absorption lengths for pions and 7 such lengths for protons. The steel plates are spot welded at two opposite ends to the 1.5 mm steel side walls of the module. The top and bottom of the module are fitted with detachable steel lids. This design makes for a rigid and stable module weighing 300 kg.

Inexpensive polymethylmethachrylic scintillators (Polipop 0180*)) with 12% naphtalene has been used. The scintillator sheets are 1/4 covered with black paper and 3/4 with aluminized mylar which considerably improves the uniformity of light collection when compared with the case in which the scintillator is fully covered with mylar (fig. 2). The collection of scintillation light is achieved by using a flat 3 mm thick plexiglas light guide loaded with a wavelength shifter*), placed on one side wall of the module. An air gap between the light guide and the scintillator is provided by two 0.2 mm diameter nylon filaments stretched along the module above the scintillator sheets. To improve light collection, the ends of the steel plates on the side of the light guide are covered with aluminium foil and the outer surface of the wavelength shifter is covered with white paper [13]. A plexiglas light guide, collecting light on the photocathode of a PM-84-3 photomultiplier, is glued to the output end of the wavelength shifter. The absorption and emission spectra of the re-emitter used (Laser dye 481) are matched with the emission spectrum of the scintillator and the spectral sensitivity of the PM-84-3 photocathode (S-20 type). An UV-absorbing chemical (Sanduvor VSU) has been added to the wavelength shifter light guide in order to reduce the contribution of Cerenkov light from relativistic particles passing through it.

The photomultiplier and its divider are placed in a removable housing at the back end of the module. The optical contact between the light guide and the PM is maintained by a silicon compound which, as has been proved in practice over a period of many years of operation [14], guarantees a

---

*) Polyvar, Pomezia, Italy.

reliable optical contact. The computer controlled voltage divider of the PM and the circuit of the high-voltage supply to the calorimeter are similar to those used in GAMS-4000 [15]. The last four dynodes are powered from separate booster supplies to guarantee PM gain stability when the load is high. The dynode signals are fed into a fast analog summation system used for triggering purposes.

The modules of the second type, which contain four 10 x 10 cm^2 counters, have a similar design. The counters are light insulated from one another and are functionally independent. Light collection is carried out by four independent light guides on to four individual PM.

The PM signals are measured with 12-bit analog to digital converters (ADC). The electronics of the calorimeter is similar to that used in GAMS-4000 [16].

3. MONITORING SYSTEMS

In order to track instabilities in the counters, two independent monitoring systems are used in MHC-200. Each hadron calorimeter module is monitored by an individual device, comprising a pulsed light emitting diode (LED) and a generator to trigger it, which is fixed on its front end (fig.1). The light pulse is fed into the wavelength shifter through a small hole. The LED signal is used as a reference during calibration of the modules in the beam and when setting the PM high voltage. The possibility of individual monitoring of the modules is particularly useful in the tuning of the fast analog summation system of the dynode signals.

The calorimeter also has a monitoring system which is common to all modules. A group of six LEDs serves as a source of reference signals; the light flashes are distributed to the modules by optical fibers. The stability of this control system is controlled by a special photomultiplier, the gain of which is calibrated using a scintillator with an Am^{241} α-source. This monitoring system is simple and reliable. It makes it possible to track the instabilities of the calorimeter counters with an accuracy of 1% over several weeks.

4. TUNING AND CALIBRATING THE CALORIMETER

The tuning and preliminary calibration of each MHC-200 counter has been carried out in a 200 GeV/c beam containing roughly equal proportions of π^+-mesons and protons as well as an important muon contamination. Each calorimeter module has been installed in the beam and its PM high voltage has been tuned so that the maximum of the hadron peak, measured by the ADC, is near a pre-set value. The amplitude of the signal from the LED of the individual monitoring system has then been tuned so as to be roughly equal to the hadron signal. Several thousand events (muons and hadrons), in addition to the signals from the LEDs, have been recorded on magnetic tape for each counter.

Figure 3 shows a typical amplitude spectrum, obtained with muons in a single MHC-200 counter. The average number of photoelectrons in the PM, emitted as the muon passes through the module, is 20 (0.6 photoelectrons per scintillator sheet). The signal of a 200 GeV hadron is ≈ 100 times larger. The hadron to muon signal ratio varies from module to module by ± 5%.

After assembly the calorimeter has been recalibrated in a wide muon beam, irradiating the whole calorimeter. Muons entering the central part of the cells were selected by two distant scintillation counters. The measured calibration coefficients were corrected taking into account the values of the hadron to muon signal ratios, obtained at the time of the preliminary calibration.

5. ENERGY AND COORDINATE RESOLUTION

Measurements of the calorimeter characteristics were carried out in the same 200 GeV positive hadron beam. The coordinates of the beam particles were determined by a 2 mm wide and 30 mm high counter. This counter could be moved horizontally and set with an accuracy of ≈ 0.5 mm.

Figure 4 shows A_{tot}, the total energy released in the calorimeter by 200 GeV hadrons when the beam enters the centre of a 20 X 20 cm^2 counter. The energy resolution is $\sigma_E/E = 6.8\%$. The same figure shows the distribution obtained with a set of 3 X 3 similar modules during test measurements in a 38 GeV pion beam at the IHEP accelerator (energy resolution is 14%). The positions of the peaks are normalized to the muon signal. The energy resolution depends weakly on the point at which the beam enters the module (fig. 5) except for the ≈ 2 cm wide area in the region of the wavelength shifter where the energy resolution becomes a factor of two worse. The A_{tot} value in this area also increases slightly (fig. 5). However, this effect is corrected later using the coordinate information obtained from the calorimeter itself.

The method used for obtaining hadron coordinates is based as in [9] on a comparison of energy release in the cells surrounding the hadron shower axis. The shower coordinates are determined by the centre of gravity x_o. Systematical errors, which are due to the exponential form of the shower, are then corrected for [2, 9, 10, 17]. The bias of the measured x_f coordinate does not then exceed 1.5 mm (fig. 6).

The accuracy in determining the hadron coordinates depends on the point at which the particle enters the cell (fig. 6). In the centre of a 20 x 20 cm^2 cell it is 14 mm (fig. 7) which coincides with data [10] for a planar calorimeter with the same cell size. On the boundary between cells the hadron coordinate is measured with an accuracy of 4 mm. The hadron coordinate is determined using the information from the 3 x 3 cells surrounding that with the maximum shower energy release. The use of a larger number of cells does not improve resolution.

Similar measurements have also been carried out for modules containing four 10 x 10 cm^2 counters. Their energy resolution is the same as of the basic modules but their coordinate resolution in the centre of the counter is 1½ times better. They also show a stronger non-homogeneity near the wavelength shifter.

Thus, the hodoscope MHC-200 calorimeter described in this paper makes it possible to measure simultaneously the energy and coordinates of high energy hadrons (charged and neutral [18]) with good precision. The energy resolution equals $\sigma_E/E = 6.8\%$ at 200 GeV; the coordinate resolution varies between 4 and 14 mm depending on the point at which the beam enters the 20 x 20 cm^2 calorimeter cell. The cellular structure of the calorimeter makes it possible to measure the coordinates and the energies of several hadrons at the same time. The presence of small "hot spots" in the region of the wavelength shifter does not have a significant effect on the overall characteristics of the detector.

Detectors of this type can also be considered for use in experiments in the TeV region, as their characteristics improve at high energies [2]. The energy resolution of such a calorimeter above 1 TeV would be less than 3% and the coordinate accuracy would be 2 to 5 mm.

The authors thank P. Giromini for discussing scintillator and wavelength shifter composition. They are grateful to the management of IHEP and CERN for their support on the GAMS programme of which this work was a part.

REFERENCES

[1] V. Eckardt et al., Nucl.Instr. Meth. 155 (1978) 389.

[2] Yu. D. Prokoshkin, Proc. Second ICFA Workshop on Possibilities and Limitations of Accelerators and Detectors, Les Diablerets, Switzerland, ed. U. Amaldi (CERN, Geneva, 1979) p. 405.

[3] O. Botner et al., Nucl. Instr. Meth. 179 (1981) 45.

[4] G. Bellettini et al., Nucl. Instr. Meth. 204 (1982) 73.

[5] C. De Marzo et al., Nucl. Instr. Meth. 217 (1983) 405.

[6] A. Beer et al., Nucl. Istr. Meth. A224 (1984) 360.

[7] C. W. Fabjan, Preprint CERN 85-84, Geneva, 1985.

[8] T. Akesson et al., Nucl. Instr. Meth. A214 (1985) 17.

[9] F. Binon et al., Nucl. Instr. Meth. 174 (1980) 369.

[10] F. Binon et al., Nucl. Instr. Meth. 206 (1983) 373.

[11] F. Binon et al., Preprint IHEP, 78-133, Serpukhov (1978).

D. Alde et al., Nucl. Phys. B269 (1986) 485.

[12] F. Binon et al., Preprint IHEP 86-113, Serpukhov (1986).

[13] D. Lacarrere, CERN internal note SB/AC/D/3164 (1982).

[14] F Binon et al., Nucl. Instr. Meth. A248 (1986) 86.

[15] F. Binon et al., Nucl. Instr. Meth. 214 (1983) 269.

[16] D. Alde et al., Nucl. Instr. Meth. A240 (1985) 343.

[17] S.V. Donskov et al., Prib. Tek. Exp. 4 (1977) 49.

[18] F. Binon et al., Yad. Fiz. 33 (1981) 1027; Nuovo Cim. 64A (1981) 89.

FIGURE CAPTIONS

Fig.1 Design of a hadron calorimeter module. 1: steel plates, 2: scintillator sheets wrapped in black paper (3) and aluminized mylar (4), 5: light guide loaded with wavelength shifter, 6: plexiglass light guide, 7: PM-84-3 photomultiplier, 8: body of the module, 9: detachable light-insulating housing, 10: individual monitoring sytem, 11: optical fiber of the monitoring system of the whole calorimeter.

Fig.2 Dependence of the average amplitude of the signal due to the Am^{241} α-source on the distance to the wavelength shifter in a 20 x 20 cm^2 scintillator (in relative units, $\bar{A} = 40$ at $x = 200$ mm). Light points: the scintillator sheets are covered with aluminized mylar. Dark points: the sheets are 1/4 covered with black paper and 3/4 covered with aluminized mylar. Here and in the other figures the shaded rectangle shows the position of the wavelength shifter.

Fig.3 Amplitude spectrum of muons (scale is given as the read-out from the ADCs; in these units a 200 GeV hadron gives a peak at ≈ 2200).

Fig.4 Spectrum of A_{tot}, the summed pulses of the calorimeter, when 200 GeV hadrons enter the centre of a 20 x 20 cm^2 counter. Data are also given for an energy of 38 GeV (see text). The mean value of the muon signal is indicated by an arrow.

Fig.5 a) Dependence of the position of the hadron peak on the point of impact into a 20 x 20 cm^2 counter (relative units). The light points are before correction.The dark points are after correction using coordinate information (the correction leads to significant changes only at the boundary, near the light guide). $x = 0$ here and below corresponds to the boundary between modules.

b) Dependence of the energy resolution of MHC-200 on the point of impact into a 20 x 20 cm^2 counter.

Fig.6 a) Mean value of the x_o coordinate measured through the centre of gravity of the hadron shower (light points) and of the coordinate x_f after correction (dark points) as a function of the true coordinate (20 x 20 cm^2 counter). The dashed curve is calculated using the exponential shower profile [2, 9, 10].

b) Dependence of the coordinate accuracy σ_x on the point of impact on a 20 x 20 cm^2 counter.

Fig.7 Distribution of the differences between the measured coordinates x_f and the true coordinates x ($\Delta x = x_f - x$) when the hadrons enter (a) at the edges, or (b) at the centre of a 20 x 20 cm^2 counter.

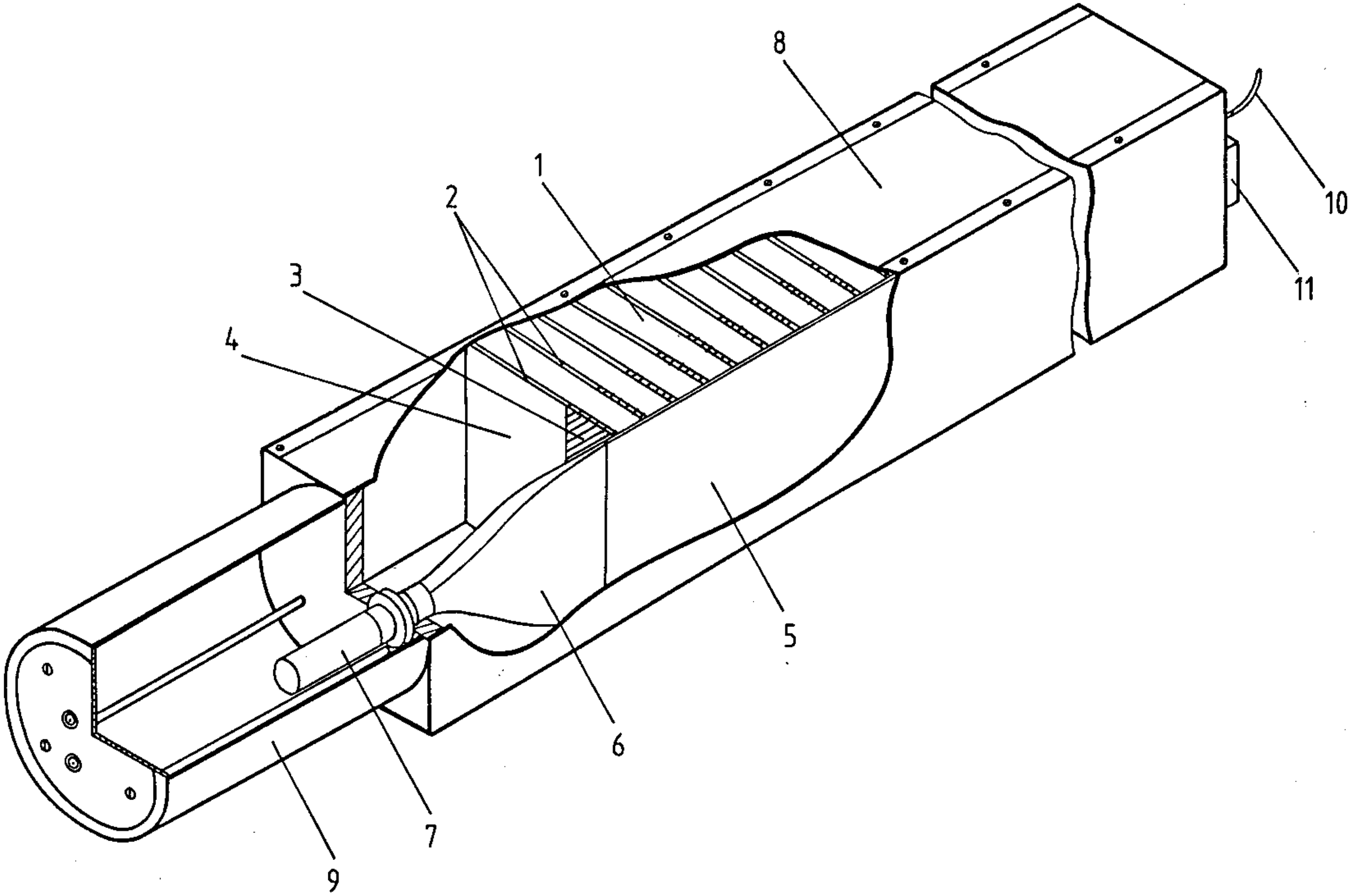

Fig. 1

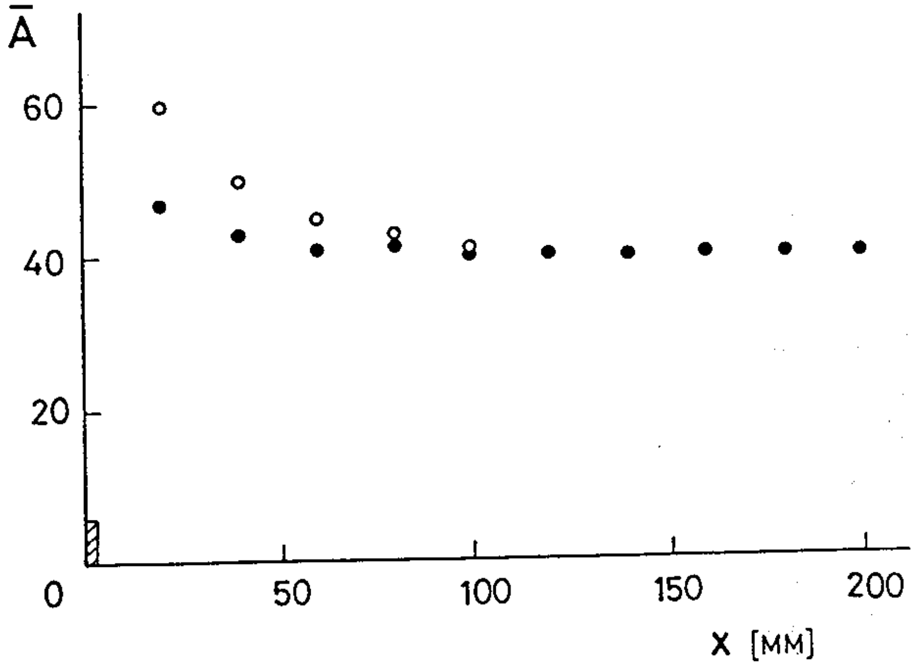

Fig. 2

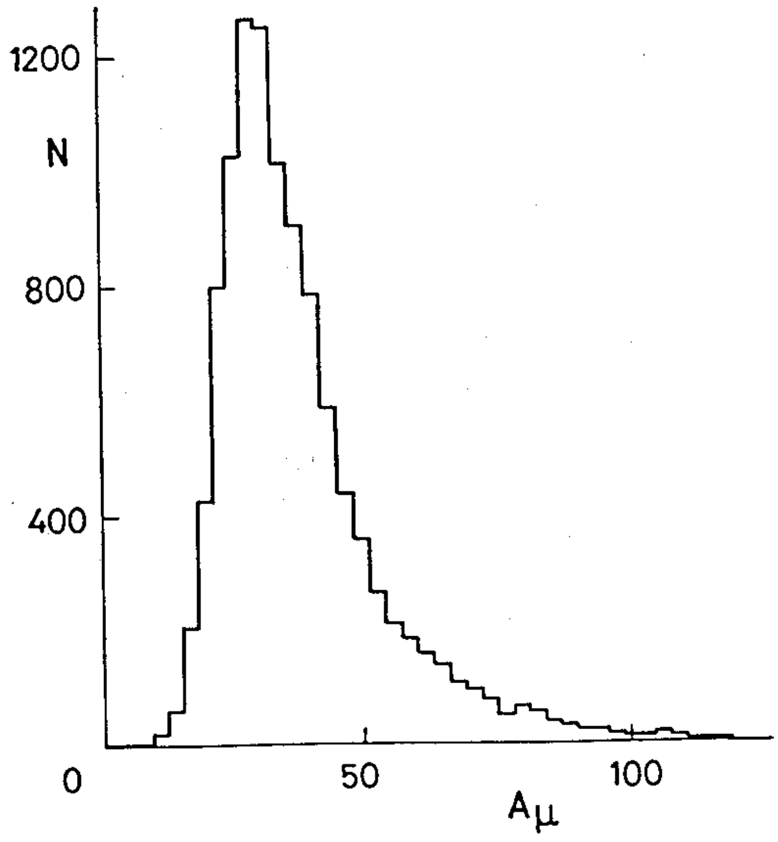

Fig. 3

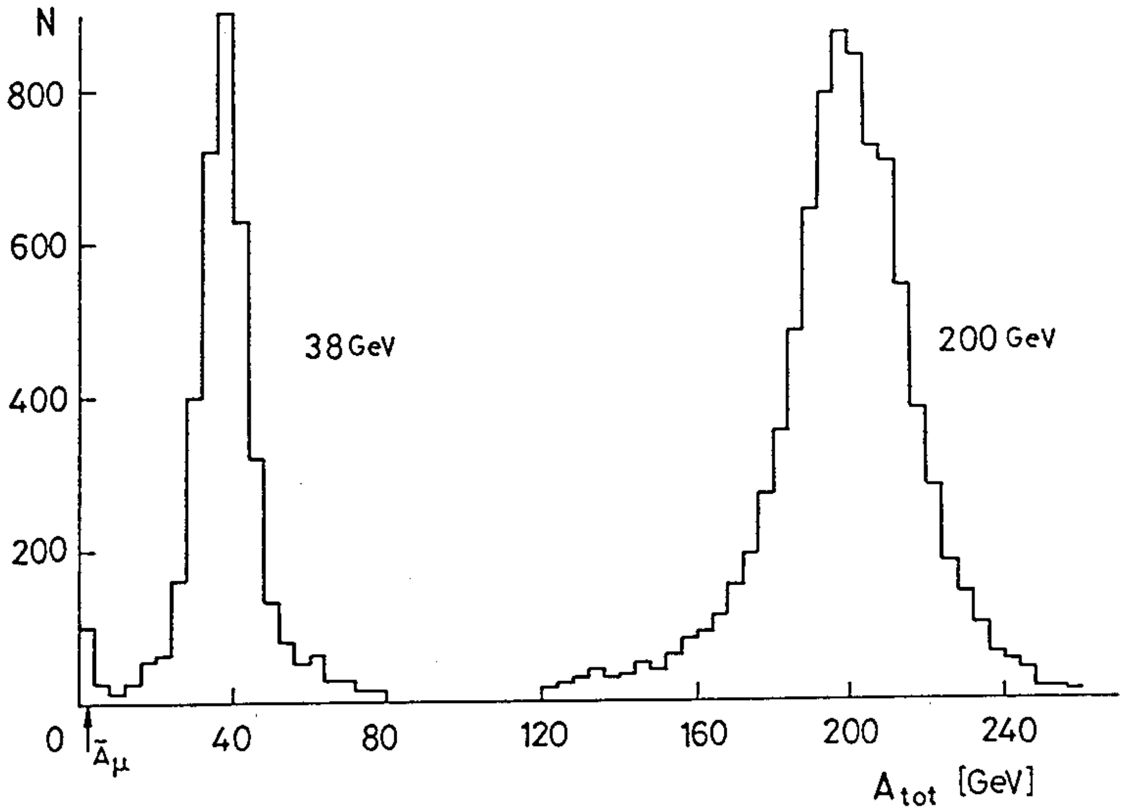
N
800
600
400
200
0
$\bar{A}_\mu$
40
80
120
160
200
240
38 GeV
200 GeV
A_{tot} [GeV]

Fig. 4

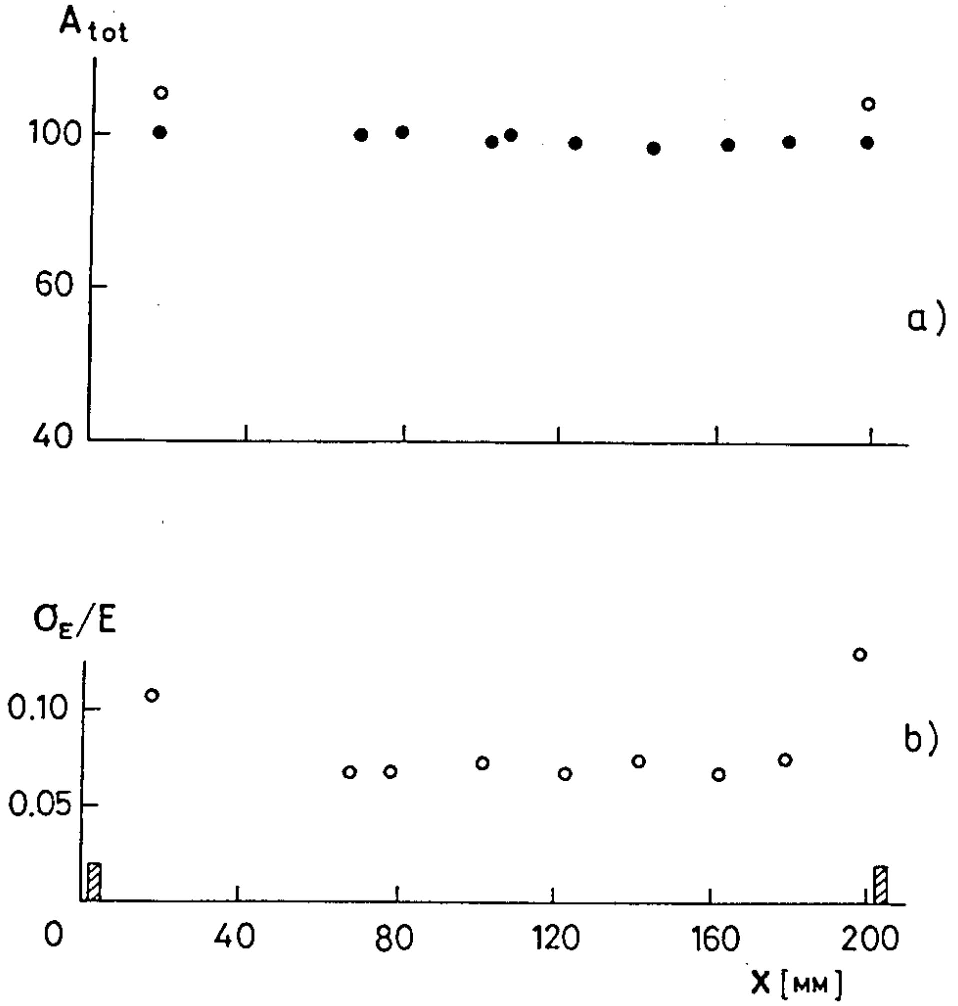

Fig. 5

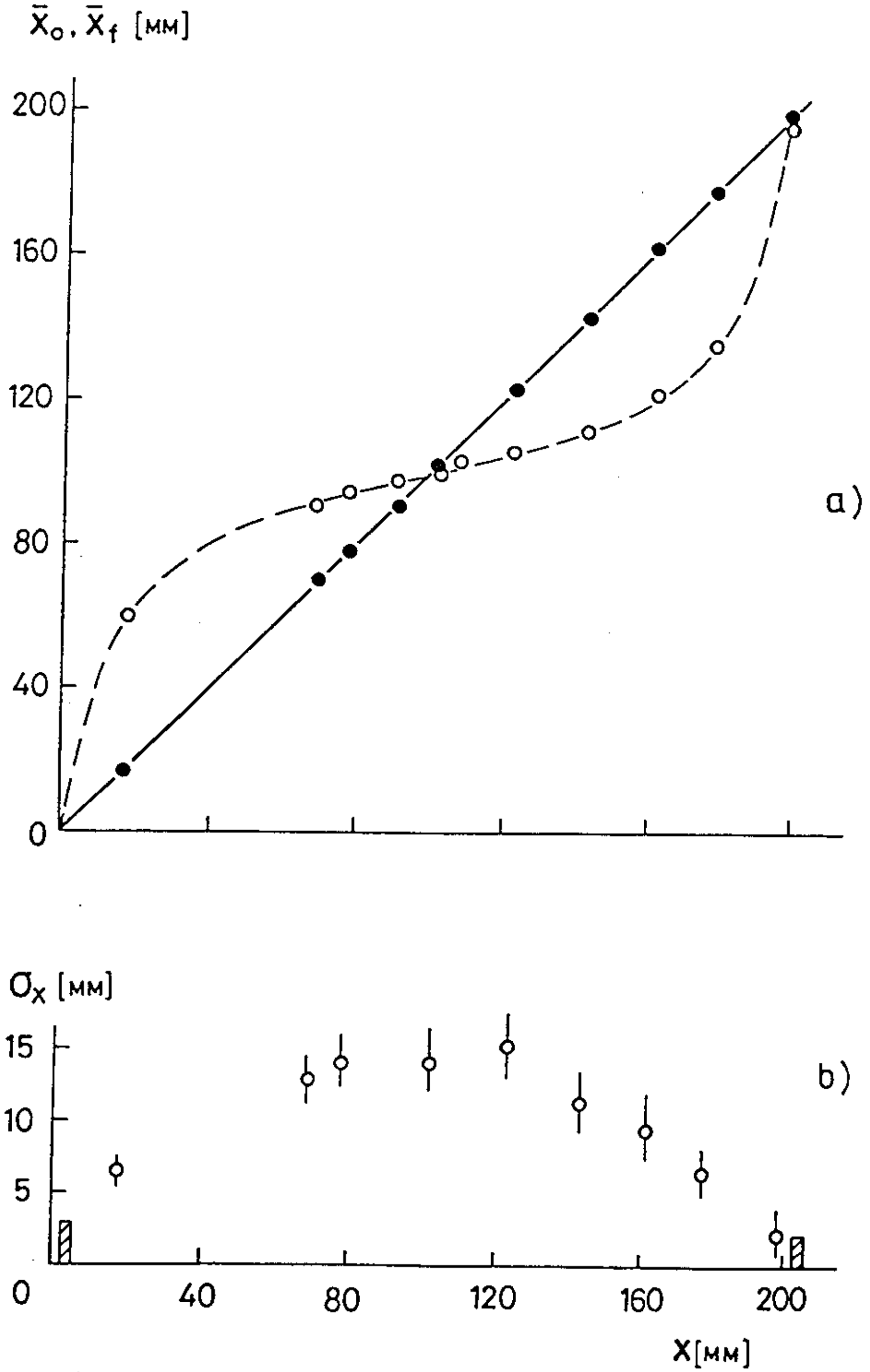
$\bar{X}_o, \bar{X}_f$ [мм]
200
160
120
80
40
0
a)
σ_X [мм]
15
10
5
b)
0
40
80
120
160
200
X[мм]

FIG. 6

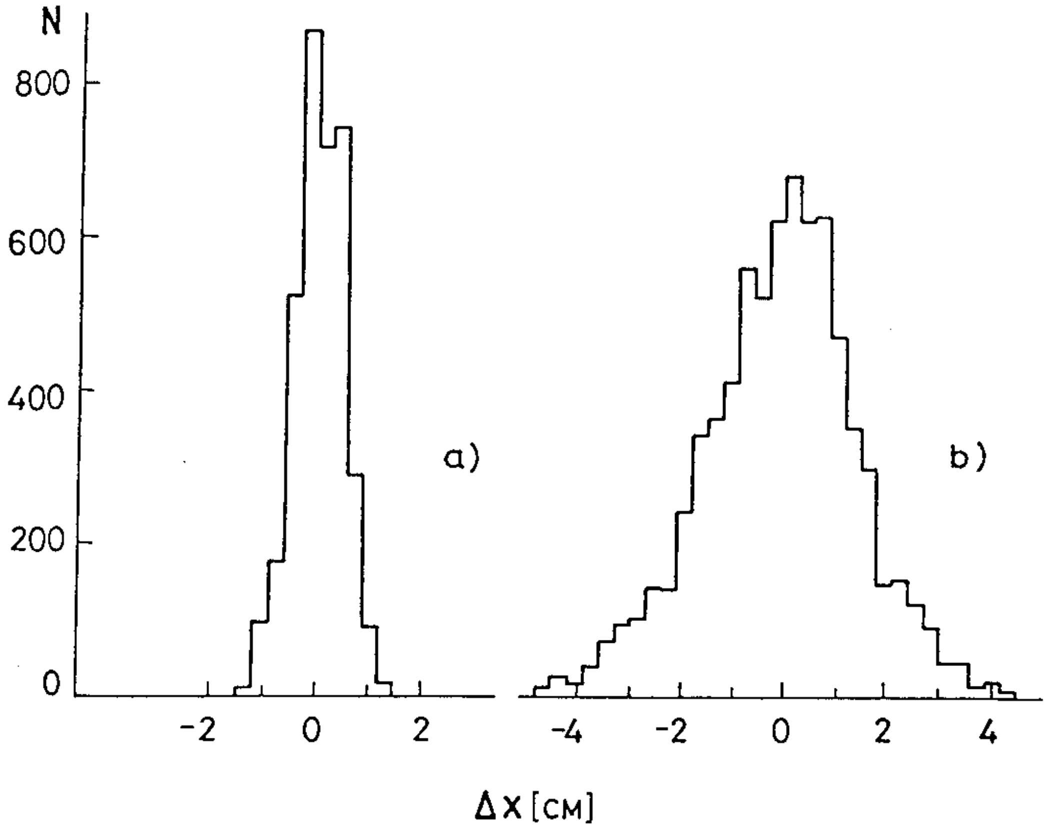

FIG. 7