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PERFORMANCE OF A URANIUM-SCINTILLATOR CALORIMETER

by

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Abstract

A calorimeter made of 3 mm depleted uranium plates and 2.5 mm scintillator sheets was exposed to a beam of electrons,muons and hadrons between 3 and 9 GeV/c. The average energy resolution for hadrons was measured as $\sigma/E = 33.5\%/\sqrt{E}$.

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1. *Introduction*

The ZEUS collaboration is planning to construct a large depleted uranium (DU) scintillator calorimeter for experimentation at HERA (Ref.1). In order to optimize the parameters several prototype calorimeters were built and tested with particle beams. This report presents results from the so called TEST35 which used three calorimeter modules on loan from the AFS-HELIOS experiments at CERN (Ref.2). These modules were restacked by us with new scintillator. The beam tests were performed at the CERN PS. The data reported here were collected during June and July of this year.

2. *Calorimeter Modules*

The calorimeter modules were formed by 20 cm wide, 120 high and 3 mm thick DU plates interleaved with 2.5 mm thick plastic scintillator sheets. The optical readout consisted of 20 cm high and about 80 cm long wave length shifter bars (WLS) followed by light guides (LG) and phototubes (PM) mounted on two sides of a calorimeter module (Fig. 1). They formed towers of 20 by 20 cm^2 cross section which measured the energy deposited in the module. The total depth of a module corresponded to 125 radiation lengths (r.l.) or 4.2 absorption lengths (λ). Note that the modules were longitudinally not subdivided and the full depth was readout in one go.

Three of such modules were tightly placed next to each other to form a calorimeter of about 60 cm width and 120 cm height (Fig. 1). In order to test the performance with different types of scintillator, the upper half of the modules was equipped with SCSN38 (Ref. 3), the lower half with Altustipe (Ref.4). The towers made of SCSN38 scintillator were optically decoupled (see Fig 2.).

The two halves were treated as two separate calorimeters. In this report only the results from the SCSN38 calorimeter are presented.

Details of the calorimeter modules are summarized in Table 1.

Table 1 Calorimeter Parameters

Number of U plates	133
Number of Sci plates	134
Size of U plates	$1200\times200\times3$ mm^3
Size of Sci plates	
upper half - SCSN38	$3\times[200\times200\times2.5$ $mm^3]$
lower half - Alustipe	$600\times200\times2.5$ mm^3
Number of optical channels to readout SCSN38 (Altustipe)	18 (18)
Doping of K-27 WLS	100 mg/l
Doping of BBQ WLS	80 mg/l
Total depth of the stack	806.5 mm =12.5 r.l.=4.2 λ
Photomultipliers	XP-2011

3. Calibration

The relative calibration of the phototubes was done using the uranium radioactivity. The light generated in the scintillator by the radioactivity was collected with a special gate over 10 μsec. The high voltage of each phototube was adjusted in such a way as to place the mean of the radioactivity signal (= uranium noise) in the ADC channel 1200. The stability of the calibration was continuously monitored during the data taking by recording the uranium noise in between beam spills. By adjusting the high voltages every 3 to 4 hours the tube-to-tube variation in the position of the noise peak was less than $\pm 0.5\%$. In Fig.3 the noise signal observed in the central tower is plotted versus the noise signal obtained by summing the 8 surrounding towers. The r.m.s. spread of the noise in the central tower is σ_{cent}=21.1 ch and in the 8 towers, σ_8= 60.5 ch. The ratio σ_8/σ_{cent} is close to the $\sqrt{8}$ expected. The mean pedestal plus the mean noise contribution were subtracted on-line from each electronic channel.

4. Beam Setup

The calorimeter was exposed to the T7 beam of the CERN PS. The layout is shown in Fig. 4. Beam particles were identified by two Cerenkov counters C1, C2 and by the scintillation counters $B_1, .., B_6$. The counters B_4, B_5 which had a 1 cm diameter hole in the center were used to veto stray particles. The counter B_6 was used to identify muons. Beam particles were defined by the coincidence

$$B_1.B_2.B_3.\overline{B}_4.\overline{B}_5$$

The calorimeter was aligned so that the beam hit the center of the central tower of the calorimeter.

The Cerenkov counters were optimized for electron recognition. They were filled with CO_2 gas. For each beam momentum the gas pressure was chosen to be near the pion threshold. The pulse heights from the two Cerenkov counters were registered for each event. As an example, in Fig.5 a correlation plot for the two counters is shown. For 3 GeV/c momentum one recognizes two clusters, the high pulse heights stem from electrons, the low ones from muons and pions. A small contribution from kaons is discernible. The Cerenkov information provided a clean separation between electrons and other particles.

Particles which produced signals in counter B_6 behind the calorimeter were identified as muons.

5. Data Taking

Data runs were performed at 3, 5, 7 and 9 GeV/c momentum. Electrons, muons and hadrons were recorded simultaneously. For studies of muons data runs with down scaled e+hadron triggers were taken.

Most of the data were collected with a 200 nsec gate. Studies as a function of gate width showed that the performance for hadrons remained unchanged within a wide range of gate widths from about 70 to 400 nsec (see below).

6. *Results*

In Figs. 6a-9a correlation plots are shown between the pulse height measured in the central tower PH_{cent} and the sum of the pulse heights from the 8 surrounding towers, PH_8 for different energies. One observes in general three clusters of events representing electrons (PH_{cent} large, PH_8 small), muons (PH_{cent} small and PH_8 small) and hadrons (PH_{cent} and PH_8 large). The particle assignment is verified by plotting the same distributions for electrons identified by the Cerenkov counters (Fig. 6c...), for muon identified by B_6 (Fig. 6b ..) and for hadrons defined as those particles which were not identified as either electrons or muons (Fig. 6d...). Most of the hadrons were pions. The hadron correlation plots show a small contamination by muons at all energies.

Muons

The pulse height spectra of muons are shown in Fig. 10 for 3, 5, 7 and 9 GeV/c. A strong low energy ionization peak is observed which at momenta of 5 GeV/c and higher is followed by long tails. Most of these tails are caused by hadron showers which also gave a signal in B_6. The low energy portion of the spectra was fit to a gaussian in the region - 2 s.d, + 1 s. d. The position of the peak and the r.m.s deviations are shown in Table 2.

Table 2 Parameters of the muon signal observed in the central tower

p (Gev/c)	peak channel	σ
3	256.0±2.0	20.8±2.0
5	266.6±1.5	23.2±1.2
7	269.0±2.3	26.1±1.7
9	272.0±1.7	28.5±1.7

Electrons

The pulse height spectra observed for electrons at 3, 5, 7 and 9 GeV/c are displayed in Fig. 11. The pulse height spectra within ± 2 s.d. limits were fit to gaussians. The deviation of the mean total pulse height from linearity is shown in Fig.12 as a function of beam momentum; it is found to be less than ±1%. The energy resolution is affected by the uranium noise. It was evaluated for the central tower alone and for the sum over all towers. The numerical values are given in Table 3. The result is $\sigma/E = 16.3\%/\sqrt{E}$. for the central tower and 17.9 $\%/\sqrt{E}$ for all towers, the increase of the latter being caused by the 8 times larger noise contribution.

If we were to use the central tower and readout only the first 25 r.l. as planned for the ZEUS calorimeter the electron resolution would improve to $\sigma/E \approx 15\%/\sqrt{E}$.

Table 3 Parameters of the electron signal

a) observed in the central tower

p (Gev/c)	mean channel	σ	$(\sigma/\text{mean})\sqrt{E}$
3	549.1±0.7	51.9±0.5	16.4±0.2 %
5	921.1±1.3	67.4±1.0	16.3±0.2 %
7	1265.9±1.5	77.8±1.6	16.3±0.3 %
9	1663.7±1.6	89.9±1.1	16.2±0.3 %

b) observed by summing all towers

p (Gev/c)	mean channel	σ	$(\sigma/\text{mean})\sqrt{E}$
3	560.8±0.8	62.3±0.5	19.2±0.2 %
5	938.7±1.6	75.1±1.5	17.9±0.4 %
7	1290.3±3.0	86.0±3.0	17.6±0.6 %
9	1695.0±2.0	95.7±2.0	16.9±0.3 %

Hadrons

In Fig.13 the fraction of energy seen in the 18 photomultipliers is displayed. About 85% of the energy is deposited in the central tower. The distribution indicates that the side leakage is at the few percent level. The pulse height spectra measured at 3, 5 , 7 and 9 GeV/c are given in Fig. 14. The small peak around channel 270 is due to muons . After suppressing the muon contamination by a cut on the pulse height the total pulse height spectra were fit to gaussians. The mean and the r.m.s. spread were determined from the events within ± 2 s.d. limits. The deviation of the mean from linearity is less than ± 1.5 % as shown in Fig. 15 as a function of beam momentum. The numerical results are listed in Table 4. The energy resolution is near $\sigma/E = 33.5\%/\sqrt{E}$ and independent of energy within the statistical errors.

Influence of the gate width

The energy resolution for electrons and hadrons was studied at 5 GeV/c as a function of the gate width Δt. The result is shown in Fig.17. For electrons, summing all towers, $\sigma/\sqrt{E}$ increases slowly from 17% to 20% between $\Delta t=$ 100 ns and 600 ns. The increase can be understood in terms of the DU noise. For pions, $\sigma/\sqrt{E}$ remains unchanged between $\Delta t=$ 100and 400 ns. At Δt=600 ns there is a slight increase to $\sigma/\sqrt{E}=$ 35% which again can be explained by the DU noise.

Table 4 Parameters of the pion signal

p (Gev/c)	mean channel	σ	$(\sigma/\text{mean})\sqrt{E}$
3	522.1±1.3	101.1±1.3	33.5±0.4 %
5	882.9±1.5	130.4±1.4	33.2±0.4 %
7	1215.7±2.3	154.2±2.3	33.6±0.5 %
9	1599.0±2.3	182.0±2.0	34.1±0.4 %

e/h ratio

By comparing the electron and hadron signals one can calculate the ratio e/h of their pulse heights. The e/h ratio was found to be 1.07, 1.06, 1.06, 1.06 at 3, 5, 7 and 9 GeV/c. It has yet to be corrected for side and rear leakage of hadrons estimated to be 5 - 10 %, and for nonuniform response of the WLS. These corrections will bring the e/h ratio close to unity.

7. Summary

We have tested a 4.2 λ deep and 60 by 60 cm^2 wide DU - scintillator calorimeter with e, μ and hadrons at 3, 5, 7 and 9 GeV/c. The gains of the phototubes were calibrated solely with the uranium radioactivity. For the electrons the mean pulse height was found to be linear to within 1 % and the energy resolution was $\sigma/E = 16\%/\sqrt{E}$. For hadrons the deviations from linearity were smaller than ± 1.5 %. An average energy resolution of $\sigma/E = 33.5\%/\sqrt{E}$ was obtained. Within the statistical errors the resolution is independent of energy. The uncorrected e/h ratio was found to be 1.06. It is expected that corrections for leakage and nonuniformities bring the the e/h ratio close to unity.

Acknowledgements

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2. T. Akesson et al, Nucl.Inst.Meth.A241(1985)17
3. Product of Kyowa-Gas, Japan
4. Altulor, Tour Gan, France

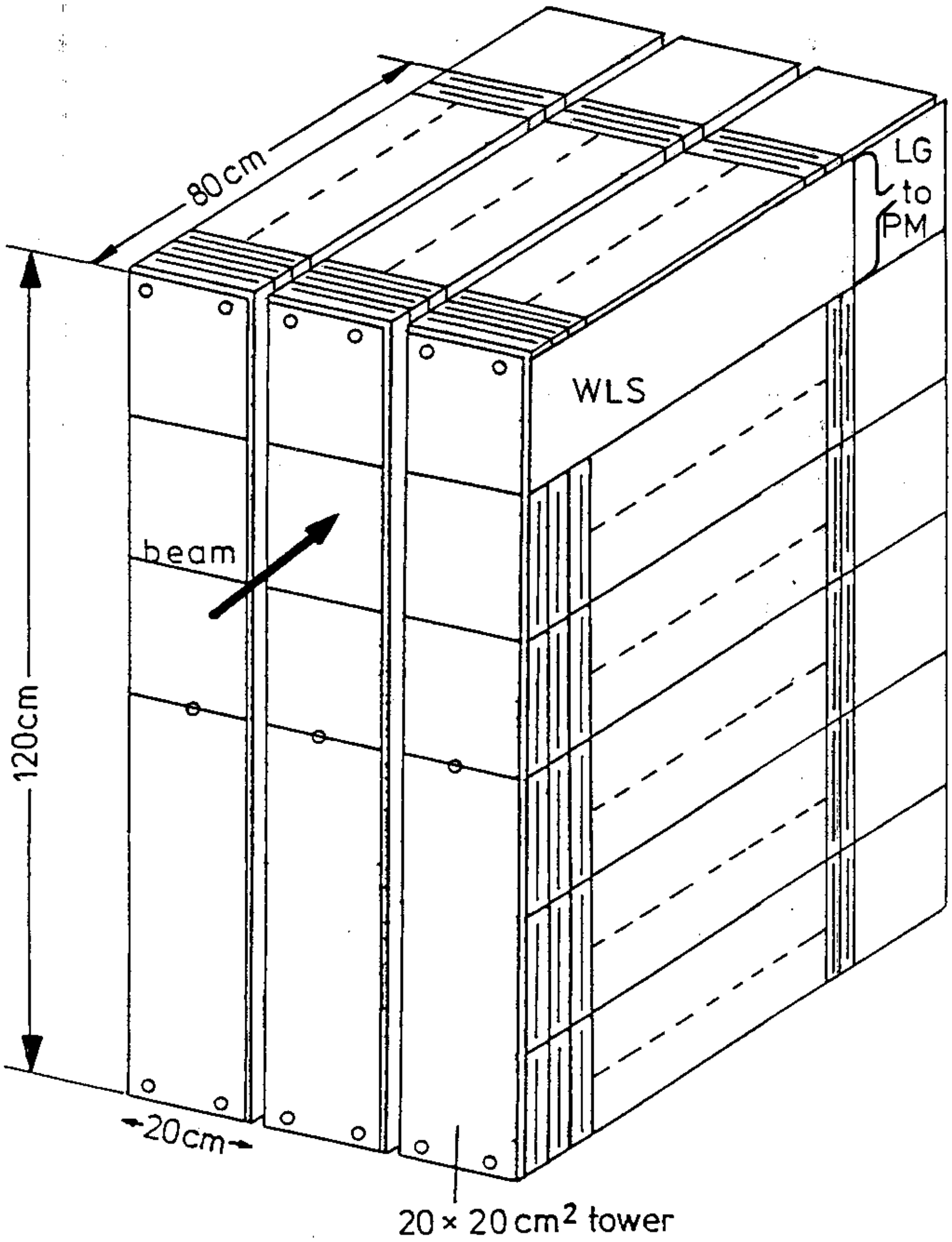


Fig. 1. Setup of TEST35 DU-scintillator calorimeter.

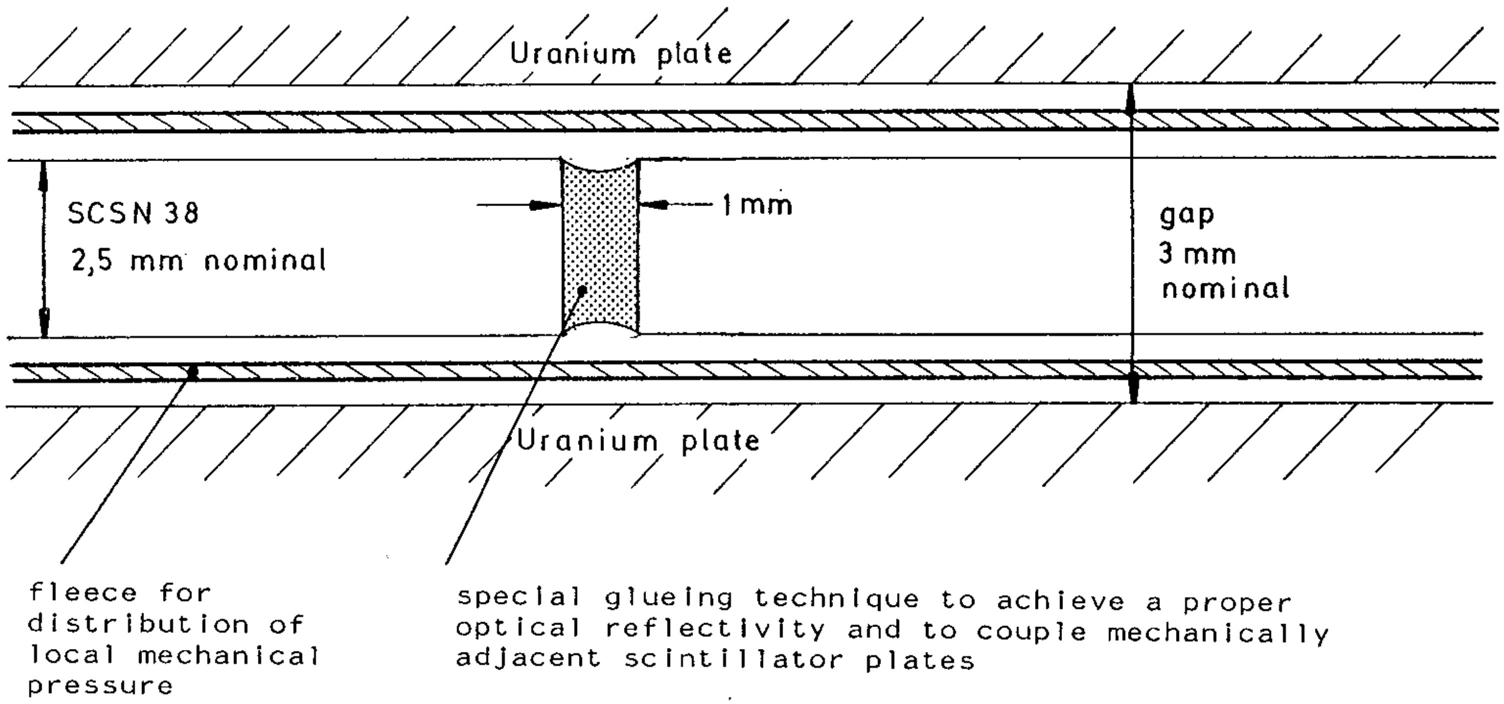


Fig. 2. Cross-section of DU-scintillator gap.

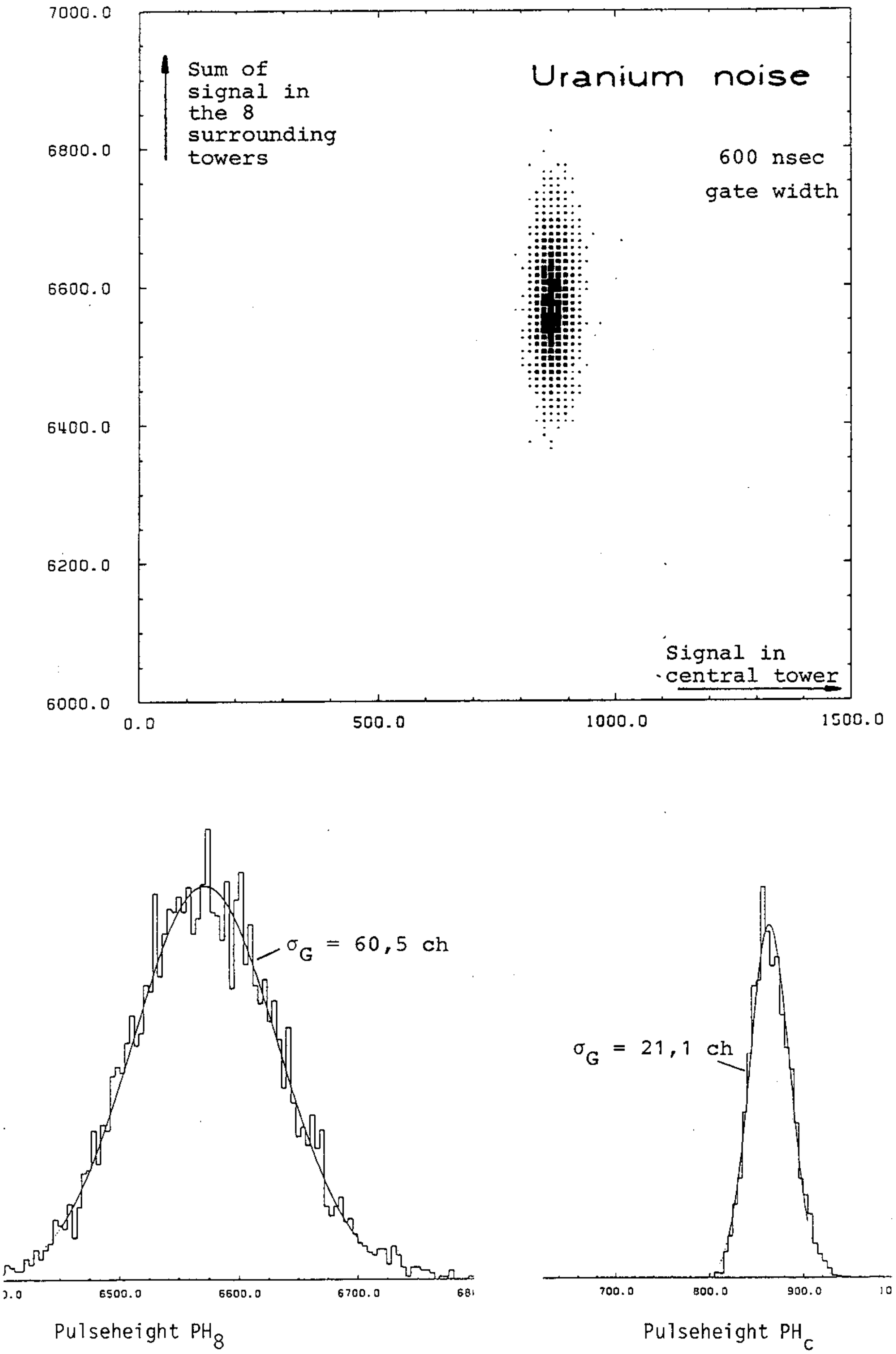
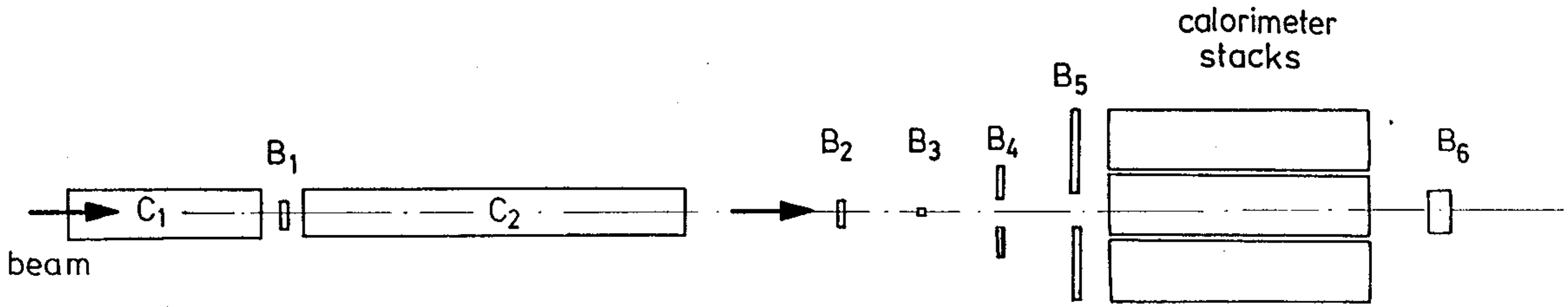


Fig. 3. DU-noise distributions :

a) sum over 8 towers versus signal in central tower

b) sum over 8 towers

c) signal in the central tower



Trigger setup

C_1, C_2	Cerenkov-counters
B_1, B_2, B_3, B_6	Finger or small paddle counters
B_4, B_5	Veto-counters

Fig. 4. Layout of the test beam at the CERN PS

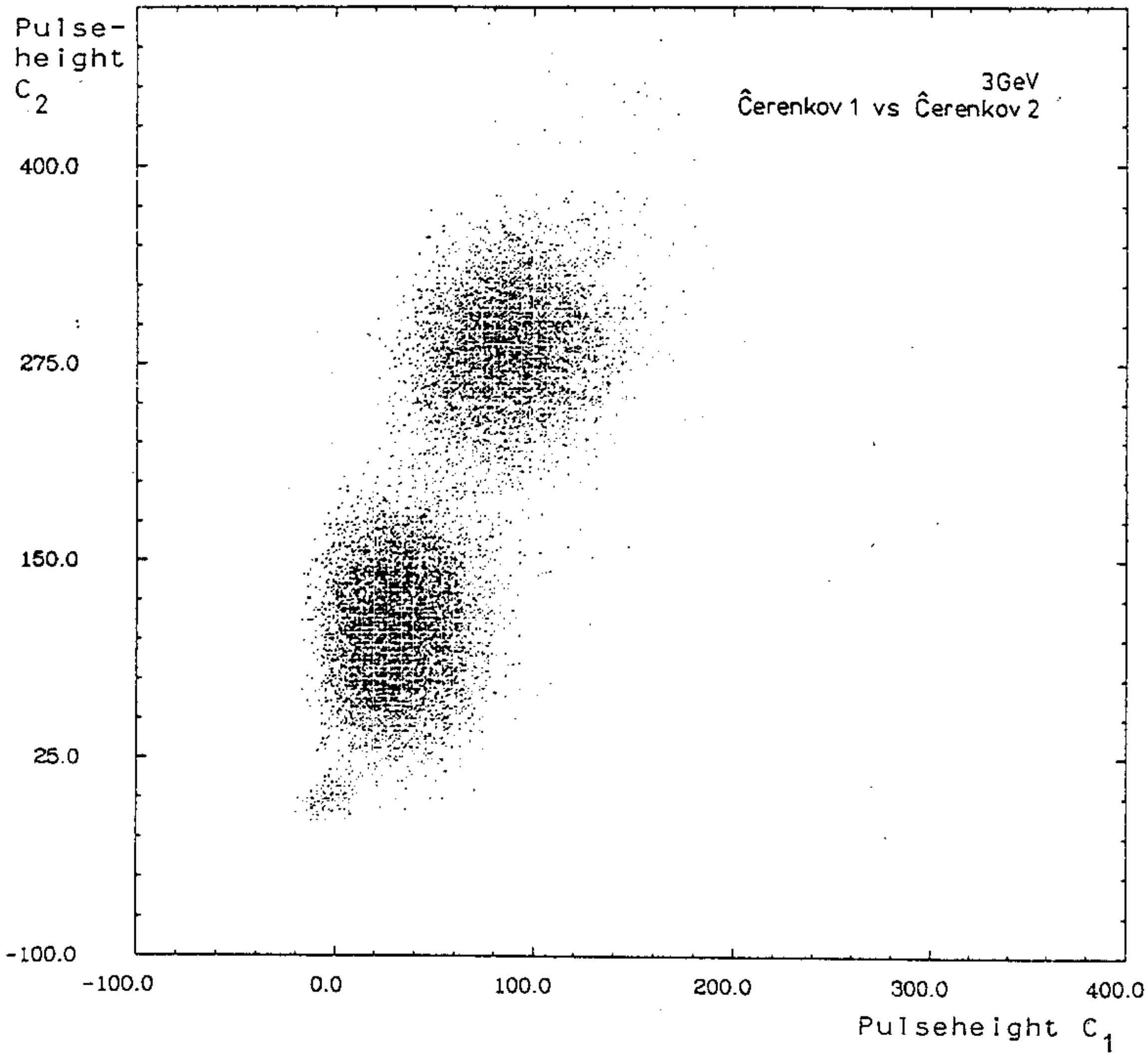


Fig. 5. Cerenkov counter pulse height distributions (C1 versus C2)

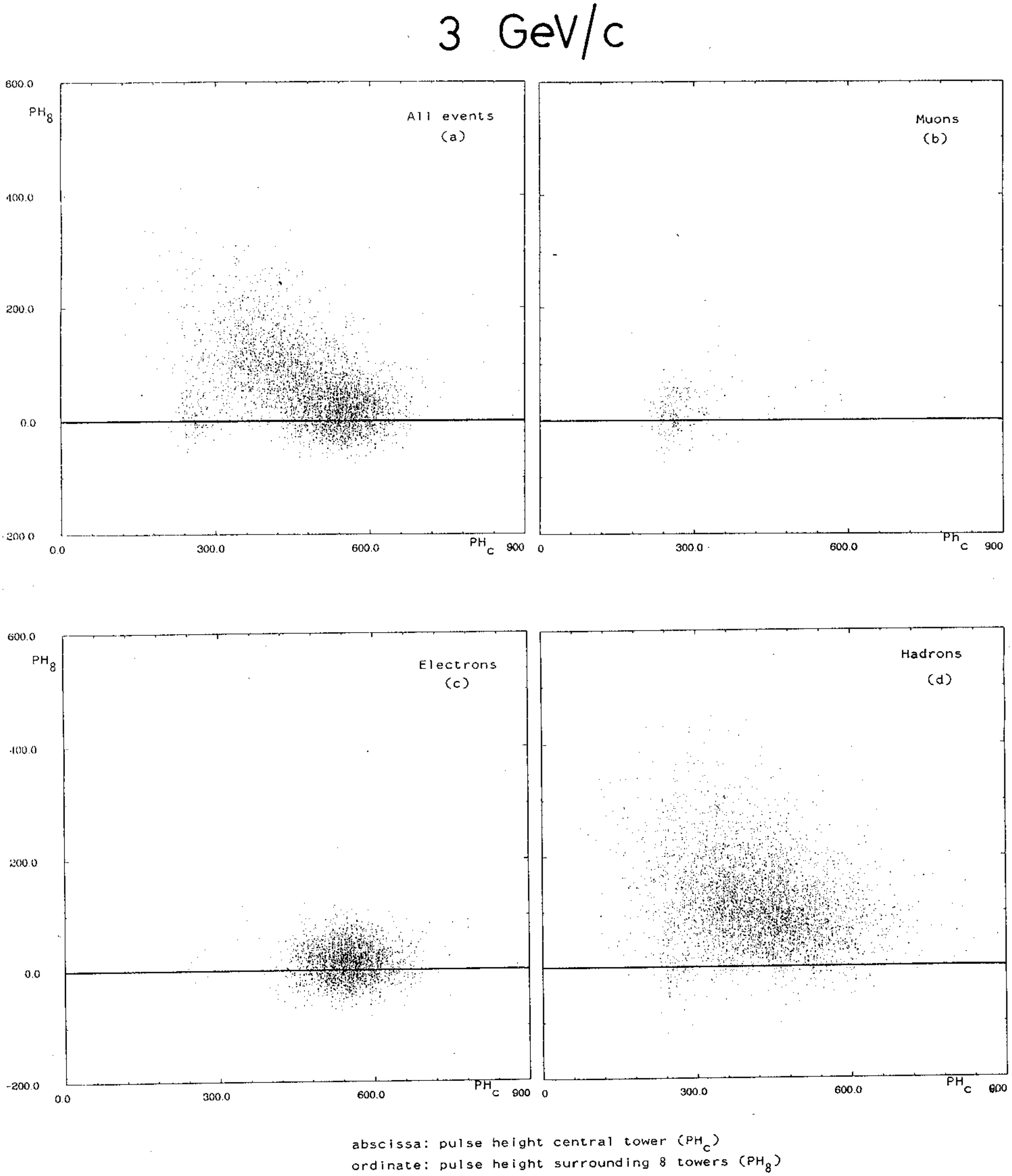


Fig. 6. Pulse height distributions observed in the central towers versus the sum in the 8 surrounding towers, at 3 GeV/c beam momentum.

a) all events
b) for muons identified by B_6
c) for electron candidates identified by C_2
d) for hadrons (mostly pions)

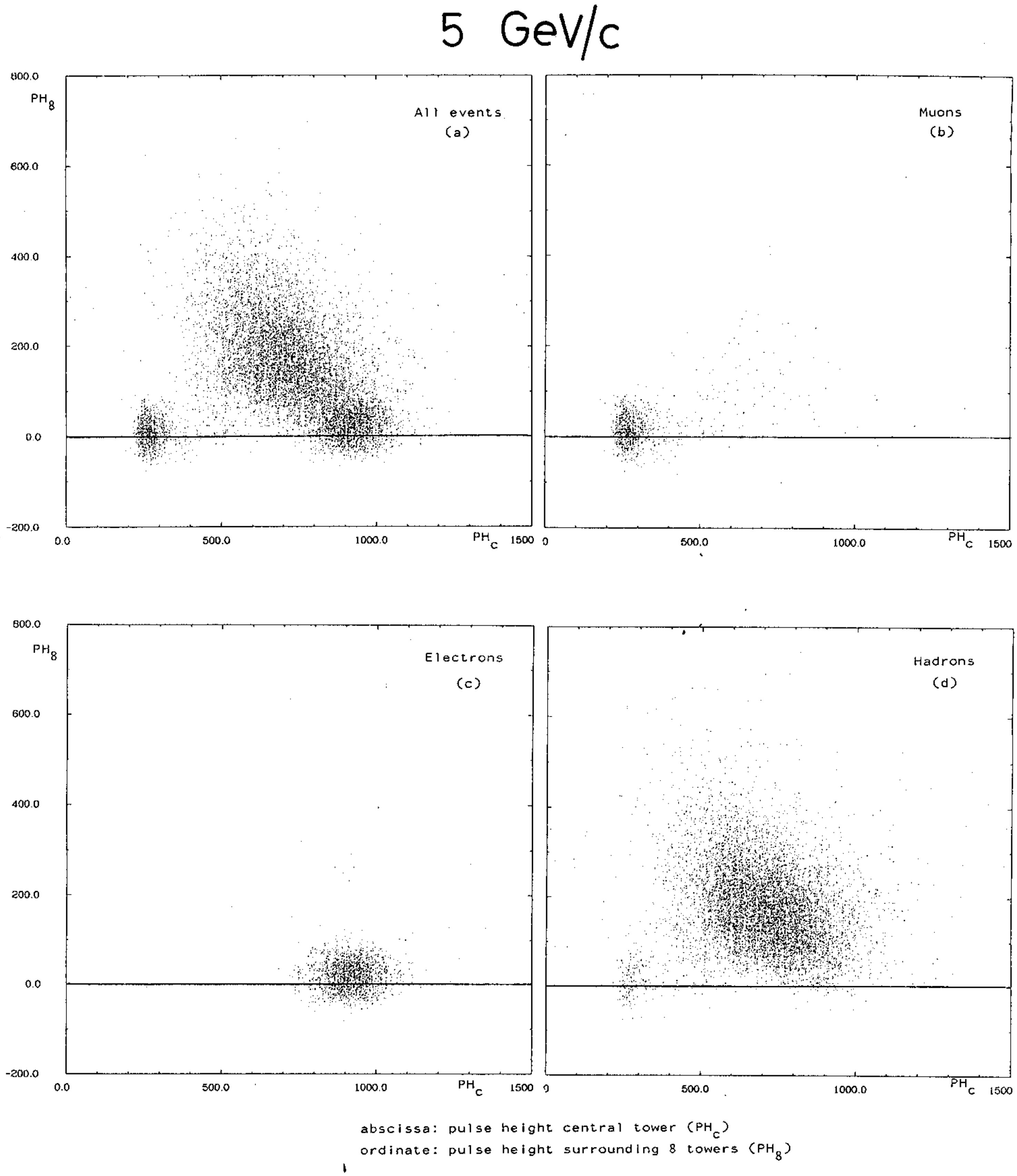


Fig. 7. Pulse height distributions observed in the central towers versus the sum in the 8 surrounding towers, at 5 GeV/c beam momentum.

a) all events

b) for muons identified by B_6

c) for electron candidates identified by C_2

d) for hadrons (mostly pions)

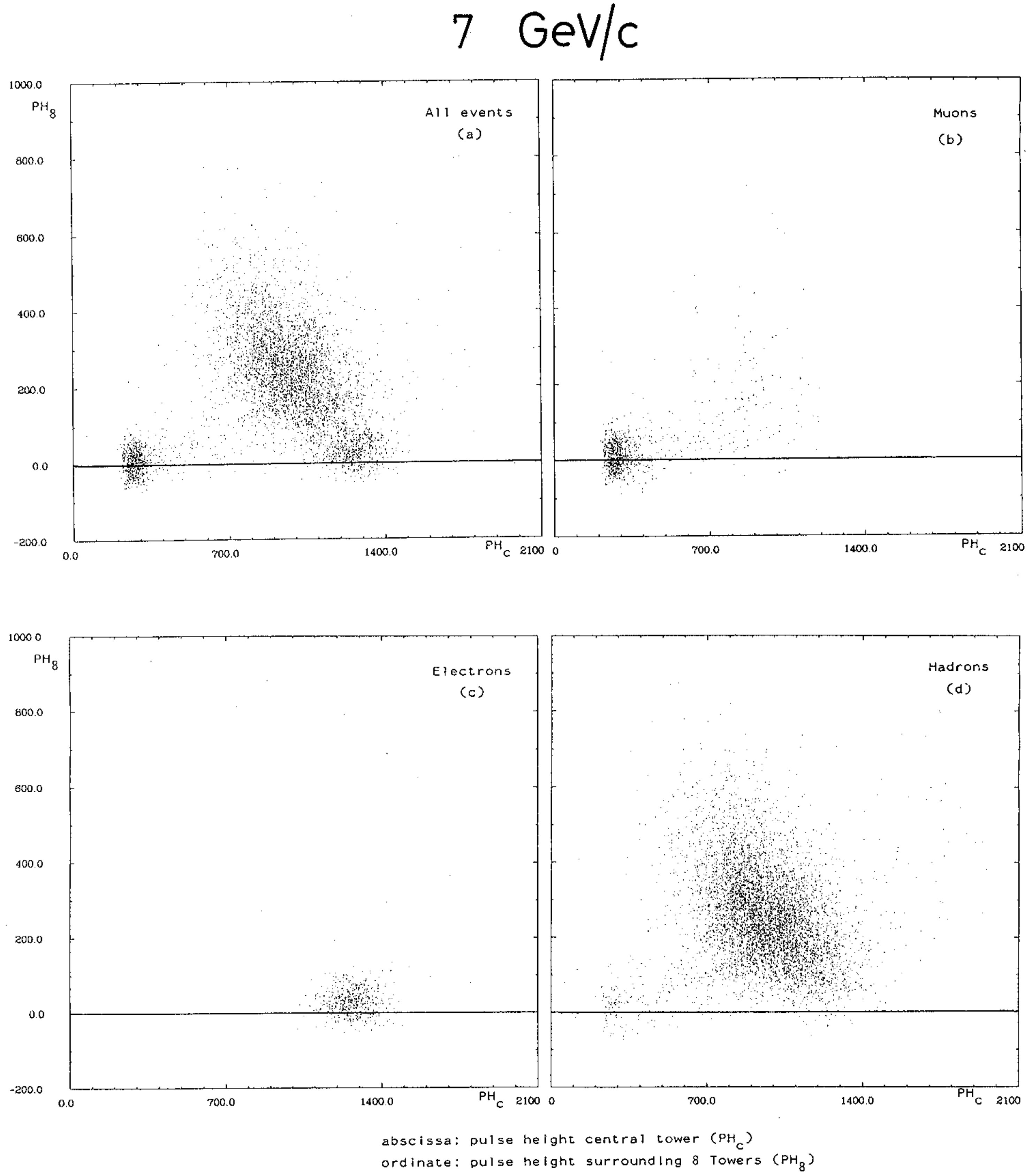


Fig. 8. Pulse height distributions observed in the central towers versus the sum in the 8 surrounding towers, at 7 GeV/c beam momentum.

a) all events
b) for muons identified by B_6
c) for electron candidates identified by C_2
d) for hadrons (mostly pions)

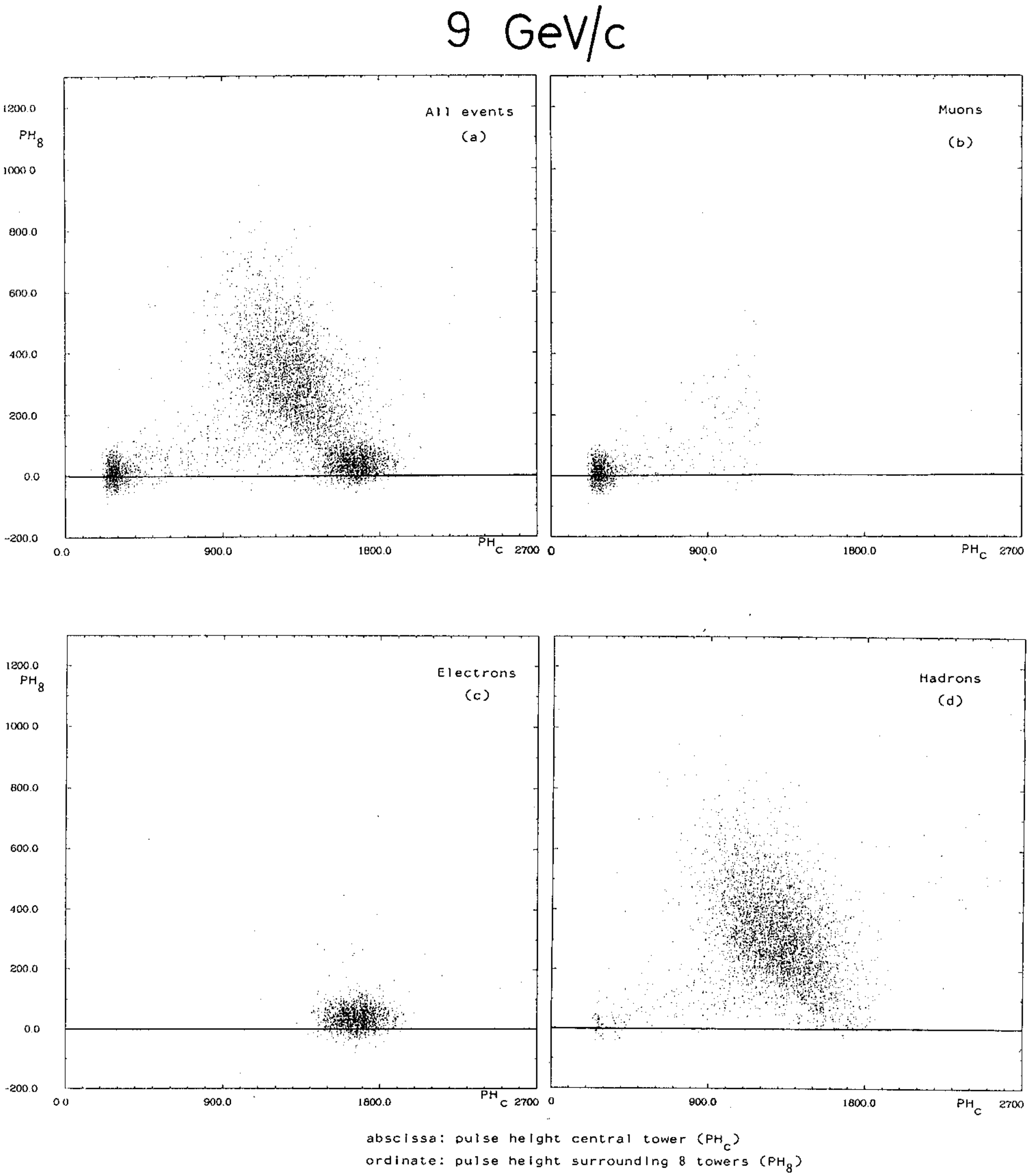


Fig. 9. Pulse height distributions observed in the central towers versus the sum in the 8 surrounding towers, at 9 GeV/c beam momentum.

a) all events
b) for muons identified by B_6
c) for electron candidates identified by C_2
d) for hadrons (mostly pions)

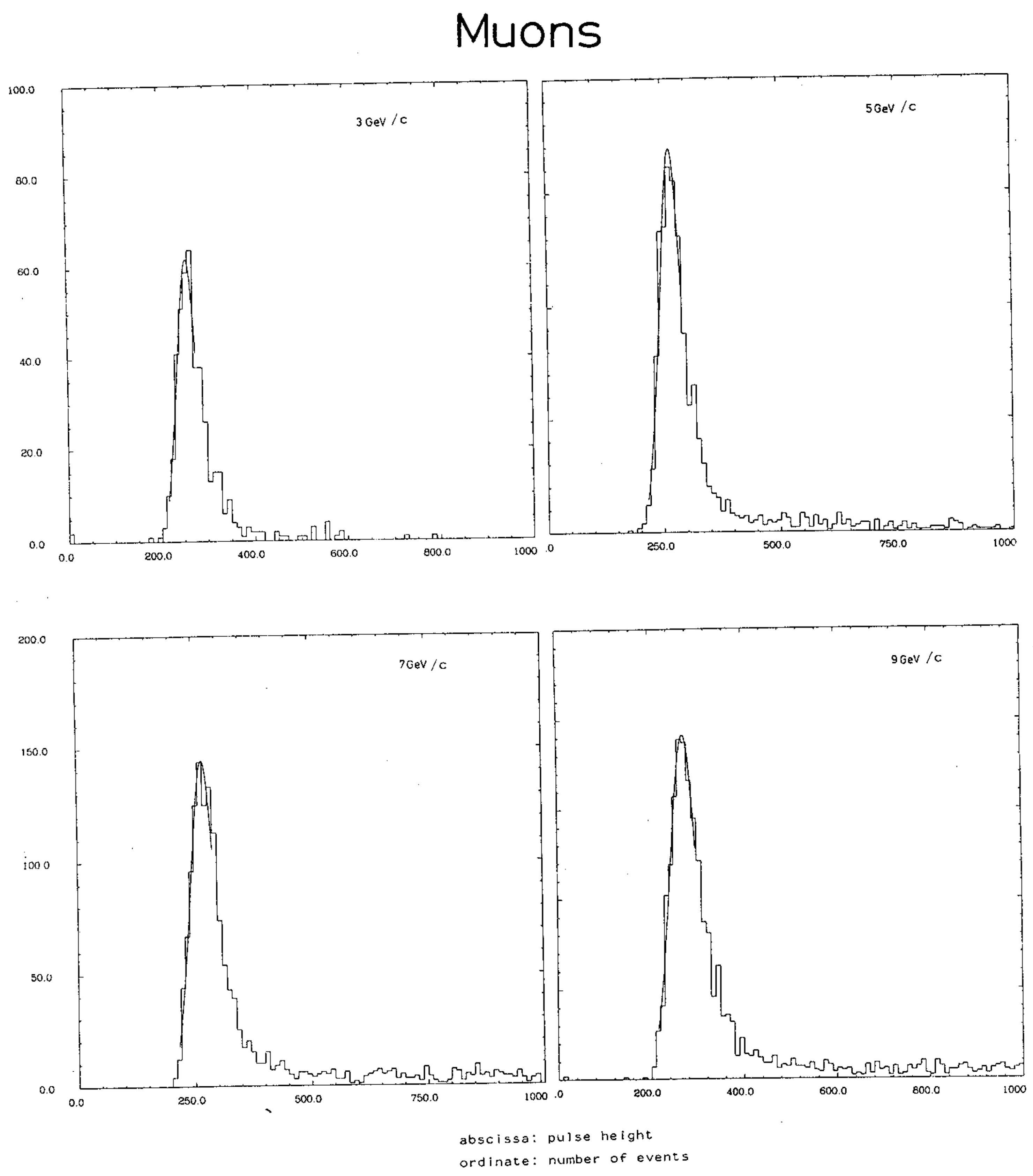


Fig. 10. Pulse height distributions for muons observed in the central tower

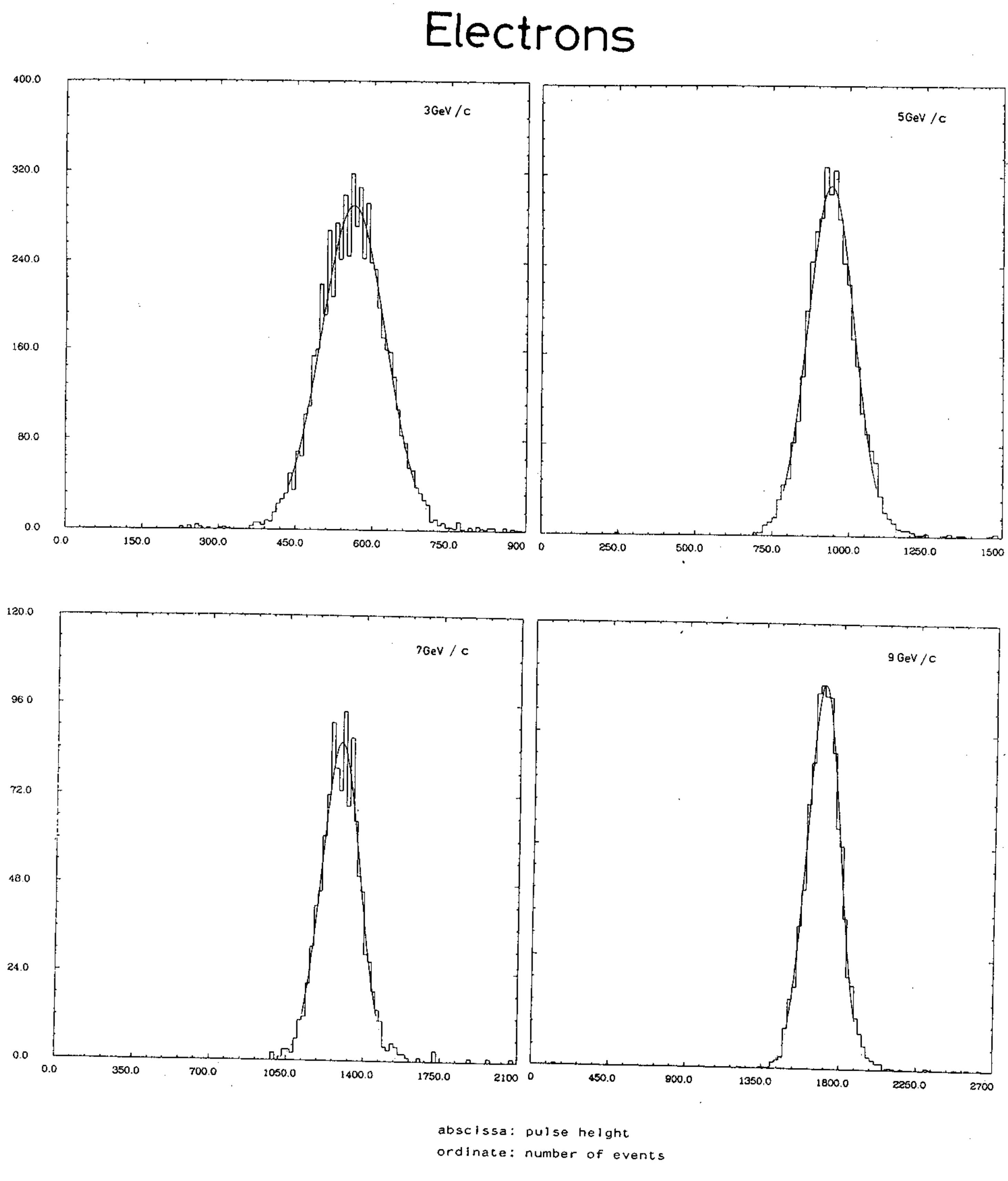


Fig. 11. Pulse height distributions for electrons observed by summing all towers

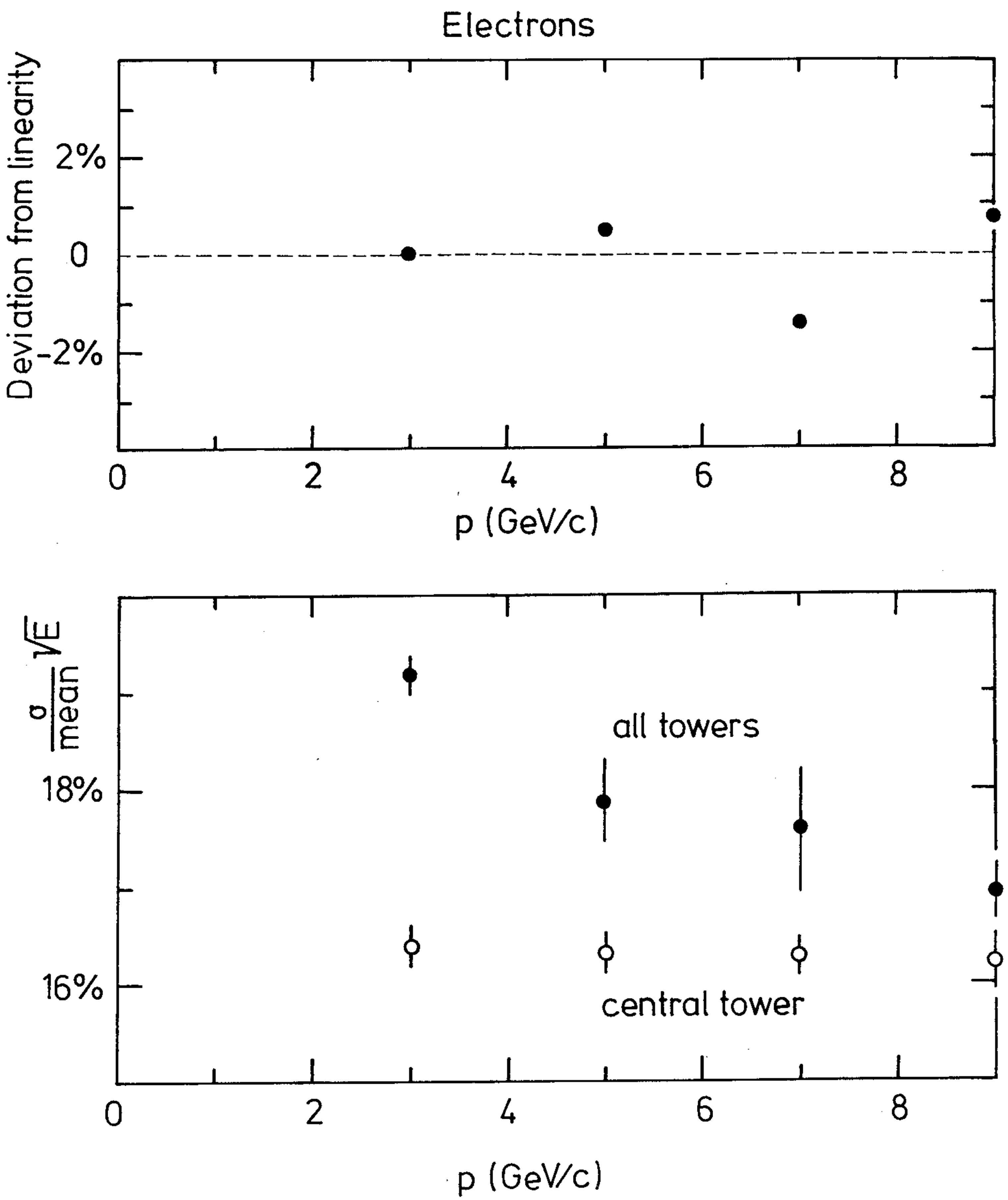


Fig. 12. Electrons: deviation of the mean pulse height from linearity (a) and the momentum dependence of the energy resolution in terms of $(\sigma/\text{mean})\sqrt{E}$, E in GeV (b).

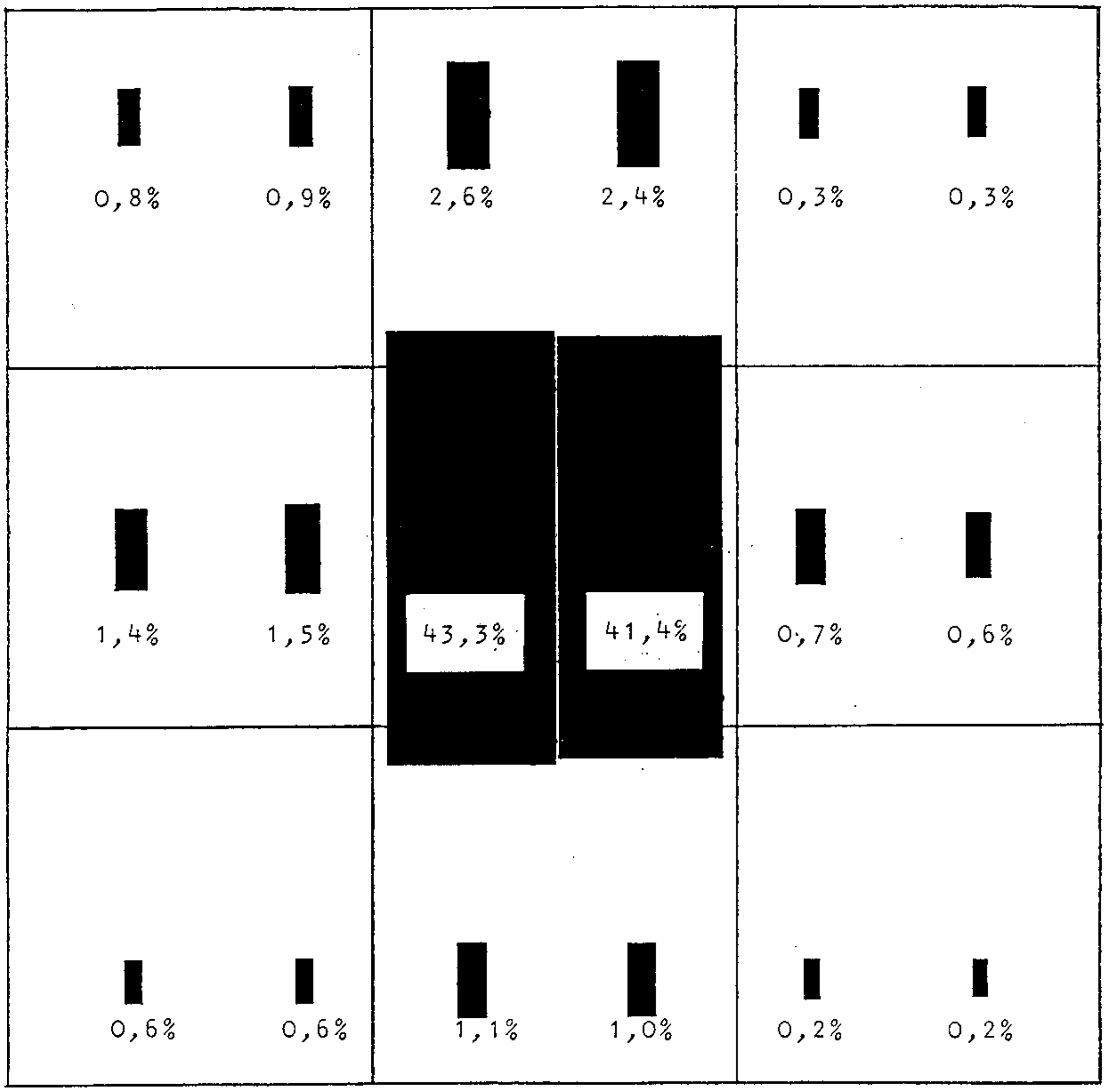


Fig.13. Transverse energy distribution for 5 GeV/c hadrons. Shown is the fraction of pulseheight observed by each of the 18 phototubes. Note that each of the 9 towers is read by 2 phototubes.

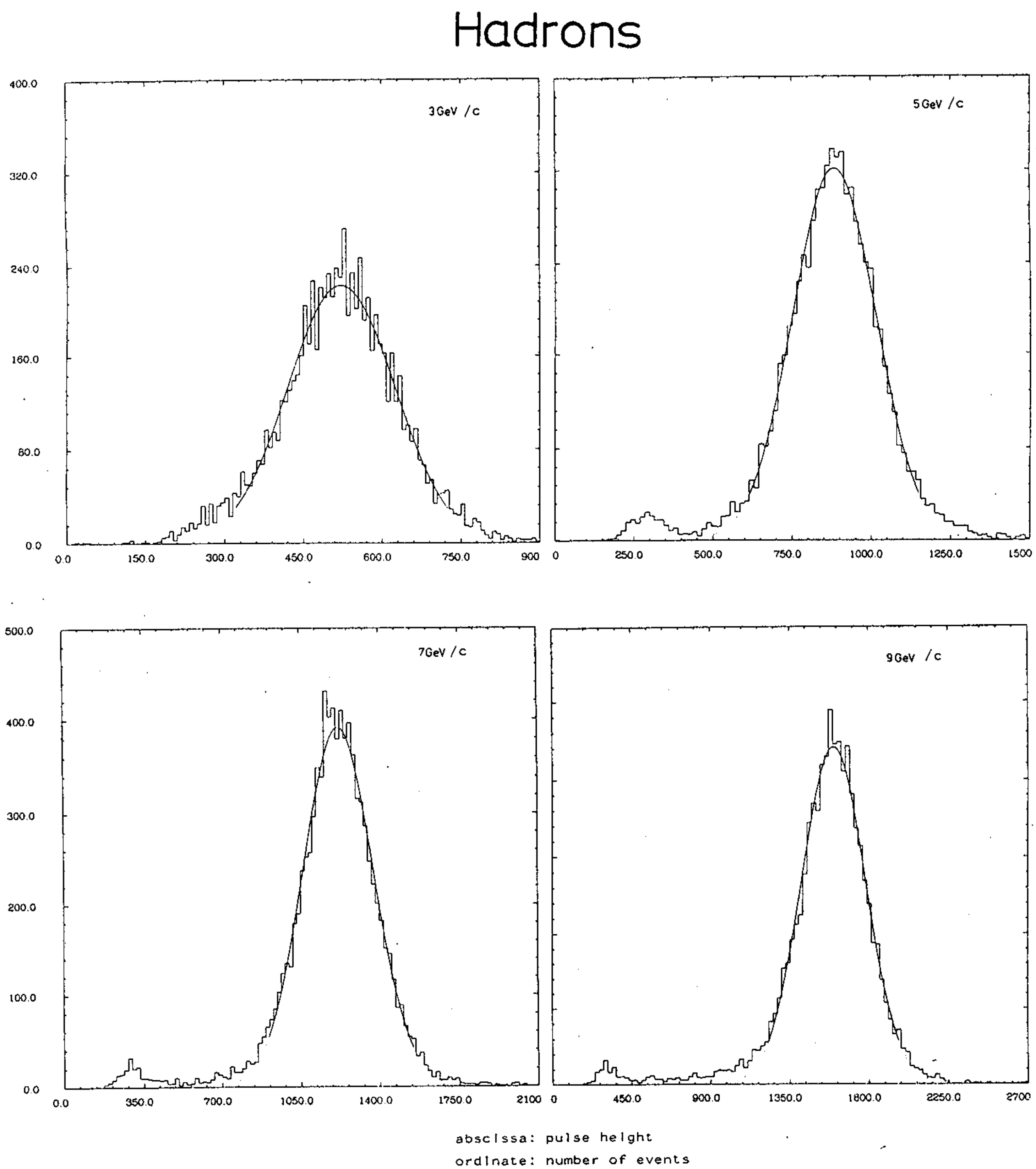


Fig. 14. Pulse height distributions for hadrons observed at 3, 5, 7 and 9 GeV/c.

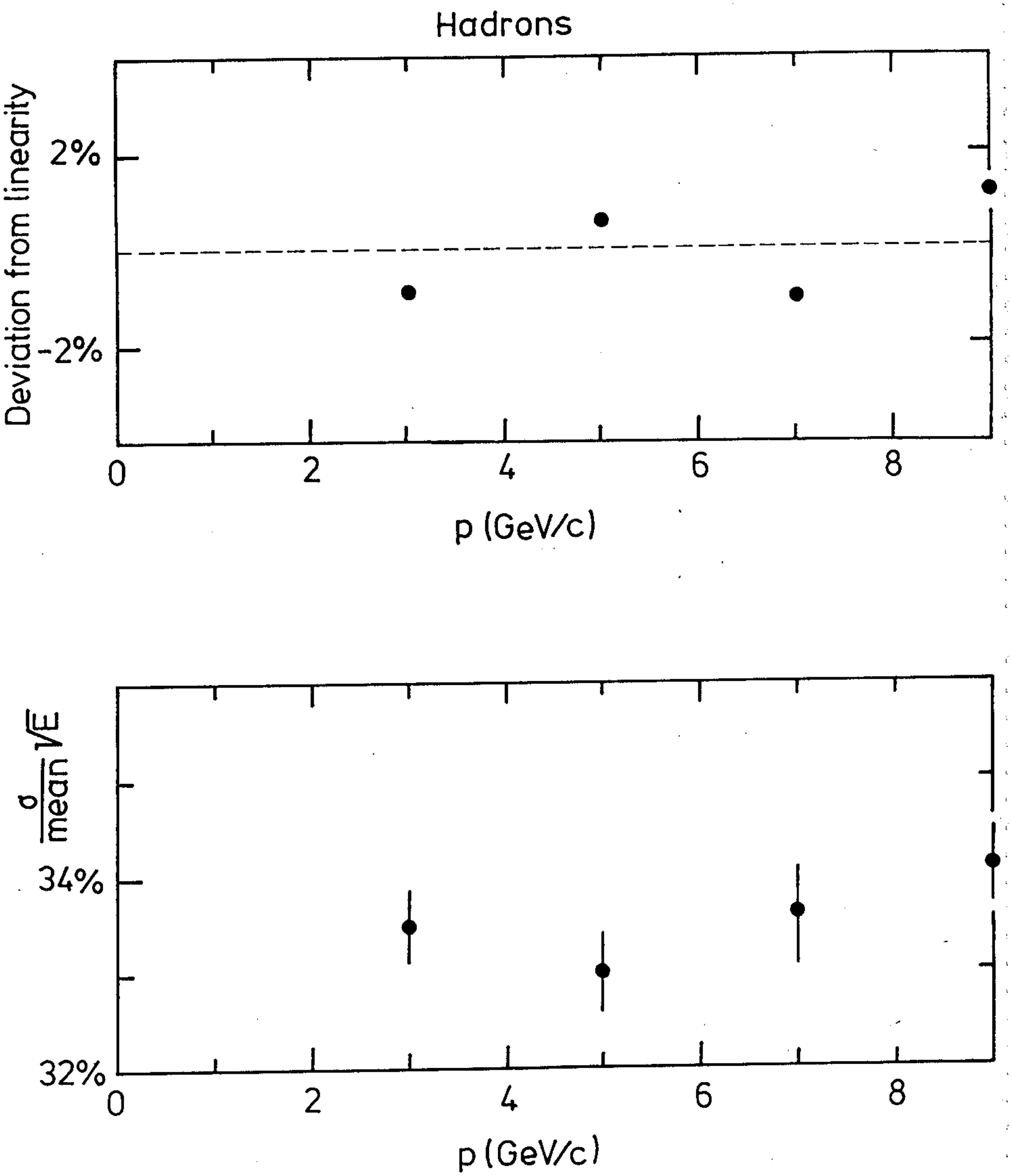


Fig. 15. Hadrons: deviation of the mean pulse height from linearity (a) and the momentum dependence of the energy resolution in terms of $(\sigma/\text{mean})\sqrt{E}$, E in GeV (b).

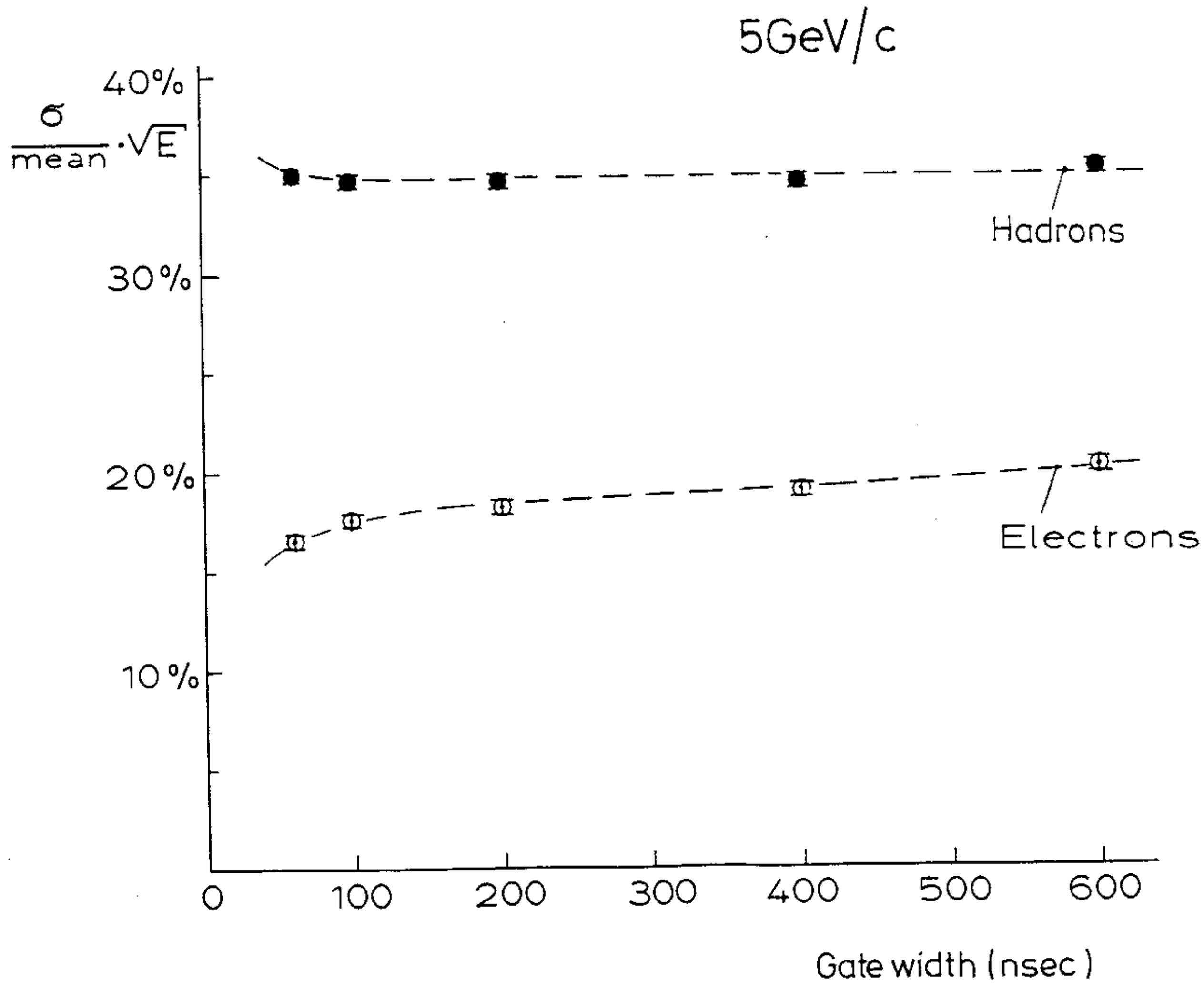


Fig. 16. Energy resolution in terms of $(\sigma/\text{mean})\sqrt{E}$ for 5 GeV/c electrons and hadrons as a function of the gate width.