SSC-SDE-23

SSC-SDE
SOLENOIDAL DETECTOR NOTES

EFFECT OF e/h RATIO ON JET ENERGY RESOLUTION

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1. Introduction

In a design of a calorimeter for experiments at high energy hadron-colliders such as SSC and LHC, e/h ratio is one of the important issues for good energy resolution. A lot of efforts and works have been done for investigating the way to achieve unit e/h ratio. The requirements for a unit e/h ratio are summarized as[1]: (1) to use high Z materials as absorbers and low Z materials as active materials with appropriate thickness. (2) to use active materials including hydrogen atoms. However, the gap between the above requirements and realistic requirements for construction of calorimeters seems to be still large. So one really wants to know that to what extent a unit e/h ratio is required for calorimeters. To answer this question, we should know how the jet energy resolution is affected by the e/h ratio. In the present report, the effect of e/h ratio on the energy resolution and linearity of hadron jets was studied.

The hadron jets were generated by using the LUND6.3 program. Energies of electrons and γ's in the jets were smeared according to σ/E=15% $/\sqrt{E}$. The hadrons in the jets ($\pi^{\pm}, K^{\pm}$, K^0_L, p and n) were smeared according to σ/E=A% $/\sqrt{E}$ (A=10, 30, 50, 70, 100) and then were reduced in accordance with the given e/h ratio. Hadrons with momenta less than 300 MeV/c were neglected. Further, energies deposited by muons were neglected for simplicity.

2 Results

Case 1: e/h is constant

In Figs. 1 and 2, the energy resolution of jets for various energy resolution of a hadron calorimeter are shown against e/h ratio for jet energies of 50 GeV and 1 TeV, respectively. The e/h ratio is constant in these figures. For low energy jets and realistic energy resolution of σ/E=50 %$/\sqrt{E}$, e/h ratio is not critical if e/h is less than about 1.2. For high energy jets, energy resolution of jets are dominated by the e/h ratio. Fig. 3 shows linearity for various e/h ratio. If e/h is constant, linearity is maintained for any value of e/h ratio.

Case 2: e/h is energy-dependent

According to Monte Carlo simulation, electromagnetic fraction in the hadron shower increases as an increase of a hadron energy. Thus, e/h ratio decreases and approaches to a unit as an increase of a hadron energy. This has been already observed by the experiments[2]. Here, I studied the effect of e/h ratio by varying the e/h ratio with energy. From the figure of energy dependence of e/h ratio in ref 2, the energy dependence of e/h ratio is parameterized by the following equation:

$$R = R_0 - (R_0 - 1)\frac{lnE}{ln1000} \qquad E > 1GeV,$$
$$R = R_0 - R_0\frac{lnE}{ln0.1} \qquad E < 1GeV,$$

where R is an e/h ratio, R_0 an e/h ratio at 1 GeV and E an energy of a hadron in units of GeV.
Figs. 4 and 5 shows the energy resolution of jets for various energy resolution of the calorimeter for jet energies of 50 GeV and 1 TeV, respectively. Horizontal axis is an e/h ratio at 1 GeV. The energy resolution of jets are less e/h-dependent and better than that for constant e/h case. This trend is clear for higher energies.
Fig. 6 shows the linearity. Value of e/h in the figure is that at 1 GeV. The effect of energy-dependent e/h ratio is severe in linearity. One can observe large deviation in linearity as e/h deviates from 1. Due to this non-linearity, P_t distribution of hadron jets deviates from the QCD prediction at higher energies. This may be mistaken as the indication of compositeness of quarks as shown in Fig.7.

3. Correction by Longitudinal Information

Since we have longitudinal segmentation in the calorimeter (at least two, EM part and Hadron part), we may correct the response of the calorimeter for hadrons using this information. In this section we try to see how we can improve the jet energy resolution. It should be remarked that the linearity cannot be recovered by this longitudinal information, which we recognized in the course of this study.

In the simulation, longitudinal shower development of hadrons is parameterized according to Bock et al.[4]:

$$dE/dX = k[ws^{a-1}e^{-bs} + (1-w)t^{c-1}e^{-dt}]$$

where w is the fraction of EM component and s and t are the depth from shower origin in radiation length and absorption length, respectively. Shower origins were fluctuated using absorption length. As for an electromagnetic shower, a following parametriztion was used:

$$dE/dX = ks^{a-1}e^{-bs}$$

where s is the depth of the calorimeter in radiation length and k is the normalization constant.

In figs.8(a) and (b), the two dimensional plots for longitudinal response of the calorimeter are shown where horizontal axis is the total energy observed in the calorimeter devided by the incident jet energy and the vertical axis is the ratio of observed energy in EM part($25X^0$ in depth) to total observed energy(EM/TOT) for (a) e/h=1.4 and (b) e/h=1.6. The figures have rather interesting feature. If EM/TOT is less than ~0.55, total energy is almost constant. As EM/TOT increases from 0.55 to 1, total energy also increases almost linearly and approaches to the initial jet energy. This latter behavior of response deteriorates the energy resolution. By using this relation between EM/TOT and total energy, one can correct the total energy and improve jet energy resolution. In Figs. 9(a) and (b), the corrected two-dimensional plots, same plots as Fig.8, are shown, One can see that corrected total energy is constant for any electromagnetic fraction in jets. In Fig.10, the jet energy resolution thus corrected are shown against e/h ratio. The jet energy resolution is almost constant for any e/h ratio.

So far, we have studied how we can improve jet energy resolution by using the EM/TOT ratio. The left problem is the non-linearity of the response. As has been said before, linearity cannot be recovered by longitudinal information. We need energy dependence of e/h ratio for the correction of linearity. Here we studied the validity of the correction by using the e/h ratio. To this end, we at first calculated correction factor for jets originated from u-quark(u-jets). The the obtained factors were applied for b-jets which had the different fragmentation from that of u-jets. In Figs.11(a) and (b), the corrected linearity for u-jets and b-jets are shown. (For u-jets, we should obtain exactly the straight line without deviation, but we stopped calculation of correction factors at deviation level of 2%.) The difference of linearity between u-jets and b-jets is less than 1%. Thus the same correction factor can be safely applied to different jets.

4. Conclusion

The effects of the non-unit e/h ratio of calorimeters on the energy resolution and linearity of hadron jets were studied, where energy dependence of e/h ratio was introduced by simply parametrized form. The conclusions of this study are summarized as follows:(1) Energy resolution of hadron jets is not so deteriorated by the non-unit e/h ratio if e/h ratio is energy-dependent as measuredby ref [2]. Further, by using longitudinal information, jet energy resolution can be improved and be same for any e/h ratio. (2) The linearity of jets is not maintained if e/h ratio is energy-dependent. This non-linearity may fake the indication of compositeness of quarks. (3) The linearity cannot be recovered only by the longitudinal information. By the information of energy dependence of e/h ratio, one can correct the linearity by simulation rather reliably.

References

[1] R. Wigmans, Nucl. Instrum., Methods, A259(1987)389.

[2] M. De Vincenzi, et al., CERN-EP/85-126, 12 August 1985.

[3] E.Eichten, Ihicliffe, K.Lane and C.Quigg, Rev. Mod. Phys. 56(1984)579.

[4] R.K.Bock, T.Hansl-kozanecka and T.P.Shah, Nucl. Instr. and Meth. 186(1981)533.

Figure Captions

Fig.1: Energy resolution of jets with energy of 50 GeV, where e/h is constant.

Fig.2: Energy resolution of jets with energy of 1 TeV, where e/h is constant.

Fig.3: Linearity of the response in hadron calorimeter for various e/h ratio(e/h constant).

Fig.4: Energy resolution of jets with energy of 50 GeV, where e/h is energy dependent(see text).

Fig.5: Energy resolution of jets with energy of 1 TeV, where e/h is energy dependent(see text).

Fig.6: Deviation in linearity of the response of a calorimeter for energy-dependent e/h ratio.

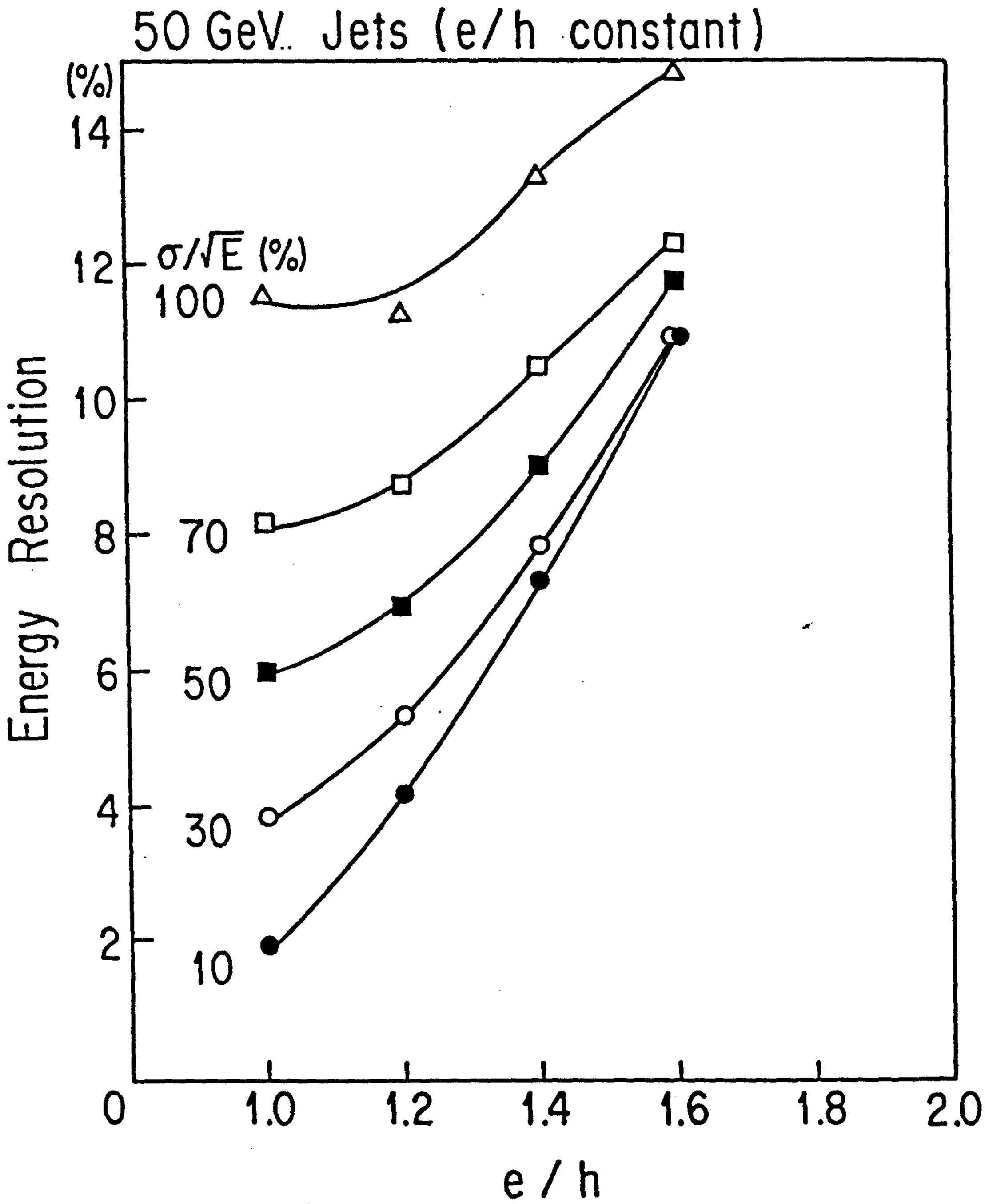
Fig.7: P_t distribution of hadron jets taken from Fig.234 of ref 3. Long-dashed, dot-dashed and dotted curves correspond to e/h ratio of 1.6, 1.4 and 1.2, respectively.

Fig.8: Two-dimensional plot of the longitudinal response of the calorimeter for 50 GeV jets. The horizontal axis is the total energy observed in the calorimeter normalized by the incident jet energy and the vertical axis is the ratio of observed energy in EM part(25X^0 in depth) to total observed energy(EM/TOT) for (a) e/h=1.4 and (b) e/h=1.6.

Fig.9: The same plots as Fig.8, where total energies are corrcted by using EM/TOT ratio for (a) e/h=1.4 and (b)e/h=1.6.

Fig.10: Energy resolution of jets with energy of 50 GeV, where total energies are corrected by EM/TOT ratio.

Fig.11: Deviation in linearity of the response of a calorimeter for (a) u-jet and (b) b-jet, where linearities are corrected by the response of u-jet.



50 GeV. Jets (e/h constant)
(%)
14
12
10
8
6
4
2
0
σ/√E (%)
100
70
50
30
10
Energy Resolution
1.0
1.2
1.4
1.6
1.8
2.0
e / h

Fig.1

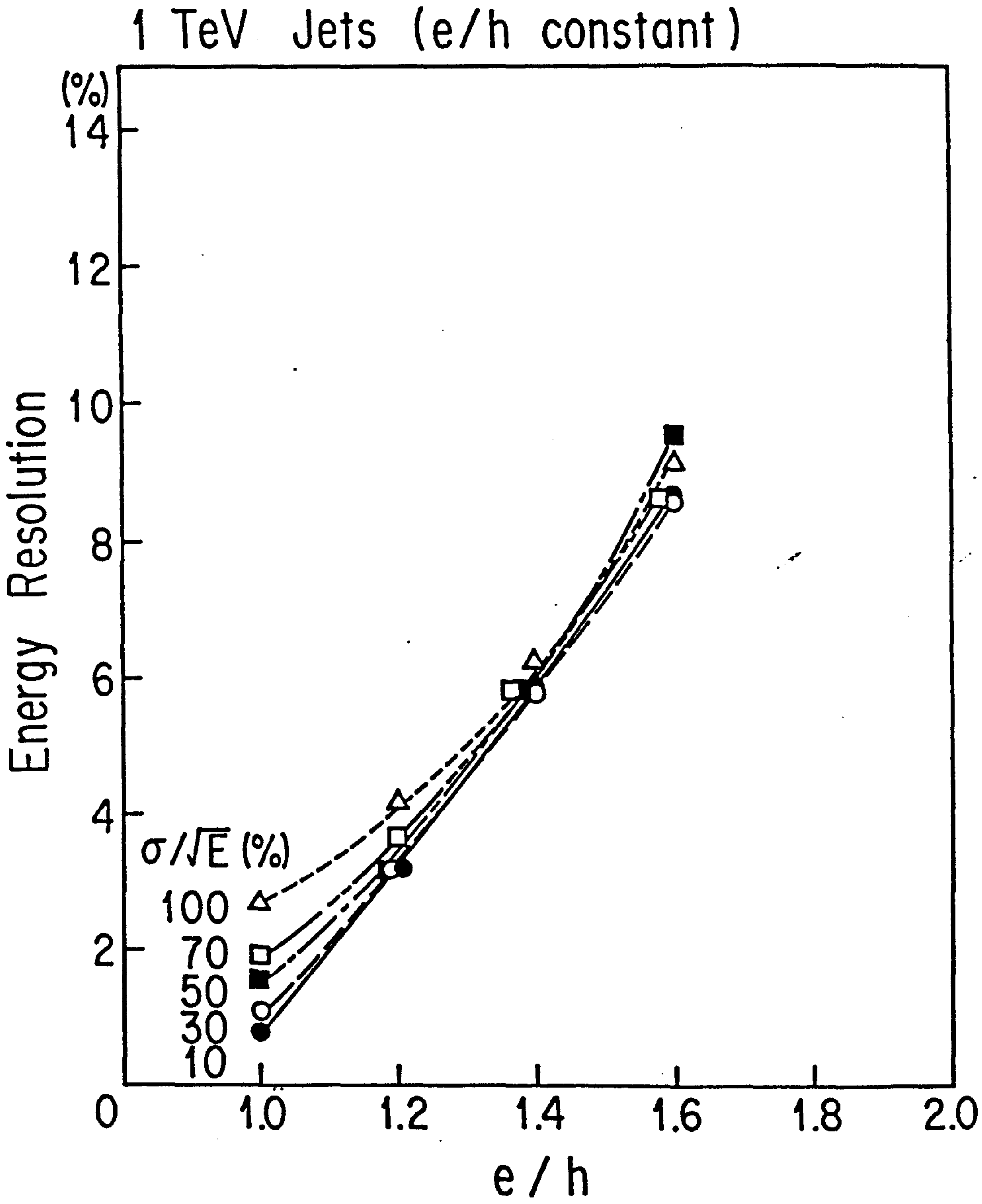

1 TeV Jets (e/h constant)
(%)
14
12
10
8
6
4
2
0
Energy Resolution
σ/√E (%)
100
70
50
30
10
1.0
1.2
1.4
1.6
1.8
2.0
e / h

Fig.2

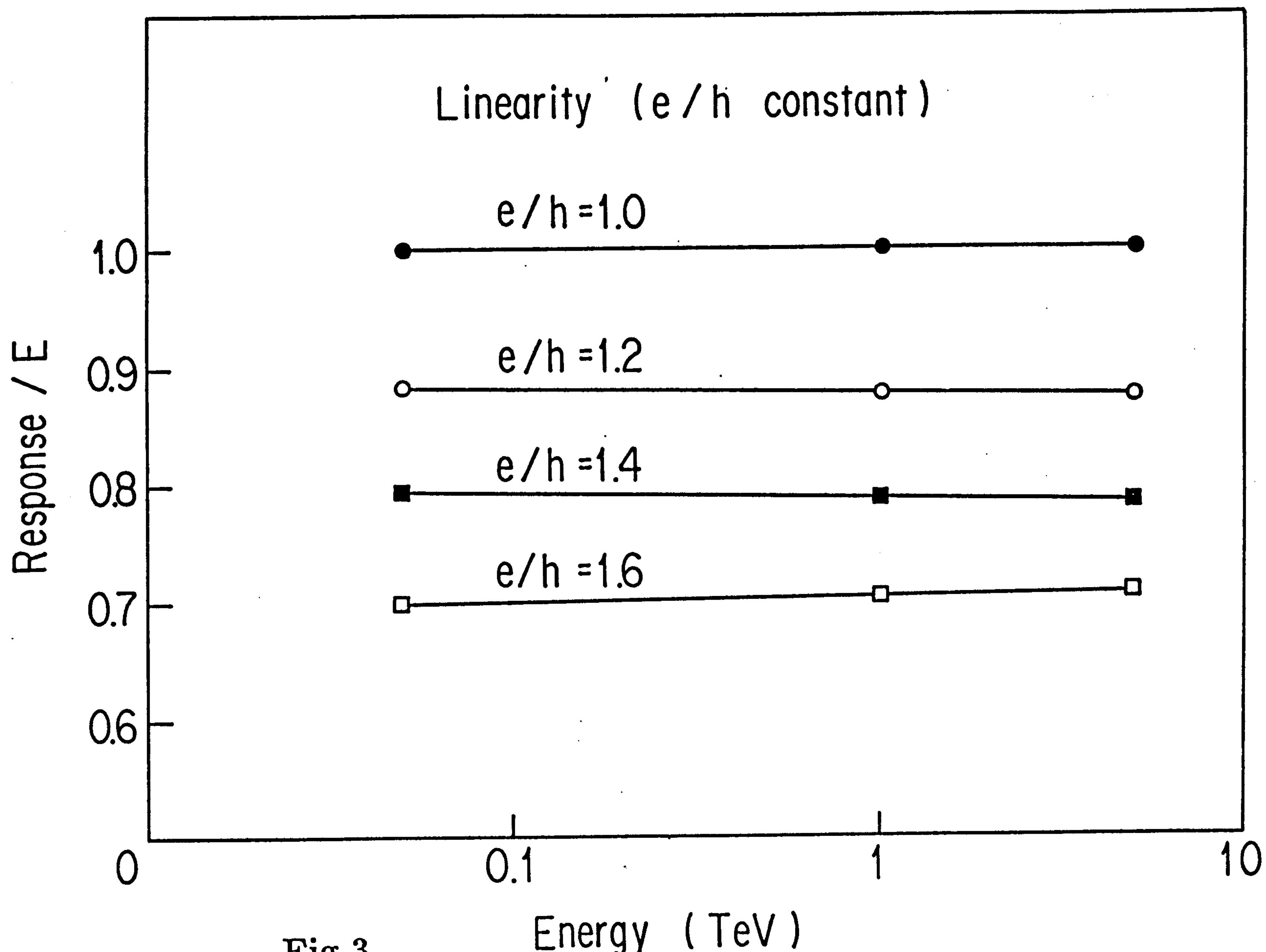
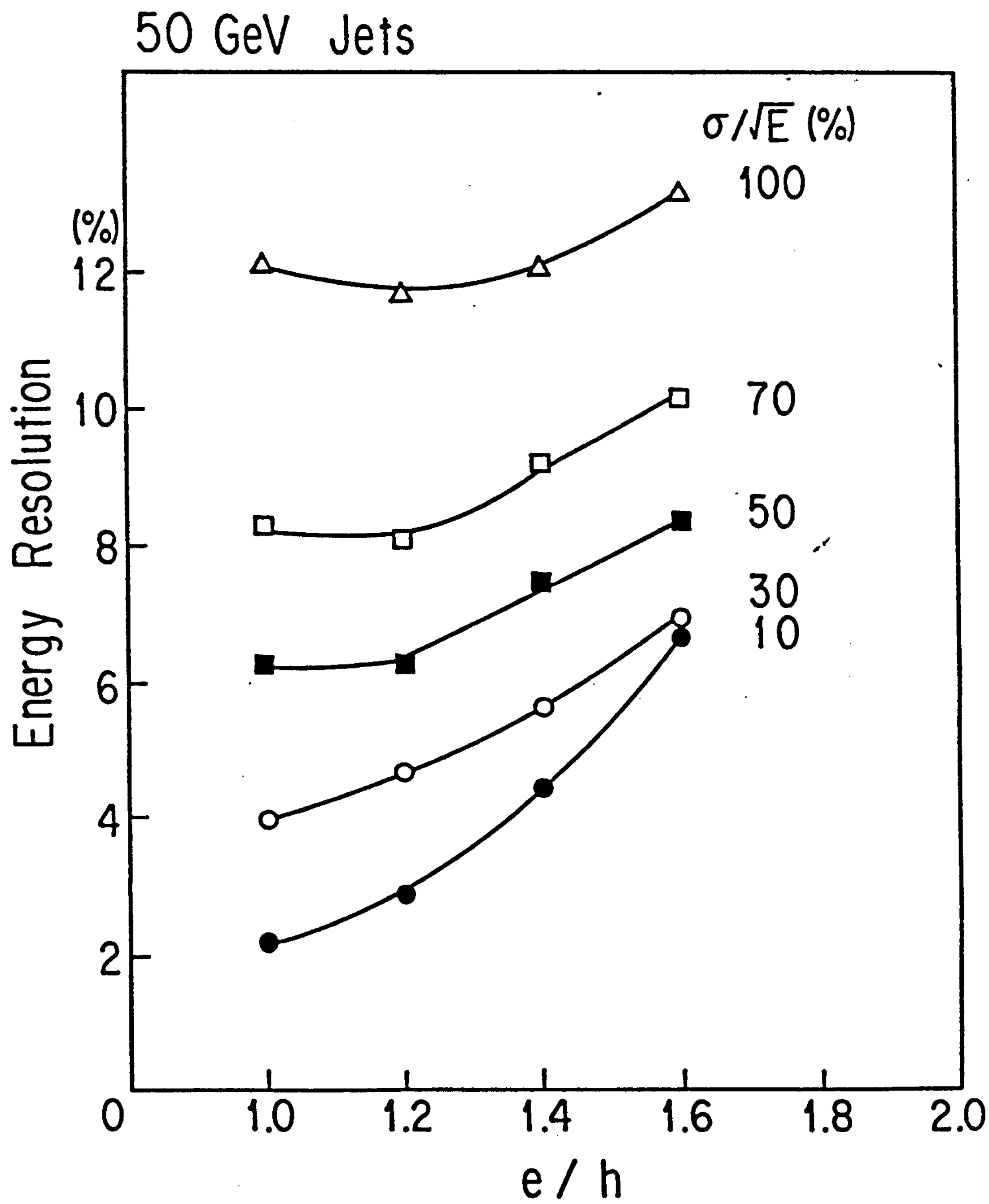

Linearity (e / h constant)
e / h = 1.0
e / h = 1.2
e / h = 1.4
e / h = 1.6
Response / E
1.0
0.9
0.8
0.7
0.6
0
0.1
1
10
Energy (TeV)

Fig.3



50 GeV Jets
σ/√E (%)
100
70
50
30
10
(%)
Energy Resolution
12
10
8
6
4
2
0
1.0
1.2
1.4
1.6
1.8
2.0
e / h

Fig.4

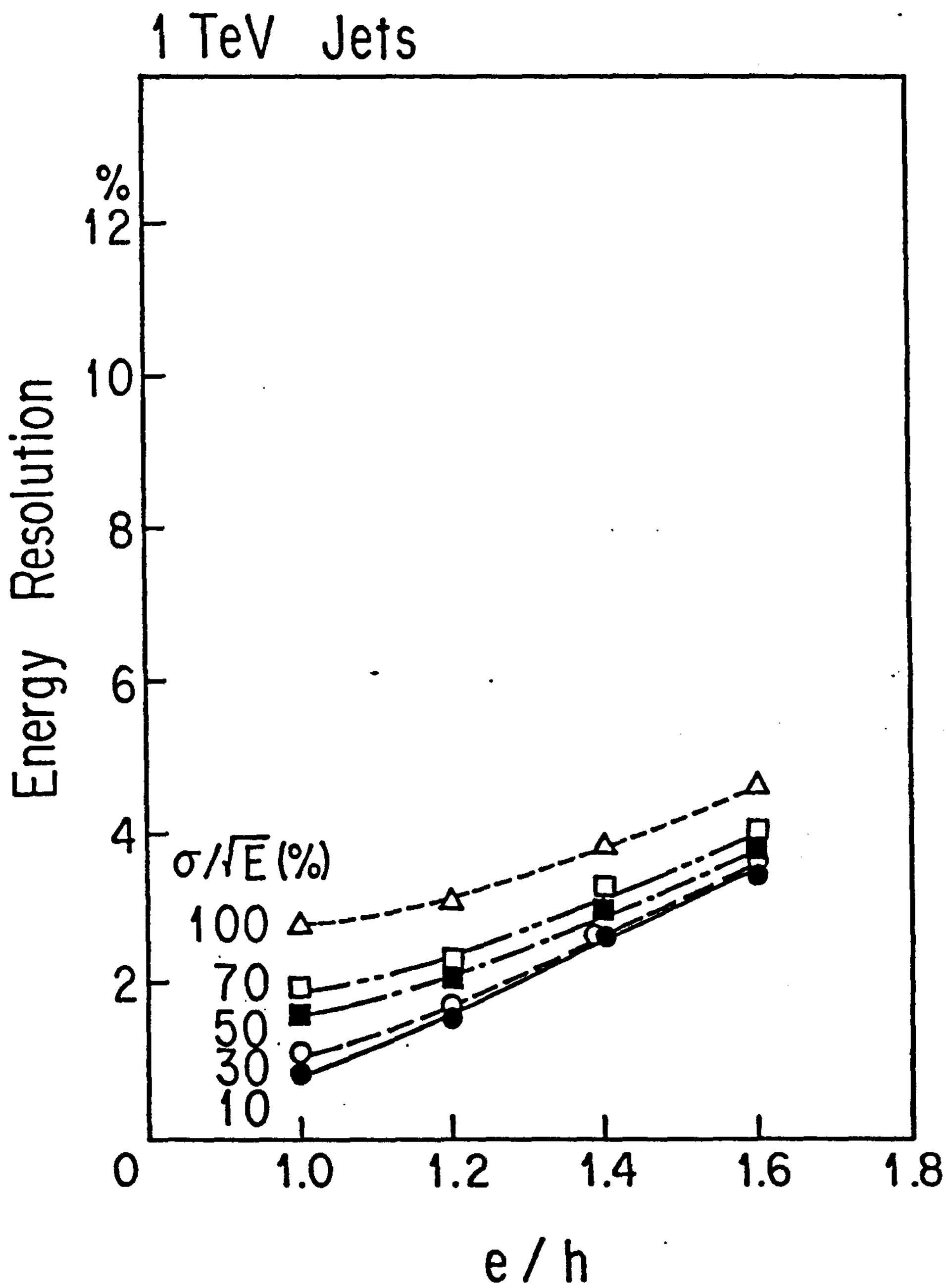

1 TeV Jets
%
Energy Resolution
12
10
8
6
4
2
0
σ/√E (%)
100
70
50
30
10
1.0
1.2
1.4
1.6
1.8
e / h

Fig.5

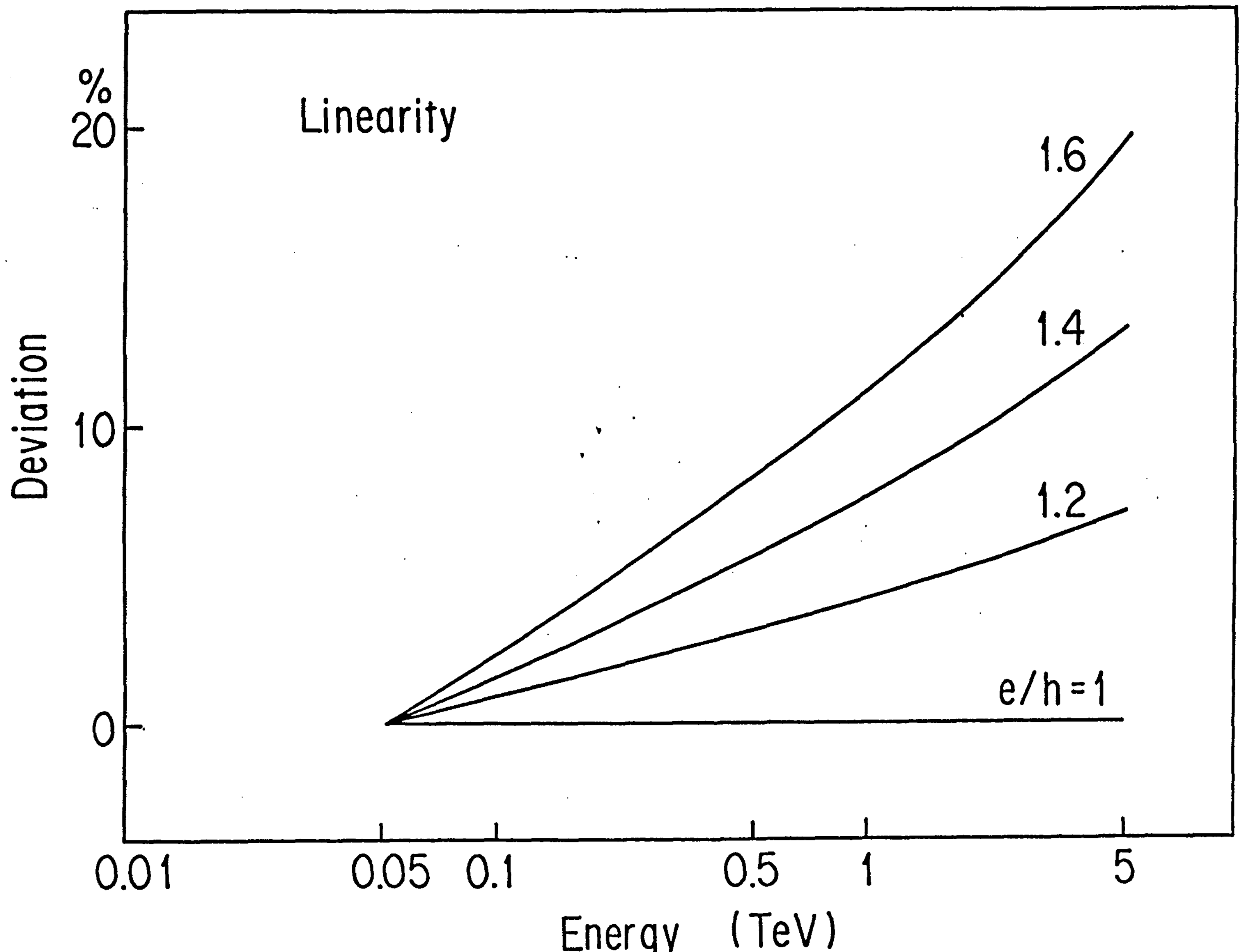
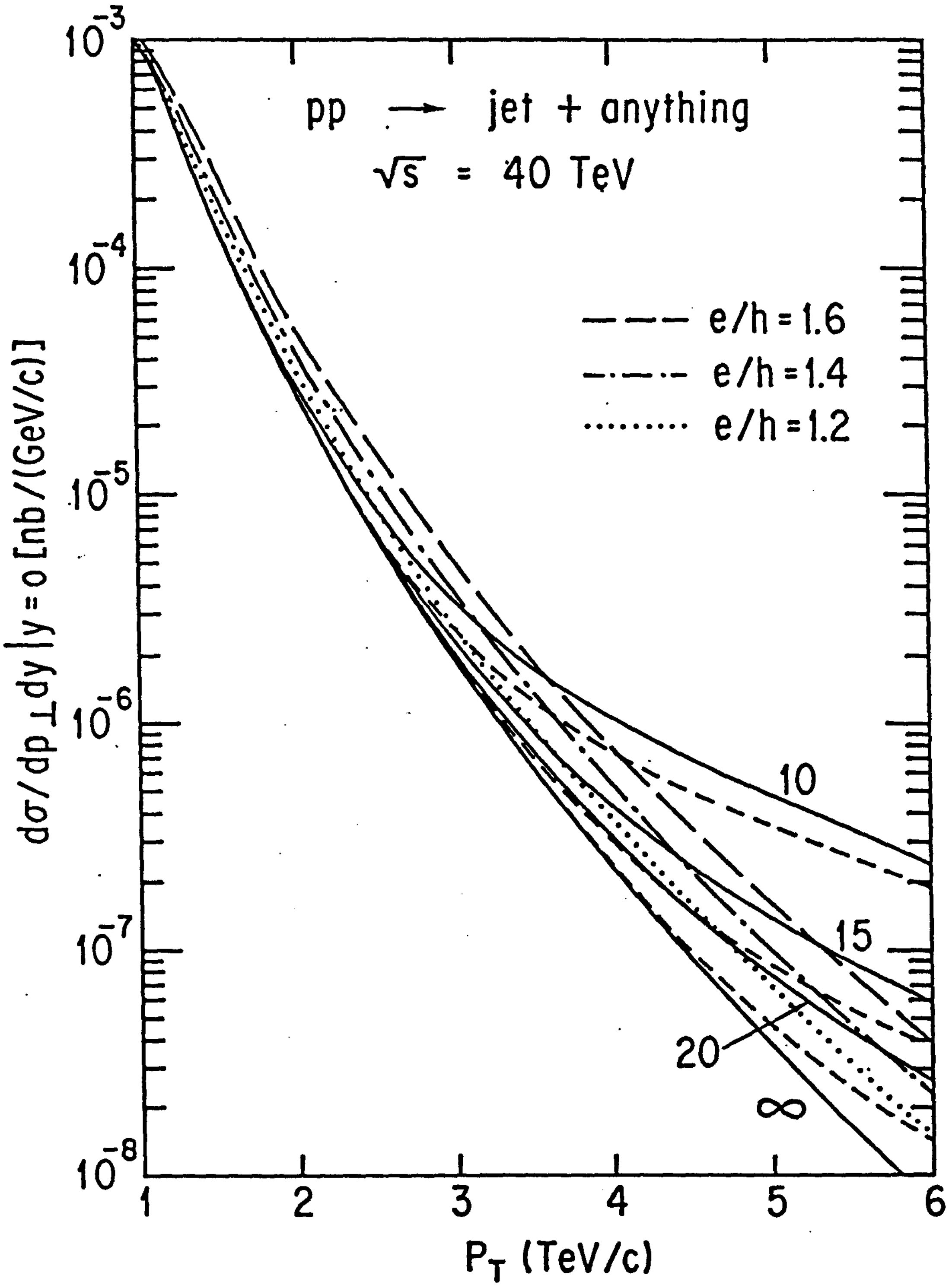

%
20
10
0
Deviation
Linearity
1.6
1.4
1.2
e/h=1
0.01
0.05
0.1
0.5
1
5
Energy (TeV)

Fig.6



pp → jet + anything
√s = 40 TeV
e/h = 1.6
e/h = 1.4
e/h = 1.2
10
15
20
∞
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
1
2
3
4
5
6
$d\sigma/dp_\perp dy|_{y=0}$ [nb/(GeV/c)]
P_T (TeV/c)

Fig.7

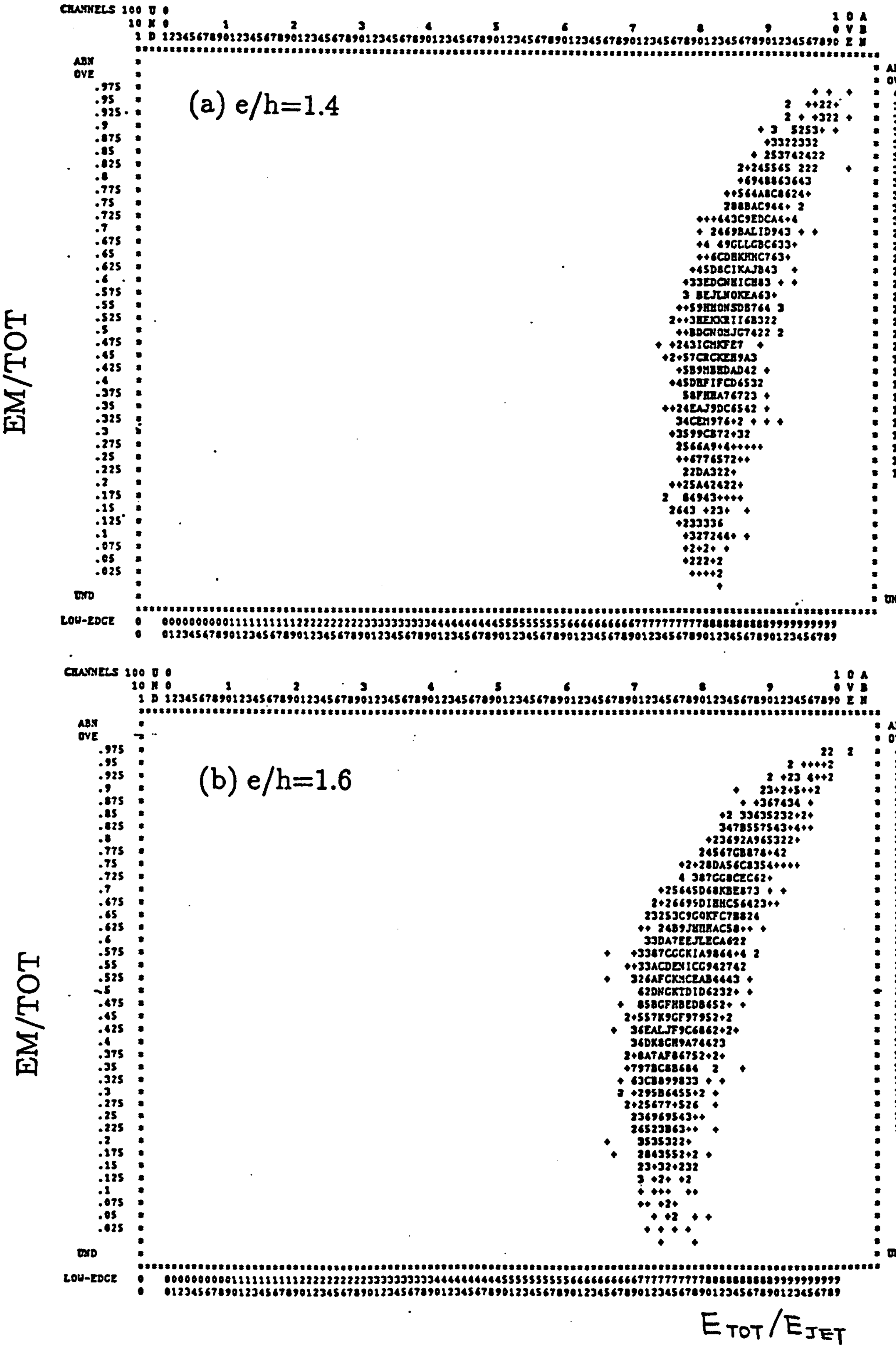


Fig.8

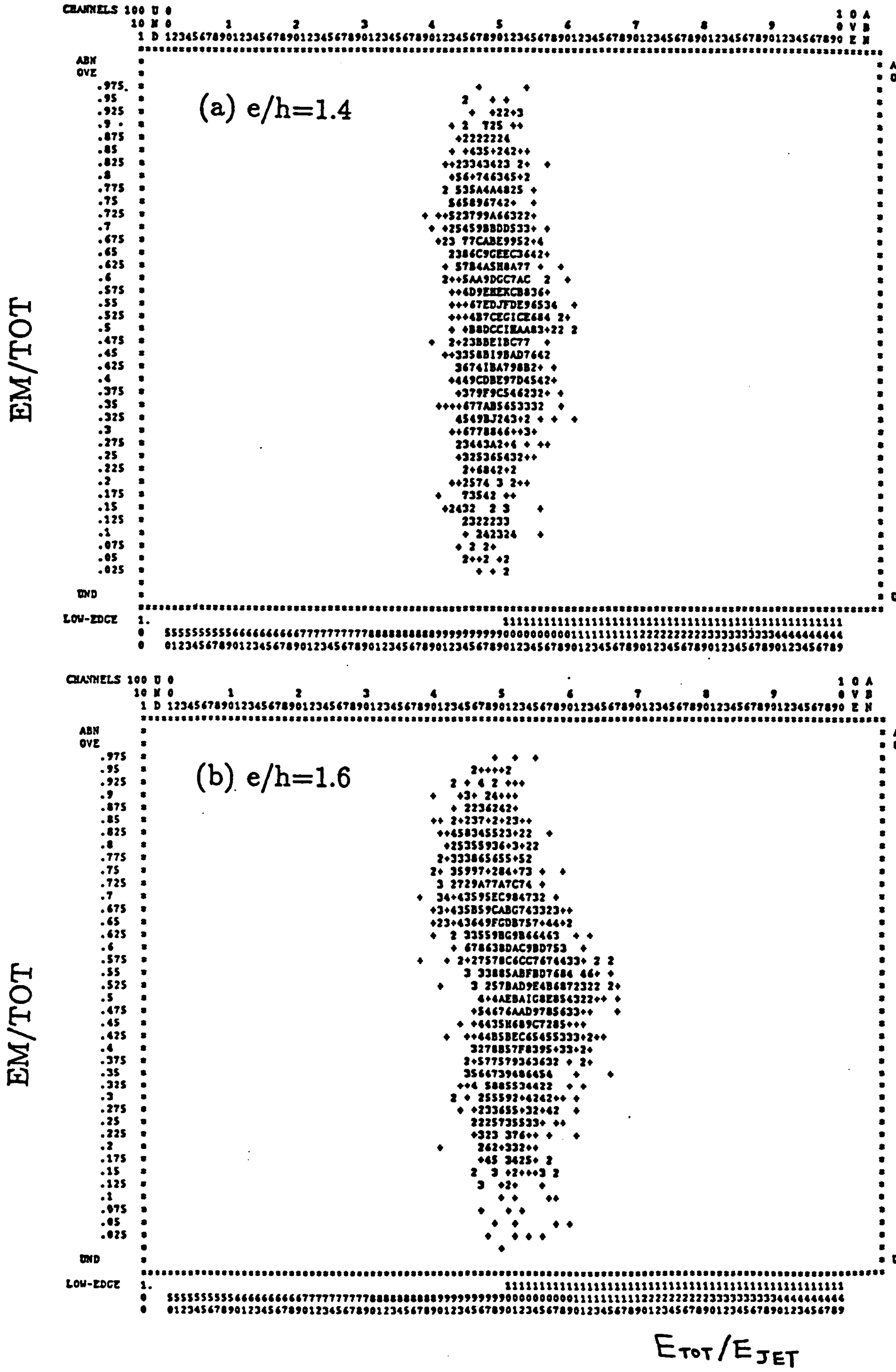


Fig.9

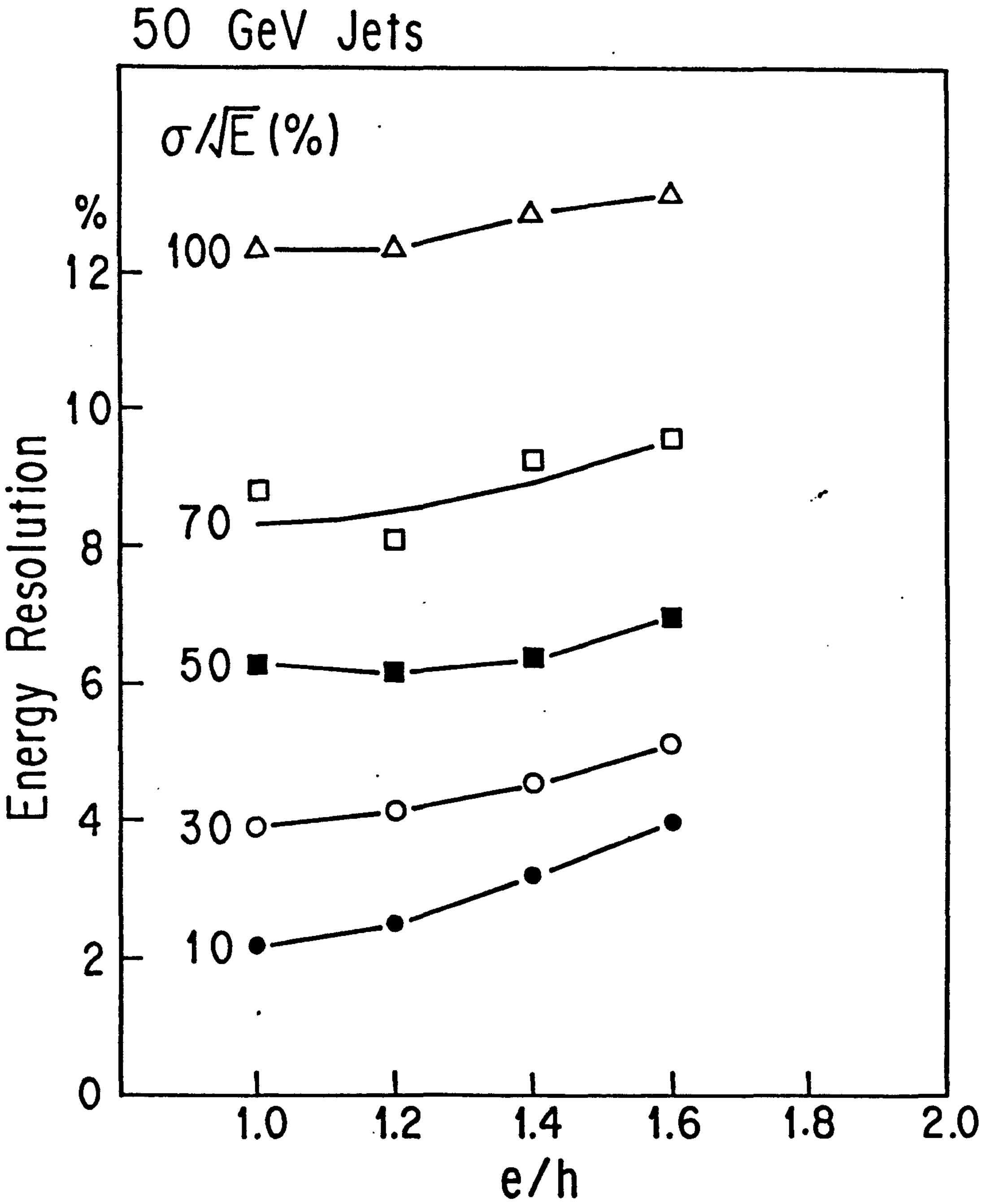
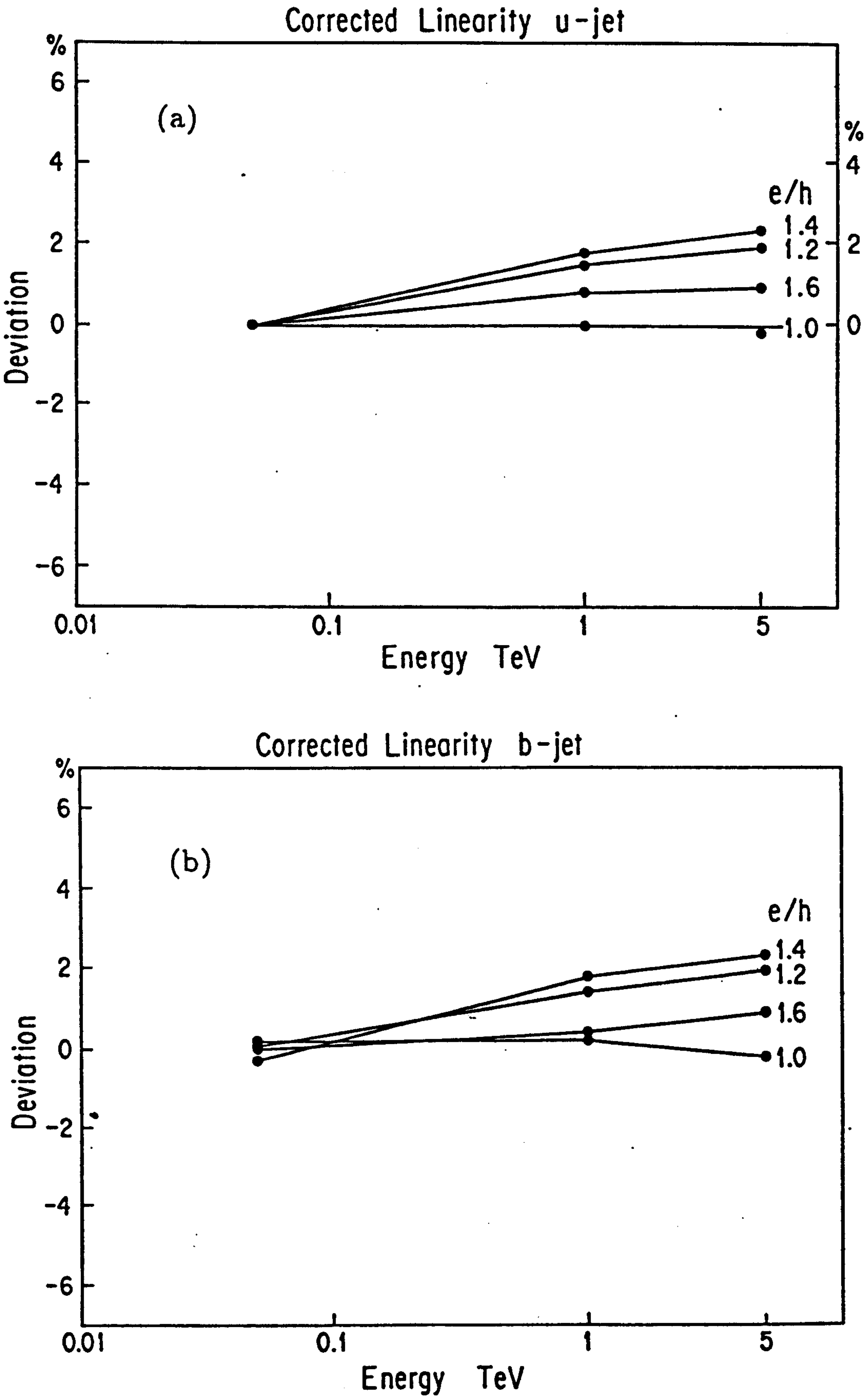

50 GeV Jets
σ/√E (%)
%
100
70
50
30
10
12
10
8
6
4
2
0
Energy Resolution
1.0
1.2
1.4
1.6
1.8
2.0
e/h

Fig.10



Corrected Linearity u-jet
(a)
%
6
4
2
0
-2
-4
-6
Deviation
%
4
2
0
e/h
1.4
1.2
1.6
1.0
0.01
0.1
1
5
Energy TeV
Corrected Linearity b-jet
(b)
%
6
4
2
0
-2
-4
-6
Deviation
e/h
1.4
1.2
1.6
1.0
0.01
0.1
1
5
Energy TeV

Fig.11