GEM TN-93-463

Reconstruction of High Energy Photons in GEM

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May 13, 1993

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Energy resolution of the accordion EM and hadron calorimeters for EM showers is discussed. For low energy photons ($E_\gamma < 0.3\ TeV$) the energy resolution almost doesn't depend on the structure of hadron calorimeter. There is no significant deterioration of energy resolution for HE photons ($E_\gamma > 0.3\ TeV$) if the resolution of hadron calorimeter for EM showers is better then $40\%/\sqrt{E}$.

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Introduction.

The barrel accordion EM calorimeter proposed for the GEM detector is a sampling calorimeter which uses 1mm thick lead plates with liquid krypton as active medium. It has 3 divisions in depth (3Xo, 10Xo, 11Xo) and provides 3 measurements of active energy e_1, e_2, e_3 respectively. In order to compensate for the deterioration of the energy resolution because of the dead material in front of the calorimeter, a massless gap in the first section is used. To determine the energy of incident photons, the signals from 5x5 towers are summed and $\sim 95\%$ of the total energy is available for analysis. The remaining 5% of the photon energy consists of a missing energy - forward, side and back leakages. The total energy is determined as

$E_{tot} = E_{5\times5} + E_{missing}$,

where $E_{5\times5}$ and $E_{missing}$ are the estimations for energy deposition in 5×5 towers and missing energy respectively. It is necessary to mention that fluctuations of the energies $E_{5\times5}$ and $E_{missing}$ are naturaly separated; the first is determined by sampling fluctuations, the second - by leakage fluctuations.

In the present design of the accordion calorimeter forward leakage is corrected with massless gap ("hardware" correction) and should be included in the definition of energy $E_{5\times5}$. For side leakage only "software" correction is possible if the calorimeter has restricted transverse sizes. Total energy deposition in the EM section could be written as

$E_{em} = E_{5\times5} + E_{side}$,

where E_{side} is the correction for side leakage.

Back leakage, which is essential for high energy photons, could be measured by first section of the hadron calorimeter

$E_{tot} = E_{em} + E_{had}$.

To get the results described in this note the MC simulation data prepared by M.Seman and M.Leltchuk for the accordion EM calorimeter were used.

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This research is supported by the U.S. Dept. of Energy under Contract DE-AC02-76CH00016

1. Energy reconstruction in the accordion EM calorimeter.

Assuming the sampling ratio α is a constant as a function of the depth of the calorimeter, the energy $E_{5\times5}$ should be proportional to the active energy

$$E_{5\times5} = 1/\alpha \cdot \sum_{i=1}^{3} e_i = E_{ss}.$$

But it is not true for a sampling calorimeter even if it has a uniform structure in depth. For example the sampling ratio for the unit cell of parallel plate calorimeter depends on the cell's number (Fig.1). In the first cells the sampling ratio is close to one for relativistic particles (0.39) and decreases up to 0.28 in the last layers.

The accordion calorimeter isn't uniform in depth and it is natural to assume that the sampling ratio could be different for different sections of the calorimeter. For the present design of the calorimeter MC simulation gives sampling ratios $\alpha_1 = 0.343$, $\alpha_2 = 0.339$, $\alpha_3 = 0.313$ and E_{ss} is not a correct estimation of energy $E_{5\times5}$. On the other side, it isn't clear why the simple sum (energy E_{ss}) should give the best estimation for energy E_{em} or E_{tot}. But the total energy deposition in the EM calorimeter should be at least a linear combination of the amplitudes e_1, e_2, e_3.

$$E_{em} = \sum_{i=1}^{3} w_i e_i.$$

The coefficients, w_i, are found by minimizing the variance

$$V = \sum_{j=1}^{n} (1 - \sum_{i=1}^{3} w_i e_i^j / E_{em}^j)^2,$$

where the sum $\sum_j$ is calculated over the data sample. The results of a calculation for the coefficients w_i $(i = 1, 2, 3)$ are shown in Table 1.

E_γ, GeV	w_1	w_2	w_3	linearity, %
25	3.057	3.044	2.948	-0.57 ± 0.03
40	2.992	3.048	2.953	-0.07 ± 0.04
80	2.991	3.041	2.954	0.12 ± 0.02
120	3.004	3.048	2.943	0.04 ± 0.02
160	2.963	3.046	2.943	-0.01 ± 0.02
240	3.009	3.044	2.942	0.01 ± 0.02
320	2.999	3.040	2.946	-0.09 ± 0.02

Table 1: Weighting coefficients and linearity for different energies of incident photons.

The coefficients are almost constant with E_γ and the average values of the coefficients were used in the calculation of energy resolution.

By the same way it is possible to find optimal coefficients to get estimation for energy E_{tot}.

$$E_{tot} = \sum_{i=1}^{3} w_i e_i.$$

In Fig.2 the distributions for E_{ss}, E_{em} and E_{tot} (E_γ) are shown. There is a tail at low energies for the E_{em} energy distribution because it isn't corrected for back leakage and the correlation between E_{em} and active energy in hadron calorimeter (Eh_{act}) is almost linear. Energy E_{tot} is corrected for the back leakage and there is no dependence on Eh_{act}. For the energy E_{ss} it is an intermediate situation. So the simple sum is naturaly corrected for leakage but the correction isn't complete.

Because of the fine longitudinal division of the EM calorimeter it is possible to correct the energy E_{em} for back leakage using correlation between amplitudes e_2 and e_3 ("software correction"). For example in Fig.3 two-dimensional plot "E_{em} vs e_3/e_2" is shown. One can see almost a linear correlation between E_em and ratio e_3/e_2.

In Fig.4 the results of energy resolution analysis for MC simulation data are shown. The four different methods described above were used to reconstruct the total energy. The points for different energies E_γ are fitted by curve

$\sigma_E/E = B + A/\sqrt{E}$.

The results of the fit are summarized in Table 2.

method	$A, \% \cdot \sqrt{(GeV)}$	$B, \%$
$E_{tot} = \sum_{i=1}^{3} w_i e_i$	5.44	0.21
$E_{tot} = \sum_{i=1}^{3} e_i + corr(Eh_{act})$	5.39	0.18
$E_{tot} = E_{em} + corr(e_3/e_2)$	5.50	0.19
$E_{tot} = E_{em} + corr(Eh_{act})$	5.28	0.15
statistical errors	~ 0.15	~ 0.02

Table 2: Energy resolution (A) and constant term (B) for the different methods of energy reconstruction.

2. Energy resolution for high energy photons.

For low energy photons ($E_\gamma < 0.3\ TeV$), the back leakage is too small and the energy resolution almost doesn't depend on the structure of hadron calorimeter. In Table 3 the results of simulation for different designs of hadron calorimeter are shown.

method	%, LKr 4mm + Pb 3mm	%, LKr 8mm + Cu 27mm
$E_{tot} = \sum_{i=1}^{3} w_i e_i$	0.375	0.394
$E_{tot} = \sum_{i=1}^{3} e_i + corr(Eh_{act})$	0.364	0.348
$E_{tot} = E_{em} + corr(e_3/e_2)$	0.366	0.351
$E_{tot} = E_{em} + corr(Eh_{act})$	0.335	0.336
statistical errors	~ 0.014	~ 0.014

Table 3: Energy resolution for different types of HC (E_γ =320 GeV).

For high energy photons ($E_\gamma \sim 0.3 - 4.\ TeV$), the back leakage is essential and could give a main contribution in the energy resolution if the hadron calorimeter is not sufficient to measure it. Unfortunately it isn't possible to have a detaile MC simulation at high energies for different types of the hadron calorimeter due to the huge amount of computer time required. In this note I try to give some realistic estimation of the energy resolution for HE photons.

The back leakage was estimated with the assumption that the mean longitudinal profile of the energy deposition in an electromagnetic cascade is described by a gamma distribution /1/.

$$\frac{dE}{dt} = E_\gamma \cdot b \cdot \frac{(bt)^{a-1} \exp -bt}{\Gamma(a)},$$

where the distance t is measured in units of radiation length and energy e in units of critical energy. For photons with energies from 1 GeV to 100 GeV the energy deposition profile are well described by the previous equation with

$(a-1)/b = \ln(e) + 0.5.$

The scale factor b is in a range 0.4-0.6 for a variety of elements and has a weak dependence on energy. For the accordion calorimeter (A=132, Z=54) $b = 0.48$ was assumed.

The mean fraction of energy (f) that escapes from the EM calorimeter (total length 24Xo) is shown in Fig.5. One can see that even for 4 TeV photons, more than 93% of energy is deposited in the EM section.

The EM section with first hadron section together is a typical example of a calorimeter with different sampling ratios. The energy resolution for such kind of calorimeters is well described by formula

$(\sigma_E/E)^2 = f \cdot \sigma_h^2 + (1-f) \cdot \sigma_e^2$

where σ_h and σ_e are the energy resolution for EM showers in hadron and EM ($\sigma_e = 5.3\%/\sqrt{E}$) sections respectively. For example, in Fig.6 the energy resolution for parallel plate calorimeter divided into two parts with rough ($\alpha = 0.15$) and fine ($\alpha = 0.3$) structure is shown. One can see that the MC simulation (stars and circles) is in good agreement with the calculation (solid line). Using the above mentioned assumptions the energy resolution for two values ($\sigma_h = 19\%/\sqrt{E}, Cu\ 27mm/LKr\ 8mm$ and $\sigma_h = 32\%/\sqrt{E}, Pb\ 27mm/LKr\ 8mm$) was calculated. The results are shown in Fig.7-8.

Conclusion

1. The simple energy sum is corrected for side and back leakages and is a good estimation for the total energy if $E_\gamma < 0.3\ TeV$. The energy reconstruction with optimal weighting coefficients gives better energy resolution but the improvement isn't significant.

2. For low energy photons ($E_\gamma < 0.3\ TeV$) back leakage is quite small and the total energy could be reconstructed using "software correction". The energy resolution for EM showers almost doesn't depend on the structure of hadron calorimeter.

3. For high energies ($E_\gamma > 0.3\ TeV$) when the back leakage gives the main contribution to the energy resolution, the "optimal" method should give exellent energy resolution because the energy E_{em} is in a strong correlation with energy Eh_{act} and could be corrected for the back leakage. The simple sum method may give significantly worse energy resolution because the correction for back leakage isn't effective.

4. Assuming the constant term is 0.4%, there is no significant deterioration of energy resolution for HE photons if the resolution of hadron calorimeter for EM showers is $40\%/\sqrt{(E)}$ or better ($\alpha > 0.04$).

Acknowledgement

I am very appreciate to H.Gordon, M.Seman and M.Lelthouk for help in this work.

/1/ E.Longo and I.Sestili. Monte Carlo calculation of photon initiated EM showers in lead glass. NIM 128 (1975) p.283-307.

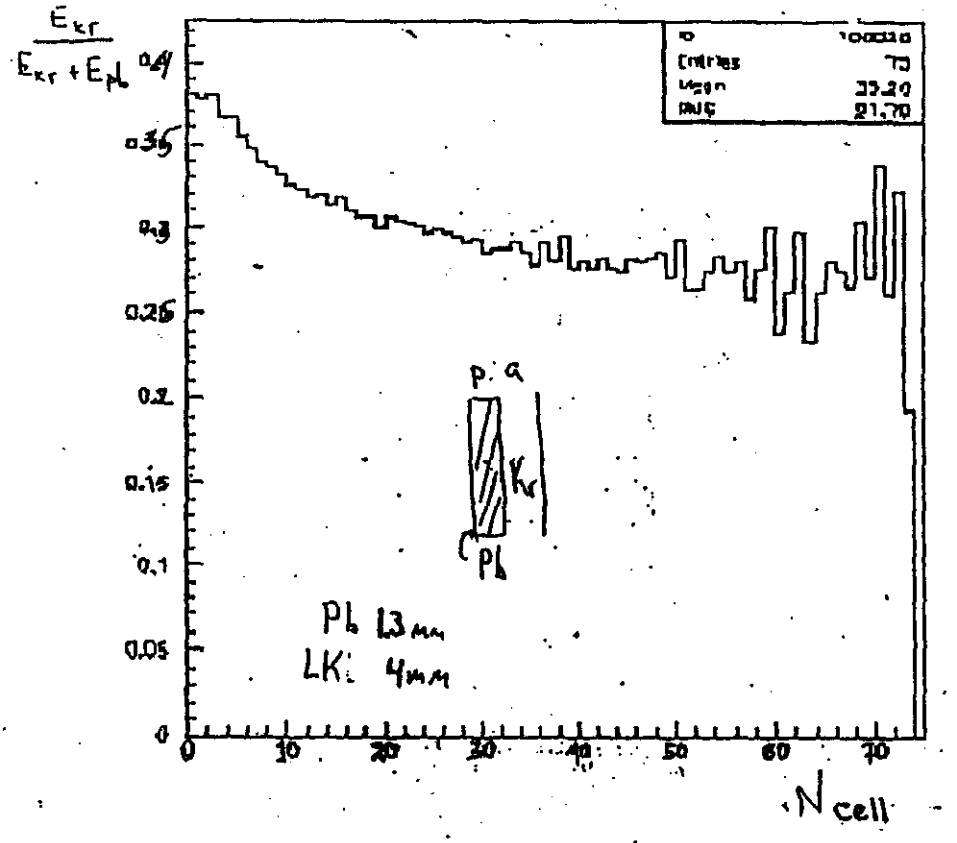


Fig.1. The sampling ratio in a unit cell of parallal plate calorimeter dependent on the cell's number (unit cell ~0.33Xo).

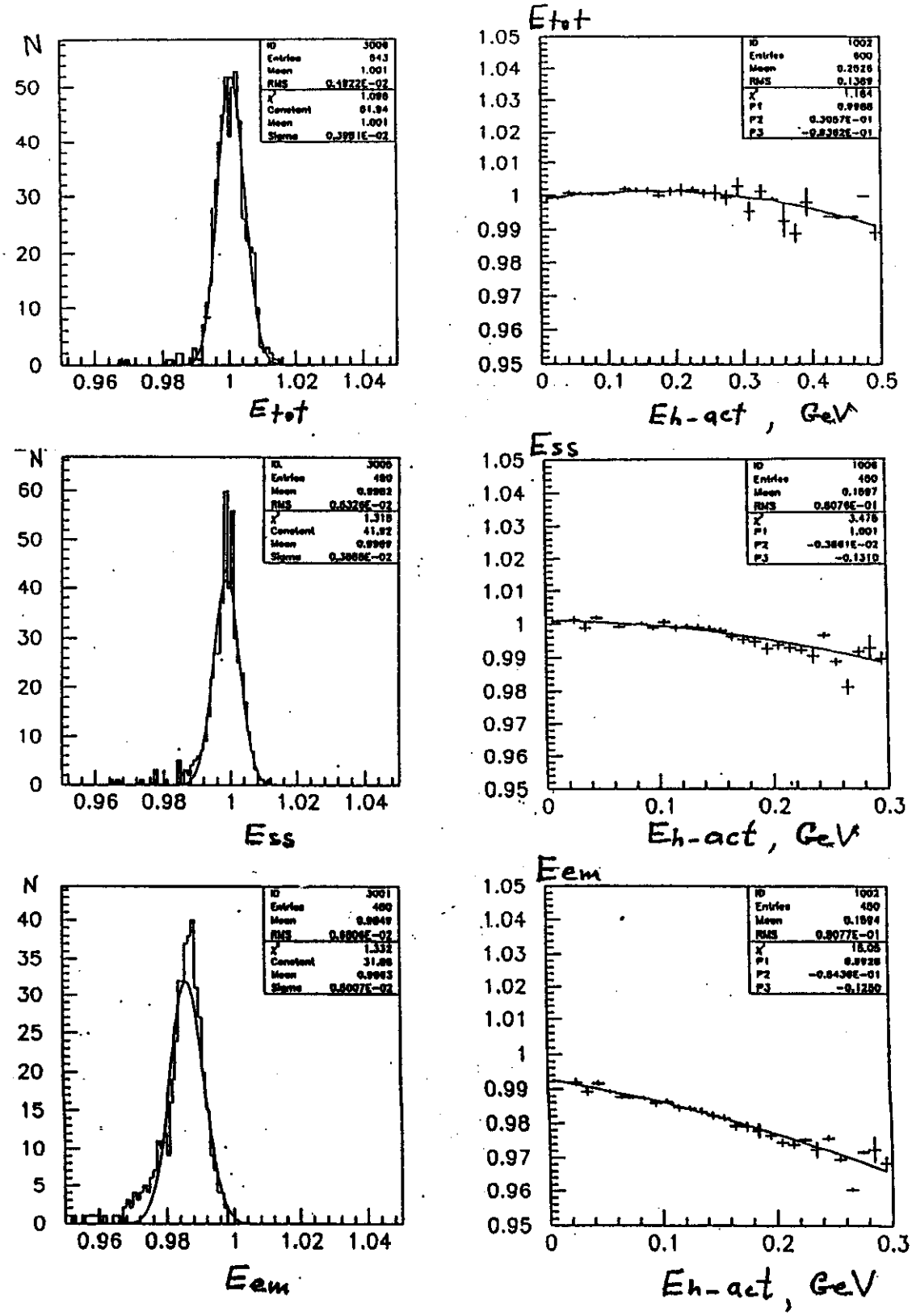


Fig.2. The distributions for Etot, Ess, Eem ($E_\gamma = 320$ GeV).

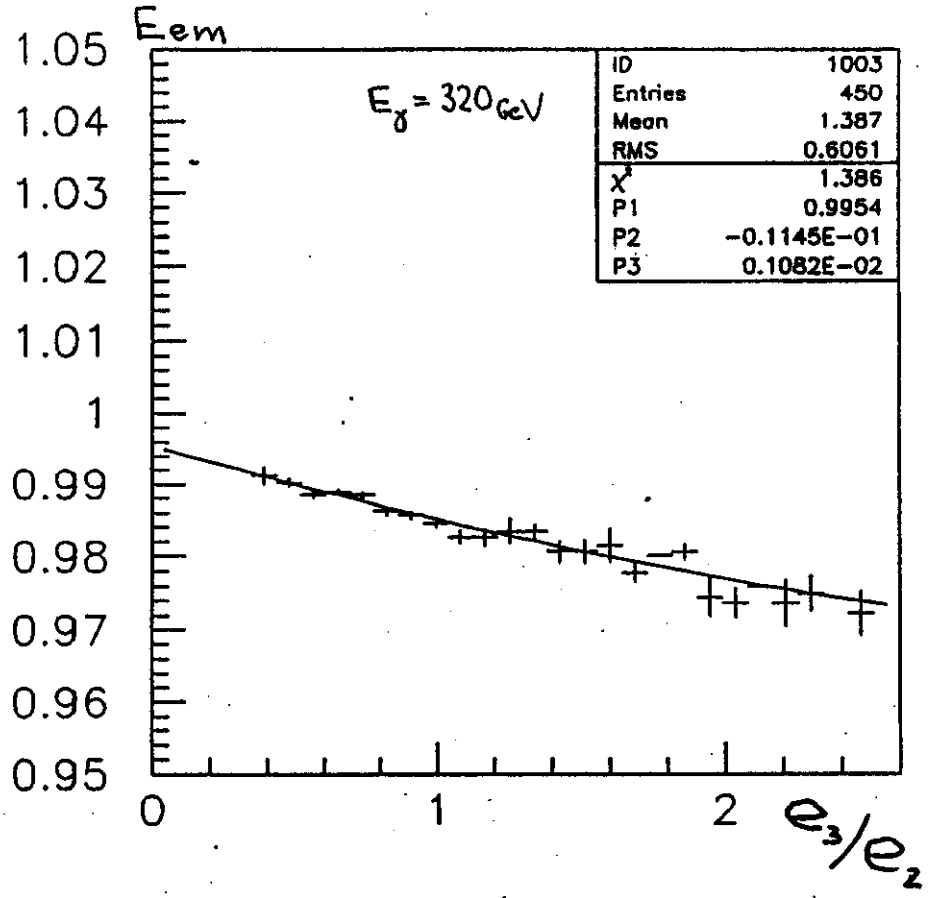


Fig.3. The correlation between Eem and the ratio e3/e2.

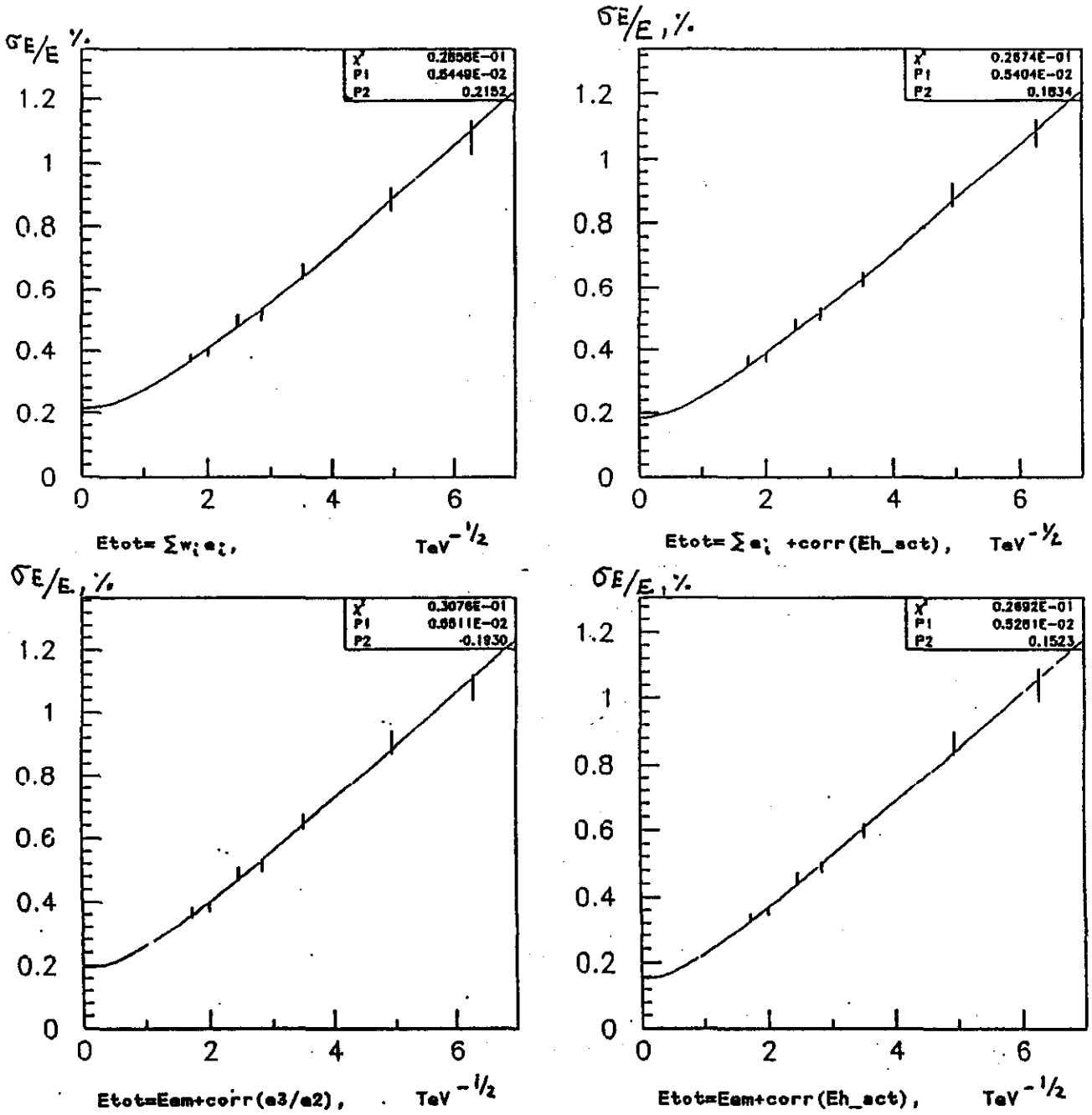


Fig.4. The energy resolution for different methods to reconstruct a photon energy.

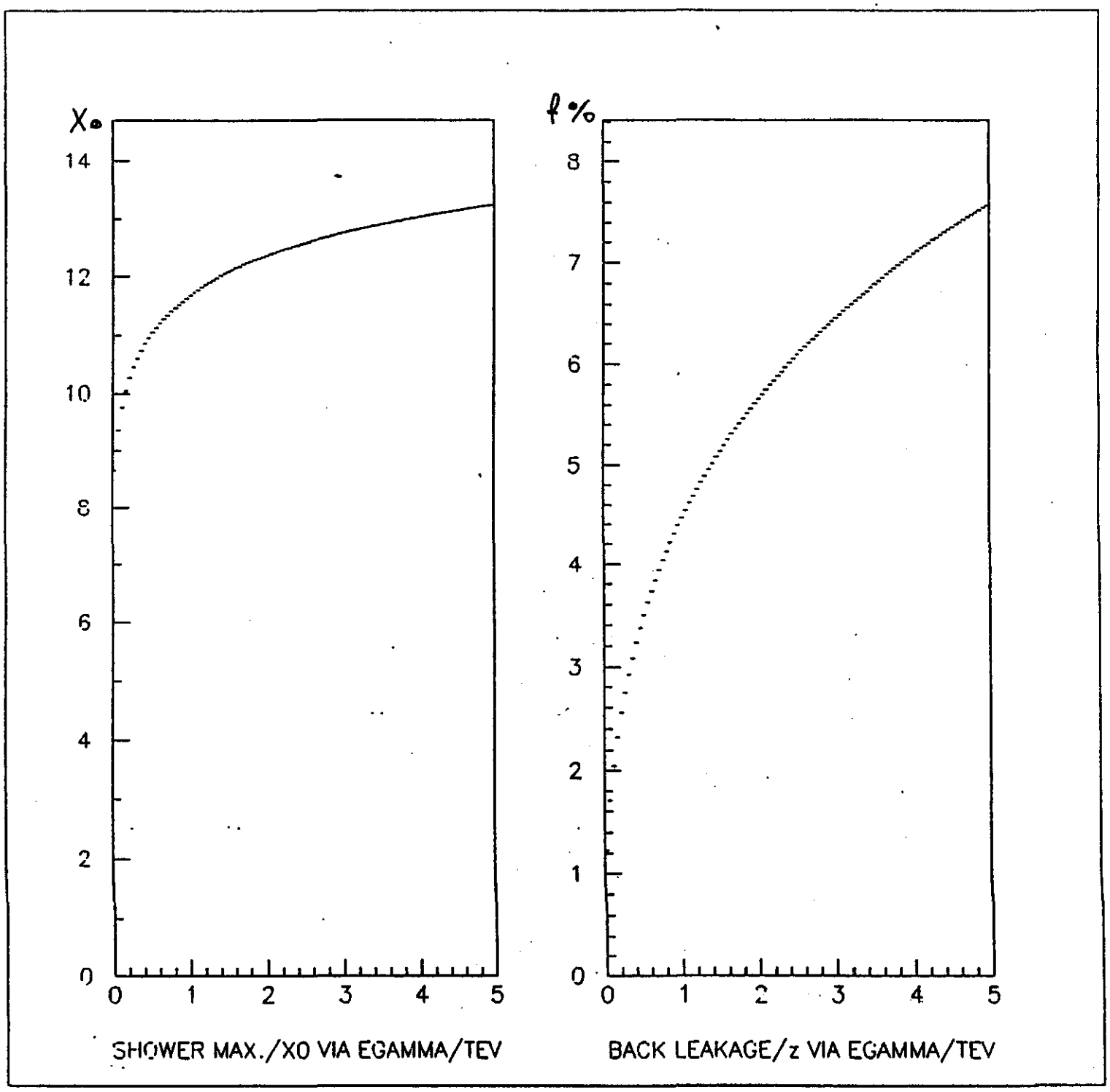
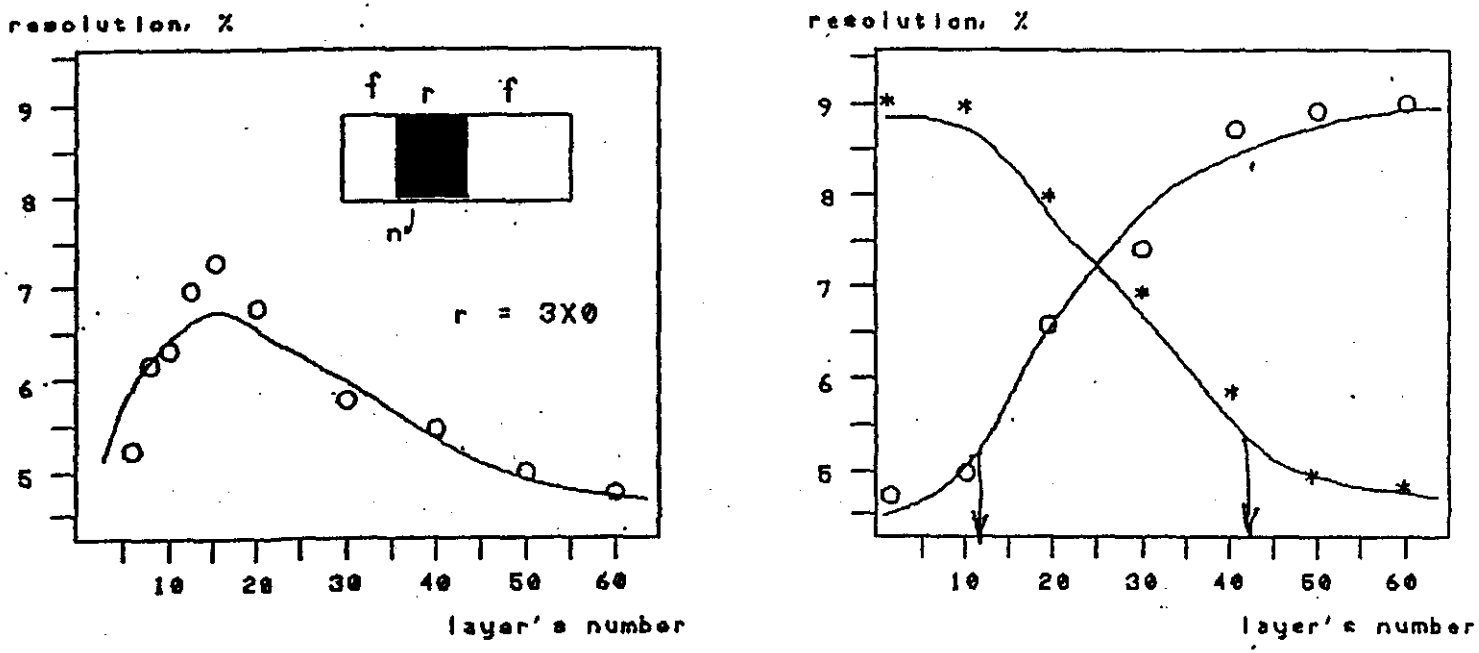


Fig.5. The mean fraction of energy leaked from the EM calorimeter.

Calorimeter with variable sampling ratio.

f - passiv matter: Pb(1.3)+Fe(0.3)+Kapt(0.5).

r - passiv matter: Pb(2.6)+Fe(0.6)+Kapt(1.0)+LKr(4)



*, O - M.C.simulation

— - calculation

n - layer's number

f - fine structure

r - rough structure

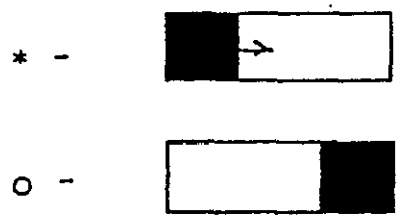
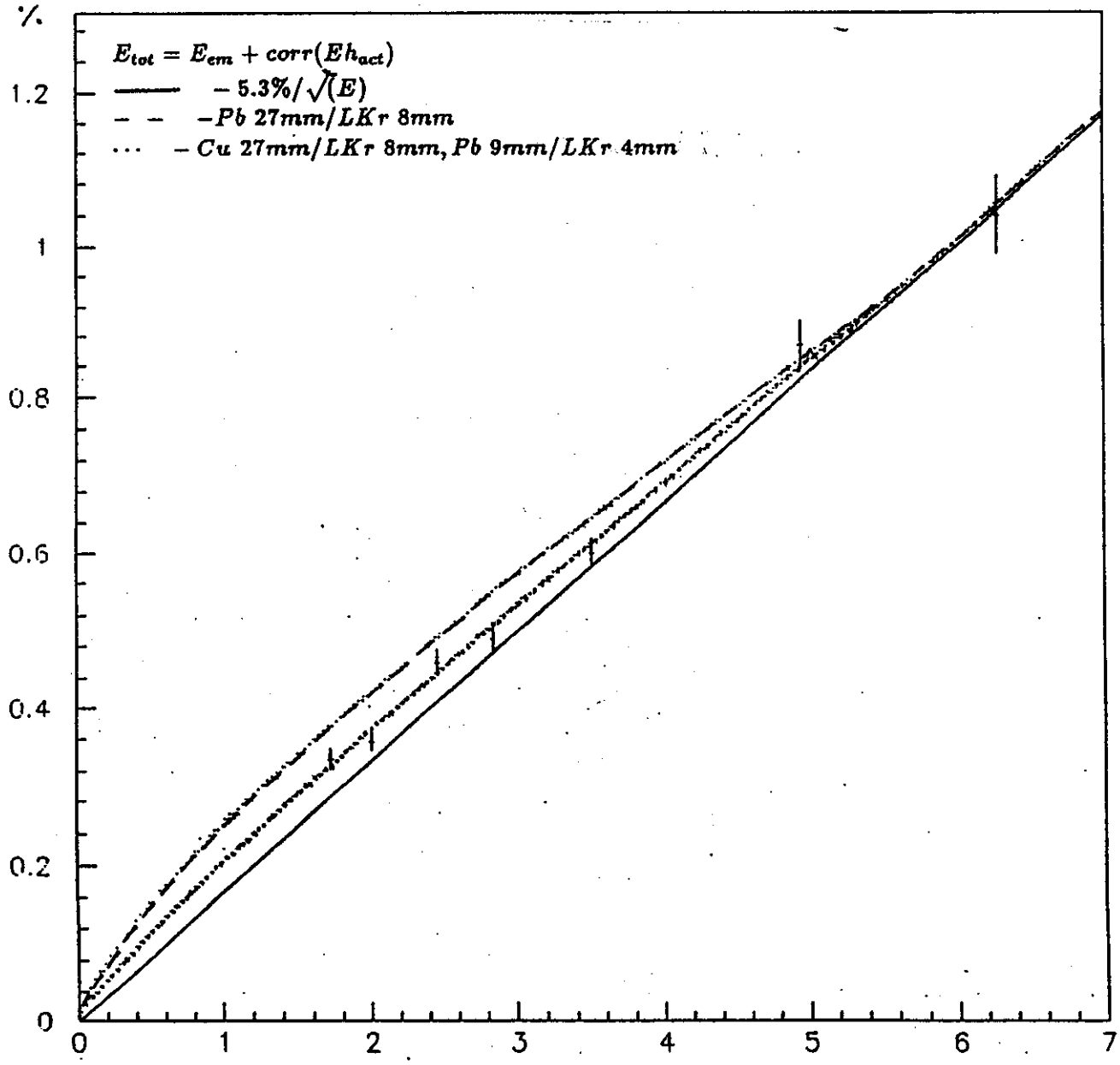


Fig.6.



Energy resolution ($\sigma_E/E, \%$) via $1/\sqrt{(E)}$ ($TeV^{-1/2}$).

Fig.7

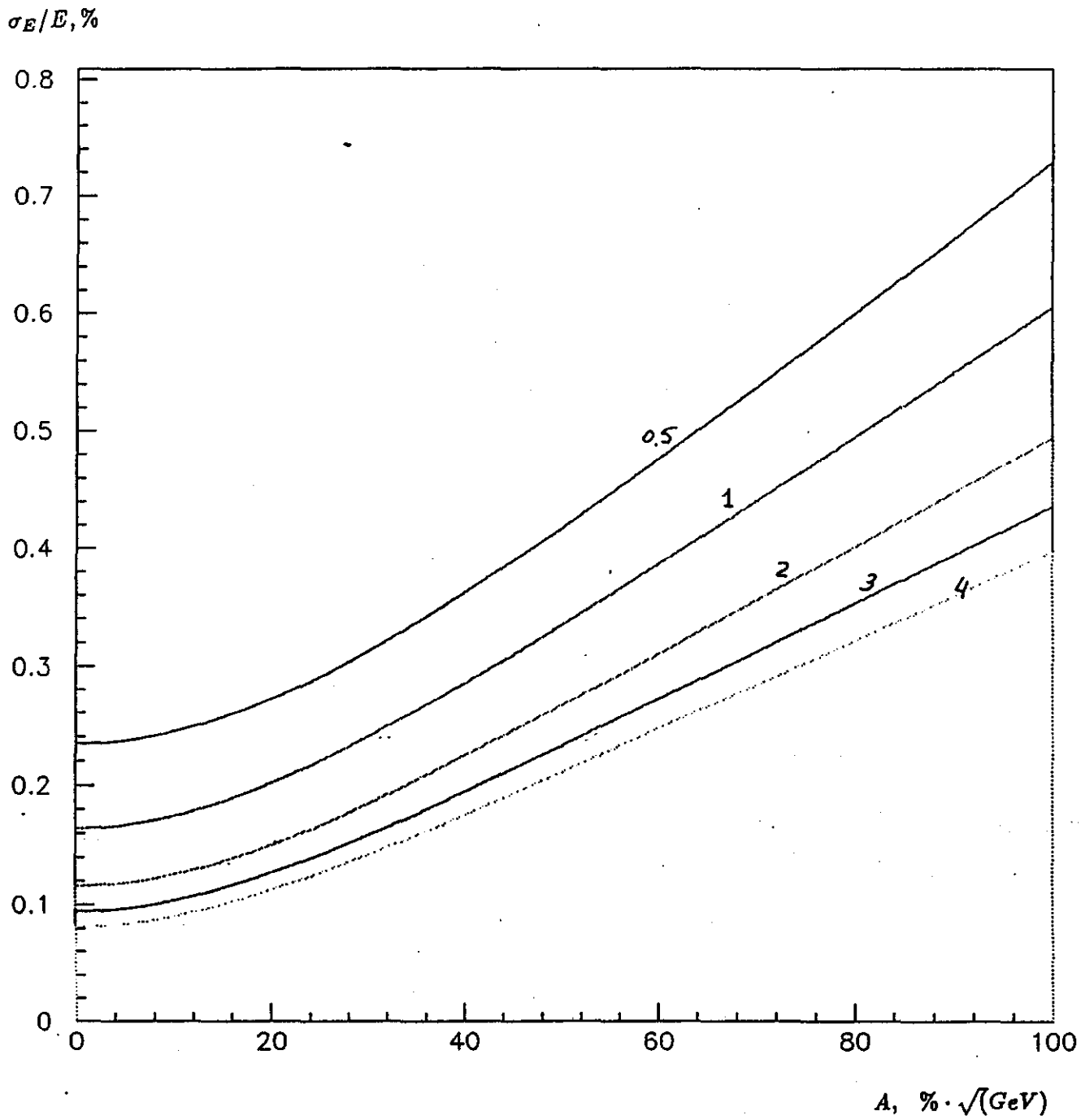


Fig. 8 Energy resolution via the resolution of hadron calorimeter for photons with energy 0.5 TeV, 1 TeV, 2 TeV, 3 TeV, 4 TeV.