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CMS NOTE 2002/xxx

The Compact Muon Solenoid Experiment

CMS Note

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

13 March 2002

Jet energy scale at CMS calorimeter using "$\gamma + jet$" channel.

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Abstract

The possibility to correct the energy of the jet found in the CMS calorimeter using one-jet events with direct photons are investigated. It is shown, that using the certain selections of events the predicted scale of the jet energy is close to the true scale. The estimation of the numbers of events, suitable for the calibration and the accuracy of the calibration are found for the luminosity $2 \cdot 10^{33} cm^{-2} s^{-1}$.

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1 Introduction.

One of the possibility to correct the energy of jet is to use the channel where energy of initial parton can be fixed by the tagging particle (Z, γ+jet channel).

The some features of the γ+jet channel with the reference to CMS were studied both at the level of particles [1]- [6], and with simulation of the detector effects [7]- [8].

However the accuracy of the jet energy scale which can be achieved for the reasonable time was not investigated. In the present paper the estimation of the statistical errors are given for the low luminosity ($2 \cdot 10^{33} cm^{-2} s^{-1}$) pile up.

The calculations are performed with the usage of the packages PYTHIA 6.156 [9], CMSIM 121 [10], ORCA 4.5.4 [11].

2 Events for the analysis.

The events with direct photons of SPRING01 generation with pile up are used [12].

The parameters of the samples "1" - "4", for the different intervals on P_T^γ, are given in table 1.

Tabl.1. The parameters of the datasets.

Parameters	"1"	"2"	"3"	"4"
P_{Tmin}^γ (GeV/c)	20	40	100	200
P_{Tmax}^γ (GeV/c)	40	100	200	300
Numbers of events	10000	10000	10000	10000

The parameters for the PYTHIA-generation are given in table 2.

Tabl.2. The PYTHIA parameters.

Parameters	**Values**
Processes	`ISUB=14` $(f\bar{f} \to g\gamma)$, `ISUB=29` $(fg \to f\gamma)$
$\sqrt{s}$	$14\,TeV$
Structure of multiple interactions	`MSTP(82) = 4`
$\hat{p}_\perp$ min	`CKIN(3) = 0.5` P_{Tmin}^γ,
$\hat{p}_\perp$ max	`CKIN(4) = 2` P_{Tmax}^γ

The values of `CKIN` were selected so that they do not impose essential restrictions on the energy of the parton of hard process in the each interval on P_T^γ. This point is very important to keep the correct spectrum of the P_T^γ / P_T^{par} ratio which defines the errors of the jet energy scale.

3 Jet energy scale.

The jet energy scale is established using the dependance of the measured energy of jet on the energy of parton (or the energy of jet on the level of particles).

This dependence, in particular, for the calibration on the jet on the particle level can be set for full and transferse energies:

$$E_{ptcl}^{jet} = E_{reco}^{jet} / k_{jet} \tag{1}$$

or

$$E_{Tptcl}^{jet} = E_{Treco}^{jet} / k_{jet}. \tag{2}$$

Here k_{jet} is calibration coefficient.

Considering the balance on the transverse momentum between the photon and the jet the usage of the "γ+jet" events allows to predict the values of E^{par} or E^{jet}_{ptcl} knowing the values of the reconstructed transverse energy of the photon (E^{γ}_{Treco}) and pseudo-rapidity of the jet (η_{jet}):

$$E^{jet}_{Texpect} = E^{\gamma}_{Treco}, \tag{3}$$
$$E^{jet}_{expect} = E^{jet}_{Texpect}\cosh(\eta_{jet}) = E^{\gamma}_{Treco}\cosh(\eta_{jet}). \tag{4}$$

According to (1)-(4) values of k_{jet} can be determined by averaging procedure:

$$x = \frac{E^{jet}_{reco}}{E^{jet}_{expect}} \approx \frac{E^{jet}_{Treco}\cosh(\eta_{jet})}{E^{\gamma}_{Treco}\cosh(\eta_{jet})} = \frac{E^{jet}_{Treco}}{E^{\gamma}_{Treco}}. \tag{5}$$

As it was shown earlier [8], the usage of the average values of x as the calibration coefficient can result in the essential systematic errors connected with the infringement of P_T-balance in hard process.

Therefore it is more preferable to define the value of the calibration coefficient using the position of the peak in the distribution of x.

In the present work calibration coefficients are determined by allocation of gaussian parts of distribution of x. The mean value (μ) of this distribution is accepted as value k_{jet} (or k^{expect}_{jet}).

The calculations are carried out for the jets collected in the calorimeters in the cone of the radius 0.5. Photons are gathered in 3 $\times$3 crystals of the electromagnetic calorimeter.

4 Selection of events.

The simulation on the particle level shows the advantage of the calibration using the position of the peak of the distribution E^{jet}_T/E^{γ}_T in comparison with the calibration using the mean value of this ratio (see. Fig.1a-1b).

The position of the peak is kept during the different selections of events and thus calibration does not demand hard selection of events to suppress the additional jets and to improve the P_T-balance between the photon and the jet.

The detailed simulation of the setup shows, that already at low luminosity the situation essentially varies.

For example, imposing the restrictions on the transverse energy of the additional jets the peak is shifted (see. Fig.1c-1d). It creates the complexities in determination of the calibration coefficients which can contain the large systematic errors (see. Fig.2b).

For the estimation of the sistematic errors predicted using the distribution of x the values of k^{expect}_{jet} are compared to the values of the calibration coefficient, found using the distribution of the $E^{jet}_{Treco}/E^{jet}_{Tptcl}$ ratio. The last ratio we shall call as the true one: k^{true}_{jet}.

During the development of the selection rules of the events for the calibration we use as the reference points:

a) the small value of the statistical and systematic errors of k_{jet},

b) the large value of S/B - the ratio of the number of "γ+jet" events to the number of the background events.

The selections on the large set of the physical parameters of the events were investigated [8]. Thus results of the analysis of the background events of the SPRING01 production [12], [8] were also used. The main effect except the selection on the additional jets is achieved with the selections on the following parameters:

$E^{isol}_{T\gamma}$ is the scalar sum of the reconstructed transverse energy (E_T) of the cells of the calorimeters inside the cone of the radius $R = 0.5$, outlined around the photon, except the area of the 7$\times$7 crystals of the electromagnetic calorimeter around photon candidate;

$\Delta\phi$ is interval in the polar angle ϕ between vectors E_T jet and the photon;

E_T^{out} is the vector sum of E_T of cells of calorimeters except the area of the 7×7 crystals of the electromagnetic calorimeter in the vicinity of the photon and area of the radius 0.8 in the vicinity of the jet.

On calculating the $E_{T\gamma}^{isol}$ the calorimeter cells with energy deposition exceeded 3σ of the noise signal are taken into account only [8].

The selections of events for the calibration are offered as "soft " and "hard".

The "Soft" selection corresponds to the values

- $Eff_S \approx 50\%$ in all bins on E_T^{γ} from the interval $20 < E_T^{\gamma} < 300\,GeV$;
- $S/B \approx 0.3 \div 3$ at $E_T^{\gamma} = 20 \div 150\,GeV$.

It includes conditions:

$$\begin{array}{rcl} Et^{jet2} & < & 40\left(Et^{jet}/\varepsilon\right)^{0.57}, \qquad [\varepsilon = 100\,GeV]; \\ Et^{out} & < & 55\,(Et^{\gamma}/\varepsilon)^{0.57}; \\ \Delta\phi & > & \pi - 0.4\,(Et^{\gamma}/\varepsilon)^{-0.5}; \\ Et_{\gamma}^{isol} & < & 5\,(Et^{\gamma}/\varepsilon)^{0.33}. \end{array}$$

The "Hard" selection corresponds to the values

- $Eff_S \approx 10\%$ in all bins on E_T^{γ} from the interval $20 < E_T^{\gamma} < 300\,GeV$;
- $S/B \approx 0.6 \div 8$ at $E_T^{\gamma} = 20 \div 150\,GeV$.

It includes conditions:

$$\begin{array}{rcl} Et^{jet2} & < & 24\left(Et^{jet}/\varepsilon\right)^{0.35}, \qquad [\varepsilon = 100\,GeV]; \\ Et^{out} & < & 40\,(Et^{\gamma}/\varepsilon)^{0.35}; \\ \Delta\phi & > & \pi - 0.27\,(Et^{\gamma}/\varepsilon)^{-0.5}; \\ Et_{\gamma}^{isol} & < & 2\,(Et^{\gamma}/\varepsilon)^{0.4}. \end{array}$$

5 Errors of calibration.

On Fig.3c-d the calibration coefficient and the corresponding systematic error $\Delta k_{jet} = k_{jet}^{expect} - k_{jet}^{true}$ (see section 4) in the bins on E_{reco}^{jet} are presented for the case of the "soft" selection.

The calibration coefficients are determined by the method described in section 3. Averaging is made in the bins on E_{expect}^{jet} (Fig.3a), then using known dependence E_{reco}^{jet} vs E_{expect}^{jet} (Fig.3b) the designed values of k_{jet} are calculated for E_{reco}^{jet} (Fig.3b). The detailed description of this procedure can be found in [13].

The insufficient statistics has not allowed to make more exact estimations both at the "soft" and "hard" selections.

Nevertheless, the result shows the opportunity of elimination of the systematic error Δk_{jet} at least at high energy $E_T^{jet} > 100\,GeV$.

Fig.4-5 illustrates the dependance of the errors of calibration on the size N of samples and on the RMS of the imbalance (5). In total for the three months of work of CMS at luminosity $2 \cdot 10^{33} cm^{-2} s^{-1}$ we shall have the following numbers of events with jets and E_T^{γ} in $20 \div 300\,GeV$ in the barrel part of the hadron calorimeter (HB) : $10^8 \div 10^4$ events at the $soft$ selection (Fig.4a) and $2 \cdot 10^7 \div 10^3$ events at the "hard" selection (Fig.5a).

Approximately the same number of events with jets we can expect when jets appear in the endcap part of the hadron calorimeter (HE).

We will have in the interval of $E_T^{\gamma} = 20 \div 300\,GeV$, values of $k_{jet} \approx 0.8 \div 1$ and $\sigma \approx 20 \div 10\,GeV$ (Fig.4b-5c, 5b-5c) the errors $\Delta/k_{jet} \approx 0.01 \div 0.5\%$ (Fig.4d, 5d).

The given values of the errors are a little bit conditional. They characterize the accuracy of the calibration coefficient calculation in the events in which η_{jet} belongs to the wide interval ($|\eta_{jet}| < 1$ or $1.5 < |\eta_{jet}| < 2.5$), and E_T^γ belongs to the bins of the size $E_T^\gamma/10$. At the other size of bins the error will be, naturally, differ reflecting their dependence on the size of the sample N.

The obtained estimations of the systematic and the statistical errors allow to hope, that for the three months of the work of CMS we shall have the sufficient number of events for achievement of accuracy of calibration about 1% in the interval $E_T^\gamma = 20 \div 300\, GeV$.

6 Acknowledgments.

Authors express gratitude for interest to work and fruitful discussions to I.A. Golutvin, S. Eno, S. Kunori, I.P. Lokhtin, A.N. Nikitenko, A.L. Ulianov, A.B. Zarubin.

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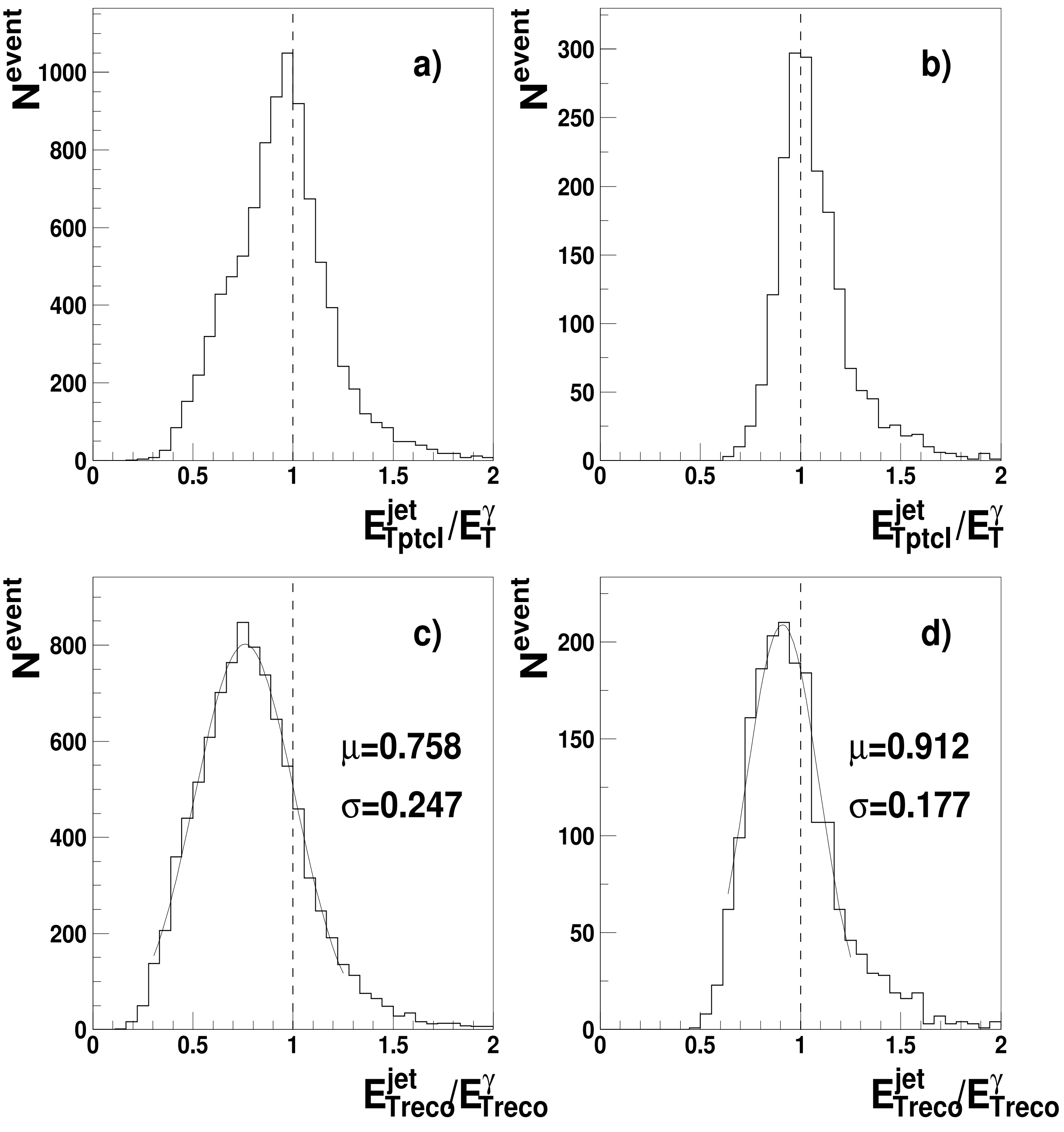

Figure 1: Spectra of E_T^{jet}/E_T^{γ} ratio in the events with direct photons at the particle level (a-b) and at low luminosity (c-d) without selections of events (a, c) and after imposing restrictions on the transverse energys of the additional jets: $E_T^{jet2} < E_T^{jet}/4$ (b, d). The calculations are performed for $40 < E_T^{\gamma} < 100 GeV$.

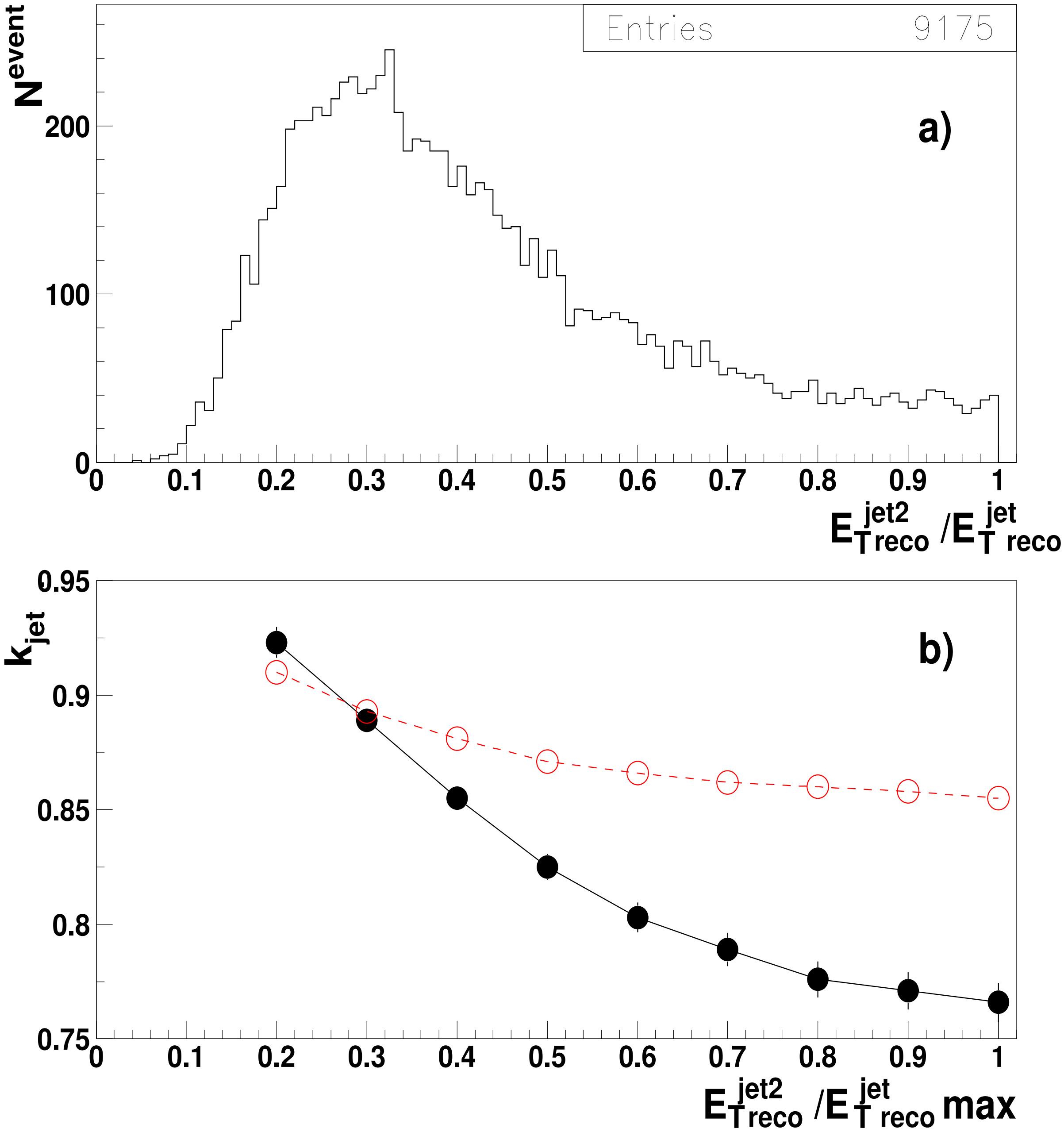

Figure 2: Spectrum of the ratio of the second leading jet transverse energy to the transverse energy of the leading jet inthe events with direct photons (a) and dependence of the true (white circles) and expected (black circles) values of the calibration coefficients (k_{jet}) on the restriction on the second leading jet transverse energy (b). "True" values of k_{jet} are determined from the spectrum of $E^{jet}_{Treco}/E^{jet}_{Tptcl}$, and the "predicted" - from the spectrum of $E^{jet}_{Treco}/E^{\gamma}_{Treco}$. The result is received for $40 < E^{\gamma}_{T} < 100 GeV$.

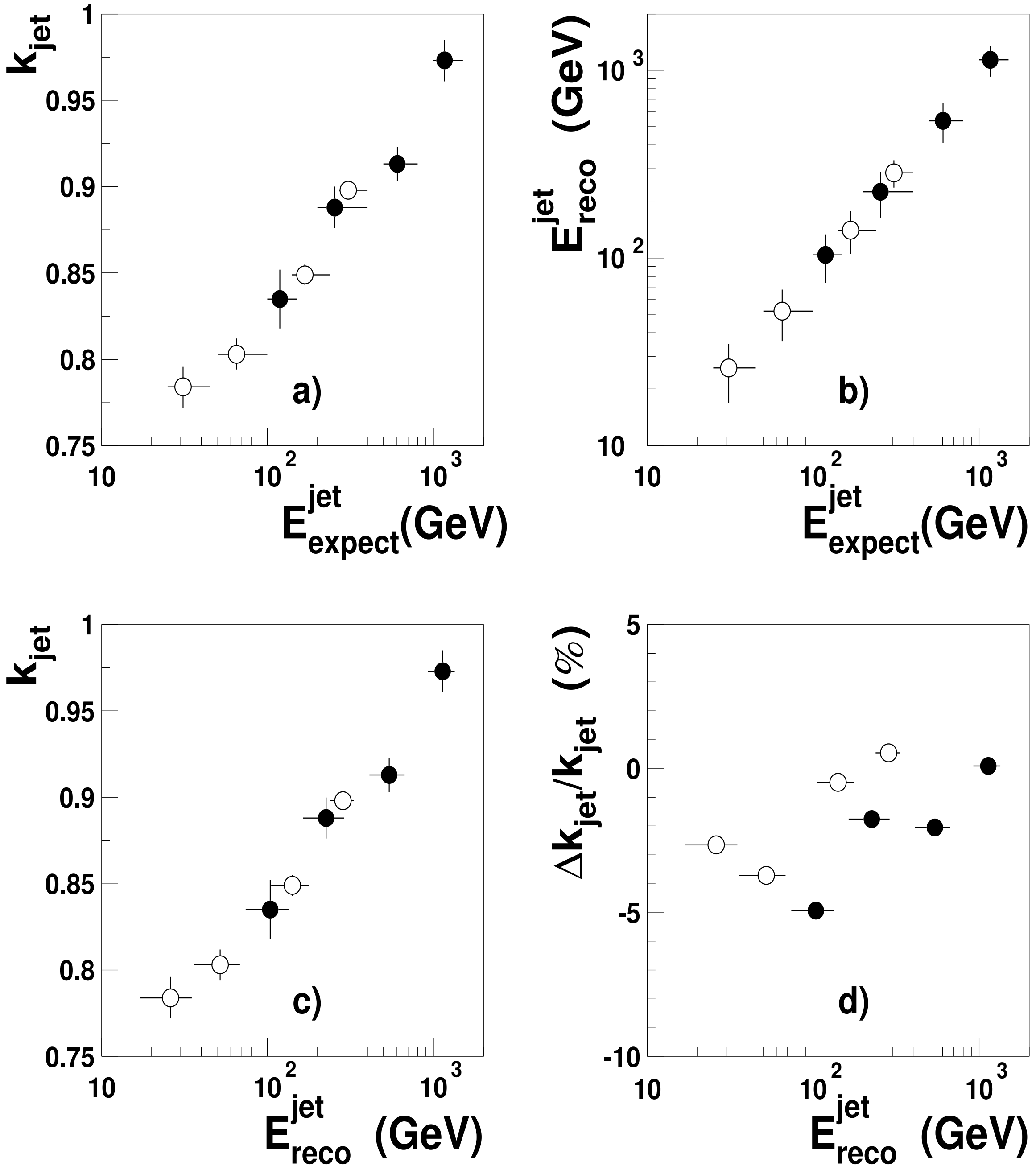

Figure 3: The values of the calibration coefficients calculated in bins of the expected energy of the jet (a); the dependence of the reconstructed jet energy from the predicted one (b); the values of the calibration coefficients in bins of the reconstructed energy of the jet (c) and the systematic errors (d), determined by a difference of k_{jet} with values of calibration coefficients found from spectra of the $E^{jet}_{Treco}/E^{jet}_{Tptcl}$ ratio. The "soft" selection case is considered. White circles correspond to values of $|\eta_{jet}| < 1$, black circles correspond to $1.5 < |\eta_{jet}| < 2.5$.

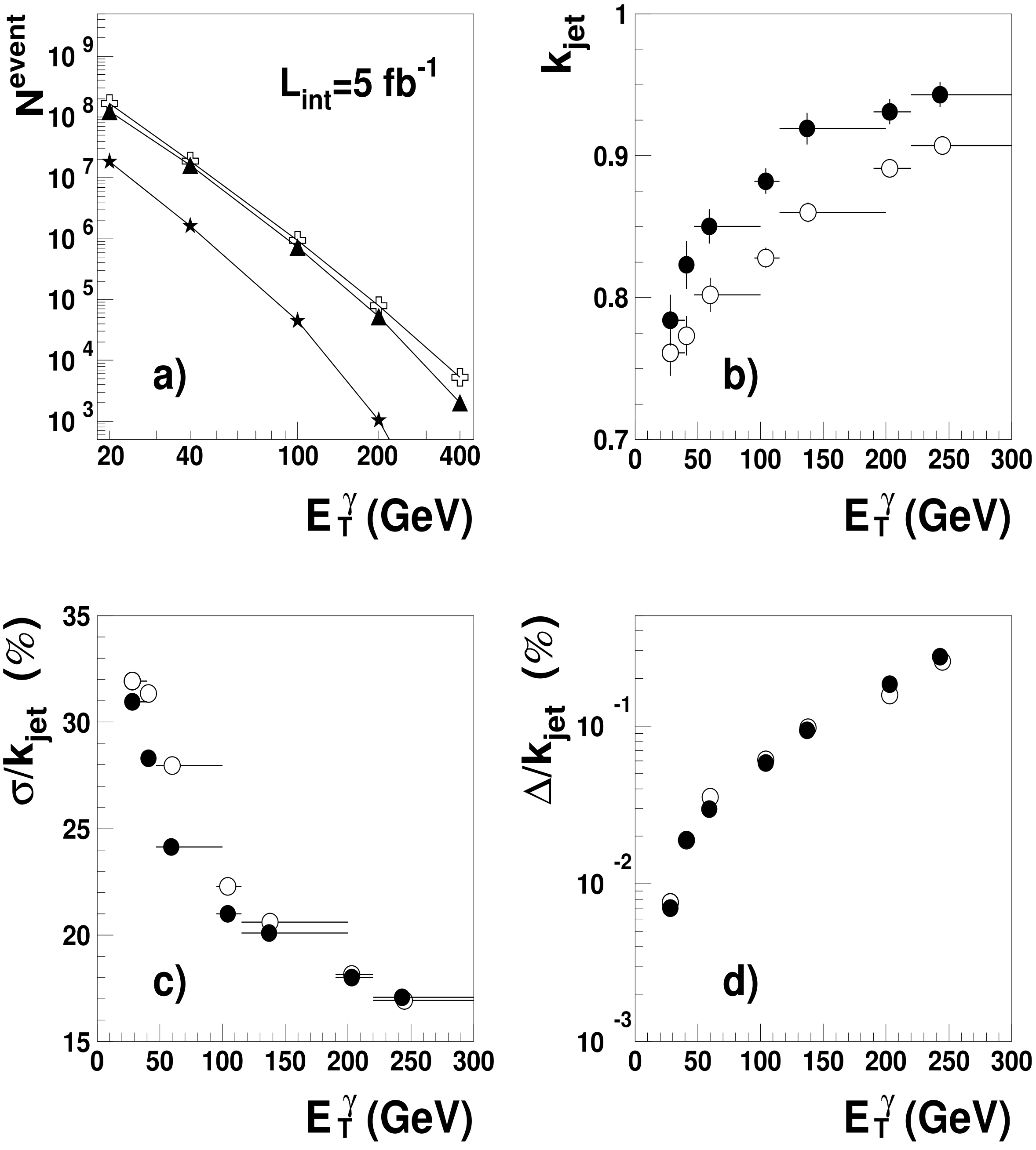

Figure 4: The estimation of the errors for the "soft" selection: a) the numbers of "$\gamma + jet$" events in the intervals of (E_T^γ, ∞) for the three months of work of setup at luminosity $2 \cdot 10^{33} cm^{-2} s^{-1}$ with the direct photons reconstructed in the electromagnetic calorimeter and with jets in the barrel of a hadron calorimeter (crosses), in the endcap of the hadron calorimeter (triangles) and in the forward calorimeter (star); b) calibration coefficients; c) σ of gaussian part of $E_{Treco}^{jet}/E_{Treco}^{\gamma}$ distributions; d) the values of $\Delta = \sigma/\sqrt{N}$, where N is numbers of events in bins of the size $E_T^\gamma/10$. White circles correspond to values of $|\eta_{jet}| < 1$, black is $1.5 < |\eta_{jet}| < 2.5$.

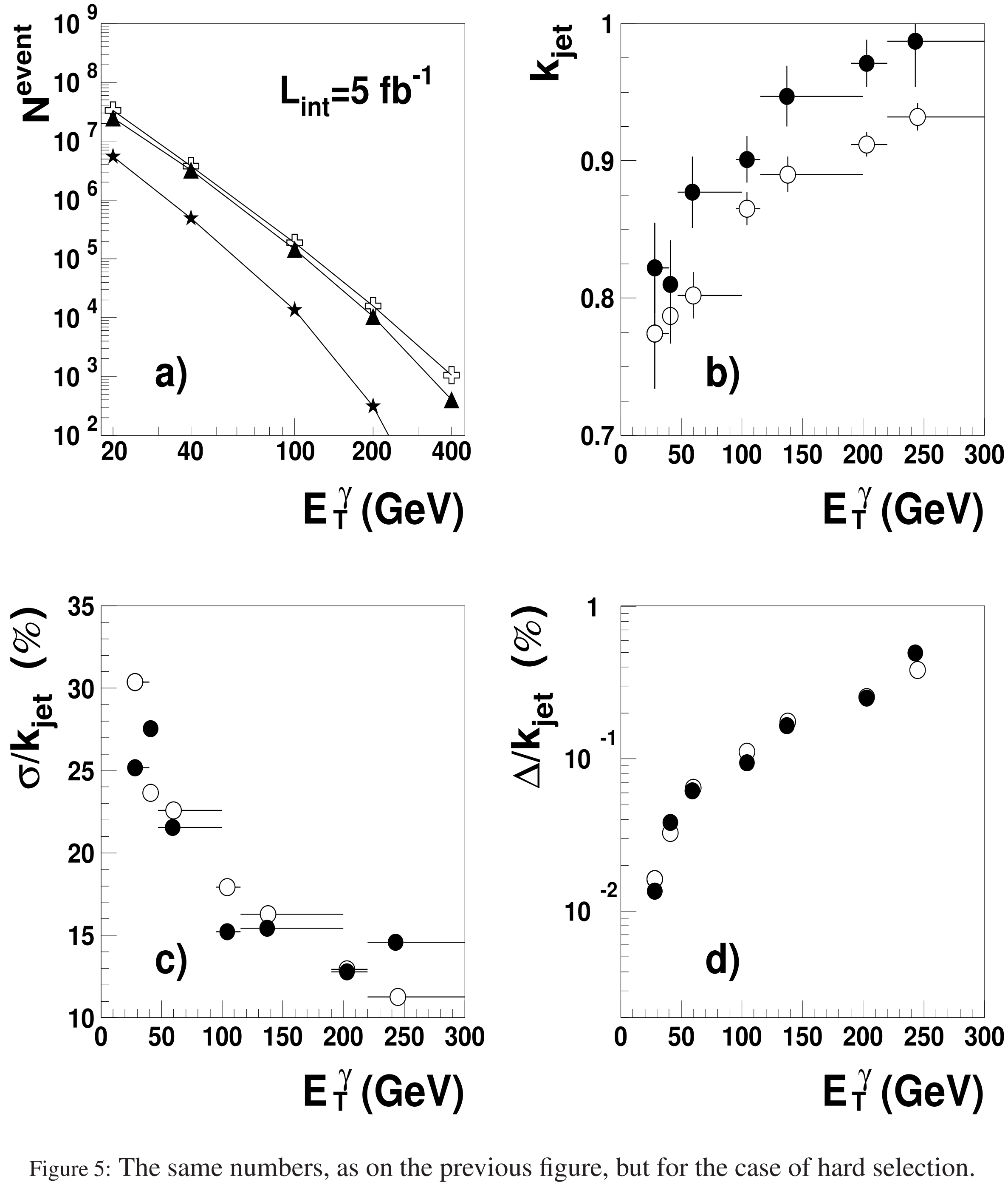

Figure 5: The same numbers, as on the previous figure, but for the case of hard selection.