γ–Jet Studies for JES

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Introduction

- Particle level or true jet energy from measured jet energy

$$E_{\rm jet}^{\rm ptcl} = \frac{E_{\rm jet}^{\rm meas} - E_{\rm O}(\mathcal{R}, \eta, \mathcal{L})}{R_{\rm jet}(\mathcal{R}, \eta, E) S(\mathcal{R}, \eta, E)}$$

- R_{jet} term (energy response)
  - function of jet energy after offset subtraction
  - second order dependence on jet algorithm cone size $\mathcal{R}$
  - dependent on detector pseudorapidity
- Determination of jet response
- Response dependencies

γ+jet Method

- Direct measurement: Conservation of p_T in photon+jet events
- Definition:
  - $\rightarrow$ 1 photon balanced in p_T by 1 (or more) jets
  - $\rightarrow$ using $\not\!\!E_T$ present in the event, defined as

$$\vec{\not\!\!E}_T = -\left(\sum_i E_{x_i}, \sum_i E_{y_i}\right)$$

- ideal case
  $\not\!\!E_T \neq 0 \Rightarrow$ presence or ν's & high-p_T μ's
- real Detector
  $\not\!\!E_T \neq 0$ measures the overall imbalance of E_T in Calorimeter

MPF Technique

"using this transverse energy *imbalance*, R_{jet} response is measured relative to precisely known γ response "

In γ-jet events:

Particle level or True γ and recoil E_T satisfy

$$\vec{E}_{T\gamma} + \vec{E}_{T\text{recoil}} = 0\,. \tag{1}$$

Or in real world

$$R_{\text{em}}\vec{E}_{T\gamma} + \quad R_{\text{recoil}}\vec{E}_{T\text{recoil}} \quad = -\vec{\not{E}}_T$$

(For γ to be EM Scale corrected $R_{\text{em}} = 1$)

$$\begin{aligned}
\vec{E}_{T\gamma} + R_{\text{recoil}}\vec{E}_{T\text{recoil}} &= -\vec{\not{E}}_T \Rightarrow \\
E_{T\gamma} + R_{\text{recoil}}\hat{n}_{T\gamma}\cdot\vec{E}_{T\text{recoil}} &= -\hat{n}_{T\gamma}\vec{\not{E}}_T \Rightarrow \\
1 + R_{\text{recoil}}\frac{\hat{n}_{T\gamma}\cdot\vec{E}_{T\text{recoil}}}{E_{T\gamma}} &= -\frac{\hat{n}_{T\gamma}\vec{\not{E}}_T}{E_{T\gamma}}\,.
\end{aligned}$$

MPF contd. ...

using (1), we have

$$\begin{aligned} R_{\text{recoil}} &= 1 + \frac{\vec{\not{E}}_T \cdot \hat{n}_{T\gamma}}{E_{T\gamma}} \\ &= 1 + MPF \end{aligned}$$

→ MPF: **M**issing E_T **P**rojection **F**raction

→ $\vec{\not{E}}_T$ is the missing E_T after Photon correction

- In γ-jet two body process with no offset and showering $R_{\text{recoil}} \Rightarrow \frac{E_{\text{jet}}^{\text{meas}}}{E_{\text{jet}}^{\text{ptcl}}}$
- Otherwise R_{recoil} is R_{jet}, the energy response of the Calorimeter to jets (jet → the leading jet and $\Delta\phi_{\gamma\text{jet}} \approx \pi$)

Energy Estimator: E'

▷ R_{jet} is measured using conservation of E_T (or p_T)

▷ Response is dependent on jet energy rather than E_T:

- Particle composition of jets &
- e/π are energy dependent

▷ Measure response as a function of energy (i.e. $E_{\text{jet}}^{\text{meas}}$)

▷ Such measurement introduces biases:

a. Trigger & reconstruction thresholds

b. Photon production cross section

c. Photon and jet energy resolution

Biases and smearing effects → Eliminated by binning response in a better measured quantity, correlated with $E_{\rm jet}^{\rm meas}$, E' – the jet energy estimator.

$$E' = E_{T\gamma} \cdot \cosh(\eta_{\rm jet})$$

→ E' would be particle energy of jet in case of two body γ-jet process

→ $E_{T\gamma}$ (after EM correction) represents parent parton E_T

→ both are well measured

- dependence of $R_{\rm jet}$ on $E_{\rm jet}^{\rm meas}$ by measuring average $E_{\rm jet}^{\rm meas}$ in each E' bin

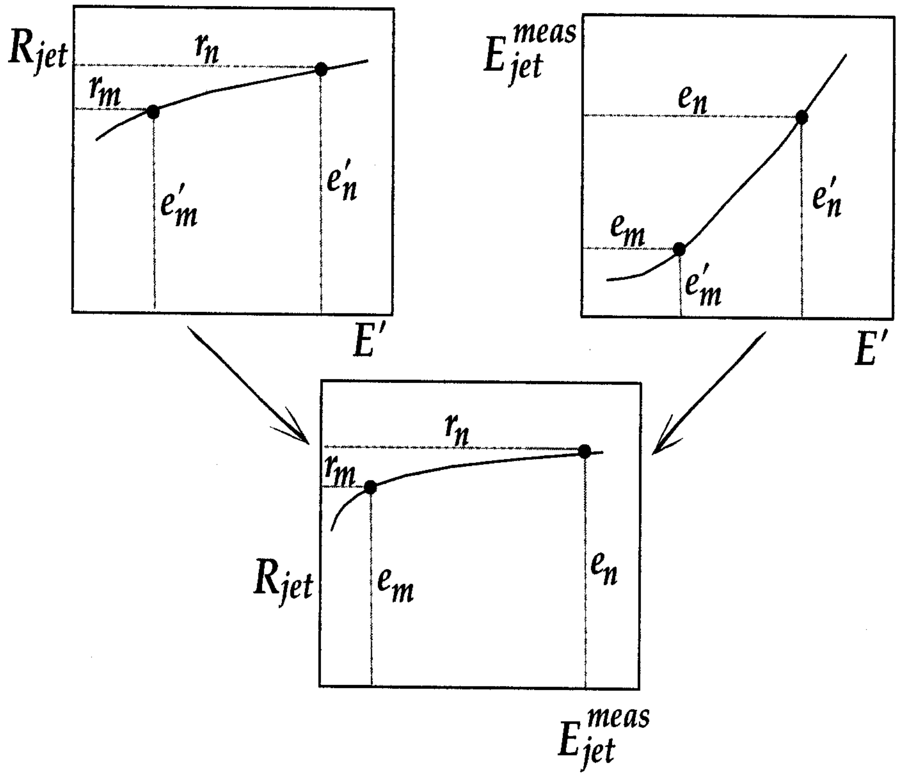

Figure 1: E' mapping to $E_{\rm jet}^{\rm meas}$.

Test of MPF Method

- using collider γ-jet data and a **parametric simulation**
  - simulation generates γ-jet events according to a cross section with a given E_T dependence
  - energies of γ and the jet are smeared and scaled with energy resolutions and responses measured from data
- simulation results
  - show E' controlling the smearing effects (from jet energy resolution)
  - unbiased measurement of jet energy response (from E_T dependence of photon cross section)

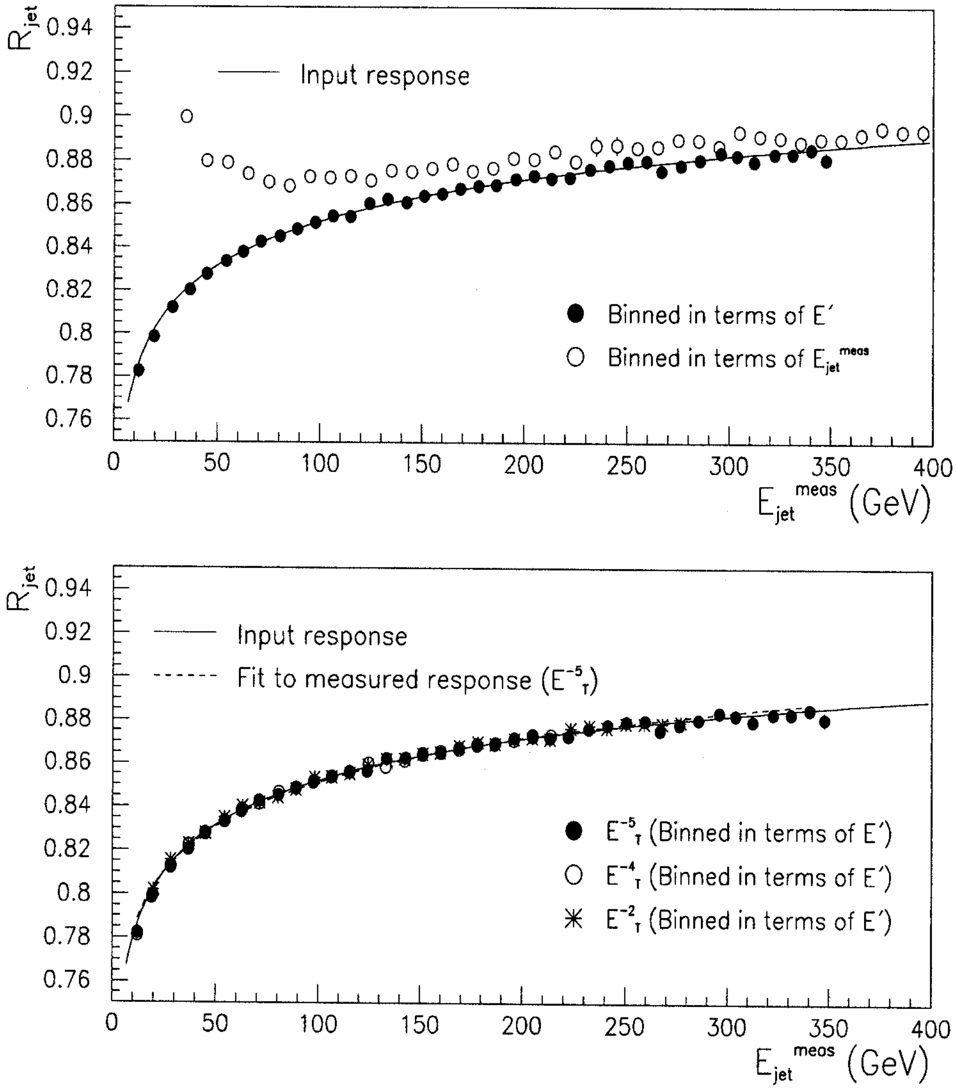

Figure 2: Parametric simulation of the $R_{\rm jet}$ measurement.

Response Dependencies

Photon Sample Selection

- γ-jet sample had direct photon plus events with 1 jet contained in EM Cal.
- General cuts:
  - 1 or more EM cluster
  - no events with noisy cells
  - Main Ring events removed
  - veto bremsstrahlug photons from cosmic muons
  - require $|z| < 70$ cm
  - $|\eta| < 1$ or $1.6 < |\eta| < 2.5$ for EM (detector)
  - at least 1 jet, leading jet $|\eta| < 0.7$ for CC and $1.6 < |\eta| < 2.5$ for EC

- Instrumental background
  A γ or a pair of photons from highly EM jets not isolated from hadronic energy.
  - fraction of cluster E_T in the EM layers, EMF
  - cluster isolation, f_{iso}:

$$f_{iso} = \frac{E_{tot}(R = 0.4) - E_{em}(R = 0.2)}{E_{em}(R = 0.2)}$$

  - total charge in transition radiation detector
  - presence of a track
  - ionization in the central tracking chambers
  - above 3 used in conjunction with $E_{T\gamma} > 25$ GeV if $\not{E}_T / E_{T\gamma} > 0.65$ otherwise only 1 required.

- Physics background
  Drell-Yan, $Z \to e^+e^-$ and $W \to e\nu$ processes

0.7% and $\lesssim 0.5\%$ are the remaining biases on $R_{\rm jet}$ from Inst. and Phys. backgrounds respectively.

- Topology Cuts
  - $R_{jet} = R_{recoil}$ is exact for 2 body process only
  - Events containing more than 1 reconstructed jets along with clusters not reconstructed as jets $\rightarrow$ systematic error to response
  - requiring $\Delta\phi > 2.8$ between photon and leading jet cuts on bias
  - $\approx 0.5 - -1\%$ bias remains
- Multiple Interaction Cuts
  - additional interactions reduce the accuracy of the vertex determination

- higher jet pseudorapidity yields large E' and lower jet E_T
- $\not\!\!E_T$ increases in jet direction and lowering the measured response
- studied using low luminosity sample with single interaction cut
- residual luminosity bias to response after this is estimated $< 0.25\%$ by measuring response as a funcion of luminosity for various E' bins in CC and EC

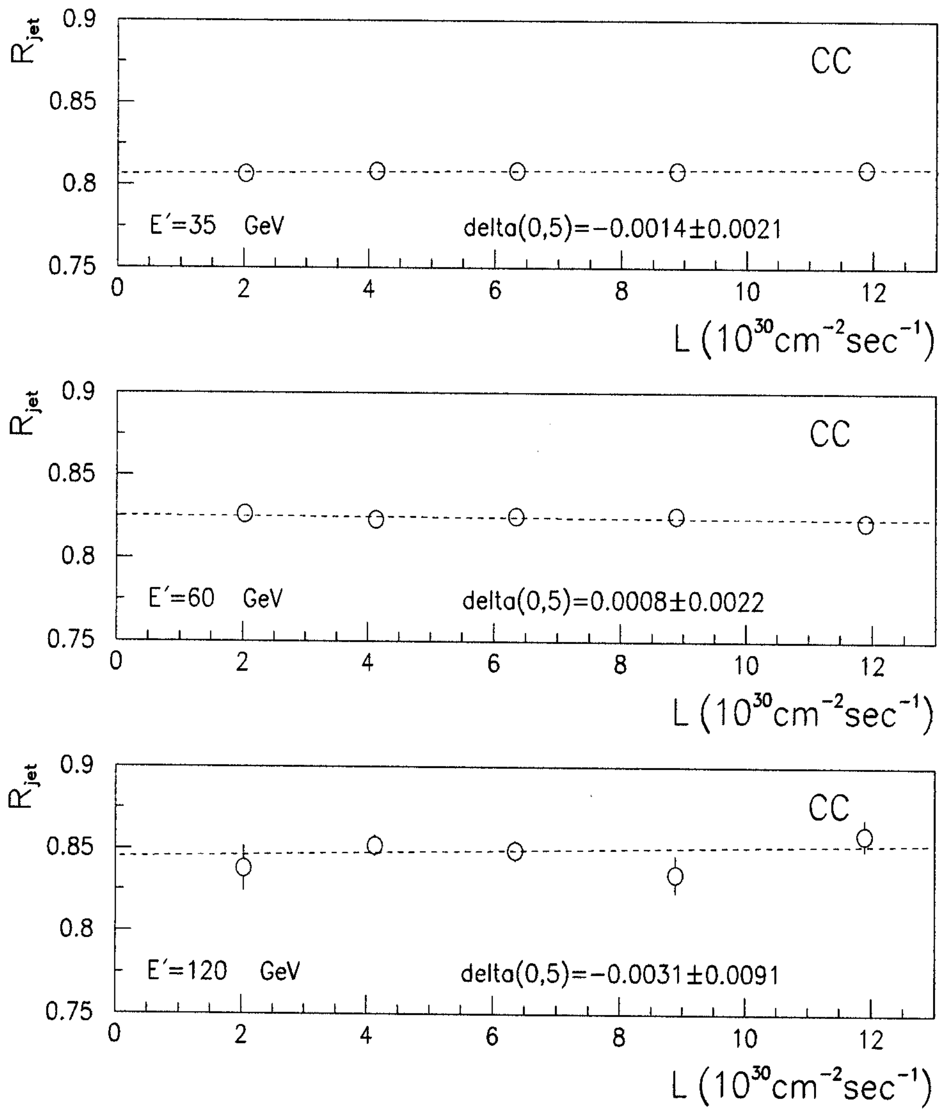

Figure 3: Response as a function of luminosity for CC jets.

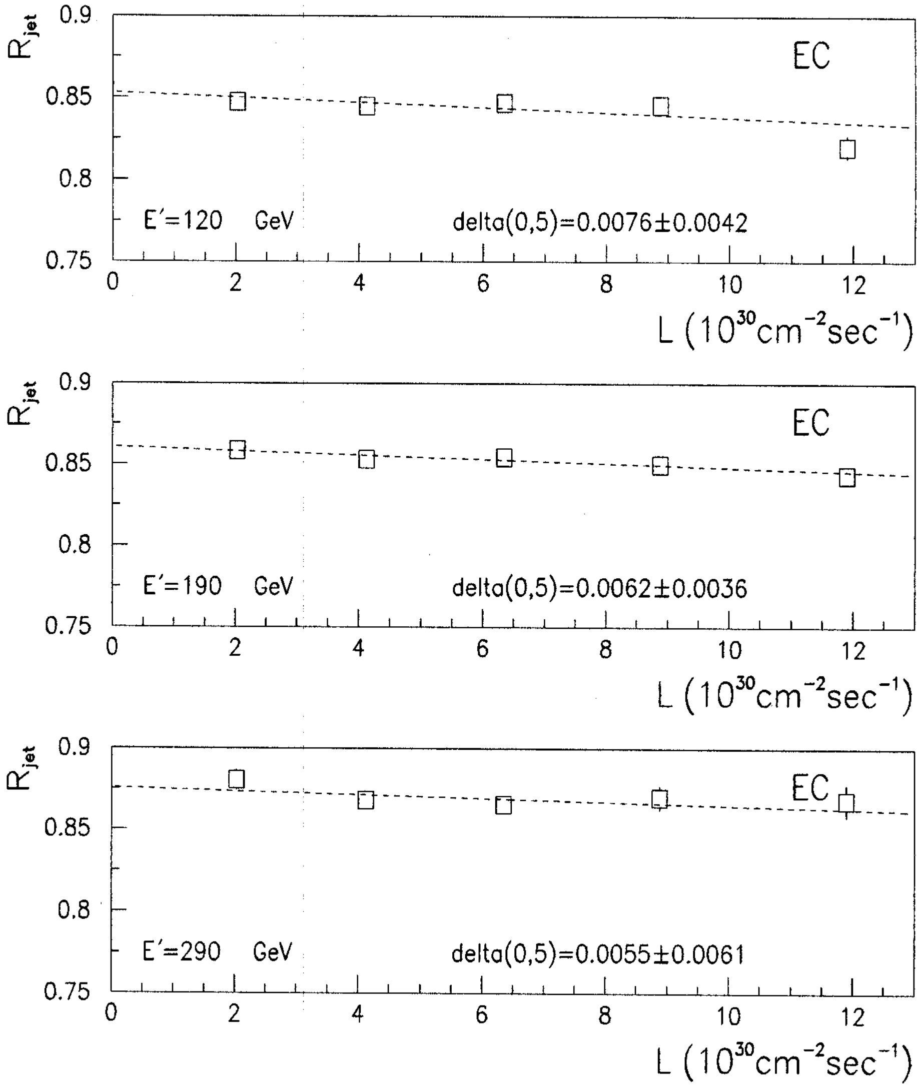

Figure 4: Response Vs luminosity for EC jets.

Rapidity & Reconstruction Dependence

- need accuracy in JES at all rapidities so η dependent correction is derived
- cryostat factor and IC corrections applied to the jet energy and the event $\not{E}_T$
- since corrections are done to physics objects, not possible to recalculate the event $\not{E}_T$

$$\vec{\not{E}}_T^{\,\mathrm{cr}} = \vec{\not{E}}_T^{\,\mathrm{ms}} + \sum_{\gamma}\left(\vec{E}_{T\gamma}^{\,\mathrm{ms}} - \vec{E}_{T\gamma}^{\,\mathrm{cr}}\right) + \sum_{\mathrm{jet}}\left(\vec{E}_{T\mathrm{jet}}^{\,\mathrm{ms}} - \vec{E}_{T\mathrm{jet}}^{\,\mathrm{cr}}\right)$$

- $\not{E}_T$ correction depends on the jet algorithm as reconstructed objects are used (large cone $\mathcal{R} = 0.7$ algorithm used for)

- Cryostat Factor & IC Correction
  - cryostat factor $F_{cry} = R_{jet}^{EC} / R_{jet}^{CC}$
  - F_{cry} measured for the CC and EC data overlap
  - $F_{cry}^{N} / F_{cry}^{S} = 0.997 \pm 0.003$ show F_{cry} same for both EC's within errors
  - independence of F_{cry} on E' allows using EC data to extend the range of CC response measurement
  - IC covers $0.8 <\mid \eta \mid< 1.6$ and least instrumented region of Cal.
  - IC response correction is measured by a smooth interpolation through it using R_{jet} vs η measurement in CC-EC from γ-jet and jet-jet events

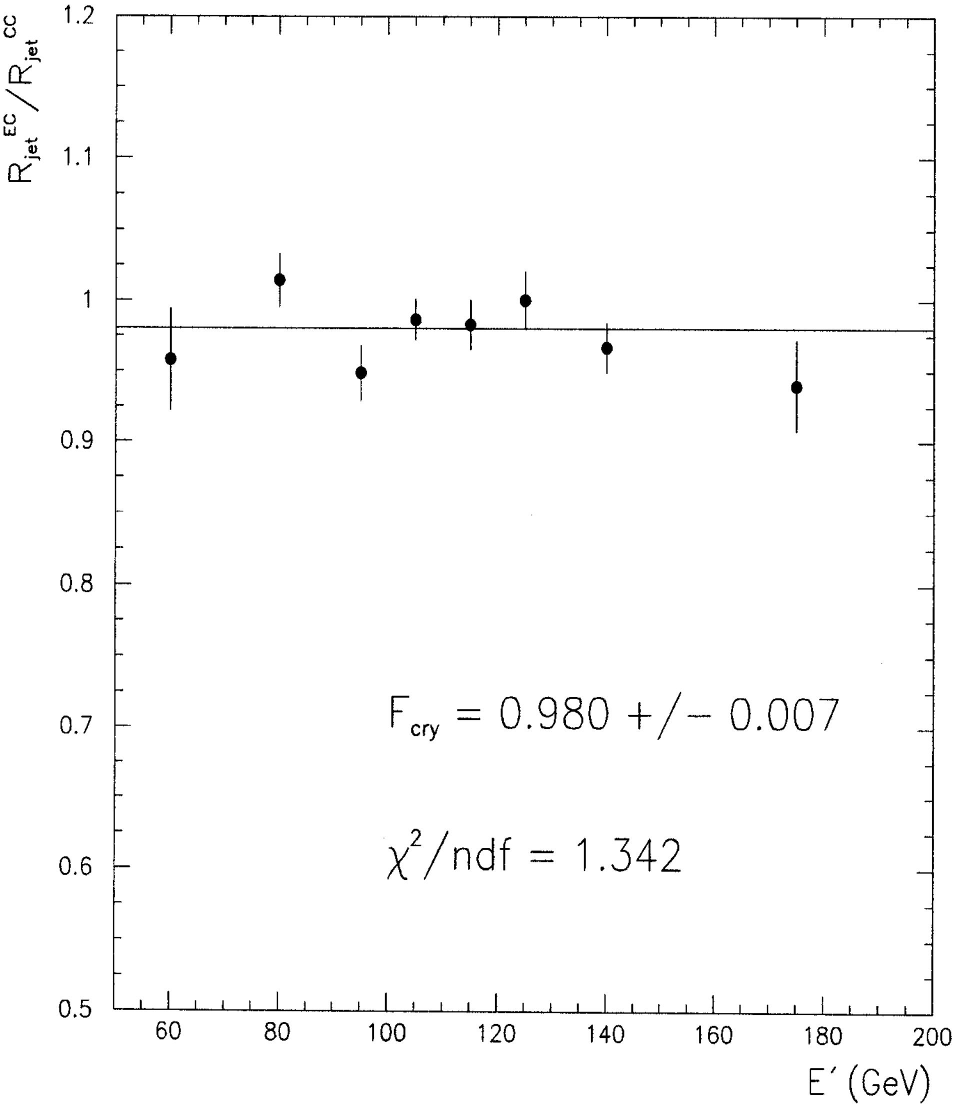

Figure 5: Cryostat factor Vs E'.

Energy Dependence

We know R_{jet} is energy dependent.

- for $E' \lesssim 100$ GeV R_{jet} is determined from low E_T photons and CC jets ($|\eta| < 0.7$)
- For high $E' (\gtrsim 100\text{GeV})$, R_{jet} is measured from EC jets (after F_{cry} and η corrections)
- Low-E_T Bias arising from reconstruction and resolution effects
  - jet reconstruction E_T threshold is 8 GeV with jet fractional E_T resolution about 50%
  - low E_T jets fluctuate to higher values
  - jets which fluctuate below 8 GeV are not reconstructed so this biases the average jet E_T to higher values $\Rightarrow$
  - lower $\not\!\!E_T$ values thus biasing the response to higher values

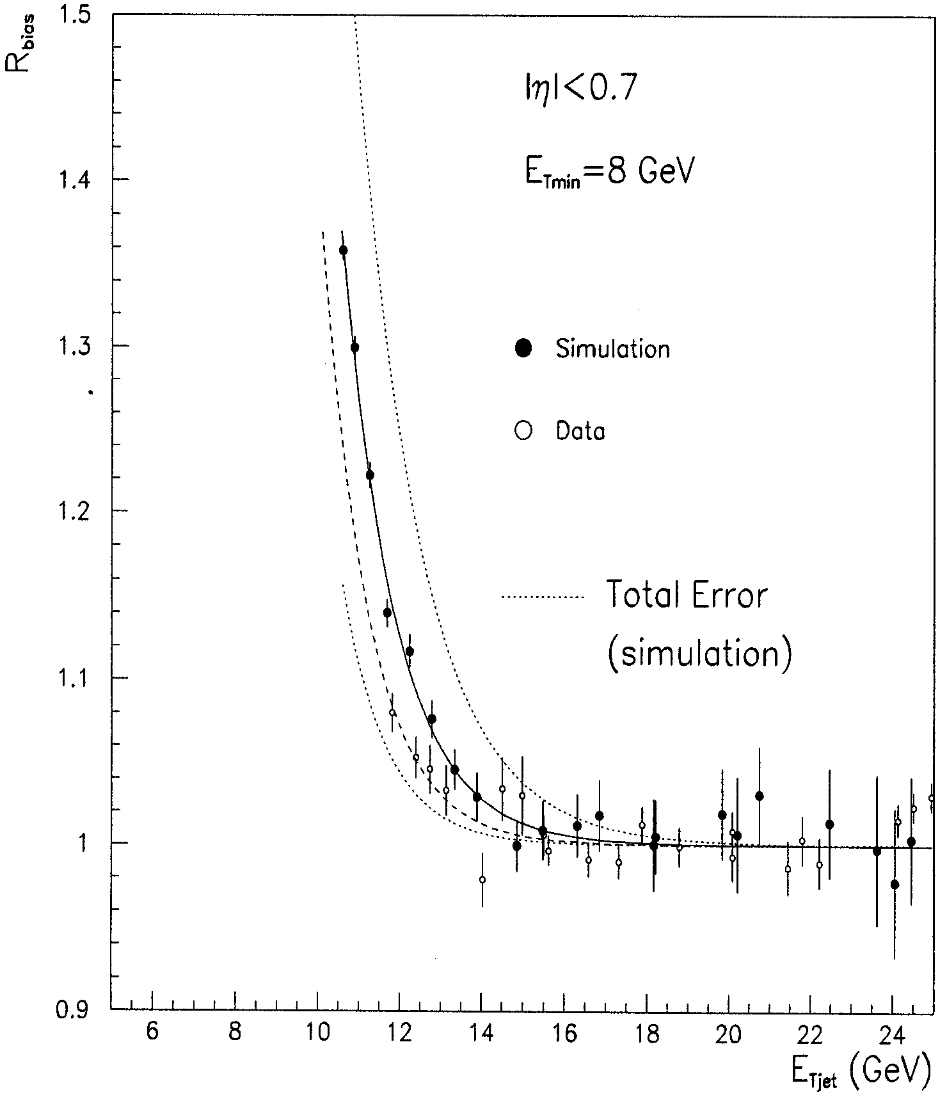

Figure 6: Low-E_T bias Vs E_{Tjet}.

- this bias is measured using the photon data sample:

$$R_{bias} = \frac{R_{jet(\geq 1)}}{R_{jet(nojet)}}$$

- Response vs E'
  - after low-E_T bias, cryo factor and IC corrections $R_{\rm jet}$ is recalulated as a function of E'
  - mapping is obtained between E' and the av. jet energy.

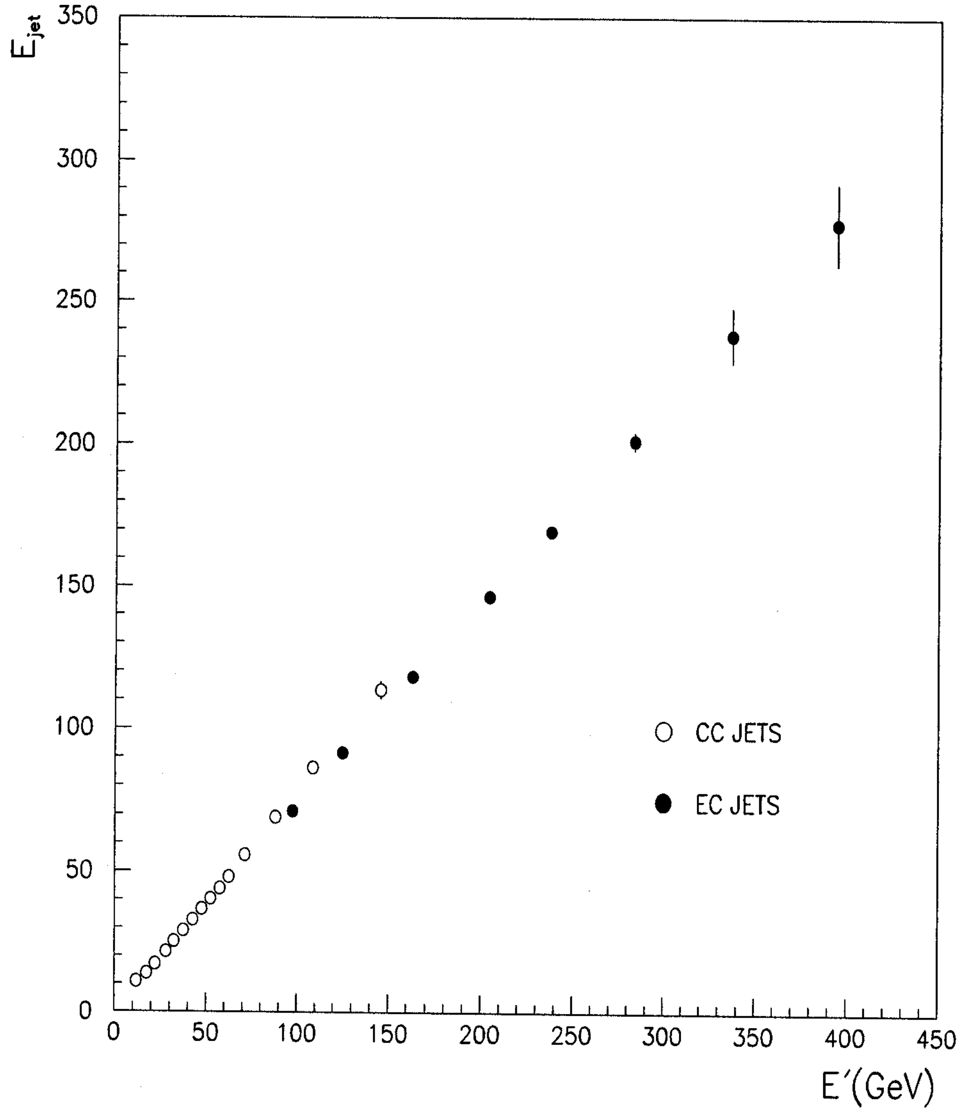

Figure 7: E_{Tjet}^{meas} versus E' for 0.7 cone.