Jet energy correction with response subtraction algorithm using charged tracks.

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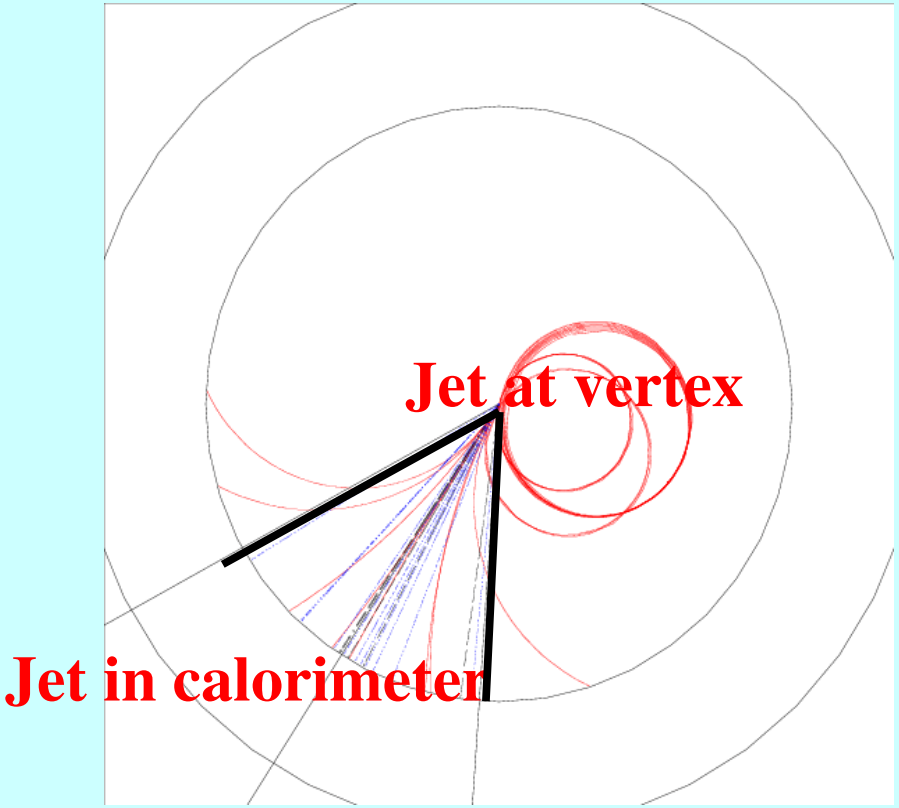
Definitions

Generated jet is considered as a set of particles at the vertex level in the definite cone R_{cone}^{gen}

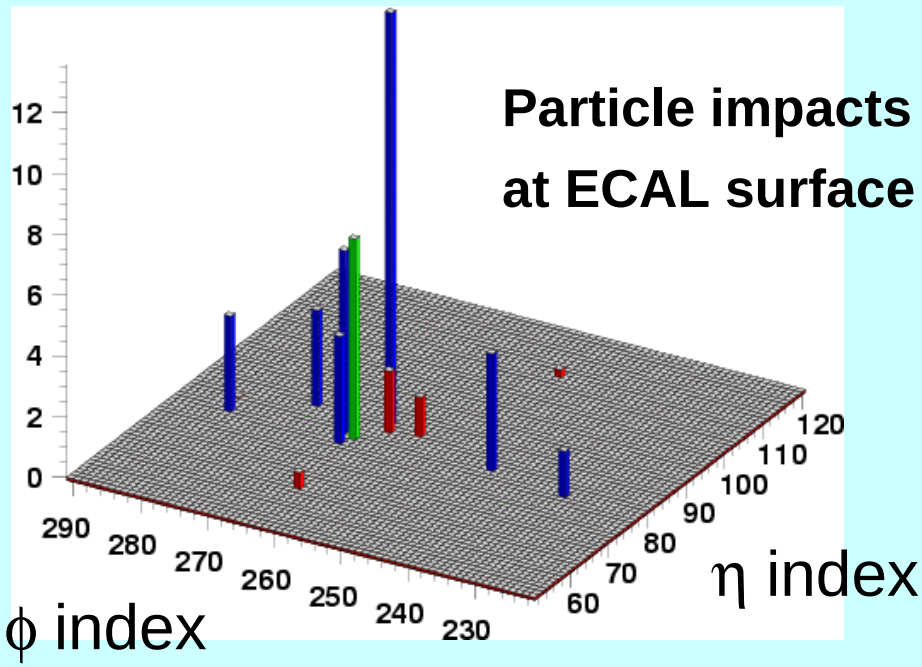
Calorimeter jet is considered as a set of calorimeter towers in the definite cone at the ECAL surface R_{cone}^{calo}

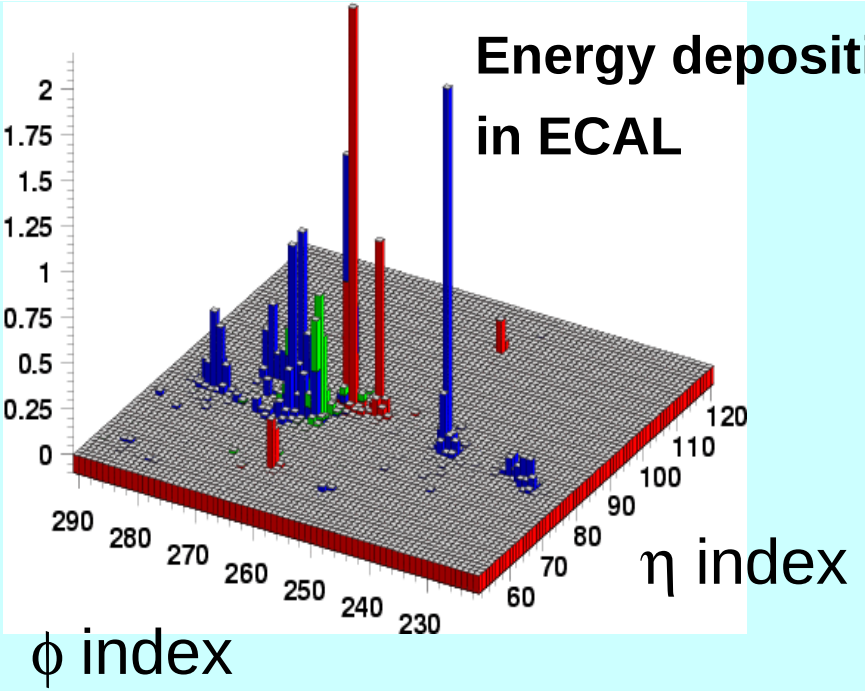
In current study: $R_{cone}^{gen} = R_{cone}^{calo}$

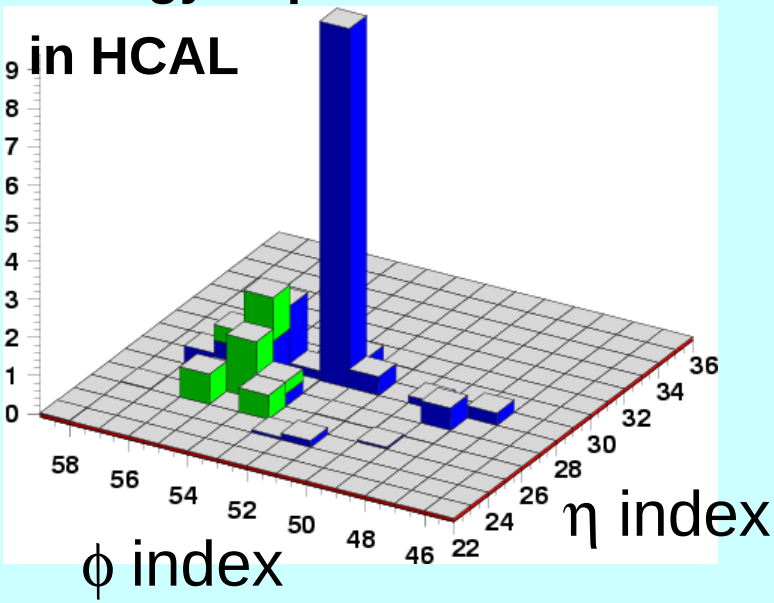
JPT correction: from calorimeter jet to particle level jet



Jet view in CMS calorimeters







45 GeV jet (A.Nikitenko) without Noise/thresholds

Red – e/gamma

green – neutral hadrons

blue – charged hadrons

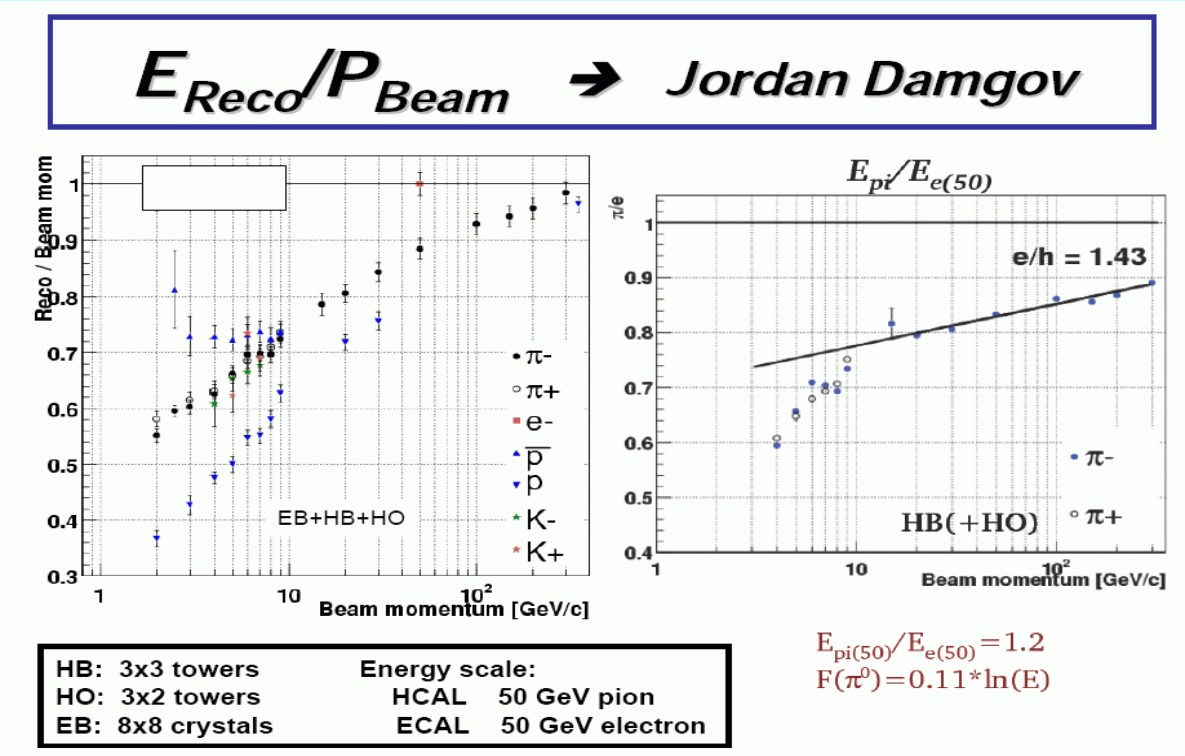
No thresholds/no noise

Detector effects

Magnetic field: charged particles with p_T<0.8 GeV/c -> looper in barrel, charged particles with p_T<1.6GeV/c deflects by 0.5 radians.

Electronic noise and thresholds applied to calorimeter readouts

Longitudinal leakage for high-p_T jets, shower size, cracks



Non-linearity of calorimeter response:

different response to electrons and hadrons, non-linear response to hadrons.

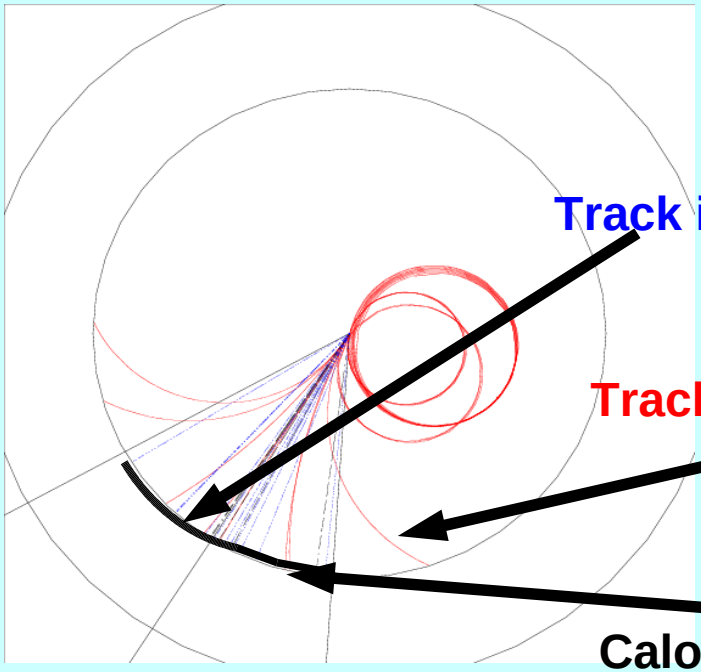
jet have both hadronic and e/γ components

Method description (I): general description

Jet energy=Response_charged+Response (e/γ)+Response (neutral)

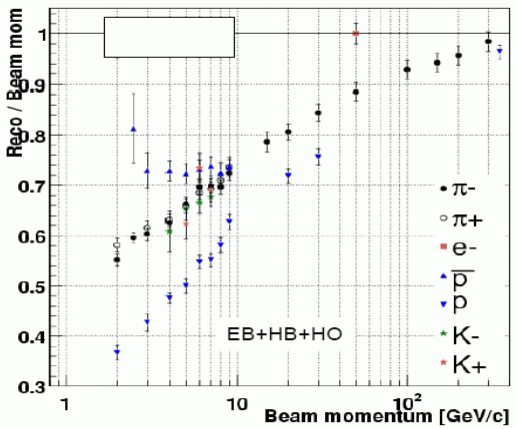
- **Replace response of charged hadron of jet in reconstruction cone with energy of charged from Tracker .**
- **Add tracks out of reconstruction cone at ECAL surface.**

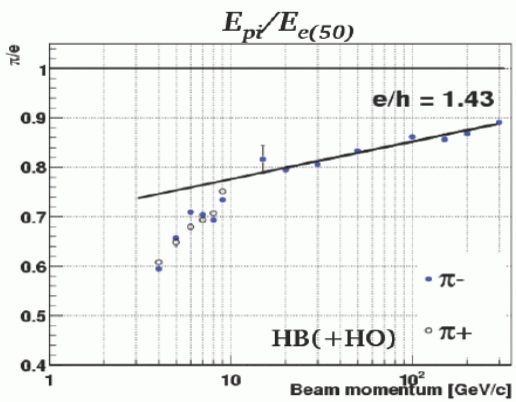
Jet energy = sum(Pin) + sum(Pout)+ Response (e/γ+neutral)_ECAL + Response (neutral)_HCAL



Method description (II) : expected response

E_{Reco}/P_{Beam} ➔ Jordan Damgov





HB: 3x3 towers	Energy scale:
HO: 3x2 towers	HCAL 50 GeV pion
EB: 8x8 crystals	ECAL 50 GeV electron

$E_{pi(50)}/E_{e(50)} = 1.2$
$F(\pi^0) = 0.11 * \ln(E)$

Expected response of charged particles can be calculated in different ways (CMS NOTE 2002/036):

e/π technique (test beam),
library of responses (isolated particles),
matched clusters (combination of Pflow and JPT)

Rates for isolated particles (low momentum)

Min bias:L= $2x10^{33}cm^{-2}s^{-1}$

High momentum particles

Purity = 96%

P < 10 GeV/c, purity = 96.2%	Rate of isolated particles	Number of calorimeter towers	Time to collect 1000 iso.particles in each tower
barrel $0 < \|\eta\| < 1.5$	0.20	2448	1.5 days
endcap $1.5 < \|\eta\| < 2.1$	0.04	980	2.5 days

CMS NOTE 1997/039
CMS NOTE-1997/097
to be reestimated in CSA07

Remark: e/π technique (Dan Green, Energy flow in CMS Calorimetry, Fermilab-FN-0709, V.V.Abramov et al, CMS NOTE 2000/003)

Isolated tracks will be done at CAF

Method description (II): concrete description

1) Find jet in calorimeters with iterative cone algorithm and evaluate jet energy with calorimeter response (Rjet).

2) Find tracks in tracker within cone around jet axis (coming from primary vertex).

3) Different treatment for tracks with impact points of reconstructed tracks on ECAL surface:

- Track out of reconstruction cone - add momentum of track to jet response.

  $$E_{jet} = R_{jet} + sum(Pout)$$

- Track in reconstruction cone - add momentum of track to jet response, calculate expected response for this track and subtract it from the jet response.

  $$E_{jet} = R_{jet} + sum(Pin) - sum(R^{expected}_{track})$$

Finally, the jet energy:

$$E_{jet} = R_{jet} + sum(Pout) + sum(Pin) - sum(R^{expected}_{track})$$

Method description (III): statistical errors

The variance after adding out-of-cone tracks:

$$D(E_{jet}) = D(R_{jet}) + sum(D(Pout))$$

The variance after response subtraction:

$$D(E_{jet}) = D(R_{jet}) + sum(D(EC+HC)^{expected}_{track}) + sum(D(Pin))$$

The final variance:

$$D(E_{jet}) = D(R_{jet}) + sum(D(EC+HC)^{expected}_{track}) + sum(D(Pin)) + sum(D(Pout))$$

$sum(D(EC+HC)^{expected}_{track})$ -> 0 with increasing the isolated tracks sample

$sum(D(Pin)) + sum(D(Pout)) << D(R_{jet})$

η-dependence of Resolution(ET):

$Resolution(E_T) = sqrt(Resolution(E) + ctg^2(\theta)*D(\theta))$

After JPT correction the resolution is improved:

$$DE_{jet}/E_{jet} = DR_{jet}/E_{jet} < DR_{jet}/R_{jet}$$

-> first term of $Resolution(E_T)$ decreases (play the main role in barrel).

The correction of jet directions leads to decreasing of $D(\theta)$

Method description (IV): systematical errors

$dE_{syst}^{1}(E_{jet}^{true}) = sum(EC+HC)^{expected}_{track} - (EC+HC)\ (charged\ hadrons)$

depends on the quality of parametrization of expected charged particle response and on the quality of the track reconstruction (efficiency, purity, accuracy, momentum cut).

$dE_{syst}^{2}(E_{jet}^{true}) = sum(EC+HC)^{expected}_{neutral_hadron} - (EC+HC)\ (neutral\ hadrons)$

pure MC correction

$dE_{syst}^{3}(E_{jet}^{true}) = E_{jet}^{with\ thrsh} - E_{jet}^{without\ thresh}$

may be corrected with non zero suppressed runs

$dE_{syst}^{4}(E_{jet}^{true})$ **connected with the difference between pions and kaons/protons**

The key of importance is to create the correct particle response parametrization and to estimate tracking inefficiency!

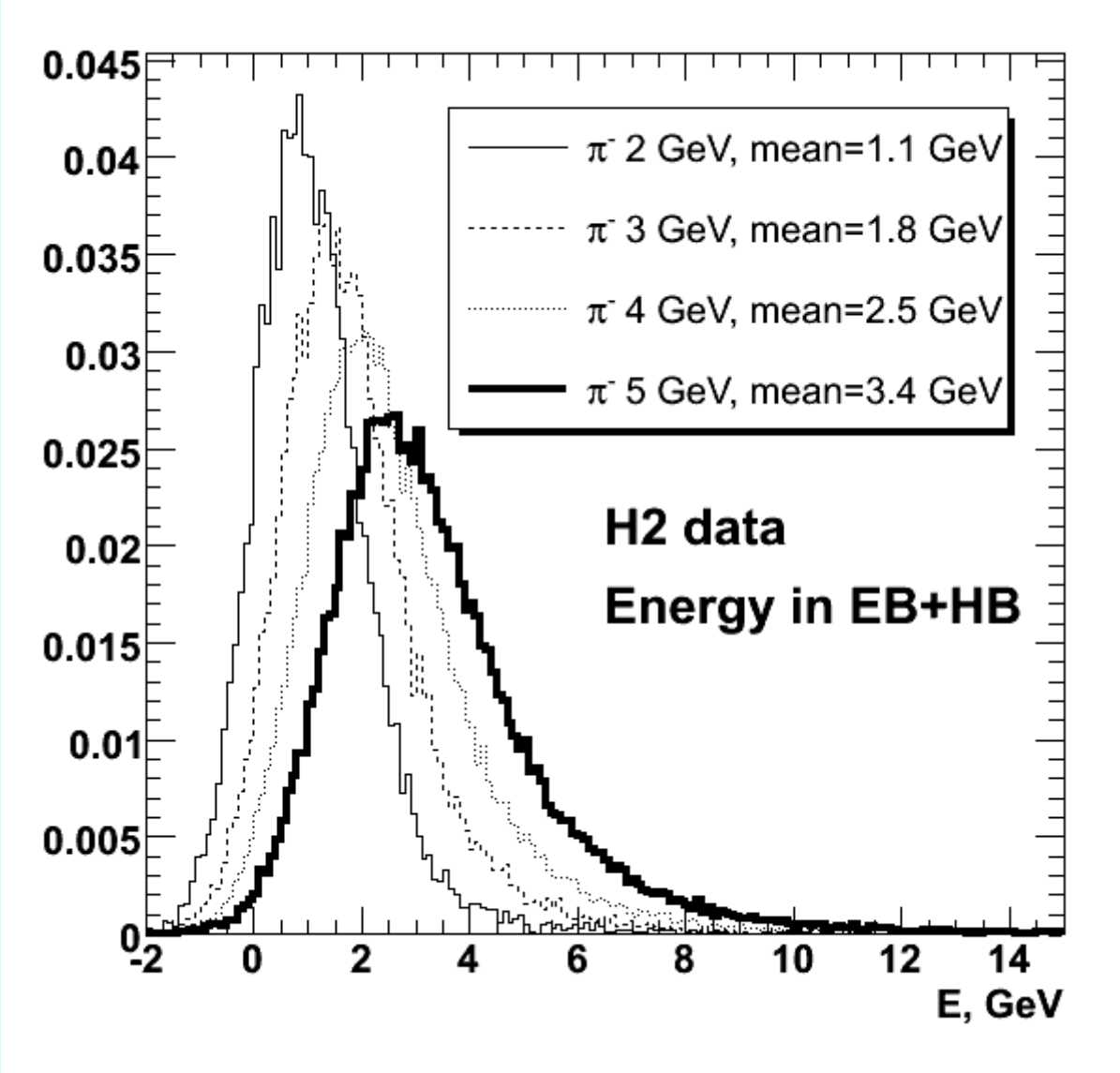
Example I: Jets made from charged pions from H2 test-beam data (A.Nikitenko)

Jet was formed from charged pions (π^-) randomly selected from the data. No zero-suppression/no thresholds during jet reconstruction in test-beam data.

Example I: jets made from charged pions from H2 test-beam data

- **Goals of exercise:**
  - check response subtraction technique of JetPlusTrack algorithm
  - study effect of tracker inefficiency
- Data
  - H2 charged pions (p^-) after data cleaning and particle ID. Many thanks to S. Kunori and H2 TB team for providing asci file with data !
  - ECAL is calibrated with 50 GeV electrons; HCAL is calibrated with 50 GeV pions
  - Energy is collected in 7x7 EB crystals, 3x3 HB towers and 3x2 HO towers (HO was not used here); data are used for beam at ieta=3, iphi=13
  - No zero suppression on cell reco energies is applied

Example I: response of pions from TB for “TB” jets



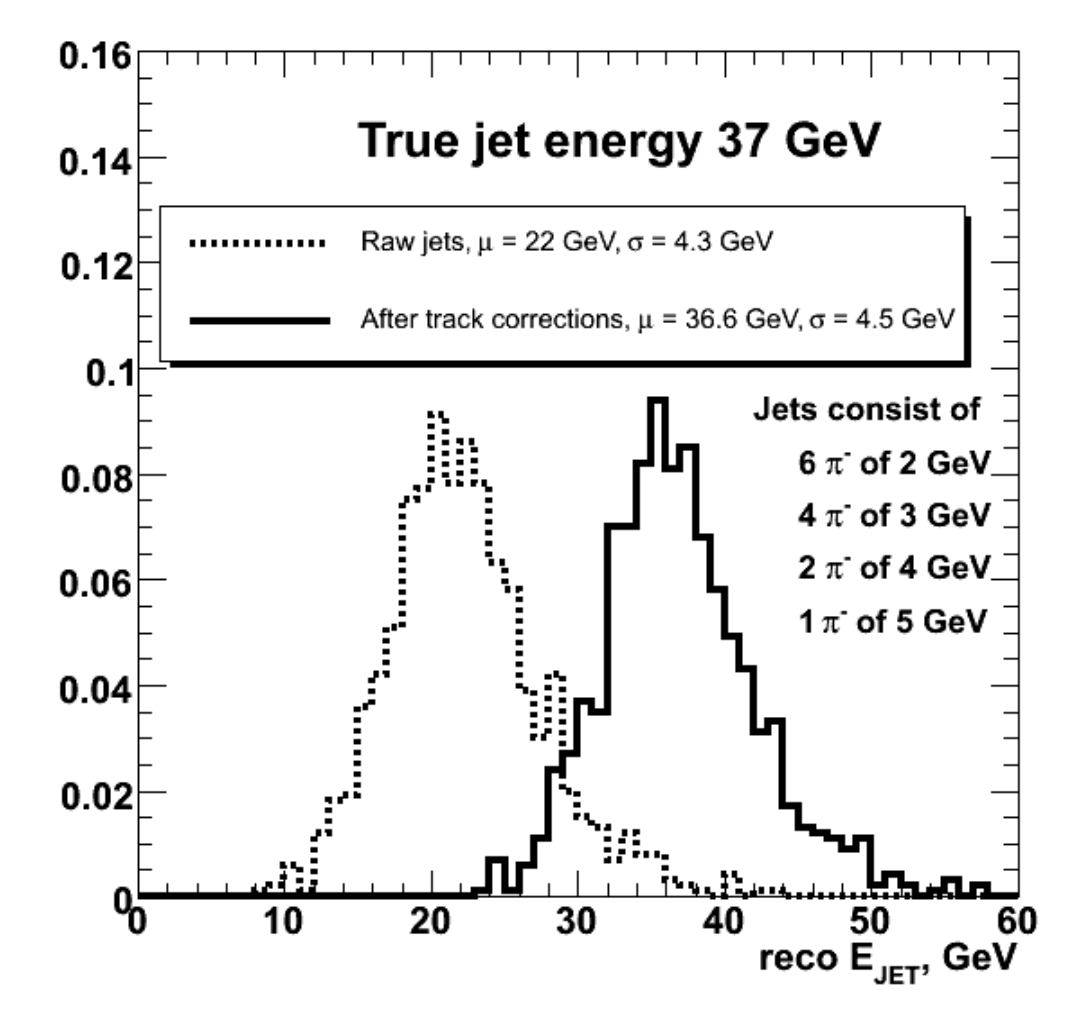
Example I: Raw jet energy and energy after response subtraction

Jet was formed from charged pions (π^-) randomly selected from the data. Number of pions in jet is fixed:

jet consists of
6 pions of 2 GeV
4 pions of 3 GeV
2 pion of 4 GeV
1 pion of 5 GeV

thus true jet energy is 37 GeV

Average particle response (see previous slide) was subtracted from jet raw energy and replaced by track momentum



Example I: Jet resolution

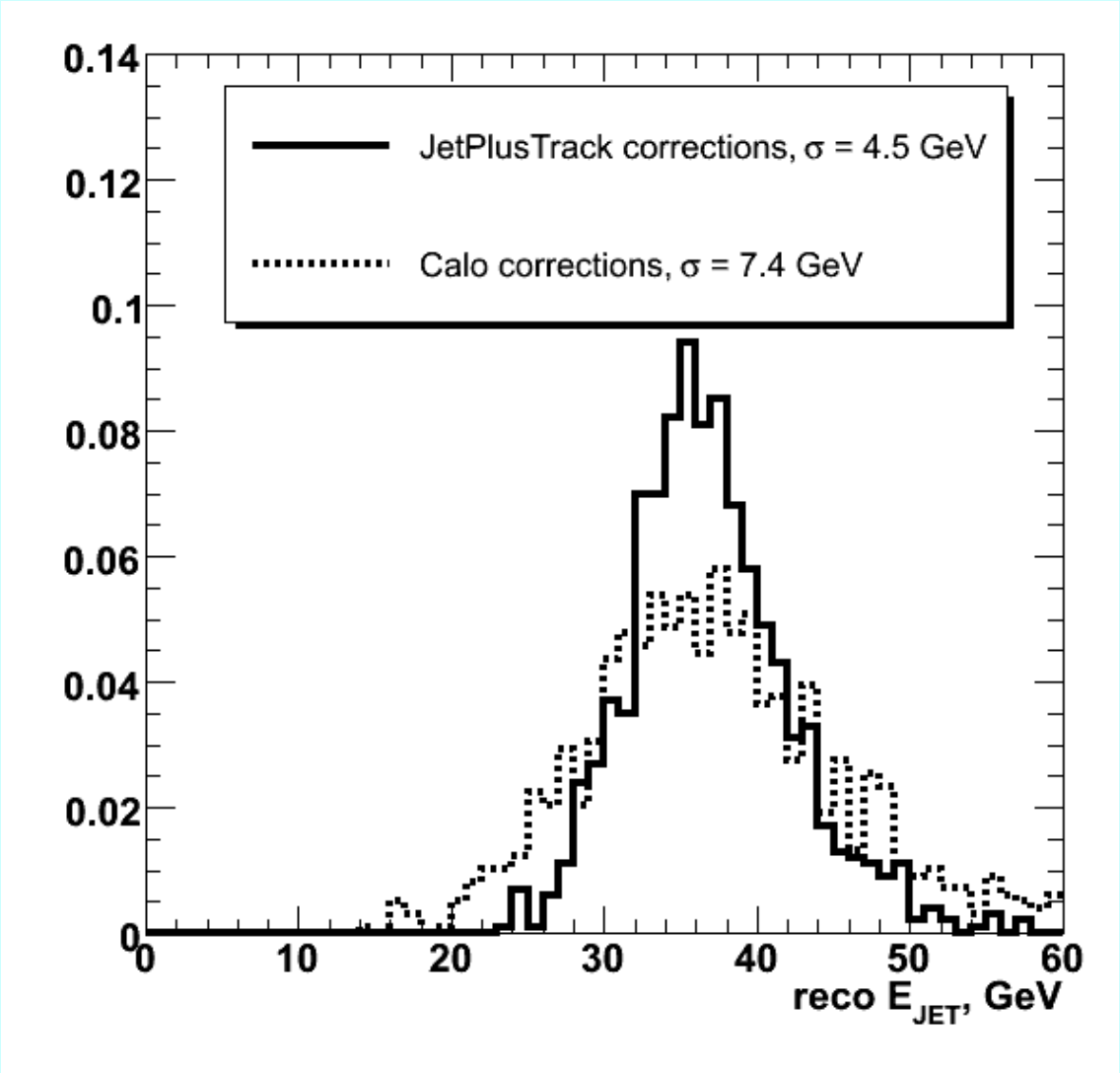
Resolution with JetPlusTrack corrections is improved by 60% in comparison with "calo corrections"

Calo Corrections:

$C = E_{True} / \langle E_{Raw} \rangle$

$C = 37. / 22. = 1.68$

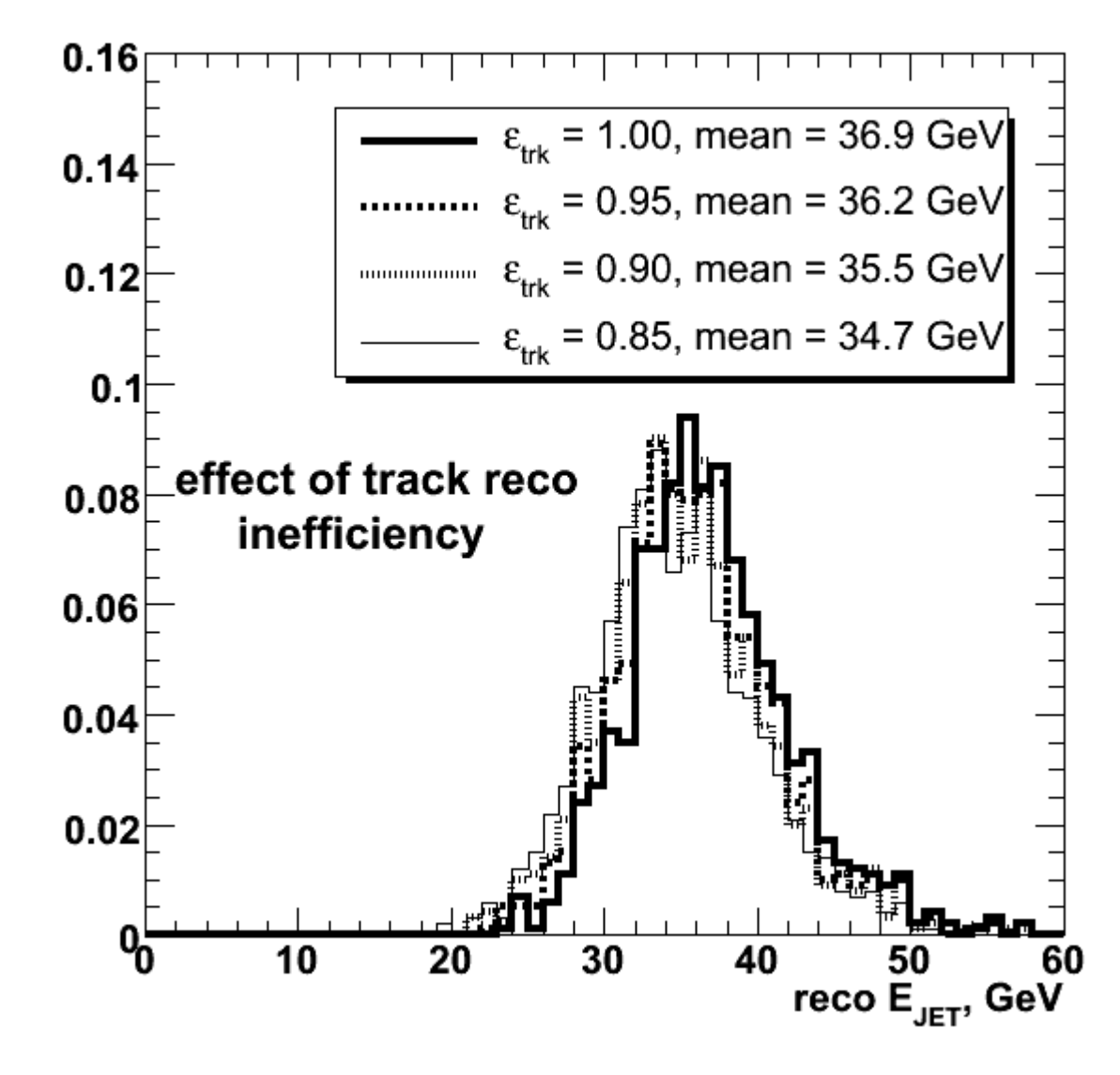
For jets with π^0's smaller improvement is expected



Example I: Effect on track inefficiency on mean jet energy

Effect of tracker inefficiency was studied randomly removing tracks in response subtraction procedure.

When tracker efficiency was varied from 100 % to 85 % with 5 % steps (see plot) the mean jet energy value was reduced by ~ 2 GeV, (which is 5.4 %) for true jet energy 37 GeV



Example II: Single jets

Dijets are generated with CMSSW123. The jet in each event is found in cone 0.5 around the leading particle on the generation level. Only particles from this jet are passed through simulation-reconstruction chain. Barrel jets with $|\eta|<0.3$.

CMSSW123 generation-simulation
CMSSW130 digitization-reconstruction

Example II: Description of procedure

- use Non-ZS runs to obtain
  - a) Energy corrections due to ZS
  - b) create Non-ZS single particle response library

- with "normal" ZS runs
  - a) find calo jet
  - b) correct energy for ZS
  - c) apply JPT using Not ZS particle response

Example II: Zero-suppression/tower threshold effect

1) Energy of jet in the calorimeter

$$\langle E_{jet} \rangle = \langle E^{signal}_{incone} + E^{noise}_{incone} \rangle$$

2) Energy of jet after the baseline subtraction (baseline is equal <Enoise>)

$$\langle E_{jet} \rangle = \langle E^{signal}_{incone} + E^{noise}_{incone} - \langle E^{noise}_{incone} \rangle \rangle = \langle E^{signal}_{incone} \rangle$$

Energy of jet is reconstructed as the sum of the true energy depositions in cell:

$$\langle E_{jet} \rangle = \frac{1}{Nev} \times \sum_{i<Nev} \sum_{j<Nreadouts \in cone} E^{signal}_{ij}$$

$$\sigma(\langle E_{jet} \rangle) = \mathrm{sqrt}(\sigma^2(\langle E^{signal}_{jet} \rangle) + \sigma^2(\langle E^{noise}_{jet} \rangle))$$

Example II: Zero-suppression/tower threshold effect

3) Energy of jet after the baseline subtraction and zero suppression

(all cells with Esignal+Enoise-<Enoise> < Ecut are excluded from the jet)

$$\langle E_{jet}\rangle = \frac{1}{Nev}\times\sum_{i<Nev}\sum_{E^{signal}+E^{noise}-\langle E^{noise}\rangle > E^{readout}_{cut}}\left(E^{signal}_{ij}+E^{noise}_{ij}-\langle E^{noise}_{j}\rangle\right)$$

sum over selected number of towers or over selected readouts above threshold, i.e.:

$$\langle E_{jet}\rangle = \langle E^{signal}_{incone}+E^{noise}_{incone}\rangle - \langle E^{noise}_{incone}\rangle \neq \langle E^{signal}_{incone}\rangle$$

Whether tower/readout contribute into jet energy depends on the contribution of jet to this tower/readout and contribution of noise, i.e. depends on the energy of jet, jet shape, jet type etc

The response of hadrons inside jet and outside jet is different.

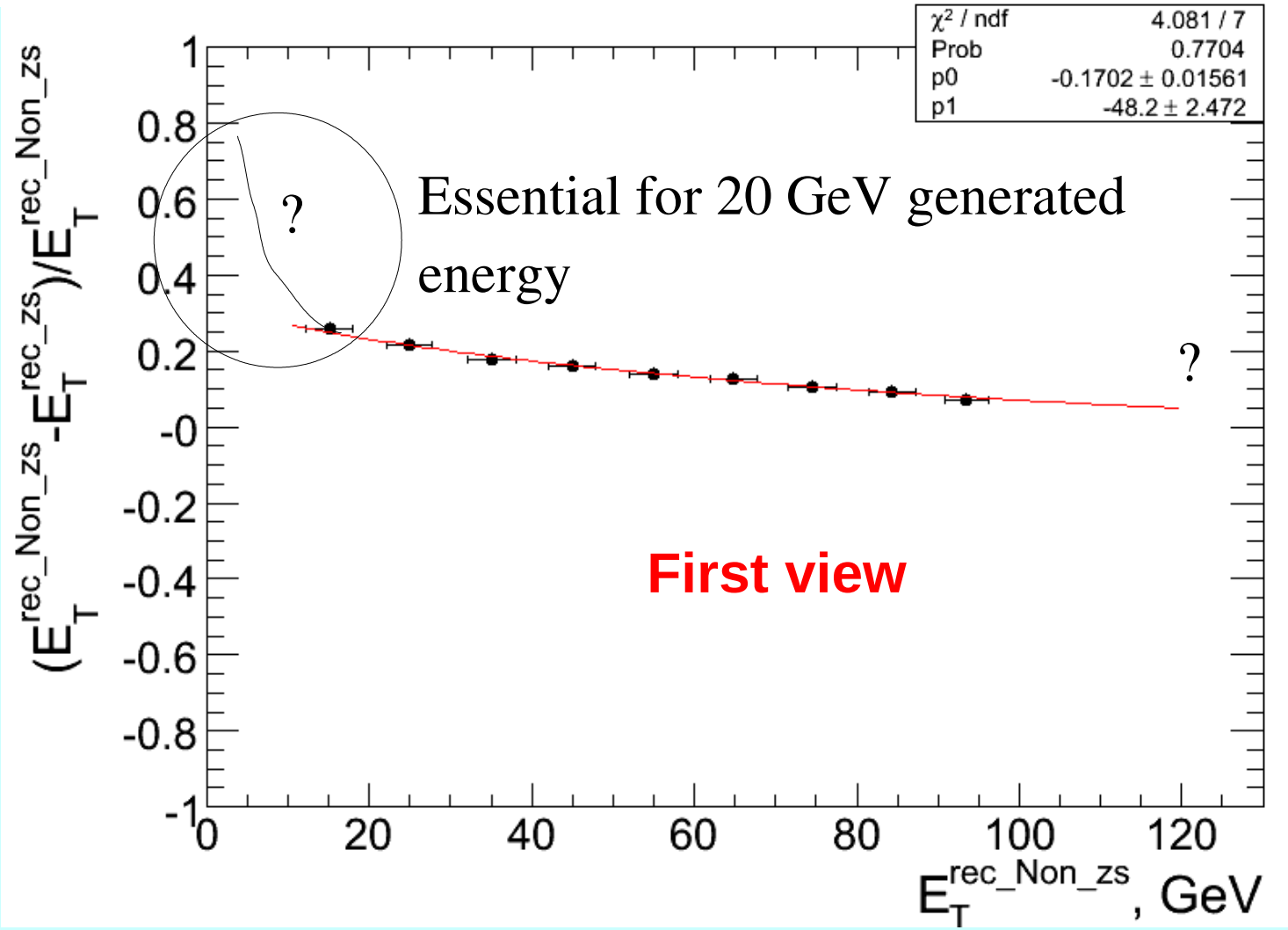
Pileup and UE contributions inside and outside jet are different

50% efficiency cut for 20 GeV Jets (CMS NOTE2006/036)

Mean energy of 20 GeV jet

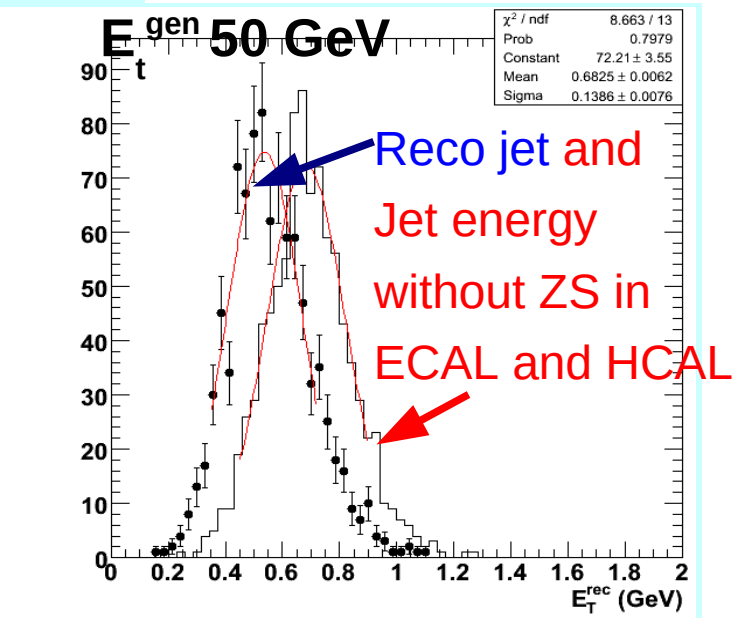
	Et>0. GeV	*Et>0.5 GeV*	*Et>0.5 GeV E>0.8 GeV*	*Et>1 GeV*	*UE (1.5 GeV in barrel)*
Etrec cut (GeV)	15	10.1	8.46	5.86	5

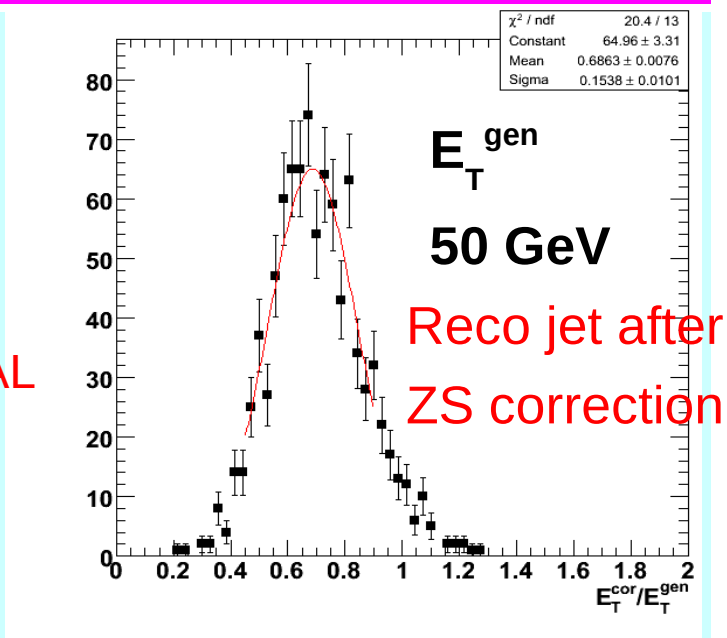
Example II: Zero-suppression/tower threshold correction

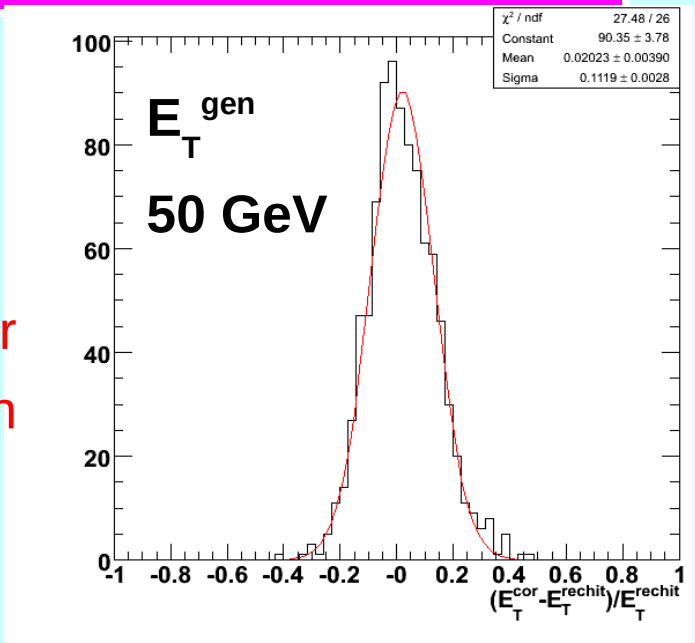


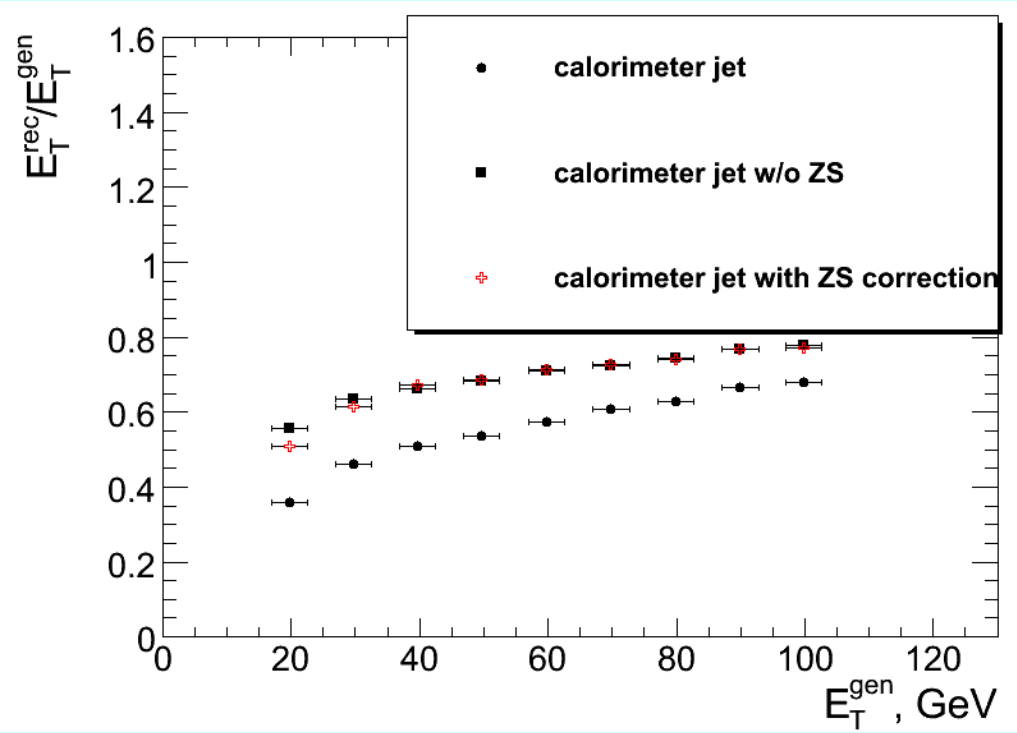
Digitization was done in CMSSW130 without selective readout in ECAL and zero-suppression in HCAL. A "prompt" sample of barrel single jets is used to create the curve. This curve is applied to the another sample ("test" sample) which was used for testing (next slide).

Example II: Zero-suppression/tower threshold correction





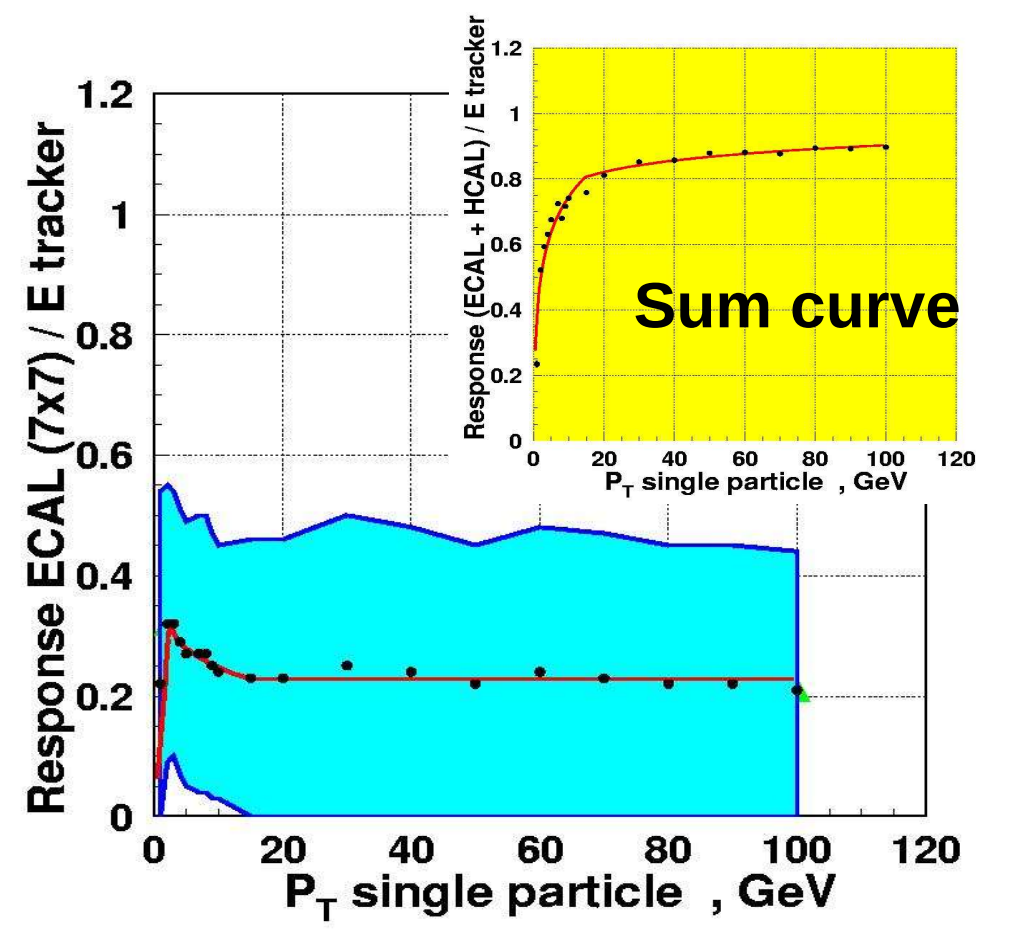


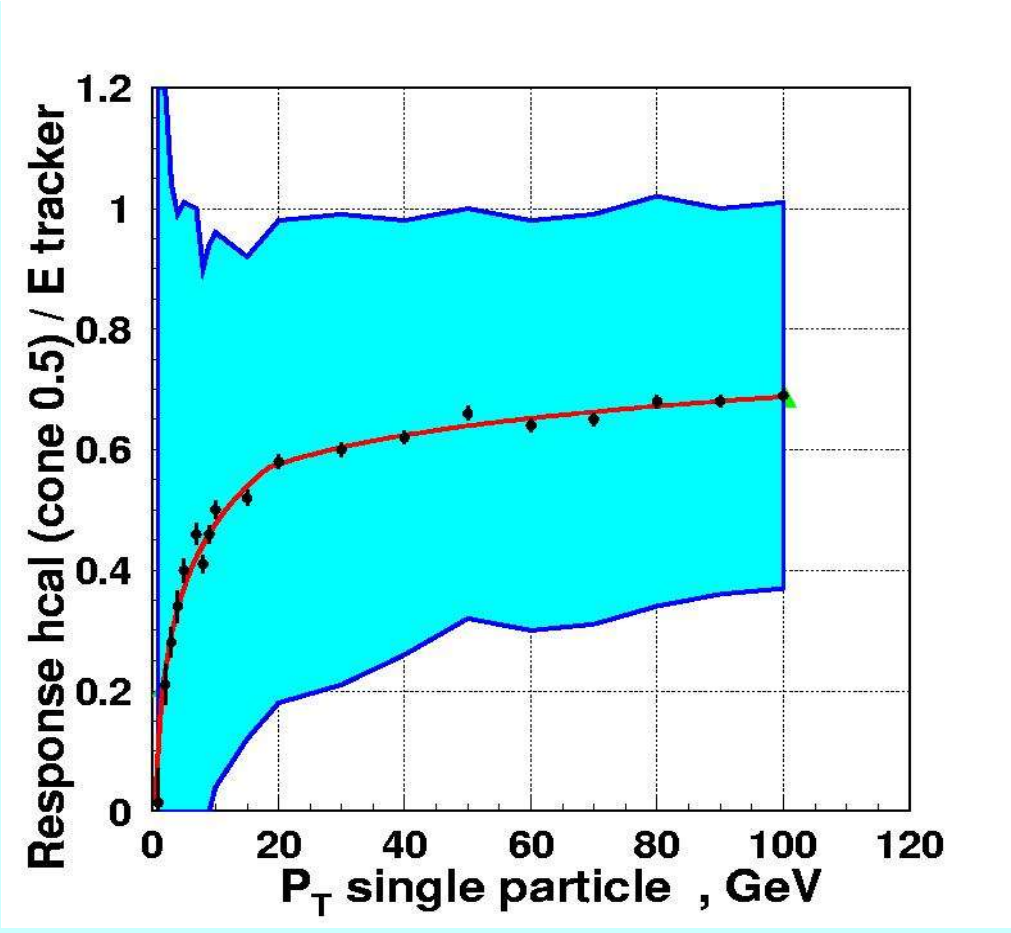


ZS correction curve was applied to a test sample of single jets, i.e. only hard interaction +UE.

Need to be created for the different pile-up conditions (Low lumi, High Lumi, HI) and η intervals.

Example II: Library of responses without zero-suppression





Responses of pions in ECAL and HCAL without separating interacting and non-interacting particles in ECAL.

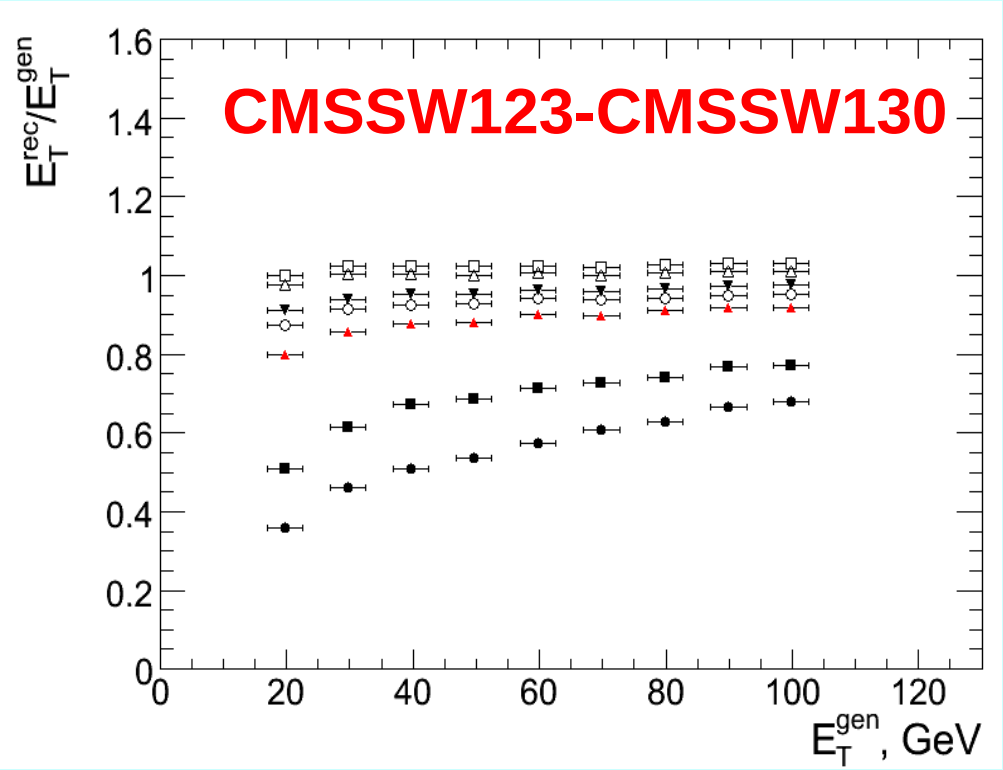
CMSSW130

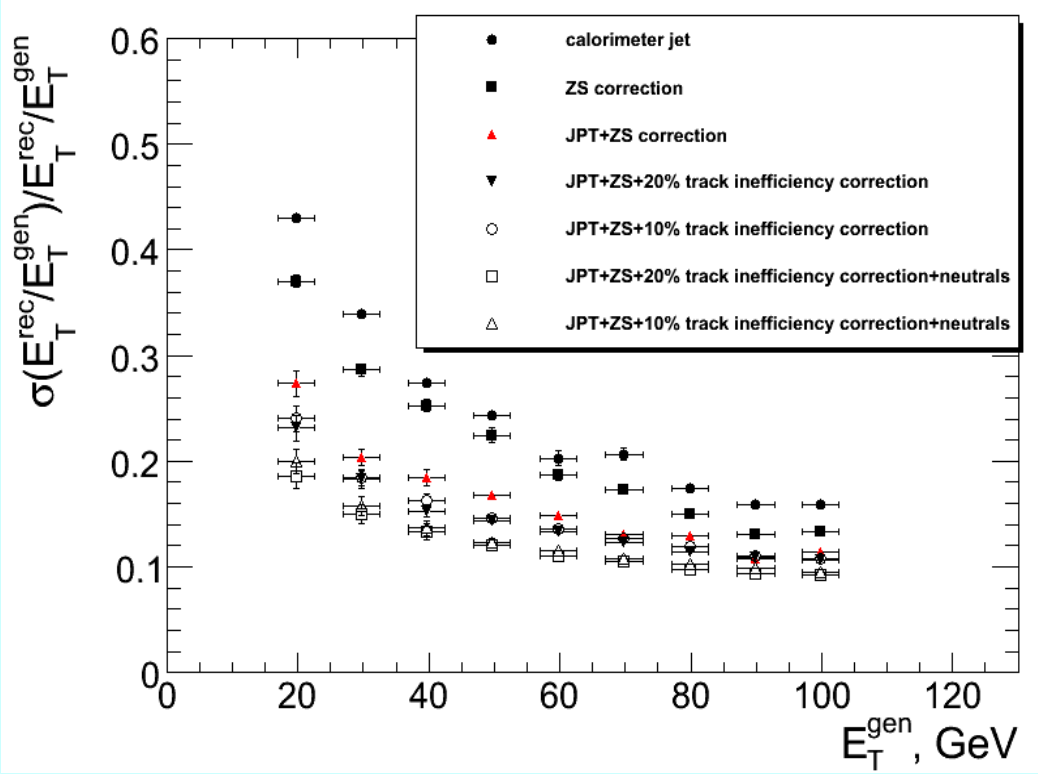
7x7 ECAL crystals

R=0.4 for HCAL

ECAL without selective readout and ZS, HCAL without ZS

Example II: Jet response linearity and resolution after JPT, ZS corrections





Correction for track inefficiency:

1. find <p> of reconstructed tracks in event
2. assume 10%, 20% inefficiency
3. $E_{jet} = E_{jet} + \Delta E_ineffic$

   $\Delta E = 0.1*Ntrack*(<p> - Resp(<p>))$
4. add tracks p<0.9 GeV/c (MC)<-pixel TF in future

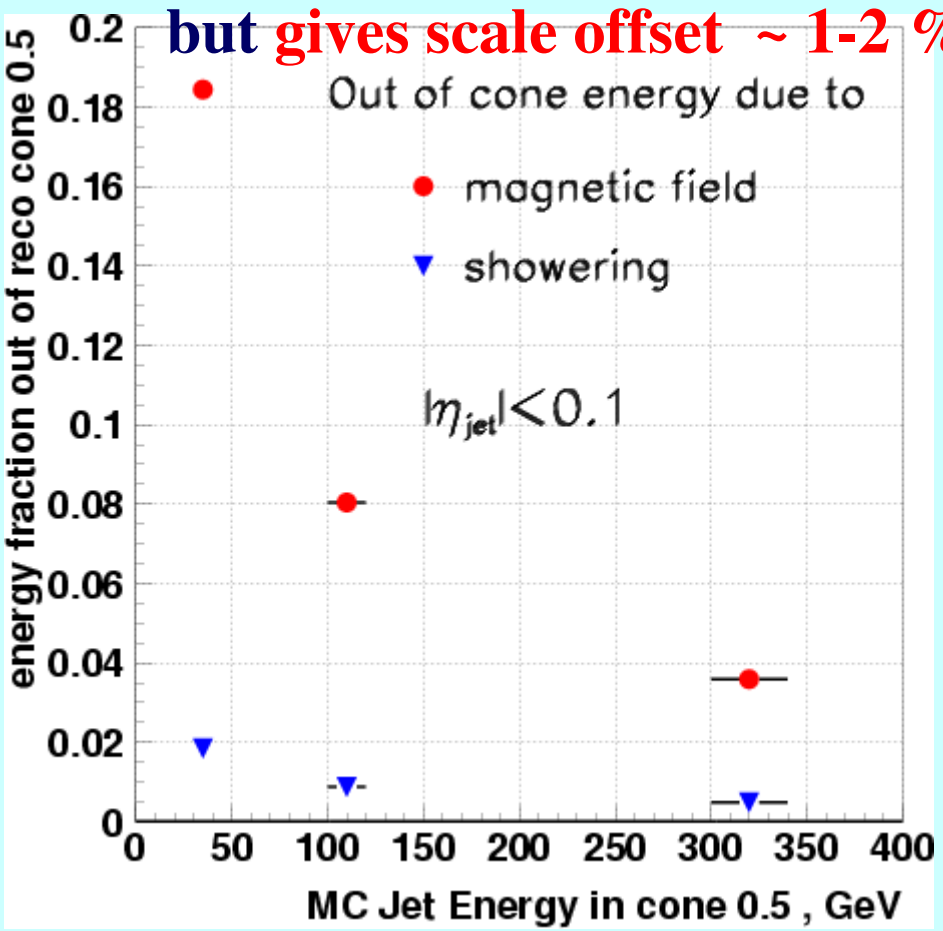
Correction for neutrals (pure MC)

1. find <p> of neutral hadrons
2. find the number of neutral h
3. $E_{jet} = E_{jet} + \Delta E_nh$

   $\Delta E_nh = Nnh*(<p> - Resp(<p>))$

Example II: Out-of-cone leakage due-to showering in calorimeter NOT APPLIED

Blue points : small effect in comparison with field effect (from CMS Note 2001/040), but gives scale offset ~ 1-2 %



This correction is not applied currently

Summary

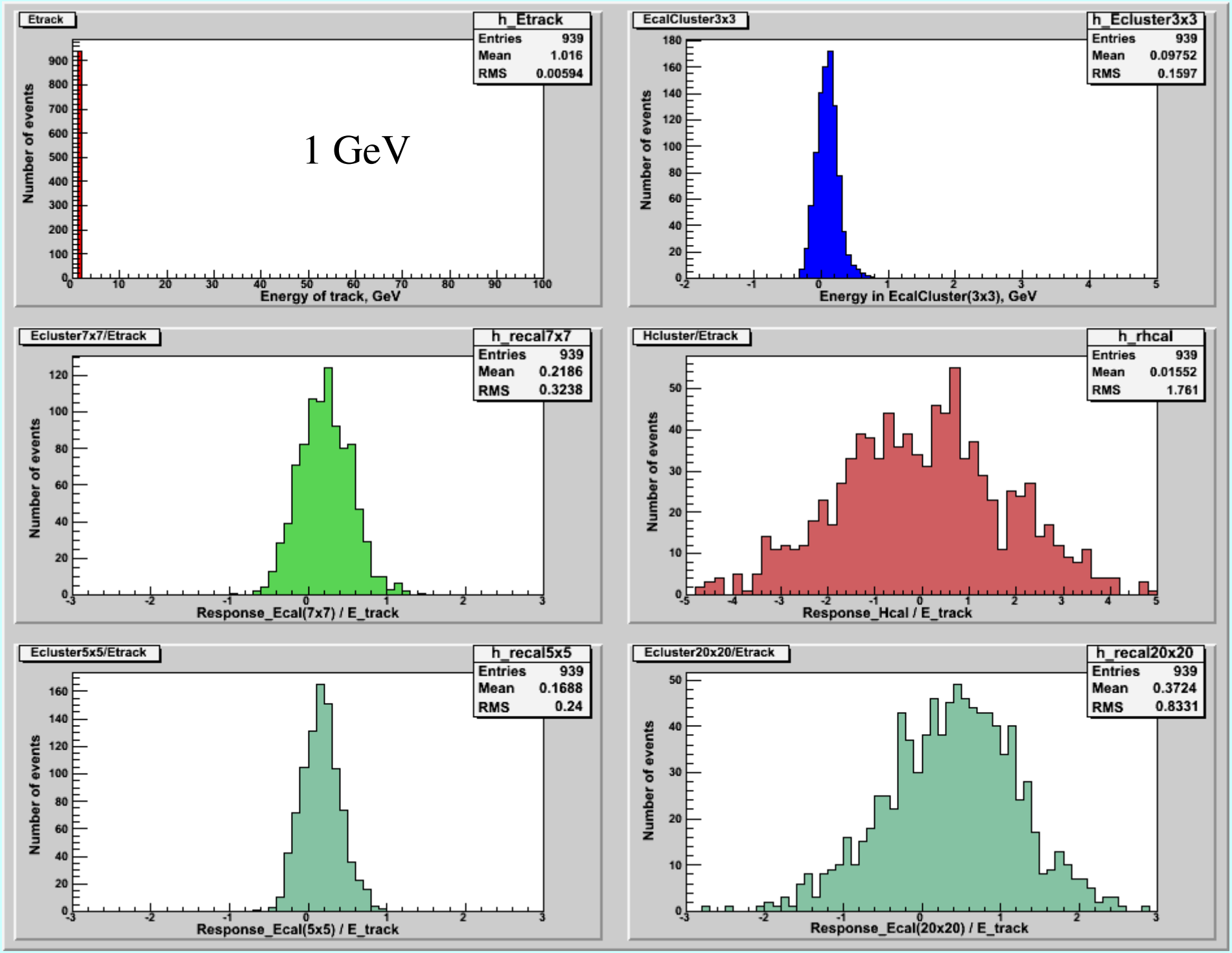
JetPlusTrack correction together with the correction for zero suppression gives essential improvement both in jet response linearity and resolution.

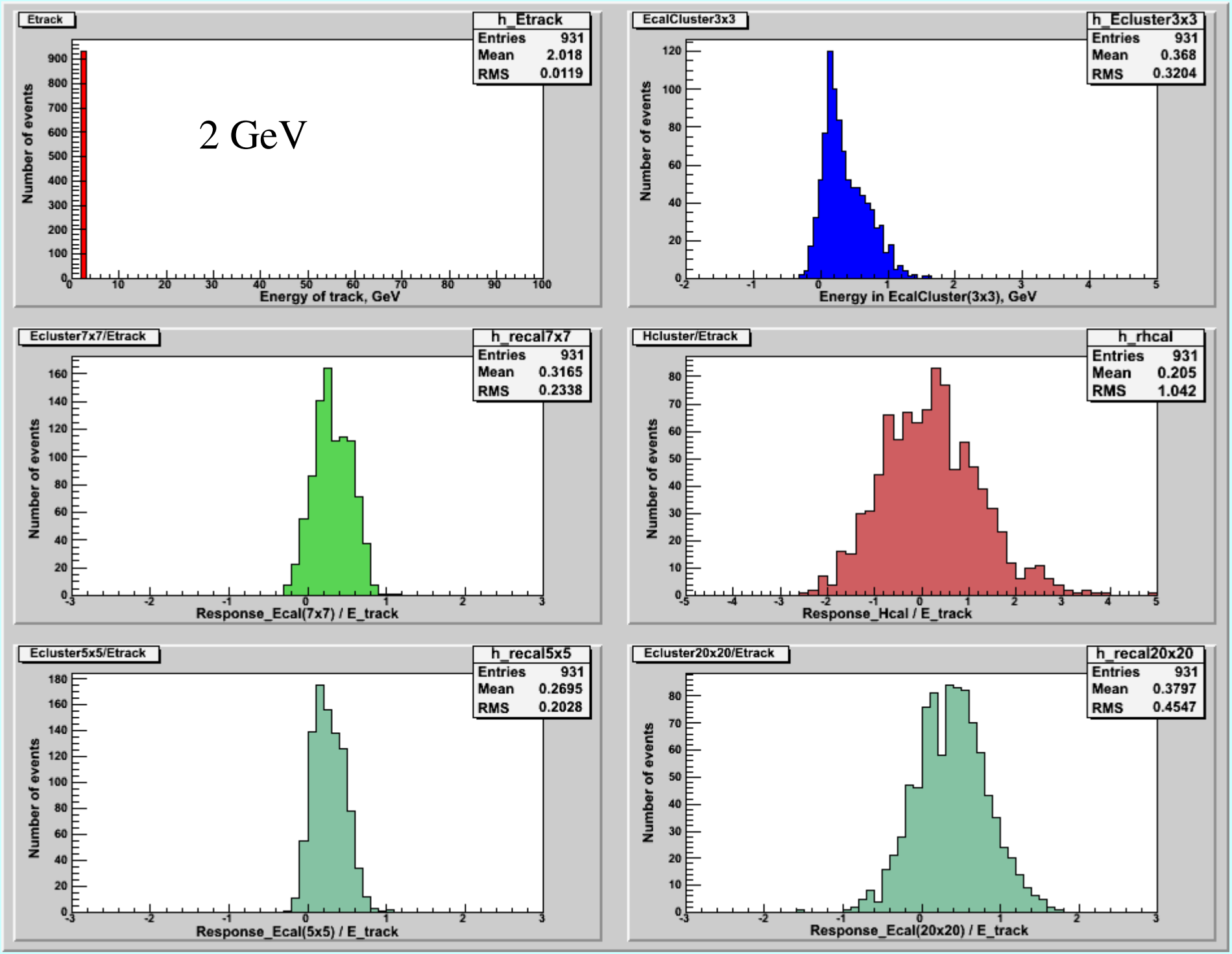
The further improvement can be achieved by:

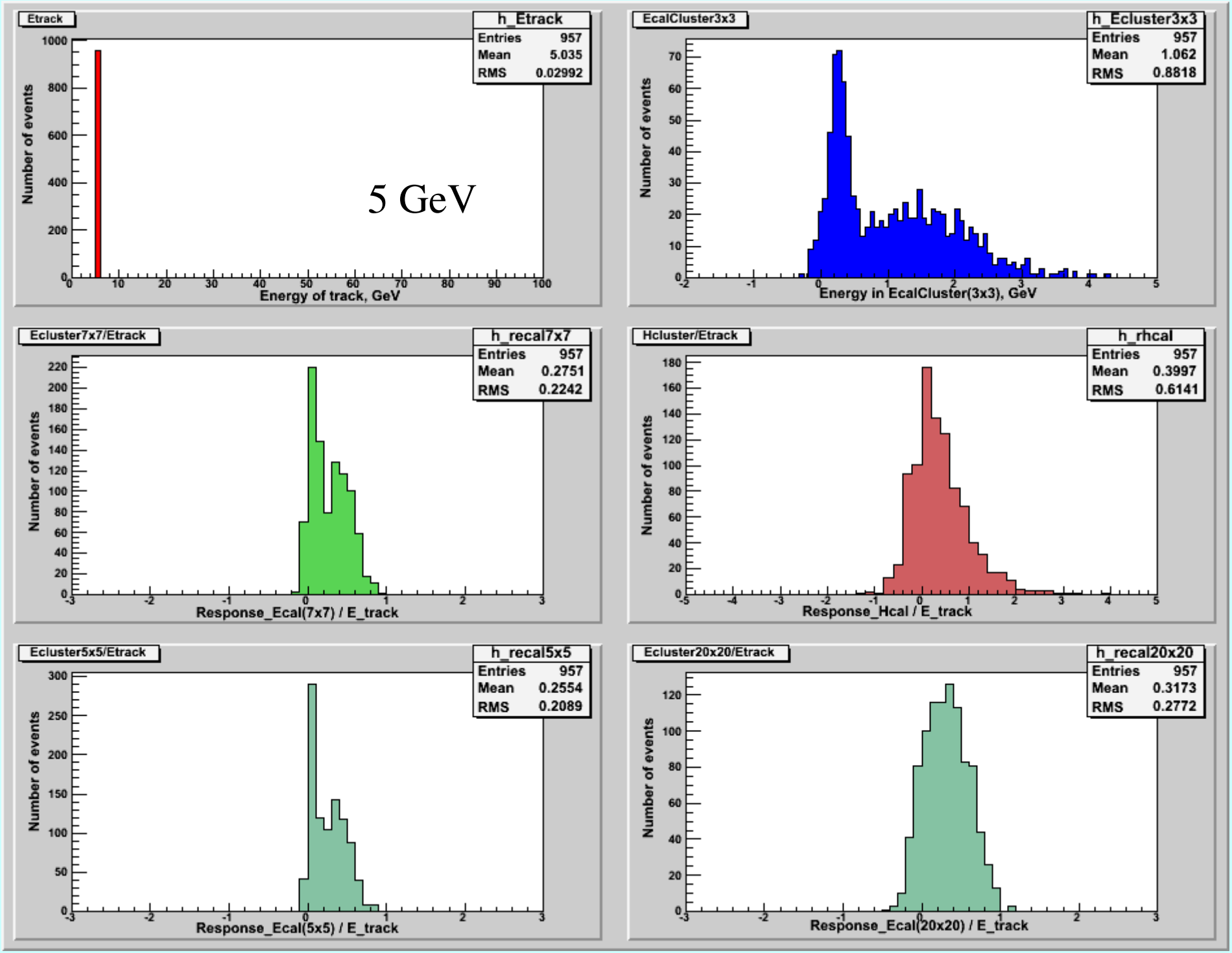
- **the estimation of tracking inefficiency for tracks with p_T>0.9 GeV**
- **low momentum particle identification and reconstruction**
  - **(pixel track finder, F.Sikler)**
- **MC correction for neutrals (optional)**
- **out-of-cone shower correction**
- **pile-up subtraction**
- **zero-suppression curves dependent on η, pile-up, increase E_T range**

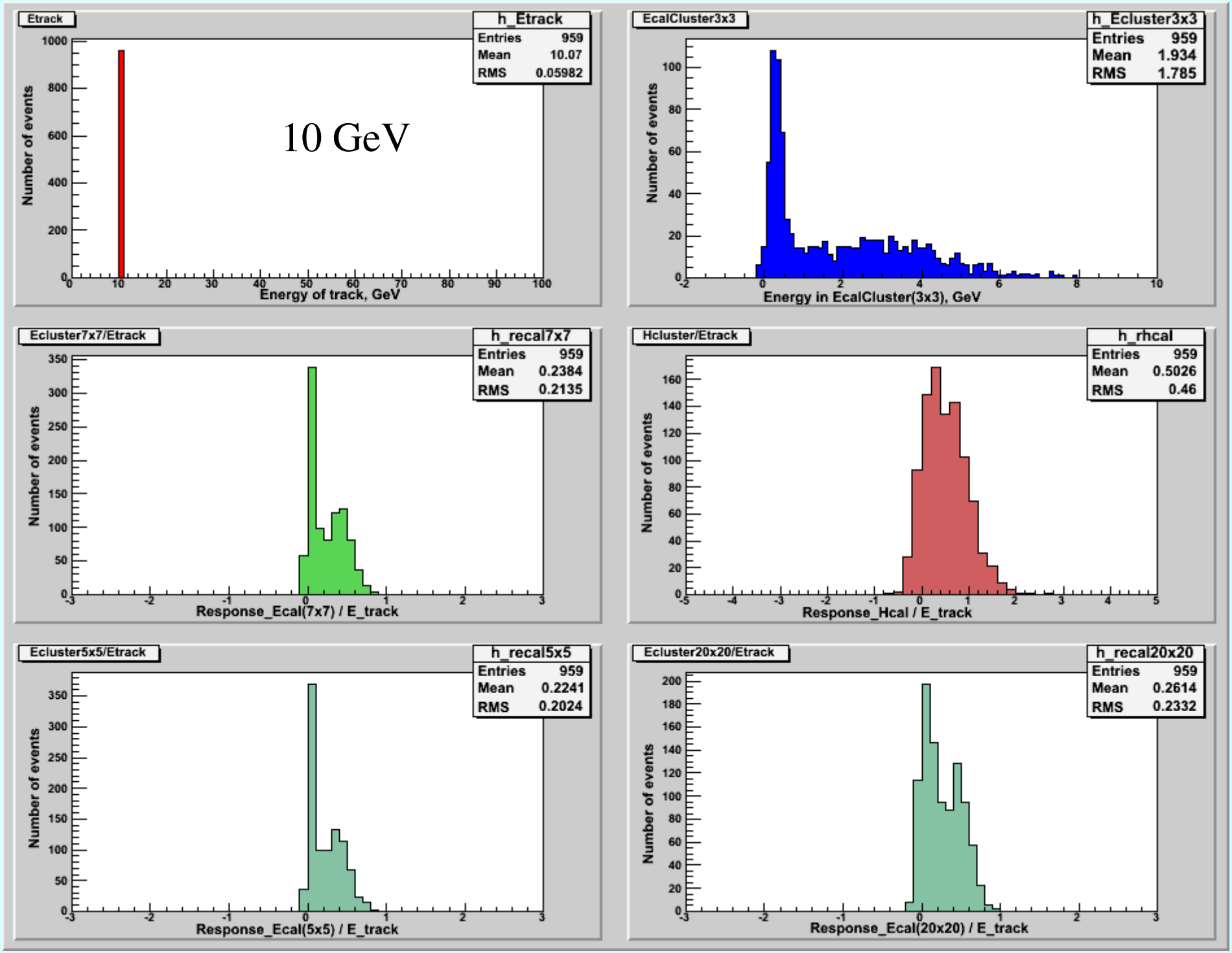
Library of responses and zero-suppression curves will be created using runs without zero-suppression at CAF

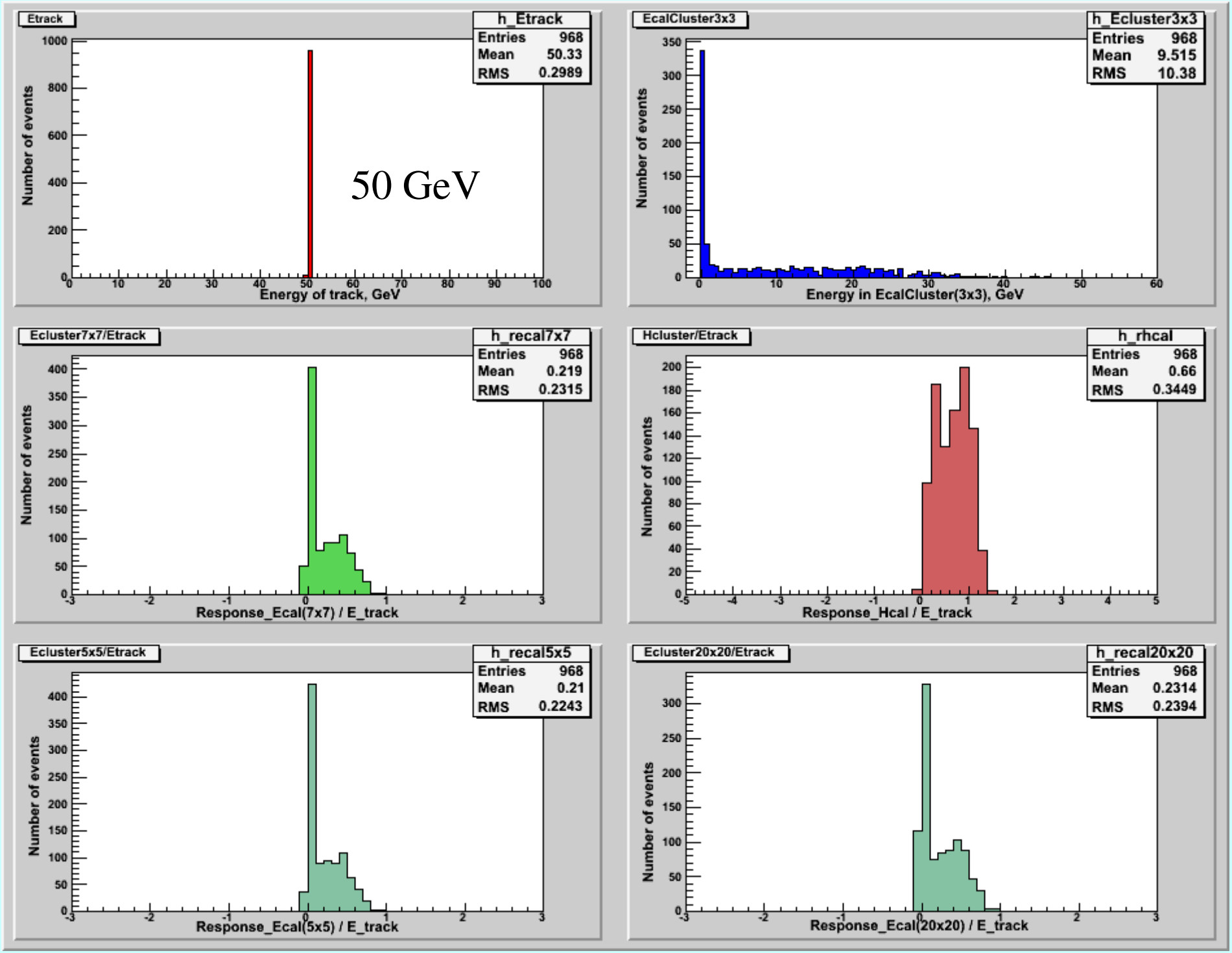
Back-up slides


Etrack
h_Etrack
Entries 939
Mean 1.016
RMS 0.00594
1 GeV
Number of events
Energy of track, GeV
EcalCluster3x3
h_Ecluster3x3
Entries 939
Mean 0.09752
RMS 0.1597
Number of events
Energy in EcalCluster(3x3), GeV
Ecluster7x7/Etrack
h_recal7x7
Entries 939
Mean 0.2186
RMS 0.3238
Number of events
Response_Ecal(7x7) / E_track
Hcluster/Etrack
h_rhcal
Entries 939
Mean 0.01552
RMS 1.761
Number of events
Response_Hcal / E_track
Ecluster5x5/Etrack
h_recal5x5
Entries 939
Mean 0.1688
RMS 0.24
Number of events
Response_Ecal(5x5) / E_track
Ecluster20x20/Etrack
h_recal20x20
Entries 939
Mean 0.3724
RMS 0.8331
Number of events
Response_Ecal(20x20) / E_track


Etrack
h_Etrack
Entries 931
Mean 2.018
RMS 0.0119
2 GeV
Number of events
Energy of track, GeV
EcalCluster3x3
h_Ecluster3x3
Entries 931
Mean 0.368
RMS 0.3204
Number of events
Energy in EcalCluster(3x3), GeV
Ecluster7x7/Etrack
h_recal7x7
Entries 931
Mean 0.3165
RMS 0.2338
Number of events
Response_Ecal(7x7) / E_track
Hcluster/Etrack
h_rhcal
Entries 931
Mean 0.205
RMS 1.042
Number of events
Response_Hcal / E_track
Ecluster5x5/Etrack
h_recal5x5
Entries 931
Mean 0.2695
RMS 0.2028
Number of events
Response_Ecal(5x5) / E_track
Ecluster20x20/Etrack
h_recal20x20
Entries 931
Mean 0.3797
RMS 0.4547
Number of events
Response_Ecal(20x20) / E_track


Etrack
h_Etrack
Entries 957
Mean 5.035
RMS 0.02992
Number of events
Energy of track, GeV
5 GeV
EcalCluster3x3
h_Ecluster3x3
Entries 957
Mean 1.062
RMS 0.8818
Number of events
Energy in EcalCluster(3x3), GeV
Ecluster7x7/Etrack
h_recal7x7
Entries 957
Mean 0.2751
RMS 0.2242
Number of events
Response_Ecal(7x7) / E_track
Hcluster/Etrack
h_rhcal
Entries 957
Mean 0.3997
RMS 0.6141
Number of events
Response_Hcal / E_track
Ecluster5x5/Etrack
h_recal5x5
Entries 957
Mean 0.2554
RMS 0.2089
Number of events
Response_Ecal(5x5) / E_track
Ecluster20x20/Etrack
h_recal20x20
Entries 957
Mean 0.3173
RMS 0.2772
Number of events
Response_Ecal(20x20) / E_track


Etrack
h_Etrack
Entries 959
Mean 10.07
RMS 0.05982
10 GeV
Number of events
Energy of track, GeV
EcalCluster3x3
h_Ecluster3x3
Entries 959
Mean 1.934
RMS 1.785
Number of events
Energy in EcalCluster(3x3), GeV
Ecluster7x7/Etrack
h_recal7x7
Entries 959
Mean 0.2384
RMS 0.2135
Number of events
Response_Ecal(7x7) / E_track
Hcluster/Etrack
h_rhcal
Entries 959
Mean 0.5026
RMS 0.46
Number of events
Response_Hcal / E_track
Ecluster5x5/Etrack
h_recal5x5
Entries 959
Mean 0.2241
RMS 0.2024
Number of events
Response_Ecal(5x5) / E_track
Ecluster20x20/Etrack
h_recal20x20
Entries 959
Mean 0.2614
RMS 0.2332
Number of events
Response_Ecal(20x20) / E_track


Etrack
h_Etrack
Entries 968
Mean 50.33
RMS 0.2989
50 GeV
Number of events
Energy of track, GeV
EcalCluster3x3
h_Ecluster3x3
Entries 968
Mean 9.515
RMS 10.38
Number of events
Energy in EcalCluster(3x3), GeV
Ecluster7x7/Etrack
h_recal7x7
Entries 968
Mean 0.219
RMS 0.2315
Number of events
Response_Ecal(7x7) / E_track
Hcluster/Etrack
h_rhcal
Entries 968
Mean 0.66
RMS 0.3449
Number of events
Response_Hcal / E_track
Ecluster5x5/Etrack
h_recal5x5
Entries 968
Mean 0.21
RMS 0.2243
Number of events
Response_Ecal(5x5) / E_track
Ecluster20x20/Etrack
h_recal20x20
Entries 968
Mean 0.2314
RMS 0.2394
Number of events
Response_Ecal(20x20) / E_track

Estimation of calorimeter response to charged particle from data.

Test beam and

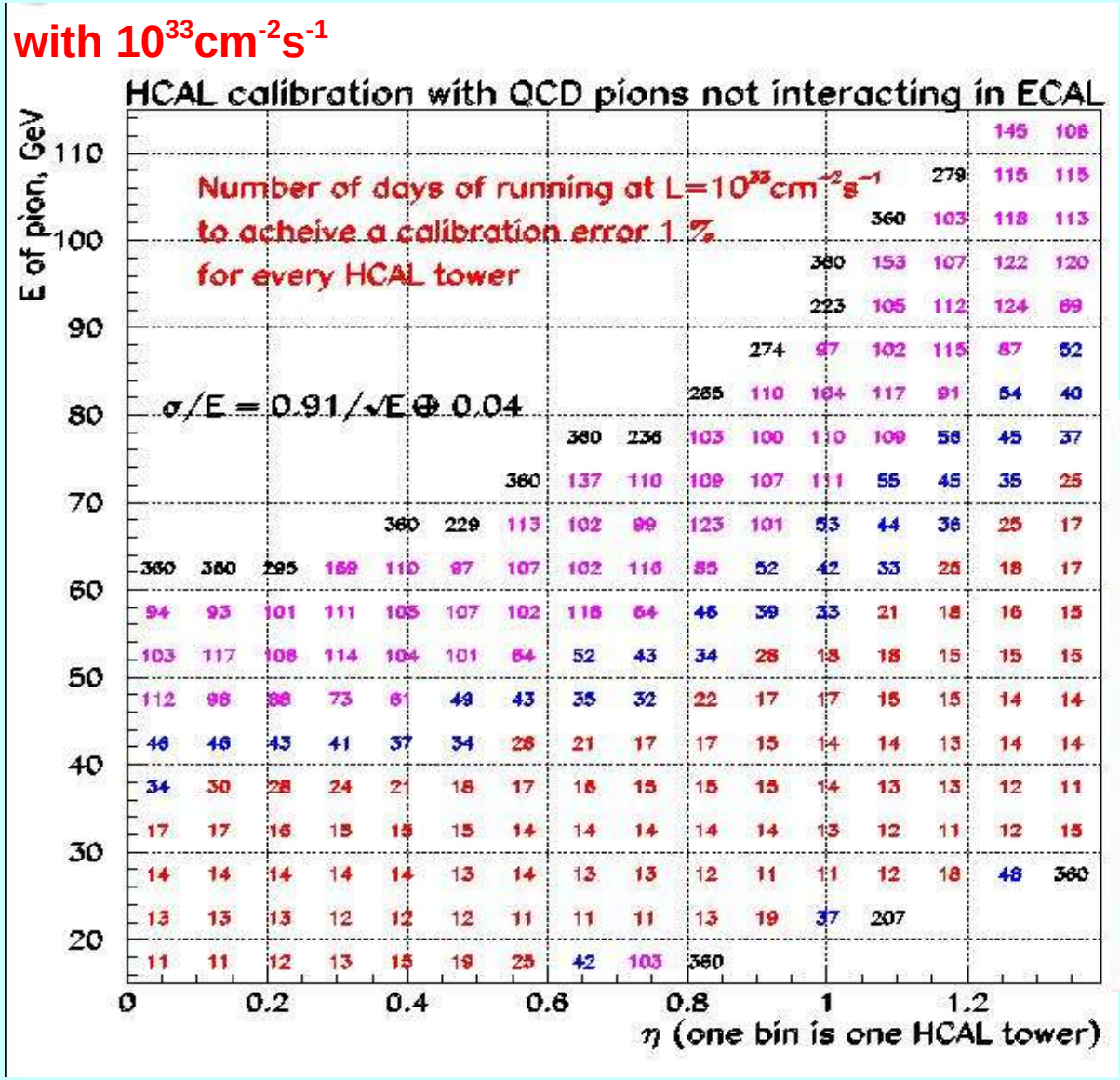
Isolated particles from different triggers

Tau trigger-CMS NOTE 1997/039,

qcd jets CMS NOTE-1997/097,

min bias, calibration talks of M.Szleper, S.Petrushanko

Isolated pions from QCD jets in one month with $10^{33}cm^{-2}s^{-1}$



Min bias: $L = 2x10^{33}cm^{-2}s^{-1}$

$P < 10$ GeV/c,

purity = 96.2%

	Rate of isolated particles	Number of calorimeter towers	Time to collect 1000 iso.particles in each tower
barrel $0 < \|\eta\| < 1.5$	0.20	2448	1.5 days
endcap $1.5 < \|\eta\| < 2.1$	0.04	980	2.5 days

Track reconstruction efficiency within jet.

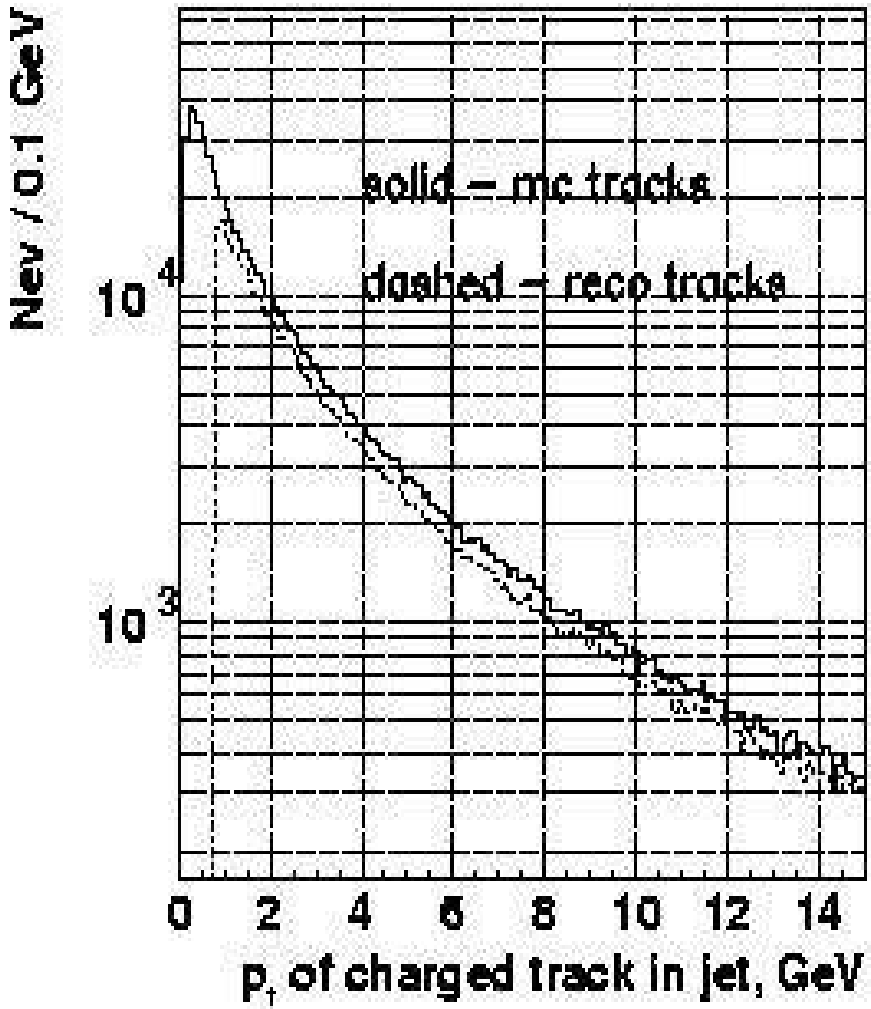


Figure 8: p_t spectra of generated charged particles (solid line) and reconstructed tracks (dashed line) inside jet cone 0.5

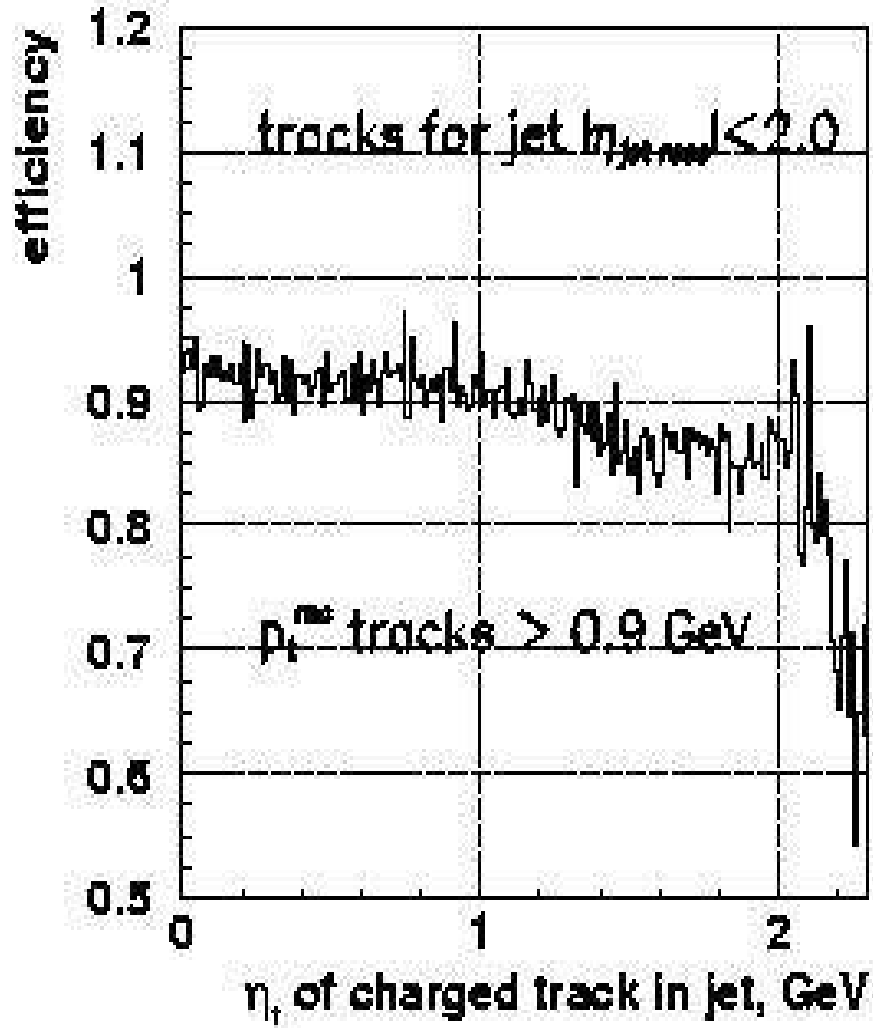


Figure 9: Efficiency of reconstruction of the tracks (p_t > 0.9 GeV) inside jet cone of ΔR=0.5 as a function of jet pseudorapidity.

Energy deposited in ECAL and HCAL from min bias events

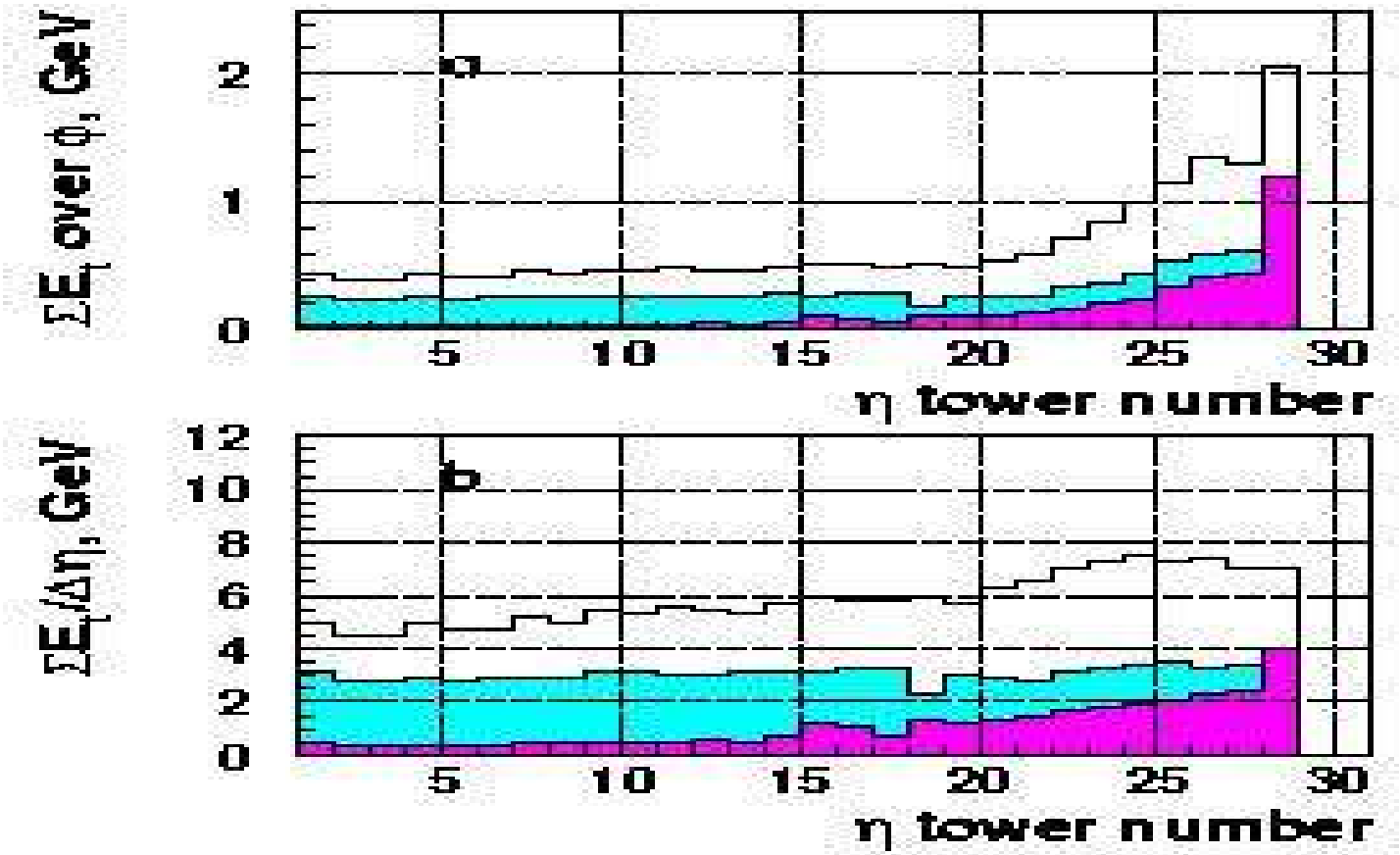
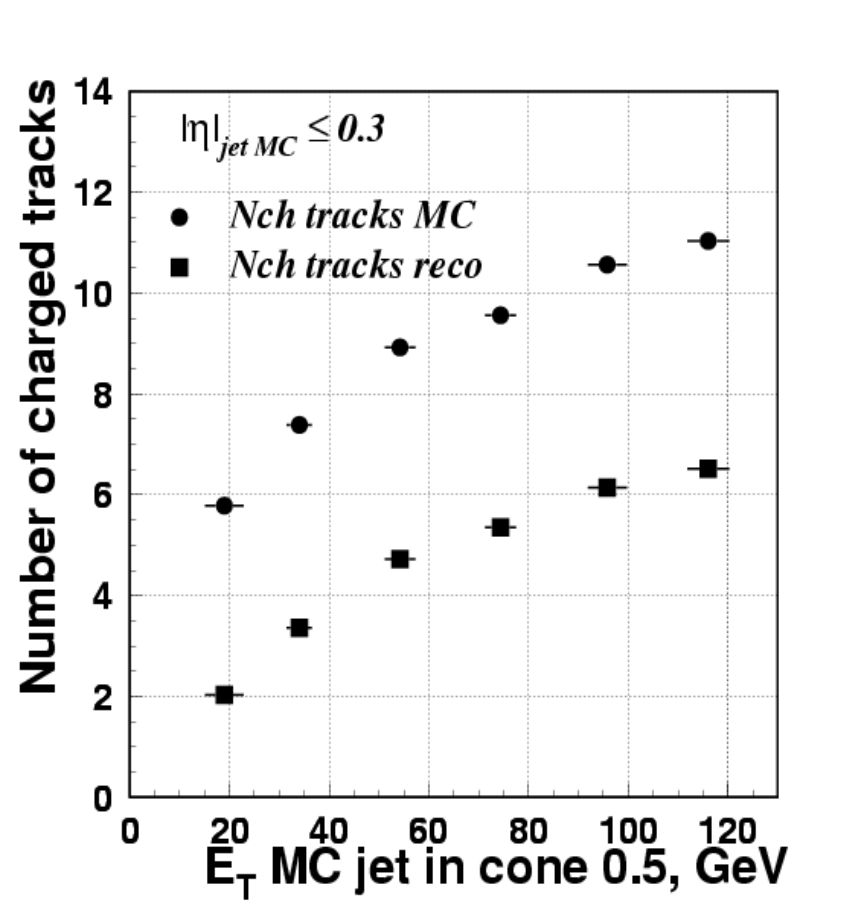
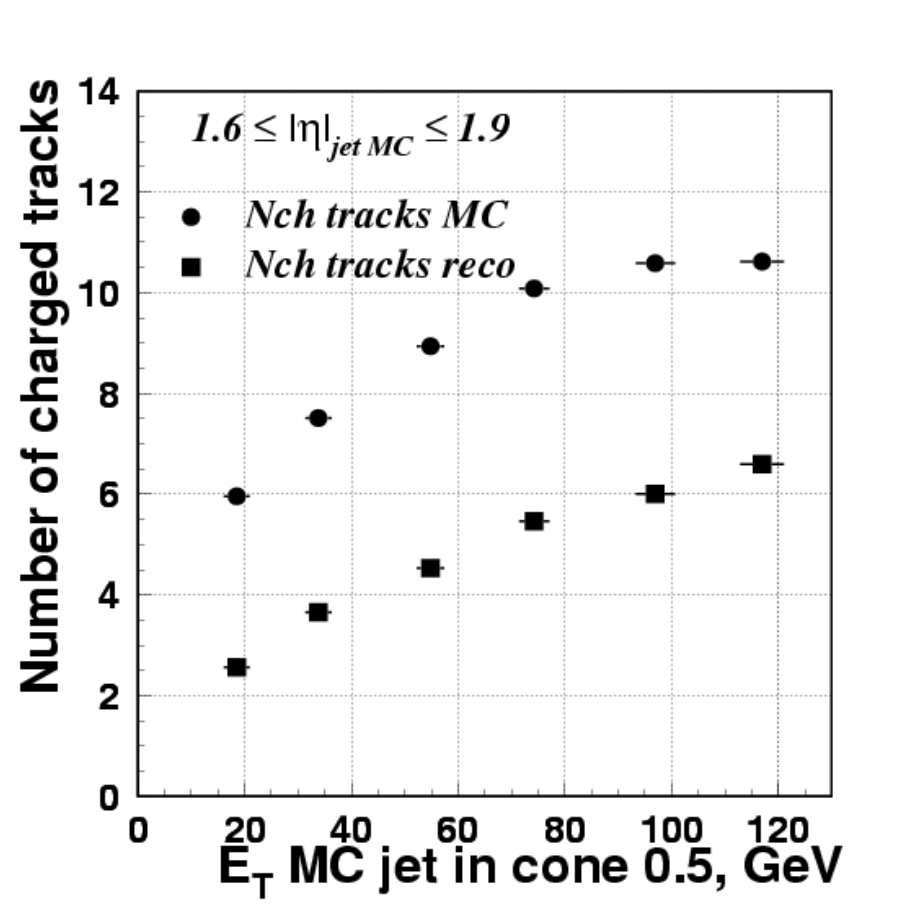


Figure 7: a - average transverse energy from min.bias events summed in ϕ per η calorimeter tower for incoming MC energy at the ECAL surface (solid line), reconstructed in ECAL (upper full histogram), reconstructed in HCAL (lower full histogram). b - the same as a) but energy is normalised on the unit of pseudorapidity.

Number of charged tracks (generated and reconstructed)



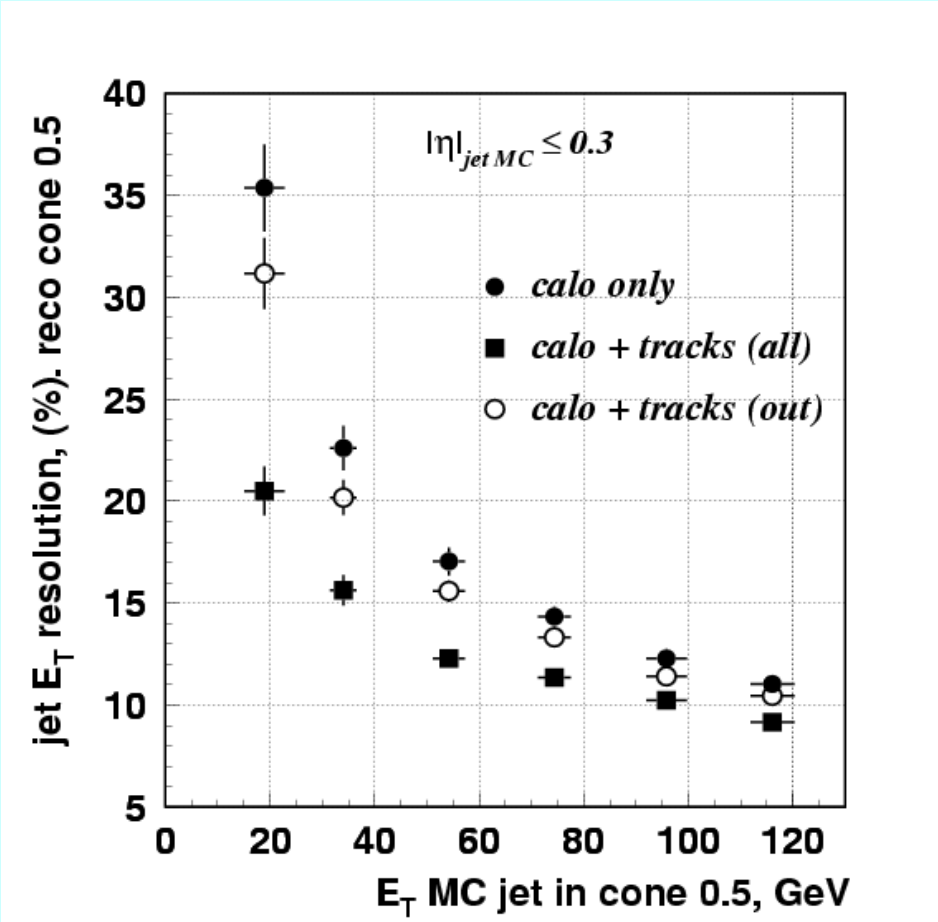


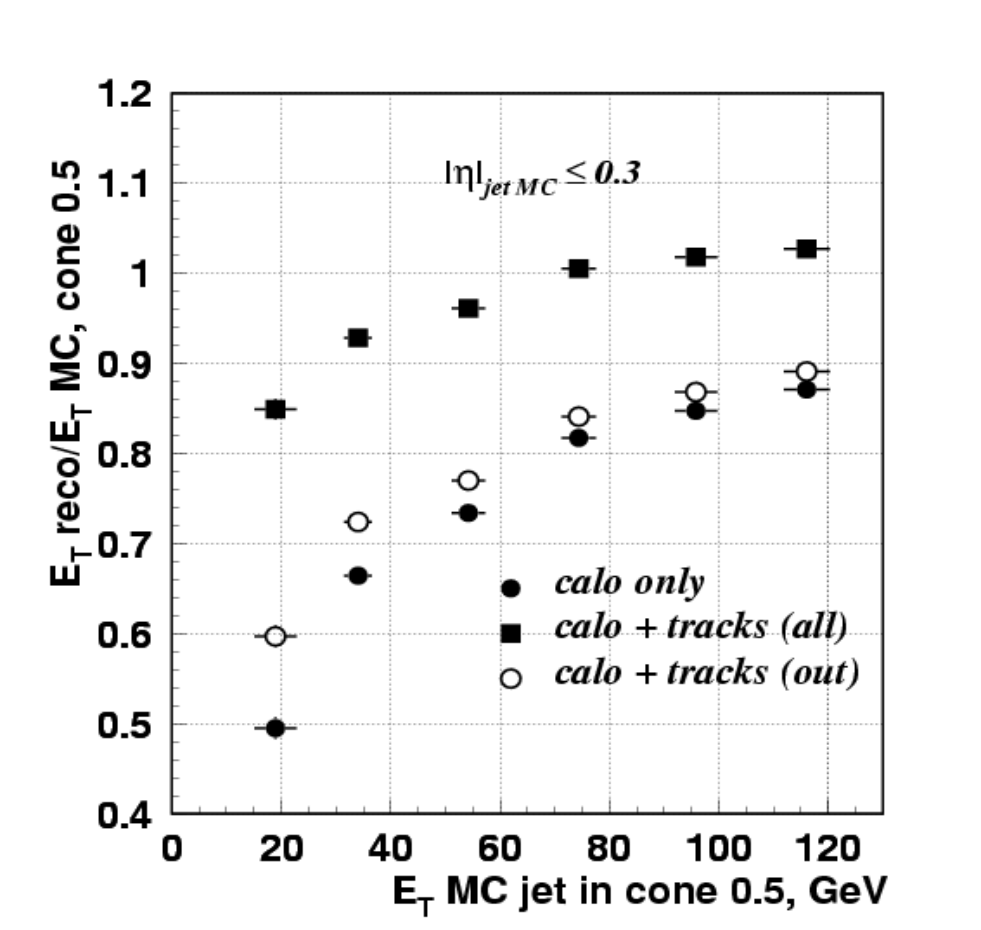
Barrel ***Endcap***

Reconstructed charged particles with Pt>1 GeV/c

Generated charged particles with Pt>0 GeV/c

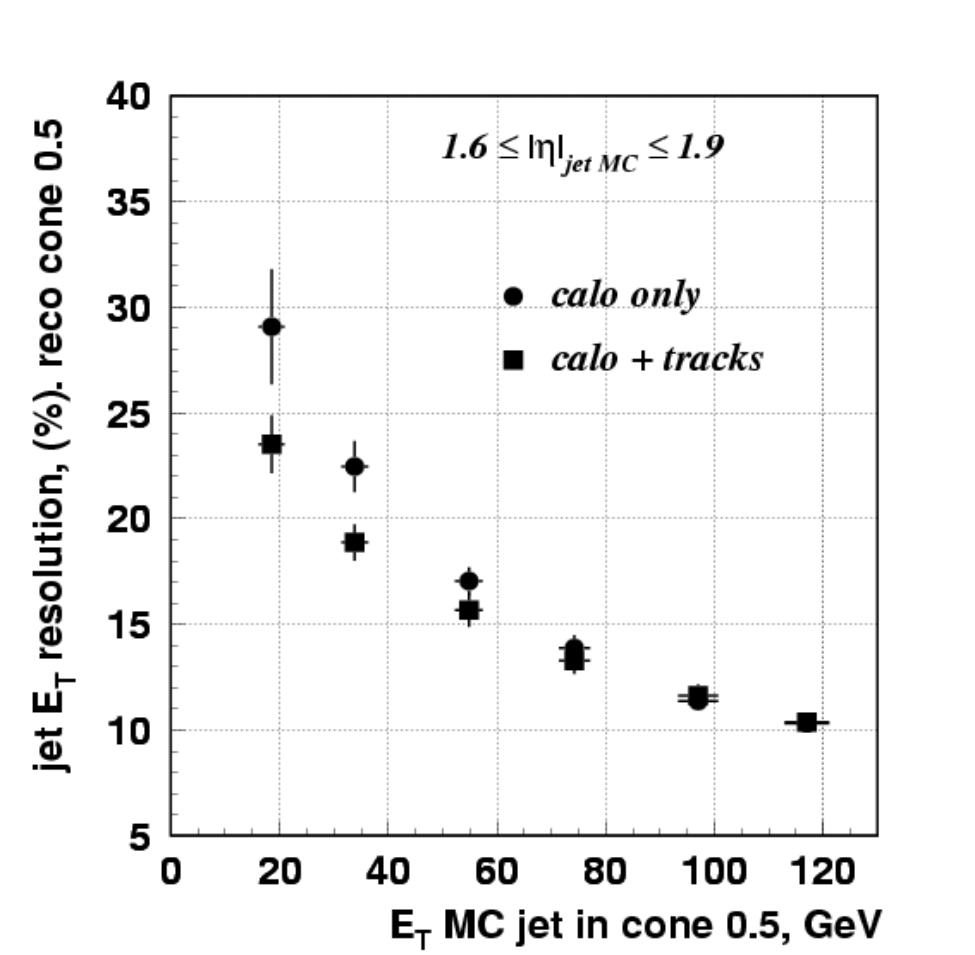
The dependance of <Etreco/ETmc> on Etmc (right) and sigma(Etreco/ETmc)/<Etreco/ETmc> (resolution) on Etmc (left)

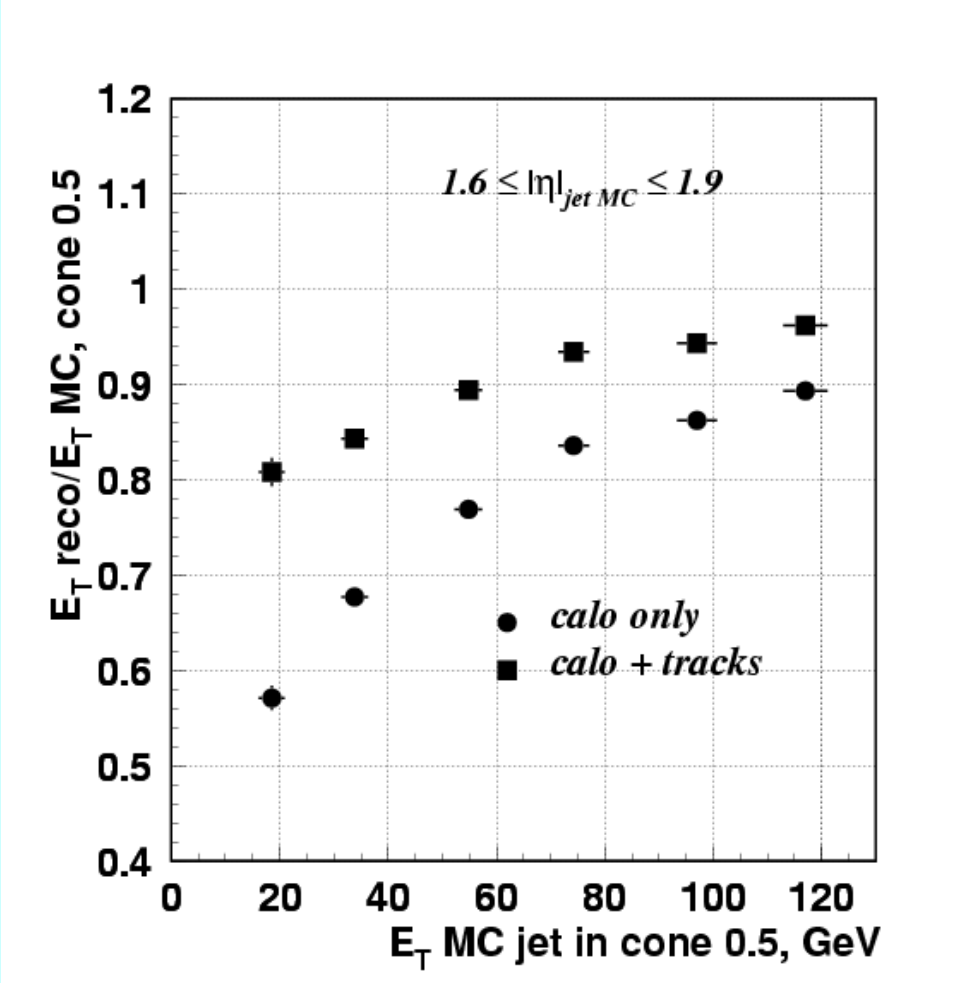




For a single jet in barrel

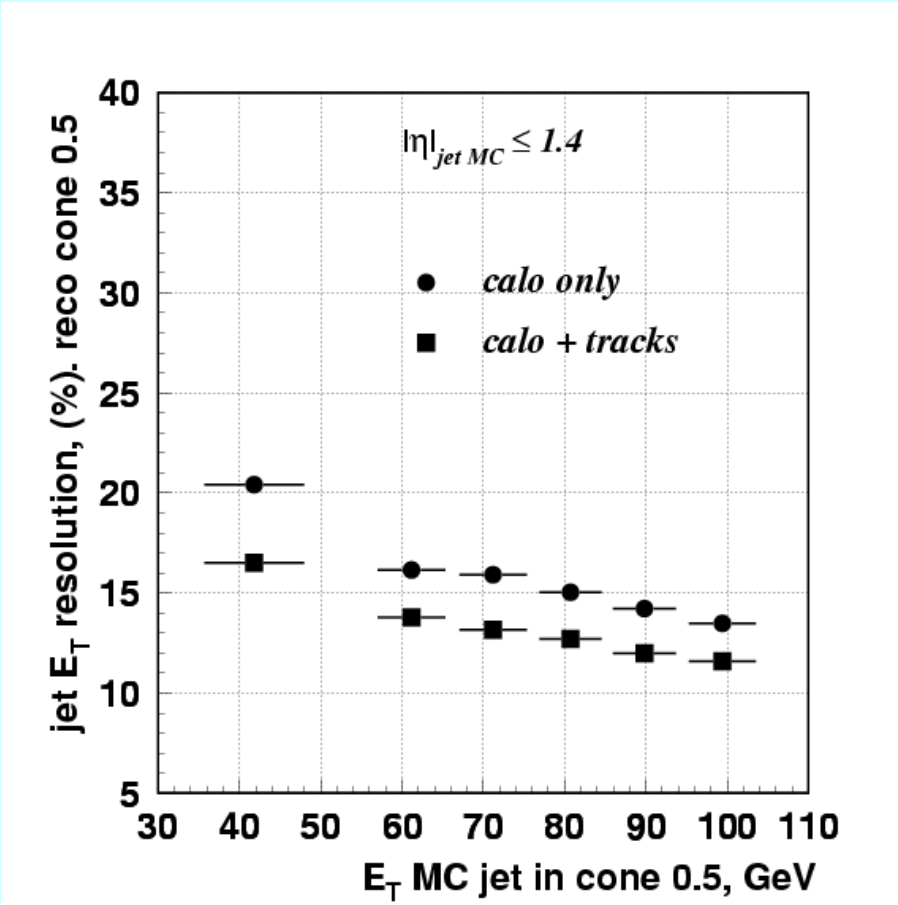
The dependance of <Etreco/ETmc> on Etmc (right) and sigma(Etreco/ETmc)/<Etreco/ETmc> (resolution) on Etmc (left)

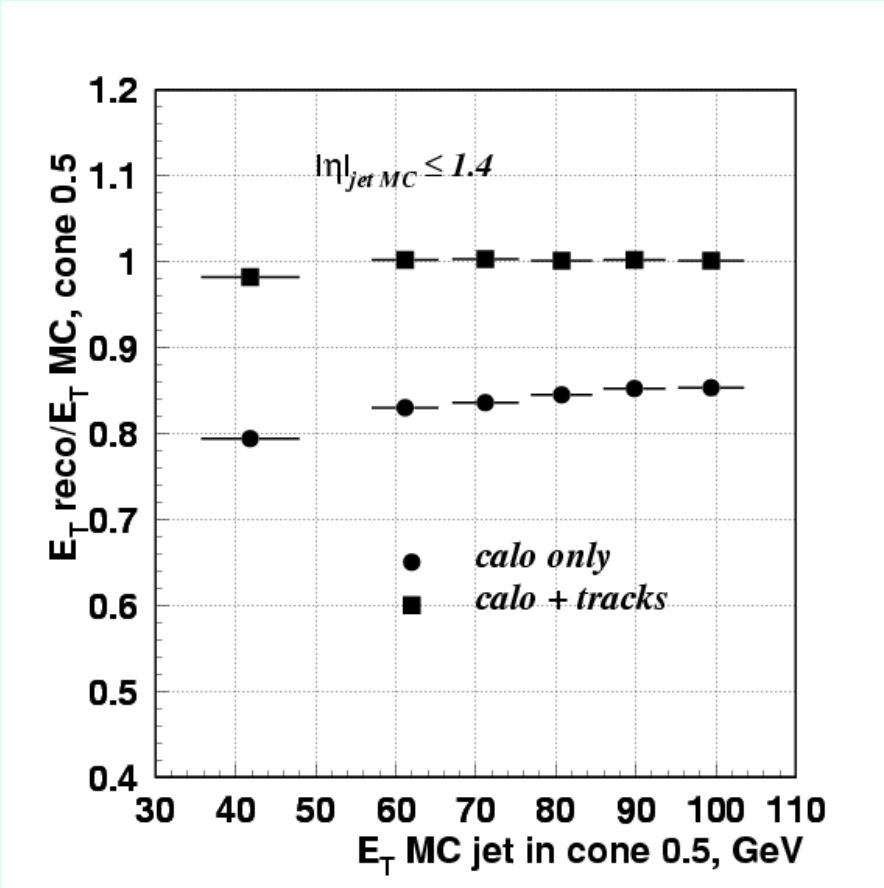




For a single jet in endcap

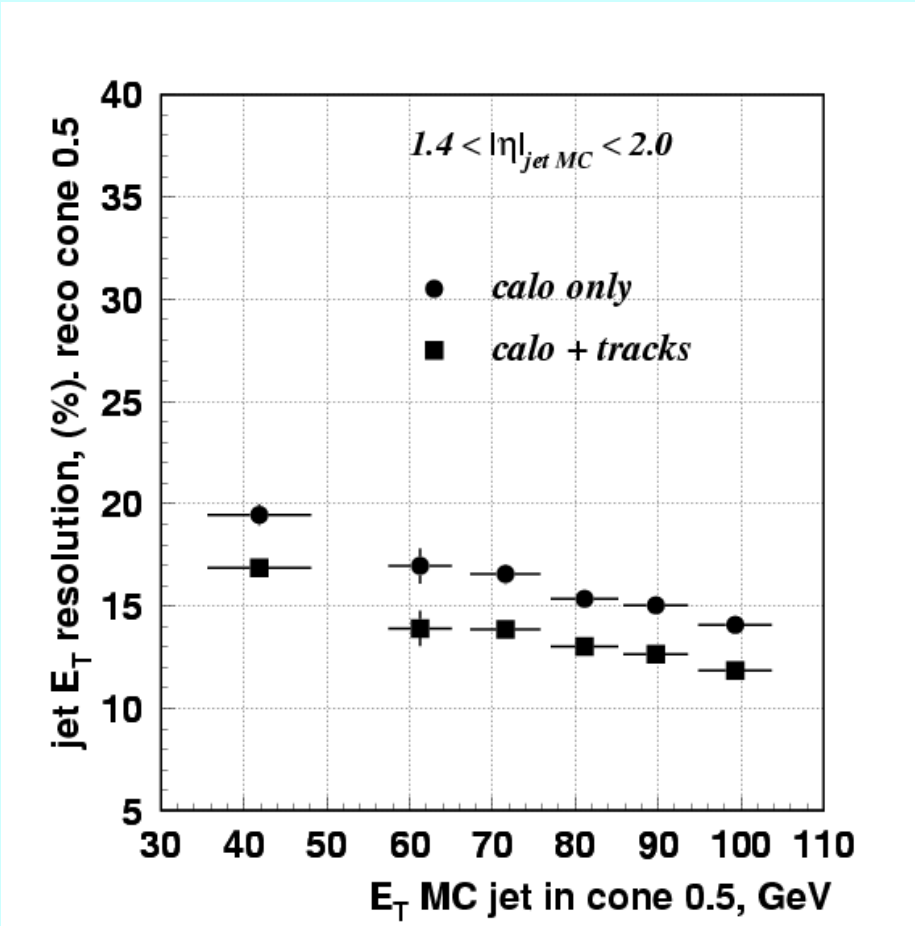
The dependance of <Etreco/ETmc> on Etmc (right) and sigma(Etreco/ETmc)/<Etreco/ETmc> (resolution) on Etmc (left)

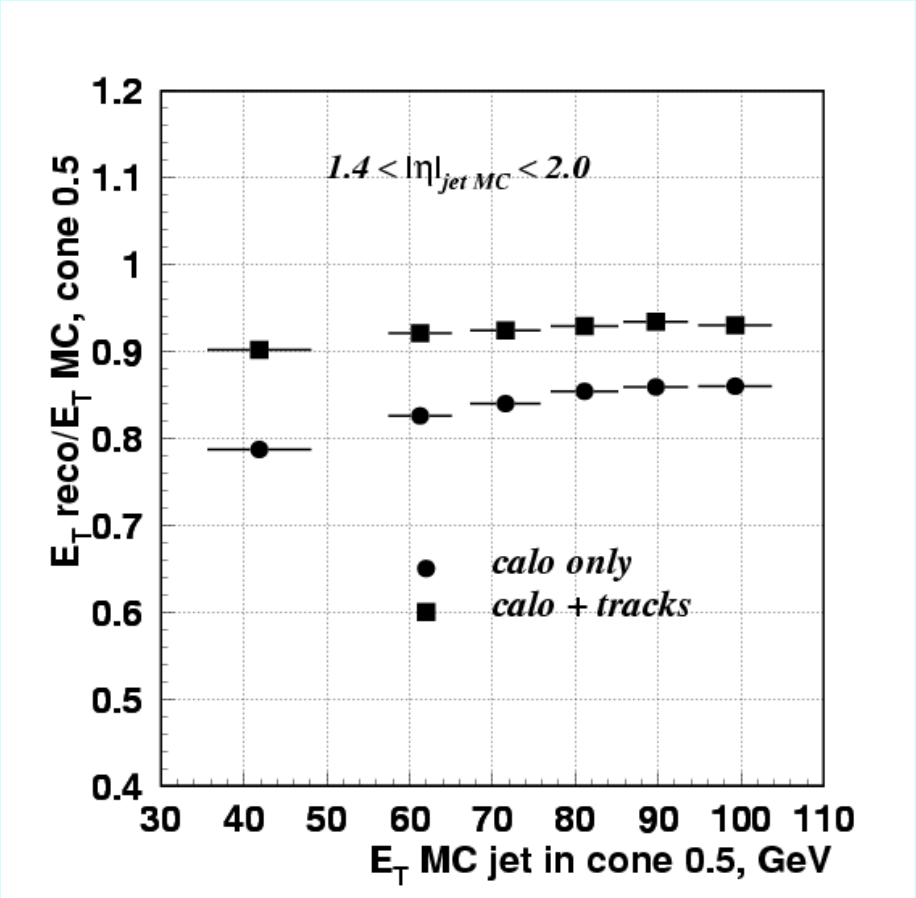




For a qcd sample bt02_qcd80_120 and bt02_qcd30_50 digitized with low luminosity pile-up (barrel part) are used. Request for matching of reconstructed and MC jet is dr<0.2, E tower>0.5 GeV

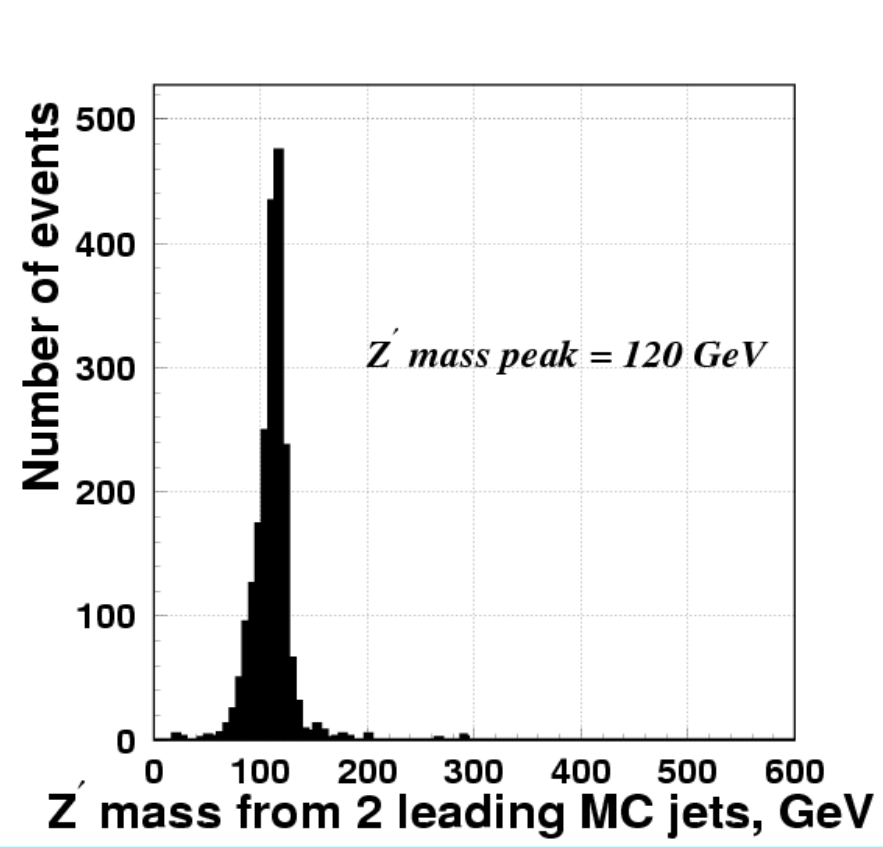
The dependance of <Etreco/ETmc> on Etmc (right) and sigma(Etreco/ETmc)/<Etreco/ETmc> (resolution) on Etmc (left)

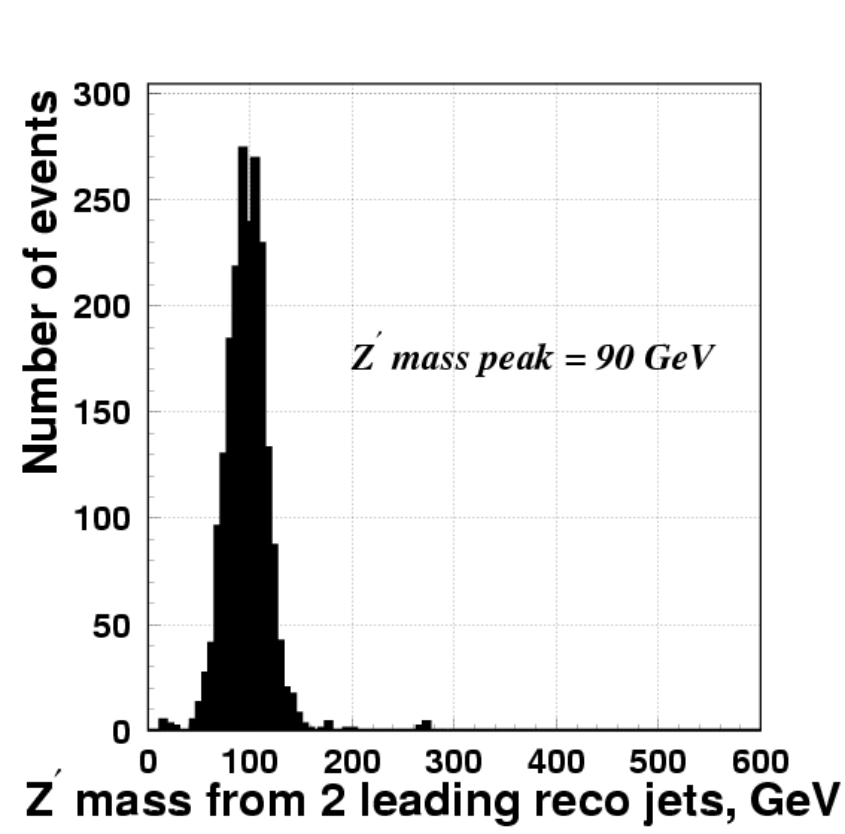




For a qcd sample bt02_qcd80_120, bt02_qcd30_50 digitized with low luminosity pile-up (endcap part) are used. Request for matching of reconstructedand MC jet is dr<0.2, E tower>0.5 GeV

The distribution of generated mass of Z' (left) and reconstructed mass of Z' (right)





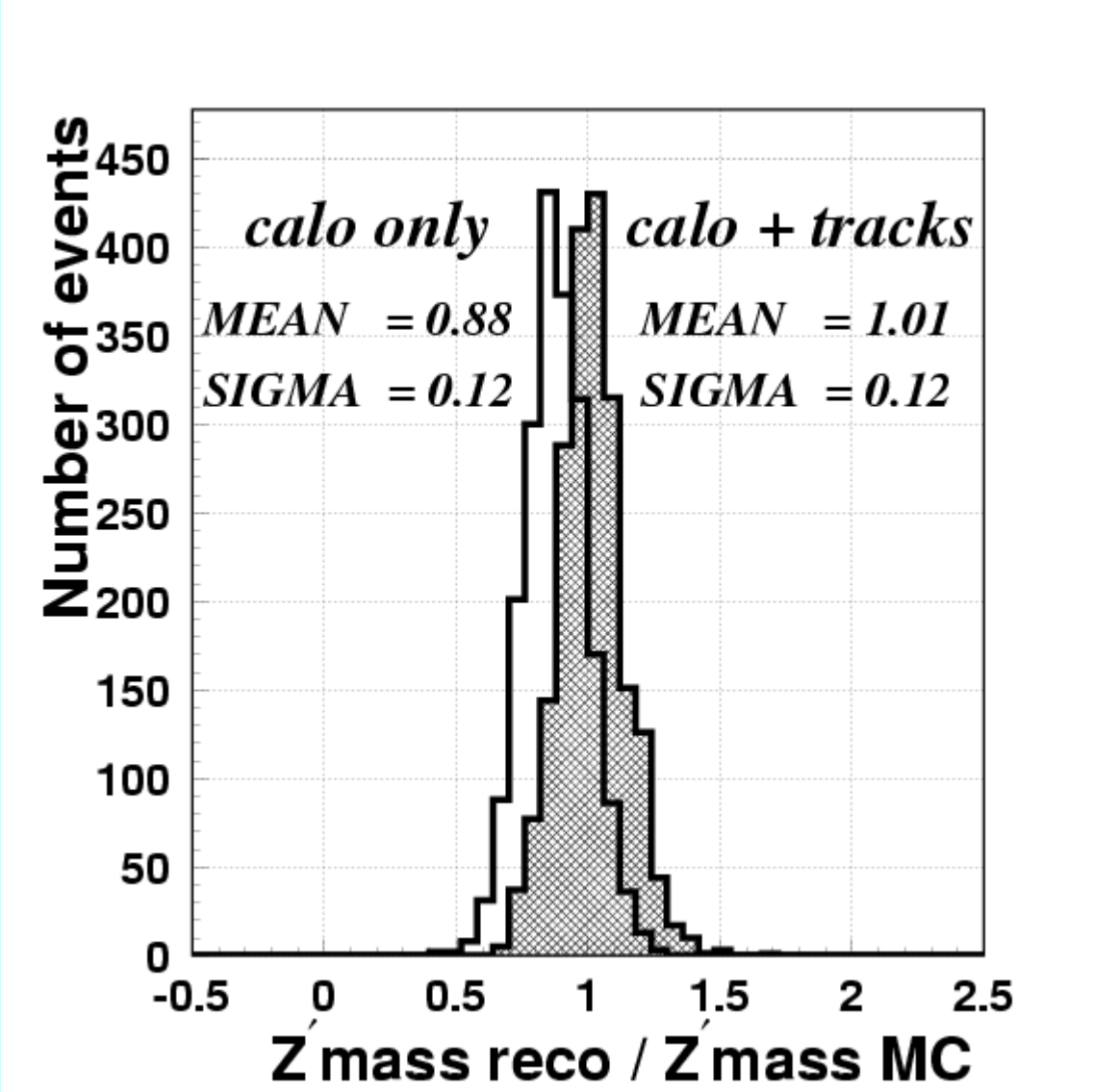
For a qcd sample jm02_zprime_m120_qq digitized with low luminosity pile-up .

Selections:

Two reconstructed leading jets with $|\eta_{reco}|<2$ *and* $Et_{reco}>20$ *GeV*

Request for matching of reconstructed and MC jet is dr<0.2.

The ratio of reconstructed to generated mass of Z'

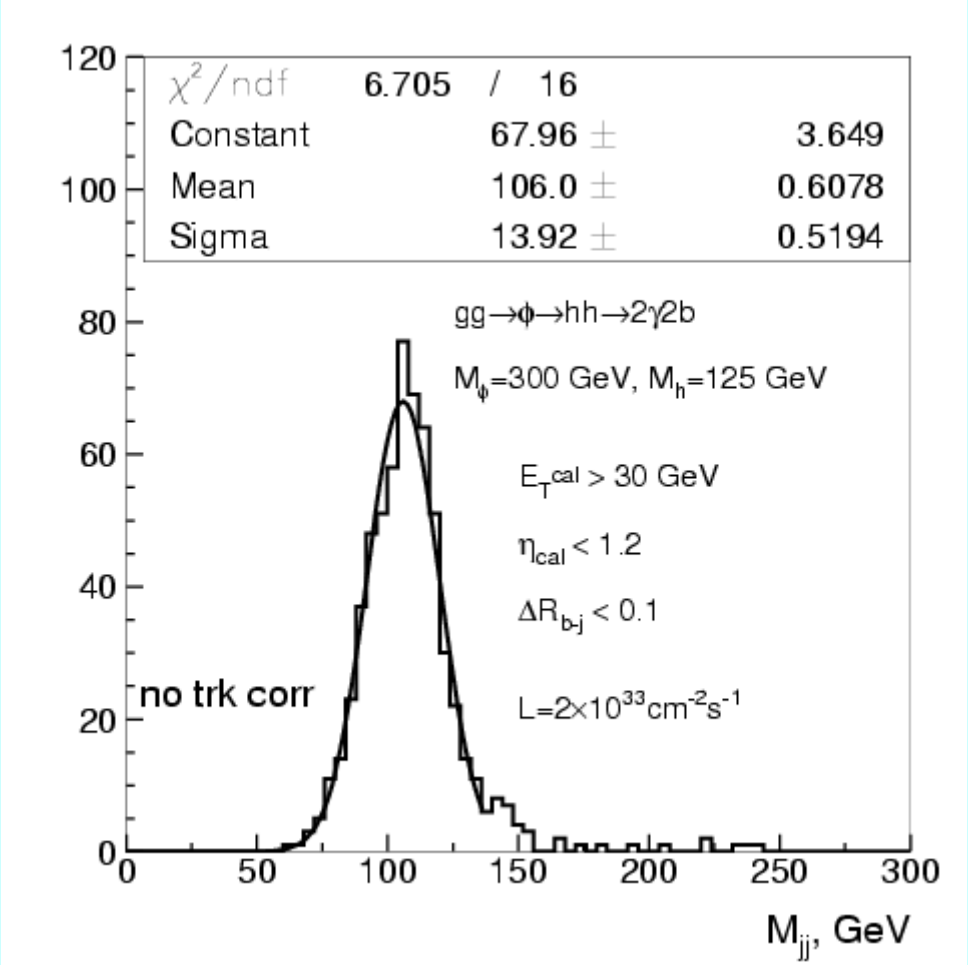


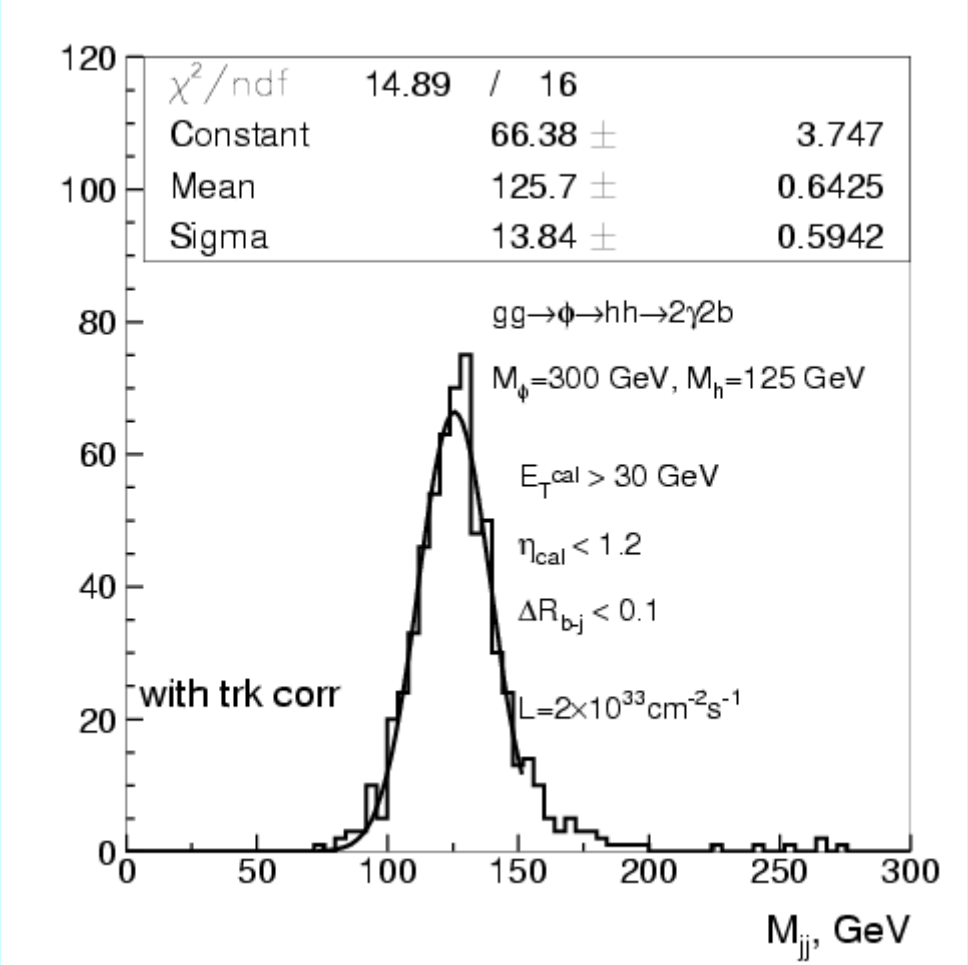
Fit	*Calo*	*Calo+tracks*
mean	*mean*	*0.875*
1.01		
sigma	*0.12*	*0.12*
resol	*13.7%*	*11.9%*

Error of fit parameters:
~0.002 for mean and sigma

gg->ϕ->hh->2γ2b digitized with Low Luminosity pile-up

M_h = 125 GeV





Resolution improves from 13% to 11%.

Mass increases from 106 GeV to 125.7 GeV