Jet Energy Scale at CMS

Anwar A Bhatti

June 8, 2006

XII International Conference on Calorimetry

Chicago IL, USA

Jets at LHC/CMS

- CMS is pp experiment at Large Hadron Collider at $\sqrt{s}$=14 TeV to find Higgs bosons, SUSY, anything beyond SM.
- Good understanding of jets are needed to

  a) us SM to confirm detector is working

  b) higgs → bbbar (DiJet resonances)

  c) missing Et as signature of SUSY

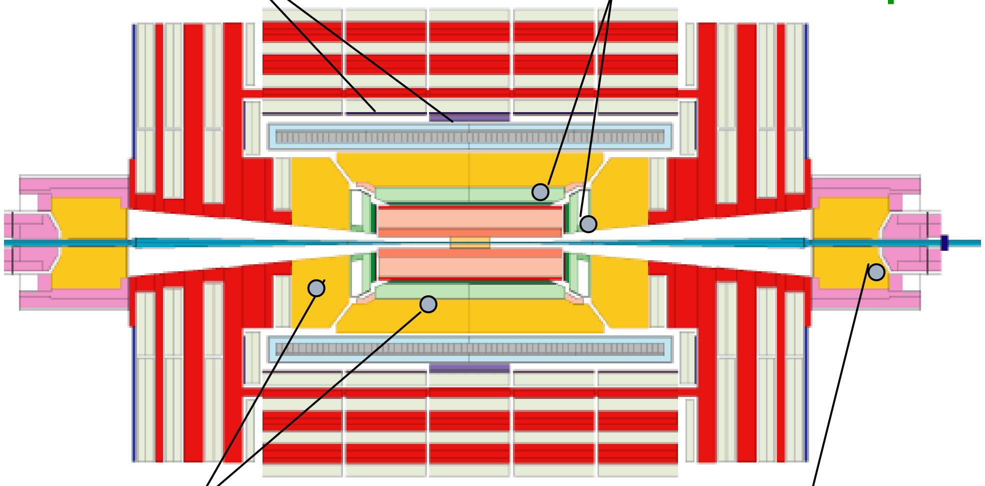
  d) missing Et in Higgs ($H \rightarrow WW \rightarrow l\nu l\nu$, $H \rightarrow ZZ \rightarrow ll\nu\nu$)

  e) rejection of backgrounds to Higgs production

  f) identification of leptons

  g) high energy jets as signatures (high mass Higgs boson, new particles, quark compositeness …)

The CMS Calorimeter



Towers of dimension $\Delta\eta\times\Delta\varphi = 0.087 \times 0.087$ gradually increasing in endcap and forward regions are formed for a total of 4176 tower.

EM calorimeter $|\eta| < 3$:

$PbW0_4$ crystals

1 longitudinal section/preshower 1.1 λ

$\Delta\eta\times\Delta\varphi = 0.0174 \times 0.0174$

Central Hadronic $|\eta| < 1.7$:

Brass/scintillator +WLS

2 + 1 Hadronic Outer – long. sections

5.9 + 3.9 λ ($|\eta| =0$)

$\Delta\eta\times\Delta\varphi = 0.087 \times 0.087$

Endcap Hadronic $1.3< |\eta| < 3$:

Brass/scintillator +WLS

2 or 3 longitudinal sections 10λ

$\Delta\eta\times\Delta\varphi = \sim 0.15 \times 0.17$

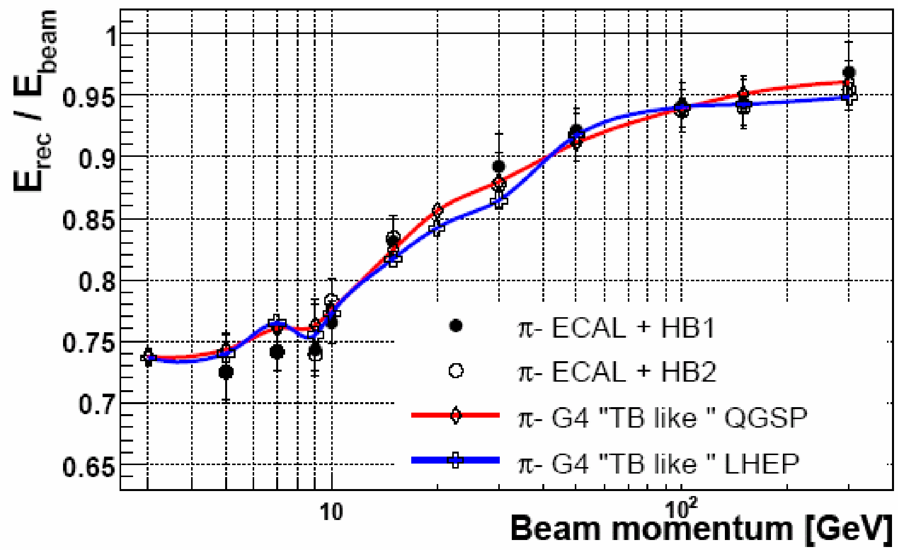
Forward $2.9 < \eta < 5$:

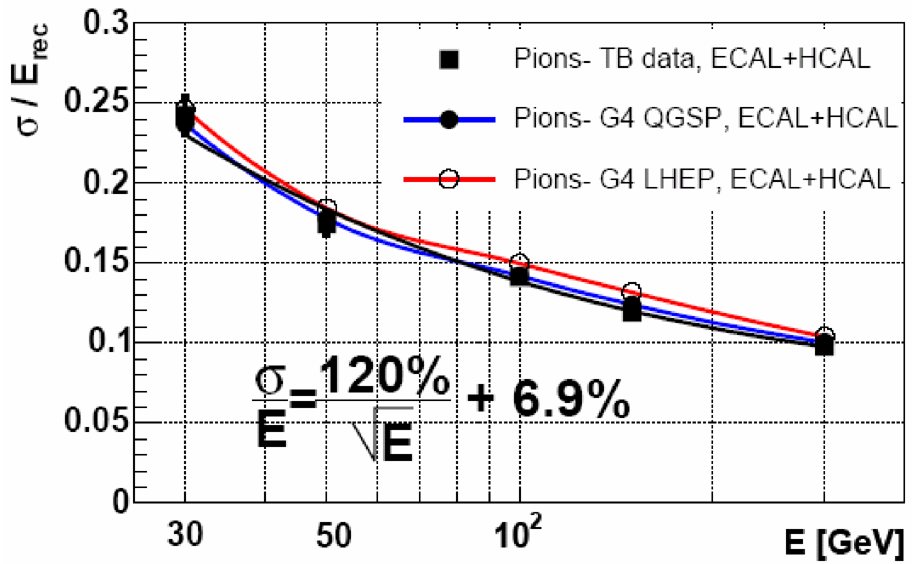
Fe/quartz fibers $\Delta\eta\times\Delta\varphi = \sim 0.175\times 0.17$

Environment

- Located within 4T magnetic field, need photo-detectors which work inside magnetic field.
- At design luminosity, ~20 pp interactions in same bunch crossing.
- Time between two bunch crossing 25 ns.
- Dynamic range up to 4 TeV.

Calorimeter Simulation:



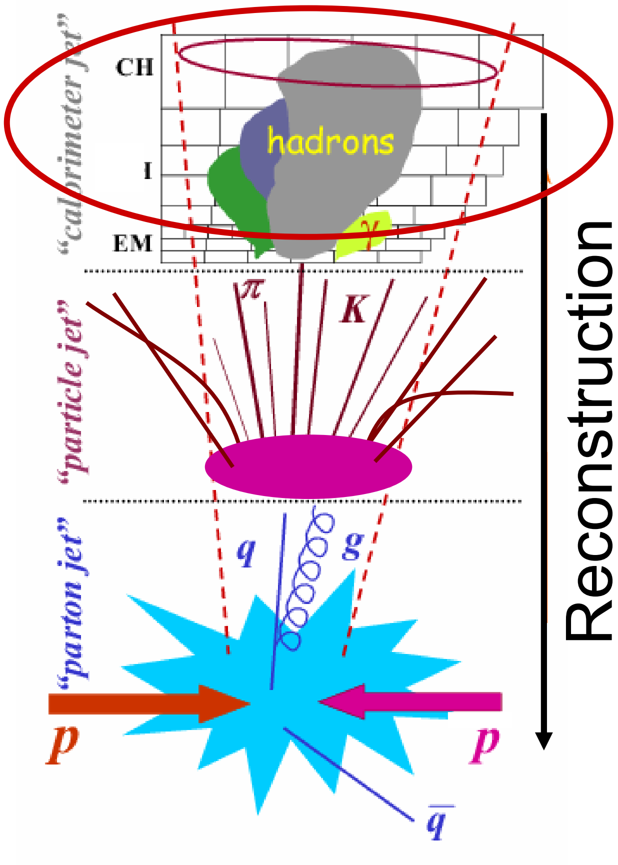


•2004 Combined TB for ECAL and HCAL, energy range 2-300 GeV.

•Monte Carlo describes the linearity and resolution within a few percent.

•More test beam data summer 2006, cleaner beam better particle identification.

Jet Reconstruction



- A calorimeter/particle jet is defined by an algorithm.
- Jet kinematics and corrections depend on the reconstruction algorithm and parameters.

Calorimeter jets

↓

Particle-level jets

↓

Parent Parton

Jet Reconstruction Algorithms

- Simple iterative cone algorithm: Starting with a seed, make cluster by adding towers with R=0.5, mark the used towers and repeat.
- MidPoint Algorithm: Like CDF/D0, make proto-jets around all seed, add extra seed between two proto-jets if separated by <2R and make proto-jets. Merge two proto-jets if 75% of lower jet Pt contained in higher Pt jet, otherwise split towers.
- Kt clustering algorithm: For each object i with transverse momentum kt calculate

$$d = \begin{cases} d_{ii} = k_{T,i}^2 \\ d_{ij} = \min(k_{T,i}^2, k_{T,j}^2)\dfrac{\Delta R_{ij}^2}{D^2} \end{cases}$$

if dmin=dii => jet, otherwise combine i and j, repeat.

Noise Suppression

Cells contribute to the tower energy if they pass the energy thresholds. Different schemes have been tried to evaulate the noise level and jet energy losses.

Scheme	HB GeV	HO GeV	HE GeV	Noise in Cone GeV $\eta = 0$	Jet Energy Loss GeV $\eta = 0$
A	0.7	0.85	0.9	1.4	-
B	0.9	1.1	1.8	0.3	1.0
C	1.2	1.3	1.8	0.2	1.9

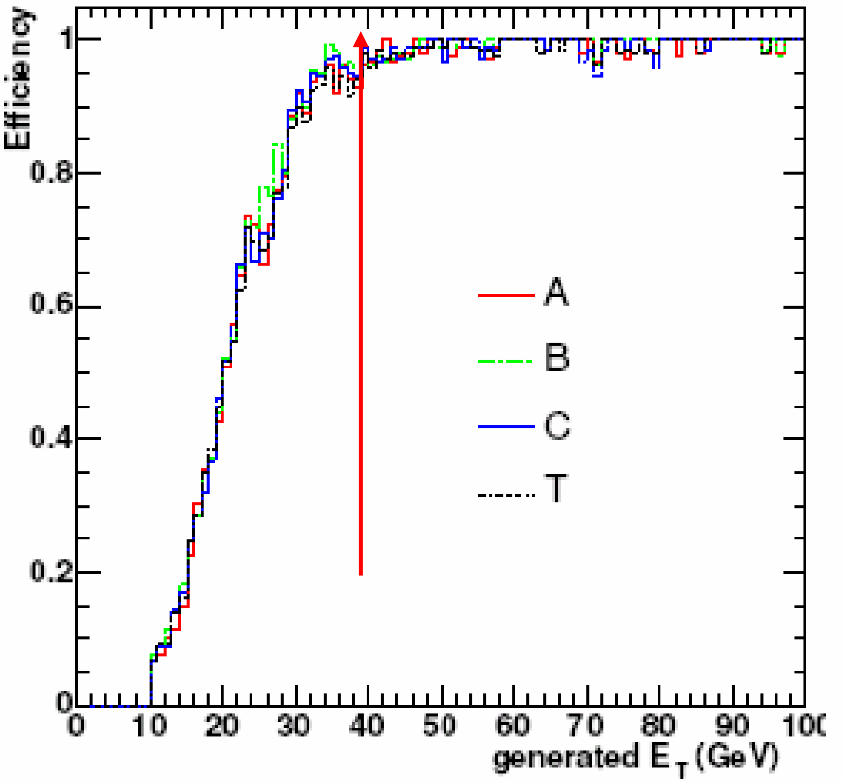
HB Hadron Barrel
HO Hadron Outer
HE Hadron Endcap

A or B schemes are used for physics studies

Reconstruction Efficiency

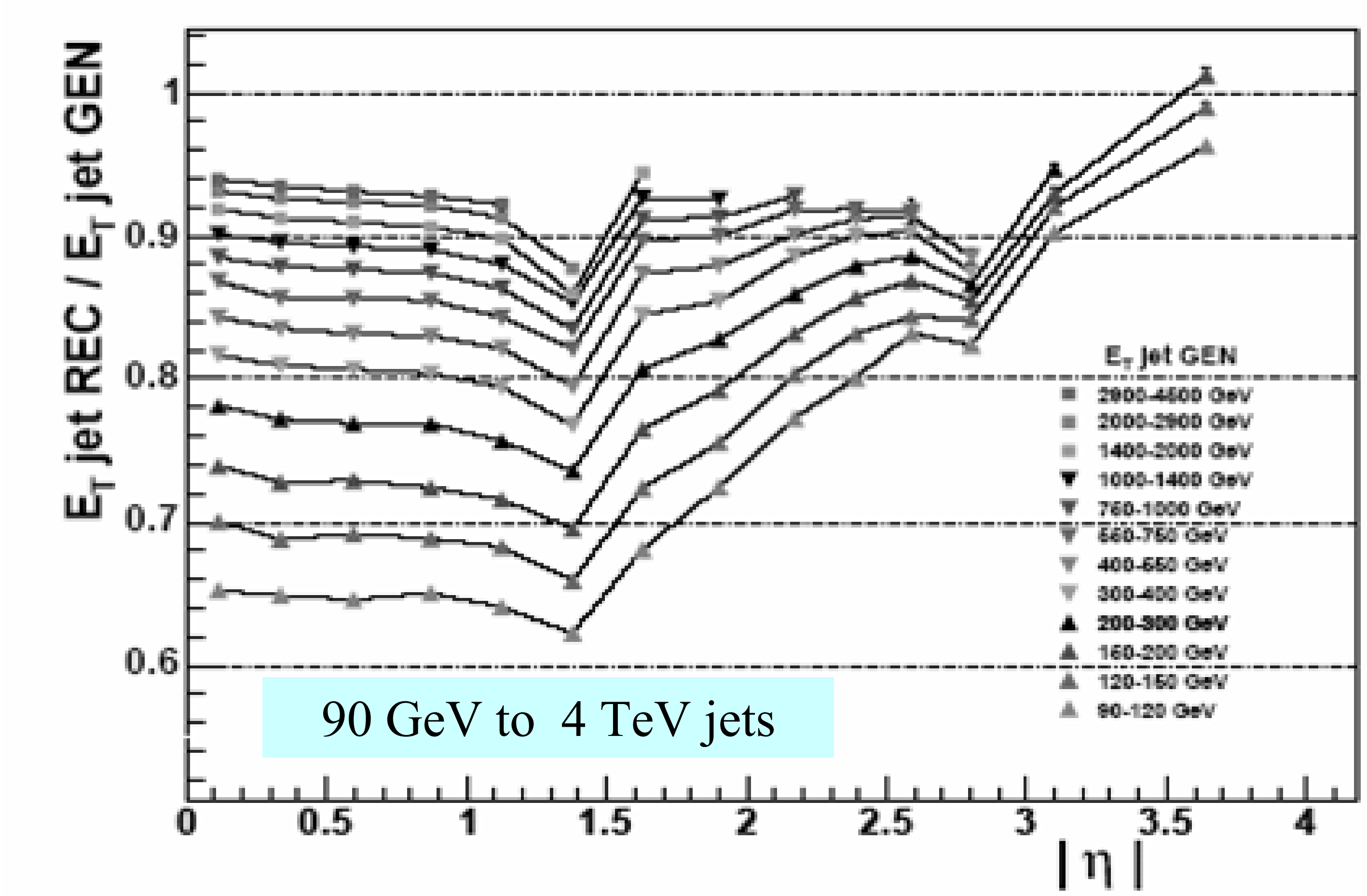
Minimum reconstructed jet E_T to reach 50% efficiency at E_T = 20 GeV has been studied for all noise suppression schemes.

Jet reconstruction are compared for various schemes. Fake rate above p_T threshold is ~0.1 jet/event.



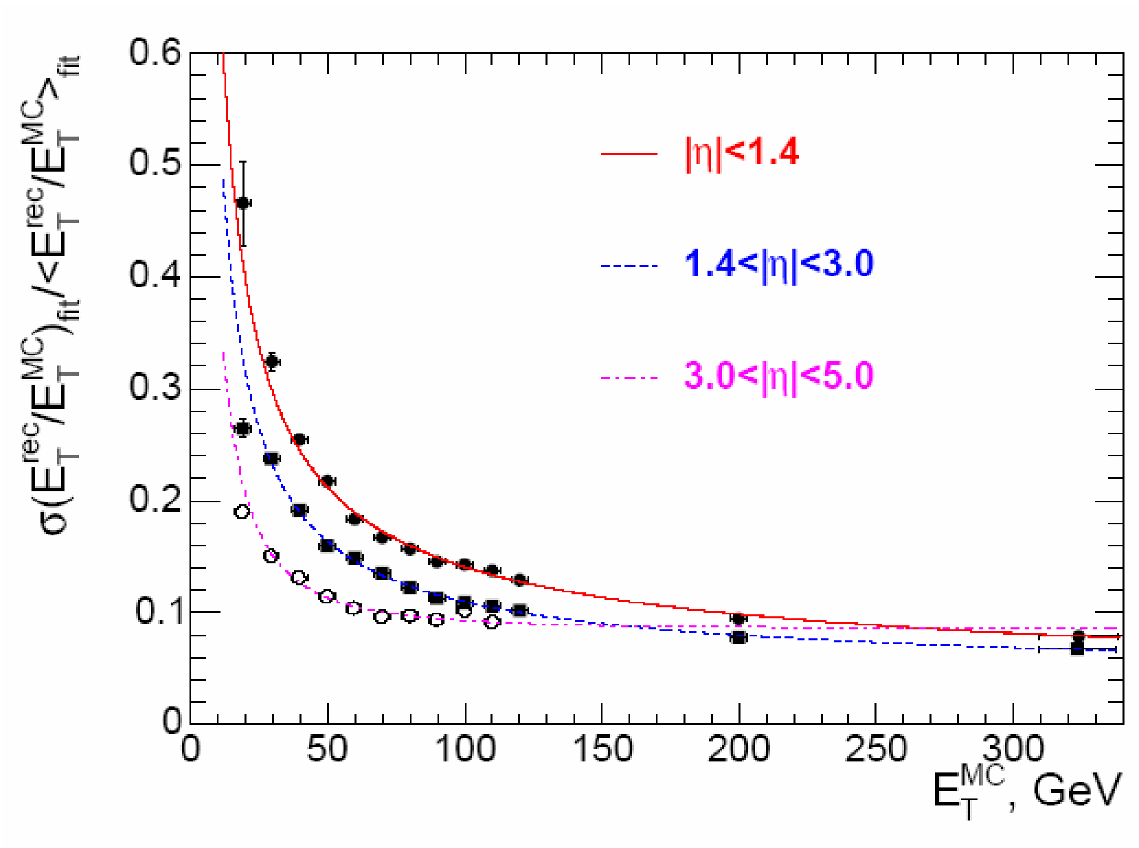
CERN/LHC 2006-1 CMSTDR

Calibrating to Particle Jet using Simulated Data

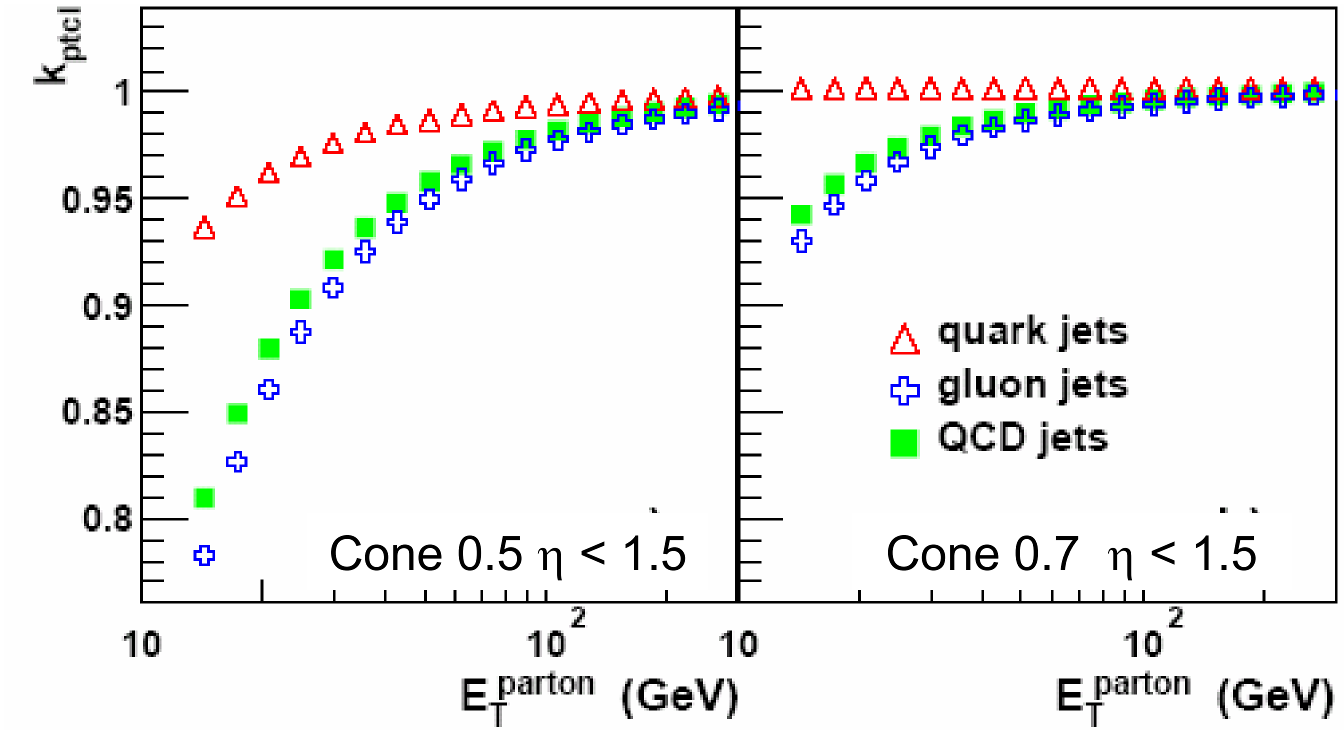


Correction Factor = ETrec/ETParticle as a function of Et and η

Jet Resolution



Parton Energy using Monte Carlo (Pythia)



$$E_T = E_T^{rec} \times \left\langle \frac{E_{Tjet}^{particle}}{E_T^{rec}} \right\rangle \times \left\langle \frac{E_T^{parton}}{E_{Tjet}^{particle}} \right\rangle$$

$1/K_{ptcl}$

- Differences in quark-gluon jets calibration are ~5% level for E_T=40 GeV.

Calibration using data

- Φ symmetry : Uniformity in azimuthal direction.
  - Minimum Bias data
  - Muon Response (Tower to tower variation of pions response may be different)
- DiJet Balancing:
  - Used to make response uniform in η direction
  - Reduce ISR/FSR effects:
    - $\Delta\varphi$> 172 deg, Et-Jet 3< 20 GeV.
- Photon-Jet/Z+Jet Balancing :
  - Check/determine energy scale

CSA06/mock data challenge in Fall 2006.

Absolute Scale using Photon-Jet balancing

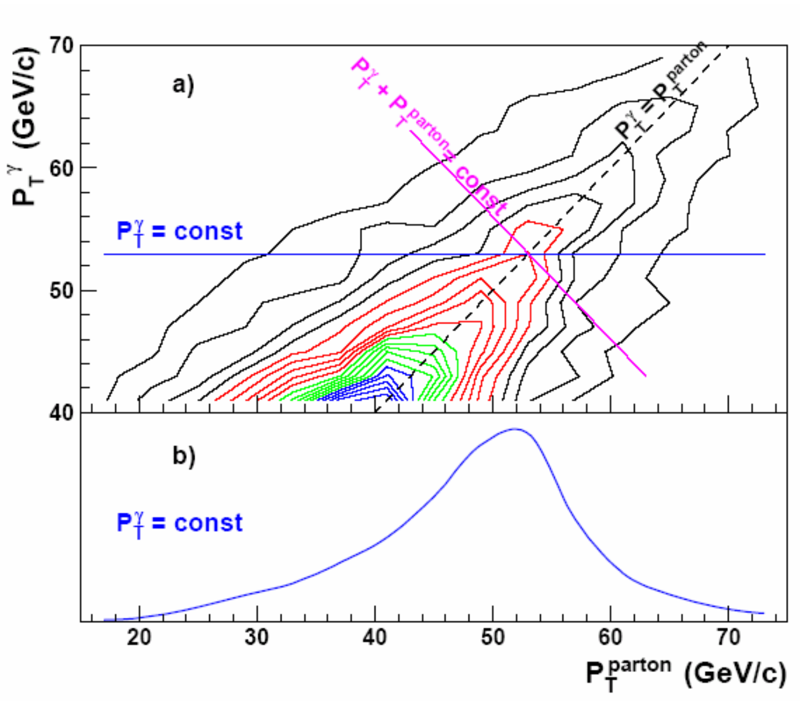
- Decouple the jet energy scale between data and MC events.
  (A short cut: Simulation need not reproduce the data exactly.)
  - Determine particle jet or parent parton energy.
  - ISR and non-linearity in the calorimeter
  - Difference in gluon/quark jets
  - DiJet background (fake photons)
- Photon-jet balancing Techniques:
  - Missing Et Projection Method: Use whole event, determine particle-level jet correction, less sensitive to radiation in the event (currently used by D0).
  - Pt-balance Method: Parent parton energy, less sensitive to low energy calorimeter response. Used by CDF as a cross check. At particle level balance is not not 0.

Calibration Using data: Photon+ Jet balancing

PtJet(parton) = Pt Photon $\rightarrow$kjet = p_TJet/p_T γ

In general photon Pt is not equal to parton Pt.

Use peak position of PtJet/Ptγ distribution to eliminate effect of tail from ISR



Event selection:

Photon isolation

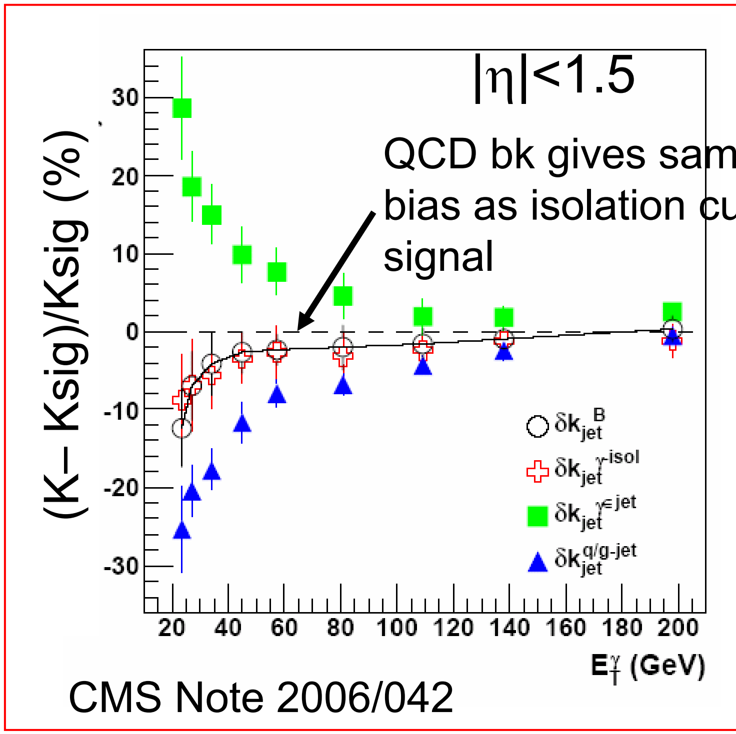
No extra jets with E_T > 20 GeV

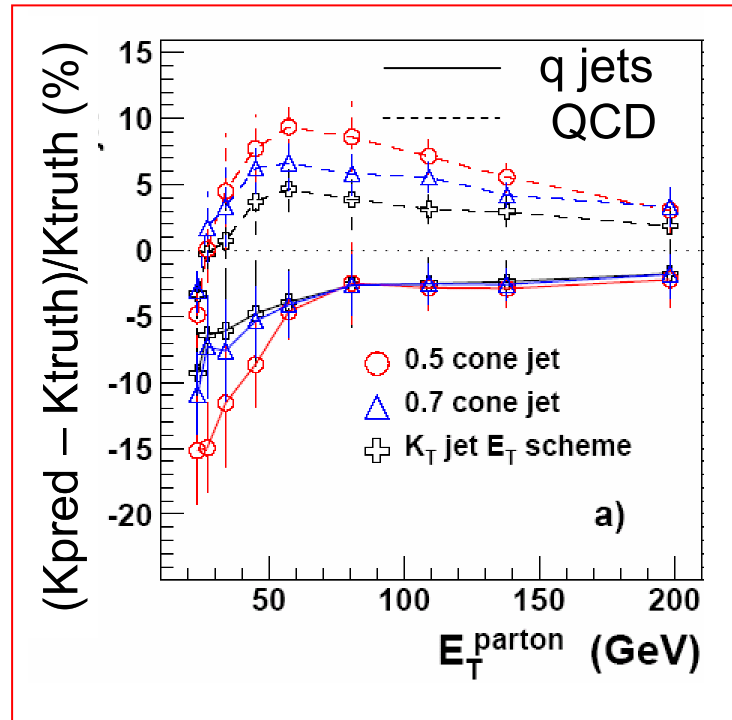
$\Delta\phi(\gamma\text{-jet})>172^o$

Calibration with Photon + jets: Systematics

QCD background, quark/gluon jet differences, jet reconstruction algorithms, analysis selection, noise subtraction schemes give systematic errors on the calibration parameters.

QCD: qg → qγ (90%) qqbar → g γ (10%)





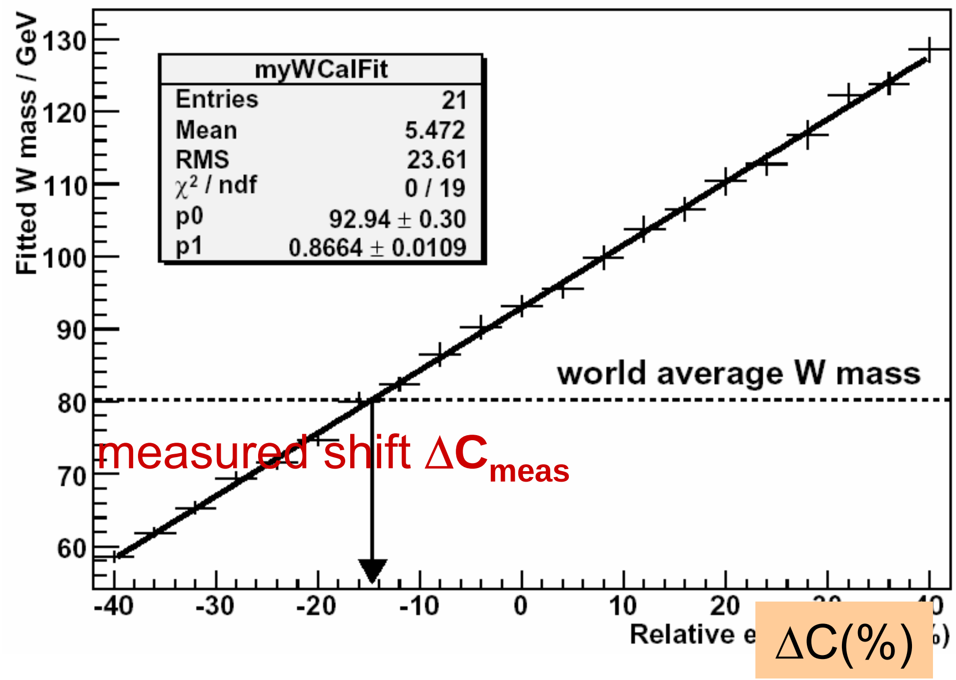
Statistical accurancy with $10fb^{-1}$ is <1% for $E_T\gamma$<800 GeV

W$\rightarrow$ jj in top quark events

❶ Rescale each jet with relative energy shift **ΔC** (rescaling |p| to keep jetmass invariant)

❷ Remake/refit the obtained W mass spectrum → **$m_W(\Delta C)$** from fit

❸ Solve the simple equation **$m_W(\Delta C|\text{data}) = M_W^{PDG}$** → best estimate for ΔC

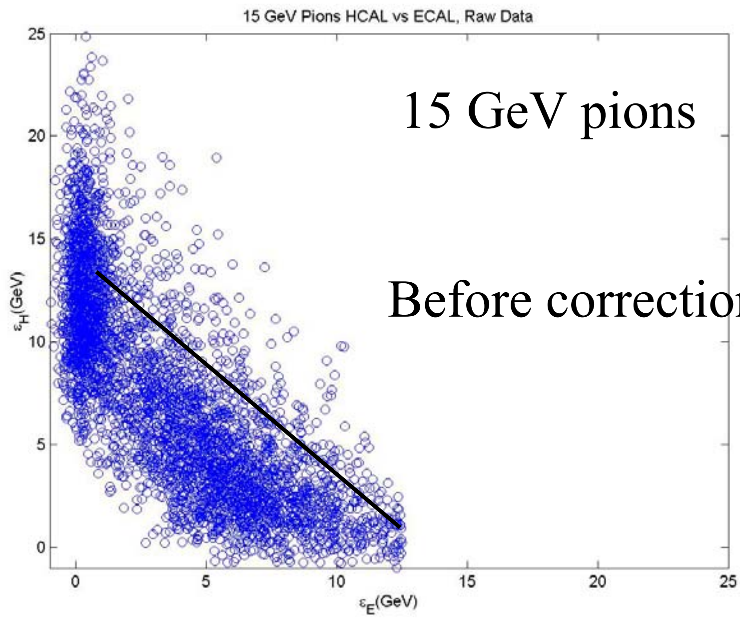


❹ Compare this measured shift with the true shift from Monte Carlo information (for well matched jet-parton couples (ΔR<0.2) one can determine the average ΔC)

<u>Result</u> : ΔC_{meas} = -14.96 ± 0.26 % (ΔC_{true} = -14.53 %) with 5.4 fb^{-1}

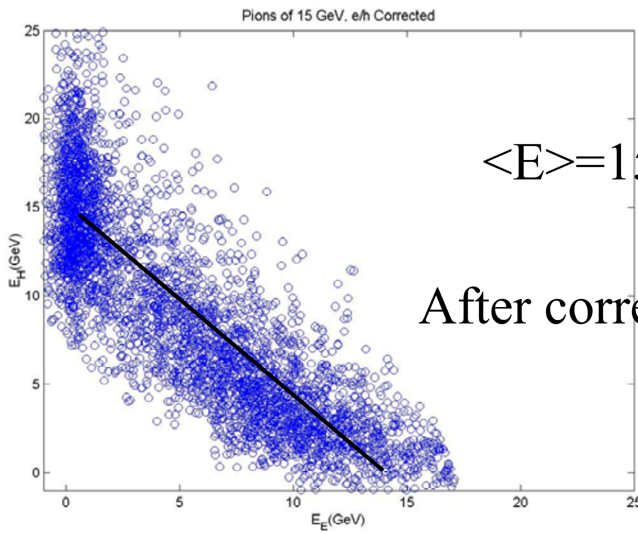
Pile-up (On/Off) = 3%

e/h corrections to single pions



15 GeV pions

Before corrections



<E>=15.41 GeV

After corrections

$$(e/\pi)_E = (e/h)_E / [1 + ((e/h)_E - 1) f_o]$$

$$(e/\pi)_H = (e/h)_H / [1 + ((e/h)_H - 1) f_o]$$

$$E = (e/\pi)_E \varepsilon_E + (e/\pi)_H \varepsilon_H$$

f0 =a3log(e_ecal+e_hcal)^a4

is average neutral fraction of shower.

Three param describe e/h of two sections

Five parameters describe the response obtained from to 10, 30, 100 and 300 GeV test beam data.

Jet energy resolution using local clusters

Identify electromagnetic and hadronic showers within a jet and correct each cluster accordingly.

- Cluster em cells within R=0.03, (3x3 cells)
- Cluster had cells within R=0.15, (0.3x3 cells)
- Match em clusters with had clusters
- Classify clusters based on had/em energies.
- Correct hadronic clusters (particle) for difference in ECAL response to hadron and electrons. ECAL is calibrated for electrons.
- Preliminary studies show ~10% improvement in $|\eta|<1.5$
- More detailed studies in progress

Startup Plan

- For start-up calibration, we rely on the test-beam/radio-active source calibration. Only a few modules have been tested in test beam but calibration is carried to other modules via radio-active sources. The cell-to-cell calibration is good to <4%.
- The minbias data and dijet balancing will be used to make response uniform in φ and η.
- The corrections derived from MC will be used initially.
  - G4-based simulation reproduces the test beam results.
- Photon-jet and Z+jet will be used as cross check or set the scale.

Calorimeter Simulation

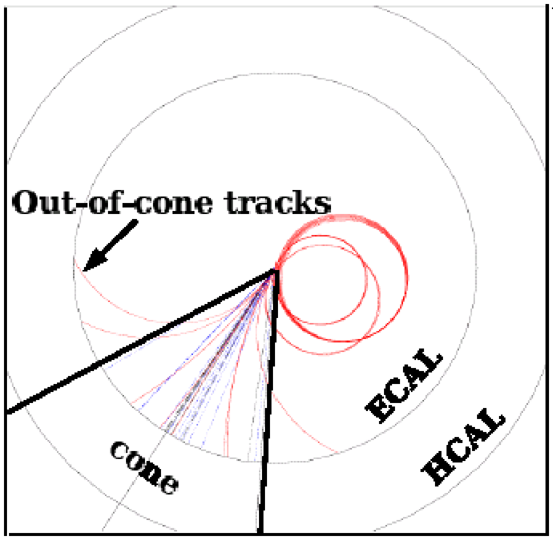
- Even if energy scale is determined from data ($W \rightarrow jj$, photon-jet), it is important to have a good simulation.
- All sophisticated analyses depend on simulations.
- We have test beam data up to 300 GeV.
- For low energy, we plan to have isolated track trigger.
- We are implementing GFlash in CMS software.

Conclusions

- Calorimeter designed, built and tested.
- With a combination of in-situ and simulation based techniques, we will be able to calibrate the jet energy scale to a few percent accuracy.

BACKUP

Energy Flow in CMS

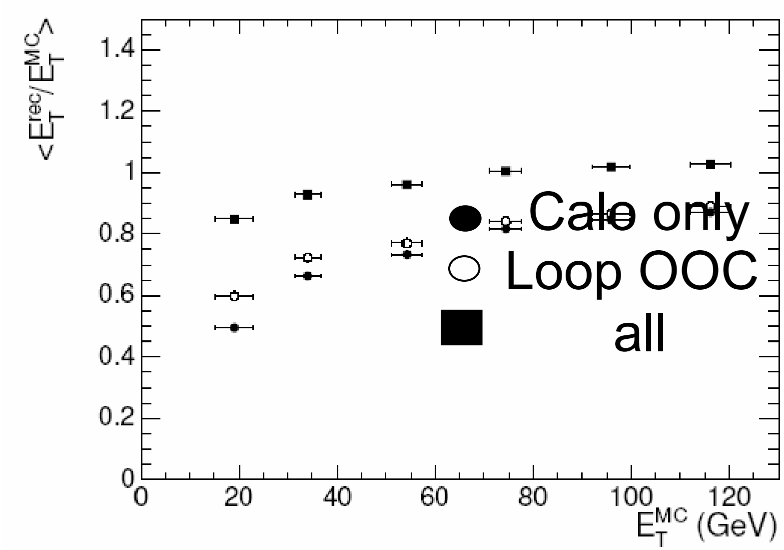


Two corrections: *1.* Loopers and swept out tracks are measured in inner detector

2. Charged tracks in cone are measured in inner detector and corresponding calorimeter response is subtracted (based on TB response)

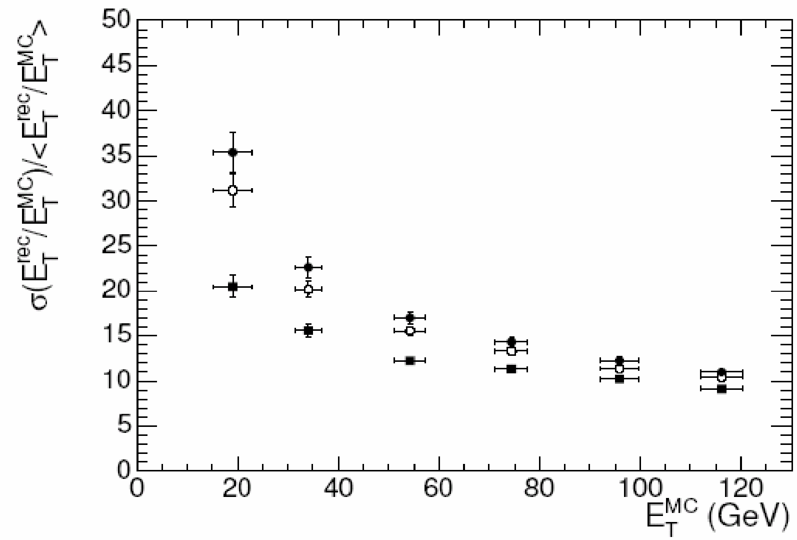
Performances are evaluated on QCD with no UE. 10% resolution improvement on Z'→jj 120 GeV

Cone 0.5 - η < 0.3

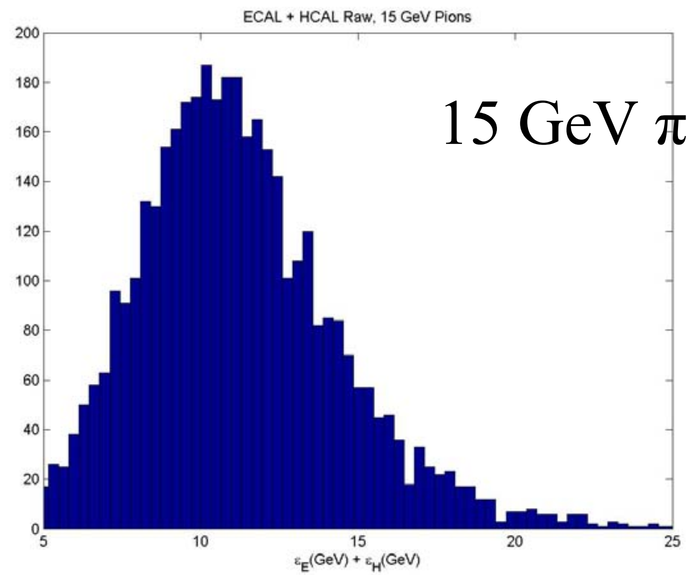


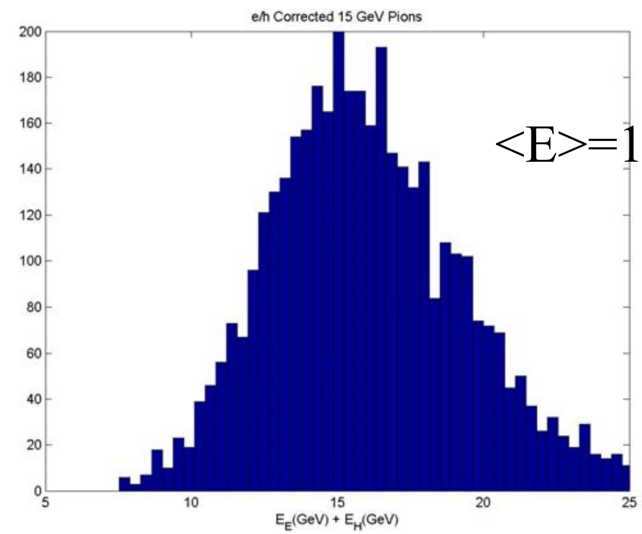
hat

Cone 0.5 - η < 0.3



e/h corrections to single pions





$$(e/\pi)_E = (e/h)_E / [1 + ((e/h)_E - 1) f_o]$$

$$(e/\pi)_H = (e/h)_H / [1 + ((e/h)_H - 1) f_o]$$

$$E = (e/\pi)_E \varepsilon_E + (e/\pi)_H \varepsilon_H$$

f0 =a3log(e_ecal+e_hcal)^a4

is average neutral fraction of shower.

Three param describe e/h of two sections

Five parameters describe the response obtained from to 10, 30, 100 and 500 GeV test beam data.