Jet Calibration Experience in CDF

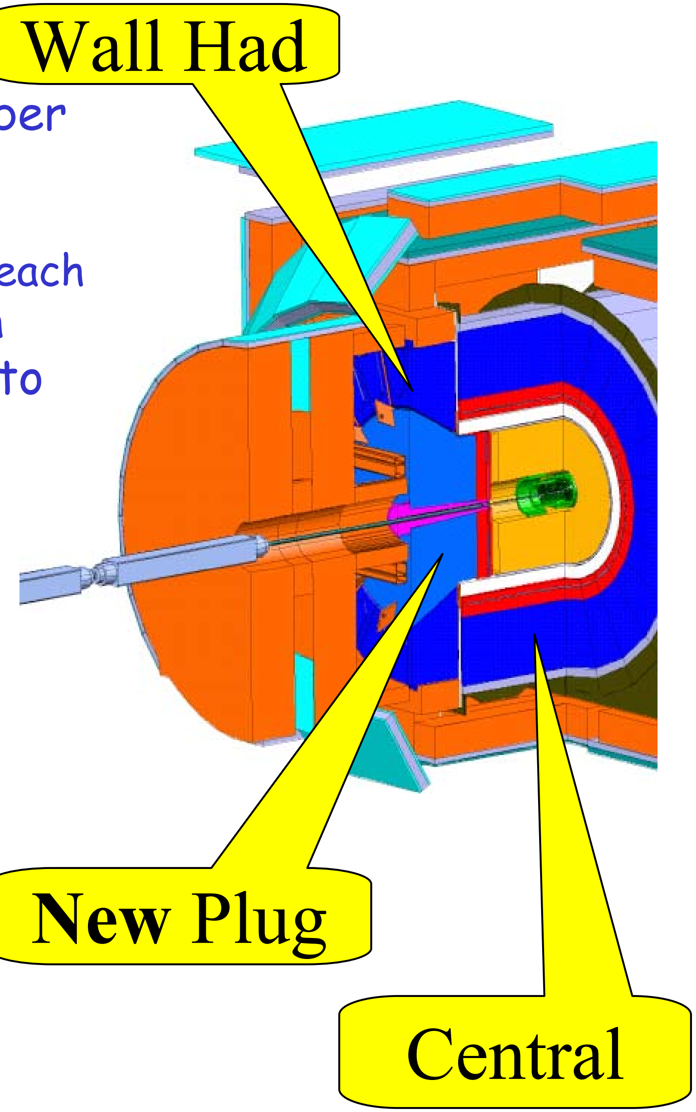
Beate Heinemann
University of Liverpool

- -CDF calorimeter
- -Relative Calibrations
- -Absolute Calibration
- -Multiple Interactions
- -Summary

CMS Jet and Met Workshop, 01/28/2004

CDF calorimeter

- Central and Wall($|\eta|<1.2$):
  - Scintillating tile with lead (iron) as absorber material in EM (HAD) section
  - Coarse granularity:
    - Φ: 24 towers cover 15 degrees in azimuth each
    - η: 10 towers cover 0.1 unit in rapidity each
  - Non-compensating➔ non-linear response to hadrons
  - Rather thin: 4 interaction lengths
  - Resolutions:
    - EM energies: $\sigma/E=13.5\% / \sqrt{E}$
    - HAD energies: $\sigma/E=80\% / \sqrt{E}$
- New Plug ($1.2<|\eta|<3.6$):
  - Similar technology to central
  - Differences
    - 48 towers in azimuth
    - EM energies: $\sigma/E=16 \% / \sqrt{E}$
    - HAD energies: $\sigma/E=80 \% / \sqrt{E}$
    - More linear response
    - Thicker: 7 interaction lengths



Overview

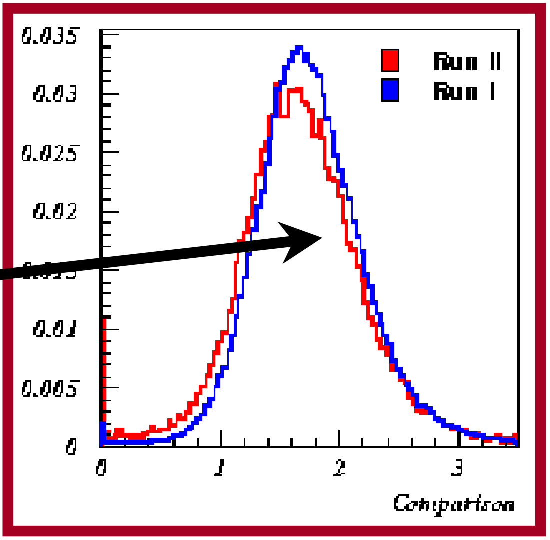
1. Calibrate EM and HAD calorimeters in situ
2. Reconstruct jets (JetClu cone algorithm):PT^{raw}
3. Correct jets in plug calorimeter w.r.t. central "relative corrections": f_{rel}
   - use di-jet data (versus η)
4. Correct for Multiple pp Interactions : UEM
5. Correct measured jets back to particle level jets: tune MC simulation: f_{abs}
   - Response of calorimeter to single particles
   - Fragmentation: Pt spectra in data
6. Correct for Underlying Event: UE
7. Correct particle jet back to parton: OC

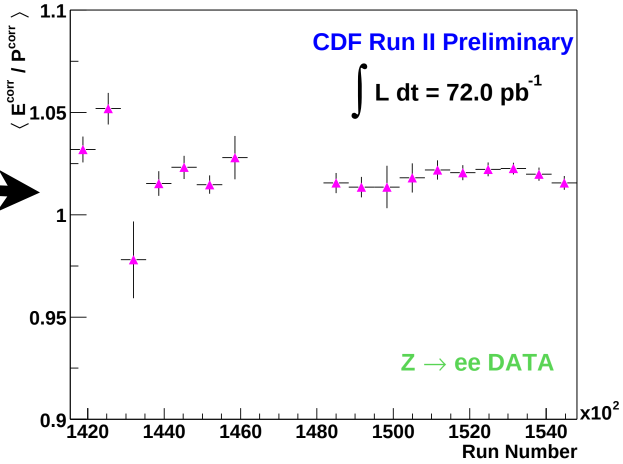
$$P_T(\Delta R) = (P_T^{raw}(\Delta R) \times f_{rel} - UEM(\Delta R)) \times f_{abs}(\Delta R) - UE(\Delta R) + OC(\Delta R)$$

Systematic error associated with each step

In Situ Calorimeter Calibration I

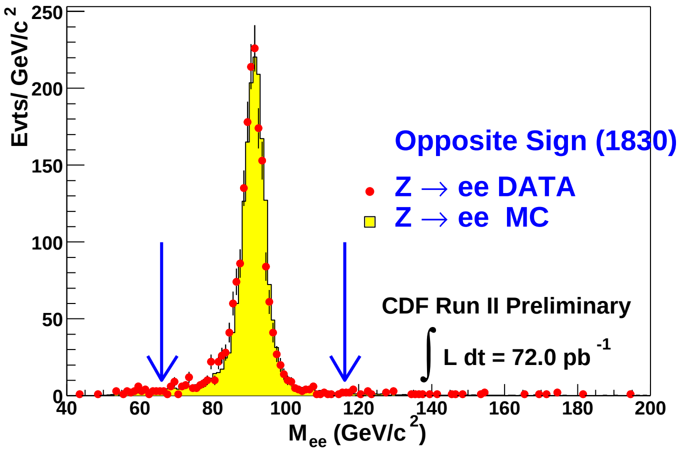
- Minimum Ionising Particle (MIP):
  - J/Ψ and W muons
  - peak in HAD calo: ≈2 GeV
  - Peak in EM calo: ≈300 MeV
  - Check time stability and run1 versus run2
  - Applicable where muon coverage: η<1.4
- E/p of electrons:
  - p calibrated on J/Ψ mass
  - Time dependence of E/p checked

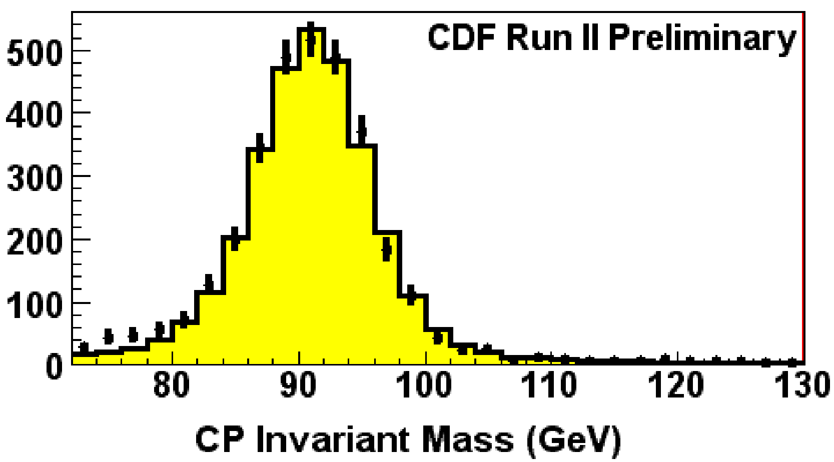




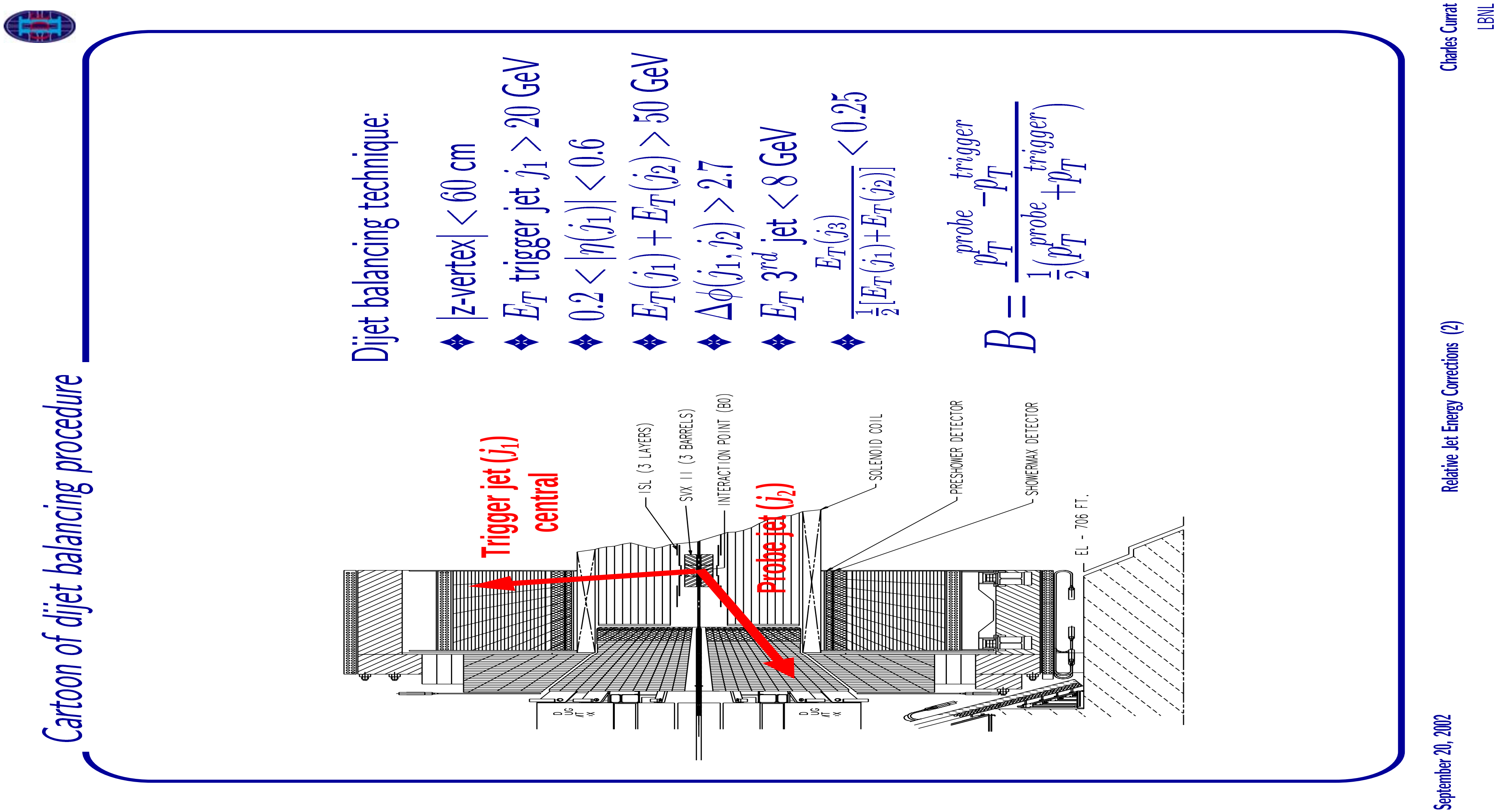
In Situ Calorimeter Calibration II

- $Z \rightarrow ee$ peak:
  - Set absolute EM scale in central and plug
  - Compare data and MC: mean and resolution
  - Applied in Central and Plug
- MinBias events:
  - Occupancy above some threshold: e.g. 500 MeV
  - Time stability
  - Phi dependent calibrations: resolution



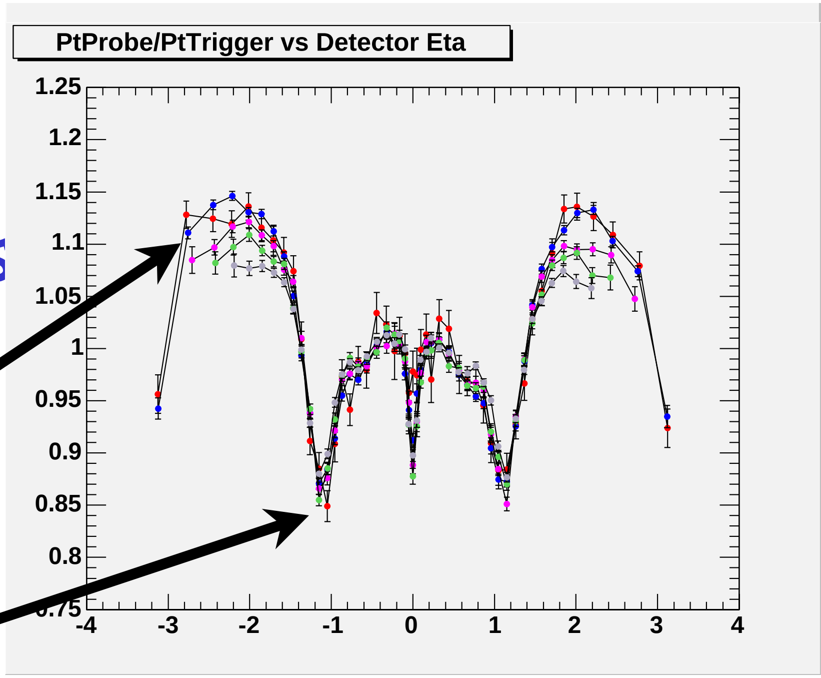


Relative Corrections: Dijet Balance



Relative Corrections

- Calibration Factor:
  Pt(probe)-Pt(trigger)/[0.5(Pt(probe)+Pt(trigger)]
- Probe jet: $0.2<\eta<0.7$
- Mapping out cracks and response of new Plug calorimeter
- Central at 1 by definition
- Colours: different Et ranges
- Use γ-jet for systematics



Plug Calorimeter

Crack between Central and Plug

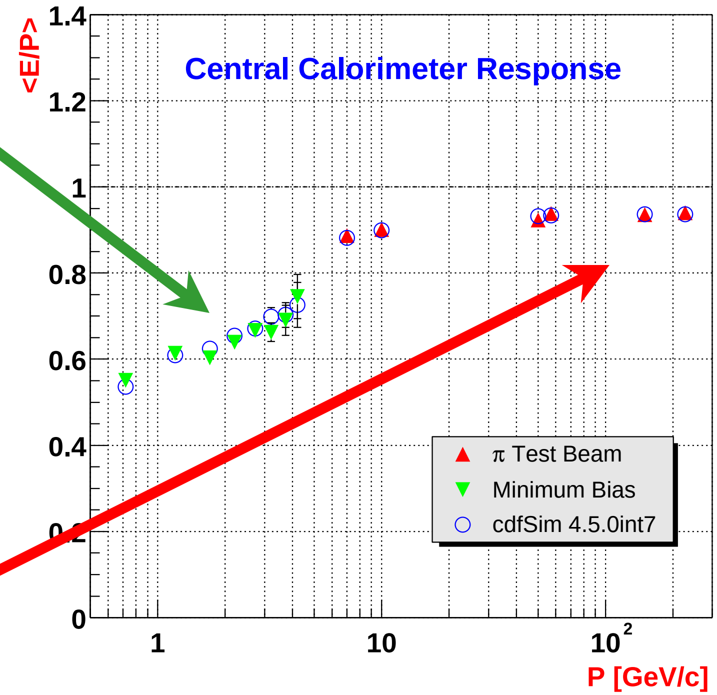
Detector to Particle Level

- Do not use data since no high statistics calibration processes at high Et>100 GeV
- Extracted from MC ➔ MC needs to
  1. Simulate accurately the response of detector to single particles (pions, protons, neutrons, etc.):
     CALORIMETER SIMULATION
  2. Describe particle spectra and densities at all jet Et:
     FRAGMENTATION
  - Measure fragmentation and single particle response in data and tune MC to describe it
  - Use MC to determine correction function to go from observed to "true"/most likely Et:

$$E^{true}=f\,(\,E^{obs},\,\eta,\,\mathrm{conesize})$$

Single Particle Response

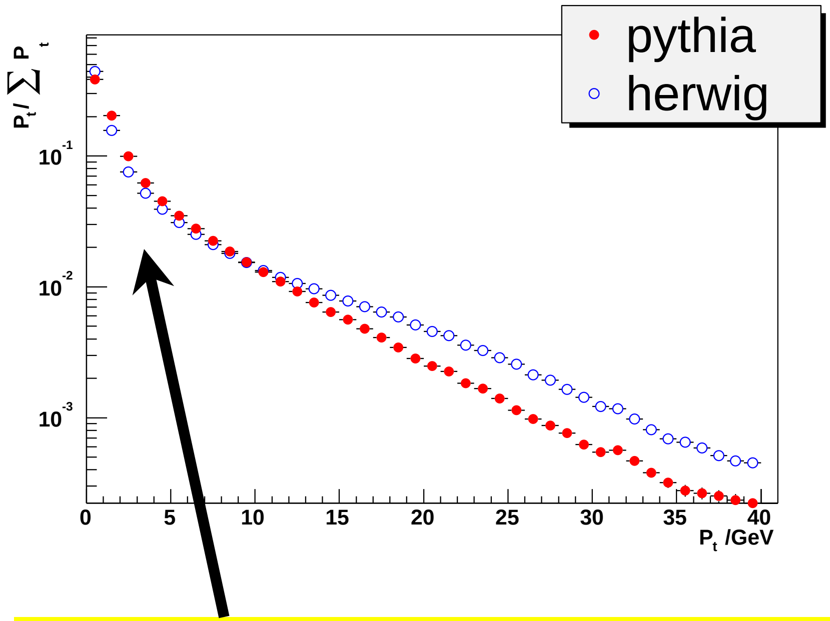
- Low Pt (1-10 GeV) in situ calibration:
  - Select "isolated" tracks and measure energy in tower behind them
  - Dedicated trigger
  - Perform average BG subtraction
  - Tune GFlash to describe E/p distributions at each p (use π/p/K average mixture in MC)
- High Pt (>8 GeV) uses test beam:
  - Could try τ-leptons
- Non-linearity: response drops by 30% between 10 and 1 GeV



B. Heinemann

Fragmentation

- Due to non-linearity of CDF calorimeter big difference between e.g.
  - 1 10 GeV pion
  - 10 1 GeV pions
- Measure number of and Pt spectra of particles in jets at different Et values as function of track Pt:
  - Requires understanding track efficiency inside jets
  - Ideally done for each particle type (π, p, K)



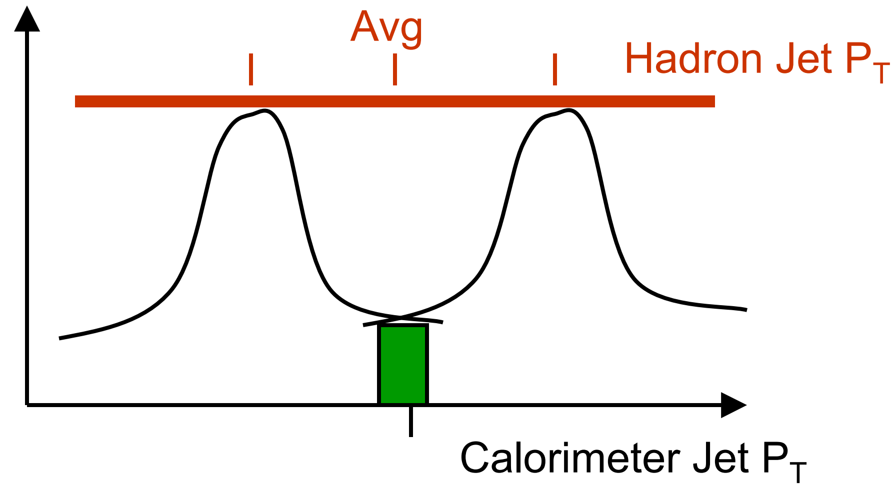
E.g. difference in fragmentation between Herwig and Pythia may result in different response

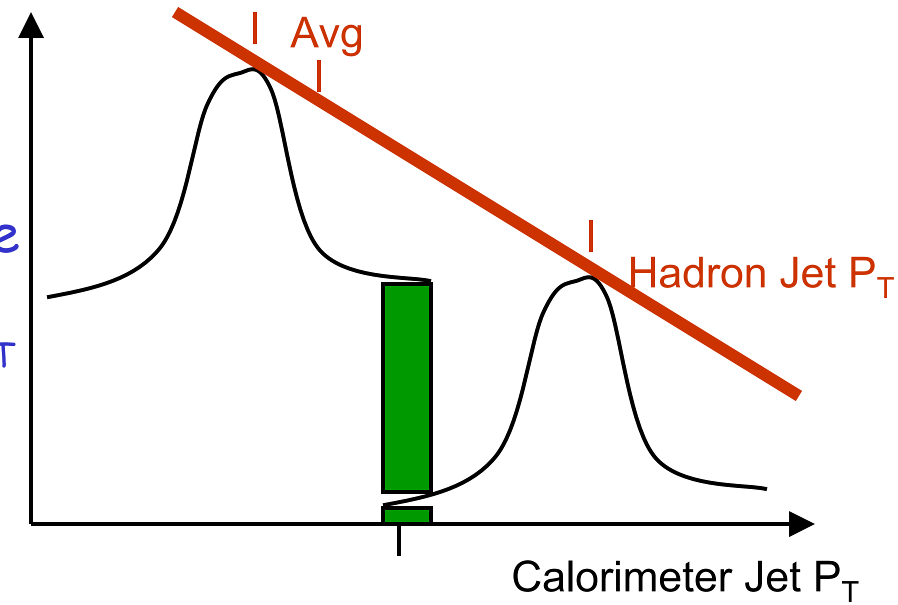
Absolute Correction from MC

- Wanted:
  - Most likely true Et value for given measured Et value
- BUT cannot be obtained universally for all analyses since it depends on Et spectrum:
  - E.g. most likely value in falling spectrum dominated by smearing from lower Et bins
  - Different for flat Et spectrum (e.g. top or new resonance)
- CDF:
  - Provide standard "generic" jet corrections using flat Pt spectrum
  - Individual analyses determine their "specific" residual corrections themselves from their MC

Flat vs. QCD Spectra

- For both spectra
  - There is an average P_T shift of hadron jets to calorimeter jets.
- With a Flat spectrum.
  - After accounting for the average shift there are roughly as many low P_T as high P_T jets "smearing" into the calorimeter P_T bin.
- With a QCD spectrum
  - After accounting for the average shift, there are significantly more low P_T jets than high P_T jets "smearing" into the calorimeter P_T bins.
- The QCD spectrum correction is therefore significantly lower.





B. Heinemann

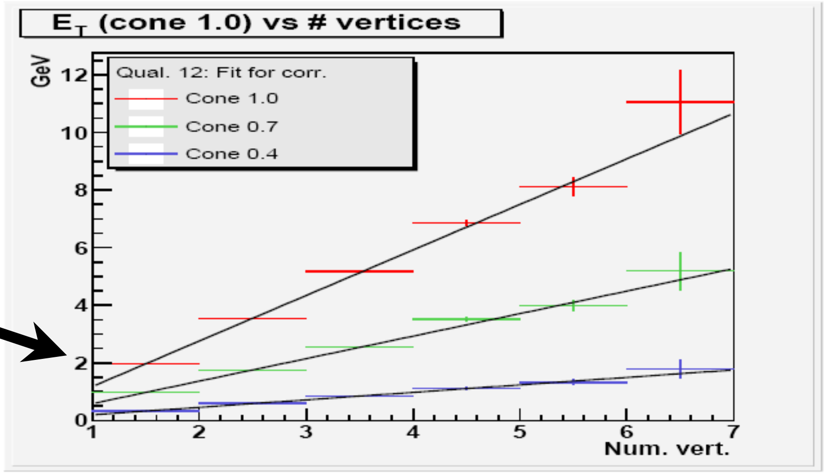
Absolute Corrections

- Use MC with "flat" Et distribution
- Separately for each cone size: 0.4, 0.7 and 1.0
- Correction factor decreases with Et due to non-linearity of calorimeter, e.g. cone 0.4:
  - 50 GeV: ≈25%
  - 500 GeV: ≈15%
- Systematic errors due to
  - Test beam precision
  - γ-Jet and Z-jet balancing agreement between data and simulation after correction➔ see later

Multiple pp Interactions

- Extra pp interactions will increase the jet Et values of primary hard interaction
- subtract off average energy in cone per interaction:
  - Number of interactions = Number of observed vertices
  - Random cone in MinBias data: E_t versus N_{vtx}

E.g. ≈0.8 GeV per vertex for cone 0.7

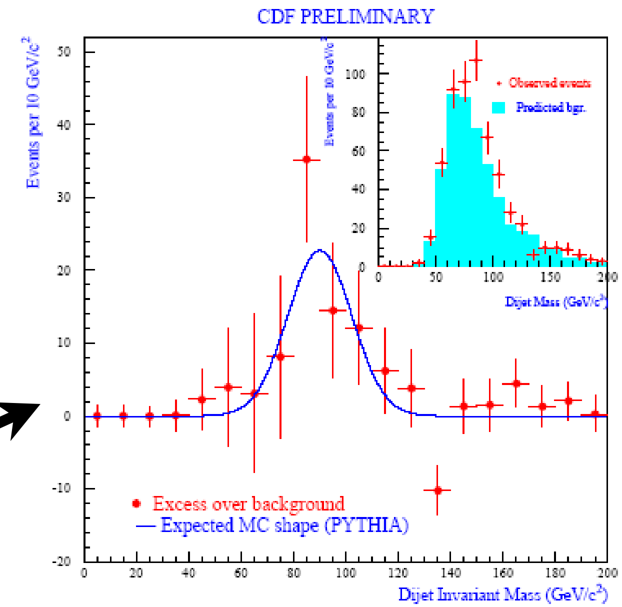


Systematic Errors I

- Procedural Errors:
  - E.g. spline of rel. corrections
  - E.g. 30% error on Multiple Interactions
  - E.g. vary fragmentation within exp. Errors
  - E.g. check Pythia vs Herwig
  - E.g. test beam precision
- Check that calibration processes are okay within the quoted errors → next slide

Systematic Checks

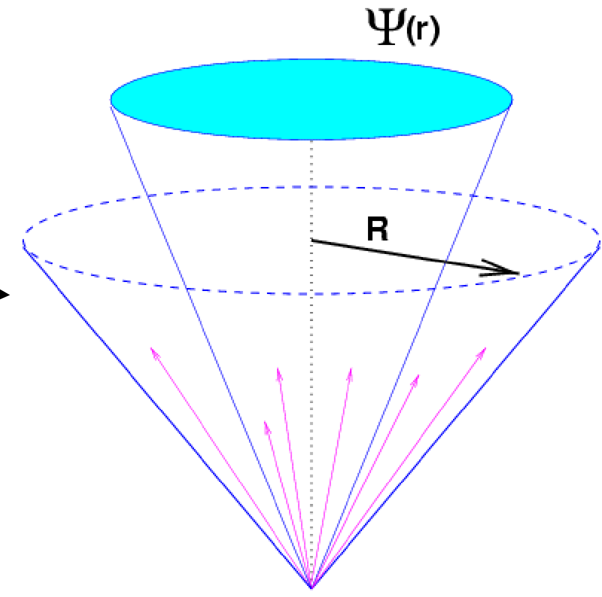
- γ-Jet:
  - highest statistics ☺
  - systematically limited (kt-kick, BG contributions: π^0) ☹
  - Not available for Et<25 GeV (trigger) ☹
- Z-Jet:
  - Usable at all Et values ☺
  - lower statistics than γ-jet at high Pt ☹
  - No kt-kick effect ☺
- Z→bb:
  - Nice to have calibration peak ☺
  - Only for b-jets and difficult to trigger 😐
  - Small signal on large background ☹
- W→jj in double b-tagged top events:
  - Expect 250 double-b-tagged top events in 2/fb ➔ 1-2 % precision? ☺
  - In LHC expect 45,000 double b-tagged ttbar per month! ☺



BUT none of them can test Jets with Et>200 GeV ☹

Some More Lessons…

- Out-of-Cone correction:
  - Jet shape in MC must describe data: measure e.g. energy flow between cones of 0.4 and 0.7
  - Material in tracking volume: e.g. conversions will change corrections (CDF sees this between run 1 and run 2 Silicon detectors)



- Test beam:
  - Cover low energies: can compare in situ E/p to test beam
  - Map out longitudinal shower profile
  - Ability to rerun test beam on extra module: in case something goes wrong…

Summary

- Calibration signals:
  - MIP peak, E/p, Z→ ee and Min Bias for calorimeter calibration
  - Di-jet balancing for relative response in cracks and in plug calorimeter
  - Isolated tracks for understanding calorimeter response to π, p, K (fragmentation needs to be modeled)
- Independent channels used for cross checks/systematic error:
  - γ-Jet and Z-jet balancing
  - Z→ bb peak and W→jj peak in tt events

Excellent simulation required, particularly for high Et jets where no physics channels available for calibration