Jet Energy Scale Determination at DØ

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CALOR 2006
Chicago, IL

Outline

- The DØ Experiment
- Calorimeter
- Jet Algorithm

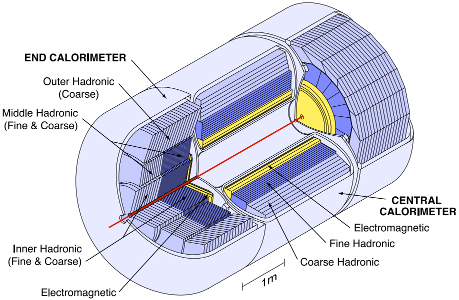
- Jet Energy Scale Determination
    - The Idea and Strategy
    - JES Subcorrections
    - Uncertainties
    - Closure Tests

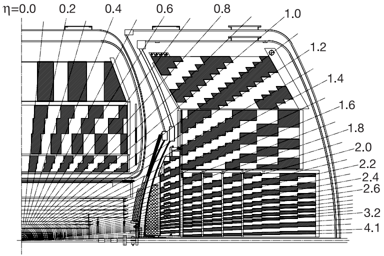
- Summary

Motivation

- With the 1fb^{-1} Run IIa dataset, we can explore a wealth of unique data.
- Most physics analyses involve jets in the final state.
- Precision jet energy calibration is an essential input to already systematics limited measurements.
- Increased luminosity yields high statistics and potential to reach high accuracy.
- Here we present the preliminary JES determination on $150\ \text{pb}^{-1}$, the full $\approx 1\ \text{fb}^{-1}$ analysis being in progress.
- DØ has performed a full Calorimeter Calibration (ϕ-intercalibration as well as absolute calibration).
- New and more advanced JES procedure and tools have been developed.

DØ Calorimeter





- With our Calorimeter, the strength of DØ at Run I, we are now challenged by the shorter bunch crossing (396ns) and shorter charge integration time at Tevatron Collider Run II.
- Uranium-Liquid Argon Calorimeter, uniform hermetic coverage $|\eta| \leq 4.2$ $[\eta \equiv -\ln\tan(\theta/2)]$
- Fine segmentation up to $|\eta| < 3.2$: $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$

Run II Cone Jet Algorithm

- Use particles as **seeds**:
  - Experiment - calorimeter clusters (above given threshold).
  - Monte Carlo - stable particles.
  - pQCD - partons.
- Use the 4-vector scheme:
  - p_T instead of E_T.
  - rapidity $y = \frac{1}{2} \ln \frac{E+p_z}{E-p_z}$ instead of pseudorapidity η.
- Combine 4-vectors within a cone of radius R_cone in $y \times \phi$

$$\Delta R = \sqrt{\Delta y^2 + \Delta\phi^2} < R_\text{cone} \, .$$

- Calculate jet axis - iterate until the solution is stable.
- Add midpoints between jets as additional seeds ⇒ infrared safe.
- Remove identical solutions, and treat overlapped jets.
- Keep only jets with transverse momentum grater then $6\,\mathrm{GeV}$.

Jet Energy Calibration: Strategy

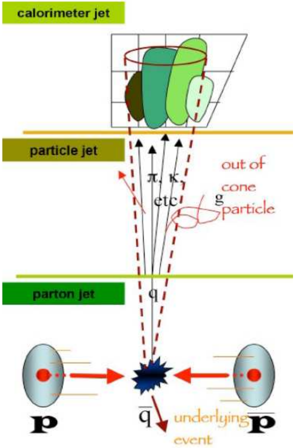
- The aim of the Jet Energy Scale (JES) procedure is to bring calorimeter jet energies to the level of stable particle jets.
- There are physics, instrumental and jet algorithm effects to be corrected for.
- The agreement between simulation and Data is not precise enough to use only Monte Carlo samples.
- We need to employ in-situ calibration, derive JES separately for Data and Monte Carlo.
- Perform systematics cross checks and detailed error analysis.
- Closure tests: compare Data, Monte Carlo and particle jets.
- Main samples: $\gamma+$jets, dijet events, $Z+$jets.
- Calibrate separately Run II Algorithm Jets of Cone 0.5 and 0.7.

Jet Energy Calibration - Method

- Correct energy to particle level:

$$E_{\text{new}} \equiv \frac{E_{\text{raw}} - \mathcal{O}}{\mathcal{F}_\eta \cdot \mathcal{R} \cdot \mathcal{S}}$$

- **Offset** (O) is the energy not associated with the hard scatter: pile-up, multiple interactions, underlying event, noise.
- **η dependent correction** $(\mathcal{F}_\eta)$ uniforms the response in η.
- **Response** (R) is calorimeter response to jets. Measured in $\gamma +$ jet events, dominant correction.
- **Showering** (S) is fraction of energy inside the jet cone after particles showering out of the cone in the calorimeter.



Jet Energy Calibration - Method

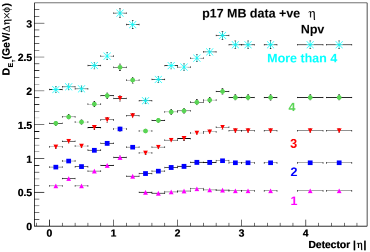
- In more detail, the corrections are derived in a sequential way, so the decomposition actually reads:

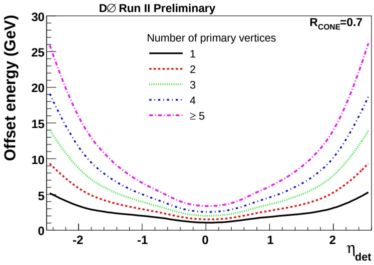
$$E_{\text{new}} \equiv \frac{E_{\text{raw}} - \mathcal{O}(R_{\text{cone}};\, \eta, \mathcal{L}, n_{\text{PV}})}{\mathcal{F}_\eta(E_{\text{raw}} - \mathcal{O}) \cdot \mathcal{R}\left(R_{\text{cone}};\, \frac{E_{\text{raw}} - \mathcal{O}}{\mathcal{F}_\eta}\right) \cdot \mathcal{S}(R_{\text{cone}};\, E_{\text{raw}})}$$

- First measure the Offset as a function of η, inst. luminosity and number of Primary Vertices (multiple interactions dependence).
- Derive η-dependent correction in several energy bins.
- Use η+Offset corrected energy as input to Response measurement.
- Derive the Showering correction separately for 0.5 and 0.7 Jets.

Offset Correction

- Offset = Underlying Event + Noise + Multiple Interactions + Signal Pile-up.
- Measure the energy density profile in detector projective towers.
- Use Minimum Bias events (luminosity monitor trigger), bin in number of primary vertices.
- For each jet, compute the energy using the density for towers contained within the cone.
- Offset in Central Calorimeter is typically $1\,\mathrm{GeV} \times n_{\mathrm{PV}}$.





MPF Method

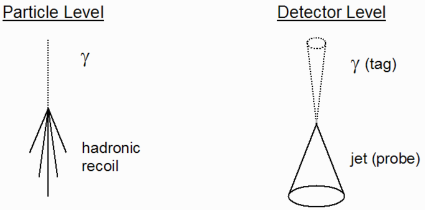
- Missing E_{T} projection fraction method (MPF) for the Response measurement uses back-to-back γ+jets events.
- Calibrated EM calorimeter $(Z \to e^+e^-)$, measure only the photon and missing transverse energy.

- Jet algorithm independent.
- From the assumed p_{T} balance one can derive the Jet Response:

$$R_{\mathrm{MPF}} \equiv 1 + \frac{\vec{\not{E}}_{\mathrm{T}} \cdot \vec{p}_{\mathrm{T}}^{\,\mathrm{EM}}}{(p_{\mathrm{T}}^{\mathrm{EM}})^2}$$

- Use dijet events for η correction.

Missing E_T Projection Fraction Method: γ+jet



$$\vec{p}_{T,\gamma} + \vec{p}_{T,had} = \vec{0}$$

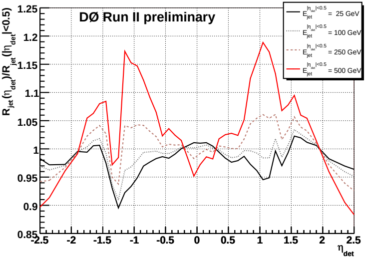
$$\vec{p}_{T,\gamma} + R_{had}\vec{p}_{T,had} = -\vec{\not{E}}_T$$

$$R_{had} = 1 + \frac{\vec{\not{E}}_T \cdot \vec{p}_{T,\gamma}}{\vec{p}_{T,\gamma}^{\,2}}$$

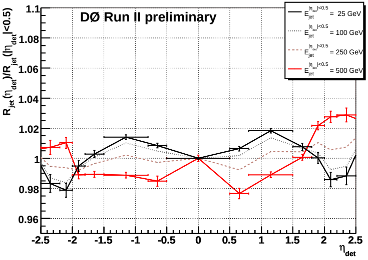
For back-to-back events: $R_{jet} \approx R_{had}$

η-dependent Correction

- The aim is to make detector response uniform in η.
- Important especially in the Inter Cryostat Region between Central and End Cap Calorimeters.
- We need to separate different instrumentation effects found over large η range.
- Measure Response relatively to Central Calorimeter Response using a Tag central object (jet or γ) and Probe jet anywhere.



η-correction



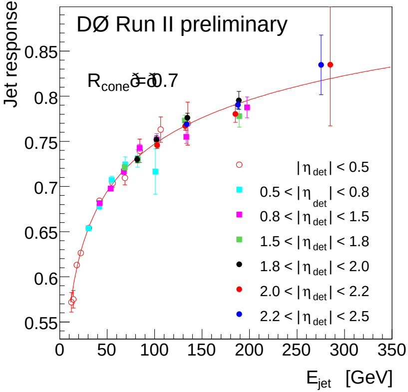
Residual in closure tests.

Jet Response

- Uses MPF method.
- Largest correction: about 30%.
- Use energy estimator combining well-measured photon energy and jet η:

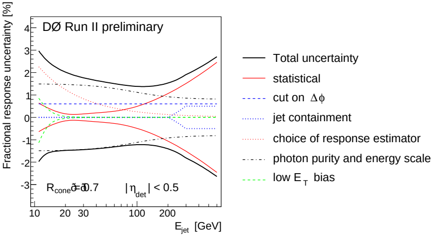
$$E' \equiv p_{\mathrm{T}}^{\gamma} \cosh \eta_{\mathrm{jet}}$$

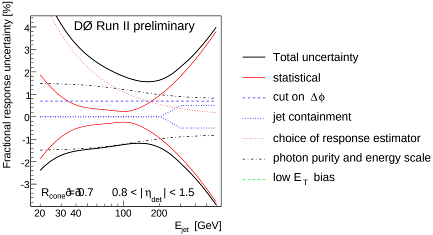
- Measure response and corrected jet energy as function of E', remap $\mathcal{R}(E')$ to $\mathcal{R}(E_{\mathrm{jet}})$.
- All η regions are on the same curve: η correction works.



Jet Response Systematics

- Due to preliminary dataset, large uncertainties at high energies.
- Photon purity: almost half of low p_T photons are background, their energy undercorrected.
- Opposite effects: we overcorrect γ scale using the electron scale.
- Both effects partially cancel, in future we correct for both.
- Non-gaussian tails in Response, esp. in ICR and in Data.

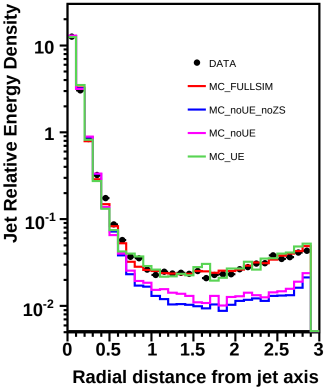




Showering Correction I

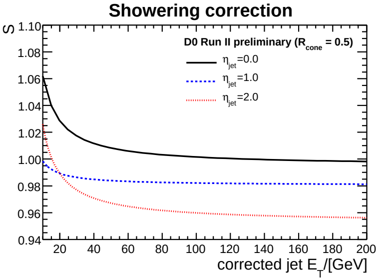
- Determine the fraction of jet energy inside the cone at detector level (detector+physics showering).
- Repeat for MC particle jets (physics showering effects only)
- Ratio of these factors is the detector effect only.

- Measure the energy density profile as a function of the distance from the jet center.
- Subtract the fitted baseline due to Offset energy.

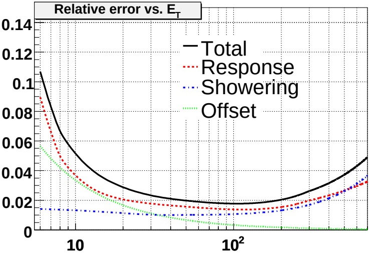


Showering Correction II

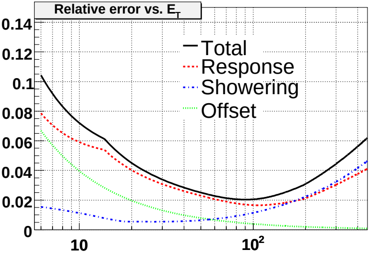
- We have to treat properly particles leaking outside the jet, which would nominally be part of it, but also particles leaking inside the jet.
- Showering is a 1-2% correction, but a large uncentainty of the order of the correction itself is assigned due to the method.

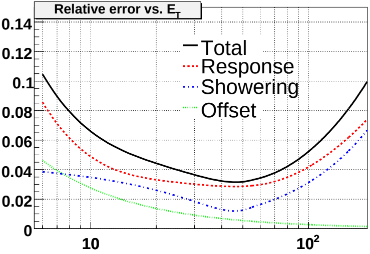


JES Uncertainties I



- Fractional jet energy scale uncertainty for $R_{\text{cone}} = 0.7$ jets in data at $\eta = 0., 1., 2.$, as a function of uncorrected jet transverse energy.





JES Uncertainties II

- Leading JES systematics is the Response.
- Response uncertainties at low energies come mainly from non-gaussian tails in distributions, photon sample purity, at high energies from statistical limitations.
- Offset uncertainties contribute mainly at low energies.
- η-dependent correction systematics comes from observed residuals after repeating the flattening procedure, being about 2% in the Inter Cryostat Region.
- Showering becomes important in forward region, i.e. at high energies, the uncertainty coming from statistics and instrumentation effects (detector edge), but mainly the method itself, which is now being significantly improved.

Closure Tests

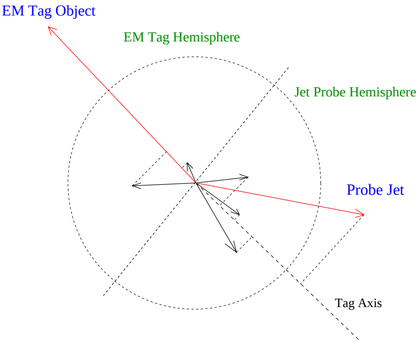
- It is important to test all corrections performance together, on broader range of samples, different topologies. . .
- The goal is to validate JES within quoted uncertainties.
- Need to disentangle many effects from the possible JES failure itself.
- For many physics analyses, the relative Data-MC scale is most important.
- It is useful to subtract Data and Monte Carlo, expected points around 0.

- Use **Tag object** (EM-like: γ/Z, or a jet) and the highest p_{T} **jet** as our **JES Probe**.
- But we can combine information from all jets in the event ⇒

Hemisphere Method

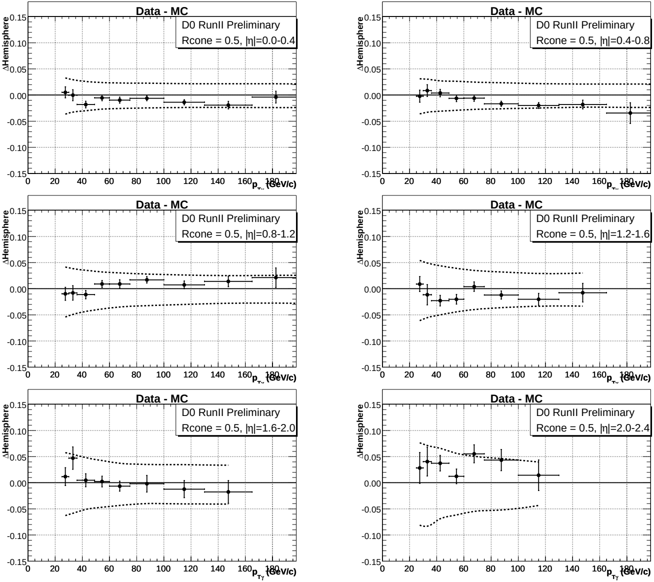
- Project p_{T}'s of all objects onto the Tag axis in the $x-y$.
- Compute separate scalar sums of projections lying in the **EM Tag** and **Jet Probe hemispheres**
- Define the **Hemisphere** imbalance:

$$\mathcal{H} \equiv \frac{\sum\limits_{\text{Probe hemi}} |\vec{p}_{\mathsf{T}} \cdot \vec{n}_{\mathsf{EM}}|}{\sum\limits_{\text{Tag hemi}} |\vec{p}_{\mathsf{T}} \cdot \vec{n}_{\mathsf{EM}}|} \approx 1.$$



- Many reasons why Hemi is not expected to be one: resolution, selection, kinematical biases. . .
- Subtract Data and Simulation points, we should observe the same biases and points centered around zero.

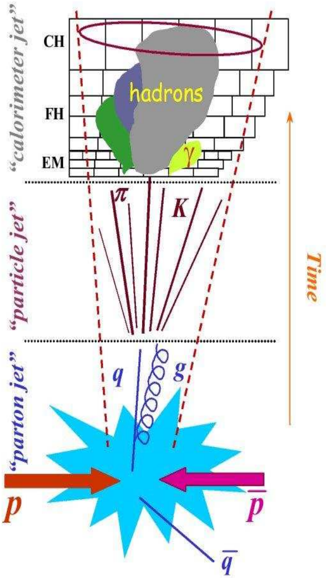
Hemisphere Method Closure, Data-MC, Cone 0.5



Summary and Conclusion

- Detailed understanding of JES at DØ has been achieved at the 2% level in Central Calorimeter at jet p_{T} in the 30-200 GeV range.
- This has only been possible due to the precision calorimeter calibration and new techniques to extract separate corrections and cross check their performance.
- Planning a NIM publication this fall.
- Current ongoing efforts to further improvement:
  - Forward and high energy jets (higher statistics), improve standard corrections.
  - b-jets Energy Scale using $\gamma + b$ events.
  - Semileptonic correction to correct semi-muonic b decays.
  - Many algorithms of this in-situ JES technique can be of great importance for LHC experiments.

Jets



- **Calorimeter jet**
  - Interaction of hadrons with calorimeter.
  - Collection of calorimeter cell energies.
- **Particle jet**
  - After hadronization and fragmentation.
  - Effect of hadronization is soft ⇒ allows comparison between particle and parton jets.
- **Parton jet**
  - Hard scattering.
  - Additional showers.