B Jet Energy Scales in the Top Mass Measurement using $W \rightarrow q\bar{q}'$

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The Problem with b Jets

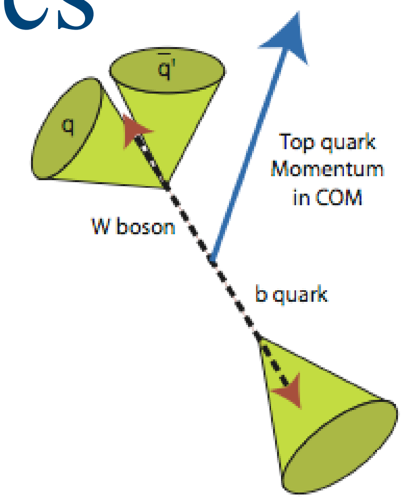
- Dominant systematic uncertainty in M_{top} measurement remains jet energy scale (JES)

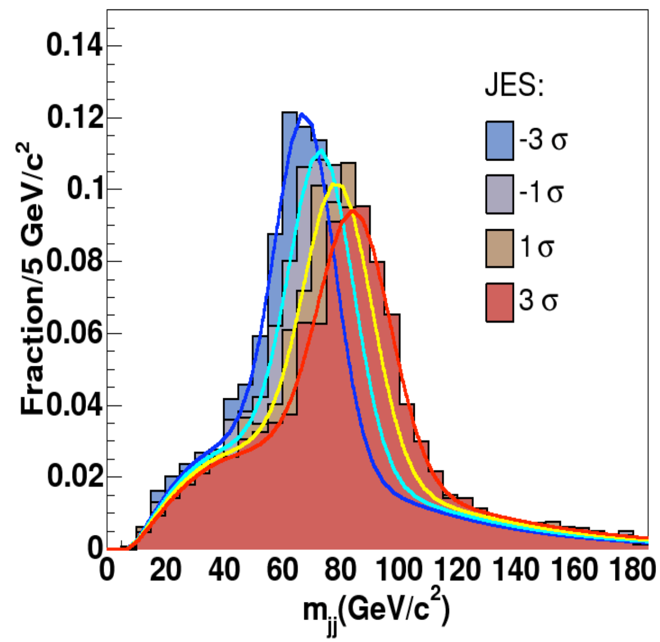
$$JES \equiv E_{scale}^{true} - E_{scale}^{MC} \Big/ \sigma_{JES}$$

- Jet energy scale set by studies of light quarks and gluons
  - Use of various *in situ* techniques
    - Dijet balancing, photon+jets, W+jets
    - Use of hadronic W to qq’ decays
  - Constrains the average jet energy scale for light quarks/gluons
  - Use Monte Carlo models to model b quark jet response
- Have to provide additional information about b jets in top quark events
  - Two possible strategies:
    - Improved knowledge of light quark and b jet differences to model uncertainties
    - Measure behaviour of b jets *in situ*

Some Useful Kinematics

- Top quark is quasi-two-body decay
  - W boson and b quark carry equal momentum in top rest frame (P_T about 45 GeV/c)
  - M_W-M_b difference softens b jet spectrum
  - 1% energy scale uncertainty --> 1 GeV/c^2 M_{top} uncertainty
- Light quark jet scale set by JES calibration and W→qq'
  - Comparable precision to energy scale from both techniques
  - No information regarding b jet energy scale

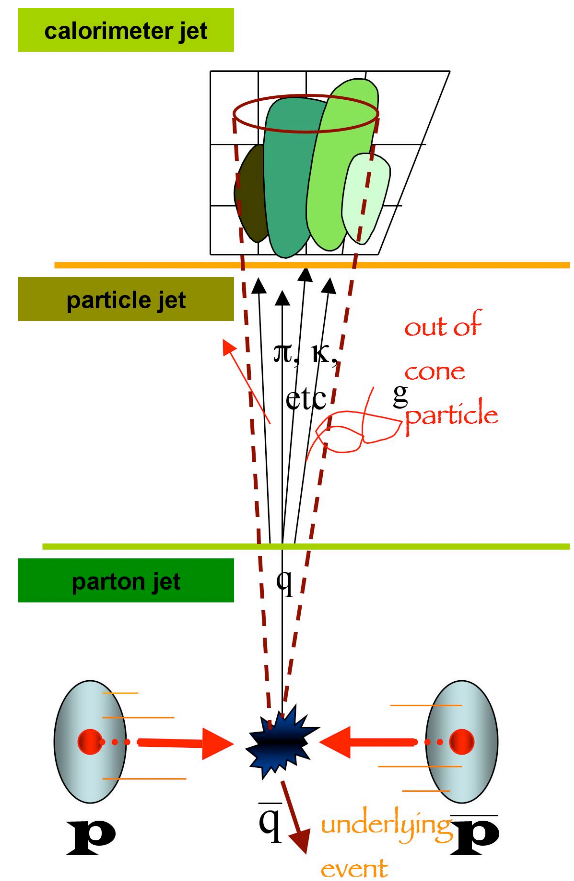




JES Systematic Uncertainty

What are the sources of JES uncertainties?

- Fragmentation:
  - Particles momentum distribution
  - Out-of-cone energy
- Detector response:
  - Dominated by hadronic particles response
- Underlying event:
  - deposits energy in jet cone



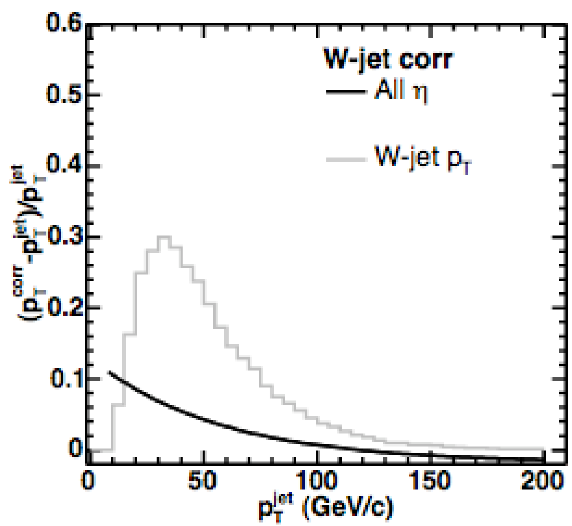
JES uncertainty from calibration: 1 $\sigma_{JES} \approx 3\%$ (3 GeV/c^2 in M_{top})
In current analysis, unit of JES is 1σ_{JES} as defined by CDF

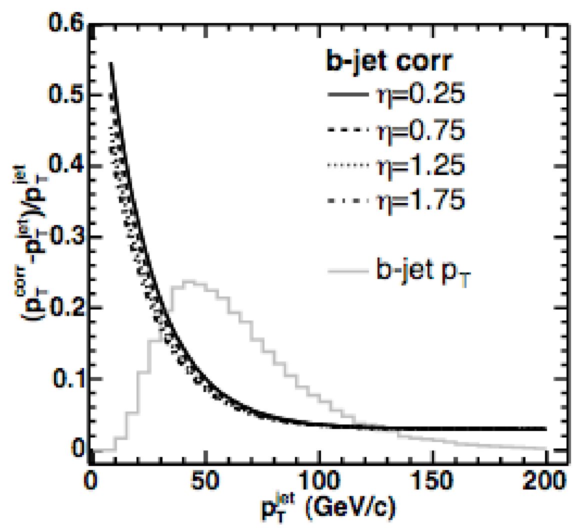
b & Light Quark Jet Differences

- Categorize the effects that make b jets different:
  - Fragmentation
  - Colour flow associated with b jet
  - B hadron decays within the jet
- Can estimate each
  - First 2 are measured
  - MC models of colour flow constrain the third
- Key assumptions
  - We know light quark jet scale to some precision
  - Uncertainties arising from b jets are uncorrelated with light quark energy scale
  - b jets Q^2 scale defined by top quark COM

Defining Jet Energy Response

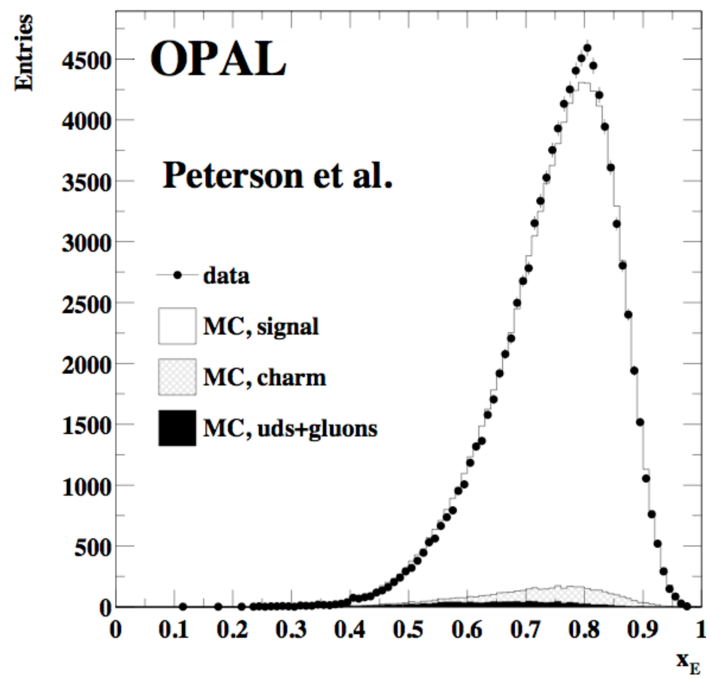
- Use "generic" jet energy corrections
  - Advantage of having a single set of responses
    - Take out most egregious detector shortcomings
    - Detector η and P_T
- Add "top-specific corrections"
  - Depend on P_T and η
  - Small dependence on M_{top}, arising from change in parent distribution





Fragmentation Uncertainty

- Fragmentation
  - Look at LEP data
    - Detailed fits of data constrain possible fragmentation models
    - Use OPAL data to see how uncertainty propogates into b jet energy scale difference
    - Peterson ε_b=25-60x10^{-4}
  - Produces a b jet energy scale uncertainty of 0.4%

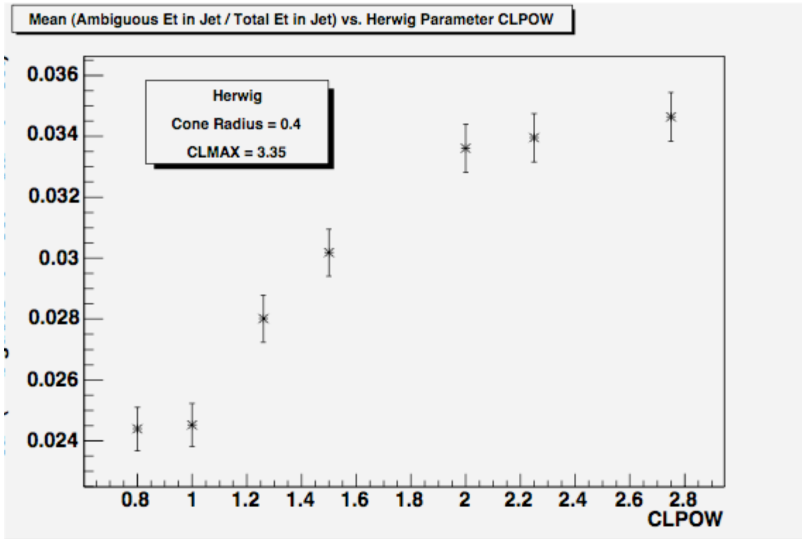


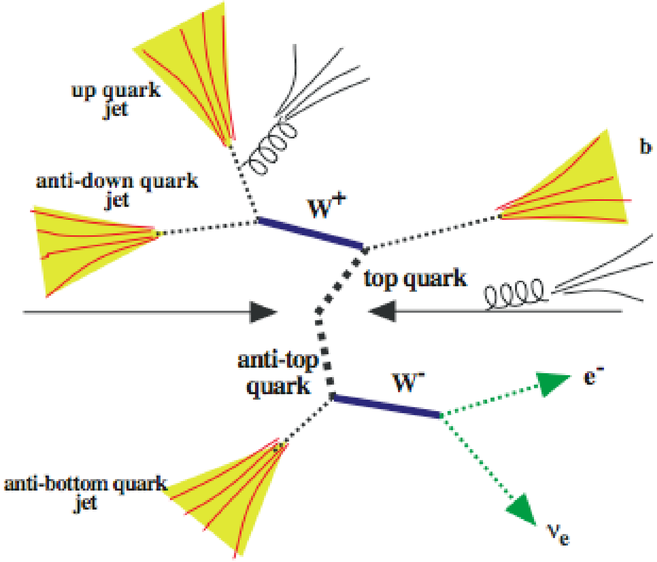
B Jet Colour Flow

- Colour flow in hadron collisions results in different flux of particles well-away from jet
  - MC models are constrained by observations at LEP, SppS and Fermilab
  - Difficult to characterize accuracy of these models
- We used MC's to determine how much "ambiguous" energy is in a given b jet cone
  - Varied the colour flow model and measure how much the "ambiguous" energy changes
- MC's use different approaches
  - PYTHIA - Lund String
  - HERWIG - Cluster hadronization
  - In either case, approximately 3% of energy in b jet cone of R=0.4 is "ambiguous"
    - Is largely independent of b jet P_T
    - Does vary with parameters used in model

HERWIG Colour Flow Results

- HERWIG employs 2-parameter model
  - CLPOW and CLMAX
  - Varied them over 50% of their range
- Results:
  - 3% of energy is “ambiguous”
  - Varies by 1.0% cranking CLPOW (or CLMAX) from rail to rail
  - PYTHIA has similar results
  - Took 0.3% as estimate of uncertainty





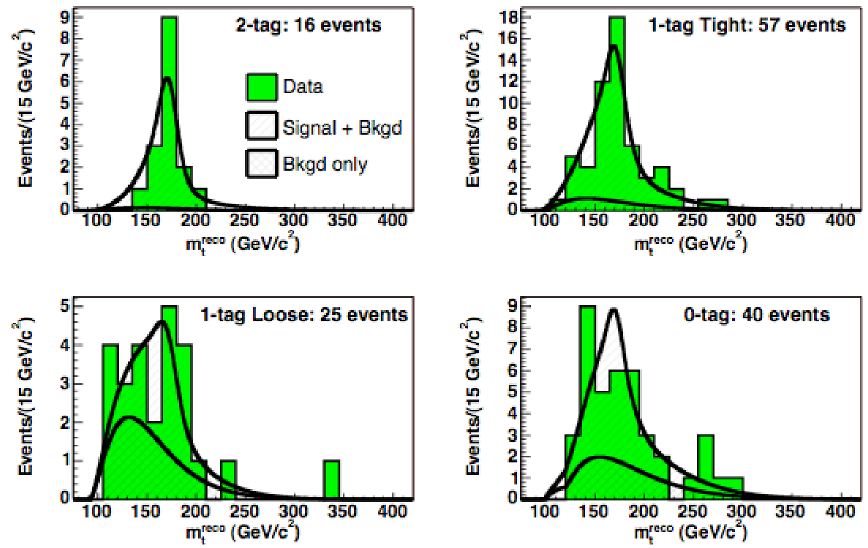
B Hadron Decay Uncertainties

- B hadrons within jets create uncertainties
  - Largest source is fraction of semi-leptonic decays
    - Recent data constrain rate of SL decays to uncertainty better than 0.5%
    - Model this effect on b jet energy scale
  - Produces an energy scale uncertainty of 0.4%
    - Note that it is not correlated with other uncertainties

- Summary of Uncertainties
  - Three sources:
    - Fragmentation: 0.4%
    - Colour Flow: 0.3%
    - Decay: 0.4%
  - Add them in quadrature
    - 0.6% additional uncertainty on b jet energy scale
    - Size is driven by well-known b-jet properties from other experiments
  - Two weaknesses:
    - Colour flow not constrained by data
    - No cross-check as of yet

CDF 2-D Template Analysis

- Use lepton+jets sample
  - Divided into 4 subsamples
    - 2, 1, 0 b-tags
    - Divide 1-tag into Loose & Tight sample
  - Find reconstructed top mass for each event, m_t^{reco}
    - Kinematic fit constraining
      - top and anti-top mass
      - W daughters to W mass
  - Fit resulting m_t^{reco} distribution to MC predictions
    - M_{top} and JES free parameters



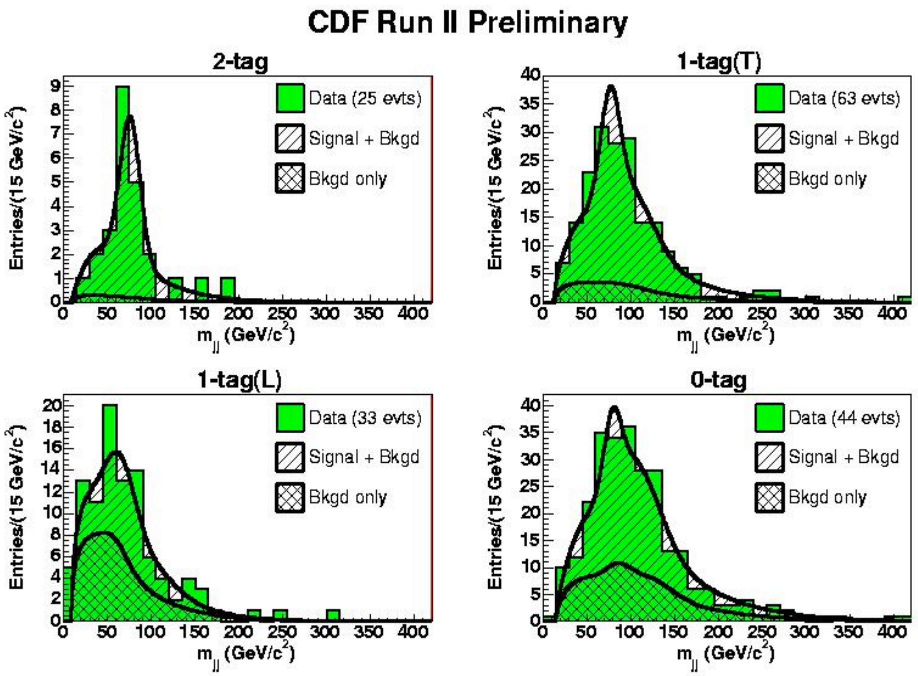
$$M_{top} = 173.5^{+2.7}_{-2.6}(stat.) \pm 2.5(JES) \pm 1.7(syst.)\ \mathrm{GeV/c^2}$$

Light Quark Jet Scale

- Can measure scale using
  - Focus on W candidates
    - Don't use W mass constraint
    - Consider all combinations
    - Location of dijet invariant mass peak a measure of JES
    - In 318 pb^{-1} of CDF data

$$JES = -0.10^{+0.78}_{-0.80}\,\sigma_{JES}$$

  - Combination of *in situ* and W mass peak location
    - Statistical uncertainty (2.5 GeV/c^2) will scale primarily as Sqrt(N)
    - Background shape largest source of uncertainty (1.1 GeV/c^2)
    - B jet modeling 2nd largest (0.6 GeV/c^2)



Systematic Uncertainties

- Remaining systematic uncertainties small
- Include uncertainty on b-jet modeling
  - Colour flow
  - Decay
  - Fragmentation
- Total: 1.7 GeV/c^2
  - Compare with JES uncertainty of 2.5 GeV/c^2

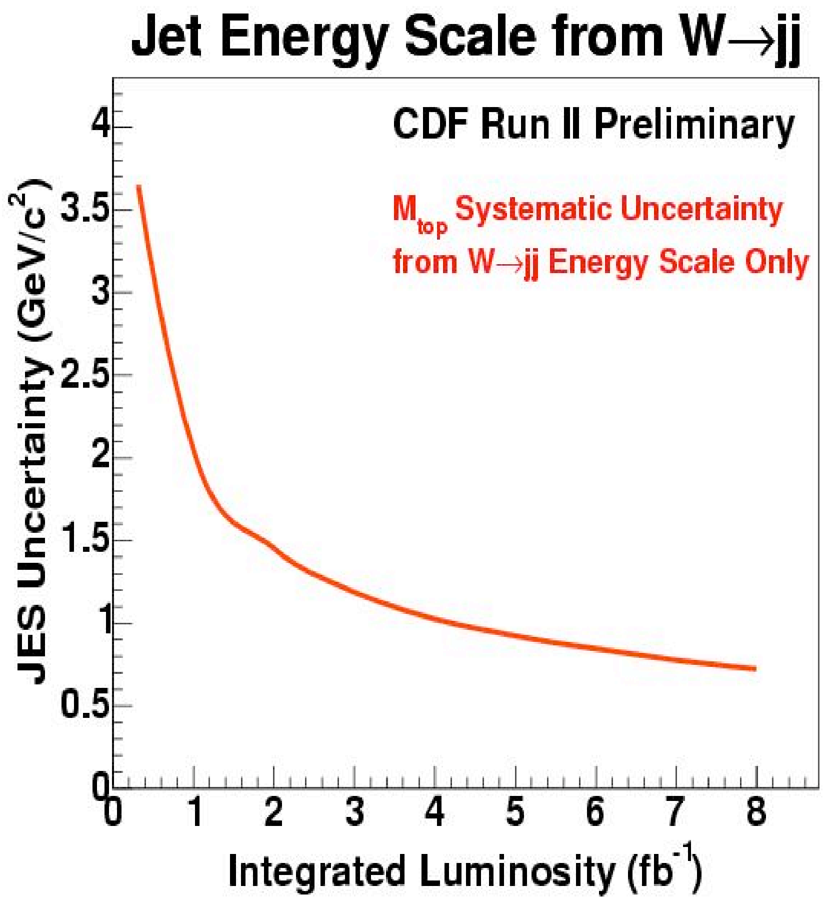
Source	**M_{top}(GeV/c^2)**
Background shape	1.1
FSR	0.6
B-jet modeling	0.6
Method	0.5
ISR	0.4
Other MC Modeling	0.4
PDF	0.3
Total	1.7

Next Steps

- Use $Z \rightarrow b\bar{b}$ to check b jet energy scale
  - With JES from W decay, will be able to separate out light quark and b jet scales
- Improve the colour flow estimates
  - Depends on definition of "ambiguous" energy
  - Prefer to constrain directly to measured data
- A few ideas:
  - Separate colour flow effects from underlying event
    - Requires even better understanding of UE
    - Use double-tagged events or dilepton events as "laboratorys"
  - Compare energy flow between b jets and light quark jets
    - Perhaps more challenging
    - But would likely have enough statistics in next year to attempt this.

Future of Top Mass Uncertainty

- Improvement to traditional calibrations of JES expected to be limited
- Using W to jj decays, JES uncertainty mostly statistical
- Can reach JES uncertainty below 1 GeV/c^2 in Run II
- **M_{top} uncertainty of 2 GeV/c^2 or less possible**



Conclusions

B jet energy scale is not the show-stopper

- Bootstrapping from light quark energy scale
- Taking into account additional b quark uncertainties
  - Adds an additional 0.6 GeV/c^2 to overall M_{top} uncertainty
- Dominant uncertainty in Run I no longer constraint on better top mass measurements
  - Expect to improve understanding with increased statistics

- Still work to be done
  - Observe $Z \rightarrow b\bar{b}$
  - Improve understanding of colour flow