Introduction to jets and jet algorithms

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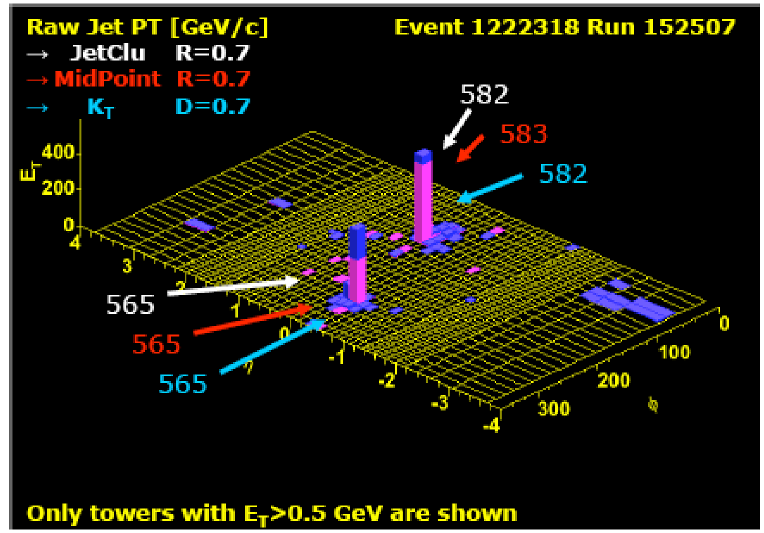
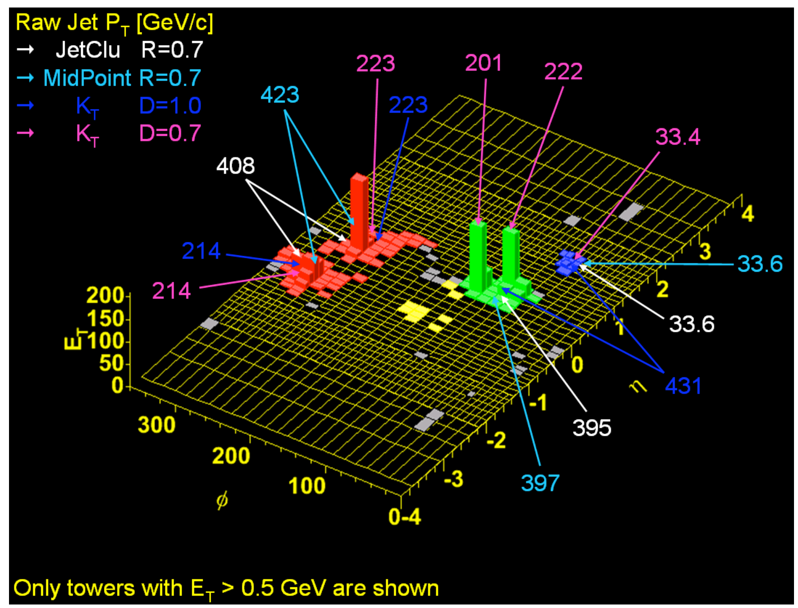
Jet algorithms at the hadron level

- For some events, the jet structure is very clear and there's little ambiguity about the assignment of towers to the jet
- But for other events, there is ambiguity and the jet algorithm must make decisions that impact precision measurements
- If comparison is to hadron-level Monte Carlo, then hope is that the Monte Carlo will reproduce all of the physics present in the data and influence of jet algorithms can be understood
  - more difficulty when comparing to parton level calculations
- Ideal is for analyses to be done with multiple algorithms to allow for cross-checks

CDF Run II events





CDF Run 2

- CDF has results with Midpoint algorithm from Run 2 extending over a much larger kinematic region than Run I

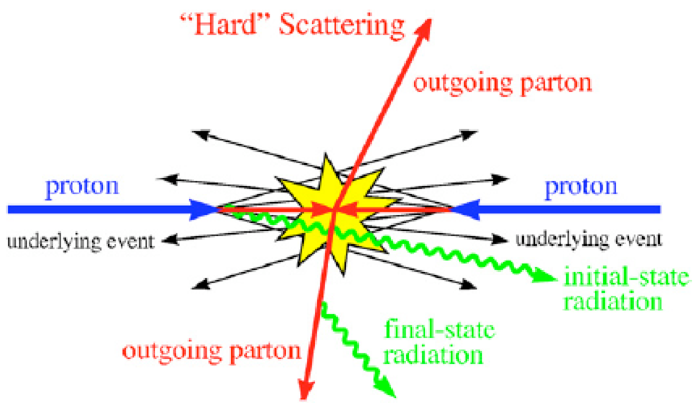
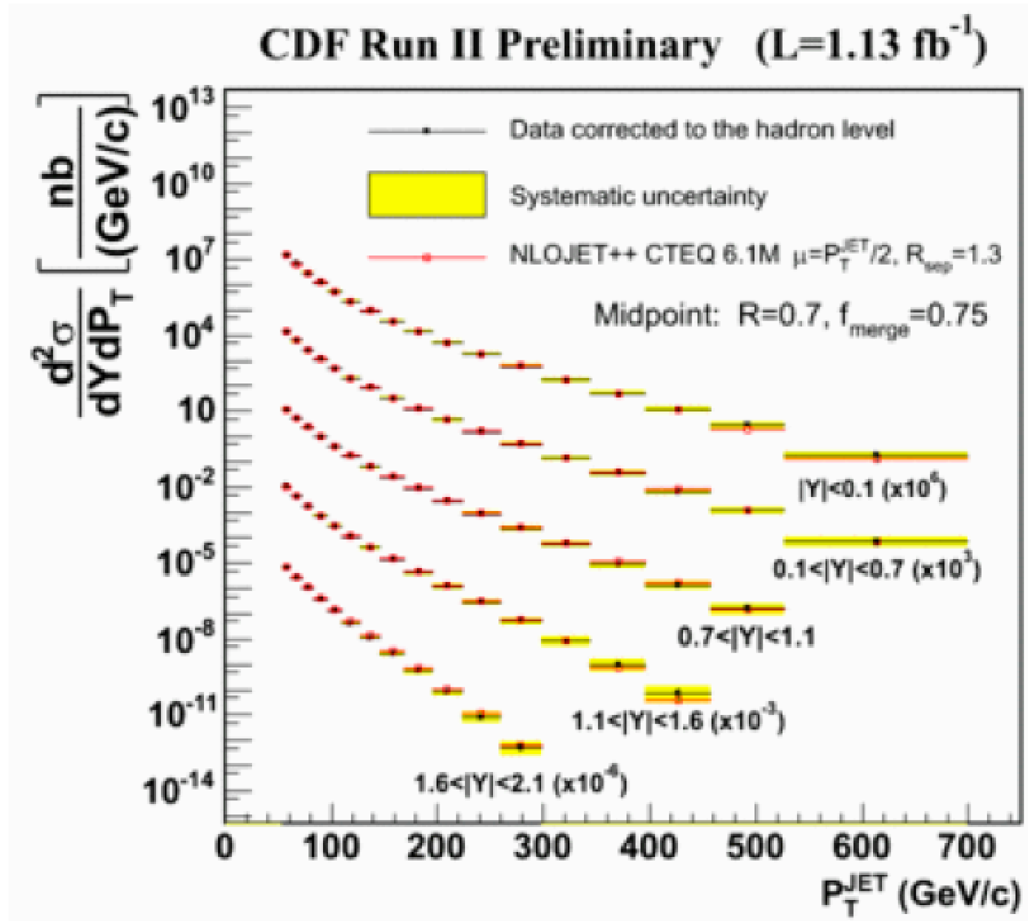
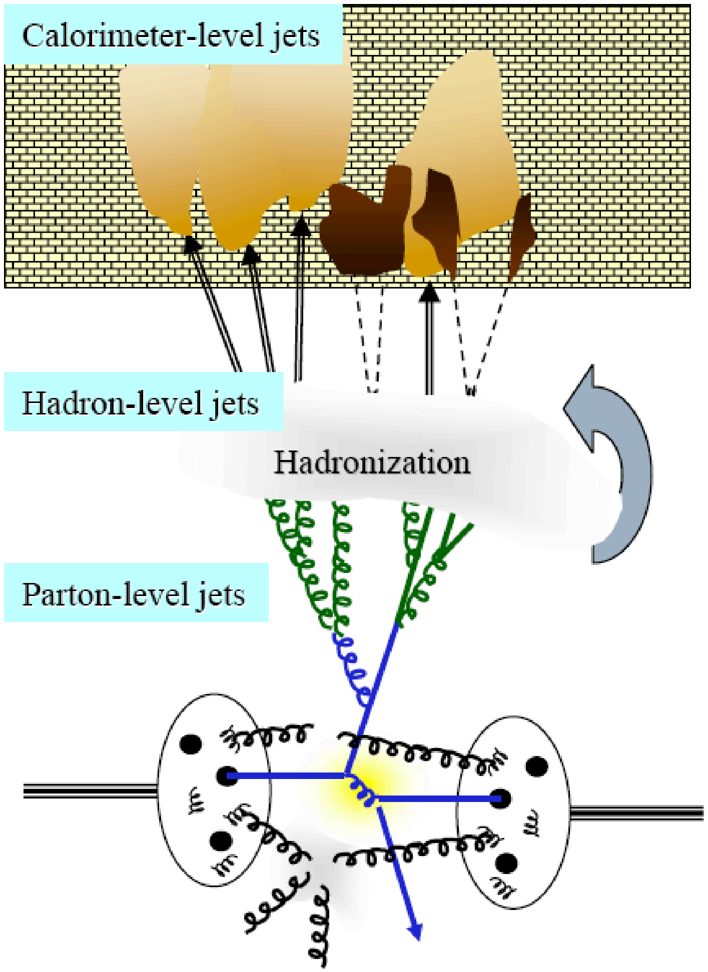


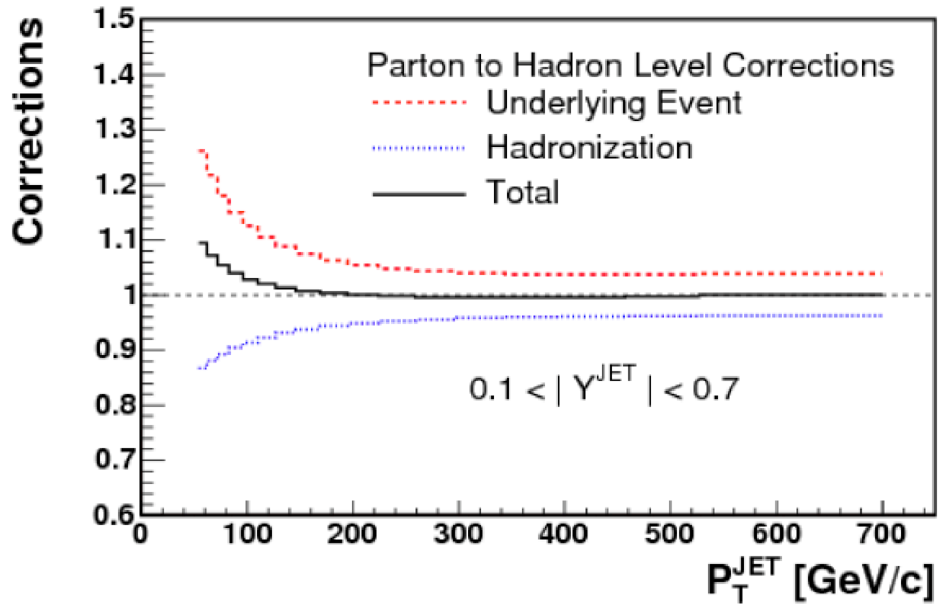
Figure 43. Schematic cartoon of a 2 → 2 hard-scattering event.



Corrections to parton level

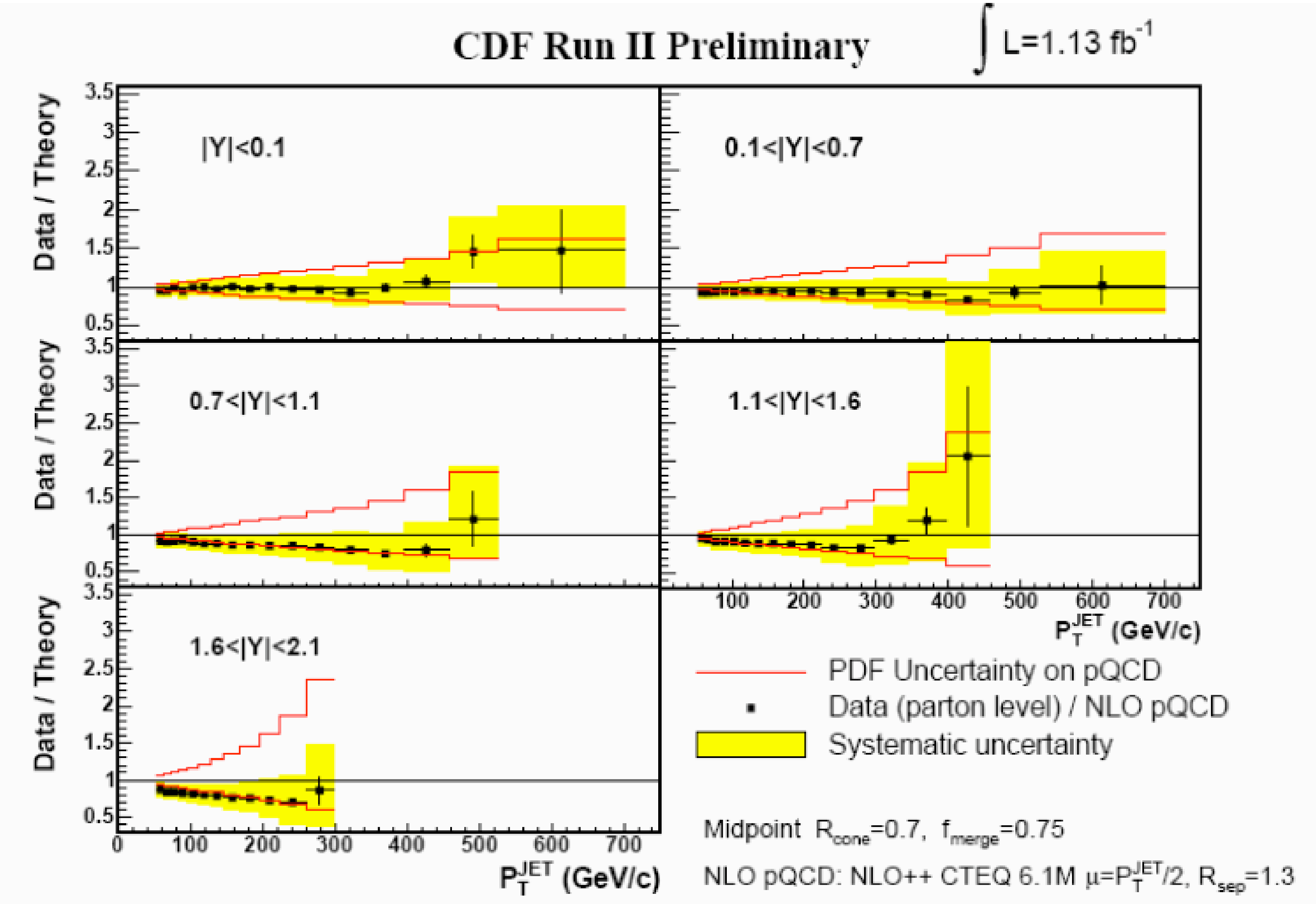


- UE and hadronization effects are in the opposite directions



- With R=0.7, the UE effect is larger than the hadronzation effects.
  - ~10% in cross section at low jet Pt

Comparison with NLO

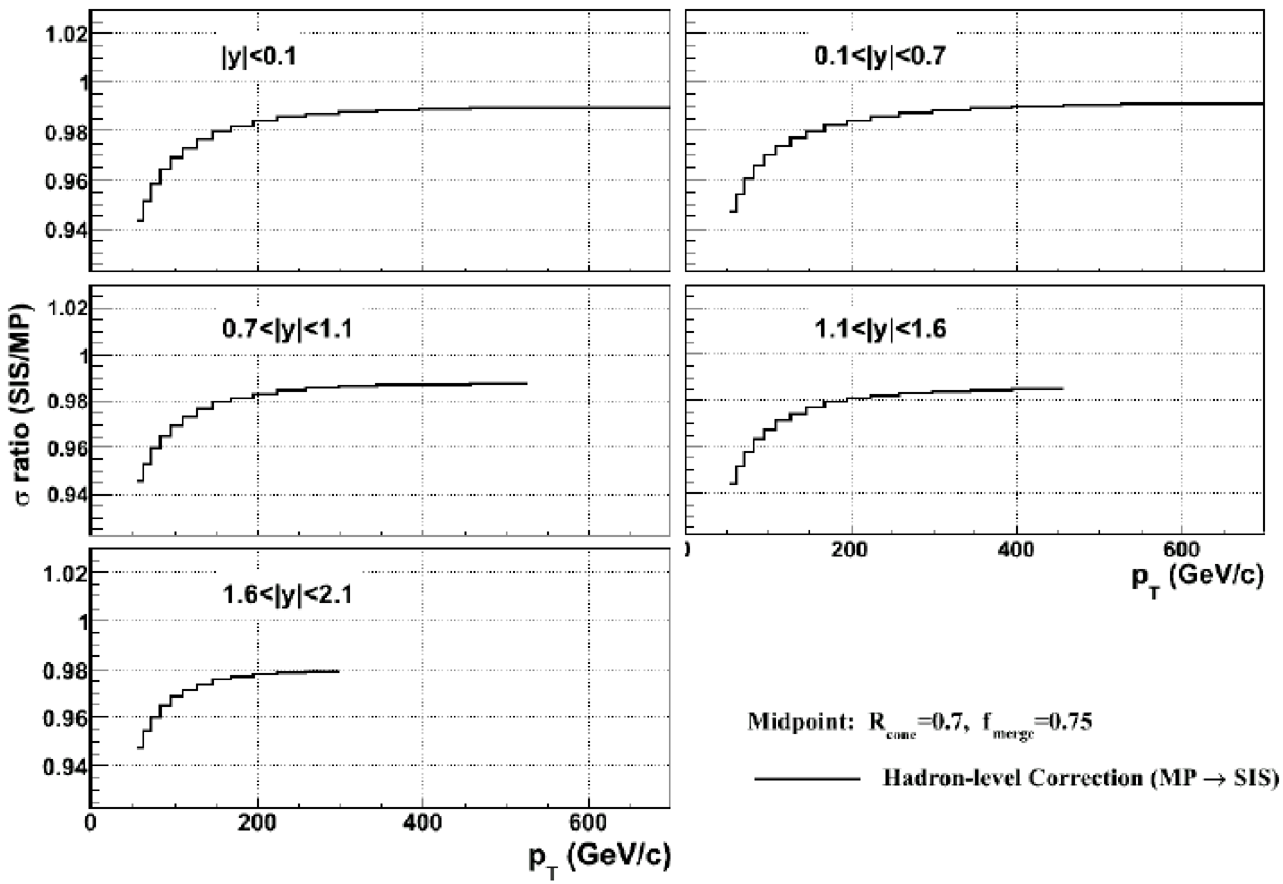


Good agreement

SISCone in CDF

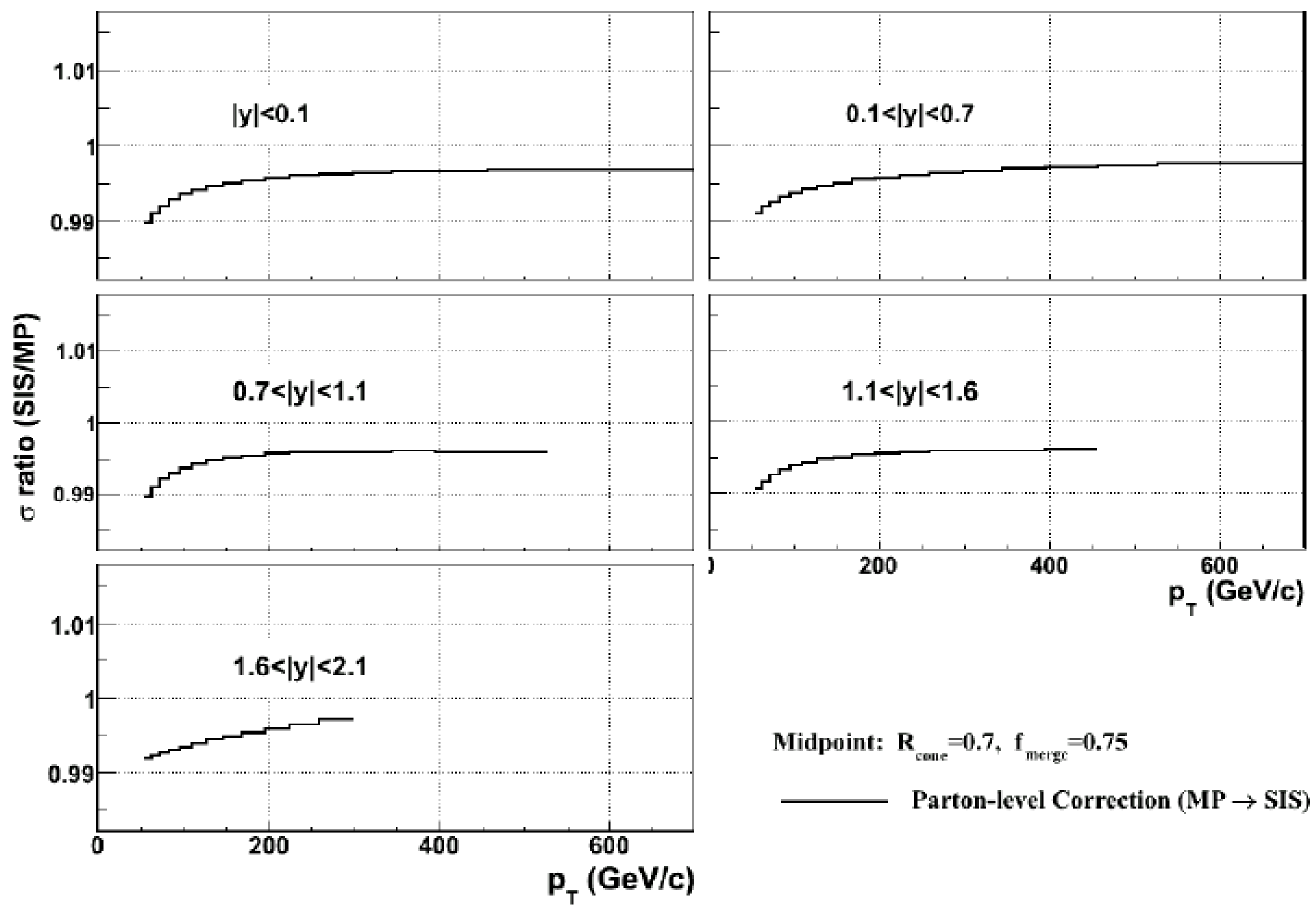
G. Salam and G. Soyez have developed a seedless cone algorithm that is more rigorous from theoretical point-of-view->FastJet package

Differences between the currently-used Midpoint algorithm and the newly developed SIScone algorithm in MC at the hadron-level.



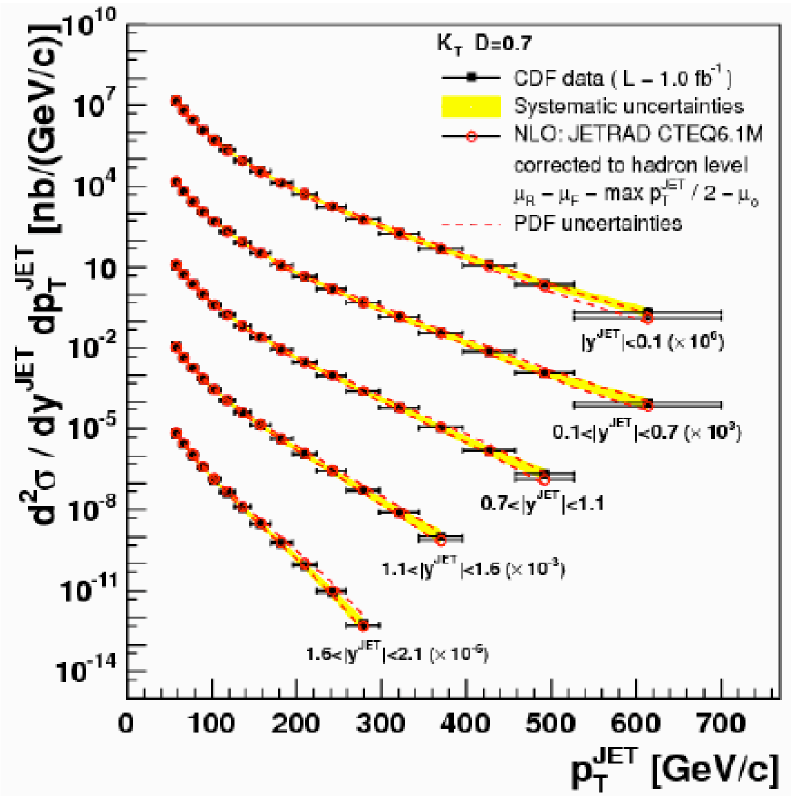
SISCone

Differences between the currently-used Midpoint algorithm and the newly developed SIScone algorithm at the parton-level.

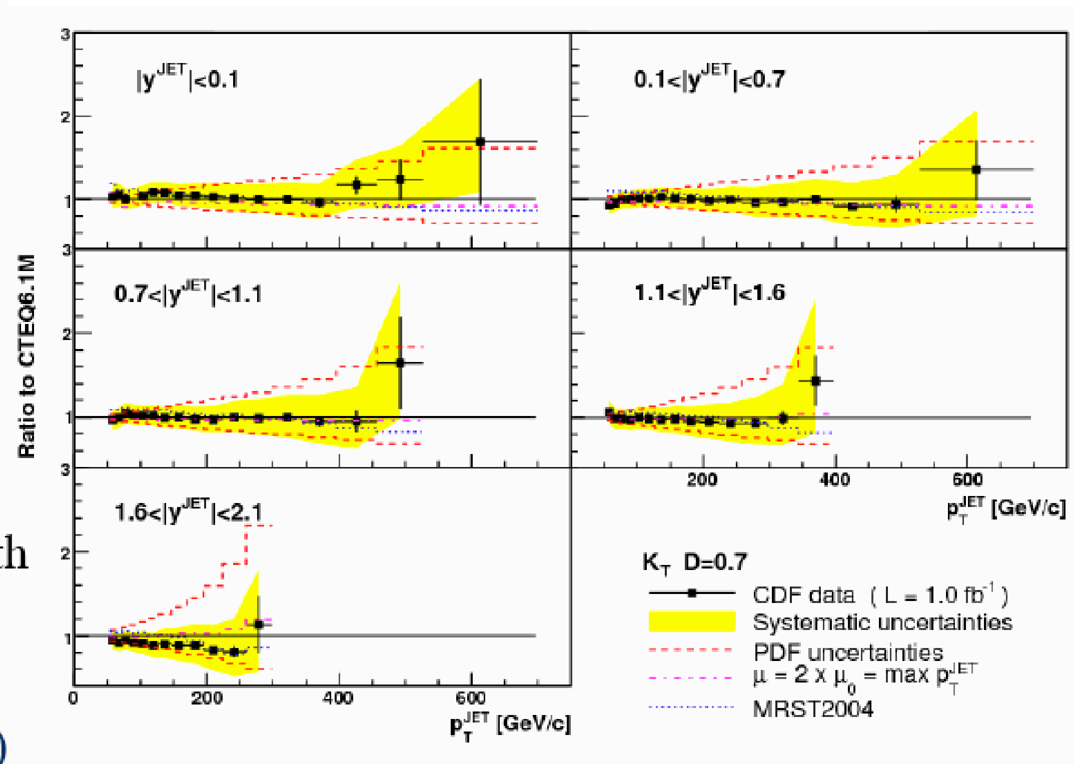


Differences < 1% $\rightarrow$ negligible effects on data-NLO comparisons

CDF k_T algorithm



- L = 1.0 fb^{-1}
- Jets reconstructed with the k_T algorithm, D= 0.7.



Again, data in good agreement with NLO pQCD predictions

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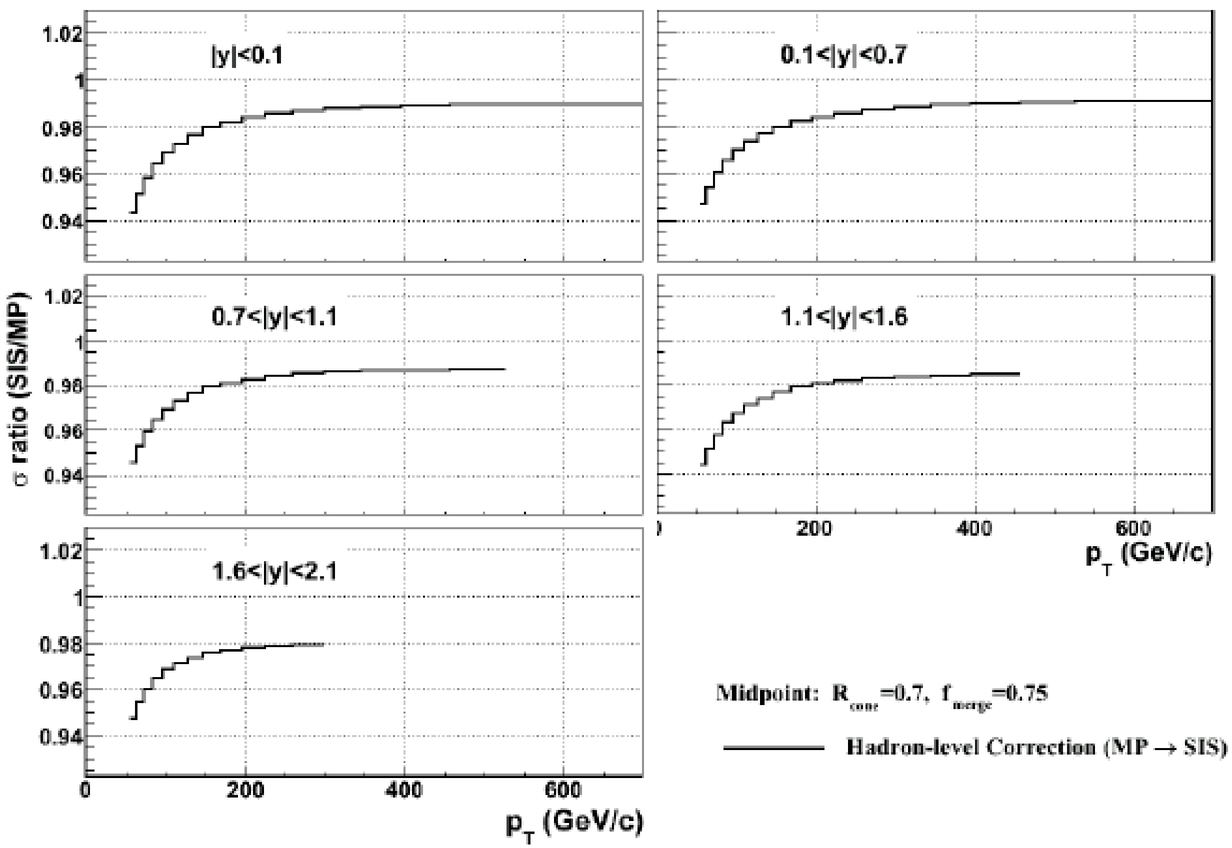
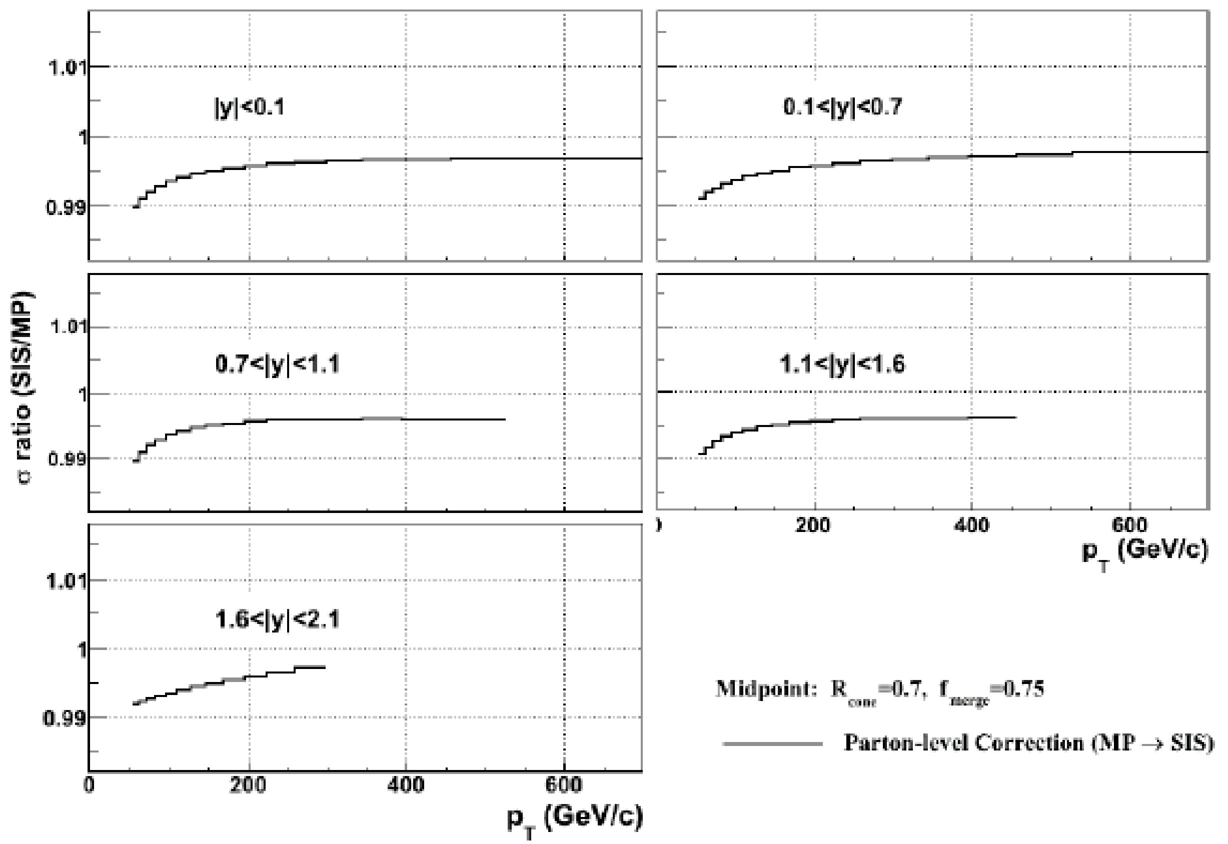
Differences between Midpoint and SISCone

- Differences between the currently-used Midpoint algorithm and the newly developed SIScone algorithm in MC at the hadron-level.



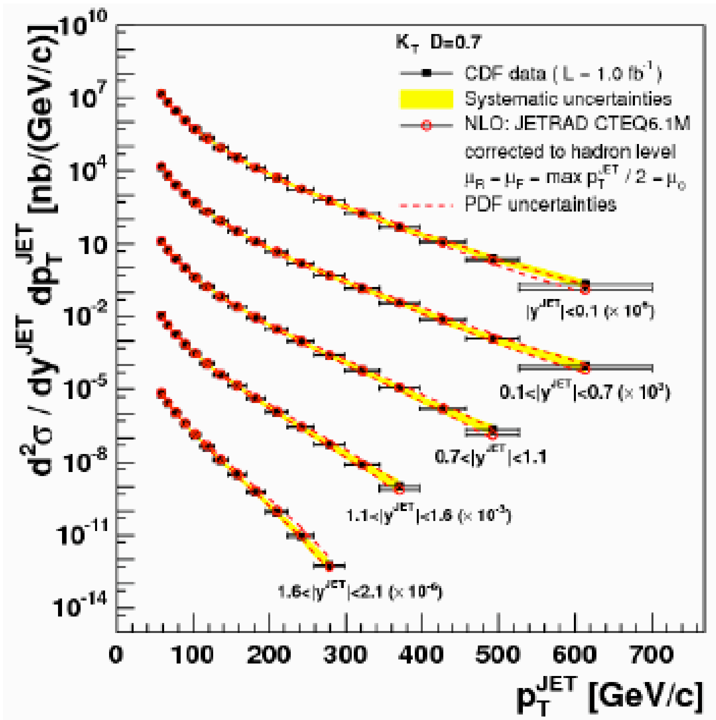
Differences between Midpoint and SISCone

- Differences between the currently-used Midpoint algorithm and the newly developed SIScone algorithm at the parton-level.



Differences < 1% → negligible effects on data-NLO comparisons

Inclusive jets with k_T



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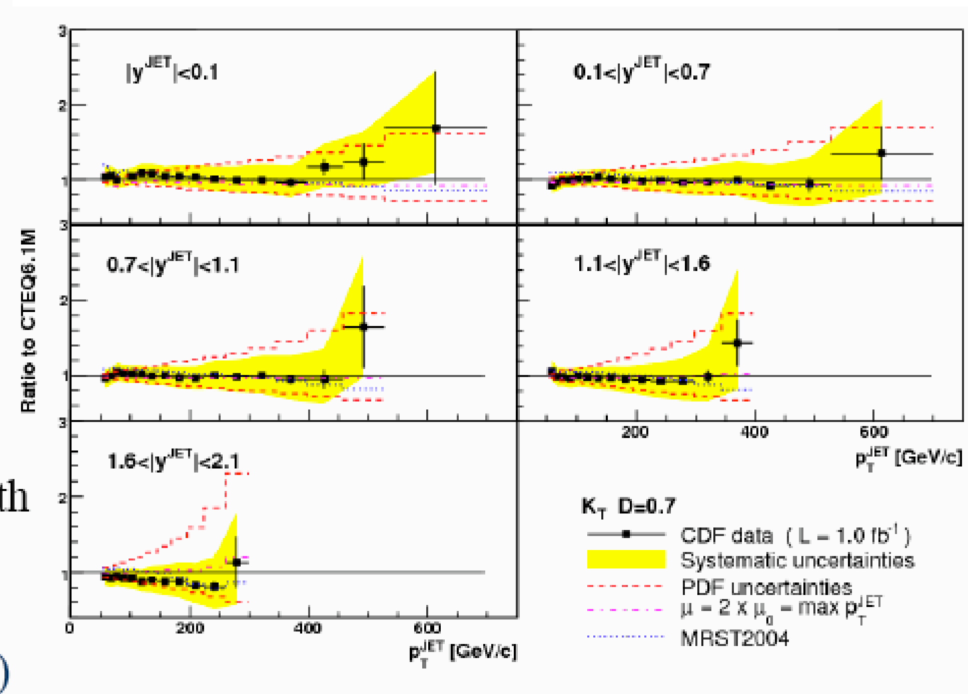

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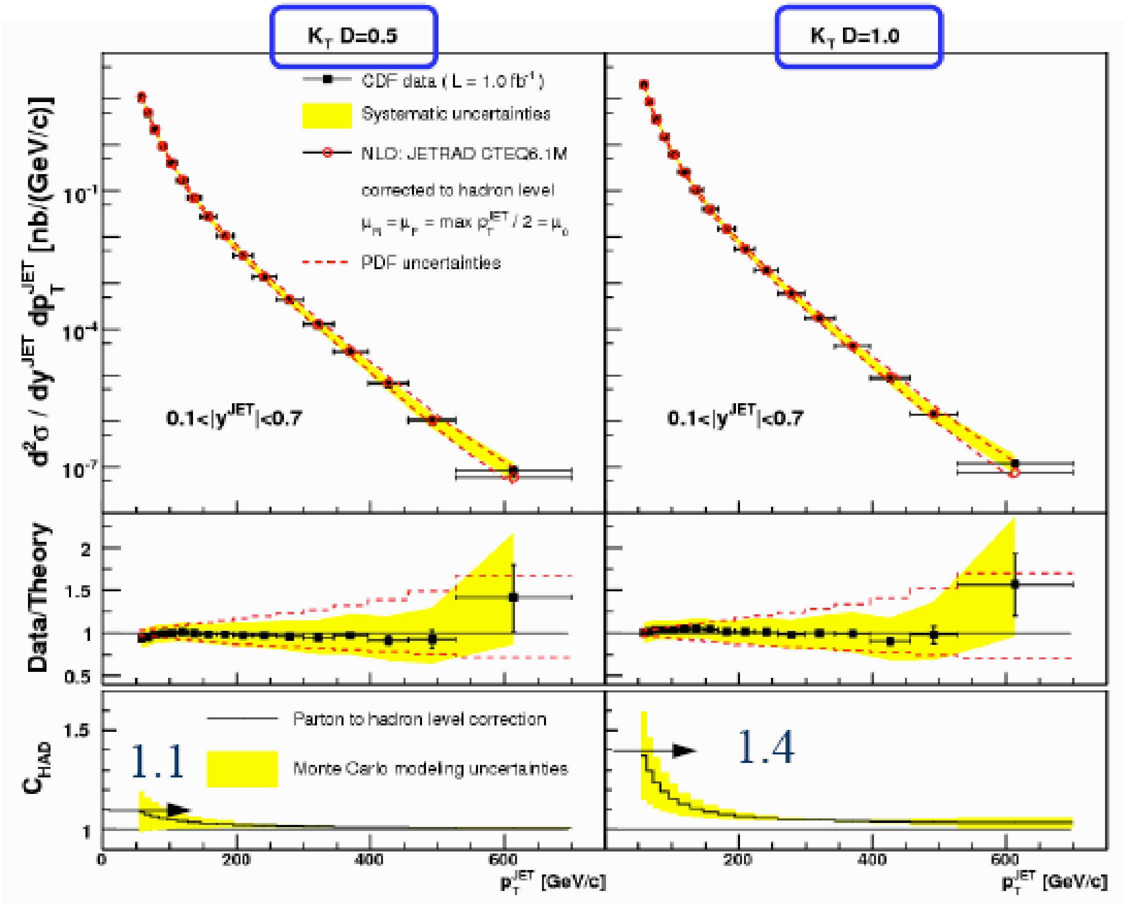
Inclusive jets with k_T

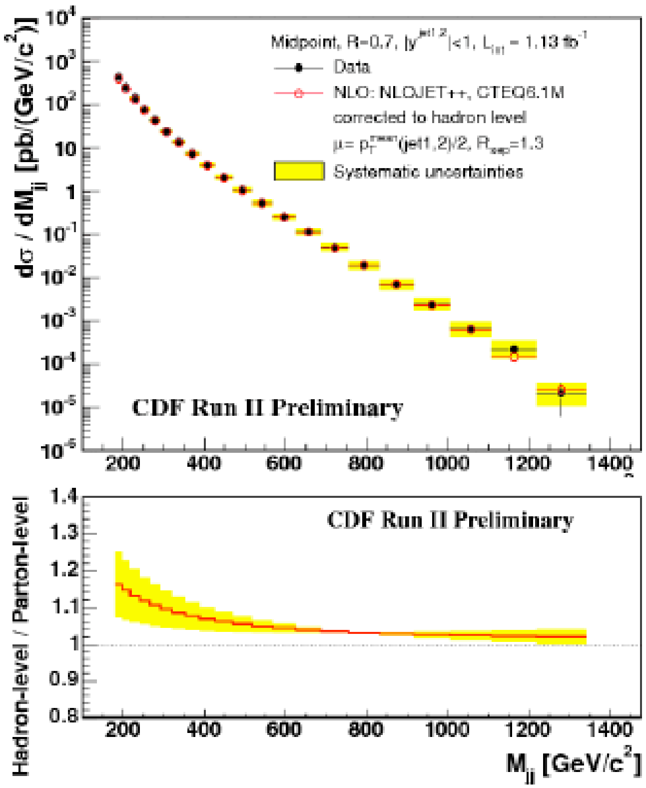


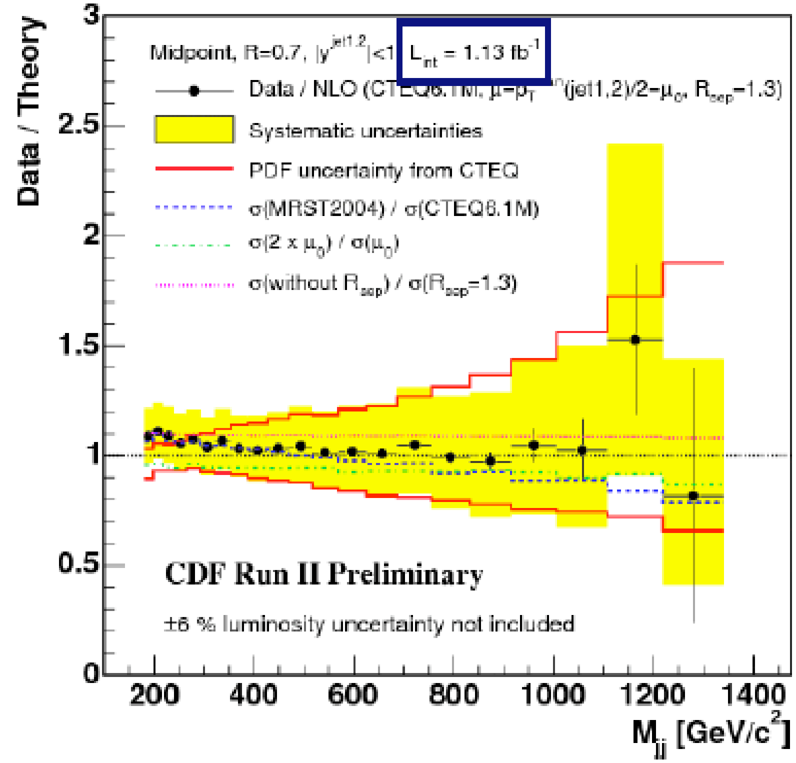
- Measurement with different *D* parameters (*D:* separation parameter that characterizes the size of jets)
- Parton-to-hadron level corrections larger for larger *D* parameters (larger UE contributions)
- Both measurements in good agreement with NLO pQCD after UE and hadronization corrections

➧ NLO pQCD provides a reasonable description of dependence on jet size.

Dijets

- Test of pQCD predictions
- Sensitive to new physics: decays of massive particles, compositeness





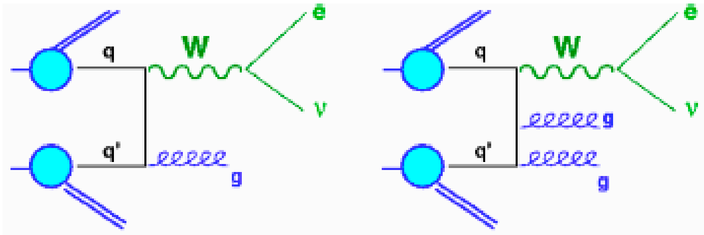
- Consistent with NLO pQCD predictions
  - Experimental uncertainties comparable to PDF uncertainties
- Limits on new physics being worked out…

W/Z + jets

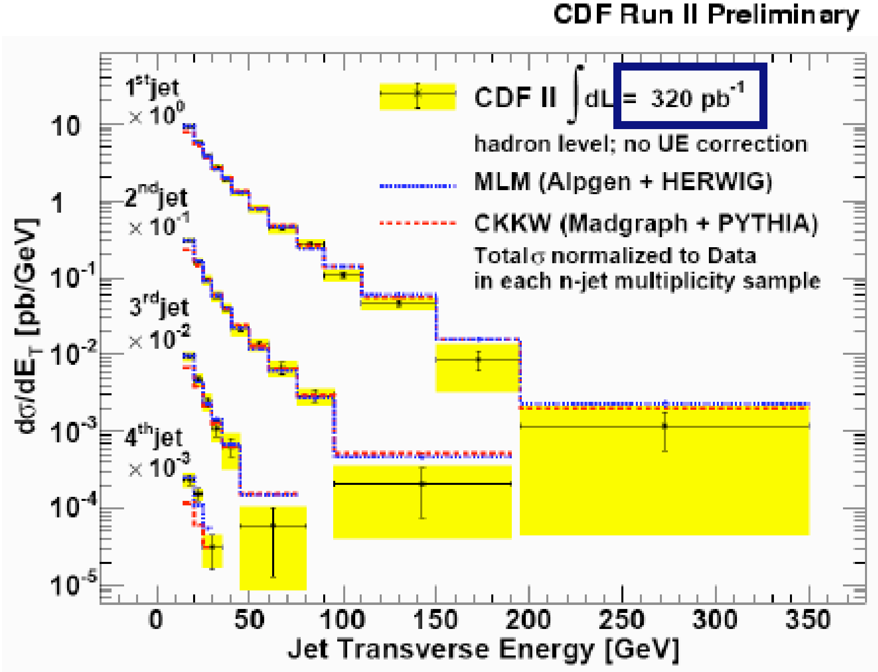
Motivation

- NLO predictions only up to Njet=2
- Higher multiplicities accessible via matrix element + parton shower (ME+PS) Monte Carlo predictions
  - Special ME-PS matching (MLM, CKKW) to avoid double counting

  Good testing ground for such predictions



... + parton showers

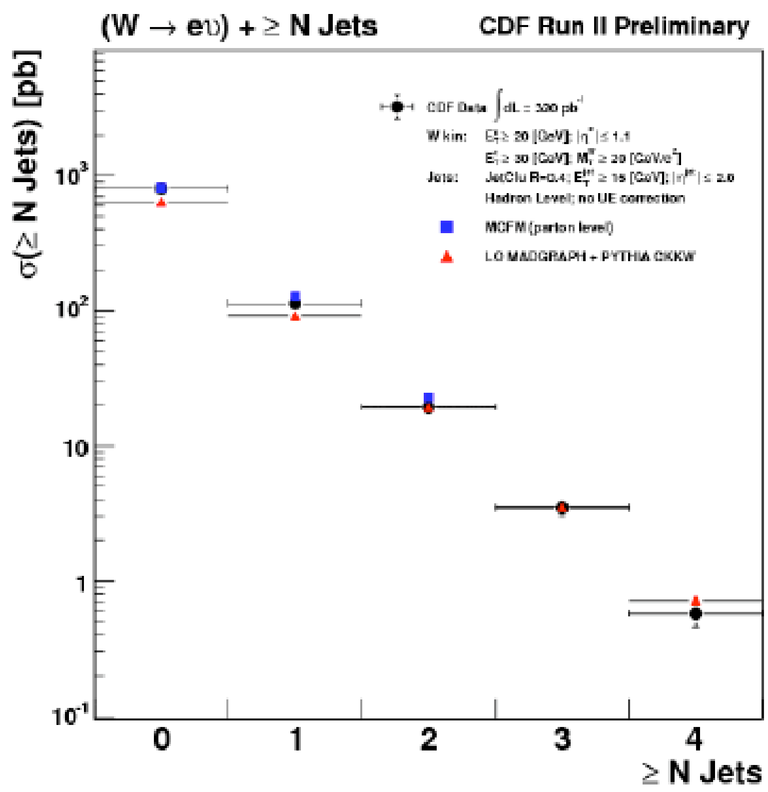


Measurement

- W events selected with electron+missing E_T ($W \to e\nu$)
- Jets clustered with JetClu R=0.4 $E_T^{jet} > 15$ GeV ; $|y^{jet}| < 2$.

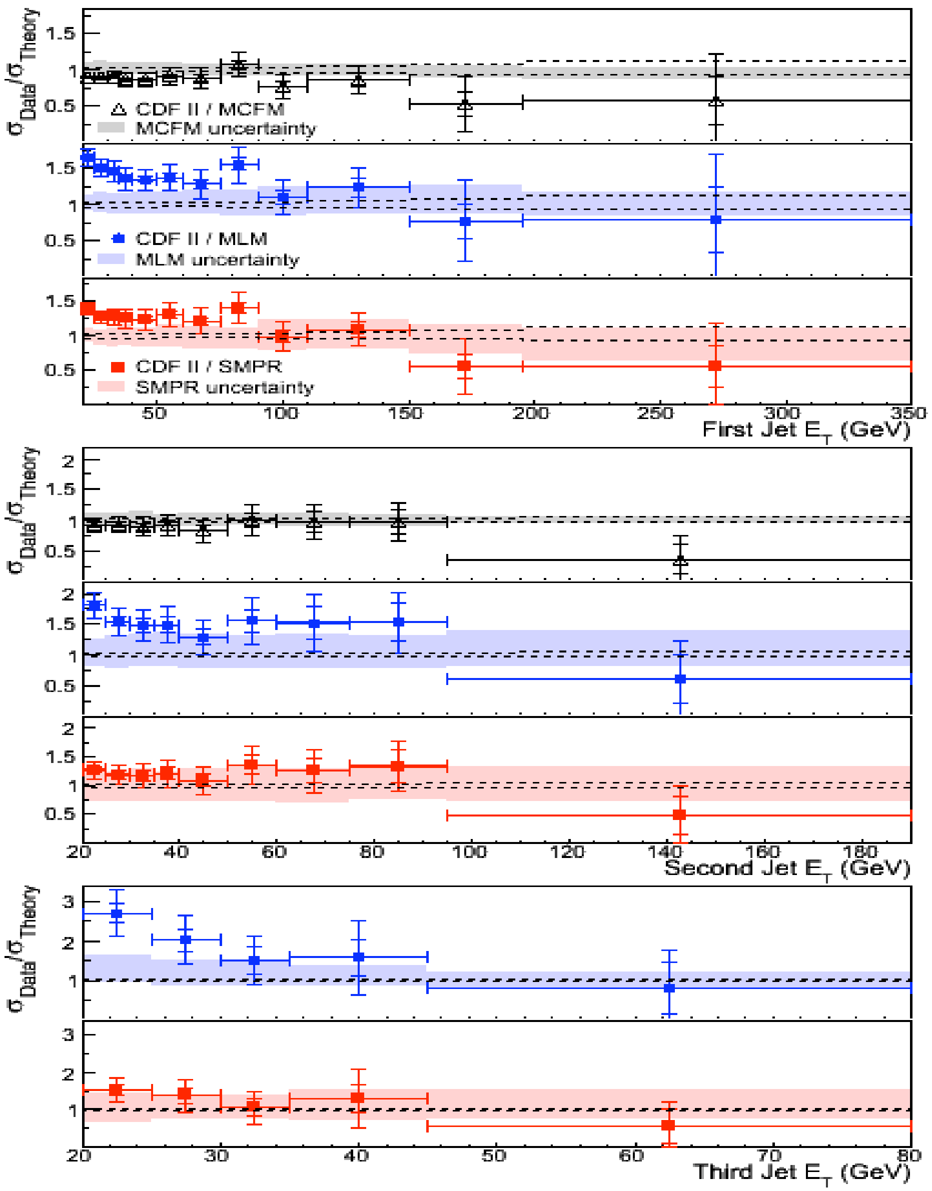
W + jets

- Measured jet multiplicity distributions compared to:
  - NLO pQCD predictions
    - Good agreement up to Njet=2 (no prediction for Njet>=3)
  - Matched LO ME+PS predictions
    - Absolute cross sections lower than the measurement (k-factor)
    - Good description of “relative” jet multiplicity rates up to Njet=4



W + jets

- Good agreement with NLO where available
- Note the data has been corrected back to the hadron level, i.e. no knowledge of the CDF detector is needed for any itinerant theorist to be able to compare this predictions to the data



SpartyJet

- At LHC, would like to use modern and varied jet algorithms
  - both ATLAS and CMS are moving to the SISCone algorithm
- SpartyJet developed to make analyses with multiple algorithms easier, especially with topoclusters in ATLAS
  - www.pa.msu.edu/~huston/SpartyJet/SpartyJet.html
  - see Pierre-Antoine's talk

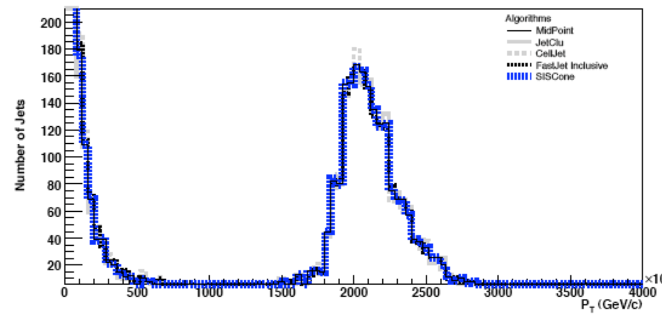


Figure 50: The inclusive jet cross section for the LHC with a $p_{T,min}$ value for the hard scattering of approximately 2 TeV/c, using several different jet algorithms with a distance scale ($D = R_{cone}$) of 0.7. The first bin has been suppressed.

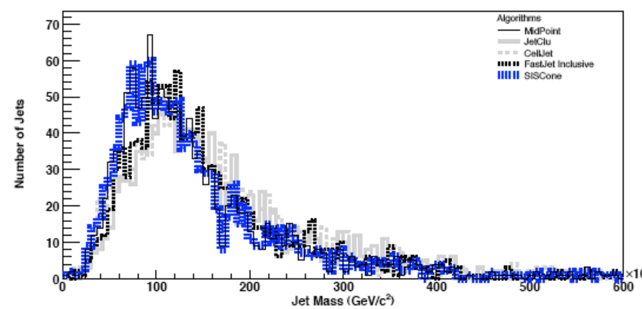


Figure 51: The jet mass distributions for an inclusive jet sample generated for the LHC with a $p_{T,min}$ value for the hard scattering of approximately 2 TeV/c, using several different jet algorithms with a distance scale ($D = R_{cone}$) of 0.7. The first bin has been suppressed.

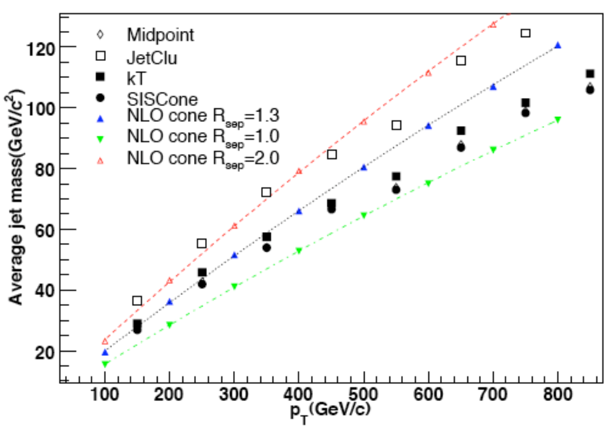


Figure 53: The average jet mass is plotted versus the transverse momentum of the jet using several different jet algorithms with a distance scale ($D = R_{cone}$) of 0.7.

Current experimental status

- ATLAS
  - iterative cone
    - R=0.4,0.7
  - k_T (will move to FastJet k_T)
    - D=0.5,0.7
  - Midpoint
    - R=0.4,0.7
  - moving to SISCone through FastJet
    - R=0.4,0.7
  - SpartyJet being moved into Athena
- CMS
  - iterative cone
    - R=0.5,0.7
  - FastJet k_T
    - D=0.4,0.6
  - Midpoint
    - R=0.5,0.7
  - SISCone
    - R=0.5,0.7
  - may eliminate IC(R=0.7) and one or both Midpoint algorithms

References

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Hard interactions of quarks and gluons: a primer for LHC physics

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Abstract

In this paper, we will develop the perturbative framework for the calculation of hard-scattering processes. We will undertake to provide both a reasonably rigorous development of the formalism of hard-scattering of quarks and gluons as well as an intuitive understanding of the physics behind the scattering. We will emphasize the role of logarithmic corrections as well as power counting in α_S in order to understand the behaviour of hard-scattering processes. We will include 'rules of thumb' as well as 'official recommendations', and where possible will seek to dispel some myths. We will also discuss the impact of soft processes on the measurements of hard-scattering processes. Experiences that have been gained at the Fermilab Tevatron will be recounted and, where appropriate, extrapolated to the LHC.

(Some figures in this article are in colour only in the electronic version)

submitted to Prog. Part. And Nucl. Physics
available from SpartyJet webpage

Jets in Hadron-Hadron Collisions

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Abstract

In this article, we review some of the complexities of jet algorithms and of the resultant comparisons of data to theory. We review the extensive experience with jet measurements at the Tevatron, the extrapolation of this acquired wisdom to the LHC and the differences between the Tevatron and LHC environments. We also describe a framework (SpartyJet) for the convenient comparison of results using different jet algorithms.

Recommendations of jet paper

…available from SpartyJet webpage

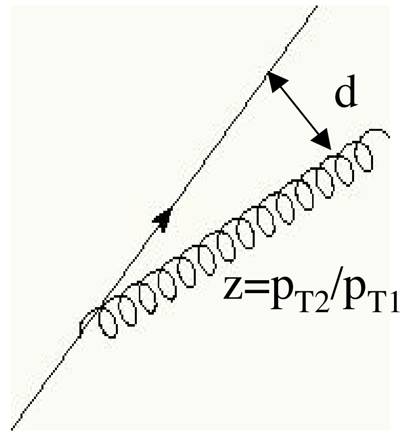
In this context of past experiences and future expectations we have made several recommendations that we feel will play an essential role in the successful analysis of the data from the LHC. These include:

- the use of a variety of jet algorithms for physics analyses with continuous cross-checking of results
- the use of 4-vector kinematics, including evaluation of the jet mass, to characterize a jet
- the use of seedless algorithms (or correction back to seedless) in cone-based jet clustering
- the correction (where possible) of jets back to the hadron level in experimental analyses

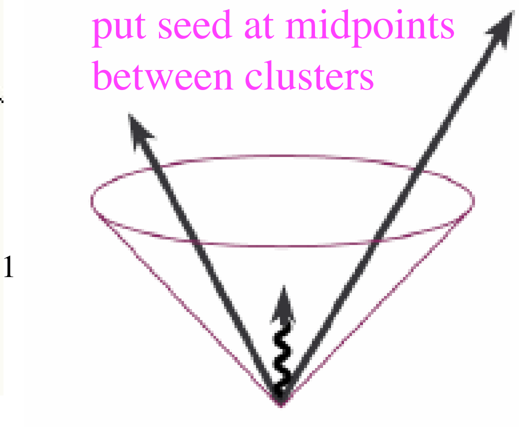
In addition, we have presented a framework (SpartyJet) that facilitates the use of multiple jet algorithms in both experimental and theoretical studies.

Extra: Jet algorithms at (N)LO parton level

- Remember at LO, 1 parton = 1 jet
- At NLO, there can be two partons in a jet and life becomes more interesting
- Let's set the p_T of the second parton = z that of the first parton and let them be separated by a distance d (=ΔR)
- Then in regions I and II (on the left), the two partons will be within R_{cone} of the jet centroid and so will be contained in the same jet
  - ~10% of the jet cross section is in Region II; this will decrease as the jet p_T increases (and α_s decreases)
  - at NLO the k_T algorithm corresponds to Region I (for D=R); <u>thus at parton level, the cone algorithm is always larger than the k_T algorithm</u>



Midpoint algorithm: put seed at midpoints between clusters



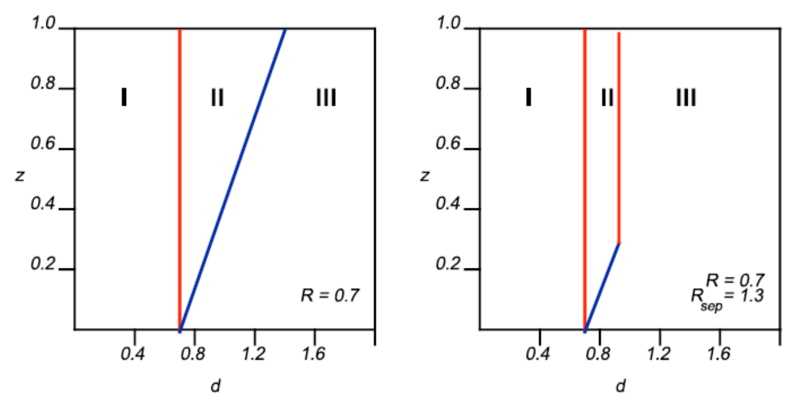


Figure 22. The parameter space (d,Z) for which two partons will be merged into a single jet.

all of the discrimination between jet algorithms is what happens in II