Simulating jet and W/Z+jets production with SHERPA

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- The SHERPA approach
- $W^{\pm}$ and Z production @ Tevatron
- jet production @ Tevatron
  - Consistency checks
  - SHERPA vs. NLO/other MC vs. DATA

The SHERPA approach

Combine LO Matrix Elements and Parton Showers according to CKKW

S. Catani, F. Krauss, R. Kuhn, B. Webber, JHEP 0111:063,2001

F. Krauss, JHEP 0208:015,2002

Motivation:

- ME are exact at some given order in the coupling constant and good for description of exclusive quantities (e.g. jet cross sections)
- PS resums $\alpha_S^n log^{2n}(s/Q_0^2)$ to all orders and is good for inclusive quantities

Aim:

- Combine strengths of both approaches
- Good description of soft and hard region
- Avoid double counting of equivalent phase space configurations
- Universality of fragmentation (energy independent)

The SHERPA approach

Solution:

- Divide multi-jet phase space into two regimes (Durham measure $Q_{\rm cut}$)
  - Jet production by ME (if available)
  - Jet evolution down to fragmentation scale by the PS
- Reweight ME's to get exclusive samples at a resolution scale $Q_{\rm cut}$

  $\Rightarrow$ This allows to add samples of different jet multiplicities
- Veto on PS configurations that have already been taken into account by a higher order ME

Method:

- Select a jet multiplicity with probability:

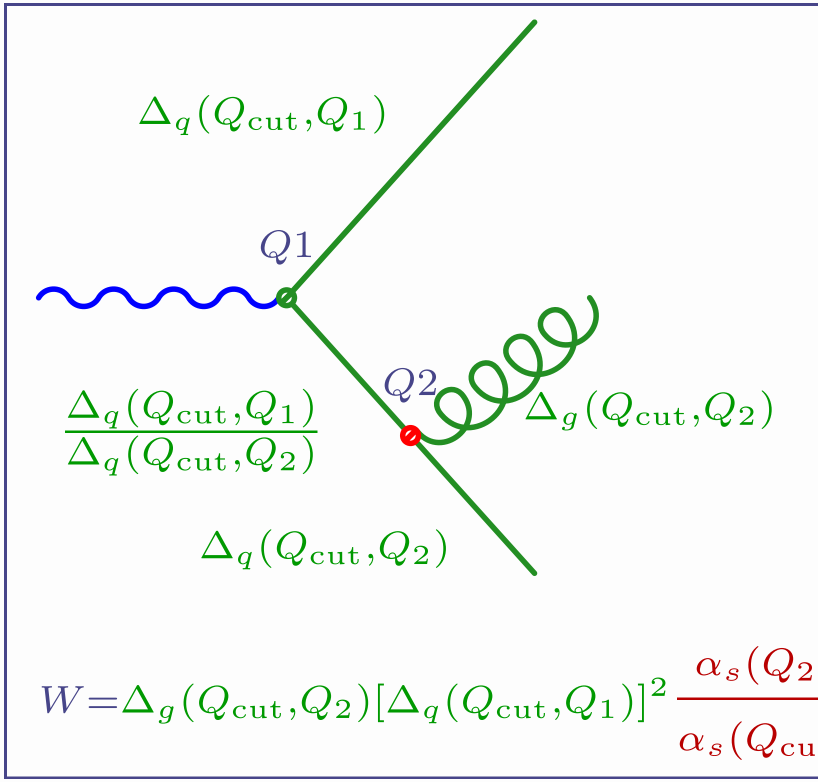
$$P_n = \frac{\sigma_n}{\sum_{i=0}^{N} \sigma_i}$$

  where σ_n is the n-jet matrix element taken at resolution scale $Q_{\rm cut}$. Use $Q_{\rm cut}$ as scale for PDF's and α_S.
- Generate final state momenta p_i according to the ME

The SHERPA approach

Method:

- k_T cluster backwards initial and final state particles until a core $2 \to 2$ process remains, this results in a chain of resolutions for 1,2,..n jets
- Recalculate α_S at each vertex in the tree at the corresponding k_T scale
- Apply Sudakov weights
  - $\Delta_{q,g}(Q_{\rm cut}, Q_{\rm prod})$ for outgoing partons
  - $\Delta_{q,g}(Q_{\rm cut}, Q_{\rm prod})/\Delta_{q,g}(Q_{\rm cut}, Q_{\rm dec})$ for lines between $Q_{\rm prod} > Q_{\rm dec}$
  - Reject events with a combined coupling and Sudakov weight smaller than random number $R \in [0, 1]$
  - Start the initial or final state parton shower for each parton of the event, starting at the scale where it was produced
  - Veto on emissions above the scale $Q_{\rm cut}$



The SHERPA approach

SHERPA specifics:

- Jet measure: $Q^2_{ij} = \min(p^2_{\perp i}, p^2_{\perp j}) \cdot R^2_{ij}$ or $Q^2_{iB} = p^2_{\perp i}$

$$R^2_{ij} = 2\left[\cosh(\eta_i - \eta_j) - \cos(\phi_i - \phi_j)\right]$$

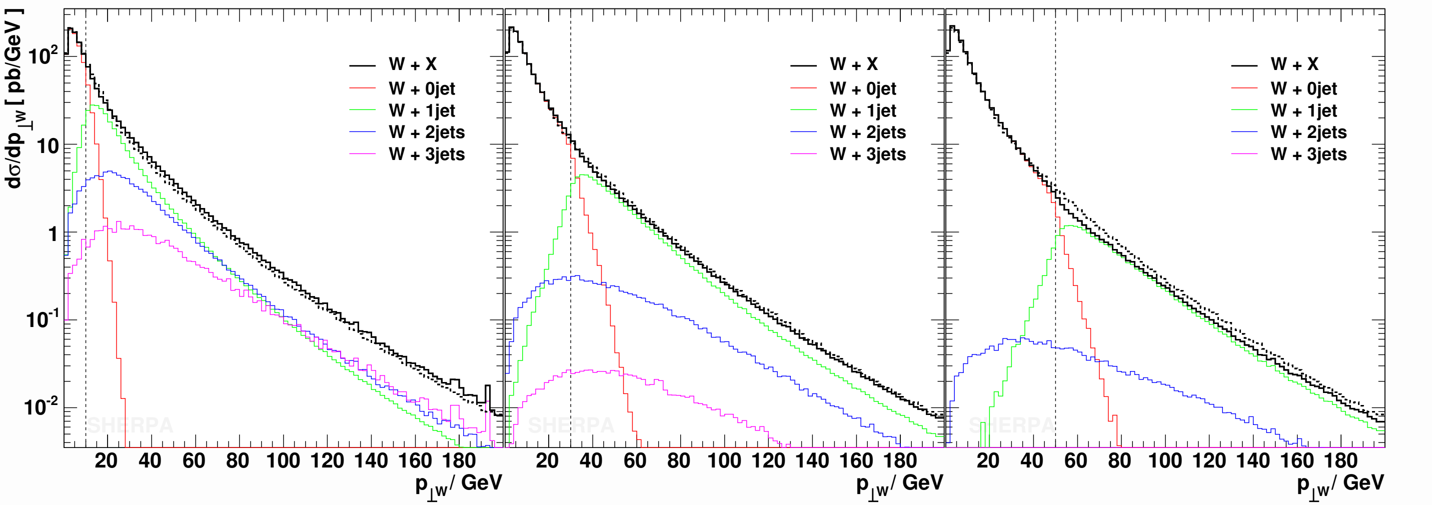
- For the highest multiplicity ME the scale Q_{cut} in the PDF's and Sudakovs is replaced by the smallest nodal scale of the clustering

Now some applications...

W/Z +jets production @ Tevatron: consitency checks

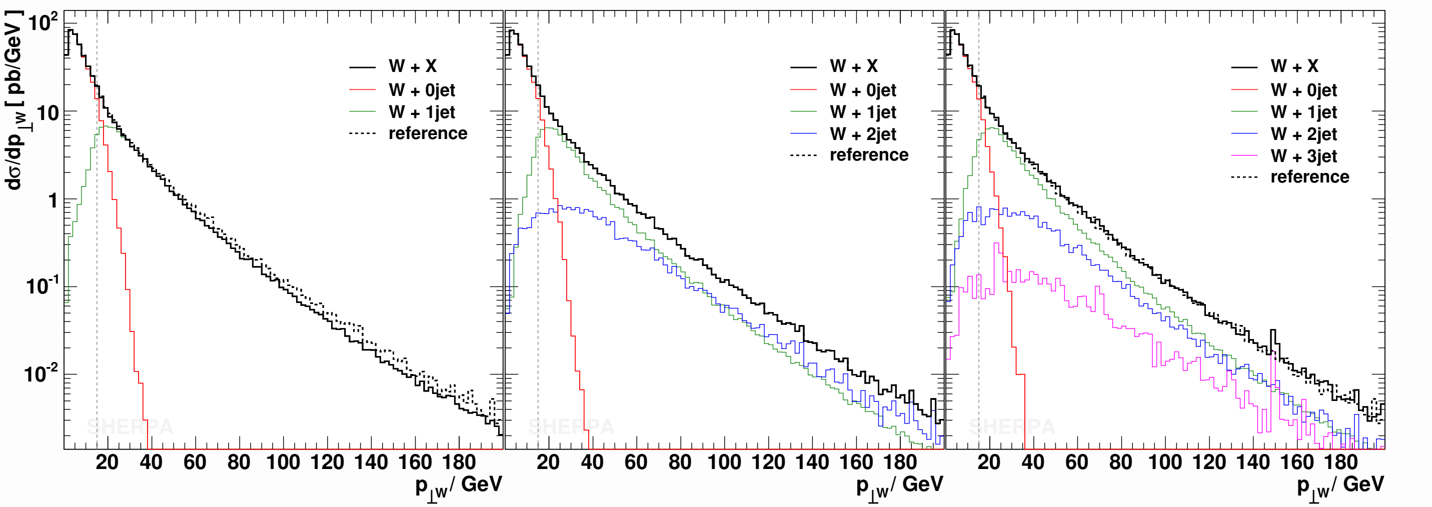
F. Krauss, A. Schälicke, S. S. and G. Soff, Phys. Rev. D 70 (2004) 114009

The $p_\perp$ distribution of the W^- in $pp \to e^-\bar{\nu}_e + X$ @ Tevatron Run II



Q_{cut}=10 GeV Q_{cut}=30 GeV Q_{cut}=50 GeV

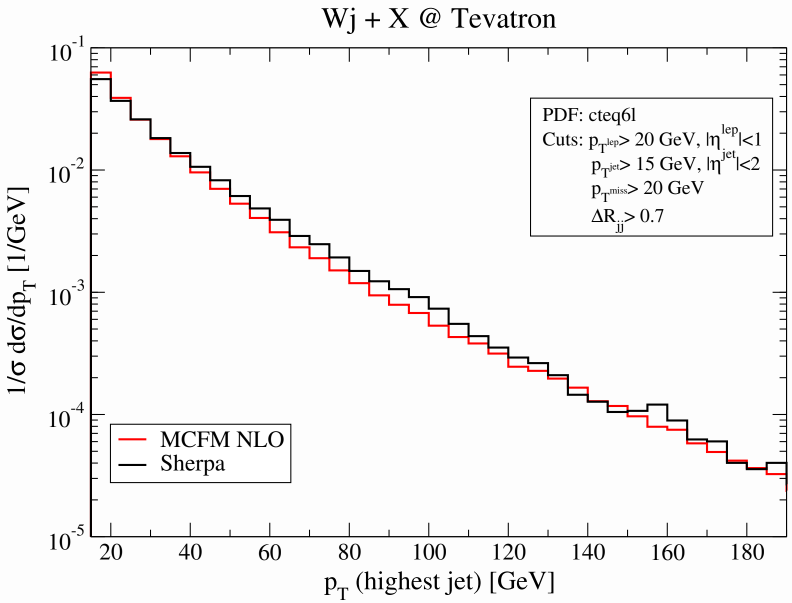
$p_{\perp Z}$ distribution

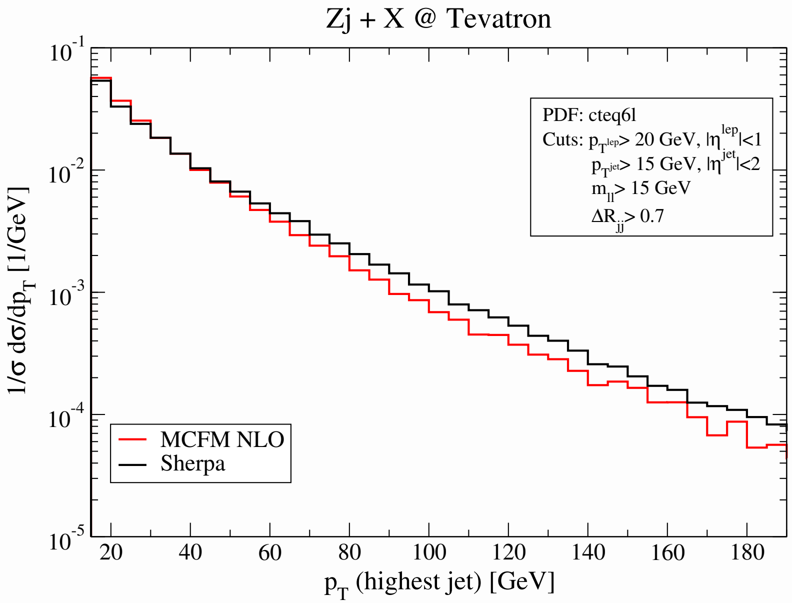


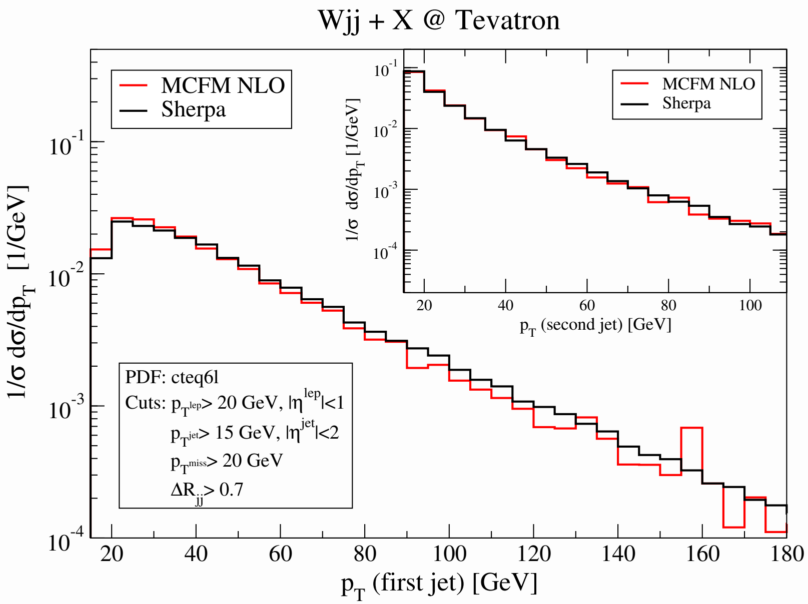
N_{max}=1 N_{max}=2 N_{max}=3

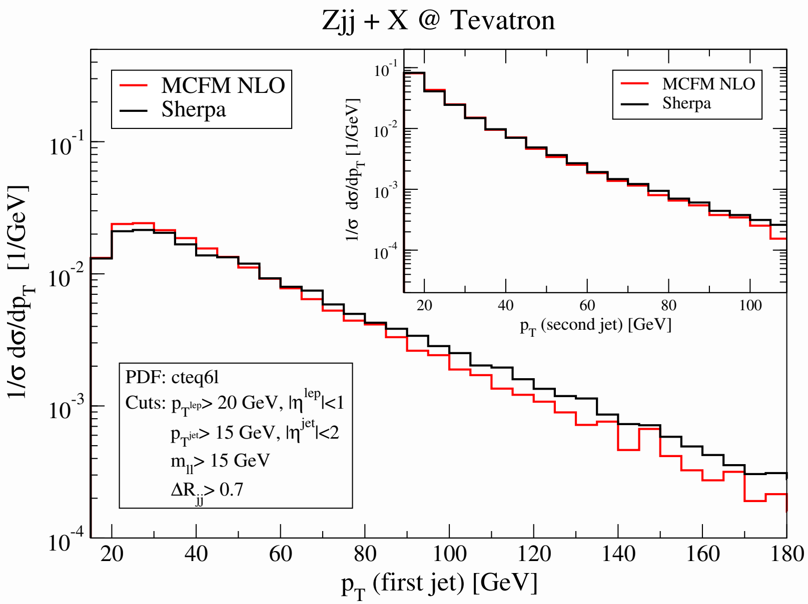
Q_{cut}=15 GeV

SHERPA vs. NLO: Incl. W^- +jet prod. @ Tevatron Run II



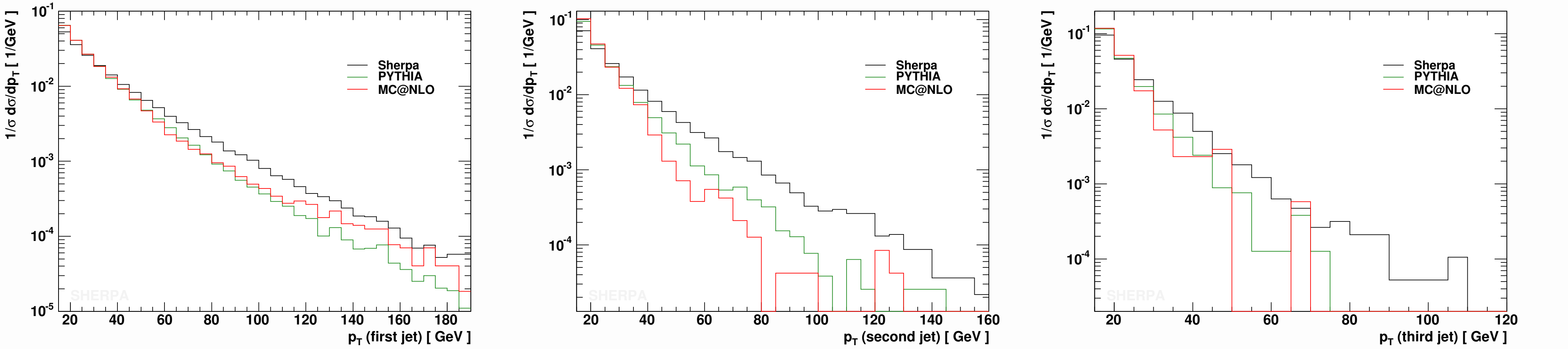






SHERPA vs. PYTHIA and MC@NLO

The $p_\perp$ of the three hardest jets in incl. W production @ Tevatron, Run II

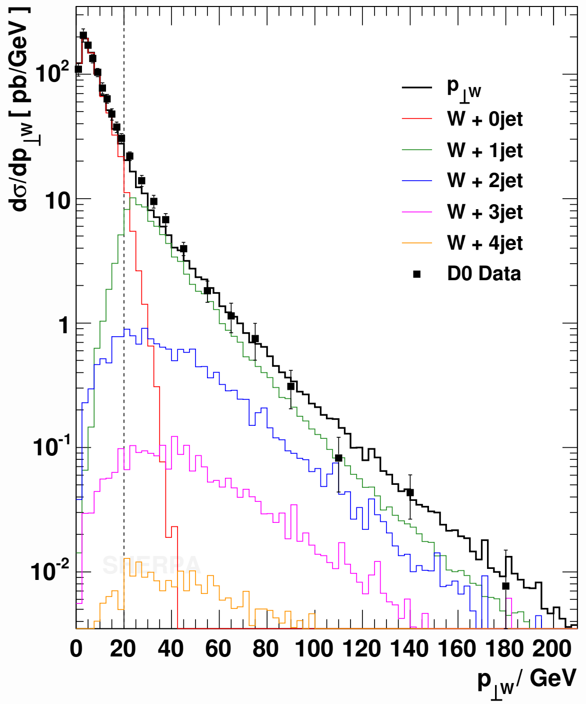


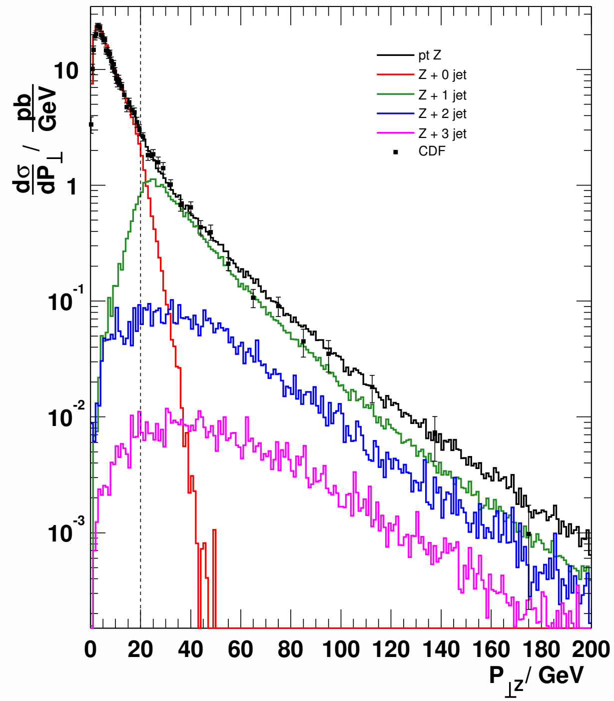
- Inclusive quantities (e.g. $p_\perp, \eta$ distributions of the W/Z) agree quite well
- More exclusive quantities (e.g. $p_\perp$ distributions of the jets) show differences, increasing with the order of jet

SHERPA vs. Data

Inclusive W and Z transverse momentum distributions from Tevatron Run I

- MEs with up to four (W) or three (Z) extra jets
- momenta smaller than merging scale are sensitive to the details of the PS
- $Q_{cut} = 20$ GeV





D0: Phys. Lett. B **513**, 292 (2001) **CDF:** Phys. Rev. Lett. **84**, 845 (2000)

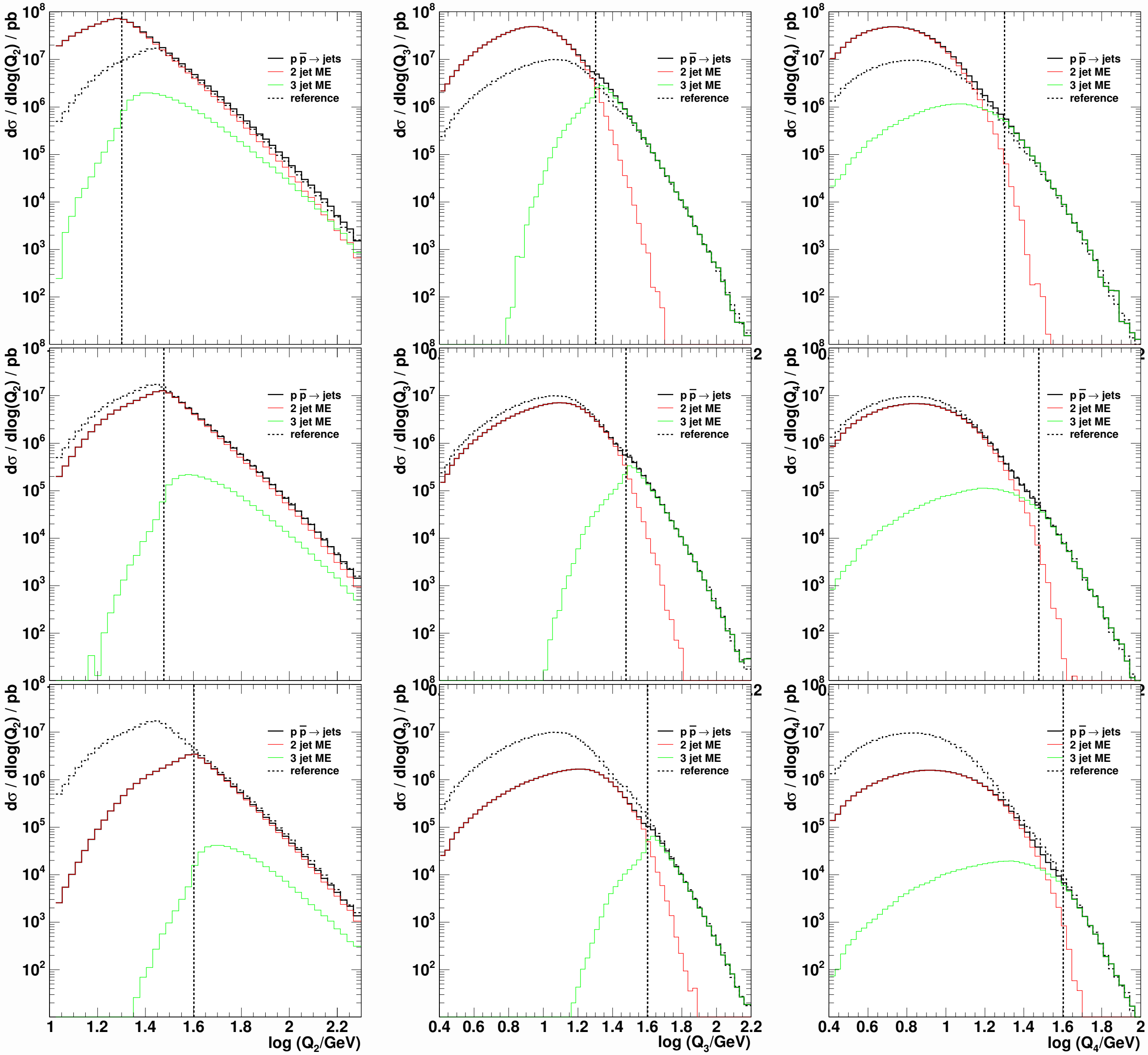
Inclusive jet production

- Specific for pure QCD: Final state parton shower start scale is

$$Q^2 = \frac{2stu}{s^2 + t^2 + u^2}$$

- For a given Q_{cut} the phase space for events with less than two jets above the cut is not filled.
  $\longrightarrow$ can be compensated by a special two scale treatment for the hard $2 \to 2$ process.
- Sherpa can take into accout up to 4-jet production matrix elements

$p\bar{p} \to jets$ @ $\sqrt{s} = 1.8$ TeV: consistency checks



Effect of varying jet separation: differential jetrates

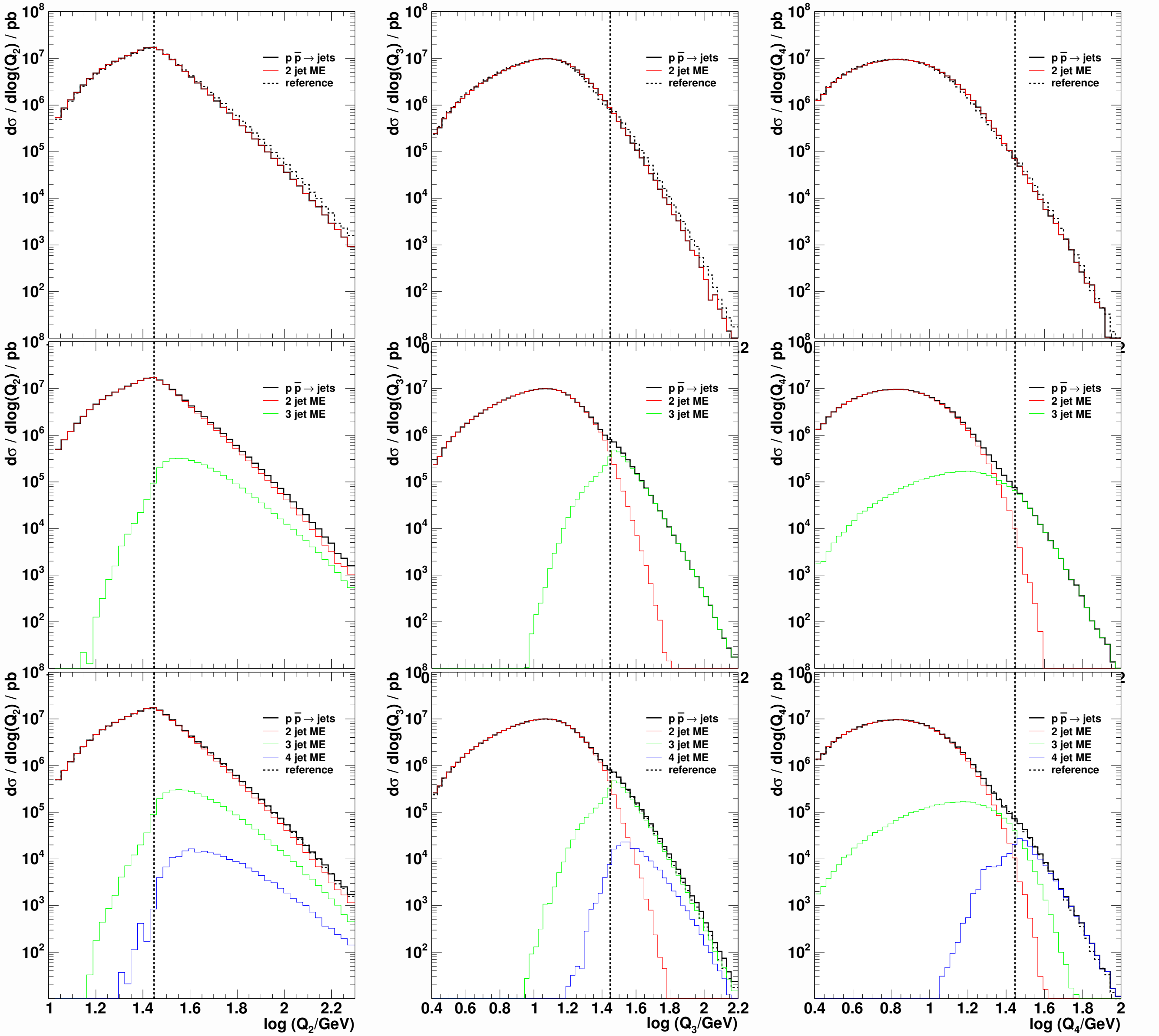
$Q_{cut} = 20$ GeV

$Q_{cut} = 30$ GeV

$Q_{cut} = 40$ GeV

$1 \longrightarrow 2$ $\quad 2 \longrightarrow 3$ $\quad 3 \longrightarrow 4$

Inclusive jet production: $p\bar{p} \to jets$ @ $\sqrt{s} = 1.8$ TeV: consister



$1 \longrightarrow 2$ $2 \longrightarrow 3$ $3 \longrightarrow 4$

Effect of varying maximal jet number: differential jetrates

$N_{max} = 2$

$N_{max} = 3$

$N_{max} = 4$

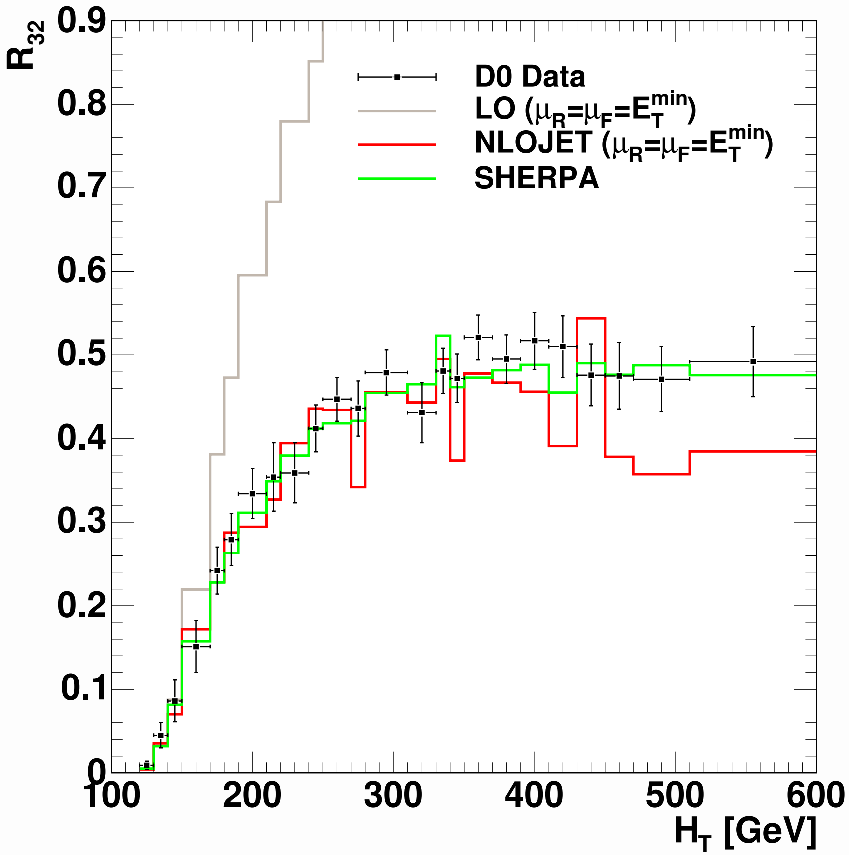
$Q_{cut} = 28$ GeV

Comparison to data: R_{32}

- Ratio of inclusive 3-jet to inclusive 2-jet cross section

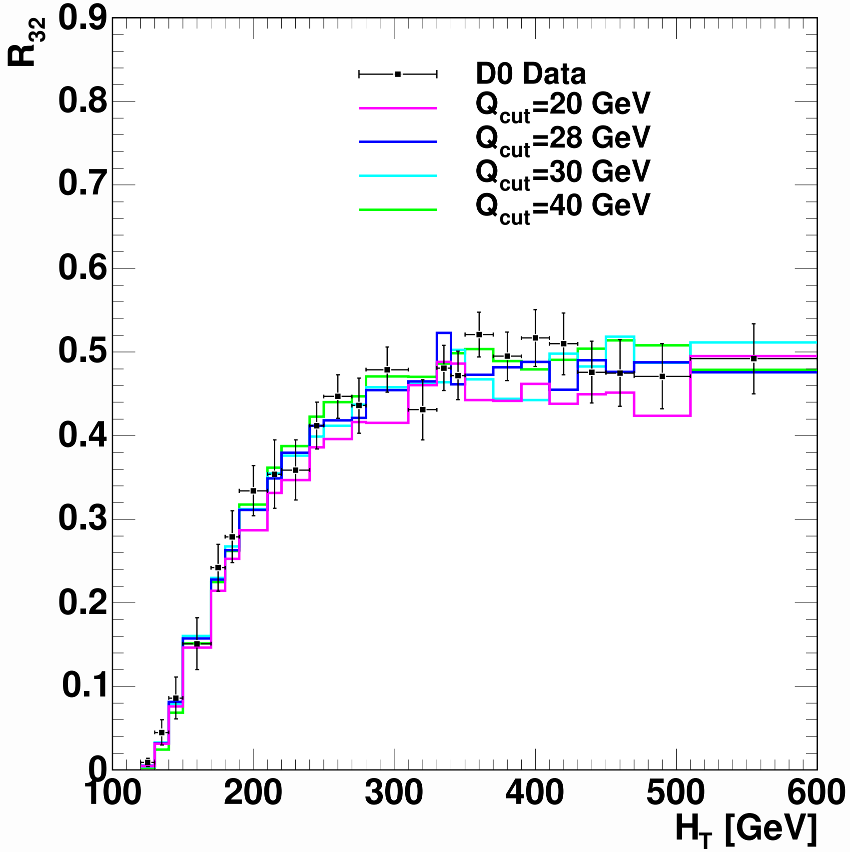
$$R_{32} = \frac{\sigma_3}{\sigma_2} = \frac{\sigma(p\bar{p} \to 2jets + X)}{\sigma(p\bar{p} \to 3jets + X)}$$

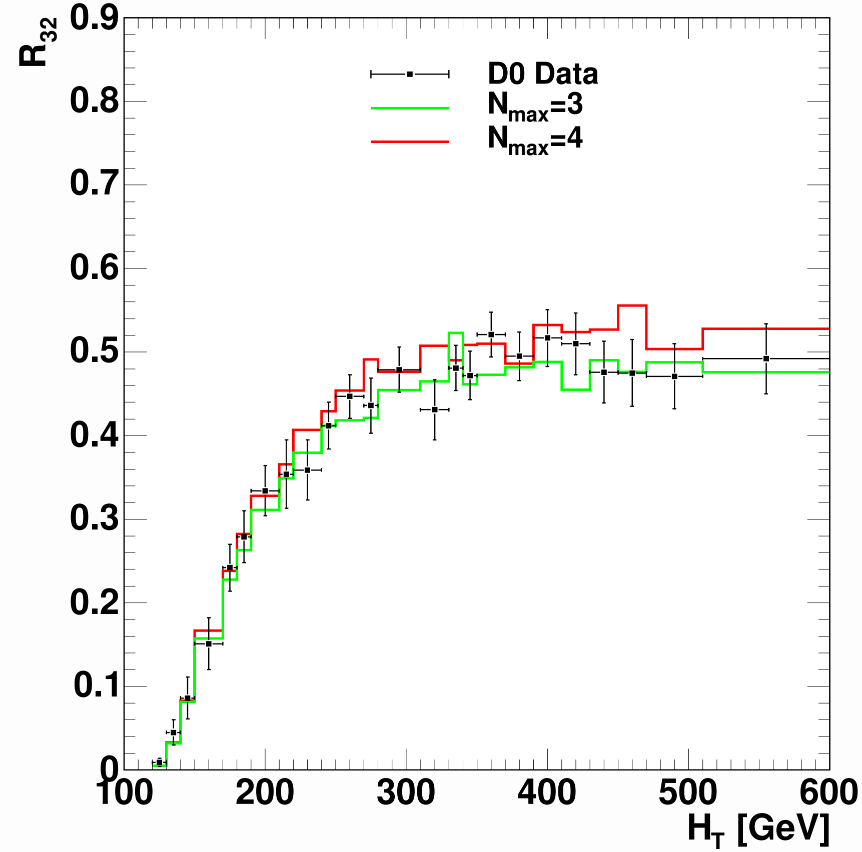
- Tevatron, Run I measurement:
  D0: Phys. Rev. Lett. **86**, 1955 (2001)
- $E_{T,jet} > 40$ GeV, $|\eta_{jet}| < 3$
- Jets analysed using a midpoint-cone algorithm (R=0.7)



Comparison to data: R_{32}

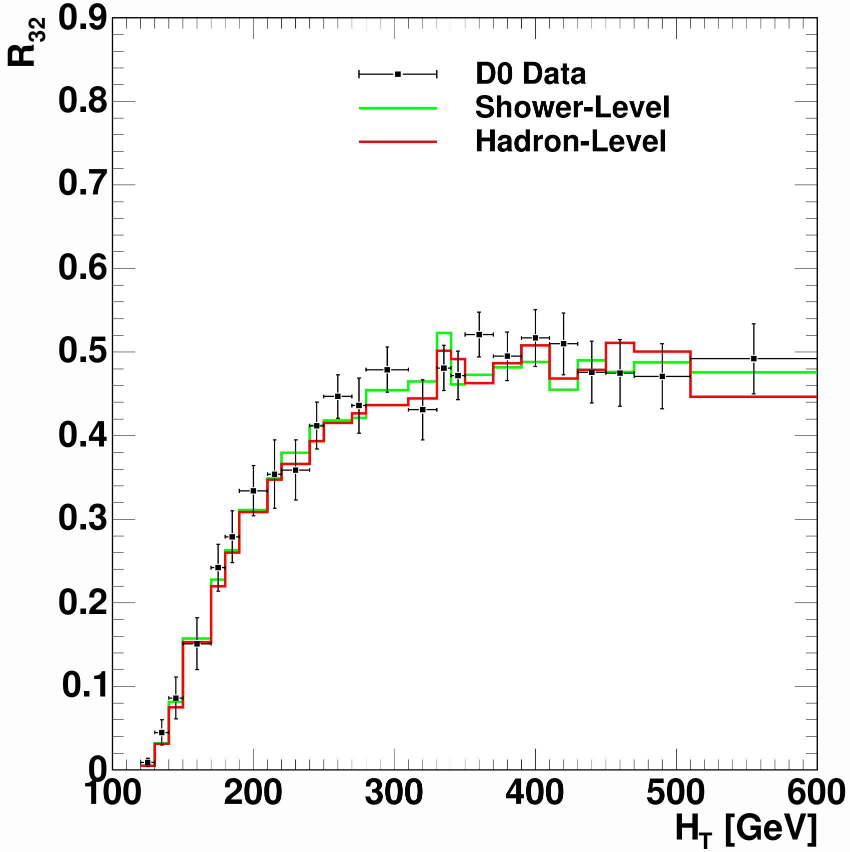
Impact of Q_{cut} / N_{max} variations on Sherpa predictions:

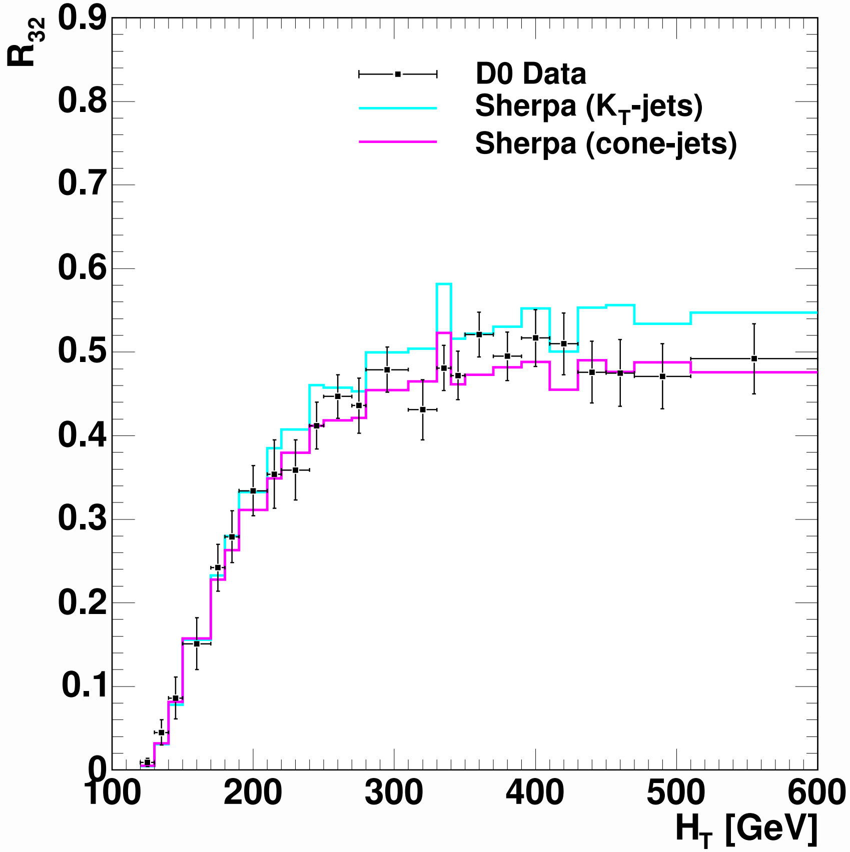




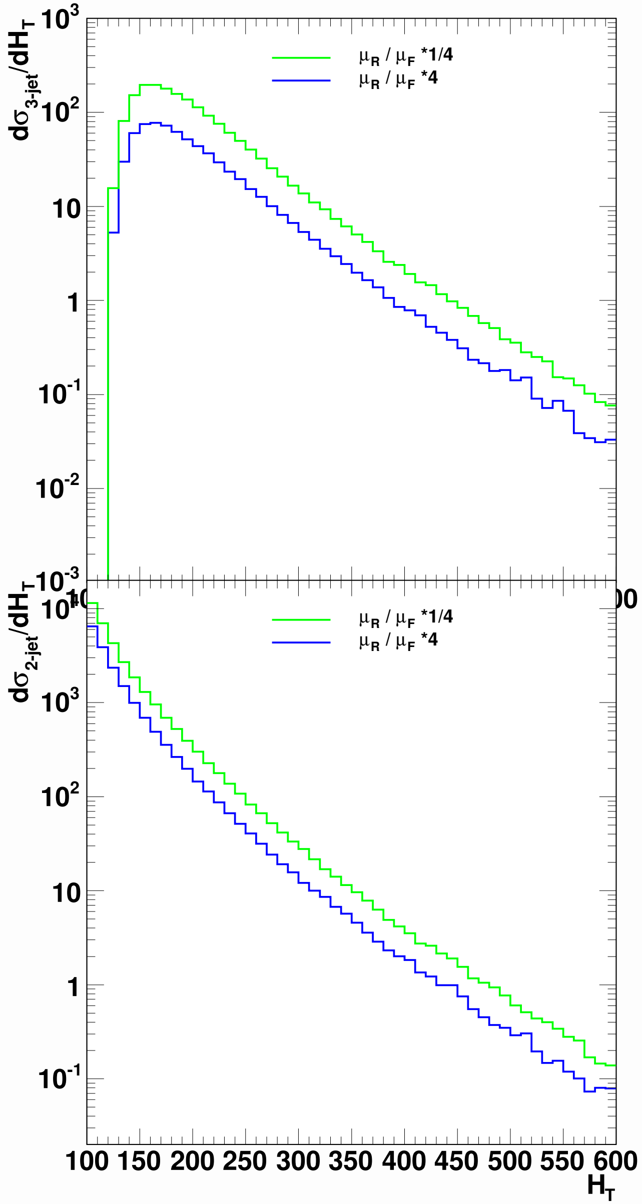
Comparison to data: R_{32}

Effects of hadronization and Jet-algorithm

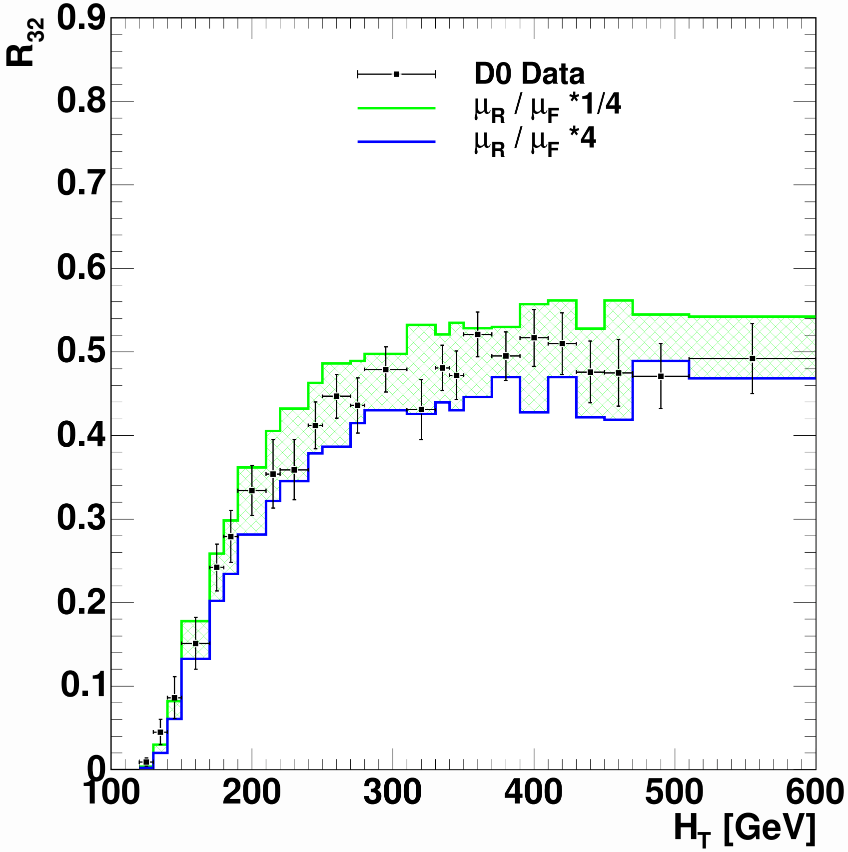




Comparison to data: R_{32}

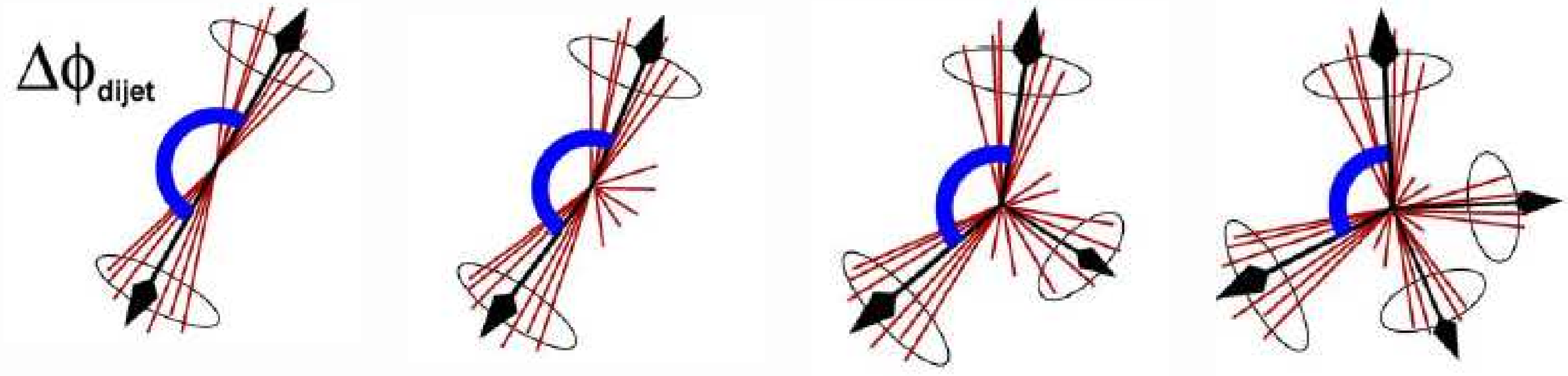


Variation of the Factorization and Renormalization scales:



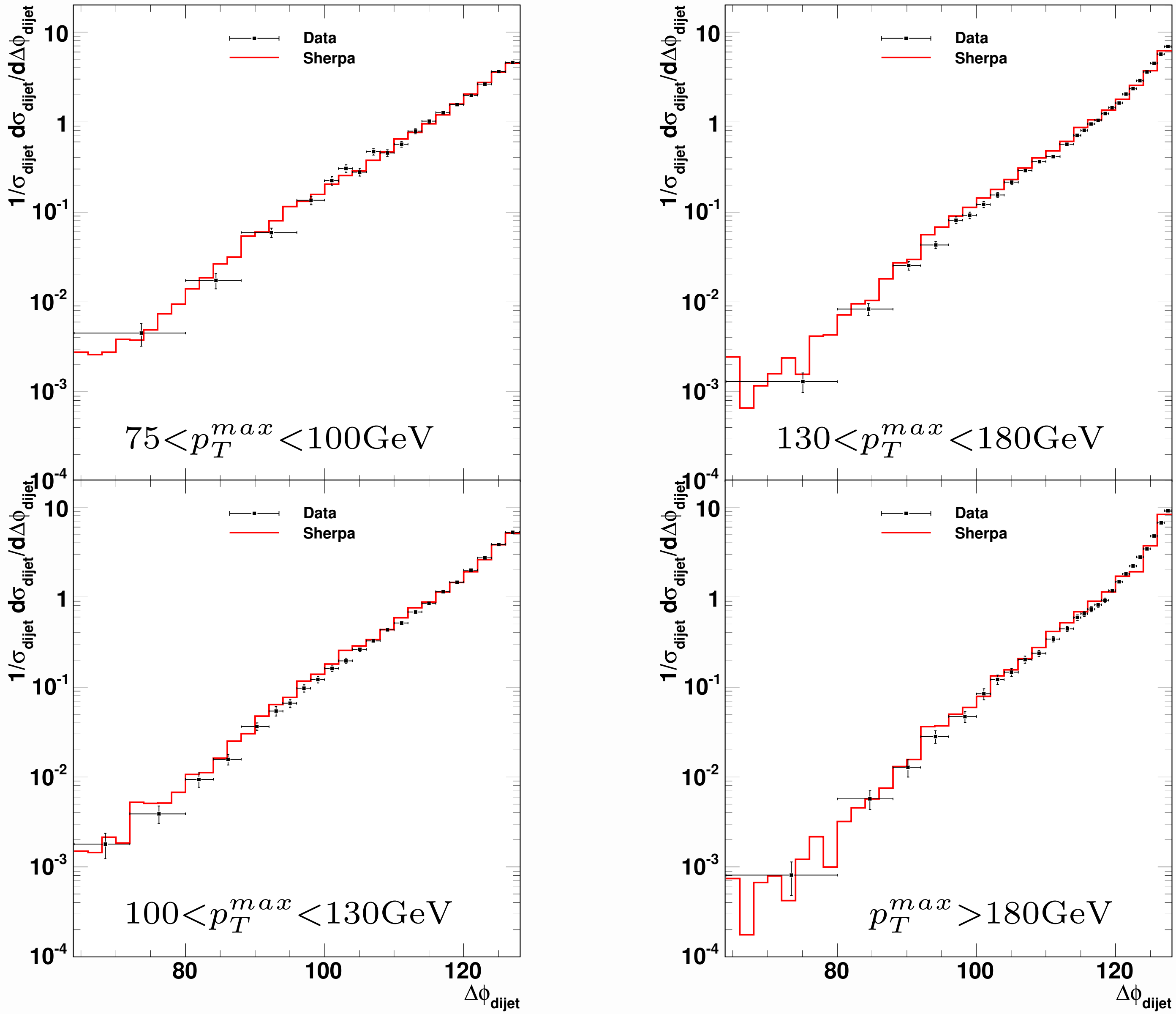
Comparison to data: Azimutal Dijet Decorrelations

- Measurement of the Φ-angle between the two hardest jets of an inclusive sample



- Different regions of $\Delta\phi$ are sensitive to different multiplicities of hard QCD jet production
- Measured at Tevatron ($\sqrt{s} = 1.96$ TeV): D$\emptyset$ hep-ex/0409040
- $p_T^{jet} > 40GeV$, $|y^{jet}| < 0.5$

Comparison to data: Azimutal Dijet Decorrelations



$Q_{cut} = 40GeV$

$N_{max} = 4$

Conclusion/Outlook

Conclusion

- The implemented CKKW-merging works quite well for W/Z +jets and pure jet production
  Also validated:
  - W/Z @ LHC: F. Krauss, A. Schälicke, S. Schumann and G. Soff, hep-ph/0503280
  - W^+W^- +jets T. G., F. Krauss, A. Schälicke, S. Schumann and J. Winter, hep-ph/0504032
- further validation is in progress
- SHERPA is able to reproduce the shapes of corresponding NLO calculations

SHERPA sources

- SHERPA: T. G., S. Höche, F. Krauss, A. Schälicke, S. Schumann and J. Winter, JHEP 0402:056,2004
- current version SHERPAα-1.0.6 is available under

  `http://www.physik.tu-dresden.de/~krauss/hep`