Predictions for Multi-Particle Final States

Steffen Schumann [a]

Institute for Theoretical Physics
Dresden University of Technology

Goal:

- Accurate and complete description of final states with multiple hard, large angle emissions including jet showering, hadronization, etc.

Method:

- Account for multi-jet production through tree level matrix elements
- Combine them with the parton showers and hadronization according to the CKKW prescription (realized in the event generator Sherpa)

[a] For the Sherpa collaboration: T. Gleisberg, S. Höche, F. Krauss, A. Schälicke, S. S., J. Winter

ME versus PS

How to simulate hard processes with additional hard radiation ?

The Matrix Element domain:

- ME is exact at some given order in the coupling constant including all quantum interferences and correlations
- Account for high energetic and well separated parton configurations
- For soft and collinear kinematics a fixed order calculation is not adequate due to the lack of multiple unresolved gluon emissions

The Parton Shower domain:

- Relates partons produced in a hard interaction to partons at the hadronization scale
- Includes logarithmically enhanced soft and collinear contributions of parton emissions
- Not enough energetic gluons are emitted that have a large angle from the shower initiator

Combining ME and PS – CKKW

S. Catani,F. Krauss, R. Kuhn, B. Webber, JHEP 0111:063,2001
F. Krauss, JHEP 0208:015,2002

Aim:

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

Solution:

- Divide multi-jet phase space into two regimes
  - Jet production by ME (if available)
  - Jet evolution down to fragmentation scale by the PS
- Reweight ME's to get exclusive samples at a given resolution scale

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

Combining ME and PS – CKKW

Method:

- Select a jet multiplicity with probability:

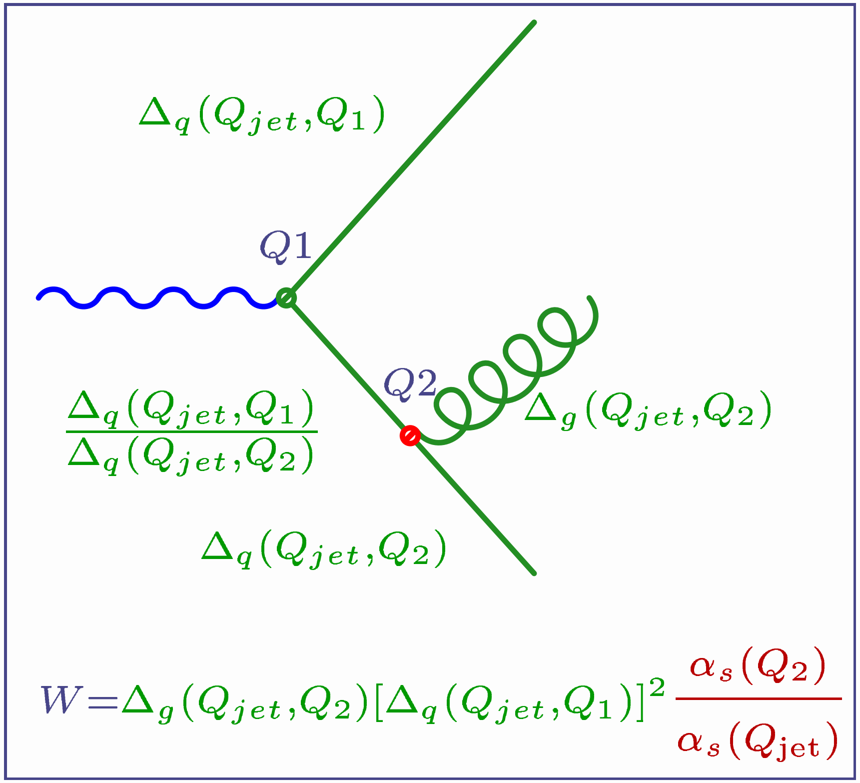
$$P_n = \frac{\sigma_n}{\sum_{i=0}^{N} \sigma_i}$$

  where σ_n is the n-jet matrix element taken at resolution scale Q_{jet}. Use Q_{jet} as scale for PDF's and α_S.

- Generate final state momenta p_i according to the ME
- 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
  - $\Delta_{q,g}(Q_{\mathrm{jet}}, Q_{\mathrm{prod}})$ for outgoing partons
  - $\Delta_{q,g}(Q_{\mathrm{jet}}, Q_{\mathrm{prod}})/\Delta_{q,g}(Q_{\mathrm{jet}}, Q_{\mathrm{dec}})$ for lines between $Q_{\mathrm{prod}} > Q_{\mathrm{dec}}$

Combining ME and PS – CKKW

- 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_{jet}

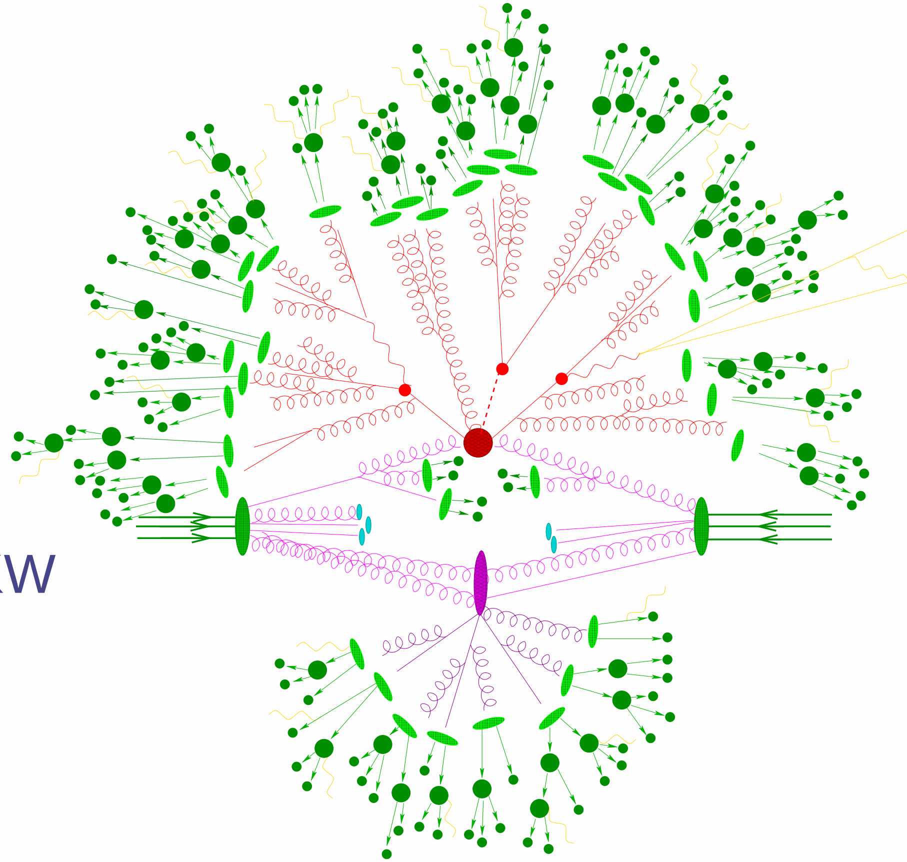


Sherpa: An event generator for the LHC

T. Gleisberg, S. Höche, F. Krauss, A. Schälicke, S. S. and J. Winter, JHEP 0402:056,2004

Sherpa is a new C++ multi-purpose event generator including:

- the ME generator AMEGIC++
  (providing the ME's for hard processes and decays in the SM, MSSM and the ADD model)
- the parton shower module APACIC++
  (containing a virtuality ordered initial and final state parton shower)
- combination of ME's and PS's á la CKKW
- an interface to the Pythia string fragmentation and hadron decays
- currently no UE model



The Matrix Elements: AMEGIC++

Validation against other codes: results of MC4LHC workshop

X-sects (pb)	Number of jets						
$e^-\bar{\nu}_e + n$ QCD jets	0	1	2	3	4	5	6
Alpgen	3904(6)	1013(2)	364(2)	136(1)	53.6(6)	21.6(2)	8.7(1)
CompHEP	3947.4(3)	1022.4(5)	364.4(4)				
MadEvent	3902(5)	1012(2)	361(1)	135.5(3)	53.6(2)		
Amegic++/Sherpa	3908(3)	1011(2)	362(1)	137.5(5)	54(1)		

X-sects (pb)	Number of jets				
$e^-\bar{\nu}_e + b\bar{b}$	0	1	2	3	4
Alpgen	9.34(4)	9.85(6)	6.82(6)	4.18(7)	2.39(5)
CompHEP	9.415(5)	9.91(2)			
MadEvent	9.32(3)	9.74(1)	6.80(2)		
Amegic++/Sherpa	9.37(1)	9.86(2)	6.87(5)		

AMEGIC++ proved to work for up to six particle final states: State of the art.

Combining ME and PS – CKKW

The CKKW method has been implemented in Sherpa in full generality

- Proofed to be successful in e^+e^- collisions
- For hadron collisions the study of systematics is still ongoing
  - Study the dependence on resolution Q_{jet} in various distributions
  - Find the optimal treatment for the highest multiplicity ME
  - Investigate the impact of different scale choices
  - Compare CKKW predictions to other approaches (MLM) and NLO results

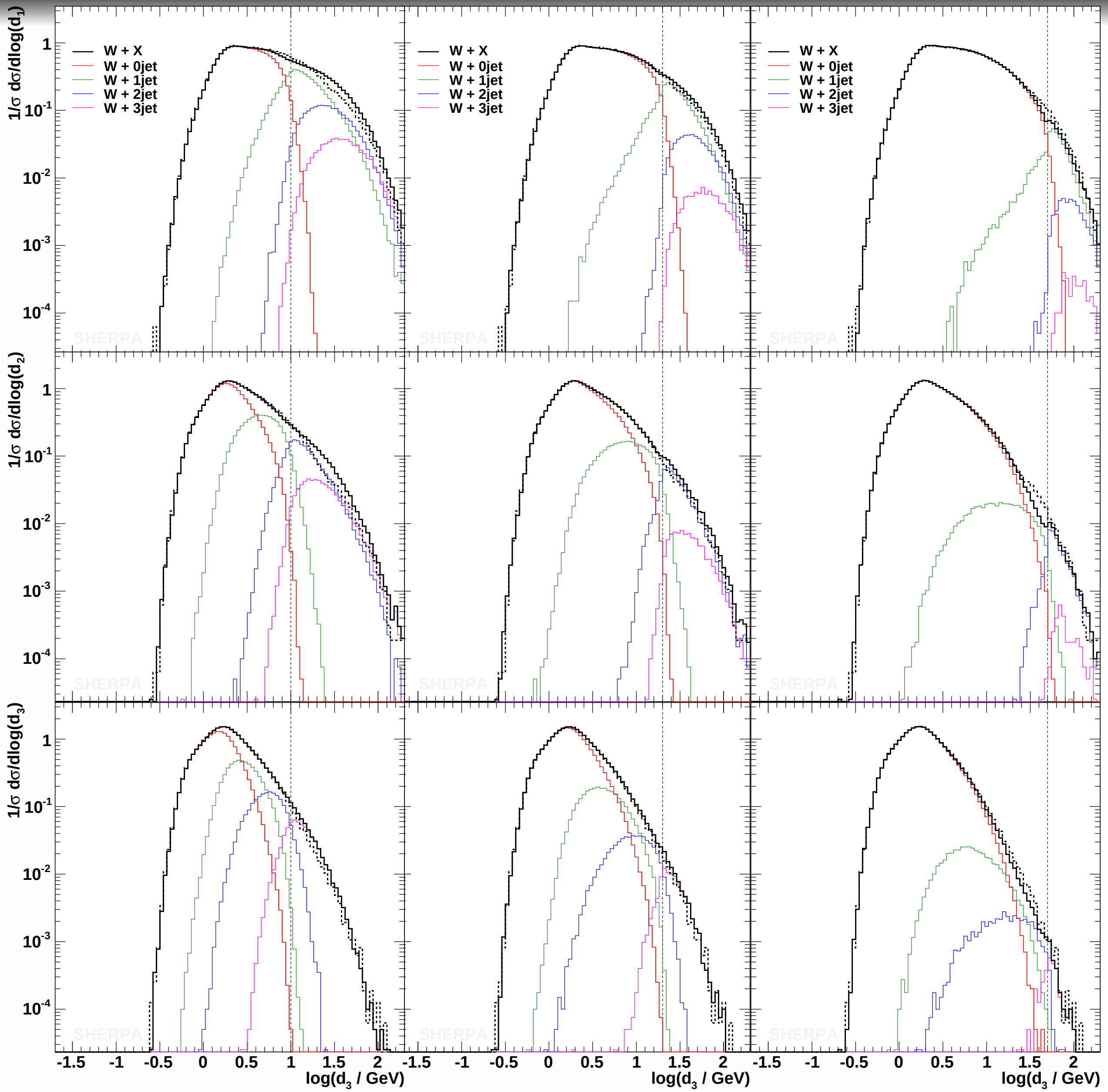
Sherpa specifics:

- Jet measure: $d_{ij} = \min(p_{\perp i}^2, p_{\perp j}^2) \cdot R_{ij}^2$ or $d_{iB} = p_{\perp i}^2$

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

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

Differential jet rates in $p\bar{p} \to e^- \bar{\nu}_e + X$ @ $\sqrt{s} = 1.96$TeV



$0 \to 1$

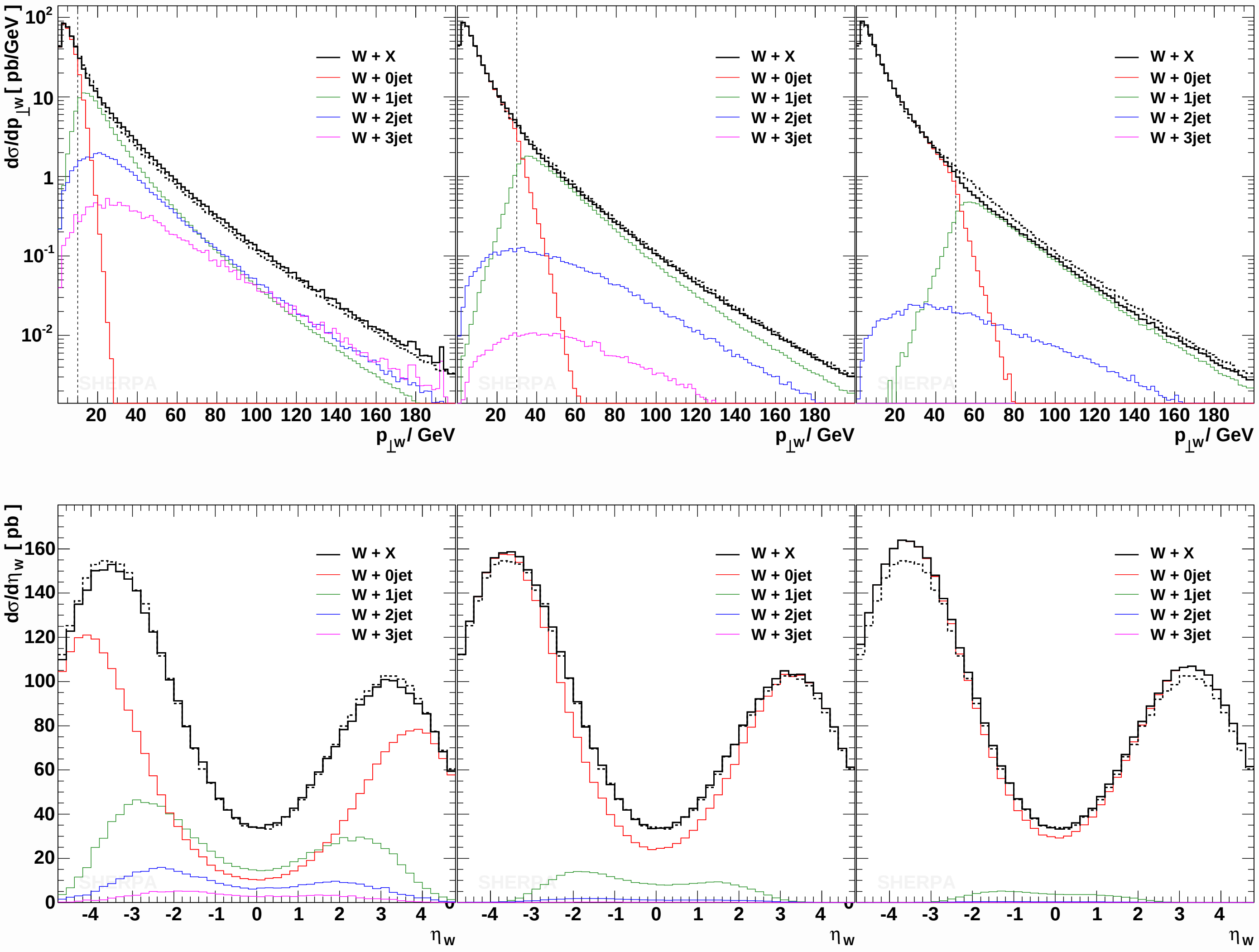
$1 \to 2$

$2 \to 3$

d_{cut}=10 GeV d_{cut}=20 GeV d_{cut}=50 GeV

dashed d_{cut}=30 GeV

W distributions in $p\bar{p} \to e^- \, \bar{\nu}_e + X$ @ $\sqrt{s} = 1.96$TeV

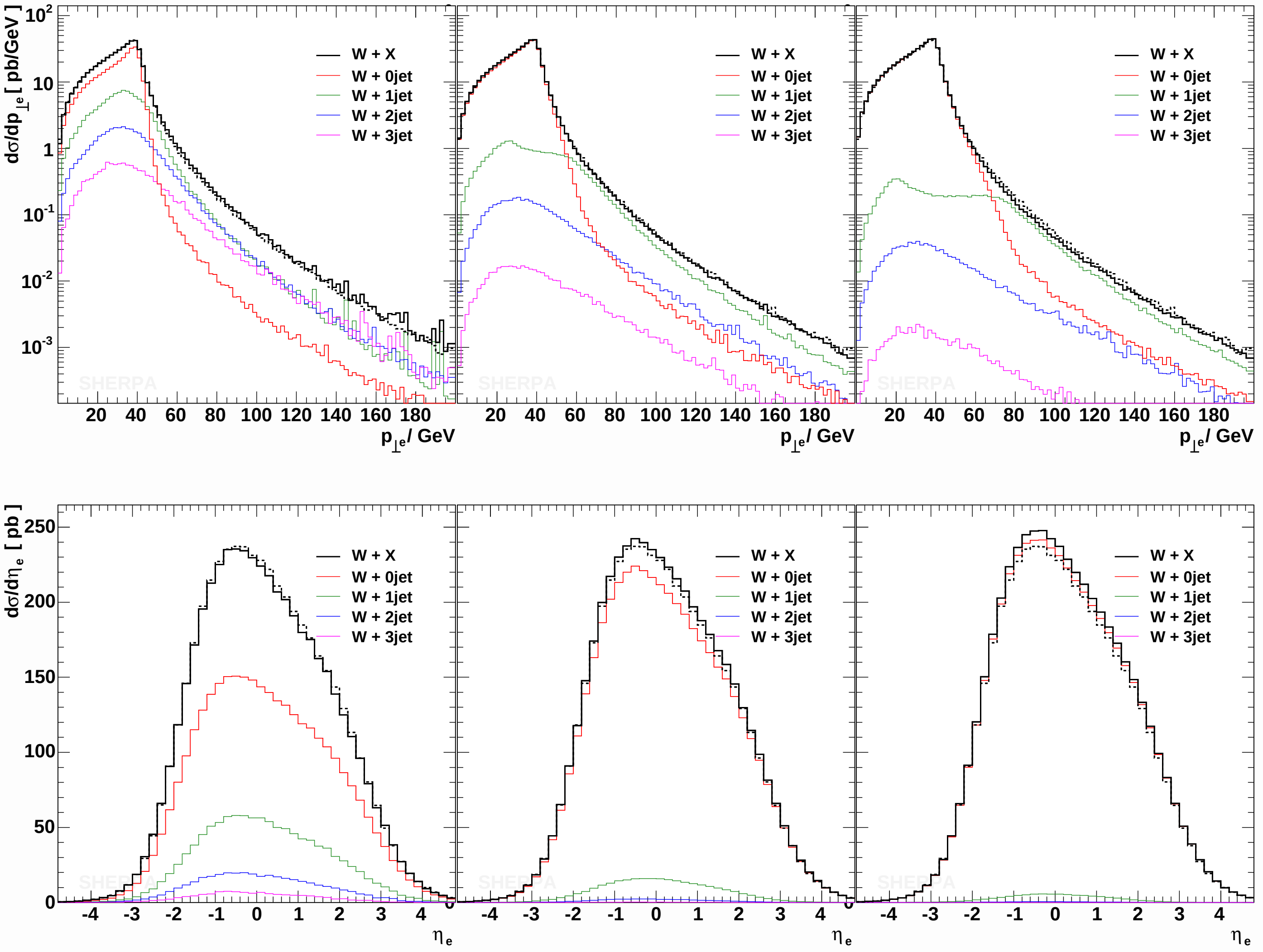


$p_{\perp W^-}$ distribution

η_{W^-} distribution

$d_{\rm cut}$=10 GeV $d_{\rm cut}$=30 GeV $d_{\rm cut}$=50 GeV dashed $d_{\rm cut}$=20 GeV

Electron distributions $p\bar{p} \to e^- \; \bar{\nu}_e + X$ @ $\sqrt{s} = 1.96\text{TeV}$

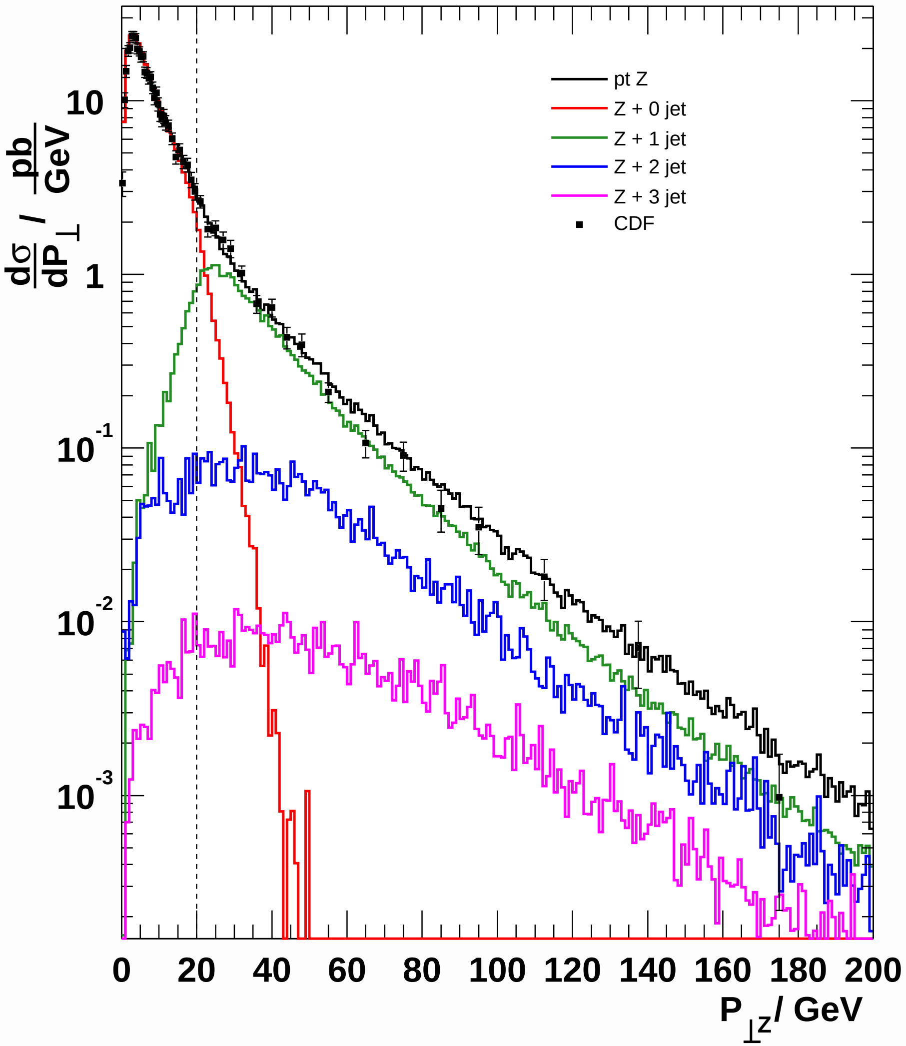


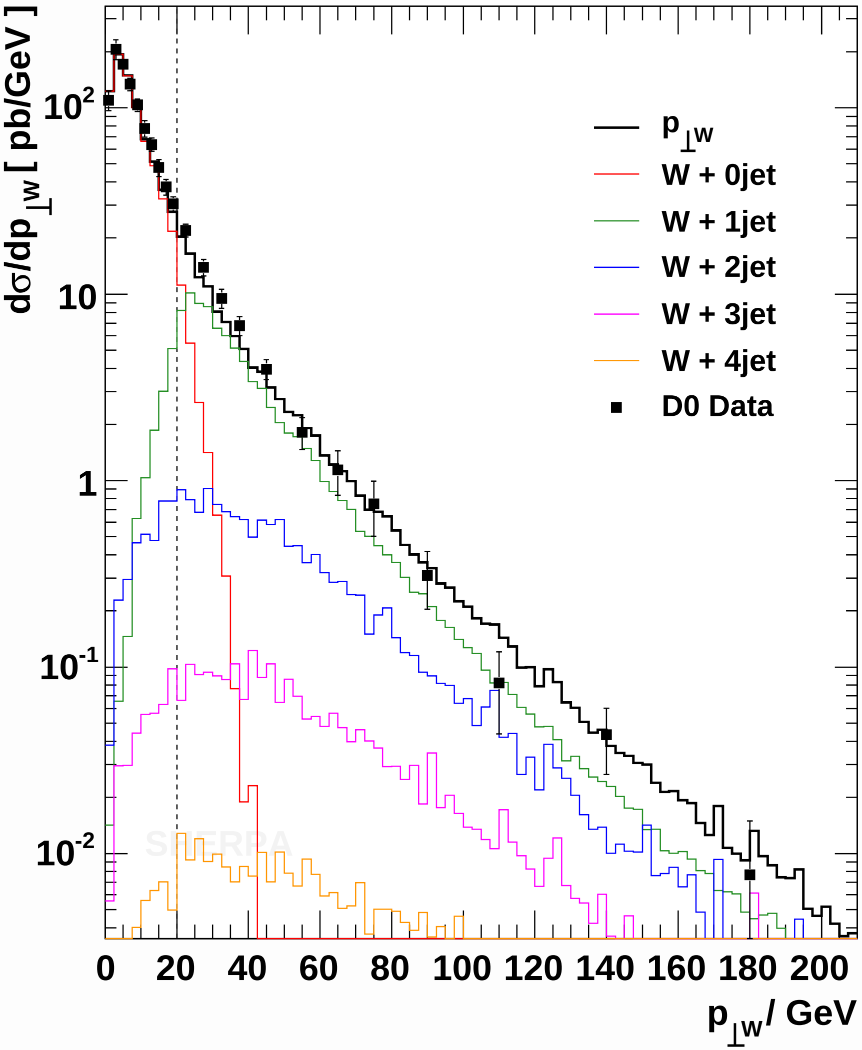
$p_{\perp e^-}$ distribution

η_{e^-} distribution

d_{cut}=10 GeV d_{cut}=30 GeV d_{cut}=50 GeV dashed d_{cut}=20 GeV

Comparison with Tevatron data @ $\sqrt{s} = 1.8\,\mathrm{TeV}$





CDF Data : Phys.Rev.Lett.84:845-850,2000

DO Data : Phys.Lett.B513:292-300,2001

Distributions multiplied by appropriate K-factors!

Sherpa vs. NLO: Step I

Consider CKKW as a scale setting prescription for tree level calculations

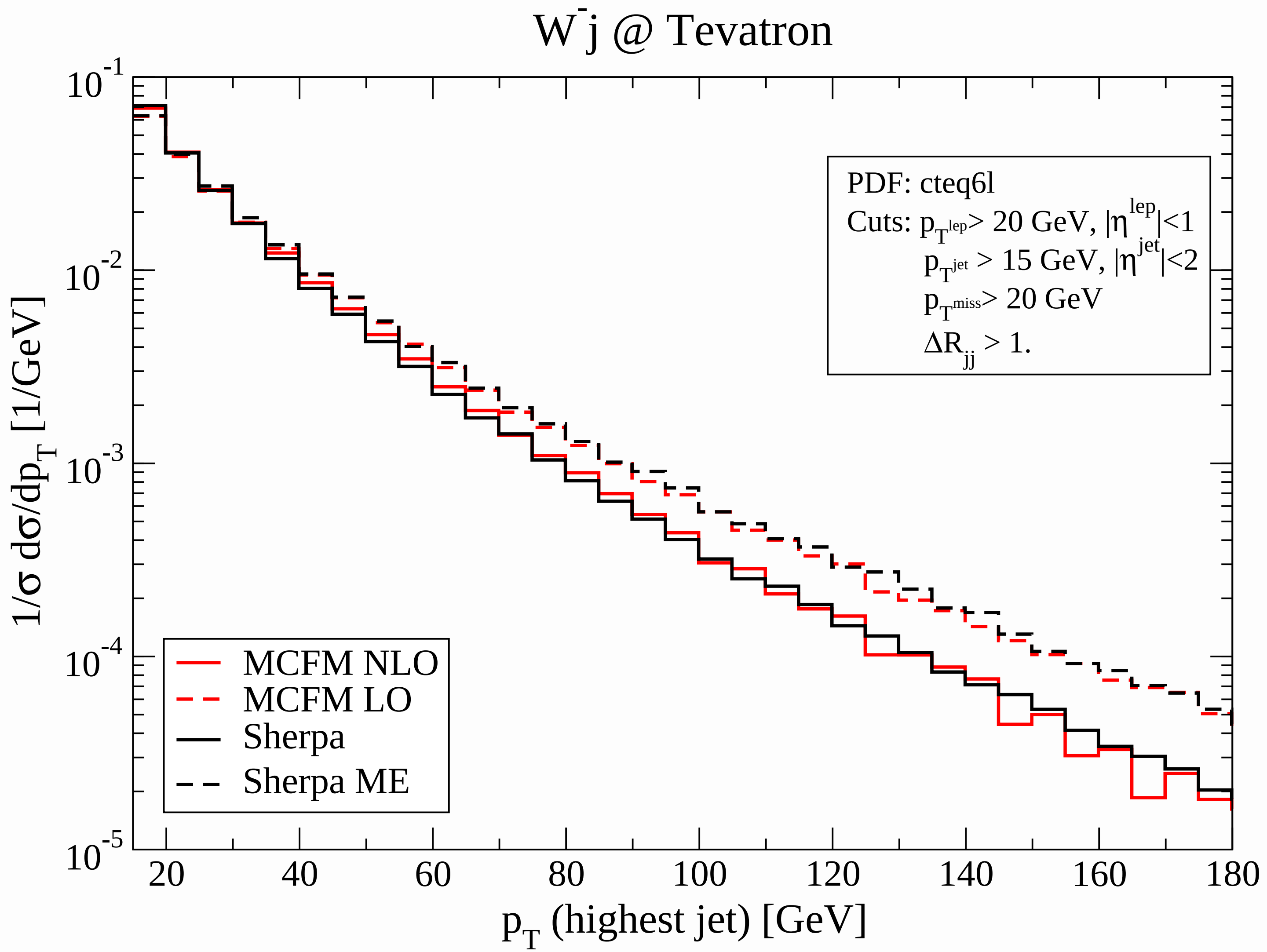
Look at α_S and Sudakov reweighted parton samples without attaching the parton shower and compare those to NLO results

- Take fully exclusive parton samples of $W+1/2$ jets and $Z+1/2$ jets ($W^+ \to e^+\nu_e$, $W^- \to e^-\bar{\nu}_e$, $Z \to e^+e^-$)
- Compare to exclusive NLO ME predictions of MCFM (J.M. Campbell, R.K. Ellis, Phys.Rev.D65:113007,2002 and Phys.Rev.D68:094021,2003)

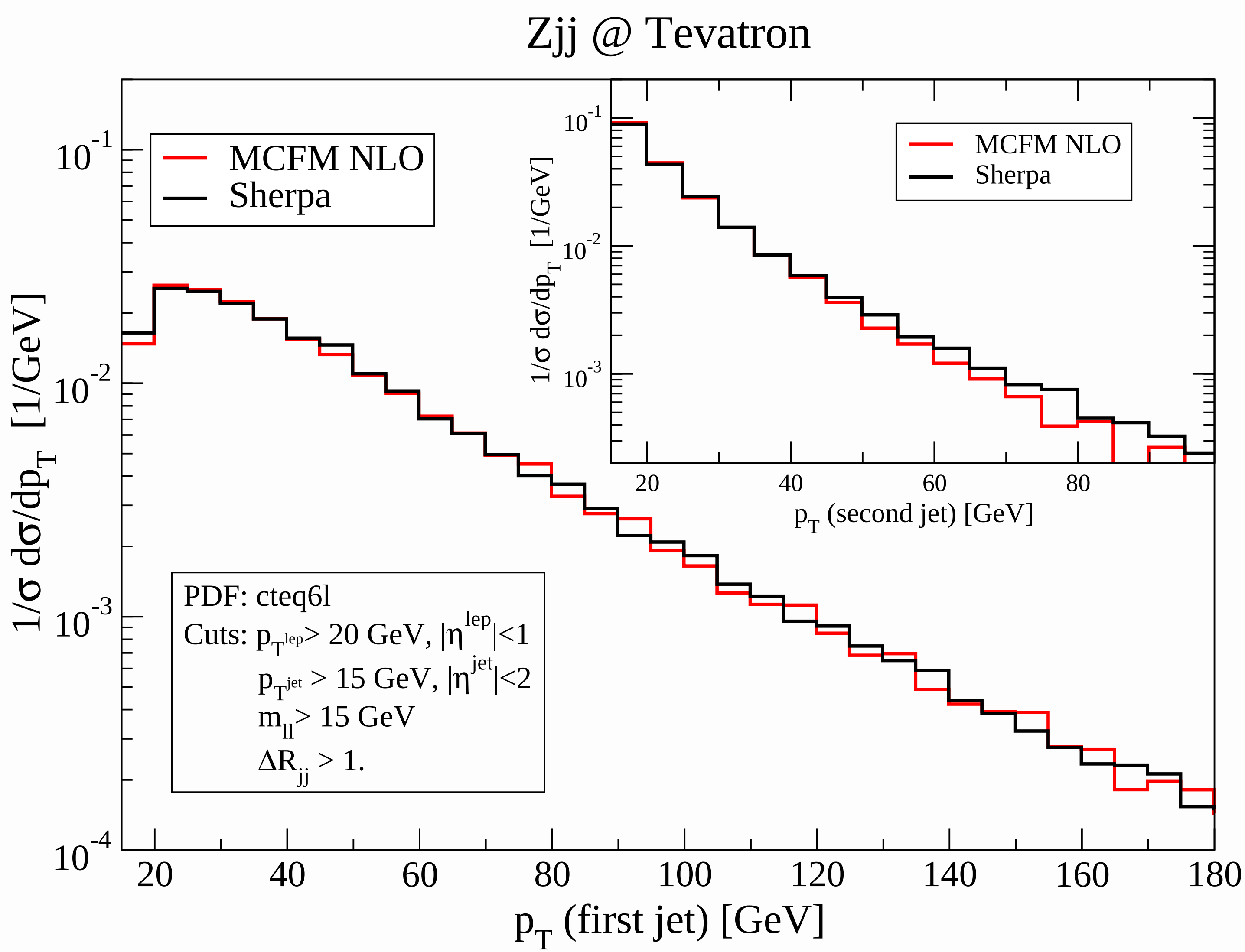
Setup:

- MCFM and Sherpa pure ME: $\mu_F = \mu_R = M_W$
- $d_{cut} = p_{\perp,min}$ of jets
- jets are defined by Run II K_T algorithm with $D = 1$. (means $\Delta R_{jj} > 1$.) (ensures that Sherpa fills the full phase space although the shower is off)

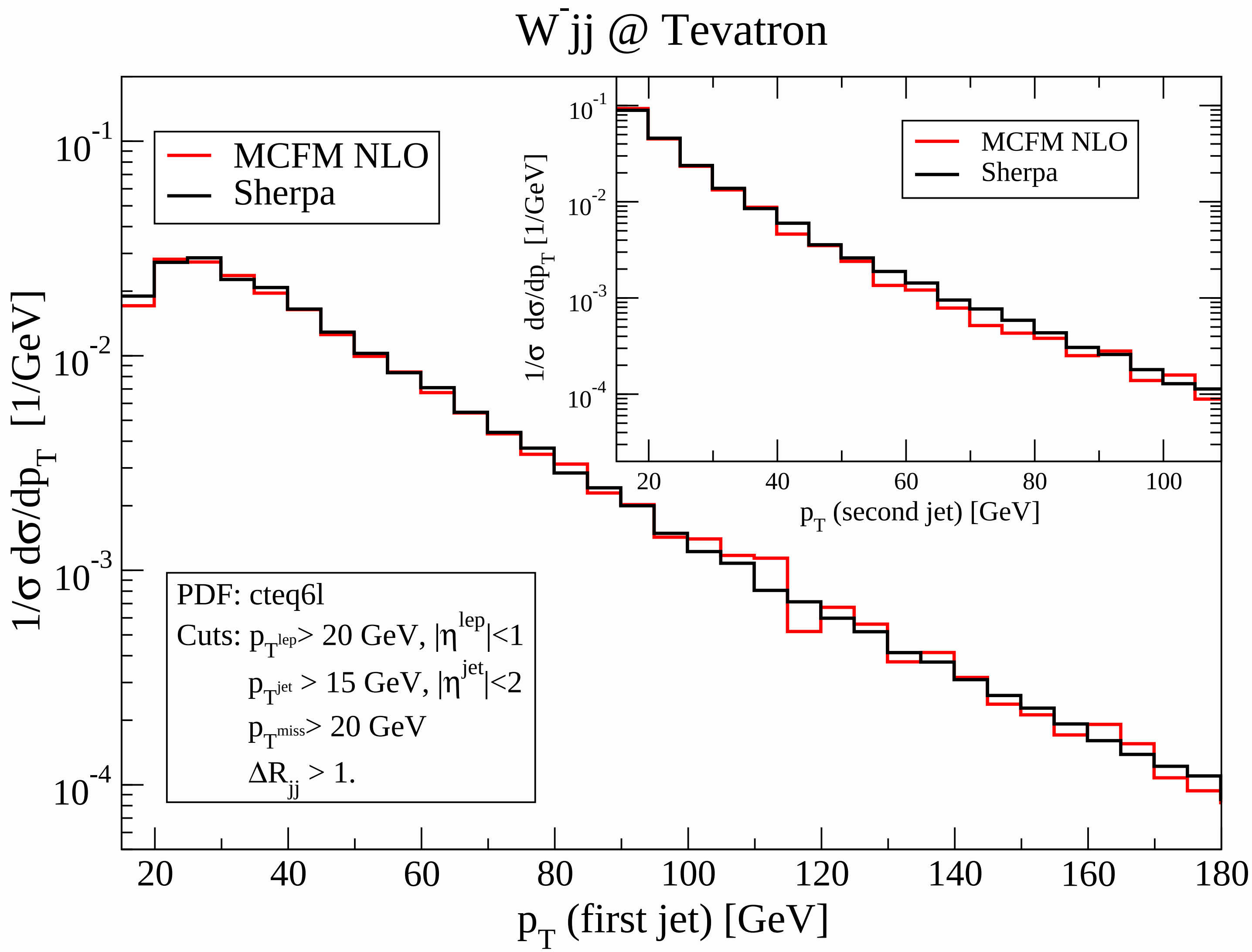
Sherpa vs. NLO: Step I



Sherpa vs. NLO: Step I



Sherpa vs. NLO: Step I



Sherpa vs. NLO: Step II

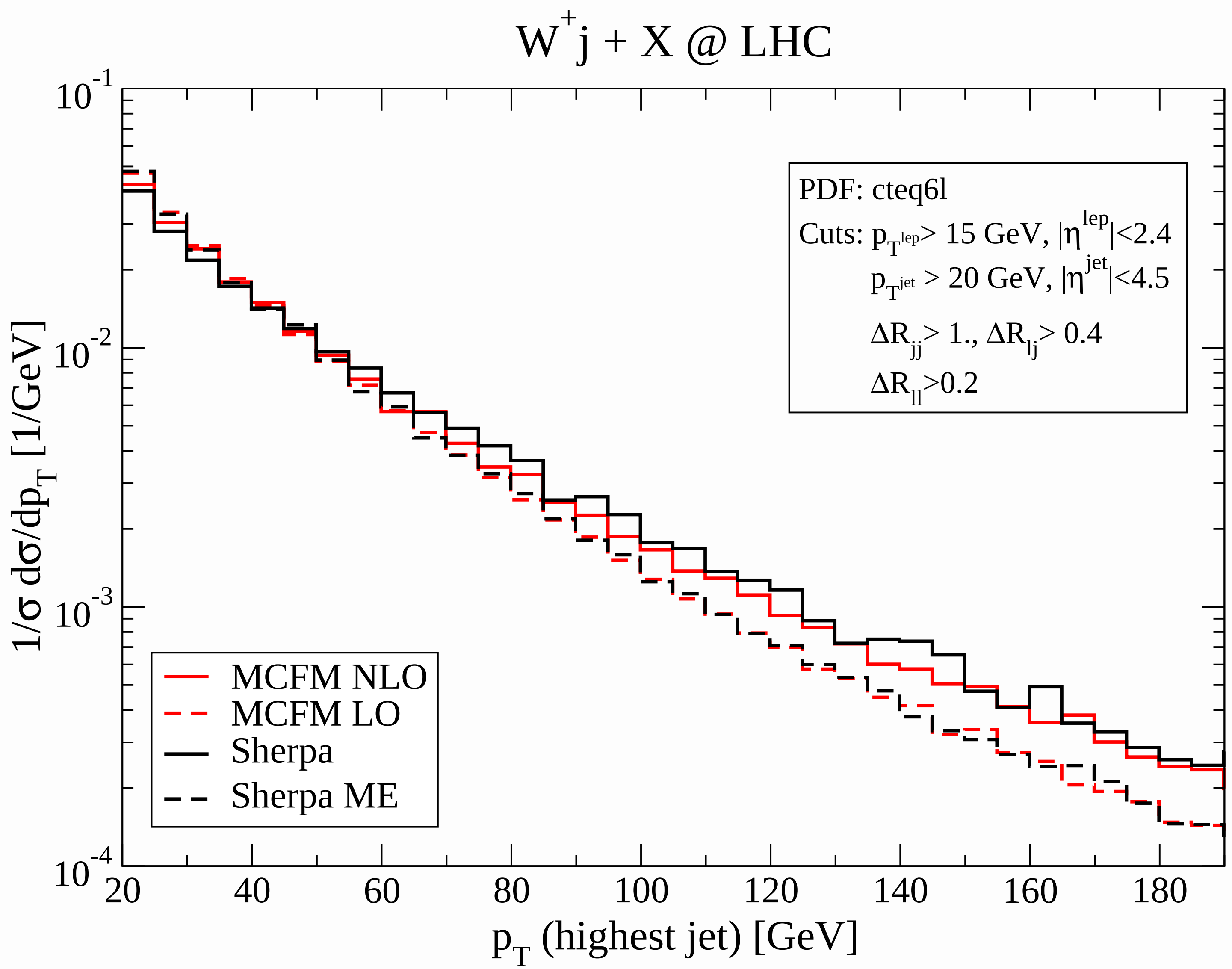
Lets look on inclusive Boson plus jet production

- Take fully inclusive samples of W and Z plus jets including shower evolution
- Compare to inclusive NLO ME predictions of MCFM (featuring potentially one jet more)

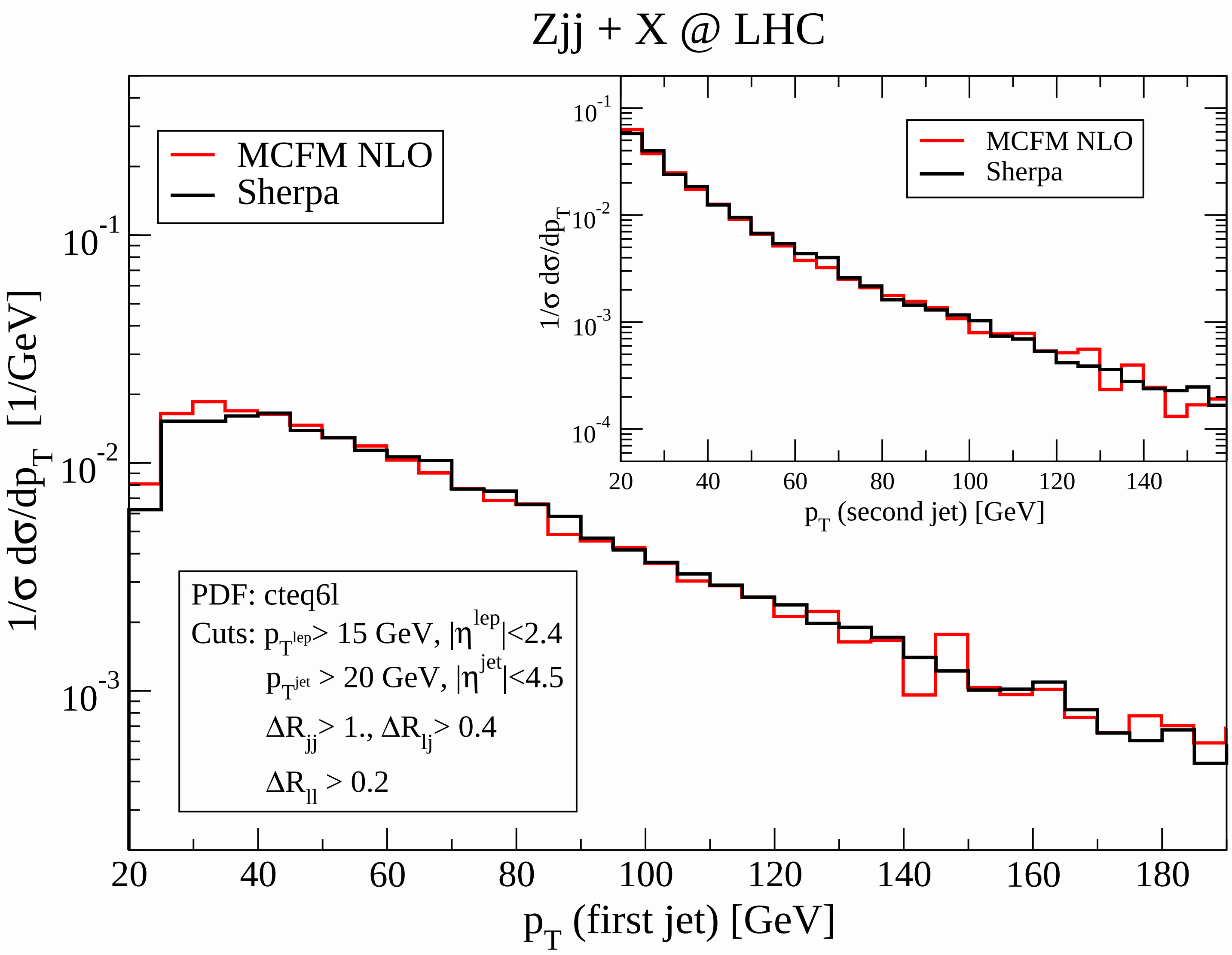
Setup:

- ME's considered: W/Z + 0,1,2,3 jets, the highest obtaining the highest multiplicity treatment
- MCFM and Sherpa pure ME: $\mu_F = \mu_R = M_W$
- $d_{cut} = p_{\perp,min}$ of jets
- jets found by Run II K_T algorithm with $D = 1$.

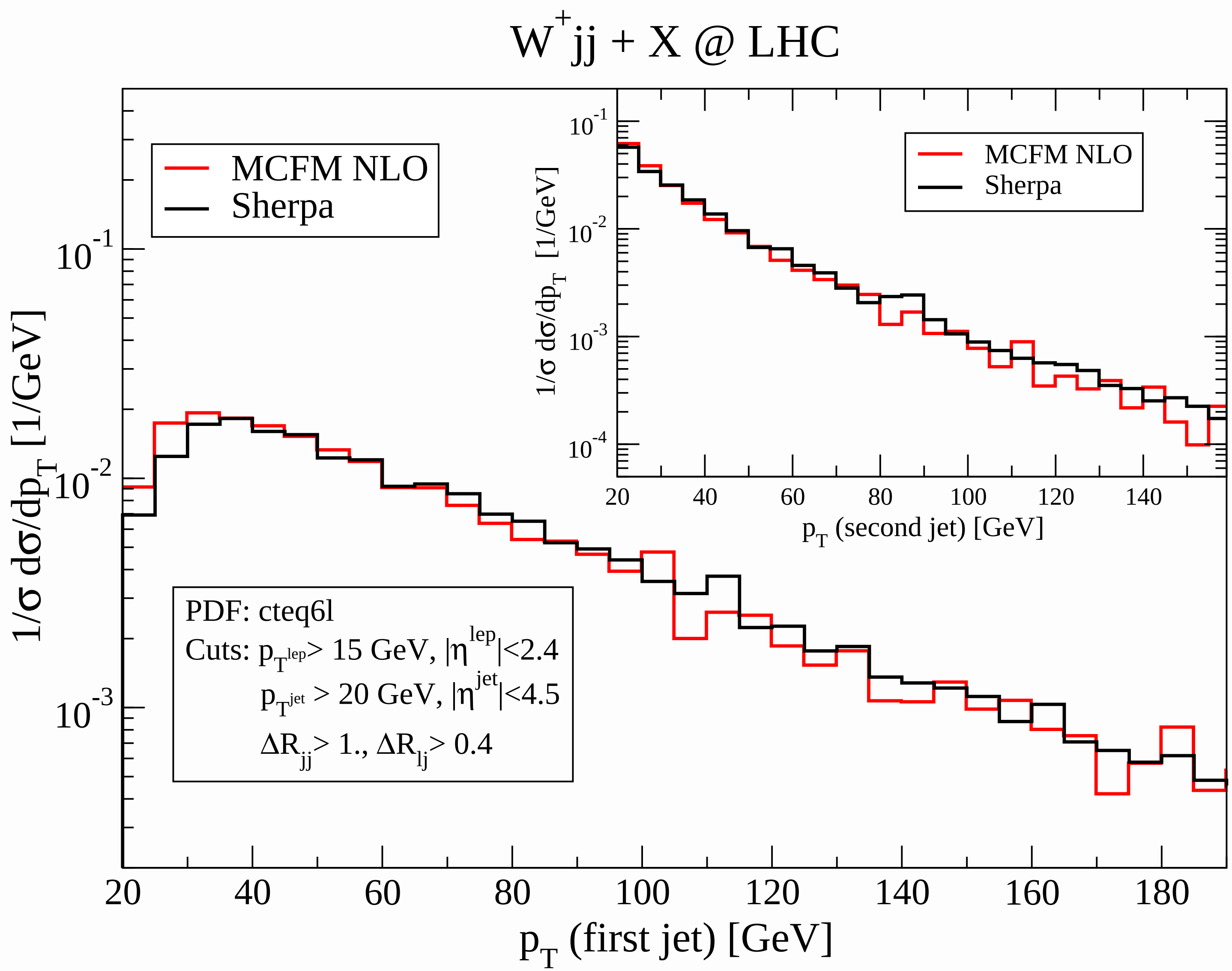
Sherpa vs. NLO: Step II



Sherpa vs. NLO: Step II



Sherpa vs. NLO: Step II



Conclusions

- The CKKW method seems to reproduce the NLO shapes for exclusive and inclusive W/Z plus jet production at Tevatron and LHC.
- The CKKW reweighting procedure seems to be a good choice.
- However, the rates are not NLO.
- All what I have said could be process dependent and has to be studied for many processes more.
- In addition we should look more thoroughly on correlations (ΔR, $\Delta\eta$, ...).

Sherpa including the ME's of AMEGIC++ and the CKKW prescription to combine them with the PS is a powerful tool to attempt the description of present-day Tevatron data and to study the extrapolation to LHC energies.

Sources

- T. Gleisberg, S. Höche, F. Krauss, A. Schälicke, S. S. and J. Winter, JHEP 0402:056,2004

- download (`Sherpa`α`-1.0.4`), manual, bug reports etc. under

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