Hadroproduction of electroweak gauge boson plus jets and TMD parton density functions

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If the production of electroweak gauge bosons final states is sensitive to effects of the initial state's transverse momentum distribution, appropriate generalizations of QCD shower evolution are required. We propose a method to treat these effects based on QCD transverse momentum dependent (TMD) factorization at high energy. We illustrate the approach presenting results for production of W-boson + n jets at the LHC.

The approach of collinear factorization, which separates the long-distance terms and the short-distance contributions in the cross section calculation in the collinear approximation, is very successful for sufficiently inclusive observables. However, for more exclusive observables, like e.g. the boson transverse momentum $p_\perp$, the cross section also depends on the scale $p_\perp$. It is necessary to include consistently $p_\perp$ effects already at the beginning of the calculation, which were neglected in the traditional approaches.

We propose an approach to electroweak boson plus jets production, which takes into account dynamical and kinematical issues via transverse momentum dependent (TMD) QCD evolution equations, with corresponding parton density functions and perturbative matrix elements. Traditional approaches have focused on the boson spectrum in the low-$p_\perp$ Sudakov region, and on the treatment of large logarithms for transverse momenta small compared to the boson invariant mass. Our work treats physical effects which persist at high $p_\perp$ and can affect final states with high jet multiplicities.

We use the transverse momentum dependent QCD factorization [1], which is valid up to arbitrarily large $p_\perp$. We couple this with CCFM [2] evolution equations for TMD gluon and valence quark densities using the results recently obtained in [3]. Using the parton branching Monte Carlo implementation of TMD evolution developed in [3] we make predictions, including uncertainties, for final-state observables associated with W-boson production. We study jet transverse momentum spectra and azimuthal correlations. We use the TMD distribution set JH-2013-set2 [3]. We compare the results to the measurements of ATLAS ($|\eta^{\rm jet}| < 4.4$) and CMS ($|\eta^{\rm jet}| < 2.4$). The uncertainties on the predictions are determined according to the method [3].

Figure 1 (top) shows the total transverse energy distribution $H_{\rm T}$ for production of W-boson $+ \geq 1$ jets, with $p_{\rm T}^{\rm jet} > 30$ GeV. In Fig. 1 (middle) we present the $p_\perp$ spectrum of the third jet associated with W production. It is observed that the detailed shapes of the subleading jets can be described by the TMD formalism. In Fig. 1 (bottom) the angular correlation in azimuthal separation between the third jet and the W-boson. Predictions of the structure of angular correlations are a distinctive feature of the TMD exclusive formulation. The shape of the experimental measurements is well described, within the theoretical uncertainties, both at

large $\Delta\phi$ and down to the decorrelated, small-$\Delta\phi$ region.

In conclusion, this work shows how TMD evolution equations at high energies can be used to take into account QCD contributions to the production of electroweak bosons plus multi-jets due to finite-angle soft gluon radiation, and estimate the associated theoretical uncertainties. This will be relevant both to precision studies of Standard Model physics and to new physics searches for which vector boson plus jets are an important background.

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References

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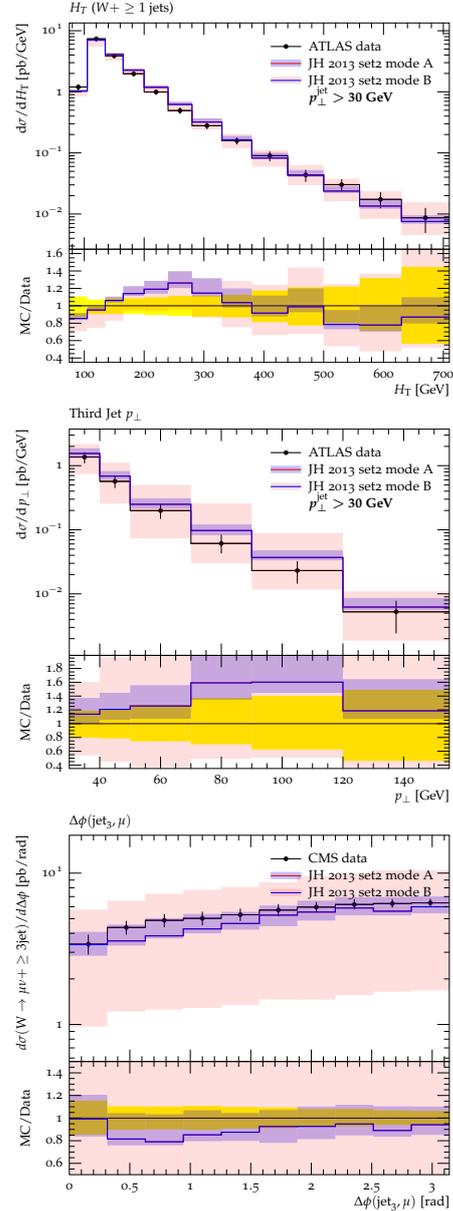Figure 1: Total transverse energy H_{T}, third jet $p_\perp$, and angular correlation in final states with W-boson + jets at the LHC.