Vector Boson Transverse Momentum Distributions at the Tevatron

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Abstract. We show vector boson transverse momentum distributions at the Tevatron, obtained by running the HERWIG Monte Carlo event generator with matrix-element corrections. We compare our results with some recent DØ and CDF data.

Vector boson production at hadron colliders is a fundamental process to test Quantum Chromodynamics and the Standard Model of the electroweak interactions. The lowest order processes $q\bar{q}' \rightarrow W$ and $q\bar{q} \rightarrow Z/\gamma^*$ are not sufficient to perform reliable phenomenological predictions, but the initial-state radiation has to be taken into account. A possible way to deal with such multiple emissions consists in running a Monte Carlo event generator. Standard Monte Carlo algorithms describe parton cascades in the soft/collinear approximation, with ‘dead zones’ in the phase space which can be filled by the using of the exact first-order matrix element.

In we implemented matrix-element corrections to the HERWIG simulation of Drell–Yan interactions: we filled the missing phase space using the exact $\mathcal{O}(\alpha_S)$ matrix element (hard corrections) and corrected the shower in the already-populated region using the exact amplitude for every hardest-so-far emission (soft corrections). For $W$ production at the Tevatron, about 4% of the events are generated in the dead zone, about half of which are $qq' \rightarrow Wg$ events. Similar results hold for $Z$ production as well.

An interesting observable to study is the vector boson transverse momentum $q_T$, which is the object of many theoretical and experimental analyses. While in the parton shower approximation it has to be $q_T < m_{W,Z}$, after matrix-element corrections a fraction of events with larger values of $q_T$ is to be expected. In Fig. (a), we plot the $W$ $q_T$ 

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Figure 1. (a): $W$ transverse momentum distribution at the Tevatron according to HERWIG before (dotted line) and after matrix-element correction for $q_{T\text{int}} = 0$; (b): comparison of the DØ data with HERWIG 6.1 after detector corrections for $q_{T\text{int}} = 0$ (solid) and 1 GeV (dashed).

As far as $Z$ production is concerned, we have some preliminary CDF data, already corrected for detector effects, which we compare with HERWIG 6.1 in Fig. 2, where the options $q_{T\text{int}} = 0$, 1 and 2 GeV are investigated. The agreement is acceptable and the role of the implemented matrix-element corrections is crucial in order to succeed in fitting in with the data for $q_T > 50$ GeV. At very low $q_T$, the best fit is obtained by setting $q_{T\text{int}} = 2$ GeV. In Fig. 3, we plot the ratio of the $W$ and the $Z$ transverse momentum spectra, both normalized to unity, for different values of $q_{T\text{int}}$. Although it can be seen from Fig. 2 (b) that the $Z$ $q_T$ spectrum depends strongly on $q_{T\text{int}}$ at low $q_T$, the ratio of the $W$ and $Z$ spectra is insensitive to it. This is good news for the $W$ mass measurement in hadron collisions, as this ratio is one of the main theory inputs that is needed. A strong dependence on unknown non-perturbative parameters like $q_{T\text{int}}$ could limit the accuracy of the $W$ mass measurement at the Tevatron and, ultimately, at the LHC.

We have added matrix-element corrections to HERWIG’s treatment of vector boson production in hadron collisions. They make an enormous difference at high transverse
Figure 2. $Z$ transverse momentum distribution according to HERWIG 5.9 with zero intrinsic transverse momentum (dotted line) and according to HERWIG 6.1 with $q_{T\text{int}} = 0$ (solid), 1 GeV (dashed) and 2 GeV (dot-dashed), compared with the CDF data over the whole spectrum (a) and for low $q_T$ values (b).

Figure 3. The ratio $R$ of the $W$ and $Z$ transverse momentum spectra, running HERWIG 6.1, for $q_{T\text{int}} = 0$ (solid), 1 GeV (dashes) and 2 GeV (dotted).

momentum $q_T$, but little at low $q_T$. Although the dependence of the results on the non-perturbative intrinsic $q_T$ of partons in the proton ($q_{T\text{int}}$) is quite strong at low $q_T$, it is very similar in the $W$ and $Z$ cases, so that the ratio of the two $q_T$ spectra is almost independent of $q_{T\text{int}}$.

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