Probing the standard model with hadronic $WZ$ production

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ABSTRACT

The cross section for producing $WZ$ pairs at hadron colliders is calculated to order $\alpha_s$ for general $C$ and $P$ conserving $WWZ$ couplings. The effects of the next-to-leading-order corrections on the derived sensitivity limits for anomalous $WWZ$ couplings are discussed. The prospects for observing the approximate amplitude zero, which is present in the standard model $WZ$ helicity amplitudes, are also discussed.

1. Introduction

The production of $WZ$ pairs at hadron colliders provides an excellent opportunity to study the $WWZ$ vertex. In addition, the reaction $p\bar{p} \rightarrow W^\pm Z$ is of interest due to the presence of an approximate zero in the amplitude of the parton level subprocess $q_1\bar{q}_2 \rightarrow W^\pm Z$ in the standard model, which is similar in nature to the well-known radiation zero in the reaction $p\bar{p} \rightarrow W^\pm \gamma$. Previous studies on probing the $WWZ$ vertex via hadronic $WZ$ production have been based on leading-order calculations. This report summarizes the results of a comprehensive study of hadronic $WZ$ production based on an $O(\alpha_s)$ calculation of the reaction $p\bar{p} \rightarrow W^\pm Z + X \rightarrow \ell_1^\pm \nu_1 \ell_2^\pm \ell_2^- + X$ for general, $C$ and $P$ conserving, $WWZ$ couplings.

2. Anomalous Couplings

In the standard model (SM), the $WWZ$ vertex is uniquely determined by the SU(2) $\otimes$ U(1) gauge structure of the electroweak sector, thus a measurement of the $WWZ$ vertex provides a stringent test of the SM. The most general $WWZ$ vertex, which is Lorentz, $C$, and $P$ invariant, contains three free parameters, $g_1$, $\kappa$, and $\lambda$, and is described by the effective Lagrangian

$$\mathcal{L}_{WWZ} = -ie\cot\theta_W \left[ g_1 (W_\mu^\dagger W_\mu^* Z^\nu - W_\mu^* Z_\nu W_\mu^\nu) + \kappa W_\mu^\dagger W_\nu^\dagger Z^{\mu\nu} + \frac{\lambda}{M_W^2} W_\lambda^\dagger W_\mu^\dagger W_\nu^\dagger Z^{\nu\lambda} \right].$$

At tree level in the SM, $g_1 = 1$, $\kappa = 1$, and $\lambda = 0$.

The $Z$ boson transverse momentum spectrum is very sensitive to anomalous $WWZ$ couplings. At the Tevatron, the $O(\alpha_s)$ QCD corrections are modest and sen-

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Fig. 1. Transverse momentum distribution of the $Z$ boson for the standard model and three values of anomalous couplings. Parts a), b), and c) are the results for the LO, NLO inclusive, and the NLO 0-jet exclusive cross sections, respectively.

Sensitivities are only slightly affected by the QCD corrections. At the LHC, on the other hand, the inclusive $\mathcal{O}(\alpha_s)$ QCD corrections in the SM are very large at high $p_T(Z)$, and have a non-negligible influence on the sensitivity bounds which can be achieved for anomalous $WWZ$ couplings; compare Figs. 1a and 1b. The large QCD corrections are caused by the combined effects of destructive interference in the Born subprocess, a log-squared enhancement factor in the $q_1\bar{q}_2 \rightarrow WZq_2$ partonic cross section at high transverse momentum, and the large quark-gluon luminosity at supercollider energies. The size of the QCD corrections at high $p_T(Z)$ can be significantly reduced, and a significant fraction of the sensitivity lost at the LHC energy can be regained, if a jet veto is imposed, i.e., if the $WZ + 0$ jet exclusive channel is considered; see Fig. 1c.

3. Approximate Amplitude Zero

Recently, it has been shown that the SM amplitude for $q_1\bar{q}_2 \rightarrow W^\pm Z$ at the Born level exhibits an approximate zero at high energies, $\hat{s} \gg M^2_Z$, located at

$$\cos \Theta^* \approx \pm \frac{1}{3} \tan^2 \theta_W \approx \pm 0.1,$$

where $\Theta^*$ is the scattering angle of the $Z$ boson relative to the quark direction in the $WZ$ center of mass frame. The approximate zero is the combined result of an exact zero in the dominant helicity amplitudes $\mathcal{M}(\pm, \mp)$ and strong gauge cancellations in the remaining amplitudes.

The approximate amplitude zero in $WZ$ production causes a slight dip in the rapidity difference distribution, $\Delta y(Z, \ell_1) = y(Z) - y(\ell_1)$, where $\ell_1$ is the charged
lepton from the decaying $W$ boson; see Fig. 2a. At the Tevatron energy, order $\alpha_s$ QCD corrections have a negligible influence on the shape of the $\Delta y(Z, \ell_1)$ distribution. At the LHC, however, $O(\alpha_s)$ QCD effects completely obscure the dip, unless a jet veto is imposed.

Cross section ratios can also be used to search for experimental consequences of the approximate amplitude zero. The ratio of $ZZ$ to $WZ$ cross sections as a function of the minimum $Z$ boson transverse momentum, $p_T^{\text{min}}$, increases with $p_T^{\text{min}}$ for values larger than 100 GeV; see Fig. 2b. This increase in the cross section ratio is a direct consequence of the approximate zero. QCD corrections have a significant impact on the $ZZ$ to $WZ$ cross section ratio at the LHC unless a jet veto is imposed.

The $\Delta y(Z, \ell_1)$ distribution and the $ZZ$ to $W^\pm Z$ cross section ratio are useful tools in searching for the approximate amplitude zero in $WZ$ production. However, for the integrated luminosities envisioned, it will not be easy to conclusively establish the approximate amplitude zero in $WZ$ production at the Tevatron or the LHC.

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5. References

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