Fragmentation Contributions to the Drell-Yan Cross Section sec3

In this section, we derive the resummed logarithmic contributions to the Drell-Yan cross section when $Q_T^2 \gg Q^2$. Since we are interested mainly in the cross section at low $Q^2$, we ignore contributions from the intermediate vector boson $Z$.

Logarithmic Contributions to the Drell-Yan Cross Section at Large $Q_T$ sec3a

As demonstrated in the last section, the Drell-Yan cross section at large transverse momentum $Q_T$ receives potentially large logarithmic terms $\ln m (Q_T^2/Q^2)$ from the part of phase space in which the virtual photon is almost collinear to one or more final-state partons. Since at least one final-state parton is needed to balance the virtual photon’s transverse momentum, the logarithmic contributions can arise only at NLO and beyond.

Because of the logarithms, the coefficient functions in Eq. (Vph-Hab) might be large, and resummation of the logarithmic contributions might be needed. As long as $Q^2$ is much larger than $\Lambda_{QCD}^2$, all coefficient functions in Eq. (Vph-Hab) are calculable in principle order by order in QCD perturbation theory. Therefore, resummation of the logarithms $\ln m (Q_T^2/Q^2)$ is actually a reorganization of the perturbative expansion in Eq. (Vph-Hab), such that all coefficient functions in the reorganized perturbative expansions are evaluated at a single hard scale and free of any large logarithms.

The energy exchange in the hard collision is of the order of $\sqrt{Q_T^2 + Q^2} \approx Q_T + O(Q^2/Q_T^2)$. When $Q_T^2 \gg Q^2$, the partonic hard collision should not be sensitive to the scale $Q^2$ at which the virtual photon is produced. If we neglect power corrections of the order $Q^2/Q_T^2$, the partonic hard collisions are effectively independent of $Q^2$, except for the logarithmic dependence $\ln m (Q_T^2/Q^2)$ from the final-state bremsstrahlung production of the virtual photon. Therefore, other than the appearance of the virtual photon’s mass $Q$ to regulate the final-state collinear divergences, the potentially large logarithmic contributions at large $Q_T$ have the same structure as the fragmentation contributions to prompt real photon production. They can be separated into two stages: (1) production of a parton of momentum $p_c$ at a very short-distance ($\sim 1/p_c T \sim 1/Q_T$), and (2) production of the lepton-pair via a virtual photon of invariant mass $Q$ through bremsstrahlung (or fragmentation) from the parton produced at the first stage. This two-stage production, shown in Fig. fig3 or in general in Fig. fig4, shares the same generic pattern of the fragmentation production of a single particle (e.g., a hadron of mass $M_h$ or a real photon) at large transverse momentum $Q_T$. If we neglect the power suppressed quantum interference between these two stages, the fragmentation (or bremsstrahlung) contributions should have the same general factored form that is present in single hadron or prompt photon production $QZ-VPFF$, equation

$$d\hat{\sigma}^{(F)}_{ab \rightarrow \gamma^*(Q)} dQ_T^2 dy = \sum_c \int dzz^2 \left[ d\hat{\sigma}^{(F)}_{ab \rightarrow cX} dp^2_{cT} dy \left( x_1, x_2, p_c = \hat{Q}/z; \mu_F \right) \right] D_{c \rightarrow \gamma^*X}(z, \mu^2_F; Q^2).DY - F$$