Theoretical perspectives on Drell-Yan production measurements

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I noticed that almost all talks in this workshop addresses the "theoretical perspectives on Drell-Yan production measurements". In this talk, I will list a number of opportunities and challenges associated with Drell-Yan production measurements, and try not to repeat too much what other people have said.

By measuring two leptons, the Drell-Yan process is a hard probe with two natural scales: invariant mass $Q = \sqrt{q^2}$ and total transverse momentum $q_\perp$ of the pair. By measuring Drell-Yan lepton pair at different combinations of these two momentum scales, the measurement can provide rich information on QCD dynamics and colliding hadron's partonic structure. For example, when $q_\perp \ll Q$, the transverse momentum dependent (TMD) factorization formalism should work for the Drell-Yan cross section, and the measurement of Drell-Yan lepton pairs in this kinematic regime probes the TMD parton distributions and dynamics of partons' transverse motion inside a colliding hadron. On the other hand, when $q_\perp \sim Q$ or $q_\perp \gg Q$, the collinear factorization formalism should work better, and the measurement should provide clean information on collinear parton distributions, in particular, the gluon distributions. Exploring the rapidity dependence of the lepton pair can help probe parton densities at very small parton momentum fractions, in particular, in the region where $Q_s \sim q_\perp$. Furthermore, by measuring the angular distribution of the lepton pair in the pair's rest frame, Drell-Yan measurement provides excellent information on the quantum interference of different spin states of the vector boson that decays into the lepton pair.

One of the most important predictions of TMD factorization formalism is the sign change of the Sivers function and the Boer-Mulder function between the SIDIS and Drell-Yan measurement. The sign change is the immediate consequence of the TMD factorization, and the parity and the time-reversal invariance of strong interaction. The test of the sign change is clearly a critical test of the TMD factorization formalism. However, one has to compare the distributions from SIDIS and Drell-Yan at the same momentum fraction x and parton transverse momentum $k_\perp$ in order to have a true test of the sign change. This is because the sign of the spin asymmetries could be different at the different effective value of x or $k_\perp$ if there is a node in either the x-dependence or $k_\perp$ dependence of the TMD distributions.

To test spin asymmetries, it is very important to understand both the numerator and the denominator. The denomenator - the spin averaged Drell-Yan cross section at low $q_\perp$ and large Q requires QCD resummation of large logarithms. For the same kinematics, the resummation is also needed for the numerator - the spin dependent cross section. Theory difficulties exist in controlling lepton angular distributions at low $q_\perp$. If one describes the low $k_\perp$ behavior in terms of TMD parton distributions, it is critical to understand the Q^2 dependence of TMD distributions, which is still lacking.

Test of the predicted strong suppression of Drell-Yan production in the very forward region of dA collisions is exciting. Quantitative comparison between various theory calculations is needed. Verify the predicted sign change of the power correction in low Q region between inclusive Drell-Yan and DIS should be very interesting too. In conclusion, Drell-Yan lepton pair production is one of the oldest hard process proposed to test QCD, and it is still a very good one!