PROCEEDINGS OF SCIENCE

Exclusive limits of Drell–Yan processes

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Various exclusive limits of Drell-Yan processes are considered and compared

Sixth International Conference on Quarks and Nuclear Physics - QNP2012,
April 16-20, 2012
Palaiseau France

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PoS(QNP2012)055

1. Semi-exclusive Drell-Yan process

The first of exclusive limits suggested [1] by Brodsky and collaborators corresponds to the situation when dilepton pair in collisions of pions (with momentum $p_1 = p$) and nucleons (with momentum $p_2 = P$) is produced in the fragmentation region of pion beam and the non-perturbative ingredient of QCD factorization corresponding to pion is its distribution amplitude (DA) rather than parton distribution (see Fig.1).

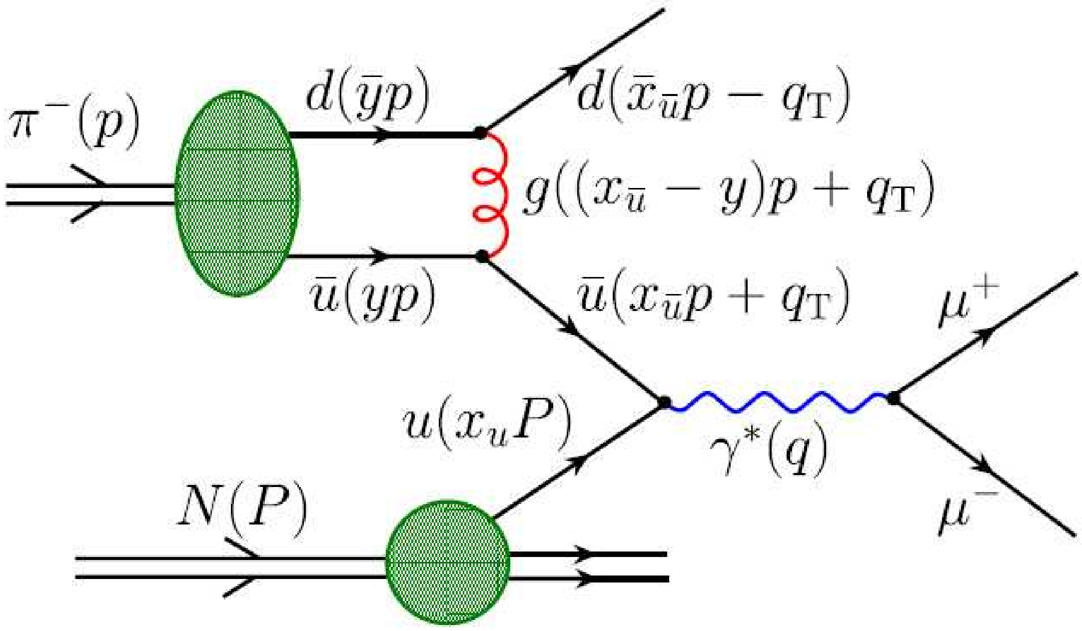

Figure 1: Semi-exclusive Drell-Yan process

It appears in the limit of the pion momentum fraction in the latter is turning to 1. The kinematical regions can be conveniently described by Sudakov decomposition of virtual photon momentum:

$$Q = x_1 P_1 + x_2 P_2 + Q_T, \tag{1.1}$$

and the semi-exclusive region correspond to $x_1 \sim 1$.

The dilepton angular asymmetries for both spin-averaged [1, 2] and (especially) polarized [3, 2] proton target are very sensitive to the pion distribution amplitude and provide its important complementary probe which is of special interest due to so-called BaBar puzzle (now questioned by BELLE).

2. Exclusive Drell-Yan processes

If one additionally assume that transverse momentum Q_T is small, the unobserved d-quark (on the top of Fig. 1) carrying the momentum $x_u p_2 + p_1 - q = (x_u - x_2)p_2 + (1 - x_1)p_1 - q_T$ becomes collinear to the proton and may be absorbed by its remnant. This process is described by the Generalized Parton Distribution (squared). It belongs to the virtual time-like processes extensively studied by Mueller, Pire, Szymanowski and Wagner [4]. Whether one have here another manifestation of duality [5] between different mechanisms of QCD factorization, remains to be studied.

As the kinematical region of exclusive DY process is determined by lepton pair kinematics ($x_1 \sim 1, Q_T \sim 0$) it can be studied even if the final proton is not detected.

In the case of proton-proton, deuteron-proton, or deuteron-deuteron collisions at NICA exclusive DY should be described by Transition Distribution Amplitudes $p \to 2p, p \to He^3, D \to He^3, D \to He^4$. These objects are now extensively studied [6] for transitions $\pi \to B$. The hard parts correspond to the exchange of three or six quarks and the latter should be strongly suppressed. It seems also promising to consider the ratio of exclusive DY amplitude and nucleon form factors, which possess the same hard parts.

There is another possibility for exclusive DY process when both colliding hadrons are described by GPDs [7, 8]. The factorization is violated if this amplitude is calculated directly, which after the possibility of the factorization violation inspired by BaBar puzzle (see e.g. [9] and Ref. therein) does not seem so dramatic.

Note that this mechanism may occur at any longitudinal momentum fractions of dilepton with small transverse momenta ($Q_T \sim 0$) and therefore the identification of final particles is required which is currently not planned neither at COMPASS nor at NICA but may be possible in the central exclusive production at LHC [8].

3. Duality between DY process and time-like formfactors

Consider the proton-antiproton DY process with growing dilepton mass $Q^2 \to s$. In complete analogy to elastic limit of DIS one should pass to the exclusive dilepton production and, consequently, to time-like formfactors. Such "extreme" limit is analogous to Drell-Yan-West (DYW) relation in DIS, while Bloom-Gilman duality in DIS corresponds to meson production in DY [10]. This cannot happen for pp DY showing that duality holds for valence distributions only. Indeed, the unpolarized cross-section shows their duality to Dirac formfactor (producing the transverse polarized, like in DY, dileptons).

It is instructive to compare the space-like and time-like formfactors related to exclusive limits of DIS and DY. respectively. While in DIS only one parton distribution enters, there are two of them in DY process. At the same time, the relation of the "duality interval" in partonic momentum fraction to the inelastic threshold is different for these two processes. Indeed for DIS one have

$$(P+q)^2 = (P_f + \delta P_{DIS}))^2 = (M + \mu_{DIS})^2, \tag{3.1}$$

where P_f is the final nucleon momentum and $\delta P_{DIS}^2 = \mu_{DIS}^2$ is the respective inelasticity threshold, leading to the $x_B (\equiv 1 - \delta_{DIS})$ deviation from unity

$$\delta_{DIS} \sim 2M\mu_{DIS}/Q^2.$$

At the same time, for (proton-antiproton) DY one have

$$(P_1 + P_2)^2 = (q + \delta P_{DY})^2, \tag{3.2}$$

leading to the similar deviation from unity of the variable $\tau = Q^2/s (\equiv 1-\delta_{DY})$ playing the role similar to x_F

$$\delta_{DY} \sim 2\mu_{DY}/Q.$$

The expressions for the given quark flavour contributions to space-like and time-like formfactors which may be deduced from the arguments [11] in the spirit of QCD sum rules are

$$F_{SL}^2 \sim \int_0^{\delta_{DIS}} d\bar{x} f(\bar{x}); \;\; F_{TL}^2 \sim \int_0^{\delta_{DY}} d\bar{x}_1 d\bar{x}_2 f(\bar{x}_1) f(\bar{x}_2) \delta(\delta_{DY} - \bar{x}_1 - \bar{x}_2). \tag{3.3}$$

Assuming that at large $x = 1-\bar{x}$ the quark distribution is $f(\bar{x}) = C\bar{x}^a$ one get

$$F_{SL}^2(Q^2) \sim \frac{C}{a+1}\left(\frac{2M\mu_{DIS}}{Q^2}\right)^{a+1}; \;\; F_{TL}^2(Q^2) \sim \frac{C^2}{2(a+1)}\left(\frac{4\mu_{DY}^2}{Q^2}\right)^{a+1}. \tag{3.4}$$

As a result, one get the same Q dependence for space-like (which is well-known for many years) and time-like formfactors, while their relative normalization appears to be determined by the normalization of parton distribution and duality intervals.

It turn, SSA in DY process [12, 13, 14] is dual (that is, one should expect, like in spin-averaged case, the closeness of respective expression for asymmetries) to SSA [15, 16] due to interference of Dirac and Pauli formfactors. Establishing DYW-correspondence results in relation of twist 3 gluonic pole (and, in turn, of the moment of Sivers function) to Pauli formfactor, more exactly, to its imaginary (with respect to Dirac one) part.

$$Im F_2/F_1(Q^2 \sim M^2/(1-x)) \sim T(x,x)/q(x)$$

As a result, one may find [17] that the ratio of (transverse moment of) Sivers and (collinear) unpolarized functions behaves like $(1-x)^{1 \div 2}$ at large x, depending on the behaviour of F_2/F_1 ratio and presence of the derivative term in DY SSA. The latter should be present when only single lepton is detected, which seems to be the right observable for the transition to exclusive limit.

The relation of Sivers function and anomalous magnetic moment appears also at matrix elements level [18, 19]. The current derivation [17] establishes it at the level of observables and explains the relation between naively T-even and T-odd quantities by appearance of imaginary part.

4. Conclusions

The exclusive limits of DY process offer the exciting new theoretical possibilities to study the important ingredients of hadron structure like DAs and GPDs. Their feasibility in planned experiments remains to be studied.

This work was supported in part by RFBR (grants 12-02-00613, 12-02-91526)

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