Momentum conservation factor in DPS

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1 Abstract

The violation of DPS factorization ansatz due to the evident restriction on the total parton momentum is discussed. Numerically the corrections from the limited partonic phase space amount to a factor 2 in the total rates at the LHCb conditions with ZD or WD associated production taken as examples.

2 Introduction

The existence of multi-parton interactions (MPI) in hadron-hadron collisions [1–4] at high energies is a natural consequence of the fast increase of the parton flux at small parton longitudinal momentum fractions and the requirement of unitarization of the cross sections in perturbative QCD. The great splash of investigation activity around MPI in last years [1–4] has been stimulated by the experimental evidence for double parton scattering (DPS) in the processes producing two independently identified hard particles in the same collision. Such processes have been observed in proton-proton and proton-antiproton collisions by a number of collaborations for the final states containing four jets, $\gamma + 3$ jets, $W + 2$ jets, double J/ψ and others.

In our recent publication [5] we have considered associated production of charged gauge bosons $W^{\pm}$ and charged charmed mesons $D^{(*)\pm}$ at the LHC and came to the conclusion that same-sign $W^{\pm}$ $D^{(*)\pm}$ events could serve as an indicator of DPS. Our investigation was only restricted to central region, i.e. to CMS [6] and ATLAS [7] kinematic conditions, since these were the only collaborations who provided the data (though not on same-sign WD configurations). LHCb Collaboration is also going to measure the production cross sections for all of the four WD charge combinations. It is very tempting to foreshow the experimental measurement with theoretical prediction. At the LHCb conditions the probed longitudinal momentum fractions are not far from the phase space boundary where the evident restriction on the total parton momentum may spoil the factorization hypothesis commonly used in DPS. The possible influence of the momentum conservation factor on the total rates at the LHCb conditions with ZD or WD associated production taken as examples is main purpose of this talk.

3 Formalism and results

As far as the single parton scattering (SPS) are concerned, the calculations were done [5] in the k_t-factorization technique. The evaluation of DPS contributions was done in accordance with the formula

$$\sigma_{\rm DPS}^{\rm WD} = \frac{\sigma_{\rm SPS}^{W}\sigma_{\rm SPS}^{D}}{\sigma_{\rm eff}}, \qquad (1)$$

where $\sigma_{\rm eff}$ is a normalization constant that encodes all "DPS unknowns" into a single phenomenological parameter (for details see the reviews [1–4] and references therein). This simple formula is usually derived under the two following simplifying approximations: (i) the double parton distribution functions can be decomposed into longitudinal and transverse components, and (ii) the longitudinal component $D_p^{ij}(x_1, x_2; Q_1^2, Q_2^2)$ reduces to the diagonal product of two independent single parton distribution functions:

$$D_p^{ij}(x_1, x_2; Q_1^2, Q_2^2) = D_p^{i}(x_1; Q_1^2) D_p^{j}(x_2; Q_2^2) \qquad (2)$$

(here x_1 and x_2 are the longitudinal momentum fractions of two parton of type i and j undergoing the hard subprocesses at scale Q_1 and Q_2). The latter approximation is acceptable in collider experiments where only small x_1 and x_2 values are probed. However, this cannot be said of the LHCb conditions, especially with respect to as heavy systems as gauge bosons. At the LHCb conditions, the probed longitudinal momentum fractions x_1 and x_2 are not far from the phase space boundary where the evident restriction on the total parton momentum $x_1 + x_2 \le 1$ violates the DPS factorization ansatz commonly used.

Setting the boundary condition in the form of theta-function $\Theta(1 - x_1 - x_2)$ would result in a step-like discontinuity at the edge of the phase space. This does not seem physically consistent for double parton distribution functions. In more accurate approach [8–15]

$$D_p^{ij}(x_1, x_2; Q_1^2, Q_2^2) = D_p^{i}(x_1; Q_1^2) D_p^{j}(x_2; Q_2^2) \times (1 - x_1 - x_2)^n. \qquad (3)$$

The factor $(1 - x_1 - x_2)^n$ smoothly imposes the kinematical constraints and $n > 0$ is a parameter to be fixed phenomenologically. One chooses n to be 2 often. This choice of phase space factor can be partly justified [8, 10] in the framework of perturbative QCD and gives the double parton distribution functions which satisfy the momentum sum rules [9] reasonably well. We use $n = 3$ also to get feeling of possible effects related to the kinematical constraints, The case without the kinematical constraints is just $n = 0$. A numerical value of $\sigma_{\rm eff} \simeq 15$ mb has earlier been obtained empirically from fits to $p\bar{p}$ and pp data.

Having considered the production of $Z^0D, W^{\pm}D$ states at the LHCb conditions we found [16]: As a general rule for the production of electroweak bosons in the DPS channel, the simple DPS factorization formula needs to be corrected for the limited partonic phase space. Numerically, these corrections amount to a factor of 2 in the total rates and, when taken into account, lead to better agreement with the available data [on Z^0D production [17]] than it seemed before.

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