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# Double parton scattering versus jet quenching

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A huge number of intriguing and exquisite observations have been made with the Relativistic Heavy Ion Collider (RHIC) and the Large Hadron Collider (LHC). Many of them could have never been systematically studied at the accelerators of previous generation. In particular, hard multiparton interactions (MPI), including double parton scattering (DPS) are just among these interesting phenomena [1]. The DPS is actively discussed for proton-nucleus ($p$-$A$) and nucleus-nucleus ($A$-$A$) collisions as well, since its relative contribution increases, compared to naive scaling expectation. Unique new options emerge for further studies and measurements of momentum correlations. For nucleus-nucleus collisions, it opens yet a unique possibility to probe the collective properties of a new state of dense matter, the quark-gluon plasma (see, e.g., [2–4]) The experiments at RHIC and the LHC have provided clear evidence that the production of hadrons in $A$-$A$ collisions goes through the formation of a fireball of hot and dense quark-gluon plasma. This follows from the observation of strong suppression of high-$p_T$ particle spectra (the so-called jet quenching phenomenon expressed in the nuclear modification factor $R_{\rm AA}$) and from the results of hydrodynamic simulations of $A$-$A$ collisions.

The main purpose of this Letter is to bring reader's attention to an interesting possibility to probe the initial and final state effects in nucleus-nucleus collisions simultaneously, with a single measurement. This can be realised by introducing a novel observable, the double nuclear modification factor:

$$R_{\rm AA}(ab) = R_{\rm AA}(a) \cdot R_{\rm AA}(b) \left[ F + \frac{C - F}{K + 1} \right], \qquad (1)$$

where $K$ is the ratio of the cross sections of production of the $ab$ state in single and double parton scattering of nucleons, the combinatorial factor $C$ determines the DPS cross section enhancement in $A$-$A$ collisions compared to simple $A^2$ scaling of the nucleon cross section, and $F = \mathcal{O}(1)$ takes into account the correlations, which are induced by the fact that the both particles are produced in the same point.

A specific interplay between the effects of DPS and jet quenching can be illustrated in the simplest case when one of the two hard particles does not lose its energy when passing through a dense matter. To be more solid, we can employ available experimental results on the associated production of two hard particles. The needed $K$-factor can be extracted directly from experimental data without appealing to Monte Carlo simulations. As an example, consider the production of $J/\psi$ mesons in association with a $W$ boson. Relying on the measurements [5] performed by ATLAS collaboration, we obtain the $K$-factor as a function of the $J/\psi$ transverse momentum as shown in Fig. 1.

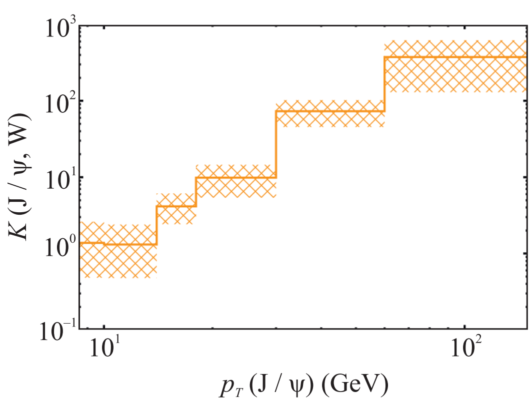


Fig. 1. (Color online) $K$-factor as a function of $J/\psi$ transverse momentum. The bands show uncertainties in the cross section determination for $J/\psi + W$ production

Since the $W$ boson passes through the nuclear matter without losing energy, our main theoretical prediction (1) reduces to

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$$R_{\mathrm{AA}}(J/\psi, W) = R_{\mathrm{AA}}(J/\psi)\left[1 + \frac{C-1}{K(J/\psi, W)+1}\right]. \quad (2)$$

The combinatorial enhancement $C$ does not depend on the process kinematics and the type of hard particles, but is mainly governed by the atomic number $A$. For the minimum bias *Pb-Pb* collisions this enhancement amounts to $C \sim 215$ [6]. The measured nuclear $J/\psi$ modification factor at the LHC [7–9] amounts to $R_{\mathrm{AA}}(J/\psi) \simeq 0.5$ at low transverse momenta ($p_T \simeq 2$ GeV/$c$) and to $R_{\mathrm{AA}}(J/\psi) \simeq 0.3$ over a wide interval of higher transverse momenta ($p_T > 5$ GeV/$c$). The "measured" $K$-factor demonstrates strong dependence on the transverse momentum: it changes from $\sim 1.4$ at $p_T$ lying in the interval [8.5-10] GeV/$c$ to $\sim 374$ at $p_T \in$ [60-150] GeV/$c$. Thus we can expect that the production of $J/\psi$ mesons in association with a $W$ boson is not suppressed, but is enhanced in the region of moderate transverse momenta, contrary to unassociated (inclusive) $J/\psi$ production. For $p_T \in$ [8.5-10] GeV/$c$, we have

$$R_{\mathrm{AA}}(J/\psi, W) \simeq 30$$

while $R_{\mathrm{AA}}(J/\psi) \simeq 0.3$! In the region of high enough transverse momentum ($p_T > 60$ GeV/$c$), the behavior of $W$-associated $J/\psi$ production converges to the unassociated case: $R_{\mathrm{AA}}(J/\psi, W) \simeq R_{\mathrm{AA}}(J/\psi)$ since the ratio $(C-1)/(K+1)$ becomes small. This example clearly demonstrates the competition between the effects of DPS (initial state effect) and jet quenching (final state effect).

The associated production of $D$ mesons and $W$ bosons shows yet a more intriguing behavior. In this case, there is a notable difference [10, 11] between the opposite-sign and same-sign production cross sections, and the $K$-factor is significantly larger for $WD$ configurations of the opposite sign than for configurations of the same sign. The sensitivity of this factor to the charge configurations takes place also for other processes with $W$ bosons in the final state [12–14]. The energy loss is independent of the sign of $D$ mesons: $R_{\mathrm{AA}}(D^+) \simeq R_{\mathrm{AA}}(D^-)$. It means that the double nuclear modification factor for the $WD$ associate production will be notably larger for the same-sign configurations than for the opposite-sign ones:

$$R_{\mathrm{AA}}(D^{\pm}, W^{\mp}) < R_{\mathrm{AA}}(D^{\pm}, W^{\pm})$$

at the same kinematics.

So, we come to the conclusion that measurements of the double nuclear modification factor potentially open a wide room for further studies of an interplay between the effects of DPS and jet quenching, extending to various types of hard final state particles in a wide interval of their transverse momenta.

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