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The small-x gluon distribution in centrality biased pA and pp collisions

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Abstract

The nuclear modification factor $R_{pA}(p_T)$ provides information on the small-x gluon distribution of a nucleus at hadron colliders. Several experiments have recently measured the nuclear modification factor not only in minimum bias but also for central pA collisions. In this paper we analyze the bias on the configurations of soft gluon fields introduced by a centrality selection via the number of hard particles. Such bias can be viewed as reweighting of configurations of small-x gluons. We find that the biased nuclear modification factor $\mathcal{Q}_{pA}(p_T)$ for central collisions is above $R_{pA}(p_T)$ for minimum bias events, and that it may redevelop a "Cronin peak" even at small x. The magnitude of the peak is predicted to increase approximately like $1/A_\perp{}^\nu$, $\nu \sim 0.6 \pm 0.1$, if one is able to select more compact configurations of the projectile proton where its gluons occupy a smaller transverse area $A_\perp$. We predict an enhanced $\mathcal{Q}_{pp}(p_T) - 1 \sim 1/(p_T^2)^\nu$ and a Cronin peak even for central pp collisions.
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1. Introduction

The nuclear modification factor $R_{pA}(k)$ of the single-inclusive transverse momentum distribution in proton-nucleus collisions has received intense scrutiny from theory as well as experiment. It provides insight into the small-x gluon distributions of a nucleus at high-energy hadron colliders. $R_{pA}(k)$ is defined as

$$R_{pA}(k) = \frac{\left\langle \frac{\mathrm{d}N}{\mathrm{d}^2k\,\mathrm{d}y} \right\rangle \Big|_{pA}}{N_{\mathrm{coll}}^{\mathrm{m.b.}} \left\langle \frac{\mathrm{d}N}{\mathrm{d}^2k\,\mathrm{d}y} \right\rangle \Big|_{pp}} . \tag{1}$$

Thus, it is given by the ratio of the single-inclusive transverse momentum distributions in *minimum bias* pA versus pp collisions, scaled by the corresponding number of binary collisions which is proportional to the average thickness $\sim A^{1/3}$ of the target nucleus. In the absence of nuclear effects, $R_{pA}(k) = 1$.

In the high-energy limit where particle production is dominated by soft, small-x gluons with semi-hard transverse momenta, $R_{pA}(k)$ is suppressed [1,2]. At high transverse momentum beyond the saturation scale $Q_{s,A}$ of the nucleus this is leading twist shadowing due to the fact that the gluon distribution acquires a BFKL anomalous dimension [3], in the presence of a saturation boundary [4], which differs from its asymptotic DGLAP limit [5]. We review the basic argument for how the suppression arises in sec. 2.

A suppression of $R_{pA}(k)$ has been observed in the central region of $p + \mathrm{Pb}$ collisions at 5 TeV for hadron transverse momenta below about 2 GeV [6–8]. (Transverse momenta degrade in gluon fragmentation by roughly a factor of 2.) The data is described reasonably well by models [9,10] which employ unintegrated gluon distributions which solve the running coupling BK equations [11].[1] These models predict a stronger suppression out to higher transverse momentum at forward rapidities. For $\mathrm{d} + \mathrm{Au}$ collisions at 200 GeV, the BRAHMS and STAR collaborations at RHIC have found a suppression of $R_{dAu}(k)$ at forward rapidities [14]. Note that the parton transverse momentum distribution is significantly steeper in the forward region of collisions at RHIC energy than in the central region at LHC energies. Consequently, the typical hadron momentum fraction $\langle z \rangle$ in fragmentation is greater at lower energy and higher rapidity.

One may also analyze the nuclear modification factor in *central* pA collisions. Naively, this corresponds to collisions where the projectile proton suffers an inelastic collision with a greater than average number of target nucleons. This would be analogous to minimum bias pA collisions with a target nucleus with many more than ~ 200 nucleons (which, of course, is not available). Accordingly, one expects a *stronger suppression* of $R_{pA}(k)$ for central versus minimum bias events. This qualitative expectation is confirmed by model calculations [10] for events with $N_{\mathrm{part,Pb}} \geq 10$, which exceeds the average $\langle N_{\mathrm{part,Pb}} \rangle \approx 7$ for minimum bias $p + \mathrm{Pb}$ collisions at 5 TeV. However, neither the number of target participants nor the number of collisions can be measured directly. Experimentally, one therefore employs a variety of different centrality measures.

Several collaborations have analyzed the nuclear modification factor for central collisions. Their main observation is that it *increases* with centrality and that it displays a Cronin like peak at transverse momenta of $3 \ldots 4$ GeV. This is in qualitative disagreement with the naive expectation

[1] Also see the compilation of predictions for the $p + \mathrm{Pb}$ 5 TeV LHC run published in ref. [12] and the follow-up comparison to data [13].

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