Cold Nuclear Modifications at RHIC and LHC

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We use recent nuclear parton distributions, among them the Hirai – Kumano – Nagai (HKN) and Eskola – Paukkunen – Salgado (EPS08) parameterizations, in our pQCD-improved parton model to calculate the nuclear modification factor, $R_{AA'}(p_T)$, at RHIC and at the LHC. At RHIC, the deuteron-gold nuclear modification factor for pions, measured at $p_T \geq 10$ GeV/c in central collisions, appears to deviate more from unity than the model results. The slopes of the calculated $R_{dAu}(p_T)$ are similar to the slopes of the PHENIX pion and photon data. At LHC, without final-state effects we see a small enhancement of $R_{dPb}(p_T)$ in the transverse momentum range 10 GeV/c $\geq p_T \geq$ 100 GeV/c for most parameterizations. The inclusion of final-state energy loss will reduce the $R_{dPb}(p_T)$ values.

I. INTRODUCTION

Nuclear modifications in the physics of partonic degrees of freedom arise either due to the environment in the initial nuclei around the incoming parton or from the interaction with the partonic matter created in the final state of a nuclear collision. Coherent quantum effects may connect and mix initial and final state phenomena. Here we investigate '*cold nuclear effects*' defined as effects that do not originate in connection with the thermalized partonic matter in collisions between two heavy nuclei [1, 2].

Cold nuclear effects are usually described as modifications of the parton distribution functions (PDF) into nuclear parton distributions (nPDF). At sufficiently small momentum fraction, this has been referred to as nuclear shadowing, but further effects, like nuclear multiple scattering, EMC, higher-twist effects, etc. need to be included in a more complete description. In this short review we present the high-p_T and high-x_T behavior of some of these modifications, using shadowing/nuclear PDF parameterizations by HIJING [3], EKS [4], EPS08 [5], and HKN [6].

At present, cold nuclear modifications can be tested by experimental data at RHIC energies on hadron spectra from dAu collisions, or by direct photon spectra from dAu or $AuAu$ collisions, which are essentially not influenced by non-Abelian jet energy loss. Note that recent theoretical studies point out the possibility of a small energy loss in pA or dA type collisions [1, 7].

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II. COLD NUCLEAR EFFECTS AT RHIC

We calculated the nuclear modifications at RHIC energies up to $p_T \lesssim 70$ GeV/c using various shadowing parameterizations in our pQCD improved parton model [8]. Results are compared to the preliminary PHENIX data up to the highest measured momenta ($p_T \lesssim 18$ GeV/c) [9, 10, 11]. On the left side of Fig. 1, $R^{\pi}_{dAu}(p_T)$ is plotted for neutral pions at $\sqrt{s} = 200$ AGeV against a logarithmic p_T scale, using the HIJING, EKS, EPS08, and HKN parameterizations. The HIJING shadowing is understood with its accompanying multiple scattering [8].

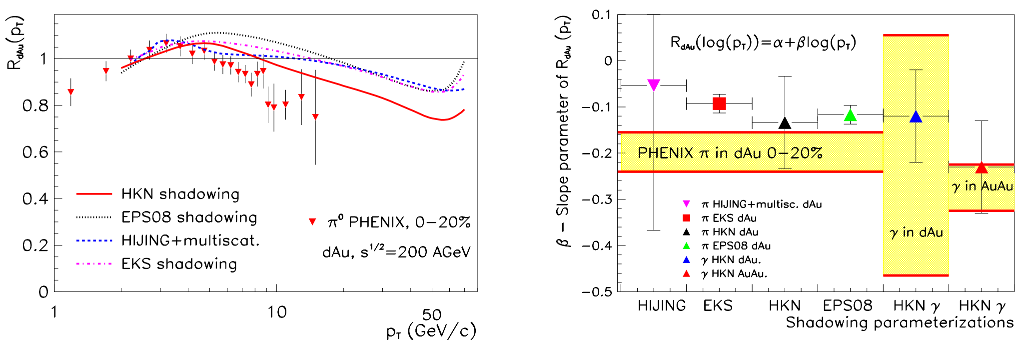

FIG. 1: Calculated $R^{\pi}_{dAu}(p_T)$ compared to most central PHENIX data [9] (*left panel*), and the extracted slope parameter, β of Eq.(1) in different models (*right panel*) and Ref.s [9, 10, 11].

All calculated $R^{\pi}_{dAu}(p_T)$ curves have an approximately linear dependence on $\log(p_T)$ in most of the EMC region (15 GeV/c $\lesssim p_T \lesssim$ 50 GeV/c). Thus, we used a simple linear function of $\log(p_T)$ to get the slope parameter β:

$$R_{dAu}(\log(p_T)) = \alpha + \beta \cdot \log(p_T) \ . \tag{1}$$

The slope β is plotted in the right panel of Fig. 1. We use the best-fitted linear curve in the above p_T interval to compare the calculated slopes to the ones extracted from the data. The slopes of the model curves are quite similar, although they are smaller (in absolute value) than the measured quantities. This may be due to final state effects [1] or isospin effects [12]. In addition to pion production slopes in dAu collisions, direct photon production in both dAu and $AuAu$ collisions is plotted. Our results are compared to the preliminary PHENIX data [9, 10, 11]. These data have decreasing tendencies with p_T, leading to negative β values similar to those in π^0 production. In the case of the dAu photon data, the large error bars manifest themselves in a large uncertainty of the extracted slope. Direct γ production in $AuAu$ shows a stronger decrease, since the initial state nuclear effects enter the convolution integral twice in this case.

We analyzed the theoretical uncertainties in our model [1, 2]. We found that at $p_T > 3$ GeV/c our model is not sensitive to the scale choice. Nuclear PDF parameterizations vary both the position of the Cronin peak and the high-p_T slope of $R_{dAu}(p_T)$. The HKN parameterization allowed us to analyze the errors via the Hessian method [6]. An almost constant $\pm 10\%$ uncertainty was found in the whole transverse momentum range.

It can be seen from Fig. 1 that the EPS08 and HKN nPDF parameterizations give slopes close to the experimental ones. However, HKN comes closer to the measured points at high p_T (see the left panel). Note that the agreement with the data can be improved by the introduction of a small opacity, as we have done in Ref. [1].

III. PREDICTIONS FOR THE LHC

Based on Ref.s [1, 2, 13] we estimated the cold nuclear modifications at LHC energies with larger intrinsic transverse momenta. We apply the same parameterizations used above. In Fig. 2 we plot $R^{\pi}_{dA}(x_T)$ in dPb collisions at midrapidity at RHIC and LHC energies as functions of transverse momentum fraction, $x_T = 2p_T/\sqrt{s}$. The preliminary PHENIX dAu data on neutral pion production are also shown. The different panels display different shadowing parameterizations as noted on Fig. 2.

Though at RHIC energies all parameterization give similar results, at LHC we see that at $x_T \approx 3 \cdot 10^{-3}$ HIJING yields a strong ($\approx 30\%$) suppression, while HKN gives a 10% enhancement at the same x_T values. The EKS and EPS08 results predict a $5-10\%$ enhancement (suppression) around $x_T \approx 10^{-2}$ (10^{-3}). The EPS08 results show somewhat stronger suppression than EKS at low x_T, due to the inclusion of high-rapidity RHIC data in the fitting procedure of this recent parameterization. For the high momentum-fraction region both of these models show a similar behavior due to the EMC effect. HIJING and HKN have a reasonable agreement between RHIC and LHC energies (they scale with x_T), while EKS and especially EPS08 display less precise scaling at around the anti-shadowing maximum.

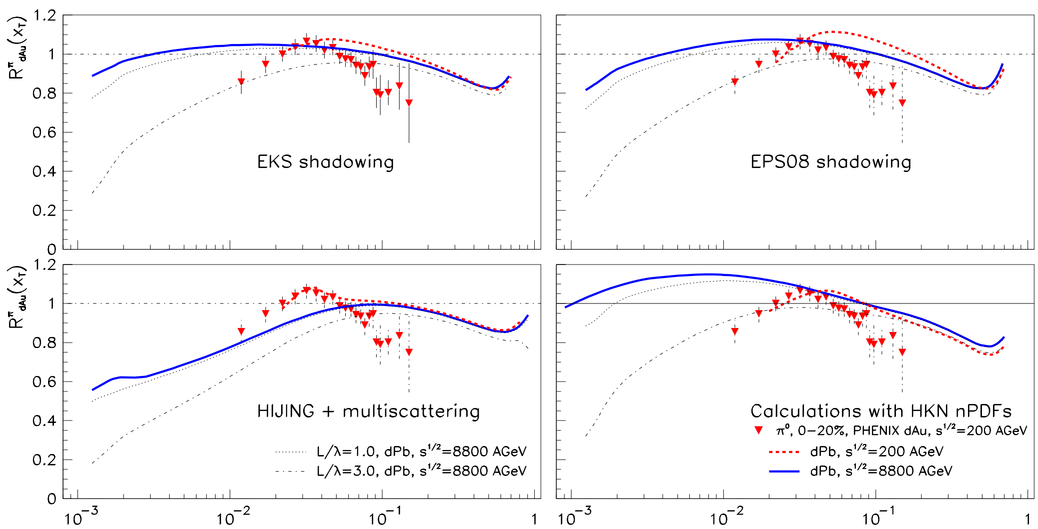

FIG. 2: Nuclear modifications $R^{\pi}_{dA}(x_T)$ at RHIC (*dashed*) and LHC (*solid*) energies with different shadowing parameterizations. Preliminary PHENIX data are plotted as functions of x_T. The effect of cold energy loss is indicated by *thin dotted* and *dot-dashed lines* for $L/\lambda_g = 1$ and 3, respectively.

Finally we turn to possible cold energy loss at the LHC. The standard estimate is $\mathrm{d}N/\mathrm{d}y \approx 1500 - 4000$ in central $PbPb$ collisions at LHC energies [14]. While in central dPb collisions the geometrical cross section is small, using $L/\lambda \sim \langle N_{part} \rangle^{1/3}$ from [8] one obtains $\mathrm{d}N/\mathrm{d}y \approx 500 - 2000$, still large, in central dPb collisions. This motivates us to examine the effect of a small energy loss in the final state. We apply opacity values $L/\lambda_g \lesssim 3$ for this illustration. The results are indicated as thin dotted ($L/\lambda_g = 1$) and dot-dashed ($L/\lambda_g = 3$) lines in Fig. 2.

The energy loss is stronger at the lower x_T values. Here the relative particle yield is suppressed, and $R_{dA}(x_T)$ is steeper. In the high p_T region the suppression loses strength as it increases with $\sim \log(E)$. We tested this effect at RHIC and LHC energies in $AuAu$ ($PbPb$) collisions [15].

IV. SUMMARY

We analyzed the high transverse-momentum behavior of the nuclear modifications in dA collisions. Using preliminary PHENIX data we checked several common nuclear shadowing parameterizations. We compared the logarithmic slopes of the nuclear modification factor in the 15 GeV/c $\lesssim p_T \lesssim$ 50 GeV/c region. The shadowing parameterizations investigated have an almost linear behavior with a negative slope in dAu collisions at RHIC, which can be attributed to the EMC effect. While we found all studied shadowing models reliable at intermediate p_T, at high transverse momenta the EPS08 and the HKN nuclear PDF seem to give the best agreement with the PHENIX data. We tested the x_T scaling of midrapidity π^0 production in dA collisions at RHIC and LHC energies in the models. At high x_T most models have a similar behavior, but EPS08 deviates from precise scaling around $x_T \approx 6 \cdot 10^{-2}$. At lower x_T, $R_{dA}(x_T)$ shows a $5 - 15\%$ enhancement in the HKN, EKS, and EPS08 models. The enhancement is absent in the HIJING with multiscattering model. We tested the effect of a small energy loss, which counteracts any enhancement in dPb collisions and yields a wide-range suppression of the $R_{dA}(x_T)$. In light of these results and open questions, we emphasize the need for pPb (or at least dPb) measurements at the LHC.

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