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DOES THE CRONIN PEAK DISAPPEAR AT LHC ENERGIES?

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In this work we compare the nuclear modification factors in proton (deuteron) – nucleus collisions at CERN SPS, FNAL and RHIC energies in a wide p_T range. In these experiments the nuclear modification factor has shown an enhancement at $p_T \approx 4$ GeV/c. The height of this "Cronin peak" depends on the c.m. energy of the collision, as it is subject to stronger shadowing at higher energies. One of the aims of this contribution is to analyze the shadowing phenomenon at lower (2 GeV/c $\lesssim p_T \lesssim$ 4 GeV/c) and intermediate (4 GeV/c $\lesssim p_T \lesssim$ 8 GeV/c) transverse momentum. Different shadowing parameterizations are considered and the obtained Cronin peaks are investigated at RHIC and LHC energies.

1. Introduction

Enhancement of the hadron spectra in nuclear collisions is a strong nuclear effect. This was discovered in pBe, pTi and pW collisions and named after J.W. Cronin [1,2] at FNAL. The measured enhancement is a $\sim 40\%$ in the lower and intermediate transverse momentum region (2 GeV/c $\lesssim p_T \lesssim$ 8 GeV/c). Relativistic Heavy Ion Collider (RHIC) experiments measured a smaller ($\sim 10\%$) Cronin peak at higher energy, $\sqrt{s_{NN}} = 200$ GeV in dAu collisions [3,4,5]. It is natural to ask the question: how will this effect appear at the energies of the forthcoming measurements at the Large Hadron Collider (LHC)?

In this paper we are presenting our predictions for the pion spectra in proton-proton collisions as a reference at $\sqrt{s_{NN}} = 900$ GeV and 8.8 TeV energies. This leads us to predict the nuclear modification factor in *dPb* collisions, taking into account initial state nuclear effects.

2. Effects on Inclusive Pion Spectra in *pp* Collisions

A comparison of inclusive spectra and hadron-hadron correlations from *pp* collisions to results of pQCD calculations shows that in this framework intrinsic transverse momentum (k_T) is necessary for the precise description of the data[6,7,8,9,10,11,12].

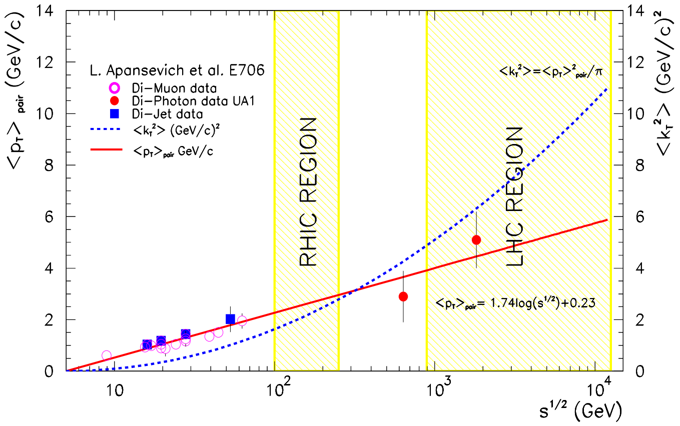

Fig. 1. Estimation for the $\langle p_T \rangle_{pair}$ and for $\langle k_T^2 \rangle$ value at different c.m. energies.

Several experiments (e.g. PHENIX[10,11], E706[13]) have measured the intrinsic transverse momentum using a produced hadron pair as a function of c.m. energy, as summarized in Ref.[14]. It was found that $\langle p_T \rangle_{pair} \sim \log(\sqrt{s})$. These experimental data and the linear fit is plotted on Fig. 1 (*solid line*). The fitted linear function can be parameterized in the following form:

$$\langle p_T \rangle_{pair} = (1.74 \pm 0.12) \cdot \log_{10}\left(\sqrt{s}\right) + (1.23 \pm 0.2)\,. \qquad (1)$$

Calculations of $\langle k_T^2 \rangle$ are also shown (*dashed curve*). The intrinsic k_T was converted to the transverse momentum of the pair via $\langle k_T^2 \rangle_{pp} = \langle p_T \rangle^2_{pair}/\pi$.

While there are only a few experimental data points beyond RHIC energies, we can apply estimate (1) in calculations of pion spectra, using the appropriate intrinsic-k_T values at given c.m. energy. The calculated π^0 spectra in *pp* collisions are displayed in Fig. 2, where we compare this to experimental data from Refs.[11,15]. Our calculations use the GRV[16] and HKN[17,18] parton distribution functions.

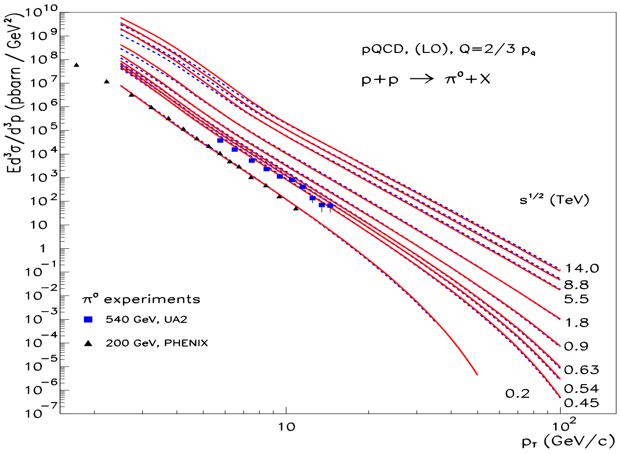

Fig. 2. Pion spectra in pp collisions at different c.m. energies from RHIC to LHC energies, applying energy dependent $\langle k_T^2 \rangle$ (see. Fig 1).

On Fig 3 we are presenting the "evolution" of the pion spectra with different $\langle k_T^2 \rangle$ values in pp collisions at 5.5 TeV c.m. energy. This shows that an increasing intrinsic k_T results in an enhancement of the pion spectra in the lower momentum region relative to the $\langle k_T^2 \rangle = 0$ case.

Considering a $\langle k_T^2 \rangle \sim 10 - 15$ GeV^2/c^2 value at $\sqrt{s_{NN}} = 5.5$ TeV c.m. energy, the modification is a factor of ~ 5 at the momentum region, $p_T \sim 5$ GeV/c. Fig 3 suggests that the effect of the intrinsic transverse momentum can be reasonably large at these high energies. This is interesting in itself, but it is even more important when we use calculated pp hadron spectra in the nuclear modification factor.

3. Predictions for Pion Spectra in *dPb* Collisions

Pion production is calculated for dPb collisions in a pQCD-improved parton model, described in Refs.[8,9]. Within this framework we are taking into account the effect on intrinsic transverse momenta in two aspects:

(i) We are using a simple generalization of the one- dimensional parton distribution functions into 3 dimensions, using a factorized form,

$$f_{a/p}(x_a, \mathbf{k}_{Ta}, Q^2) \quad = \quad f_{a/p}(x_a, Q^2) \cdot g_{a/p}(\mathbf{k}_{Ta}) \ , \tag{2}$$

where the function $f_{a/p}(x_a, Q^2)$ represents the standard longitudinal PDF as a function of x_a at the factorization scale Q. In the present calculation we use the GRV[16] or HKN[17,18] parameterizations. The partonic transverse-momentum distribution in two dimensions, $g_{a/p}(\mathbf{k}_T)$, is assumed to be a Gaussian, characterized by the width $\langle k_T^2 \rangle$, sometimes referred to as the intrinsic-k_T parameter.

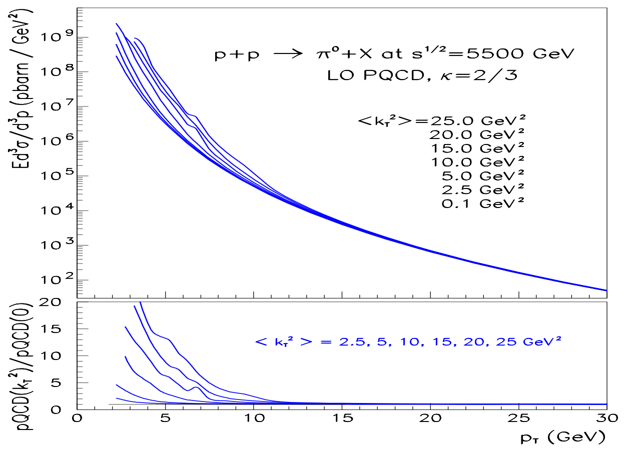

Fig. 3. The effect of the intrinsic k_T in pion production in pp collisions at $\sqrt{s_{NN}} = 5.5$ TeV. *Upper panel* shows the spectra and the *lower panel* presents the ratio relative to the zero intrinsic-k_T calculation.

(ii) Nuclear multiscattering is accounted for through a broadening of the incoming parton's transverse momentum distribution function, namely an increase in the width of the Gaussian:

$$\langle k_T^2 \rangle_{pA} = \langle k_T^2 \rangle_{pp} + C \cdot h_{pA}(b) \ . \tag{3}$$

Here, $\langle k_T^2 \rangle_{pp}$ is the width of the transverse momentum distribution of partons in pp collisions[8,9,19], $h_{pA}(b)$ describes the number of *effective* NN collisions at impact parameter b, which impart an average transverse momentum squared C. The effectivity function $h_{pA}(b)$ can be written in terms of the number of collisions suffered by the incoming proton in the target nucleus. In Ref.[8] we have found a limited number of semi-hard collisions, $3 \leq \nu_m \leq 4$ and the value $C = 0.35$ GeV^2/c^2.

We calculate the nuclear modification factor as a function of c.m. energy. With increasing intrinsic k_T the Cronin peak is found to shift towards higher p_T values. At $\sqrt{s} = 200$ GeV c.m. energy, the maximum of the Cronin peak was located at $p_T \approx 4$ GeV/c; at the LHC we expect this peak at $p_T \approx 5$ GeV/c and 8 GeV/c, respectively, at $\sqrt{s} = 900$ GeV and 8.8 TeV c.m. energies. This effect mirrors the recently measured experimental data by the WA98[20] and NA49[21] collaborations, where the Cronin peak seems to be at lower p_T ($p_T \approx 2 - 3$ GeV/c) at $\sqrt{s} = 17.3$ GeV c.m. energy.

On Fig. 4 we plot the R_{dPb} nuclear modification factor for the cases of the above mentioned two energies. For comparison we also show the latest experimental

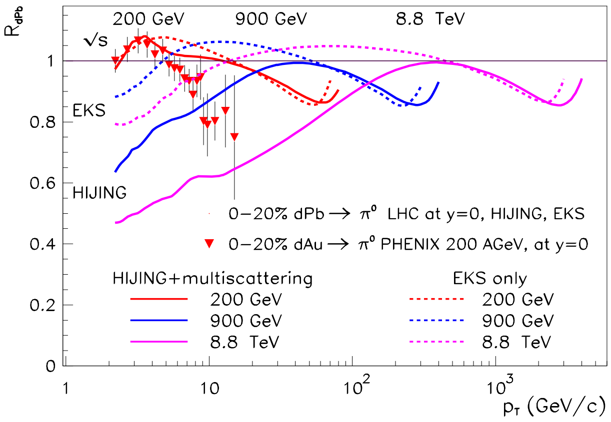

Fig. 4. The nuclear modification factor for pion production in $0 - 10\%$ most central dPb collisions at different c.m. energies. Calculations have been performed with EKS (*dashed lines*) and HIJING (*solid lines*) shadowing parameterizations.

data by the PHENIX[3,4] on R_{dAu} at $\sqrt{s} = 200$ GeV. We calculated the nuclear modification factor applying the $\sqrt{s}$-dependent intrinsic k_T based on eq. (1).

In order to develop a feeling for the uncertainty of the shadowing parameterizations, we carried out our calculations with two shadowing parameterizations, EKS[22] (*dashed lines*) and HIJING[23,24] (*solid lines*)[a]. As Fig. 4 shows, at lower p_T the uncertainty is growing with increasing $\sqrt{s}$, corresponding to the limited information on shadowing with decreasing x. Close to $x \sim 1$ another ambiguity can be seen at the EMC region[25,26].

The shifting Cronin peak is suppressed by the strong shadowing which is $\sim 40\%$ for HIJING and $\sim 20\%$ for EKS. A remaining small ‘bump’ is seen on the solid curves (HIJING parameterization).

4. Conclusions

Based on experimental data we developed an approximation for the values of $\langle k_T^2 \rangle_{pp}$ at various c.m. energies. We have shown that the intrinsic k_T has a non-negligible effect on inclusive pion production in proton-proton collisions at LHC energies. The increasing intrinsic k_T causes a slight shift of the Cronin peak toward higher p_T values. However, at LHC energies the strong $\sim 20 - 40\%$ shadowing suppresses the Cronin peak. Overall, we expect that the Cronin peak will be totally suppressed at LHC energies in dPb collisions by initial state effects.

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[a] The EKS parameterization contains some enhancement by definition as an anti-shadowing. Thus no multiple scattering was taken into account in this case.

It is important to note on the other hand that, as it was pointed out in Refs.[26], at these high c.m. energies final state effects can also play a role, yielding more suppression in the nuclear modification factor.

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