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Identified particle transverse momentum spectra in $p+p$ and $d+Au$ collisions at $\sqrt{s_{NN}} = 200$ GeV

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Abstract. The transverse momentum ($p_T$) spectra for identified charged pions, protons and anti-protons from $p+p$ and $d+Au$ collisions are measured around midrapidity ($|y| < 0.5$) over the range of 0.3 $< p_T < 10$ GeV/c at $\sqrt{s_{NN}} = 200$ GeV. The charged pion and proton+anti-proton spectra at high $p_T$ in $p+p$ collisions have been compared with the next-to-leading order perturbative quantum chromodynamic (NLO pQCD) calculations with a specific fragmentation scheme. The $p/\pi^+$ and $p/\pi^-$ has been studied at high $p_T$. The nuclear modification factor ($R_{dAu}$) shows that the identified particle Cronin effects around midrapidity are significantly non-zero for charged pions and to be even larger for protons at intermediate $p_T$ ($2 < p_T < 5$ GeV/c).

Keywords: Particle production, perturbative quantum chromodynamics, fragmentation function

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INTRODUCTION

The study of identified hadron spectra at large transverse momentum ($p_T$) in $p+p$ collisions can be used to test the predictions from perturbative quantum chromodynamics (pQCD) [1]. Comparisons between experimentally measured $p_T$ spectra and theory can help to constrain the quark and gluon fragmentation functions. Within the framework of pQCD, the expected initial-state nuclear effects in $d+Au$ collisions are multiple scattering (Cronin effect [2]) and shadowing of the parton distribution function. The study of the nuclear modification factor ($R_{dAu}$) will help us in understanding the nuclear effects involved in $d+Au$ collisions. The particle ratios at high $p_T$ constrains particle production models and also gives unique data on FF ratios, although extraction of this information is model-dependent. For example, $p/\pi^+$ reflects the relative probability of a parton to fragment into proton or pion at high $p_T$ [3]. The above aspects have been discussed in this manuscript.

EXPERIMENT AND ANALYSIS

The detectors used in the present analysis are the Time Projection Chamber (TPC), the Time-Of-Flight (TOF) detector, a set of trigger detectors used for obtaining the minimum bias data, and the Forward Time Projection Chamber (FTPC) for the collision centrality determination in $d+Au$ collisions in STAR experiment. The details of the design and other characteristics of the detectors can be found in Ref. [4]. The data from TOF is used to obtain the identified hadron spectra for $p_T < 2.5$ GeV/c. The procedure for particle identification in TOF has been described in Ref. [7]. For $p_T > 2.5$ GeV/c, we use data from the TPC. Particle identification at $p_T$ in the TPC comes from the relativistic rise of the ionization energy loss ($\tau dE/dx$). Details of the method are described in Ref. [8].
COMPARISON TO NLO PQCD AND MODEL CALCULATIONS

In Fig. 1 we compare \((\pi^+ + \pi^-)/2\) and \((p+p)/2\) yields in minimum bias \(p+p\) collisions at midrapidity to those from NLO pQCD calculations. The NLO pQCD results are based on calculations performed with Albino-Kniehl-Kranier (AKK) set of fragmentation functions [12]. We observe that our charged pion data for \(p_T > 2\) GeV/c in \(p+p\) collisions are reasonably well-explained by the NLO pQCD calculations using the AKK set of FFs. The calculations for the factorization scales of \(\mu = p_T/2\), \(\mu = p_T\), and \(\mu = 2 p_T\) have been shown. The combined proton and anti-proton yield in \(p+p\) is lower compared to NLO pQCD calculations using AKK FFs for the factorization scale \(\mu = p_T\). The \((p+p)/2\) yield in \(p+p\) collisions, however, is reasonably well-explained by AKK set of FFs for \(\mu = 2 p_T\). For the first time in \(p+p\) collisions we observe a reasonably good agreement between the NLO pQCD calculations (using AKK FFs) and data at high \(p_T\). This reflects the importance of the flavor-separated measurements in \(e^+e^-\) collisions in determining the FFs to baryons as used in AKK FFs calculation.

NUCLEAR MODIFICATION FACTOR

The nuclear modification factor \(R_{dAu}\) can be used to study the effects of cold nuclear matter on particle production. It is defined as a ratio of the invariant yields of the produced particles in \(d+Au\) collisions to those in \(p+p\) collisions scaled by the underlying number of nucleon-nucleon binary collisions.

\[
R_{dAu}(p_T) = \frac{d^2N_{dAu}/dy dp_T}{\langle N_{\text{bin}} \rangle / \langle \sigma_{pp}^{\text{inel}} \rangle d^2\sigma_{pp}/dy dp_T},
\]

where \(\langle N_{\text{bin}} \rangle\) is the average number of binary nucleon-nucleon (NN) collisions per event, and \(\langle \sigma_{pp}^{\text{inel}} \rangle\) is the nuclear overlap function \(T_s(b)\) [5, 6]. The \(\sigma_{pp}^{\text{inel}}\) is taken to be 42 mb.

In Fig. 2 shows the \(R_{dAu}\) for charged pions \(((\pi^+ + \pi^-)/2)\) and combined proton and anti-proton \((p+p)\) in minimum-bias collisions at \(|y| < 0.5\). The \(R_{dAu}\) > 1 indicates a slight enhancement of high \(p_T\) charged pions yields in \(d+Au\) collisions compared to binary collision scaled charged pion yields in \(p+p\) collisions within the measured \((y, p_T)\) range. The \(R_{dAu}\) for \(p+p\) is again greater than unity for \(p_T > 1.0\) GeV/c and is larger than that of the charged pions. The \(R_{dAu}\) results for identified particles has also been compared to the inclusive charged hadrons. The uncertainty in determining the number of binary collisions in \(d+Au\) minimum-bias collisions is \(-5.3\%\).

PARTICLE RATIO

The \(p/\pi^+\) and \(\bar{p}/\pi^-\) at midrapidity as a function of \(p_T\) for \(p+p\) and \(d+Au\) minimum bias collisions are shown in Fig. 3. At RHIC, the \(p/\pi^+\) and \(\bar{p}/\pi^-\) ratios increase with \(p_T\) up to 2 GeV/c and then start to decrease for higher \(p_T\) in both \(p+p\) and \(d+Au\) collisions. The \(\bar{p}/\pi^-\) ratio rapidly approaches a value of 0.2, which is also observed in \(e^+e^-\) collisions for both quark and gluon jets [9]. The \(p/\pi^+\) ratios in \(p+p\) collisions compare well with results from lower energy ISR and FNAL fixed target experiments [10, 11], while \(\bar{p}/\pi^-\) ratios at high \(p_T\) have a strong energy dependence with larger values at higher beam energies.

SUMMARY

We have measured the transverse momentum spectra for identified charged pions, protons and anti-protons from \(p+p\) and \(d+Au\) collisions at \(\sqrt{s_{NN}} = 200\) GeV around midrapidity \((|y| < 0.5)\) over the range of \(0.3 < p_T < 10\) GeV/c. For particle identification we use the ionization energy loss and its relativistic rise in the Time Projection Chamber and the Time-of-Flight in STAR. The charged pions, combined proton and anti-proton spectra in \(p+p\) and collisions have been compared to calculations with the next-to-leading order perturbative.
FIGURE 3. Ratio of $p/\pi^+$ and $\bar{p}/\pi^-$ at midrapidity ($|y| < 0.5$) as a function of $p_T$ in $p+p$ and $d+Au$ minimum bias collisions. For comparison the results from lower energies at ISR and FNAL are also shown for $p/\pi^+$ and $\bar{p}/\pi^-$. The errors represented by boxes are the point-to-point systematic.

QCD calculations with a specific fragmentation scheme. The NLO pQCD calculation explains the high $p_T$ data for charged pions reasonably well for $p_T > 2$ GeV/c in $p+p$ collisions. The $p+\bar{p}$ spectra are reasonably well-explained for the first time by NLO pQCD calculation using the AKK set of FFs with the factorization scale of $\mu = 2p_T$. An improved description of experimental data in RHIC's $p+p$ collisions by AKK FFs, which comes from NLO pQCD fits to the flavor separated $e^+e^-$ data, is extremely interesting. These findings may provide a better foundation for applications of jet quenching and quark recombination models to explain the phenomena in A+A collisions in this $p_T$ range. Cronin effect around midrapidity is observed to be significantly non-zero for pions, while the effect on proton and anti-proton spectra is even larger at the intermediate $p_T$ ($2 < p_T < 5$ GeV/c). The $p/\pi^+$ and $\bar{p}/\pi^-$ ratios have been studied at high $p_T$ for $p+p$ and $d+Au$ collisions. $p/\pi$ ratios peak at $p_T \simeq 2$ GeV/c with a value of $\sim 0.5$, and then decrease to $\sim 0.2$ at high $p_T$ with the possible exception of the $p/\pi^+$ ratio in $d+Au$ collisions.

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