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 $\bar{p}/\pi^-$ 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 ($\mu E/dx$). Details of the method are described in Ref. [8].
pions (π^+ + π^-)/2 and p+\bar{p} at |y| < 0.5 in minimum bias d+Au collisions. For comparison results on inclusive charged hadrons (STAR) from Ref. [5] at |\eta| < 0.5 are shown. The shaded band is the normalization uncertainty from trigger and luminosity in p+p and d+Au collisions.

**COMPARISON TO NLO PQCD AND MODEL CALCULATIONS**

In Fig. 1 we compare (π^+ + π^-)/2 and (p+\bar{p})/2 yields in minimum bias p+p collisions at midrapidity for high p_T to those from NLO pQCD calculations. The NLO pQCD results are based on calculations performed with Albino-Kniehl-Kramer (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 = 2p_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+\bar{p})/2 yield in p+p collisions, however, is reasonably well-explained by AKK set of FFs for \mu = 2p_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.

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

where \langle N_{bin}\rangle is the average number of binary nucleon-nucleon (NN) collisions per event, and \sigma_{pp}^{inel} is the nuclear overlap function T_A(b) [5, 6]. The \sigma_{pp}^{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+\bar{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+\bar{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 \sim 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...
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 $p_T \approx 2$ 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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