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

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**Abstract.** The transverse momentum ($p_{\rm T}$) 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 $0.3 < p_{\rm T} < 10$ GeV/$c$ at $\sqrt{s_{\rm NN}}$ = 200 GeV. The charged pion and proton+anti-proton spectra at high $p_{\rm T}$ 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 $p_{\rm T}$. 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 $p_{\rm T}$ ($2 < p_{\rm T} < 5$ GeV/$c$).

**Keywords:** Particle production, perturbative quantum chromodynamics,fragmentation function
**PACS:** 25.75.-q,25.75.Dw,24.85.+p

## INTRODUCTION

The study of identified hadron spectra at large transverse momentum ($p_{\rm T}$) in $p$+$p$ collisions can be used to test the predictions from perturbative quantum chromodynamics (pQCD) [1]. Comparisons between experimentally measured $p_{\rm T}$ 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 $p_{\rm T}$ 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 $p_{\rm T}$ [3]. The above aspects have been discussed in this manuscript.

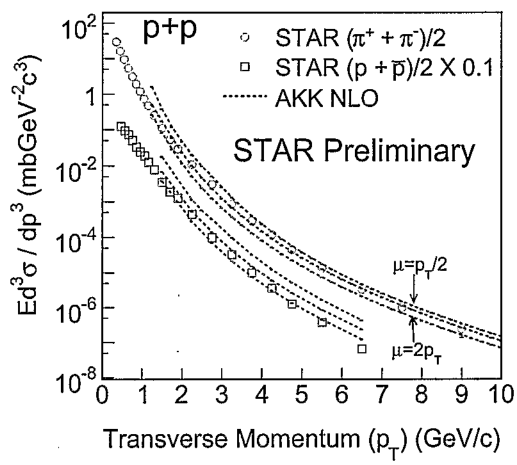


**FIGURE 1.** Midrapidity invariant yields for $(\pi^+ + \pi^-)/2$ and $(p+\bar{p})/2$ at high $p_{\rm T}$ for minimum bias $p$+$p$ collisions compared to results from NLO pQCD calculations using AKK [12] (PDF: CTEQ6M) set of fragmentation functions. The calculations from AKK are for three different factorization scales: $\mu = p_{\rm T}/2$, $\mu = p_{\rm T}$, and $\mu = 2p_{\rm T}$.

## 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 $p_{\rm T} < 2.5$ GeV/$c$. The procedure for particle identification in TOF has been described in Ref. [7].For $p_{\rm T} > 2.5$ GeV/$c$, we use data from the TPC. Particle identification at $p_{\rm T}$ in the TPC comes from the relativistic rise of the ionization energy loss ($rdE/dx$). Details of the method are described in Ref. [8].

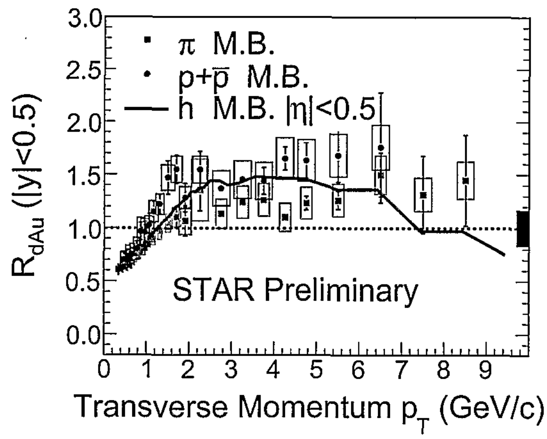


**FIGURE 2.** Nuclear modification factor $R_{dAu}$ for charged pions $(\pi^+ + \pi^-)/2$ and $p$+$\bar{p}$ at $|y| < 0.5$ in minimum bias $d$+Au collisions. For comparison results on inclusive charged hadrons (STAR) from Ref. [5] at $|\eta| < 0.5$ are shown. The shaded band is the normalization uncertainty from trigger and luminosity in $p$+$p$ and $d$+Au collisions.

## COMPARISON TO NLO PQCD AND MODEL CALCULATIONS

In Fig. 1 we compare $(\pi^+ + \pi^-)/2$ 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.

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

where $\langle N_{bin}\rangle$ is the average number of binary nucleon-nucleon (NN) collisions per event, and $\langle N_{bin}\rangle/\sigma_{pp}^{inel}$ 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 ~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

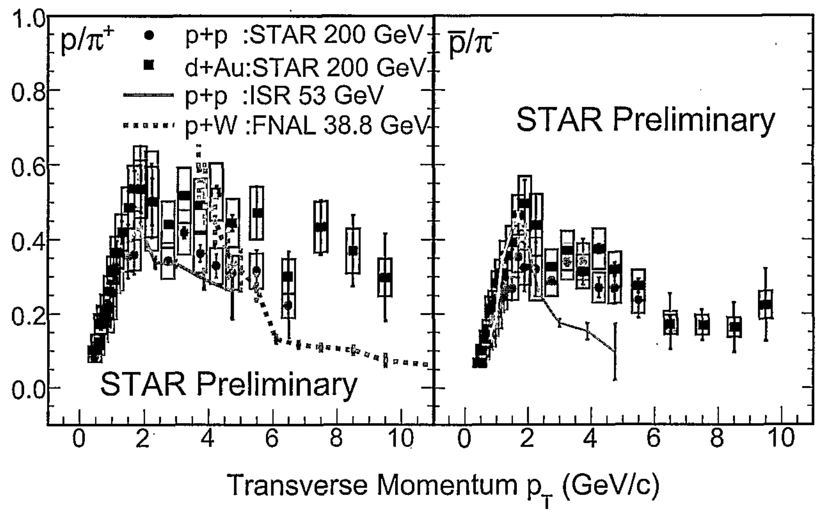


**FIGURE 3.** Ratio of $p/\pi^+$ and $\bar{p}/\pi^-$ at midrapidity ($|y| < 0.5$) as a function of $p_T$ in $p$+$p$ and $d$+Au minimum bias collisions. For comparison the results from lower energies at ISR and FNAL are also shown for $p/\pi^+$ and $\bar{p}/\pi^-$. The errors represented by boxes are 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 obsereved 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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