

STAR Identified Particle Measurements at High Transverse Momentum in $p+p$ $\sqrt{s} = 200$ GeV

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We present the STAR measurement of transverse momentum spectra at mid-rapidity for identified particles in $p+p$ collisions at $\sqrt{s} = 200$ GeV. These high statistics data are ideal for comparing to existing leading- and next-to-leading order (NLO) perturbative QCD calculations. Next-to-leading models have been successful in describing inclusive hadron production using parameterized fragmentation functions (FF) for quarks and gluons. However, in order to describe baryon spectra at NLO, knowledge of flavor separated FF is essential. Such FF have recently been parameterized using data by the OPAL experiment and allow for the first time to obtain good agreement between NLO and identified baryons from $p + p$ collisions.

1 Introduction

Perturbative QCD has proven to be successful in describing inclusive hadron production in elementary collisions. Within the theory's range of applicability, calculations at next-to-leading order (NLO) have produced accurate predictions for transverse momentum spectra of inclusive hadrons at different energy scales [2]. With the new high statistics proton-proton data at $\sqrt{s} = 200$ GeV collected by STAR, we can now extend the study to identified baryons and mesons to $p_T \sim 9$ GeV/c. Perturbative QCD calculation apply the factorization ansatz to calculate hadron production and rely on three ingredients. The first part are the non-perturbative parton distribution functions (PDF) which are obtained by parameterizations of deep inelastic scattering data. They describe quantitatively how the partons share momentum within a nucleus. The second part, which is perturbatively calculable, consists of the parton cross-section amplitude evaluated to LO or NLO using Feynman diagrams. The third part consists of the non-perturbative Fragmentation functions (FF) obtained from $e^+ + e^-$ collider data using quark-tagging algorithms. These parameterized functions are sufficiently well known for fragmenting light quarks, but less well known for fragmenting gluons and heavy quarks. Recently, Kniehl, Kramer and Pötter (KKP) have shown that FF are universal between $e^+ + e^-$ and $p+p$ collisions [3]. At leading-order, we compare to string fragmentation models such as PYTHIA to investigate the dependence between hadrons and underlying parton-parton interactions [4]. In the string fragmentation approach the production of baryons is intimately related to di-quark production from strings. They then combine with a quark to produce a baryon. In NLO calculations, the accuracy of a given baryon cross-section is based on the knowledge of that specific baryon fragmentation function (FF) extracted $e^+ + e^-$ collisions.

2 Data Analysis

The present data were reconstructed using the STAR detector system which is described in more detail elsewhere [5]. The main detectors used in this analysis are the Time Projection

Chamber (TPC) and the Time of Flight detector (TOF). A total of 14 million non-singly diffractive (NSD) events were triggered with the STAR beam-beam counters (BBC) requiring two coincident charged tracks at forward rapidity ($3.3 < |\eta| < 5.0$). By simulation it was determined that the trigger measured 87% of the 30.0 ± 3.5 mb NSD cross-section. The offline primary vertex reconstruction was 76% efficient which lead to a total usable event sample of 7×10^6 events. Protons and pions in this analysis were identified using the TOF detector at p_T below 2.5 GeV/c and the TPC using the relativistic rise dE/dx at higher p_T . Details of both methods are described in [7, 8]. At $p_T \sim 3$ GeV/c the pion dE/dx is about 10-20% higher than that of kaons and protons due to the relativistic rise, resulting in a few standard deviations of separation. The strange particles were identified from their weak decay to charged daughter particles. The following decay channels and the corresponding anti-particles were analyzed: $K_S^0 \rightarrow \pi^+ + \pi^-$ (b.r. 68.6%), $\Lambda \rightarrow p + \pi^-$ (b.r. 63.9%). Particle identification of the daughters was achieved by requiring the TPC-measured dE/dx to fall within the 3σ -bands of the theoretical Bethe-Bloch parameterizations. Further background in the invariant mass was removed by applying topological cuts to the decay geometry.

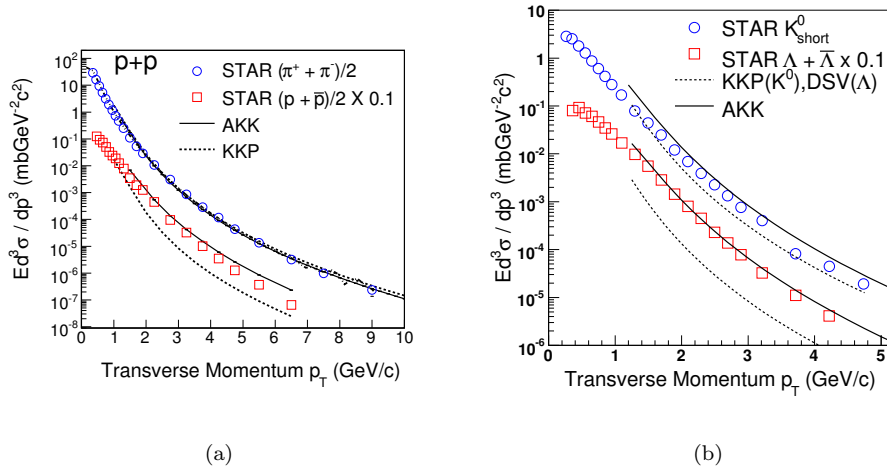


Figure 1: (a) $(p + \bar{p})$ and $(\pi^+ + \pi^-)$ p_T -spectra at $|\mathbf{y}| < 0.5$ from NSD p+p at 200 GeV [9] (b) K_S^0 and Λ p_T spectra at $|\mathbf{y}| < 0.5$ compared to NLO calculations using KKP, DSV and AKK fragmentation functions. [10]

3 Results

3.1 Comparison to next-to-leading order

In figure 1 we compare our transverse momentum spectra to recent next-to-leading order calculations using two different fragmentation functions (FF). The previous ones were by Kniehl-Kramer-Poetter (KKP) for pions, kaons and protons and from deFlorian-Stratmann-Vogelsang (DSV) for Λ [6, 11]. More recently Albino-Kramer-Kniehl (AKK) [12] have published FF based on the light quark-flavor tagged data from the OPAL Collaboration [13]. Clearly, these newer parameterizations improve the description of the baryon data

considerably. In order to achieve this agreement with the data, the initial gluon to Λ fragmentation function is determined by fixing its shape to that of the proton, and then varying the normalization for the best fit. A scaling factor of 3 with respect to the proton is necessary to achieve agreement with STAR data. However, this modified FF is then tested by comparing to the Λ measurement from $p + \bar{p}$ at $\sqrt{s} = 630$ GeV and agrees well [12].

3.2 Baryon to meson ratios vs p_T

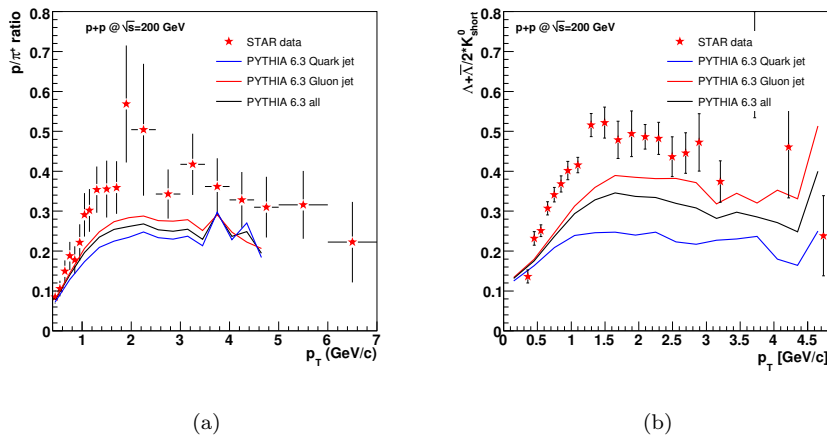


Figure 2: (a) p/π ratio compared to PYTHIA for different event samples, (b) $(\Lambda + \bar{\Lambda})/2 \cdot K_S^0$ ratio compared to PYTHIA.

In order to further investigate the sensitivity of the baryon spectra to the fragmentation of gluons, we used a leading-order (LO) Monte Carlo simulator, PYTHIA. PYTHIA 6.3 generates events by using $2 \rightarrow 2$ LO parton processes plus additional leading-log showers and multiple interactions. We define a ‘‘Gluon-jet’’ event as one where the underlying partons are g-g or g-q and a ‘‘Quark-jet’’ event one where the underlying partons are q-q. According to the model default settings the $p + p$ events at our energy are dominated by gluon-jets (62%) with respect to quark-jets (38%). Figure 2 compares baryon-to-meson ratios to three different event types from PYTHIA. In both cases the overall ratio in the data is significantly larger at $p_T \sim 1-3$ GeV/c than the PYTHIA result. In addition, this shows that pure gluon jet events will produce a larger baryon-to-meson ratio than quark jet events.

3.3 Transverse mass (m_T) scaling

Universal transverse mass scaling of particle spectra was previously seen in $p+p$ collisions at lower ISR-energies [14]. We have compiled STAR identified particle spectra to investigate m_T -scaling. The particle spectra were arbitrarily normalized to pion spectra at $m_T = 1$ GeV. Interestingly we observe that a splitting occurs at ~ 2 GeV and that the meson spectra are harder than the baryon spectra. We compared this result to PYTHIA simulations scaled in the same manner. We again observe that gluon jets will fragment very differently into baryons and mesons than quark jets. For gluon jets, there is a clear shape difference between baryons and mesons consistent with the data. For quark jets, the shape difference is modified

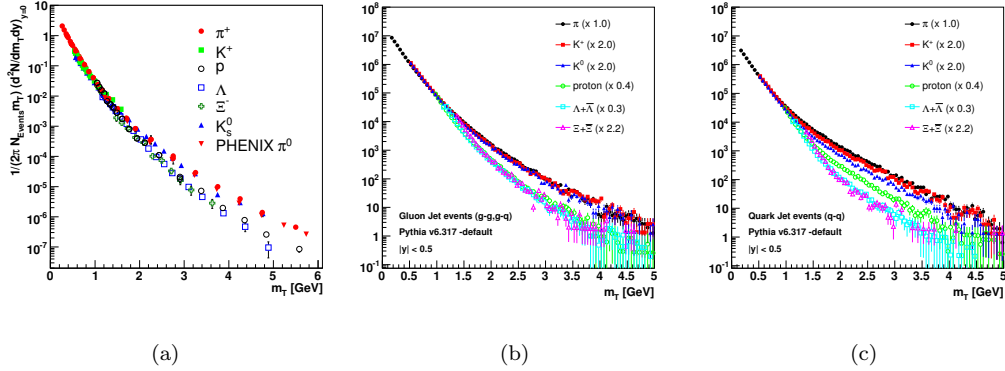


Figure 3: (a) Arbitrarily scaled m_T spectra for baryons and mesons from $p + p$ collisions at $\sqrt{s} = 200$ GeV. (b) Scaled m_T spectra for “Gluon-jet” events from PYTHIA. (c) Scaled m_T spectra for “Quark-jet” events from PYTHIA.

by an additional dependency on the mass of the produced particle. This may be a further indication that we observe dominance of gluon jets in $p + p$ collisions at RHIC energies.

4 Summary

We have shown that the theoretical description of identified baryons and mesons in $p + p$ collisions has recently improved thanks to new NLO calculations using light quark-flavor tagged fragmentation functions. Considerable uncertainties remain in the high- z (p_{hadron}/p_{parton}) range of the gluon FF for baryons. It appears that previous baryon-FF extracted from $e^+ + e^-$ data are inconsistent with STAR’s $p + p$ data, indicating that RHIC is a valuable test of FF. Arbitrarily scaled m_T spectra for strange particles exhibit partial m_T scaling and confirm the dominance of gluon jets in $p + p$ and therefore the importance of understanding gluon fragmentation.

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