Measurements of neutral and charged kaon production at high $p_T$ up to 15 GeV/c at STAR

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Abstract

We report an extension of charged kaon transverse momentum ($p_T$) spectra at mid-rapidity ($|y|<0.5$) up to 15 GeV/c, neutral kaon $p_T$ spectra up to 12 GeV/c using events triggered by the Barrel Electro-Magnetic Calorimeter (BEMC) from $p+p$ collisions at $\sqrt{s_{NN}} = 200$ GeV. The $K^\pm/\pi^\pm$ and $K^0/\pi^\pm$ at high $p_T$ are compared in $p+p$ and $Au+Au$ collisions, and nuclear modification factor ($R_{AA}$) for pion, kaon, proton and rho are discussed. The $R_{AA}$ for kaon in central collisions are consistent with theory calculation having jet conversion in a plasma of quarks and gluons.

1. Introduction

The study of identified hadron ($\pi^\pm$, $K^\pm$, $p(\bar{p})$) spectra at high $p_T$ in $p+p$ collisions provides a good test of perturbative Quantum Chromodynamics (pQCD) [1]. In different NLO pQCD calculations, the inclusive production of single hadron is described by the convolution of parton distribution functions (PDF), parton interaction cross-sections and fragmentation functions (FF) which are parameterized by measured hadron spectra by now. In order to understand mechanism of hadron production, it is necessary to make a strict constraint on the quark and gluon FFs by comparing theory with experimental data. In addition, it’s also a good baseline for studying color charge effect of parton energy loss in heavy ion collisions, in which hadron spectra are measured up to 12 GeV/c now [2]. Kaon measurements are restricted at high $p_T$ due to significant uncertainties of ionization energy loss ($dE/dx$) from Time Projection Chamber (TPC), while pion and proton results have been published before [3]. In this article, we’ll present the $p_T$ spectra for charged and neutral kaons in $p+p$ collisions at $\sqrt{s_{NN}} = 200$ GeV as measured by the STAR experiment at RHIC, which will be compared with NLO pQCD calculations. The $K/\pi$ ratios in $p+p$ and $Au+Au$ collisions will be compared in this paper. Finally, $R_{AA}$, defined by the spectra in $Au+Au$ collisions divided by spectra in $p+p$ collisions scaled by the number of binary collisions, are discussed and compared with predictions from jet conversion [4].
2. Experiment and Analysis

The data used for this analysis were p+p collisions and Au+Au collisions collected in the year 2005 and 2004 respectively. The STAR main tracking detector, TPC covering full azimuthal angle (2π) and |η| < 1.8 in pseudo-rapidity provides a way to identify charged hadrons by measuring momentum and dE/dx information of charged particles [5]. The BEMC [6] covering 2π azimuthal angle and 0 < η < 1.0 was used as online trigger to collect ∼5.6 million events with transverse energy $E_T > 6.4$ GeV (JP2), ∼5.1 million events with $E_T > 2.5$ GeV (HT1), and ∼3.4 million events with $E_T > 3.6$ GeV (HT2) from p+p collisions in year 2005. Those triggers can improve the possibility of events with high momentum track, and this helps us to extend our measurements up to high $p_T$. JP2 triggered events are used to identify charged kaons, while HT1 and HT2 triggered events are used to reconstructed neutral kaons through $K^0_S \rightarrow \pi^+ \pi^-$ decay mode, which are used to cross check if there are trigger bias by comparing $K^0_S$ in different triggered events and $K^0_S$ with $K^\pm$. In addition, ∼21.2 million events from central Au+Au collisions were used to reconstruct neutral kaons and identify charged kaons.

![Figure 1: Charged and neutral kaon $p_T$ spectra and K/π ratios in p+p collisions, compared with pQCD NLO calculations from DSS, AKK 2008. Squares and triangles are from minimum bias events, and circles and stars are from the BEMC triggered events. The shaded band are systematic uncertainties for $K^0_S$.](image1)

With the dE/dx information from the TPC, charged particles are identified at $3 < p_T < 15$ GeV/c at mid-rapidity, and the yields of charged kaons can be extracted from a 8-Gaussian fit to the inclusive positively and negatively charged particle dE/dx distributions at given momenta [7]. Unfortunately, the experimental dE/dx value is deviated from theoretical predictions due to empirical parameters in theory, gas multiplication gains and noise of the TPC electronics, and pileup in high luminosity environment. In addition, the dominant pion yields shadowing kaon yields will induce more uncertainties for kaon. Re-calibration method [8, 9] was used to improve the precision of dE/dx in TPC here, and results in more precise yields for charged kaons by fixing re-calibrated dE/dx peak position. To correct for trigger enhancement, PYTHIA is used to generate events, and GEANT is used to select different trigger events by passing different detector thresholds as real events in STAR experiment. The trigger enhancement factor can be calculated by the spectra in triggered events divided by that in minimum bias events. Acceptance and efficiency (88%) are studied by Monte Carlo GEANT simulations. Final spectra at |η| < 0.5 are shown on the left panel of Fig. 1 which is consistent with previous published spectra in minimum bias events.

In order to cross-check if there are trigger bias in the BEMC triggered events, $K^0_S$ was reconstructed through $K^0_S \rightarrow \pi^+ \pi^-$ using V0 method [10] in different triggers, HT1 and HT2 trigger.
In this analysis, one daughter pion was required to trigger the event by depositing energy to the BEMC tower. The trigger efficiency can be extracted by comparing pion spectra from triggered events with pion spectra in the minimum bias events. After trigger efficiency for triggered daughter ($\pi$), tracking efficiency for another daughter and V0 efficiency ($\sim$ 50%) were corrected for, yields of $K_0^0$ are shown as star on the left panel of Fig. 1 and consistent with charged kaon spectra with uncertainties. The uncertainties include statistical uncertainties and systematical errors which contain trigger uncertainty ($\sim$ 10%), momentum resolution (1−20%), efficiency uncertainty (5%) and methods of getting $K_0^0$ yields ($\sim$ 1%). Some NLO pQCD calculations (AKK 2008 [11] and DSS) shown on left panel of Fig. 1 cannot describe our charged kaon and neutral kaon spectra, although they show good agreements with charged pion spectra [9]. This indicates our data can provide a good constraint for the NLO pQCD calculation.

The $K/\pi$ ratios at mid-rapidity in the BEMC triggered events from $p+p$ collisions as a function of $p_T$ are shown on right panel of Fig. 1 and compared with published results from minimum bias $p+p$ collisions [12] and some predictions from pQCD calculations (DSS and AKK 2008). All the boxes and bars on this figure represent systematic and statistic errors. Our measurements are consistent with published results from minimum bias events in $p+p$ collisions at overlapping $p_T$ range, but lower than the predictions from DSS and AKK 2008 at high $p_T$.

Left panel on the Fig. 2 shows the $K/\pi$ ratios in $p+p$ and Au+Au collisions. The enhancement of $K/\pi$ ratio in Au+Au collisions shows less suppression for kaons than pions at high $p_T$. To further understand this phenomena, $R_{AA}$ in central Au+Au collisions are shown on the right panel of Fig. 2 for kaon, pion, proton and rho [13]. We observed that $R_{AuAu}(K^\pm, K_0^0)$ is larger than $R_{AuAu}(\pi^\pm)$, which is in contradiction to the prediction from energy loss [14]. Beside, $R_{AuAu}(\pi^\pm)$ is similar to $R_{AuAu}(\rho)$. On the other hand, $R_{AuAu}(K^\pm, K_0^0)$ is consistent with the prediction with jet conversion in the hot dense medium, as shown by dashed line [14]. The same factor, scaling the lowest-order QCD jet conversion rate, applied to calculate proton $R_{AA}$ [2, 15] is used in this prediction.
3. Summary and discussion

We report charged kaon transverse momentum spectra up to 15 GeV/c, neutral kaon $p_T$ spectra up to 12 GeV/c using events triggered by the BEMC at $|\eta| < 0.5$ from $p+p$ collisions at $\sqrt{s_{NN}} = 200$ GeV. In $p+p$ collisions, the NLO pQCD calculations cannot describe our kaon spectra and over-predict kaon yields at high $p_T$, which indicates our data could provide a good constraint to FFs. At high $p_T > 6$ GeV/c, $R_{AA}(p + \bar{p}) \geq R_{AA}(K^0, K^\pm) > R_{AA}(\pi^+ + \pi^-) \approx R_{AA}(\rho^0)$. The measurements of $R_{AA}$ for kaon are consistent with jet conversion mechanism. Other mechanisms, such as parton splitting [16] might be able to explain the observation.

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