Measurements of azimuthal anisotropy for high $p_T$ charged hadrons at $\sqrt{s_{NN}} = 200\text{GeV}$ in $\text{Au}+\text{Au}$ at RHIC-PHENIX

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Abstract. The azimuthal anisotropy of particle emission is a good observable to study the property of the quark gluon plasma (QGP), from the point of view of not only its collective dynamics but also the energy loss of hard scattered partons in it. We measured charged hadron $v_2$ as a function of $p_T$ in $0.5 < p_T < 10 \text{GeV}/c$ for minimum bias and several centrality $\text{Au}+\text{Au}$ collisions at $\sqrt{s_{NN}}=200 \text{GeV}$ using the RHIC Year-2014 data, which significantly improved the statistical precision compared to the previous results. It was found that the $v_2$'s for charged hadrons are consistently above zero up to $p_T = 10 \text{GeV}/c$ over the centralities. It was also found that there is a difference in $v_2$ between charged hadrons and neutral pions for $p_T < 7 \text{GeV}/c$.

1. Introduction

It has been said that in a few microseconds after the Big Bang, there was a state called quark gluon plasma (QGP) where quarks and gluons are not bound in nucleons. In order to create the QGP and investigate its property on the ground, high energy heavy ion collisions have been utilized for decades. The relativistic heavy ion collider (RHIC) at the Brookhaven National Laboratory was constructed specifically for this purpose. RHIC succeeded to accelerate and collide the gold ions up to $\sqrt{s_{NN}} = 200 \text{GeV}$.

During the first one and half decades of its experimental running, there have been many positive results that support the successful creation of the QGP at RHIC. The results also suggest that the QGP created at RHIC is strongly coupled. Among many observables, the transverse momentum distribution ($p_T$) and the emission angle anisotropy of the high $p_T$ hadrons have been of strong interest. The partons scattered with a high $Q^2$ by the initial hard scattering lose their energies in the hot and dense medium created in the collisions, and result in a strongly suppressed yield compared to the one in the $p + p$ collisions scaled by the number of binary nucleon-nucleon collisions. The high $p_T$ hadrons are considered as leading particles of hard scattered partons, i.e., jets.

The energy loss mechanism can further be investigated in detail with the azimuthal anisotropy of the high $p_T$ hadrons. For non-central collisions, the initial collision geometry becomes an elliptic shape. In this case, the hard scattered partons will pass through the QGP by different path-lengths depending on the azimuthal angles with respect to the reaction plane. This gives different suppression strength and therefore results in a different shape of $p_T$ spectra especially
at high $p_T$ depending on the azimuthal angle. The effect will be most clearly observed in the
coefficient of the second term ($v_2$) of Fourier expansion of azimuthal distribution with respect
to the reaction plane.

In this paper, we show the latest PHENIX results on the high $p_T$ charged hadron $v_2$ in
Au+Au collisions at $\sqrt{s_{NN}}=200\text{ GeV}$ using the data taken in the RHIC Year-2014 run.

2. PHENIX detectors

The PHENIX experiment [1] at RHIC consists of four spectrometer arms (two central and two
muon arms) and a set of global detectors as shown in the left and middle panels of Fig.1. Each

central arm covers the pseudorapidity range $|\eta| \leq 0.35$ and 90 degrees in azimuth. Charged
particle tracks are reconstructed by the drift chamber (DC), and associated with the hits in the
pad chamber (PC) and the electromagnetic calorimeter (EMCal). The silicon vertex tracker
(VTX) installed in the RHIC Year-2011 run is used for further refining the track reconstruction
and collision-vertex determination. The VTX consists of the two pixel detector layers followed
by the two stripixel detector layers. The resolution of the distance of closest approach (DCA) of
the VTX is $60\mu m$ at $p_T > 2\text{ GeV}/c$ [3]. The beam beam counters (BBC) in the global detector
set are used to trigger events and determine the event centrality.

3. Analysis

The azimuthal angle distribution is expressed by the following equation:

$$\frac{dN}{d(\phi - \Psi)} \propto 1 + 2v_2 \cos [2(\phi - \Psi)],$$

where the $\phi$ is the azimuthal angle of particles, $\Psi$ is the angle of the reaction plane, and the $v_2$
is second order anisotropy parameter. In this analysis, the eventplane was determined using the
tower hits in the North and South BBC’s located at $3.1 < |\eta| < 3.9$ [2]. We used the two-subevent
method to calculate the resolution of the eventplane of the BBC as described below.

$$\text{resolution} = \sqrt{2\langle \cos[2(\Psi_{BBC, North} - \Psi_{BBC, South})]\rangle}$$
The true $v_2$ values are then obtained by the following equation:

$$v_2 = \frac{v_2^{\text{measured}}}{\text{resolution}}$$  \hspace{1cm} (3)

One of the key analysis issues in the $v_2$ measurement at high $p_T$ is to reduce background tracks and improve signal to background ratios. The main sources of the background (BG) are fake tracks produced in the DC, decay particles, and electrons from photon conversion. Of these source, the fake tracks contribute most under the high multiplicity in Au+Au collisions. The ratio of the fake tracks to genuine tracks increases as going to a higher $p_T$. We tried two different methods (so called E/p cut and DCA cut) to reduce the background. The E/p cut uses the energy measured by the EMCal (E) and the momentum (p) measured by the DC. The fake track will be measured with a certain momentum from the DC, but will be matched with an EMCal cluster that carries small or almost zero energy, resulting likely in a small E/p. Therefore, by applying E/p cut of $0.2 \leq E/p \leq 0.8$, we are able to remove most of the BG tracks. The DCA is defined as the closest distance between the collision vertex and the reconstructed track. Since the charged hadrons come from the collision vertex, the DCA should be small for a true track, while that for BG is large for a fake track. Therefore, BG can be removed by selecting the tracks with small DCAs (DCA cut). We compared the raw $v_2$ from the E/p cut and the DCA cut, and found that they give very consistent result, as shown in the right panel of Fig.1. The results presented in this paper employed the E/p cut because the statistical precision is better. The differences of $v_2$ from the two cuts are included in the systematic uncertainty of the results.

4. Results

The left panel of Fig.2 shows the charged hadron $v_2$ as a function of $p_T$ in minimum bias Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV obtained from the data collected in the RHIC Year-2014 run. It can be seen that $v_2$ is consistently above zero up to $p_T=10$ GeV/c. The result implies that the charged hadrons are fragments of hard scattered partons that suffered the energy loss in QGP, and the path-length dependent energy loss is reflected to the yield difference between in-plane and out-of-plane.

Figure 2. (left) $v_2$ of charged hadrons as a function of $p_T$ in minimum bias Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV, and (right) that in 0-10% centrality. Red points are from this work.

The right panel of Fig.2 shows the charged hadron $v_2$ in 0-10% Au+Au collisions from the same dataset. The $v_2$ for 10-20% and 20-30% central collisions are shown in the Fig.3 in the same manner. In all of the four plots, red points are from this work, pink points are neutral.
Figure 3. (left) $v_2$ of charged hadrons as a function of $p_T$ in 10-20% Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV, and (right) that in 20-30% centrality. Red points are from this work.

protons from the RHIC Year-2007 data [4], and light blue points are protons from the RHIC Year-2007 data [5]. There is a difference in $v_2$ between charged hadrons and neutral pions for $p_T < 7$ GeV/c. The difference becomes smaller as going to more peripheral collisions. The trend is qualitatively consistent with the baryon anomaly phenomena which becomes prominent as going to central collisions. If the effect of the energy loss to pions and charged hadrons were the same and the energy loss were the only mechanism to create the $v_2$, their $v_2$ would also become same. However, the hypothesis is not supported by the measurement.

5. Summary

We measured charged hadron $v_2$ as a function of $p_T$ in $0.5 < p_T < 10$ GeV/c for minimum bias and several centrality Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV using the RHIC Year-2014 data, which significantly improved the statistical precision compared to previous analyses. It was found that the $v_2$’s for charged hadrons are consistently above zero up to $p_T = 10$ GeV/c for the centralities shown in this paper. It was also found that there is a difference in $v_2$ between charged hadrons and neutral pions for $p_T < 7$ GeV/c. Four times more data from the RHIC Year-2014 run are expected compared to the samples analyzed here. They are under the process of reconstruction and will become available in the very near future. We are planning to measure $v_2$ in more peripheral collisions and perform a detailed systematic study.

References
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