Abstract

The first measurement of the $\rho^0$ - vector meson elliptic flow $v_2$ at mid-rapidity ($|y| < 0.5$) in 40 – 80 % centrality in $Au + Au$ collisions at $\sqrt{s_{NN}} = 200$ GeV from the STAR experiment at RHIC is presented. The study is through the $\pi^+\pi^-$ hadronic decay channel of $\rho^0$ which has a branching ratio of $\sim 100\%$. The analysis is being carried out in two different methods. The $v_2$ results obtained in these methods are consistent. Number of Constituent Quark (NCQ) scaling of $v_2$ of $\rho^0$ meson with respect to other hadrons at intermediate $p_T$ is observed. The $\rho^0$ $v_2$ favors NCQ = 2 scaling, supporting the coalescence being the dominant mechanism of hadronization in the intermediate $p_T$ region at RHIC.

1. Introduction

The primary aim of ultra-relativistic heavy-ion collisions is to produce and study a state of high-density nuclear matter called the Quark-Gluon Plasma (QGP). In the search of this new form of matter, penetrating probes are essential in order to gain information from the early stage of the collisions. The lifetime of the $\rho^0$ meson is about 1.3 fm/c, which is smaller than the life time of the system formed in $Au + Au$ collisions at such energy. The $\rho^0$ measured via its hadronic decay channel (branching ratio $\sim 100\%$) can be used as a sensitive tool to examine the collision dynamics in the hadronic medium through its decay and regeneration.

Elliptic flow, $v_2$, is an observable which is thought to reflect conditions from early stage of the collisions [1, 2]. In non-central heavy-ion collisions, the initial spatial anisotropy of the overlap region of the colliding nuclei is transformed into an anisotropy in momentum space through interactions among the produced particles. Systematic measurements of the $v_2$ of hadrons show that the $v_2$ scales with the number of constituent quarks in the intermediate $p_T$ region ($1.5 \leq p_T \leq 5$ GeV/c). It has been proposed that the measurement of the $v_2$ of resonances can distinguish whether the resonances were produced from
a hadronizing quark gluon plasma (QGP-mechanism) or in the hadronic final state via hadron-hadron rescattering (HG mechanism) \[3\].

2. Results

The results presented in this paper were obtained with the STAR detector \[4\] at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL), USA. The sub-detectors used in this analysis were the Time Projection Chamber (TPC), and the trigger detectors, namely Zero Degree Calorimeter (ZDC). The collision centrality was determined by charged hadron multiplicity measured in TPC within the pseudorapidity $|\eta| < 0.5$.

![Fig. 1. $\pi^+\pi^-$ invariant mass distribution after background subtraction in Au + Au collisions.](image)

**Fig. 1.** $\pi^+\pi^-$ invariant mass distribution after background subtraction in Au + Au collisions.

The $\rho^0$ yield in each $p_T$ bin was extracted from the invariant mass ($m_{inv}$) distribution of $\pi^+$ and $\pi^-$ candidates after subtraction of like-sign combinatorial background obtained from the geometric mean of the $\pi^+\pi^+$ and $\pi^-\pi^-$ invariant mass distributions in the same event. The $\pi^+\pi^-$ invariant mass distribution and the combinatorial background are normalized in the invariant mass range from 1.5 GeV/$c^2$ to 2.5 GeV/$c^2$ before subtraction. The pions were identified through their $dE/dx$ energy loss in the STAR TPC \[4\]. A typical $\pi^+\pi^-$ invariant mass distributions after background subtraction for 40 – 80% centrality and $0.6 \leq p_T < 0.8$ GeV/$c$ in Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV is shown in Fig. 1. The solid black line in Fig. 1 is the sum of all the contributions in hadronic cocktail. The $K_0$ was fit to a gaussian. The $\omega$ shape was obtained from the HIJING event generator \[5\]. The $\rho^0(770)$, the $f_0(980)$, the $f_2(1270)$ and the $\sigma^0$ were fit by relativistic Breit-Wigner functions \[6\] times the Boltzmann factor which accounts for the phase space \[7,8\] in the hadronic cocktail. In the cocktail fit, the $\rho^0$ width was fixed at 160 MeV/$c^2$. The $\sigma^0$ mass and width were fixed at 630 MeV/$c^2$ and 160 MeV/$c^2$, respectively. The temperature in the phase space was taken to be 120 MeV \[8\].

Two different techniques are being used to find out the $v_2$ of the $\rho^0$-meson. One is $v_2$ vs. invariant mass method \[9\] and the other one is $(\phi - \Psi_2)$ method \[10\]. The invariant mass method involves calculating the $v_2$ of the same-event distribution as a function of $m_{inv}$ and then fitting the resulting $v_2(m_{inv})$ distribution using a multi parameters function:
\[ v_2(m_{inv}) = v_{2S} \alpha(m_{inv}) + v_{2B}(m_{inv}) \beta(m_{inv}) \]  

where \( v_{2S} \) is the signal \( v_2 \) and \( v_{2B} \) is the background \( v_2 \). The signal \( v_{2S} \) contribution is coming from \( \rho^0, \sigma^0, \omega^0, K_S^0, f_0 \) and \( f_2 \), i.e. \( v_{2S} = v_{2\rho^0} + v_{2\sigma^0} + v_{2\omega^0} + v_{2K_S^0} + v_{2f_0} \). The background \( v_{2B} \) is calculated from the \( \pi^+\pi^- \) and \( \pi^-\pi^- \) pairs \( v_2 \). The parameters \( \alpha(m_{inv}) = S/(S+B) \) and \( \beta(m_{inv}) = B/(S+B) \) where \( S \) is the sum of all the individual particles signal in the cocktail and \( B \) is the background contribution from the \( \pi^+\pi^- \) and \( \pi^-\pi^- \) invariant mass distributions. Fig. 2 represents the \( v_2 \) (Total) as a function of invariant mass for a particular \( p_T \) bin\((p_T = 0.7 \text{ GeV/c})\). The \( v_2 \) (Total) is the total \( v_2 \) of all the \( \pi^+\pi^- \) combinations in the same event. The signal \( v_2 \) is extracted by doing a fit using Eq. (1) to the \( v_2 \) (Total) as shown in Fig. 2.

In order to compare the results obtained in the above method, we used another method to calculate the \( v_2 \) of \( \rho^0 \) which is called the standard (\( \phi - \Psi_2 \)) method and described in the reference [10]. Fig. 3 shows the \( \rho^0 \)-meson yield after background subtraction as a function of \( (\phi - \Psi_2) \). The observed \( v_2 \) is obtained from the distribution by fitting a function of the form \( dN/d\phi = P_0[1 + 2v_2 \cos(2(\phi - \Psi_2))] \). The observed \( v_2 \) parameters were corrected for the event plane resolution to get the final \( v_2 \) values. Fig. 4 shows the corrected \( v_2 \) as a function of \( p_T \). Solid closed circles are the data points obtained from the invariant mass technique whereas the open closed circles are for the standard (\( \phi - \Psi_2 \) bin) method. It is clear from the figure that the results obtained in both the techniques are consistent within the statistical error. Fig. 5 represents the comparison of \( \rho^0 \) \( v_2 \) with \( K_S^0 \) and \( \Lambda^0 \) \( v_2 \) for the same centrality class, i.e. 40 – 80\%, in \( Au + Au \) collisions. The solid circles are the data points for \( \rho^0 \) \( v_2 \) obtained from invariant mass method. The open circles are the data points for \( K_S^0 \) and open squares are for \( \Lambda^0 \). The \( K_S^0 \) and \( \Lambda^0 \) data points are taken from [11]. It is clear from Fig. 5 that the \( v_2 \) of \( \rho^0 \) is more close to the \( v_2 \) of \( K_S^0 \) than \( v_2 \) of \( \Lambda^0 \) in the region \( p_T > 1.5 \text{ GeV/c} \). In the low \( p_T \) region (\( \sim 0.3 - 1.0 \) GeV/c) \( \rho^0 \)-meson seems to deviate from the usual mass ordering.

The number of constituent quark (NCQ) scaling of \( v_2 \) of \( \rho^0 \)-vector meson in the intermediate \( p_T \) is shown in Fig. 6. The \( K_S^0 \) and \( \Lambda \) \( v_2 \) are plotted in the same figure for comparison after scaling with \( n = 2 \) and \( n = 3 \) quarks, respectively. This measurement shows that the \( \rho^0 \) \( v_2 \) scales with \( n = 2 \) quarks in the intermediate \( p_T \) range.
Fig. 4. Comparison of $\rho^0 v_2$ obtained in $v_2$ vs. invariant mass method and the standard event plane method. Only the statistical error bars were shown in the plot.

Fig. 5. $p_T$ dependence of elliptic flow ($v_2$) of $\rho^0$-meson in $Au + Au$ collisions ($40 - 80\%$ centrality). Data points of $\rho^0$ meson are from $v_2$ vs. invariant mass method. The vertical error bars represent the statistical errors.

Fig. 6. Constituent quark number scaling of elliptic flow ($v_2$) for the $\rho^0$-meson, the $K^0_s$ meson and the $\Lambda^0$ baryon in $Au + Au$ 200 GeV for $40 - 80\%$ centrality. The vertical error bars represent the statistical errors.

3. Conclusion

The $\rho^0 v_2$ is measured in $Au + Au$ collisions at 200 GeV in two different methods and the results obtained are consistent within the statistical errors. From the number of constituent quark scaling of $v_2$, it is clear that $\rho^0$-vector meson follows $n = 2$ quarks in the intermediate $p_T$ range which implies most of the $\rho^0$s are formed from the quarks coalescence.

References

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