ρ^0 - vector meson elliptic flow (v_2) in $Au + Au$ collisions at $\sqrt{s_{NN}} = 200$ GeV in STAR at RHIC

Prabhat R. Pujahari (for the STAR collaboration)

Department of Physics, Indian Institute of Technology bombay, Mumbai - India

Abstract

The first measurement of the ρ^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 ρ^0 which has a branching ratio of ~ 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 ρ^0 meson with respect to other hadrons at intermediate p_T is observed. The ρ^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 ρ^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 ρ^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 pseudo-rapidity $|\eta| < 0.5$.

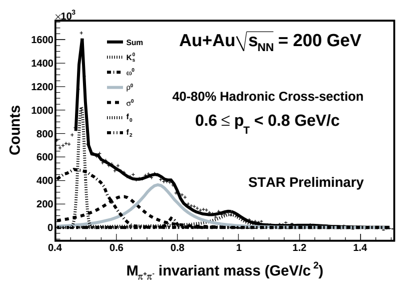

Fig. 1. $\pi^+\pi^-$ invariant mass distribution after background subtraction in $Au + Au$ collisions.

The ρ^0 yield in each p_T bin was extracted from the invariant mass (m_{inv}) distribution of π^+ and π^- 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_s^0 was fit to a gaussian. The ω shape was obtained from the HIJING event generator [5]. The $\rho^0(770)$, the $f_0(980)$, the f_2 (1270) and the σ^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 ρ^0 width was fixed at 160 MeV/c^2. The σ^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 ρ^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:

$$v_2(m_{inv}) = v_{2S}\alpha(m_{inv}) + v_{2B}(m_{inv})\beta(m_{inv}) \tag{1}$$

where v_{2S} is the signal v_2 and v_{2B} is the background v_2. The signal v_{2S} contribution is coming from ρ^0, σ^0, ω^0, K^0_S, f_0 and f_2, i.e. $v_{2S} = v_{2\rho^0} + v_{2\sigma^0} + v_{2\omega^0} + v_{2K^0_s} + v_{2f_0} + v_{2f_2}$. 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 ($p_T = 0.7$ 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.

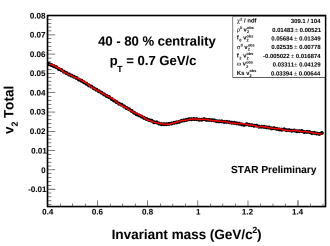

Fig. 2. The v_2 vs. invariant mass. The solid line is the result from the fitting function.

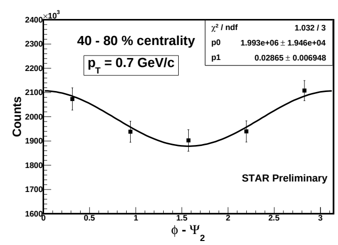

Fig. 3. The ρ^0 counts as a function of $\phi - \Psi_2$. The solid line is the result of the fitting function.

In order to compare the results obtained in the above method, we used another method to calculate the v_2 of ρ^0 which is called the standard $(\phi - \Psi_2)$ method and described in the reference [10]. Fig. 3 shows the ρ^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 ρ^0 v_2 with K^0_s and Λ^0 v_2 for the same centrality class, i.e. $40-80\%$, in $Au+Au$ collisions. The solid circles are the data points for ρ^0 v_2 obtained from invariant mass method. The open circles are the data points for K^0_s and open squares are for Λ^0. The K^0_s and Λ^0 data points are taken from [11]. It is clear from Fig. 5 that the v_2 of ρ^0 is more close to the v_2 of K^0_s than v_2 of Λ^0 in the region $p_T > 1.5$ GeV/c. In the low p_T region ($\sim 0.3-1.0$ GeV/c) ρ^0-meson seems to deviate from the usual mass ordering.

The number of constituent quark (NCQ) scaling of v_2 of ρ^0-vector meson in the intermidiate p_T is shown in Fig. 6. The K^0_S and Λ 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 ρ^0 v_2 scales with $n = 2$ quarks in the intermediate p_T range.

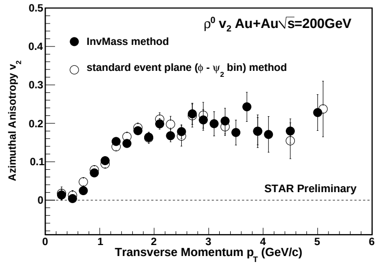

Fig. 4. Comparison of ρ^0 v_2 obtained in v_2 vs. invariant mass method and the standard event plane method. Only the statistical error bars were shown in the plot.

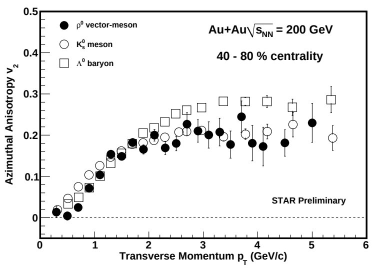

Fig. 5. p_T dependence of elliptic flow (v_2) of ρ^0-meson in $Au + Au$ collisions ($40 - 80$ % centrality). Data poins of ρ^0 meson are from v_2 vs. invariant mass method. The vertical error bars represent the statistical errors.

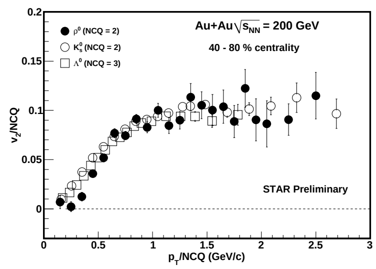

Fig. 6. Constituent quark number scaling of elliptic flow (v_2) for the ρ^0-meson, the K_s^0 meson and the Λ^0 baryon in $Au+Au$ 200 GeV for $40-80$% centrality. The vertical error bars represent the statistical errors.

3. Conclusion

The ρ^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 ρ^0-vector meson follows $n = 2$ quarks in the intermediate p_T range which implies most of the ρ^0s are formed from the quarks coalescence.

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