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Measurement of D-meson azimuthal anisotropy in Au+Au 200 GeV collisions at RHIC

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Abstract

Heavy quarks are produced through initial hard scatterings and they are affected by the hot and dense medium created in heavy-ion collisions throughout its whole evolution. Due to their heavy mass, charm quarks are expected to thermalize much more slowly than light flavor quarks. The charm quark flow is a unique tool to study the extent of thermalization of the bulk medium dominated by light quarks and gluons. At high p_T, D-meson azimuthal anisotropy is sensitive to the path length dependence of charm quark energy loss in the medium, which offers new insights into heavy quark energy loss mechanisms - gluon radiation vs. collisional processes.

We present the STAR measurement of elliptic flow (v_2) of D^0 and $D^{\pm}$ mesons in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV, for a wide transverse momentum range. These results are obtained from the data taken in the first year of physics running of the new STAR Heavy Flavor Tracker detector, which greatly improves open heavy flavor hadron measurements by the topological reconstruction of secondary decay vertices. The D-meson v_2 is finite for $p_T > 2$ GeV/c and systematically below the measurement of light particle species at the same energy. Comparison to a series of model calculations favors scenarios where charm flows with the medium and is used to infer a range for the charm diffusion coefficient $2\pi T D_s$.

Keywords: Quark-gluon plasma, elliptic flow, Heavy Flavor Tracker

1. Introduction

Heavy flavor quarks are suggested to be an excellent probe to study the strongly coupled quark-gluon plasma (sQGP) as they are produced early in heavy-ion collisions through hard scattering processes and experience the full evolution of the system, while their large masses are mostly unaffected by the QCD medium. Furthermore, drawing an analogy to Brownian motion the heavy quarks propagating through the medium are sensitive to the sQGP transport properties, for example $2\pi T D_s$, which is given in term of the temperature T and the charm diffusion coefficient D_s [1].

Recent measurements at RHIC and LHC show that high p_T charmed hadron yields in central collisions are considerably suppressed suggesting strong interactions, while the elliptic flow v_2 measured at LHC is comparable to that of light hadrons [2, 3, 4]. At RHIC the enhancement, relative to the p+p baseline, in the nuclear modification factor at intermediate p_T is suggestive of both charm flow and production via coalescence. However, charm flow inferred from measurements of semi-leptonic decays suffer from large

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uncertainties. A precise measurement of v_2 over a broad p_T range, and in particular at low momenta, will provide useful insights into the properties of sQGP medium.

2. Experimental setup

The data used in this analysis were recorded in year 2014 by the STAR experiment at the Relativistic Heavy ion Collider (RHIC) in Brookhaven National Laboratory, USA. The STAR experiment possesses full azimuthal coverage at mid-rapidity using the Time Projection Chamber (TPC) to reconstruct tracks inside a uniform 0.5 T magnetic field. The entire Heavy Flavor Tracker (HFT) micro-vertexing detector was included for the first time in 2014 and greatly improved STAR's tracking resolution, providing track pointing resolution of less than 50 μm for kaons with p_T = 750 MeV/c.
About 780 million Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV events recorded with a Minimum Bias (MB) trigger in 2014 were analyzed to reconstruct charmed hadrons. A cut on the reconstructed collision position along the beam line (| primary vertex | < 6 cm) is applied to ensure good detector acceptance.
D-mesons are reconstructed in the hadronic channels:

$$D^0(\overline{D^0}) \to K^{\mp}\pi^{\pm},\, c\tau \sim 120\,\mu m \text{ B.R. } 3.9\% \qquad D^{\pm} \to K^{\mp}2\pi^{\pm},\, c\tau \sim 300\,\mu m \text{ B.R. } 9.1\%$$

Daughter tracks are required to have a minimum of 20 hits in the TPC and hits in all three layers of the HFT, p_T > 0.6 GeV/c and pseudorapidity $|\eta| < 1$. Particle identification is done using energy loss dE/dx from the TPC, selecting candidates within 2 to 3 standard deviations from the expected value and is further enhanced by use of the Time of Flight detector(TOF) when available. $1/\beta$ is estimated from the momentum and timing from TOF, and is required to be less than 0.03 from the expected value.
Once daughter candidates have been identified, the decay vertex can be reconstructed, which is displaced from the primary vertex of collision. In the case of two body decays the decay is reconstructed at the mid point on their distance of closest approach (DCA). For three body decays, such as $D^{\pm}$, the average between the midpoints of pairwise DCA's is taken as the decay position.
The combinatorial background can be greatly suppressed by cutting on the following topological variables: decay length (distance between primary and decay vertices), DCA between daughter tracks, DCA between reconstructed parent and the primary vertex (PV), DCA between daughter tracks and the PV; and in the case of $D^{\pm}$ the distances between the midpoints from each pairwise combination.

3. Azimuthal anisotropy

Once D-meson candidates have been selected, the second order azimuthal anisotropy, v_2, is studied using two different methods: the event plane method and the two particle correlation method, which will be discussed briefly in the following paragraphs.
In the event plane method the second order event plane, Ψ, is reconstructed from TPC tracks and corrected for the non-uniform detector efficiency [5]. In order to reduce the non-flow contributions from other two or multi-body correlations, a relative pseudorapidity gap $|\Delta\eta| \leq 0.15$ around D^0 candidates is excluded from the event plane reconstruction. The azimuthal distribution of D-mesons with respect to the event plane $\phi - \Psi$ is then obtained and weighted by $1/\epsilon/R$, the inverse of the D^0 reconstruction efficiency ϵ and the event plane resolution R [6] for each centrality.
In each $\phi - \Psi$ bin the mixed-event background is scaled to the like-sign background and subtracted from the unlike-sign invariant mass spectrum. The D^0 yield is obtained by either the fit or sideband method: at low p_T the invariant mass spectrum is fitted with a Gaussian, representing the signal, and a first order polynomial describing the correlated background; for the last p_T bin (5-10 GeV/c) the fit is limited by low background statistics, and the D^0 yield is obtained by subtracting scaled counts in two invariant mass regions around the signal region.
The observed v_2^{obs} is then obtained by fitting the yield versus $\phi - \Psi$ with the functional form $A(1+2v_2^{obs}\cos(2(\phi-\Psi)))$. Finally, the observed v_2^{obs} is corrected for the average even plane resolution $< 1/R >$ to obtain the true