Global spin alignment of ϕ and K^{*0} vector mesons in Au+Au collisions from RHIC BES-II program

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Abstract. Global spin alignment is a preferential alignment of a particle's spin along the orbital angular momentum produced in heavy-ion collisions. The global spin alignment of vector mesons ($J^P = 1^-$) ϕ and K^{*0} may be sensitive to the vorticity in the medium and hadronization mechanisms. The second phase of RHIC Beam Energy Scan (BES-II) program provides higher statistics data sets for Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 7.7-19.6 GeV. From this data, we can make high precision measurements of ϕ and K^{*0} global spin alignment, allowing for more differential studies not possible with the BES-I data. We can also compare global spin alignment between ϕ and K^{*0}, where the lifetime of ϕ is roughly ten times larger than that of K^{*0} and the latter is more sensitive to hadronic re-scattering. We report high precision measurements for the global spin alignment of ϕ at $\sqrt{s_{\mathrm{NN}}}$ = 19.6 GeV from BES-II.

1 Introduction

In non-central heavy-ion collisions, a large orbital angular momentum (OAM) is generated. This OAM may preferentially align a particle's spin projection on the spin quantization axis through spin-orbit couplings, a phenomenon known as global spin alignment [1].

Preliminary results from the first phase of the RHIC Beam Energy Scan prgram (BES-I) showed a positive global spin alignment ($\rho_{00} > 1/3$) for ϕ-mesons and zero spin alignment ($\rho_{00} \sim 1/3$) for K^{*0} mesons over the $\sqrt{s_{\mathrm{NN}}}$ of 11.5 to 200 GeV for Au+Au collisions [4]. The $\sqrt{s_{\mathrm{NN}}}$ dependence of the ϕ-meson ρ_{00} can be accommodated by a theoretical model invoking a ϕ-meson mean field, which is supported by the existence of this field [4,6,7]. In these proceedings, we present the ϕ-meson global spin alignment from the BES-II Au+Au 19.6 GeV data set.

2 Analysis Details

As discussed, the global spin alignment of vector mesons is a measurement of the 00th component of the spin density matrix called ρ_{00}. This quantity can be extracted from a fit to the vector meson yield as a function of the daughter's angular distribution,

$$\frac{dN}{d(\cos\theta^*)} \propto (1 - \rho_{00}) + (3\rho_{00} - 1)\cos^2\theta^*, \tag{1}$$

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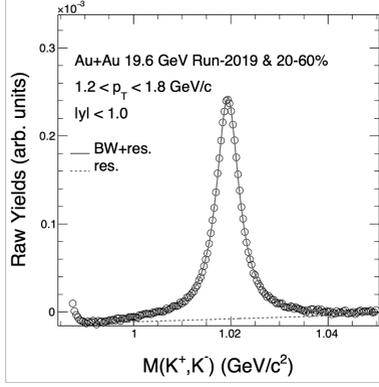
Figure 1. Invariant mass of K^+K^- pairs integrated over $\cos\theta^*$ for 20-60% central Au+Au collisions at $\sqrt{s_{NN}} = 19.6$ GeV. The solid line represents the combined fit of a Breit-Wigner and first order polynomial. The dashed lines is the first order polynomial, which is subtracted to extract the final yields.

where N is the number of ϕ-mesons and θ^* is the angle of the daughter K^+ with respect to the polarization axis in the parent's rest frame. The polarization axis is taken to be the orbital angular momentum direction, which is estimated by the normal of the second order event plane. The determination of the second order event plane in this analysis is achieved through the use of the Time Projection Chamber (TPC) at STAR. To avoid self correlation and short range non-flow contributions, we use the sub-event plane method for second order event plane reconstruction [10]. Two sub-event windows were defined $\eta_{east}(-1.0 < \eta < -0.05)$ and $\eta_{west}(0.05 < \eta < 1.0)$ with an η-gap of 0.1. The second order sub-event plane resolution achieved for mid-central collisions (20-60% centrality) was roughly 0.4. The acceptance inefficiency of the detectors in STAR leads to a non-uniform event plane distribution and we must therefore apply a recentering correction to the flow vector run-by-run for each centrality and vertex z position range [11]. After the recentering correction a shift correction is applied on an event-by-event basis to further correct for this non-uniformity [12].
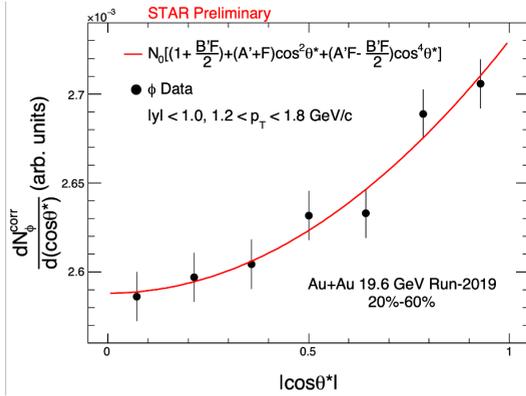
Figure 2. Efficiency corrected ϕ meson yields as a function of $\cos\theta^*$ for 20-60% central Au+Au collisions at $\sqrt{s_{NN}} = 19.6$ GeV. The red line is the fit to the data used to extract ρ_{00}, given in detail by Eqs. (2-4). Only statistical uncertainties are shown.

In addition to the efficiency correction, we need to correct for the STAR detector's finite acceptance in $|\eta|$, which can artificially contribute to the ρ_{00} signal. Also, since we are unable to know the exact reaction plane, we must therefore correct for the effect of the event plane resolution. The final fit function for the $\cos\theta^*$ dependent yields is

$$\frac{dN^{corr}}{d(\cos\theta^*)} = N_0[(1 + \frac{B'F}{2}) + (A' + F)\cos^2\theta^* + (A'F - \frac{B'F}{2})\cos^4\theta^*], \qquad (2)$$

where

$$A' = \frac{A(1 + 3R)}{4 + A(1 - R)}, B' = \frac{A(1 - R)}{4 + A(1 - R)}, \qquad (3)$$

and

$$A = \frac{3\rho_{00} - 1}{1 - \rho_{00}}. \tag{4}$$

In the above equations, N^{corr} is the efficiency corrected yield, N_0 is the normalization factor, R is the event plane resolution and F is the acceptance parameter found through STAR detector simulations. Figure 2 shows an example of ϕ-meson yield as a function of $\cos\theta^*$. Details of the acceptance and resolution corrections can be found in [5].

3 Results and Discussion

In Figure 3, we show the ϕ-meson ρ_{00} calculated for Au+Au collisions from BES-II at $\sqrt{s_{NN}}$ = 19.6 GeV in four p_T bins at 20-60% centrality. The transverse momentum integrated global spin alignment for ϕ-meson at $\sqrt{s_{NN}}$ = 19.6 GeV from BES-II mid-central collisions was measured to be ρ_{00} = 0.3622 ± 0.0026 (stat.) ± 0.0049 (sys.), which is larger than 1/3 with 5.2σ significance. Further theoretical progress is needed to understand this p_T dependence and is currently being investigated with a model invoking a ϕ-meson mean field [6,7,8].
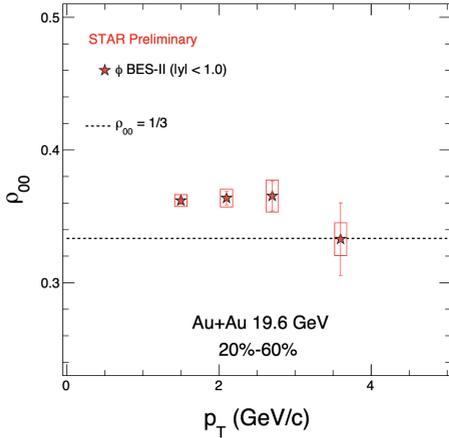
Figure 3. p_T dependent ρ_{00} for 20-60% centrality Au+Au collisions at $\sqrt{s_{NN}}$ = 19.6 GeV. The p_T dependence is currently being investigated using a ϕ-meson mean field model [8]. The vertical lines are statistical uncertainties and boxes represent systematic uncertainties.

The analysis for ρ_{00} of K^{*0} is currently ongoing for the BES-II $\sqrt{s_{NN}}$ = 19.6 GeV data set. In the BES-I results, K^{*0} was found to have no global spin alignment. This could be due to K^{*0} having a roughly 10 times smaller lifetime than that of ϕ, resulting in different in medium interactions and a different late stage hadronic reaction [9]. Additionally, the fluctuating vector meson fields for the d and $\bar{s}$ quarks are expected to be weaker than s and $\bar{s}$, leading to a negligible contribution to ρ_{00} for K^{*0} [7].

4 Conclusion

We presented results for the ϕ-meson ρ_{00} from the BES-II 19.6 GeV Au+Au data set. The measured global spin alignment is significantly positive ($\rho_{00} > 1/3$). Our precision is greatly improved by the high-statistics BES-II data sets, which contains 478 million events for $\sqrt{s_{NN}}$ = 19.6 GeV compared to 19 million in BES-I. This will allow us to perform differential studies at these energies that were previously unachievable with the BES-I data sets, such as centrality and rapidity dependent studies. These precise studies of vector meson ρ_{00} aim to further theoretical progress towards understanding of this quantity and how it can be used to probe other physical phenomena, such as spin polarization by a possible vector meson strong force field.

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