Light Vector Mesons from dAu in PHENIX

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Abstract. A first measurement of the $e^+e^-$ decay rate of $\phi$ mesons in dAu collisions from the PHENIX detector at RHIC and its comparison to the $K^+K^-$ decay channel is described. The comparison of the two decay channels can be sensitive to chiral symmetry restoration.

1. Introduction

Deconfinement is the first and most familiar manifestation of the QCD phase transition. Of equal importance is the chiral transition. The spontaneous breakdown of chiral symmetry responsible for the masses of the hadrons. The study of low mass vector mesons is an ideal probe of chiral symmetry restoration in heavy ion collisions. As an example, the lifetime of the $\phi$ is about 50 fm/c in the vacuum and a fraction of $\phi$’s produced in a heavy collision will decay in the fireball. Decays to di-leptons are particularly attractive since the daughter particles are not strongly interacting and can reach the experimental apparatus without rescattering, hence any effects such as mass shifts or broadening of spectral functions due to the onset of chiral symmetry restoration would show themselves in the invariant mass spectra. The E325 experiment at KEK [1] and CERES at CERN [2] have seen hints of such effects in both pA and AA collisions.

Because of the small Q value of the KK decay channel, a comparison of the $\phi \rightarrow KK/\phi \rightarrow ee$ rate is a particularly sensitive measure of a mass modification of either the $\phi$ or the kaon [3]. The PHENIX detector is ideally suited for such measurements in that it has good particle identification for kaons with momentum between 300 MeV/c and 2 GeV/c and electrons to 5 GeV/c, as well as good momentum resolution. All data presented in this paper are from deuteron-Gold collisions at $\sqrt{s_{NN}}=200$ GeV measured by PHENIX in 2003.

2. di-electron Analysis

About 31M single-electron triggered events were used for the electron analysis. The trigger required matching hits in the Ring Imaging Cerenkov Counter (RICH) and the Electromagnetic Calorimeter (EMC), where the threshold was set to 600 MeV. An
Electrons were identified by requiring two or more phototubes firing in the RICH and an E/p match between the energy measured by the EMC and the momentum measured by the tracking system. Specifically, we required $0.5 < E/p < 1.5$. Cuts are then made to remove electron candidates coming from conversions. The invariant mass spectrum of $e^+e^-$ pairs is then formed as shown in figure 1.

In order to form a background sample, opposite sign pairs were taken from different events. Because our sample was triggered, care was taken that the mixed event background had the same characteristics as the events themselves. In particular minimum bias events were used to form the mixed pair, where one of the electrons was required to pass the trigger requirements. Additionally, event used to form the mixed pair were required to have similar centralities and vertex positions. Normalization of the background distribution was done by matching the data to the background in a sideband region between 850 and 950 MeV below the signal and 1100-1200 MeV above the signal. Other methods of normalization were used to estimate the systematic error from this procedure.

The background subtracted signal was then fit to a relativistic Breit-Wigner convoluted with a Gaussian to account for the experimental resolution (figure 2). The width $\Gamma$ was held fixed at the particle data book value. Values obtained from the fit are shown in Table I. The value of the mass is consistent with the known value of the mass in the vacuum. In addition, the fitted experimental resolution is consistent with simulations of the detector performance. The signal was then divided into 3 bins of $M_T$, and corrections were made for acceptance and efficiencies. A fit was then done to the invariant yield resulting in the yield and inverse slope shown in the table. Major contributors to the systematic error on dN/dy are the normalization of the background and its effect on the inverse slope, and the run-by-run variations from the electron-trigger.
3. $K^+K^-$ Analysis

About 62M minimum bias events were used for the $K^+K^-$ analysis. Kaons were identified in the time-of-flight detector (TOF) which covers $\Delta \phi \approx 40^\circ$. Because of the limited coverage of the TOF, the analysis preferentially accepted higher momentum $\phi'$s as compared with the electron analysis. The invariant mass spectrum was generated by combining unlike sign pairs of kaons. The background shape was formed in a similar manner to the electrons by mixing pairs from events with similar centralities and vertices. The normalization in this case was determined by adjusting the integral of the background to $2\sqrt{N_{++}N_{--}}$ where $N_{++}$ and $N_{--}$ refer to the like sign combinations in each event. Once again the signal was fit to a relativistic Breit-Wigner convoluted with a Gaussian for the experimental resolution. Since the resolution of the $\phi$ in the KK decay channel is rather insensitive to momentum effects, we chose to hold the experimental resolution fixed to the value obtained from the simulation - 1.2 MeV. Results of the fit are shown in the table and figure 3. Both the mass and width are consistent with PDG vacuum values. For both decay channels, $\Gamma$ and $\sigma_{\text{exp}}$ are highly correlated, when they are both allowed to vary in the fit.

The data are then divided into bins of $M_T$, corrections are made for acceptance and efficiencies and a fit is done to obtain the yield. Because of the good signal to background in the KK channel, systematic errors are considerably smaller than in the electron channel. The systematic errors are dominated by the range in $M_T$ over which the fit was done, the run-by-run changes in efficiency, and the corrections due to the fiducial cuts. Figure 4 shows a comparison of the data points from both the electron and kaon analyses. The fit shown in the figure is to all of the points. When fits were done to extract yields for comparison, the fits were done separately for the electron and kaon channels. The two data samples are consistent in both the yield and the inverse slope as can be seen by looking at the comparisons in figures 5 and 6 of the extracted inverse slopes and yields.

4. Conclusions

Within the substantial errors - particularly from the electron analysis - the yields of the $\phi \rightarrow ee$ and $\phi \rightarrow KK$ are consistent with one another. Because of the small fraction which decay inside the relevant volume, the effects from chiral symmetry restoration, particularly in dAu collisions, are expected to be small. PHENIX will make further improvements to this analysis by including the data with a higher trigger threshold.
and improving systematic errors - particularly from background normalization in the electron channel. PHENIX also sees a clear $\omega \rightarrow ee$ signal, which, with a shorter lifetime than the $\phi$ will increase the number of decays in the fireball. In addition, effects in Au-Au collisions could be considerably stronger since energy densities are higher. Further in the future, upgrades to PHENIX such as the Hadron Blind Detector (HBD) will significantly enhance our capabilities to reject conversion and Dalitz pairs which are the dominant source of background. This will open up the possibility of studying the $\rho \rightarrow ee$ as well as thermal di-electrons.

<table>
<thead>
<tr>
<th></th>
<th>$\phi \rightarrow ee$</th>
<th>$\phi \rightarrow KK$</th>
<th>PDG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass ($GeV/c^2$)</td>
<td>1.0177±0.0023</td>
<td>1.0193±0.0003</td>
<td>1.01946</td>
</tr>
<tr>
<td>$\Gamma$ ($MeV/c^2$)</td>
<td>4.26(fixed)</td>
<td>4.750±0.67</td>
<td>4.26</td>
</tr>
<tr>
<td>$\sigma_{exp}$ ($MeV/c^2$)</td>
<td>8.1±2.1</td>
<td>1.2(fixed)</td>
<td></td>
</tr>
<tr>
<td>$N$</td>
<td>120</td>
<td>207</td>
<td></td>
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<tr>
<td>$dN/dy$</td>
<td>0.056±0.015±50%</td>
<td>0.0468±0.0092±0.0095</td>
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<tr>
<td>$T$ ($MeV$)</td>
<td>326±94±53%</td>
<td>414±13±23</td>
<td></td>
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</table>

**Table 1.** Results of fits to the invariant mass spectra and the yields for both the electron and kaon decay channels of the $\phi$. Statistical errors are listed first, followed by systematic errors.