Resonance studies at STAR

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We report on the observed signals of $K^{*0}(892) \rightarrow \pi K$ and $\phi(1020) \rightarrow K^+K^-$ using the mixed-event method with powerful statistics from the large acceptance and highly efficient STAR TPC. Preliminary results from the first observation of such states from the year-one STAR data in $\sqrt{s_{NN}} = 130$ GeV Au-Au collisions are presented. The $K^{*0}/h^-$ ratios with an assumed $K^{*0}p_T$ inverse slope of 300MeV are compatible with that from pp at ISR. For 14% central Au+Au collisions, we observe $K^{*0}/h^- = 0.060 \pm 0.007(stat)$ and $\bar{K}^{*0}/h^- = 0.058 \pm 0.007(stat)$. We show that $\Lambda/\Lambda = 0.77 \pm 0.07(stat)$ from this method is consistent with the measurement via decay topology.

1. Introduction

Resonance (vector meson, etc.) production and the modification to their properties by the medium are important signals of phase transition in relativistic heavy ion collisions. Leptonic decay channels of vector mesons have been extensively studied [2]. Their dominant decay branches to hadrons, however, are less extensively studied, partially due to the final state interactions of decay products, the large background from the abundantly produced hadrons ($\pi$, $K$’s) and the broad mass width. This is especially true for mesons like $\rho(770)$ and $K^{*0}(892)$ whose daughters consist of $\pi$’s and the decay widths are 130MeV and 50MeV, respectively. On the other hand, due to their short lifetime which is comparable to the lifetime of the dense matter, their measured properties may be sensitive to the lifetime of the dense matter. For example, model calculations show that the $K^{*0}/K$ ratio is sensitive to the mass modification [3] of particles in the medium and the dynamic evolution of the source. From detailed comparison of yields and $p_T$ distributions of resonances and other particles, we may be able to distinguish different freeze-out conditions [4,5].

Simulation has shown that we should be able to reconstruct these resonances with good statistics at RHIC energies through the mixed-event method because the significance of the signal rises with the square root of number of events [6]. However, other effects from flow and detector complicate the situation when the signal is less than 1% of the combinatorics. We can also apply the same mixed-event method to reconstruct lambda, l-bar, and Ks which are complementary to those from secondary vertex identification.

2. Experimental setup and data analysis

The main detector for STAR is the Time Projection Chamber (TPC) [1] allowing measurement of track multiplicity and momenta of the tracks. The Zero Degree Calorimeters (ZDC) are used to define a minimum bias trigger and an additional scintillating central trigger barrel (CTB) to select the top 14% central events [1]. In this analysis, we take advantage of STAR TPC’s large acceptance ($\approx 95\%$) and high efficiency ($\approx 85\%$) at mid-rapidity ($|y| < 0.5$) to overcome the large combinatoric background.
Data were taken in the summer of 2000 for Au+Au collisions with $\sqrt{s_{NN}} = 130$ GeV. There are 307K central and 160K minimum bias Au+Au nuclear interactions surviving the cuts described below and used in this analysis. Event vertex is required to be within $|Z| < 95 cm$ along the beam direction of the center of the TPC for uniform acceptance in the range we study. Particles are selected based on momenta measured from track curvature in the TPC at 0.25T solenoidal magnetic field, track quality and particle identification from energy loss in the TPC. The cuts used depend on the daughter particle species. Since $K\pi$ from $K^*$ and $\phi$ decays are particles originating from the interaction point, we select tracks with $DCA < 3 cm$ where DCA is the distance of closest approach to the primary vertex. For $p, \bar{p}, \pi$ from $\Lambda, \bar{\Lambda}$ with $c\tau = 7.8 cm$, we select tracks with $DCA < 7 cm$. The purity of the PID selection is good only for low momentum. For example, for $p > 0.8$ GeV/c, more than 80% of the produced particles have $dE/dx$ consistent with being a kaon. In addition, we require that pseudorapidity of the daughters $|\eta| < 0.8$ and opening angle between the daughters $\Delta \theta > 0.2$ for $K^*$ and $\Delta \theta > 0.05$ for $\phi$ and $\Lambda$.

Fig.1 and Fig.2 shows the mixed-event subtracted mass plots of $\Lambda, \bar{\Lambda}$ and $\phi$. From these distributions, we fit the $\Lambda$ and $\bar{\Lambda}$ mass peaks and calculate the $p_T$ and rapidity integrated ratio of $\bar{\Lambda}/\Lambda = 0.77 \pm 0.07(\text{stat})$ for minimum-bias events. The $p_T$ and rapidity range of the parent particle are $p_T < 2$ GeV/c and $|y| < 0.5$ in addition to the cuts on daughter particles. In this calculation, the efficiencies of $\Lambda$ and $\bar{\Lambda}$ cancel out due to the cylindrical symmetry of the TPC and its magnetic field. This result is consistent with the result of $\bar{\Lambda}/\Lambda = 0.73 \pm 0.03(\text{stat})$ from topological method. It shows that there is net strange baryon in the middle rapidity. We observe about 0.26 reconstructed $\phi$ per central event with good statistics from $\phi \rightarrow K^+K^-$ (B.R. 49.1%). Analysis on $p_T$ spectra and centrality dependence is under way.

$K^* \rightarrow K^+\pi^-$ and its antiparticle $\bar{K}^* \rightarrow K^-\pi^+$ (B.R. 67%) can be reconstructed from the charged kaons and pions. The invariant mass of every $K\pi$ pair from the same event and a pool of mixed events is calculated and entered in the same-event spectra and the mixed-event spectra separately. Usually three or more events are “mixed” with each other in same centrality bin and close in vertex position ($|\Delta Z| < 10 cm$). From the 300K 14% central events, there are more than $14 \times 10^9$ pairs of the selected kaons and pions. Substantial computation is required to calculate both same-event spectra and mixed-event spectra. The invariant mass distribution of $K^+\pi^-$ after background subtraction is shown.
in Fig. 3 for 300K 14% central events. The signal-to-background ratio before background subtraction is about 1/1000 for central events, 1/50 for peripheral Au+Au interactions and 1/4 for pp at ISR [9]. However, the important parameter of the significance of the signal is not S/N but the ratio of signal to the fluctuation in the background $S/\sqrt{N}$. We observe a 10σ $K^{*0}$ signal above the background fluctuation and the raw count of $K^{*0}$ is 2.7 per central event. Similarly, a 9σ $K^{*0}$ signal is observed above the $K^{-}\pi^{+}$ combinatoric background with the raw count of 2.6 per central event. The masses and widths are measured to be $m_{K^{*0}} = 0.893 \pm 0.003 \text{ GeV}/c^2$, $\Gamma_{K^{*0}} = 0.058 \pm 0.015 \text{ GeV}/c^2$, $m_{K^{*0}} = 0.896 \pm 0.004 \text{ GeV}/c^2$ and $\Gamma_{K^{*0}} = 0.063 \pm 0.011 \text{ GeV}/c^2$. These are consistent with the values of $m_{K^{*0}} = 0.896 \text{ GeV}/c^2$ and $\Gamma_{K^{*0}} = 0.0505 \text{ GeV}/c^2$ in the Particle Data Book [10]. Linear and exponential shapes are used to fit the residual background under the signal as shown in Fig.3. The difference is about 20% which is used to estimate the systematic errors of the measurements. In order to get the yields, we have to calculate the detector acceptance and efficiency. This is done by embedding GEANT simulated kaons and pions to the real events which then go through the full reconstruction chain [8]. The overall acceptance and efficiency factor $\epsilon$ depends on centrality, $p_T$ and rapidity of the parent and daughter particles. $\epsilon$ changes from under 20% for $p_T \approx 0$ to above 50% for $p_T \approx 2 \text{ GeV}/c$. In current studies, there is only one integrated $p_T$ and rapidity bin at each centrality from the data analysis. An inverse slope of $T = 300\text{MeV}$ and flat in rapidity are assumed for $K^{*0}$ to calculate the correction factor $\epsilon$. $\epsilon = 31\%$ for central events and increases for lower multiplicity events. However, because the efficiency increases with $p_T$, an assumed $T = 600\text{MeV}$ results in $\epsilon > 40\%$.

![Figure 3. $K^{*0}$ mass plot.](image3)

![Figure 4. $K^{*0}/h_-$ for four centrality bins.](image4)

### 3. Results and Discussion

We take $K^{*0}/h_-$ yield ratio and compare the results for different centralities and with those from pp at ISR [9] and $e^+e^-$ at LEP [11]. $h_-$ is the corrected total primary negatively charged hadrons with $|\eta| < 0.5$ and $0 < p_T < 2.0 \text{ GeV}/c$ [8]. The preliminary results as shown in Fig.4 are $(K^{*0} + \bar{K}^{*0})/2h_- = 0.058 \pm 0.01 (70\% \rightarrow 40\%)$, $(K^{*0} + \bar{K}^{*0})/2h_- = 0.085 \pm 0.01 (40\% \rightarrow 20\%)$, $\bar{K}^{*0}/h_- = 0.058 \pm 0.006$, $K^{*0}/h_- = 0.06 \pm 0.007$ (top 14%) and $K^{*0}/h_- = 0.068 \pm 0.009$ (top 5%) for four centrality bins. Errors are statistical only and the systematic errors are estimated to be about 25%. These results are to be compared
with $K^{*0}/\pi = 0.044 \pm 0.003$ from $e^+e^-$ at $\sqrt{s} = 91$ GeV and $K^{*0}/\pi = 0.057 \pm 0.009 \pm 0.009$ from pp at $\sqrt{s} = 63$ GeV. We observe that the $K^{*0}/h^-\overline{p}$ does not change much from low multiplicity to high multiplicity and is compatible to $K^{*0}/\pi$ in elementary particle collisions. It is noticed that the composition of $h^-$ has on the order of 80% $\pi^-$ and the $h^-$ per participant pair in central Au+Au has an increase of 30% from $p\overline{p}$ collision at same energies [3]. This implies about 50% increase of the $K^{*0}$ per participant pair. A better comparison could be made for $K^{*0}/K$ since they have same quark content and only differ in spins. By simple spin counting, the vector meson to meson (psuedoscalar+vector) ratio is $V/(P+V) = 0.75$. However, due to the mass difference between these two states, $V/(P+V)$ is much smaller from elementary collisions. Preliminary comparison indicates that the $K^{*0}/K$ of 0.42 $\pm$ 0.14 in central Au+Au at RHIC is between the results of $K^{*0}/K^{\pm} = 0.64(0.55) \pm 0.09 \pm 0.03$ at ISR and $K^{*0}/K = 0.32 \pm 0.02$ at LEP. The preliminary kaon results are from [3].

However, since the lifetime of $K^{*0}$ is short ($\epsilon_\tau = 4 fm$) and is comparable to the time scale of the evolution of the system, we need to take into account the surviving possibility of $K^{*0}$ when comparing the results from Au+Au with those from pp. For example, during the time $\Delta t$ between chemical freeze-out and kinetic freeze-out, the daughter $K\pi$ from $K^{*0}$ decay may rescatter and the $K^{*0}$ may not be reconstructed. A simple model simulation which assumes that a $K^{*0}$ decaying before kinetic freeze out can not be reconstructed experimentally shows that $\Delta t$ can only be on the order of a few fm with the current measured $K^{*0}/K$ ratio. The consistency of the measured masses and widths of $K^{*0}$ to the PDG values seems to indicate that there is no small angle elastic scatttering undergone by daughter kaon and pion when they emerge from the dense matter. In reality, the surviving possibility depends on $\Delta t$, source size and $p_T$ of $K^{*0}$. This may give us a unique tool to measure the time of the evolution of the system.

In conclusion, we observe $\phi(1020), K^{*0}(892), \overline{K}^{*0}(892)$ from first-year data at RHIC taken with the STAR TPC. The measured $K^{*0}/h^-$ are compared with $K^{*0}/\pi$ from pp at ISR and $e^+e^-$ at LEP. Although data indicate slight enhancement of $K^{*0}$ production per participant pair from pp to Au+Au, $K^{*0}/K$ seems to decrease from pp to Au+Au. A more detailed study including momentum distributions should be done with improved statistical and systematic precision from future Au+Au and pp runs at RHIC. We plan to measure the $p_T$ spectra of $K^{*0}$ and $\phi$ from this data set and future data sets. We will explore the feasibility of measuring many other resonances.

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