Measurement of Δ++ resonance production in d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

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Measurement of $\Delta^{++}$ resonance production in $d+Au$ collisions at $\sqrt{s_{NN}} = 200$ GeV.

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Abstract. The production of $\Delta^{++}$ resonance in $d+Au$ collisions at $\sqrt{s_{NN}} = 200$ GeV is investigated using the data taken by the STAR detector at RHIC. Systematics of $\Delta^{++}$ resonance production relative to $p$ and $\bar{p}$ yields have been studied. The nuclear modification factor $R_{CP}$, defined in terms of the ratio of $\Delta^{++}$ yields for central to peripheral data shows a rise in the intermediate $p_T$ region, in line with Cronin enhancement.

1. Introduction
Relativistic heavy ion collisions provide a unique opportunity to study nuclear matter in states of high temperature and energy density. Under these conditions, it is expected that nuclear matter would go through a phase transition from a (confined) hadronic matter to a deconfined phase or quark-gluon plasma (QGP). The study of hadronic resonances with extremely short life-times ($\sim$ few fm/c), comparable with the lifetime of the fireball source, may provide a unique tool to probe the collision dynamics.

At high temperature and density, the hadron production and the collision dynamics can be studied through the resonance decays and regeneration. In heavy ion collision a hot and dense fireball source is created. During the expansion of the fireball source, the short lived resonances and their hadronic decay daughters may undergo rescattering with other particles inside the medium, which causes signal loss and modification in the observed momentum distribution of resonances. This introduces a mass shift while reconstructing the resonance from detected daughter particles. In some cases even the resonances can not be reconstructed from rescattered daughter particles in which case the corresponding primordial resonance yields can get reduced. On the other hand, regeneration of resonances through the interaction of daughter particles with the medium can lead to enhancement over primordial resonance yields. The measurement of the resonance yield, in particular the ratio with respect to the corresponding stable particles, its mass and momentum distribution, when compared to those for $p+p$ collisions, can thus provide information about hadronization and the time evolution of source from chemical to kinetic freeze-out [1].

In this connection, it has been suggested that the properties of $\Delta$ resonances formed in heavy ion collisions may differ considerably from those of the free resonances [2, 3], possibly yielding new information about nuclear matter at high temperature and energy density. Further, it has been shown that the relative yields of resonances such as $N^*(1440)$ and $\Delta(1232)$ compared to the nucleon are smaller than that in the case of stable strange baryons [4]. This is because the
widths are much larger ($\Gamma_N \simeq 300$ MeV, $\Gamma_\Delta \simeq 120$ MeV) and the final state nucleon has a greater scattering cross section in hadronic matter than the strangeness carrying stable hadron. Therefore, it was of interest to look at the $\Delta(1232)$ state whose detection might suggest whether or not chemical and kinetic freeze-out are indeed nearly coincident.

In the present note we report some results on the above mentioned study through the production of $\Delta^{++}$ resonance in $d + Au$ data as taken by the STAR experiment. The main idea behind this analysis has been to compare the results with the corresponding $p + p$ and $Au + Au$ data taken by the same experiment earlier to understand the in-medium effects in a consistent manner.

2. Analysis

The data set used for this analysis was taken in the 2002 - 2003 RHIC run for $d + Au$ collisions at $\sqrt{s_{NN}} = 200$ GeV. The main tracking device here is the Time Projection Chamber (TPC) [5], which provides, for charged particles, both momentum information and particle identification. Through the ionization energy loss ($dE/dx$) in the TPC, charged pions and kaons are identified with momenta up to about 0.75 GeV/c while protons and anti-protons are identified with momenta up to about 1.1 GeV/c. In the STAR detector, a minimum bias trigger for $d + Au$ collisions was defined by requiring at least one beam-rapidity neutron in the Zero Degree Calorimeter in the Au beam direction, which is assigned negative pseudorapidity ($\eta$) [6]. The events with $z$-vertices within $\pm 50$ cm from the center of TPC were accepted for analysis. Centrality of the $d + Au$ collisions was determined by the uncorrected charged particle multiplicity ($N_{ch}$) within a pseudorapidity window of $-3.8 < \eta < -2.8$ as measured by the Forward Time Projection Chamber (FTPC) along the Au beam direction. The $d + Au$ events were divided into three collision centrality classes: (0 - 20)% ($N_{ch} \geq 17$), (20 - 40)% (10 $\leq N_{ch} < 17$) and (40 - 100)% ($N_{ch} < 10$) of the total inelastic cross section. In the present analysis, about 11.7M $d + Au$ minimum bias events have been used.

The $\Delta^{++}$ and $\overline{\Delta}^-$ signals were obtained by the invariant mass reconstruction from their potential daughter track combinations, substracting in both cases the combinatorial backgrounds obtained from mixed-events [7] via the decay channels $\Delta^{++}(1232) \rightarrow p\pi^+$ and $\overline{\Delta}^-(1232) \rightarrow \overline{p}\pi^-$. Fig. 1(a) shows the invariant mass distribution from the same-event pair superposed on results obtained from mixed-events. Since the $\Delta$ signal is only a small fraction ($\sim 1.5\%$) of the background in the $\Delta$ mass range one has to substract a huge combinatorial background obtained from mixed events to get the real $\Delta$ signal. Fig. 1(b) shows the invariant mass distribution after background substraction fitted to the function: $PS \times BW + RBG$ [8]. Where $BW$ is the relativistic $p$-wave Breit-Wigner function, $BW = \frac{M_{\pi p} \Gamma_{\Delta} M_0}{(M_{\pi p} - M_0)^2 + P_T^2}$, $PS$ is the Boltzmann phase space factor, $PS = \frac{M_{\pi p}}{\sqrt{M_{\pi p}^2 + P_T^2}} \times exp(-\frac{\sqrt{M_{\pi p}^2 + P_T^2}}{T_{fo}})$ and RBG is the residual Gaussian background, $RBG = exp(-\frac{1}{2}(\frac{M_0 - M_{\pi p}}{T_{fo}})^2)$. Within these parametrization, $T_{fo}$ is the temperature at which the resonance is emitted, $M_0$ is the $\Delta$ mass, $\Gamma$ is the momentum dependent $\Delta$ width, $P_T$ is the $\Delta$ transverse momentum.

From the fits to the invariant mass spectra at mid-rapidity $|y| < 0.5$ for each $P_T$ bin, the raw resonance yields were extracted for minimum bias data sample. The raw yields were then corrected for acceptance and efficiency by using the corresponding numbers from Monte-Carlo simulations. The corrected yields as mentioned above are then used to get the resonance yield $((2\pi)^{-1} dN/dy)/(2\pi T(T + m_0))exp(-((\sqrt{P_T^2 + m_0^2} - m_0)/T))$, where $dN/dy$ is the mid-rapidity yield, $T$ being the inverse slope parameter and $m_0$ is the $\Delta$
mass = 1232 MeV. From the fit, we can extract the integrated $\Delta^{++}$ yields at mid-rapidity and the inverse slope parameters $T$.

3. Results

Figure 2(b) shows the $\Delta^{--}/\Delta^{++}$ ratio for different $p_T$ bins along with the corresponding $\bar{p}/p$ ratio. It doesn’t show any significant $p_T$ dependence.

The yields $dN/dy$ for the stable charged hadrons ($\pi^\pm, K^\pm, p$ and $\bar{p}$) have also been measured in the STAR experiment for the $d+Au$ collisions at $\sqrt{s_{NN}} = 200$ GeV. Using those data on stable hadrons ($p, \bar{p}$) together with the present results one can calculate the ratio of resonance yield relative to corresponding value of $p, \bar{p}$. Figure 3(a) shows the $(\Delta^{++} + \Delta^{--})/(p + \bar{p})$ ratio as a function of corresponding mean value of uncorrected charged hadron multiplicity at midrapidity $dN_{ch}/d\eta$ for different centrality bins. In the case of the $\Delta$ resonance, $p-\pi$ total interaction cross section, which determines the regeneration effect, is comparable to the $\pi-\pi$ total interaction cross section, which determines rescattering effect [9]. The over all effect is that the observed $(\Delta^{++} + \Delta^{--})/(p + \bar{p})$ ratios are flat from peripheral $d+Au$ to central $d+Au$ collisions. In
the same figure (Fig. 3(a)) the $\Delta^{++} dN/dy$, has also been plotted as a function of number of charged hadrons for different collision centralities. It shows that, $dN/dy$ for $\Delta$ increases as we go from peripheral to central collisions.

![Figure 3](image)

**Figure 3.** (a) The $(\Delta^{++} + \Delta^{--})/(p + \bar{p})$ ratio and $dN/dy$ for $\Delta$ as a function of centrality $(dN_{ch}/d\eta)$, closed symbols are for minimum bias, (b) The $\Delta^{++}$ nuclear modification factor $R_{CP}$ as a function of $p_T$. The error bars on the data points are statistical errors.

The nuclear modification factor, as given by

$$R_{CP} = \frac{<N_{\text{central}}^{\Delta^{++}}>/d^2N_{\text{central}}/dp_Td\eta}{<N_{\text{peripheral}}^{\Delta^{++}}>/d^2N_{\text{peripheral}}/dp_Td\eta}$$

for $\Delta$ resonance has also been estimated in $d + Au$ collisions. Fig. 3(b) shows the $R_{CP}$ values between central ((0 − 20)%) and peripheral ((40 − 100)%) collisions for the $\Delta$ production as a function of $p_T$. The ratio $R_{CP}$ is seen to be lower than unity in the low $p_T$ region. It is larger than unity for $p_T > 1$ GeV/c, which shows enhancement that can be explained by Cronin effect at the intermediate $p_T$ region [11].

4. Conclusions
In this report, preiliminary STAR results on $\Delta^{++}(1232)$ resonance production at mid-rapidity in $d + Au$ collisions at $\sqrt{s_{NN}}= 200$ GeV are presented. The ratio of $\Delta^{++}$ yield to that of p and $\bar{p}$ has been found to be independent of collision centrality. This indicates regeneration may be compensating for loss in the observed yield due to rescattering of the daughter particles. $dN/dy$ of $\Delta$ is found to increase with collision centrality. The $\Delta^{--}/\Delta^{++}$ ratio has been found to be close to 0.85, independent of $p_T$. This indicates that the mid-rapidity region is not net-baryon free. In the intermediate $p_T$ region, the nuclear modification factor, $R_{CP}$, for $\Delta^{++}$ shows a rise indicating Cronin enhancement.

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