Modifications in resonance life times and cross sections in a test-particle description of off-shell processes in transport theory

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For the understanding of heavy-ion collisions semi-classical transport theory has become an indispensable tool. While former works have focused their attention more or less on the quasi-particle regime the extension of the formalism to off-shell phenomena has become a topic of growing interest in the last few years since it has been realized that the collision rates present in high energetic nucleus-nucleus collisions typically are so large that an on-shell approximation seems to be inappropriate. In addition, the resonances excited during the reaction may have large decay widths. Therefore, a representation of these states by stable particles may not be a proper approximation. The usual approach to solve a transport equation is the representation of the phase-space density by test-particles. If not only asymptotically stable states but also resonances are simulated by test-particles, one has to attribute to those 'resonance test-particles' finite life times and arbitrary invariant masses (chosen according to their spectral distribution), i.e. the generalized test-particle representation is given by $\sum_i \delta^{(3)}(\vec{x}-\vec{x}_i(t))\,\delta(p_0^2-E_i^2(t))\,\delta^{(3)}(\vec{p}-\vec{p}_i(t))$. Note that here in contrast to the quasi-particle approximation the test-particles are allowed to have arbitrary energies. The question which (in general energy- or mass-dependent) life time has to be attributed to the resonance test-particles is under present discussion. The commonly used recipe is to take the inverse of the decay width Γ of the resonance, evaluated for the respective invariant mass. Near threshold the width becomes small due to the available phase-space. Hence the life time — if identified with the inverse width — becomes large. In [1] it was suggested to rather calculate the life time from the time delay that the particles suffer which form the resonance. This time delay is given by the energy derivative of the scattering phase shift of these particles: $\tau = \partial\delta/\partial p_0$. This quantity vanishes near threshold. Hence the two expressions for the life time show a completely different behavior as functions of the invariant mass of the resonance as shown in Fig. 1 for the $\Delta(1232)$ resonance. Recently a novel approach to solve these questions has been presented [2, 3]. It has been shown there that the life time of an off-shell test-particle is indeed given by $\tau = \partial\delta/\partial p_0$. In addition, the cross section for any collision which involves an off-shell test-particle in the incoming channel is subject to an in-medium modification: the cross section has to be divided by $r = 2\sqrt{s}\Gamma\,\mathcal{A}\,(1-K)$ where Γ is the total width of the particle, $\mathcal{A}$ its spectral function and $1-K$ a renormalization factor (cf. [2, 3] for details).

To test the ideas above, we applied the BUU model in version [4] with the resonance production/absorption quenching [5]. The most sensitive observable for the Δ-resonance life time modifications turns out to be the invariant mass spectrum of the correlated proton-pion pairs.

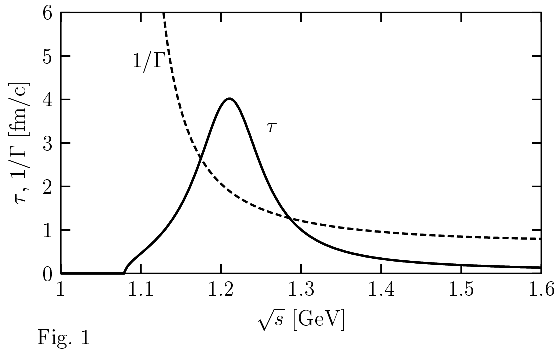

Fig. 1

Fig. 2 shows the invariant mass (p,π^+) spectra for a central Au+Au collision at 1.06 AGeV calculated without life time modifications (solid line), with modified Δ-resonance life time only (dashed line) and with both modified Δ-resonance life and $N\Delta \rightarrow NN$ cross section (dotted line). The life time modification leads to a sharper peaked spectrum at $M \simeq 1.2$ GeV due to longer life time of the Δ-resonances near the pole mass (Fig. 1). An additional modification of the $N\Delta \rightarrow NN$ cross section produces an even more sharp spectrum, since the absorption of the Δ-resonances near the pole mass gets reduced. Thus we conclude that the resonance life time modifications somewhat increase the deviation of the BUU calculation with the data [6] on the spectrum of the (p,π^+) pairs. Further studies will show if this effect could be counterbalanced by the off-shellness of the produced pions (work in progress).

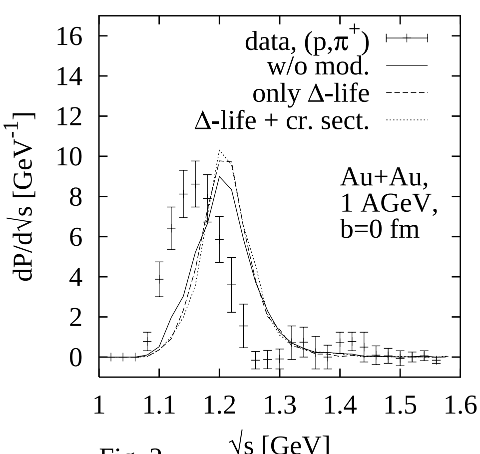

Fig. 2

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