

# Off-shell pions in the BUU transport theory

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Due to the large resonance  $\pi N$  scattering cross section a pion with momentum  $\sim 0.3$  GeV/c acquires a width in nuclear matter. The pion spectral function in nuclear matter is, therefore, different from the vacuum one. The present work is the first attempt to include the pion spectral function into the BUU transport theory.

We have calculated the pion polarization function  $\Pi_c(k)$  in isospin symmetric nuclear matter applying the  $\Delta$ -hole model (c.f. [1, 2]) with the relativistic nucleon and delta propagators [3]. The pion spectral function is defined as follows:

$$A_\pi(k) \equiv -\frac{1}{\pi} \text{Im} G(k), \quad (1)$$

where  $G(k) = (k^2 - m_\pi^2 - \Pi_c(k))^{-1}$  is the pion propagator,  $m_\pi = 0.138$  GeV is the vacuum pion mass.

The mass squared of the outgoing pion in the decay of a resonance with mass  $M_R$  has been sampled in the interval  $[0; (M_R - m_N)^2]$  according to the distribution  $\propto A_\pi(\mathbf{k}, M_\pi^2)$ . In the case of the direct (background) pion production  $NN \rightarrow NN\pi$  the value of  $M_\pi^2$  has been sampled in the interval  $[0; (\sqrt{s} - 2m_N)^2]$  using the same distribution.

The propagation of the off-shell pion between its production in the resonance decay (or in the direct process  $NN \rightarrow NN\pi$ ) and absorption in the collision with a nucleon  $\pi N \rightarrow R$  (or with two nucleons  $\pi NN \rightarrow NN$ ) has been described according to Refs. [4, 5] by introduction of an artificial scalar off-shell potential  $s_{\pi,i}$  acting on the  $i$ -th pion test particle:

$$s_{\pi,i}(\mathbf{r}_i(t), t) = \frac{M_{\pi,i}(t_{cr}) - m_\pi}{\rho_N(\mathbf{r}_i(t_{cr}), t_{cr})} \rho_N(\mathbf{r}_i(t), t), \quad (2)$$

where  $\rho_N(\mathbf{r}, t)$  is the density of nucleons in the local rest frame of nuclear matter.  $t_{cr}$  is the production time of the test particle. Thus pions are propagated by solving the Hamiltonian equations of motion with the single-particle Hamiltonian

$$H_{off-shell,i} = \sqrt{\mathbf{k}_i^2 + M_{\pi,i}^2(t)} \quad (3)$$

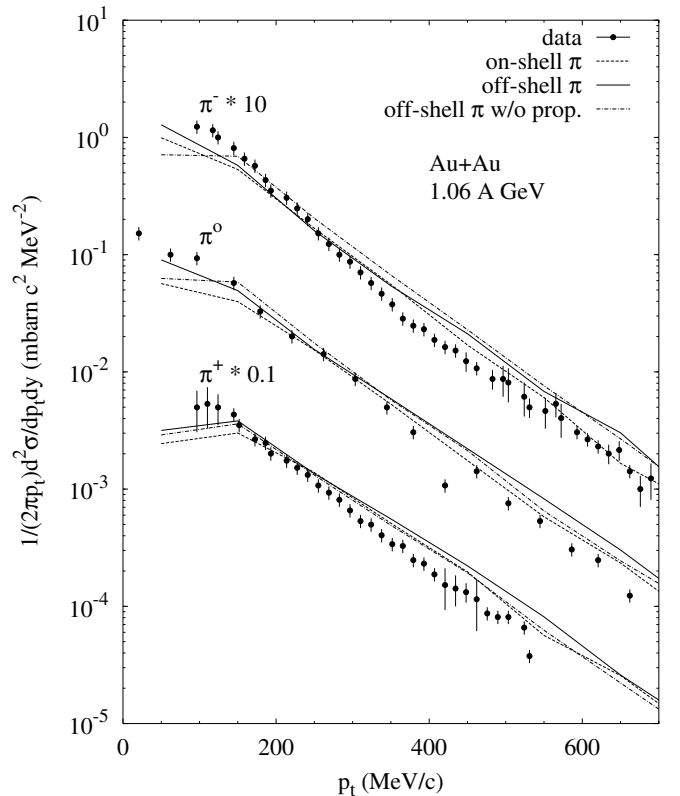
with

$$M_{\pi,i}(t) = m_\pi + s_{\pi,i}(\mathbf{r}_i(t), t). \quad (4)$$

being the mass of the  $i$ -th pion test particle. Eqs. (2),(4) provide the correct boundary condition for large times, i.e. the pions once emitted in vacuum come back to their mass shell.

In Fig. 1 we present the inclusive transverse momentum spectra at midrapidity for the system Au+Au at 1.06 A GeV in comparison with the experimental data from Refs. [6, 7]. The calculation with on-shell pions (dashed lines) describes reasonably well the high- $p_t$  part of the spectra, but underpredicts the data at low  $p_t$ . Taking into account

the pion off-shellness (solid lines) increases the low- $p_t$  pion yields improving, thus, the agreement with the data. The low- $p_t$  pion enhancement is caused by the off-shell pion propagation. To check this, we performed the BUU calculation without off-shell potential, i.e. keeping the off-shell masses of pions time independent (dash-dotted lines). We see that, indeed in this case the low- $p_t$  enhancement disappears. The effect is caused by the low mass pions ( $M_\pi < m_\pi$ ) produced by the resonance decays at early stage of the collision. These pions experience the attractive off-shell potential (2), and, therefore, they are decelerated propagating out of the dense region of the nuclear system.



## References

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