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Hadron Production in terms of Green's Functions in Non-Equilibrium Matter

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Abstract

Following the quark-hadron duality concept, we show that the number of hadrons generated in the deconfinement matter is entirely determined by the exact non-equilibrium Green's functions of partons in the medium and the vertex function governing the probability of the confinement-deconfinement phase transition. In such an approach, compactifying the standard (3+1) chromodynamics into $QCD_{xy} + QCD_{zt}$, the rate of the hadrons produced in particle collisions is derived in the explicit form provided that the hadronization is the first order phase transition. The pion production is found to be in good agreement to the experimental results on the pion yield in pp collisions.

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1 Introduction

The hadronization of the deconfined matter arising in high-energy particle collisions plays a key role in hadron production in pp, pA and AA collisions. Such a problem is however an extremely complicate to be solved in the unified approach, starting from the fundamental theory of QCD that leads to development of various models describing the hadronization of the deconfined matter, whose applicability depends essentially on the energies of colliding particles. One of them is the color flux tube approach based on the longitudinal dominance and transverse confinement. The hadron production is found to be the leading process in the hadron generation at the low and intermediate-p_T region in high-energy e^+e^- annihilations and pp collisions [1-7], where the tube arises between a quark and antiquark in e^+e^- annihilation reaction, and between the valence quarks and antiquarks in nucleon-nucleon collisions, respectively.

2 Hadron production in quark-hadron duality concept

The key assumption we follow in the derivation of hadron rate is the concept of the quark-hadron duality [8]. The central point of this concept is that partons are the same particles in the confinement and deconfinement phases of the strong interaction matter. Then, the probability of the hadronization is proportional to the projection of the state vector of partons $|q_{deconf}>$ in the deconfinement matter on the such a vector determining the parton states $|q_{conf}>$ in the confinement medium

$$\mathcal{M} =< out|in >=< \bar{q}_{deconf}|q_{conf} >, \tag{1}$$

where $|q_{deconf}>$ and $|q_{conf}>$ mean the exact dressed quark states in the corresponding matters. When the transition of the quark states is governed by some unitarian operator U

$$|q_{conf} >= U|q_{deconf} >, \tag{2}$$

then, the matrix element given by Eq.(1) is

$$\mathcal{M} =< \bar{q}_{deconf}|U|q_{deconf} >, \tag{3}$$

When $|q_{deconf}>$ describes a single quark state the squared matrix element is expressed in terms of the single particle Green's function in a non-equilibrium medium $G^{-+}(x_1, x_2)$ [9]

$$< |\mathcal{M}|^2 >= -Tr\left\{(U_2^{\dagger}\gamma^0 G_{21}^{-+})(\gamma^0 U_1 G_{12}^{-+})\right\} = Tr\left\{|\gamma^0 U_1 G_{12}^{-+})|^2\right\}, \tag{4}$$

where the trace symbol means summing with respect to all quantum number, including integration over x_1 and x_2, and averaging with respect to the deconfinement quark vacuum; the indexes denote the coordinate x and spin σ variables, $1 = (\sigma, x)$. The subscribe at U implies acting on the corresponding variable.

In the momentum representation we have the following

$$\frac{d < |\mathcal{M}|^2 >}{dp} = -Tr\left\{\int\frac{dq}{(2\pi)^8}\bar{G}^{-+}(p+q/2)\,\varrho(p+q/2, p-q/2)\,G^{-+}(p-q/2)\right\}. \tag{5}$$

where $\varrho(p+q/2, p-q/2)\,G^{-+}(p-q/2)$ is the probability to couple a quark-antiquark pair into a hadron whose 4-momentum is p.

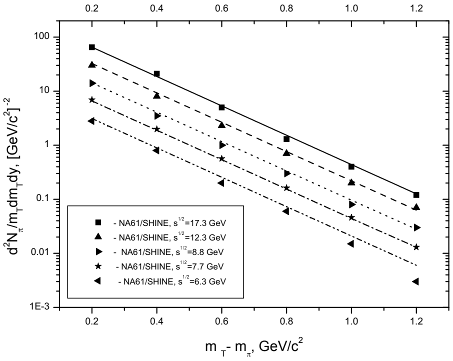
3 Hadron rate in longitudinal dominance approach

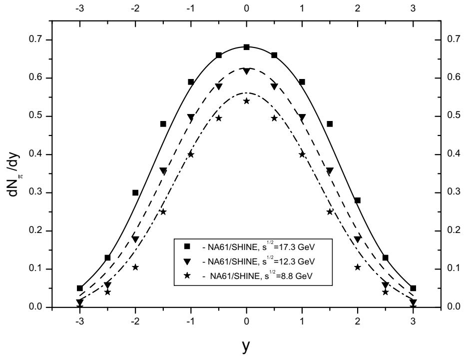
In the case of the longitudinal dominance and transverse confinement (the flux tube approximation) [7], and provided that the hadronization is the equilibrium first order transition, the hadron distribution $dN_h/dyd^2p_\perp$ with respect to the transverse momentum $p_\perp$ and rapidity y is given by a formula

$$\frac{dN_h}{dyd^2p_\perp} = \frac{< N_{ch}(s) > \exp(m_h/T)\theta(T_c - T)}{(2\pi)^{3/2}(1 + (T/m_h)) \sum\limits_{a=1}^{N} \sigma_a^{-1}} \sum_{a=1}^{N} \frac{\exp\left(-\frac{E_T}{T}\right)}{m_h T \sigma_a^2}$$
$$\left\{ \exp\left(-\frac{2(y - y_a)^2}{\sigma_a^2}\right) + \exp\left(-\frac{2(y + y_a)^2}{\sigma_a^2}\right) \right\}, \tag{6}$$

where m_h is a hadron mass, T and T_c are the matter temperature and the phase transition temperature, respectively, σ_a and y_a are the parameter characterizing the initial beams of particles, $\theta(z)$ is the unit step function. The obtained rate is assumed to be normalized by total hadron multiplicity $< N_{ch}(s) >$.

The results of the comparison of the derived hadron distribution with the experimental results on pion production in pp collisions are presented in Figs.1,2.





In Fig.1 the lines of various types are the p_T and rapidity distributions of pions coming from Eq.(6) at $T_c = 160MeV$, and are normalized by the experimental value of the pion rate at $(m_T - m_\pi) = 0.2GeV/c$, v.s. the pion rate in pp collisions [6](the scattered symbols) at the same projectile energies, where $m_T = \sqrt{p_T^2 + m_\pi^2}$, whereas m_π is the pion mass. In Fig2. the rapidity distributions coming from Eq.(6) at $\sqrt{s} = 17,3GeV$ (solid lines), $\sqrt{s} = 12,3GeV$ (dashed line), $\sqrt{s} = 8,8GeV$ (dot-dashed line), and at $T_c = 160MeV$ v.s. the rapidity distributions in pp collisions [6].

4 Conclusion

Based on the quark-hadron duality concept [8] we study the hadronization of the deconfinement matter in the case of a single quark-antiquark coupling. The hadron rate is found to be expressed in terms of the exact quark Green's functions in non-equilibrium matter and of the probability of the first-order equilibrium phase transition. Based on the QCD$_{xy}$+QCD$_{zt}$ compactification [14] we derived both the p_T and rapidity distributions of hadrons in the explicit form, provided that the hadronization is the equilibrium first-order phase transition. When hadrons are the pions generated in the proton collisions of intermediate energies, we have compared the hadron rate with the experimental results [6], and have gotten to a good relation to the experimental data for all proton energies used in the experiment.

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