Comment on "Transverse-Mass $M_\perp$ Dependence of Dilepton Emission from Preequilibrium and Quark-Gluon Plasma in High Energy Nucleus-Nucleus Collisions"

In a recent Letter [1], Geiger presents calculations of the dilepton emission from the early stage of ultrarelativistic heavy ion collisions using the parton cascade model (PCM). He shows that the $M_\perp$ scaling [2] found in Ref. [3] is not observed. In this Comment, we point out that this is largely due to a defect in the PCM.

The PCM is based on the perturbative QCD and inevitably contains two infrared cutoffs. In particular, it has the lower limit of the timelike virtuality of partons, $\mu_0 = 1$ GeV. As a result, each parton has an effective mass larger than 1 GeV. During the nuclear collision, many partons acquire large timelike virtuality and it decreases gradually to μ_0. In the PCM, once the virtuality reaches μ_0, it is kept unchanged. This is expected to happen typically by $\tau \simeq 1/\mu_0 = 0.2$ fm $\equiv \tau_{\text{cut}}$ [4], where the proper time τ is defined as $\tau = \text{sgn}(t - t_0) \times \sqrt{(t-t_0)^2 - z^2}$ [1] and in the center of mass frame, at $z = 0$, the maximum density is achieved at $\tau = 0$. In reality, the virtuality of partons continues to decrease below μ_0 as time increases according to the uncertainty principle. Therefore, the partons in the PCM have inappropriately large virtualities after $\tau \simeq \tau_{\text{cut}}$.

This unphysical virtuality drastically affects the dilepton production, especially that from $\overline{q}q$ annihilations with M comparable to $\sim 2\mu_0$ or less, where M is the invariant mass of the dilepton. A remarkable feature in Fig. 3 of Ref. [5], on which the formalism of Ref. [1] is based, is strong suppression of the dilepton yield from $\overline{q}q$ annihilations below $M \simeq 2.8$ GeV. At a glance, this might look like a nonequilibrium effect. This is, however, not the case. Note that schematic calculations of the dilepton emission from the preequilibrium stage with on-shell quarks show enhancement of the dilepton production from the $\overline{q}q$ process at small M [6]. Since this is a QED process and there is no divergence in the process, the other cutoff in the PCM, $p_{\perp\text{cut}}$, does not play a role here. This suppression is due to phase space suppression by the large effective quark mass. In this PCM calculation, there is no $\overline{q}q$ contribution below $M = 2$ GeV, whereas in conventional calculations $\overline{q}q$ annihilations dominate this region. From Fig. 3 of Ref. [5], it is natural to expect that the $\overline{q}q$ contribution would be dominant also at $M \lesssim 3$ GeV if it were not excessively suppressed by the large unphysical effective quark mass.

According to Fig. 3 of Ref. [1], most of the $M_\perp$ scaling breaking dileptons are created after $\tau = 0.5$ fm, when the PCM has too large effective quark masses. In the PCM local thermalization is achieved as early as $\tau \simeq 0.3$ fm [7] and the transverse expansion does not establish in the early stage of the collisions. Therefore, neither the preequilibrium state nor transverse expansion is the reason for the $M_\perp$ scaling breaking. It is the dileptons from the bremsstrahlung that are responsible for the $M_\perp$ scaling breaking. The bremsstrahlung contribution is dominant at small M in the PCM [5] and does not generally realize the $M_\perp$ scaling. For the $M_\perp$ scaling, the Boltzmann approximation is essential [2], in which diagrams with outgoing (anti)quarks or gluons are neglected. It cannot be used for the bremsstrahlung.

Since, as stated above, the other conditions for the $M_\perp$ scaling are approximately satisfied as early as $\tau \simeq 0.3$ fm, if the virtuality of the partons is appropriately treated and the unphysical artificial suppression of the $\overline{q}q$ process at small M is removed, the large $M_\perp$ scaling breaking obtained in Ref. [1] is expected to disappear.

In summary, the large $M_\perp$ scaling breaking reported in Ref. [1] is due to the use of the inappropriately large virtualities $\geq \mu_0$ after $\tau \simeq \tau_{\text{cut}}$ and the consequent suppression of $\overline{q}q$ annihilations at low M, and is not physical. It is not justified to use the present version of the PCM to calculate the dilepton yield and confirm the $M_\perp$ scaling in the region of $M \sim 2 - 3$ GeV.

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