FR9001191

1

LAPP-TH-226/88
July 88

RADIATIVE CORRECTIONS TO DRELL-YAN PRODUCTION IN A QUARK-GLUON PLASMA †

T.Altherr
L.A.P.P. , BP 909, 74019 Annecy-le-Vieux, France

Abstract

First order QCD corrections to the production of lepton pairs in a quark-gluon plasma at finite temperature are presented, within the real-time formalism. We show that both infrared and mass singularities cancel in the final result.

† Invited talk at the XIXth Symposium on Multiparticle Dynamics, Arles, France, June 13-17, 1988.

1) Introduction

This talk, which is about an attempt for using perturbative QCD calculation in this particular state of matter called the quark-gluon plasma, is a summary of a work presently done by three groups of people [1,2,3]. In fact, it is more than a resume in the sense that the shortest paper actually in preparation is thirty pages long, but I shall try to do it.

First, is it possible to do perturbative QCD calculation in a plasma ? For instance we know that in ultra-relativistic heavy ion collisions, which is the main domain of application of our work, the temperature achieved is roughly at most 500 Mev, which is also of the same order as the expected critical temperature for the phase transition between the hadronic matter and the quark-gluon plasma. This is not so large compared to Λ, the parameter scale of QCD, (so α_S maybe not so small) but still possible.

Now, what are we interested in ? What type of signals can we expect from the plasma in heavy ion collisions ? Many people [4] have already written a lot about it and it turns out, because the mean free path of the photon is much larger than the size of the plasma that electromagnetic signals are indeed a good signature. That means virtual or real photons. The first ones are easily detected as dileptons pairs (fig.1), $\mu^+\mu^-$ or e^+e^- in some experiments, for instance at CERN where the beam energy could be sufficient to create a plasma.

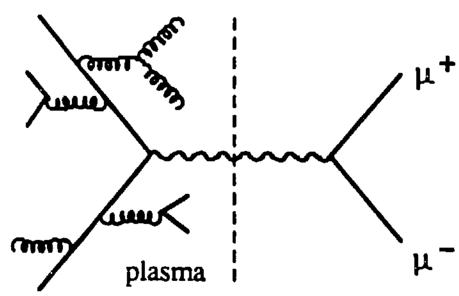

Fig.1 : Thermal process for the dilepton pair production.

So we will try the virtual photon production from the plasma (the electromagnetic current for the dilepton pair is without interest). The Born rate may be a good approximation, but we must check its validity by looking at higher orders and see if there are singularities such as $\ln m_{quark}$ because we know that such terms occur very often in perturbative QCD. Indeed, it would be cumbersome if such terms remain in the final result because there are no structure functions at finite temperature and these singularities cannot be reabsorbed. So it is very important to look at the behaviour of the perturbation series for QCD in a plasma, where the Feynman rules are a bit changed as we are going to see it now.

2) Calculation of the dilepton rate

The diagrams to be considered are shown fig.2. We have the Born rate (2.a), the virtual corrections (2.b and 2.c), and the real diagrams (2.d,2.e and 2.f) corresponding respectively to the following processes : emission of a gluon, absorption of a gluon and compton scattering of a quark (or an antiquark). Crossed diagrams are not shown. We note the presence of diagram 2.e because of the plasma.

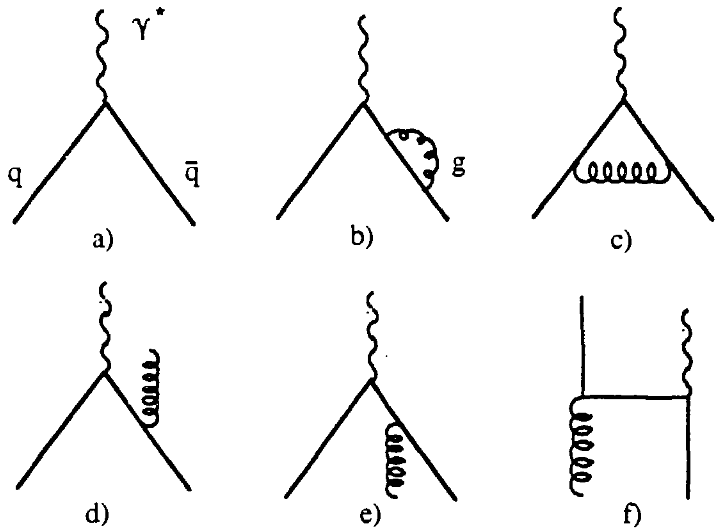

Fig.2 : diagrams for the virtual photon production in a QGP.

As we only see the photon, we have to integrate over the three other momenta, with appropriate statistical factors. Of course, the plasma is supposed to be in equilibrium (which is expected to be reached in heavy-ion collisions). Obviously, the quarks obey to the Fermi-Dirac statistic

$$n_F(E) = \frac{1}{e^{\beta(E-\mu)} + 1} \tag{1}$$

where $\beta = 1/T$, T the temperature and μ the chemical potential. While the gluon obeys to the Bose-Einstein statistic

$$n_B(k) = \frac{1}{e^{\beta k_o} - 1} \tag{2}$$

Rules for external lines are the following : take the weight $n_F/(1 - n_F)$ for an incoming/outgoing quark and $n_B/(1 + n_B)$ for an incoming/outgoing gluon. The factors for the outgoing particles are related to the Pauli blocking for fermions and to the stimulated emission for bosons.

Futhermore, we have also temperarure effects on the internal lines, that is, we must use another formalism, the Finite Temperature Quantum Field Theory on which

I have no time to dwell upon (see [5] for a review and references included). In fact there are two formalisms which can be used : the "imaginary time" formalism and the "real-time" formalism. Equivalent at the one loop level (but in the case of concern here, we are at the two loops level since we integrate over all the momenta except the one of the photon), there can be analytical problems in the "imaginary time" formalism at higher orders. Futhermore, we are obviously computing a dynamical process and the lack of a time component does not correspond to the physical picture. That are the reasons why we choosed the "real-time" formalism in which the propagators are for the fermions

$$S_F(p) = \frac{i}{\not p - m + i\eta} - 2\pi\delta(p^2 - m^2)(\not p + m)n_F(E) \tag{3}$$

and for scalar bosons

$$D(k) = \frac{i}{k^2 + i\eta} + 2\pi\delta(k^2)n_B(k) \tag{4}$$

In fact, the real-time propagator is a 2x2 matrix but I have no time to speak about this, and it turns out, though it is not at all obvious, that the first diagonal element 11 of the matrices presented above is the only relevant part (this is discussed at length in our papers).

One advantage of this formalism is that, as anyone can see, the propagators are separated between a $T = 0$ and a $T \neq 0$ piece. The statistical factors present in the $T \neq 0$ piece prevent additionnal ultraviolet divergences at finite temperature. The U.V. part comes exclusively from the $T = 0$ piece and is well known. But because of the behaviour of the Bose-Eintein factor, we have another infrared singularity which is worst than at $T = 0$. Anyway, we have to regularize our expressions and this can be done in two ways, giving a mass to the gluon [1,3] or going to n-dimensions [2].

We have of course another type of singularity, the collinear one, appearing as a $\ln m_{quark}$ which is dangerous since the quarks are supposed massless.

Now, because of lack of time and not because it has no interest, I skip completly off the many pages of calculation and I come to the

3) Results

on which the three groups agree, though the diagrams are not identical between [1] and [2,3] but the singularity structure is the same.

As I said above, the ultraviolet part is not different from the $T = 0$ case and is reabsorbed via the usual renormalization procedure.

The cancellation of the infrared singularities can be shown in a general case, with massive quarks and using anyone of the two regularization procedures. There is no infrared singularity left in the final result (this was already known a few years ago for similar processes).

The dangerous part, $\ln m_{quark}$, which is often present at $T = 0$ and, when found, must be reabsorbed in the parton structure functions, was difficult to extract. In our case [2], we choosed to take massless quarks, and in the n-dimensional regularization sheme the $\ln m_{quark}$ becomes a $1/\epsilon$ (when the dimension is $n = 4 - 2\epsilon$). We found that there is no more $1/\epsilon^2$ and $1/\epsilon$ in the final result (we can take the limit $\epsilon = 0$).

Our result can be put as

$$W = W_{Born}\left[1 + \frac{\alpha_S}{\pi} + \frac{4\alpha_S}{3\pi}F\left(\frac{Q}{T}\right) + O(\alpha_S^2)\right] \qquad (5)$$

where F represents the temperature correction. If we take the limit $T = 0$ we recover a well-known result (eq.(5) without F) which is obvious because at $T = 0$ the diagrams 2.e and 2.f are not present so this rate is related to the inverse one, $e^+e^- \rightarrow$ hadrons. The temperature dependent terms are computable, see fig.3, and there are small in the region of interest, $Q \gg T$ (Q is the mass of the Drell-Yan pair).

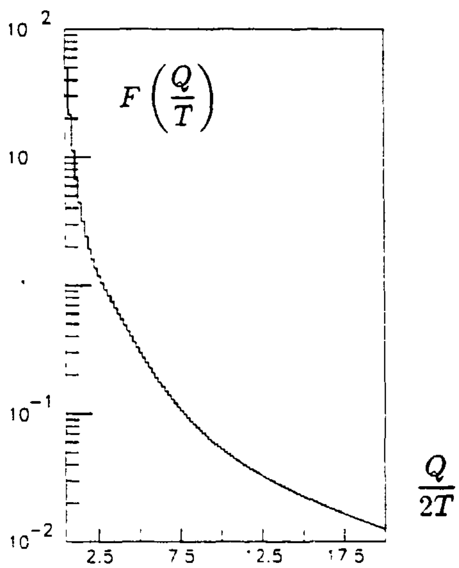

Fig.3 : Temperature dependent radiative correction.

4) Conclusion

There is a good behaviour of finite temperature QCD at first order α_S. No factorization procedure was required to deal about mass singularities as the result is completly finite (this is different from Drell-Yan at $T = 0$). This is an indication that a K.L.N. theorem [6] might exist at finite temperature, but this has to be proved to all orders !

It should be possible in the near future to predict signals coming directly from the plasma as this result seems to tell us that QCD radiative corrections are very small at finite temperature.

Questions

Author : G.Cohen-Tannoudji (Saclay)

Is it possible to account for temperature or density effects in a dependance of α_S in, say, E_T ? Since, in order to produce a ψ one has α_S^3, one would have this way a suppression of ψ at large E_T.

Answer :

The temperature effects in the running coupling constant α_S have recently been computed [7] and one finds that $\alpha_S(T,Q)$ decreases like $(Q/T)^2$ as temperature increases (Q would be here the mass of the ψ). Then one has to connect the temperature T inside the plasma with the total transverse energy E_T through the energy density and the impact parameter of the collision. But the formation of a plasma is already in itself the main phenomenum for the suppression of ψ at large E_T. α_S dependence of E_T would be higher order corrections.

Author : H.Satz (Bielefeld)

Do you conclude that the K-factor for Drell-Yan production does not change very much as the temperature is increased from zero to several MeV ?

Answer :

This is not exactly the K-factor because we work at finite temperature but could be a possible definition with temperature effects. And as you note, fisrt order corrections are small as long as Q/T is large ($Q/T > 2$).

References

[1] J.Cleymans and I.Dadic : Bielefeld preprint BI-TP 87/13, and preprint in preparation.

[2] T.Altherr, P.Aurenche and T.Becherrawy : Lapp preprint, LAPP-TH-221/88.

[3] R.Baier, B.Pire and D.Schiff : Bielefeld preprint BI-TP 88/20.

[4] L.D.Mc Lerran and T.Toimela : Phys.Rev.**D31** (1985) 545.
See also works of E.V.Shuryak, B.Sinha, K.Kajantie etc...

[5] N.P. Landsman and Ch.G. Van Weert : Phys.Rep.**145C** (1987) 141.

[6] T. Kinoshita : J.Math.Phys.**3** (1962) 650.
T.D. Lee and M. Nauenberg : Phys.Rev.**133** (1964) 1549.

[7] Y.Fujimoto and H.Yamada : Phys.Lett.**B195** (1987) 231, Phys.Lett.**B200** (1988) 167, INS preprint (april 1988).