Theoretical evaluations of probability of photons yield depending on quantum chromodynamics theory

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Abstract

Aim of this research is the description with evaluation the photons rate probability at quark-gluon reactions processes theoretically depending on quantum color theory. In high energy physics as well as quantum field theory and quantum chromodynamics theory are very importance for physical processes. In quark–gluon interaction there are many processes, the Compton scattering, annihilation pairs and quark–gluon plasma. There are many quantum features, each of three $u\bar{d}$, $u\bar{u}$ and dd systems that taken which could making a quark–gluon plasma in character system. First, electric quark charge and color quantum charge that's satisfied by quantum number. Second, the critical temperature and photon energy. Moreover, for such three systems have variety quantum flavor numbers: 2, 3 and 4, the photons rate are evaluated at system energy limited $150\,\text{MeV} \leq T \leq 350\,\text{MeV}$ with critical temperature: 144 MeV. However, due to the quark–gluon plasma producing in heavy ions collisions, the photons rate is increasing with decreasing of coupling constant and photons energy in quark-quark interaction systems.

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1. Introduction

Elementary particle physics is a field of physics that describes the basic building blocks of matter and the elementary interactions between them [1]. At the end of the 19th century, the meaning of word "atom" was indivisible, attributable to things that were in fact fully divisible [2]. The development of technology and science gives more detailed information about the matter. The elementary particles were considered as "unbreakable" components of small particles. This change of picture of the elementary particles was repeated in the history of science [3]. The idea of quarks was introduced independently in 1964 by Zweig and Gill Mann, as basic elements of hadron material. The quarks in protons and neutrons were bound due to strong nuclear forces, which is transmitted by non-charged and massless gluons particles. However, the corresponding quarks particle is an antiquark that's have same mass and spin, and opposite charge.

Quarks were founded in different six type having same spin 1/2 [4]. All particles containing quarks particle is called hadrons. Hadrons were subdivided to two groups, first is named baryons (such as the proton and neutron). Another group is called mesons, containing binding pairs of quarks and antiquarks [5].

One of theoretical approach to investigation an elementary particle in good system is the Standard Model, which has evolved in the 1970's. The basic elements of Standard Model are electroweak and quantum chromodynamics theory. It was based upon six spin 1/2. Gluons was mediated to exchange energy between quarks in the strong interaction [6]. QCD is an asymptotic free theory, that is, the coupling constant depends on the distance, and the quarks are semi-free particles at very small distances [7].

In this paper, quantum chromodynamics theory was applied to evaluate the probability of the photon yield rate of quark-gluon interaction processes $\mathbb{R}_{Q|G}$.

2. Theory

The probability of photons yield can be estimated depending on quantum chromodynamics theory according to quantum field theory that satisfies the strong force between quarks due to gluons and color charge. Probability photons rate, $\mathbb{R}_{Q|G_{1-loop}}$ is photons number of dN due to energies emitted E_γ per volume per time and momentum P and given by [8]:

$$\mathbb{R}_{Q|G_{1-loop}} = \frac{n_c C_F}{8\pi^2}\left(\sum_f Q_f^2\right)\alpha\alpha_s\, Ln\left(\frac{2.912 E_\gamma}{4\pi\alpha_s\, T}\right)T^2 e^{-\frac{E_\gamma}{T}} \tag{1}$$

Where n_c is the color quantum number, Q_f is electric charge for quark due to flavor quantum number , α is quantum electro dynamic constant:

$$\alpha \approx \frac{1}{137} \tag{2}$$

The two completely different systems of QCD are described through the coupling constant. This states that strength coupling constant was a length function or momentum scale μ [9]. It's a function of μ^2 and specified due to renormalization technique [10]:

$$\mu^2 \frac{\partial \alpha_s}{\partial \mu^2} = \beta_s \tag{3}$$

The renormalization technique depending on effective QCD coupling strength constant: $\alpha_s = g_s^2/4\pi$ was controlling on β_s function as a Taylor series [3]:

$$\beta_s = -\alpha_s\left[\beta_o\frac{\alpha_s}{4\pi} + \beta_1\left(\frac{\alpha_s}{4\pi}\right)^2 + \beta_2\left(\frac{\alpha_s}{4\pi}\right)^3 + \beta_3\left(\frac{\alpha_s}{4\pi}\right)^4 + \dots\right] \tag{4}$$

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Eq.(3) was solved as a power expansion of β_s.

$$\mu^2 \frac{\partial \alpha_s}{\partial \mu^2} = -\alpha_s^2 \frac{\beta_o}{4\pi} \tag{5}$$

By integrating; $\quad \int_{\alpha_{s(q_o^2)}}^{\alpha_s(q^2)} \frac{\partial \alpha_s}{\alpha_s^2} = -\frac{\beta_o}{4\pi} \int_{lnq_o^2}^{lnq^2} \partial(ln\mu^2) \tag{6}$

Where q2 is the momentum transfer of reaction. The result gives:

$$\frac{1}{\alpha_s(q^2)} = \frac{1}{\alpha_s(q_o^2)} + \frac{\beta_o}{4\pi} ln\frac{q^2}{q_o^2} \tag{7}$$

Then for $q^2 = \Lambda^2$:

$$\frac{1}{\alpha_s(\Lambda^2)} = 0 \quad \text{that's} \quad \alpha_s(\Lambda^2) = \infty \tag{8}$$

By inserting $\Lambda = q_o$, results of Eq. (7) is:

$$\alpha_s(q^2) = \frac{4\pi}{\beta_o ln(q^2/\Lambda^2)} \tag{9}$$

$$\text{where}^{[11]}: \quad \beta_o = \frac{11}{3} n_c - \frac{2}{3} n_f = 11 - \frac{2}{3} n_f \tag{10}$$

Where n_c is the number of colors and n_f was quark flavors quantum number.

The substituting Eq. (10) in Eq. (9) is:

$$\alpha_s(q^2) = \frac{4\pi}{(11 - \frac{2}{3} n_f) ln(q^2/\Lambda^2)} \tag{11}$$

Simply to reduce to:

$$\alpha_s(q^2) = \frac{12\pi}{(33 - 2n_f) ln(q^2/\Lambda^2)} \tag{12}$$

By using the simple mathematical treatment Eq. (12) became:

$$\alpha_s(\mu) = \frac{6\pi}{(33 - 2n_f) ln(\mu/\Lambda_{QCD})} \tag{13}$$

The cut off limited at high energy collision $T_c \approx \Lambda_{QCD}$ at $\mu \approx 8T$, then Eq. (13) as:

$$\alpha_s(T) = \frac{6\pi}{(33 - 2n_f) ln(\frac{8T}{T_c})} \tag{14}$$

T_c is critical transition temperature.

3. Results

The photonic yield rate at a quark-gluon interaction processes have been evaluated using Eq.(1) relatively to strength coupling $\alpha_s(T)$, and energy of photons E_γ using MATLAB version 7.6 (R2008a). The coupling constant $\alpha_s(T)$ as a function of T is one of the important parameters to describe and calculate the photon yield rate at quark–gluon plasma. Its evaluated using Eq. (14). Result of $\alpha_s(T)$ indicate the strong force features; asymptotic freedom and confinement. The scale Λ_{QCD} is roughly 200 MeV [12], [13] the same scale as the pion mass [14] with the experimental values of $\alpha_s(T)$ that summarized and given in table (1) and figure (1) for $u\bar{u}, u\bar{d}$ and $dd,$ quark systems.

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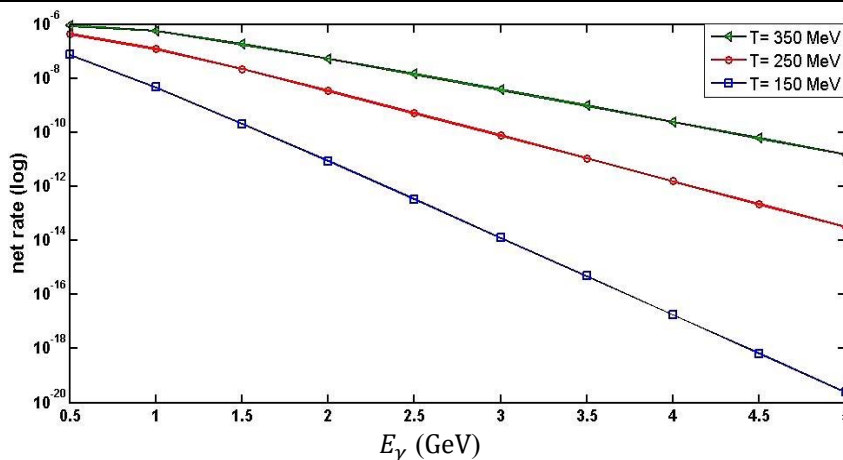**http://www.ihsciconf.org/conf/**
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Table (1): Data result of coupling constant $\alpha_s(T)$ due to quantum flavors numbers.

n_f	$\alpha_s(T)\ GeV$								
	T= 350 MeV			T= 250 MeV			T= 150 MeV		
	$T_c=$ 144 MeV	$T_c=$ 170 MeV	$T_c=$ 200 MeV	$T_c=$ 144 MeV	$T_c=$ 170 MeV	$T_c=$ 200 MeV	$T_c=$ 144 MeV	$T_c=$ 170 MeV	$T_c=$ 200 MeV
2	0.219	0.232	0.246	0.247	0.264	0.282	0.307	0.333	0.363
3	0.235	0.249	0.265	0.265	0.283	0.303	0.329	0.357	0.390
4	0.254	0.269	0.286	0.287	0.306	0.327	0.356	0.386	0.421

The probability of rate of photon yield $\mathbb{R}_{Q|G}$ at quark-gluon interaction system. $\mathbb{R}_{Q|G}$ has been calculated according to Eq.(1) with photons energy limited range $0.5\text{GeV} \leq E_\gamma \leq 5\text{GeV}$ [15] for $u\bar{u}, u\bar{d}$ and dd systems respectively have n_f = 2, 3 and 4. Results are summarized in tables (2 to 4) and figures (1 to 3) for three temperatures: T = 150 ,250 and 350 MeV and transition temperature T_c= 144 MeV.

Table (2): Rate of photon yields for $N_f = 2$ as annihilation process; $u\bar{u} \rightarrow \gamma g$.

E_γ (GeV)	$\mathbb{R}_{Q|G}$		
	T= 350 MeV $\alpha_s = 0.2190 GeV$	T= 250 MeV $\alpha_s = 0.2470 GeV$	T= 150 MeV $\alpha_s = 0.3065\ GeV$
0.5	8.57×10^{-7}	4.27×10^{-7}	7.41×10^{-8}
1	5.56×10^{-7}	1.22×10^{-7}	4.64×10^{-9}
1.5	1.82×10^{-7}	2.16×10^{-8}	2.07×10^{-10}
2	5.21×10^{-8}	3.41×10^{-9}	8.45×10^{-12}
2.5	1.40×10^{-8}	5.14×10^{-10}	3.30×10^{-13}
3	3.67×10^{-9}	7.52×10^{-11}	1.26×10^{-14}
3.5	9.41×10^{-10}	1.08×10^{-11}	4.77×10^{-16}
4	2.38×10^{-10}	1.54×10^{-12}	1.78×10^{-17}
4.5	5.98×10^{-11}	2.17×10^{-13}	6.60×10^{-19}
5	1.49×10^{-11}	3.05×10^{-14}	2.43×10^{-20}

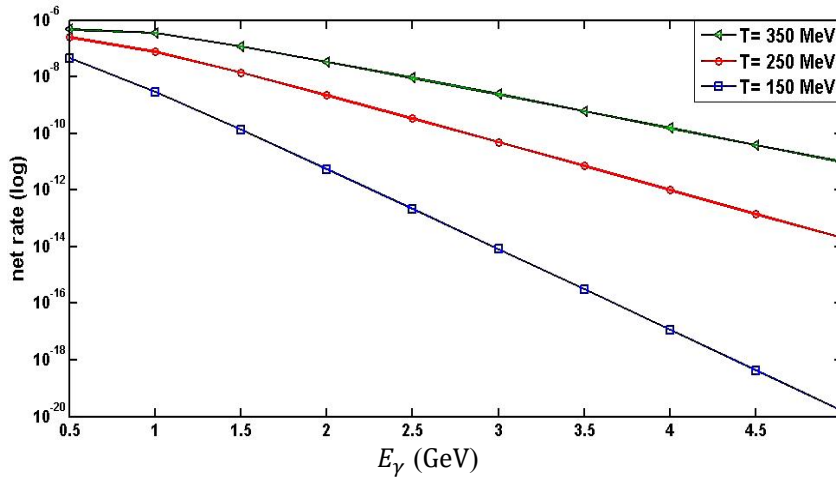

Figure (1): Net rate as a function of E_γ for $u\bar{u} \rightarrow \gamma g$.

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Table (3): Rate of photon yields for $N_f = 3$ as annihilation process; $u\bar{d} \rightarrow \gamma g$.

| E_γ (GeV)	$\Gamma_\gamma(\alpha_s, T) \frac{1}{GeV^2 fm^4}$		
	$T= 350$ MeV $\alpha_s = 0.2352\ GeV$	$T= 250$ MeV $\alpha_s = 0.2653\ GeV$	$T= 150$ MeV $\alpha_s = 0.3292 GeV$
0.5	4.74×10^{-7}	2.53×10^{-7}	4.58×10^{-8}
1	3.49×10^{-7}	7.75×10^{-8}	2.97×10^{-9}
1.5	1.16×10^{-7}	1.39×10^{-8}	1.34×10^{-10}
2	3.35×10^{-8}	2.21×10^{-9}	5.49×10^{-12}
2.5	9.09×10^{-9}	3.34×10^{-10}	2.15×10^{-13}
3	2.38×10^{-9}	4.90×10^{-11}	8.27×10^{-15}
3.5	6.12×10^{-10}	7.07×10^{-12}	3.12×10^{-16}
4	1.55×10^{-10}	1.00×10^{-12}	1.16×10^{-17}
4.5	3.90×10^{-11}	1.42×10^{-13}	4.33×10^{-19}
5	9.75×10^{-12}	2.00×10^{-14}	1.59×10^{-20}

Figure (2): Net rate as a function of E_γ for $u\bar{d} \rightarrow \gamma g$.

Table (4): Rate of photon yields for $N_f = 4$ as bremsstrahlung process; $dd \rightarrow \gamma qq$.

E_γ (GeV)	$\Gamma_\gamma(\alpha_s, T) \frac{1}{GeV^2 fm^4}$		
	$T= 350$ MeV $\alpha_s = 0.2540\ GeV$	$T= 250$ MeV $\alpha_s = 0.2865\ GeV$	$T= 150$ MeV $\alpha_s = 0.3556\ GeV$
0.5	1.57×10^{-7}	9.42×10^{-8}	1.80×10^{-8}
1	1.39×10^{-7}	3.14×10^{-8}	1.22×10^{-9}
1.5	4.77×10^{-8}	5.73×10^{-9}	5.57×10^{-11}
2	1.38×10^{-8}	9.18×10^{-10}	2.29×10^{-12}
2.5	3.77×10^{-9}	1.39×10^{-10}	9.03×10^{-14}
3	9.92×10^{-10}	2.04×10^{-11}	3.46×10^{-15}
3.5	2.55×10^{-10}	2.96×10^{-12}	1.31×10^{-16}
4	6.50×10^{-11}	4.22×10^{-13}	4.91×10^{-18}
4.5	1.63×10^{-11}	5.98×10^{-14}	1.82×10^{-19}
5	4.09×10^{-12}	8.41×10^{-15}	6.73×10^{-21}

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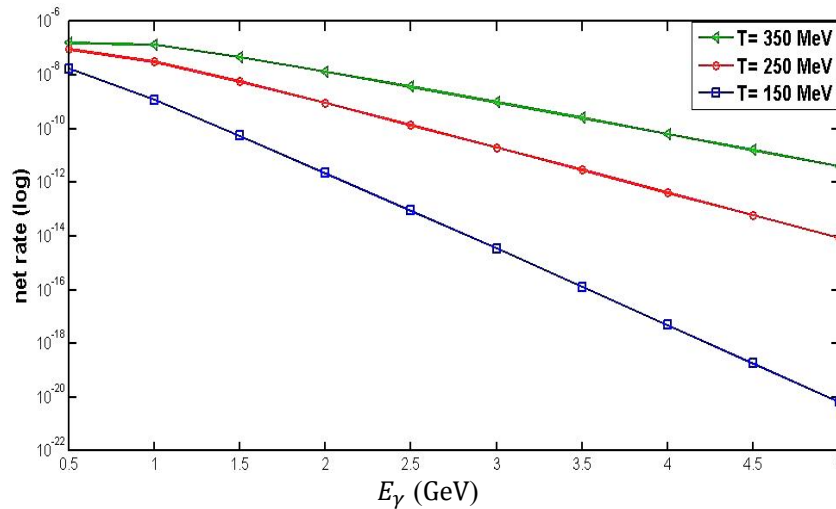
Figure (3): Net rate as a function of E_γ for $dd \rightarrow \gamma qq$.

4. Discussion

The probability of photon yield at quark-gluon system provides valuable information on the structure of protons and neutrons. It occurs at high energy at the overlap of the wave functions for initial wave vector state system and final (outgoing) wave vector state system. The estimation of coupling constant enables us to calculate the photon yield rate. It is calculated according to renormalization scale theory dependence on the effective QCD coupling constant $\alpha_s = g_s^2/4\pi$. These calculations can describe the behaviour of the system at asymptotic freedom or confinement.

At such high energy; the proton beam can be regarded as a bundle of quarks and gluons. Therefore, quark-quark, quark-gluon and gluon-gluon collisions take place, which are very useful for study QCD. The quarks and gluons are able to move freely inside the created medium; thus, forming a QGP, if only for a short time. Scientists are looking for insights into the properties of QGP through the study of particles emitted from a collision. It was thought that QGP would behave much like a weak interacting plasma of an atomic substance [16].

The quarks interaction due to gluon mediator explains the nuclear strong force. Its indicate both behavior of quarks QCD asymptotic freedom and quarks confinement at long distances.

Since the photonic rate values increasing at system have least strength constant $\alpha_s(T)$ and photonic rate decreases when increasing of $\alpha_s(T)$, this indicates that system having small coupling strength is more reactive towards emitting photon than other system have large strength coupling and photon yield rate occurs actively with less strength coupling system.

Results in tables 2 to 4 show that the rates of photon yield are increasing at decreasing of $\alpha_s(T)$ with increasing T and vice versa.

This refers that strength coupling is weakly at high energy at short distance and the quarks behave asymptotic freedom, and more photons emission to increases photonic rate. This rate could be trace back to $T^2 e^{-E_\gamma/T}$.

Other factors could be effected on $\mathbb{R}_{Q|G}$ at all system is photonic energies E_γ. From previous results we could show the photonic rate increases when decreases the photonic energies E_γ, this indicate that photonic yield rate less at large energy of emitting photon, and vice versa.

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Furthermore, $\alpha_s(T)$, temperature and the photon energy E_γ are the base of photon yield rate in quark-gluon system. Data of the photon rate depend on these parameters and enable us to understand the idea of the behaviour of the photon rate.

5. Conclusions

According to the present data that have been discussed above; several conclusions could be listed as:

- Photonic rate yield at quark-gluon system has enabled us to elaborate and test the quantum chromodynamics theory.
- The coupling constant $\alpha_s(T)$ of the system should be affected on the   probabilities of rate of photon yield $\mathbb{R}_{Q|G}$ at quark-gluon system, and $\mathbb{R}_{Q|G}$ is large for system with least $\alpha_s(T)$ and increasing due to $\alpha_s(T)$.decreasing.
- Photonic rate was proportional inversely with temperature at asymptotic separation and the resolution energy of gamma; in the other word, the rates of photons are increase when $\alpha_s(T)$ decrease due to increases of temperature T.
- $\alpha_s(T)$ at system have high flavor number n_f is greater than system have small flavor number.
- The fact that strength coupling was large, is related to the small energy, that means when $\alpha_s(T)$ is large, this makes perturbative calculations impossible, or at least very difficult.

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