PHENOMENAOLOGICAL MODELING OF ELECTROMAGNETIC EMISSION IN UTRA-RELATIVISTIC HEAVY-ION COLLISION

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OUTLINE

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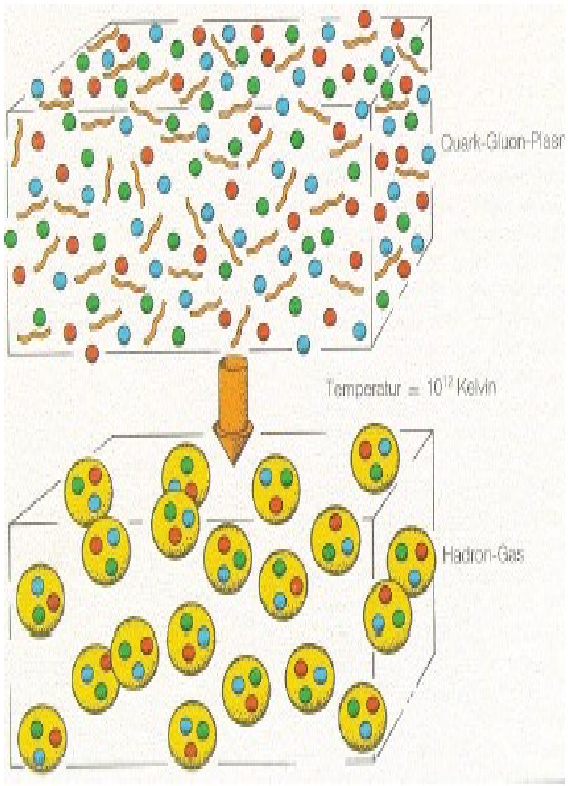
Quark-Gluon Plasma

A new phase of matter called the Quark Gluon Plasma (QGP)

QGP : ***a (locally) thermally equilibrated state of matter in which quarks and gluons are deconfined from hadrons, so that color degrees of freedom become manifest over nuclear, rather than merely nucleonic, volumes.***

What is the QGP?



Heating QCD in a Box

$\alpha_S \to \alpha_S(T) << 1$ for $T >> \Lambda_{QCD}$

Asymptotic Freedom => Deconfined quarks and gluons at high T

Quantum Chromo Dynamics

$V(r) \sim \alpha_s(Q)/r + \sigma r$

Small r (large Q): $\alpha_s(Q^2) \rightarrow 0$,

quarks & gluons are weakly interacting at high energies.

quarks behave as free particles:

Asymptotic Freedom.

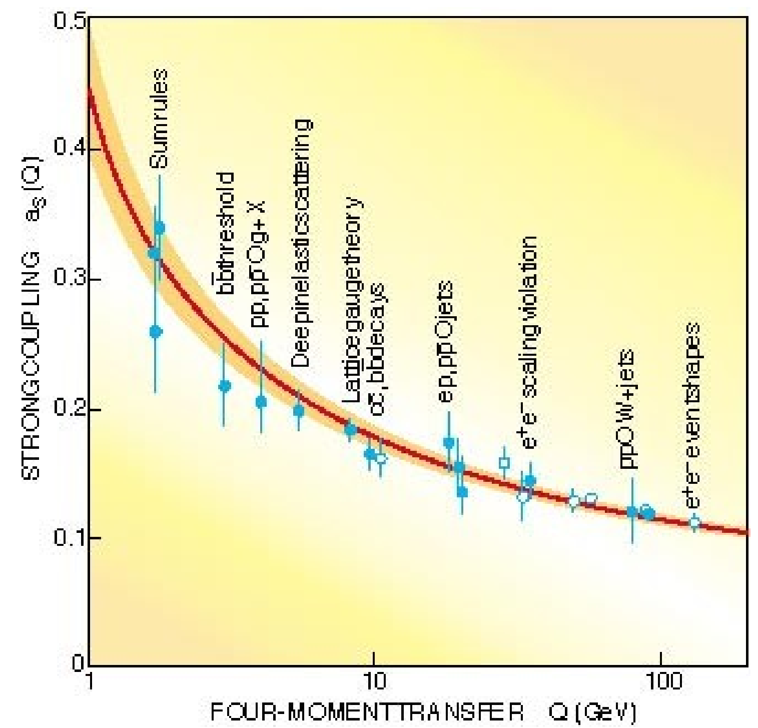
Large r (small Q):

the second term goes to infinity;

No Free Quarks or Gluons.

Hence, non-perturbative QCD can be useful tool in this domain

Color Confinement.



$$a_s(Q^2) \approx \frac{4}{(33 - 2n_f)\ln\left(1 + Q^2/\Lambda^2_{QCD}\right)}$$

Achieved via quarks in 3 colours and 8 type of gluons all of which carry colour charge.

Basic model for heavy-ion collisions

Statistical Model

Transport Model

Hydrodynamical Model

Motivation

>An important objective of CERN & BNL is to explore the phase diagram of quark matter in various region of temperature & baryon density .

>There are many models for creation of QGP formation. A fully relativistic framework is used for calculating the photon production of leading order process from quark-gluon plasma (QGP) using phenomenological parameter.

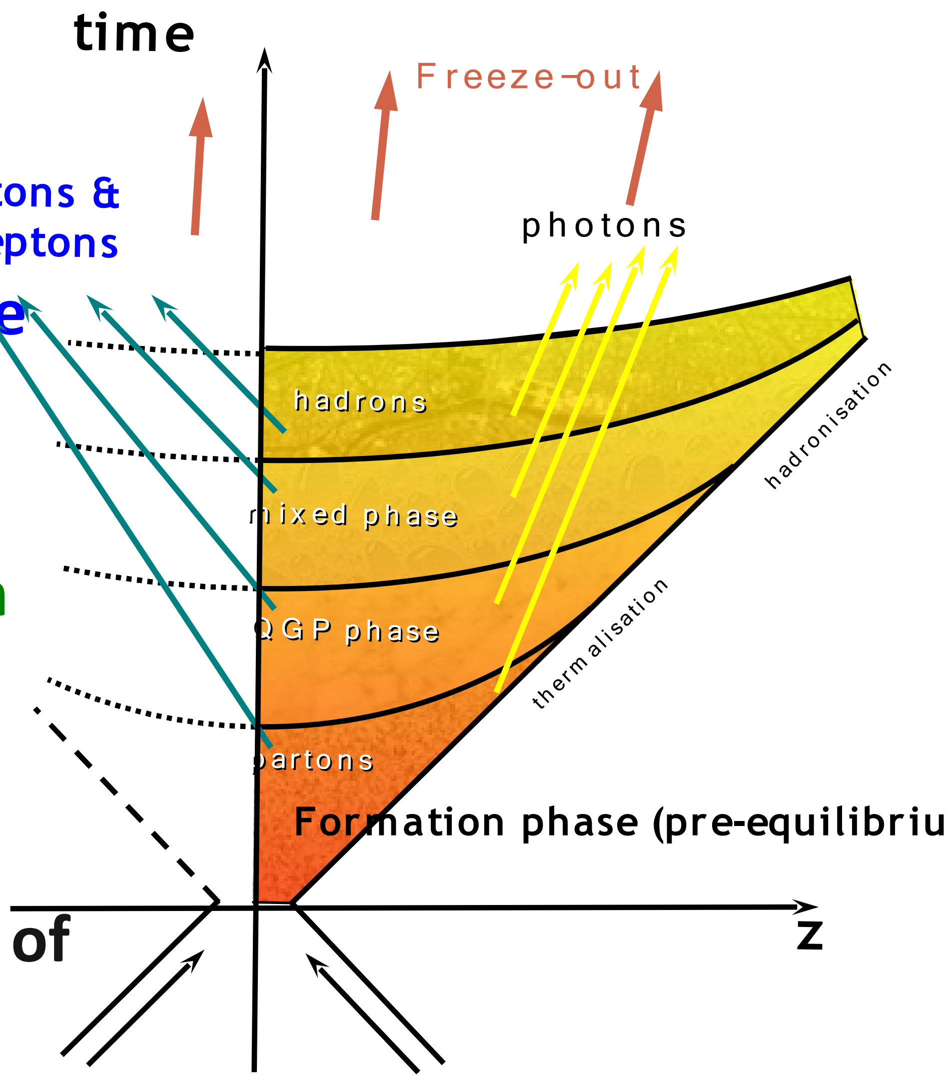
>A phenomenological parameters of quark and gluon are used in quark mass with the variation of quark chemical potential

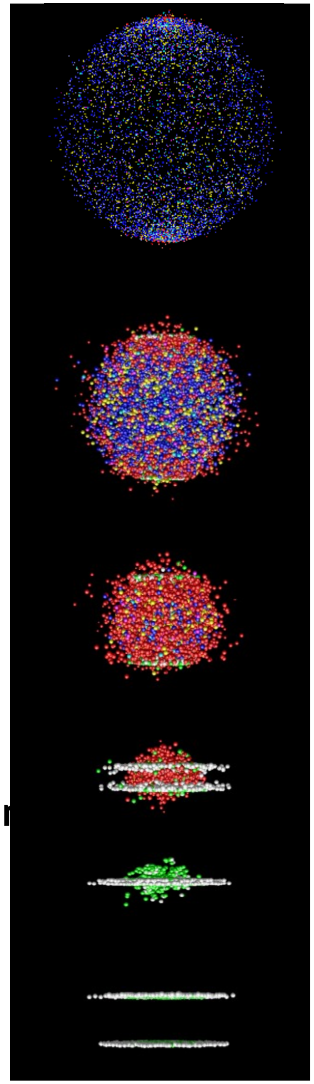
>The model has its merits in its simplicity and robustness to give a qualitative and quantitative idea to show the production rate from QGP.

Electromagnetic radiations

Why studying electromagnetic radiations ?

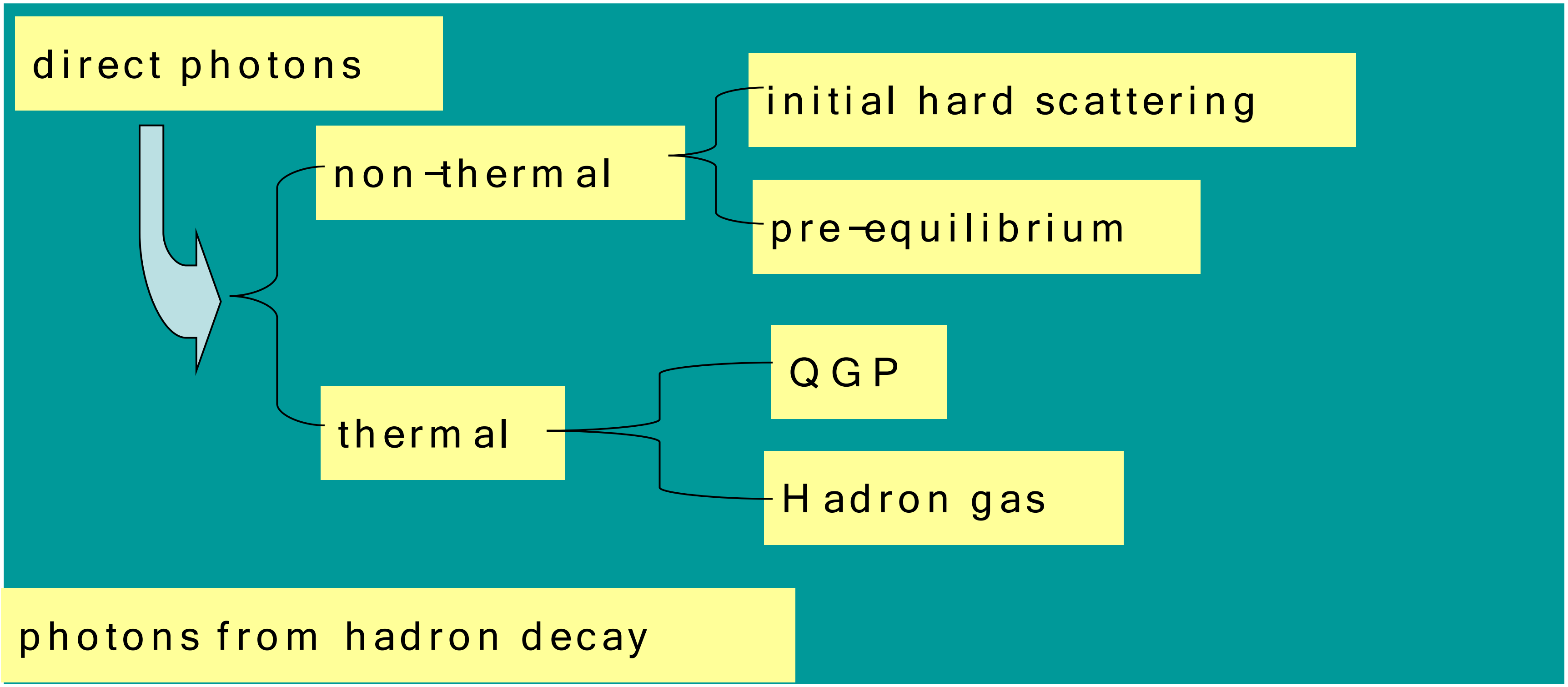
- **Electromagnetic probes do not interact strongly**
- **Suffer little or no final state interaction**
- **Give access to the hot and dense phase of the reaction**
- **Carry information of the system at the time of their production**
- **Shine through for all times of the fireball evolution.**





Direct photons

- Direct photon is a unique probe, which provides direct information of its birth, because of penetrating property.
- Photons can come from every stage of collisions, and can have various origins.



Observables depending on the thermodynamics of the phases

Electromagnetic radiations from QGP:

Photons are not a very clean signature of QGP due to massive pollution from lots of sources and small production rate, but still useful as a supplement and for extracting information directly from the collision zone.

(The mean free path of photons in nuclear matter is about 600 fm. So about 98% of the photons leave the zone of reaction without interacting)

Overall these probes play interesting
and
important roles in diagonising the QGP state

A simple phenomenological model uses as quasiparticle in which mass is dependent on temperature and parametrization factors. Due to the thermal interactions among the quarks and/or gluons, the mass of there particle generated and shows well behaviour above the critical temperature.

The finite quark mass is defined as :

$$m_q^2 = \gamma'_{q,g} g^2(p) T^2$$

Singh & Kumar et al.
IJMPA 29 (2014) 1450110
IJMPA 30 (2015) 1550020

Where $\gamma'_{q,g}$ is the phenomenological paprameter of quarks and gluons, p is the quarks (gluons) momentum and g(p) is first order QCD running coupling constant.

In this model, the finite value of quark chemical potential is used through the phenomenological parameters of quarks. γ_g is the phenomenological parameter used to take care the hydrodynamics of the hot QGP. The parameter γ'_q is taken by modifying the earlier value of γ_q. We replace γ'_q as :

$$\gamma'_q = \gamma_q \left[1 + \frac{\mu_q^2}{\pi^2 T^2} \right]$$

Gosain et al
Pram J. Phys 78 (2012) 719

On the other hand, there is no change in the gluon parameter and put it remain same as the erlier one i.e. γ'_g as γ_g. The value of is fixed as 1/3 given in the Gosain et al.

The first order QCD running coupling constant is given as :

$$g^2(p) = \frac{N}{\ln\left(1 + \frac{p^2}{\Lambda^2}\right)}$$

Ramanathan et al. PRC 70 (2004) 027903
Kumar et al. CJP 90 (2012) 955

Here Λ is the QCD parameter and N is $\left(\frac{4}{3}\right)\left(\frac{12\pi}{33-2nf}\right)$

The momentum is defined as :

$$p = \left(\frac{\gamma N^{\frac{1}{3}} T^2 \Lambda^2}{2}\right)^{\frac{1}{4}}$$

The parametrization factor $\gamma^{2} = 2\left[\frac{1}{\gamma_{q}^{2}} + \frac{1}{\gamma_{g}^{2}}\right]$ is used because they nicely fit into our calculatios.

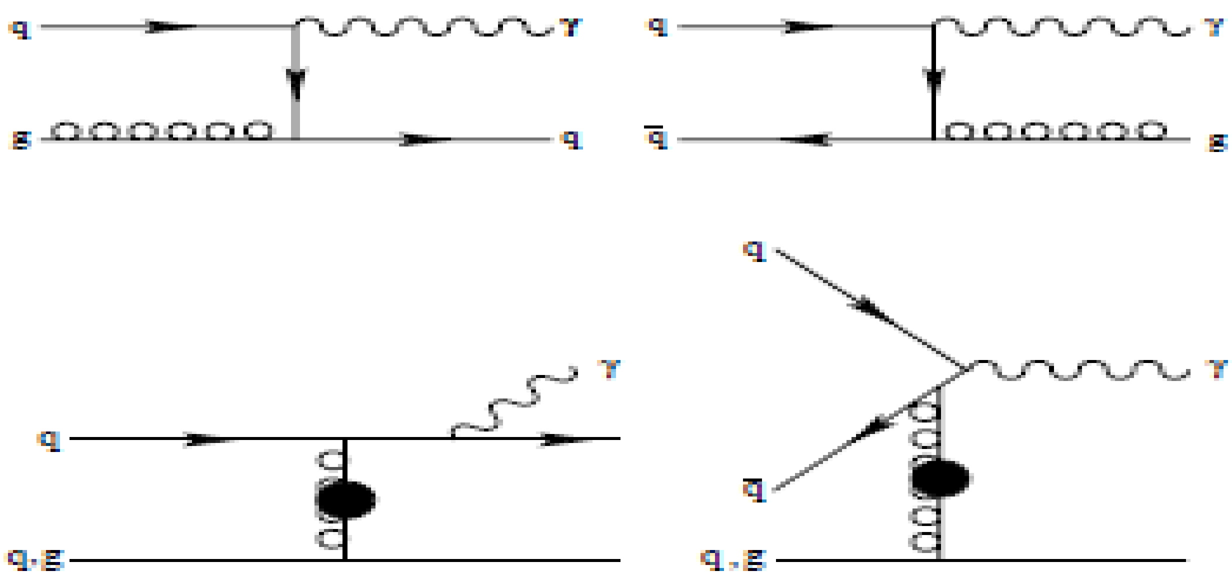
Fix the range of y_q as $\gamma_{q} = 2\gamma_{g} to 8\gamma_{g}$ **and** $\gamma_{g} = \frac{1}{3}$

Refer : Gosain et al. PJP 78 (2012) 719

The value of quark mass removes the infrared divergence produced in photon production. We compute the thermal photon emission from quark-gluon plasma of complete leading order results as temperature T=0.35 GeV with the various value of quark chemical potential for two quark flavors.

Photons emission

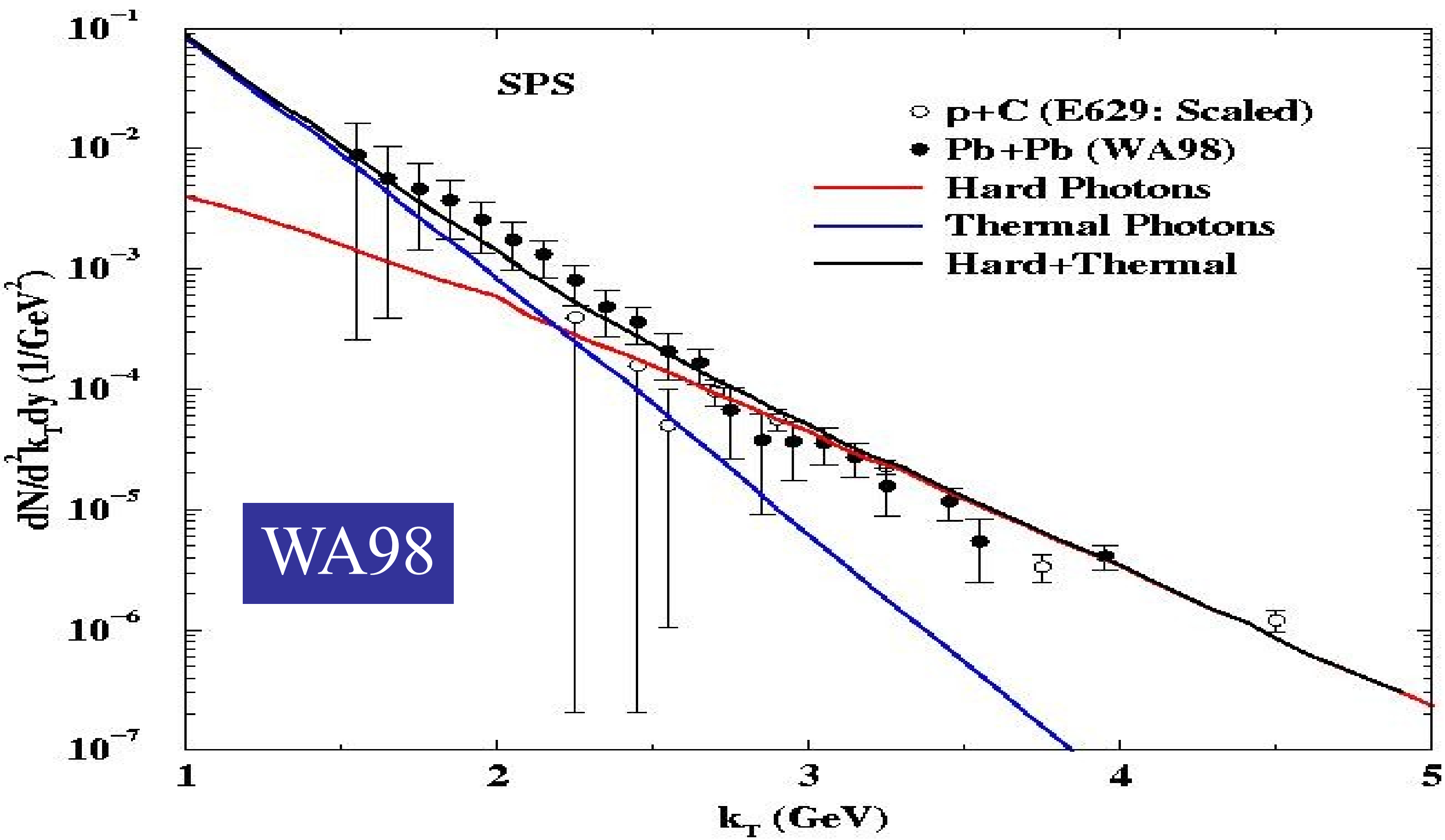
Photons in the QGP-phase are mainly produced via the following processes:



Leading order processes for photon production in the QGP (from left to right): QCD Compton scattering, $q\bar{q}$ annihilation, Bremsstrahlung (bremss), and annihilation with scattering (aws).

Direct Photon Spectra

photon spectra at SPS/CERN



Photon from SPS data cannot distinguish between hadronic and QGP initial states. The picture would be more clear at RHIC/LHC.

The photon emission rate from Comp + Ann. processes has been calculated from the imaginary part of the photon self-energy by Kapusta et al. in the 1-loop approximation. However, it has been shown by Auranche et al. that the two loop contribution is of the same order as the one loop due to the shielding of infra-red singularities.The complete calculation upto two loop is expressed as :

$$\frac{dN}{d^3p\,d^4x} = \frac{1}{(2\pi)^3} A(p) \left[\ln\left(\frac{T}{m_q} \right) + \frac{1}{2} \ln\left(\frac{2E}{T} \right) + C_{tot}\left(\frac{E}{T} \right) \right]$$

Refer : Arnold et al . JHEP 0112 (2001) 009 ; Renk et al. PRC 67 (2003) 064901

With E=p and m_q^2 is the leading order large momentum limit of the quark mass.

The leading log coefficient A(p) is given as :

$$A(p) = 6\alpha\,{}_e\sum_f e_f^2 \frac{m_q^2}{E} f_D(E)$$

The dependence on the specific photon production process is written in the term C_{tot}(E/T),

$$C_{tot}\left(\frac{E}{T}\right) = C_{2\leftrightarrow 2}\left(\frac{E}{T}\right) + C_{bremss}\left(\frac{E}{T}\right) + C_{aws}\left(\frac{E}{T}\right)$$

The C_{tot}(E/T) is the non-trivial function that can only be solved numerically. The results of C_{tot}(E/T) is taken by Arnold and Renk et al.

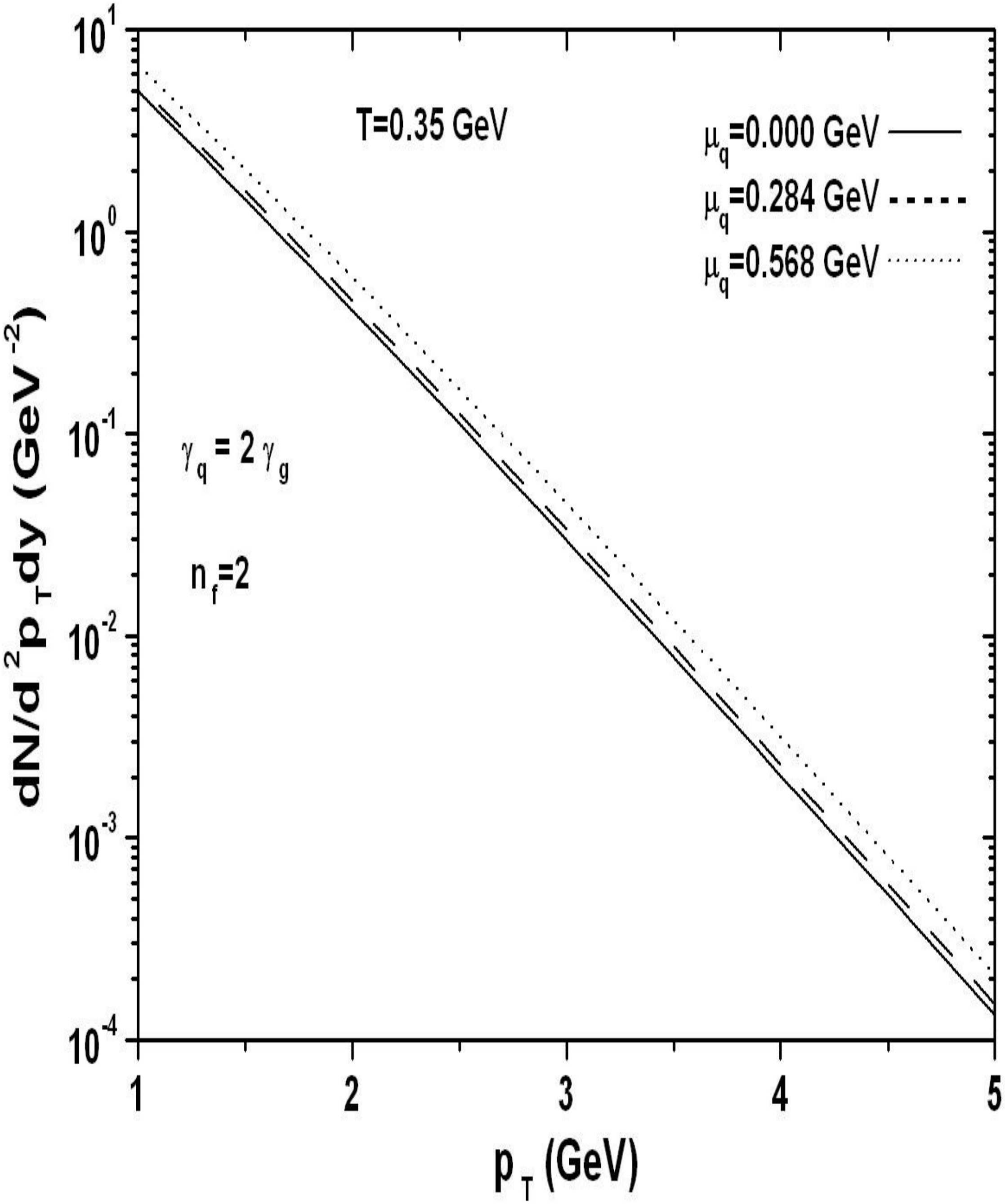
The total photon spectrum is studied above the critical temperature by integrating the total rate over the space-time history of the collision for all the leading order processes after getting the trmperature of evolution from the model. It is expressed as :

$$\frac{dN}{d^2p_T dy} = \int d^4x \left(E\frac{dN}{d^3p d^4x} \right) = Q\int_{\tau_i}^{\tau_f} \tau\, d\tau \int_{-y_{nuc}}^{+y_{nuc}} dy \left(E\frac{dN}{d^3p d^4x} \right)$$

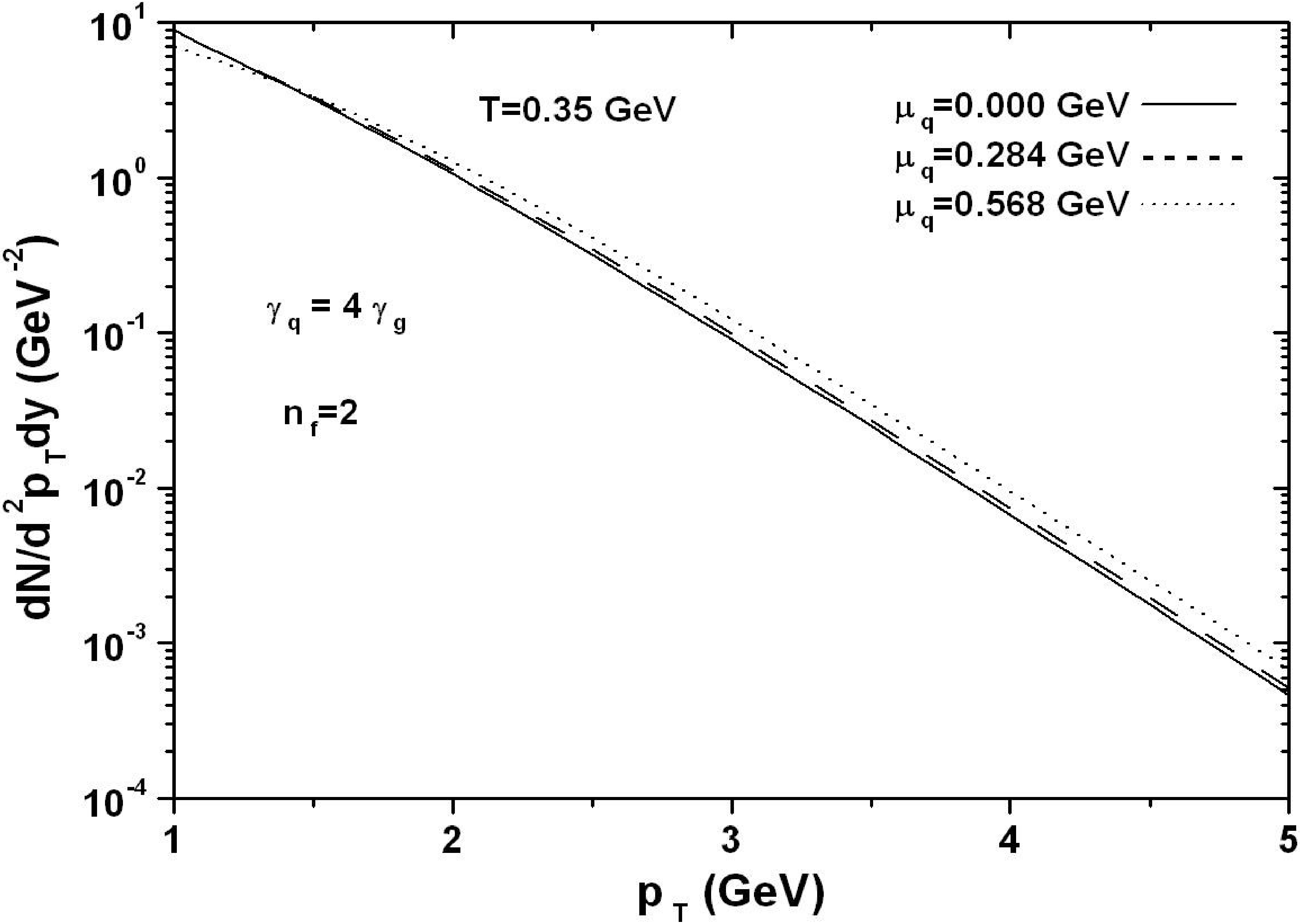
From RHIC energy :

y_{nuc}=+(-)5.3 and Q~ 180 fm^2 is the transverse momentum.

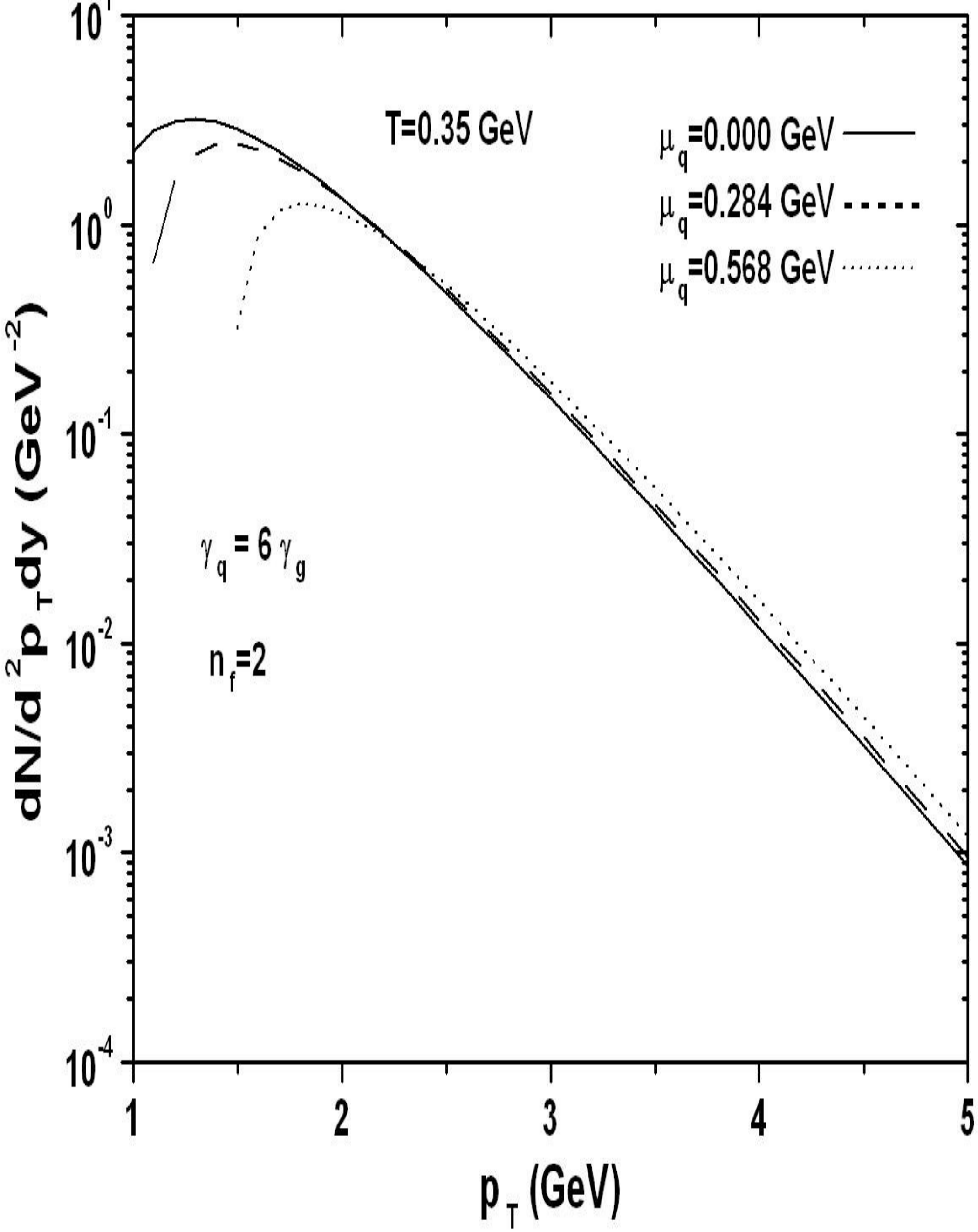
The approximation is suitable during the early stage where our interest is focussed. Thus, with the values of rapidity and p_T, we get total photon spectrum.



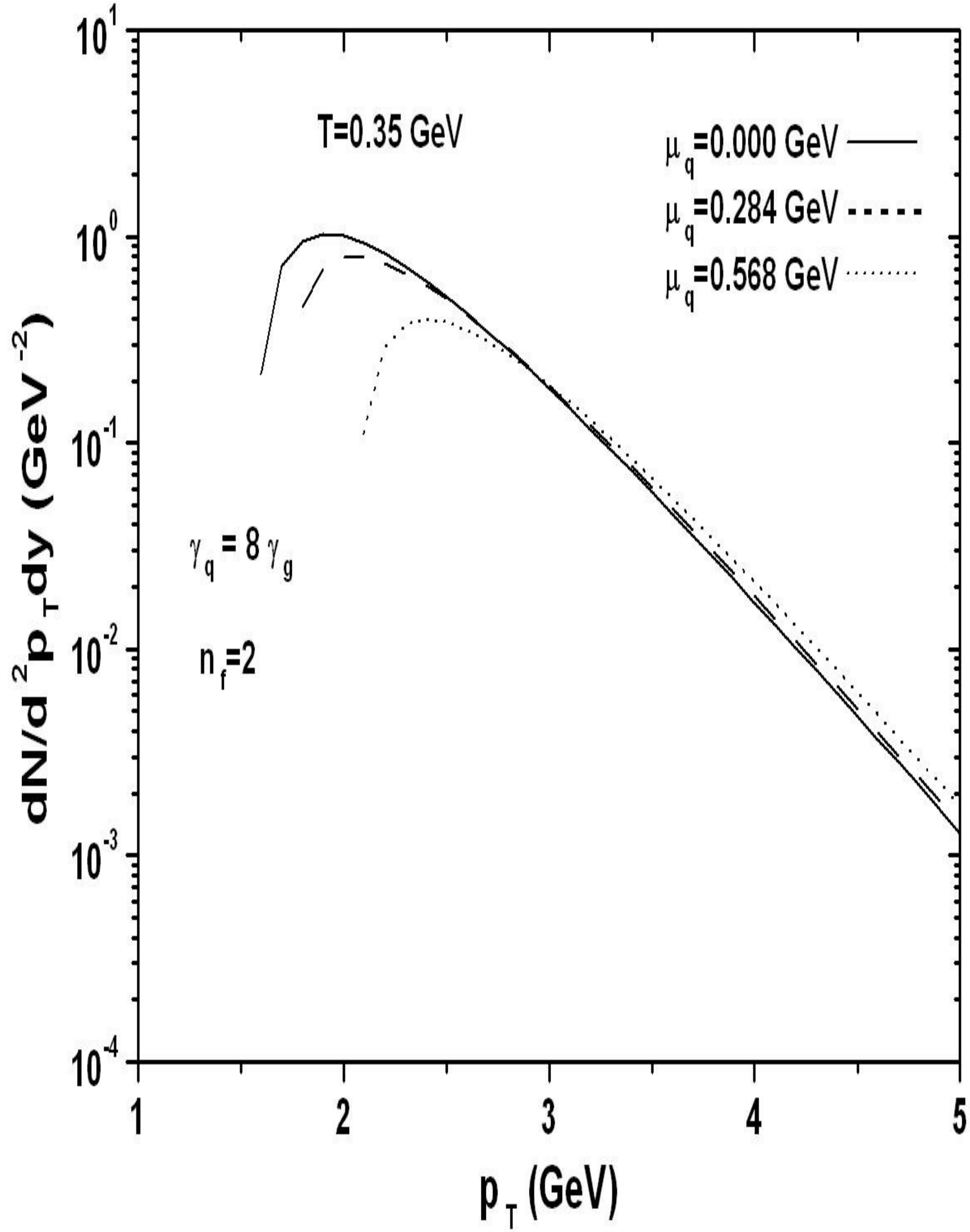
- It is found that photon production increases with increases the quark chemical potential at fix T=0.35 GeV
- There is uniform fall in total emission rate as a function of transverse momentum for all values of quark chemical potential with γq=2γg for flavor n_f=2.
- The increase in emission rate is highly effected by the temperature as well as the μq of the system with various set of condition.



10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
dN/d^2p_Tdy (GeV^{-2})
1
2
3
4
5
p_T (GeV)
T=0.35 GeV
$\gamma_q = 4\,\gamma_g$
n_f=2
μ_q=0.000 GeV
μ_q=0.284 GeV
μ_q=0.568 GeV



- **We observe photon rate goes on increses at low value up to P_T=1.5 GeV and afterwards follow the same pattern with the variation of quark chemical potential.**



- **Here, photon production is insensitive for low value of transverse momentum and the consideration of this parametrization value is not reliable in this range.**
- **We observe incomplete picture of the total photon spectra.**
- **It is not reliable to take any higher values of quarkphenomenological parameters to get the complete pattern of photon spectra. At the same time, it is also not right to take low values as photon rate diverges.**

Conclusion

- The measurement of leading order processes for photon production in the QGP provides a good opportunity to study the evolution of fireball with the effect of quark chemical potential in high energy heavy-ion collisions.
- The consideration of phenomenological parameter in quark mass for different value of quark chemical potential shows the important role in the photon measurements.
- The outcome of photon production production as a function of transverse momentum incorporating paramerization factors give new improved results in the photon yield with quark chemical potential and also enhanced as comparison to zero chemical potential.

THANK YOU