Hard and Thermal Photon Absorption in a QGP

Eric Palmerduca[1,2]
Advisor: Dr. Rainer Fries[2]
[1]Colgate University
[2]Cyclotron Institute, Department of Physics and Astronomy, Texas A&M University

National Science Foundation WHERE DISCOVERIES BEGIN
Office of Science U.S. DEPARTMENT OF ENERGY
CYCLOTRON INSTITUTE TEXAS A&M UNIVERSITY

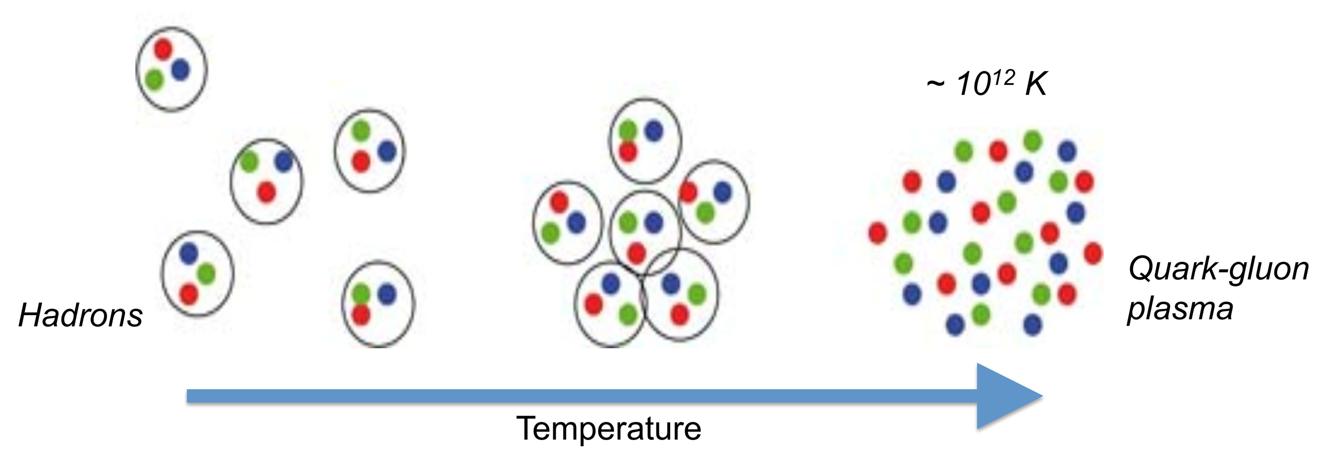
Abstract

The direct photon spectrum in nuclear collisions is of interest as it holds information such as the temperature of the quark-gluon plasma (QGP) and of the hot hadron gas (HG) created. Re-interactions between emitted photons and the medium are often omitted in calculations due to the assumption that these photons' mean free path is significantly longer than the spatial dimensions of the fireball. This study tests the validity of this assumption by modeling hard and thermal photon reabsorption in a rapidly expanding and cooling fireball. Thermal photon production rates, calculated using complete leading order perturbative quantum chromodynamics (pQCD) for QGP and state-of-the-art rates for HG, are used to compute absorption rates of hard and thermal photons. The hot fireball of QGP and HG is simulated by ideal hydrodynamics. The spectrum and elliptic flow of these photons are calculated and compared both to p-p collisions and to data from ultrarelativistic heavy-ion collisions (URHIC) at the Relativistic Heavy Ion Collider (RHIC) and the Large Hadron Collider (LHC).

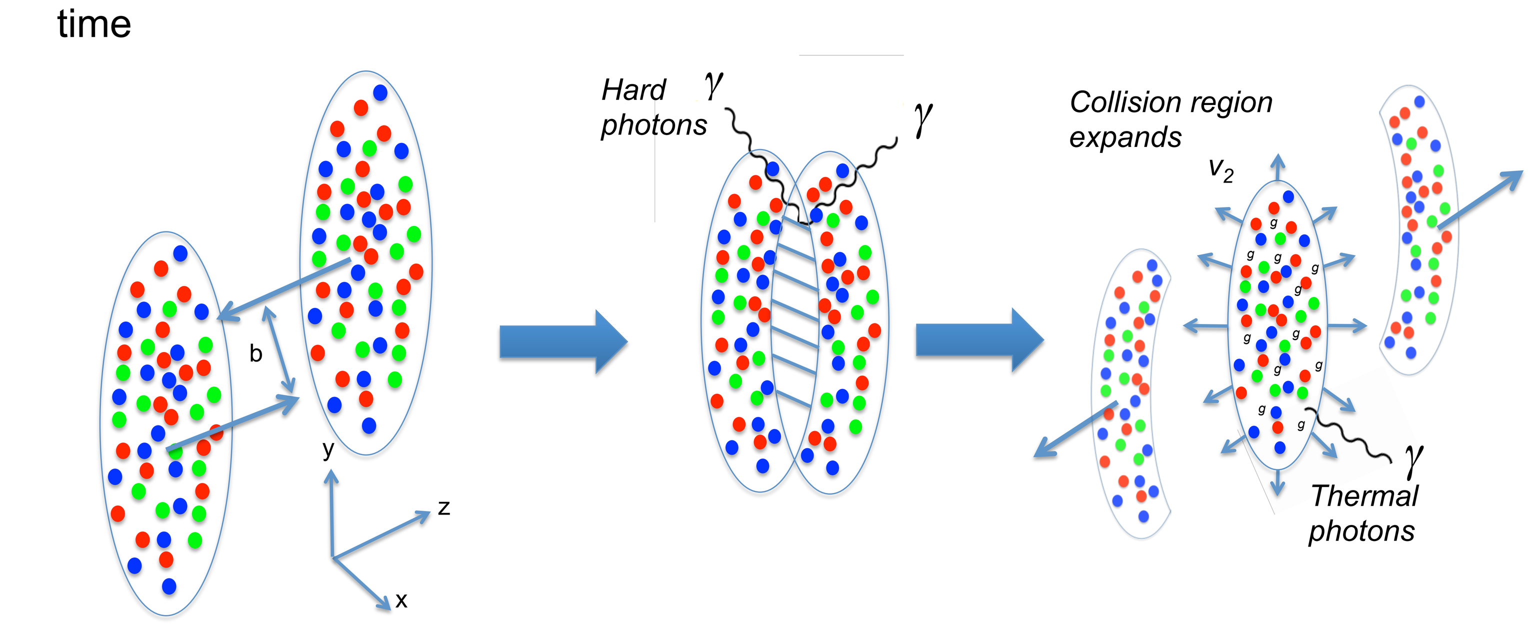
Introduction

What is a Quark Gluon Plasma (QGP)?

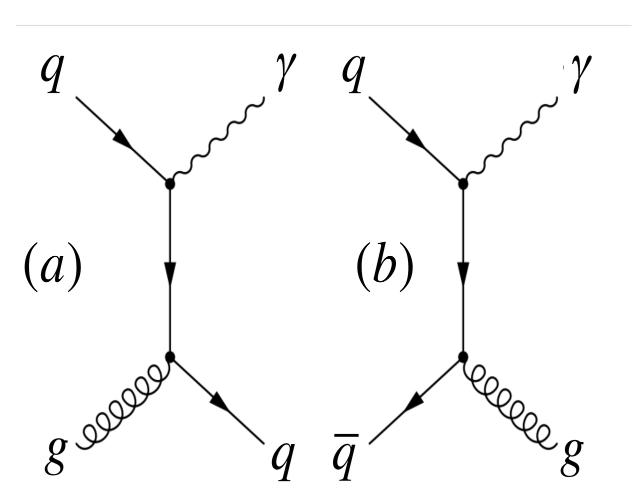
- QGP is a state of matter that exists at extremely high temperatures
- Quarks and gluons are asymptotically free and no longer bound in hadrons



- QGP can be produced in heavy ion collisions at RHIC and LHC for a very short time



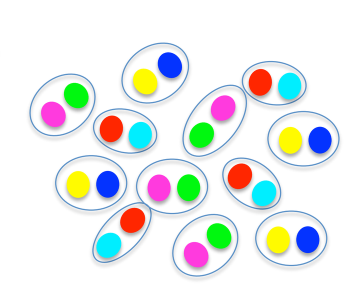
- Lorentz contracted heavy nuclei generally collide off-center with some impact parameter b
- Colliding region is elliptical
- Partons initially interact producing *hard photons*
- Collision region thermalizes into a QGP
- Releases *thermal photons*



Hard and thermal photons are primarily produced via:
(a) Compton scattering (b) annihilation

Hadronization

- QGP expands and cools into hadron gas around 170 MeV
- HG also emits thermal photons



Anisotropy

- Anisotropy in collision region leads to anisotropy in photon spectrum (elliptic flow, v_2)

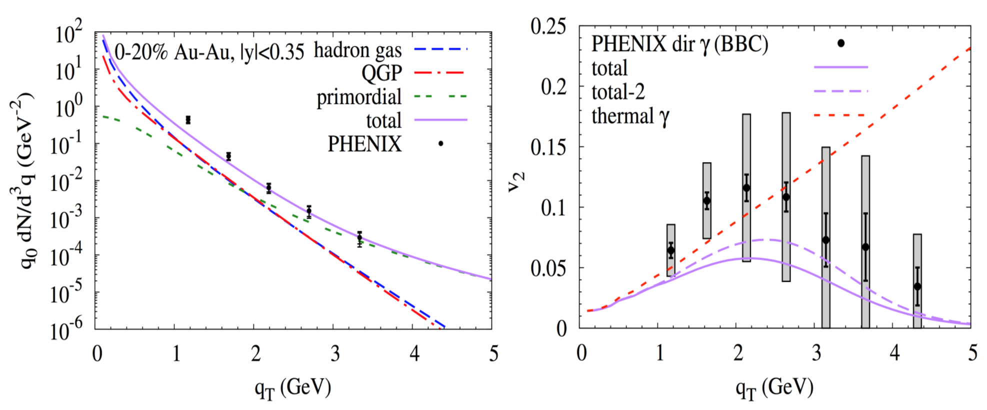
Photon Probes

- Photons are a major probe of QGP as they do not interact strongly
- Are assumed to have mean free paths significantly longer than the spatial dimensions of the QGP i.e. they are all assumed to escape the QGP. *However …*

Research Project

Challenge

State-of-the-art calculations [1] of the photon momenta spectra (*left*) and elliptic flow, v_2 (*right*), deviate somewhat with data from RHIC and LHC.



Project

We revisit the question of reabsorption of photons. The effects of reabsorption of hard and thermal photons in a QGP and HG on the photon spectra and v_2 are explored in the hopes of better fitting data from RHIC and LHC.

Modeling

Thermal and Spatial Evolution of QGP

- QGP found to behave like a near-ideal fluid.
- Thermal and spatial evolution modeled with an ideal-hydrodynamic code, AZHYDRO [2], [3].

Photon Production

- The initial momentum distribution of hard photons is calculated using complete leading-order (LO) perturbative quantum chromodynamics (pQCD) [4]. A Glauber model gives their initial spatial distribution.
- AMY complete LO pQCD calculations give thermal photon production rates, Γ_{prod}, in QGP [5]

$$\Gamma_{prod} \equiv \frac{EdN}{d^3p\, d^4x}$$

N = number of photons
p = momentum of photons
E = energy of photons

We use state-of-the-art rates for HG from ref [1]. The effects of a "pseudo-critical enhancement" around the transition temperature are also tested [1].

Photon Absorption

- Photon production processes can be inverted to give photon absorption processes

$$q+\gamma \rightarrow q+g$$

Compton scattering

$$g+\gamma \rightarrow q+\bar{q}$$

Quark pair production

- Absorption rates are related to production rates by the principle of detailed balance [6]:

$$\Gamma_{abs} = \frac{(2\pi)^3}{2p} e^{\frac{p}{T}} \Gamma_{prod} \quad (1)$$

Production and propagation of both hard and thermal photons in the AZHYDRO are simulated using the code PPM [7]. Absorption in the thermal medium is calculated in PPM using (1). The following observables are calculated:

- S_{AA} compares spectra with and without absorption effects in nuclear collisions
- v_2 is a measure of azimuthal anisotropy in the spectra. It's positive if more γ emitted along the x-axis, and negative if more γ emitted along the y-axis

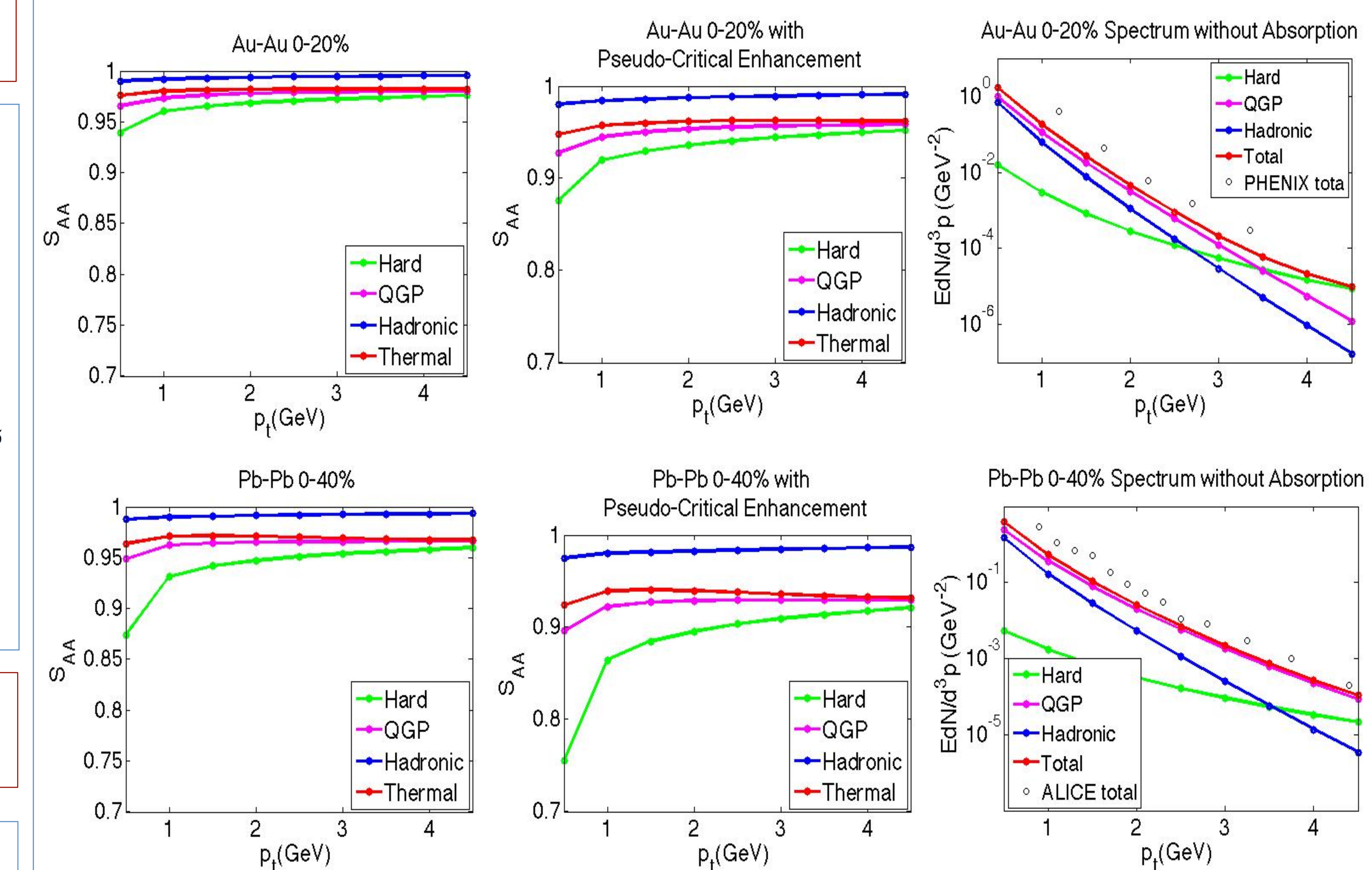
$$S_{AA} = \frac{(dN^{AA}/d^2p_t)\ \text{(w/ absorption)}}{(dN^{AA}/d^2p_t)\ \text{(w/o absorption)}} \qquad v_2 = \frac{\int_\psi (dN^{AA}/d^2p_t)\cos(2\psi)\,d\psi}{\int_\psi (dN^{AA}/d^2p_t)\,d\psi}$$

p_t = momentum transverse to beam axis

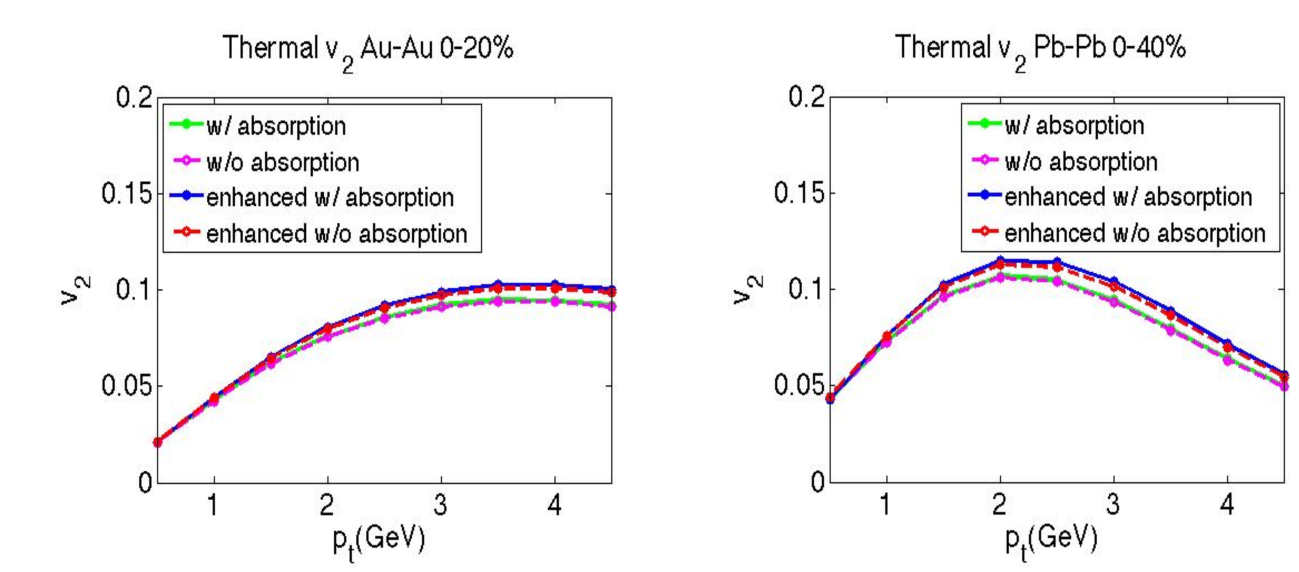
Results

The observables are plotted for each photon source as functions of p_t for both Au-Au (200 GeV) and Pb-Pb collisions (2.76 TeV). The scenario of a "pseudo-critical enhancement" is also tested.

(*Left*): S_{AA} without a pseudo-critical enhancement. (*Middle):* S_{AA} with a pseudo-critical enhancement. (*Right):* Photon spectra without absorption.



Thermal elliptic flow (v_2):



Conclusions

- Hard photons show significant suppression (up to 13%) and even more so with a pseudo-critical enhancement (up to 24%).
- Thermal photons originating from the QGP also show some suppression, while those from the HG show little to no suppression.
- Mean free path is shortest for soft photons, about 30 fm for p = 0.5 Gev photons in T = 400 MeV QGP.
- Absorption slightly increases thermal photons' v_2 for p > 0.5 GeV photons.

References

[1] H. van Hees, M. He and R. Rapp, Pseudo-Critical Enhancement of Thermal Photons in Relativistic Heavy-Ion Collisions, Nucl. Phys. A933, 256 (2015).
[2] P. F. Kolb, U. W. Heinz, Hydrodynamic description of ultrarelativistic heavy ion collisions, In "Quark Gluon Plasma", ed. R. C. Hwa, 634 (2003), e-Print: nucl-th/0305084.
[3] M. He, R. J. Fries and R. Rapp, Ideal Hydrodynamics for Bulk and Multistrange Hadrons in sNN=sqrt(200) AGeV Au-Au Collisions, Phys. Rev. C85, 044911 (2012).
[4] R. J. Fries, B. Muller, D. K. Srivastava, "High-energy photons from passage of jets through quark gluon plasma", Phys. Rev. Lett. 90, 132301 (2003).
[5] P.B. Arnold, G.D. Moore and L.G. Yaffe, Photon emission from quark gluon plasma: Complete leading order results, JHEP 0111, 057 (2001).
[6] M.H. Thoma, Damping rate of a hard photon in a relativistic plasma, Phys. Rev. D 51, 862 (1995).
[7] R. Rodriguez, R. J. Fries and E. Ramirez, "Event-by-Event Jet Quenching", Phys. Lett. B 693 108 (2010).

Acknowledgments

I sincerely thank my advisor, Dr. Fries, for his invaluable help and guidance. We thank J. Winchell and S. Somanathan for help with the PPM code, and M. He for the hadronic gas photon production rates. EP was supported by the Cyclotron REU program and NSF Research Fellowship, Grant No. 1263281
RJF acknowledges support from the NSF through CAREER Grant PHY-0847538, and from the JET Collaboration and DOE Grant DE-FG02-10ER41682.