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Photon Absorption in Quark-Gluon Plasma

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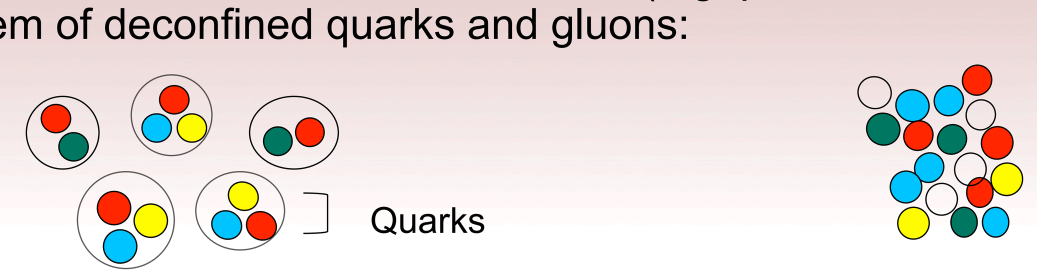
Abstract

Heavy ion collisions may produce quark-gluon plasma (QGP), a state wherein quarks and gluons are deconfined. Photons are one of the major probes of QGP. While it is generally assumed that the photons created throughout the collision have sufficiently large mean free paths to escape the system, some may be reabsorbed. We study the degree to which this happens and its effect on the observables S_{AA}, R_{AA}, and v_2. We simulate a QGP fireball, the relevant photon sources, and the photon absorption rates.

Introduction

Quark-Gluon Plasma (QGP):

- State where hadronic matter (e.g. protons or neutrons) gives way to a system of deconfined quarks and gluons:



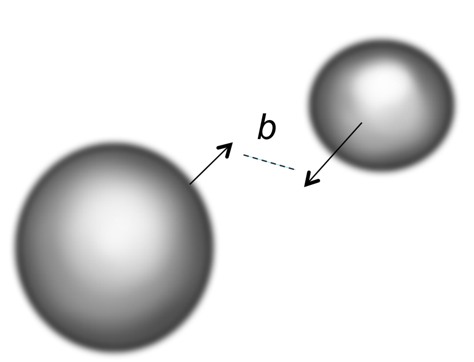
- Requires very high temperatures (T≥150 MeV).
- Thought to have been present in the Big Bang, may be found inside neutron stars, and is studied experimentally in high-energy collisions of heavy nuclei.

Photons in QGP :

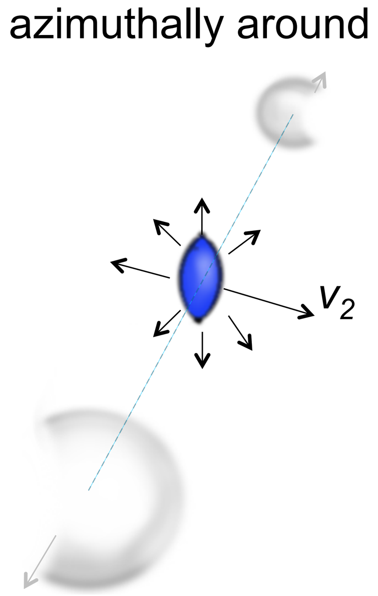
- Can be used to determine the temperature of the QGP and the following hadronic gas.
- Test of our understanding of the fundamental mechanisms involved in the collision.

Observables:

- Nuclear suppression factor R_{AA}: change between the spectra produced by collisions of nuclei and those of nucleons. (S_{AA} is similar)
- Elliptic flow v_2 (the second coefficient of a Fourier series): represents the asymmetrical outflow of particles azimuthally around the particle beam axis.

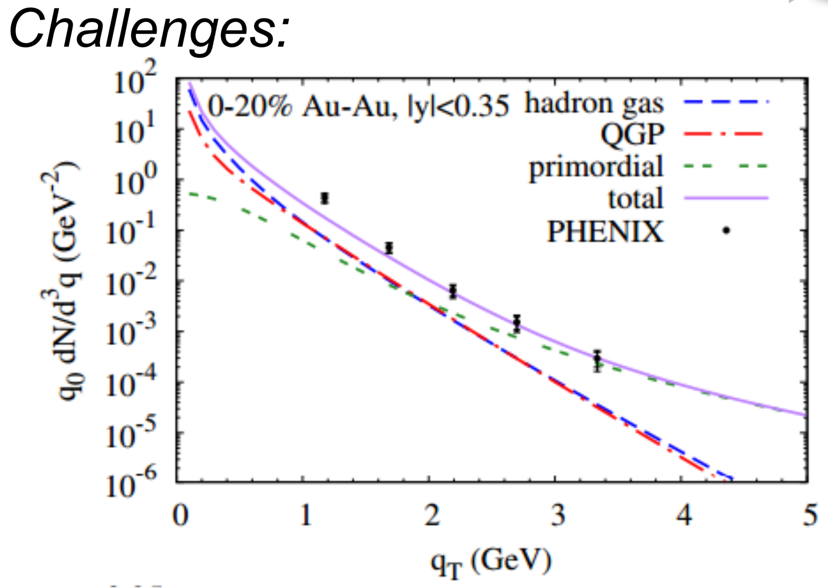


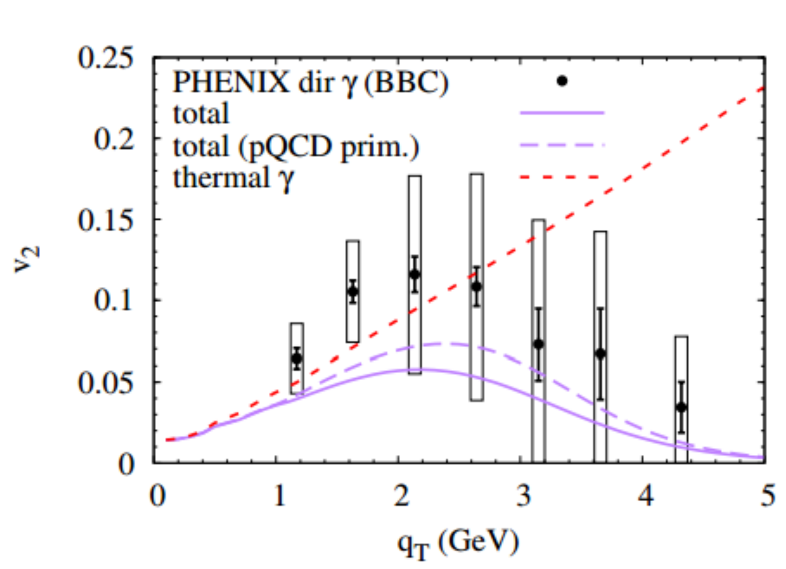
Nuclei about to collide
(With a finite impact parameter b)



The fireball is left behind where the nuclei overlap—an elliptic shape.

Challenges:





Direct photon spectrum (right) and v2 (right) for Au-Au collisions at RHIC. From Ref. [1]

State of the art theoretical calculations, e.g. [1], are not able to explain photon spectra and v2 completely; the above graphs show slight discrepancies at low energies.

Our Project

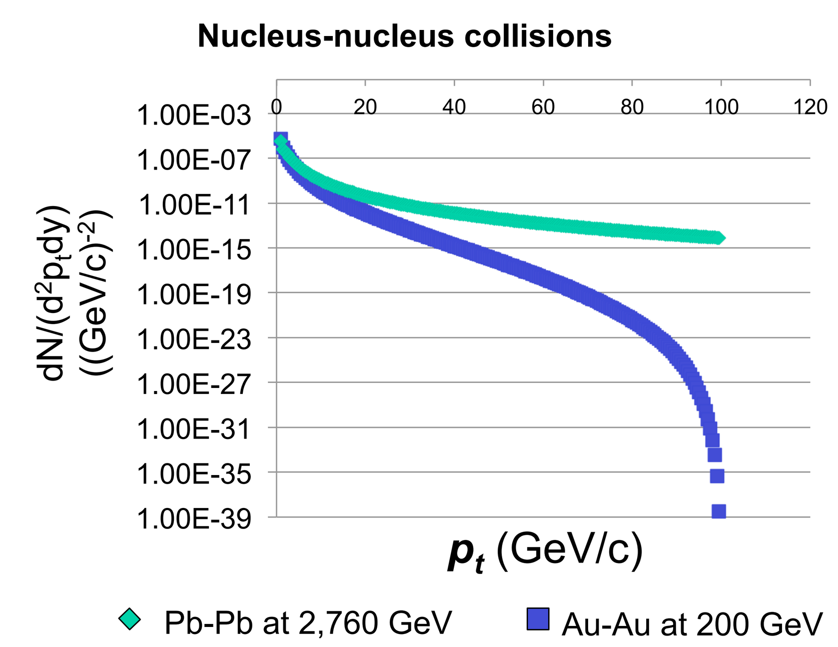
Central question: **Photon reabsorption is usually neglected in calculations due to the large mean-free-paths of the photons, but how much of an effect does photon absorption actually have on the QGP observables?**

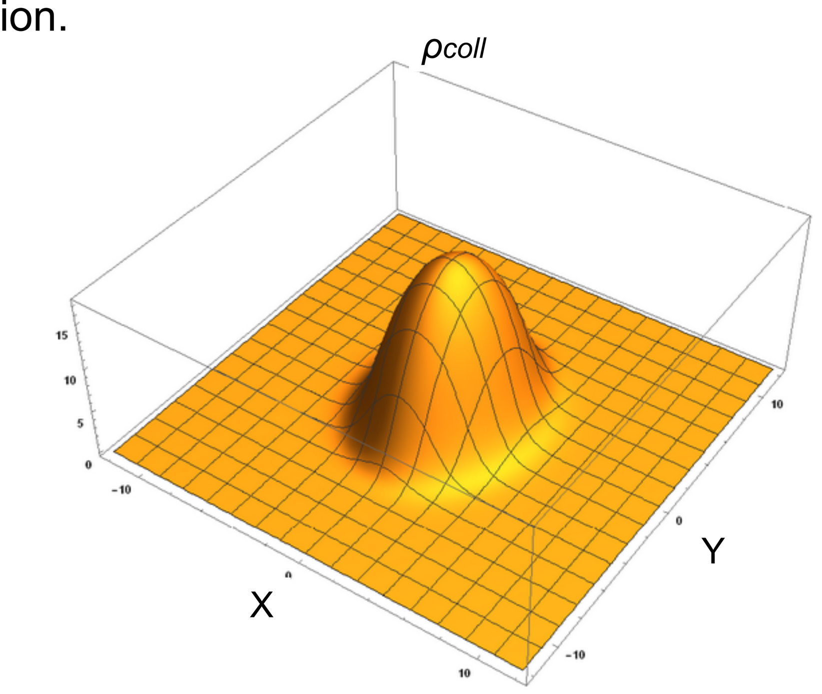
We simulated collisions of gold and lead nuclei, proceeding in three main steps:

1. Model photon sources
2. Calculate photon absorption rates
3. Propagate photons in a QGP fireball simulation.

Model Photon Sources

Photons are created via several processes throughout the collision. We focus on those due to primary hard collisions (due mostly to Compton and annihilation events); we use a leading-order perturbative QCD calculation to determine the initial momentum distribution of hard photons and a Glauber model calculation for their spatial distribution.





The data in these graphs are used to model initial hard photon density in momentum space (left) and their density (right) in a QGP fireball for their specific elements.

Calculate Photon Absorption Rates

The Lambert-Beer law is used to model the change in photon number:
*dN/dx=-N*Γ*, where N is the number of (in this case) photons and *Γ* is the absorption rate.
We used several methods to calculate *Γ* (the absorption rate) for QGP:

1) **Static approximation (neglecting thermal motion) where *Γ=nσ* (medium density multiplied by Compton or pair production cross-sections)**
2) **Photon damping model calculated by M. H. Thoma (Ref. [2]):**

$$\Gamma = \frac{12\pi}{9}\frac{\alpha \alpha_s T^2}{p}\ln\frac{0.2317p}{\alpha_s T}$$

3) **Photon production rates calculated by AMY (Ref. [3])**

$$\Gamma = \Gamma_{prod}\frac{e^{E/T}}{E}\frac{(2\pi)^3}{2}$$

Because QGP gradually becomes a hadron gas, we also added a simple hadronic absorption model that matches AMY calculations at Tc = 170MeV.

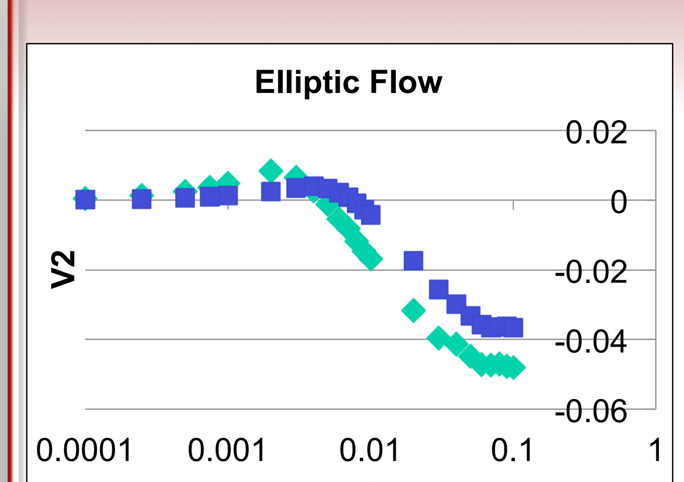
Propagate Photons in a QGP Fireball Simulation

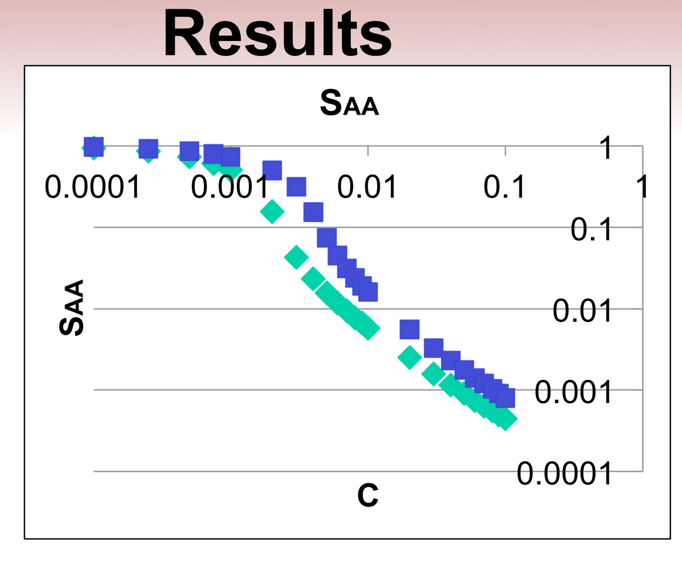
Using the code PPM, we model a photon's path through a simulation of a fireball created by nuclear collisions, applying the absorption rates above and calculating observables:

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

Also to be noted is that two fireball simulations were used: 1)A boost-invariant model without transverse expansion based on Glauber calculations, and 2) An ideal AZHYDRO simulation.

Results

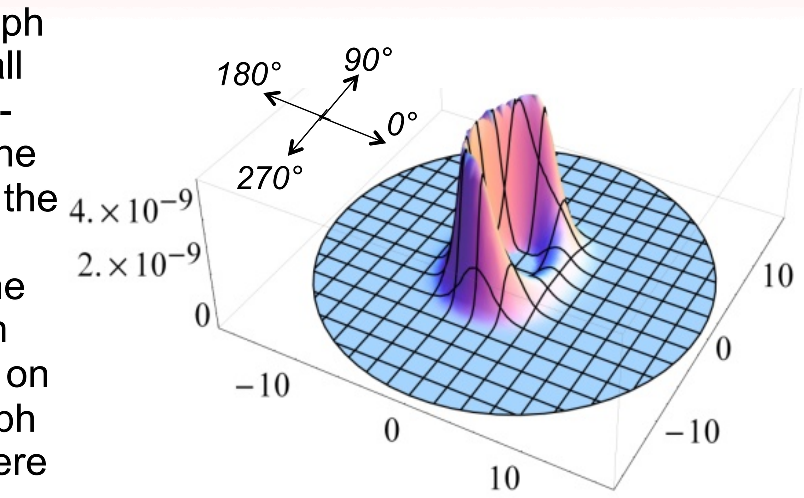




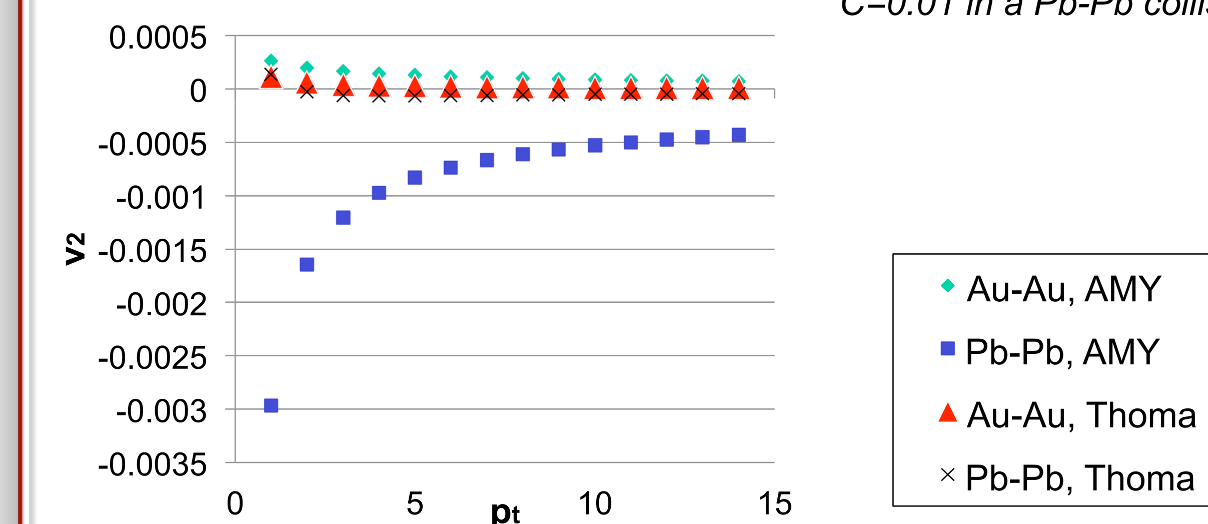
These graphs show v2 and SAA as they change with the absorption coefficient C (*Γ=C*s* where s is the entropy density). SAA suppression is increased monotonically with C, while the v2 first rises and then dips to negative values, which is unusual.

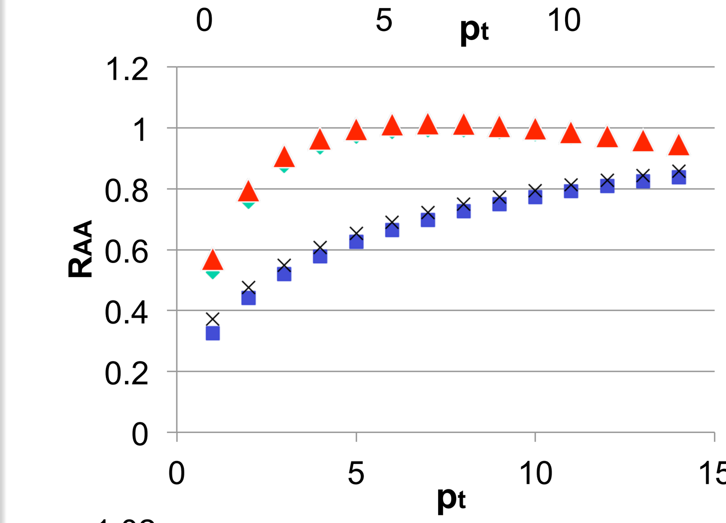
Results (cont'd)

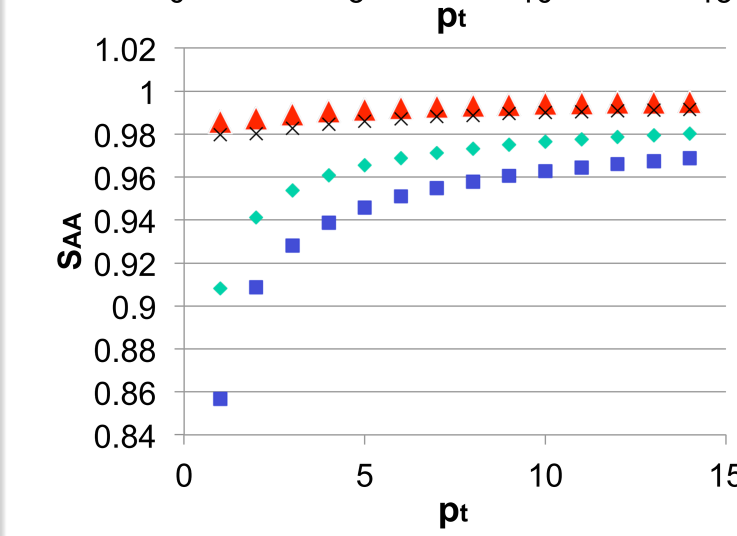
PPM keeps track of all the photons leaving at every angle from every position. This graph shows the initial position of all the photons leaving at a 180-degree angle (away and to the left in this graph)—height is the emissivity (arbitrary units). It would be expected that all the photons that leave at a given angle would have originated on the closest side, but this graph shows that some photons were created on the opposite side.



This graph depends on C; here, C=0.01 in a Pb-Pb collision.







These graphs compare the observables from PPM as calculated by AMY and Thoma's models for collisions of both gold and lead nuclei. The small and negative v2 values again are notable.

Conclusions

Preliminary results show relatively large suppression (~10%) and changes in v2 of up to 1/3 of a percent for hard photons with pt >1 GeV. However, we find the v2 to become negative due to fireball expansion.
Future improvements to be implemented include more realistic hadronic absorption rates and application to thermal photons.

Acknowledgements

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References

[1] H. van Hees, M. He and R. Rapp, Pseudo-Critical Enhancement of Thermal Photons in Relativistic Heavy-Ion Collisions, preprint arXiv:1404:2846
[2] M.H. Thoma, Damping rate of a hard photon in a relativistic plasma, Phys. Rev. D 51, 862 (1995)
[3] P.B. Arnold, G.D. Moore and L.G. Yaffe, Photon emission from quark gluon plasma: Complete leading order results, JHEP 0111, 057 (2001).