ABSORPTION OF HARD AND THERMAL PHOTONS IN A QUARK-GLUON PLASMA AND HADRONT GAS

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Quark-Gluon Plasma (QGP)

Temperature ~ $10^{12}$ K
Direct Photons in Heavy Ion Collisions

QGP briefly forms and expands and cools to ~170 MeV.

No interaction

Kinetic freeze-out at ~100 MeV

Hot hadron gas
Modeling Photon Production

- The initial momentum distribution of hard photons is calculated using leading-order (LO) pQCD [1]
- A Glauber model gives their initial spatial distribution
- AMY complete LO pQCD calculations give thermal production rates [2]
- State-of-the-art rates for HG [3]
Discrepancies with Data

- Tension fitting photon spectrum and elliptic flow \((v_2)\) simultaneously
- Recent calculations from He et al. are an example [3]
Motivation

• Photons are a major probe of QGP as they do not interact strongly.
• They are assumed to have mean free paths of ~400 fm, significantly longer than the spatial dimensions of the QGP (~15 fm). [4]
• We explore the possibility that some of these photons are reabsorbed in the hopes of better fitting experimental data.
Photon Production and Absorption

Production processes

\[ \begin{align*}
\text{(a)} & \quad \text{Compton scattering} \\
\text{(b)} & \quad \text{Quark annihilation}
\end{align*} \]

Absorption processes

\[ \begin{align*}
\text{(a)} & \quad \text{Compton scattering} \\
\text{(b)} & \quad \text{Quark pair-production}
\end{align*} \]

Production Rate:

\[ \Gamma_{\text{prod}} \equiv \frac{EdN}{d^3p \; d^4x} \]

Absorption Rate:

\[ \Gamma_{\text{abs}} = \frac{(2\pi)^3}{2p} e^T \Gamma_{\text{prod}} \]

Time reversal symmetry
Methodology

- Thermal and spatial evolution of fireball modeled with ideal hydrodynamics (AZHYDRO) [5][6]
- 170 MeV phase transition
- 100 MeV kinetic freeze out
- Calculate absorption rates
- PPM applies the production and absorption rates to hard and thermal photons and propagates them through the fireball [7]
- Note: Production/absorption of photons prior to thermalization is neglected
Observables

- Spectrum: Boost invariant measure of number of photons with a given momentum:

\[
\frac{EdN}{d^3 p}
\]

- Suppression factor:

\[
S_{AA} = \frac{(dN_{AA}^{AA} / d^2 p_t)}{(dN_{AA}^{AA} / d^2 p_t)}
\]

\[(w/ \text{ absorption})\]

\[(w/o \text{ absorption})\]
Elliptic Flow

- Second Fourier coefficient, $v_2$, of the azimuthal asymmetry of spectrum

$$\frac{EdN}{d^3 p} = \frac{1}{2\pi} \frac{dN}{p_t dp_t dy} (1 + \sum_n v_n \cos(n\psi))$$

$$v_2 = \frac{\int_{\psi} (dN / d^2 p_t) \cos(2\psi) d\psi}{\int_{\psi} (dN / d^2 p_t) d\psi}$$
Elliptic Flow: Competing Effects

• Early anisotropy $\rightarrow$ shorter $x$ distance traveled $\rightarrow$ increased $v_2$

• Late anisotropy $\rightarrow$ longer $x$ distance traveled $\rightarrow$ decreased $v_2$

• Flow: faster expansion along $x$ $\rightarrow$ lower momentum in medium’s rest frame $\rightarrow$ more absorption along $x$ $\rightarrow$ decreased $v_2$
Photon Spectra for Au-Au and Pb-Pb Collisions

Au-Au 0-20% Spectrum without Absorption

Pb-Pb 0-40% Spectrum without Absorption
$S_{AA}$ for Au-Au and Pb-Pb Collisions

Au-Au 0-20%

Pb-Pb 0-40%

RHIC 200 GeV collisions

LHC 2.76 TeV collisions
$S_{AA}$ for Au-Au and Pb-Pb Collisions with a Pseudo-Critical Enhancement

**Au-Au 0-20% with Pseudo-Critical Enhancement**

- **Hard** (green line)
- **QGP** (purple line)
- **Hadronic** (blue line)
- **Total** (red line)

**RHIC 200 GeV collisions**

**Pb-Pb 0-40% with Pseudo-Critical Enhancement**

- **Hard** (green line)
- **QGP** (purple line)
- **Hadronic** (blue line)
- **Total** (red line)

**LHC 2.76 TeV collisions**
$v_2$ for Au-Au and Pb-Pb Collisions with and without Absorption
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 and 70 fm at $T = 170$ MeV. These number go to 15 and 23 fm when the pseudo-critical enhancement is applied.
- Absorption slightly increases $v_2$ hard and thermal photons
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References


References


