Photon emission in initial and hydrodynamic stages of nuclear collisions

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Introduction

Key word: **pre-equilibrium photons**

A **missing component** in direct photon estimation in (most) hydrodynamic models for nuclear collisions

AM, 1812.08987, 1907.09266, Garcia-Montero et al. 1909.12246, 1909.12294
Direct photons

- Model overview

**Prompt photons:** $N_{\text{coll}}$-scaled pp results

$$E \frac{dN_{\text{dir}}^\gamma}{d^3p} = 6745 \frac{\sqrt{s}}{(p_T)^5} \frac{N_{\text{coll}}}{\sigma_{pp}^{\text{in}}[\text{pb}]}$$

Turbide, Rapp and Gale, PRC 69, 014903

**Pre-equilibrium photons:** Turbulent thermalization

$$E \frac{dR_{a,b}^\gamma}{d^3p} = \frac{20}{9\pi^2} \alpha_{\text{EM}} \alpha_s f_q(p) \log \left(1 + \frac{2.919}{g^2}\right) \int \frac{d^3p'}{(2\pi)^3} \frac{1}{p'} \left[f_g(p') + f_q(p')\right]$$

Berges et. al., PRC 95, 054904; Tanji and Venugopalan PRD 95, 094009

**Thermal photons:** Hydrodynamic model

$$E \frac{dR^\gamma}{d^3p} = \frac{1}{2} \left(1 - \tanh \frac{T - T_c}{\Delta T}\right) E \frac{dR_{\text{hadron}}^\gamma}{d^3p} + \frac{1}{2} \left(1 + \tanh \frac{T - T_c}{\Delta T}\right) E \frac{dR_{\text{QGP}}^\gamma}{d^3p}$$

Turbide, Rapp and Gale, PRC 69, 014903; Arnold, Moore and Yaffe, JHEP 0112, 009

\[f_q , f_g : \text{parton distributions}\]
Pre-equilibrium stage

- Parametrize self-similar distributions

\[ f_i = (Q_s \tau)^{-2/3} f_i^{s}(p_T, (Q_s \tau)^{1/3} p_z) \]
\[ f_i^{s}(p_T, p_z) = A_i p_T^{-1} \exp(-p_z^2/\sigma_z^2) \]

+ cut-off above \( p_T > Q_s \)
\[ \times \frac{1}{2} \left[ 1 - \tanh \left( \frac{p_T - Q_s}{\Delta p_T} \right) \right] \]

\( (i = q, g) \)
\[ A_q \sim \alpha_s A_g \]
\[ A_i : \text{Normalization} \]
\[ \sigma_z : \text{Longitudinal momentum scale} \]
\[ Q_s : \text{Saturation momentum} \]

- Scale bottom-up thermalization into the hydro model timeline
QCD matter

- Initial energy density distribution for the **pre-equilibrium stage**

  Event-averaged MC Glauber model at $b = 4.6$ fm normalized by $\sqrt{s_{NN}} = 2.76$ TeV Pb+Pb data at LHC

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$A_i$ : Normalization

$\tau_{ini}$  
Pre-eq.  
$\tau_{hyd}$  
Hydro  
$T_f$  
Freeze-out + hadronic decay

dN/dy, spectra, ...

Glauber model

Glauber model

LHC data
Results and conclusion

Pre-equilibrium photons

Smaller $\sigma_z \rightarrow$ Higher peak in $p_T$ spectra
Larger $Q_s \rightarrow$ Lower peak at larger $p_T$ in spectra

*Phase space volume is constrained by normalization

$\sigma_z$: Longitudinal momentum scale
$Q_s$: Saturation momentum
Results and conclusion

- Thermal + pre-equilibrium + prompt photons

- Typical momentum scale: enhanced around $Q_S$
- $v_2$: reduced around $Q_S$

Pre-equilibrium photons can be important near $p_T \sim Q_S$
The end

- Thank you for listening!

- If you have further questions, contact me at:
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