Jet induced photon production in the QGP

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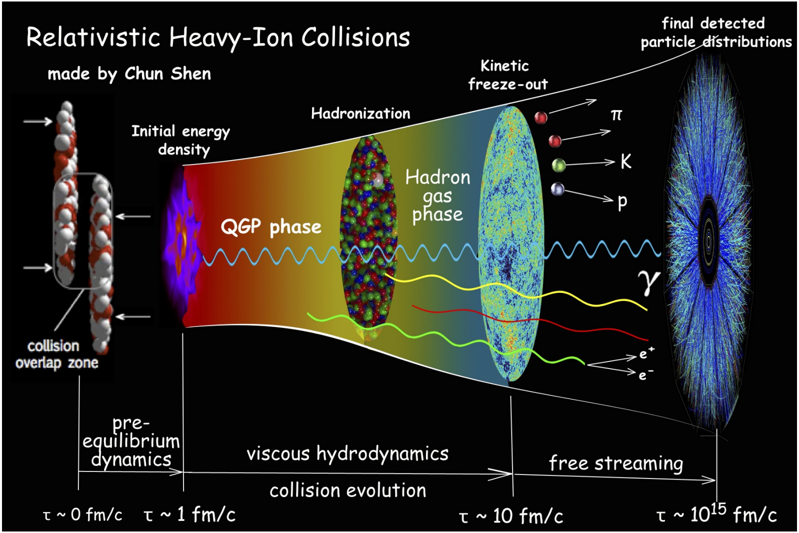
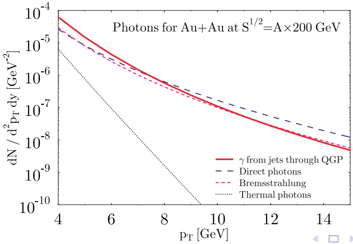
Photons from the QGP



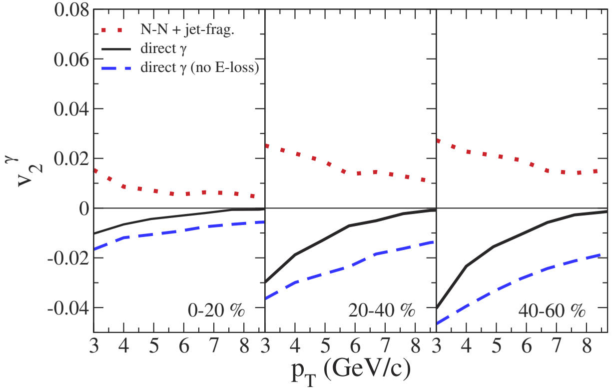
Motivation

- Why studying photons?
  - Photons produced in the QGP are very unlikely to interact again with other particles
    $\Rightarrow$ Carry information about the system at the time of their production to the detectors
- Why are jet induced photons important?
  - *R. Fries et al., PhysRevLett.90.132301 (2003)*:
    "Conversion of quark jets into photons is the leading source of direct photons in the region $p_T \leq 6\mathrm{GeV/c}$ *at RHIC"*



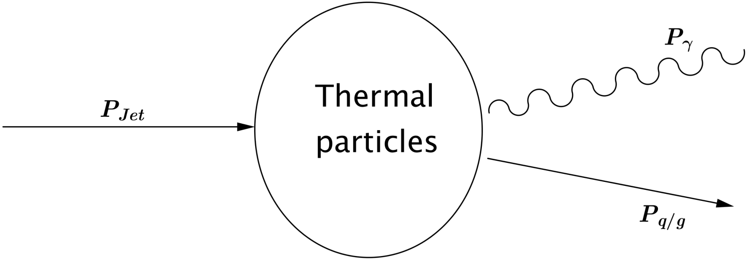
Motivation

- *Turbide, Gale, Fries: PhysRevLett.96.032303 (2006)*:
  Photons produced by jets may lead to a negative v_2



Simulation: Sampling of photon processes

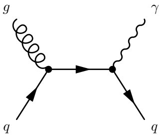
- Goal: Calculation of photon rates



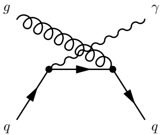
- Massless jet (quark, gluon) with fixed energy
- Collision with thermal particle
- Momentum transfer $\sim \frac{1}{\sigma}\frac{\mathrm{d}\sigma}{\mathrm{d}t}$; Rate $\sim \sigma_{\text{tot}}$

Photon production mechanisms

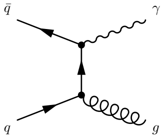
$\underline{2 \to 2:}$



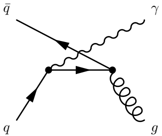
s-channel



u-channel

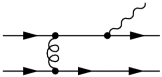


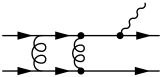
t-channel



u-channel

$\underline{2 \to 3:}$





... $\to$ Outlook

Analytic approach

$$R = \int \frac{\mathrm{d}^3 p_1}{(2\pi)^3 2p_1^0} \int \frac{\mathrm{d}^3 p_2}{(2\pi)^3 2p_2^0} \int \frac{\mathrm{d}^3 p_3}{(2\pi)^3 2p_3^0} \int \frac{\mathrm{d}^3 k}{(2\pi)^3 2k^0} \times (2\pi)^4 \, \delta^{(4)}(P_1 + P_2 - P_3 - K) \, |\mathcal{M}|^2 \, f_1(P_1) \, f_2(P_2)$$

- *Physical Review C91, 014908 (2015)* $\rightarrow$ Reduction to 3-dim. Integral which can be integrated numerically
- Collision of a jet with a thermal particle:
  - $f_1 = f_{\mathrm{Boltz}}$: Boltzmann distribution for thermal particle
  - $f_2 = f_{\mathrm{jet}}$: Distribution for a jet with fixed energy

What is f_{jet}?

- Fixed energy $\Rightarrow f_{Jet}(p) = c\,\delta(p - p_{jet})$
- Determine the constant c:

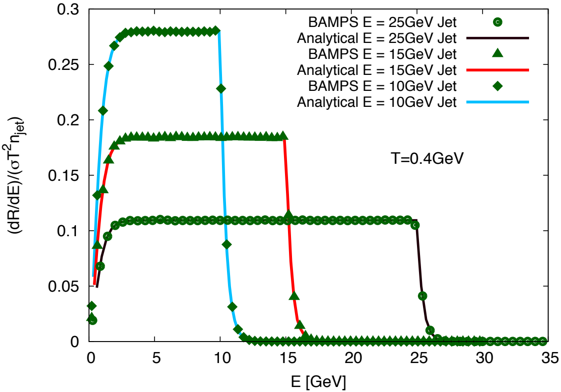
$$
\begin{aligned}
n_{\mathrm{jet}} &= \int \frac{\mathrm{d}^3 p}{(2\pi)^3}\, f_{\mathrm{jet}}(p) \\
&= \int \frac{\mathrm{d}p}{2\pi^2}\, p^2\, c\,\delta(p - p_{\mathrm{jet}}) \\
&= \frac{p_{\mathrm{jet}}^2}{2\pi^2}\, c \\
\Rightarrow c &= \frac{2\pi^2}{p_{\mathrm{jet}}^2}\, n_{\mathrm{jet}}
\end{aligned}
$$

n_{jet}: Density of jet particles

$$\Rightarrow \boxed{f_{\mathrm{jet}}(p) = \frac{2\pi^2}{p_{jet}^2}\, n_{\mathrm{jet}}\,\delta(p - p_{\mathrm{jet}})}$$

Constant isotropic cross section

- Test the conformity of the methods
- No QCD processes but hard sphere collisions: $|\mathcal{M}|^2 = 16\pi\, s\, \sigma_{\rm tot}$



2 → 2 photon processes

- Matrix elements:

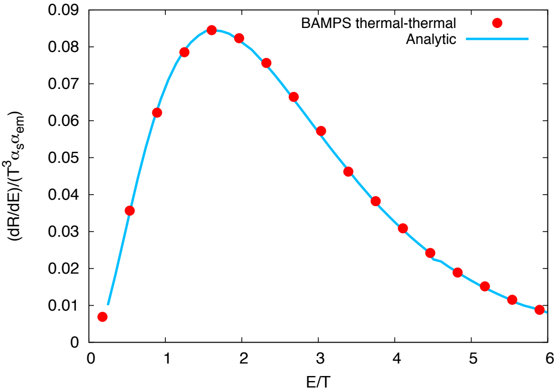
$$|\mathcal{M}_{\mathrm{compton}}|^2 = 128 \cdot \frac{16}{3}\pi^2 \alpha \alpha_s \left(\frac{s^2 + st}{(s + \kappa m_{D,q}^2)^2} + \frac{s^2 + st}{(u - \kappa m_{D,q}^2)^2} \right)$$

$$|\mathcal{M}_{\mathrm{annihilation}}|^2 = 24 \cdot \frac{128}{9}\pi^2 \alpha \alpha_s \left(\frac{tu}{(t - \kappa m_{D,q}^2)^2} + \frac{tu}{(u - \kappa m_{D,q}^2)^2} \right)$$

- $\kappa = 2.45$ to fit to the full HTL AMY result

$2 \rightarrow 2$ photon processes: Thermal-thermal collisions

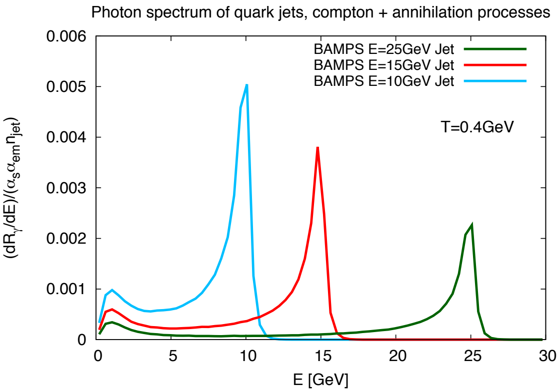
- Collision of two Boltzmann distributed partons:



⇒ Simulation still matches the analytic approach

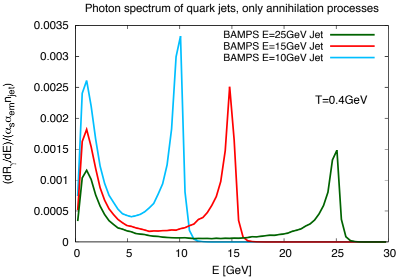
$2 \to 2$ photon processes: Jet-thermal collisions

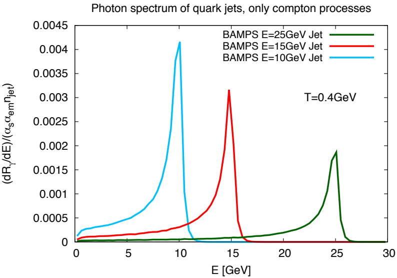
- Collision of a thermally distributed particle with fixed energy quark-jet



- Spectra highly peaked at jet energies $\Rightarrow$ Jet-γ-conversion

Difference between the compton and annihilation contribution

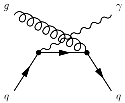




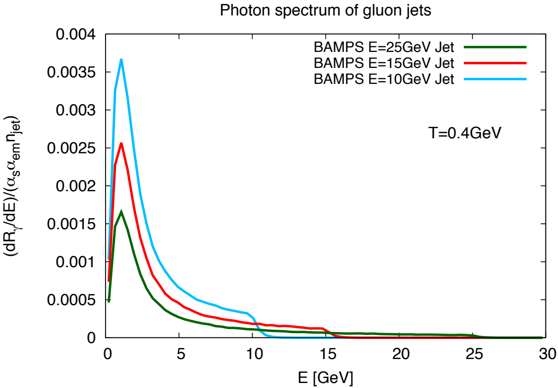
$$|\mathcal{M}|^2 \sim \frac{u}{t} + \frac{t}{u}$$

$$|\mathcal{M}|^2 \sim \frac{s^2+st}{u^2} + \text{s-channel}$$

$$t = (P_1 - P_3)^2 \ , \ u = (P_2 - P_3)^2$$

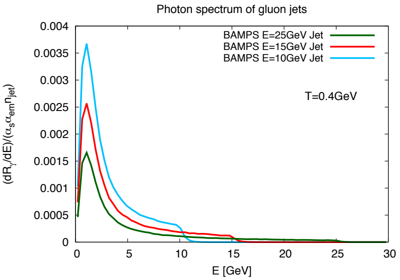


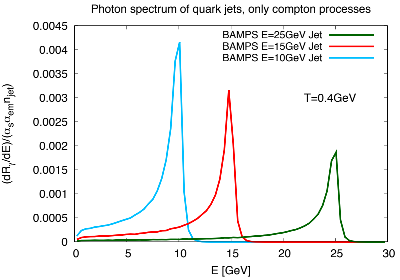
Photon spectra induced by gluon jets



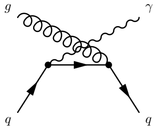
- Very different from the spectra of quark-jets
- Jet-γ-conversion suppressed
- Only compton processes for gluon jets

Photons produced by gluon and quark jets

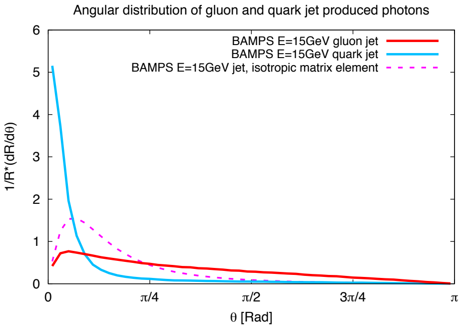




$$|\mathcal{M}|^2 \sim \frac{s^2+st}{u^2} + \text{s-channel}$$



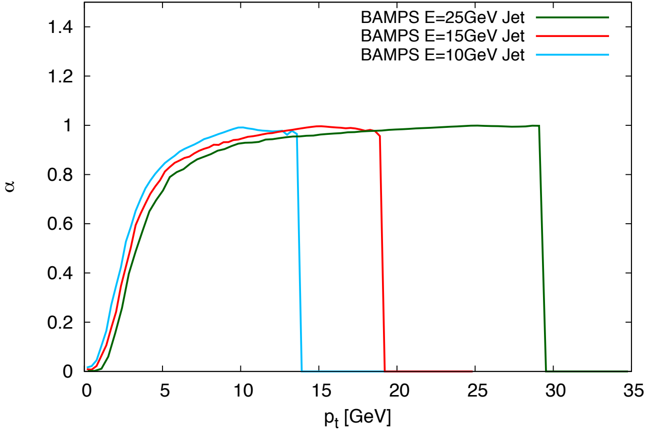
Angular distribution of jet produced photons



- Quark jet produced photons are predominantly collinear ($\rightarrow$ Jet-γ-conversion)
- Gluon jet produced photons are nearly isotropic (thermal source)

Momentum anisotropy

$$\alpha = \frac{p_x^2 - p_y^2}{p_x^2 + p_y^2}$$



Outlook

- $2 \to 3$ bremsstrahlung processes
- Realistic jet distributions f_{jet} according to jet spectra
- Negative photon v_2 due to jet-γ-conversion
- Expanding heavy-ion collisions

Summary

- Photon spectra of quark jets highly peaked at jet energy $\rightarrow$ Jet-γ-conversion
- Photons produced by gluon jets have a momentum and angle distribution similar to thermal particles