High Momentum Dilepton Production from Jets in a Quark-Gluon Plasma

Simon Turbide

McGill University

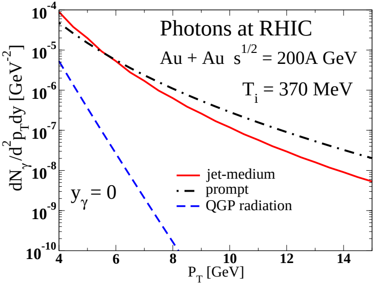
Quark Matter, November 14-20 2006

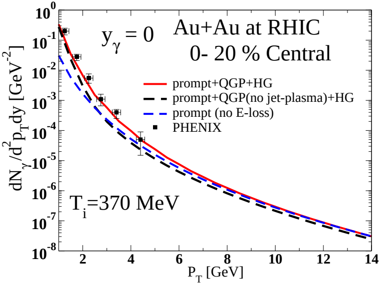
Motivations

- High-p_T suppression explained by the quenching of jets in the dense medium.
- This suggest electromagnetic interactions of jets as an important source of photons.
- It has been calculated that jet-medium was the dominant mechanism for real photons around $p_T = 4$GeV. **Fries, Muller, Srivastava, Phys.Rev.Lett.90, 132301(2003), Turbide, Gale, Jeon, Moore, Phys.Rev. C72, 014906(2005)**.

Real direct photons at RHIC with jet-plasma

Turbide, Gale, Jeon, Moore, Phys.Rev. C72, 014906(2005)





Turbide, Gale, Jeon, Moore, Phys.Rev. C72, 014906(2005).

Motivations

- We present here the calculations for virtual photons produced from jet-medium interactions.

REFERENCE:

Turbide, Gale, Srivastava, Fries, Phys.Rev. C74, 014903(2006).

Outline

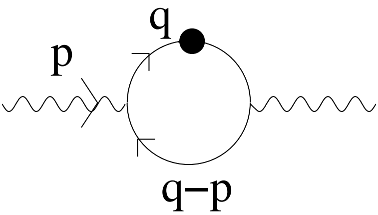
1. Non-collinear dilepton production from jets
2. In-medium bremsstrahlung from jets
3. In-medium evolution of jets
4. Predictions for RHIC and LHC
5. Conclusion

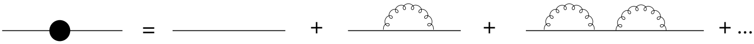
Dilepton production from thermal field theory (TFT)

- From finite-temperature field theory, the dilepton production rate is given by

$$\frac{dR^{e^+e^-}}{d^4p} = \frac{\alpha}{12\pi^4 M^2}\frac{\mathrm{Im}\Pi_\mu^{R\mu}}{1-e^{E/T}}$$

- In the hard-thermal loops (HTL) formalism, the photon self-energy at leading order in QGP is ($E \gg T$)





Spectral density of quarks in the HTL formalism

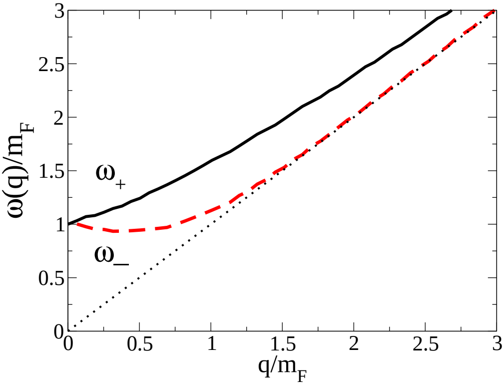
- The resummed quark propagator is

$$S_D(q) = \frac{\gamma^0 - \hat{\gamma}\cdot\hat{\mathbf{q}}}{2D_+(q)} + \frac{\gamma^0 + \hat{\gamma}\cdot\hat{\mathbf{q}}}{2D_-(q)}$$

- The spectral density is expressed as

$$\begin{aligned}\rho_\pm(\omega,|\vec{q}\,|) &= -2\,\mathrm{Im}\frac{1}{D_\pm(iq_0,|\vec{q}\,|)} \\ &= -2\pi\frac{\omega^2-|\vec{q}\,|^2}{2m_F^2}\sum_{a=\pm}\delta\left(\omega - a\,\omega_\pm(|\vec{q}\,|)\right) \quad \text{(pole)} \\ &\quad -2\pi\beta_\pm\left(\omega,|\vec{q}\,|\right)\Theta\left(|\vec{q}\,|^2-\omega^2\right) \quad \text{(cut)}\end{aligned}$$

Dispersion relation of fermionic modes in HTL



- At high q, plasminos (ω_-) decouple from the plasma:

$$\rho_- \propto \frac{\omega_-^2 - q^2}{2\,m_F^2} \to 0$$

e^+e^- production rate with HTL effects

$$
\begin{aligned}
\frac{dR^{e^+e^-}_{TFT}}{d^4p} = \; & \frac{2\alpha^2}{\pi^2 M^2}\sum_f \left(\frac{e_f}{e}\right)^2 \int_0^\infty 2\left|\vec{q}\right|^2 d\left|\vec{q}\right| \int \frac{d\Omega}{(2\pi)^3} \\
& \sum_{a=\pm}\Bigg[f_{FD}(\omega_a) f_{FD}(|\overrightarrow{q}-\overrightarrow{p}|)\frac{\omega_a^2-\left|\vec{q}\right|^2}{2m_F^2} \\
& \times\delta(E-\omega_a-|\overrightarrow{q}-\overrightarrow{p}|)(1+a\,\hat{\mathbf{q}}\cdot\hat{\mathbf{k}})\Theta(|\overrightarrow{q}-\overrightarrow{p}|-|\vec{q}|) \\
& +\int_{-\infty}^{\infty} d\omega f_{FD}(\omega) f_{FD}(|\overrightarrow{q}-\overrightarrow{p}|)\delta(E-\omega-|\overrightarrow{q}-\overrightarrow{p}|) \\
& \times\Theta(|\overrightarrow{q}-\overrightarrow{p}|-|\vec{q}|)\;\beta_a(\omega,|\vec{q}|)(1+a\,\hat{\mathbf{q}}\cdot\hat{\mathbf{k}})\Bigg]
\end{aligned}
$$

- We have not integrated yet over f_{FD}, to allow latter a $f_{FD} \rightarrow f_{jet}$ substitution.

Dilepton production from relativistic kinetic theory (KT)

- The production rate for a process $1 + 2 \to e^+e^- + 3 + ...$ is

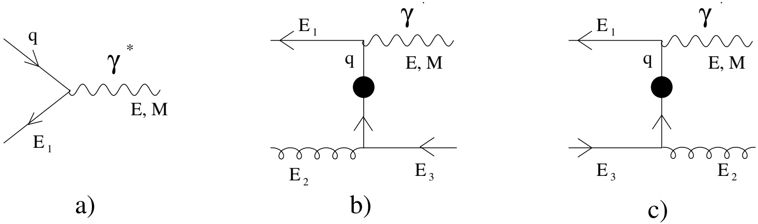
$$\frac{dR^{e^+e^-}_{KT}}{d^4p} = \frac{2\alpha}{3\pi M^2} \int \frac{d^3p_1}{2(2\pi)^3E_1} \frac{d^3p_2}{2(2\pi)^3E_2} \frac{d^3p_3}{2(2\pi)^3E_3} ...(2\pi)^4$$

$$\delta^4(p_1 + p_2 - p - p_3 - ...) \, |\mathcal{M}|^2 \, \frac{f(E_1)f(E_2)(1 \pm f(E_3))...}{2(2\pi)^3}$$

- dR_{TFT}/d^4p is re-organized to have the form of dR_{KT}/d^4p.
- Then we extract $|\mathcal{M}|^2$.
- We can find the $f(E_i)$ corresponding to incoming particles.

Physical processes

- The processes included in the photon self-energy shown previously are



a) b) c)

- We get the jet-medium interaction by:

$$f_{th}(E_1) = \frac{1}{exp(E_1/T) + 1} \rightarrow f_{jet}(E_1) = \frac{(2\pi)^3}{g_q} \frac{dN^{jet}}{d^3p d^3x}$$

- The jet distribution evolves in time with energy loss

Yield of dileptons in the expanding matter

- The yield of dileptons at midrapidity (mass distribution) is

$$\frac{dN^{e^+e^-}(y_d=0)}{dM^2dy_d} = \int \tau d\tau d^2r_\perp \int dp_T p_T \int dp_z \frac{2\pi}{E_0}\frac{1}{2}\frac{dR^{e^+e^-}(\eta=0)}{d^4p}$$

- The p_T distribution is

$$\frac{dN^{e^+e^-}(y_d=0)}{d^2p_T dy_d} = \int \tau d\tau d^2r_\perp \int dM^2 \int dp_z \frac{1}{E_0}\frac{1}{2}\frac{dR^{e^+e^-}(\eta=0)}{d^4p}$$

Space-time evolution of QGP

- A 1-D Bjorken expansion is assumed, with initial transverse profile

$$T(r,\tau) = T_i \left(\frac{\tau_i}{\tau}\right)^{1/3} \left[2\left(1 - \frac{r^2}{R_\perp^2}\right)\right]^{1/4}$$

- The initial conditions are adjusted by

$$T_i^3 \tau_i = \frac{\pi^2}{\chi(3) g_q} \frac{1}{\pi R_\perp^2} \frac{dN}{dy}$$

- We take the initial conditions

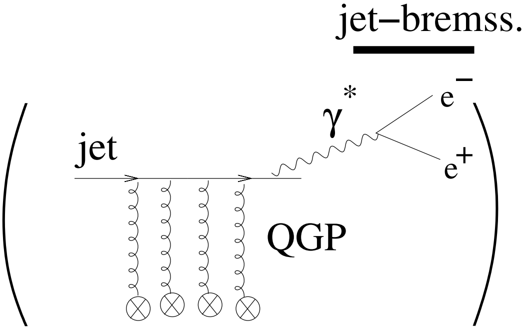
$$T_i = 0.37\,\mathrm{GeV}\,, \quad \tau_i = 0.26\,\mathrm{fm/c}\,.$$

Outline

1. Non-collinear dilepton production from jets
2. In-medium bremsstrahlung from jets
3. In-medium evolution of jets
4. Predictions for RHIC and LHC
5. Conclusion

Bremsstrahlung dileptons

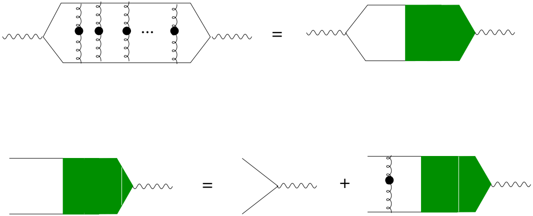
- As for real photons, (Zakharov, JETP Lett. 80, 1 (2004).), jet-bremsstrahlung should be included



- Cross-section dominated by collinear radiations.
  $\rightarrow t_f \sim \lambda$.
- LPM effects must be taken into account.

Bremsstrahlung dileptons

- The photon self-energy, including LPM effects, is written as the solution of a linear integral equation



P.Arnold,G.D.Moore,L. Yaffe,JHEP0111, 057(2001). (γ)
P.Aurenche,F.Gelis,G.D.Moore,H.Zaraket,JHEP 0212,006(2002). (γ^*)

- The quark-dilepton transition Γ rate is extracted, and convolved with the jet-distribution:

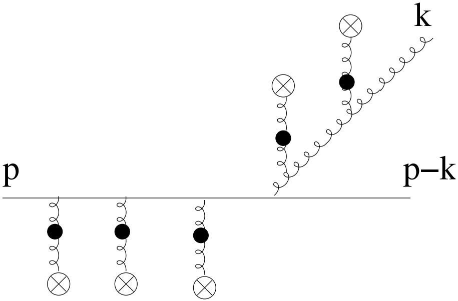
$$\frac{dN^{e^+e^-}}{d^2p_T dy dM^2} = \int dt \int dq_T q_T \frac{dN^{q\bar{q}}_{jet}}{d^2q_T dy} \frac{1}{p_T} \frac{d\Gamma_{q\to q+e^+e^-}}{dp_T dM^2 dt}$$

Outline

1. Non-collinear dilepton production from jets
2. In-medium bremsstrahlung from jets
3. In-medium evolution of jets
4. Predictions for RHIC and LHC
5. Conclusion

Gluon bremsstrahlung

- AMY has been extended to gluon bremsstrahlung
  P.Arnold, G.D.Moore, L.Yaffe, JHEP0206, 030 (2002).
  S. Jeon and G.D. Moore, Phys. Rev C71, 034901 (2005).



- Complete leading order in α_s treatment;
- Fully thermal calculations : scatterers are all dynamic;
- Absorption of thermal gluons and annihilation with thermal partons also included.

Solving the time evolution of jet distribution

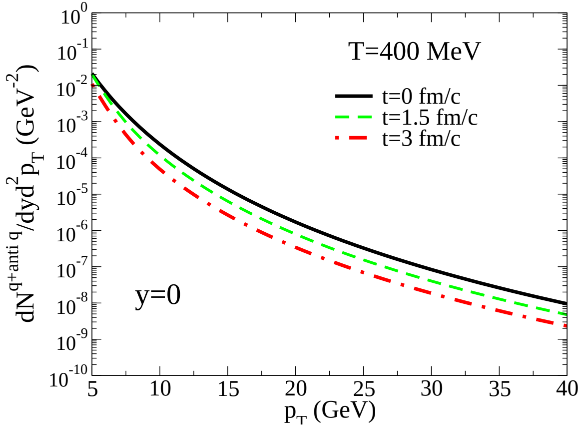
- We assume a Bjorken $y - \eta$ correlation

$$f_{jet}^{q\bar{q}}(\mathbf{x}, \mathbf{p}, t) = \frac{(2\pi)^3 \mathcal{P}(\mathbf{r}_\perp)}{g_q \tau p_T} \frac{dN_{jet}^{q\bar{q}}}{dy d^2 p_T} \delta(y - \eta)$$

- The joint equation for jet distributions are

$$\begin{aligned}
\frac{dN^{q\bar{q}}(p)}{dpdydt} &= \int_k \frac{dN^{q\bar{q}}}{dpdy}(p+k) \frac{d\Gamma_{qg}^{q}(p+k, k)}{dkdt} - \frac{dN^{q\bar{q}}}{dpdy}(p) \frac{d\Gamma_{qg}^{q}(p, k)}{dkdt} \\
&\quad + 2 \frac{dN^{g}}{dpdy}(p+k) \frac{d\Gamma_{q\bar{q}}^{g}(p+k, k)}{dkdt} , \\
\frac{dN^{g}(p)}{dpdydt} &= \int_k \frac{dN^{q\bar{q}}}{dpdy}(p+k) \frac{d\Gamma_{qg}^{q}(p+k, p)}{dkdt} + \frac{dN^{g}}{dpdy}(p+k) \frac{d\Gamma_{gg}^{g}(p+k, k)}{dkdt} \\
&\quad - \frac{dN^{g}}{dpdy}(p) \left(\frac{d\Gamma_{q\bar{q}}^{g}(p, k)}{dkdt} + \frac{d\Gamma_{gg}^{g}(p, k)}{dkdt} \Theta(2k - p) \right) .
\end{aligned}$$

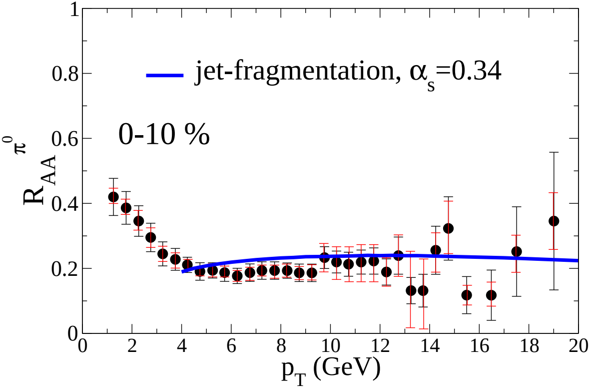
Time evolution of $q + \bar{q}$ in a stationary QGP



- Jet-quenching less important at low-p_T, due to absoption of thermal gluons.

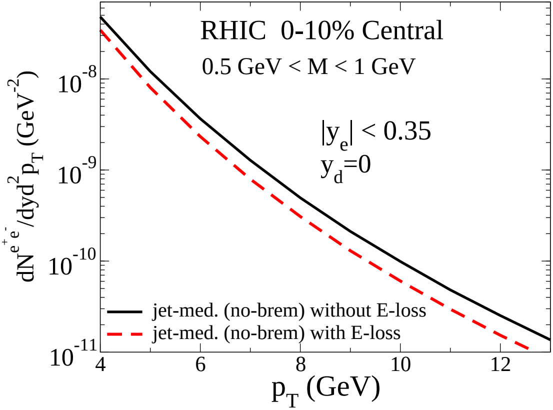
R_{AA} for π^0

- The strength of jet-quenching in AMY is adjusted by R_{AA} at high-p_T



- The parameter in AMY is α_s: we set α_s=0.34

Jet-quenching effect on dileptons from jet-plasma



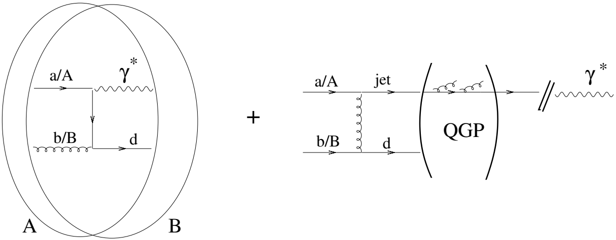
- While jet E-loss reduces high-p_T π^0 by a factor $\sim 4-5$, it reduces the dilepton yield by a factor $\sim 1.4-1.6$. **Jet has to cross all the medium before producing π^0.**

Outline

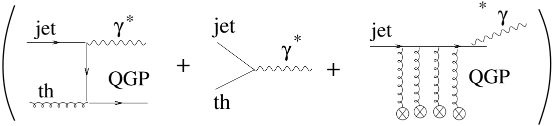
1. Non-collinear dilepton production from jets
2. In-medium bremsstrahlung from jets
3. In-medium evolution of jets
4. Predictions for RHIC and LHC
5. Conclusion

Sources of high-p_T dileptons after B.Gr. substraction

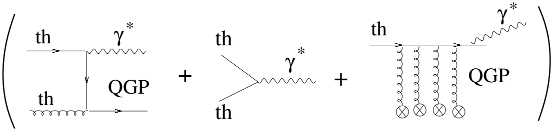
DRELL–YAN



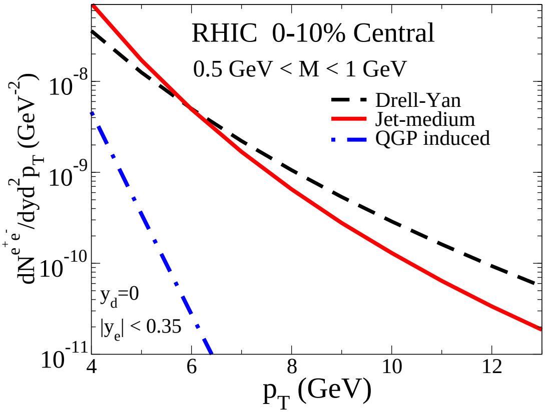
JET–MEDIUM



QGP–INDUCED



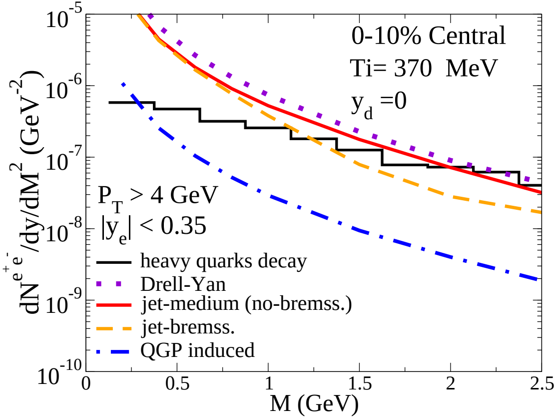
High-p_T dilepton production in Au-Au at RHIC



- Jet-medium contribution is dominant around $p_T = 4$ GeV.
- Interaction of jets with medium seems to be as important for virtual than for real photons.

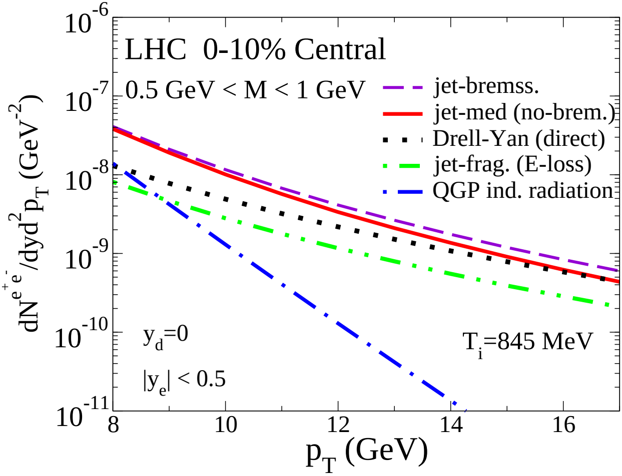
Dilepton mass distribution in Au-Au at RHIC

- An estimate (no energy-loss) of the background coming from heavy quark is shown:



- At high-p_T and low invariant mass, experimental detection of jet-medium contribution should be feasible.

Dileptons at LHC



- Jet-medium interactions more important than Drell-Yan

Conclusion

- Dilepton production from jet-plasma interaction is the dominant mechanism at low-M and $p_T \sim 4$ GeV.
- Advantage of dileptons over real photons : dilepton contribution from jet-plasma is as important as background.
- Study of electromagnetic signals from jets provides a complementary tool to high-p_T mesons suppression, for informations about the dynamical evolution and the size of the dense and hot medium created at RHIC.

Thanks to the collaborators:
C. Gale, D.K. Srivastava and R.J. Fries.