Radiative energy loss in the absorptive QGP

Marcus Bluhm

Laboratoire SUBATECH, Nantes

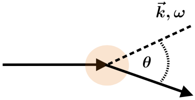
with P. B. Gossiaux, T. Gousset, J. Aichelin

Hard Probes 2012, Cagliari, Italy, May 28$^{\mathrm{th}}$, 2012

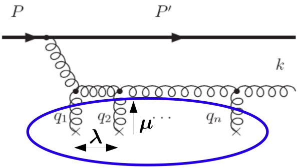
based on: MB, P. B. Gossiaux, J. Aichelin, arXiv:1106.2856
MB, P. B. Gossiaux, T. Gousset, J. Aichelin, arXiv:1204.2469

Introduction

- formation of gluon bremsstrahlung is a *quantum phenomenon*
- *quantum decoherence* of parton and radiated gluon takes time
- **formation time**: parton-gluon transverse separation is of order of gluon-transverse wavelength: $\tau_f \simeq \frac{\omega}{k_\perp^2} \simeq \frac{1}{\omega\theta^2}$

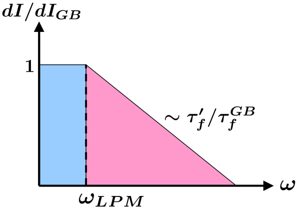


- in case $\tau_f \gg \lambda$ (parton mean free path in medium), $N_{coh} \simeq \tau_f/\lambda$ scatterings contribute coherently to formation of radiation



Introduction

- gluon rescatterings alter the formation time to $\tau_f' \simeq \sqrt{\omega/\hat{q}}$, where $\hat{q} \sim \mu^2/\lambda$ (*quenching parameter*)
- consequence: radiation spectrum reduced compared with spectrum due to independent successive scatterings (**LPM effect**)



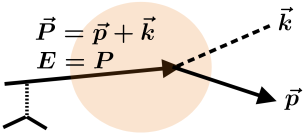
- gluon dispersion relation that is not *light-like* (e.g. due to medium polarization) alters the probability of bremsstrahlung production at soft ω (**TM effect** analogon)

Kampfer+Pavlenko (2000), Djordjevic+Gyulassy(2003)

Formation time in QCD

cf. P. Arnold Phys. Rev. D **79** (2009) 065025

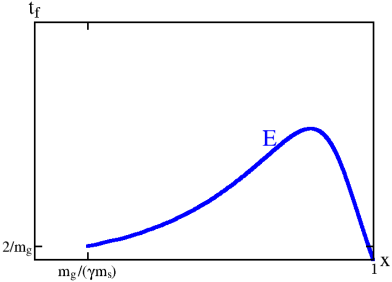
estimate for formation time t_f from *off-shellness* of intermediate particle



formation time: quantum mechanical duration of off-shell "state"

$$t_f^2 \frac{(1-x)\hat{q}}{2xE} + t_f \frac{[x^2 m_s^2 + m_g^2(1-x)]}{2x(1-x)E} \simeq 1$$

assuming $\langle k_\perp^2 \rangle \simeq \hat{q} t_f$
$x = \omega / E$



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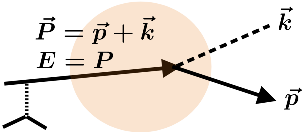

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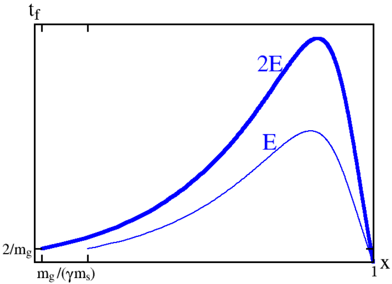
- t_f increases with E



Qualitative discussion

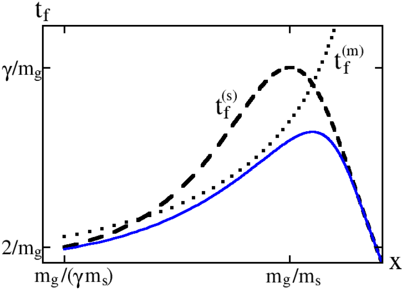
Qualitative behaviour can be discussed via an approximate solution of

$$t_f^2 \frac{(1-x)\hat{q}}{2xE} + t_f \frac{[x^2 m_s^2 + m_g^2(1-x)]}{2x(1-x)E} \simeq 1$$

by defining

$$t_f^{(s)} = \frac{2x(1-x)E}{x^2 m_s^2 + m_g^2(1-x)}$$

$$t_f^{(m)} = \sqrt{\frac{2xE}{(1-x)\hat{q}}}$$



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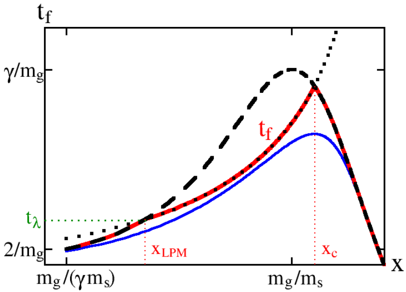

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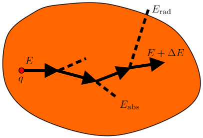
and assuming

$$t_f = \min(t_f^{(s)}, t_f^{(m)})$$

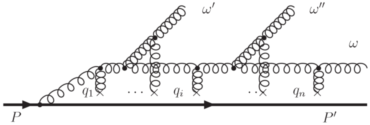
- LPM-suppression for $x \geq x_{LPM} \sim m_g^4/(\hat{q}E)$ when $t_f \geq t_\lambda$

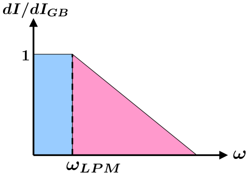
Damping of gluon radiation

- assume gluons to be **time-like** excitations with in-medium effective *mass* m_g and *width* (associated with damping rate Γ)



- damping of already formed gluons *"trivial"*
- Is it possible that damping mechanisms influence the formation of radiation itself?
- mechanisms: pair creation or secondary bremsstrahlung $\rightarrow$ in pQCD (BDMPS-like): $\Gamma \sim g^4 T$



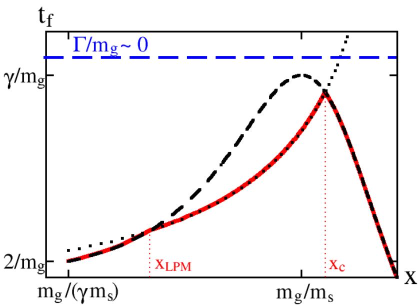


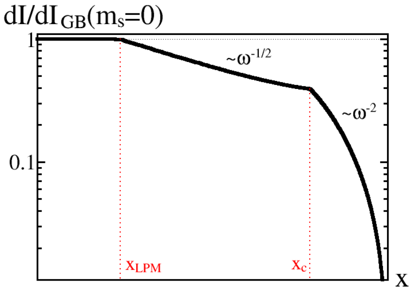
- higher order effect
- associated **damping time** $t_d \sim 1/\Gamma$: formation influenced if $t_d \lesssim t_f$

Influence on the radiation spectrum

exploit spectra scaling $\frac{dI}{dI_{GB}} \simeq \frac{\tilde{t}_f}{t_{GB}}$: $\tilde{t}_f = \min(t_f^{(s)}, t_f^{(m)}, t_d)$, $t_{GB} \simeq \frac{\omega}{m_g^2}$

negligible damping:





- LPM-suppression for $x_{LPM} \le x \le x_c \sim (\hat{q}E/m_s^4)^{1/3}$

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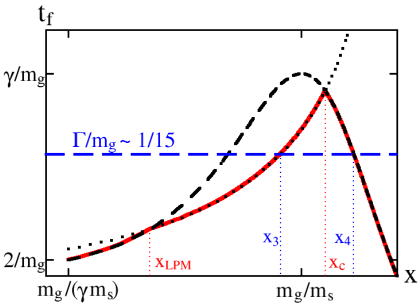
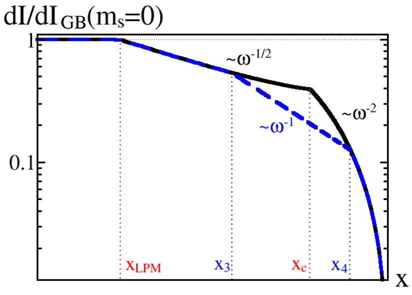
intermediate damping:





- development of a NEW additional regime due to gluon damping between $x_3 \sim \hat{q}/(\Gamma^2 E)$ and $x_4 \sim \Gamma E/m_s^2$

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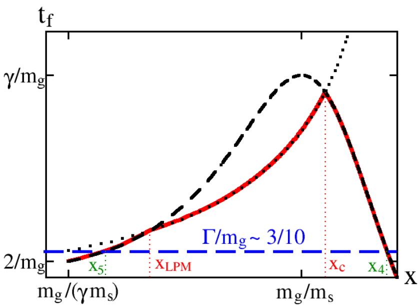
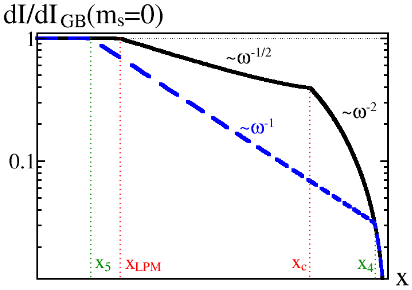
large damping:



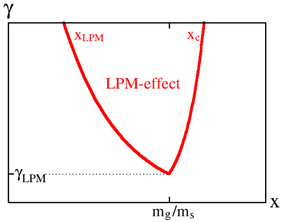


- development of a NEW additional regime due to gluon damping between $x_5 \sim m_g^2/(\Gamma E)$ and $x_4 \sim \Gamma E/m_s^2$
- for fixed E, increasing Γ influences shape of the spectrum (at formation point)

Behaviour with increasing energy

- for fixed Γ, effect should show up with increasing $\gamma = E/m_s$

negligible
$\Gamma/m_g = 0$



$\gamma_{LPM} \sim m_g^3/\hat{q}$

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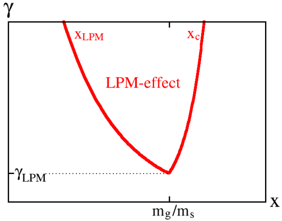
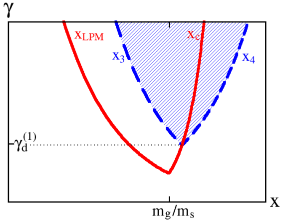


$\gamma_{LPM} \sim m_g^3/\hat{q}$

intermediate
$\Gamma/m_g < \hat{q}/m_g^3$



$\gamma_d^{(1)} \sim \sqrt{\hat{q}/\Gamma^3}$

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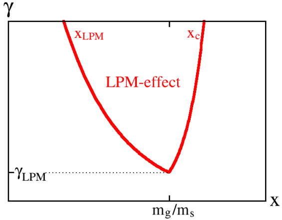

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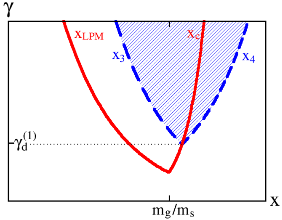
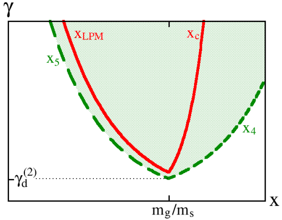


$\gamma_d^{(1)} \sim \sqrt{\hat{q}/\Gamma^3}$

large

$\Gamma/m_g > \hat{q}/m_g^3$



$\gamma_d^{(2)} \sim m_g/\Gamma$

- both increasing E and Γ make effect more pronounced

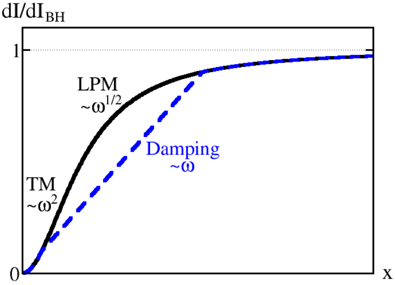
Remarks

- this qualitative discussion indicates that gluon damping mechanisms might be of relevance for parton energy loss
- used parameter values (or ranges) in shown plots:
  $\rightarrow m_s = 1.5$ GeV
  $\rightarrow m_g = 0.6$ GeV
  $\rightarrow \Gamma / m_g \simeq 0 \ldots 1/3$
  $\rightarrow \hat{q} = (0.1 \ldots 2)$ GeV^2/fm
- more quantitative statements (impact on observables) in talk by P. B. Gossiaux on 28$^{\text{th}}$ May, Parallel IIA: Heavy flavour, 17:50

Absorptive QED-plasma

$\rightarrow$ investigation of photon damping effects for $\omega \ll E$:

- difference to formation time in QCD: $t_f^{(m)} \simeq \sqrt{E/(\hat{q}x)}$
  $\rightarrow$ LPM-suppression of spectrum in soft ω-region
- photon damping leads to competing time scale $t_d \sim 1/\Gamma$
- spectra scaling ($t_{BH} \simeq E^2/(\omega M^2)$): $\dfrac{dI}{dI_{BH}} \simeq \dfrac{\tilde{t}_f}{t_{BH}}$



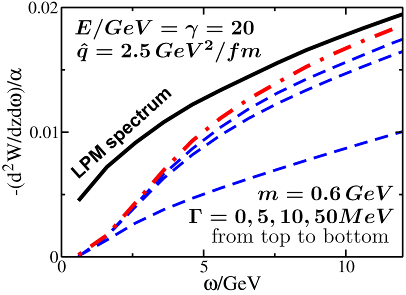
Absorptive QED-plasma

$\longrightarrow$ investigation of photon damping effects for $\omega \ll E$:

- complex medium index of refraction $n(\omega) = n_r(\omega) + in_i(\omega)$
- energy loss spectrum per unit length:

$$-\frac{d^2W}{dz d\omega} \simeq \frac{\alpha}{3\pi}\frac{\hat{q}}{E^2}\int_0^\infty d\bar{t}\, e^{-\omega|n_i|\beta\bar{t}}\,\omega\sin\left[\omega\bar{t}\,(1-|n_r|\beta) + \frac{\omega|n_r|\beta\;\hat{q}}{6E^2}\,\bar{t}^2\right]$$

- exponential damping factor $\longrightarrow$ damping time scale
- for $n_r = 1$, $n_i = 0$ reduced to LPM radiation spectrum



Conclusions

- qualitative discussion of possible effects of gluon damping on radiative energy loss of partons
  $\longrightarrow$ development of new, mass-independent scale t_d
  $\longrightarrow$ reduction of radiation spectrum stronger than in LPM-regime
  $\longrightarrow$ region of effect increases with Γ and/or E
- damping medium hampers formation of hard(er) gluons in favour of soft gluons
- some interesting features:
  $\longrightarrow$ damped gluons accumulate within t_d average angle
  $\theta_d \sim (\hat{q}/\Gamma\omega^2)^{1/2} \ll \theta_f \sim (\hat{q}/\omega^3)^{1/4}$
  $\longrightarrow$ in case $1/\Gamma < L$, averaged radiative energy loss of parton proportional to L/Γ
- in general, Γ should be ω-dependent