Radiative energy loss and damping effects

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Energy loss

- quark and gluon energy loss is a central topic in ultra-relativistic heavy ion collisions

- collisional and radiative

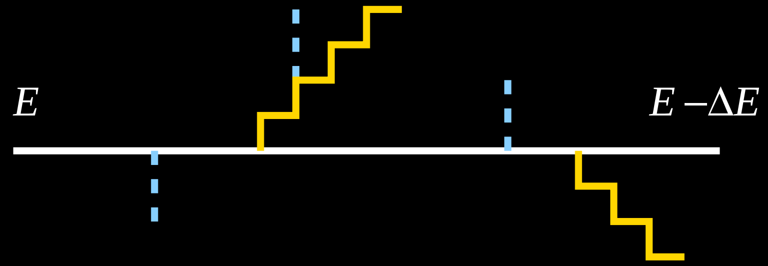
- Bethe-Heitler regime, LPM effect. . .

. . . and damping

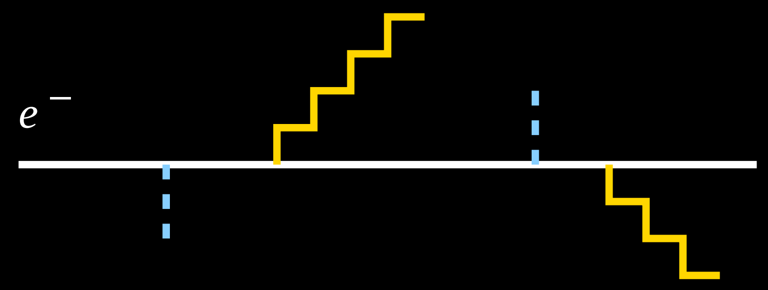
radiation and energy loss

radiative energy loss of quarks or gluons

an energetic parton in a hot medium ($E \gg T$)



in electrodynamics



relativistic electron

- Bethe-Heitler spectrum

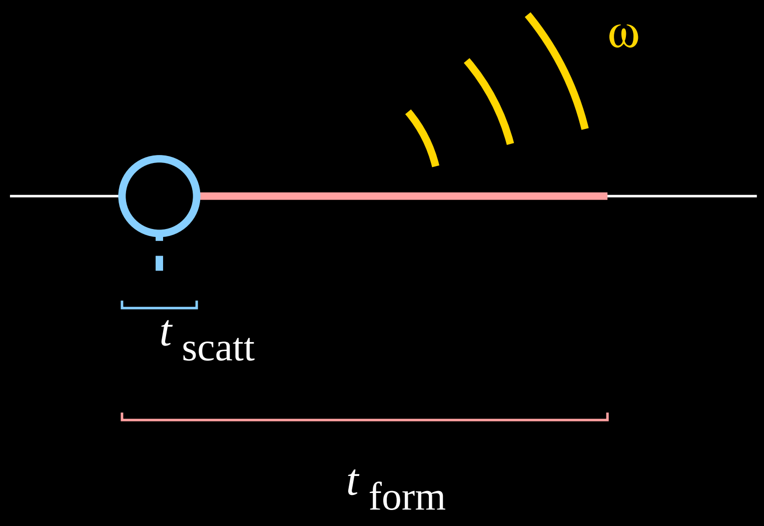
$\longrightarrow$ radiation loss in matter

$X_0 =$ radiation length

length scale on which e^- looses its energy (on average)

coherence

to be accommodated with another essential of bremsstrahlung

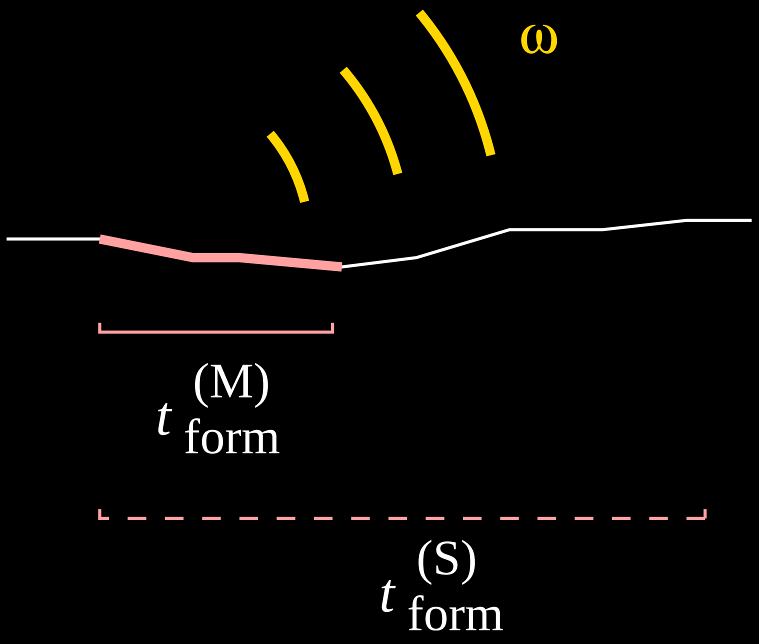


formation time $<$ radiation length

$(v \approx c = 1)$

breaks down at small ω and large E

including multiple scattering: LPM effect



e^- multiple scattering speeds up decoherence

$\Rightarrow$ emission process cannot occur at full rate

radiation spectrum

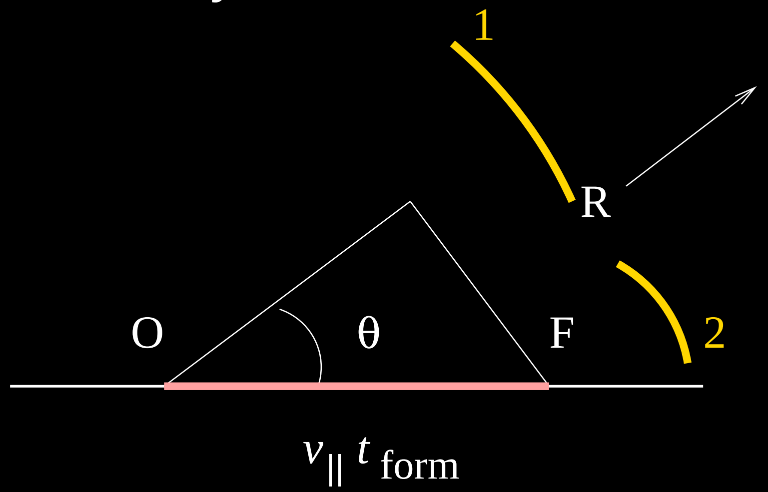
$dW/d\omega$ for an energetic parton using the scaling behavior

$$dW/d\omega \propto t_{\rm form}$$

specifically

$$\frac{dW}{d\omega} = \frac{t_{\rm form}}{t_{\rm BH}} \times \frac{dW_{\rm BH}}{d\omega}$$

$t_{\rm form}$? $\longrightarrow$ diffraction theory



formation time

$$\Delta\varphi(t,R) = \omega(t - t_{\rm form}) - \vec{k}\cdot\overrightarrow{FR} - \omega(t-0) + \vec{k}\cdot\overrightarrow{OR}$$

$$\Delta\varphi = -\omega\, t_{\rm form} + \underbrace{\vec{k}\cdot\overrightarrow{OF}}_{k_{||}\, v_{||}\, t_{\rm form}}$$

$$k_{||} = n\frac{\omega}{c}\cos\theta, \quad v_{||} = v\cos\theta_s$$

$$|\Delta\varphi| \equiv 1 \rightarrow t_{\rm form}$$

$$t_{\rm form} = \frac{1}{\omega\ |1 - nv\cos\theta_s\cos\theta|}$$

large formation time for ultrarelativistic particles, and small angles, and n close to 1

competing effects

1. wave propagation in medium (no damping)

$$n(\omega) = \sqrt{1 - \frac{m_g^2}{\omega^2}}$$

competing effects

1. wave propagation in medium (no damping) : n-driven regime $(v\cos\theta_s \to 1, \theta \to 0)$

$$t_1 = \frac{1}{\omega(n-1)} \sim \frac{2\omega}{m_g^2}$$

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2. (gluon) multiple scattering

$$k_{||}(t) = n\omega(1 - \hat{q}\, t/\omega^2)$$

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2. (gluon) multiple scattering : multiple-scattering-driven regime $(n \to 1, v\cos\theta_s \to 1)$

$$t_2 = \frac{1}{\omega(\hat{q}\, t_2/\omega^2)} = \sqrt{\frac{\omega}{\hat{q}}}$$

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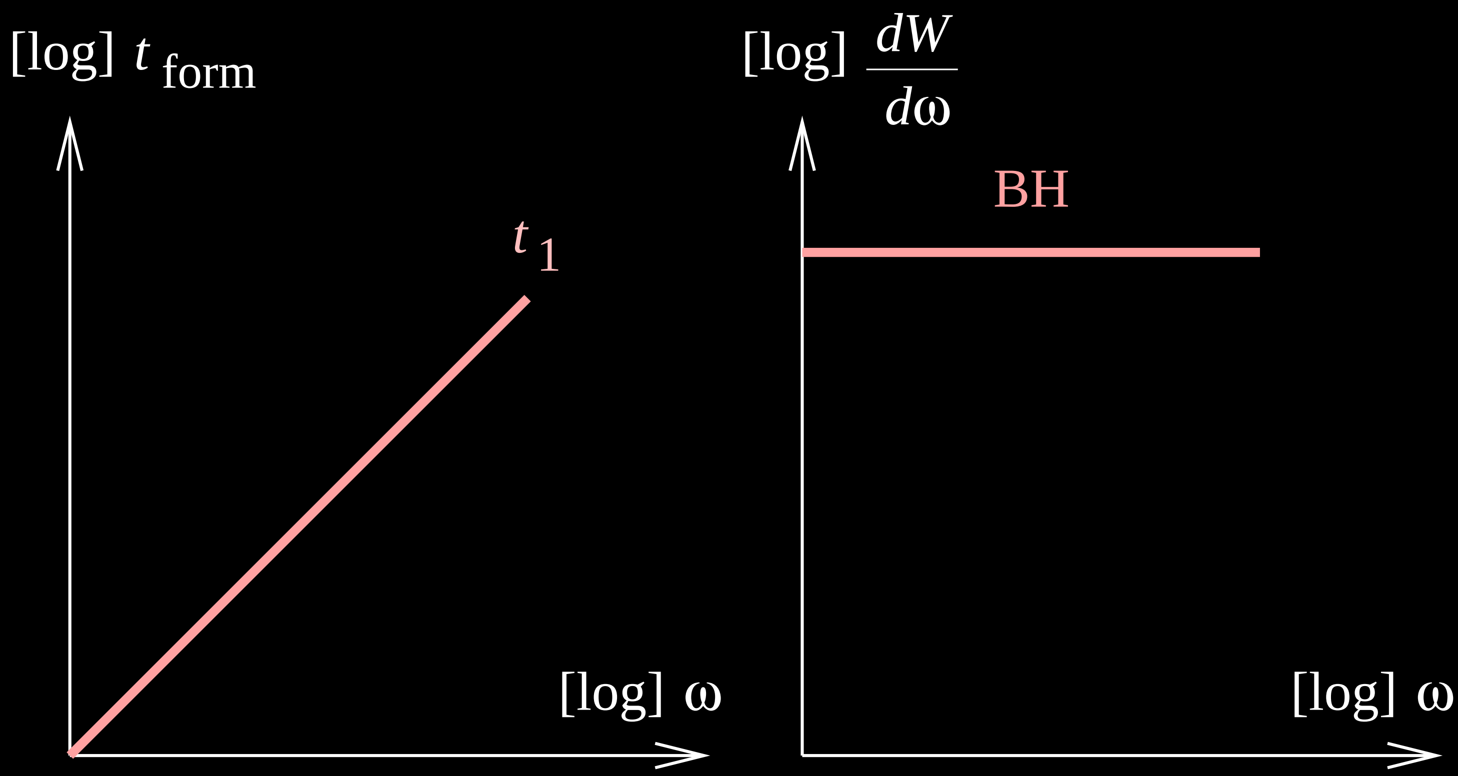
3. damping

1 and 2



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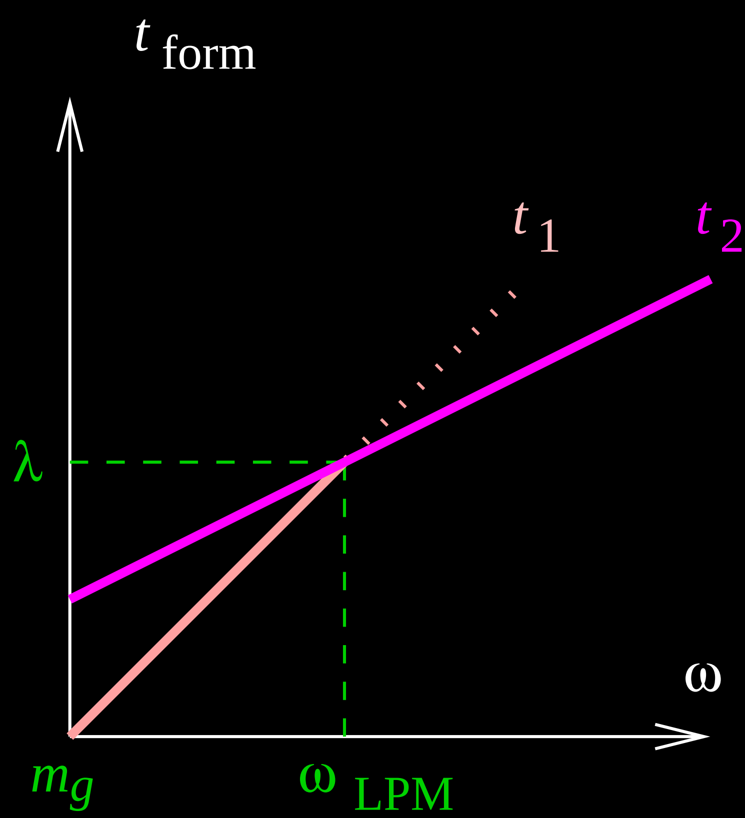

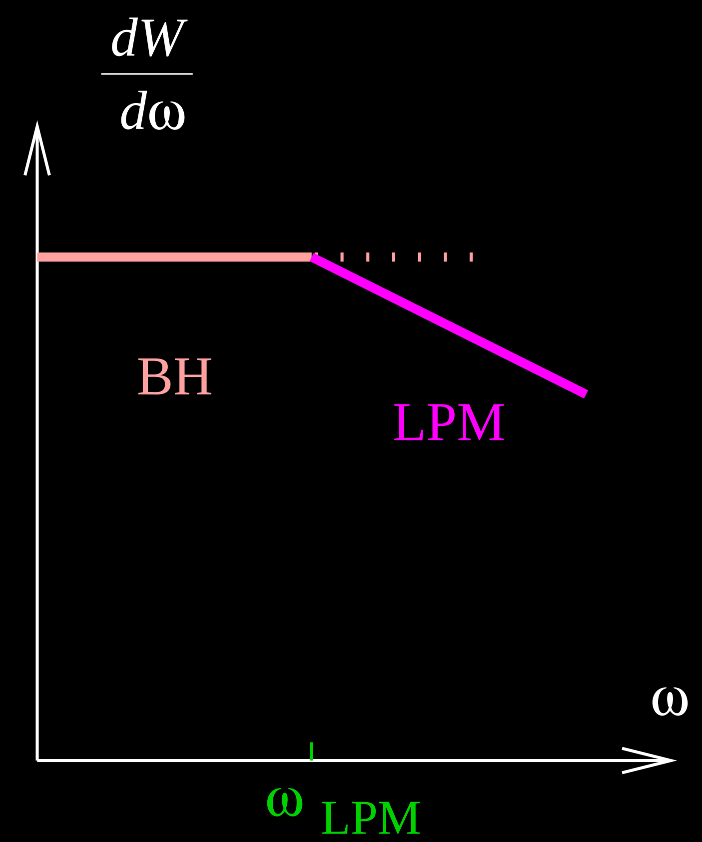

$$t_1 = t_2 \quad \Rightarrow \quad \omega_{\rm LPM} = \frac{m_g^4}{\hat{q}}$$ at which $t_1 = m_g^2/\hat{q} = \lambda$

$+$ damping

$\sim e^{-\Gamma t} \Rightarrow$ damping regime when $t_{\mathrm{form}} \gg 1/\Gamma$

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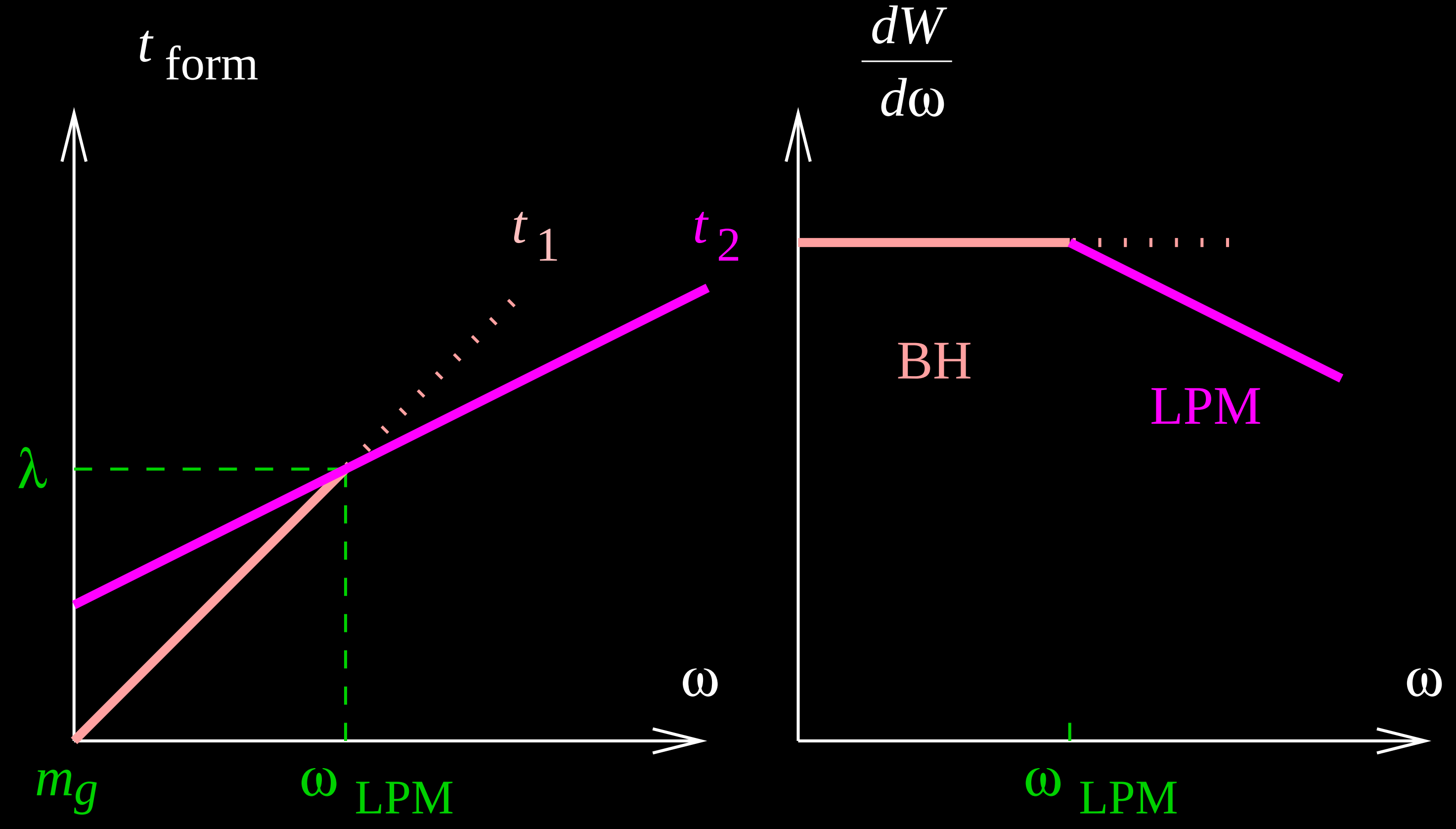

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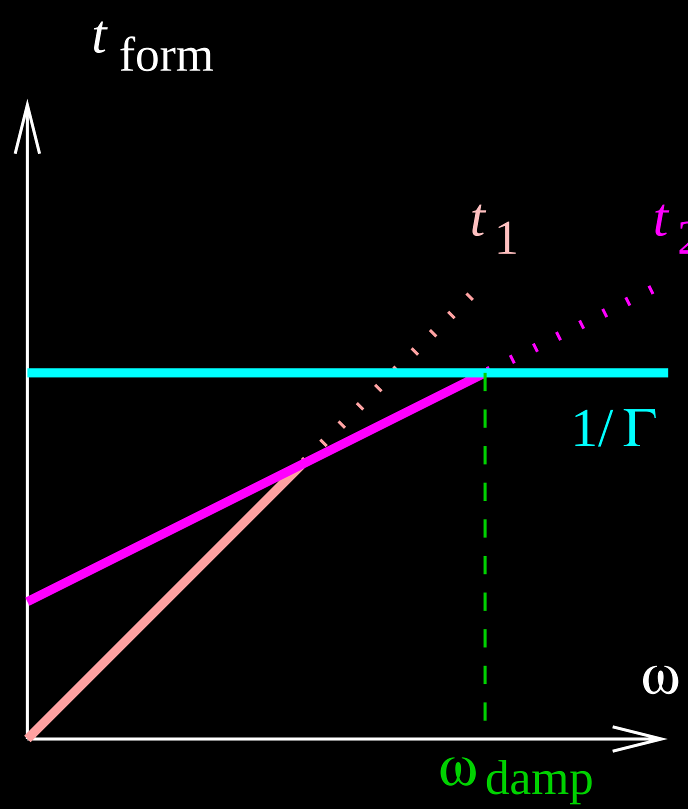
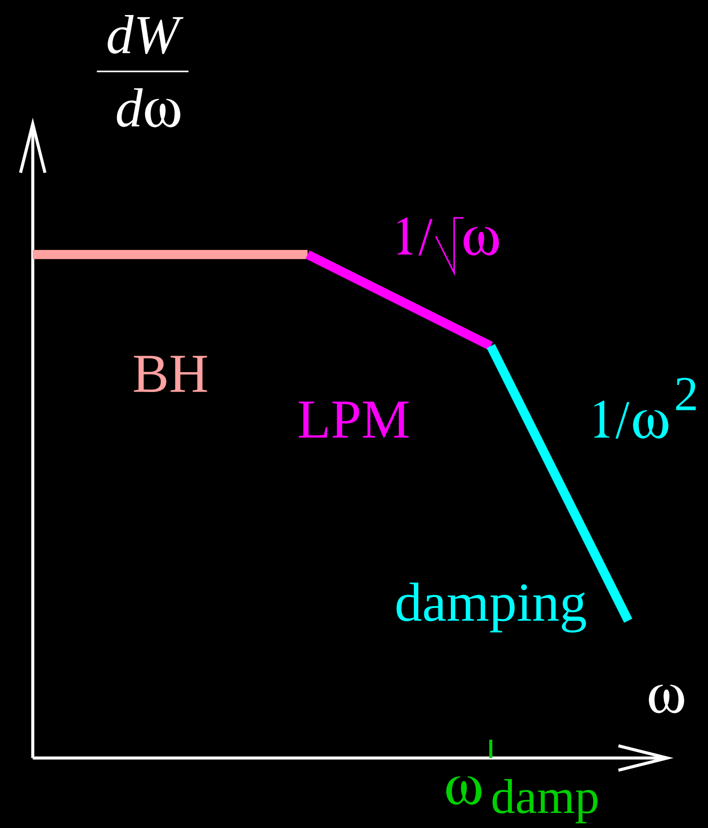
$\sim e^{-\Gamma t} \Rightarrow$ damping regime when $t_{\text{form}} \gg 1/\Gamma$





$$t_2 = 1/\Gamma \quad \Rightarrow \quad \omega_{\text{damp}} = \frac{\hat{q}}{\Gamma^2}$$

discussion

- detailed kinematic- (E, ω) and parameter- $(m_Q, \hat{q}, m_g, \Gamma)$ space exploration $\rightarrow$ arXiv:1204.2469
- $\lambda = O\left(1/(g^2T)\right)$ and $\Gamma = O\left(g^2T\right)$

$$\frac{1}{\Gamma} \sim \lambda$$

- is data (jet quenching) compatible with $\Gamma \sim \frac{1}{\lambda}$?
- quantitatively?
- microscopic origin of Γ?

goals

- confronting the above reasoning with a true calculation
- trace back formation time and damping factor
- compare computed spectrum with the formation-time scaling law

$$\frac{dW}{d\omega} = \frac{t_{\rm form}}{t_{\rm BH}} \times \frac{dW_{\rm BH}}{d\omega}$$

(with ED-type formation times)

from PRL107-265004

energy loss in an absorptive dielectric medium

$$n^2(\omega) = 1 - \frac{m^2}{\omega^2} + 2i\frac{\Gamma}{\omega}$$

using linear response theory $\rightarrow$ mechanical work on charge

$$W = 2\,\mathrm{Re}\left(\int d^3\vec{r}' \int d\omega\, \vec{E}(\vec{r}', \omega) \cdot \vec{j}(\vec{r}', \omega)^*\right)$$

$$\frac{d^2W}{dz d\omega} \simeq -\mathrm{Re}\left(\frac{2i\alpha}{3\pi}\frac{\hat{q}}{E^2}\int_0^\infty d\bar{t}\,\frac{\omega n^2}{\epsilon}\,\exp\left[-\omega|n_i|\beta\bar{t}\right] \times \cos(\omega\bar{t})\,\exp\left[i\omega n_r\beta\bar{t}\left(1 - \frac{\hat{q}}{6E^2}\bar{t}\right)\right]\right)$$

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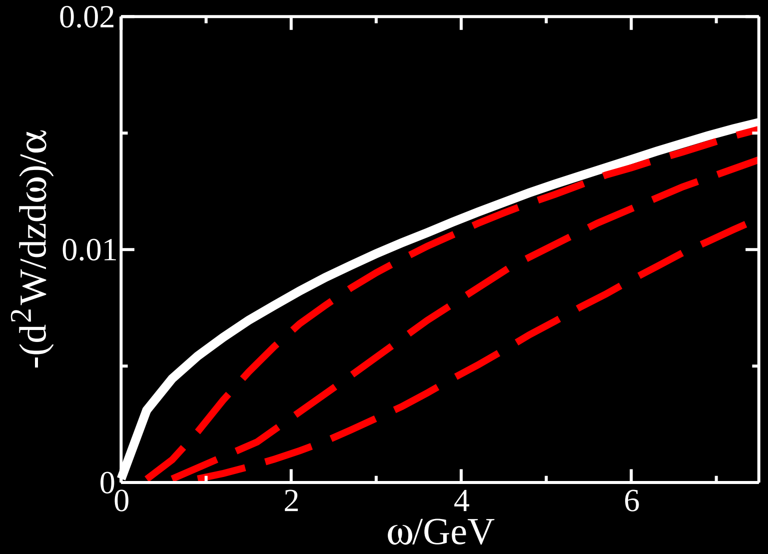
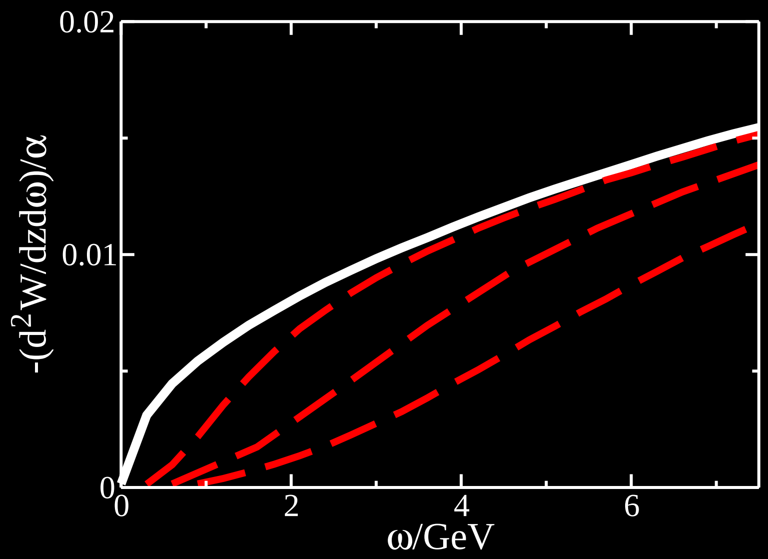
without damping

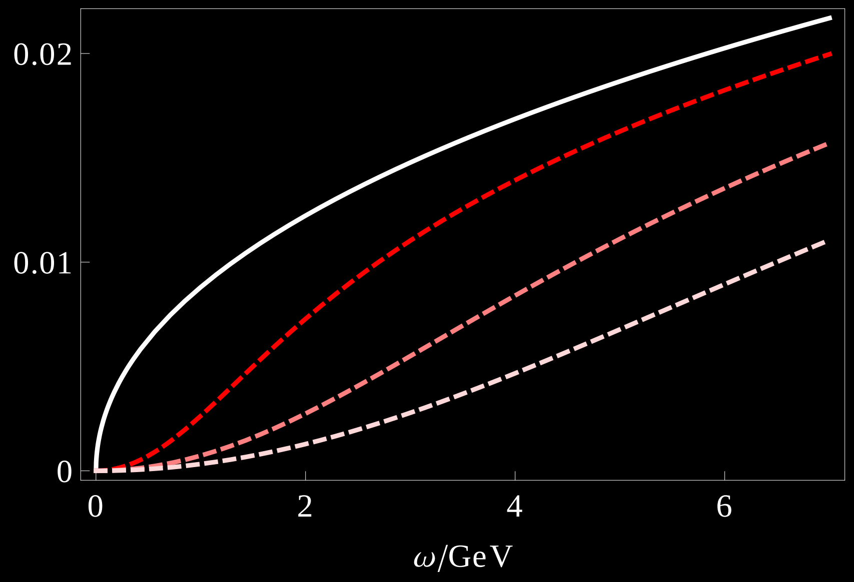


$\Gamma = 0, \quad m = 0, 0.3, 0.6, 0.9$ GeV

$\hat{q} = 2.5$ GeV^2/fm, $E = 20$ GeV, $M = 1$ GeV

without damping





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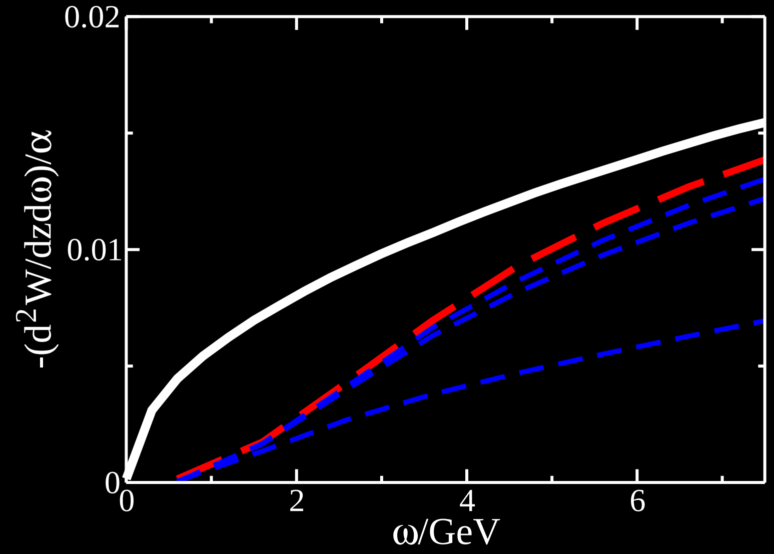
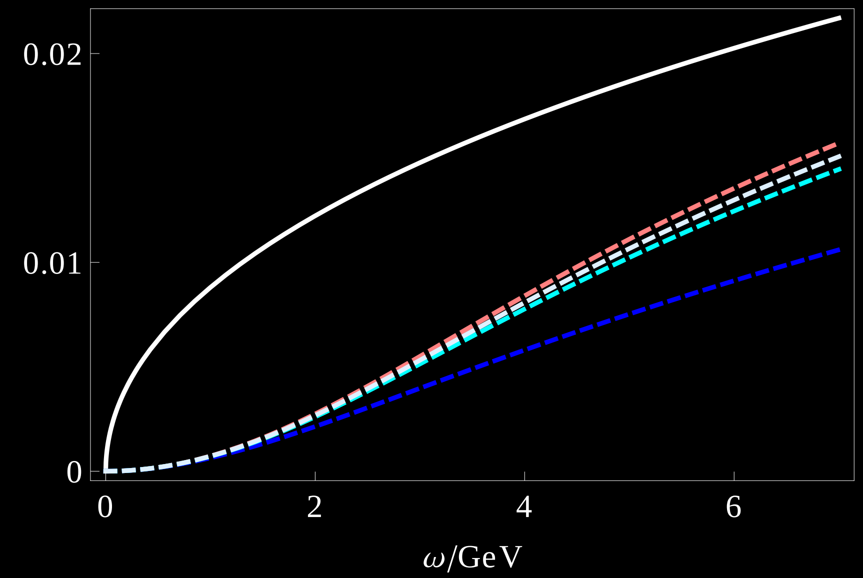
with damping





$m = 0.6$ GeV, $\Gamma = 0, 5, 10, 50$ MeV

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$$\frac{dW}{d\omega} = \frac{t_{\rm form}}{t_{\rm BH}} \times \frac{dW_{\rm BH}}{d\omega}$$

Summary

- Effect of damping on radiative energy loss
- Energy loss spectrum from formation time
  - light parton, heavy quark
  - comparison with complete calculation in ED
- Questions:
  - strength of damping in a QCD plasma?
  - visible effects in quenching?