Marcus Bluhm, Jörg Aichelin and Pol Bernard Gossiaux[1]

Radiative Energy Loss Reduction due to Damping

- The Disappearance of the LPM Effect -

Introduction

- Strong jet quenching and suppression of hadron spectra at high transverse momenta in high-energy nuclear collisions are interpreted as signatures for the formation of a deconfined QCD plasma, in which partons suffer medium-induced energy loss by collisional and radiative processes
- Radiation spectrum of an accelerated charge in a plasma is influenced by the dielectric properties of the medium (**Ter-Mikaelian effect**) [1]
- Color-dielectric modification of the gluon dispersion relation reduces the radiative energy loss [2,3]
- *Damping* of radiated *time-like* excitations in an *absorptive medium* so far not taken into account; damping mechanisms lead to a finite *collisional width* of the excitations

Method

- Study the influence of damping of radiation within the plasma on the radiative energy loss of an energetic charged probe per travelled unit distance
- Following original approach of Landau and Pomeranchuk [4], a classical current for the point-charge with non-constant velocity is considered, where deflections are induced by multiple scatterings: $\vec{j}(\vec{r}\,',t) = q\vec{v}(t)\delta^{(3)}(\vec{r}\,' - \vec{r}(t))$
- Considerations apply in cases, where medium is infinite in size or its size is comparable to the formation length of radiated quanta
- Local approach: Energy loss determined from the medium-induced mechanical work (no disentanglement of *detected* and *absorbed radiation*)

$$W = 2\,Re\left(\int d^3\vec{r}\,' \int_0^\infty d\omega\, \vec{E}(\vec{r}\,',\omega)\,\vec{j}(\vec{r}\,',\omega)^*\right)$$

with electric field determined from Maxwell's equations

$$\frac{1}{\omega\mu(\omega)}\left[k^2\vec{E}_{\vec{k}}(\omega) - \vec{k}(\vec{k}\vec{E}_{\vec{k}}(\omega))\right] - \omega\epsilon(\omega)\vec{E}_{\vec{k}}(\omega) = \frac{iq}{(2\pi)^2}\int dt'\,\vec{v}(t')e^{i\omega t' - i\vec{k}\vec{r}(t')}$$

- Properly defined self-field of the charge gives no contribution to the stopping power of the medium
- Permittivity and permeability depend on frequency only, i.e. no spatial distortion in the plasma is considered, and are *complex* for an absorptive medium: Mechanical work is *sensitive to poles* in the complex momentum plane only
- Different from *collisional energy loss* calculations [5], which are sensitive to *cuts* in the *space-like* region
- Decomposing *complex index of refraction* $n = n_r + in_i$, where $n^2(\omega) = \epsilon(\omega)\mu(\omega)$

$$\frac{dW}{d\omega} = Re\left(\frac{iq^2}{4\pi^2}\int dt \int dt'\,\frac{\omega^2 n^3(\omega)}{\epsilon(\omega)}e^{-i\omega(t-t')}\mathcal{A}(t,t')\right)$$

$$\mathcal{A}(t,t') = \left(\vec{v}(t)\vec{v}(t') + (\vec{\nabla}_g\vec{v}(t))(\vec{\nabla}_g\vec{v}(t'))\right)\frac{e^{i\,sgn(n_i)g}}{g}$$

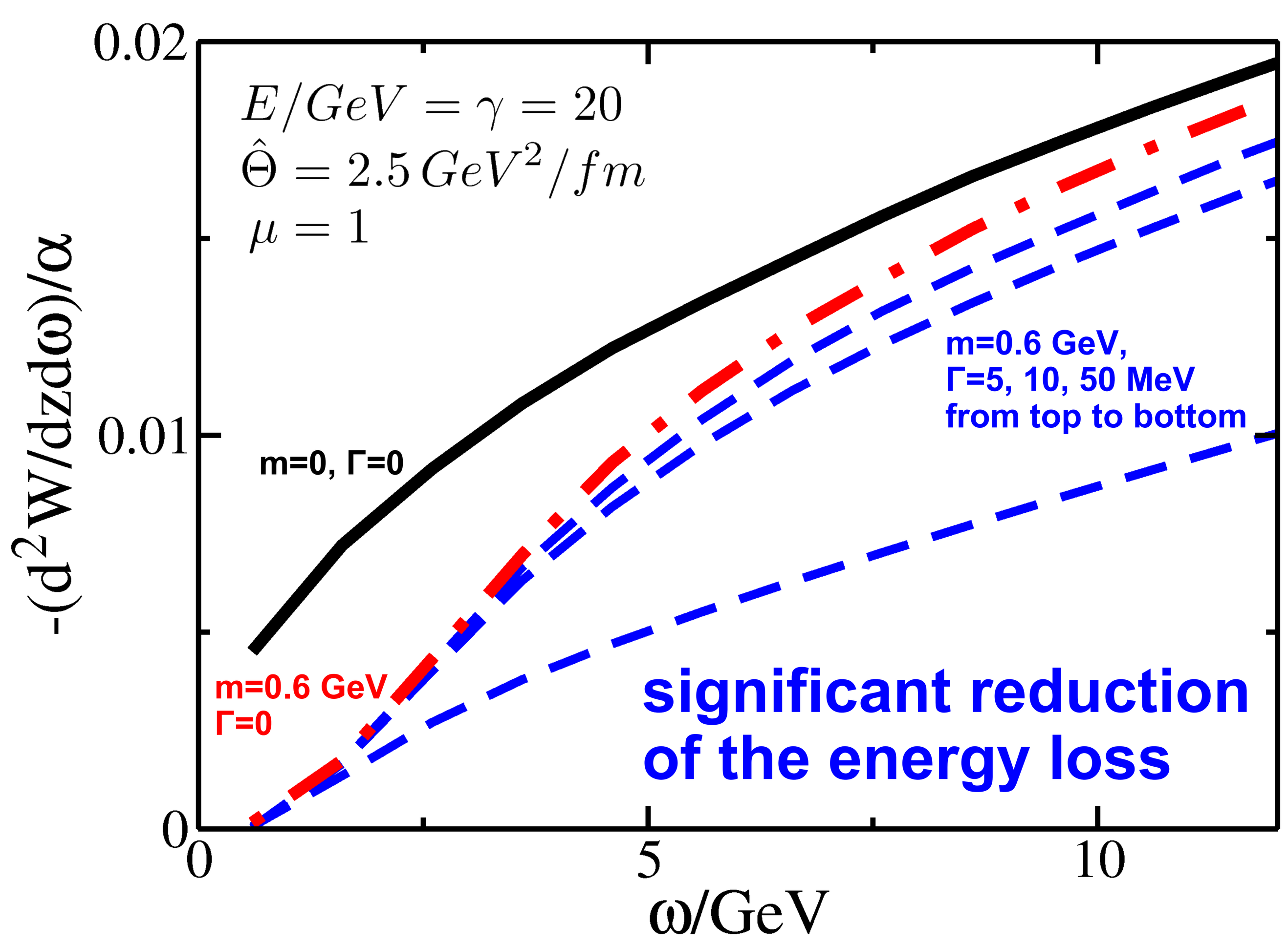
with $\vec{g} = \omega n(\omega)\vec{\Delta r}$

- Essential is the **exponential factor**, which implies *always damping for complex index of refraction*

$$e^{i\,sgn(n_i)g} = e^{i\,sgn(n_i)\Delta r\omega n_r}e^{-\Delta r\omega|n_i|}$$

- Following exactly [4], i.e. omitting action of $\vec{\nabla}_g$ on $1/g$ as well as specifying $\vec{v}(t'+\tilde{t}) = v'\hat{z}\cos\theta_{\tilde{t}} + v'\vec{e}_\perp\sin\theta_{\tilde{t}}$, where by averaging over small deflection angles $\langle\theta_\tau^2\rangle \sim \hat{\Theta}$ with units $[\hat{\Theta}] = GeV^2/fm$, one finds

$$\frac{d^2W}{dzd\omega} = -Re\left(\frac{2i\alpha}{3\pi}\frac{\hat{\Theta}}{E^2}\int_0^\infty d\bar{t}\cos(\omega\bar{t})\frac{\omega n^2}{\epsilon}\exp\left[-\omega|n_i|\beta\bar{t}\left(1-\frac{\hat{\Theta}}{6E^2}\bar{t}\right)\right]\exp\left[isgn(n_i)\omega n_r\beta\bar{t}\left(1-\frac{\hat{\Theta}}{6E^2}\bar{t}\right)\right]\right)$$

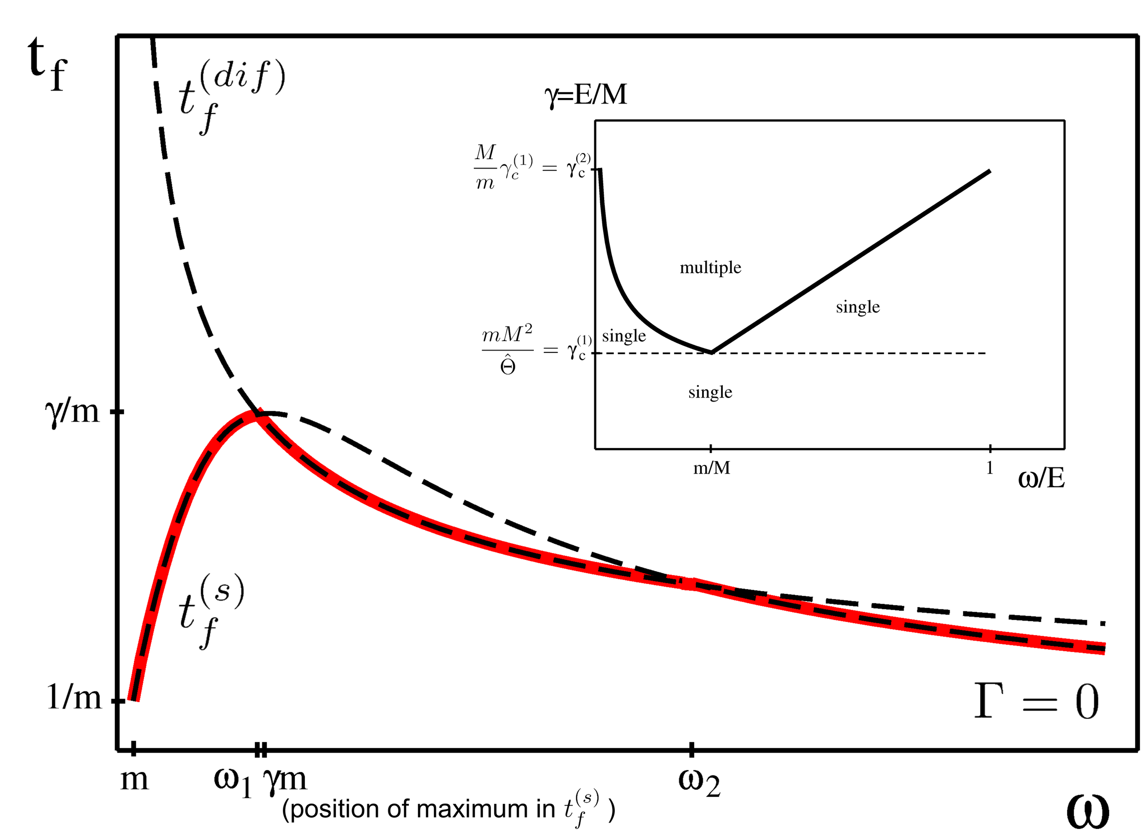


Observations

- Medium-induced energy loss depends *linearly* on $\hat{\Theta}$ (*radiative*, for constant velocity vector it is zero)
- Expression resembles in vacuum exactly the negative of the radiation intensity in [4]
- Conceivable to view emitted (hard) quanta as *time-like* excitations with *thermal mass* and *collisional width* [6]
- Ansatz for propagator of these quanta [7] results in ($\mu = 1$)

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

- Sensitivity to the poles implies a *non-negligible* effect of a finite width compared to the thermal mass even if $m \sim gT$, $\Gamma \sim g^2T$
- Observed relative reduction increases with increasing width (cf. Fig.) and/or initial energy [8]



Formation Time

- Making use of the *phase condition* for $\Gamma = 0$ case, estimate for *formation time* taking multiple scatterings into account follows with $k(\omega) = (\omega^2 - m^2)^{1/2}$ from

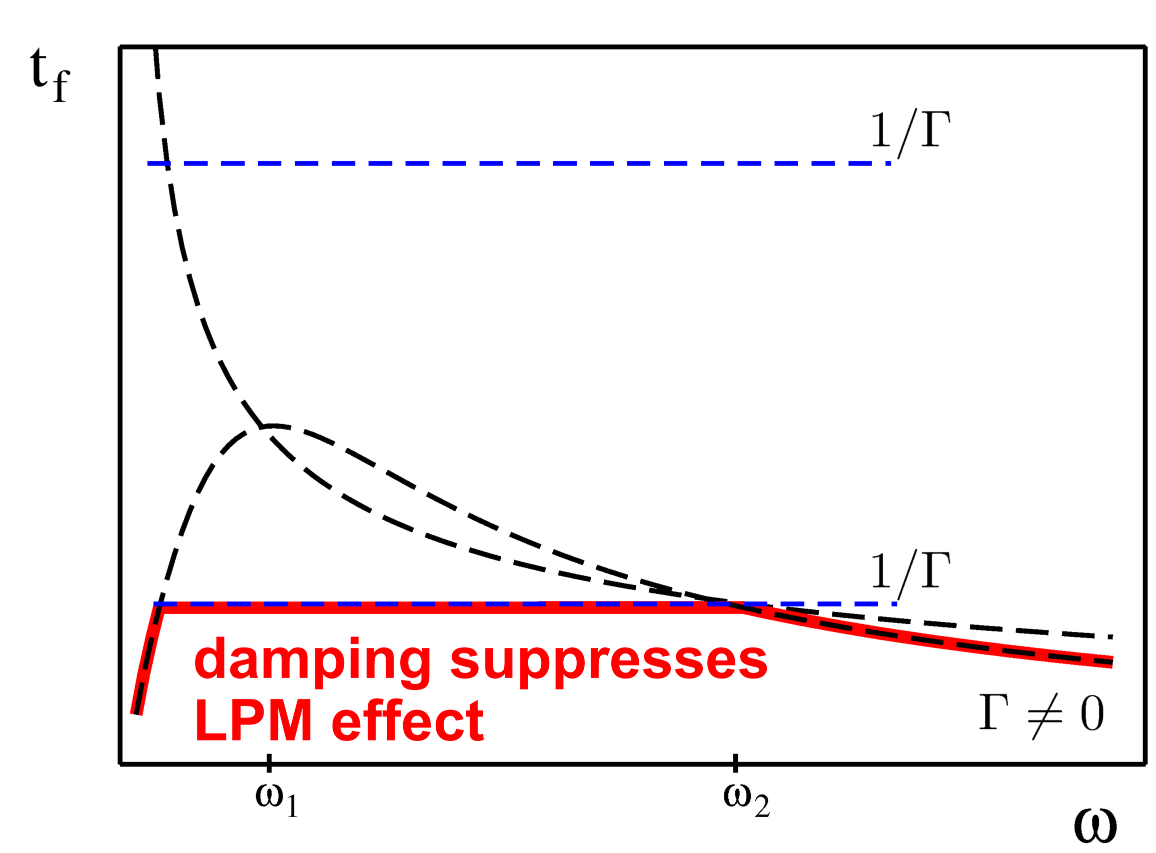
$$1 \simeq t(\omega - k(\omega)\beta) + \frac{\beta}{6}\frac{\hat{\Theta}}{E^2}k(\omega)t^2 \equiv \frac{t}{t_f^{(s)}} + \frac{t^2}{\left(t_f^{(dif)}\right)^2}$$

$$\Rightarrow \quad t_f \sim min\left(t_f^{(s)}, t_f^{(dif)}\right)$$

- Multiple scatterings dominate (**LPM effect**) for (cf. Fig.)

$$\omega_1 \sim \gamma m\left(\frac{\gamma_c^{(1)}}{\gamma}\right)^{1/3} < \omega < \omega_2 \sim \gamma M\frac{\gamma}{\gamma_c^{(2)}}$$

- Competition with a second time scale for $\Gamma \neq 0$, where exponential damping factor becomes $\sim 1/e$: $t_d \sim 1/\Gamma$
- Damping irrelevant for $1/\Gamma \gg t_f(\omega_1)$
- Damping **negates** effect of multiple scatterings (cf. Fig.) for $1/\Gamma \ll t_f(\omega_2)$: $\Gamma \gg \hat{\Theta}/M^2$
- If $\Gamma \sim g^2T$, $\hat{\Theta} \sim g^2T^3$ then condition is $T^2 \ll M^2$



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[1] SUBATECH, Université de Nantes, EMN, IN2P3/CNRS; 4 rue Alfred Kastler, 44307 Nantes cedex 3, France

Contact: Marcus Bluhm - Email: bluhm@subatech.in2p3.fr - Phone: +33 251 85 8476