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Memory effects in the Bremsstrahlung emission from a fermion jet in a non equilibrated hot plasma

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Outline of the talk

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- **Introduction and Motivation**
- **Non equilibrium photon production**
- **Numerical investigations and results**
- **Summary of our results**

Introduction and Motivation

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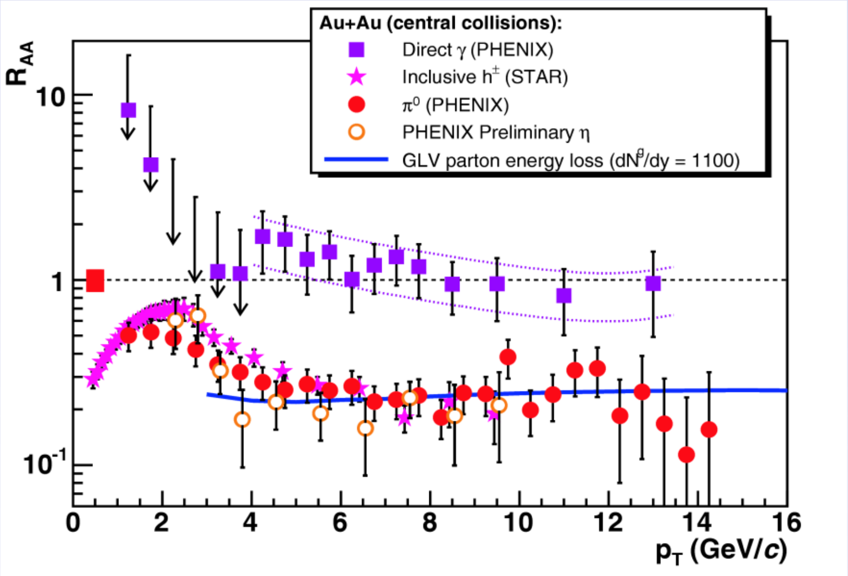
Direct observation of QGP not possible ► signatures needed

Partonic energy loss described by the nuclear modification factor R_{AA}.

Radiative processes are the main reason for partonic energy loss.

Interference effects from different propagation segments lead to a suppression of the standard pQFT cross section at small energies (LPM-effect).



QGP is no static medium but expands and cools down ($\tau \approx 4$ fm/c)

Do we have memory effects in the radiative behavior or does it follow changes in the medium instantaneously ► Motivation of the present study

Calculation of memory times and total energy loss with the Keldysh Schwinger formalism + comparison of results to equilibrium calculations

Restriction to photon emission, i.e., to QED-like interactions

Non equilibrium photon production I

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(Non equilibrium) photon production rate:

$$2k\frac{d^7n}{d^4xd^3k} = \frac{1}{(2\pi)^3}\gamma^{\mu\nu}(k)\int_{-\infty}^{t} i\Pi^{<}_{\mu\nu}(\vec{k},t,u)e^{ik(t-u)}du$$

One loop approximation for photon self energy:

$$i\Pi^{<}_{\mu\nu}(\vec{k},t,u) = e^2\int\frac{d^3p}{(2\pi)^3}Tr\left\{\gamma_\mu S^{<}_F(\vec{p}+\vec{k},t,u)\gamma_\nu S^{>}_F(\vec{p},u,t)\right\}$$

Propagators for fermion jet with momentum p':

$$S^{<}_F(\vec{p}+\vec{k},E) = 2\pi i\frac{(2\pi)^3}{V}\delta^3(\vec{p}+\vec{k}-\vec{p'})A_F(\vec{p}+\vec{k},E)$$

$$S^{>}_F(\vec{p},E) = -2\pi i A_F(\vec{p}+\vec{k},E)$$

Radiation from fermion ► use Breit Wigner model with fermion component only:

$$A_F(p) = \frac{1}{2\pi\varepsilon_{\vec{p}}}\left\{\frac{\gamma_0\varepsilon_{\vec{p}} - \vec{\gamma}\cdot\vec{p} + m}{(E-\varepsilon_{\vec{p}})^2+\Gamma^2}\right\}$$

Non equilibrium photon production II

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Fourier transform of fermion propagators into two time representation and calculation of photon self energy:

$$i\Pi^{<}_{\mu\nu}(\vec{k},t,u) = \frac{e^2 V}{\varepsilon_{\vec{p}}\varepsilon_{\vec{p}-\vec{k}}} \left\{ p_\mu(p_\nu - k_\nu) + p_\nu(p_\mu - k_\mu) - g_{\mu\nu}\left[p\cdot(p-k) - m^2\right]\right\}$$
$$\times e^{-i(\varepsilon_{\vec{p}}-\varepsilon_{\vec{p}-\vec{k}}-k)} e^{-2\Gamma|t-u|}$$

LPM effect and Bethe Heitler cross section are included in this description

Numerical investigations and results I

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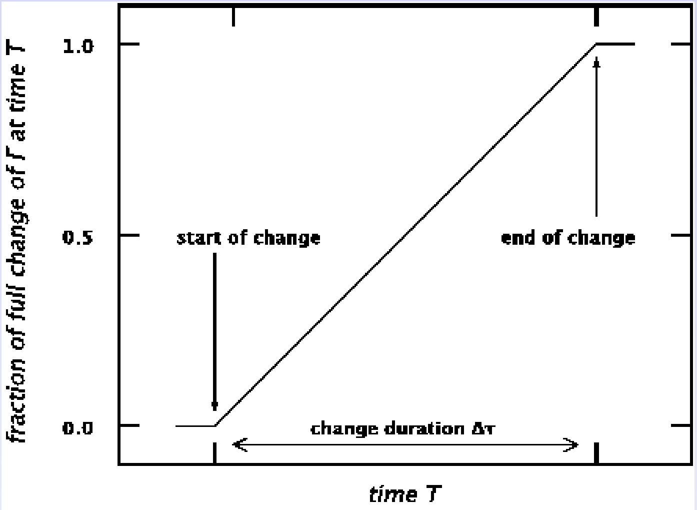
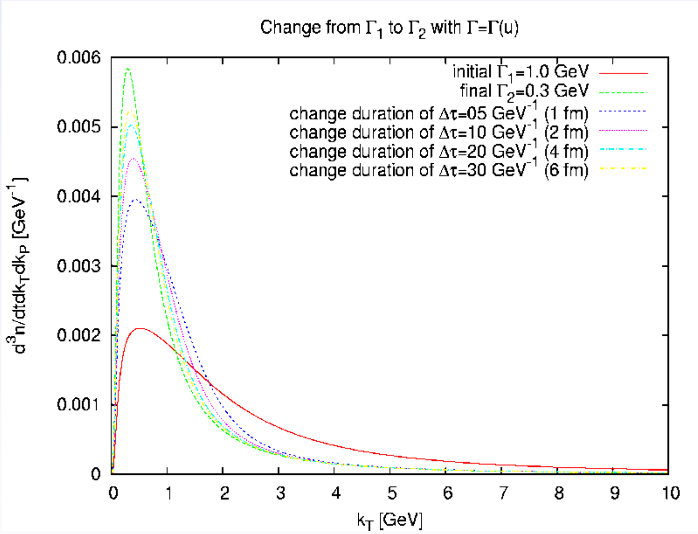
- **QGP: expansion time $\Delta\tau \approx 4$ fm/c;**

  $$\Gamma \in [1.0\ \mathrm{GeV}; 0.1\ \mathrm{GeV}]$$

- **linear decrement of Γ from Γ_1 to Γ_2 over $\Delta\tau$**
- **Direct introduction of time dependent Γ in $i\Pi^{<}_{\mu\nu}$; $\Gamma=\Gamma(u)$**
- **Comparison of photon rates at the end of $\Delta\tau$ to equilibrium calculations reveals possible memory effects**
- **Consider relative difference r between equilibrium and dynamic case at the end of $\Delta\tau$ for several $\Delta\tau$**
- **The faster Γ is switched down, the bigger is that difference**



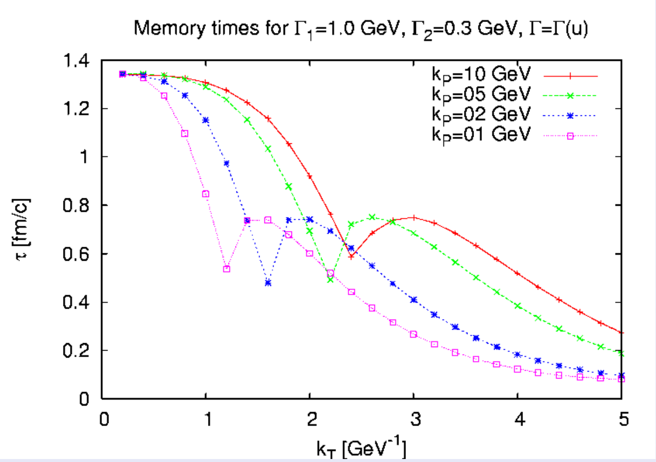


Numerical investigations and results II

Memory times for particular photon modes

Functional relation between r and Δτ:

$$r \sim e^{-\Delta\tau/\tau} \text{ for soft photons } \omega \ll \Gamma$$
$$r \sim (\Delta\tau/\tau) e^{-\Delta\tau/\tau} \text{ for hard photons } \omega \gg \Gamma$$
$$\omega = \varepsilon_{\vec{p}} - \varepsilon_{\vec{p}-\vec{k}} - k$$



Fit parameter τ defines the memory time

Memory times for different photon modes behave as the characteristic timescale:

$$\tau \sim 2\Gamma/(\omega^2 + 4\Gamma^2)$$

Scattering time t_S = 1/2Γ sets upper bound for the memory times (decorrelation time)

In general: $\tau \neq \tau_F = 2\pi/\omega$; equality only holds for the transition from the LPM region to the BH region

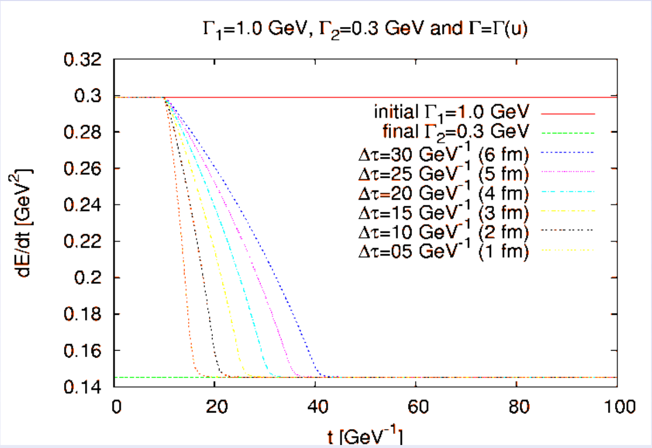
Memory effects quite small, τ < 1.4 fm/c

Numerical investigations and results III

Memory times for total radiation power / Energy loss

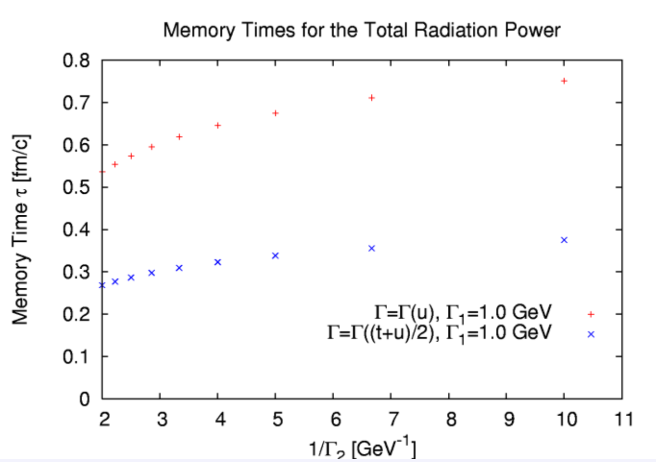
Problem: energy rate ~ const. for large k (Γ independent of ω)

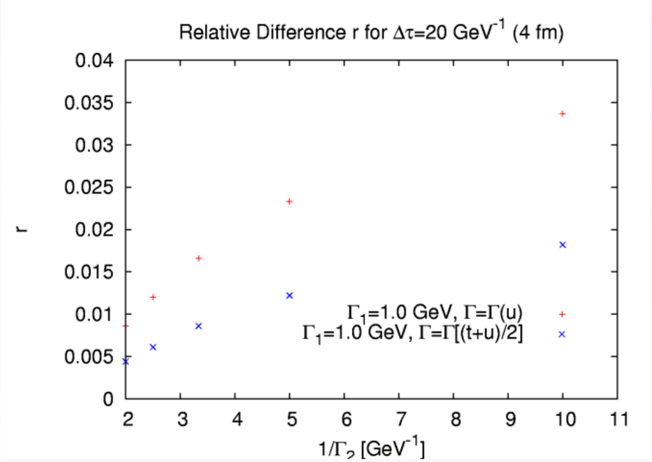
► dE/dt linearly divergent



Introduction of **Cutoff** at k=p; emitted photons cannot have higher energy than the fermion

Memory effects are quite **small** (τ ≤ 1 fm/c) for both time dependencies of Γ





Energy Loss: no tremendous differences between static and dynamic case (< 5% for Δτ = 4 fm/c); -ΔE ≈ 4.5 GeV

Numerical Investigations and results IV

Plausibility of our results

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Energy loss amounts 20 – 25 % of fermion energy ; large for photon emission

Gluon emission, α_e ► α_s, energy loss increases by a factor of 10, fermion damped off immediately

Main reason: ansatz allows for transition between arbitrarily offshell energy states, Γ independent of ω:

$$S_F^<(\vec{p}+\vec{k},E) = 2\pi i \frac{(2\pi)^3}{V}\delta^3(\vec{p}+\vec{k}-\vec{p'})A_F(\vec{p}+\vec{k},E)$$
$$S_F^>(\vec{p},E) = -2\pi i A_F(\vec{p}+\vec{k},E)$$

Modified ansatz: only transitions between energy states which do not differ from onshell energy with more than n*Γ

Propagators get step functions $\theta(n\Gamma-|E-\varepsilon_p|)$

Consequence: photon emission suppressed for $|\varepsilon_p-\varepsilon_{p-k}-k| > 2n\Gamma$

ΔE reduced by a factor of 20 for n=1

n	- ΔE [GeV]
1	0.20
2	1.16
5	3.28
10	4.43

Summary of our results

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Memory times for the particular photon modes (LPM, BH) essentially show the following behavior:

$$\tau \sim 2\Gamma/(\omega^2 + 4\Gamma^2)$$

Memory times for total radiation power are dominated by the low energy scale, as the photon modes have tremendously higher memory time

All memory times are below 1 fm/c ►Adjustment process close to Markovian

Mainly due to the large scattering rates in a QGP which result in a fast decorrelation of the source particle

Claim confirmed by the total energy loss; difference to static calculation less than 5 % for typical parameters of a QGP

But: High energy modes are unphysical as they violate energy conservation
They have to be cutted off properly
Memory effects can become more important