Exciting the QGP with a relativistic jet

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(based on arXiv:0705.1047, see also C.M. and S. Mrówczyński PRD74, 105003 (2006))

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Motivation

Mach cone structures in RHIC ??
Phenix; Casalderrey-Solana, Shuryak, Teaney, '05

... but (colorless) hydrodynamical simulations, with realistic values of all variables, suggest that the effect is too weak to explain data
Chaudhuri, Heinz '06

New colored hydrodynamical effects:
they might **enhance** the signals; they also describe **jet quenching** (new mechanism: not collisional, not radiative, but based on a collective effect)

Charged beam of particles crossing an E.M. Plasma

- For certain values of the beam parameters $\Rightarrow$ there are unstable gauge field modes (growing $\mathbf{E}, \mathbf{B}$)
- Specific example of the so-called **two-stream instabilities** widely studied in different physical contexts (inertial confinement fusion, astrophysics, cosmology, ...)
- Different methodologies to address the problem (kinetic theory, hydrodynamics, etc).
  Also experimental data ....

Neutral beam of fast particles traversing the QGP

Same phenomena that in an electromagnetic plasma should occur!!
Pavlenko '92

We use a chromohydrodynamical approach to adress the problem because it does not rely on $g \ll 1$ and on the quasi-particle picture (but the kinetic theory approach is on the way ....)

also assuming the conformal limit $c_s^2 = \frac{1}{3}$
(no generated scales, as suggested by lattice)

Chromohydrodynamical approach

Hydrodynamics ($\sim$ conservation laws) requires the system to be in a local equilibrium state

Even if this is color neutral, hydrodynamical fluctuations can be colored (and may grow in some cases rather than being damped)

$$n = \bar{n} + \delta n \quad u^\mu = \bar{u}^\mu + \delta u^\mu$$
$$\epsilon = \bar{\epsilon} + \delta\epsilon \quad p = \bar{p} + \delta p$$

Hydro approach to the QGP

Linearized fluid equations

$$(D_\mu \delta n)\, \bar{u}^\mu + \bar{n}\, D_\mu \delta u^\mu = 0$$

$$\bar{u}^\mu D_\mu \delta\epsilon + (\bar{\epsilon} + \bar{p}) D_\mu \delta u^\mu = 0$$

$$(\bar{\epsilon} + \bar{p}) \bar{u}_\mu D^\mu \delta u^\nu - (D^\nu - \bar{u}^\nu \bar{u}_\mu D^\mu) \delta p - g \bar{n} \bar{u}_\mu F^{\mu\nu} = 0$$

which have to be solved in order to find an induced colored current

$$j^\mu = \bar{j}^\mu + \delta j^\mu \qquad \bar{j}^\mu = 0$$

$$\delta j^\mu = -\frac{g}{2} (\bar{n}\, \delta u^\mu + \bar{u}^\mu\, \delta n) \qquad \delta j^\mu = \Pi^{\mu\nu} A_\mu + \cdots$$

Hydro approach to the jet+QGP

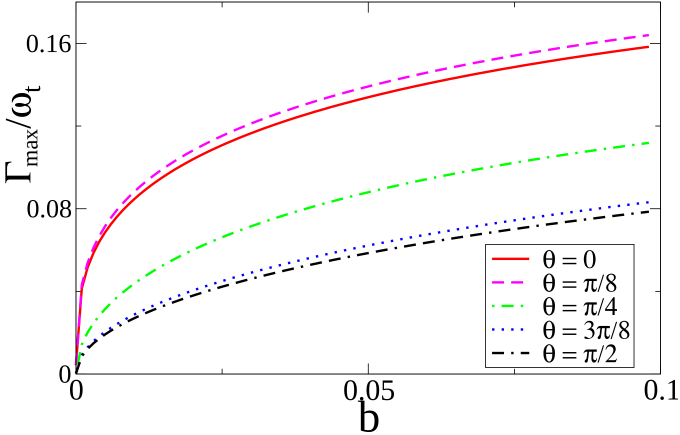
- For the beam, with velocity v: pressure gradients are entirely neglected - evolution only due to the mean fields ("cold beam approximation", valid for $\gamma \gg 1$)
- For the plasma $p(x) = c_s^2 \epsilon(x)$

We have found that there are always instabilities iff $v > c_s$.
Growing rates for a mode of momenta k depend on v and on the plasma frequency

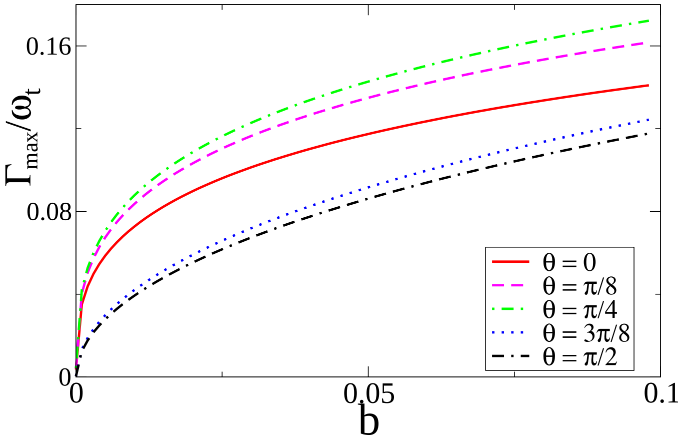
$$\omega_t^2 = \omega_p^2 + \omega_{\rm jet}^2 \text{ and on } b = \frac{\omega_{\rm jet}^2}{\omega_t^2}$$

also on θ the angle between $\mathbf{k}$ and $\mathbf{v}$.
Unstable modes in IR sector, up to $k_{\rm max} \gtrsim \omega_t$

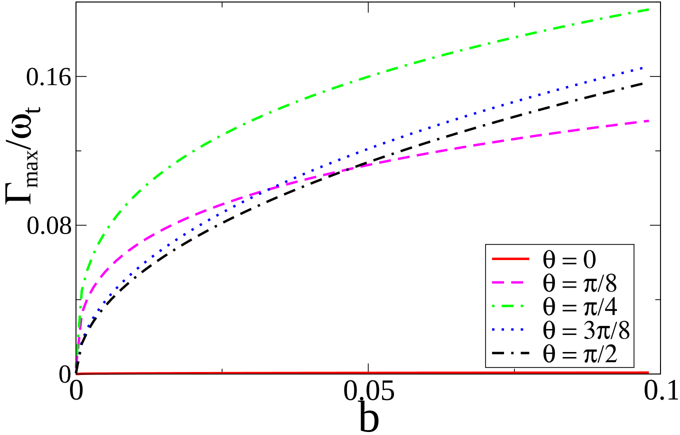
Growing rates for v=0.8



Growing rates for v=0.9



Growing rates for v=1



Conclusions

- The jet transfers energy and momentum to the gauge fields (collective effect). The gauge fields should decay finally into soft hadrons.
- The effect occurs whenever $v > c_s$, that is, when the beam also produces a shock wave and a Mach cone structure.
- Energy loss??
  Sorry, not yet, but it is on the way ....
- In the LHC one may expect to create more energetic high p_T particles. Values of the beam parameter may differ with respect to RHIC $\Rightarrow$ shorter time for the appearance of instabilities.