Suppression of forward dilepton production from an anisotropic QGP

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GOETHE UNIVERSITÄT FRANKFURT AM MAIN

H-QM Helmholtz Research School Quark Matter Studies

FIAS Frankfurt Institute for Advanced Studies

Understanding first moments of QGP

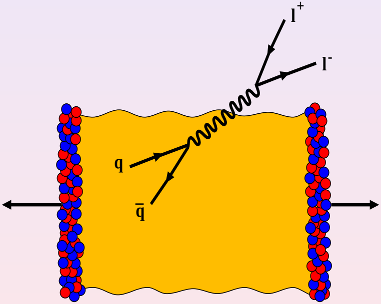
- At RHIC energies, ideal hydrodynamical models seems to describe the elliptic flow, v_2, for $p_T < 2$ GeV.
- This has been taken as evidence for short thermalization/isotropization time $\tau_{iso} \approx 0.6$ fm/c (Kolb. et al.) and low shear viscosity. However...
- Recent results from viscous hydro (Romatschke et al.) seem to indicate that $\tau_{iso} \sim 2$ fm/c can also describe low p_T elliptic flow.
- Hydrodynamical results depend strongly on initial conditions, spatial profile, flow velocity, viscous hadronic phase, etc...
- It would be nice to have other independent observables others than v_2, sensitive to early-time dynamics of the collision....

Theory says...

- In the framework of pQCD, it is estimated that $\tau_{iso} = \alpha_s^{-13/5} Q_s^{-1}$. (Bottom-up thermalization scenario; Baier, Mueller, Son and Schiff).
- If α_s ~0.3, at RHIC energies, this give us τ_{iso} ~**2-3 fm/c** while at LHC energies τ_{iso} ~**1-2 fm/c**.
- **Plasma instabilities** are important in the thermalization/isotropization process, it accelerates it. However, it is unknown how much (Mrowczynski, Strickland, Romatschke, Arnold, Lenaghan, Moore, Rebhan, Yaffe, Venugopalan, Dumitru, Nara, Bödeker, Rummukainen, Fukushima, Gelis, McLerran, Berges, Sexty, Scheffler, . . .)

Try to determine τ_{iso} from E&M observables

E&M observables are good candidates to explore early-time dynamics of the collision. They can provide independent information about τ_{iso}.

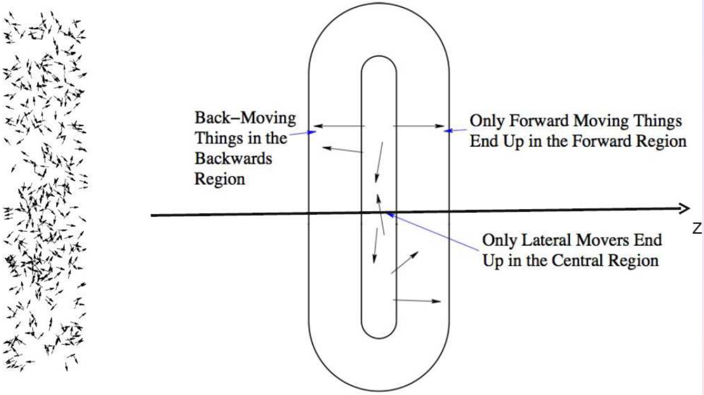


- Electromagnetic probes **do not** interact with the hot and dense medium.
- Provide information about q, $\bar{q}$ parton distributions in the early stage of the collision.

- Can we learn if the plasma becomes isotropic in momentum space from dileptons?
- What is the impact of momentum anisotropies on forward dileptons?

Anisotropic nature of the QGP

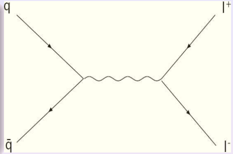
After the collision



Central plasma is anisotropic (Oblate p distribution).

Dilepton rate from anisotropic QGP plasma

The differential dilepton rate $dN^{l^+l^-}/d^4pd^4x$ depends on plasma anisotropy and the angle of the dilepton pair with respect to the anisotropy (beam) axis.



- To leading order it can be obtained using anisotropic momentum distributions of the form:

$$f^{q,\bar{q}}(\mathbf{p},\mathbf{x},p_{hard}) = f^{q,\bar{q}}_{iso}(p^2 + \xi(\mathbf{p}\cdot\hat{\mathbf{n}})^2, p_{hard})$$

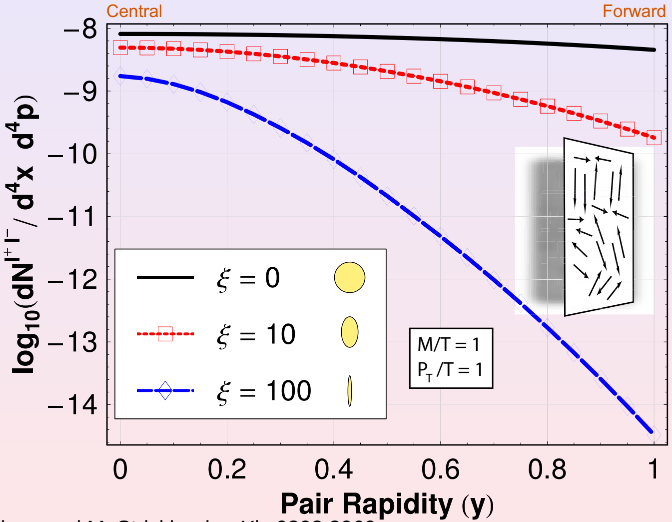
- Anisotropy parameter is related with the partonic kinematic variables:

$$\xi = \frac{\langle p_T^2 \rangle}{2\langle p_L^2 \rangle} - 1$$

$$\xi = 0 \Longrightarrow \text{Isotropic.}$$

$$\xi > 0 \Longrightarrow \text{Oblate (anisotropic).}$$

Forward production is highly sensitive to early-time dynamics.



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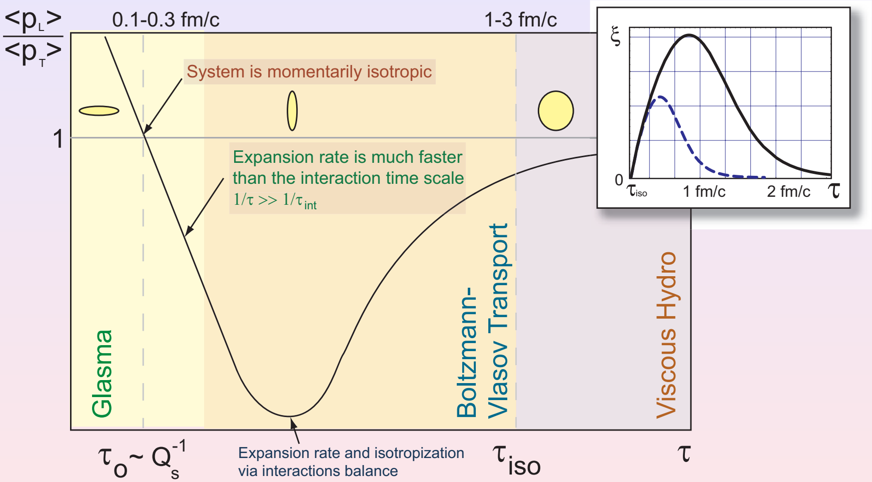
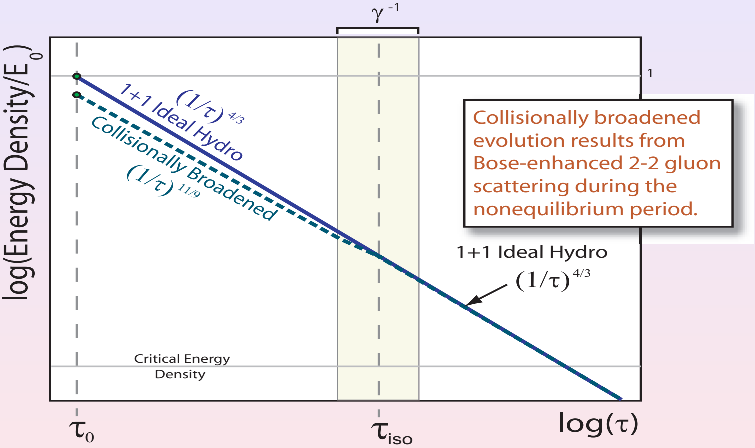
Momentum-Space Anisotropy time dependence



Interpolating Model I: Temporal evolution



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Interpolating model II: rapidity dependence

We use a Gaussian pion rapidity dependence which fits AGS through RHIC data (M. Bleicher, arXiv:hep-ph/0509314):

$$\exp\left(-\frac{\eta^2}{2\sigma_\eta^2}\right)$$

with

$$\sigma_\eta^2 = \frac{8}{3}\frac{c_s^2}{(1-c_s^4)}\ln\left(\sqrt{s_{NN}}/2m_p\right)$$

where c_s is the sound velocity and m_p is the proton mass.

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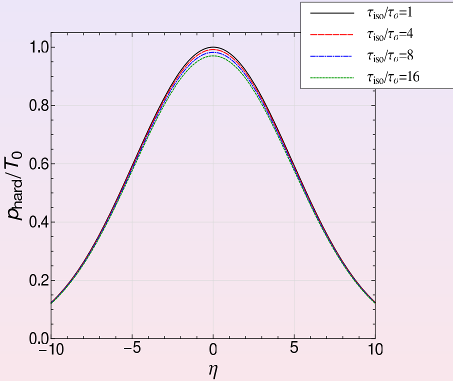
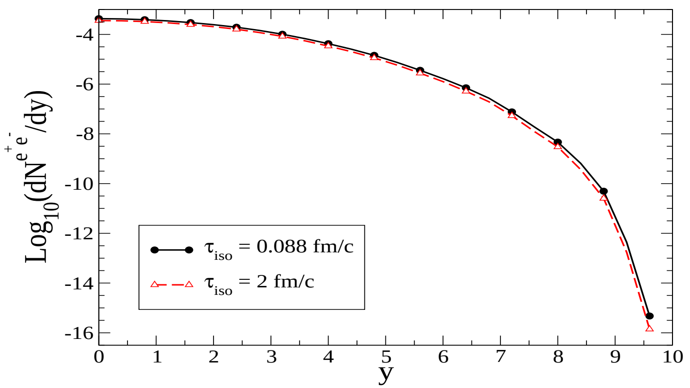


Dileptons vs. y

$T_0 = 845$ MeV, $\gamma = 2$, $T_c = 160$ MeV.
Cuts: $M \geqslant 2$ GeV, $P_T \geqslant 0.1$ GeV.



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Dilepton modification factor

Compare lepton pairs when you assume that plasma is isotropic at τ_{iso} to those produced if you assume an **instantaneously isotropized** plasma at τ_0 through the Dilepton modification factor:

$$\Phi(\tau_{\rm iso}) \equiv \left(\frac{dN^{e^+e^-}(\tau_{\rm iso})}{dy}\right) \Bigg/ \left(\frac{dN^{e^+e^-}(\tau_{\rm iso}=\tau_0)}{dy}\right)$$

The amplitude of the suppression of $\Phi(\tau_{\rm iso})$ could help us to experimentally constrain $\tau_{\rm iso}$ given sufficiently precise data in the forthcoming LHC experiments.

Dilepton modification vs. y

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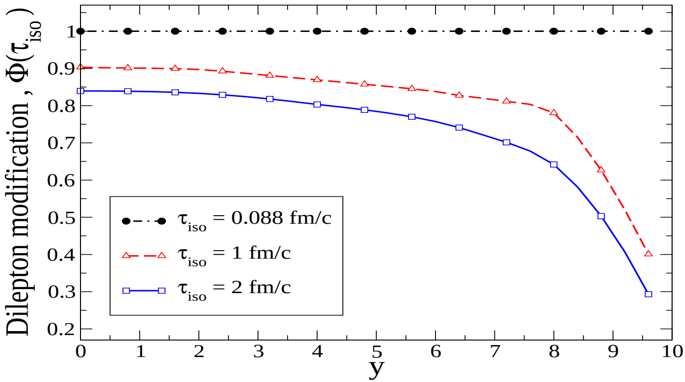

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Conclusions

- Dileptons is a good observable that allows to know independent information about τ_{iso}.
- We propose an interpolating model from early-time collisionally broadening to late-time 0+1 ideal hydrodynamics which includes pre-equilibrium anisotropies in momentum-space. Moreover, the model includes the rapidity dependence of the hard momentum scale.
- **Forward dileptons** is a **promising observable** to determine τ_{iso}. At LHC energies, forward dileptons can be suppressed up to 3 times when $\tau_{iso} = 2$ fm/c.

Backup Slides

Temporal evolution: Interpolating between two phases

1) $\tau \lesssim \tau_{\rm iso}$ - Collisionally Broadened

$$\langle p_T^2\rangle/\langle p_L^2\rangle = 2(\tau/\tau_0)^{2/3}$$

$$\xi(\tau) = \frac{1}{2}\langle p_T^2\rangle/\langle p_L^2\rangle - 1$$

$$\Downarrow$$

$$\xi(\tau) = \left(\frac{\tau}{\tau_0}\right)^{\frac{2}{3}} - 1$$

$$\lim_{\tau\gg\tau_0} \mathcal{E}(\tau) \rightarrow \mathcal{E}_0 \left(\frac{\tau_0}{\tau}\right)^{\frac{11}{9}}$$

$$\text{``}T\text{''}(\tau) = T_0 \sim \left(\frac{\tau_0}{\tau}\right)^{\frac{2}{9}}$$

In the limit $\tau_{\rm iso} \rightarrow \infty$ the system never becomes isotropic.

2) $\tau \gtrsim \tau_{\rm iso}$ - 1d ideal hydro

$$\langle p_T^2\rangle = 2\langle p_L^2\rangle$$

$$\xi(\tau) = \frac{1}{2}\langle p_T^2\rangle/\langle p_L^2\rangle - 1$$

$$\Downarrow$$

$$\xi(\tau) = 0$$

$$\mathcal{E}(\tau) = \mathcal{E}_0 \left(\frac{\tau_0}{\tau}\right)^{4/3}$$

$$T(\tau) = T_0 \left(\frac{\tau_0}{\tau}\right)^{1/3}$$

In the limit $\tau_{\rm iso} \rightarrow \tau_0$ the system begins ideal 1d hydrodynamic flow “instantly”.