Dilepton production as a measure of QGP thermalization time

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Work done in collaboration with M. Strickland

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Quark Matter 2008
Jaipur, India
9th February 2008

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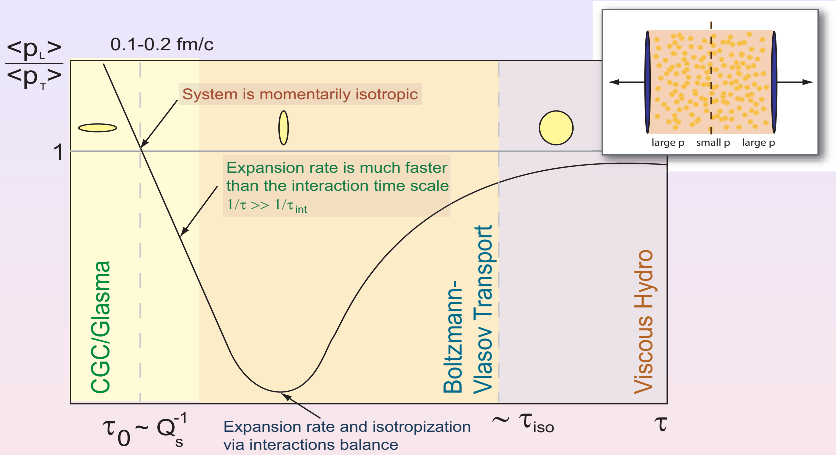
H-QM Helmholtz Research School
Quark Matter Studies

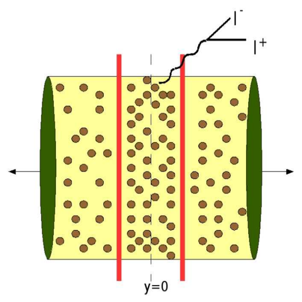
FIAS Frankfurt Institute
for Advanced Studies

Pre-equilibrium phase of the QGP



As a result of the rapid expansion along the beam axis, an anisotropy in the momentum-space is developed.

Electromagnetic probes in heavy ion collisions

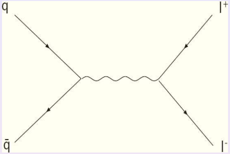


- Electromagnetic signatures give information about initial parton distributions and early time dynamics of the collision.
- Photons are more difficult for experimentalists to measure due to large backgrounds.
- Dileptons offer a better option from the experimental point of view.

Influence of non equilibrium dynamics on dilepton production?

Dilepton emission from an anisotropic QGP

Dilepton rate d^4R/d^4P depends on the direction of the anisotropy and the angle of the dilepton pair with respect to the longitudinal axis.



- As an ansatz, we choose an anisotropic phase space distribution in momentum-space:

$$\boxed{f^i\ (\mathbf{p},\mathbf{x}) = f^i_{\rm iso}\left(\mathbf{p_T^2} + (1+\xi)\mathbf{p_L^2}\right)}$$

- ξ measures the strength of the anisotropy and it's related with the kinematic variables:

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

Model for an anisotropy in momentum-space

In a free streaming plasma:

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

$$\lim_{\tau \gg \tau_0} \mathcal{E}(\tau) \Rightarrow \mathcal{E}_0 \left(\frac{\tau_0}{\tau}\right)$$

$$\text{“}T\text{”} = T_0$$

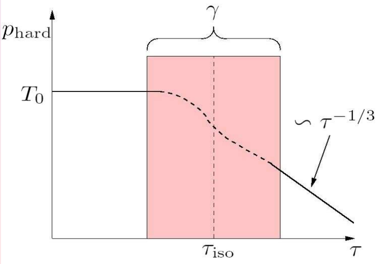
In a hydrodynamical plasma:

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

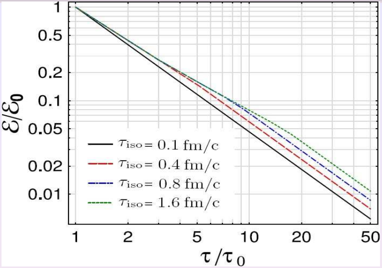
$$\mathcal{E}(\tau) = \mathcal{E}_0 \left(\frac{\tau_0}{\tau}\right)^{4/3}$$

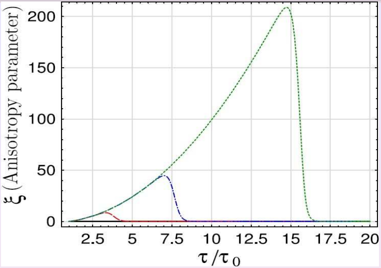
$$T = T_0 \left(\frac{\tau_{iso}}{\tau}\right)^{1/3}$$

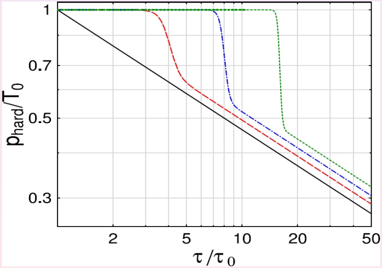
Propose a model that interpolates between free streaming and hydrodynamical expansion :



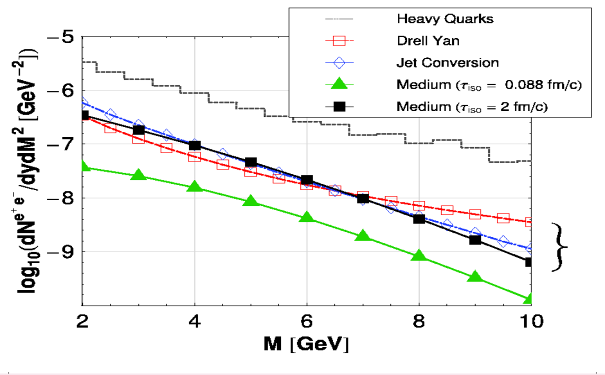
Space-time evolution with anisotropies







Dilepton production vs. M



$\Leftarrow$ No difference!!!

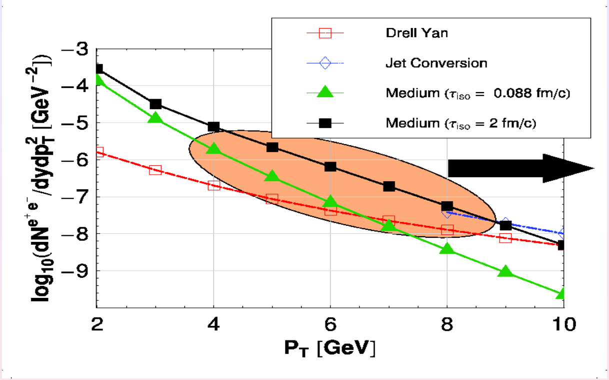
A K factor of 1.5 was applied to account for NLO corrections.

T_0= 845 MeV, τ_0= 0.088 fm/c, T_c= 160 MeV.

Cuts: $P_T > 8$ GeV.

M. Martinez and M. Strickland, arXiv:0709.3576 [hep-ph].

Dilepton production vs. P_T



Large enhancement at intermediate P_T from anisotropy!!!

A K factor of 6 was applied to account for NLO corrections.

T_0= 845 MeV, τ_0= 0.088 fm/c, T_c= 160 MeV.

Cuts: $M > 2$ GeV.

M. Martinez and M. Strickland, arXiv:0709.3576 [hep-ph].

Conclusions

- We construct a model that interpolates between free streaming and hydrodynamics evolution. The model takes into account the time dependence of the anisotropy in the momentum-space.
- Dilepton production in the kinematic range 3$< P_T <$8 GeV provides an estimate of the momentum-space anisotropy and a possible measure of the isotropization time, τ_{iso}.

Backup slides

Dilepton rate at leading order

From relativistic kinetic theory, the dilepton rate production for $q\bar{q} \rightarrow l^+l^-$ is:

$$\frac{dN}{d^4x d^4p} = \frac{dR}{d^4P} = \int \frac{d^3\mathbf{p_1}}{(2\pi)^3}\frac{d^3\mathbf{p_2}}{(2\pi)^3} f_q(p_1,T) f_{\bar{q}}(p_2,T) \times \upsilon_{rel}\sigma^{LO}_{q\bar{q}\rightarrow l^+l_-}\delta^4(P-p_1-p_2)$$

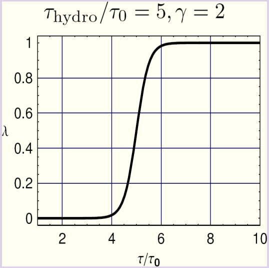
The invariant distributions of dileptons as a function of invariant mass and transverse momementum are respectively:

$$\frac{dN}{dM^2dy} = \pi R^2 \int d^2P_T \int_{\tau_0}^{\tau_f}\int_{-\infty}^{\infty}\frac{dR}{d^4P}\tau d\tau d\eta.$$

$$\frac{dN}{d^2P_Tdy} = \pi R^2 \int dM^2 \int_{\tau_0}^{\tau_f}\int_{-\infty}^{\infty}\frac{dR}{d^4P}\tau d\tau d\eta.$$

Some details about the interpolating model

Smeared step function $\lambda_\gamma(\tau - \tau_{\rm iso})$



Time-dependence of $\mathcal{E}$, $p_{\rm hard}$ and ξ

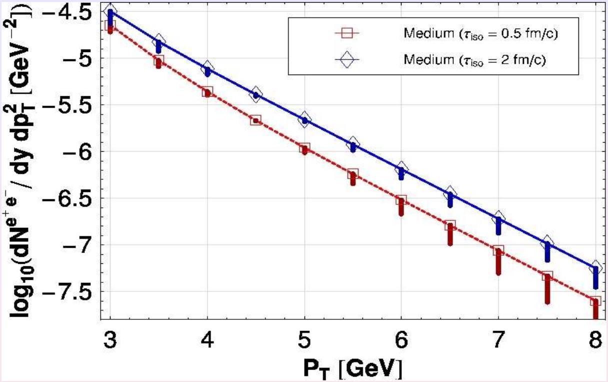
$$\begin{aligned} \mathcal{E}(\tau) &= \mathcal{E}_{\rm FS}(\tau)\,\left[\mathcal{U}(\tau)/\mathcal{U}(\tau_0)\right]^{4/3}\,, \\ p_{\rm hard}(\tau) &= T_0\,\left[\mathcal{U}(\tau)/\mathcal{U}(\tau_0)\right]^{1/3}\,, \\ \xi(\tau) &= a^{2(1-\lambda(\tau))} - 1\,, \end{aligned}$$

$$\begin{aligned} \mathcal{U}(\tau) &= \left[\mathcal{R}\left(\left(\frac{\tau_{\rm iso}}{\tau}\right)^2 - 1\right)\right]^{\frac{3\lambda(\tau)}{4}} \left(\frac{\tau_{\rm iso}}{\tau}\right)^{\lambda(\tau)} \\ \mathcal{R}(\xi(\tau)) &= \left(\frac{1}{1+\xi(\tau)} + \frac{\arctan(\sqrt{\xi(\tau)})}{\sqrt{\xi(\tau)}}\right) \end{aligned}$$

$$\lim_{\tau_{iso} \gg \tau} \mathcal{E}(\tau) \Rightarrow \mathcal{E}_0\left(\frac{\tau_0}{\tau}\right)$$ Free streaming limit

$$\lim_{\tau \gg \tau_{iso}} \mathcal{E}(\tau) \Rightarrow \mathcal{E}_0\left(\frac{\tau_{iso}}{\tau}\right)^{4/3}$$ Hydrodynamical limit

Dependence on the model parameter γ



A K factor of 6 was applied to account for NLO corrections.

T_0= 845 MeV, τ_0= 0.088 fm/c, T_c= 160 MeV.

Cuts: $M > 2$ GeV.

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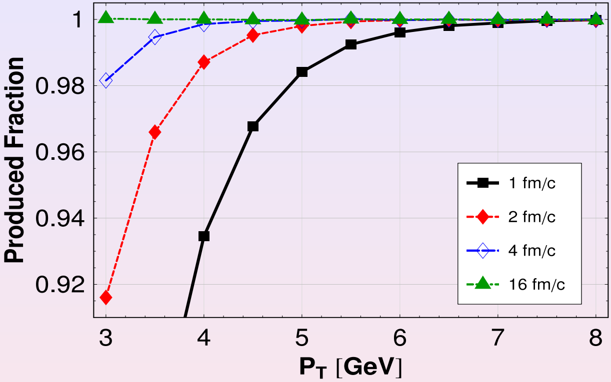
Produced fraction of Medium Dileptons in time



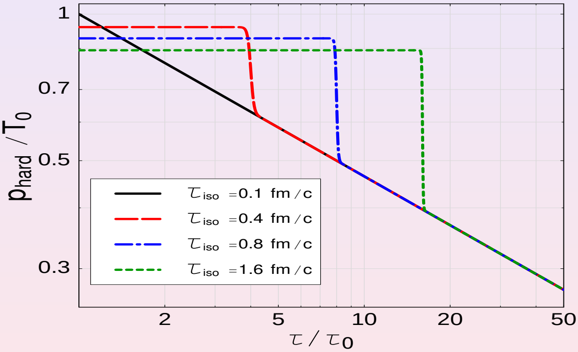
T_0= 845 MeV, τ_0= 0.088 fm/c, T_c= 160 MeV, τ_{iso}= 0.5 fm/c.

Cuts: $M > 2$ GeV.

M. Martinez and M. Strickland, arXiv:0709.3576 [hep-ph]

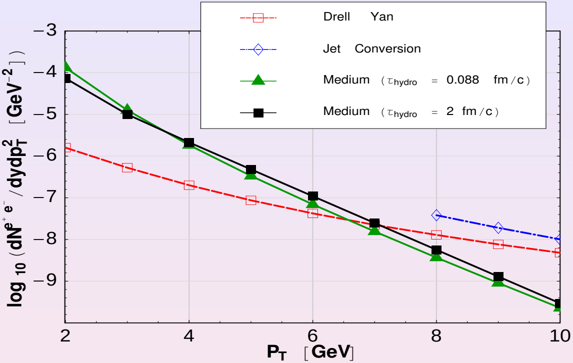
Fixing multiplicities

We could modify the model for the non equilibrium region fixing the final multiplicities. For doing so, we demand that after a given $\tau_{\rm iso}$, the hard momentum scale is the same.



As a consequence, the initial conditions will change and will depend on $\tau_{\rm iso}$.

Fixing multiplicities: dilepton spectrum vs. P_T



Dilepton production will be smaller compared with the case when the initial conditions are fixed but the effect from an anisotropy remains.

A K factor of 6 was applied to account for NLO corrections.

T_0= 845 MeV, τ_0= 0.088 fm/c, T_c= 160 MeV, $\tau_0 \leq \tau_{iso} \leq$ 1 fm/c. Cuts: $M > 2$ GeV.

M. Martinez and M. Strickland, forthcoming