Dilepton production from an anisotropic QGP

Mauricio Martinez[1]

Work done in collaboration with M. Strickland

[1]Helmholtz Research School,
Frankfurt Institute for Advanced Studies,
Johann Wolfgang Goethe Universität Frankfurt

School on "Hadronic collisions at the LHC and QCD at high density", Mar 25 - Apr 4, 2008, Les Houches, France

JOHANN WOLFGANG GOETHE UNIVERSITÄT FRANKFURT AM MAIN

H-QM Helmholtz Research School Quark Matter Studies

FIAS Frankfurt Institute for Advanced Studies

Towards thermalization of the QGP: Experimental facts

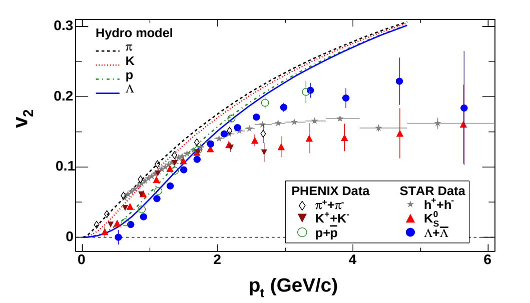


Figure adapted from M. J. Tannenbaum,

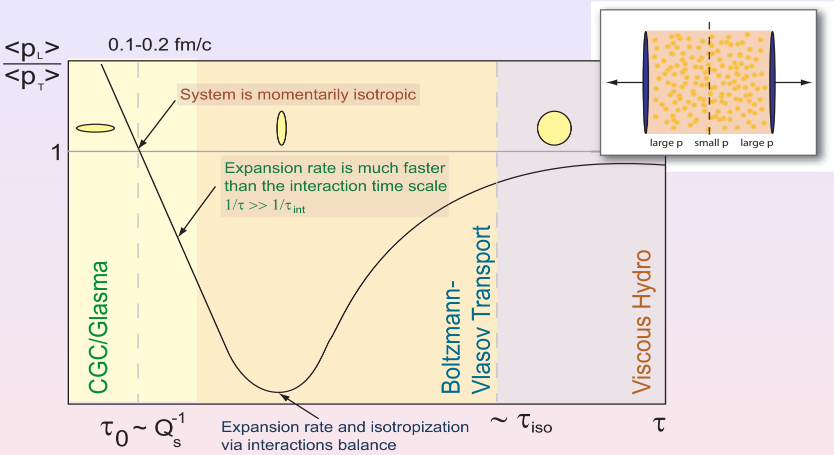
Rept.Prog.Phys.69:2005-2060,2006

- Ideal hydro seems to describe v_2 implying early isotropization time, $\tau_{iso} \sim 1$ fm/c.
- v_2 has a strong dependence of the late-time evolution ($\gtrsim$2-3 fm/c), initial conditions, Eq. of State, etc.

Towards thermalization of the QGP: Theoretical advances

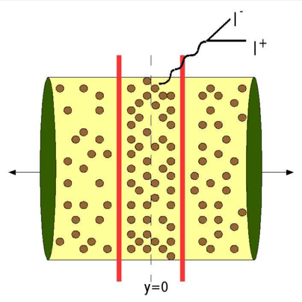
1. Bottom-up scenario:Thermalization in the framework of perturbative QCD. Soft modes isotropize and equilibrate first, then the hard modes $\tau_{iso} \sim \alpha_s^{-13/5} Q_s^{-1}$. (Baier, Mueller, Son and Schiff)
2. At RHIC Q_s ~1.5-2 GeV and α_s ~0.3 $\rightarrow$ τ_{iso} ~2-3 fm/c!!!
3. Bottom up calculation doesn't take into account the effects of the momentum-space anisotropy in the $p_T - p_L$ plane.
4. Plasma instabilities become important in equilibration processes (Mrówczyński, Lenaghan, Moore, Strickland, Romatschke and others).
5. Numerical evidence of plasma instabilities (Dumitru, Nara, Strickland, Venugopalan, Romatschke and others).

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 rate at leading order

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

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

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

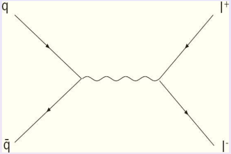
$$\frac{dN}{dM^2 dy} = \pi R^2 \int d^2P_T \int_{\tau_0}^{\tau_f}\int_{-\infty}^{\infty}\frac{dR}{d^4P}\tau d\tau d\eta.$$

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

The evolution of the system is encoded in the phase space distribution $f(x,p)$.

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:

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

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

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

Model for an anisotropy in momentum-space

In a free streaming plasma:

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

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

$$\text{“}T\text{”} = T_0$$

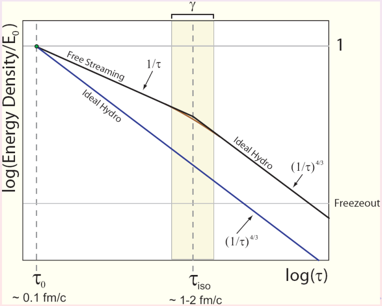
In a hydrodynamical plasma:

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

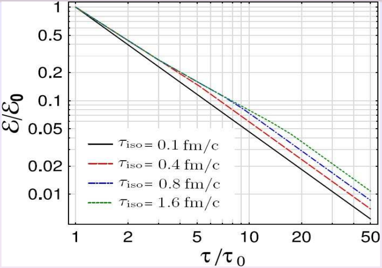
$$\mathcal{E}(\tau) = \mathcal{E}_0 \left(\frac{\tau_0}{\tau}\right)^{4/3}$$

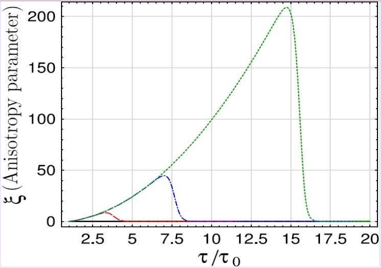
$$T = T_0 \left(\frac{\tau_{iso}}{\tau}\right)^{1/3}$$

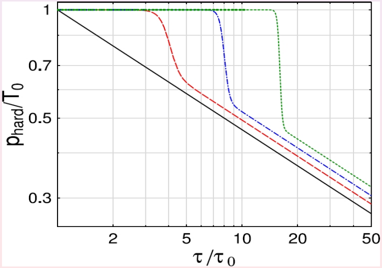
We propose a model that interpolates between free streaming and hydrodynamical evolution :



Space-time evolution with anisotropies





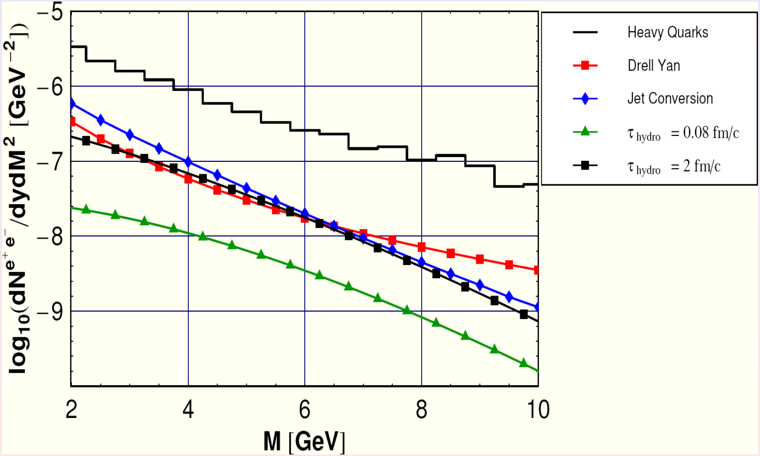


Dilepton production vs. M

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.



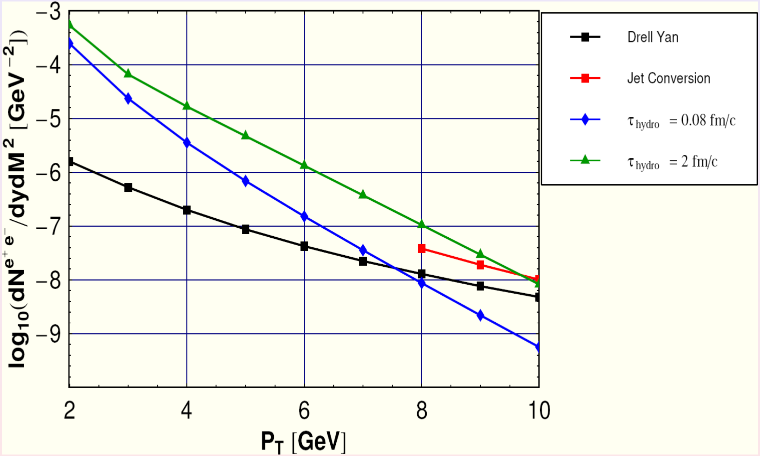
M. Martinez and M. Strickland, Phys. Rev. Lett. **100**, 102301 (2008), arXiv:0709.3576 [hep-ph].

Dilepton production vs. P_T

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.

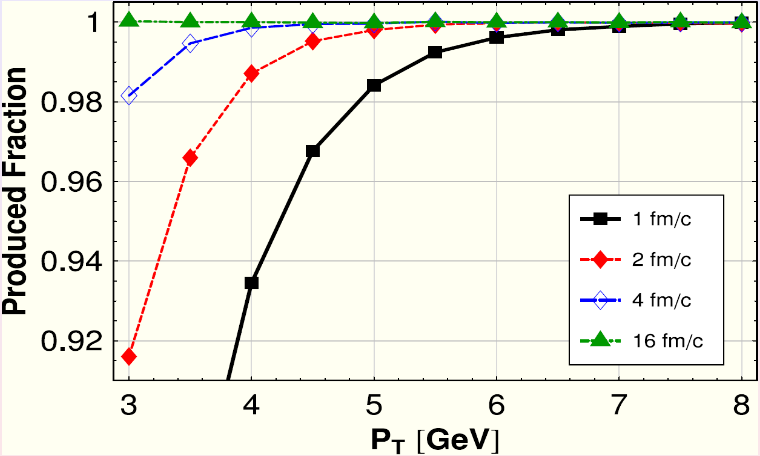
Cuts: $M > 2$ GeV.



M. Martinez and M. Strickland, Phys. Rev. Lett. **100**, 102301 (2008), arXiv:0709.3576 [hep-ph].

T_0= 845 MeV, τ_0= 0.088 fm/c, T_c= 160 MeV, $\tau_{\rm iso}$= 0.5 fm/c.

Cuts: $M > 2$ GeV.



M. Martinez and M. Strickland, Phys. Rev. Lett. **100**, 102301 (2008), 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}.

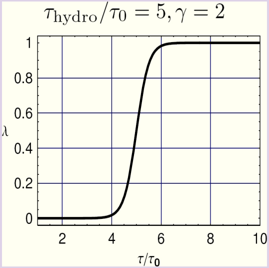
Future perspectives

- Our chief uncertainty is the NLO order corrections to dilepton production incorporating anisotropies. In principle, NLO order corrections has to be included (work in progress).
- Naively chemical potentials should affect isotropic and anisotropic plasmas equally so one expects that although the total yields could change one would still see a sensitivity to the assumed isotropization/thermalization time.

Backup slides

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

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

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

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

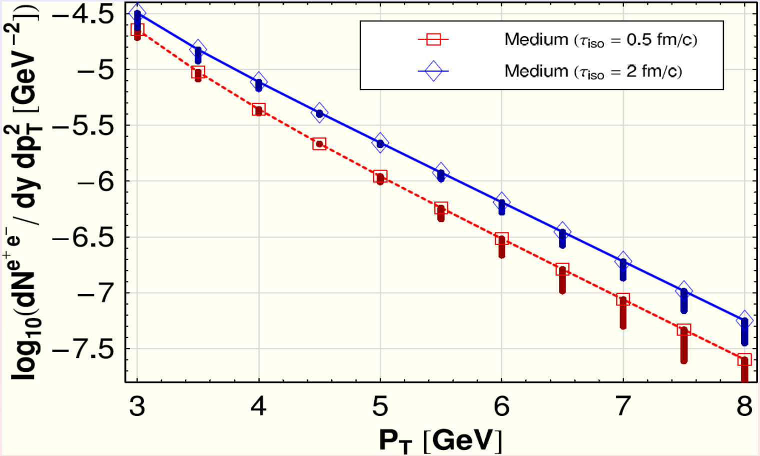
$$\lim_{\tau\gg\tau_{iso}} \mathcal{E}(\tau) \Rightarrow \mathcal{E}_0\left(\frac{\tau_{iso}}{\tau}\right)^{4/3}$$ Hydrodynamical limit

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.

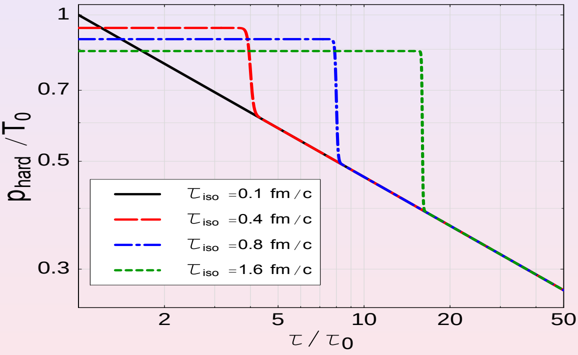
Cuts: $M > 2$ GeV.



M. Martinez and M. Strickland, Phys. Rev. Lett. **100**, 102301 (2008), arXiv:0709.3576 [hep-ph].

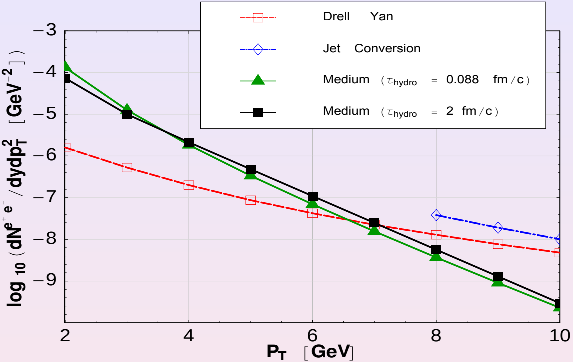
Fixing multiplicities

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