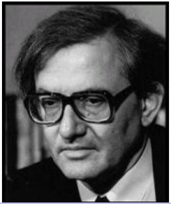
Dilepton creation based on an analytic hydrodynamic solution

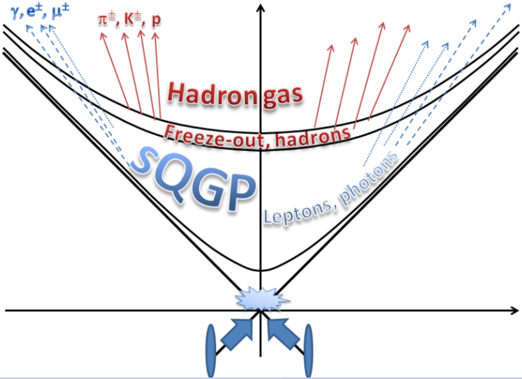
Levente Krizsán, Máté Csanád
Eötvös University, Budapest

13. Zimányi WINTER SCHOOL ON HEAVY ION PHYSICS

December 3, 2013



- Hydrodynamic models → relation between Initial, final state and EoS
- exact, 1+3D, relativistict solution
- time evolution : leptons and photons
- transverse momentum distribution and invariant mass distribution
- sources: QGP, hadron gas



- rate of a process:

$$(A + B \to X) = n_A n_B \langle \sigma_{A+B\to X} v \rangle \tag{1}$$

- dilepton source:

$$\frac{dN}{d^4x} = \int \frac{d^3\mathbf{k}_1}{(2\pi)^3} \frac{d^3\mathbf{k}_2}{(2\pi)^3} f(k_1) f(k_2) v_{rel} \sigma \tag{2}$$

- Jüttner-distribution:

$$f(k) \propto \exp\left[-\frac{k_\mu u^\mu}{T(x)}\right] \tag{3}$$

- general result:

$$\frac{dN}{dyMdMd^2P_t} = \frac{g^2\pi}{16(2\pi)^5} M^2 \left(1 - \frac{4m^2}{M^2}\right) \sigma(M^2) \int e^{-\frac{P^\mu u_\mu(x)}{T(x)}} d^4x \tag{4}$$

- through a quasireal photon or a vector meson

Quark annihilation:

$$\sigma_q(M^2) = \frac{4\pi\alpha^2}{3N_c} \sum_{i=u,d,s} \frac{e_i^2}{e^2} \frac{1 + 2m_q^2/M^2}{M^2\sqrt{1 - 4m_q^2/M^2}} \tag{5}$$

Pion annihilation:

$$\sigma_\pi(M^2) = \frac{4\pi\alpha^2}{3} \frac{\left|F(M^2)\right|^2}{M^2} \sqrt{1 - \frac{4m_\pi^2}{M^2}} \tag{6}$$

Electromagnetic form factor of pions

$$\left|F_\pi(M^2)\right|^2 = \sum_{i=\rho,\rho',\rho"} \frac{N_i m_i^4}{\left(m_i^2 - M^2\right)^2 + m_i^2\Gamma_i^2} \tag{7}$$

- the solution:
  - 1+3 dimensional
  - relativistic
  - Hubble velocity field: $u^\mu(x) = x^\mu/\tau$
  - ellipsoidal symmetry

$$s = \frac{r_x^2}{X(t)^2} + \frac{r_y^2}{Y(t)^2} + \frac{r_z^2}{Z(t)^2} \tag{8}$$

- X(t), Y (t), and Z(t) are time dependent scale parameters
- the temperature distribution:

$$T\left(\mathbf{x}, \tau\right) = T_0 \left(\frac{\tau_0}{\tau}\right)^{3/\kappa} e^{bs/2} \tag{9}$$

the final result is, if we neglect the azimuthal asymmetry and $y = 0$:

$$\frac{dN}{MdMP_t dP_t} = \frac{g^2}{16\,(2\pi)^{5/2}} M^2 \left(1 - \frac{4m^2}{M^2}\right) \sigma(M^2) \sqrt{\rho_x \rho_y \rho_z} \times$$

$$\tau_0^4 \left(\frac{T_0}{\sqrt{M^2 + P_t^2}}\right)^{3/2} \kappa A^{\frac{3}{2} - \frac{4\kappa}{3}} \Gamma\left(\frac{4\kappa}{3} - \frac{3}{2}; A\zeta^{3/\kappa}\right) \Bigg|_{\zeta = t_i/t_0}^{\zeta = t_f/t_0} \tag{10}$$

$$\rho_x = \frac{\kappa}{\kappa - 3 - \kappa \frac{b}{\dot{X}^2}} \tag{11}$$

$$A = \frac{M^2 - P_t^2 \left(1 + \frac{\rho_x + \rho_y}{4}\right)}{T_0 \sqrt{M^2 + P_t^2}} \tag{12}$$

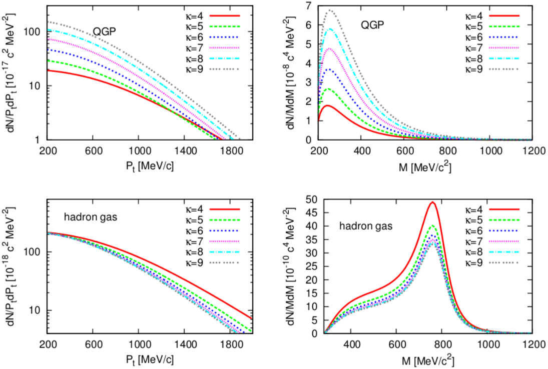
$t_0 = t_{fo}$ QGP:$[t_{ini}, t_{fo}]$ hadron gas:$[t_{fo}, t_{final}]$

Model parameters based on comparison to hadron and photon production

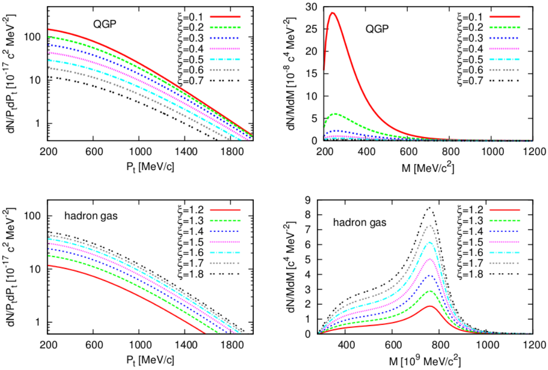
Parameter	Notation	Value
Freeze out temperature	T_0	$204 MeV$
Freeze out proper time	τ_0	$7.7 fm/c$
Transvers extension over T gradient	$\dot{X}_0^2/b = \dot{Y}_0^2/b$	-0,36
Longitudinal extension over T gradient	$\dot{Z}_0^2/b$	-0,84

We analyze:

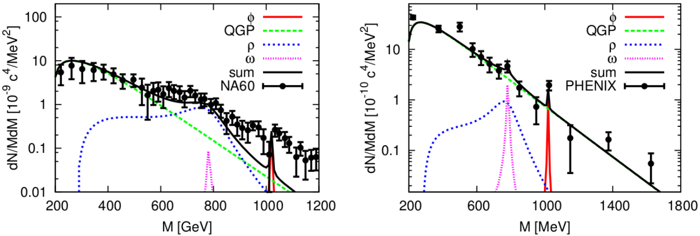
- κ (the EoS parameter)
- κ changes throughout the evolution, it is an average value
- the dilpeton creation interval (ζ)
- invariant mass is integrated out on $P_t[100 - 2000 MeV]$
- transverze momentum is taken at $M = 1000 MeV$



- All distributions depend strongly on the Equation of State
- the magnitude of M changes with κ
- κ is big $\rightarrow$ the system spends more time near the freeze-out T
- if $\kappa > 5$ $\rightarrow$hadron gas is not sensitive to κ



- ζ: the ratio of the time integration limits
- $\zeta < 1$ for QGP and $\zeta > 1$ for hadron gas
- extract informations (M. Csanád and I. Májer, Central Eur.J.Phys.10, 850 (2012))
  - $\kappa = 1/c_s^2 \rightarrow c_s = 0.36 \pm 0.02$
  - inital temperature $T_0 = 500 MeV$



- the parameters are from: M. Csanád and M. Vargyas, Eur. Phys. J. A44, 473 (2010)
- tuning the parameters :
  - RHIC: $T_{ini} = 270 MeV$
  - SPS: $T_{ini} = 200 MeV$ and $T_{final} = 130 MeV$
- small excess around $M = 500 MeV \rightarrow$ from the modification of η' mass
- at SPS ρ dominate and at RHIC QGP
- excess at 800-1000 MeV at SPS $\leftarrow$ vacuum parameters for vector mesons
- we did not take into account η η' mesons and $\pi^0 \rightarrow \gamma e^+ e^-$

- hadrons created at the freeze-out
- thermal photons and leptons constantly
- thermal dilepton production
- dependence on emission duration and equation of state
- compare to SPS and RHIC data

Thank you for your attention.