Event-by-event hydrodynamical description of QCD matter

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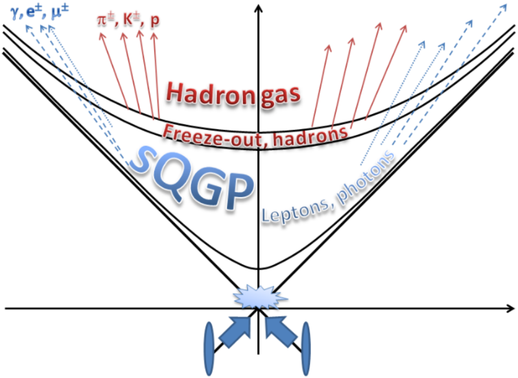
Outline

1. sQGP and the hydrodynamical approach
2. N-pole asymmetries in the description
3. The elliptical Buda-Lund model and its properties
4. General asymmetries in the model
5. Observables from the generalized model

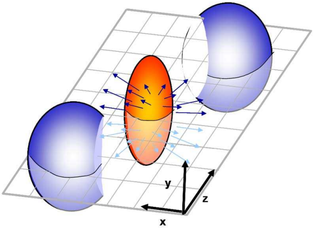
sQGP

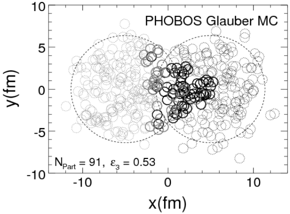
- sQGP discovered at RHIC and also created at LHC
- Almost perfect fluid, expanding hydrodynamical system
- Hadrons created at the freeze-out, leptons, photons created previous the freeze-out too



Perfect fluid hydrodynamics

- Hydro solutions or models
- Relativistic, exact, analytic solution:
  - Famous solution: Landau-Khalatnikov, Hwa-Bjorken
  - There is many new solutions
  - Geometry?
- The most basic concept: spherical symmetry
- Non-central collisions $\rightarrow$ assuming elliptical asymmetry
- More precise description: higher order asymmetries including!
- Generalize the space-time and the velocity field distribution too!





The elliptical Buda-Lund model

Csanád, Csörgő, Lorstad Nucl.Phys.A742, 80-94 (2004)

- Final state parametrization with source function:

$$S(x,p) = \frac{g}{(2\pi)^3} \frac{p^\mu d^4\Sigma_\mu(x)}{B(x,p)+s_q}$$

$p^\mu d^4\Sigma_\mu(x) = p_\mu u^\mu \delta(\tau-\tau_0) d^4x$ the Cooper-Frye factor, assuming instant freeze-out. $B(x,p)$ is the Boltzmann-factor.

- Scaling variable:

$$s = \frac{r_x^2}{2X^2} + \frac{r_y^2}{2Y^2} + \frac{r_z^2}{2Z^2}$$

- Thermodynamical quantities depend only on s not on the coordinates
- Derived the velocity field from a potential: $u_\mu = \gamma\left(1, \partial_x\Phi, \partial_y\Phi, \partial_z\Phi\right)$

$$\Phi = \left(r_x^2 \frac{\dot{X}}{2X} + r_y^2 \frac{\dot{Y}}{2Y} + r_z^2 \frac{\dot{Z}}{2Z} \right)$$

Generalization

Spatial distribution (with ϵ_n asymmetry parameter):

- Elliptical symmetry: $s = \frac{r^2}{R^2}(1 + \epsilon_2 \cos(2\varphi)) + \frac{r_z^2}{Z^2}$
- Triangular symmetry: $s = \frac{r^2}{R^2}(1 + \epsilon_3 \cos(3\varphi)) + \frac{r_z^2}{Z^2}$
- Generally:

$$s = \frac{r^2}{R^2}\left(1 + \sum_{n=2}^{N} \epsilon_n \cos(n\varphi)\right) + \frac{r_z^2}{Z^2}$$

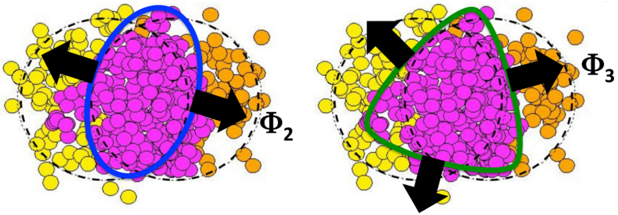
This s can be use in a hydro solution: Csanád, Szabó PhysRevC.90.054911
The generalized potential of velocity field (with χ_n asymmetry parameter):

- Elliptical symmetry: $\Phi = \frac{r^2}{2H}(1 + \chi_2 \cos(2\varphi)) + \frac{r_z^2}{2H_z}$
- Triangular symmetry: $\Phi = \frac{r^2}{2H}(1 + \chi_3 \cos(3\varphi)) + \frac{r_z^2}{2H_z}$
- Generally:

$$\Phi = \frac{r^2}{2H}\left(1 + \sum_{n=2}^{N} \chi_n \cos(n\varphi)\right) + \frac{r_z^2}{2H_z}$$

Observables from the new model

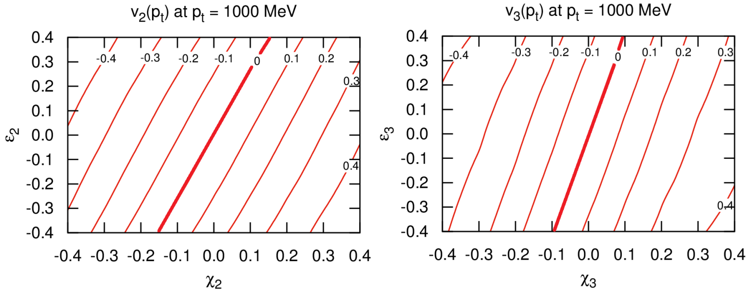
- Invariant momentum distribution: $N_1(p) = \int S(x,p) d^4x$
- Flows: $N_1(p) = N_1(p_t)\left(1 + 2\sum_{n=1}^{\infty} v_n \cos(n\alpha)\right)$
  where the flow $v_n(p_t) = \langle \cos(n\alpha) \rangle$
- Bose-Einstein correlations: The correlation function is the Fourier transformation of the source function: $C(q) = 1 + \left| \int S(r) \exp(iqr) dr \right|^2$
- The asymmetries is measured in the corresponding event plane
  - Elliptical asymmetry $\rightarrow$ 2$^{\text{nd}}$ order event plane
  - Triangular asymmetry $\rightarrow$ 3$^{\text{rd}}$ order event plane



- No interplay among the asymmetries!

Flows from the model

- Elliptic (v_2) and triangular (v_3) flows can be derived from the model
- Mixing of the parameters: the spatial distribution asymmetry ($\epsilon_{2,3}$) and the velocity field asymmetry ($\chi_{2,3}$) form the flows together



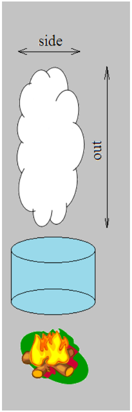
Azimuthally sensitive HBT radii

Useful to describe the geometry of the source

- The correlation
  function is the Fourier transformation of the source
- Elliptical
  case: both of it is Gaussian but with inverse width

$$S(r) \sim e^{-\frac{r_x^2}{2R_x^2}-\frac{r_y^2}{2R_y^2}-\frac{r_z^2}{2R_z^2}} \rightarrow C(k) = 1 + e^{-k_x^2 R_x^2 - k_y^2 R_y^2 - k_z^2 R_z^2}$$

- Size and geometry of the source can be measured!
- Experimentally it is measured
  in the *out* – *side* – *long* pair coordinates: $R_{x,y,z} \rightarrow R_{o,s,l}$
- The difference between
  out and side radii is indicate the kind of phase transition



Azimuthally sensitive HBT radii

The transverse angle which is appear in momentum space: (p_t, α, p_z).

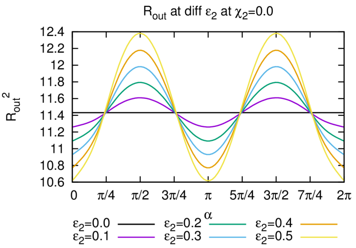
$$R_o^2 = \langle x_o^2 \rangle - \langle x_o \rangle^2 \quad , \quad R_s^2 = \langle x_s^2 \rangle - \langle x_s \rangle^2$$

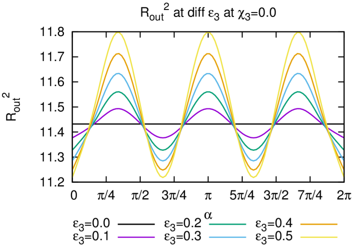
$$\text{where: } x_o = r\cos(\varphi - \alpha) \quad , \quad x_s = r\sin(\varphi - \alpha)$$

The average is an integrating over the source function with weight x_o or x_s respect the spatial coordinates (r, φ, r_z)

Parametrization: Elliptical case: $R^2_{o/s} = R^2_{o/s,0} + R^2_{o/s,2}\cos(2\alpha)$

Parametrization: Triangular case: $R^2_{o/s} = R^2_{o/s,0} + R^2_{o/s,3}\cos(3\alpha)$





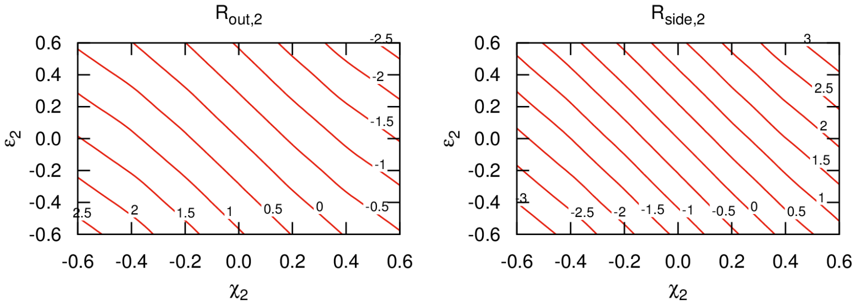
Azimuthally sensitive HBT radii

Mixing of the parameters: spatial distribution and velocity field form the azimuthally sensitive HBT radii together.

Elliptical case: in the second order reaction plane

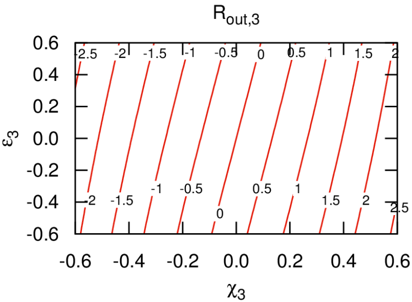
ϵ_2: asymmetry in space-time, χ_2: asymmetry in velocity field

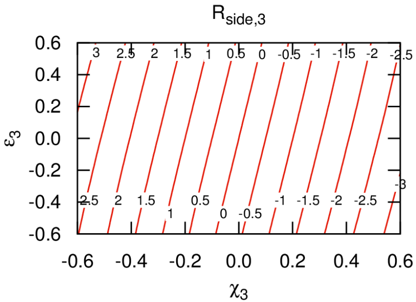
Parametrization: Elliptical case: $R^2_{o/s} = R^2_{o/s,0} + R^2_{o/s,2}\cos(2\alpha)$



Azimuthally sensitive HBT radii

Mixing of the parameters: spatial distribution and velocity field form the azimuthally sensitive HBT radii together.
Triangular case: in the third order reaction plane
ϵ_3: asymmetry in space-time, χ_3: asymmetry in velocity field
Parametrization: Triangular case: $R^2_{o/s} = R^2_{o/s,0} + R^2_{o/s,3}\cos(3\alpha)$





Conclusion and outlook

- Hydrodynamical approach can be used as a phenomenological tool to describe QCD matter
- The geometry of the source can be investigated
- General asymmetries can be built into a model
- Observables can be derived from the generalized model
- No mixing between 2^{nd} and 3^{rd} order asymmetries
- There is mixing between the spatial and velocity field asymmetries
- It is important to explore these mixing based on a realistic model

THANK YOU FOR YOUR ATTENTION!

Values of the parameters

Name	Value
m	140
T_0	170
a^2	0.1
b	-0.1
R	10
Z	15
H	10
H_z	16
ϵ_2	0.0
χ_2	0.0
ϵ_3	0.0
χ_3	0.0

Effect of the parameter on the source