Description of oscillating HBT radii in Buda-Lund hydrodynamical model

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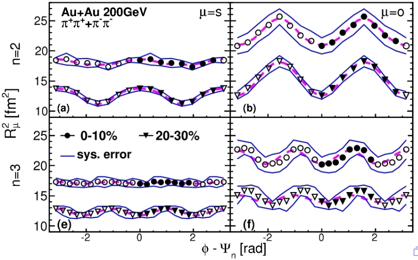
Zimányi School, 2015

Introduction

- QGP behaves like perfect fluid → hydro description
- Finite number of nucleons → generalized geometry is nescessary
- Generalize the space-time and the velocity field distribution
- Higher order flows can be investigated
- HBT radii have cos($n\phi$) dependences in the respective reaction plane
- These can be studied experimentally:

  Nucl.Phys. A904-905 (2013) 439c-442c

  Phys.Rev.Lett. 112 (2014) 22, 222301



The Buda-Lund model

Phys.Rev. C54 (1996) 1390 and Nucl.Phys. A742 (2004) 80-94

- Hydro-model: $S(x,p) = \frac{g}{(2\pi)^3} \frac{p^\nu d^4\Sigma_\nu(x)}{B(x,p)+s_q}$ where $B(x,p) = \exp\left[\frac{p^\nu u_\nu(x) - \mu(x)}{T(x)}\right]$ is the Boltzmann phase-space distribution and the $p^\nu d^4\Sigma_\nu(x) = p^\nu u_\nu H(\tau) d^4x$
- Spatial elliptical asymmetry is ensured by the scaling variable

$$s = \frac{r_x^2}{2X^2} + \frac{r_y^2}{2Y^2} + \frac{r_z^2}{2Z^2} \quad \rightarrow \quad \frac{r^2}{2R^2}\left(1 + \epsilon_2 \cos(2\phi)\right) + \frac{r_z^2}{2Z^2}$$

- The asymmetry in the velocity field is also elliptical

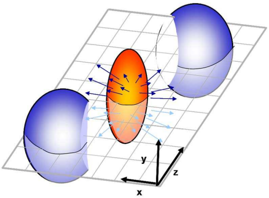
$$u_\mu = \left(\gamma, r_x\frac{\dot{X}}{X}, r_y\frac{\dot{Y}}{Y}, r_z\frac{\dot{Z}}{Z}\right) \rightarrow (\gamma, rH(1+\chi_2)\cos\phi, rH(1-\chi_2)\sin\phi, H_z r_z)$$

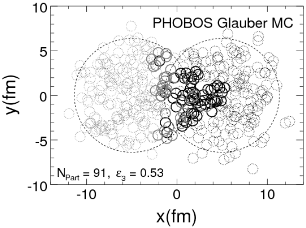
Generalization of the model I.

- The spatial asymmetry is described by the scaling variable
- General n-pole spatial asymmetry (elliptical case: $n = 2$):

$$s = \frac{r^2}{2R^2}\left(1 + \sum_n \epsilon_n \cos(n(\phi - \Psi_n))\right) + \frac{r_z^2}{2Z^2}$$

- Ψ_n is the angle of the n-th order reaction plane



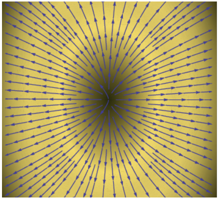


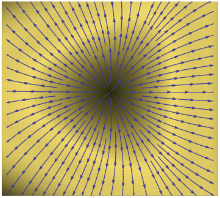
Generalization of the model II.

- Derive the velocity field from a potential: $u_\mu = \gamma(1, \partial_x\Phi, \partial_y\Phi, \partial_z\Phi)$
- General n-pole asymmetrical potential (elliptical case: $n = 2$):

$$\Phi = Hr^2\left(1 + \sum_n \chi_n \cos(n(\phi - \Psi_n))\right) + H_z r_z^2$$

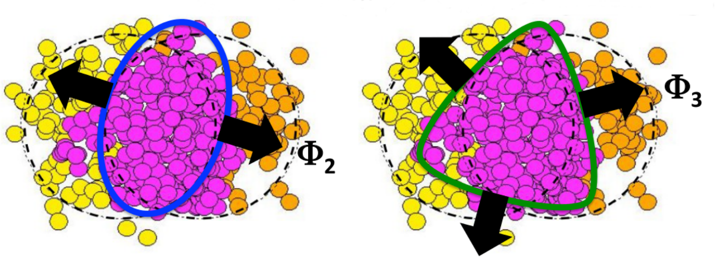
- There is multipole solution: Phys.Rev.C90,054911 (2014) based on HeavyIonPhys.A21:73-84,2004





Observables at freeze-out

- Invariant transverse momentum distribution, flows, azimuthally sensitive HBT radii
- All asymmetries are investigated in their respective reaction plane
- Rotate the system to the second / third order plane and average on the angle of the third / second order plane



Averaging on event planes

- The spatial asymmetry:
  $s = \frac{r^2}{R^2}(1 + \epsilon_2 \cos(2\phi - \Psi_2) + \epsilon_3 \cos(3\phi - \Psi_3)) + \frac{r_z^2}{Z^2}$
- If we rotate the system to the second order event plane:

$$s = \frac{r^2}{R^2}(1 + \epsilon_2 \cos(2\phi) + \epsilon_3 \cos(3\phi - \Delta\Psi_{2,3})) + \frac{r_z^2}{Z^2}$$

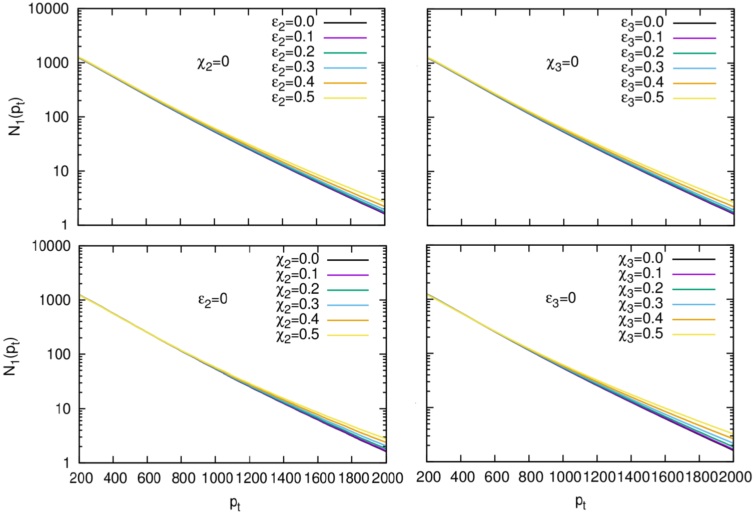
- If we rotate the system to the third order event plane:

$$s = \frac{r^2}{R^2}(1 + \epsilon_2 \cos(2\phi + \Delta\Psi_{2,3}) + \epsilon_3 \cos(3\phi)) + \frac{r_z^2}{Z^2}$$

  where $\Delta\Psi_{2,3} = \Psi_3 - \Psi_2$.
- The method is the same in the case of the velocity field.
- Set to zero the parameter directly or averaging on $\Delta\Psi_{2,3}$?

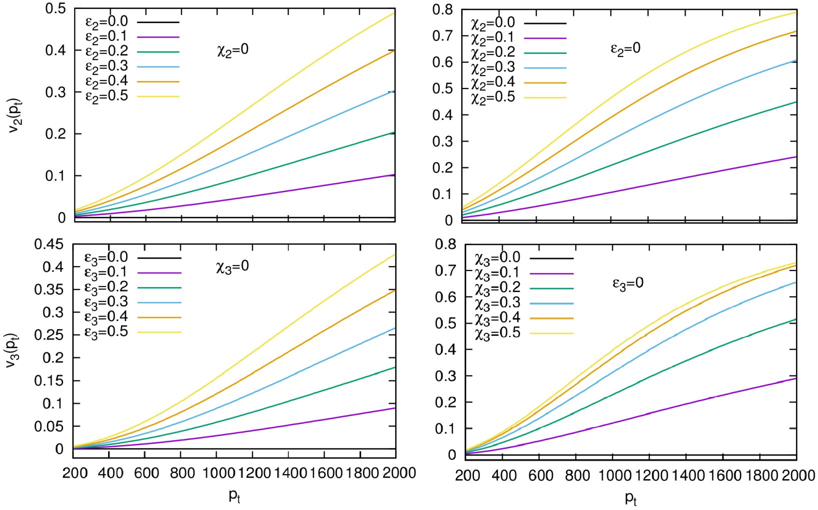
Invariant momentum distribution

Significant change could be at high p_t, the log slope is not affected strongly



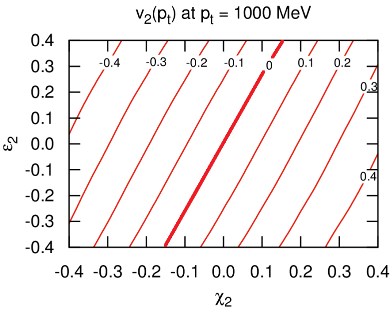
Flows

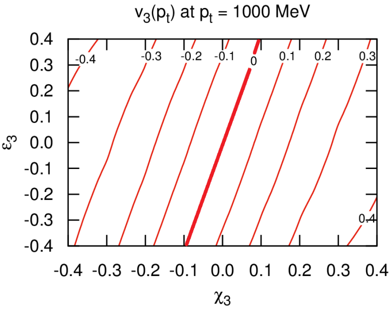
Elliptic and triangular flows are affected by their own asymmetry parameters



Mixing of parameters

- The parameters affect the flows together
- The generalization of velocity field is nescessary





HBT radii

- Calculate in the *out* − *side* − *long* system

$$R^2_{\text{out}} = \langle r^2_{\text{out}} \rangle - \langle r_{\text{out}} \rangle^2 \text{ and } R^2_{\text{side}} = \langle r^2_{\text{side}} \rangle - \langle r_{\text{side}} \rangle^2$$

  where $r_{\text{out}} = r\cos(\phi - \alpha) - \beta_t t$ and $r_{\text{side}} = r\sin(\phi - \alpha)$

  → C. J. Plumberg, C. Shen, U. W. Heinz Phys.Rev. C88 (2013) 044914

- There can be higher order parts

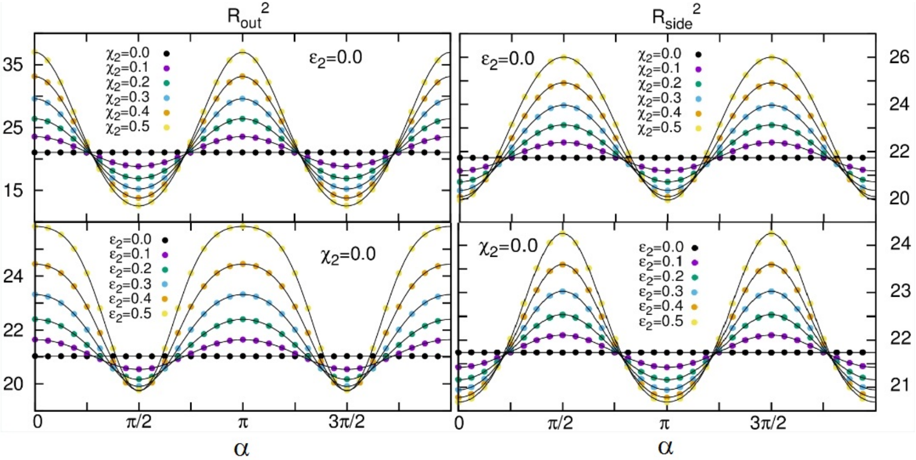
  → B. Tomášik and U. A. Wiedemann, in *QGP3*, pp. 715–777.

- We use the following parameterization in
  - elliptical case:
    $R^2_{\text{out}} = R^2_{\text{out},0} + R^2_{\text{out},2}\cos(2\alpha) + +R^2_{\text{out},4}\cos(4\alpha) + R^2_{\text{out},6}\cos(6\alpha)$
  - triangular case:
    $R^2_{\text{out}} = R^2_{\text{out},0} + R^2_{\text{out},3}\cos(3\alpha) + R^2_{\text{out},6}\cos(6\alpha) + R^2_{\text{out},9}\cos(9\alpha)$

- Similar to the R^2_{side}

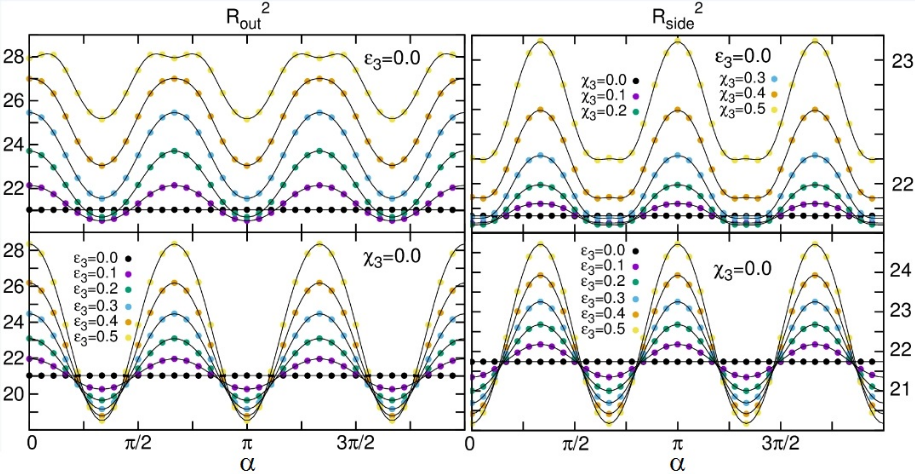
Results of the parametrization – Second order case

This case already have investigated: Eur.Phys.J.A37:111-119,2008
Mainly cos(2ϕ) behavior but higher order oscillations are also present



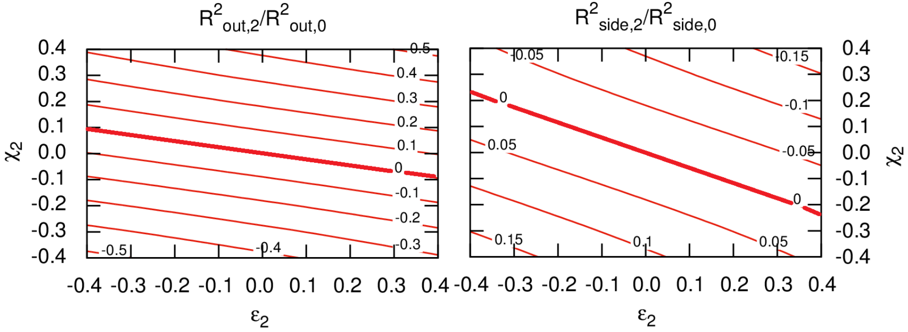
Results of the parametrization – Third order case

Mainly $\cos(3\phi)$ behavior but higher order oscillations are also present



Mixing of the parameters

The dependence of the amplitudes of the R^2_{out} and R^2_{side} in the second order case



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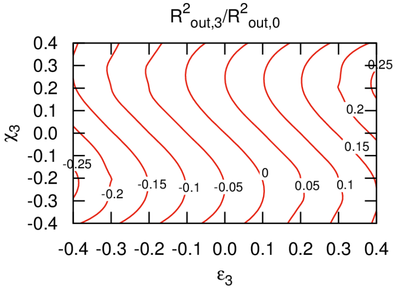

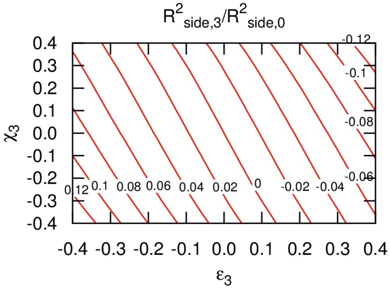

Conclusions

- Generalization of the spatial and the velocity field distribution is done
- The averaging between the different event plane is nescesary
- Higher order oscillation can be observed in HBT radii
- Absolute value of the azimuthal HBT radii depend on asymmetries
- The spatial and velocity field anisotropies both influence the v_n coefficient and the HBT radii
- The asymmetry parameters can be disentangle from the flows and the amplitudes

Thank you for your attention!

Value of the parameters

Meaning	Sign	Value
Mass of the particle	m	140 MeV
Freeze-out time	τ_0	7 fm/c
Freeze-out temperature	T_0	170 MeV
Temperature-asymmetry parameter	a^2	0.3
Spatial slope parameter	b	-0.1
Transverse size of the source	R	10 fm
Longitudinal size of the source	Z	15 fm
Velocity-space transverse size	H	10 c/fm
Velocity-space longitudinal size	H_z	16 c/fm
Elliptical spatial asymmetry parameter	ϵ_2	0.0
Triangular spatial asymmetry parameter	ϵ_3	0.0
Elliptical velocity-field asymmetry parameter	χ_2	0.0
Triangular velocity-field asymmetry parameter	χ_3	0.0

Usually one anisotropy parameter is varied, and the others are kept zero

About the spectra

Plot the N_1 with non zero coefficient divide by N_1 with zero coefficient