Multipole asymmetries in relativistic hydrodynamics

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Hydrodynamics

- Collective behavior observed at RHIC [1]
- Hydro solutions and parametrizations can be applied to measure the initial state of the sQGP
- Famous solutions: Landau, Hwa, Bjorken
- Many new 1+1D solutions, a few 1+3D solutions with spherical, elliptical symmetry
- Parametrizations with spherical, elliptical symmetry

Buda-Lund model

- Hydro parametrization in final state [2, 3]
- Describe an expanding ellipsoid with a source function

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

The spatial symmetry is ensured by

$$s = \frac{x^2}{X^2} + \frac{y^2}{Y^2} + \frac{z^2}{Z^2} \quad u_\mu = \left(\gamma, \frac{\dot{X}}{X}x, \frac{\dot{Y}}{Y}y, \frac{\dot{Z}}{Z}z\right)$$

The velocity field asymmetry is ellipsoidal too

- Successful fit with data [4, 5, 6]

Higher order anisotropy

- Finite number of nucleons ⇒ generalized geometry

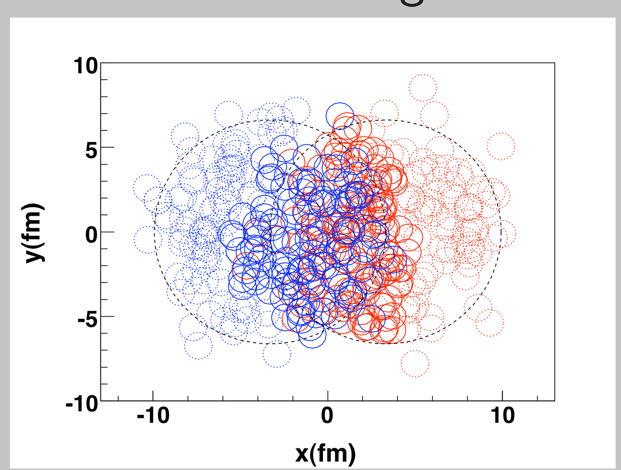


Figure 1: Glauber simulation of a Pb+Pb collision [7]

- Experimentally observable [8]

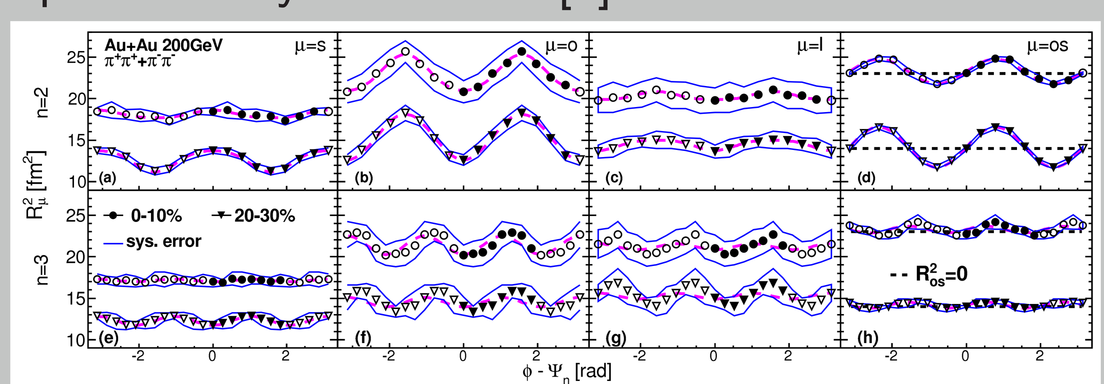


Figure 2: 2^{nd} and 3^{rd} order oscillation in PHENIX experiment.

- Existing solution with arbitrary spatial geometry [9]
- Higher order anisotropies can be described in generalized Buda-Lund model
- Second order case have already been investigated [10]
- Generalization of the ...
  - ... spatial distribution

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

    $\Phi = \frac{r^2}{2}H\left(1 + \sum_n \chi_n \cos(n(\phi - \Psi_n))\right) + \frac{r_z^2}{2}H_z$
- Basically any kind of symmetry can be described in the space-time and in the velocity field

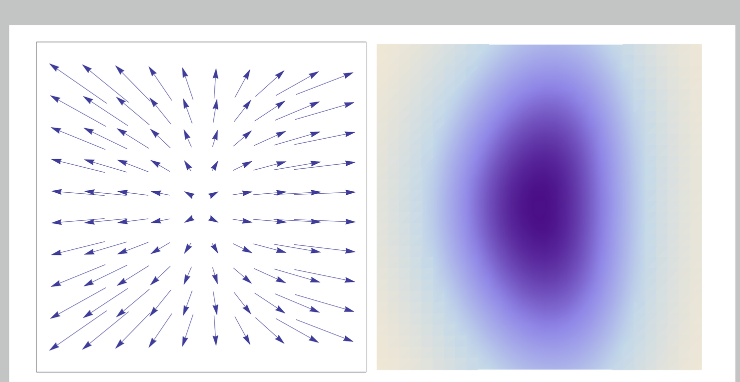
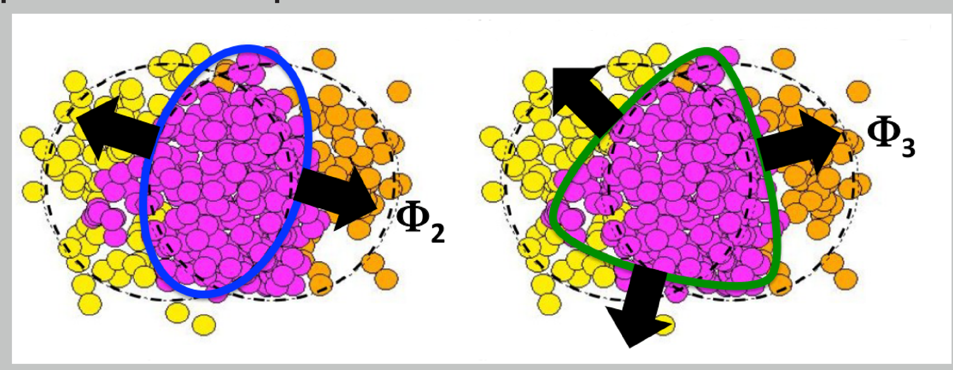


Figure 3: Example flow (left hand side) and density distribution (right hand side) with $\epsilon_2 = \chi_2 = 0.3$ and $\epsilon_3 = \chi_3 = 0.1$

Observables

- All symmetries have to be investigated in the proper reaction plane



- The angle between the reaction planes ($\Delta_{2,3}$) should be averaged out
- If the calculation should be fast then the angle can be set to zero

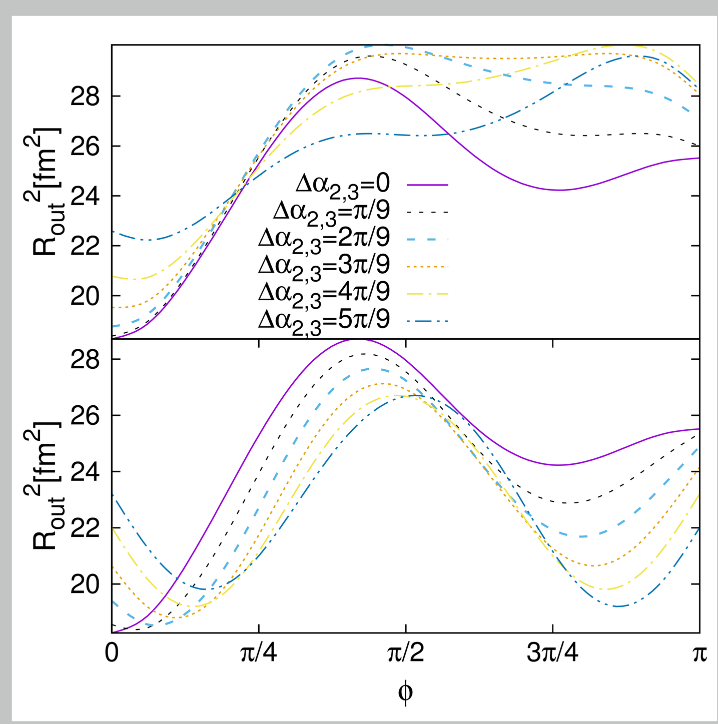


Figure 4: Different radii with different values of $\Delta_{2,3}$

Invariant spectra

- Invariant spectra: $N_1(p) = \int d^4x S(x,p)$
- The symmetry parameters have no qualitative effect

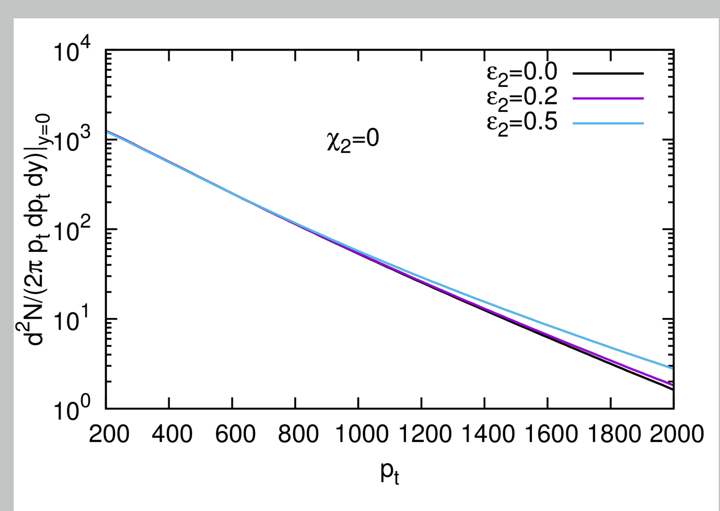
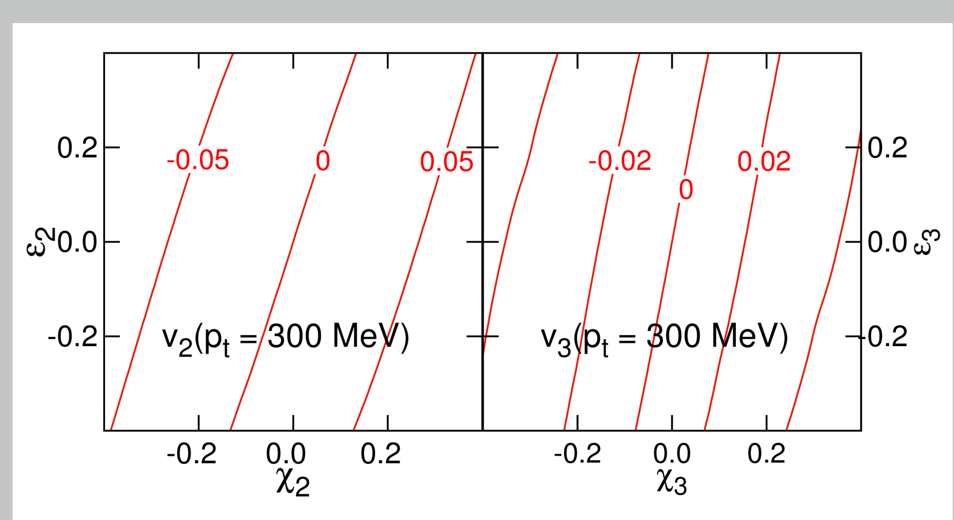


Figure 5: Azimuthally integrated single-particle p_t spectra

Flows

- Flow: $v_n = \langle\cos(n\phi)\rangle_S$
- n-th order flow only depend on n-th order symmetry parameters
- From the flow measurements the value of the parameters cannot be determined



Oscillating HBT radii

- HBT radii:
  - $R^2_{out} = \langle(r^2_{out} - \beta_t t)^2\rangle - \langle r^2_{out} - \beta_t t\rangle^2$
  - $R^2_{out} = \langle(r^2_{side})^2\rangle - \langle r^2_{side}\rangle^2$

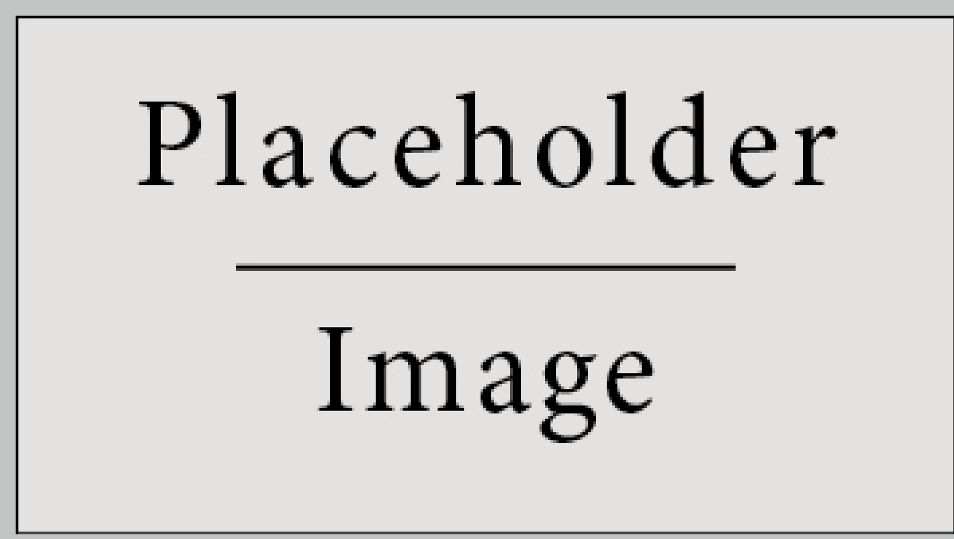


Figure 6: Figure caption

Conclusion

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Acknowledgments

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