Rotating generalization of the Buda-Lund hydrodynamical model

Viktor Könye

Eötvös Loránd University

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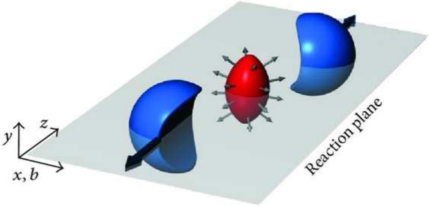
Motivation

- Heavy Ion Physics
- Hydrodynamics
- Rotation
- Buda-Lund model [1]



[1] T. Csörgő and B. Lörstad, Bose-Einstein correlations for three-dimensionally expanding, cylindrically symmetric, finite systems, Phys.Rev. C54, 1390 (1996)

Definitions of the model

- Relativistic extension of a non-relativistic exact solution [2]
- Observables calculated from source function parametrized with quantities taken at the freeze-out
- Source function:

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

- Maxwell-Jüttner distribution:

$$B(x,p) = \exp\left[\frac{p^\nu u_\nu(x)}{T(x)} - \frac{\mu(x)}{T(x)}\right]$$

- Cooper-Frye prefactor: $p^\mu \mathrm{d}^4\Sigma_\mu(x) = p^\mu u_\mu H(\tau)\mathrm{d}^4x$

[2] M. Csanád, T. Csörgő, and B. Lörstad, Buda-Lund hydro model for ellipsoidally symmetric fireballs and the elliptic flow at RHIC, Nucl.Phys. A742, 80 (2004)

The rotating velocity field

New parameter ω describing rotation. $\omega = 0$ is the original model.

- The four-velocity based on the non-relativistic solution [3]

$$\mathbf{v}_{\text{rot}} = \begin{pmatrix} r_x \frac{\dot{X}}{X} + r_z \frac{\omega}{Z} \frac{X+Z}{2} \\ r_y \frac{\dot{Y}}{Y} \\ r_z \frac{\dot{Z}}{Z} - r_x \frac{\omega}{X} \frac{X+Z}{2} \end{pmatrix} \rightarrow u^\mu = \begin{pmatrix} G \\ r_x \frac{\dot{X}}{X} + r_z \frac{\omega}{Z} \frac{X+Z}{2} \\ r_y \frac{\dot{Y}}{Y} \\ r_z \frac{\dot{Z}}{Z} - r_x \frac{\omega}{X} \frac{X+Z}{2} \end{pmatrix}$$

- $u_\mu u^\mu = 1 \Rightarrow G$
- Normalization convention to provide $v < 1$

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[3] M. I. Nagy and T. Csörgő, An analytic hydrodynamical model of rotating 3D expansion in heavy-ion collisions, arXiv:1512.00888 [nucl-th].

Temperature and chemical potential

- Scaling variable for ellipsodial symmetry

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

- Chemical potential

$$\frac{\mu(x)}{T(x)} = \frac{\mu_0}{T_0} - b^2 s \ ,$$

- Temperature

$$\frac{1}{T(x)} = \frac{1}{T_0}\left(1 + a^2 s\right)\left(1 + d^2 \frac{(\tau - \tau_0)^2}{2\Delta\tau^2}\right) \ .$$

- 15 free parameters:
  τ_0, $\Delta\tau$, X, Y, Z, $\dot{X}$, $\dot{Y}$, $\dot{Z}$, ω, ϑ, μ_0, T_0, b^2, a^2 and d^2

Saddle-point integration

- Sharp distribution

$$S_0(x,p) := \frac{H(\tau)}{B(x,p)+s_q}$$

- Approximation with Gaussian

$$S(x,p) \approx \frac{g_s}{(2\pi)^3} p_\mu u^\mu(x_s) S_0(x_s,p) \exp\left\{ -\frac{1}{2} R^{-2}_{\mu\nu} (x-x_s)^\mu (x-x_s)^\nu \right\}$$

- The covariance matrix

$$R^{-2}_{\mu\nu} = \partial_\mu \partial_\nu \left[-\ln(S_0(x_s,p)) \right]$$

Definitions of observables

- Invariant momentum distribution

$$N_1(\mathbf{p}) = \int S(x,p)\mathrm{d}^4x$$

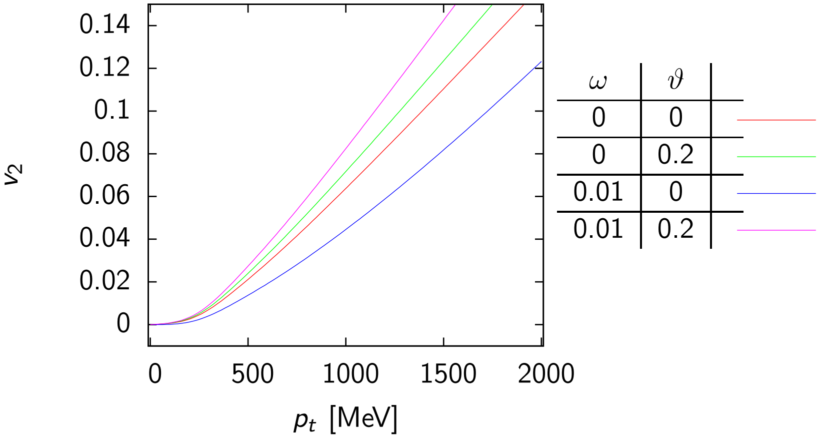
- Elliptic flow

$$v_2 = \frac{\int_0^{2\pi} N_1(p_z,p_t,\varphi)\cos(2\varphi)\mathrm{d}\varphi}{\int_0^{2\pi} N_1(p_z,p_t,\varphi)\mathrm{d}\varphi}$$

- Bose-Einstein correlation and HBT radii

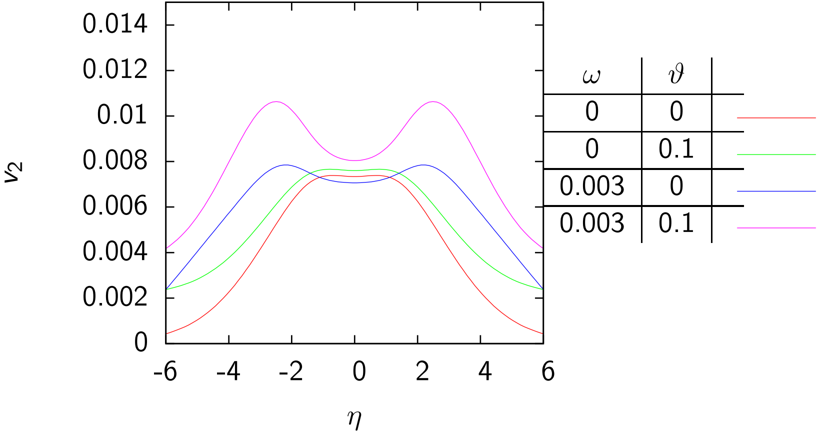
$$C(\mathbf{q}_{osl},p) = 1 + \lambda_* \exp\left(-\sum_{i,j} R_{ij}^2(p)q_iq_j\right) \qquad i,j = o,s,l$$

Elliptic flow



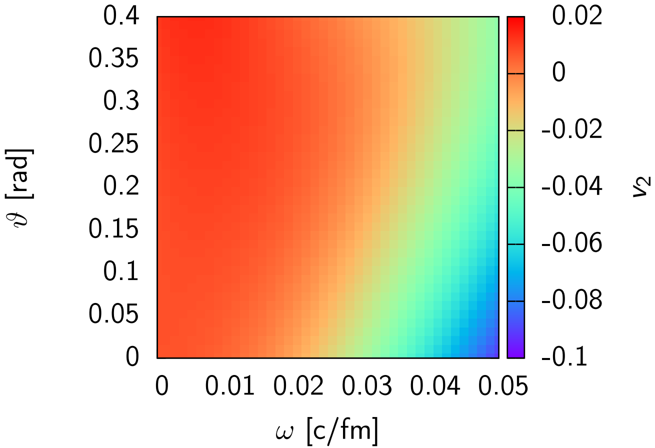
The elliptic flow as a function of transverse momentum, at $p_z = 0$ for different ϑ and ω parameters

Elliptic flow



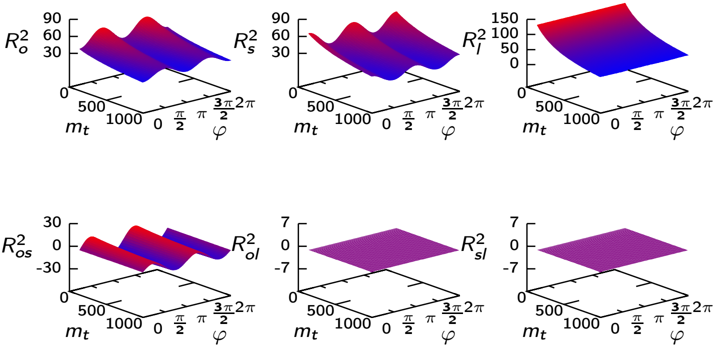
The elliptic flow as a function of pseudorapidity, at $p_t = 300\,\mathrm{MeV}$ for different ϑ and ω parameters

Elliptic flow



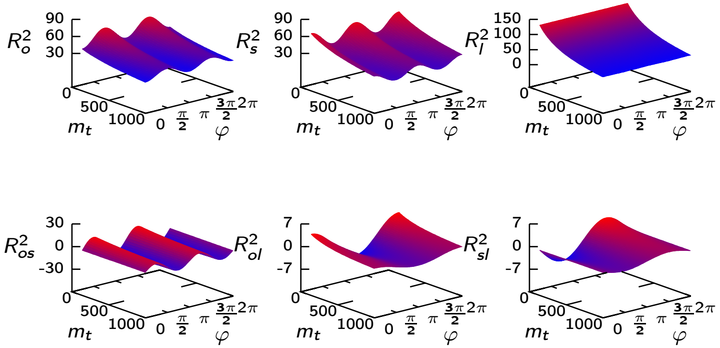
The elliptic flow as a function of ϑ and ω, at $p_t = 300\,\text{MeV}$, $p_z = 0$

HBT radii



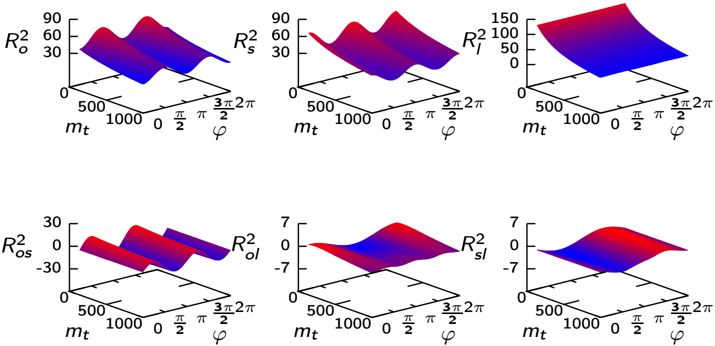
The HBT radii (R_{ij}^2 [fm^2]) without rotation, at $p_z = 0$ as a function of transverse mass (m_t [MeV]) and the azimuth angle of the momentum (φ [rad]). The angle of the rotated ellipsoid $\vartheta = 0$.

HBT radii



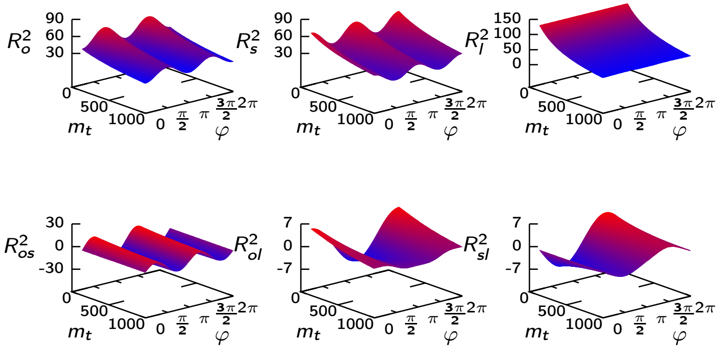
The HBT radii (R_{ij}^2 [fm^2]) without rotation, at $p_z = 0$ as a function of transverse mass (m_t [MeV]) and the azimuth angle of the momentum (φ [rad]). The angle of the rotated ellipsoid $\vartheta = 0.05$.

HBT radii



The HBT radii (R_{ij}^2 [fm^2]) with rotation ($\omega = 0.01$), at $p_z = 0$ as a function of transverse mass (m_t [MeV]) and the azimuth angle of the momentum (φ [rad]). The angle of the rotated ellipsoid $\vartheta = 0$.

HBT radii



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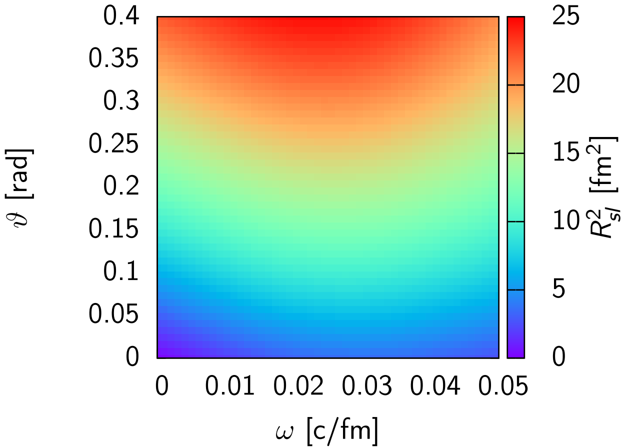
HBT radii



R_{sl}^2 as a function of ϑ and ω, at $p_t = 300\,\text{MeV}$, $p_z = 0$

Summary:

- Extension of non-relativistic rotating solution to a relativistic parametrization via the Buda-Lund model
- Generalization of the model taking into account rotation
- Calculation of observables using saddle-point approximation

Outlook:

- Comparison with experimental data
- Other flow components $(v_1, v_3 \ldots)$
- Analytic approximations

Thank you for your attention!