Balance functions from a thermal model

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Abstract. A calculation of the pion balance functions in a thermal model is presented. The total result consists of resonance and non-resonance parts. A satisfactory agreement with the data on Au+Au collisions at \( \sqrt{s_{NN}} = 130 \text{ GeV} \) is found.

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1. Introduction

In the last years the thermal (statistical) models of particle production in ultra-relativistic heavy-ion collisions turned out to be very successful in describing hadron yields [1–3], spectra [4], the elliptic-flow coefficients \( v_2 \) [5,6], and the HBT radii [5,7]. In view of this fact it is interesting to study further observables in the thermal approach and compare the results of the model calculations with the data. One particular example of such observables are balance functions [8,9], which describe correlation between opposite-charge particles in the rapidity space and are closely related to charge fluctuations [10,11].

The balance functions measured by the STAR Collaboration [12,13] at RHIC are defined by the formula

\[
B(\delta, Y) = \frac{1}{2} \left\{ \frac{\langle N_{+-}(\delta) \rangle - \langle N_{++}(\delta) \rangle}{\langle N_+ \rangle} + \frac{\langle N_{-+}(\delta) \rangle - \langle N_{--}(\delta) \rangle}{\langle N_- \rangle} \right\},
\]

where \( N_{+-}(\delta) \) is the number of the opposite-charge pairs such that both members of the pair fall into the rapidity window \( Y \) and their relative rapidity is \( |y_2 - y_1| = \delta \).
Fig. 1. Contributions to the balance function from the neutral resonances (solid line) and from the non-resonance pions (dashed line), plotted as a function of the rapidity difference of the two pions. The temperature of the system is $T = 165$ MeV, and the expansion parameters of the model correspond to the average transverse flow $\langle \beta_\perp \rangle = 0.5$.

$N_+$ is the number of positive particles in the interval $Y$, and other quantities are defined in an analogous way.

The measurement [12] showed that the widths of the balance functions are smaller than expected from models discussed in Ref. [8] and significantly smaller than observed in elementary particle collisions. This problem was discussed by Bialas in Ref. [14], where the small widths of the balance functions were explained in the framework of the coalescence model [15]. In this paper we present the results of an alternative calculation of the $\pi^+\pi^-$ balance function [16], which is based on a thermal model with resonances [4]. In a more recent paper by Pratt et al. [17], it was shown that the measured balance function may be well reproduced in the canonical blast wave model.

In our approach, the $\pi^+\pi^-$ balance function has two contributions related to two different mechanisms of the creation of an opposite-charge pair. The first one (resonance contribution) is determined by the decays of neutral hadronic resonances, whereas the second one (non-resonance contribution) is related to other possible correlations among the charged particles. We assume that the second mechanism forces the two opposite-charge pions to be produced at the same space-time point with thermal velocities. On the other hand, the first contribution refers only to the decays of neutral resonances which have a $\pi^+\pi^-$ pair in the final state (we explicitly include $K_S$, $\eta$, $\eta'$, $\rho^0$, $\omega$, $\sigma$, and $f_0$). In this case the correlations among emitted pions are completely determined by the kinematics of the decays. The details of the
modeling of the non-resonance contribution and other technical remarks are given in Ref. [16].

Fig. 2. Balance functions for the pions in the thermal model calculated for four different centrality classes and compared to the experimental data of Ref. [12]. The normalization of the model curves was adjusted in each case and is listed near the plot labels.

2. Results

According to the discussion presented above, the $\pi^+\pi^-$ balance function can be constructed as a sum of the two terms

$$B(\delta) = B_R(\delta) + B_{NR}(\delta).$$

The functions $B_R(\delta)$ and $B_{NR}(\delta)$ resulting from our model calculation are presented separately in Fig. 1. The value of the temperature used in the calculation was $T = 165$ MeV, and the expansion parameters of the model were fitted to the spectra of hadrons. This procedure yields the average transverse flow of $0.5c$. One can observe that the widths of the two contributions are similar. The calculated total width, $\langle \delta \rangle = 0.66$, turns out to be slightly larger than the experimental value for the most central collisions. The STAR result for the most central events ($c = 0 - 10\%$) is
\langle \delta \rangle = 0.594 \pm 0.019, \text{ for the mid-central } (c = 10 - 40\%) \quad \langle \delta \rangle = 0.622 \pm 0.020, \text{ for the mid-peripheral } (c = 40 - 70\%) \quad \langle \delta \rangle = 0.633 \pm 0.024, \text{ and for the peripheral } (c = 70 - 96\%) \quad \langle \delta \rangle = 0.664 \pm 0.029. \text{ Such dependence of the width of the balance function on centrality cannot be reproduced in our model by changes of the transverse flow within limits consistent with the single-particle spectra.}

In Fig. 2 our results are compared with the experimental values obtained for four different centrality classes. The normalization of the model curves was adjusted in each case, since we were not able to take into account, in a different way, the effect of a limited detector efficiency and acceptance. On the other hand, the kinematic cuts in pseudorapidity and transverse momentum were included exactly in [16]. The shapes of the model balance functions agree well with the data except for the most central case where the theoretical width is slightly larger. We note that dips of the experimental balance functions at very small values of \( \delta \) are caused by the HBT correlations. This type of effects is not included in our approach. We also note that the effects of the detector efficiency may influence the width of the balance function.

As a conclusion we state that our simple thermal model with thermal and expansion parameters fixed earlier by fitting the ratios of particle abundances and the transverse-momentum spectra gives a quite satisfactory description of the balance functions.

References

1. P. Braun-Munzinger, D. Magestro, K. Redlich, and J. Stachel, \textit{Phys.Lett.} \textbf{B518} (2001) 41.
2. W. Florkowski, W. Broniowski, M. Michalec, \textit{Acta Phys. Pol.} \textbf{B33} (2002) 761.
3. J. Rafelski and J. Letessier, \textit{Nucl. Phys.} \textbf{A715} (2003) 98.
4. W. Broniowski and W. Florkowski, \textit{Phys. Rev. Lett.} \textbf{87} (2001) 272302.
5. W. Broniowski, A. Baran, and W. Florkowski, AIP Conf. Proc. \textbf{660} (2003) 185.
6. M. Csanád, T. Csörgő, and B. Lőrstad, nucl-th/0310040.
7. T. Csörgő, \textit{Heavy Ion Phys.} \textbf{15} (2002) 1.
8. S. A. Bass, P. Danielewicz, and S. Pratt, \textit{Phys. Rev. Lett.} \textbf{85} (2000) 2689.
9. S. Jeon and S. Pratt, \textit{Phys. Rev.} \textbf{C65} (2002) 044902.
10. S. Jeon and V. Koch, \textit{Phys. Rev. Lett.} \textbf{85} (2000) 2076.
11. M. Asakawa, U. W. Heinz, and B. Müller, \textit{Phys. Rev. Lett.} \textbf{85} (2000) 2072.
12. J. Adams et al., STAR Collaboration, \textit{Phys. Rev. Lett.} \textbf{90} (2003) 172301; http://www.star.bnl.gov/STAR/sds/1/all1/physicsdatabase/17/data.html.
13. M. B. Tonjes, PhD thesis, Michigan State University (2002).
14. A. Bialas, \textit{Phys. Lett.} \textbf{B579} (2004), 31.
15. T. S. Biro, P. Levai, and J. Zimanyi, \textit{Phys. Lett.} \textbf{B347} (1995) 6.
16. P. Božek, W. Broniowski, and W. Florkowski, nucl-th/0310062.
17. S. Cheng, C. Gale, S. Jeon, S. Petriconi, S. Pratt, M. Skoby, V. Topor Pop, Q. H. Zhang, nucl-th/0401008.