THREE-DIMENSIONAL TWO-PION SOURCE FUNCTION EXTRACTION FROM SPS TO RHIC*

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(Received October 16, 2008)

Model-independent, three-dimensional source functions for pion pairs have been extracted from heavy ion collisions from SPS to RHIC energies. The source functions exhibit long-range non-Gaussian tails in the direction of the pion pair transverse momentum and in the beam. Comparison with the Therminator model allows extraction of the pion source proper breakup time and emission duration from SPS to RHIC.

PACS numbers: 25.75.–q, 25.75.Gz, 25.70.Pq

1. Introduction

A deconfined phase of nuclear matter is expected to be formed at the high energy densities created in relativistic heavy ion collisions [1]. It is widely believed that important signatures of such a phase are reflected in the space-time extent and shape of particle emission source functions.

Recently, one-dimensional source imaging techniques [2, 3] have revealed a non-trivial long range structure in the two-pion emission source at RHIC [4, 5]. The origins of this structure are still unresolved. Probing the three-dimensional (3D) shape of the two-pion source function could yield important information which could shed light on the structure's origins.

* Presented at the XXXVII International Symposium on Multiparticle Dynamics, Berkeley, USA, August 4–9, 2007.

2. Data analysis

Experimental 3D correlation functions for pion pairs, free from the effects of track merging and splitting, were analysed following the Cartesian surface-spherical harmonic decomposition technique of Danielewicz and Pratt [6]. The latter expresses the 3D correlation function as

$$C(\boldsymbol{q}) - 1 = R(\boldsymbol{q}) = \sum_{l} \sum_{\alpha_1 \ldots \alpha_l} R^l_{\alpha_1 \ldots \alpha_l}(q)\, A^l_{\alpha_1 \ldots \alpha_l}(\Omega_{\boldsymbol{q}})\,, \tag{1}$$

where $l = 0, 1, 2, \ldots$, $\alpha_i = x, y$ or z, $A^l_{\alpha_1 \ldots \alpha_l}(\Omega_{\boldsymbol{q}})$ are Cartesian harmonic basis elements ($\Omega_{\boldsymbol{q}}$ is solid angle in $\boldsymbol{q}$ space) and $R^l_{\alpha_1 \ldots \alpha_l}(q)$ are Cartesian correlation moments given by

$$R^l_{\alpha_1 \ldots \alpha_l}(q) = \frac{(2l+1)!!}{l!} \int \frac{d\Omega_{\boldsymbol{q}}}{4\pi} A^l_{\alpha_1 \ldots \alpha_l}(\Omega_{\boldsymbol{q}}) R(\boldsymbol{q})\,. \tag{2}$$

The coordinate axes are oriented so that z is parallel to the beam (long) direction, x points in the direction of the total momentum of the pair in the Locally Co-Moving System (LCMS) (out) and y is perpendicular to the other two axes (side).

The correlation moments, for each order l, can be calculated from the measured 3D correlation function using Eq. (2). In this analysis, Eq. (1) is truncated at $l = 2$ for SPS data and $l = 6$ for RHIC data and expressed in terms of independent moments only. Higher order moments were found to be negligible. Up to order 6, there are 10 independent moments: R^0, R^2_{x2}, R^2_{y2}, R^4_{x4}, R^4_{y4}, R^4_{x2y2}, R^6_{x6}, R^6_{y6}, R^6_{x4y2} and R^6_{x2y4} where R^2_{x2} is shorthand for R^2_{xx} *etc.* These independent moments were extracted as a function of q, by fitting the truncated series to the measured 3D correlation function with the moments as the parameters of the fit.

Each independent correlation moment is then imaged using the 1D Source Imaging code of Brown and Danielewicz [2, 3] to obtain the corresponding source moment for each order l. Bose–Einstein symmetrisation and Coulomb interaction (the sources of the observed correlations) are contained in the source imaging code. Thereafter, the total source function is constructed by combining the source moments for each l as in Eq. (3)

$$S(\boldsymbol{r}) = \sum_{l} \sum_{\alpha_1 \ldots \alpha_l} S^l_{\alpha_1 \ldots \alpha_l}(r)\, A^l_{\alpha_1 \ldots \alpha_l}(\Omega_{\boldsymbol{r}})\,. \tag{3}$$

Alternatively, the 3D source function can be extracted directly by fitting the independent correlation moments simultaneously with an assumed shaped for the source function. In this analysis, fits with both a 3D Gaussian (ellipsoid) and a Hump function have been attempted.

3. Results and discussions

Fig. 1(a)–(f) shows the six independent moments (circles), up to multi-polarity $l = 4$, for low p_{T}, mid-rapidity pion pairs in Pb+Pb collisions at $\sqrt{s_{NN}} = 17.3$ GeV. The 3D Gaussian (ellipsoid) fit (dotted line) misses the data points at low q while the Hump function (solid line) fits the data fairly well. These differences can also be seen in the correlation function profiles (g)–(i) for $q < 15$ MeV. The corresponding source function profiles (j)–(l) show that source image is in good agreement with the Hump function in all 3 directions and the 3D Gaussian fit underestimates the tail for $r > 10$ fm.

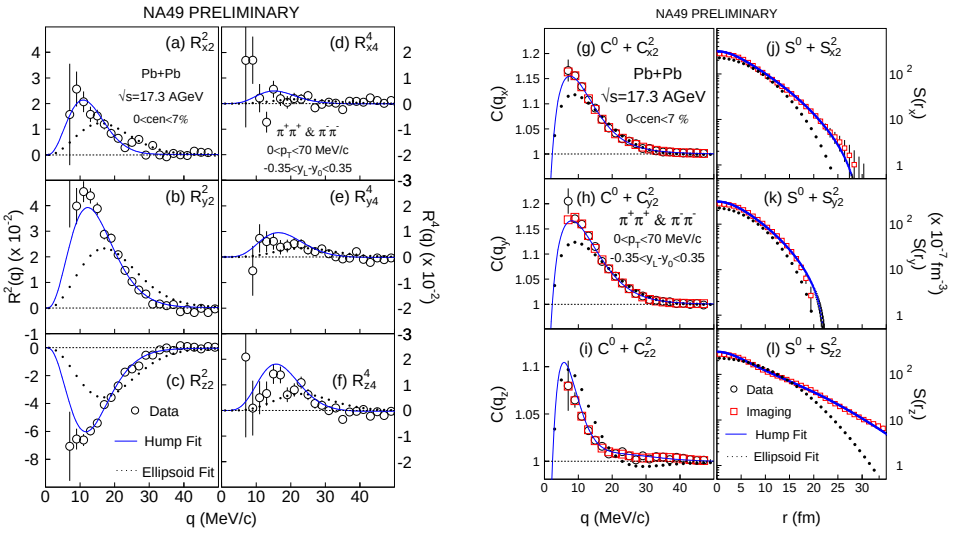


Fig. 1. (a)–(f): Correlation moments (circles) of multi-polarity $l = 2$ and $l = 4$ for pion pairs in central Pb+Pb collisions at $\sqrt{s_{NN}}$=17.3 GeV. Error bars indicate statistical errors. Systematic errors are less than size of data points. (g)–(l): Net correlation and source function profiles in the x, y and z directions.

The event generator, Therminator [7, 8], can shed more light on the source breakup and emission dynamics. It gives thermal emission from a longitudinal cylinder of radius $\rho_{\max}$, assuming Bjorken longitudinal boost invariance and Blast–Wave transverse expansion. A fluid element, located at cylindrical coordinates z and ρ, breaks up at proper time τ given by $\tau = \tau_0 - \rho/2$, and emits particles over a duration of $\Delta\tau$ in its rest frame.

Fig. 2 shows a comparison between the pion source image (squares) and Therminator calculations (circles) at $\sqrt{s_{NN}} = 17.3$ GeV ((a)–(c)) and $\sqrt{s_{NN}} = 200$ GeV ((d)-(f)). Even with all resonance decays turned on, it is necessary to invoke a non-zero proper emission duration $\Delta\tau = 3.7\,\mathrm{fm}/c$ at $\sqrt{s_{NN}} = 17.3$ GeV and $\Delta\tau = 2\,\mathrm{fm}/c$ at $\sqrt{s_{NN}} = 200\,\mathrm{GeV}$, in order to describe the extracted two-pion source images at SPS and RHIC.

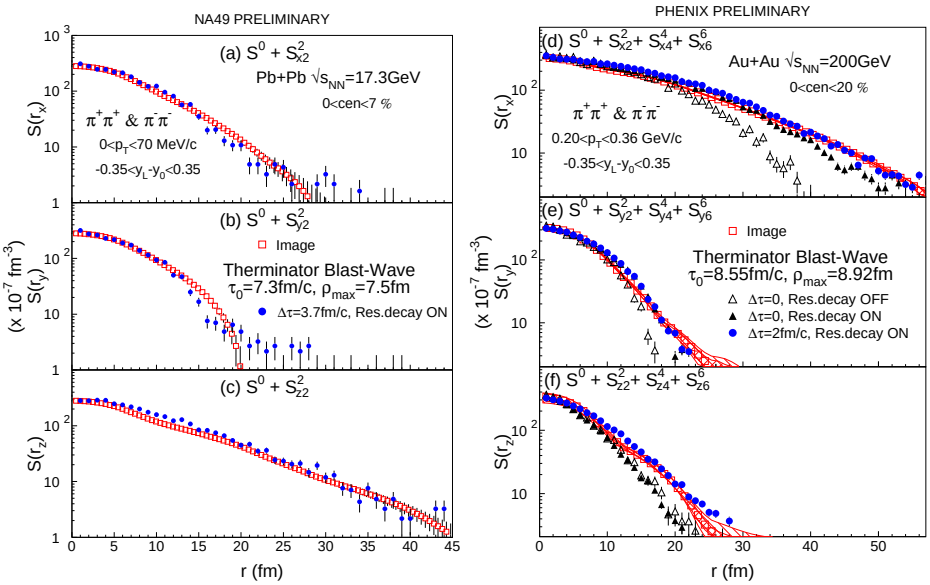


Fig. 2. Two-pion Source function comparison between image (squares) and Therminator Blast–Wave model at $\sqrt{s}_{NN} = 17.3$ GeV (a)–(c) and $\sqrt{s}_{NN} = 200$ GeV (d)–(f).

REFERENCES

[1] QM2005 Proceedings of the 18th International Conference on Ultra-Relativistic Nucleus–Nucleus Collisions, *Nucl. Phys.* **A774**, (2006).

[2] D.A. Brown, P. Danielewicz, *Phys. Lett.* **B398**, 252 (1997).

[3] D.A. Brown, P. Danielewicz, *Phys. Rev.* **C57**, 2474 (1998).

[4] P. Chung *et al., Nucl. Phys.* **A749**, 275c (2005).

[5] S.S. Adler *et al.*, [PHENIX Collaboration], *Phys. Rev. Lett.* **98**, 132301 (2007).

[6] P. Danielewicz, S. Pratt, *Phys. Lett.* **B18**, 60 (2005).

[7] A. Kisiel *et al.*, *Phys. Rev.* **C73**, 064902 (2006); *Comput. Phys. Commun.* **174**, 669 (2006) [nucl-th/0504047].

[8] A. Kisiel, *Braz. J. Phys.* **37**, No 3A, 917 (2007).