# Evidence for non-Gaussian tail in 3-D im ensional pion em ission source at SPS

P Chung<sup>1</sup> and P D an ielew  $icz^2$  for T he N A 49 C ollaboration

<sup>1</sup> Dept of Chem istry, SUNY Stony Brook, Stony Brook, NY 11794-3400, USA

<sup>2</sup> National Superconducting C yelotron Laboratory and D epartm ent of Physics and A stronom y, M ichigan State University, East Lansing, M I 48824-1321, USA

E-m ail: pchung@mail.chem.sunysb.edu

A bstract. The NA49 experiment at CERN SPS has acquired a huge data set of Pb+Pb events over a broad range of energy and centrality during the last several years. This high statistics data set, coupled with a state-of-the-art analysis technique, allows for the rst model-independent extraction and energy scan of 3D emission sources for pion pairs at SPS energies. These 3D pion emission sources provide new insights into the nature of a long-range source previously reported by PHENIX at RHIC. The new results indicate that the pion source displays signi cant non-G aussian tails in the longitudinal direction at 40 and 158 AG eV and in the outward direction at 158 AG eV.

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#### 1. Introduction

A decon ned 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 rejected in the space-time extent and shape of particle emission source functions.

Recently, 1-D in ensional source in aging techniques [4,5] have revealed a non-trivial long range structure in the two-pion emission source at RHIC [2,3]. The origins of this structure are still unclear. The presence/absence of such a structure in the pion emission sources in heavy ion collisions at intermediate SPS energies could yield important information which could help resolve the structure's origins. The NA 49 C ollaboration has carried out Pb+Pb collisions over a wide range of bom barding energies at the CER N SPS during the last decade [6]. Such a rich data set provides a unique opportunity to search for this long range structure at the SPS and study its evolution with beam energy with a view to unraveling its nature.

In this paper, the 3-D in ensional emission source in ages for pions produced in centralPb+Pb collisions over the incident energy range 40 and 158 AG eV are presented. The results are discussed in the context of a Gaussian shape assumption.

### 2. Experim ental Setup and Data Analysis

The data presented here were taken by the NA 49 C ollaboration during the years 1996-2002. The incident beam s of 40 and 158 AG eV were provided by the CERN SPS accelerator. The NA 49 Large A coeptance H adron D etector [7] achieves large acceptance precision tracking ( $p=p^2$  (0:3 7):10  $^4$  (G eV=c) 1) and particle identi cation using time projection chambers. Charged particles are detected by tracks left in the TPC and identified by the energy deposited in the TPC gas. M id-rapidity particle identication is further enhanced by a time-of- ight wall (resolution 60ps). Event centrality is determined by a forward calorim eter which measures the energy of spectator matter.

3D correlation functions, C (q), were obtained as the ratio of pair to uncorrelated reference distributions in relative m om entum q for pairs. Here,  $q = \frac{(p_1 - p_2)}{2}$  is half of the relative m om entum between the two particles in the Pair C enter-of-M ass System (PCM S). The pair distribution was obtained using pairs of particles from the same event and the uncorrelated distribution was obtained by pairing particles from di erent events. Track m erging and splitting e ects were removed by appropriate cuts on both the pair and uncorrelated distributions. M om entum resolution e ects were negligible.

In the cartesian harmonic decomposition technique [8, 2], the 3D correlation function is expressed as

C (q) 
$$1 = R (q) = {\begin{array}{*{20}c} X & X \\ & & R^{1}_{1} \dots & (q) A^{1}_{1} \dots & (q) \\ & & & 1 & 1 & 1 & 1 \end{array}} (q) A^{1}_{1} \dots & (1)$$

where  $l = 0;1;2;..., i = x;y \text{ or } z, A_{1,...,1}^{l}(q)$  are cartesian harm onic basis elements ( q is solid angle in q space) and  $R_{1,...,1}^{l}(q)$  are cartesian correlation m on ents given by (2l+1)!!<sup>Z</sup> d q l

$$R_{1}^{1} \dots (q) = \frac{(2l+1)!!}{l!} - \frac{(d-q)}{4} A_{1}^{1} \dots (q) R(q)$$
(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-M oving System (LCM S) (out) and y is perpendicular to the other two axes (side).

The correlation m om ents, for each order 1, are calculated from the m easured 3D correlation function using equation (2). Each independent correlation m om ent is then in aged using the 1D Source Im aging code of B rown and D anielew icz [4, 5] to obtain the corresponding source m om ent for each order 1. B ose-E instein symmetrisation and C oulom b interaction (the sources of the observed correlations) are contained in the source im aging code. Thereafter, the total source function is constructed by com bining the source m om ents for each las in equation (3)

$$S(r) = \sum_{1}^{X} \sum_{1}^{X} S_{1}^{1} \dots S$$

### 3. R esults

Figure 1 shows the l = 0 (R<sup>0</sup>) and l = 2 (R<sup>2</sup><sub>x2</sub> and R<sup>2</sup><sub>y2</sub>) m oments for m id-rapidity (jy<sub>L</sub> y<sub>0</sub> j < 0.35, where y<sub>L</sub> is particle laboratory rapidity and y<sub>0</sub> is CM rapidity), low p<sub>T</sub>



Figure 1. l = 0 and l = 2 m oments for mid-rapidity low  $p_T$  pairs from 158 AG eV central Pb+Pb collisions as a function q. D at are shown as solid circles while the squares represent the result of a simultaneous t of the m oments with an ellipsoid shape ((a)-(c)) and a 2-source model ((d)-(f)).

 $(0 < p_T < 70M \text{ eV}=c)$  pairs from 158 AG eV central (7%) Pb+Pb collisions, as a function of the relativem on entum q in the PCM S fram e. Here,  $R_{x2}^2$  is shorthand for  $R_{xx}^2$  etc. M on ents for other l's are either zero or negligible. The Lorentz transform ation of q from the laboratory fram e to the PCM S is done by transform ing to the LCM S along the beam axis and then transform ing to the PCM S along the pair transverse m on entum.

The data are represented in Fig. 1 by solid circles, while squares represent the results of ts to the independent moments with model sources, an ellipsoid shape (3D Gaussian) in panels (a)-(c) and a 2-source shape in panels (d)-(f). The last function arises by assuming a linear combination of two Gaussians for the single particle distribution. The best-t parameters for the two shapes are listed in the lower panels. The 2-source shape yields a much better representation of the data.

Given that the only signi cant imaged moments are found for l = 0 and 2 multipolarities, the net imaged source function in the x, y and z directions is simply the sum of the 1D source S<sup>0</sup> and the corresponding  $l = 2 \text{ mom ent S}_{ii}^2$  where i = x, y or z. In panels (a)-(c), Figure 2 compares the net imaged source (squares) for mid-rapidity, low  $p_T$  pion pairs from central Pb+ Pb collisions at 40 AG eV (i.e p = 6:4AG eV) to the best-t parametrized functions, G aussian (triangles) and 2-source model (circles). The source image and the 2-source model agree very well in all 3 directions and both disagree with the G aussian t in the z direction.

At 158 AG eV (i.e  $rac{P}{s} = 17:3AG eV$ ), represented in panels (d)-(f) of Fig. 2, the ndings are similar, but in addition to the z direction, the source function starts to develop a non-Gaussian tail in the x direction.



Figure 2. Source function in x (out), top panels, y (side), m iddle panels, and z (long) directions for low  $p_T$  m id-rapidity pairs from centralPb+ Pb events at p = 8.9AG eV (incident beam energy of 40 AG eV) and p = 17.3AG eV (incident beam energy of 158 AG eV). The imaged, G aussian and 2-source functions are represented, respectively, by squares, circles and triangles.

### 4. D iscussions

The ratio of the RMS radii of the source functions in the x and y directions is  $1.3 \quad 0.1$  at 40 AG eV and  $1.2 \quad 0.1$  at 158 AG eV. This deviation from unity, evident visually, points to a nite pion emission time.

Moreover, the RMS pair separation in the z direction, from gure 2(c) and (f), is 11fm at 40 AG eV and 12fm at 158 AG eV. These dimensions are much smaller than the Lorentz-contracted nuclear diameters of 3fm at 40 AG eV and 1.5fm at 158 AG eV and in fact give the RMS pair separation due to the longidutional spread of nuclear matter created by the passage of the two nuclei. Since the latter are moving with alm ost the speed of light, one can infer the lower bound form ation time of the created nuclear matter matter to be 8fm /c at 40 AG eV and 10fm /c at 158 AG eV.

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