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Pion-source geometry deduced from soft-pion interferometry in heavy-ion collisions at 650 A MeV

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We report transverse, R_T, and longitudinal, R_L, source sizes extracted from two-pion interferometry analysis in the Au+Au and Nb+Nb interactions at 650 A MeV. For the Nb+Nb interactions, both, R_T and R_L, do not exceed the niobium nucleus radius. In the case of Au+Au collisions, the transverse size is larger than the longitudinal one being about 12 fm for the selection of $p_\pi^+ < 120$ MeV/c. We also corroborate the existence of the previously reported specific three-pion correlations.

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1. Introduction

In this paper we present further experimental results on intensity interferometry of soft positive pions produced in symmetric Nb+Nb and Au+Au collisions at 650 A MeV. Our Au+Au data are the only existing measurements in collision between two systems each containing about two hundred nucleons. It is therefore very tempting to supplement our previous interferometric analysis [1, 2] with a study of the shape of the pion source by determining its transverse and longitudinal sizes.

We recall here briefly the basic information about the experimental set-up, referring the reader to [1-3] for the details.

The experiment has been performed at the Bevalac in Berkeley with Nb and Au ion beams, both with an energy of 650 MeV per nucleon. We have used the Plastic Ball spectrometer which is an azimuthally symmetric assembly of 815 ΔE-E telescopes. The spectrometer covers 97% of the 4π solid angle which corresponds to the interval 10-160° of the polar angle in the laboratory system. Each telescope provides identification and energy measurement of positive pions in the kinetic energy interval 20-100 MeV. The two event samples consist of 67 000 Au+Au and 120 000 Nb+Nb interactions in which at least two particles were identified as positive pions.

2. Two-pion correlations

We shall use throughout this section the variable $q = |\mathbf{p}_1 - \mathbf{p}_2|$ where $\mathbf{p}_i$ is the momentum of the i-th pion. Expanding q in terms of the transverse and the longitudinal components gives:

$$q^2 = q_T^2 + q_L^2$$

where q_L and q_T are the differences of the longitudinal and the transverse momenta of two pions.

Two different correlation functions will be compared with the data. The first one results from the standard Gaussian model of the pion source points. It leads to the following spatial part of the correlation function:

$$C(2) = 1 + \lambda \exp(-q_T^2 R_T^2/2 - q_L^2 R_L^2/2) \tag{1}$$

where $0 \leqq \lambda \leqq 1$ is the chaoticity parameter and R_L and R_T are the longitudinal and the transverse source sizes, respectively.

Another correlation function which will be tested here follows from a quantum statistical scheme introduced by Weiner [5], in which the particle field is built of coherent and chaotic components. This approach, with Gaussian parametrization of both fields, leads to the following correlation function in terms of the q variable:

$$C(2) = 1 + 2\lambda(1-\lambda)\exp(-q_T^2 R_T^2/2 - q_L^2 R_T^2/2) + \lambda^2 \exp(-q_T^2 R_T^2 - q_L^2 R_L^2). \tag{2}$$

The parameters:

$$\lambda_1 = 2\lambda(1-\lambda), \quad \lambda_2 = \lambda^2 \tag{3}$$

could be regarded as effective coherence factors corresponding to two sources with different but related sizes ($R_1 = \sqrt{2} R_2$). Formula (2) has been recently derived in [8] without making use of the coherent state technique [4, 6, 7]. The model of [8] considers an interaction in which not only one, but occasionally also several identical

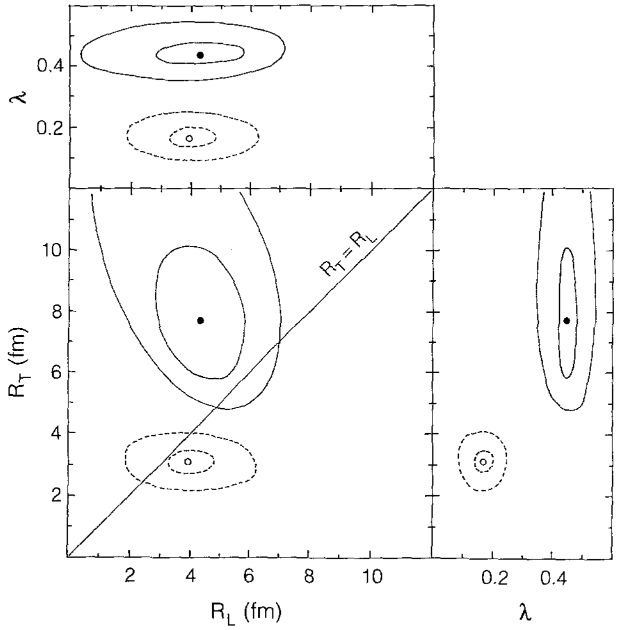

Fig. 1. The minimum χ^2 contours for fits of correlation function (1). Solid- and dashed-line contours refer to the Au + Au and Nb + Nb systes, respectively. The contours spacing corresponds to one standard deviation in a confidence level

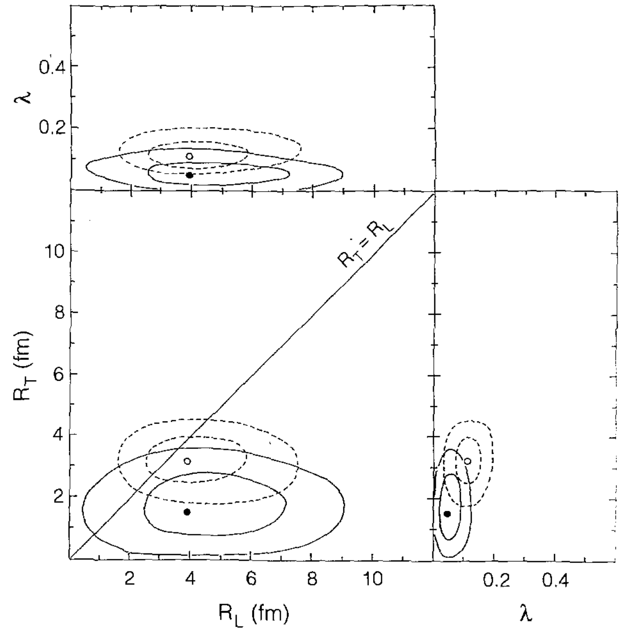

Fig. 3. The same as in Fig. 1, but for the $p_{\pi^+} \geqq 120$ MeV/c selection

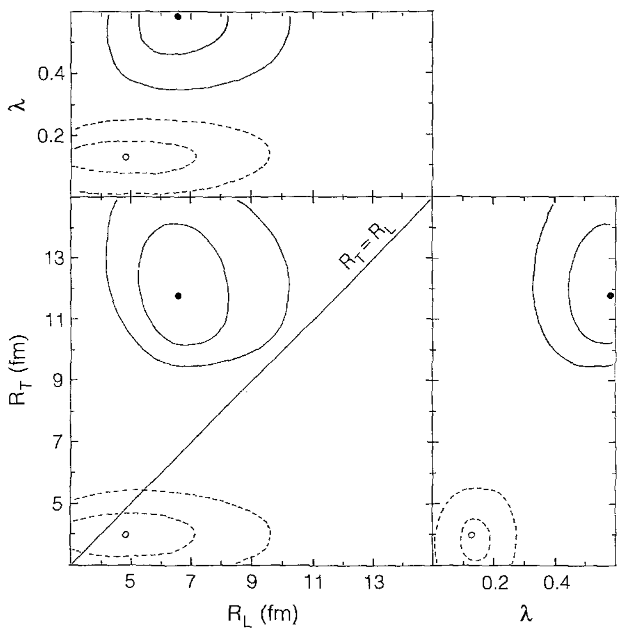

Fig. 2. The same as in Fig. 1, but for the $p_{\pi^+} < 120$ MeV/c selection

pions can be emitted simultaneously from one point-like source or from different points located at distances very small as compared with the pion wave length $\lambda \approx 1/p$. Within this model, the parameter λ in (2) describes a fraction of chaotically located one-particle point-like sources relative to all point-like sources, provided the numbers of those sources fluctuate according to the Poisson law.

The experimental correlation functions have been calculated by dividing the experimental q spectra by the normalized reference distributions. The latter have been constructed by random mixing pions from different events having the same multiplicity of positive pions and about the same multiplicity of charged particles. A reference sample of one million pion pairs has been generated. To account for the Coulomb interaction, each pion pair in the reference distribution has been weighted with the inverse of the Gamov factor $G(\eta)$ [4].

In Fig. 1 we display the results of fitting formula (1) to the two studied systems. The black dot together with solid line contours and the open circle with dashed line contours refer to the Au + Au and Nb + Nb systems, respectively. The contours spacing corresponds to one standard deviation in confidence level. One can see from Fig. 1 that both the Nb + Nb and the Au + Au systems exhibit about the same longitudinal source sizes, whereas the transverse source size for the Au + Au system is about twice the one for the Nb + Nb system. The chaoticity parameter λ for the Au + Au collisions is about two times larger than the one for the Nb + Nb reactions. To investigate the momentum dependence of the source parameters, we selected two subsamples of events: one with every pion having in the nucleon-nucleon center-of-mass system momentum $p_{\pi^+} < 120$ MeV/c, another with $p_{\pi^+} \geqq 120$ MeV/c . Figures 2 and 3 show the results of fitting formula (1) to the experimental correlation functions. The solid and the dashed line contours have the same meaning as those in Fig. 1. In Table 1 we list the values of the fitted parameters. Inspection of them leads to the following observations:

(i) For the Nb + Nb system, transverse and longitudinal sizes do not show any significant momentum dependence, nor do the transverse and longitudinal sizes differ much from each other. The magnitudes of R_T and R_L do not exceed the radius of the niobium nucleus.

Table 1.
$C=1+\lambda\,\exp(-q_T^2R_T^2/2-q_L^2R_L^2/2)$

	λ	R_T (fm)	R_L (fm)	χ^2/ndf
Au + Au				
Overall sample	$0.437^{+0.035}_{-0.019}$	$7.73^{+2.35}_{-1.95}$	$4.29^{+1.60}_{-1.47}$	1.1
$p_\pi < 120$ MeV/c	$0.591^{+0.147}_{-0.131}$	$11.80^{+2.04}_{-1.72}$	$6.56^{+1.64}_{-1.27}$	1.3
$p_\pi \geqq 120$ MeV/c	$0.049^{+0.037}_{-0.028}$	$1.54^{+1.18}_{-0.85}$	$3.89^{+3.13}_{-1.43}$	1.2
Nb + Nb				
Overall sample	$0.166^{+0.028}_{-0.026}$	$3.15^{+0.33}_{-0.30}$	$3.92^{+0.80}_{-0.72}$	1.2
$p_\pi < 120$ MeV/c	$0.131^{+0.048}_{-0.041}$	$3.97^{+0.74}_{-0.61}$	$4.85^{+2.37}_{-2.32}$	1.1
$p_\pi \geqq 120$ MeV/c	$0.107^{+0.046}_{-0.040}$	$3.19^{+0.82}_{-0.73}$	$3.87^{+1.87}_{-1.15}$	1.1

(ii) In the Au + Au reactions, both the longitudinal and the transverse sizes tend to increase with decreasing pion momenta. For the $p_{\pi^+} < 120$ MeV/c events, the transverse size R_T is about 12 fm, exceeding about two times R_L, whereas for the $p_{\pi^+} > 120$ MeV/c selection longitudinal and transverse sizes are about the same within the limit of errors.

(iii) There is no significant momentum dependence of the chaoticity parameter λ for the Nb + Nb reactions. For the Au + Au system λ depends markedly on p_{π^+}; it is getting much smaller for larger pion momenta. The chaoticity parameter for the $p_{\pi^+} < 120$ MeV/c selection is three times larger for the Au + Au system than for the Nb + Nb reactions. On the other hand, for the $p_{\pi^+} \geqq 120$ MeV/c sample, the chaoticity parameters for both systems are quite small and do not differ within errors.

Figures 4–6 and Table 2 are the counterparts of Figs. 1–3 and Table 1 for Weiner's correlation function.

From a first look, one would conclude from Tables 1 and 2 that for the overall sample of pion pairs the two-exponential fit is as good as the one-exponential one. One must not forget, however, that the particular relation between λ_1 and λ_2 in (3) requires in derivation of [5] the variables used (in our case q_T and q_L) to be stationary, which they are not. This may lead to a q dependence of λ. The same with the model of [8]: to get Weiner's formula (2), a Poisson distribution of the number of sources has to be assumed, which is not necessarily the case in this experiment. To check the relation between λ_1 and λ_2 given by (3), we allowed the coefficients λ_1 and λ_2 to change freely in the fit, but kept the $R_1=\sqrt{2}\,R_2$ relation by fitting to the data the correlation function in terms of q

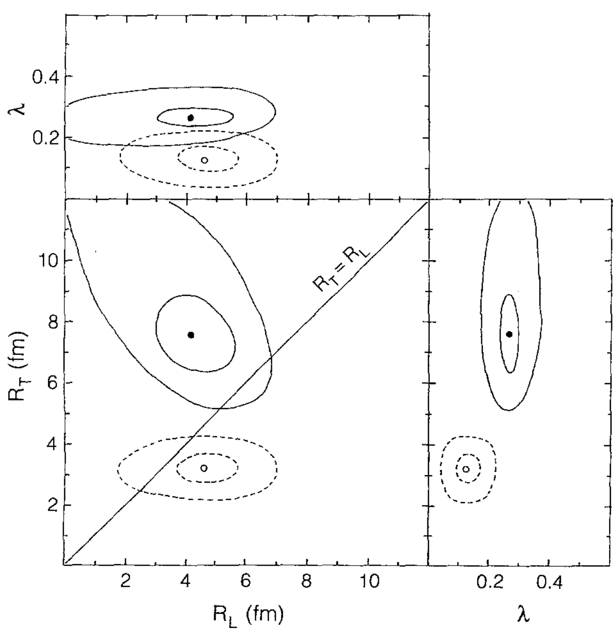

Fig. 4. The same as in Fig. 1, but for the correlation function (2)

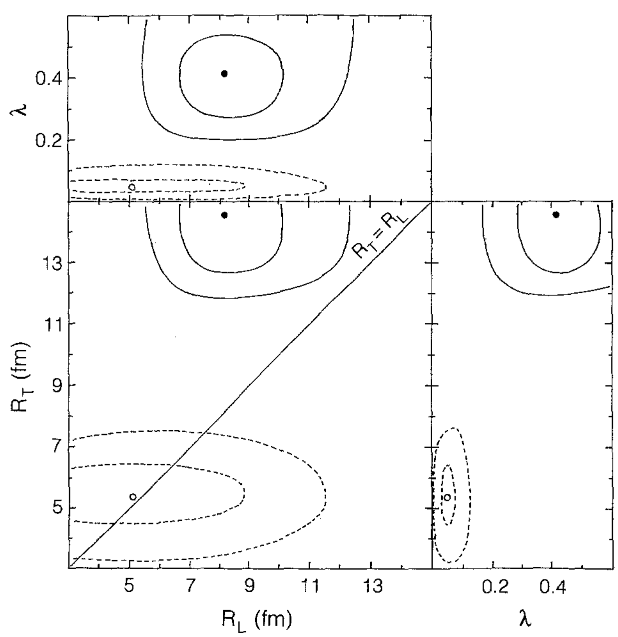

Fig. 5. The same as in Fig. 4, but for the $p_{\pi^+} < 120$ MeV/c selection

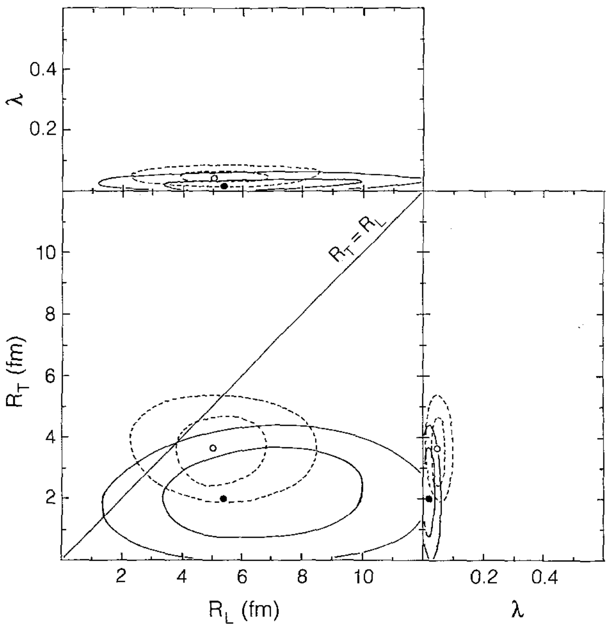

Fig. 6. The same as in Fig. 4, but for the $p_{\pi^+} \geqq 120$ MeV/c selection

$$C(2) = 1 + \lambda_1 \exp(-q^2 R^2/2) + \lambda_2 \exp(-q^2 R^2). \tag{4}$$

Table 3 lists the results of the fits. Not surprisingly, the fitted λ_1 and λ_2 do not fulfill (3). Allowing for all four parameters R_1, R_2, λ_1 and λ_2 to change in the fit we were not able to recover the relation $R_1 = \sqrt{2} R_2$ (see Table 4). In the Nb + Nb case, the fit yields the same R_1 and R_2 and for the Au + Au system R_2 exceeds R_1 three times. The statistical significance of these observations is not sufficient though to rule out the two-component correlation function for the Nb + Nb. Note also that the considerations of [5, 8] apply to directly produced pions, and not to pions originating from resonance decay which may be present in our data. Furtheron in the text we discuss the possible influence of the resonances on the measured radii.

To account for the non-stationarity of variables used in the framework of Weiner's quantum statistical approach we examined the recently proposed correlation function [9] in the (k_1, k_2) variables, where $k_i = \{\mathbf{k}_i, k_{0i}\}$ are four-vectors (Euclidean metric) and $\mathbf{k}_i$ and k_{0i} correspond to the three-momentum and the energy of the i-th pion, respectively. The authors derive the correlation function

Table 2. $C = 1 + 2\lambda(1-\lambda)\exp(-q_T^2 R_T^2/2 - q_L^2 R_L^2/2) + \lambda^2 \exp(-q_T^2 R_T^2 - q_L^2 R_L^2)$

	λ	$\lambda_1 = 2\lambda(1-\lambda)$	$\lambda_2 = \lambda^2$	$R_{T1} = R_T$ (fm)	$R_{T2} = R_T\sqrt{2}$ (fm)	$R_{L1} = R_L$ (fm)	$R_{L2} = R_L\sqrt{2}$ (fm)	χ^2/ndf
Au + Au								
Overall sample	$0.264^{+0.023}_{-0.018}$	$0.389^{+0.022}_{-0.017}$	$0.070^{+0.012}_{-0.010}$	$7.57^{+1.24}_{-1.20}$	$10.71^{+1.75}_{-1.70}$	$4.17^{+1.47}_{-1.20}$	$5.90^{+2.08}_{-1.70}$	1.1
$p_\pi < 120$ MeV/c	$0.414^{+0.144}_{-0.131}$	$0.485^{+0.050}_{-0.045}$	$0.171^{+0.119}_{-0.108}$	$14.58^{+2.33}_{-1.85}$	$20.62^{+3.30}_{-2.62}$	$8.13^{+1.95}_{-1.51}$	$11.50^{+2.76}_{-2.14}$	1.3
$p_\pi \geqq 120$ MeV/c	$0.021^{+0.015}_{-0.012}$	$0.041^{+0.029}_{-0.023}$	$0.001^{+0.001}_{-0.001}$	$2.02^{+1.71}_{-1.24}$	$2.86^{+2.42}_{-1.75}$	$5.39^{+4.61}_{-2.08}$	$7.62^{+6.52}_{-2.94}$	1.1
Nb + Nb								
Overall sample	$0.125^{+0.046}_{-0.033}$	$0.219^{+0.069}_{-0.050}$	$0.016^{+0.011}_{-0.008}$	$3.18^{+0.47}_{-0.41}$	$4.50^{+0.66}_{-0.58}$	$4.58^{+1.12}_{-0.96}$	$6.48^{+1.58}_{-1.36}$	1.1
$p_\pi < 120$ MeV/c	$0.046^{+0.016}_{-0.014}$	$0.088^{+0.029}_{-0.025}$	$0.002^{+0.001}_{-0.001}$	$5.36^{+1.09}_{-0.89}$	$7.58^{+1.54}_{-1.26}$	$5.08^{+3.76}_{-2.98}$	$7.18^{+5.32}_{-4.21}$	1.1
$p_\pi \geqq 120$ MeV/c	$0.047^{+0.017}_{-0.016}$	$0.090^{+0.031}_{-0.029}$	$0.002^{+0.002}_{-0.002}$	$3.66^{+1.10}_{-1.19}$	$5.18^{+1.56}_{-1.68}$	$4.54^{+1.78}_{-1.24}$	$6.42^{+2.52}_{-1.75}$	1.1

Table 3. $C = 1 + \lambda_1 \exp(-q^2 R^2/2) + \lambda_2 \exp(-q^2 R^2)$

	λ_1	λ_2	$\lambda = (1+\sqrt{1-2\lambda_1})/2$	$\lambda = (1-\sqrt{1-2\lambda_1})/2$	$\lambda = \sqrt{\lambda_2}$	χ^2/ndf
Au + Au	0.143 ± 0.122	0.235 ± 0.125	0.922 ± 0.036	0.078 ± 0.036	0.485 ± 0.129	1.7
Nb + Nb	0.166 ± 0.154	0.169 ± 0.172	0.908 ± 0.047	0.091 ± 0.047	0.411 ± 0.209	1.2

Table 4. $C = 1 + \lambda_1 \exp(q^2 R_1^2/2) + \lambda_2 \exp(-q^2 R_2^2/2)$

	λ_1	λ_2	R_1 (fm)	R_2 (fm)	χ^2/ndf
Au + Au	0.208 ± 0.078	0.547 ± 0.233	3.74 ± 0.65	11.74 ± 3.46	1.6
Nb + Nb	0.228 ± 0.019	0.095 ± 0.020	3.51 ± 0.48	3.51 ± 1.07	1.2

Table 5. Fit of the formula (5) with λ_1, λ_2 and λ being free

	Parameters						
	λ	λ_1	λ_2	$\lambda_1=2\lambda(1-\lambda)$	$\lambda_2=\lambda^2$	$r=\sqrt{R^2-R_L^2}$ (fm)	χ^2/ndf
Au+Au	0.123±0.051	0.132±0.018	0.003±0.002	0.216±0.077	0.015±0.013	5.37±1.72	0.7
Nb+Nb	0.399±0.027	0.998±0.066	0.001±0.002	0.480±0.011	0.159±0.022	3.31±1.10	1.0

$$
\begin{aligned}
C_2(k_1,k_2) & \\
=1+\lambda_1 & \exp[-r^2(k_1^2+k_2^2)/4] \\
& \times\exp[-r^2(k_1-k_2)^2/8]/[A(k_1)A(k_2)] \\
& +\lambda_2\exp[-r^2(k_1-k_2)^2/4]/[A(k_1)A(k_2)]
\end{aligned}
\tag{5}
$$

where

$$A(k_i)=\lambda+(1-\lambda)\exp[-r^2k_i^2/2]$$

and

$$r^2=R^2-R_L^2$$

and the relations (3) are expected between the λ, λ_1 and λ_2 parameters.

In (5) the parameter R corresponds to the space-time extension of the source and R_L is related to the coherence length in space-time. The parameter λ is the chaoticity of the pion source and it might be related to the ratio of the mean numbers of particles due to the chaotic field and to the sum of that for the chaotic and the coherent fields. In Table 5 we report the results of the fits of (5) to the data with all the parameters λ, λ_1, λ_2 and r being free in the fit. By using the fitted parameter λ and (3) one can calculate λ_1 and λ_2. The fitted values of $\lambda_{1(2)}$ are given in the third and the fourth columns of Table 5 and the calculated $\lambda_{1(2)}$ are displayed in the next two columns. In the Au+Au case the calculated $\lambda_{1(2)}$ are consistent with the fitted values of $\lambda_{1(2)}$ within one standard deviation, whereas for the Nb+Nb system we observe considerable disagreement. In Table 6 the results are displayed of the fit of (5) with constraints (3) on the parameters λ, λ_1 and λ_2. For the Au+Au interactions the values of λ in Tables 5 and 6 differ siginificantly, whereas for the Nb+Nb case these values of λ are consistent within errors. For the Nb+Nb interactions the values of the parameter r obtained without the constraints (3) are inconsistent with those obtained when (3) is assumed in the fit. For the Au+Au system the difference between r parameters does not exceed two standard deviations. The values of χ^2, listed in Tables 5 and 6, indicate that the correlation function (5) with no constraints on the parameters λ_1 and λ_2 fits the data better as compared to the case when (3) are imposed. The improvement of χ^2 is somewhat more evident for the Nb+Nb system.

In our analysis no assumptions were done on the origin of the measured π-mesons. In particular, they might be products of the decays of Δ-resonances produced in nucleon-nucleon collisions. There is no way to distinguish experimentally the Δ decay products from the pions produced directly in the collisions of nucleons. We can estimate, however, how the measured radii could be influenced by the Δ lifetime. At our energy the Δ-resonance produced by the incoming nucleon on the target nucleon being at rest in the laboratory ($NN\rightarrow N\Delta$) has the momentum of 85 MeV/c and the velocity $\beta=0.07$ in the $N-N$ center-of-mass system. The Δ with this velocity can travel a distance of about 0.12 fm before it decays. This is below the values of the experimental errors of measured radii. This tiny smearing of the measured radii can not explain the difference in the radii between the Nb+Nb and the Au+Au interactions even if the rates of Δ production are different for Au and Nb nuclei. The average number of π^+'s in an event was 2.61 and 2.66 for Nb+Nb and Au+Au, respectively. These numbers suggest that the rates of the production of Δ-resonances do not differ too much for the Nb+Nb and the Au+Au interactions.

Table 6. Fit of the formula (5)

	λ	$r=\sqrt{R^2-R_L^2}$ (fm)	χ^2/ndf
Au+Au	0.942±0.069	7.90±1.22	0.8
Nb+Nb	0.325±0.048	8.74±1.29	1.3

To account for the possible influence of the experimental resolution on the results all the hypotheses, (1)-(5), were convoluted with a Gaussian with the q-dependent variance $\sigma(q)$ and then fitted to the data. It was found to affect the values of the parameters by a few tenths of a percent. In Table 7 we recall the q-dependence of the experimental resolution $\sigma(q)$, presented in [1]. The resolution $\sigma(q)$ allows reliable measurement of radii below, roughly, 25 fm.

Concluding this section, we wish to emphasize the observation of the transverse expansion of the pion source well beyond the gold nucleus radius. For the smaller system, Nb+Nb, both the transverse and longitudinal source sizes are approximately within the radius of the niobium nucleus.

3. Three-pion correlations

In the previous paper [2] we have reported the observation of specific three-pion correlations not reducible to the two-pion ones. This conclusion has been challenged in [10], where it was pointed out that the reference distribution we have used in [2] accounted only partly for the

Table 7. Experimental resolutions

Two-pion correlations									
q (MeV/c)	40	80	120	160	200	240	280	320	360
$\sigma(q)$ (MeV/c)	6.3	7.2	7.7	8.1	8.2	8.4	8.6	8.7	8.9

Three-pion correlations								
Q (MeV)	100	150	200	250	300	350	400	450
$\sigma(Q)$ (MeV)	14.3	15.1	15.4	15.4	15.4	16.6	16.1	16.9

Table 8. $C=1+\lambda_{3\pi}\exp(-Q_{3\pi}^2 R^2)$

	[2]			This paper		
	$\lambda_{3\pi}$	R (fm)	χ^2/ndf	$\lambda_{3\pi}$	R (fm)	χ^2/ndf
Au+Au	0.929 ± 0.138	1.51 ± 0.13	1.0	0.689 ± 0.094	1.37 ± 0.13	1.1
Nb+Nb	0.306 ± 0.092	0.87 ± 0.43	0.9	0.298 ± 0.090	0.86 ± 0.43	0.9

two-pion correlations. We recall here that the reference distribution in [2] has been constructed by combining a random pair from one event with a random single pion from another event. Indeed, the correlation function for the identical pion triplets reads [10]

$$C(3)=1+|F_{12}|^2+|F_{23}|^2+|F_{13}|^2 + 2\,\mathrm{Re}(F_{12}F_{23}F_{13}) \tag{6}$$

where F_{ij} is the Fourier transform of the two-pion source distribution. Assuming $|F_{ij}|^2=\lambda\exp(-R^2Q_{ij}^2/2)$ and neglecting phase factors, making thus the interference term maximal, one gets

$$C(3)=1+\lambda\sum_{\substack{i=1\\j=1\\i>j}}^{3}\exp(-R^2Q_{ij}^2/2) + 2\lambda^{3/2}\exp(-R^2Q_{3\pi}^2/4) \tag{7}$$

where λ and R are the chaoticity parameter and the source-size deduced from the two-pion correlations in the Q_{ij} variable ([2]), $Q_{ij}^2=M_{ij}^2-(2m_\pi)^2$, $Q_{3\pi}^2=M_{3\pi}^2-(3m_\pi)^2$, M_{ij} and $M_{3\pi}$ are the effective masses of two and three pions, respectively. And, indeed, the last term in formula (6) has not been accounted for in the reference distribution of [2], as it has been correctly pointed out in [10]. In the following we shall demonstrate that its contribution is small and can be safely neglected. Since the phase factors in (6) are not known, the exact evaluation of the $\mathrm{Re}(F_{12}F_{23}F_{13})$ term is not possible. One can estimate, however, its maximal contribution, which appears to be marginal. To illustrate this we have calculated the reference distribution according to (7). The two-pion λ and R parameters have been taken from this experiment and their values for the Q variable are given in [2]. Two approaches were tried:

(i) the uncorrelated three-pion combinations, which were built by selecting pions from different events, were weighted, event by event, with (7);

(ii) the last term of (7) was constructed by using the uncorrelated three-pion combinations, whereas the remaining term of the reference distribution was calculated by combining a random pion-pair from one event with a random single pion from another event.

Both approaches yield practically the same correlation functions. The results of the fit are compared in Table 8 with those presented in our previous paper [2]. One can see from the table that the interference term, set to its maximal value in (6), does nothing for the Nb+Nb system and changes very little the source size for the Au+Au interactions. In Fig. 7 we show the three-pion correlation function for the latter case with reference distribution calculated by taking three random pions from different events. It represents, therefore, the overall three-pion effect. The curve in Fig. 7 results from the fit of the cor-

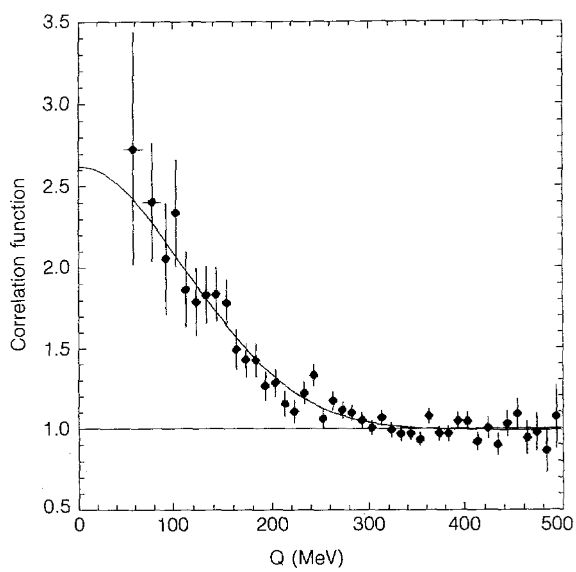

Fig. 7. The correlation function for pion triplets for the Au+Au system, calculated by using the reference distribution with total destruction of two-pion correlations

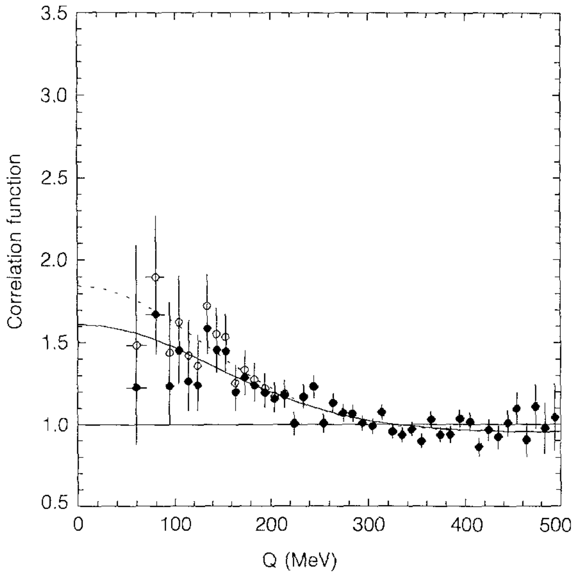

Fig. 8. The same as in Fig. 7, but with the reference distribution calculated according to (6)

relation function $C_3 = 1 + \lambda_{3\pi} \exp(-Q_{3\pi}^2 R^2/2)$ with Gamov corrections taken into account. The fitted parameters are: $\lambda = 1.645 \pm 0.199$, $R = 1.74 \pm 0.10$ and $\chi^2/n = 1$. In Fig. 8 one sees what remains from three-pion correlations after removing the two-pion contribution and assuming the maximal value of the interference term (black dots) in (6). The open circles in Fig. 8 represent the correlation function calculated using the reference distribution in which the interference term in (6) was disregarded. All the data presented in Figs. 7 and 8 are corrected for the Coulomb repulsion [4, 2]. The experimental resolution $\sigma(Q_{3\pi})$ for the three-pion correlations was taken into account in the same way as for the two-pion case. The values of $\sigma(Q_{3\pi})$ for different $Q_{3\pi}$ are given in Table 7. The resolution $\sigma(Q_{3\pi})$ allows estimation of R less than about 13 fm.

Inspection of Table 8 and Figs. 7 and 8 corroborates our previous finding: there are significant specific three-pion correlations for the Au + Au system and quite a weak signal for the Nb + Nb interactions. The hypothesis of the constant correlation function for the Au + Au data, which are shown by the black points in Fig. 8, fits the data with the $\chi^2/ndf = 3.7$ which corresponds to the confidence level of the order of 10^{-5}%. The best χ^2 fit with the parameters displayed in Table 8 gives the $\chi^2/ndf = 1.1$ which corresponds to the confidence of 69%.

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