Two-Pion Bose-Einstein Correlations at SPS Energies

H. Tilsner[a] and H. Appelshäuser[a] for the CERES Collaboration*

[a]Physikalisches Institut, Heidelberg University, Germany

1. Introduction

In this paper the results of a centrality dependent analysis of two-pion Bose-Einstein correlations in Pb-Au collisions at beam energies of 40, 80, and 158 AGeV are presented. The data were recorded with the new cylindrical Time Projection Chamber of the CERES spectrometer at CERN-SPS. The HBT analysis of like-sign pion pairs at midrapidity was performed in bins of the pair transverse momentum $k_t = \frac{1}{2}|\vec{p}_{t,1} + \vec{p}_{t,2}|$. The three-dimensional correlation function C_2, depending on the relative momentum components of the particle pair, was parameterized using a three-dimensional Gaussian, modified to consider the final state Coulomb interaction. The parameterization was done in the Cartesian *out-side-long* system proposed by Bertsch and Pratt [1]. The three components of the relative pair momentum were determined in the LCMS, where the pair has zero longitudinal momentum in the laboratory. Details of the analysis can be found in [2].

2. Coulomb Correction

Traditionally, Coulomb repulsion has been accounted for by applying weights dependent on the 4-momentum difference q_{inv} of each pair pair in the background distribution. The correlation function C_2 corrected in this way was afterwards fitted by a Gaussian parameterization which then should describe the pure Bose-Einstein correlation peak. This approach assumes that all particle pairs in the signal distribution are subject to the Coulomb correlation, which is in general not true under realistic physical and experimental conditions. Physics and detector related effects lead to a reduction of the observed Bose-Einstein correlation strength, usually expressed in terms of the parameter λ. The same effects also lead to a similar reduction of the Coulomb repulsion and therefore the strength of the applied Coulomb correction has to be linked to the experimentally observed λ parameter. Since the value of the λ parameter is *a priori* unknown, the effect of Coulomb repulsion is included into the fit function:

$$C_2(\vec{q}) = N \cdot \Big[1 + \lambda'\big((1+G) \cdot F^\star - 1\big)\Big] \tag{1}$$

with

$$\begin{aligned} G &= \exp(-R^2_{\text{long}} q^2_{\text{long}} - R^2_{\text{side}} q^2_{\text{side}} - R^2_{\text{out}} q^2_{\text{out}} - 2R^2_{\text{out,long}} q_{\text{out}} q_{\text{long}}) && (2) \\ F^\star &= \omega(k_t) \cdot \big(F_{\text{coul}}(q_{\text{inv}}) - 1\big) + 1 && (3) \end{aligned}$$

*For the full CERES Collaboration author list see the contribution by J. P. Wessels (D. Adamová *et al.*) in this volume.

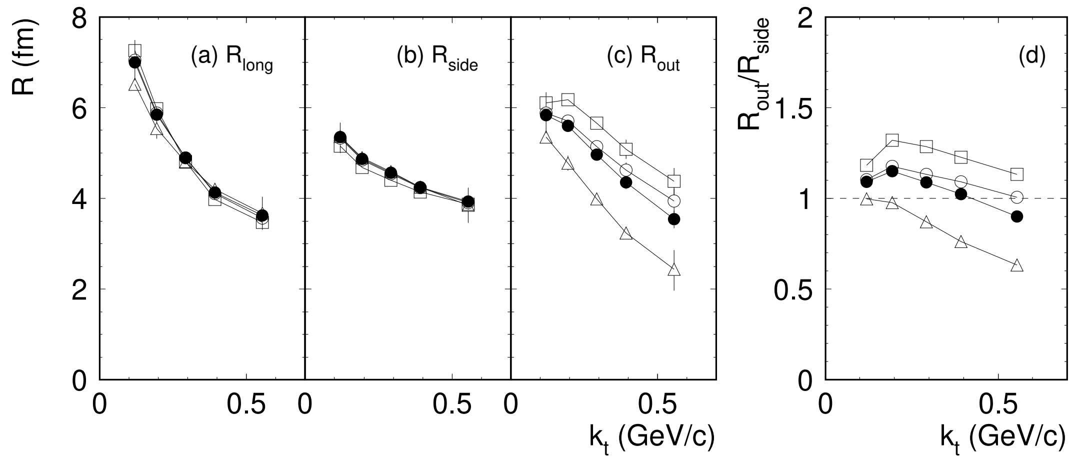

Figure 1. Effect of different Coulomb corrections on the radius parameters. Open squares: no Coulomb, open triangles: full Coulomb, full circles: results of the fit of Eq. (3), open circles: same as full circles but with $\omega(k_t) = 1$.

The Coulomb term $F^{\star}$ contains the two-pion Coulomb correlation function F_{coul} which was calculated by integration of the relative Coulomb wave function over a Gaussian source of 5 fm size [3], folded with the impact of the finite detector resolution [2].

An additional complication arises due to the finite momentum resolution of the TPC which leads to a k_t dependent reduction of λ by 13% to 45%, i. e. $\lambda = \lambda' \cdot \omega(k_t)$. The k_t dependent correction factors $\omega(k_t)$ were determined by a Monte-Carlo simulation and vary between 1.15 for the lowest k_t-bin and 1.82 for the highest k_t-bin. The inclusion of $\omega(k_t)$ into the Coulomb term $F^{\star}$ accounts for the apparent depletion of λ due to the finite momentum resolution and assures the appropriate scaling of the Coulomb correction. For perfect momentum resolution, e. g. $\omega(k_t) = 1$, Eq. (1) becomes identical to the parameterization proposed in [4].

The sensitivity of the radius parameter on the Coulomb correction scheme was studied by applying different implementations of the Coulomb term $F^{\star}$ in Eq. (1). The results are shown in Fig. 1 for $F^{\star} = 1$, corresponding to no Coulomb correction (open squares), $F^{\star} = F_{\text{coul}}(q_{\text{inv}})$ (open circles) as proposed in [4], and finally $F^{\star} = \omega(k_t) \cdot (F_{\text{coul}}(q_{\text{inv}} - 1) + 1$, as given in Eq. 3 (full circles). Also shown are the results obtained by assuming full Coulomb strength (open triangles) where all background pairs were corrected by $F_{\text{coul}}(q_{\text{inv}})$. The parameters R_{long} and R_{side} depend very little on the assumed strength of the Coulomb repulsion, however, the results for R_{out} and $R_{\text{out}}/R_{\text{side}}$ are very sensitive.

The remaining uncertainties in the treatment of the Coulomb repulsion and the corrections for the finite momentum resolution are the main sources of systematic errors. They were estimated by varying the Coulomb strength and the momentum resolution within realistic limits, resulting in a value of 4% for R_{long} and R_{side}. In R_{out}, the systematic error is larger and depends on k_t, leading to a value of 5% in the lowest and 20% in the highest k_t-bin.

3. HBT Results

Figure 2 shows the results for the HBT parameters R_{long}, R_{side}, and R_{out} as function of k_t for all three beam energies for central events ($\sigma/\sigma_{\text{geo}} < 5\%$).

The parameter R_{long} shows a very strong dependence on k_t for all beam energies, consistent

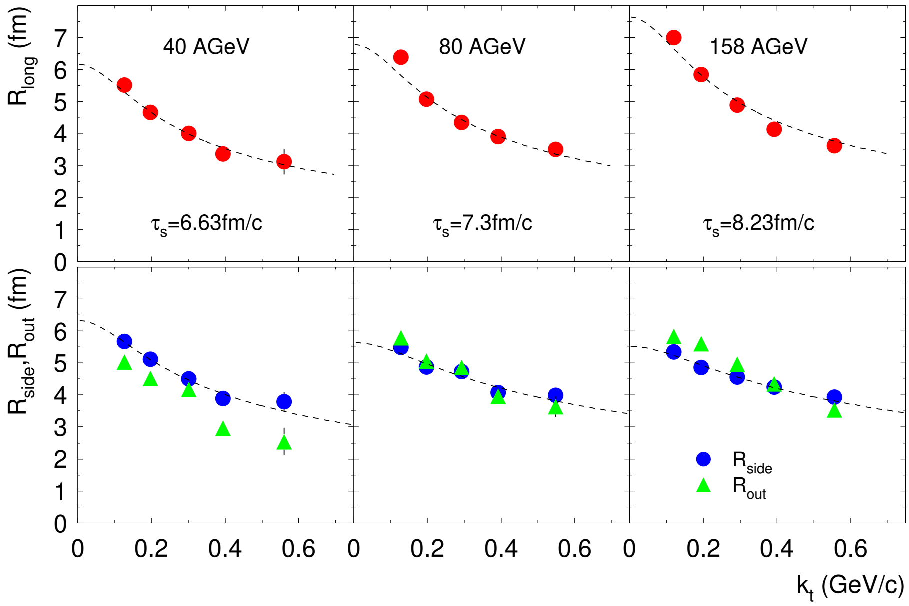

Figure 2. The HBT radius parameters R_{long}, R_{side}, and R_{out} as function of k_t at 40, 80, and 158 AGeV beam energy in central Pb+Au collisions ($\sigma/\sigma_{\text{geo}} < 5\%$). The dashed lines show fits to the data (see text).

with a strong longitudinal expansion. Assuming longitudinal boost-invariance and a constant thermal freeze-out temperature of $T_f = 120$ MeV, the lifetime τ_f of the expanding system can be determined by fitting Sinyukov's relation [5] $R_{\text{long}} = \tau_f(T_f/m_t)^{1/2}$ to the data (dashed lines in top of Fig. 2). The extracted lifetimes are 6-8 fm/c and increase smoothly with beam energy and centrality (not shown, see [2]).

The results for R_{side} are also shown in Fig. 2, together with the results for R_{out}. The k_t dependence, approximated by $R_{\text{side}} = R_{\text{geo}}/(1 + m_t \cdot \eta_f^2/T_f)^{1/2}$ [6] and shown by the dashed line, indicates a collective expansion also in transverse direction. At all beam energies, a radial expansion velocity of about $0.5c$ is observed.

The expansion is followed by a sudden freeze-out with a short duration $\Delta\tau$ of pion emission. This can be deduced from the small difference between R_{out} and R_{side} [7]: $\Delta\tau^2 = \frac{1}{\beta_t^2}\left(R_{\text{out}}^2 - R_{\text{side}}^2\right)$ At all beam energies the presented radii R_{out} are similar to R_{side}. At a beam energy of 40 AGeV R_{side} is even slightly larger than R_{out}. At 158 AGeV, the data are consistent with a short but finite emission duration of about 2-3 fm/c. A detailed discussion of the results can be found in [2].

HBT source radii published by experiments at AGS and RHIC together with the data presented here can be combined to perform a systematic study of the source parameters over a wide range of beam energies. Fig. 3 shows the k_t-dependence of R_{long}, R_{side}, and R_{out} in central Pb(Au)+Pb(Au) collisions near midrapidity. The parameter R_{long} is approximately constant from AGS to the lower SPS energies, but starts to increase significantly within the SPS regime and towards RHIC, indicating a smooth increase of the lifetime. R_{side} is slightly decreasing at small k_t up to top SPS energies, connected with a continuous flattening of the k_t-dependence. At RHIC, R_{side} is again slightly larger than at the SPS. The flattening would indicate a decrease of the radial flow velocity with increasing beam energy which is in contradiction to the present interpretation of single particle transverse mass spectra. These spectra indicate an increase of

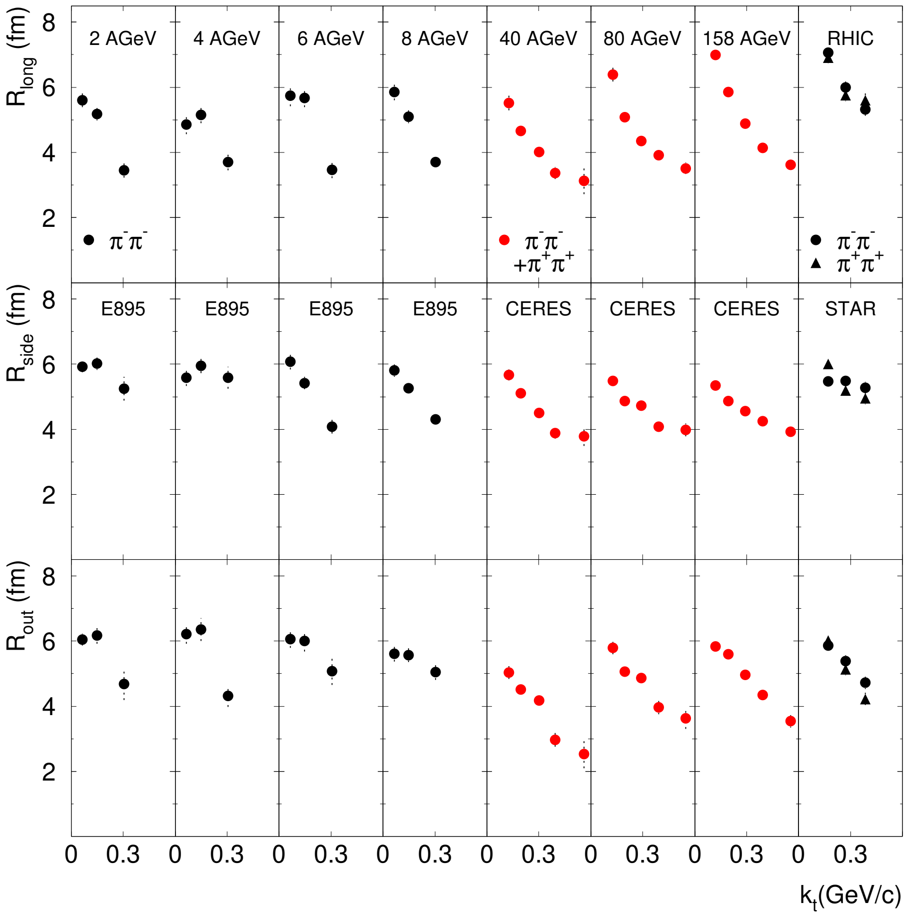

Figure 3. Beam energy dependence of R_{long}, R_{side}, and R_{out}. For references see [8].

radial flow with beam energy. The radius parameter R_{out} shows a rather weak energy dependence with a slight minimum around the lowest SPS energy.

The rather undramatic variations of the source parameters observed in Figure 3 can be investigated further by relating the measured radii to an effective freeze-out volume. These studies show that the data are consistent with a scenario, where thermal pion freeze-out occurs at a constant mean free path of pions in the surrounding medium, independent of beam energy from AGS to RHIC [8].

REFERENCES

1. G. Bertsch, Nucl. Phys. **A498** (1989) 173c, S. Pratt, Phys. Rev. **D33** (1986) 1314.
2. CERES Collaboration, D. Adamova et al., nucl-ex/0207005, submitted to Nucl. Phys. A.
3. G. Baym and P. Braun-Munzinger, Nucl. Phys. **A610** (1996) 286c.
4. Y.M. Sinyukov, R. Lednicky, S. V. Akkelin, J. Pluta, B. Erazmus, Phys. Lett. **B432** (1998) 249.
5. Y. M. Sinyukov, Nucl. Phys. **A498** (1989) 151c.
6. S. Chapman, J. R. Nix, U. W. Heinz, Phys. Rev. **C52** (1995) 2694.
7. U. W. Heinz, B. Tomasik, U. A. Wiedemann, Y. F. Wu, Phys. Lett. **B382** (1996) 181.
8. CERES Collaboration, D. Adamova et al., nucl-ex/0207008, submitted to Phys. Rev. Let.