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BOSE-EINSTEIN CORRELATIONS IN THE TARGET FRAGMENTATION REGION OF 200 A GEV ^{16}O + NUCLEUS COLLISIONS

WA80 Collaboration

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Abstract

Correlations of positive pions are investigated in the target fragmentation region of 200 A GeV ^{16}O + nucleus collisions. The pions are measured with the Plastic Ball detector in the WA80 experiment at the CERN SPS. The detailed behaviour of the fitted parameters on rapidity, centrality and the number of spectator nucleons is studied. The data indicate a large source in central O + Au collisions for $y_{lab} \leq 0$. The observations are compatible with a substantial amount of rescattering in the target.

1 Introduction

Pion interferometry allows to study the space-time properties of the particle emitting source in high energy collisions [1]. An enhancement in the production of identical pions with similar momentum - known as Bose-Einstein Correlations, the Hanbury-Brown - Twiss effect (HBT) [2] or the Goldhaber-Goldhaber-Lee-Pais effect (GGLP) [3] - has been observed in various experimental studies. The most commonly chosen analytic expressions for the two particle correlation function contain a suitable correlation length R. While this parameter seems to measure dynamical properties of the produced strings in e^+e^- or pp collisions, it can provide geometrical information in medium energy heavy ion collisions.

The importance of rescattering of secondaries in the target spectator matter in high energy nuclear reactions has been emphasized in earlier publications [4]. It is therefore of interest to study pion correlations in the target fragmentation region to clarify both the general role of the target spectators and their influence on pion interferometry. In this paper we will present a study of $\pi^+\pi^+$ correlations in reactions of 200 A GeV ^{16}O ions with various targets in the target rapidity region ($y_{lab} \leq 1$).

2 Data analysis

Data were taken in the WA80 experiment [5] at the CERN SPS during the ^{16}O run in fall 1986. The pions were identified with the Plastic Ball detector in $30° \leq \theta_{lab} \leq 160°$ using both ΔE-E-information and the time delayed positron signal of the π^+-decay. Details on the detector design and performance and the identification are given in [6]. Only pions, which are stopped in the detector modules ($E_{kin} \leq 120\,\mathrm{MeV}$), are used. The contamination of misidentified particles was estimated to be of the order of 5 % for all samples. The resolution in relative momentum is $\delta q \approx 10\,\mathrm{MeV/c}$.

Reactions with C, Cu, Ag and Au targets were investigated. Background distributions were obtained by the event-mixing procedure: A pion from one event was combined with a pion from another event with the same apparent π^+ multiplicity. The correlation functions were corrected for the Coulomb-interaction with the standard Gamow-factor [7]. The data were analyzed both in terms of the absolute value of the four momentum difference: $Q \equiv \sqrt{-(p_1^\mu - p_2^\mu)^2}$ and in terms of the energy- and momentum-difference in the lab-system: $(|\vec{q}|, q_0) \equiv (|\vec{p}_1 - \vec{p}_2|, |E_1 - E_2|)$. For simplicity, gaussian functions have been used both for one- and two-dimensional analysis:

$$C_2(Q) = 1 + \lambda_{inv} \cdot \exp(-\frac{1}{2} R_{inv}^2 Q^2)$$

$$C_2(|\vec{q}|, q_0) = 1 + \lambda_{lab} \cdot \exp(-\frac{1}{2} R_{lab}^2 |\vec{q}|^2 - \frac{1}{2} \tau^2 q_0^2).$$

For the analysis in Q an exponential function:

$$C_2(Q) = 1 + \lambda_{exp} \cdot \exp(-R_{exp} Q)$$

has in addition been used for comparison. Fits were performed in the region of $Q \leq 400\,\mathrm{MeV}$ by maximizing the logarithm of a likelihood function.

3 Results and discussion

Fig. 1 shows correlation functions for central reactions of ^{16}O with different targets in the rapidity region $-1 \leq y_{lab} \leq 1$. A clear enhancement for small values of Q is visible in all cases. Fits with a gaussian parametrization are shown as solid lines. Counterintuitively the radii R_{inv} decrease with increasing target mass, also the intercept λ_{inv} goes down for the heavier systems. The correlation functions have also been fitted with an exponential distribution to investigate systematic effects connected to the choice of the parametrization. In addition, the same data sets have been analyzed in $(|\vec{q}|, q_0)$ and fitted with a two-dimensional gaussian. The resulting fit parameters are summarized in table 1. In contrast to R_{inv} and R_{exp}, which both show a significant decrease with increasing target size, the space-component R_{lab} appears to be only weakly dependent on the target mass. Here, the time parameter τ exhibits a drastic decrease.

How can the variations in the parameters be understood in our current picture of ultrarelativistic nuclear collisions? A reduction of the value of λ may be caused by a variety of mechanisms. Most of these, as e.g. final state interaction, resonance production or coherence, should not show such a drastic variation for different targets. It is however easy to realize that pions observed in the target rapidity region might have undergone very different evolutions; they may be directly produced by the participant nucleons or they may be rescattered in the target spectator matter. It has been noted that data from the target

Table 1: Pion Correlation Fit Parameters ($-1 \leq y_{lab} \leq 1$)

	R_{inv} (fm)	λ_{inv}	R_{ezp} (fm)	λ_{ezp}	R_{lab} (fm)	τ (fm/c)	λ_{lab}
Au	$2.5^{+0.1}_{-0.1}$	$0.094^{+0.003}_{-0.003}$	$2.5^{+0.1}_{-0.1}$	$0.162^{+0.006}_{-0.006}$	$2.8^{+0.1}_{-0.1}$	$1.8^{+0.5}_{-0.7}$	$0.116^{+0.003}_{-0.003}$
Ag	$3.1^{+0.2}_{-0.2}$	$0.14^{+0.01}_{-0.01}$	$3.3^{+0.4}_{-0.4}$	$0.22^{+0.02}_{-0.03}$	$3.2^{+2.2}_{-0.2}$	$0.0^{+1.2}$	$0.16^{+0.01}_{-0.01}$
Cu	$3.5^{+0.1}_{-0.1}$	$0.16^{+0.01}_{-0.01}$	$4.2^{+0.3}_{-0.3}$	$0.29^{+0.03}_{-0.01}$	$3.5^{+0.3}_{-0.3}$	$3.4^{+0.8}_{-0.8}$	$0.20^{+0.10}_{-0.10}$
C	$4.1^{+0.3}_{-0.3}$	$0.40^{+0.05}_{-0.02}$	$5.7^{+0.6}_{-0.6}$	$0.92^{+0.14}_{-0.03}$	$3.3^{+0.1}_{-0.1}$	$12.1^{+1.4}_{-1.4}$	$0.60^{+0.04}_{-0.04}$

fragmentation region indicate rescattering effects [4]. Rescattering need not affect the pion multiplicities, but it would alter the volume measured by interferometry to the "freeze-out" volume of the excited spectator matter. The rescattered pions might come from very large volumes or late times, and their correlation could thus be hidden at very small values of Q, hardly accessible to experiment. In fact, there is an indication of a steep rise in the high statistics O + Au correlation function for $Q \leq 30$ MeV (see Fig. 1). These data points do however depend crucially on the Coulomb correction, whereas the overall fit is not very sensitive to this correction.

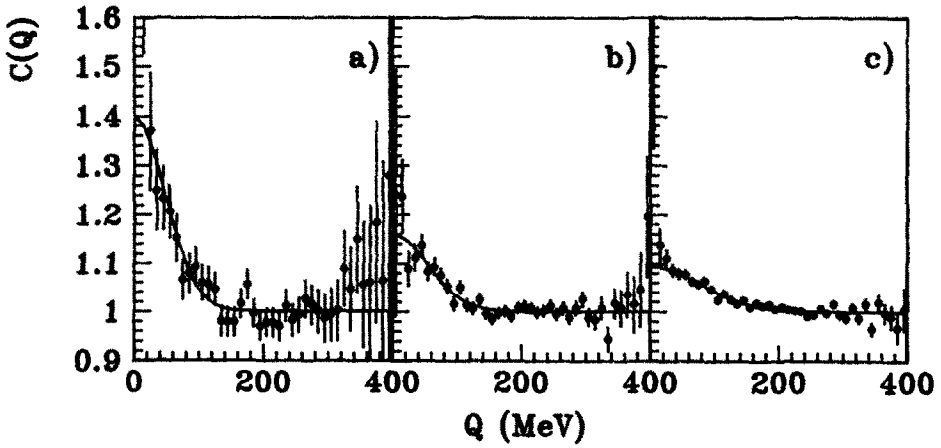

Figure 1: π^+ correlation functions in dependence of Q for $-1 \leq y_{lab} \leq 1$. a) O + C, b) O + Cu, c) O + Au.

The rapidity dependence of R_{inv} and λ_{inv} has been investigated by selecting pions from $-1 \leq y_{lab} \leq 0$ and $0 \leq y_{lab} \leq 1$, respectively. The variation in the parameters with target mass is found to be much stronger for the backward interval, indicating that we observe a physical effect connected to the target and not created by e.g. accidental double hits or other detector effects. The λ_{inv}-values are systematically smaller for the more forward interval.

In order to study the impact parameter dependence, the O + Au data were divided into three subsamples selected by the forward energy flow ($\theta_{lab} \leq 0.3°$), and were again analyzed separately in the two rapidity intervals listed above. In the more forward region

Table 2: Spectator dependence of the pion correlation ($-1 \leq y_{lab} \leq 1$)

	$< N_{part} >$	$< y_{cm} >$	$< N_{spect} >$	R_{inv} (fm)	λ_{inv}
Cu *central*	39.5	2.8	38.4	$3.5^{+0.1}_{-0.1}$	$0.16^{+0.01}_{-0.01}$
Au *medium*	37.4	2.7	172.9	$2.2^{+0.2}_{-0.2}$	$0.12^{+0.01}_{-0.01}$
C *central*	19.2	3.1	3.2	$4.1^{+0.3}_{-0.3}$	$0.40^{+0.05}_{-0.05}$
Au *peripheral*	21.2	2.9	184.3	$2.8^{+0.2}_{-0.2}$	$0.25^{+0.02}_{-0.02}$

R_{inv} increases from $\approx 2.3 - 2.4$ fm for the peripheral and medium central reactions to 2.7 fm for central collisions. λ_{inv} decreases with centrality – it is small ($\lambda_{inv} < 0.2$) for all cases. In the backward rapidity region R_{inv} increases from 3.8 fm to 5.9 fm when going from peripheral to medium central collisions and λ_{inv} decreases slightly, but is rather large (0.90 and 0.64 resp.). Both parameters drop to small values for the central reactions; if there is a two-component source, this might be due to the fact that the fit is more sensitive to the smaller component. Indeed, if we divide the data sample again into pions of low and high transverse momentum (fig. 2), we observe a larger component ($R_{inv} = 7.0 \pm 0.8$ fm; $\lambda_{inv} = 0.52 \pm 0.08$) for the lower p_T-pions, while only a small source ($R_{inv} = 1.5 \pm 0.2$ fm; $\lambda_{inv} = 0.14 \pm 0.01$) is visible from the high p_T-particles.

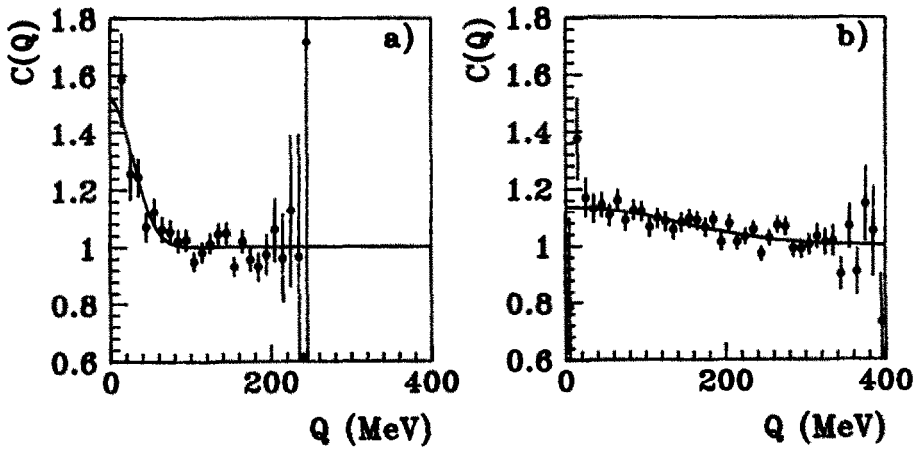

Figure 2: π^+ correlation functions in dependence of Q for central O + Au in $-1 \leq y_{lab} \leq 0$. a) $p_T \leq 100$ MeV/c, b) $p_T \geq 100$ MeV/c

The parameters are consistent with the assumptions that we observe in the more forward interval only the fraction of pions coming directly from the participant volume and that in the backward region the full source including spectator matter is seen.

Finally we can compare systems, which are similar according to the number of participants and the effective center-of-mass rapidity, but which differ by the number of target

spectators. We know from analysis with the FRITIOF Monte-Carlo that the data sets given in table 2 are pairwise comparable in this sense. The fit parameters for these systems vary significantly. Both parameters are substantially smaller for the systems with larger number of spectators, when all other relevant parameters are fixed. The presence of spectator matter seems to diminish the "visible" fraction of the pions, and their apparent radius is reduced.

4 Summary and Conclusions

We have observed correlations of positive pions in the target fragmentation region for reactions of 200 A GeV ^{16}O on C, Cu, Ag and Au targets. The interpretation of the enhancement in terms of Bose-Einstein correlations parameterized as a gaussian yields the following results:

1. Applying a simple one component fit gives a decrease in R_{inv} and λ_{inv} with increasing target mass. A two-dimensional (R_{lab}, τ) analysis indicates a more or less constant R_{lab} and a decrease in the τ-parameter.
2. This decrease in the parameters is obviously connected to the number of spectators. It is consistent with a substantial amount of rescattered pions emerging from a large freeze-out space-time volume of the excited spectator matter in the case of the heavy targets.
3. At backward rapidities in O + Au reactions we observe a large source whose size increases from 3.8 fm for peripheral to 7.0 fm for central collisions. The large component in central collisions is most easily seen with an additional cut in transverse momentum: $p_T \leq 100\,\mathrm{MeV/c}$. The λ_{inv}-parameters are above 0.5 in all these cases.
4. In the rapidity interval $0 \leq y_{lab} \leq 1$, which gives the dominant contribution to our overall correlation functions, we see in O + Au a smaller source increasing slightly for central collisions. The measured λ_{inv}-values are smaller than 0.2.

This analysis emphasizes the need to study the dynamics of the so-called "spectator nucleons", which in fact seem to participate strongly in a later stage of the collision. Care should be taken, if one compares pion interferometry in different rapidity regions, when the presence of target spectators may obscur the interpretation.

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