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RESULTS ON IDENTIFIED PARTICLE INTERFEROMETRY FROM NA44, THE FOCUSING SPECTROMETER[1]

NA44 Collaboration

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New results from NA44, **the Focusing Spectrometer**, on two particle, or Bose-Einstein (BEC), correlations, are presented. With increasing statistics we are able to analyse the BEC data in multi dimensional space. With data from sulphur ions and protons on different targets a systematic behaviour can be studied.

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1. Introduction

Two-particle intensity interferometry can provide information on the space–time extent of the particle-emitting source [1, 2, 3], and shed light on the dynamical evolution of heavy-ion collisions. This technique of analysis follows the approach of Hanbury-Brown and Twiss (HBT) [1]. Results from early experiments indicate that pions are emitted from a source of approximately the same radius as the projectile at BNL energies [4, 5], but from a larger source in the higher energy collisions explored at CERN [5, 6]. Additionally, intensity interferometry may yield information about the time span of particle emission, and provide evidence for the existence of a first-order phase transition in these collisions [7]. Such analyses require good resolution and high statistics in the two-particle distributions. The physics interpretation needs a good understanding of the connection between a functional form to fit to the data and the corresponding space–time distribution of the emitting source.

NA44 is a second generation experiment, building on the results of the early surveys. It is optimized for the study of identified single- and two-particle distributions at mid-rapidity. The spectrometer is a focusing spectrometer, a design which optimizes the acceptance for pairs of particles with small momentum difference. This allows small statistical uncertainties in the two-particle correlation function in the region of the signal from Bose–Einstein correlations. Additionally, we apply a Coulomb correction based on the integration of Coulomb waves [8], in the place of the more common but less accurate Gamow correction. Details of these corrections can be found in [9].

2. The Spectrometer

The NA44 Spectrometer can easiest be described in three parts. The target area with beam defining elements, signaling interactions in the target and giving the timing information for the time-of-flight (TOF) measurements, see Fig. 1, Ref. [10, 11]. Second, the momentum analyzing Dipole Magnets, D1 and D2, and the three superconducting quadrupoles, Q1, Q2 and Q3, which focus the particles of selected momentum (±20%Δp around the nominal setting) and sign into the third part of the spectrometer. Here the particle are tracked and identified by means of three scintillator hodoscopes, H1, H2 and H3, see Ref. [12], and two threshold gas-Cherenkovs, C1 and C2. With the finely segmented hodoscopes we achieve a momentum resolution of $\delta p/p \sim 0.2\%$ and a TOF resolution of $\sigma \approx 100$ psec (Fig. 2).

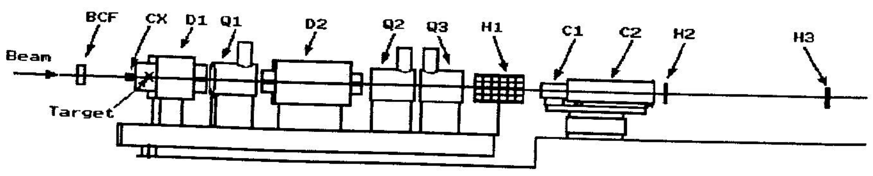

Fig. 1. Diagram of NA44, the Focusing Spectrometer.

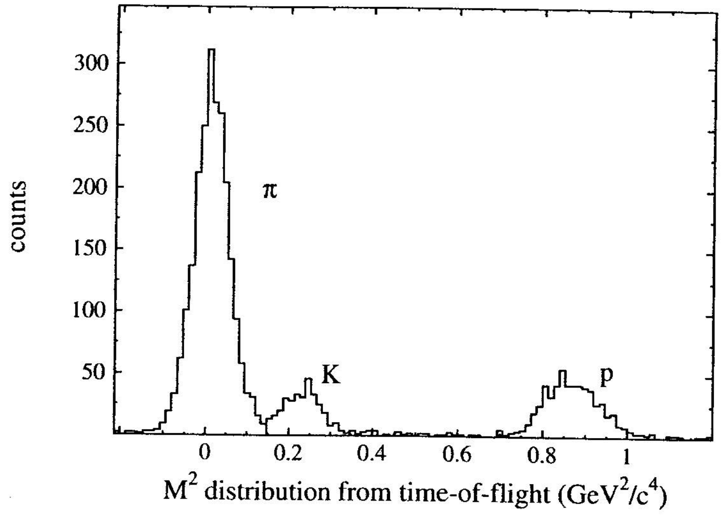

Fig. 2. Typical m^2 distribution as the basis of particle identification.

3. Results

The results on $\pi\pi$ correlations analyzed in Q_{inv} , as defined in Eq. (1), have been published in [9] with source parametrizations as shown in Eq. (2) and Eq. (3).

$$Q_{inv}^2 = Q^2 - Q_0^2,\ Q = |\vec{p_1} - \vec{p_2}|,\ Q_0 = |E_1 - E_2| \tag{1}$$

$$C_{HBT}^{Gaussian}(Q_{inv}\ ) = A[1 + \lambda \exp(-Q_{inv}^2 R_{inv}^2)] \tag{2}$$

$$C_{HBT}^{exp}(Q_{inv}\ ) = A[1 + \lambda \exp(-2Q_{inv}\ R_{inv}\ )]\ . \tag{3}$$

As the fitted results depend strongly on the error bars of the first few datapoints where also the corrections are the strongest, all data presented in the following are **preliminary** if not stated otherwise.

The parametrization in Q_{inv} contains the geometrical and time dependent information of the source and makes it difficult to compare results from different particle species which are in different Lorenz frames. In agreement with other experiments we use the following parametrization

$$C_{HBT}^{Gaussian}(q) = A[1 + \lambda \exp(-Q^2 R^2 - Q_0^2 \tau^2)]\ . \tag{4}$$

For a one-dimensional analysis we assume $R = \tau$.

In Table 1 we present data of $\pi\pi$ and K K correlations from fits to a Gaussian distribution as in Eq. (4) for pPb and SPb interactions, see also Ref. [13]. The data show a striking difference between the freeze-out radius of Kaons to pions. This can be understood when taking the different cross-sections for pion-pion and pion-Kaon into account.

Table 1. Fitted results for a one-dimensional Gaussian distribution

System	λ	R (fm)
p Pb, $\pi^+\pi^+$	0.51 ± 0.01	2.10 ± 0.06
S Pb, $\pi^+\pi^+$	0.71 ± 0.02	4.02 ± 0.10
S Pb, $\pi^-\pi^-$	0.65 ± 0.03	3.90 ± 0.14
p Pb, K^+K^+	0.50 ± 0.07	1.53 ± 0.21
S Pb, K^+K^+	0.88 ± 0.06	2.73 ± 0.13
S Pb, K^-K^-	0.98 ± 0.13	2.78 ± 0.26

Table 2. Fitted results for a three-dimensional Gaussian distribution

System	λ	R_{Tside} (fm)	R_{Tout} (fm)	R_L (fm)
p Pb, $\pi^+\pi^+$	0.43 ± 0.01	1.43 ± 0.06	1.77 ± 0.06	2.54 ± 0.12
S Pb, $\pi^+\pi^+$	0.55 ± 0.02	4.35 ± 0.24	4.08 ± 0.13	4.90 ± 0.25
S Pb, $\pi^-\pi^-$	0.49 ± 0.03	3.71 ± 0.80	3.61 ± 0.20	4.43 ± 0.35
S Pb, K^+K^+	0.76 ± 0.06	2.43 ± 0.26	2.67 ± 0.17	2.82 ± 0.27

Our data samples permit us to analyse the data assuming a three dimensional source distribution, as shown in Eq. (5). The longitudinal component, Q_L , is in direction of the incoming beam, whereas the outward components, Q_T , are perpendicular in the two particle rest frame.

$$C_{HBT}^{Gaussian}(Q) = A[1 + \lambda \exp(-Q_L^2 R_L^2 - Q_{Tside}^2 R_{Tside}^2 - Q_{Tout}^2 R_{Tout}^2)] \quad (5)$$

The results from a fit with a three-dimensional Gaussian source parametrization are summarized in Table 2. The correlation of K K pairs offers a possibility to study a channel with a much different production mechanism and cross-sections in baryonic matter. It was expected that Kaons would freeze out earlier than pions, so showing a smaller correlation radius. The correlation function for K^+K^+ and $\pi^+\pi^+$ are shown in Fig. 3. The earlier freeze-out radius for Kaons is here clearly visible as a wider correlation function. The lines are fits to the data as shown in Table 1.

A detailed description of our HBT results as a function of p_T can be found in the contribution by Rama Jayanti in these proceedings.

4. Discussion

To compare data from different experiment the p_T and rapidity coverage has to be taken into account which makes direct comparisons difficult. Assuming a simple geometrical model one could assume the projectile punching a cylinder out of the target nucleus. This simple picture will only be valid if a small projectile hits a large target nucleus. From that cylinder a radius can be recalculated representing this volume:

$$R_{vol} = \sqrt[3]{2\pi(1.2A_{proj}^{\frac{1}{3}})^2 1.2A_{targ}^{\frac{1}{3}}} \, . \quad (6)$$

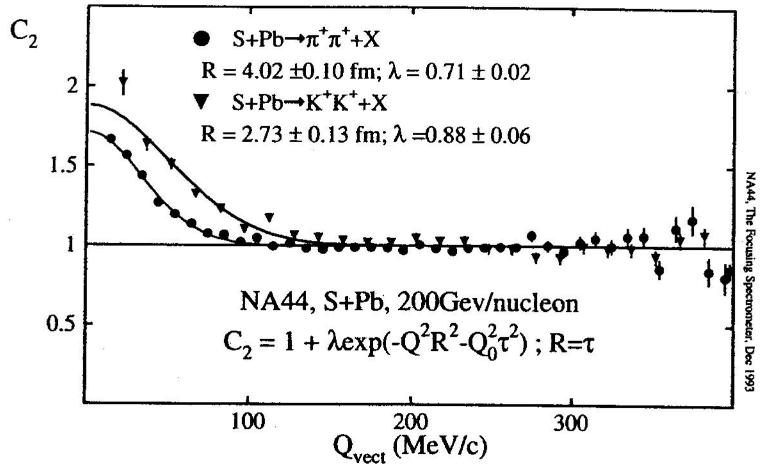

Fig. 3. C_{HBT} as a function of Q, as defined in Eq. (4), for K^+K^+ and $\pi^+\pi^+$ plotted onto the same scale to show the effect of the different radii on the correlation function

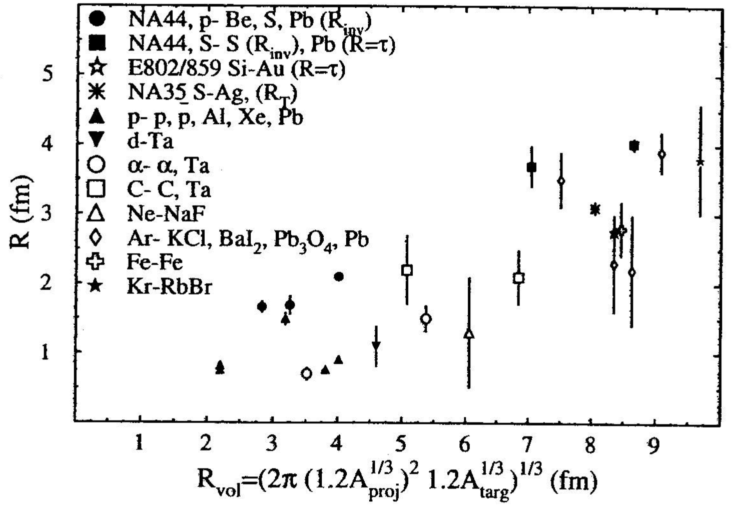

Fig. 4. Fitted R_{inv} as a function of the assumed volume radius R_{vol} from different projectile target systems.

In Fig. 4, the data from [3, 5] are summarized together with the results from NA44. The data seem to indicate two lines: the lower line represents the low energy data and the upper line the data from higher energies and central events. Even so the

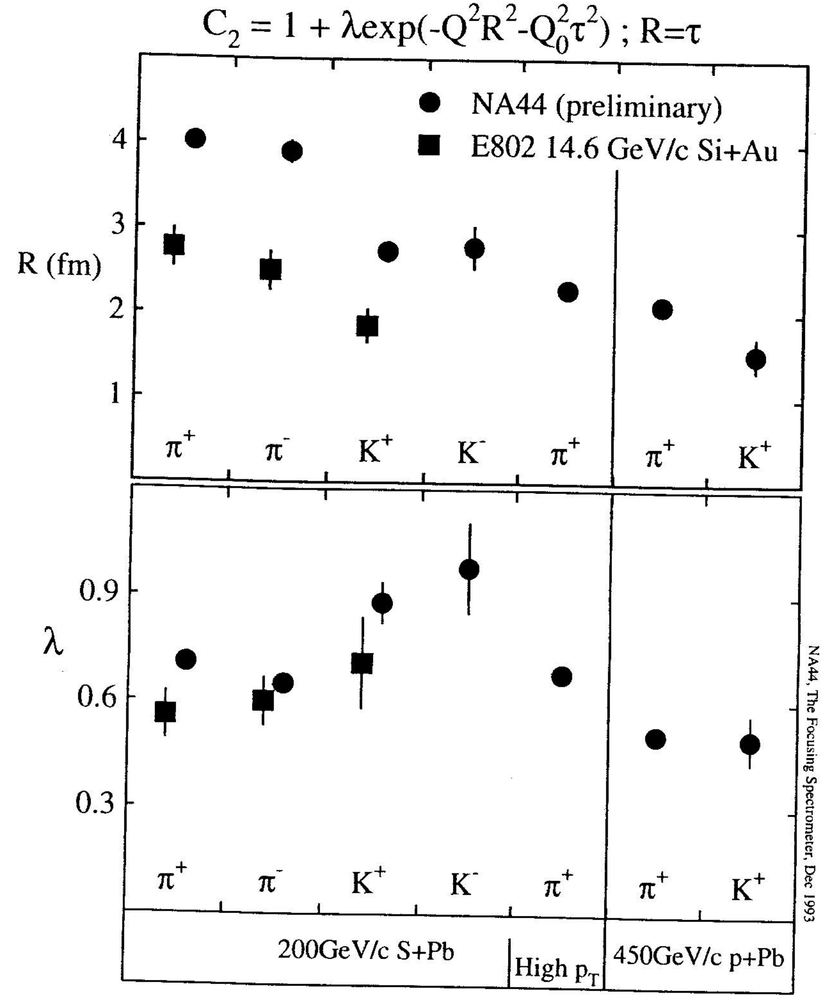

Fig. 5. (upper) Summary of the $R = \tau$ analysis for different systems and comparison with the E802 data; (lower) summary of the results on the chaoticity parameter λ for different systems.

approach is not valid for all data the systematic behaviour is quite striking.

Another comparison with the lower-energy AGS data is shown in Fig. 5. We find a significant difference in the observed radii, depending on the particle observed ($R_{\pi^+\pi^+} \approx R_{\pi^-\pi^-} > R_{K\,K}$). The radii measured by E802 [14] are significantly lower than our data, even so the projectile-target system is of similar size. As the beam energy in the AGS is lower, so is the available energy density ϵ in the collision,

resulting in a smaller expansion of the colliding system.

The comparison of the chaoticity parameter λ is also interesting. The pion correlations show $\lambda \sim 0.6$ to 0.7; this is usually attributed to the dilution of the correlation strength due to the presence of pions from resonance decays (ω, η, η', ...). In the K K system the contribution from resonances (ϕ) is estimated to be much smaller and indeed we find $\lambda \approx 1$.

From an initial Quark-Gluon-Plasma phase a long hadronization phase was predicted, resulting in $\mathrm{R}_{Tout} \gg \mathrm{R}_{Tside}$. Whereas a dense hadron gas would yield $\mathrm{R}_{Tout} \approx \mathrm{R}_{Tside}$ because of the fast hadronization. Our first preliminary results indicate similar results for the two radii.

5. Conclusion

The high statistic data sample of identified boson pairs obtained in SPb collisions can be summarized as follows:

$$
\begin{gathered}
R_{\pi^+\pi^+} \sim R_{\pi^-\pi^-} \sim 4fm \\
R_{K^+K^+} \sim R_{K^-K^-} \sim 3fm \\
\lambda_{\pi\pi} < \lambda_{K\,K} \sim 1. \\
\mathrm{R}_{Tout} \approx \mathrm{R}_{Tside} \\
R_{\pi\pi} \simeq 2R_{projectile} \\
R(200AGeV/c) > R(14.6AGeV/c)
\end{gathered}
$$

Available NA44 data on $\pi\pi$, K K and p p correlation data and single inclusive spectra of pions, Kaons, protons and deuterons from S and proton induced collisions on Be, S, Ag and Pb targets should provide further insight into the dynamics of these dense nuclear systems. Comparisons with event generators, such as RQMD [15], provide important tools for the analysis of these collisions. We are specially looking forward to the newly available Pb beams at CERN in late 1994.

Acknowledgements

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