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Rapport Interne SUBATECH - 94-13

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Influence of the emitting nucleus on the light-particle correlation function

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Abstract : Proton-neutron correlation functions measured in Ar induced reactions at 30 MeV per nucleon are presented. Significant suppression of correlation as compared to that expected from nuclear final state attraction is observed. This effect can only partly be due to Coulomb repulsion of the protons from the emitting nucleus. Three-body classical and quantum calculations show that substantial correlations survive even in a strong Coulomb field of the emitter.

1. INTRODUCTION

In nucleus-nucleus reactions the correlation function of light particles reflects not only features of fermion or boson pairs but it is also sensitive to their final state interaction and to the space-time development of heavy-ion collision.

Usually, quantum statistics effects (due to the identity of particles) as well as final state interaction are contained in the two-particle wave function. As far as the emitting nucleus is concerned it can be simply described using a gaussian or exponential parametrization or distributions predicted by a model taking into account the dynamics of the reaction.

Thus, the correlation function, which can be represented as a convolution of the the modulus squared of the two-particle wave function with the source distribution, contains information about spatial dimension and time development of the emitting source. However, in order to be complete, the description of correlations in heavy-ion reactions should properly include the interaction of particles with the emitter.

This interaction cannot itself be a source of correlations but it can, in principle, modify the shape of the correlation function.

The experimental data strongly indicating such an effect are provided by recent measurements of proton-neutron correlations. We analyse the influence of the Coulomb field of the emitter in frame of three different approaches : a simple shift of the proton momentum and three-body classical and three-body quantum models.

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Presented at the Fifth International Conference on Nucleus Nucleus Collisions
Taormina, Italy, 30 may - 4 june 1994

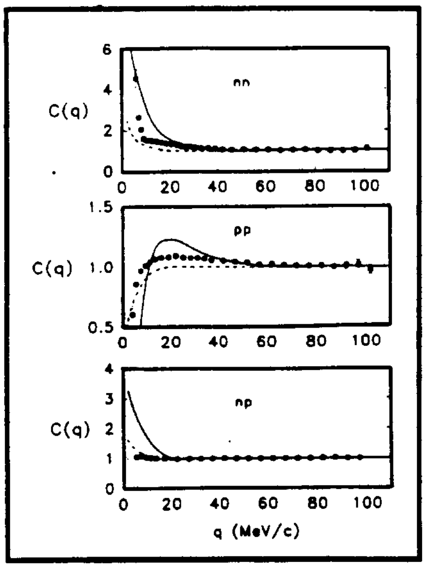


Figure 1. Experimental n-n,p-p and p-n correlation functions measured in Ar+Au collisions at 30 MeV per nucleon compared to calculations based on a pure evaporative (dashed curves) and on BUU approach including pre-equilibrium emission (solid curves).

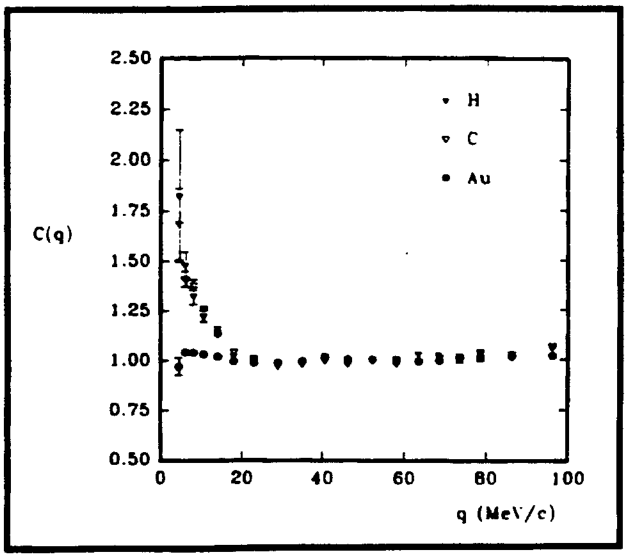


Figure 2. Experimental p-n correlation functions for Ar induced reactions.

2. EXPERIMENTAL RESULTS

A proton-neutron interferometer consisting of an array of CsI detectors placed at 60 cm from the target and large liquid scintillators placed at 3.5 m from the target behind holes in- or beside the CsI detectors were built up at the SARA two-cyclotron accelerator system to measure small-angle correlation functions in Ar induced reactions at 30 MeV per nucleon [1,2]. The most important experimental corrections for (n,n') scattering and neutron detection efficiency are determined both experimentally and by Monte-Carlo simulations [1].

The results of simultaneous measurement of the correlation functions for n-n, p-p and p-n pairs in Ar + Au reactions are shown in Fig. 1. They are all compared to calculations of the correlation functions in the Koonin-Pratt formalism [3] based on a time dependent evaporation emission process and on Boltzmann-Uehling-Uhlenbeck (BUU) model including a more realistic reaction dynamics. Essentially the p-p and n-n correlations follow the expected combination of quantum symmetrization- and final state effects if one assumes a certain mixture between a pre-equilibrium and an evaporative equilibrium component among those nucleons which belong to the correlated pairs (energies above 3 MeV for neutrons and above 8 MeV for protons). A strong deviation from this behaviour is found in case of p-n pairs for which the overall correlation exhibits a much weaker strength than expected in contrast to the results for O + Al reactions at lower energy (13 MeV per nucleon) obtained by Kryger et al. [4].

In Fig.2 we show that when a much smaller target and therefore a much weaker Coulomb source is introduced the correlation do come back, to a certain extent, for the smallest relative mometum $q = \frac{|\vec{p}_1 - \vec{p}_2|}{2}$. It is also obvious from Fig. 3 that when the highest energy

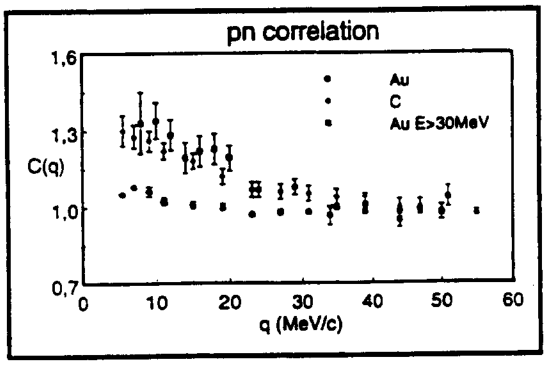


Figure 3. Proton-neutron correlation functions measured in Ar induced reactions.

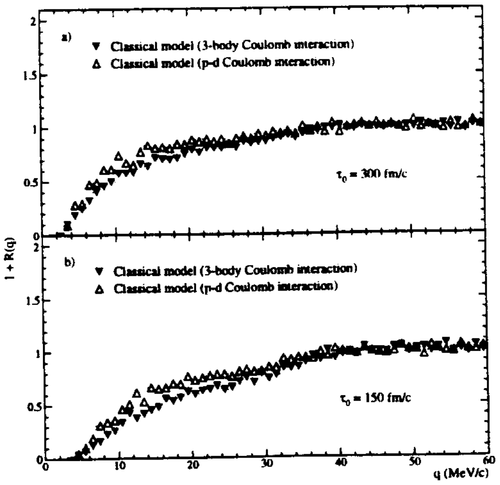


Figure 4. Predictions of classical calculations for p-d correlation function with and without treatment of the interaction with the emitting nucleus.

nucleons (>30 MeV) are selected in Ar + Au reactions the correlation strength reappears. The two Ar + C data samples are not identical in Figs. 2 and 3 which may cause some differences in the correlation functions.

The reason for the suppression of proton-neutron correlations has essentially been attributed to a strong Coulomb repulsion of the protons from the emitting nucleus.

3. DISCUSSION IN TERMS OF COULOMB EFFECTS

3.1. Classical shift of particle momenta

The effect of the nucleus Coulomb field is considered as a classical shift of the particle momenta [5]. The proton is accelerated and gains an energy of :

$$V_c \approx \frac{Ze^2}{r_0 A^{1/3}}$$

and an additional momentum with respect to the neutron of the order

$$\Delta p_c \approx \frac{V_c}{v_p},$$

where v_p is the velocity of the proton. Since the momentum shift is typically several tens of MeV/c, such a procedure can indeed completely destroy proton-neutron correlations. This simple correction cannot however be applied for correlated pairs since both the shift of the particle momenta and the correlation effect develop simultaneously.

A correct analysis of the influence of the Coulomb field of the emitter on the two-particle correlations implies a three-body calculations.

3.2. Classical approach

At characteristic emission times τ of several hundreds of fm/c or higher, when the distances between particles in their c.m.s. are large compared with their Bohr radius, this problem can be solved in the classical approximation [6,7]. We performed trajectory calculations with and without treatment of the Coulomb interaction with the emitter. We observe that in case of two identical particles this interaction has no influence on the calculated correlation function within range of characteristic distances between particles

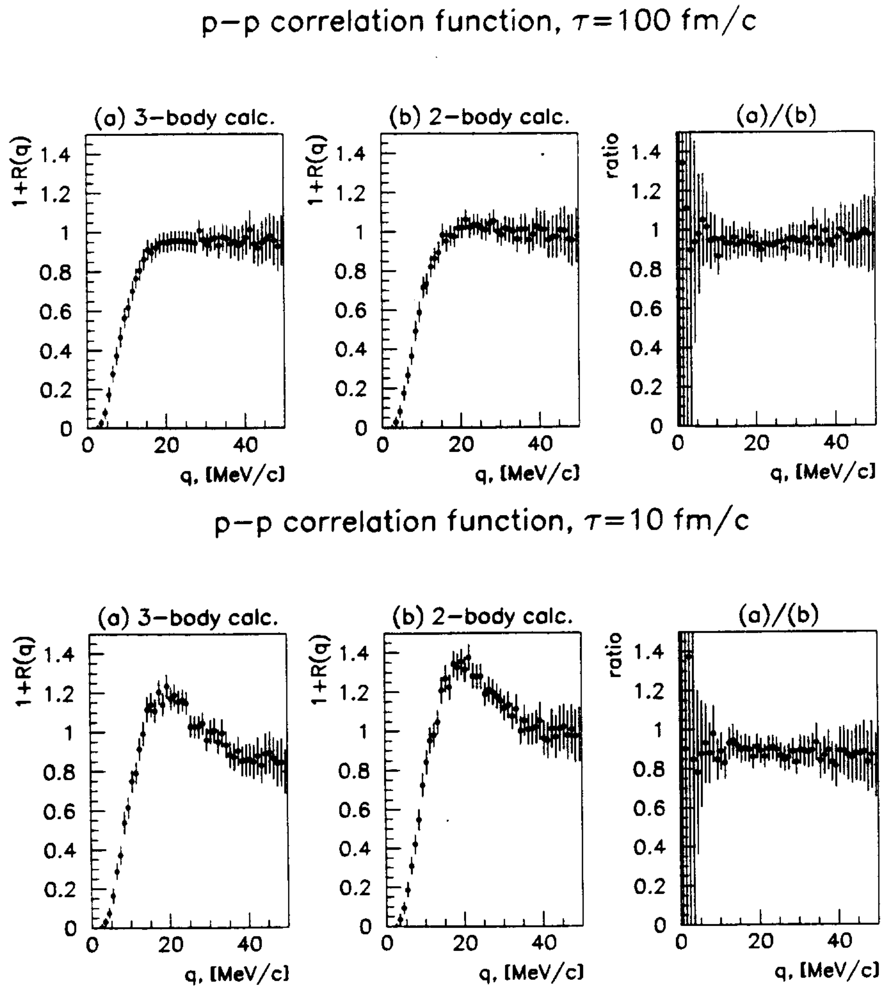


Figure 5. Predictions of three-body (a) and two-body (b) quantum calculations for p-p correlation functions. Influence of the Coulomb field of the emitting nucleus is represented by the ratio (a)/(b).

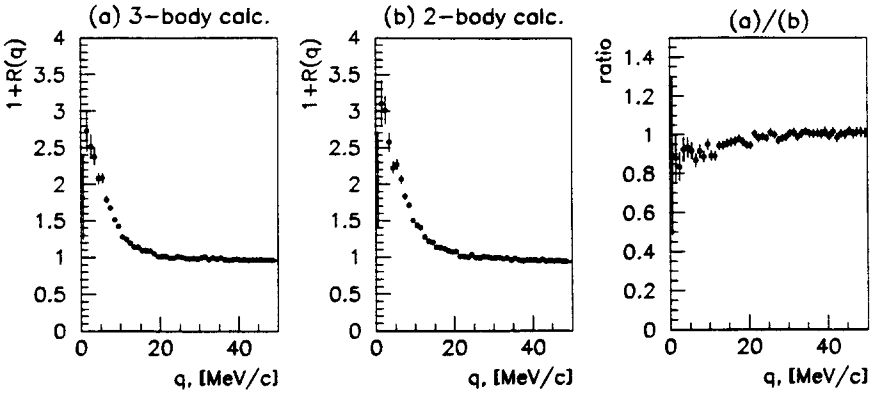
$v\tau > 25$fm, where v is the velocity of the pair. On the other hand, the influence of the residual nucleus is noticeable in case of p-d correlation function for $\tau \leq 300$ fm/c (Fig.4). The acceleration in the Coulomb field of the emitter is different for proton and deuteron due to the different mass-to-charge ratio of these two particles.

3.3. Quantum model

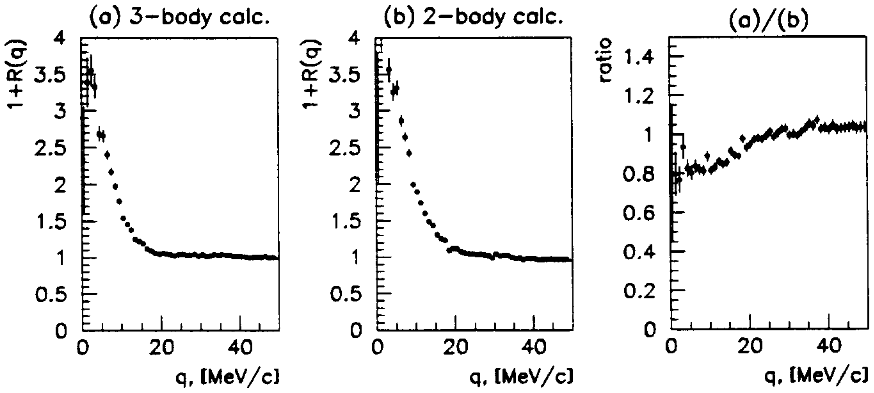
At lower lifetimes, smaller particle distances, the importance of the two-particle nuclear interaction and quantum effects (in particular effects of quantum statistics) increases. To extend the description to lower values of τ, we have developed a quantum approach in the adiabatic approximation, assuming the relative motion of the two particles much slower than their motion with respect to the emitter [8].

This adiabatic approximation is justified in the region we are interested in where the relative momenta are of the order of tens MeV/c and particle momenta of several hundreds MeV/c.The lifetime τ should not be however too small, say less than 10 fm/c.

The three-body quantum model predicts the influence of the emitter even in case of two identical particle p-p correlations for small emission time (Fig.5).



n−p correlation function, τ=100 fm/c



n−p correlation function, τ=50 fm/c

Figure 6. Same as Fig.5 for proton-neutron correlation function.

In case of p-n correlations, calculations show an increasing influence of the emitting nucleus with decreasing τ (Fig.6). Though the modification appears to be much less significant than expected from simple Coulomb shift arguments, even for a nucleus with an important charge.

For the emission time τ= 100 fm/c, the Coulomb field of a nucleus with charge Z = 51 leads to a supppression of the p-n correlation at small relative momenta by ~ 10% only.

4. CONCLUSIONS

A suppression of the p-n correlation function has been observed for the bulk part of the nucleons in the Ar induced reactions. This effect seems to be less important for the high energy particles but also for lighter targets. Thus, the very weak p-n correlations, observed in experimental data, might indicate the influence of the interaction of the proton with the charged emitting nucleus.

Three-body classical and quantum calculations show indeed that the Coulomb field of the emitter influences two-particle correlations at small relative momenta. This effect is stronger for particles with different mass-to-charge ratio and increases with decreasing

emission times. However, substantial correlations survive even in a strong Coulomb field.

Another explanation of the observed suppression of the correlation is based on the fact that the correlation functions for the spin S=0 and S=1 states of the p-n pair are different, with an anticorrelation for the S=1 state [9]. Thus, if for the measured pair the population of the S=1 state is more important as compared to the normal quantum weight then the correlation may become weaker. This question is of course closely related to the problem of the formation of deuteron in its ground state for which only the S=1 state is allowed.

Simultaneous, high quality measurements of the yields of different two-particle systems sensitive to different effects (p-p, p-n, n-n) and also deuterons are clearly needed.

REFERENCES

1. R. Ghetti et al., Nucl. Instr. and Methods A 335 (1993) 156.
2. M. Cronqvist et al., Phys. Lett. B317 (1993) 505.
3. W. Bauer, C.K. Gelbke and S. Pratt, Ann. Rev. of Nucl. and Particle Sci., 42 (1992) and references therein.
4. R.A. Kryger et al., Phys. Rev.C 46 (1992) 1887.
5. G. Bertsch, P. Danielewicz and H. Schulz, Europhys. Lett. 21 (1993) 817.
6. B. Erazmus, N. Carjan and D. Ardouin, Phys. Rev. C 44 (1991) 2663.
7. B. Erazmus, L. Martin, R. Lednicky and N. Carjan, Phys. Rev. C 49 (1994) 349.
8. R. Lednicky, V.L. Lyuboshitz, B. Erazmus, D. Nouais, submitted for publication
9. S. Mrówczyński, Phys. Lett. B 277 (1992) 43.