LIFE TIME MEASUREMENT BY LIGHT PARTICLE INTERFEROMETRY WITH INDRA

Gourio D., Reposeur T., Eudes Ph., Lebrun C., Assenard M., Germain M., Lautridou P., Laville J.L., Métivier V., Rahmani A. and the INDRA Collaboration*.
(March 12, 1996)

SUBATECH, Université de Nantes-Ecole des Mines-IN2P3/CNRS
Ecole des Mines de Nantes ,4 rue Alfred Kastler, La Chantrerie
F-44072 Nantes Cedex 03, France.

Abstract: Experimental data from the GANIL's 4π INDRA detector are available for the ^{129}Xe + ^{119}Sn system at incident energies ranging from 25 to 50 AMeV. Features of the detector show that both energy thresholds and granularity are quite good for $\theta < 45°$ making possible the study of light charged particles correlation at small relative momentum. Strong effects in terms of emission time are observed. Large multiplicities of Z=1,2 particles might influence the shape of correlation functions.

I. INTRODUCTION

The technique of intensity interferometry between light charged particles has been extensively used to measure the space-time characteristics of the emission sources produced in nuclear collisions [1–4].
For the shortest times or simultaneous emissions, the correlation function is sensitive to the mean distance between the emitting points. As the emission time τ increases, the source size effects become negligible as compared to the mean distance between the particles, and data depend only of the emission time of particles. Information about the order of emission of these two particles can also be deduced from particular set of particle pairs [5].

Experiments were performed at GANIL with the 4π detector INDRA providing very nice data and allowing us to investigate the behaviour of well identified sources with the evolution of the violence of the collision [6]. Moreover many beam energies and systems have been performed, opening for the first time wider studies of time emission with a 4π setup. The main goals of these preliminary results are first to fix

---

* Auger G., Bacri Ch.O., Benkirane A., Benlliure J., Berthier B., Bisquer E., Bocage F., Borderie B., Box P., Brou R., Cassagnou Y., Charvet J.L., Chbihi A., Colin J., Cussol D., Dayras R., Durand D., Demeyer A., Desesquelles P., De Fillipo E., Dore D., Ecomard P., Genouin-Duhamel E., Gerlic E., Guinet D., Gulminelli F., Heuer D., Lautesse P., Lebreton L., Le Brun C., Lecolley J.F., Le Fevre A., Lefort T., Legrain R., Lleres A., Lopez O., Louvel M., Mahi M., Marie N., Nagakawa T., Nalpas L., Nguyen A.D., Ouatizerga A., Parlog M., Peter J., Plagnol E., Politi G., Pollaco E., Pouthas J., Regimbart R., Rivet M.F., Rosato E., Saint-Laurent F., Salou S., Squalli M., Steckmeyer J.C., Stern M., Tamain B., Tassan-got L., Tirell O., Vient E., Volant C., Wielezko J.P., Yuasa-Nakagawa K.

to what extent such a study is possible with INDRA, then to show that we observe very clear signals of emission time effects and finally to look at the first observation of a Coulomb influence from the large multiplicity events on the correlation function shapes.

II. INDRA FEATURES AND THE LIGHT PARTICLES INTERFEROMETRY TECHNIQUE

The two particle correlation function is defined in terms of coincidence yields, $Y_{12}(p_1, p_2)$ and the single particle yields $Y_1(p_1)$ and $Y_2(p_2)$ where p_1, p_2 are the laboratory momenta of the particles.

$$C(q) = N \frac{Y_{12}}{Y_1 Y_2} \quad (1)$$

q is the relative momentum of the particle pair in its center of mass frame and N a normalisation coefficient choosen to have C=1 for large q values (region where final-state interactions are negligible). The effect of interaction between particles on the correlation function is located at small relative momentum, typically below 100 MeV/c depending on the particles of interest. The access of this region depends on both energy thresholds and the granularity of the detector. The smallest momentum available is given by :

$$q_{th} = p_{th}\, sin(\frac{\alpha_{min}}{2}) \quad (2)$$

where p_{th} is the lowest momentum which can be detected and α_{min} the smallest relative angle between two modules of the detector. Although INDRA has been designed to study mainly the fragments emission [7–9], the detection of all the products, particularly light particles is very efficient. The detection thresholds for light particles are very low. Moreover, the granularity of INDRA is quite good especially at forward angles. The Figure 1 shows the smallest relative angle and (taking into account the energy thresholds) the smallest relative momentum for all radial angles θ. We have decided to concentrate our study only for angles $\theta < 45^o$.

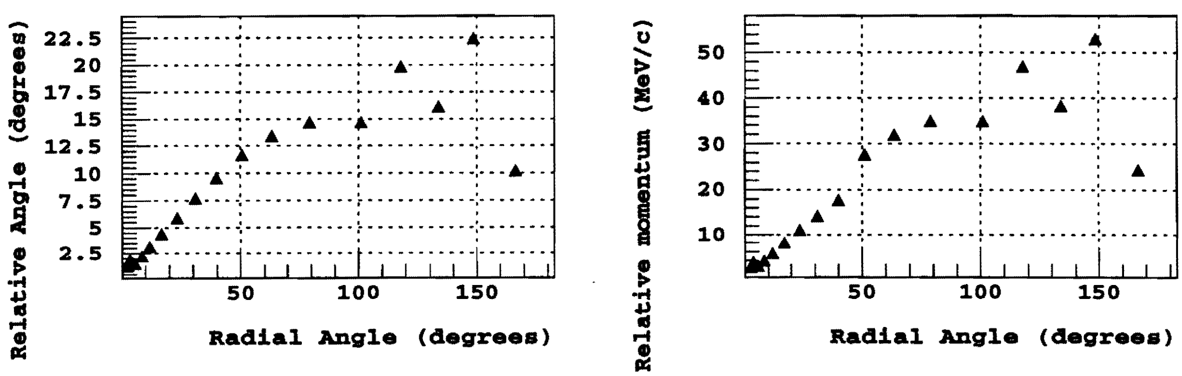


FIG. 1. Relative angles and relative momentum thresholds as function of the radial angle θ

On a other hand, care has to be taken to the statistical precision in the small relative momentum. For standard selections, the Figure 2 displays a typical spectrum of real coincidences between deuterons from which the lower limit is estimated to be $q = 20$ MeV/c.

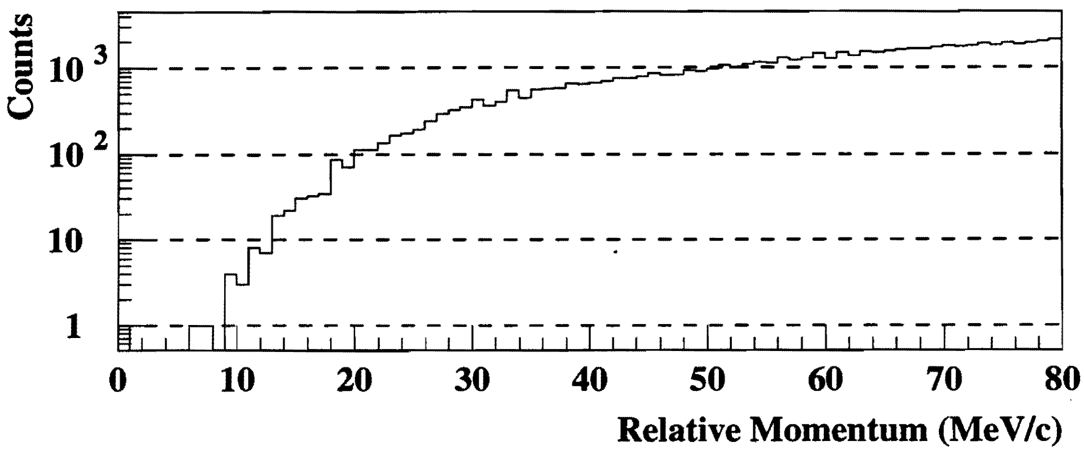


FIG. 2. True coincidences distribution of deuteron-deuteron pairs from the forward source and for the more peripheral events (cf. III)

III. EVENTS SORTING AND SOURCE SELECTION

The reaction ^{129}Xe on ^{119}Sn at a beam energy of 50 AMeV was chosen because of large light particles multiplicities and to take benefits of the already performed analysis in terms of events selection and source determination [8].

In the first step, only complete events for whose at least 80% of the total charge and 80% of the initial parallel momentum were detected have been investigated. Because of lack of statistics, the events in whose the target-like has not been detected were added: the measured parallel momentum is still close to the beam's one thanks to the low energy threshold for the target-like detection. Since a large part of the charge has been lost, the trajectory and the velocity of that fragment is reconstructed by a simple kinematic study where all the other particles trajectories are taken into account. Figure 3 shows the total detected charge as a function of the total detected parallel momentum. The hatched area represents the events kept in our analysis.

In order to characterize the violence of the collision we have constructed the quantity E_t as the sum of the transverse kinetic energies of the Z=1,2 particles. It is assumed that larger is E_t, smaller is the impact parameter [10]. The information given by E_t keeps being relevant even if the event is fairly complete because the detection of light particles is always good and their multiplicities are large. In the calculation of E_t, particles used in the construction of the correlation function have been removed in order to avoid any autocorrelation between the observed signal and the selection.

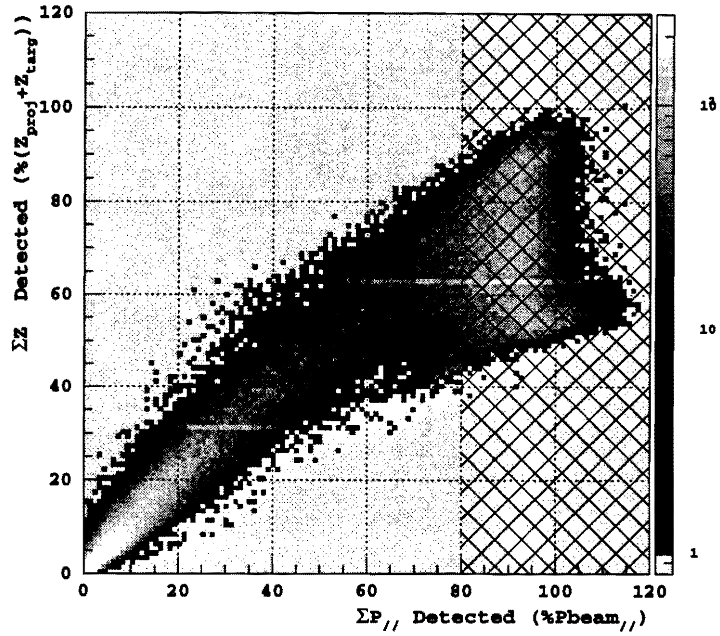


FIG. 3. Total detected charge versus the total detected parallel momentum

In this first study two cuts have been applied : the first one , $E_t < 400 MeV$, was related to the more peripheral events, the second one , $400 MeV < E_t$, characterizes more central events.

According to Ref. [8] most collisions produce two equilibrated sources, the target-like and the projectile-like. These two sources can be seen on the corresponding Lorentz invariant velocity plots for deuterons particularly in the peripheral case (Figure 4). Moreover some particles coming from dynamical processes can be observed in the mid-rapidity region and for the more central events.

Following this analysis two particle emission regions were defined by:

$$V_{particule} > 0.8\, V_{source}$$
$$27^o < \theta_{particule} < 45^o$$

where $V_{particule}$ and V_{source} are ,in a event-by-event analysis, the parallel velocities of the particle and of the forward source, respectively .

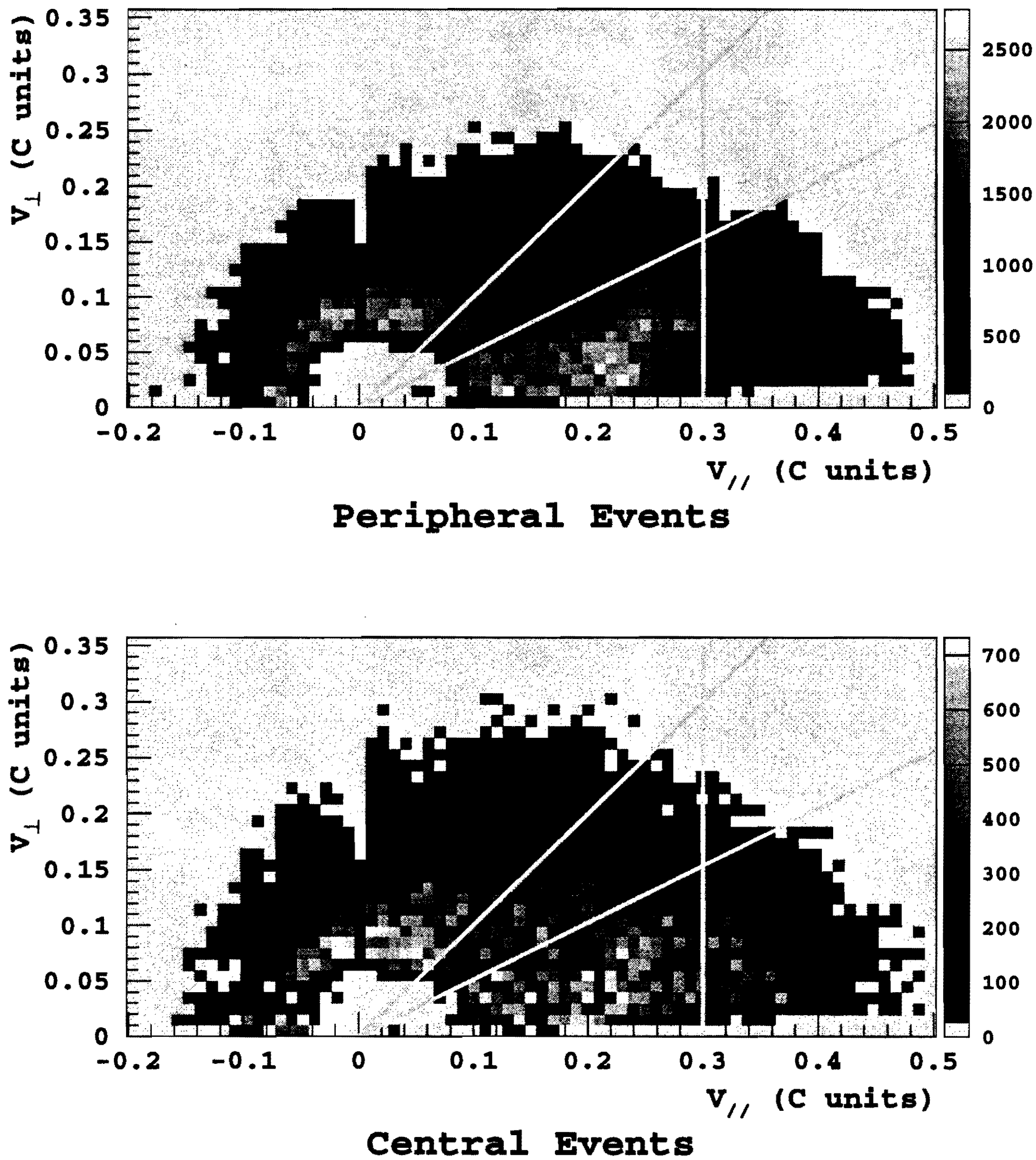


FIG. 4. Invariant cross-section plots of the transverse velocity versus parallel velocity for deuterons

The value of $0.8V_{source}$ instead of V_{source} is taken to increase statistics, nevertheless one can assume that the selected particles are still emitted by the forward equilibrated source.

The second cut can favor the dynamical emission in the "mid-rapidity" region. The upper limit $\theta = 45^o$ is anyway fixed by the performances of the detector as shown before (Figure 1). The two emitting regions are delimited on Fig. 4 with straight lines.

IV. EMISSION TIME DEPENDENCE WITH CENTRALITY AND EQUILIBRATION

In this first approach the analysis is focused on p-d and d-d pairs, for whose the final state interaction can be mainly described by Coulomb forces.

Figures 5 display the experimental correlation functions for the deuteron-deuteron system. The upper panels show the evolution of the "forward" source as a function of centrality. A clear dependence of the mean emission time which gets larger as the violence of the reaction decreases can be observed.

Concerning the so-called "mid-rapidity" region (lower panels), no significant difference in the shape of the correlation function despite the large error bars for the more central collisions case can be deduced. Assuming these particles are emitted in the first steps of the collision, it is not surprising to find that the emission time is quite independent of the violence of the collision. One also has to keep in mind that both centrality and mid-rapidity selections are here pretty rough and therefore we do expect to see only the strongest effects. Under this last restriction one can conclude that the mean emission times for deuterons does not strongly depend on the violence of the reaction for the "mid-rapidity" case.

Figure 6 shows the correlation function for the proton-deuteron system and for more peripheral collisions only. In the "mid-rapidity" case the pronounced anticorrelation effect is consistent with the one obtained in the d-d result.
On the other hand the flat correlation function observed for the forward source is inconsistent with a realistic proton emission time value.
We will see in the next chapter that the light charged particles multiplicity may influence the shape of the correlation function.

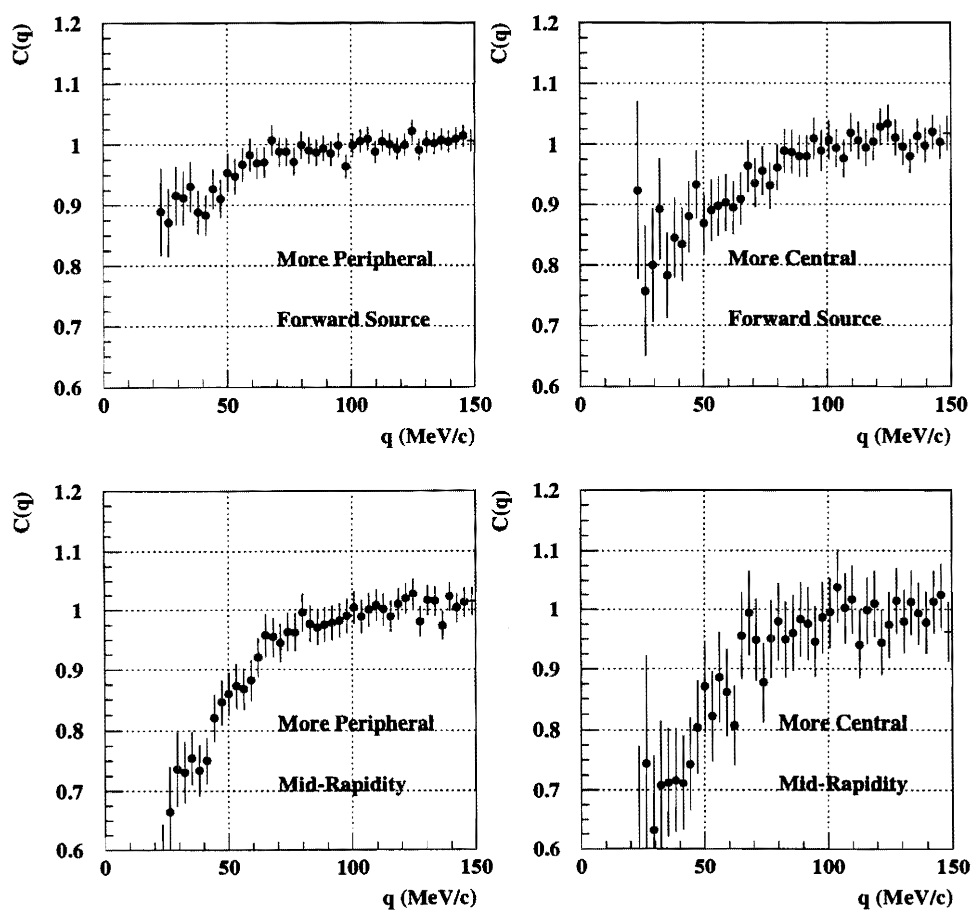


FIG. 5. Deuteron-Deuteron correlation functions for the two E_t selections and for the two zones of emission

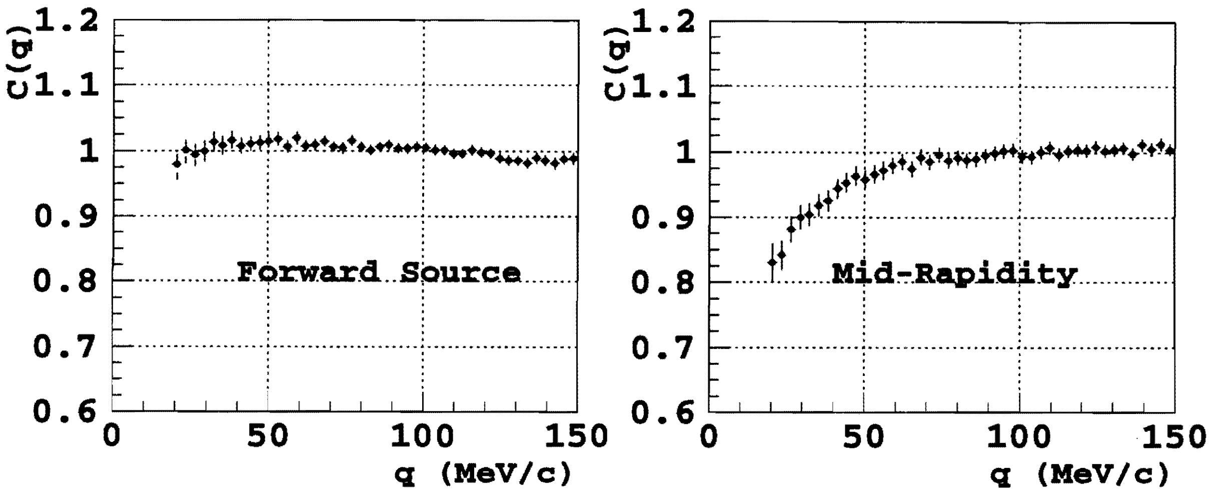


FIG. 6. Proton-Deuteron correlation functions for the more peripheral events and for the two zones of emission

V. N-BODY CODE SIMULATION TO EXTRACT TIME

To reproduce correlation functions for p-d and d-d pairs, a simple N-Body calculation which follows the coulomb trajectories of each particle has been used. The model is based on the classical scheme of an evaporative emission from a thermalized source and particles are emitted radially from the surface of the source with an isotropic angular distribution and kinetic energies following a Maxwell-Boltzmann distribution.

The characteristics of the source are extracted from the INDRA data as follow : the velocity is the one of the heaviest fragment detected at forward angle.
The size is deduced from the sum multiplied by two of all particles and fragments detected with a parallel velocity greater than the source's one in order to avoid other contributions.
The temperature is extracted from deuteron's kinetic energy spectra.
In the calculation, the size and the velocity of the source are selected from gaussian distributions but the temperature is kept constant.
In order to fit the experimental correlation functions, we just have to adjust the particle emission time which follows an exponential distribution.

The Figure 7 shows the experimental and calculated correlation functions for d-d pairs in the more peripheral collisions for the forward source.
The best agreement is found for an emission time of $\tau = 100 \pm 20 fm/c$ which is consistent with an evaporating process from a source at a temperature of about 5 MeV. We must point out that in this simple 3-body case (no multiplicity effect) the agreement if poor below q=40 MeV/c.

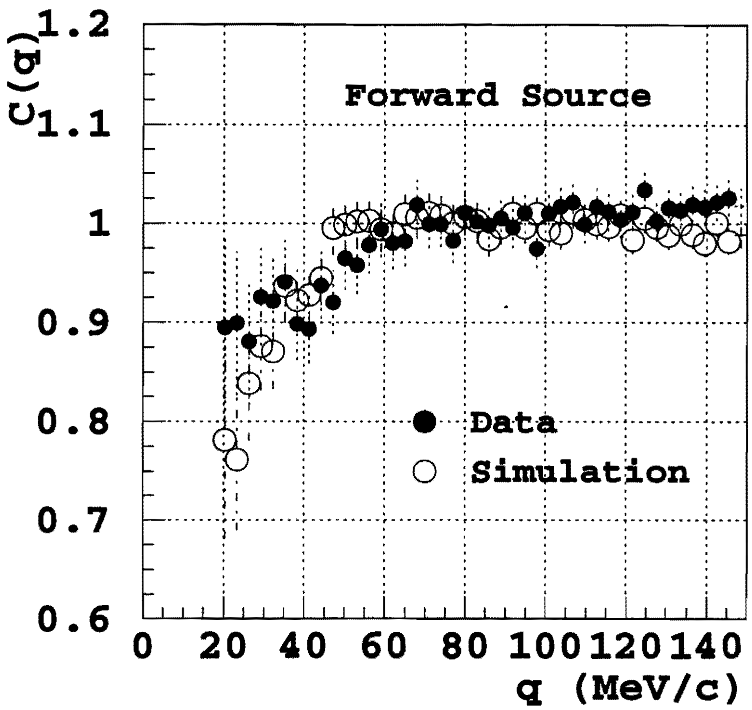


FIG. 7. Deuteron-Deuteron correlation functions for the forward source in the case of the peripheral events : comparison between the simulation and the data

As shown before the p-d correlation function for the forward source is rather flat and to reproduce such a behaviour, it would be necessary to take a very large and unrealistic proton emission time (typically several hundred fm/c) assuming the deuterons' one is fixed from the d-d study.
To get rid of this difficulty one may recall that we are dealing with a 4π solid angle and that two particle correlation functions are built by taking all combinations from the whole multiplicity. Then the other fragments emitted in between the correlated particles might cancel the anticorrelation leading to an overestimated τ value.

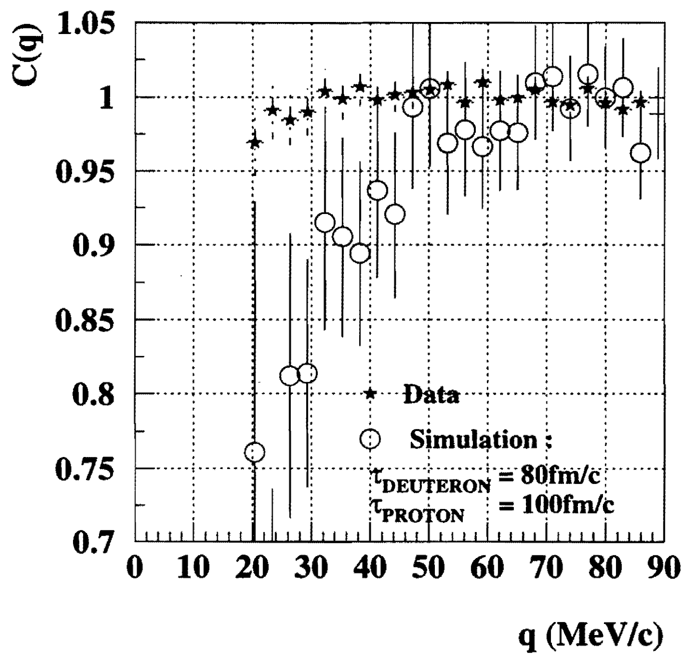
In order to analyse this influence, the average multiplicities of particles emitted by the forward source in the more peripheral collisions have been fixed from data at values of 5, 2 and 5 for protons, deuterons and alphas, respectively. The contribution of tritons, ^3He and other fragments is very weak and will be neglected in this first approach. An emission time of 80 fm/c for deuterons has been taken consistently with the value extracted in the d-d case by assuming it might have been overestimated. For proton emission we have taken τ = 100 fm/c to take into account the order of emission as found in [5,13]. The upper panel of Figure 8 shows the result of our calculation in a pure 3-body configuration, which is totally inconsistent with the data.

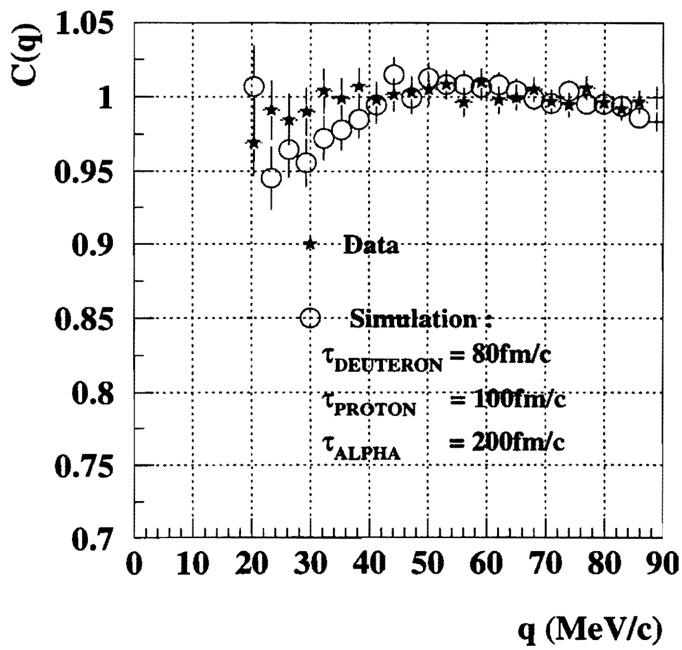
To estimate the effect of alpha multipicity, two emission time values were tested assuming that the corresponding final state interaction will be different.
The correlation function of the first calculation with τ_α=200 fm/c is plotted with open circles on Figure 8, mid-panel. As expected, the anticorrelation effect due to the coulomb repulsion is clearly present but no so strong than in the simple

simulation with one proton and one deuteron only. In particular, at small relative momentum, the function does not reach values lower than 0.9.

In the second case, alphas are emitted with τ_α=90 fm/c in order to increase the interaction with the other particles. The result of this last calculation is shown on the bottom of figure 8. The anticorrelation effect is clearly weaker than before and we obtain a better agreement with data.

In conclusion we may expect that alpha particles play an important role in the final state interaction between light particles. This assumption is strengthened by the behavior of the p-d correlation function selected from the mid-rapidity area (see Figure 6) which shows a clear anticorrelation effect consistent with a smaller multiplicity of light charged particules (3, 2 and 3 for protons, deuterons and alphas, respectively).





Cont'd

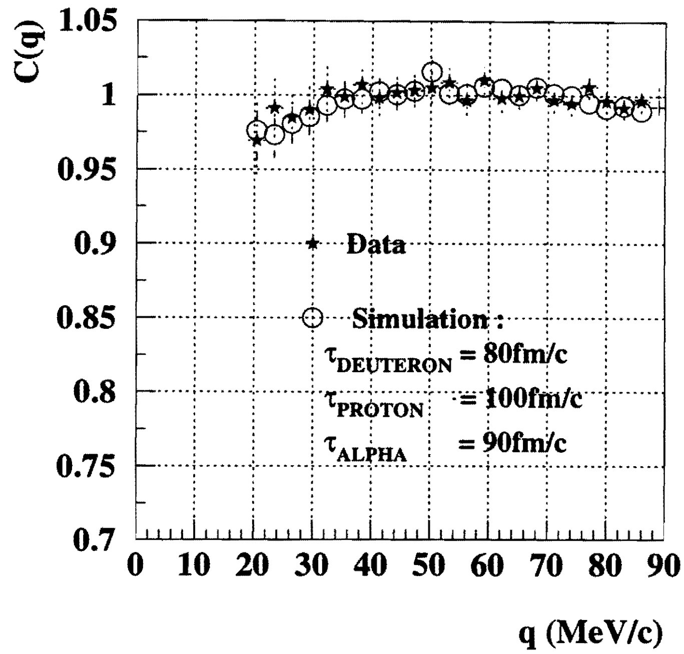


FIG. 8. Proton-Deuteron correlation functions for the forward source compared to calculations. On the top panel no alpha are emitted. On the mid panel, alphas are emitted later than protons and deuterons. On the bottom panel, alphas are emitted with the same time than protons and deuterons

VI. CONCLUSIONS AND OUTLOOKS

We have seen that analysis of light charged particles correlations are possible with INDRA. The detection for such particles is very efficient in terms of granularity and energy thresholds for the $\theta < 45^o$ region.

Even with rough selections, sizeable effects are observed.

As expected, the emission time of light particles decreases as the violence of the collision increases for the equilibrated forward source.

The shape of the p-d correlation function which is almost flat for the forward source and the more peripheral events can be explained in terms of multi-emission processes which involve other charged particles as alphas. Consequently, τ values extracted in the d-d case must be taken with care since the calculations have been performed with the emission of two deuterons only.

The next step of this study will be first to select more properly the sources of emission. Then the selection of well detected events can be extend allowing us to perform a better selection of the violence of the collision. This technique of interferometry will provide us emission times for protons and deuterons and also the order of emission [5,13].

To extract smaller emission times one has to use a more sophisticated model which takes all the interactions into account [12]. The extraction of τ values out of equilibrium will require a model taking into account the dynamic of the reaction. This possibility is already under study [14].

We will also be looking at the p-p correlations which are strongly sensitive to the nuclear interaction when the distance between the two particles becomes small.

Finally, the actual role of the multi-emission will have to be studied carefully.

[1] S.E.Koonin, Phys. Lett. 70B, 43 (1977)
[2] J.Pochodzalla et al, Phys. Rev. C35 (1987) 1695.
[3] B.Erazmus et al, Int. Workshop on Multiparticle Correlation and Nuclear Collision, CORINNE II, Nantes, France, 1994 (ed. J.Aichelin, D.Ardouin, World Scientific, 1994) p.116.
[4] J.Alexander et al, Phys. Rev. C48 (1993) 2874.
[5] C.Ghisalberti et al, comminucation at XXX Int. Winter Meeting on Nuclear Phycics, Bormio, Italy, 1993.
[6] V.Metivier et al, communication at XXXII Int. Winter Meeting on Nuclear Phycics, Bormio, Italy, 1995.
[7] J.Pouthas et al, Nucl. Instr. and Meth. A 357 (1994) 418
[8] V.Metivier, Ph.D Thesis, Université de Caen (1995).
[9] Saint-Laurent et al, Nucl. Phys. A583 (1995) 481.
[10] J. Lukasic, this conference.
[11] C. Ghisalberti et al Nucl. Phys. A583(1995)401-406
[12] B.Erazmus et al, Phys. Rev. C49 (1994) 349.
[13] C.J. Gelderloos et al, Phys. Rev. C52 (1995) R2834
[14] B.Erazmus, this conference.
D.Nouais, PhD thesis, in progress.