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TWO-NUCLEON CORRELATIONS AT SMALL RELATIVE VELOCITIES IN HEAVY ION COLLISIONS*

J. Pluta[a], T. Pawlak[a], P.B. Gossiaux[b], A. Kieliszek[a], F. Hanappe[c]
Th. Materna[c], L. Stuttge[d], J.C. Angelique[e], B. Benoit[c]
E. de Goes Brennand[c], G. Bizard[e], J. Colin[e], G. Costa[d]
P. Desesquelles[f], O. Dorvaux[d], D. Durand[e], B. Erazmus[b]
C. Hartnack[b], T. Kirchner[b], S. Kuleshov[h], C. Lebrun[b]
R. Lednicky[g], P. Leszczyński[a], M. Marques[e], L. Martin[b]
K. Mikhailov[h], K. Miller[a], R. Neubauer[b], G. Papatheofanous[c]
M. Przewłocki[a], A. Staranowicz[a], A. Stavinsky[h], B. Tamain[e]
A. Vlasov[h], L. Vorobyev[h] and K. Wosińska[a]

[a] Faculty of Physics, Warsaw University of Technology
Koszykowa 75, 00662 Warsaw, Poland
[b] SUBATECH, UMR Univ., EMN, IN2P3/CNRS
4 rue A. Kastler, 44307 Nantes, France
[c] Universite Libre de Bruxelles, CP229
Av. F. D. Roosevelt, 50, B1050, Bruxelles, Belgium
[d] IRES, IN2P3-CNRS / Universite Louis Pasteur, BP28
F67037 Strasbourg Cedex 2, France
[e] Laboratoire de Physique Corpusculaire, IN2P3, CNRS/ISMRA
F-14050 Caen Cedex, France
[f] ISN, IN2P3/CNRS, et Univ. J. Fourier
53 Av. des Martyrs, F-38026 Grenoble Cedex, France
[g] Institute of Physics, Czech Academy of Sciences
Na Slovance 2, 18040 Prague 8, Czech Republic
[h] Inst. of Theor. and Experim. Physics
B. Cheremushinskaya 25, 117259, Moscow, Russia

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The study of correlations of different two-nucleon systems, which were measured simultaneously in recent E286 experiment at GANIL, is regarded as an appropriate method to shed light on dynamics of intermediate energy heavy-ion collisions. The Quantum Molecular Dynamics model is argued to be a perspective approach for such an analysis.

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1. Introduction

Emission of nucleons in intermediate energy heavy-ion collisions is an accompanying process in different stages of nuclear disintegration. In general, nucleons carry information about the dynamical and statistical properties of the process leading to their emission. The inclusive single-particle data are rather weakly sensitive to the development of the emission process in space and time, however. Analysis of particle correlations gives information which cannot be easily obtained with the other methods. Correlations of particles emitted with small relative velocities arise mainly due to the effects of quantum statistics and of final state interaction, strong and Coulomb [1]. All these effects depend strongly on the space-time evolution of the emission process. The well known method of intensity interferometry links two-particle correlations with the space-time parameters of their emission and is widely used to study the space-time properties of the emission process in lepton, hadron and heavy-ion collisions [2].

2. Specific points of two-nucleon correlations

Similarity in mass and difference in charge of neutron and proton gives some specific possibilities for simultaneous analysis of two-nucleon correlations. The list below gives a short review of different forms of analysis of two-nucleon correlations. It is related to the dedicated two-nucleon interferometry experiment, E286, performed recently at GANIL. Special attention is paid to the role of dynamics in nucleon emission and to the sensitivity of two-nucleon correlation function to the space-time properties of the emission process.

1. *Space-time parameters of neutron emission*
   Momenta of emitted neutrons are not distorted by the long range Coulomb field. It means that emitted neutron characteristics give direct information about the parameters of hot nuclear medium and can be used as a probe of the properties of emitting source. Moreover, the absence of Coulomb repulsion in the system of two neutrons leads to maximum of correlations in the most sensitive region of smallest relative momenta.

2. *Influence of the Coulomb field on charged particle emission*
   Simultaneous measurement of (nn) and (pp) correlations in identical experimental conditions gives possibility to make comparative analysis in order to study influence of the Coulomb interaction on the proton emission process.

3. *Sequence of proton, neutron and light particle emission*
   A complicated process leading to nucleon and light fragment emission in different stages of heavy-ion reaction can be probed by non-identical particle correlations which are sensitive to the sequence in which the particle emission occurs [3]. The difference in emission time of neutrons and protons can be related to the Coulomb barrier for charged particles.

4. *Mechanism of deuteron formation*
   Proton-neutron correlations and a deuteron formation are in fact two different features of the same final state interaction effect [4]. Simultaneous analysis of both, in the identical experimental conditions, gives additional information on the space-time scale of particle emission and about the mechanism of deuteron formation.

5. *The role of reaction dynamics*
   Correlation of particles with close velocities is very sensitive to the dynamical properties of the emission process. A static description fails if dynamical features impose the dependence between space-time and momentum parameters. We have studied it starting from a simple static approach, with the model "SIMON" [5], Landau–Vlasov equations [6] and QMD model of heavy-ion reactions [7].

In this paper we have used the QMD approach to test the dynamical properties of nucleon emission and the reflection of it in two-nucleon correlations.

3. Quantum Molecular Dynamics (QMD) model applied to E286 experiment

QMD is based on a microscopic n-body semiclassical theory. The wave function of the total system, is taken as the product of gaussian test functions containing 6 time-dependent parameters per nucleon (mean position and mean momentum).

The reader will find an extensive discussion of the QMD model in [8] and a comparative study of its various[1] numerical implementations in [7].

For the purpose of our study, the important advantages of the QMD model are:

- account of n-body correlations
- a natural fragment identification
- event-by-event analysis.

[1] We are using the *B* QMD version.

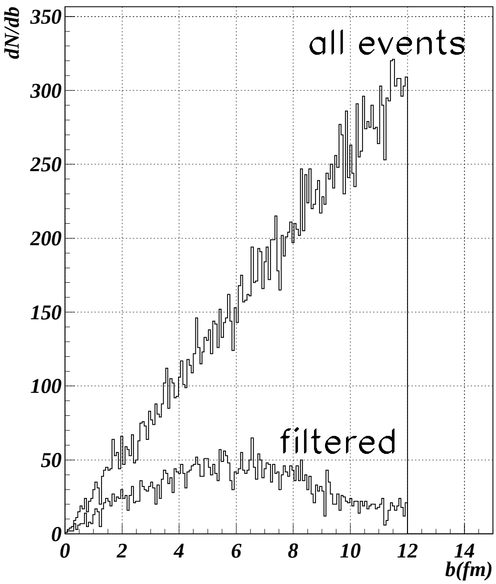

Fig. 1. The influence of the experimental filter on the QMD impact parameter distribution.

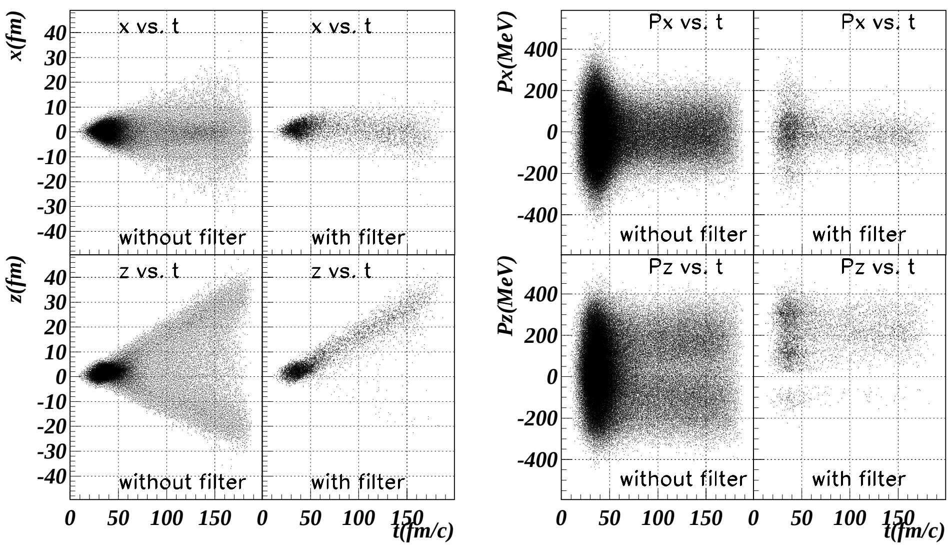

Fig. 2. Left: CMS emitted nucleon coordinates from QMD versus time, without and with experimental filter applied. Emission was supposed to be achieved at the last collision point. Right: CMS emitted nucleon momenta from QMD versus time, without and with experimental filter applied.

In order to use the simulated data for interferometry analysis, we modified the QMD output. In the new format, we are including not only the asymptotic information but also the particle last collision point (or the point where particle leaves a region of given density value) which is crucial for the correlations study.

We have produced 50.000 QMD ^{40}Ar+^{58}Ni events at 77 MeV/u and filtered them with the experimental filter, which incorporates the geometry of the detection setup, detectors efficiencies and the trigger with at least two registered particles. The experimental filter cuts off most of the periferal events, figure 1, and exhibits influence on space and momentum parameters of the emitted nucleons, figure 2.

In figure 3 one can observe dynamical correlations between the coordinate and the momentum, the most pronounced one being along the beam

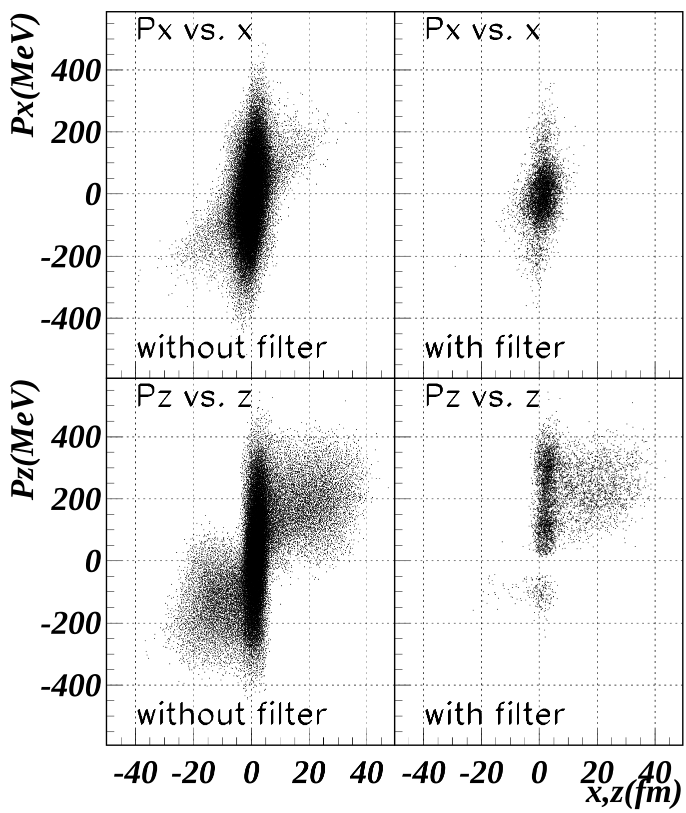

Fig. 3. CMS emitted nucleon momenta versus coordinates from QMD, without (left) and with (right) experimental filter applied. Emission was supposed to be achieved at the last collision point.

direction (the z-axis). Nucleons are preferently emitted in the direction of the position vector.

These coordinate-momentum correlations should be also present in other microscopic approaches like Landau–Vlasov. On the other side, they disappear if one describes the reaction in terms of a unique "static" source, as it is traditionally done. They have a strong influence on the correlations functions [9].

We have then calculated the nucleon-nucleon correlation functions using the effective source deduced from QMD as an input for the quantum correlation code of [1]. In figure 4 an example of such a correlation function is given in the case of neutron-neutron system.

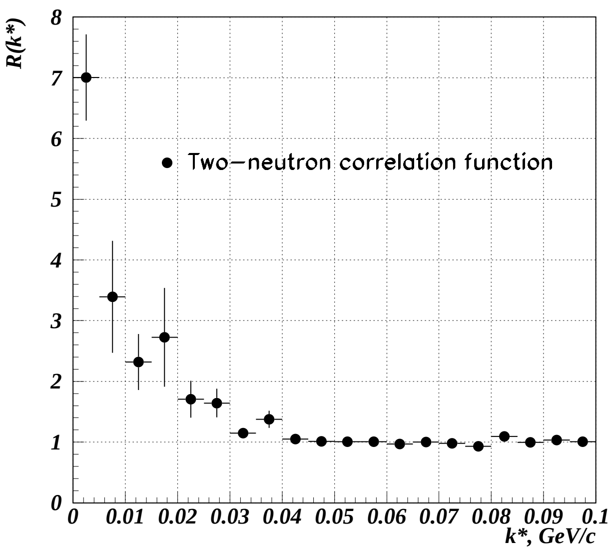

Fig. 4. Neutron-neutron correlation function from QMD. Filtered data and last-collision-point criteria have been used.

We are presently investigating the role of the "emission" criteria, that is what should be considered as the emission point of a particle. Indeed, even after their last collision, particles are still under the influence of the mean field and can be strongly deviated.

We also plan to extend our analysis to the case of deuterons and tritons, where we will benefit from the dynamical fragment formation processes already implemented in QMD. However one may argue that more refined physics should be added to QMD in order to treat the production of small fragments like deuterons or tritons.

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