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SPACE-TIME AMBIGUITY OF TWO- AND THREE-FRAGMENT REDUCED VELOCITY CORRELATION FUNCTIONS

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Abstract

Reduced-velocity correlation functions between two and three intermediate mass fragments are compared for central $^{36}Ar+^{197}Au$ collisions at E/A=50 MeV. Previously published N-body Coulomb-trajectory calculations, capable of reprodudng the measured two-fragment reduced velocity-correlation function, describe the measured three-fragment correlation function equally well. Moreover, ambiguities between source size and lifetime observed in the analysis of two-fragment correlations remain unresolved in the three-fragment correlation function.

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Highly excited nuclear systems formed in intermediata-energy heavy-ion collisions (E/A ≤ 1 GeV) can decay by the emission of several intermediate mass fragments (IMF) [1-14]. Statistical descriptions of these multifragment disintegrations are either based upon rate-equation [15,16] or microcanonical approaches [17-19]. For example, in the expanding compound nucleus model of ref. [16] multifragment emission is calculated as a sequence of binary decay steps from a hot, possibly expanding nuclear system undergoing equilibration between the individual decay steps. In microcanonical treatments [17-19], on the other hand, the expansion dynamics is neglected and multifragmentation is calculated from the statistical partitions of a finite, equilibrated, dilute nuclear system in a fixed volume. At high excitation energies, the two models predict comparable fragment multiplicities [20]. Which of these approximation is more appropriate for a given reaction scenario is the subject of intense debate, and observables are being sought which could provide more detailed information about the space-time configuration of multifragmenting systems.

Two-fragment correlations at small relative velocities are sensitive to source dimensions and emission times through the spatial dependence of final-state interactions [21-33]. Unfortunately, these correlation functions depend both on the source dimension and on the time scale of fragment emission. Thus existing data could often [23,28,32,33] be reproduced by trading shorter emission time-scales against larger source dimensions. This space-time ambiguity may be reduced by exploring additional cuts on the relative angle between the relative velocity of the fragment pair and the velocity of its center-of-mass [33]. One may also hope to obtain more incisive information by considering higher-order fragment correlations [34]. Indeed, recent calculations [34] with the microcanonical model [18] have shown that three (or more) fragment-correlation functions should produce a larger "Coulomb-hole" at small relative velocities. It is therefore of interest to explore whether such higher order correlation functions are capable of providing more information about the space-time characteristics of multifragmenting systems than two-fragment correlation functions. In this note, we address this question by investigating correlations between two and three fragments measured [35] for central $^{36}Ar+^{197}Au$ collisions at E/A = 50 MeV.

The experiment was performed at the National Superconducting Cyclotron Laboratory at Michigan State University. The K1200 cyclotron provided an ^{36}Ar beam of E/A=50 MeV with an intensity of approximately 10^8 particles per second incident on a ^{197}Au target of about 1 mg/cm^2 thickness. Intermediate mass fragments and light charged particles in the angular range $9^o \leq \theta_{lab} \leq 160^o$ were detected with the MSU Miniball phoswich detector array [36] which covered approximately 89% of 4π in solid angle. Details of the experimental setup have been described previously [25,33,35]. As was done in ref. [33], we analyze reduced-velocity correlations between intermediate mass fragments ($4 \leq Z_{IMF} \leq 9$) detected in an angular range of $9^\circ \leq \theta_{lab} \leq 40^\circ$. Central collisions were selected by a cut on charged-particle multiplicity, $N_C \geq 19$ [33]. This centrality cut corresponds to a reduced impact parameter [37] of $b/b_{max} \leq 0.3$ and less than 10% of the reaction cross section.

Following the notation of ref. [34], we define a correlation function of order ω as

$$1 + R(\Psi_\omega) = C\frac{N_{cor}(\Psi_\omega)}{N_{uncor}(\Psi_\omega)}] \qquad (1)$$

Here, $N_{cor}(\Psi_\omega)$ is the observed Ψ_ω distribution for fragments observed in the same event and $N_{uncor}(\Psi_\omega)$ is the Ψ_ω distribution constructed from mixed events. (Specifically, we mixed fragment yields from the previous five events with fragment multiplicity ω.) In Eq. 1, Ψ_ω denotes the geometric mean of all reduced velocities $(v_{red})_{ij}$ between distinct pairs of fragments ij. For the particular case of two- and three-fragment correlation functions we have

$$\Psi_2 = (v_{red})_{12} \text{ and } \Psi_3 = \left(\prod_{ij=12,23,13} (v_{red})_{ij} \right)^{1/3} , \qquad (2)$$

where the reduced velocity $(v_{red})_{ij}$ is defined as [23,24]

$$\left(v_{red}\right)_{ij} = \frac{\left(v_{rel}\right)_{ij}}{\sqrt{Z_i + Z_j}} = \frac{p_i / m_i - p_j / m_j}{\sqrt{Z_i + Z_j}} \qquad (3)$$

Here the charge, mass and momentum of a fragment i are denoted by Z_i, m_i, and p_i, respectively. The constant C in eq. 1 was chosen such that the correlation functions are normalized to unity for large reduced velocities ($0.035\,c \leq v_{red} \leq 0.05c$).

In Fig. 1, measured two-fragment (solid points) and three-fragment (open points) correlation functions are compared. These data corroborate the qualitative prediction of ref. [34]: the three-fragment correlation function exhibits a wider minimum ("Coulomb hole") at small reduced velocities than the two-fragment correlation function.

In order to investigate whether this wider minimum reflects an increased sensitivity to the space-time configuration of the emitting source, we performed many-body Coulomb trajectory calculations as detailed in ref. [33]. In these calculations, charge, energy, and angular distributions of the emitted fragments ($4 \leq Z_{IMF} \leq 9$) were selected by randomly sampling the experimental single-particle yields. The intermediate mass fragments were then assumed to be sequentially emitted from the surface of a spherical source of radius R_S and charge Z_S, moving in the beam direction with the center-of-mass velocity of the $^{36}Ar + ^{197}Au$ system. The individual emission times for each fragment are assumed to follow an exponential probability distribution, characterized by a decay constant τ. (For additional details of the simulations see ref. [33].) After filtering the simulated events by the geometrical acceptance, granularity, and energy threshold of the MSU Miniball, the calculated events were treated in exactly the same way as the experimental data, and correlation functions were constructed as described above.

Figure 2 summarizes the space-time ambiguity reported previously [33]. The solid points show the experimental two-fragment reduced-velocity correlation function (without cuts on the angle between the reduced velocity and the velocity of the two-fragment center-of-mass). These correlations functions can be reproduced equally well by assuming fragment emission from a relatively large and short-lived source (R_S=10 fm and τ=10 fm/c) or from a smaller, but longer-lived source (R_S= 8 fm and τ=50 fm/c, or R_S= 5.5 fm and τ=100 fm/c). As demonstrated in ref. [33], this ambiguity can be reduced by selective cuts on the orientation of the reduced velocity vector.

Figure 3 compares the predicted three-fragment correlation functions to the experimental data. The calculations were performed with the same initial conditions as those shown in Fig. 2, and they provide a satisfactory description of the measured three-fragment correlation function. However, the space-time ambiguity is not reduced by the construction of the three-fragment correlation function, i.e. the previously noted ambiguity [33] between radius and lifetime remains. Our study shows that for the present reaction two- and three-fragment reduced velocity correlation functions appear to contain more or less the same information about the emitting source.

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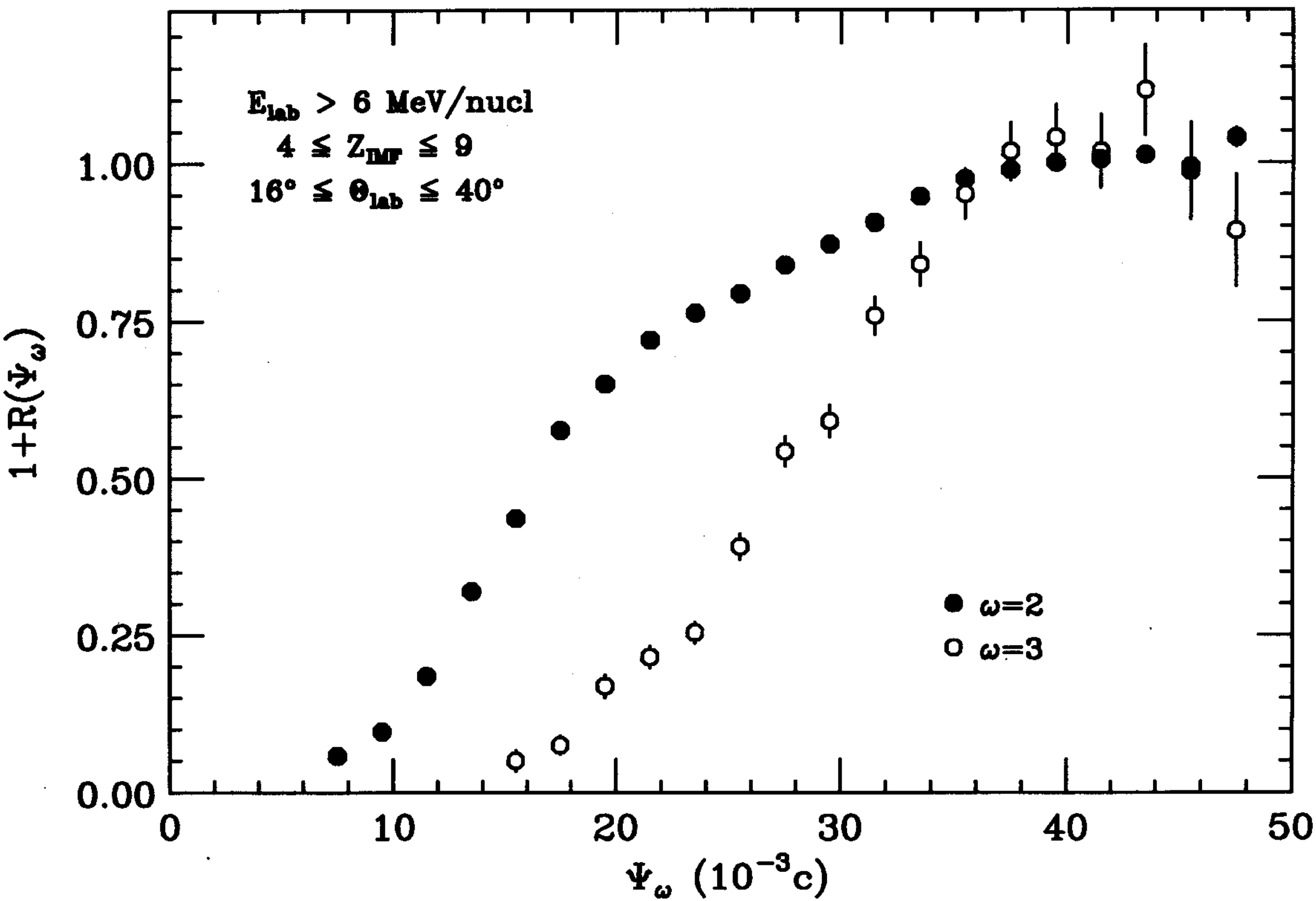
Figure captions

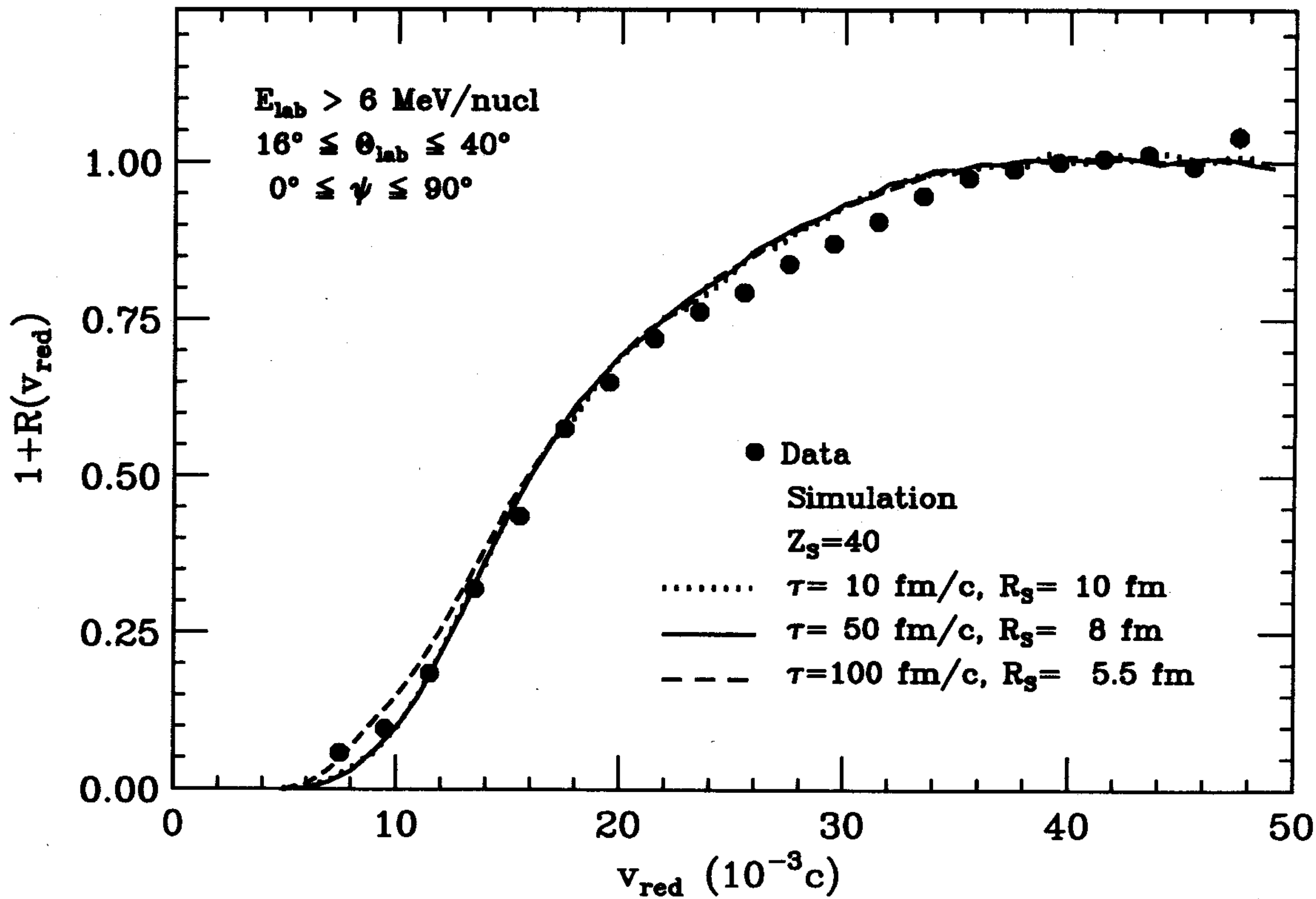
FIG. 1. Experimental two-fragment (solid points) and three-fragment (open points) correlation functions for intermediate mass fragments ($4 \leq Z_{IMF} \leq 9$) emitted in central ($b/b_{max} \leq 0.3$) ^{36}Ar + ^{197}Au collisions at E/A = 50 MeV. The correlation functions are shown for fragments detected at forward angles ($16° \leq \theta_{lab} \leq 40°$). A uniform energy threshold of $E_{lab} > 6$ MeV/A was applied by a software cut. The experimental error bars are indicated only when they are larger than the size of the plotted symbol.

FIG. 2. Measured (solid points) and simulated (curves) fragment-fragment correlation functions. The source parameters [33] are given in the figure. The simulated correlation functions are virtually indistinguishable [33].

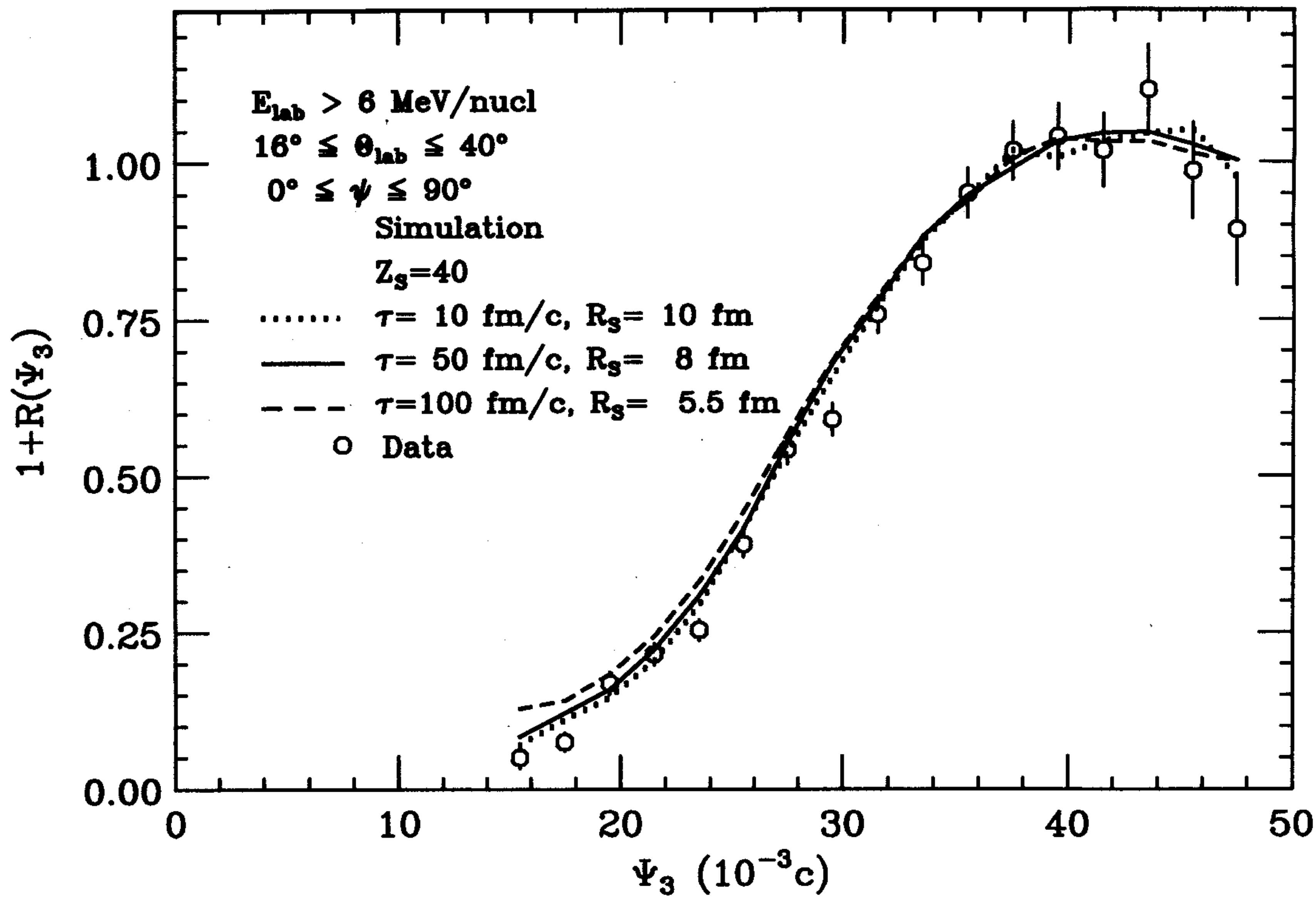
FIG. 3. Measured (open points) and simulated (curves) three-fragment correlation functions. The source parameters [33] are given in the figure. They are identical to those used for the calculations shown in Fig. 2.



Glasmacher – Figure 1



Glasmacher – Figure 2



Glasmacher – Figure 3