FRAGMENT MULTIPLICITY DISTRIBUTIONS, A SIGNAL OF TRUE NUCLEAR MULTIFRAGMENTATION

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Recently, Moretto and collaborators [1] have put forth the measurement of fragment multiplicity distributions as an insightful tool for understanding the mechanisms and the driving principles of nuclear fragmentation. Experimental fragment yields have shown themselves to be well described by binomial distributions, while the interpretation of the binomial parameters has been deeply debated [2,3,4]) .

Here, we present calculations of fragment multiplicity distributions for percolation calculations [5,6,7]. Our aim is to address the following questions:

1. Are fragment multiplicity distributions from percolation calculations of a binomial nature?
2. Is the variance of the multiplicity distribution governed by simple conservation laws or by other principles?

At first glance, percolation models seem to have little in common with a nuclear multifragmentative event. No dynamics are present, and bulk properties such as pressure and specific heat do not even have analogs in a percolative description. However, percolation models do allow one to study the effects of particle number conservation and geometry, and therefore can prove insightful in modeling nuclear fragmentation. For our studies we employ bond percolation where p is the probability of breaking an individual bond. For values of p below $p_c = .7512$ the majority of sites belong to a single large cluster. When p exceeds p_c, the lattice is broken into smaller clusters. For each event the number n of intermediate-mass fragments (IMFs) is recorded. The default definition of an IMF is that it is of size, $3 \leq Z \leq 20$. By recording thousands of events multiplicity distributions were generated for given values of p. Figure 1 displays multiplicity distributions for p= 0.7 and p=0.8 for the 123-site case.

Moretto and collaborators have reported that the multiplicity distributions of IMFs in nuclear fragmentation are observed to be well described by binomial distributions. Binomial distributions are defined by two parameters p_b and N_b. The mean and variance of binomial distributions are given by:

$$\begin{aligned} \langle n \rangle &= p_b N_b \\ \sigma^2 &= \langle n \rangle (1 - p_b), \end{aligned} \tag{1}$$

with the variance always being less than the mean. Thus, by measuring the mean and variance, one can determine the binomial parameters, p_b and N_b. In the limit that the variance equals the mean the distribution becomes Poissonian, and if the variance is larger than the mean (super-Poissonian), the distribution can no longer be considered binomial. However, one might then consider the distribution to be a negative binomial.

The lines in Figure 1 represent negative binomial and binomial fits for the p=0.7 and the p=0.8 cases respectively, where the parameters were chosen to match the mean and variance of the two distributions. In all the calculations we have performed, two-parameter fits have been remarkably successful in describing multiplicity distributions.

Figure 2 displays $\langle n \rangle / N_{sites}$ and $\sigma^2 / \langle n \rangle$ as a function of p for the small and large lattices. The distributions are super-Poissonian for $p < p_c$ and become sub-Poissonian just above p_c. The super-Poissonian behavior is a signal of a positive correlation between IMFs, as it signals that the presence

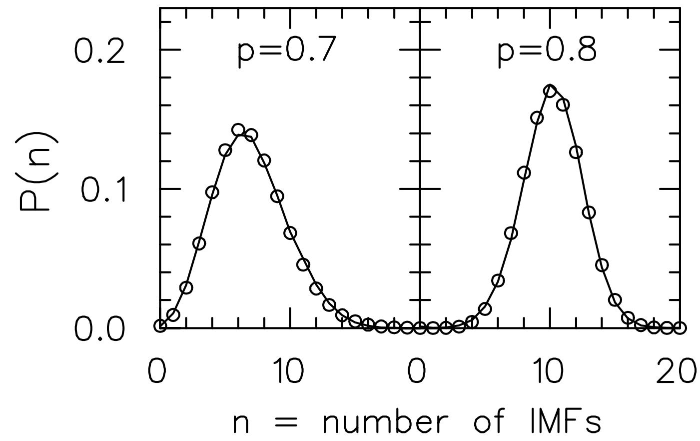

Figure 1: IMF multiplicity distributions from percolation calculations using 123 sites (circles) are well described by two-parameter fits to binomial or negative binomial distributions.

of an IMF will be positively correlated with the production of other IMFS. We argue that this positive correlation is a signal of the fragmentative nature of the percolation model.

To understand the correlation, we rewrite the expression for the difference of the variance and mean in terms of a correlation function,

$$\sigma^2 - \langle n \rangle = \sum_{a \neq b} \langle (n_a - \bar{n}_a)(n_b - \bar{n}_b) \rangle + \sum_a \langle n_a^2 - n_a - \bar{n}_a^2 \rangle \qquad (2)$$

$$\approx \sum_{a \neq b} \langle (n_a - \bar{n}_a)(n_b - \bar{n}_b) \rangle$$

The sums over a and b represent the sums over all types of IMFs, where a type a refers to a specific size, shape and position. The first sum on the right-hand side of Eq. (2) represents the correlation between different IMFs. The second sum can be neglected, as the first two terms of the second sum cancel each other since n_a can only be zero or unity, and the last term, which is negative, is small. This last term becomes zero in the limit that the probability of any specific IMF (defined by size, shape and position) is small.

Since the bond breaking is random, only fragment types that share the same sites or the same boundaries are correlated. If type a and type b share any of the same sites, the correlation is clearly negative as they can not coexist. This is related to particle number conservation. However, if a and b merely share some section of their boundaries a positive correlation can exist. This positive correlation appears only for values of p where a majority of the sites are taken up by large clusters, larger than the size of an IMF. The presence of an IMF a then creates extra surface within some larger cluster. The increased surface area eases the production of a second IMF of type b which borders the first IMF. As p is increased to the point where most of the sites are assigned to fragments the same size or smaller than IMFs, the positive correlation disappears, and the effects of particle-number conservation are dominant.

The super-Poissonian variance of the IMF multiplicity distribution is a signal of the fragmentative aspect of the percolation model. The positive correlation arises from the additional surface created by the production of a fragment. For sequential models of fragment formation, e.g. an evaporative picture, surface area is not increased by the production of a fragment, as the nucleus is assumed to return to

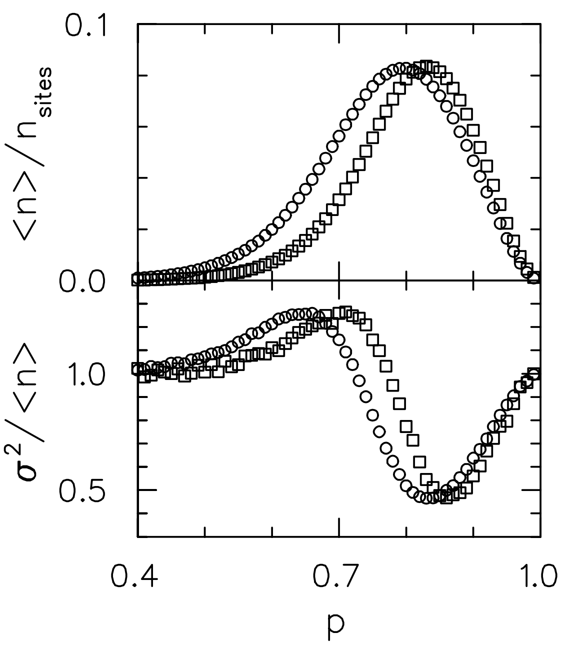

Figure 2: The average multiplicity of IMFs and the variance is shown for percolation calculations of 123 sites (circles) and 4169 sites (squares). The super-Poissonian behavior indicates a positive correlation between IMFs that signals true fragmentative behavior.

it's spherical shape before the production of the next fragment. In fact, evaporative pictures introduce additional negative correlations due to energy conservation since the production of an IMF uses a large amount of energy to surpass the Coulomb barrier, which then makes subsequent IMF production difficult. Thus, the study of IMF multiplicity distribution in nuclear collisions provides insight into the general principles of the fragmentation mechanism.

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