

## Fluctuations of the second order observables for dissipative processes in $^{19}\text{F} + ^{27}\text{Al}$ system

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**Abstract.** The excitation function (EF) data for dissipative processes in  $^{19}\text{F} + ^{27}\text{Al}$  system in the incident energy interval from 113.5 to 130 MeV are used to obtain the dependence of the charge variance and of the interaction time as a function of the incident energy. Fluctuations are observed in the EFs of both these secondary observables. Their correlation is supported by a mechanism based on stochastic exchange of nucleons.

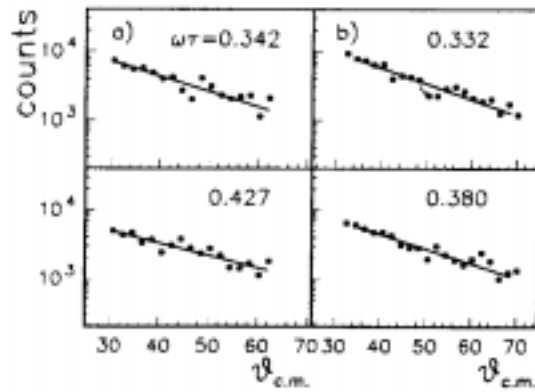
**Keywords.** Deep inelastic processes; excitation function; non-statistical fluctuations.

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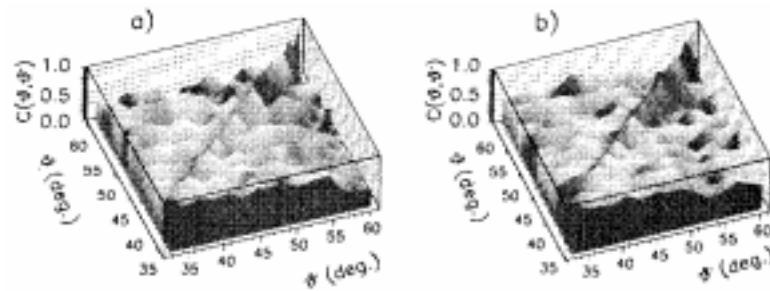
Non-statistical fluctuations in the EFs of dissipative heavy ion collisions (DHIC) was rather unexpected due to the fact that cross sections are always obtained on a 'coarse cell' of total kinetic energy loss (TKEL) and center of mass angle of observation ( $\vartheta_{\text{cm}}$ ) [1]. The contribution of a large number of microchannels to the measured cross section is expected to attenuate the fluctuation amplitude. The partially overlapping molecular levels model (POMLM) introduces, besides the angular momentum correlation, the hypothesis that the dinuclear system (DNS) formed in the first stage of a dissipative process is excited in a region of low level density situated in the vicinity of the yrast line in order to describe such fluctuation phenomena [2].

A detailed experimental study of the  $^{19}\text{F}$  on  $^{27}\text{Al}$  and  $^{19}\text{F}$  on  $^{12}\text{C}$  collisions at 111.4, 125.0 and 136.9 MeV has been realized. The correlations between different observables evidenced that even for such light combinations, in this energy range, a full dynamics specific for deep inelastic processes from quasielastic down to complete damping is present [3,4]. This systematic study of dissipative processes in light systems was completed with experiments dedicated to the measurement of the excitation functions in  $^{19}\text{F} + ^{27}\text{Al}$  and  $^{27}\text{Al} + ^{27}\text{Al}$  systems in order to obtain deeper insight on DNS configuration and its time evolution.

The excitation function for  $^{19}\text{F} + ^{27}\text{Al}$  system has been measured between 113.5



**Figure 1.** Angular distributions at incident energies 121 and 123 MeV for (a)  $Z = 6$  fragment and (b)  $Z = 8$  fragments for W4 window.



**Figure 2.** Angular correlation coefficients for (a)  $Z = 7$  and (b)  $Z = 8$  fragments for W4 window.

and 130.0 MeV with a 250 keV energy step [5]. The EF for  $^{27}\text{Al} + ^{27}\text{Al}$  collision has been measured with the same step on the incident energy interval from 120.0 to 130.0 MeV and some preliminary results are presented in this communication. The experiments were performed at the SMP tandem accelerator from LNS, Catania. The outgoing fragments were detected using experimental device DRACULA having as a main component two large area position sensitive ionization chambers [6].

The EFs for  $Z = 6-12$  fragments from  $^{19}\text{F} + ^{27}\text{Al}$  collision having TKEL and  $\vartheta_{\text{cm}}$  in the W1–W5 windows given in figure 3 were obtained. The windows have been chosen in order to select dissipative processes which take place in this interaction but to avoid the complete energy dissipation. Fluctuations with amplitude larger than the statistical errors were observed. Large  $Z$  and angular cross correlation coefficients show their non-statistical nature.

For angular correlation analysis, the angular distributions with a  $2^\circ$  bin for bombarding energy from 116.75 to 122.25 MeV have been obtained for windows W2, W4 and W5. As an example angular distributions for  $Z = 6$  and 8 for W4 window are given in figure 1. The angular correlation coefficients  $C(\vartheta, \vartheta')$  have large values as can be seen in figure 2. An oscillating pattern could be seen. The minima are filled as predicted for the case of deep inelastic reactions in contrast with the case of compound elastic and

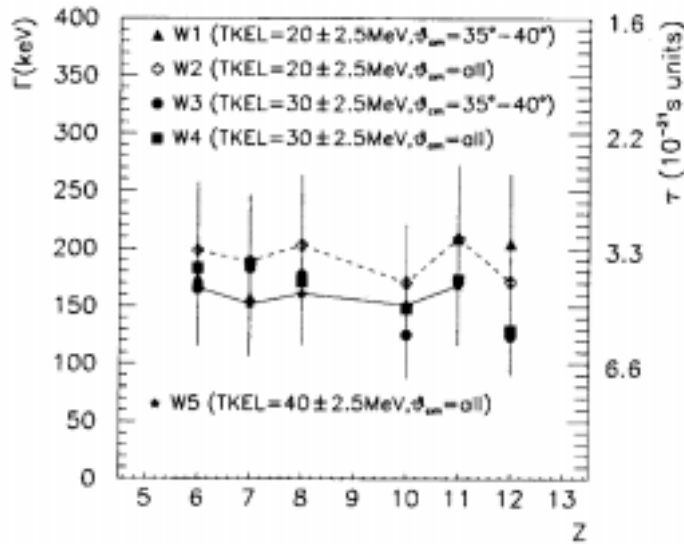


Figure 3. The dependence of the energy correlation width  $\Gamma$  on fragment charge.

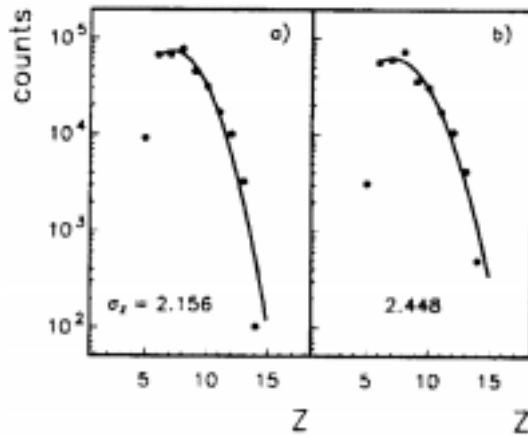


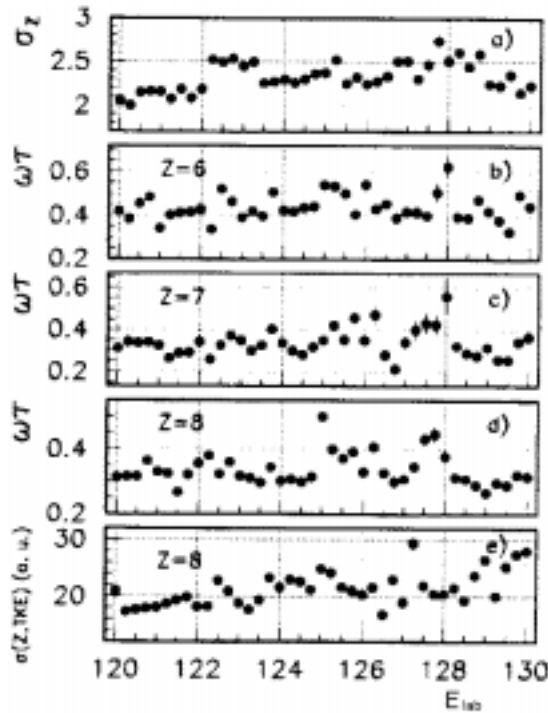
Figure 4. Charge distributions for  $\text{TKEL} = 30 \pm 2.5$  MeV at incident energy: (a) 121 MeV and (b) 123 MeV.

inelastic scattering when minima are close to zero [7].

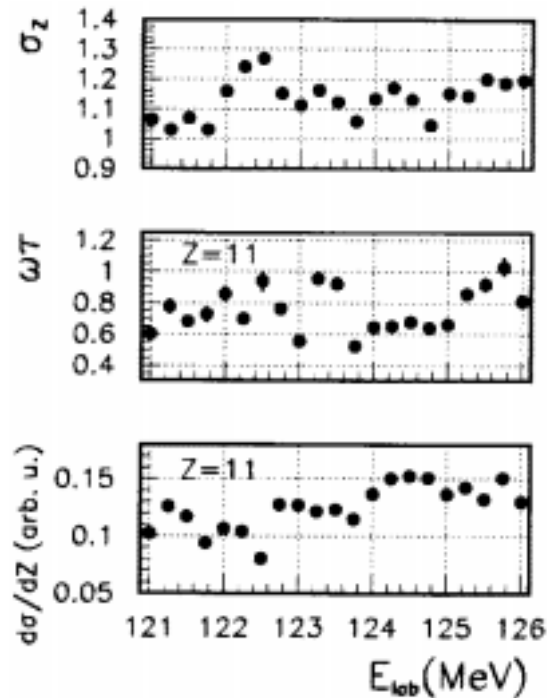
The energy correlation width  $\Gamma$  of the fluctuations was determined by energy autocorrelation function (EAF) method. The results are represented as a function of fragment charge number  $Z$  for all  $(\text{TKEL}, \vartheta_{\text{cm}})$  windows in figure 3. Within the errors, the  $\Gamma$  values do not show any clear dependence on  $\vartheta_{\text{cm}}$ ,  $Z$  or  $\text{TKEL}$ . An average  $\Gamma$  value of  $170 \pm 65$  keV was calculated. The corresponding DNS lifetime  $\tau = (3.9 \pm 1.1) \cdot 10^{-21}$  s is almost equal to its rotation period. Secondary structures were observed in the experimental EAF as predicted in ref. [8] for this case. Their period ( $\approx 1$  MeV) agrees with the predicted one considering deformed fragments.

In this work the dependence of second order observables, namely the second moment of the charge distribution and the product  $\omega \cdot \tau$  ( $\omega$  is the angular velocity of the DNS and  $\tau$  its mean lifetime) extracted from the angular distributions, on the incident energy was studied. The fluctuations observed in the cross section EFs should propagate in the second order observable excitation functions if their origin is due to the relatively simple structure of the DNS levels as proposed by POMLM. The above data for  $^{19}\text{F} + ^{27}\text{Al}$  system were used. The statistics allowed the analysis of the charge distributions and angular distributions for W2 and W4 windows on the incident energy from 120 to 130 MeV.

The charge distributions corresponding to W4 window for incident energy  $E_{\text{lab}} = 121$  and 123 MeV are given in figure 4(a) and (b). The variance of the charge distribution,  $\sigma_Z$ , was obtained by the fit of the charge distribution with a Gaussian. In the panel (a) of the figure 5 is represented the dependence of  $\sigma_Z$  values as a function of  $E_{\text{lab}}$ . Fluctuations with quite large amplitude can be seen. The product  $\omega \cdot \tau$  was extracted from the angular distributions described by the expression [9]:  $d\sigma/d\vartheta_{\text{cm}} \propto \exp(-\vartheta_{\text{cm}}/\omega \cdot \tau) + \exp(-(2\pi - \vartheta_{\text{cm}})/\omega \cdot \tau)$ . The continuous lines on figure 2 represent the result of the fit. The EFs of  $\omega \cdot \tau$  for  $Z = 6 - 8$  fragments with TKEL in W4 window can be followed in panels (b)–(d) of figure 5. The fluctuations with amplitude larger than statistical errors are present and some of them are nicely correlated with those from  $\sigma_Z$  excitation function. Also a correlation of the second order observable fluctuations with those from cross section EF for  $Z = 8$  fragment is represented in the last panel of figure 5 in order to follow this.



**Figure 5.** Excitation functions of (a) charge variance and  $\omega \cdot \tau$  for (b)  $Z = 6$ , (c)  $Z = 7$ , (d, e)  $Z = 8$  from  $^{19}\text{F} + ^{27}\text{Al}$  system for W4 window.



**Figure 6.** Excitation functions for fragments having TKEL from 20 to 32 MeV from  $^{27}\text{Al} + ^{27}\text{Al}$  collision; (a) charge variance, (b)  $\omega \cdot \tau$ , (c) cross section.

The above results are confirmed by a preliminary analysis of the EF data for  $^{27}\text{Al} + ^{27}\text{Al}$  system. Fluctuations correlated in the final channels corresponding to different charge numbers could be observed in the EFs obtained for  $Z = 10-12$  and 14 fragments having TKEL in the range from 20 to 32 MeV. The charge variance was obtained by the fit with a Gaussian of the peak centered at  $Z = 13$ . For the fragment with  $Z = 11$  the product  $\omega \cdot \tau$  was extracted from the angular distribution. The charge variance,  $\omega \cdot \tau$  and cross section excitation functions for  $Z = 11$  fragment are represented in figure 6. A correlation of the fluctuations from the excitation functions of these three observables could also be noticed.

One has to mention that the data for  $^{27}\text{Al} + ^{27}\text{Al}$  system are not corrected for particle evaporation processes. In the case of  $^{19}\text{F} + ^{27}\text{Al}$  system evaporation corrections have been evaluated by an iterative procedure similar to that from ref. [10] which takes into account evaporation of neutrons and protons.

For  $^{27}\text{Al} + ^{27}\text{Al}$  system an evaluation of the evaporation corrections was done using a Monte Carlo simulation. The excitation functions for  $^{27}\text{Al} + ^{27}\text{Al}$  system for primary fragments and after giving them the possibility to evaporate particle were simulated. No structures in the EFs due to particle evaporation were observed.

The observed correlation of the fluctuations from the cross section and  $\omega \cdot \tau$  EFs could be interpreted as an evidence of the excitation of simple states of rotational nature in the DNS as proposed by POMLM. In a diffusion approach of deep inelastic processes the charge distribution and DNS lifetime are related by the expression:  $\sigma_Z^2 = 2D_Z \cdot \tau$ , where  $D_Z$  represents charge diffusion coefficient. As it is known the diffusion models have been

elaborated for describing the dissipative processes in heavier systems [11]. The observed correlated fluctuations in  $\sigma_Z$  and  $\omega \cdot \tau$  EFs support a mechanism based on a stochastic exchange of nucleons. This speaks in favour of a common reaction mechanism of dissipative processes in light systems and in medium and heavy ones. The same conclusion is sustained by the fact that the correlation  $\ln(\sigma_Z^2)$  as a function of  $\text{TKEL}/l_{\text{gr}}$  for light systems could be comprised in the same systematics with medium and heavy systems [4].

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