Even-odd structural phenomena in the cooling down of excited nuclear systems

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Recently, a complex even-odd structure was observed in the production cross sections from the projectile fragmentation of 1 *A* GeV ^{238}U nuclei in a titanium target, measured at the FRS at GSI [1]. Although in the past the even-odd effect was already observed in the charge distributions of several nuclear reactions at high energies, it was with the reaction 1*A* GeV ^{238}U on Ti that for the first time the staggering phenomena could be systematically investigated with full nuclide identification over an extended area of the chart of the nuclides. In subsequent experiments, the formation cross sections of all the produced nuclides of four other systems, ^{56}Fe and ^{136}Xe on proton and on titanium at several energies were determined [2,3]. Part of the results is presented in Figure 1. The data are filtered according to the *N-Z* value. As it was found for the system ^{238}U+Ti, the data reveal a complex structure. All even-mass nuclei present a visible even-odd effect, which seems particularly strong for *N*=*Z* nuclei. Odd-mass nuclei show a "reversed" even-odd effect, with enhanced production of odd-*Z* nuclei. This enhancement is stronger for nuclei with larger values of *N-Z*. However, for nuclei with *N-Z*=1 the reversed even-odd effect vanished out at about *Z*=16, and again an enhanced production of even-*Z* nuclei can be observed.

All the above mentioned reactions can be quite violent and are expected to introduce a large range of excitation energies in the nucleus. Although the initial steps of the interaction can be rather different form one reaction to the other, all the reactions have in common that the excited nucleus will later cool down through the evaporation of particle. Therefore, we tested the hypothesis that the even-odd staggering is produced at the end of the evaporation cascade due to the influence of nuclear structure on the properties of excited levels and on the masses. Applying a statistical evaporation model, where pairing was introduced both in the masses and in the level densities in a consistent way, the yields were determined. In Figure 2, the calculation for the system ^{238}U+Ti is presented. All the features of the complex staggering behaviour are reproduced, with the remarkable exception of the *N*=*Z* chain, whose peculiarity could be connected to phenomena that go beyond pairing (as e.g. alpha clustering). The vanishing of the effect with increases mass of the fragment was also reproduced considering the competition between the particle-decay and gamma-emission channels.

In the past, the even-odd effect in the production yields in specific nuclear reactions at low energies, e.g. low-energy fission, was explained by means of the theory of nuclear superfluidity. However, the nucleus is expected to exit the superfluid phase and enter into the normal liquid phase at about 10 MeV of excitation energy. Above 10 MeV, any structural effect should be lost. So, we cannot assume that structural effects are preserved in the spectator nuclei. But the results of the statistical model show that the structural properties can be restored. We interpreted our results as the manifestation of the liquid-superfluid phase transition. The structure appears as a result of the condensation process of the heated nuclear matter while cooling down in the evaporation process. Our results could have consequences on the evaluation of the nuclear temperature using isotopes ratios.

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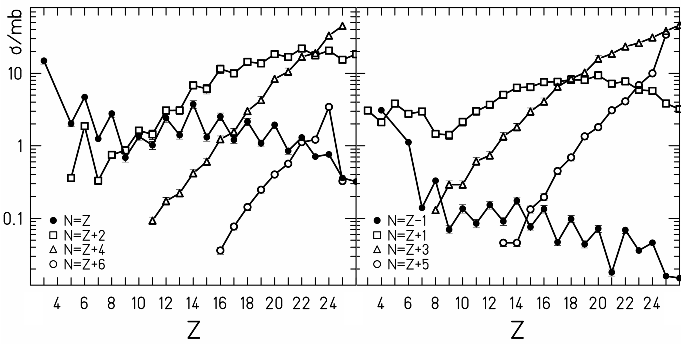

Figure 1: Experimental production cross sections for the residues of 1 *A* GeV ^{56}Fe on ^{1}H (data are from ref. [2]).

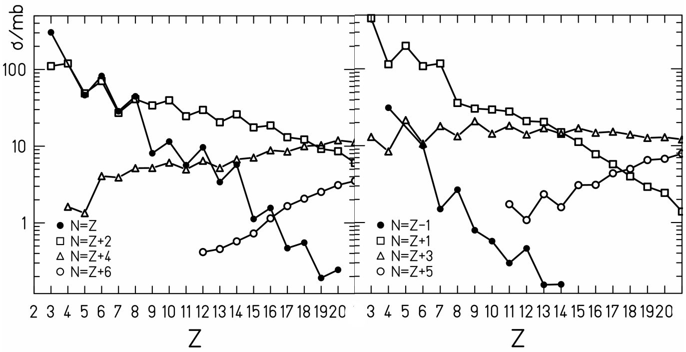

Figure 2: Experimental production cross sections for the residues of 1 *A* GeV ^{136}Xe on Ti (data are from ref. [3]).

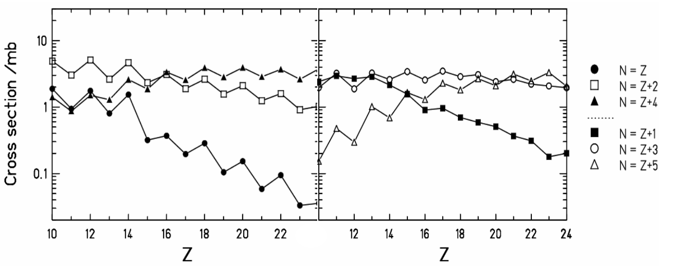

Figure 3: Production cross sections for the reaction 1 *A* GeV ^{238}U on Ti calculated with a statistical model. Details on the calculation are presented in ref. [1].

References

[1] M. V. Ricciardi et al., Nucl. Phys. A 733 (2004) 299-318

[2] C.Villagrasa-Canton, PhD Thesis, Université de Paris XI, France (December 2003)

[3] P. Napolitani, PhD Thesis, Université de Paris XI, France (September 2004)