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Clustering states in the ^{62}Ni(^{58}Ni,^{58}Ni)^{62}Ni reaction

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Abstract. Excitation function and angular distributions of the ^{62}Ni(^{58}Ni,^{58}Ni)^{62}Ni elastic scattering have been measured at incident ^{58}Ni energies from 220.0 to 230.0 MeV in steps of 0.5 MeV. Evidence of two structures was found in the excitation function; a statistical analysis suggests a possible nuclear cluster quasi-molecular nature for these structures.

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Within the still open questions in the field of the resonant behaviour of heavy ion systems, two problems are of particular interest. The first one is connected with the fact that resonances can be interpreted both as structural effects in the composite system (group-theoretical and anharmonic rotator-vibrator models [1, 2]) and as phenomena related to the dynamics of the interacting nuclei (Orbiting Cluster Model [3, 4]). The second one concerns the possible presence of resonances in composite systems with $A \cong 100$, that could demonstrate that this behaviour is a general feature of heavy-ion interaction [5]. The first question can be solved, for example, by comparing resonant states observed both in two and in three-body exit channels, whereas an appropriate beam-target combination can contribute to the understanding of the second problem.

Preliminary results concerning the ^{62}Ni(^{58}Ni, ^{58}Ni)^{62}Ni reaction, to be compared with the data of the $^{58}\mathrm{Ni}+{}^{66}\mathrm{Zn} \to \alpha + {}^{58}\mathrm{Ni} + {}^{62}\mathrm{Ni}$ process, are presented in this contribution. The measurements were performed at the XTU Tandem accelerator of the LNL (Laboratori Nazionali di Legnaro, Padua, Italy). Excitation function and angular distributions for the ^{62}Ni(^{58}Ni, ^{58}Ni)^{62}Ni reaction were measured from $E_{\mathrm{lab}} = 220$ MeV to $E_{\mathrm{lab}} = 230$ MeV, in steps of 0.5 MeV. The excitation function relative to selected events in the center-of-mass angular range from 70° to 94° is reported in Fig. 1; the overall error was evaluated to be smaller than 7%. The mass identification was obtained, with a resolution of $\pm 1u$, by means of a kinematic coincidence using two position sensitive Si detectors. In these measurements, the good angular resolution (1.5×10^{-3} rad) allowed us to discriminate between elastic and inelastic events by the difference of the relative angle, because the energy resolution (1.5%) was not sufficient to do it.

Two structures were observed in the elastic scattering excitation function at $E_{\mathrm{cm}} = 115.7$ and $E_{\mathrm{cm}} = 116.5$ MeV (Fig. 1). For what concerns the angular distributions, due to the large Coulomb contribution to the elastic cross section, the characteristic narrow oscillations usually related to the presence of a single-wave state were not observed (see, for example, Fig. 2). So, statistical methods using the autocorrelation and correlation functions were used to overcome this difficulty [6, 7].

We started by examining the autocorrelation function calculated for the differential cross-section $\sigma(\theta)$

$$C(\theta, 0, \Delta) = \overline{\left(\frac{\sigma(\theta)}{\langle \sigma(\theta) \rangle_{\Delta}} - 1\right)^2}$$

as a function of the median angular interval Δ to obtain the most appropriate value for averaging out the statistical fluctuations. This value was then used to calculate the correlation function

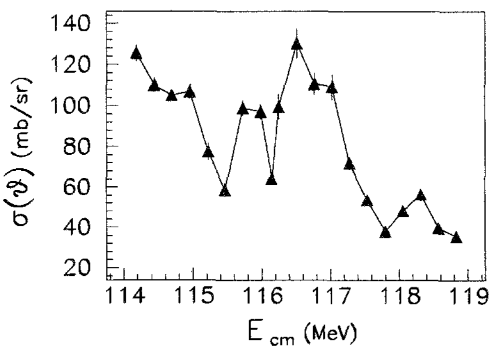

Fig. 1. Excitation function of the ^{62}Ni(^{58}Ni, ^{58}Ni)^{62}Ni reaction

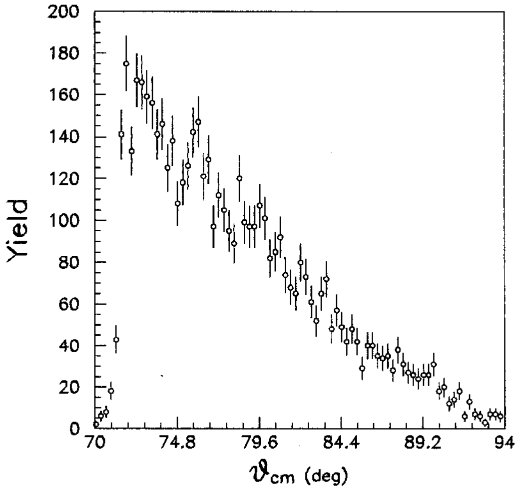

Fig. 2. Angular distribution of $^{62}Ni(^{58}Ni, {}^{58}Ni)^{62}Ni$, measured at $E_{cm} = 115.7$ MeV

$$C(\theta, \Delta\theta, \Delta) = \overline{\left(\frac{\sigma(\theta)}{\langle\sigma(\theta)\rangle_\Delta} - 1\right)\left(\frac{\sigma(\theta+\Delta\theta)}{\langle\sigma(\theta+\Delta\theta)\rangle_\Delta} - 1\right)}$$

varying the width of the angular interval $\Delta\theta$. It is in fact well known that, if the function $\sigma(\theta)$ has a period $\Delta\theta_{per}$, the correlation function too, plotted as a function of $\Delta\theta$, must have a period $\Delta\theta_{per}$.

An oscillatory behaviour of the correlation function is present (Fig. 3) for energies corresponding to the structures observed in the elastic excitation function ($E_{cm} = 115.7$ and $E_{cm} = 116.5$ MeV); at energies far from the region of the structures, such as, for example, $E_{cm} = 118.6$ MeV, this behaviour is not observed. In order to reveal the periodicity of these oscillations and to extract its numerical value, a function χ^2 was calculated within the limits of the values that the function $C(\theta, \Delta\theta, \Delta)$ assumes at angles $\theta = \theta_n$ and $\theta = \theta_n + \theta_0$. This function χ^2, depending on the step θ_0, is given by

$$\chi^2(\theta_0) = \frac{1}{(N-1)} \sum_{n=1}^{N} \left(\frac{C(\theta_n, \Delta\theta, \Delta) - C((\theta_n + \theta_0), \Delta\theta, \Delta)}{\sigma}\right)^2$$

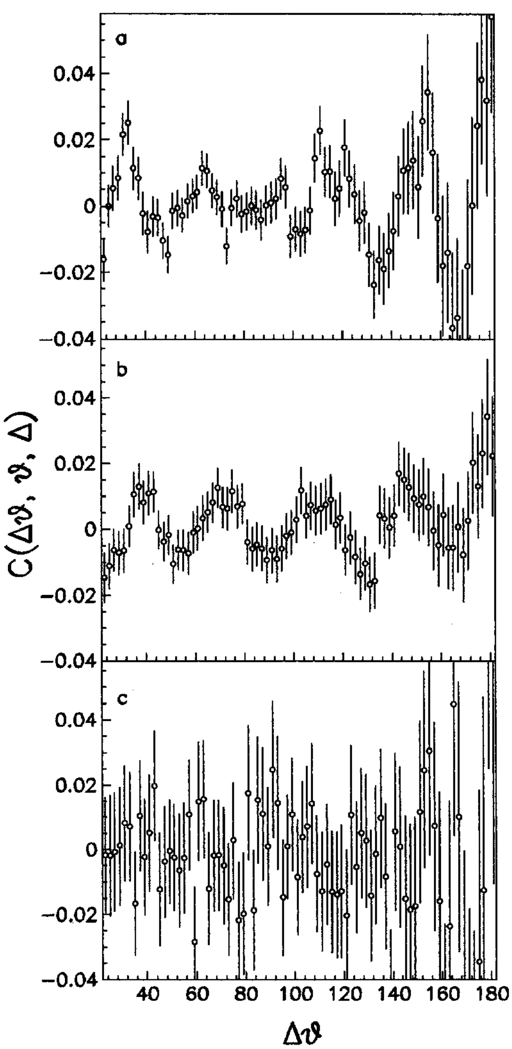

Fig. 3. Correlation functions $C(\theta, \Delta\theta, \Delta)$ vs. the angular interval $\Delta\theta$ for $E_{cm} =$ **a** 115.7, **b** 116.2, and **c** 118.6 MeV

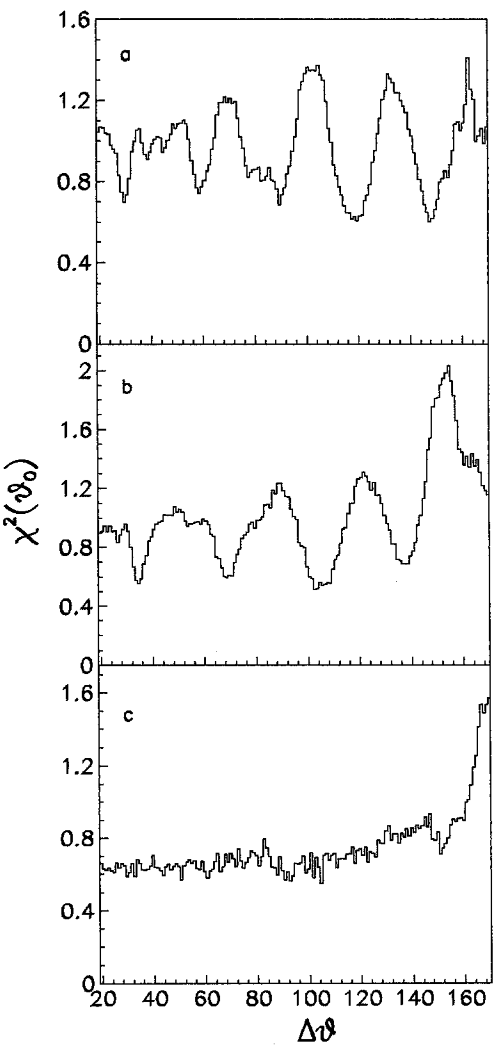

Fig. 4. The values of χ^2 plotted as a function of θ_0 for $E_{cm} =$ **a** 115.7, **b** 116.5, and **c** 118.6 MeV

Table 1. Analysis of the structures observed in the $^{58}Ni + ^{62}Ni$ reaction

E_{lab}(MeV)	E_{cm}(MeV)	$\Delta\theta_{per}$(deg)	$J(\hbar)_{exp}$	$J(\hbar)_{calc}$
224.0	115.7	2.95	61 ± 1	57
225.5	116.5	3.42	53 ± 1	59

with

$$\sigma = \sqrt{\sigma^2(\theta_n) + \sigma^2(\theta_n + \theta_0)}.$$

The values of χ^2 plotted as a function of θ_0 at the same energies as the correlation function reported in Fig. 3 are presented in Fig. 4. The value of χ^2 reaches its minimum when the value of θ_0 matches the value of $\Delta\theta_{per}$, and is minimum again for each value of θ_0 multiple of $\Delta\theta_{per}$. The numerical value of the periodicity in the χ^2 function, when such a periodicity was observed, was calculated as the mean value of the ratios of the angular position at each minimum to the corresponding number of observed periods.

The systematic application of this analysis method to all the data of the present work gives a clear indication of periodicity for the angular distributions measured at energies corresponding to the two peaks observed in the excitation function. As the periodicity of the correlation function is the same as that of the angular distribution $\sigma(\theta)$, we could, then, temptatively assign value of $J = \pi/\Delta\theta_{per}$ to the predominant single waves associated to the angular distributions corresponding to the peaks in the excitation function.

The deduced J-values, together with the corresponding values calculated be means of the Orbiting Cluster Model [3], are reported in Table 1: within the crudity of the preliminary analysis and of the adopted models, the general agreement can be considered satisfactory, suggesting a possible quasi-molecular nature of the observed structures.

References

1. Iachello, F.: Phys. Rev. C**23**, 2778 (1981)
2. Cindro, N., Greiner, W.: J. Phys. G**9**, L175 (1983)
3. Cindro, N., Počsanić, D.: J. Phys. G**6**, 359 (1980)
4. Počanić, D., Cindro, N.: Nucl. Phys. A**433**, 531 (1985)
5. Abbondanno, U., Cindro, N.: Int. J. Mod. Phys. E**2**, 1 (1993)
6. Pappalardo, G.: Phys. Lett. **13**, 320 (1964)
7. Gadioli, E., Iori, I., Mangialaio, M., Pappalardo, G.: Nuovo Cimento **38**, 1105 (1965)