Tandem-Alpi proposal: ACLUST-GARFIELD

PRE-EQUILIBIRUM α-PARTICLE EMISSION AS A PROBE TO STUDY α-CLUSTERING IN NUCLEI

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ABSTRACT

We propose to investigate the alpha-particle emission from hot ^{81}Rb nucleus, formed in the reactions with alpha-cluster ^{16}O projectile on ^{65}Cu target and with non alpha-cluster ^{19}F projectile on ^{62}Ni target, using the GARFIELD and RCo detector arrays. The main goal of the proposal is to measure the pre-equilibrium alpha-particle emission for the two systems indicated above in order to extract information about the influence of alpha-clustering in the ^{16}O projectile on productions alpha particles during the non-equilibrium stage of the nuclear reactions. Experimental study of the effect is a perspective way for investigation of alpha clusterization in exotic neutron rich nucleus. We propose to study two cases. In the first one the projectile energy per nucleon will be the same: 16 MeV/u for the ^{16}O and ^{19}F beams. In the second case the composite system formed in the same two reactions will have the same excitation energy of 209 MeV. The total request of beam time is 10 days (not including tuning of ALPI). 1 pnA pulsed beams with a resolution of 1 ns and a repetition time of 400 ns (or 800ns depending on the accelerator performances) is required. Targets, ^{65}Cu and ^{62}Ni, will be 0.5 mg/cm^2 thick each.

1. Motivation

The study of nuclear states built on clusters bound by valence neutrons in their molecular configurations is a field of large interest. In particular clustering will become important at the drip–line, where weakly bound systems will prevail [1]. In the case of light nuclei (for example $^{17,19}B$) clustering might actually be the preferred structural mode [2]. Presently these structures are still mainly described by theory and must be experimentally verified at the new generation of radioactive beam facilities (for example see Fig. 1).

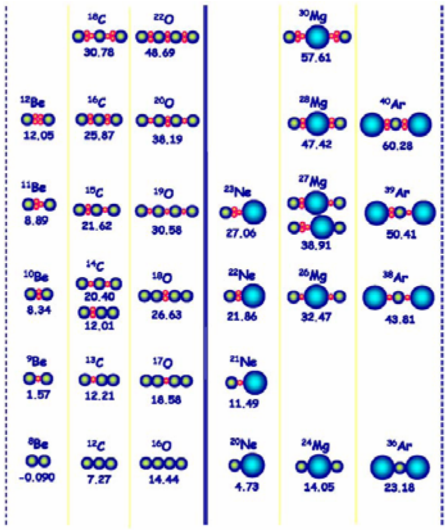

Fig 1. *Extended Ikeda threshold diagram [1]. Some molecular structures with clusters and covalent valence neutrons are shown. Only alpha particles and ^{16}O-nuclei are shown. The schematic shapes are given together with the threshold energies (in MeV) for the decomposition into the constituents.*

In this regard, it is particulary interesting to confirm the existence of alpha clusterization in nuclei through the new generation of experiments. The search of the alpha clustering effects in the non-traditional observables is very important for bringing new information on the investigation of the nuclear clustering process. Our recent work, based on the results from the GARFIELD + HECTOR experiment at LNL, Legnaro [3-6] and related to the α-particles emission in the 250 and 130 MeV ^{16}O +^{116}Sn reactions, brought to the conclusion that a pronounced production of $\alpha -$particle have been observed which can be ascribed to alpha clustering in the projectile nucleus. These are linked to the production of secondary alpha particles during non-equilibrium stage of fusion nuclear reaction (see Fig. 2-3).

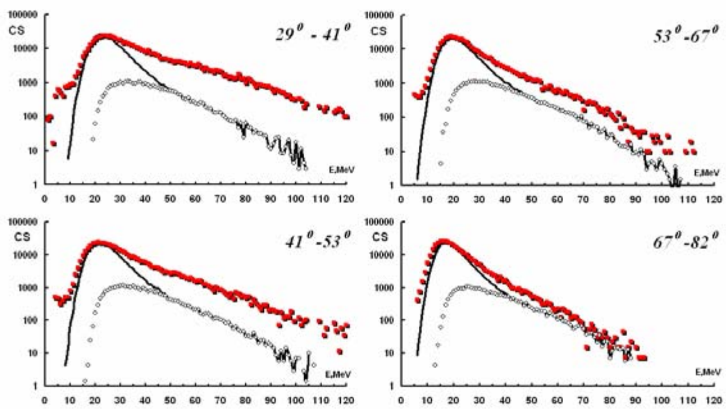

Fig 2. *Double differential spectra (Cross-Section (CS) in arbitrary units) for α particles for the 250 Mev ^{16}O + ^{116}Sn reaction. Experimental data are shown in red. Open circles show the pre-equilibrium part of the spectra. The continuous line is the sum of evaporative plus pre-equilibrium contribution from the calculation [6-8].*

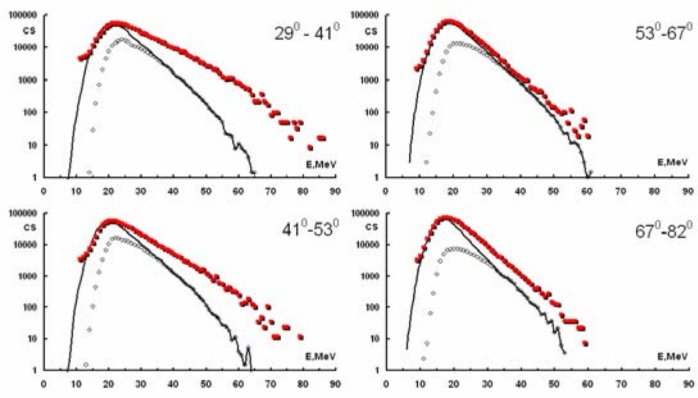

Fig 3. *Double differential spectra (CS in arbitrary units) for α-particles for the 130 MeV ^{16}O + ^{116}Sn reaction. Symbols are the same as in Fig. 2.*

The significant increase observed in the yield of the secondary alpha particles at small angles in the pre-equilibrium part of spectra may be, in fact, connected with the presence of α–cluster in the ^{16}O projectile nucleus. A confirmation of this effect can be obtained comparing the secondary alpha particles emitted in fusion reactions where a clustering projectile (for example ^{16}O) and projectile without alpha clusterization (^{19}F) are used. These data have been shown to provide an important testing ground for the theoretical models [9-11].

2. The Physics Case

We propose a comparative study of two nuclear reactions ^{16}O + ^{65}Cu and ^{19}F + ^{62}Ni. The ^{16}O beam energy is chosen to be E_O=256 MeV (16 MeV/u) while for ^{19}F we propose the energies of 304 (16 MeV/u) and 263 MeV (13.9 MeV/u). In these reactions the same compound system ^{81}Rb is produced. In the first case projectile energy per nucleon will be the same (16 MeV/u) and, from the systematic work of J. Cabrera et al. [12] and our previous experimental campaign with the GARFIELD apparatus, we can conclude that the pre-equilibrium emission is mainly dependent on the projectile energy per nucleon. In this framework at 16 MeV/u we expect the pre-equilibrium α-particle multiplicity to be around 0.35. In the presented cases the situations for standard non-equilibrium process are predicted to be almost the same for both reactions (see Fig. 4a), but some little differences may appear in the evaporative part of the spectra due to different initial excitation energies of the Compound Nucleus. For the case E_F=263 MeV (13.9 MeV/u) the compound nucleus is produced with the same excitation energy of the complete fusion in the 16 MeV/u ^{16}O induced reaction. However, small differences are, in this case, expected in the pre-equilibrium part of the spectra (see Fig. 4b). The green squares denote the predictions of the Oxygen clustering effects in our model which results in the shown over-production of alpha particles in the different angular range. These estimations were performed fixing the parameters chosen on the bases of the experimental results for the reaction 250 MeV ^{16}O +^{116}Sn mentioned above. The calculations without projectile clustering effects were performed in the frame of the modified Griffin model of non-equilibrium processes and the simulation of the compound system decay was carried out using a Monte – Carlo method [6-8].

If the experimental results for the two reactions will be similar like the calculated ones (^{16}O + ^{65}Cu – dark blue and ^{19}F + ^{62}Ni - brown lines in Fig. 4), it will indicate that the influence of ^{16}O α–clustering on the α–particles production is absent. On the contrary the observation of a difference (green squares for O induced reaction and brown lines for F) in the resulting spectra will be a direct proof of the influence of ^{16}O α–clustering and in particular an enhanced α-particles emission during the pre-equilibrium stage of the reaction. In this last case, from the amount of the difference between the two reactions in the whole detected angular region, together with a more complex calculation which take into account the percentage of clusterization in the projectiles, we will be able to have an estimate of the α-clustering probability in ^{16}O. Examples of the effects on the emitted spectra of different clustering probabilities will be shown in the presentation.

The results of this experimental approach will be a first outlook, which could be eventually used to investigate alpha clusterization in exotic nuclei.

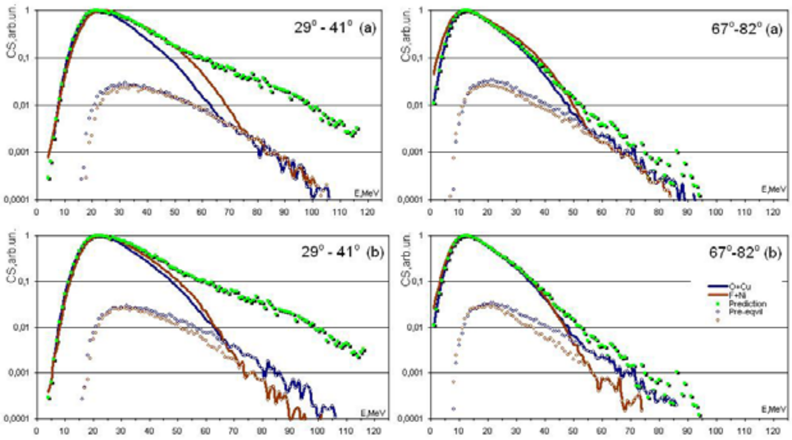

Fig 4. *Double differential spectra (CS in arbitrary units) for α-particles for the E_O=256 MeV and E_F=304 MeV (case* **a***) and E_F=263 MeV (case* **b***). Predictions of clustering effects are shown by the green squares, while blue and brown curves are for non-clustering systems. The brown line is for the reaction ^{19}F + ^{62}Ni. The dark blue line is for the reaction ^{16}O + ^{65}Cu. The open circles show the spectra of pre-equilibrium emitted particles (larger energy tails). The sensitivity of clustering effects in different angular range is shown.*

3. On the Experimental Conditions

a) Choice of the reaction

The main purpose of the proposal is to get more precise experimental information on the pre-equilibrium light charged particles emission employing the GARFIELD 4π apparatus: in particular we aim to underline possible α-clustering effects by measuring the angular distributions and α-particles emission spectra for the following three reactions, the characteristics of which are listed in Table 1.

Beam energy, MeV	Beam energy per nucleon, MeV/u	Projectile	Target	Compound system excitation energy, MeV	Compound nucleus recoil velocity, cm/ns
256	**16.0**	^{16}O	^{65}Cu	***209***	1.10
304	**16.0**	^{19}F	^{62}Ni	240	1.30
263	13.9	^{19}F	^{62}Ni	***209***	1.21

Table 1. Main characteristics of the proposed reactions. The key values are highlighted for the two different reactions.

Apart from the main purpose of the proposal as a result of these measurements we will get information on the evaporative emission of light charged particles (p, d, t, ^{3}He, ^{4}He) from ^{81}Rb compound system, which will be a possible way to study the nuclear level density in the framework of the Hauser-Feshbach model calculations [13].

b) GARFIELD+RCo Set-up

The proposed setup consists of the GARFIELD [14-15] and the RCo [16] multi-detection arrays. The GARFIELD array was specially designed to study nuclear processes in the low and intermediate energy range (5-20 MeV/u). The operation of the GARFIELD apparatus is based on the ΔE-E technique, in which the ΔE signal is given by the drift chamber, where gaseous micro-strip detectors collect and amplify the primary electrons produced along the ionization track of the detected particle. The CsI(Tl) scintillation detectors are used to get information on the residual energy E. The two GARFIELD chambers are employed to measure light charged particles and fragments from $\theta=29^o$ to $\theta=82^o$ (first chamber), from $\theta=98^o$ to $\theta=151^o$ (second chamber) and 4π of φ.

The RCo is an array of three-stage telescopes (Ionization Chamber – Silicon Strip Detector – CsI(Tl) Scintillator) realized in a truncated cone shape and covers the polar angles from $\theta=3.5^o$ to $\theta=17.5^o$, corresponding to a solid angle of about 0.27 sr. The Evaporation Residues (ER) and light charged particles in the forward direction will be detected by the RCo array. Due to the elastic scattering large count-rate the smaller angles has to be avoided through an opportune collimation: in this way the ER will be collected in the range between $\theta = 9°$ and 17.5°, just over the grazing angle. This will cover in any case a large part of the ER spectra.

This setup allows to measure the alpha particles in coincidence with evaporation residues in a wide angular range. It should be stressed the importance of an accurate measurement of the alpha-particle spectra high-energy tails (high statistics) for the quantitative description of the possible alpha-clustering effects.

c) Beam time request

The beam-time required is based both on fusion cross-section estimates and on our previous experiments [3-6] with the GARFIELD apparatus.

A 1 pnA pulsed beam with a resolution of 1 ns and a repetition time of 400 ns (or 800ns depending on the accelerator performances) is required. Targets, ^{65}Cu and ^{62}Ni, will be 0.5 mg/cm^2 thick.

The request of the beam time was estimated deducing the information from our previous experiment to obtain the statistics necessary to perform the comparison with the models. This is calculated in order to obtain, for example, in the α-particle emission spectra obtained in coincidence with the ER at least 200 counts at 100 MeV in the laboratory angular range θ=40°-50°. This is underlined by the importance of having the experimental α-particle spectra shape in the high-energy tail, with the sufficient sensitivity to deduce the most precise information on the alpha-clustering effect.

The **total request of beam time is 10 days** (not including tuning of ALPI) divided as follows:
3 days for 256 MeV ^{16}O beam on ^{65}Cu target (required beam: 1 pnA, 2 stripper foils);
3 days for 304 MeV ^{19}F beam on ^{62}Ni target (required beam: 1 pnA, 2 stripper foils);
3 days for 263 MeV ^{19}F beam on ^{62}Ni target (required beam: 1 pnA, 2 stripper foils);
1 day for electronics tuning and calibration of GARFIELD detectors.

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