BB

SW9508

CEA/DAPNIA/SPhN 94 36

07/1994

SUB-COULOMB FUSION WITH HALO NUCLEI

V. Fekou-Youmbi, J.L. Sida, N. Alamanos,
F. Auger, D. Bazin, C. Borcea, C. Cabot,
A. Cunsolo, A. Foti, A. Gillibert, A. Lépine,
M. Lewitowicz, R. Liguori-Neto, W. Mittig,
E.C. Pollacco, P. Roussel-Chomaz, C. Volant,
Y. Yong Feng

DAPNIA

Le DAPNIA (Département d'Astrophysique, de physique des Particules, de physique Nucléaire et de l'Instrumentation Associée) regroupe les activités du Service d'Astrophysique (SAp), du Département de Physique des Particules Élémentaires (DPhPE) et du Département de Physique Nucléaire (DPhN).

Adresse : DAPNIA, Bâtiment 141
CEA Saclay
F - 91191 Gif-sur-Yvette Cedex

Exposé invité à 5th International conference on :
Nucleus-nucleus collisions
Taormina, Sicile, Italie
du 30 mai au 04 juin 1994

Sub-Coulomb fusion with halo nuclei

V. Fekou-Youmbi^a, J.L. Sida^a, N. Alamanos^a, F. Auger^a, D. Bazin^b,
C. Borcea^c, C. Cabot^d, A. Cunsolo^e, A. Foti^e, A. Gillibert^a, A.
Lépine^{b,f}, M. Lewitowicz^b, R. Liguori-Neto^f, W. Mittig^b, E. Pollacco^a,
P. Roussel-Chomaz^b, C. Volant^a, Y. Yong Feng^g

- a. CEA/DSM/DAPNIA/SPhN, CE Saclay, 91191 Gif sur Yvette, France
- b. GANIL, B.P 5027, F-14021 Caen, France
- c. Institute for Physics and Nuclear Engineering, Bucharest —Magurke, P.O. Box MG6, Romania
- d. IPN Orsay, 91406 Orsay Cedex, France
- e. Dipartimento di Fisica and INFN-Sez. CT, 95129 Catania, Italy
- f. IFU Sao Paulo, CP 20516, Sao Paulo, Brazil
- g. IMP, Academia Sinica, Lanzhou, China

The nuclear structure of halo nuclei may have strong influence on the fusion cross section at sub-barrier energies. The actual theoretical debate is briefly reviewed and sub-barrier fusion calculations for the system $^{11}\text{Be}+^{238}\text{U}$ are presented. An experimental program on sub-barrier fusion for the systems $^{7,9,10,11}\text{Be}+^{238}\text{U}$ is underway at GANIL. First results with ^9Be and ^{11}Be beams were obtained using the F.U.S.ION detector. Relative fission cross sections are presented.

1. MOTIVATIONS

It is well known that the sub-barrier fusion cross section of stable nuclei is larger, by several orders of magnitude, than what one would expect from one-dimensional barrier penetration calculations. This enhancement has been described in terms of couplings to inelastic and transfer channels. The couplings result in a reduction of the fusion barrier height [1].

Recently, the sub-barrier fusion cross section has been calculated in the case where one of the partners has a neutron halo. These studies are expected to contribute to further understanding of the structure of exotic nuclei and in particular of very neutron-rich nuclei. The near and sub-barrier fusion cross section may be greatly enhanced when one of the partners has weakly bound neutrons because its density distribution extends to larger distances compared to the extension of the density distribution of stable nuclei with the same atomic number. As a result, the nuclear potential acts at larger distances and therefore the potential barrier for halo nuclei is lower than for their stable counterparts. Some experimental results [2] indicate that halo nuclei may also have strong, low energy E1 states, the so-called soft dipole modes (see ref.[3] and references therein for a theoretical discussion on soft dipole

modes). The excitation of these modes may also couple to the fusion channel leading to a further enhancement of the sub-barrier fusion cross section.

The first calculations on sub-barrier fusion with light and medium mass neutron-rich projectiles were performed by N. Takigawa and H. Sagawa [4] and by C. Dasso and R. Donangelo [5]. They have found indeed that the fusion cross section should be drastically enhanced at sub-coulomb energies because of the lowering of the fusion barrier and the coupling to the low excitation energy modes associated with the neutron halo. These findings have been challenged by M. Hussein *et al.* [6], who argue that the coupling to the break-up channel, which has been ignored in the previous calculations, would seriously inhibit the total fusion cross section. This possible "hindrance" of the fusion cross section has generated an interesting theoretical debate. N. Takigawa *et al.* [7], in defining the fusion cross section as the sum of the incoming particle plus that of the break up channel, agreed that the effect of the break-up may reduce the large enhancement of the fusion cross section predicted in their first calculations [4]. They have found however, that the halo still leads to a larger fusion cross section than for the other stable isotopes, at variance to ref. [6]. C. Dasso and A. Vitturi, in a recent theoretical work [8], have also investigated the way in which the break-up of neutron-rich nuclei should affect the fusion probabilities at energies close to the Coulomb barrier. By performing coupled channel calculations that incorporate the break-up process, they come to the conclusion that the inclusion of the break-up channel leads always to an enhancement of the fusion cross section, result inconsistent with both refs. [6] and [7].

Figure 1. The optical potential as a function of the radius is generated with the ^{11}B density distribution (dashed line) and with the ^{11}Be density distribution (solid line)

Figure 2. Excitation function for the fusion cross section for $^{11}\text{Be} + ^{238}\text{U}$

As an example and to better evaluate the expected effects, we have calculated the fusion cross section excitation function, for the system $^{11}\text{Be}+^{238}\text{U}$. The interaction potentials were generated using the M3Y interaction, following the folding procedure of ref. [9]. In a first calculation we used for the ^{11}Be density distribution the same nuclear matter distribution, as that of the more standard ^{11}B nucleus. In the second case we used the density distribution of ^{11}Be deduced from fragmentation measurements [10]. The results are presented in figure 1. Assuming that the difference in the density distribution, $\rho_{^{11}\text{Be}}(r)-\rho_{^{11}\text{B}}(r)$, reflects essentially the effect of the halo, one can observe that the halo lowers the interaction potential by 2 MeV.

The solid and dashed lines in figure 2 correspond to single barrier penetration calculations of the fusion cross sections with the two optical potentials discussed above. These excitation functions were calculated with the ECIS code [11]. As a result of the lowering of the coulomb barrier, due to the neutron halo, a significant enhancement of the fusion cross section is obtained. The dashed-dotted line corresponds to a calculation in which the excitation of a low energy ($E=1.5$ MeV) E1 mode exhausting 10% of the E1 energy weighted sum rule, was also assumed. The coupling of this mode results in a further enhancement of the sub-barrier fusion cross section.

2. THE EXPERIMENT

A 75 A.MeV ^{13}C beam was delivered by the GANIL accelerator. The velocity of the secondary beams produced by projectile fragmentation is close to that of the primary beam. Hence, the major experimental difficulty is the reduction of the secondary beam energy down to the Coulomb barrier with the minimum loss of intensity. Two methods may be envisaged; the use of a thick target or of a thick achromatic degrader. In a dedicated experiment [12] it was shown that the thick target method is more practical and efficient than the achromatic degrader method. Secondary ^7Be , ^9Be , ^{10}Be and ^{11}Be beams were produced by fragmentation of the ^{13}C primary beam on a target, located at the usual object position of the doubly achromatic spectrometer LISE. In order to improve the beam selection, a thin aluminium achromatic degrader was placed at the intermediate focal plane between the two dipoles of LISE. The isotopic purity of the secondary beams was further improved with the Wien velocity filter [13] reaching values higher than 95 %. In the case of the ^{11}Be beam at an incident energy of 41.8 MeV, we obtained 1600 p/sec. The main contaminants at this energy were ^{13}B (2.3%) and ^9Li (0.2%).

The width in energy of the secondary beams was of the order of 10% due to the momentum acceptance of the LISE spectrometer. In forthcoming experiments, that will use the Superconducting Intense Source for Secondary Ions, SISSI [14], the energy width of the secondary ion beams is expected to be reduced to 2%.

The secondary ion beams impinged on a 2.26mg/cm^2 U_3O_8 target placed in the center of the F.U.S.ION detector [15]. For such a fissile target, most of the reaction channels lead to fission, the fusion-fission probability being close to one. In the case of quasi-elastic fission reactions, the fission products are accompanied by a fragment of the projectile but, in fusion-fission reactions, this is not the case. The low intensity of the secondary beams and the necessity to separate the quasi-elastic fission from the fusion-fission events led us to build a detector, the F.U.S.ION detector [16], having a very large solid angle. The detector is made

up of two cubes of parallel plate avalanche counters (PPAC) placed in front and at the back of the target [17]. The active area is $(29 \times 29) \text{ cm}^2$. This gives a geometrical coverage better than 70% of 4π . The PPACs provide intrinsic timing with a resolution of less than 1 ns and the spacial positions with a precision of 5 mm. The charge resolution is of the order of 20%. The PPACs were surrounded by twenty plastic scintillator detectors which were fired only by light particles since the fission fragments were stopped inside the PPACs.

3. EXPERIMENTAL RESULTS AND DISCUSSION

Figure 3. The relative angle of emission of the two fragments Θ_{ff} (degrees), for the system ${}^9\text{Be}+\text{U}$ at $E_{\text{inc}}=67.5$ MeV, as a function of their relative time of flight (arbitrary units).

Some results of a first experiment carried out in 1993 are discussed here in. The relative angle between the two fragments, Θ_{ff} , as a function of their relative time of flight, is shown in figure 3, for the system ${}^9\text{Be}+\text{U}$ at $E_{\text{inc}}=67.5$ MeV, ($E_{\text{cm}} / V_b=1.51$). The spectrum on the left corresponds to raw events with two main components for Θ_{ff} close to 180° . These two components correspond to fission fragments (box) and background correlated to the beam hitting the forward/backward PPACs. The relative time of flight gives a good separation.

The spectrum on the right was obtained by not including the PPACs which are traversed by the beam particles, in order to make a clear separation between fission fragments and the beam often at very low counting rate, and by imposing that the two events come from the target position. The box indicates the events which are attributed to fission. Including the condition on the charge, it is clear that the fission events are well identified by these different conditions and this is also true at the lowest bombarding energy.

In the present analysis, information given by the scintillator detectors, which may help to disentangle quasi-elastic fission and fusion-fission events have not been taken into account [17].

Figure 4. Fission cross sections for the systems ${}^9\text{Be}+\text{U}$ (triangles) and ${}^{11}\text{Be}+\text{U}$ (asterisks) as a function of E_{cm}/V_b .

Fusion-fission cross sections for ${}^9\text{Be}$ (asterisks) and ${}^{11}\text{Be}$ (triangles) on U as a function of E_{cm}/V_b are presented on figure 4 on arbitrary units. The error bars indicate the statistical and energy uncertainties. Obviously this first measurements suffer from a lack of statistics and it is impossible to draw any definitive conclusion. It can be observed that on average the ${}^{11}\text{Be}+\text{U}$ cross section is higher than that of ${}^9\text{Be}+\text{U}$. However the behavior of the data points near $E_{cm}/V_b=1.1-1.2$ is puzzling. The analysis is continuing and we are still evaluating the systematic uncertainties.

In conclusion, a first experiment to measure near and sub-barrier fusion cross sections for the systems ${}^9\text{Be}$ and ${}^{11}\text{Be}$ on an U target was performed at GANIL. We have demonstrated the feasibility of measuring sub-barrier fusion cross sections induced by very weak beams of unstable nuclei. However the fission cross sections extracted in this first measurement suffer from the low statistics and do not allow clear conclusions. The experimental situation should be considerably improved in a forthcoming experiment scheduled for the fall of 1994.

We would like to thank Jean Barette for his careful reading of the script.

REFERENCES

1. M. Beckerman, Rep. Prog. Phys. **51** (1988) 1047.
2. D. Sackett *et al.*, Phys. Rev. **C48** (1993) 118.
3. H. Sagawa *et al.*, Nuc. Phys. **A543** (1992) 575.
4. N. Takigawa and H. Sagawa, Phys. Lett. **B265** (1991) 23
N. Takigawa, H. Sagawa and T. Shinozuka, Nuc. Phys. **A538** (1992) 221c-228c.
5. C. H. Dasso and R. Donangelo, Phys. Lett. **B 276** (1992) 1.
6. M. S. Hussein, M.P. Pato, L.F. Canto and R. Donangelo, Phys. Rev. **C46** (1992) 377.
7. N. Takigawa, M. Kuratani and H. Sagawa, Phys. Rev. **C47** (1993) 2470.
8. C.H. Dasso and A. Vitturi, will be published in Phys. Rev. C rapid communication.
9. G.R. Satchler and W.G. Love, Phys. Rep. **55** (1979) 183.
10. N. Alamanos, F. Auger and R. Liguori-Neto, in *International Workshop on the Physics and Techniques of secondary nuclear beams* (Dourdan, 1992) 29.
11. J. Raynal, Phys. Rev. **C23** (1981) 2571.
12. Yang Yong Feng *et al.*, NIM **B 82** (1993) 175-179.
13. A.C. Mueller and R. Anne, NIM **B 56/57** (1991) 559-563.

14. M.D. Cortina-Gil *et al.*, Contribution to *Nucleus-Nucleus Collisions* (Taormina, 1994).
15. J.L. Sida *et al.*, Proceedings of the *XXX International Winter Meeting on Nuclear Physics* (Bormio, 1992) 289.
16. J.L. Sida *et al.*, will be submitted to *NIM* .
17. V. Fekou-Youmbi *et al.*, contribution in the workshop on Heavy-Ion Fusion, Padova May 25-27 1994.