PAPER • OPEN ACCESS

Dynamical Dipole mode in heavy-ion fusion reactions

To cite this article: C Parascandolo et al 2017 J. Phys.: Conf. Ser. 863 012060

View the article online for updates and enhancements.

You may also like

- Symmetry analysis of trimer-based alldielectric metasurfaces with toroidal dipole modes
 Victor Dmitriev, Anton S Kupriianov, Silvio Domingos Silva Santos et al.
- <u>Dynamics of ⁷Li breakup and its influence</u> on elastic scattering: a study of ⁷Li + ¹⁴⁴Sm system A. Morzabayev, N. Amangeldi, Awad A. Ibraheem et al.
- Toward a new approach for the pygmy dipole resonance in even-even nuclei. Application to isotopes 144,148,150,152,154 Sm

A A Raduta, C M Raduta and Alexandru Horia Raduta





DISCOVER how sustainability intersects with electrochemistry & solid state science research



This content was downloaded from IP address 18.227.228.95 on 04/05/2024 at 11:41

Dynamical Dipole mode in heavy-ion fusion reactions

C Parascandolo¹, D Pierroutsakou¹, R Alba², A Del Zoppo², C Maiolino², D Santonocito², C Agodi², V Baran^{3,2}, A Boiano¹, M Colonna², R Coniglione², E De Filippo⁴, M Di Toro^{2,5}, U Emanuele⁶, F Farinon⁷, A Guglielmetti⁸, M La Commara^{9,1}, B Martin^{9,1}, C Mazzocchi⁸, M Mazzocco¹⁰, C Rizzo^{2,5}, M Romoli¹, C Signorini¹⁰, R Silvestri^{9,1}, F Soramel¹⁰, E Strano¹⁰, D Torresi¹⁰, A Trifirò⁶, M **Trimarchi**⁶

¹INFN - Napoli, Napoli, Italy ²INFN - LNS, Catania, Italy ³University of Bucharest, Bucharest and NIPNE-HH, Magurele, Romania ⁴INFN - Catania, Catania, Italy ⁵Dip. di Fisica e Astronomia, Università di Catania, Catania, Italy ⁶INFN - Gr. Col. di Messina and Università di Messina, Messina, Italy ⁷GSI, Darmstadt, Germany ⁸Dip. di Fisica, Università di Milano and INFN - Milano, Milano, Italy ⁹Dip. di Fisica, Università di Napoli, Napoli, Italy ¹⁰Dip. di Fisica e Astronomia, Università di Padova and INFN - Padova, Padova, Italy

E-mail: concetta.parascandolo@na.infn.it

Abstract. In this work we give evidence for the first time of the Dynamical Dipole mode in a heavy system in the A \sim 190 mass region, in both fusion–evaporation and fission events. The 40,48 Ca + 152,144 Sm reactions at E_{lab} =11(10.1) MeV/nucleon were employed. Our results for evaporation and fission events (preliminary) show that the dynamical dipole mode survives in reactions involving heavier nuclei than those studied previously.

1. The physical problem

The "Dynamical Dipole mode" (DD) is a collective oscillation of protons against neutrons with a dipole spatial pattern inside the atomic nucleus. It is a pre-equilibrium phenomenon, being excited along the fusion path of nuclei with a different ratio of neutrons and protons and decaying through emission of prompt γ -rays [1, 2, 3, 4]. The DD radiation is characterized by i) a centroid energy lower than that of the compound nucleus (CN) GDR in the same mass region due to the high deformation of the emitting source [2, 3] ii) an anisotropic angular distribution with respect to the beam axis since the oscillation is confined in the reaction plane [5] and iii) a γ yield that should depend on both the reaction dynamics and the symmetry term of the EOS [3]. The existence of the DD mode has been probed in deep inelastic and fusion-evaporation heavy-ion collisions [4, 6, 7, 8, 9, 10]. An excess of γ -rays was observed in the GDR energy region for a charge asymmetric reaction, with respect to that of a more charge symmetric one forming the same CN at identical conditions [7, 8, 9] or with respect to statistical model calculations [10]. This γ excess was attributed to the decay of the predicted DD. The emission of DD γ rays decreases the excitation energy and the initial temperature of the nucleus reaching the statistical phase. This cooling mechanism could be suitable to favour the production of superheavy elements in hot fusion processes. TDHF calculations [11] showed that the DD γ yield decreases as the mass of colliding ions increases since the reactions with small nuclei are less damped than those involving more nucleons. In order to understand the behavior of the DD in heavier systems than those studied before and to test its usefulness in super-heavy element production, we decided to study the DD in a composite system in the mass region A=190 [12].

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI. Published under licence by IOP Publishing Ltd 1

2. The experiment: 40,48 Ca $+{}^{152,144}$ Sm at 11 MeV/nucleon

The experiment was performed by using the ⁴⁰Ca (⁴⁸Ca) pulsed beam provided by the Superconducting Cyclotron of the Laboratori Nazionali del Sud (LNS, Italy), impinging on a 1 mg/cm² thick self-supporting ¹⁵²Sm (¹⁴⁴Sm) target enriched to 98.4%(93.8%) in ¹⁵²Sm (¹⁴⁴Sm) at $E_{lab} = 440$ (485) MeV. Both entrance channels populate the same CN through a quite different initial dipole moment, 30.6 fm for the ${}^{40}Ca + {}^{152}Sm$ charge asymmetric reaction and 5.3 fm for the ${}^{48}Ca + {}^{144}Sm$ more charge symmetric one. The mass asymmetry of the two entrance channels is very similar, namely 0.22(0.18) for the ${}^{40}\text{Ca} + {}^{152}\text{Sm}$ (${}^{48}\text{Ca} + {}^{144}\text{Sm}$) system. The formed CN had identical excitation energy in both reactions, $E^* = (220\pm7)$ MeV, and identical spin distribution: $L_{max} = 74\hbar$ for fusion and $L_{max} = 42\hbar$ for fusion-evaporation, according to PACE2 calculations [13] with a level density parameter $a = A/9.5 \text{ MeV}^{-1}$, A being the CN mass. The γ -rays and the light particles were detected by using the MEDEA BaF_2 sphere [14], with a full azimuthal coverage in the polar angular range between 42° and 170° . The fusion-evaporation residues were detected by four position sensitive Parallel Plate Avalanche Counters (PPACs) placed symmetrically around the beam direction at 70 cm from the target at $\theta = 7^{\circ}$ and subtending 7° in θ . The fission events were selected by detecting the two kinematically coincident fission fragments with position sensitive PPACs, centered at $\theta =$ 52.5° symmetrically around the beam axis, at 16 cm from the target covering 22° in both θ and ϕ and allowing the study of γ -ray - fragment angular correlations. Down-scaled single events and coincidence events between at least one fired BaF₂ and a PPAC (two PPACs) for evaporation (fission) events were collected during the experiment. The coincidence request eliminated any cosmic-ray contamination of the γ -ray spectra. The analysis of the light charged particles energy spectra in evaporation events demonstrated that the two reactions lead to the formation of the same CN with the same average excitation energy (see [12]). Therefore any difference in the γ -ray emission between the two reactions can be related to an entrance channel effect.



Figure 1. Difference between the charge asymmetric and charge symmetric reaction centerof-mass bremsstrahlung-subtracted γ -ray spectra for fusion-evaporation (a) and fission (b) events. (c) 9 MeV $\leq E_{\gamma} \leq 15$ MeV γ -ray angular distribution of the ${}^{40}\text{Ca}+{}^{152}\text{Sm}$ (squares) and ${}^{48}\text{Ca}+{}^{144}\text{Sm}$ (circles) reactions, corrected for the detection efficiency. (d) Angular distribution of the difference between the data of panel (c). The lines are described in the text.

Panels (a) and (b) of Figure 1 show the difference between the center-of-mass bremsstrahlungsubtracted γ -ray spectra of the two reactions in coincidence with the evaporation residues and fission fragments, respectively. The data show an excess of γ -rays in the range $E_{\gamma}=8-15$ MeV in the charge asymmetric channel. This excess can only be related to the DD excitation in the composite system of the ${}^{40}\text{Ca}+{}^{152}\text{Sm}$ reaction because of its larger charge asymmetry. The DD γ spectrum (symbols in panels (a) and (b)) can be reproduced well by means of a Lorentzian curve folded by the experimental setup response function [15] (lines in the figure), with the DD centroid energy $E_{DD} = 11$ MeV and the width $\Gamma_{DD} = 3.5$ MeV, in both exit channels. E_{DD} is lower than the centroid energy of the GDR built on the ground state of a nucleus of similar mass, $E_{GDR} = 14$ MeV, confirming the high deformation of the emitting source during the DD γ emission. This result is in agreement with expectations [2, 3] and with previous works [7, 8, 9].

Panels (c) and (d) of Figure 1 display the fusion-evaporation γ -rays angular distribution with respect to the beam axis for the two reactions (c) and for their difference (d), integrated over energy from 9 to 15 MeV and corrected for the detection efficiency. The lines describe the angular distribution of the emitted γ -rays given by the Legendre polynomial expansion $M_{\gamma}(\theta_{\gamma})$ $= M_0 [1 + Q_2 a_2 P_2 \cos(\theta_{\gamma})]$, where a_2 is the anisotropy coefficient and Q_2 is an attenuation factor for the finite γ -ray counter [16] (0.98 in our case). From a best fit to the data, shown with a solid (dashed) line for the ${}^{40}\text{Ca}+{}^{152}\text{Sm}$ (${}^{48}\text{Ca}+{}^{144}\text{Sm}$) reaction, we found $a_2 = -0.13 \pm 0.03$ for the ${}^{40}\text{Ca}+{}^{152}\text{Sm}$ reaction and $a_2 = -0.06 \pm 0.02$ for the ${}^{48}\text{Ca}+{}^{144}\text{Sm}$ one. By using the same argument as previously for the spectra, the observed difference in the γ -ray angular distribution of the two systems can only be ascribed to entrance channel effects, namely the DD excitation. Consequently, the experimental angular distribution of the difference between the data of panel (c) (panel (d)) is very anisotropic around 90° and can be reproduced well with $a_2 = -1$ (solid line) that describes an emission from a dipole oscillation along the beam axis. The dashed line corresponds to a value of $a_2 = -0.84$ obtained within BNV calculations [3] for evaporation events, while the dotted one shows a more isotropic angular distribution ($a_2 = -0.25$). The above a₂ values indicate a preferential oscillation axis of the DD along an axis that has not rotated much on the reaction plane during the DD lifetime. Our data therefore suggest that the DD γ -emission time scale is confined at the beginning of the reaction, in agreement with our previous results for evaporation events [9] and with theoretical expectations [5]. By taking into account the DD γ -ray angular distribution (a₂ = -1) for evaporation events and the response function of the experimental setup, the DD yield, integrated over energy and over angle, is $(1.2 \pm 0.2)^{*}10^{-3}$ [12]. The analysis for the DD angular distribution for fission events is under way. The experimental results on the DD in ${}^{40}Ca+{}^{152}Sm$ reaction were compared with BNV calculations, based on a collective bremsstrahlung approach of the entrance channel reaction dynamics. These calculations give centroid energy, width and angular distribution of the DD in good agreement with those of the experiment. However, the theoretical DD yield for evaporation events overpredicted the data, calling for further investigation to clarify this aspect.

References

- [1] Chomaz P, Di Toro M and Smerzi A 2993 Nucl. Phys. A 563 509
- [2] Simenel C, Chomaz P and de France G 2001 Phys. Rev. Letl. 86 2971
- [3] Baran V et al 2001 Phys. Rev. Lett. 86 182501 and 2001 Nucl. Phys. A 679 373
- [4] Papa M et al 2005 Phys. Rev. C 72 064608
- [5] Baran V et al 2009 Phys. Rev. C 79 021603 (R)
- [6] Pierroutsakou D et al 2003 Eur. Phys. Jour. A 16 423
- [7] Flibotte S et al 1996 Phys. Rev. Lett. 77 1448; Amorini F et al 2004 Phys. Rev. C 69 014608
- [8] Pierroutsakou D et al 2003 Eur. Phys. Jour. A 17 71 and 2005 Phys. Rev. C 71 54605
- [9] Martin B et al 2008 Phys. Lett. B 664 47; Pierroutsakou D et al 2009 Phys. Rev. C 80 024612
- [10] Corsi A et al 2009 Phys. Lett. B 679 197; Giaz A et al 2014 Phys. Rev. C 90 014609
- [11] Simenel C, Chomaz Ph and de France G 2007 Phys. Rev. C 76 024609
- [12] Parascandolo C, Pierroutsakou D et al 2016 Phys. Rev. C 93 044619
- [13] Gavron A 1980 Phys. Rev. C 21 230
- [14] Migneco E et al 1992 Nucl. Inst. and Meth. A 314 31
- [15] Bellia G et al 1993 Nucl. Inst. and Meth. A 329 173
- [16] Rose M E 1953 Phys. Rev. **91** 610