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High spin resonances in ^{12}C+^{12}C scattering

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Abstract

We propose to measure excitation functions for the ^{12}C+^{12}C inelastic scattering to the single and mutual excited states at 9.64 MeV (3_1^-) and 14.08 MeV (4_1^+) in the energy range $E_{lab} = 90$ to 120 MeV. New coupled channels calculations may suggest that new high spin resonances will be observed in this energy region.

1 Introduction

We have recently reported on the observation of high spin resonances in ^{12}C+^{12}C scattering [1]. Excitation functions were measured for the ^{12}C[^{12}C, ^{12}C(3_1^-)] ^{12}C(3_1^-) reaction over the centre of mass energy range $E_{c.m.} = 31$ to 45 MeV and resonances were observed at $E_{c.m.} = 32.5$, 37.5 and 43 MeV. The results are shown in figure 1. Detailed angular correlation measurements [1] suggest that the resonances have spins $J = 18, 20$ and 22 respectively. The cranked Bloch-Brink α cluster model calculations of Marsh and Rae [2] predict that only two configurations in ^{24}Mg can support angular momenta of $J \geq 16$. One of these configurations, labelled F1 [3], has a well developed ^{12}C+^{12}C cluster structure. The other is a 6α-chain state. Thus at high spins, well above the maximum that the compound nucleus ^{24}Mg can support at normal deformations, the ^{12}C+^{12}C system should show only resonances corresponding to a maximum of two comparatively simple highly deformed configurations. The ^{12}C(3_1^-)+^{12}C(3_1^-) resonances observed in ref. [1] are believed to be associated with the F1 configuration in ^{24}Mg, extending the sequence of broad resonances first observed by Cormier et al. [4]. A comparison of resonance energies and spins with theoretical calculations supports this view [1]. In the strong coupling limit, inside the barrier the F1 alpha cluster model configuration is triaxial. Zhang [5] has performed angular momentum projected calculations for this configuration which give rise to a number of bands with different K values. For the lowest values of K, these bands are nearly degenerate (see figure 2). Despite this Zhang estimates that K mixing is quite small. In Zhang's calculations K is the projection of the total spin along the longest axis of the system and this is parallel to the line joining the centres of the two ^{12}C nuclei. In this picture K must be less than or equal to the sum of the spins of the two nuclei, thus for the single excitation of one nucleus to the 2_1^+ state $K \leq 2$. The $K = 5$ and 6 bands can only be observed in the 3_1^-+3_1^- channel.

Cranked cluster model calculations suggest that this band may terminate around $J = 20$ [6]. This is close to the highest spin observed for the $^{12}C(3_1^-)+^{12}C(3_1^-)$ resonances [1]. It is therefore believed that this configuration may not support higher J values. However, the maximum limit in the shell model is $J = 28$ and so resonances higher in spin than those observed to date may exist.

Indeed, there are indications from new coupled channels calculations performed at Oxford [7,8] for the $^{12}C+^{12}C$ system that absorption increases in the energy range $E_{c.m.} = 50$ to 60 MeV (figure 3a). In these calculations the strength of the imaginary potential has been found to increase near the resonances observed in the 2_1^+ [4] and 3_1^- [1] channels (The 3_1^- and 4_1^+ channels are not included in the calculations at the present time). The calculations suggest that another channel, perhaps involving the 14.08 MeV 4_1^+ in ^{12}C in single or mutual excitation, may open in the high energy range and further resonances may be observed. The investigation of a similar increase in absorption for $^{16}O+^{16}O$ around $E_{lab} = 90$ MeV is the subject of another proposal [9]. The Oxford calculations consistently reproduce the experimental data for the $^{12}C+^{12}C$ system including angular distributions and excitation functions for the ground state, single and mutual 2_1^+ states (see figure 4). Comparisons of calculated excitation functions with the resonances observed by Cormier et al. [4] are shown in figure 3b. The calculations have also been applied successfully to $^{16}O+^{28}Si$ and $^{12}C+^{24}Mg$ elastic and inelastic scattering [7,8].

2 Proposed Measurements

Our previous measurements [1] of $^{12}C+^{12}C$ scattering to multiple α-particle final states using position sensitive strip detectors (PSSD's) have proved successful. We propose to extend the excitation function shown in figure 1, up to $E_{c.m.} = 60$ MeV to test for the termination of the $^{12}C(3_1^-)+^{12}C(3_1^-)$ band. Yields for the angular correlation measurements reported in ref. [1] are also shown in figure 1, along with data for $E_{c.m.} = 46.5$ MeV. These measurements were performed at ANU using eight PSSD's in the Charissa MEGHA chamber. This gave angular coverage from 5° to 60° in the laboratory. We also intend to measure excitation functions for scattering to the 4_1^+ state in ^{12}C. The large angular coverage provided by our strip detector array makes this measurement possible. In figure 5 we demonstrate the reconstruction of highly excited states in ^{12}C from a previous measurement of $^{12}C(^{12}C,3\alpha)^{12}C(0_1^+)$ at $E_{lab} = 93$ MeV [10]. The 3_1^- and 4_1^+ states and the decays to $^8Be(0^+,2^+)$ are clearly resolved. Although the detection arrangement will be optimised for the measurements discussed above, some information on other scattering channels should also be recorded simultaneously in the data. A data acquisition trigger of four or more coincident particles would allow, for example, $^{12}C(3\alpha)+^{12}C$, $^{16}O(4\alpha)+^8Be$ and $^{16}O(^{12}C\alpha)+^8Be$ channels to be stored for later analysis.

From our previous measurements we estimate that a minimum of 6 hours will be required to collect sufficient data at each energy. This estimate is based upon collecting around 1000 counts for 6fold α-particle coincidences in the mutual 3_1^- channel at $E_{lab} = 93$ MeV using a 10 μgcm^{-2} natural carbon target foil and an average beam intensity of 20 enA. Hence an excitation function in the range $E_{lab} = 90$ to 120 MeV in 2 MeV steps would take approximately 4 days. An additional day is required for the necessary calibrations. In total 5 days of beamtime are requested for this measurement.

3 Summary

In summary, we propose to extend our previous measurements of high spin resonances in $^{12}C+^{12}C$ scattering to the energy range $E_{lab} = 90$ to 120 MeV. This will test for the presence of resonances in the scattering to the single and mutual 9.64 MeV 3_1^- and 14.08 MeV 4_1^+ excitations in ^{12}C. 5 days of beamtime are requested for this measurement. This experiment will form a significant part of the thesis work of an EPSRC funded D.Phil student at Oxford (C.A.B.). The experimental set-up detailed for this measurement is similar to that required in another proposal [11]. These two experiments could be run in parallel without difficulty.

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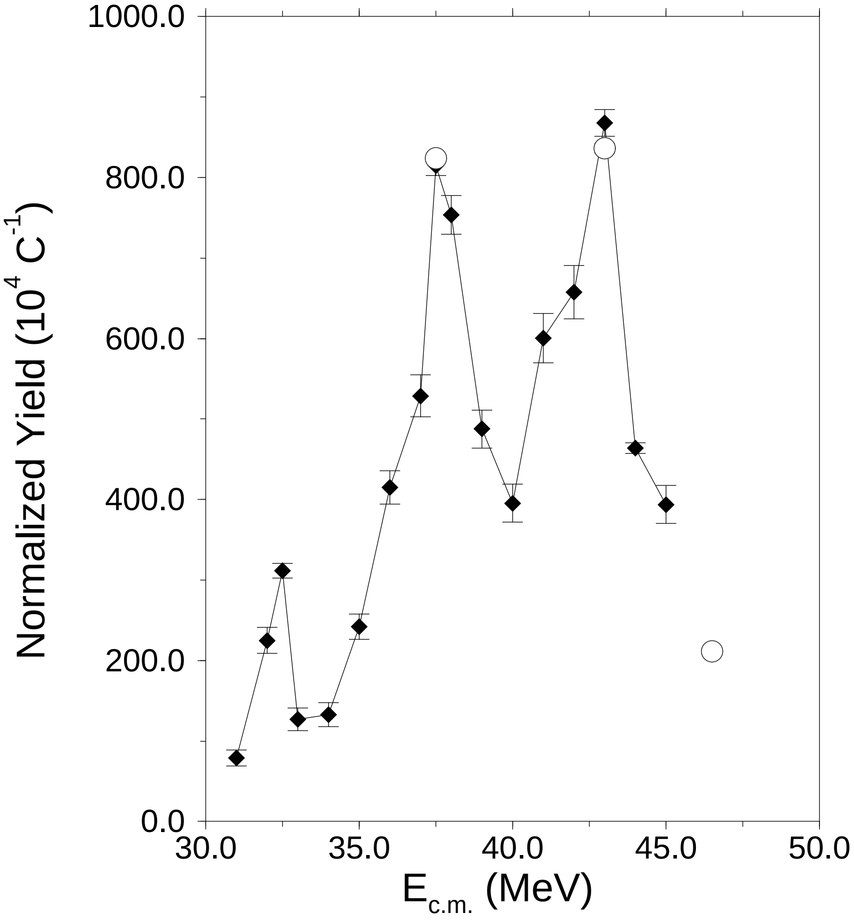

Figure 1: Excitation function for the ^{12}C[^{12}C, ^{12}C(3_1^-)] ^{12}C(3_1^-) reaction (Diamonds from the 4 PSSD measurement of ref. [1]. Open circles from 8 PSSD measurement at ANU)

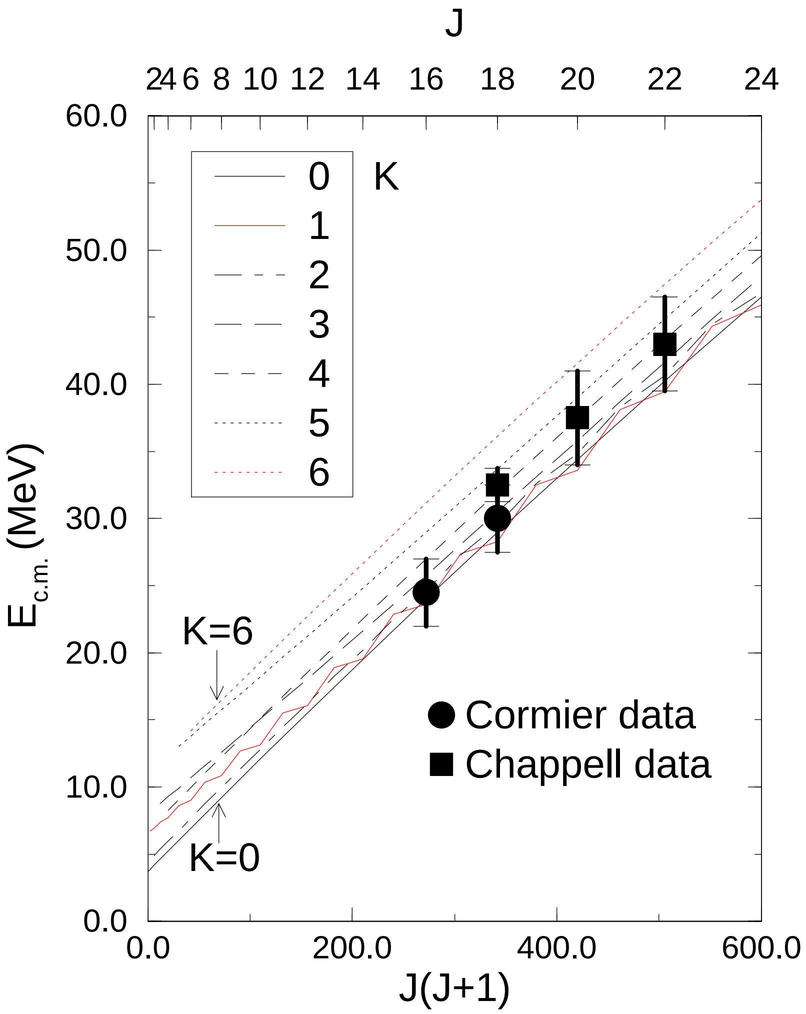

Figure 2: Angular momentum projected α-cluster model calculations [5] for the F1 configuration in ^{24}Mg and the resonances in the data of ref. [1] and those of Cormier et al [4].

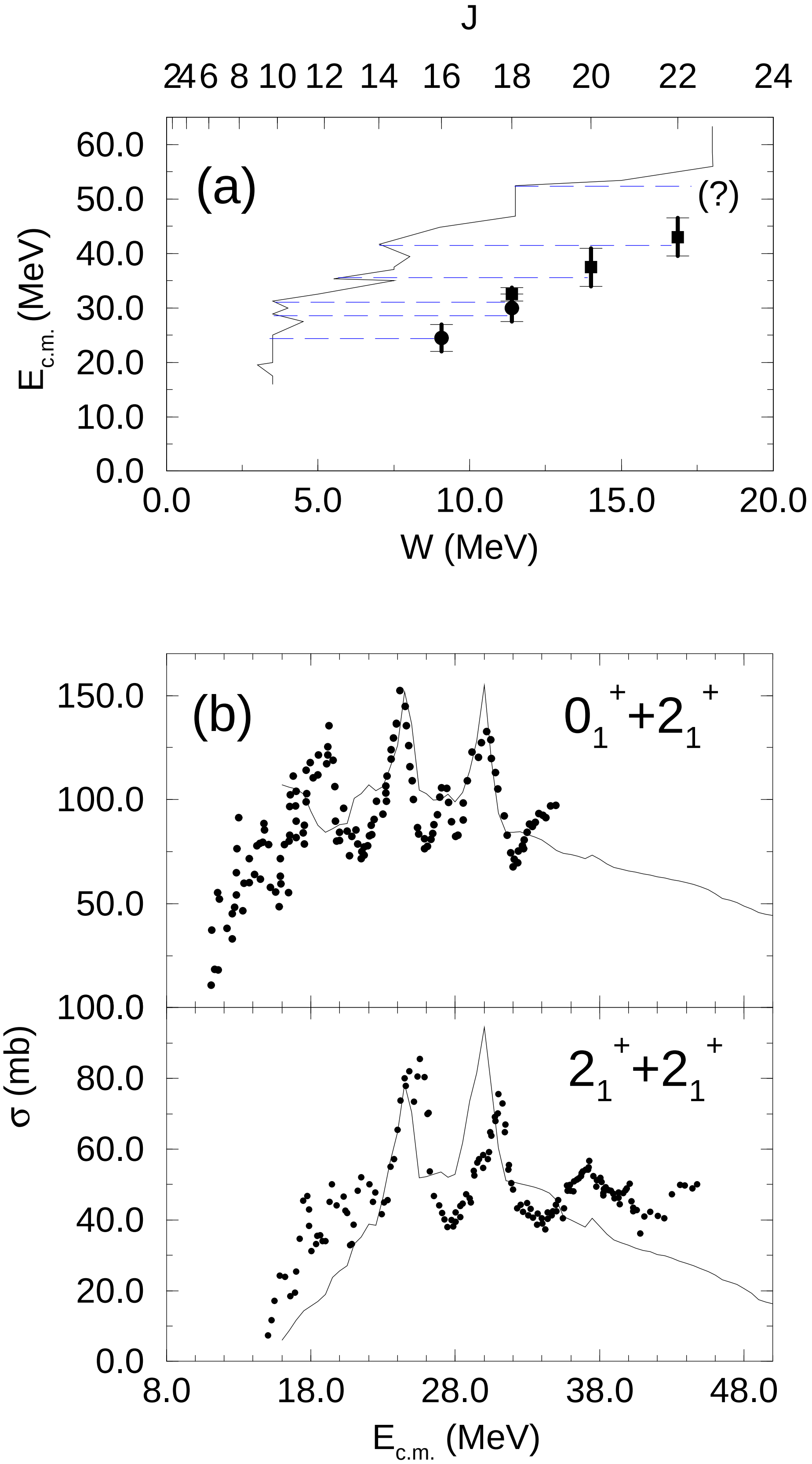

Figure 3: Results of coupled channels calculations [6] for the $^{12}C+^{12}C$ system. (a) Imaginary potential strength (solid line) compared to observation of resonances by Cormier (circles) [4] and Chappell (squares) [1]. (b) Calculations (solid lines) for scattering to the single and mutual 2_1^+ state compared to the data (circles) of Cormier et al [4].

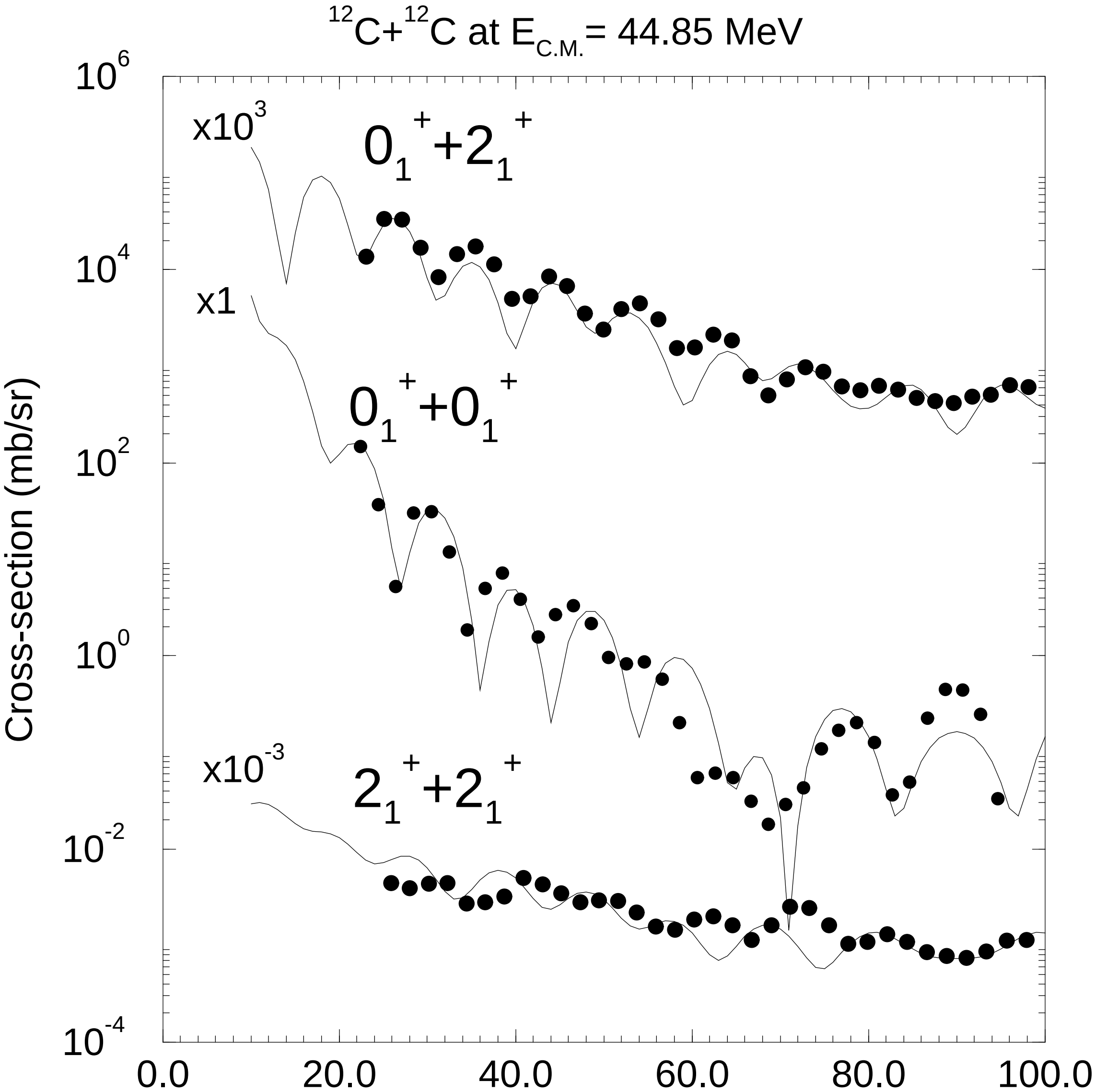

Figure 4: Example results of coupled channels calculations [6] for the $^{12}C+^{12}C$ system compared to experimental data.

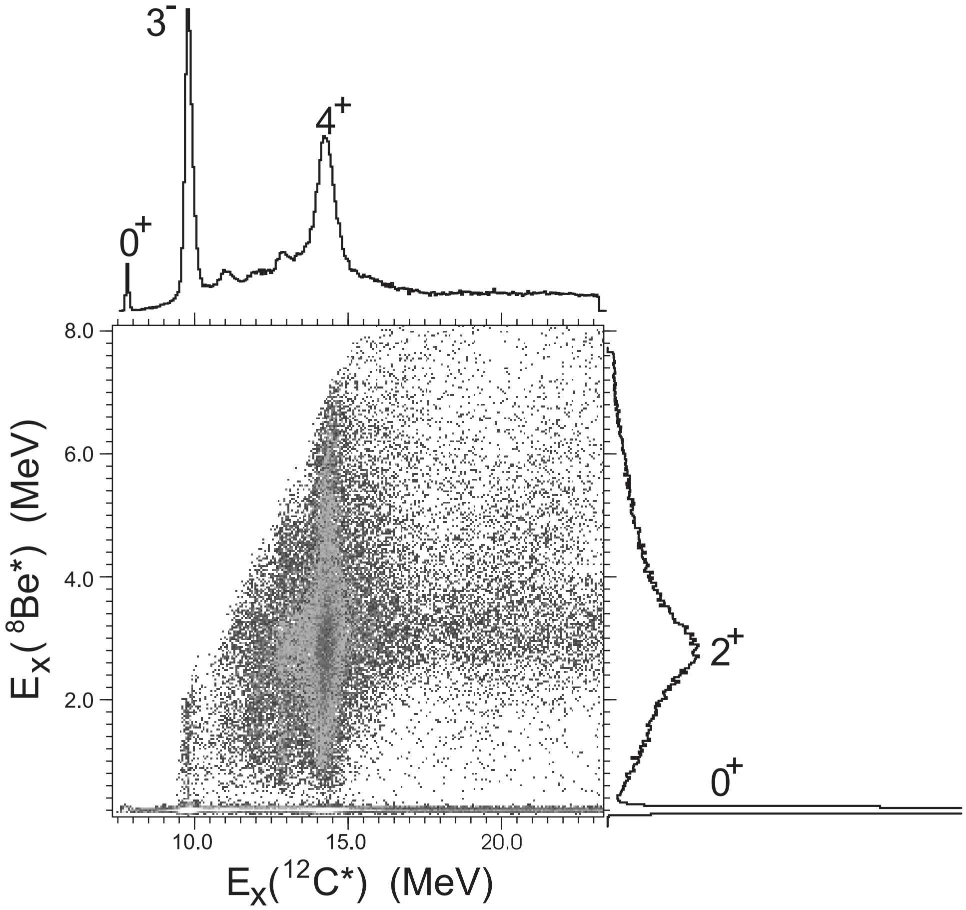

Figure 5: Excitation in ^{12}C* versus excitation in ^{8}Be* for ^{12}C*$\rightarrow$ ^{8}Be*+α decays.