Results from Charissa runs at ANU during 1998 (SPGC)

1 ANU running Jan/Feb '98

A new strip detector array was installed in the Charissa MEGHA vacuum chamber and commissioned with a series of experiments during January and February 1998. In total 19 days of beamtime were used during this period including 1 day for the installation and commissioning of the new array and associated electronics. The measurements used a common set-up of eight 16-strip detectors which provided angular coverage from 5° to 60° in the laboratory. A summary of results to date from this period are given in this section following a brief description of the new array.

1.1 The Strip detector array

The array [1] consists of a mounting plate which can accommodate either position sensitive strip detectors (PSSD's) or two-dimensional position sensitive detectors (PSD's) in a selection of thirty fixed positions at a typical distance of 150mm from the target. With all positions filled the array has almost complete angular coverage from 5° to 85° degrees in the laboratory. At present, the MEGHA data acquisition system provides for up to 320 signal channels. This allows for up to ten PSSD's to be independently instrumented in the array. The mount is designed such that removal of the detectors at forward angles allows PSSD's to be used in conjunction with the MEGHA module Gas-Si-CsI telescopes. Twisted-pair 36way ribbon cables connect the detectors to 42-pin hermetically sealed "Amphenol" connectors fixed in one of the MEGHA chamber side flanges. Custom designed preamplifiers are located in racks immediately adjacent to the vacuum vessel.

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

We have previously observed [2–4] large resonant like structures in the cross section of the 3^-+3^- channel in ^{12}C+^{12}C scattering at $E_{c.m.} = 32.5, 37.5$ and 43 MeV (figure 1). Unfortunately, the angular coverage of the detection system used in the measurements (four position sensitive strip detectors (PSSD's)) was not sufficient to determine the dominant spins of these structures. Following the installation of the new strip detector array, we performed detailed angular correlation measurements at the energies corresponding to the peaks of each resonance. These measurements used 6 days of beamtime. The new strip detector array gave a large efficiency for the detection of high particle multiplicities. This enabled us to use a thin target (10μgcm^{-2}). As a result the resolution obtained in these measurements is significantly improved.

The details of the data analysis and angular correlation method are well described elsewhere [4]. Briefly, the angular correlation for the present case depends on five angles, namely the primary scattering angle ϕ^*_B and the two decay angles χ_B and ψ_B of the ^{8}Be-α relative velocity with respect to the beam for each ^{12}C nucleus. In ref. [4] we demonstrated

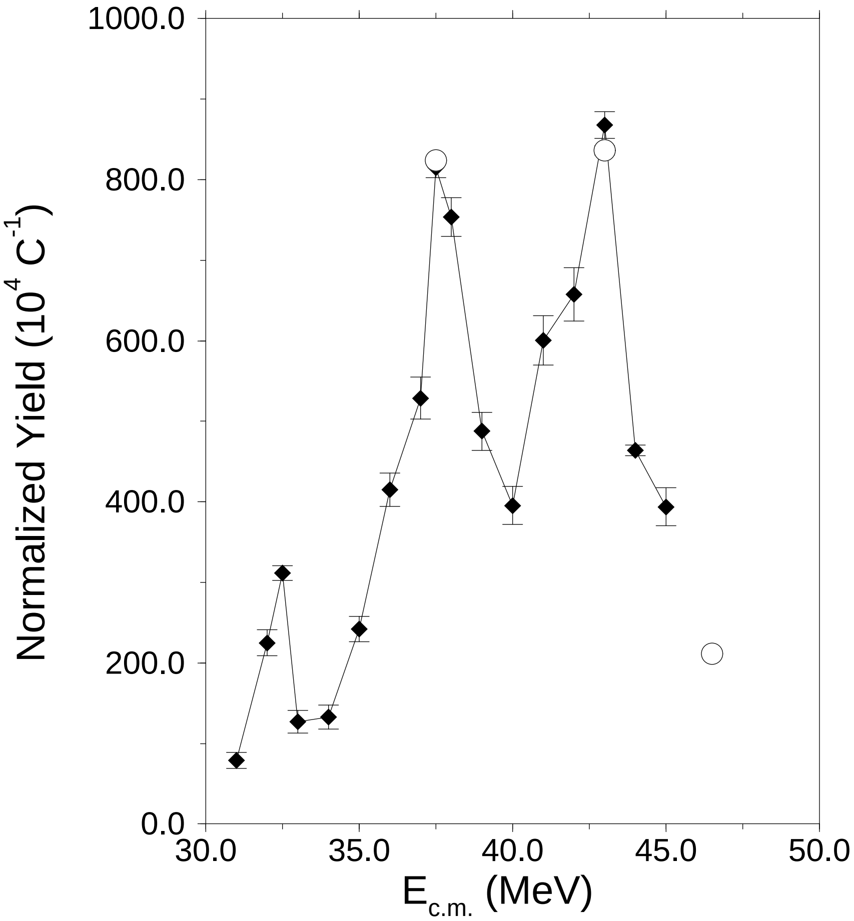

Figure 1: Excitation function for the ^{12}C[^{12}C, ^{12}C(3_1^-)] ^{12}C(3_1^-) reaction (Diamonds from the 4 PSSD measurement of ref. [2]. Open circles from 8 PSSD measurement at ANU)

that the semiclassical angular correlation function for mutual decay could be approximated over the measured angular range by

$$W(\phi_B^*, \chi_B, \chi_B', \psi_B, \psi_B') \;\propto\; \frac{1}{\sin\phi_B^*}\left|\sum_{L'} a_{L'} \sin\left[\left(L' + \frac{1}{2}\right)\phi_B^* + k\chi_B + k'\chi_B' + \frac{\pi}{4}\right]\right|^2 d_{k0}^{I}(\psi_B)^2 d_{k'0}^{I'}(\psi_B')^2 + \frac{A^2}{\sin\phi_B^*} \tag{1}$$

where ψ_B,$\psi_B' \simeq \pi/2$. Here $a_{L'}$ is the amplitude for a single value of the partial wave in the final channel L' and A^2 is an incoherent background. The projections of the ^{12}C angular momentum on the z-axis, which is perpendicular to the reaction plane, are k and k'. In ref. [3] we showed that by making assumptions about the quantum numbers k and k' we could define a two-dimensional correlation function $W(\phi_B^*, X)$ where $X = \chi_B \pm \chi_B'$ and hence determine the dominant L' and total angular momentum $J = L' + k + k'$ from the projections of the "ridge" pattern onto a single axis labelled by ϕ_P^*. A slightly different and more rigorous approach is presented in figure 2. In the figure, we compare the projected correlation data with full Monte-Carlo simulations of the reaction for three different consecutive partial waves at each centre of mass energy (figure 2a to 2c). Note that the different partial waves are out of phase away from the centre of the ϕ_P^* range for each energy. In figures 2d to 2f we compare the data with simulations for a coherent

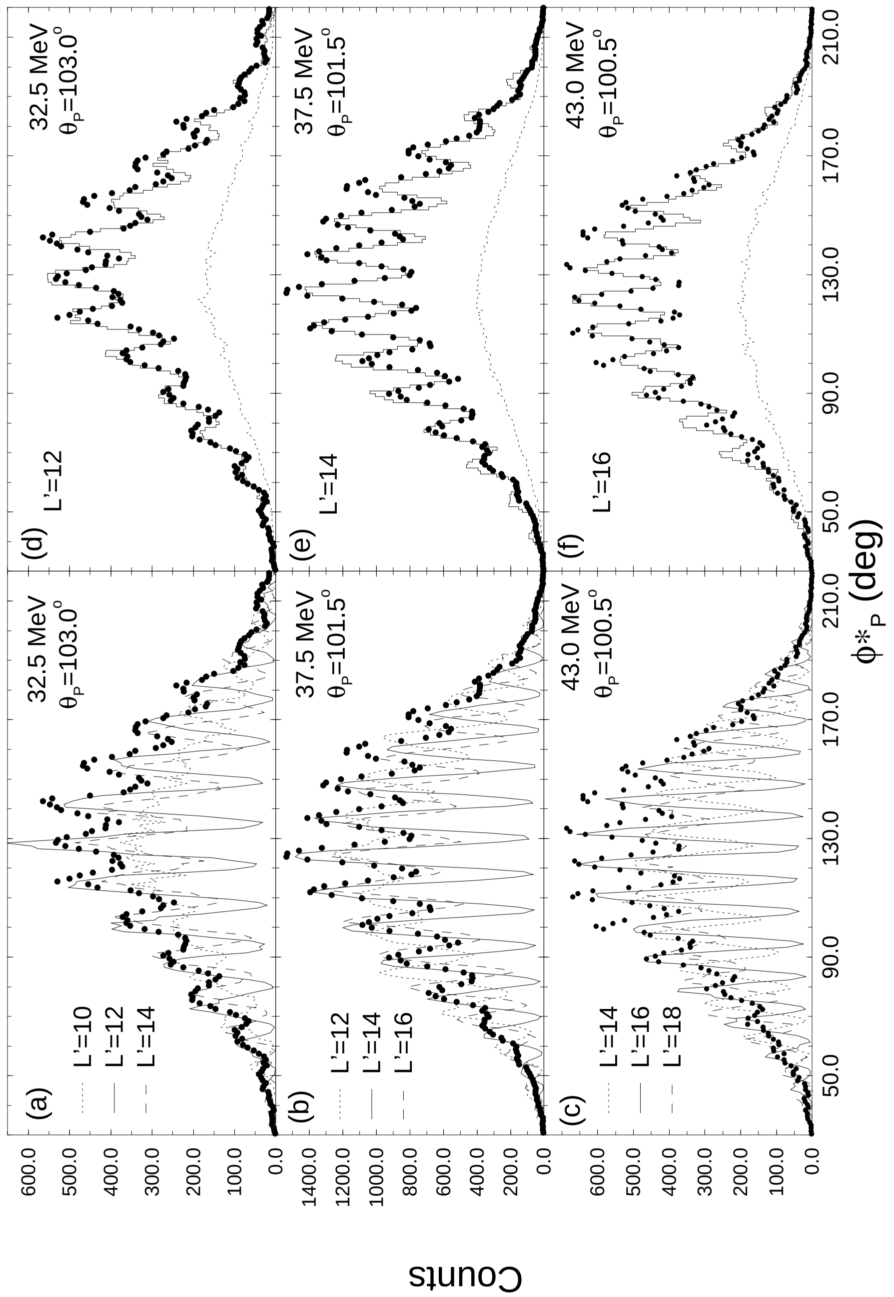

Figure 2: Comparisons of measured and simulated angular correlations projected onto a single axis using the optimum projection angle θ_P indicated at each of the three centre of mass energies. (a–c) Simulation for three consecutive L' values and no incoherent background. (d–f) Simulation including a coherent contribution of two partial waves and an incoherent background. (The background is shown as the dotted curves in the figures scaled by a factor of 0.5 for clarity). (d) $E_{c.m.} = 32.5$ MeV with $a_{12} = 0.92$, $a_{14} = -0.39$ (e) $E_{c.m.} = 37.5$ MeV with $a_{14} = 0.95$, $a_{16} = 0.32$ (f) $E_{c.m.} = 43.0$ MeV with $a_{16} = 0.98$, $a_{18} = -0.22$. The projection angles $\theta_P = 103°, 101.5°$ and $100.5°$ yield $L' = 12.5, 14.2$ and 15.7 respectively which is consistent with our assignments.

sum of two L' values and an incoherent background. The suggested dominant L' values indicated in the figure are consistent with the optimum projection angle θ_P at each energy. We suggest that the dominant L' values for the structures at $E_{c.m.} = 32.5, 37.5$ and 43 MeV are 12, 14 and 16 respectively.

Assuming that these resonances dominate the angular correlations at the centre of each peak in the excitation function they have angular momenta up to $J = L' + 6 = 22$ and are consistent with a rotational band. We believe that these resonances extend the sequence of broad resonances first observed by Cormier *et al.* [5]. A comparison of resonance energies and spins with theoretical calculations support this view [6]. These results have been submitted for publication [6]. We also have results for a number of other channels from this experiment that are being prepared for publication.

1.2.1 ^{8}Be decay of ^{16}O and ^{12}C

The ^{12}C+^{12}C reaction at $E_{lab} = 93$ MeV was used to study the ^{8}Be decay of highly excited states in ^{16}O and ^{12}C. Approximately 2 days of beamtime were used for these measurements.

The ^{12}C(^{12}C,^{8}Be$_{\rm g.s.}$,^{8}Be$_{\rm g.s.}$)^{8}Be$_{\rm g.s.}$ channel was isolated by detecting 4α particles in the final state and then gating on the ^{8}Be$_{\rm g.s.}$ peak in each $\alpha - \alpha$ relative energy spectrum. Undetected particles were reconstructed from the missing momentum. The parenthood of the three ^{8}Be$_{\rm g.s.}$ nuclei in these events was investigated using a "modified Dalitz plot" [7], as presented in figure 3a. In the geometry of the Dalitz plot, an excited state of the parent nucleus (in this case ^{16}O*) is identified as a stripe at a fixed relative energy E_{ij} between the daughter particles parallel to the sides of the triangle shown. The data are confined to a circle of diameter equal to the available energy in the triple ^{8}Be$_{\rm g.s.}$ final state. The lack of symmetry in the plot is a result of non random particle order in the data sorting routine. Three states in ^{16}O* have been identified (fig. 3b) at $E_x \simeq 19$, 23 and 30 MeV. The spins of the states have been determined using angular correlation techniques. The 6^+ states at 19 and 23 MeV are consistent with those found in previous work [8]. Interestingly, the 8^+ state at 30 MeV is close to the energy predicted for the ^{16}O 4α chain in a coupled-channels cluster model [9]. This model predicts a 10^+ state some 4 MeV higher in energy than the 8^+. Such a state would lie at the edge of the Dalitz plot in figure 3a and is out of the range of the present experiment. We propose to search for the 10^+ state using the technique demonstrated in this measurement [10].

The analysis of ^{12}C(^{12}C,3α)^{12}C$_{\rm g.s.}$ events is slightly more complicated than for the case described above, since the three particles under examination have their energies fixed by the excitation in ^{12}C*, which may take several values. In particular, the decays to ^{8}Be(2^+) are not easily identified due to the large width of the state. In order to examine these events the spectrum in figure 4 was constructed. Only one of the three possible $\alpha - \alpha$ relative energies is plotted in this spectrum. If a pair of α particles was found to be consistent with ^{8}Be$_{\rm g.s.}$ decay then that relative energy was plotted, otherwise there was no selection. Hence the ^{8}Be* spectrum contains a background of events where the alpha particle daughters in the sequential decay ^{12}C*$\rightarrow$^{8}Be*+$\alpha$$\rightarrow$$3\alpha$ are incorrectly assigned. These data confirm that the 14.08 MeV 4^+ state in ^{12}C decays predominantly via the 2.9 MeV 2^+ state in ^{8}Be [11].

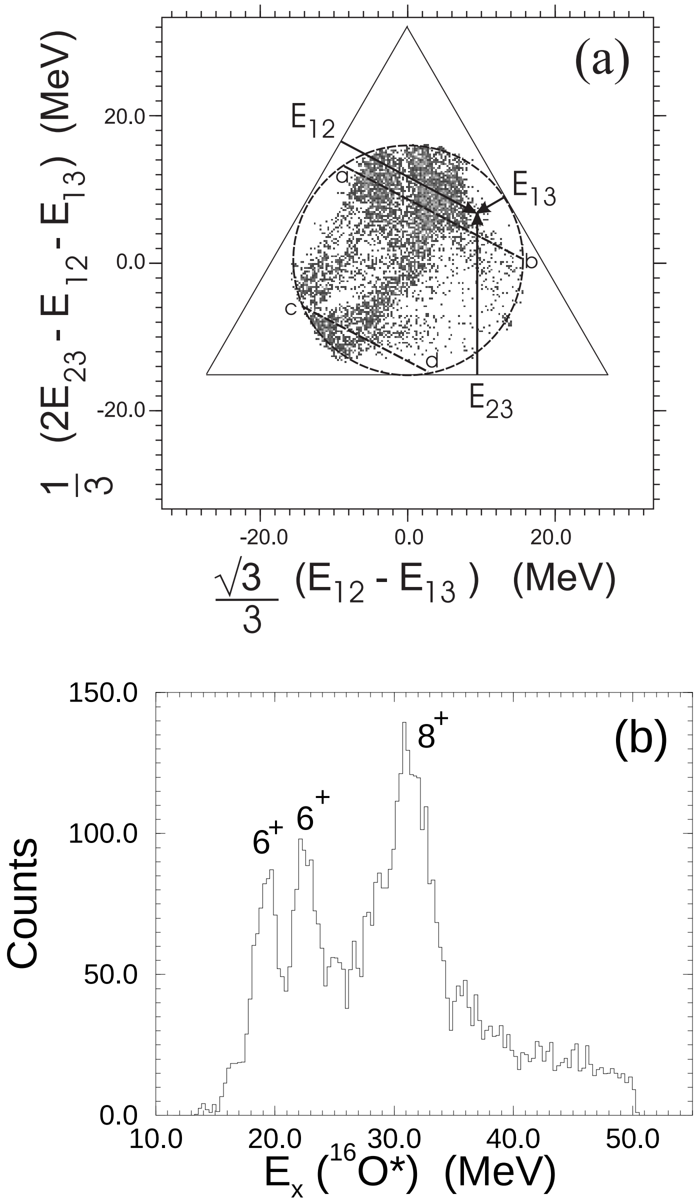

Figure 3: (a) Modified Dalitz plot for the $^{8}\mathrm{Be}_{\mathrm{g.s.}}$+$^{8}\mathrm{Be}_{\mathrm{g.s.}}$+$^{8}\mathrm{Be}_{\mathrm{g.s.}}$ final state. (b) Projection of the region abcd (defined in frame a) onto an axis perpendicular to E_{12}.

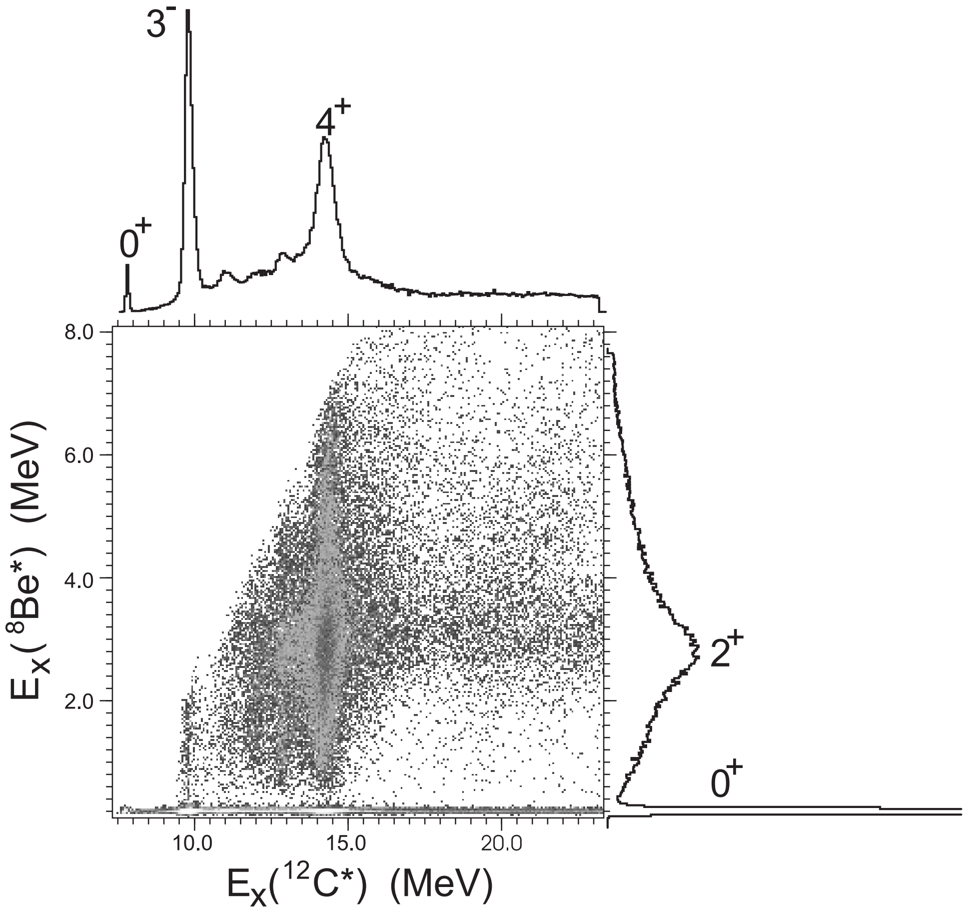

Figure 4: Excitation in ^{12}C* versus excitation in ^{8}Be* for ^{12}C*→ ^{8}Be*+α decays.

We measure a branching fraction of 0.71±0.01 for this decay.

We propose to investigate the inelastic scattering of ^{12}C+^{12}C to the single and mutual 4_1^+ channels using these analysis techniques [12].

1.3 ^{28}Si+^{12}C orbiting

A pilot study was made into the suitability of the new strip detector array for investigating the phenomenon of dinuclear orbiting [3]. We used approximately 2 days of beamtime to study the ^{28}Si+^{12}C reaction in a kinematic coincidence measurement at $E_{c.m.} = 20.1, 26.0$ and 33.6 MeV. All events in which at least two particles were detected in the strip array were recorded. Following a detailed offline analysis of the data we have discovered that the strip detector array is not well suited to such measurements without more specific event selection. The desired 2-fold elastic and inelastic scattering events in the data were swamped by high fold events. The cross section for scattering to multi-particle final states coupled with the large efficiency for detection of these events in the new array has been found to give an unacceptably large deadtime for the recording of 2-fold coincidences.

1.4 Investigation of ^{16}O*→ ^{12}C$_{g.s.}$+α breakup

Reactions between an ^{16}O beam and a LiO target (with a natural carbon backing) were used to investigate the energy dependence of the breakup ^{16}O*→ ^{12}C$_{g.s.}$+α via the single excitation of ^{16}O to the 11.09 MeV 4^+ excited state. Eight days of beamtime were used to measure excitation functions between 26 and 47 MeV in the centre-of-mass. Final state determination and resonant nucleus reconstruction was achieved using a new technique, which relies on a variety of kinematic gates to identify and isolate the breakup channels of interest [17].

Excitation functions for the excitation of $^{16}O^*$ to the 2^+ (9.84 MeV), 4^+ (10.35 MeV) and 4^+ (11.09 MeV) states are given in figure 5. Angular correlation techniques [4] were used to determine the dominant angular momentum associated with specific energies in the centre-of-mass where sufficient data were available (See figure 5). It is interesting to note that the enhancements at 31 MeV and 36 MeV (in the centre-of-mass) in the excitation function for the 11.09 MeV 4^+ excited state are correlated with enhancements observed by Wells *et al* [16] for the single and mutual excitation of ^{16}O to the 3^- (6.13MeV) state. It has been proposed [13] that the ground state of ^{16}O has tetrahedral symmetry. The states usually associated with the ground state rotational band are 0^+ (the ground state), 3^- (6.13 MeV), 4^+ (10.35 MeV), 6^+ (16.29 MeV), 7^- (21.19 MeV) and 8^+ (29.18 MeV). However the 4^+ (10.35 MeV) and 6^+ (16.29 MeV) states also fit into the 4p-4h K=0^+ "kite" rotational band [14]. Better candidates for the tetrahedral band may be the states at 4^+ (11.09 MeV) and 6^+ (14.82 MeV) [15]. If the 4^+ (11.09 MeV) state is a member of the tetrahedral band, it is expected that strong correlations should exist between the excitation function for $^{16}O^* \rightarrow {}^{12}C_{g.s.}+\alpha$ breakup from the 4^+ (11.09 MeV) state, and the measured excitation function for single and mutual excitation to the 3^- (6.13MeV) state. The present results suggest that the 4^+ (11.09 MeV) excited state may indeed be associated with the tetrahedral band in ^{16}O. These results and those on a number of other final state channels are being prepared for publication [17].

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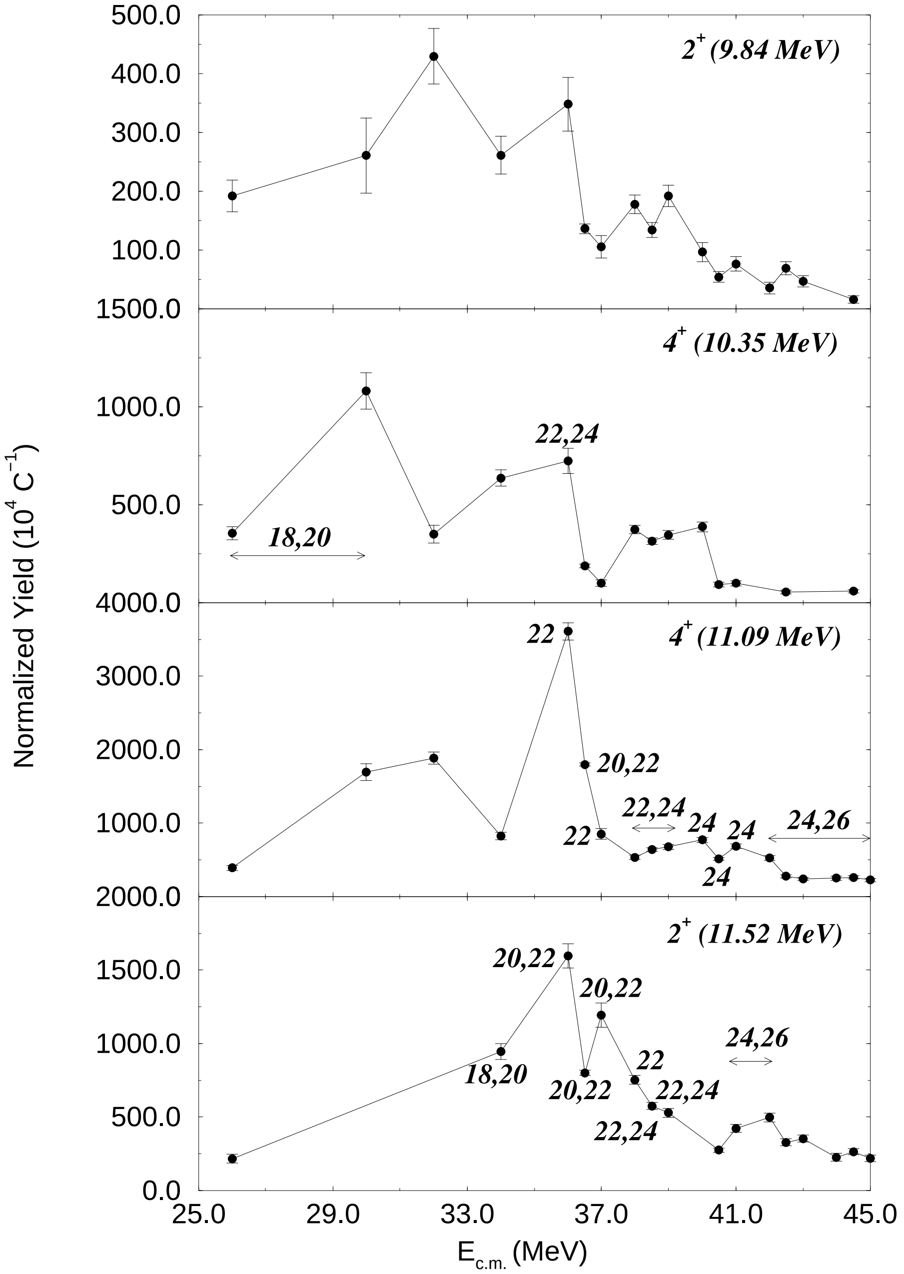

Figure 5: Energy dependence of the ^{16}O(^{16}O,^{16}O$^{*}\rightarrow$ ^{12}C$_{g.s.}$+α)^{16}O$_{g.s.}$ reaction for the ^{16}O* states indicated. Dominant partial waves are given in the figure.

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