Journal of Physics: Conference Series

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To cite this article: J Bishop *et al* 2017 *J. Phys.: Conf. Ser.* **863** 012070

IOP Conf. Series: Journal of Physics: Conf. Series **863** (2017) 012070 doi:10.1088/1742-6596/863/1/012070

High multiplicity α-particle breakup measurements to study α-condensate states

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Abstract.
An experiment was performed to investigate α-condensate states via high α-particle multiplicity breakup. The nucleus of interest was ^{28}Si therefore to measure multiplicity 7 particle breakup events, a highly granular detector with a high solid angle coverage was required. For this purpose, the CHIMERA and FARCOS detectors at INFN LNS were employed. Particle identification was achieved through ΔE-E energy loss. The α-particle multiplicity was measured at three beam energies to investigate different excitation regimes in ^{28}Si. At a beam energy where the energy is sufficient to provide the 7 α-particles with enough energy to be identified using the ΔE-E method, multiplicity 7 events can be seen. Given these high multiplicity events, the particles can be reconstructed to investigate the breakup of α-condensate states. Analysing the decay paths of these states can elucidate whether the state of interest corresponds to a non-cluster, clustered or condensed state.

1. Introduction

In order to investigate to what degree α-particles can form a condensate in light nuclei, an experiment was performed to measure the high α-particle multiplicity break-up of high excitation states in ^{28}Si to measure their decay channels. By measuring the branching ratios corresponding to these different decay paths, information about the wave function of the state can be extracted. The compound nucleus state in ^{28}Si which will decay into 7 α-particles can be populated. The wave functions this level can therefore decay into can be represented as:

$$|\Psi(7\alpha)>= C_1\,|^8\mathrm{Be}\rangle\,|^8\mathrm{Be}\rangle\,|^8\mathrm{Be}\rangle\,|\alpha\rangle\; = C_2\,|^{12}\mathrm{C}\rangle\,|^8\mathrm{Be}\rangle\,|^8\mathrm{Be}\rangle\; = C_3\,|^{16}\mathrm{O}\rangle\,|^{12}\mathrm{C}\rangle = \ldots \qquad (1)$$

The coefficients for each of these decays' wave function can then be calculated from the branching ratios and their values compared [1]. This can be achieved from the proportionality of the decay width to the overlap of the wave functions for the initial $\Psi(7\alpha)$ and final state ψ_i:

$$\Gamma_i(E) \propto |\langle\Psi(7\alpha)|\psi_i\rangle|^2 = |C_i|^2 \prod_{j=1}^{N} P_j(E) \tag{2}$$

with $P_j(E)$ being the penetrability. For an α-condensate state the coefficients C_i should all be equal.

Therefore, to verify the existence of such α-condensate states the various decay channels must be measured; especially the channels comprising of high multiplicity break-ups.

2. Experimental

Measuring a high number of final states products has many difficulties; the primary one being the need for a large angular coverage detector system. Secondly, the beam current must also be sufficiently low such that pileup events are not affecting the detection of these high particle multiplicity events. Finally, the granularity of such a large solid-angular coverage detector must be small enough that while reconstructing events, the resolution is sufficient to distinguish between different excited states.

A good fulfillment of these criteria was available at INFN LNS Catania using the CHIMERA [2] and FARCOS [3] detectors in tandem. The compound nucleus was populated using a ^{16}O beam at 160, 280 and 400 MeV impinging on a carbon target of 58 and 92 μg/cm^2 with beam currents of $\sim$ 300 pA. These two different detector arrays will briefly be examined.

The CHIMERA detector [2] was originally developed for studying heavy ion collisions, it is however well suited to the current experiment and general nuclear structure studies due to its 1192 telescopes. These telescopes span 94% solid angle coverage with scattering angles from 1° to 176°. These detectors have an angular size ranging from 0.8° for small scattering angles to 8° at large scattering angles. Each telescope comprises of a 290 μm nominal thickness silicon detector followed by a CsI(Tl) crystal which can provide particle identification using ΔE-E. The CsI(Tl) light output is passed through two different readouts which allows for the rise time to be inferred, giving an additional form of particle identification using solely the CsI(Tl) signal. Finally, the timing information of each telescope is also available which can be used for mass identification where the fragment has insufficient energy to pass through the silicon into the CsI(Tl) crystal. For α-particles this corresponds to 24 MeV although the energy required for detection must be higher than this to be above the CsI(Tl) threshold.

The FARCOS detector [3] is an ongoing project to produce a modular detector system with good energy and position information which can be tessellated to provide large solid angle coverage. Each FARCOS module comprises of a 2×2 grid of CsI(Tl) detectors at the rear covered by a DSSD of width 1500 μm. These are then in turn covered by another DSSD of width 300 μm. As with the CHIMERA detector, the primary particle identification is performed by ΔE-E, however, with the FARCOS detector there is a choice between 3 detection stages of performing this identification. The FARCOS detector was employed at low scattering angles to provide improved resolution by virtue of the improved granularity and energy resolution compared to CHIMERA.

3. Analysis

To verify the sufficient solid angular coverage of the detector systems, the multiplicity of α-particles at the three different beam energies can be examined. With the combined detector systems of CHIMERA and FARCOS, and considering any telescopes which were not functionally sufficiently to contribute to the data (i.e. silicon or CsI(Tl) faulty), the overall solid angle coverage was around 80%.

In Figure 1, the α-particle multiplicities can be seen for different beam energies as measured using ΔE-E only. The lowest beam energy of 160 MeV shows a highest multiplicity of 5, this is due to the $>$ 24 MeV needed for an α-particle to punch-through to the CsI(Tl). With only 160 MeV available to share amongst many α-particles, a very equitable distribution of energy is needed for the α-particles to be identified using ΔE-E. It can be seen at 280 MeV, where the available energy is larger, that the required multiplicity of 7 is reached however statistics for this are limited. At 400 MeV, the overall multiplicities are higher than the other beam energies and a reasonable number of multiplicity 7 events are detected. As well as multiplicity 7 events from the ^{16}O+^{12}C reaction with the target, multiplicity 8 events may also be attributed to ^{16}O+^{16}O events with oxygen contaminants in the target. These interactions can be distinguished by looking at the total Q-value of the reaction which can also distinguish from any pile up occurring.

Once α-particles are included which are solely measured in the silicon detector and identified using time-of-flight, the overall multiplicities will increase due to the effective lowering of the α-particle energy threshold. This will particularly affect the 160 MeV beam data where the average α-particle energy is lower and allow for a more unbiased comparison of high multiplicity decays.

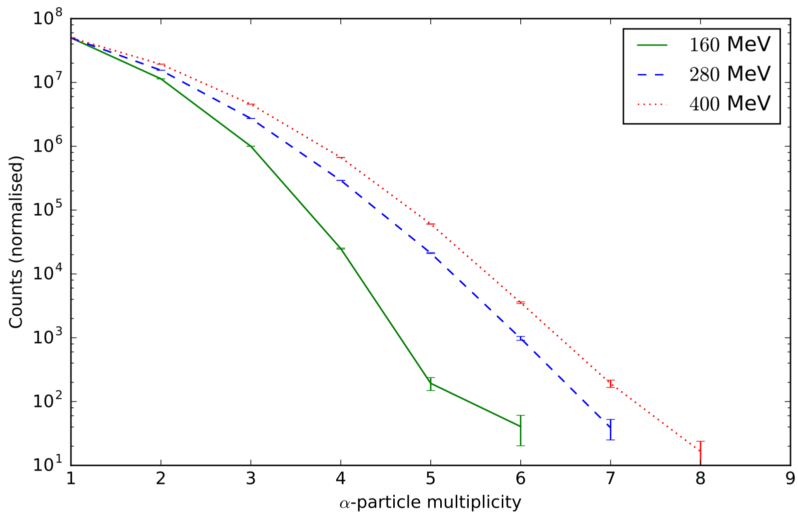

Figure 1. α-particle multiplicities for three different beam energies normalised to multiplicity=1 counts

3.1. Reconstructed spectra

Once an event of high α-particle multiplicity has been identified, all the possible permutations of α-particles can be reconstructed to form an α-α correlation function. In such a statistical decay, a large number of break-up products are expected to proceed via the ^{8}Be ground state. By forming the α-α correlation function, a large contribution at 91.84 keV corresponding to the break-up energy of ^{8}Be can be seen. By further reconstructing the ^{8}Be and remaining α-particles, the breakup of ^{12}C(0_2^+) and ^{16}O* (including the 0_6^+ which is predicted to be a condensate state [4, 5]) can therefore be calculated. It is through these repeated reconstructions that the branching ratios for the decay of the high excitation in ^{28}Si can be determined and therefore the coefficients of the wave function calculated which will provide a distinction between a condensed state, a clustered state and a non-clustered state.

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