Contribution ID: **120** Type: **Talk**

The Hoyle Family: precision break-up measurements to explore nuclear α-condensates

Thursday 5 September 2019 11:30 (35 minutes)

The 0^+ excited state of ^{12}C at 7.65 MeV is named after Sir Fred Hoyle, who proposed its existence in order to account for stellar abundances of carbon [1,2]. Aside from this astrophysical significance, it is thought to possess a curious α-cluster structure. However, many questions still remain. To what extent can this state be described as three interacting α-particles, and if so, what geometric configuration do they take — a linear chain, equilateral triangle or something in-between? Is it that the bosonic nature of the α-particle dominates the dynamics of this nucleus meaning that it could be the nuclear analogue of a Bose Einstein Condensate?

Since its discovery [3], measurements of the Hoyle state excitations and radius have provided indirect insights into its structure [4]. However, another way to examine its structure could be to examine the energy distributions of the α-particles emitted during its rare three-body direct break-up [5]. Their relative energies in the final state could reflect the initial structure. Previous studies have set an upper limit on the branching ratio for the direct break-up process at 0.2\% [6].

We present a recent high statistics, low background measurement of the 3α decay of the Hoyle state \cite{Seven}. The ^{12}C(α,α)3α reaction at 40 MeV beam energy was measured using the Birmingham MC40 cyclotron. The particles were detected in complete kinematics and the upper limit on the direct break-up branching ratio was lowered by almost an order of magnitude compared with previous measurements. This places it below what is predicted by a number of theoretical models, opening new intriguing questions about the structure of this important state.

I will finally discuss the Optical Readout Time Projection Chamber (O-TPC) at HIγS [8] and the previous determination of the direct 3α decay branching ratio of the Hoyle state 2^+ excitation [9]. This has allowed us to extrapolate down in energy and calculate a theoretical upper limit for the direct 3α branching ratio of the Hoyle state.

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Session Classification: Young Researcher's Award Session

Track Classification: Plenary