First Spectroscopy of ^{110}Zr

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The first spectroscopy measurement of ^{110}Zr was performed as part of the SEASTAR campaign in 2015 [1]. This nucleus has been much debated in the literature as its 40 protons and 70 neutrons correspond with magic numbers of both the harmonic oscillator and tetrahedral symmetry. Whether or not signatures of these symmetries emerge in the structure of ^{110}Zr is key information to help constrain our understanding of shell evolution far from stability. Furthermore, a stabilization effect associated with these magic numbers at ^{110}Zr has been proposed in the literature as a potential explanation of deficiencies in r-process simulations near mass 110[2].

The experiment was performed at the RIBF using a 30 pnA ^{238}U primary beam at 345 MeV/nucleon. ^{111}Nb was produced via in-flight fission on a thin Be production target at the F0 focal plane of the BigRIPS spectrometer, and focused onto a 10 cm thick liquid hydrogen target at F8 with an intensity of 20 particles per second. ^{110}Zr was produced via proton knockout in the MINOS[3] hydrogen target, emitted gamma rays were detected with the DALI2 array, and the MINOS TPC[3] tracked the outgoing protons to provide a precise doppler correction of the gamma rays. The reaction residues were identified in the ZeroDegree spectrometer.

The observed transitions in ^{110}Zr lie close in energy to the Bremsstrahlung background generated from high velocity ions colliding with electrons in the hydrogen target. This Bremsstrahlung component was measured, normalized according to the number of nuclei incident on the target, and subtracted from the gamma ray spectrum. The subtracted spectrum was fit with GEANT4 simulated DALI2 response functions, including lifetime and feeding effects. Gamma-gamma coincidences and systematics in the region were used to identify the three visible transitions as the $2^+_1 \to 0^+_1$, $4^+_1 \to 2^+_1$, and $2^+_2 \to 0^+_1$ transitions, and construct a level scheme consisting of a 2^+_1, 4^+_1, and 2^+_2 at 185(11), 565(21), and 485(11) keV, respectively .

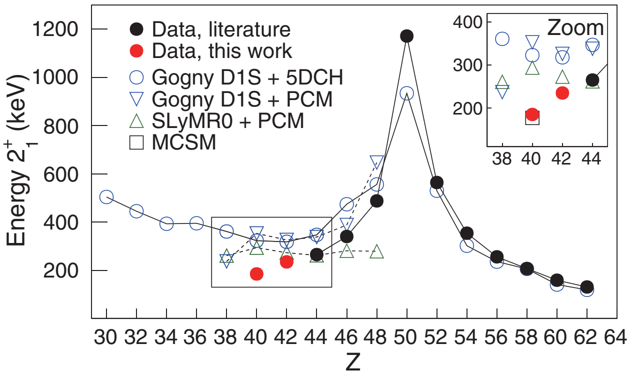

Fig. 1.: E^+_2 systematics for the N=70 isotones compared with theory: 5DCH[4] and PCM[5] with the Gogny D1S interaction, PCM with Skyrme SLyMR0[6], and MCSM calculations[7]. Experimental data are taken from Ref[8] and this work.

These results were compared with state-of-the-art beyond mean field calculations, as well as the most advanced Monte Carlo shell model (MCSM) calculations[7]. E^+_2 systematics are shown in Figure 1. We find that ^{110}Zr shows no increased E^+_2 energy that would indicate a stabilization associated with a spherical or tetrahedral symmetry, but rather it continues the sharp downward trend of E^+_2 energies going towards midshell. The $R_{42} = E^+_4/E^+_2$ ratio for this nucleus is 3.1(2), approaching the rigid rotor value of 3.33. Both these trends are even more pronounced than predicted by beyond-mean-field calculations. MCSM calculations provide the best agreement with our data. The constructed level scheme is not consistent with a tetrahedral symmetry in the ground state. Thus our data shows that ^{110}Zr is a well deformed nucleus with no indications of special stability either isotonically or isotopically associated with its 40 protons and 70 neutrons. This result also discredits a stabilized ^{110}Zr as an explanation for the r-process model deficiencies near mass 110.

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