Low-lying Level Structure of ^{94}Zr: Puzzling Past and Exciting Present

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Introduction

The low-lying level structure of ^{94}Zr was recently studied at the University of Kentucky Accelerator Laboratory with the $(n,n'\gamma)$ reaction, and lifetimes were obtained for the majority of the levels up to about 3.5 MeV in excitation [1]. A remarkable outcome from this study was that the measured lifetime for the 2_2^+ state, found to be 183^{+13}_{-12} fs, yielded a $B(E2)$ value for the $2_2^+ \rightarrow 0_1^+$ transition about 1.5 times larger than that for the $2_1^+ \rightarrow 0_1^+$ transition, thus making this a unique case among even-even nuclei. Recent results obtained in subsequent measurements in other laboratories using different probes [2] indicate that the value of the lifetime for the state must be somewhat larger than reported in Ref.[1]. This discrepancy motivated our remeasurement of the lifetime for the 2_2^+ state in ^{94}Zr using the $(n,n'\gamma)$ reaction, and an extensive set of measurements was conducted.

Due to the geometrical constraints of the large samples typically used in $(n,n'\gamma)$ experiments, it is possible to miss low-energy, low-intensity γ rays, which may reveal additional interesting structural insights in this semi-magic nucleus. Therefore, a high-statistics measurement of $\gamma - \gamma$ coincidences following the decay of ^{94}Y into ^{94}Zr was also carried out at TRIUMF in Vancouver, Canada.

Experimental Procedure and Results

A. Inelastic Neutron Scattering at the University of Kentucky Accelerator Laboratory

Measurements of the lifetime of the 1671-keV 2_2^+ state with the DSAM method using various scattering samples of natural isotopic composition are currently underway, and revised level lifetimes in this nucleus will soon be available. Our preliminary analysis indicates that the new lifetime value of the 1671-keV level will be significantly longer than that reported in Ref.[1], which will reduce the value of the $B(E2)$ for the $2_2^+ \rightarrow 0_1^+$ transition.

B. β^- Decay of ^{94}Y at TRIUMF

A study of the β^-decay of ^{94}Y ($T_{1/2}$ = 18.7 minutes) with the 8π array (consisting of

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20 Compton-suppressed HPGe detectors) was undertaken to obtain a fuller characterization of the low-lying levels of ^{94}Zr. Representative

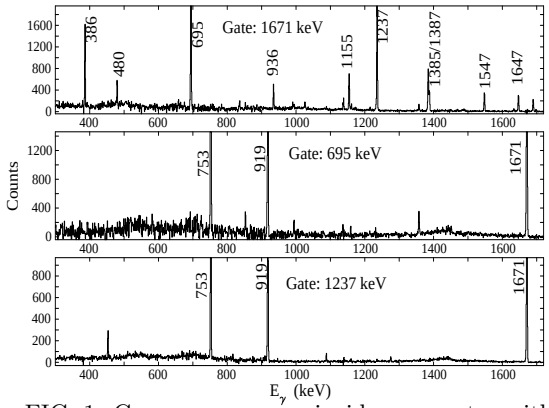

FIG. 1: Gamma-gamma coincidence spectra with gates set on specific γ rays of interest. The 371-keV γ ray from the 1671-keV level cannot be seen with gates on the intense γ rays at 695 and 1237 keV feeding the 1671-keV level because of its very low draining intensity [3]. However, this γ ray is clearly visible (see Fig. 2) when gating from below the level.

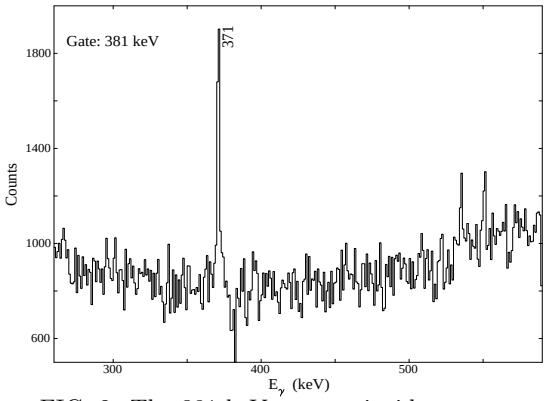

FIG. 2: The 381-keV γ-ray coincidence gate provides distinct evidence for the existence of the weak 371-keV decay branch.

gated γ-ray spectra are shown in Figs. 1 and 2. The newly observed 371-keV transition from the 1671-keV level (see Fig. 3) with 0.1% intensity is clearly visible in Fig. 2. The observation of this weak decay branch, which carries a significant amount of collective strength, provides evidence for the existence of a deformed band built on the 0_2^+ state at 1300 keV and may represent the first observation of an excited deformed band coexisting with the nearly spherical ground state of a semi-magic nucleus like ^{94}Zr. These new results from radioactive decay, in combination with the revised lifetime value of the 1671-keV level, lead to a new interpretation of the low-lying nuclear structure of ^{94}Zr and should facilitate a better understanding of the role of sub-shells in shape coexistence.

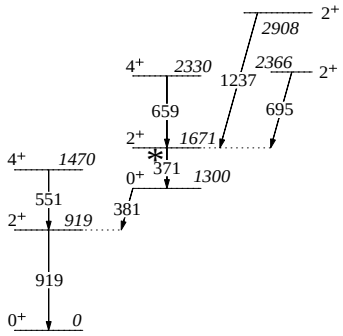

FIG. 3: Partial level scheme showing the different structures in ^{94}Zr. The newly observed transition has been marked with $*$.

Acknowledgments

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References

[1] E. Elhami *et al.*, Phy. Rev. C. **78**, 064303 (2008).
[2] M. Scheck and V. Werner, private communications.
[3] W.D. Kulp *et al.*, Phy. Rev. C. **76**, 034319 (2007).