Fast Timing Lifetime Measurements of 2_1^+ States in Hf Isotopes

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We propose to measure the lifetimes of first excited 2^+ states in the stable Hf isotopes via fast-timing using the ROSPHERE array of HPGe and $LaBr_3$ detectors. With Coulomb excitation as the excitation mechanism, only the population of states within the ground state band is expected, yielding spectra which allow for clean gates using the $LaBr_3$ scintillators. Literature data from a number of different experiments suggest a saturation of B(E2) excitation strength at mid-shell, that is at ^{176}Hf. A recent remeasurement of the 2_1^+ lifetime in ^{172}Hf at WNSL led to a significant increase of its B(E2) excitation strength. Hence, we propose to measure the 2_1^+ lifetimes near the N=104 mid-shell within the same experiment, using the same technique for all, with nowadays dramatically increased sensitivity, to provide a stringent test for the B(E2) saturation at N=104.

I. SCIENTIFIC MOTIVATION

In a number of isotopic chains crossing N=104, a saturation of B(E2) excitation strength around mid-shell has been identified [1, 2], indicating a slowed growth of collectivity when

approaching mid-shell. A qualitative reason for this evolution was found [1] in the occupation of proton and neutron orbitals with large differences in spin, hence, small overlap between both near mid-shell. Microscopic calculation using a projected shell model approach [2], as well as the use of effective boson charges (fractional filling) within the interacting boson model (IBM) [1], were also able to reproduce data.

However, much data on 2_1^+ lifetimes in this region (typically on the order of ns) stems from times when detection efficiencies, as well as the resolutions of scintillators used for fast timing measurements, were quite limited. In recent experiments at WNSL [3] and Cologne [4, 5] several lifetimes in the W isotopic chain have significantly been revised, leading to a very different picture of B(E2) evolution in that isotopic chain. Another measurement at WNSL led to a significant increase of the B(E2) strength in ^{172}Hf, compared to literature data. In fact, that measurement placed the data point for ^{172}Hf precisely on the prediction of the ordinary IBM, in which B(E2) values show a near-parabolic rise toward mid-shell, where they peak due to the maximum valence space. The left panels of Fig. 1 show the evolution of data in the Hf isotopic chain, indicating the new value for ^{172}Hf, in comparison to an ordinary IBM and an IBM calculation using effective boson numbers.

At this point, data seem to indicate a considerable attenuation of B(E2) strength at mid-shell. However, not only have recent measurements using fast timing with $LaBr_3$ scintillators or electron spectrometers significantly changed literature data in this mass region, in the W isotopic chain the new B(E2) systematics revealed a picture very different from a maximum valence space at mid-shell. Namely, B(E2) values indicate a possible change in structure at N=98. Moreover, no saturation effect is apparent in the recent W data, (re-)measured with modern techniques (Fig. 1, right panels).

We propose to remeasure B(E2) excitation strengths of the stable Hf isotopes around mid-shell, using the powerful array of $LaBr_3$ scintillators at IFIN-HH. Literature data on ^{174}Hf, compiled in the NNDC data base, shows conflicting 2_1^+ lifetime values from fast timing (average 1.66(6) ns) and Coulomb excitation (1.38(9) ns), all determined in the 60's and early 70's. Lifetime values in $^{176-180}$Hf are from the late 50's and early 60's. With nowadays much improved detection techniques, far less prone to systematic error (e.g., from Compton background or other contaminants in time gates), a far more stringent test of the B(E2) evolution in Hf isotopes is possible. The good energy and time resolution of $LaBr_3$ detectors will allow clean gates on well-separated peaks, as well as reliable random subtraction. Should

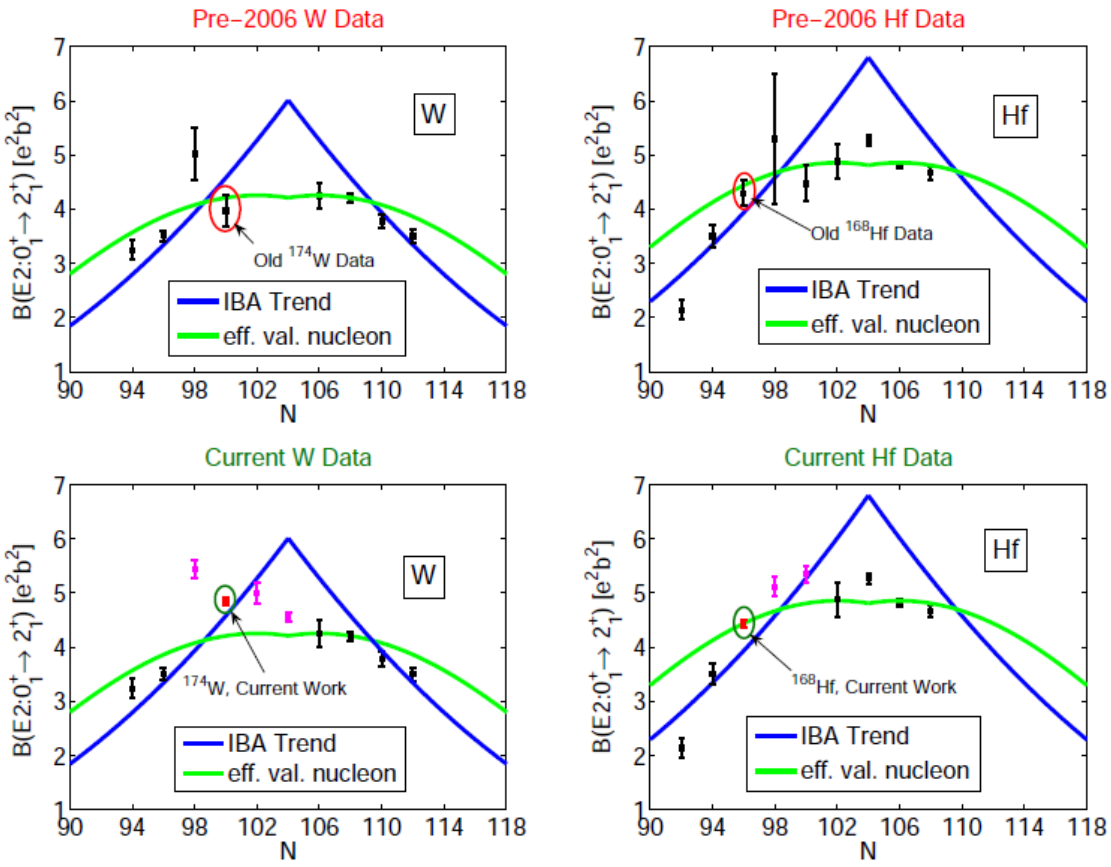

FIG. 1: Systematics of B(E2) excitation strengths to the 2_1^+ state in the W and Hf isotopic chains. The top panels include data that has been listed prior to 2006, the bottom two panels include the newly remeasured values. Red points, marked with a circle, are the B(E2) values measured at WNSL, magenta points are from recent data from Cologne and Stony Brook [4–6]. The curves are only given for qualitative comparison with the collective IBM; the blue curves illustrate the expected maximization of E2 strength at mid-shell, the green curves take into account fractional filling.

any contaminant peaks appear, an additional gating condition on the HPGe array can be used to eliminate them.

In addition to the fast timing measurement for the 2_1^+ state, we expect to observe the ground state bands at least up to spin 6^+, and will be able to measure B(E2) strengths from Coulomb excitation, relative to the B(E2) strength from the 2_1^+ state which we will derive from the direct lifetime measurement. B(E2) values within the ground state band of ^{174,176}Hf (except for that from the 2_1^+ state) are unknown to date.

II. EXPERIMENTAL DETAILS

We propose to use an ^{16}O beam at an average energy of 55 MeV (varies within few MeV for the different isotopes) to impinge on targets of isotopically enriched $^{174-180}$Hf. Targets of about 5 mg/cm^2 thickness will be provided by the collaboration. The Coulomb excitation cross section of the 2_1^+ states in these isotopes is estimated to 1-2 b from literature data, and the cross section of the 4_1^+ state is about 100 mb. Even though cross sections of higher-lying states fall off quickly, some of those states (6_1^+, 8_1^+) should be should be observed in the highly efficient ROSPHERE array. γ-rays from the 2_1^+ and 4_1^+ states will be observed by the array of $LaBr_3$ detectors and serve as start (stop) signals for the direct lifetime measurement of the 2_1^+ states.

Further E2 matrix elements within the ground state band will be determined from the Coulomb excitation mechanism, relative to the independently measured B(E2) from the 2_1^+ state. To achieve sufficient statistics in the scintillator time-difference spectra, as well as in the HPGe spectra, we request 3 days of beam time per isotope, hence, a total of **12 days beam on target**. Calibrations can be done during beam preparation at the beginning of the measurement of each isotope with standard sources.

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