Interpretation of New High-Spin Rotational Sequences in ^{168}W

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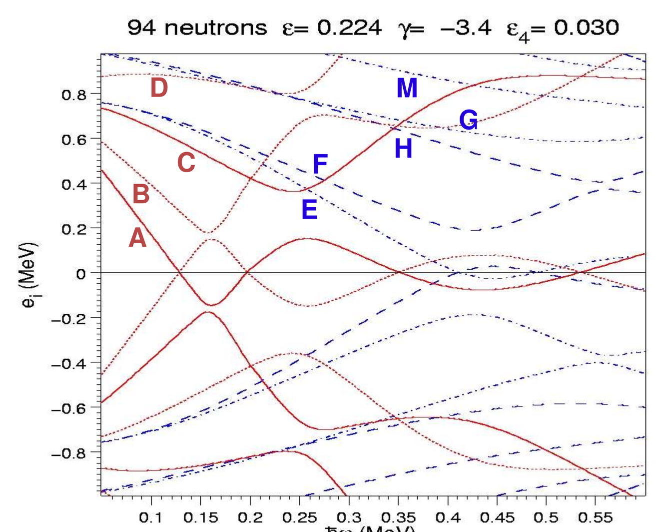
Abstract

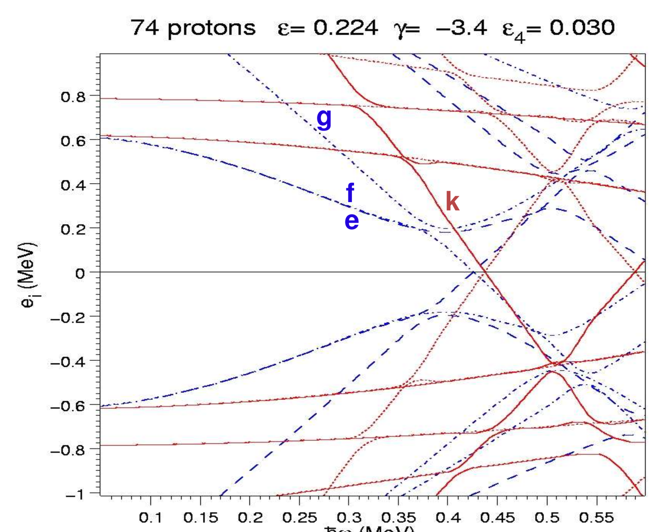
Rotational sequences in the ^{168}W nucleus were studied with data from the ^{118}Sn(^{55}Mn,*p*4*n*) reaction, produced at 260 MeV as part of the GSFMA247 experiment conducted at Argonne National Laboratory. This data set yielded a multitude of new findings for ^{168}W, including 8 new bands and over 90 new transitions. These new structures are interpreted within the framework of the cranked shell model, and tentative configuration assignments along with methods of identification are discussed.

Introduction:

Research into the structures of rare-earth nuclei produced at high excitation energies and rotational frequencies is part of an ongoing effort to investigate the roles of collectivity and deformation on nuclear structure evolution. While many experiments focus on producing nuclei at higher and higher excitation energies, where collective rotation can break down and more exotic excitation modes may take over, it is still important to understand the low- to medium-spin behavior of nuclei in order to properly interpret more and more non-yrast configurations. The first three to four configurations are usually very easy to identify, especially with the abundance of data provided by modern detector arrays like Gammasphere, however more non-yrast configurations are much more difficult to properly identify and a combination of techniques must be used in order to assign configurations to these structures with any degree of certainty.

Discussed herein are a combination of such techniques used to identify the newly observed structures in ^{168}W.



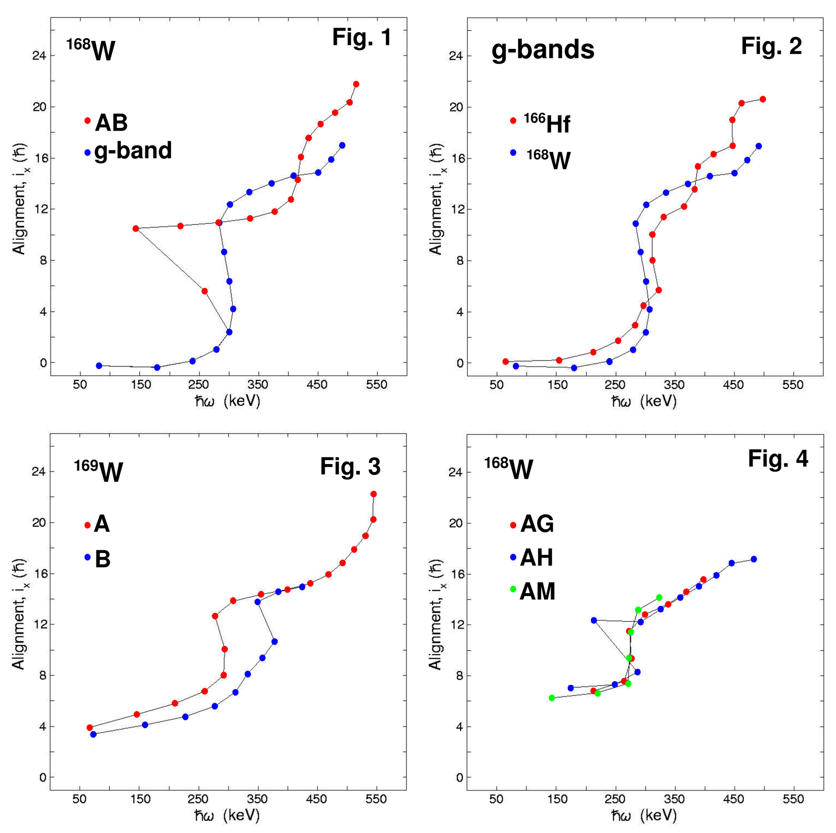


S.S.M. States	Nilsson orbitals	α = +1/2	α = -1/2
$\nu i_{13/2}$	$\nu[642]5/2^+$	A	B
$\nu i_{13/2}$	$\nu[651]3/2^+$	C	D
$\nu h_{9/2}$	$\nu[523]5/2^-$	E	F
$\nu f_{7/2}$	$\nu[521]3/2^-$	G	H
$\nu p_{3/2}$	$\nu[521]1/2^-$	M	

S.S.M. States	Nilsson orbitals	α = +1/2	α = -1/2
$\pi h_{11/2}$	$\pi[514]9/2^-$	e	f
$\pi h_{9/2}$	$\pi[541]1/2^-$	g	
$\pi i_{13/2}$	$\pi[660]1/2^+$	k	

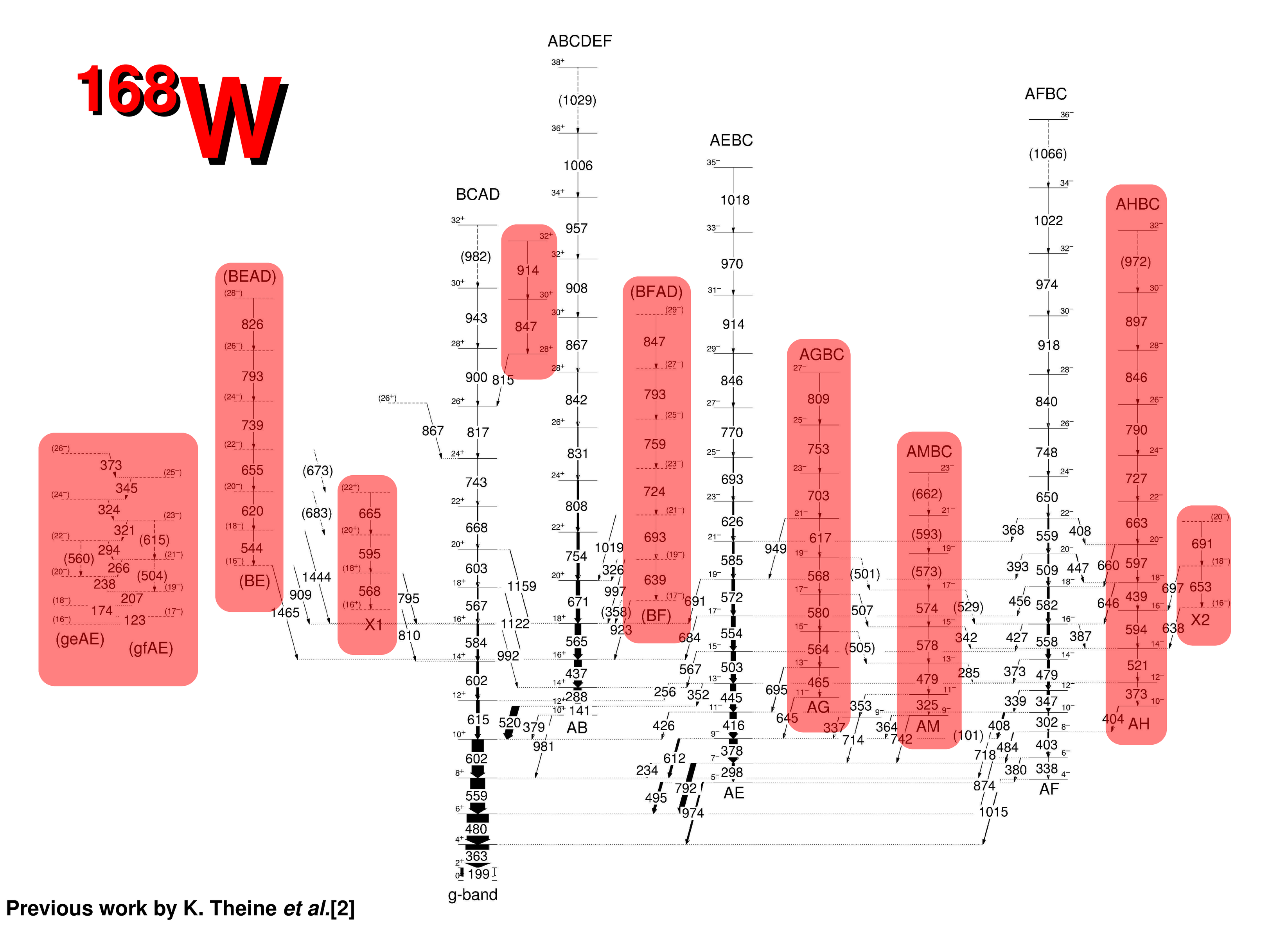
Theoretical Calculations:

The first step in identifying new sequences comes in determining what, if any, quasiparticle crossings are observed, as well as what nearby orbitals are not already represented in the nucleus. Theoretical crossing frequencies are obtained by examining the routhians (see figures and tables above) yields insight into what orbitals should have well represented signature partners (e.g. E and F, and G and H) and what orbitals exhibit significant signature splitting, (e.g. A and B, and M and N(unlabeled)). The alignment plots (shown below) can be examined to estimate the experimental crossing frequencies of the various quasiparticle bands. In general, one should establish a metric of expected crossing frequencies based on stronger bands, either from the nucleus in question or from its nearest isotopes/isotones. These expected crossing frequencies can then be used to help identify what crossings, if any, are present in newly observed structures. Great care had to be taken in the case of the BC and AD crossings in ^{168}W since in the continuation of the ground band both crossings occur simultaneously, and in the first two negative parity bands coupling occurs to octupole vibrational bandheads that could alter the BC crossing frequency. In this case, the BC and AD crossings in ^{169}W[3] and ^{166}Hf[4] were used to assist in identification



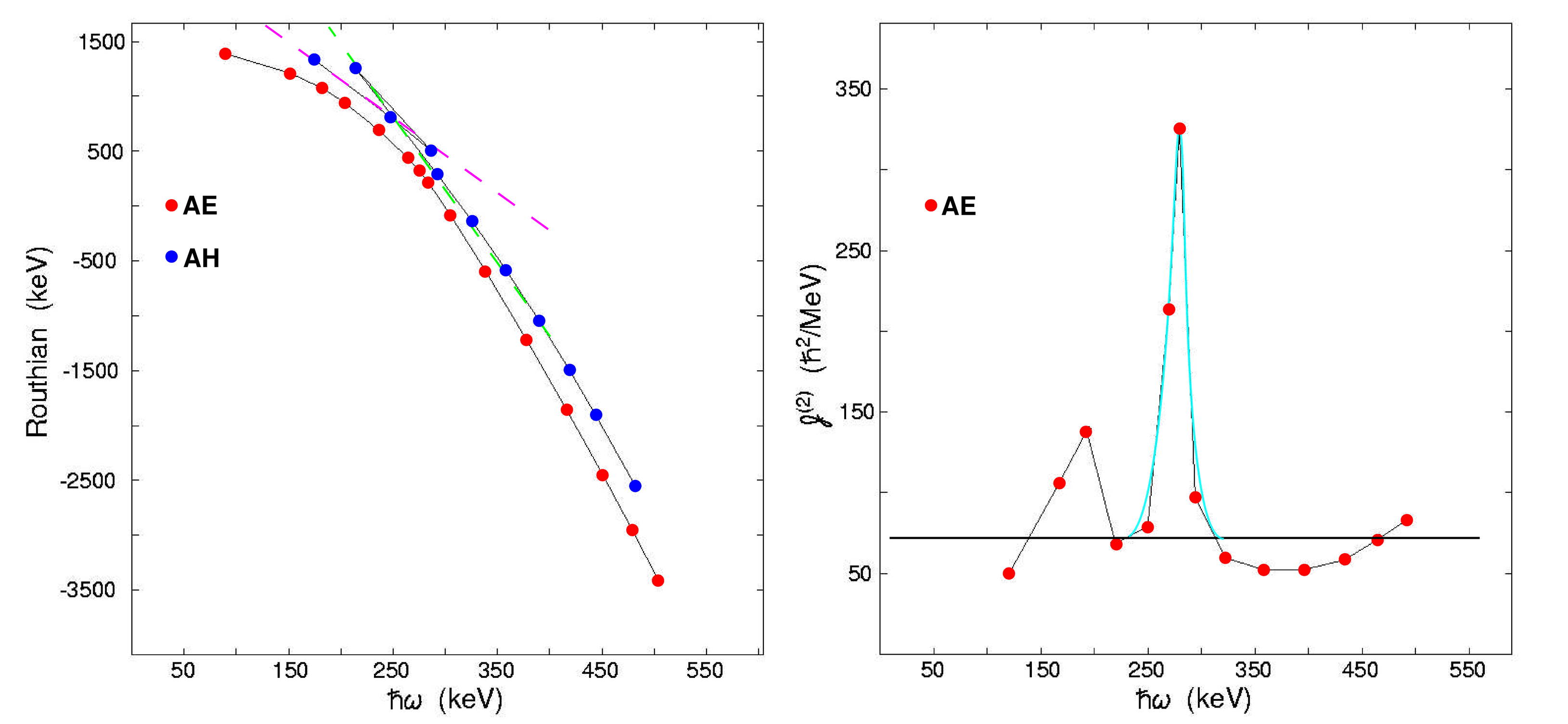
Alignment Plots:

Figure 1 shows the alignment plots for the ground band and the AB band in ^{168}W. The simultaneous BCAD crossing is clearly evident in the ground band, especially when compared in Figure 2 to the discrete BC and AD crossings seen in ^{166}Hf. From this figure, and the BC and AD crossings observed in the A and B bands of ^{169}W, shown in Figure 3, estimates of the locations of the AB, BC, AD, and CD crossing were determined. The alignment plots are useful in determining what bands see the same crossing (e.g. Figure 4) but the exact crossing frequencies can not be measured from these figures so other techniques, such as routhian and dynamic moment-of-inertia analysis, were employed.



Previous work by K. Theine *et al.*[2]

Current level scheme for ^{168}W, including tentative configuration assignments for all identified rotational bands. New sequences are highlighted in red.

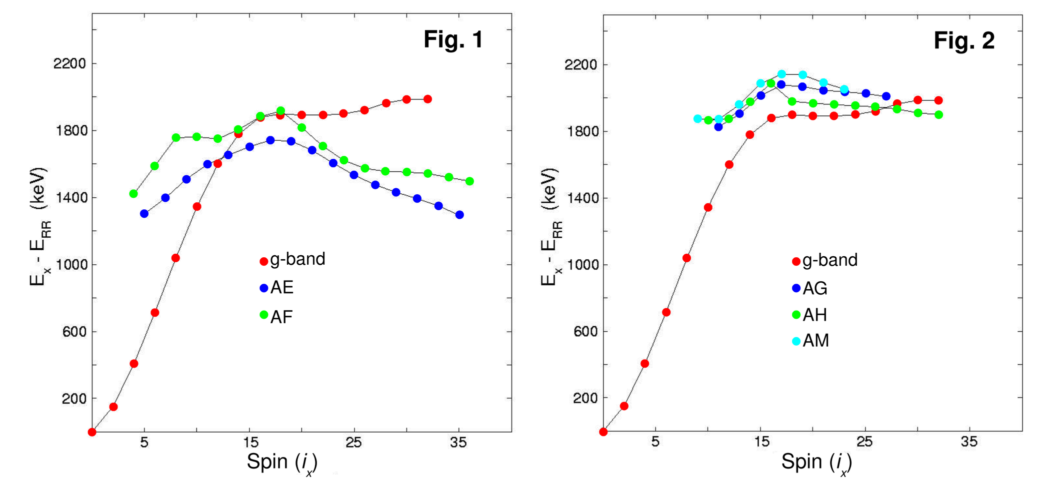


Routhians and Dynamic Moment-of-Inertia:

The left figure shows the energy routhians for the AE and AH bands in ^{168}W. When a configuration experiences a quasiparticle crossing, it's routhian changes orientation to match that of the new structure. For example, when the AH configuration experiences the BC quasiparticle excitation, it's routhian will change to that of the AHBC configuration. For bands that undergo pronounced backbending, like the AH band in ^{168}W, this crossing is visibly evident in the routhian diagram and the point of intersection of the two configurations denotes the crossing frequency of the excitation. The presence of pronounced backbending in only one of two signature partners appears not only here in ^{168}W but also in the negative parity bands of the odd-N channel, ^{169}W, and is the result of a signature-dependent interaction strength. When there is a more gradual change in alignment (e.g. band AE) the point of intersection cannot be readily observed. It is possible to do a linear regression-style fit to attempt to find it, however a more accurate way of determining the crossing frequency in this case lies in the analysis of the dynamic moment-of-inertia ($J^{(2)}$) of the structure[5]. For gradual changes in alignment, this plot produces a well defined peak which can be modeled with a Gaussian-like approximation in order to extract the centroid which corresponds to the crossing frequency of the quasiparticle excitation. The right figure shows such a fit for the upbend observed in the AE band in ^{168}W. The smaller peak just prior to it is the result of decoupling from an octupole vibrational bandhead.

Excitation Energies:

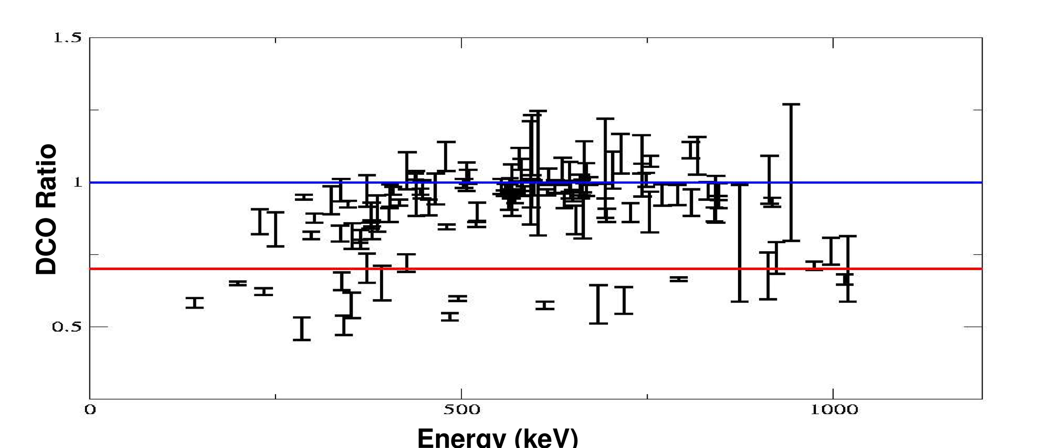
When one observes two new, nearly identical bands, merely knowing their respective crossing frequencies is not enough to give distinct identifications to the pair. In most cases these bands will correspond to a pair of signature partners, however sometimes more then two nearly identical bands may be present (e.g. bands AG, AH, and AM in ^{168}W). In order to provide separate identications to these structures, it becomes necessary to examine their relative excitation energies and compare them to the theoretically predicted values that come from the cranked shell model. Theoretical calculations for N=94 neutrons predict a favoritism of the E signature over the F signature. Bands built on the E signature rather then the F signature will as a result have a lower total excitation energy. Figure 1 (below) shows such an affect seen in the AE and AF bands in ^{168}W. Similarly, the H orbital is calculated to lie slightly lower in excitation then the G orbital, with both being slightly lower then the M orbital. This phenomenon was also clearly observed in the odd-N channel, ^{169}W[3]. These relative excitation energy predictions were used to help assign configurations to the AG, AH, and AM bands in ^{168}W based on the experimental values seen in Figure 2.



Excitation energy plots minus a rigid-rotor reference of 7.8*I*(*I*+1) for the AE and AF bands (Fig. 1) and the AG, AH, and AM bands (Fig 2.). In both figures the ground band is used as a reference.

DCO Ratios:

The final stage of the analysis performed was the measurement of the angularly dependency of transitions. This is very helpful in confirming spin and parity assignments of new bands, and can be used to rule out certain configurations in tentative bands. One takes a selection of detectors at backward angle and mid-angle, and normalizes their respective spectra so that the ratio of their intensities for known E2 transitions is equal to 1. A a result, most E1 transitions will have a normalized ratio close to 0.7. The chart below shows the calculated DCO ratios (with error bars) versus energy for 168W, with highlighted standard values for E1 (red) and E2 (blue) transitions.



Future Work:

A paper is currently in the works which includes the updated ^{168}W and ^{169}W analysis performed using data obtained from GSFMA247 as part of a collaborative search for triaxially strongly-deformed structures in N ≈ 94 Re and W nuclei. A second, similar experiment, GSFMA281, was also conducted and data obtained from it will be used to analyze N ≈ 96 Re and W nuclei.

Acknowledgments

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