Study of the Order-to-Chaos Transition in $^{174}$W with the AGATA-Demonstrator

V. Vandone$^1$, S. Leoni$^1$, G. Benzoni$^2$, N. Blasi$^2$, C. Boiano$^2$, S. Bottini$^1$, A. Bracco$^1$, S. Brambilla$^1$, A. Corsi$^1$, F.C.L. Crespi$^1$, A. Giaz$^2$, B. Million$^2$, R. Nicolini$^1$, O. Wieland$^1$, D. Bortolato$^3$, E. Calore$^1$, A. Gottardo$^3$, D.R. Napoli$^2$, E. Sahin$^3$, J.J. Valiente Dobon$^3$, B. Million$^2$, E. Farnea$^4$, S. Lunardi$^4$, D. Mengoni$^4$, A. Giaz$^2$, D. Bortolato$^3$, E. Farnea$^4$, S. Lunardi$^4$, D. Mengoni$^4$, A. Giaz$^2$, D. Montanari$^5$, F. Recchia$^1$, C.A. Ur$^4$, A. Gadea$^5$, T. Huyuk$^5$, N. Cieplicka$^6$, A. Maj$^6$, M. Kmiecik$^6$, A. Atac$^7$, S. Akkoyun$^7$, A. Kaskas$^7$, S. Ketenci$^8$, J. Nyberg$^9$, P.A. Söderström$^9$

1 Università degli Studi e INFN, sezione di Milano, Milano, Italy. 2 INFN, sezione di Milano, Milano, Italy. 3 INFN, Laboratori Nazionali di Legnaro, Legnaro, Italy. 4 Università di Padova e INFN, sezione di Padova, Padova, Italy. 5 IFIC, Valencia, Spain. 6 The Niewodniczanski Institute of Nuclear Physics, PAN, Krakow, Poland. 7 Dept of Physics, Faculty of Science, Ankara University, Ankara, Turkey. 8 Dept of Physics, Nige University, Nige, Turkey. 9 Dept of Physics and Astronomy, Uppsala University, Uppsala, Sweden.

The transition between order and chaos in a quantum mechanical system is a subject that is investigated in different research fields, including nuclear physics. In the case of the nuclear system, close to the yrast line (at temperature $T \sim 0$), the nucleus behaves as an order quantum-mechanical system with well-defined quantum numbers and associated selection rules. Moving toward higher excitation energy, energy levels start to interact giving rise to a gradual loss of selection rules and quantum number. The extreme regime is the chaotic region of the compound nucleus, where only energy, spin and parity are well defined for each energy level. A useful probe to study the weakening of the selection rules with temperature is the $K$-quantum number, i.e. the projection of the total angular momentum on the symmetry axis. In particular, by studying the $\gamma$-decay flow in the large region between the cold regime close to the yrast line and the chaotic compound nucleus, information on the order-to-chaos transition can be obtained [1,2,3].

An interesting case is the nucleus $^{174}$W [3] which is characterized by the existence of low-$K$ ($K\sim3-4$) and high-$K$ ($K\sim8-12$) rotational bands extending up to spin $\sim39h$, with two high-$K$ bands ($K=8$ and $K=12$) built on isomeric states with lifetime larger than 120 ns.

In this Report we present preliminary results from an experiment performed in July 2010 at Legnaro National Laboratory aiming at studying the $\gamma$-decay flow of the warm rotating $^{174}$W nucleus.

The $^{174}$W nucleus has been populated by the fusion-evaporation reaction of $^{50}$Ti (at 217 MeV) on a $^{128}$Te target (1 mg/cm$^2$ thick backed by 50 mg/cm$^2$ of natPb). The experimental setup consisted of four triple clusters of the AGATA HPGe-array placed at 16 cm from the target (with an absolute efficiency of $\sim$5% at 1.3 MeV), coupled with an array of 27 BaF$_2$ scintillator detectors (named Helena), covering $\sim$25% of the total solid angle. Figure 1 shows a picture of the experimental setup. The experiment has been performed with an average current of 1 pA (in order to prevent target damage), requiring as trigger conditions either four-fold events in AGATA or three-fold events in AGATA in coincidence with at least one event in Helena. Typical count-rates were $\sim$1.5 kHz for AGATA and $\sim$1 kHz for the scintillator array. In approximately one-week experiment the total amount of collected data was roughly 40 TB.

Fig. 1. The experimental setup used in the $^{174}$W experiment, comprising four triple clusters of AGATA (in the back of the picture) and an array of 27 BaF$_2$ detectors, grouped in five clusters (8+8+4+4+3 detectors).

The data analysis has mainly focused, so far, on the presorting of the data: all AGATA detectors have been carefully calibrated in energy over a 20 MeV range, making use of an AmBe(Ni) source which provides calibration lines up to 9 MeV. The AGATA detectors are found very stable over the entire experiment, with gain fluctuations within 3%. In addition, time difference spectra between the 12 AGATA detectors have been constructed and carefully aligned, resulting in a time resolution of the order of 20 ns. A tracking algorithm has been applied to
the calibrated Ge energies in order to reduce the Compton scattering and improve the peak-to-background of the Ge array. In figure 2 we show a comparison between a γ-ray spectrum constructed using only the core electrode signals (raw data) and the energy spectrum obtained after applying the tracking procedure [4].

Fig. 2. Comparison between γ-ray spectra before and after the γ-ray tracking procedure. The strong peaks correspond to the γ-transitions of the yrast line of 174W. The inset shows the Ge fold distribution.

One can notice the large reduction of low-energy background events, resulting in a significant improvement of the peak-to-background ratio. The inset of figure 2 shows the Ge fold distribution, which is found to be peaked around 3, an essential requirement for the subsequent analysis of the data.

The Helena BaF2 detectors have also been calibrated in energy (making use of 137Cs, 60Co and 88Y sources) and their time spectra (constructed with respect to the trigger signal) have been aligned to each other. Figure 3 shows a typical BaF2 time spectrum, evidencing the regions of prompt and delayed γ events, the latter ones being mainly associated to high-K transitions built on isomeric states.

To enhance the selectivity to the 174W nucleus and to focus on the high-multiplicity and high-energy part of the γ-cascades (where the transition into the chaotic regime is expected to take place) the fold and sum-energy measured in Helena are used. Figure 4 shows projections on the sum-energy and fold distributions of Helena, in coincidence with low spin transitions of 173W and 174W. These are the only two evaporation channels open in the reaction, with relative intensity of the order of 50% and 40%, respectively. As expected, the sum-energy and fold distributions associated to 174W are peaked at higher values, indicating the possibility to favor the selection of this type of events by requiring a high-fold and high-sum energy gating condition.

The future analysis of the data will require the construction of γ-γ matrices gated by low-K and high-K structures and their analysis by statistical fluctuation techniques [5]. This will allow to estimate the number of low-K and high-K bands and their correlations (as a function of excitation energy), which are key quantities for the understanding of the transition between order and chaos in the atomic nucleus [6].