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First Measurement of the Degree of Fragmentation of the Decay Out Cascade from the Superdeformed Yrast Band in ^{192}Hg

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Abstract

The decay spectrum of the yrast superdeformed band in ^{192}Hg comprises a quasicontinuum with discrete lines ranging from 1 to 3.2 MeV . The intensity fluctuations of this quasicontinuum give information on the degree of fragmentation of the decay cascades and on the effect of pairing correlations on the level density ρ(U) in the normal deformed well ($0 < U < U_{SD}$).

As was explained in the previous talk by Torben Lauritsen, if we compare superdeformed (SD) and normal-deformed (ND) gated spectra in Hg and Pb isotopes, the SD-gated spectrum lies above the ND-gated spectrum for a broad range of transition energies when both spectra are normalised to the same number of γ cascades. This excess intensity has been indentified in previous work [1] to be the spectrum of γ rays connecting the SD to ND states. It is a quasicontinuum with intermediate-width structures. From a quasicontinuum analysis, the excitation energy of the decaying SD state in ^{192}Hg was found to be U=4.3±0.9 MeV above the yrast line [1]. If we zoom in on the decay spectrum, we see that it also contains sharp lines which account for only a few percent of the total decay flux. In ^{192}Hg, for example, 51 resolved lines have been identified [2]. However, no single-step decays could be observed. So far, these have been reported only in 2 nuclei of the mass 190 region: ^{194}Hg and ^{194}Pb [3,4,5].

A quasicontinuum as well as primary and secondary lines are also observed in the γ spectrum following thermal neutron capture. This is further evidence for the stochastic coupling of the localised SD state with highly excited ND states across the potential barrier [6]. So, effectively, it is the statistical decay from the hot ND states which is observed.

What spectrum does one expect in such a decay ?

T. Dossing et al have calculated the spectra corresponding to the statistical decay

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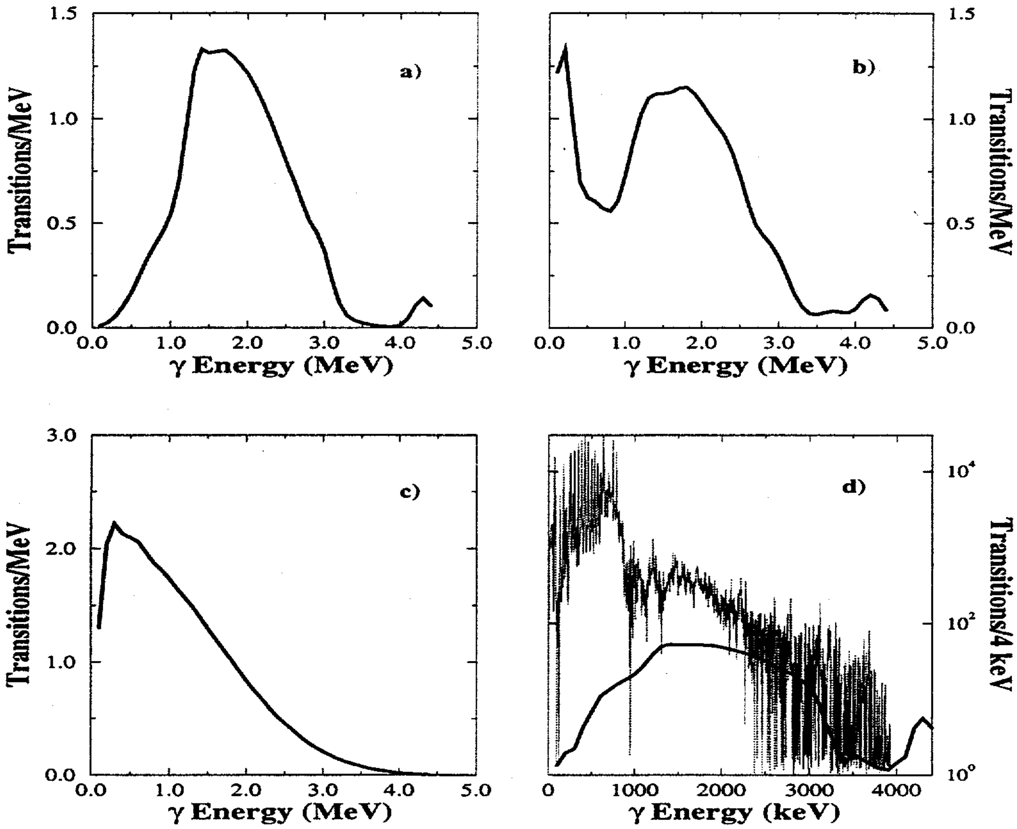

Figure 1: Statistical decay spectra from an initial state at U=4.3 MeV calculated with (a) the paired even-even level density, (b) the paired odd-even level density and (c) the unpaired even-even level density. (d) Efficiency-corrected experimental decay spectrum and calculated decay spectrum from (a)

from a ND state at 4.3 MeV in three different cases [7]. The level densities are obtained by counting quasiparticle energies starting from equidistant single-particle levels, with pairing treated using the BCS method, followed by particle-number projection and diagonalisation. The decay spectra for an even-even and odd-even paired nucleus and for an even-even nucleus without pairing are shown in fig 1a-c. In the unpaired case, the monotonic increase of the level density with excitation energy gives rise to a smooth decay spectrum. In the even-even paired case, there is a depleted yield below 1.2 MeV and between 3.2 and 4 MeV. Both these features are due to the pair gap below the energy for 2 quasiparticle excitations. The compression of the spectrum, together with the last step transitions across the pair gap, give rise to a broad bump centered around 1.6 MeV. For the odd-even case, the filling of the pair gap gives an appreciable yield at low energy. Above 1 MeV transition energy, the best experimental approximation of the spectrum of γ rays feeding the SD band is the ND-gated spectrum stripped of all strong high-energy lines. The difference between the SD-gated spectrum and this smoothed ND-gated spectrum is then the decay spectrum. In fig 1d, the efficiency-corrected decay spectrum is shown together with the calculated spectrum obtained with the even-even paired level density. The qualitative agreement is very good since the calculations reproduce the general shape of the decay spectrum. The model also predicts up to 5% yield at high energy which corresponds to the expected intensity for single-step decays. The fact that this yield varies so much from one nucleus to the other may be due to the chaoticity of the excited decaying ND state, in which case, we would expect the fluctuations in the strengths of the primary γ rays to follow a Porter-Thomas distribution [8].

What can we learn from the decay spectrum ?

If it contains strong sharp lines, we can directly deduce the excitation energy, spin and parity of the SD state. If these lines are too weak, we can carry out a quasicontinuum analysis [9] to extract the average excitation energy and spin of the SD state. With the Fluctuation Analysis Method (FAM), we can extract the effective number of transitions sampled by the nucleus in the decay; in other words, we can measure *the degree of fragmentation of the decay.* As it turns out, this method goes even further and can be used as a new probe of the ND level density up to high excitation energy.

How does it work ?

The aim of the FAM [10,11,12] is to determine the effective number of transitions sampled by the nucleus without knowing the details of the transition energies or transitions strengths involved. This number can be directly extracted from the first (mean) and second (variance) moments (μ_1 and μ_2) of the intensity distribution of the decay spectrum. The method relies on the fact that, below the excitation energy of the SD state at the point of decay, the level density in the 1^{st} well, although large, is finite. If the number of recorded events (N_{evt}) is larger than the number of available transitions (N_t), this will lead to an enhancement of the intensity fluctuations in the decay spectrum above those generated by pure counting statistics. Correction factors have to be added to account for finite detector resolution (p), probable Porter-Thomas fluctuations (2), background subtraction and the separation of true coincidences into 2 components, such as into the SD decay spectrum and the underlying continuous statistical feeding spectrum in the 1 to 3 MeV region of the SD-gated spectrum. One then obtains the following equation for the effective number of transitions:

$$N_t = 2 \times p \times f^2 \times \frac{N_{evt}(A) \times \mu_1(A)}{\mu_2(A) - \mu_1(C) - g^2\mu_1(B)} \qquad (1)$$

Spectrum A = C - gB, where C is the raw spectrum of all the events in coincidence with the SD band and B the appropriate background spectrum scaled by a factor g. Spectrum A needs to be corrected for the detector response [13]. f is the fraction of events belonging to the decay in spectrum A. Fig 2a shows the effective number of sampled transitions as a function of transition energy obtained for the SD decay and feeding cascades in ^{192}Hg studied with the Eurogam 2 array [14]. Above 2 MeV, fewer transitions are sampled by the nucleus in its decay from the SD band. This can be explained by the fact that these transitions are primary γ rays starting off from a few initial states and taking the nucleus down to regions of low level density. Thus, for the decay cascade, the number of transitions is expected to decrease at high transition energy in proportion to the final state level density $\rho(U_{final})$. On the other hand, the feeding cascade starts from a multitude of initial states populated by the neutron decay; in this case, the number of transitions reflects the product of the final and initial state level densities $\rho(U_{initial})\rho(U_{final})$. The low-energy transitions of the

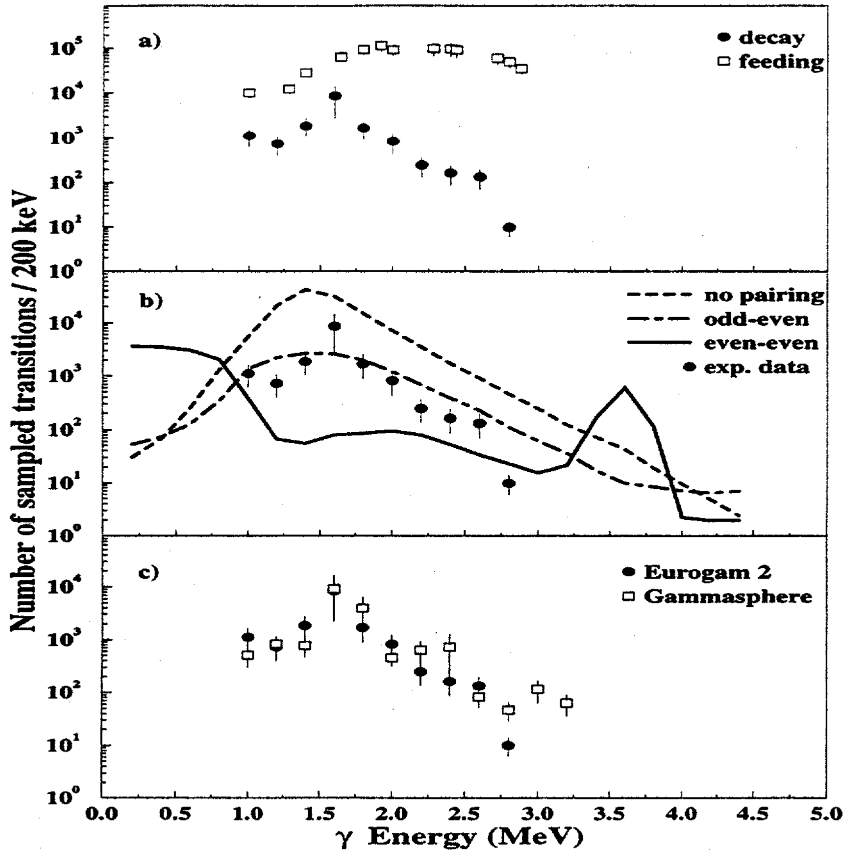

Figure 2: (a) Experimental effective number of transition sampled in the decay and feeding cascades in ^{192}Hg. (b) Calculated and experimental effective number of transitions sampled in the decay cascade. (c) Comparison between the experimental effective number of transitions in the decay cascade obtained with Eurogam 2 and Gammasphere data

decay cascade tend to come from the last decay steps. They connect states in a region of low level density. This explains the initial increase in the number of transitions as a function of transition energy. A total of ~9000 transitions are sampled in the decay out of the SD band in ^{192}Hg. By examining figure 2a above 2 MeV where the first decay steps dominate the fluctuations, one can see that ~1000 transitions are available in the initial stage of the decay [2]. This tells us that the decay is indeed highly fragmented, as expected in a statistical decay. In figure 2b, the experimental effective number of transitions is compared to calculations based on the schematic model described earlier on. The comparison between the experimental data and the calculations is satisfactory and is a stringent test for calculations of the decay and of $\rho(U)$ up to high excitation energy. The fact that the experimental values are in better agreement with the odd-even calculated values may be due to factors that have not been included in the model: first of all, angular momentum which causes the pairing correlations in the even-even nucleus to weaken and hence lowers the ground state

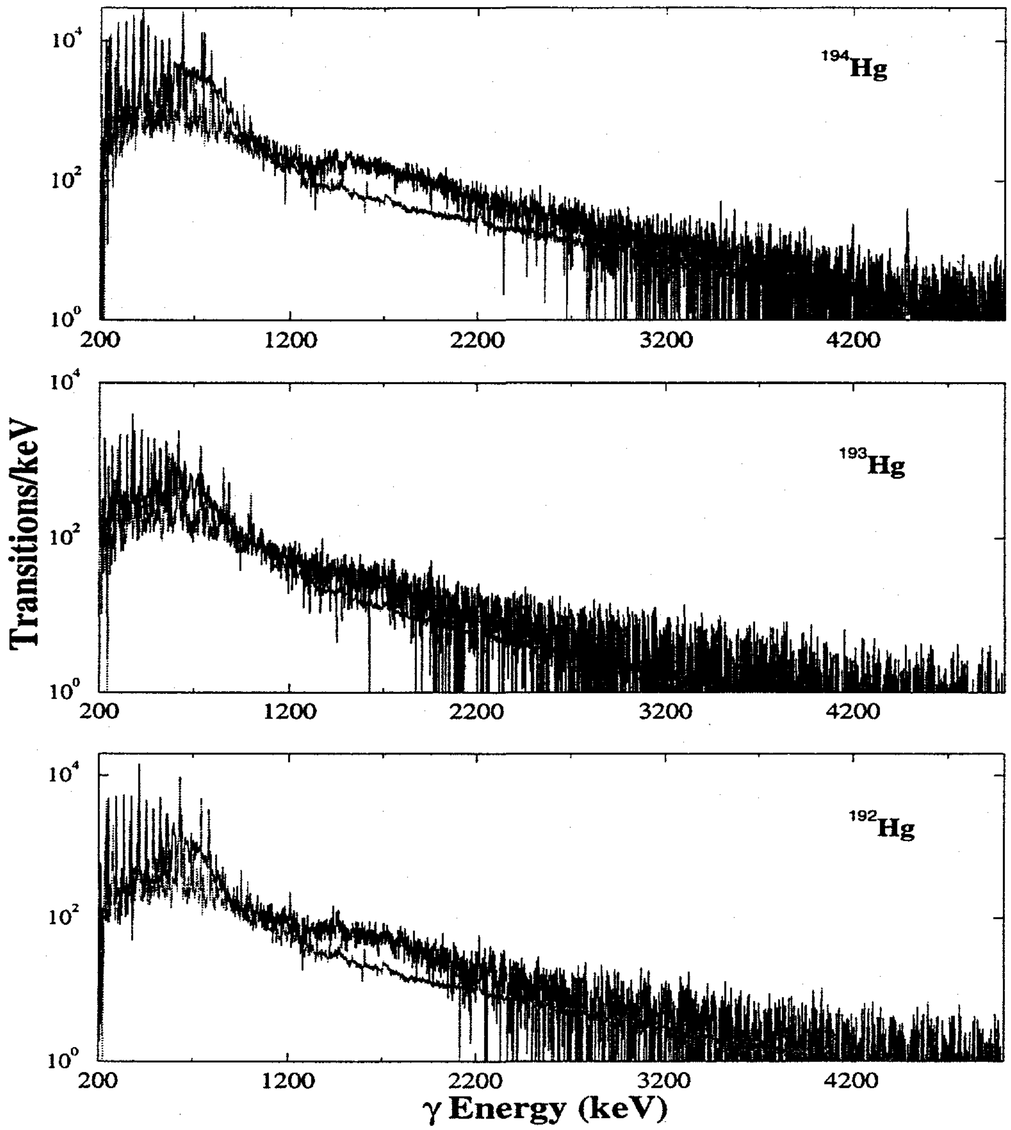

Figure 3: SD and ND-gated spectra obtained in ^{192,193,194}Hg

pairing gap, secondly, symmetries in the nuclear potential and shell effects which may slightly displace both calculated curves. It is essential to carry out a similar analysis on other nuclei and especially an odd-even nucleus of the same mass region. In fig 3 are shown the SD and ND-gated spectra for 3 Hg isotopes studied at Gammasphere [15]. We can immediately see that both even-even nuclei present a more pronounced bump than the odd-even nucleus. A careful inspection of the ^{193}Hg spectra reveals an excess intensity at low energy, as predicted by T. Dossing's calculations. A preliminary Fluctuation Analysis on the ^{192}Hg decay spectrum gives practically an identical distribution of effective number of transitions as the Eurogam ^{192}Hg data. The comparison is shown in fig 2c. The analysis of the ^{193}Hg and ^{194}Hg decay spectra is still in progress.

In conclusion, we have shown that the decay from the SD band in ^{192}Hg starts off from a few initial states and is highly fragmented. We have measured of the order of 1000 different first step transitions. The decay has been shown to be of statistical nature but it remains to be proven that Porter-Thomas fluctuations govern the distribution of the SD intensity among the different decay paths. This can be done by measuring the intensity distribution of the discrete transitions lying above 2 MeV which stem directly from the hot ND states. This analysis could then provide a direct measure of the onset of chaos in excited nuclear states. By studying the various components of the decay spectrum, we are able to extract the fundamental spectroscopic quantities for the SD band, such as excitation energy, spin and parity. These quantities can help us check the assignments of yrast and excited SD bands and measure the mixing of the SD and ND states. We can also study the statistical feeding via the single-step decays. Finally, we have direct access to the ND level density and the quenching of pairing with excitation energy and spin via the Fluctuation Analysis Method. The decay spectrum is thus a very good laboratory for the study of fundamental properties of SD and ND nuclei and the study of the SD-to-ND shape transition.

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