EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Addendum to the IS452 proposal

Measurements of shape co-existence in ^{182,184}Hg using Coulomb excitation

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Abstract

In this addendum we ask for beam time to perform Coulomb excitation of ^{180,182}Hg in order to finish the programme to study the evolution of collectivity and shape coexistence in the neutron-deficient mercury isotopes via Coulomb excitation. The low production yield for ^{182}Hg during the August 2007 run was not sufficient for a measurement of its Coulomb excitation but successful measurements on ^{184,186,188}Hg were performed. The preliminary analysis shows the feasibility to perform these experiments using heavy mass beams at REX-ISOLDE and indicates feeding of other excited states apart from the 2^+_1 state. With this addendum we propose to study ^{182}Hg and, in view of the success of the first experiment, to extend the original proposal to include ^{180}Hg as well. Combined with the data already obtained, the proposed measurement will give quantitative information about the nature of the shape coexistence in these nuclei and will allow the sign of the quadrupole deformation be determined for the ^{180,182,184,186,188}Hg for the first time. We require **24 shifts** to fulfil the aims of the experiment.

Preamble

We propose to measure the transitional matrix element of the very neutron deficient ^{180,182}Hg isotopes. In a recent experiment at the JYFL accelerator centre, the half life of the first 2^+ state of these nuclei has been measured [1]. These results combined with the proposed measurement will allow the sign of the quadrupole moment to be determined as well.
In this addendum we will shortly review the physics case which has not been changed compared to the original proposal [2]. This will be followed by a brief report on the August 2007 run and the status of the analysis. Finally, the specific case for ^{180,182}Hg is made and the beam time request is presented.

Physics Case

The evolution and microscopic origin of quadrupole collectivity and shape coexistence at low excitation energies in neutron mid-shell nuclei near the $Z = 82$ shell closure are still not fully understood (for a recent review, see [3]). The shape coexistence phenomenon in neutron-deficient nuclei close to $Z = 82$ was first observed when isotope shift measurements at CERN for Hg nuclides revealed a sharp transition between ^{187}Hg and ^{185}Hg [4]. This change was interpreted as a transition from a weakly oblate shape [5] to a more deformed prolate structure [6,7]. Nowadays there exists a large body of experimental information supporting the coexistence of different shapes at low excitation energies in mercury isotopes. Similarly, in neutron deficient even-mass Pb isotopes intruder states were first identified in α- and β-decay studies using on-line isotope separators [8]. The low-lying excited 0^+ states associated with weakly deformed oblate proton 2p–2h intruder structures have been observed in α-decay in several Pb isotopes with $N \geq 106$ [9,10], and prolate deformed bands built upon 4p-4h excitations have also been identified in separate experiments (e.g. [11]). The lowest excited states in ^{186}Pb were found to have spin and parity 0+ and are associated with oblate and (predicted) more deformed prolate shape respectively [12].

While much has been learnt in recent years concerning the behaviour of the light Hg and Pb nuclei, several key questions remain outstanding, such as the degree of mixing between the various different configurations. We have embarked on a study of the close to mid-shell nuclei ^{184}Hg where the co-existing configurations lie closest to each other (see figure 1) [3] and have extended this study to the heavier mass ^{186,188}Hg isotopes. These radionuclides are readily obtainable from the REX-ISOLDE facility.

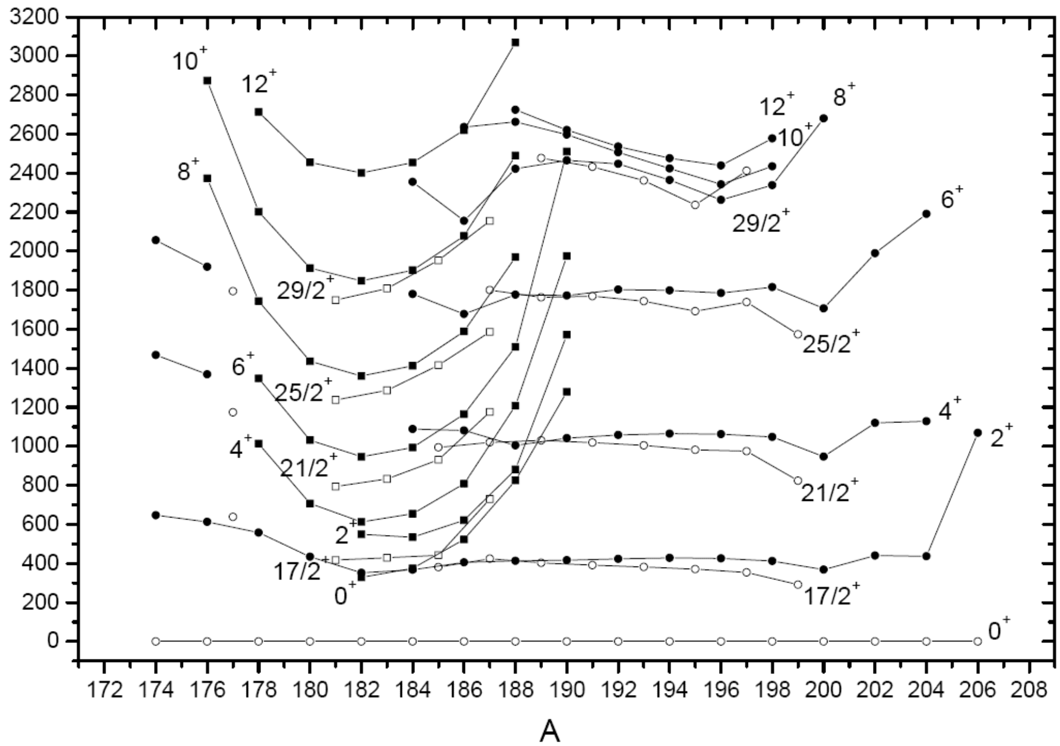

Figure 1: level systematics of Hg isotopes, taken from reference [3]. Full (open) circles and squares represent the oblate and prolate deformed structures in even-N (odd-N) Hg nuclei, respectively.

The ground states of the ^{182,184,186}Hg isotopes are predicted [13] to be weakly deformed 2h oblate states (β ~ -0.15) whereas the 4p-6h prolate (β ~ 0.25) band heads are expected to lie at about 300-400 keV. As Figure 1 shows, the oblate excited 2^+_1 state is rather constant in energy starting from the heavy mercury isotopes down to ^{182}Hg, but from ^{180}Hg onwards the energy of the first excited 2^+_1 state starts to rise [14,15]. This might indicate that ^{180}Hg is more spherical or even has a weak prolate deformation as might be concluded from recent studies of the neighbouring odd-mass mercury isotopes [16,17].

As was shown from the previous campaign, the availability of accelerated radioactive heavy ions at REX and the application of Coulomb excitation (Coulex) allow a number of unique observations to be made: (i) Coulex will preferentially excite states strongly coupled to the ground state so the oblate excited states will be readily observed and identified; (ii) low energy Coulex will measure the sign of the diagonal quadrupole matrix element and hence distinguish between prolate and oblate excitation (iii) the degree of mixing between the oblate and prolate structures is determined directly from the transition matrix elements.

Coulomb excitation of ^{184,186,188}Hg: results from the August 2007 run

Beams of ^{184,186,188}Hg with charge states of 43^+ (^{184,186}Hg) and 44^+ (^{188}Hg) were accelerated with the REX-ISOLDE accelerator to an energy of 2.85 MeV/u and delivered to the MINIBALL set-up. Coulomb excitation was induced in ^{120}Sn as well as ^{107}Ag targets. Beam intensities on target for ^{184}Hg was 3000 pps and the measuring time was 77h02 m, for ^{186}Hg 2.0 10^5 pps and 5h34m, and for ^{188}Hg 2.5 10^5 pps and 12h56m. The average proton beam intensity used during the experiment was 0.5 μA and the total REX-ISOLDE transmission efficiency was about 0.19 %. The primary production of the light mercury isotopes from the ISOLDE target was lower compared to the yield book values and the small total REX-transmission efficiency (0.19 % compared to an expected >2 % value) was due to a number of technical reasons mainly related to the incorrect scaling from the pilot beam to the radioactive beam of the low- and high-energy part of REX. Important to note is that this low number was not due to trapping or charge state breeding process [18]. The data analysis is in progress.

Figure 2 shows part of the Doppler corrected gamma-ray spectrum obtained for ^{184}Hg on ^{120}Sn. The population of the first and second 2^+ state as well as the 4^+ state is clearly observed. From the particle spectrum (Fig. 3) the scattering of the projectile (^{184}Hg) and target (^{120}Sn) particles is clearly observed. These data will allow the extraction of the transition matrix elements of the different transitions involved and will enable the magnitude and sign of the 2+ diagonal matrix element to be determined, using the known lifetimes and the dependence of the integral yield on this quantity. Additional information will come from the angular dependence of the Coulex cross section.

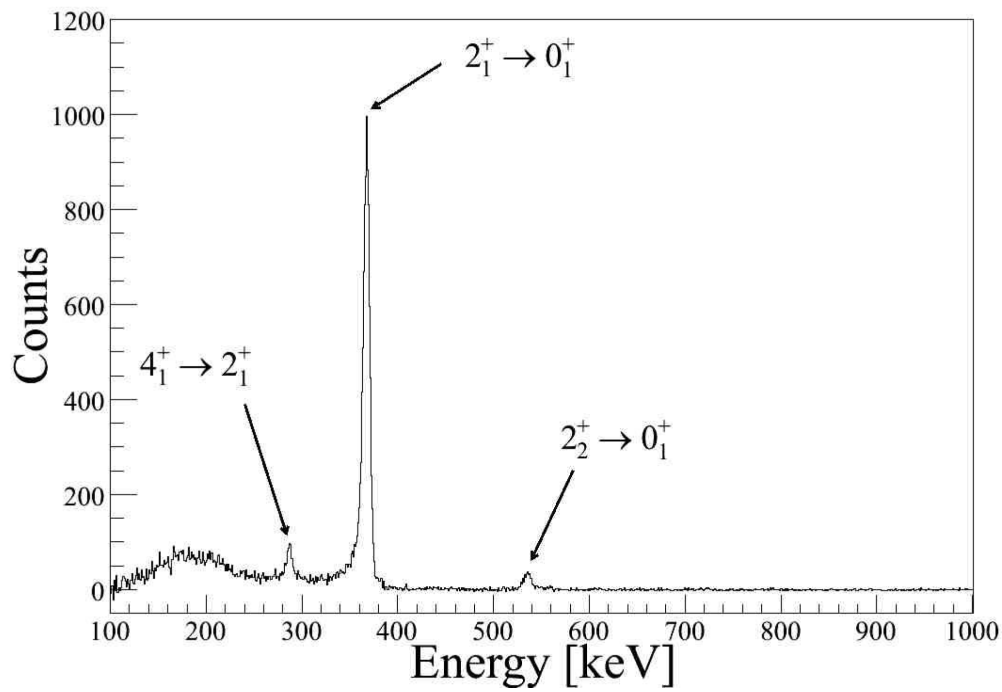

Figure 2: Part of the gamma-ray spectrum detected in the MINIBALL detector for the ^{184}Hg on ^{120}Sn experiment. The spectrum is Doppler corrected for the projectile. Population of the first and second excited 2^+ and 4^+ states is observed.

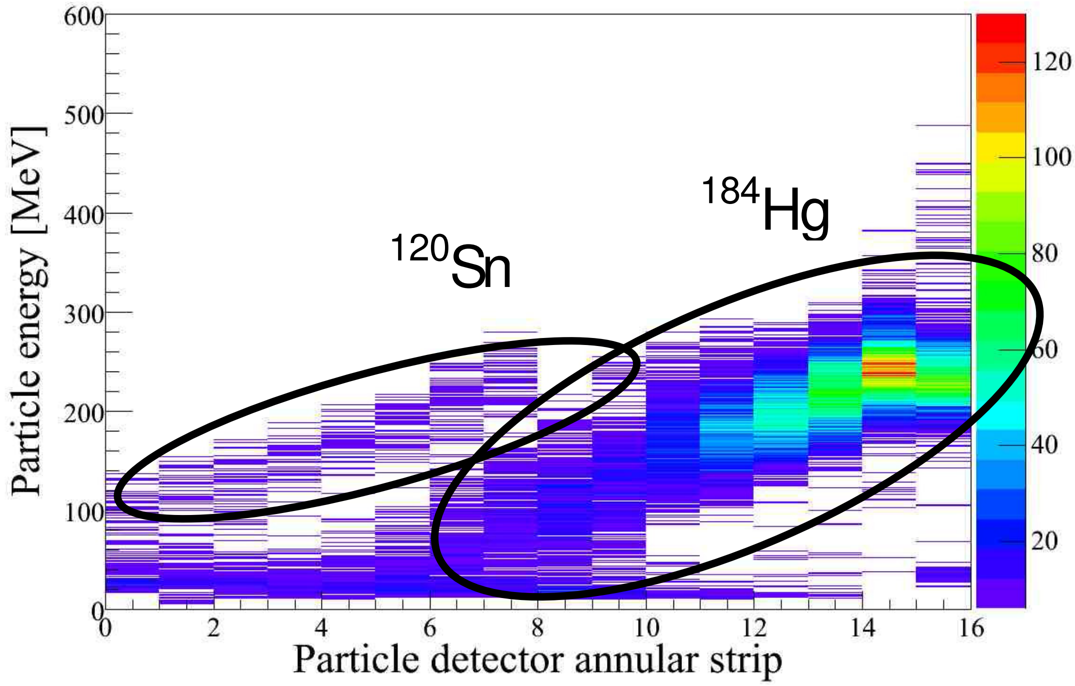

Figure 3: Particle spectra (energy versus annular strip number) obtained for the ^{184}Hg on ^{120}Sn experiment. The projectile and target particles are clearly separated.

Structure of ^{180,182}Hg and Coulomb excitation yields

The experimentally observed low-lying structure of ^{182}Hg relevant to sub-barrier Coulomb studies is shown in figure 4 [19-22]. The relative α-decay hindrance factors were given in a similar figure in the original proposal [2,19,20]. The supposition is that the ground state is oblate, whereas the excited 0^+ state at 328 keV is the bandhead of a prolate deformed band having a π (4p-6h) configuration. A band-mixing analysis leads to the conclusion that there is little mixing (< 4%) between the bandheads, whereas an analysis of the α hindrance factor data suggests a mixing of ~20% [19,20]. For the lowest 2^+ states, the band-mixing seems to be substantial as can be seen from the systematics shown in Fig. 1. It is notable that the observed alpha-decay hindrance to the 2^+ member of the ground state band is rather large as compared with heavier, more deformed nuclei.

The knowledge of the low-lying level structure of ^{180}Hg, shown in Fig. 4, is less detailed. In a recent experiment a candidate for the 2^+_2 state at 797 keV has been suggested [23] while the alpha decay work did not reveal feeding to the excited states [24]. However, as mentioned above and illustrated in Figure 1, ^{180}Hg is an important nucleus in understanding the evolution of structure of the light mercury isotopes. A transition seems to occur at ^{180}Hg when the neutron shell gap at N=100 between the i13/2 shell and the f7/2 and h9/2 shells is crossed. Below A=180 the 2^+_1 state definitely rises in energy in contrast to the heavier Hg isotopes where it stays rather constant [14,15]. The proposed measurement will determine the sign of the quadrupole deformation, a parameter that is essential in this discussion.

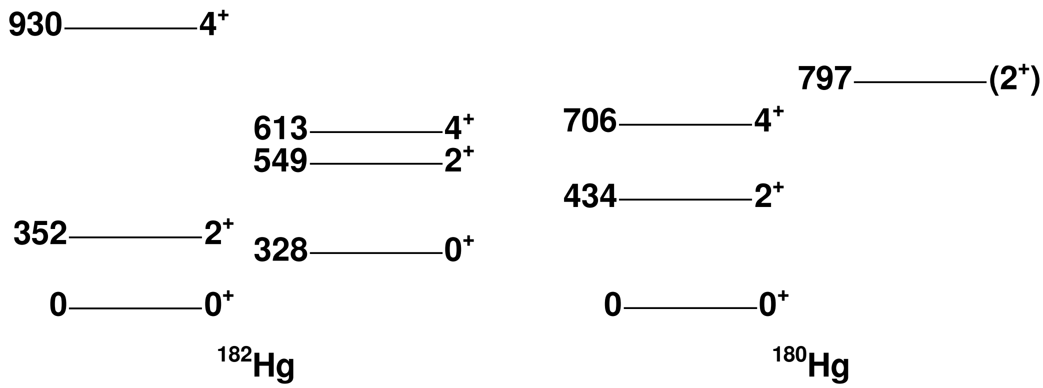

Figure 4: Low lying states in $^{180,\ 182}$Hg. Information on the relative alpha decay hindrance factors from the Pb decay can be found in Figure 2 of the original proposal.

The Coulex γ-ray yields for a 2.85 MeV/u Hg beam onto a 1 mg/cm^2 ^{120}Sn target can be calculated with a number of assumptions as given in table 1 for ^{182}Hg in the original proposal [2]. It results in about 50.000 counts in the 2^+_1-0^+_1 transition and about 200 counts in the 2^+_2-0^+_1 transition. An efficiency of 0.1 for γ-ray detection, and 100 hours of 5.10^4 ions/s irradiation was assumed. Furthermore the in-band matrix elements assumed the following: (i) rotational model values for β=0.15, (ii) the ground state and 2^+_1 states are pure, and (iii) an arbitrary reduction by a factor of 10 for the inter-band matrix element. A similar calculation for ^{180}Hg assuming a beam intensity of 1000 pps (see further) results in 700 counts in the 2^+_1-0^+_1 transition in 100 h beam on target.

Experimental set-up

The August 2007 experimental campaign has convincingly shown that intense and pure radioactive Hg beams can be provided by REX-ISOLDE. Combining this world-wide unique capability of delivering 2.85 MeV/u Hg beams with the MINIBALL set-up allowed to perform Coulomb excitation experiments of ^{184,186,188}Hg (see above). The total REX-efficiency to accelerate the 43$^+$ charge state Hg beams delivered from a molten lead plus plasma ion source with heated line obtained was measured to be 0.19%. This low number was due to a number technical reasons and a total REX transmission efficiency of > 2 % for this mass region has been demonstrated before [18]. Based on the measured ISOLDE yields for ^{182,180}Hg of 7.9 10^6 /μC and 5.3 10^4 /μC respectively we expect a post-accelerated beam intensity on the MINIBALL target of >10^5 and >10^3 pps (taking a proton beam intensity of 1 μA). The secondary target, ^{120}Sn (E_{2+} = 1171 keV) will be surrounded by the MINIBALL array containing 8 triple clusters of 6-fold segmented Ge detectors [25], which has an efficiency of 7% for 1.3 MeV photons. Both scattered projectiles (maximum laboratory angle ~ 40^0) and target recoils will be detected using the DSSSD CD detector which subtends an angular range 16^0- 53^0.

Aim of experiment and request for beam time

The primary aims of the experiment are to determine the matrix elements, for ^{182}Hg, between the ground state, (oblate) 2^+ state, (oblate) 4^+ state, and second (prolate) $2^{+,}$ state, as well as the diagonal matrix element and sign of the deformation of the lowest 2^+ state. For ^{180}Hg the transition matrix element of the first 2^+ state will be determined as well as the sign of the quadrupole deformation. Lifetime measurements on these two nuclei have been performed at the University of Jyväskylä [1]. Using the count rate estimates mentioned above and the expected production rates as a guide, we estimate that **12 shifts** will be sufficient for yield measurements of transitions in ^{182}Hg, **9 shifts** for ^{180}Hg, as well as **3 shifts** for setting up REX. As Z separation cannot be achieved using an ionisation counter, the radio-isotopic content will be assayed by measuring the γ-ray activity at the beam dump and at the CD detector respectively. In total **24 shifts** are requested. Note that the presence of ^{178}W ($T_{1/2}$ = 22d) in the α-branch decay chain of ^{182}Hg will lead to a maximum activity of 10^5 decays/s (2.6μCi) activity at the low-energy end of REX; this may have consequences for the scheduling of this experiment.

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