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Autoreferát dizertačnej práce

Spectroscopy of excited states in light Au isotopes (Spektroskopia vzbudených stavov ľahkých izotopov zlata)

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Abstrakt

Predkladaná práca prezentuje výsledky in-beam spektroskopie izotpu ^{179}Au, ktorý je súčasťou systematického štúdia nízkoenergetickej tvarovej koexistencie v izotopoch zlata s nepárnou hmotnosťou, ktoré sa nachádzajú v oblasti s neutrónovým číslom $N = 104$. Experiment bol uskutočnený na Univerzite v Jyväskylä (Fínsko) s využitím aparatúry pozostávajúcej z RITU, GREAT, Jurogam2 a SAGE. Bol objavený nový rotačný pás a niekoľko prechodov, jednoznačne priradených izotopu ^{179}Au. Nový izomérny stav s dobou polpremeny $2.14\,\mu$s a excitačnou energiou 1750 keV bol identifikovaný prvýkrát. Bol pozorovaný nový rotačný strongly-coupled pás rozpadávajúci sa na novoobjavený izomérny stav. Spin izoméru bol predbežne určený ako $19/2^+$ a je interpretovaný ako protón nachádzajúci sa v $1h_{9/2}$ orbitály previazaný s jadrom ^{178}Pt v excitovanom stave 5^-. Axiálne a triaxiálne parametre deformácie boli určené pomocou výpočtov, ktoré využívali model popisujúci jadro ako časticu previazanú s triaxiálne deformovaným jadrom. V práci sú popísane dve nové a zatiaľ nepublikované techniky: prvá slúži na korekciu časovej nestability germániových detektorov, a druhá navrhuje nový spôsob určovania časov polpremeny izomérnych stavov.

Abstract

The thesis presents results of the in-beam spectroscopy of the ^{179}Au isotope, which is a part of the systematic study of low-energy shape coexistence in odd-mass Au isotopes in the vicinity of the $N = 104$ neutron mid-shell. The experiment took place at the University of Jyväskylä (Finland) utilizing the RITU, GREAT, Jurogam 2 and SAGE apparatus. New rotational band and several new transitions, unambiguously assigned to the ^{179}Au are reported. New isomeric state with half-life of $2.14\,\mu$s and excitation energy 1750 keV is reported for the first time. The strongly-coupled band feeding the newly-discovered isomer was identified. Spin of $19/2^+$ is tentatively assigned to the isomer and is interpreted as the $1h_{9/2}$ proton coupled with the ^{178}Pt core in excited 5^- state. Deformation parameters, both axial and triaxial of the ^{179}Au were estimated by the Particle + Triaxial Rotor Model calculation. Description of two new yet unpublished techniques is given; one is made to correct time-instability of germanium detectors, the second one provides a novel approach for extracting half lives of isomeric states.

Introduction

The work presented here is a part of the systematic study of the nuclear shape coexistence in odd-mass Au isotopes. Neutron-deficient isotopes in the region surrounding the $Z = 82$ shell closure are the most prolific region of low-energy shape coexistence [1]. Here, shape coexistence is a result of a stabilizing effect of proton shell structure preferring the spherical geometry competing against residual interaction between neutrons increasing correlation energy favoring deformed shapes. The Au isotopes are interpreted within the framework of the particle-core model, in which the independent particle is used as a probe of the even-even core providing an information on the independent particle states, nuclear deformation (both axial and triaxial), collectivity and intruder states.

The present work deals predominantly with the ^{179}Au isotope, while results of the ^{177}Au are referenced through already published articles. These are extremely neutron-deficient isotopes, located 18 and 20 neutrons away from the stable isotope ^{197}Au. Note, that ^{177}Au is already proton-unbound isotope. For such exotic isotopes, it is very rare to obtain such detailed information, as it is presented here.

In-beam studies of both isotopes took place at the Accelerator Laboratory of the University of Jyväskylä, Finland. Prompt γ-ray radiation was measured using the Jurogam2 Compton-suppressed germanium-detector array [2–4]. Reaction products separated by gas-filled separator RITU [5] were implanted into GREAT spectrometer [6]. Data were collected using the Total Data Readout (TDR) system [7] employing standard tagging techniques [8, 9] to separate events of interest.

Several germanium detectors exhibited time-unstable operation during the course of both experiments. This issue was solved by introducing offline correction procedure called Cross-correlation Correction Method (CCM), which is an upgraded version of an algorithm proposed in author's master's thesis [10]. New isomeric state in the ^{179}Au was identified. Its half-life, as well as half-life of the ^{177}Pt isomer (produced via lower-yield reaction channel) was extracted using novel approach - the running integral. Strongly-coupled band, feeding the newly discovered isomeric state was identified for the first time. Analysis of prompt g rays, following the reaction, revealed a new rotational band. It is interpreted within the framework of the particle-plus-rotor-model calculations, performed within the scope of the thesis.

Prompt-γ ray analysis revealed new band interpreted as a signature partner of the $1f_{7/2}$ configuration. In addition to that, several new transitions in previously reported bands [11] were discovered.

Experimental setup and experiments

Experimental studies of the ^{177,179}Au took place at the Accelerator Laboratory of the University of Jyväskylä (JyFL), Finland. Experimental setup was comprised of the RITU (Recoil-Ion Tagging Unit) gas-filled separator [5], Jurogam 2 γ-ray detector array [2–4] and the GREAT (Gamma Recoil Electron Alpha Tagging) [6] spectrometer. In case of the ^{179}Au study, the conversion-electron spectrometer SAGE (Silicon And GErmanium) [12, 13] was installed at the target position requiring removal of one detector ring from the Jurogam 2. Beam was delivered by the K130 cyclotron. Data were acquired with the trigerless TDR (Total Data Readout) system [7], operating all channels asynchronously in a free running mode. All digital readouts were time-stamped using globally distributed 100 MHz clock.

RITU RITU is a gas-filled separator for heavy ion studies [5]. Separation is performed in the dipole magnet filled with diluted gas, where the collisions of gas atoms and the reaction products lead to the charge state focusing. This causes ions of certain species to follow approximately trajectory determined by the average ionic charge state in the gas, independent from the original charge state at the exit of the ion from the target. Separator was filled with He gas in both experiments.

Jurogam 2 Jurogam 2 is a modern array of HPGe detectors [2–4] arranged around target chamber in spherical configuration mounted on supporting frame with open-

ing mechanism. Detector array is arranged in 4 rings relative to the beam direction. First two rings ($157.6°$, $133.57°$) are comprised of 15 Eurogam Phase 1 coaxial detectors while the reminding rings (($104.5°$, $75.5°$) carry 24 composite Clover-type HPGe detectors (Eurogam type). All detectors are equipped with active BGO Compton suppression shields. Clover type detectors are segmented into 4 crystals connected to the same cryostat. Segmentation decreases Doppler broadening effect, which occur as the recoiling nuclei reaches speed in order of percent of the speed of light. All detectors are equipped with Lyrtech VHS-ADC digitizers with 14-bit resolution allowing count rates of 30 kHz/detector.

SAGE The SAGE spectrometer [12, 13] is a conversion-electron silicon detector with concentric ring structure consisting of 90 active pads. Its placed upstream relative to the beam direction. Electrons are transported from the target onto the SAGE using 3 solenoid coils, background δ-electrons are suppressed by high voltage barrier adjustable up to 50 kV. Energy of electrons must be corrected for Doppler shift via non-trivial calculation. Signals are processed with Lyrtech VHS-ADC digitizers. The SAGE was used only for the ^{179}Au experiment and only limited statistics was acquired.

GREAT The Gamma Recoil Electron Alpha Tagging (GREAT) spectrometer [6] is a implantation detection system designed to measure protons, α, β particles, γ rays, X rays and conversion electrons emitted by reaction products transported to the focal plane via recoil separator RITU. It includes the MWPC (MultiWire Proportional Counter), Double-sided Silicon Strip Detector (DSSD), Conversion electron detection array, Planar germanium detector and 3 Clover-type germanium detectors.

MWPC is isobutan-filled transmission detector placed at the entrance of the GREAT. Its main purpose is to distinguish between incoming reaction products and their subsequent radioactive decay, and to veto undesired recoils not separated by RITU.

The DSSD is an implantation detector made of two $300\,\mu$m thick silicon detectors each segmented into 2400 pixels. It measure energy of incident recoil and its subsequent α/β decay. Signals from the DSSD are processed by analogue electronics due to large amount of channels.

Planar is a double-sided strip germanium detector mounted behind the DSSD in the vacuum chamber of the GREAT. Its active area covers both DSSD detectors and is only 15 mm thick designed to measure X-rays and low energy γ-rays.

Three clover detectors are positioned around the GREAT vacuum chamber, 2 from the sides and 1 from the top. As in Jurogam 2, each clover is equipped with active BGO Compton shielding and is segmented into 4 crystals.

JR115 (^{177}Au)

Experiment with codename JR115 took place at the University of Jyväskylä during October 18-30. 2012 with total of 226.5 hours of beam on target. To populate excited states of ^{177}Au the reaction ^{92}Mo (^{88}Sr , 2pn) ^{177}Au was used. The ^{88}Sr projectiles impacted the $600\,\mu\mathrm{g/cm^2}$ thick ^{92}Mo target ($98\,\%$ enrichment) at energy of 399 MeV. Average intensity of approximately 2 particle nA was delivered by K130 cyclotron [14].

Experiment used the Jurogam 2 array in conjunction with the RITU separator and the GREAT spectrometer. Two $700\,\mu$m and $280\,\mu$m degrader foils have been placed between MWPC and DSSD to suppress high rates produced by scattered low-energy

beam to the focal plane. In total 1.3 TB of data were collected. For duration of the experiment only minor issues arose, most significant was failure of automatic LN_2 system which has been resolved by manual filling.

Experiment S17 (^{179}Au)

Experiment was carried out during 21.10. - 4.11.2013 at the University of Jyväskylä, Finland. Proposed reaction ^{103}Rh (^{82}Kr , α2n) ^{179}Au for S17 had to be changed on-site due to presence of numerous small perforation on all three ^{103}Rh foils. Reaction had been changed to ^{100}Ru (^{82}Kr , p2n) ^{179}Au .

Beam ^{82}Kr at charge state 15+ was delivered at 352 MeV. With only single ^{100}Ru foil available, concerns about possible target breakage arose causing the beam intensity to be set at lower values for the duration of the experiment.

The course of the experiment was accompanied by several technical drawbacks, concerning mainly the SAGE's changing HV barrier due to various problem with Carbon foils. The experiment had ended 2 days earlier than scheduled due to fatal failure of the beam delivering dipole magnet. Cleared from the interruptions, experiment S17 lasted 267 hours and 2.4 TB of data have been acquired.

Previous study of ^{179}Au

The ^{179}Au isotope was studied [11] at Argonne National Laboratory, using the Gammasphere [15] array consisting of 97 large-volume hyper-pure germanium detectors with BGO Compton-suppression units and four low-energy photon spectrometers (LEPS). Experimental setup lacked γ-ray detectors in the focal plane. Two separate experiments were performed, in first the excited states of the ^{179}Au isotope were produced via the ^{104}Ru(^{78}Kr,$p2n$)^{179}Au fusion-evaporation reaction. This channel could not be used due to large isobaric contaminants. Therefore, second experiment was performed, which used the ^{90}Zr(^{90}Zr,p)^{179}Au reaction. The ^{179}Au level scheme was constructed on the basis of the A = 179 recoil-gated γ-γ and γ-γ-γ coincidences from both separate experiments. In total, four rotational bands were identified. Three with negative parity, associated with the $1h_{9/2}$ and $2f_{7/2}$ proton-intruder configuration; and one with positive parity, associated with the $1i_{13/2}$ proton-intruder configuration. Note that no states associated with proton-hole configurations were observed.

Recent laser spectroscopy experiment at ISOLDE was performed. Spin of both ^{177}Au and ^{179}Au ground states was unambiguously established as $1/2$ and while their respective magnetic moments $\mu = 1.15(5)\,\mu_N$ and $\mu = 1.01(5)\,\mu_N$ were measured. These values suggest the $3s_{1/2} \oplus 2d_{3/2}$ proton-hole configuration for ground states of these isotopes.

The $326\,\mathrm{ns}$ isomeric state was discovered at the University of Jyväskylä, employing the RITU separator [5] coupled with the GREAT focal plane spectrometer [6]. Nuclei were produced via fusion-evaporation ^{107}Ag(^{78}Kr,$\alpha 2p$)^{179}Au reaction. Additionally, the ^{179}Au was also produced via α decay of the ^{183}Tl^{m} produced via $2p$ evaporation channel. Analysis was carried out utilizing a combination of mass measurements, isomer and α-decay spectroscopy. It involved also GEANT4 simulations of alpha-electron summing effects, including all atomic relaxation processes.

The α-decay of $9/2^-$ intruder state in ^{183}Tl^{m} was found to strongly populate the isomer, suggesting its intruder nature. Spin of the isomeric state was assigned as $(3/2^-)$ based on similar structure found in ^{181}Au [16]. The $E1$ transition between isomer and ground state was deduced from internal conversion coefficients.

Decay of the $9/2^-$ state into $3/2^-$ isomer is assumed to proceed via collective $5/2^-$ state formed by negative-parity state coupled with anti-aligned core rotation. No γ rays were detected due to strong conversion, as the energy difference between $(9/2^-)$ and $3/2^-$ was established as $44(15)\,\mathrm{keV}$ based on difference α-decay energies of ^{183}Tl^{m} due to electron summing.

Experimental techniques

Half-life measurement using running integral method

Conventional procedure for extracting half-life of atomic nuclei or its excited states is fitting the time distribution of delayed coincidence events associated with studied decay (further denoted as differential method). Alternative way for analyzing decay time is the logarithmic method [17], which is suitable for low-counting experiments. In present work we propose novel approach called running integral[1] for decay analysis, which is based on time evolution of the population of non-decayed excited states/nuclei in the sample. Running integral fully utilizes the time resolution of a measurement system, i.e. no re-binning is necessary and thus effect of binning is greatly reduced. It is also suitable in case of contamination with non-uniformly time-distributed background events, e.g. from isomeric Compton scattered γ rays with energy approximately matching characteristic energy of the decay. Monte-Carlo simulation showed that statistical error of running integral is at least by factor of 2 smaller than conventional fitting procedure.

Running integral is based on counting events that satisfy energy gate and varying delayed time coincidence window whilst subtracting background events. Time window range is set as $[x, T_{max}]$ where bottom limit x is a variable[2] while T_{max} is a constant upper limit. Aim is to obtain distribution of counted events as a function of bottom time limit x. It is performed by creating N energy spectra each for unique time limit x. Non-background events in peak-of-interest are counted and plotted for given x. Formally, number of counted events for given x is a result of a definite integral

$$N(x) = \int_{x}^{T_{max}} f(t)dt \tag{1}$$

where $f(t)$ is a distribution of decay events. In this case, $f(t)$ is given by convolution of exponential decay function with Gaussian due to timing resolution of start and stop detectors, and addition of offset parameter to account for random recoil correlations. Resulting integral is therefore

$$N(x) = \int_{x}^{T_{max}} A + Be^{-\lambda\left(\Delta t - +\mu - \frac{\sigma^2\lambda}{2}\right)}\left[1 + Erf\left(\frac{\Delta t - \mu - \sigma^2\lambda}{\sqrt{2}\sigma}\right)\right] d(\Delta t) \tag{2}$$

[1] As it was inspired by the running gate technique [18].

[2] The x clearly denotes time, but it representation is chosen this way to avoid confusion with the Δt.

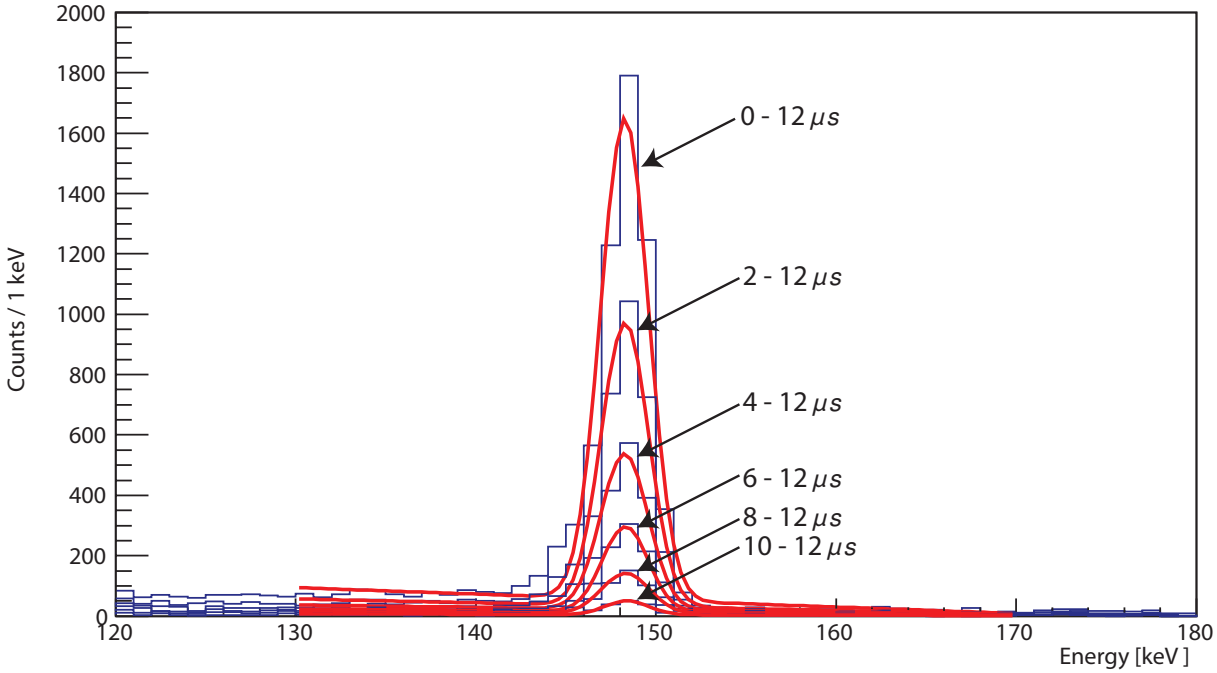


Figure 1: Example fits of the planar γ-ray energy spectra satisfying outlined timing windows between the DSSD and planar. Peak area of given lower bound x represents the $N(x)$ distribution in Eq. (2). This figure serve only for illustration, thus the second peak at $E_\gamma \approx 144$ keV is ignored in fits presented.

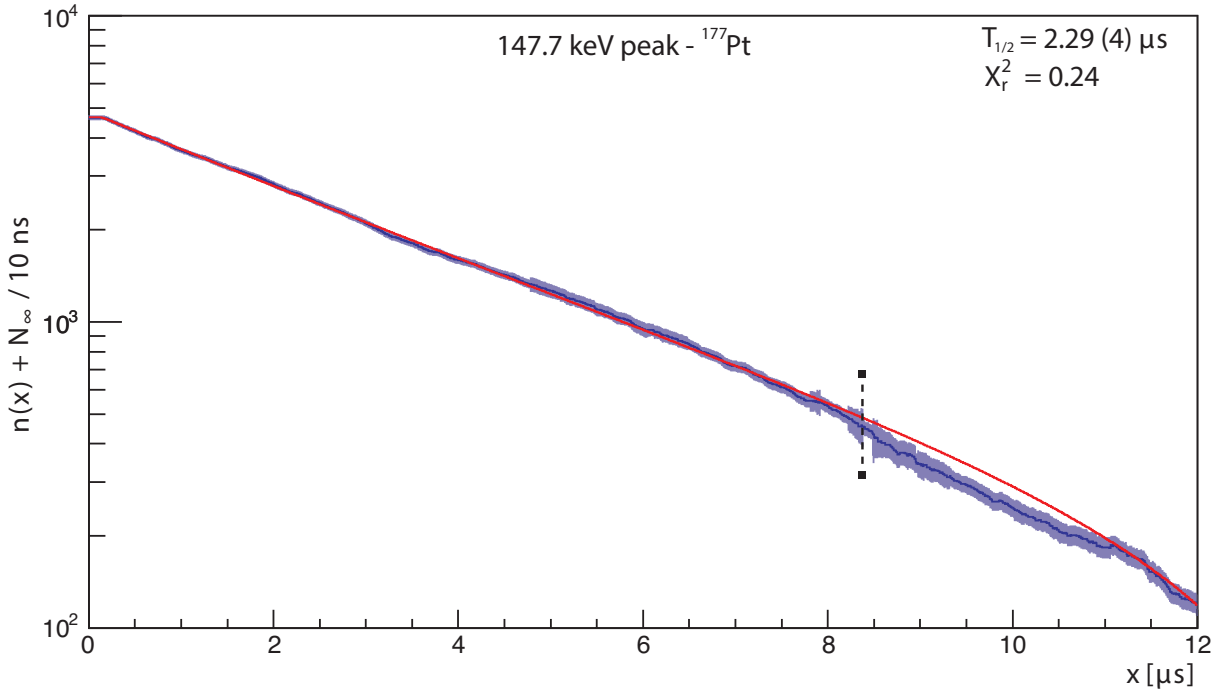


Figure 2: Half-live fit of the $n(x) + N_\infty$ distribution. Fit is performed on range of (0, 8.4) μs, end is shown with dashed line.

where μ and σ are the Gaussian mean and standard deviation, respectively; and λ is a decay constant. Gaussian parameters were determined by fitting timing spectrum between the DSSD as start detector and the focal plane clover and planar as stop detectors.

Unaccounted contribution of the (T_{max}, ∞) interval, denoted as N_∞, can be estimated by solving Eq. (3) with parameters α extracted from preliminary fit as

$$N_\infty(\alpha) = \int_{T_{max}}^{\infty} f'(t, \alpha_1, ..., \alpha_i)dt \tag{3}$$

The $f'(t, \alpha)$ is a decay function $f(t)$ modified to assure integral convergence. Iteratively fitting the $N(x)+N_\infty(x)$ distribution and estimating new N_∞ will gradually converge to the final set of parameters α. Error of N_∞ estimation is calculated using $N(x)$ covariant matrix.

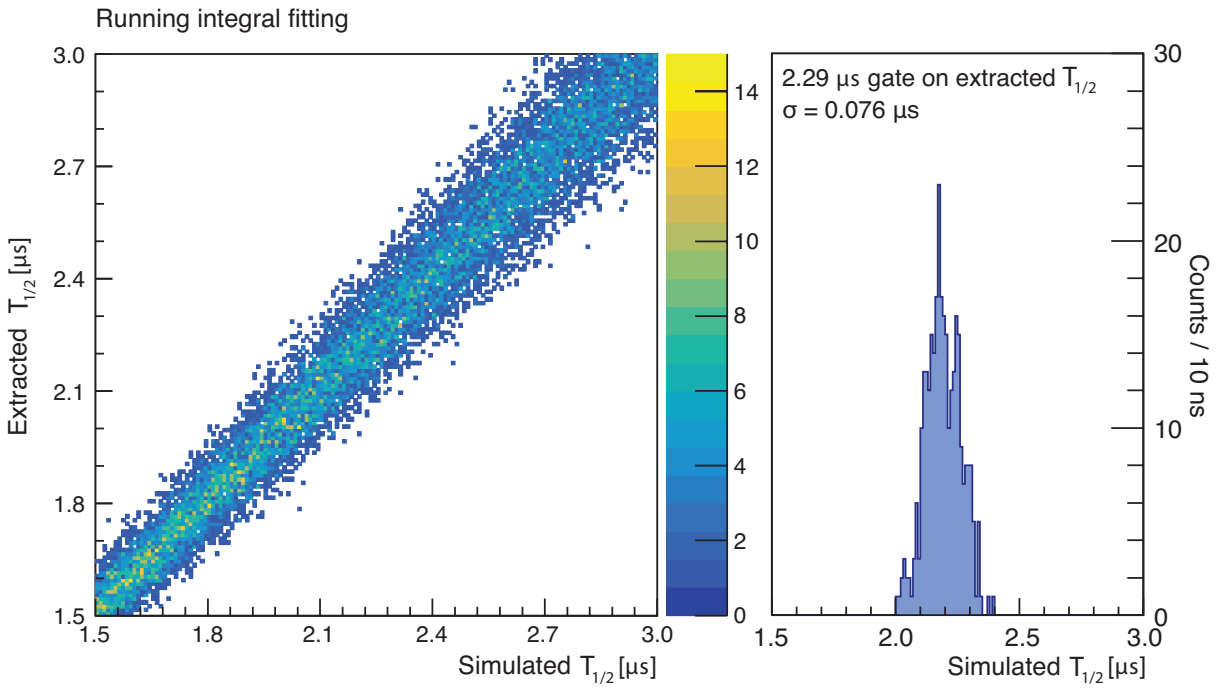
The experimental $n(x)$ distribution of non-decayed population was in present thesis extracted using the Gaussian fit of events in time-gated energy spectrum as illustrated in Fig. 1. Number of events $n(x)$ and its deviation is estimated from the area of the Gaussian fit. It is important to inspect goodness of the Gaussian fit in order to evaluate end point of running integral fit of the $n(x) + N_\infty$ distribution.

Running integral method was tested on the decay of the known $2.2\,(3)\,\mu s$ isomeric state in the ^{177}Pt [19]. The ^{177}Pt was produced in S17 experiment from ^{182}Hg compound nucleus via αn evaporation channel. Half-life of $2.29(4)\,\mu$s was extracted for the ^{177}Pt isomer, see Fig. 2. Statistical error was estimated from Monte-Carlo generated data. A 100 data sets emulating original spectrum (number of events, FWHM, background etc.) for each half-life value ranging from 1.5 to $3.0\,\mu$s with $0.01\,\mu$s step was generated. Half-lives of these data sets were evaluated with both differential and running integral methods, and sorted into matrices shown in Fig. 3, in which half-lives extracted with given method are on y-axis and true half-lives of generated spectra are on x-axis. Statistical error is estimated by gating extracted half-live in these matrices. Accounting for statistical error, the half-life of the ^{177}Pt isomer is evaluated as $T_{1/2} = 2.29 \pm 0.09\,\mu s$. This value is in good agreement with the previously reported half-life of $2.2\,(3)\,\mu s$ [19].

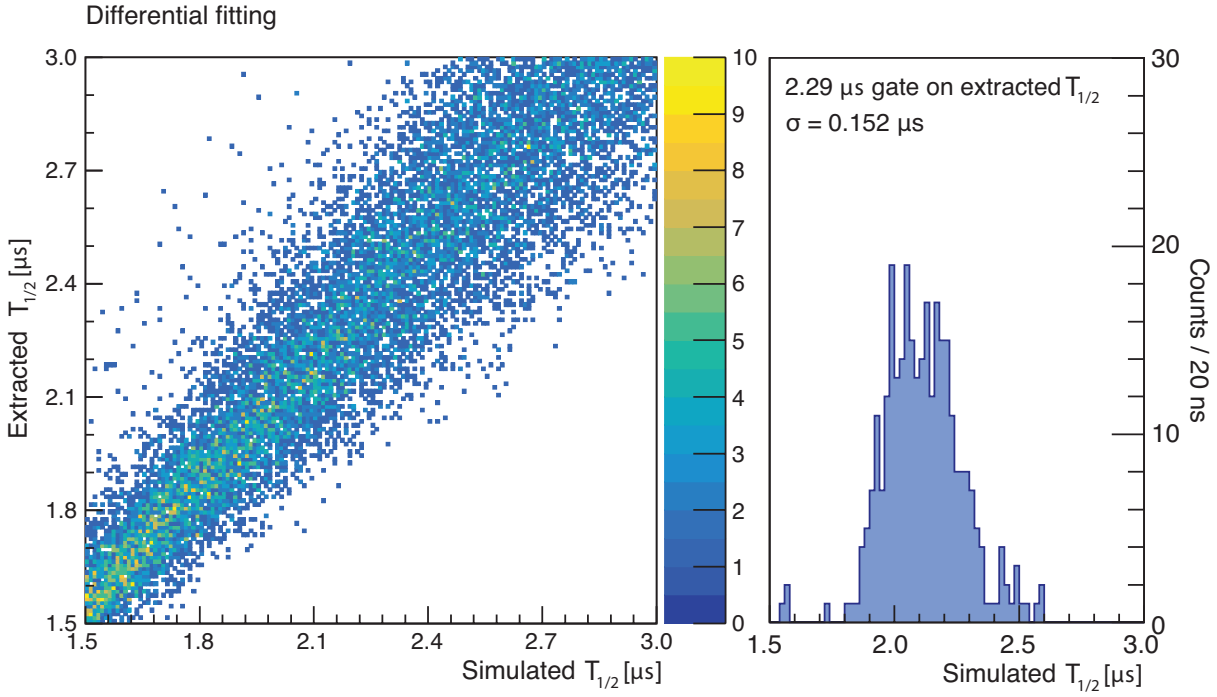
Correction of time instability in experimental data - the CCM method

The inconsistent behavior of a detector in time is in general attributed to the problems with stability of its processing electronics. Probably due deterioration over time and external factors (temperature, humidity etc.) it is possible to observe relatively slow or even sudden shift of the measured spectra in time.

Problem of time instability of the data measured in experiment S17 was revealed only after the experiment while performing fine-calibration. In total 7 of the Jurogam 2 Clover crystals and 3 focal-plane Clover detectors were affected in the S17 experiment; and 3 of the Jurogam 2 Clover crystals in the JR115 experiment. A new method for correction of time-unstable detector output was developed - the Cross-correlation Correction Method (CCM). Unlike the total-spectrum fitting method proposed by [20], the CCM is localized and is suitable not only for the in-beam, but also for the decay spectroscopy. The CCM used in this work is an upgraded version of an Floating Vector Comparison Method (FVCM) proposed in author's master thesis, see [10].



(a) Estimation of statistical error with the Monte-Carlo simulations of the running integral method of half-lives measurement.



(b) Estimation of statistical error with the Monte-Carlo simulations of the differential method of half-lives measurement.

Figure 3: Estimation of statistical error with the Monte-Carlo simulations of the differential and running integral methods of half-lives measurement. Matrix on the left displays relation between the half-life used for data set generation and half-lives extracted from these data sets with given method. Histogram on the right panel is a $2.29\,\mu s$ projection on X-axis presenting statistical error of given fitting method.

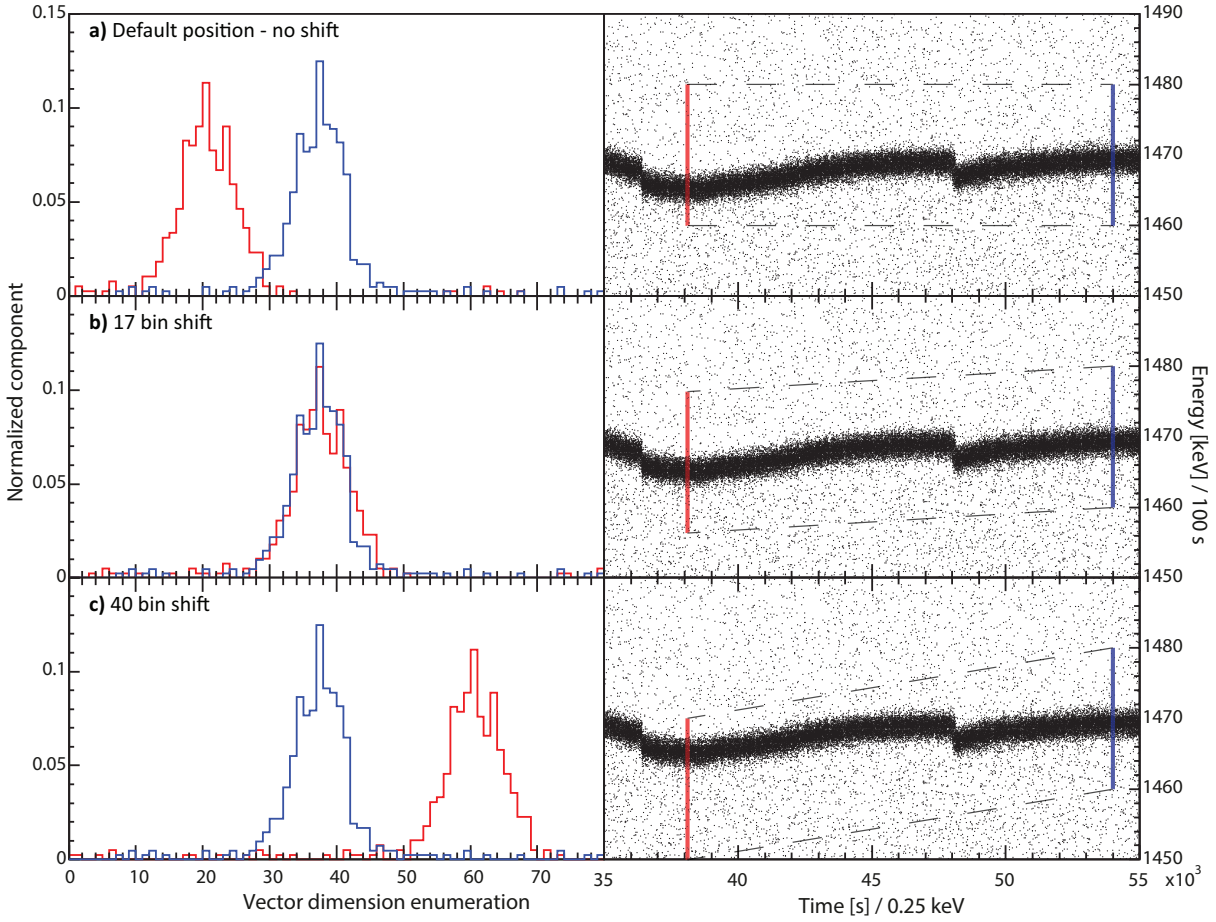


Figure 4: Illustration of the discrete cross correlation method applied on time vs. energy matrix in search of the displacement between two spectra. Figure shows three different displacements of slice vector (blue color) relative to the reference vector (red) as vectors (left panel) and in time vs. energy matrix (right panel).

The CCM algorithm Data sorted into the time vs. energy matrix are time-sliced and correction parameters are to-be-found individually for each sliced spectrum. One spectrum is chosen as a reference for correction. If possible, the reference spectrum should be selected from time-stable region and can be constructed as a sum of several stable slices to increase statistical precision. Corrections are determined by fitting relative displacement between the reference spectrum and the to-be-corrected slice as a function of the energy. Selection of a fit function is arbitrary, but a simple polynomial fit was found to be sufficient for correction of the HPGe detectors. Function selection is only restricted by number of fitting points.

Relative displacement at given energy is extracted by comparing suitable pre-selected parts of the slice and the reference spectra given that they contain sufficient statistics. The measure of their relative similarity is calculated with the discrete cross-correlation. Selected region of the slice and the reference are formally treated as N-dimensional vectors in Euclidean space. If normalized, dot product of two vectors is equal to $cos(\phi)$ with ϕ being their mutual angle which is by definition a good measure of their similarity. Gradually displacing slice vector by redefining its bounds allows calculation of a multiple dot products. Relative displacement is determined by identifying the highest value of from the calculated dot products. Energy of relative displacement is calcu-

lated from the reference region as a mean energy weighted by bin content. Illustration of this procedure is shown in Fig. 4.

Outcome of the CCM performed on the focal-plane Clover crystal 10 (for experiment S17) is shown in Fig. 5. FWHM of the post-CCM is within margin of error identical with the FWHM of the focal-plane Clover crystals not affected by time instability.

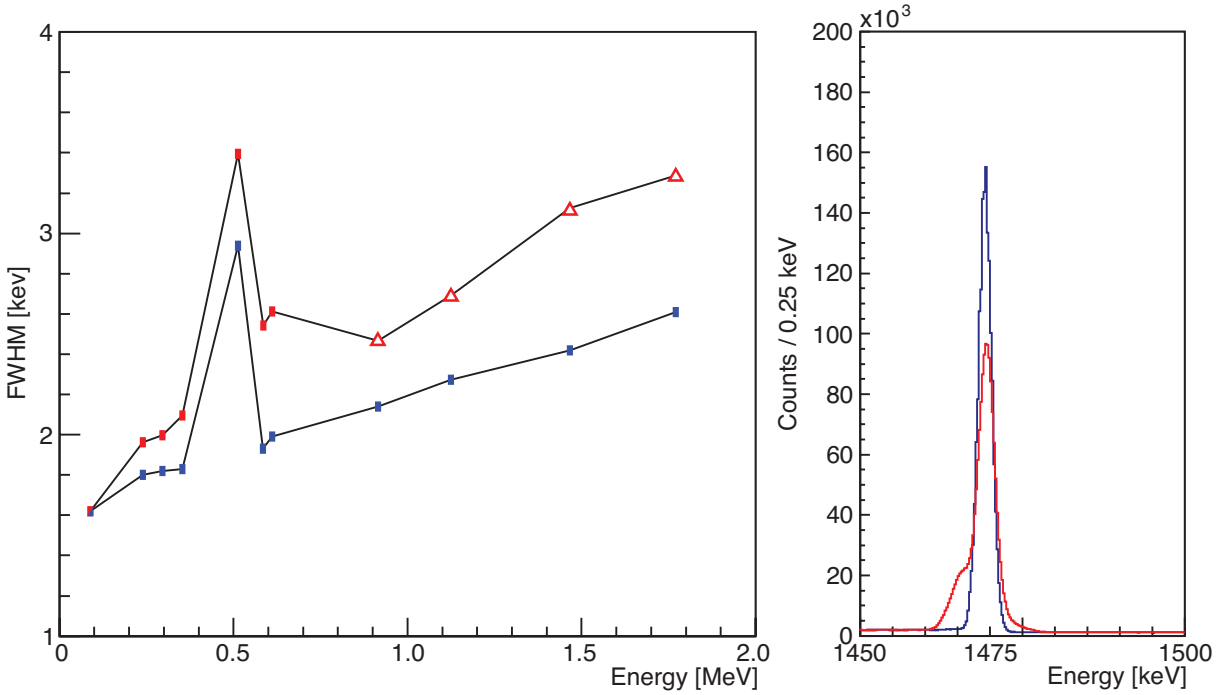


Figure 5: Comparison of the pre-CCM (red) and the post-CCM spectra and FWHM evolution performed on the Clover crystal 10 in the focal plane. Points marked by triangle in the left panel indicate use of two Gaussian functions in the pre-CCM spectrum as the peak separation (i.e. fake doublet) became evident. Energies in this figure are not correct due to absence of the post-calibration and are as extracted from original and corrected spectra.

Summary of experimental results and discussion

Brief overview of published results

Results of the ^{177}Au experiment have been reported in submitted PhD. thesis [21], while the publications [22, 23] report further findings.

Important in context of the present work focused on the ^{179}Au is the identification of the 452.6 keV transition in ^{177}Au between the positive-parity $1i_{13/2}$ band into the $5/2^+$ state associated with the mixed $3s_{1/2} \oplus 2d_{3/2}$ ground state [23]. Such transition would bypass the 326 ns isomer in ^{179}Au, but is not observed in the recoil-gated spectrum. Different de-excitation pattern is explained by the configuration mixing of the two close-laying $9/2^+$ states, with one state being the anti-aligned $1i_{13/2}$ configuration and the other member of the ground state band.

The 349.9 and 370.5 keV γ rays depopulating the $1i_{13/2}$ positive-parity band in the ^{179}Au were reassigned [23]. These transitions were observed in the 326 ns $3/2^-$ isomer-tagged spectrum, gate set on the 370.5 keV γ-ray revealed only the members of the

$1i_{13/2}$ rotational band. Furthermore, the energy difference between the 349.9 and 370.5 keV transitions exactly matches the difference between the known $9/2^-$ and $7/2^-$ states. As a conclusion, the 349.9 and 370.5 keV transitions must depopulate the anti-aligned $9/2^+$ member of the $1i_{13/2}$ band. Due to conversion, transition between the $13/2^+$ and $9/2^+$ states was not observed.

Partial level schemes deduced in [23] are shown in Fig. 6.

Prompt γ rays

Prompt γ rays detected with Jurogam 2 array were sorted into the recoil-tagged γ-γ matrix and γ-γ-γ cube. Relatively long half-life of the ^{179}Au ($T_{1/2} = 7.1(3)$ s [25]) and high recoil-rate did not allow use of the recoil-(α)decay tagging. Fortunately, discovery of the 328 ns $3/2^-$ isomer [24] enabled construction of contamination-free isomer-tagged γ-γ matrix. Their analysis revealed several new transitions and one new rotational band, all shown in Fig. 7. Newly discovered rotational band, labeled as band 5, was interpreted as the signature partner of the negative parity band 3 in $2f_{7/2}$ configuration.

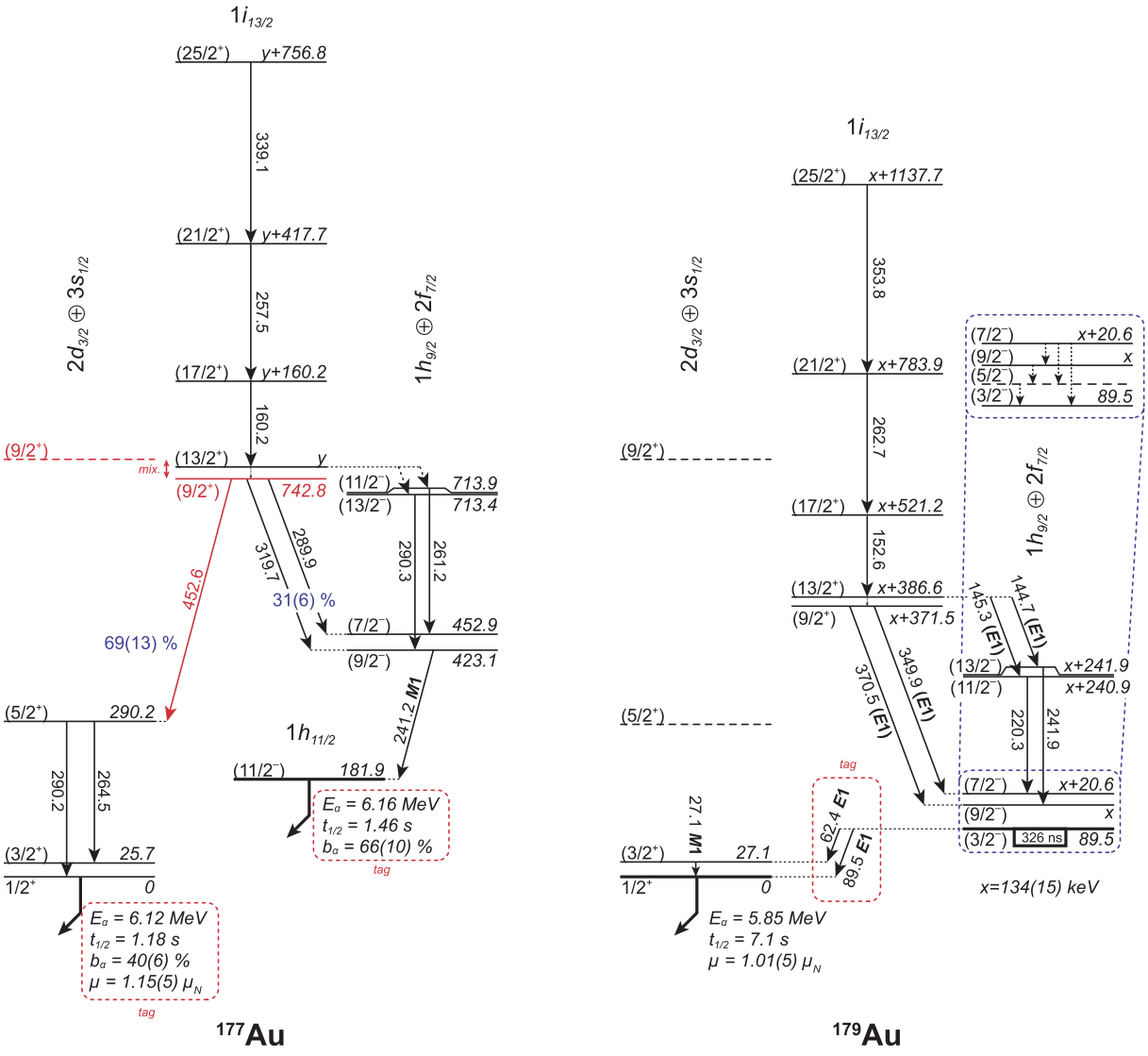


Figure 6: Partial level schemes of the ^{177,179}Au taken from [23].

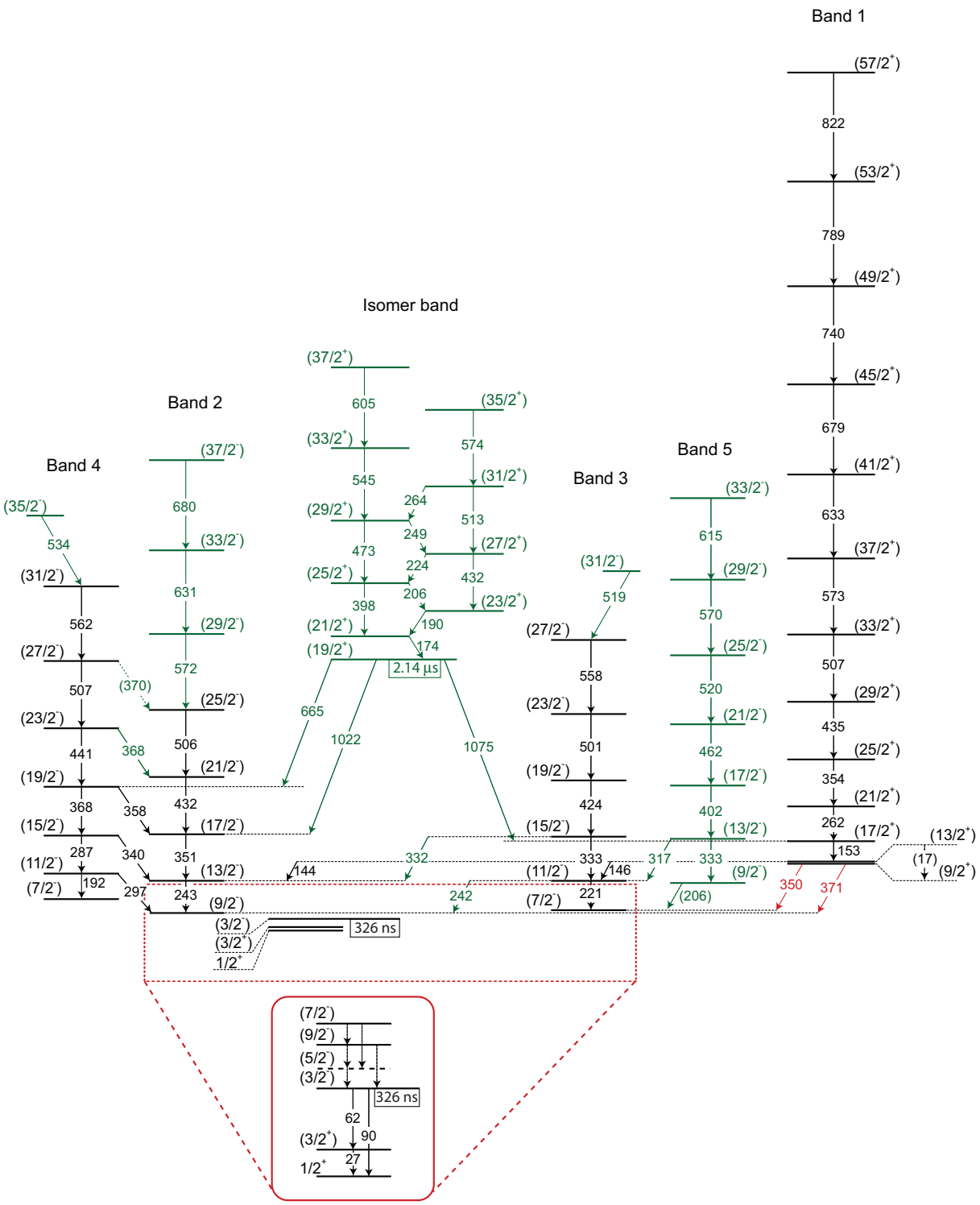


Figure 7: Complete level scheme of ^{179}Au combining result of previous publications [11, 23, 24] and present work. Newly reported transitions are in green color, while red color show reassigned transitions, see [23].

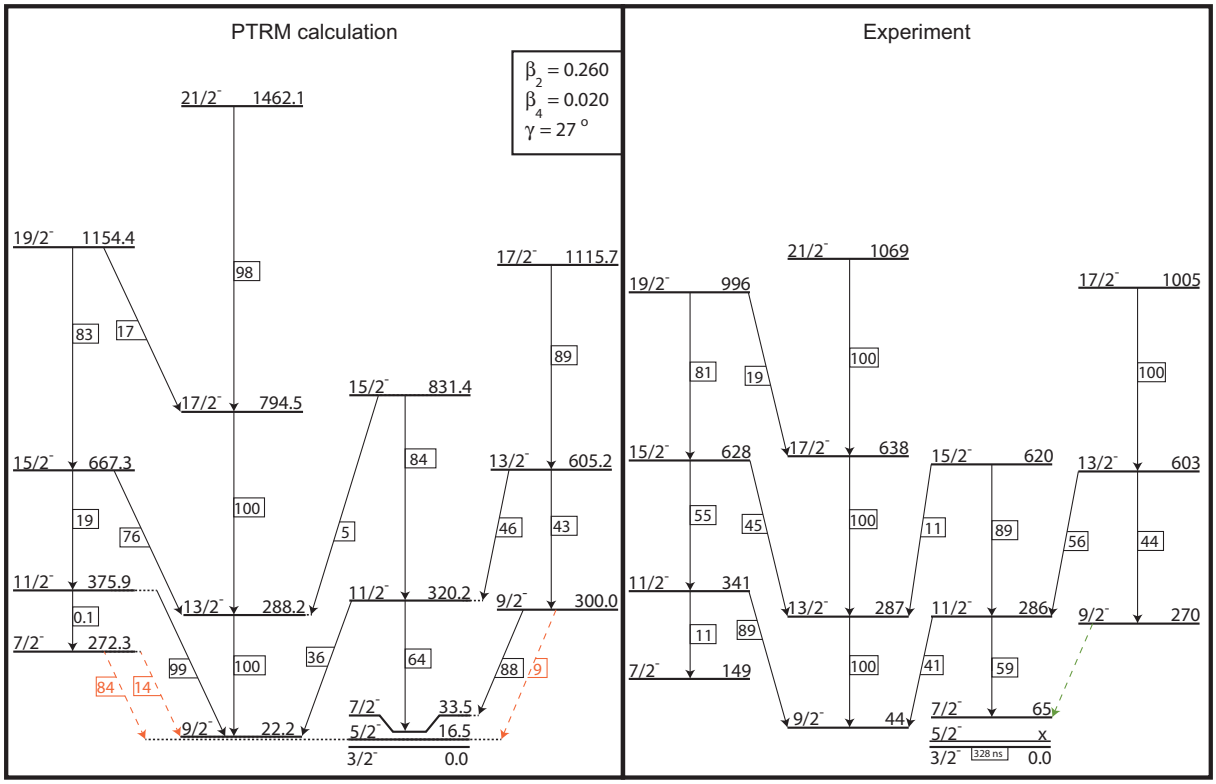


Figure 8: Calculated PTRM level scheme for negative-parity states compared to the experimentally-deduced level scheme. Only negative parity states were calculated, thus level energy $E = 0$ is assigned to the lowest laying state $3/2^-$, experimental level scheme is modified accordingly. Branching ratios for transitions is shown in $\%$ units. Missing intensity in PTRM scheme is due to minor branching into experimentally unobserved states. Orange dashed lines show experimentally unobserved transitions; tentatively assigned transition is shown in green.

Multiple γ rays from band 3 in coincidence with 243 keV were previously dismissed as the ^{179}Hg contamination [11]. In present work, they were unambiguously assigned to the ^{179}Au using the isomer-tagged γ-γ matrix. Direct gating was not possible, since the energies of the inter-band transitions were almost identical with the in-band γ rays, see Fig. 7. Therefore, assignment of these transitions was made based on missing intensity and the PTRM calculation. New transitions indicating the band crossing were observed in bands associated with $2f_{7/2}$ and $1h_{9/2}$. Similar band-crossing was observed in ^{181}Au [26] albeit at higher angular momenta.

Calculations based on the PTRM model [27] were carried out using the computer programs written by Semmes and Ragnarsson [28]. Calculations were performed on the negative-parity states, which for ^{179}Au involve $1h_{11/2}$, $2f_{7/2}$ and $1h_{9/2}$ configurations. Best agreement with experimental observation was achieved with the $\beta_2 = 0.26$ and $\gamma = 27°$ triaxial deformation parameters. In particular, the $3/2-$ and $5/2-$ states are reproduced very well and the level sequence also matches the experimental observations. Note that $5/2-$ was not observed so-far, but there is indirect evidence for its existence via alpha-electron summing effects, see detailed discussion in [24].

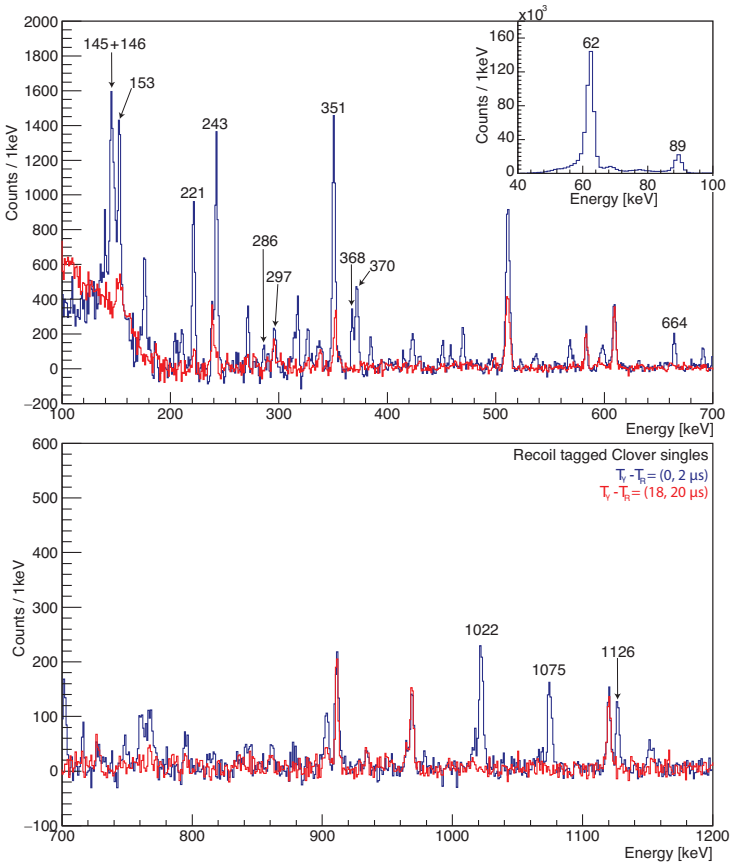


Figure 9: Spectra of γ-ray singles detected with focal plane Clover detectors in a delayed coincidence with the recoil implantation. Blue and red spectrum represents time coincidence window $0 - 2\,\mu s$ and $18 - 20\,\mu s$ respectively. Background is subtracted. Relevant ^{179}Au transition are labeled.

New isomer in ^{179}Au

A new $2.14\,\mu$s isomer in ^{179}Au at excitation energy of 1750 keV was observed for the first time. Its decay was observed to populate the $19/2^-$, $17/2^-$ and $17/2^+$ states via 664.7, 1022.4 and 1074.6 keV transitions, respectively. Half-life of isomeric state was extracted by fitting each γ ray with sufficient intensity detected in focal plane above the $326\,ns$ isomer [24]. Both the differential and running integral methods were employed, resulting half-life values are shown in Fig. 10. Based on observed γ rays depopulating the isomer, spin and parity was tentatively assigned as $19/2^+$. Isomer configuration is proposed as the two-quasiproton $1i_{13/2} \oplus 1h_{9/2}$ core state coupled with the $1h_{9/2}$ proton-particle state. The excitation energy of the two-quasiproton core could be decreased as a result of proton-core correlation. Such configuration provides qualitative explanation for the missing transition into the bands 3 and 5, i.e. bands associated with the $2f_{7/2}$, as the quasiparticles would prefer pairing of two protons and leaving one proton in given $1i_{13/2}$ or $1h_{9/2}$ state. If a K-hindered nature of the isomer is assumed, systematics of the K isomers suggest the $\Delta K = 6$, but due to inevitable K-mixing in the triaxial nuclei, the ΔK value could differ significantly.

A new strongly coupled band was observed to feed the $2.14\,\mu$s isomer, see Fig. 11.

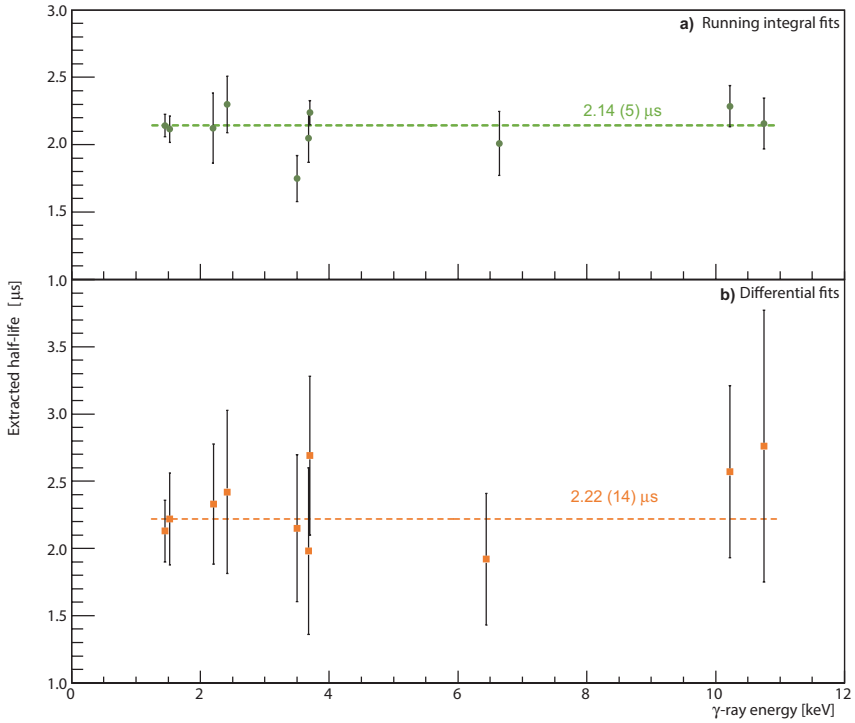


Figure 10: Extracted half lives of isomeric γ rays using both running integral (**a)**) and differential fitting (**b)**). Dashed lines represents weighted average half-life for respective fitting method. Error bars represent combination of fit and statistical errors.

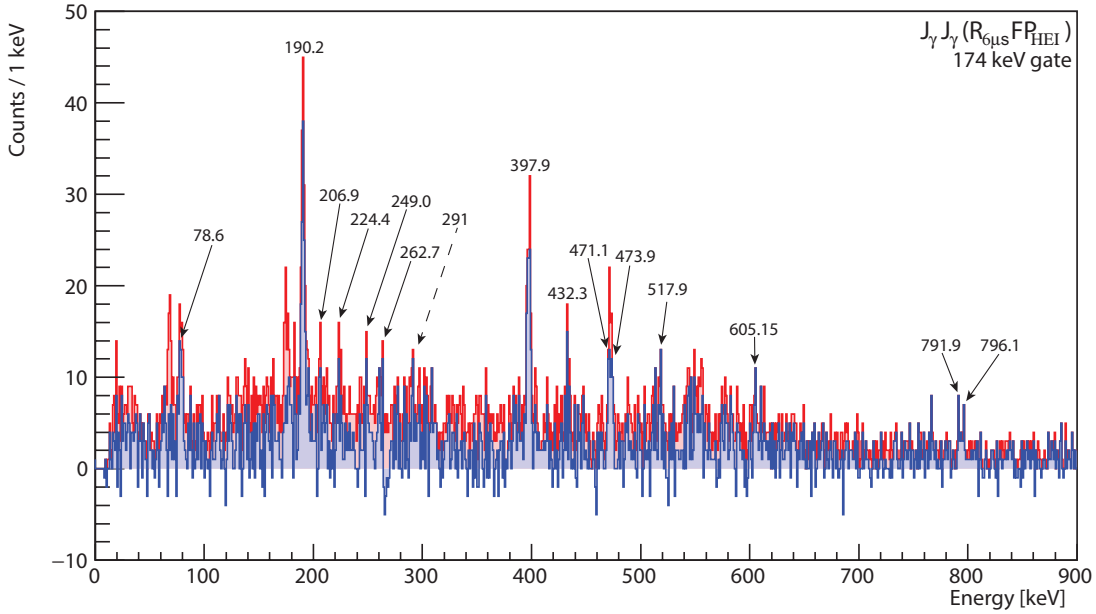


Figure 11: Coincidence spectrum of the 174 keV transition of the Jurogam 2 γ-γ matrix tagged with transitions depopulating the 2.14 μs isomer in focal plane within 6 μs after recoil implantation (denoted as $J_\gamma J_\gamma(R_{6\mu s}FP_{HEI})$. Blue and red spectrum are with and without subtracted background.

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