EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

**Status report to the ISOLDE and Neutron Time-of-Flight Committee**

# Simultaneous spectroscopy of $\gamma$-rays and conversion electrons : Systematic study of $E0$ transitions and intruder states in close vicinity of mid-shell point in odd-Au isotopes

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**Abstract:** This status report gives overview on the results of the IS521 experiment. It studied decay of $^{181,183}$Hg isotopes by means of simultaneous $\gamma$-ray and conversion electron spectroscopy with the TATRA system. Results are summarised and brief overview of future plans is given.

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**Requested shifts:** no request

# 1 Summary of completed experimental runs

Two separate experimental runs were performed:

- **August 2014**
  12 shifts
  Summary:
  First use of the TATRA system [1] at ISOLDE. Data for decay of $^{181,183,185,189}$Hg isotopes were collected. Conversion electrons were not measured due to non-functioning Si(Li) detector. TATRA worked without any serious problems. The tape failure could be repaired by intervention of the chamber.

- **August 2016**
  10 shifts in total: 5 shifts spent
  Summary:
  Second use of the TATRA system at ISOLDE. Data for decay of $^{183,189}$Hg isotopes were collected. Conversion electrons were measured with Si(Li) detector - resolution 1.5 keV reached. Tuning of the ISOLDE beam was very problematic. This caused large contamination of the collimator at the entrance of the TATRA. Accumulated activity changed the ratio between conversion electrons and $\gamma$ rays and made the data almost useless. After 3 day of attempts acceptable (although not perfect) beam spot was reached. Data for $^{183}$Au isotope was collected. The experiment was finished by rupture of welding point of the tape of the TATRA system.

# 2 Broad Energy Germanium detector

A general complication related to studies of odd-Au isotopes is a large density of excited states at low energies, see e.g. [2]. This leads to the complexity of odd-mass decay schemes (several hundreds of $\gamma$ rays), that renders the Rydberg-Ritz technique too ambiguous to be useful, unless $\gamma$-ray energies are measured to a precision better than 50 eV. Therefore, advanced coincidence analysis has to be performed, which includes, e.g, running gates technique. This makes the analysis procedure very complicated a leaves a risk of serious mistakes to be made, see [3]. Further, the use of coincidence spectroscopy to reliably sequence decay paths can be difficult or impossible because of isomerism (coincidence delay) occurring for some of the low-lying excited states. In the face of such challenges, we have developed and applied a dedicated experimental technique [4], which is based on novel Broad Energy Germanium (BEGe) detector [5], for these studies.
A BE2020 BEGe detector operated at ultra-high gain was successfully used to construct the level scheme of $^{181,183}$Au [6, 7], which are nuclei with large densities of excited states at low energies. The advantage of the BEGe detector is not only excellent resolution, and nearly ideal gaussian peak shape, but also the ability to detect high-energy $\gamma$ rays. Using this detector, $\gamma$-ray energies with a precision below 50 eV (in most cases even down to 10 eV) could be determined. To reach such precision, it is critical to operate the detector at ultra-high gains and also to ensure the stability of the electronics. With precisely determined $\gamma$-ray energies, the Rydberg-Ritz combination principle at the level of 30 eV

precision could be used, which makes the process of complex level scheme construction much more simple.
Properties of the BEGe detector, particularly the smooth background continuum (which helps normalisation and deconvolution), allowed the peaks of interest to be distinguished from other processes such as from the decay of daughter activities. This is very important since it simplifies the analysis and reduces the risk of misinterpreting observed transitions. It also provides additional information on the daughter isotopes, which can be analysed separately. Even with the precision of the BEGe detector, the $\gamma$–$\gamma$ coincidence analysis cannot be omitted. Therefore it appears an optimum solution to combine the BEGe detectors with either larger volume BEGe detectors or conventional coaxial detectors or clovers, which offer higher efficiency for $\gamma$ rays above 1 MeV. Such systems will play a major role in the future $\beta$-decay studies of isotopes that have many excited states at low energies.

# 3 Conversion electrons

Conversion electrons are detected with 5 mm thick Si(Li) detector with surface of 80 $\mathrm{mm}^2$. The detector is windowless, cooled with liquid nitrogen and it is housed in the retractable cryostat. It detects conversion electrons approximately up to 2.5 MeV with full width at half maximum of 1.5 keV. The TATRA system reaches vacuum below $10^{-7}$ mbar, which allows operation of such detector. The system is equipped with cryogenic module to ensure safe cooling and warming of the detector. Conversion electrons are detected both in singles and coincidence modes.

# 4 Results summary

Decay schemes of $^{181,183}$Hg were constructed and published. Serious mistakes in previous decay scheme of $^{183}$Hg were identified and corrected. The decay scheme of $^{181}$Hg was established for the first time. The key outcome of this work, which is depicted in Fig. 1, is the elucidation of the intruder states relative to the shell model states. This suggests that the "parabolic" trend, widely observed to be characteristic of the intruder states, has a minimum in $^{183}$Au, i.e., at the $\mathrm{N} = 104$ the mid-neutron shell. These results are corroborated by recent in-source laser spectroscopy measurements.
The first excited state of $^{181}$Au has energy of 1.8 keV only, which is the lowest in Au isotopic chain. Two electric monopole transitions were identified in $^{183}$Au.
States associated with $1h_{11/2}$ proton-hole configuration were also observed. They allow insight into the deformation, both axial and triaxial, of corresponding even-even Hg cores, within a framework of the particle-plus-triaxial-rotor model [9]. This makes the data acquired with the TATRA system complementary to the Coulomb excitation studies of neutron-deficient, even-Hg isotopes.

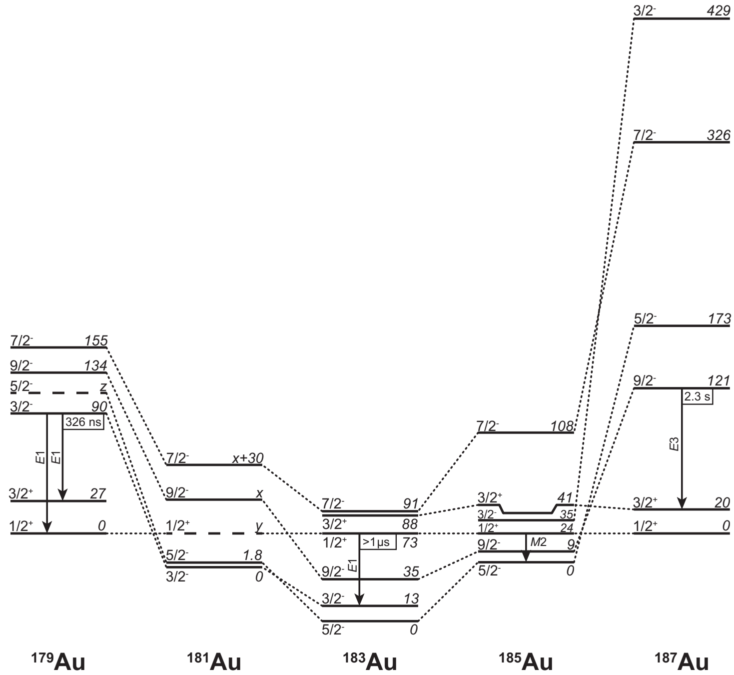


Figure 1: Systematics of $3/2^-$, $5/2^-$, $7/2^-$, and $9/2^-$ states associated with intruder configurations, depicted relatively to $1/2^+$, and $3/2^+$ states associated with $2d_{3/2}$, $3s_{1/2}$ proton-hole configurations in odd-Au isotopes. The data are taken from [2, 3, 6, 8].

# 5 Future prospect

TATRA is using rapidly quenched metallic tape to transport the activity. Tensile strength of this material is very large, it is radiation hard, and has excellent vacuum properties. However it is difficult to produce in acceptable quality and length and its mechanical properties are nearly unknown.

To study decay of isotopes with half lives of the order of few seconds, the main limitation is length of the tape of existing TATRA system. Existing system can accommodate only approximately 30 m. This causes a large background from daughter activities, that complicate the data analysis. Therefore, a development of the system with tape length exceeding 500 m has been started. Rapidly quenched tape with sufficient length was already produced at the Institute of Physics and welding procedure of its alloy was developed. Due to this material, the vacuum properties of existing system will be kept, or even improved. We expect to have the first prototype by the end of 2019 and final system by the end of 2020.

As a next step in our research program, the $^{185}$Hg isotope need to be studied. This experiment require the assistance of the laser ion source, since $^{185}$Hg has two $\beta$-decaying isomers ($1/2^-$ and $13/2^+$), that need to be studied separately. The details on the physics motivation, and choice of isotope will be in detail explained in future proposal. It will be submitted to INTC as soon as the call for proposal appears. This experiment can be performed with existing TATRA system without any modifications or limitations, therefore it does not rely on above described research and development.

Remaining 5 shifts, that are presently available, cannot be effectively used. The ground transport of the TATRA from Bratislava to CERN is complicated and expensive. There are two possible solutions:

- **Remove all shifts** In this case we will submit a full new addendum on study of $^{185}$Hg isotope as a separated physics case.
- **Keep all shifts** In this case we will submit addendum in which we will propose to change the purpose of remaining shifts from study of $^{183}$Hg to $^{185}$Hg and add needed number of new shifts.

For us, both options are equivalent, they only require slightly different formulation of future proposal. However, it is very important to keep the IS521 experiment listed in the Greybook, since it gained enormously positive impact in Slovak society. Presently, there is ongoing discussion on increasing the contribution of Slovakia to ISOLDE collaboration budget. Having the IS521 registered as official CERN experiment significantly strengthens our position in negotiations with the Ministry of Education, Science, Research and Sport of Slovak Republic, even if there will be no shifts available for some time.

# 6 RECFA report

On 18 - 19 May 2018, meeting of Restricted ECFA was held at the Slovak Academy of Sciences, in Bratislava. In the letter addressed to Dr. Martina Lubyová, Minister of Education, Science, Research and Sport of Slovak Republic, RECFA states that: *"The committee congratulates the Slovak ISOLDE research team for its expansion since 2010 and its clear impact on the field. Its leadership and achievements are internationally admired. We encourage the team to continue in this strong, yet realistic and well-motivated ambition. In the same vein, we advise the policy makers to establish continuous support at a level that will enable the team to succeed in its ambitions."*

# 7 Outcomes of IS521

## 7.1 Published articles

Following articles were published:

M. Venhart, J. L. Wood, M. Sedlák, M. Balogh, M. Bírová, A. J. Boston, T. E. Cocolios, L. J. Harkness-Brennan, R.-D. Herzberg, L. Holub, D. T. Joss, D. S. Judson, J. Kliman, J. Klimo, L. Krupa, J. Lušnák, L. Makhathini, V. Matoušek, Š. Motyčák, R. D. Page, A. Patel, K. Petrík, A. V. Podshibyakin, P. M. Prajapati, A. M. Rodin, A. Špaček, R. Urban, C. Unsworth and M. Veselský
**New systematic features in the neutron-deficient Au isotopes**
J. Phys. G: Nucl. and Part. Phys. **44**, 074003 (2017).

M. Venhart, J. L. Wood, A. J. Boston, T. E. Cocolios, L. J. Harkness-Brennan, R.-D. Herzberg, D. T. Joss, D. S. Judson, J. Kliman, V. Matoušek, Š. Motyčák, R. D. Page, A. Patel, K. Petrík, M. Sedlák, M. Veselský
**Application of the Broad Energy Germanium detector: A technique for elucidating $\beta$-decay schemes which involve daughter nuclei with very low energy excited states**
Nucl. Instrum. and Methods in Phys. Res., Sect. A **849**, 112 (2017).

V. Matoušek, M. Sedlák, M. Venhart, D. Janičkovič, J. Kliman, K. Petrík, P. Švec, P. Švec, Sr., M. Veselský
**TATRA: a versatile high-vacuum tape transportation system for decay studies at radioactive-ion beam facilities**
Nucl. Instrum. and Methods in Phys. Res., Sect. A **812**, 118 (2016).

Presently, the article on nuclear structure of $^{181}$Au isotope is under preparation.

## 7.2 Theses

M. Sedlák: *Gamma-ray and conversion-electron spectroscopy at CERN-ISOLDE facility.*. Dissertation thesis was submitted at the Institute of Physics on April 26, 2019. The thesis deals with nuclear structure of $^{181,183}$Au isotopes and its defence is expected in August 2019.

Several master and bachelor theses were defended at Comenius University in Bratislava, Slovakia.

# References


[1] V. Matoušek *et al.*, Nucl. Instrum. and Methods in Phys. Res., Sect. A **812**, 118 (2016).

[2] D. Rupnik *et al.*, Phys. Rev. C **58**, 771 (1998).

[3] M. O. Kortelahti *et al.*, J. Phys. G. **14**, 1361 (1988).

[4] M. Venhart *et al.*, Nucl. Instrum. and Methods in Phys. Res., Sect. A **849**, 112 (2017).

[5] L. J. Harkness-Brennan *et al.*, Nucl. Instrum, and Methods in Phys. Res., Sect. A **760**, 28 (2014).

[6] M. Venhart *et al.*, J. Phys. G **44**, 074003 (2017).

[7] M. Sedlák *et al.*, to be published.

[8] M. Venhart *et al.*, Phys. Lett. B **695**, 82 (2011).

[9] J. Meyer-ter-Vehn, Phys. Rev. Lett. **32**, 24 (1974).