First results of the (n,\(\gamma\)) EXILL campaigns at the Institut Laue Langevin using EXOGAM and FATIMA

J Jolie\textsuperscript{1a}, J.-M. Régis\textsuperscript{1}, D. Wilmsen\textsuperscript{1}, S. Ahmed\textsuperscript{1b}, M. Pfeiffer\textsuperscript{1}, N. Saed-Samii\textsuperscript{1}, N. Warr\textsuperscript{1}, A. Blanc\textsuperscript{2}, M. Jentschel\textsuperscript{2}, U. Köster\textsuperscript{2}, P. Mutti\textsuperscript{2}, T Soldner\textsuperscript{2}, G. Simpson\textsuperscript{3}, G. de France\textsuperscript{4}, W. Urban\textsuperscript{5}, A.M. Bruce\textsuperscript{6}, O.J. Roberts\textsuperscript{6}, L.M. Fraile\textsuperscript{7}, V. Paziy\textsuperscript{7}, A. Ignatov\textsuperscript{8}, S. Ilieva\textsuperscript{8}, Th. Kröll\textsuperscript{8}, M. Scheck\textsuperscript{8}, M. Thürau\textsuperscript{8}, D. Ivanova\textsuperscript{9}, S. Kisyov\textsuperscript{9}, S. Lalkovski\textsuperscript{9}, Zs. Podolyak\textsuperscript{10}, P.H. Regan\textsuperscript{10}, W. Korten\textsuperscript{11}, D. Habs\textsuperscript{12}, P.G. Thirolf\textsuperscript{12}, C.A. Ur\textsuperscript{13}

\textsuperscript{1} IKP, University of Cologne, Zülpicher Str. 77, D-50937 Köln, Germany,
\textsuperscript{2} ILL, 6 rue Jules Horowitz, 38042 Grenoble Cedex 9, France
\textsuperscript{3} LPSC, 53 rue des Martyrs, 38026 Grenoble Cedex, France
\textsuperscript{4} GANIL, BP 55027, 14076 Caen Cedex 5, France
\textsuperscript{5} Institute of Experimental Physics, University of Warsaw, ul. Hoza 69,00681 Warsaw, Poland
\textsuperscript{6} SCEM, University of Brighton, Lewes Road, Brighton BN2 4GJ, UK
\textsuperscript{7} Departamento de Física Atómica y Nuclear, Universidad Complutense, 28040 Madrid Spain
\textsuperscript{8} Institut für Kernphysik, TU Darmstadt, Germany
\textsuperscript{9} Faculty of Physics, University of Sofia, Bulgaria
\textsuperscript{10} Dept. of Physics, University of Surrey, Guildford GU2 7XH, and National Physical Laboratory, Teddington, Middlesex, UK TW11 0LW
\textsuperscript{11} CEA, Centre de Saclay, IRFU, F-91191 Gif-sur-Yvette, France
\textsuperscript{12} Fakultät für Physik, Ludwig Maximilian Universität, 85748 Garching, Germany
\textsuperscript{13} INFN Sezione di Padova, 35131 Padova, Italy

E-mail: j.jolie@ikp.uni-koeln.de

Abstract. At the PF1B cold neutron beam line at the Institut Laue Langevin the EXILL array consisting of EXOGAM, GASP and LOHENGRIIN detectors was used to perform (n,\(\gamma\)) measurements under very high coincidence rates. About ten different reactions were then measured in autumn 2012. In spring 2013 the EXOGAM array was combined with 16 LaBr\textsubscript{3}(Ce) scintillators in the FATIMA@EXILL campaign for the measurement of lifetimes using the generalised centroid difference method. We report on the properties of both set-ups and present first results on Pt isotopes from both campaigns.

1. Introduction
During autumn 2012 and spring 2013 the EXOGAM spectrometer\cite{1} and additional detectors were installed on the high intensity cold neutron guide PF1B of the Institut Laue Langevin (ILL) for the EXILL campaign. EXILL is partially a follow-up of a previous campaign using 8 EUROBALL capsule Ge
detectors and a highly collimated cold neutron beam for \((n,\gamma)\) measurements [2]. The EXILL campaigns, which took two reactor cycles of 49 days, used beside the \((n,\gamma)\) also the \((n,fission)\) reaction on \(^{235}\text{U}\) and \(^{241}\text{Pu}\) targets. Here we will only report on very first results from the \((n,\gamma)\) reaction on \(^{194}\text{Pt}\) and \(^{195}\text{Pt}\).

2. The used set-ups

The same collimator used in Ref [2] provided, at the target position, a 12-mm diameter cold neutron beam of \(10^8 n/(s\cdot cm^2)\). Perpendicular to the beam 8 EXOGAM Clover detectors with their BGO shields were mounted in a ring while the additional detectors were mounted in the forwards and backwards directions under 45°. During the first reactor cycle and part of the second one, 6 shielded GASP Ge detectors and 2 unshielded LOHENGRIN Clovers were mounted in addition to EXOGAM. Digital data acquisition allowed to handle event rates up to 0.84 MHz. With this set-up we have measured gamma-rays from the \(^{194}\text{Pt}(n,\gamma)^{195}\text{Pt}\) reactions. During 30 days of the second cycle 16 \(\text{LaBr}_3(\text{Ce})\) scintillators from the fast-timing array (FATIMA) collaboration were combined with the EXOGAM detectors for fast-timing measurements. From this campaign we report on results with the \(^{195}\text{Pt}(n,\gamma)^{196}\text{Pt}\) reaction.

3. First results for the \(^{194}\text{Pt}(n,\gamma)^{195}\text{Pt}\) reaction

Three 96% enriched targets of masses 200,140 and 70 mg were irradiated for a total of 3 days. Of interest was the population of the 4 days 13/2\(^+\) isomer, which is populated with a thermal capture cross section of less than 0.1 barn. Gamma-ray cascades leading to this isomer after thermal neutron capture were first observed by D. D. Warner \textit{et al.} in 1982 [3] and a \(3/2^+,5/2^- \rightarrow 5/2^- \rightarrow 9/2^- \rightarrow 13/2^+\) cascade was identified populating the isomer from the capture state. Using only the EXOGAM data, the population of the isomer could be corrected and extended as shown in Figure 1 [4]. The full analysis of these data is still ongoing.

![Gamma-ray cascade](image-url)

Figure 1: Comparison between the Warner cascade and the extended cascade.
3. First results for the $^{195}$Pt(n,$\gamma$)$^{196}$Pt reaction

Many years ago the even-even nucleus $^{196}$Pt was proposed as an example of the SO(6)-limit of the Interacting Boson Model (IBM) [5]. When the Hamiltonian for N s,d bosons is composed by the linear combination of second order Casimir operators of the group chain: SO(3) $\subset$ SO(5) $\subset$ SO(6) $\subset$ U(6), the quantum numbers classifying the irreducible representation (irrep) of these groups: $L$, $\nu$, $\sigma$, $N$ are valid and the Hamiltonian is analytically solvable. The lowest states have $\sigma=N$. States at higher energies can have $\sigma=N-2$, $N-4$, ....

Recently, the need to test the SO(6) symmetry and not only the SO(5) properties in $^{196}$Pt was stressed [6]. When testing the goodness of the description of an SO(6) nucleus one thus should look for properties involving states with different $\sigma$. One of these properties concerns the electric quadrupole transition operator. In the SO(6) limit, the E2 transition operator is a generator of SO(6). Now generators cannot act outside their irrep and the strict selection rule $\Delta \sigma=0$ follows. In order to test this selection rule, absolute B(E2) values between $\sigma=N-2$ and $\sigma=N$ states need to be measured. This is not an easy task as the first $\sigma=N-2$ states in $^{196}$Pt are at high energy and have low spins. They are not populated by standard in-beam reactions with ions, but well by neutron capture. It is, therefore, not an accident that Ref [5] relied on ILL data. In 1990 we made an attempt to measure the lifetime of the lowest $\sigma=N-2$ state at 1402.7 keV using the GRID method [6] at GAMS4 [7]. For this $0^+_3$ state a lower lifetime limit of $\tau > 1.8$ ps could be established showing that the B(E2) towards the $2^+_1$ was smaller than 0.034e$^2$b$^2$ and, as such, at least an order of magnitude smaller than allowed transitions between states with $\sigma=N$. Using the FATIMA set-up at EXILL triple coincidences can be used in which a Ge gate selects the cascade of gamma-rays to be measured by the LaBr$_3$(Ce) scintillators. These fast signals can then be used for the generalised mirror symmetric centroid difference method [9,10] to measure lifetimes. The prompt response difference curve (PRD) was obtained using an $^{153}$Eu source and transitions in $^{49}$Ti after neutron capture. The method can be used to measure lifetimes down to about 10 ps. Figure 2 shows the time spectra of the 333-356 keV cascade gated by the 1978 keV transition in $^{196}$Pt. The observed centroid difference between both spectra corresponds to 108.4(48) ps. Using the PRD curve a lifetime of $\tau = 50(5)$ ps is deduced which agrees very well with the literature value of 49.2(2) ps. Being confident that the method works, the lifetime of the 1402 keV $0^+$ state was then measured. Again the 356 keV transition provided the decay signal for the fast timing. The feeding signal was obtained from the 566 keV transition feeding the $1402$ keV state. The Ge gate was set on the 1048 keV transition of the decay towards the first excited state. The effective lifetime deduced from the centroid shift $\tau_{\text{eff}} = \tau_2 + \tau_0$ was 54(7) ps leading to an upper limit for the lifetime of $\tau_0 < 12$ ps. Using also the lower limit from [8] we find that 0.56 W.u $< B(E2; 0^+_3 \rightarrow 2^+_1) < 5$ W.u and 0.05 W.u $< B(E2; 0^+_3 \rightarrow 2^+_2) < 0.41$ W.u. Clearly no collective B(E2) values are found between the states, confirming the validity of the SO(6) symmetry.
Figure 2: The binned time spectra using the 356 keV ground state transition as start for the TAC (left curve) and once as stop (right curve) (color online).

4. Acknowledgements
This work was supported by NUPNET by contract 05P12PKNUF (BMBF) and DNC7RP01/4, by the Science and Technology Facilities Councils (UK), by the DFG cluster of Excellence ‘Origin and Structure of the Universe’. The EXILL campaign would not have been possible without the support of several services at the ILL and the LPSC. We are grateful to the EXOGAM collaboration for the loan of the detectors, to GANIL for assistance during installation and dismantling, and to the INFN Legnaro laboratory for the loan of the GASP detectors.

References
[1] J. Simpson et al., 2000, Acta Physica Hungarica, New Series, Heavy Ion Physics 11, 159.
[2] W. Urban et al, 2013, JINST 8 3014.
[3] D. D. Warner, et al. 1982, Phys. Rev. C 26 1921.
[4] D. Wilmsen 2013, Diploma thesis, University of Cologne.
[5] J.A. Cizewski et al. 1978, Phys. Rev. Lett. 40 167.
[6] G. Rainovski et al. 2010, Phys. Lett. B683 11.
[7] H.G. Börner, J. Jolie1993, Journ. Phys. G19 217.
[8] H.G. Börner, et al.1990, Phys. Rev. C42 R2271.
[9] J.-M. Régis et al. Nucl. Instr. Meth. Phys. Res. A 726 (2013) 191.
Corrigendum: First results of the (n,γ) EXILL campaigns at the Institut Laue Langevin using EXOGAM and FATIMA

Journal of Physics Conference Series 533 (2014)012026

J Jolie1a, J.-M. Régis1, D. Wilmsen1, S. Ahmed1b, M. Pfeiffer1, N. SaedSamii1, N. Warr1, A. Blanc2, M. Jentschel2, U. Köster2, P. Mutti2, T Soldner2, G. de France4, W. Urban5, A.M. Bruce6, O.J. Roberts6, L.M. Fraile7, V. Paziy7, A. Ignatov8, S. Ilieva8, Th. Kröll8, M. Scheck8, M. Thürauf8, D. Ivanova9, S. Kisyov9, S. Lalkovski9, Zs. Podolyak10, P.H. Regan10, W. Korten11, D. Habs12, P. G. Thirolf12, C. A. Ur13

1 IKP, University of Cologne, Zülpicher Str. 77, D-50937 Köln, Germany,
2 ILL, 6 rue Jules Horowitz, 38042 Grenoble Cedex 9, France
3 LPSC, 53 rue des Martyrs, 38026 Grenoble Cedex, France
4 GANIL, BP.55027, 14076 Caen Cedex 5, France
5 Institute of Experimental Physics, University of Warsaw, ul. Hoza 69,00681 Warsaw, Poland
6 SCEM, University of Brighton, Lewes Road, Brighton BN2 4Gd, UK
7 Departamento de Fisica Atómica y Nuclear, Universidad Complutense, 28040 Madrid Spain
8 Institut für Kernphysik, TU Darmstadt, Germany
9 Faculty of Physics, University of Sofia, Bulgaria
10 Dept. of Physics, University of Surrey, Guildford GU2 7XH, and National Physical Laboratory, Teddington, Middlesex, UK TW11 0LW
11 CEA, Centre de Saclay, IRFU, F-91191 Gif-sur-Yvette, France
12 Fakultät für Physik, Ludwig Maximilian Universität, 85748 Garching, Germany
13 INFN Sezione di Padova, 35131 Padova, Italy

E-mail: j.jolie@ikp.uni-koeln.de

The lower limits on the B(E2) values in W.u should be: $0.75 \text{ W.u} < B(E2;0^+_3 \rightarrow 2^+_1) < 5 \text{ W.u}$ and $0.06 \text{ W.u} < B(E2;0^+_3 \rightarrow 2^+_2) < 0.41 \text{ W.u}$. This small change doesn’t affect the conclusions.

---

a To whom any correspondence should be addressed.