PAPER • **OPEN ACCESS**

^{208}Po populated through EC/β^{+} decay

To cite this article: M. Brunet *et al* 2020 *J. Phys.: Conf. Ser.* **1643** 012116

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M. Brunet[1] T. A. Berry[1], Zs. Podolyák[1], R. J. Carroll[1], R. Lica[2,3], Ch. Sotty[3,4], A. N. Andreyev [5], M. J. G. Borge[2], J. G. Cubiss[2,5] L. M. Fraile[6], H. O. U. Fynbo[7], E. Gamba[8], P. Greenless[9], L. J. Harkness-Brennan[10], M. Huyse[4], D. S. Judson[10], J. Konki[9], J. Kurcewicz[2], I. Lazarus[11], M. Madurga[2], N. Marginean[3], R. Marginean[3], I. Marroquin[12], C. Mihai[3], E. Nácher[12], A. Negret[3], S. Pascu[3], R. D. Page[10], A. Perea[12], J. Phrompao[13], M. Piersa[14], V. Pucknell[11], P. Rahkila[9], E. Rapisarda[2], P. H. Regan [1,15], F. Rotaru[3], M. Rudigier[1], C. M. Shand[1], R. Shearman[1,15], E. C. Simpson[16], T. Stora[2], O. Tengblad[12], P. Van Duppen[4], V. Vedia[6], S. Vinals[12], R. Wadsworth[5], N. Warr[16], and H. De Witte[4].

[1]Department of Physics, University of Surrey, Guildford, GU2 7XH, United Kingdom
[2]CERN, Physics Department, 1211 Geneva 23, Switzerland
[3]H. Hulubei National Institute for Physics and Nuclear Engineering, Bucharest, Romania
[4]KU Leuven, Institut voor Kern- en Stralingsfysica, Celestijnenlaan 200D, 3001 Leuven, Belgium
[5]Department of Physics, University of York YO10 5DD, N Yorkshire, United Kingdom
[6]Grupo de Física Nuclear & IPARCOS, Universidad Complutense de Madrid, CEI Moncloa, 28040 Madrid, Spain
[7]Department of Physics and Astronomy, Aarhus University, DK-8000 Aarhus, Denmark
[8]University of Brighton, Brighton BN2 4GJ, United Kingdom
[9]Department of Physics, PO Box 35 (YFL), FI-40014 University of Jyväskylä, Finland
[10]Department of Physics Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom
[11]STFC, Daresbury Laboratory, Warrington, WA4 4AD, United Kingdom
[12]Instituto de Estructura de la Materia, CSIC, Serrano 113 bis, E-28006 Madrid, Spain
[13]Department of Physics and Material Science, Chiang Mai University, Chiang Mai, Thailand
[14]Faculty of Physics, University of Warsaw, PL 02-093 Warsaw, Poland
[15]National Physical Laboratory, Teddington, Middlesex, TW11 OLW, United Kingdom
[16]Department of Nuclear Physics, Research School of Physics, Australian National University, Canberra, ACT 2601, Australia
[17]Institut für Kernphysik der Universität zu Köln, Zülpicher Str. 77, 50937 Köln, Germany.

Abstract. The structure of ^{208}Po resulting from the EC/β^+ decay of ^{208}At was studied at CERN's ISOLDE Decay Station (IDS). The high statistics afforded by the high yield of ^{208}At and the high efficiency HPGe clusters at the IDS allowed for greater insight into lower intensity transitions and thus significant expansion of the ^{208}Po level scheme. Furthermore, investigation into the isomeric state yielded a new half life 377(9) ns in addition to uncovering new transitions populating the state.

1. Introduction

With only four valence nucleons (two protons particles and two neutron holes) ^{208}Po's proximity to the doubly-magic ^{208}Pb nucleus means that its structure can be reasonably described by the shell model. However, ^{208}Po is also in a region which exhibits strong octupole collectively, most famously in the first excited state of ^{208}Pb at an energy of 2614.5 keV [1]. Consequently, ^{208}Po offers an opportunity to investigate both collective and shell structures and how such states interact within a nucleus.

Phenomena such as octupole collectivity, core breaking, and configuration mixing make it difficult to produce accurate predictions particularly for higher energy states. Thus experimental data is key to better our understanding of nuclear structure in this mass region.

By investigating the structure of ^{208}Po through the decay of its parent nucleus ^{208}At ($J^{\pi} = 6^{+}, Q_{\beta} = 4978(26)$ keV [1]) the populated states are limited to relatively low-energy, low-spin states through beta-decay selection rules.

The structure of ^{208}Po resulting from the decay of ^{208}At was studied once before in the early 1980s [2]. A significant number of transitions and states were identified from this dataset and a level scheme was produced. However, due to the low efficiency of the small Ge(Li) detectors used (particularly at higher energies), many transitions remain unplaced in the level scheme [1, 3].

2. Experimental Setup

The nuclei of interest were produced at ISOLDE via a pulsed proton beam at 1.4 GeV provided by the Proton-Synchrotron Booster (PS-Booster) [4] incident on a molten lead target equipped with a VD5 FEBIAD type ion source [5]. ^{208}At would typically not result in large quantities from this reaction, as such the cause of the unexpectedly high production of ^{208}At in this experiment remains unclear. Three potential production methods are outlined in a paper by Y. Tall *et al.* [6] which suggest a significant ^{209}Bi contaminant could have been present in the target.

The resultant cocktail beam was extracted at 50 kV and passed through the General Purpose Separator (GPS) set for mass A=208. The nuclei from the beam were then implanted on to the tape at the ISOLDE Decay Station. The tape is set up such that it can be moved periodically to avoid decays from longer-lived isotopes or daughter nuclei obscuring the data.

Four High-Purity Germanium (HPGe) clover detectors and a fifth germanium detector from TIGRESS [7] were set up to measure the resultant γ rays with a total γ efficiency of 11% at 100 keV and 4% at 1 MeV [8]. The IDS is also capable of β detection using a plastic scintillator and photomultiplier tube arrangement surrounding the tape upon which the nuclei are implanted. However, due to ^{208}At predominantly decaying via electron capture, β coincidences are significantly less effective for distinguishing decays in ^{208}Po.

3. Results

Figure 1 shows a full projection of γ-γ coincidence data with the majority of the strong peaks labelled. The full projection demonstrates an abundance of peaks resulting from transitions in ^{208}Po, the majority of which have been placed in the current level scheme [1, 3]. The spectrum also features a number of gamma rays, particularly at higher energies, which were previously observed [2, 3] but are yet to be placed. The high detection efficiency provided by the large HPGe cluster detectors in place at the IDS result in a high level of statistics for these peaks ($\sim$$10^3$ counts) even at higher energies.

Another feature visible in the full projection is several contaminant peaks, which have been attributed to various sources. As is typical for spectra of this nature two of the strongest background peaks 1460.8 keV and 2614.5 keV which correspond to the decay of ^{40}K and ^{208}Tl respectively are clearly visible [9]. These random-coincidence, background peaks feature prominently in the spectrum due to the wide coincidence window (1 μs) used to produce the

Journal of Physics: Conference Series **1643** (2020) 012116 doi:10.1088/1742-6596/1643/1/012116

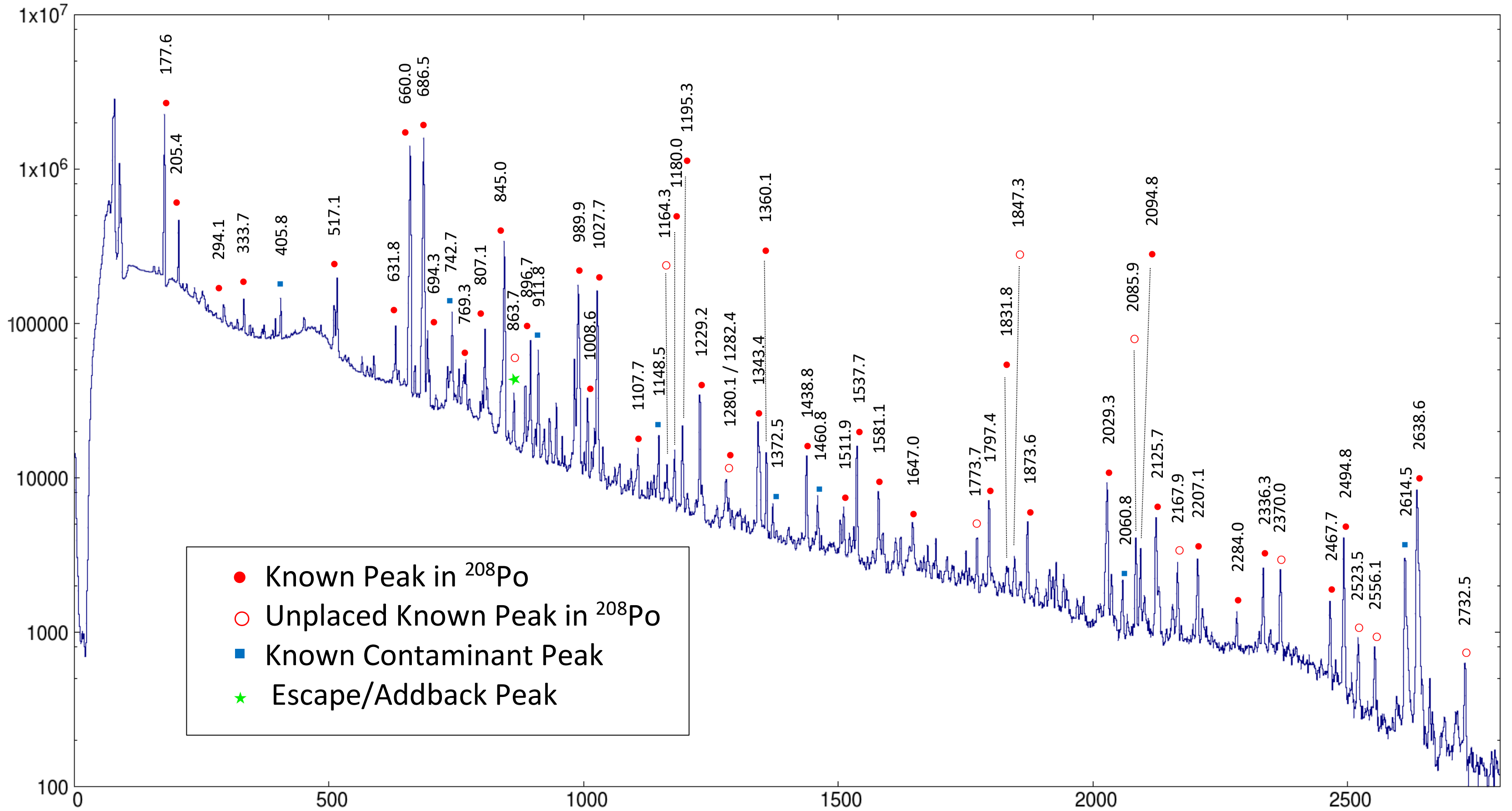

Figure 1. Full projection of the γ-γ matrix for the A=208 dataset (1 μs coincidence window). Notable peaks in the spectrum have been labelled, the contaminant peaks featured result from decays in ^{207}Bi which is a known beam contaminant. Strong background peaks (^{40}K at 1460.8 keV and ^{208}Tl at 2614.5 keV) are also visible.

γ-γ matrix. This time window is necessary to account for the long-lived isomeric state ($T_{1/2}$ = 350(20) ns [1, 10]) in ^{208}Po.

In addition to the typical background the spectrum also features a number of peaks attributable to contaminants from the beam itself. The most notable of these, and the only one present in the full projection, is ^{207}Bi (produced via the β decay of ^{207}Po) of which many of its higher intensity transitions (405.8, 742.7, and 911.8 keV [11]) can be observed.

The structure of ^{208}Po features a relatively long-lived isomeric state at 1528 keV [1]. The majority of possible decays from the isomeric state feature high multipolarity, consequently the isomer decays solely via a 4 keV, E2 transition. This results in a half life with a current accepted value of 350(20) ns [1]. The high level of statistics, mentioned previously, allow for a determination of the half life using coincidence timing. The coincidence time spectrum shown in figure 2 was produced using a γ-γ-Δt cube and selecting transitions above and below the isomeric transition. Fitting this data yielded a half life of 377(9) ns. This is in agreement with both the accepted value and the previous measurement of the half life obtained from the decay of ^{208}At (380(90) ns [12]), but with a smaller error bar.

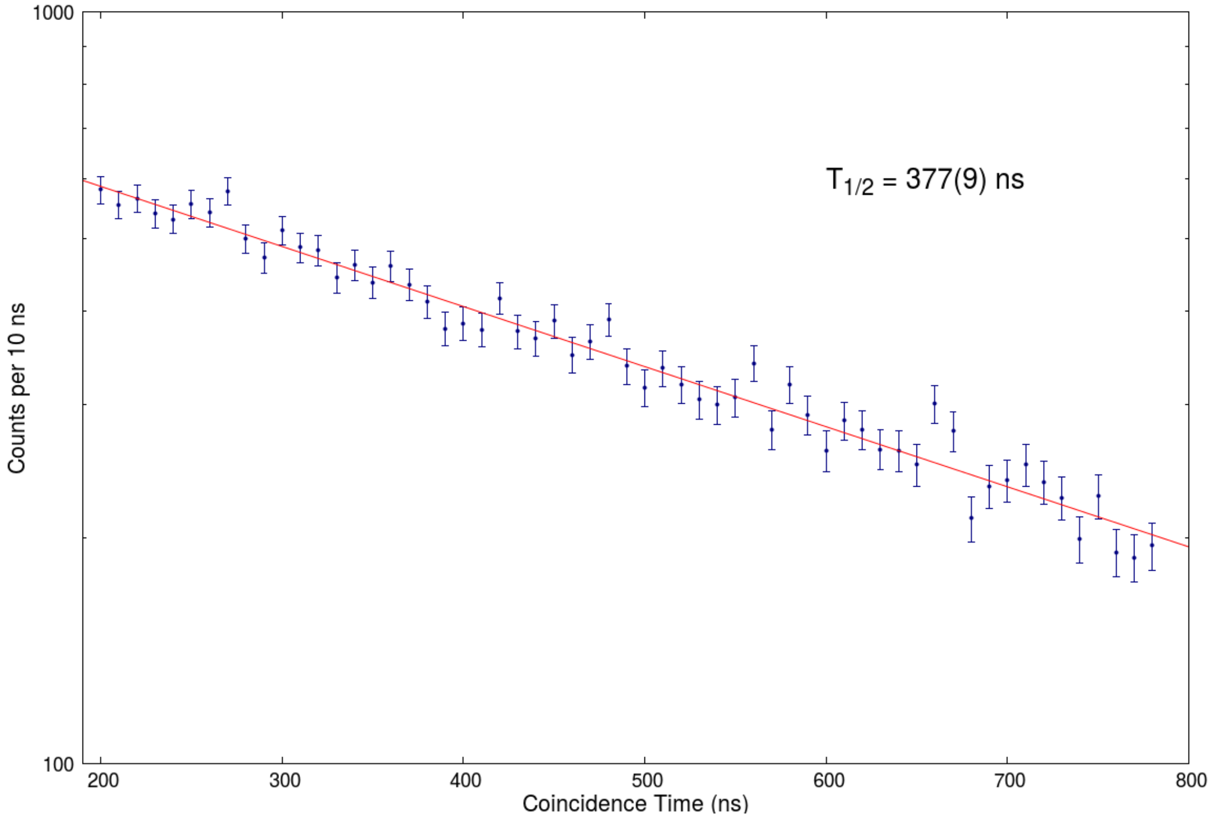

Figure 2. Coincidence time spectrum for the 1528 keV isomeric state. The time difference between the 631.6 keV and 177.4 keV transitions is shown.

As the 4 keV decay is too low in energy to be observed, coincidence spectra for transitions onto the isomeric state are indistinguishable from those which directly populate the state just below it. However due to the long half life of the J^{π} =8^{+} state it is possible to identify these transitions by coincidence time. Figure 3 shows a γ spectrum produced by selecting delayed coincidences and subtracting prompt gammas with coincidence times <20 ns.

The spectrum in figure 3 features a number of negative peaks, which correspond to transitions

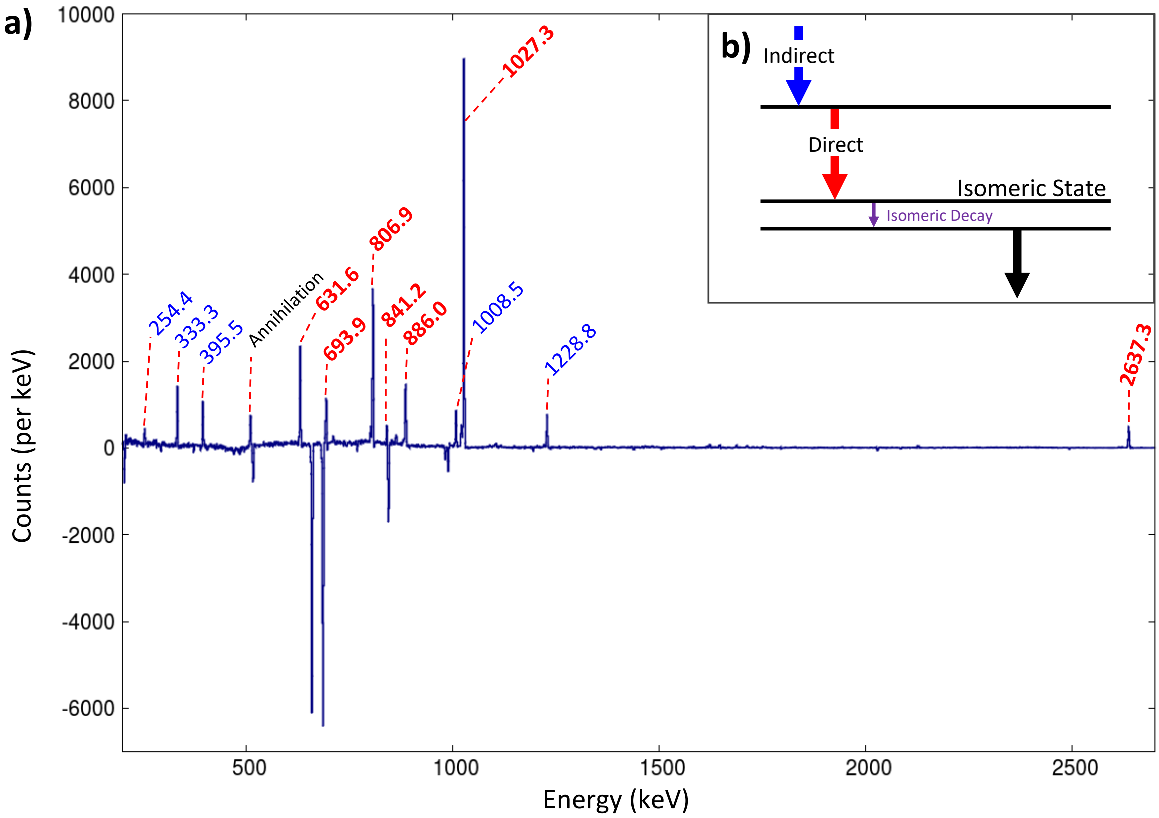

Figure 3. a) Gamma spectrum of delayed decays (coincidence time ¿100ns) with prompt decays (¡20ns) subtracted. Prominent peaks have been labelled and direct decays have been labelled in bold according to the simplified level scheme shown in **b)**.

that bypass the isomeric state. When the prompt gammas are subtracted they appear as negative peaks.

The positive peaks decay through the isomeric state either directly or indirectly, direct population is indicated by the bold labels and described in the diagram in figure 3.

Selecting the delayed coincidences includes transitions which directly populate the isomeric state (indicated by bold labels). This allowed for the confirmation of a new transition (693.9 keV) which is otherwise obscured by another higher intensity transition at a similar energy. A number of gammas in the spectrum are the result of decays which populate the isomeric state indirectly. This is the case for the three lowest energy peaks in the spectrum (indicated by non-bold labels) which each decay to states with subsequent transitions visible in this spectrum.

4. Discussion

It is important to compare experimental results to theoretical calculations in order to better understand the structure and improve the predictive properties of the models. The shell model calculations were performed using the NuShellX code [13]. The ”pbpop” interaction was used [14], which considers only the nucleons in the proton orbitals $h_{9/2}$, $f_{7/2}$, and $i_{13/2}$ above Z=82, as well as the neutrons orbitals $f_{5/2}$, $p_{3/2}$, $p_{1/2}$, and $i_{13/2}$ below N=126.

There is reasonable agreement in energies between the lowest levels in the current decay scheme and the corresponding predicted states. It is, however, far from perfect, as the low

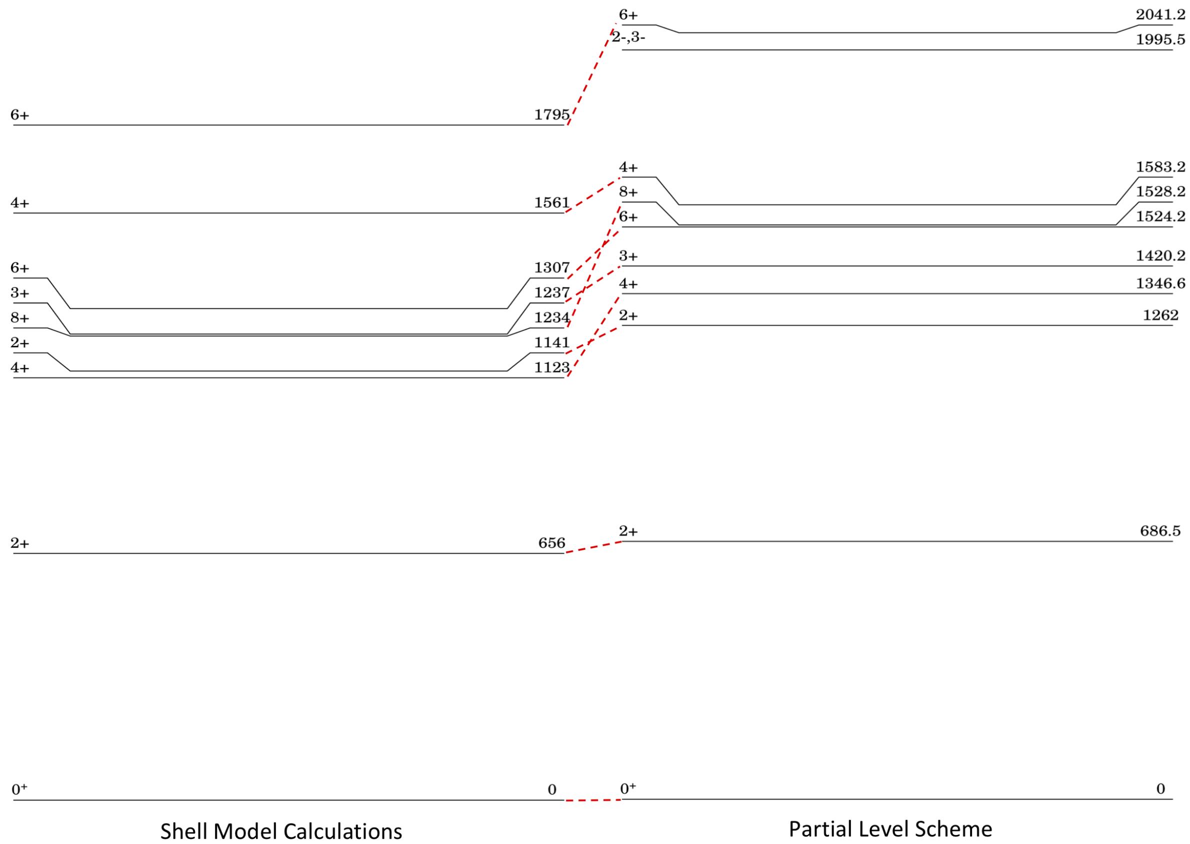

Figure 4. Comparison between the lowest states of the ^{208}Po level scheme [1] with the corresponding states from shell model calculations.

energy states are noticeably compressed in the shell model calculations. This effect could be resolved by considering a greater number of orbitals which would increase mixing between states and lower the ground state.

The most notable discrepancy however is the absence of negative parity states at low energies. This contradicts the previous measurement of a low energy (2^-,3^-) state at 1995 keV [1, 3]. 2^- and 3^- states are predicted in the shell model calculations, but at significantly higher energies, 3344 keV and 3181 keV respectively. In order to gain a better understanding of lower-energy, negative-parity states additional orbitals should be taken into account allowing for excitations across the proton and neutron shell gaps.

5. Summary

Through analysis of high statistic data taken at the IDS for the decay of ^{208}At, the low-energy states of ^{208}Po were studied. The 8^+ isomeric state was investigated in great detail leading to the discovery of several new transitions populating the isomer. Furthermore, a value for the half life of the isomer of 377(9) ns was determined which is in good agreement with previous measurements.

6. Acknowledgements

The authors would like to thank the operators of the ISOLDE facility for providing the beam for this experiment. The research leading to these results has received funding from the European

Union's Horizon 2020 research and innovation programme under grant agreement no. 654002. As well as the Science and Technology Facilities Council (UK) through grants ST/P005314/1, ST/L005743/1, ST/J000051/1, ST/L005670/1, and ST/P004598/1 and (PHR) by the UK Department of Business, Energy and Industrial Strategy (BEIS) via the National Measurement System. Further funding was provided by the German BMBF under contract 05P18PKCIA and "Verbundprojekt 05P2018" as well as the Spanish MINECO grant FPA2015-65035-P.

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