IS456
Study of polonium isotopes ground-state properties by simultaneous atomic & nuclear spectroscopy

Spokesperson: Prof Thomas Elias Cocolios
Local contact: Dr Reinhard Heinke
IS456: 22.5 shifts remaining

- IS456 so far
  - Shape evolution across the isotopic chain
  - Kink and odd-even staggering
  - Complementary decay spectroscopy

- Remaining scientific case
  - Long-lived high-spin isomers just beyond N=126
  - Neutron-rich isotopes near N=136

- Challenges and how to address them
  - From the LIST to the 2-repeller LIST
  - Detection setups
IS456: in-source laser spectroscopy

Decay spectroscopy using either the Windmill (LA1/2 or GLM) or the ISOLDE Tape Station (CA0)

In-source method
Laser beams step-wise resonantly ionize the reaction products leaving the target (one laser will scan over the resonances)
IS456: Timeline

Phase 0: 2006
- First laser ionization tests
- Saturation of the optical transitions
- Yields of $^{193-204}$Po

Phase 1: 2007
- Simultaneous GLM / CA0 beams
- Windmill: $^{193-199}$Po
- Tape station: $^{199-200,202,204}$Po

Phase 2: 2009
- Repeat of key measurements
- Faraday cup: $^{206,208-210}$Po
- Pseudo offline: $^{211g}$Po
- Not using GLM to reach $^{216,218}$Po
- Extra tape station: $^{201-203}$Po
- Extreme sensitivity: $^{191}$Po

Phase 3: 2012
- LIST test
- Proof-of-principle measurements
- HFS: $^{217}$Po
- Alpha decay: $^{219}$Po
Somewhat unexpected picture where the polonium isotopes depart steadily from sphericity, in contrast to how mercury staggers.

All observables are in agreement: $\delta r^2$, moments from hfs, lifetime measurements and CoulEx.
The kink at the shell closure is not in itself a surprise, however its reproduction by nuclear theory remains a challenge, as much as its experimental investigation.
IS456: furthering the study around N=126

- Isotopes north-east of $^{208}$Pb are all short-lived, down to μs and even ns. This has greatly limited the study of N=127-128 isotones, especially for the understanding of the kink in $\text{dr}^2$.
- High-spin isomers exist in $^{211-212}$Po, which could give an insight into these features.
- Magnetic dipole moments will be studied to confirm the configuration.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Half-life</th>
<th>Spin</th>
<th>Proton configuration</th>
<th>Neutron configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{211\text{g}}$Po</td>
<td>0.516 s</td>
<td>$9/2^+$</td>
<td>$(\pi h_{9/2})^2_{0+}$</td>
<td>$(\nu g_{9/2})$</td>
</tr>
<tr>
<td>$^{211\text{m}}$Po</td>
<td>25.2 s</td>
<td>(25/2$^+$)</td>
<td>$(\pi h_{9/2})^2_{8+}$</td>
<td>$(\nu g_{9/2})^2_{0+}$</td>
</tr>
<tr>
<td>$^{212\text{g}}$Po</td>
<td>0.3 μs</td>
<td>$0^+$</td>
<td>$(\pi h_{9/2})^2_{0+}$</td>
<td>$(\nu g_{9/2})^2_{0+}$</td>
</tr>
<tr>
<td>$^{212\text{m}}$Po</td>
<td>45.1 s</td>
<td>(18$^+$)</td>
<td>$(\pi h_{9/2})^2_{8+}$</td>
<td>$(\nu g_{9/2})(\nu i_{11/2})_{10+}$</td>
</tr>
</tbody>
</table>

- The $(\nu i_{11/2})$ orbital is supposedly responsible for the kink and this could become more evident in the measurement of $^{212\text{m}}$Po!
IS456: Beyond N=126

- Recent Energy Density Functionals calculations for Ac have highlighted how the trend in the $\delta r^2$ is not a linear extrapolation from N=126, but rather undergoes a step in the vicinity of N=130.
- This behavior coincides with where the calculations suggest an onset of octupole deformation.

- Measurements of $\delta r^2$ between N=126 and 132 are necessary to benchmark this with experimental observation.
- Odd-even staggering investigation in the region N=132-140 in polonium would also shed light on the possible correlations between the $\delta r^2$ behavior and the shapes in this region.

Isobaric contamination!

- * Yields estimated based on ABRABLA calculations
- ** Constant in-target feeding by $^{223}$Ac with $T_{1/2} = 2$ min

### A | Polonium | Francium
--- | --- | ---
| | $T_{1/2}$ | Yield* [ions/μC] | | $T_{1/2}$ | Yield [ions/μC] |
| 211 | 25.2 s | $2 \times 10^4$ | | 3 min | $10^8$ |
| 212 | 45.1 s | $2 \times 10^4$ | | 20 min | $10^8$ |
| 219 | 10.3 min | $3 \times 10^1$ | | 20 ms** | $10^3$ |
| 220 | - | $1 \times 10^1$ | | 27.4 s | $10^7$ |
IS456: Solutions

LIST 2.0!

- 2012 attempt showed promise (e.g. hfs of $^{217}$Po, first $\alpha$ decay spectroscopy of $^{219}$Po) but suppression of $^{212}$Fr was far inferior to that of $^{205}$Fr.
- Electron impact ionization of decay products of radioactive material deposited on the LIST surfaces (namely from deposited isobaric Ra) is the reason.
- A new LIST has been designed in Mainz with a double repeller system to prevent surface ions AND electrons from entering the RFQ.
- The LIST 2.0 will be implemented as an ISOLDE standard ion source in the course of 2020 ready for the facility restart in 2021.

Reinhard Heinke starting at ISOLDE on 2 Dec 2019

M. Truemper, BSc Thesis (2015), Mainz.
IS456: challenges

- The Windmill is dead and buried and never to be seen again...
- FC is not an option for those beams
- $T_{1/2}$ in $^{219-220}$Po is not favorable for decay counting

<table>
<thead>
<tr>
<th>A</th>
<th>Polonium</th>
<th>Francium</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$T_{1/2}$</td>
<td>Decay mode</td>
</tr>
<tr>
<td>211m</td>
<td>25.2 s</td>
<td>&gt;99.9% $\alpha$</td>
</tr>
<tr>
<td>212m</td>
<td>45.1 s</td>
<td>&gt;99.9% $\alpha$</td>
</tr>
<tr>
<td>219</td>
<td>10.3 min</td>
<td>28% $\alpha$ / 72% $\beta$</td>
</tr>
<tr>
<td>220</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
IS456: Solutions

New α chamber & IDS

- IDS is equipped with a moving tape to remove the long-lived activity, perfect for $^{219,220}\text{Po}$.
- The implantation point is surrounded by charged particle detectors and γ-ray detectors for a comprehensive measurement of the decay of the implanted activity.
- Full synchronization with RILIS is established for scanning.

- A replacement for the Windmill has been developed and tested for IS637.
- It consists of a similar Si sandwich around a ladder with 10 C foils.
- An integrated FC is available for beam transport / tuning.

Free decay spectroscopy data acquired in the process.
IS456: Solutions

Single-ion counting

- Single-ion counting capability is currently available in the ISOLDE Central Beam Line.
- This would allow to measure long-lived isotopes like $^{219-220}$Po quickly and efficiently.

NOT for $^{208-210}$Po
### IS456: Shifts breakdown

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Number of shifts</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIST test</td>
<td>2</td>
</tr>
<tr>
<td>Reference measurements</td>
<td>2.5</td>
</tr>
<tr>
<td>HFS &amp; IS</td>
<td>2</td>
</tr>
<tr>
<td>HFS &amp; IS</td>
<td>2</td>
</tr>
<tr>
<td>HFS, IS &amp; decay</td>
<td>7</td>
</tr>
<tr>
<td>HFS, IS &amp; decay</td>
<td>7</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>22.5</strong></td>
</tr>
</tbody>
</table>

- The IS456 scientific case remains current and unchallenged
  - No dr2 data on N=128, Z>83
  - No new information on the configuration of the high-spin isomers
  - New insight into the dr2 for N=130-140 requires new experimental data
  - No new decay data on $^{219,220}\text{Po}$

- Main challenges have been addressed
  - New LIST with double repeller to be fully integrated at ISOLDE
  - New detection systems: $\alpha$ chamber, IDS, single-ion counting
Extra slides
IS456: Collaboration

IS456: scientific output

- 6 papers & 5 conference proceedings with >250 citations
  - 2 technical conference proceedings (EMIS NIMB) + 3 conference proceedings with results
  - 1x EPJA, JPG, PLB, PRA, PRL, PRX

- 3 theses
  - 1 MSc
    - Wim Dexters, KU Leuven 2010
  - 2 PhD
    - Thomas Cocolios, KU Leuven 2010
    - Daniel Fink, Heidelberg 2015
IS456: Timeline

Phase 0: 2006
- First laser ionization tests
- Saturation of the optical transitions
- Yields of $^{193-204}\text{Po}$

IS456: Timeline

Phase 0: 2006
- First laser ionization tests
- Saturation of the optical transitions

Phase 1: 2007
- Simultaneous GLM / CA0 beams
- Windmill: $^{193-199}\text{Po}$
- Tape station: $^{199-200,202,204}\text{Po}$

Too little overlap with literature data to extract the observables of interest!
IS456: Timeline

Phase 0: 2006
- First laser ionization tests
- Saturation of the optical transitions

Phase 1: 2007
- Simultaneous GLM / CA0 beams
- Windmill: 193–199Po
- Tape station: 199, 202, 204Po

Interdisciplinary Research Group
Instituut voor Kern-en Stralingsfysica
Department of Physics & Astronomy

Phase 2: 2009
- Repeat of key measurements
- Faraday cup: $^{206,208-210}$Po
- Pseudo offline: $^{211g}$Po
- Not using GLM to reach $^{216,218}$Po
- Extra tape station: $^{201-203}$Po
- Extreme sensitivity: $^{191}$Po

Isobaric Fr/Ra was the limiting factor in the neutron-rich isotopes

Phase 0: 2006
- First laser ionization tests
- Saturation of the optical transitions

Phase 1: 2007
- Simultaneous GLM / CA0 beams
- Windmill: 193–199\textsuperscript{Po}
- Tape station: 199–200, 202, 204\textsuperscript{Po}

Phase 2: 2009
- Repeat of key measurements
- Faraday cup: 206, 208–210\textsuperscript{Po}
- Pseudo offline: 211\textsuperscript{gPo}
- Not using GLM to reach 216, 218\textsuperscript{Po}
- Extra tape station: 201–203\textsuperscript{Po}
- Extreme sensitivity: 191\textsuperscript{Po}

Phase 3: 2012
- LIST test
- Proof-of-principle measurements
- HFS: 217\textsuperscript{Po}
- Alpha decay: 219\textsuperscript{Po}

Repeat of key measurements
- Faraday cup: 206, 208–210\textsuperscript{Po}
- Pseudo offline: 211\textsuperscript{gPo}
- Not using GLM to reach 216, 218\textsuperscript{Po}
- Extra tape station: 201–203\textsuperscript{Po}
- Extreme sensitivity: 191\textsuperscript{Po}

---

IS456: decay spectroscopy results

IS456: Shape coexistence near $^{186}$Pb

M. Bender, private communication, adapted from M. Bender et al, PRC 73 (2006) 034322.
The reversal of the odd-even staggering in $\text{dr}2$ has been observed in the region also known for its reflection asymmetry. As polonium is located at the low-Z edge of this region, investigating its charge distribution is crucial to further understand the link between these two properties.

IS456: Publications

- **Main scientific publications**

- **Conference proceedings**