**KU LEUVEN** 

NUCLEAR AND RADIATION PHYSICS

## IS456 Study of polonium isotopes groundstate 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









#### Phase 0: 2006

- First laser ionization tests 0
- Saturation of the optical transitions • Yields of <sup>193-204</sup>Po •

#### Phase 1: 2007

11/2 9/2 7/2 5/2

13/2

11/2

9/2

F = 5/2

- Simultaneous GLM / CA0 beams
- Windmill: <sup>193-199</sup>Po
- Tape station: 199-200,202,204Po

#### Phase 2: 2009

- Repeat of key measurements
- Faraday cup: <sup>206,208-210</sup>Po
- Pseudo offline: <sup>211g</sup>Po
- Not using GLM to reach <sup>216,218</sup>Po •
- Extra tape station: <sup>201-203</sup>Po
- Extreme sensitivity: <sup>191</sup>Po

#### Phase 3: 2012

- LIST test
- Proof-of-principle measurements
- HFS: <sup>217</sup>Po
- Alpha decay: <sup>219</sup>Po •

## IS456: Shape coexistence near <sup>186</sup>Pb



Somewhat unexpected picture where the polonium isotopes depart steadily from sphericity, in contrast to how mercury staggers.

Rn

All observables are in agreement: dr2, moments from hfs, lifetime measurements and CoulEx.

T.E. Cocolios et al, Physical Review Letters 106 (2011) 052503. M.D. Seliverstov et al, Physical Review C 89 (2014) 034323. N. Kesteloot et al, Physical Review C 92 (2015) 054301.

 $\mathcal{N}$ 







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.



P.M. Goddard, P.D. Stevenson and A. Rios, Physical Review Letters 110 (2013) 032503.
G.J. Farooq-Smith et al, PRC 94 (2016) 054305 & PhD Thesis (2019) KU Leuven.
& picture adapted from A.E. Barzakh et al, Physical Review C 97 (2018) 014322.



## IS456: furthering the study around N=126



- Isotopes north-east of <sup>208</sup>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 dr2.
- High-spin isomers exist in <sup>211-212</sup>Po, which could give an insight into these features.
- Magnetic dipole moments will be studied to confirm the configuration.

d <sub>3/2</sub> 210Po	Isotope	Half-life	Spin	Proton configuration	Neutron configuration
	<sup>211</sup> g <b>Po</b>	0.516 s	9/2+	( $\pi h_{9/2})^2_{0+}$	(vg <sub>9/2</sub> )
<ul> <li>I he (VI<sub>11/2</sub>) orbital is supposedly responsible for the kink and this could</li> </ul>	<sup>211m</sup> Po	25.2 s	(25/2+)	$(\pi h_{9/2})^2_{8+}$	(vg <sub>9/2</sub> )
become more evident in the measurement	<sup>212g</sup> Po	0.3 µs	0+	$(\pi h_{9/2})^2_{0+}$	(vg <sub>9/2</sub> ) <sup>2</sup> <sub>0+</sub>
of <sup>212m</sup> Po!	<sup>212m</sup> Po	45.1 s	(18+)	$(\pi h_{9/2})^2_{8+}$	$(vg_{9/2})(vi_{11/2})_{10+}$

H. Nakada & T. Inakura, Physical Review C 91 (2015) 021302R.



## IS456: Beyond N=126



- Recent Energy Density Functionals calculations for Ac have highlighted how the trend in the dr2 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 dr2 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 dr2 behavior and the shapes in this region.



E. Verstraelen et al, Physical Review C **100** (2019) 044321. D. Fink et al, Physical Review X **5** (2015) 011018.

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\* Yields estimated based on

\*\* Constant in-target feeding

**ABRABLA** calculations

by <sup>223</sup>Ac with  $T_{1/2} = 2$  min

4	Pc	olonium	Fra	ancium
A	T <sub>1/2</sub>	Yield* [ions/µC]	T <sub>1/2</sub>	Yield [ions/µC]
211	25.2 s	2 x 10 <sup>4</sup>	3 min	10 <sup>8</sup>
212	45.1 s	2 x 10 <sup>4</sup>	20 min	10 <sup>8</sup>
219	10.3 min	3 x 10 <sup>1</sup>	20 ms**	10 <sup>3</sup>
220	-	1 x 10 <sup>1</sup>	27.4 s	10 <sup>7</sup>

## Isobaric contamination!

	<sup>209</sup> Ac 94 ms	<sup>210</sup> Ac 350 ms	<sup>211</sup> Ac 213 ms	<sup>212</sup> Ac 895 ms	<sup>213</sup> Ac 738 ms	<sup>214</sup> Ac 8.2 s	<sup>215</sup> Ac 170 ms	<sup>216</sup> Ас 440 µs	<sup>217</sup> Ac <sub>69 ns</sub>	<sup>218</sup> Ac 1000 ns	<sup>219</sup> Ас 11.8 µs	<sup>220</sup> Ac 26.36 ms	<sup>221</sup> Ac <sub>52 ms</sub>	<sup>222</sup> Ac 5 s	<sup>223</sup> Ac 126 s	<sup>224</sup> Ac 166.8 m	<sup>225</sup> Ac 9.92 d	<sup>226</sup> Ac 29.37 h	<sup>227</sup> Ac 21.772 y	<sup>228</sup> Ac 6.15 h	2
	<sup>208</sup> Ra 1.11 s	<sup>209</sup> Ra <sub>4.71 s</sub>	<sup>210</sup> Ra 4s	<sup>211</sup> Ra <sup>13.2 s</sup>	<sup>212</sup> Ra <sup>13 s</sup>	<sup>213</sup> Ra <sub>163.8 s</sub>	<sup>214</sup> Ra 2.437 s	<sup>215</sup> Ra 1.67 ms	<sup>216</sup> Ra <sup>182 ns</sup>	<sup>217</sup> Rа 1.63 µs	<sup>218</sup> Ra <sup>25.2 µs</sup>	<sup>219</sup> Ra <sup>10 ms</sup>	<sup>220</sup> Ra 17.9 ms	221 <b>Pa</b> 28 s	<sup>222</sup> Ra <sup>33.6 s</sup>	<sup>223</sup> Ra 11.4377 d	<sup>224</sup> Ra 87.1656 h	<sup>225</sup> Ra 14.9 d	<sup>226</sup> Ra <sup>1.6 ky</sup>	<sup>227</sup> Ra <sup>42.2 m</sup>	2
15456: challenges	<sup>207</sup> Fr 14.8 s	<sup>208</sup> Fr 59.1 s	<sup>209</sup> Fr <sup>50.5 s</sup>	<sup>210</sup> Fr 190.8 s	<sup>211</sup> Fr 186 s	<sup>212</sup> Fr <sup>20 m</sup>	<sup>213</sup> Fr 34.14 s	<sup>214</sup> Fr 5.18 ms	<sup>215</sup> Fr 86 ns	<sup>216</sup> Fr 700 ns	<sup>217</sup> Fr 16.8 µs	<sup>218</sup> Fr 1000 µs	<sup>219</sup> Fr <sup>20 ms</sup>	<sup>220</sup> Fr <sup>27.4 s</sup>	<sup>221</sup> Fr 4.801 m	<sup>222</sup> Fr 14.2 m	<sup>223</sup> Fr <sub>22 m</sub>	<sup>224</sup> Fr 199.8 s	<sup>225</sup> Fr <sup>237 s</sup>	<sup>226</sup> Fr <sup>49 s</sup>	12
	<sup>206</sup> Rn 5.67 m	<sup>207</sup> Rn 9.25 m	<sup>208</sup> Rn 24.35 m	<sup>209</sup> Rn <sup>28.8 m</sup>	<sup>210</sup> Rn 144 m	<sup>211</sup> Rn 14.6 h	<sup>212</sup> Rn <sup>23.9 m</sup>	<sup>213</sup> Rn 19.5 ms	<sup>214</sup> Rn <sub>270 ns</sub>	<sup>215</sup> Rn 2.3 µs	<sup>216</sup> Rn 45 µs	<sup>217</sup> Rn <sup>540 به</sup>	<sup>218</sup> Rn 33.75 ms	<sup>219</sup> Rn 3.96 s	<sup>220</sup> Rn 55.6 s	<sup>221</sup> Rn 25.7 m	<sup>222</sup> Rn 91.716 h	<sup>223</sup> Rn <sup>24.3 m</sup>	<sup>224</sup> Rn 107 m	<sup>225</sup> Rn 4.66 m	2
	<sup>205</sup> At <sup>33.8 m</sup>	<sup>206</sup> At <sup>30.6 m</sup>	<sup>207</sup> At 108.6 m	<sup>208</sup> At <sup>97.8 m</sup>	<sup>209</sup> At <sup>5.42 h</sup>	<sup>210</sup> At 8.1 h	<sup>211</sup> At 7.214 h	<sup>212</sup> At <sub>314 ms</sub>	<sup>213</sup> At 125 ns	<sup>214</sup> At 558 ns	<sup>215</sup> At 100 µs	<sup>216</sup> At 300 µs	<sup>217</sup> At 32.62 ms	<sup>218</sup> At 1.5 s	<sup>219</sup> At 56 s	<sup>220</sup> At 222.6 s	<sup>221</sup> At <sup>138 s</sup>	<sup>222</sup> At <sup>54 s</sup>	<sup>223</sup> At 50 s	<sup>224</sup> At 150 s	2
Isobaric contamination!	<sup>204</sup> Po 211.14 m	<sup>205</sup> Po 104.4 m	<sup>206</sup> Po 8.8 d	<sup>207</sup> Po 5.8 h	<sup>208</sup> Po 2.898 y	<sup>209</sup> Po 124 y	<sup>210</sup> Po 138.376 d	<sup>211</sup> Po 516 ms	<sup>212</sup> Po 294.7 ns	<sup>213</sup> Ро 3.708 µs	<sup>214</sup> Ро 163.72 µs	<sup>215</sup> Po 1.781 ms	<sup>216</sup> P0 145 ms	<sup>217</sup> Po 1.514 s	<sup>218</sup> Po 185.88 s	<sup>219</sup> Po 10.3 m	# <sup>220</sup> Po 40 s	<sup>221</sup> Po 132 s	<sup>222</sup> Po <sub>9.1 m</sub>	≇ 223 <b>PO</b> 60 s	2
	<sup>203</sup> Bi 11.76 h	<sup>204</sup> Bi 11.22 h	<sup>205</sup> Bi 15.31 d	<sup>206</sup> Bi 6.243 d	<sup>207</sup> Bi <sub>31.2 y</sub>	<sup>208</sup> Ві 368 ку	<sup>209</sup> Bi 20.1 Ey	<sup>210</sup> Bi 5.012 d	<sup>211</sup> Bi <sub>128.4 s</sub>	<sup>212</sup> Bi 60.55 m	<sup>213</sup> Bi 45.61 m	<sup>214</sup> Bi 19.9 m	<sup>215</sup> Bi <sub>7.6 m</sub>	<sup>216</sup> Bi 135 s	<sup>217</sup> Bi 98.5 s	<sup>218</sup> Bi ₃₃ ₅	<sup>219</sup> Bi <sup>8.7 s</sup>	<sup>220</sup> Bi <sub>9.5 s</sub>	# <sup>221</sup> Bi 55	≇ 222Bi 2\$	1
	<sup>202</sup> Pb 52.5 ky	<sup>203</sup> Pb 51.916 h	<sup>204</sup> Pb	<sup>205</sup> Pb 17.3 My	<sup>206</sup> Pb	<sup>207</sup> Pb	<sup>208</sup> Pb	<sup>209</sup> Pb <sup>194.04 m</sup>	<sup>210</sup> Pb <sub>22.2 y</sub>	<sup>211</sup> Pb 36.164 m	<sup>212</sup> Pb <sup>10.64 h</sup>	<sup>213</sup> Pb 10.2 m	<sup>214</sup> Pb <sub>27.06 m</sub>	<sup>215</sup> Pb 140.4 s	<sup>216</sup> Pb <sub>99 s</sub>	<sup>217</sup> Pb <sub>20 s</sub>	<sup>218</sup> Pb 15 s	# <sup>219</sup> Pb 10 s	# <sup>220</sup> Pb 30 s		
	<sup>201</sup> TI 73.0608 h	<sup>202</sup> TI 12.31 d	<sup>203</sup> TI	<sup>204</sup> TI 3.783 y	<sup>205</sup> TI	<sup>206</sup> TI 4.202 m	<sup>207</sup> TI 4.77 m	<sup>208</sup> TI 183.18 s	<sup>209</sup> TI 129.72 s	210 <b>TI</b> 78 s	<sup>211</sup> TI 80 s	<sup>212</sup> TI 31 s	<sup>213</sup> TI <sup>24 s</sup>	<sup>214</sup> TI 11 s	<sup>215</sup> TI <sup>10 s</sup>	<sup>216</sup> TI 6 s	# <sup>217</sup> TI 1000 ms	# 218 <b>T </b> 200 ms			
	<sup>200</sup> Hg	<sup>201</sup> Hg	<sup>202</sup> Hg	<sup>203</sup> Hg	<sup>204</sup> Hg	<sup>205</sup> Hg	<sup>206</sup> Hg	<sup>207</sup> Hg	<sup>208</sup> Hg	<sup>209</sup> Hg	<sup>210</sup> Hg	<sup>211</sup> Hg	≇ <sup>212</sup> Hg	* <sup>213</sup> Hg	≇ <sup>214</sup> Hg	* <sup>215</sup> Hg	# <sup>216</sup> Hg				

## **IS456: Solutions**

#### LIST 2.0!

- 2012 attempt showed promise (e.g. hfs of <sup>217</sup>Po, first α decay spectroscopy of <sup>219</sup>Po) but suppression of <sup>212</sup>Fr was far inferior to that of <sup>205</sup>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.

<sup>10</sup> *M.* Truemper, BSc Thesis (2015), Mainz. *R. Heinke, PhD Thesis (2019), Mainz.* 



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## IS456: challenges



- The Windmill is dead and buried and never to be seen again...
- FC is not an option for those beams
- T<sub>1/2</sub> in <sup>219-220</sup>Po is not favorable for decay counting

<sup>200</sup> Hg	<sup>202</sup> Hg 46.613 d <sup>204</sup> Hg 5.14m	200Hg 207Hg 208Hg 209Hg 210Hg 8.32m 174s 42m 38s 64s	21°Hg 212Hg 213Hg 21°Hg 26 s 60 s 1000ms 1000ms	1000 ms 100 ms			
Δ	Po	lonium	Fra	ancium			
A	T <sub>1/2</sub>	Decay mode	T <sub>1/2</sub>	Decay mode			
211m	25.2 s	>99.9% α	3 min	87% α / 13% β			
212m	45.1 s	>99.9% α	20 min	43% α / 57% β			
219	10.3 min	28% α / 72% β	20 ms	α			
220	-	-	27.4 s	>99.6% α			

<sup>211</sup>Ra <sup>212</sup>Ra <sup>213</sup>Ra <sub>163.8 s</sub> <sup>214</sup>Ra <sup>215</sup>Ra <sup>218</sup>Ra <sup>221</sup>Ra <sup>222</sup>Ra <sup>226</sup>Ra 1.6 ky <sup>223</sup>Ra 11.4377 d <sup>224</sup>Ra ¹⁰Ra <sup>217</sup>Ra <sup>219</sup>Ra <sup>220</sup>Ra <sup>225</sup>Ra 14.9 d <sup>227</sup>Ra <sub>42.2 m</sub> 'Ra ⁰Ra 13.2 s 33.6 s 13 s 25.2 µs 28 s 87.1656 h 4.71 s 4 s 2.437 s 1.67 ms 182 ns 1.63 µs 10 ms 17.9 ms <sup>209</sup>Fr 50.5 s <sup>220</sup>Fr <sub>27.4 s</sub> <sup>223</sup>Fr <sub>22 m</sub> <sup>224</sup>Fr 199.8 s <sup>210</sup>Fr <sup>213</sup>Fr <sup>214</sup>Fr <sup>217</sup>Fr <sup>218</sup>Fr <sup>208</sup>Fr <sup>211</sup>Fr 186 s <sup>212</sup>Fr 20 m 215Fr <sup>216</sup>Fr <sup>219</sup>Fr <sup>221</sup>**Fr** 4.801 m <sup>222</sup>Fr 14.2 m <sup>225</sup>Fr 237 s <sup>226</sup>Fr 190.8 s 59.1 s 34.14 s 5.18 ms 86 ns 700 ns 16.8 µs 1000 µs 20 ms 49 s <sup>212</sup>Rn 23.9 m <sup>221</sup>Rn 25.7 m 209 Rn <sup>213</sup>Rn 216 Rn <sup>217</sup>Rn <sup>220</sup>Rn 55.6 s 222Rn 225 Rn <sup>207</sup>Rn 9.25 m 208 Rn 24.35 m <sup>210</sup>Rn 144 m <sup>211</sup>Rn 14.6 h ¹⁴Rn 215 Rn <sup>219</sup>Rn 3.96 s <sup>223</sup>Rn 24.3 m <sup>224</sup>Rn 107 m <sup>18</sup>Rn 28.8 m 19.5 ms 270 ns 2.3 µs 540 µs 33.75 ms 91.716 h 4.66 m 45 µs <sup>212</sup>At <sup>218</sup>At 216At <sup>207</sup>At 108.6 m <sup>208</sup>At 97.8 m <sup>209</sup>At 5.42 h <sup>210</sup>At 8.1 h <sup>211</sup>At 7.214 h <sup>214</sup>At 215At 219At <sup>220</sup>At 222.6 s <sup>221</sup>At 138 s <sup>222</sup>At <sup>223</sup>At 50 s 224At 206At 213At 217At 314 ms 30.6 m 125 ns 1.5 s 56 s 54 s 150 s 558 ns 100 µs 300 µs 32.62 ms <sup>209</sup>Po 124 y <sup>217</sup>PO <sup>208</sup>Po 2.898 y <sup>210</sup>Po 138.376 d <sup>220</sup>Po 40 s 214Po <sup>218</sup>Po <sup>205</sup>Po 104.4 m <sup>206</sup>Po 8.8 d <sup>207</sup>Po 5.8 h <sup>211</sup>Po <sup>212</sup>Po <sup>213</sup>Po <sup>215</sup>Po <sup>216</sup>Po <sup>219</sup>Po 10.3 m <sup>221</sup>Po 132 s <sup>222</sup>Po 9.1 m 294.7 ns 185.88 s 🧹 516 ms 3.708 µs 163.72 µs 1.781 ms 145 ms 1.514 s <sup>209</sup>Bi 20.1 Ey <sup>213</sup>Bi <sup>214</sup>Bi 215Bi <sup>217</sup>Bi <sup>218</sup>Bi <sup>221</sup>Bi <sup>211</sup>Bi <sup>212</sup>Bi <sup>219</sup>Bi 220Bi <sup>204</sup>Bi <sup>205</sup>Bi ²º⁰Bi <sup>207</sup>Bi <sup>208</sup>Bi <sup>210</sup>Bi <sup>216</sup>Bi 31.2 y 15.31 d 11.22 h 6.243 d 368 ky 5.012 d 128.4 s 60.55 m 45.61 m 19.9 m 7.6 m 135 s 98.5 s 33 s 8.7 s 9.5 s 5 s 207Pb 208 Pb <sup>212</sup>Pb 10.64 h <sup>213</sup>Pb 10.2 m <sup>214</sup>Pb 27.06 m <sup>216</sup>Pb 99 s <sup>217</sup>Pb <sup>220</sup>Pb <sup>203</sup>Pb 51.916 h <sup>204</sup>Pb 205Pb 206Pb 210Pb <sup>211</sup>Pb <sup>215</sup>Pb 140.4 s <sup>218</sup>Pb <sup>219</sup>Pb 209Pb 17.3 My 194.04 m 22.2 y 36.164 m 20 s 10 s 15 s 30 s <sup>202</sup>TI <sup>203</sup>TI <sup>204</sup>TI <sup>205</sup>TI <sup>206</sup>TI <sup>207</sup>TI 208TI 209TI <sup>211</sup>TI <sup>212</sup>TI <sup>214</sup>TI <sup>216</sup>TI <sup>210</sup>TI <sup>213</sup>TI 215TI <sup>217</sup>TI 218TI 12.31 d 3.783 y 4.202 m 4.77 m 183.18 s 129.72 s 78 s 80 s 31 s 1000 ms 24 s 11 s 10 s 6 s 

219AC

11.8 µs

AC

52 ms

26.36 ms

°Ac

1000 ns

<sup>223</sup>Ac 126 s

Ac

5 s

<sup>225</sup>Ac 9.92 d

\*Ac

166.8 m

226AC 29.37 h <sup>227</sup>Ac 21.772 y

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<sup>228</sup>Ac 6.15 h

216AC

440 µs

Ac

69 ns

<sup>15</sup>Ac

170 ms

<sup>214</sup>AC

8.2 s

<sup>213</sup>Ac

738 ms

<sup>212</sup>Ac

895 ms

Ac

213 ms

<sup>210</sup>AC

350 ms

0.4 ms

™Ra

1.11 s

207 Fr

14.8 s

206Rn

5.67 m

205At

33.8 m

<sup>204</sup>Po

211.14 m

™Bi

11.76 h

202 Pb

52.5 ky

201TI

73 0608 F

## **IS456:** Solutions

#### New α chamber & IDS

- IDS is equipped with a moving tape to remove the long-lived activity, perfect for <sup>219,220</sup>Po.
- The implantation point is surrounded by charged particle detectors and y-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 Interdisciplinary Research Group Instituut voor Kern- en Stralingsfysica **Department of Physics & Astronomy** 



## **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 <sup>219-</sup>
   <sup>220</sup>Po quickly and efficiently.

#### NOT for <sup>208-210</sup>Po







## IS456: Shifts breakdown

	Isotope	Number of shifts
LIST test		2
Reference measurements	<sup>196,208-210</sup> Po	2.5
HFS & IS	<sup>211m</sup> Po	2
HFS & IS	<sup>212m</sup> Po	2
HFS, IS & decay	<sup>219</sup> Po	7
HFS, IS & decay	<sup>220</sup> Po	7
	TOTAL	22.5

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 <sup>219,220</sup>Po

### Main challenges have been addressed

- New LIST with double repeller to be fully integrated at ISOLDE
- New detection systems: α chamber, IDS, single-ion counting



## Extra slides



## **IS456: Collaboration**



E. Ahmed, A. Algora, B. Andel, A.N. Andreyev, S. Antalic, A.E. Barzakh, B. Bastin, M. Bissell, M. Borge, K. Chrysalidis, T.E. Cocolios, B. Cooper, J. Cubiss, H. De Witte, K. Dockx, D.V. Fedorov, V.N. Fedosseev, R. Ferrer, K.T. Flanagan, S. Franchoo, L. Fraile, H. Fynbo, L. Ghys, L.J. Harkness-Brennan, R. Heinke, D.S. Judson, J. Konki, U. Koster, I. Lazarus, N. Lecesne, R. Lica, N. Marginean, B.A. Marsh, C. Mihai, P.L. Molkanov, E. Nacher, A. Negret, J. Ojala, R.D. Page, J. Pakarinen, A. Perea, H. Perrett, L. Popescu, V. Pucknell, C. Ricketts, S.R. Rothe, H. Savajols, M.D. Seliverstov, S. Sels, C. Sotty, M. Stryjczyk, O. Tengblad, J. Van de Walle, P. Van den Bergh, P. Van Duppen, M. Vandebrouck, V. Vedia, M. Venhart, S. Vinals, R. Wadsworth, N. Warr, K.D.A. Wendt, S.G. Zemlyanoy



## 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
    - $_{\odot}$  Wim Dexters, KU Leuven 2010
  - 2 PhD
    - Thomas Cocolios, KU Leuven 2010
    - o Daniel Fink, Heidelberg 2015





# Phase 0: 2006 First laser ionization tests Saturation of the optical transitions Yields of <sup>193-204</sup>Po



T.E. Cocolios et al, NIMB **266** (2008) 4403-4406.



Phase 0: 2006First laser ionization testsSaturation of the optical transitions



Department of Physics & Astronomy



 Saturation of the optical transitions Phase 2: 2009 Repeat of key measurements • Faraday cup: <sup>206,208-210</sup>Po

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Phase 0: 2006

First laser ionization tests

- Pseudo offline: <sup>211g</sup>Po
- Not using GLM to reach <sup>216,218</sup>Po
- Extra tape station: <sup>201-203</sup>Po
- Extreme sensitivity: <sup>191</sup>Po

peams

Isobaric Fr/Ra was the limiting factor in the neutron-rich isotopes Modified isotope shift (255.8 nm) [GHz]

T.E. Cocolios et al, Physical Review Letters 106 (2011) 052503. B. Cheal, T.E. Cocolios, S. Fritzsche, Physical Review A 86 (2012) 042501. Instituut voor Kern- en Stralingsrys **Department of Physics & Astronomy** 

Counts



<sup>21</sup> D. Fink et al, NIMB **317** (2013) 417-421.
 D. Fink et al, Physical Review X **5** (2015) 011018.

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

Phase 0: 2006

0

First laser ionization tests







M. Bender, private communication, adapted from M. Bender et al, PRC 73 (2006) 034322.
<sup>23</sup> T. Grahn et al, Nuclear Physics A 801 (2008) 83-100.
T.E. Cocolios, Hyperfine Interactions 238 (2017) 16.



## IS456: odd-even staggering



The reversal of the odd-even staggering in dr2 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

- 1. T.E. Cocolios et al, *Structure of 191Pb from*  $\alpha$  *and*  $\beta$ *-decay spectroscopy*, Journal of Physics G **37** (2010) 125103.
- 2. B. Cheal, T.E. Cocolios, T.E. Cocolios, W. Dexters, M.D. Seliverstov et al, *Early onset of ground state deformation in neutron deficient polonium isotopes*, Physical Review Letters **106** (2011) 052503.
- 3. S. Fritzsche, Laser spectroscopy of radioactive isotopes: Role and limitations of accurate isotope-shift calculations, Physical Review A 86 (2012) 042501.
- 4. M.D. Seliverstov, T.E. Cocolios, W. Dexters et al, *Charge radii of odd-A*<sup>191-211</sup>*Po isotopes*, Physics Letters B **719** (2013) 362-366.
- 5. M.D. Seliverstov, T.E. Cocolios, W. Dexters et al, *Electromagnetic moments of odd-A*<sup>191-203,211</sup>*Po isotopes*, Physical Review C **89** (2014) 034323.
- 6. D.A. Fink, T.E. Cocolios et al, *In-source laser spectroscopy with the Laser Ion Source and Trap: first direct study of the ground-state properties of* <sup>217,219</sup>Po, Physical Review X **5** (2015) 011018.

#### Conference proceedings

- 1. T.E. Cocolios, B.A. Marsh et al, *Resonant laser ionization of polonium at RILIS-ISOLDE for the study of ground- and isomer-state properties*, NIMB **266** (2008) 4403-4406, Proceedings to the EMIS Conference 2007 in Deauville, France.
- 2. T.E. Cocolios et al, *Early onset of deformation in the neutron-deficient polonium isotopes (decay spectroscopy of <sup>199</sup>Po)*, Journal of Physics: Conference Series **381** (2012) 012072.
- 3. D.A. Fink, S.D. Richter et al, *First application of the Laser Ion Source and Trap (LIST) for on-line experiments at ISOLDE*, NIMB **317** (2013) 417-421, Proceedings to the EMIS Conference 2012 in Matsue, Japan.
- 4. T.E. Cocolios, *Shape coexistence in the lead region from a ground-state perspective*, xxx, (2015) page 43-49, Proceedings to the ISTROS Conference 2013 in Častá-Papiernička, Slovakia.
- T.E. Cocolios, A new perspective on charge radii around Z=82, Hyperfine Interactions 238 (2017) 16, Proceedings of the 10th International Workshop on Application of Lasers and Storage Devices in Atomic Nuclei Research: "Recent Achievements and Future Prospects" (LASER 2016), Poznan, Poland

