Proposal to the ISOLDE and Neutron Time-of-Flight Committee

Probing the structure of yrast states in even-even $^{214,216,218}Po$ through fast-timing measurements following the β-decay of $^{214,216,218}Bi$

Spokespersons:

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8 November 2017, CERN

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  - Previous studies of isomeric states/seniority scheme in even-even Po
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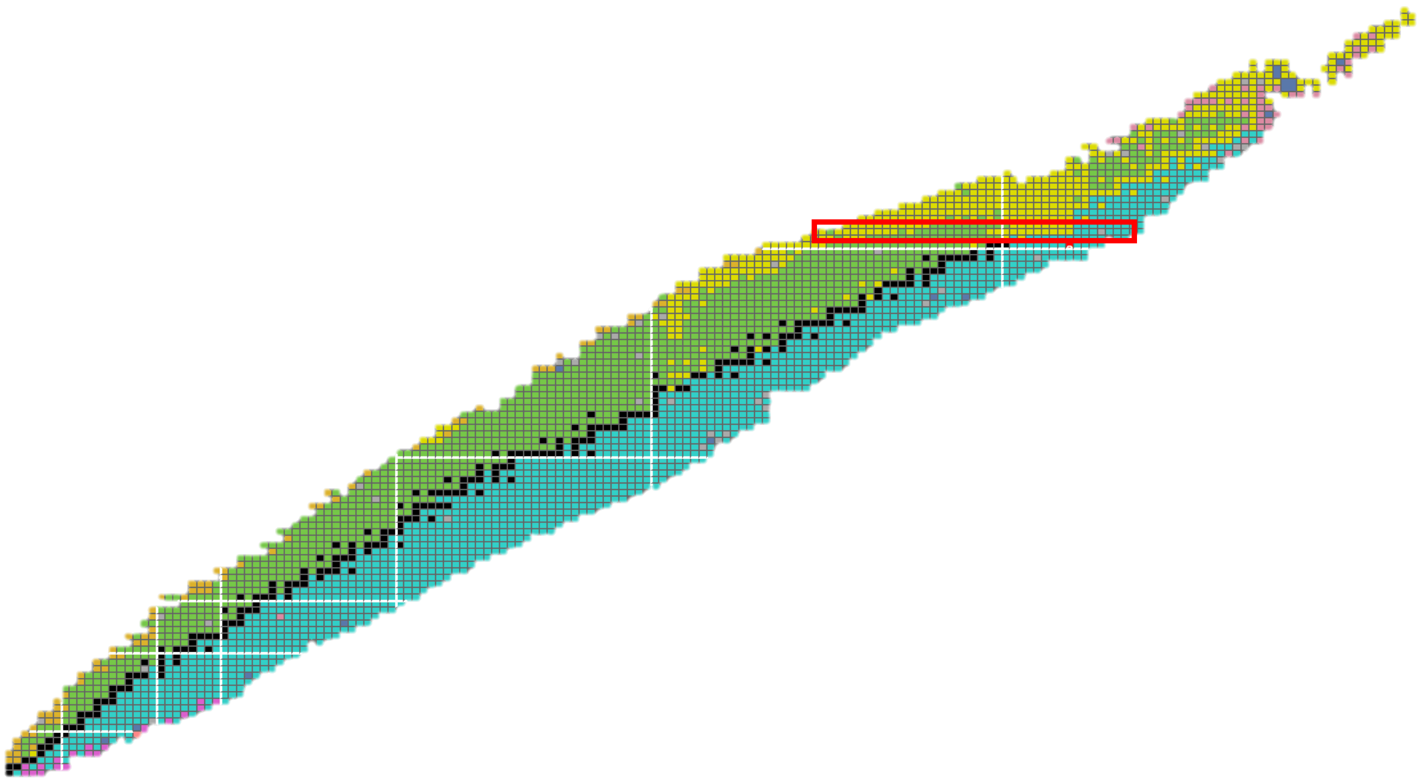
Physics motivation

- Po isotopes

→ text-book example for studying the seniority scheme
→ presence of $\pi(h_{9/2})$ 8^+ isomers in the even-even Po



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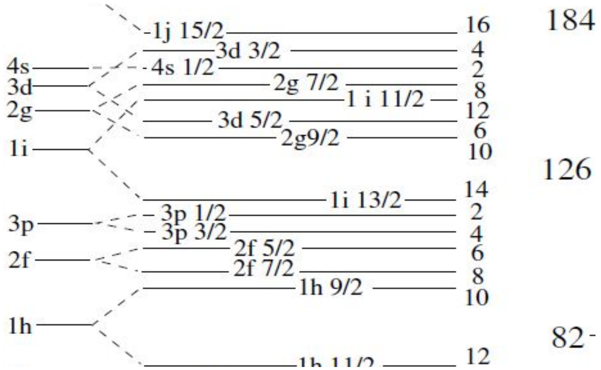
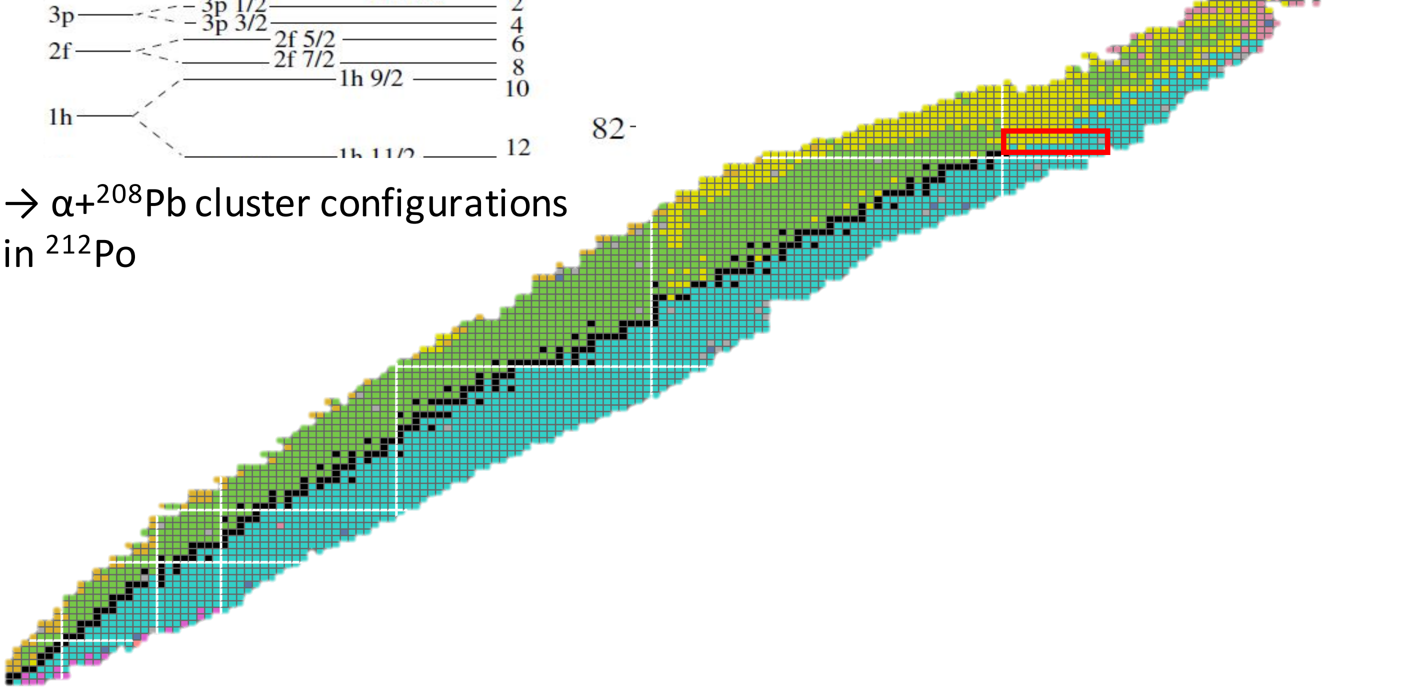
- Po isotopes with N>126

→ shell-model test using ^{208}Pb as an inert core

→ study the filling of the $\nu g_{9/2}$ orbital





→ α+^{208}Pb cluster configurations in ^{212}Po

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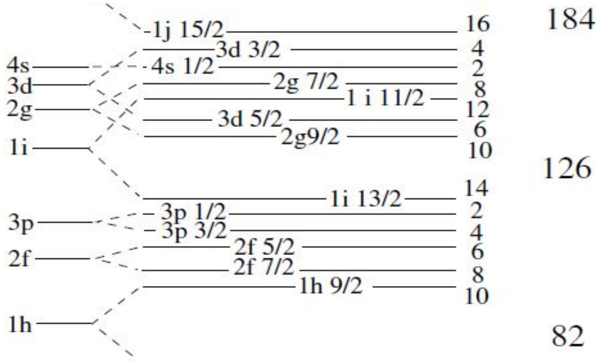
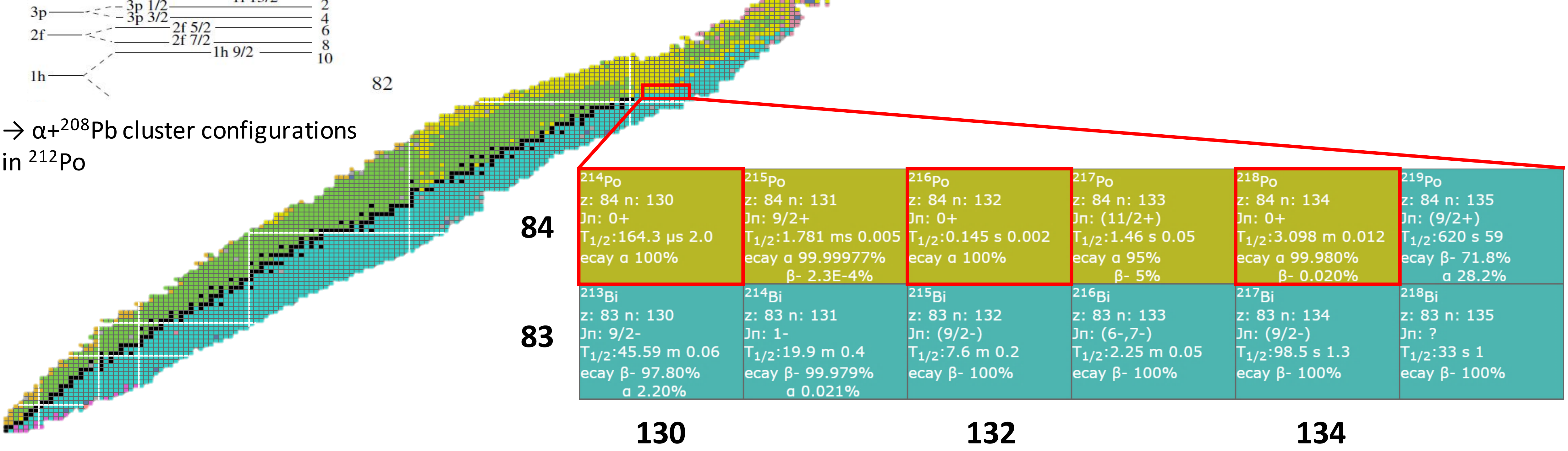


→ α+^{208}Pb cluster configurations in ^{212}Po

- ^{214,216,218}Po

→ Lack of experimental data for the heavier Po isotopes due to difficulties in producing them using stable beams



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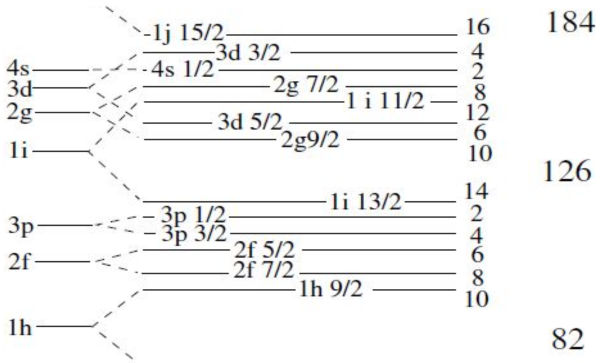
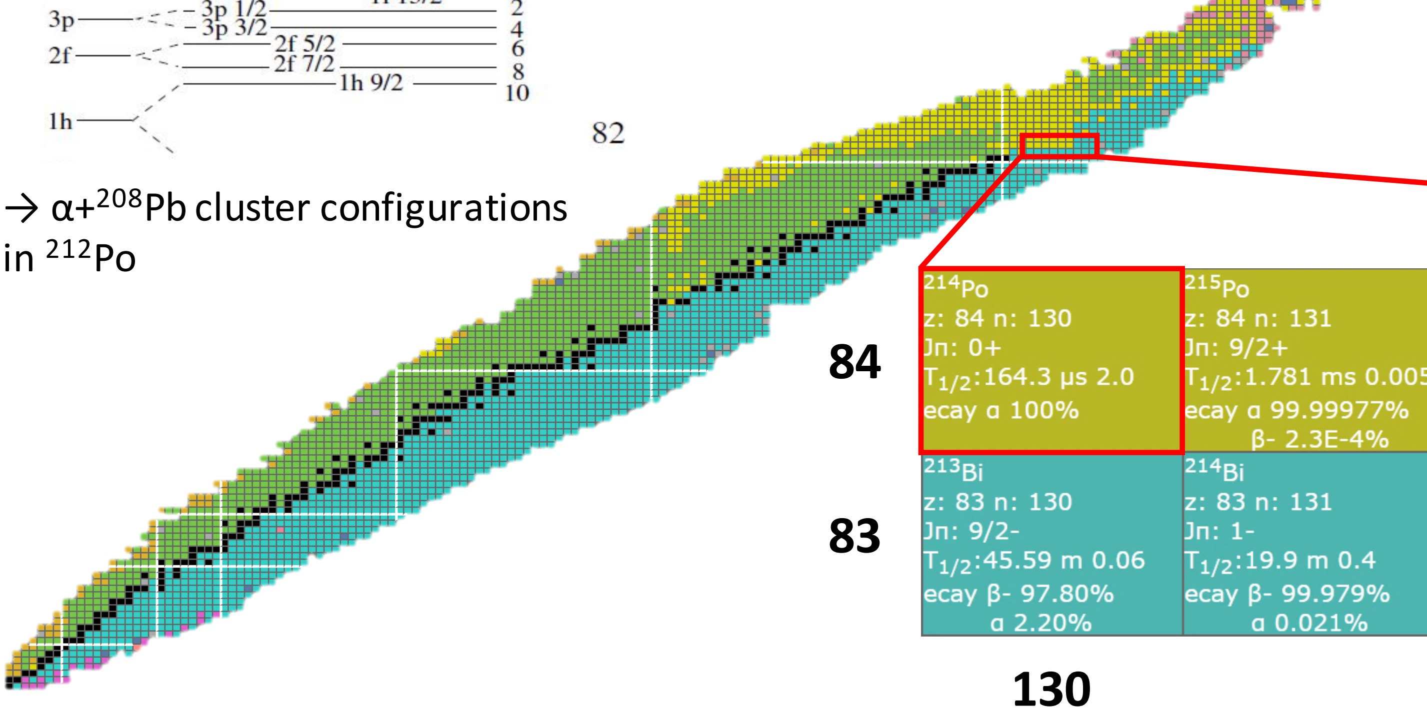


→ α+^{208}Pb cluster configurations in ^{212}Po

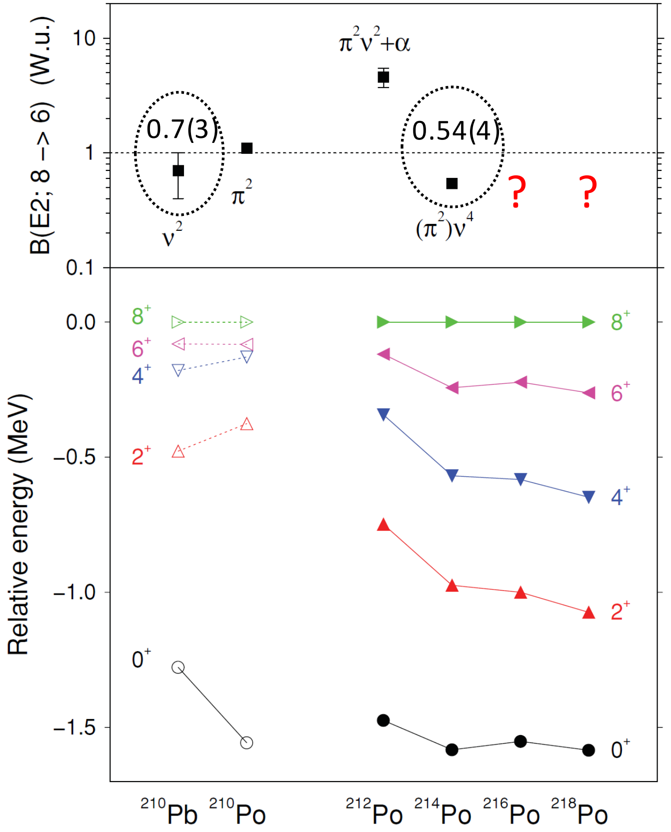
- ^{214,216,218}Po

→ Lack of experimental data for the heavier Po isotopes due to difficulties in producing them using stable beams

→ Recent measurement by *Astier et al.* [1] of the 8_1^+ state half-life $T_{1/2}$= 13(1) ns in ^{214}Po indicating a similar excitation mechanism as for ^{210}Pb, one-neutron-pair breaking



^{214}Po z: 84 n: 130 Jπ: 0+ $T_{1/2}$:164.3 μs 2.0 ecay α 100%	^{215}Po z: 84 n: 131 Jπ: 9/2+ $T_{1/2}$:1.781 ms 0.005 ecay α 99.99977% β- 2.3E-4%	^{216}Po z: 84 n: 132 Jπ: 0+ $T_{1/2}$:0.145 s 0.002 ecay α 100%	^{217}Po z: 84 n: 133 Jπ: (11/2+) $T_{1/2}$:1.46 s 0.05 ecay α 95% β- 5%	^{218}Po z: 84 n: 134 Jπ: 0+ $T_{1/2}$:3.098 m 0.012 ecay α 99.980% β- 0.020%	^{219}Po z: 84 n: 135 Jπ: (9/2+) $T_{1/2}$:620 s 59 ecay β- 71.8% α 28.2%
^{213}Bi z: 83 n: 130 Jπ: 9/2- $T_{1/2}$:45.59 m 0.06 ecay β- 97.80% α 2.20%	^{214}Bi z: 83 n: 131 Jπ: 1- $T_{1/2}$:19.9 m 0.4 ecay β- 99.979% α 0.021%	^{215}Bi z: 83 n: 132 Jπ: (9/2-) $T_{1/2}$:7.6 m 0.2 ecay β- 100%	^{216}Bi z: 83 n: 133 Jπ: (6-,7-) $T_{1/2}$:2.25 m 0.05 ecay β- 100%	^{217}Bi z: 83 n: 134 Jπ: (9/2-) $T_{1/2}$:98.5 s 1.3 ecay β- 100%	^{218}Bi z: 83 n: 135 Jπ: ? $T_{1/2}$:33 s 1 ecay β- 100%



[1] A. Astier and M.-G. Porquet, Phys. Rev. C83, 014311 (2011).

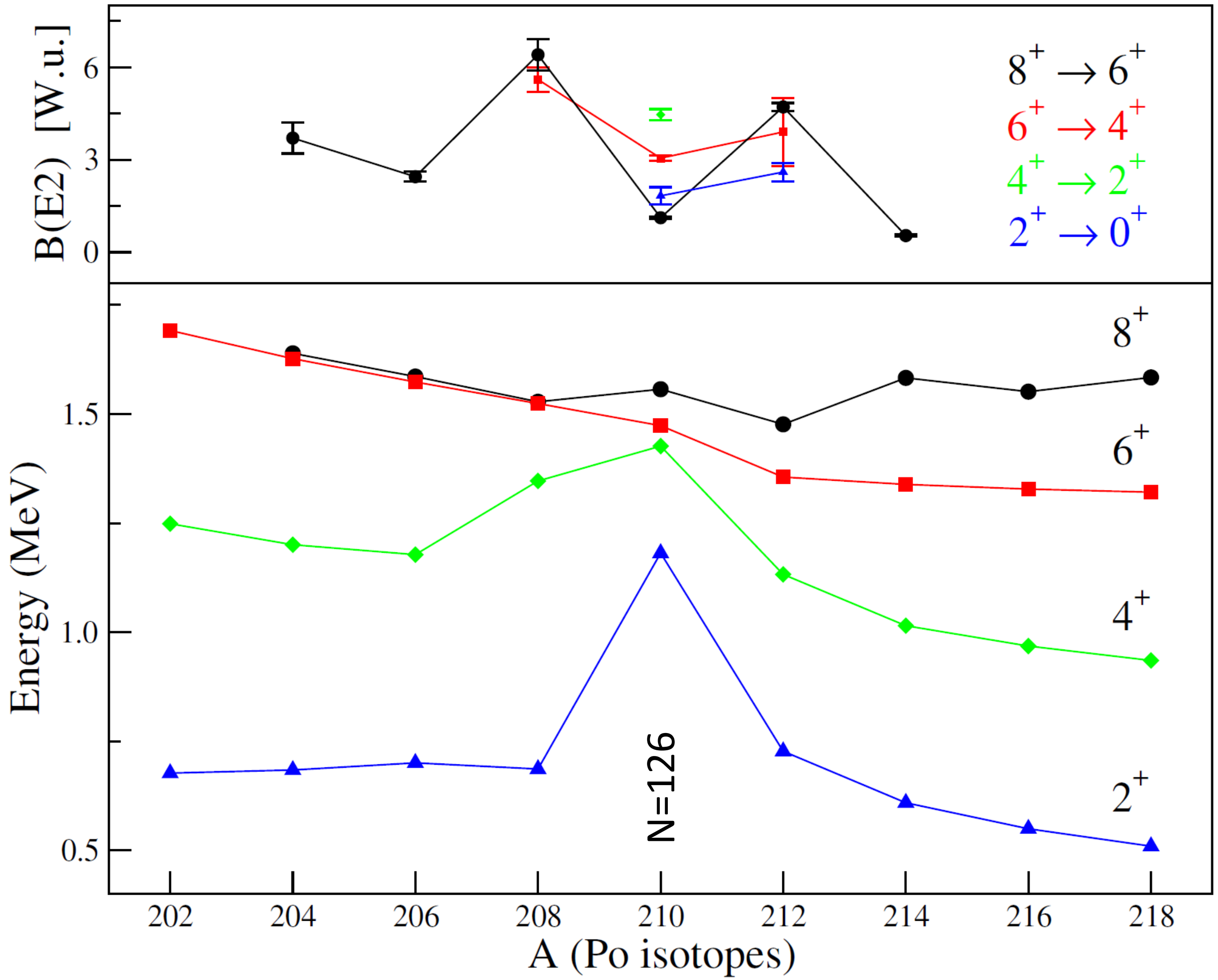
Physics motivation

We updated the B(E2) figure with known experimental data for Po isotopes (ENSDF + Kocheva et al. [1,2])

→ A staggering can be noticed around ^{210}Po for the $8^+ \rightarrow 6^+$ transition probability (present also for the 6^+, 4^+, 2^+ cases?)

→ The large value measured in ^{212}Po was proposed to be due to the α+^{208}Pb cluster structures
[A. Astier et al., Eur. Phys. J. A46, 165-185 (2010)]

→ The first four excited states measured in ^{216,218}Po have similar excitation energies to those known in ^{214}Po , indicating a structural similarity (needs to be confirmed by B(E2) values in ^{216,218}Po)



[1] D. Kocheva et al., Eur. Phys. J. A53, 175 (2017).
[2] D. Kocheva et al., Phys. Rev. C96, 044305 (2017).

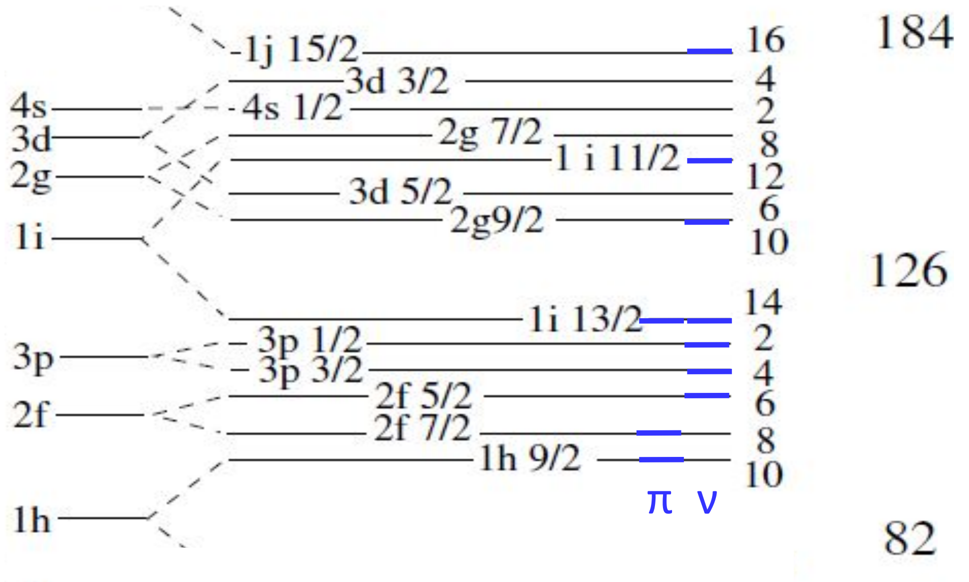
Physics motivation

Shell model calculations were recently performed for selected transitions in the Po isotope chain for two model spaces and interactions: *[H. Grawe, Private Communication, Oct 2017]*

$\pi(h_{9/2}, f_{7/2}, i_{13/2})\ \nu(p, f_{5/2}, i, g_{9/2}, j_{15/2})$ - denoted by **hfi-gij**, with interaction **PBPKH** [1].
$\pi(h_{9/2}, f, i_{13/2}, p)\ \nu(h_{9/2}, p, f, i, g, d, s_{1/2}, j_{15/2})$ - denoted by **r5i-r6j**, with interaction **PBKH7** [2].

- Non-truncated calculations were performed for $^{208-212}$Po. For the other, truncation must be applied, which requires tuning of the pairing part of the interaction.
- Excitations across the ^{208}Pb shell closure were blocked.
- Transition rates were calculated with effective operators [3]

  e_p=1.5 *e*; e_n=0.85 *e*; g_s=0.6 g_s^{free}; $g_{\pi l}$=1.115; $g_{\nu l}$=0



[1] E.K. Warburton, Phys. Rev. C 44, 233 (1991).
[2] E.K. Warburton, B.A. Brown, Phys. Rev. C 43, 602 (1991)
[3] R. Ferrer et al., Nat. Commun. 8, 14520 (2017)
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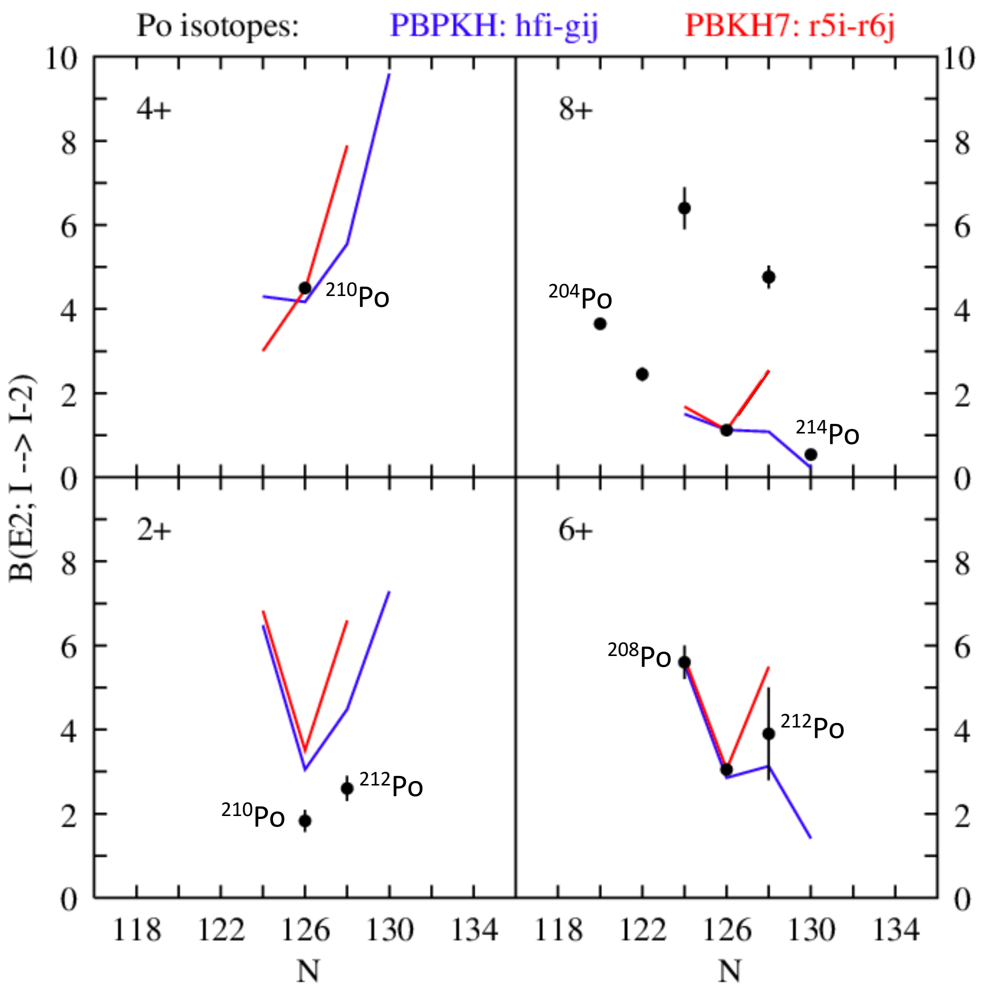
Observations:

- For **N>126** the importance of truncation and the low-spin N=6 orbits is clearly visible in contrast to earlier statements that a single- or two-orbit model space for protons and neutrons is appropriate [4].
- The importance of precise new lifetime measurements for $^{212-218}$Po 6^+ and 8^+ states is clearly exhibited in the figure.



Systematic of *B(E2; I → I-2)* in Po isotopes in comparison to shell model results.

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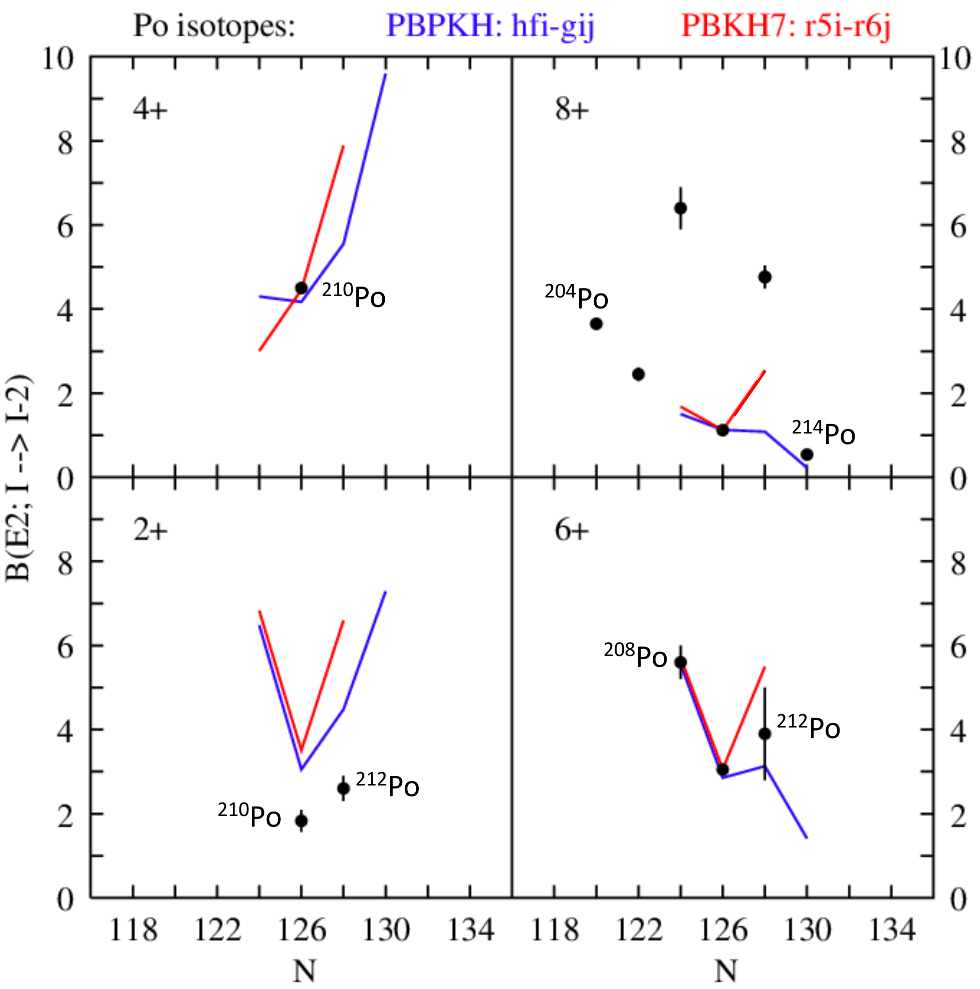

Systematic of *B(E2; I → I-2)* in Po isotopes in comparison to shell model results.

Conclusion:

B(E2) values in the Po chain will be decisive to verify shell model interactions and disentangle the correlation of model space and interaction. A staggering except when crossing the N=126 shell closure is not really supported by shell model calculations.

[1] E.K. Warburton, Phys. Rev. C 44, 233 (1991).
[2] E.K. Warburton, B.A. Brown, Phys. Rev. C 43, 602 (1991)
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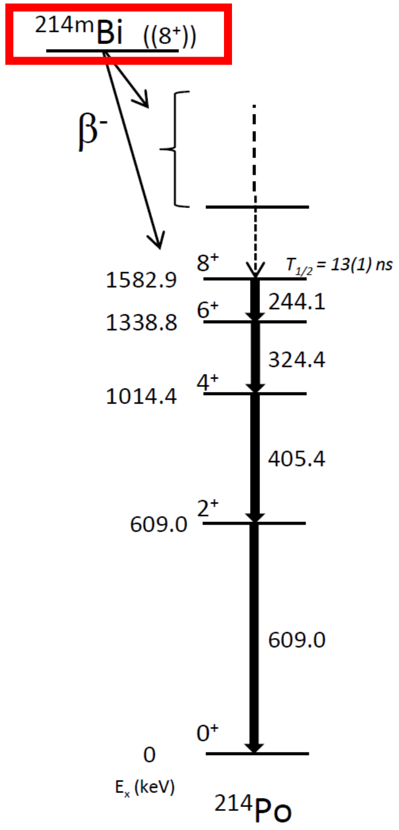
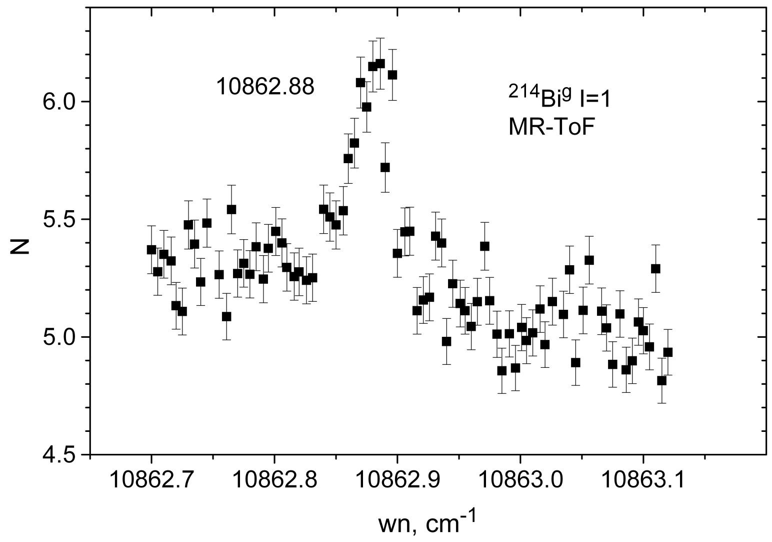
β-decay studies of ^{214,216,218}Bi at ISOLDE

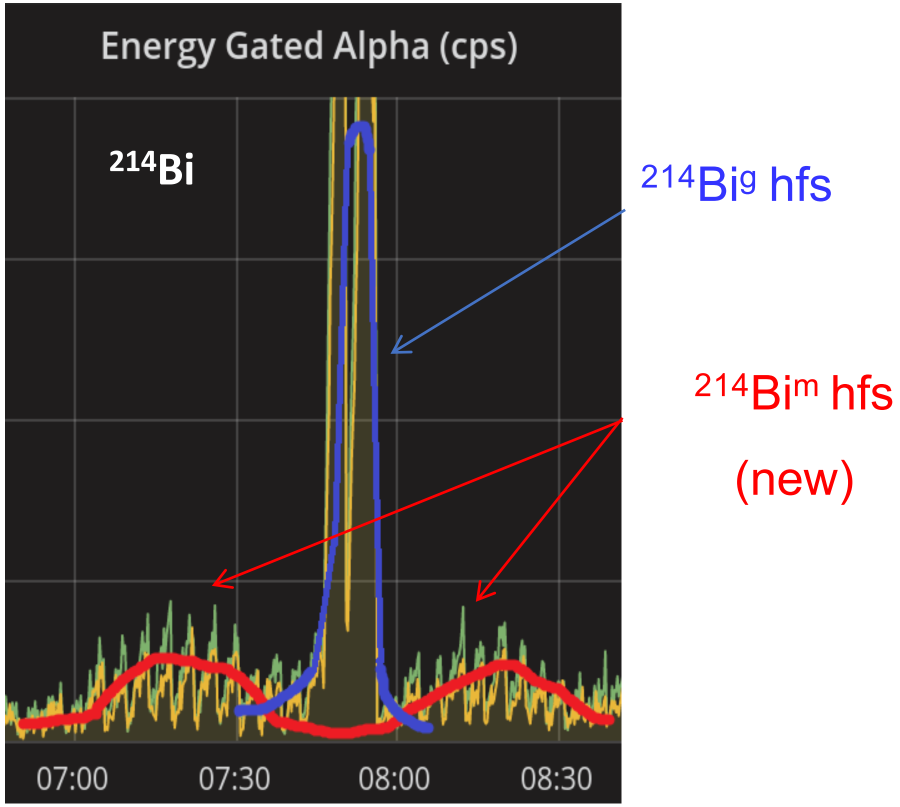
^{214}Bi
- HFS recently studied at ISOLDE (IS608: MR-ToF 2016 and IDS 2017)
- direct identification and spectroscopy of an 8^+ isomer using RILIS+IDS (including HFS/isomer shift measurements, spin, decay pattern and half-life)



MR-ToF 2016 – Ground state



IDS 2017



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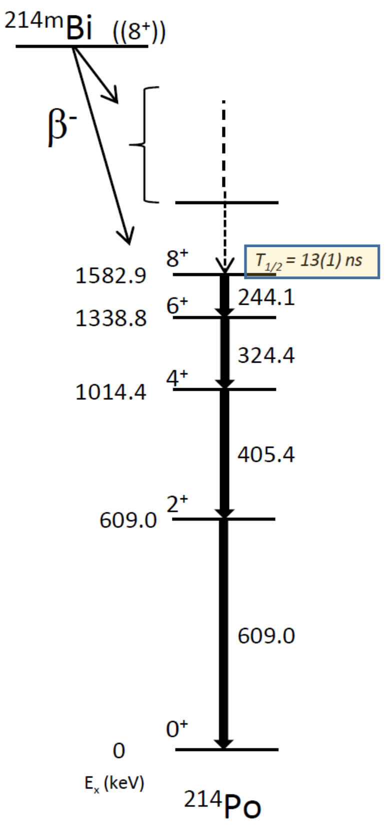

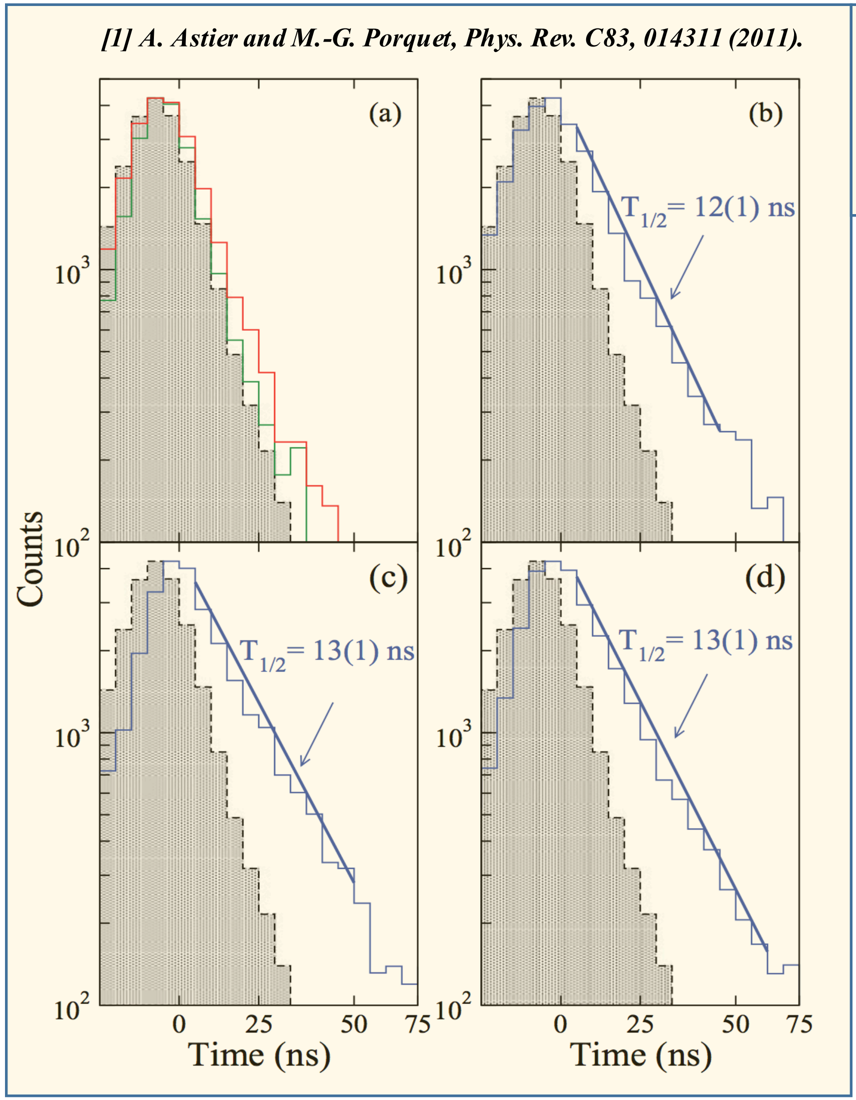

Time distributions between the emissions of γ rays of ^{214}Po showing either prompt coincidences [curves in red and green, panel (a)] or delayed ones corresponding to the decay of the 1583-keV state [curves in blue, panels (b), (c), and (d)].

$T_{1/2}$= 13(1) ns using HPGe detectors [1]

→ can be re-checked using fast-timing detectors

→ *B(E2; 8^+ → 6^+)* = 0.54(4) W.u. used to estimate the $T_{1/2}$ of *8^+ states in ^{216,218}Po*

Lifetimes of 6^+,4^+,2^+ states can be accessed through fast-timing measurement.

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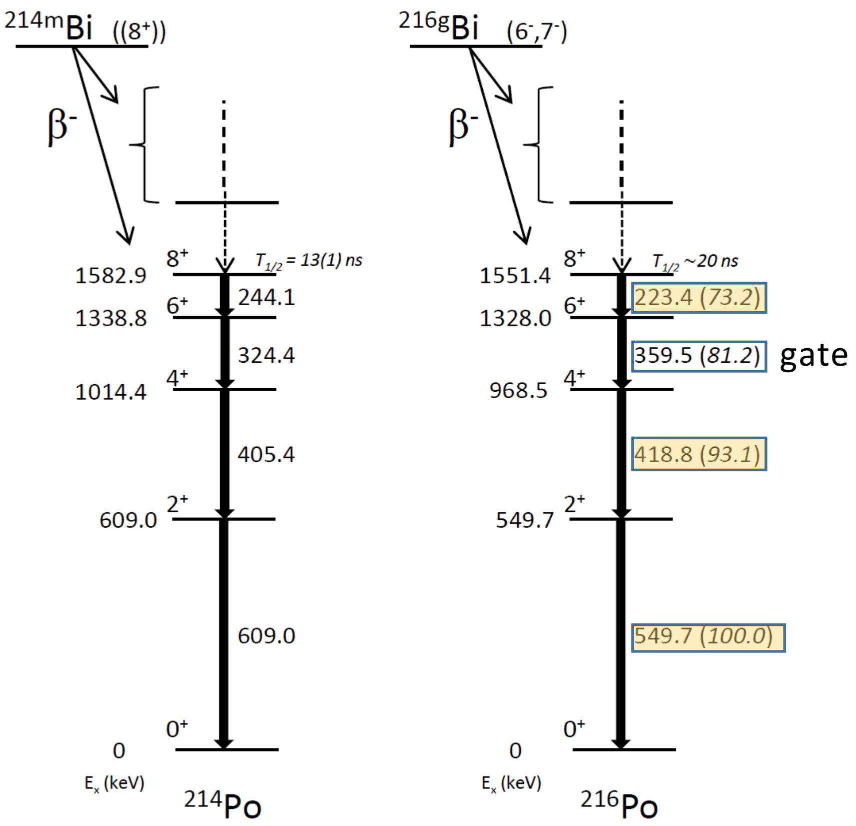
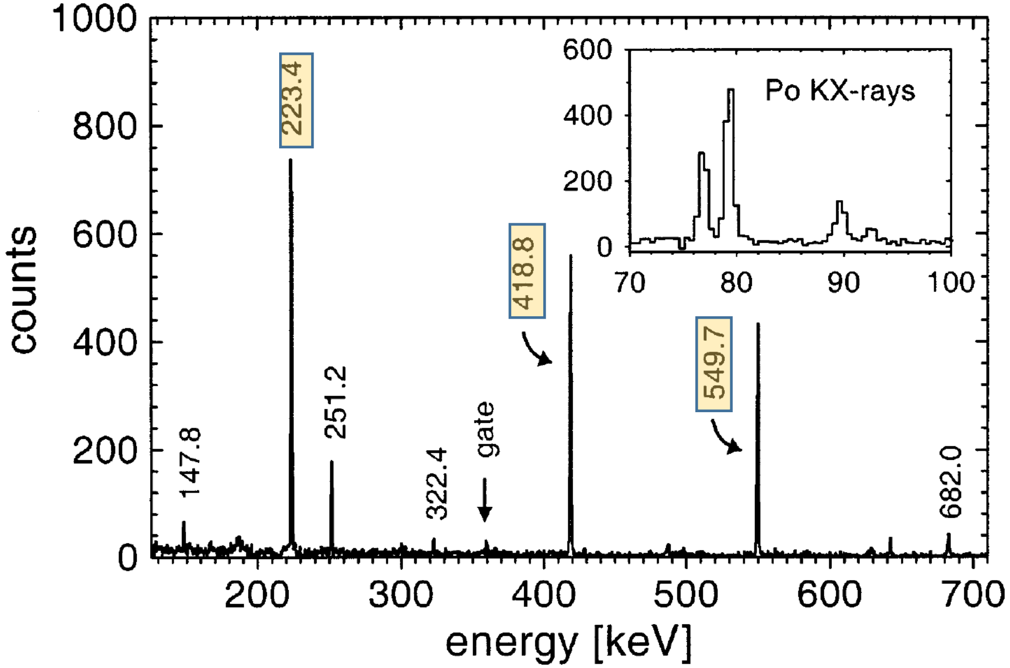
^{216}Bi
- the decay populates clearly the yrast band up to the 8^+ state [1] but no lifetimes are known



γ-ray energy spectrum recorded with the LEGe detector coincident with the 359.5 keV line of ^{216}Bi [1]



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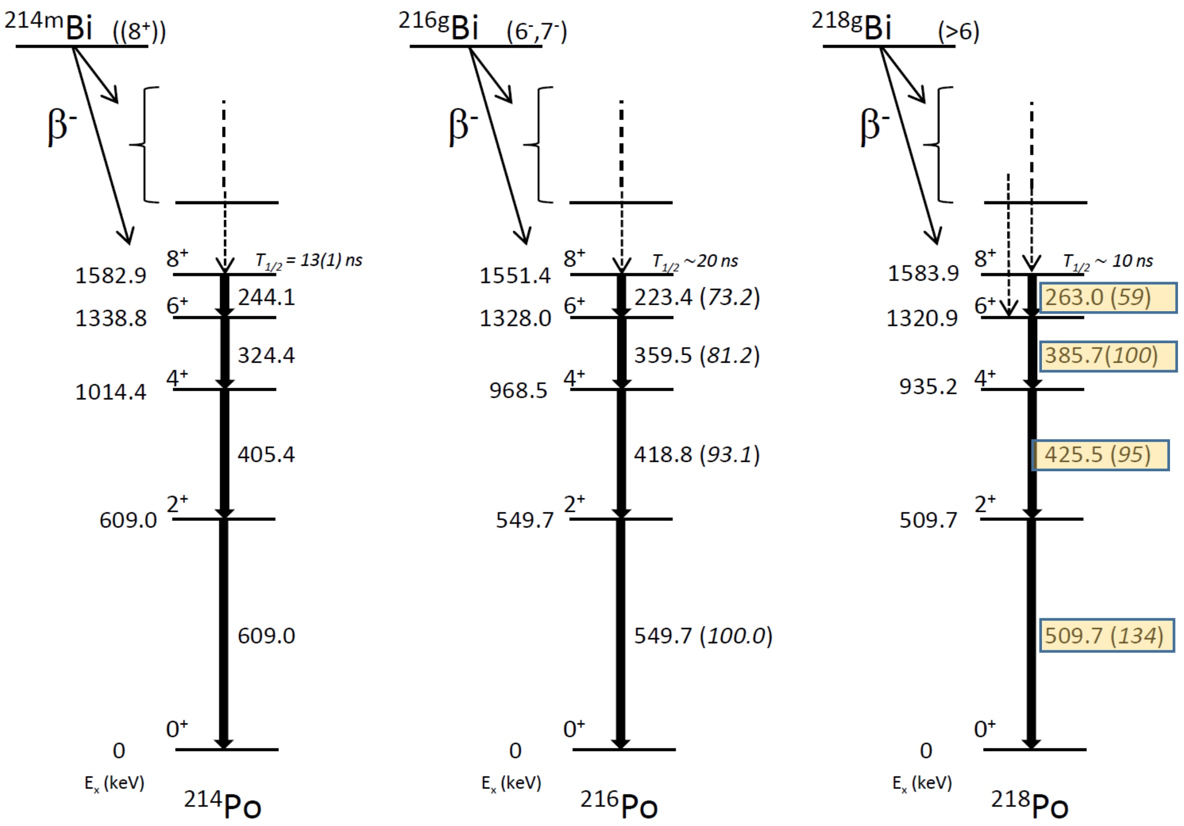
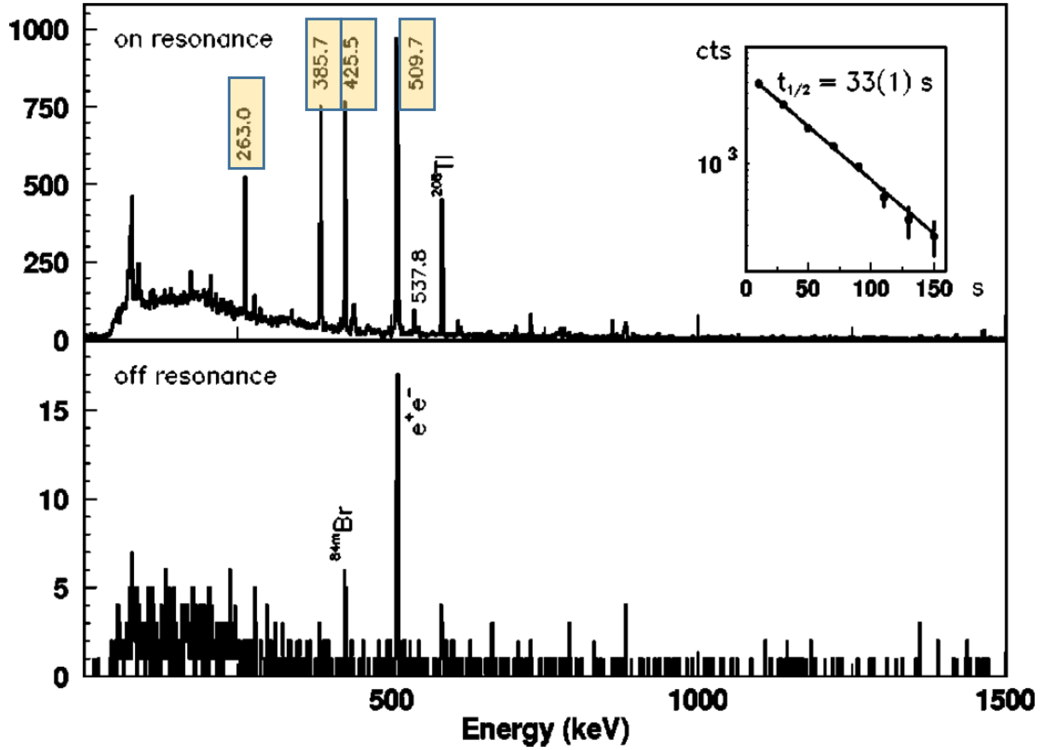
^{216}Bi
- the decay populates clearly the yrast band up to the 8^+ state [1] but no lifetimes are known

^{218}Bi
- beam intensity of 44(8) ions/μC [2] using UCx target + RILIS
- similar decay level scheme as ^{216}Bi but no known lifetimes



β-gated γ-ray energy spectrum from ^{218}Bi β-decay with (top) and without (bottom) laser ionization [2]



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[2] H. De Witte et al., Phys. Rev. C**69**, 044305 (2004).

Beam production

- Use the same proven method: **UCx** target + **RILIS** [1,2]
- Yields recently extracted during IS608 at MR-ToF in 2016

Isotope	Rate estimate (ions/s)
^{214}Bi	2 x 10^4
^{216}Bi	2 x 10^3
^{218}Bi	2 x 10^2

(2 μA proton current)

[1] H. De Witte, PhD Thesis, KU Leuven (2004)
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Beam production

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- Yields recently extracted during IS608 at MR-ToF in 2016.
- Short-lived contaminants such as **Fr** can be easily removed using the pulsed release technique and **HRS** (instead of GPS used in 2017 at IDS)

Isotope	Rate estimate (ions/s)
^{214}Bi	2×10^4
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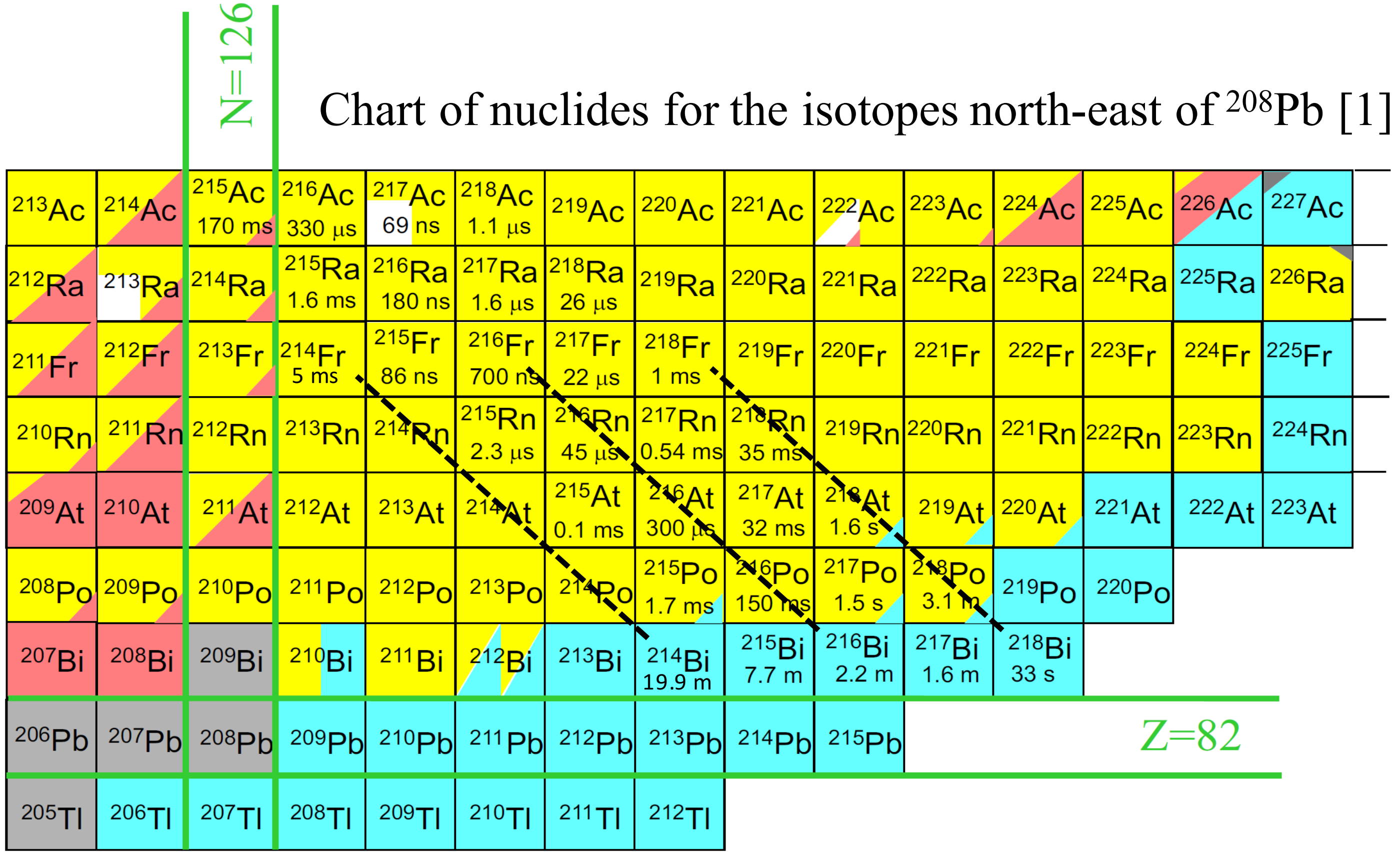
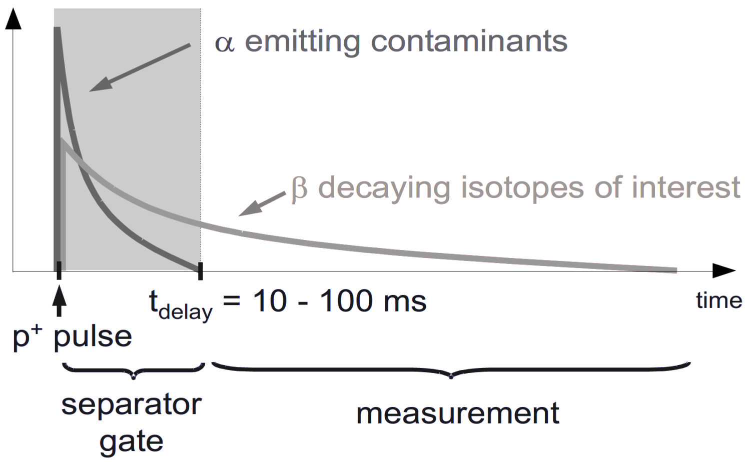
Chart of nuclides for the isotopes north-east of ^{208}Pb [1]



The pulsed release technique [1]: the different time scales for the α decay of the contaminants and the β^- decay under investigation allow for a selective suppression.



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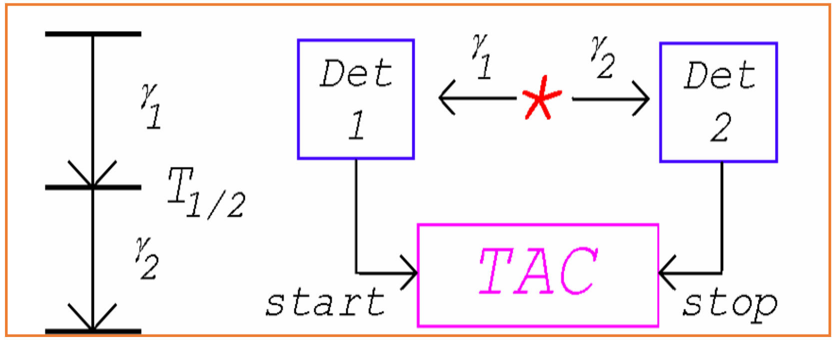
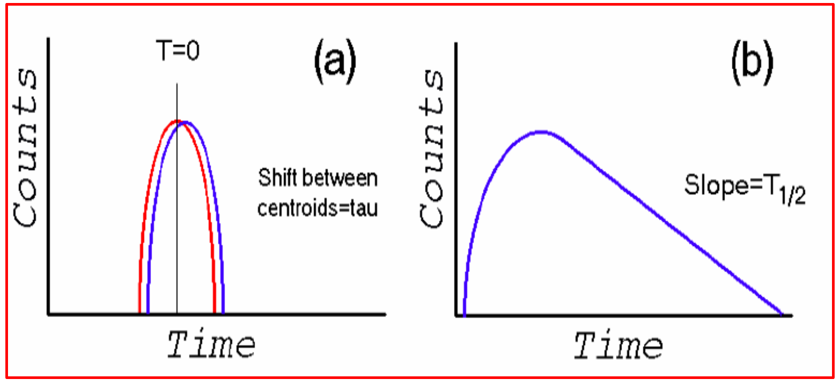
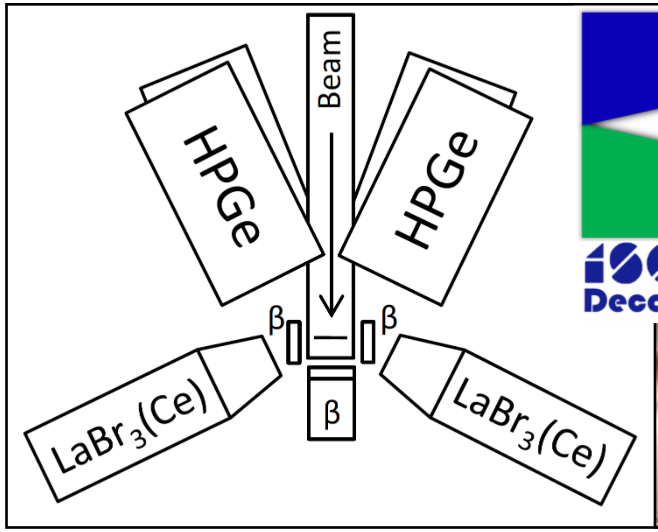
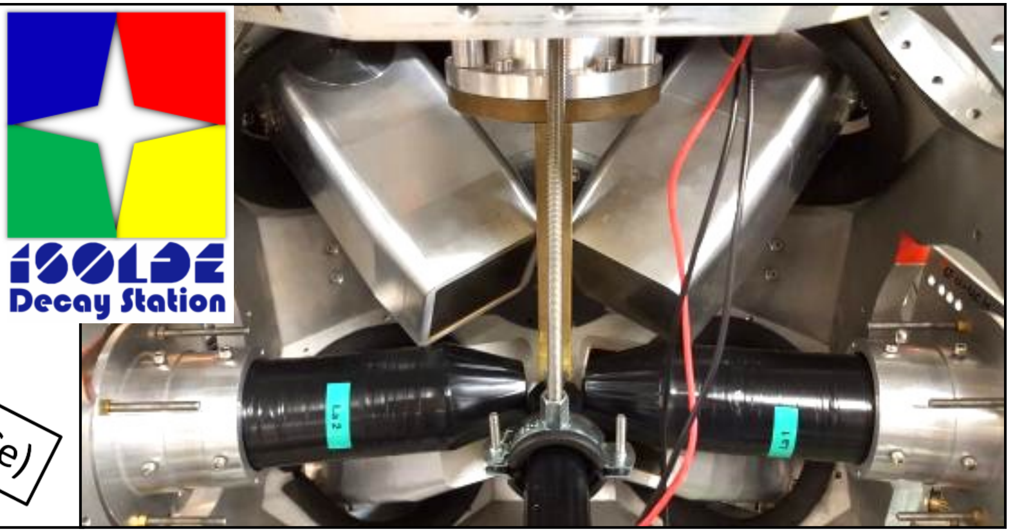
Fast-timing measurements at the ISOLDE Decay station





Ranges:
Centroid shift method: - **10 ps - 100 ps**
Slope method - **50 ps - 50 ns** (or longer)
[H. Mach et al. NIM A 280, 49 (1989)]

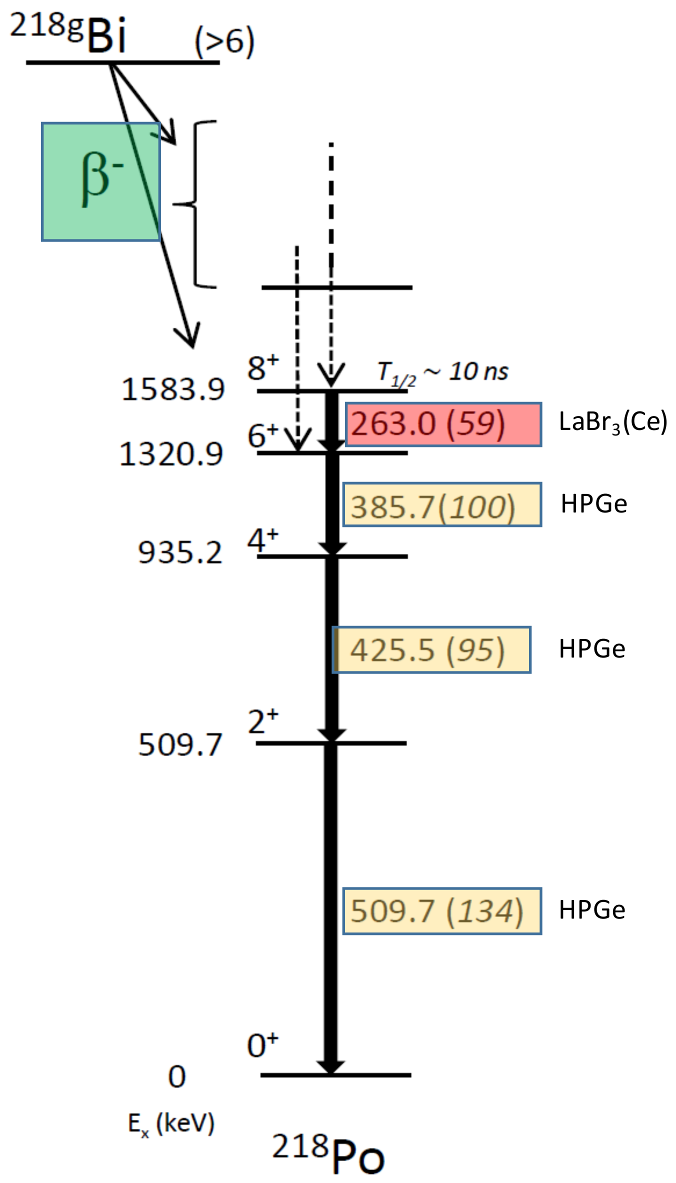




- Well established technique at IDS since 2014 [1,2,3]
- Detection system comprising of:
  - 4 Clover HPGe - 7% abs. eff. at 500keV
  - 2 $LaBr_3(Ce)$ - 3% abs. eff. at 500keV
  - 1 Plastic Scintillator - 20% abs. eff.

[1] R. Lica et al., Phys. Rev. C 93, 044303 (2016).
[2] R. Lica et al., J. Phys. G 44, 054002 (2017).
[3] L.M. Fraile, J. Phys. G 44, 094004 (2017).

Example: lifetime measurement of 8^+ state in ^{218}Po



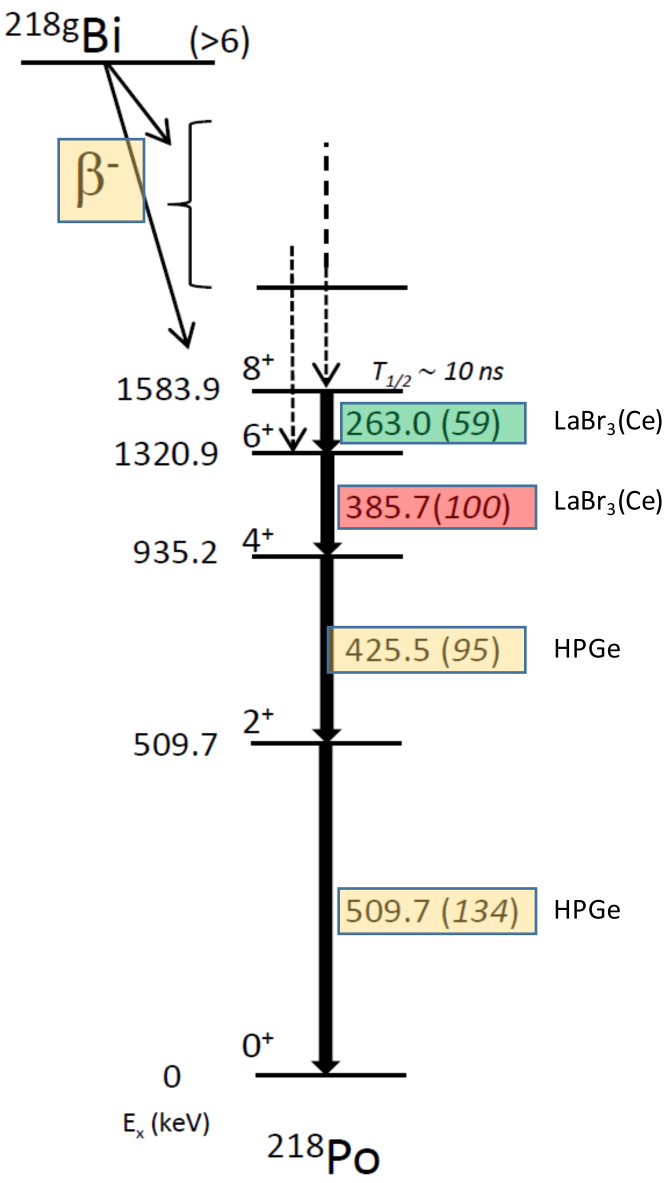
β - γ^{LaBr} - γ^{HPGe} method

Level	Start (eff)	Stop (eff)	Cleaning gate (eff)
8^+	β (20%)	263.0 (2 x 4%)	385.7 or 425.5 or 509.7 (23%)

Rate = 59% * 20% * 8% * 23% * 100 ions/s
= 0.2 counts/s
= 6.1 * 10^3 counts/shift

Observation: a conservative rate of 100 ions/s instead of 200 ions/s considering transmission to IDS (70-80%) and beam downtime.

Example: lifetime measurement of 6^+ state in ^{218}Po



γ^{LaBr} - γ^{LaBr} - γ^{HPGe} method

Level	Start (eff)	Stop (eff)	Cleaning gate (eff)
8^+	β (20%)	263.0 (2 x 4%)	385.7 or 425.5 or 509.7 (23%)
6^+ (2^+,4^+)	263.0 (4%)	385.7 (3%)	425.5 or 509.7 or β (14%+20%)

Rate = 59% * (4% * 3% * 2) * (14%+20%) * 100 ions/s
= 0.05 counts/s
= 1.4 * 10^3 counts/shift

Rate estimates

Nucleus/Yield	J^π	E_γ (keV)	$T_{1/2}$	Events/shift
^{214}Po 10^4 ions/s	2_1^+	609.0	>9 ps	4.9×10^4
	4_1^+	405.4	>68 ps	9.5×10^4
	6_1^+	324.4	>210 ps	1.7×10^5
	8_1^+	244.1	13(1) ns [6]	7.7×10^5
^{216}Po 10^3 ions/s	2_1^+	549.7	>15 ps	5.9×10^3
	4_1^+	418.8	>58 ps	9.7×10^3
	6_1^+	359.5	>120 ps	1.7×10^4
	8_1^+	223.4	∼27 ns	7.6×10^4
^{218}Po 10^2 ions/s	2_1^+	509.7	>21 ps	6.5×10^2
	4_1^+	425.5	>52 ps	1.1×10^3
	6_1^+	385.7	>86 ps	1.4×10^3
	8_1^+	263.0	∼12 ns	6.1×10^3

Rate estimates

- Half-lives for yrast states in $^{214,216,218}Po$ estimated using:

B(E2) < 10 W.u. for 2,4,6$^+$ states

B(E2) ~ 0.5 W.u. [1] for 8$^+$ states

Nucleus/Yield	J^π	E_γ (keV)	$T_{1/2}$	Events/shift
^{214}Po 10^4 ions/s	2_1^+	609.0	>9 ps	4.9×10^4
	4_1^+	405.4	>68 ps	9.5×10^4
	6_1^+	324.4	>210 ps	1.7×10^5
	8_1^+	244.1	13(1) ns [6]	7.7×10^5
^{216}Po 10^3 ions/s	2_1^+	549.7	>15 ps	5.9×10^3
	4_1^+	418.8	>58 ps	9.7×10^3
	6_1^+	359.5	>120 ps	1.7×10^4
	8_1^+	223.4	~27 ns	7.6×10^4
^{218}Po 10^2 ions/s	2_1^+	509.7	>21 ps	6.5×10^2
	4_1^+	425.5	>52 ps	1.1×10^3
	6_1^+	385.7	>86 ps	1.4×10^3
	8_1^+	263.0	~12 ns	6.1×10^3

Within the reach of the fast-timing setup available at IDS (> 10 ps)

[1] A. Astier and M.-G. Porquet, Phys. Rev. C83, 014311 (2011).

Beamtime request: 7 shifts

- **2 shifts** for ^{218}Bi (in order to reach a statistics > 1000 counts for the time distribution of the 2_1^+ state)
- **1 shift** for ^{216}Bi
- **1 shift** for ^{214}Bi (the incoming rate will be reduced in order to avoid pile-up effects)
- **1 shift** for online fast-timing calibrations using implantation sources (eg. ^{138}Cs, ^{88}Rb, ^{140}Ba)
- **2 shifts** for laser tuning

Nucleus/Yield	J^π	E_γ (keV)	$T_{1/2}$	Events/shift
^{214}Po	2_1^+	609.0	>9 ps	4.9×10^4
10^4 ions/s	4_1^+	405.4	>68 ps	9.5×10^4
1 shift	6_1^+	324.4	>210 ps	1.7×10^5
	8_1^+	244.1	13(1) ns [6]	7.7×10^5
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^{218}Po	2_1^+	509.7	>21 ps	6.5×10^2
10^2 ions/s	4_1^+	425.5	>52 ps	1.1×10^3
2 shifts	6_1^+	385.7	>86 ps	1.4×10^3
	8_1^+	263.0	~12 ns	6.1×10^3

Observation:
If approved, this experiment can be scheduled together with the remaining 3 shifts of the IS608 experiment (HFS measurements of $^{216,218}Bi$) because of the following considerations:
- both measurements can be performed using the same fast-timing configuration of IDS
- the stable beam and RILIS tuning will be done only once

Collaboration

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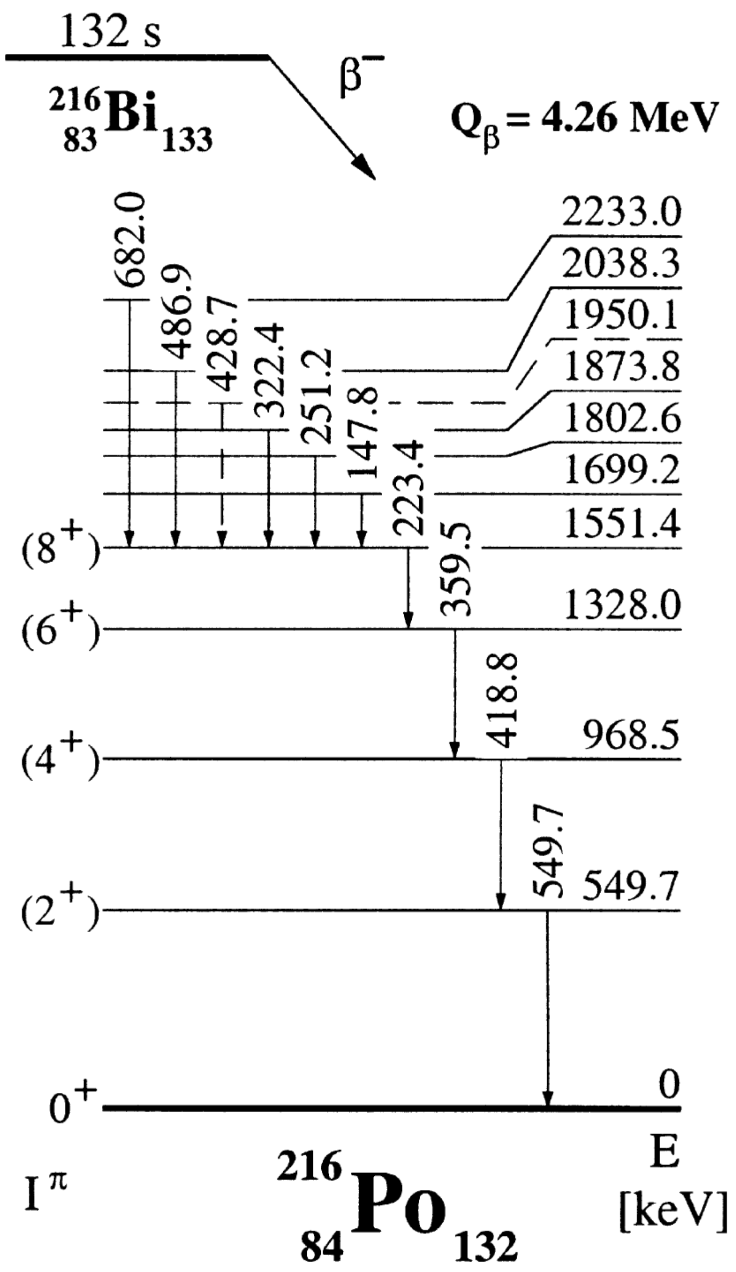
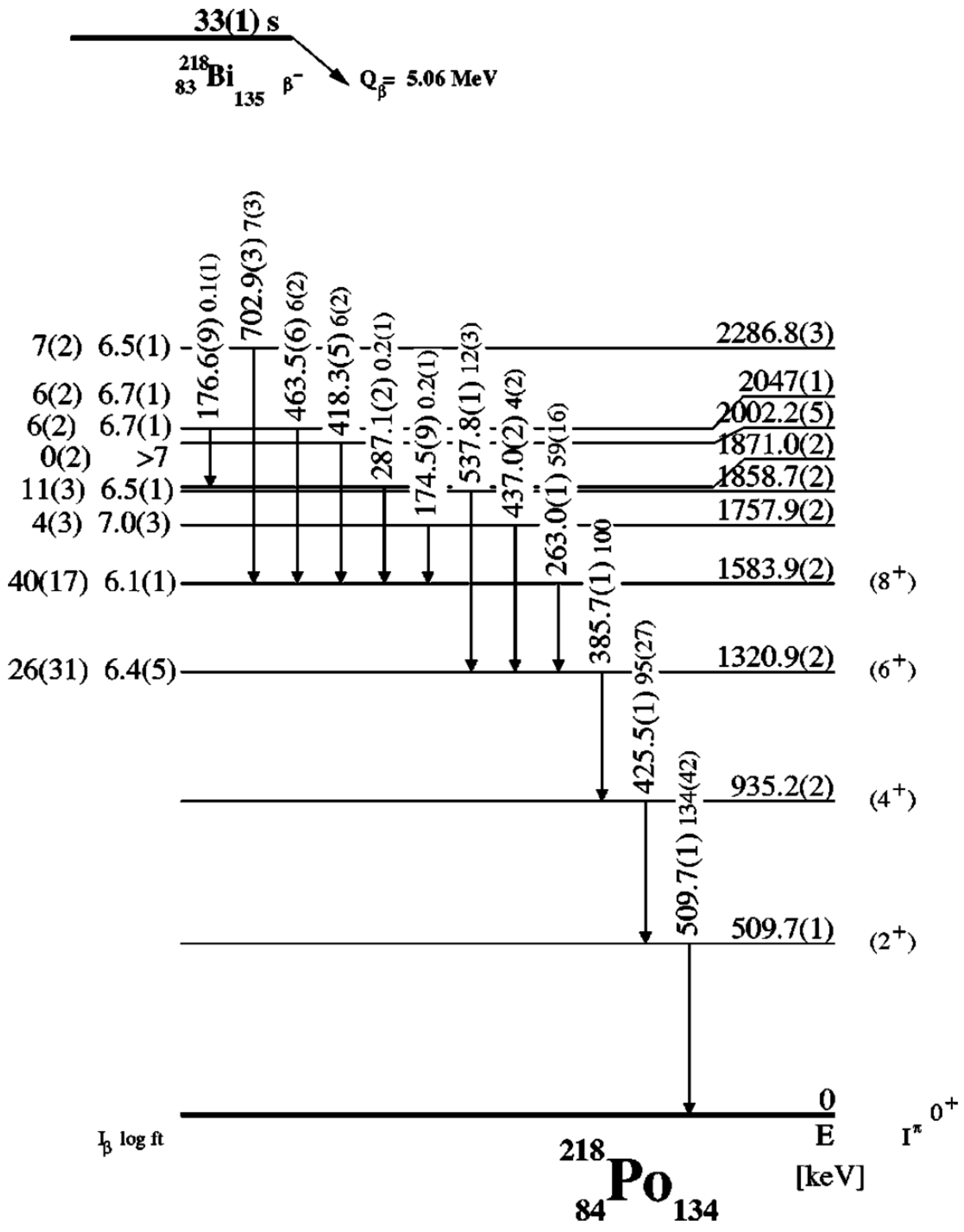
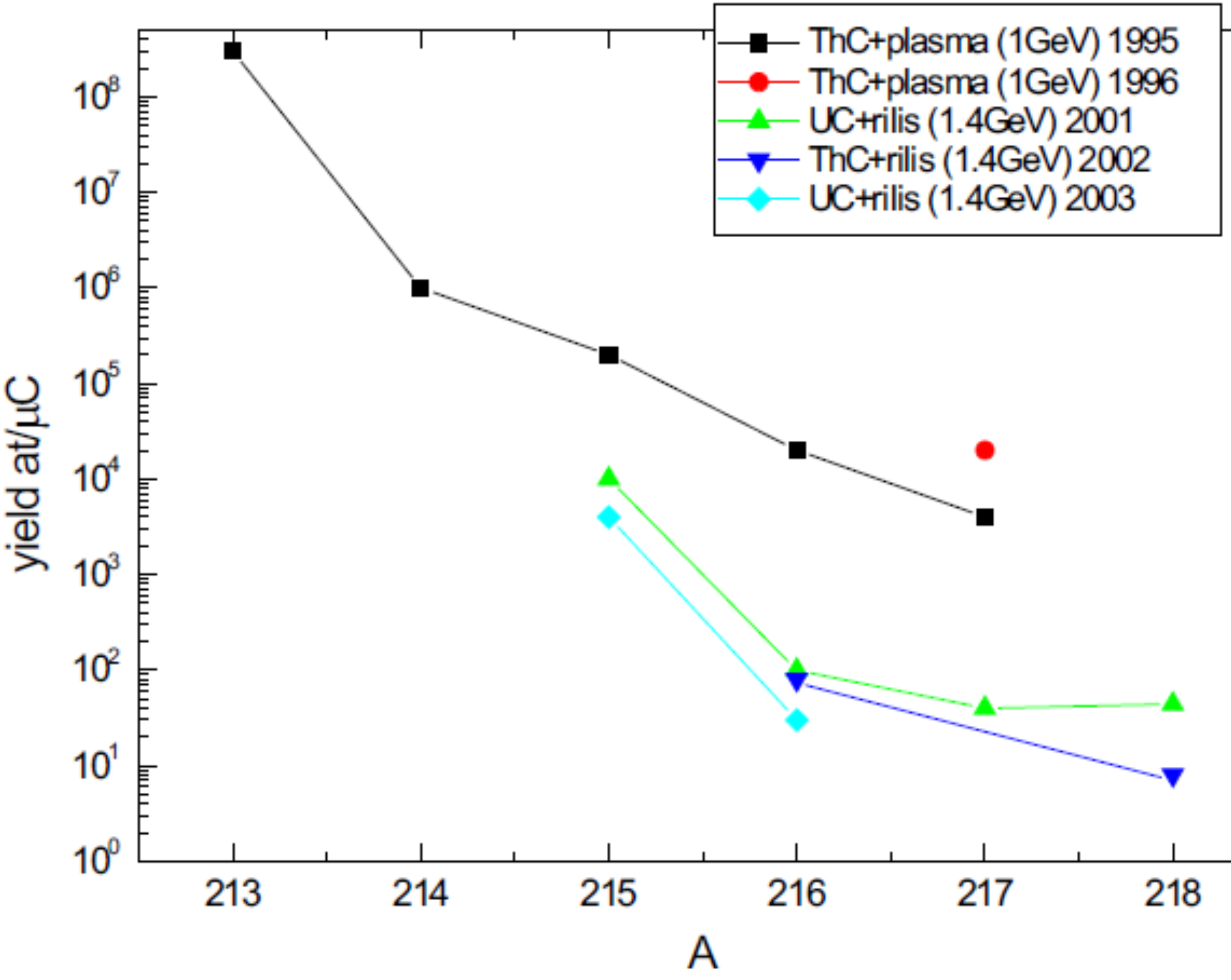


Fig. 3. The decay scheme of ^{216}Bi





ThC+plasma (1GeV) 1995
ThC+plasma (1GeV) 1996
UC+rilis (1.4GeV) 2001
ThC+rilis (1.4GeV) 2002
UC+rilis (1.4GeV) 2003
yield at/μC
A