Transition probabilities of low-lying excited states in ^{210}Po and ^{210}Pb

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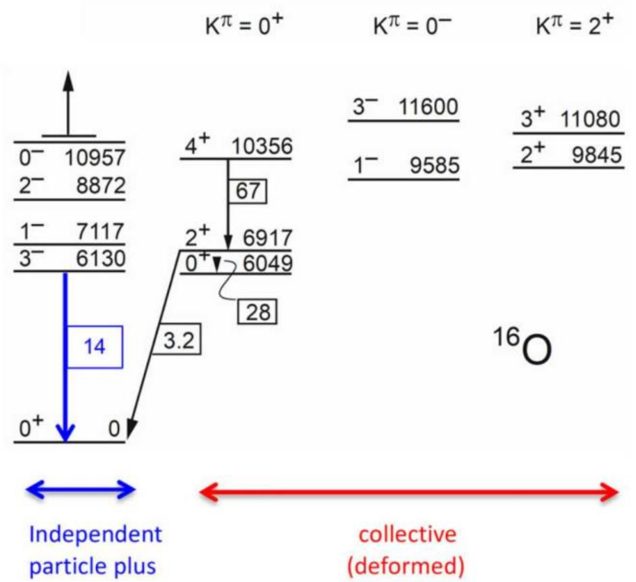
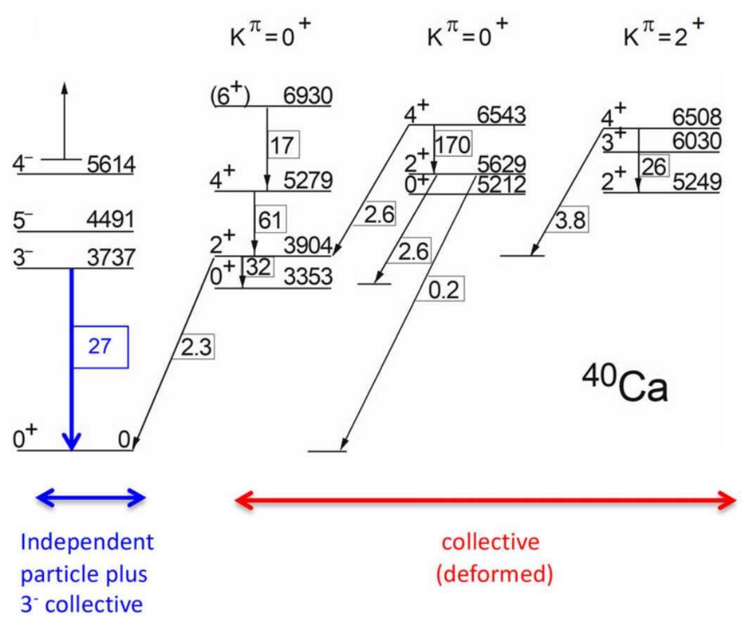
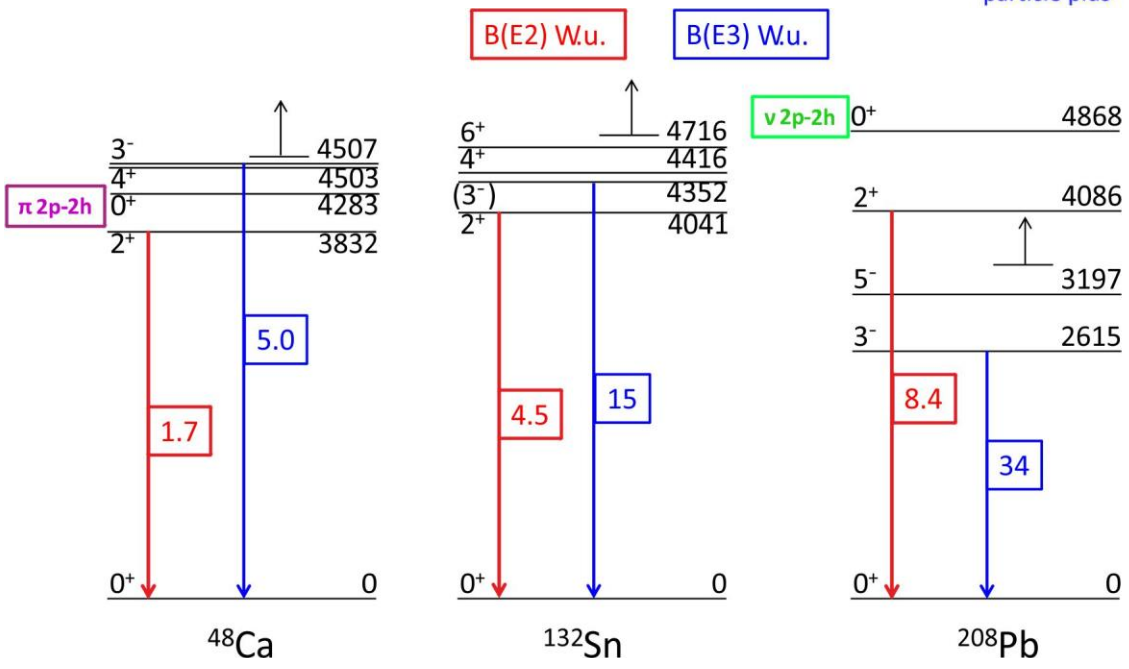
How magic are the doubly magic nuclei?

A.E. Stuchbery and J.L. Wood, *Physics* **2022**, *4*(3), 697-773

N=Z doubly magic nuclei (^{16}O and ^{40}Ca)
→ examples of ***shape coexistence*** at the level of fist excited states



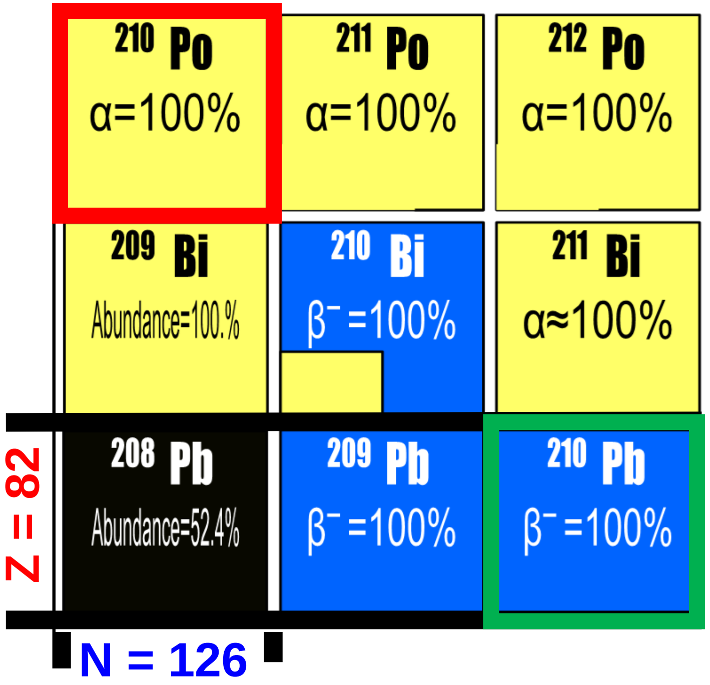


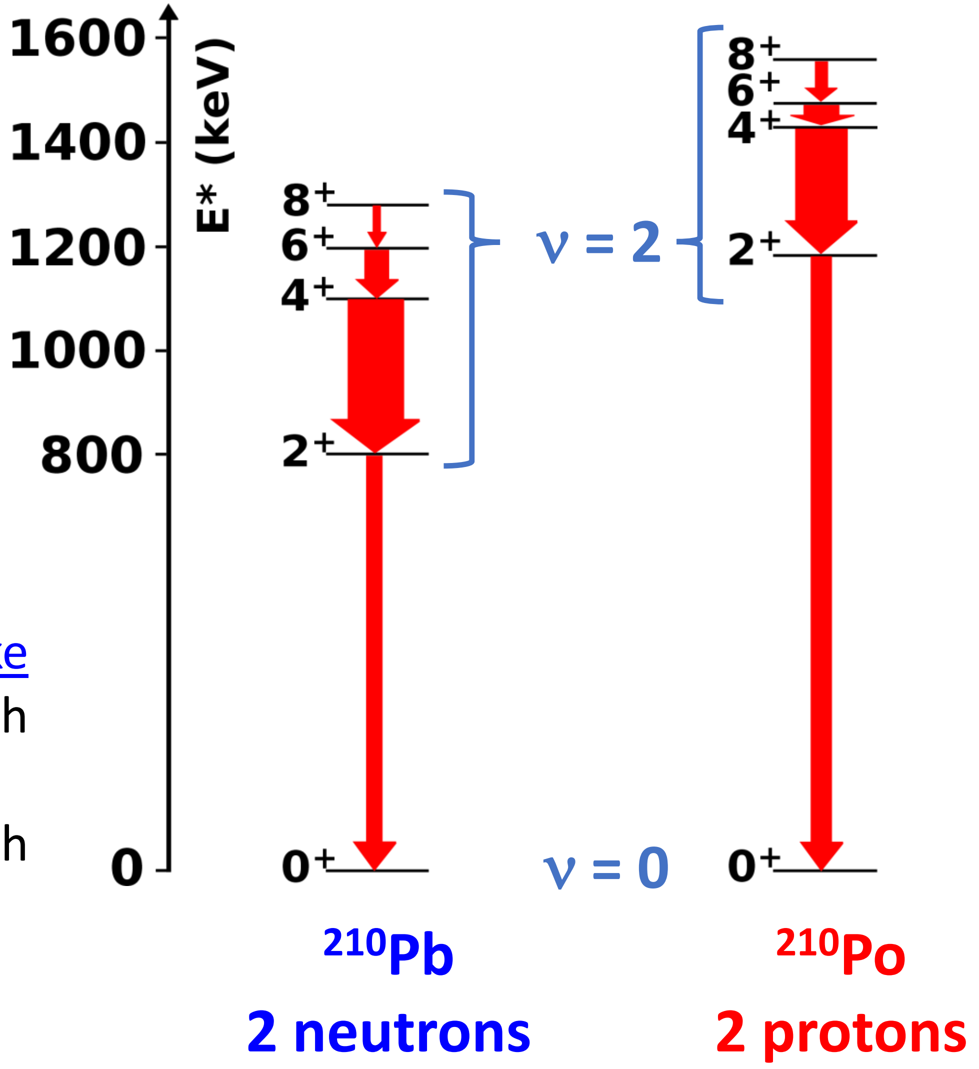


N > Z doubly magic nuclei (^{48}Ca, ^{132}Sn, **^{208}Pb**)
→ ***octupole correlations*** at the (very) low excitation energies

Do we understand the structure of ^{208}Pb and its vicinity???

Properties of the 2-particle configurations above ^{208}Pb





- The energies of the yrast 2^+, 4^+, 6^+, and 8^+ states follow seniority-like pattern of decreasing energy splitting between adjacent states with increasing spin;
- The magnetic moments of the 6^+ and the 8^+ states are known in both nuclei:

$g(8^+;{}^{210}Pb) = -0.312(8)$ $g(8^+;{}^{210}Po) = +0.891(6)$

$g(6^+;{}^{210}Pb) = -0.312(15)$ $g(6^+;{}^{210}Po) = +0.913(8)$

$\nu(g_{9/2})^2$ $\pi(h_{9/2})^2$

In both nuclei the structure of the 2^+, 4^+, 6^+, and 8^+ states is dominated by the seniority 2 configuration

Properties of the 2 – particle configurations above ^{208}Pb
Shell model calculations

Kuo-Herling interaction (E. K. Warburton and B. A. Brown, Phys. Rev. C 43, 602 (1991)).

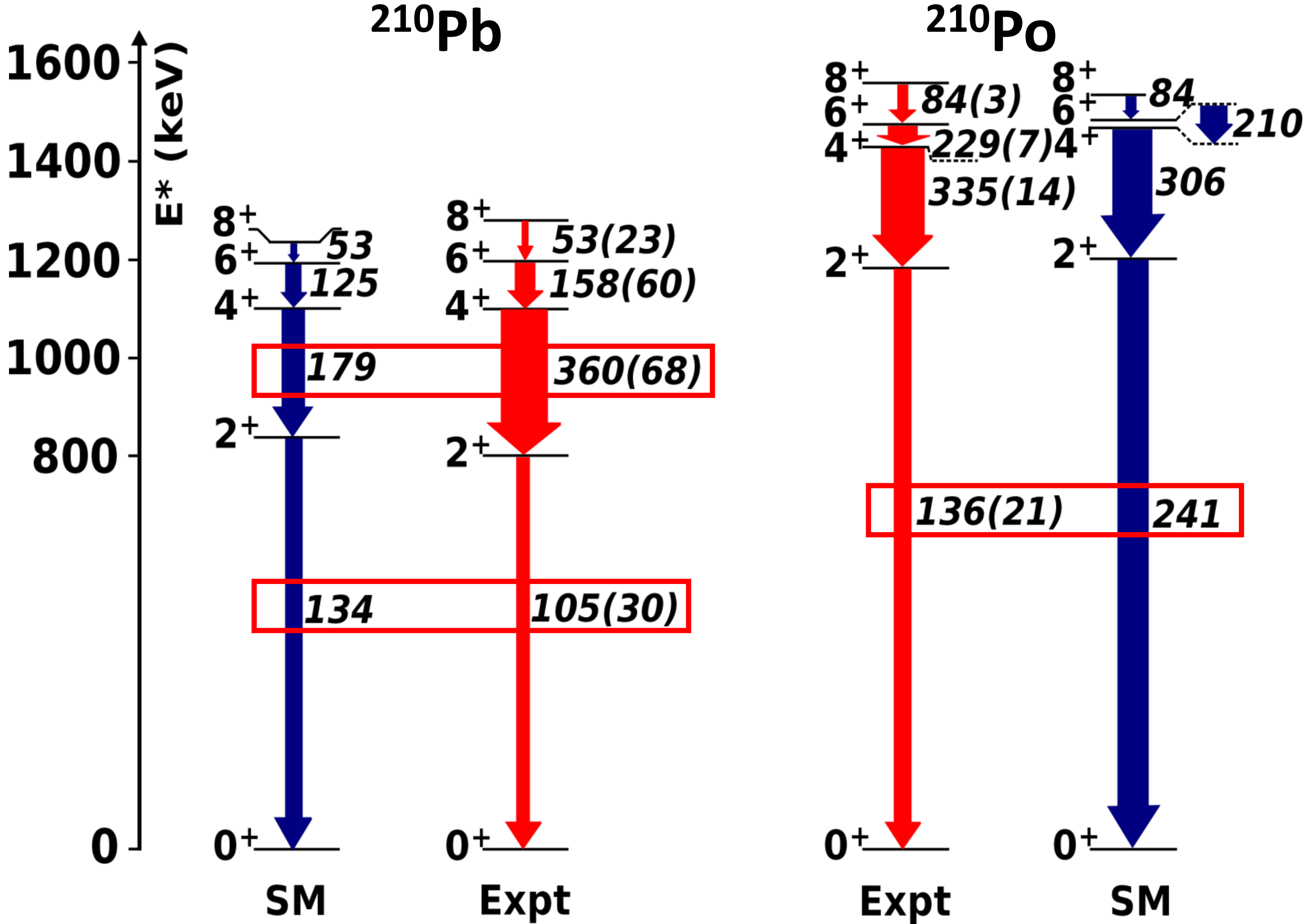
2 protons in ($2p_{1/2}$, $2p_{3/2}$, $1f_{5/2}$, $1f_{7/2}$, $0h_{9/2}$, $0i_{13/2}$) and 2 neutrons in ($3s_{1/2}$, $2d_{3/2}$, $2d_{5/2}$, $1g_{7/2}$, $1g_{9/2}$, $0h_{11/2}$, $0j_{15/2}$)

$(e_\pi, e_\nu) = (1.44e, 0.91e)$ fixed to the $B(E2;8^+_1 \to 6^+_1)$ values in ^{210}Po and ^{210}Pb, respectively

Results:

- Almost perfect reproductions of the energies of the yrast states;
- Good agreement between the experimental and the calculated static moments;
- Good agreement between all experimental and theoretical $B(E2)$ but the **$B(E2;\ 2^+_1 \to 0^+_1)$** values (and $B(E2;\ 4^+_1 \to 2^+_1)$ in ^{210}Pb)

The problem is present in all shell model calculations available in this mass region (CD Bonn potential, H208 interaction) but also appears in QPM calculations.



Properties of the 2 – particle configurations above ^{208}Pb?

Two hypothesis:

1) There are some **deficiencies** in the shell model
2) The experimental results for the lifetimes of the 2^+_1 states of ^{210}Pb and ^{210}Po **contain systematic errors**.

PHYSICAL REVIEW C **67**, 054310 (2003)

Large-scale shell model calculations for the $N=126$ isotones Po–Pu

E. Caurier,[1] M. Rejmund,[2] and H. Grawe[3]

particle units (W.u.). The agreement for the two- and three-particle nuclei ^{210}Po and ^{211}At is noteworthy and corroborates the choice of the polarization charge. The deviation observed for the $2^+ \rightarrow 0^+$ transition in ^{210}Po can be ascribed both to a systematic uncertainty in the experimental data as deduced from (d,d') inelastic scattering [33], and to the neglect of ^{208}Pb ph excitations in the shell model, which enter most sensitively the $I^\pi=2^+$ states [34] (see footnote in Table

M.S.M. Gerathy et al., Phys. Lett. **B823**, 136738 (2021).

^{210}Po: B(E2; $2^+_1 \rightarrow 0^+_1$)

C. Ellegaard *et al*., Nucl. Phys. **A206**, 83 (1973)

(d,d') & (p,p') **42(9) e^{2}fm^4**

The same technique used for the B(E2; $2^+_1 \rightarrow 0^+_1$) of ^{210}Pb

D. Kocheva *et al*., Eur. Phys. J. **A53**, 175 (2017)

DSAM in a transfer reaction **136(21) e^{2}fm^4**

Shell model gives **241 e^{2}fm^4**

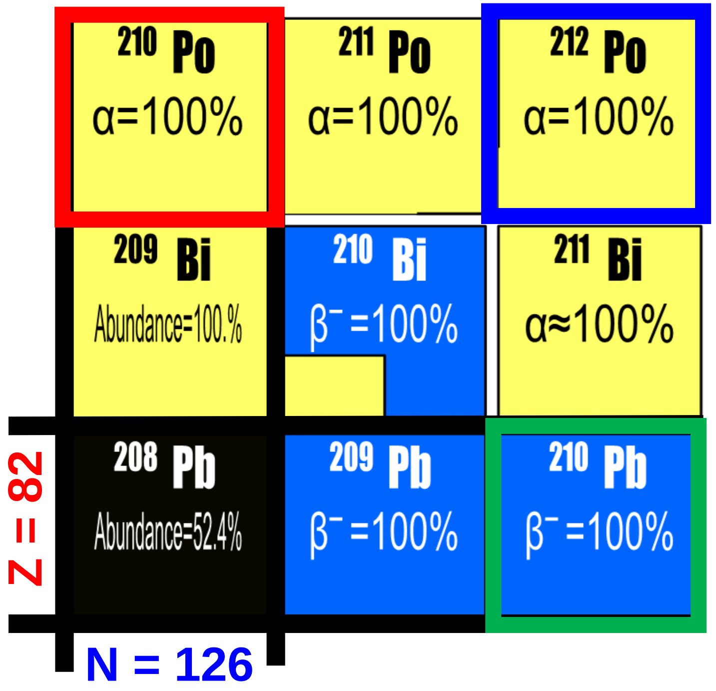
Possible impact of the long-lived states feeding the level of interest - is it correctly accounted for?

A. E. Stuchbery and J. L. Wood, Physics 4, 697 (2022).

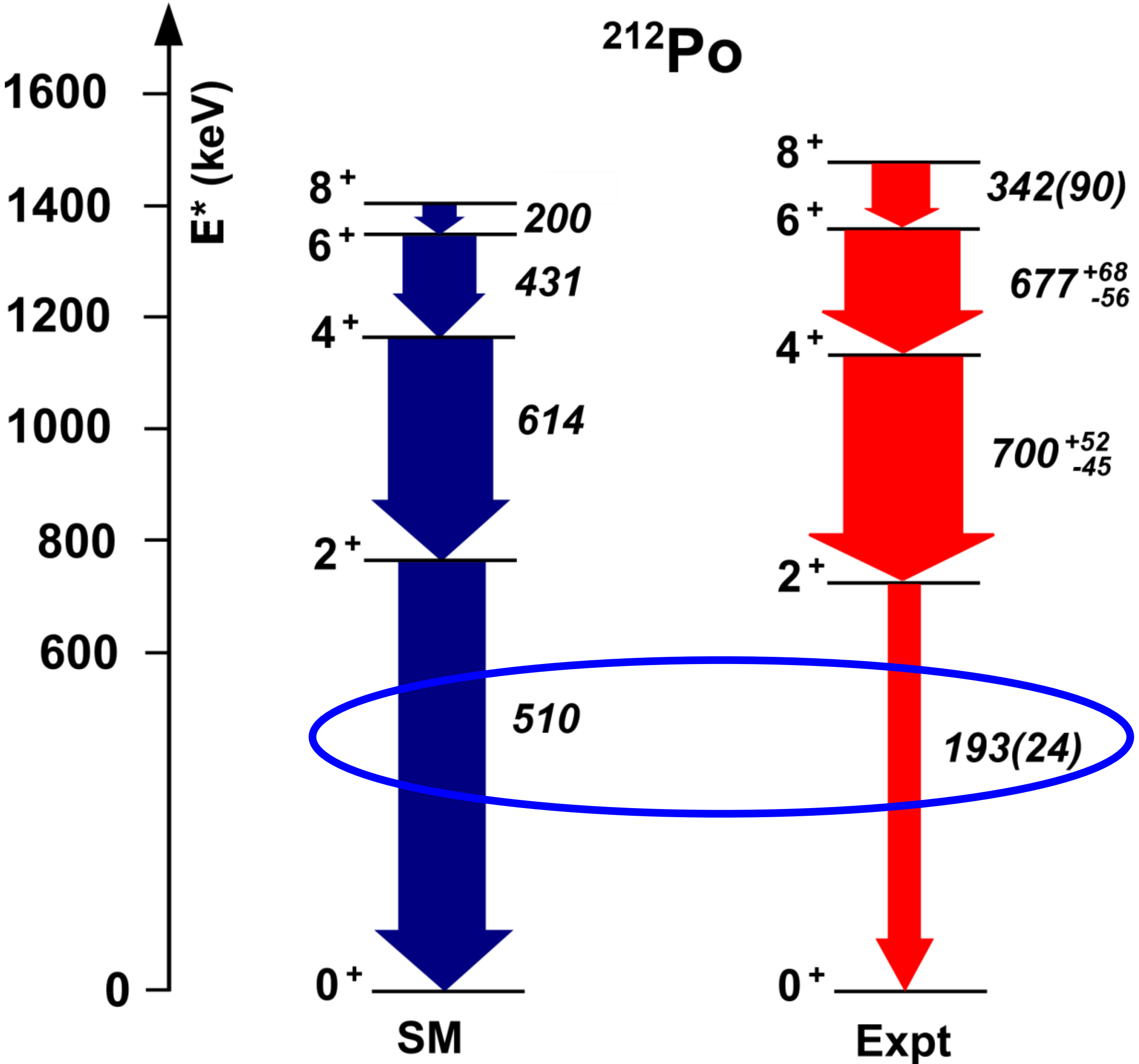
…. The discrepancy between theory and experiment for the 2$^+$ state in ^{210}Po (1.8(3)W.u. cf. 3.4W.u.) is well known and has been attributed to a lack of particle-hole excitations in the theoretical calculations [31,36,37]. However, ***it should also be recognized that the data evaluators for the A=210 mass chain [38] note that the 2$^+$ lifetime measurement in ^{210}Po should be tested****, so excessive interpretation of this potential discrepancy is not warranted. …*

Properties of the 2 – particle configurations above ^{208}Pb?

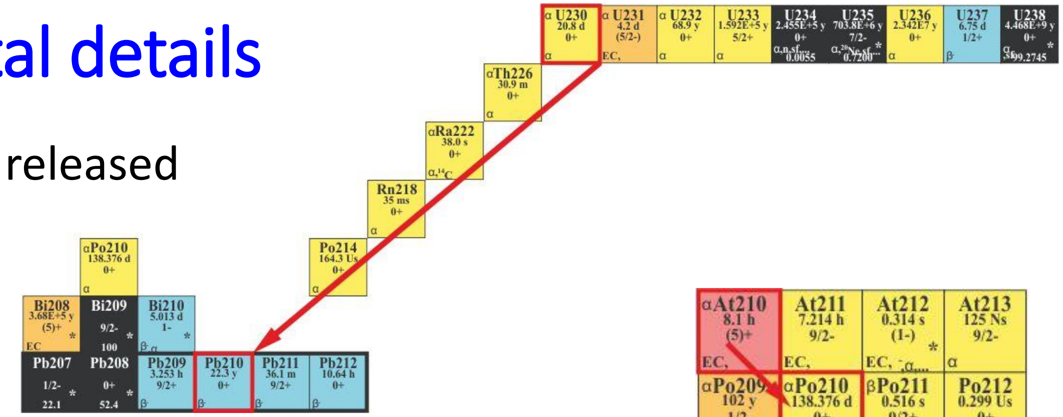
It is necessary to <u>remeasure/test/verify</u> the B(E2; $2^+_1 \rightarrow 0^+_1$) values in ^{210}Po and ^{210}Pb and eventually the B(E2; $4^+_1 \rightarrow 2^+_1$) value in ^{210}Pb by using <u>alternative experimental methods</u>!

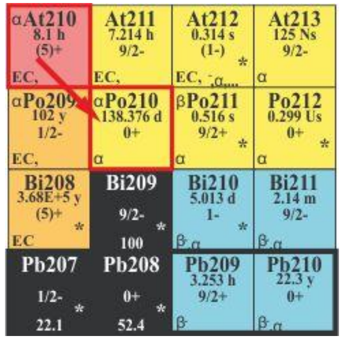


To understand the structures of the "open shell" nuclei north-east of ^{208}Pb we have to understand completely the properties of the simplest 2-particle configurations above ^{208}Pb.



RIB production from ISOLDE and experimental details





- **^{210}Pb** – produced in UC_x target as a **daughter of ^{230}U** (20.8 d) – not released during target irradiation
  - (conservative) in-target production estimate **~1x10^7 p/µC**

- ^{210}Po – considering only ^{210}At decay (8.3h) – **cold target irradiation**
  - (conservative) in-target production estimate **~1x10^8 p/µC**

RILIS Ionization efficiencies, **corrected** (*B. Marsh,private communication*):
- **~5 % for Po** (*estimated*, no mass marker available)
- **~25 % for Pb** (using the new ionization scheme)

Charge breeding and low-energy transport *(F. Wenander)* → ~5%

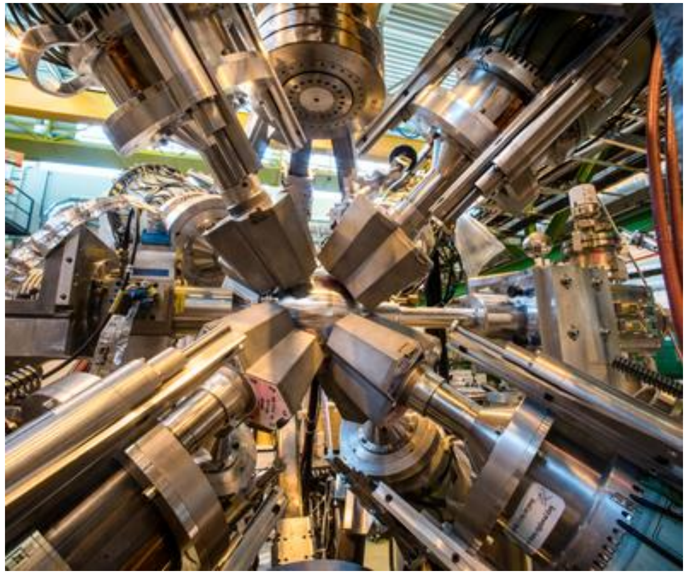
Post-acceleration *(J.A. Rodriguez)* → 75%

Beam intensity on Miniball target – ***at least 2x10^5 pps*** for 1 day of beam on target

Considering all of the above efficiencies those intensities should be achievable after:

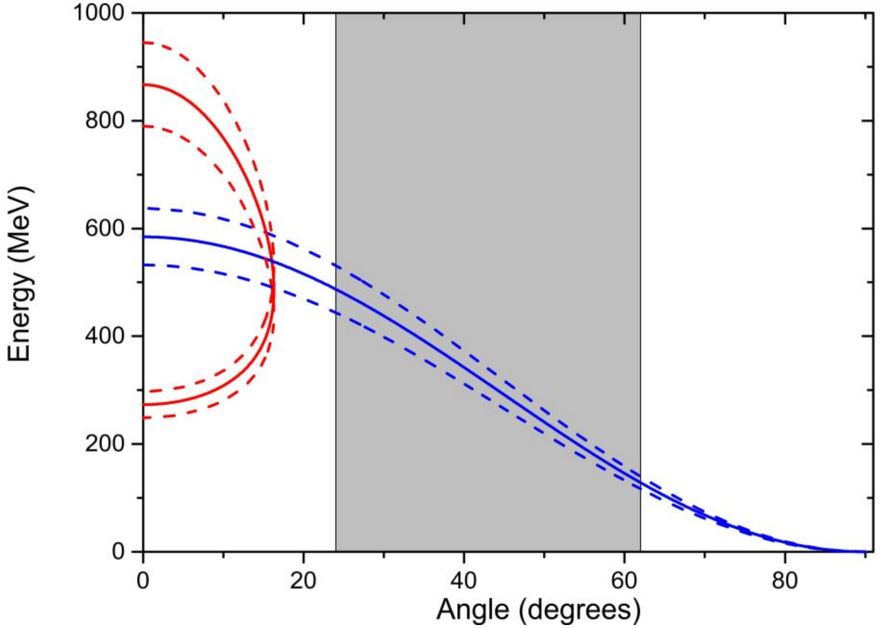
- 1 week irradiation of UCx target (@ 1 µA) – in the ^{210}Pb case
- 1.5 days of a cold target irradiation (@ 1 µA) – in the ^{210}Po case

Coulomb excitation using Miniball @ 4.5 MeV/u



- **Heavy beam** ($^{210}Po/^{210}Pb$) @ 4.5 MeV on
- Light target – ^{58}Ni of 2 mg/cm^2

Kinematics →



- ***912 γ's per day*** in the $2^+_1 \rightarrow 0^+_1$ in ^{210}**Po** (3% statistical uncertainty).
- ***2352 γ's per day*** in the $2^+_1 \rightarrow 0^+_1$ in ^{210}**Pb** (2% statistical uncertainty).
  - ***55 γ's per day*** in the $4^+_1 \rightarrow 2^+_1$ in ^{210}**Pb** (13% statistical uncertainty).

Beam-time request

Summary of requested shifts (modified):

- 3 shifts (1 day) with $2x10^5$ pps ^{210}Po beam at 4.5 MeV/u on a ^{58}Ni target;
  - from a "cold irradiated" UC_x target
  - a total of **10^{10} ^{210}Po ions** @ Miniball target
- 3 shifts (1 day) with $2x10^5$ pps ^{210}Pb beam at 4.5 MeV/u on a ^{58}Ni target
  - from (any) already used UC_x (RILIS) target
- 2 x 1 shift for tuning/calibrations with beam (at lower beam intensity)

→ **A total of 8 shifts *(without protons)* requested**

Yield estimates, Thierry Stora and Simon Stegemann

	In-target prod **210At** [/muC]	Comment			Eff. Cascade [%]	Comment	
FLUKA	1.00E+08	> taking pessimistic one		production	93.75%	build-up for irrad time (4*Thalf)	
ABRABLA	2.00E+08			release	100.00%	long-lived-> assume all is released	
				ionization	40.00%	https://doi.org/10.1016/j.nimb.2008.05.142	
				transport	5.00%		
				post-acc	80.00%		
				Post-acc yield 210Po [/muC]			
				1.50E+06			

	In-target prod **230U** [/muC]	Comment			Eff. Cascade [%]	Comment
FLUKA	6.00E+08			production	21.54%	build-up for irrad time (7d)
ABRABLA	8.00E+07	> taking pessimistic one		release	100.00%	long-lived-> assume all is released
				ionization	30.00%	RILIS improved scheme x10
				transport	5.00%	
				post-acc	80.00%	
				Post-acc yield 210Pb [/muC]		
				2.07E+05		