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Decay spectroscopy of neutron-rich Lead isotopes

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1. Experimental details
2. Preliminary results
3. Seniority scheme and shell-model calculations

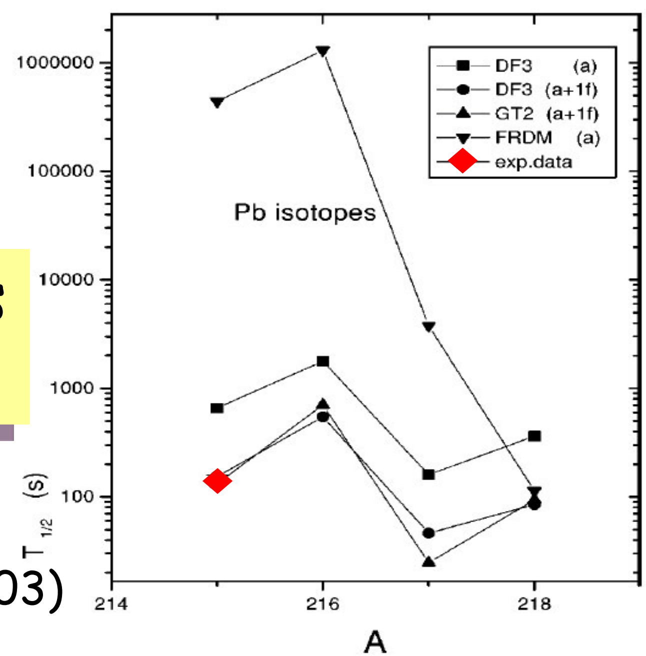
PRESPEC Decay Physics Workshop, Brighton, UK

The physical motivations

Need to test stability of shell structure in this region (N=126, Z=82): weakening of Z=82 when approaching drip-line ?

Presence of isomers involving high-j orbitals $\nu g_{9/2}$, $\nu i_{11/2}$, $\nu j_{15/2}$. Taking advantage of these isomers we want to study the developmet of nuclear structure from ^{212}Pb up to ^{220}Pb and nearby nuclei

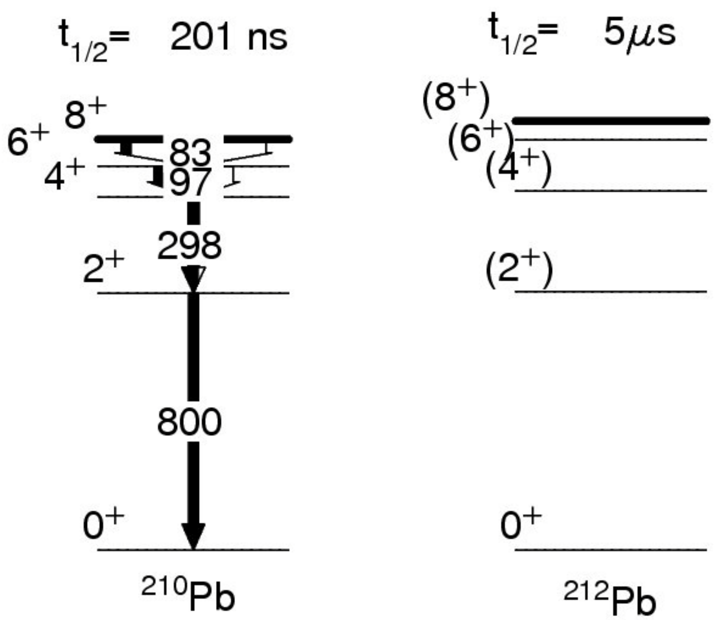
Beta-decay half-lives for the r-process

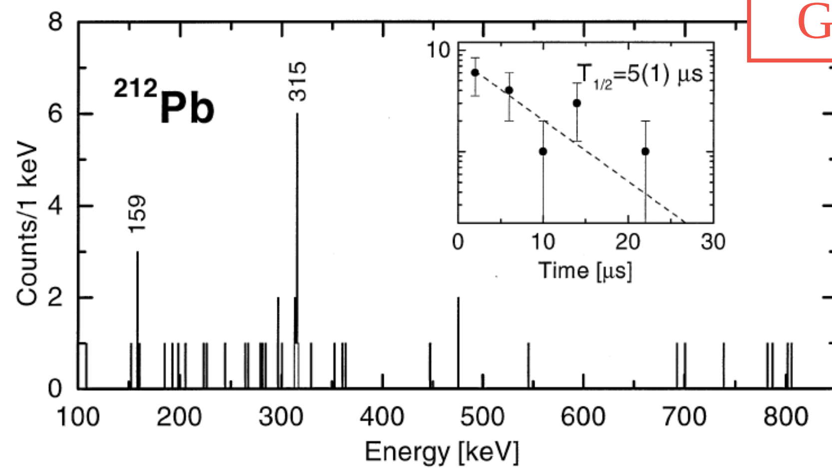


I.N. Borzov PRC67, 025802 (2003)

- Experimental β-decay data needed around ^{208}Pb to validate theoretical models.
- β-lifetimes needed r-process calculations.
- Last lifetime measured for ^{215}Pb

The experimental challanges





GSI

- 5×10^6 pps
- 2 HPGe detectors (Eff_{γ}=1%)
- 350 ions implanted

M. Pfutzner, PLB 444 (1998) 32

	$COFRA(mb)$	Ions/hour
^{212}Pb	9.05×10^{-4}	41.60×10^3
^{214}Pb	1.84×10^{-4}	9.30×10^3
^{216}Pb	3.01×10^{-5}	1.30×10^3
^{218}Pb	3.69×10^{-6}	1.80×10^2
^{220}Pb	3.17×10^{-7}	15.0

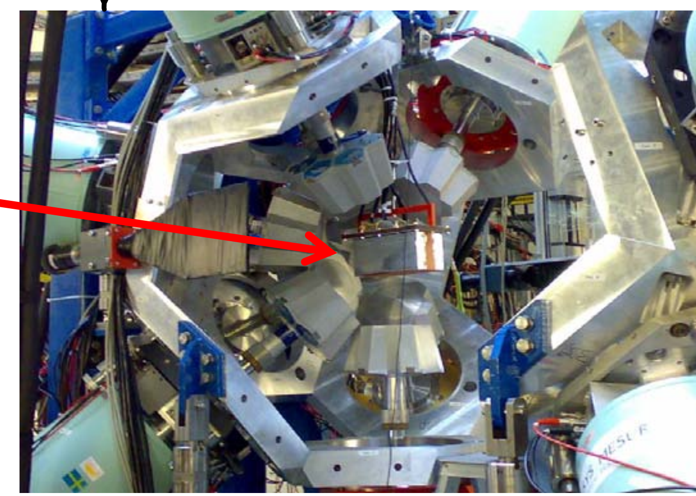
Difficult region to explore: only fragmentation possible, primary beam charge states!

The experimental setup

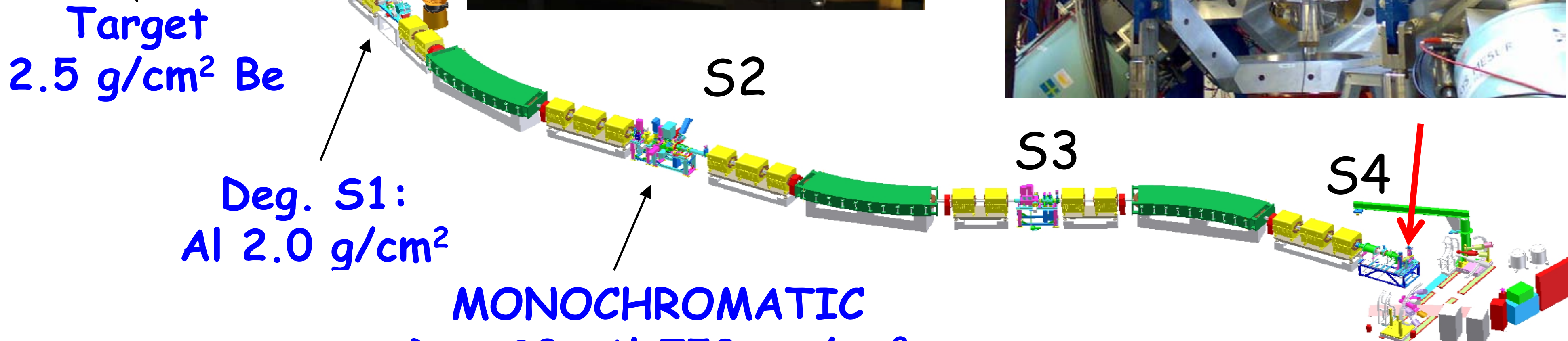
FRS-Rising at GSI: stopped beam campaign

9 DSSSD, 1mm thick, 5x5 cm^2
16x16 x-y strips

15 CLUSTERs x 7 crystals
ε_γ = 11% at 1.3MeV



Beam: ^{238}U @ 1GevA



Target
2.5 g/cm^2 Be

Deg. S1:
Al 2.0 g/cm^2

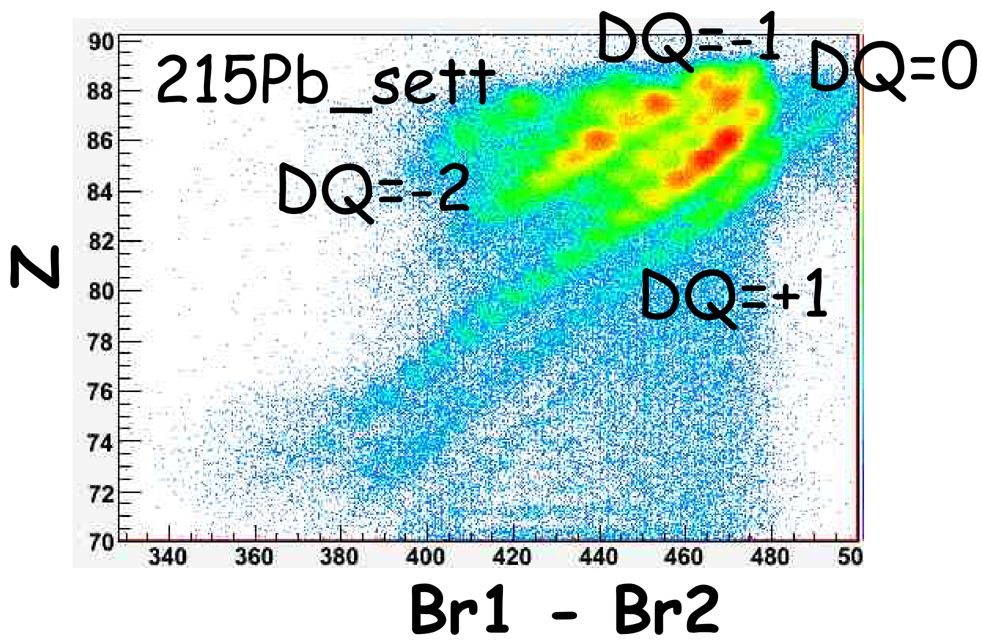
MONOCHROMATIC
Deg S2: Al 758 mg/cm^2

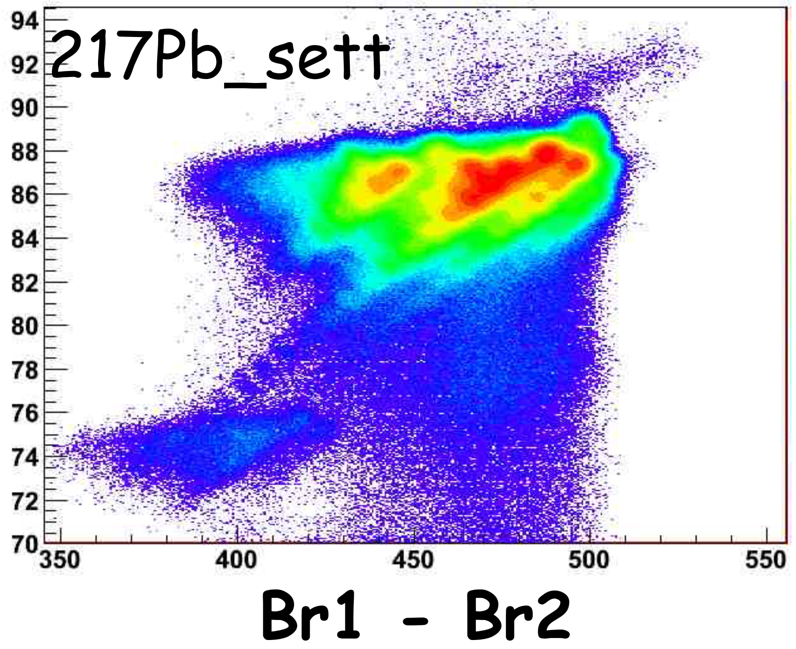
Picture courtesy of P. Boutachkov, GSI

Charged-states selection

Formation of many charge states owing to interactions with materials
➔Isotope identification is more complicated
➔ Need to disentangle nuclei that change their charge state after S2 deg.

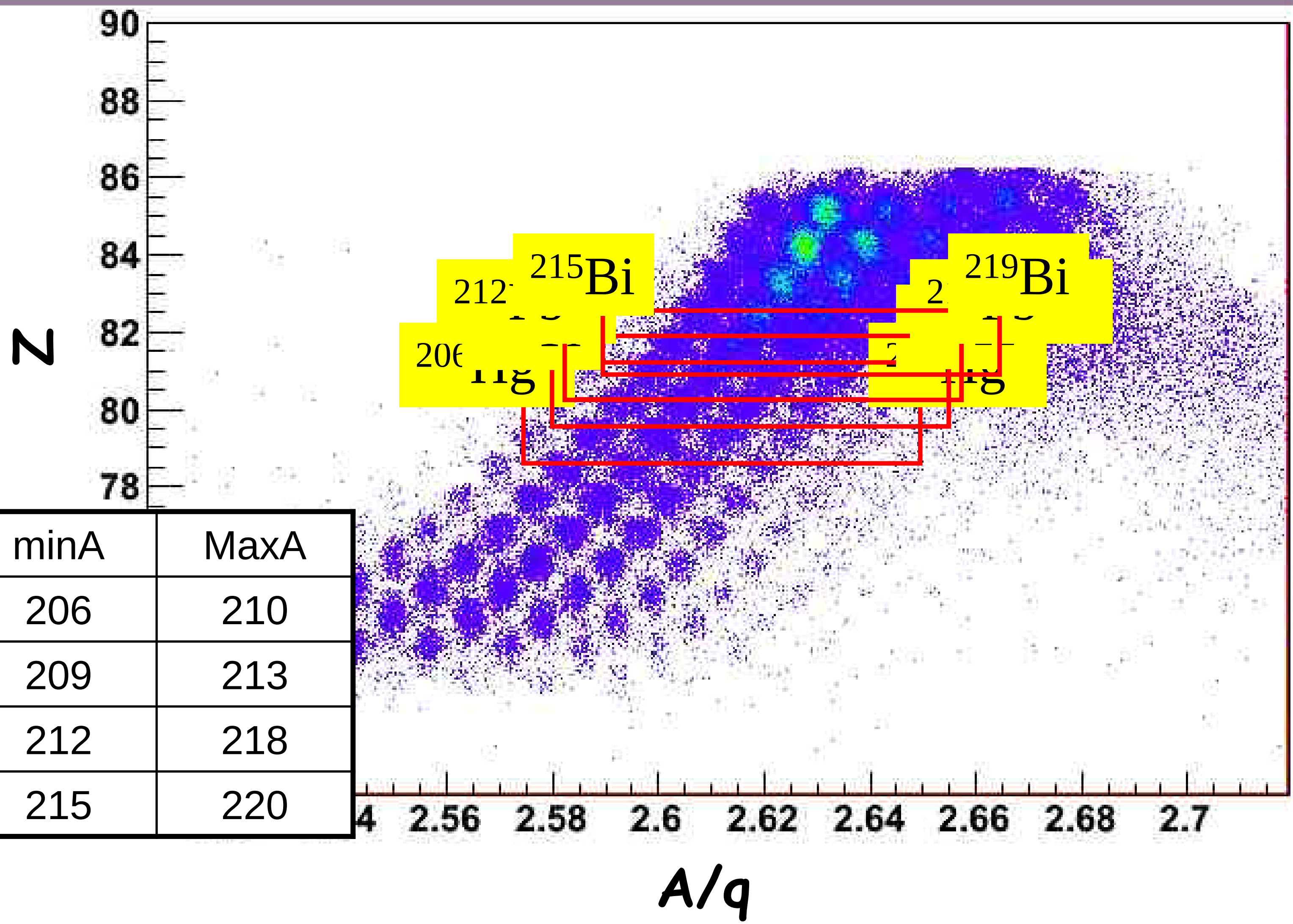
$$(Br)_{Ta\text{-}S2} - (Br)_{S2\text{-}S4}$$





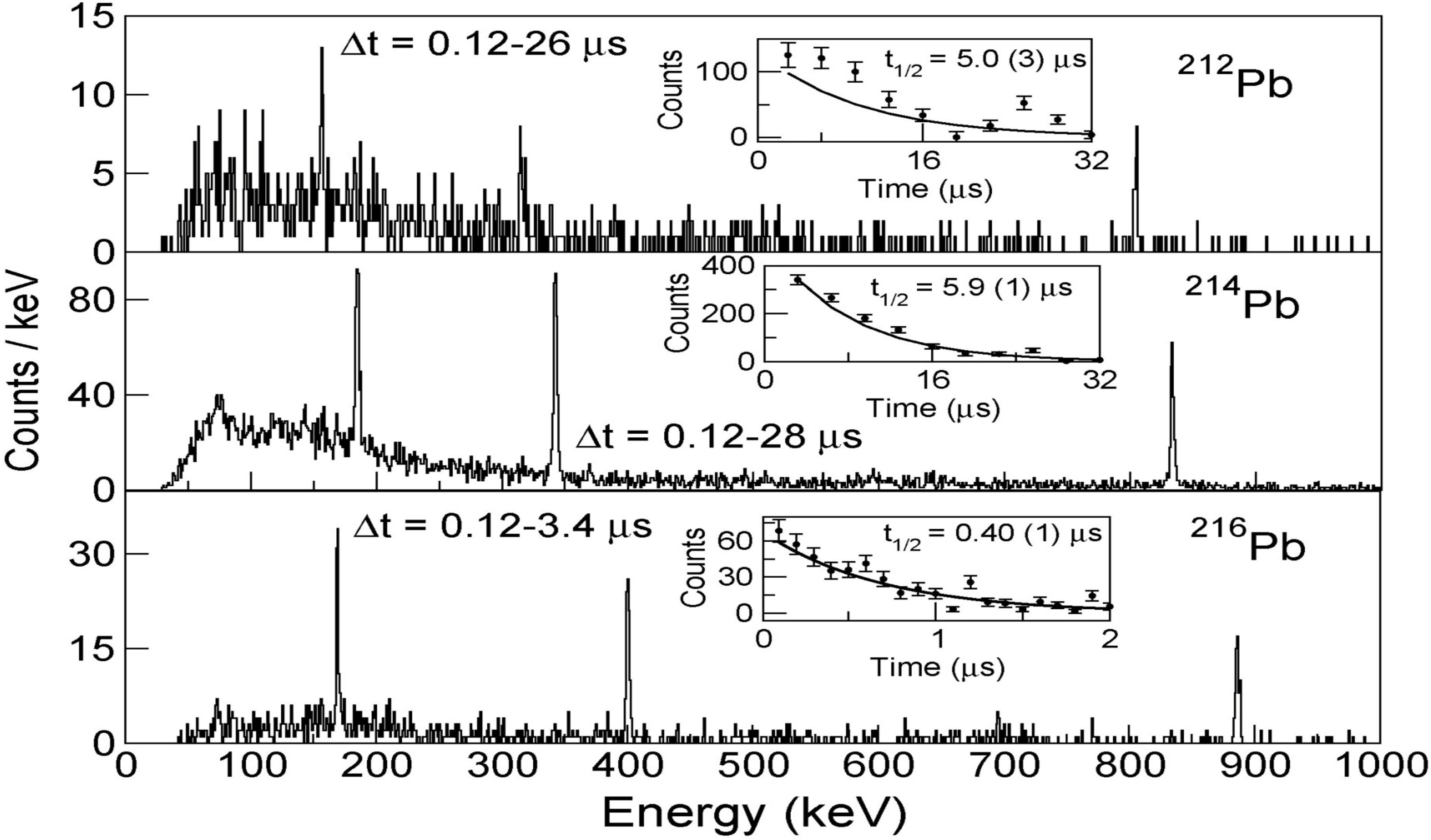
The exotic nuclei production

1 GeVA ^{238}U beam from UNILAC-SIS at 10^9 pps



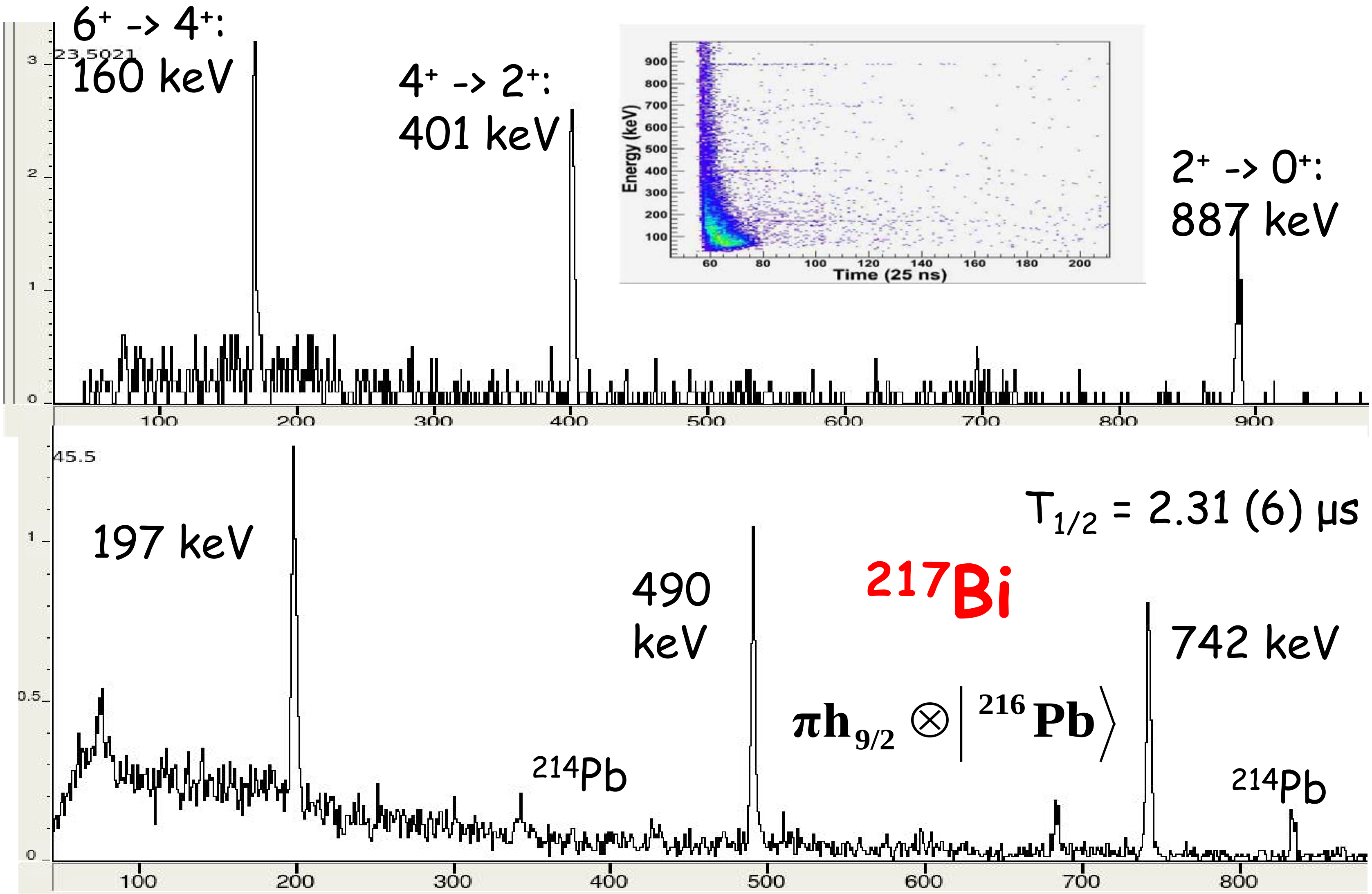
Z	minA	MaxA
80	206	210
81	209	213
82	212	218
83	215	220

$^{212,214,216}Pb$: 8^+ isomer



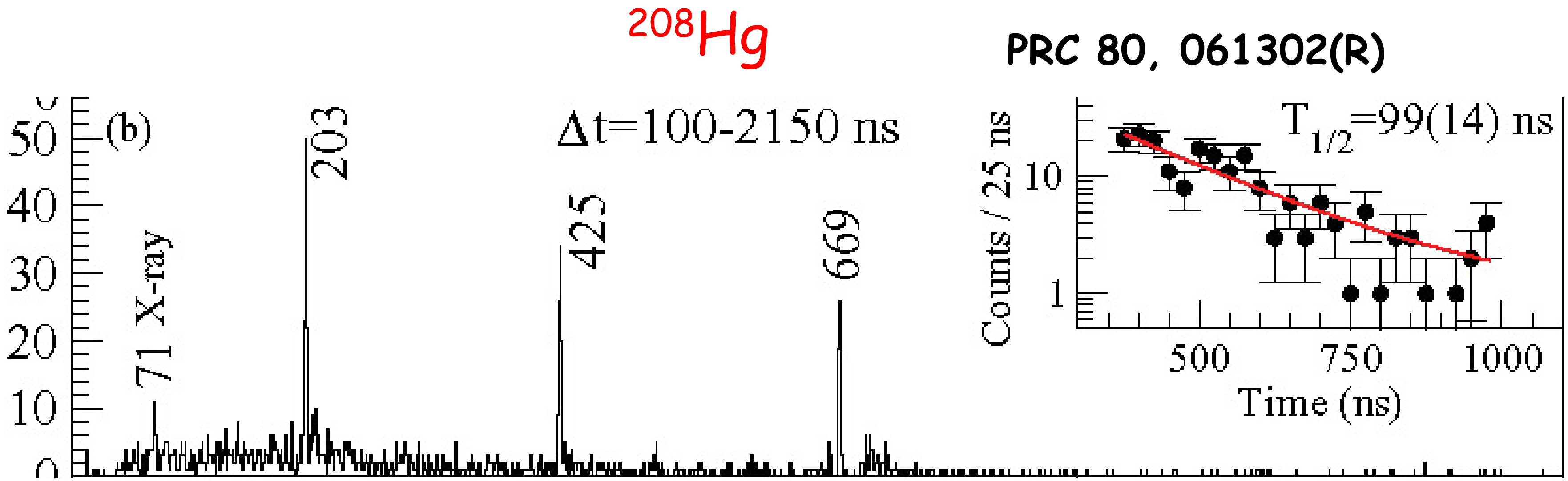
^{216}Pb : 8^+ isomer

$T_{1/2}$ = 0.40 (1) μs

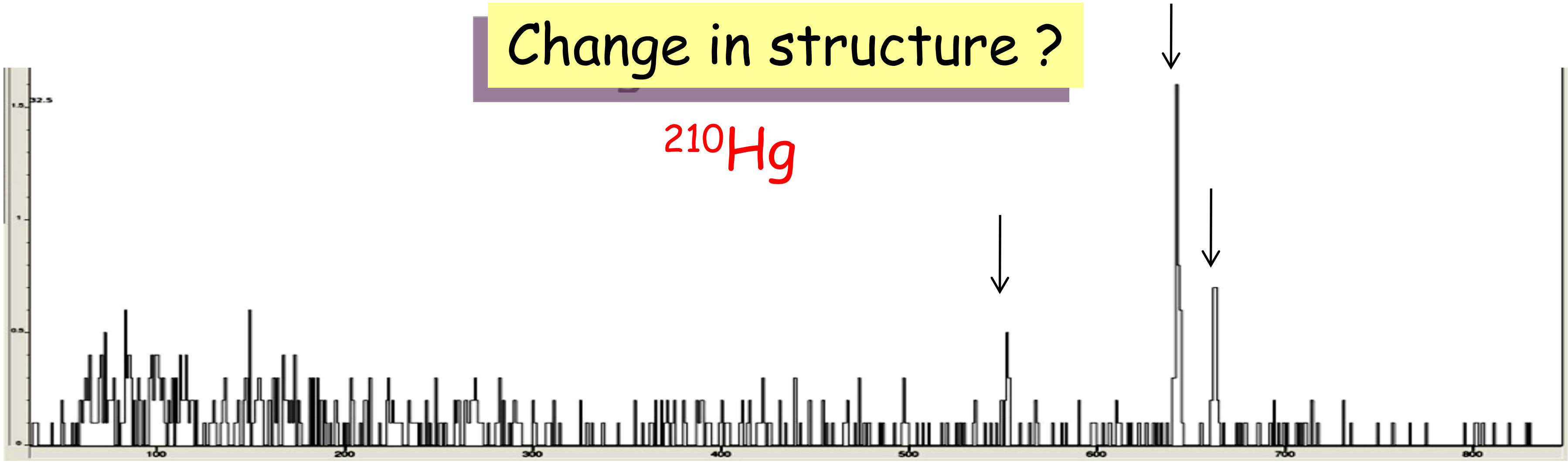


Energy (keV)

^{210}Hg isomer



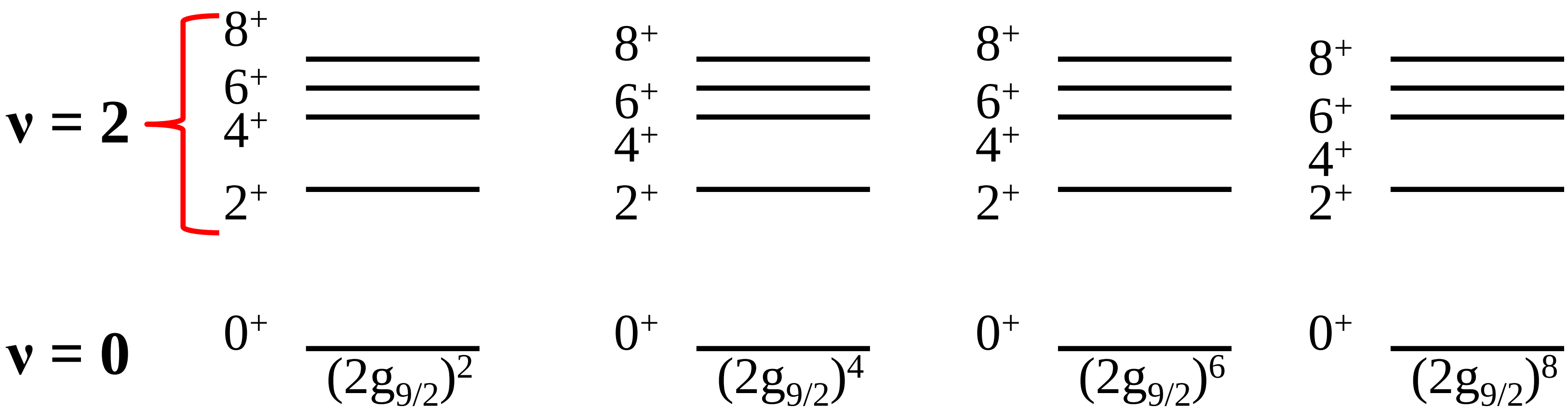
Change in structure ?



The seniority scheme

Nucleons in a valence j^n configuration behave according to a seniority scheme: the states can be labelled by their seniority ν

SENIORITY SCHEME

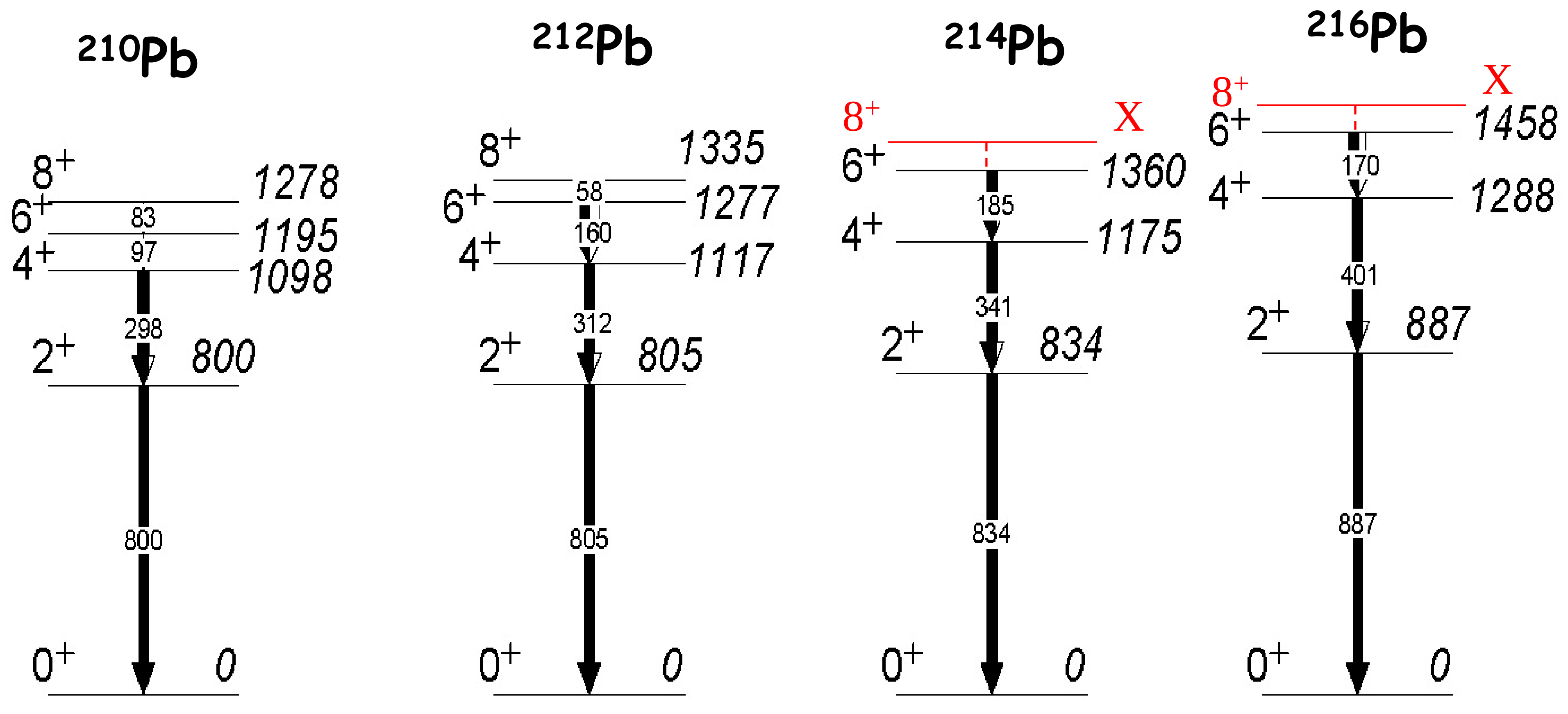


For even-even nuclei, the 0^+ ground state has seniority $\nu = 0$, while the 2^+, 4^+, 6^+, 8^+ states have $\nu = 2$

In a pure seniority scheme, the relative level energies do not depend on the number of particles in the shell j

The experimental levels and the seniority scheme

The 8^+ isomer is a seniority isomer, involving neutrons in the $2g_{9/2}$



The valence space in the Kuo-Herling interaction

^{208}Pb is a doubly-magic nucleus (Z=82, N=126).

For neutron-rich Lead isotopes, the N=6 major shell is involved

PRC 43, 602 (1992)

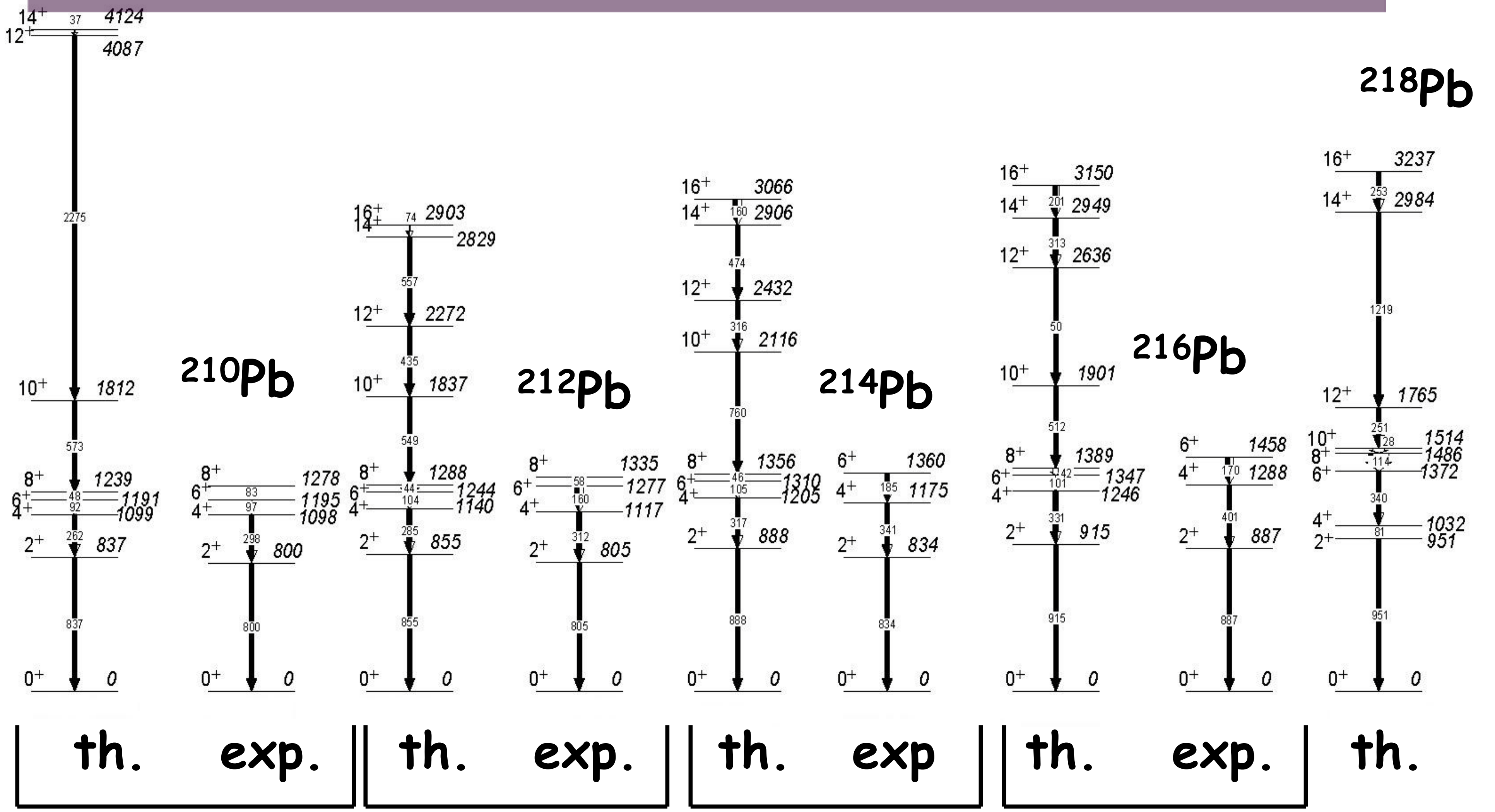
N=184

S.p. energies (MeV)	Shells	
-1.40	$3d_{3/2}$	
-1.45	$2g_{7/2}$	
-1.90	$4s_{1/2}$	
-2.37	$3d_{5/2}$	
-2.51	$1j_{15/2}$	N=7 major shell
-3.16	$1i_{11/2}$	
-3.94	$2g_{9/2}$	

N=126

Shell model calculations with K-H

Calculations with Antoine code and K-H interaction



Wave functions with K-H int.

The neutron $2g_{9/2}$ shell has a dominant role for the 8^+ isomeric state. $1i_{11/2}$, $1j_{15/2}$ and $3d_{5/2}$ also play a role

<u>8^+ state wave functions: occupational numbers show quite pure wave functions</u>

	^{210}Pb n = 2	^{212}Pb n = 4	^{214}Pb n = 6	^{216}Pb n = 8	^{218}Pb n = 10
$2g_{9/2}$	1.99	3.39	4.78	6.21	6.96
$1i_{11/2}$	0.005	0.33	0.68	1.04	2.16
$1j_{15/2}$	0.002	0.16	0.32	0.43	0.59
$3d_{5/2}$	0.0008	0.04	0.08	0.11	0.14

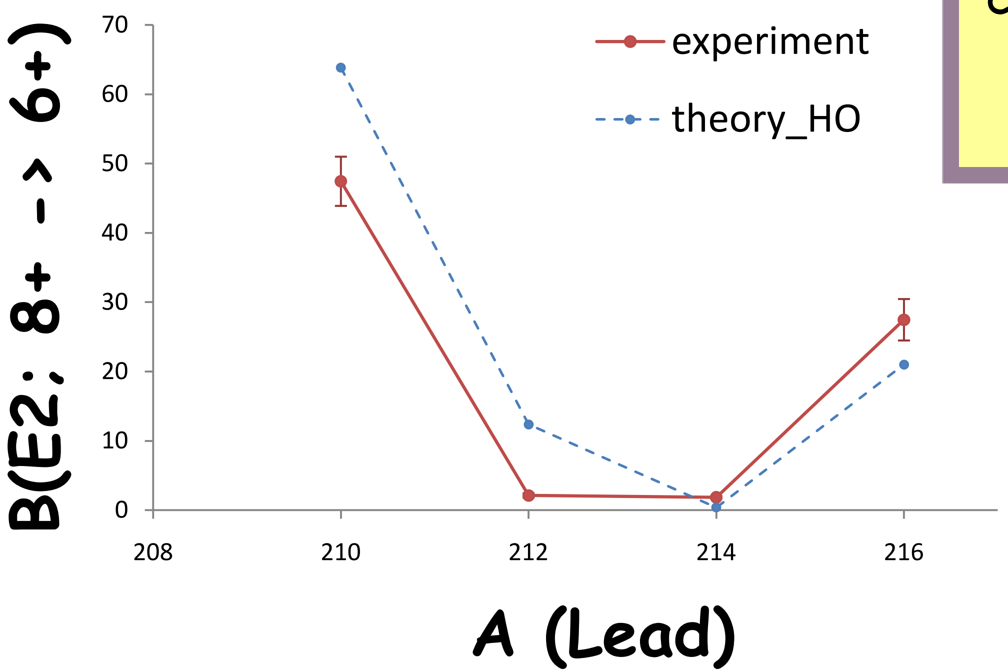
Occupational numbers

The ground state wave functions are in general more fragmented, with the $1i_{11/2}$ shell around 25 - 30 %

Isomer lifetimes and B(E2)

Preliminary results on B(E2) estimations. Theoretical values are using an effective charge of 1 for neutrons.

^{210}Pb	^{212}Pb	^{214}Pb	^{216}Pb
$T_{1/2}$ = 0.20 (2) μs	$T_{1/2}$ = 5.0 (3) μs	$T_{1/2}$ = 5.9 (1) μs	$T_{1/2}$ = 0.40 (1) μs



B(E2) calculated considering internal conversion coefficients, and a 20-80 keV energy interval for unknown transitions.

There are large discrepancies!

Isomer lifetimes and B(E2)

	^{210}Pb	^{212}Pb	^{214}Pb	^{216}Pb
B(E2) e^2fm^4 Experiment	47(4)	2.1(3)	1.66-2.4	24.7-30.5
B(E2) e^2fm^4 Theory	64	12.4	0.4	25.7

Pure seniority scheme for $g_{9/2}$:   9 : 1 : 1 : 9

PLB 606, 34 (2005) ???

The results are roughly indipendent of the interaction used: K-H, CD-Bonn, Delta, Gaussian

One possibility is the mixing of states (6+) with seniority 4: need to modify the interaction (pairing, 3-body ?)

Another possibility is the inclusion of 2p-2h excitations from the N=126 core

B.A. Brown *et al.* PLB 695, 507 (2011)

Conclusions

1- The neutron-rich region along Z = 82 was populated, enabling to study the nuclear structure in this region

2- The observed shell structure seems to follow a seniority scheme…

However, a closer look reveals that the B(E2) values have an unexpected behaviour

3 –The observed transitions in ^{210}Hg suggest a significant change in structure

Future: more exotic nuclei in this region, GSI very competitive

Collaboration (Rising)

A. Gottardo, J.J. Valiente-Dobon, G. Benzoni, R. Nicolini,
A. Bracco, G. de Angelis, F.C.L. Crespi,F. Camera, A. Corsi, S. Leoni, B. Million, O. Wieland, D.R. Napoli, E. Sahin, S.Lunardi,R. Menegazzo, D. Mengoni, F. Recchia, P. Boutachkov, L. Cortes, C. Domingo-Prado,F. Farinon, H. Geissel, J. Gerl, N. Goel, M. Gorska, J. Grebosz, E. Gregor, T.Haberman,I. Kojouharov, N. Kurz, C. Nociforo, S. Pietri, A. Prochazka, W.Prokopowicz, H. Schaffner,A. Sharma, H. Weick, H-J.Wollersheim, A.M. Bruce, A.M. Denis Bacelar, A. Algora,A. Gadea, M. Pf¨utzner, Zs. Podolyak, N. Al-Dahan, N. Alkhomashi, M. Bowry, M. Bunce,A. Deo, G.F. Farrelly, M.W. Reed, P.H. Regan, T.P.D. Swan, P.M. Walker, K. Eppinger,S. Klupp, K. Steger, J. Alcantara Nunez, Y. Ayyad, J. Benlliure, E. Casarejos,R. Janik,B. Sitar, P. Strmen, I. Szarka, M. Doncel, S.Mandal, D. Siwal, F. Naqvi,T. Pissulla,D. Rudolph,R. Hoischen,P.R.P. Allegro, R.V.Ribas,Zs. Dombradi and the **Rising collaboration**

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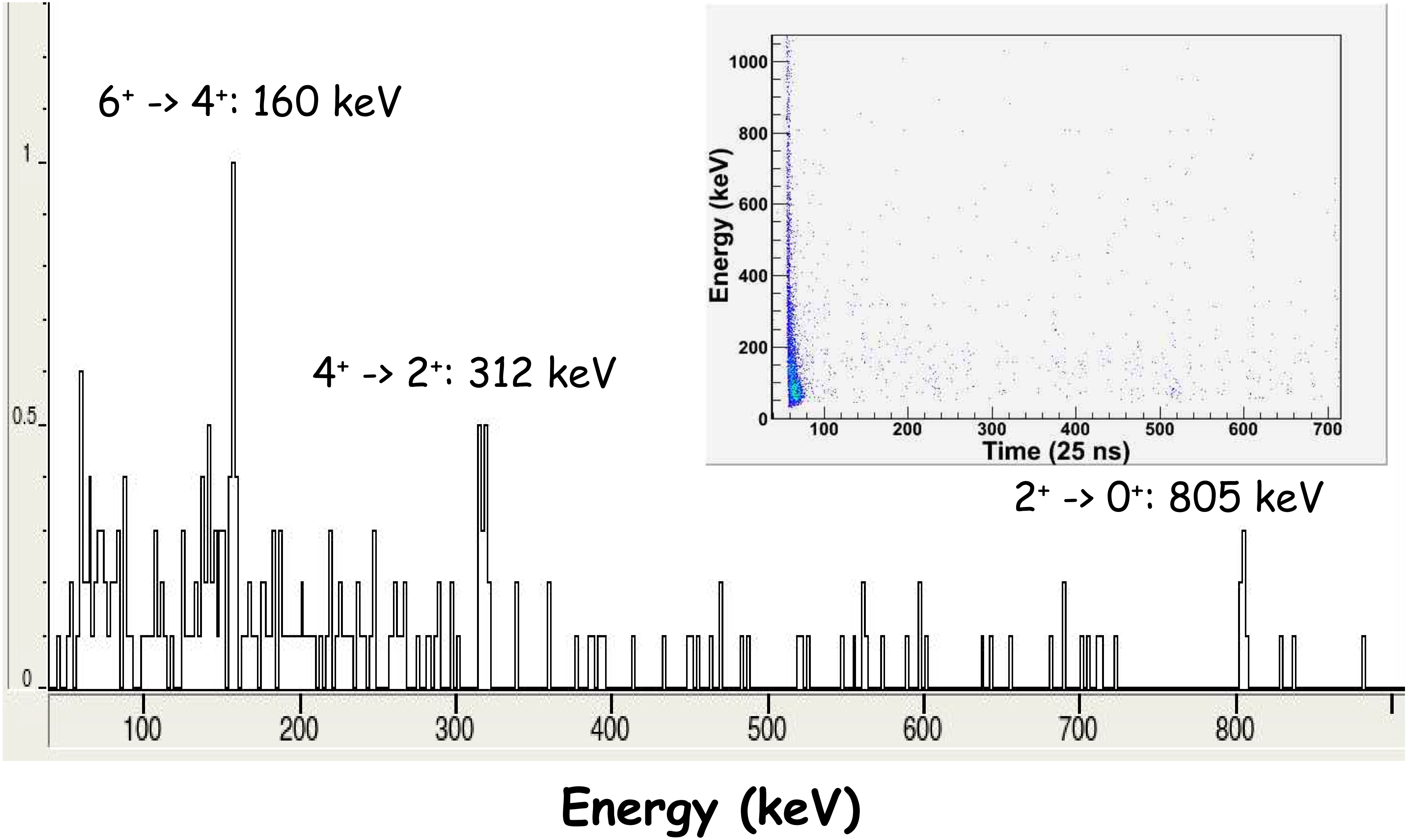
17ATOMKI, Debrecen, H.

HAPPY BIRTHDAY !

^{212}Pb: 8^+ isomer

$T_{1/2}$ = 5.0 (3) μs



^{214}Pb : 8^+ isomer

$T_{1/2}$ = 5.9 (1) μs