"Universa Universis Patavina Libertas"

Decay spectroscopy of neutron-rich lead isotopes

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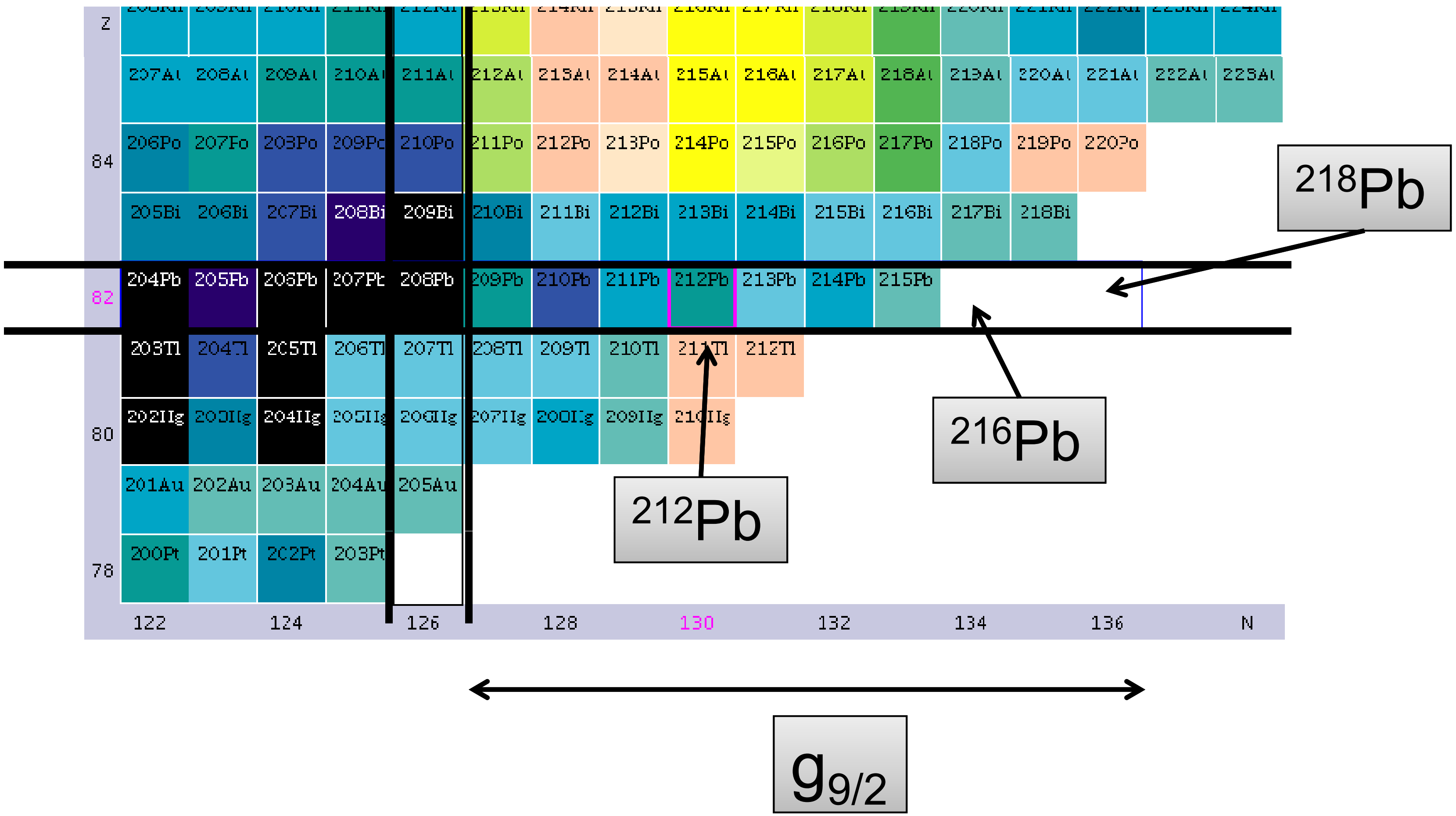
- Neutron-rich Pb nuclei beyond N=126
- Experimental setup
- Seniority Pb isomers → the B(E2) probes

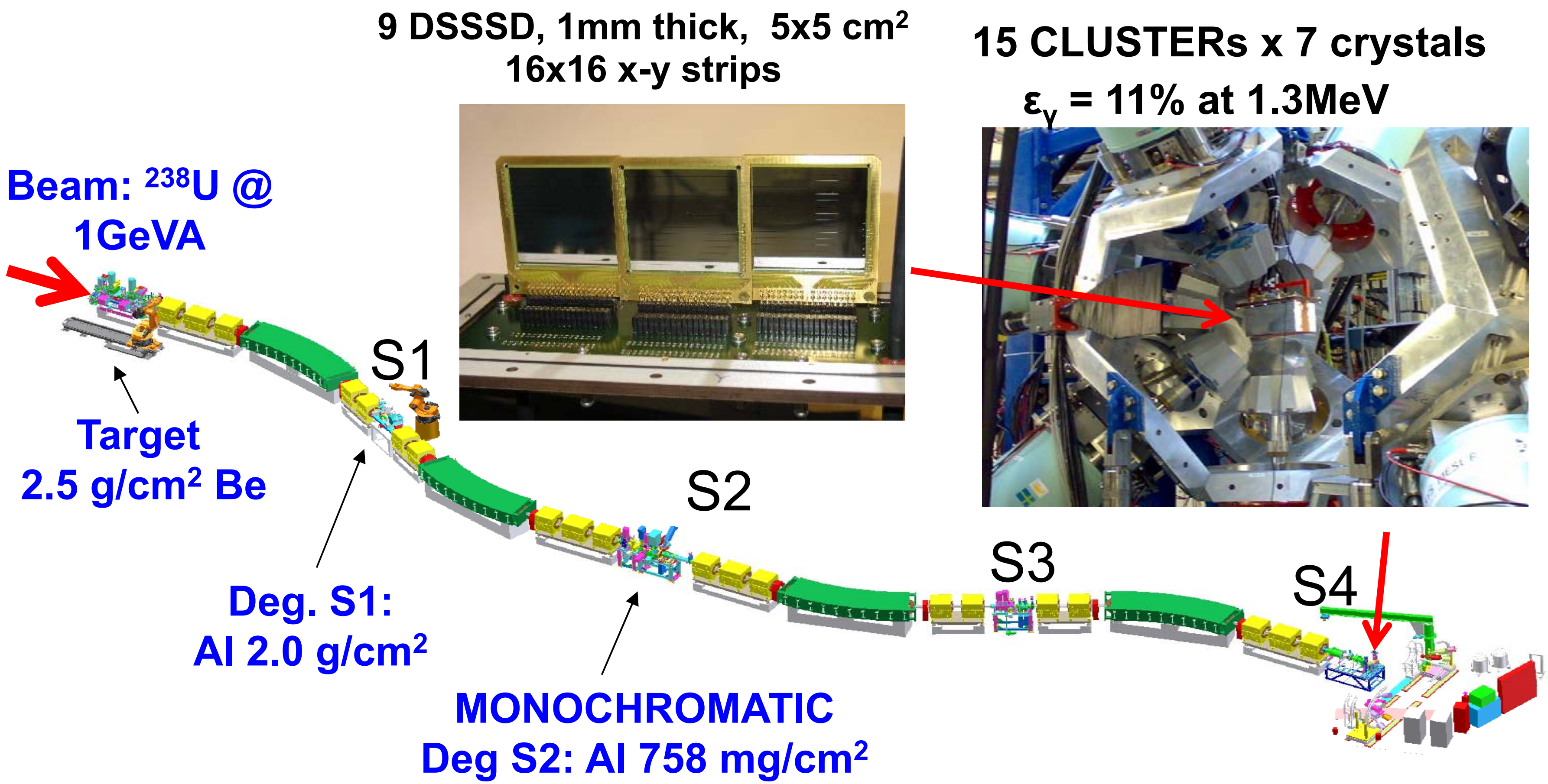
The Z=82 and beyond N=126

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

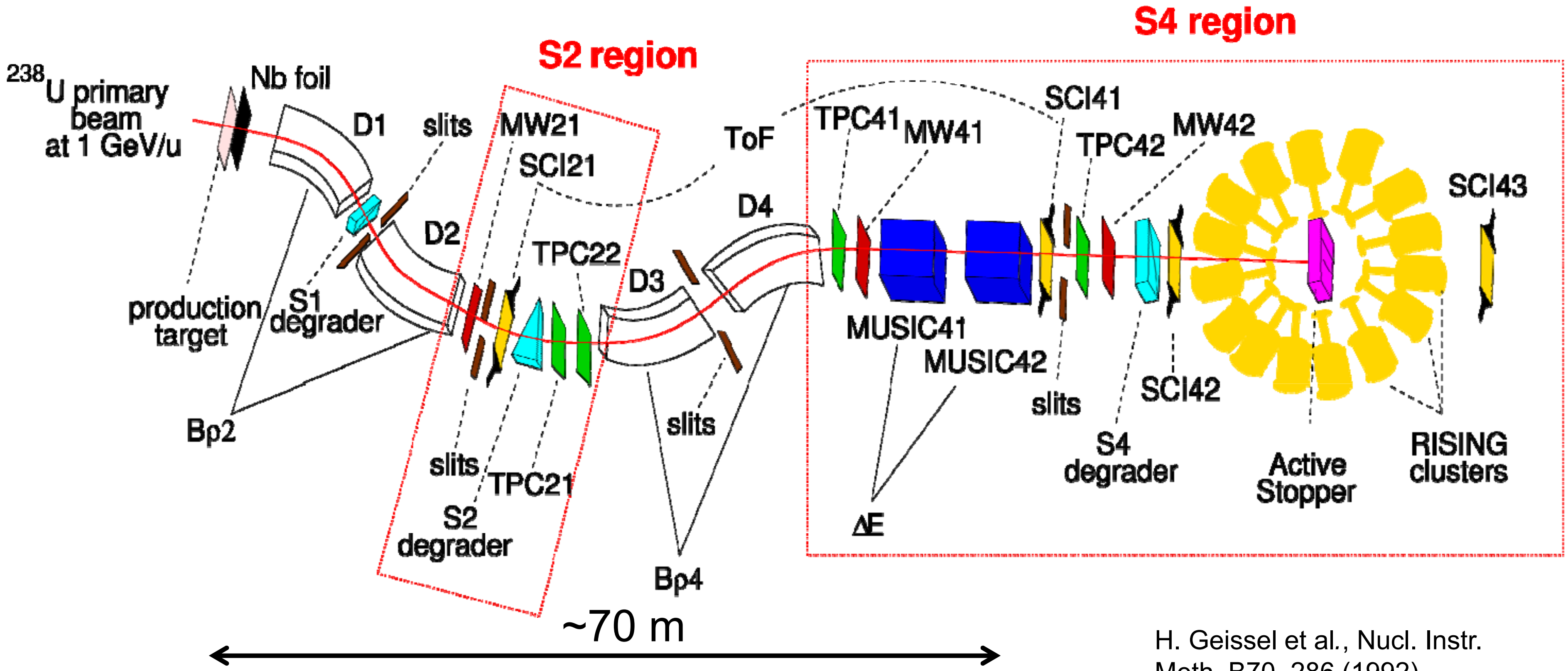


Experimental setup

FRS-Rising at GSI: stopped beam campaign



Experimental setup: FRS

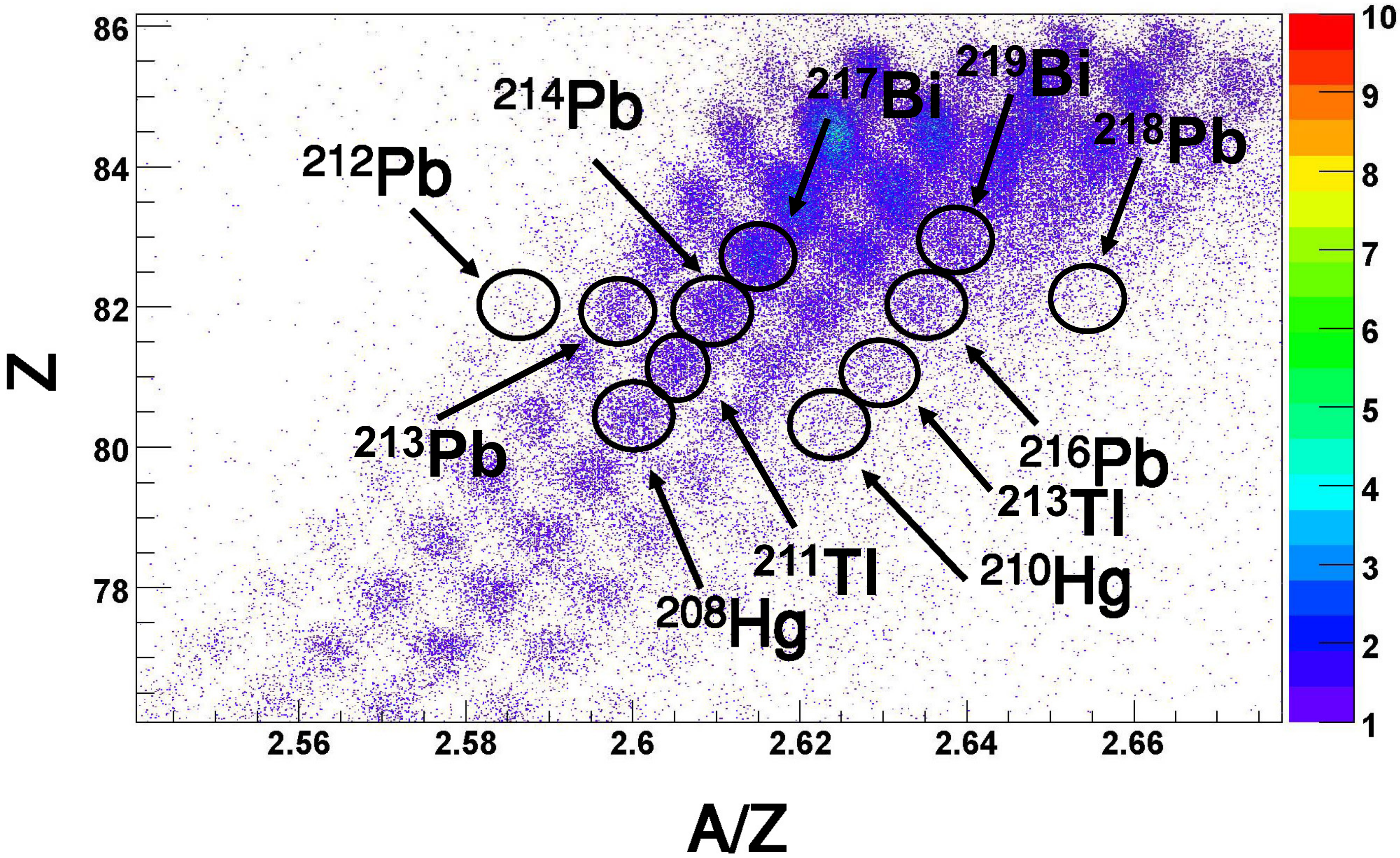


H. Geissel et al., Nucl. Instr. Meth. B70, 286 (1992)

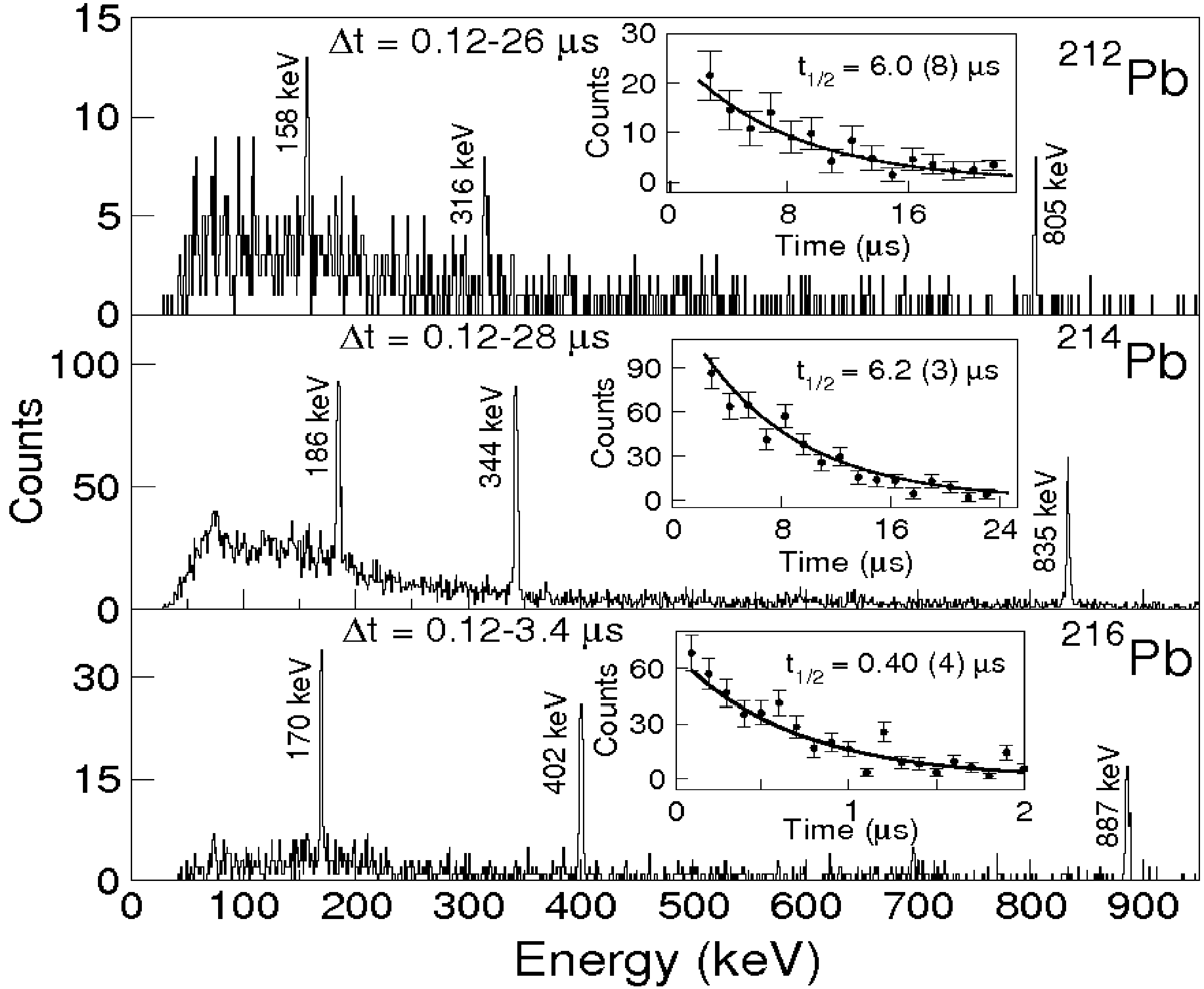
- Fragment position: TPC, MWPC, Scintillators
- Time Of Flight TOF: Scintillators
- Atomic number: MUSIC

Nuclei populated in the fragmentation

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



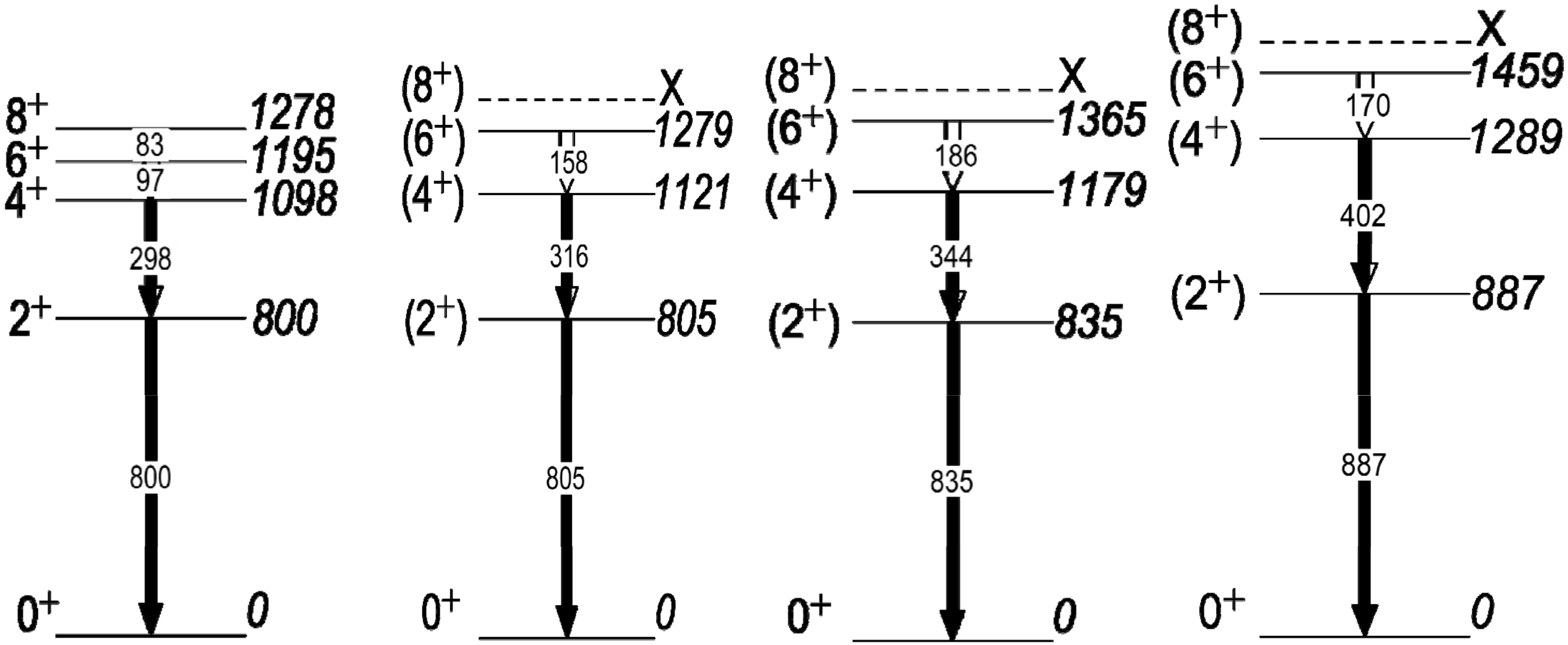
$^{212,214,216}Pb$: 8^+ isomer



Experimental level schemes

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

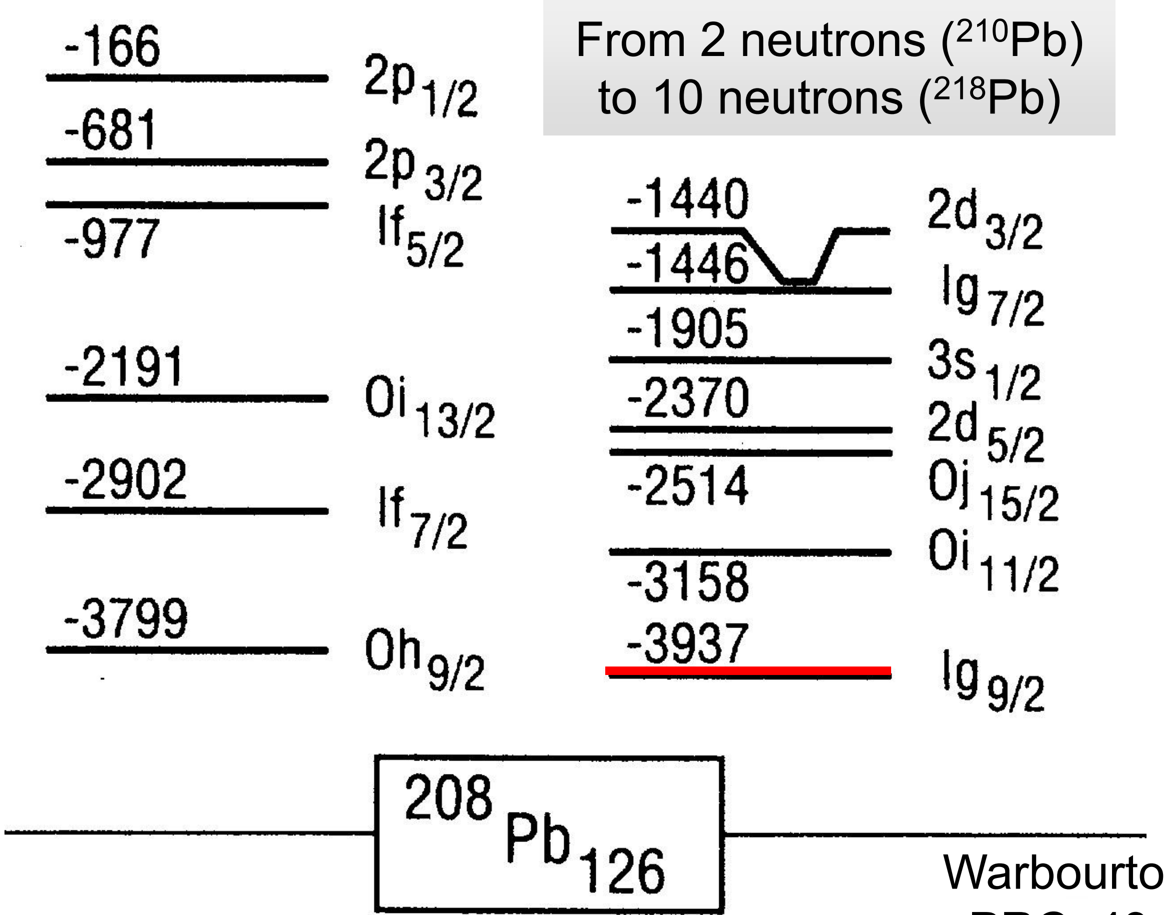
^{210}Pb	^{212}Pb	^{214}Pb	^{216}Pb
$t_{1/2}$ = 0.201(17) μs	$t_{1/2}$ = 6.0(8) μs	$t_{1/2}$ = 6.2(3) μs	$t_{1/2}$ = 0.4(4) μs



Kuo-Herling interaction: Valence space

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

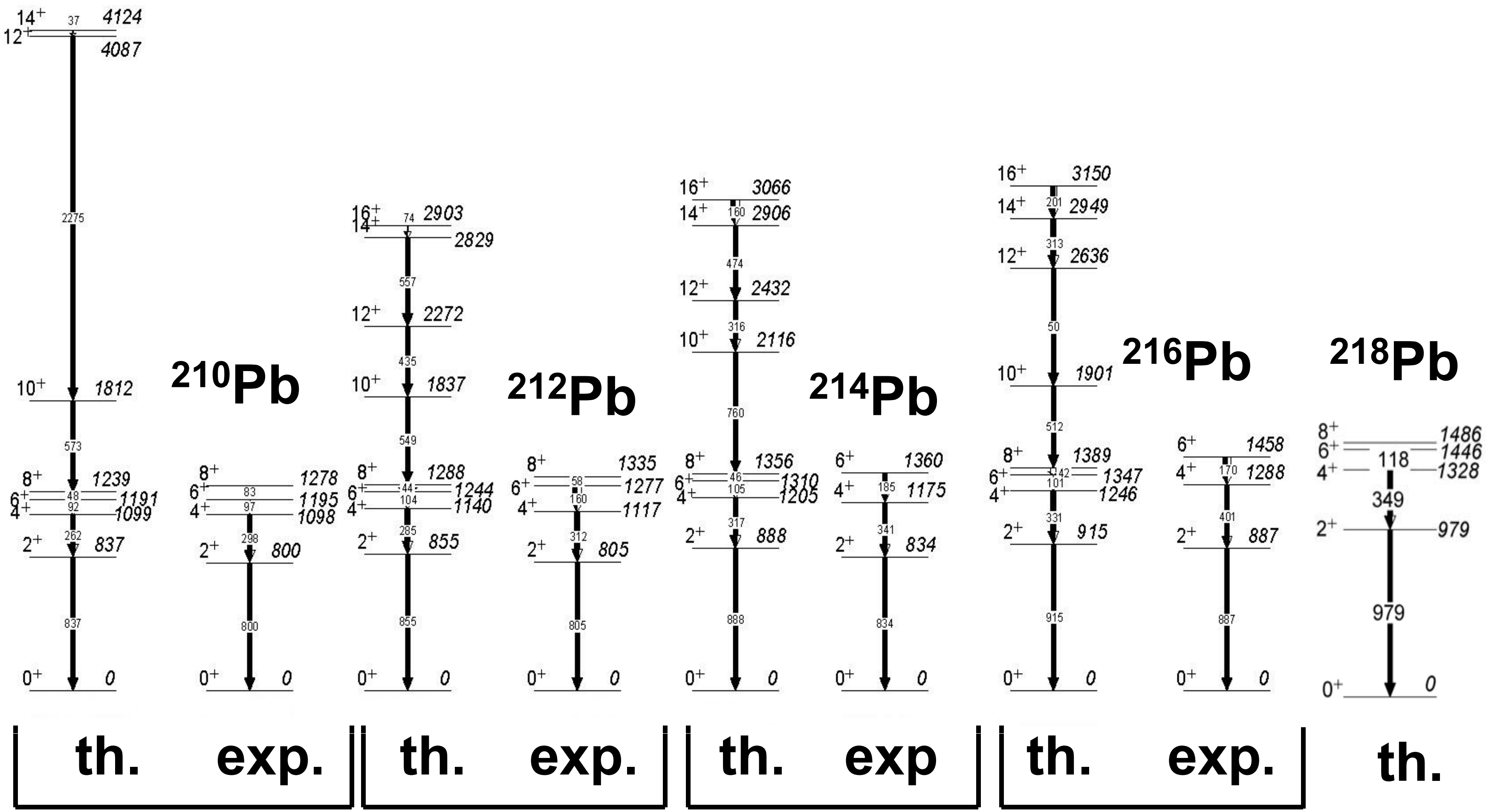
For neutron-rich Lead isotopes, the N=6 major shell is involved



Warbourton and Brown
PRC 43, 602 (1992)

Shell Model calculations Kuo-Herling

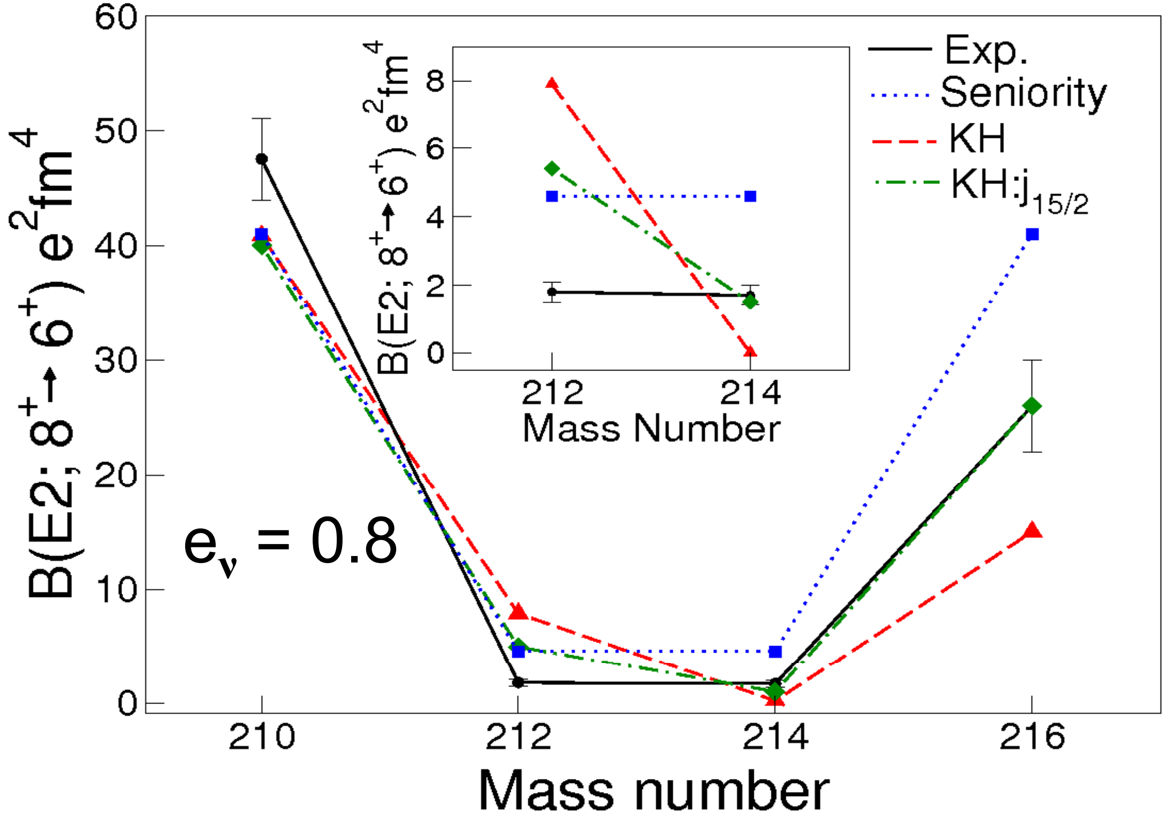
Calculations with Antoine and Nathan codes and K-H interaction



Reduced transition prob. B(E2)

B(E2) calculated considering internal conversion coefficients, and a 20-90 keV energy interval for unknown transitions.

	^{210}Pb	^{212}Pb	^{214}Pb	^{216}Pb
Isomer $t_{1/2}$ (μs)	**0.20 (2)**	**6.0 (8)**	**6.2 (3)**	**0.40 (4)**
B(E2) e^2fm^4 Exp.	**47(4)**	**1.8(3)**	**1.4-1.9**	**24.7-30.5**
B(E2) e^2fm^4 KH	**41**	**8**	**0.26**	**16.4**



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

9 : 1 : 1 : 9

Large discrepancies:
- Seniority scheme
- Shell model KH

PLB 606, 34 (2005) ?

Origin of discrepancies

- The results are roughly independent of the interaction used: KH, CD-Bonn, Delta, Gaussian
- One possibility is the mixing of states 6^+ with different seniorites, but requires too large change of the realistic interaction
- Problems with $g_{9/2}$ seniority isomers also for the first $g_{9/2}$ (^{72}Ni, ^{98}Cd), attributed to seniority mixing or dripline

Need to introduce state-dependent effective charges ?

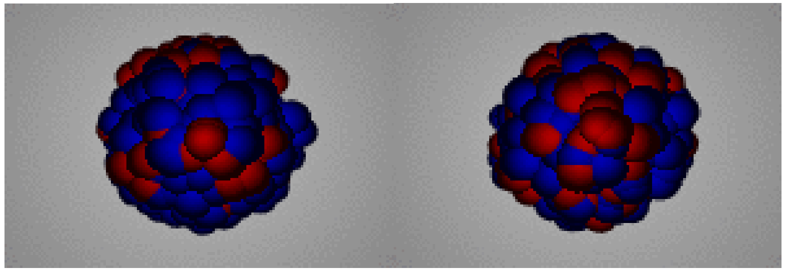
Maybe NO : caution when using renormalized interactions!

Effective three-body forces (I)

When an interaction is adapted to a model space, it has to be RENORMALISED

The renormalisation takes into account the coupling to the core excitation modes, as the giant quadrupole resonance

Isoscalar



Isovector

Bohr and Mottleson, Nuclear Structure (1975)

⇒ Constant effective charges $e_\nu \sim 0.5e$, $e_\pi \sim 1.5e$

Dufour and Zuker PRC 54, 1641 (1996)

BUT the two-body renormalised hamiltonian also includes three-body terms already at the lower orders!

Poves and Zuker, Phys Rep. 71, 141 (1981)

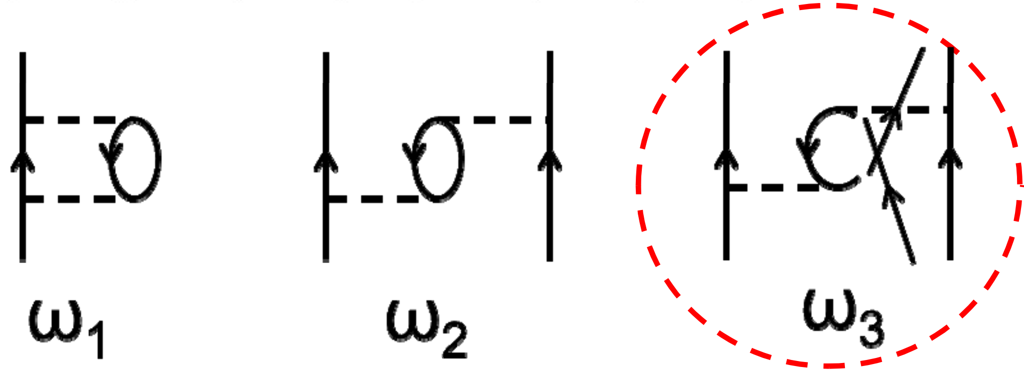
Poves et al., Phys. Lett. B82, 319 (1979)

Effective three-body forces (II)

The hamiltonian matrix elements are determined as:

$$\langle \overline{\overline{f^n i}} | H | \overline{\overline{f^n i'}} \rangle = \langle f^n i | H | f^n i' \rangle + \langle f^n i | \omega_1 + \omega_2 + \omega_3 | f^n i' \rangle$$

where:



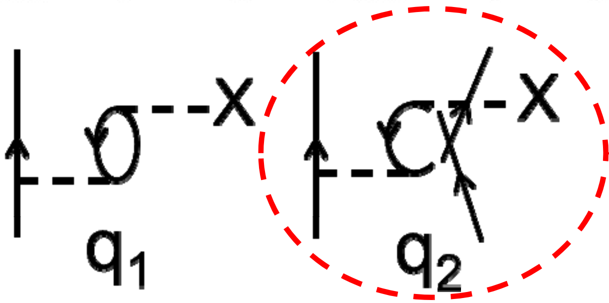
One body **Two body** **Three body**

Usually neglected!

Same calculations for transition operators (e.g. electric quadrupole)

$$\langle \overline{\overline{f^n i}} | Q | \overline{\overline{f^n i'}} \rangle = \langle f^n i | Q | f^n i' \rangle + \langle f^n i | q_1 + q_2 | f^n i' \rangle$$

where:



One body **Two body**

Usually neglected!

Poves and Zuker, Phys Rep. 71, 141 (1981)

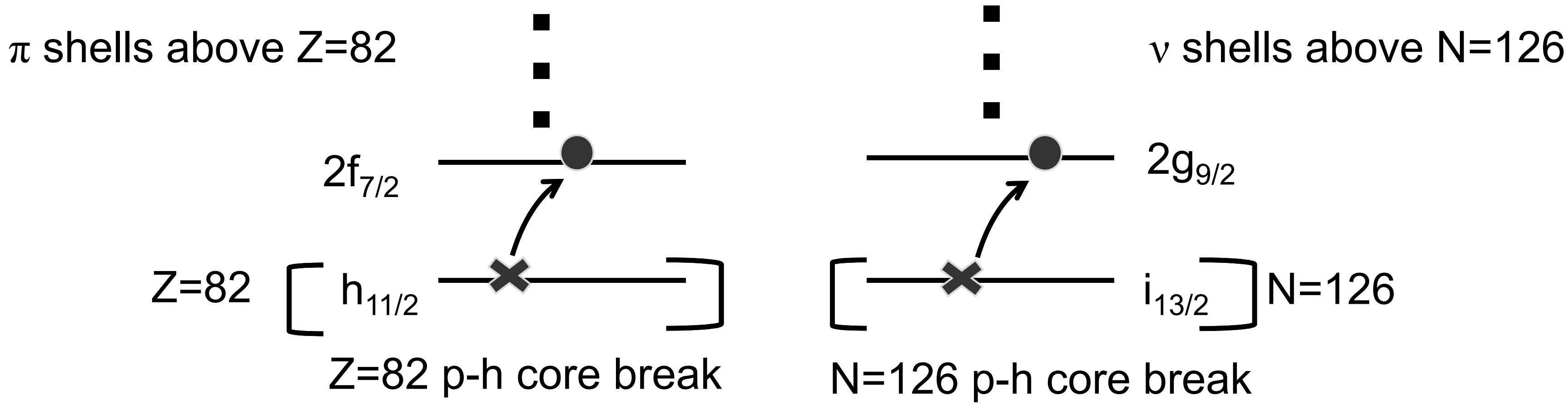
Poves et al., Phys. Lett. B82, 319 (1979)

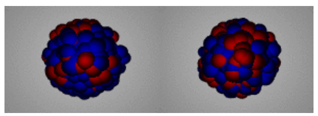
Effective three-body forces (III)

Effective 3-body terms appear naturally in the renormalization process, but they are **NOT** included in shell-model codes (ANTOINE and NATHAN):

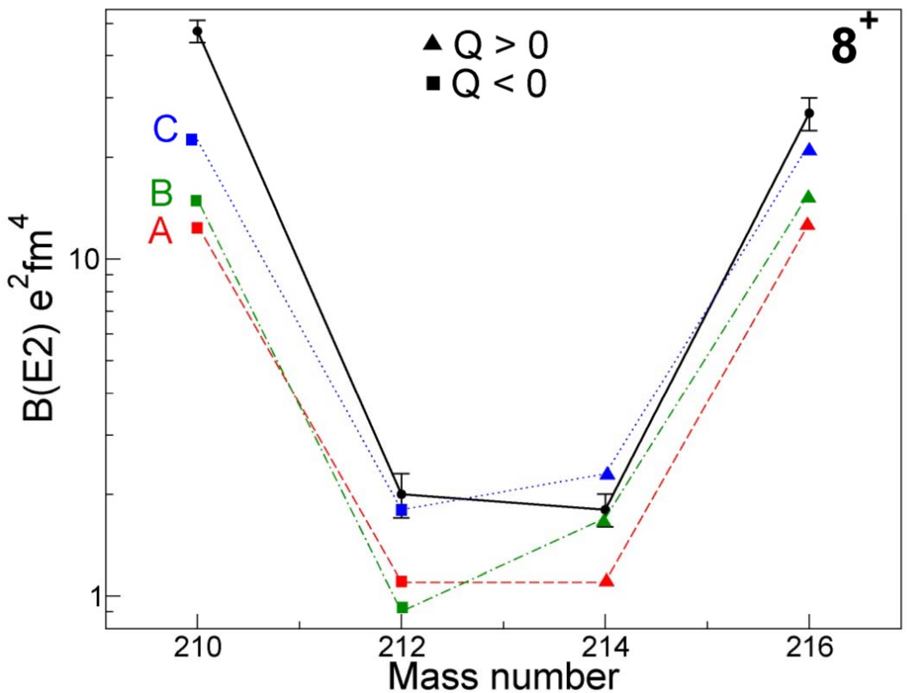
- Two-body operators (H) become effective 3-body operators
- One-body transition operators (B(E2)) become effective 2-body operators

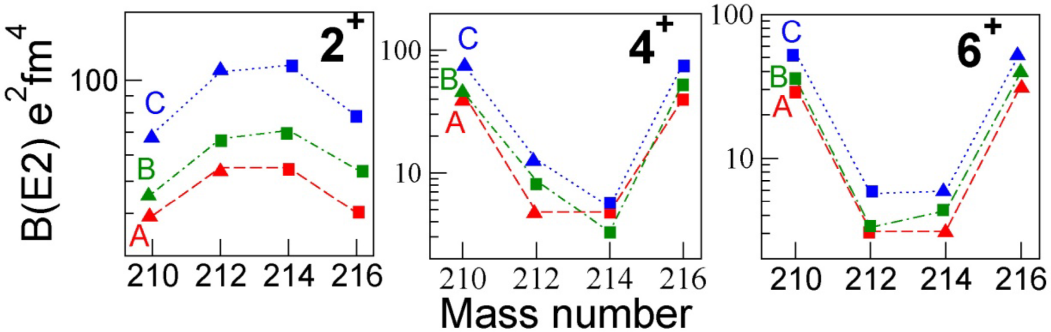
The only way to include these terms in a standard shell-model calculation is to diagonalize using the dressed wave function



GQR  + coupling to 2^+ (and 3^-) excitations from the core

Effective 3-body interaction: results





Exp. data

$g_{9/2}$

$g_{9/2}$ + ν shells above

$g_{9/2}$ + ν shells above + core exc.

Standard eff. charges:

$e_\nu = 0.5$, $e_\pi = 1.5$

The explicit coupling to the core restores a seniority-like behaviour

The restoring of particle-hole conjugation symmetry also for the other shells strengthens the result

Conclusions

- Experiment with radioactive beam, with the in-flight technique. Several experimental challenges overcome. State-of-the-art experimental devices.
- The neutron-rich region along Z = 82 was populated, enabling to study the nuclear structure in this region up to now unknown due to experimental difficulties
- The observed shell structure seems to follow a seniority scheme. However, a closer look reveals that the B(E2) values have an unexpected behaviour. B(E2) values are a sensitive probe to understand in detail the features of the nuclear force The mechanism of effective 3-body forces is general, and could be relevant also for other parts of the nuclide chart (Sn?, Ni?, Cd?).
- Several isotopes (^{213}Pb, ^{210}Hg) seem to present an unexpected deviation from standard theoretical predictions.

Collaboration

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