Istituto Nazionale di Fisica Nucleare

THE HENRYK NIEWODNICZAŃSKI INSTITUTE OF NUCLEAR PHYSICS POLISH ACADEMY OF SCIENCES

Low-spin structure of ^{210}Bi investigated in cold neutron capture reaction on ^{209}Bi

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3RD EXILL WORKSHOP, JANUARY 22ND – 23RD, 2015, CSNSM ORSAY, FRANCE

Physics motivation

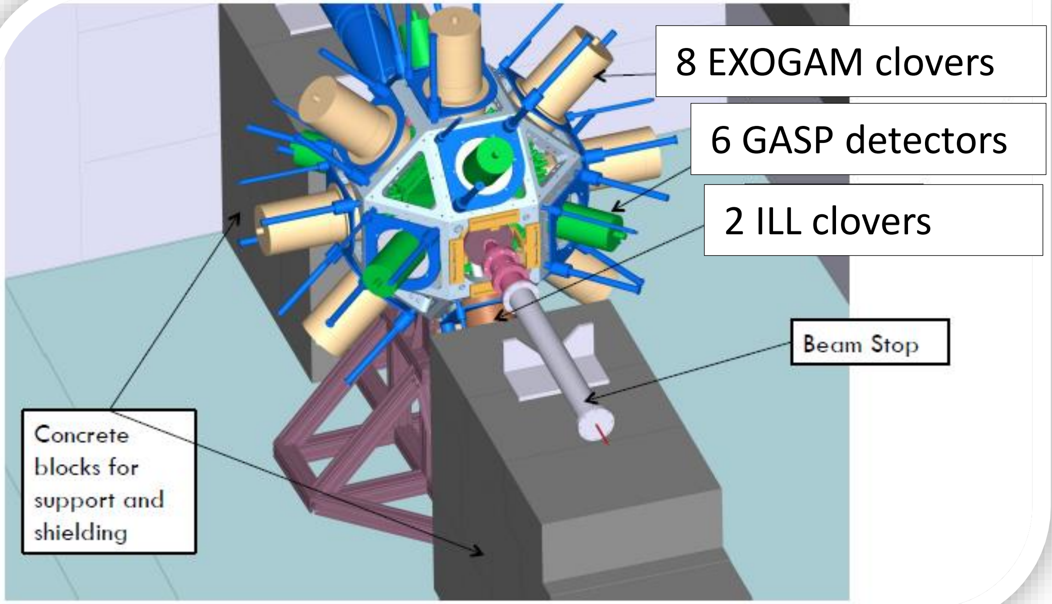
- Why the ^{210}Bi nucleus is an ideal nucleus for testing the shell-model calculations?

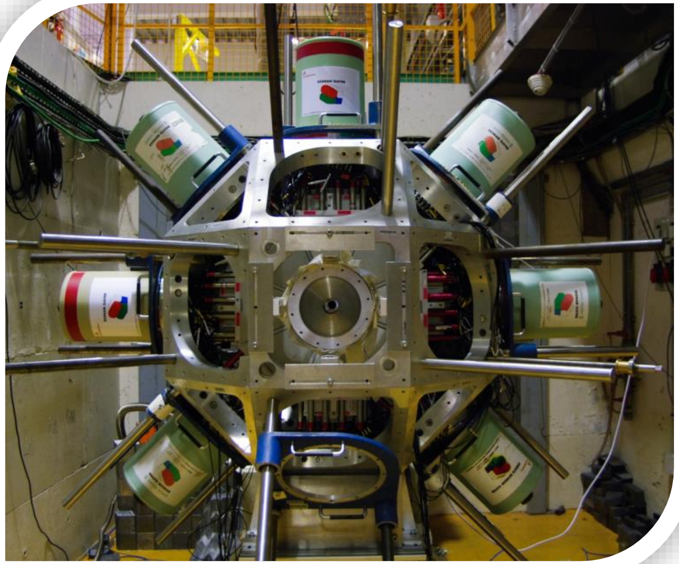
- A rich ground for comparisons with theory, also states arising from coupling of proton and neutron particles excitations to the 3^- first excited state of octupole character in doubly-magic ^{208}Pb are also expected.

- The unknown multipolarity of the main transition feeding the ground state introduced rather large uncertainties in measurements of the capture cross section to the ground state in ^{210}Bi.

- The measured lifetimes may be compared to predictions of shell-model calculations.

Experiment – ILL Grenoble (PF1B line)





16 Ge detectors of EXILL array: 8 of EXOGAM, 6 of GASP, and 2 from ILL collaboration – coincidence measurements of gamma rays

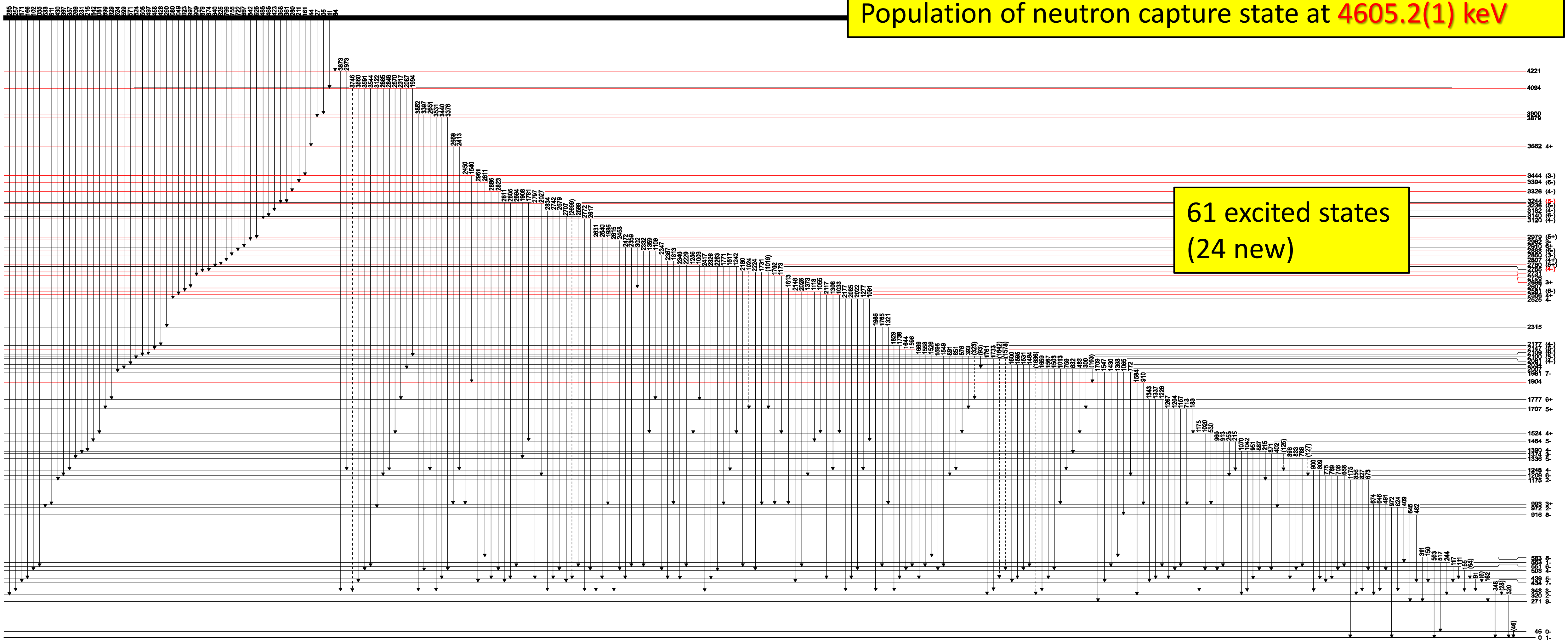
- 8 detectors of EXOGAM arranged into ring around the target at every 45° so angular correlation measurements could be performed
- Additional 4^{th} angle (60°) from GASP detectors (correction factor of 0.115261)
- Measurements of the lifetimes with FATIMA detectors

Experimental results: level scheme

55 primary transitions
(31 new)

Population of neutron capture state at 4605.2(1) keV

61 excited states
(24 new)

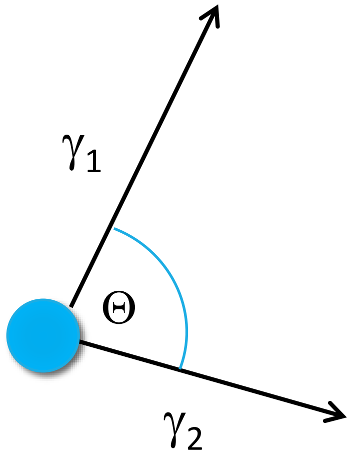


^{210}Bi

Angular correlations of γ rays from ^{210}Bi

The angular correlation function for a pair of coincident γ rays connecting the nuclear states with spins $J_i \rightarrow J \rightarrow J_f$ is usually expressed as:

$$\boldsymbol{W(\Theta) = 1 + A_2 P_2(\cos\Theta) + A_4 P_4(\cos\Theta)}$$

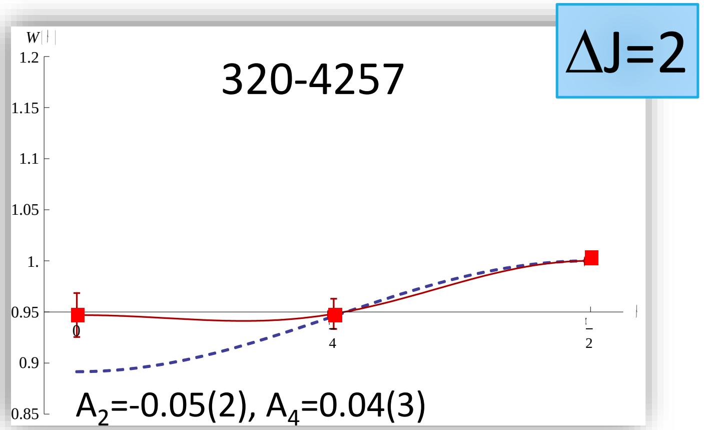


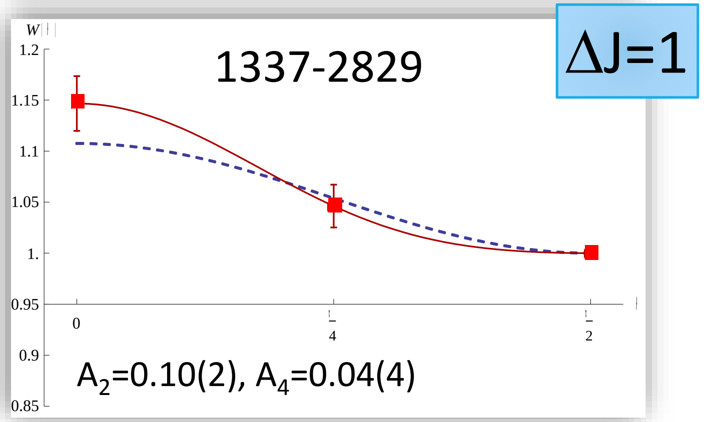
Θ – the angle between the direction of emission of two γ rays

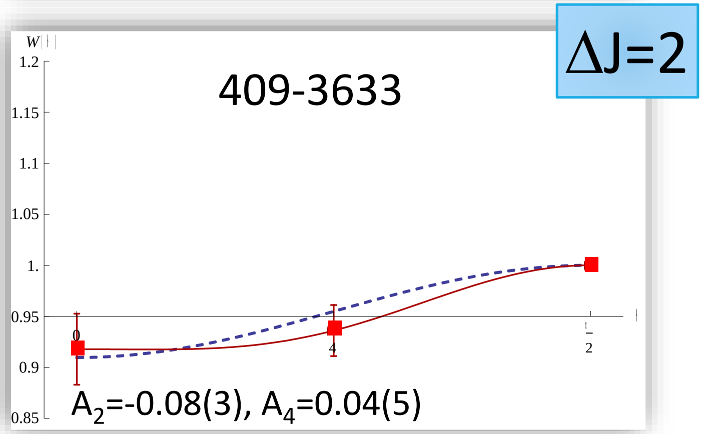
$P_n(\cos\Theta)$ –Legendre polynomials

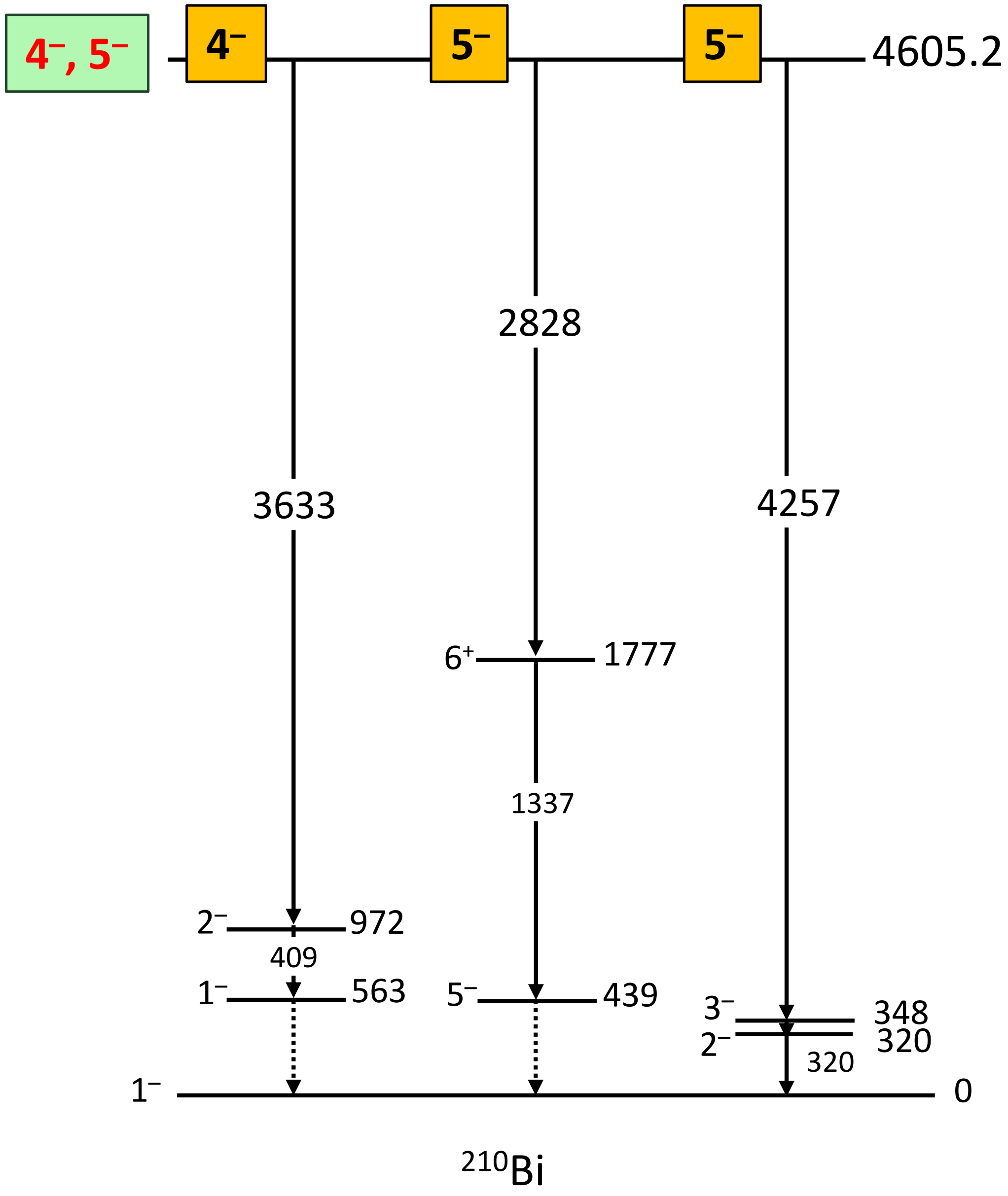
$A_n = q_n A(1) A(2)$ – the coefficients which depend on the attenuation factor q_n as well as on the multipolarities of 1 and 2 γ rays and the spins of involved nuclear states experiment

theory









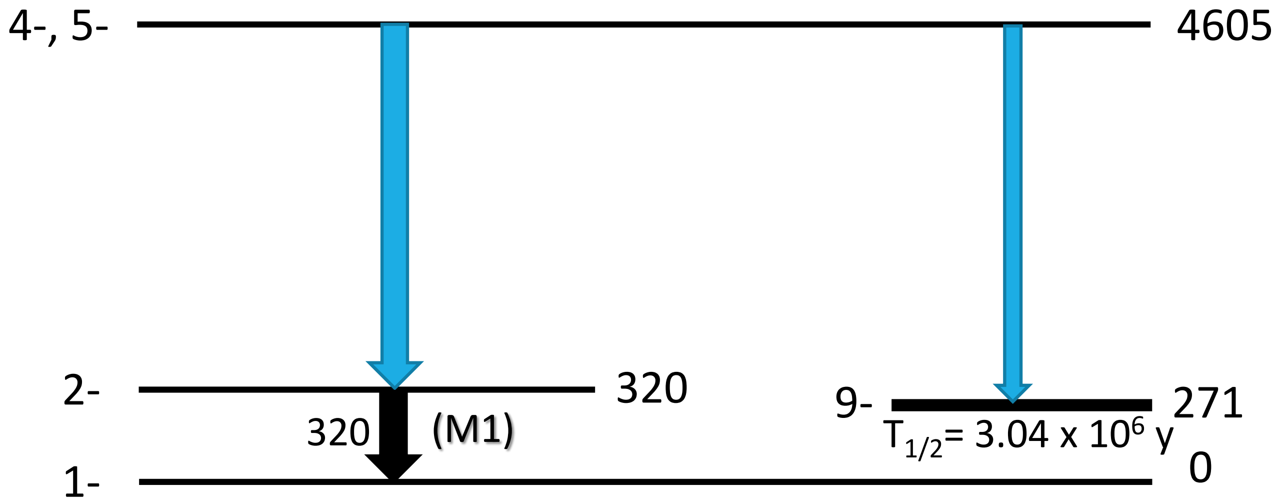
Multipolarity of the main transition leading to the ground state

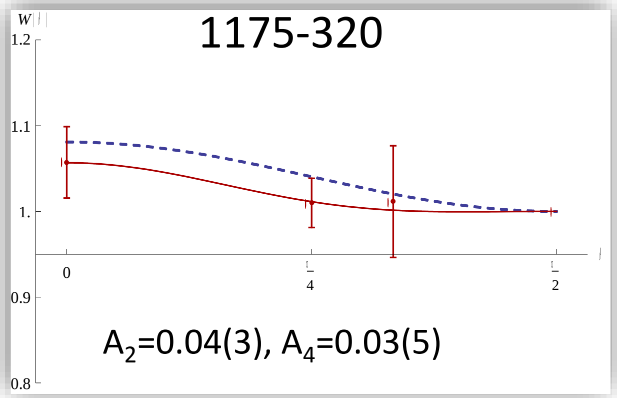
Not confirmed experimentally M1 multipolarity of 320-keV line

A. Borella et al., Nucl. Phys. A 850, 1 (2011)

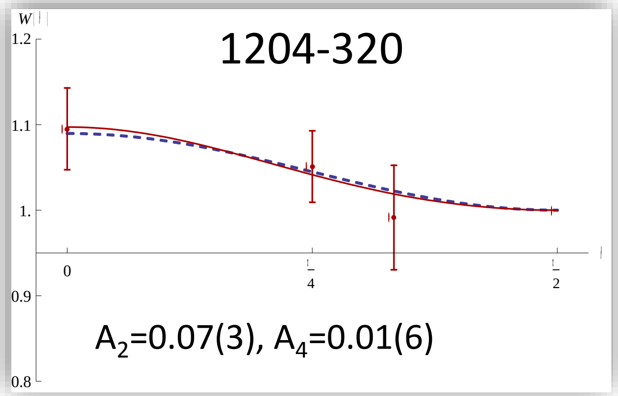
Thermal capture cross section for the $^{209}Bi(n,\gamma)^{210}Bi$ reaction to the ground state [mb]		
100% M1	**50% M1 +50 % E2**	**100% E2**
21.5(0.9)	19.3(0.8)	17.2(0.7)

A. Borella et al., AIP Conf. Proc. 769, 648 (2005)

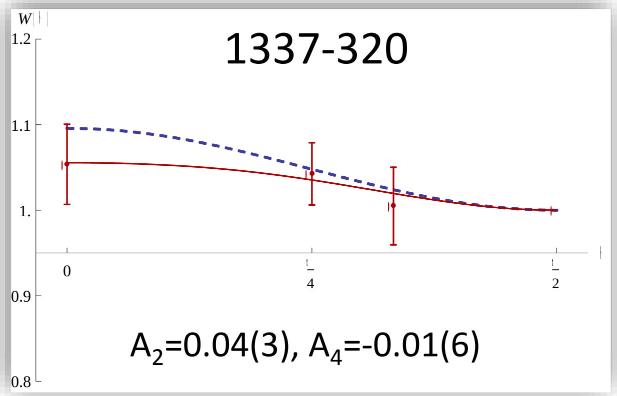




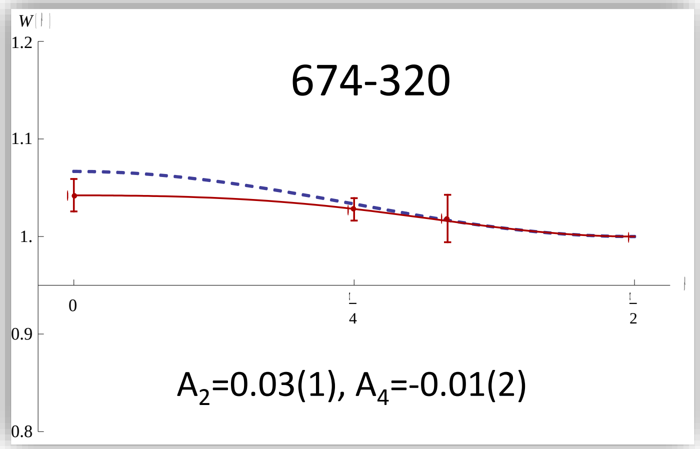
Theory E1-M1
A_2=0.06, A_4=0.00



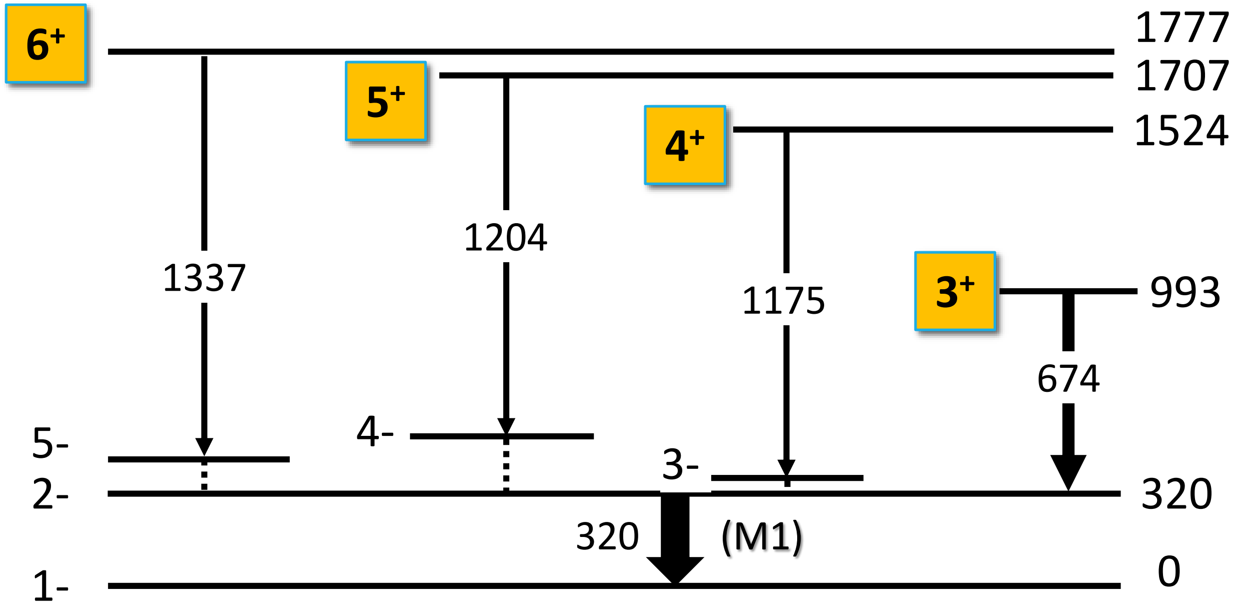
Theory E1-M1
A_2=0.07, A_4=0.00

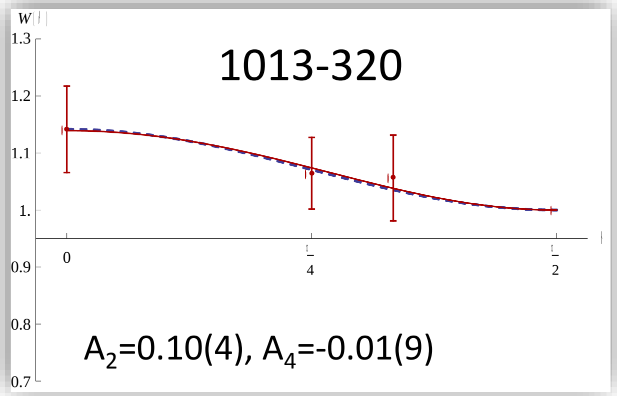


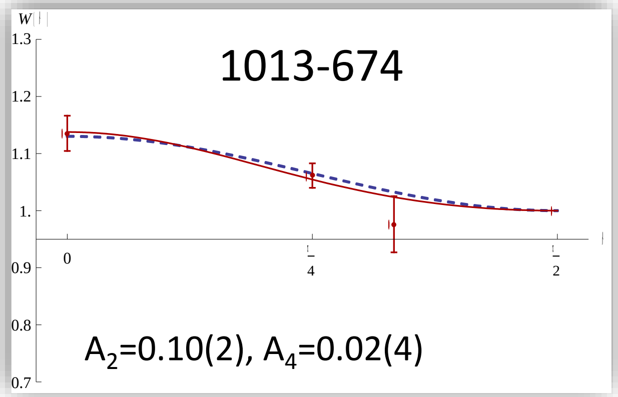
Theory E1-M1
A_2=0.07, A_4=0.00



Theory E1-M1
A_2=0.05, A_4=0.00

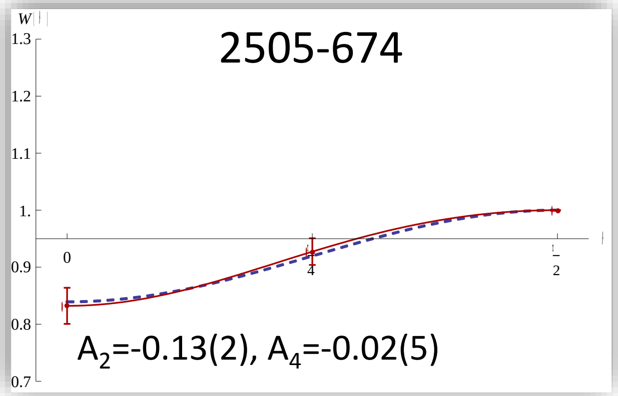


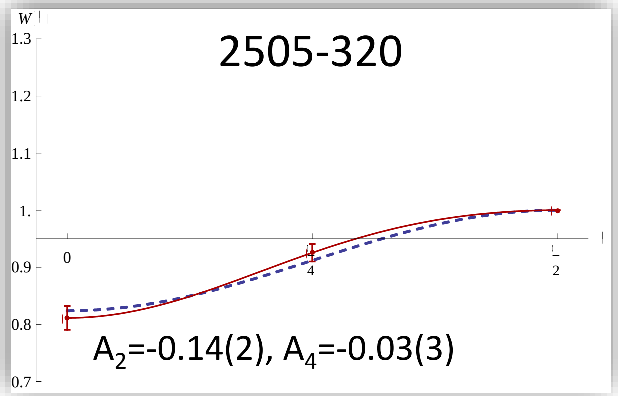




δ_{1013}=-0.108

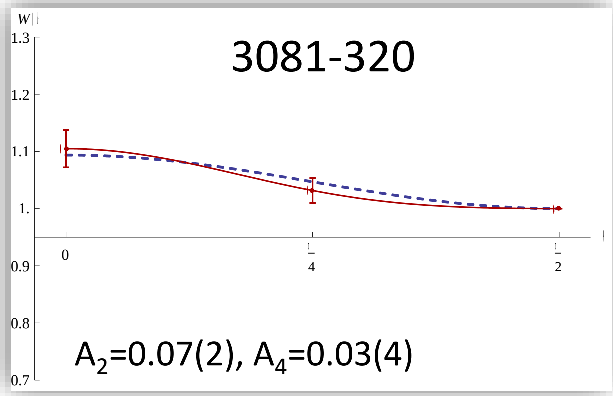
δ_{674}=0.015(32)
δ_{320}=0.04(8)

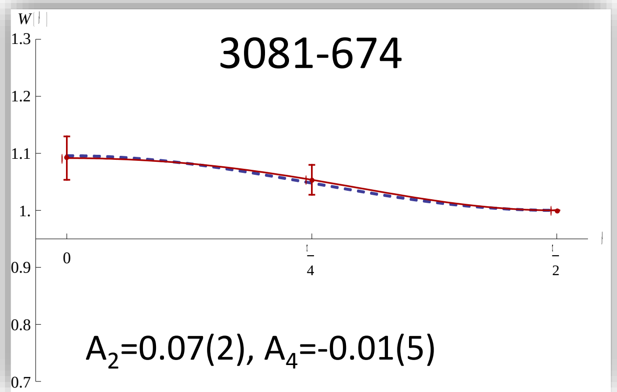




δ_{2505}=0.055
(δ_{2505}=-0.845)

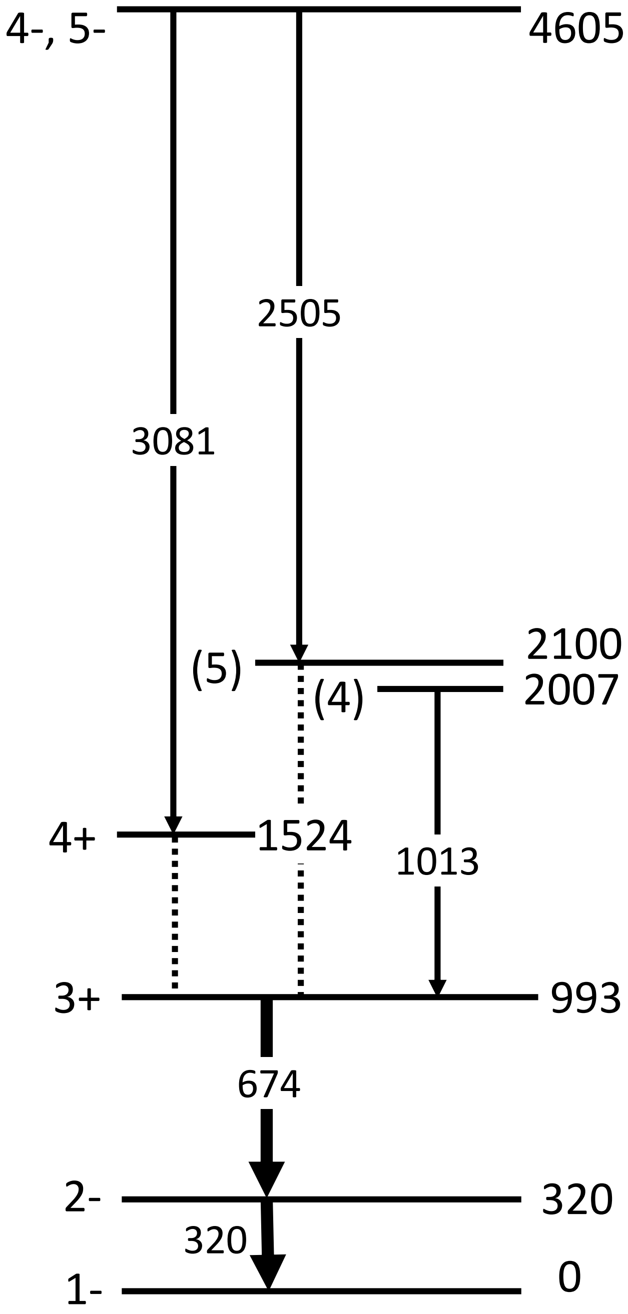
δ_{674}=0.015(29)
δ_{320}=0.036(20)



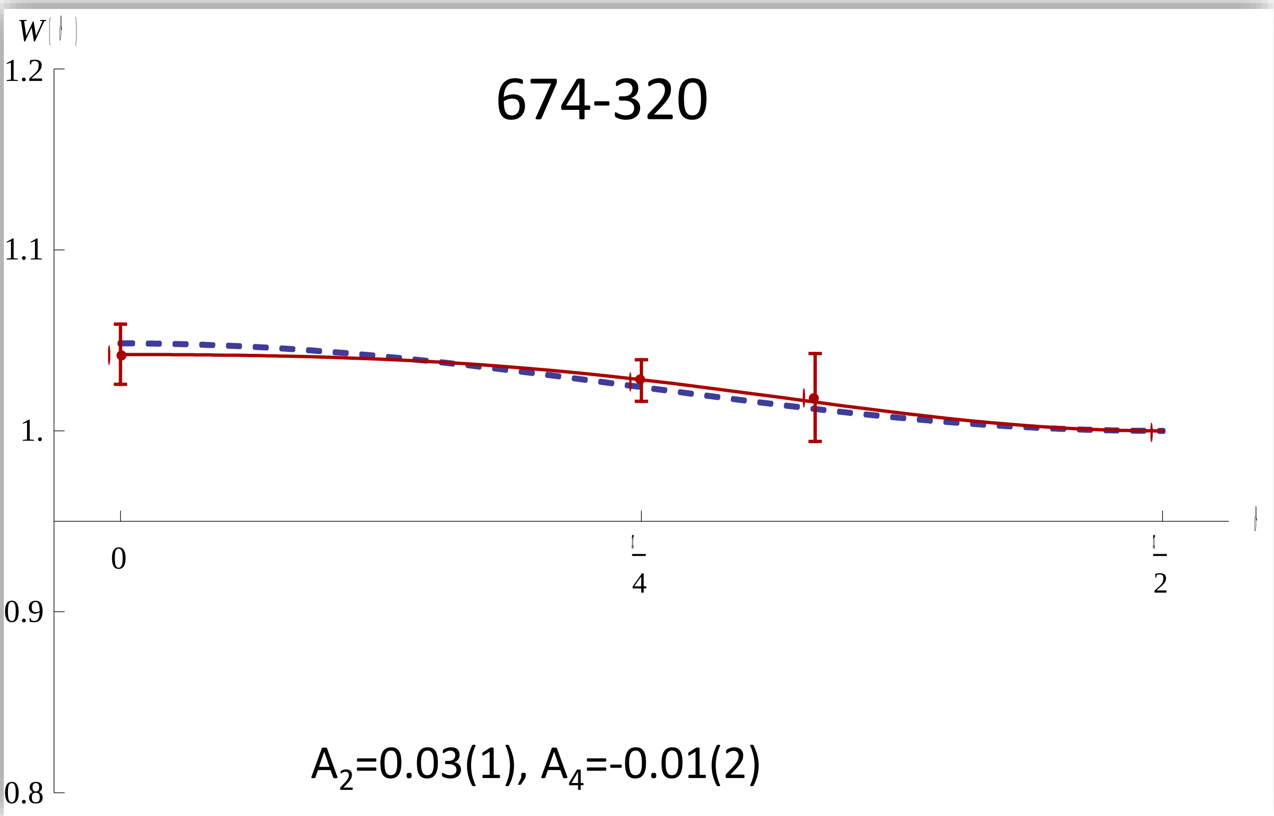


δ_{3081}=-0.037

δ_{674}=0.009(56)
δ_{320}=0.05(5)



Multipolarity of 320-keV transition



δ_{674}=0.01(3)

δ_{320}=0.04(3)

$$\delta^2 = \frac{I_{L'}}{I_L}$$

$$I(L) = \frac{1}{\delta^2 + 1}$$

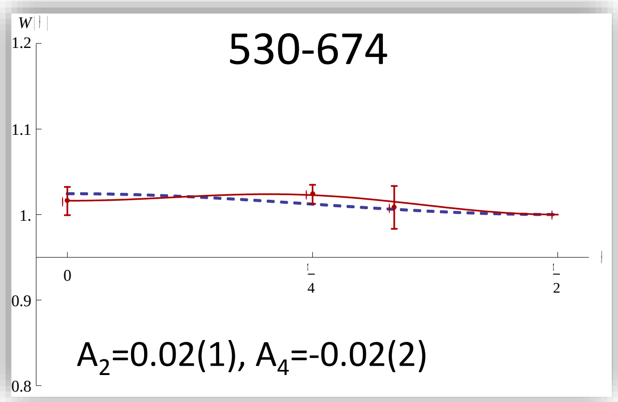
$$I(L') = \frac{\delta^2}{\delta^2 + 1}$$

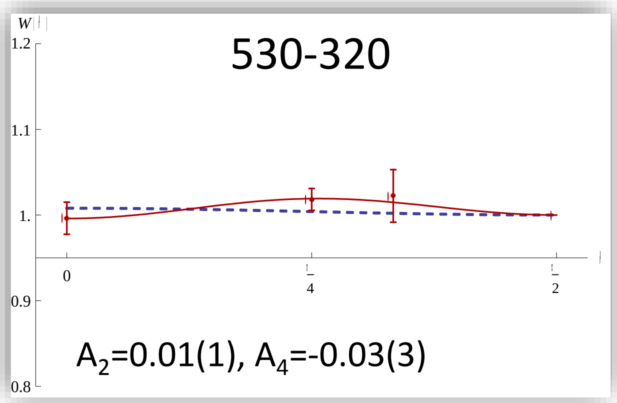
674 keV: 99.99% E1 + 0.01% M2

320 keV: 99.84% M1 + 0.16% E2

Decays to:
3+, 4-, 3-

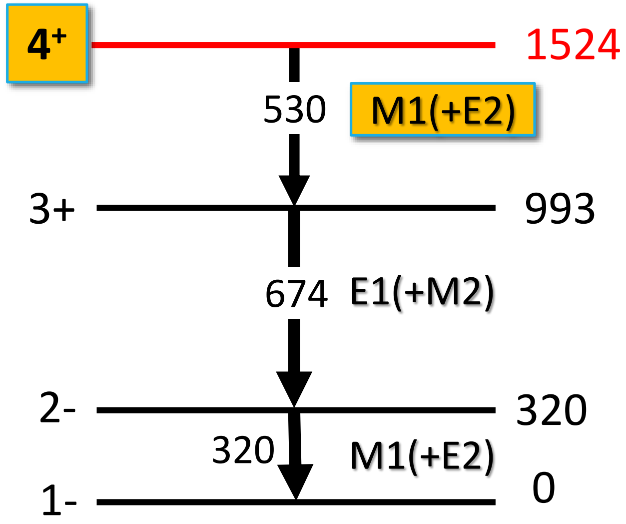
Spin-parity values: state at 1524 keV





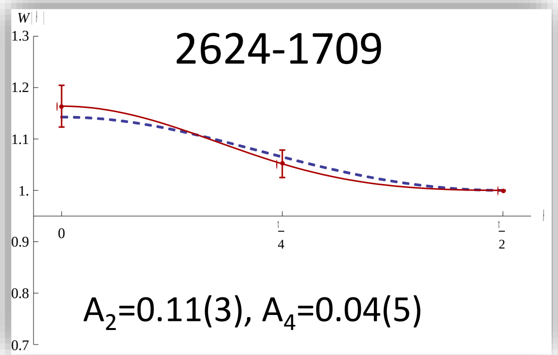
δ_{530}=0.06(2)
(δ_{530}=5.7(8))

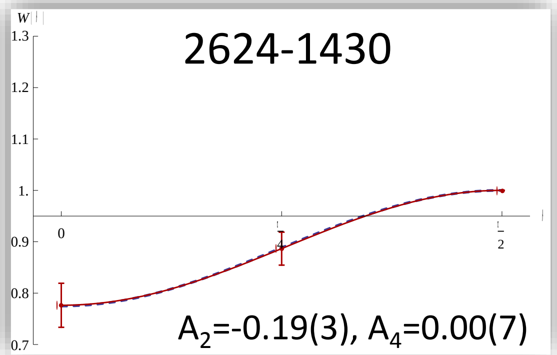
δ_{530}=0.09(3)
(δ_{530}=4.9(7))

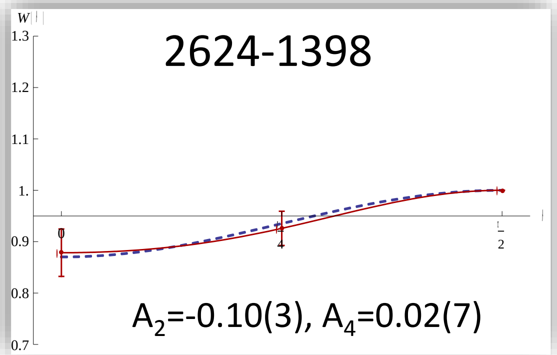


Decays to:
(6-), 8-, 8-, 6-, 7-, 9-

Spin-parity values: state at 1981 keV



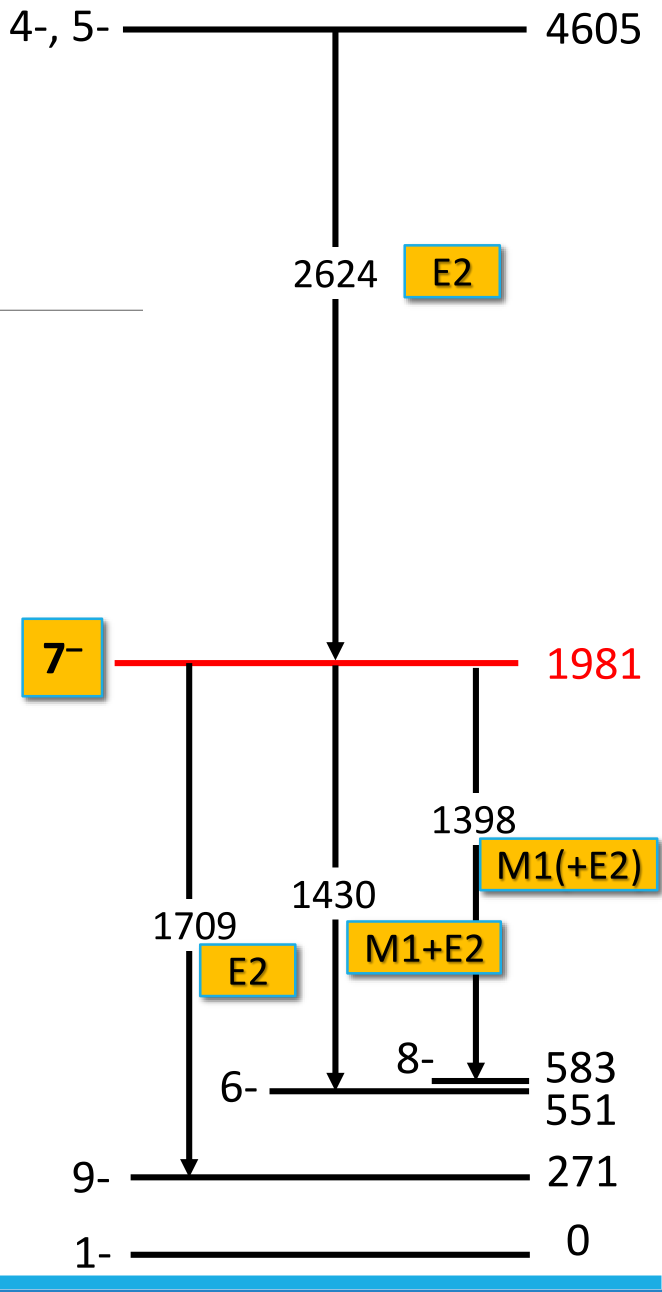




Theory E2-E2
A_2=0.10, A_4=0.01

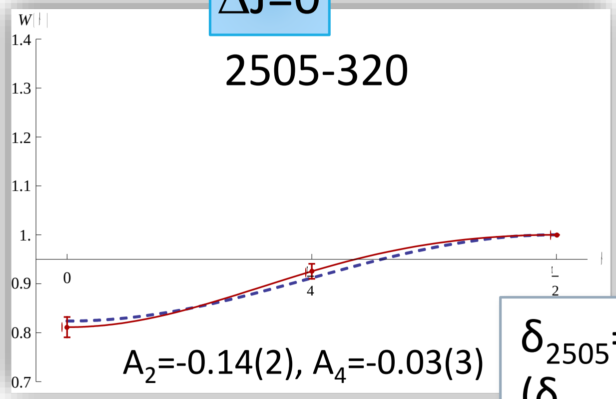
δ_{1430}=-0.11(5)

δ_{1398}=0.05(5)

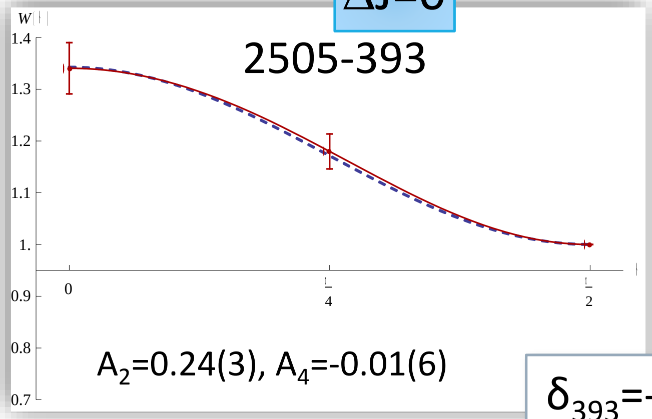


Decays to:
(6+), (5+), (4+), (4-), (6-), 6-, 4-

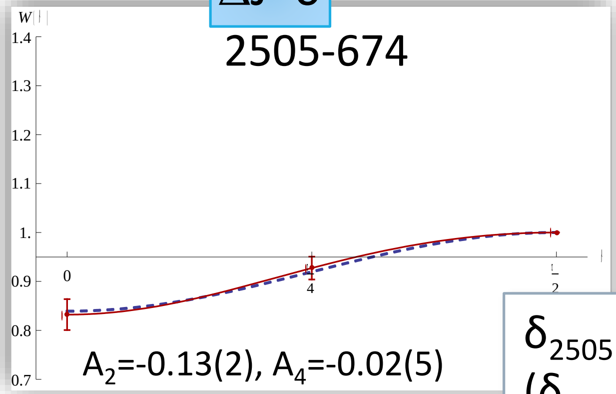
Spin-parity values: state at 2100 keV



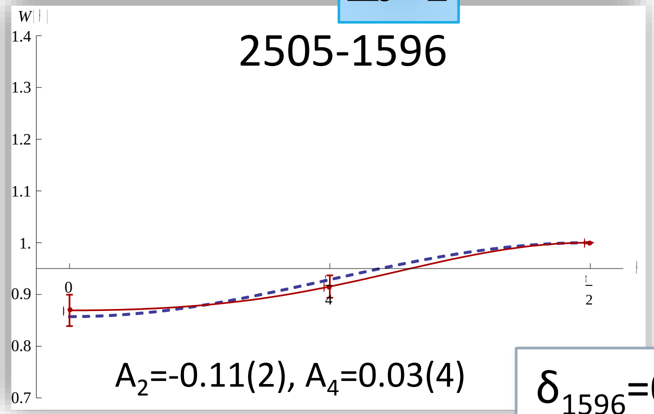
δ_{2505}=0.04(8)
(δ_{2505}=-0.82(12))



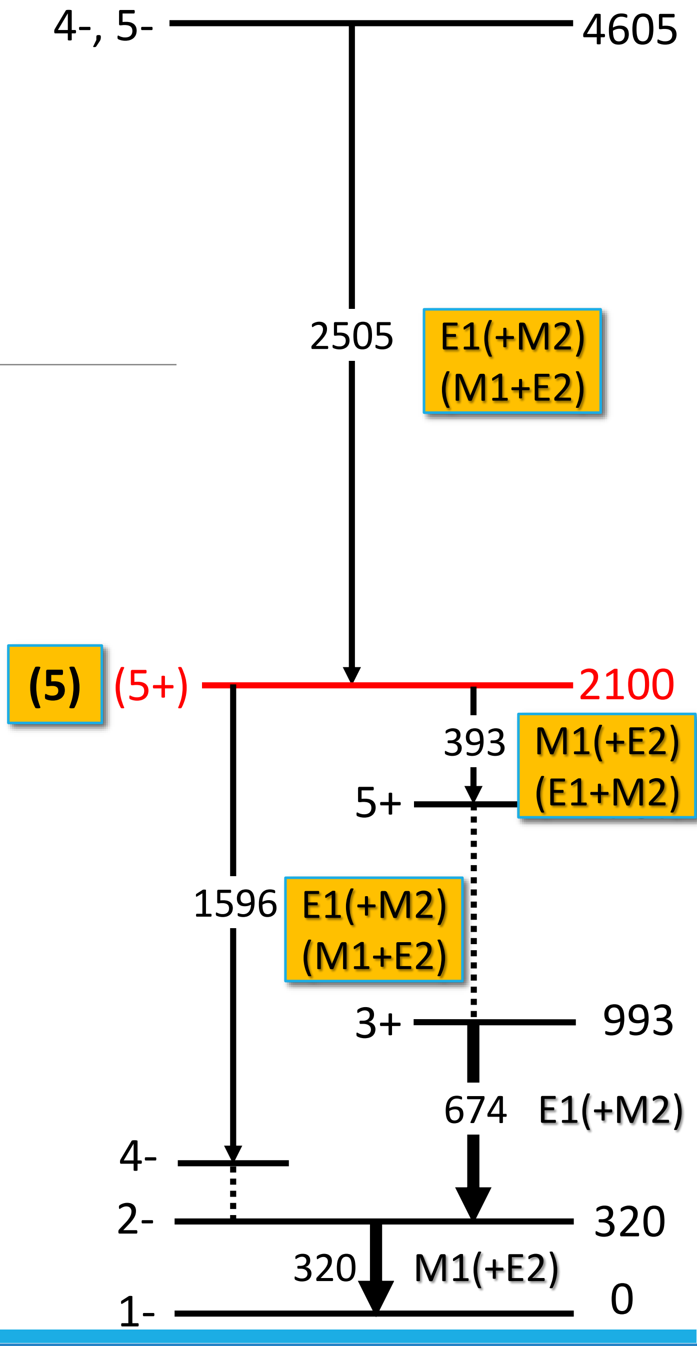
δ_{393}=-0.3(3)



δ_{2505}=0.07(12)
(δ_{2505}=-0.88(19))

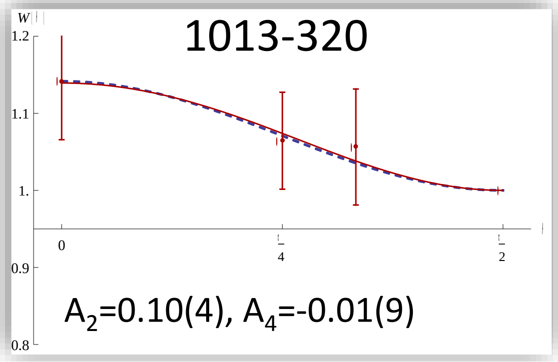


δ_{1596}=0.01(3)

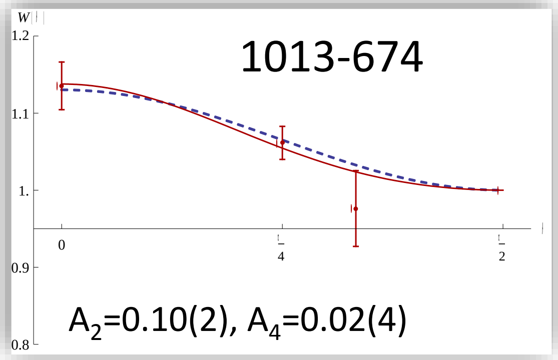


Decays to:
5+, 4+, 3-, 4-, 3+, 4-, 5-, 3-, 2-

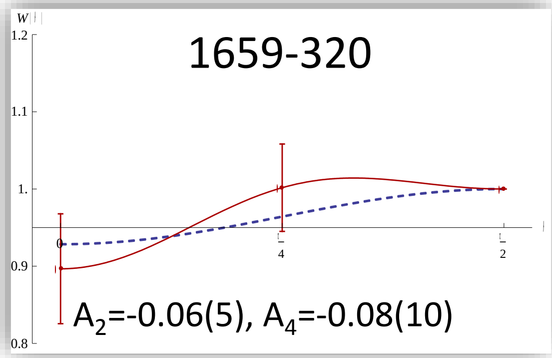
Spin-parity values: state at 2007 keV



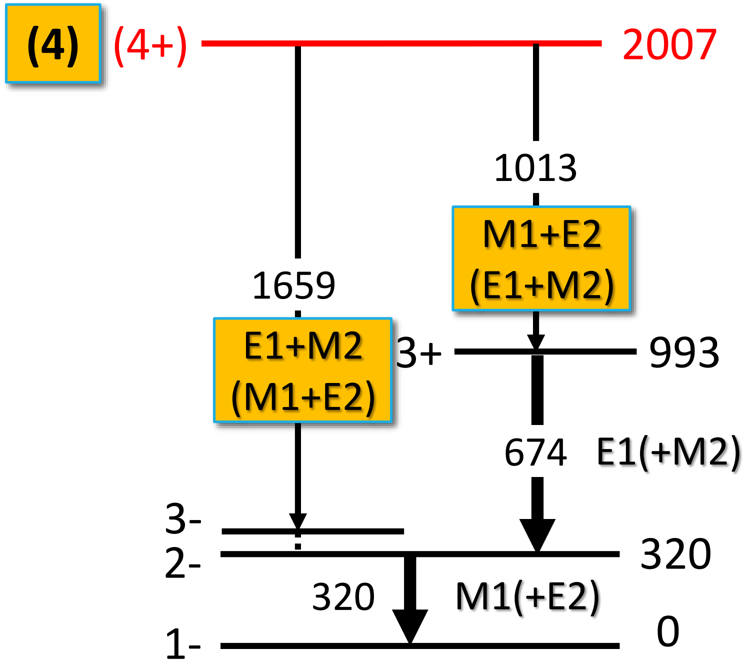
δ_{1013}=-0.11(9)



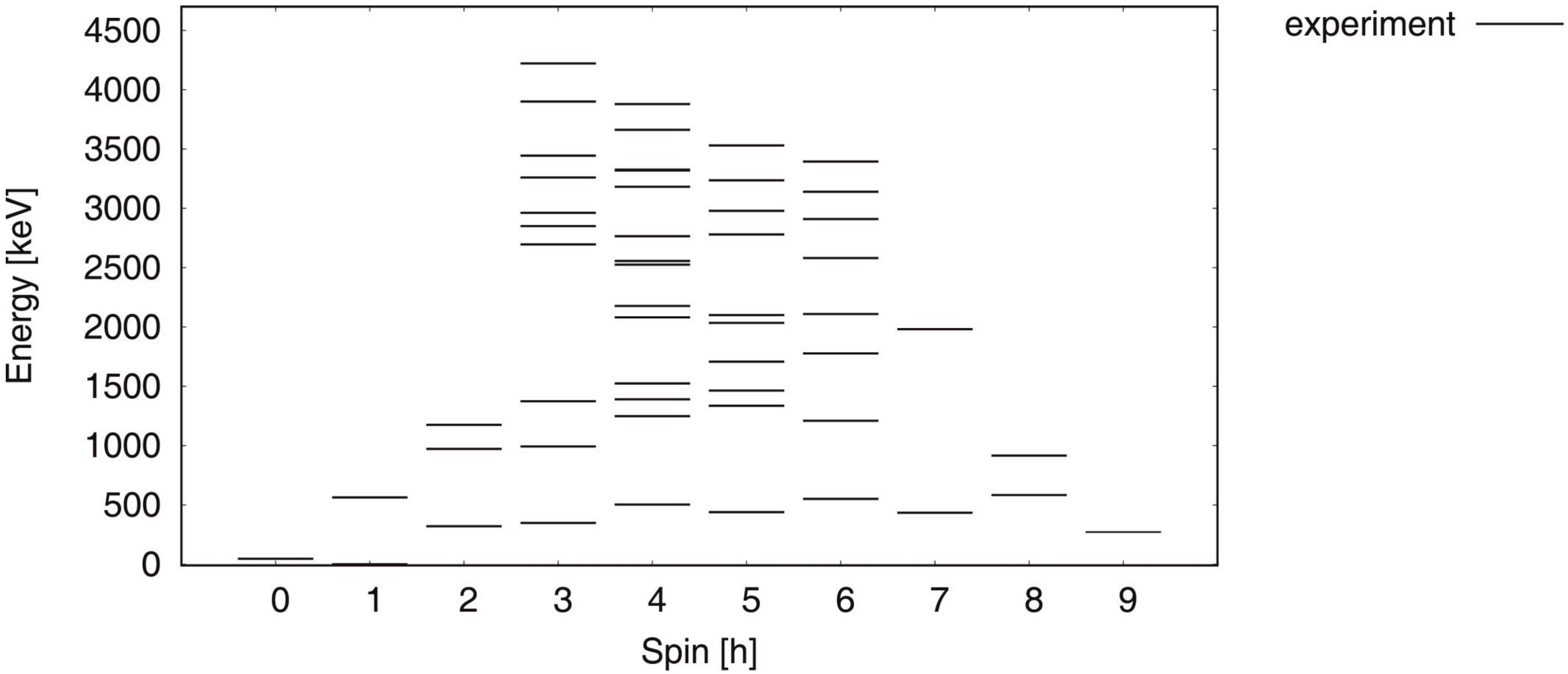
δ_{1013}=-0.10(4)



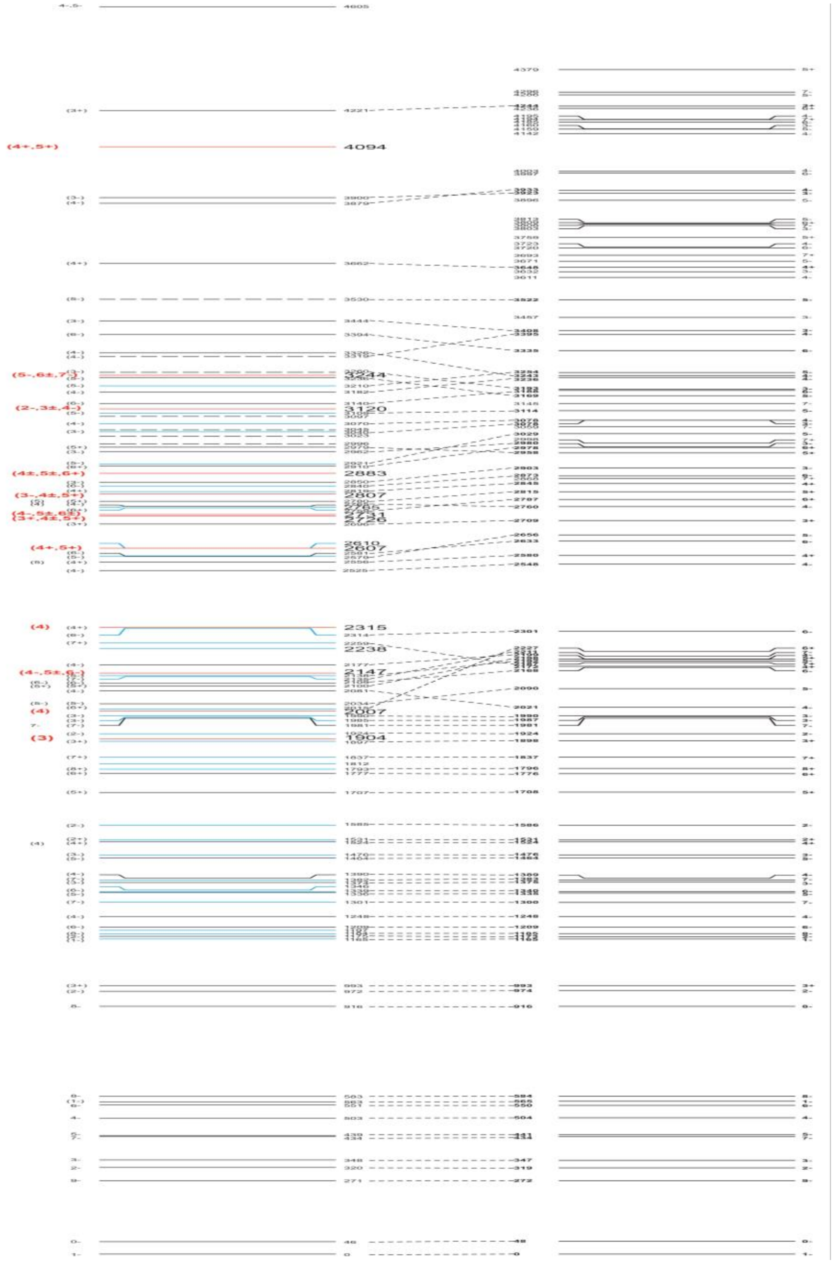
δ_{1659}=0.23(14)



Spin distribution from $^{209}Bi(n,\gamma)^{210}Bi$ reaction



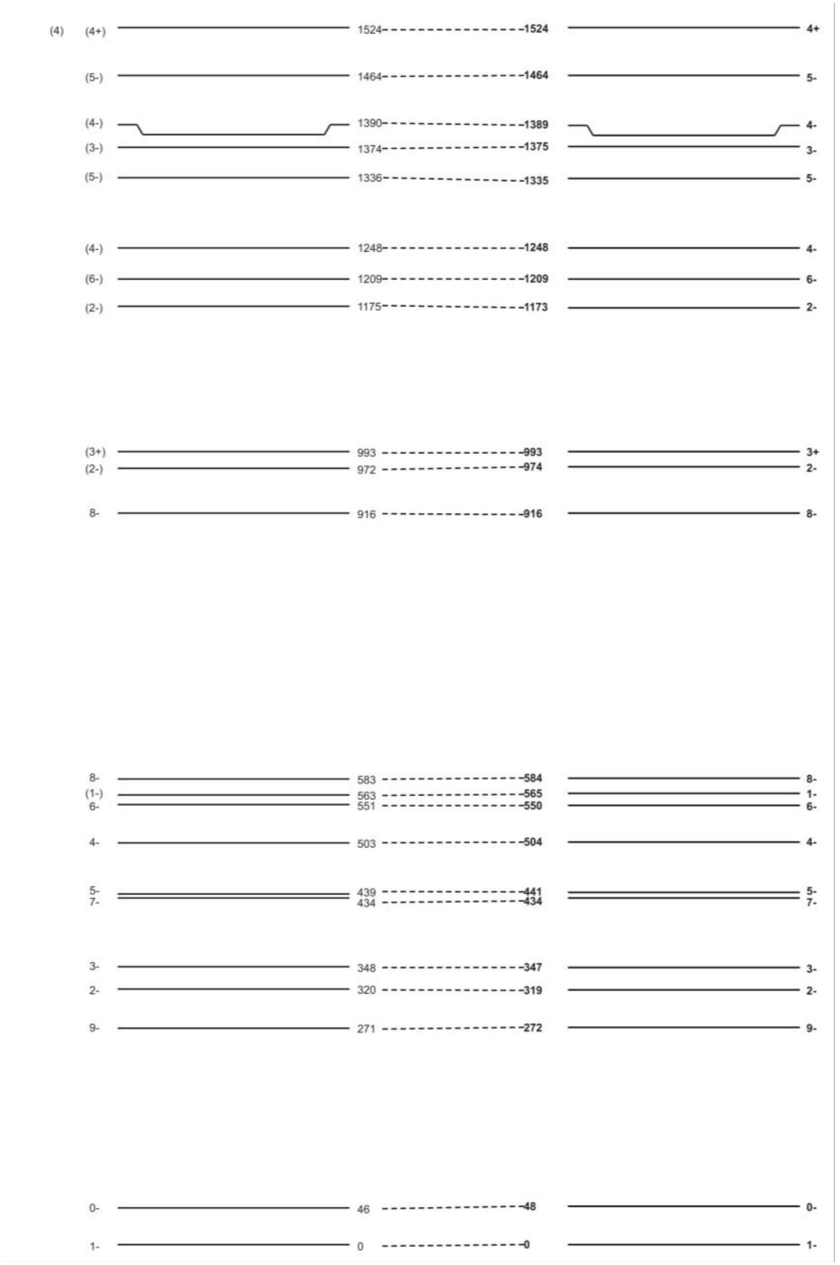
Comparison with shell-model calculations



Experimental results

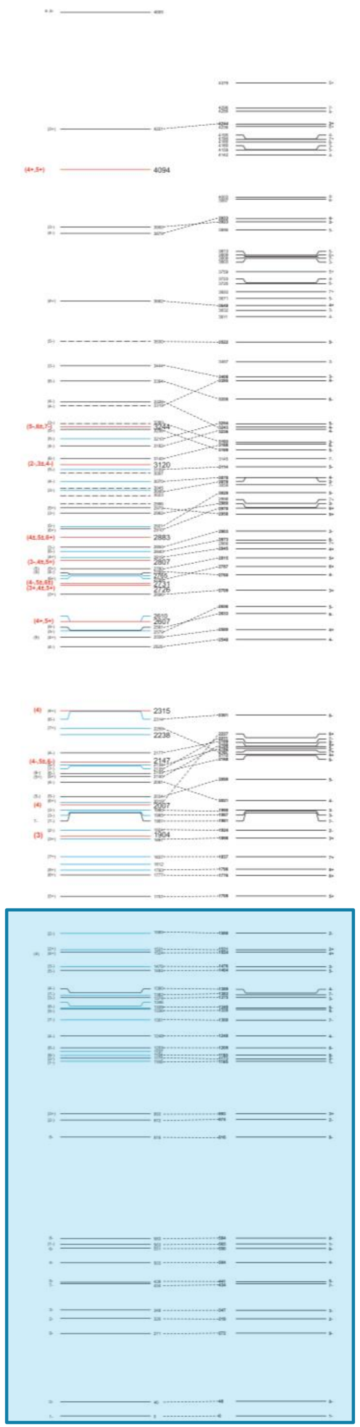
Shell-model calculations

Comparison with shell-model calculations

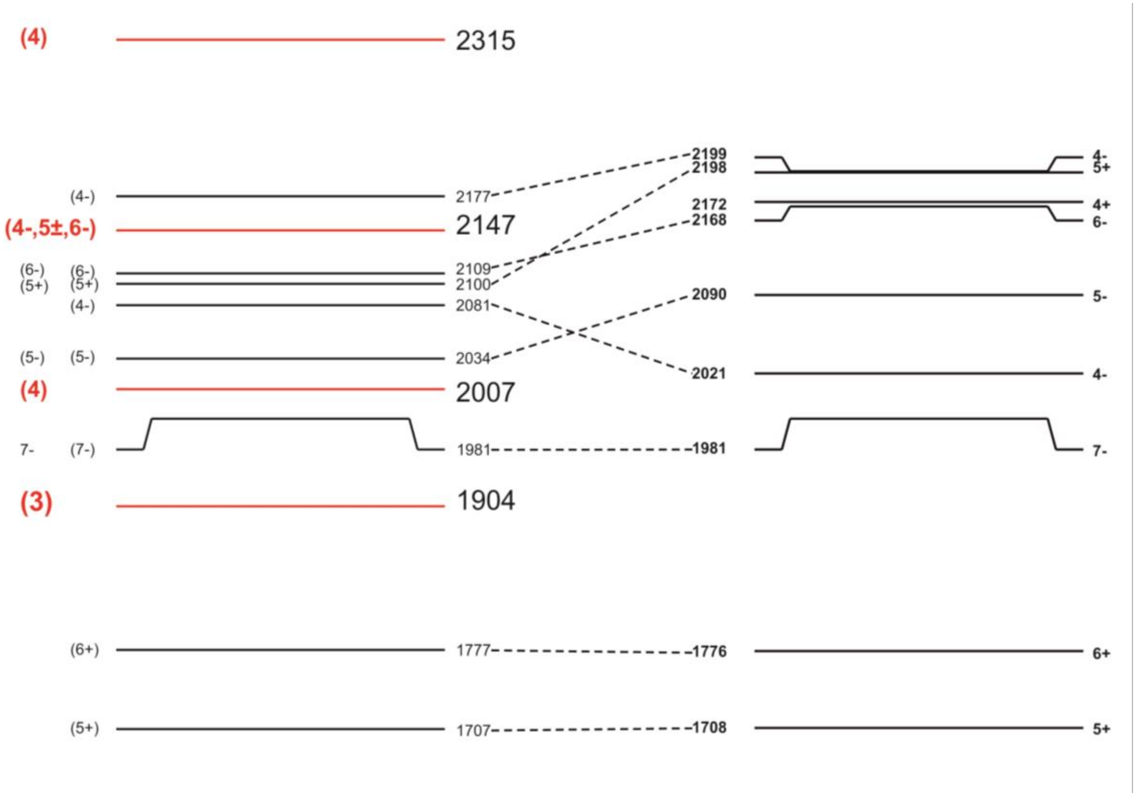


Experimental results

Shell-model calculations

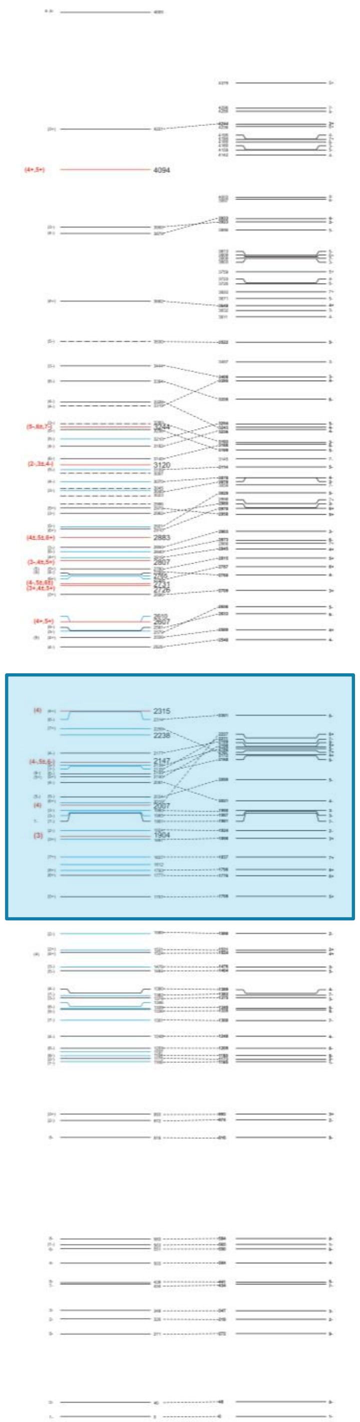


Comparison with shell-model calculations



Experimental results

Shell-model calculations



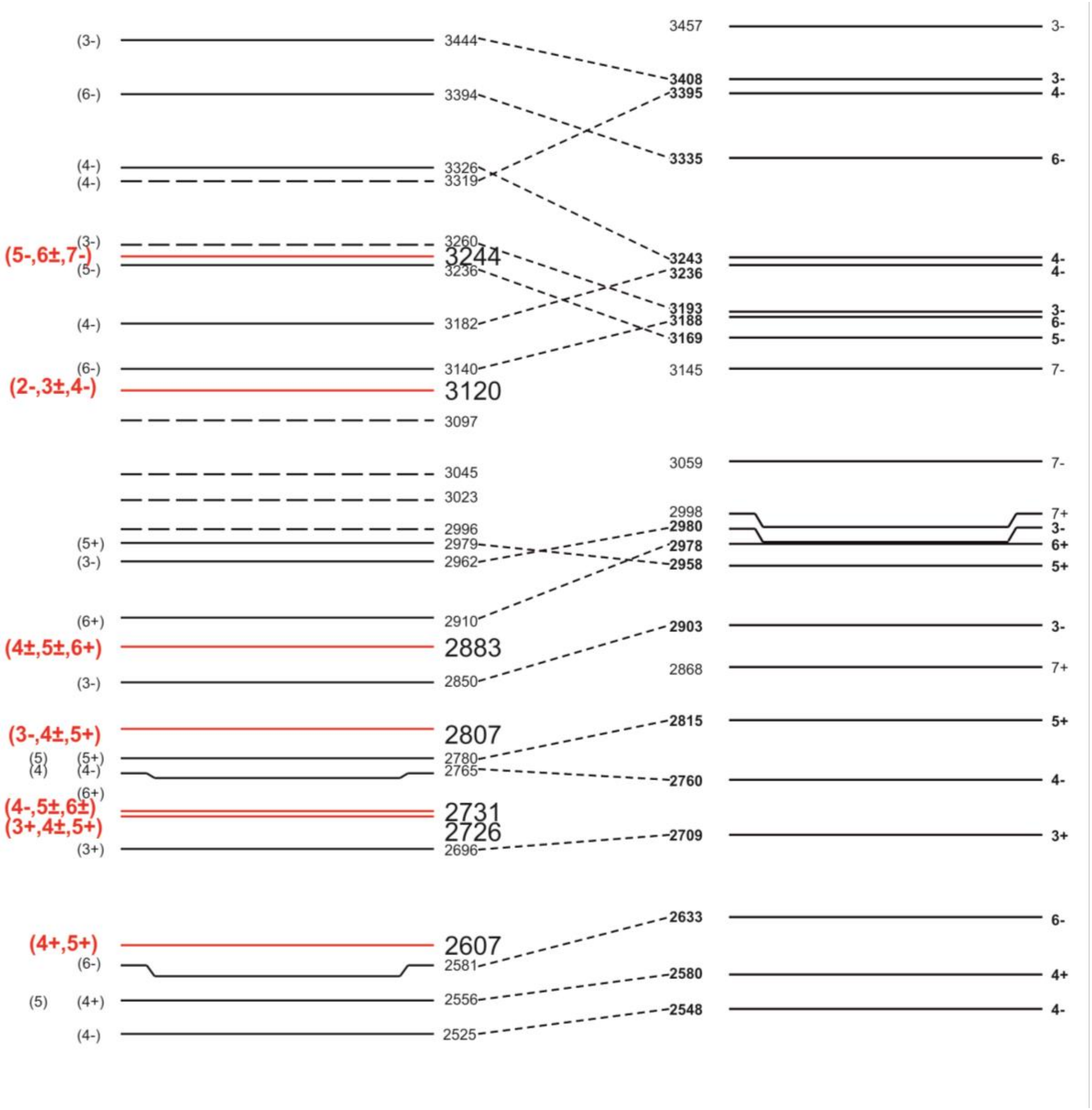
Comparison with shell-model calculations

3- × ($\pi h_{9/2} \nu g_{9/2}$)

3- × 0- → 3+
3- × 1- → 2+, 3+, 4+
3- × 9- → 6+, 7+, 8+, (9+, 10+, 11+, 12+)

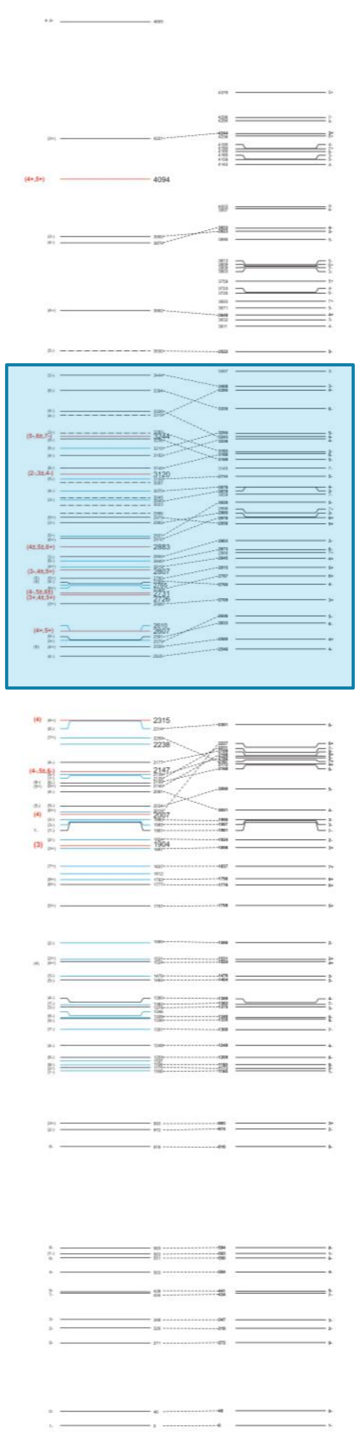
3- 2.6 MeV

208Pb

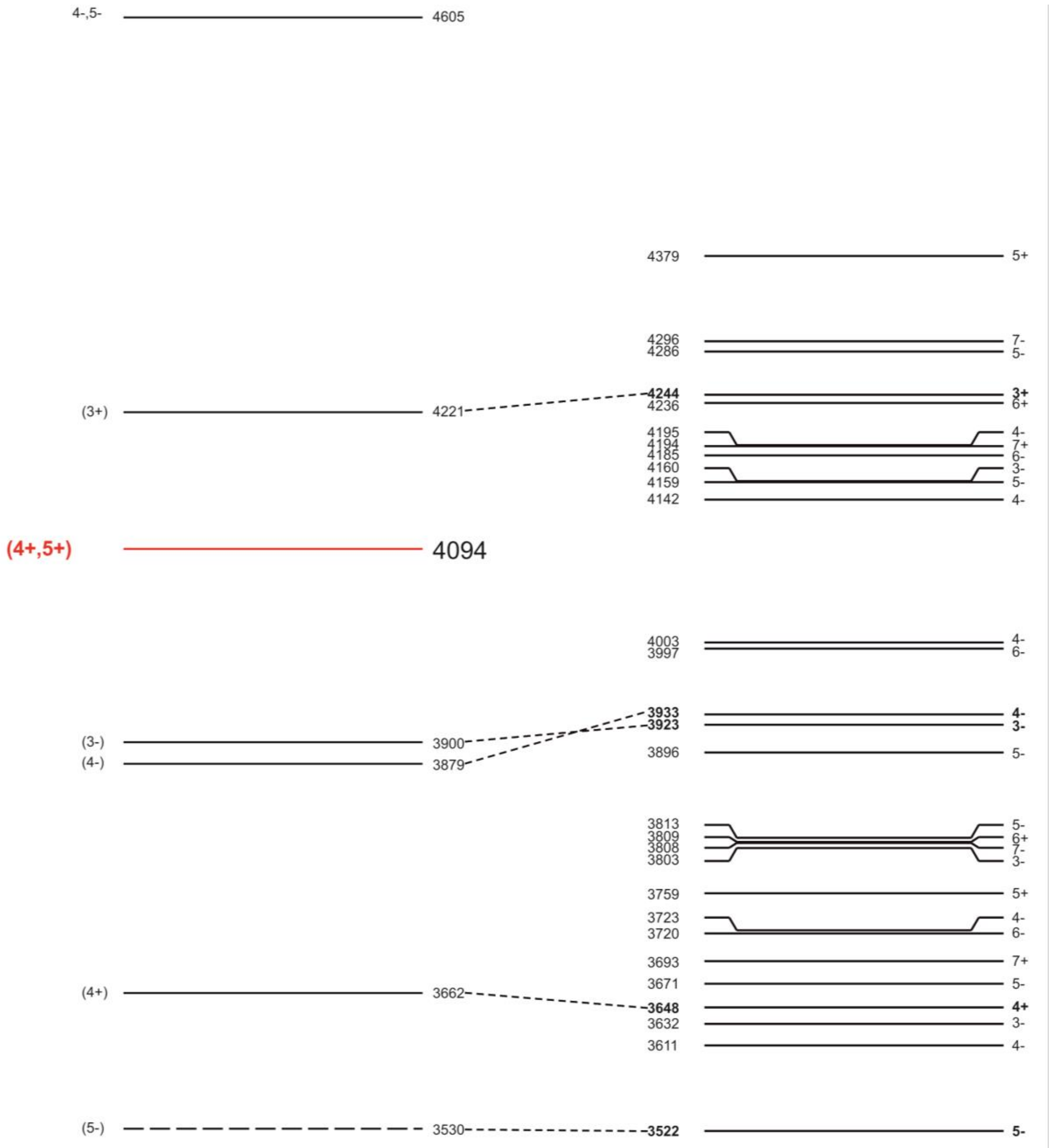


Experimental results

Shell-model calculations

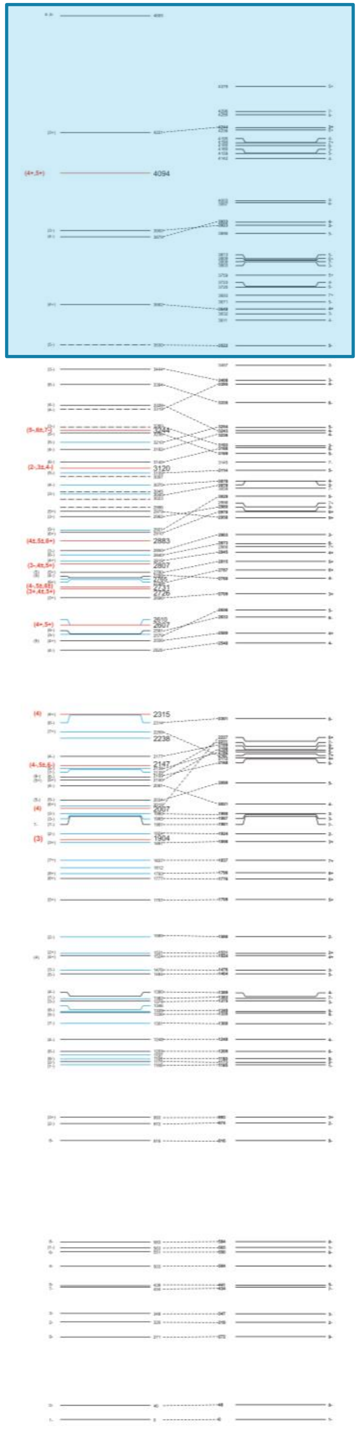


Comparison with shell-model calculations

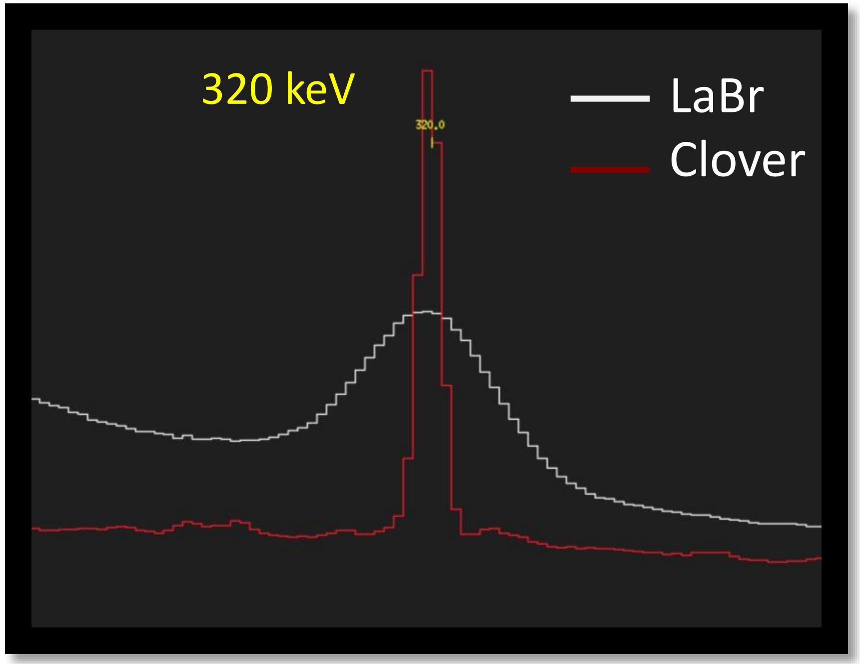


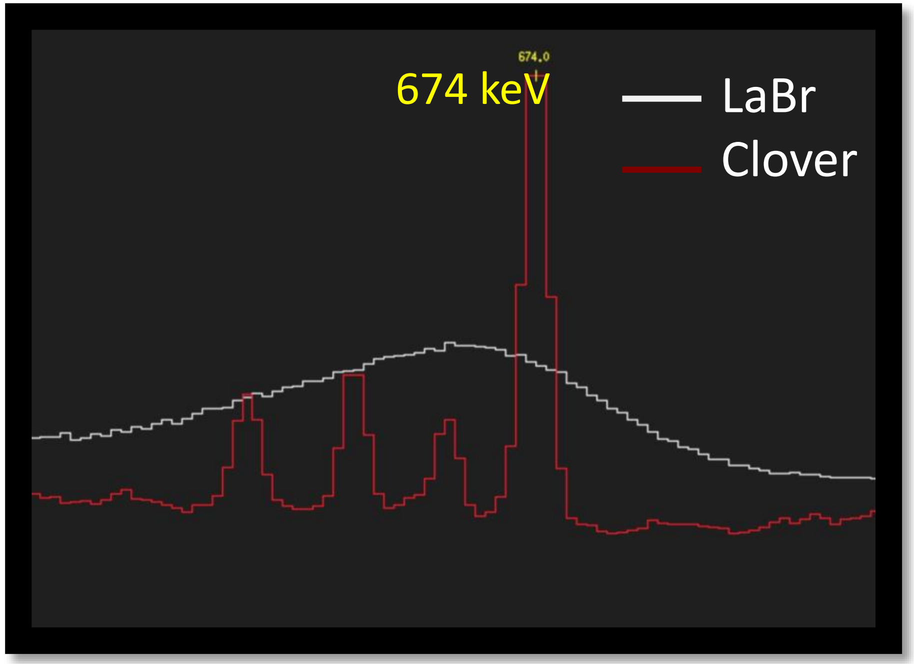
Experimental results

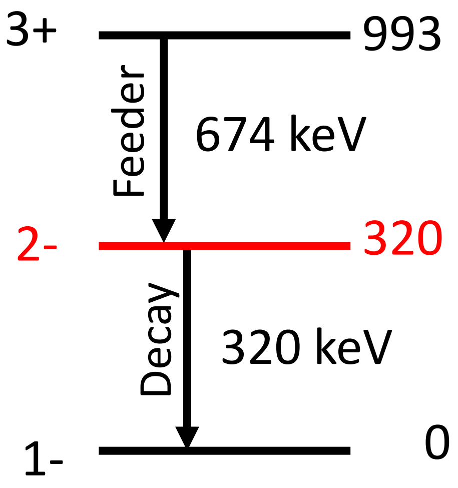
Shell-model calculations



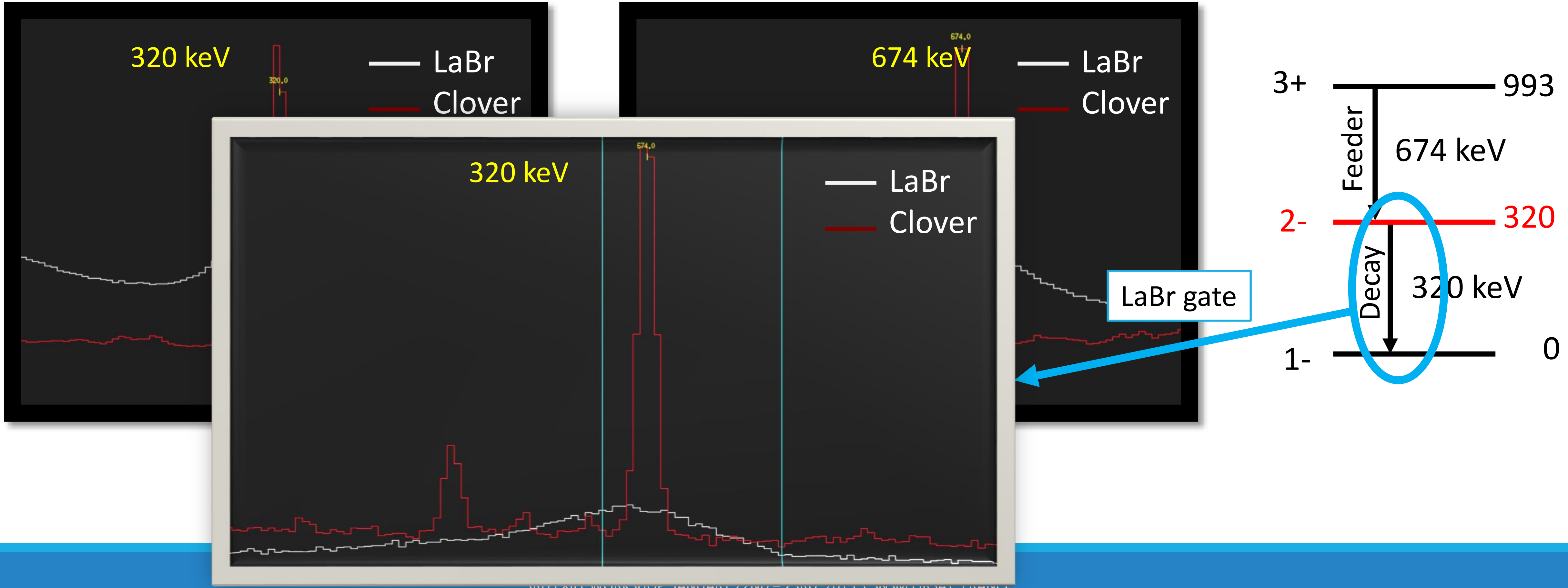
Measurements of the lifetimes of excited states in ^{210}Bi







Measurements of the lifetimes of excited states in ^{210}Bi



Measurements of the lifetimes of excited states in ^{210}Bi

$$\tau = \frac{1}{2}\left[\frac{\Delta C - \Delta C_{compton}}{\pi} + \Delta C - PRD\right]$$

ΔC = 22 ps
$\Delta C_{compton}$ = 106.8 ps
PRD ($E_{feeder} - E_{decay}$) = -83.4 ps
π = 0.8

τ = 2.4 ps

τ_{lit} = 7.5(14) ps

Phys Rev. C 12, 1547(1975)

With this method the lower limit is between 5 and 10 ps

Summary

- The level structure of ^{210}Bi investigated in cold neutron capture on ^{209}Bi was compared to shell model calculations – some of the states must come from the core excitations.

- The analysis of angular correlations allowed to confirm almost pure M1 character of the main transition leading to the ground state.

- The results of present analysis of ^{210}Bi structure, including the measurements of the lifetimes will serve as an excellent testing ground for the future calculataions.

Thank you for your attention!