The 5th international conference on "COLLECTIVE MOTION IN NUCLEI UNDER EXTREME CONDITIONS"

COMEX5

High- and low-spin structures in the proton-particle neutron-particle ^{210}Bi nucleus

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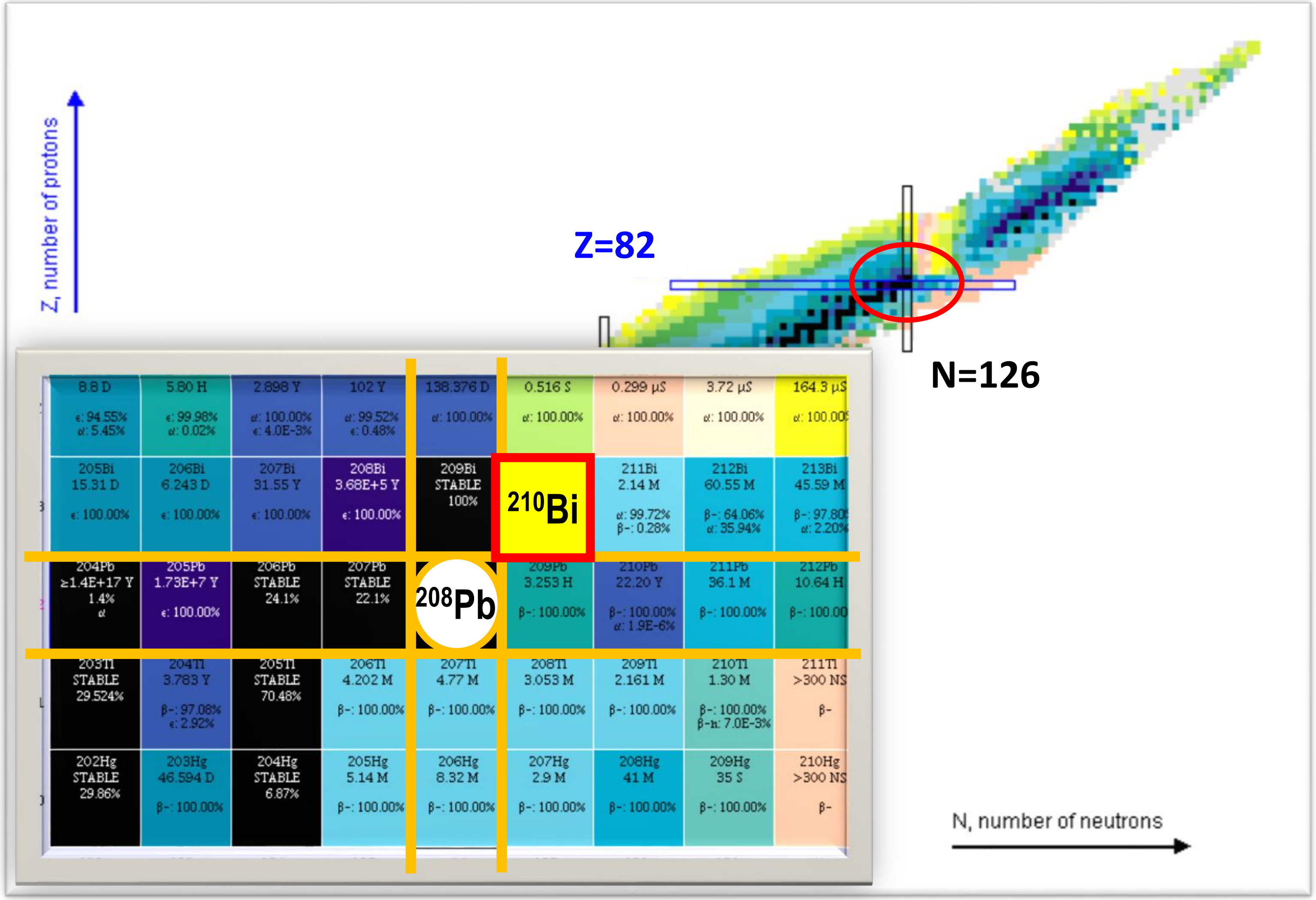
INFN

Outline

Why the ^{210}Bi nucleus?

- **An ideal nucleus for testing the shell-model calculations**: couplings between valence proton and valence neutron

- An ideal system for studying **phonon (3⁻ of ^{208}Pb)-valence particles coupling**

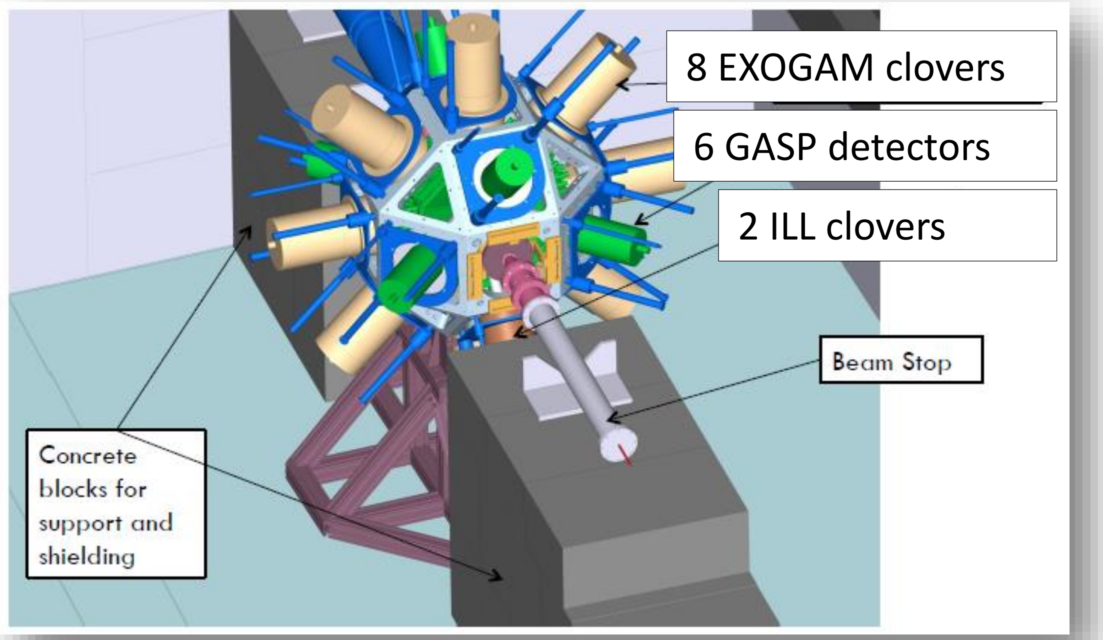


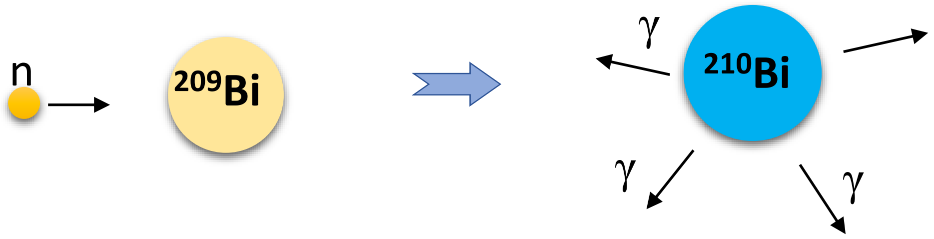
Experimental data

- **Low-spin structure** – neutron capture experiment at Institute Laue-Langevin (Grenoble, France)

- **High-lying yrast states** – deep-inelastic reactions for the system ^{208}Pb + ^{208}Pb (Argonne National Laboratory, USA)

Experiment – ILL Grenoble (PF1B line)





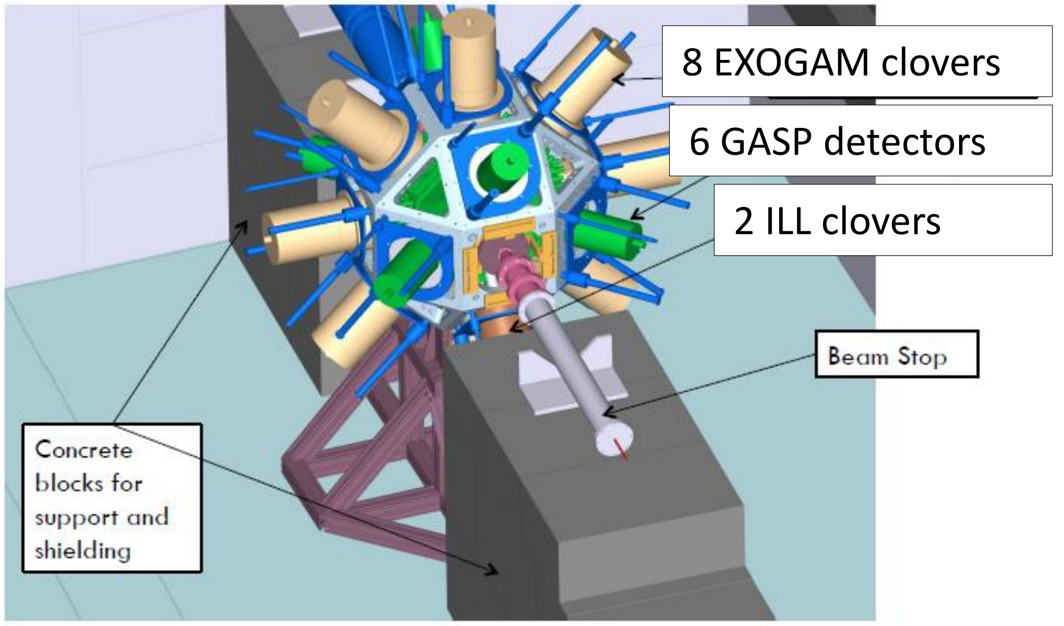
Cold neutron flux of $2{\cdot}10^{10}/(\text{ns} \cdot \text{cm}^2)$ from the ILL reactor with energy < 5 meV

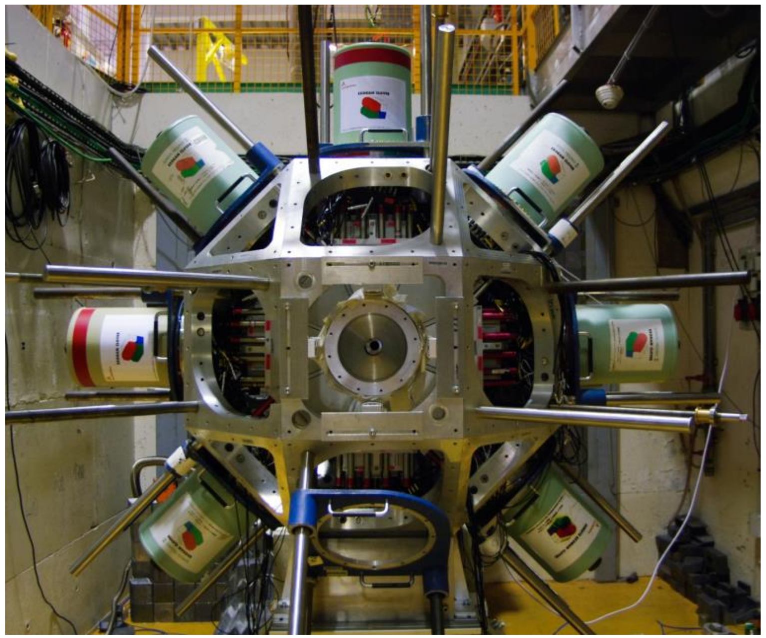
^{209}Bi solid target (3g)

Population of capture state in ^{210}Bi at binding energy of 4.6 MeV

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

Experiment – ILL Grenoble (PF1B line)

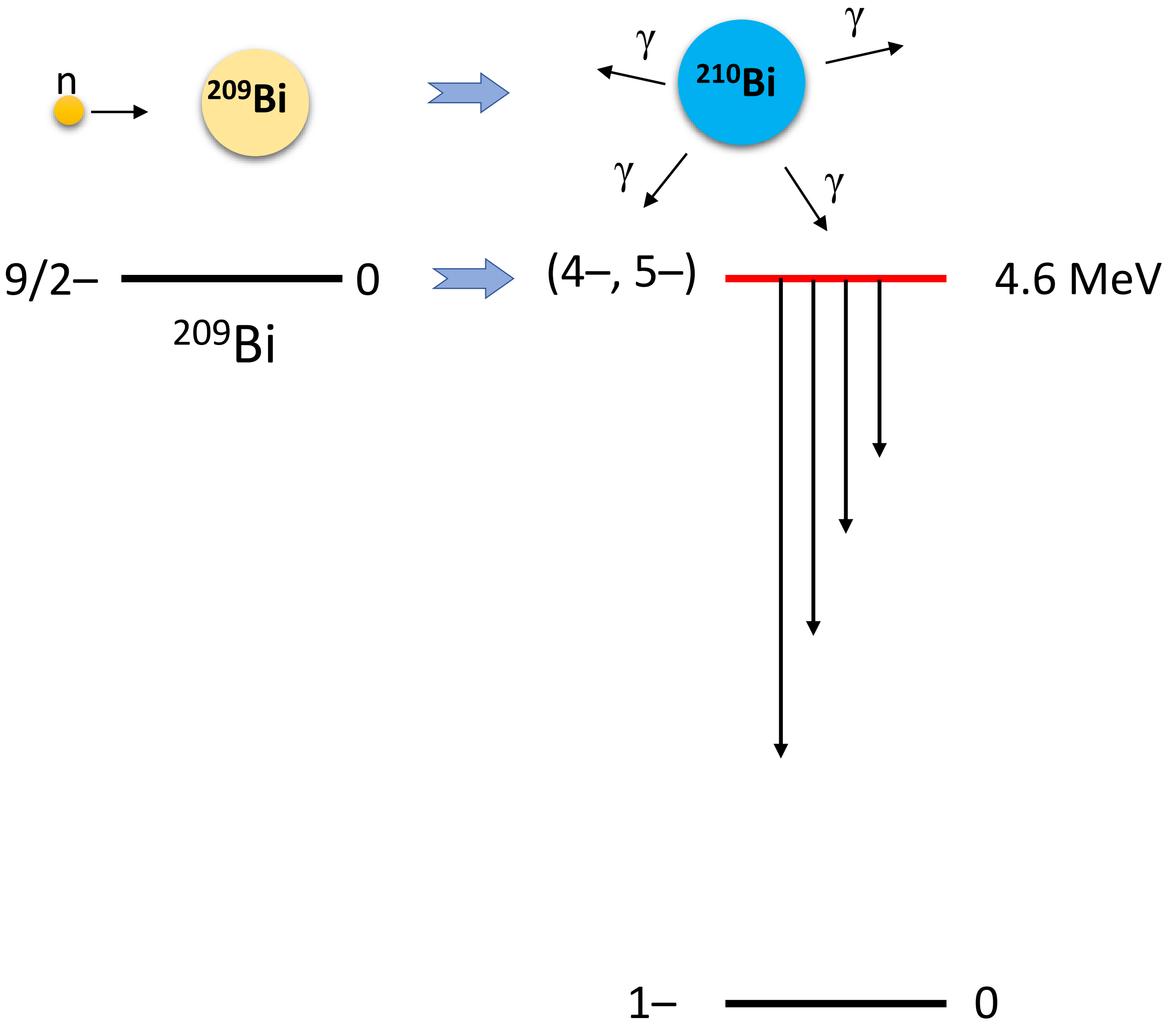




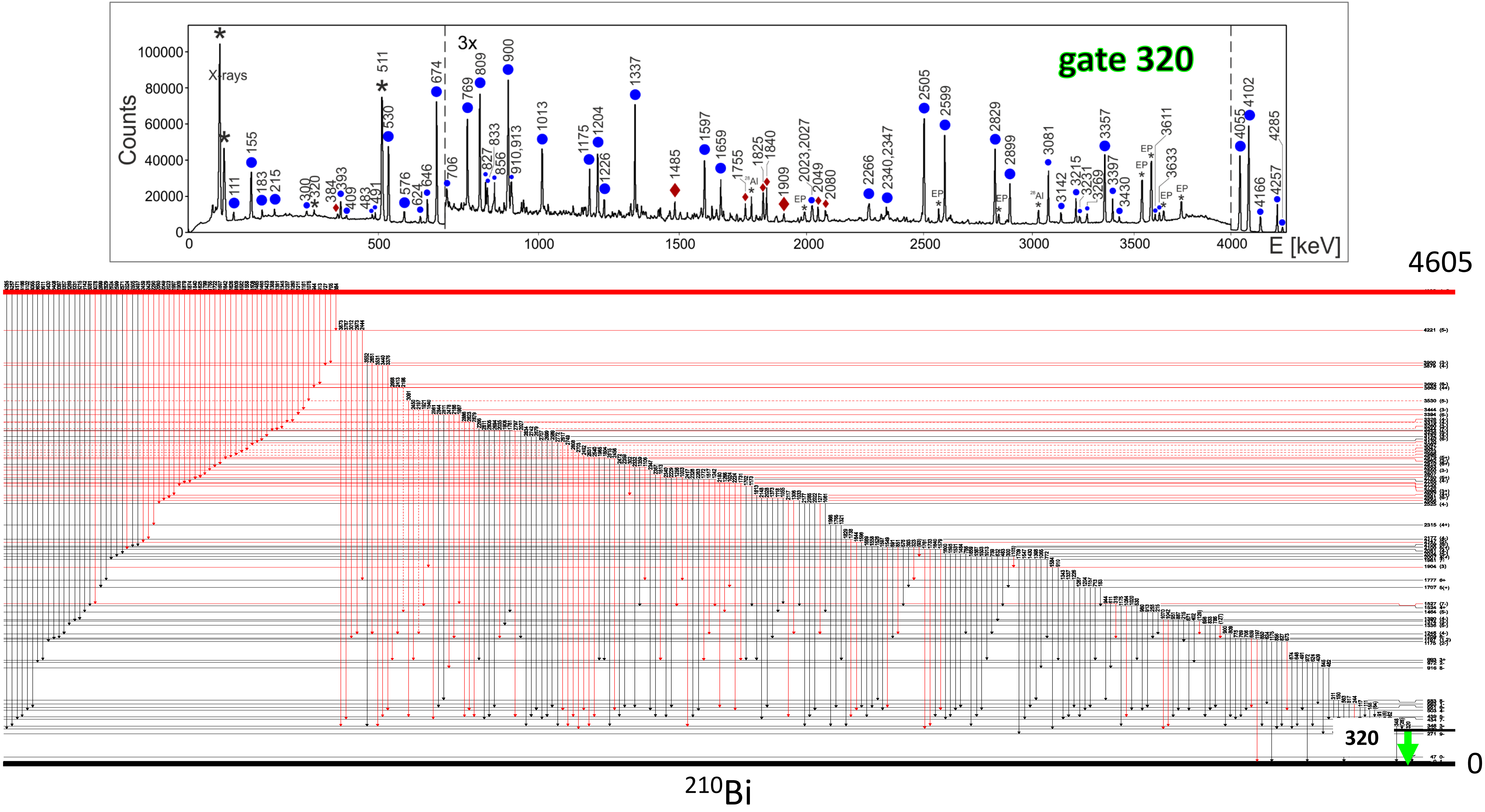
16 Ge detectors of EXILL array: 8 of EXOGAM, 6 of GASP, and 2 from ILL collaboration – coincidence measurements of gamma rays

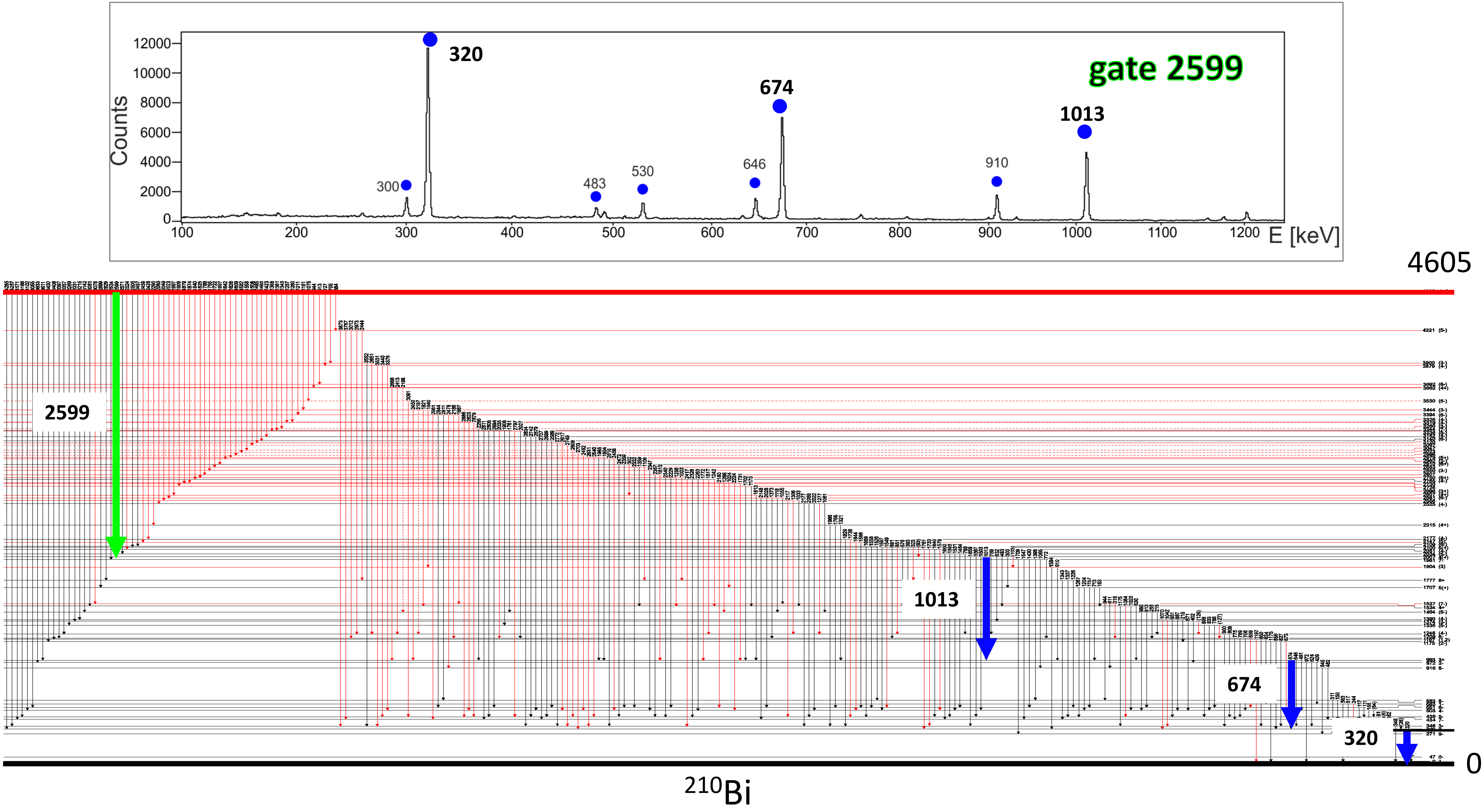
8 detectors of EXOGAM arranged into ring around the target at every 45° so angular correlation measurements could be performed

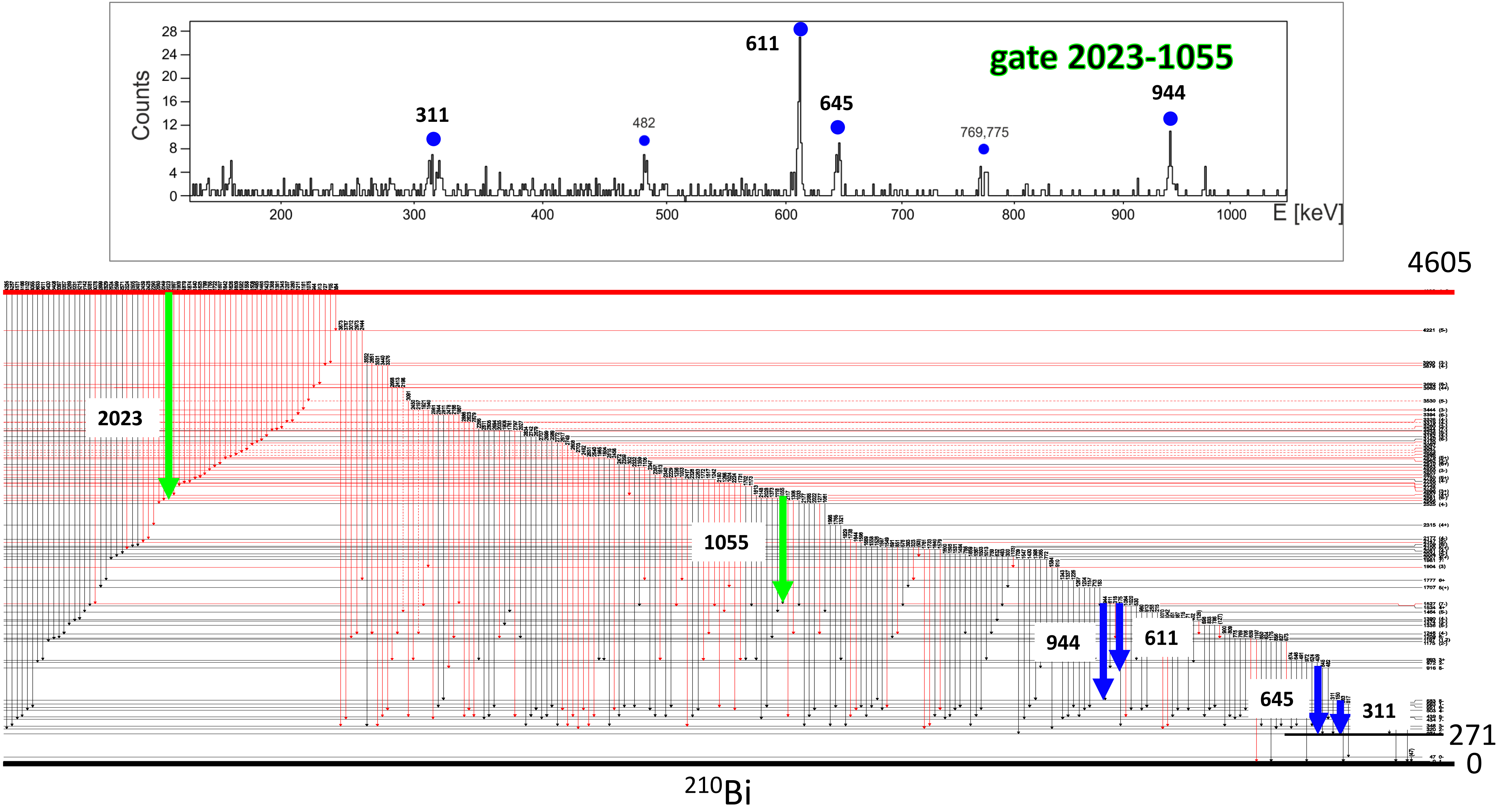
Experimental results: level scheme



Capture state
at neutron binding energy


gate 320
Counts
E [keV]
X-rays
3x
100000
80000
60000
40000
20000
0
500
1000
1500
2000
2500
3000
3500
4000
111
155
183
215
300
320
384
393
409
483
491
511
530
576
624
646
674
706
769
809
827
833
856
900
910,913
1013
1175
1204
1226
1337
1485
1597
1659
1755
28Al
1825
1840
1909
EP
2023,2027
2049
2080
2266
2340,2347
2505
2599
2829
2899
3081
3142
3215
3231
3269
3357
3397
3430
3611
3633
4055
4102
4166
4257
4285
4605
320
0
210Bi


Counts
12000
10000
8000
6000
4000
2000
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
E [keV]
gate 2599
320
674
1013
300
483
530
646
910
4605
2599
1013
674
320
0
210Bi

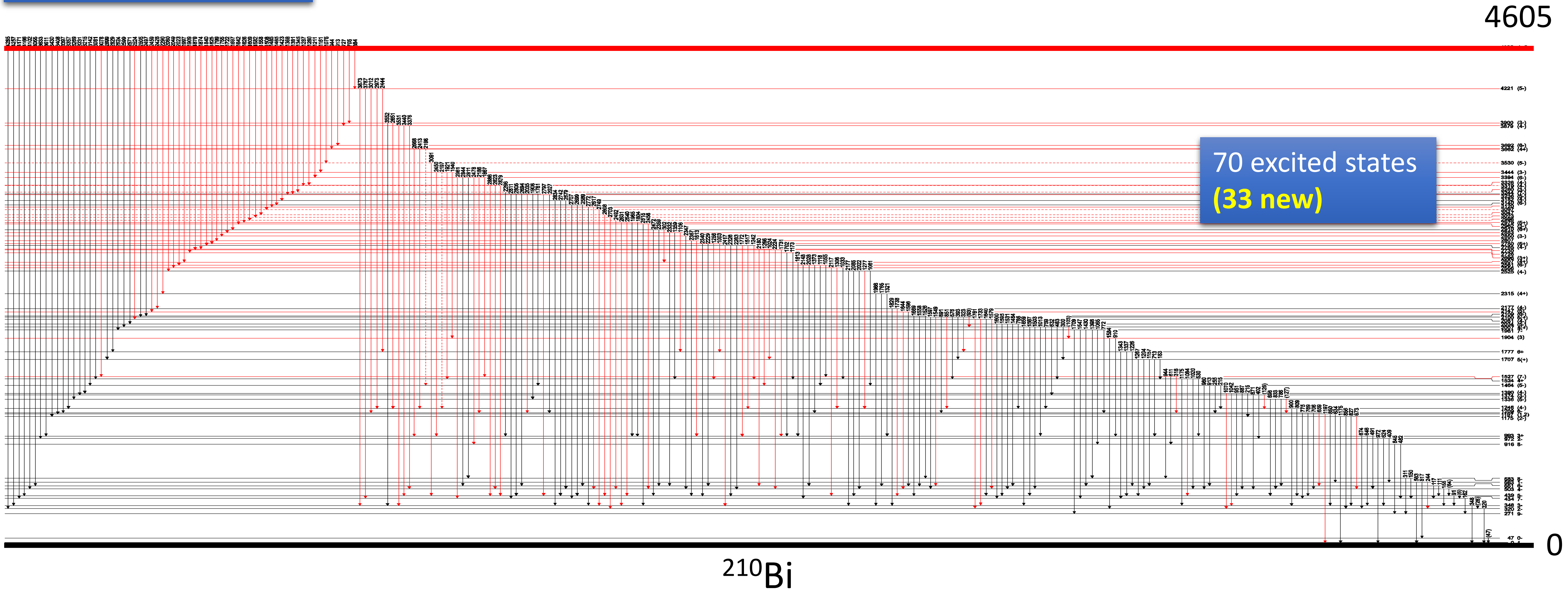

gate 2023-1055
Counts
E [keV]
311
482
611
645
769,775
944
4605
2023
1055
944
611
645
311
271
0
^{210}Bi

Experimental results: level scheme

64 primary transitions
(40 new)

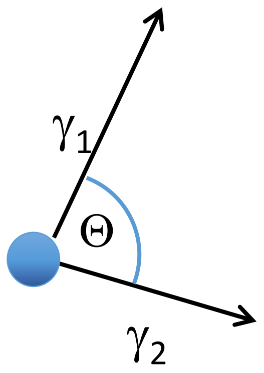
Population of neutron capture state at **4605.2(1) keV**

70 excited states
(33 new)

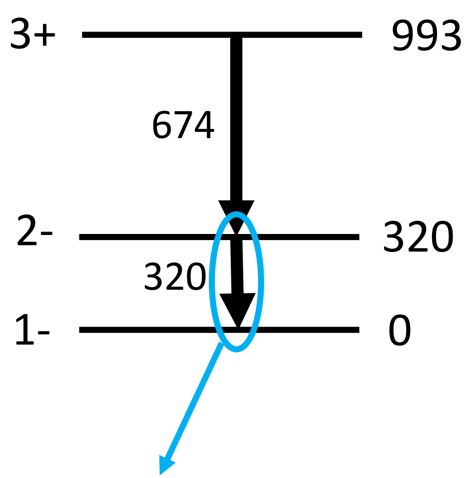


Angular correlations of γ rays from ^{210}Bi

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:



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



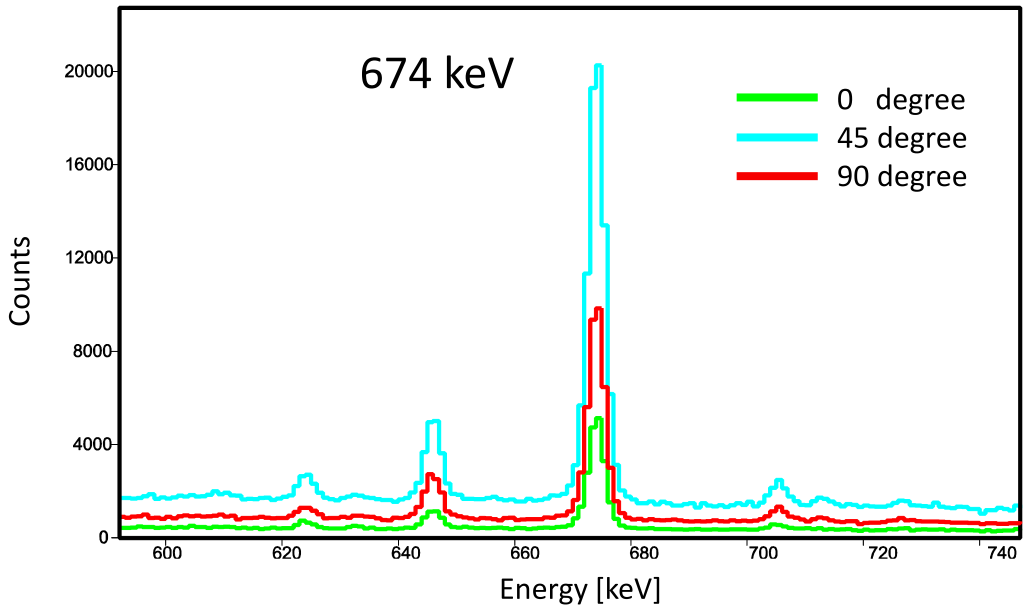
Θ – the angle between the direction of emission of two γ rays

$P_n(\cos\Theta)$ – 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

$q_2 = 0.86(2)$

$q_4 = 0.60(3)$



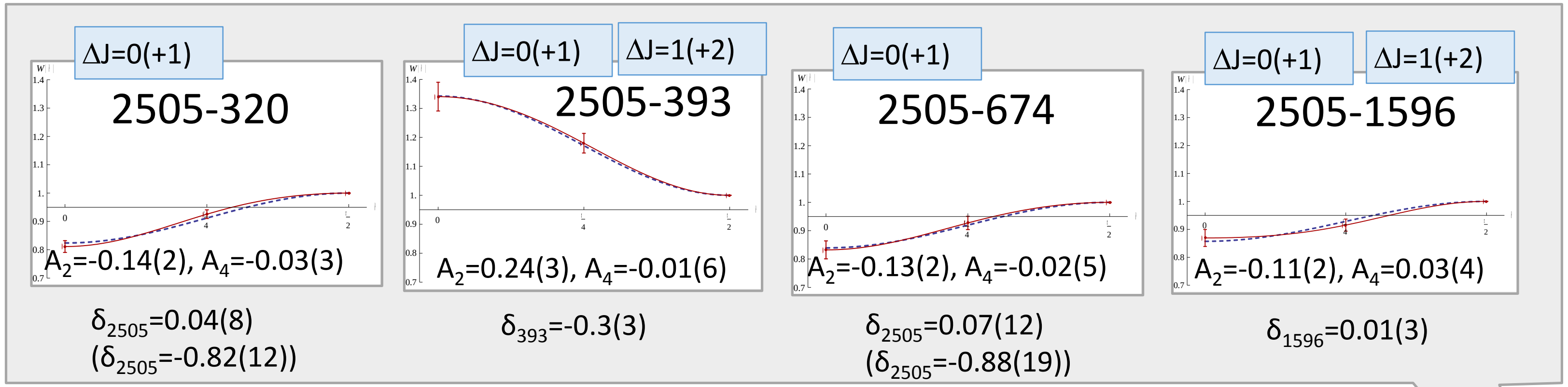
Normalization: number of pairs of the detectors, efficiency → W(Θ)

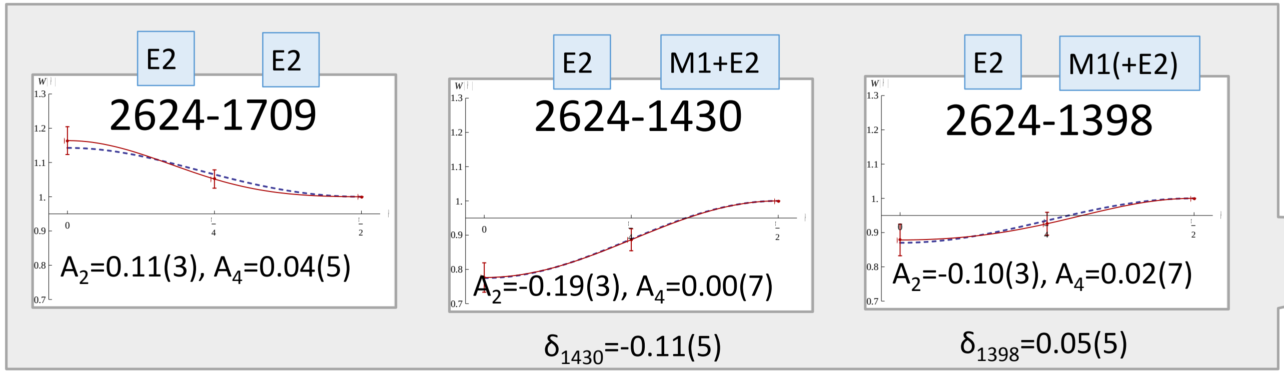
norm0 = 0.495(5) (4 combinations)

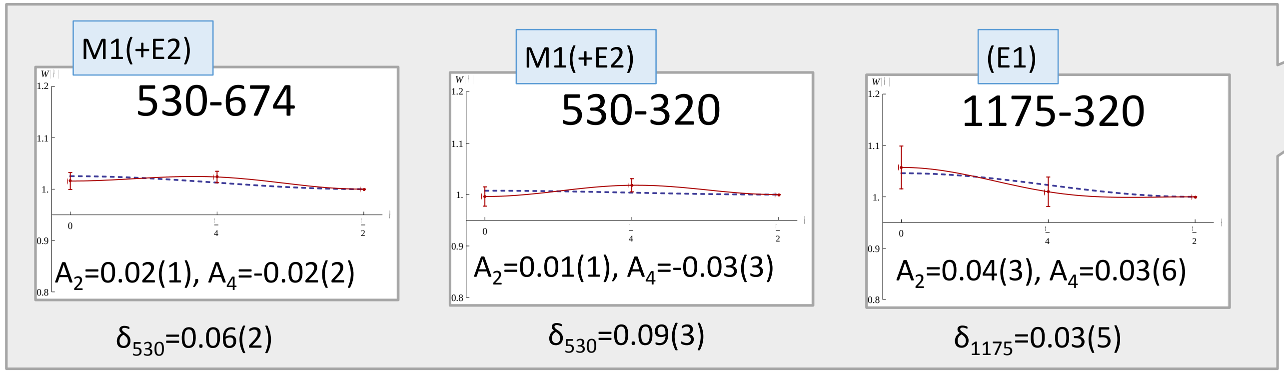
norm45 = 2.020(12) (16 combinations)

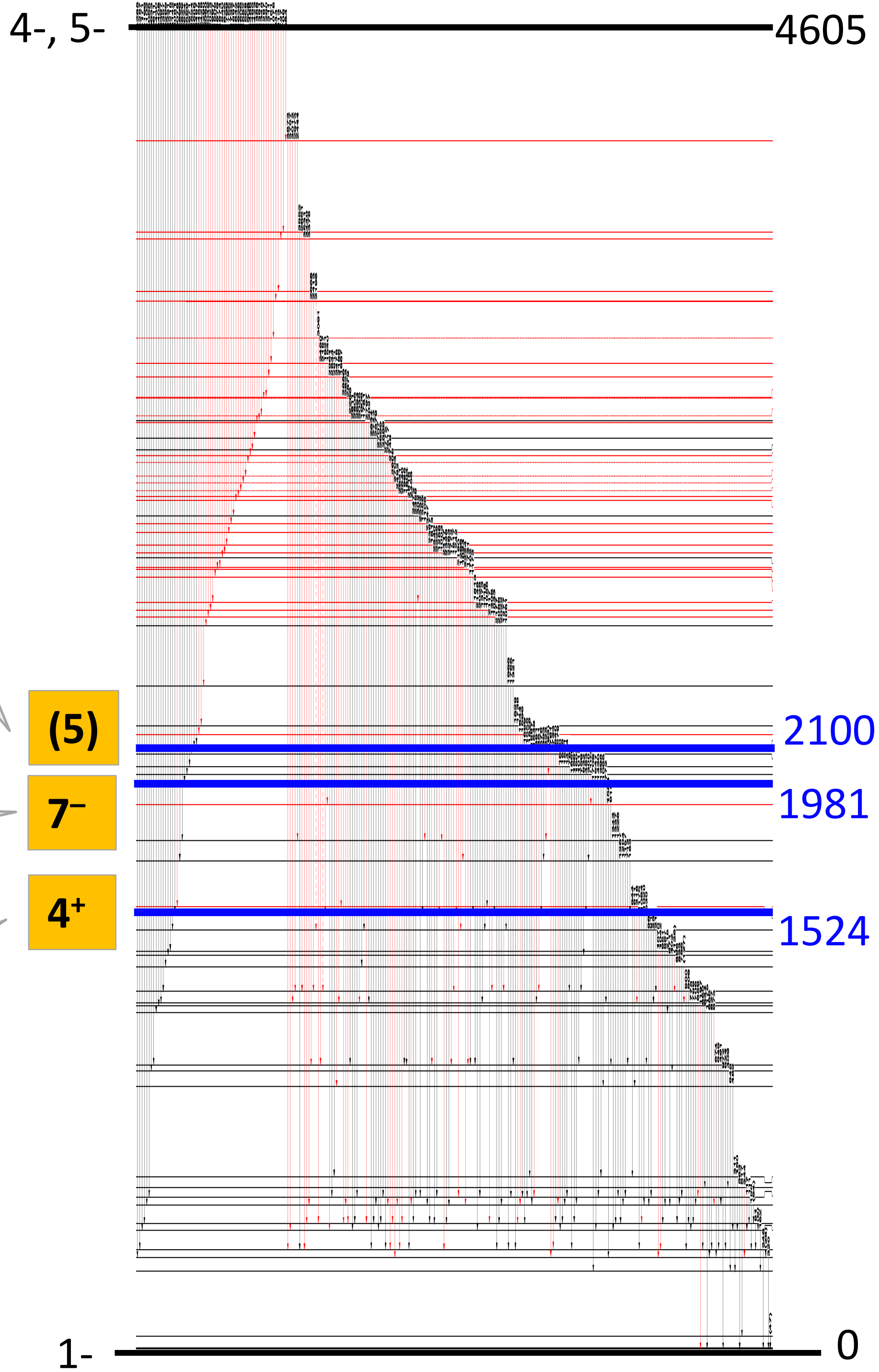
norm90 = 1 (8 combinations)

Spin-parity assignments

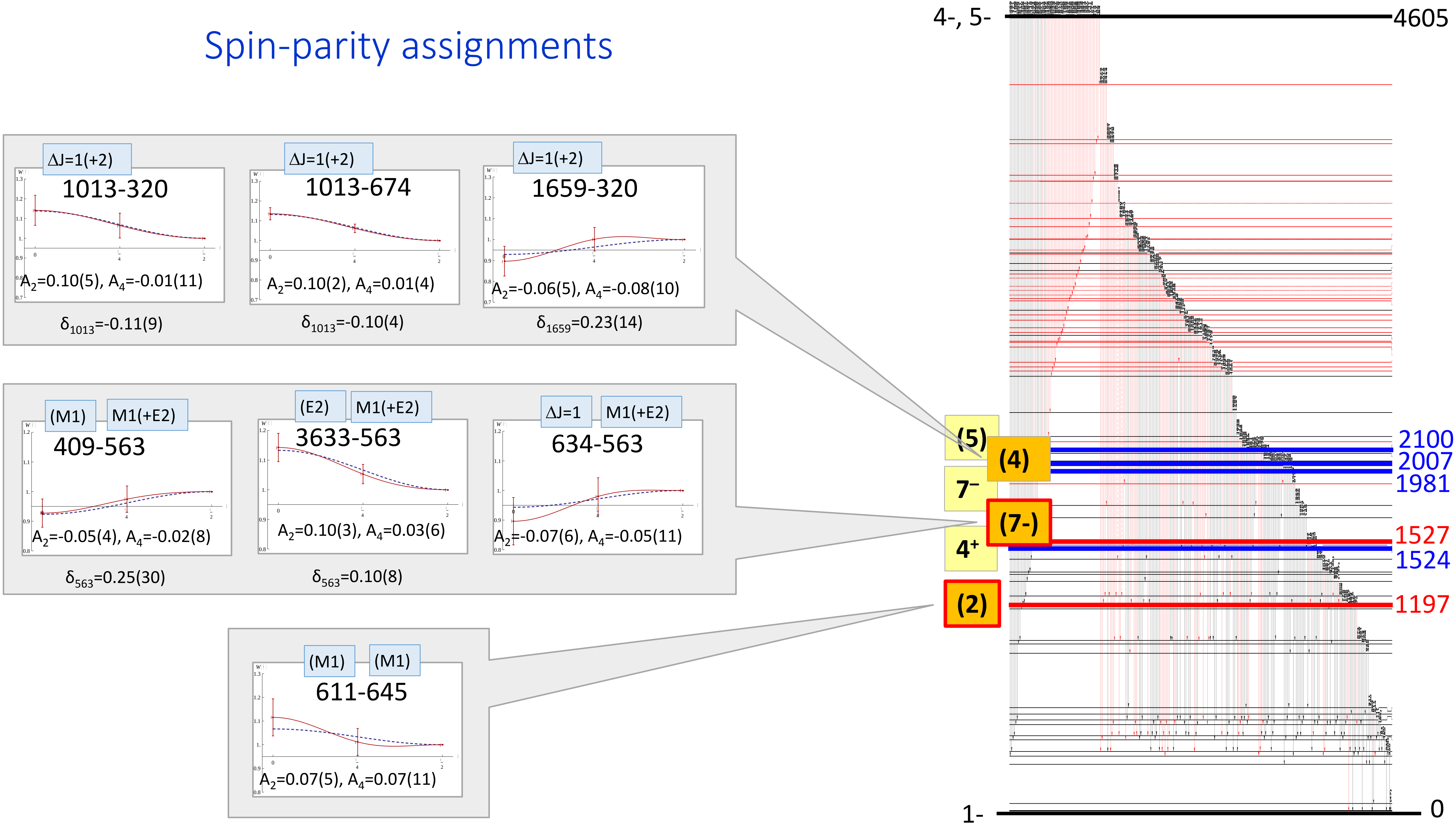




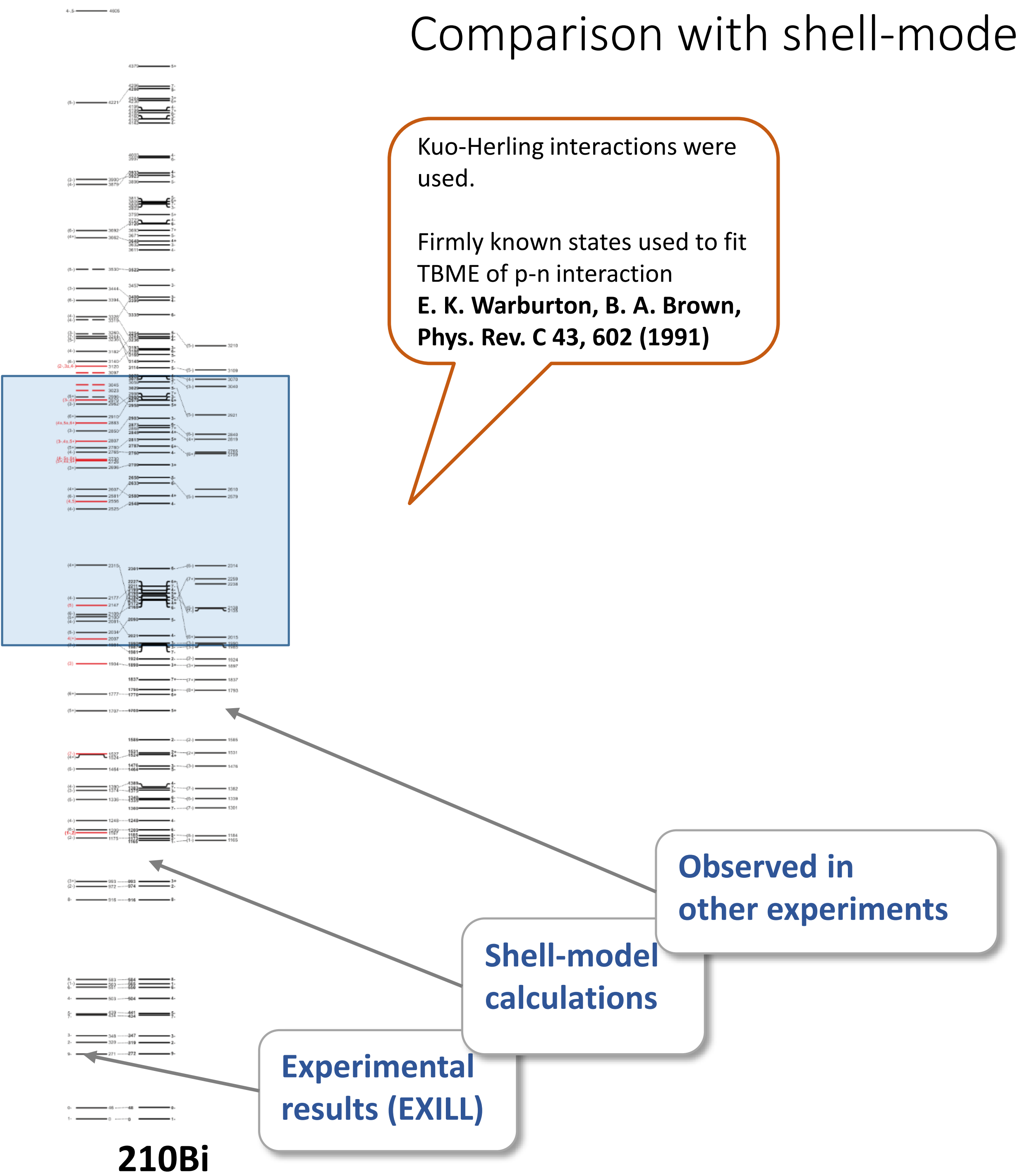




Spin-parity assignments



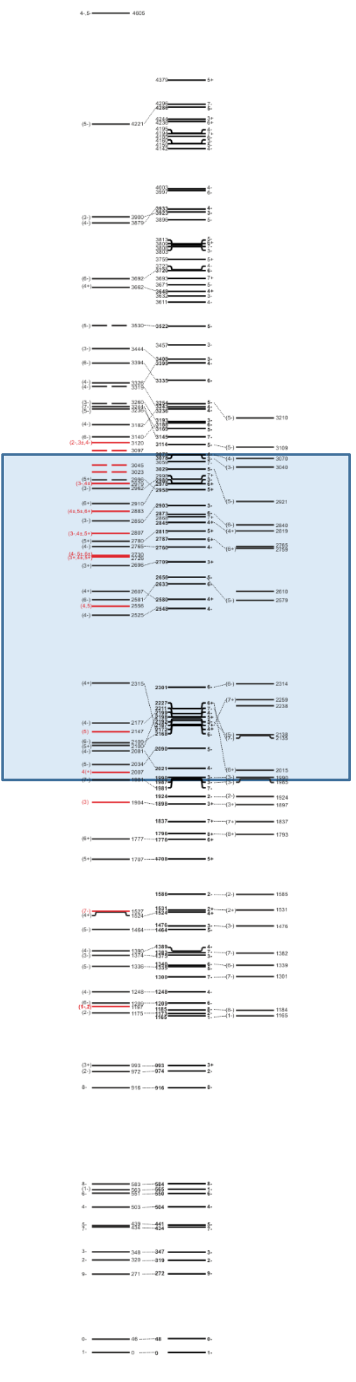
Comparison with shell-model calculations for low-spin states



Kuo-Herling interactions were used.

Firmly known states used to fit TBME of p-n interaction
E. K. Warburton, B. A. Brown, Phys. Rev. C 43, 602 (1991)

Comparison with shell-model calculations for low-spin states



$3^{-} \times (\pi h_{9/2} \nu g_{9/2})$

3- × 0- → 3+

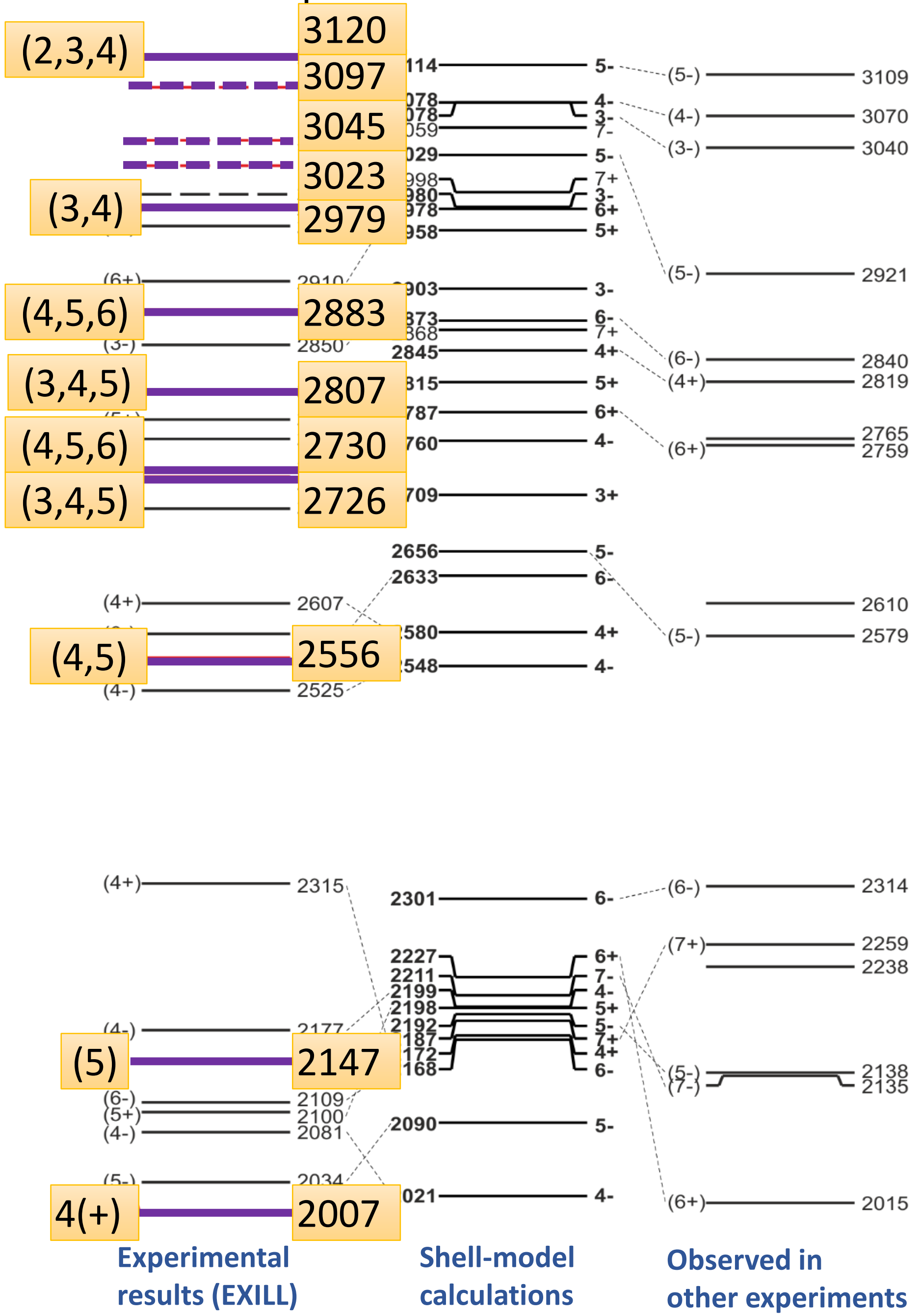
3- × 1- → 2+, 3+, 4+

3- × 9- → 6+, 7+, 8+, (9+, 10+, 11+, 12+)

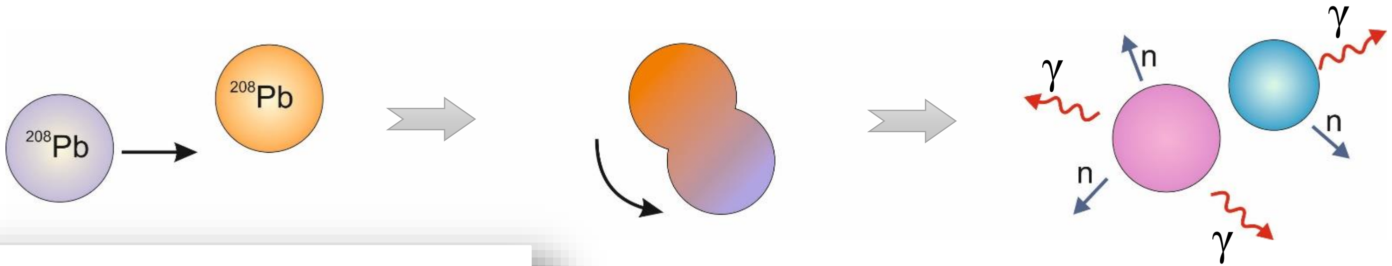
3– 2.6 MeV

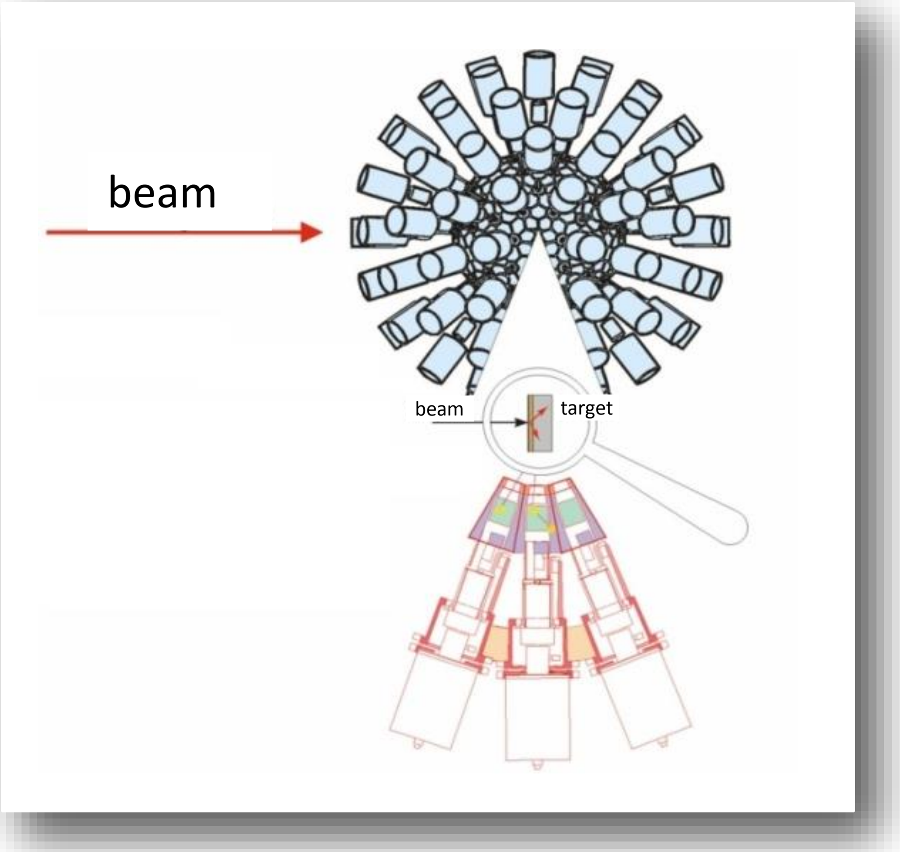
0+ 0

208Pb



Deep-inelastic collisions

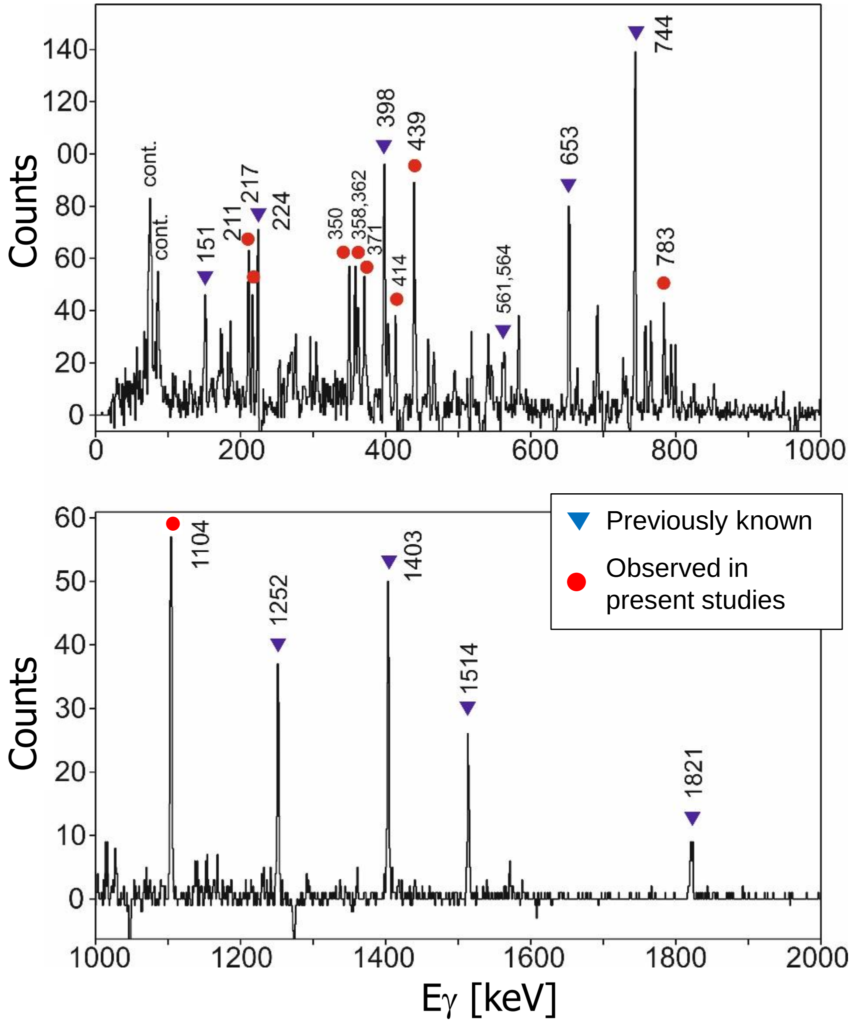




Gammasphere, Argonne National Laboratory, USA

- ^{208}Pb beam on ^{208}Pb target (76mg/cm^2)
- Energy: 1446 MeV (7 MeV/nucleon)
- Pulsed beam ⟹ prompt and delayed gamma-gamma coincidences
- Detectors of Gammasphere divided into 6 rings around beam axis with average values of Θ angle: 17.3°, 35.5°, 52.8°, 69.8°, 79.9°, 90.0°

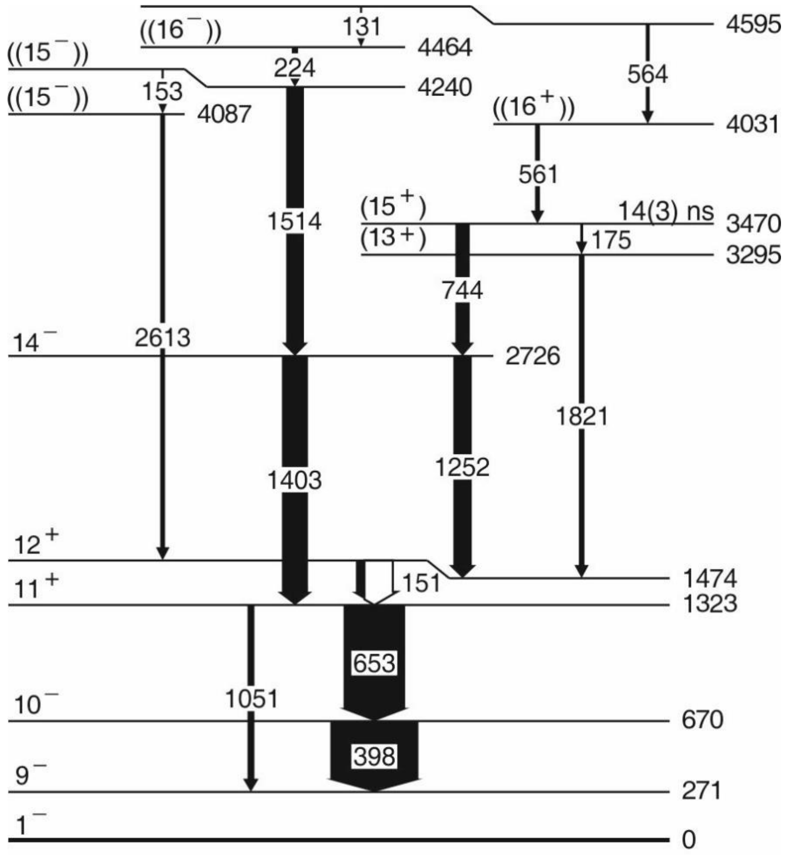
^{210}Bi – level scheme



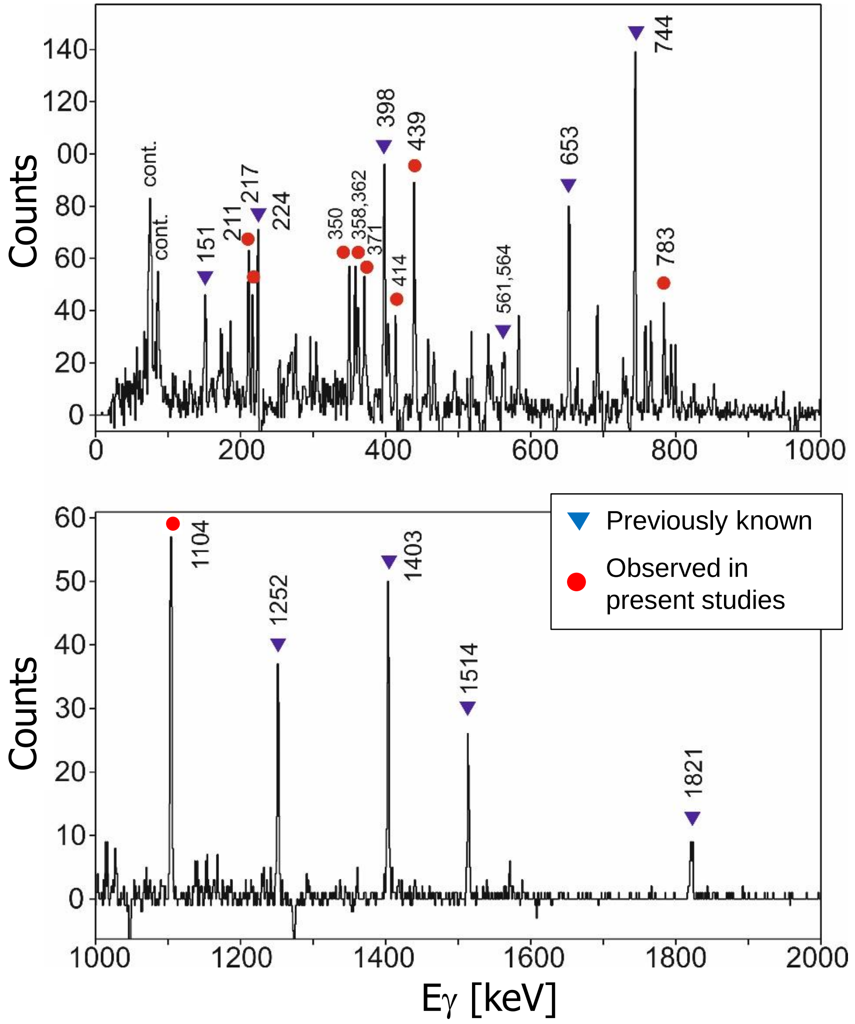
The sum of delayed spectra (double gates on every pair of previously known transitions: 398, 653, 1403, 1514 keV)

Previously known part of the level scheme

(B. Fornal, Habilitation thesis, Raport No. 1939/PL (2004))

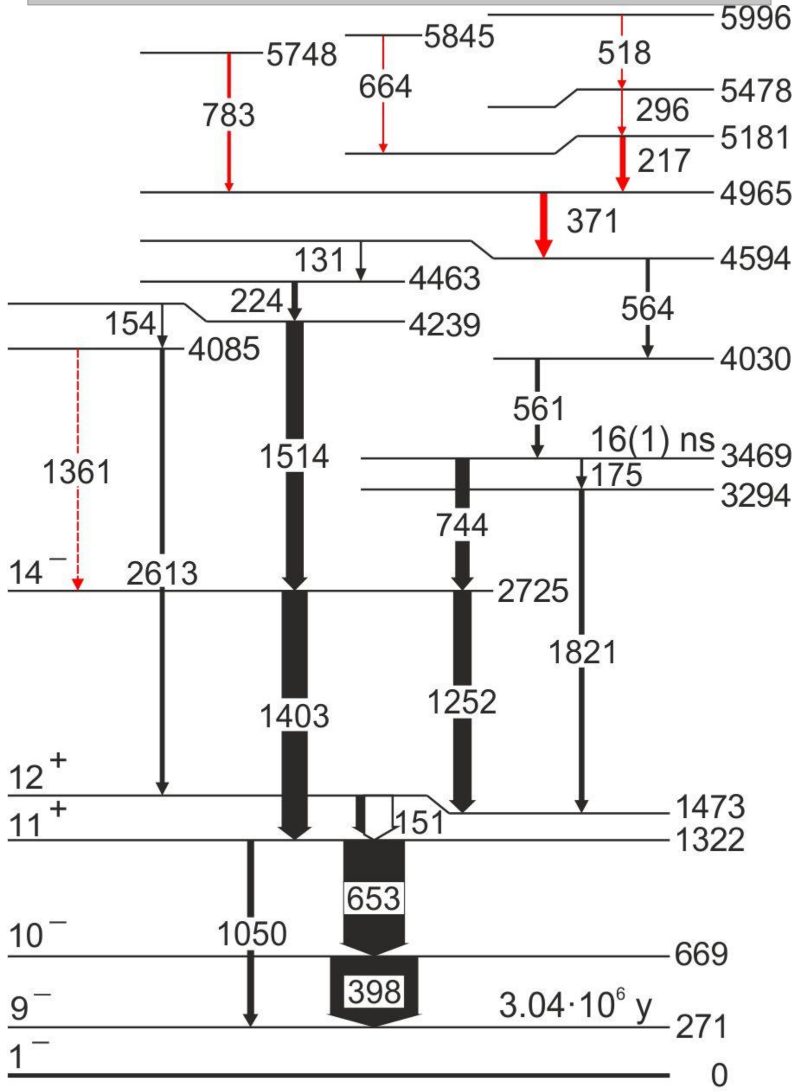


^{210}Bi – Evidence of high-lying isomer at ~10 MeV excitation



The sum of delayed spectra (double gates on every pair of previously known transitions: 398, 653, 1403, 1514 keV)

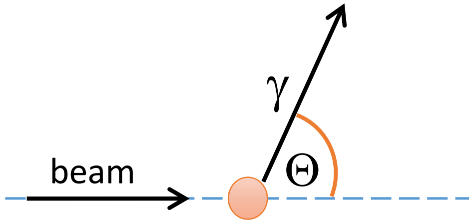
211, 217, 350, 358, 362, 371, 414, 439, 783, 1104 keV



Angular distributions of γ rays from ^{210}Bi

The angular distribution function for a transition $J_i \rightarrow J_f$, where J represents the spin of nuclear state, is usually expressed as:

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



Θ – the angle between the beam direction and the direction of γ ray emission

***P*$_n$(cos Θ)** – Legendre polynomials

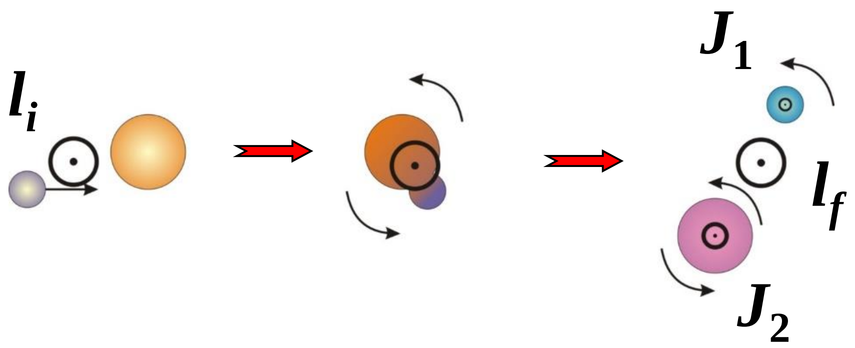
$A_n=\alpha_n A_n^{max}$ – the coefficients which depend on the attenuation factor α_n as well as on the multipolarity of a γ ray and the spins of involved nuclear states

$\alpha_2 = 0.6(1)$

$\alpha_4 = 0.2(5)$

Normalization: isotropic distribution of the 516-881-803-keV cascade deexciting the 125-μs isomer in 206Pb.

Spin alignment



Entrance angular momentum l_i

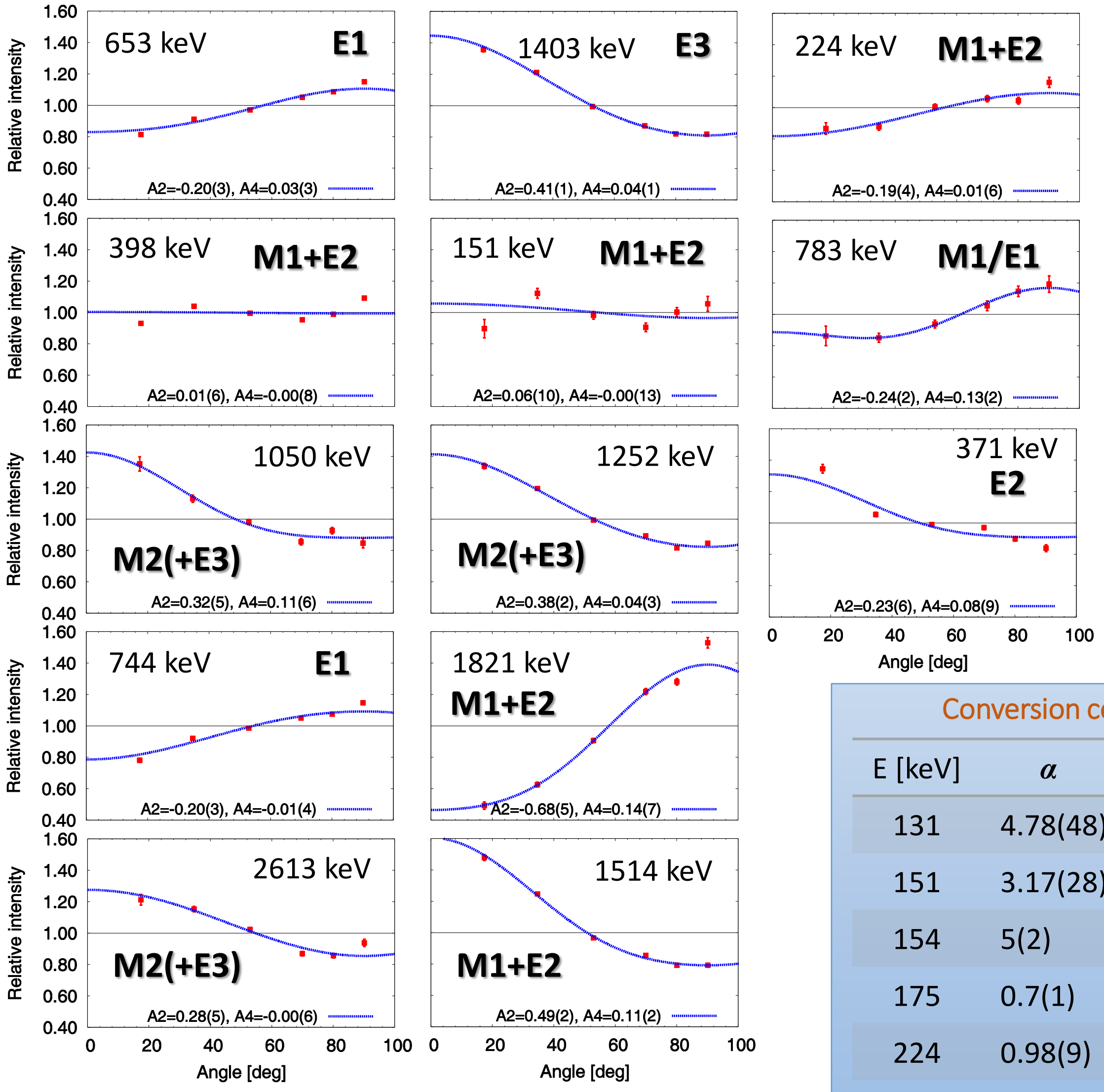
Angular momentum transfer from orbital into intrinsic spin

Exit relative angular momentum l_f and intrinsic spins J_1, J_2 of the fragments

Angular momentum is divided between the fragments according to their masses (assuming rigid rotation)

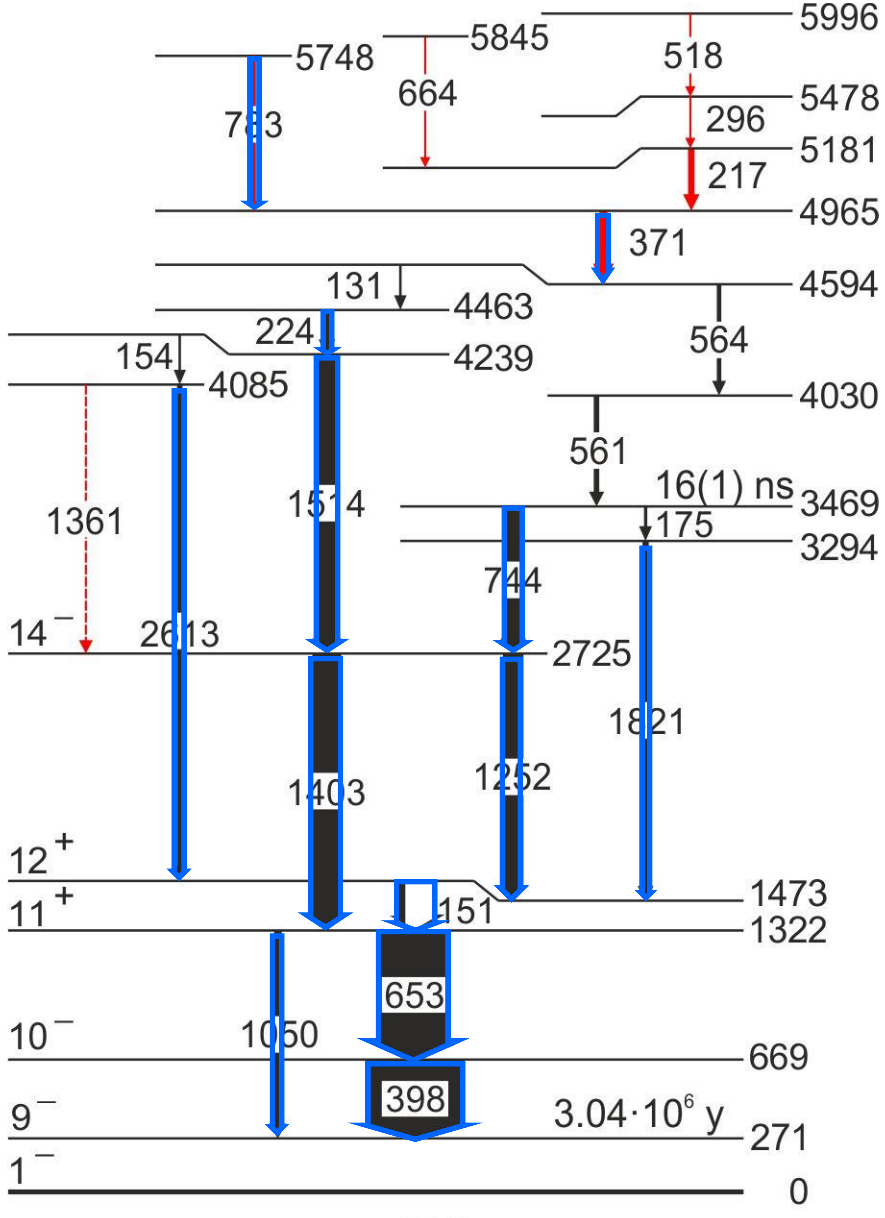
$$\frac{J_1}{J_2} = \left(\frac{A_1}{A_2}\right)^{\frac{5}{3}}$$

Angular distributions of γ rays from ^{210}Bi

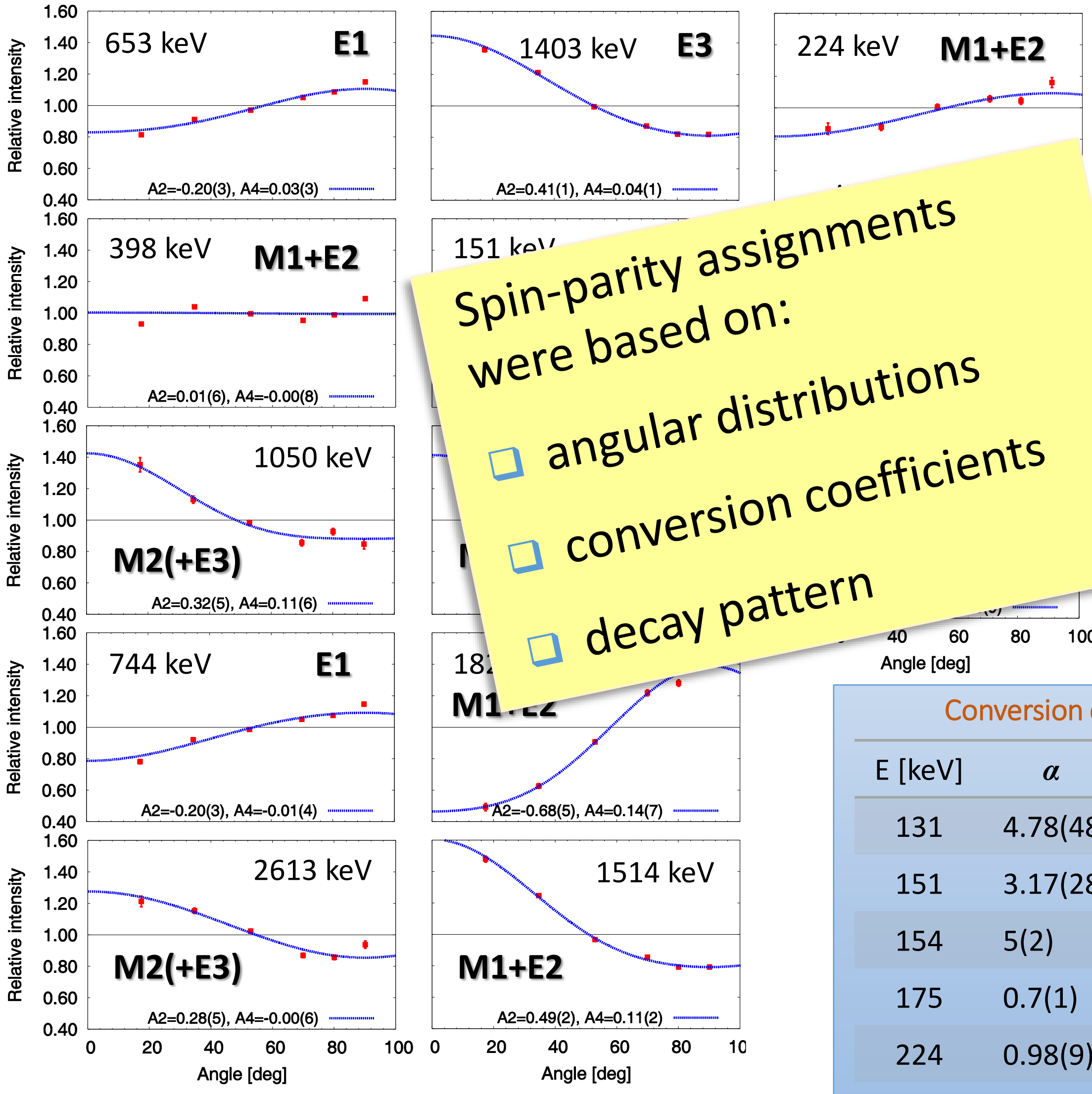


Conversion coefficients

E [keV]	α	Type
131	4.78(48)	M1
151	3.17(28)	M1(+E2)
154	5(2)	M1
175	0.7(1)	E2
224	0.98(9)	M1(+E2)
398	0.19(5)	M1(+E2)



^{210}Bi – spin-parity assignments for the yrast states



Spin-parity assignments were based on:

- angular distributions
- conversion coefficients
- decay pattern

E [keV]	α	Type
131	4.78(48)	M1
151	3.17(28)	M1(+E2)
154	5(2)	M1
175	0.7(1)	E2
224	0.98(9)	M1(+E2)
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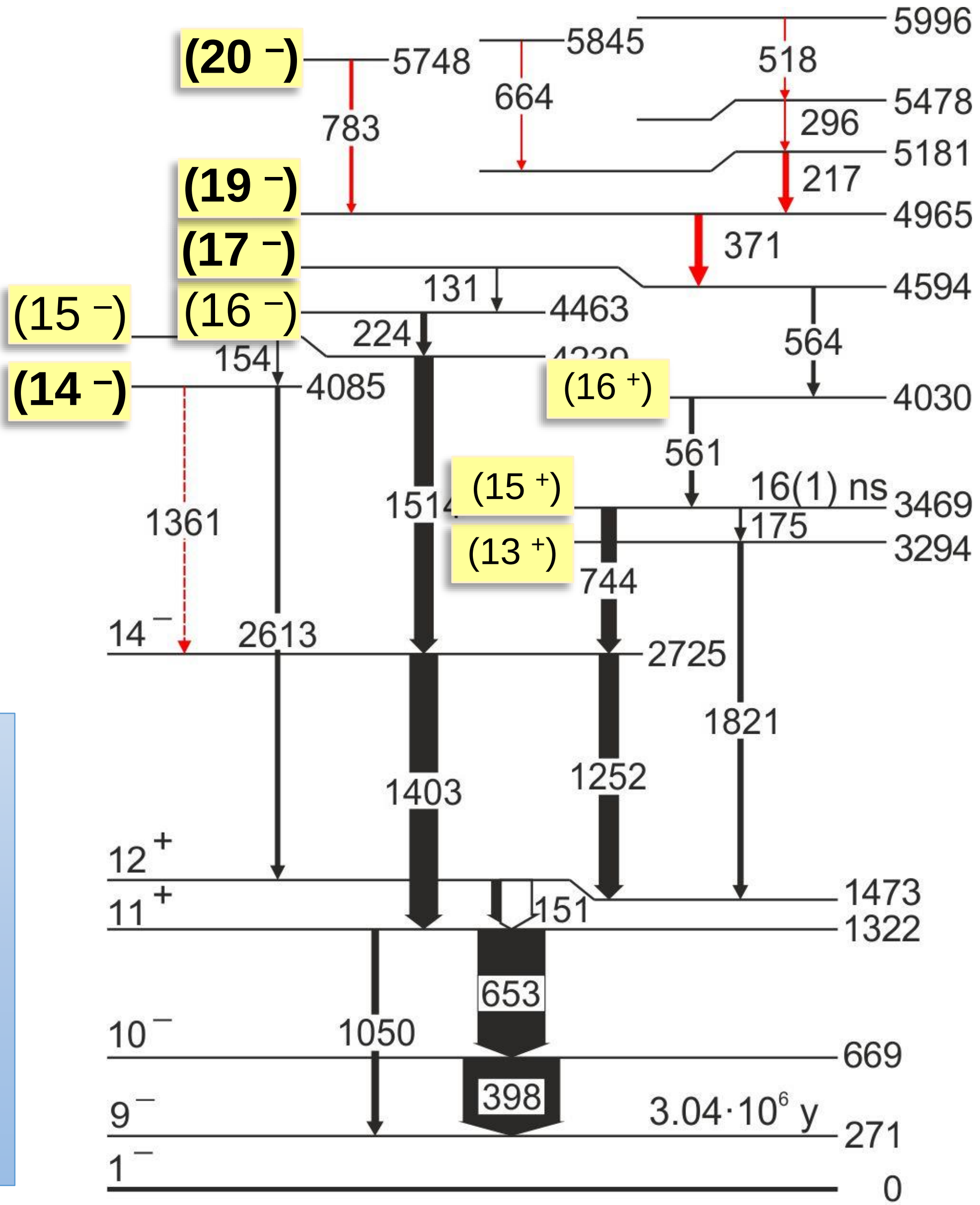
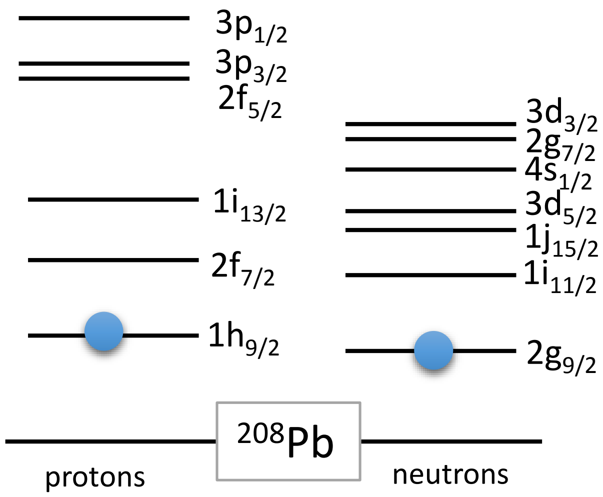
Conversion coefficients



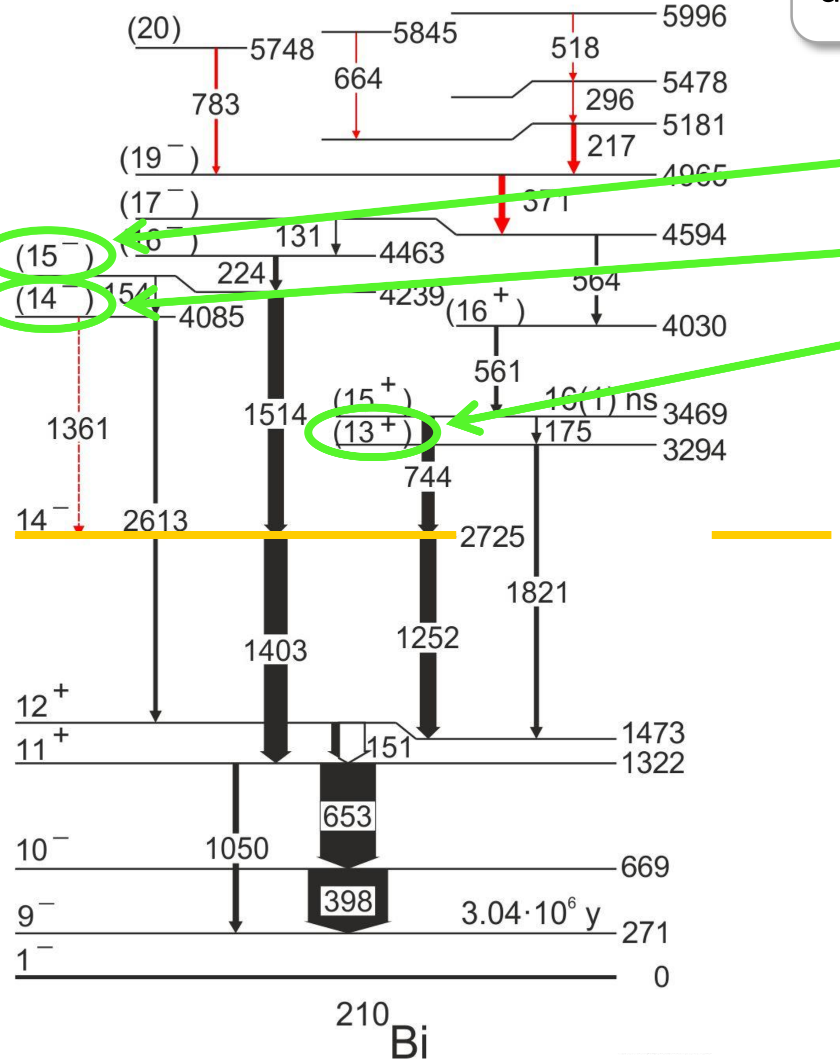
^{210}Bi – shell-model calculations for the yrast states

The higher states involve the promotions of proton or neutron across the energy gap – the calculations with the core excitations must be performed

^{210}Bi structure arises from 1-p 1-n couplings up to the 2725-keV state (14 $^-$)



Couplings with 3$^-$ excitation at 2615 keV in ^{208}Pb



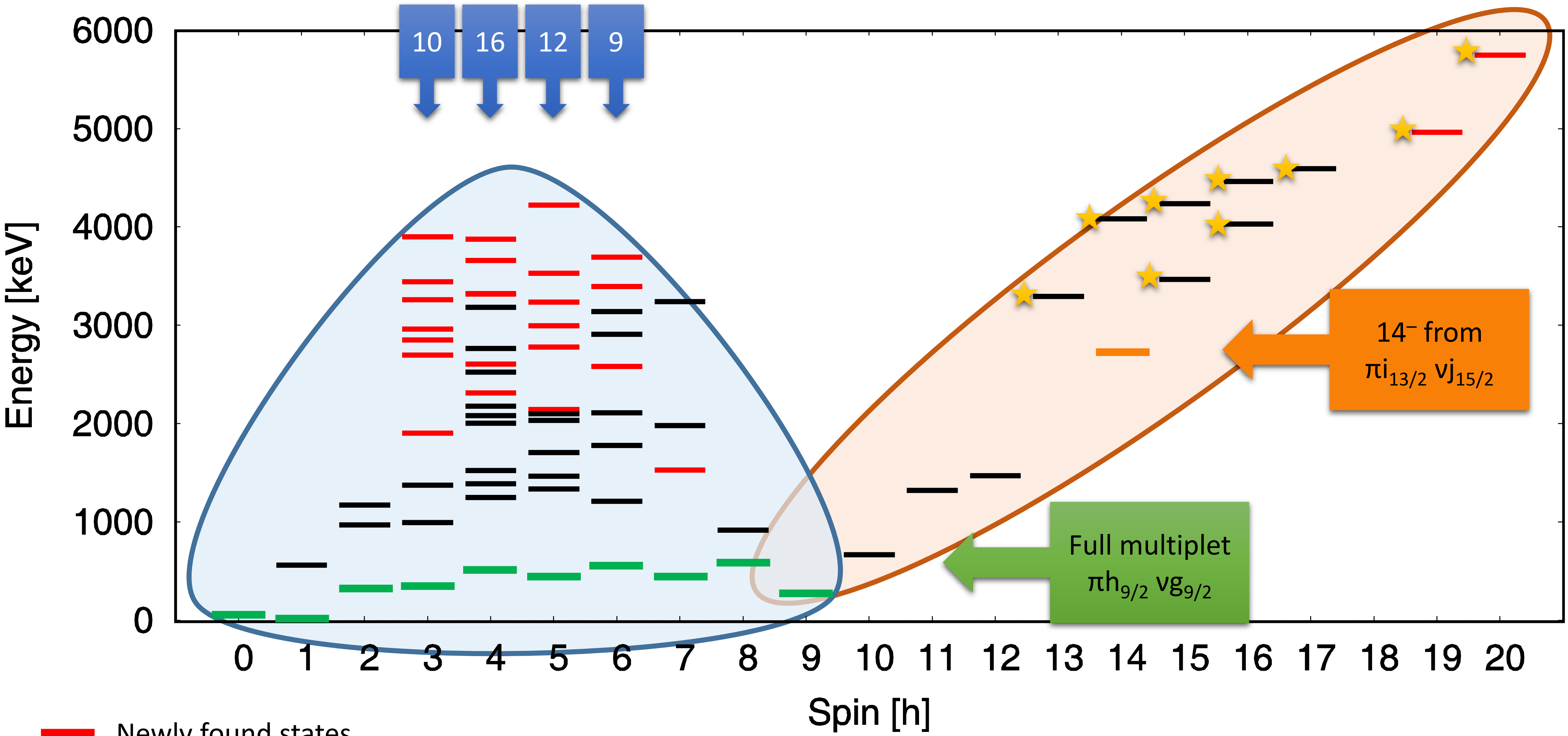
$(\pi h_{9/2}\ \nu\ j_{15/2})12^+ \times 3^-$

$(\pi i_{13/2}\ \nu\ g_{9/2})11^+ \times 3^-$

$(\pi h_{9/2}\ \nu\ g_{9/2})10^- \times 3^-$

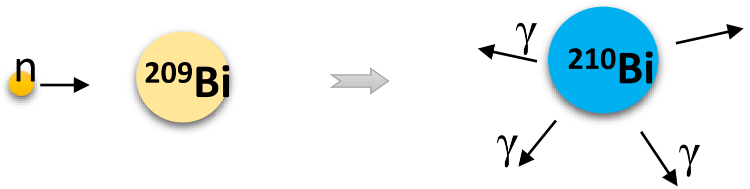
Firmly known states used to fit TBME of p-n interaction
E. K. Warburton, B. A. Brown, Phys. Rev. C 43, 602 (1991)

Spin distribution (experimental results)

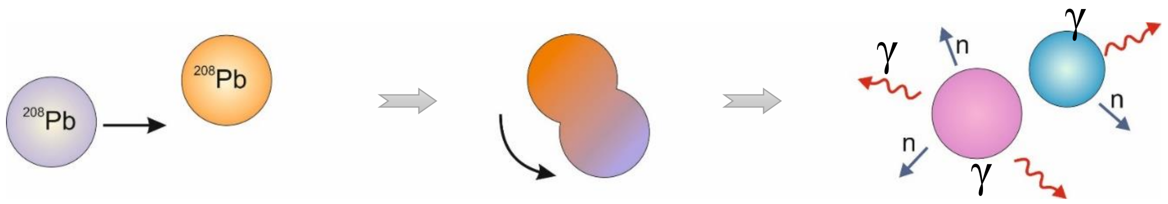


Newly found states

Summary



Cold neutron capture on ^{209}Bi allowed to investigate the low-spin states in ^{210}Bi nucleus below ~4.6 MeV excitation



Deep-inelastic reactions made possible to study high-spin yrast structure of ^{210}Bi nucleus up to ~6 MeV excitation

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

- The results of present analysis of ^{210}Bi structure will serve as an excellent testing ground for the future calculations.

Collaboration

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Thank you for your attention!