Spin alignment in deep-inelastic reactions – how high is it in experiments with thick target?

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Physics motivation

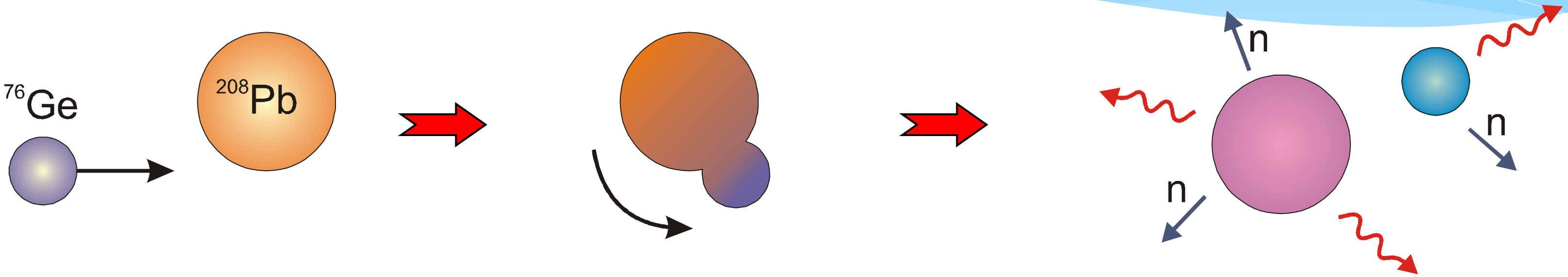
1. Spins of isomers produced in a **fusion-evaporation** reactions show **high degree of alignment** in the plane perpendicular to the beam direction, this is used in the measurements of magnetic moments.

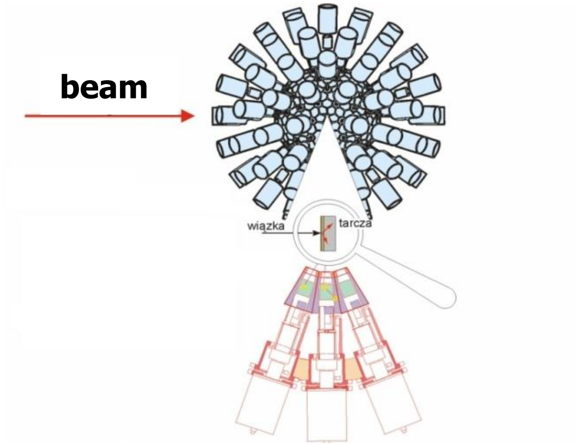
2. Some nuclei (e.g. neutron-rich) cannot be reached in fusion reactions.

3. A way of getting to them are **deep-inelastic collisions**.

4. Do the products of deep-inelastic reactions show sufficient spin alignment for the measurements of magnetic moments? – angular distributions as a way to check it.

Deep-inelastic collisions

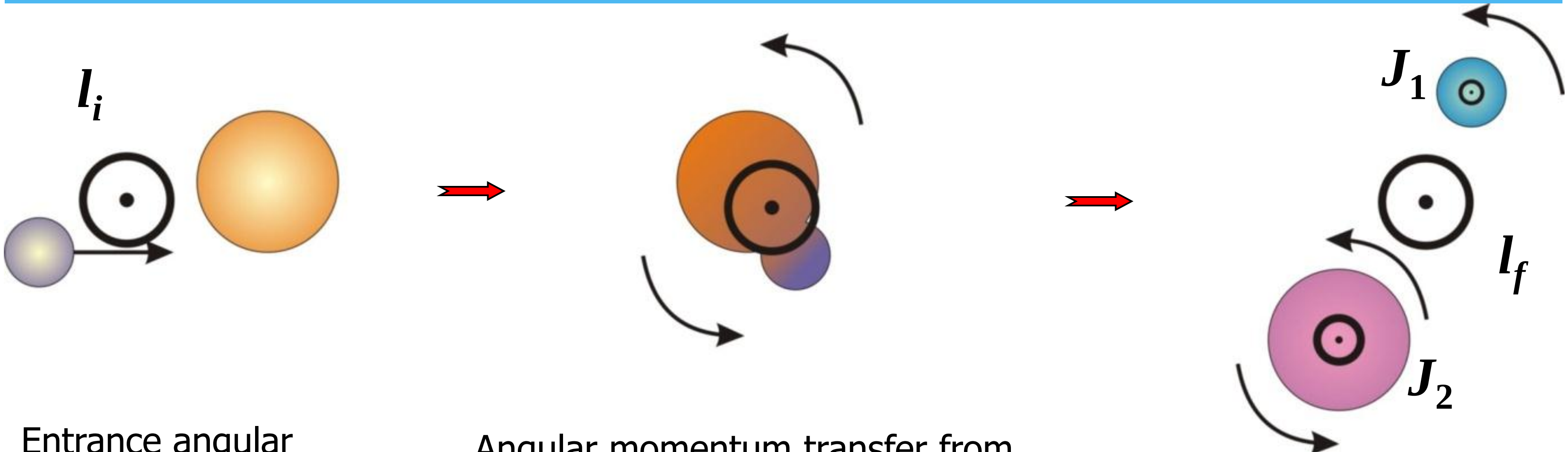




GAMMASPHERE, Argonne National Laboratory, USA

- ^{76}Ge (450MeV) beam on ^{208}Pb (50mg/cm^2) target ⟹ deep-inelastic collisions
- Pulsed beam ⟹ prompt and delayed gamma-gamma coincidences

Spin transfer in deep-inelastic reactions



Entrance angular momentum l_i

Angular momentum transfer from orbital into intrinsic rotation

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

$$l_i = J_1 + J_2 + l_f$$

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

Previous works in 70', 80'

* „The anisotropy of E2 transitions rises with increasing spin transfer"
G. J. Wozniak et. al., Phys. Rev. Lett. ***45****, 1081 (1980)*

* „The anisotropies of stretched E2 transitions (…) imply rather strong alignment"
G. Mouchaty et. al., Z. Phys. A ***316****, 285 (1984)*

* „The angular momentum gained by the reactants should be oriented perpendicular to the reaction plane. In reality, however, they have sizable dispersion in their orientation"
K. Krishan et. al., J. Phys. G ***14****, 1423 (1988)*

Angular distributions – Yamazaki formalism

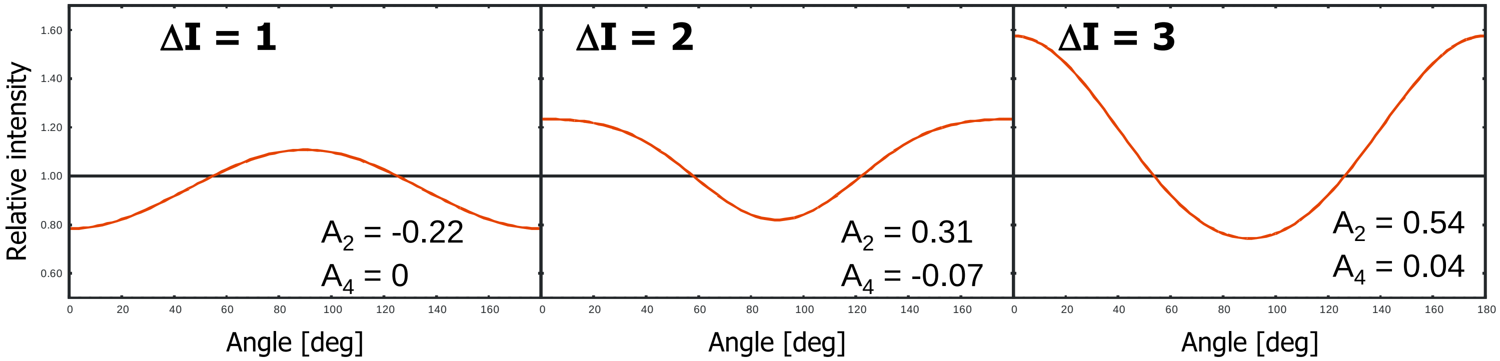
The angular-distribution function for a transition $J_i \rightarrow J_f$, where J represents the spin of the nuclear state is usually expressed as:

$$W(\Theta) = 1 + \alpha_2 A_2^{max} P_2(\cos\Theta) + \alpha_4 A_4^{max} P_4(\cos\Theta)$$

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

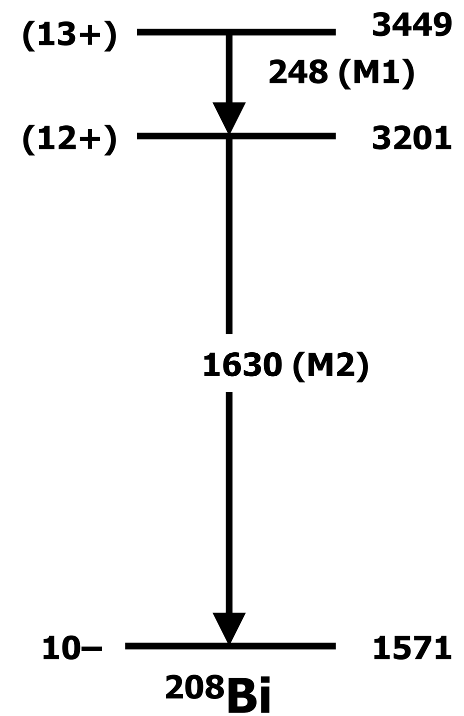
$P_n(\cos\Theta)$ – Legendre polynomials

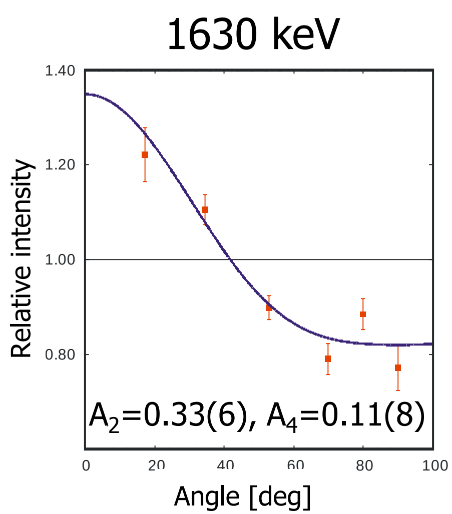
α_n – attenuation coefficient

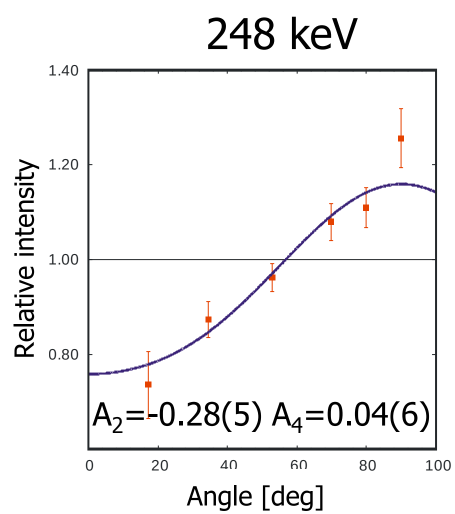


Angular distributions for nuclei around ^{208}Pb

Z \ N	122	123	124	125	126	127	128	129	N
Z	206Po 8.8 D ϵ: 94.55% α: 5.45%	207Po 5.80 H ϵ: 99.98% α: 0.02%	208Po 2.898 Y α: 100.00% ϵ: 4.0E-3%	209Po 102 Y α: 99.52% ϵ: 0.48%	210Po 138.376 D α: 100.00%	211Po 0.516 S α: 100.00%	212Po 0.299 µS α: 100.00%	213Po 3.72 µS α: 100.00%	214Po 164.3 µS α: 100.00%
83	205Bi 15.31 D ϵ: 100.00%	206Bi 6.243 D ϵ: 100.00%	207Bi 31.55 Y ϵ: 100.00%	^{208}Bi	209Bi STABLE 100%	210Bi 5.012 D β-: 100.00% α: 1.3E-4%	211Bi 2.14 M α: 99.72% β-: 0.28%	212Bi 60.55 M β-: 64.06% α: 35.94%	213Bi 45.59 M β-: 97.80% α: 2.20%
82	204Pb ≥1.4E+17 Y 1.4% α	205Pb 1.73E+7 Y ϵ: 100.00%	206Pb STABLE 24.1%	207Pb STABLE 22.1%	^{208}Pb	209Pb 3.253 H β-: 100.00%	210Pb 22.20 Y β-: 100.00% α: 1.9E-6%	211Pb 36.1 M β-: 100.00%	212Pb 10.64 H β-: 100.00%
81	203Tl STABLE 29.524%	204Tl 3.783 Y β-: 97.08% ϵ: 2.92%	205Tl STABLE 70.48%	206Tl 4.202 M β-: 100.00%	207Tl 4.77 M β-: 100.00%	208Tl 3.053 M β-: 100.00%	209Tl 2.161 M β-: 100.00%	210Tl 1.30 M β-: 100.00% β-n: 7.0E-3%	211Tl >300 NS β-
80	202Hg STABLE 29.86%	203Hg 46.594 D β-: 100.00%	204Hg STABLE 6.87%	205Hg 5.14 M β-: 100.00%	206Hg 8.32 M β-: 100.00%	207Hg 2.9 M β-: 100.00%	208Hg 41 M β-: 100.00%	209Hg 35 S β-: 100.00%	210Hg >300 NS β-







Angular distributions for nuclei around ^{208}Pb

Z									
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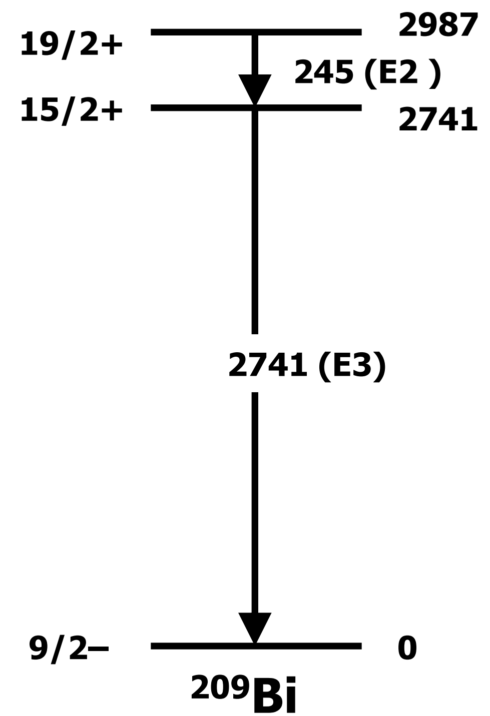
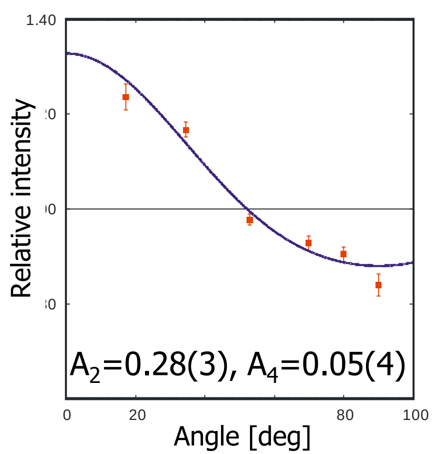
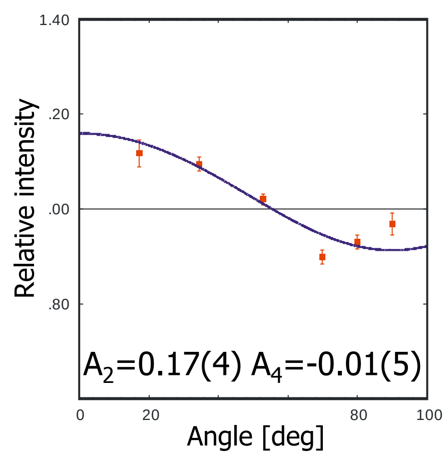


2741 keV



245 keV



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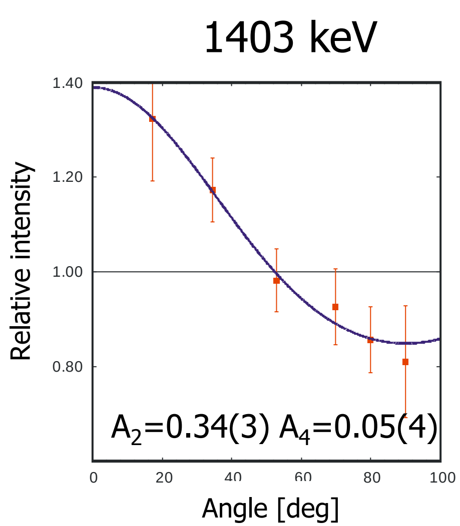
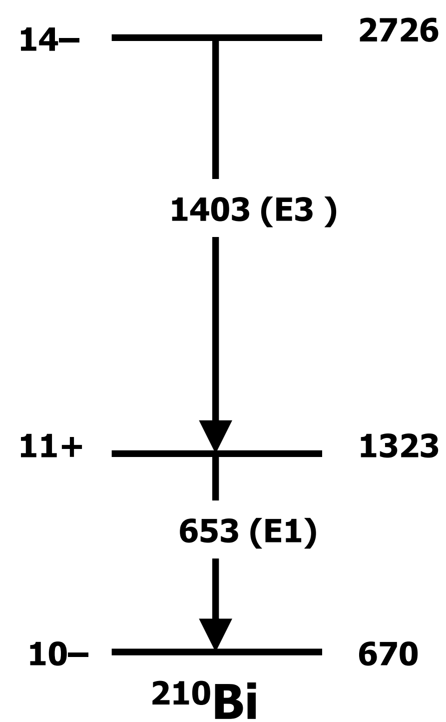
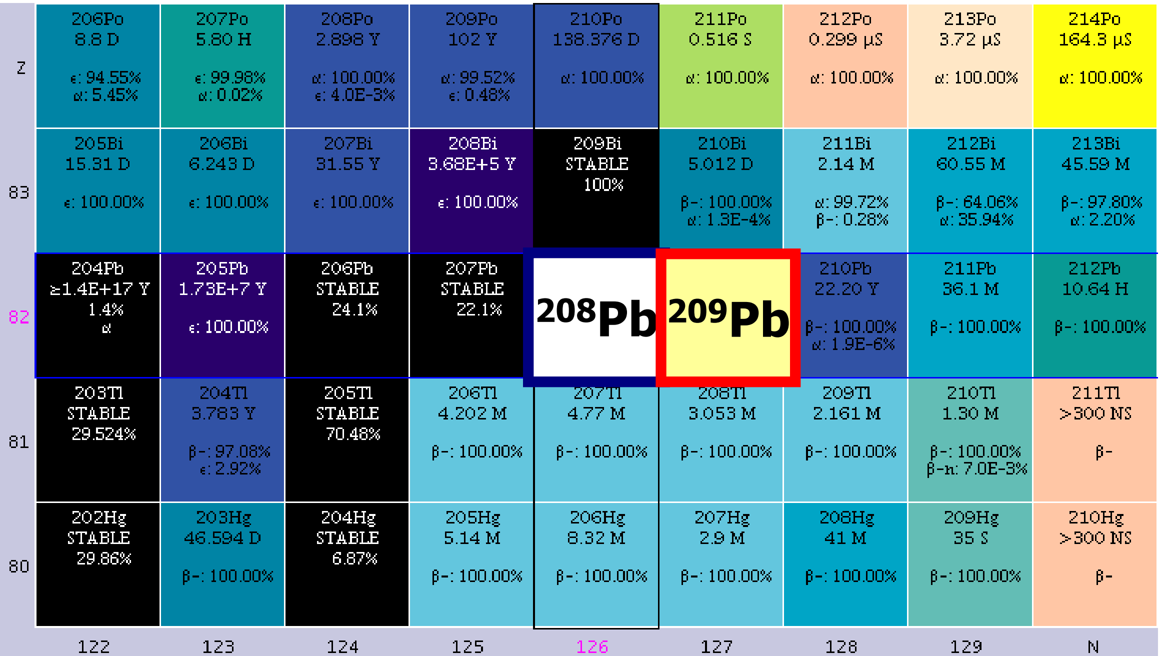
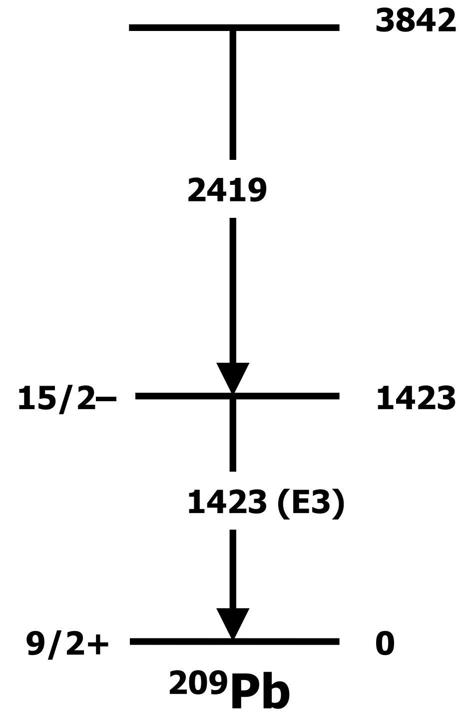
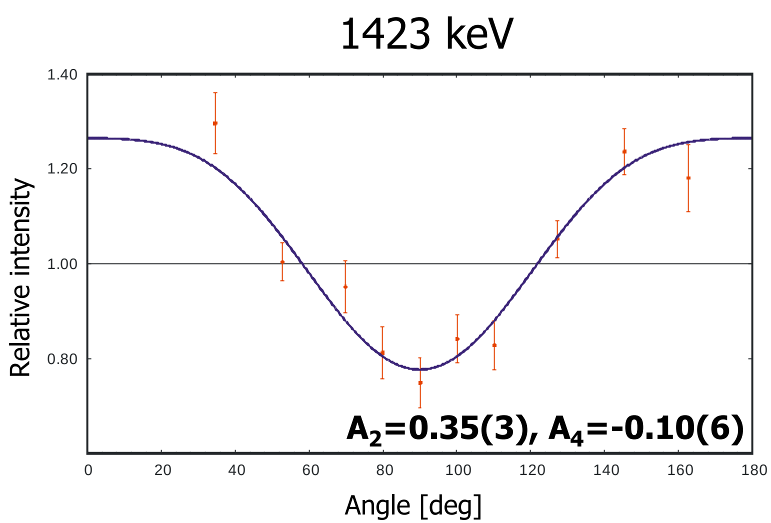


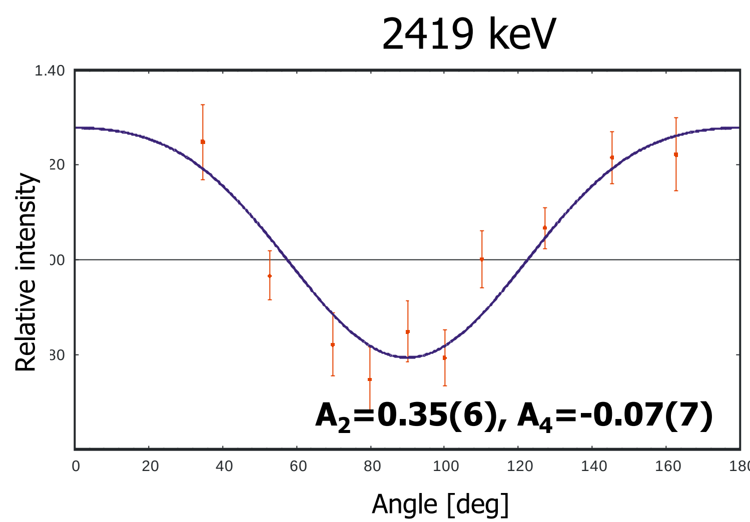


Angular distributions for nuclei around ^{208}Pb

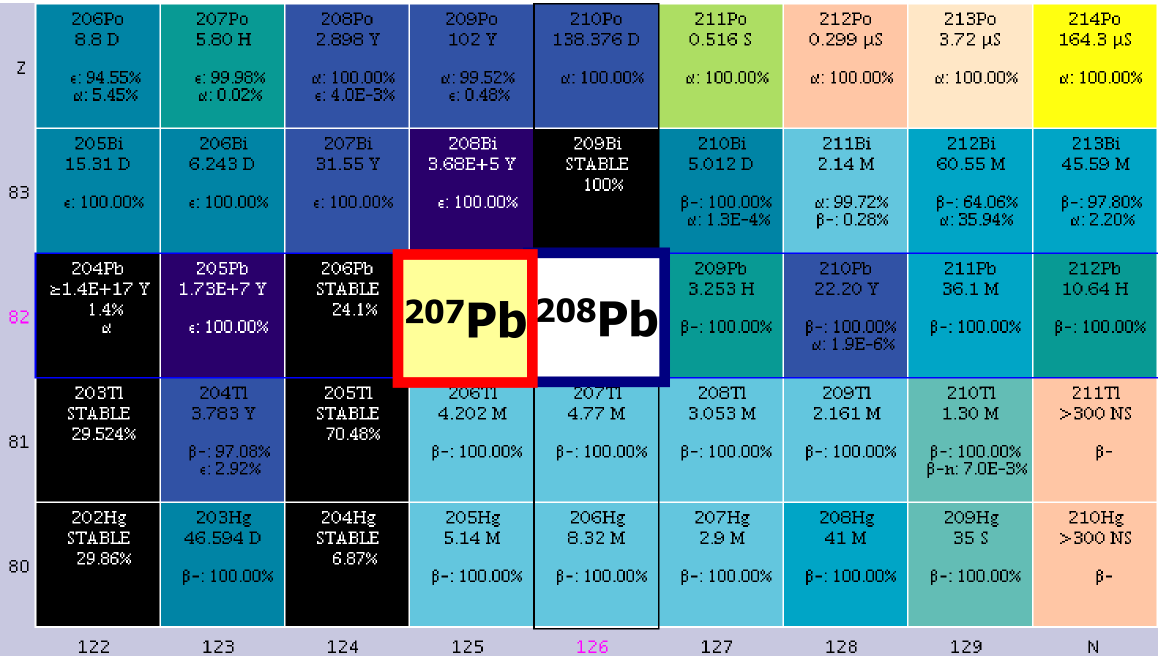


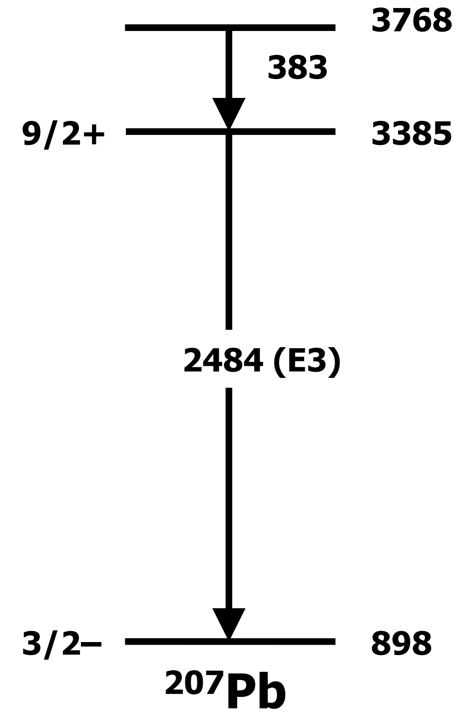




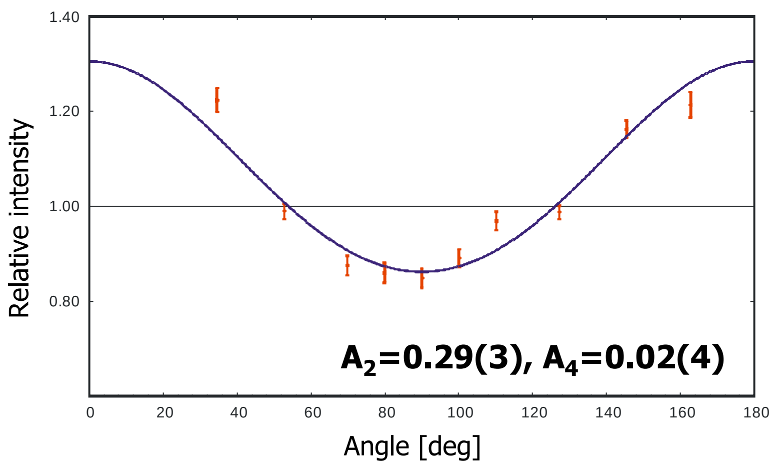


Angular distributions for nuclei around ^{208}Pb

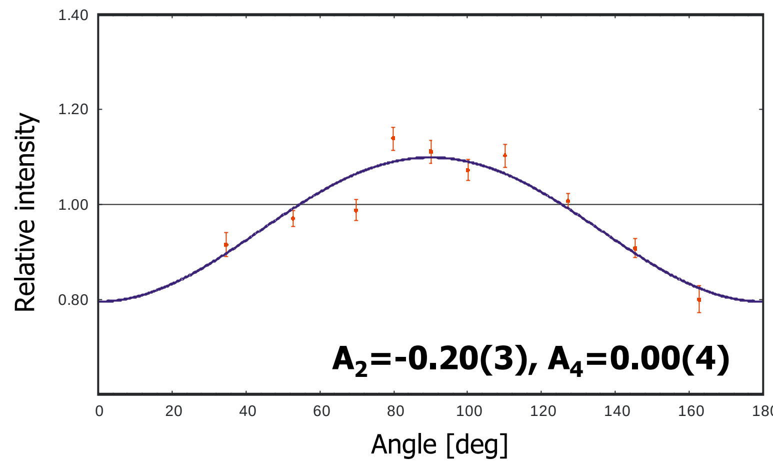




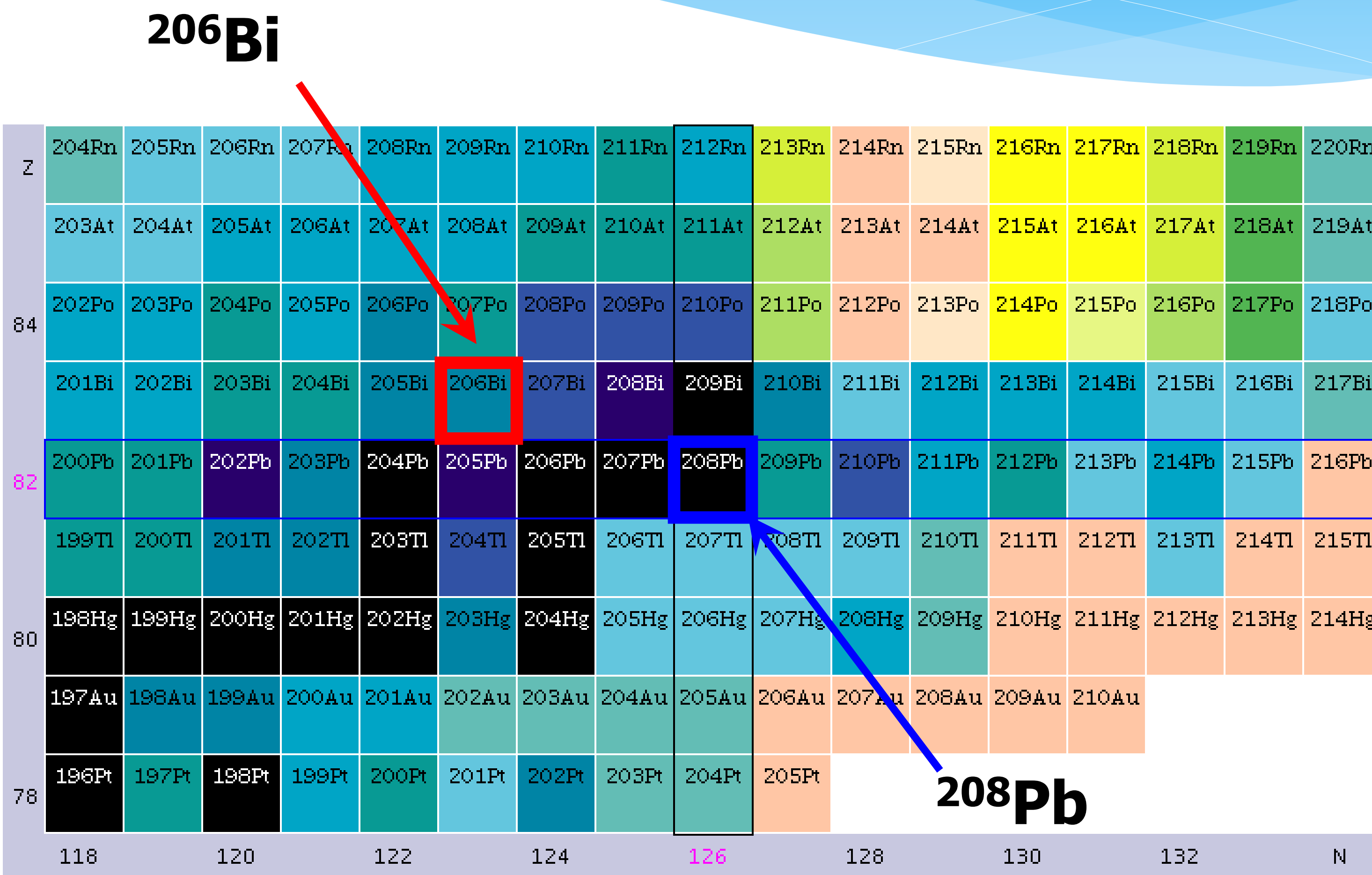
2484 keV

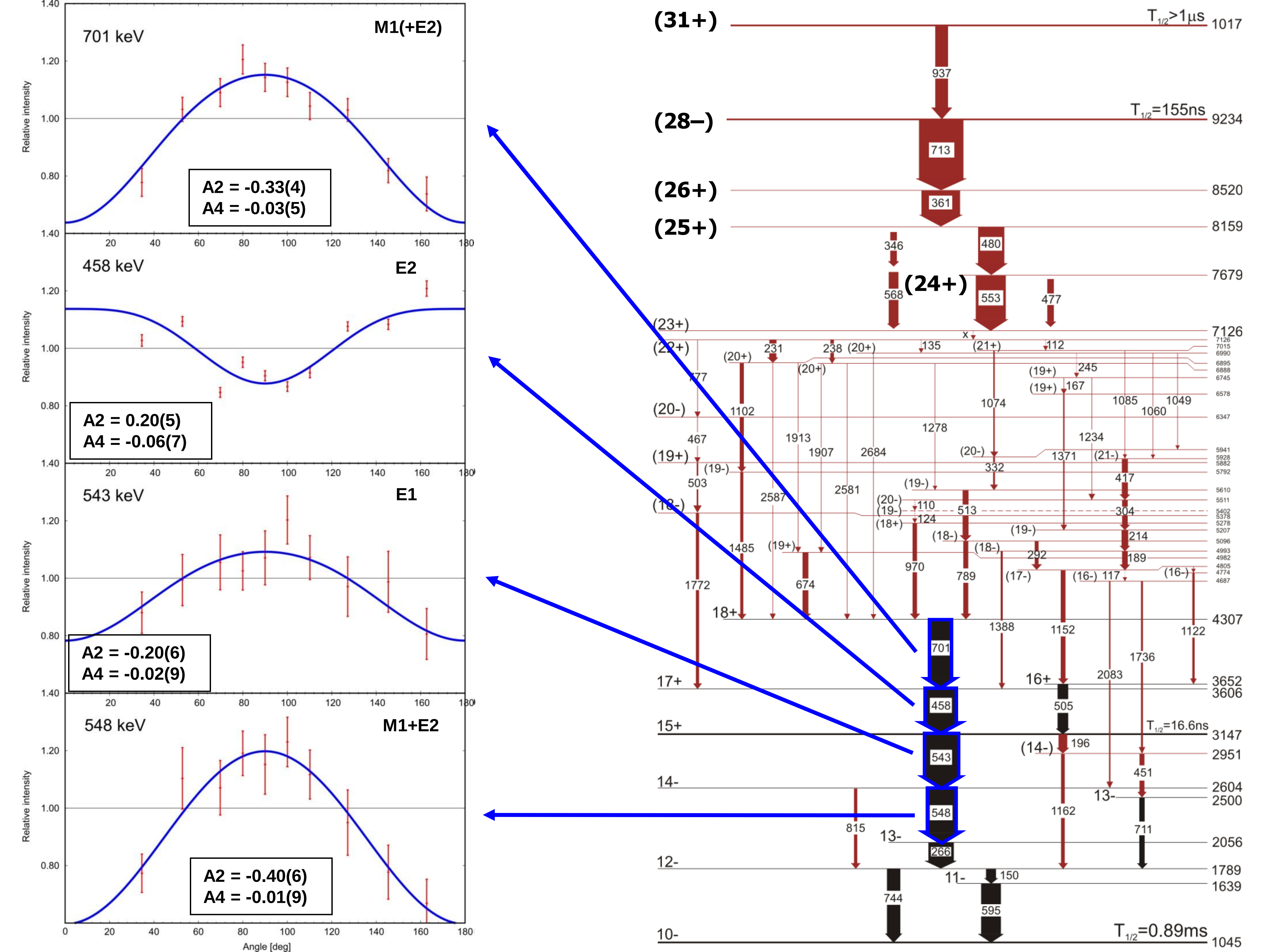


383 keV

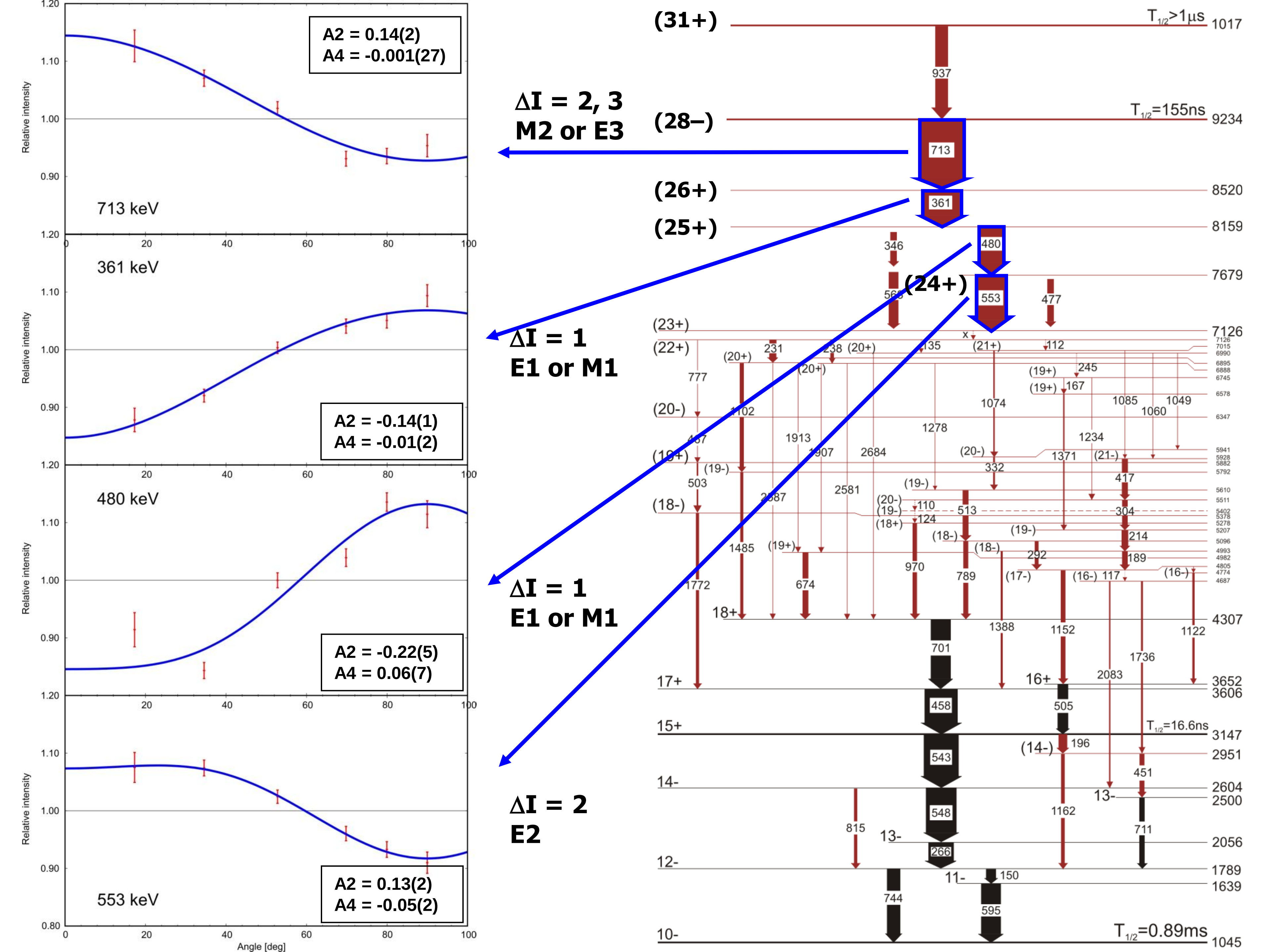


^{206}Bi: 1 *proton 3 neutron holes*



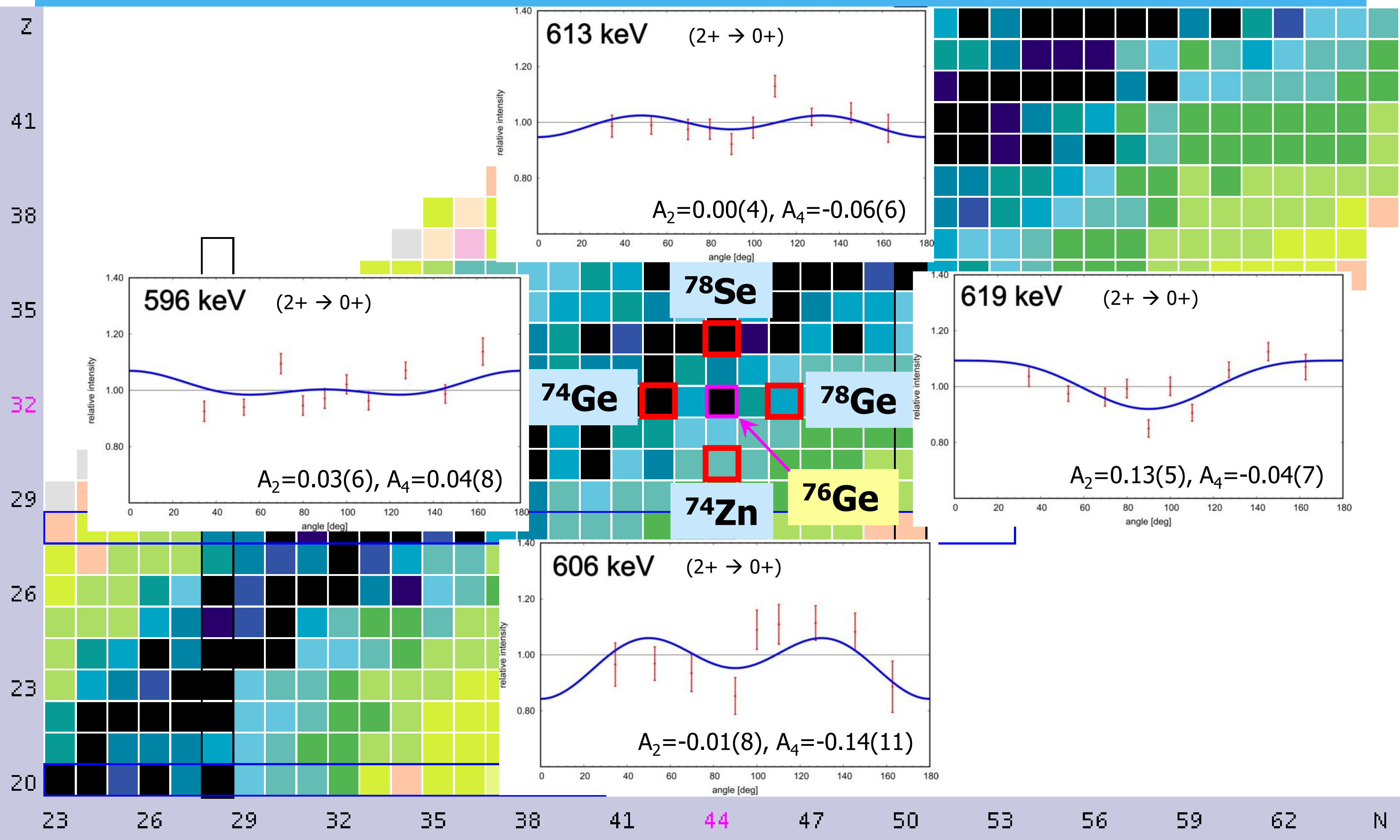


701 keV
M1(+E2)
A2 = -0.33(4)
A4 = -0.03(5)
458 keV
E2
A2 = 0.20(5)
A4 = -0.06(7)
543 keV
E1
A2 = -0.20(6)
A4 = -0.02(9)
548 keV
M1+E2
A2 = -0.40(6)
A4 = -0.01(9)
Relative intensity
Angle [deg]
(31+)
(28–)
(26+)
(25+)
(24+)
(23+)
(22+)
(20-)
(19+)
(18-)
18+
17+
16+
15+
14-
13-
12-
11-
10-
$T_{1/2}$>1µs
$T_{1/2}$=155ns
$T_{1/2}$=16.6ns
$T_{1/2}$=0.89ms
1017
9234
8520
8159
7679
7126
4307
3652
3606
3147
2951
2604
2500
2056
1789
1639
1045
937
713
361
480
553
346
568
477
701
458
543
548
266
744
595
150

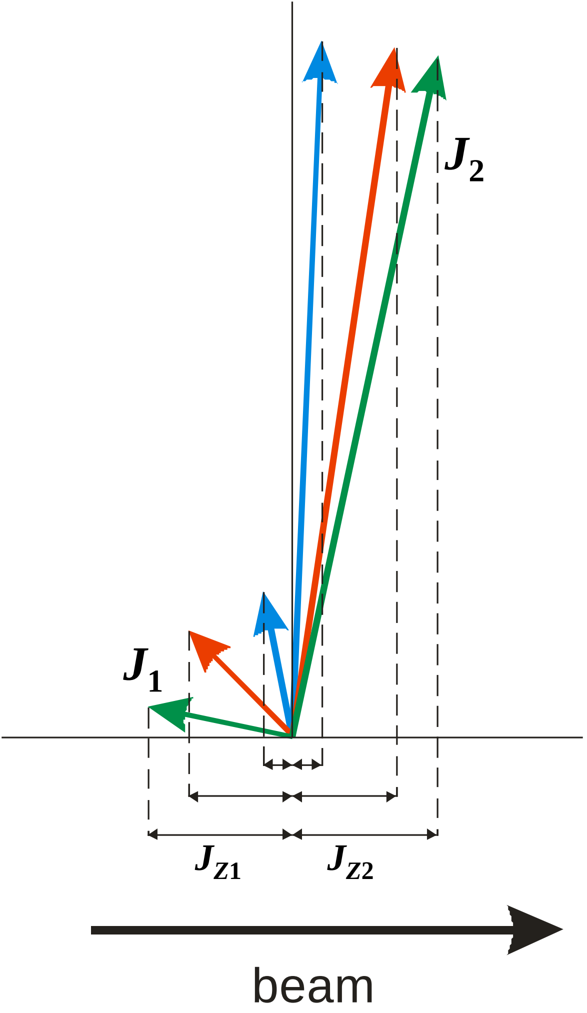


A2 = 0.14(2)
A4 = -0.001(27)
713 keV
361 keV
A2 = -0.14(1)
A4 = -0.01(2)
480 keV
A2 = -0.22(5)
A4 = 0.06(7)
553 keV
A2 = 0.13(2)
A4 = -0.05(2)
Relative intensity
Angle [deg]
ΔI = 2, 3
M2 or E3
ΔI = 1
E1 or M1
ΔI = 1
E1 or M1
ΔI = 2
E2
(31+)
T1/2>1μs
1017
937
(28–)
T1/2=155ns
9234
713
(26+)
8520
361
(25+)
8159
480
7679
(24+)
553
(23+)
7126
(22+)
(20-)
(19+)
(18-)
18+
4307
17+
3652
16+
3606
15+
T1/2=16.6ns
3147
(14-)
2951
14-
2604
13-
2500
13-
2056
12-
1789
11-
1639
10-
T1/2=0.89ms
1045
701
458
543
548
266
744
595
505
196
1162
711
451
1736
2083
1122
1152
1388
789
970
674
1485
1772
815
150

Angular distributions for nuclei around ^{76}Ge

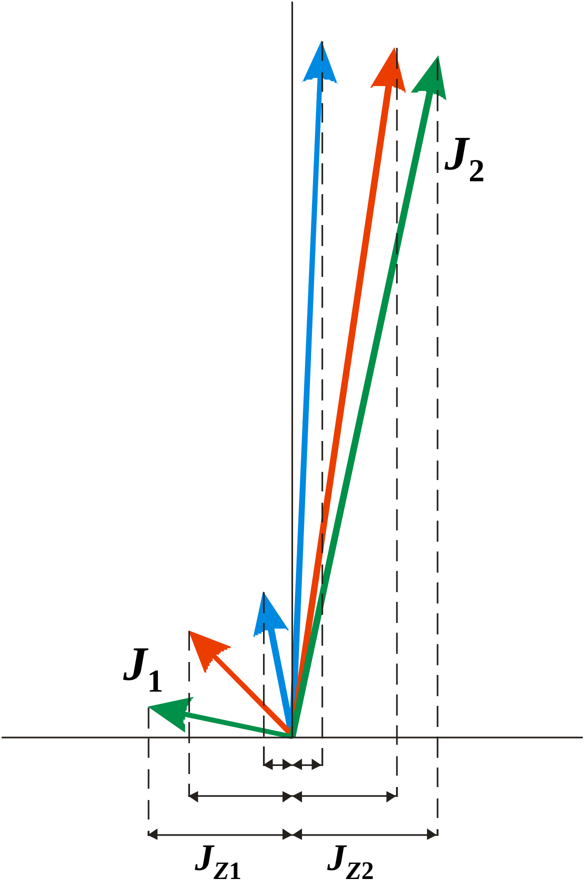


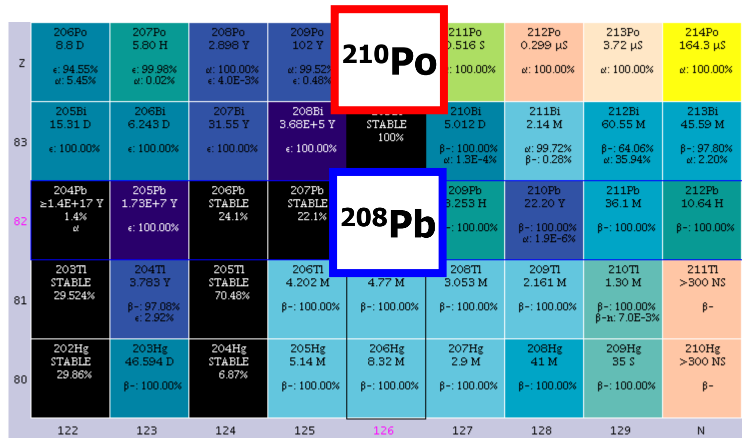
Cross coincidences



Vectorial sum of J_z component is equal to zero

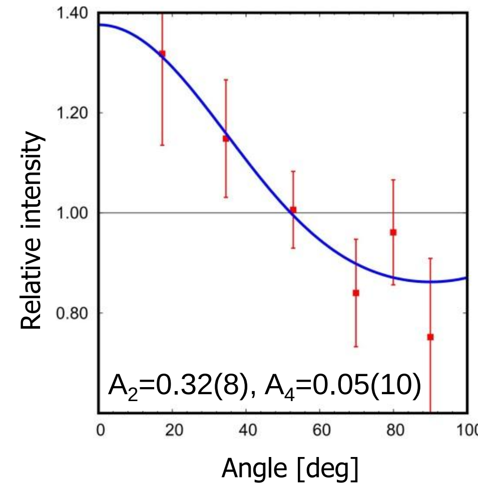
Cross coincidences





^{210}Po 1181 keV (E2)

(gated on 885 keV in ^{70}Zn)



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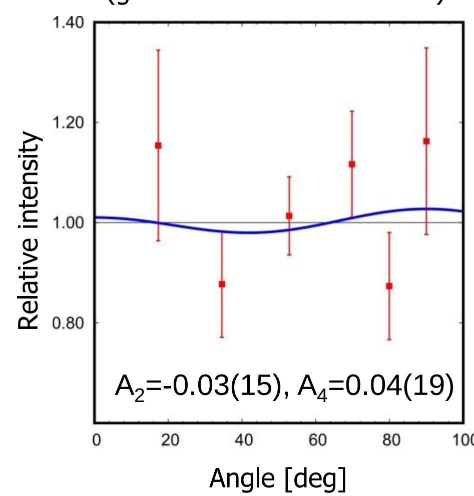
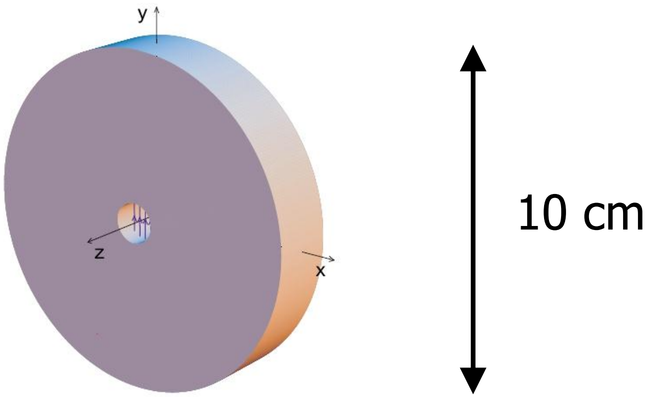


Summary

* Products of deep-inelactic collisions show high degree of spin alignment
* The statistic in coincidence measurements is not high – highly efficient gamma arrays needed (Gammasphere, AGATA)
* The magnet must be small enough to put it in the center of the system of the detectors



1T magnet

Thank you for your attention