COLLOQUE GANIL

21 au 25 septembre 2026

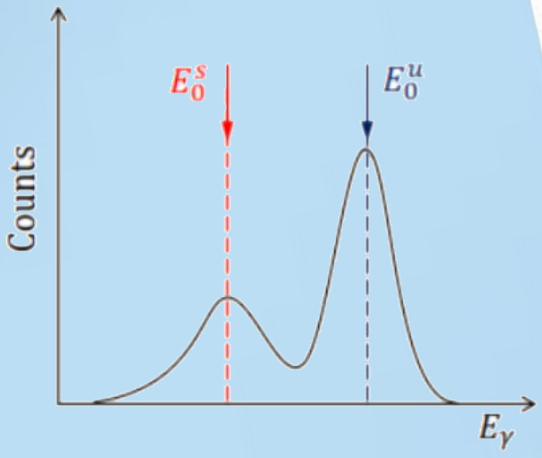
Bussang, France

Quadrupole and octupole collectivity in ^{106}Cd explored via "unsafe" Coulomb excitation

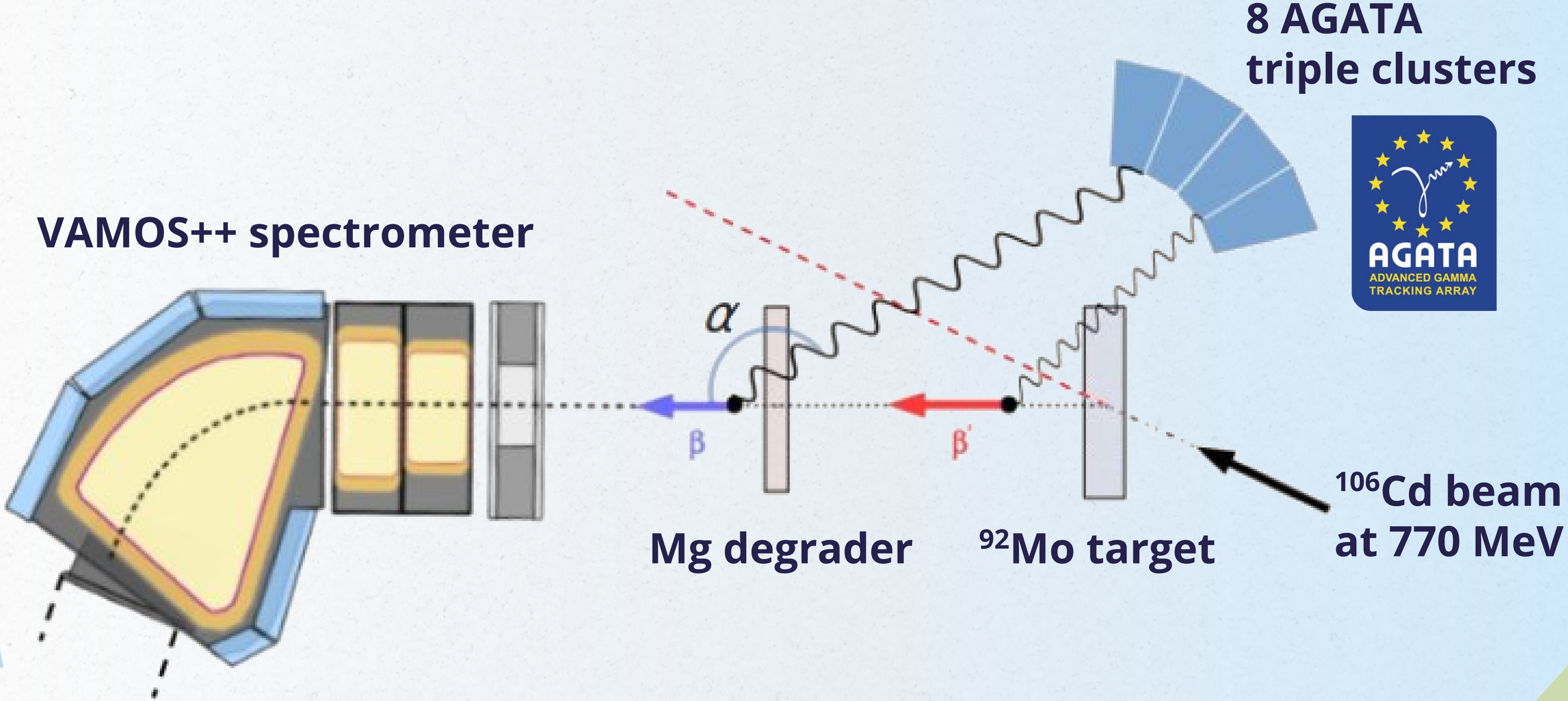
Desislava Kalaydjieva

Experiment 664 at GANIL

- **Main goal:** to obtain lifetimes in neutron-deficient Sn and Cd isotopes.
- **Population mechanism:** multi-nucleon transfer reactions.
- **Technique:** Recoil Distance Doppler Shift (RDDS).



$E \approx E_0 (1 + \beta \cos(\alpha))$



Experiment 664 at GANIL

Physics Letters B

Date: 10 July 2020
Article: 135474
Volume: Volume 806

Pairing-quadrupole interplay in the neutron-deficient tin nuclei: First lifetime measurements of low-lying states in ^{106,108}Sn

M. Siciliano [a b c], J.J. Valiente-Dobón [a], A. Goasduff [a b d], F. Nowacki [e], A.P. Zuker [e], D. Bazzacco [d], A. Lopez-Martens [f], E. Clément [g], G. Benzoni [h], T. Braunroth [i], F.C.L. Crespi [h j], N. Cieplicka-Oryńczak [h 1], M. Doncel [k], S. Ertürk [l], G. de France [g], C. Fransen [i], A. Gadea [m], G. Georgiev [f], A. Goldkuhle [i], U. Jakobsson [n], G. Jaworski [a 2], P.R. John [b d 3], I. Kuti [o], A. Lemasson [g], T. Marchi [a], D. Mengoni [b d], C. Michelagnoli [g 4], T. Mijatović [r], C. Müller-Gatermann [i], D.R. Napoli [a], J. Nyberg [p], M. Palacz [q], R.M. Pérez-Vidal [m], B. Sayği [a 5], D. Sohler [o], S. Szilner [r], D. Testov [b d], M. Zielińska [c], D. Barrientos [s], B. Birkenbach [i], H.C. Boston [t], A.J. Boston [t], B. Cederwall [n], J. Collado [u], D.M. Cullen [v], P. Désesquelles [f], C. Domingo-Pardo [m], J. Dudouet [f 6], J. Eberth [i], F.J. Egea-Canet [a], V. González [u], L.J. Harkness-Brennan [t], H. Hess [i], D.S. Judson [t], A. Jungclaus [w], W. Korten [c], M. Labiche [x], A. Lefevre [g], S. Leoni [h j], H. Li [n], A. Maj [y], R. Menegazzo [d], B. Million [h], A. Pullia [h j], F. Recchia [b d], P. Reiter [i], M.D. Salsac [c], E. Sanchis [u], O. Stezowski [z], Ch. Theisen [c]

Physical Review C

Lifetime measurements in the even-even $^{102-108}$Cd isotopes

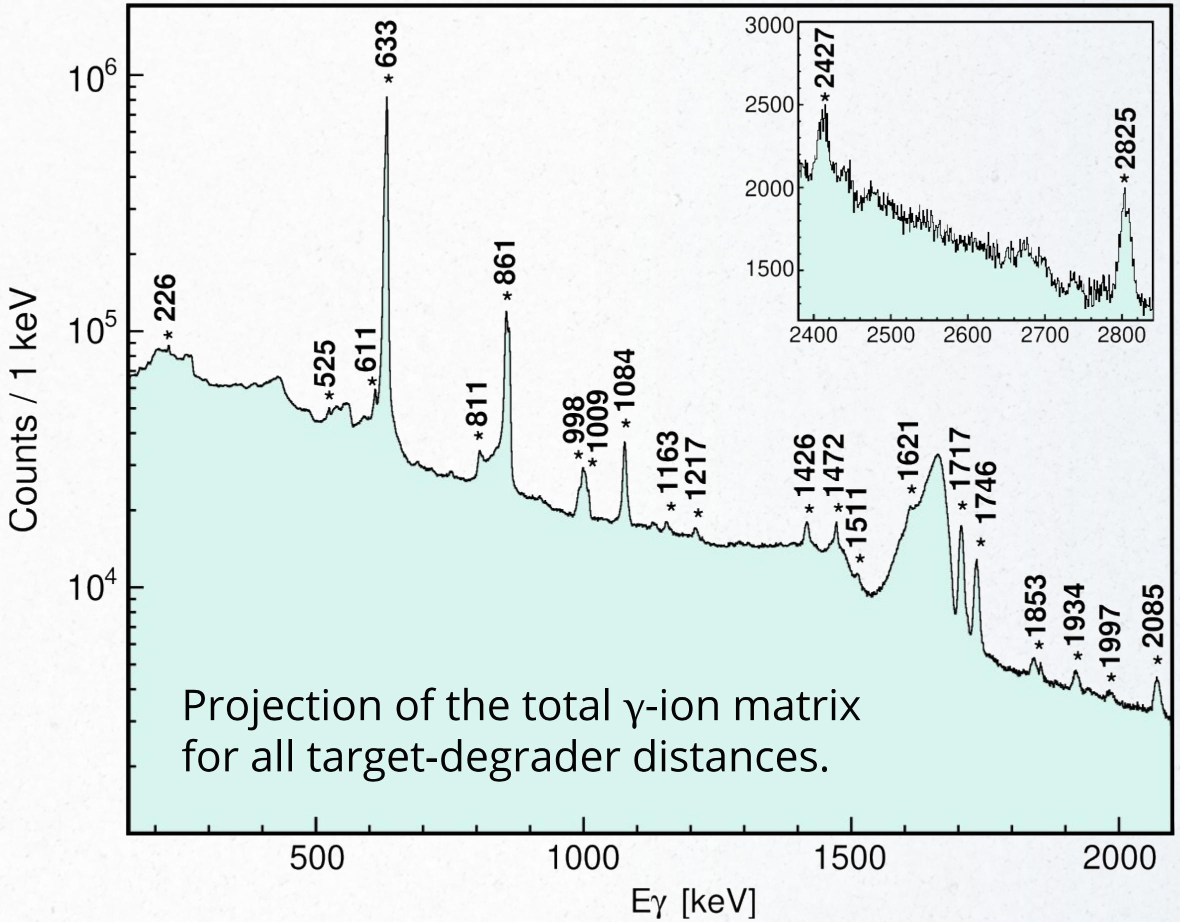
M. Siciliano [1,2,3,*], J. J. Valiente-Dobón[2], A. Goasduff[2,3,4], T. R. Rodríguez[5], D. Bazzacco[4], G. Benzoni[6], T. Braunroth[7], N. Cieplicka-Oryńczak[6,8], E. Clément[9] *et al.*

Phys. Rev. C **104**, 034320 – **Published 30 September, 2021**

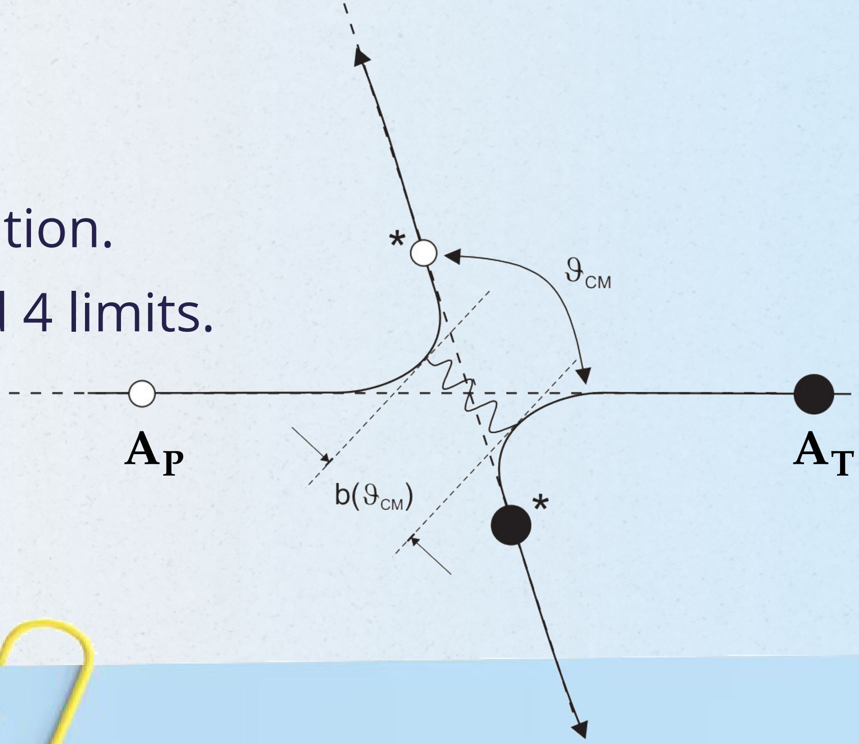
DOI: https://doi.org/10.1103/PhysRevC.104.034320

Measurements in ^{106}Cd

- **Population mechanism:** "unsafe" Coulomb excitation.
- **RDDS results:** 21 populated states, 9 lifetimes and 4 limits.



Projection of the total γ-ion matrix for all target-degrader distances.

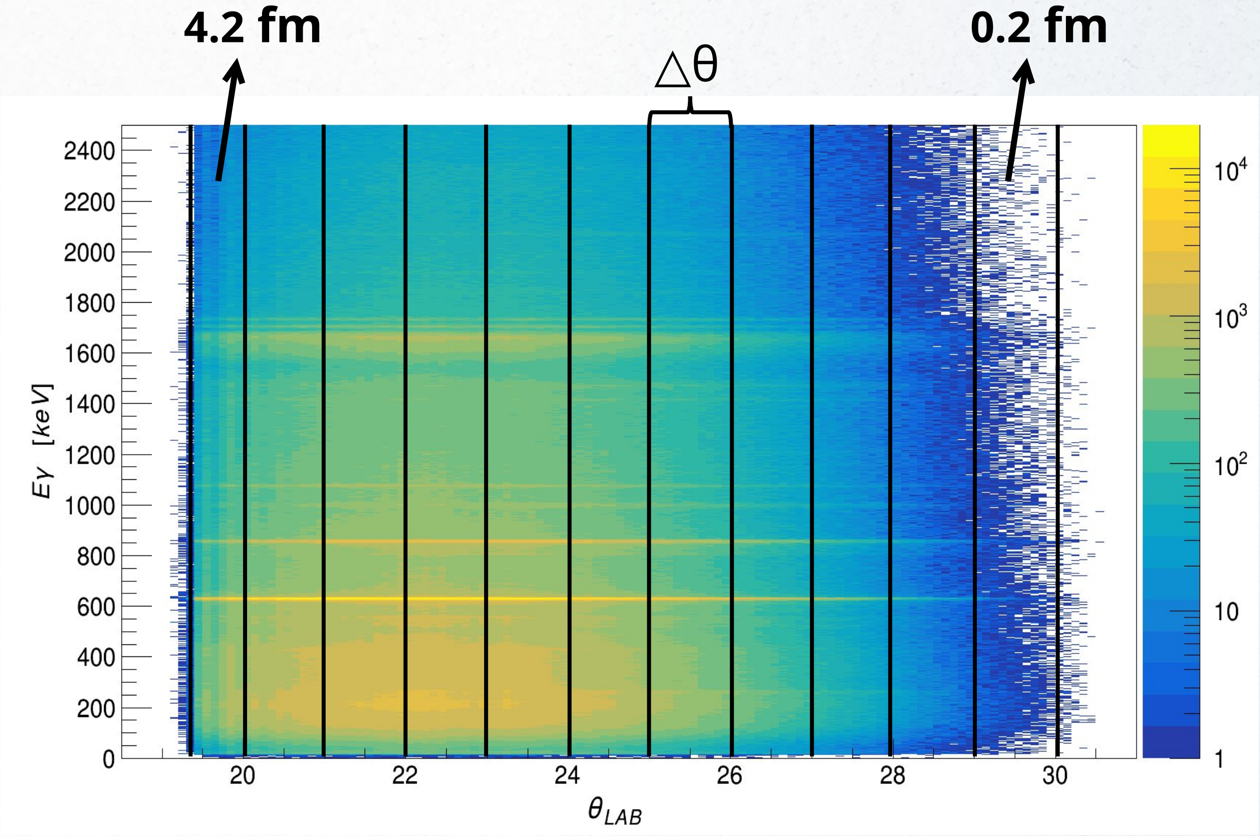


$$b_{min} = 1.25\,(A_P^{1/3} + A_T^{1/3}) + 5\text{ fm}$$

- **Can a complementary technique be used to confirm the RDDS results?**
- **What are the effects from Coulomb-nuclear interference on excitation cross sections?**

Experimental observables

- **Study the γ-ray yields as a function of the scattering angle.**
- **Observables**: γ-ray intensities obtained in coincidence with ^{106}Cd ions scattered in a certain Δθ range.



Total γ-ion matrix with ^{106}Cd identified in VAMOS

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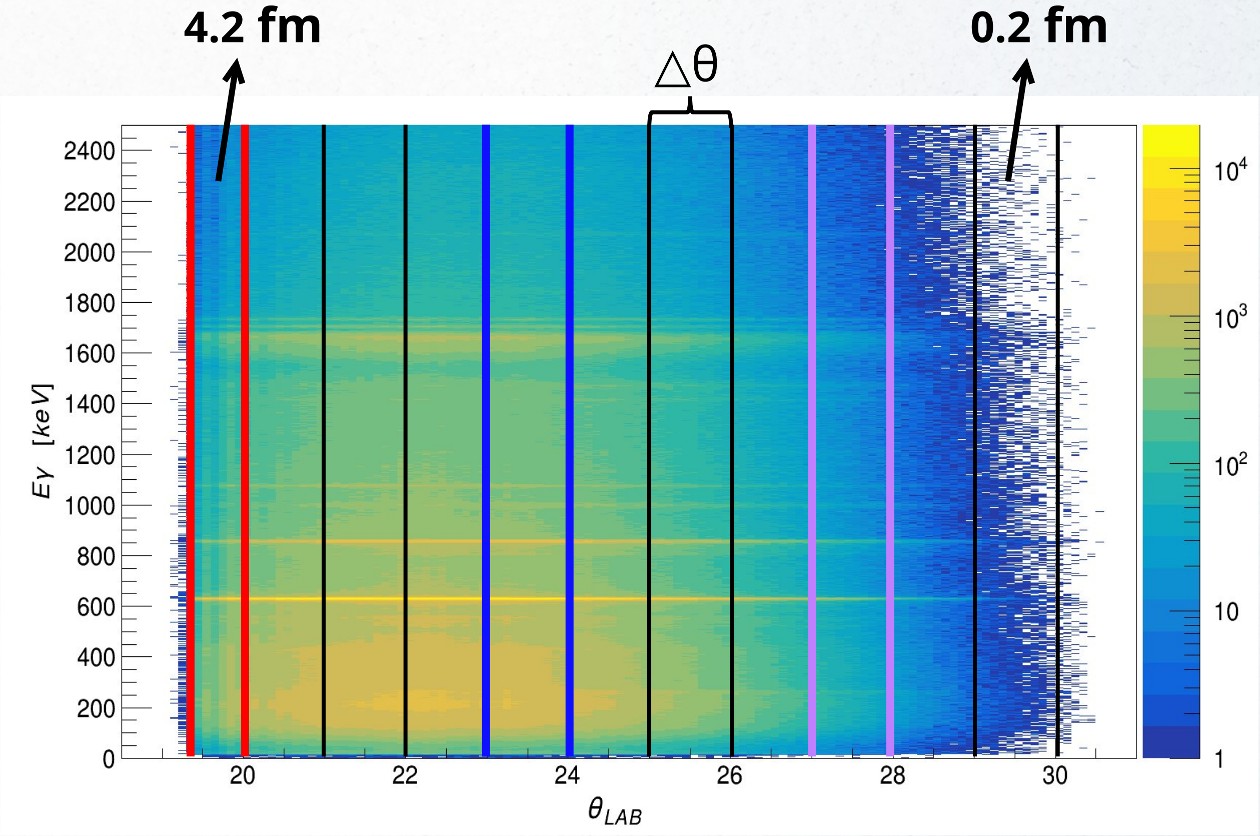

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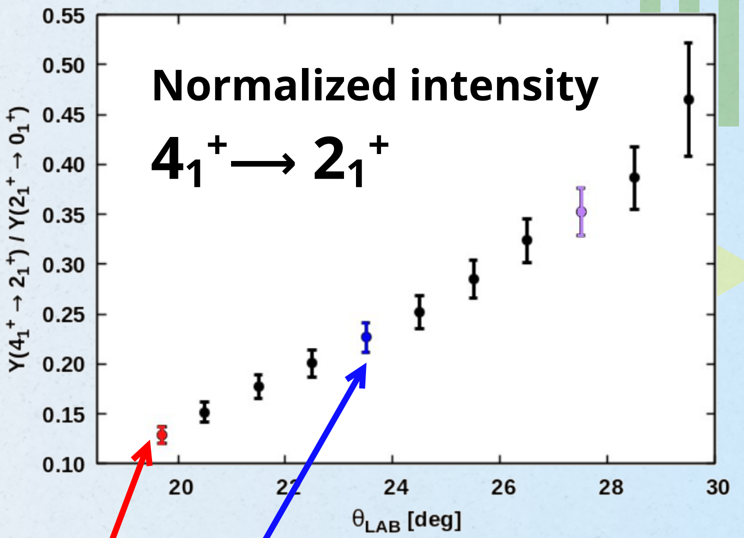

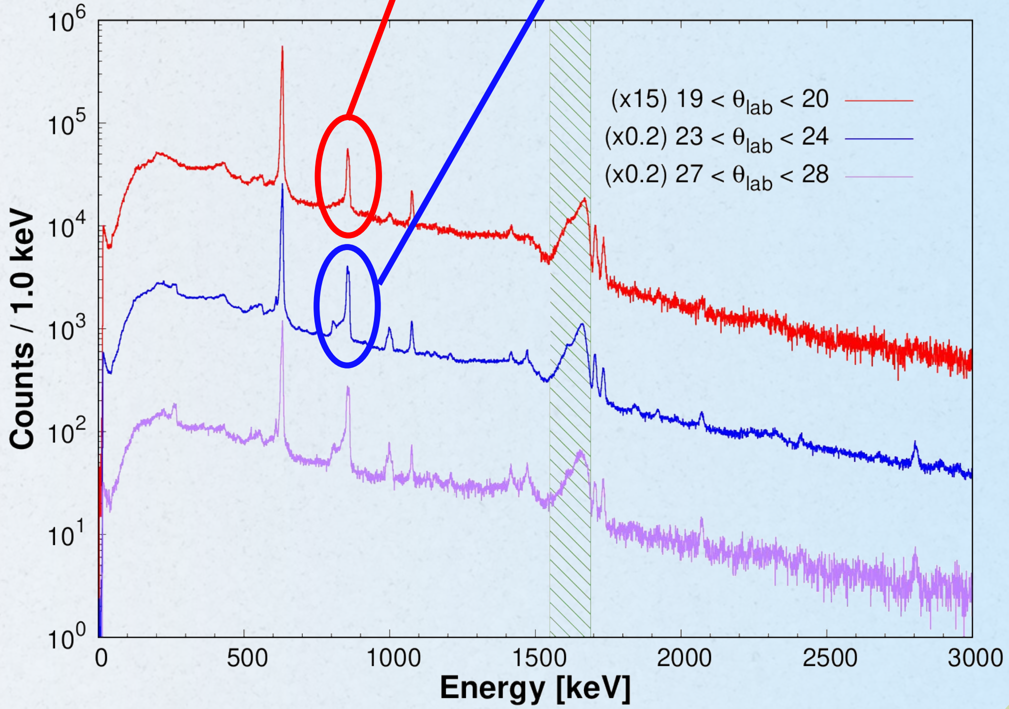

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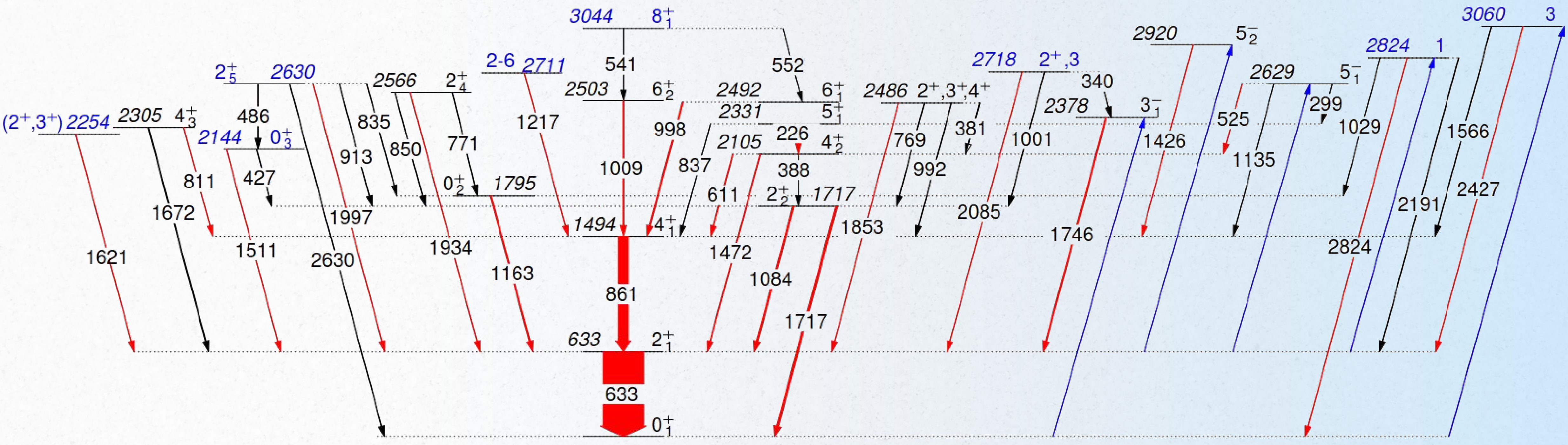


^{106}Cd

Analysis strategy (safe CoulEx)

Experimental γ-ray yields

Spectroscopic data from literature

Information on the experimental setup

→ **GOSIA** →

Set of matrix elements of the electromagnetic operator (MEs)

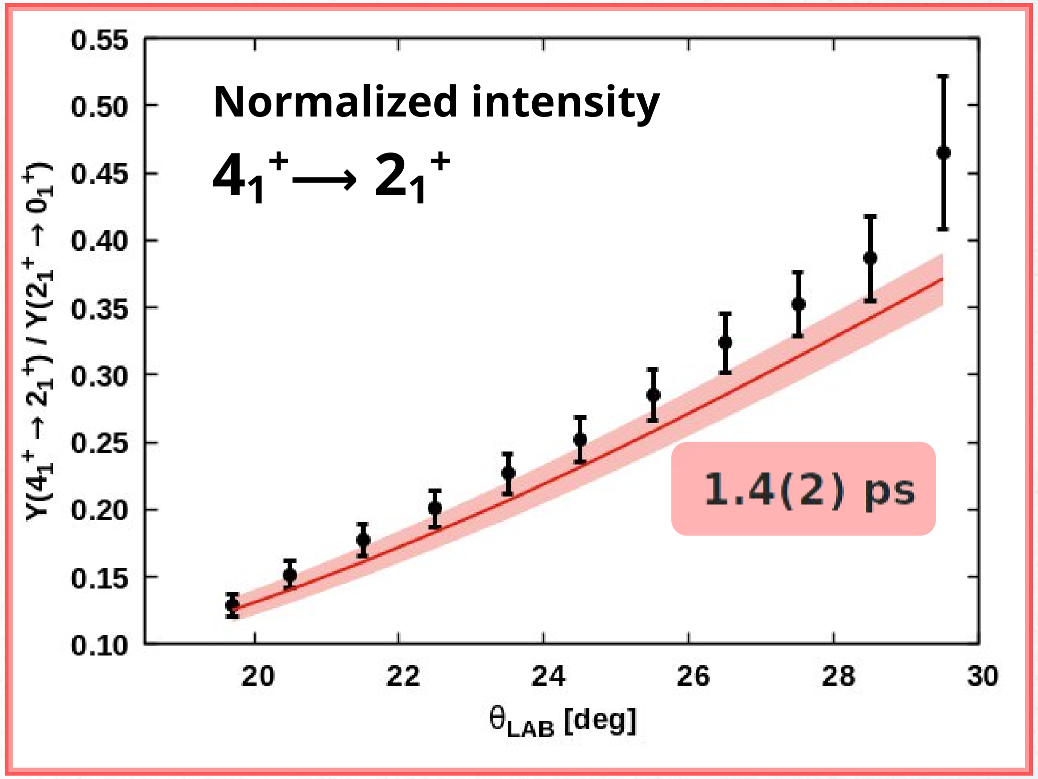
- Multi-dimensional χ^2 minimization.

- Diagonal MEs carry information for the nuclear shape.
- Transitional MEs are related to **B(E2) values and lifetimes**.

- **Level scheme**: energies and J^{π}.
- **Branching and mixing ratios**.
- **Lifetimes** of some states (2_1^+).

Analysis strategy (unsafe CoulEx)

Simulated γ-ray intensities for pure Coulomb excitation ← **GOSIA** ← **Set of matrix elements of the electromagnetic operator (MEs)**



- **Diagonal MEs from safe CoulEx:**

T. J. Gray et al., PLB 834 137446 (2022).

D. Rhodes et al., PRC 103, L051301 (2021).

- **Transitional MEs calculated from τ:**

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- **and branching and mixing ratios:**

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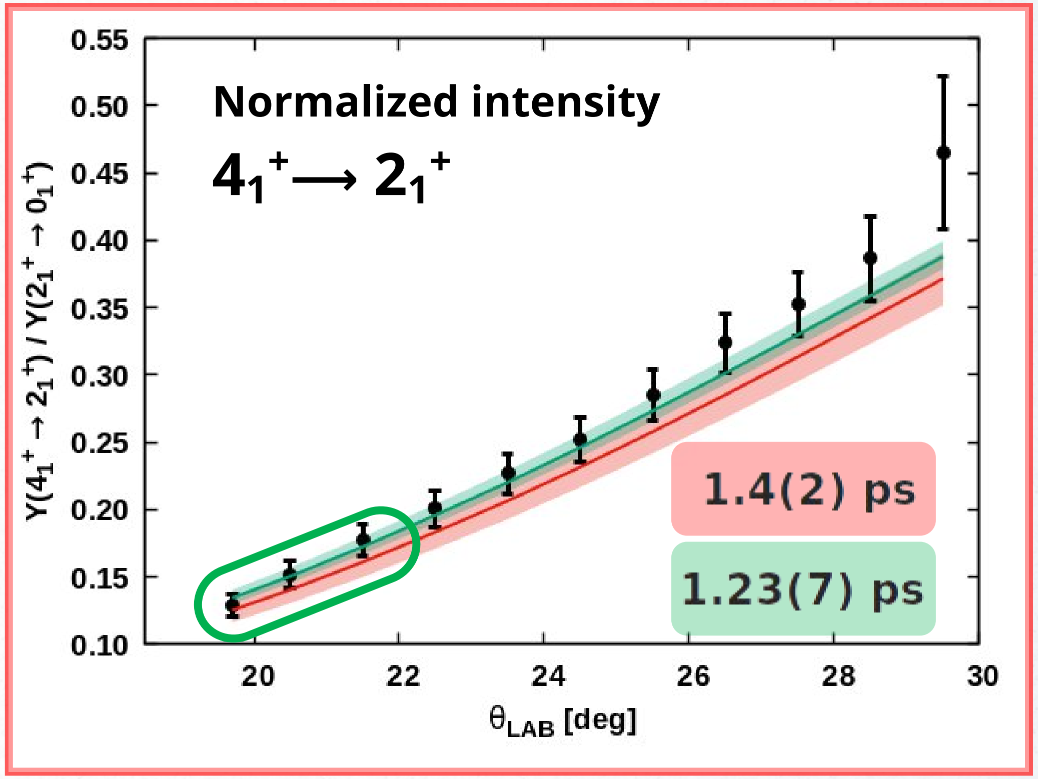

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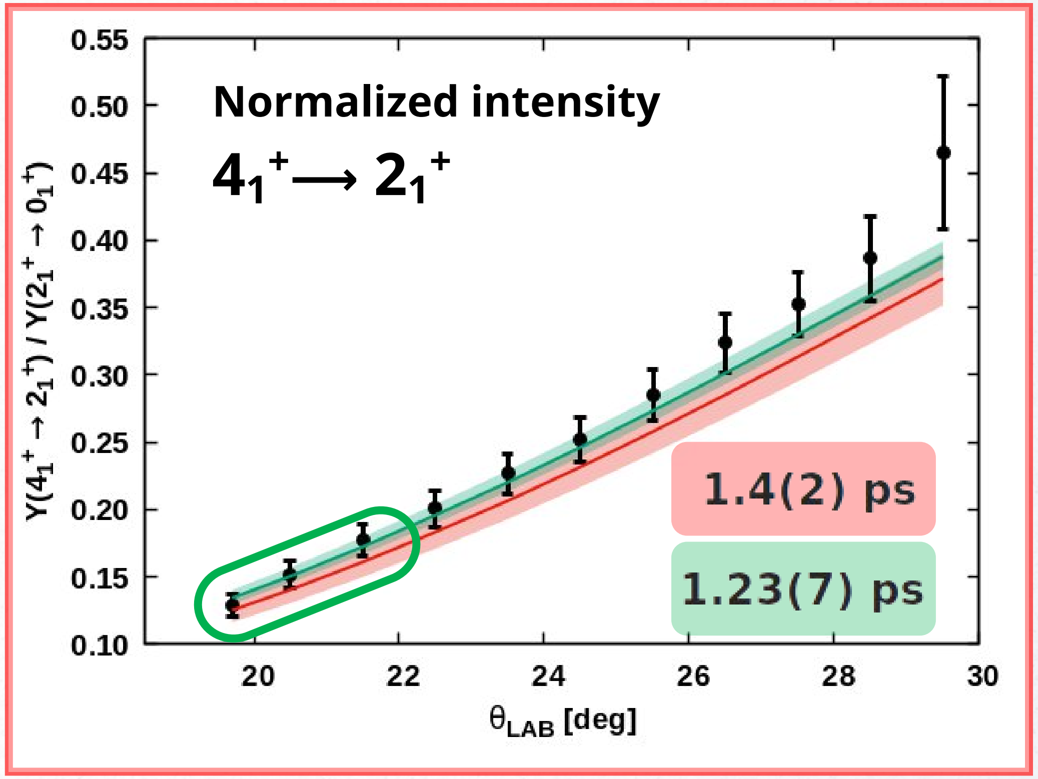
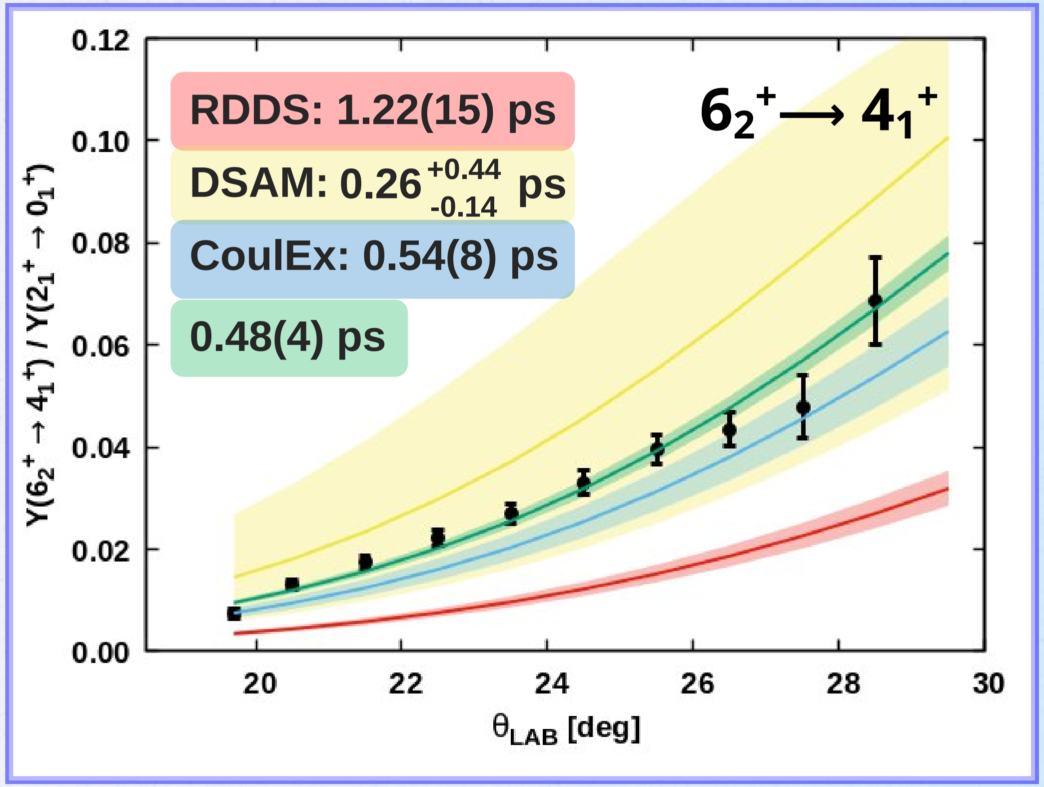
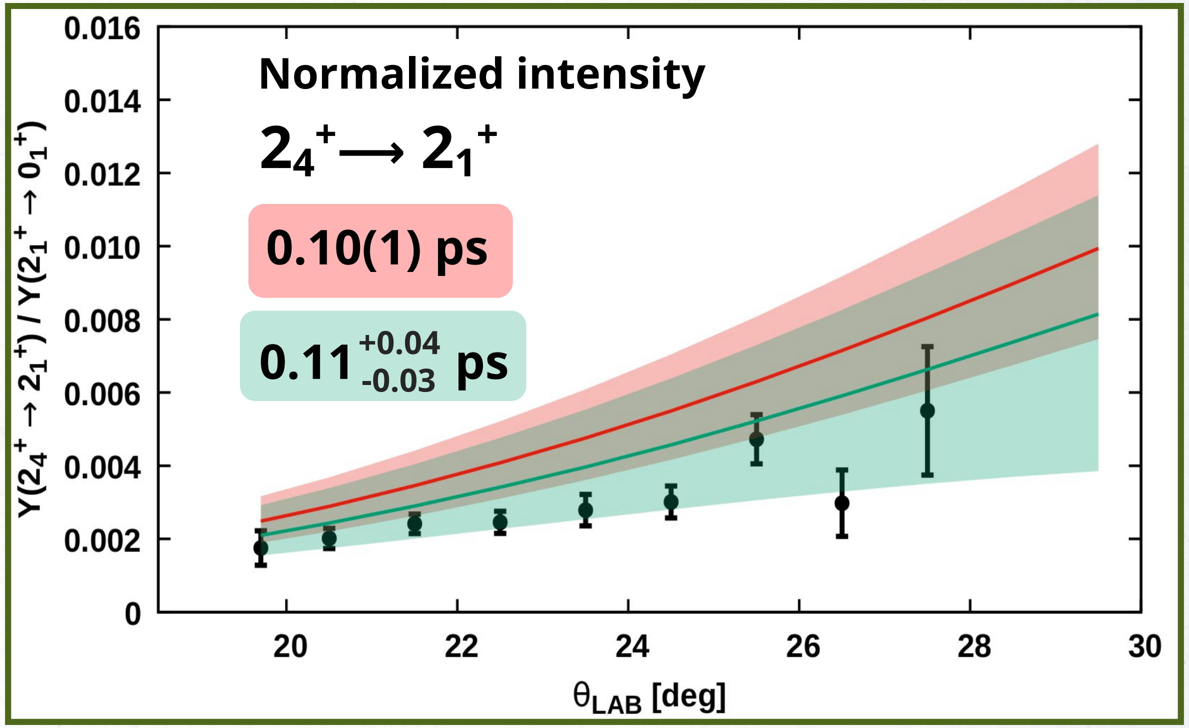




Results beyond the limitations

- **Probing lifetimes outside of the RDDS sensitivity range** (e.g. $\tau(2_4^+) < 0.3$ ps).
- **Literature lifetime:** Doppler Shift Attenuation Method - A. Linnemann, PhD thesis, 2005.



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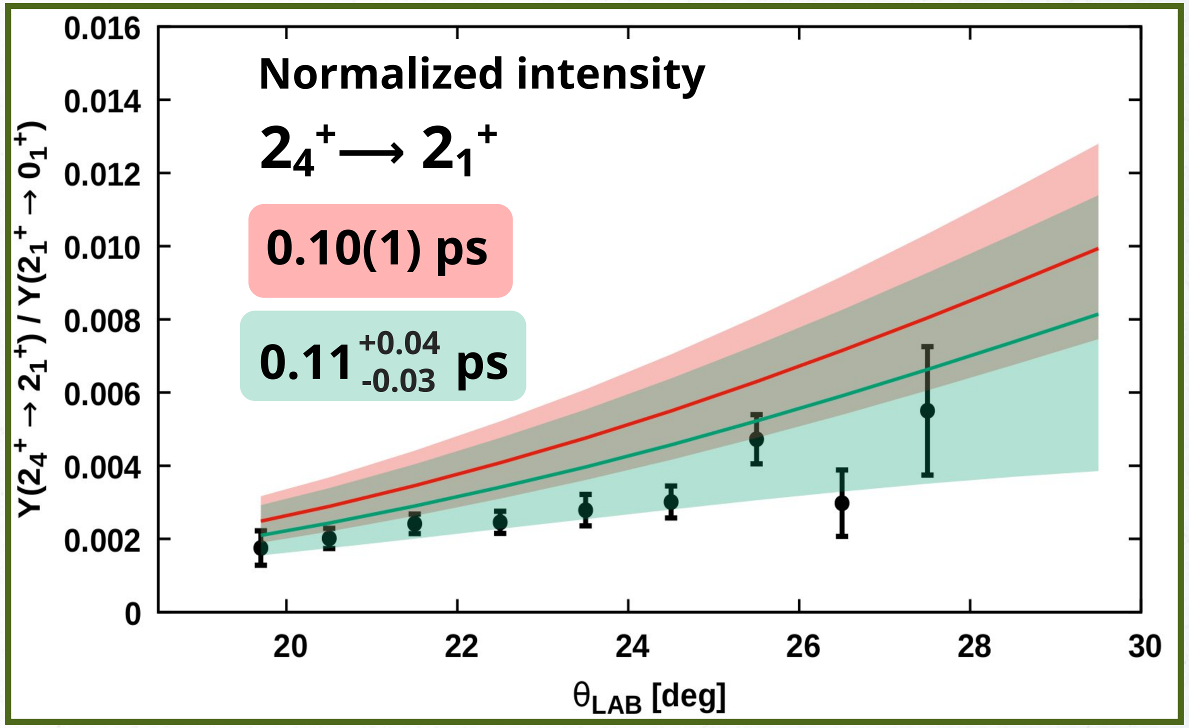
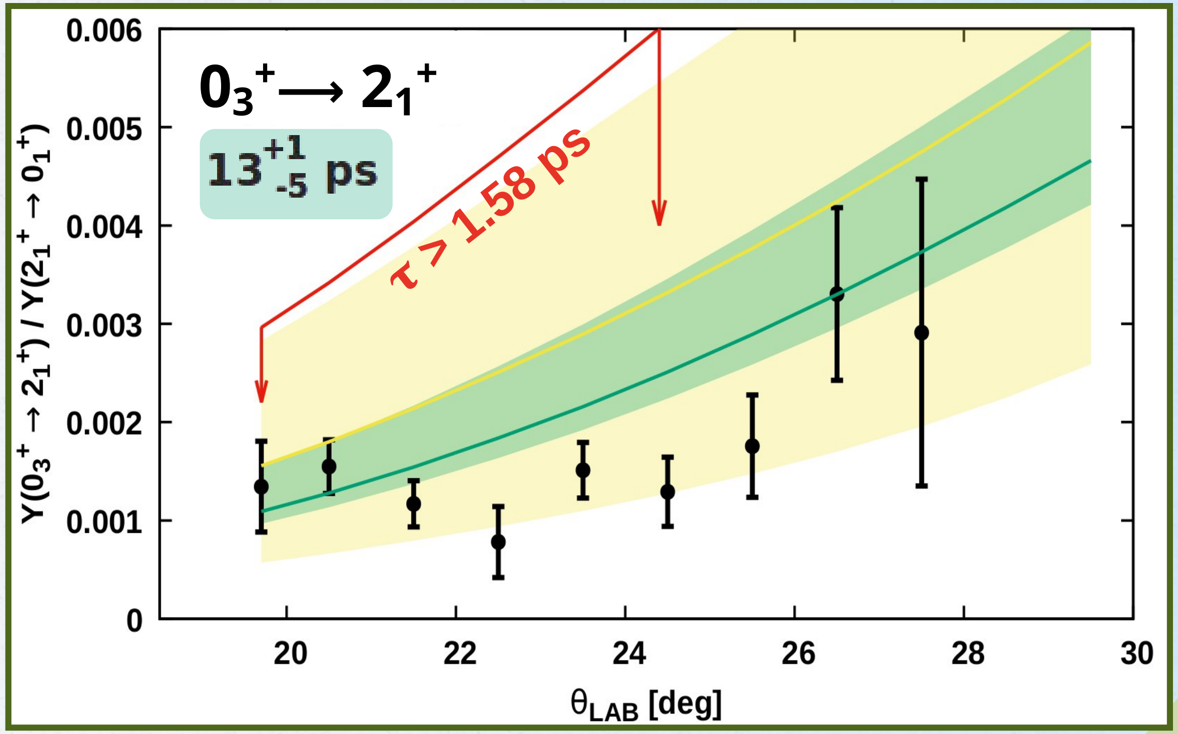
- **Literature matrix elements**: Safe CoulEx in T. J. Gray et al., PLB 834 137446 (2022).

$\langle 0_3^+||E2||2_1^+\rangle = 0.026(13)\ eb$

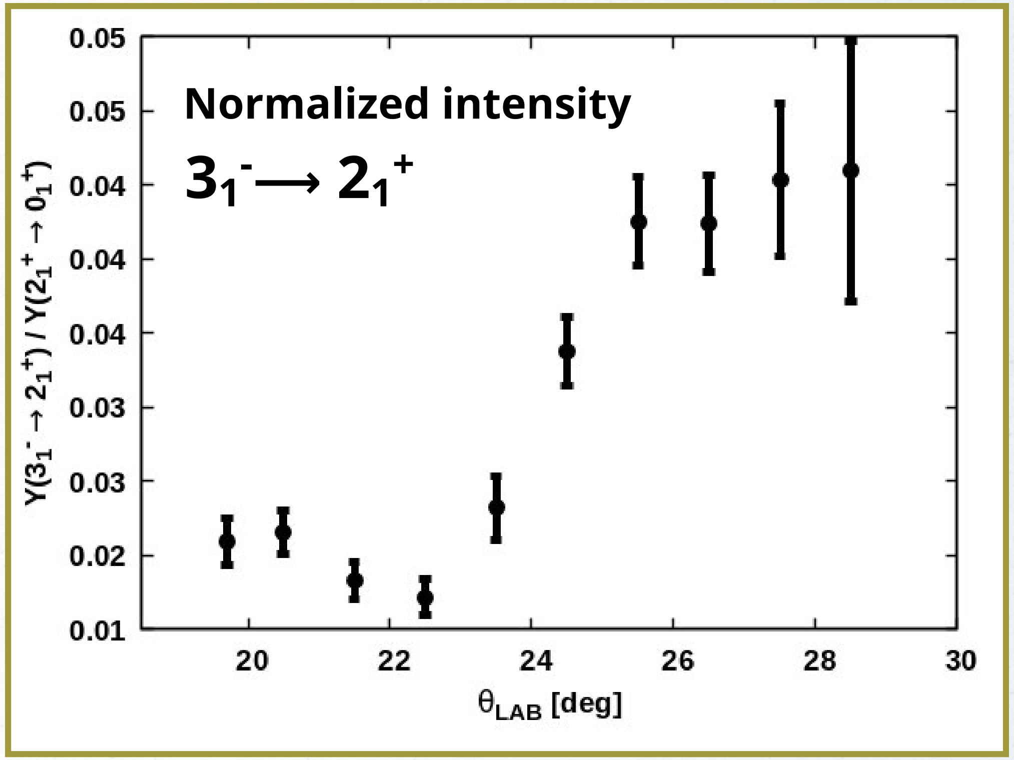
$\langle 0_3^+||E2||2_1^+\rangle = 0.024^{+0.006}_{-0.001}\ eb$





Negative-parity state

- **Significant effects from Coulomb-nuclear interference:** for the states populated via higher-order multipolarity transitions (e.g. E3).



Matrix elements from safe CoulEx:

$\langle 0_1^+ || E3 || 3_1^- \rangle = 0.40(5)\ eb^{3/2}$

M. P. Fewell et al., Aust. J. Phys. 38, 555 (1985).

$\langle 0_1^+ || E3 || 3_1^- \rangle = 0.28(14)\ eb^{3/2}$

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$\langle 0_1^+ || E3 || 3_1^- \rangle$ **< 0.4 eb$^{3/2}$**

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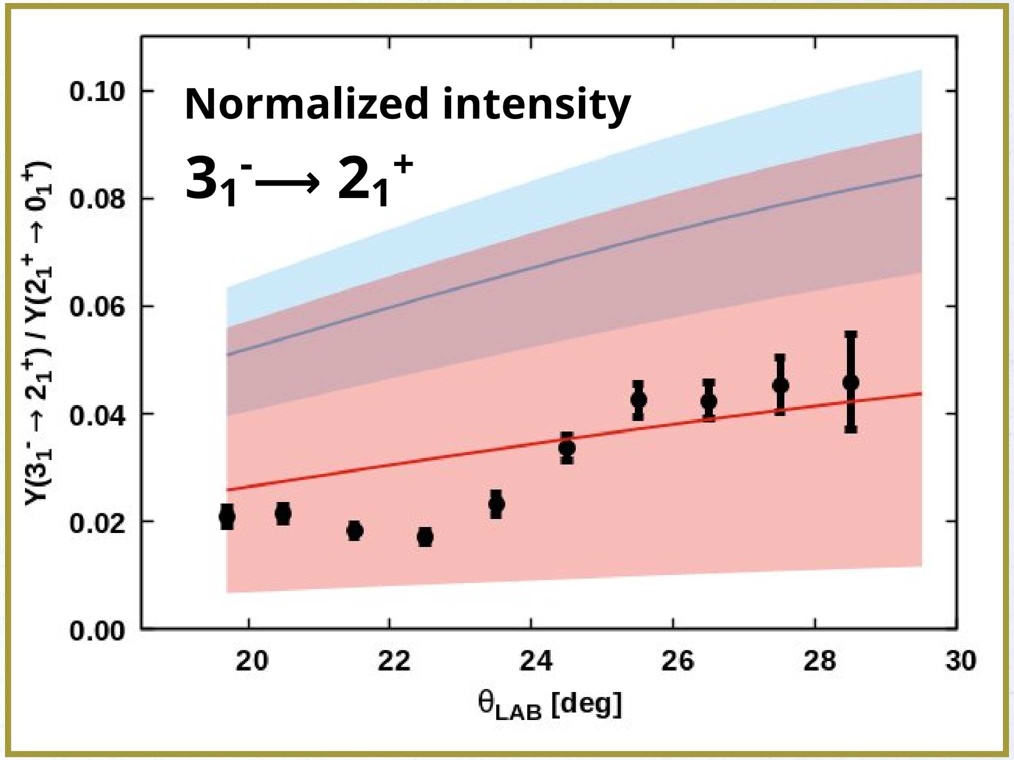

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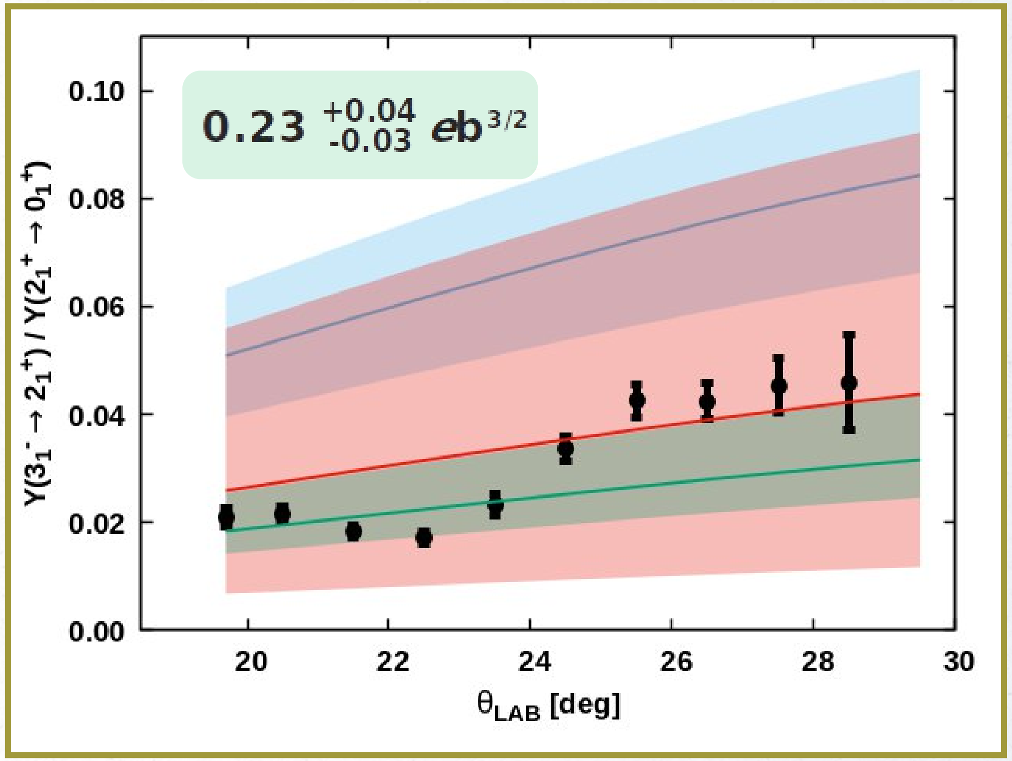

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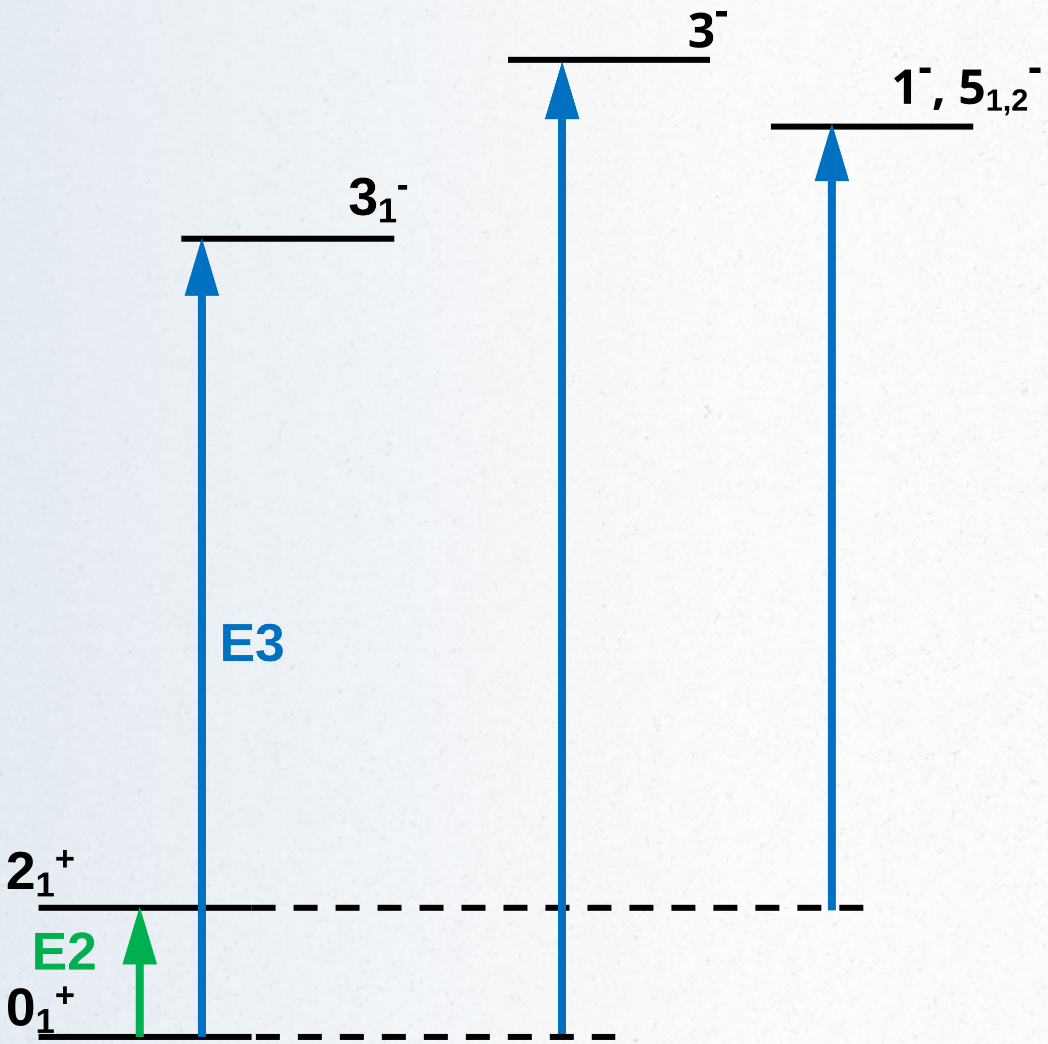
- **No literature data is available for the remaining negative-parity states.**

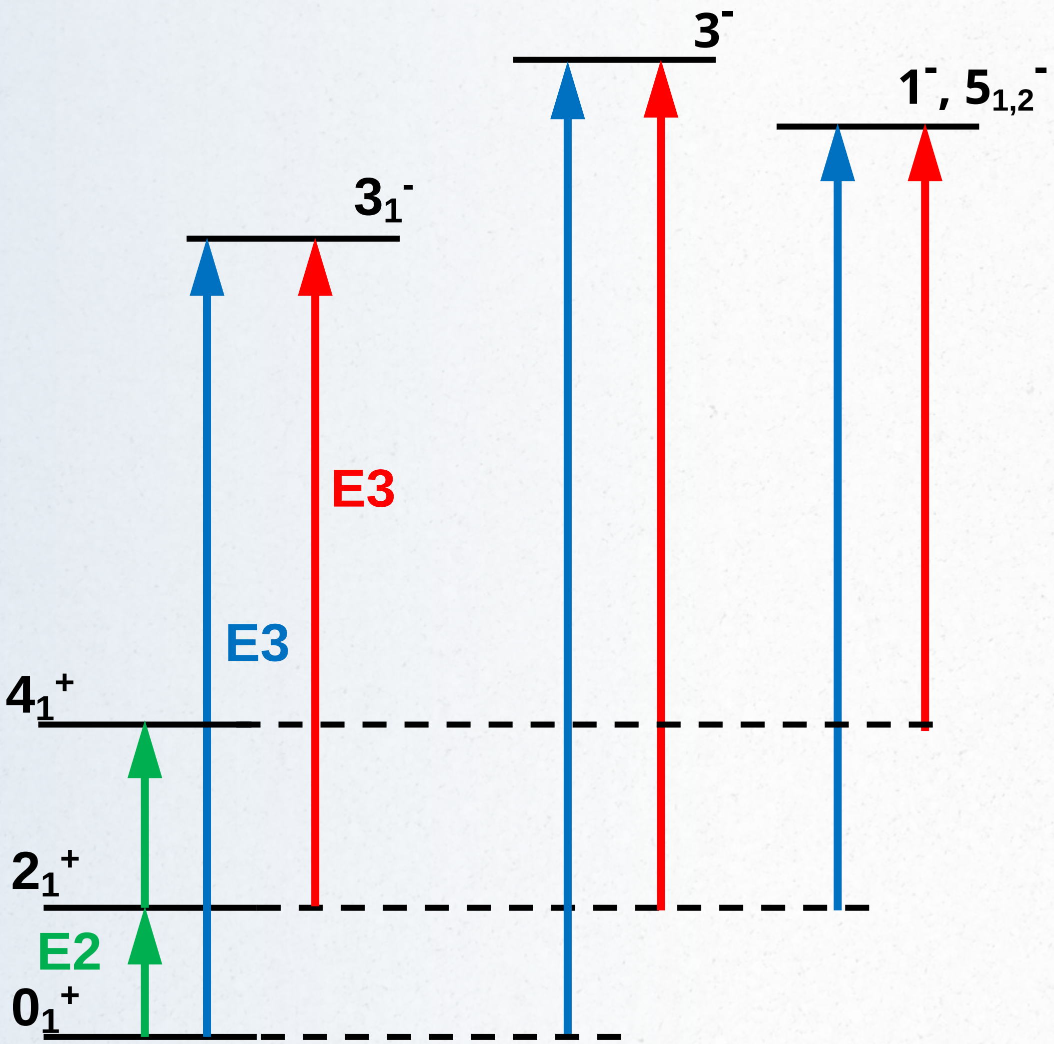
Coupling schemes



- **Different coupling schemes** must be tested involving multi-step excitation (E3, E2) in addition to the primary excitation path (E3).

$\langle I_f^\pi \vert\vert E3 \vert\vert I_i^\pi \rangle$	E3 $[e b^{3/2}]$
$\langle 3_1^- \vert\vert E3 \vert\vert 0_1^+ \rangle$	0.233(5)
$\langle 5_1^- \vert\vert E3 \vert\vert 2_1^+ \rangle$	0.25(3)
$\langle 5_2^- \vert\vert E3 \vert\vert 2_1^+ \rangle$	0.54(2)
$\langle 1 \vert\vert E3 \vert\vert 2_1^+ \rangle$	0.30(1)
$\langle 3 \vert\vert E3 \vert\vert 0_1^+ \rangle$	0.062(7)

Coupling schemes



- **Different coupling schemes** must be tested involving multi-step excitation (**E3**, **E2**) in addition to the primary excitation path (**E3**).

Matrix elements fixed at 2 x $\langle 3_1^- || E3 || 0_1^+ \rangle$

$[eb^{3/2}]$ $\langle I_f^\pi \| E3 \| I_i^\pi \rangle$	E3	E3 + E3
$\langle 3_1^- \| E3 \| 0_1^+ \rangle$	0.233(5)	0.211(6)
$\langle 5_1^- \| E3 \| 2_1^+ \rangle$	0.25(3)	0.23(2)
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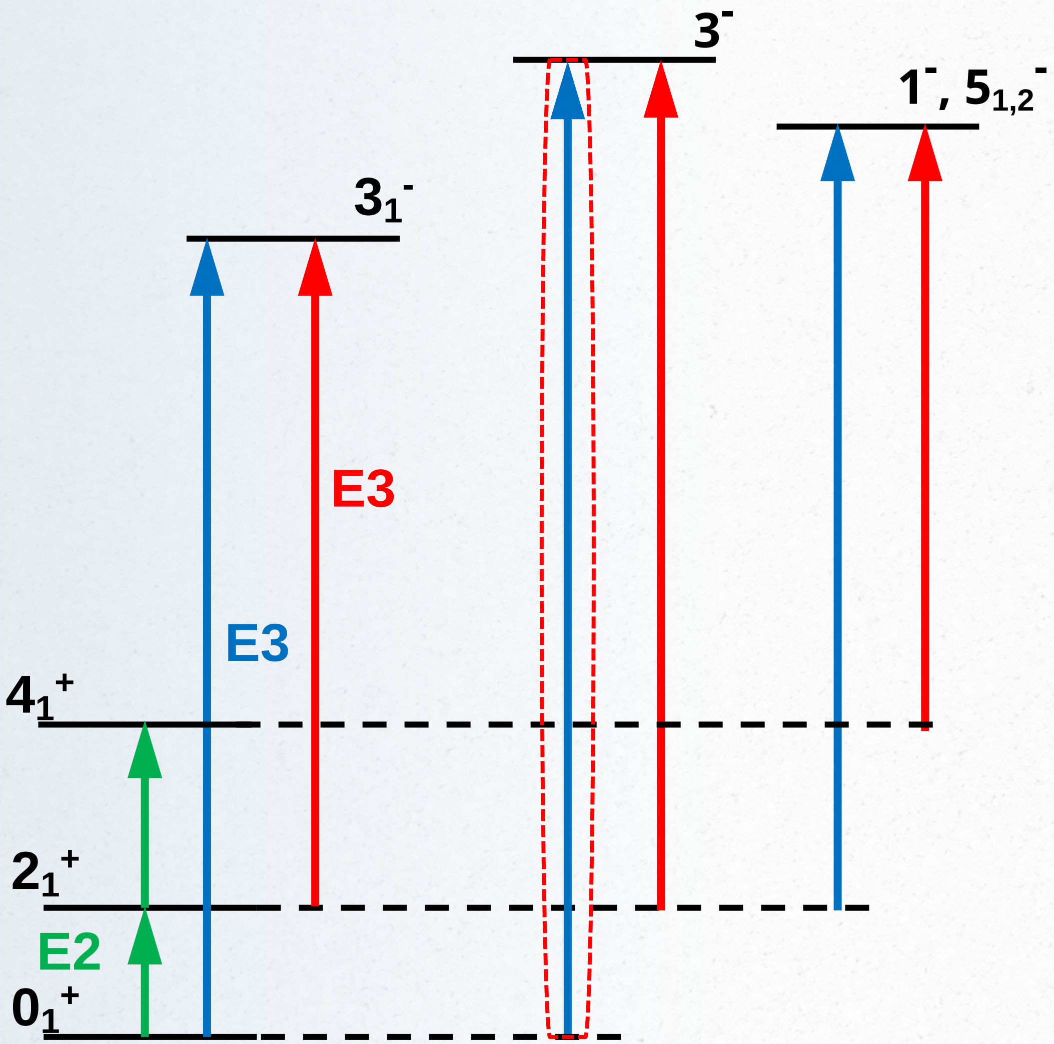
$\langle 1 \| E3 \| 2_1^+ \rangle$	0.30(1)	0.32(2)
$\langle 3 \| E3 \| 0_1^+ \rangle$	0.062(7)	0

Coupling schemes



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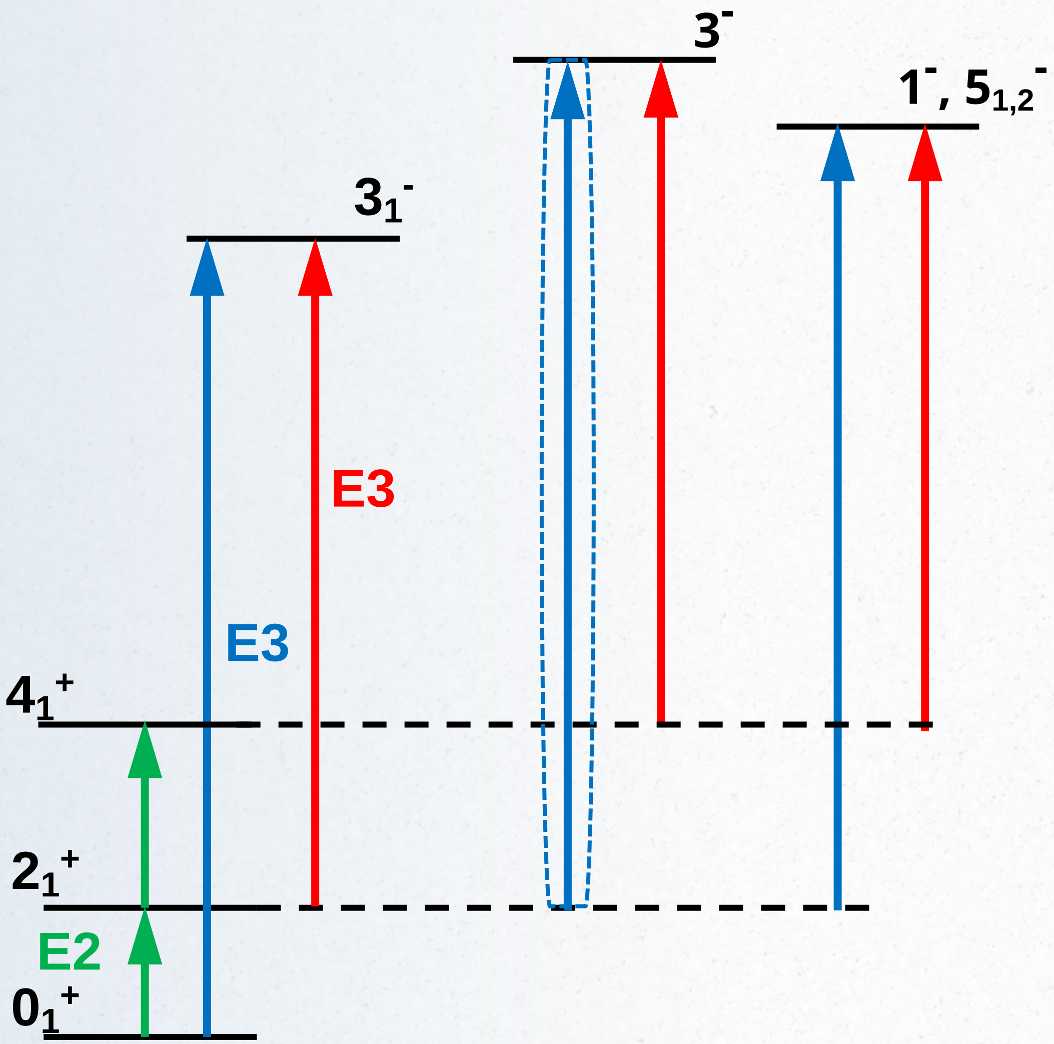
Coupling schemes



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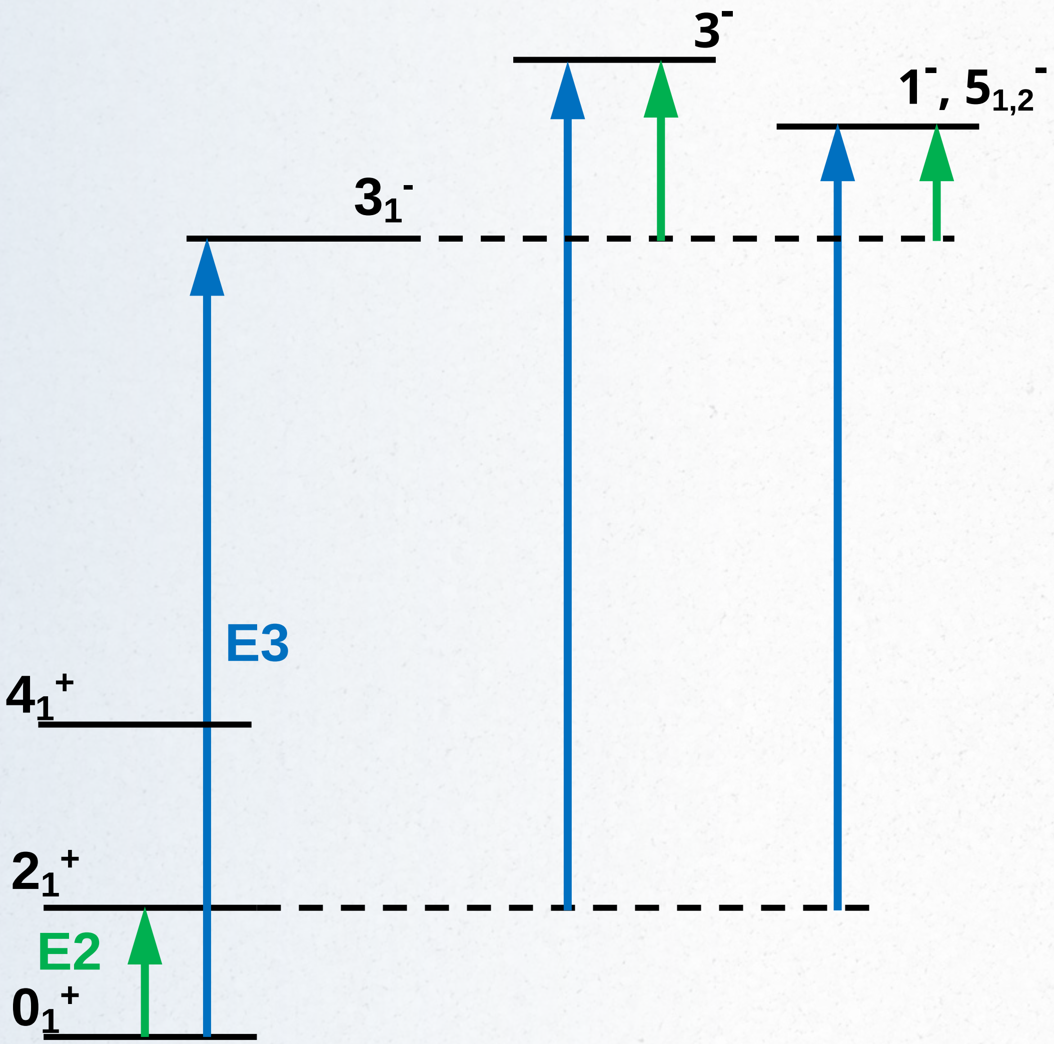
Coupling schemes



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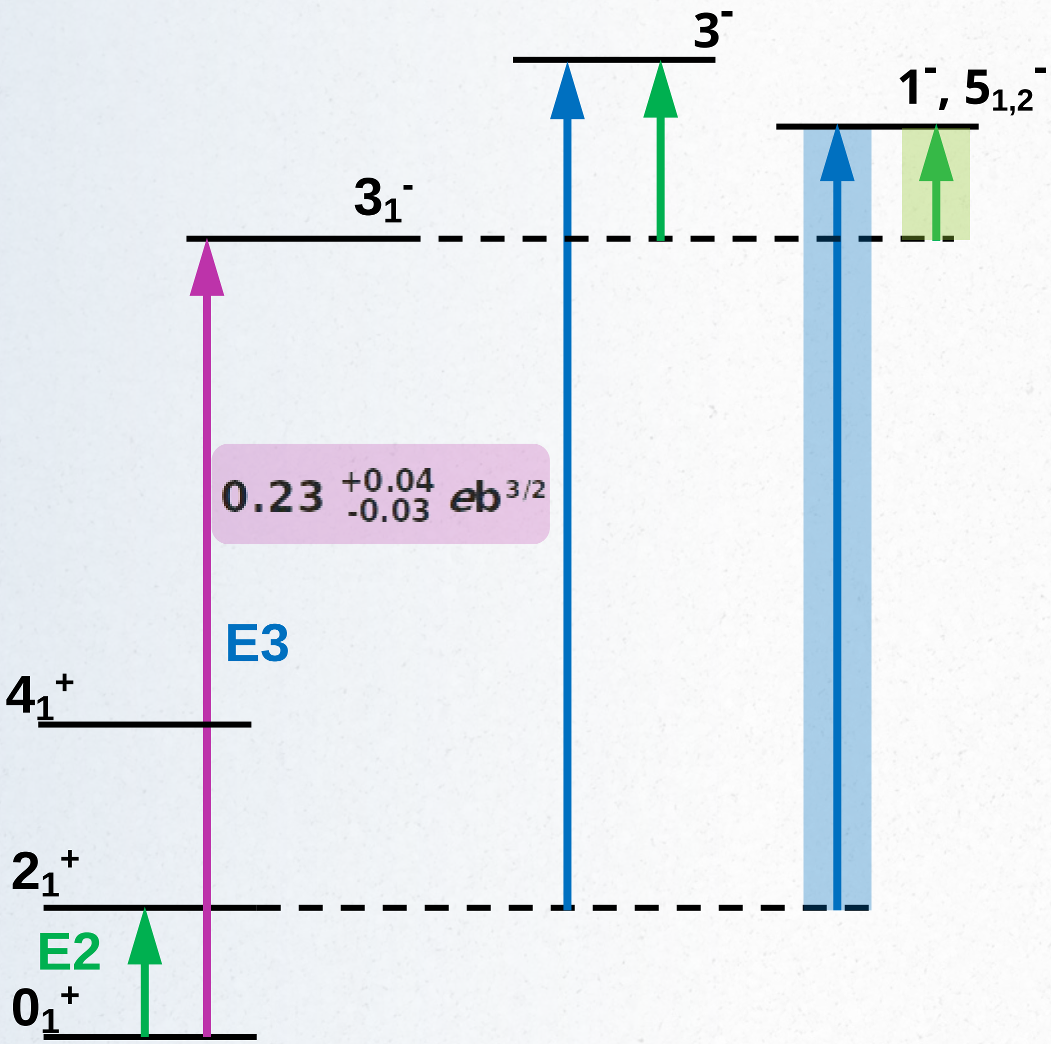
Fixed at 26 W.u. = B(E2, $2_1^+ \rightarrow 0_1^+$)

$[eb^{3/2}]$ $\langle I_f^\pi \| E3 \| I_i^\pi \rangle$	E3	E3 + E3	E3 + E2
$\langle 3_1^- \| E3 \| 0_1^+ \rangle$	0.233(5)	0.211(6)	0.25(2)
$\langle 5_1^- \| E3 \| 2_1^+ \rangle$	0.25(3)	0.23(2)	0
$\langle 5_2^- \| E3 \| 2_1^+ \rangle$	0.54(2)	0.54(2)	0.24(2)
$\langle 1 \| E3 \| 2_1^+ \rangle$	0.30(1)	0.32(2)	0.16(2)
$\langle 3 \| E3 \| 0_1^+ \rangle$	0.062(7)	0	-
$\langle 3 \| E3 \| 2_1^+ \rangle$	0.33(3)	0.35(3)	$0.10^{+0.03}_{-0.06}$

Coupling schemes



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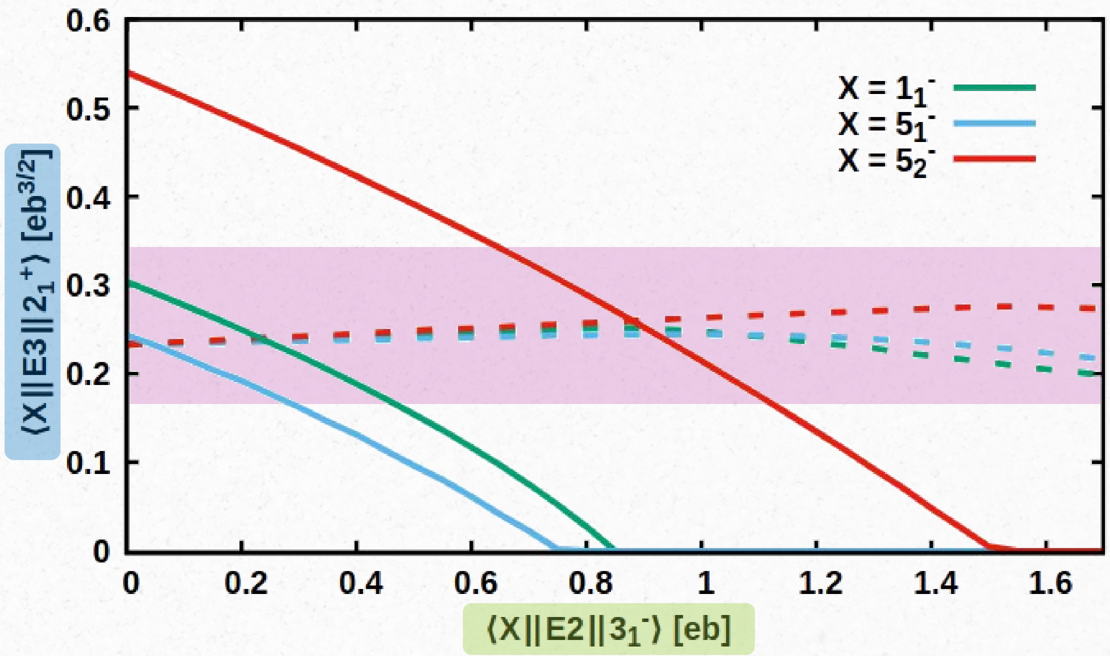
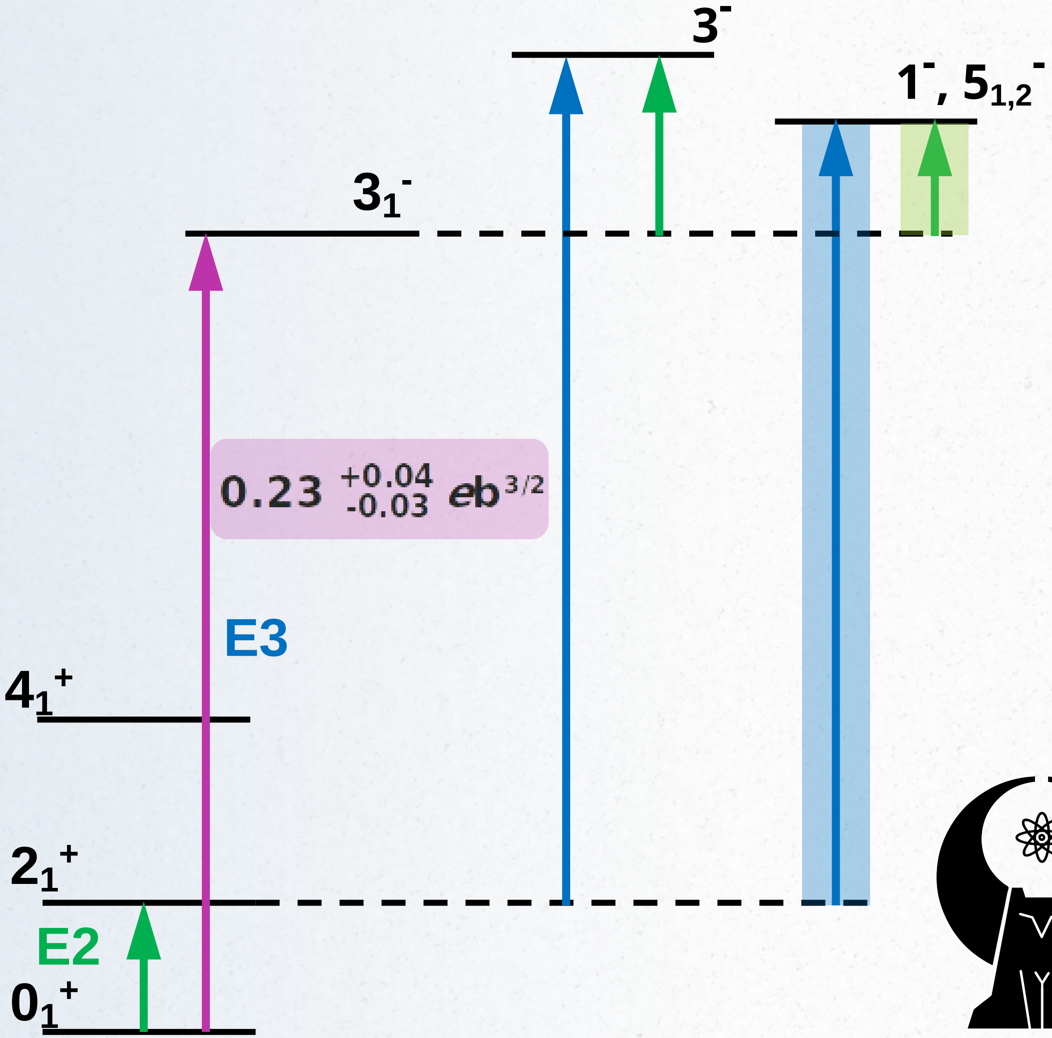


- A dependence between the E2 and E3 matrix elements can be obtained.

Coupling schemes



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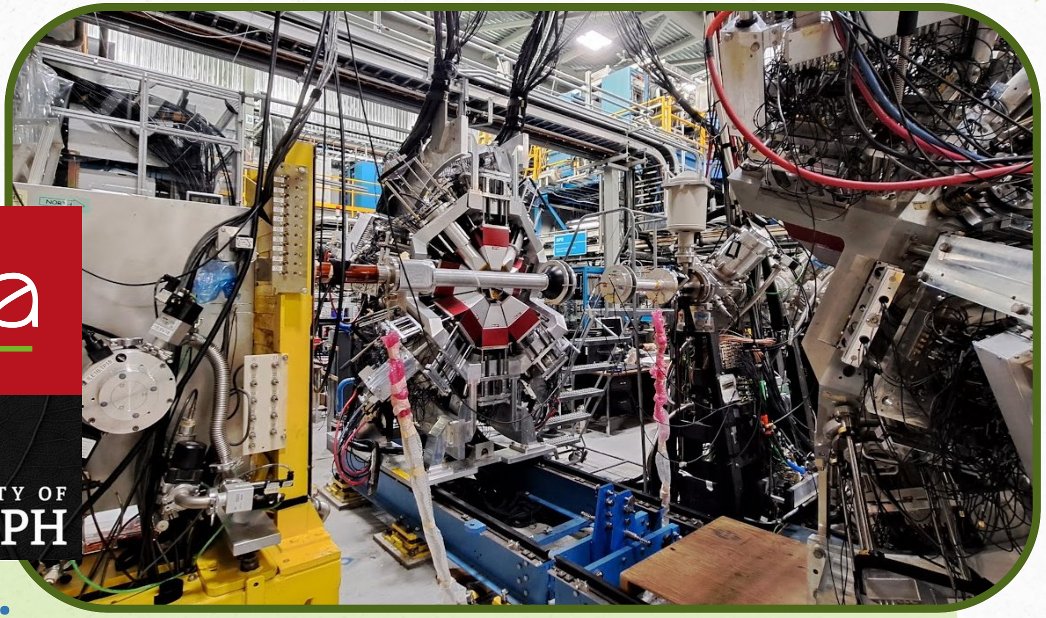
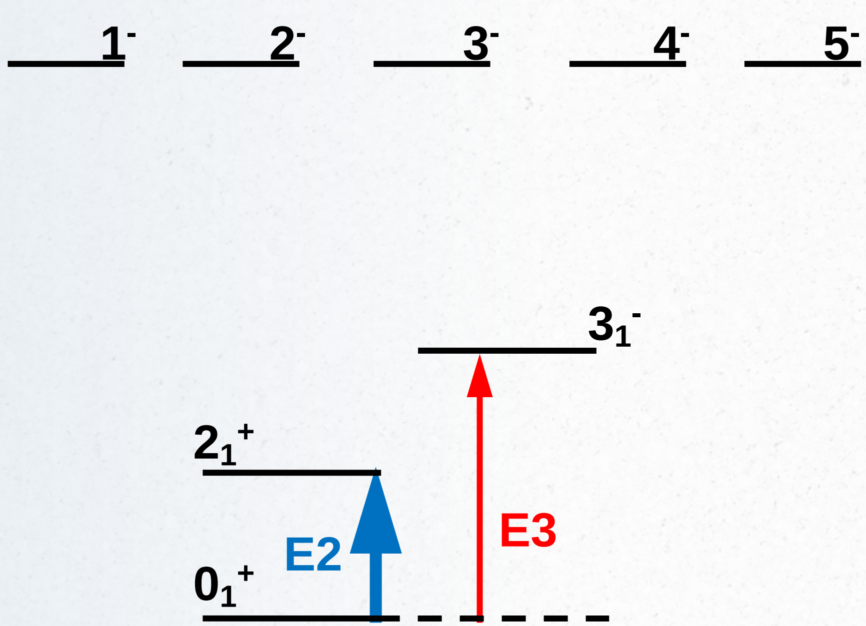


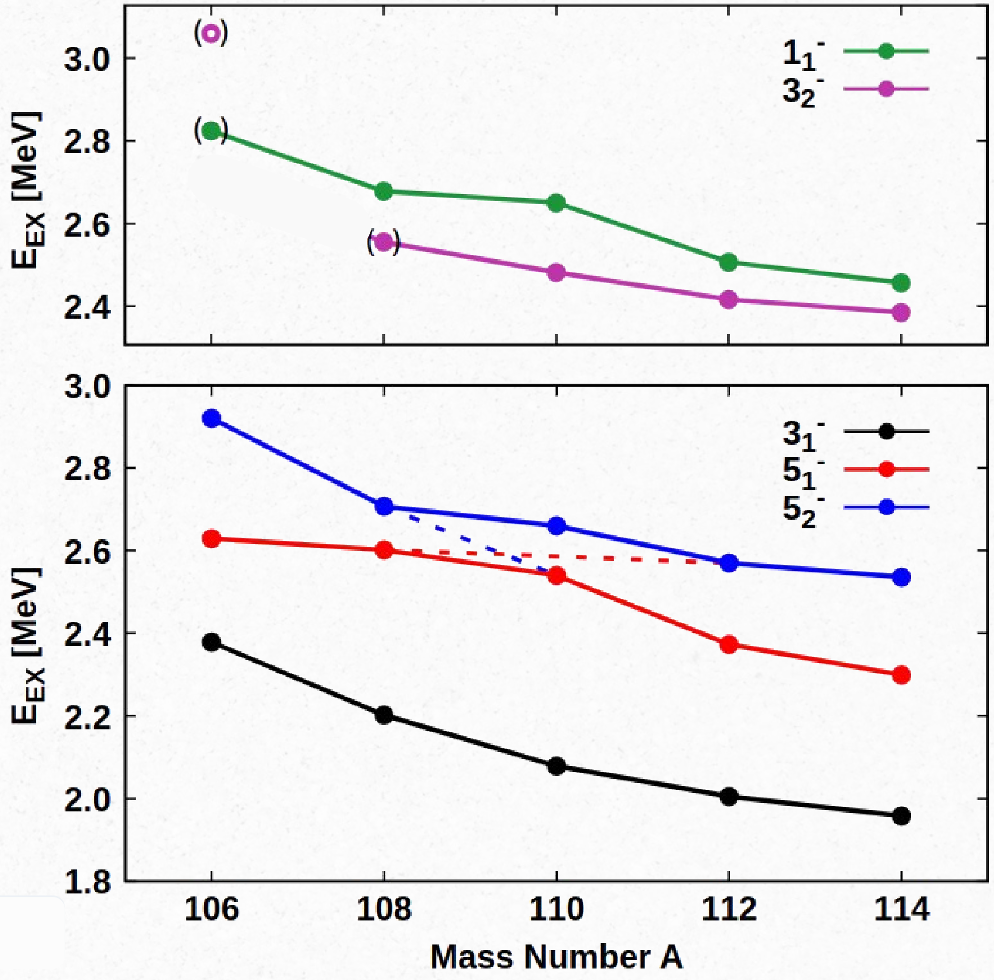
Outlook:

- **Beta-decay study of ^{106}In to ^{106}Cd at TRIUMF**.
- PIs: M. Zielinska, D. Kalaydjieva, P. E. Garrett.
- Experiment successfully performed in August 2025; under analysis by L. L. Luperi (PhD at CEA Saclay).

Quadrupole-octupole coupling

- Coupling of one-phonon quadrupole and one-phonon octupole surface vibrations would result in the appearance of **quintuplet of negative-parity states.**





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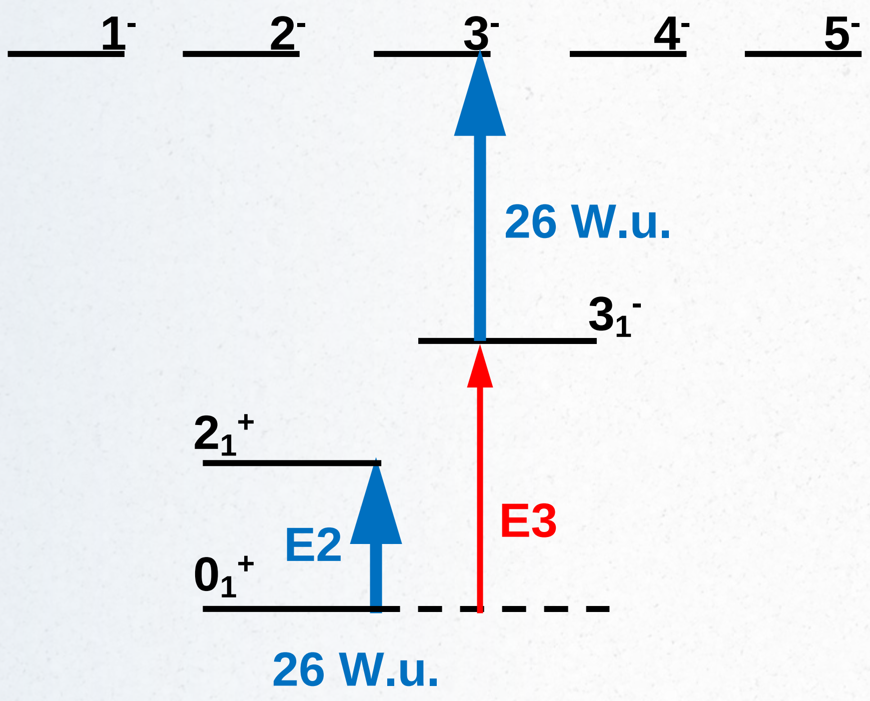

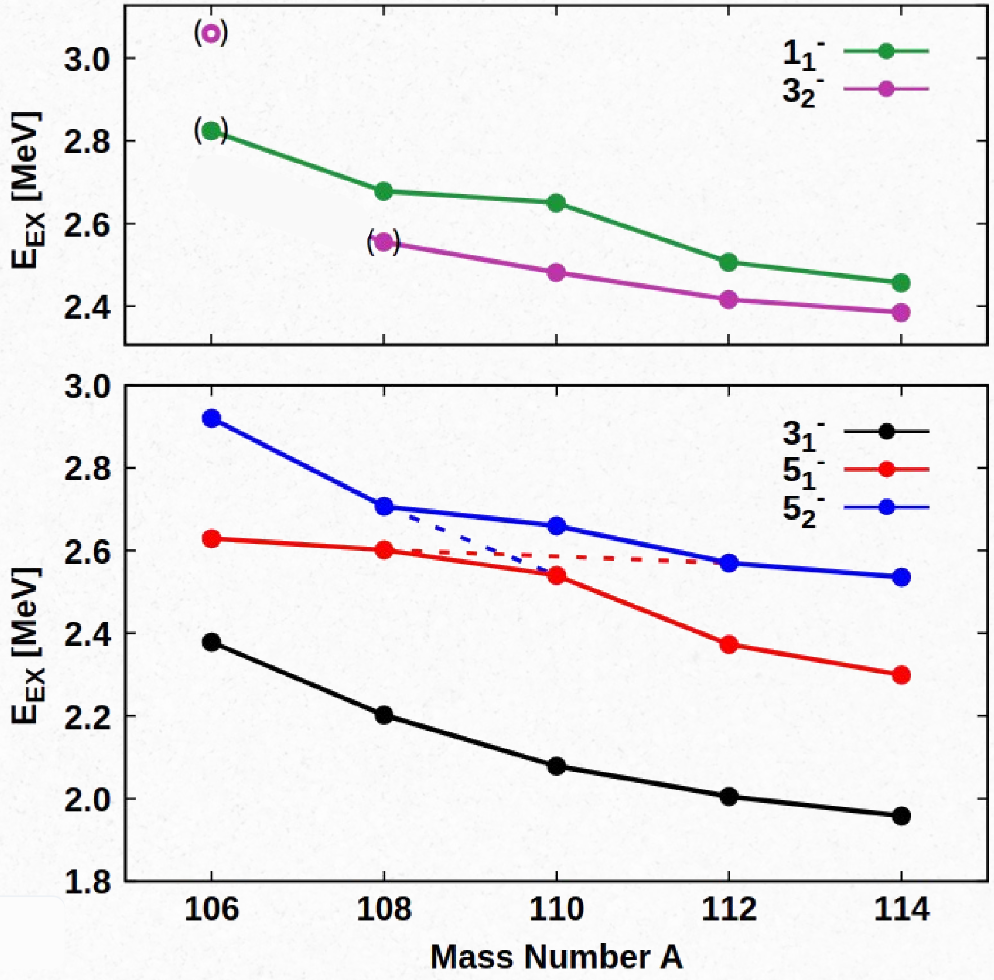

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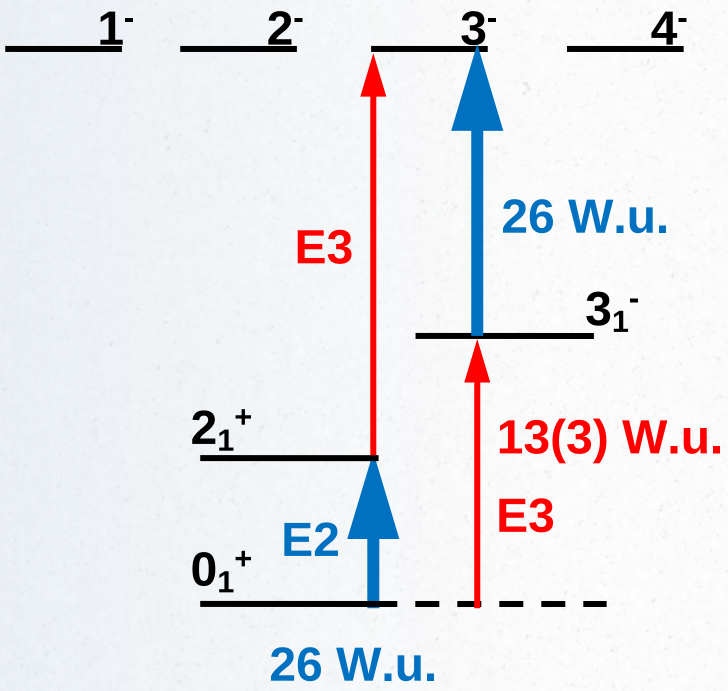
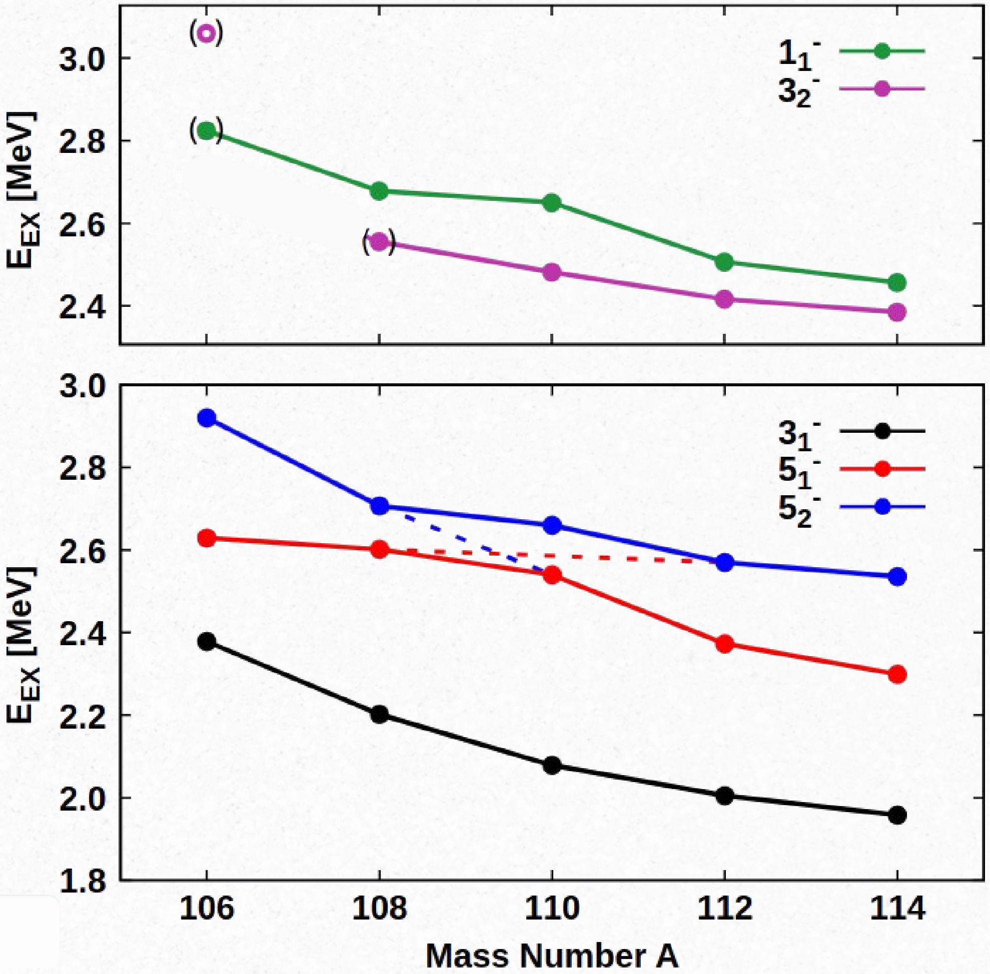
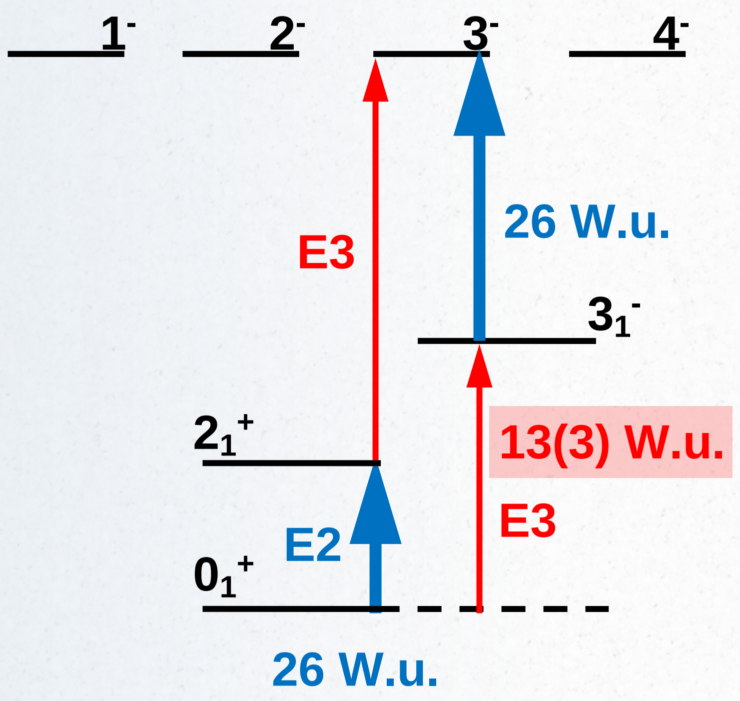
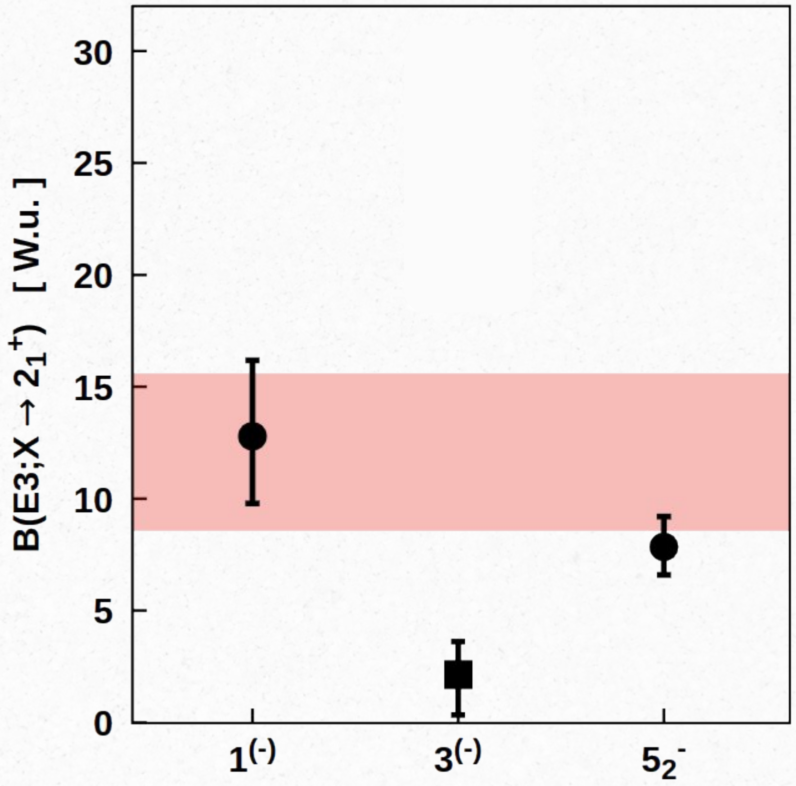




Quadrupole-octupole coupling

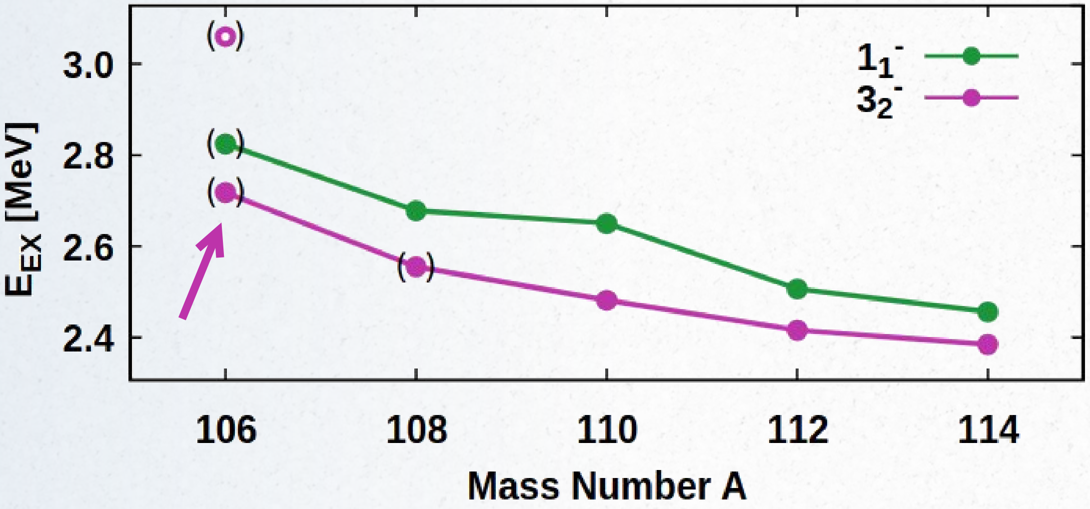
- Coupling of one-phonon quadrupole and one-phonon octupole surface vibrations would result in the appearance of **quintuplet of negative-parity states.**
- **The 1_1^- and 5_2^- states are good candidates for members of the QOC quintiplet**.

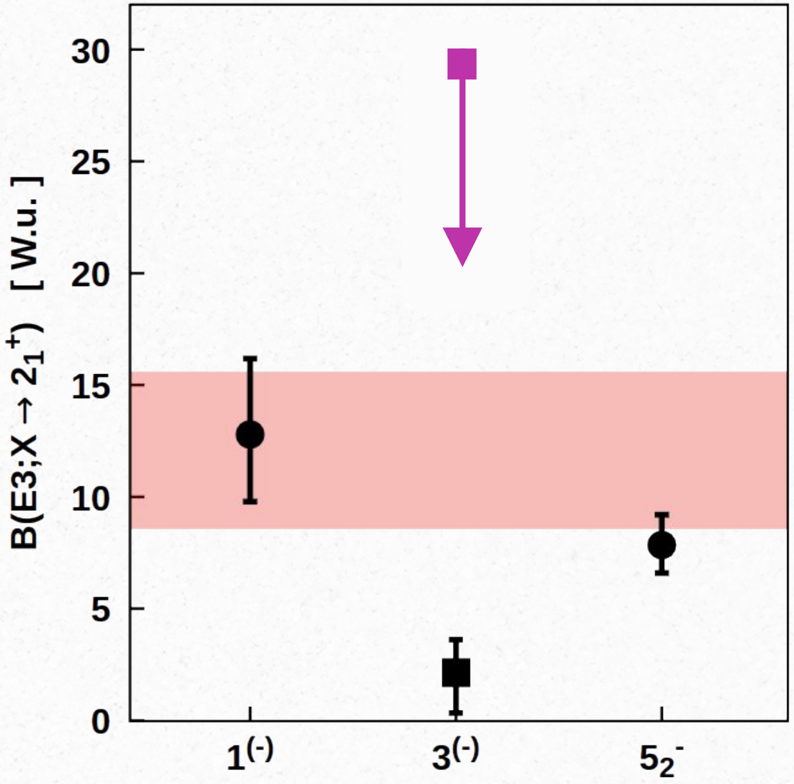




Quadrupole-octupole coupling

- Coupling of one-phonon quadrupole and one-phonon octupole surface vibrations would result in the appearance of **quintuplet of negative-parity states.**
- **The 1_1^- and 5_2^- states are good candidates for members of the QOC quintiplet**.
- The **(2⁺,3) state at 2718 keV** is a possible spin-3 candidate, but no firm spin assignment is available.





The long-standing Cd debate

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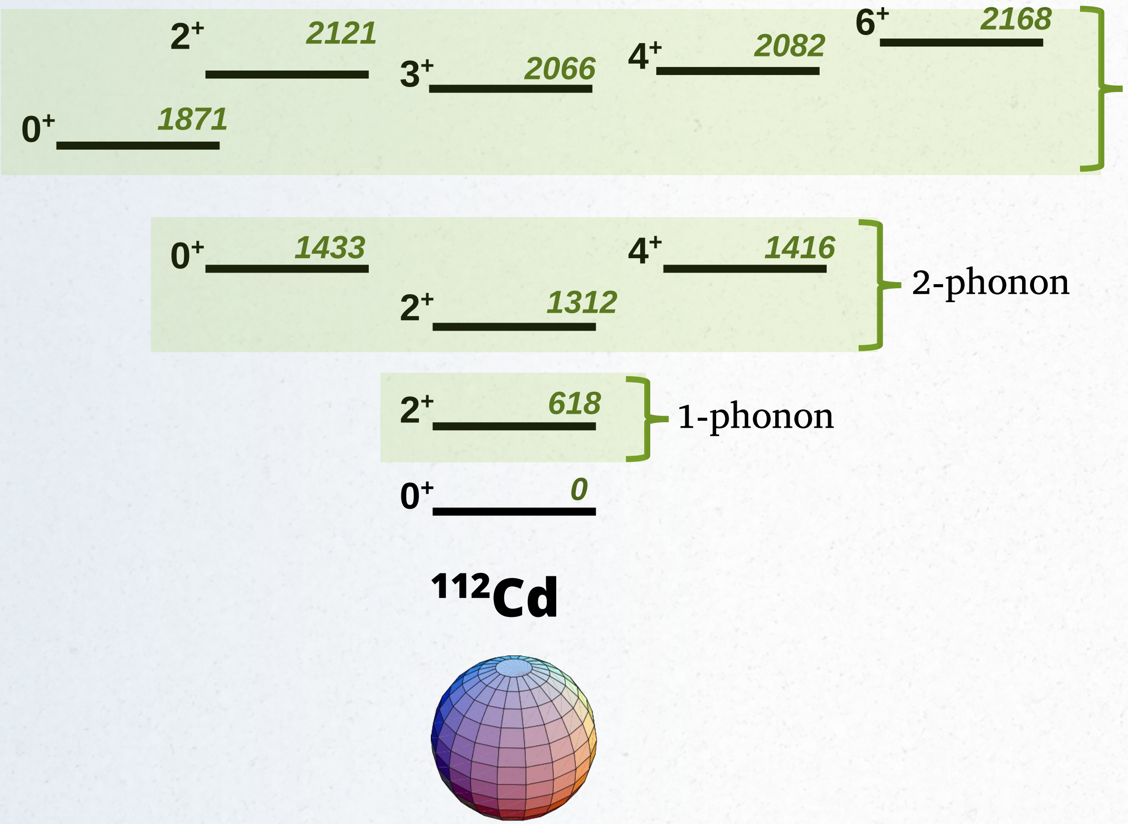

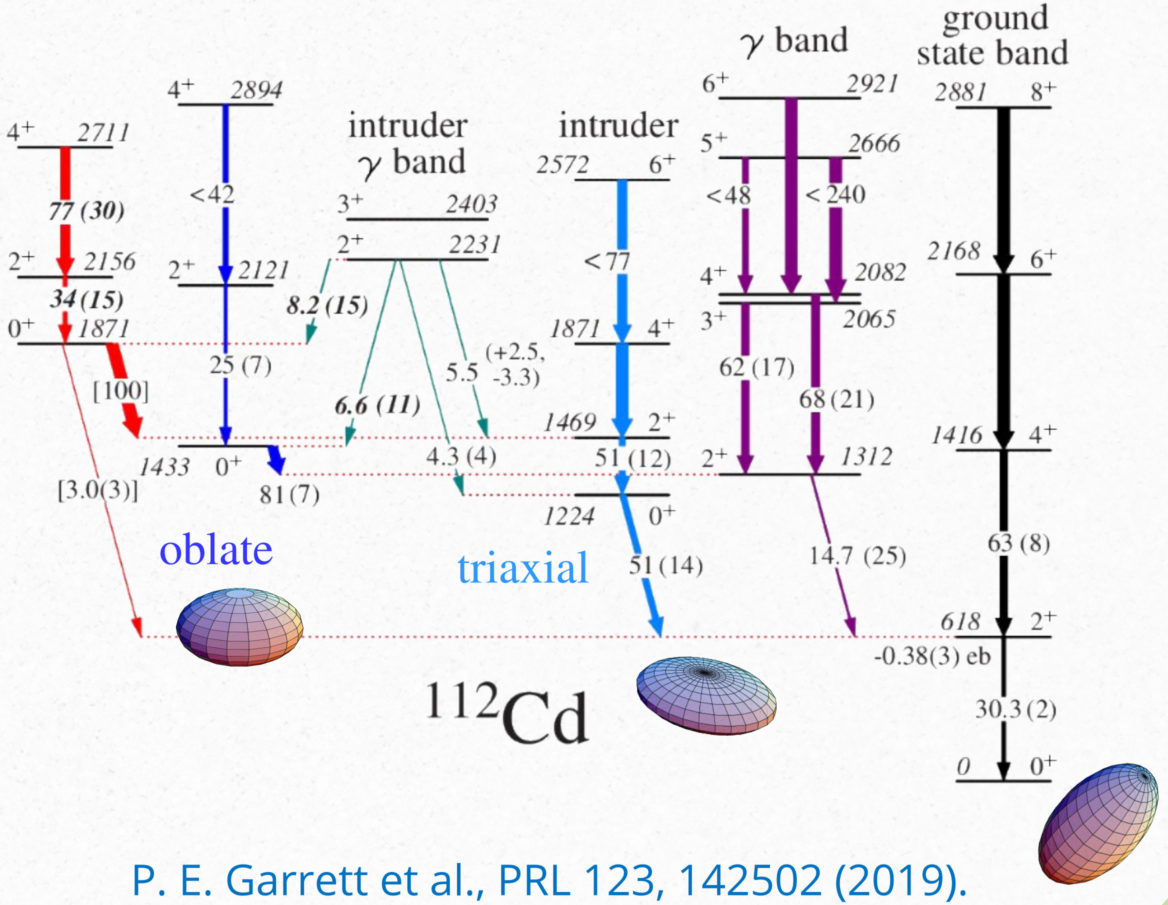

P. E. Garrett et al., PRL 123, 142502 (2019).

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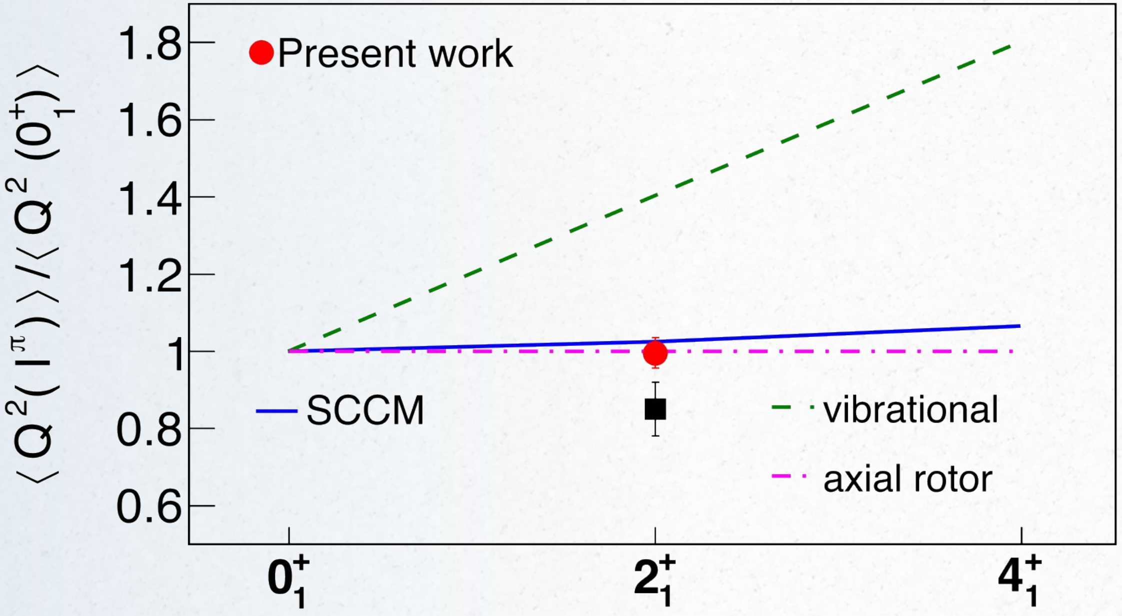

T. J. Gray et al., PLB 834 137446 (2022).

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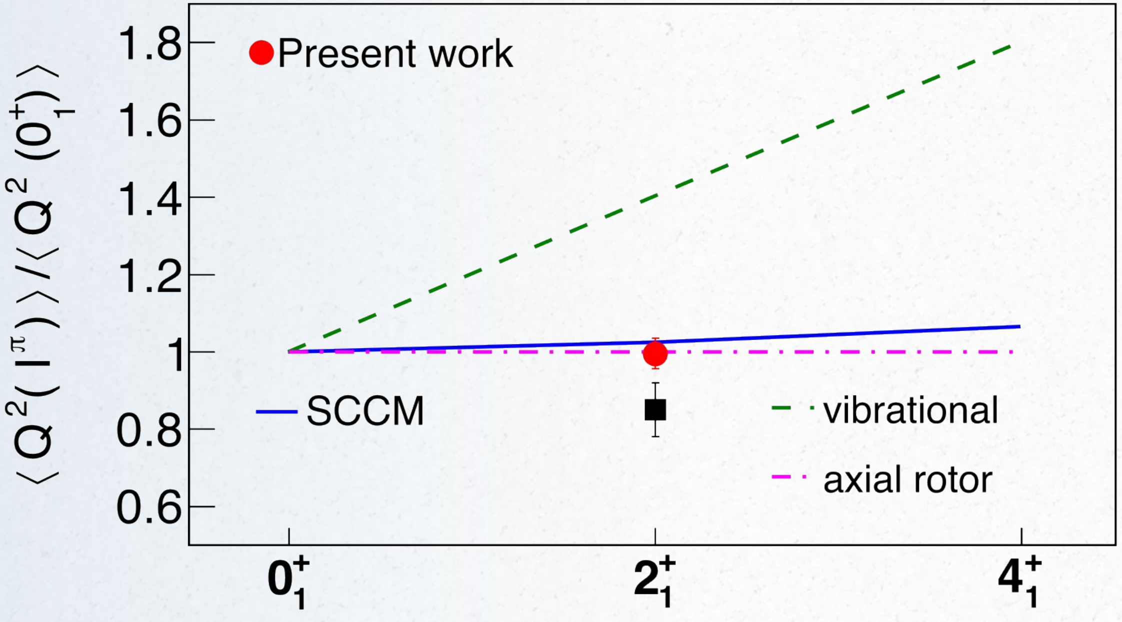

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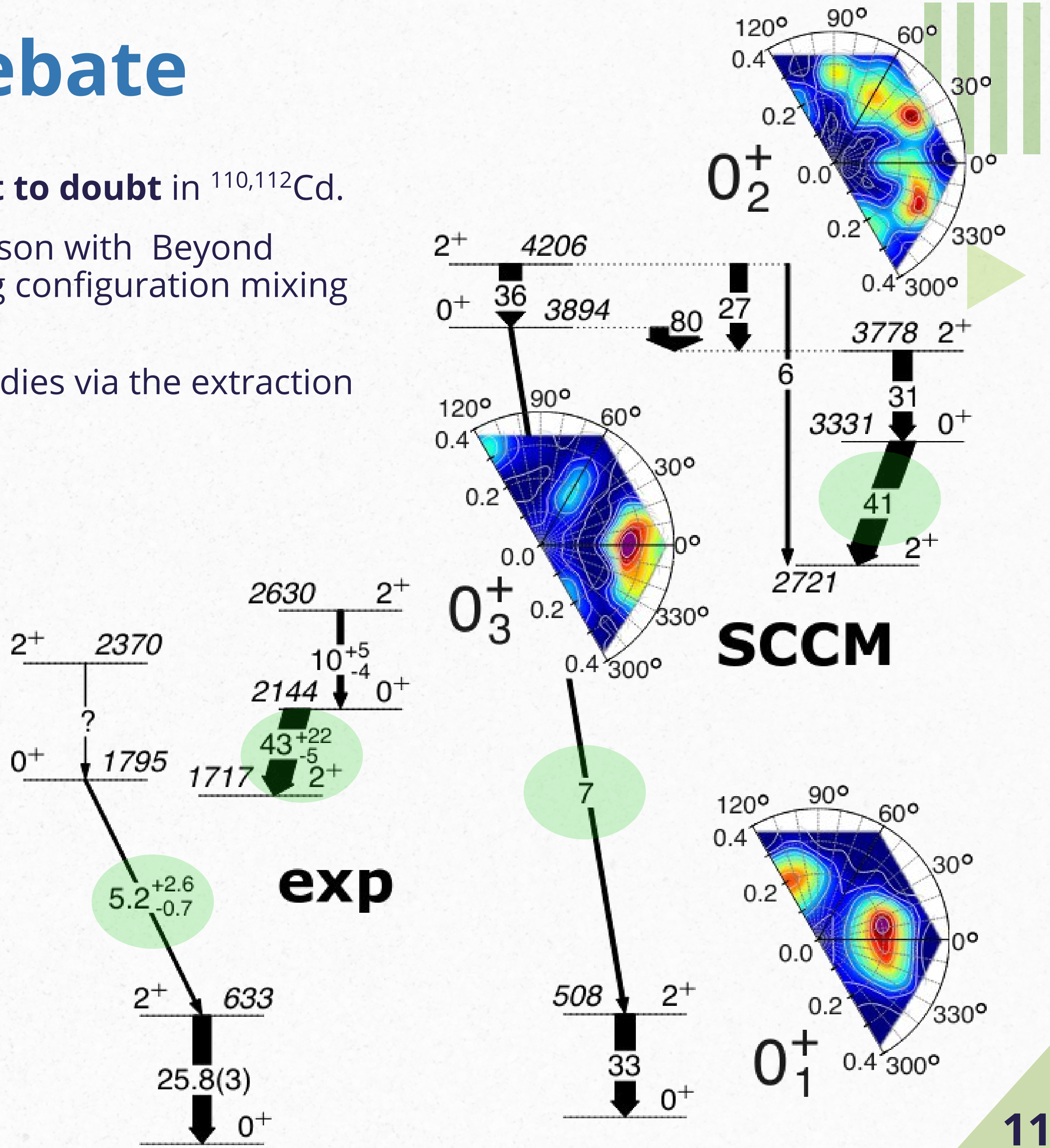

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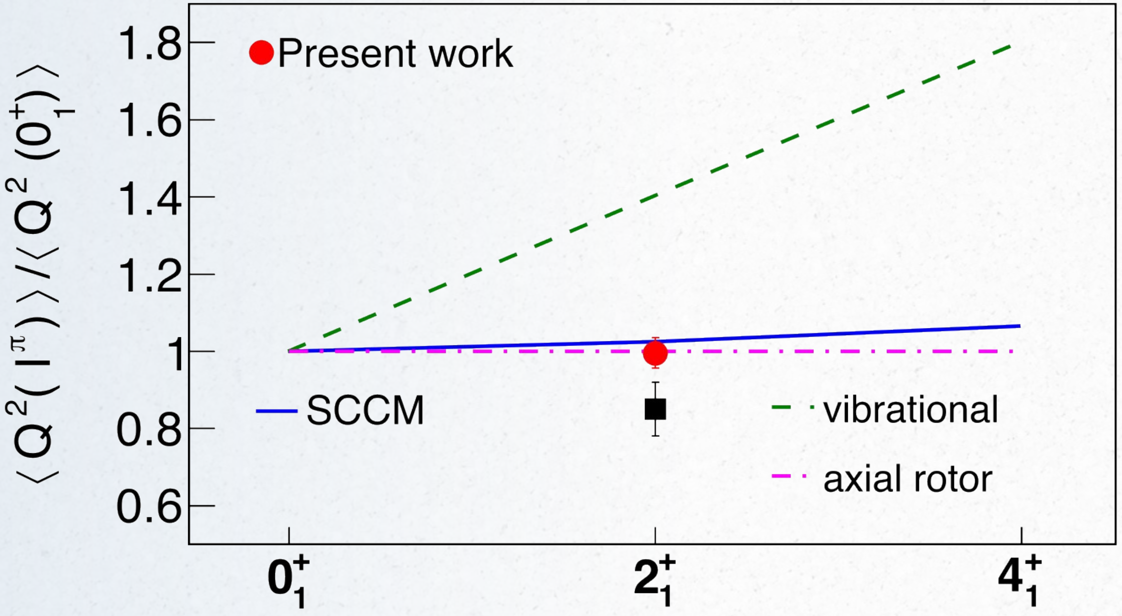

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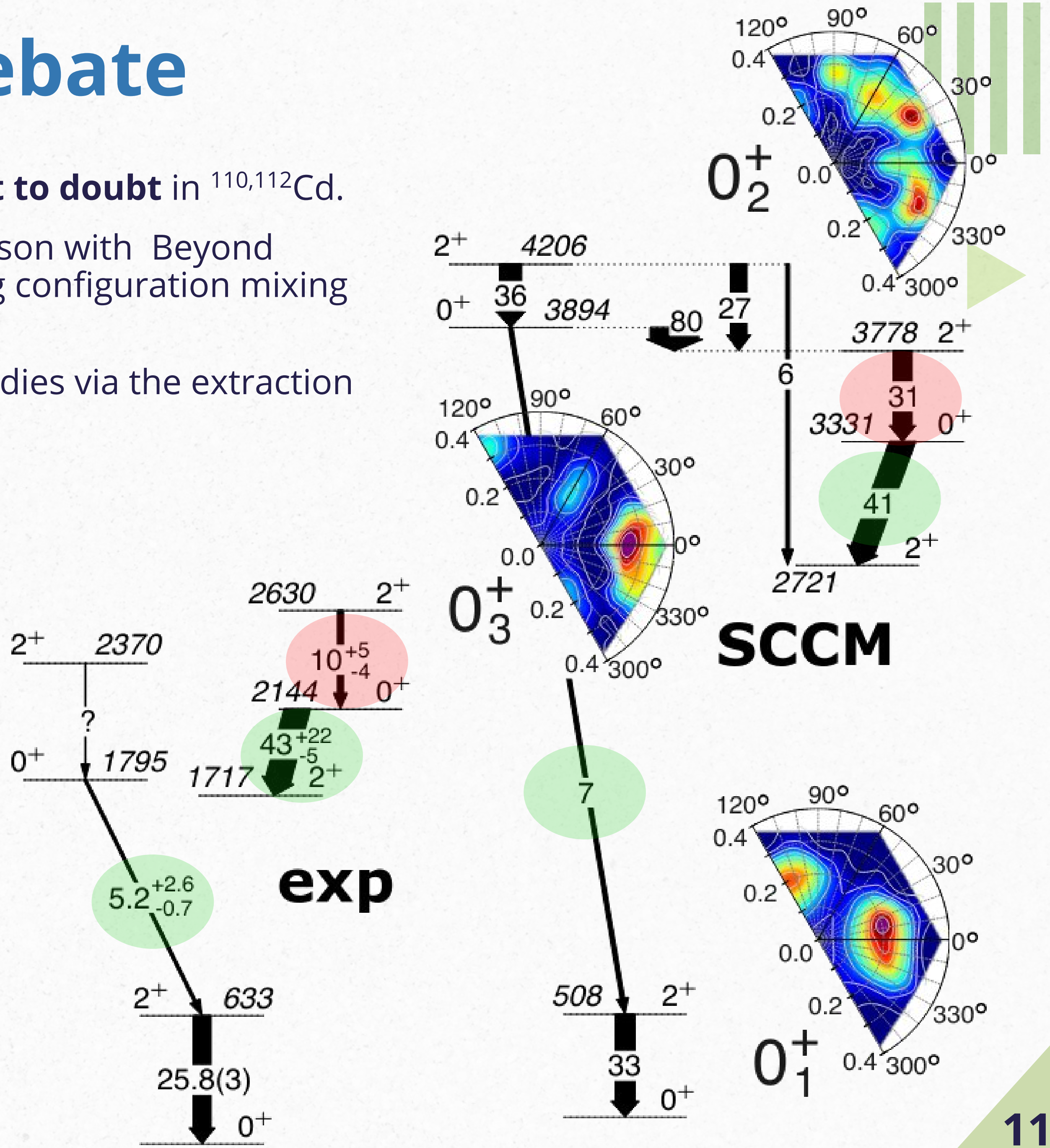

Conclusions

- Slightly “unsafe” Coulomb-excitation data on ^{106}Cd from experiment E664 at GANIL was analysed with a **complementary to the RDDS technique**.

- Majority of the literature lifetimes were confirmed studying the evolution of γ-ray yields as a function of the scattering angle.

- **Results beyond the limitations of the RDDS technique** were obtained, including first evaluation of E3 matrix elements for several negative-parity states in ^{106}Cd interpreted within a QOC scenario.

- A **successful experiment at TRIUMF**, Canada was inspired by this work (under analysis at CEA Saclay in collaboration with UoGuelph).

- Results are described well by SCCM calculations supporing a possible shape-coexistence scenario in ^{106}Cd, yet **further spectroscopic data is needed** to fully disentangle the “Cd debate”.

Thank you for your attention!

More details in our publication soon available in EPJ A!

Probing quadrupole and octupole collectivity in ^{106}Cd via "unsafe" Coulomb excitation

D. Kalaydjieva[1,2], M. Zielińska[1], M. Siciliano[1,3,4], T.R. Rodríguez[5], P.E. Garrett[2,6], J.J. Valiente-Dobón[4], A. Goasduff[4], D. Bazzacco[7], G. Benzoni[8], T. Braunroth[9], N. Cieplicka-Oryńczak[10], E. Clément[11], F.C.L. Crespi[8,12], G. de France[11], M. Doncel[13], S. Ertürk[14], C. Fransen[9], A. Gadea[15], G. Georgiev[16], A. Goldkuhle[9], U. Jakobsson[17], G. Jaworski[4,18], N. Keeley[19], W. Korten[1], I. Kuti[20], P.R. John[7,21], A. Lemasson[11], H. Li[17], A. Lopez-Martens[16], T. Marchi[4], D. Mengoni[7,21], C. Michelagnoli[11,22], T. Mijatović[23], C. Müller-Gatermann[3,9], D.R. Napoli[4], J. Nyberg[24], M. Palacz[18], R.M. Pérez-Vidal[4,15], B. Saygi[4,25], D. Sohler[20], S. Szilner[23], and D. Testov[7,21,26]