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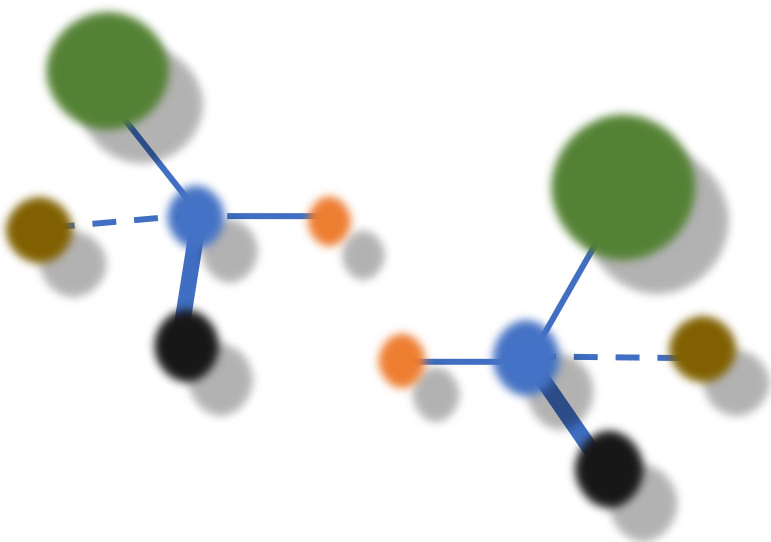
University of Chinese Academy of Sciences

Collectivity and chirality in neutron deficient ^{119}Cs, ^{119}Ba, and ^{118}Cs nuclei



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Chirality and Wobbling in Atomic Nuclei, July 10 - July 14, 2023, Huizhou, China

Outline

- **Motivation**
  - Chirality
- **Experimental setup**
- **Results and discussion**
  - Isomer
  - Chirality
- **Summary**

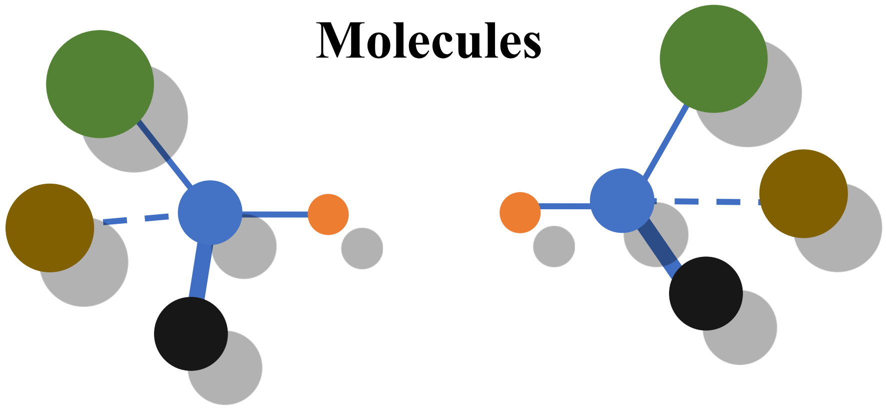
Chirality

- It is a **common phenomenon** in nature.
- It is a simple **symmetry property** of an object or system which cannot be superimposed onto its mirror image.
- It can occur in a **static** or **dynamic** regime.

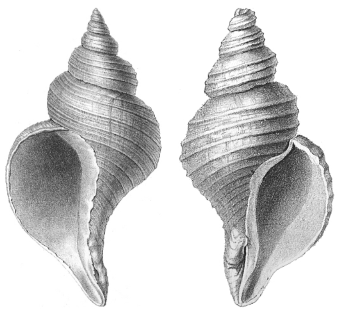
Chiral symmetry **Chiral symmetry breaking (chirality)**

Hands

Molecules



Shells of sea snail



It should be pointed out that the chirality in nature is often **static**.

How about in nuclei ???

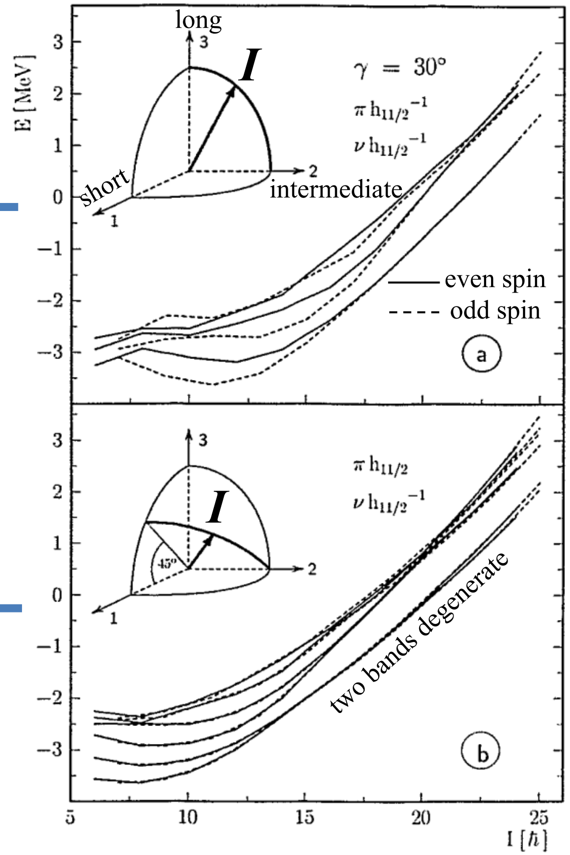
Nuclear Chirality

Chirality in nuclei was proposed in 1997 by Frauendorf and Meng.

Collective core (**R**); Quasi-proton (**j**$_\pi$); Quasi-neutron (**j**$_\nu$); Total angular momentum (***I***).

Band head: R=0;
I is parallel to the 3-axis.
Rotation: R≠0;
I moves into the 2-3 plane.

Band head: R=0;
I lies in the 1-3 plane.
Rotation: R≠0;
I points to 3D.

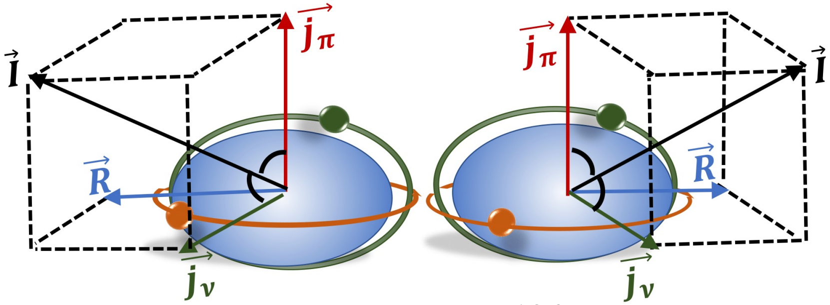


The nuclei exhibit the chirality when two conditions are satisfied, **axial-asymmetry** and **dynamic regime**: triaxial shape, and rotating around an axis out of the principal planes of the intrinsic reference system.

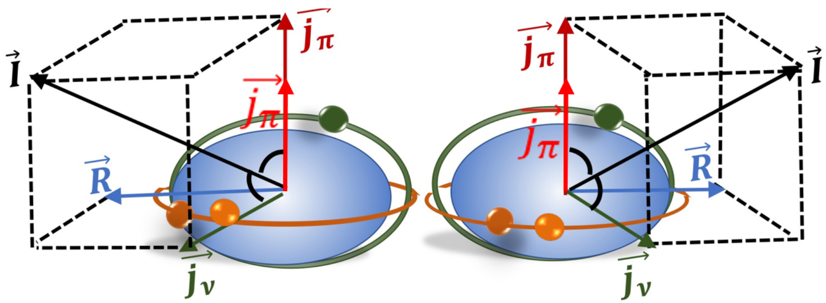
Chiral operator: $\chi = TR(\pi)$ → **Time reversal + rotation**

Nuclear Physics A, 617(2):131–147, 1997

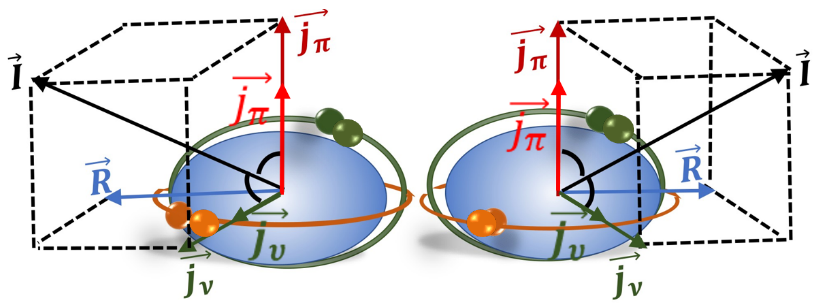
Nuclear Chirality



Odd-odd nucleus ^{134}Pr (2-qp)



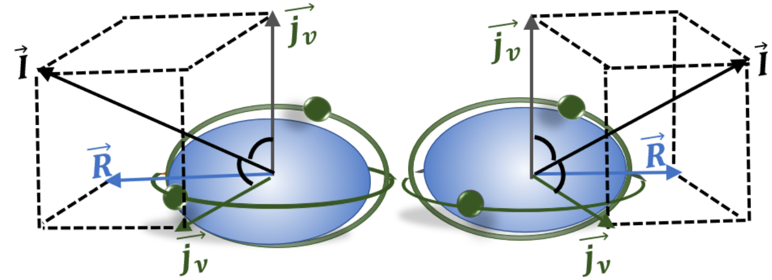
Odd-even nucleus ^{135}Nd (3-qp)



Even-even nucleus ^{136}Nd (4-qp)

The chiral phenomenon is spread over the different systems in **odd-odd**, **odd-even**, **even-even** nuclei with **complicated configurations**.

For a configuration with only neutrons? yes



^{106}Mo (2-neutrons)

The chirality is generated by a neutron $h_{11/2}$ particle and a mixed ($d_{5/2}$, $g_{7/2}$) hole aligned to the short and long axes, respectively.

For a configuration with only protons?

C. M. Petrache Phys. Rev. C **97**, 041304(R). S. Zhu Phys. Rev. Lett. **91**, 132501. S.J. Zhu Eur. Phys. J. A 25, s01, 459–462 (2005).

Motivation

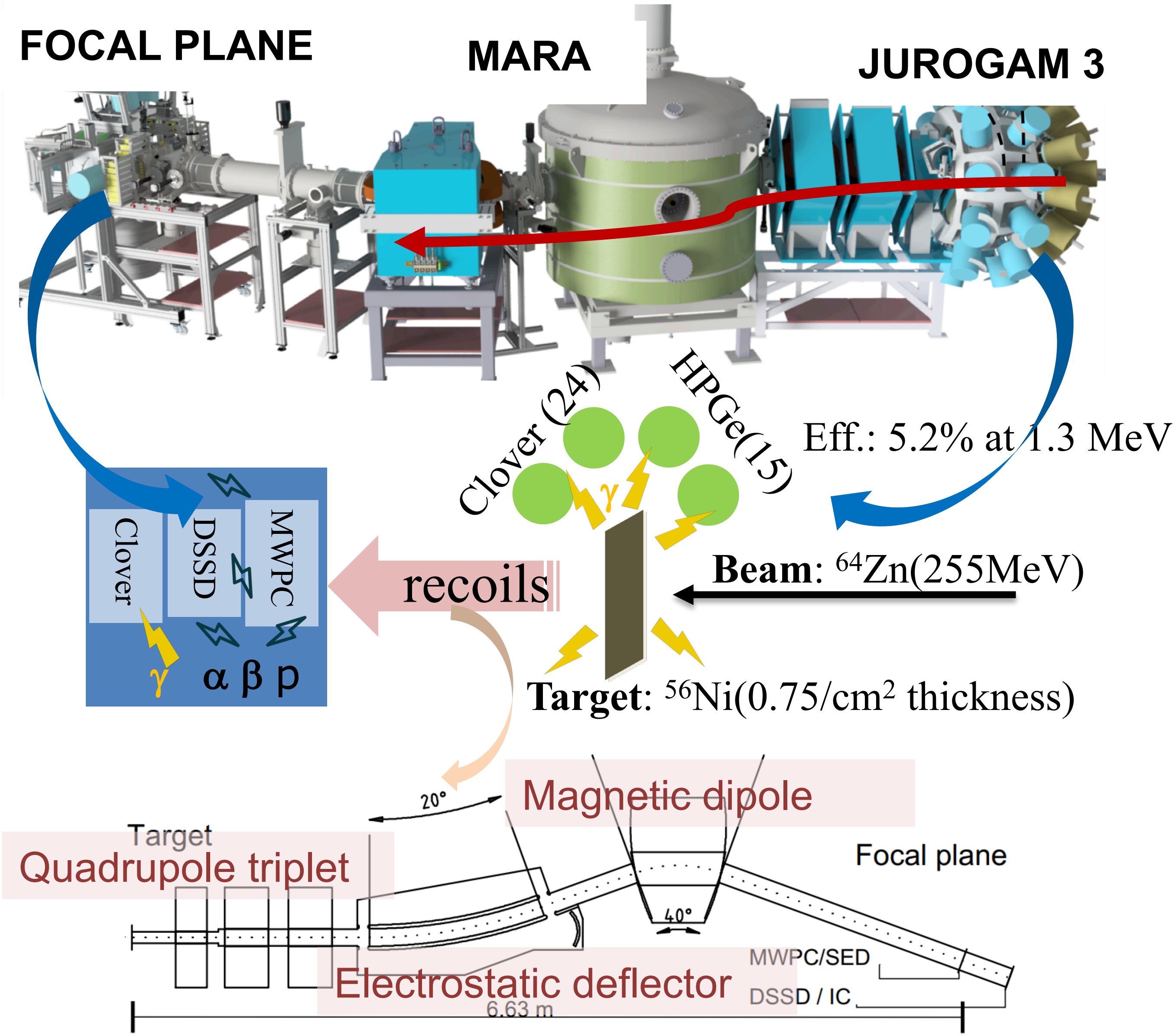
The primary motivation is to study the evolution of the nuclear structure and exotic phenomena towards the proton drip line in the 120 mass region.

Nuclei of interest: ^{119}Cs, ^{118}Cs, and ^{119}Ba.

- To study the properties of **collective rotational bands** from low to very high spin and to identify and extract the half-lives of the **isomeric states**;

- To search for **chiral doublet bands** and other exotic phenomena in the proton-rich deformed nuclei.

Experimental Setup



Location: JYFL;

Beam: ^{64}Zn, 255 MeV, 2-3 pnA;

Target: ^{58}Ni (self-supporting enriched), 0.75 mg/cm^2 ;

Populated nuclei: ^{119}Cs (150 mb), ^{119}Ba (20 mb) , ^{118}Cs (40 mb).

Data analysis

Data: **700 Gb**
350 files
4×10^{10} prompt γ-ray (fold ≥ 3) by JUROGAM 3 array.
Trigger: **Total Data Readout** data acquisition system.
Time-stamped: **100 MHz** clock with the time resolution of **10 ns**.
Analysis: the **GRAIN** and **RADWARE** packages.

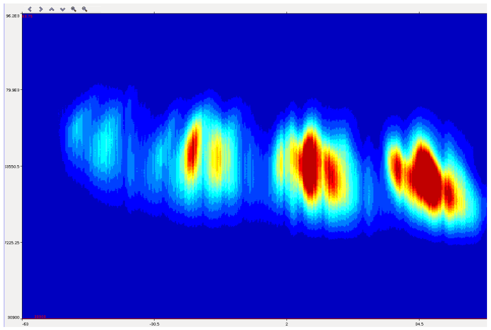
1. Setting of the low-energy thresholds, **energy calibrations**, gain matching, and **efficiency calibrations**
2. Doppler shift correction, add-back
3. Analysis of the γγγ, γγγ + **recoil**, prompt γγ (target position) + delayed γ (focal plane) coincidences
4. Assignment of multipolarities by using $\mathbf{R_{DCO}}$ and $\mathbf{R_{ac}}$

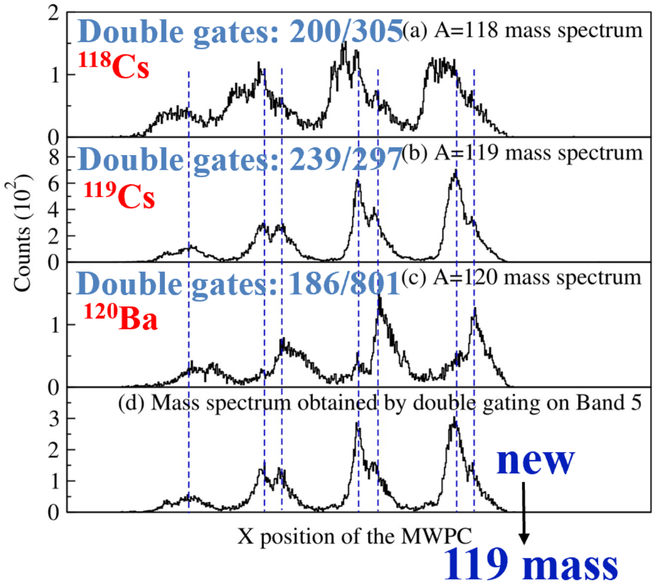
Results: The assignment of the bands to nuclei

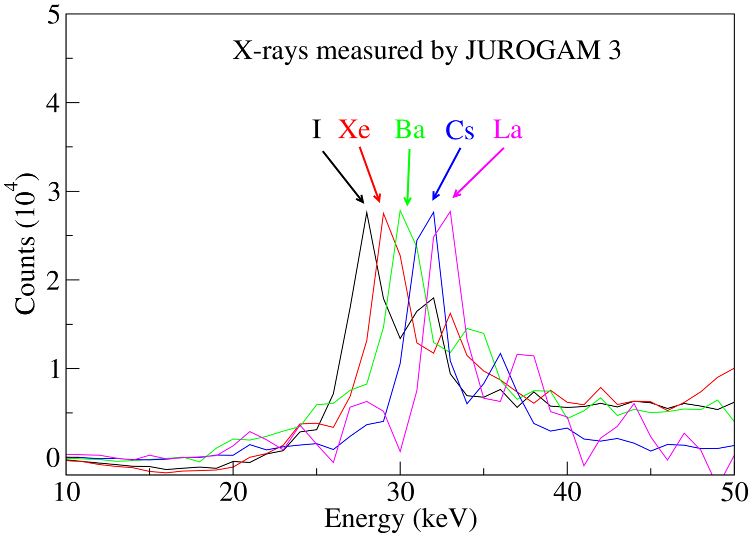
The assignments of the bands to ^{119}Cs, ^{119}Ba, and ^{118}Cs are based on:

1. The mass 119 and 118 detected at the MARA focal plane in coincidence with transitions detected in JUROGAM 3;

2. The 31 and 32 keV K_α X rays of cesium and barium nuclides detected in prompt coincidence with in-band transitions.

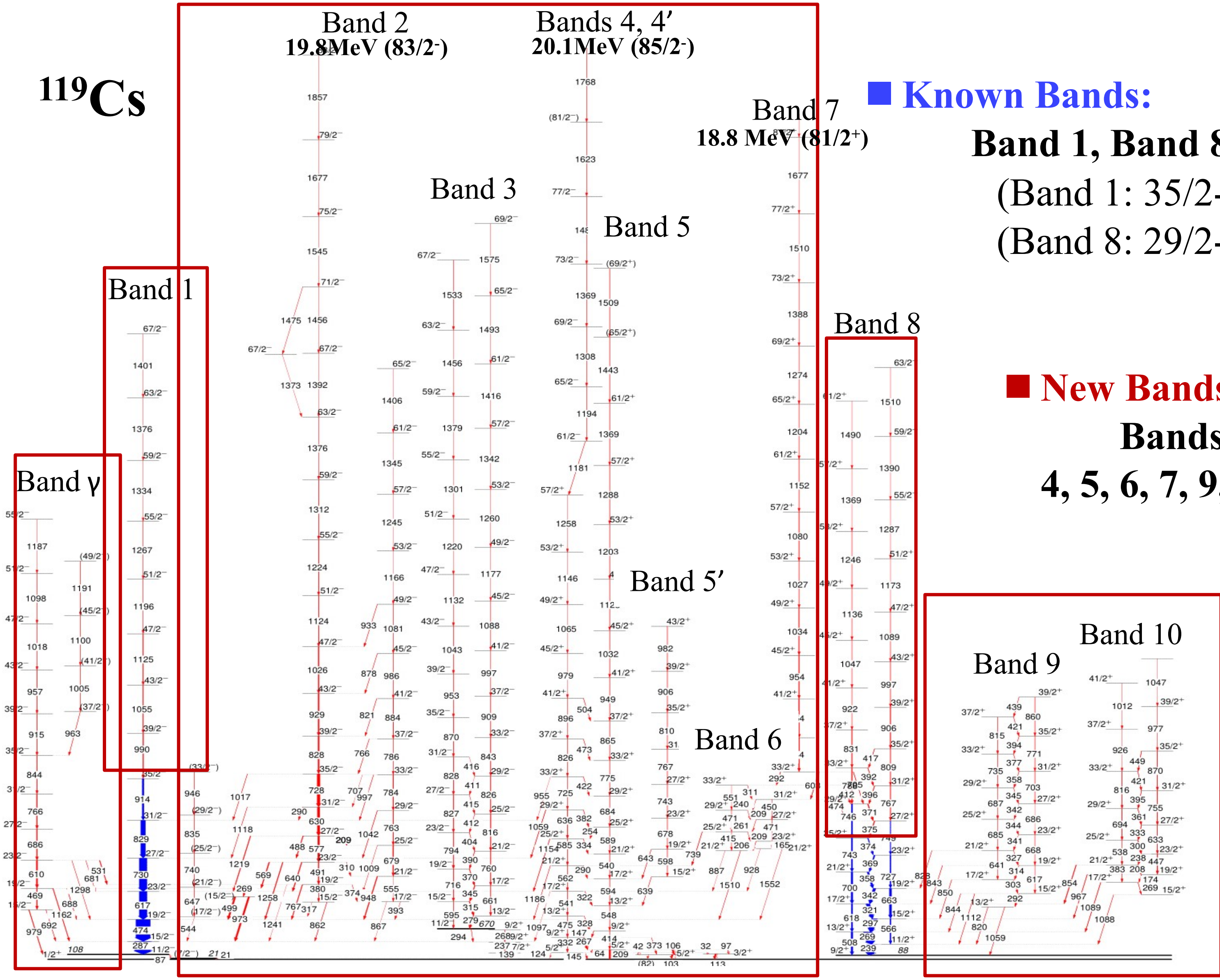






Combining information on the mass spectra and on the X-rays, we could assign new bands.

Results: Towards complete spectroscopy of ^{119}Cs



■ **Known Bands:**

Band 1, Band 8

(Band 1: 35/2-67/2)

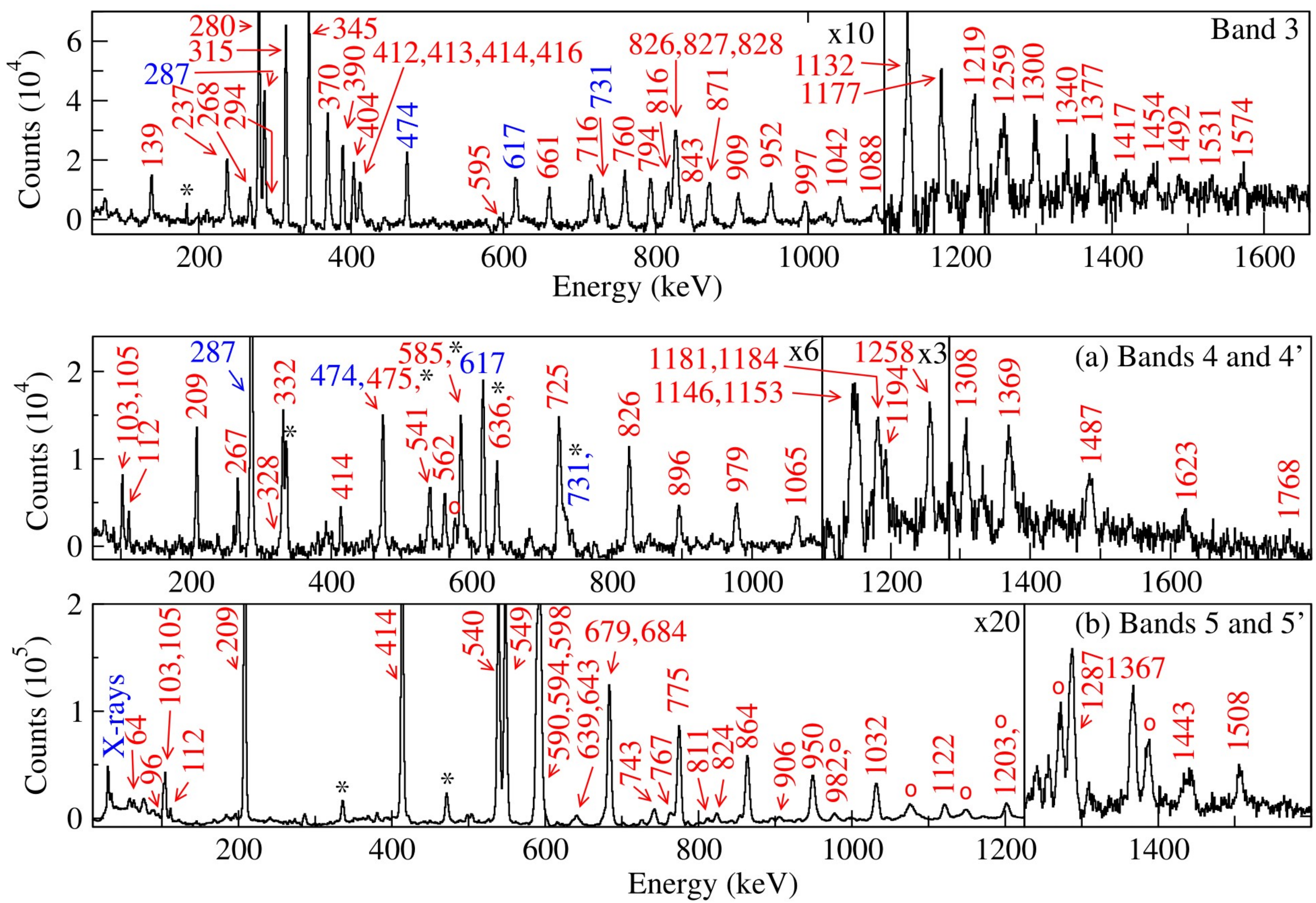
(Band 8: 29/2-63/2)

■ **New Bands:**

Bands γ, 2, 3, 4, 5, 6, 7, 9, 10

K. K. Zheng, C. M. Petrache, et al. Phys. Rev. C104 (2021) 044305

Results: examples of energy spectra of ^{119}Cs

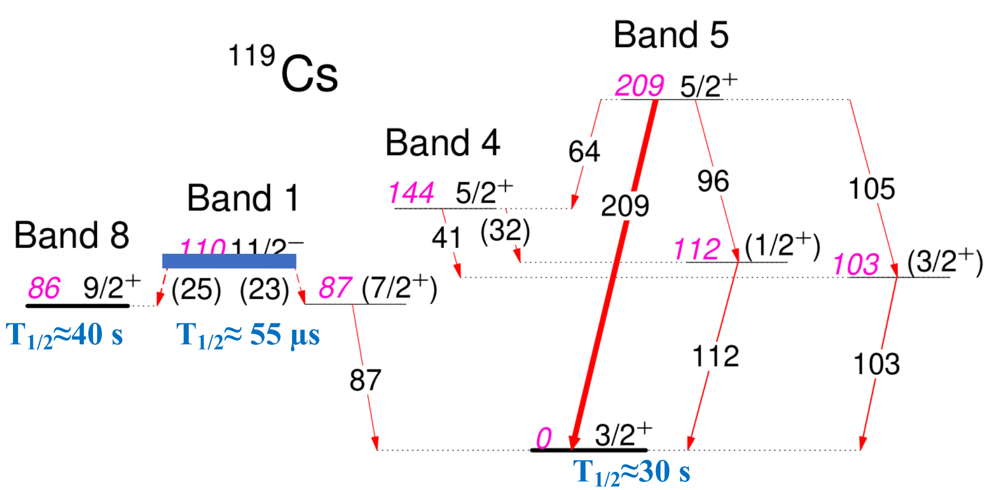


K. K. Zheng, C. M. Petrache, et al. Phys. Rev. C104 (2021) 044305

Results: Towards complete spectroscopy of ^{119}Cs

- The extension of the known bands to very high spin (B1 35/2-67/2) (B8 29/2-63/2);
- Identifying eight new rotational bands;
- All bands are interconnected by multiple transitions, thus fixing their relative intensities;
- Spins and parities are determined for most of the observed bands;
- The configurations of the observed bands are assigned based on PNC-CSM calculations.

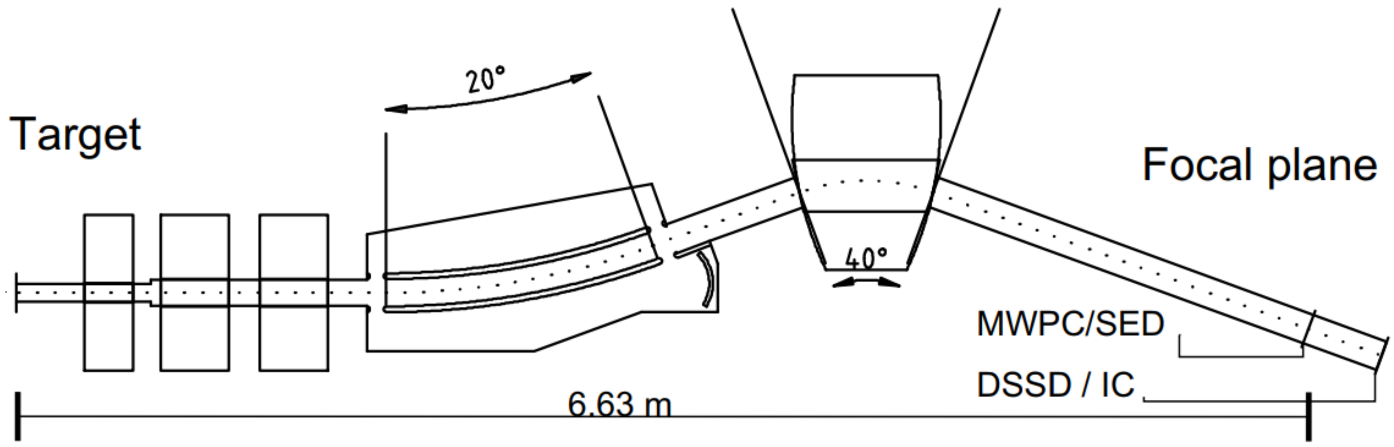
The several new bands observed in ^{119}Cs lead to one of the most complete level schemes of proton-rich Cs nuclei

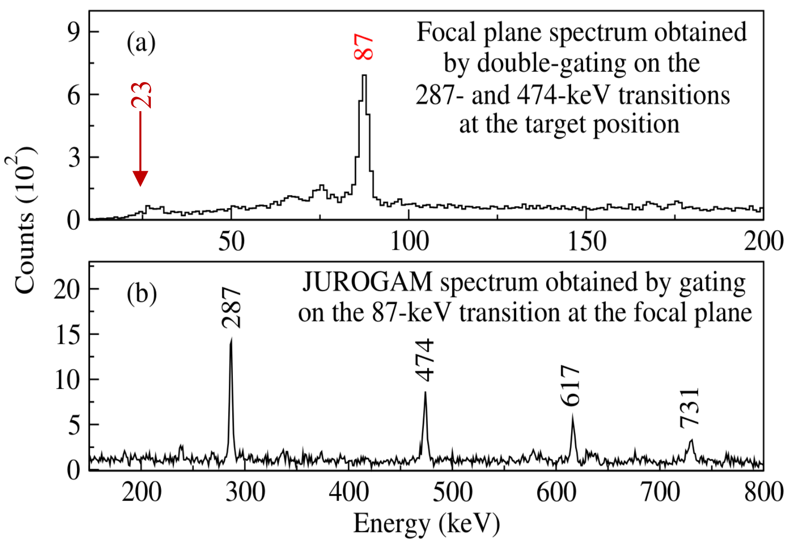


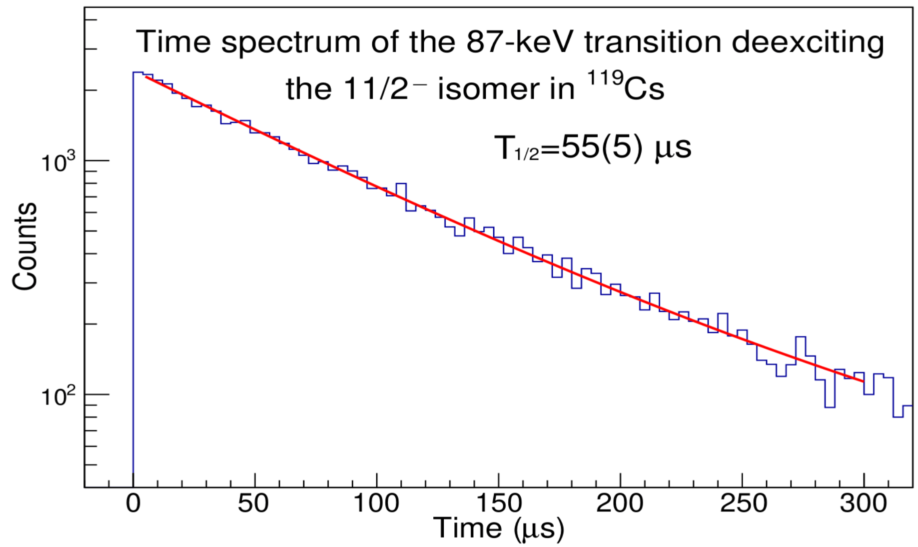
- Low-lying states:

Long-lived 9/2$^+$ (40 s) and 3/2$^+$ (30 s) isomer were known;
Ground state: 9/2$^+$ → **3/2$^+$** Fixed by the 209-keV (B5), 738-keV (B6-B4) four parallel cascades (105-103, 41-103, 96-112, (32)-112);
New isomer: 11/2$^-$ (order (23)-87 or 87-(23)).

Results: isomeric states of ^{119}Cs







The extracted lifetime of the 11/2⁻ state is **$T_{1/2}$ = 55(5) μs**.

K. K. Zheng, C. M. Petrache, et al. Phys. Lett. B 822 (2021) 136645

Results of PNC-CSM calculations of ^{119}Cs

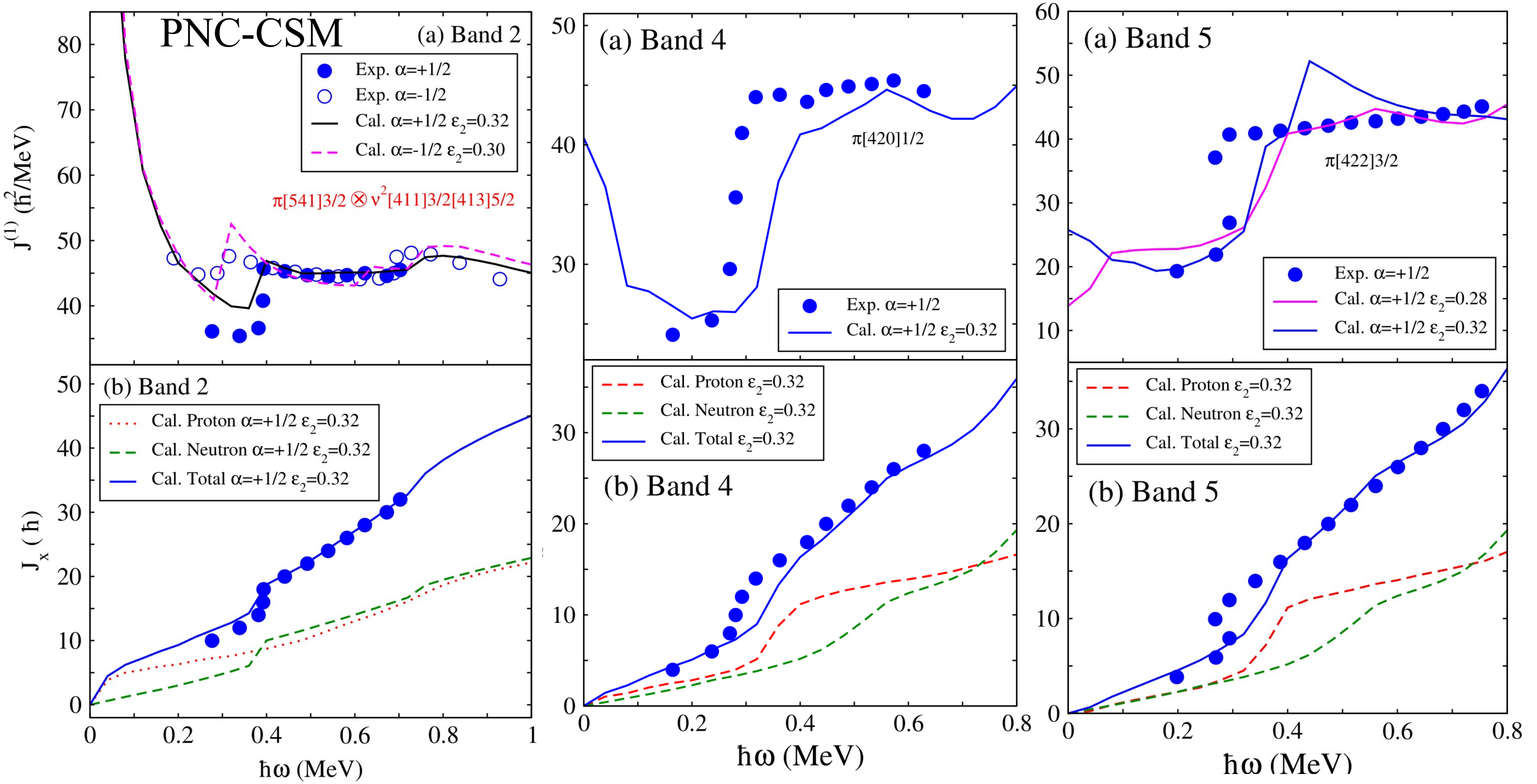
PNC-CSM: **p**article **n**umber **c**onserving **c**ranked **s**hell **m**odel

This model was recently used to successfully describe the band structure in rare-earth nuclei.

1. The calculations have been performed assuming axially symmetric shape.
2. The parameters κ and μ taken from Ref. [D. R. Inglis, Phys. Rev. 103, 1786 (1956)].
3. Effective monopole pairing strengths of 0.8 MeV for protons and 0.6 MeV for neutrons.
4. The deformation parameters $\varepsilon_2 = 0.32$ for most prolate bands, Band 2 (α=-1/2) ($\varepsilon_2 = 0.30$) and Band 3 ($\varepsilon_2 = -0.17$).

Z. H. Zhang, Phys. Rev. C 101, 055506 (2020)

Results: examples of PNC-CSM calculations of ^{119}Cs



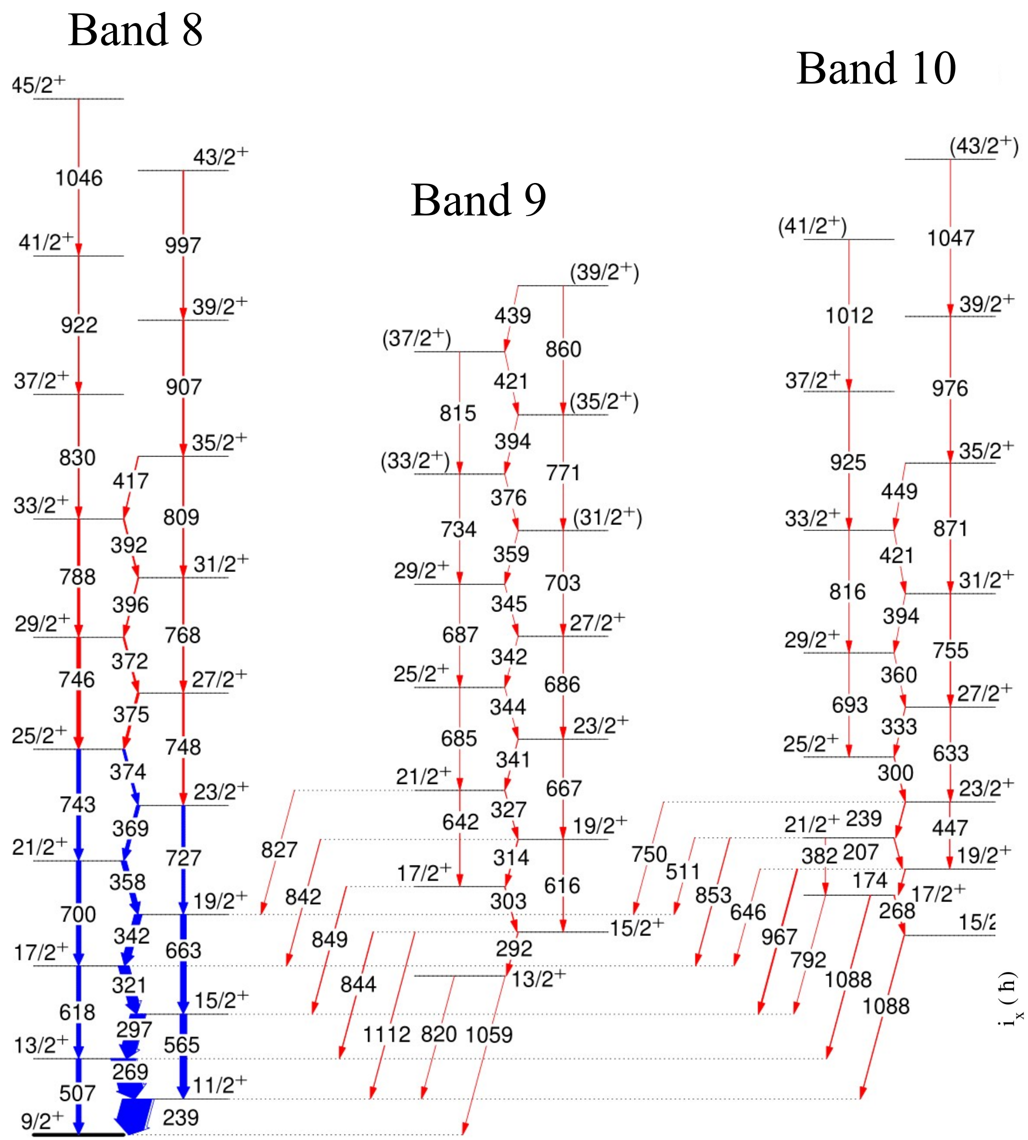
Assign the π[541]3/2$^-$⊗ν[411]3/2$^+$[415]5/2$^+$, π[420]1/2$^+$ and π[422]3/2$^+$ **configurations** to Bands 2, 4 and 5, respectively.

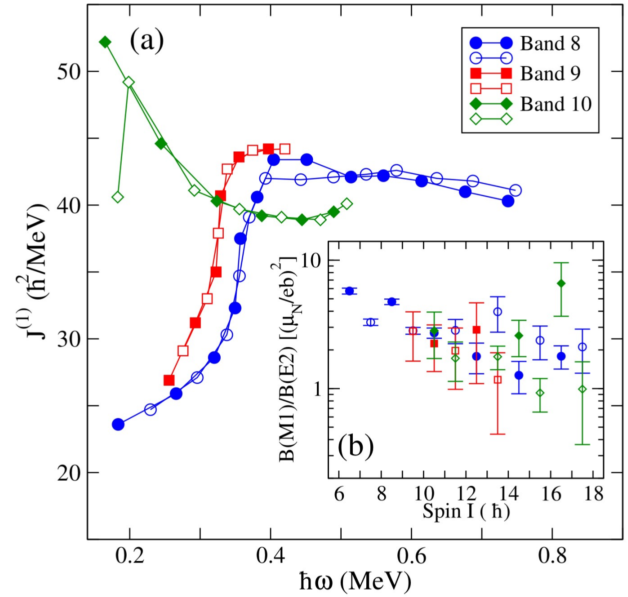
Identify the nature of upbending (backbending).

Configurations of ^{119}Cs

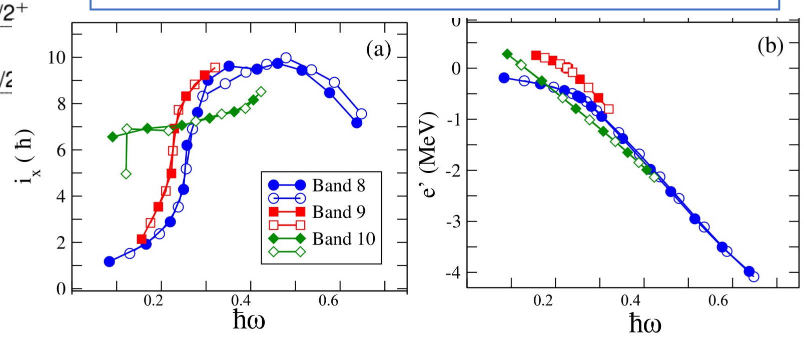
Band	Configuration	1st crossing (ħω)	2nd crossing (ħω)	π	ε_2
1	**Mixed** π[541]3/2⁻[550]1/2⁻	$\nu^2 h_{11/2}$ **(0.45)**	$\nu^2(g_{7/2}d_{5/2})$ (0.70)	-	0.32
2	**Mixed** π[541]3/2⁻[550]1/2⁻ (α=1/2)	$\nu^2(g_{7/2}d_{5/2})$ (0.36)		-	0.32
2	**Mixed** π[541]3/2⁻[550]1/2⁻ (α=-1/2)	$\nu^2(g_{7/2}d_{5/2})$ (0.30)	$\nu^2(g_{7/2}d_{5/2})$ (0.70)	-	0.30
3	π[505]11/2⁻	$\nu^2 h_{11/2}$ (0.38)		-	-0.17
4	π[420]1/2⁺(α=1/2)	$\pi^2 h_{11/2}$ **(0.26)**	$\nu^2 h_{11/2}$ (0.40)	+	0.32
4'	π[420]1/2⁺(α=1/2) ⊗$\pi^2(h_{11/2})$ ⊗$\nu^2(h_{11/2})$			+	0.32
5	π[422]3/2⁺(α=1/2)	$\pi^2 h_{11/2}$ (0.26)	$\nu^2 h_{11/2}$ (0.50)	+	0.32
5'	π[422]3/2⁺(α=1/2) ⊗$\nu^2(h_{11/2})$			+	0.32
6	π[541]3/2⁻(α=1/2) ⊗$\nu^2(h_{11/2}g_{7/2})$			+	0.32
7	π[420]1/2⁺(α=1/2) ⊗$\pi^2(h_{11/2})$ ⊗$\nu^2(g_{7/2}d_{5/2})$			+	0.32
8	π[404]9/2⁺	$\pi^2 h_{11/2}$ (0.36)		+	0.32
9	π[404]9/2⁺	$\pi^2 h_{11/2}$ (0.30)		+	0.32
10	π[541]3/2⁻⊗$\nu^2(h_{11/2}g_{7/2})$			+	0.32

Proton based revolving chiral bands in ^{119}Cs



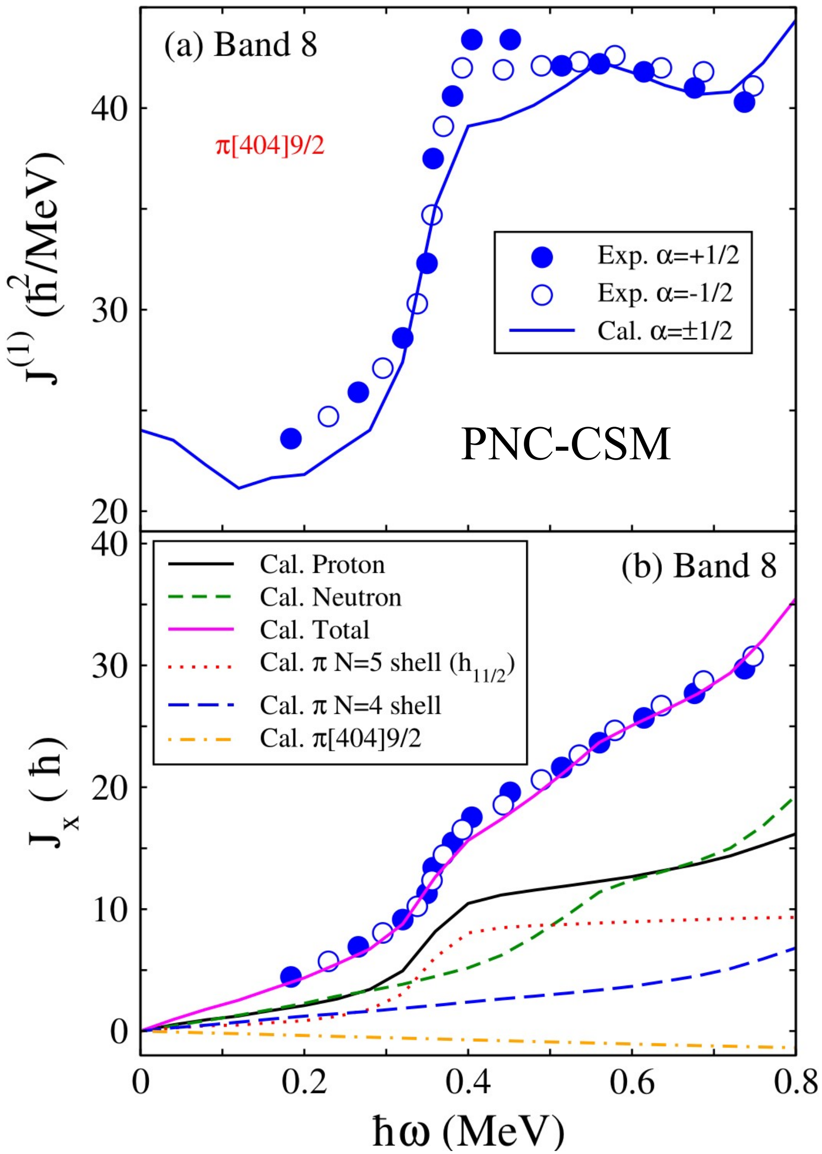


Bands 8, 9 are nearly degenerate, have similar moments of inertia and B(M1)/B(E2) ratios of reduced transition probabilities.



Chiral character？

Proton based revolving chiral bands in ^{119}Cs

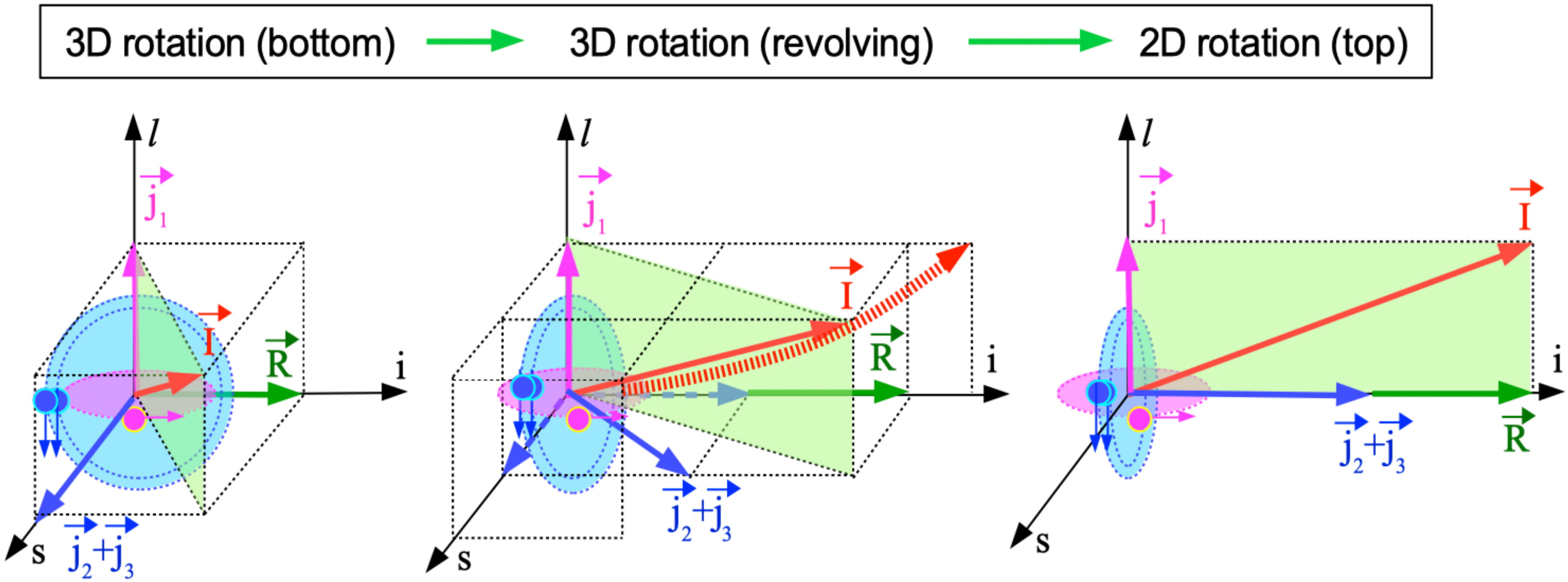


Bands 8, 9 are built on the three-proton configuration in the backbending region, one in the high-Ω [404]9/2 orbital and two in low-Ω $h_{11/2}$ orbitals.

As for the contribution from the [404]9/2 orbital, it keeps nearly constant with rotational frequency, which means that this orbital keeps aligned along the long axis.

The gain of angular momentum is 8ħ, indicating the alignment of a pair of $h_{11/2}$ particles, and the negligible contribution of the strongly-coupled [404]9/2 proton orbital.

Proton based revolving chiral bands in ^{119}Cs



Gamma band with Chiral character

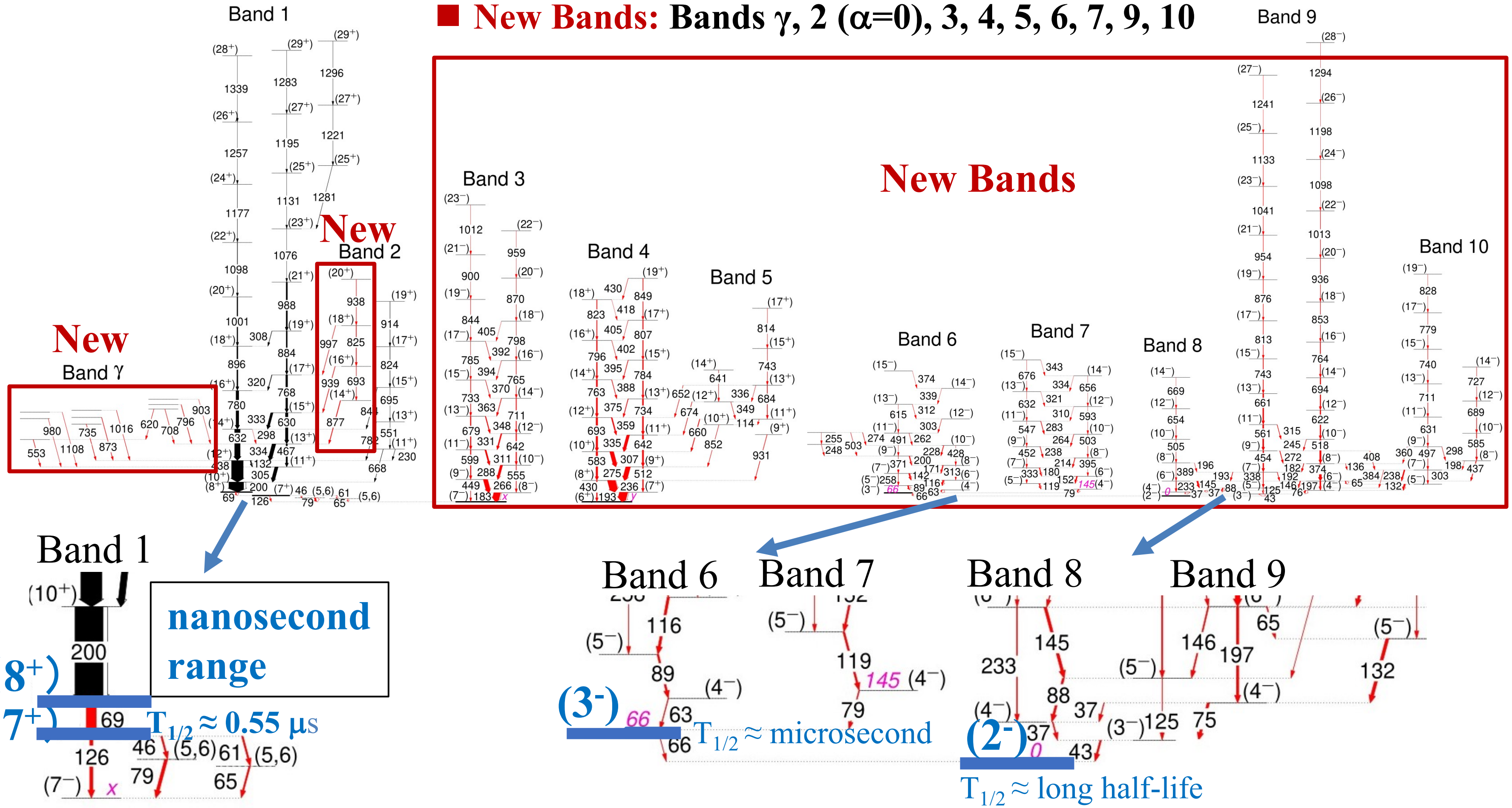
We observed for **the first time such chiral doublet band**:
the configuration is formed by only protons;
the total angular momentum is revolving in 3D;
the triaxiality is not maximum (10°-15 °);
one proton keeps aligned along the long axis, while the other two are changing their orientation.

K. K. Zheng, C. M. Petrache, et al. EPJ A 59 (2022) 50

Results: Rich band structure in ^{118}Cs

■ **Known Bands: Band 1, Band 2 (α=1)**

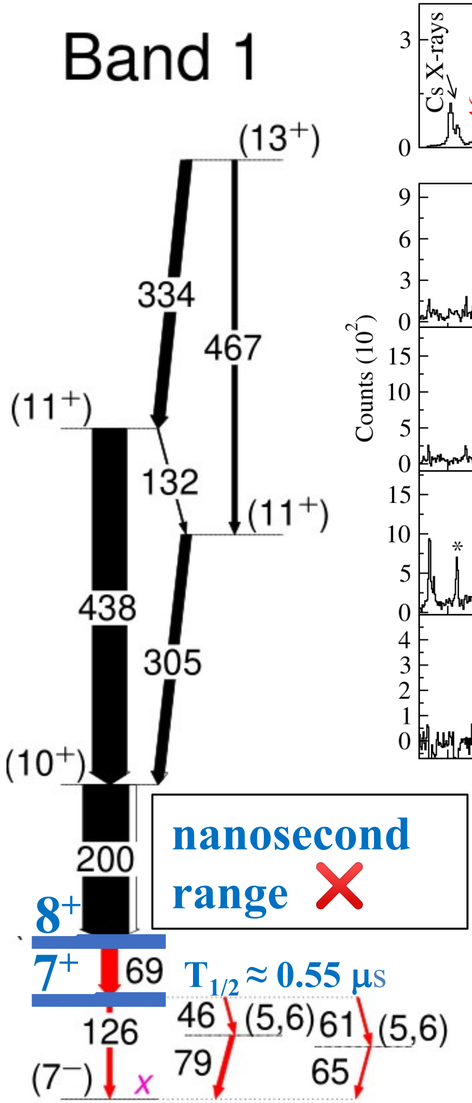
■ **New Bands: Bands γ, 2 (α=0), 3, 4, 5, 6, 7, 9, 10**

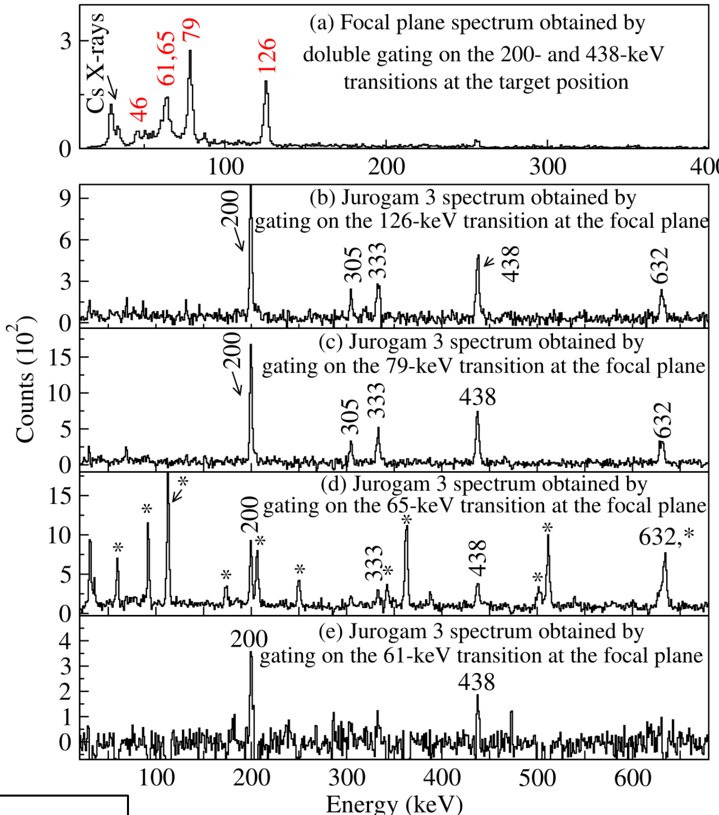


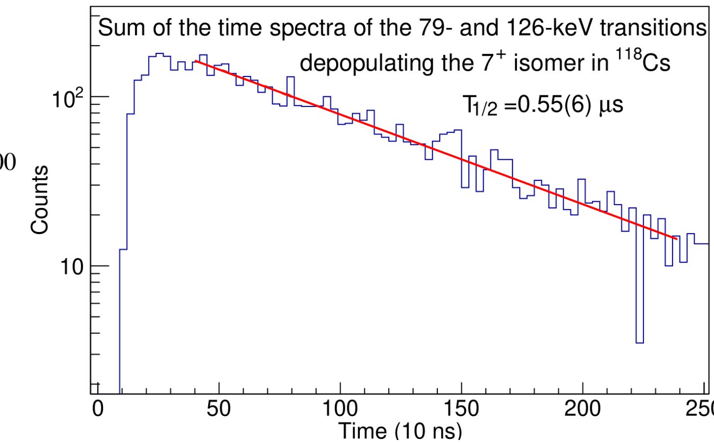
● We reported **ten new bands**, **low-lying states**, several **isomeric states**, which leads to **the largest set of proton-neutron excitations of odd-odd Cs nuclei close to the proton drip line**.

K. K. Zheng, C. M. Petrache, et al. Phys. Rev. C104 (2021) 044325

Results: isomeric states of ^{118}Cs

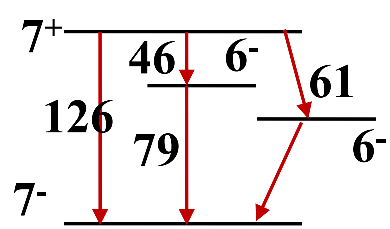






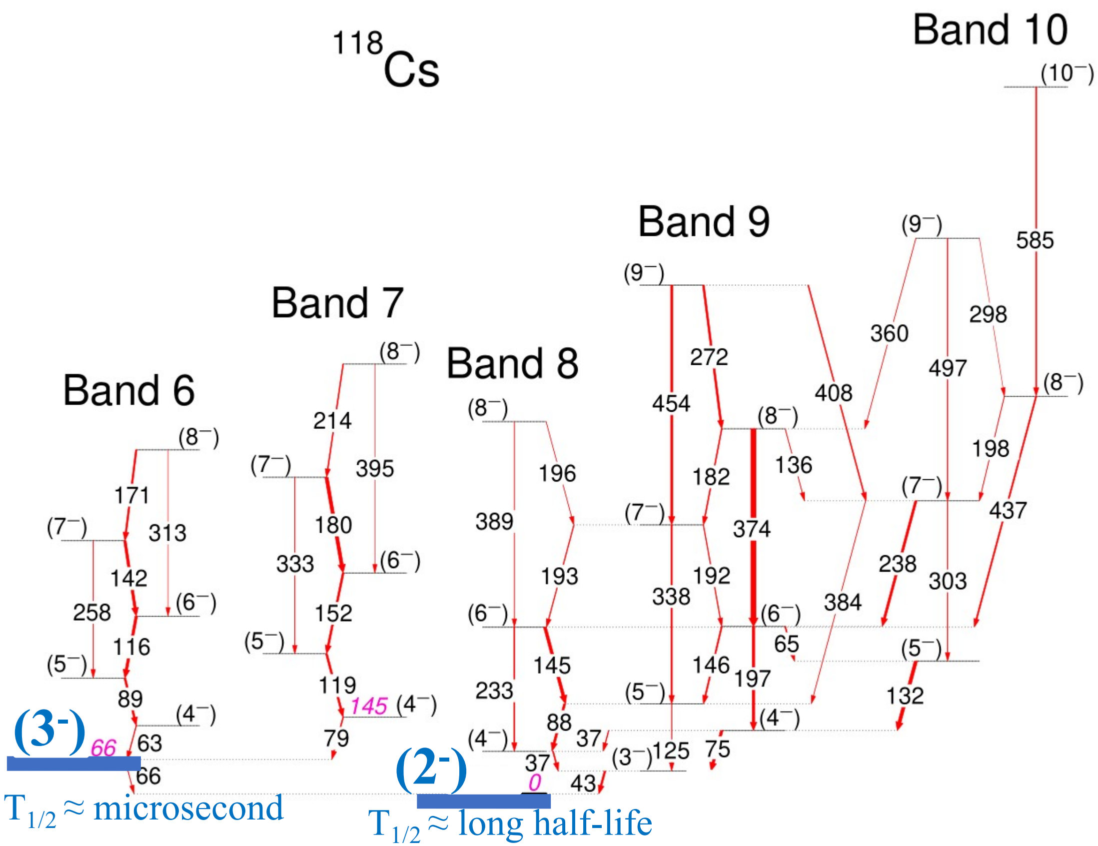
We extracted a half-life of $T_{1/2} = 0.55(6)$ μs from the fit of the time spectrum of the 66-keV transition.

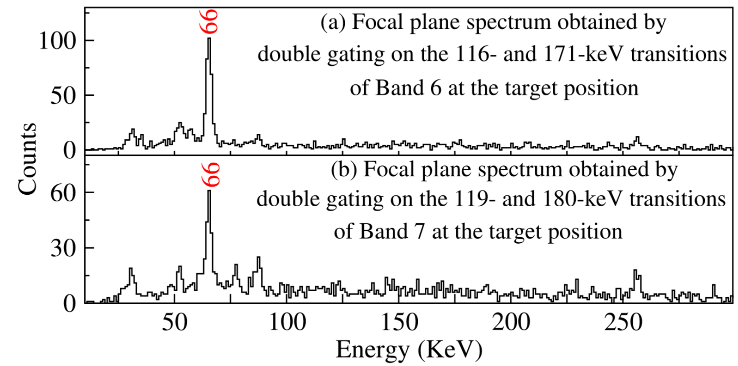
$$\text{Weisskopf estimate:} \frac{1}{T^{W}_{1/2}} = \sum_k \frac{I_\gamma(1+\alpha_k)}{T^{w}_{k}}$$



$T_{1/2} = 0.43$ μs

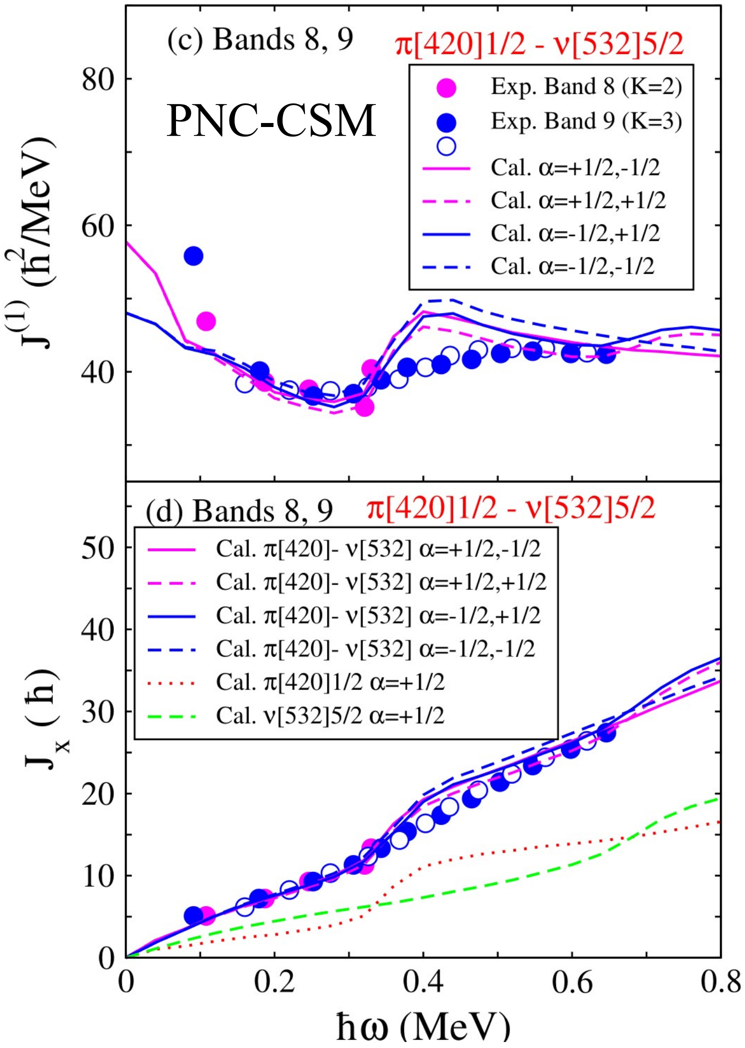
Results: isomeric states of ^{118}Cs





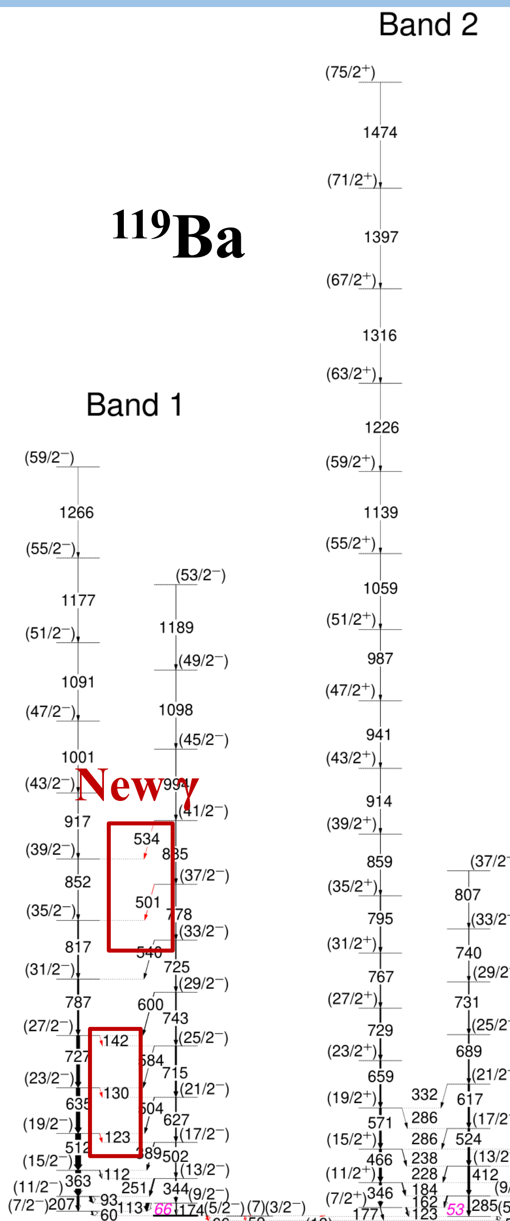
Two long-lived isomers have been identified: **a 66-keV transition detected** at the MARA focal plane depopulates one of them, indicating **a half-life in the microsecond range**, while **no depopulating transitions** have been identified for the other, indicating a **much longer half-life**.

Results of PNC-CSM calculations of ^{118}Cs



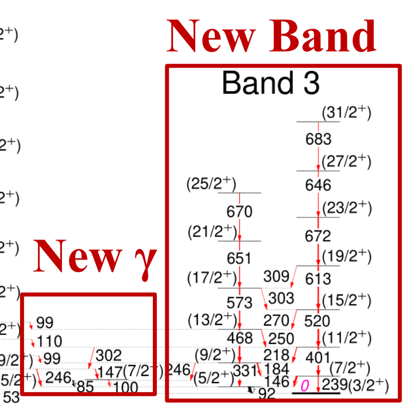
Bands 1,2 : π[541]3/2⊗ν[532]5/2
Band 3: π[404]9/2⊗ν[532]5/2
Band 4: π[404]9/2⊗ν[411]3/2, ν[413]5/2
Band 6: π[541]3/2⊗ν[411]3/2
Bands 7, 10: π[422]3/2⊗ν[532]5/2
Bands 8, 9: π[420]1/2⊗ν[532]5/2

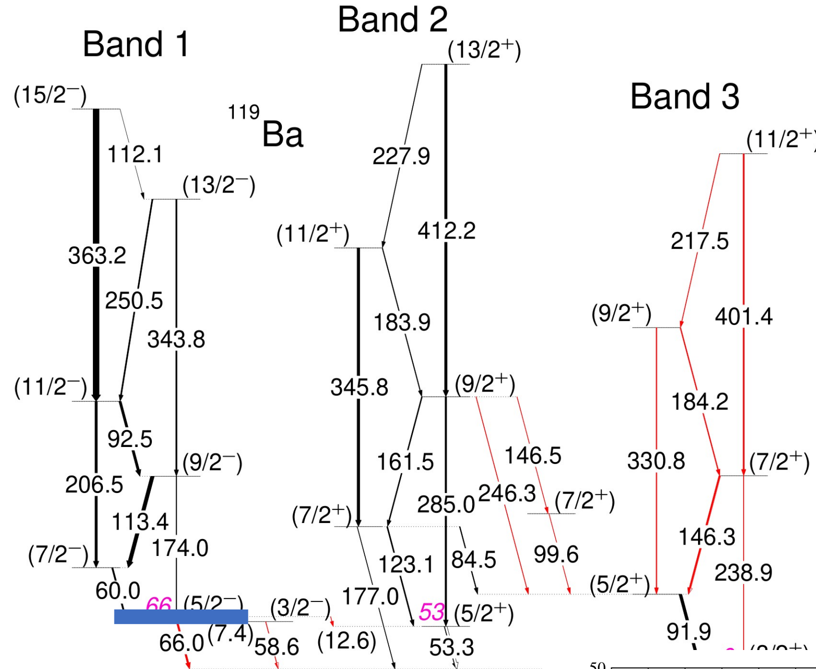
Results: Neutron excitations in ^{119}Ba



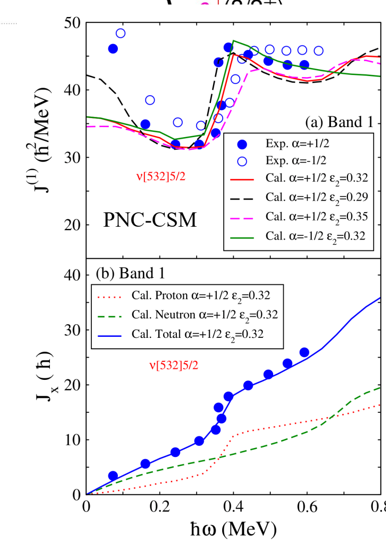
- Identified a **new positive-parity band** and several **low-lying states.**

- Identified an **isomeric state** 5/2⁻ (B1).





$T_{1/2}$ = 0.36(2) μs



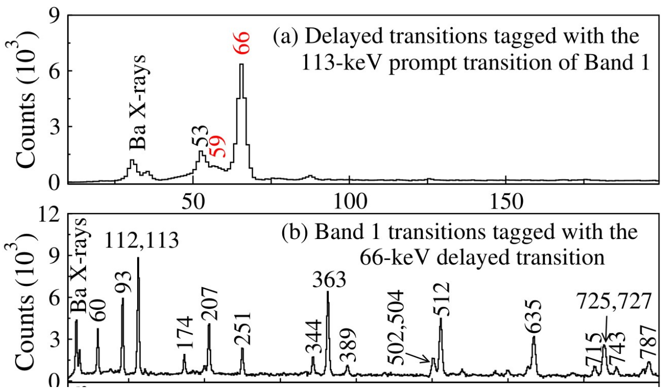
Band 1: $\nu[532]5/2^-$ $\varepsilon_2 = 0.32$

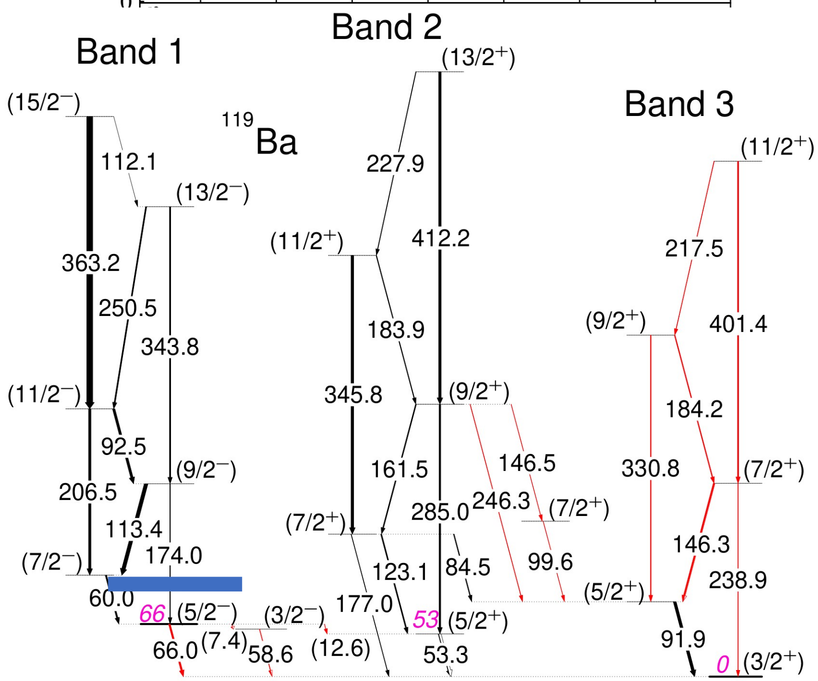
Band 2: $\nu[413]5/2^+$ $\varepsilon_2 = 0.32$

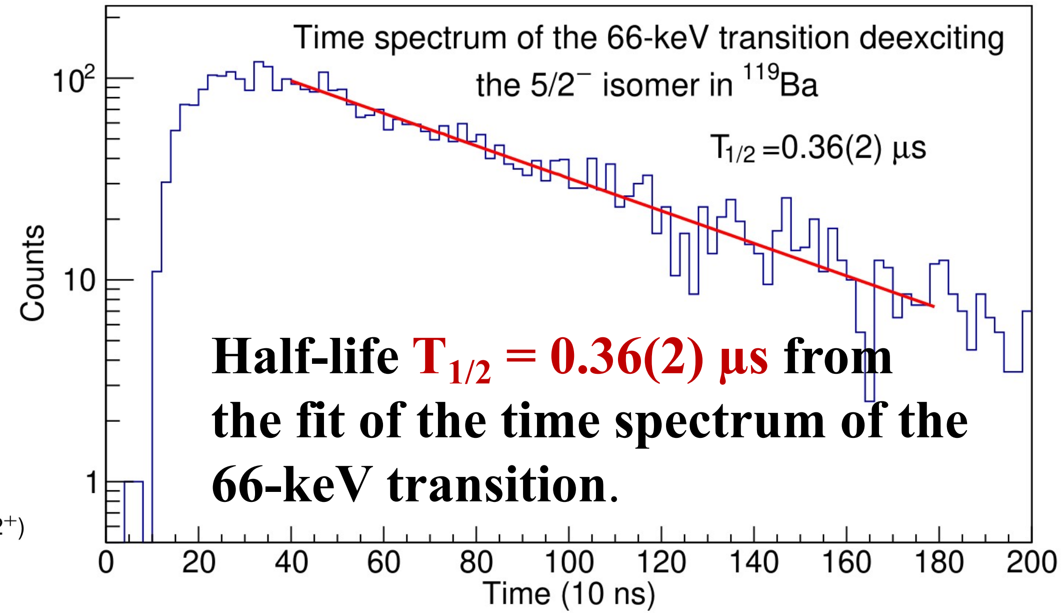
Band 3: $\nu[411]3/2^+$ $\varepsilon_2 = 0.32$

K. K. Zheng, C. M. Petrache, et al. Phys. Rev. C104 (2021) 014326

Results: isomeric states of ^{119}Ba

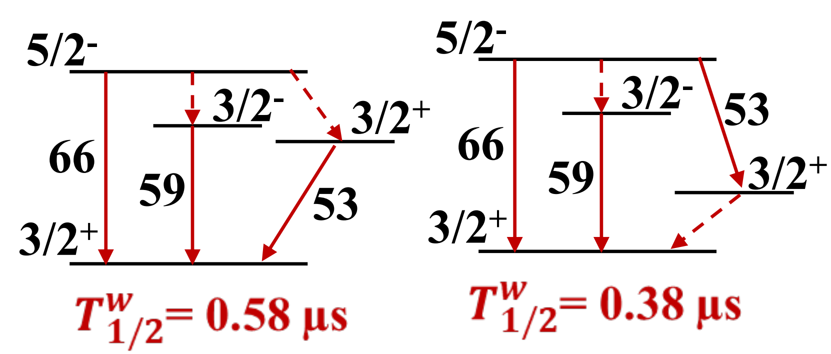




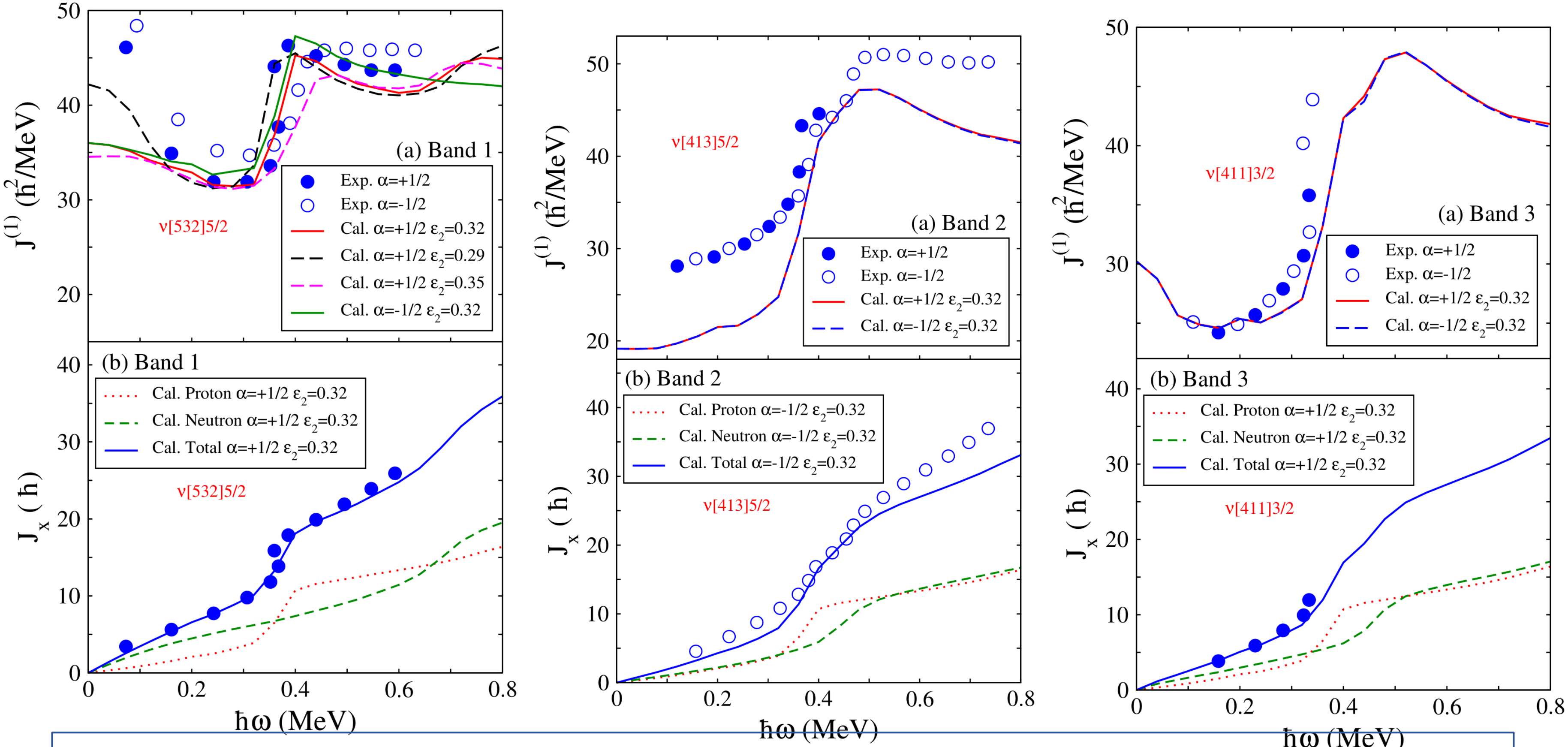


Half-life $T_{1/2}$ = 0.36(2) µs from the fit of the time spectrum of the 66-keV transition.

Weisskopf estimate: $\frac{1}{T_{1/2}^{W}} = \sum_k \frac{I_\gamma(1+\alpha_k)}{T_k^W}$



Results of PNC-CSM calculations of ^{119}Ba



Band 1: ν**[532]5/2$^-$ (ε_2 = 0.32)** configuration.

Band 2: ν**[413]5/2$^+$ (ε_2 = 0.32)** configuration, not good agreement for $J^{(1)}$ and for J_x at high spin, but good agreement for the crossing frequency.

Band 3: ν**[411]3/2$^+$ (ε_2 = 0.32)** configuration.

Published in Phys. Rev. C **104**, 014326, 2021

Summary

The neutron-deficient deformed ^{119}Cs, ^{119}Ba, and ^{118}Cs nuclei have been studied with the JUROGAM 3 + MARA setup.

- two most complete level schemes from low to high spin in the odd-even and odd-odd proton-rich nuclei, ^{119}Cs and ^{118}Cs, were observed.
- one new rotational band and several low-lying states were newly identified in ^{119}Ba.

The identifications of the low-lying isomers.

- $T_{1/2}$ = 0.36(2) μs and $T_{1/2}$ = 55(5) μs, for the $5/2^-$ and $11/2^-$ band heads of the bands based on neutron and proton $h_{11/2}$ orbitals in ^{119}Ba and ^{119}Cs, respectively.
- $T_{1/2}$ = 0.55(6) μs has been measured for the 7^+ state below the 8^+ band-head of the $\pi h_{11/2} \otimes \nu h_{11/2}$ band in ^{118}Cs.

The configurations of the observed bands were assigned based on PNC-CSM calculations.

- based on the analysis of the alignment properties of the bands, on systematics.

Summary

The chiral bands built on a configuration with only protons in the transient backbending regime was also observed for the first time in ^{119}Cs.

- two $h_{11/2}$ protons revolving from the short to the intermediate axis of the triaxial core, and a strongly coupled $g_{9/2}$ proton sticked along the long axis. The direction of the total angular momentum moves in 3D, giving rise to chiral bands that can be called RχD (Revolving Chiral Doublet) bands.

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Thanks for your attention!

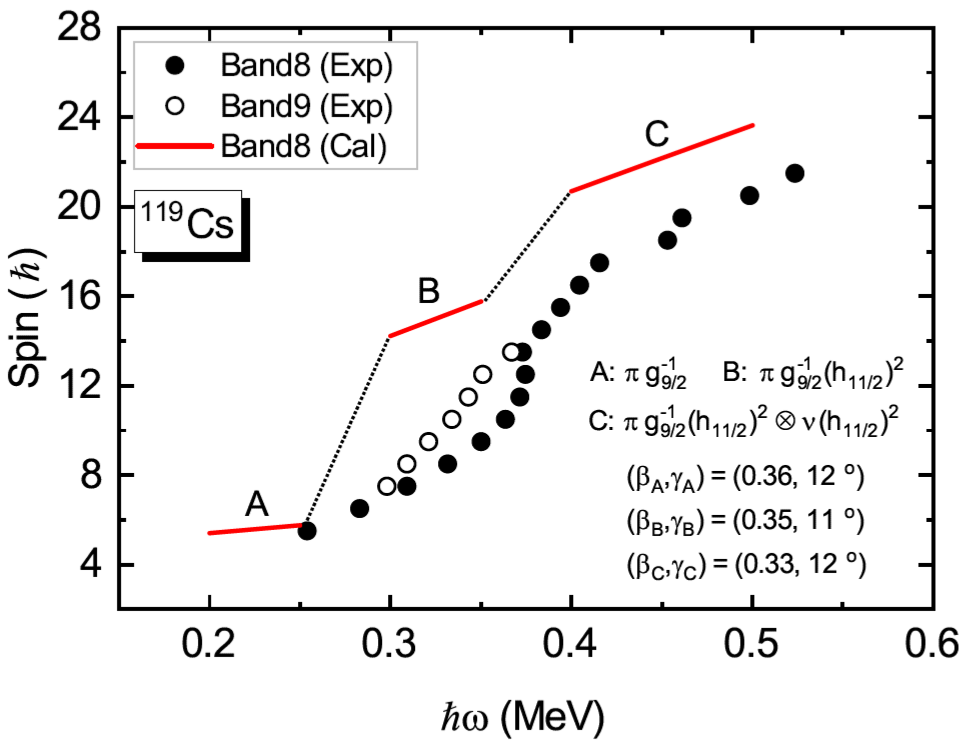


FIG. 2. (Color online) Comparison between the experimental spin versus rotational frequency and the TAC-CDFT calculations for bands 8 and 9 of ^{119}Cs.

moderate

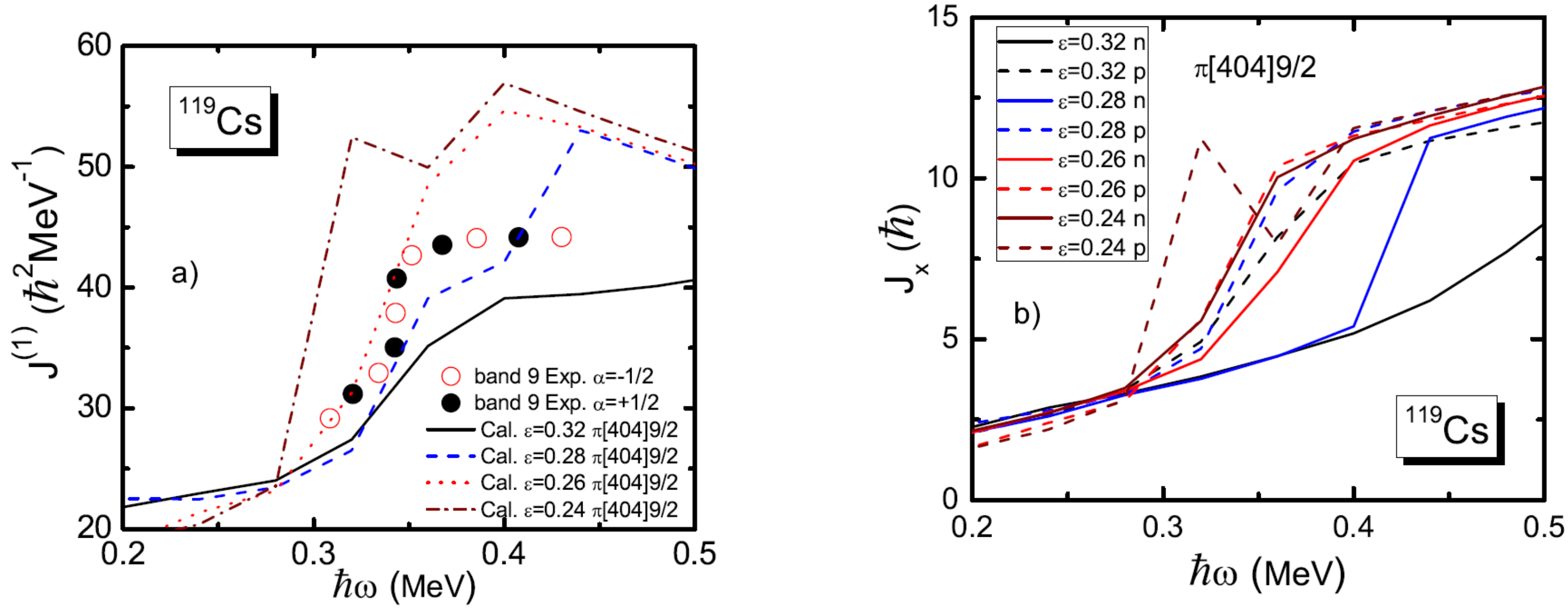
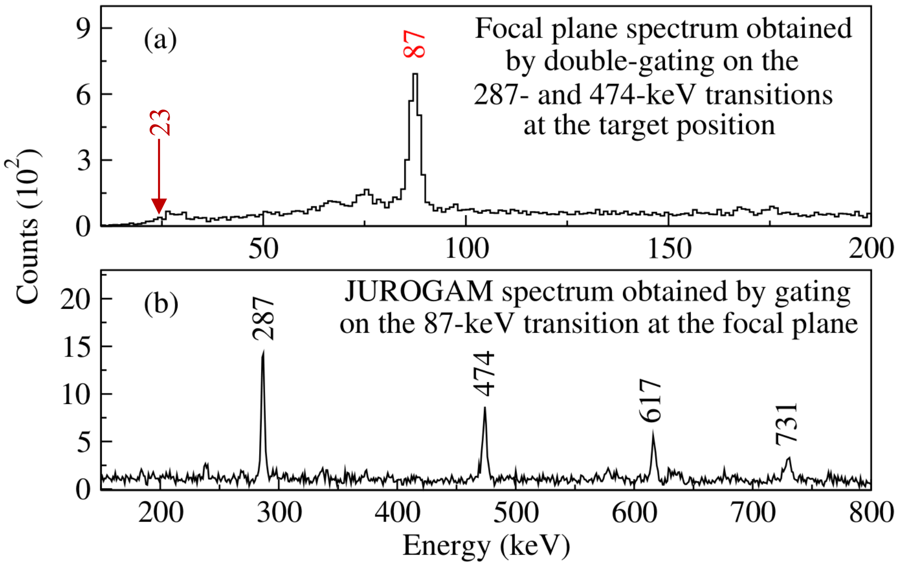


Figure 5.30: Moments of inertia $J^{(1)}$ and projection of the angular momenta on the cranking axis J_x for Band 9 of ^{119}Cs for different deformations. The states with signature $\alpha = +1/2$ and $\alpha = -1/2$ are drawn with filled and open symbols, respectively.

spin versus rotational frequency and the TAC-CDFT calcula-
tions for bands 8 and 9 of ^{119}Cs.

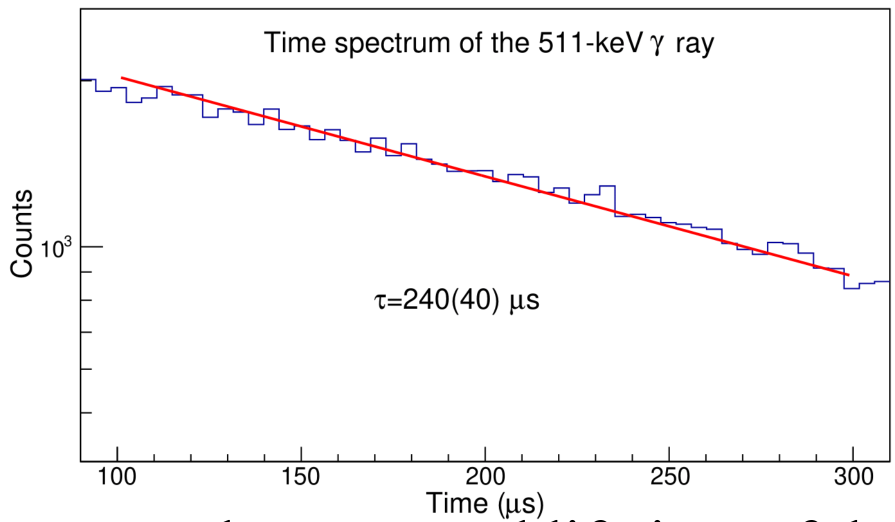
K. K. Zheng, C. M. Petrache, et al. EPJ A 59 (2022) 50
K. K. Zheng, C. M. Petrache, et al. Phys. Rev. C104 (2021) 044325
K. K. Zheng, C. M. Petrache, et al. Phys. Rev. C104 (2021) 044305
K. K. Zheng, C. M. Petrache, et al. Phys. Lett. B 822 (2021) 136645
K. K. Zheng, C. M. Petrache, et al. Phys. Rev. C104 (2021) 014326

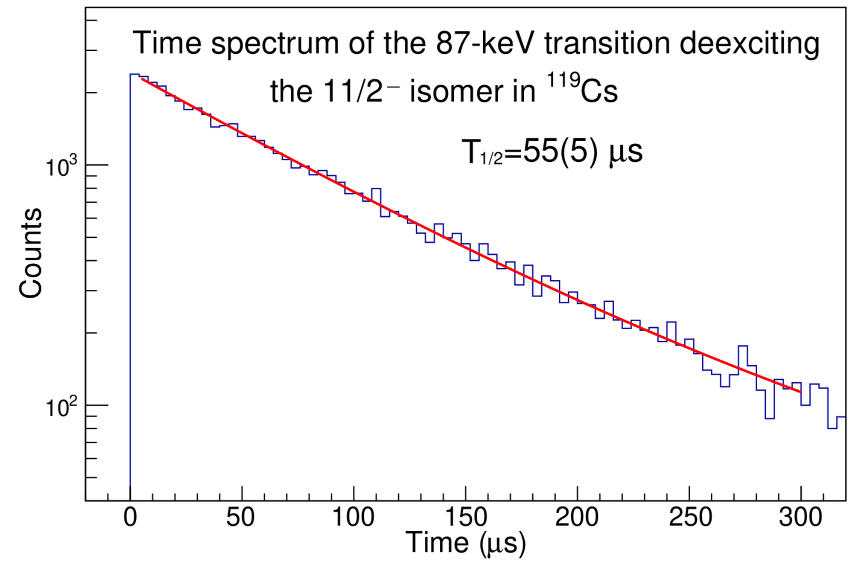
Results: isomeric states of ^{119}Cs



The time spectrum of the background 511-keV γ ray has a slight slope. Thus, we fit isomer spectra with two exponentials, one with a fixed lifetime of **τ = 240 μs** deduced from the fit of the background.

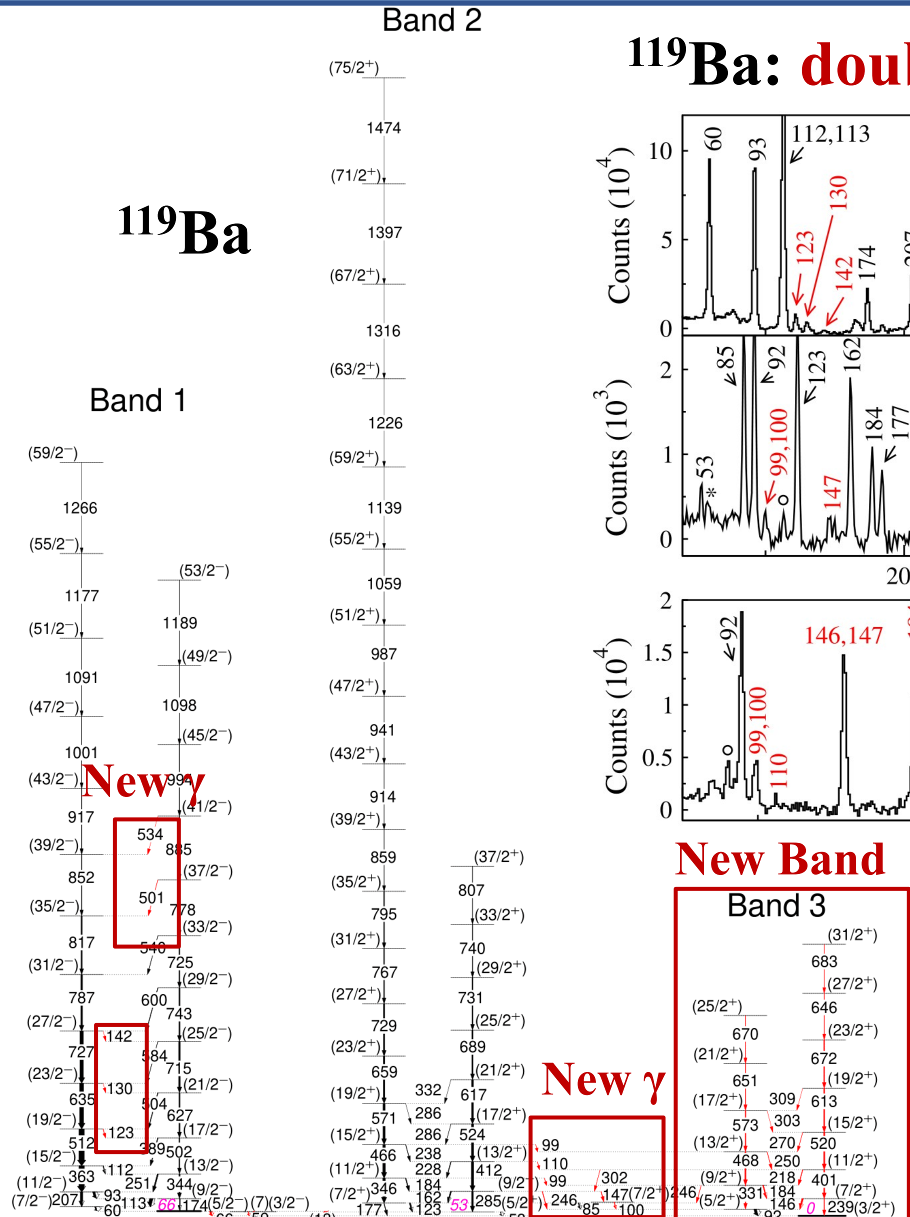
$$y = N_0 e^{\frac{-t}{240\mu s}} + N_1 e^{\frac{-t}{\tau}}$$



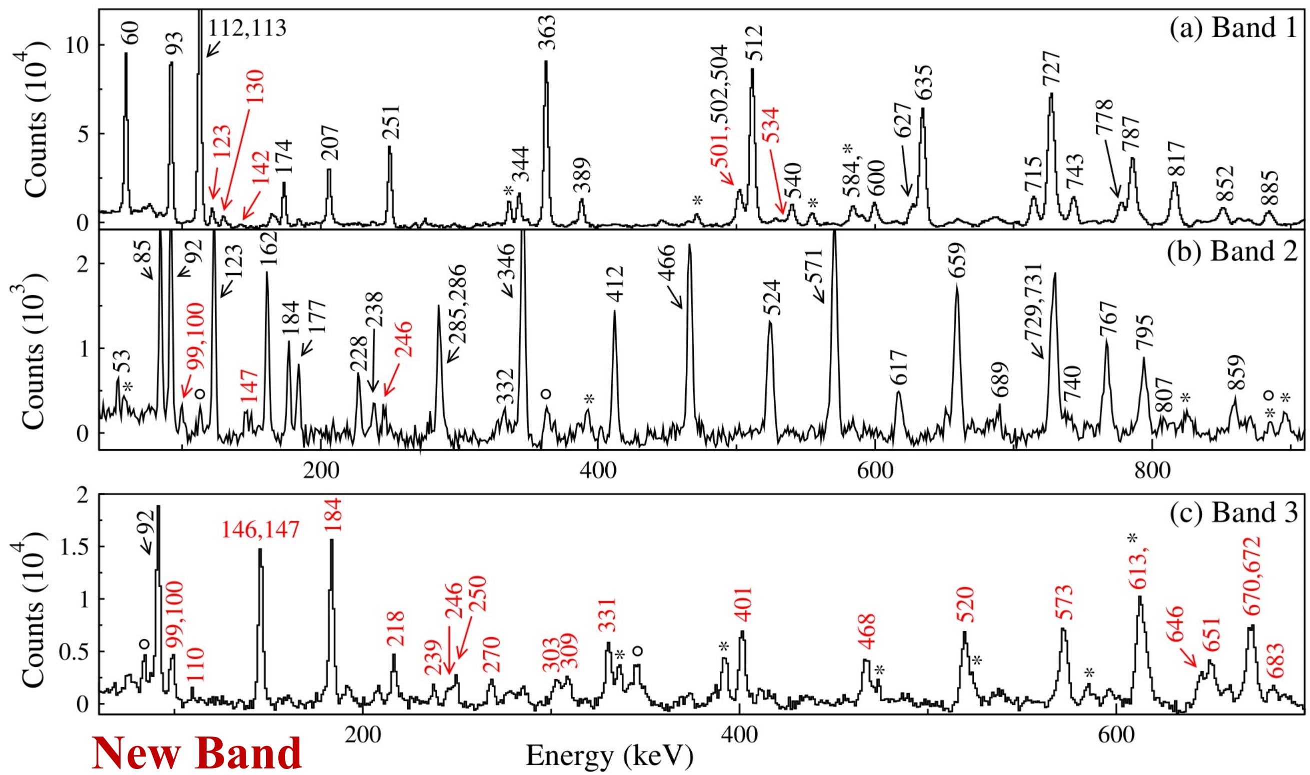


The extracted lifetime of the $11/2^-$ state is $T_{1/2}$ = **55(5) μs**.

Results: Neutron excitations in ^{119}Ba



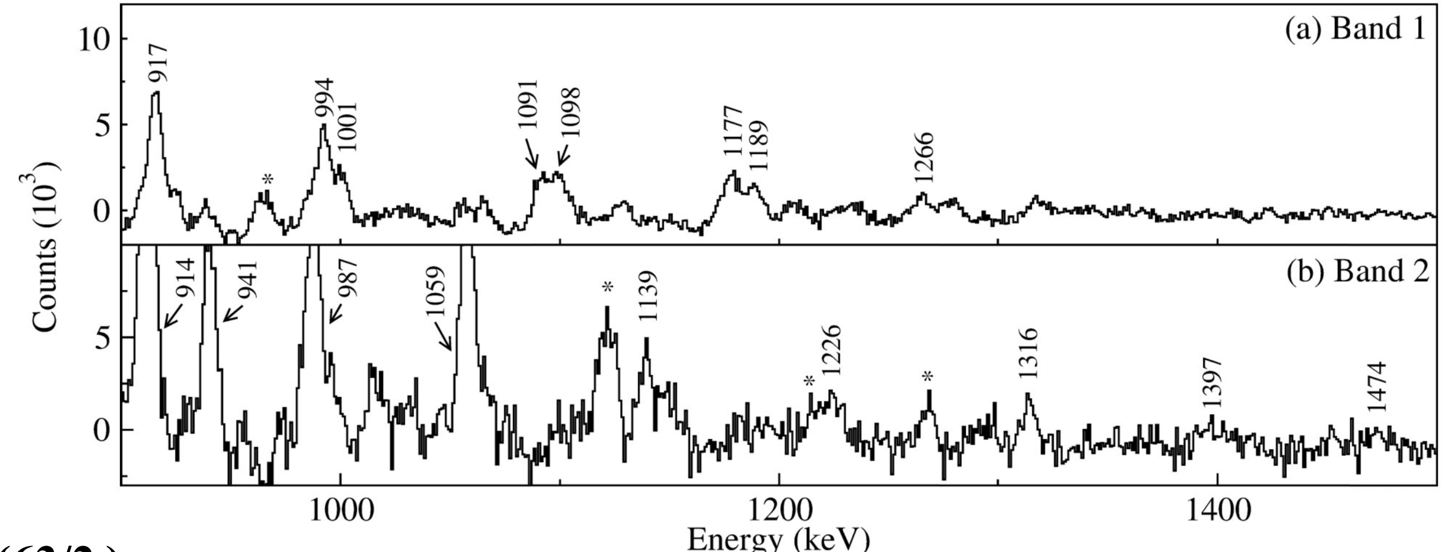
^{119}Ba: double gates spectra of low-spin states

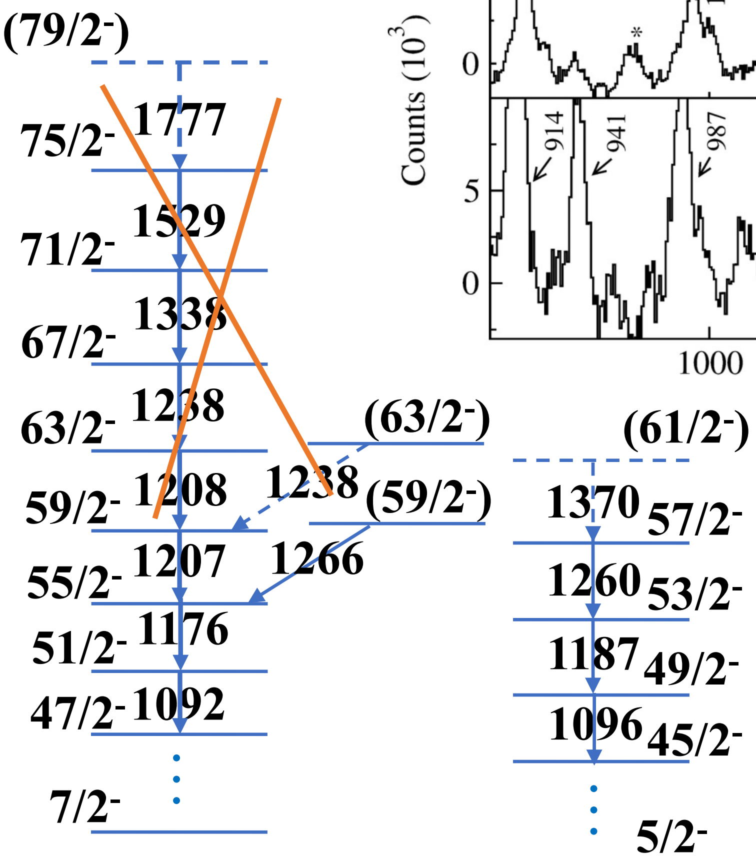


- Identified a new positive-parity band and several low-lying states.
- Identified a isomeric state 5/2⁻ (B1).

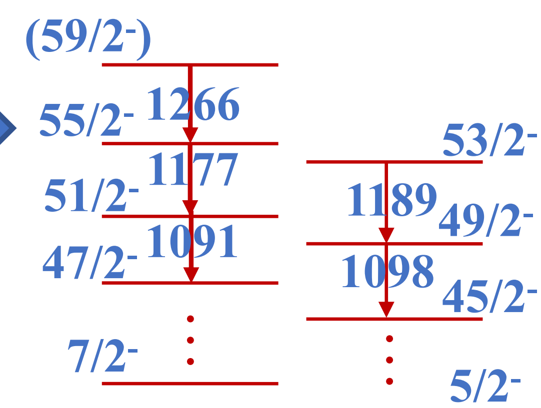
Results: Neutron excitations in ^{119}Ba

^{119}Ba: double gates spectra of high-spin states





Based on the spectra

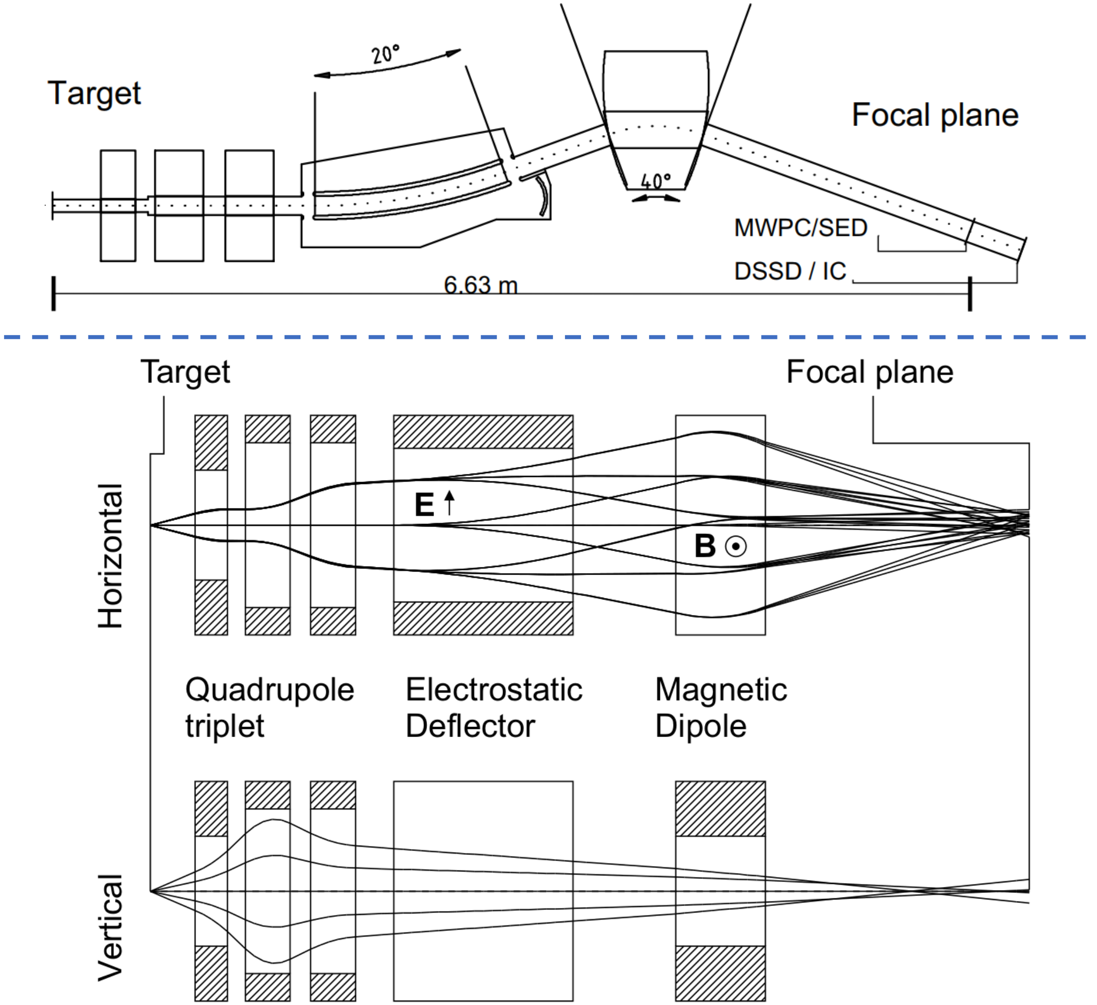


Band 1 : J. F. Smith, Phys. Rev. C **61**, 044329 (2000)

Band 1: Our work

Experimental Setup: MARA

Configuration: $QQQD_ED_M$.



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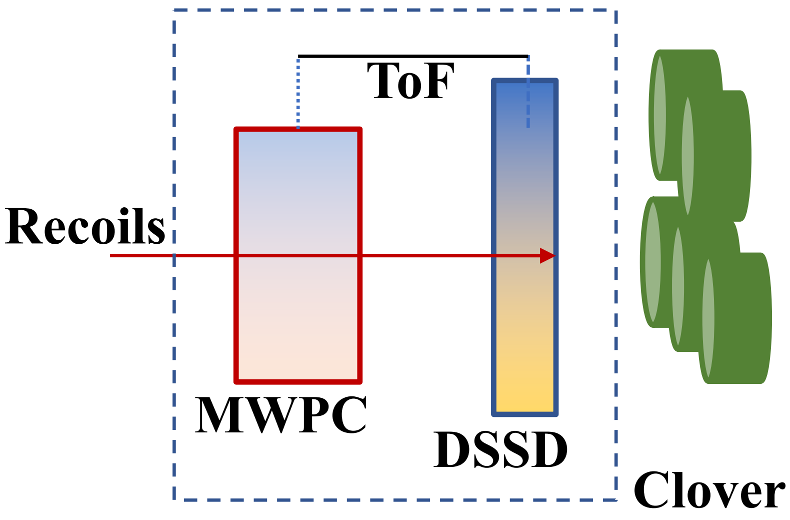
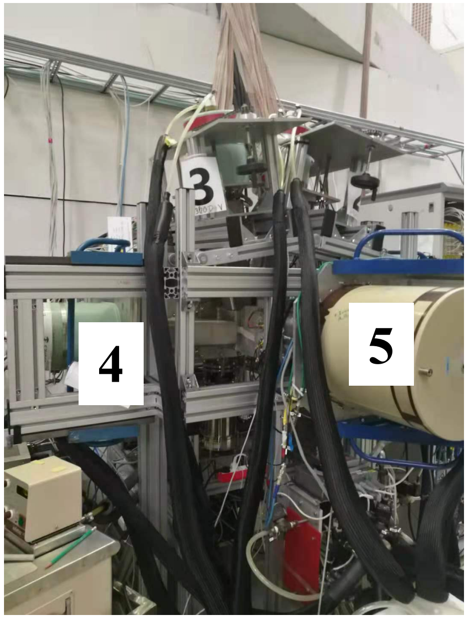
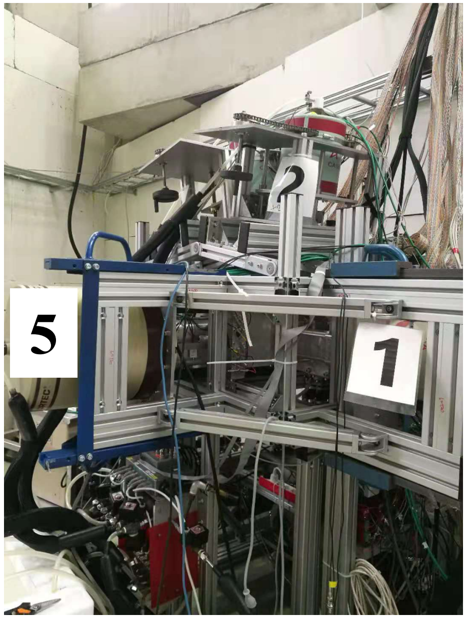
D_E separates primary beam and recoils residues

D_M provides a fixed energy focus for the separated ions with different m/q ratio.

Experimental Setup: Focal plane







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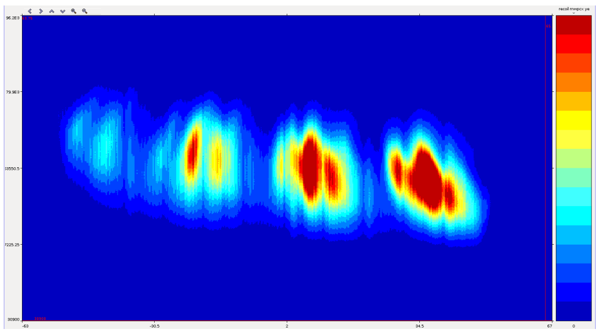
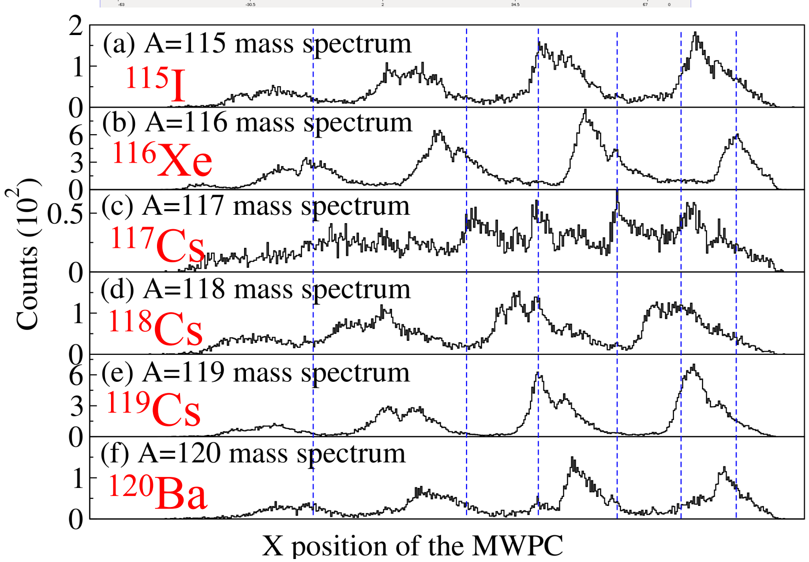
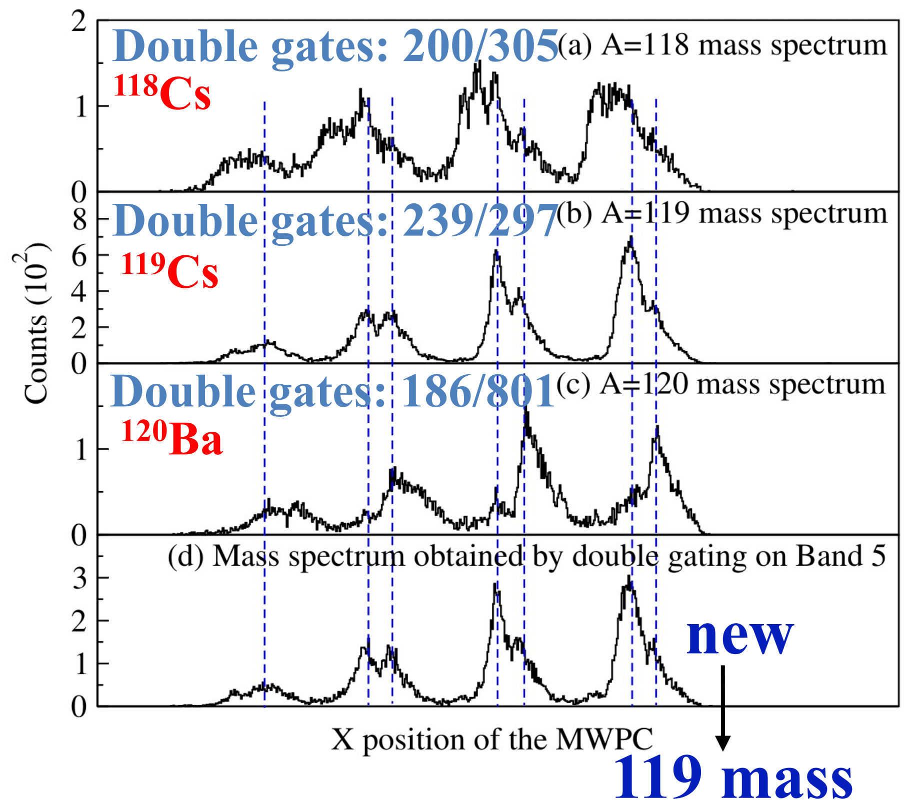
The assignments of the bands to ^{119}Cs, ^{119}Ba, and ^{118}Cs are based on:

1. The mass 119 and 118 detected at the MARA focal plane in coincidence with transitions detected in JUROGAM 3;







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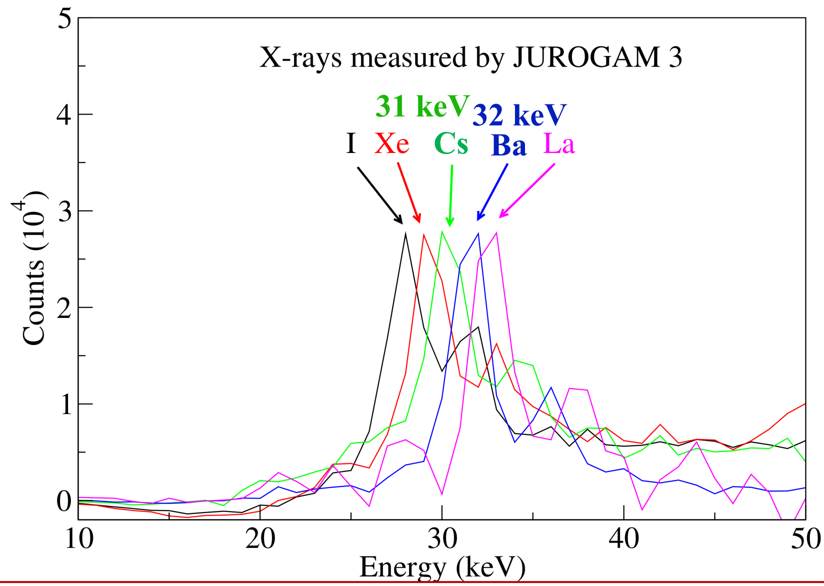
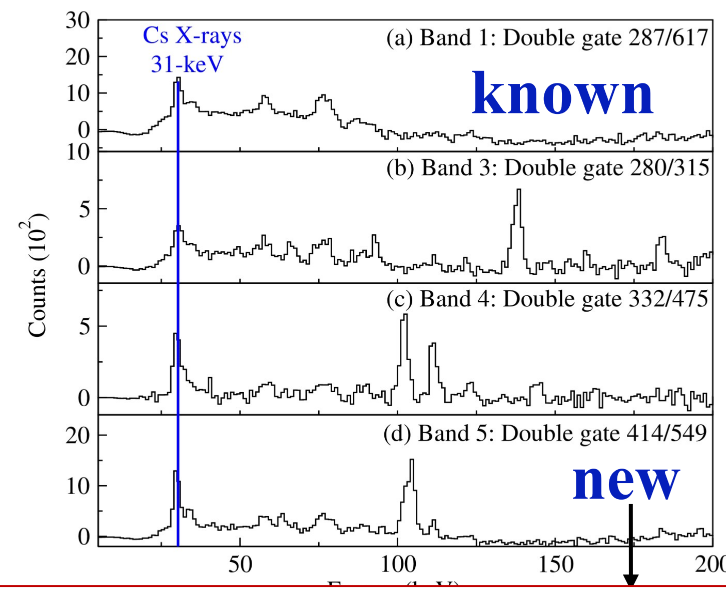
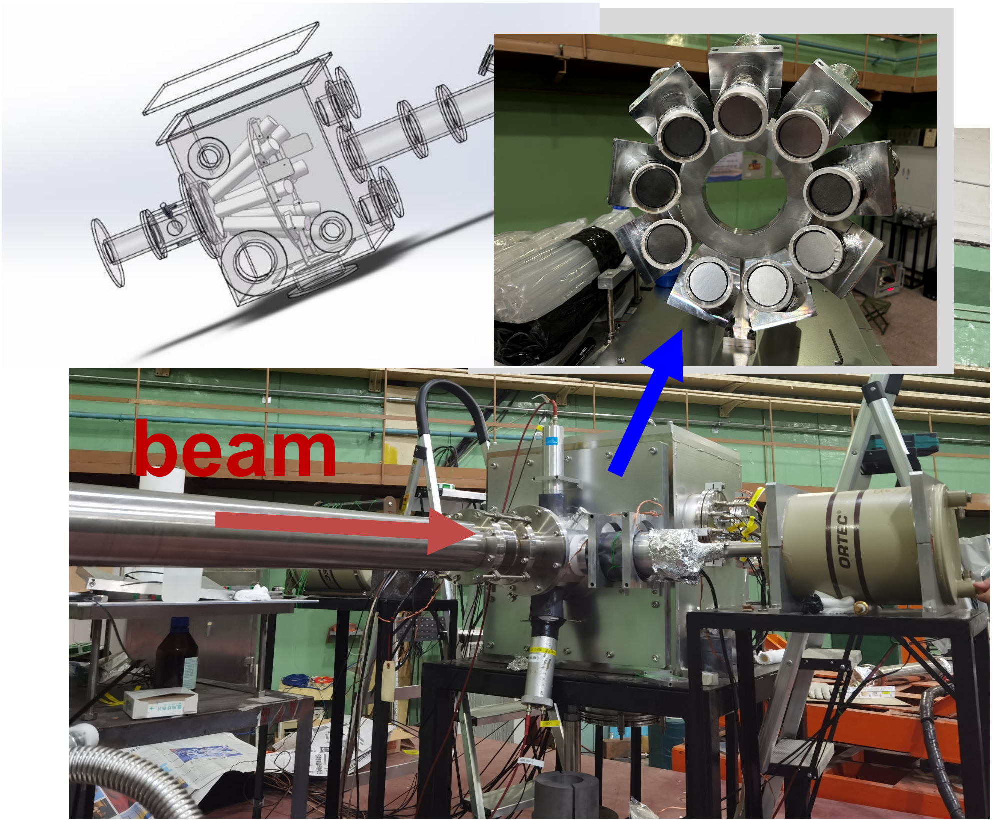
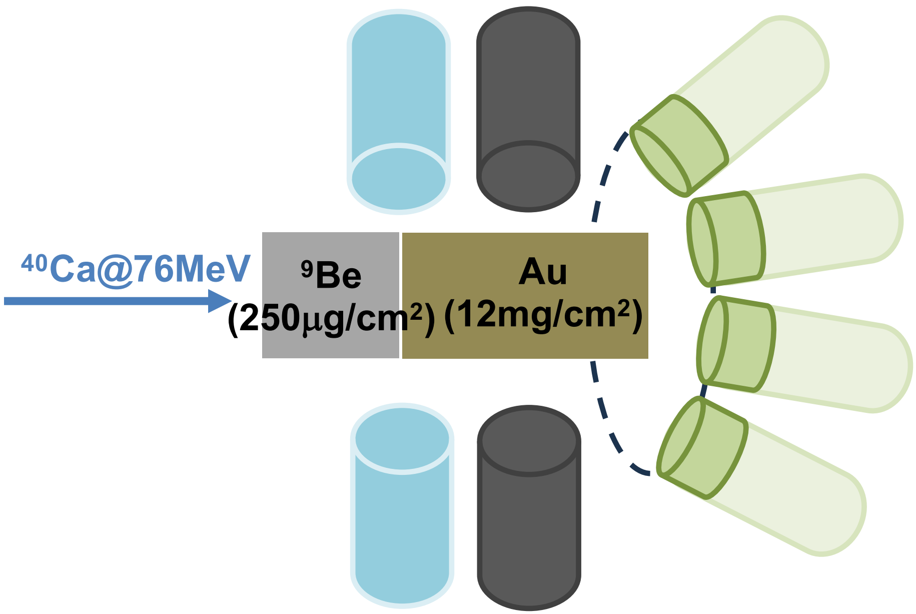




Combining information on the mass spectra and on the X-rays, we could assign new bands.

Test ex





^{40}Ca+9Be

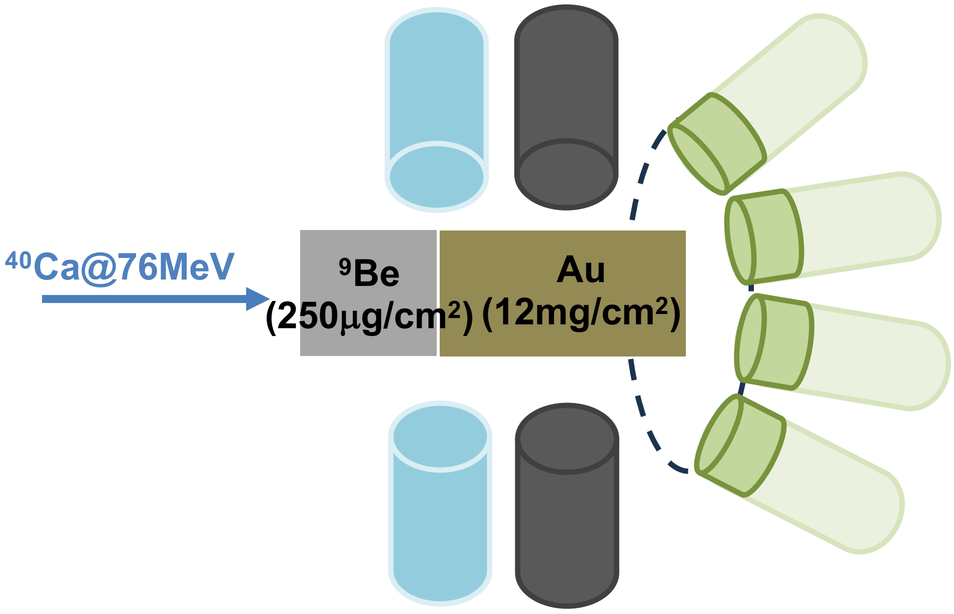
Experimental Setup:

- HPGe 2
- $LaBr_3$ 4
- Liquid scintillation detector 2
- Laminated plastic scintillator 9

Conclusion

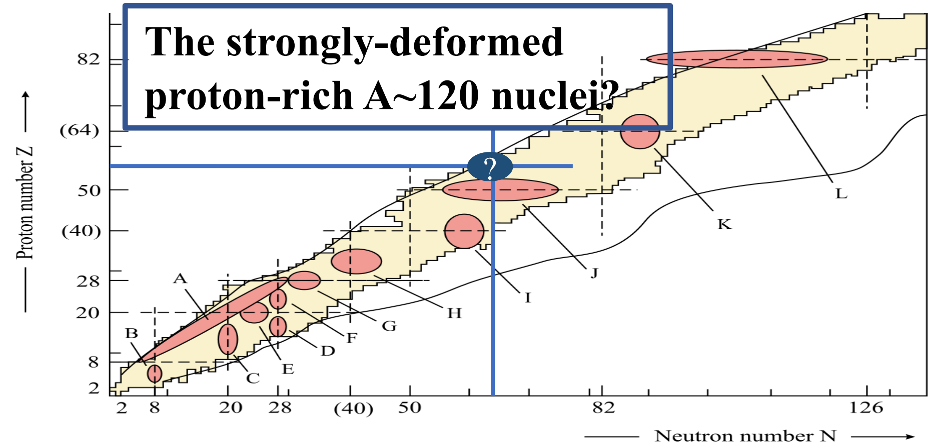
Digital Acquisition System

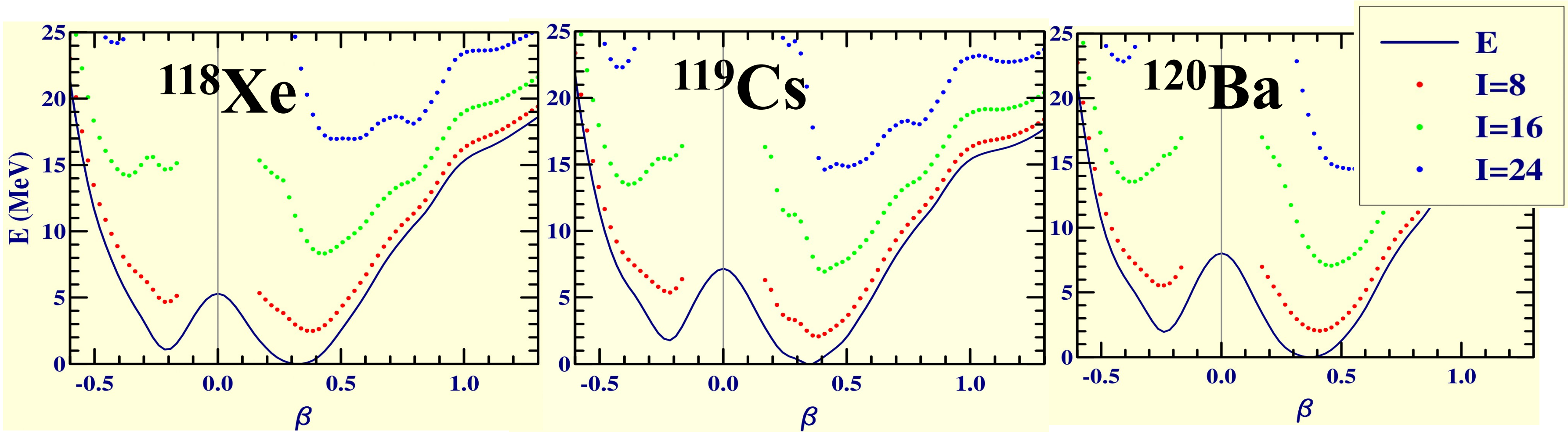
Motivation



Shape coexistence

In 1956, the **first experimental** evidence of **spherical-prolate shape** coexistence was observed in the **^{16}O** isotope.
Many regions of shape coexistence are known.





Two minima in the potential energy of ^{118}Xe, ^{119}Cs, and ^{120}Ba, for positive and negative quadrupole deformation corresponding to **prolate and oblate shapes**, respectively.

H. Morinaga Phys. Rev. 101, 254. Kris Heyde. Rev. Mod. Phys. **83**, 1467.
http://www-phynu.cea.fr/science_en_ligne/carte_potentiels_microscopiques/carte_potentiel_ nucleaire_eng.htm.

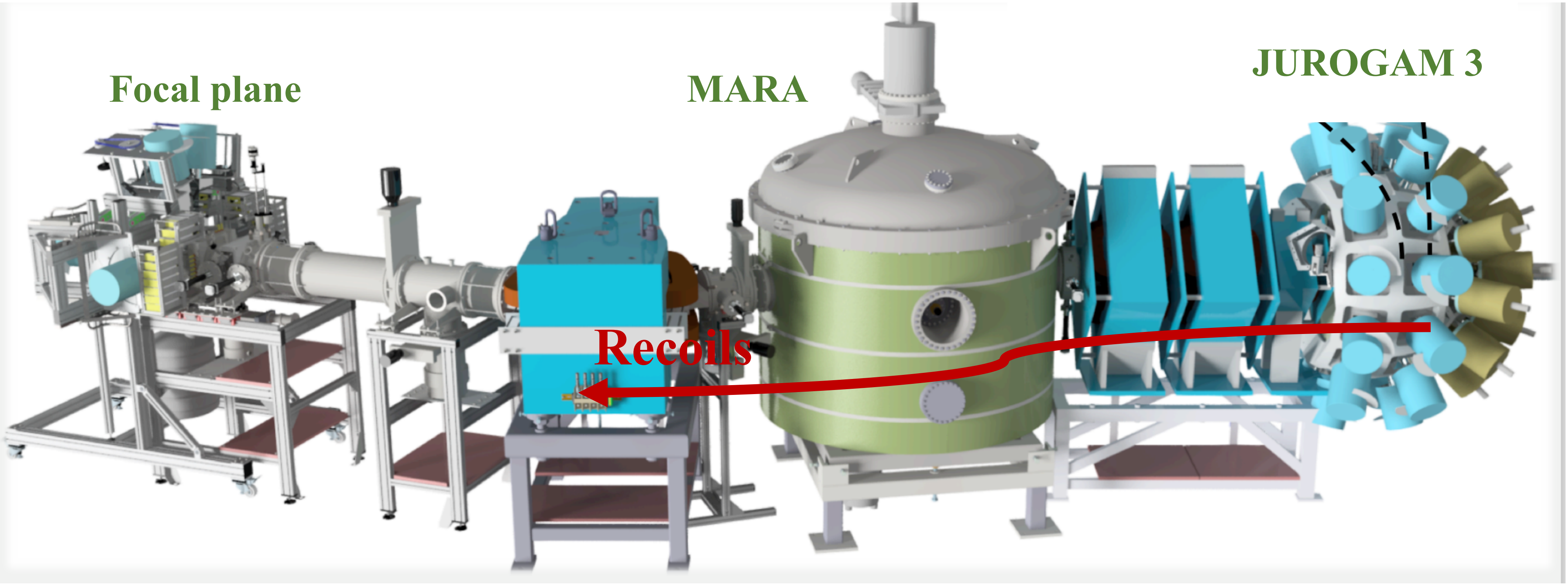
Experimental Setup

Location: JYFL;

Beam: ^{64}Zn, 255 MeV, 2-3 pnA;

Target: ^{58}Ni (self-supporting enriched), 0.75 mg/cm^2 ;

Populated nuclei: ^{119}Cs (150 mb), ^{119}Ba (20 mb) and ^{118}Cs (40 mb).

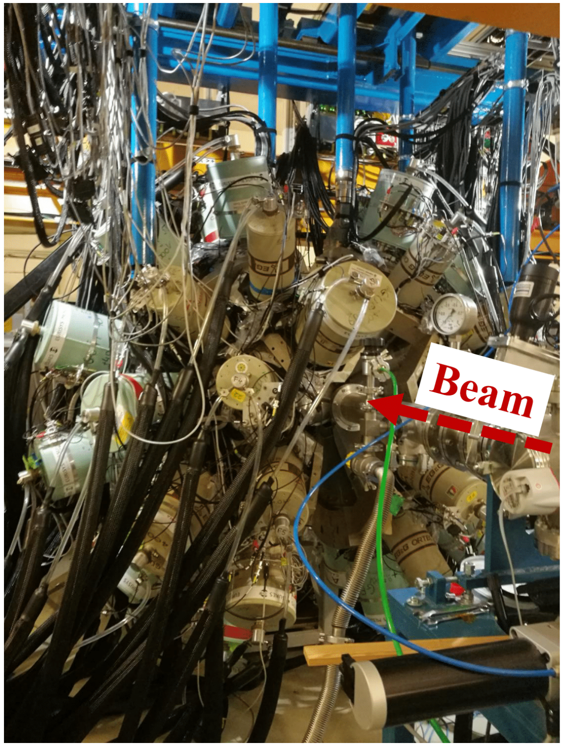


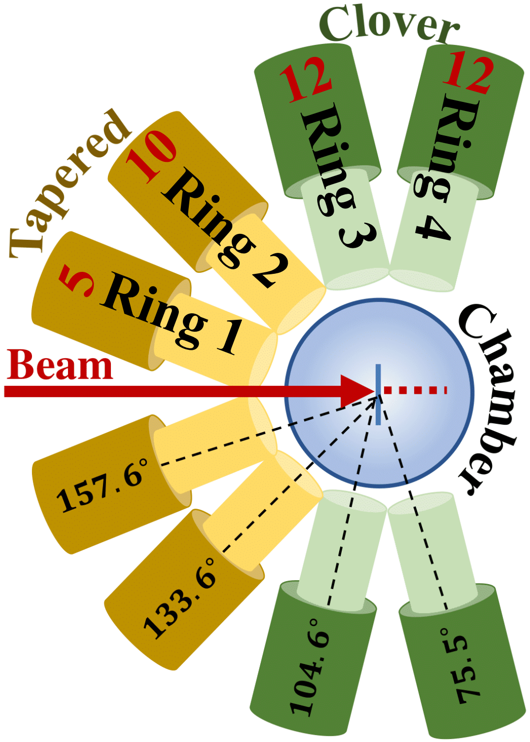
Experimental Setup: JUROGAM 3

Detector: 15 tapered + 24 clover +39 BGO shields;

Efficiency: 5.2% at 1.3 MeV;

Extraction: R_{ac}, R_{DCO}, linear polarization.





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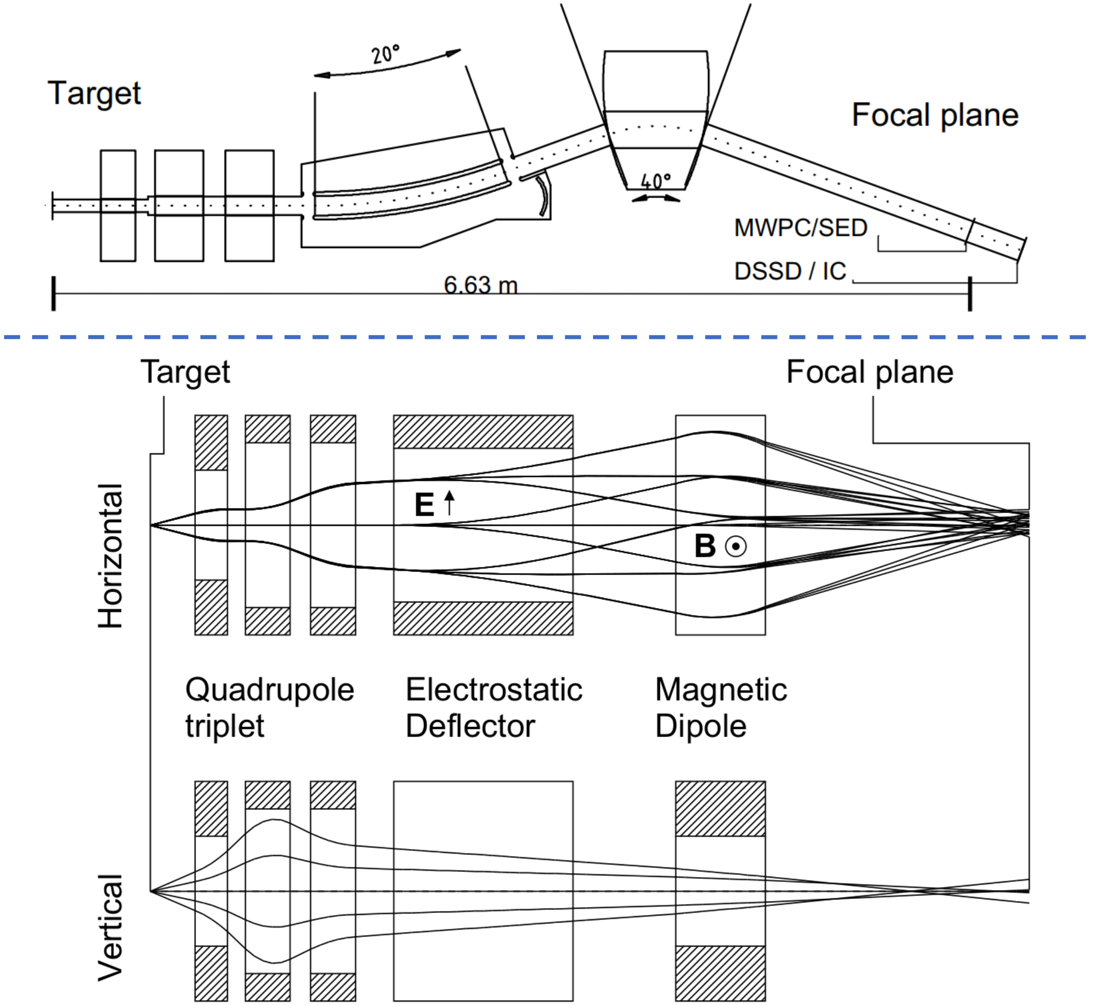

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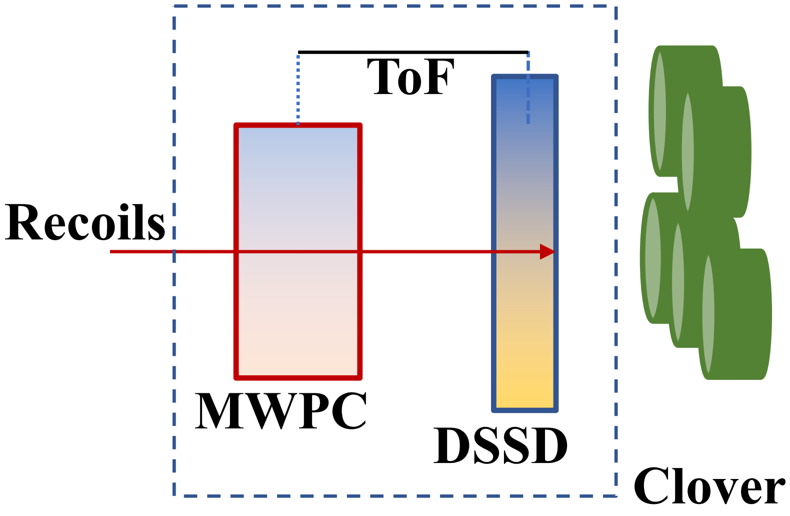

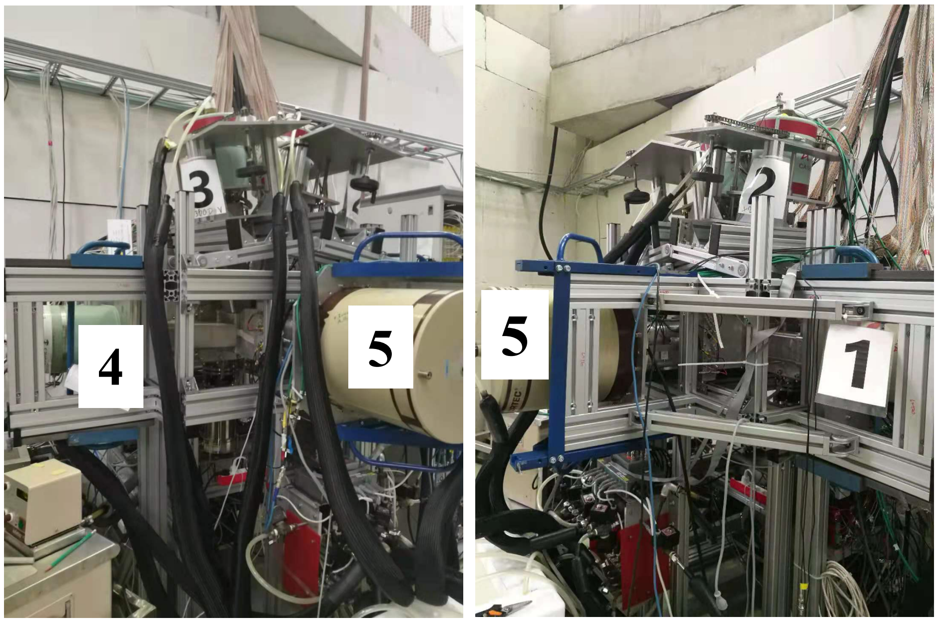

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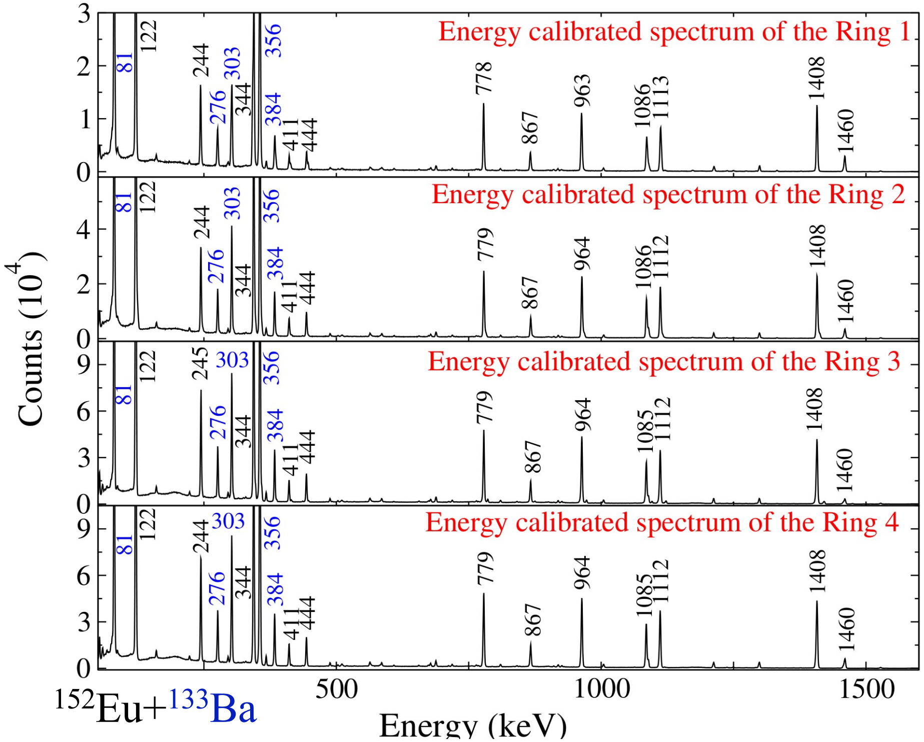
Five clover detectors surrounding the focal-plane detection system were used to detect γ-rays emitted by **long-lived isomers of the implanted recoils and the daughter nuclei produced by β-decay**.

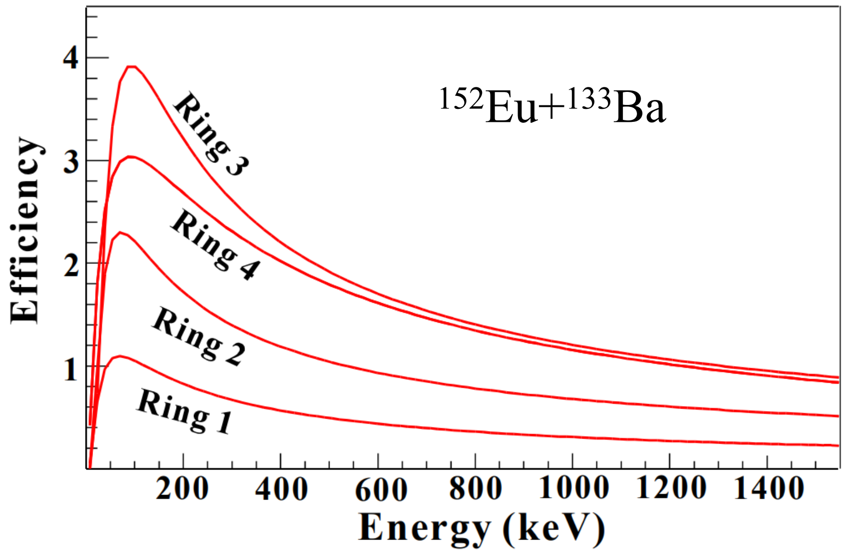
Data analysis

1 Setting of the low-energy thresholds, **energy calibrations**, gain matching, and **efficiency calibrations**

The low-energy **thresholds** of most detectors were set to ≈ **25 keV**.



The energy calibrated spectra of the 4 rings of the JUROGAM 3 array using the $E_\gamma = a + bx + cx^2$ formula.



The efficiency curves of the 4 rings of the JUROGAM 3 array by fitting the $ln\epsilon = (A + Bx - e^{C+Dx})$ formula to the experimental points.

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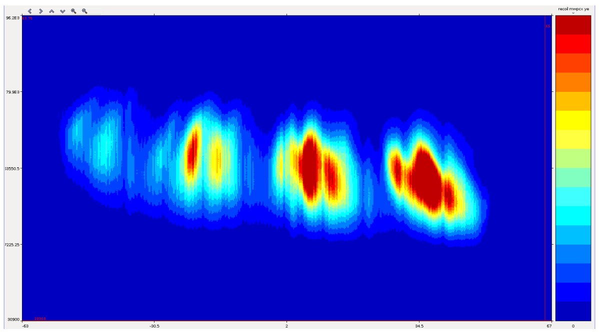

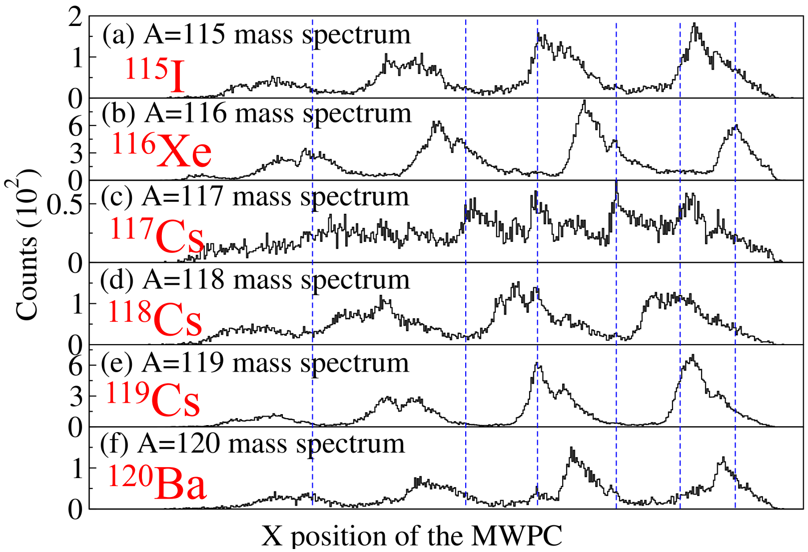

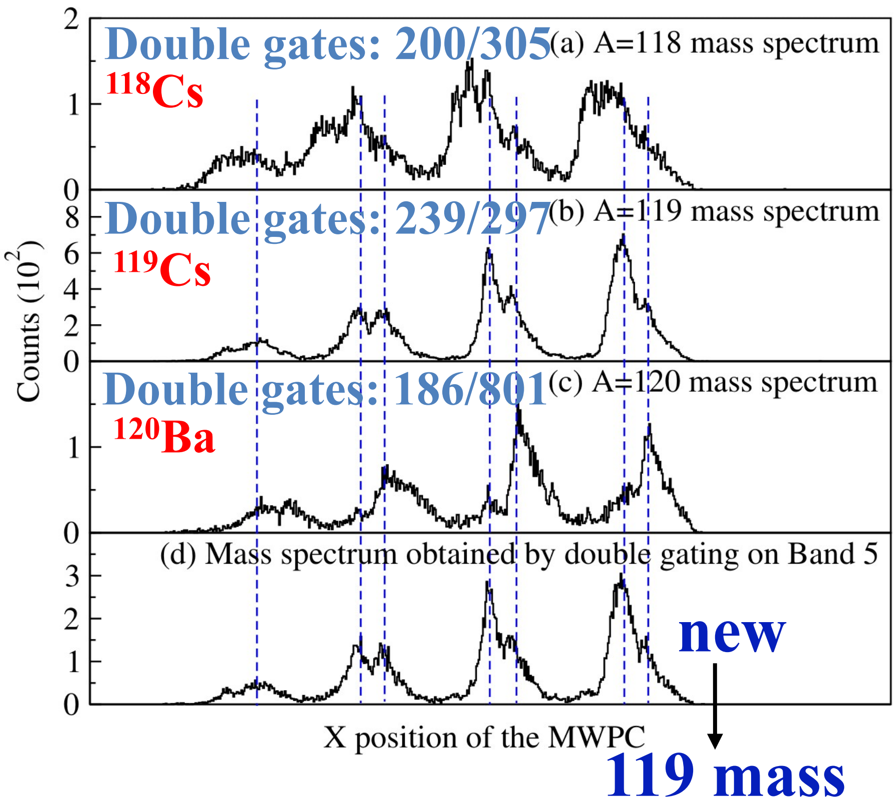

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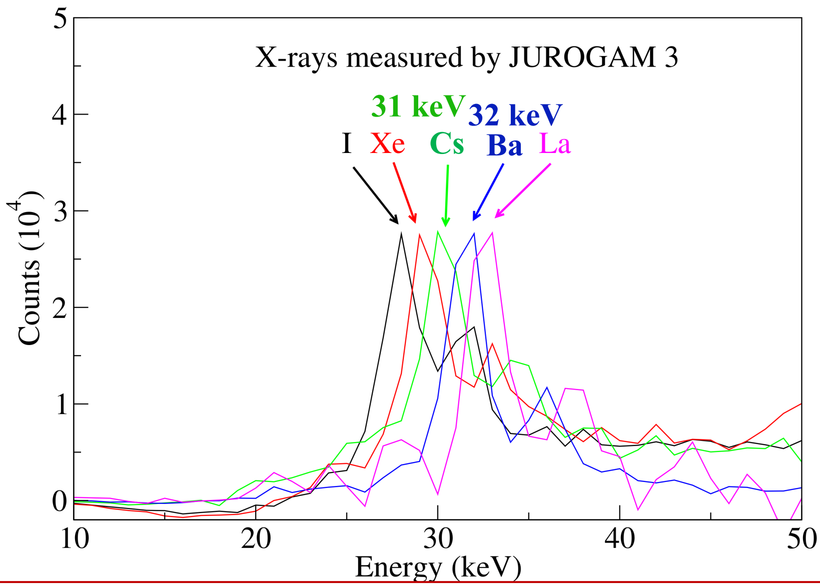
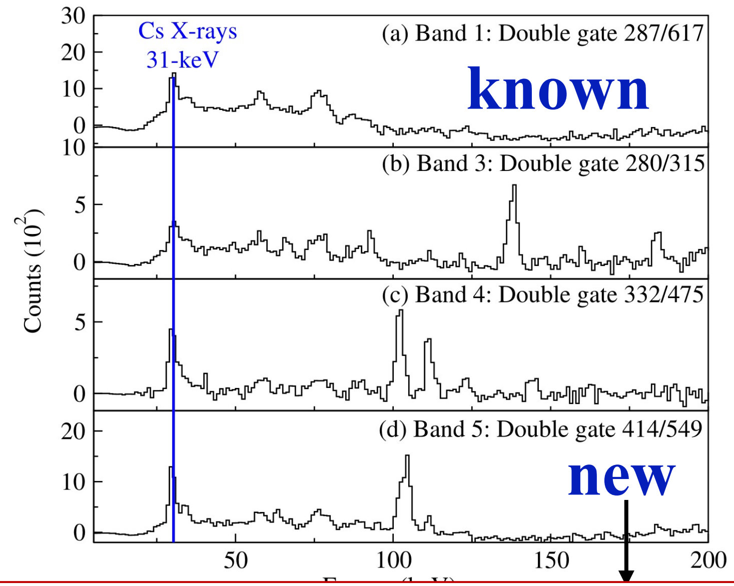
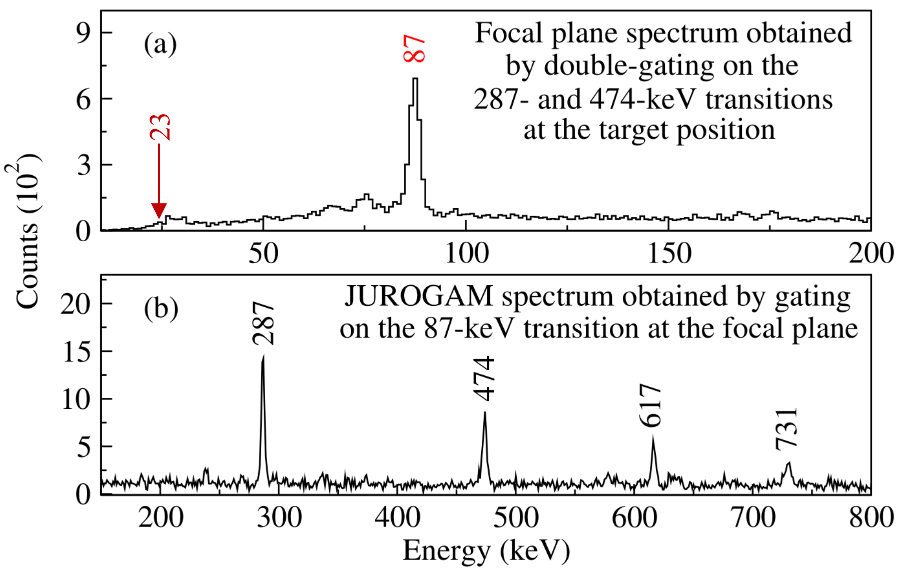




Combining information on the mass spectra and on the X-rays, we could assign new bands.

Results: isomeric states of ^{119}Cs



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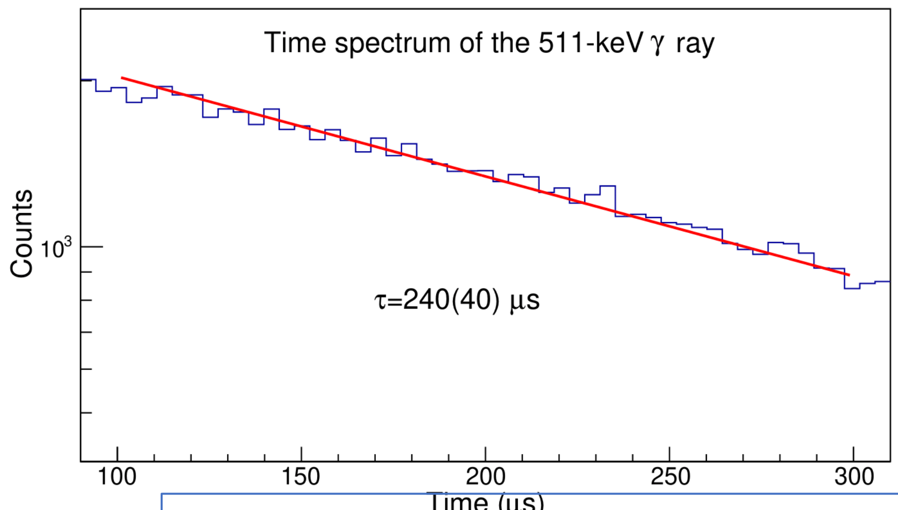
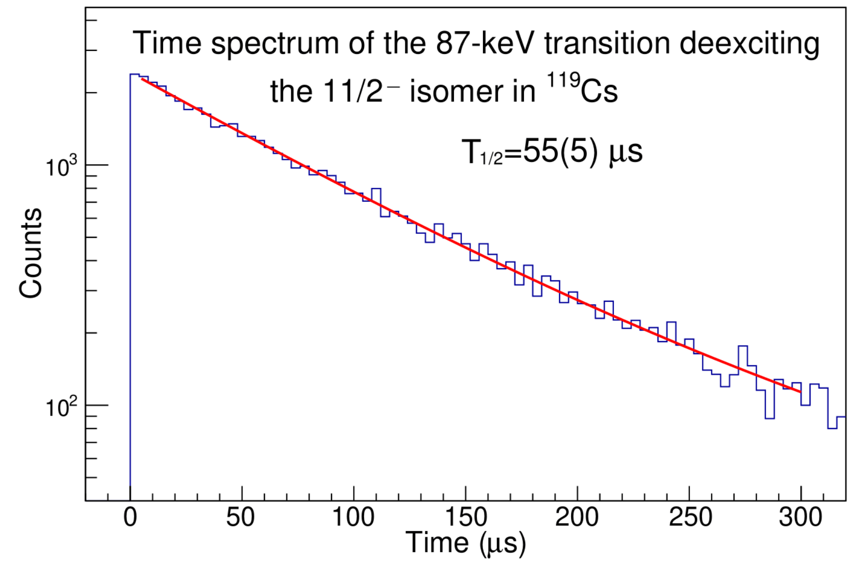




The extracted lifetime of the 11/2⁻ state is $T_{1/2}$ = 55(5) μs.

Data analysis

2 Doppler shift correction, add-back

$$E_\gamma(\theta) = E_\gamma(0)\frac{\sqrt{1-\beta^2}}{1-\beta cos\theta}$$

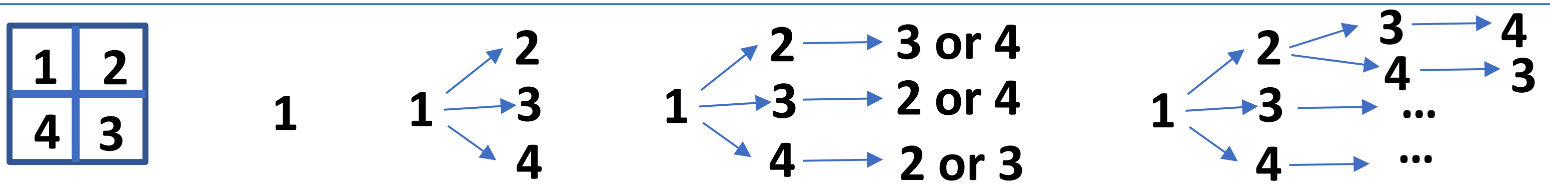
If v<<c, β<<1

$$E_\gamma(\theta) = E_\gamma(0)(1+\beta cos\theta)$$

a: $E_\gamma(0)$ is the energy of γ-ray emitted by the recoils at rest.
b: θ is the detector angle which is defined with respect to the recoil velocity direction.
c: β = v/c.

In our experiment, we used a value **β = 0.044** for all γ rays detected in the JUROGAM 3 which resulted in the **best resolution** for high energy γ rays.

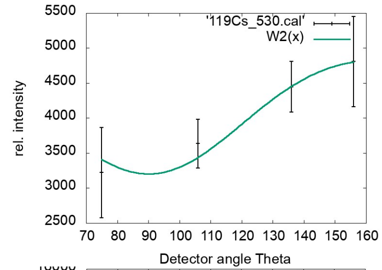
The clover detector can be operated in two modes: single crystal and **add-back mode**.

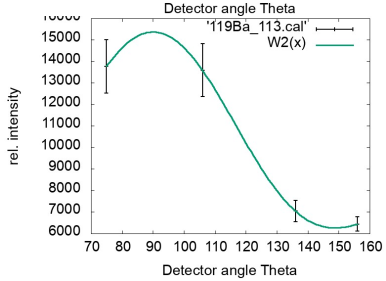


Data analysis

4 Assignment the multipolarities by using $\mathbf{R_{DCO}}$ and $\mathbf{R_{ac}}$

DCO ratio is defined as $$R_{DCO} = \frac{I_\gamma(157.6^\circ, \approx 90^\circ)}{I_\gamma(\approx 90^\circ, 157.6^\circ)}$$





Gating on a quadrupole:

R_{DCO}≈1 (pure quadrupole)
R_{DCO}≈0.46 (pure dipole)

Gating on a dipole:

R_{DCO}≈2.1 (pure quadrupole)
R_{DCO}≈1 (pure dipole)

R_{ac} is defined as $$R_{ac} = \frac{I_\gamma(133.6^\circ + 157.6^\circ)}{I_\gamma(75.5^\circ + 104.5^\circ)}$$

R_{ac} ≈1.4 (pure quadrupole)
R_{ac} ≈ 0.8 (pure dipole)

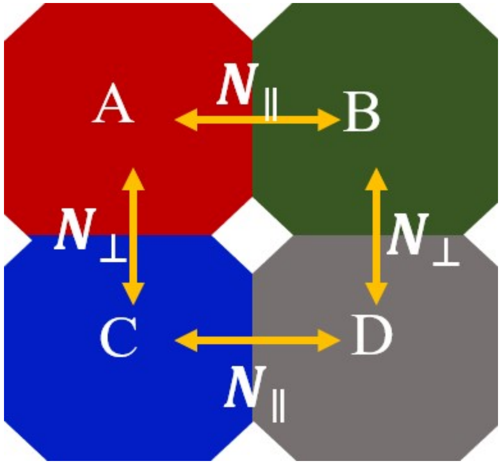
→ **It's very useful for weak transitions**

A. Krämer-Flecken, Meth. Phys. Res. A 275, 333 (1989)
C. J. Chiara et al., Phys. Rev. C 75, 054305 (2007)

Data analysis

The asymmetry *A* is defined as

$$A = \frac{aN_\perp - N_\parallel}{aN_\perp + N_\parallel}$$



where a is a correction coefficient

$$a(E_\gamma) = 1.113(7) - 5.4(8) \times 10^{-5} E_\gamma$$

A positive asymmetry *A* implies **electric nature**, while **a negative asymmetry** implies **magnetic nature**.

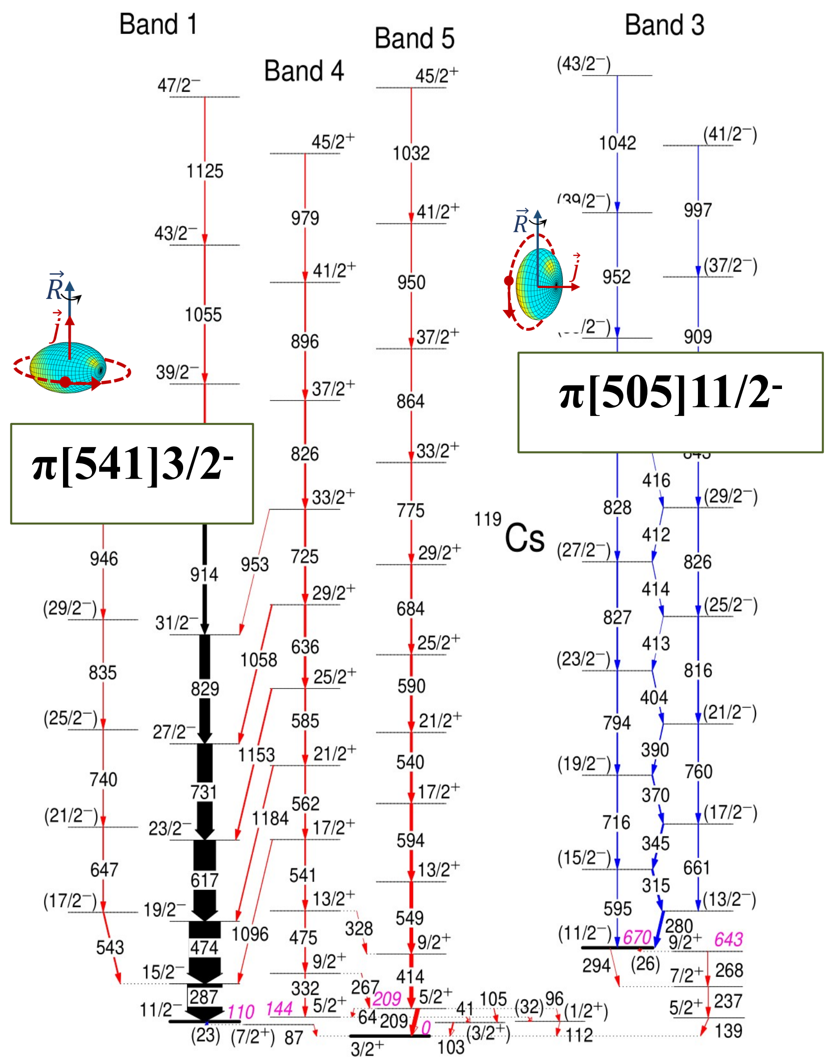
K. Starosta, Nucl. Instrum. Meth. Phys. Res. A423, 16 (1999)

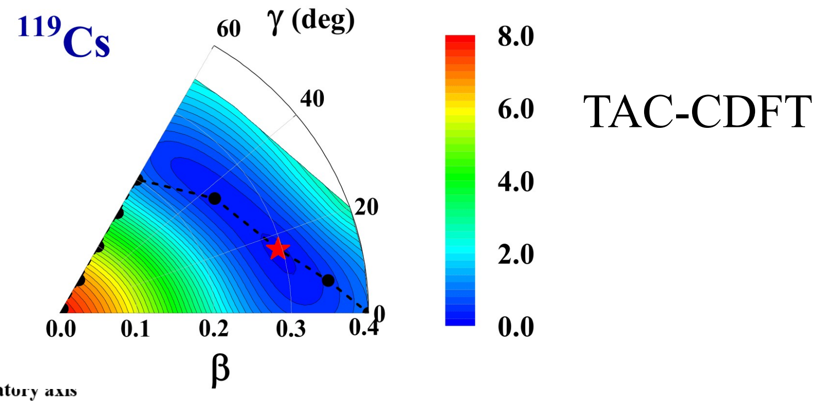
A. Herzáň, Phys. Rev. C 92, 044310 (2015)

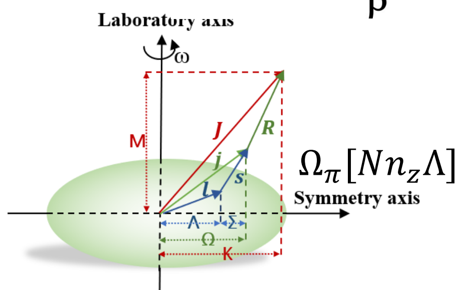
Outline

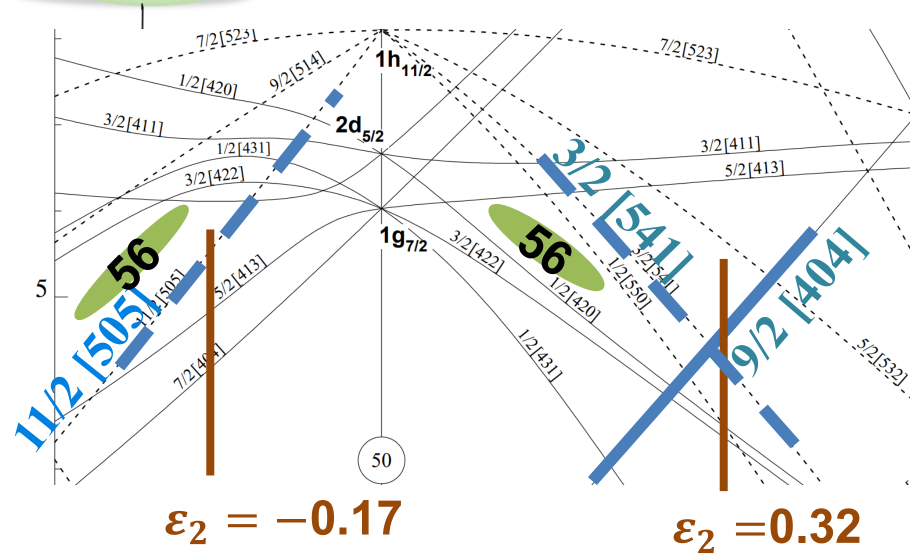
- Introduction
- Experimental details
- **Results and discussion**
  - ^{119}Cs
  - ^{119}Ba
  - ^{118}Cs
- Conclusion

Oblate-prolate shape coexistence in ^{119}Cs

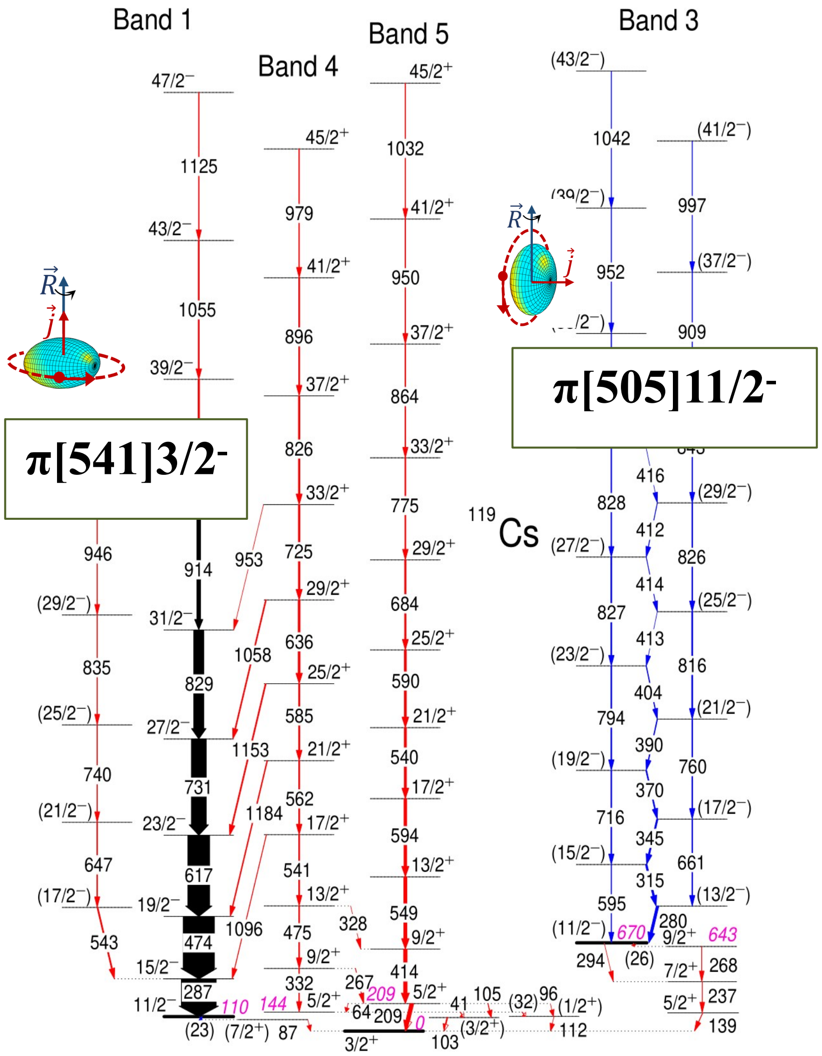


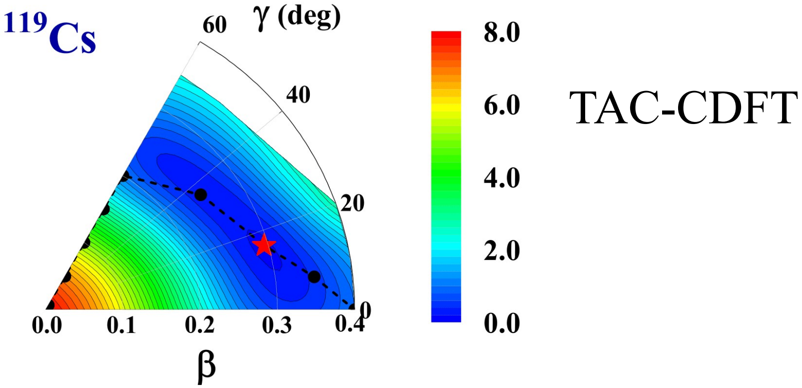


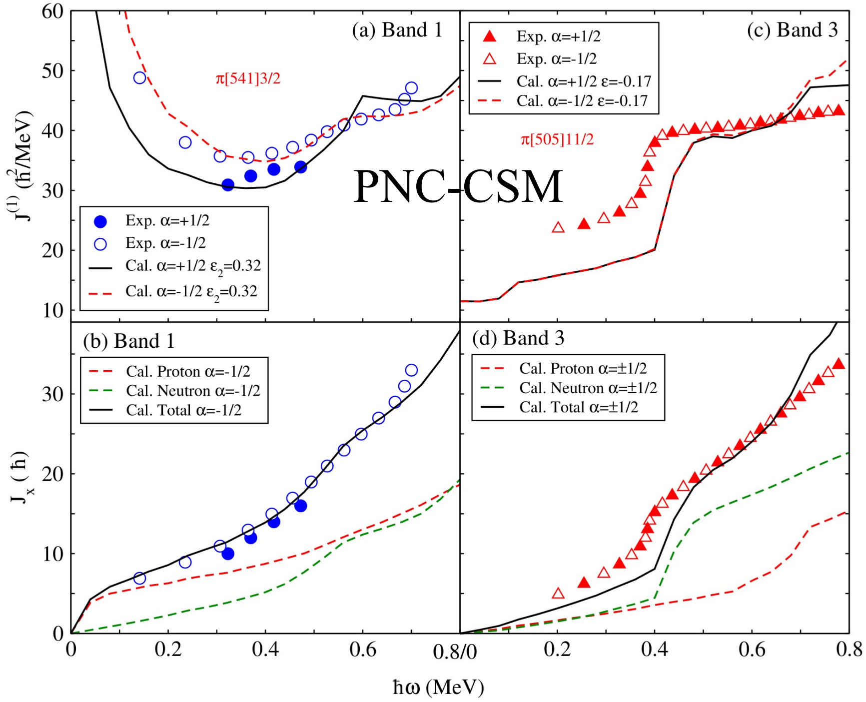




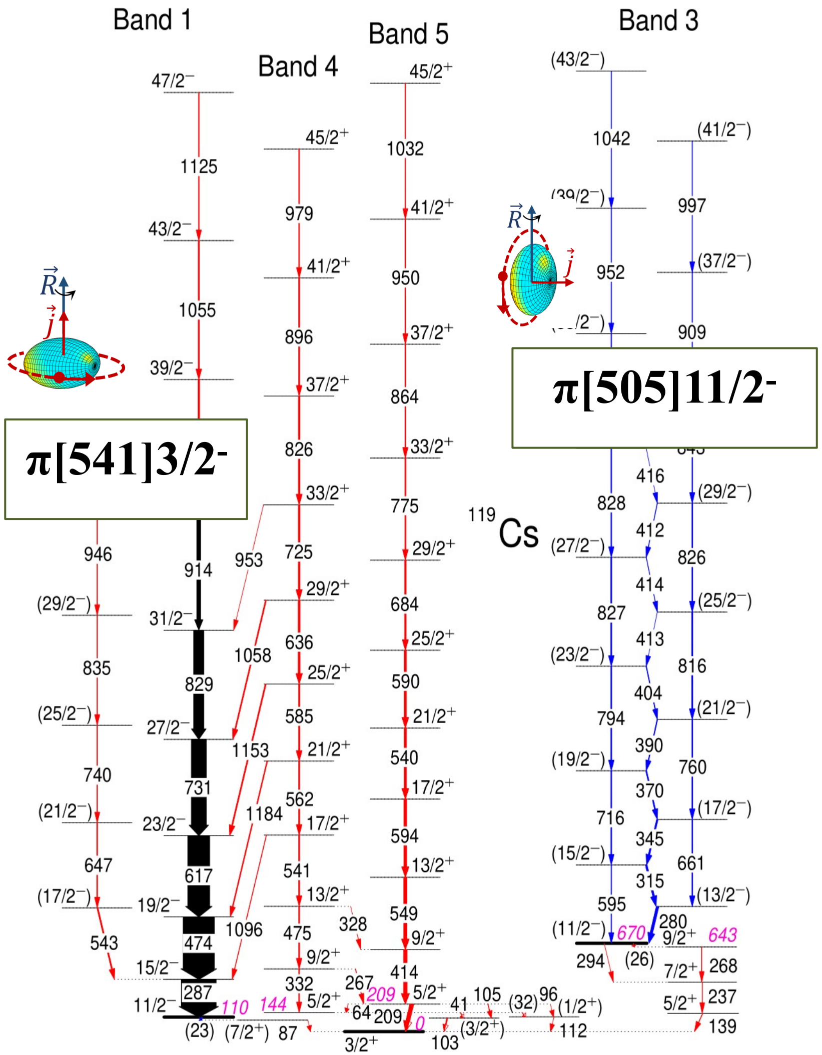
Oblate-prolate shape coexistence in ^{119}Cs

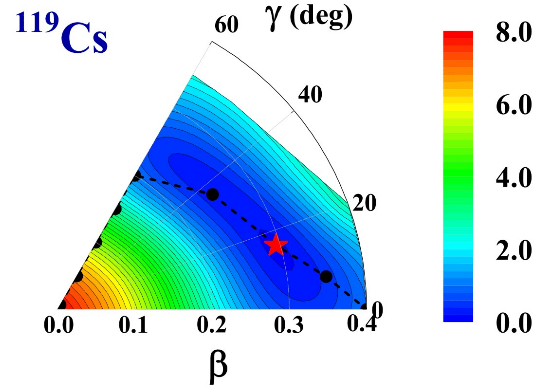




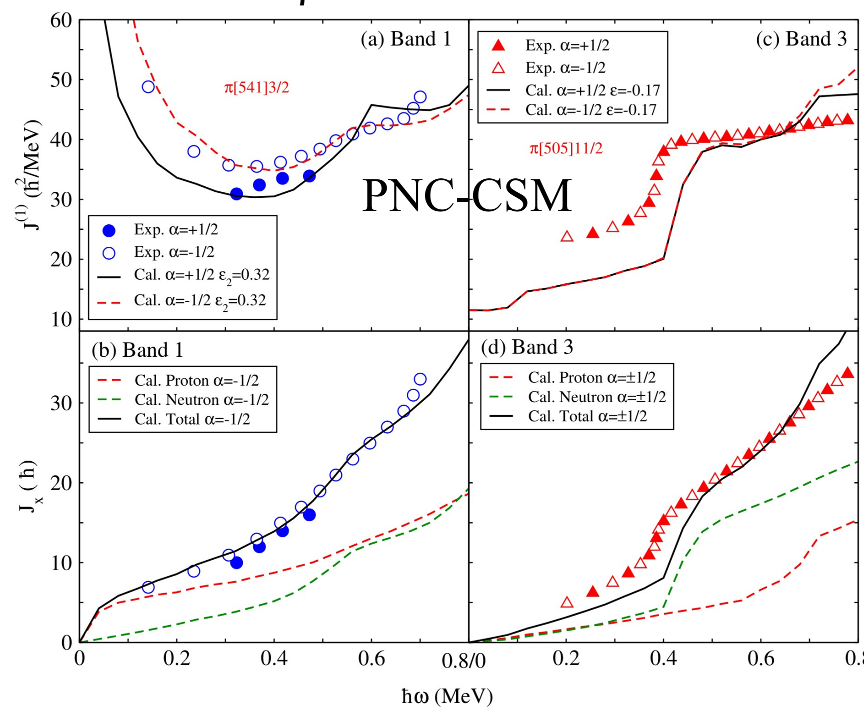


Oblate-prolate shape coexistence in ^{119}Cs



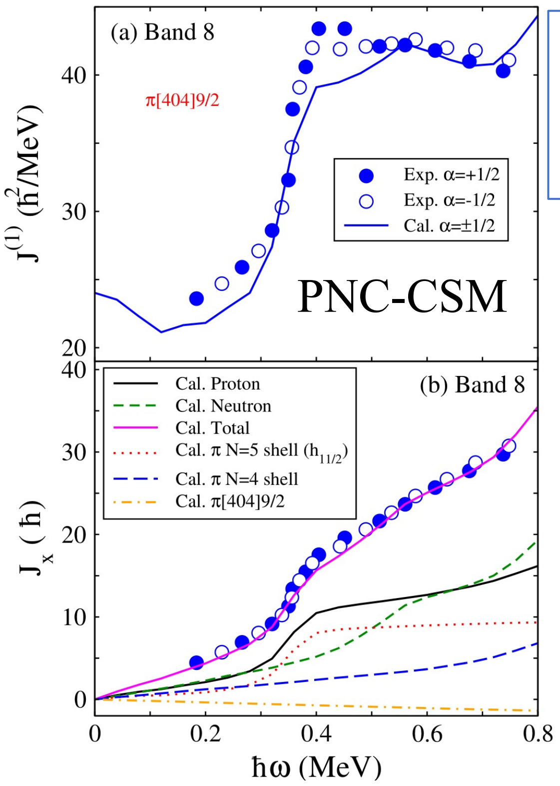


TAC-CDFT

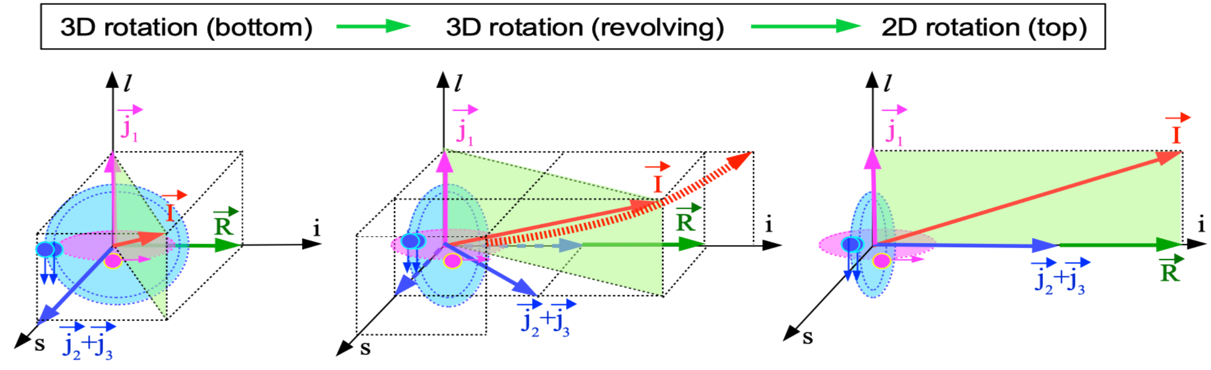


We observed for the first time the oblate-prolate shape coexistence in the 120 mass region.

Proton based revolving chiral bands in ^{119}Cs



Bands 8, 9 are built on the three-proton configuration in the backbending region, one in the high-Ω [404]9/2 orbital and two in low-Ω $h_{11/2}$ orbitals.



Gamma band with Chiral character

We observed for **the first time such chiral doublet band**:
the configuration is formed by only protons;
the total angular momentum is revolving in 3D;
the triaxiality is not maximum (10°-15 °);
one proton keeps aligned along the long axis, while the other two are changing their orientation.

Acknowledgments

Neutron excitations in ^{119}Ba

K. K. Zheng,[1,2] C. M. Petrache,[1] Z. H
M. Luoma,[4] J. Ojala,[4] J. Pakarinen,[4] J
J. Uusitalo,[4] G. Zimba,[4] B. Cederwall,[6]
B. M. Nyakó,[8] D. Sohler
[1]Universit

Evidence of oblate-prolate shape coexistence in the strongly-deformed nucleus ^{119}Cs

K.K. Zheng[a,b], C.M. Petrache[a,*], Z.H. Zhang[c], P.W. Zhao[d], Y.K. Wang[d], A. Astier[a],
nen[e], M. Luoma[e], J. Ojala[e],
[e], M. Sandzelius[e], J. Sarén[e],
ang[g],
I. Doncel[f],

Complete set of proton excitations in ^{119}Cs

K. K. Z
M. L
J. Uusit
[2]K
[3]M
[7]Scho

Rich band structure and multiple long-lived isomers in the odd-odd ^{118}Cs nucleus

K. K. Zheng,[1,2] C. M. Petrache,[1] Z. H. Zhang,[3] A. Astier,[1] B. F. Lv,[1,*] P. T. Greenlees,[4] T. Grahn,[4] R. Julin,[4] S. Juutinen,[4] M. Luoma,[4] J. Ojala,[4] J. Pakarinen,[4] J. Partanen,[4,†] P. Rahkila,[4] P. Ruotsalainen,[4] M. Sandzelius,[4] J. Sarén,[4] H. Tann,[4,5] J. Uusitalo,[4] G. Zimba,[4] B. Cederwall,[6] Ö. Aktas,[6] A. Ertoprak,[6] W. Zhang,[6] S. Guo,[2,7] M. L. Liu,[2,7] X. H. Zhou,[2,7] I. Kuti,[8] B. M. Nyakó,[8] D. Sohler,[8] J. Timár,[8] C. Andreoiu,[9] M. Doncel,[5] D. T. Joss,[5] and R. D. Page[5]

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Thanks for your attention

Cross section

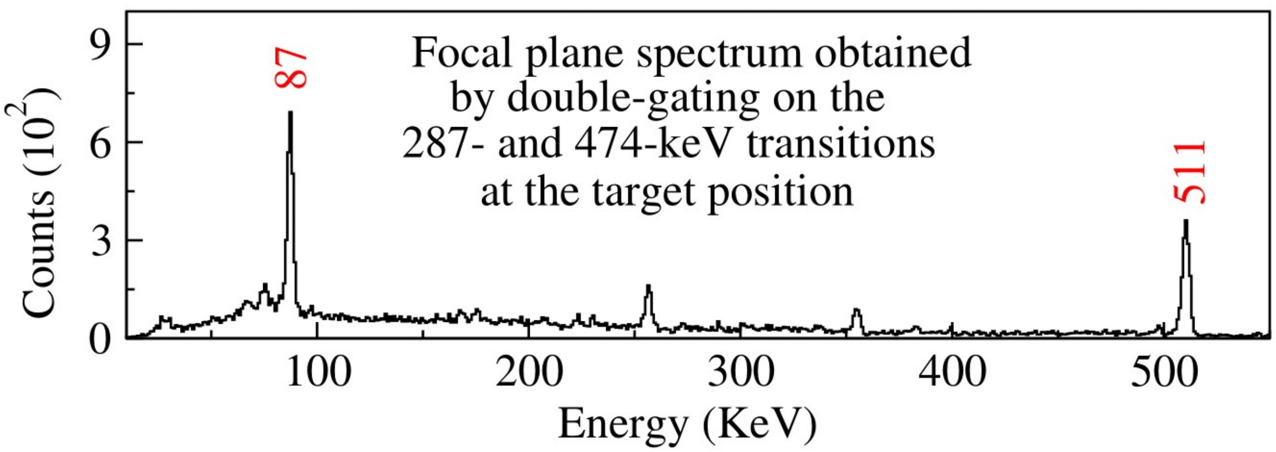
Mass	114	115	116	117	118	119	120	121
$_{52}Te$	2 mb							
$_{53}I$		20 mb						
$_{54}Xe$		2 mb	20 mb	6 mb	**90 mb**			
$_{55}Cs$				6 mb	35 mb	**140 mb**		
$_{56}Ba$					1 mb	20 mb	**100 mb**	
$_{57}La$							4 mb	7 mb

Changed states: 27, 28, 29, 30

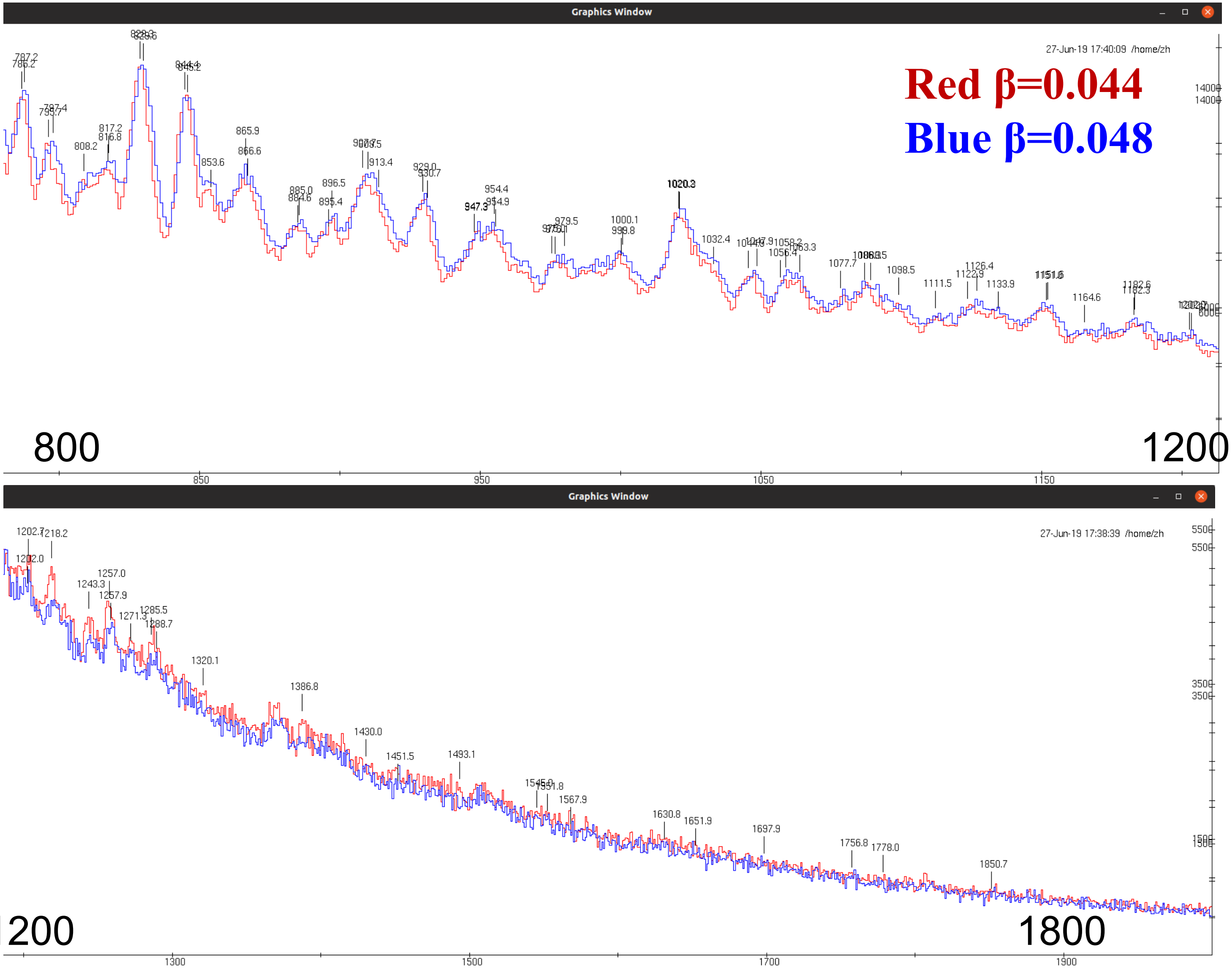
m/q overlap: 120/116   119/115   118/114

isomer of ^{119}Cs

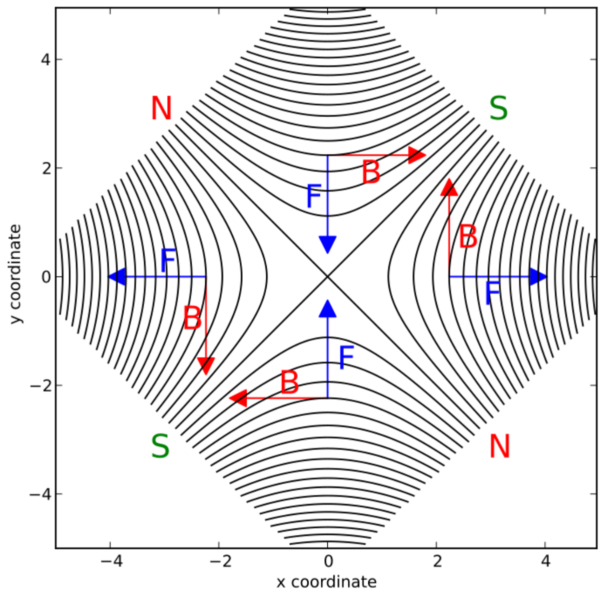
Background 511–keV



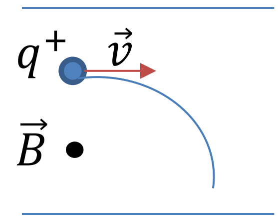
Doppler shift correction



QQQ D_E D_M



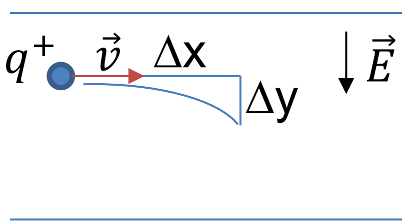
$\vec{F} = q\, \vec{v} \times \vec{B}$



Centrifugal= Lorentz force

$$m\frac{v^2}{\rho} = qvB$$

$$\frac{p}{q} = B\rho$$



$$m\ddot{y} = qE$$

$$\Delta y = \frac{qE}{m}\left(\frac{\Delta x}{v}\right)^2$$

$$\Delta y \propto \frac{1}{mv^2} \propto \frac{1}{E_c}$$

κ and μ

The term V' of the Nilsson potential is of the form

$$V' = -\kappa(N)\hbar\omega_0\{2\boldsymbol{l}_t\cdot \boldsymbol{s} + \mu(N)(l_t^2 - \langle l_t^2\rangle_N)\}$$

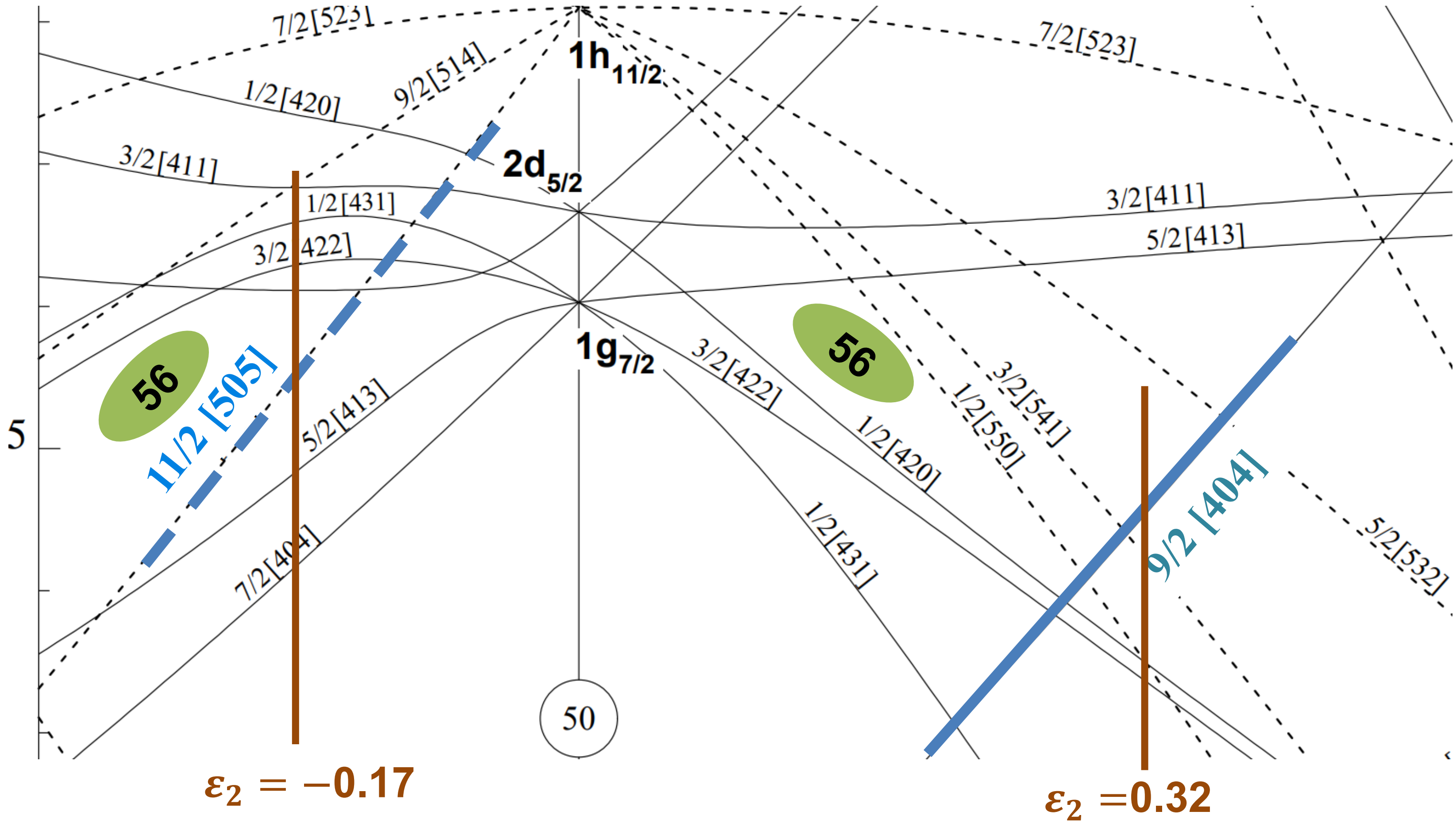
T. Bengtsson, I. Ragnarsson / Rotational bands

TABLE 1

The modified oscillator parameters, κ and μ, which have been used in this work

N_{rot}	Protons		Neutrons	
	κ	μ	κ	μ
0	0.120	0.00	0.120	0.00
1	0.120	0.00	0.120	0.00
2	0.105	0.00	0.105	0.00
3	0.090	0.30	0.090	0.25
4	0.065	0.57	0.070	0.39
5	0.060	0.65	0.062	0.43
6	0.054	0.69	0.062	0.34
7	0.054	0.69	0.062	0.26
8	0.054	0.69	0.062	0.26

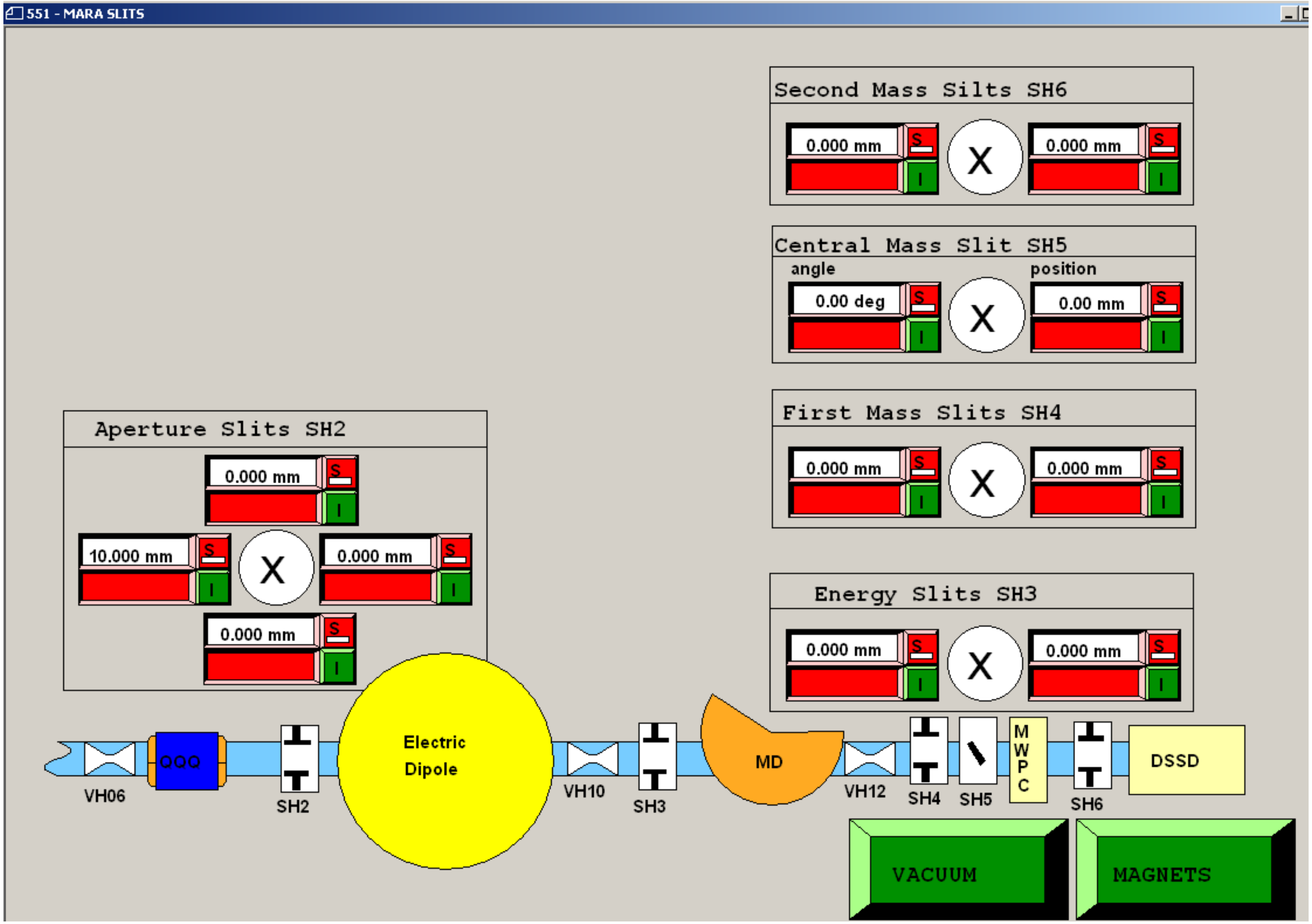
Nilsson_Diagram (Proton)



MARA

Quadrupole triplet	Q_1	$Q_{2,3}$
Optical length	25 cm	35 cm
Bore diameter	10 cm	15 cm
Maximum field gradient	10 T/m	10 T/m
Nominal field relative to $B\rho$	0.4698 T/$B\rho$	0.5859, 0.2387 T/$B\rho$
Sector fields	**Electrostatic**	**Magnetic**
Radius of curvature, ρ	4.000 m	1.000 m
Bending angle, ϕ	20°	40°
Vertical gap	14 cm	20 cm (active)
Horizontal gap	10 cm (active)	10 cm
Maximum rigidity	14.2 MV	1 Tm
Inclination of EFB (entrance and exit)		8°
EFB curvature radii (entrance and exit)		2.0 m
Height of the gap in the anode	1.5 cm (extending from ≈10° to ≈19°)	
Drift lengths	**Length [cm]**	
Target – Q_1	35	
Q_1 – Q_2	14	
Q_2 – Q_3	16	
Q_3 – Deflector EFB	30	
Deflector EFB – Dipole EFB	80	
Dipole EFB – Focal plane	205.8	

Slits

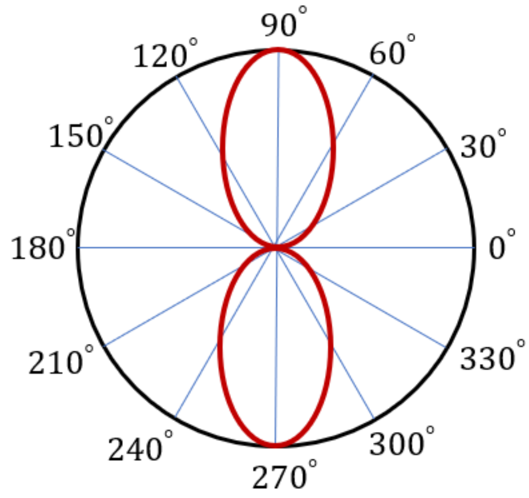

551 - MARA SLITS
Second Mass Slits SH6
0.000 mm
0.000 mm
Central Mass Slit SH5
angle
position
0.00 deg
0.00 mm
First Mass Slits SH4
0.000 mm
0.000 mm
Aperture Slits SH2
0.000 mm
10.000 mm
0.000 mm
0.000 mm
Energy Slits SH3
0.000 mm
0.000 mm
QQQ
Electric Dipole
MD
MWPC
DSSD
VH06
SH2
VH10
SH3
VH12
SH4
SH5
SH6
VACUUM
MAGNETS

PDCO

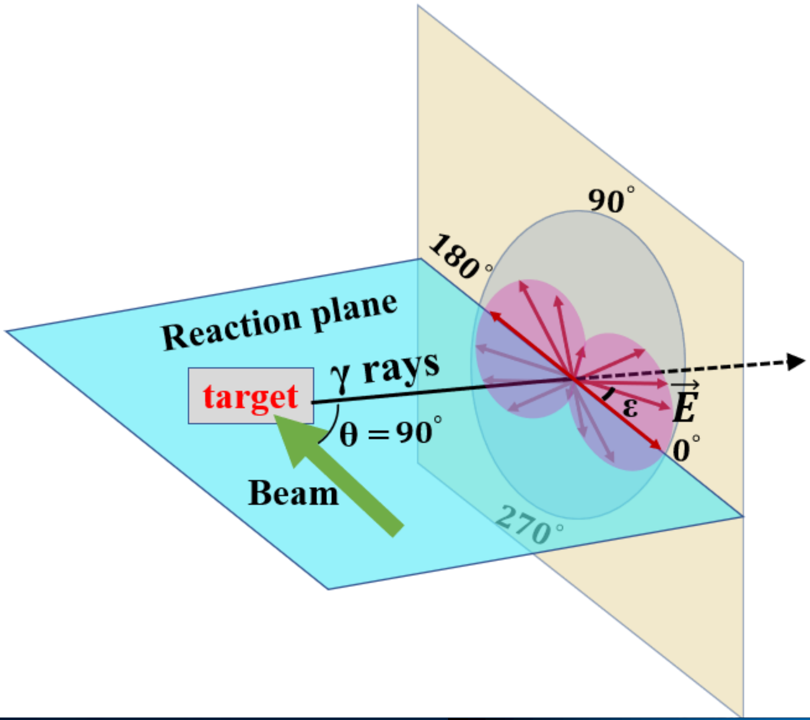
For an axially oriented nucleus, the transitions have a linear polarization defined by

$$p(\theta) = \frac{w(\theta, \epsilon = 0^{\circ}) - w(\theta, \epsilon = 90^{\circ})}{w(\theta, \epsilon = 0^{\circ}) + w(\theta, \epsilon = 90^{\circ})}$$

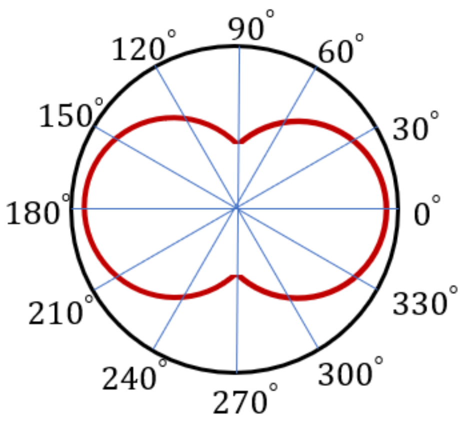
$$W(\theta, \epsilon) = \frac{d\Omega}{8\pi} \sum_{\lambda = even} B_{\lambda} U_{\lambda} [A_{\lambda} P_{\lambda}(\cos\theta) + 2A_{2\lambda} P_{2\lambda}^{(2)}(\cos\theta)\cos 2\epsilon]$$



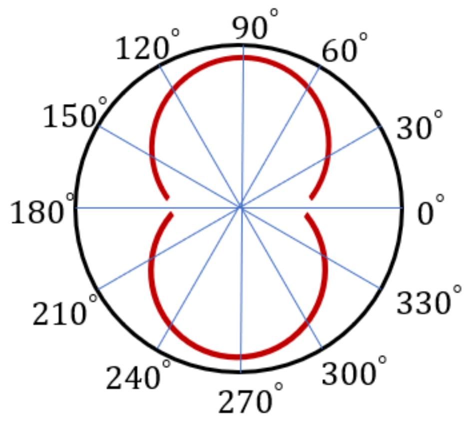
$p(\theta)$ for E_1 E_2 or M_1



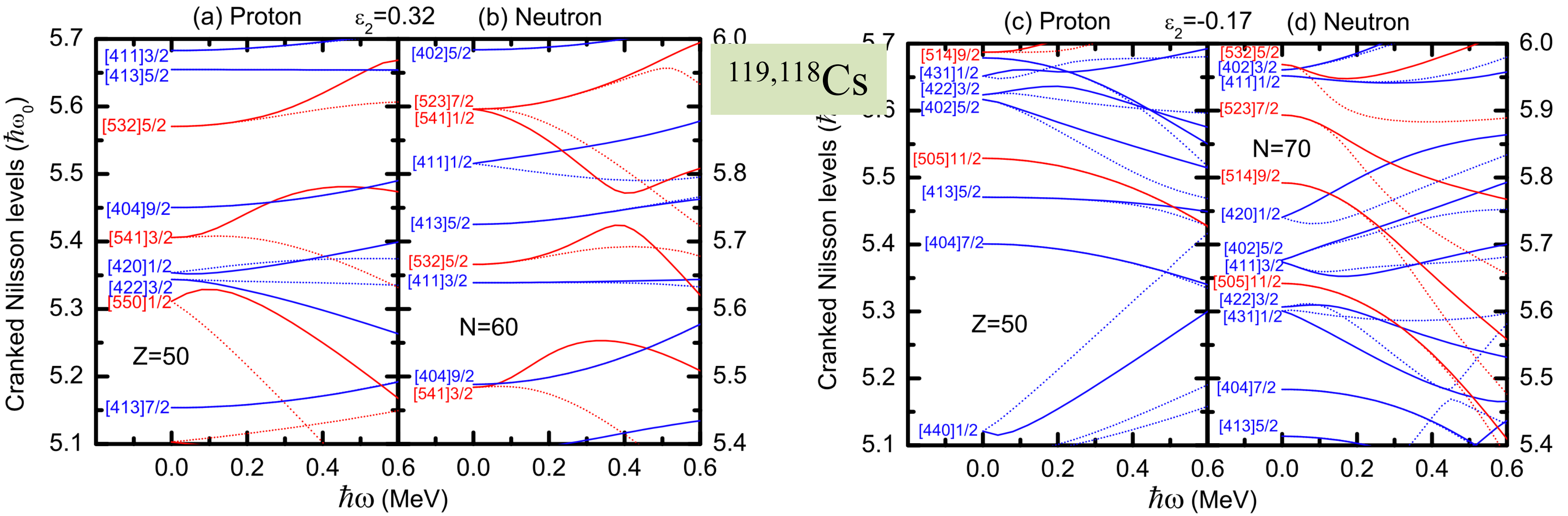
$W^{E_1\ or\ E_2}$ $(\theta = 90^{\circ}, \varepsilon)$

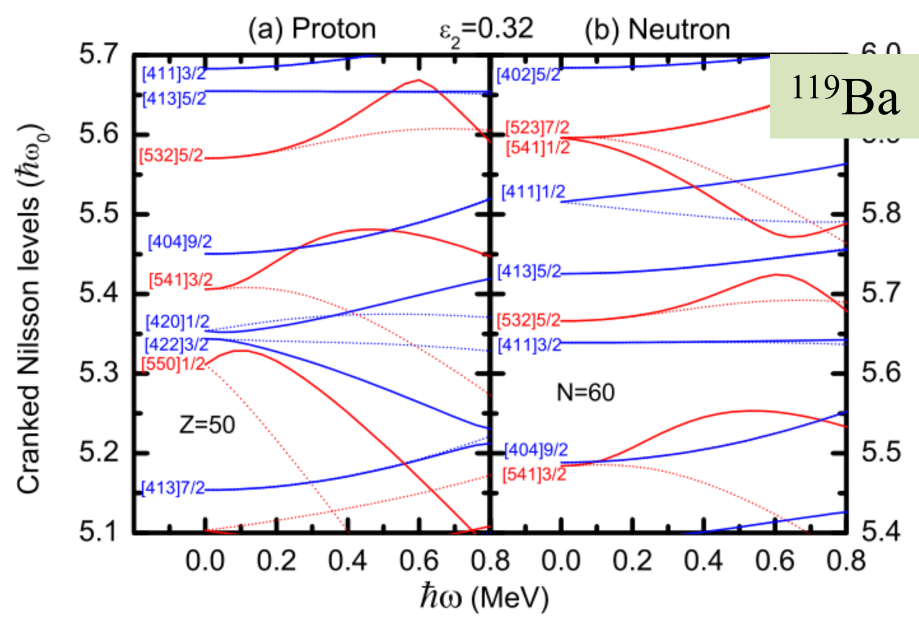


W^{M_1} $(\theta = 90^{\circ}, \varepsilon)$



Cranked Nilsson levels

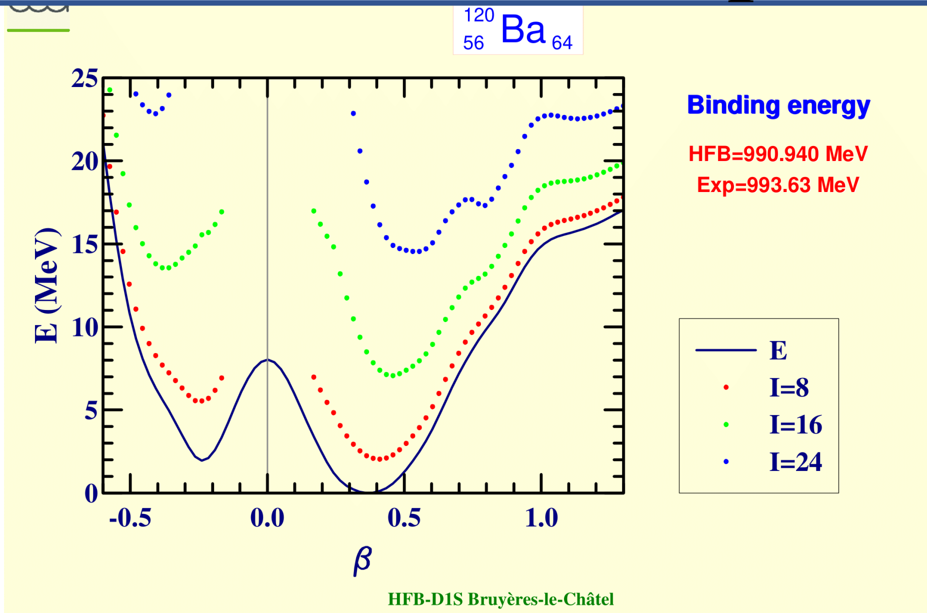


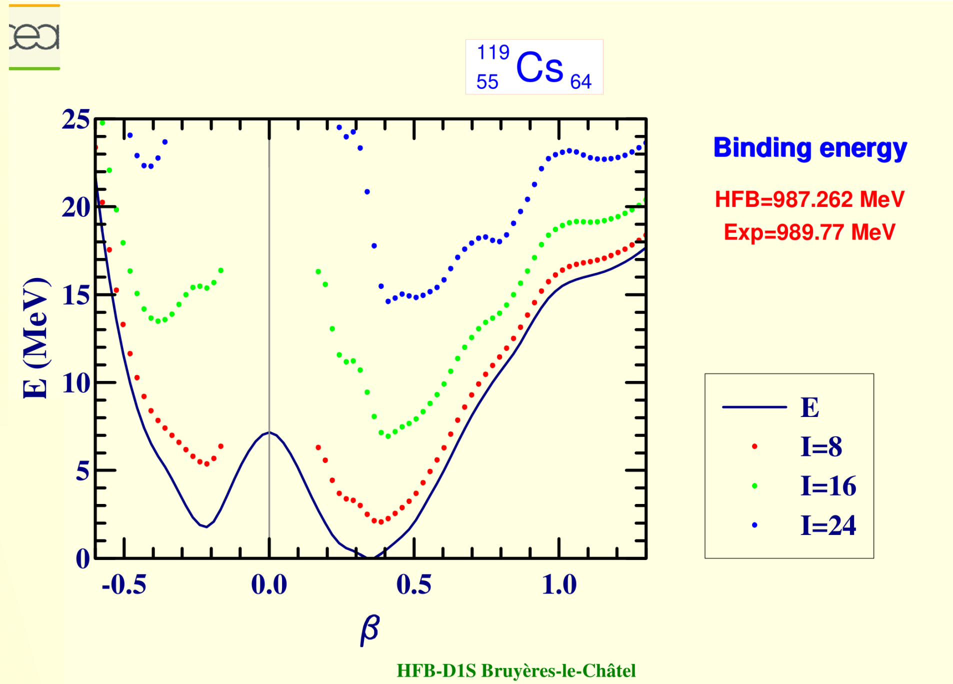


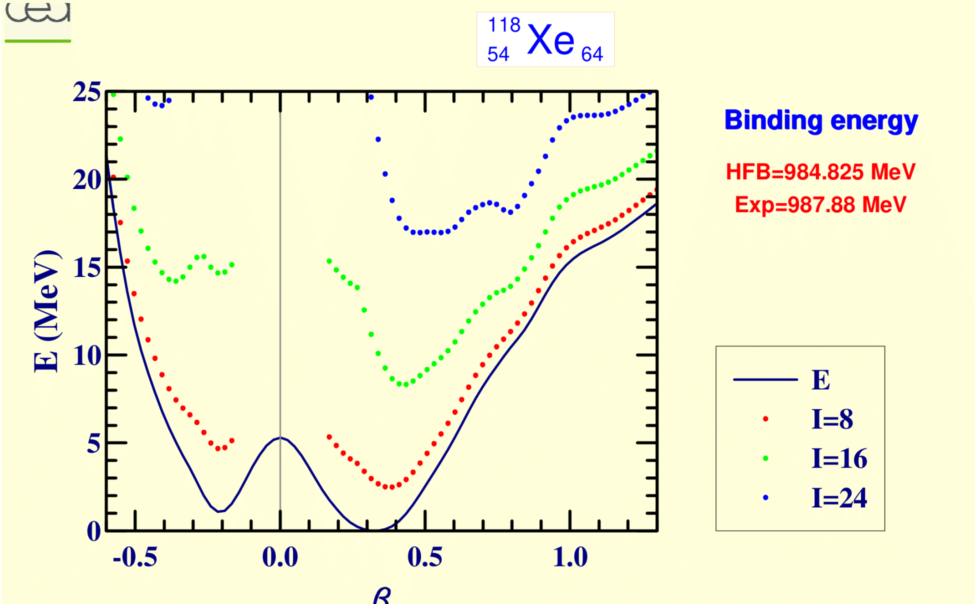
Positive parity

Negative parity

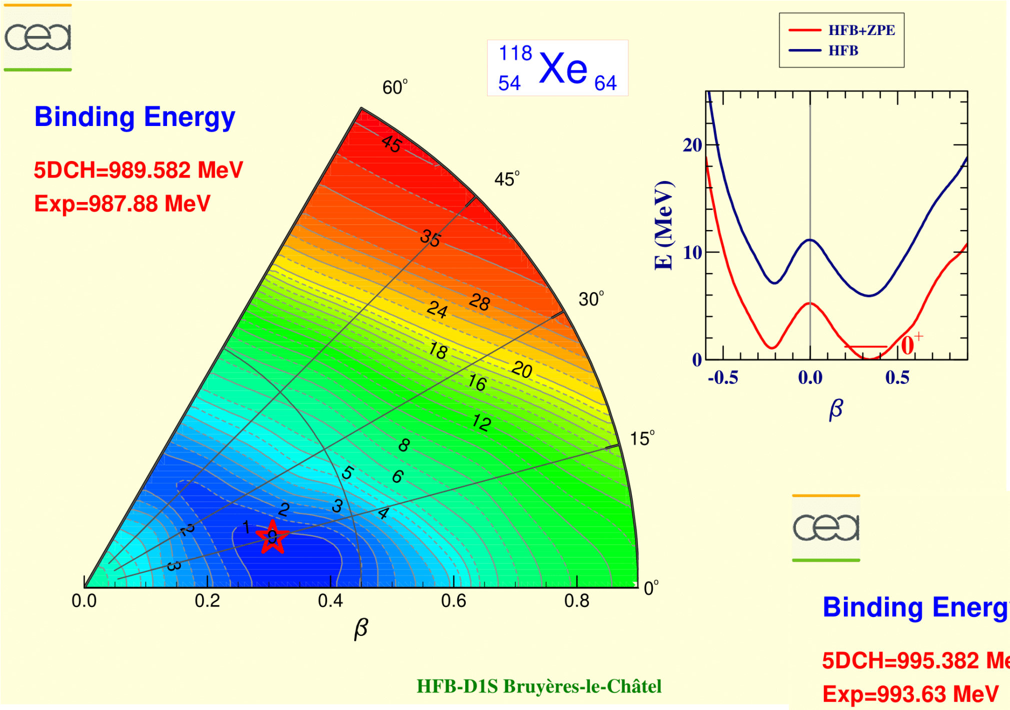
Shape coexistence

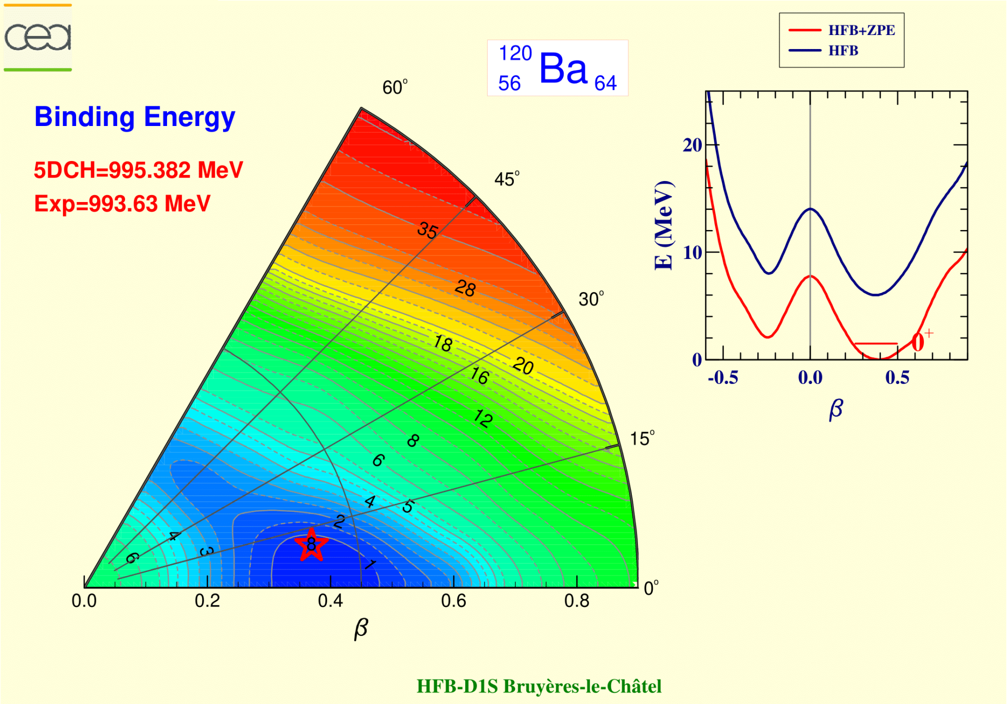




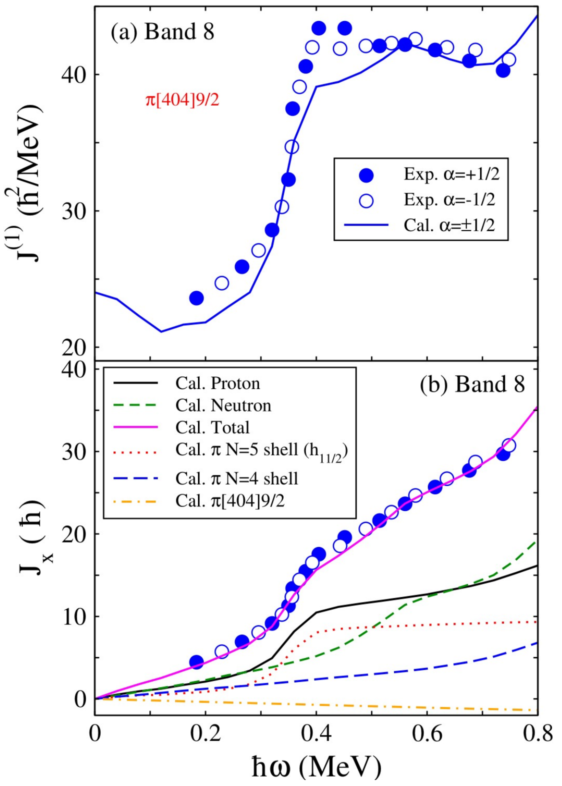


Shape coexistence





Proton based revolving chiral bands in ^{119}Cs



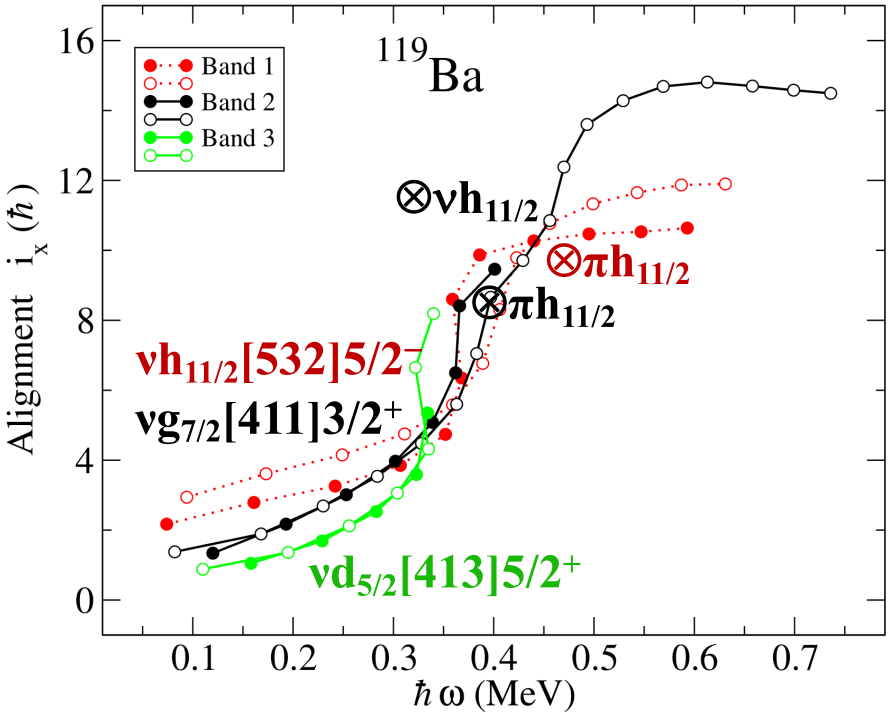
K value：K=4.5(B8,B9);
K=0.5 (B10).

The Harris parameters:
$J_0 = 17\ \hbar^2\mathrm{MeV}^{-1}$
$J_1 = 25\ \hbar^4\mathrm{MeV}^{-3}$.

The gain of angular momentum is ≈8ħ, alignment of a pair of $h^{11/2}$ particle, negligible contribution of the strongly-coupled $[404]9/2^+$ proton orbital.

Bands 8, 9 are nearly degenerate, have similar moments of inertia and B(M1)/B(E2) ratios of reduced transition probabilities.

Results: alignment analysis of ^{119}Ba



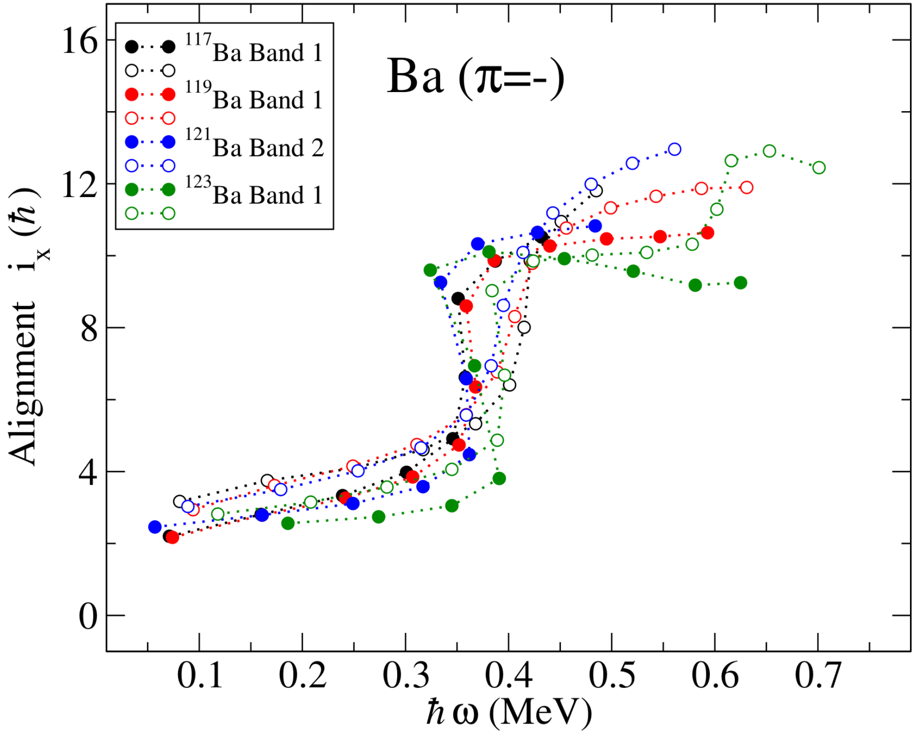
The **K values:** 2.5, 2.5, and 1.5 for Bands 1, 2, and 3.

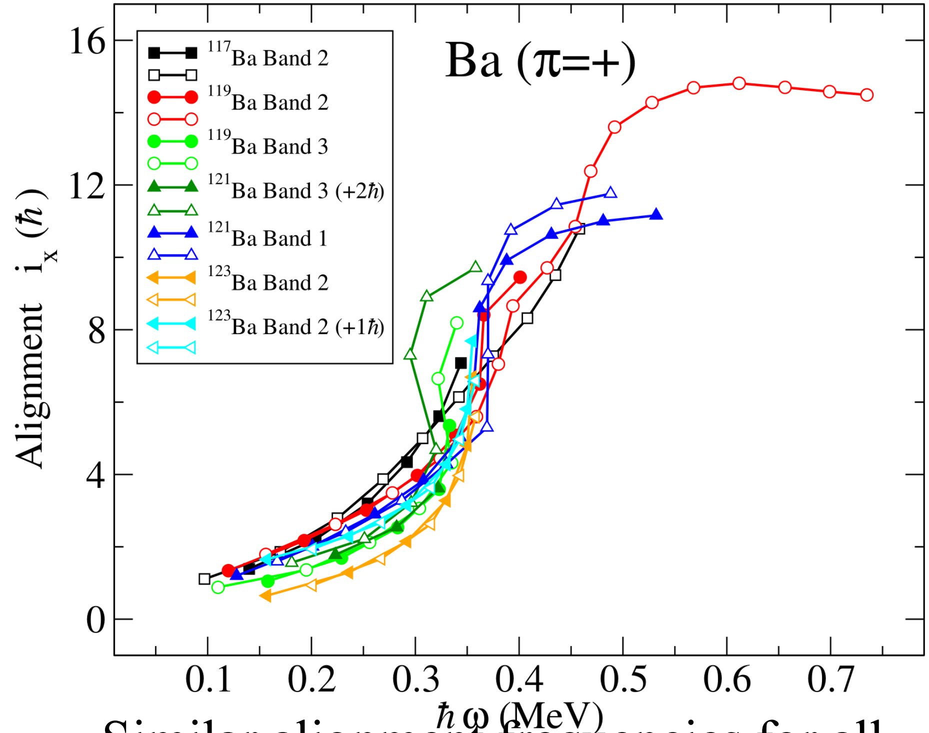
Band 1: a large signature splitting **Bands 2, 3**: zero signature splitting.

Bands 1, 2: alignment occurs at rotational frequency of $\hbar\omega \approx 0.35$ MeV
Band 3: more sharp, lower deformation

As Bands 2 and 3 are assigned to the $\nu d_{5/2}[413]5/2^+$ and $\nu g_{7/2}[411]3/2^+$ configurations, respectively, one would expect a higher alignment in Band 3, which is in contrast with the experimental alignment which is smaller than in Band 2. However, as the two configurations assigned to Bands 2 and 3 are **strongly mixed**, the K-values are difficult to define. An intermediate K = 2 value would lead to very similar alignments of the two bands.

Results: alignment analysis of ^{119}Ba

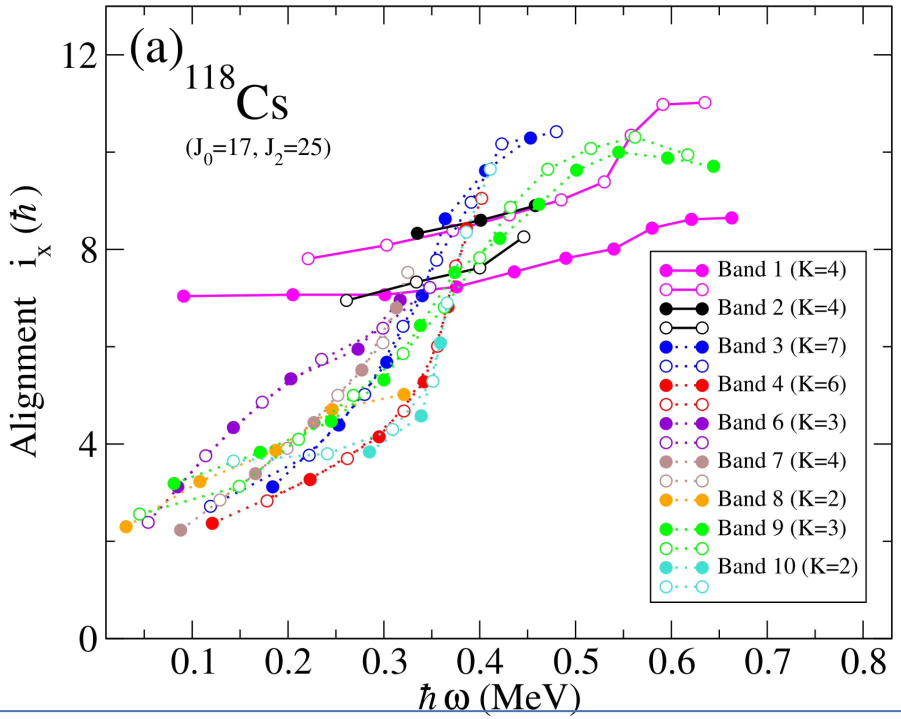




α = -1/2 signature partners are sharper than that of the α = +1/2. This sharpness increases with the neutron number; Only in the negative-parity signature of Band 1 in ^{123}Ba a second alignment at ħω ≈ 0.6 MeV has been observed.

Similar alignment frequencies for all bands excepting Bands 3 of ^{119}Ba and ^{121}Ba (sharper).
^{119}Ba, α = -1/2 signature partners of Band 3 was observed after the second alignment up to high spin.
^{117}Ba, the alignment of the negative-signature partner of Band 2 is more gradual, and no second alignment was

Results: alignment analysis of ^{118}Cs



Bands 1, 2: the alignment exhibited in Band 1 is around 7ħ, in agreement with the π[541]3/2 − ⊗ ν[532]5/2 − configuration previously assigned. the alignments exhibited by the two signature partners are very similar.

Bands 3, 4: The alignment of Band 3 is around 2.5ħ at low frequency, exhibits an alignment gain of ≈ 8ħ at ħω ≈ 0.35 MeV, and saturates at ix ≈ 10ħ at high frequency.

Bands 6, 7: exhibiting smooth up-bends with steeper slopes than in the other bands. They are composed of degenerate signature partners, and are not connected by any transition.

Bands 8, 9, 10: interconnected by several transitions. the alignment exhibited by Bands 8 and 9 are similar, but more gradual than those of Bands 3 and 4. An alignment gain of ≈ 7ħ at ħω≈ 0.35 MeV is exhibited, which saturates at high frequency at i x ≈ 10ħ, like in Band 3.