Shape coexistence and band termination in ^{127}I

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Shapes and Symmetries in Nuclei: from experiment to theory (SSNET'24), 4 – 8 November 2024

Map of India

Mumbai

- IIT Bombay
- Pelletron facility (TIFR)

Talk outline

Shapes and symmetries seen through the measurement of lifetimes

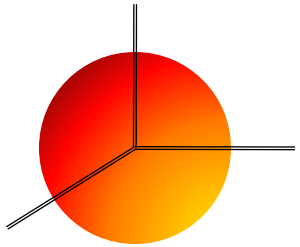
Observables: B(M1) and B(E2)

- Nuclear shapes (basics)
  - Shape parameters (Lund convention)
- Experimental details
  - Accelerator facility (Pelletron)
  - Indian National Gamma Array (INGA)
  - Doppler Shift Attenuation Method (DSAM)
    - Lineshape analysis
- Theoretical analysis
  - Particle rotor model (PRM)
  - Total Routhian surface (TRS)

Results: Shape coexistence and band termination in ^{127}I

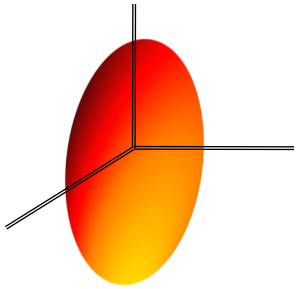
Comparison with ^{129}Cs

Nuclear shapes and symmetries

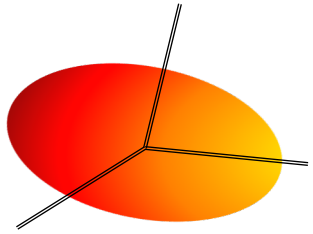


Spherical

- ✓Rotational symmetry
- ✓No collective rotation possible
- ✓Single particle excitations

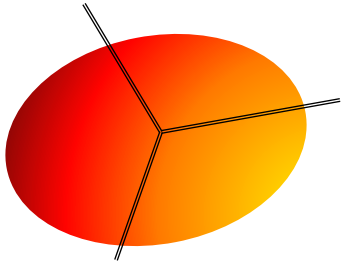


Axial Prolate



Axial Oblate

- ✓Rotational symmetry broken
- ✓a = b < c or a = b > c
- ✓Signature symmetry exist
- ✓Collective rotation possible about axis perpendicular to symmetry axis
- ✓*K* is good quantum number.



Triaxial

- ✓Rotational symmetry broken
- ✓Collective rotation possible with two different signatures causing **Signature splitting and inversion.**
- ✓*K* is not a good quantum number.
- ✓Rotational freedom
- ✓Suitable for **Chiral symmetry**

Nuclear deformation

$$R(\vartheta,\varphi) = R_0[1+\sum_{\lambda=2}^{\infty}\sum_{\mu=-\lambda}^{\lambda} a_{\lambda\mu}Y_{\lambda\mu}(\vartheta,\varphi)];$$

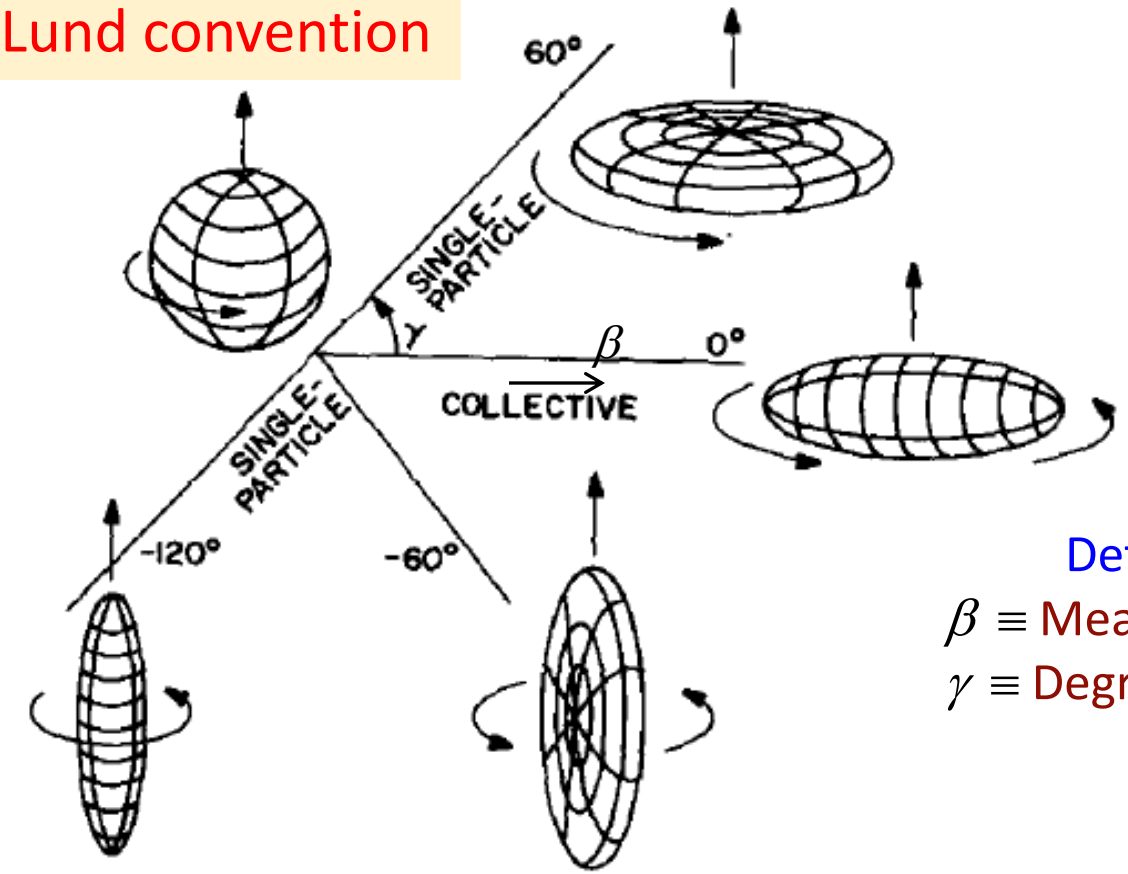
R_0 : Radius of sphere

$Y_{\lambda\mu}$: Spherical harmonics

$\lambda = 2$ Quadrupole deformation

$\lambda = 3$ Octupole deformation

Lund convention



Quadrupole deformation

$$a_{20} = \beta\cos\gamma$$
$$a_{22} = a_{2-2} = \frac{1}{\sqrt{2}}\beta\sin\gamma$$

Deformation parameters

$\beta \equiv$ Measure of axial deformation

$\gamma \equiv$ Degree of triaxiality

$$\varepsilon_2 \equiv 0.95\beta$$

Tata Institute of Fundamental Research (TIFR)
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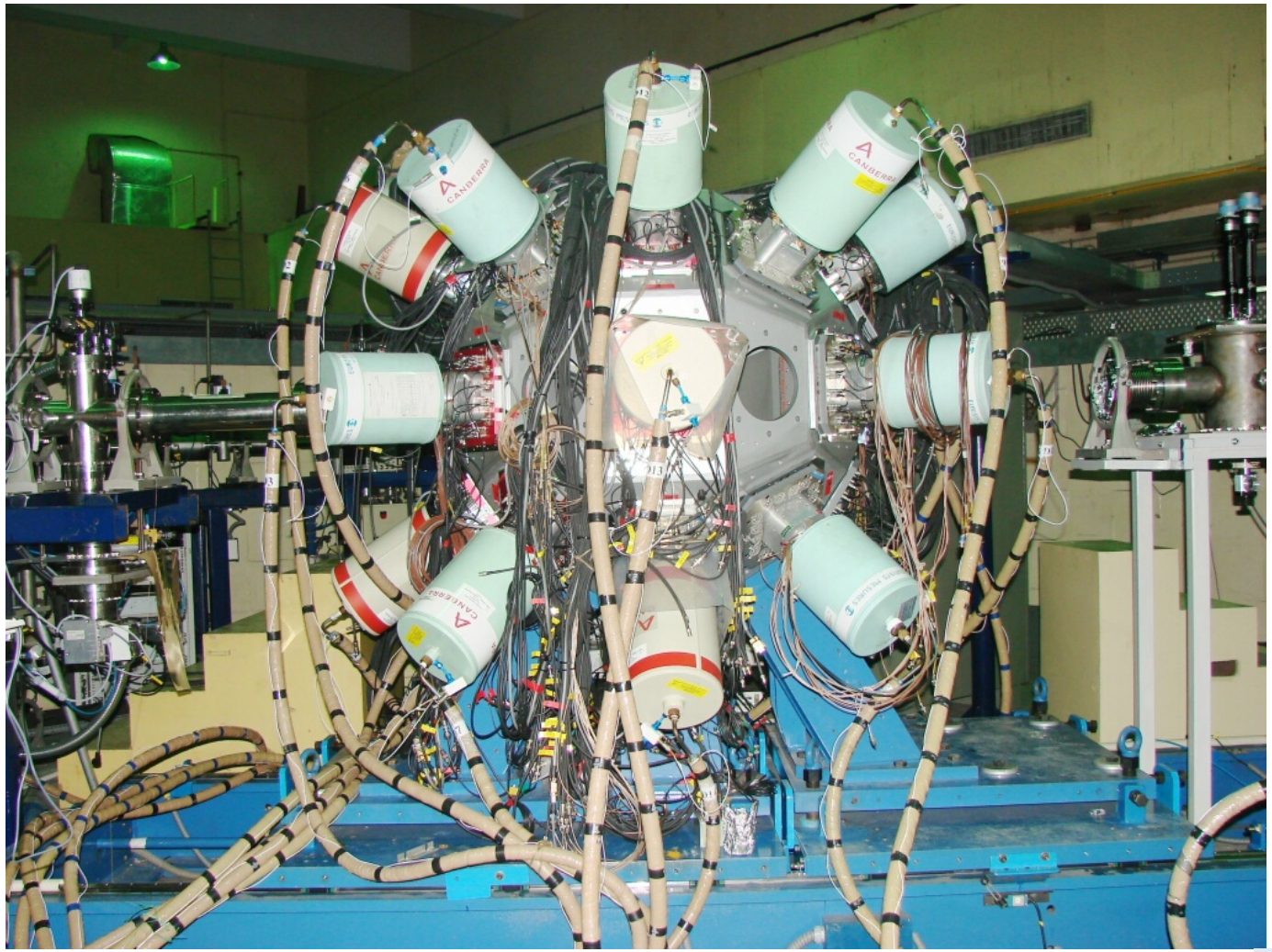
14 MV Heavy ion accelerator (Pelletron)
Heaviest beam delivered so far ^{127}I

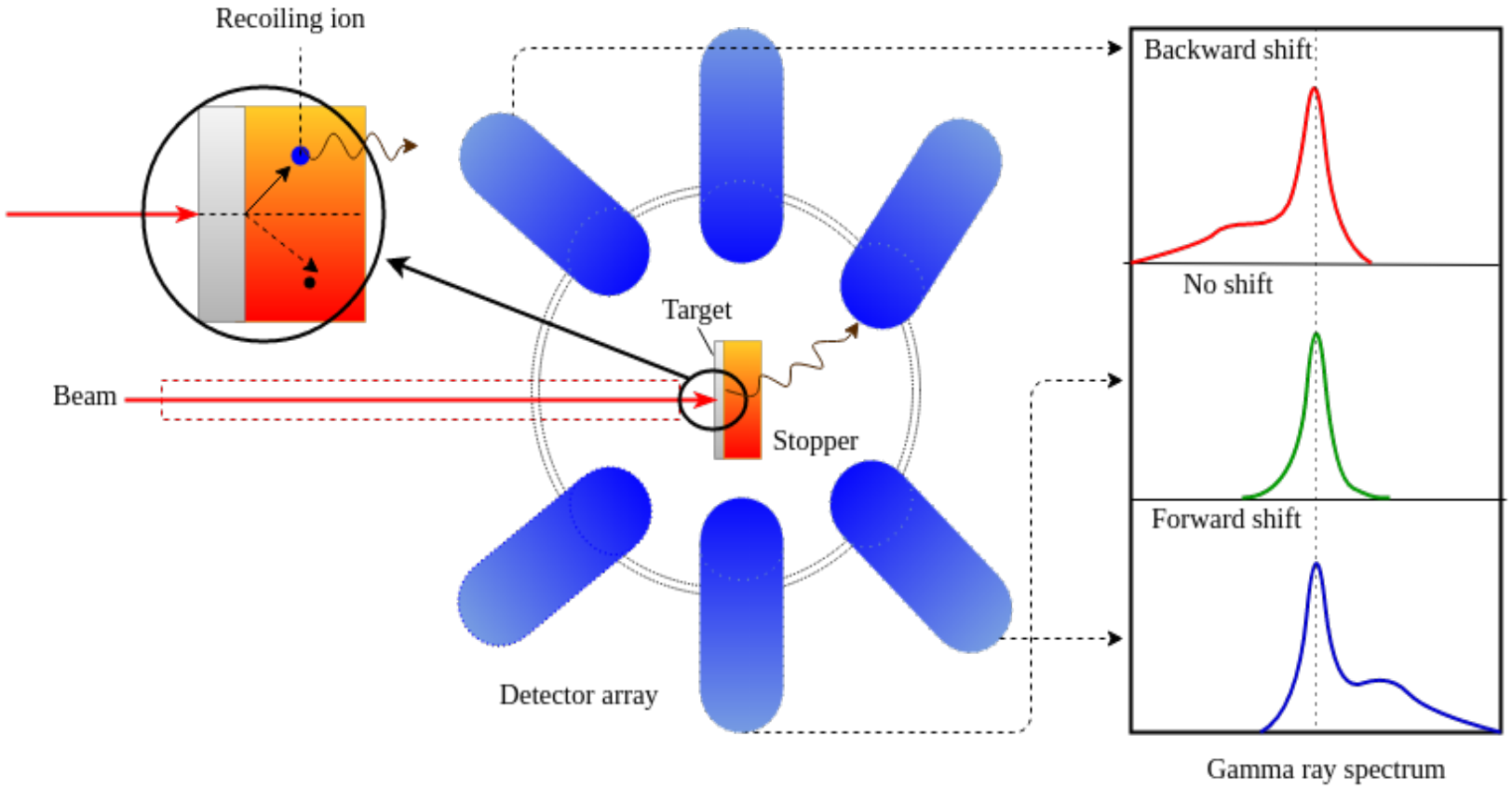
Arabian Sea

Indian National Gamma Array (INGA)
(Clover detector setup)
at Inter University Accelerator Center (IUAC), New Delhi, India



Short lifetimes: lineshape analysis *via* DSAM

$$E_\gamma(\theta) = E_\gamma^0(1+\beta\cos\theta)$$ For small value of β



- The stopping power from Lindhard and Northcliff table.

- The time dependent velocity profile convoluted with the detector response and its orientation *via* Monte-Carlo simulations.

- The lineshape profile fitted by the "Lineshape program*" with a chi-square minimization subroutine **"Simplex".**

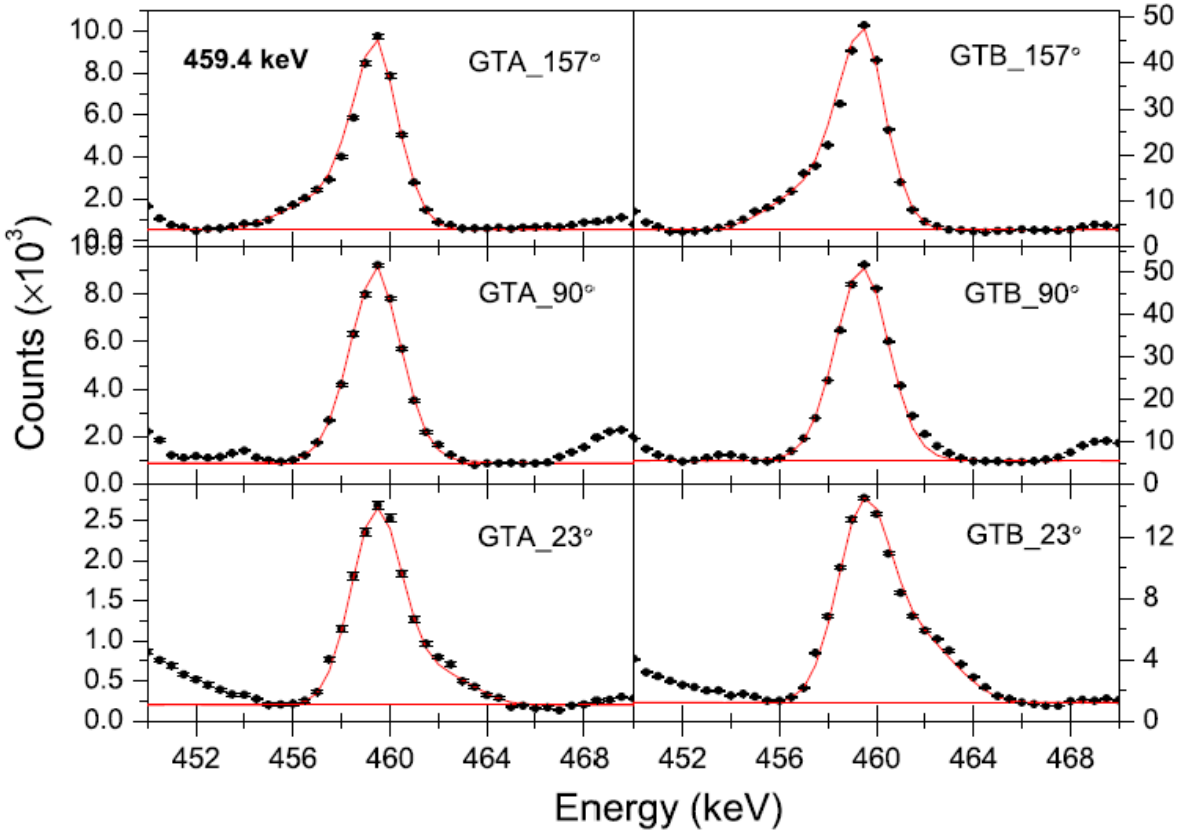
- Parabolic error analysis done by Minos subroutine.

J. C. wells and N. R. Johnson, ORNL Report, 6689, 44 (1991).

Derived experimental values
Evaluated deformation parameters

^{124}Sn (^{11}B, 6n) ^{129}Cs at E_{beam} = 70 MeV (Experiment at TIFR)

U. Lamani, P. Das et al. Nucl. Phys. A 1014 (2021) 122220



$$\tau = \frac{16\pi f_y\left(E2: I, I-2\right)}{61.2 E_\gamma^5 Q_t^2 CB_{IK}^2}$$

$$Q_t = \frac{3}{\sqrt{5\pi}} Z\left(r_0 A^{1/3}\right)^2 \beta \frac{\cos\left(\gamma + 30^0\right)}{\cos\left(30^0\right)}$$

$$CB_{IK}^2 = \frac{3}{8}\left(\frac{I(I-1)}{I^2-0.25}\frac{I^2-K^2}{I^2}\frac{(I-1)^2-K^2}{(I-1)^2}\right)$$

$$B(E2) = \frac{0.0816 f_\gamma(E2)}{E_\gamma^5(E2)[1+\alpha_t(E2)]\tau}[(eb)^2]$$

$$\frac{B(M1; I, I-1)}{B(E2; I, I-2)} = \frac{0.697}{\lambda}\frac{E_\gamma^5(I, I-2)}{E_\gamma^3(I, I-1)}\frac{1}{1+\delta^2}\left(\frac{\mu_N^2}{e^2b^2}\right)$$

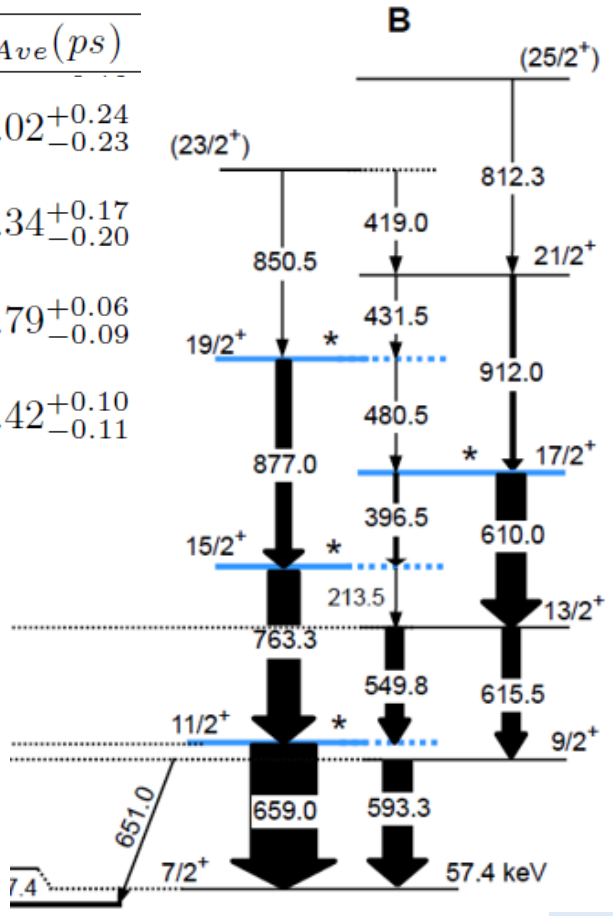
List mode data analysis: **GTA** (gating above), **GTB** (gating below)

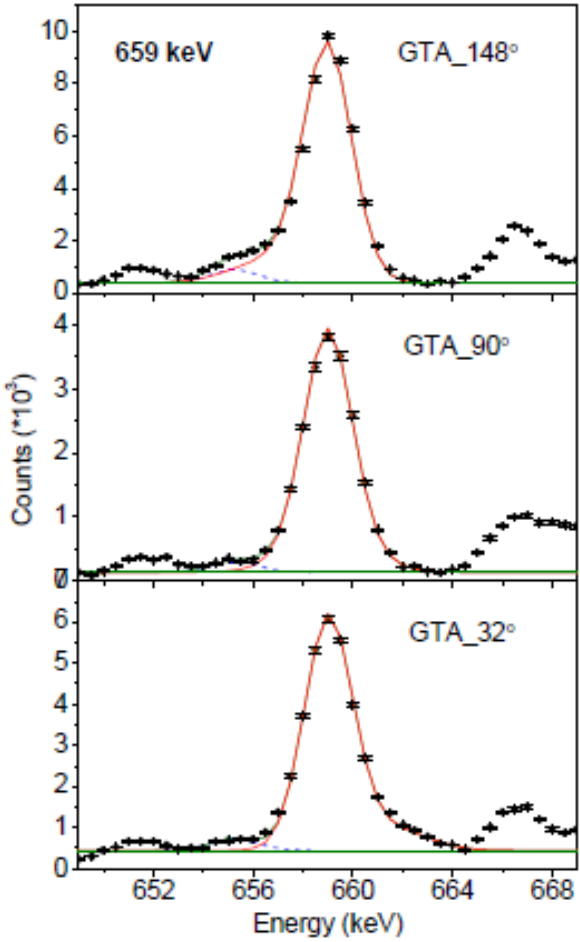
^{127}I

^{124}Sn(^{7}Li, 4n)^{127}I at E_{beam} = 50 MeV (Experiment at IUAC)

Positive-parity

E_x (keV)	$(I_i^\pi) \rightarrow (I_f^\pi)$	E_γ (keV)	$\tau_{GTA}(ps)$	$\tau_{GTB}(ps)$	$\tau_{Ave}(ps)$
2356.7	$19/2^+ \rightarrow 15/2^+$	877.0		$1.02^{+0.24}_{-0.23}$	$1.02^{+0.24}_{-0.23}$
1876.2	$17/2^+ \rightarrow 13/2^+$	610.0		$1.34^{+0.17}_{-0.20}$	$1.34^{+0.17}_{-0.20}$
1479.7	$15/2^+ \rightarrow 11/2^+$	763.3	$0.86^{+0.05}_{-0.07}$	$0.72^{+0.03}_{-0.06}$	$0.79^{+0.06}_{-0.09}$
716.4	$11/2^+ \rightarrow 7/2^+$	659.0	$1.42^{+0.10}_{-0.11}$		$1.42^{+0.10}_{-0.11}$

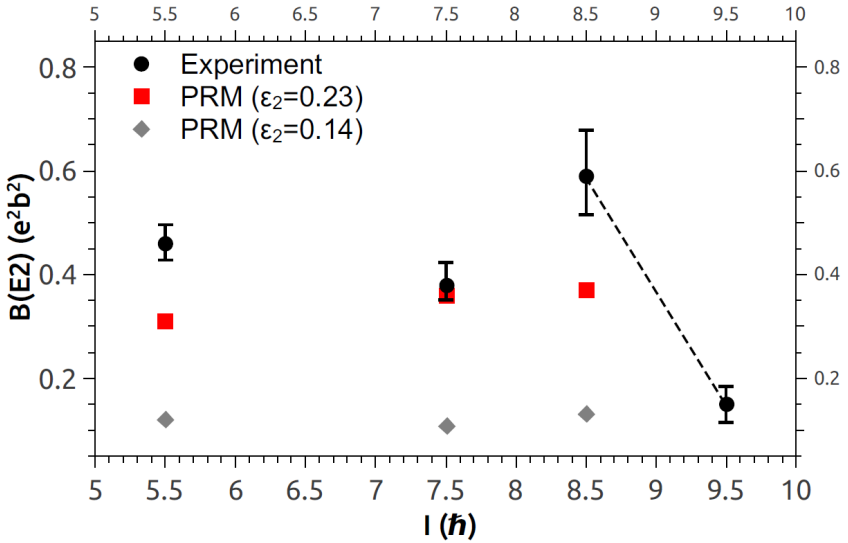




^{127}I

Positive-parity band

Deformation (β, γ) estimated from TRS calculation: Triaxial shape

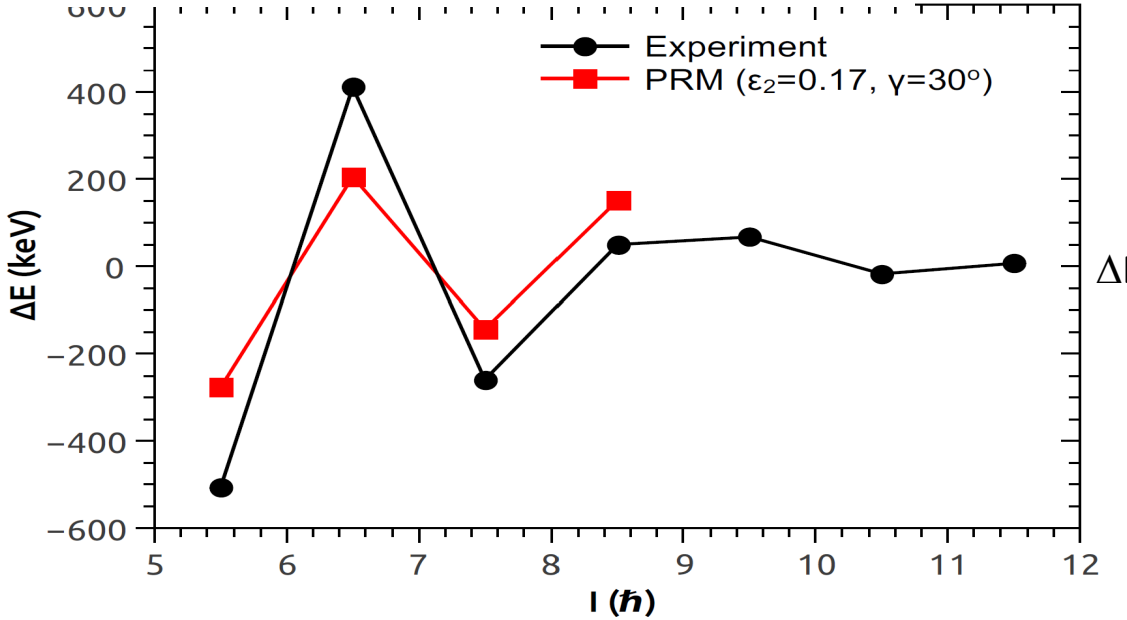


PRM results

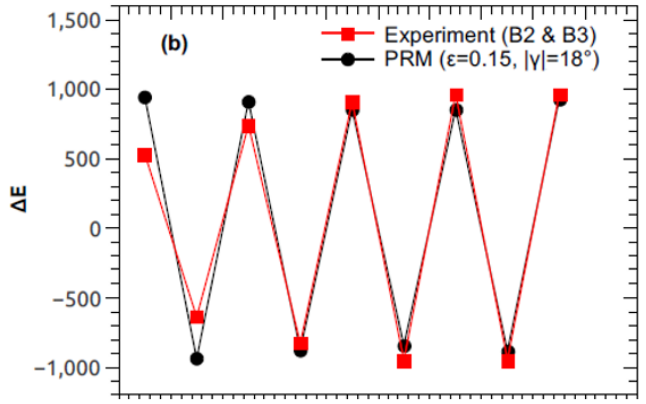
Predominantly $\pi g_{7/2}$ orbital

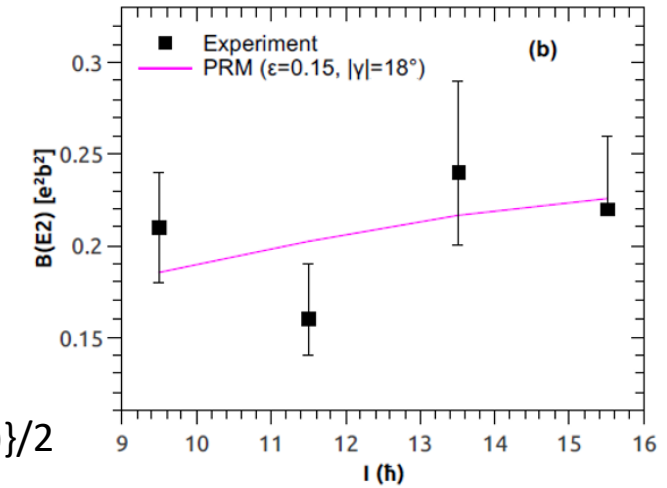
- Signature inversion
- Decrease in B(E2) values

at spin $19/2^+$



$\Delta E \equiv [E(I) - E(I-1)] - \{E(I+1)-E(I)+E(I-1)-E(I-2)\}/2$





^{129}Cs (for comparison)

Positive-parity

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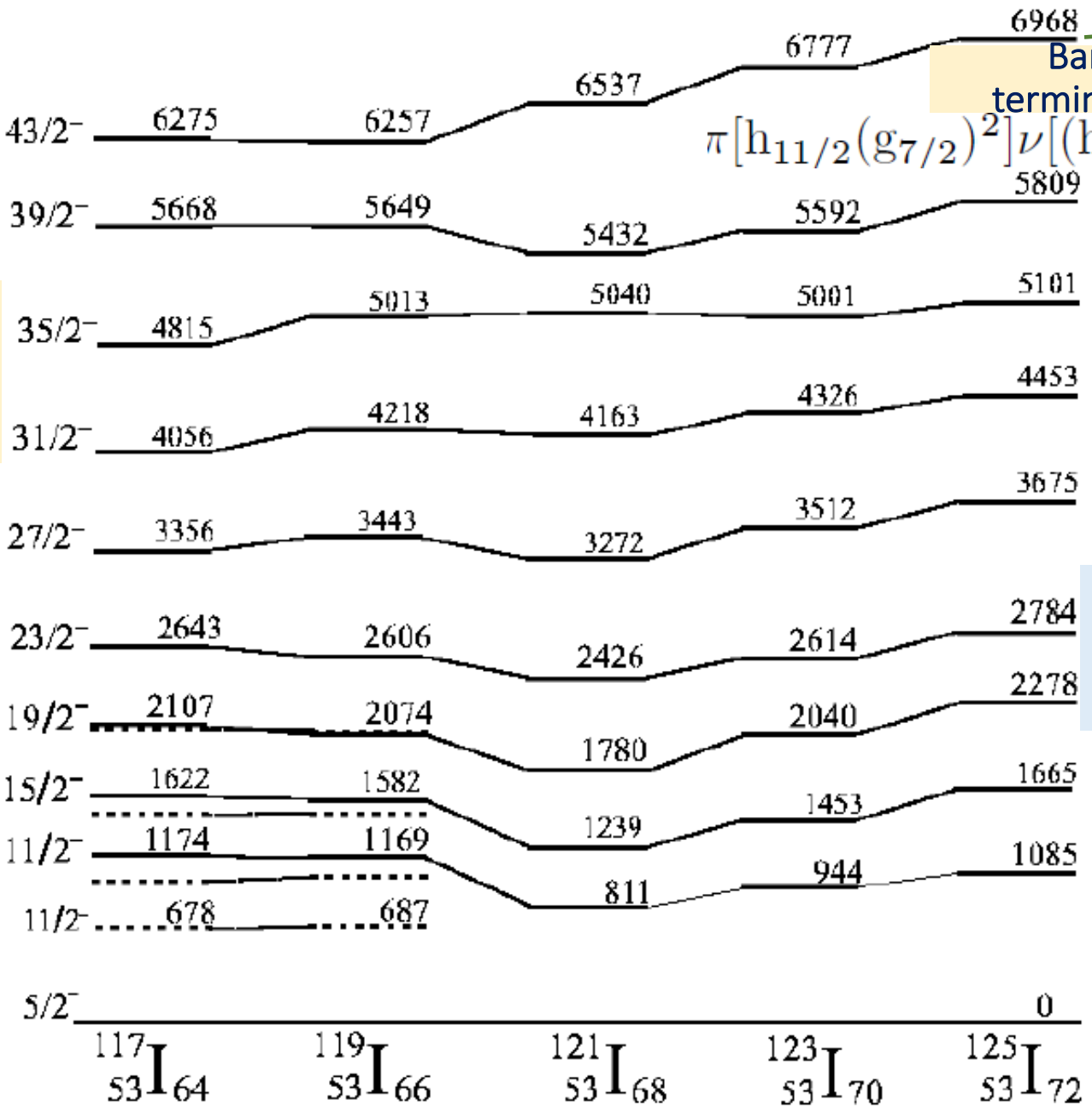
Negative-parity band systematics

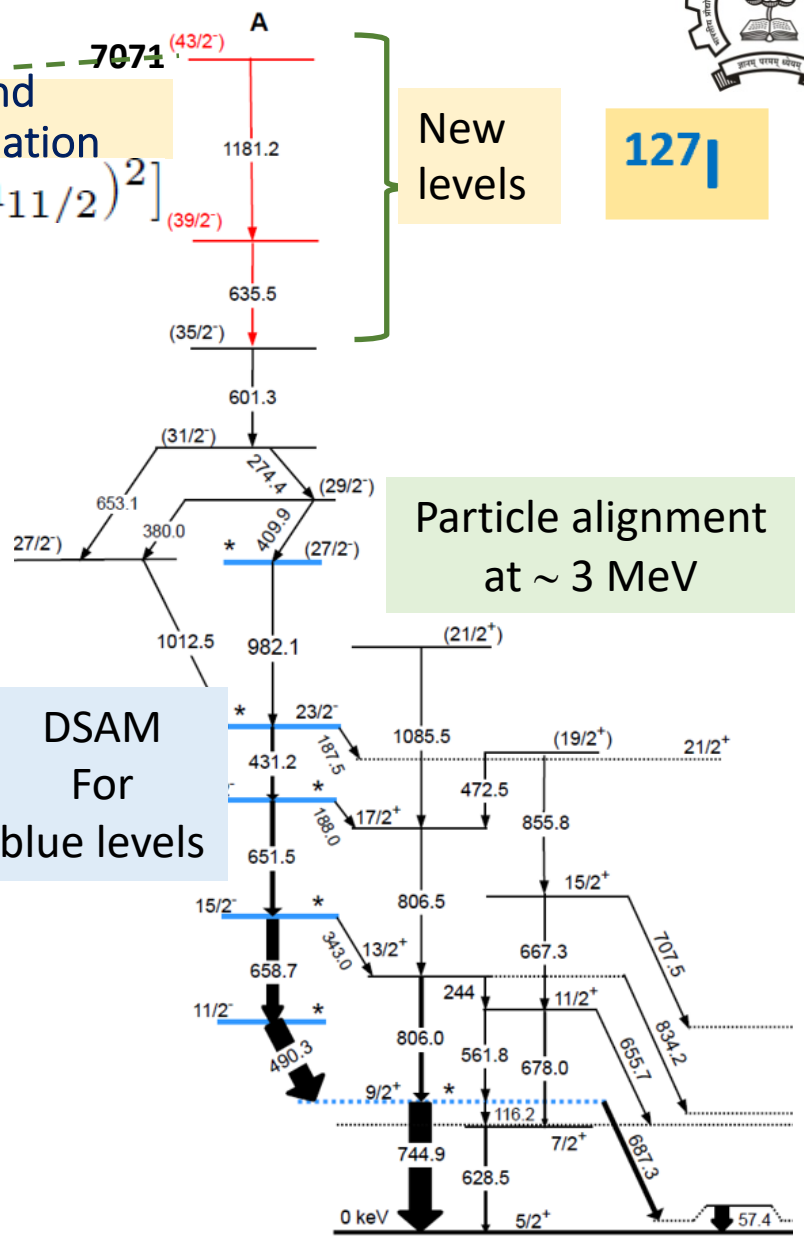
J. Korean Phys. Soc. Vol. 45, 2004, 859.



Our results

Band termination

$\pi[h_{11/2}(g_{7/2})^2]\nu[(h_{11/2})^2]$



New levels

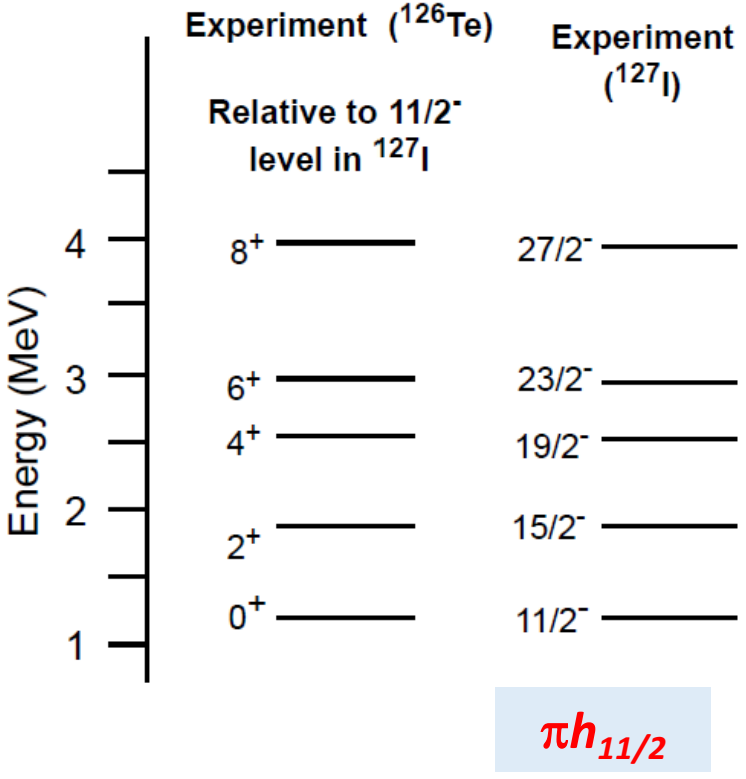
Particle alignment at ~ 3 MeV

DSAM For blue levels

^{127}I

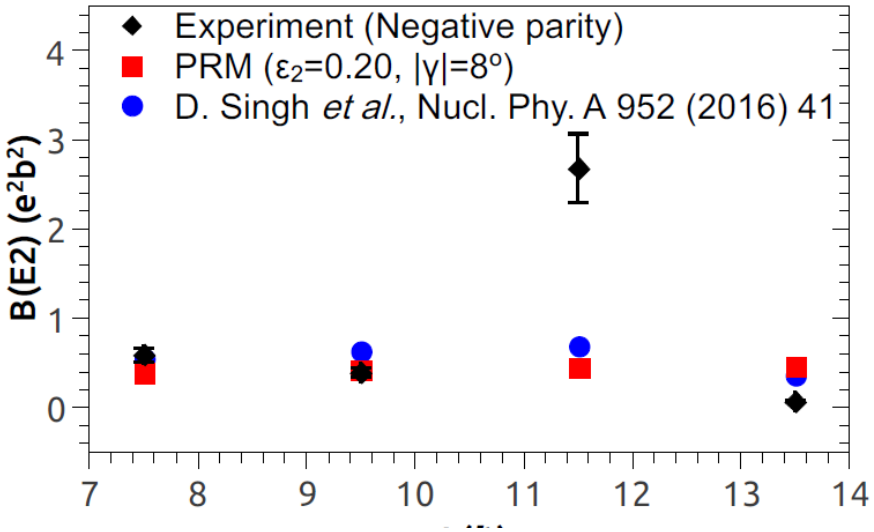
^{127}I

Negative-parity band



$\pi h_{11/2}$

Decoupling

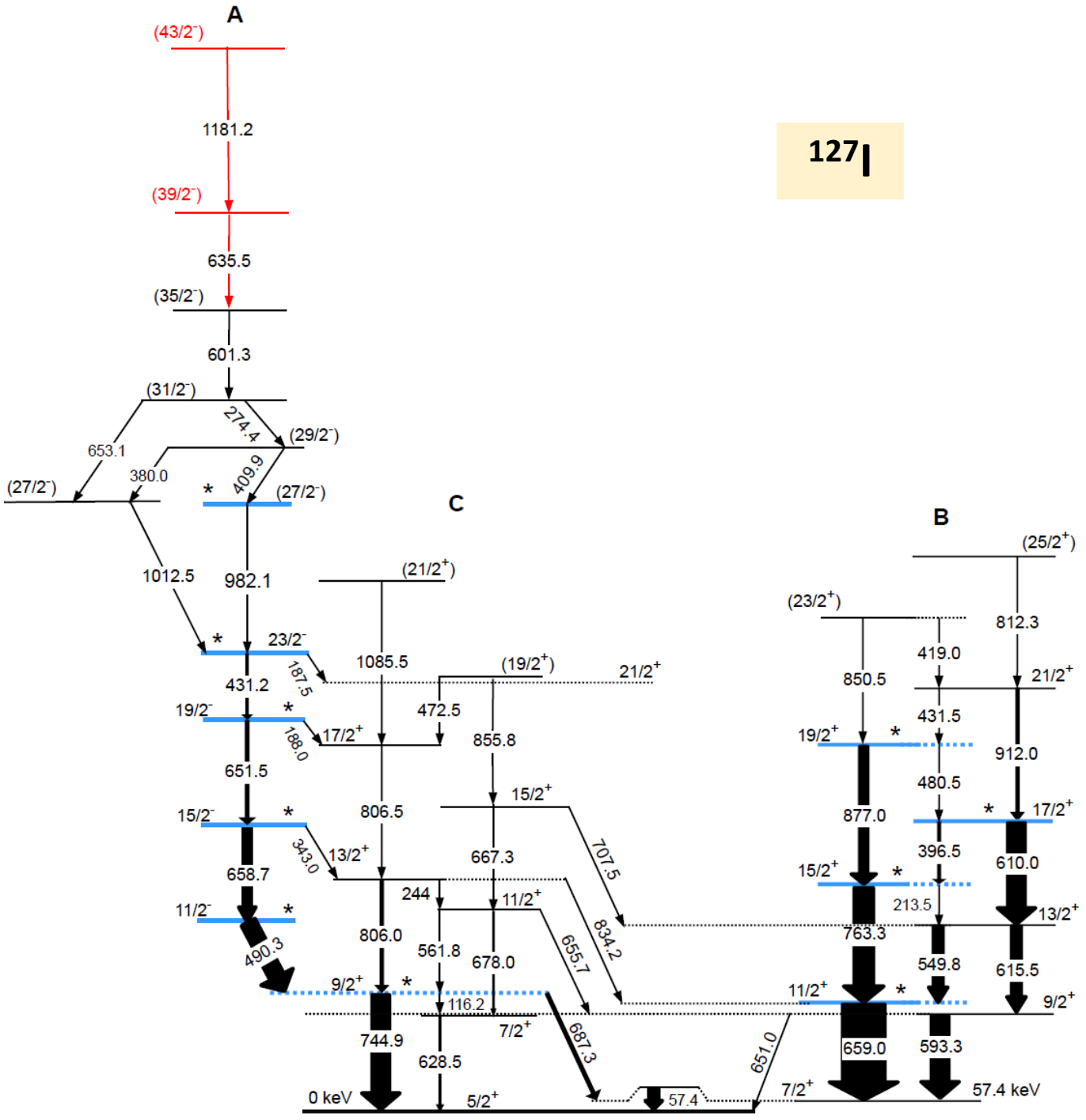


Alignment at $23/2^-$

$$\left[\pi h_{\frac{11}{2}}\left(\pi g_{\frac{7}{2}}\right)^2\right]_{23/2^-}$$

Above $23/2^-$
slope change for B(E2)

E_x (keV)	$(I_i^\pi) \rightarrow (I_f^\pi)$	E_γ (keV)	$\tau_{GTA}(ps)$	$\tau_{GTB}(ps)$	$\tau_{Ave}(ps)$	$B(E2)(\mathrm{e^2b^2})$
3958.7	$27/2^- \rightarrow 23/2^-$	982.1		$1.32^{+0.12}_{-0.13}$	$1.32^{+0.12}_{-0.13}$	$0.07^{+0.006}_{-0.007}$
2976.6	$23/2^- \rightarrow 19/2^-$	431.2	$2.02^{+0.22}_{-0.23}$	$1.97^{+0.19}_{-0.18}$	$2.00^{+0.29}_{-0.29}$	$2.68^{+0.387}_{-0.387}$ A
2545.4	$19/2^- \rightarrow 15/2^-$	651.5	$1.66^{+0.14}_{-0.12}$	$1.80^{+0.17}_{-0.16}$	$1.73^{+0.22}_{-0.20}$	$0.39^{+0.050}_{-0.045}$
1893.9	$15/2^- \rightarrow 11/2^-$	658.7	$0.88^{+0.07}_{-0.07}$	$1.14^{+0.10}_{-0.12}$	$1.01^{+0.12}_{-0.14}$	$0.59^{+0.070}_{-0.082}$
1235.2	$11/2^- \rightarrow 9/2^+$	490.3	$1.10^{+0.08}_{-0.09}$	$0.71^{+0.08}_{-0.07}$	$0.91^{+0.11}_{-0.11}$	


A
(43/2⁻)
1181.2
(39/2⁻)
635.5
(35/2⁻)
601.3
(31/2⁻)
274.4
(29/2⁻)
653.1
380.0
409.9
(27/2⁻)
(27/2⁻)
C
1012.5
982.1
(21/2⁺)
23/2⁻
1085.5
(19/2⁺)
21/2⁺
187.5
431.2
472.5
855.8
19/2⁻
188.0
17/2⁺
651.5
15/2⁺
15/2⁻
806.5
343.0
13/2⁺
667.3
707.5
658.7
244
11/2⁺
11/2⁻
806.0
561.8
678.0
655.7
834.2
490.3
9/2⁺
116.2
7/2⁺
744.9
687.3
628.5
651.0
0 keV
5/2⁺
57.4
B
(25/2⁺)
(23/2⁺)
812.3
419.0
850.5
21/2⁺
431.5
19/2⁺
912.0
480.5
877.0
17/2⁺
396.5
610.0
15/2⁺
213.5
763.3
13/2⁺
549.8
615.5
11/2⁺
9/2⁺
659.0
593.3
7/2⁺
57.4 keV

127I

Summary

- DSAM technique utilized for measuring lifetimes in ps range in ^{127}**I**,
  (earlier in ^{129}**Cs** [NPA 1014 (2021) 122220]).
- Experiments performed at IUAC (New Delhi, India) and TIFR (Mumbai, India).
- INGA set-up consisting of 16 - 20 HPGe clover detectors used.
- Different shapes inferred from the B(E2) values:

  Positive parity ($\pi g_{7/2}$): Triaxial shape

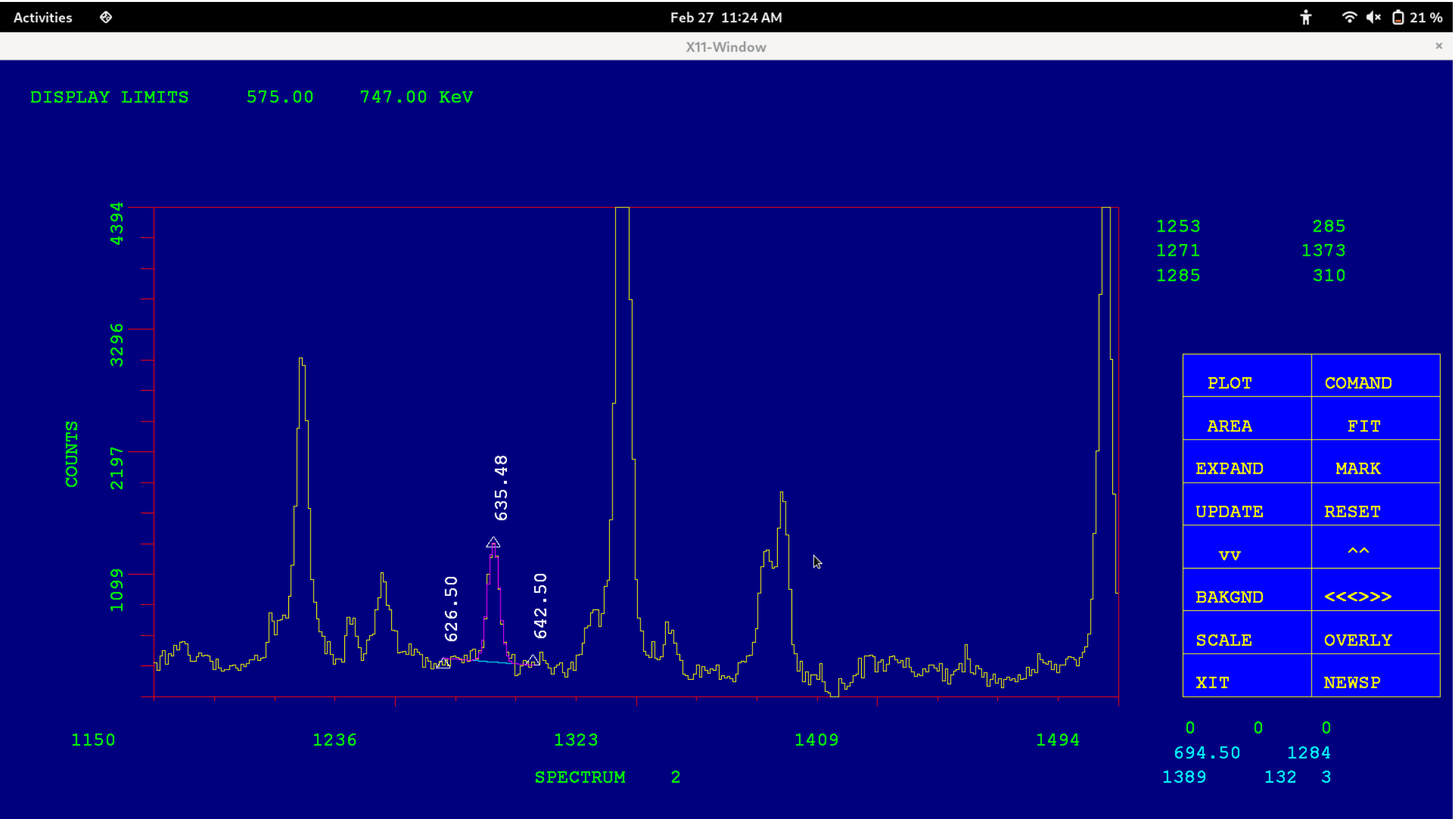
  Negative parity ($\pi h_{11/2}$): Nearly prolate at low spin,

  Features of band termination at high spins.

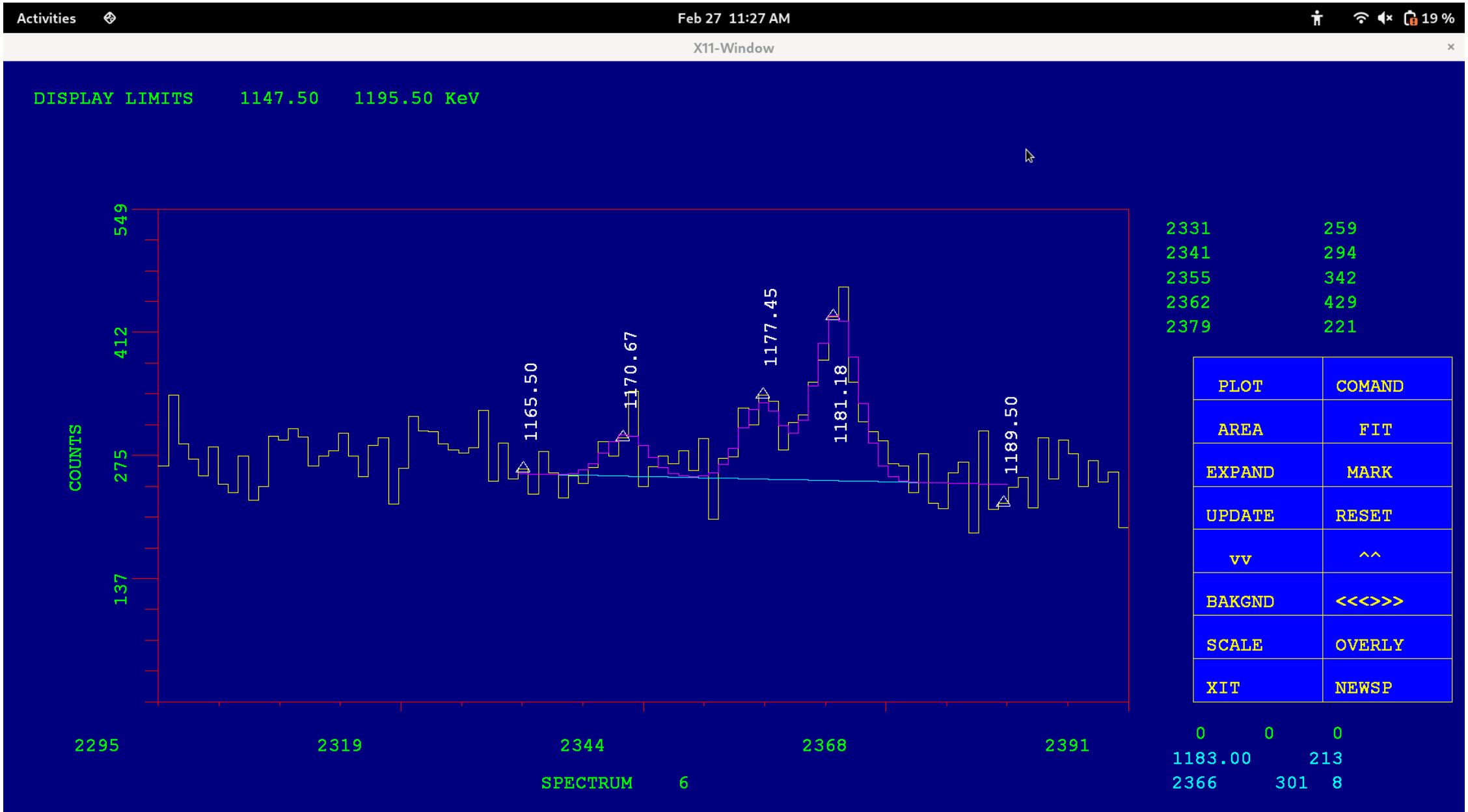
Acknowledgements:

- R. Palit (TIFR), R. P. Singh and S. Muralithar (IUAC) for experimental facility,
- I. Ragnarsson for providing PRM code.

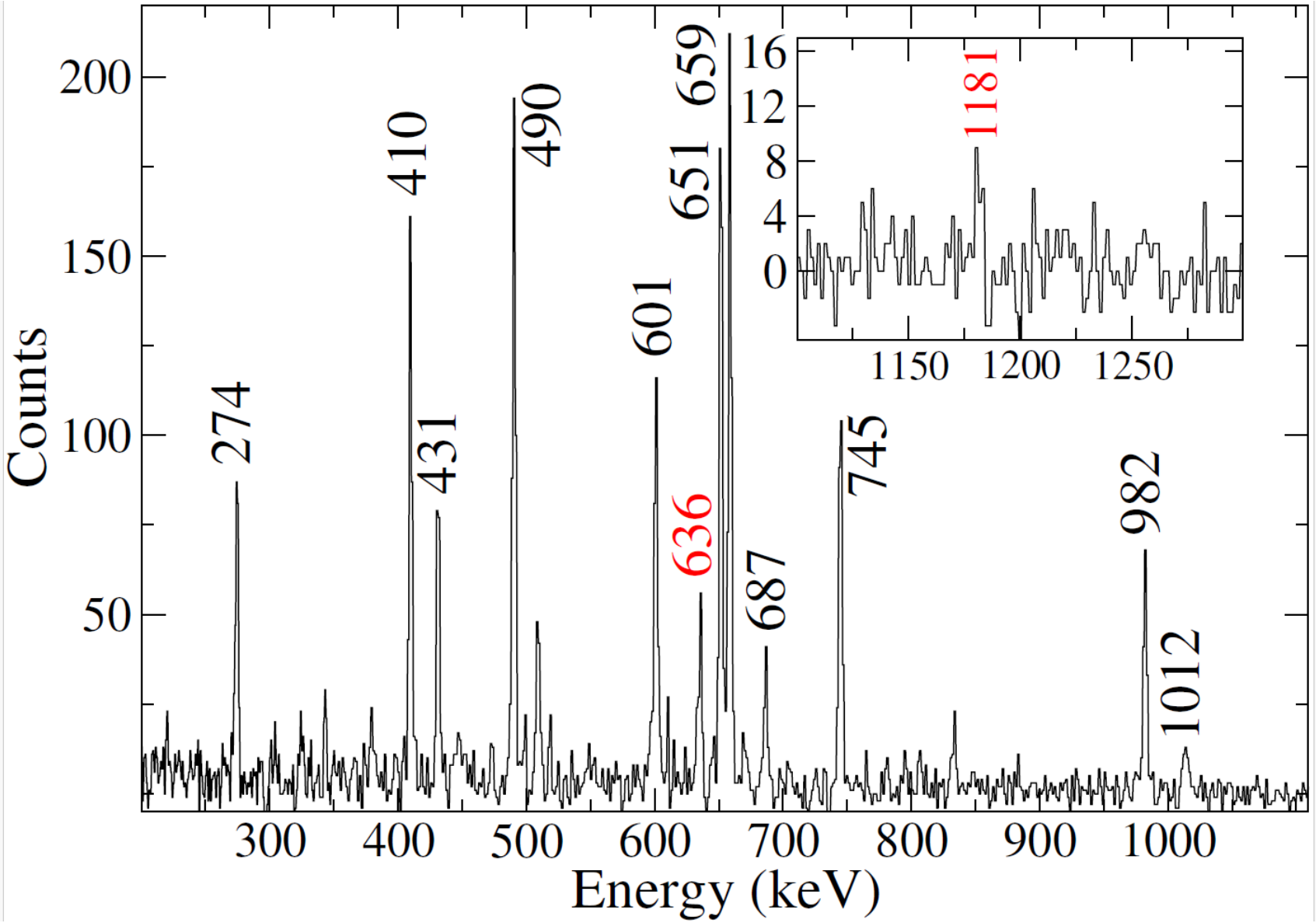
Gate on 601 keV



Gate on 601 keV



Tripe gamma coincidence: Gate on 431-982 keV + Gate on 274 -410 keV



Axially symmetric shape $\Rightarrow$ Symmetry in rotation by angle π

$\Rightarrow$ conserved quantum number Signature (α)

For nuclear state of spin I

$I = \alpha \bmod 2$

Even-even or odd-odd nuclei

$\alpha = 0$ for I = 0, 2, 4, 6.....

$\alpha = 1$ for I = 1, 3, 5, 7.....

Even-odd or odd-even nuclei

$\alpha = +1/2$ for I = 1/2, 5/2, 9/2,.....

$\alpha = -1/2$ for I = 3/2, 7/2, 11/2,.....

Odd-odd nuclei in mass region 130

Hartley *et al.*, Phys. Rev. C65, 044329 (2002)

$\pi h_{11/2} \otimes \nu h_{11/2}$

Possible cause of signature inversion

↓

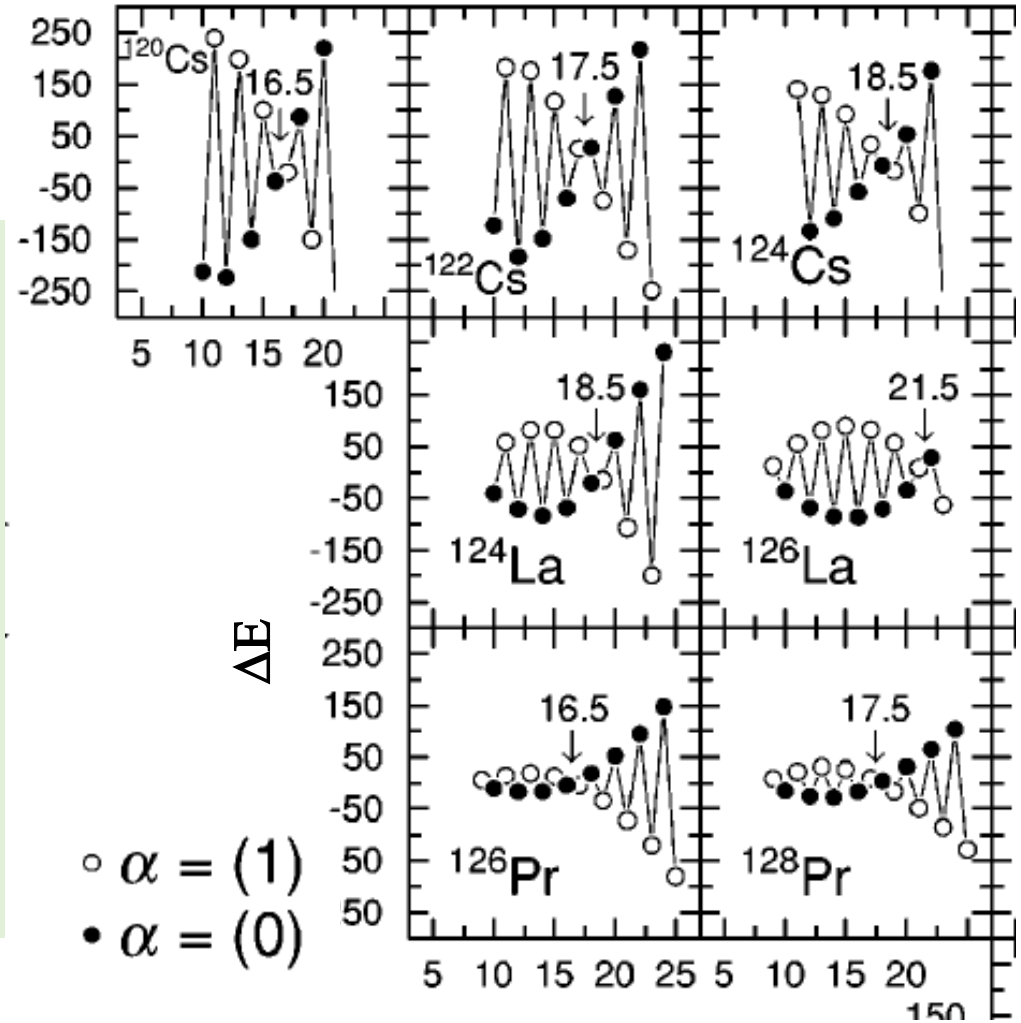
Change in the rotational axis

OR

Change in shape

OR

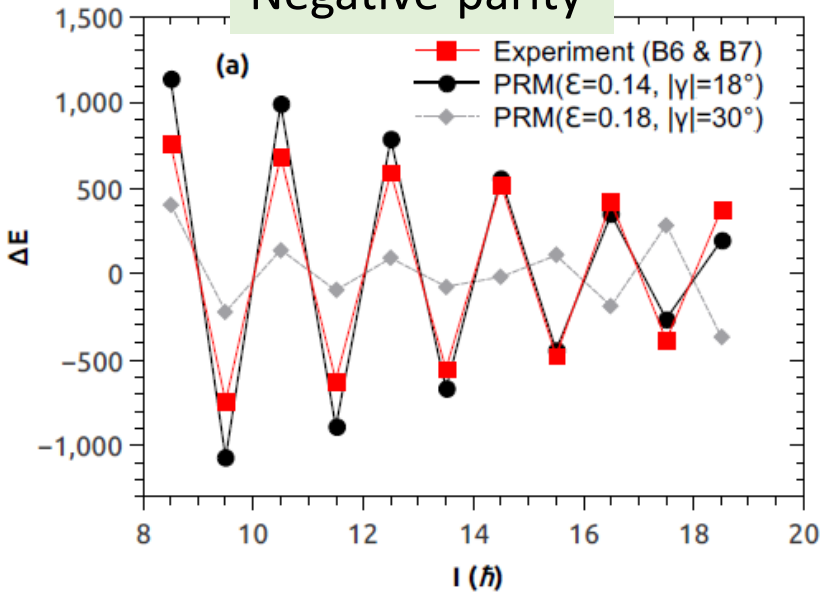
Combination of both



$S(I) \equiv \Delta E \equiv [E(I) - E(I-1)] - \{E(I+1)-E(I)+E(I-1)-E(I-2)\}/2$

Signature splitting but no inversion in ^{129}Cs (N=74)

Negative-parity



Positive-parity