

# Recent Results from the Hybrid Gamma Array at BARC-TIFR Pelletron Linac Facility



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Allahabad University (*Allahabad*)  
Guru Nanak Dev University (*Amritsar*)



2009

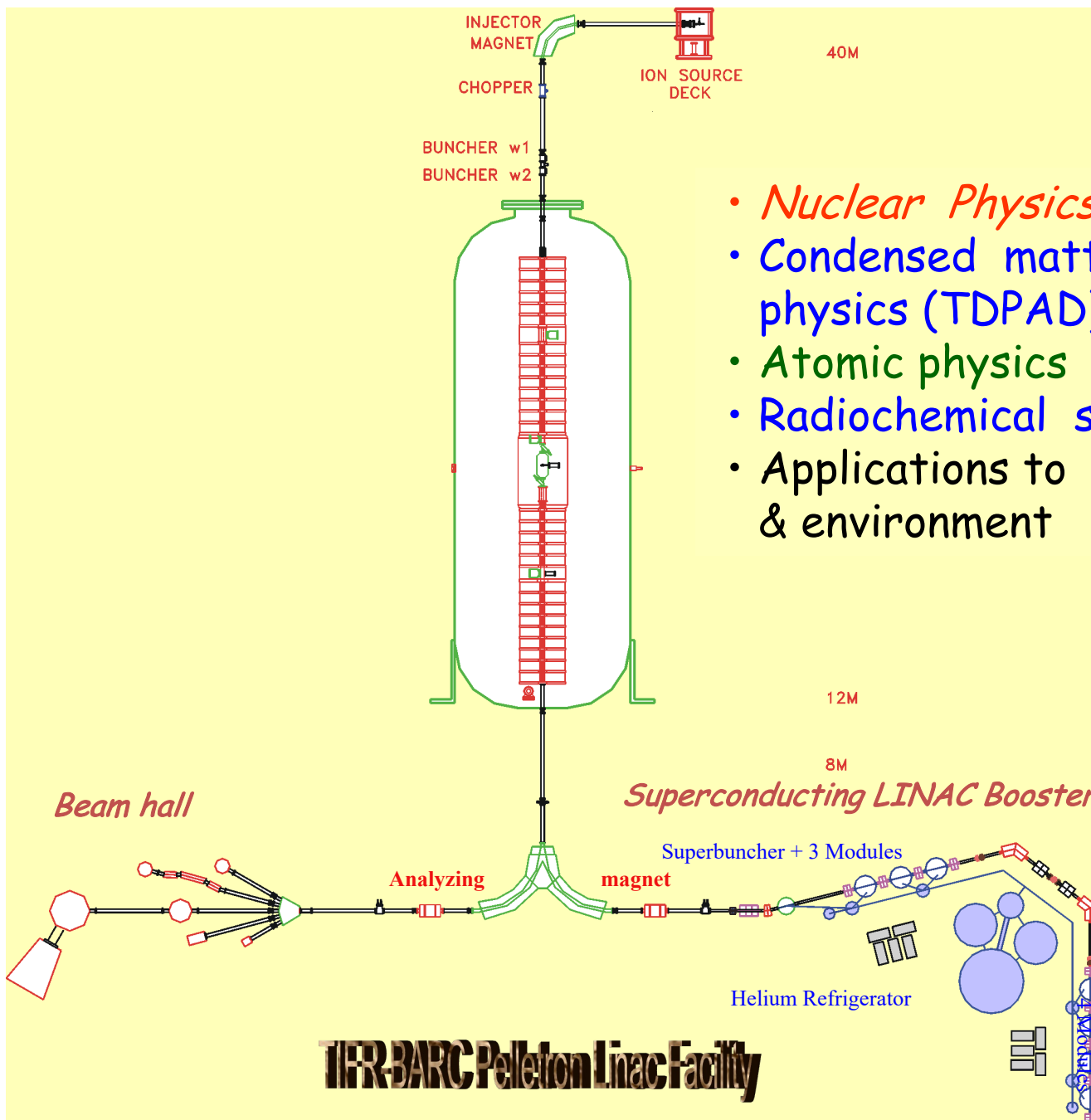
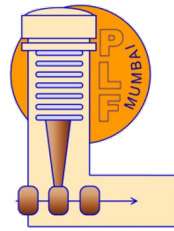
Happy Birth Day Dimiter !!



2018

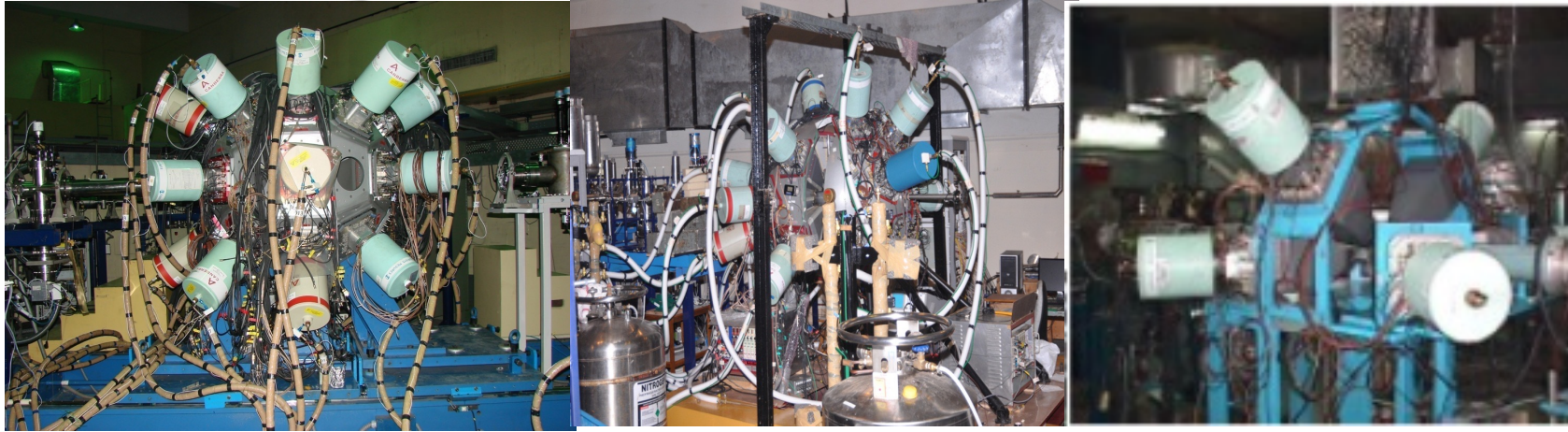


2024



- Nuclear Physics
- Condensed matter physics (TDPAD)
- Atomic physics
- Radiochemical studies
- Applications to medicine & environment

to new beam hall



SD et al., NIMA 893, 138 (2018)

R.P et al., NIMA 680, 90 (2012)

S.M et al., NIMA 622, 281 (2010)



Novelty in target preparation and DSAM for molecular target.

S.D et al. NIM (2016)

## Novelty in Instrumentation @ IUAC

Development of instrumentation:

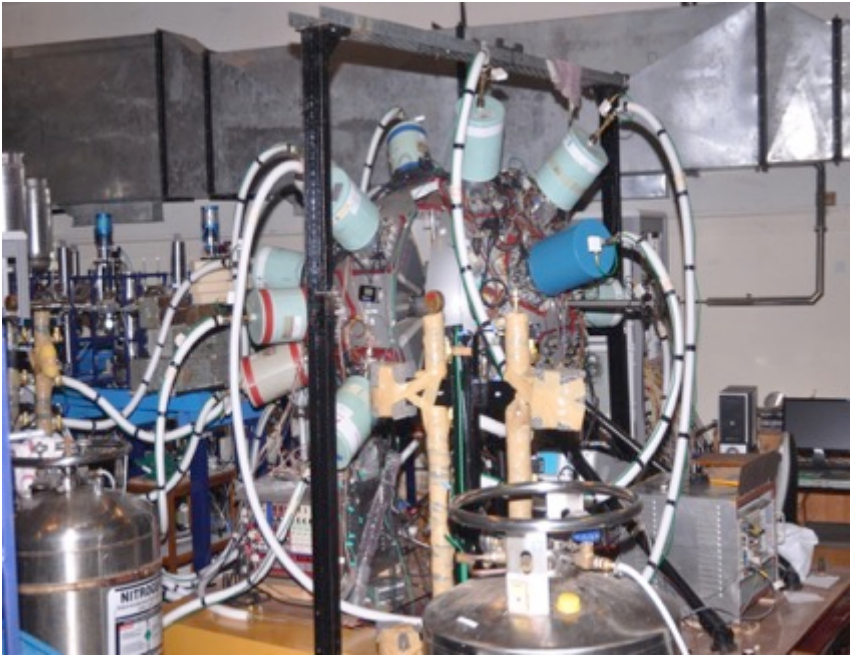
- Energy and timing electronics
- High density ADC
- Power supplies for Clover and ACS
- Multi-crate Data Acquisition system
- Digital g-multiplicity detection with time stamp

DSP-DAQ has increased the data throughput by 10 times for INGA.

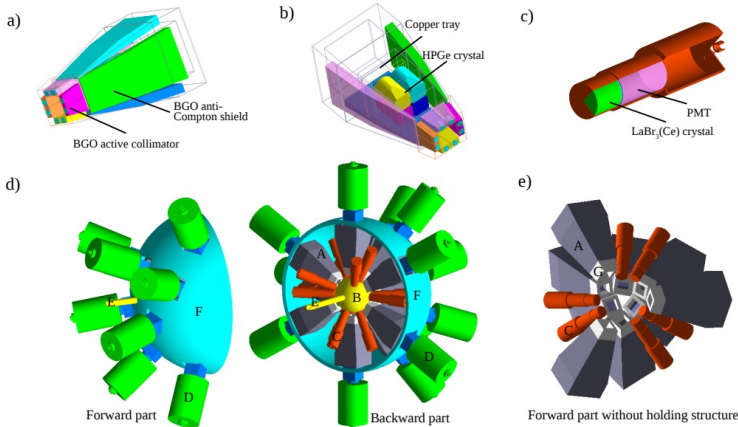
- Gain stability & high count rate
- Innovation in data analysis for prompt delayed spectroscopy for fission fragments.

# Digital INGA at TIFR

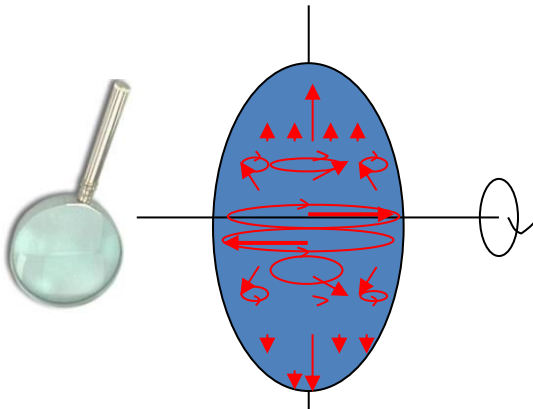
BARC, IUAC, IUC-KC, SINP, TIFR, VECC, IITs, Univ



**DSP Implementation for INGA**  
 ➤ Up to ~200 channels  
 ➤ Provision for Ancillary detectors (CsI(Tl), Si and LaBr<sub>3</sub>(Ce))



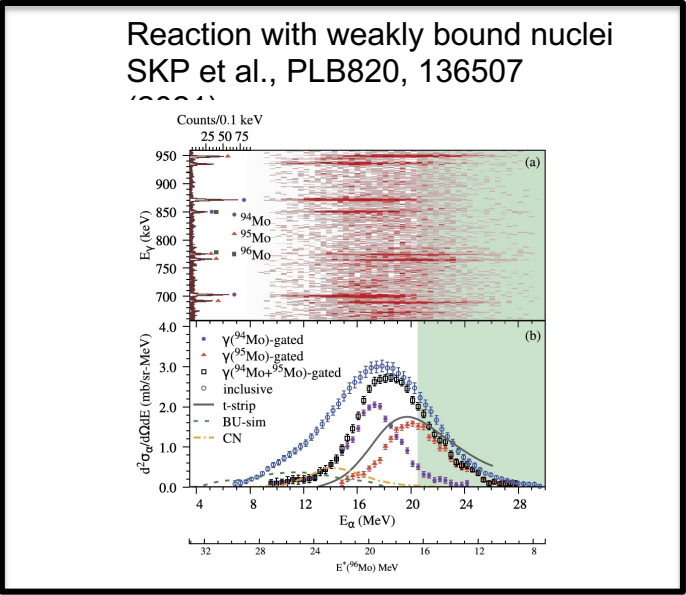
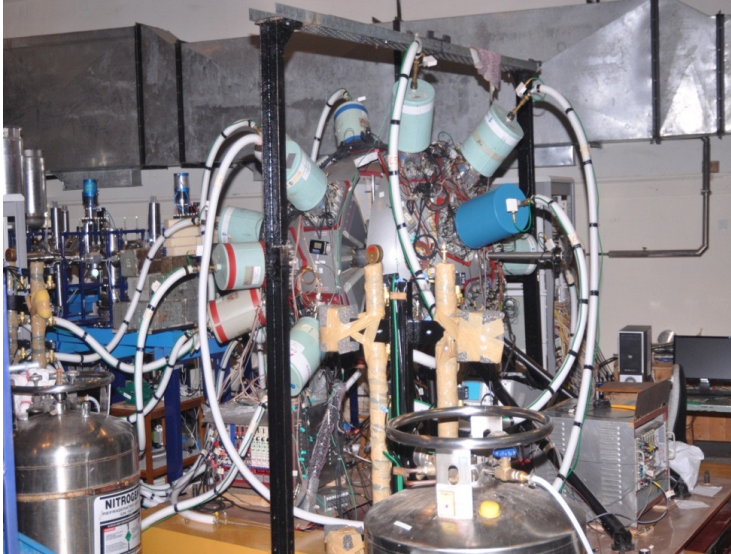
R. Palit, et al. NIMA 680 90 (2012).  
 S. Saha et al., JINST 11, 03030 (2016).  
 B. Das et al., Jl. Of Instrum. Soc. Of India 51, 44 (2021).  
 B. Das et al., NIMA 1048 167928 (2023).  
 B. Das et al, NIMA 1060, 169030 (2024).



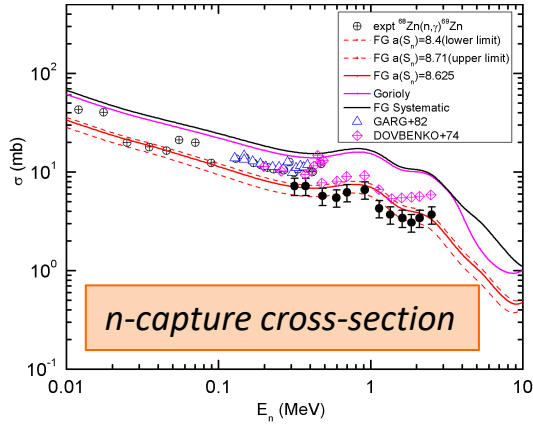
DSP based DAQ has increased the data throughput by 10 times for INGA

# Digital INGA with CPDA

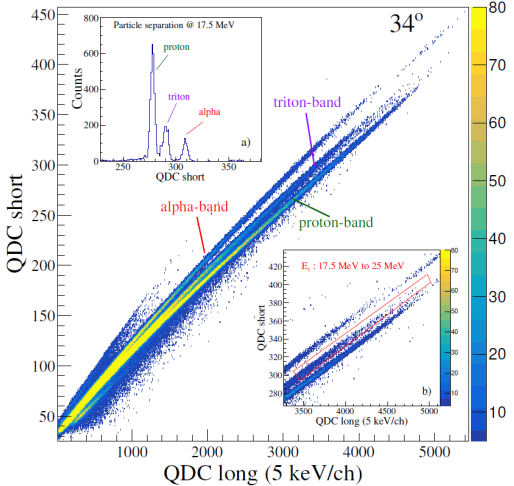
INGA (HPGe Clover det)



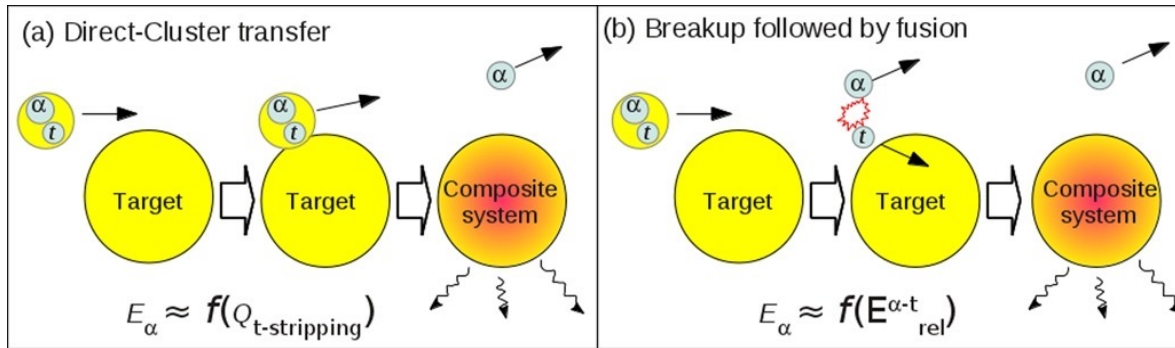
Gamma-gated particle spectrum  
RS et al., PLB 806 (2020) 135487



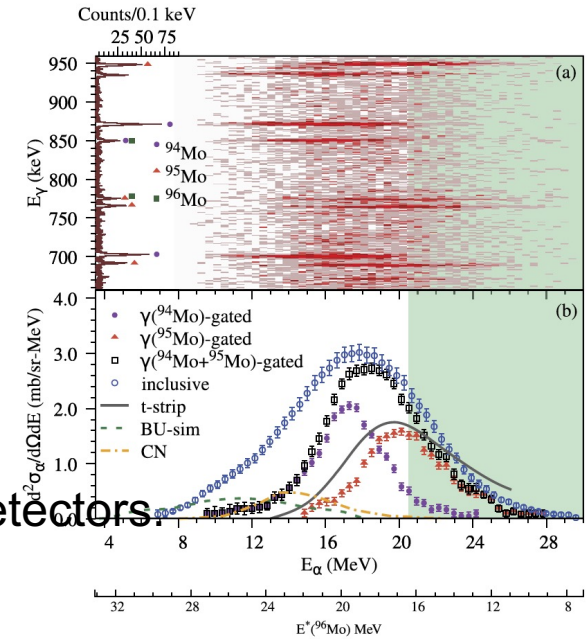
Alpha-cluster structure in <sup>54</sup>Cr  
BD et al., submitted



Origin of large *alpha* particle production in weakly bound nuclei is unknown.



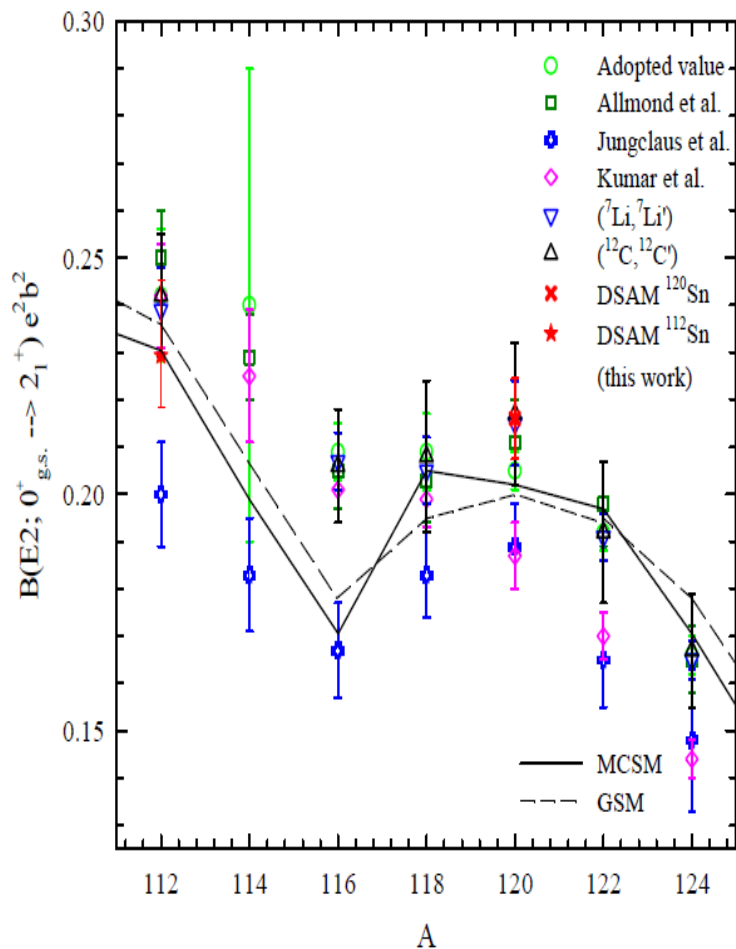
18 Compton suppressed clover HPGe and Si telescope detectors.



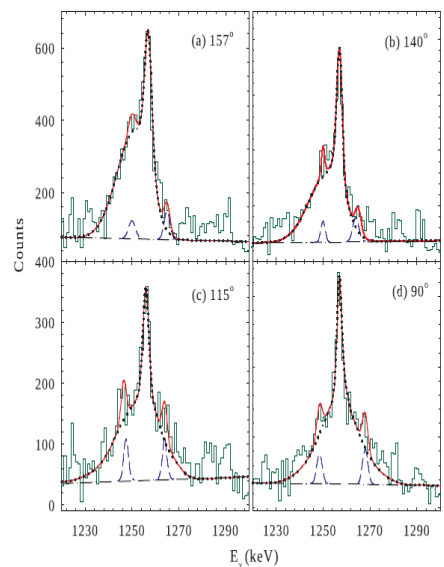
Proper choice of kinematical conditions allowed for the first time a significant population of the region accessible only to the direct triton stripping process.

Reaction with weakly bound nuclei  
SKPandit et al., PLB820, 136507 (2021)

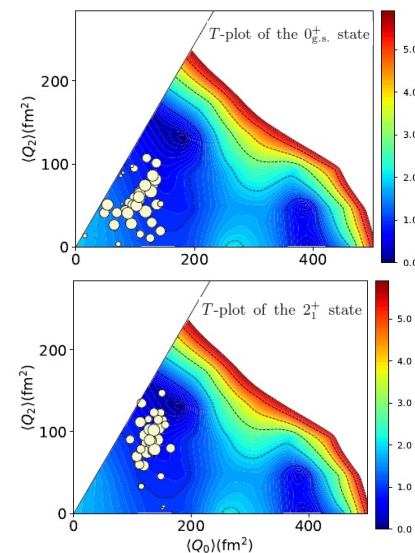




### Lineshape



### T-plots



Novel shape evolution in Sn isotopes

Lifetime for  $2^+$  state (0.57(3) ps) in  $^{112}\text{Sn}$  probes the modest oblate shapes for both the ground state and  $2^+$  state by comparison of measured  $B(E2)$  with Monte Carlo Shell Model results.

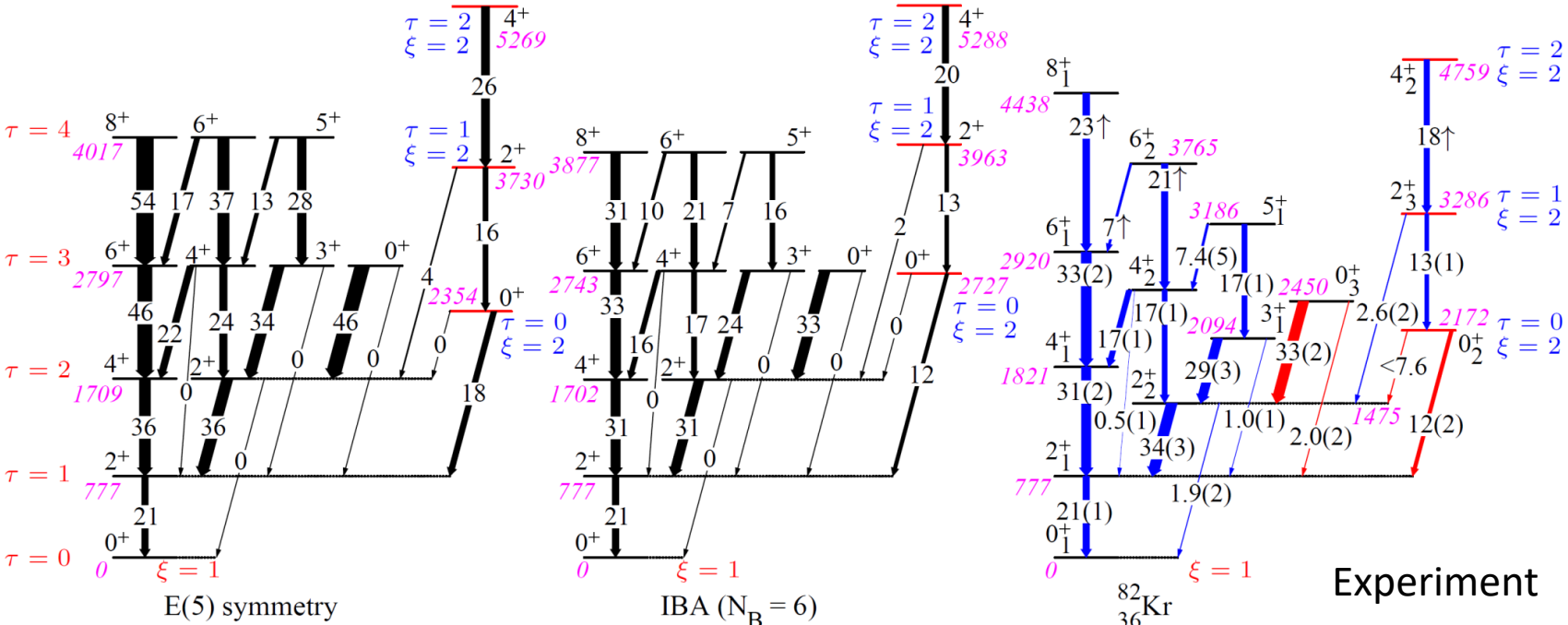
A. Kundu et al., PRC 103, 034315 (2021)

GSM - B. Maheshwari et al., Nucl. Phys. A **952**, 62 (2016).

MCSM - T. Togashi et al., Phys. Rev. Lett. **121**, 062501 (2018).

# E(5) symmetry in $^{82}\text{Kr}$

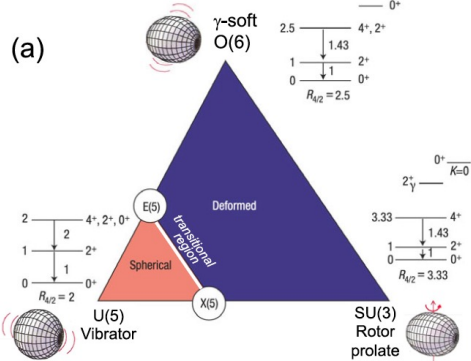
## Comparison of Experimental Transition Probability and Excitation Energy with IBM



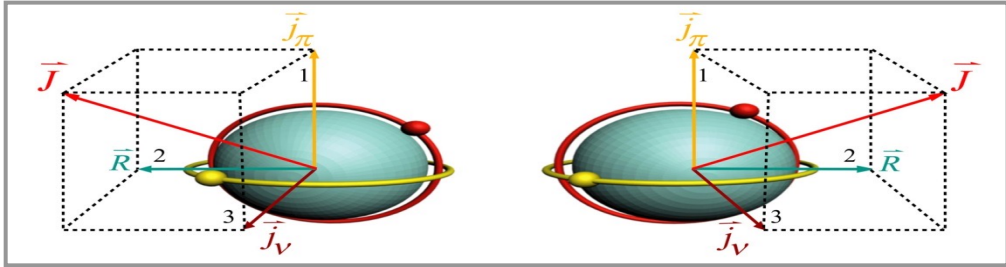
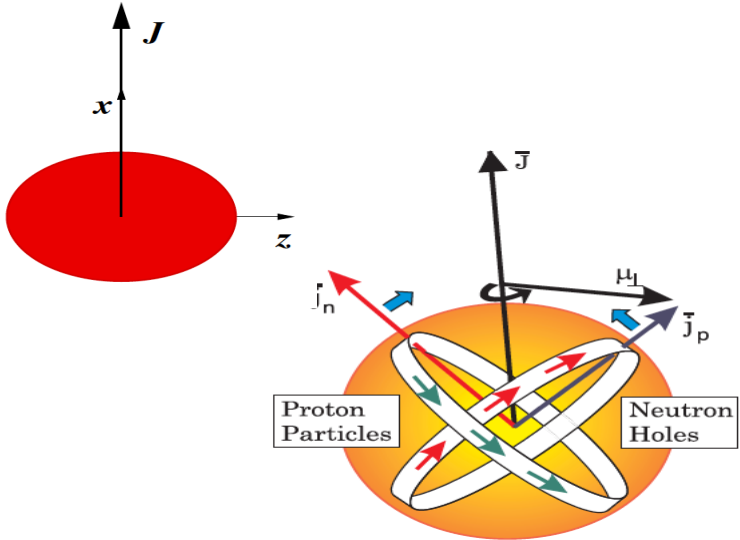
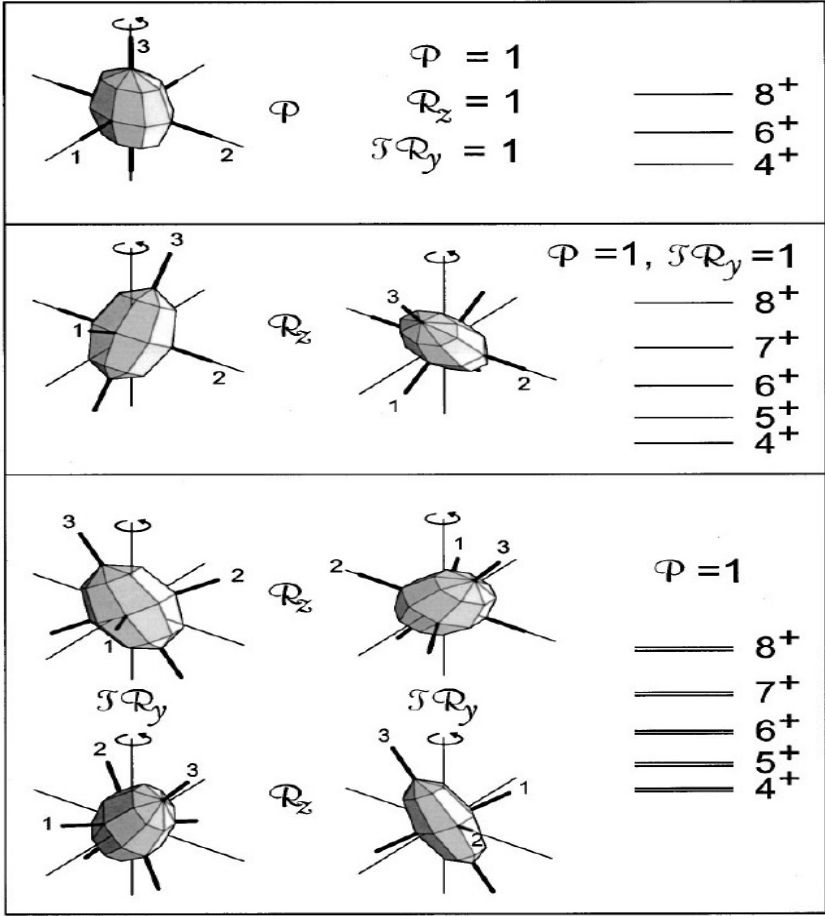
### Availability of $^9\text{Be}$ beam

As, absolute  $B(E2)$  strengths are not measured for 2<sup>nd</sup> and 3<sup>rd</sup>  $0^+$  states; their relative ratio are indicated in figure considering the respective branching and the strongest one to 100.

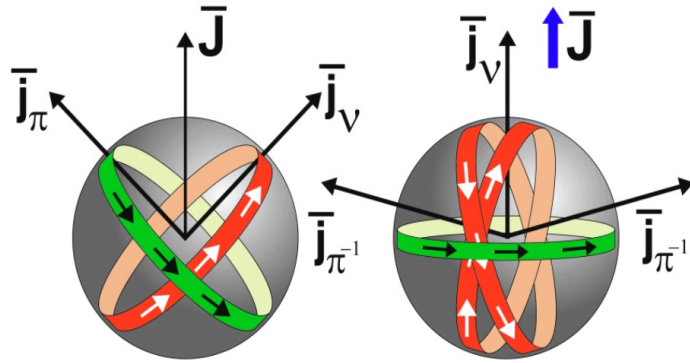
SR et al., PRC Letter 031302 (2021)



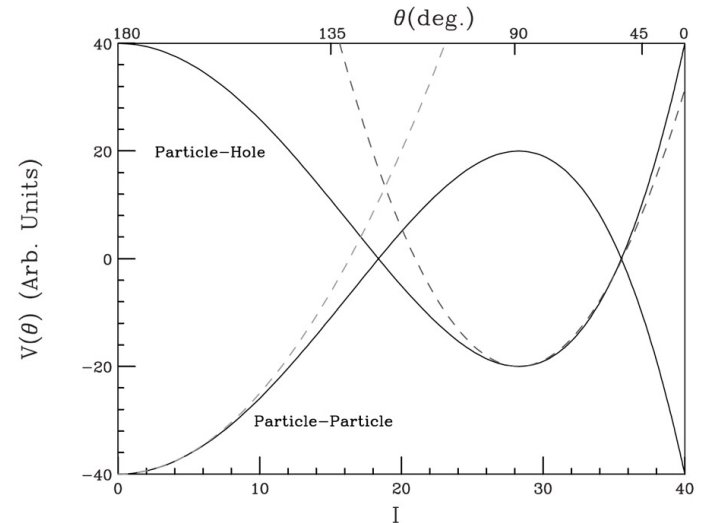
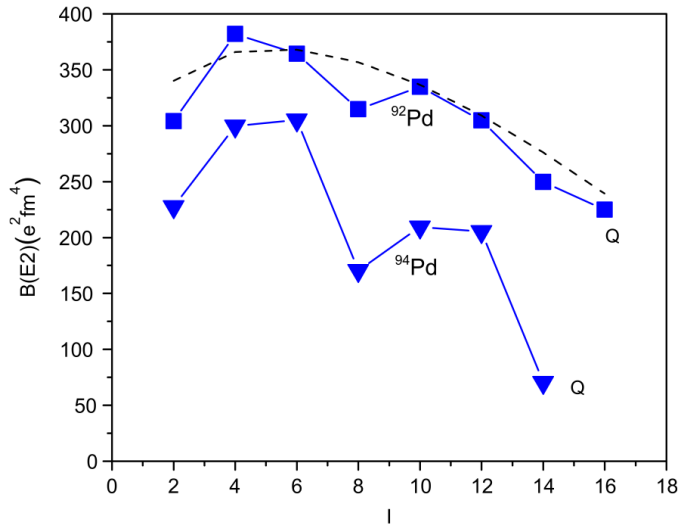
# Nuclear rotations: Electrical, Magnetic and Chiral rotations



# Magnetic and Anti-Magnetic rotations



- AMR due to particles and holes in the same orbitals
- Role of particle-particle interaction for dipole band

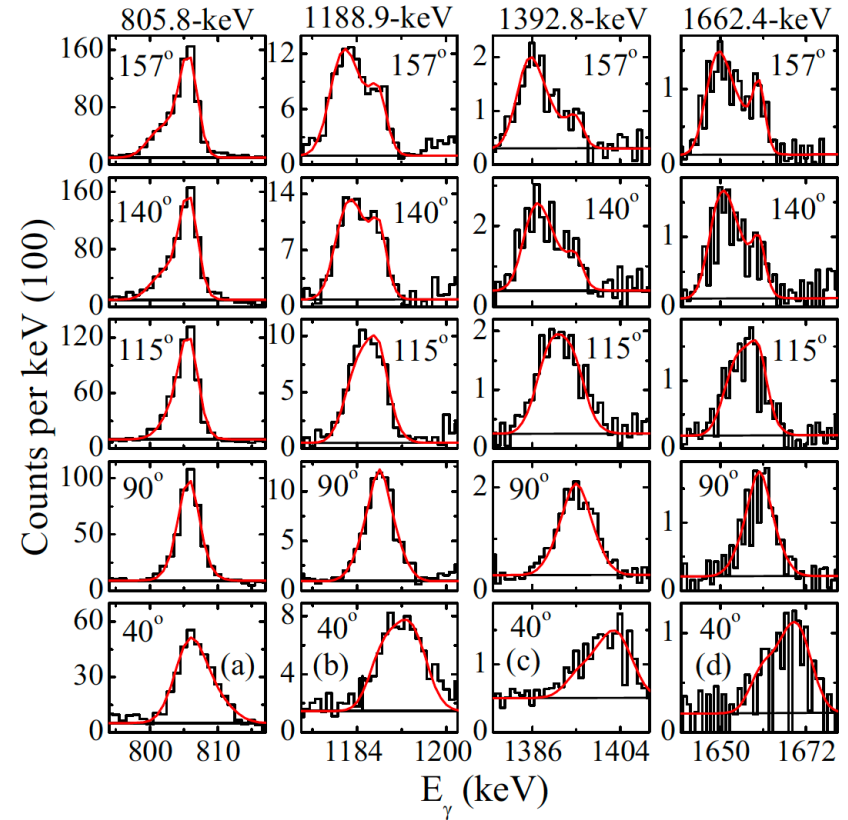
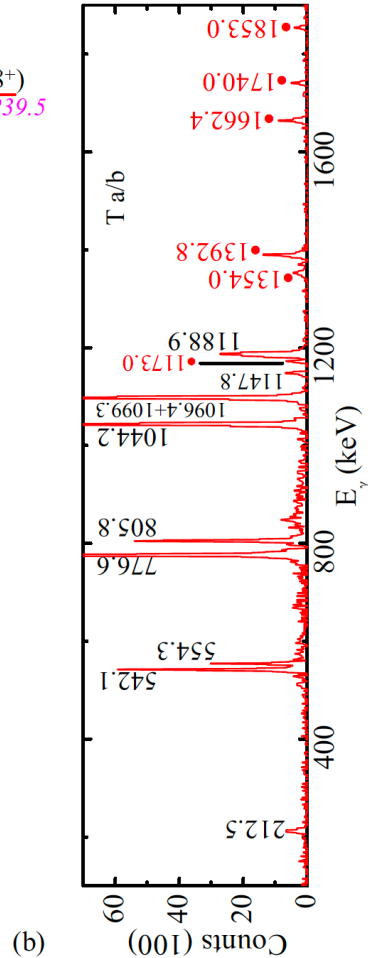
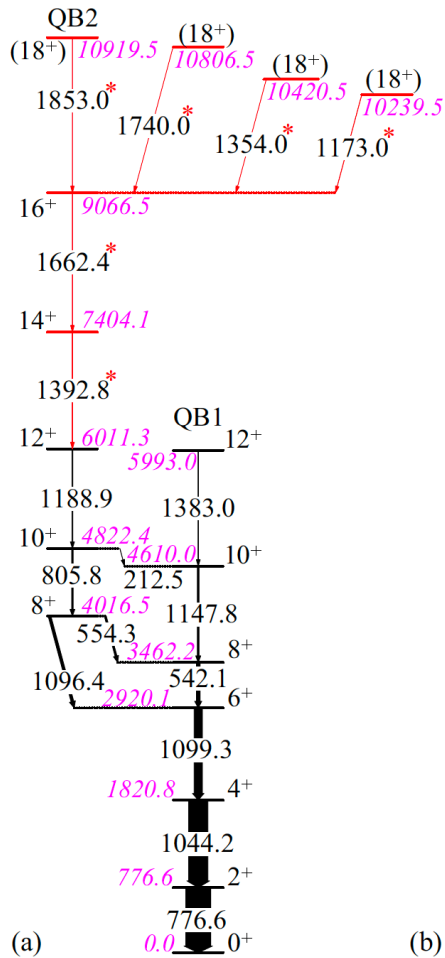


*S. Frauendorf, A. O. Macchiavelli, PPNP 78, 24 (2014).*

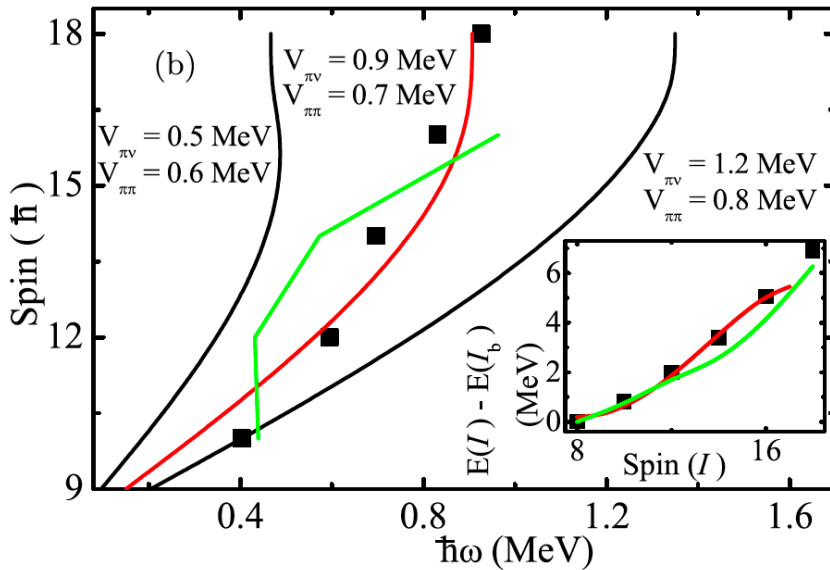
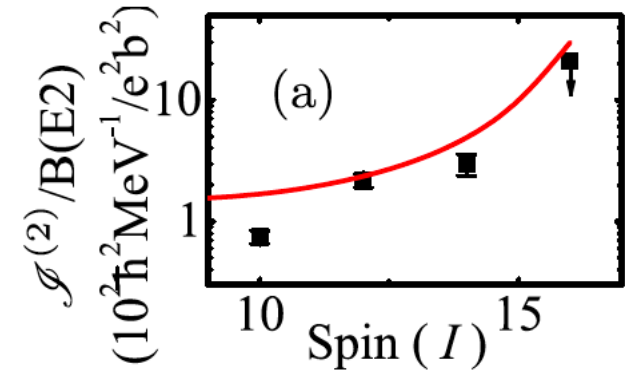
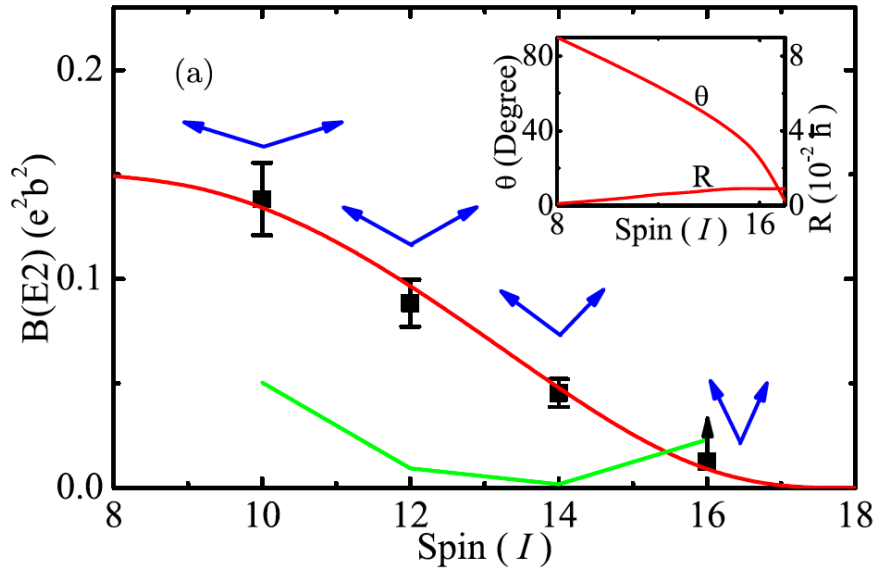
*A. Yaneva et al., PLB 855 138850 (2024).*

*R. M. Clark, A. O. Macchiavelli, Annu. Rev. NP Sci., 50(1) (2000).*

# Anti-Magnetic rotation in $^{82}\text{Kr}$



# Anti-Magnetic rotation in $^{82}\text{Kr}$

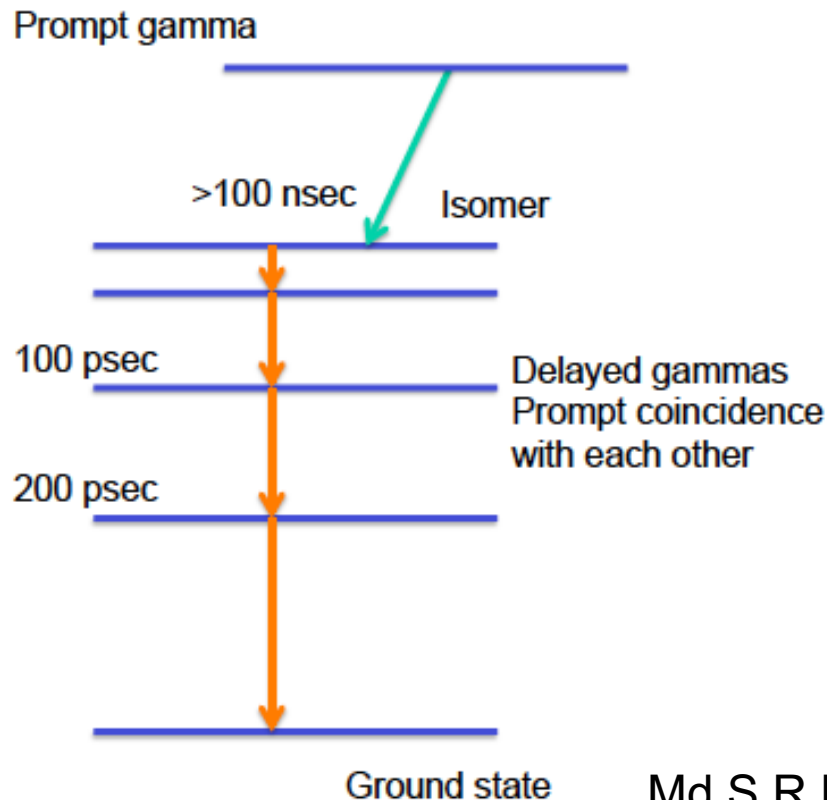
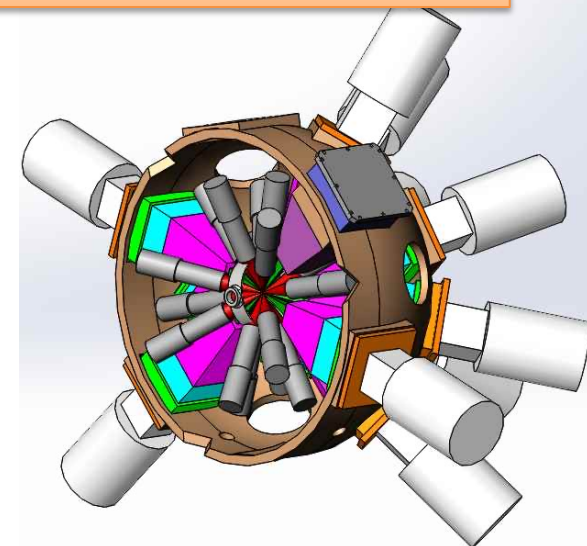


$g_{9/2}$  neutron holes  
 $g_{9/2}$  proton particles

The first example of AMR with neutron holes and proton particles in same orbitals

# Hybrid Array HPGe Clover – LaBr3(Ce)

Use of HPGe for enhanced, highly selective decay path isolation  
and  
Use of LaBr3(Ce) for gated sub-nanosecond lifetime measurements  
(With other ancillary detectors/set-up (CsI(Tl), Si detectors, plunger )



Physics cases:  
Isomer depletion  
Lifetime measurements for E1 decays,  
Octupole shapes, Gamma bands, Wobbling  
mode, Test of K-hindrance, Collectivity in  
heavy nuclei, Shell model states

Md S R Laskar et al., PRC104, Letter 011301(2021).  
B. Das et al., Jl. Of Instrum. Soc. Of India 51, 44 (2021).

- 11/2<sup>-</sup> state (isomers) in odd-La isotopes

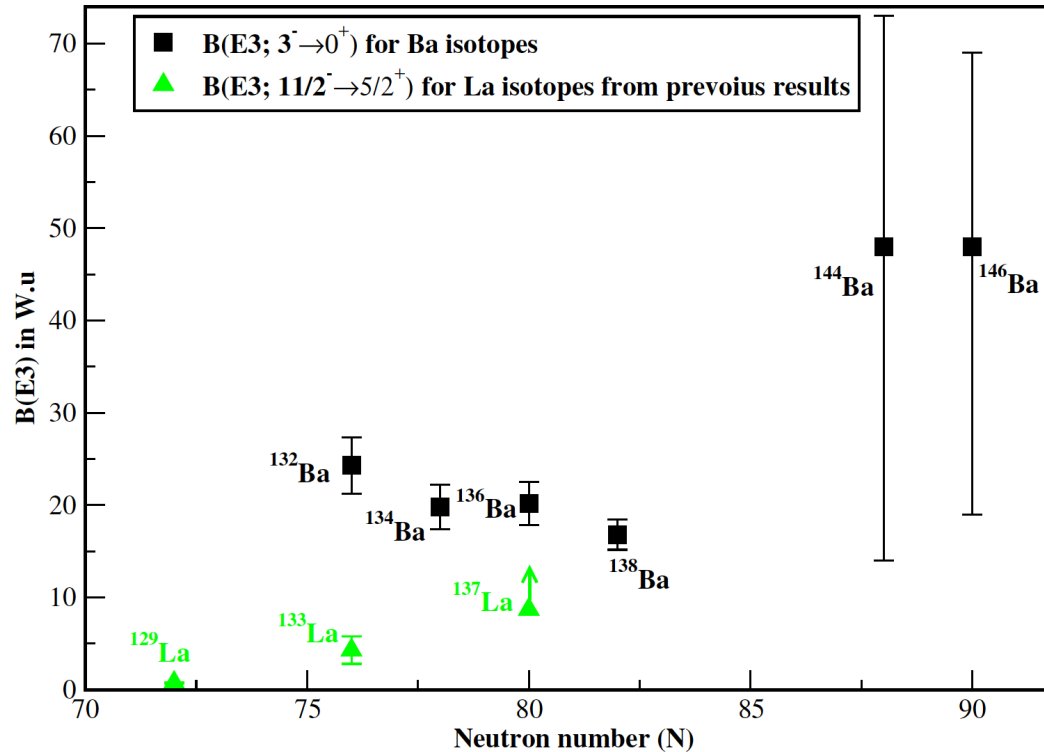
*Md S R Laskar et al., PRC104, L011301 (2021)*

- Octupole-particle coupling in <sup>91</sup>Zr

*P. Dey et al. (submitted)*



# Octupole correlations in Ba isotopes



S. M. Burnett et al., NPA432, 51 (1985).

B. Bucher et al., PRL116 112503 (2016).

B. Bucher et al., PRL118 152504 (2016).

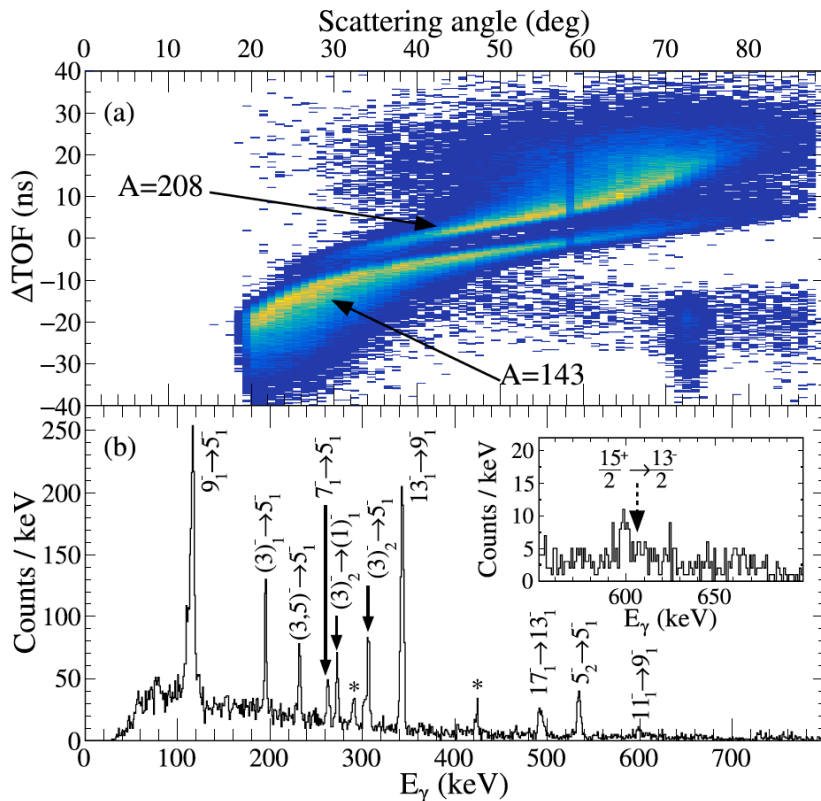
<http://nndc.bnl.gov.in>

R. Yokoyama et al., PTEP (2018) 041D02.

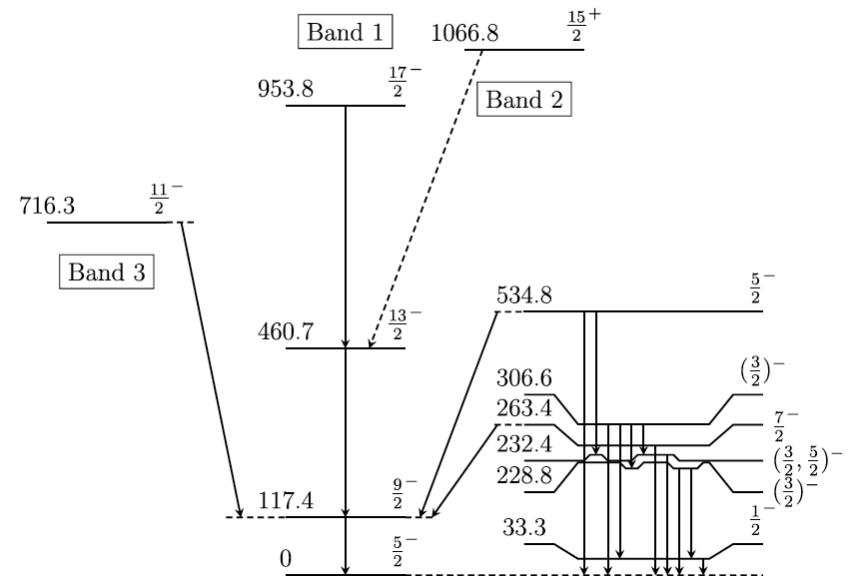
Md S R Laskar et al., PRC104, L011301 (2021)

# Quadrupole and octupole collectivity in $^{143}\text{Ba}$

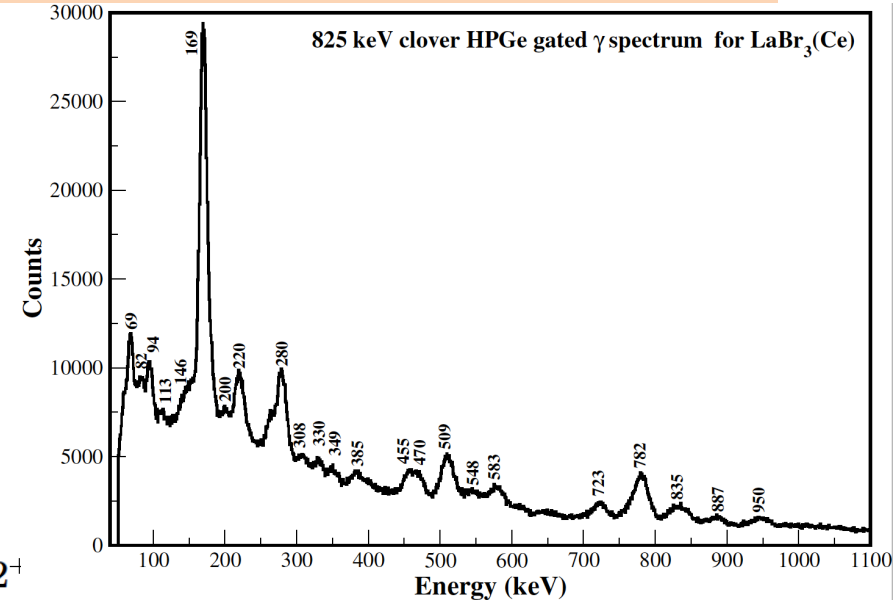
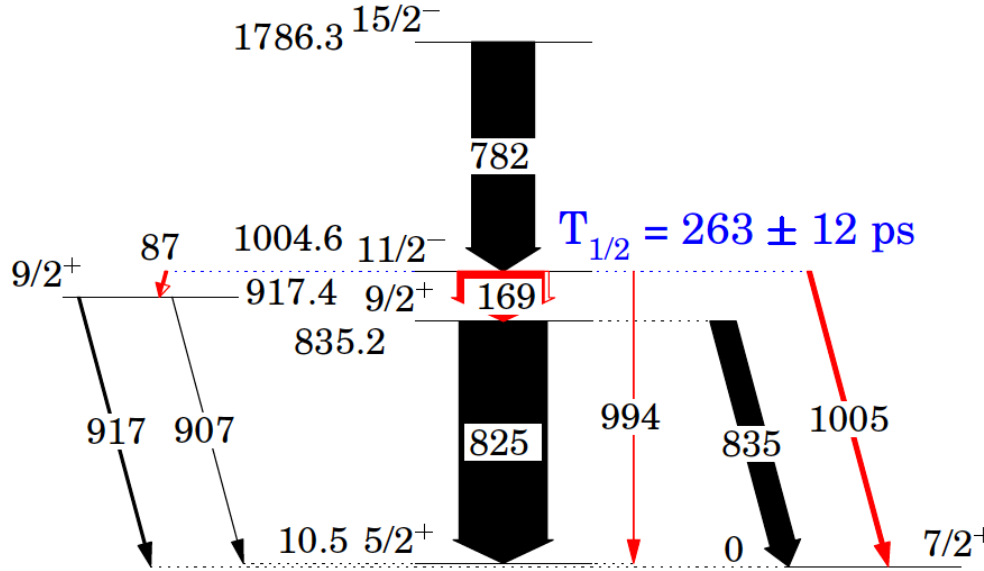
C. Morse,<sup>1</sup> A. O. Macchiavelli,<sup>1</sup> H. L. Crawford,<sup>1</sup> S. Zhu,<sup>2,3</sup> C. Y. Wu,<sup>4</sup> Y. Y. Wang,<sup>5</sup> J. Meng,<sup>5,6</sup> B. B. Back,<sup>2</sup> B. Bucher,<sup>7</sup> C. M. Campbell,<sup>1</sup> M. P. Carpenter,<sup>2</sup> J. Chen,<sup>2</sup> R. M. Clark,<sup>1</sup> M. Cromaz,<sup>1</sup> P. Fallon,<sup>1</sup> J. Henderson,<sup>4</sup> R. V. F. Janssens,<sup>8,9</sup> M. D. Jones,<sup>8</sup> T. L. Khoo,<sup>2</sup> F. G. Kondev,<sup>2</sup> T. Lauritsen,<sup>2</sup> I. Y. Lee,<sup>1</sup> J. Li,<sup>2</sup> D. Potterveld,<sup>2</sup> C. Santamaria,<sup>1</sup> G. Savard,<sup>2</sup> D. Seweryniak,<sup>2</sup> S. Stolze,<sup>2</sup> and D. Weisshaar<sup>10</sup>



No evidence of E3 excitation

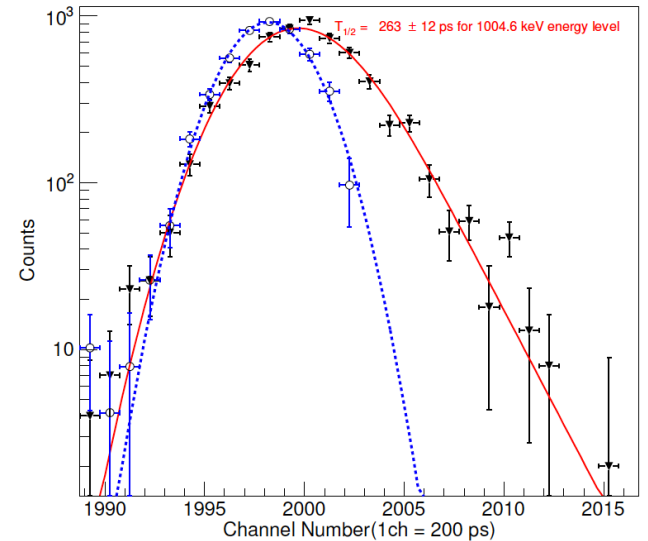


C. Morse et al. PRC102, 054328 (2020).

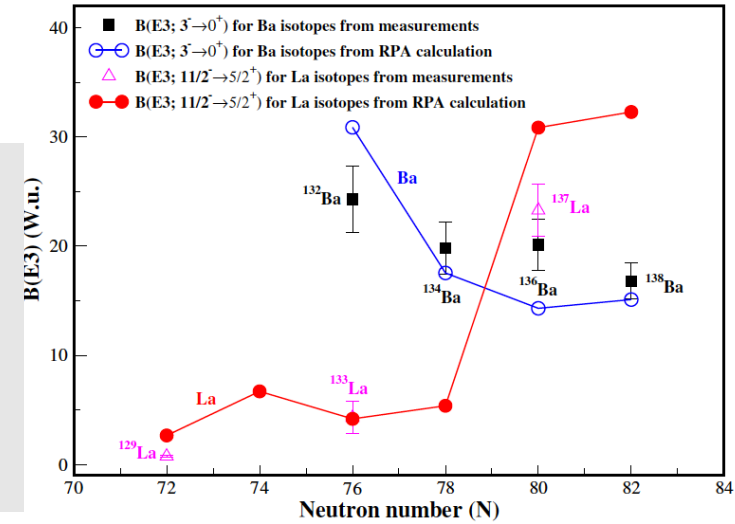
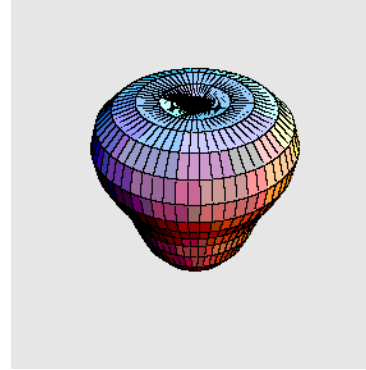
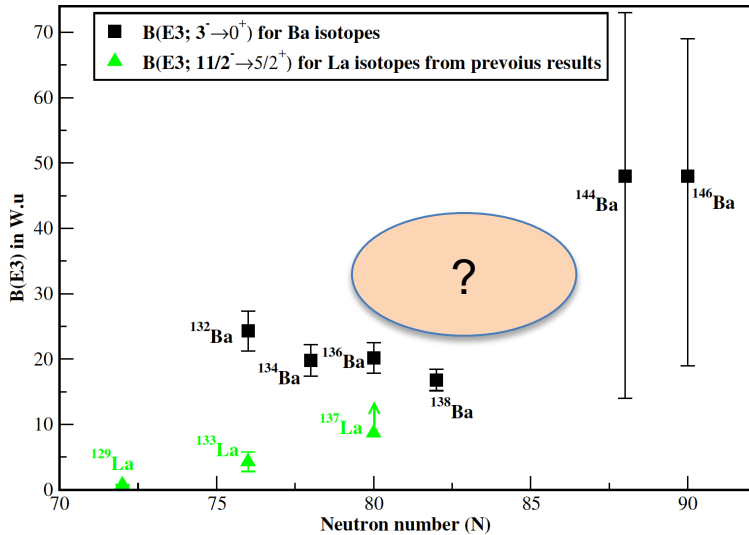


Hybrid array of CS Clover and LaBr<sub>3</sub>(Ce) detectors @BARC-TIFR PLF

The measured lifetime of 1004.6-keV state is 263(12) ps

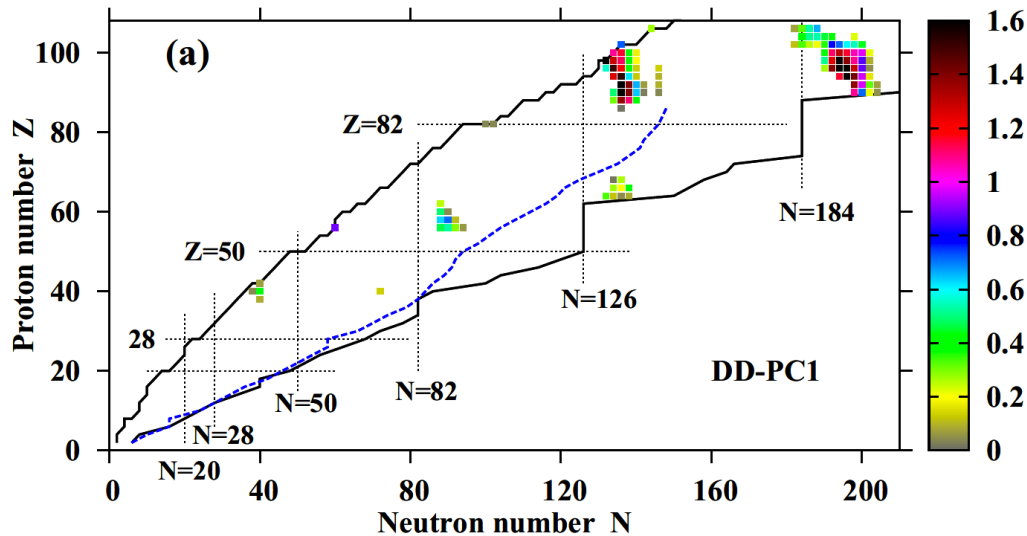


# Octupole correlations in Ba isotopes



T. Inakura

Beta-decay study of Xe, Cs isotopes



S.E. Agbemava et al., PRC 93, 044304 (2016)

S. M. Burnett et al., NPA432, 51 (1985).

B. Bucher et al., PRL116 112503 (2016).

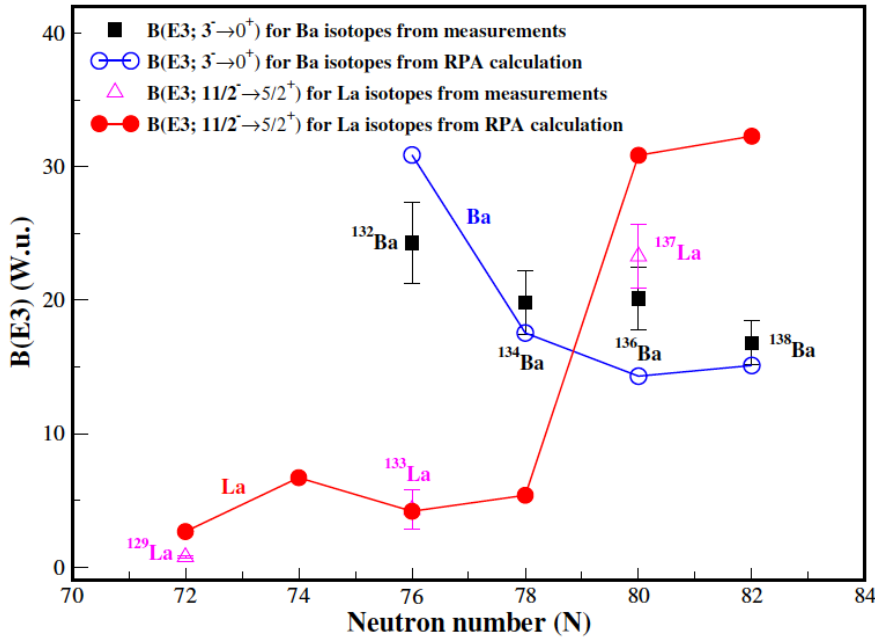
B. Bucher et al., PRL118 152504 (2016).

<http://nndc.bnl.gov/in>

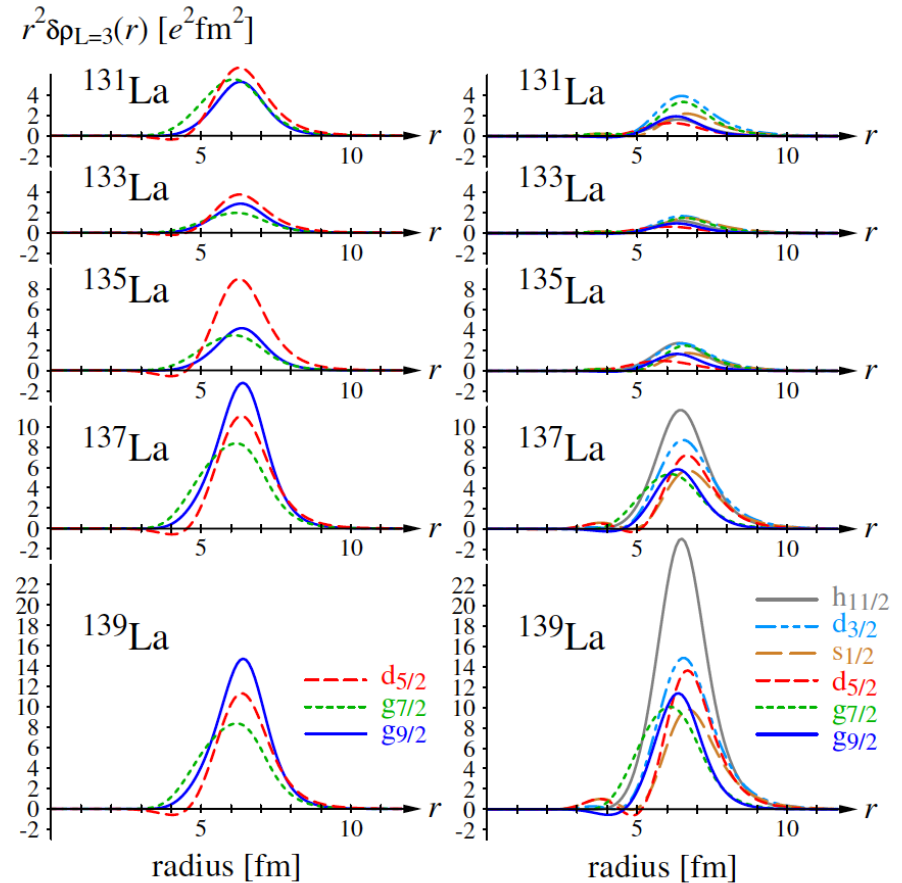
R. Yokoyama et al., PTEP (2018) 041D02.

Md S R Laskar et al., PRC104, L011301 (2021).

# Enhanced B(E3) in $^{137}\text{La}$ isotope



Proton

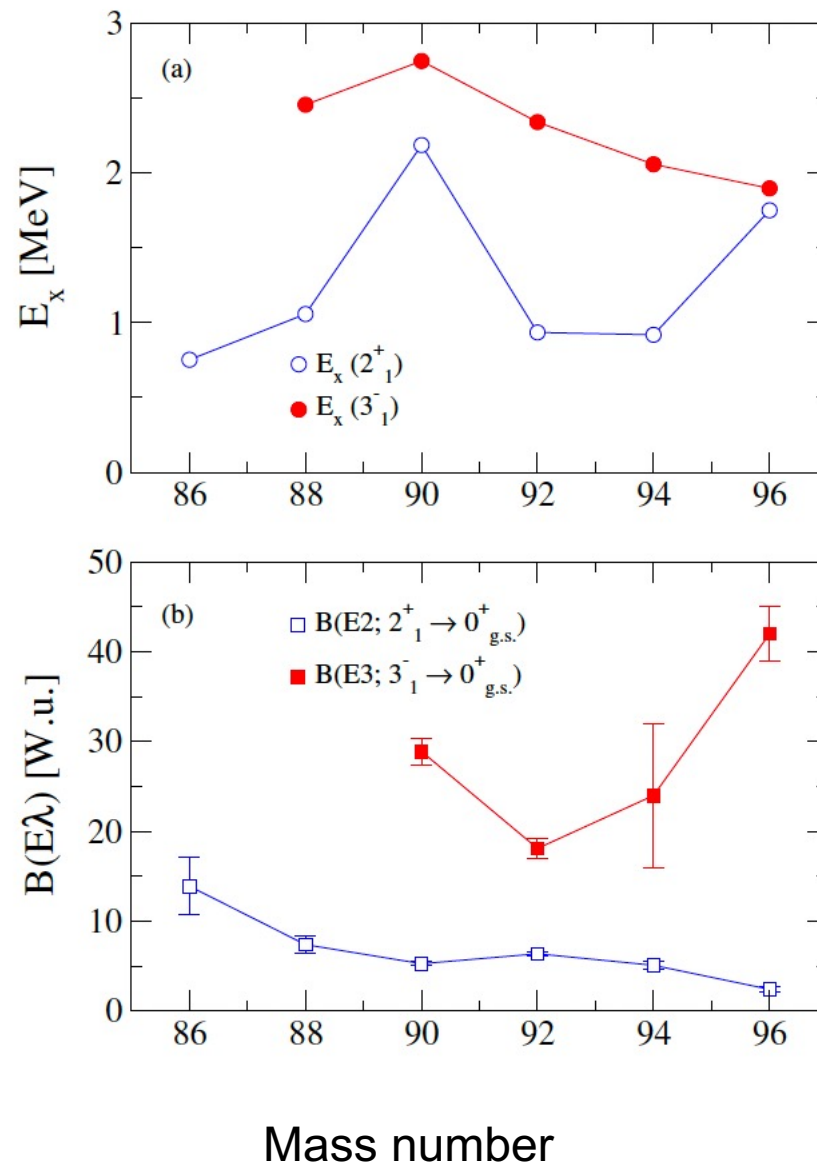


Neutron

RPA calculations with Skyrme SLy4 interaction

Role of  $g_{9/2}$  proton with increasing occupancy of neutron in  $h_{11/2}$

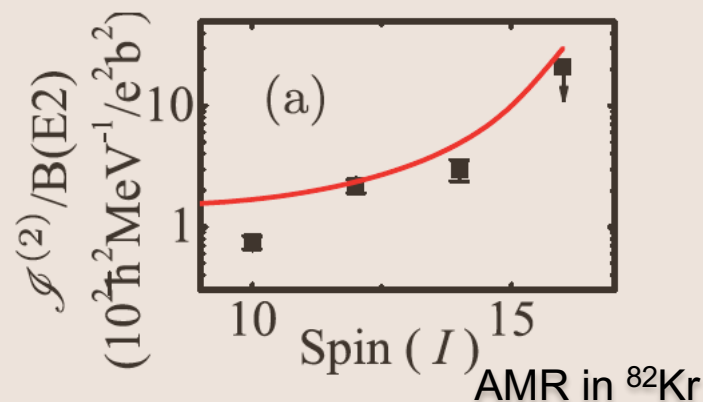
# Octupole-phonon vibration in Zr isotopes



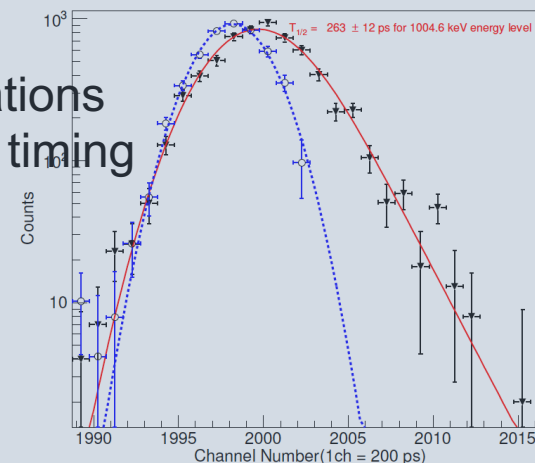
Results on lifetime measurements

- Anti Magnetic Rotation in  $^{82}\text{Kr}$  with particles and holes in the same orbit
- Novel coupling scheme in  $^{88}\text{Sr}$
- Particle-octupole coupling in  $^{91}\text{Zr}$  and  $^{137}\text{La}$

Results on nuclear reactions involving weakly bound nuclei.



Octupole correlations  
in  $^{137}\text{La}$  with fast timing



- Investigation of exotic nuclear shapes with Coulex, lifetime measurements and spectroscopy.
- Nuclear isomers
- Nuclear reaction dynamics
- Reactions for nuclear astrophysics

*Exclusive spectroscopy measurements with Hybrid Array of HPGe Clover – LaBr3(Ce) and Charged Particle detector Array*

Thank you for your attention !!

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**Biswajit Das, A. Kundu, B. Das, P. Dey, V. Malik, A. Sindhu, Md. S. R. Laskar, F. S. Babra, S. Biswas, S. Saha, J. Sethi, A.T. Thomas, S. K. Jadav, B. S. Naidu, R. Donthi**

**S. Rajabanshi, S. Sihotra, D. Mehta, S. Kumar, T. Trivedi, S. Nag, D. Choudhury, S. Mukhopadhyaya, D.C. Biswas, R. P. Singh, S. Muralithar, S.S. Ghugre, R. Raut, S. Chattopadhyaya, G. Mukherjee, S. Bhattacharyya**

J. Sheikh, G. Bhat, S. Jehangir, Z. Naik,  
P.C. Srivastava

E. Ideguchi (RCNP), T. Inakura (Tokyo Inst Tech), N. Shimizu (CNS), T. Togashi (CNS)

### **INGA Collaboration**

The staff members at the TIFR-BARC Pelletron Linac Facility, the TIFR central workshop, and the TIFR Low-Temperature Facility.

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