Possible coupling of INGA and PARIS for the study of nuclear structure

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PARIS Collaboration meeting 28-29 Nov 2019, Legnaro (Italy)

Outline

- Overview of INGA at Pelletron LINAC Facility
- DAQ, Ancillary detectors
- Selected results
- Future proposals
  - High energy transitions feeding triaxial and axial shapes
  - High spin structure near ^{90}Zr
  - ^{4}He + ^{4}He experiments

- Summary

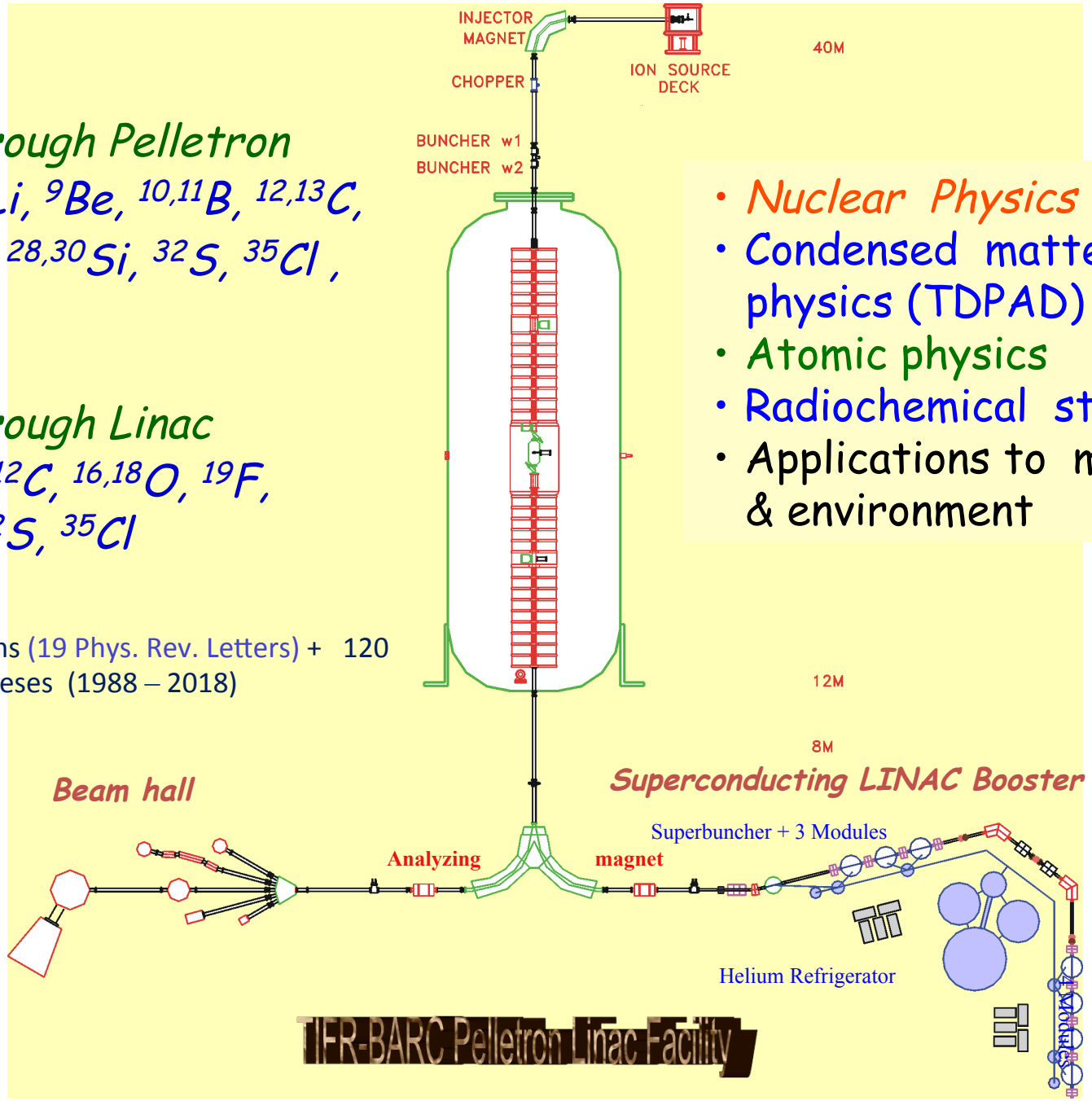
Beams through Pelletron

$^{1}H, ^{4}He, ^{6,7}Li, ^{9}Be, ^{10,11}B, ^{12,13}C,$
$^{16,18}O, ^{19}F, ^{28,30}Si, ^{32}S, ^{35}Cl,$
... $Ag, ^{129}I$

Beams through Linac

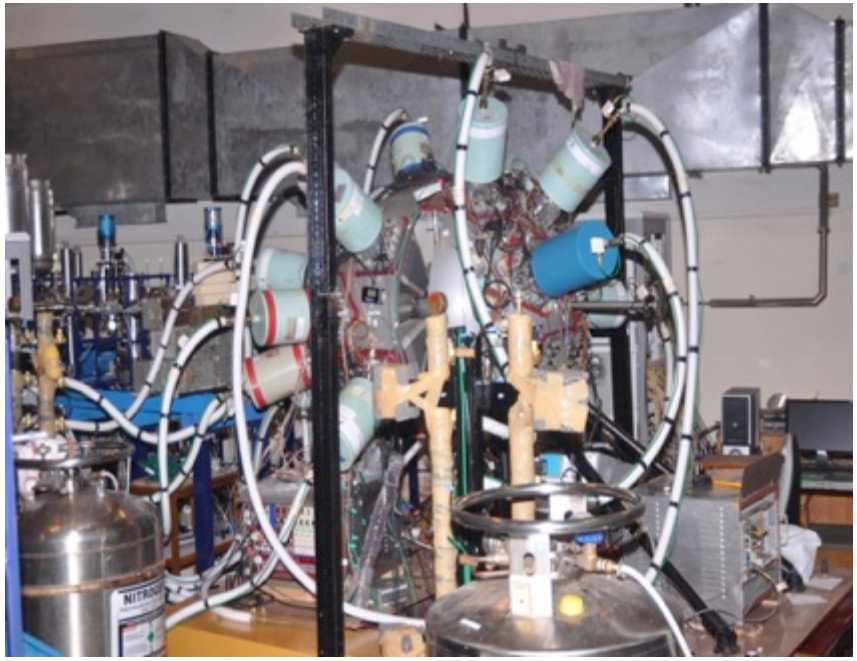
$^{7}Li, ^{10,11}B, ^{12}C, ^{16,18}O, ^{19}F,$
$^{28,30}Si, ^{32}S, ^{35}Cl$

750 publications (19 Phys. Rev. Letters) + 120 Theses (1988 – 2018)



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

INGA at TIFR



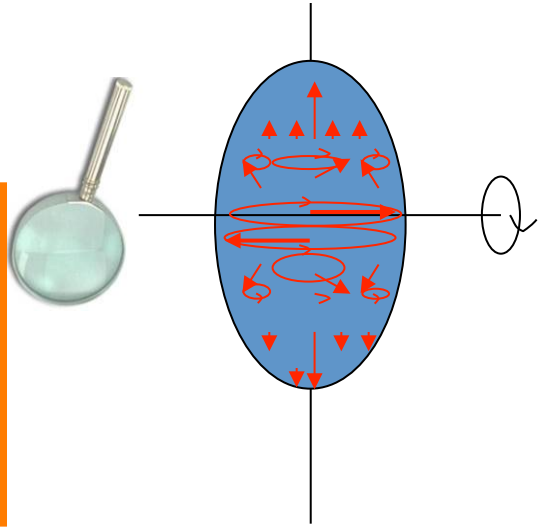
DSP Implementation for INGA

- **Up to ~200 channels**
- **Provision for Ancillary detectors (CsI(Tl), Si and $LaBr_3(Ce)$))**

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

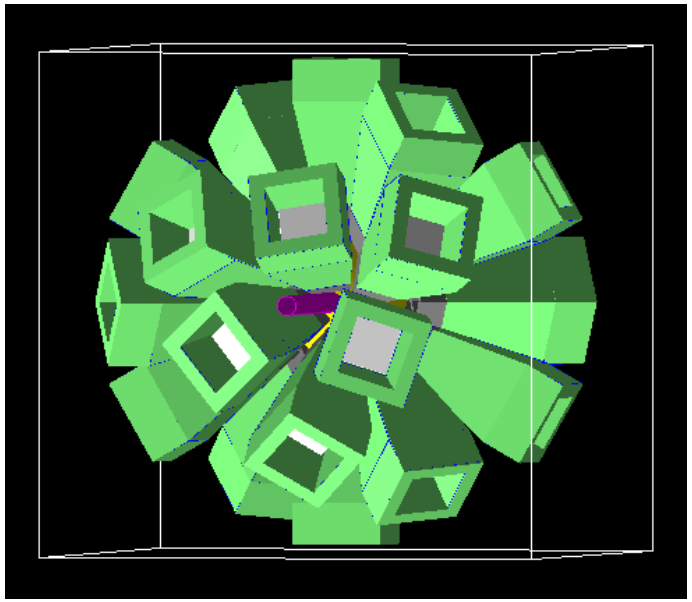
BARC, IUAC, IUC-KC, SINP, TIFR, VECC, IITs, Univ

Investing in the polarization measurements of gamma rays and "wide-range timing spectroscopy" proved to be a successful approach for creating our specific "niche" and complement research at large scale facilities.
Experiments: ~50 (Current experimental campaign 180 days)
60 researchers including 25 PhD students (2012-2019)

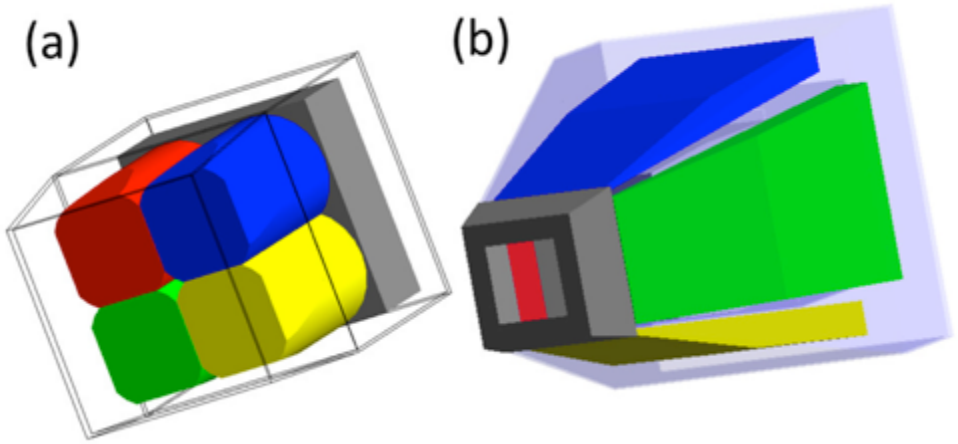


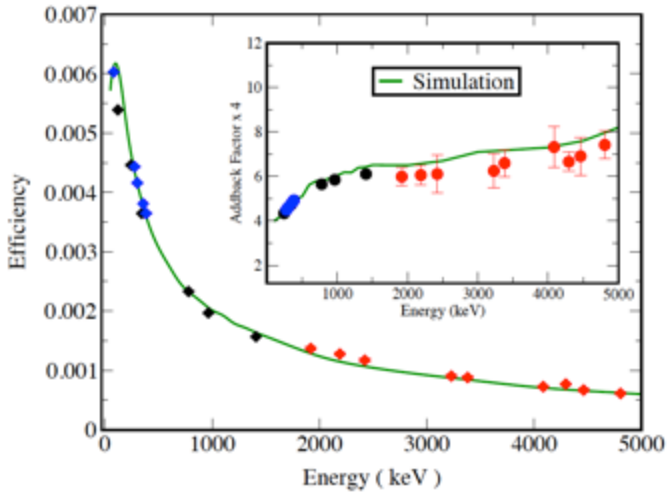
DSP based DAQ has Increased the data throughput by 10 times for INGA

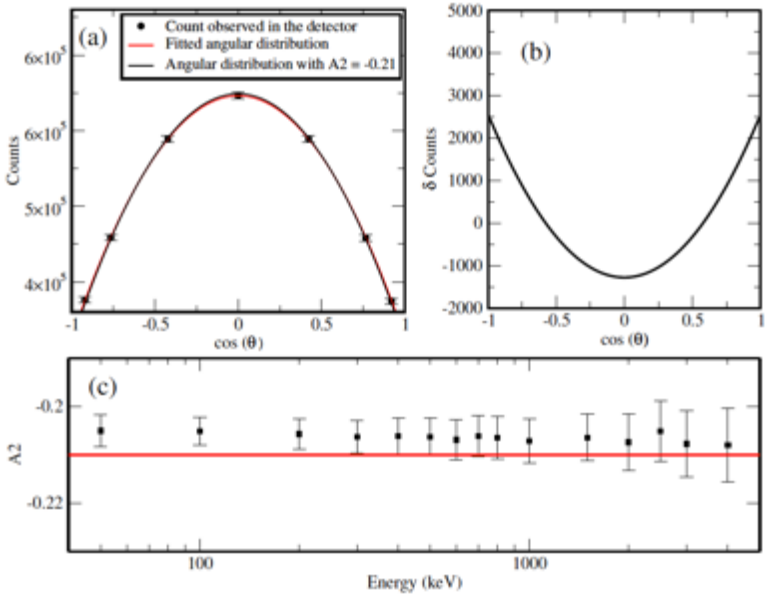
Geant4 Simulation for INGA



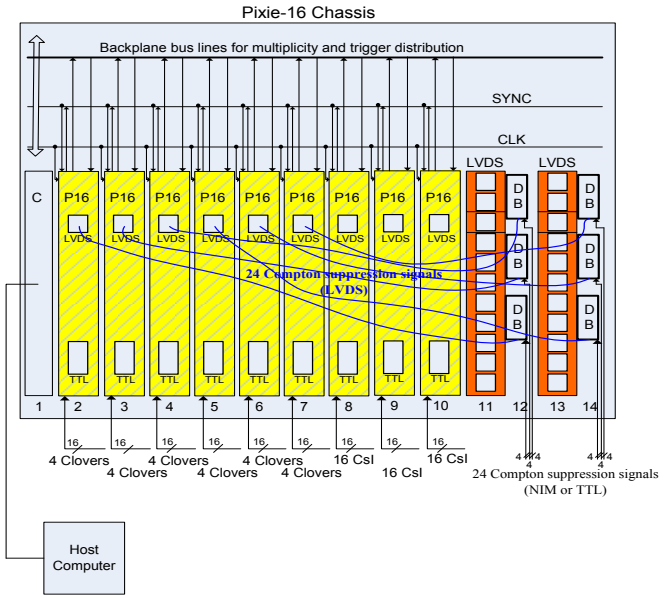
S. Saha et al. JINST 11 (2016) 03030







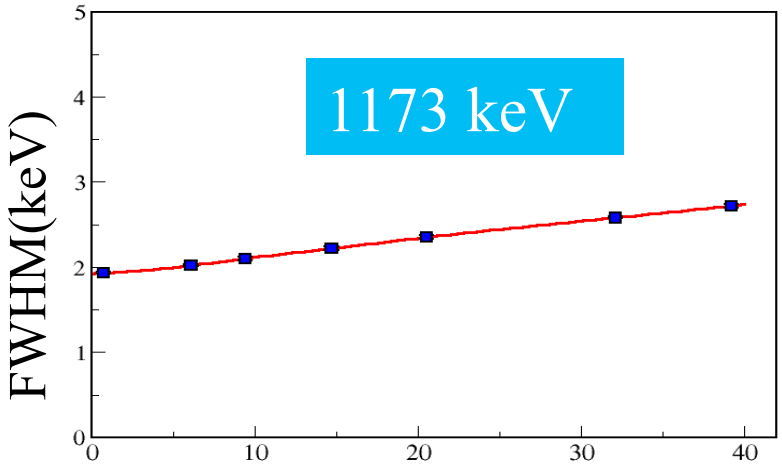
DSP Based DAQ for INGA and its Ancillary detectors

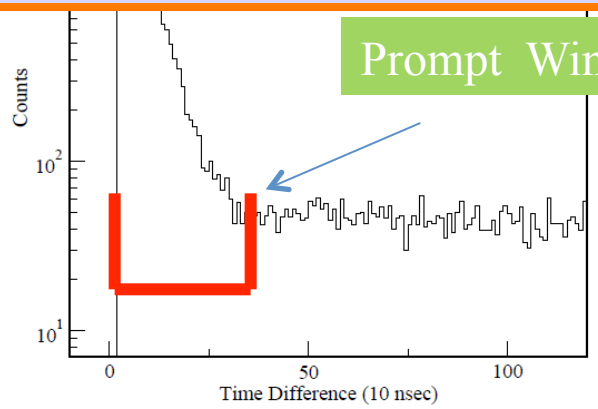


Salient features of DDAQ

- 100 MHz & 12-bit ADC's
- Versatile with complex trigger
- High count rate handing capability
- High stability
- Trigger less system
- Long lived isomer measurements

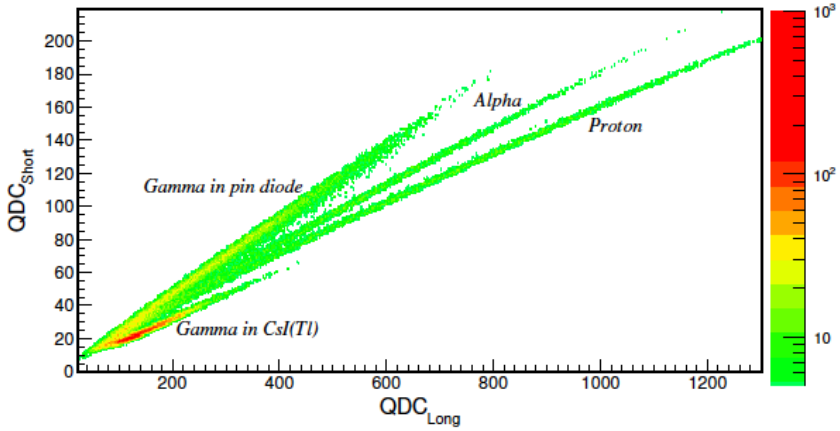
R. Palit, et al. NIMA 680 (2012) 90

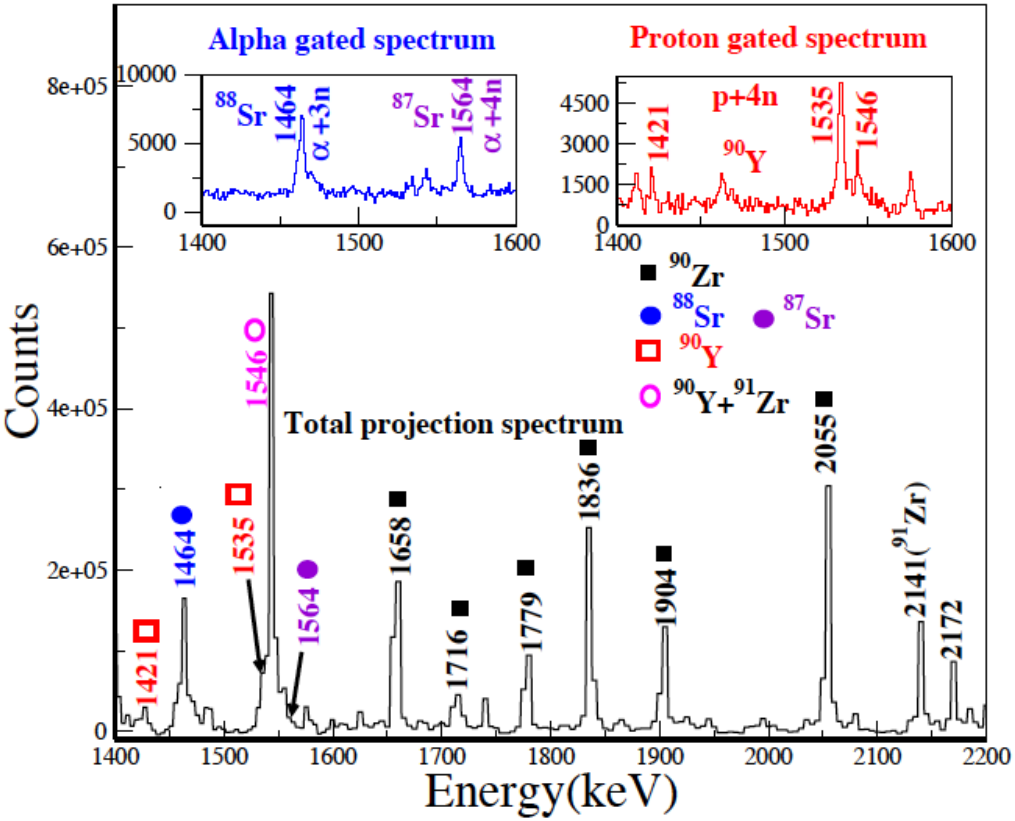


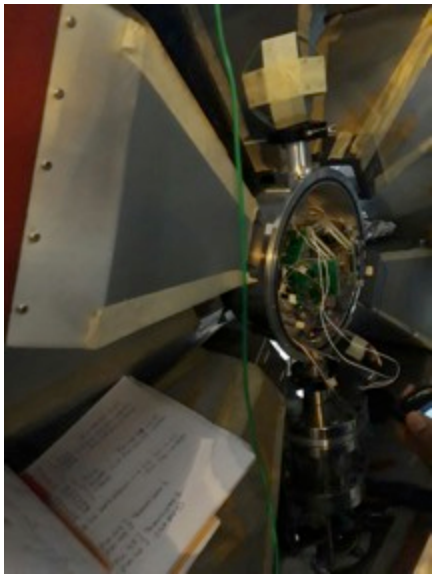


4π CsI(Tl) array

$^{13}C+^{82}Se$ @60 MeV at TIFR (2017)
Au backed target
11 CS-Clover + 24 CsI(Tl)



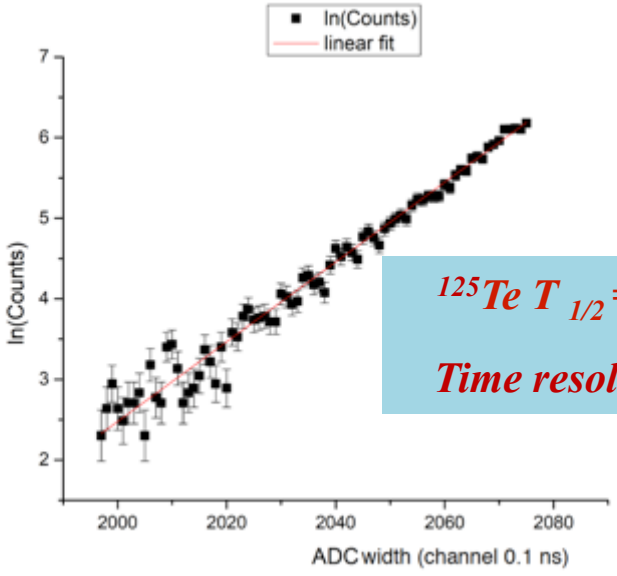




Md. S. R. Laskar

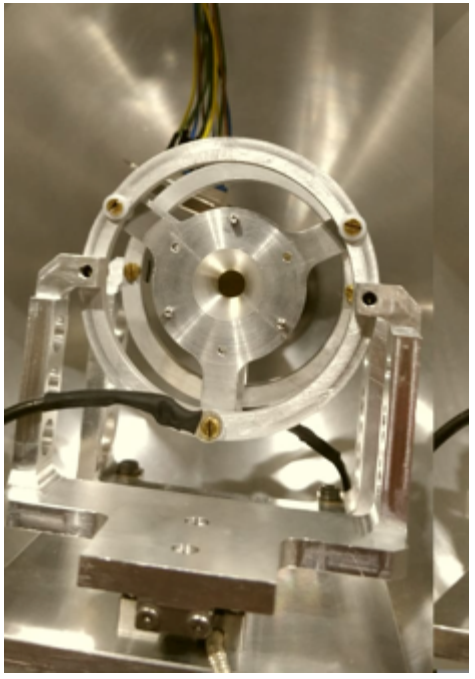
TIFR - IUAC Collaboration

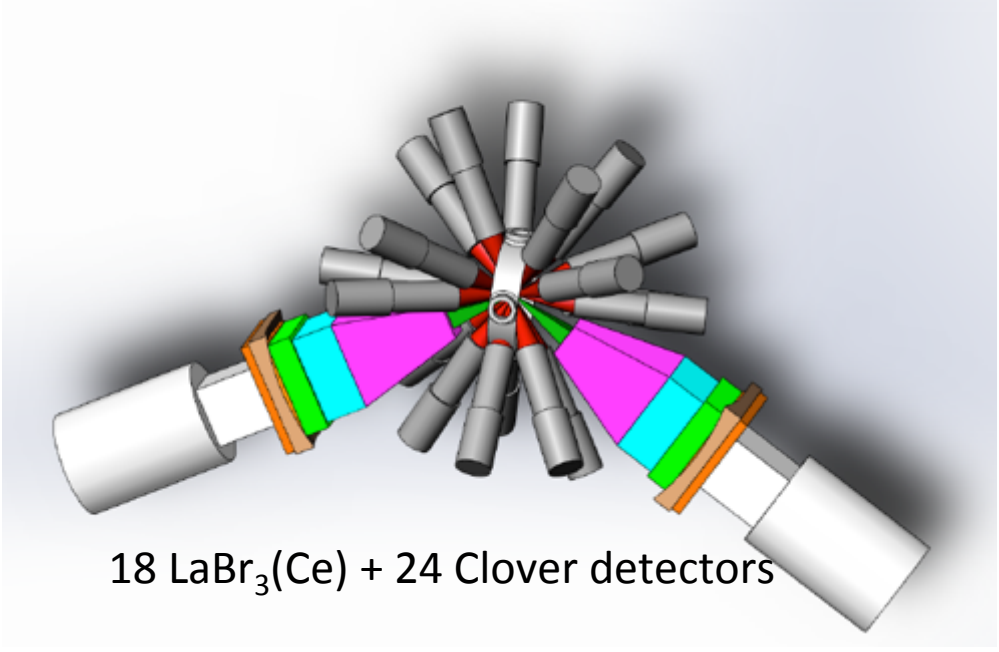
LaBr3(Ce) array (>50 ps) and Plunger (1 – 100 ps) for INGA



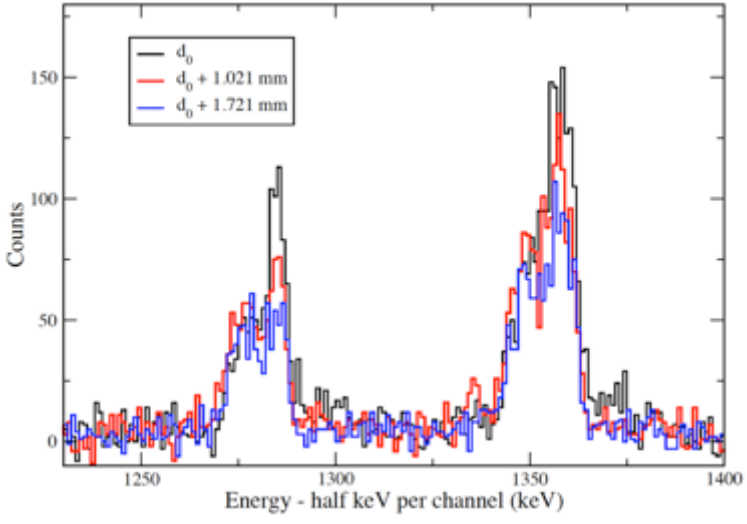
^{125}Te $T_{1/2}$ = 615(11) ps

Time resolving ~400 ps

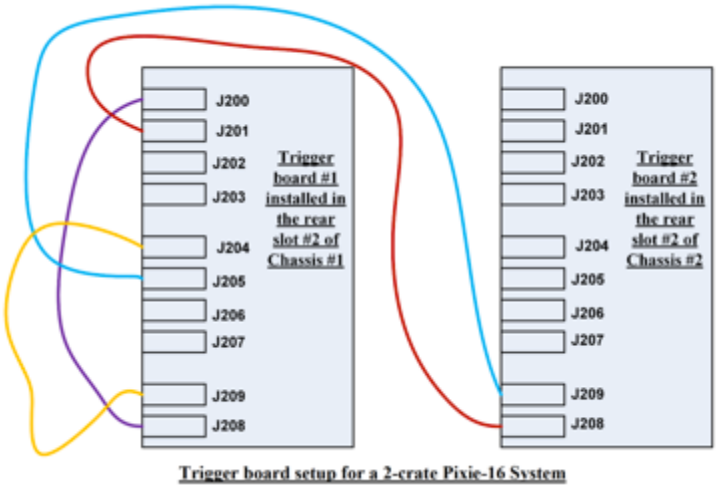




18 $LaBr_3$(Ce) + 24 Clover detectors



Synchronization of multiple crates

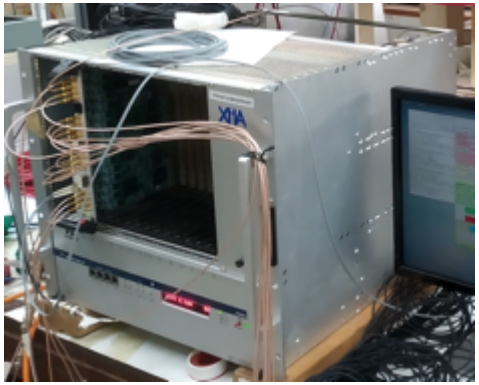


Trigger board setup for a 2-crate Pixie-16 System

Trigger modules

100 MHz Digitizers for Clovers

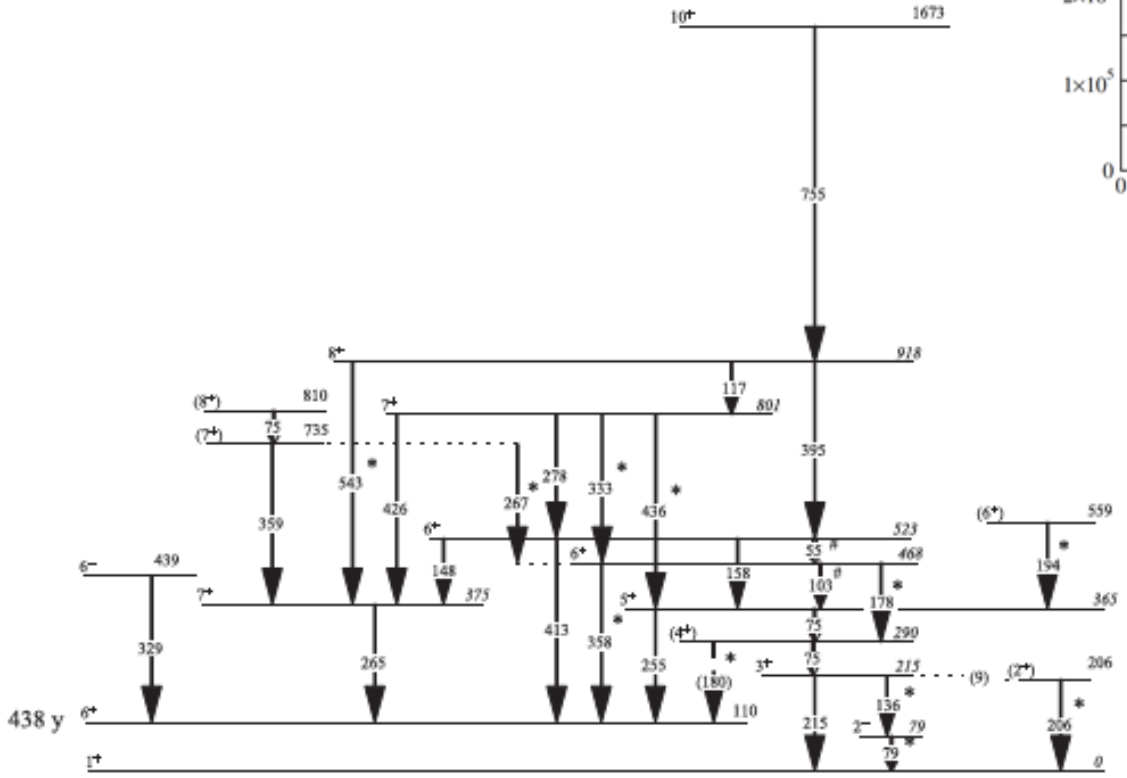
250 MHz Digitizers for $LaBr_3(Ce)$



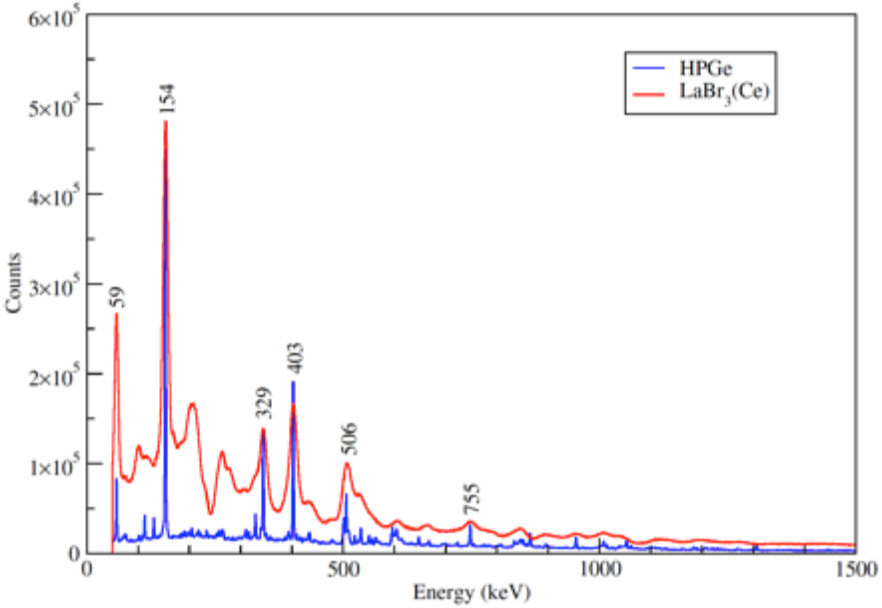
IOP Publishing Journal of Physics G: Nuclear and Particle Physics
J. Phys. G: Nucl. Part. Phys. **43** (2016) 015103 (15pp) doi:10.1088/0954-3899/43/1/015103

Low-lying states near the $I^{\pi} = 6^{+}$ isomer in ^{108}Ag

J Sethi[1], R Palit[1], J J Carroll[2], S Karamian[3,12], S Saha[1], S Biswas[1], Z Naik[4], T Trivedi[1], M S Litz[2], P Datta[5], S Chattopadhyay[6], R Donthi[1], U Garg[7], S Jadhav[1], H C Jain[1], S Kumar[8], D Mehta[9], B S Naidu[1], G H Bhat[10], J A Sheikh[10], S Sihotra[9] and P M Walker[11]



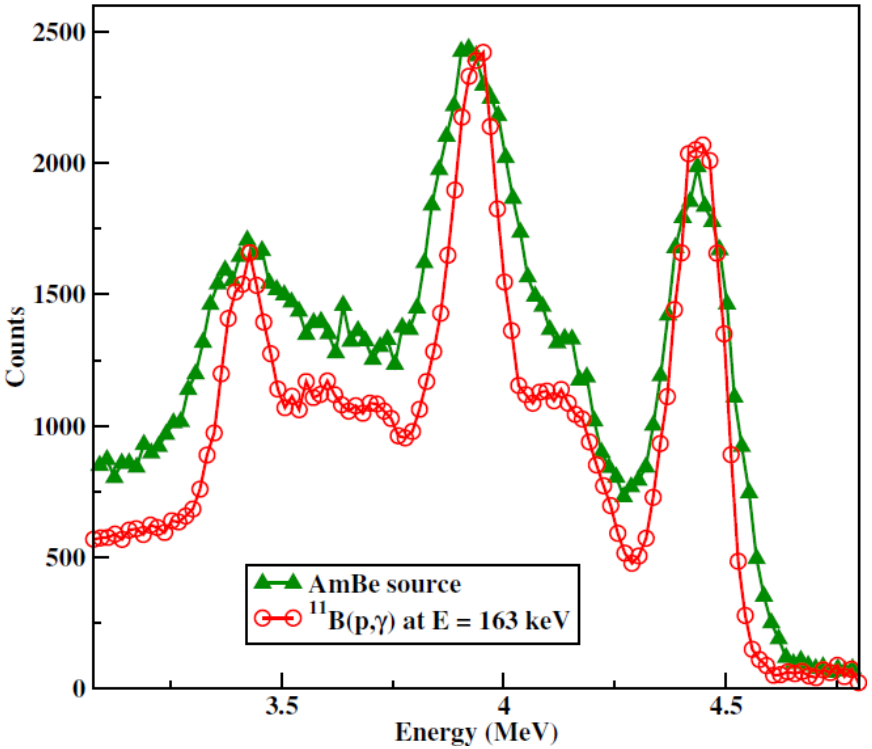
Data from Clover + LaBr3(Ce) array



Lifetime measurement of low-lying states will be crucial for estimation of isomer depletion efficiency.

Lifetime analysis is in progress

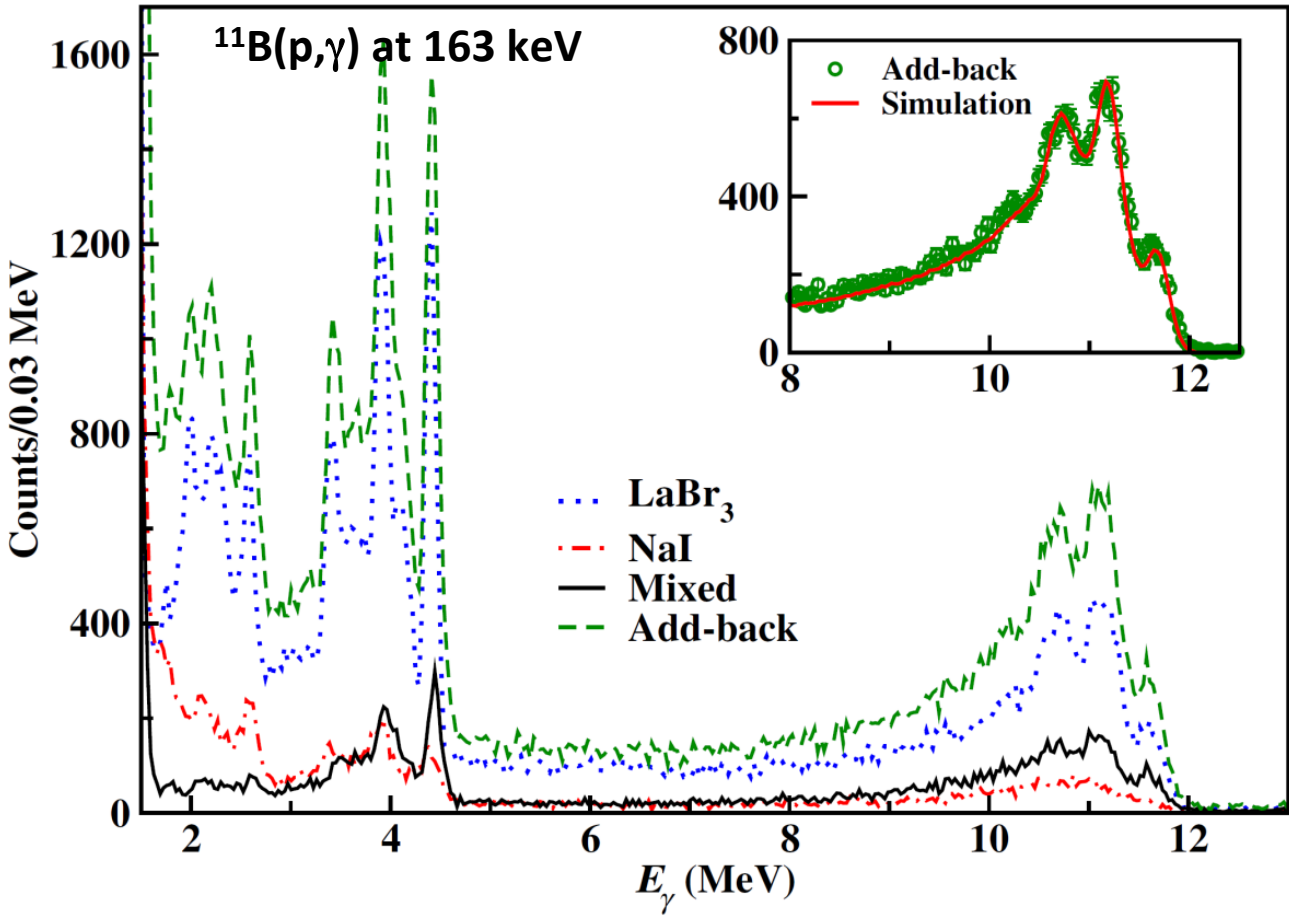
Intrinsic Broadening of AmBe Source demonstration of phoswich resolution



The broadening due to source recoil ~ 2%

C. Ghosh *et al* 2016 *JINST* **11** P05023

Demonstration of phoswich add back concept (4-12 MeV)

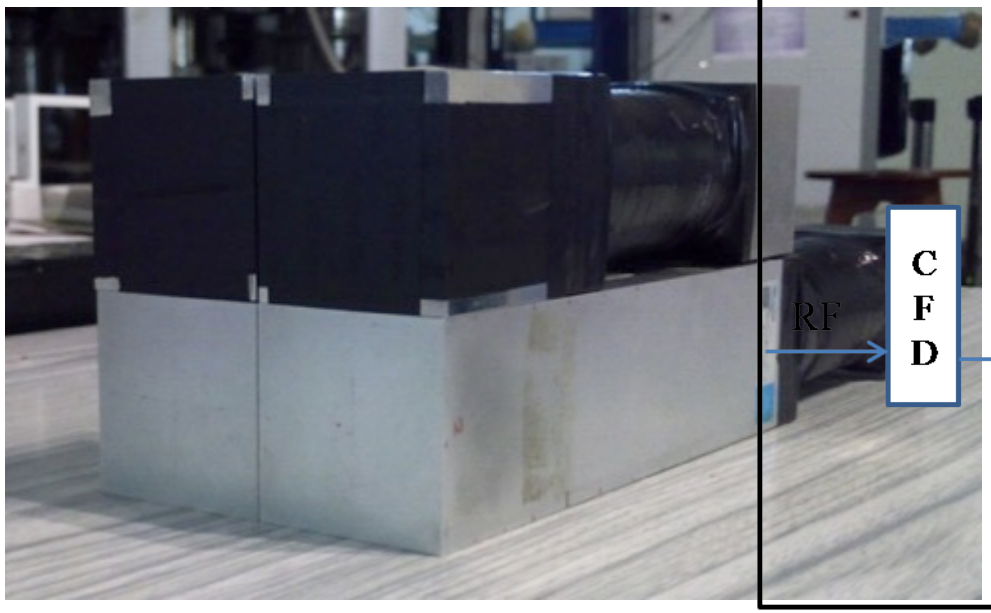


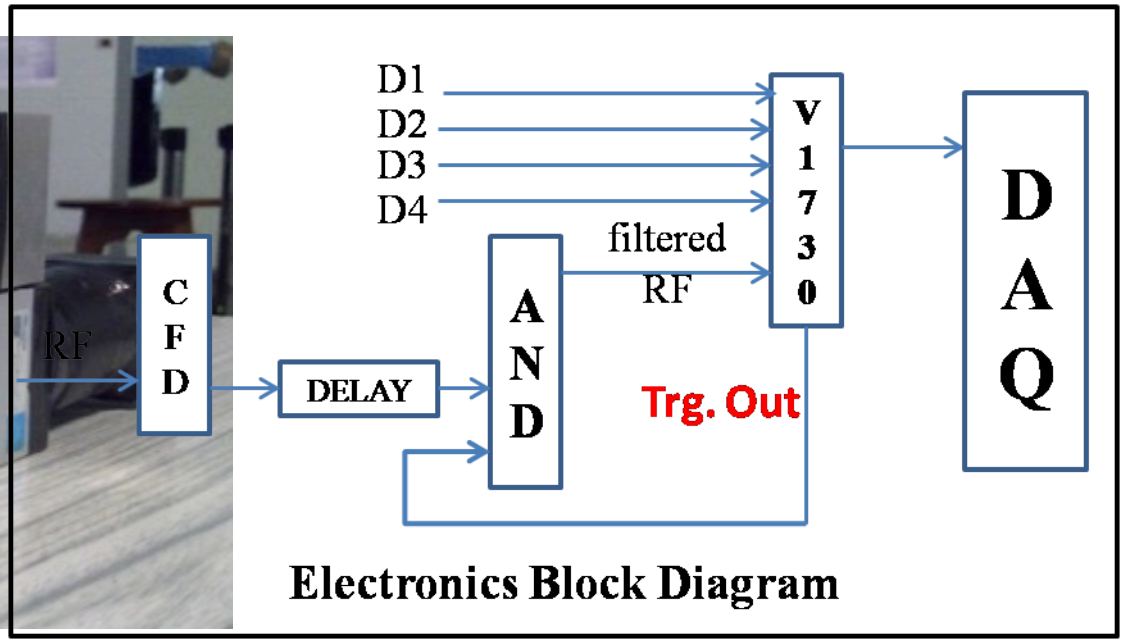
$N(E_{add})/N(E_1)$ ~1.4 @4.4 MeV
~ 1.5 @ 12 MeV

C. Ghosh *et al* 2016 *JINST* **11** P05023

In-beam test of PARIS mini-cluster (2x2) @ Mumbai

- Test carried out as a satellite in the experiment to study Jacobian shape transitions using ^{16}O (E_{lab} = 125 MeV) on ^{12}C target at PLF, Mumbai
- With V1730 digitizer and digiTES-4.2.6, for each event Time stamp, PSD $[(Q_L-Q_S)/Q_L]$ and Energy were recorded

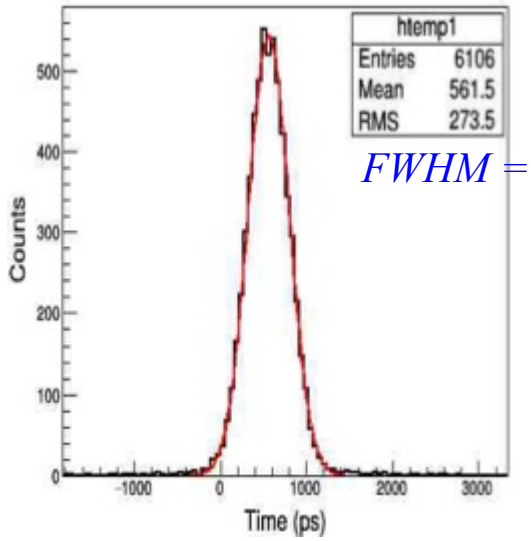




- TOF measured w.r.t. beam pulse (RF).
- The RF (~4.68MHz) was filtered using 'OR' output of V1730 with suitable masking for inputs and recorded as input

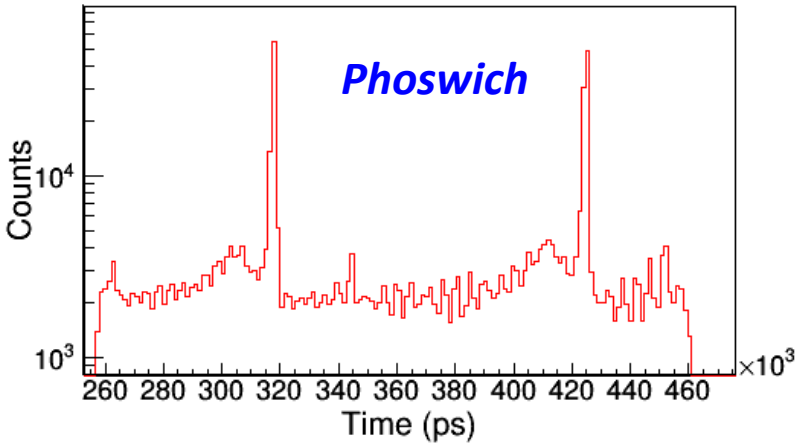
B. Dey, S. Pal, C. Ghosh, V. Nanal & Paris-India group

Energy gated (^{60}Co) time spectrum with two phoswich detectors

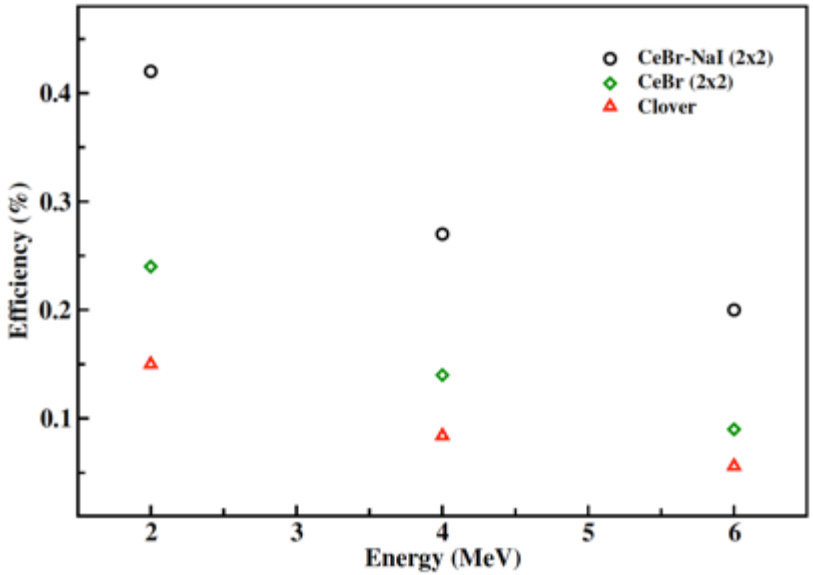


FWHM = 560 ps

RF- TOF spectrum



FWHM = 1.2 ns (beam width)



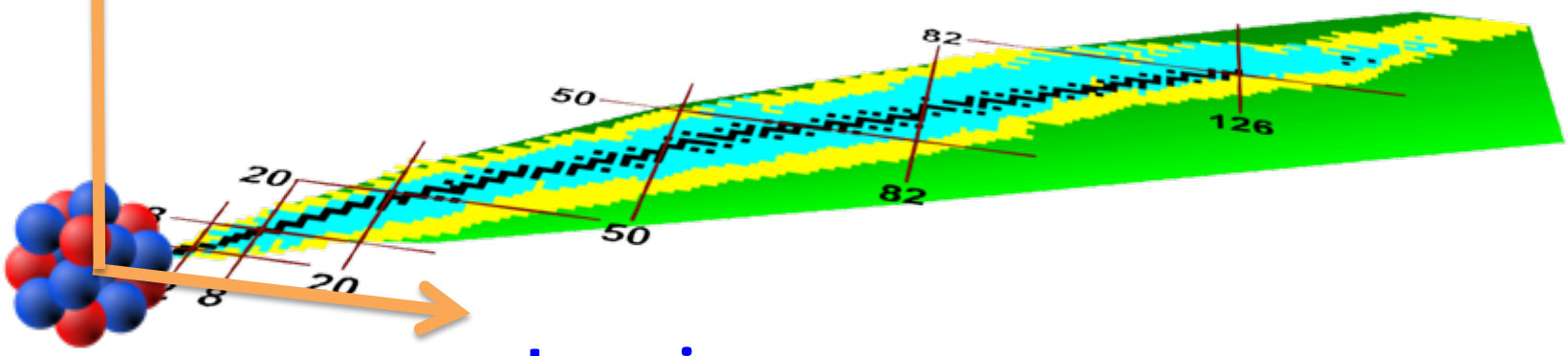
GEANT4 Simulation for 2x2 PARIS Cluster

C. Ghosh *et al*

Key experimental questions

Spin

- ✓ Collectivity and exotic shapes
- ✓ Novel excitation modes
- ✓ Evolution of shell structure
- ✓ High-K bands
- ✓ Pairing interaction
- ✓ Octupole collectivity
- ✓ Isomer depletion
- ✓ Fission



Isospin

Physics overview of the INGA Campaign at TIFR

Magnetic and Antimagnetic rotation in ^{107}Cd, ^{105}Pd, ^{143}Eu, ^{135}La
PRC101, 014308 (2019), PRC87, 034304 (2013); PRC89, 061308(R) (2014); PLB 748, 387 (2015);

Spectroscopy across isomers in 132Te, 88Zr, 66Cu
EPJA53 (2017), PRC93, 034324 (2016); PRC89, 044315 (2014);

Degenerate dipole bands in 106Ag, 108Ag, 195Tl
PLB 725, 85 (2013); PRL 112, 202503 (2014); PLB782 (2018)

Collectivity in 33S
PRC90, 024328 (2014)

Octupole collectivity in 221Th
PRC 87, 034319 (2013);

Shape co-existence and high-K in 188Pt
PLB 739, 462 (2014);

Band crossing in 169Tm
PRC (2017);

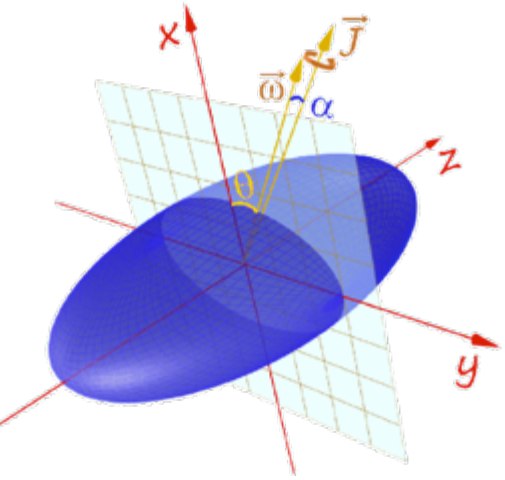
Wobbling bands in 135Pr, 133La
PRL 114, 082501 (2015); EPJA 55 159 (2019)

Depletion of 413 yr isomer in 108Ag
JPG43, 015103 (2016);

Shell model in 26Mg, 28Si, 30Si, 34Cl, 89Zr, 89Nb
PRC89, 024303 (2014); PRC90, 014306 (2014); PRC90, 014306 (2014); PRC89, 024324 (2014); PRC91, 044306 (2015), PRC99, 014315 (2019)

Implications of triaxial shape nuclei and experimental challenges

Robust triaxial shapes have been sought after for decades!



- Nuclear mass and binding energy
- Beta-decay rate
- n-capture rates
- Photo-absorption cross-section
- Fission barrier
- Rotational response

P. Moller et al., Phys. Rev. Lett. 97 (2006) 162502.
J. Pereira et al., Jour. Of Phys.: Conf Series 312 (2011) 042019.
Q. Chai et al., Prog. Theor. Exp. Phys. (2018) (053D02).
E. Groose et al., Phys. Scr. 94 (2019) 14008.

Implications of triaxial shape nuclei and experimental challenges

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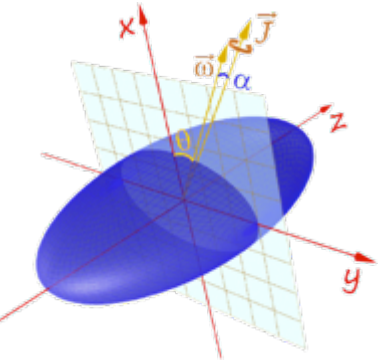
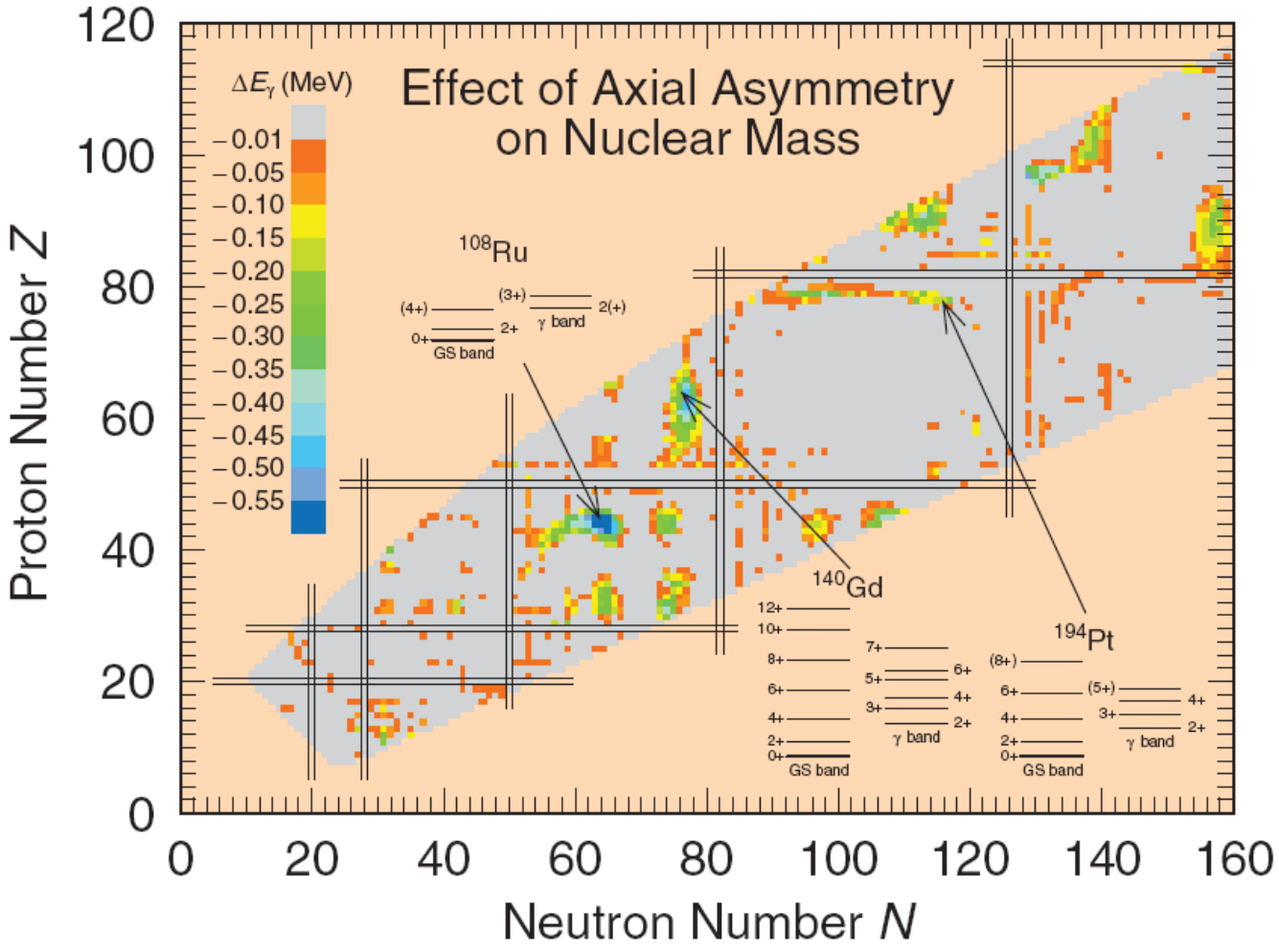
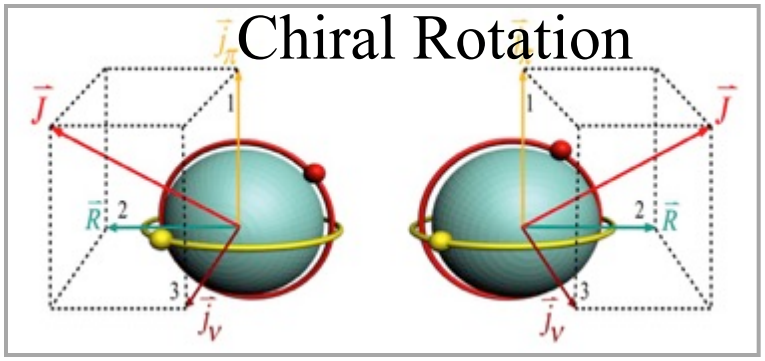




P. Moller et al., Phys. Rev. Lett. 97 (2006) 162502.

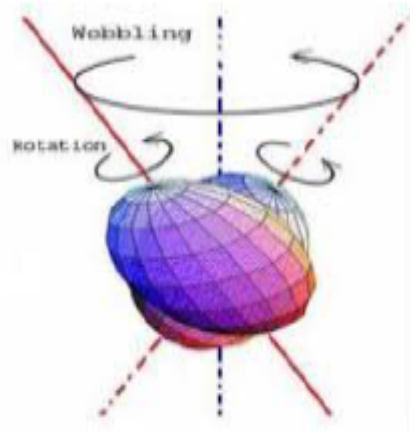
Rotation of triaxial nuclei and symmetries

Chiral Rotation



SF, JM NPA (1997)

Wobbling Mode



SF, FD PRC (2014)

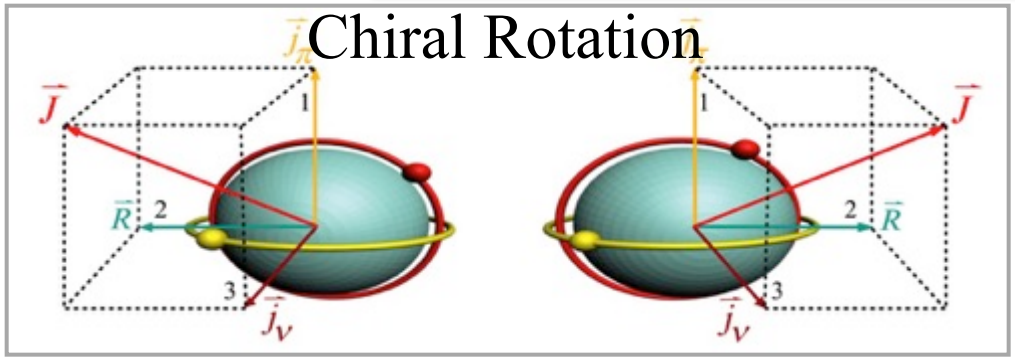
Robust triaxial shapes have been sought after for decades!

"The study of rotational motion in nuclei with asymmetric shapes is potentially a field of broad scope."
Aage Bohr and Ben Mottelson
Nuclear Structure Vol. 2 pg. 176

In order to pin down triaxial deformation, it is essential to find the phenomena which are unique in axially asymmetric shape.

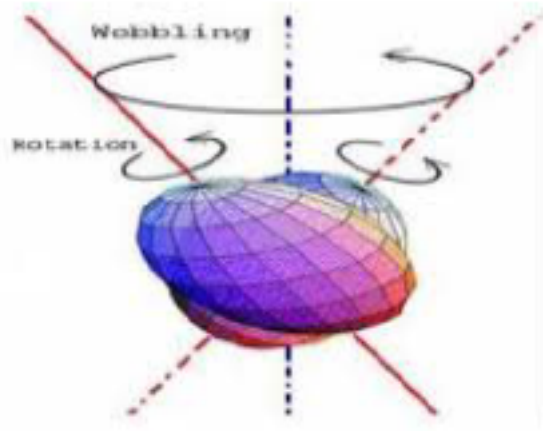
Rotation of triaxial nuclei and symmetries

Chiral Rotation



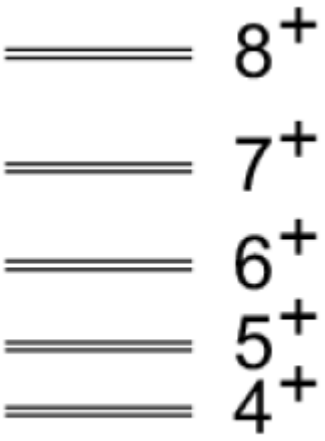
SF, JM NPA (1997)

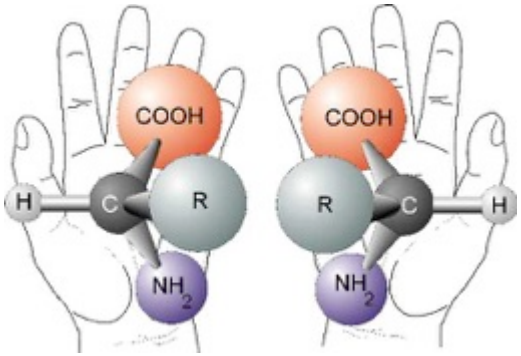
Wobbling Mode

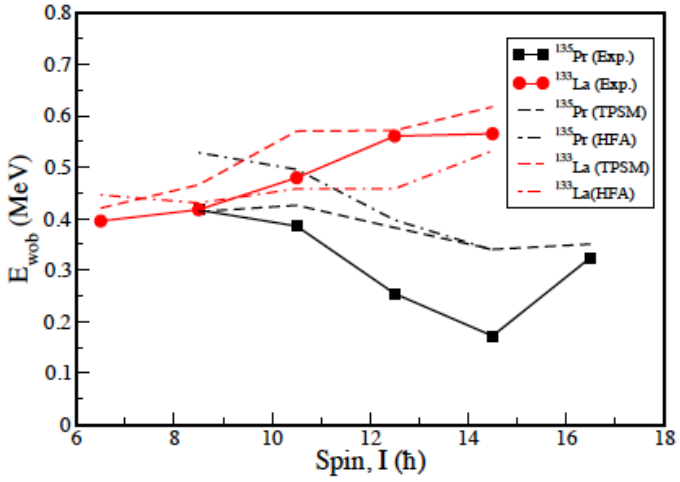


SF, FD PRC (2014)

Polarization, Angular distribution, $T_{1/2}$



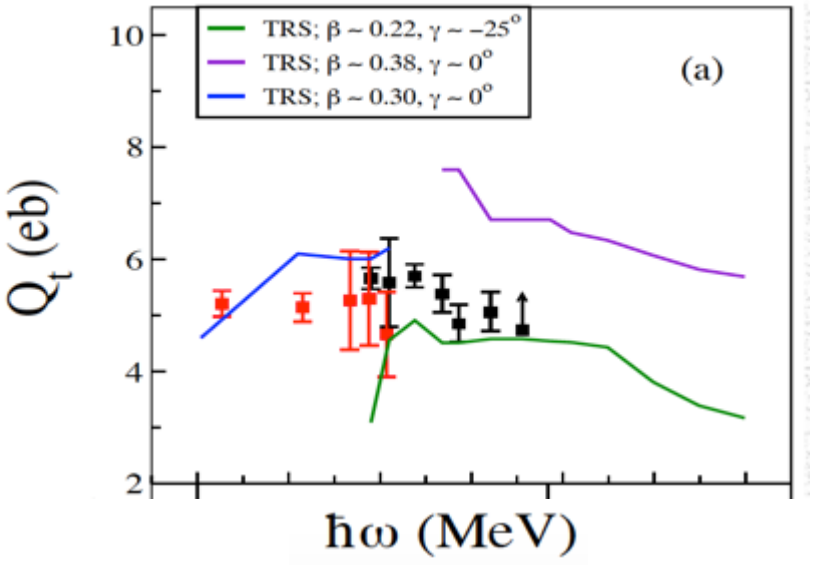


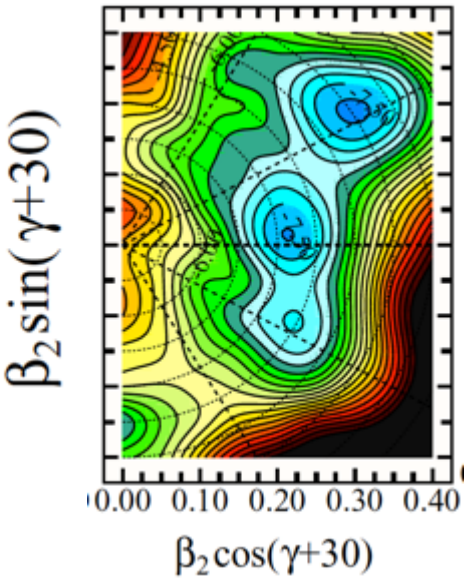


T. Roy et al. PLB 782, 768 (2018)
N. Rather, etal.,PRL112,202503(2014)
J. Sethi, et al., PLB 725, 85 (2013)

S. Biswas, et al., EPJA 55 159 (2019) ^{133}La
J. Matta et al., PRL 114 082501 (2015) ^{135}Pr

Proposal for high energy gamma ray measurement feeding triaxial and axial shapes in ^{136}Sm



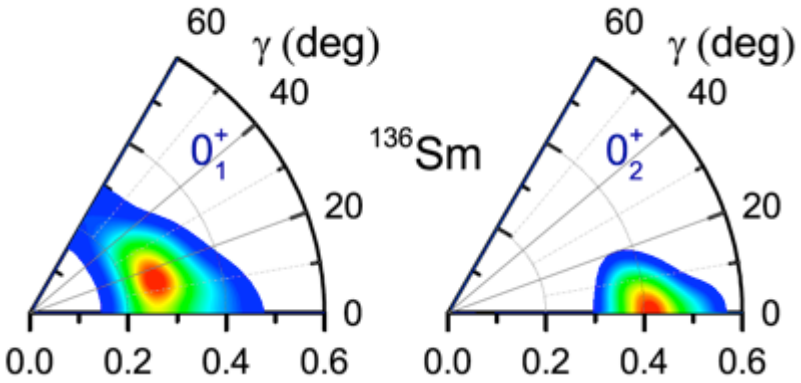


Gamma soft at low-spin to rigid triaxial shape
F. Babra et al., PRC 100, 054308 (2019)

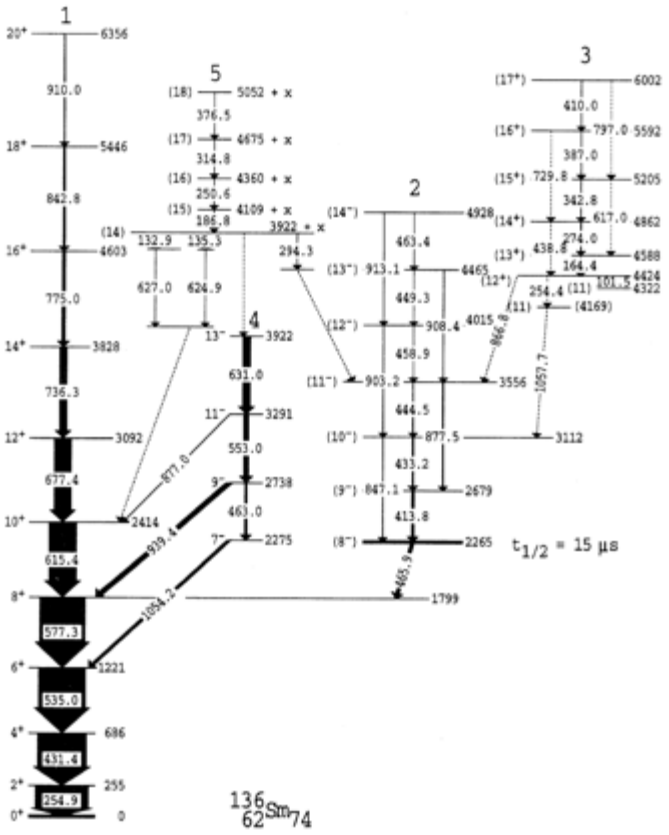
High-K 8$^-$ isomer axial symmetric shape
P.G. Regan et al., PRC 51, 1745 (1995)

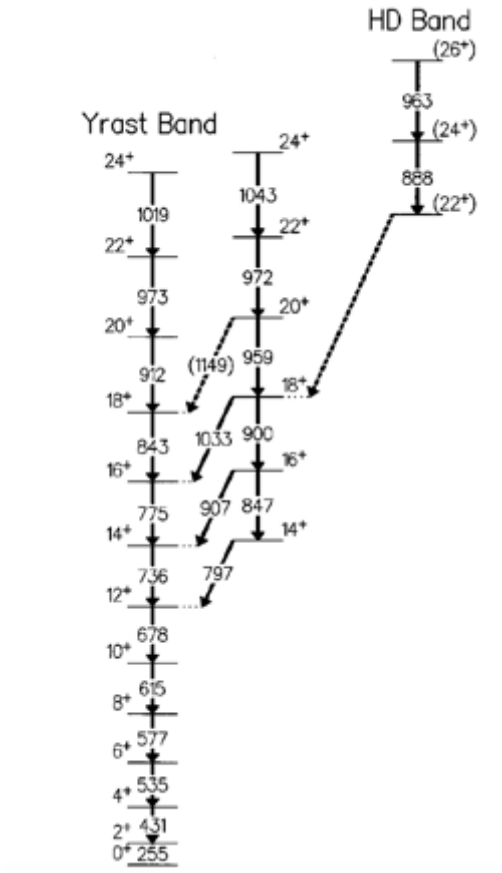
Highly deformed band
N. J. O'Brien et al. PRC 58, 3212 (1998)

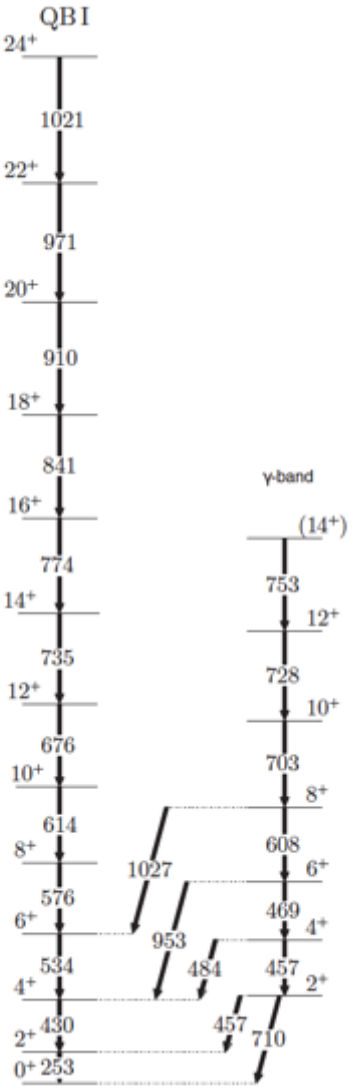
Shape coexistence at low spin
J. Xiang at al., PRC 98, 054108 (2018)



Proposal for high energy gamma ray measurement feeding triaxial and axial shapes in ^{136}Sm

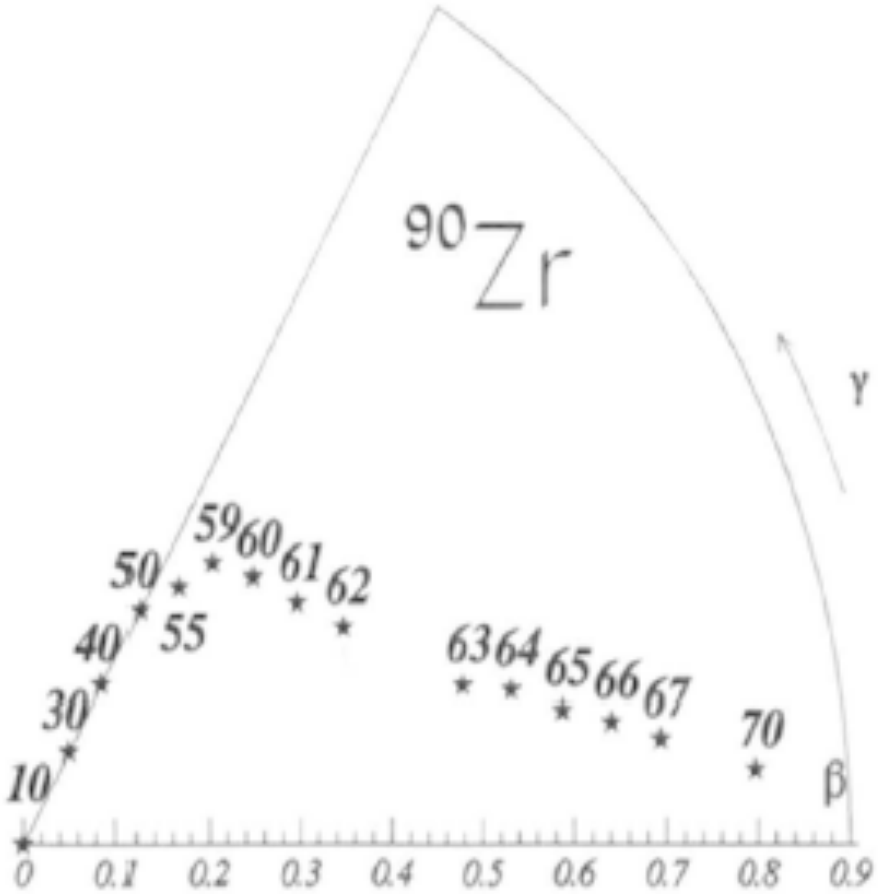






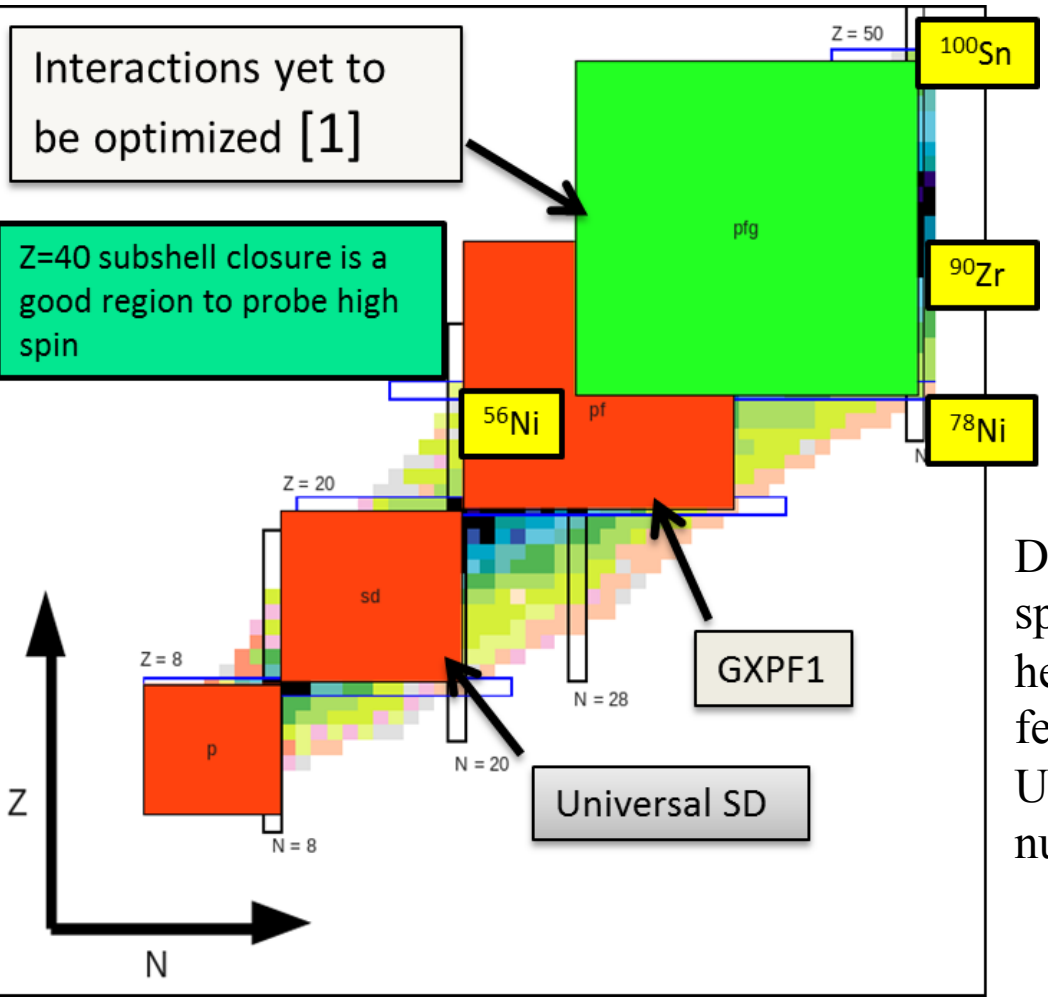
E.S.Paul et al., JPG 19, 861 (1993)
P.G. Regan et al., PRC 51, 1745 (1995)
N. J. O'Brien et al. PRC 58, 3212 (1998)

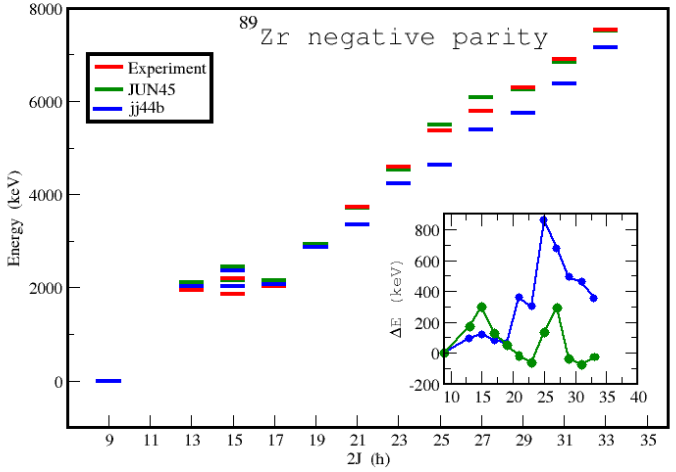
Shape variation at high spin for ^{90}Zr



J. Bartel, K. Pomorski, Int.J.Mod.Phys. E17, 100 (2008)

Test of shell model interactions for high spin states near ^{90}Zr





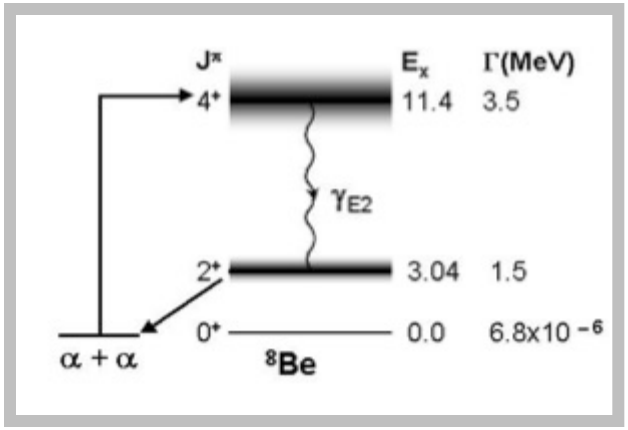
Difficult to extend the level scheme beyond spin 25ħ. HPGe array coupled to PARIS will help in search for high energy transitions feeding the low spin states.Essential for Understanding the decay of hot and rotating nuclei near 90Zr.

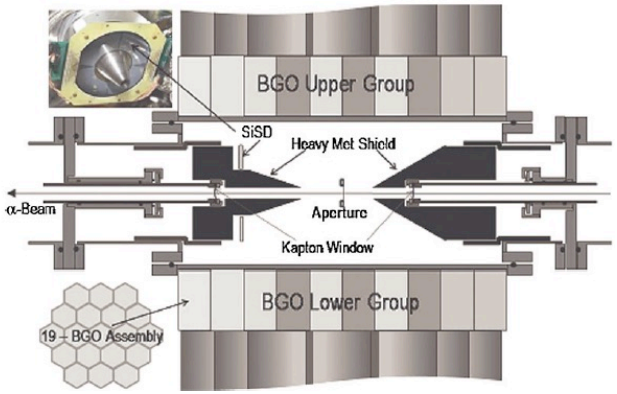
S. Saha et al., PRC 86 (2012)
S. Saha et al., PRC 89 (2014)
P. Singh et al., PRC 90 (2014)
S. Saha et al., PRC 99 (2019)

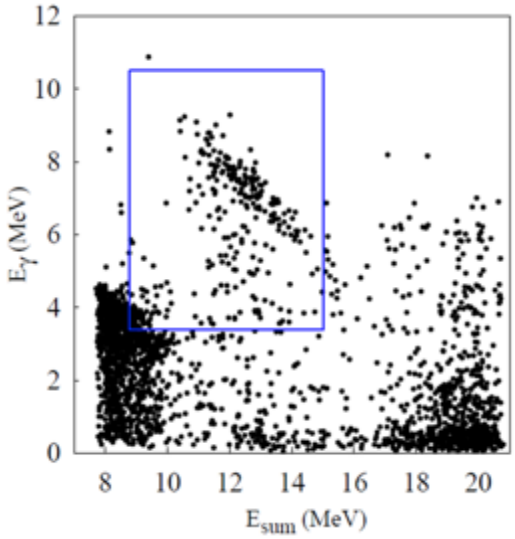
1) M. Honma et. al. Phys. Rev. C 80, 064323 (2009)

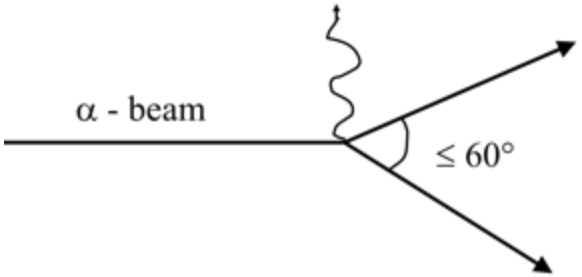
EM transition from 4^+-to-2^+ in ^{8}Be

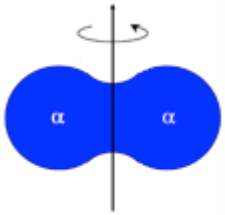
First measurement of radiative transition from ^{8}Be(4^+) resonance





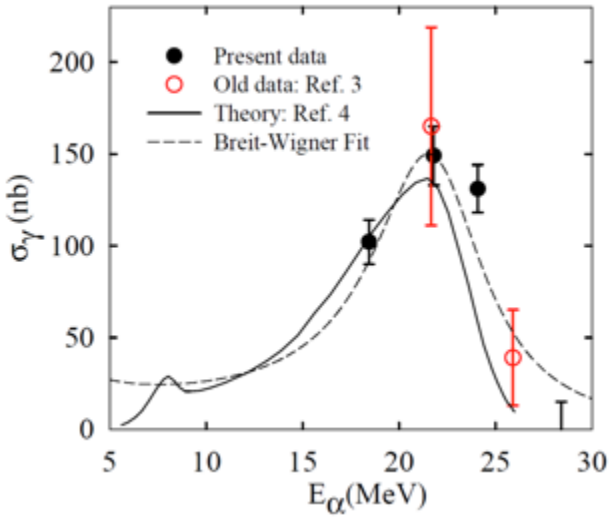






B(E2; $4^+ \rightarrow 2^+$) e^2fm^4

Cluster model	21.6
Ab initio (GFMC)	27.2 ± 1.5
Expt.	21.0 ± 2.3



*V. M. Datar et al, Phys. Rev. Lett . **111**, 062502 (2013)*

Courtesy of V. Datar

PARIS in Mumbai

We have

CeBr3+NaI : 9 no.s,

LaBr3+NaI : 4 (2 TIFR+2 BARC) + 3 ordered (VECC)

LaBr3 (2x 2") : 2

Possibility to use as 2 x2 mini clusters with INGA or a detector wall, full cluster

Possible experiments

- High-spin physics
  - Nuclei near ^{90}Zr, ^{136}Sm, Light nuclei near ^{20}Ne
- Coulex experiments
- $\alpha+\alpha \rightarrow$ ^{8}Be (4^{+}--2^{+}, 2^{+}--0^{+}) decay in coinc with CD detectors.
- C+C → particle- gamma coincidences

Summary

- Configuration of INGA, Ancillary detectors and Digital DAQ
- Possibility of combing the PARIS detector modules with INGA DAQ
- Few examples

Thank You for Your Attention!!

Acknowledgement:

INGA Collaboration,
PARIS Collaboration,
BARC-TIFR PLFC Staff