# *INGA goes Digital:*
# *Recent Results and Future Possibilities*

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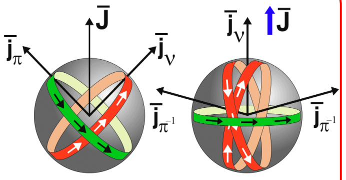
# Outline

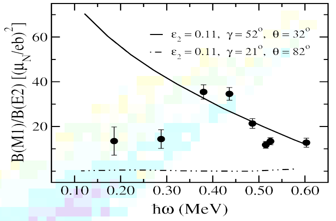
- Motivation for the INGA
- New features of present array at TIFR
- Recent results for odd-odd nuclei
  - Novel excitation modes
  - Interesting isomers
- Future possibilities

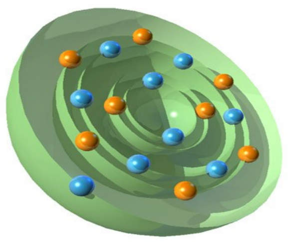
# *Physics focus with the INGA*

## Study of emergent phenomena in nuclei at varying spin, nuclear shape, correlations

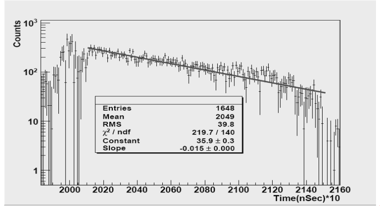


Magnetic and Anti-magnetic rotation in A~110 and 130 region.

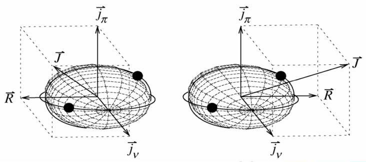




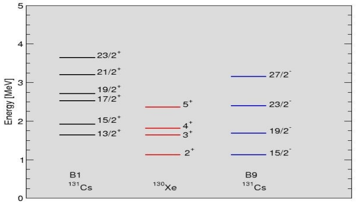
High spin states in neutron rich nuclei
Isomers near shell closure

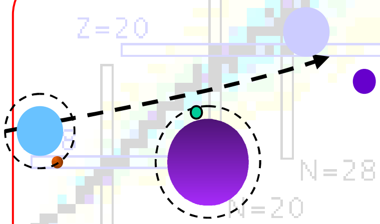


```
Entries               1648
Mean                  2049
RMS                   39.8
χ² / ndf       219.7 / 140
Constant        35.9 ± 0.3
Slope      -0.015 ± 0.000
```

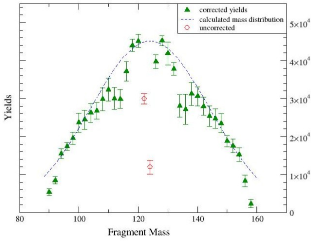


Transitional nuclei and excitations related to tri-axial degrees of freedom. Degenerate dipole bands





Fusion of weakly bound nuclei and fission dynamics



2011

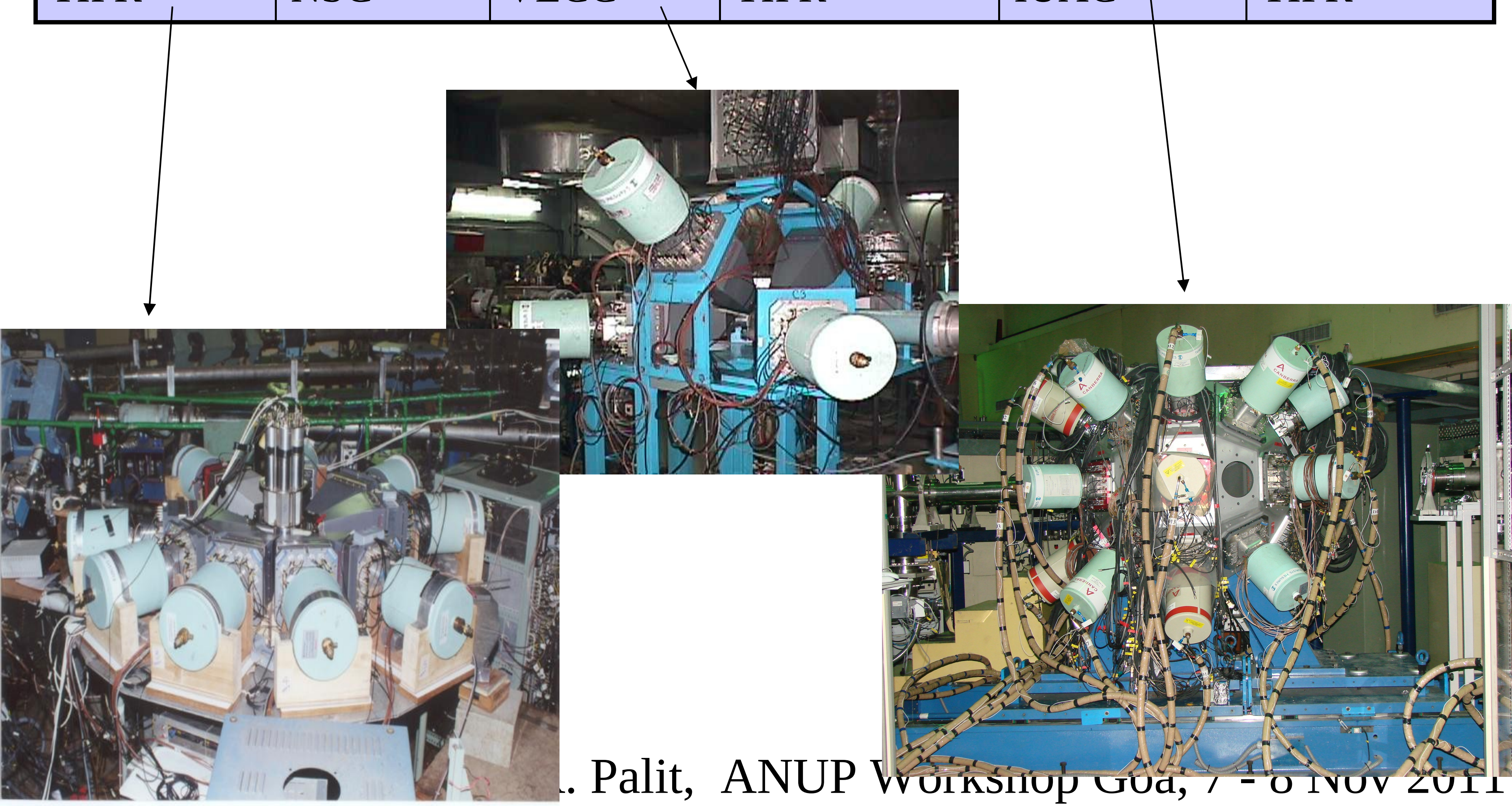
# *National Facility for Gamma Spectroscopy*

- Formal agreement between institutions for pooling resources: TIFR, IUAC, BARC, IUC-DAEF, SINP & VECC
- Three short campaigns carried out at TIFR, IUAC & VECC using existing resources during 2001-2006
- Fourth campaign (2008 - 09) with the augmented facility just completed at IUAC
- Fifth campaign has started at TIFR from Dec 2010

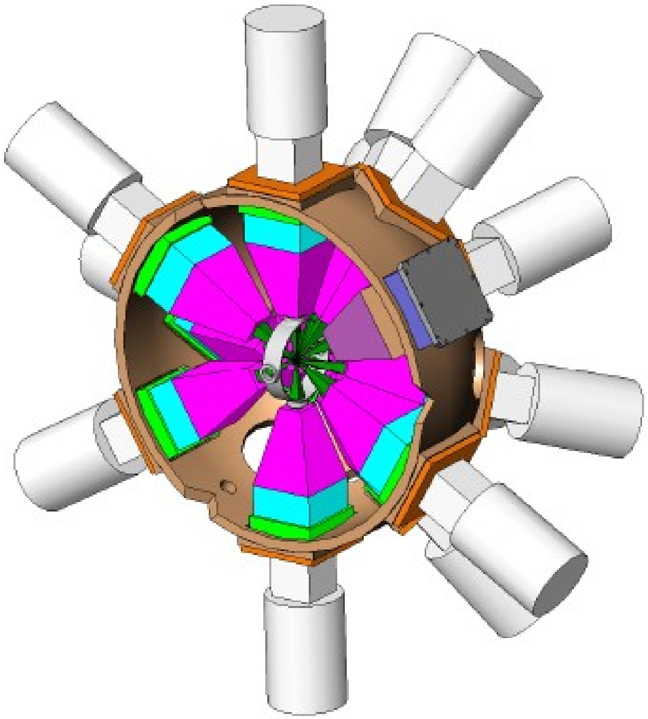
6 Institutes and 10 Universities within India
50 – 60 researchers within India and abroad are participating in different experiments
36 experimental proposal
15 experiments were completed

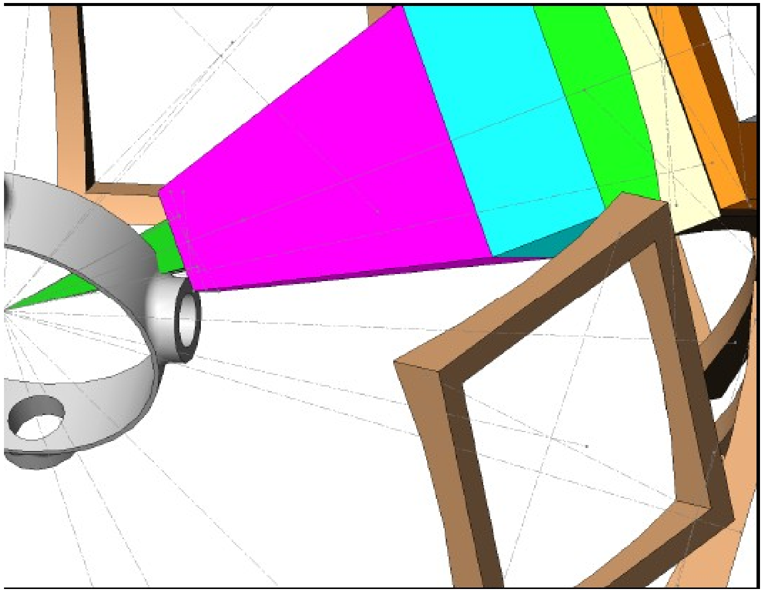
# INGA campaigns at different accelerator facilities

| INGA01 | INGA03 | INGA05 | sINGA07-8 | INGA08-9 | INGA10-11- |
|---|---|---|---|---|---|
| TIFR | NSC | VECC | TIFR | IUAC | TIFR |



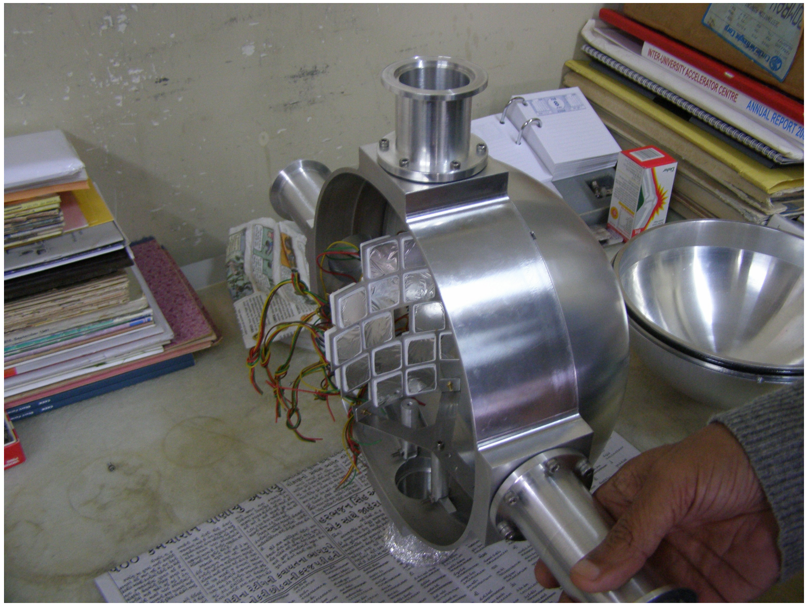
# Clover array at TIFR

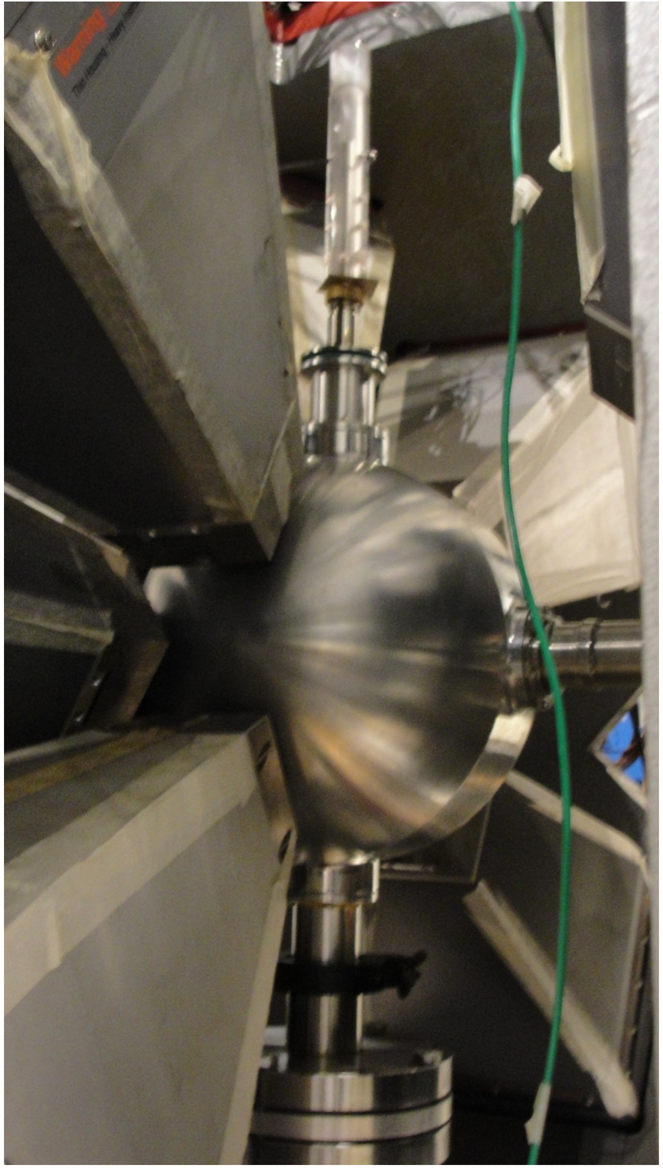




R. Palit,  ANUP Workshop Goa, 7 - 8 Nov 2011

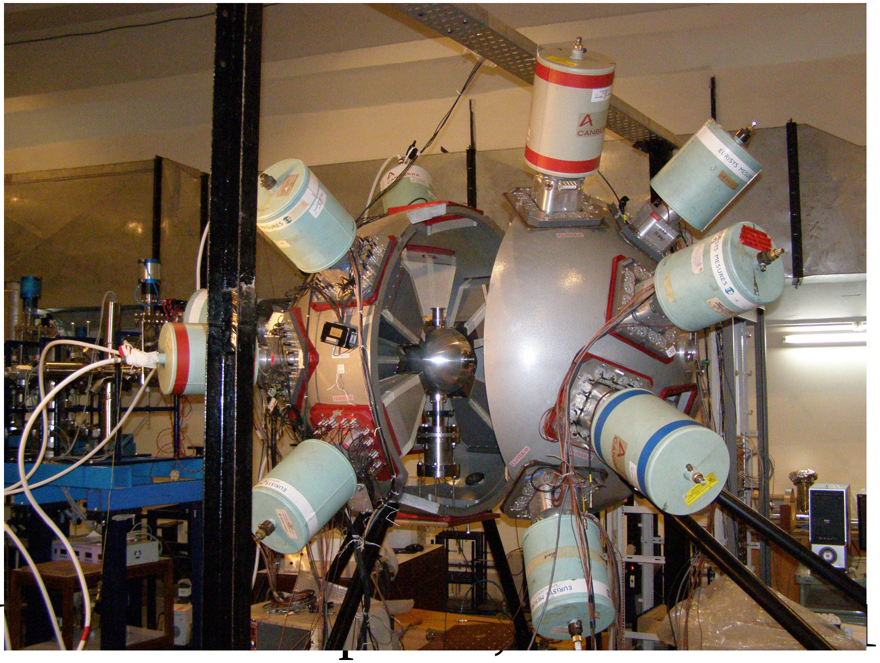
# Target chamber for INGA



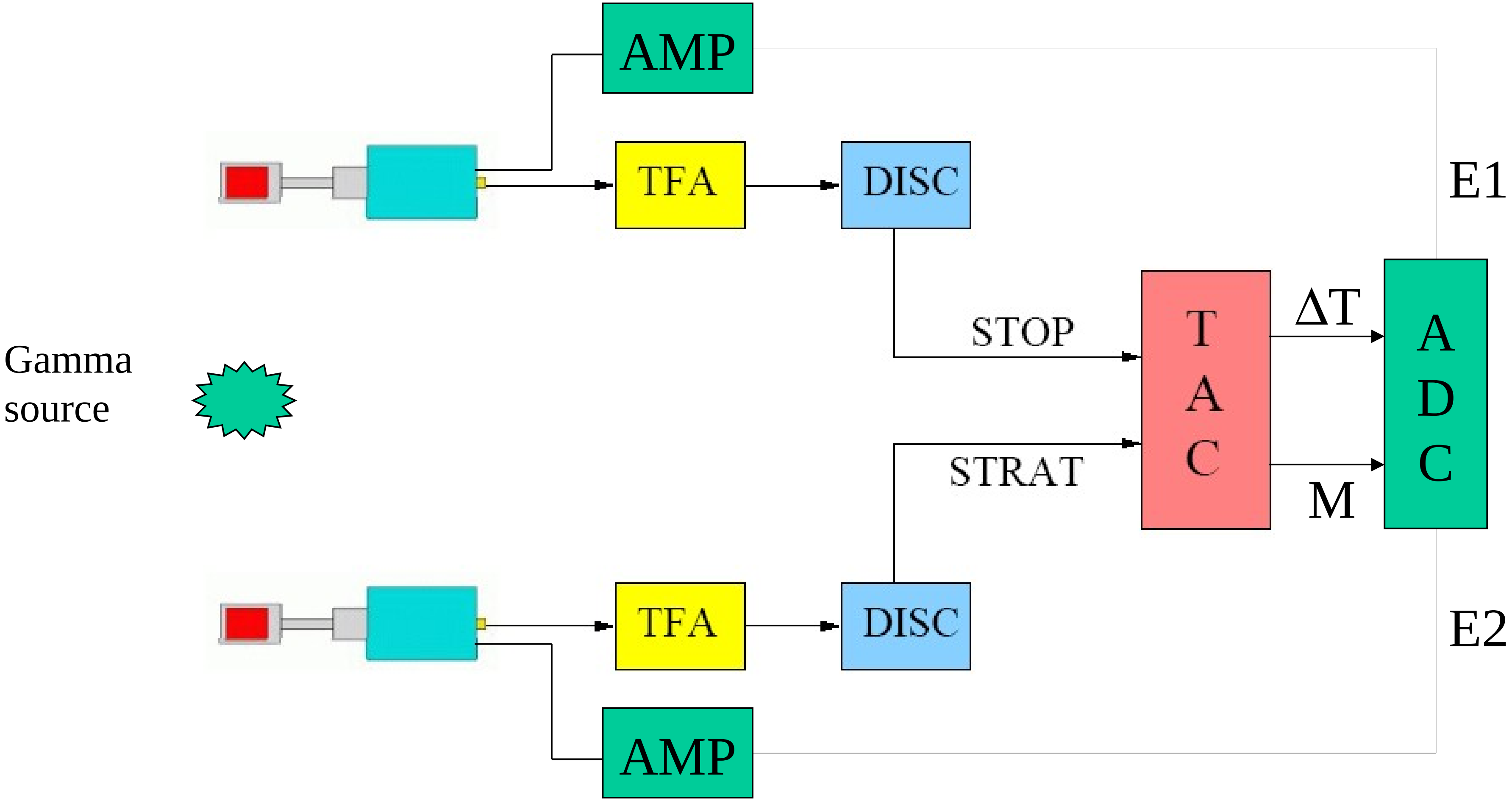


# Basic Configuration at TIFR from 2010

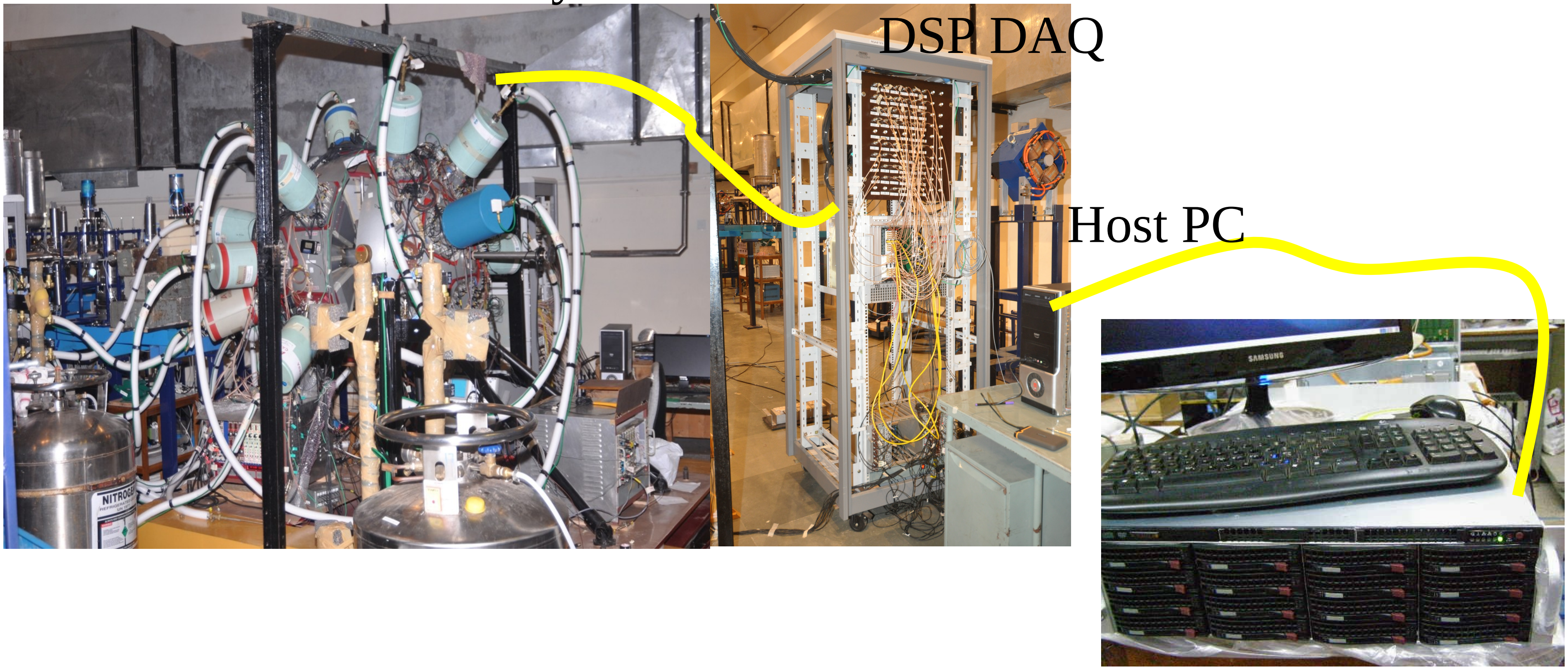
- Set up in Beam hall II of TIFR-BARC (LINAC beam hall)
- Mounting position for 24 Clovers (~5% $\varepsilon_P$ )
- Movement on rails for precision alignment
- *Space for mounting Charged Particle Array*
- *3 at $23^{o}$, $40^{o}$, $65^{o}$, $115^{o}$, $140^{o}$, $157^{o}$ and 6 at $90^{o}$*



# *Slow-Fast coincidence techniques: Old school*



# DDAQ with INGA



Detector Array

DSP DAQ

Host PC

PC for Storage & Analysis

Detectors -> DSP cards -> PCI Bridge -> PC-> Gigabit -> PC

# *DSP based DAQ for 24 CS-Clovers and Ancillary detectors at TIFR*

## Technical specifications

- 100 MHz & 12-bit ADC‘s
- Data rate: 80 MB/sec
- Particle ID in CsI detectors using digital pulse shaping
- Trigger less system
- XIA based system

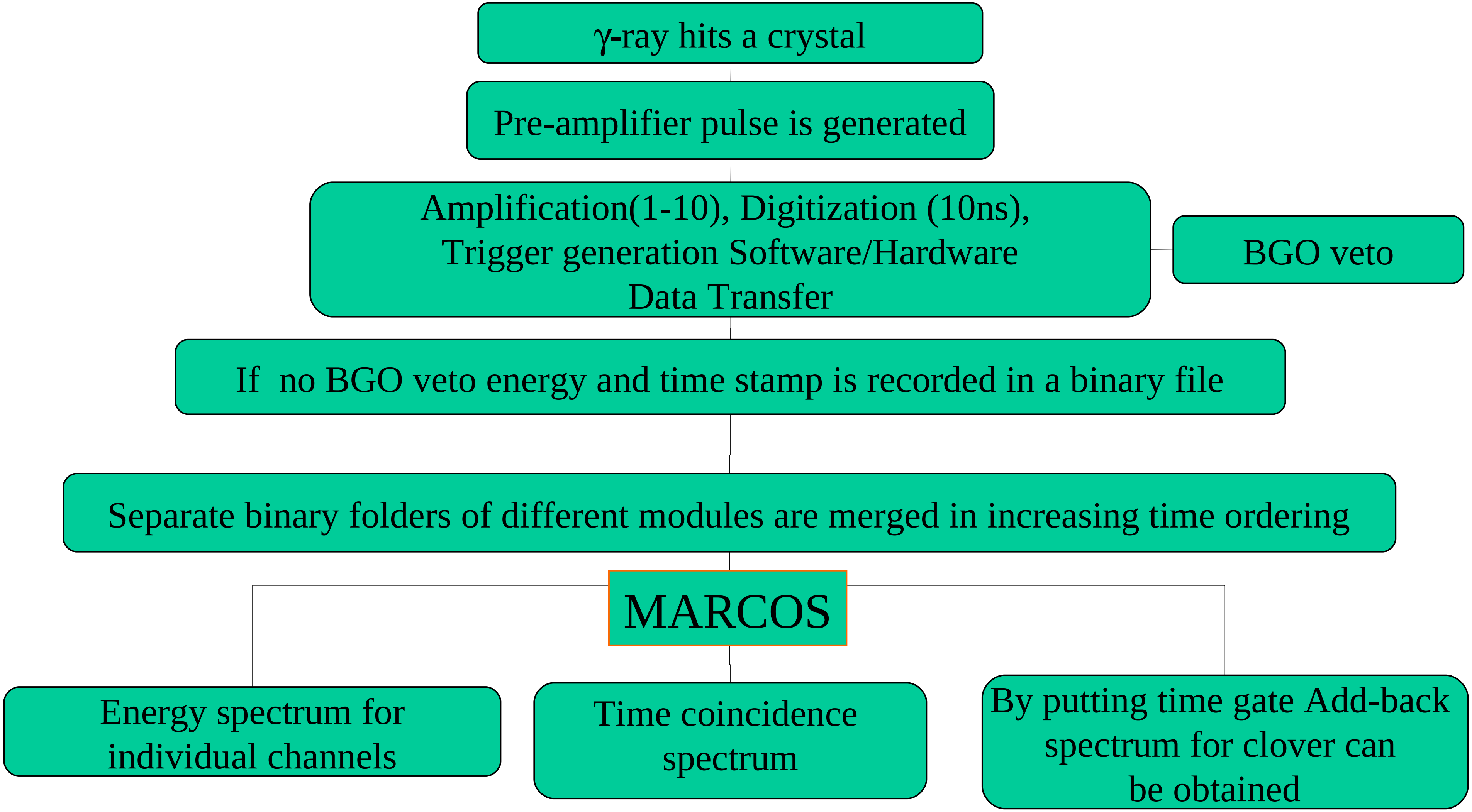
H. Tan et l., NSS 08, IEEE (2008) p 3196

## Implementation for INGA

- ➢Modular so easily expandable
- ➢Versatile with complex trigger
- ➢High count rate
- ➢High stability
- ➢Zero dead-time
- ➢Long lived isomer measurements

R. Palit AIP Conf Proc. 1336 (2011) 573

# Signal processing with DDAQ



$\gamma$-ray hits a crystal

Pre-amplifier pulse is generated

Amplification(1-10), Digitization (10ns),
Trigger generation Software/Hardware
Data Transfer

BGO veto

If no BGO veto energy and time stamp is recorded in a binary file

Separate binary folders of different modules are merged in increasing time ordering

MARCOS

Energy spectrum for individual channels

Time coincidence spectrum

By putting time gate Add-back spectrum for clover can be obtained

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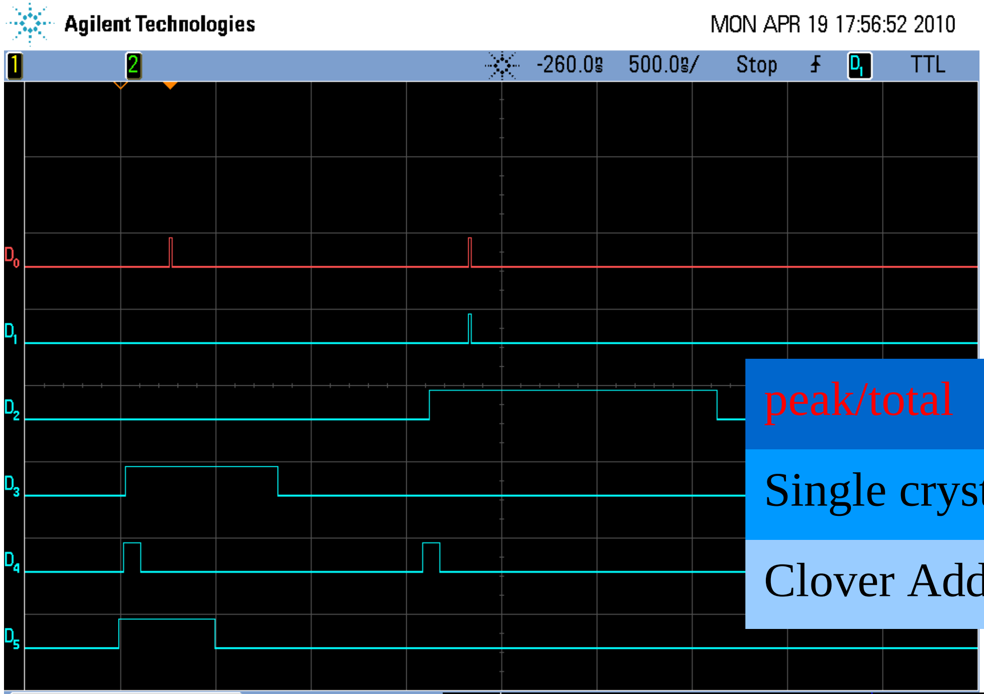
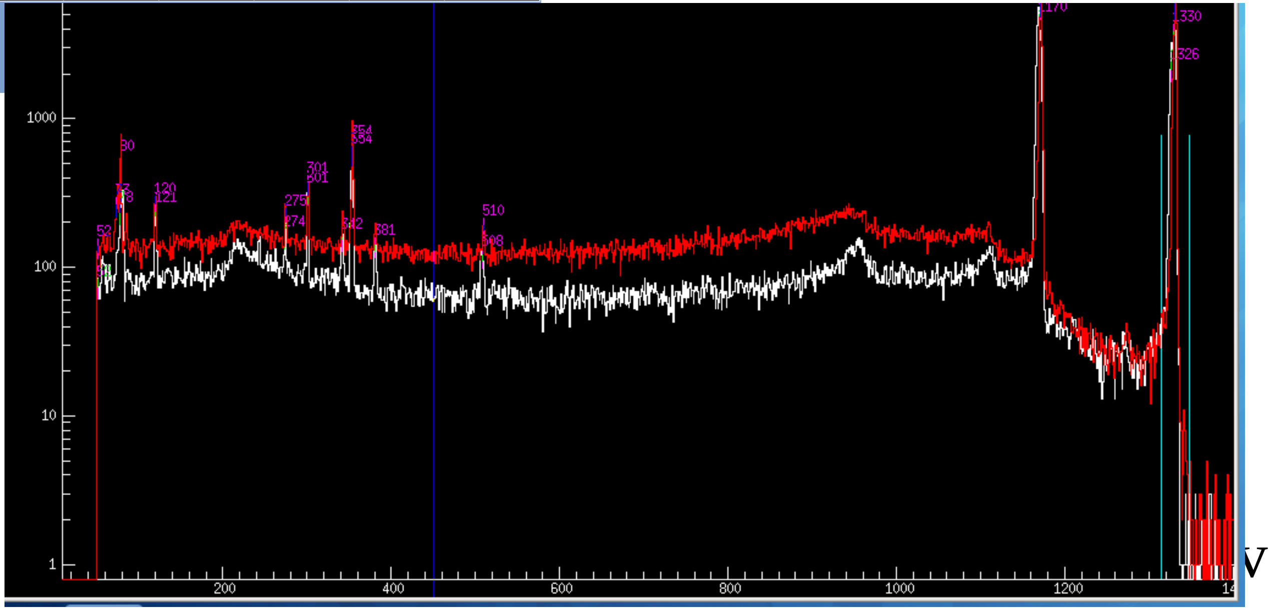
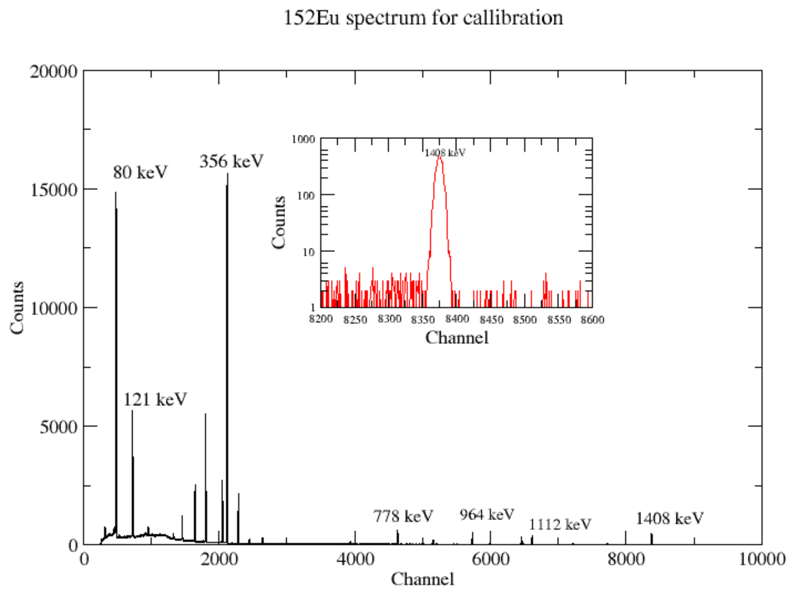
# Compton suppression in Clover

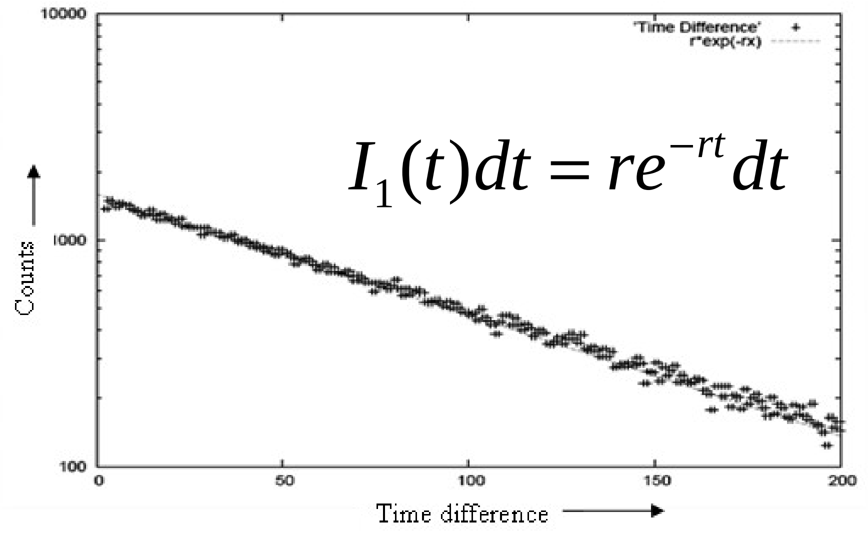


| peak/total | BGO off | BGO on |
|---|---|---|
| Single crystal of Clover | ~ 10% | ~ 15 % |
| Clover Add-back | ~ 22% | ~ 40% |



# *Energy: comparison with Analog system*



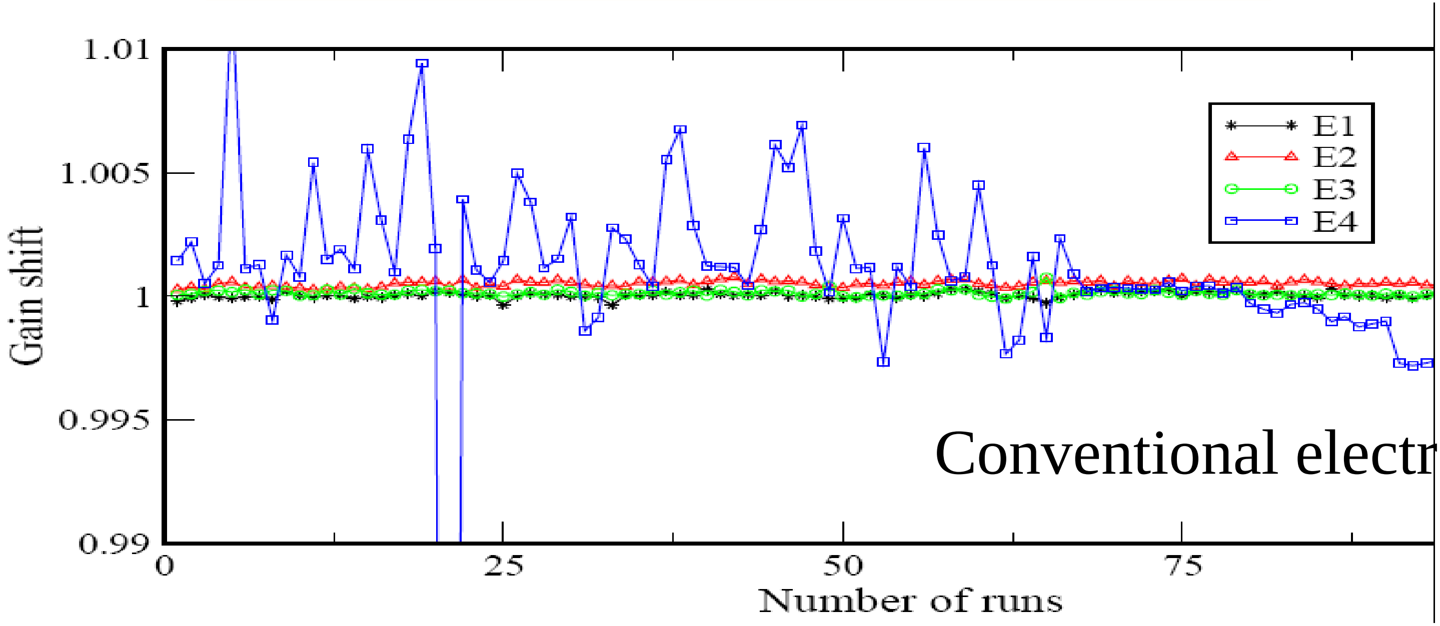


$$I_1(t)dt = re^{-rt}dt$$

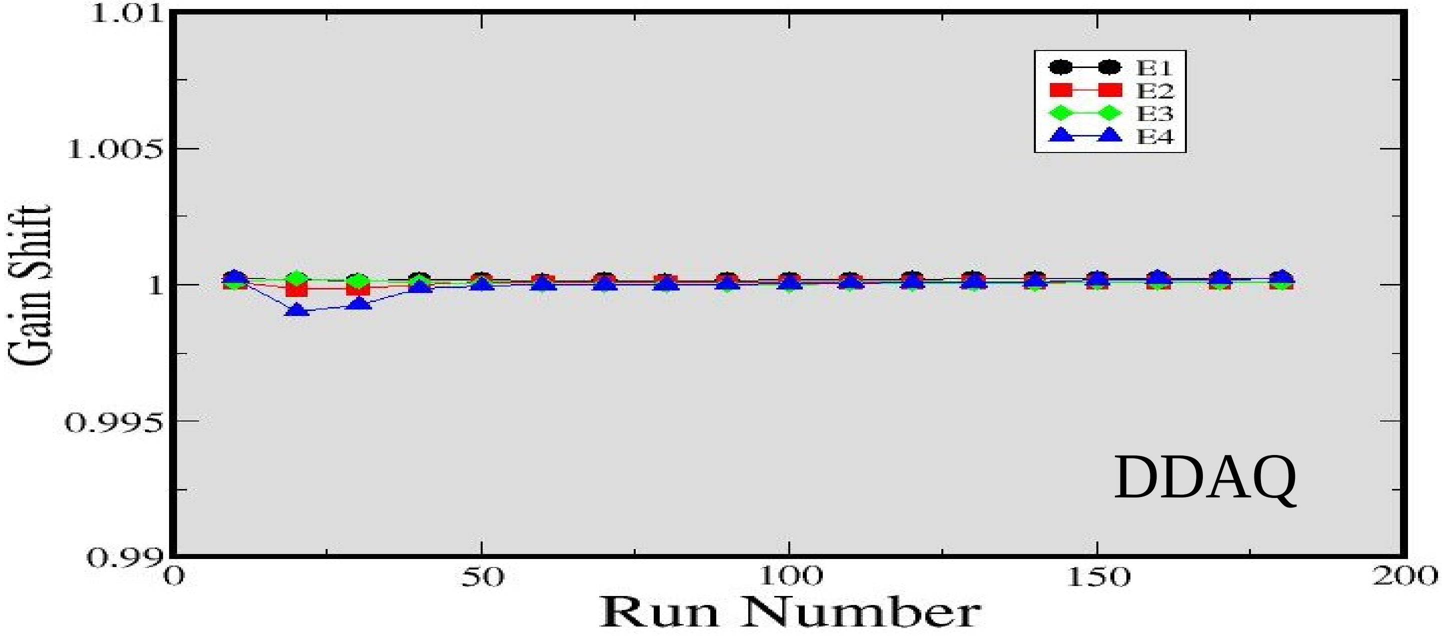
| Eg (keV) | Area (DDAQ) | Area (MCA) |
|---|---|---|
| 778 | 5604 | 5226 |
| 1112 | 4489 | 4583 |
| 1408 | 5849 | 5710 |

Comparison of count rates in DDAQ & MCA along with Time difference spectrum analysis implies zero dead-time

# *Better gain stability*

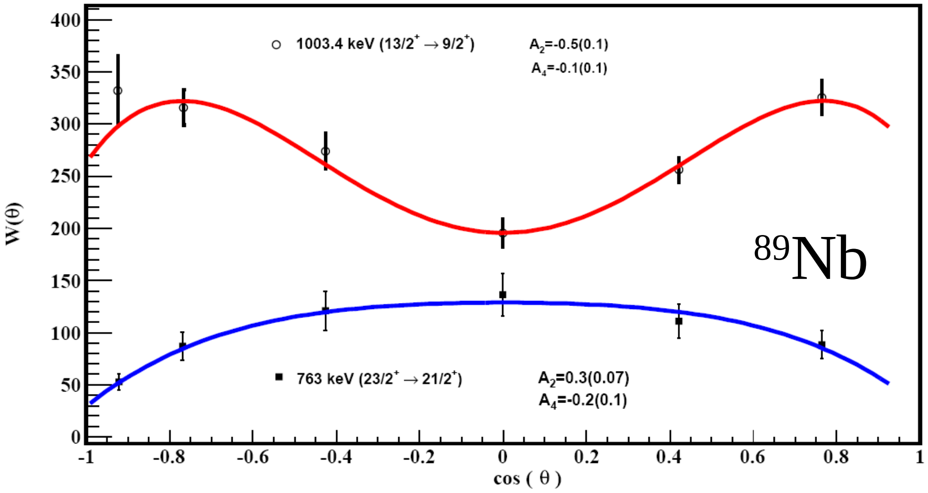


Conventional electronics

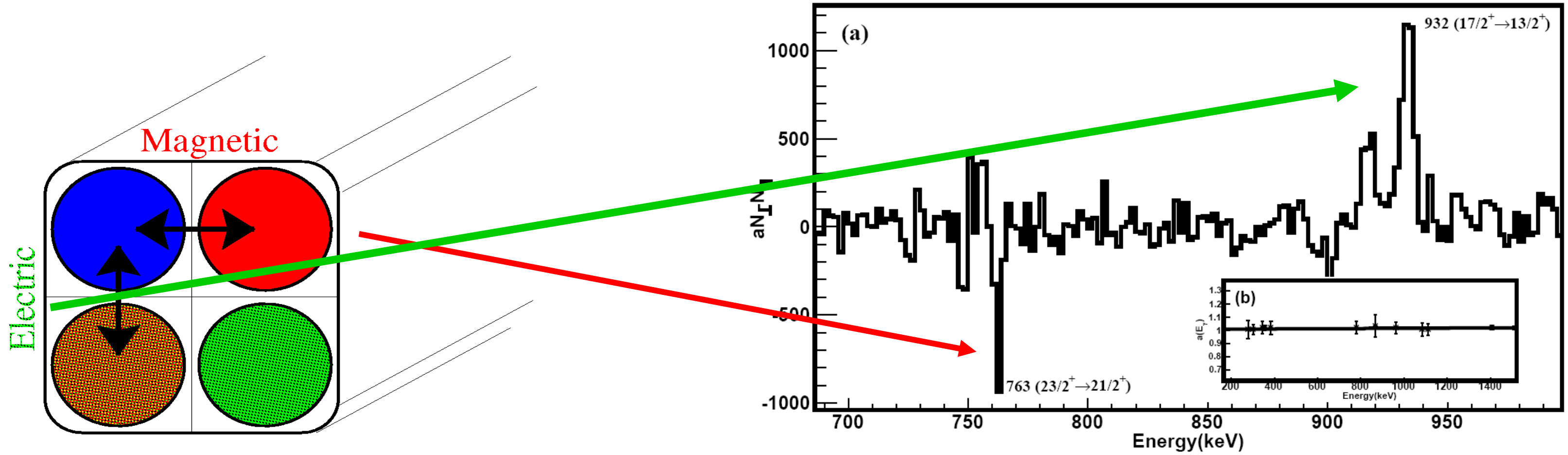


DDAQ

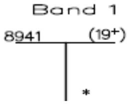
# *Angular Distribution & Polarization*



- ➢Singles measurement with 60 crystals each counting at 4- 5 kHz
- ➢Total throughput is 260 kHz
- ➢Data rate: 15 MB/sec
- ➢Trigger less mode
- ➢Cross section measurement

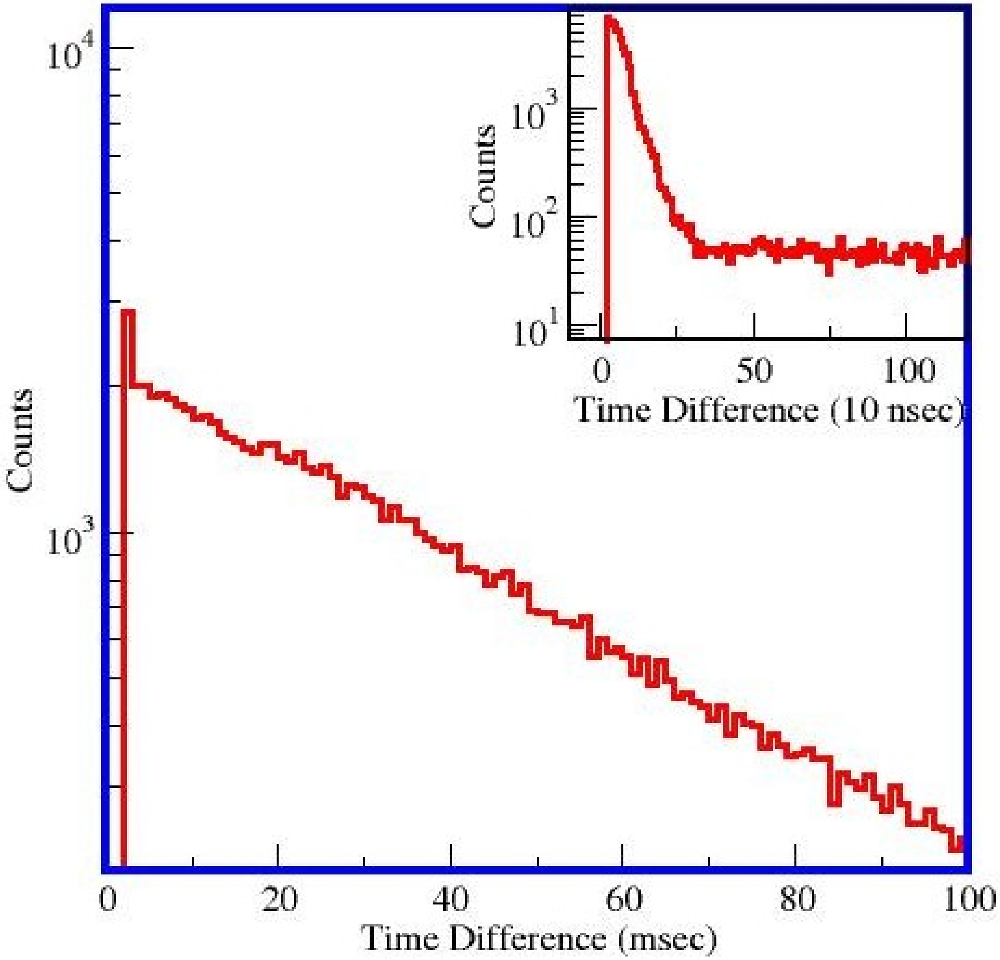


# Generating coincidence events from time stamped data



7 -10 kHz per crystal
15 – 20 kHz 2-fold clover
3.5 – 5 kHz 3-fold clover
with 16 clovers

>10 kHz 3-fold with 24 clov

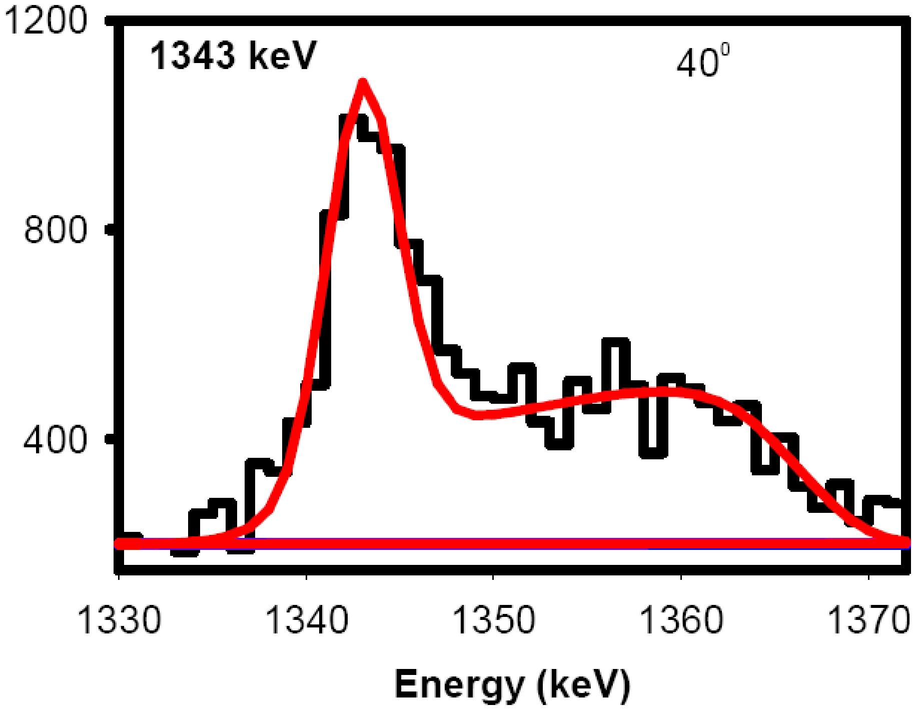


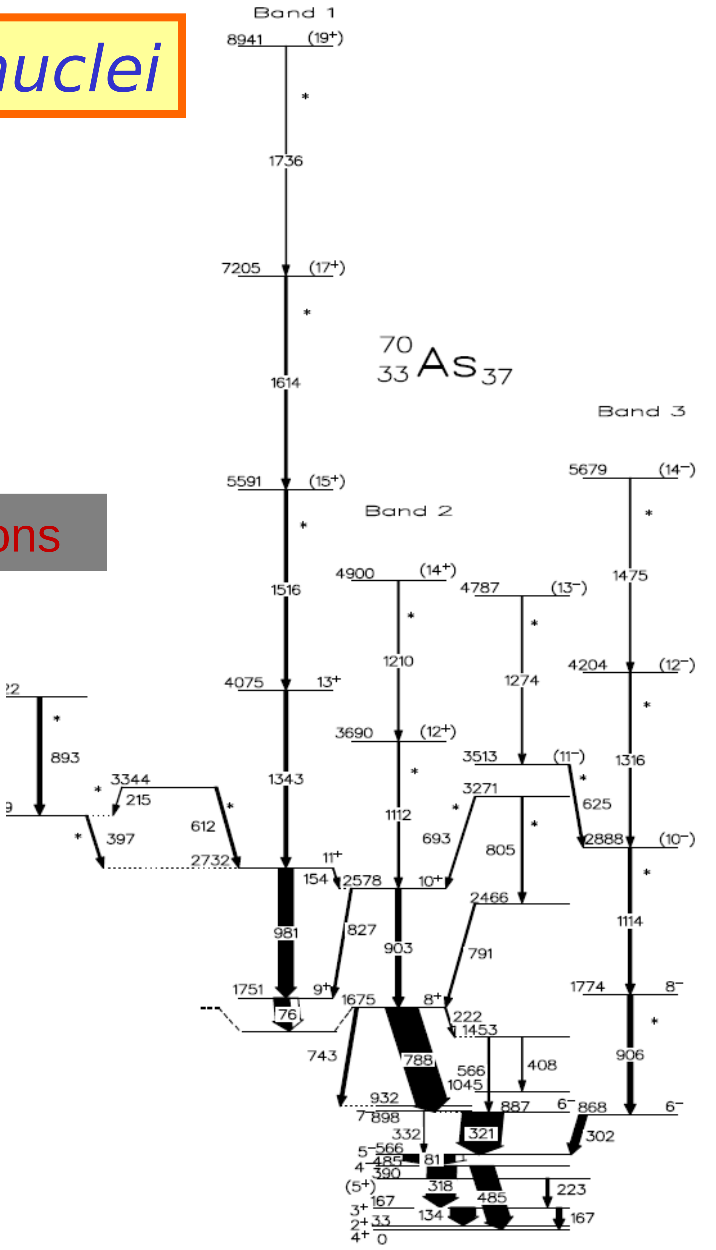
R. Pa

# *Shape evolution in f-p-g nuclei*

- The shape of the $^{70}$As is interpreted as almost spherical near the g.s. Whereas, at higher spins, corresponding to the population of $g_{9/2}$ sub-shell by the odd particles the shape becomes deformed ($\beta_2$ = 0.26).

Gated spectra with gate on 302 &788 keV transitions





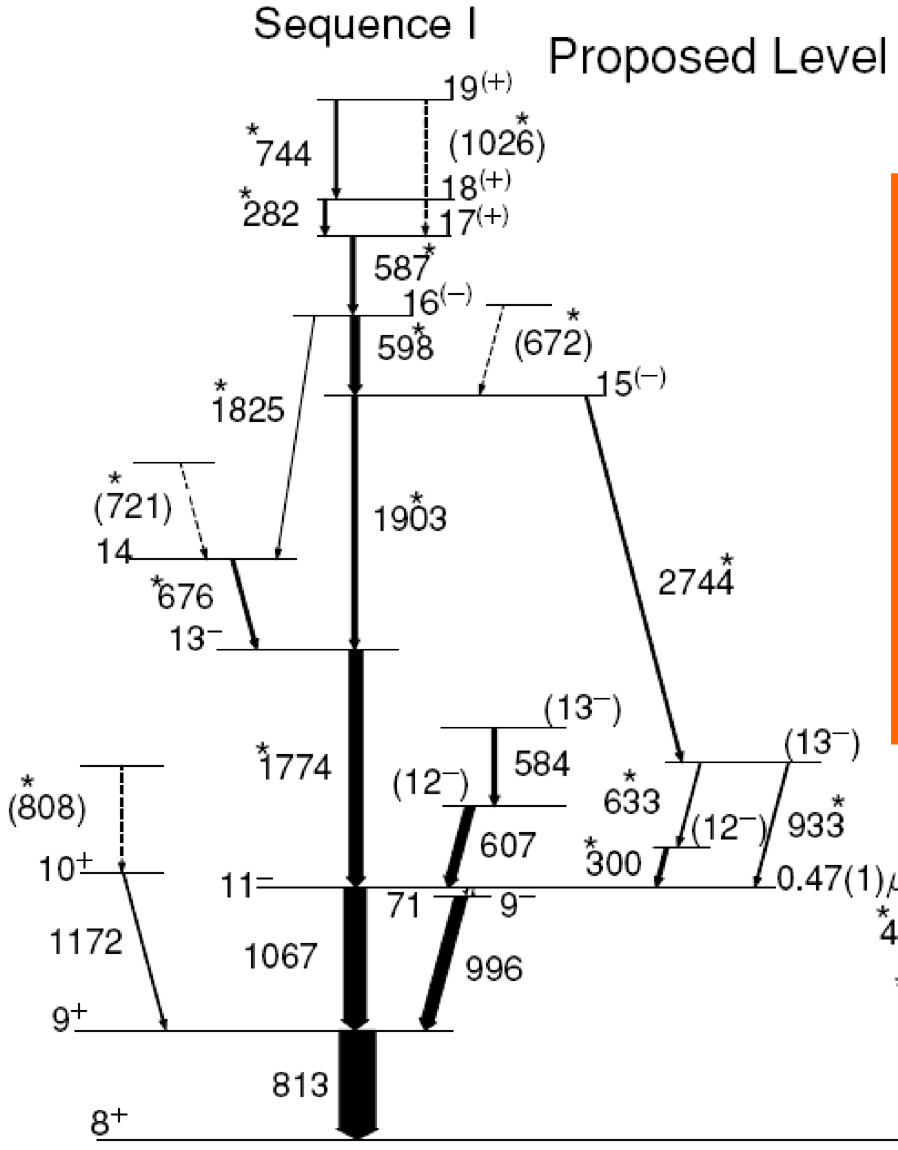
Level scheme from previous wor

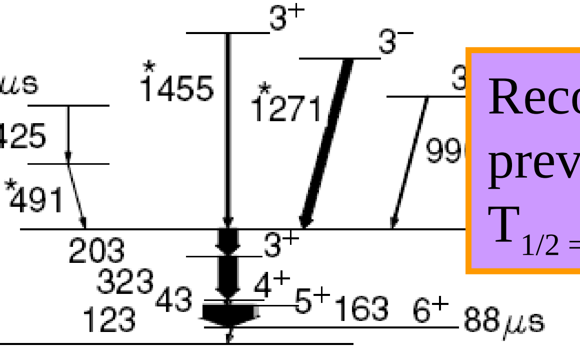
T. Tribedi, R. Palit, et al.

# Long Lived Isomers near N=50

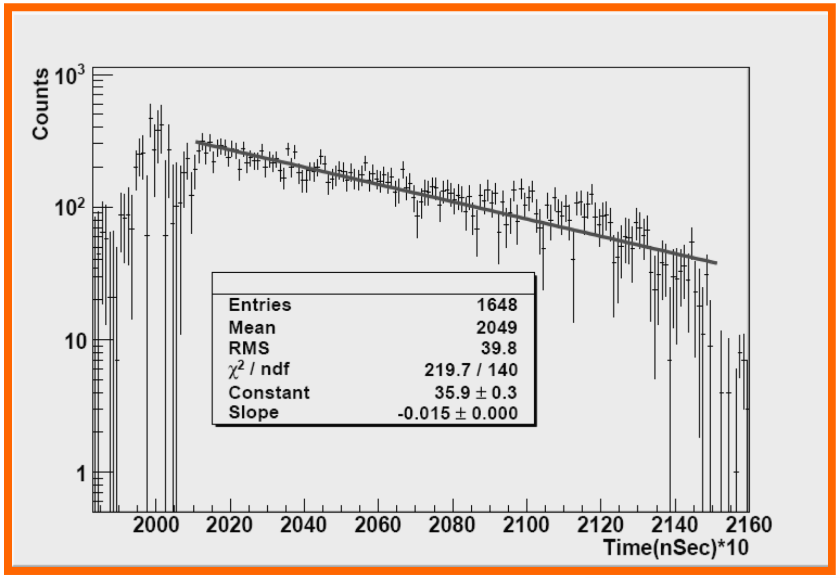
$^{28}$Si + $^{65}$Cu @105 MeV

Proposed Level Scheme of $^{90}$Nb





T-stamped data

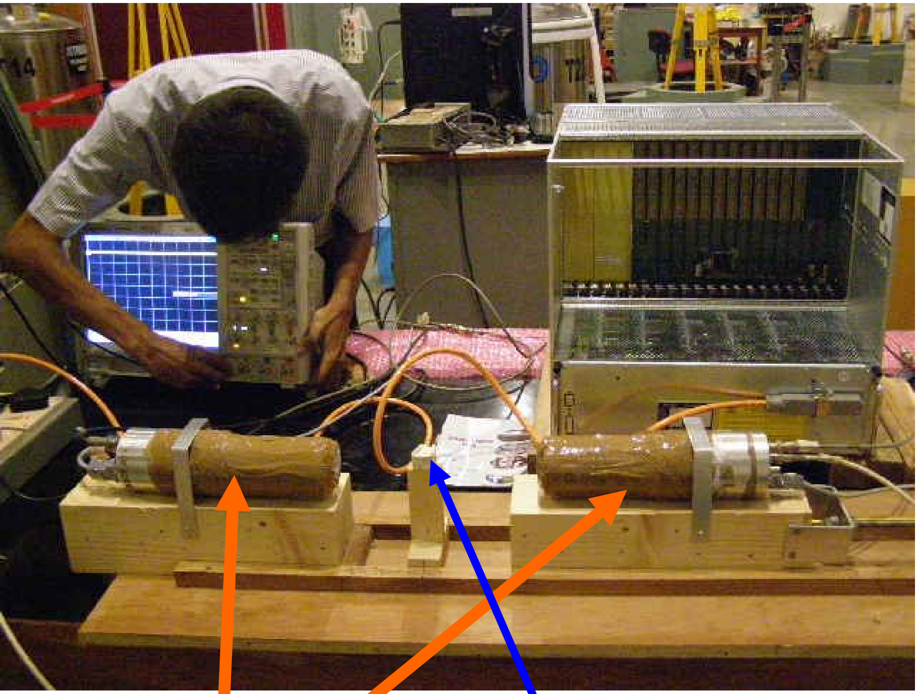


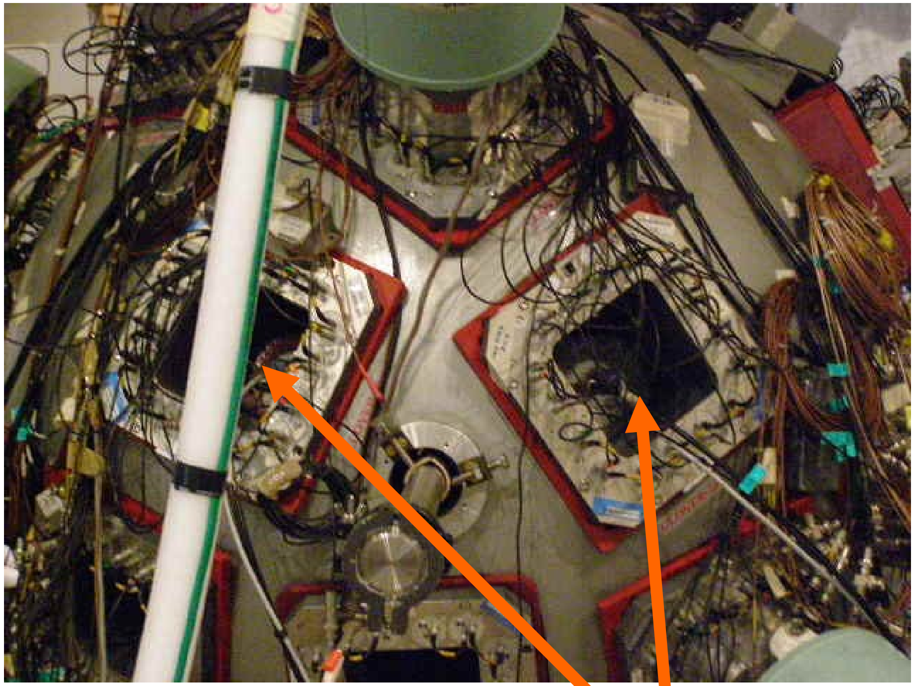
R. Palit, et al,

Reconfirmed the previous reported $T_{1/2}$ = 460 (10) nsec

A. Chakrabarti, et al. PRC 72, 054309 (2005)

# *Timing with Fast Scintillators $LaBr_3(Ce)$*





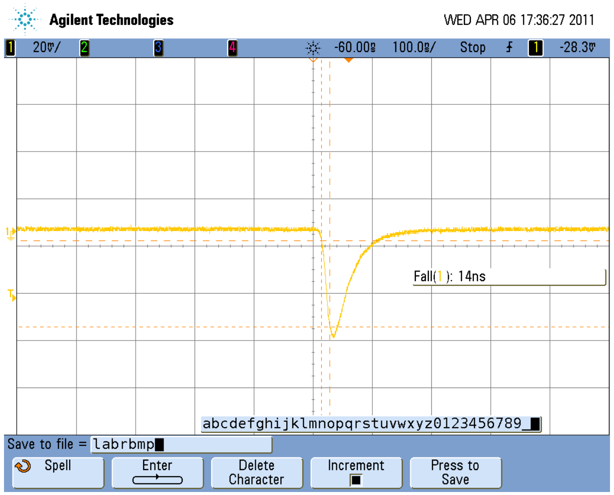
$LaBr_3(Ce)$

Source

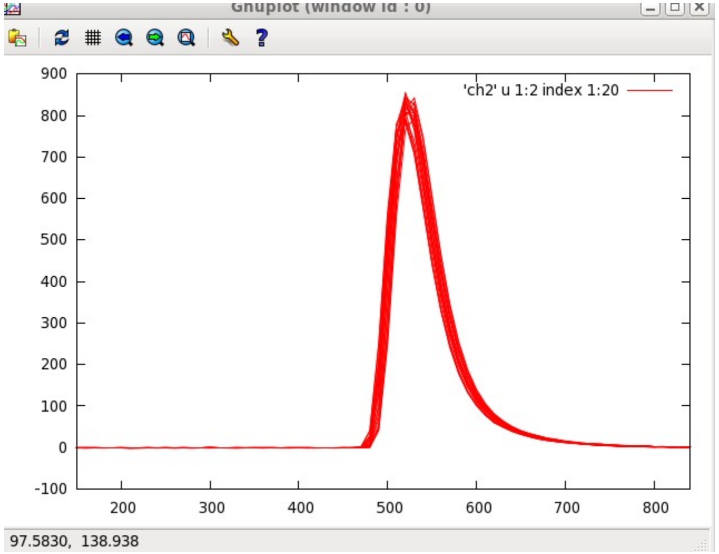
$LaBr_3(Ce)$

R. Palit, ANUP Workshop Goa, 7 - 8 Nov 2011

# *Timing with Fast Scintillators $LaBr_3(Ce)$*

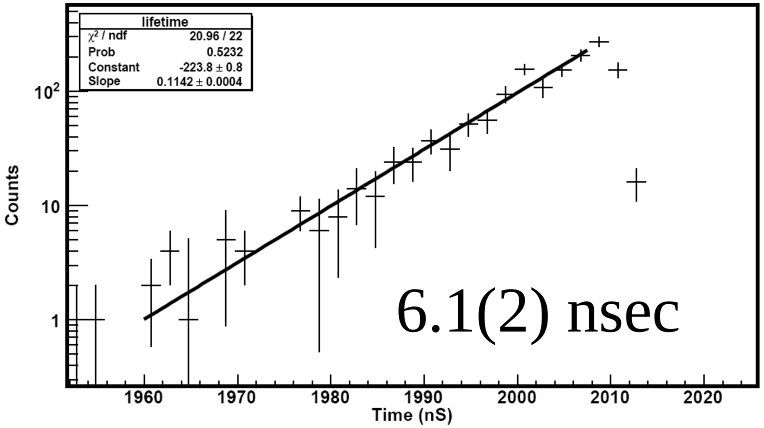


Effect of low pass Filter (Nyquist) →

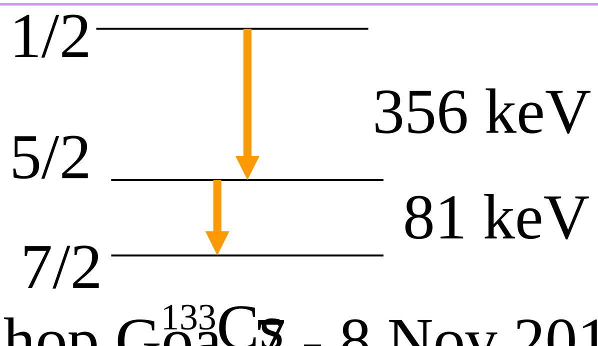


Rise time: Increases from 14 nsec to 50 nsec

Original signal is faster



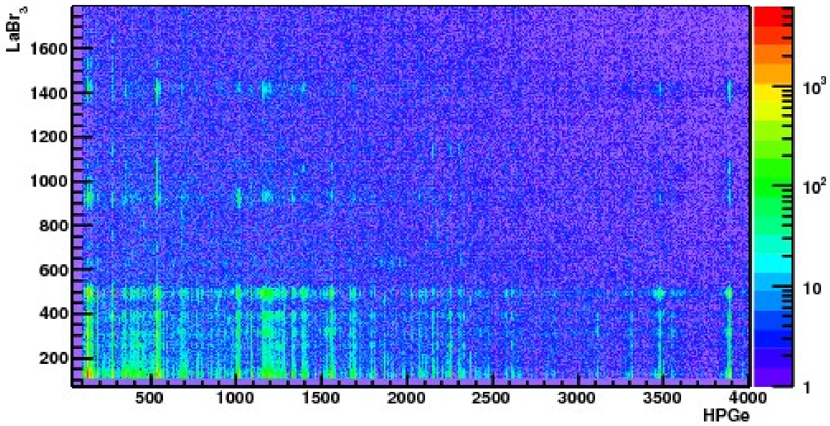
Time resolution ~ 520 psec with Na Source

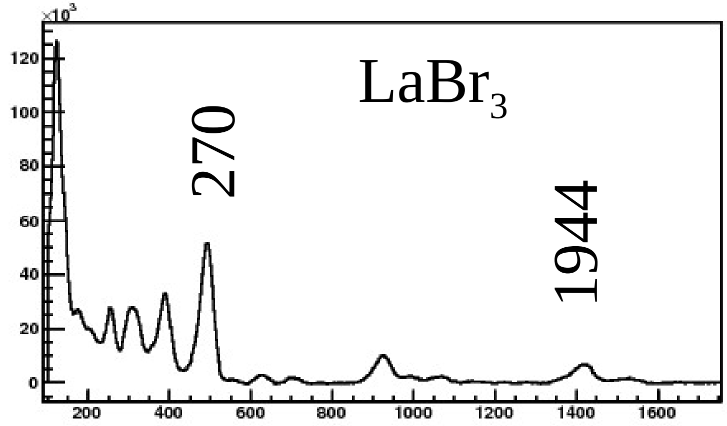


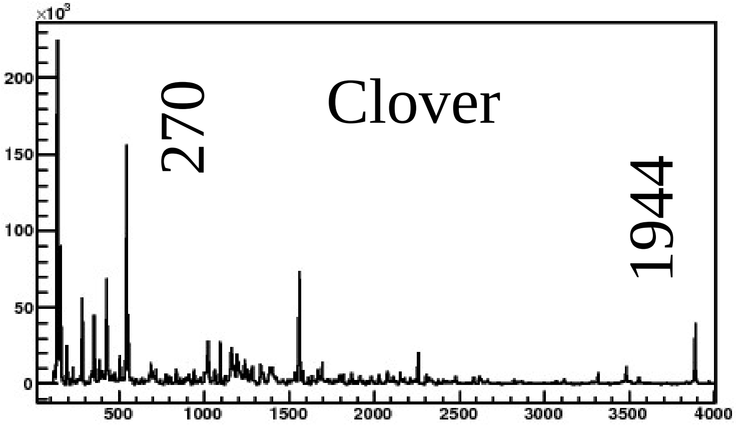
Sudipta et al.

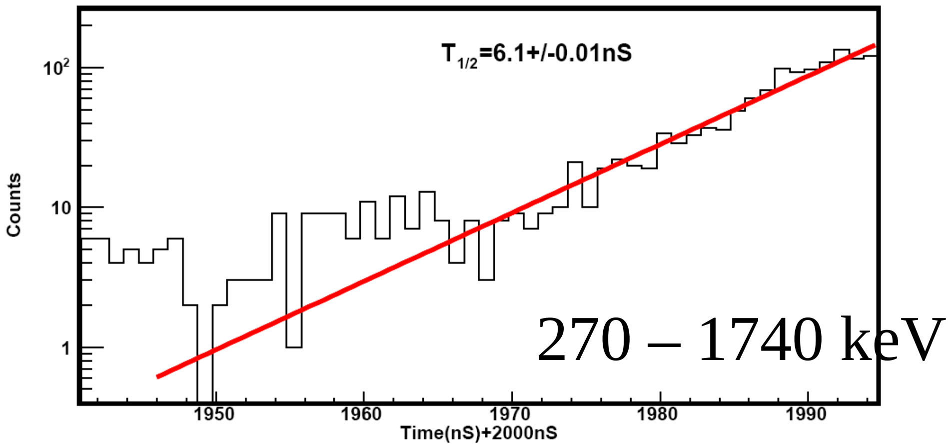
# High spin Isomers with two $LaBr_3$(Ce) coupled to INGA

$^{89}$Zr: 1944 – 780 – 270 – 1740 cascade extending the level scheme to 25/2$^+$



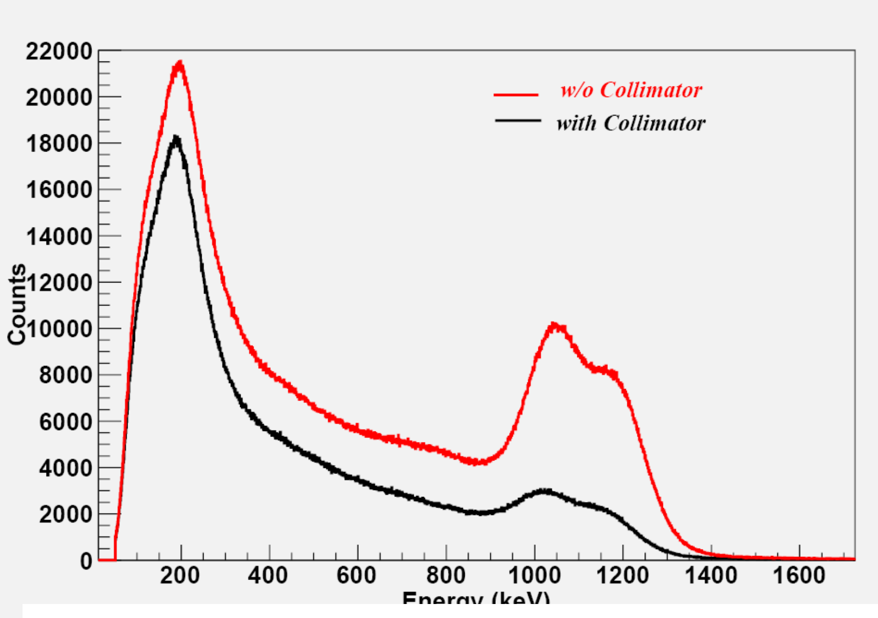






Sudipta et al.

# BGO Compton suppressed shield for multiplicity measurement



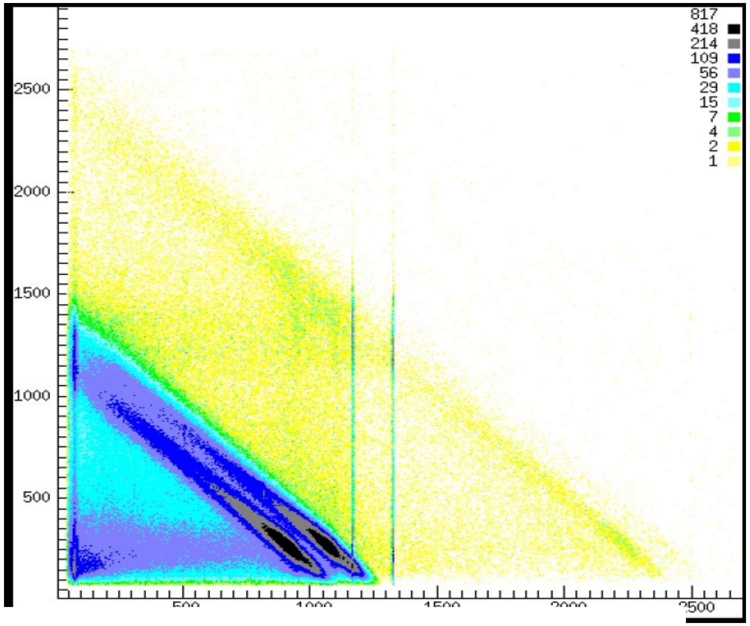


TABLE II: Relative Photo peak Efficiency and Total hit efficiency of Clover and BGO

| | Relative Photo peak Efficiency (within 1 %error) | Relative Hit Efficiency (within 1 %error) |
|---|---|---|
| Clover Add-back (w/o Compton Suppression) | 0.20% | 1.00% |
| Clover Add-back (Compton Suppressed) | 0.19% | 0.56% |
| Sum BGO | 0.57% | 1.99% |
| Sum BGO (Only BGO, no clover) | 0.54% | 1.56% |

J. Sethi, R. Palit, A.K. Sinha, S. S. Ghugre, et al.

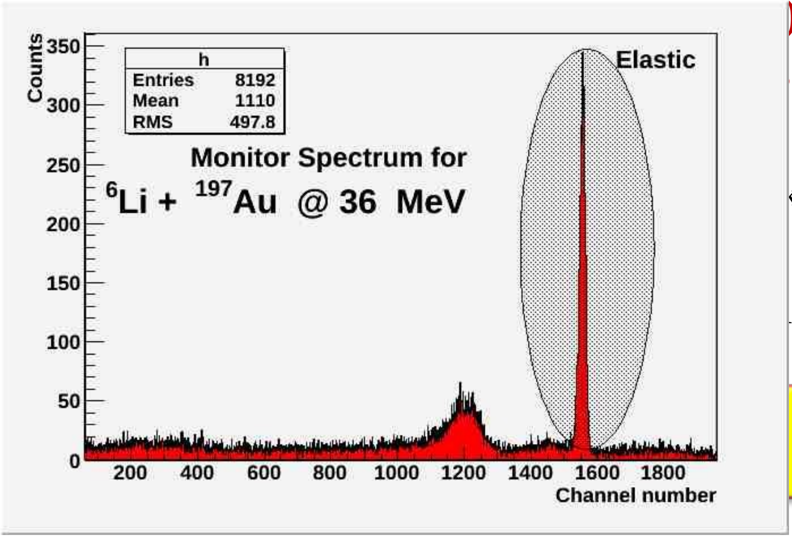
# Study of fusion in $^{6,7}$Li + $^{197}$Au at near barrier energies

- To study the influence of ) on complete fusion in reactions with weakly bound target $^{197}$Au at energies around the barrier.

Complete fusion cross sections ha kur *et al*, FUSION11 proceedings)

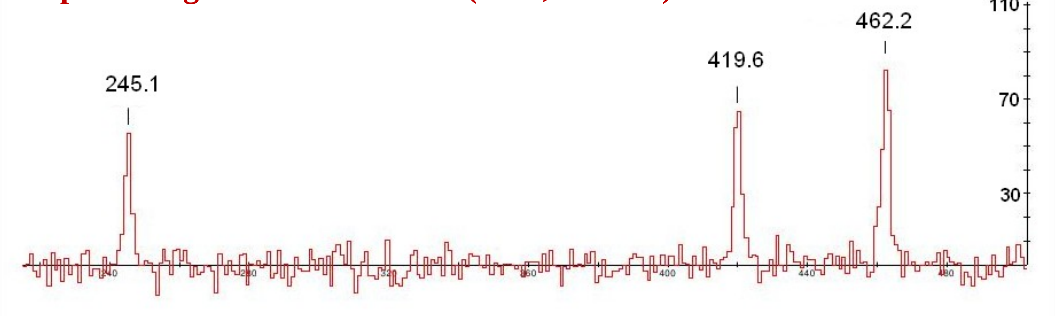
- INGA experiment to measure d/

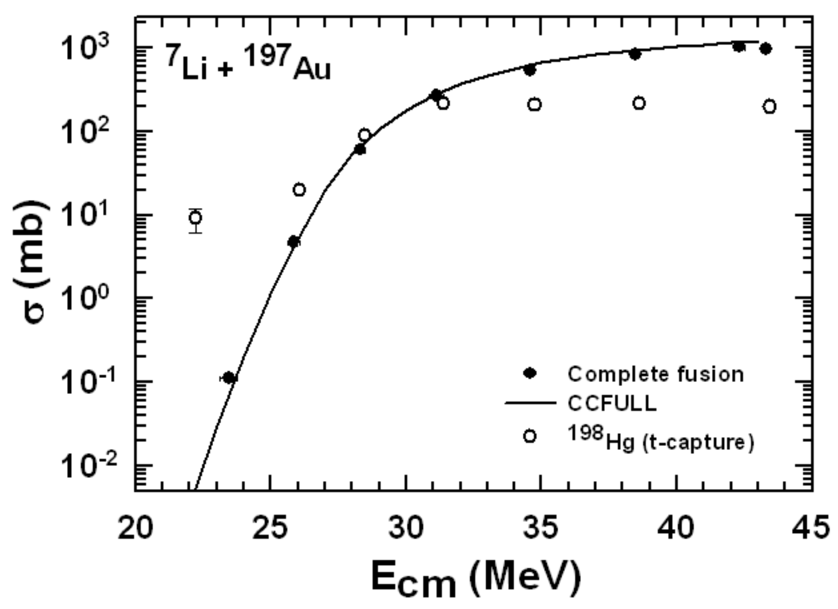
$^{6,7}$Li + $^{197}$Au at energies 21-45Me ency of 5% at 1332keV )



$^{6}$Li (E=26.5MeV) +$^{197}$Au (1.5mg/cm$^{2}$)
Gated spectrum of $^{200}$Pb (3n channel), σ($^{200}$Pb) = 3mb
~2pnA beam current , 30mins data with 2clover trigger

**Spectrum gated on 1026.6keV ($^{200}$Pb, $2^+ \rightarrow 0^+$ )**

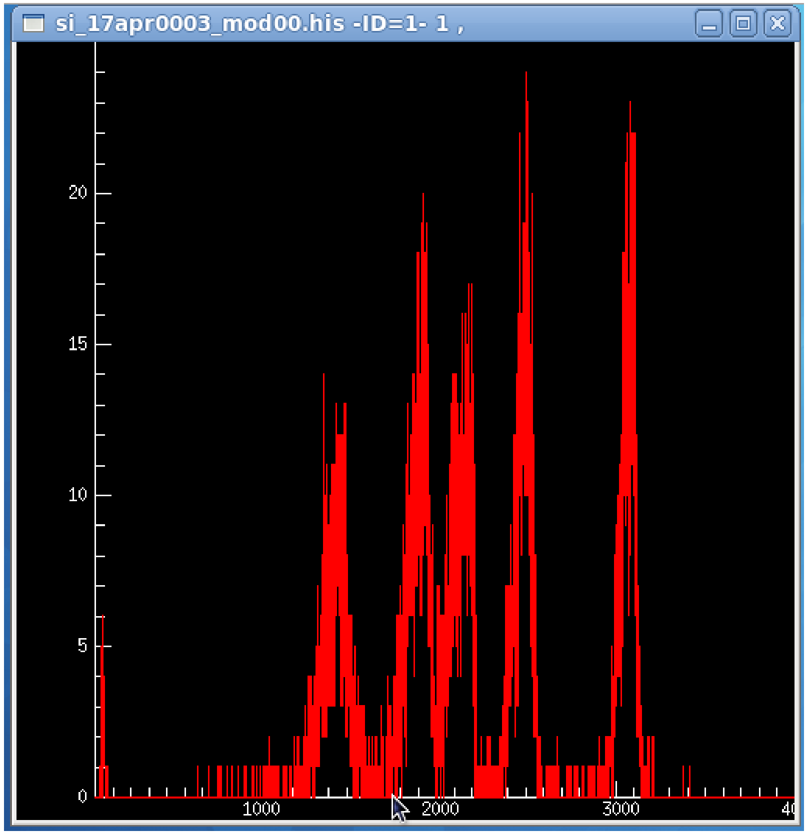




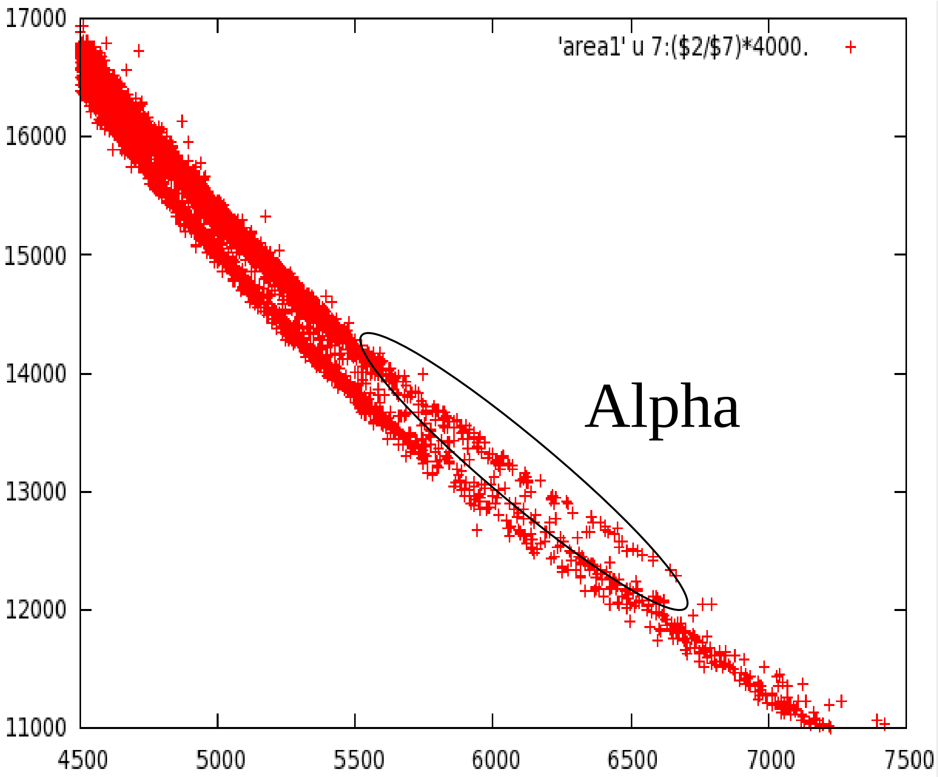
S. Thakur et al.

# DSP test results with charged particle detectors

Alpha test with Si



Preliminary result from beam test of CsI(Tl)



DSP: Energy threshold will reduce for PID

# Physics with the array

- <u>Exotic nuclear shapes</u>
  - **M1 bands, Anti-magnetic bands**
  - **Chiral bands**
  - **Tetrahedral, Oblate bands**
- <u>Exotic isomers</u>
- Symmetries in medium mass nuclei near N~Z
- Spectroscopy of the heaviest nuclei
- Experiments with radioactive targets (e.g., $^3$H and many others)
- Neutron-rich nuclei
  - **Towards neutron shell closure**
- *'Horizontal growth' of level scheme*

# Where to look for tri-axial shapes?

Results

- Spectroscopy of Transitional Nuclei in A ~ 130

PRC 76, 014306 (2007), PRC 78, 034313 (2008)
PRC 81, 067304 (2010)

- Gamma vibrations & its coupling

Nucl Phys. A 824, 58(2009)

- Degenerate dipole bands & chirality

PRC 79, 067304 (2009), EPJ A 43, 45 (2010), NPA 834, 81c (2010),
PRC 84, 0431010R (2011)

- Reactions for population of high spin states in transitional nuclei

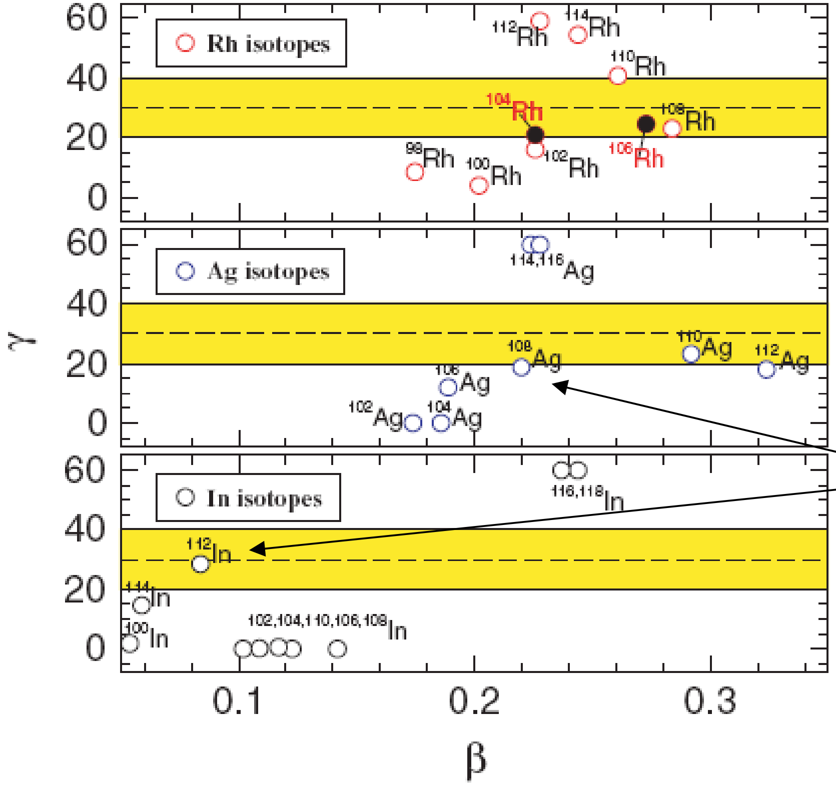
PRC 82, 054601 (2010)

# Odd-odd Isotopes near A ~ 110

- Ma ... > 107 in In ... isotopes

- Recently, presence of chiral doublet is predicted in $^{112}$In.

- Active orbitals :== $\pi\, g_{9/2}$, $\nu(h_{11/2}, g_{7/2}, d_{5/2})$



Deformations of Odd-odd Rh, Ag & In

Results:

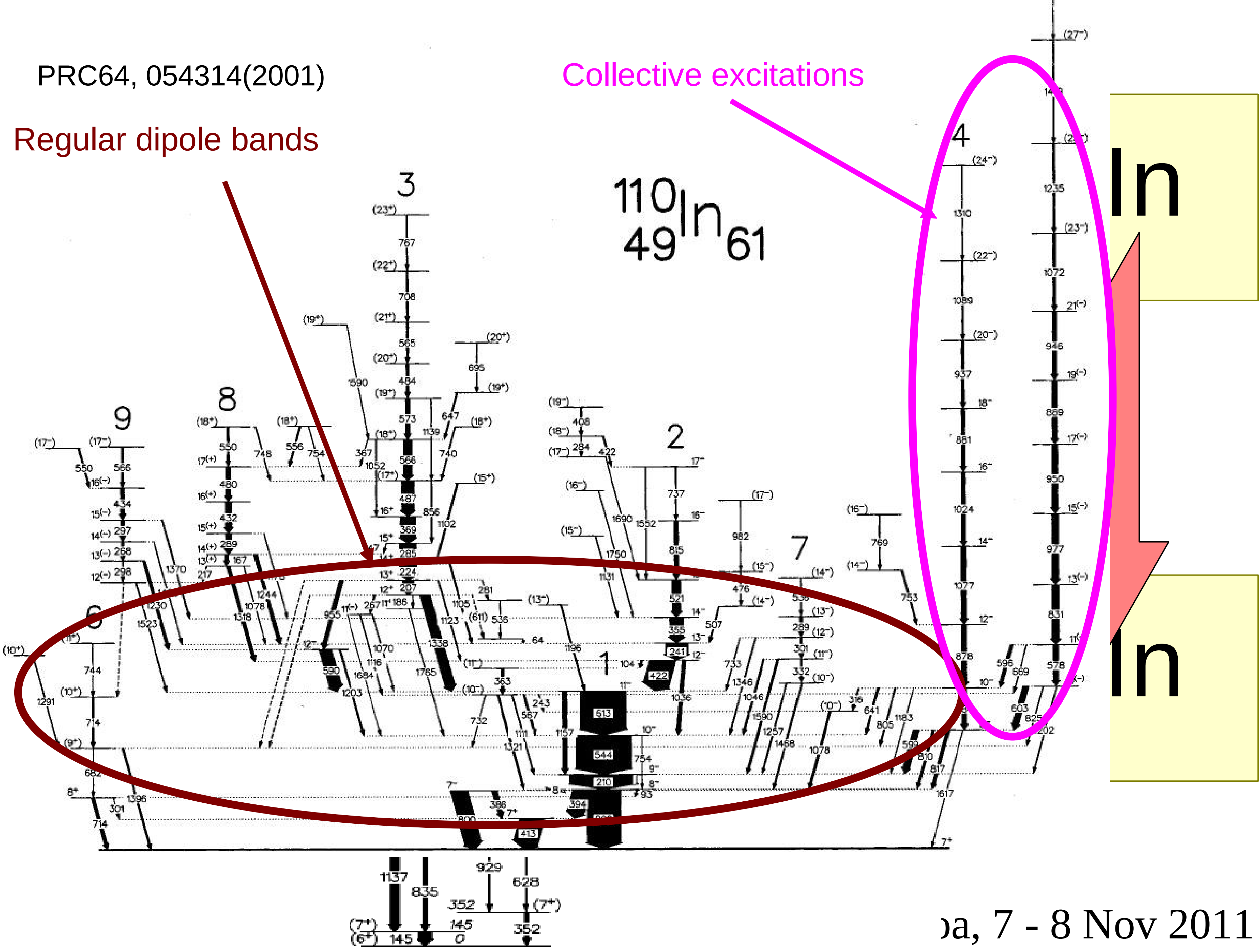
Detailed Spectroscopy of $^{108}$Ag & $^{112}$In isotopes using INGA

*Meng et. al. PRC73 037303 (2006)*

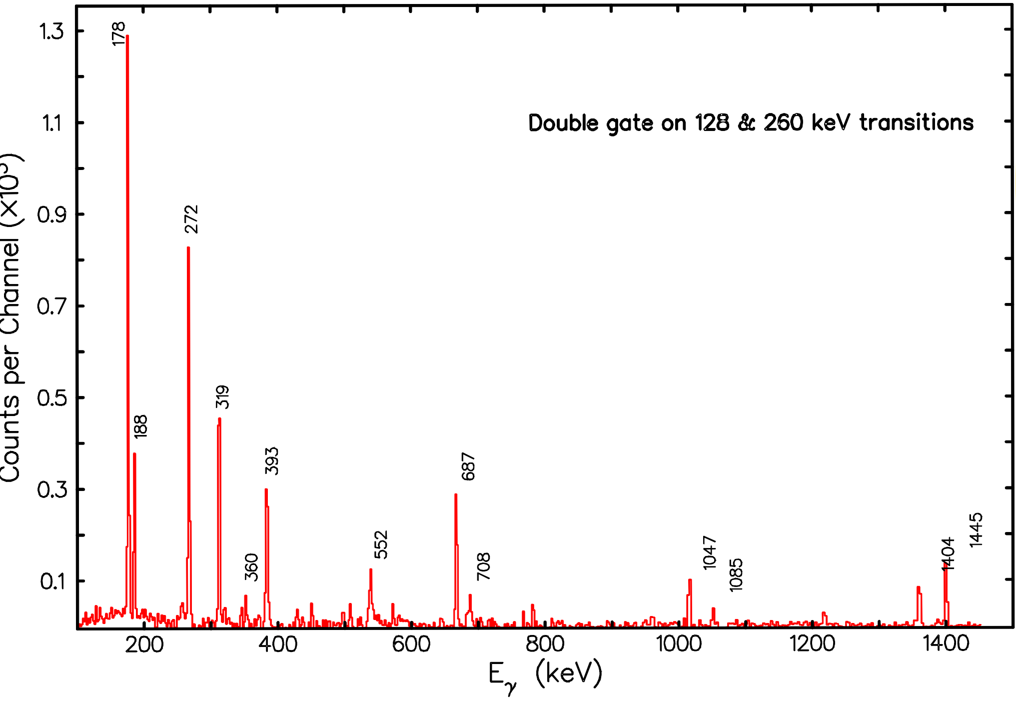
PRC64, 054314(2001)

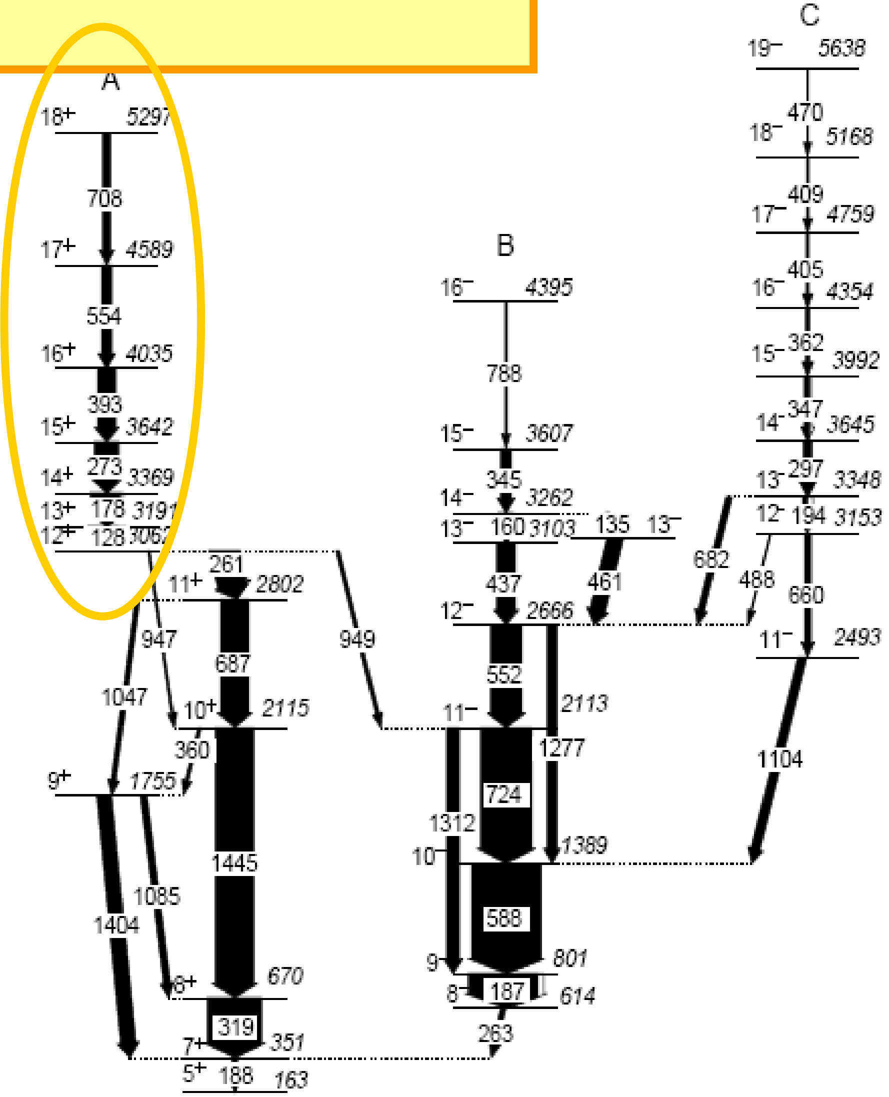
Collective excitations

Regular dipole bands



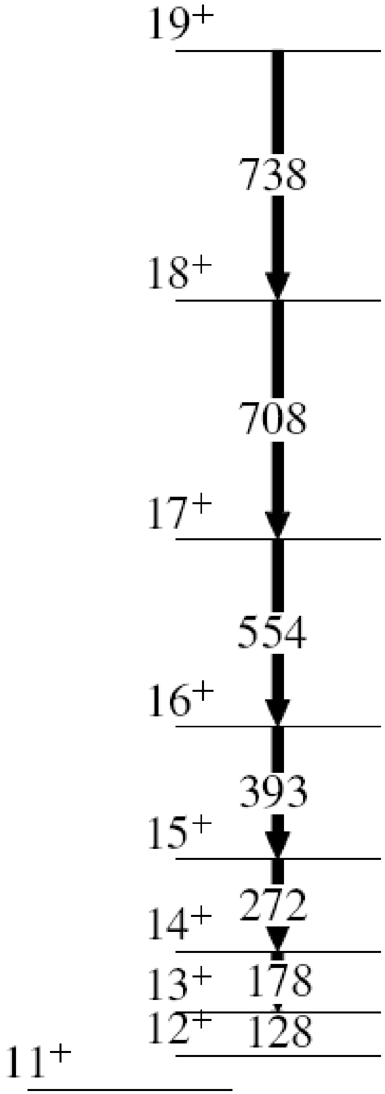
# High spin structure of $^{112}$In

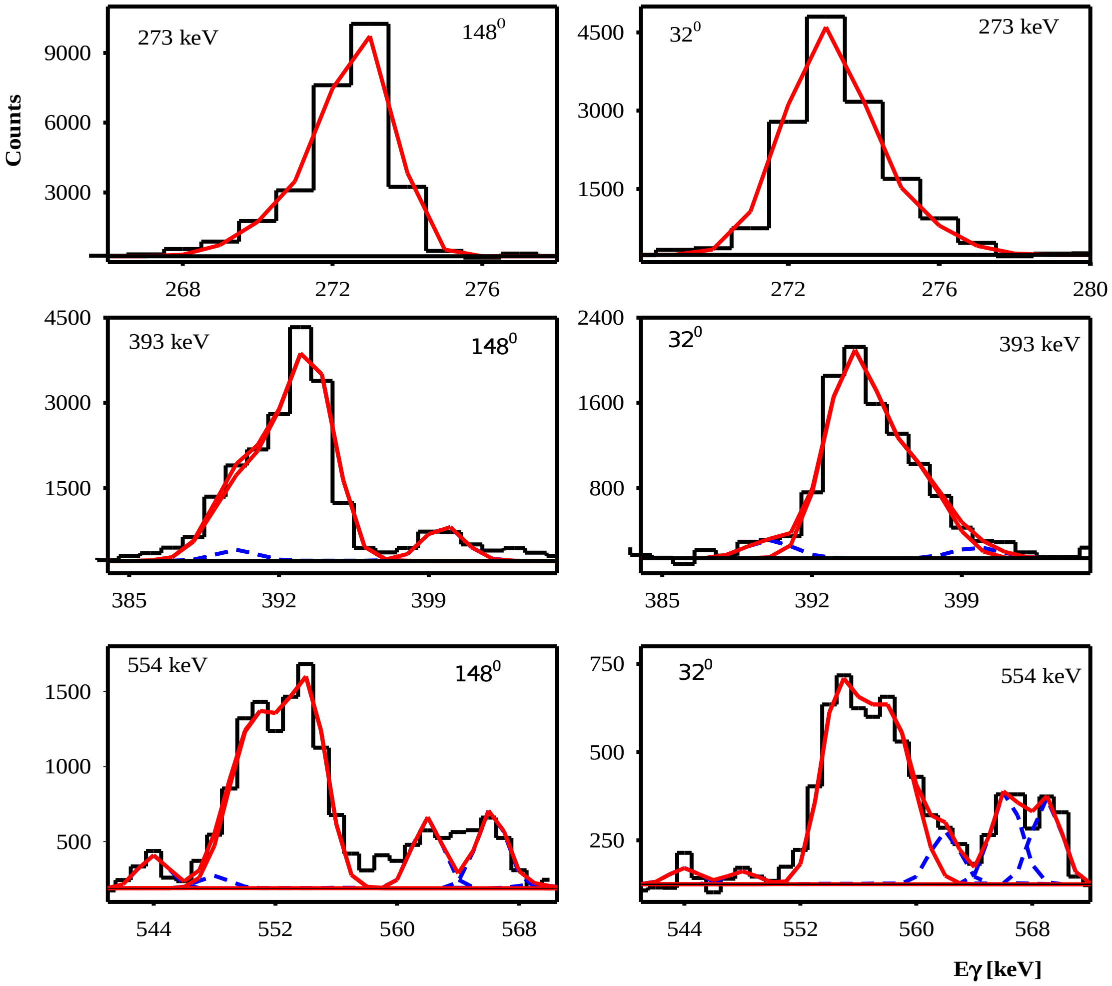




C.Y. He et al., Phys. Rev. C 83, 024309, 2010

# *Lifetime measurement for dipole band in $^{112}$In*

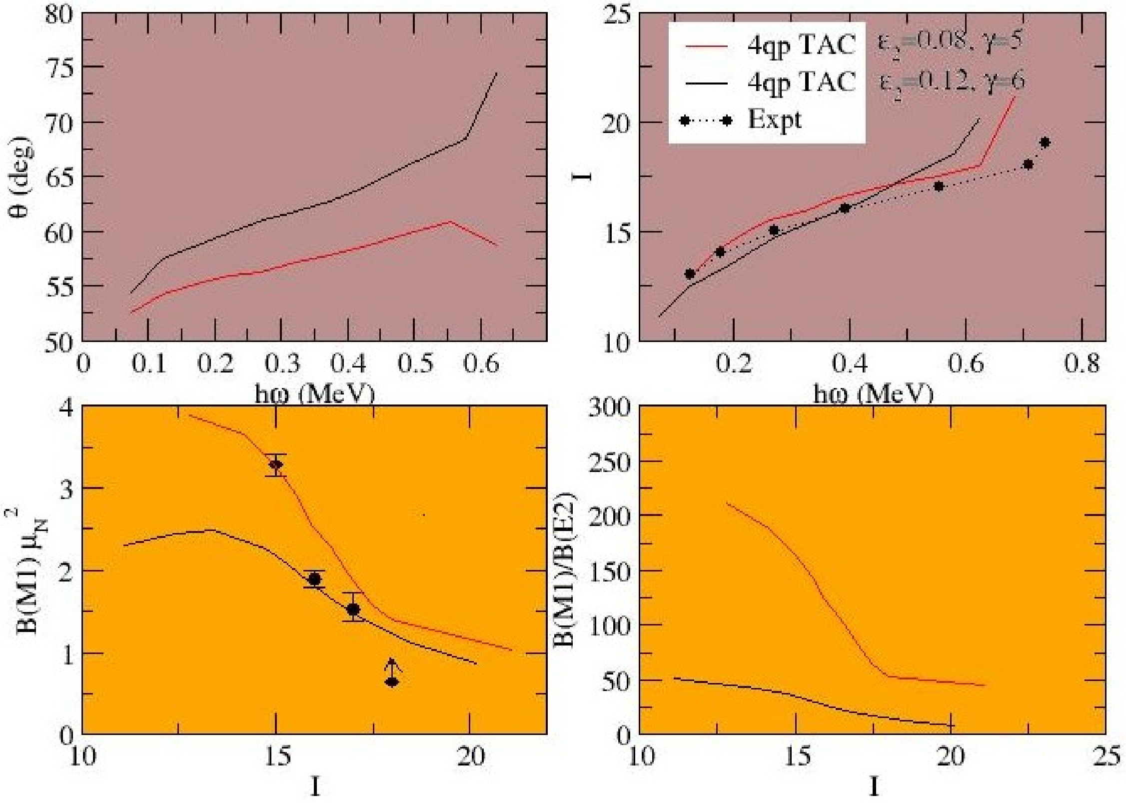




Doppler Shift Attenuation study for sub-pico sec $T_{1/2}$ levels decaying by 272, 393, 554, and 708 keV transitions

T. Trivedi, R. Palit et al.

# Comparison of B(M1) values with TAC calculations



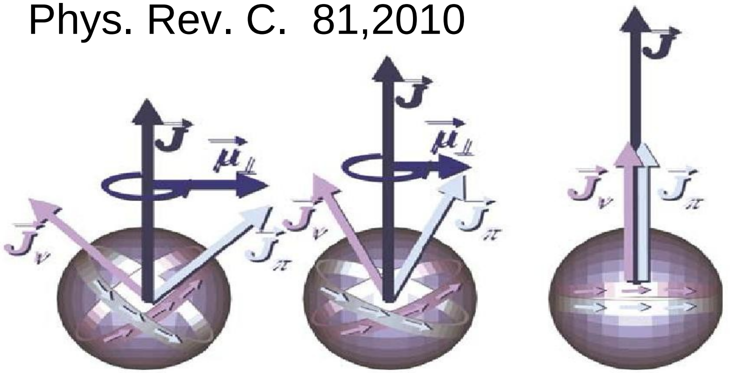
TAC configuration

$\pi g_{9/2}$ - $\nu((h_{11/2})^2 d_{5/2}/g_{7/2})$

$\varepsilon_2$ = 0.12 and $\gamma = 6^0$

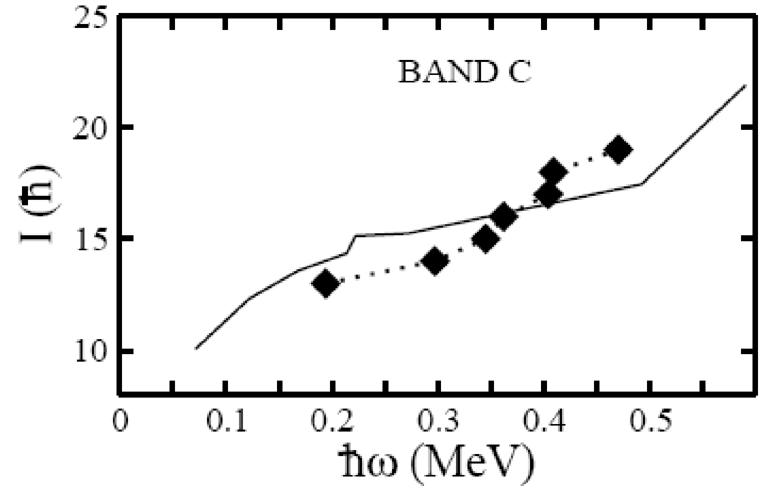
$\varepsilon_2$ = 0.08 and $\gamma = 5^0$

Similar situation have been assigned in lighter In isotopes Phys. Rev. C. 81,2010



1. Regular sequences of M1 transitions
2. Weak or absent E2 transitions
3. B(M1) decreases with angular momentum

# *Comparison of B(M1) values with TAC lations*

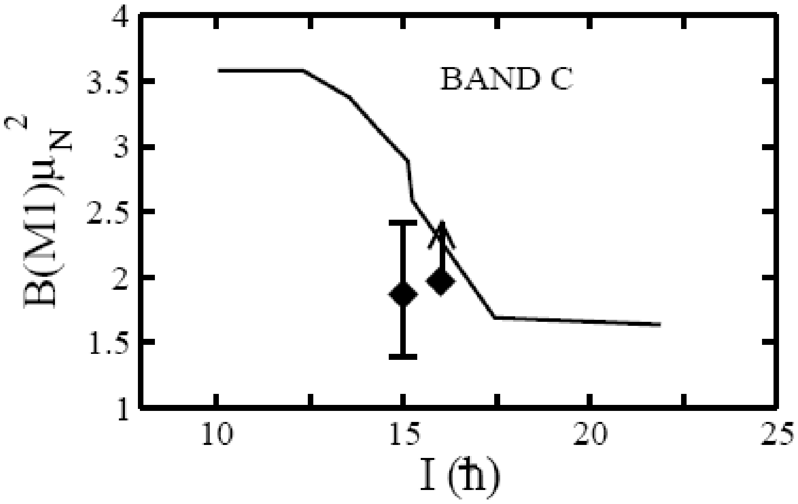


*TAC configuration for band C*

$\pi g_{9/2}\ (\nu h_{11/2})^3$

$\epsilon_2 = 0.13$ *and* $\gamma = 0^0$

Some more measurement are required to get better inside of these bands.

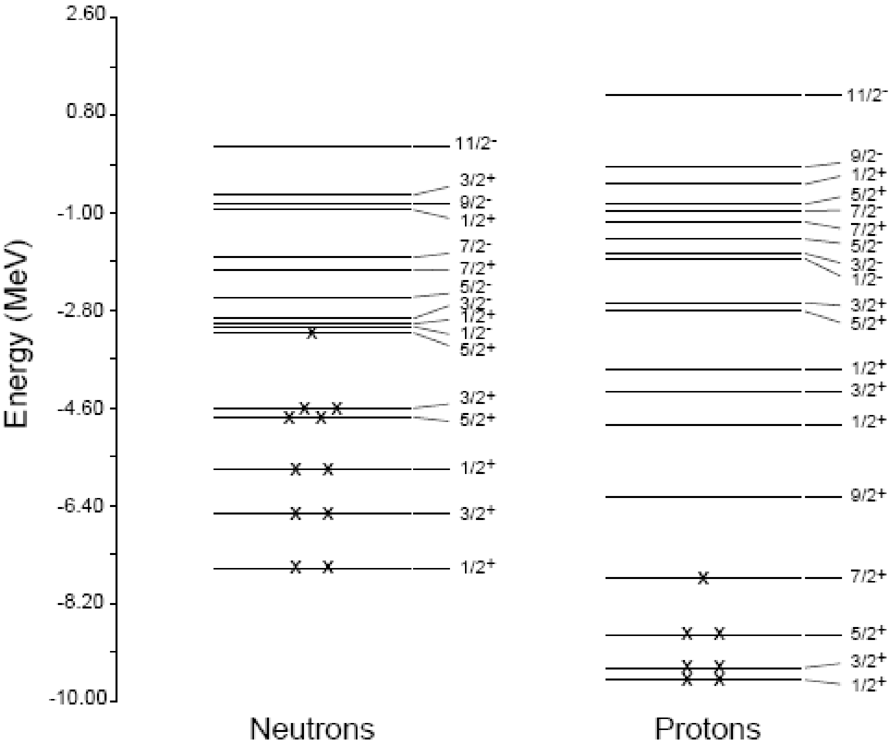


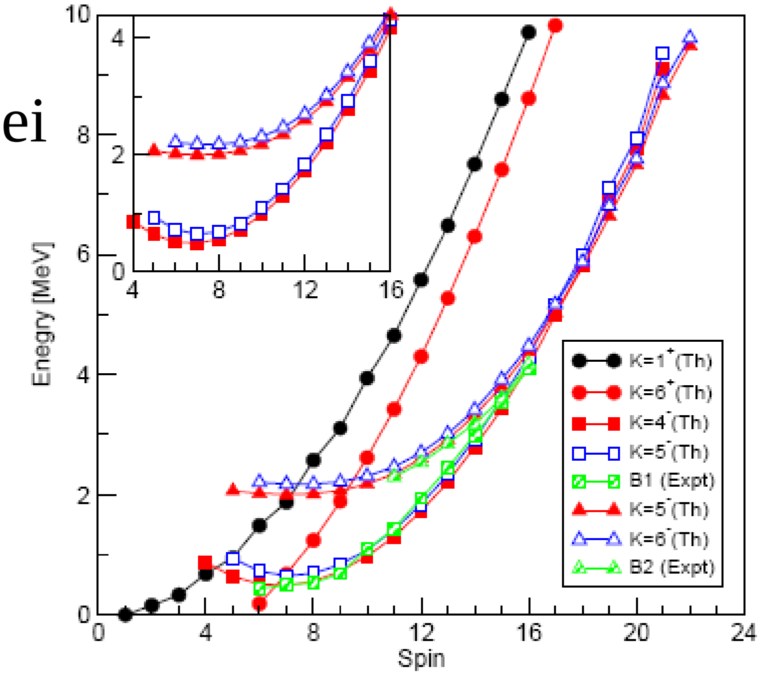
Bands A and C are found to have weakly deformed axially symmetric structure contrary to the prediction of RMF calculations which indicates multiple chiral bands on triaxial deformation

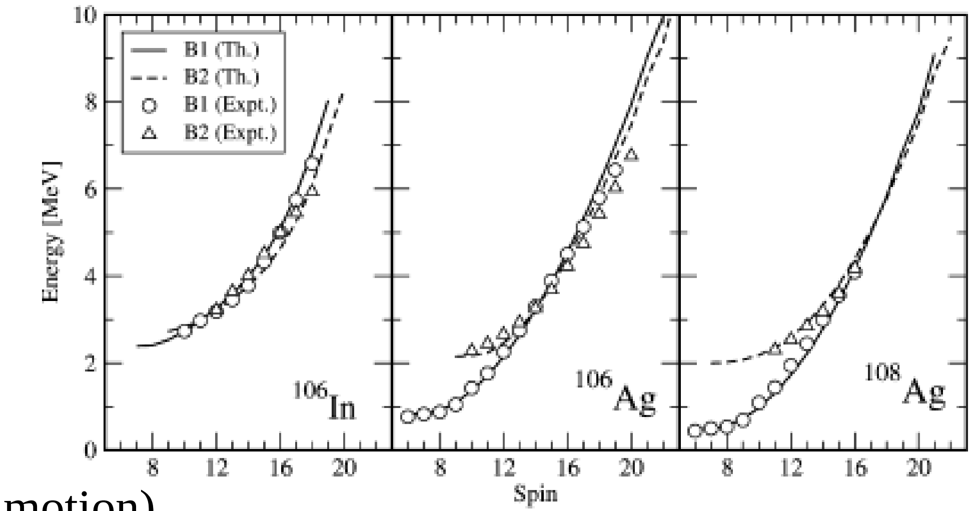
# Dipole bands in $^{108}$Ag

The second favorable case of odd-odd nuclei with triaxial shape.

HF orbits for $^{108}$ Ag



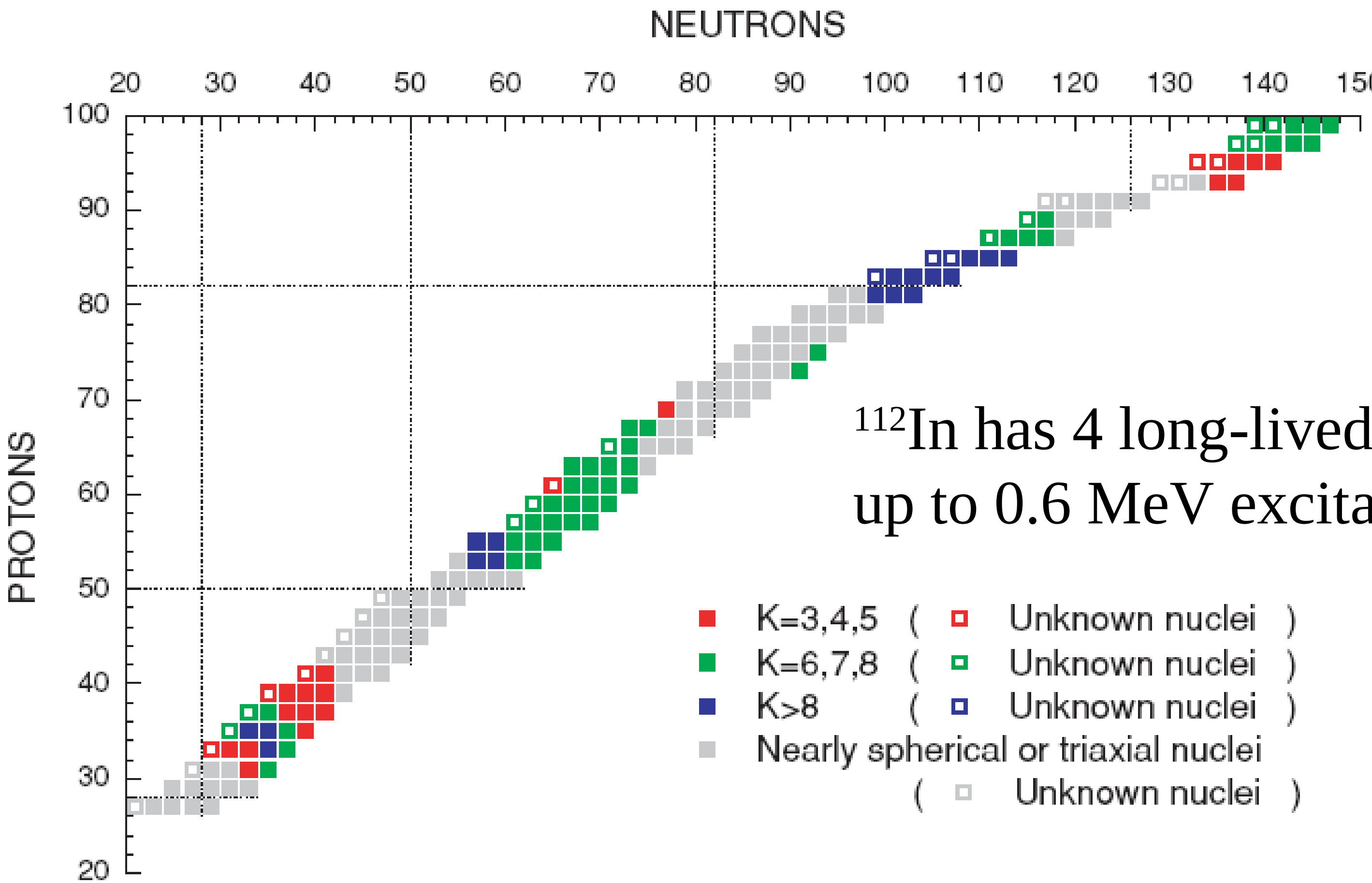




Prediction of low lying dipole bands with different qp-structure (Indication of chopsticks motion)

A.Y. Deo, et al., PRC (2009),
R. Palit et al., NPA834 (2010).

# *Isomers in odd-odd nuclei*



$^{112}$In has 4 long-lived isomers up to 0.6 MeV excitation energy

H.L. Liu, et al PRC 76 34313 (2007)

Famous Examples: $^{94}$Ag, $^{108}$Ag, $^{180}$Ta

P. Walker et al.,

# Depletion of long lived isomer

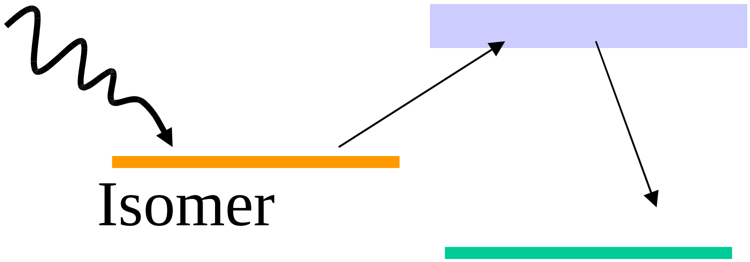
Can one store energy in a nuclear isomeric state?

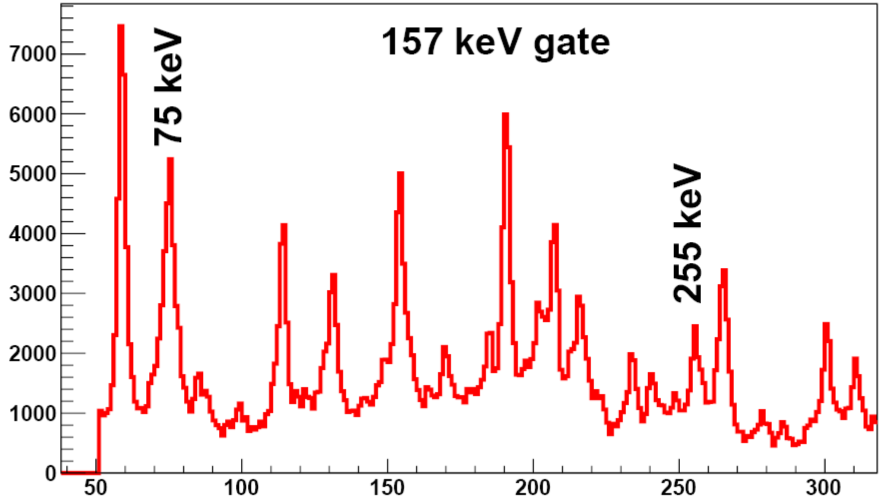
Can one Extract it in a controlled way when required?

In-beam gamma spectroscopy play a crucial role in such investigation!!!

Example: $^{107}Ag(n,\gamma)^{108}Ag^{m}$ (high cross section)

Need to do low lying structure study





Preliminary result

Needs to be measured:

Branching ratio

Multipolarity

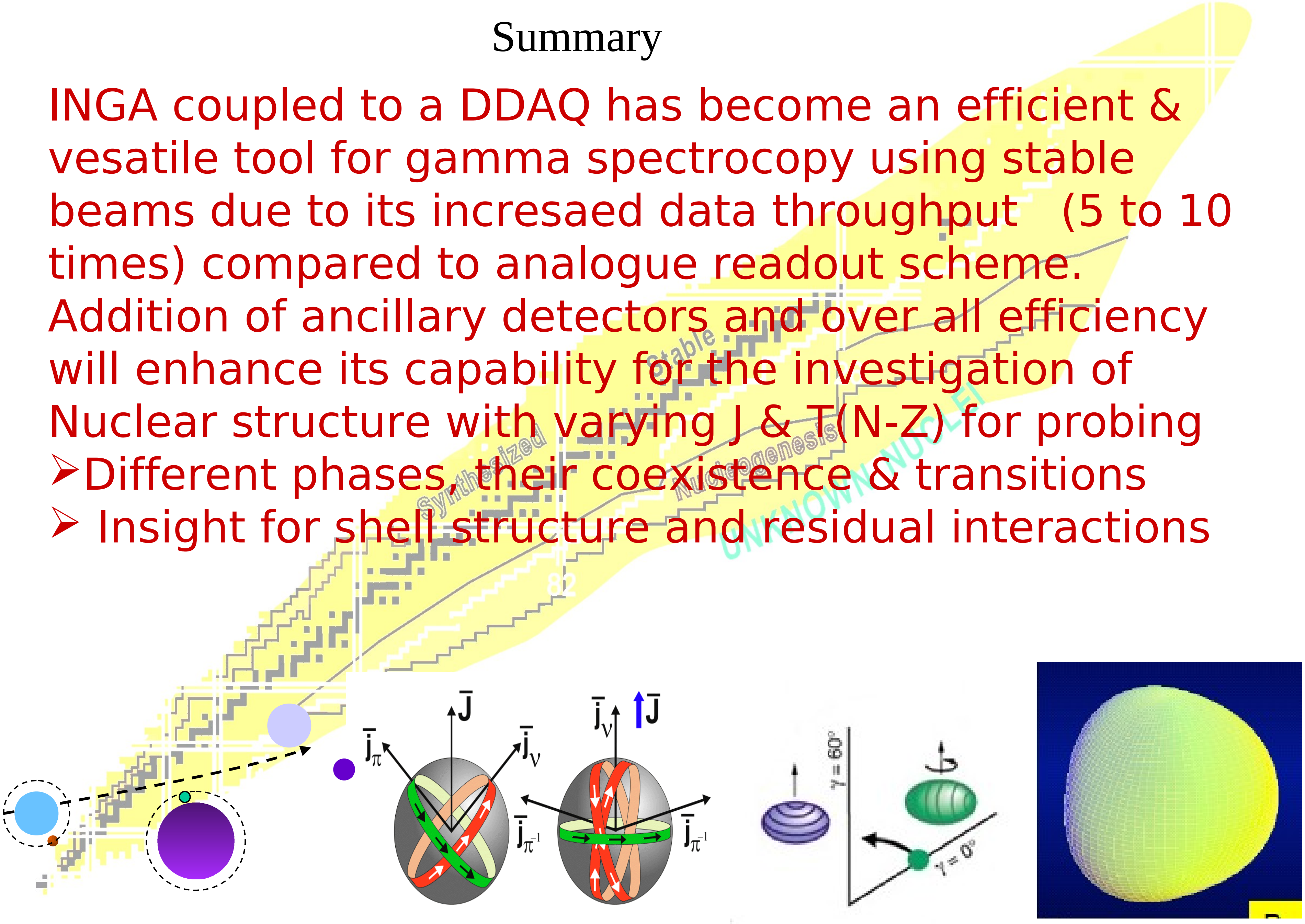
Spectroscopy of nearby states

Carroll, Palit, Sethi, Walker, et al

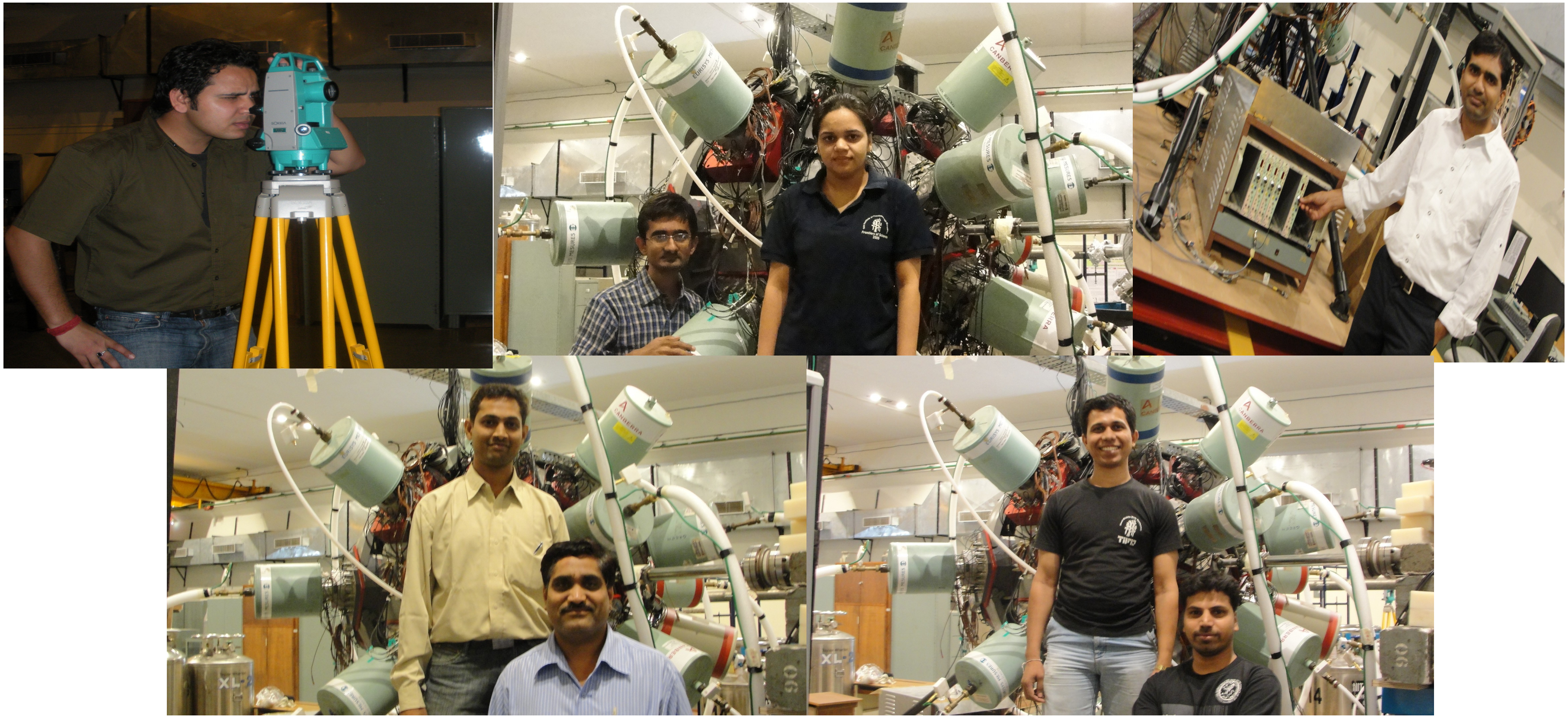
# Summary

INGA coupled to a DDAQ has become an efficient & vesatile tool for gamma spectrocopy using stable beams due to its incresaed data throughput (5 to 10 times) compared to analogue readout scheme. Addition of ancillary detectors and over all efficiency will enhance its capability for the investigation of Nuclear structure with varying J & T(N-Z) for probing

- ➢Different phases, their coexistence & transitions
- ➢ Insight for shell structure and residual interactions



# Collectivity!!!



And

INGA Collaboration

(TIFR-BARC-IUAC-IUC-SINP-VECC-Universities- IITs)

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# Thank You