Overview of Nuclear Physics Programmes Pelletron Linac Facility, Mumbai

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Tata Institute of Fundamental Research

Advances in Nuclear Physics

International Centre for Theoretical Sciences

Tata Institute of Fundamental Research

Major Accelerator Centres in India

RRCAT, Indore (DAE)

Electron synchrotron storage rings

Indus-1 & Indus-2 450MeV 61Å, 2.5GeV 2Å

VECC, Kolkata (DAE)

Variable energy cyclotron K-100

Superconducting cyclotron K-500

Low energy RIB 400keV/u

BARC, Mumbai (DAE)

Folded 6MV Tandem

High current proton driver development for ADS

TIFR, Mumbai (DAE)

14MV Tandem & heavy ion SLinac booster

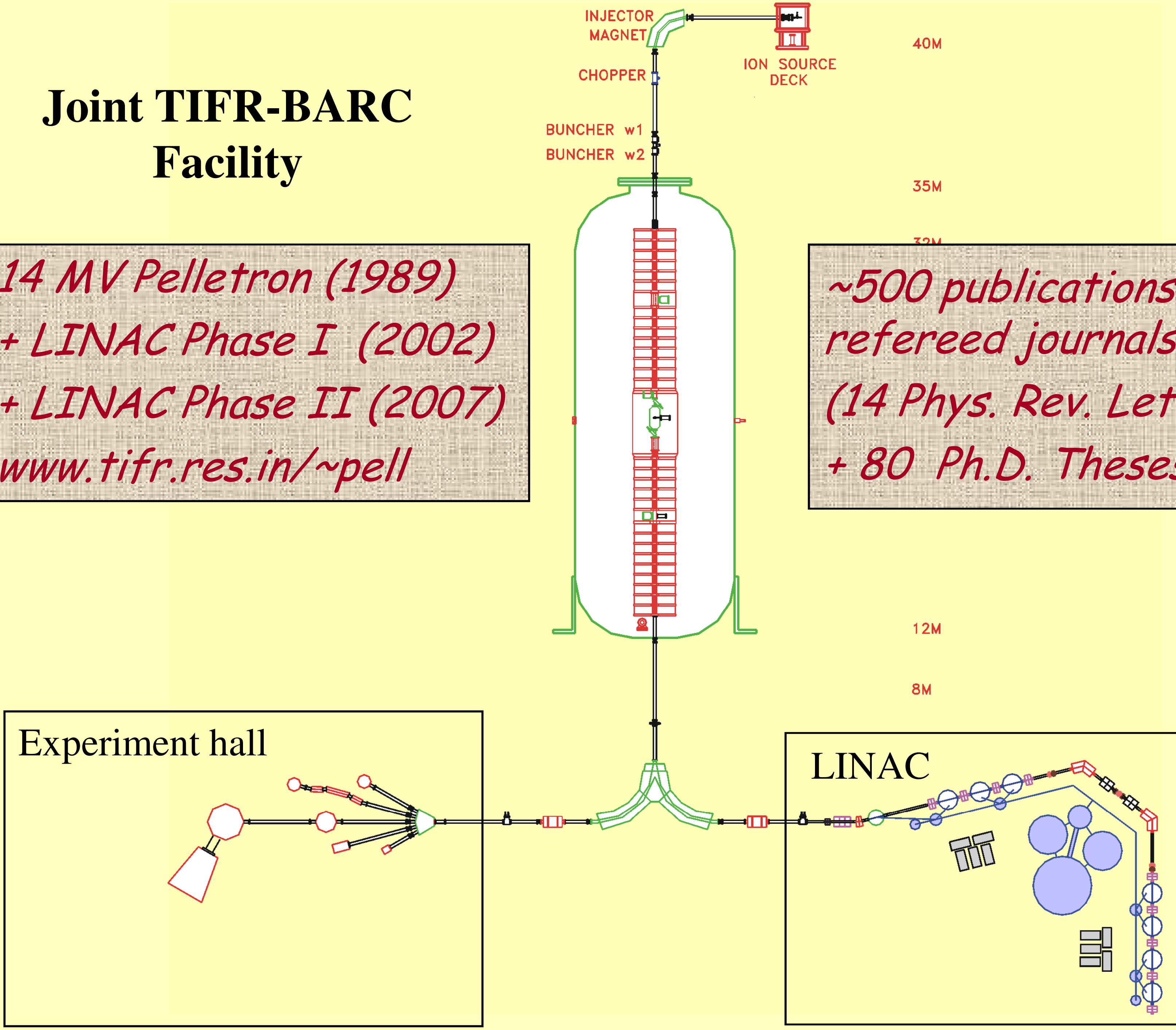
IUAC, New Delhi (UGC, DST)

15MV Tandem & heavy ion SLinac booster

Joint TIFR-BARC Facility

14 MV Pelletron (1989)
+ LINAC Phase I (2002)
+ LINAC Phase II (2007)
www.tifr.res.in/~pell

~500 publications in refereed journals
(14 Phys. Rev. Lett.)
+ 80 Ph.D. Theses



At our lab (DNAP, TIFR & NPD, BARC)

14 MV UD Pelletron accelerator + LINAC booster

- **Nuclear Reaction Studies**
  - Fission Dynamics
  - Sub-barrier Fusion & Transfer reactions
  - Reactions with weakly bound nuclei
- **Nuclear Structure Studies**
  - Discrete γ-ray spectroscopy
  - High energy γ-ray (GDR) studies
  - Heavy ion resonances
- **Hyperfine interaction studies**
- **Atomic, Molecular and Cluster dynamics**
- **Applications**
  - Medicine: Tracer packets for radionuclide delivery
  - Accelerator mass spectroscopy
  - Track etched membranes: submicron pore filters
  - Radiation damage: materials, electronic components, etc.

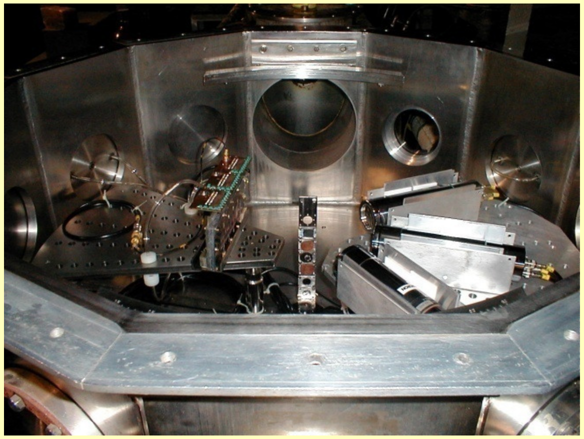
- **Nuclear Theory**
- **Hadron Physics**
- **Neutrino-less Double Beta Decay (Indian Neutrino Observatory)**
- **Developmental activities (Si Detectors, electronics, DAQ etc.)**
- **Spiral 2 (Exogam, Gaspard, Paris, ..)**
- **FAIR (Nustar: HiSpec, DeSpec, R3B, ..)**

Heavy Ion induced fission

Fission Dynamics

Understanding the fission mechanism in heavy ion collisions

- Fragment mass, energy and angular correlations
- Pre-equilibrium fission
- Transfer induced fission
- Mass resolved FAD using recoil catcher technique
- Fission hindrance
- Pre-fission Neutron, Light Charged Particles and GDR Gamma rays



Heavy Ion induced fission

Role of entrance channel mass asymmetry (α) on fission fragment anisotropy

$\Rightarrow$Memory of the entrance channel is retained for $\alpha < \alpha_{BG}$

(Businaro-Gallone Critical point)

V.S. Ramamurthy *et al*., PRL 65, 25 (1990)

Shell effects reduce the effective moment of Inertia at saddle point

$\Rightarrow$ Larger fission fragment anisotropies.

A. Shrivastava *et al*., PRL 82, 699 (1999)

Fusion- Fission Time scales

Pre-scission neutron multiplicities A. Saxena *et al*., PRC 49, 932(1994)

$^{16}O+^{232}Th$ & $^{11}B+^{237}Np$ $\Rightarrow$ Difference in the formation time

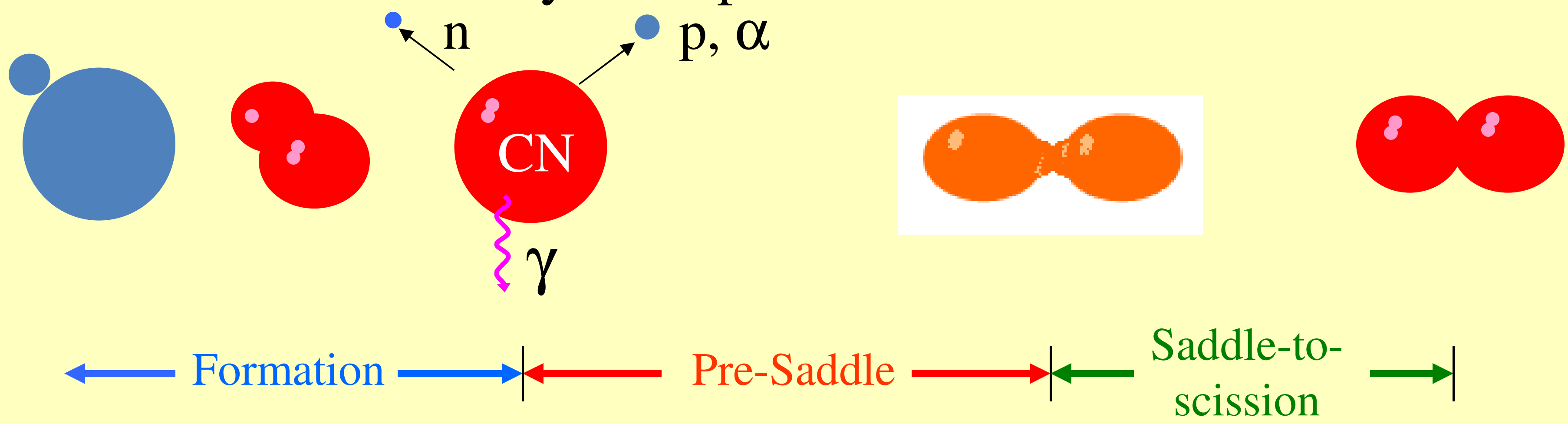
Pre-scission charged particle multiplicities A. Chatterjee *et al*., PRC 52, 3167 (1995)

Fission time scale from pre-scission neutron, proton, and α particle multiplicities in $^{28}Si+^{175}Lu$

K.Ramachandran,.., V.Nanal, R.G.Pillay,.. *et al.,* PRC 73, 064609 (2006)

Fusion- Fission Time scales

Fission time delay from particle emission measurements



1. Neutron measurements: Entrance Channel Effects : Role of formation Time
   Phys. Rev. C**49**, 932 (1994)
2. Simultaneous Measurement of neutrons and charged Particles: Neutron emission favoured towards larger deformation compared to charged particles
   Phys.Rev. C**73**, 064609 (2006)

Study of GDR in excited nuclei

Evolution of nuclear properties as a function of temperature and angular momentum

Measurement of GDR strength function and angular distribution

- Systematic studies in A~80 and A~ 200

- Angular momentum dependence of GDR in $^{28}Si+^{124}Sn$ at $E(^{28}Si)$~150, 188 MeV

  Results consistent with liquid drop behaviour

  D.R. Chakrabarty, V. Nanal*, et al.,* Nuclear physics A770, 126 (2006)

- Resonant dipole strengths built on 15.1 MeV, T=1 state in ^{12}C

  Isobaric Analog State of ^{12}B & ^{12}N, different from ground state GDR in ^{12}C

  D.R. Chakrabarty, ..V. Nanal,.. *et al.,* PRC 77, 051302R (2008)

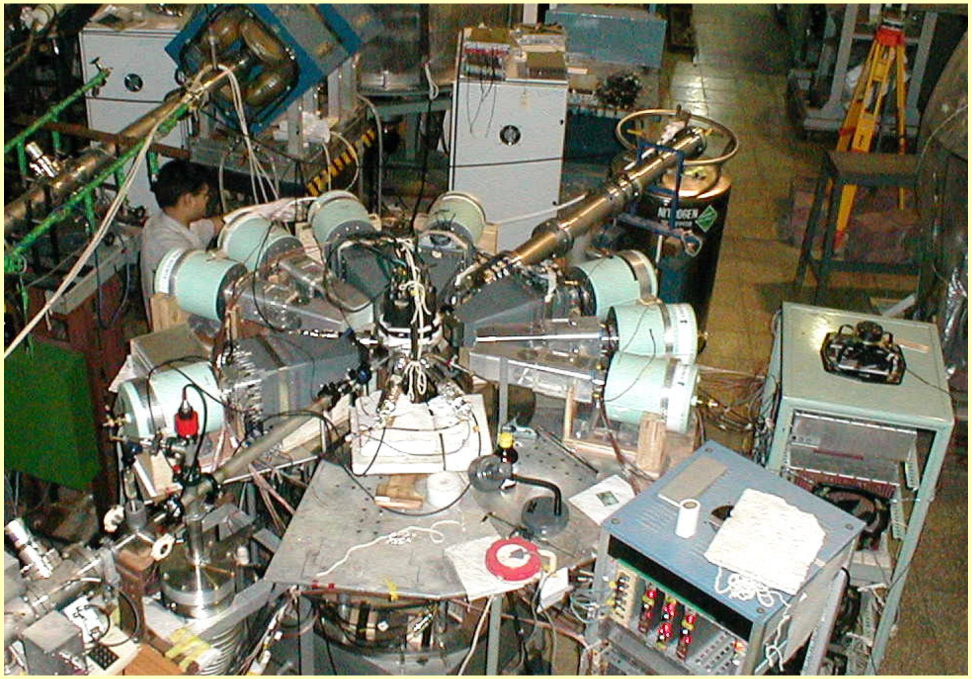
- Search for rare shape-phase transitions in nuclei around mass A~190

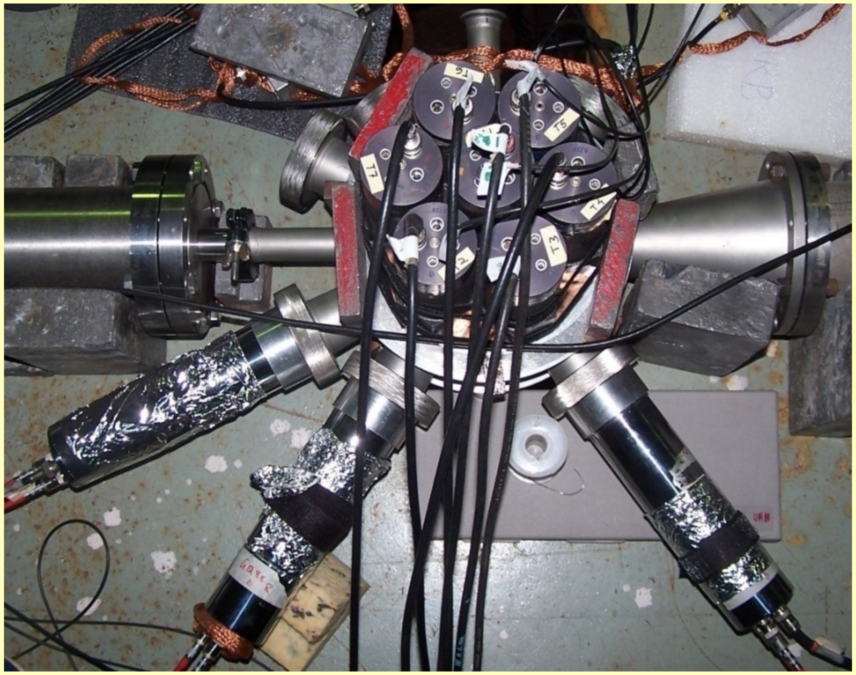
  I. Mazumdar *et al.,* Acta.Phys. Polonica, 38, 1463 (2007)

Nuclear level density (NLD)

- Fundamental property of the nucleus
- Key input to the statistical model calculation of CN

Very little experimental data on E_x and J for diff. Mass regions





$^{12}C+^{89}Y, ^{93}Nb$, $^{16}O+^{89}Y$

Study of Nuclear Level Density

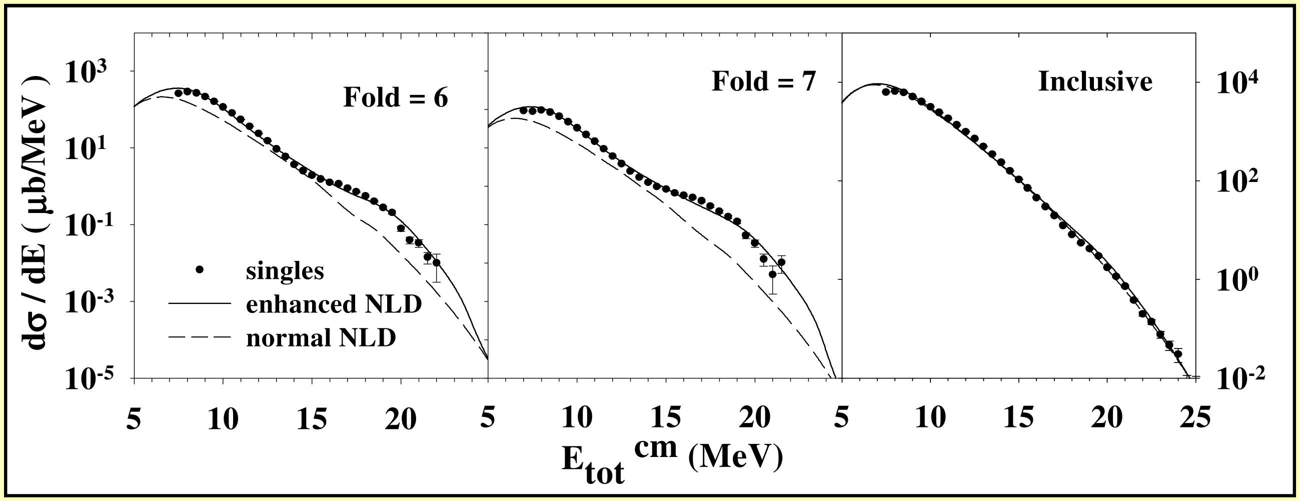
NLD – an important physical quantity

very little experimental data on E_x and J for diff. Mass regions

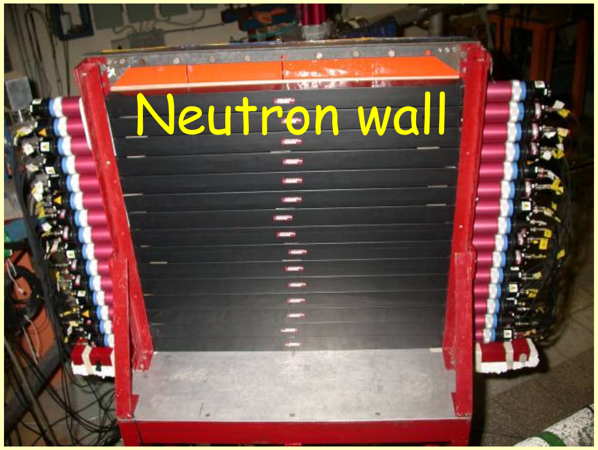
$^{12}C(E_{lab} = 40\text{ MeV}) + {}^{93}Nb \rightarrow {}^{105}Ag^* \rightarrow p + {}^{104}Pd^*$

First step proton spectra measured with 3 NaI(Tl) (@backward angles)
in coincidence with
8 Clovers (residue identification) & 14 -BGO multiplicity setup (Angular momentum)

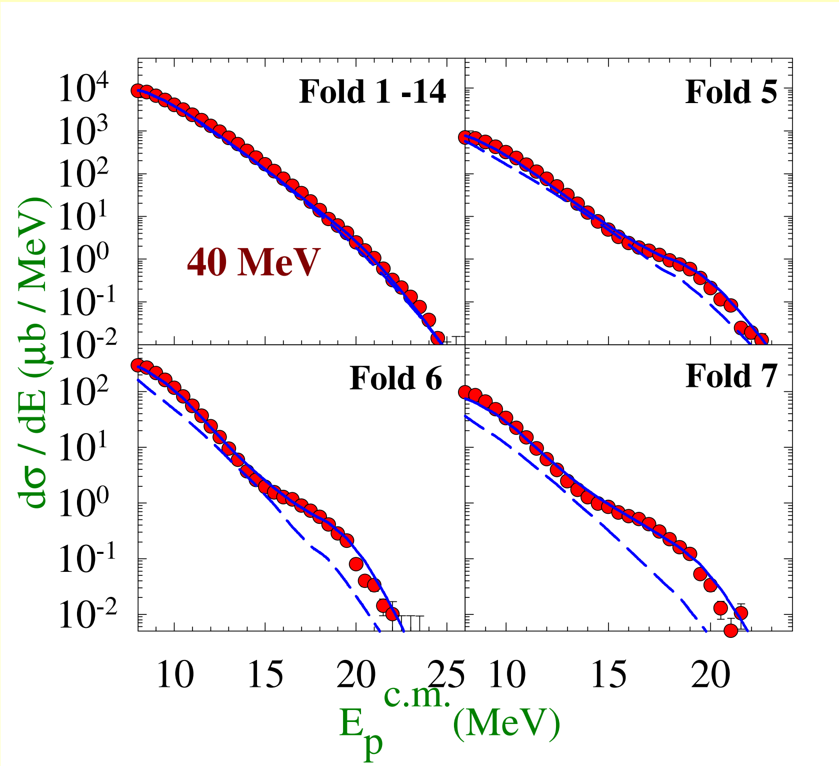
Bumps at high fold $\rightarrow E_x$, J dependent enhancement in NLD due to J induced deformation

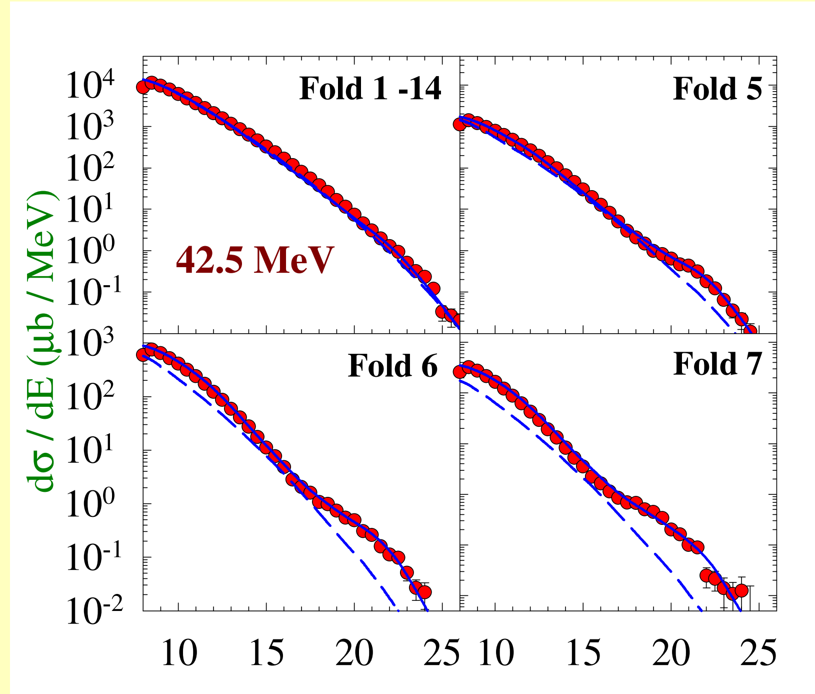


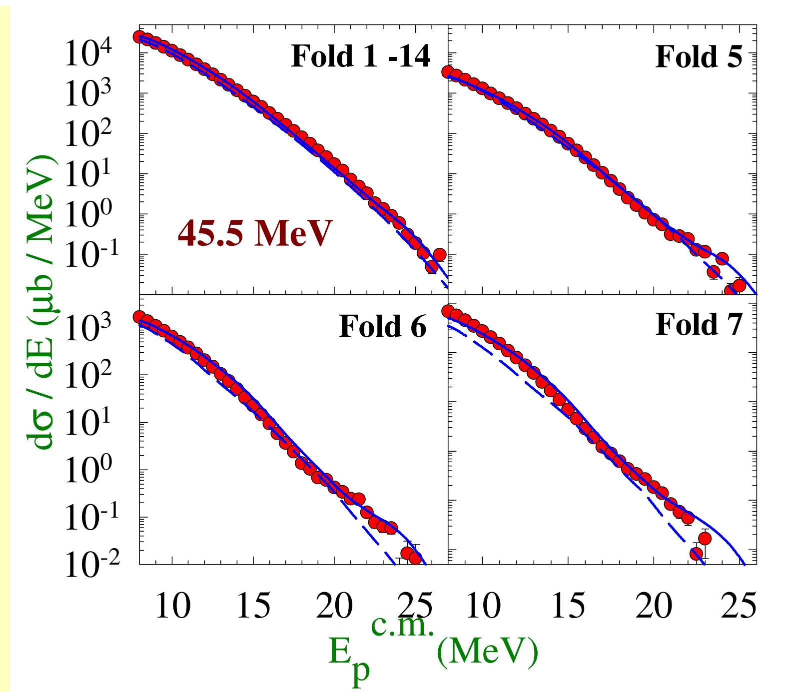
A. Mitra et al. Nucl. Phys. A 707, *343 (2002)*



1m x 1m array of 16
plastic detectors







A. Mitra *et al.*

NPA 707 (2002) 343

NPA 765 (2006) 277

J. Phys. G 36 (2009) 95103

SM fit to $^{12}C + ^{93}Nb$

With E,J dependent level density

Alpha cluster states in ^{8}Be

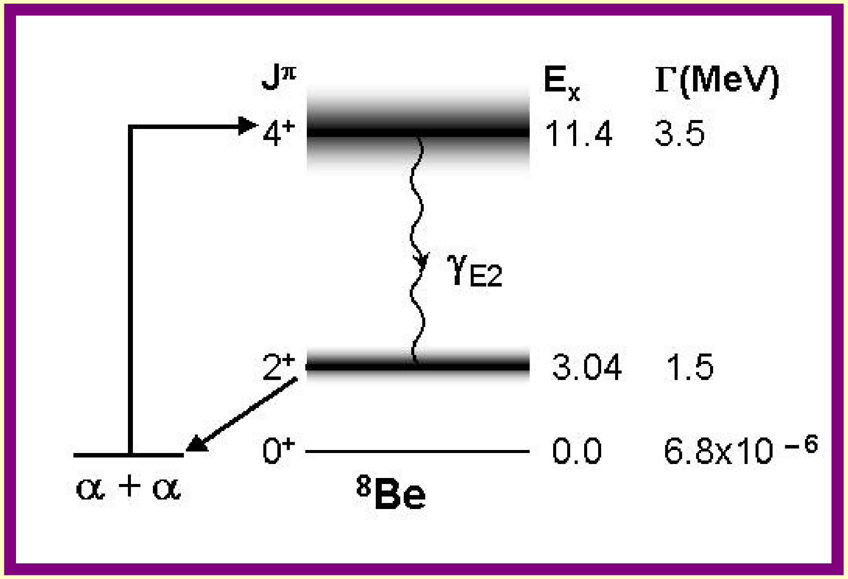
Direct observation of 4^+ to 2^+ γ- transition

Low lying states in ^{8}Be are α–cluster states with dumbbell-like shape

No electromagnetic evidence was available so far

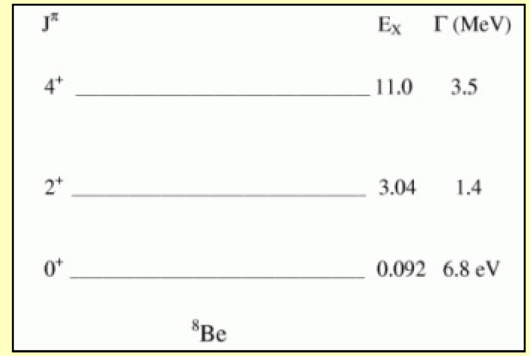
Large E2 collectivity predicted (75 W.u. for $2^+ \rightarrow 0^+$, 19 W.u. for $4^+ \rightarrow 2^+$)

Still: extremely low ($<10^{-7}$) branching ratios



Stepping stone to larger linear α cluster states

4_1^+ to 2_1^+ gamma transition in ^8Be



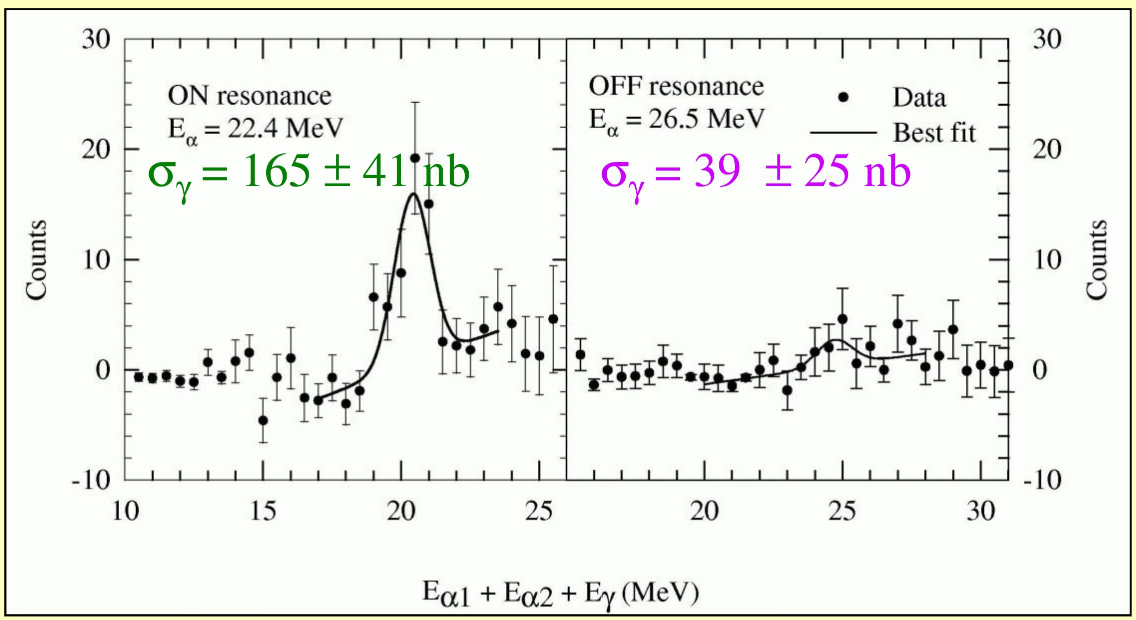
Motivation

- Collective enhancement expected (~ 19 W.U.)

  $\Rightarrow \gamma$ branch $\sim 1.3\times10^{-7}$
- Stepping stone to larger linear α cluster states

Method

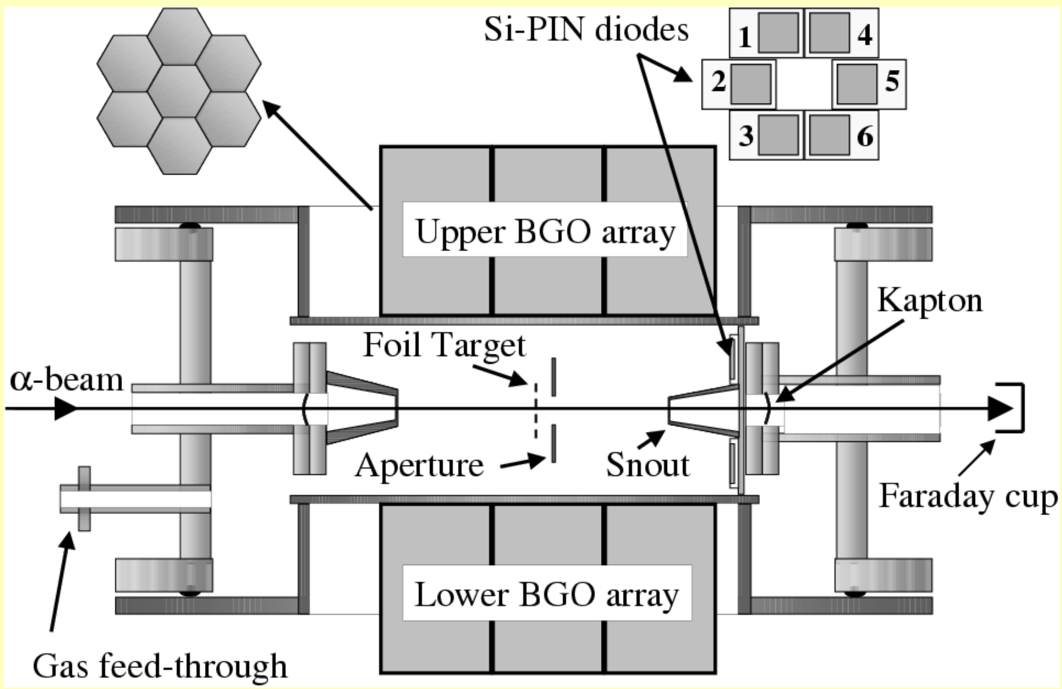
- 22.4 & 26.5 MeV α beams from Mumbai Pelletron on 0.8 bar He gas target
- γ-α-α coincidences using 2×7 BGO arrays with $\varepsilon_\gamma \sim 0.24$, 6 Si PINs at forward angles 15°-35° with $\varepsilon_{\alpha\alpha} \sim 0.15$ for L_{eff} (He target) ~ 1 cm



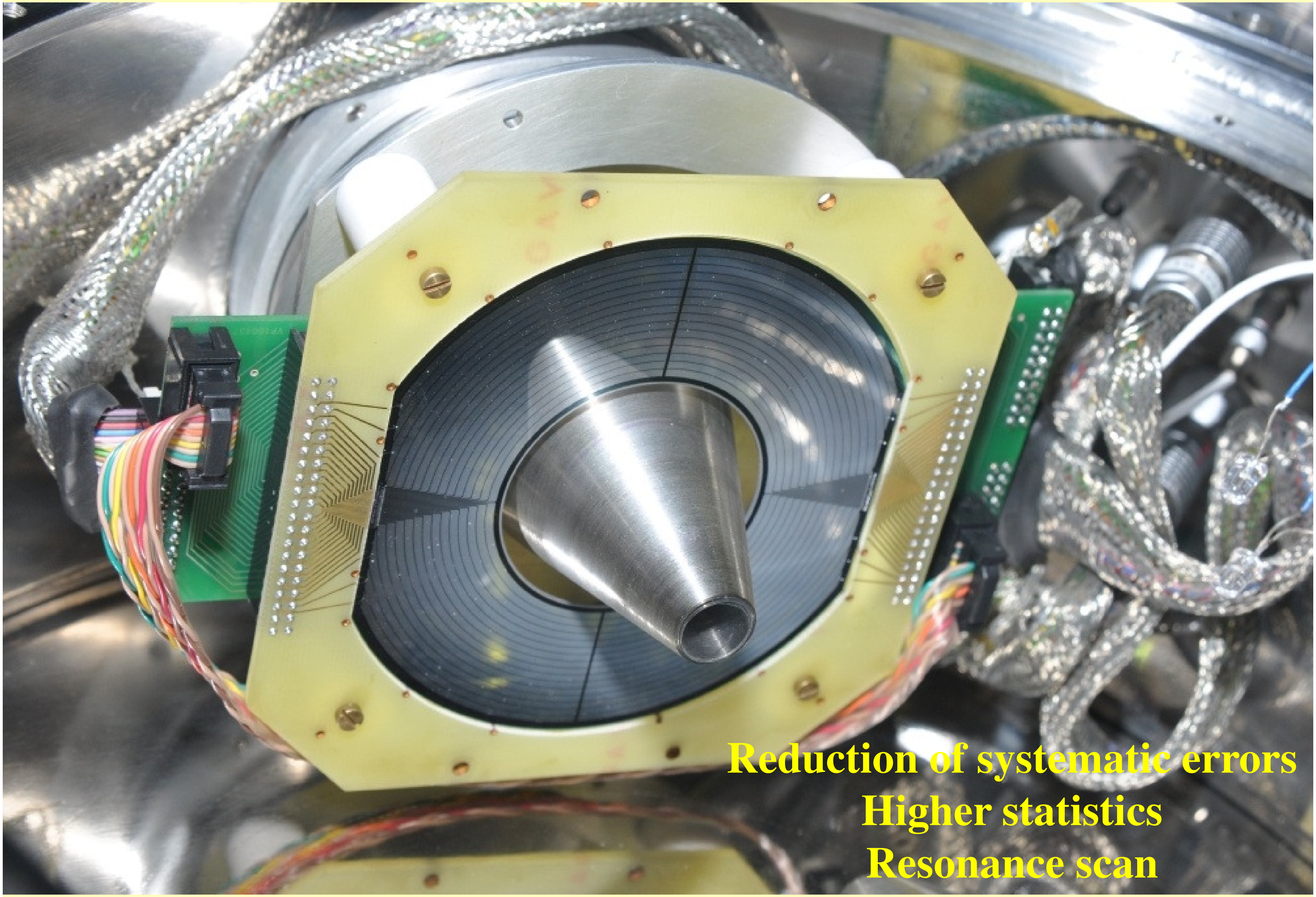
Observed cross-section provides the first crucial evidence for the alpha cluster structure of ^{8}Be.

V.M. Datar, .., V. Nanal ,.. et al., Phys. Rev. Lett. 94, 122502(2005)

- 22.4 & 26.5 MeV α beams fron 0.8 bar He gas target
- γ-α-α coincidences using 2 × 7 BGO arrays with $\varepsilon_\gamma \sim 0.24$, 6 Si PINs at forward angles 15°-35° with $\varepsilon_{\alpha\alpha} \sim 0.15$ for L_{eff} (He target) ~ 1 cm



$$\alpha + {}^4He \rightarrow {}^8Be^{**} \rightarrow \gamma + {}^8Be^{*} \rightarrow \gamma + \alpha + \alpha$$


Reduction of systematic errors
Higher statistics
Resonance scan

Reactions at near barrier energies

Interplay of Structure & Dynamics

- Relation between fusion excitation function & <ℓ> in ^{96}Ru compound nucleus
  M. Dasgupta *et al*. PRL 66, 1414 (1991)

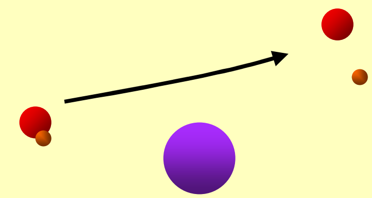
Weakly bound projectiles (^{7}Li, ^{9}Be)

- σ & <ℓ> for complete fusion ^{7}Li + ^{165}Ho ⇒ coherent coupling to projectile breakup channel
  V. Tripathi *et al.* PRL 88, 172701 (2002)
- Exclusive Charged particle measurements ^{7}Li + ^{65}Cu ⇒ neutron transfer followed by breakup
  A. Shrivastava,…V. Nanal,.. *et al.* Phys. Letts. B 633, 463 (2006)

^{6,8}He + ^{63,65}Cu @GANIL

- p-γ coincidence ⇒Large cross section for transfer as compared to breakup for ^{6}He
  A. Navin, …, V. Nanal, ..., R.G. Pillay,.. *et al*. PRC 70, 044601 (2004)
- Energy & Angular correlations (p-n-γ) ⇒ 2n transfer > 1n transfer, implying di-neutron dominant in ^{6}He
  A. Chatterjee,...V. Nanal,.. R.G. Pillay,.. *et al*. PRL 101, 032701 (2008)

Weakly bound nuclei



- *Coupling to Breakup channel most important*
- *Detailed Study of Breakup mechanism necessary*

Reactions around the Coulomb barrier

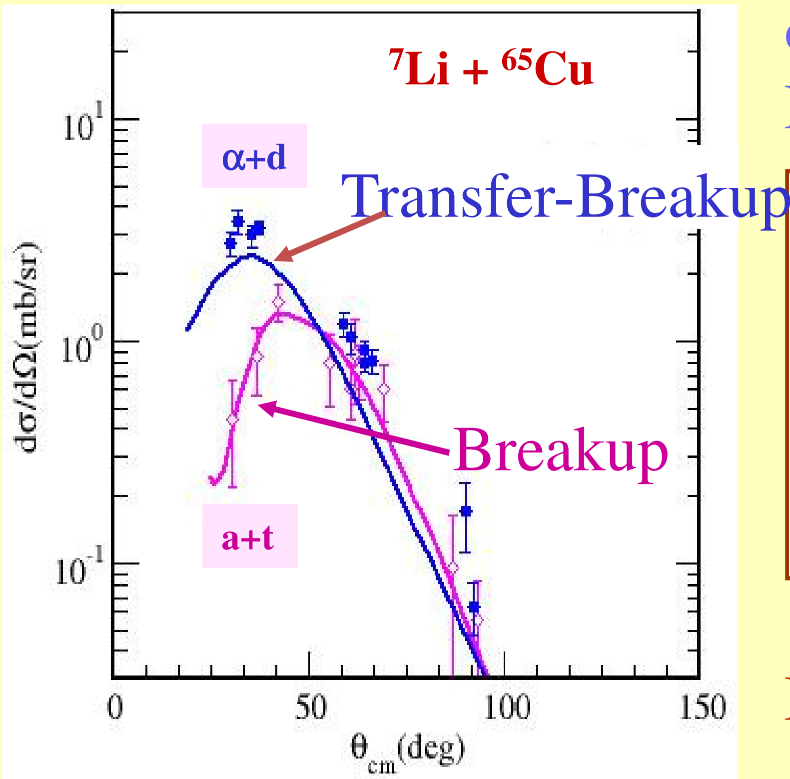
INDO-FRENCH collaboration

- ^{6,7}Li + ^{60}Ni, ^{65}Cu, ^{198}Pt @ PLF, Mumbai

  -- ^{9}Be, ^{7}Li+^{197}Au, ^{9}Be +^{89}Y
- ^{6,8}He + ^{65}Cu @ GANIL, France

A. Navin *et al*. PRC **70**, 044601 (2004)
A. Chatterjee *et al*. PRL **101**, 032701 (2008)
A. Lemasson *et al* Phys. Rev. Letts **103**(2009) 232701

Exclusive Charged particle measurements ^{7}Li+^{65}Cu 25 MeV



^{7}Li (α+t cluster)

σ(α+d) > σ(α+t)

observed correlation between E_{α} and E_{d}

↓

neutron transfer **followed by breakup**

^{7}Li + ^{65}Cu → ^{6}Li + ^{66}Cu

↓

α + d

(not ^{7}Li → α+d+n)

Multi step Breakup **>** Direct Breakup

A. Shrivastava *et al.*

Phys. Letts. B **633**, 463 (2006)

Fusion with weakly bound nuclei at deep sub-barrier energies

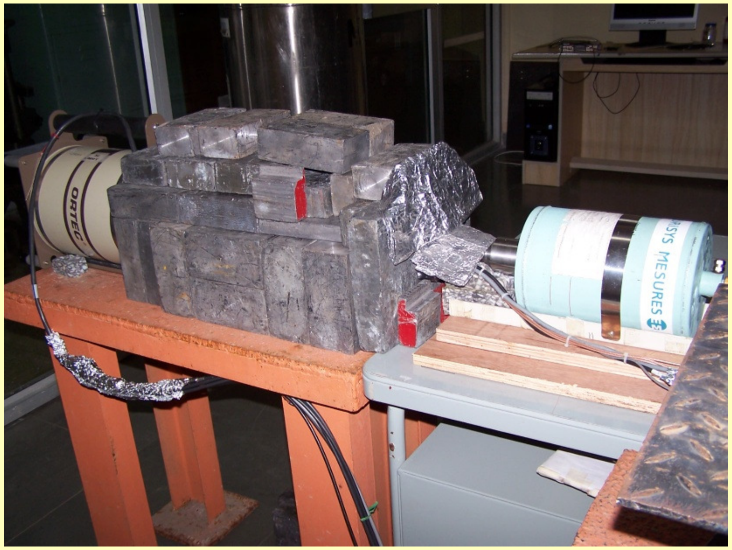
To study phenomenon of fusion hindrance

^{6}Li + ^{198}Pt (~ 1 mg/cm^2, 95.7 % enriched) $\rightarrow$ ^{205}Tl (CN)
Positive Q value (+8.5MeV)

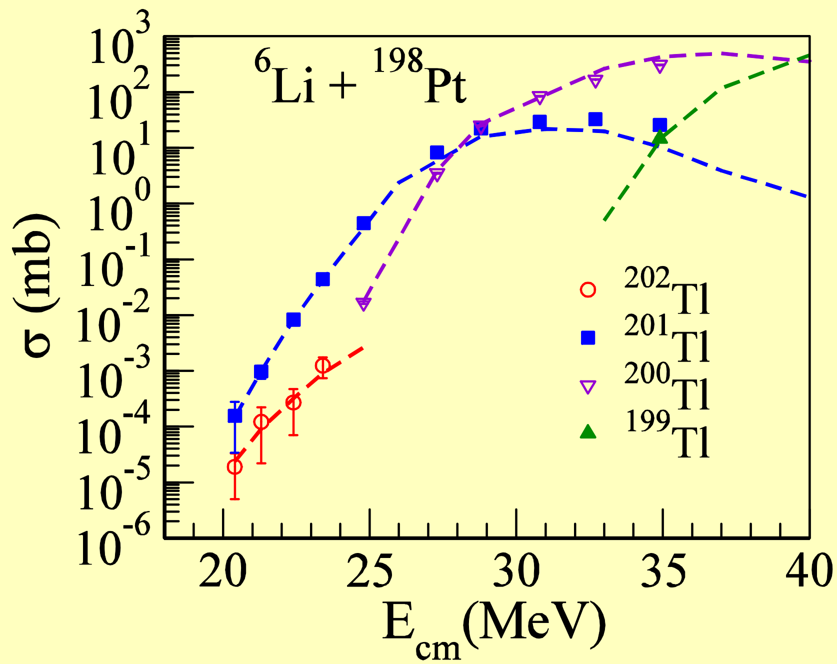
First measurement with weakly bound projectile at $0.68 < E/V_b < 1.3$

New sensitive off-beam gamma spectroscopy Technique:
coincidence between characteristic KX rays and gamma rays of daughter nuclei
NIM **598**, 445 (2009)

2 HPGe inside low background setup

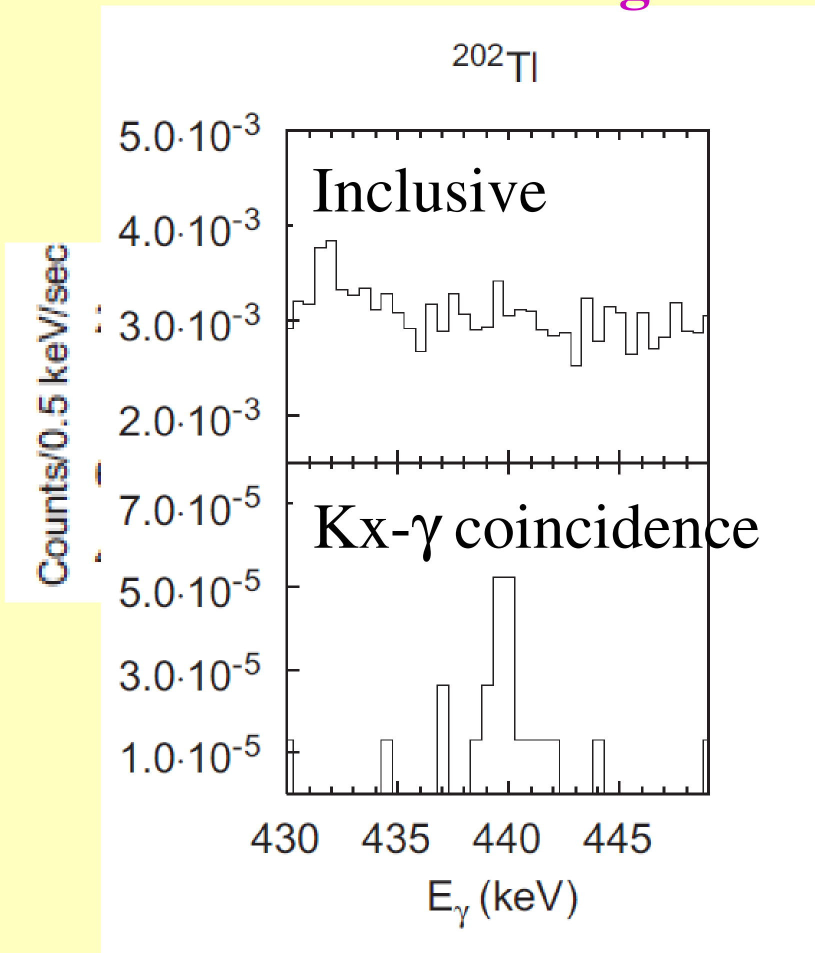


Evaporation residue cross-sections



Lowest x-sec up to 20 nb

Reduction of background



Statistical model calculations (PACE) with shell corrected level densities.

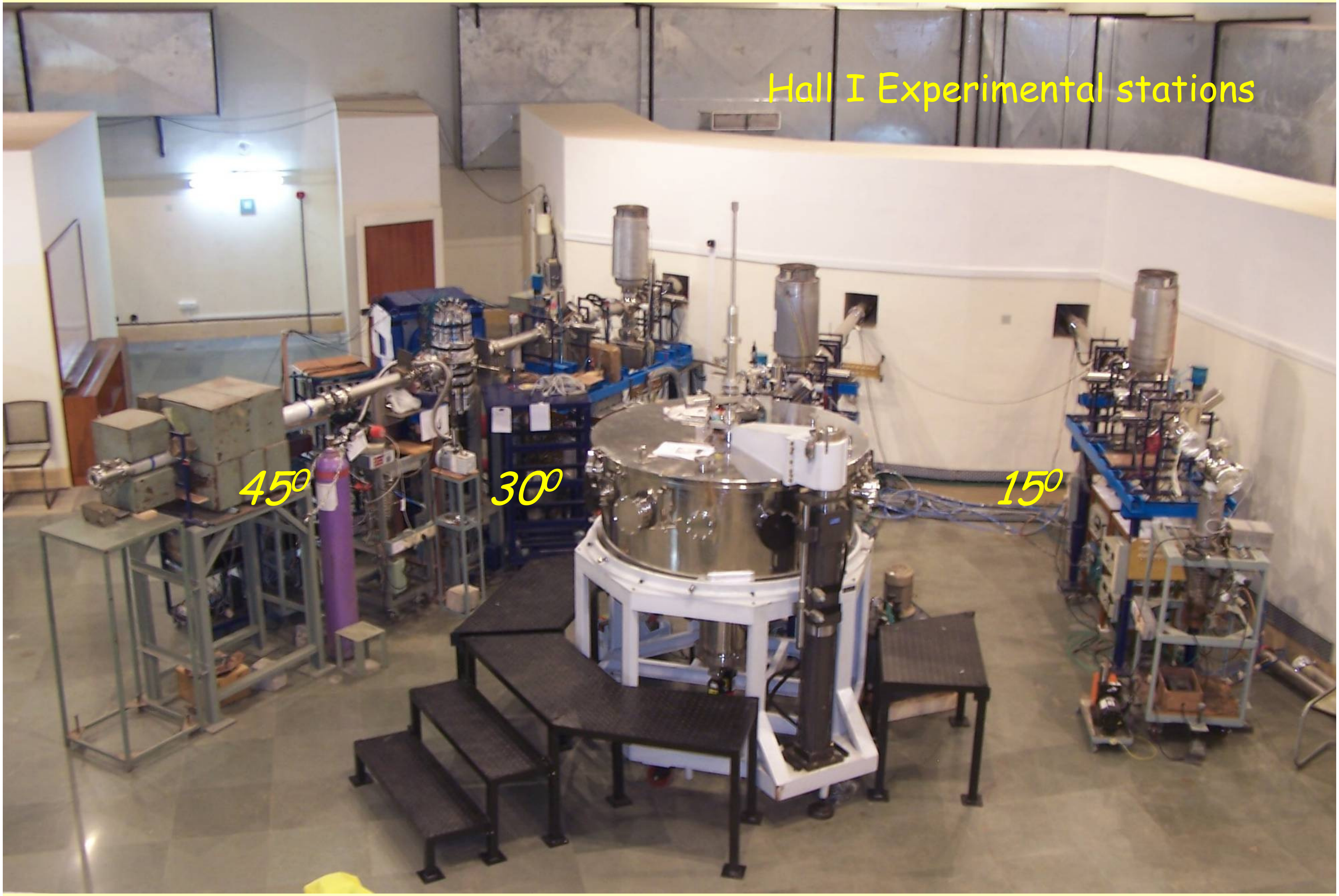
Discrete γ-ray spectroscopy

- Structure of high spin states of nuclei close to shell closure N~50 & Z~50 : identical bands, rigid rotation, magnetic rotation and non-axial shapes.
- Study of gamma soft nuclei around A ~ 80 : shape coexistence, shape evolution and signature inversion.
- Measurements of ground state hexadecupole deformation (β_4) in the rare earth nuclei

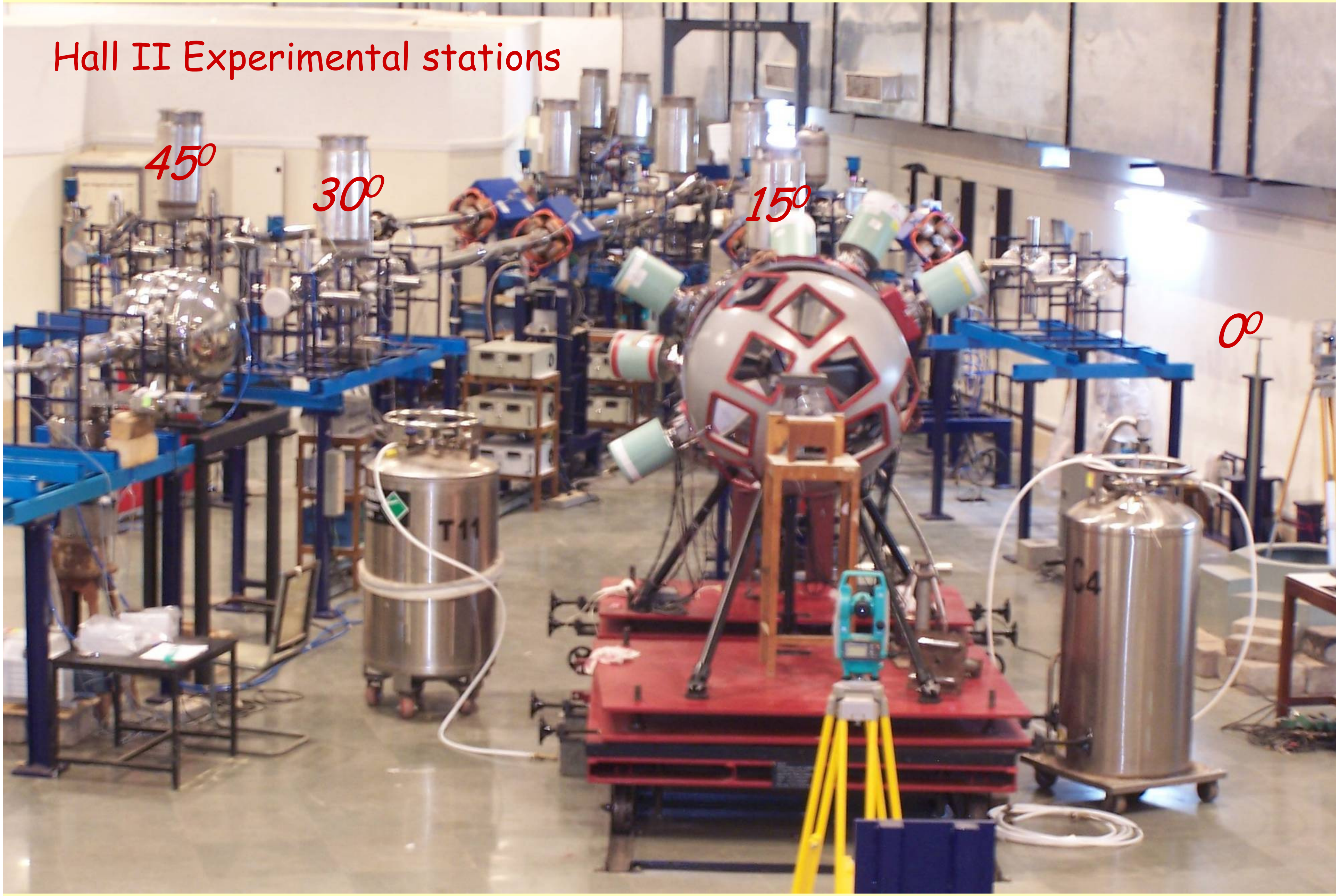
^{124}Sn + ^{16}O → ^{136}Ce + 4n *INGA* @ TIFR (2001)

Clear evidence of magnetic rotation in A~ 130

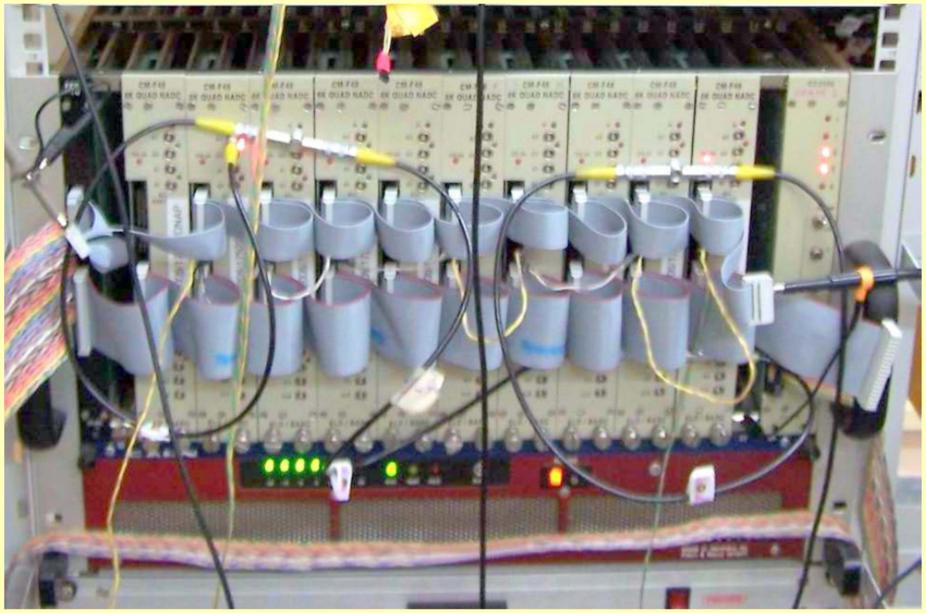
S. Lakshmi et al., Phys. Rev. C66, 41303R (2002)



Hall I Experimental stations
45^0
30^0
15^0


Hall II Experimental stations
45^0
30^0
15^0
0^0
T11
C4

Data Acquisition System



Welcome & Thank you