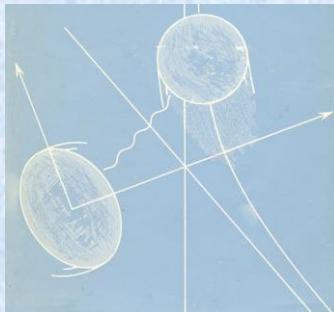


# An Overview of Coulomb excitation activities at IUAC

**3<sup>rd</sup> GOSIA workshop 9th – 11<sup>th</sup> April, 2018**



**Rakesh Kumar  
IUAC, New Delhi**

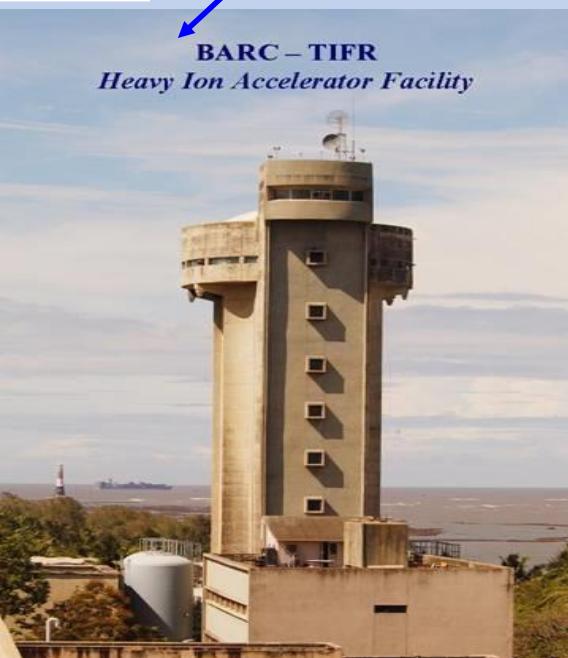


# 3<sup>rd</sup> GOSIA workshop 9th – 11<sup>th</sup> April, 2018





Inter University Accelerator Centre,  
New Delhi



Variable Energy Cyclotron  
Centre  
Kolkata

Before July, 1986



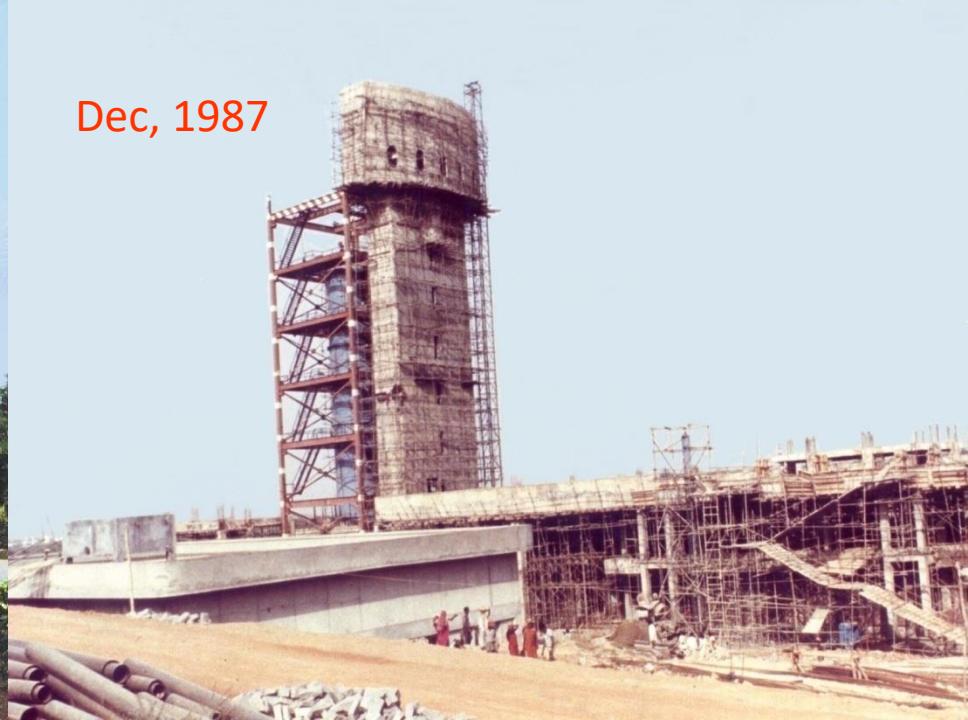
August, 1986



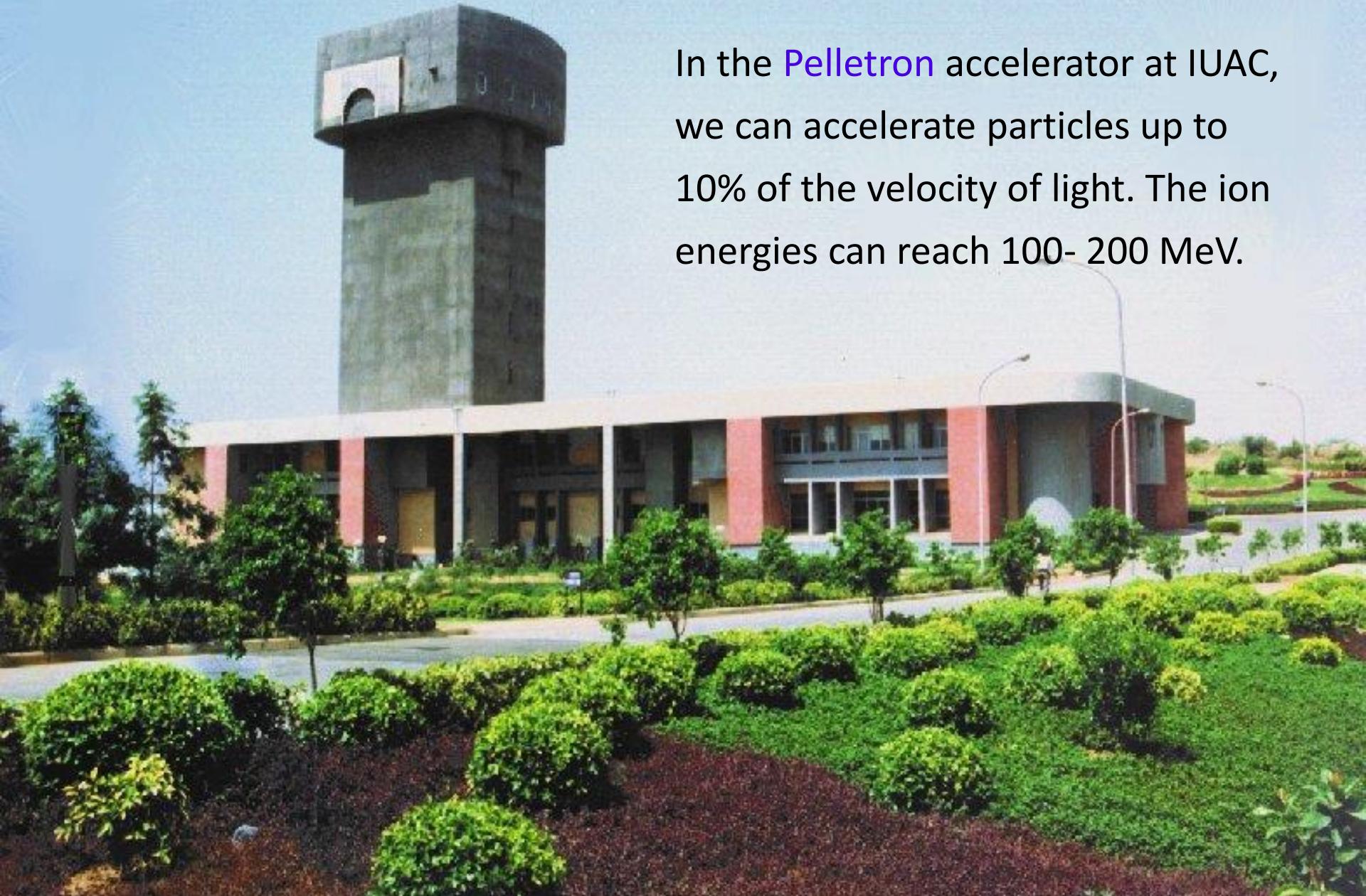
Nov, 1989



Dec, 1987

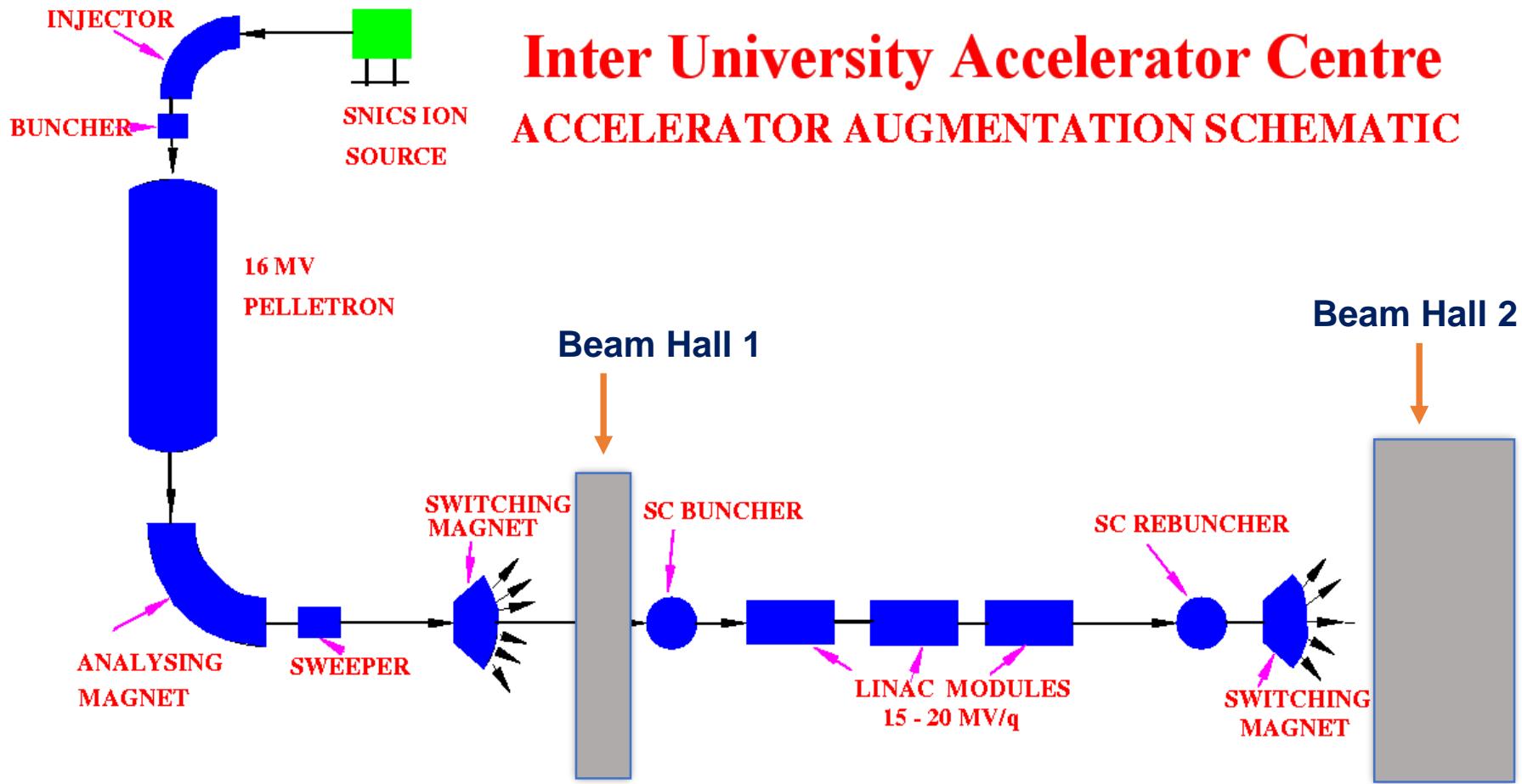


# Inter University Accelerator Centre

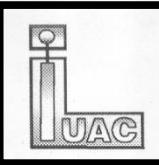


In the **Pelletron** accelerator at IUAC, we can accelerate particles up to 10% of the velocity of light. The ion energies can reach 100- 200 MeV.

# ENERGY BOOSTER LINAC



# Major Nuclear Physics Facilities at IUAC



- **Gamma arrays**

**S. Muralithar** ([murali@iuac.res.in](mailto:murali@iuac.res.in))

Gamma detector array (GDA)

Indian National Gamma Array (INGA)



- **Recoil separators**

**N. Madhavan** ([madhavan@iuac.res.in](mailto:madhavan@iuac.res.in))

Heavy Ion Reaction Analyzer (HIRA)

Hybrid Recoil mass Analyzer (HYRA)

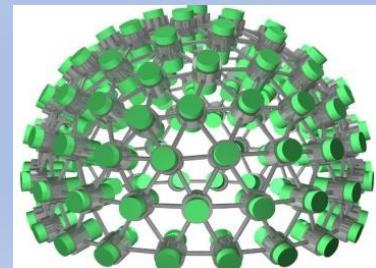


- **Scattering chamber / Neutron array**

**Dr. P. Sugathan** ([sugathan@iuac.res.in](mailto:sugathan@iuac.res.in))

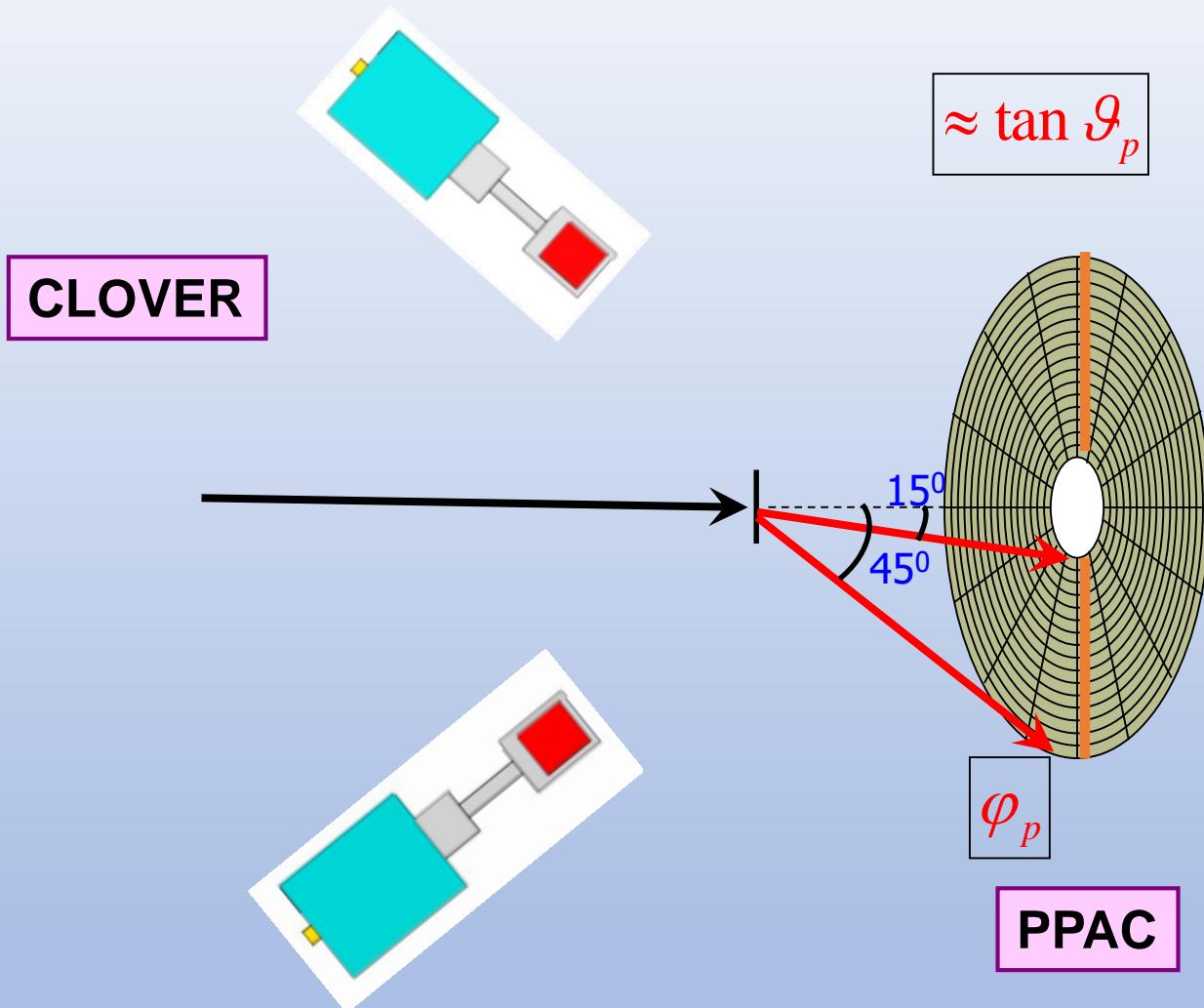
General Purpose Scattering Chamber (GPSC)

National Array of Neutron Detectors (NAND)

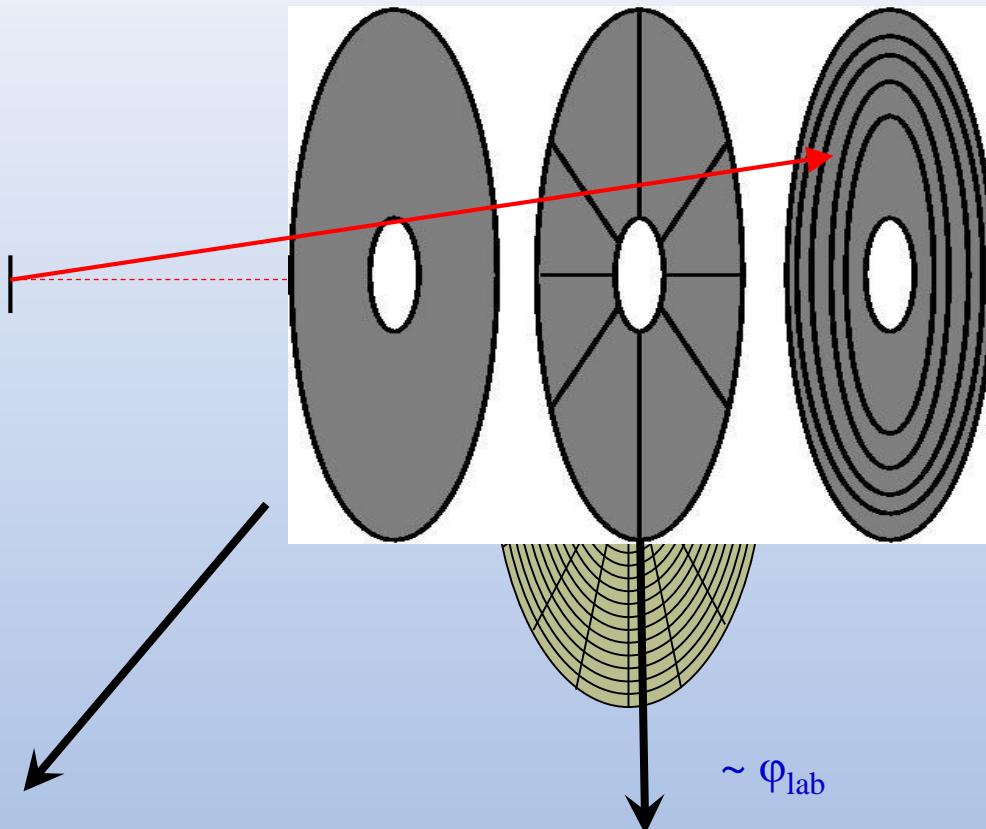


# **Coulomb excitation activities at IUAC**

# Present experimental set up at IUAC in GDA beam line



# Proportional Counter



$V_0 \sim 500$  V

$p = 7\text{-}13$  mbar iso-butane gas

$\sim 3$  mm gap cathode-anode

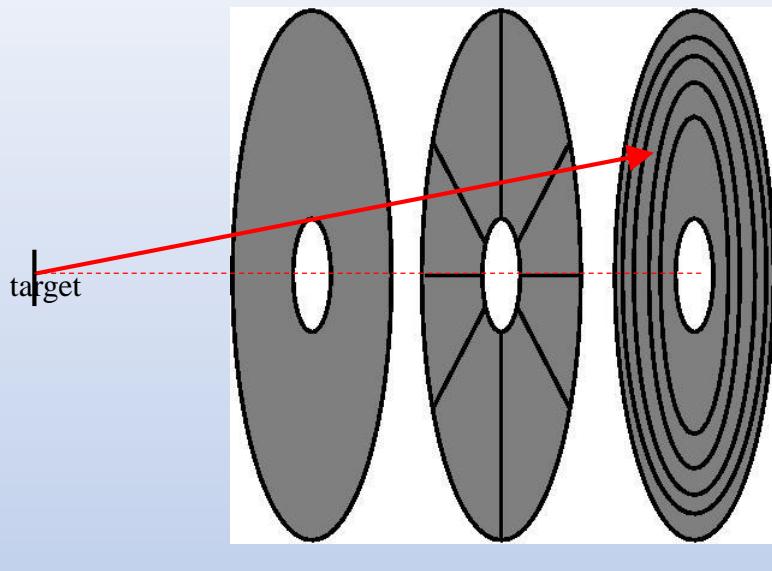
$\sim \vartheta_{lab}$

Detector is isolated from Vacuum through entrance window of 2um mylar foil

Cathode is segmented to provide azimuthal angle  $\varphi$ , foil is segmented into a cake-like structure with 16 sectors so as to provide  $\varphi$  information with an angular pitch of 22.5 degrees.

Anode is segmented to provide polar angles  $\vartheta$  of the reaction products. The anode is segmented into two halves with each half having concentric rings. Each ring has a width of 1 mm.

# Proportional Counter



entrance window

$\sim \Phi_{\text{lab}}$

$\sim \tan\theta_{\text{lab}}$

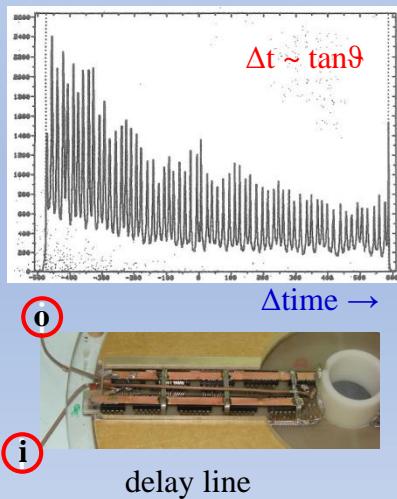
Front  $\rightarrow \phi$ -information

A. Jhingan et. al., DAE-BRNS Symp. on Nucl. Phys. 61 (2016) 966.

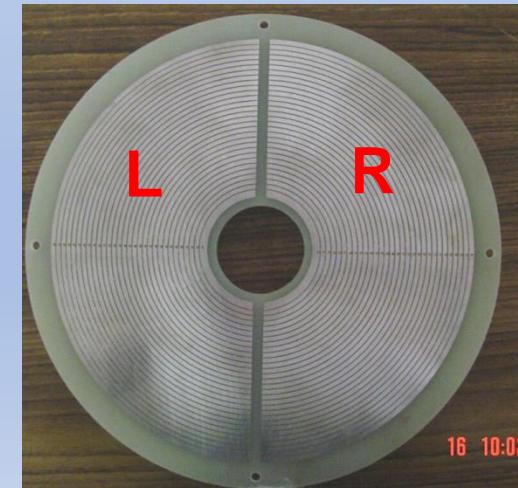
$V_0 \sim 500 \text{ V}$

$p = 7-13 \text{ Torr}$

$\sim 3 \text{ mm gap anode-cathode}$



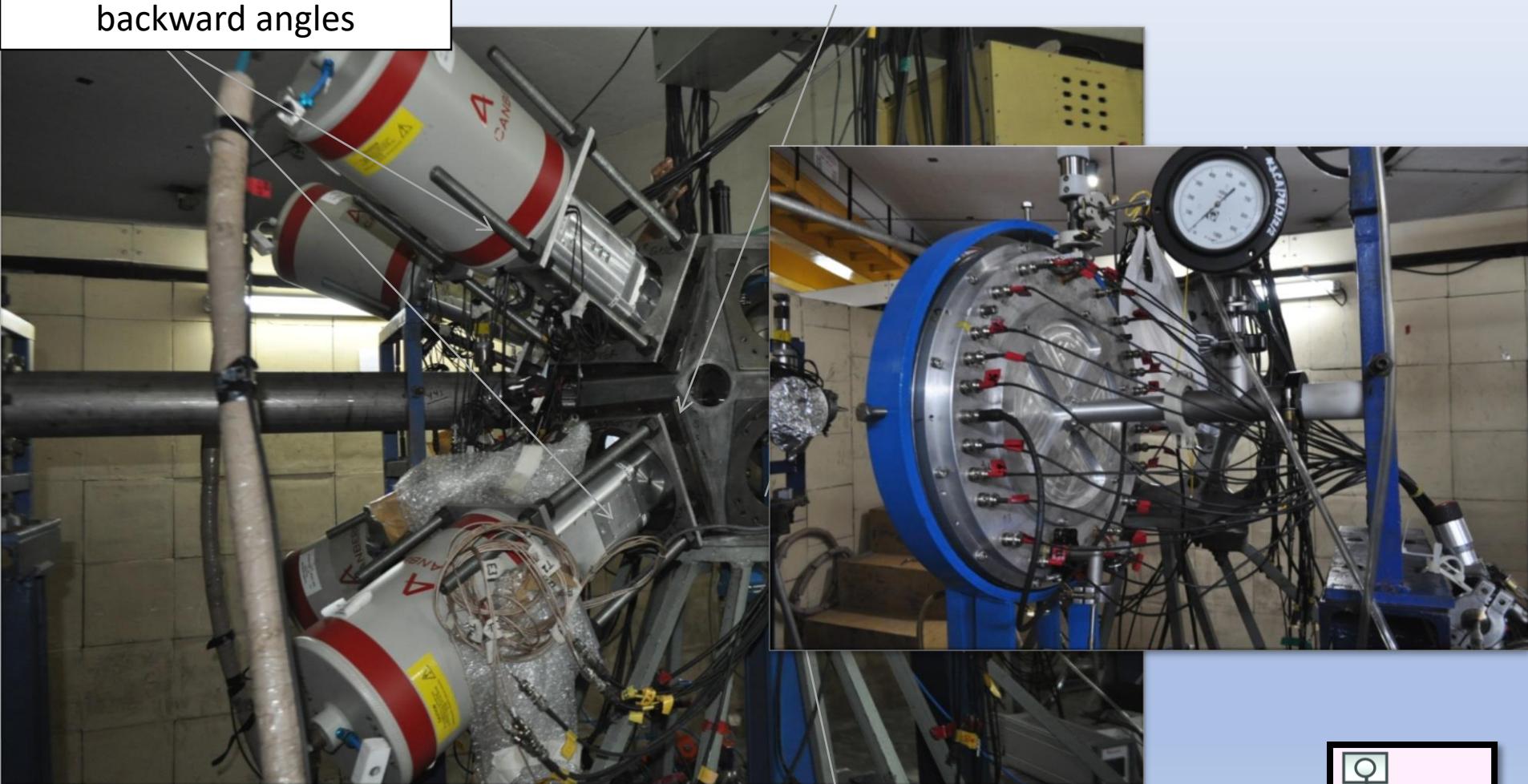
Back  $\rightarrow \theta$ -information



# Experimental set up at IUAC

CLOVER DETECTORS  
@  
backward angles

TARGET

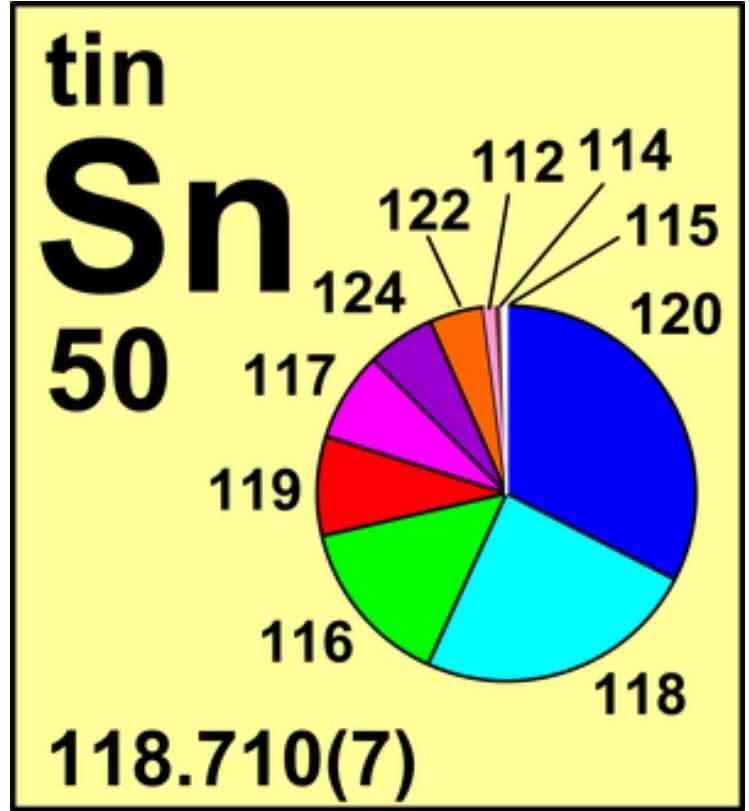


PPAC @ forward angle



# Coulex Experiments at I.U.A.C

# Brief Introduction to Sn Region



# The $^{100}\text{Sn}$ / $^{132}\text{Sn}$ region, a brief background

$Z = 50$

$g_{7/2}$

<b>Sn102</b>	<b>Sn103</b> 7 s	<b>Sn104</b> 20.8 s	<b>Sn105</b> 31 s	<b>Sn106</b> 115 s	<b>Sn107</b> 2.90 m (5/2+)	<b>Sn108</b> 10.30 m	<b>Sn109</b> 18.0 m 5/2(+)	<b>Sn110</b> 4.11 h	<b>Sn111</b> 35.3 m 7/2+
0+	EC	EC	ECp	EC	EC	EC	EC	EC	EC

Single particle energies



$d_{5/2}$

$s_{1/2}$

$d_{3/2}$

$h_{11/2}$

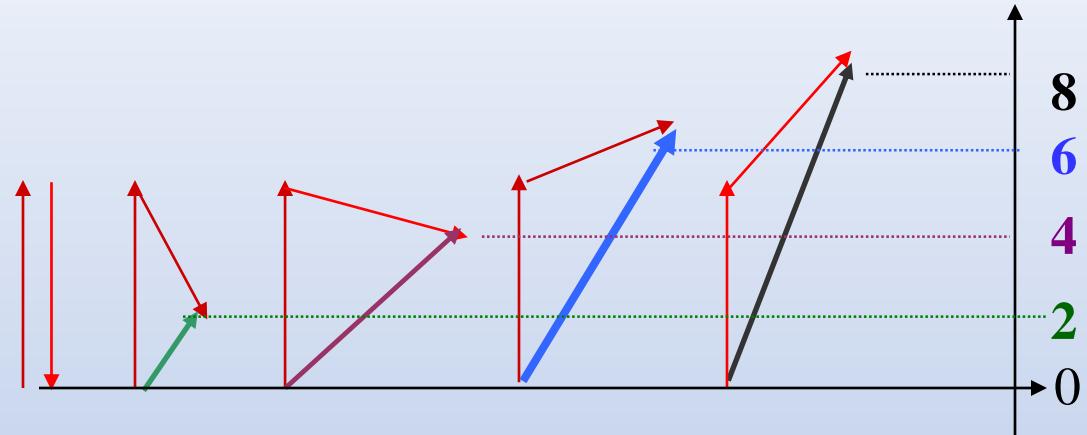
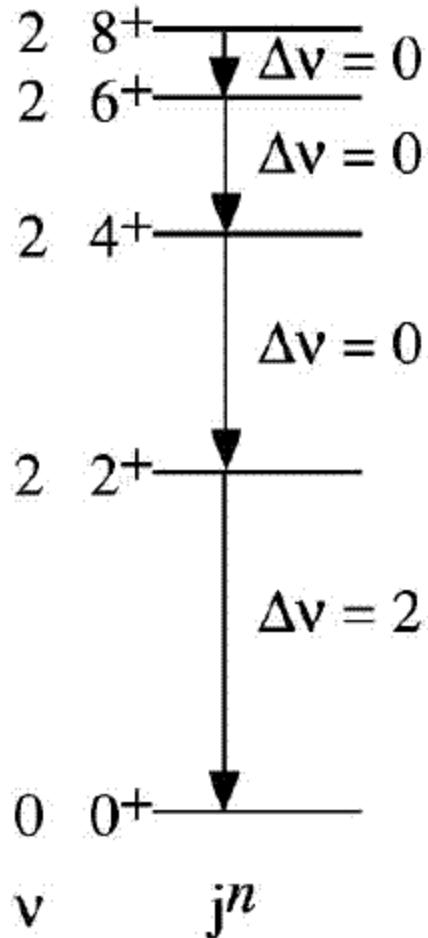
<b>Sn112</b>	<b>Sn113</b> 115.09 d	<b>Sn114</b>	<b>Sn115</b>	<b>Sn116</b>	<b>Sn117</b>	<b>Sn118</b>	<b>Sn119</b>	<b>Sn120</b>
0+ *	1/2+ *	0+ *	1/2+ *	0+ *	1/2+ *	0+ *	1/2+ *	0+ *

<b>Sn121</b> 27.06 h	<b>Sn122</b> 0+ *	<b>Sn123</b> 129.2 d	<b>Sn124</b> 0+ *	<b>Sn125</b> 9.64 d	<b>Sn126</b> 1E+5 y	<b>Sn127</b> 2.10 h	<b>Sn128</b> 59.07 m	<b>Sn129</b> 2.23 m (3/2+)	<b>Sn130</b> 3.72 m	<b>Sn131</b> 56.0 s (3/2+)	<b>Sn132</b> 39.7 s
$\beta^+$	4.63	$\beta^-$	5.79	$\beta^+$	$\beta^-$	$\beta^-$	$\beta^-$	$\beta^-$	$\beta^-$	$\beta^-$	$\beta^-$

Naïve single particle filling



# Seniority Scheme



δ-interaction yields a simple geometrical expression for coupling of two particles

$$\Delta E \sim -V_o \cdot F_r \cdot \tan(\theta/2)$$

Energy intervals between states  $0^+, 2^+, 4^+, \dots (2j - 1)^+$  decrease with increasing spin.

# Generalized Seniority Scheme



$$T_{1/2} = 13.8(4) \text{ ns}$$

$6^+$

2548.9

$4^+$

301.7

2247.2

990.6

$$T_{1/2} = 0.35 \text{ ps}$$

$2^+$

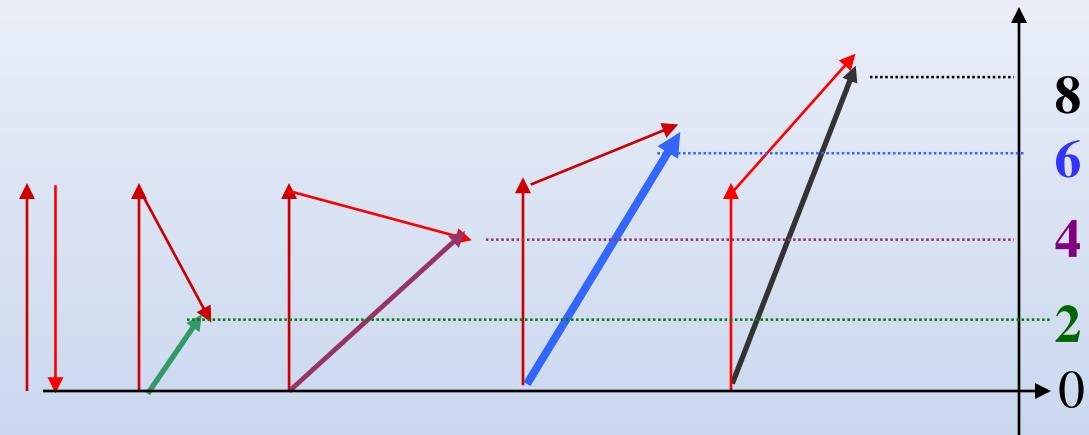
1256.6

$0^+$

1256.6

$^{112}\text{Sn}$

0

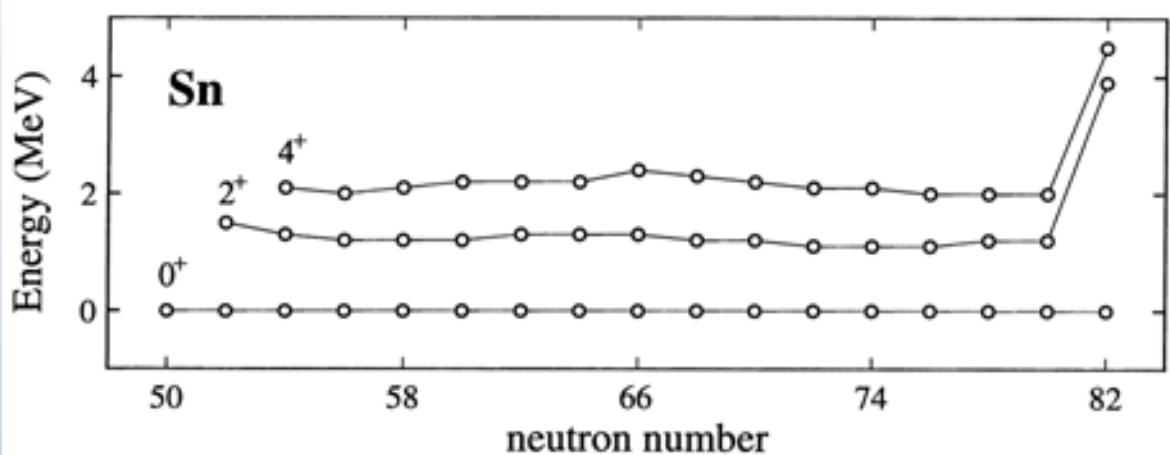


$\delta$ -interaction yields a simple geometrical expression for coupling of two particles

$$\Delta E \sim -V_o \cdot F_r \cdot \tan(\theta/2)$$

Energy intervals between states  $0^+, 2^+, 4^+, \dots (2j - 1)^+$  decrease with increasing spin.

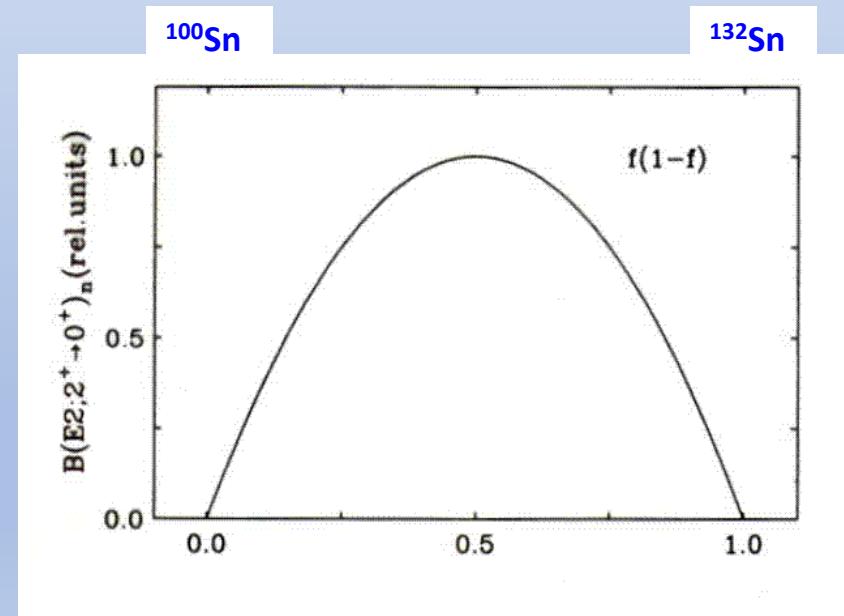
# Generalized Seniority Scheme



$$B(E2; 2_1^+ \rightarrow 0_1^+) \approx f \cdot (1-f) \\ \approx N_{\text{particles}} * N_{\text{holes}}$$

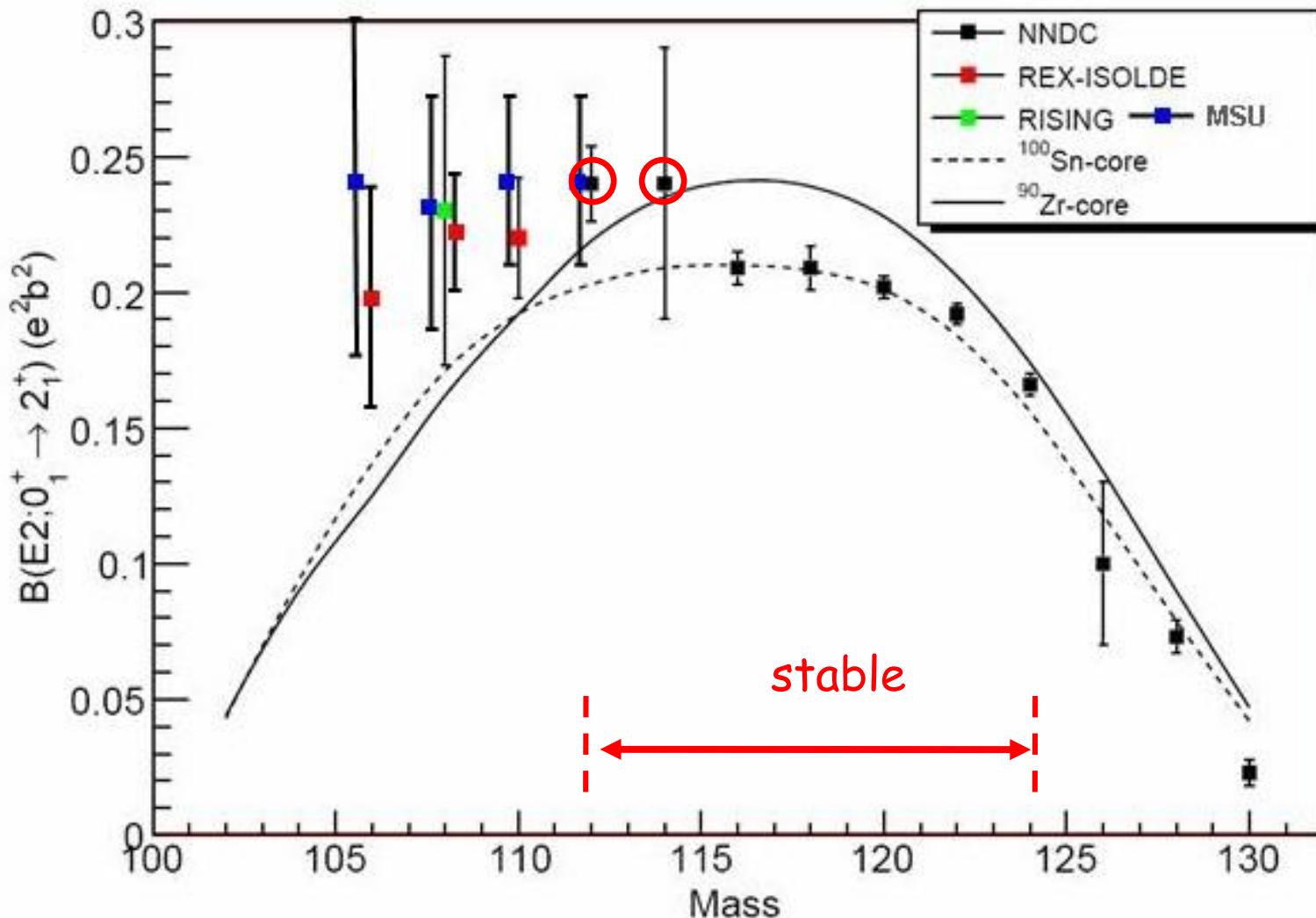


number of nucleons  
between shell closures



$$B(E2; 2^+ \rightarrow 0^+) \sim N_{\text{particles}} * N_{\text{holes}}$$

# B(E2) values before our measurements

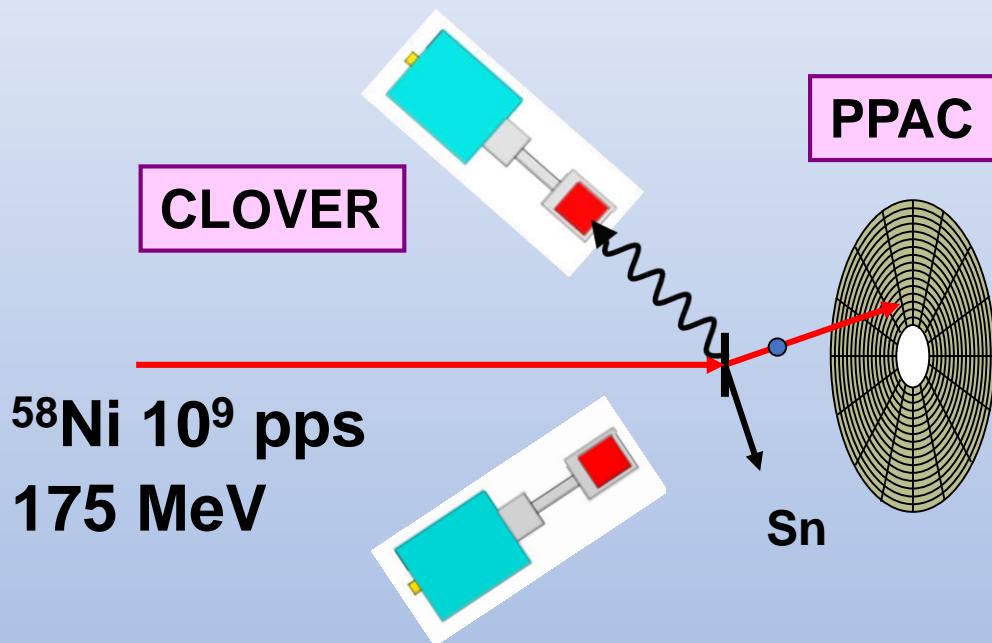


Does  $^{112}\text{Sn}$  and  $^{114}\text{Sn}$  follow the trend of high B(E2) values?

# Coulomb Excitation of $^{112,114,116}\text{Sn}$



## Experimental setup at IUAC



$^{58}\text{Ni} \rightarrow ^{112,116}\text{Sn}$  at 175MeV

$E_x = 1257, 1294\text{keV}$   
 $B(E2)\uparrow = 0.24(2), 0.209(5)e^2b^2$

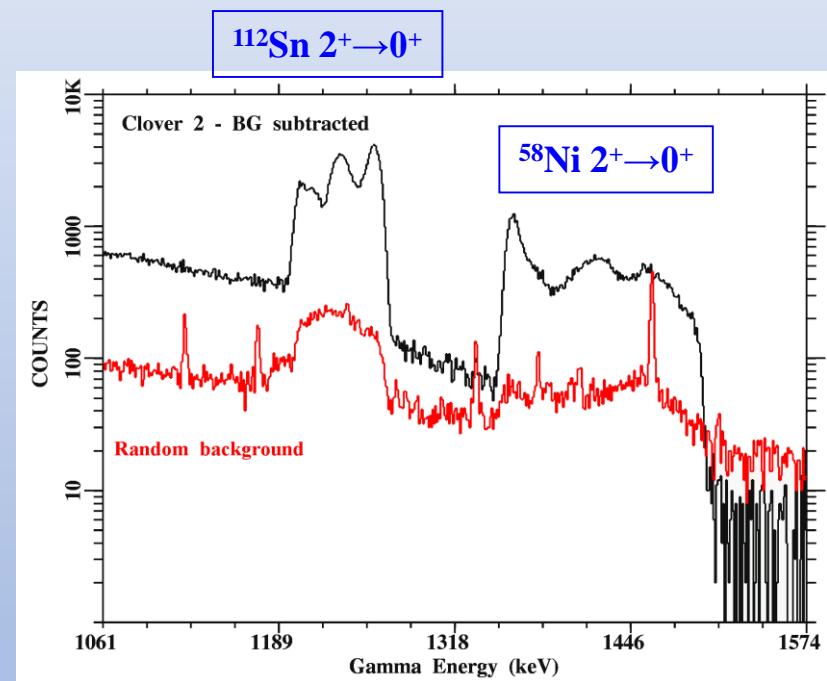
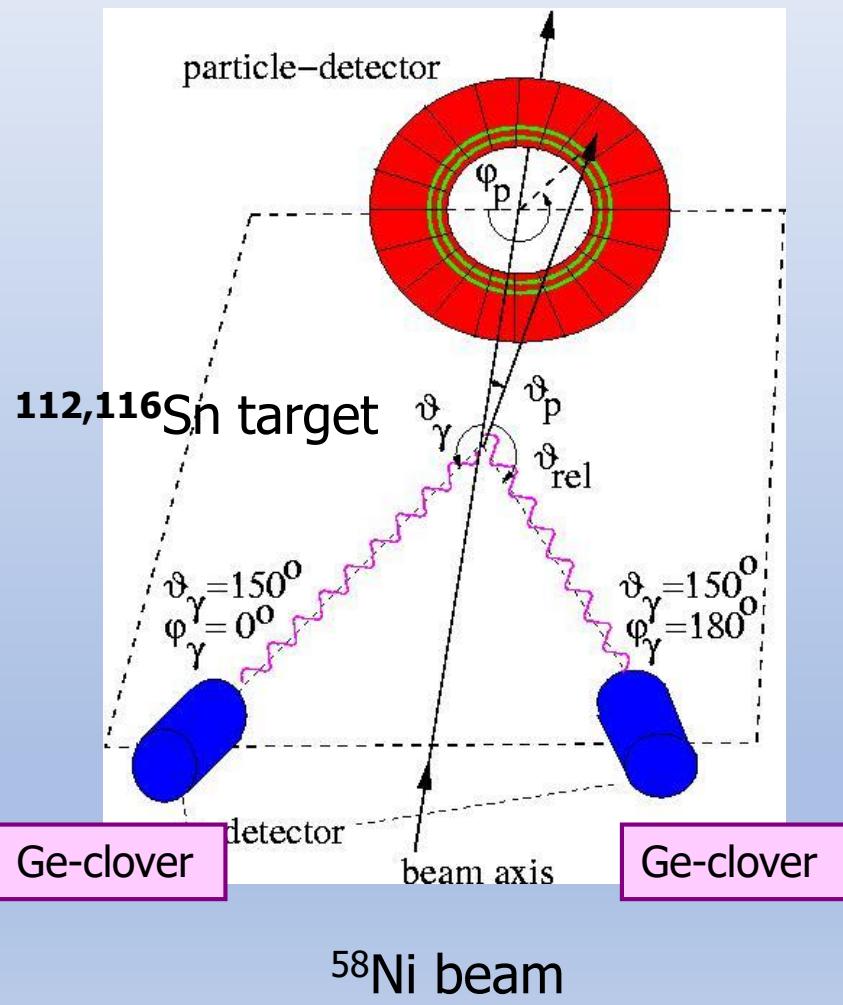


$^{114,116}\text{Sn} \rightarrow ^{58}\text{Ni}$  at 3.4MeV/u

$E_x = 1300, 1294\text{keV}$   
 $B(E2)\uparrow = 0.25(5), 0.209(5)e^2b^2$

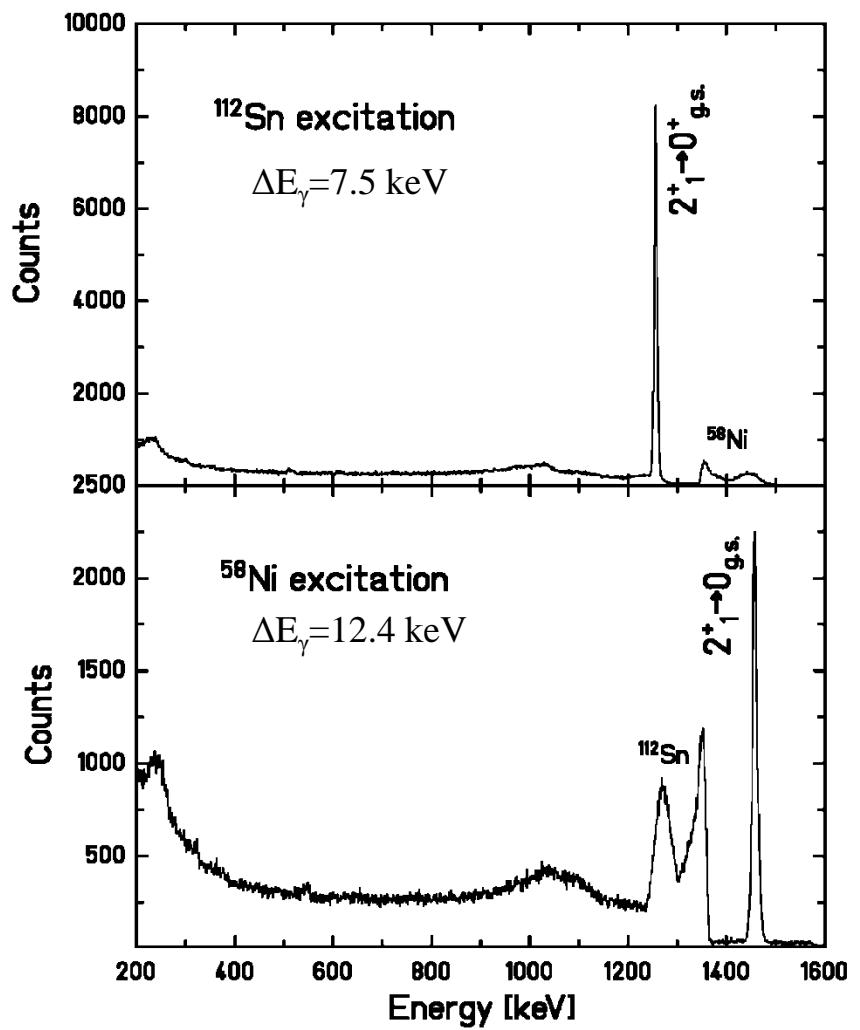
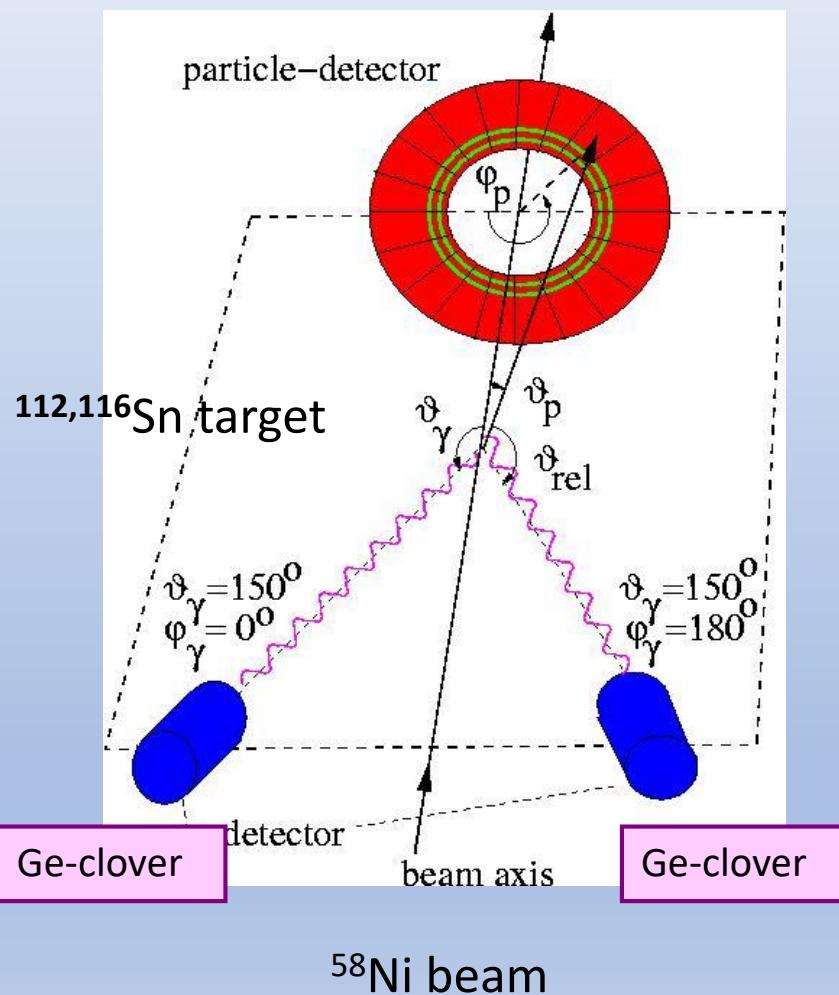


# Coulomb Excitation of $^{112,114,116}\text{Sn}$



# Coulomb Excitation of $^{112,114,116}\text{Sn}$

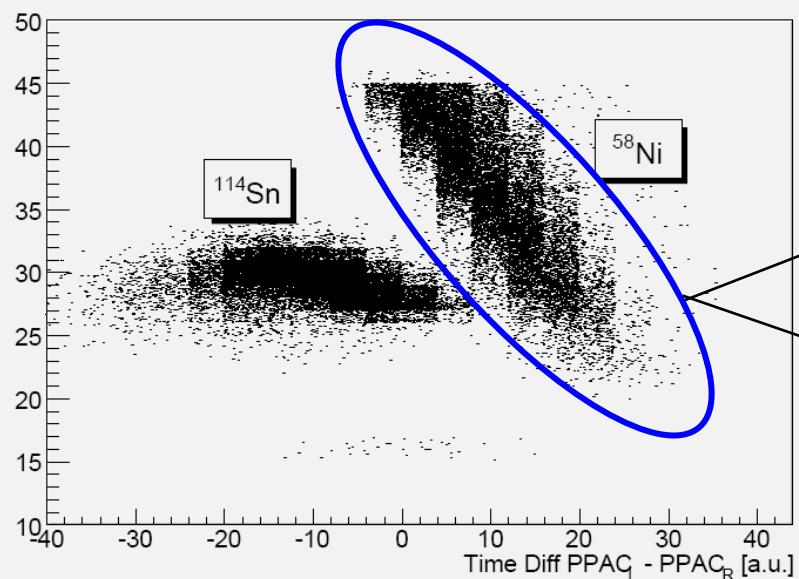
Doppler shift correction for Ni in PPAC



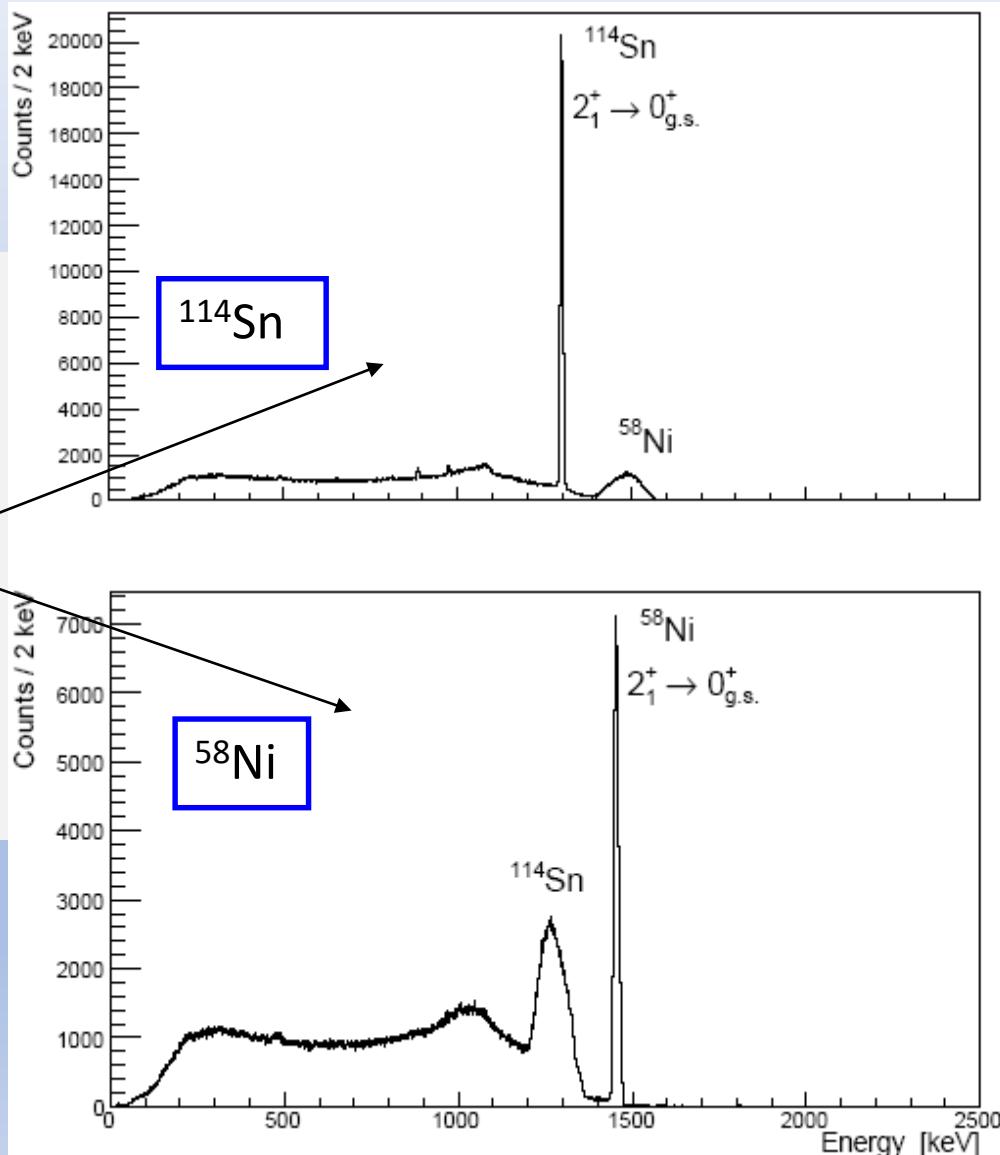
# Particle Identification and Doppler correction at GSI

particle identification with PPAC  
2 particles +  $\gamma$ -ray required

Scattering Angle



Time (PPAC<sub>L</sub>-PPAC<sub>R</sub>)



# B(E2) value determination

- Literature value for  $^{116}\text{Sn}$   $B(\text{E}2\uparrow) = 0.209(6) \text{ e}^2\text{b}^2$
- Literature value for  $^{58}\text{Ni}$   $B(\text{E}2\uparrow) = 0.0493(7) \text{ e}^2\text{b}^2$
- Two possibilities to determine  $B(\text{E}2)$  of  $^{112}\text{Sn}$ :  
Relative to  $^{58}\text{Ni}$ :

$$B(E2, ^{112}\text{Sn}) = B(E2, ^{58}\text{Ni}) \frac{\sigma_{^{58}\text{Ni}}}{\sigma_{^{112}\text{Sn}}} \frac{I_\gamma(^{112}\text{Sn})}{I_\gamma(^{58}\text{Ni})}$$

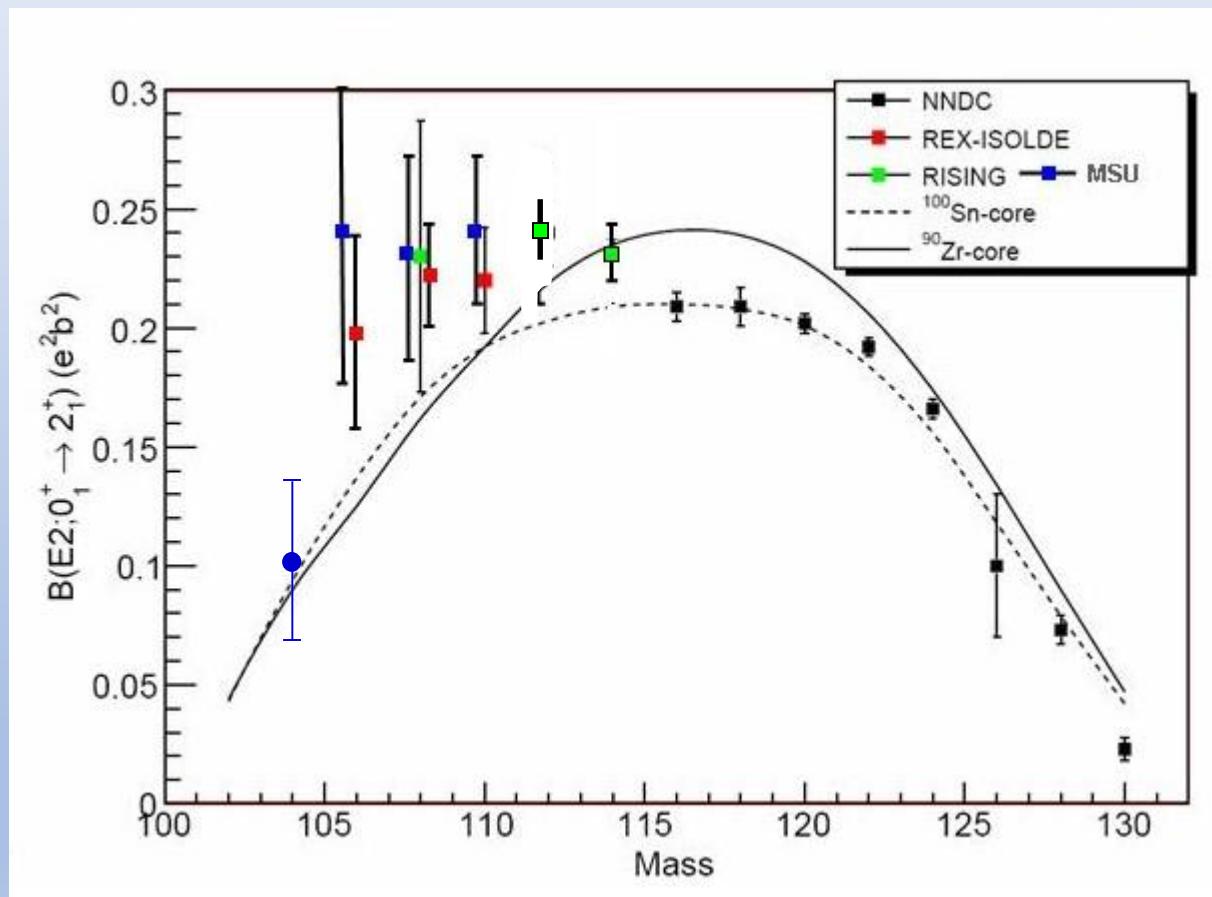
Relative to  $^{116}\text{Sn}$ :

$$B(E2, ^{112}\text{Sn}) = B(E2, ^{116}\text{Sn}) \frac{\sigma_{^{116}\text{Sn}}}{\sigma_{^{112}\text{Sn}}} \frac{I_\gamma(^{112}\text{Sn})}{I_\gamma(^{58}\text{Ni})} \frac{I_\gamma(^{58}\text{Ni})}{I_\gamma(^{116}\text{Sn})} = 0.242(8) \text{ } e^2\text{b}^2$$



# Enhanced strength of the $2_1^+ \rightarrow 0_{g.s.}^+$ transition in $^{114}\text{Sn}$ studied via Coulomb excitation in inverse kinematics

P. Doornenbal,<sup>1,2,\*</sup> P. Reiter,<sup>1</sup> H. Grawe,<sup>2</sup> H. J. Wollersheim,<sup>2</sup> P. Bednarczyk,<sup>2,3</sup> L. Caceres,<sup>2,4</sup> J. Cederkäll,<sup>5,6</sup> A. Ekström,<sup>6</sup>,<sup>5</sup> J. Gerl,<sup>2</sup> M. Górska,<sup>2</sup> A. Jhingan,<sup>7</sup> I. Kojouharov,<sup>2</sup> R. Kumar,<sup>7</sup> W. Prokopowicz,<sup>2</sup> H. Schaffner,<sup>2</sup> and R. P. Singh<sup>7</sup>



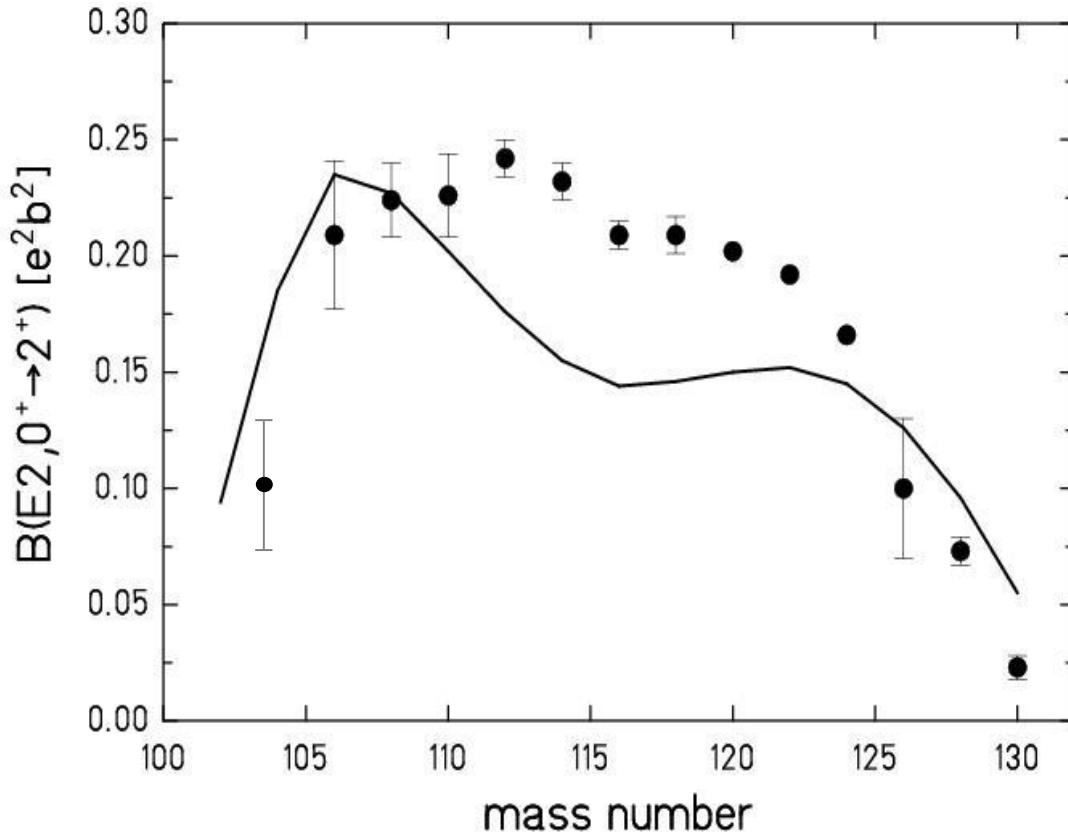
For  $^{112}\text{Sn}$  we determined  
 $B(E2; 0^+ \rightarrow 2^+) = 0.242(8) \text{ e}^2 \text{b}^2$

For  $^{114}\text{Sn}$  we determined  
 $B(E2; 0^+ \rightarrow 2^+) = 0.232(8) \text{ e}^2 \text{b}^2$



# Comparison with RQRPA

relativistic quasiparticle random-phase approximation calculation

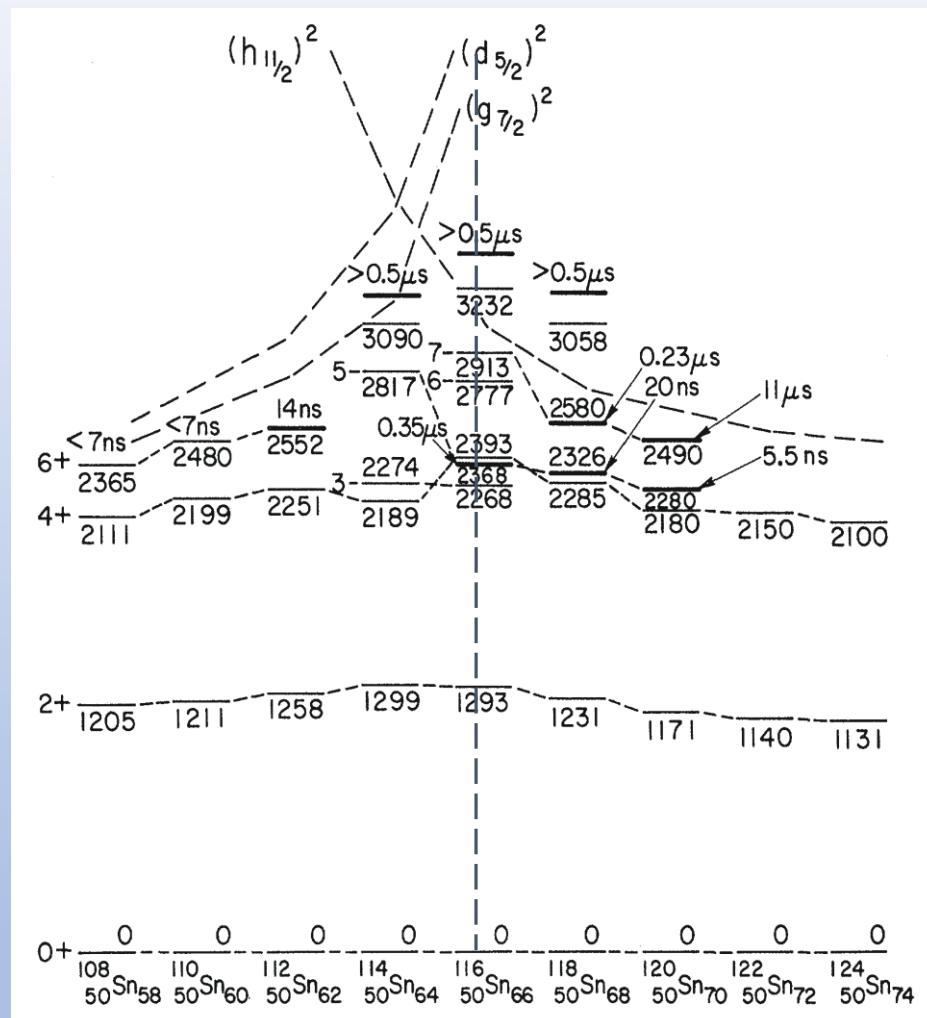
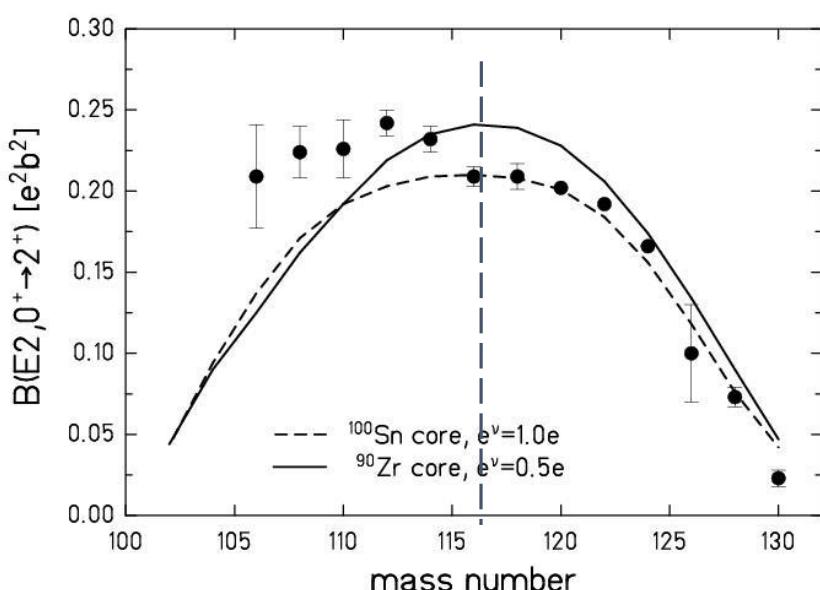


- no effective charges
- no core required
- satisfactory agreement also for the Ni and Pb isotopes



# Asymmetry between $^{100}\text{Sn}$ and $^{132}\text{Sn}$

- $^{112}\text{Sn}$ :  $B(E2, 0^+ \rightarrow 2^+) = 0.242(8) \text{ e}^2\text{b}^2$
- $^{114}\text{Sn}$ :  $B(E2, 0^+ \rightarrow 2^+) = 0.232(8) \text{ e}^2\text{b}^2$



# Coulomb Excitation of $^{120,122,124}\text{Te}$ isotopes

Z=52

Z=50

La119	La120 2.8 s	La121 5.3 s	La122 8.7 s	La123 17 s	La124 29 s	*	La125 76 s (11/2-)	La126 54 s	La127 5.1 m (11/2-)	La128 5.0 m (5+)	La129 11.6 m 3/2+	*	La130 8.7 m 3(+)	La131 59 m 3/2+	La132 4.8 h 2-	*	La133 39.12 h 5/2+	La134 6.45 m 1+	La135 19.51 h 5/2+	La136 9.87 m 1+*
EC	ECp	ECp	ECp	EC	EC	*	EC	EC	EC	EC	EC	*	EC	EC	EC	EC	EC	EC	EC	
Ba118 5.5 s 0+	Ba119 5.4 s (5/2+)	Ba120 32 s 0+	Ba121 29.7 s 5/2(+)	Ba122 1.95 m 0+	Ba123 2.7 m 5/2+	Ba124 11.0 m 0+	Ba125 3.5 m 1/2(+)	Ba126 100 m 0+	Ba127 12.7 m 1/2+	Ba128 2.43 d 0+	Ba129 2.23 h 1/2+	*	Ba130 0+	*	Ba131 11.50 d 1/2+	Ba132 0+	Ba133 10.51 y 1/2+*	Ba134 0+*	Ba135 3/2+*	
EC	ECp	EC	ECp	EC	EC	*	EC	EC	EC	EC	EC	*	0.106	EC	0.101	EC	2.417	0.592		
Cs117 8.4 s (9/2+)*	Cs118 14 s 2*	Cs119 43.0 s 2*	Cs120 6.4 s 2*	Cs121 155 s 3/2(+)*	Cs122 21.0 s 1+*	Cs123 2.94 m 1/2+*	Cs124 30.8 s 1+*	Cs125 45 m (1/2+)	Cs126 1.64 m 1+	Cs127 6.25 m 1/2+	Cs128 3.66 m 1+	Cs129 32.06 m 1/2+*	Cs130 29.21 m 1+*	Cs131 9.689 d 5/2+	Cs132 6.479 d 7+*	Cs133 2.0648 y 4+*	Cs134 2.0648 y 7/2+*	Cs135 100	ECp*	EC
Xe116 59 s 0+	Xe117 61 s 5/2(+)	Xe118 3.8 m 0+	Xe119 5.8 m (5/2+)	Xe120 40 m 0+	Xe121 40.1 m 5/2(+)	Xe122 20.1 h 0+	Xe123 2.08 h (1/2+)	Xe124 1.6E+14 y 0+	Xe125 16.9 h (1/2+)	Xe126 3.64 d 0+	Xe127 3.64 d 1/2+*	*	Xe128 0+	Xe129 1/2+*	Xe130 0+	Xe131 3/2+*	Xe132 0+	Xe133 3/2+ d 3/2+*		
EC	ECp	EC	EC	EC	EC	*	EC	EC	EC	EC	EC	*	0.09	EC	1.91	2.64	4.1	21.2	26.9	
I115 1.3 m (5/2+)	I116 2.91 s 1+*	I117 2.22 m 2*	I118 13.7 m 2*	I119 19.1 m 5/2+	I120 81.0 m 2*	I121 2.12 h 5/2+	I122 3.63 m 1+*	I123 13.27 h 5/2+	I124 4.1760 d 2*	I125 59.408 d 5/2+	I126 13.11 d 2*	I127 5/2+*	I128 24.99 m 1+*	I129 1.57 E7 y 7/2+*	I130 12.36 h 5+*	I131 8.02070 d 7/2+*	I132 2.295 h 4+*	I133 5.243 d 3/2+*		
EC	EC	EC	EC	EC	EC	*	EC	EC	EC	EC	EC	*	100	ECp*	B-	B-	B-	B-		
Tel114 15.2 m 0+	Tel115 5.8 m 7/2+*	Tel116 2.49 h 0+	Tel117 62 m 1/2+*	Tel118 6.00 d 0+	Tel119 16.3 h 1+*	Tel120 0.096 s 0+	Tel121 6.78 d 1/2+*	Tel122 0+	Tel123 1E+13 y 1/2+*	Tel124 0+	Tel125 1/2+*	*	Tel126 0+	Tel127 9.35 h 3/2+*	Tel128 2.2E24 y 0+	Tel129 69.6 m 3/2+*	Tel130 7.9E20 y 0+	Tel131 25.0 m 3/2+*		
EC	EC	EC	EC	EC	EC	*	EC	EC	EC	EC	EC	*	0.908	4.816	7.130	18.95	B-	B-	B-	
Sb113 6.67 m 5/2+*	Sb114 3.49 m 3+*	Sb115 32.1 m 5/2+*	Sb116 15.8 m 3+*	Sb117 2.80 h 5/2+*	Sb118 3.6 m 1+*	Sb119 38.19 h 5/2+*	Sb120 15.89 m 1+*	Sb121 5/2+*	Sb122 2.7238 d 2-	Sb123 7/2+*	Sb124 60.20 d 3-*	Sb125 2.7582 y 7/2+*	Sb126 12.46 d (8)-*	Sb127 3.85 d 7/2+*	Sb128 9.01 h 8-*	Sb129 4.40 h 7/2+*	Sb130 39.5 m (8)-*	Sb130		
Sn112 0+	Sn113 115.96 h 1+*	Sn114 0+	Sn115 0+	Sn116 1/2+	Sn117 0+	Sn118 1/2+*	Sn119 0+	Sn120 1/2+*	Sn121 37.06 h 3/2+*	Sn122 0+	Sn123 11.79 d 11/2+*	Sn124 0+	Sn125 9.64 d 11/2+*	Sn126 1E+5 y 11/2+*	Sn127 2.10 h 0+	Sn128 50.07 m (3/2+)*	Sn129 2.23 m 0+			
EC	ECp*	ECp	EC	EC	EC	*	EC	EC	EC	EC	EC	*	0.92	0.65	14.73	7.60	24.73	9.59	33.79	
In111 2.80E+4 d 0/2+*	In112 14.97 m 1+*	In113 9.24 s 1+*	In114 71.9 s 9/2+*	In115 4.41E+14 y 1+*	In116 14.10 s 9/2+*	In117 43.2 m 1+*	In118 5.0 s 1+*	In119 2.4 m 0/2+*	In120 3.08 s 1+*	In121 23.1 s 0/2+*	In122 1.5 s 1+*	In123 5.98 s 0/2+*	In124 3.11 s 3+*	In125 2.36 s 0/2+*	In126 1.60 s 3+*	In127 1.09 s (9/2+)*	In128 0.84 s (3+)*			
EC	ECp*	EC	ECp*	EC	EC	*	EC	EC	EC	EC	EC	*	4.3	95.7	B-	B-	B-	B-		
Cd110 0+	Cd111 1/2+*	Cd112 0+	Cd113 7.7E+15 y 1/2+*	Cd114 0+	Cd115 53.46 h 1/2+*	Cd116 0+	Cd117 2.49 h 1/2+*	Cd118 50.3 m 0+	Cd119 2.69 m 3/2+*	Cd120 50.80 s 0+	Cd121 13.5 s (3/2+)*	Cd122 5.24 s 0+	Cd123 2.19 s (3/2+)*	Cd124 1.25 s 0+	Cd125 0.65 s (3/2+)*	Cd126 0.506 s 0+	Cd127 0.578 s (3/2+)*			
12.49	12.80	24.13	12.22	28.73	B-	7.49	B-	B-	B-	B-	B-	B-	B-	B-	B-	B-	B-	B-		

N

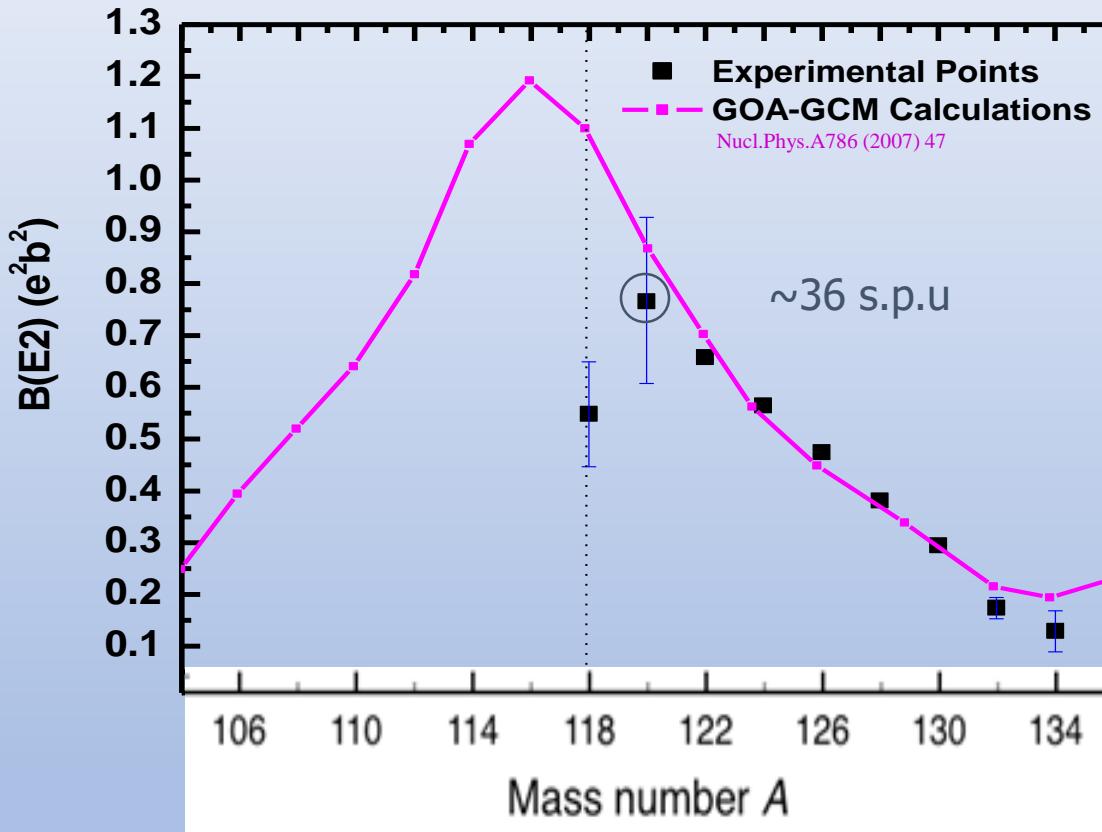
# Coulomb Excitation of $^{120,122,124}\text{Te}$ isotopes

Mansi Saxena

HIL, Warsaw



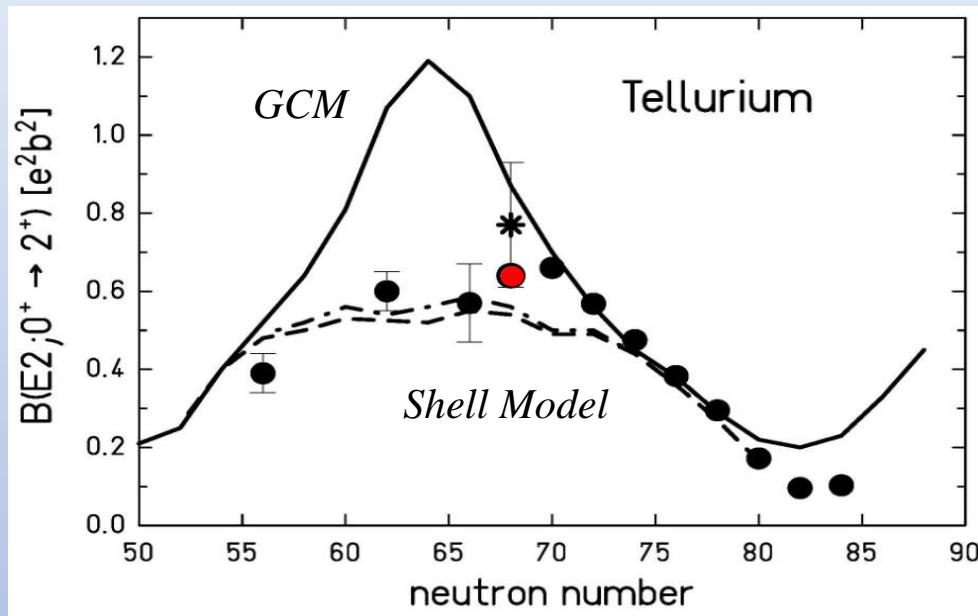
# Collectivity of the Te isotopes (Z=52)



Remeasurement of  $B(E2)$  value in  $^{120}\text{Te}$  using the double ratio method ( $^{122}\text{Te}$  is the reference nucleus)

# Rotational behavior of $^{120,122,124}\text{Te}$

M. Saxena,<sup>1</sup> R. Kumar,<sup>2</sup> A. Jhingan,<sup>2</sup> S. Mandal,<sup>1</sup> A. Stolarz,<sup>3</sup> A. Banerjee,<sup>1</sup> R. K. Bhowmik,<sup>2</sup> S. Dutt,<sup>4</sup> J. Kaur,<sup>5</sup> V. Kumar,<sup>6</sup> M. Modou Mbaye,<sup>7</sup> V. R. Sharma,<sup>8</sup> and H.-J. Wollersheim<sup>9</sup>



Comparison with LSSM and GCM

$$B(E2) \uparrow = 0.666(20)$$

Effective charge used were  $e_v = 0.8e$ ,  $e_n = 1.5e$

SM calculation bottom dashed line with  $d_{5/2} g_{7/2}$  inverted

Model space ( $g_{7/2}, d, s, h_{11/2}$ ) was used , allowing excitation of four neutrons above the Fermi level in the  $h_{11/2}$  sub shell

# The Ba isotopes, a brief background

Z=56

La119	La120 2.8 s	La121 5.3 s	La122 8.7 s	La123 17 s	La124 29 s	*	La125 76 s (11/2-)	La126 54 s	La127 5.1 m (11/2-)	*	La128 5.0 m (5+)	La129 11.6 m 3/2+	*	La130 8.7 m 3(+)	La131 59 m 3/2+	La132 4.8 h 2-	*	La133 39.12 h 5/2+	La134 6.45 m 1+	La135 19.51 h 5/2+	La136 9.87 m 1+*
EC	ECp	ECp	ECp	EC	EC	*	EC	EC	EC	*	EC	EC	*	EC	EC	EC	*	EC	EC	EC	
Ba118 5.5 s 0+	Ba119 5.4 s (5/2+)	Ba120 32 s 0+	Ba121 29.7 s 5/2(+)	Ba122 1.95 m 0+	Ba123 2.7 m 5/2+	Ba124 11.0 m 0+	Ba125 3.5 m 1/2(+)	Ba126 100 m 0+	Ba127 12.7 m 1/2+	Ba128 2.43 d 0+	Ba129 2.23 h 1/2+	*	Ba130 0+	Ba131 0.106	Ba132 11.5 d 1+	Ba133 0.51 y 0+	Ba134 0+	Ba135 0.592	Ba136 0+		
EC	ECp	EC	ECp	EC	EC	*	EC	EC	EC	*	EC	EC	*	EC	EC	EC	*	EC	EC	EC	
Cs117 8.4 s (9/2+)*	Cs118 14 s 2*	Cs119 43.0 s 2*	Cs120 6.4 s 2*	Cs121 155 s 3/2(+)*	Cs122 21.0 s 1+	Cs123 2.94 m 1/2+	Cs124 30.8 s 1+	Cs125 45 m (1/2+)	Cs126 1.64 m 1+	Cs127 6.25 h 1/2+	Cs128 3.66 m 1+	Cs129 32.06 h 1/2+	Cs130 29.21 m 1+	Cs131 6.479 d 5/2+	Cs132 7.74 s 7+	Cs133 2.0648 y 4+	Cs134 5.243 d 3/2+	Cs135 2.417	Cs136 6.592	Cs137 100	
EC	ECp, EC <sub>β+</sub>	EC	EC	EC	EC	*	EC	EC	EC	*	EC	EC	*	EC	EC	EC	*	EC	EC	EC	
Xe116 59 s 0+	Xe117 61 s 5/2(+)	Xe118 3.8 m 0+	Xe119 5.8 m (5/2+)	Xe120 40 m 0+	Xe121 40.1 m 5/2(+)	Xe122 20.1 h 0+	Xe123 2.08 h 0+	Xe124 1.6E+14 y 0+	Xe125 16.9 h (1/2+)	Xe126 3.64 d 0+	Xe127 3.64 d 1/2+	*	Xe128 0+	Xe129 1.91	Xe130 2.64	Xe131 4.1	Xe132 21.2	Xe133 26.9	Xe134 3.243 d 3/2+		
EC	ECp	EC	EC	EC	EC	*	EC	EC	EC	*	EC	EC	*	EC	EC	EC	*	EC	EC	EC	
I115 1.3 m (5/2+)	I116 2.91 s 1+	I117 2.22 m (5/2+)*	I118 13.7 m 2*	I119 19.1 m 5/2+	I120 81.0 m 2*	I121 2.12 h 5/2+	I122 3.63 m 1+	I123 13.27 h 5/2+	I124 4.1760 d 2+	I125 59.408 d 5/2+	I126 13.11 d 2+	I127 5/2+	I128 24.99 m 1+	I129 1.57 E7 y 7/2+	I130 12.36 h 5+	I131 8.02070 d 7/2+	I132 2.295 h 4+	I133 8.02070 d 3/2+	I134 2.2295 h 3/2+		
EC	EC	EC	EC	EC	EC	*	EC	EC	EC	*	EC	EC	*	EC	EC	EC	*	EC	EC	EC	
Tel114 15.2 m 0+	Tel115 5.8 m 7/2+	Tel116 2.49 h 0+	Tel117 62 m 1/2+	Tel118 6.00 d 0+	Tel119 16.3 h 1/2+	Tel120 0.096 s 0+	Tel121 6.78 d 1/2+	Tel122 0+	Tel123 1E+13 y 1/2+	Tel124 0+	Tel125 1/2+	Tel126 0+	Tel127 2.603	Tel128 0.935 h 3/2+	Tel129 2.2E24 y 0+	Tel130 69.6 m 3/2+	Tel131 7.9E20 y 0+	Tel132 25.0 m 3/2+	Tel133 4.40 h 3/2+		
EC	EC	EC	EC	EC	EC	*	EC	EC	EC	*	EC	EC	*	EC	EC	EC	*	EC	EC	EC	
Sb113 6.67 m 5/2+	Sb114 3.49 m 3+	Sb115 32.1 m 5/2+	Sb116 15.8 m 3+	Sb117 2.80 h 5/2+	Sb118 3.6 m 1+	Sb119 38.19 m 5/2+	Sb120 15.89 m 1+	Sb121 5/2+	Sb122 2.7238 d 2-	Sb123 7/2+	Sb124 60.20 d 3-	Sb125 2.7582 y 7/2+	Sb126 12.46 d (8)-	Sb127 3.85 d 7/2+	Sb128 9.01 h 8-	Sb129 4.40 h 7/2+	Sb130 39.5 m (8)-	Sb131 2.33 m 3/2+	Sb132 50.07 m 0+		
EC	EC	EC	EC	EC	EC	*	EC	EC	EC	*	EC	EC	*	EC	EC	EC	*	EC	EC	EC	

Z=52

Sn112 0+	Sn113 115.96 d 1/2+	Sn114 0+	Sn115 1/2+	Sn116 0+	Sn117 1/2+	Sn118 0+	Sn119 1/2+	Sn120 0+	Sn121 37.06 h 3/2+	Sn122 0+	Sn123 17.92 d 11/2+	Sn124 0+	Sn125 9.64 d 11/2-	Sn126 1E+5 y 11/2-	Sn127 2.10 h 0+	Sn128 50.07 m (3/2+)	Sn129 2.23 m 0+		
EC	ECp	EC	EC	EC	EC	*	EC	EC	EC	*	EC	EC	*	EC	EC	*	EC	EC	
In111 2.80 d 9/2+	In112 14.97 m 1+	In113 9/2+	In114 1+	In115 4.41E+14 y 9/2+	In116 14.10 s 1+	In117 43.2 m 9/2+	In118 5.0 s 1+	In119 2.4 m 9/2+	In120 3.08 s 1+	In121 23.1 s 1+	In122 1.5 s 1+	In123 5.98 s 9/2+	In124 3.11 s 3+	In125 2.36 s 9/2+	In126 1.60 s 3/2+	In127 1.09 s (9/2+)	In128 6.84 s (3/2+)	In129 6.57 s (3/2+)	
EC	ECp	4.3	ECp	95.7	EC	*	EC	EC	EC	*	EC	EC	*	EC	EC	*	EC	EC	
Cd110 0+	Cd111 1/2+	Cd112 0+	Cd113 7.7E+15 y 1/2+	Cd114 0+	Cd115 53.46 h 1/2+	Cd116 0+	Cd117 2.49 h 1/2+	Cd118 50.3 m 0+	Cd119 2.69 m 3/2+	Cd120 50.80 s 0+	Cd121 13.5 s (3/2+)	Cd122 5.24 s 0+	Cd123 2.10 s (3/2+)	Cd124 1.25 s 0+	Cd125 0.65 s (3/2+)	Cd126 0.506 s 0+	Cd127 0.578 s (3/2+)	Cd128 0.578 s 0+	
12.49	12.80	24.13	12.22	28.73	12.22	*	7.49	12.22	12.22	*	12.22	12.22	*	12.22	12.22	*	12.22	12.22	*

N

# Probing the low-level nuclear structure of $^{132}\text{Ba}$ by using Coulomb excitation measurements

- Thesis work of Mr. Sunil Dutt
- A.M.U., Aligarh INDIA

Guide:  
Prof. I. A. Rizvi  
A.M.U, India

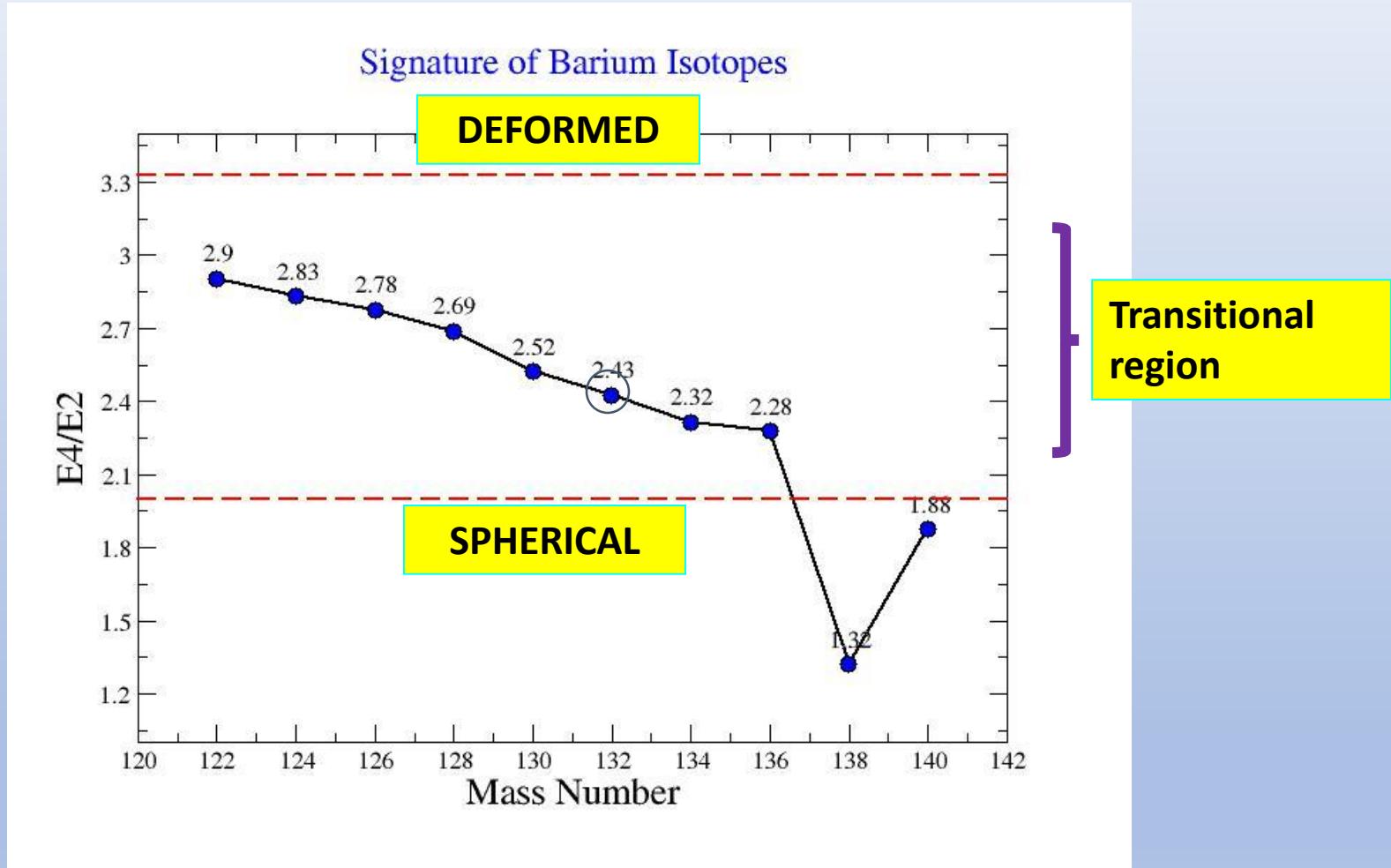
Co-Guide:  
Dr. Rakesh Kumar  
IUAC, New Delhi, India

Mentor:  
Dr. P. J. Napiorkowski  
HIL, Warsaw, Poland

Mentor:  
Dr. H. J. Wollersheim  
GSI, Dramstadt, Germany



# The Ba isotopes, a brief background



The even–even nuclei of this mass region seem to be soft with respect to the  $\gamma$ -deformation at an effective triaxiality of  $\gamma \approx 30^\circ$

# Motivations for $^{132}\text{Ba}$

$^{132}\text{Ba}$   
 $_{56} \text{Ba}_{76}$

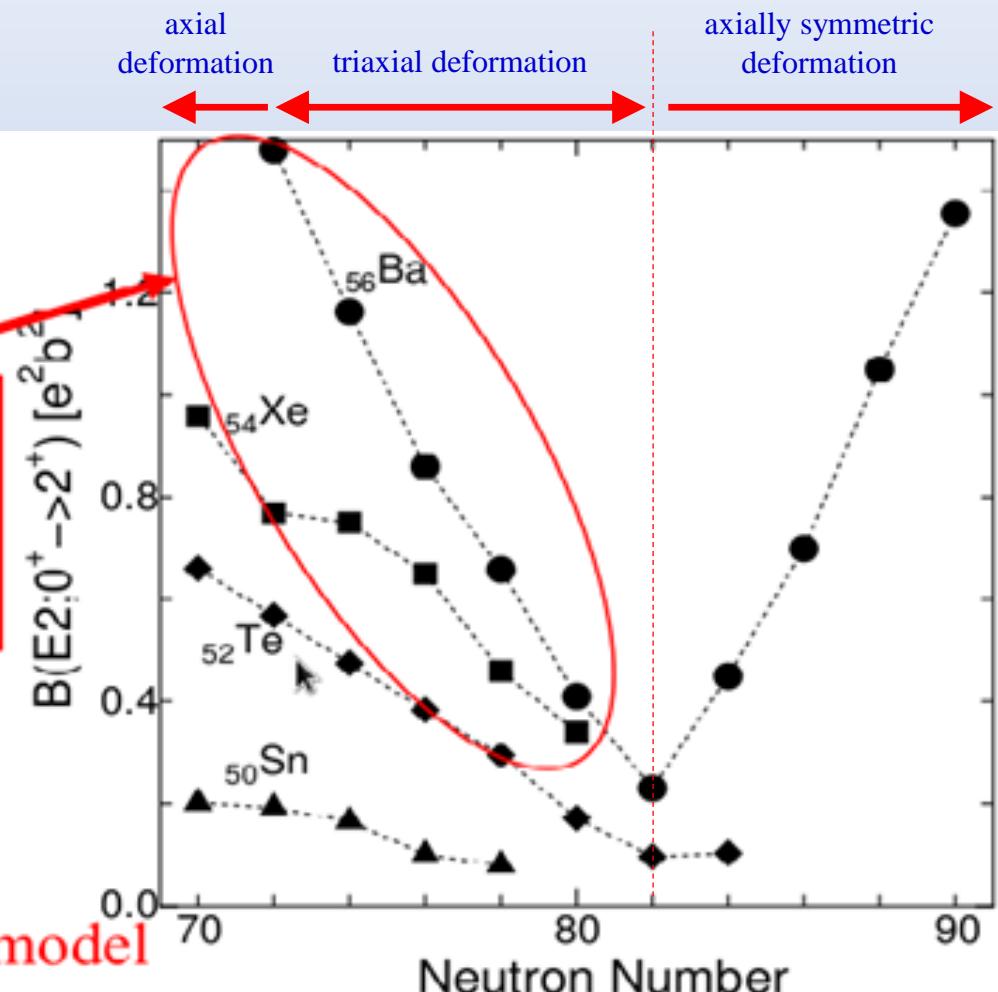
+6 protons to Z=50  
-6 neutrons to N=82

N = 82

B(E2) transition probabilities  
of quadrupole collective states

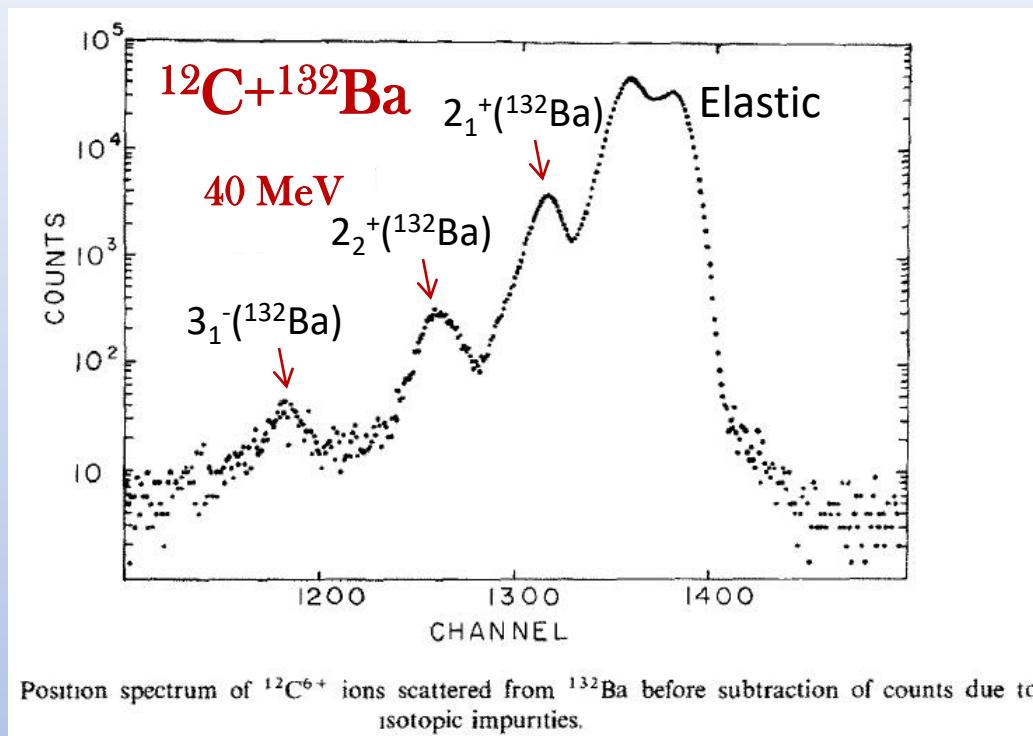
Transitional region  
between spherical  
vibrator and triaxially  
deformed rotor.

Microscopic study  
using the nuclear shell model



The even-even nuclei of this mass region seem to be soft with respect to the  $\gamma$ -deformation at an effective triaxiality of  $\gamma \approx 30^\circ$

# Previous Measurement



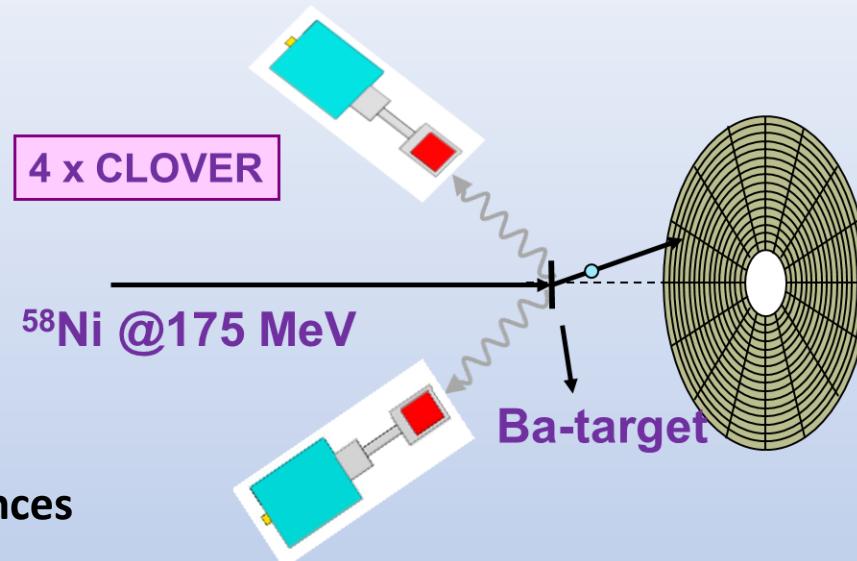
Ba-Isotope	Enrichment (%)
130	0.16±0.05
132	48.0±0.2
134	6.2±0.1
135	6.9±0.1
136	5.4±0.1
137	5.3±0.1
138	28.0±0.2

S.M.Burnett et al., Nucl. Phys. A 432(1985)514

- Energy resolution  $\sim 135$  keV
- Safe Bombarding Energy = 37.1 MeV

# Experimental Setup at IUAC

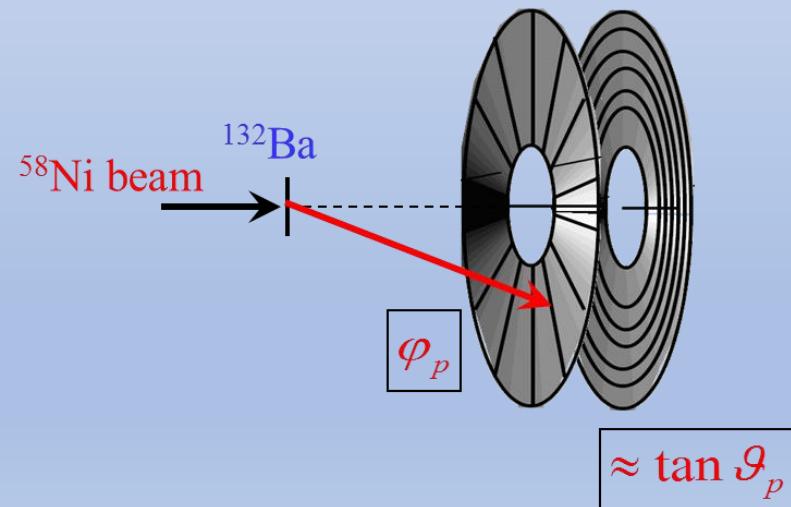
Enriched  $^{132}\text{Ba}$  target  $\sim 550\mu\text{g}/\text{cm}^2$   
thickness on  $\sim 30\mu\text{g}/\text{cm}^2$  thick  
Carbon backing



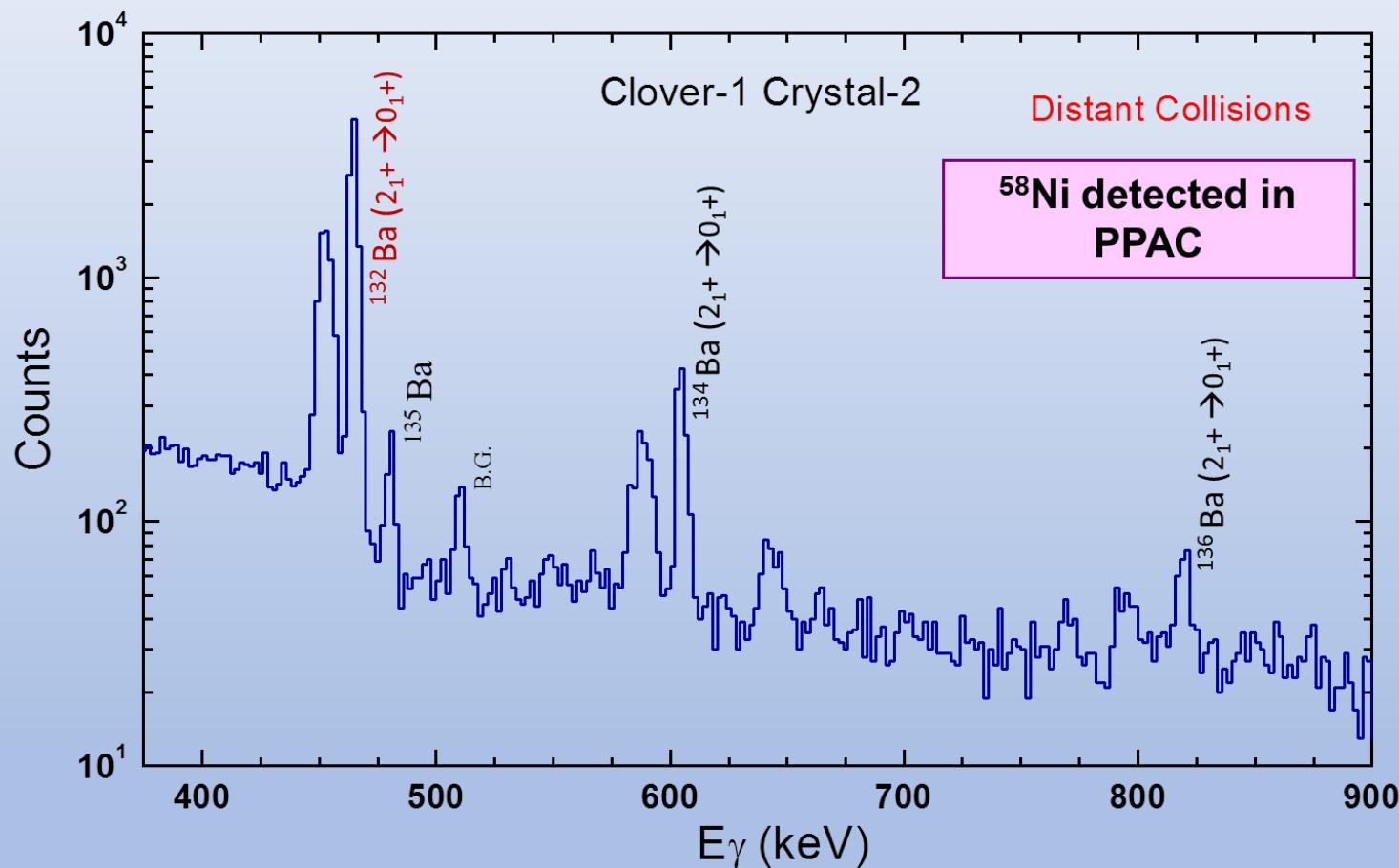
**TRIGGER :** Particle-Gamma Coincidences  
and Scale Down Particles

**Doppler-Shift correction :**

$$\frac{E_{\gamma_0}}{E_\gamma} = \frac{1 - v_2 * \cos \theta_{\gamma_2}}{\sqrt{1 - v_2^2}}$$

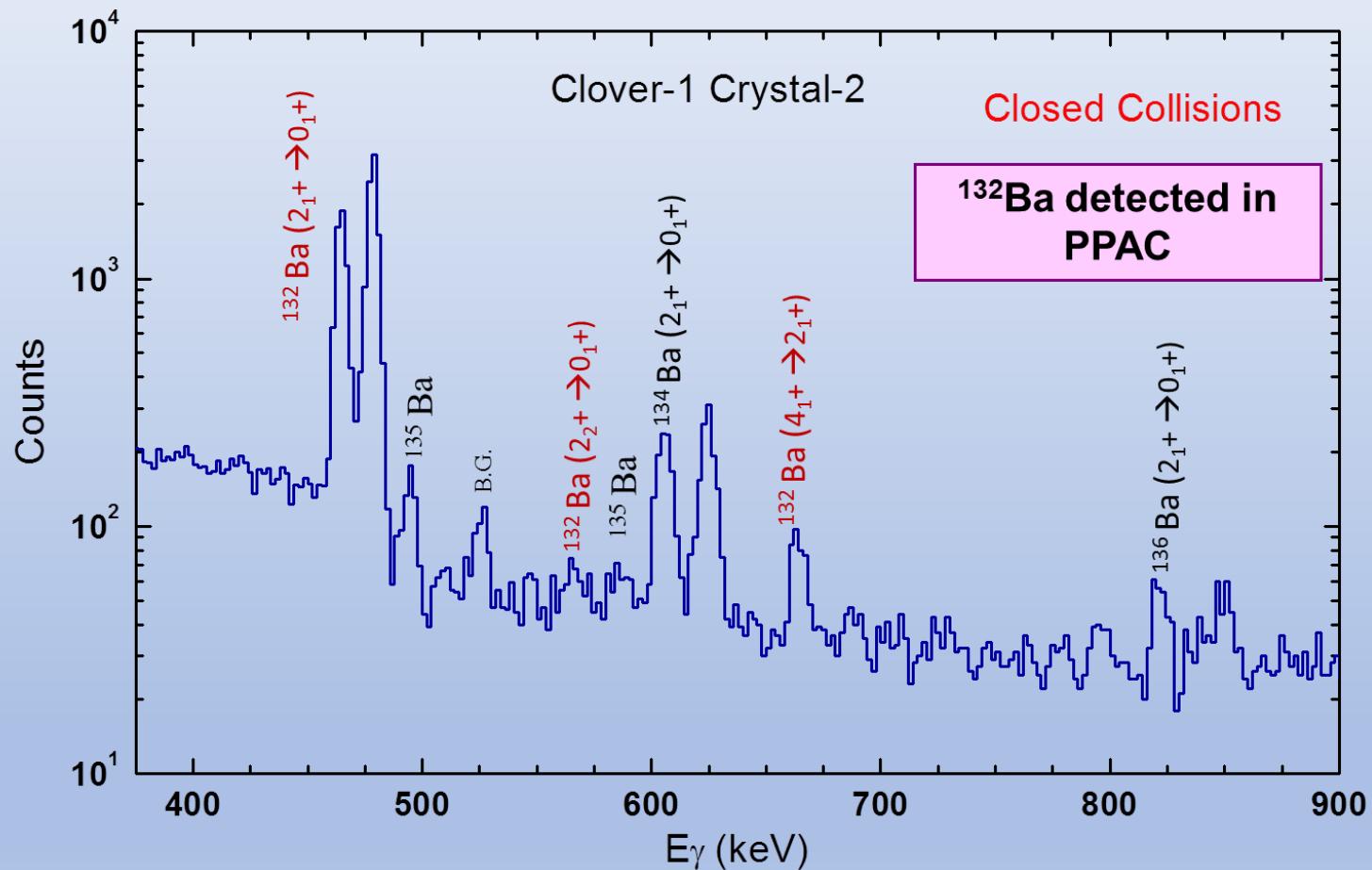


# Doppler Shift Corrected $\gamma$ -Ray Spectrum for $^{58}\text{Ni} + ^{132}\text{Ba}$



Doppler-shift corrected  $\gamma$ -ray spectrum from Clover-1 crystal-2 in coincidence with scattered projectiles detected in PPAC.

# Doppler Shift Corrected $\gamma$ -Ray Spectrum for $^{58}\text{Ni} + ^{132}\text{Ba}$



Doppler-shift corrected  $\gamma$ -ray spectrum from Clover-1 crystal-1 in coincidence with **recoils** detected in PPAC.

Comparison of the measured  $B(E2\uparrow)$  values for  $^{132}\text{Ba}$  isotope deduced from the present experiment (in W.u.) with previous Coulomb excitation measurement [1] and model calculations [2, 3].

S. No.	Transition $I_i \rightarrow I_f$	$B(E2\downarrow)$ Present	$B(E2\downarrow)$ Ref-1	$B(E2\downarrow)$ Ref-2	$B(E2\downarrow)$ Ref-3 ( $\beta = 0.21$ & $\gamma = 26.5^\circ$ )
1.	$2_1^+ \rightarrow 0_{\text{g.s.}}^+$	<b>54.5</b>	<b>43.0</b>	<b>53.1</b>	<b>53.6</b>
2.	$4_1^+ \rightarrow 2_1^+$	<b>78.3</b>	--	<b>76.9</b>	<b>75.5</b>
3.	$2_2^+ \rightarrow 2_1^+$	<b>66.8</b>	<b>29.1</b>	--	<b>60.0</b>
4.	$2_2^+ \rightarrow 0_{\text{g.s.}}^+$	<b>1.8</b>	<b>3.9</b>	<b>1.8</b>	<b>1.4</b>

Ref-1: S.M. Burnett et al., Nucl. Phys. A 432(1985) 514.

Ref-2: E. Teruya et al., Phys. Rev. C 92 (2015) 034320.

Ref-3: A.S. Davydov and G.F. Filippov Nucl. Phys. 8 (1958) 237.

## RE-MEASUREMENT OF REDUCED TRANSITION PROBABILITIES IN $^{132}\text{Ba}^*$

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 A. BANERJEE<sup>e</sup>, R.K. BHOWMIK<sup>c</sup>, C. JOSHI<sup>f</sup>, J. KAUR<sup>g</sup>, A. KUMAR<sup>h</sup>  
 M. MATEJSKA-MINDA<sup>b</sup>, V. MISHRA<sup>h</sup>, I.A. RIZVI<sup>a</sup>, A. STOLARZ<sup>b</sup>  
 H.J. WOLLERSHEIM<sup>i</sup>, P.J. NAPIORKOWSKI<sup>b</sup>

# Re-measurement of Stable Sn-isotopes

Z=56

La119	La120 2.8 s	La121 5.3 s	La122 8.7 s	La123 17 s	La124 29 s	La125 76 s (11/2-)	La126 54 s	La127 5.1 m (11/2-)	La128 5.0 m (5+)	La129 11.6 m 3/2+	La130 8.7 m 3(+)	La131 59 m 3/2+	La132 4.8 h 2-	La133 39.12 h 5/2+	La134 6.45 m 1+	La135 19.5 h 5/2+	La136 9.87 m 1+ *
EC	ECp	ECp	ECp	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC
Ba118 5.5 s 0+	Ba119 5.4 s (5/2+)	Ba120 32 s 0+	Ba121 29.7 s 5/2(+)	Ba122 1.95 m 0+	Ba123 2.7 m 5/2+	Ba124 11.0 m 0+	Ba125 3.5 m 1/2(+)	Ba126 100 m 0+	Ba127 12.7 m 1/2+	Ba128 2.43 d 0+	Ba129 2.23 h 1/2+	Ba130 0.43 d 0+	Ba131 11.5 d 1/2+	Ba132 0.51 y 0+	Ba133 0.51 y 1/2+	Ba134 0+ *	Ba135 3/2+ *
EC	ECp	EC	ECp	EC	EC	EC	EC	EC	EC	EC	EC	0.106	EC	0.101	EC	2.417	EC
Cs117 8.4 s (9/2+) *	Cs118 14 s 2- *	Cs119 43.0 s 2- *	Cs120 6.4 s 2- *	Cs121 155 s 3/2(+)	Cs122 21.0 s 1+ *	Cs123 2.94 m 1/2+	Cs124 30.8 s 1+ *	Cs125 45 m (1/2+)	Cs126 1.64 m 1+	Cs127 6.25 h 1/2+	Cs128 3.66 m 1+	Cs129 32.06 h 1/2+	Cs130 29.21 m 1+ *	Cs131 6.479 d 5/2+	Cs132 7.74 s 7+	Cs133 2.0648 y 7/2+	Cs134 5.243 d 3/2+ *
EC	ECp, EC <sub>133</sub> , EC	EC	ECp	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC <sub>133</sub>	
Xe116 59 s 0+	Xe117 61 s 5/2(+)	Xe118 3.8 m 0+	Xe119 5.8 m (5/2+)	Xe120 40 m 0+	Xe121 40.1 m 5/2(+)	Xe122 20.1 h 0+	Xe123 2.08 h 0+	Xe124 1.6E+14 y 0+	Xe125 16.9 h (1/2+)	Xe126 3.64 d 0+	Xe127 3.64 d 1/2+	Xe128 0.41	Xe129 1.2/2+	Xe130 0.41	Xe131 21.2	Xe132 26.9	Xe133 5.243 d 3/2+ *
EC	ECp	EC	EC	EC	EC	EC	EC	ECFC 0.10	EC	0.09	EC	1.91	2.64	4.1	21.2	26.9	
I115 1.3 m (5/2+)	I116 2.91 s 1+ *	I117 2.22 m 2- *	I118 13.7 m 2*	I119 19.1 m 5/2+	I120 81.0 m 2*	I121 2.12 h 5/2+	I122 3.63 m 1+	I123 13.27 h 5/2+	I124 4.1760 d 2+	I125 59.408 d 5/2+	I126 13.11 d 2+	I127 5/2+	I128 24.99 m 1+	I129 1.57 E7 y 7/2+	I130 12.36 h 5+	I131 8.02070 d 7/2+	I132 2.295 h 4+ *
EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	100	EC <sub>β</sub>	β-	β-	β-	
Tel114 15.2 m 0+	Tel115 5.8 m 7/2+	Tel116 2.49 h 0+	Tel117 62 m 1/2+ *	Tel118 6.00 d 0+	Tel119 16.3 h 1/2+ *	Tel120 6.78 d 0+	Tel121 0.096 s 1/2+ *	Tel122 2.603	Tel123 1E+13 y 0+	Tel124 1.1E+13 y 1/2+	Tel125 0+	Tel126 4.816	Tel127 7.130	Tel128 18.95	Tel129 β- v.v.v	Tel130 69.6 m 3/2+ *	Tel131 7.9 E20 y 0+
EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	0.908	EC	β- v.v.v	β- v.v.v	β- v.v.v	
Sb113 6.67 m 5/2+	Sb114 3.49 m 3+	Sb115 32.1 m 5/2+	Sb116 15.8 m 3+	Sb117 2.80 h	Sb118 3.6 m 1+ *	Sb119 38.19 m 5/2+ *	Sb120 15.89 m 1+ *	Sb121 5/2+	Sb122 2.7238 d 2-	Sb123 7/2+	Sb124 60.20 d 3-	Sb125 2.7582 y 7/2+	Sb126 12.46 d (8)- *	Sb127 3.85 d 7/2+	Sb128 9.01 h 8- *	Sb129 4.40 h 7/2+ *	Sb130 39.5 m (8)- *
EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	

Z=52

Sn112 0+	Sn113 11/2- *	Sn114 0+	Sn115 1/2+	Sn116 0+	Sn117 1/2+	Sn118 0+	Sn119 1/2+	Sn120 0+	Sn121 37.06 h 3/2+	Sn122 0+	Sn123 17.92 d 11/2- *	Sn124 0+	Sn125 9.64 d 11/2- *	Sn126 1E+5 y 0+	Sn127 2.10 h (11/2-)	Sn128 50.07 m (3/2+)	Sn129 2.23 m 0+
EC	EC <sub>112</sub> , EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	
In111 2.80+ d 9/2+ *	In112 14.97 m 1+	In113 9/2+ *	In114 1+	In115 4.41E+14 y 9/2+ *	In116 14.10 s 1+	In117 43.2 m 9/2+	In118 5.0 s 1+	In119 2.4 m 9/2+	In120 3.08 s 1+	In121 23.1 s 1+	In122 1.5 s 1+	In123 5.98 s 9/2+ *	In124 3.11 s 3+	In125 2.36 s 9/2+ *	In126 1.60 s 3/2+ *	In127 1.09 s (9/2+)	In128 6.84 s (3/2+)
EC	EC <sub>112</sub> , EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	
Cd110 0+	Cd111 1/2+ *	Cd112 0+	Cd113 7.7E+15 y 1/2+ *	Cd114 0+	Cd115 53.46 h 1/2+	Cd116 0+	Cd117 2.49 h 1/2+	Cd118 50.3 m 0+	Cd119 2.69 m 3/2+	Cd120 50.80 s 0+	Cd121 13.5 s (3/2+)	Cd122 5.24 s 0+	Cd123 2.19 s (3/2+)	Cd124 1.25 s 0+	Cd125 0.65 s (3/2+)	Cd126 0.506 s 0+	Cd127 0.578 s (3/2+)
12.49	12.80	24.13	12.22	28.73	β-	7.49	β-	β-	β-	β-	β-	β-	β-	β-	β-	β-	β-

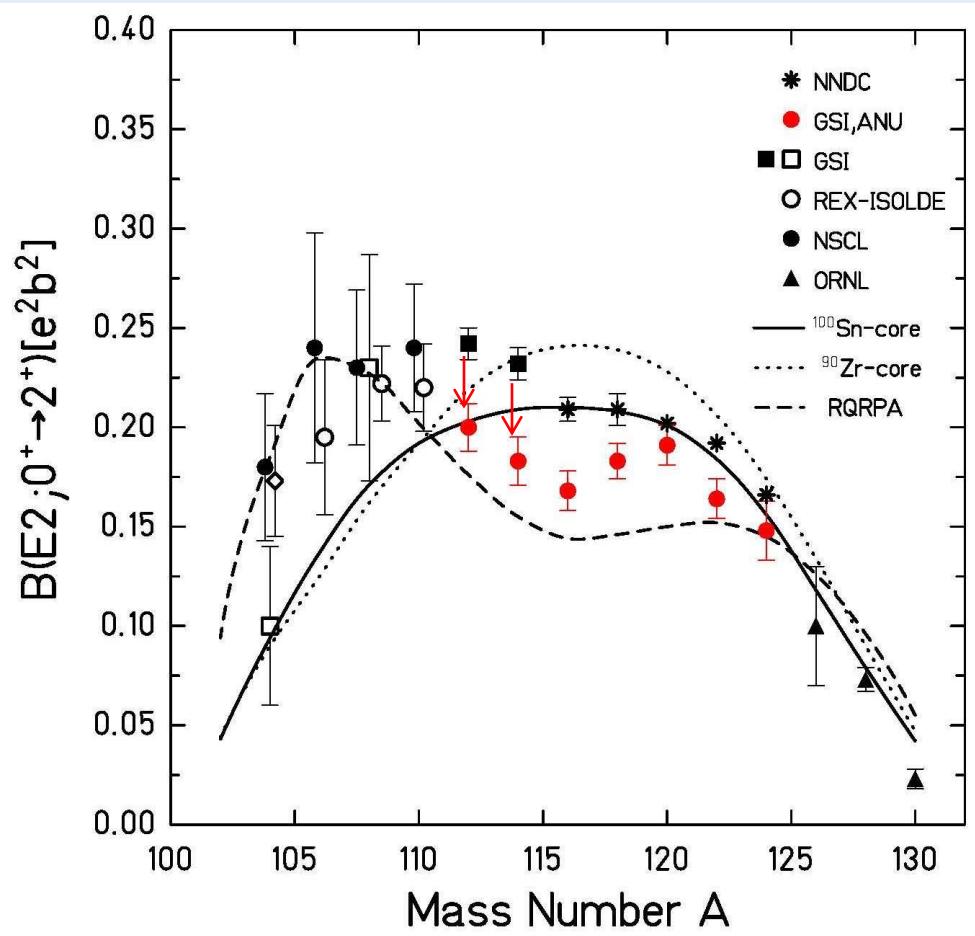
N

# Re-measurement of Stable Sn-isotopes

Z=56

La119	La120 2.8 s	La121 5.3 s	La122 8.7 s	La123 17 s	La124 29 s	*	La125 76 s (11/2-)	La126 54 s	La127 5.1 m (11/2-)*	La128 5.0 m (5+)*	La129 11.6 m (3/2+)*	La130 8.7 m (3+)*	La131 59 m (3/2+)*	La132 4.8 h (2+)*	La133 39.12 h (5/2+)*	La134 6.45 m (1+)*	La135 19.5 h (5/2+)*	La136 9.87 m (1+)*																																																																																																																																																																																																																																																																																																																																																																																																																																																														
EC	ECp	ECp	ECp	EC	EC	*	EC	EC	EC	EC	EC	*	EC	EC	EC	EC	EC																																																																																																																																																																																																																																																																																																																																																																																																																																																															
Ba118 5.5 s 0+	Ba119 5.4 s (5/2+)*	Ba120 32 s 0+	Ba121 29.7 s 5/2(+)	Ba122 1.95 m 0+	Ba123 2.7 m 5/2+	Ba124 11.0 m 0+	Ba125 3.5 m 1/2(+)	Ba126 100 m 0+	Ba127 12.7 m 1/2+	Ba128 2.43 d 0+	Ba129 2.23 h 1/2+*	Ba130 0+	Ba131 11.50 d 1/2+*	Ba132 0.106	Ba133 10.51 y 1/2+*	Ba134 0+	Ba135 2.417																																																																																																																																																																																																																																																																																																																																																																																																																																																															
EC	ECp	EC	ECp	EC	EC	*	EC	EC	EC	EC	EC	*	EC	0.101	EC	EC	EC																																																																																																																																																																																																																																																																																																																																																																																																																																																															
Cs117 8.4 s (9/2+)*	Cs118 14 s 2*	Cs119 43.0 s 2*	Cs120 6.4 s 2*	Cs121 155 s 3/2(+)*	Cs122 21.0 s 1+*	Cs123 2.94 m 1/2+*	Cs124 30.8 s 1+*	Cs125 45 m (1/2+)	Cs126 1.64 m 1+*	Cs127 6.25 h 1/2+*	Cs128 3.66 m 1+*	Cs129 32.06 h 1/2+*	Cs130 29.21 m 1+*	Cs131 9.689 d 5/2+	Cs132 6.479 d 7+*	Cs133 2.0648 y 7/2+*	Cs134 Xe116 5.9 s 0+	Xe117 61 s 5/2(+)	Xe118 3.8 m 0+	Xe119 5.8 m (5/2+)	Xe120 40 m 0+	Xe121 40.1 m 5/2(+)	Xe122 20.1 h 0+	Xe123 2.08 h 0+	Xe124 1.6E+14 y 0+	Xe125 16.9 h (1/2+)*	Xe126 3.64 d 0+	Xe127 3.64 d 1/2+*	Xe128 0+	Xe129 1/2+*	Xe130 0+	Xe131 3/2+*	Xe132 0+	Xe133 5.243 d 3/2+*																																																																																																																																																																																																																																																																																																																																																																																																																																														
EC	ECp, EC <sub>133</sub>	EC	EC	EC	EC	*	EC	EC	EC	EC	EC	*	EC	EC	EC	EC	EC																																																																																																																																																																																																																																																																																																																																																																																																																																																															
Xe116 5.9 s 0+	Xe117 61 s 5/2(+)	Xe118 3.8 m 0+	Xe119 5.8 m (5/2+)	Xe120 40 m 0+	Xe121 40.1 m 5/2(+)	Xe122 20.1 h 0+	Xe123 2.08 h 0+	Xe124 1.6E+14 y 0.10	Xe125 16.9 h (1/2+)*	Xe126 3.64 d 0.09	Xe127 3.64 d 1.91	Xe128 0.1	Xe129 1/2+*	Xe130 0.264	Xe131 4.1	Xe132 21.2	Xe133 26.9	β-	β-	β-	β-	β-	β-	β-	β-	β-	β-																																																																																																																																																																																																																																																																																																																																																																																																																																																					
I115 1.3 m (5/2+)	I116 2.91 s 1+*	I117 2.22 m (5/2+)	I118 13.7 m 2*	I119 19.1 m 5/2+	I120 81.0 m 2+*	I121 2.12 h 5/2+*	I122 3.63 m 1+*	I123 13.27 h 5/2+*	I124 4.1760 d 2+*	I125 59.408 d 5/2+	I126 13.11 d 2+*	I127 5/2+*	I128 24.99 m 1+*	I129 1.57E7 y 7/2+*	I130 12.36 h 5+*	I131 8.02070 d 7/2+*	I132 2.295 h 4+*	I133 1.3 m (5/2+)	I134 2.91 s 1+*	I135 2.22 m (5/2+)	I136 13.7 m 2*	I137 19.1 m 5/2+*	I138 81.0 m 2+*	I139 2.12 h 5/2+*	I140 3.63 m 1+*	I141 13.27 h 5/2+*	I142 4.1760 d 2+*	I143 59.408 d 5/2+	I144 13.11 d 2+*	I145 5/2+*	I146 24.99 m 1+*	I147 1.57E7 y 7/2+*	I148 12.36 h 5+*	I149 8.02070 d 7/2+*	I150 2.295 h 4+*	I151 13.7 m 2*	I152 19.1 m 5/2+*	I153 81.0 m 2+*	I154 2.12 h 5/2+*	I155 3.63 m 1+*	I156 13.27 h 5/2+*	I157 4.1760 d 2+*	I158 59.408 d 5/2+	I159 13.11 d 2+*	I160 5/2+*	I161 24.99 m 1+*	I162 1.57E7 y 7/2+*	I163 12.36 h 5+*	I164 8.02070 d 7/2+*	I165 2.295 h 4+*	I166 13.7 m 2*	I167 19.1 m 5/2+*	I168 81.0 m 2+*	I169 2.12 h 5/2+*	I170 3.63 m 1+*	I171 13.27 h 5/2+*	I172 4.1760 d 2+*	I173 59.408 d 5/2+	I174 13.11 d 2+*	I175 5/2+*	I176 24.99 m 1+*	I177 1.57E7 y 7/2+*	I178 12.36 h 5+*	I179 8.02070 d 7/2+*	I180 2.295 h 4+*	I181 13.7 m 2*	I182 19.1 m 5/2+*	I183 81.0 m 2+*	I184 2.12 h 5/2+*	I185 3.63 m 1+*	I186 13.27 h 5/2+*	I187 4.1760 d 2+*	I188 59.408 d 5/2+	I189 13.11 d 2+*	I190 5/2+*	I191 24.99 m 1+*	I192 1.57E7 y 7/2+*	I193 12.36 h 5+*	I194 8.02070 d 7/2+*	I195 2.295 h 4+*	I196 13.7 m 2*	I197 19.1 m 5/2+*	I198 81.0 m 2+*	I199 2.12 h 5/2+*	I200 3.63 m 1+*	I201 13.27 h 5/2+*	I202 4.1760 d 2+*	I203 59.408 d 5/2+	I204 13.11 d 2+*	I205 5/2+*	I206 24.99 m 1+*	I207 1.57E7 y 7/2+*	I208 12.36 h 5+*	I209 8.02070 d 7/2+*	I210 2.295 h 4+*	I211 13.7 m 2*	I212 19.1 m 5/2+*	I213 81.0 m 2+*	I214 2.12 h 5/2+*	I215 3.63 m 1+*	I216 13.27 h 5/2+*	I217 4.1760 d 2+*	I218 59.408 d 5/2+	I219 13.11 d 2+*	I220 5/2+*	I221 24.99 m 1+*	I222 1.57E7 y 7/2+*	I223 12.36 h 5+*	I224 8.02070 d 7/2+*	I225 2.295 h 4+*	I226 13.7 m 2*	I227 19.1 m 5/2+*	I228 81.0 m 2+*	I229 2.12 h 5/2+*	I230 3.63 m 1+*	I231 13.27 h 5/2+*	I232 4.1760 d 2+*	I233 59.408 d 5/2+	I234 13.11 d 2+*	I235 5/2+*	I236 24.99 m 1+*	I237 1.57E7 y 7/2+*	I238 12.36 h 5+*	I239 8.02070 d 7/2+*	I240 2.295 h 4+*	I241 13.7 m 2*	I242 19.1 m 5/2+*	I243 81.0 m 2+*	I244 2.12 h 5/2+*	I245 3.63 m 1+*	I246 13.27 h 5/2+*	I247 4.1760 d 2+*	I248 59.408 d 5/2+	I249 13.11 d 2+*	I250 5/2+*	I251 24.99 m 1+*	I252 1.57E7 y 7/2+*	I253 12.36 h 5+*	I254 8.02070 d 7/2+*	I255 2.295 h 4+*	I256 13.7 m 2*	I257 19.1 m 5/2+*	I258 81.0 m 2+*	I259 2.12 h 5/2+*	I260 3.63 m 1+*	I261 13.27 h 5/2+*	I262 4.1760 d 2+*	I263 59.408 d 5/2+	I264 13.11 d 2+*	I265 5/2+*	I266 24.99 m 1+*	I267 1.57E7 y 7/2+*	I268 12.36 h 5+*	I269 8.02070 d 7/2+*	I270 2.295 h 4+*	I271 13.7 m 2*	I272 19.1 m 5/2+*	I273 81.0 m 2+*	I274 2.12 h 5/2+*	I275 3.63 m 1+*	I276 13.27 h 5/2+*	I277 4.1760 d 2+*	I278 59.408 d 5/2+	I279 13.11 d 2+*	I280 5/2+*	I281 24.99 m 1+*	I282 1.57E7 y 7/2+*	I283 12.36 h 5+*	I284 8.02070 d 7/2+*	I285 2.295 h 4+*	I286 13.7 m 2*	I287 19.1 m 5/2+*	I288 81.0 m 2+*	I289 2.12 h 5/2+*	I290 3.63 m 1+*	I291 13.27 h 5/2+*	I292 4.1760 d 2+*	I293 59.408 d 5/2+	I294 13.11 d 2+*	I295 5/2+*	I296 24.99 m 1+*	I297 1.57E7 y 7/2+*	I298 12.36 h 5+*	I299 8.02070 d 7/2+*	I300 2.295 h 4+*	I301 13.7 m 2*	I302 19.1 m 5/2+*	I303 81.0 m 2+*	I304 2.12 h 5/2+*	I305 3.63 m 1+*	I306 13.27 h 5/2+*	I307 4.1760 d 2+*	I308 59.408 d 5/2+	I309 13.11 d 2+*	I310 5/2+*	I311 24.99 m 1+*	I312 1.57E7 y 7/2+*	I313 12.36 h 5+*	I314 8.02070 d 7/2+*	I315 2.295 h 4+*	I316 13.7 m 2*	I317 19.1 m 5/2+*	I318 81.0 m 2+*	I319 2.12 h 5/2+*	I320 3.63 m 1+*	I321 13.27 h 5/2+*	I322 4.1760 d 2+*	I323 59.408 d 5/2+	I324 13.11 d 2+*	I325 5/2+*	I326 24.99 m 1+*	I327 1.57E7 y 7/2+*	I328 12.36 h 5+*	I329 8.02070 d 7/2+*	I330 2.295 h 4+*	I331 13.7 m 2*	I332 19.1 m 5/2+*	I333 81.0 m 2+*	I334 2.12 h 5/2+*	I335 3.63 m 1+*	I336 13.27 h 5/2+*	I337 4.1760 d 2+*	I338 59.408 d 5/2+	I339 13.11 d 2+*	I340 5/2+*	I341 24.99 m 1+*	I342 1.57E7 y 7/2+*	I343 12.36 h 5+*	I344 8.02070 d 7/2+*	I345 2.295 h 4+*	I346 13.7 m 2*	I347 19.1 m 5/2+*	I348 81.0 m 2+*	I349 2.12 h 5/2+*	I350 3.63 m 1+*	I351 13.27 h 5/2+*	I352 4.1760 d 2+*	I353 59.408 d 5/2+	I354 13.11 d 2+*	I355 5/2+*	I356 24.99 m 1+*	I357 1.57E7 y 7/2+*	I358 12.36 h 5+*	I359 8.02070 d 7/2+*	I360 2.295 h 4+*	I361 13.7 m 2*	I362 19.1 m 5/2+*	I363 81.0 m 2+*	I364 2.12 h 5/2+*	I365 3.63 m 1+*	I366 13.27 h 5/2+*	I367 4.1760 d 2+*	I368 59.408 d 5/2+	I369 13.11 d 2+*	I370 5/2+*	I371 24.99 m 1+*	I372 1.57E7 y 7/2+*	I373 12.36 h 5+*	I374 8.02070 d 7/2+*	I375 2.295 h 4+*	I376 13.7 m 2*	I377 19.1 m 5/2+*	I378 81.0 m 2+*	I379 2.12 h 5/2+*	I380 3.63 m 1+*	I381 13.27 h 5/2+*	I382 4.1760 d 2+*	I383 59.408 d 5/2+	I384 13.11 d 2+*	I385 5/2+*	I386 24.99 m 1+*	I387 1.57E7 y 7/2+*	I388 12.36 h 5+*	I389 8.02070 d 7/2+*	I390 2.295 h 4+*	I391 13.7 m 2*	I392 19.1 m 5/2+*	I393 81.0 m 2+*	I394 2.12 h 5/2+*	I395 3.63 m 1+*	I396 13.27 h 5/2+*	I397 4.1760 d 2+*	I398 59.408 d 5/2+	I399 13.11 d 2+*	I400 5/2+*	I401 24.99 m 1+*	I402 1.57E7 y 7/2+*	I403 12.36 h 5+*	I404 8.02070 d 7/2+*	I405 2.295 h 4+*	I406 13.7 m 2*	I407 19.1 m 5/2+*	I408 81.0 m 2+*	I409 2.12 h 5/2+*	I410 3.63 m 1+*	I411 13.27 h 5/2+*	I412 4.1760 d 2+*	I413 59.408 d 5/2+	I414 13.11 d 2+*	I415 5/2+*	I416 24.99 m 1+*	I417 1.57E7 y 7/2+*	I418 12.36 h 5+*	I419 8.02070 d 7/2+*	I420 2.295 h 4+*	I421 13.7 m 2*	I422 19.1 m 5/2+*	I423 81.0 m 2+*	I424 2.12 h 5/2+*	I425 3.63 m 1+*	I426 13.27 h 5/2+*	I427 4.1760 d 2+*	I428 59.408 d 5/2+	I429 13.11 d 2+*	I430 5/2+*	I431 24.99 m 1+*	I432 1.57E7 y 7/2+*	I433 12.36 h 5+*	I434 8.02070 d 7/2+*	I435 2.295 h 4+*	I436 13.7 m 2*	I437 19.1 m 5/2+*	I438 81.0 m 2+*	I439 2.12 h 5/2+*	I440 3.63 m 1+*	I441 13.27 h 5/2+*	I442 4.1760 d 2+*	I443 59.408 d 5/2+	I444 13.11 d 2+*	I445 5/2+*	I446 24.99 m 1+*	I447 1.57E7 y 7/2+*	I448 12.36 h 5+*	I449 8.02070 d 7/2+*	I450 2.295 h 4+*	I451 13.7 m 2*	I452 19.1 m 5/2+*	I453 81.0 m 2+*	I454 2.12 h 5/2+*	I455 3.63 m 1+*	I456 13.27 h 5/2+*	I457 4.1760 d 2+*	I458 59.408 d 5/2+	I459 13.11 d 2+*	I460 5/2+*	I461 24.99 m 1+*	I462 1.57E7 y 7/2+*	I463 12.36 h 5+*	I464 8.02070 d 7/2+*	I465 2.295 h 4+*	I466 13.7 m 2*	I467 19.1 m 5/2+*	I468 81.0 m 2+*	I469 2.12 h 5/2+*	I470 3.63 m 1+*	I471 13.27 h 5/2+*	I472 4.1760 d 2+*	I473 59.408 d 5/2+	I474 13.11 d 2+*	I475 5/2+*	I476 24.99 m 1+*	I477 1.57E7 y 7/2+*	I478 12.36 h 5+*	I479 8.02070 d 7/2+*	I480 2.295 h 4+*	I481 13.7 m 2*	I482 19.1 m 5/2+*	I483 81.0 m 2+*	I484 2.12 h 5/2+*	I485 3.63 m 1+*	I486 13.27 h 5/2+*	I487 4.1760 d 2+*	I488 59.408 d 5/2+	I489 13.11 d 2+*	I490 5/2+*	I491 24.99 m 1+*	I492 1.57E7 y 7/2+*	I493 12.36 h 5+*	I494 8.02070 d 7/2+*	I495 2.295 h 4+*	I496 13.7 m 2*	I497 19.1 m 5/2+*	I498 81.0 m 2+*	I499 2.12 h 5/2+*	I500 3.63 m 1+*	I501 13.27 h 5/2+*	I502 4.1760 d 2+*	I503 59.408 d 5/2+	I504 13.11 d 2+*	I505 5/2+*	I506 24.99 m 1+*	I507 1.57E7 y 7/2+*	I508 12.36 h 5+*	I509 8.02070 d 7/2+*	I510 2.295 h 4+*	I511 13.7 m 2*	I512 19.1 m 5/2+*	I513 81.0 m 2+*	I514 2.12 h 5/2+*	I515 3.63 m 1+*	I516 13.27 h 5/2+*	I517 4.1760 d 2+*	I518 59.408 d 5/2+	I519 13.11 d 2+*	I520 5/2+*	I521 24.99 m 1+*	I522 1.57E7 y 7/2+*	I523 12.36 h 5+*	I524 8.02070 d 7/2+*	I525 2.295 h 4+*	I526 13.7 m 2*	I527 19.1 m 5/2+*	I528 81.0 m 2+*	I529 2.12 h 5/2+*	I530 3.63 m 1+*	I531 13.27 h 5/2+*	I532 4.1760 d 2+*	I533 59.408 d 5/2+	I534 13.11 d 2+*	I535 5/2+*	I536 24.99 m 1+*	I537 1.57E7 y 7/2+*	I538 12.36 h 5+*	I539 8.02070 d 7/2+*	I540 2.295 h 4+*	I541 13.7 m 2*	I542 19.1 m 5/2+*	I543 81.0 m 2+*	I544 2.12 h 5/2+*	I545 3.63 m 1+*	I546 13.27 h 5/2+*	I547 4.1760 d 2+*	I548 59.408 d 5/2+	I549 13.11 d 2+*	I550 5/2+*	I551 24.99 m 1+*	I552 1.57E7 y 7/2+*	I553 12.36 h 5+*	I554 8.02070 d 7/2+*	I555 2.295 h 4+*	I556 13.7 m 2*	I557 19.1 m 5/2+*	I558 81.0 m 2+*	I559 2.12 h 5/2+*	I560 3.63 m 1+*	I561 13.27 h 5/2+*	I562 4.1760 d 2+*	I563 59.408 d 5/2+	I564 13.11 d 2+*	I565 5/2+*	I566 24.99 m 1+*	I567 1.57E7 y 7/2+*	I568 12.36 h 5+*	I569 8.02070 d 7/2+*	I570 2.295 h 4+*	I571 13.7 m 2*	I572 19.1 m 5/2+*	I573 81.0 m 2+*	I574 2.12 h 5/2+*	I575 3.63 m 1+*	I576 13.27 h 5/2+*	I577 4.1760 d 2+*	I578 59.408 d 5/2+	I579 13.11 d 2+*</td

# Evidence for reduced collectivity in Sn isotopes



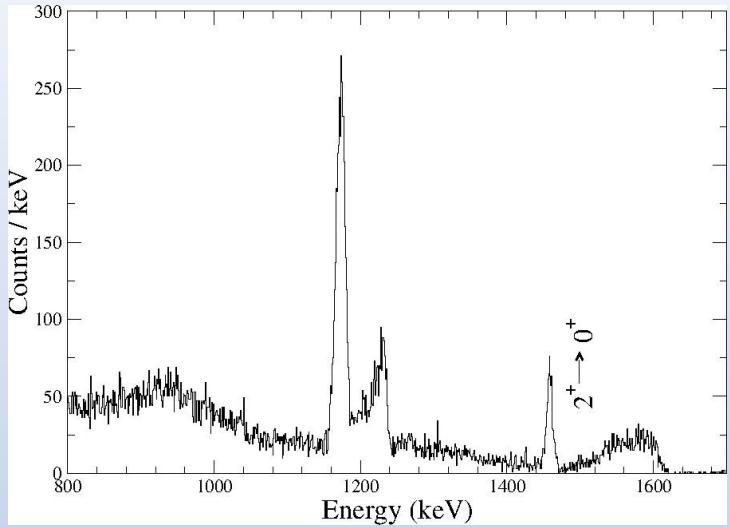
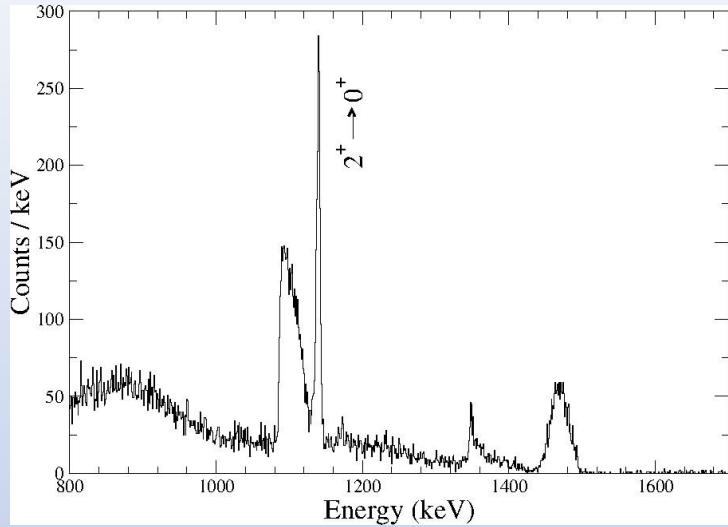
A recent Doppler Shift attenuation (DSA) measurement yield, however low  $B(E2\uparrow)$  values (up to 20%) than previously found in the literature .

To draw firm conclusions on the  $B(E2\uparrow)$  pattern for Sn isotopes, Coulomb excitation of all stable isotopes using a relatively heavy beam (e.g.  $^{58}\text{Ni}$ ) is necessary.

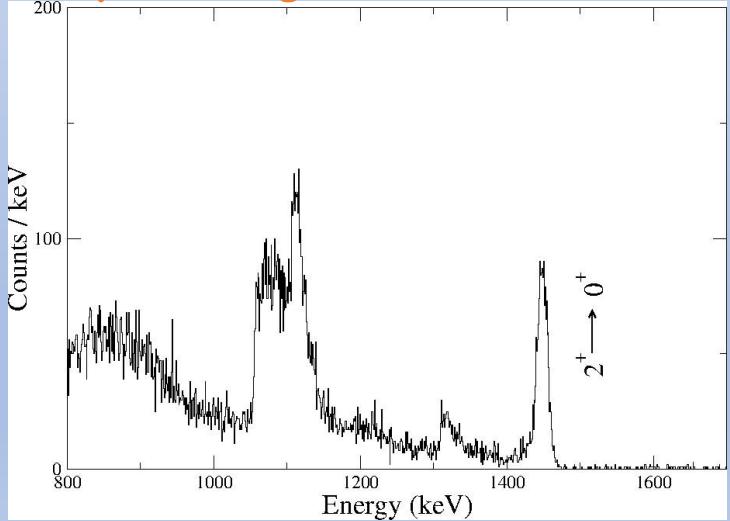
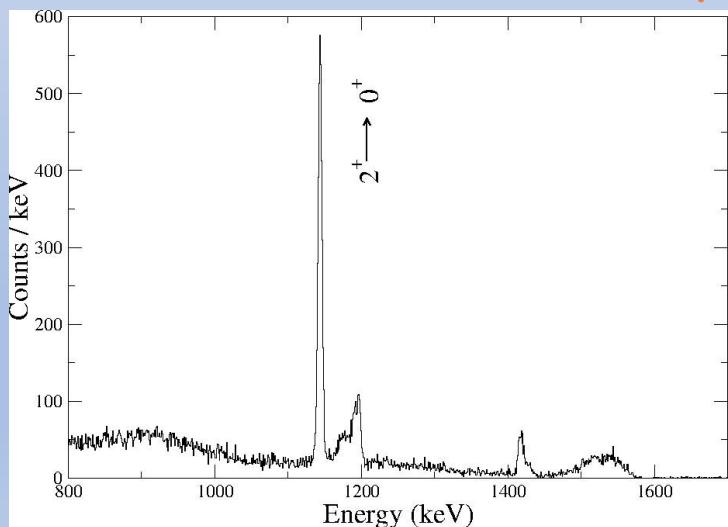
The proposed study will shed light on whether the surprising DSA results will be conformed or not.

The stable beam facility of IUAC is perfect to settle the agreement or disagreement.

# Doppler shift corrected $\gamma$ -spectra emitted from the $^{122}\text{Sn}$ target nuclei and the $^{58}\text{Ni}$ projectiles at 175 MeV

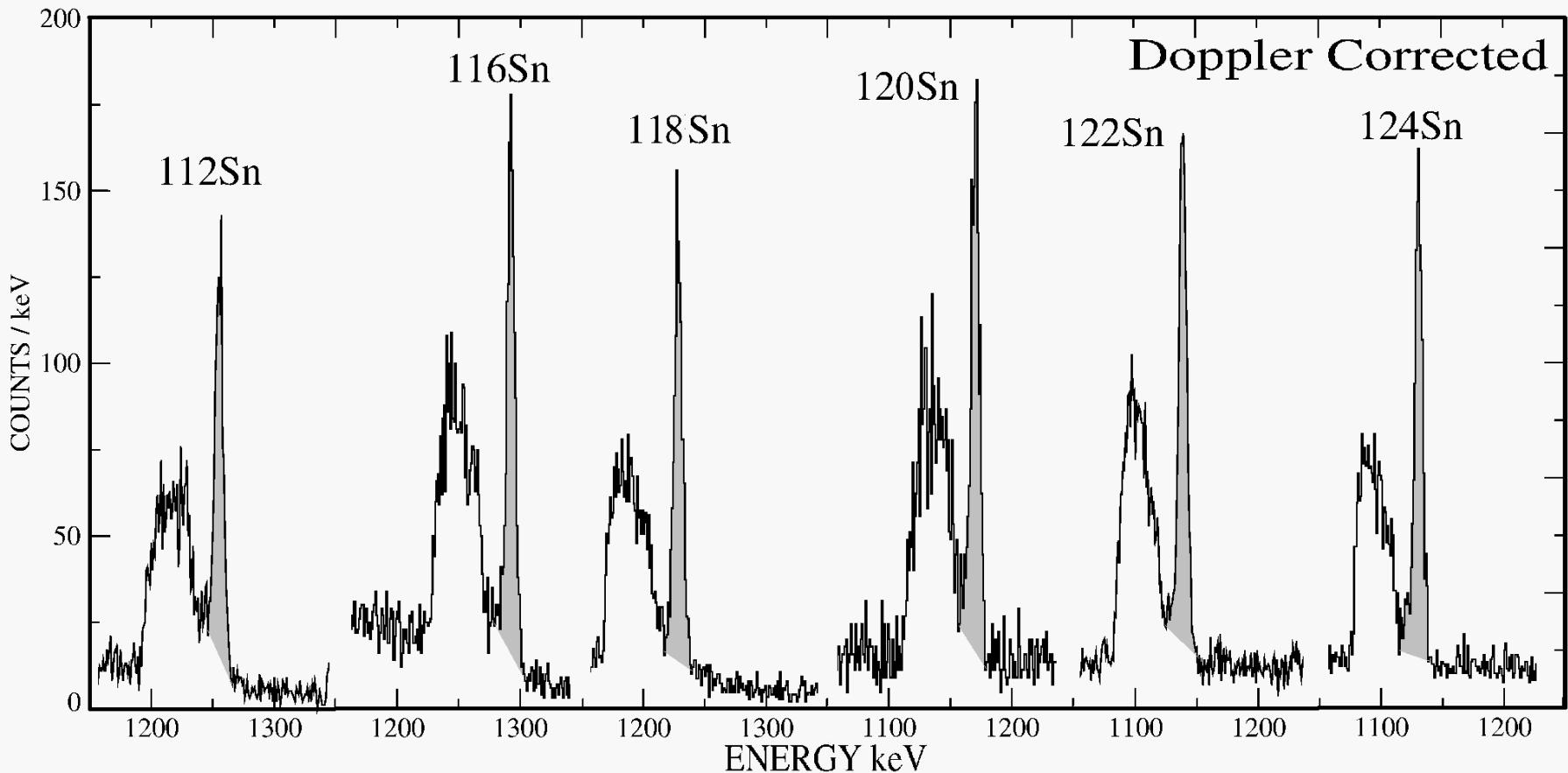


For distant collision ( $22.1^\circ \leq \theta_{\text{cm}} \leq 64.6^\circ$ )  $^{58}\text{Ni}$  detected in PPAC,  
The corrected  $^{122}\text{Sn}$  spectra left and  $^{58}\text{Ni}$  spectra right



For close collision ( $90^\circ \leq \theta_{\text{cm}} \leq 150^\circ$ )  $^{122}\text{Sn}$  detected in PPAC,  
The corrected  $^{122}\text{Sn}$  spectra left and  $^{58}\text{Ni}$  spectra right

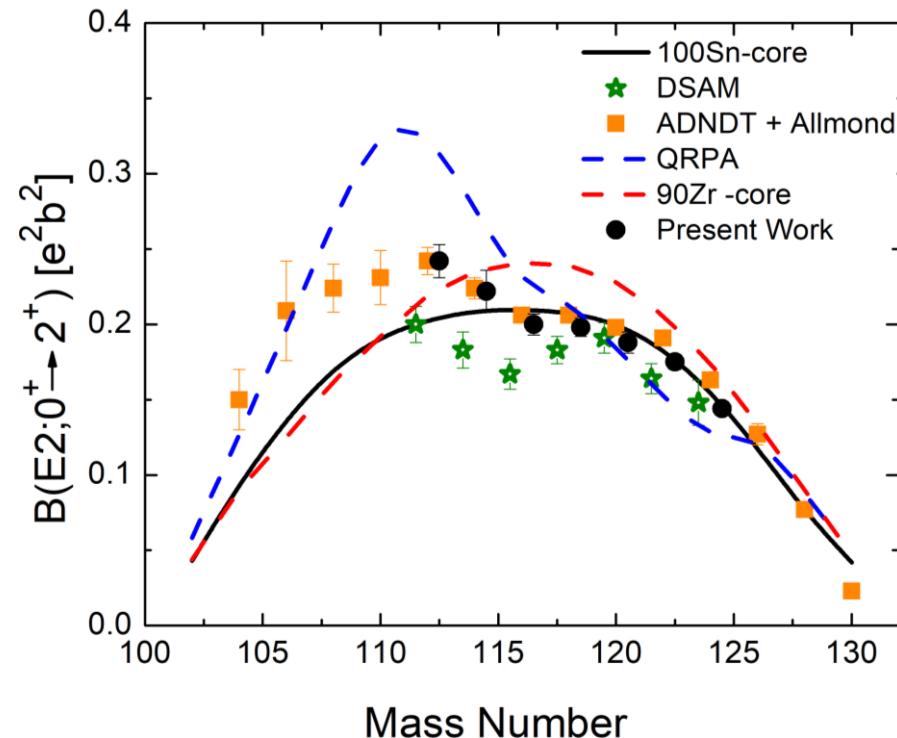
# Energy Spectra from Sn Targets



**Data from one Ge detector only (out of 16)**

# <Results>

Sn	B(E2;0 <sup>+</sup> → 2 <sup>+</sup> ) ADNDT+Allmond	B(E2;0 <sup>+</sup> → 2 <sup>+</sup> ) A. Jungclaus	B(E2;0 <sup>+</sup> → 2 <sup>+</sup> ) Present
112	0.242(9)	0.200(12)	0.242(11)
114	0.224(7)	0.183(12)	0.222(14)
116	0.206(4)	0.167(10)	0.200(7)
118	0.206(4)	0.183(9)	0.198(6)
120	0.198(3)	0.191(10)	0.188(7)
122	0.191(4)	0.164(10)	0.175(5)
124	0.163(3)	0.148(15)	0.144(4)



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## No evidence of reduced collectivity in Coulomb-excited Sn isotopes

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# Coulomb excitation of $^{45}\text{Sc}$

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## Summary

- Precise  $B(E2; 0^+ \rightarrow 2^+)$  values -- stable  $^{112}\text{Sn}$ ,  $^{114}\text{Sn}$  ----- relative to  $^{116}\text{Sn}$ .  $B(E2\uparrow)$  value increases upon going from  $^{116}\text{Sn}$  to  $^{112}\text{Sn}$ , indicating failure of generalized seniority scheme for the  $B(E2\uparrow)$  systematics for Sn isotopes.  
The experimental data --- compared with RQRPA calculations that predict the observed asymmetric behaviour of the  $B(E2\uparrow)$  values with respect to the mid shell nucleus with  $N = 66$ .
- For the Te isotopes, the  $B(E2 \uparrow)$  values connecting higher-lying states, the nuclear structure of the  $^{120,122,124}\text{Te}$  isotopes was determined, which shows the behaviour of a soft triaxial nucleus.
- For Ba isotopes, the  $B(E2; 2^+ \rightarrow 4^+)$  value was measured for the first time. Recent shell model calculations reported a  $B(E2; 0^+ \rightarrow 2^+)$  value of 53.1 W.u. which is in agreement with our measured value of  $54.5 \pm 4.3$  W.u.
- Remeasured  $B(E2\uparrow)$  values of stable Sn isotopes agree well with the recent Coulomb excitation result--confirming the disagreement with the DSA lifetime data.

Results of the DSA measurement should not be considered any more if the key nuclei between  $^{100}\text{Sn}$  and  $^{132}\text{Sn}$  are compared with theoretical predictions.

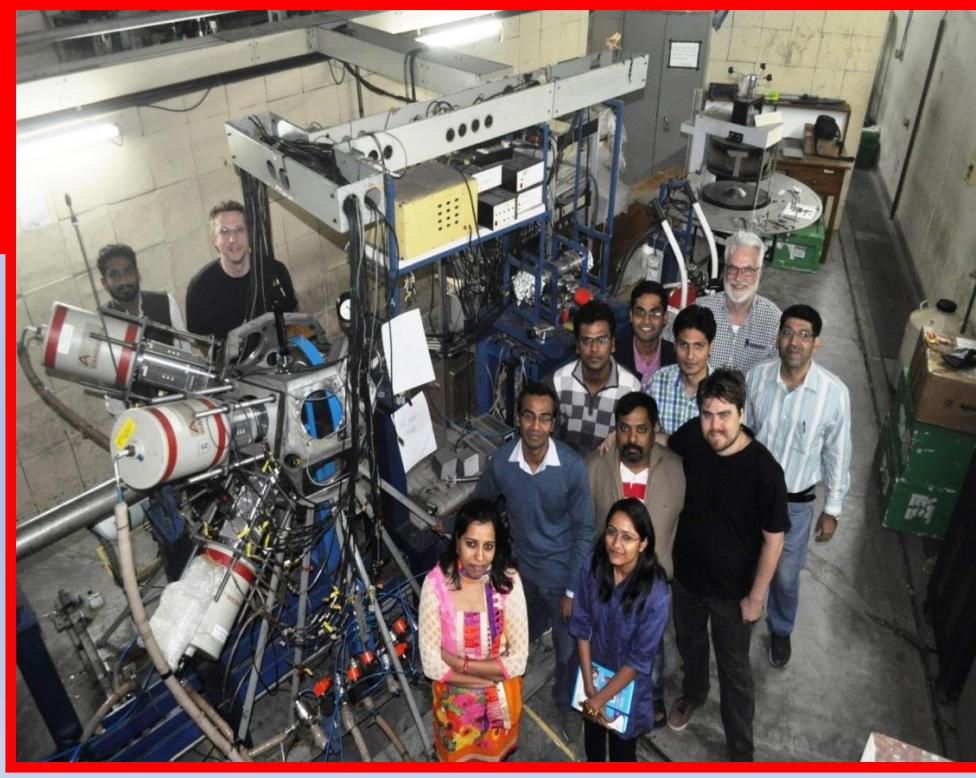
# Thanks to Anna Stolarz for Targets



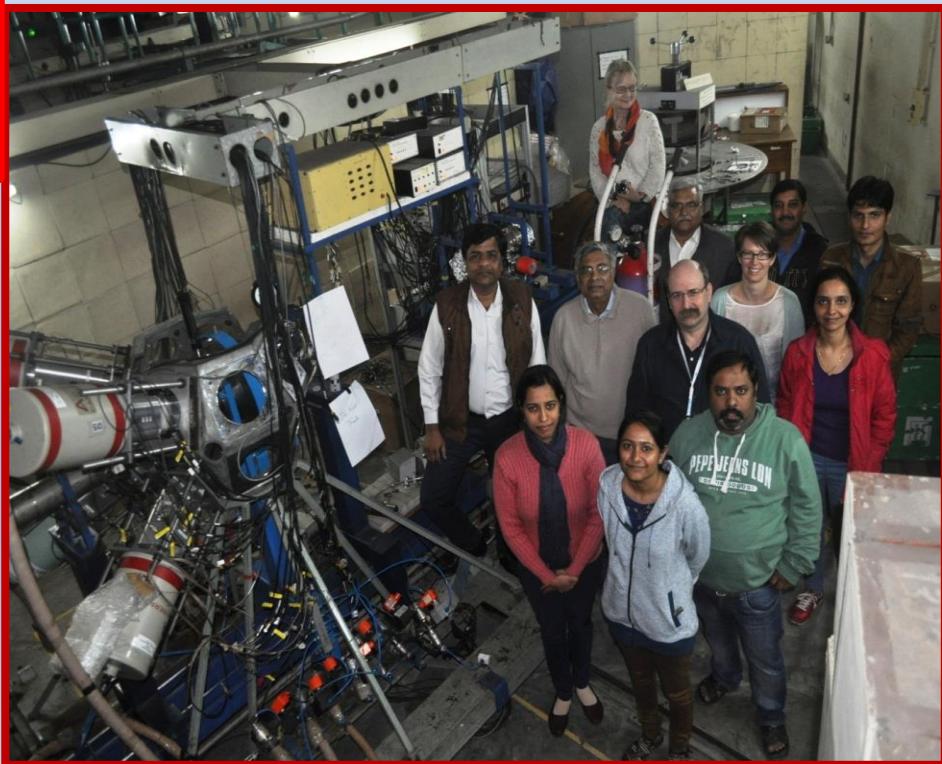
Te, Ba and Sc targets



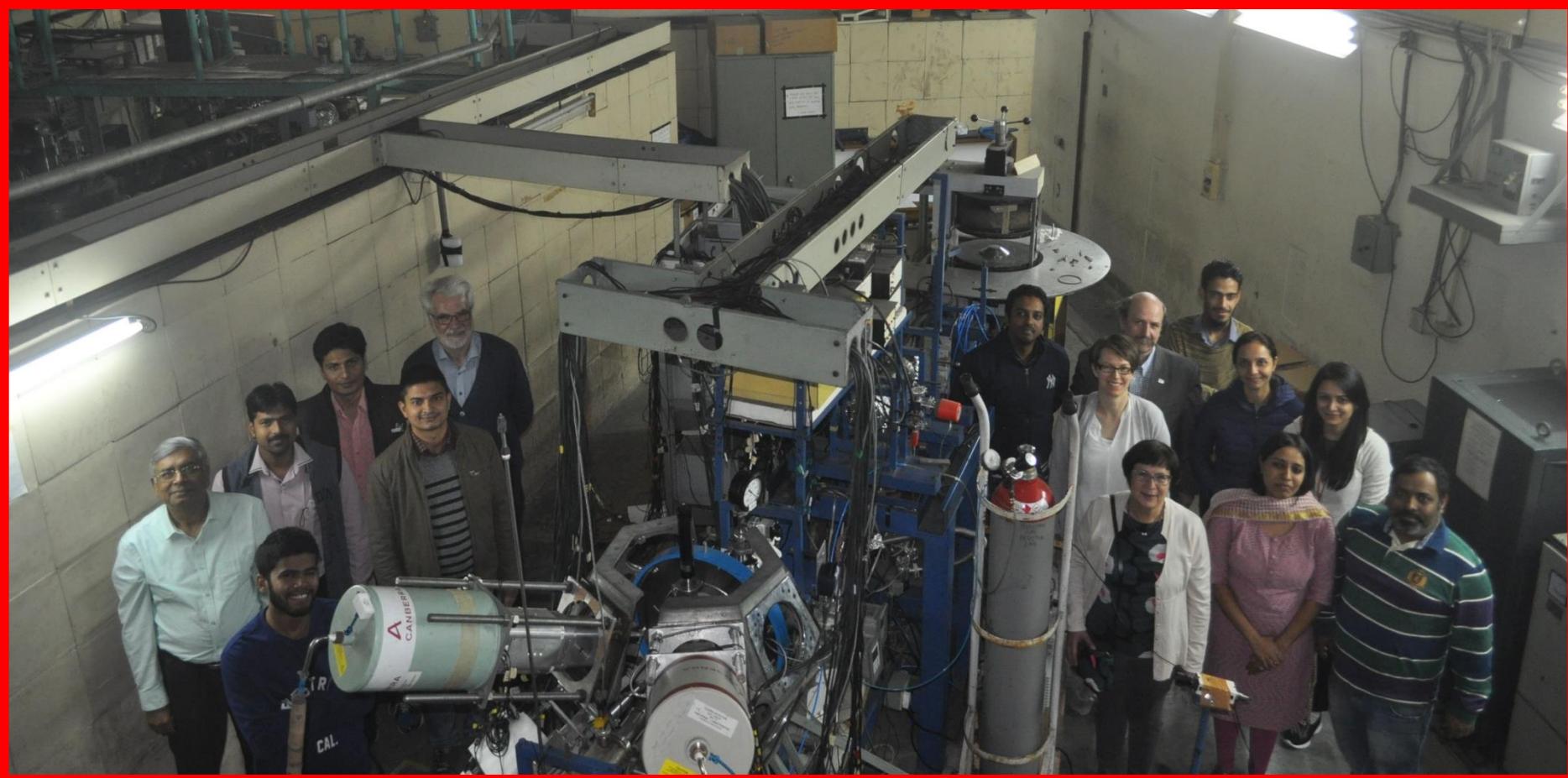
# List of collaborators



# Coulomb Excitation of $^{120}\text{Te}$ and $^{132}\text{Ba}$ at IUAC



# Coulomb Excitation of $^{45}\text{Sc}$ at IUAC



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*Thank you for your  
kind attention*



Dziękuję

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