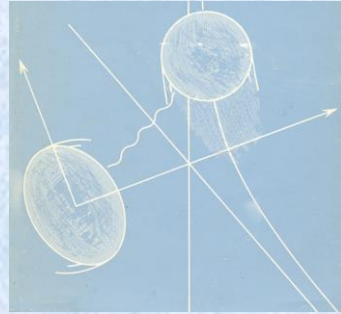


An Overview of Coulomb excitation activities at IUAC

3rd GOSIA workshop 9th – 11th April, 2018



Rakesh Kumar
IUAC, New Delhi

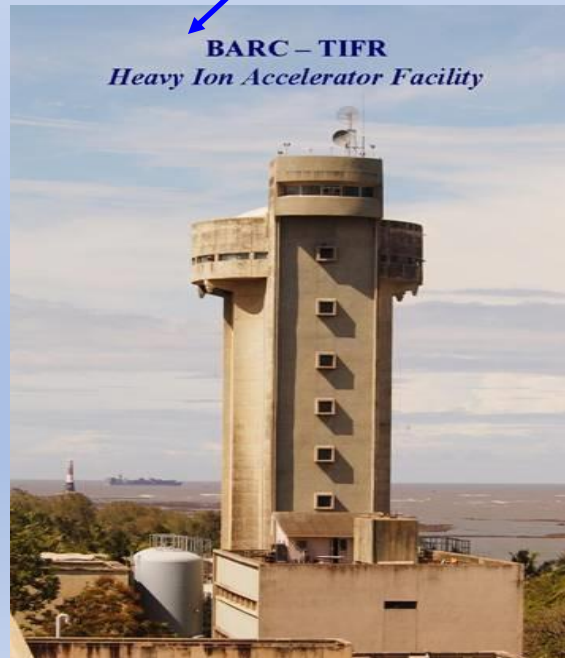


3rd GOSIA workshop 9th – 11th April, 2018

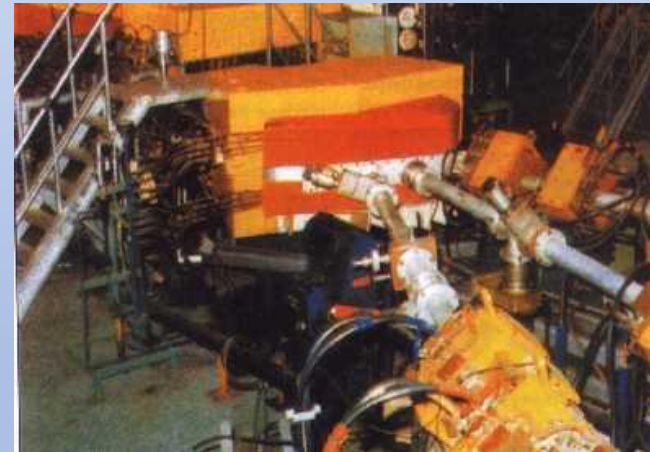




Inter University Accelerator Centre,
New Delhi



BARC – TIFR
Heavy Ion Accelerator Facility

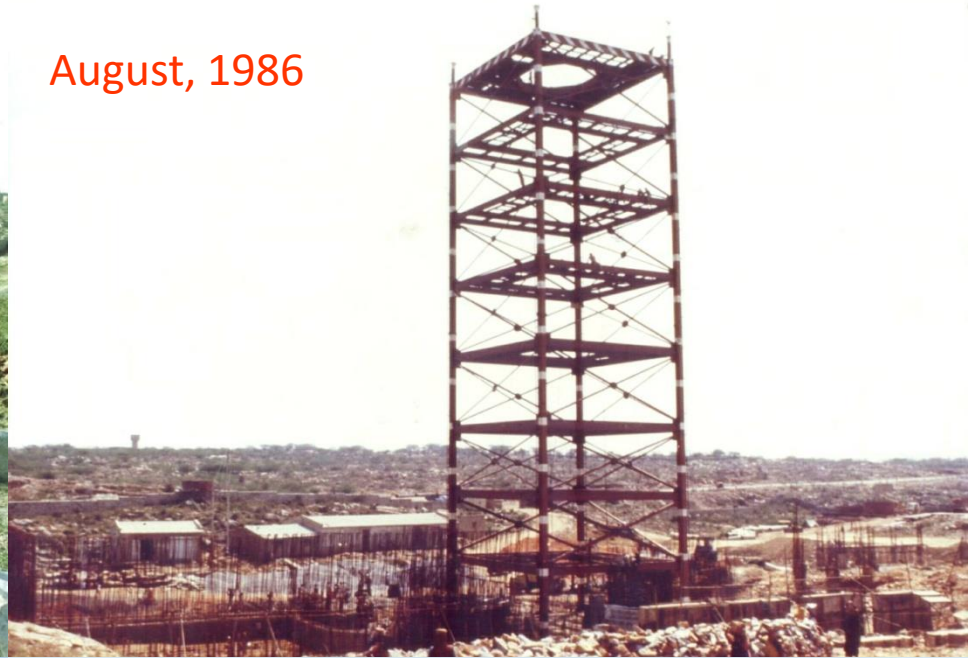


Variable Energy Cyclotron
Centre
Kolkata

Before July, 1986



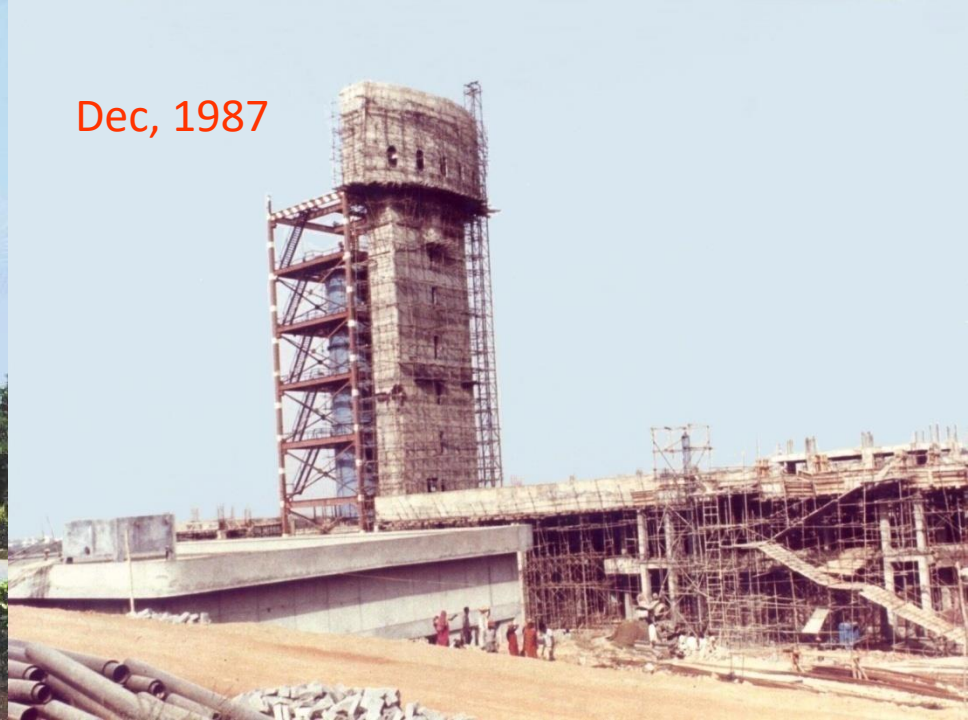
August, 1986



Nov, 1989

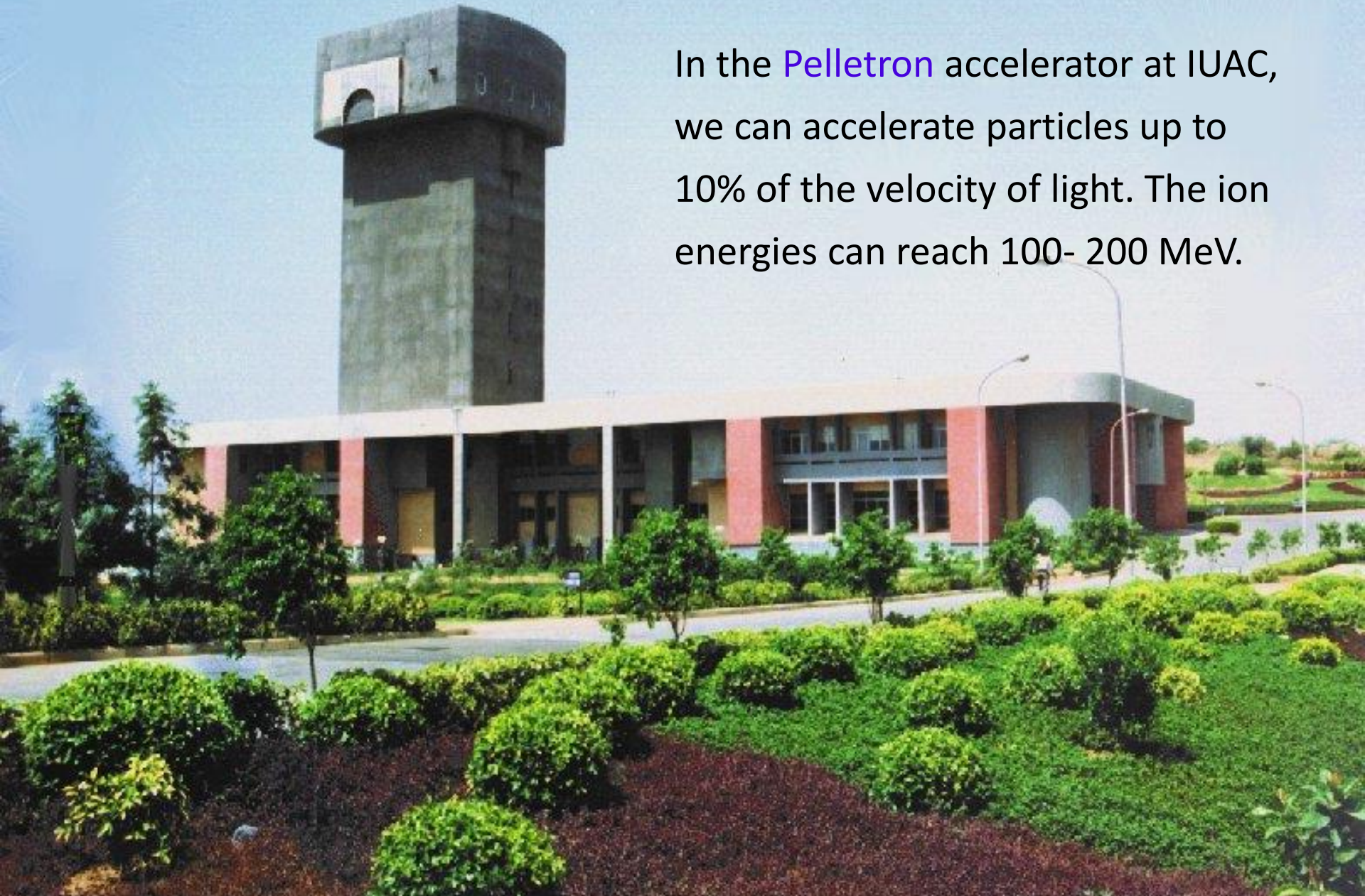


Dec, 1987

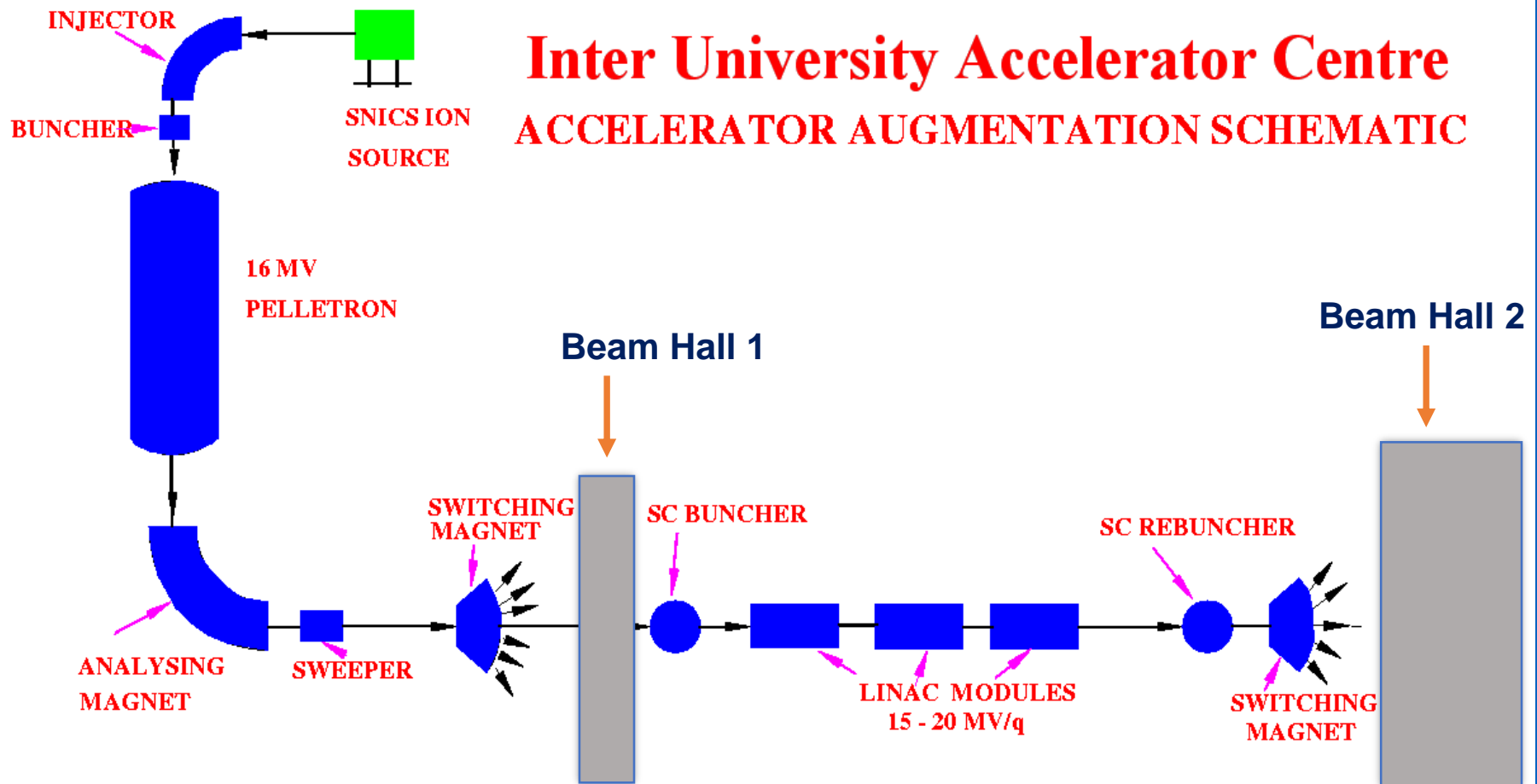


Inter University Accelerator Centre

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)

Gamma detector array (GDA)
Indian National Gamma Array (INGA)



- **Recoil separators**

N. Madhavan (madhavan@iuac.res.in)

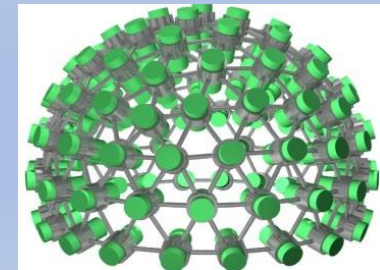
Heavy Ion Reaction Analyzer (HIRA)
Hybrid Recoil mass Analyzer (HYRA)



- **Scattering chamber / Neutron array**

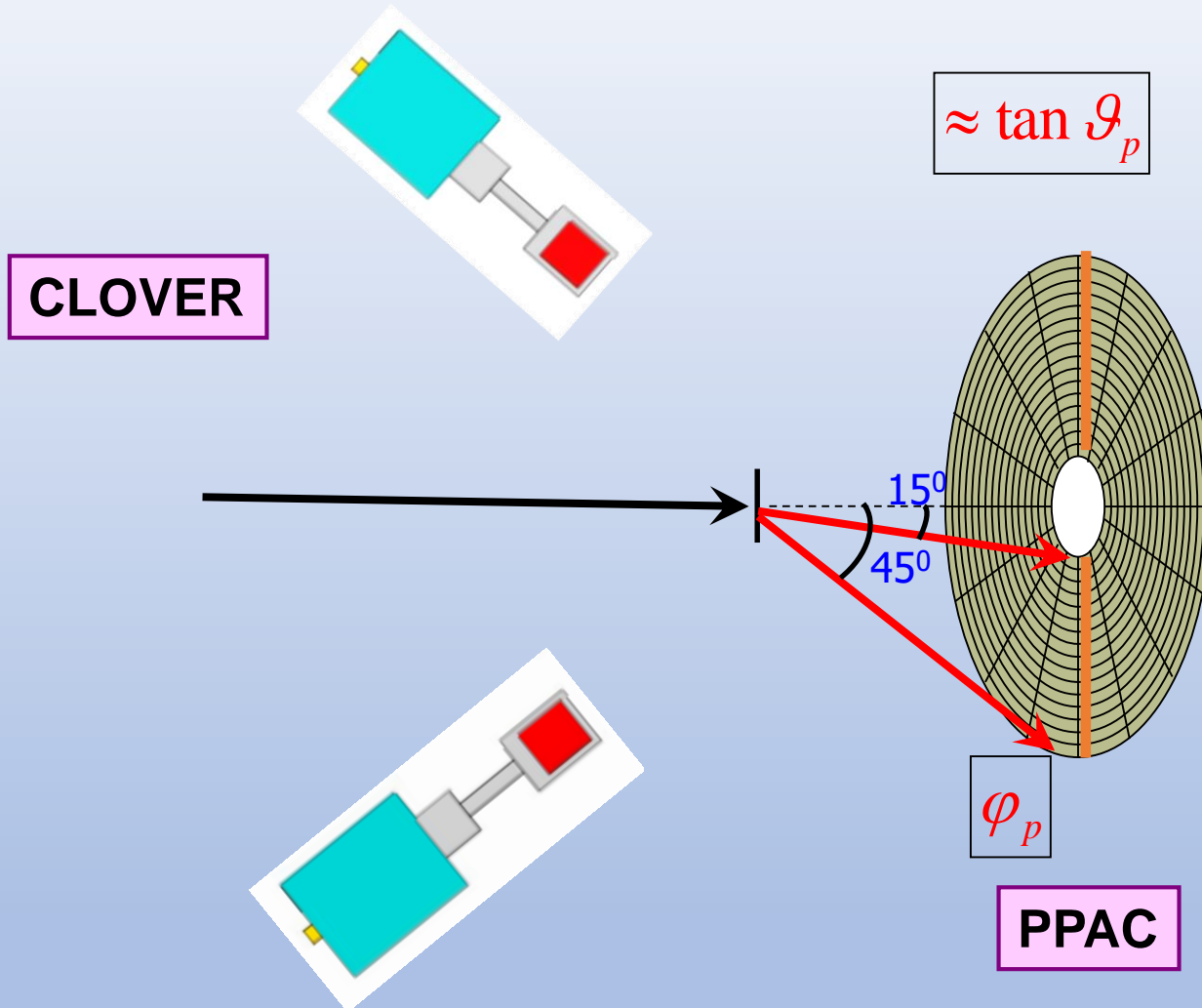
Dr. P. Sugathan (sugathan@iuac.res.in)

General Purpose Scattering Chamber (GPSC)
National Array of Neutron Detectors (NAND)

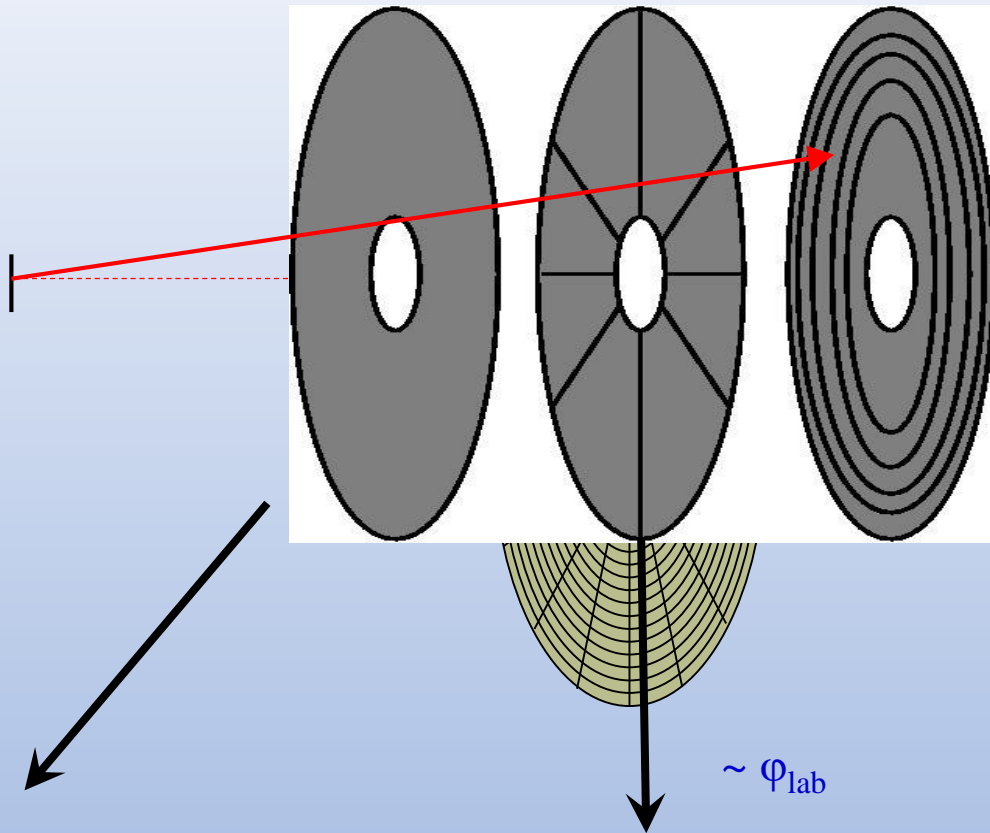


Coulomb excitation activities at IUAC

Present experimental set up at IUAC in GDA beam line



Proportional Counter



$V_0 \sim 500 \text{ V}$

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

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

$\sim \vartheta_{\text{lab}}$

$\sim \varphi_{\text{lab}}$

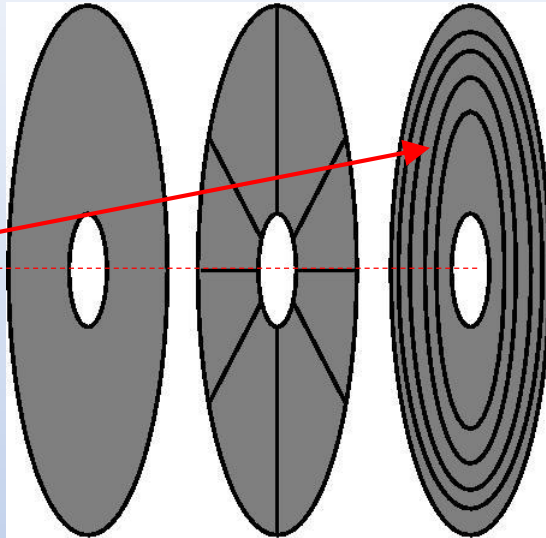
Detector is isolated from Vacuum through entrance window of 2 μm mylar foil

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

Anode is segmented to provide polar angles ϑ 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

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

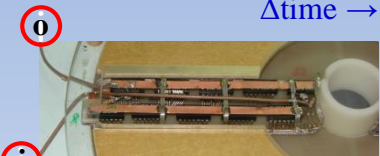
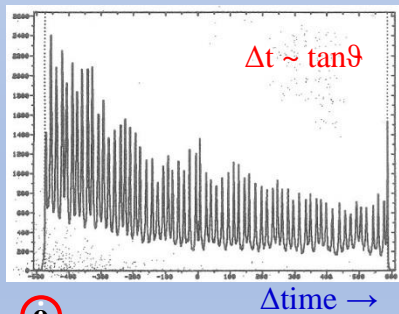


$V_0 \sim 500$ V
 $p = 7-13$ Torr
 ~ 3 mm gap anode-cathode

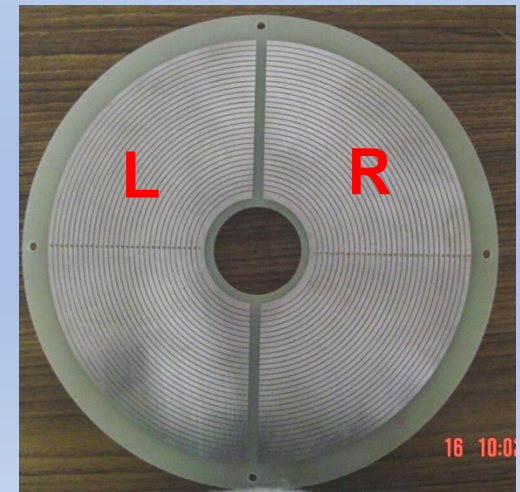
entrance window $\sim \phi_{lab}$ $\sim \tan\theta_{lab}$

Front $\rightarrow \phi$ -information

Back $\rightarrow \theta$ -information



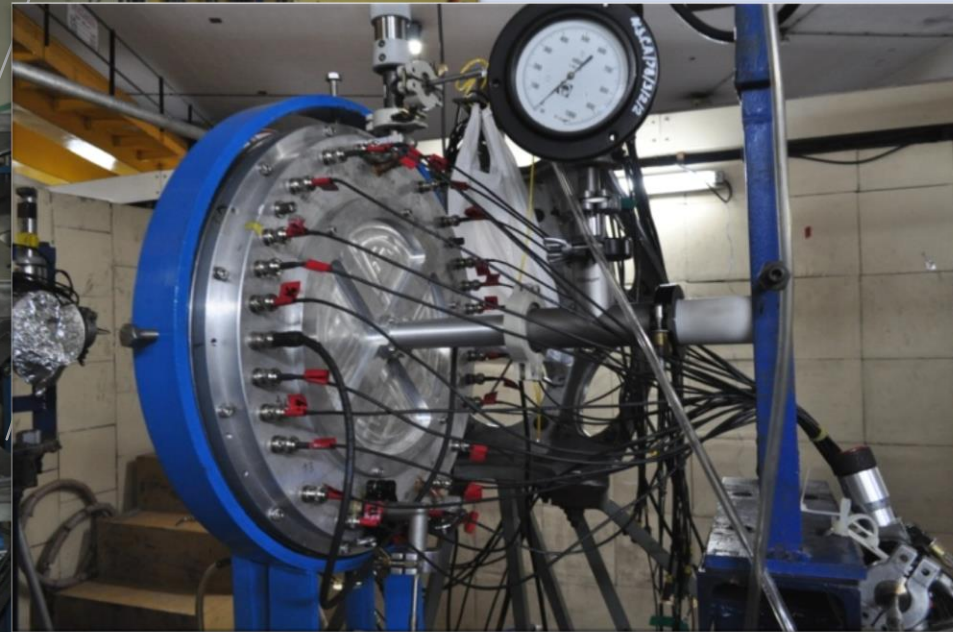
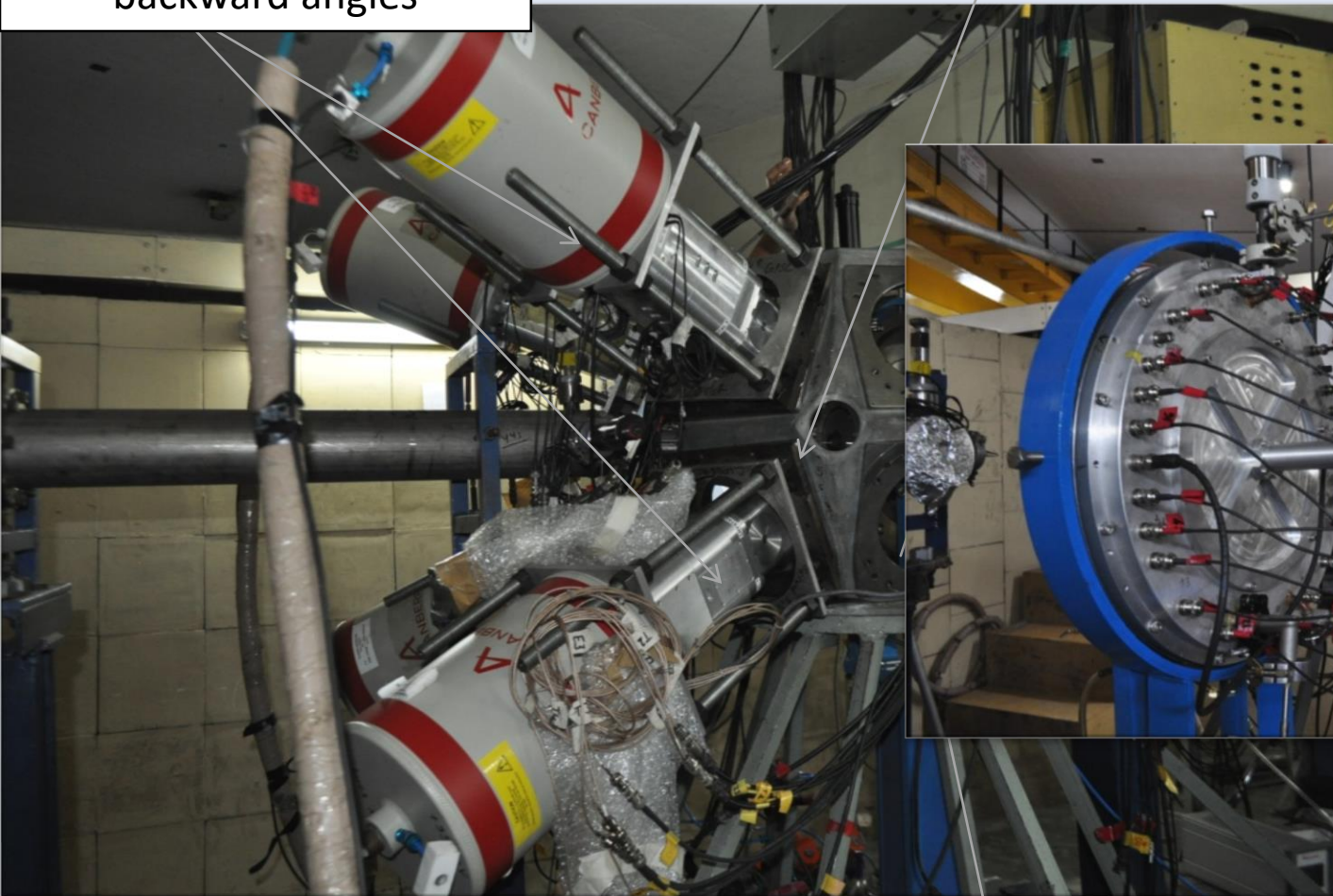
delay line



Experimental set up at IUAC

CLOVER DETECTORS
@
backward angles

TARGET

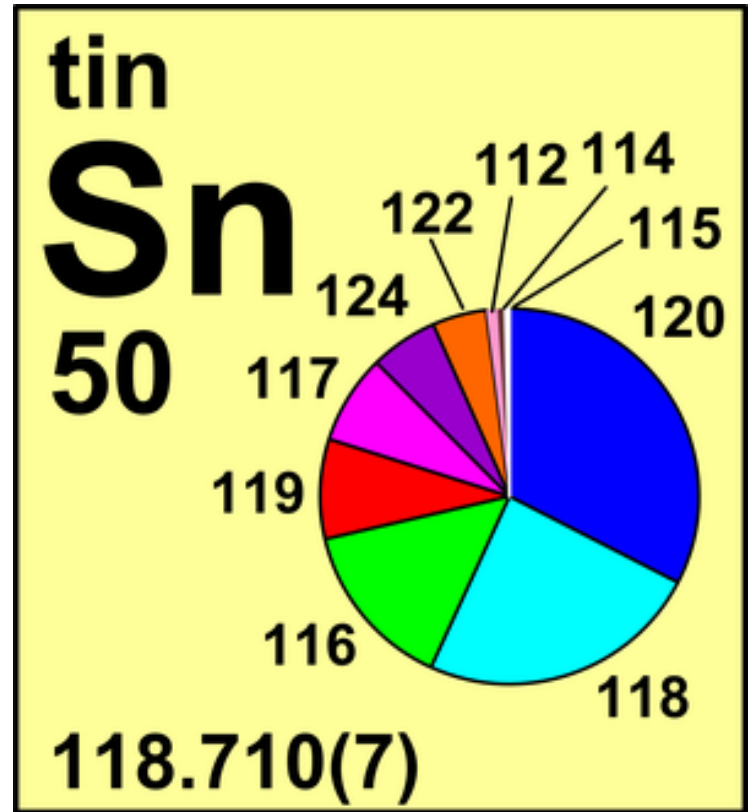


PPAC @ forward angle



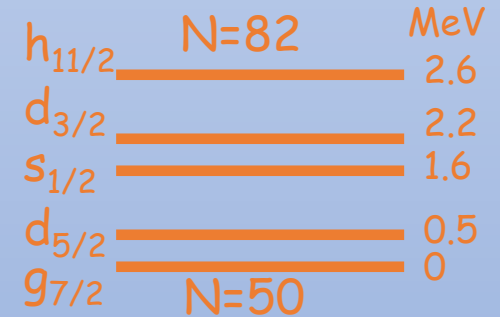
Coulex Experiments at I.U.A.C

Brief Introduction to Sn Region



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

Single particle energies



Z = 50

$g_{7/2}$ →

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

$d_{5/2}$ →

$s_{1/2}$ →

$d_{3/2}$ →

Sn112 0+ 0.97 *	Sn113 115.09 d 1/2+ EC *	Sn114 0+ 0.65 *	Sn115 1/2+ 0.34 *	Sn116 0+ 14.53 *	Sn117 1/2+ 7.68 *	Sn118 0+ 24.23 *	Sn119 1/2+ 8.59 *	Sn120 0+ 32.59 *
------------------------------	--	------------------------------	--------------------------------	-------------------------------	--------------------------------	-------------------------------	--------------------------------	-------------------------------

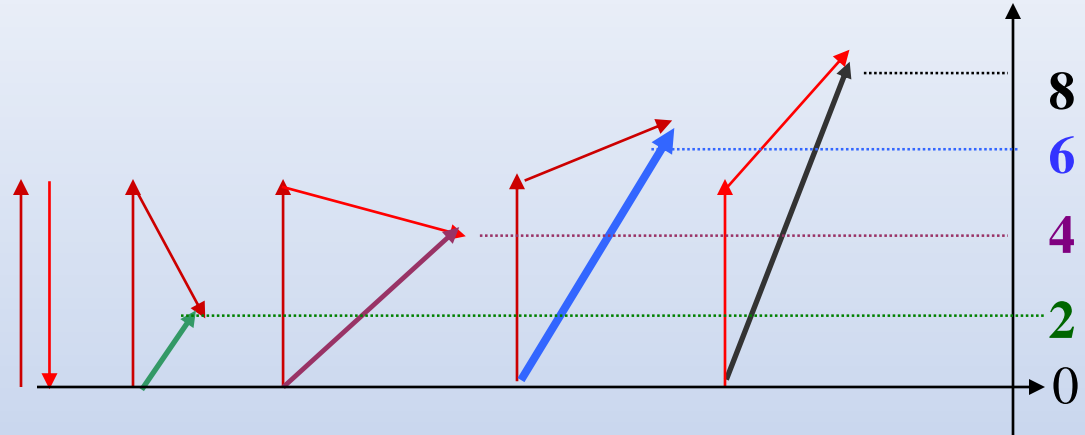
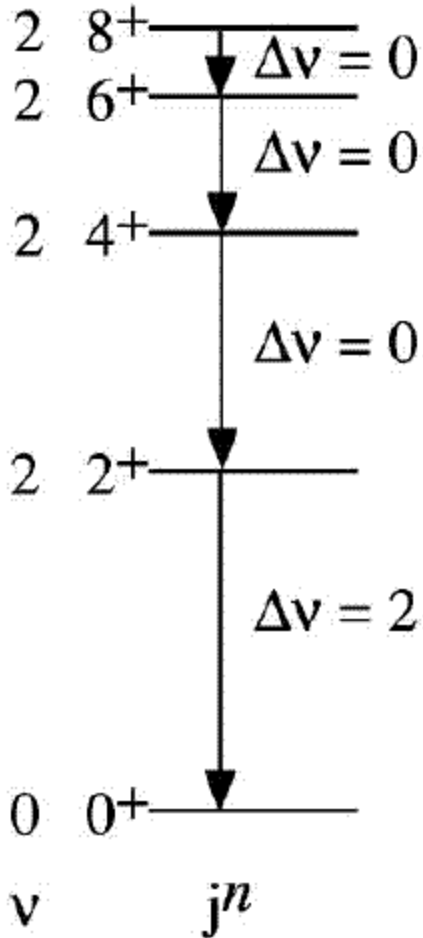
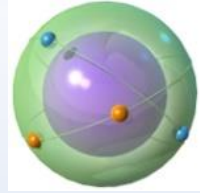
$h_{11/2}$ →

Naïve single particle filling

Sn121 27.06 h 3/2+ β *	Sn122 0+ 4.63 *	Sn123 129.2 d 11/2- β *	Sn124 0+ 5.79 *	Sn125 9.64 d 11/2- β *	Sn126 1E+5 y 0+ β *	Sn127 2.10 h (11/2-) β *	Sn128 59.07 m 0+ β *	Sn129 2.23 m (3/2+) β *	Sn130 3.72 m 0+ β *	Sn131 56.0 s (3/2+) β *	Sn132 39.7 s 0+ β *
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Seniority Scheme



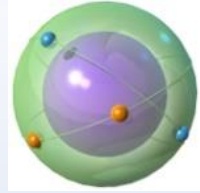
δ -interaction yields a simple geometrical expression for coupling of two particles

$$\Delta E \sim -V_0 \cdot F_r \cdot \tan(\theta/2)$$

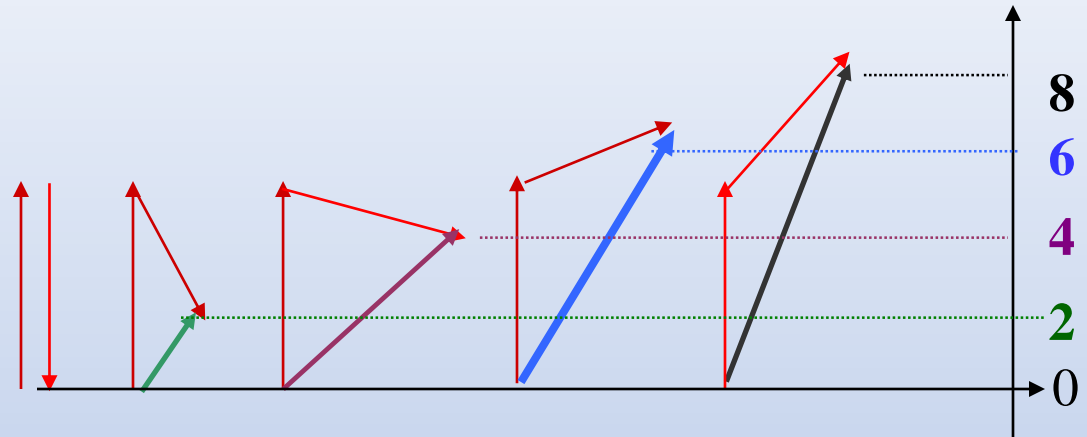
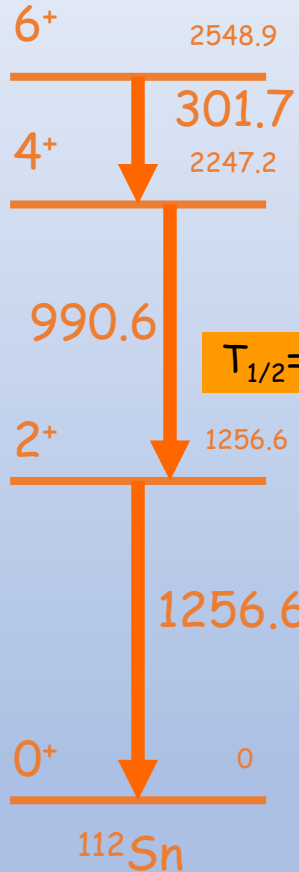
Energy intervals between states $0^+, 2^+, 4^+, \dots (2j - 1)^+$ decrease with increasing spin.



Generalized Seniority Scheme



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



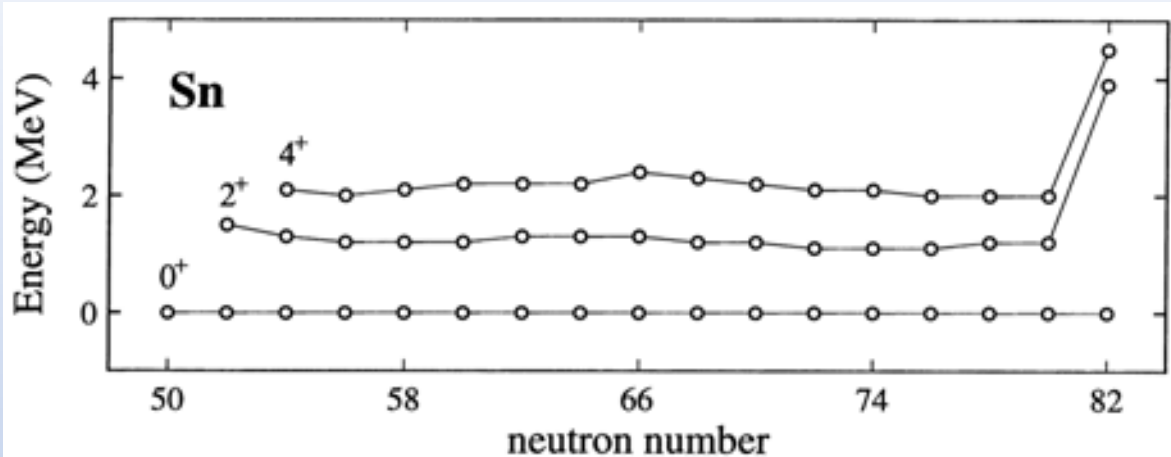
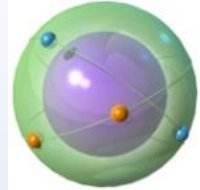
δ -interaction yields a simple geometrical expression for coupling of two particles

$$\Delta E \sim -V_0 \cdot F_r \cdot \tan(\theta/2)$$

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

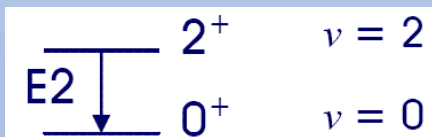


Generalized Seniority Scheme

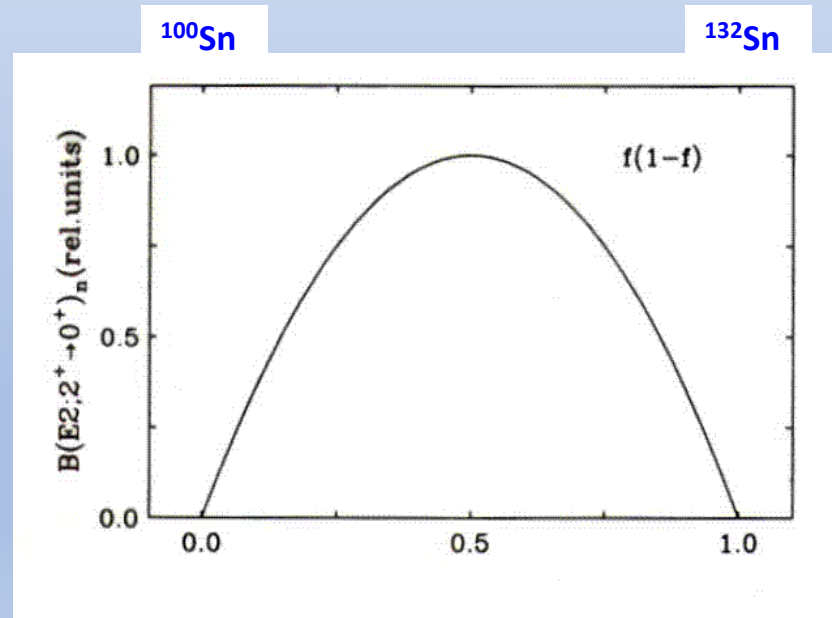


$$B(E2; 2_1^+ \rightarrow 0_1^+) \approx f \cdot (1-f)$$

$$\approx N_{\text{particles}} * N_{\text{holes}}$$

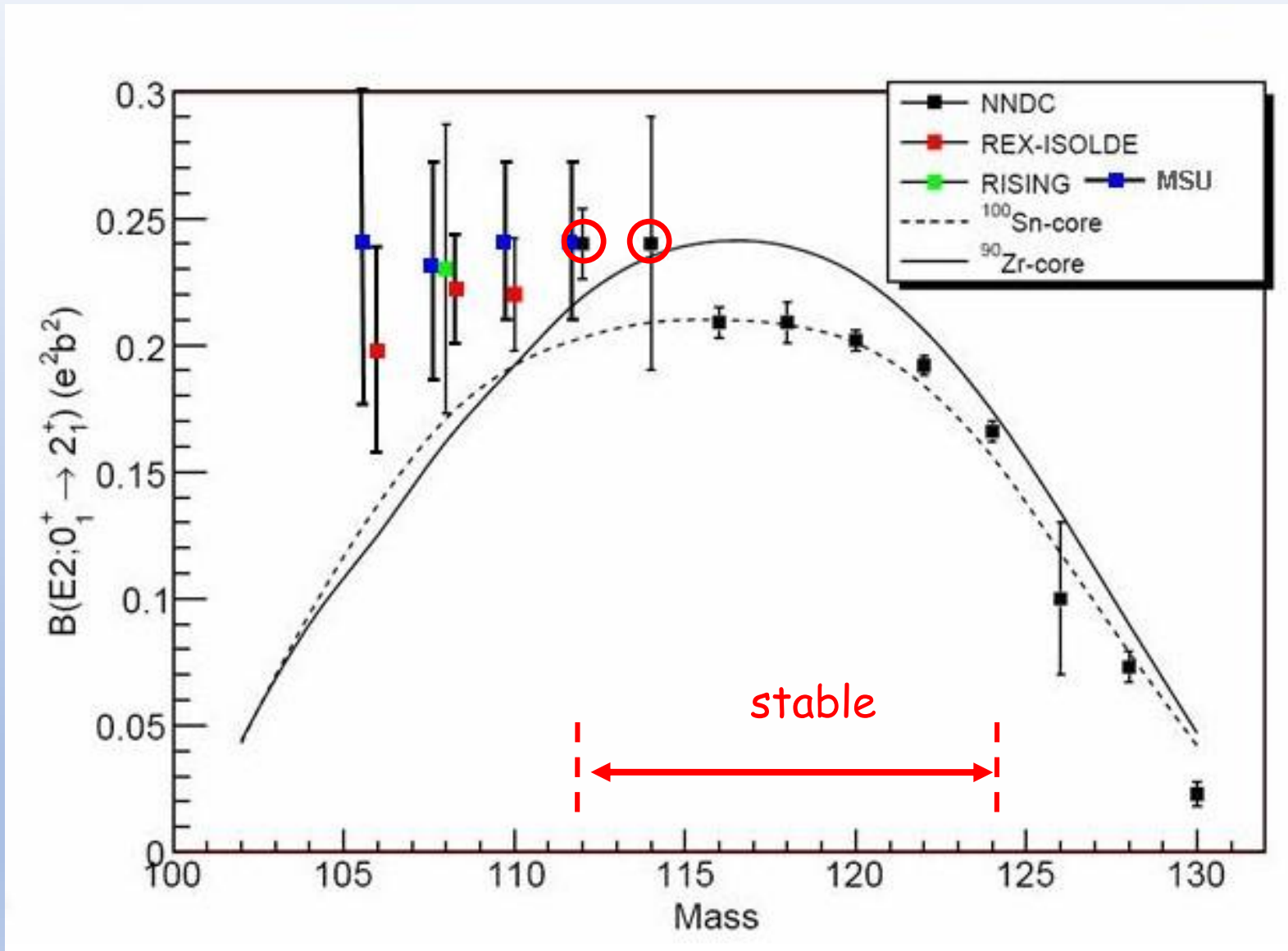


number of nucleons
between shell closures



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

B (E2) values before our measurements

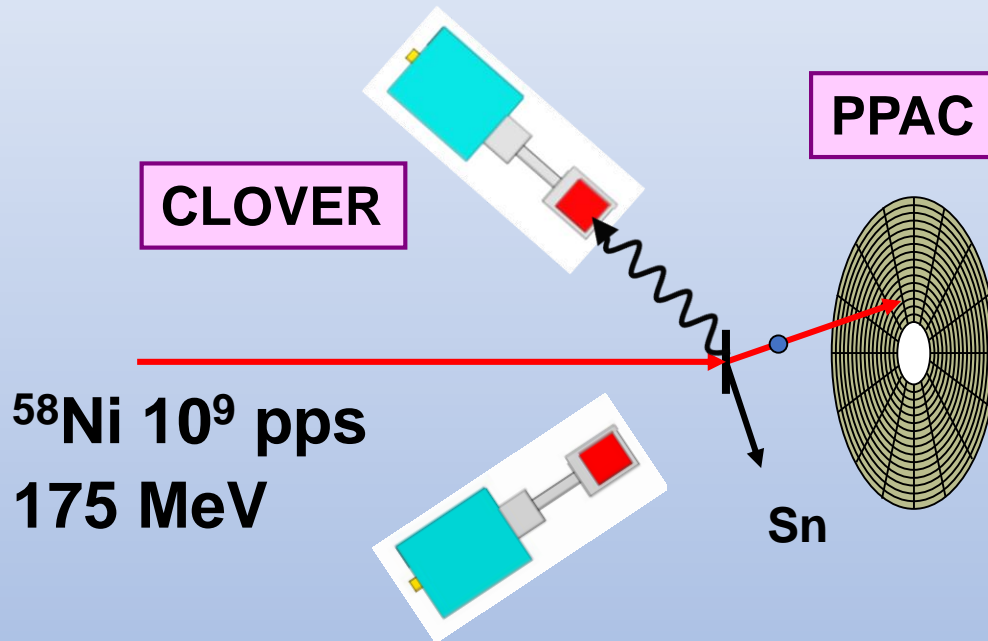


Does ^{112}Sn and ^{114}Sn follow the trend of high B(E2) values?

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



Experimental setup at IUAC



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

$E_x = 1257, 1294 \text{ keV}$

$B(E2)_{\uparrow} = 0.24(2), 0.209(5) e^2 b^2$



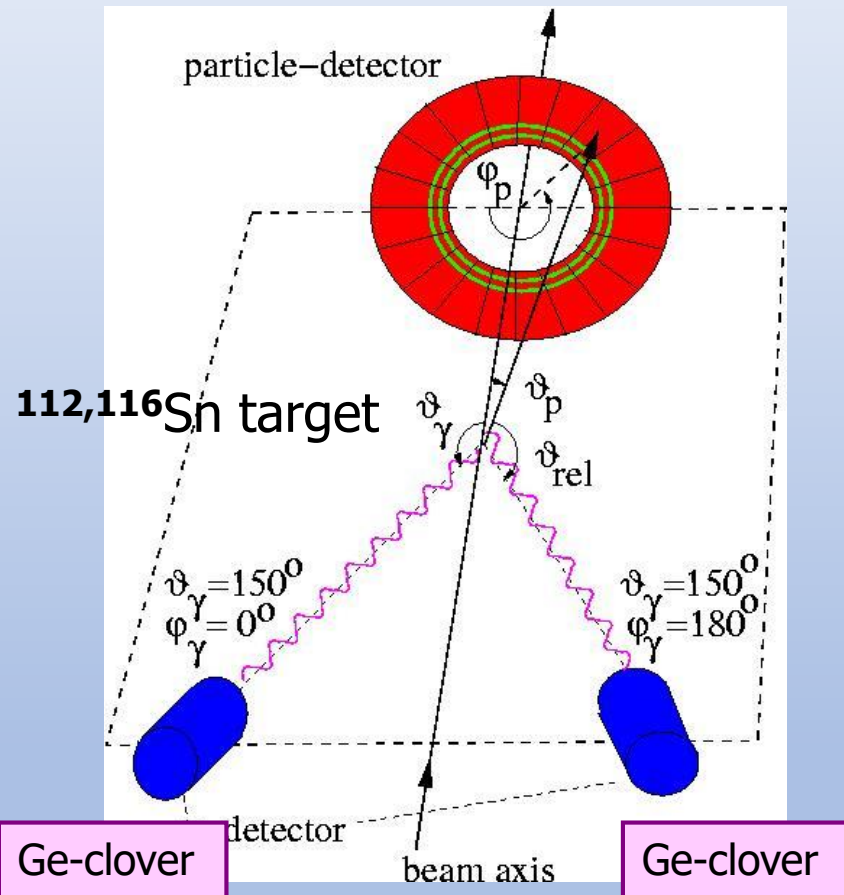
$^{114,116}\text{Sn} \rightarrow ^{58}\text{Ni}$ at 3.4 MeV/u

$E_x = 1300, 1294 \text{ keV}$

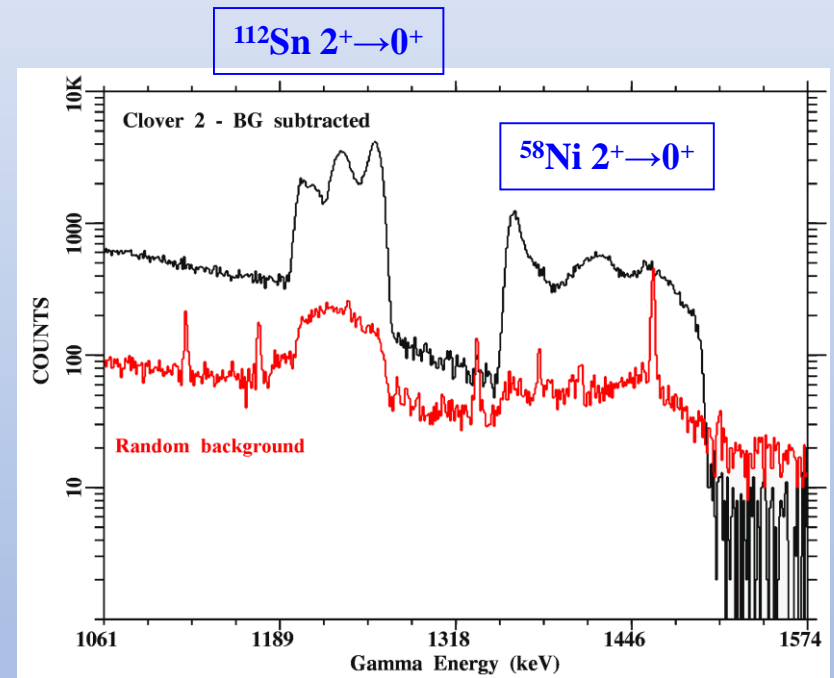
$B(E2)_{\uparrow} = 0.25(5), 0.209(5) e^2 b^2$



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

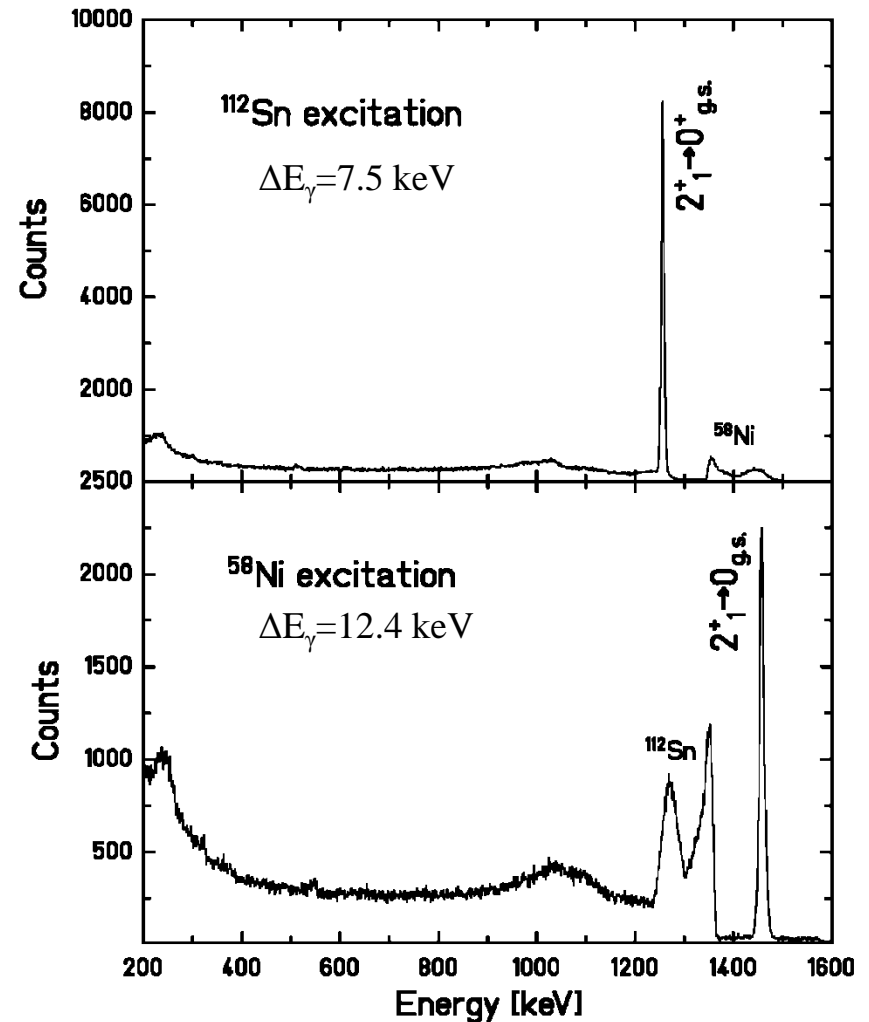
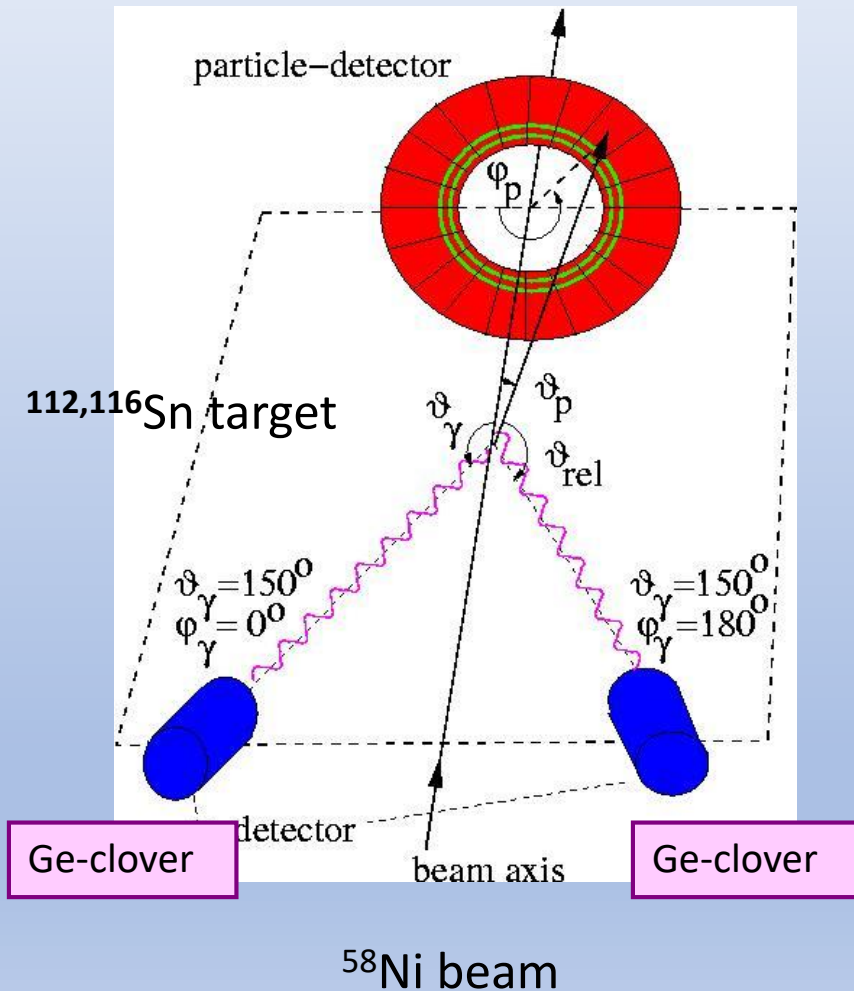


^{58}Ni beam



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

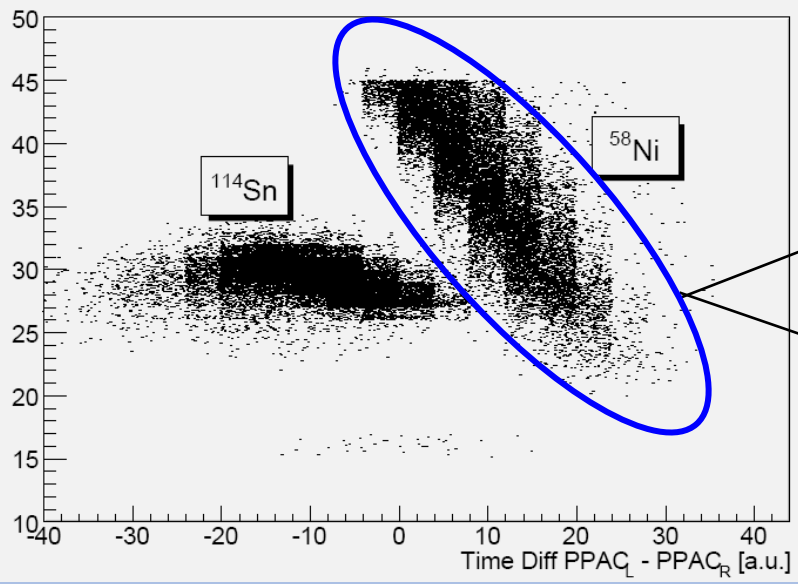
Doppler shift correction for Ni in PPAC



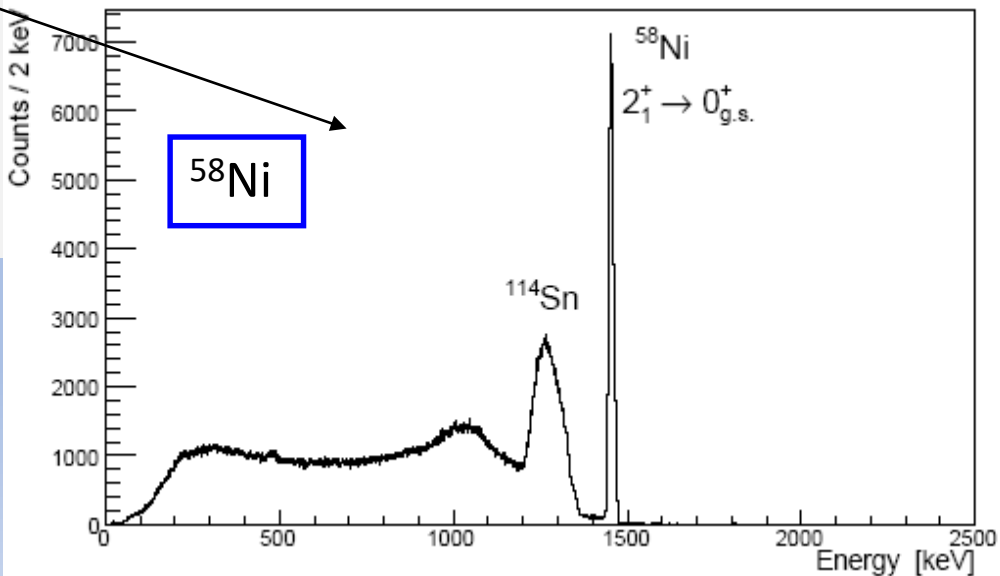
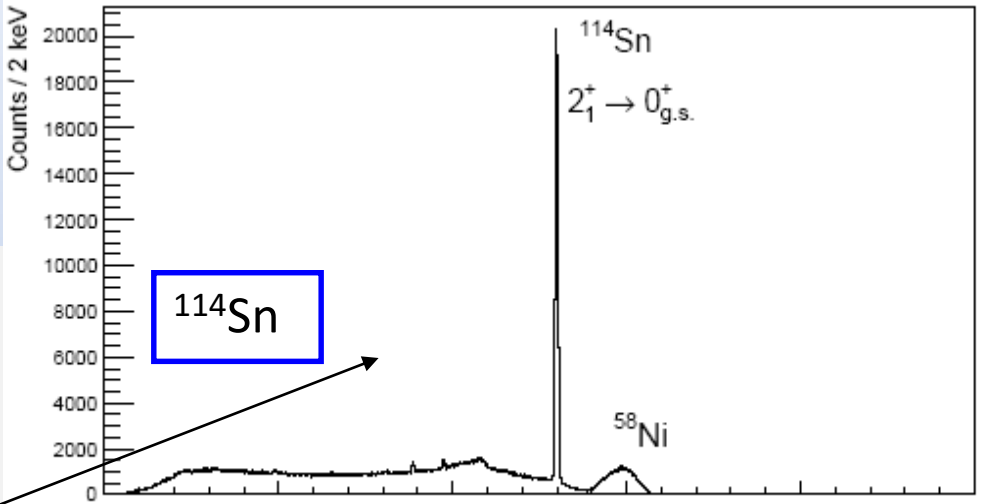
Particle Identification and Doppler correction at GSI

particle identification with PPAC
2 particles + γ -ray required

Scattering Angle



Time (PPAC_L-PPAC_R)



B(E2) value determination

- Literature value for ^{116}Sn $B(E2\uparrow) = 0.209(6) e^2b^2$
- Literature value for ^{58}Ni $B(E2\uparrow) = 0.0493(7) e^2b^2$
- Two possibilities to determine B(E2) of ^{112}Sn :
Relative to ^{58}Ni :

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

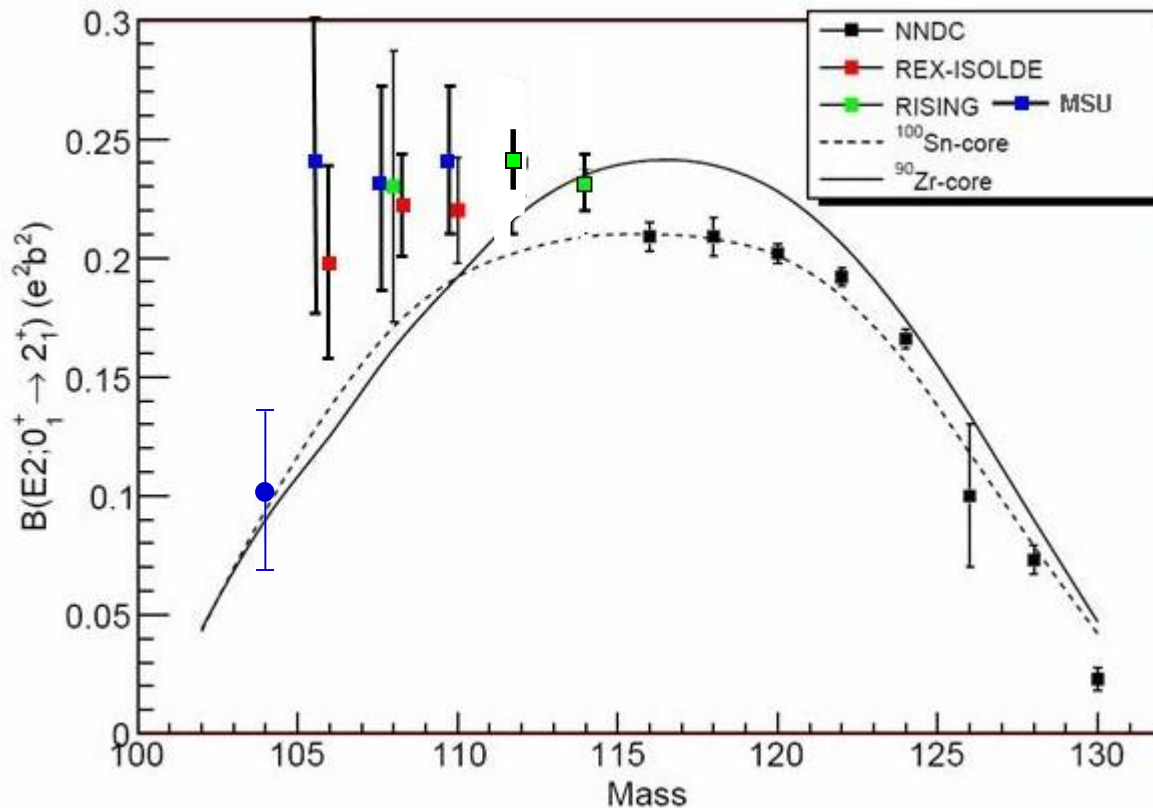
Relative to ^{116}Sn :

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



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

P. Doornenbal,^{1,2,*} P. Reiter,¹ H. Grawe,² H. J. Wollersheim,² P. Bednarczyk,^{2,3} L. Caceres,^{2,4} J. Cederkäll,^{5,6} A. Ekström,^{6,5} J. Gerl,² M. Górska,² A. Jhingan,⁷ I. Kojouharov,² R. Kumar,⁷ W. Prokopowicz,² H. Schaffner,² and R. P. Singh⁷



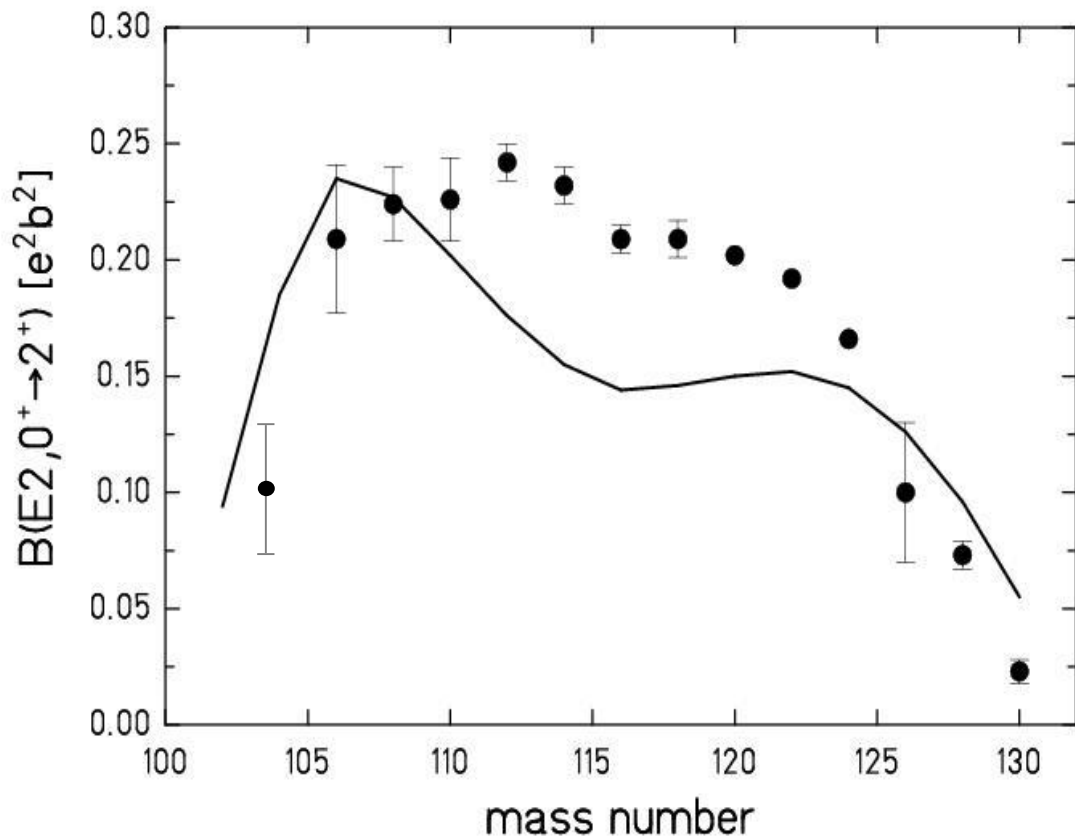
For ^{112}Sn we determined
 $B(E2; 0^+ \rightarrow 2^+) = 0.242(8) e^2 b^2$

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



Comparison with RQRPA

relativistic quasiparticle random-phase approximation calculation



•no effective charges

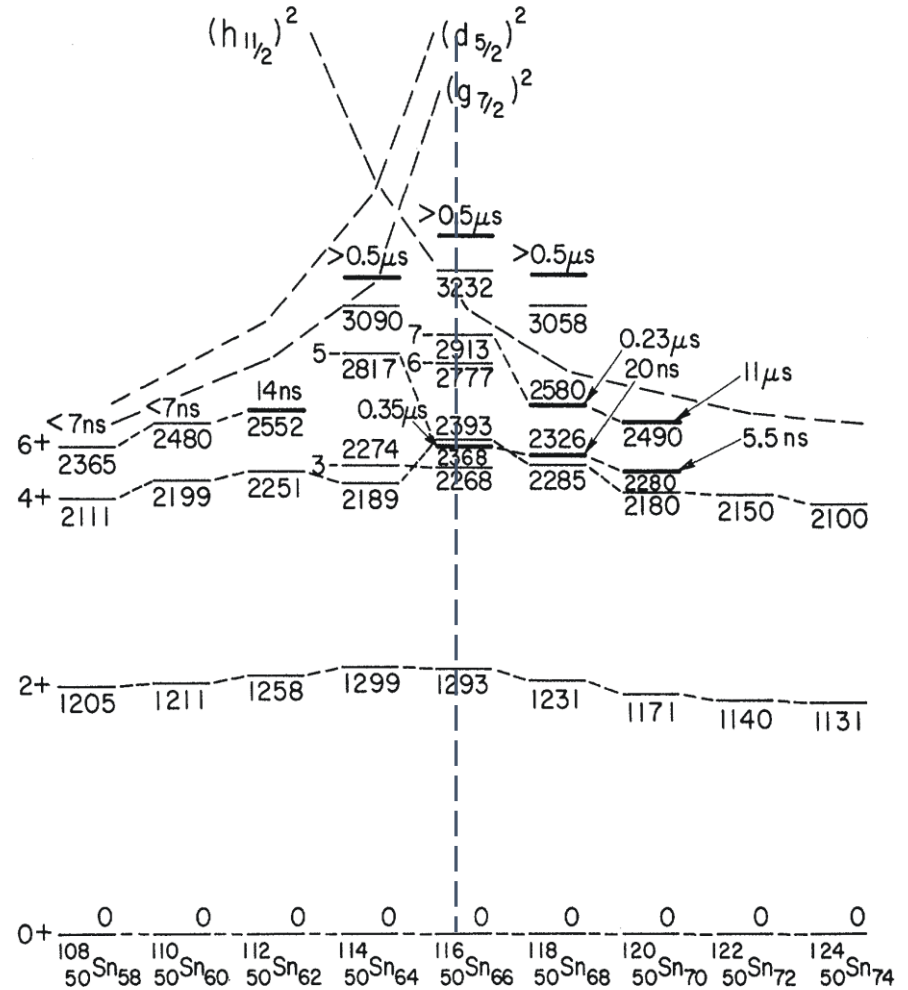
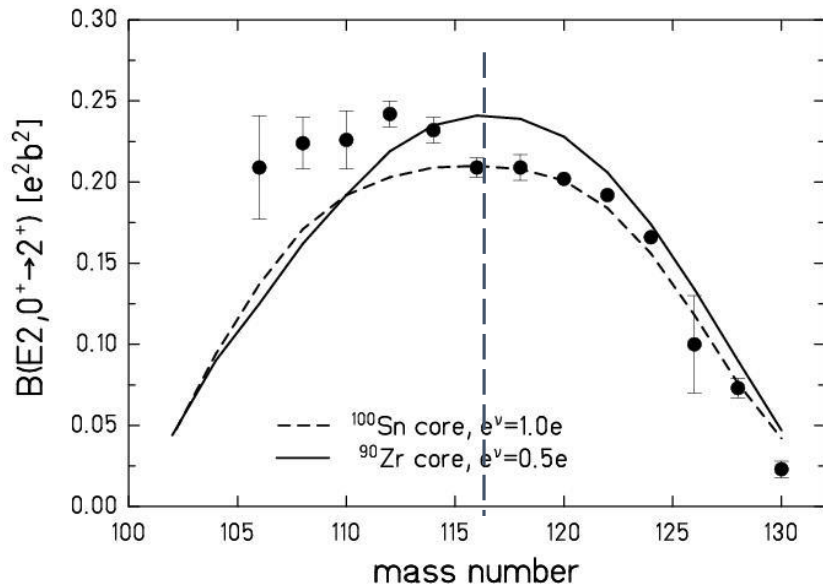
•no core required

•satisfactory agreement
also for the Ni and Pb
isotopes



Asymmetry between ^{100}Sn and ^{132}Sn

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



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

La119	La120 28 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 3.912 h 5/2+	La134 6.45 m 1+	La135 19.5 h 5/2+	La136 987 m 1+
Ba118	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 2.417	Ba135 6.592
Cs117 8.4 s (9/2+)	Cs118 14 s 2	Cs119 43.0 s 9/2+	Cs120 64 s 2	Cs121 155 s 3/2(+)	Cs122 21.0 s 1+	Cs123 594 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 2+	Cs133 7/2+	Cs134 2.0648 y 4+
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 1.0E+14 y 0+	Xe125 16.9 h (1/2+)	Xe126 0+	Xe127 36.4 d 1/2+	Xe128 0+	Xe129 1/2+	Xe130 0+	Xe131 3/2+	Xe132 0+	Xe133 5.243 d 3/2+
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 100	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+
Te114 15.2 m 0+	Te115 5.8 m 7/2+	Te116 2.49 h 0+	Te117 62 m 1/2+	Te118 6.00 d 0+	Te119 16.3 h 1/2+	Te120 0+	Te121 6.78 d 1/2+	Te122 0+	Te123 1E+13 y 1/2+	Te124 0+	Te125 1/2+	Te126 0+	Te127 9.35 h 3/2+	Te128 2.2E24 y 0+	Te129 69.6 m 3/2+	Te130 7.9E20 y 0+	Te131 25.0 m 3/2+
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-)
Sn112 0+	Sn113 1.1 s 1/2+	Sn114 0+	Sn115 1/2+	Sn116 0+	Sn117 1/2+	Sn118 0+	Sn119 1/2+	Sn120 0+	Sn121 27.06 h 3/2+	Sn122 0+	Sn123 179.2 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 0+	Sn129 2.23 m (3/2+)
In111 2.80 s 9/2+	In112 14.97 m 1+	In113 9/2+	In114 71.9 s 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 9/2+	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(+)	In127 1.09 s (9/2+)	In128 6.84 s (3+)
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 0.500 s 0+	Cd127 0.37 s (3/2+)

Z=52

Z=50

N

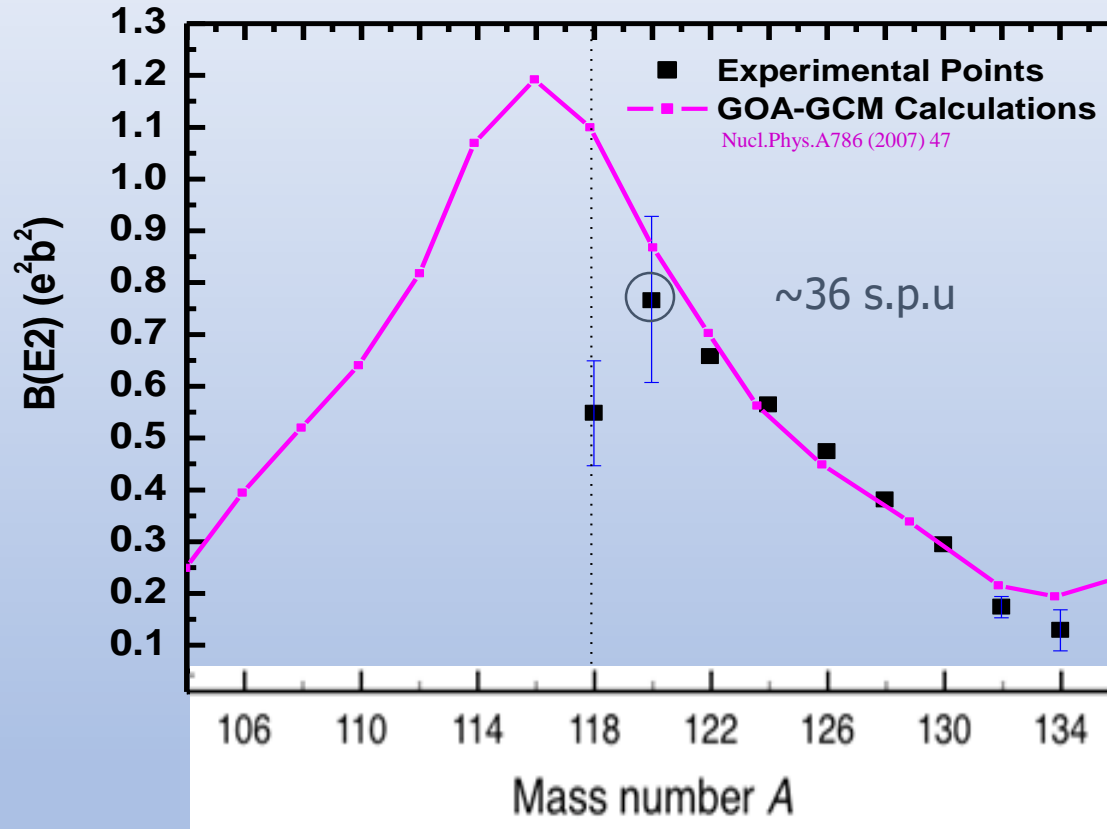
Coulomb Excitation of $^{120,122,124}\text{Te}$ isotopes

Mansi Saxena

HIL, Warsaw



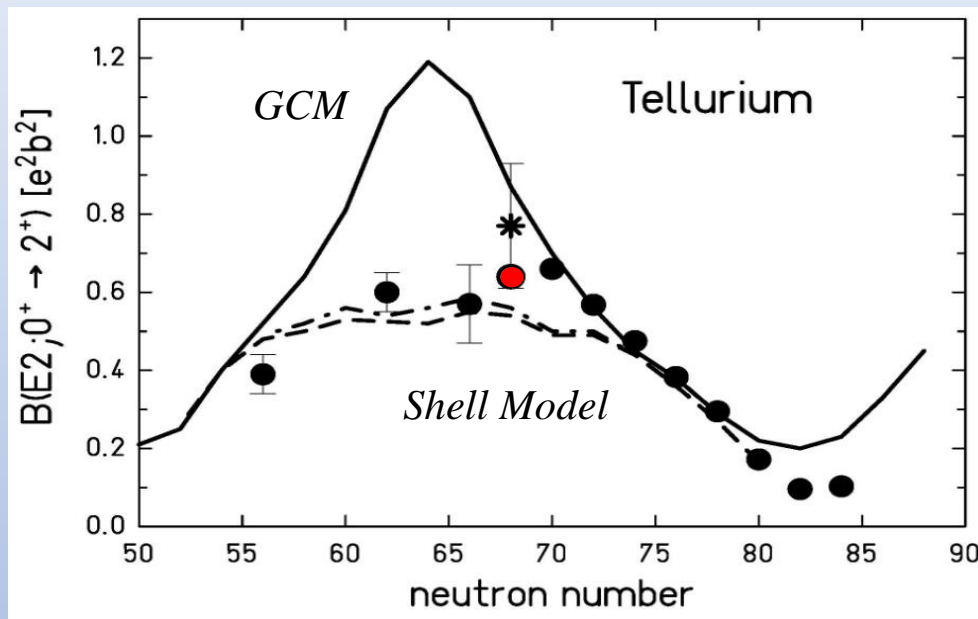
Collectivity of the Te isotopes (Z=52)



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

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

M. Saxena,¹ R. Kumar,² A. Jhingan,² S. Mandal,¹ A. Stolarz,³ A. Banerjee,¹ R. K. Bhowmik,² S. Dutt,⁴ J. Kaur,⁵ V. Kumar,⁶ M. Modou Mbaye,⁷ V. R. Sharma,⁸ and H.-J. Wollersheim⁹



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

Z=52

Z=50

La119	La120	La121	La122	La123	La124	La125	La126	La127	La128	La129	La130	La131	La132	La133	La134	La135	La136
	28 s	5.3 s	8.7 s	17 s	29 s	76 s (11/2-)	54 s	5.1 m (11/2-)	5.0 m (5+)	11.6 m 3/2+	8.7 m 3(+)	59 m 3/2+	4.8 h 2-	3.912 h 5/2+	6.45 m 1+	19.5 h 5/2+	987 m 1+
EC	EC	ECp	ECp	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC
Ba118	Ba119	Ba120	Ba121	Ba122	Ba123	Ba124	Ba125	Ba126	Ba127	Ba128	Ba129	Ba130	Ba131	Ba132	Ba133	Ba134	Ba135
5.5 s 0+	5.4 s (5/2+)	32 s 0+	29.7 s 5/2(+)	1.95 m 0+	2.7 m 5/2+	11.0 m 0+	3.5 m 1/2(+)	100 m 0+	12.7 m 1/2+	2.43 d 0+	2.23 h 1/2+	0+	0.106	11.7 d 1+	0.51 y 1/2+	2.417	3/2+
EC	ECp	EC	ECp	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC
Cs117	Cs118	Cs119	Cs120	Cs121	Cs122	Cs123	Cs124	Cs125	Cs126	Cs127	Cs128	Cs129	Cs130	Cs131	Cs132	Cs133	Cs134
8.4 s (9/2+)	14 s 2	43.0 s 9/2+	64 s 2	155 s 3/2(+)	21.0 s 1+	594 m 1/2+	30.8 s 1+	45 m (1/2+)	1.64 m 1+	6.25 h 1/2+	3.66 m 1+	32.06 h 1/2+	29.21 m 1+	0.101	6.479 d 2+	7/2+	2.0648 y 4+
EC	ECp,ECα	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	100	ECβ-
Xe116	Xe117	Xe118	Xe119	Xe120	Xe121	Xe122	Xe123	Xe124	Xe125	Xe126	Xe127	Xe128	Xe129	Xe130	Xe131	Xe132	Xe133
59 s 0+	5/2(+)	3.8 m 0+	5/2(+)	40 m 0+	40.1 m 5/2(+)	20.1 h 0+	2.08 h (1/2+)	1.0E+14 y 0+	16.9 h (1/2+)	0+	36.4 d 1/2+	0+	1/2+	0+	3/2+	0+	3/2+
EC	ECp	EC	EC	EC	EC	EC	EC	FFEC 0.10	EC	0.09	EC	EC	EC	EC	EC	EC	β-
I115	I116	I117	I118	I119	I120	I121	I122	I123	I124	I125	I126	I127	I128	I129	I130	I131	I132
1.3 m (5/2+)	2.91 s 1+	2.22 m (5/2)+	13.7 m 2-	19.1 m 5/2+	81.0 m 2-	2.12 h 5/2+	3.63 m 1+	13.27 h 5/2+	4.1760 d 2-	59.408 d 5/2+	13.11 d 2-	100	24.99 m 1+	1.57E7 y 7/2+	12.36 h 5+	8.02070 d 7/2+	2.295 h 4+
EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	ECβ-	100	ECβ-	ECβ-	β-	β-	β-
Te114	Te115	Te116	Te117	Te118	Te119	Te120	Te121	Te122	Te123	Te124	Te125	Te126	Te127	Te128	Te129	Te130	Te131
15.2 m 0+	5.8 m 7/2+	2.49 h 0+	62 m 1/2+	6.00 d 0+	16.3 h 1+	0+	6.78 d 1/2+	0+	1E+13 y 1/2+	0+	0+	1/2+	0+	9.35 h 3/2+	2.2E24 y 0+	69.6 m 3/2+	7.9E20 y 0+
EC	EC	EC	EC	EC	EC	0.096	EC	2.603	EC 0.908	4.816	7.139	18.95	β-	β- 31.60	β-	β-	β-
Sb113	Sb114	Sb115	Sb116	Sb117	Sb118	Sb119	Sb120	Sb121	Sb122	Sb123	Sb124	Sb125	Sb126	Sb127	Sb128	Sb129	Sb130
6.67 m 5/2+	3.49 m 3+	32.1 m 5/2+	15.8 m 3+	2.80 h 5/2+	3.6 m 1+	38.19 h 5/2+	15.89 m 1+	5/2+	2.7238 d 2-	7/2+	60.20 d 3-	2.7582 y 7/2+	12.46 d (8-)	3.85 d 7/2+	9.01 h 8-	4.40 h 7/2+	39.5 m (8-)
EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC
Sn112	Sn113	Sn114	Sn115	Sn116	Sn117	Sn118	Sn119	Sn120	Sn121	Sn122	Sn123	Sn124	Sn125	Sn126	Sn127	Sn128	Sn129
0+	1/2+	0+	1/2+	0+	1/2+	0+	1/2+	0+	27.06 h 3/2+	0+	11/2-	0+	9.64 d 11/2-	1E+5 y 0+	2.10 h (11/2-)	50.07 m 0+	2.23 m (3/2+)
EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC
In111	In112	In113	In114	In115	In116	In117	In118	In119	In120	In121	In122	In123	In124	In125	In126	In127	In128
2.80 s 9/2+	14.97 m 1+	9/2+	71.9 s 1+	4.41E+14 y 9/2+	14.10 s 1+	43.2 m 9/2+	5.0 s 1+	2.4 m 9/2+	3.08 s 1+	23.1 s 9/2+	1.5 s 1+	5.98 s 9/2+	3.11 s 3+	2.36 s 9/2(+)	1.60 s 3(+)	1.09 s (9/2+)	6.84 s (3+)
EC	ECβ-	EC	ECβ-	β-	ECβ-	ECβ-	β-	β-	β-	β-	β-	β-	β-	β-	β-	βm	βm
Cd110	Cd111	Cd112	Cd113	Cd114	Cd115	Cd116	Cd117	Cd118	Cd119	Cd120	Cd121	Cd122	Cd123	Cd124	Cd125	Cd126	Cd127
0+	1/2+	0+	7.7E+15 y 1/2+	0+	53.46 h 1/2+	0+	2.49 h 1/2+	50.3 m 0+	2.69 m 3/2+	50.80 s 0+	13.5 s (3/2+)	5.24 s 0+	2.10 s (3/2-)	1.25 s 0+	0.65 s (3/2+)	0.500 s 0+	0.37 s (3/2+)
12.49	12.80	24.13	β-	1222	28.73	β-	7.49	β-	β-	β-	β-	β-	β-	β-	β-	β-	β-

N

Probing the low-level nuclear structure of ^{132}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:

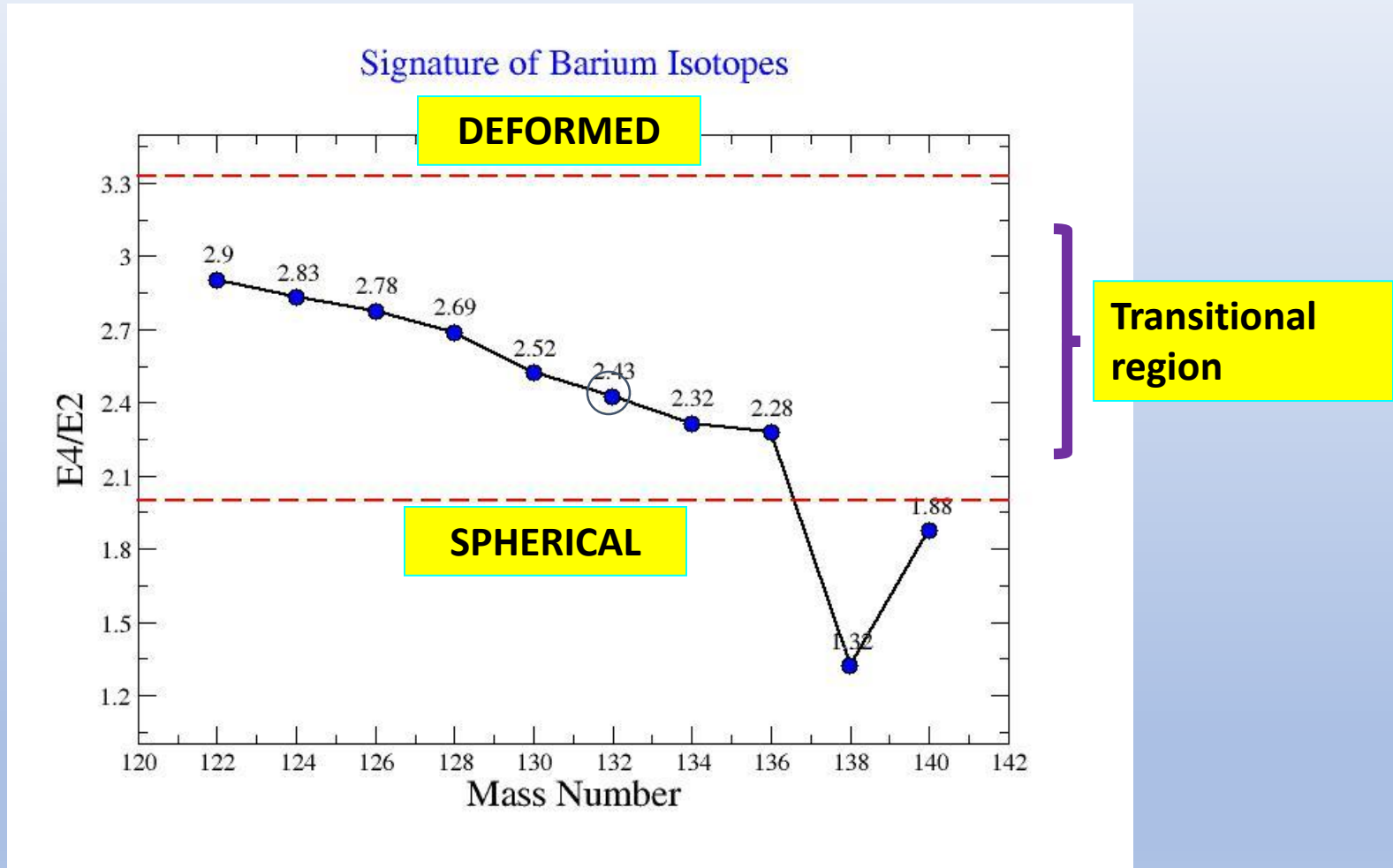
Dr. P. J. Napiorkowski
HIL, Warsaw, Poland

Mentor:

Dr. H. J. Wollersheim
GSI, Darmstadt, Germany



The Ba isotopes, a brief background



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

Motivations for ^{132}Ba

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

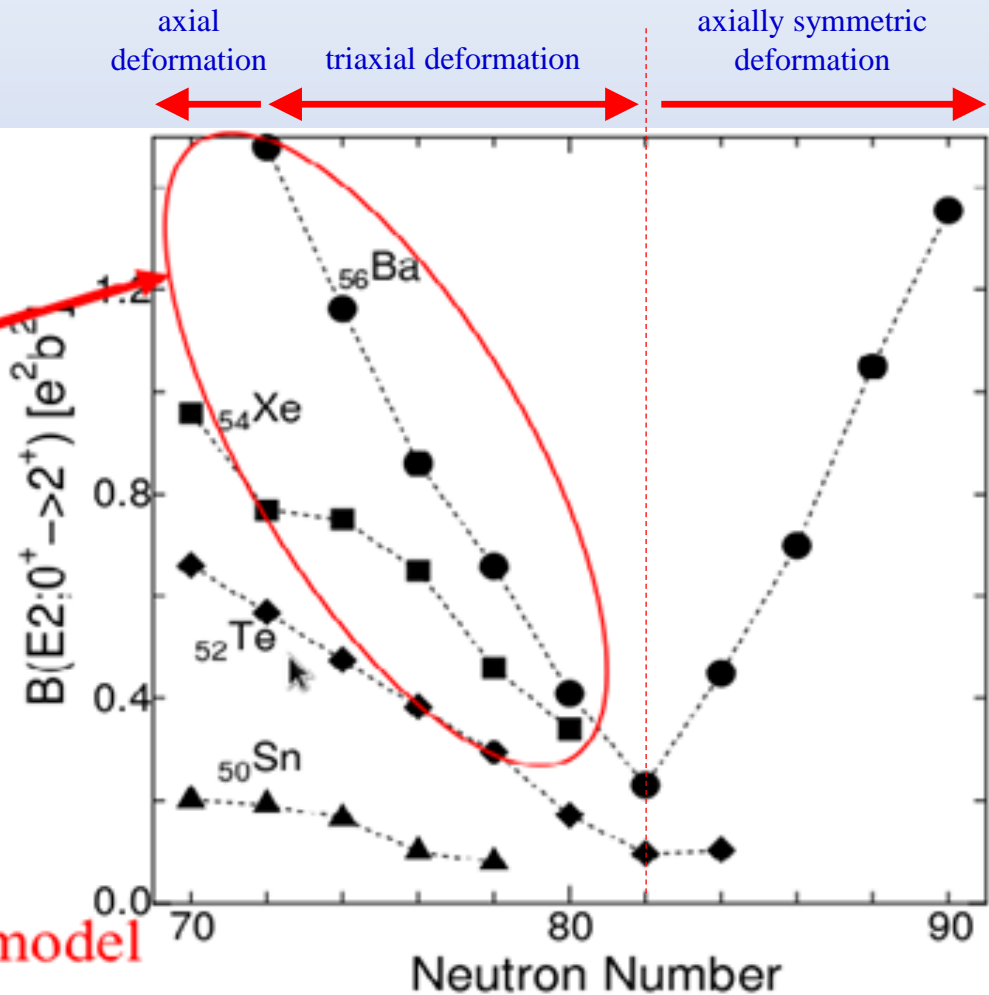
+6 protons to $Z=50$
-6 neutrons to $N=82$

$N = 82$

B(E2) transition probabilities
of quadrupole collective states

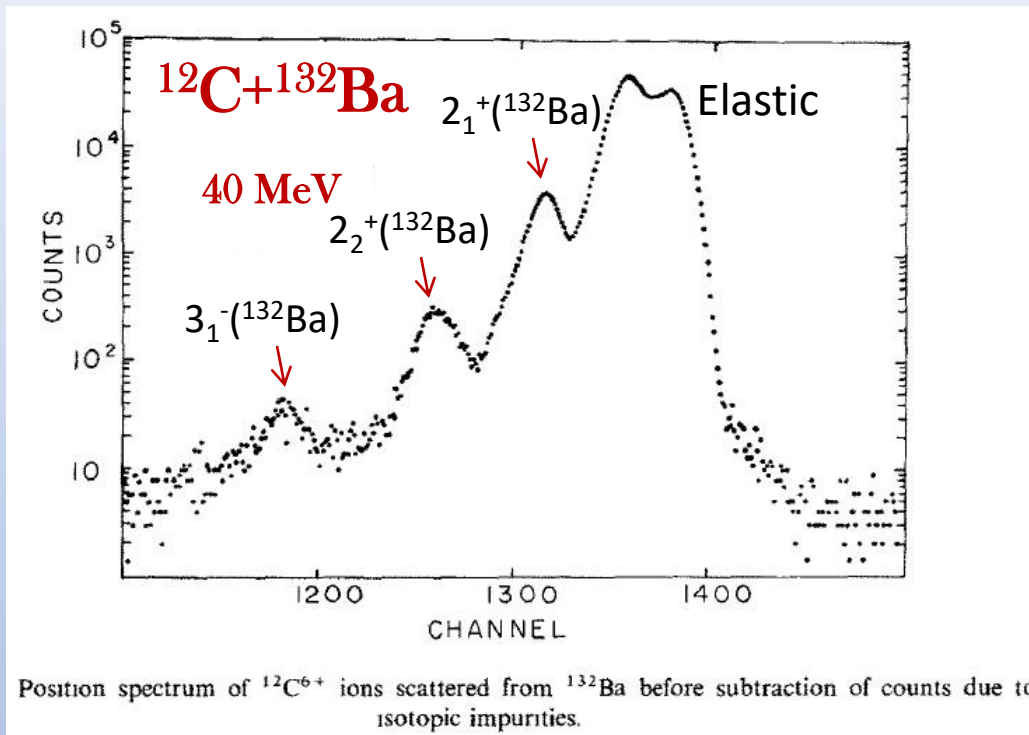
Transitional region
between spherical
vibrator and triaxially
deformed rotor.

Microscopic study
using **the nuclear shell model**



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

Previous Measurement



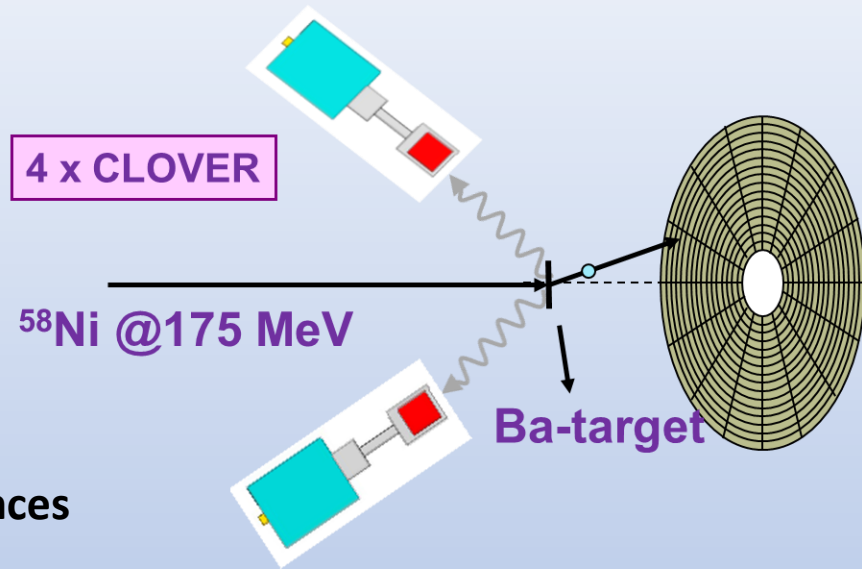
S.M.Burnett et al., Nucl. Phys. A 432(1985)514

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

- Energy resolution ~ 135 keV
- Safe Bombarding Energy = 37.1 MeV

Experimental Setup at IUAC

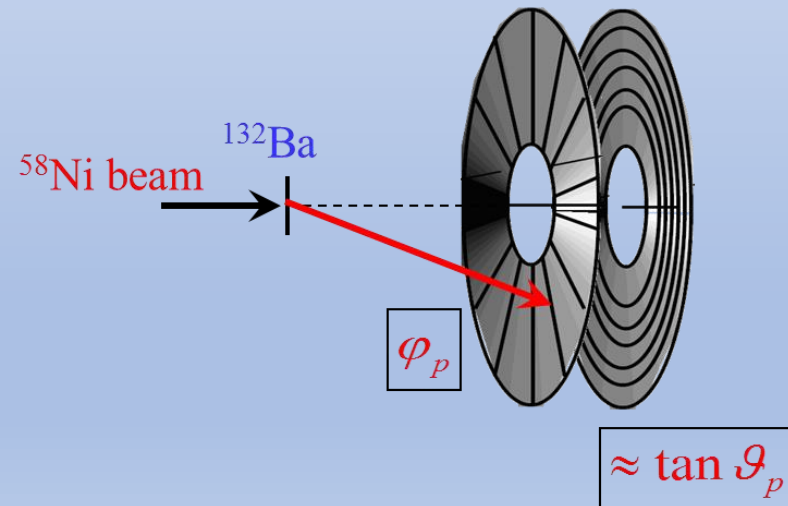
Enriched ^{132}Ba target $\sim 550\mu\text{g}/\text{cm}^2$
 thickness on $\sim 30\mu\text{g}/\text{cm}^2$ thick
 Carbon backing



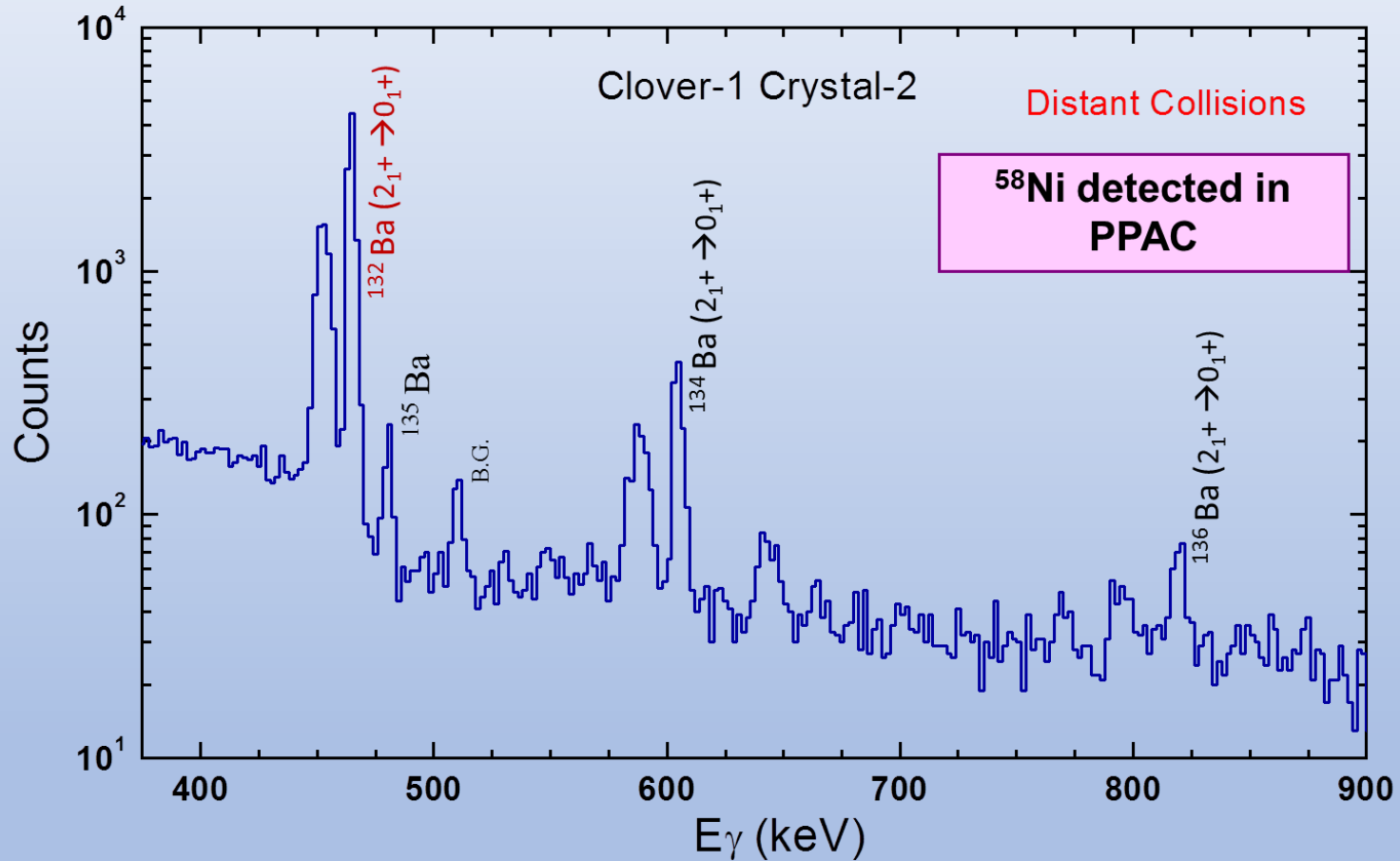
TRIGGER : Particle-Gamma Coincidences
 and Scale Down Particles

Doppler-Shift correction :

$$\frac{E_{\gamma 0}}{E_{\gamma}} = \frac{1 - v_2 * \cos \theta_{\gamma 2}}{\sqrt{1 - v_2^2}}$$

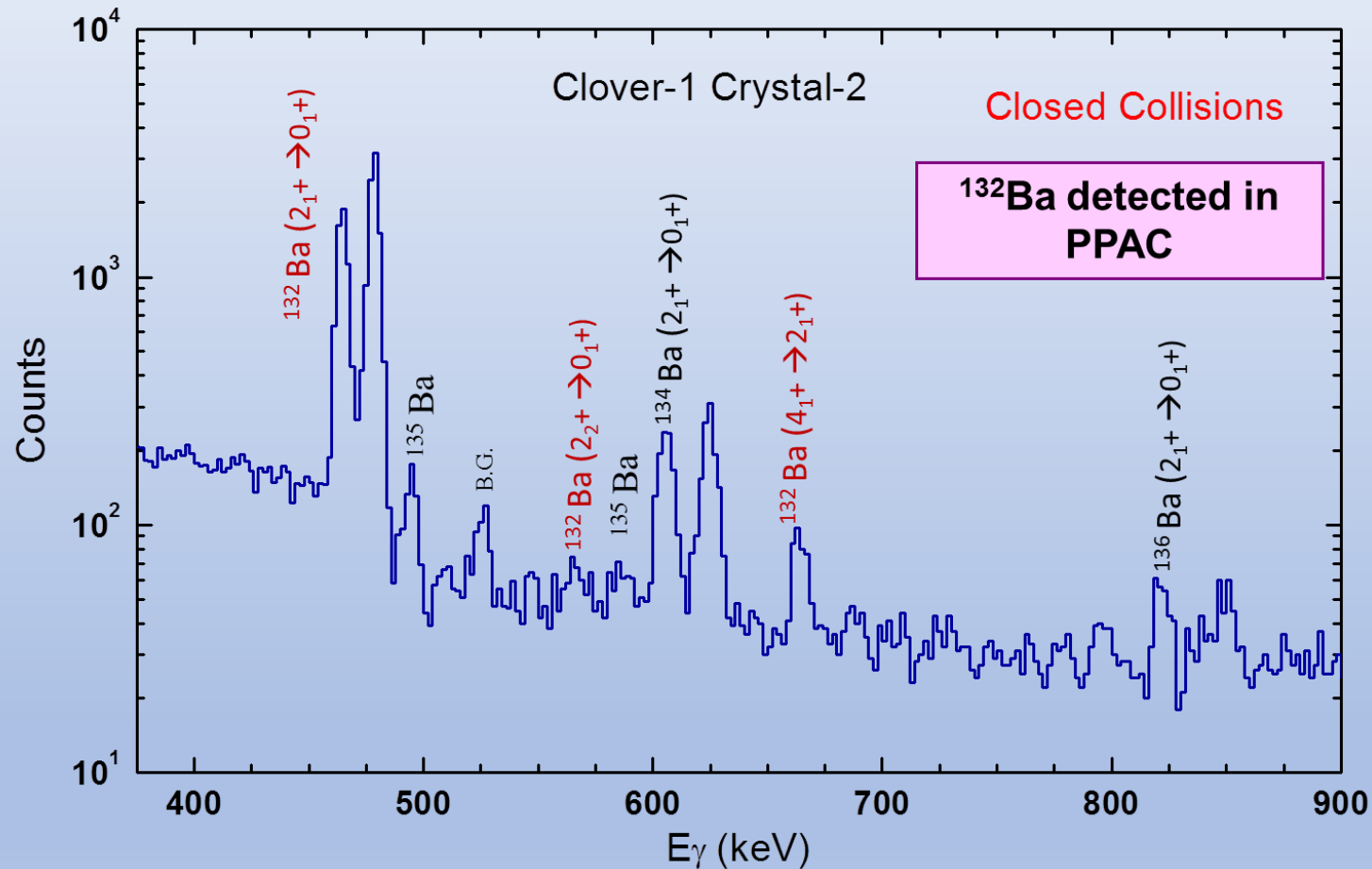


Doppler Shift Corrected γ -Ray Spectrum for $^{58}\text{Ni} + ^{132}\text{Ba}$



Doppler-shift corrected γ -ray spectrum from Clover-1 crystal-2 in coincidence with scattered **projectiles** detected in PPAC.

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



Doppler-shift corrected γ -ray spectrum from Clover-1 crystal-1 in coincidence with recoils detected in PPAC.

Comparison of the measured $B(E2\uparrow)$ values for ^{132}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.	$2_1^+ \rightarrow 0_{g.s.}^+$	54.5	43.0	53.1	53.6
2.	$4_1^+ \rightarrow 2_1^+$	78.3	--	76.9	75.5
3.	$2_2^+ \rightarrow 2_1^+$	66.8	29.1	--	60.0
4.	$2_2^+ \rightarrow 0_{g.s.}^+$	1.8	3.9	1.8	1.4

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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M. MATEJSKA-MINDA^b, V. MISHRA^h, I.A. RIZVI^a, A. STOLARZ^b
H.J. WOLLERSHEIMⁱ, P.J. NAPIORKOWSKI^b

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 3.912 h 5/2+	La134 6.45 m 1+	La135 19.5 h 5/2+	La136 987 m 1+
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 11.7 d 1+	Ba132 0+	Ba133 0.51 y 1/2+	Ba134 2.417	Ba135 6.592
Cs117 8.4 s (9/2+)	Cs118 14 s 2	Cs119 43.0 s 9/2+	Cs120 64 s 2	Cs121 155 s 3/2(+)	Cs122 21.0 s 1+	Cs123 594 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 0.101	Cs132 6.479 d 2+	Cs133 7/2+	Cs134 2.0648 y 4+
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 1.0E+14 y 0+	Xe125 16.9 h (1/2+)	Xe126 0+	Xe127 36.4 d 1/2+	Xe128 0+	Xe129 1/2+	Xe130 0+	Xe131 3/2+	Xe132 0+	Xe133 3/2+
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 100	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+
Te114 15.2 m 0+	Te115 5.8 m 7/2+	Te116 2.49 h 0+	Te117 62 m 1/2+	Te118 6.00 d 0+	Te119 16.3 h 1/2+	Te120 0+	Te121 6.78 d 1/2+	Te122 0+	Te123 1E+13 y 1/2+	Te124 0+	Te125 1/2+	Te126 0+	Te127 9.35 h 3/2+	Te128 2.2E24 y 0+	Te129 69.6 m 3/2+	Te130 7.9E20 y 0+	Te131 25.0 m 3/2+
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-)

Z=52

Z=50

Sn112 0+	Sn113 1.13 m 1/2+	Sn114 0+	Sn115 1/2+	Sn116 0+	Sn117 1/2+	Sn118 0+	Sn119 1/2+	Sn120 0+	Sn121 27.06 h 3/2+	Sn122 0+	Sn123 179.2 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 0+	Sn129 2.23 m (3/2+)
In111 2.807 d 9/2+	In112 14.97 m 1+	In113 9/2+	In114 71.9 s 1+	In115 4.41E+14 y 9/2+	In116 1410 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 9/2+	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(+)	In127 1.09 s (9/2+)	In128 6.84 s (3+)
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 0.05 s (3/2+)	Cd126 0.500 s 0+	Cd127 0.37 s (3/2+)

N

Re-measurement of Stable Sn-isotopes

Z=56

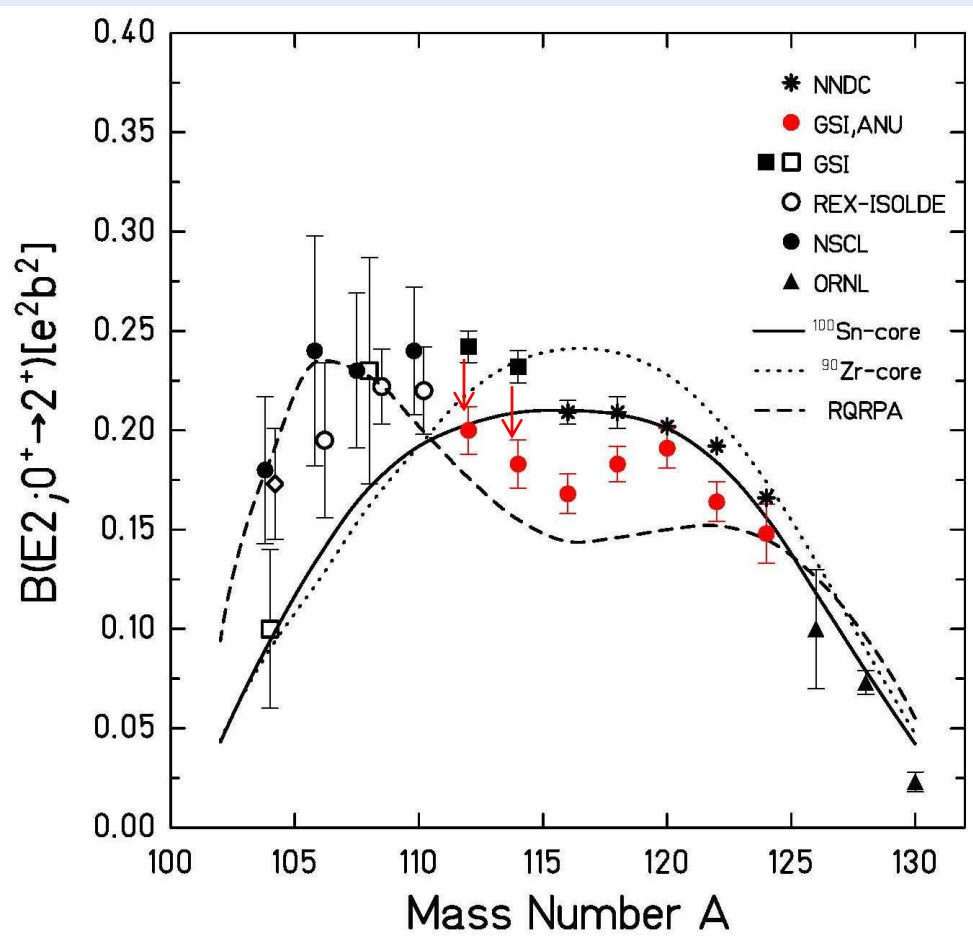
Z=52

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 3.912 h 5/2+	La134 6.45 m 1+	La135 19.5 h 5/2+	La136 987 m 1+
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 2.417 3/2+
EC	EC _p	EC _p	EC _p	EC	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 9/2+	Cs120 64 s 2	Cs121 155 s 3/2(+)	Cs122 21.0 s 1+	Cs123 59.4 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 2+	Cs133 7/2+	Cs134 2.0648 y 4+
EC	EC _p , EC _α	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC _β	EC	EC _β	EC	EC _β
Xe116 59 s 0+	Xe117 61 s 5/2(+)	Xe118 3.8 m 0+	Xe119 40.1 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 1.0E+14 y 0+	Xe125 16.9 h (1/2+)	Xe126 0+	Xe127 36.4 d 1/2+	Xe128 0+	Xe129 1/2+	Xe130 0+	Xe131 3/2+	Xe132 0+	Xe133 3/2+
EC	EC _p	EC	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 100	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+
EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC _β	EC	EC _β	EC _β	EC _β	EC _β	EC _β
Te114 15.2 m 0+	Te115 5.8 m 7/2+	Te116 2.49 h 0+	Te117 62 m 1/2+	Te118 6.00 d 0+	Te119 16.03 h 1/2+	Te120 0+	Te121 16.78 d 1/2+	Te122 0+	Te123 1E+13 y 1/2+	Te124 0+	Te125 1/2+	Te126 0+	Te127 9.35 h 3/2+	Te128 2.2E24 y 0+	Te129 69.6 m 3/2+	Te130 7.9E20 y 0+	Te131 25.0 m 3/2+
EC	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 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-)
Sn112 0+	Sn113 113.9 d 1/2+	Sn114 0+	Sn115 112.9 d 1/2+	Sn116 0+	Sn117 112.9 d 1/2+	Sn118 0+	Sn119 112.9 d 1/2+	Sn120 0+	Sn121 112.9 d 1/2+	Sn122 0+	Sn123 112.9 d 1/2+	Sn124 0+	Sn125 112.9 d 1/2+	Sn126 0+	Sn127 112.9 d (11/2-)	Sn128 0+	Sn129 112.9 d (3/2+)
EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC
In111 2.80 s 9/2+	In112 14.97 m 1+	In113 9/2+	In114 71.9 s 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 9/2+	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(+)	In127 1.09 s (9/2+)	In128 6.84 s (3+)
EC	EC _β	EC	EC _β	EC _β	EC _β	EC _β	EC _β	EC _β	EC _β	EC _β	EC _β	EC _β	EC _β	EC _β	EC _β	EC _β	EC _β
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 0.05 s (3/2+)	Cd126 0.500 s 0+	Cd127 0.37 s (3/2+)
EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC

N

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 .

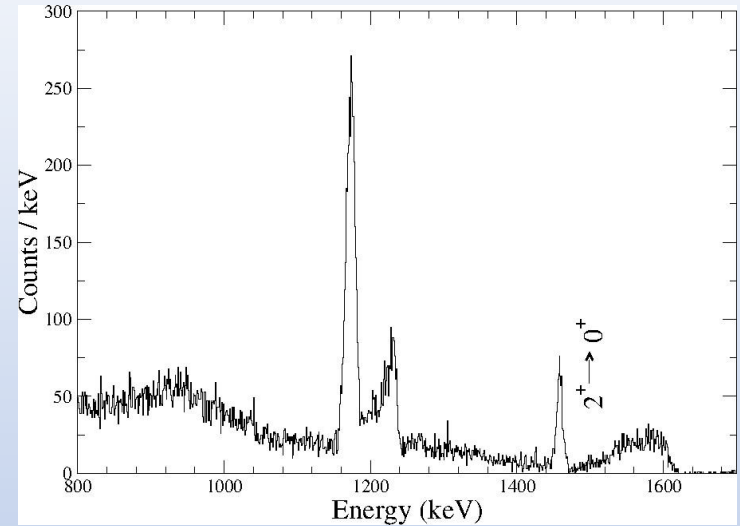
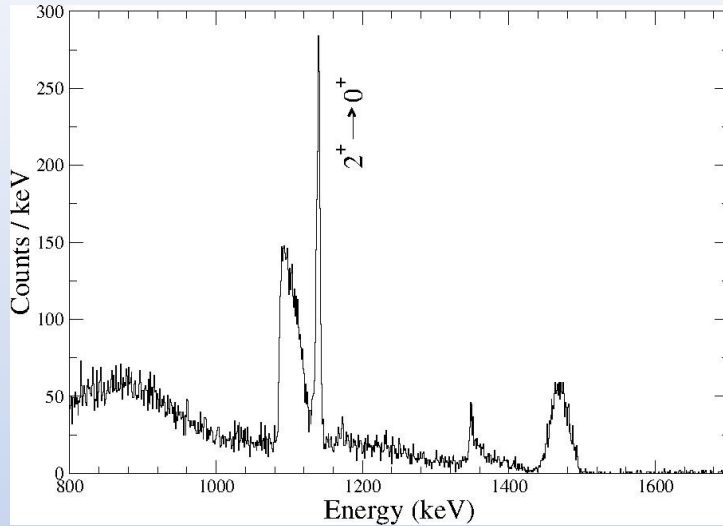
To draw firm conclusions on the $B(E2\uparrow)$ pattern for Sn isotopes, Coulomb excitation of all stable isotopes using a relatively heavy beam (e.g. ^{58}Ni) is necessary.

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

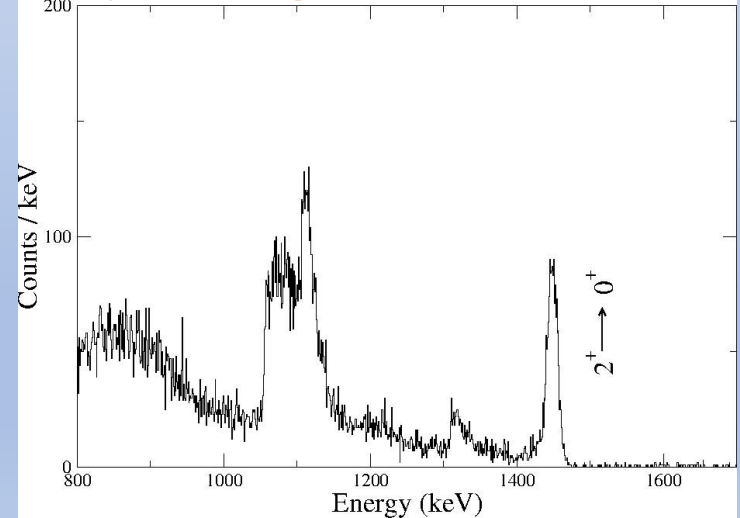
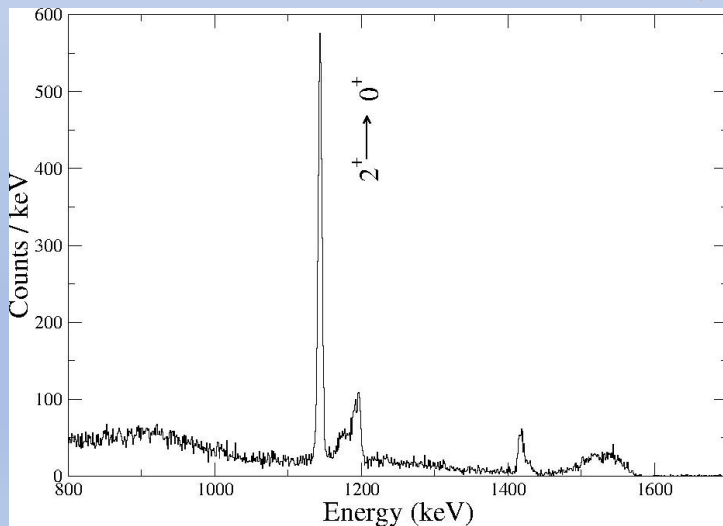
The stable beam facility of IUAC is perfect to settle the agreement or disagreement.

A.Jungclaus et al.
Phys. Lett. B 110, 695 (2011)

Doppler shift corrected γ -spectra emitted from the ^{122}Sn target nuclei and the ^{58}Ni projectiles at 175 MeV

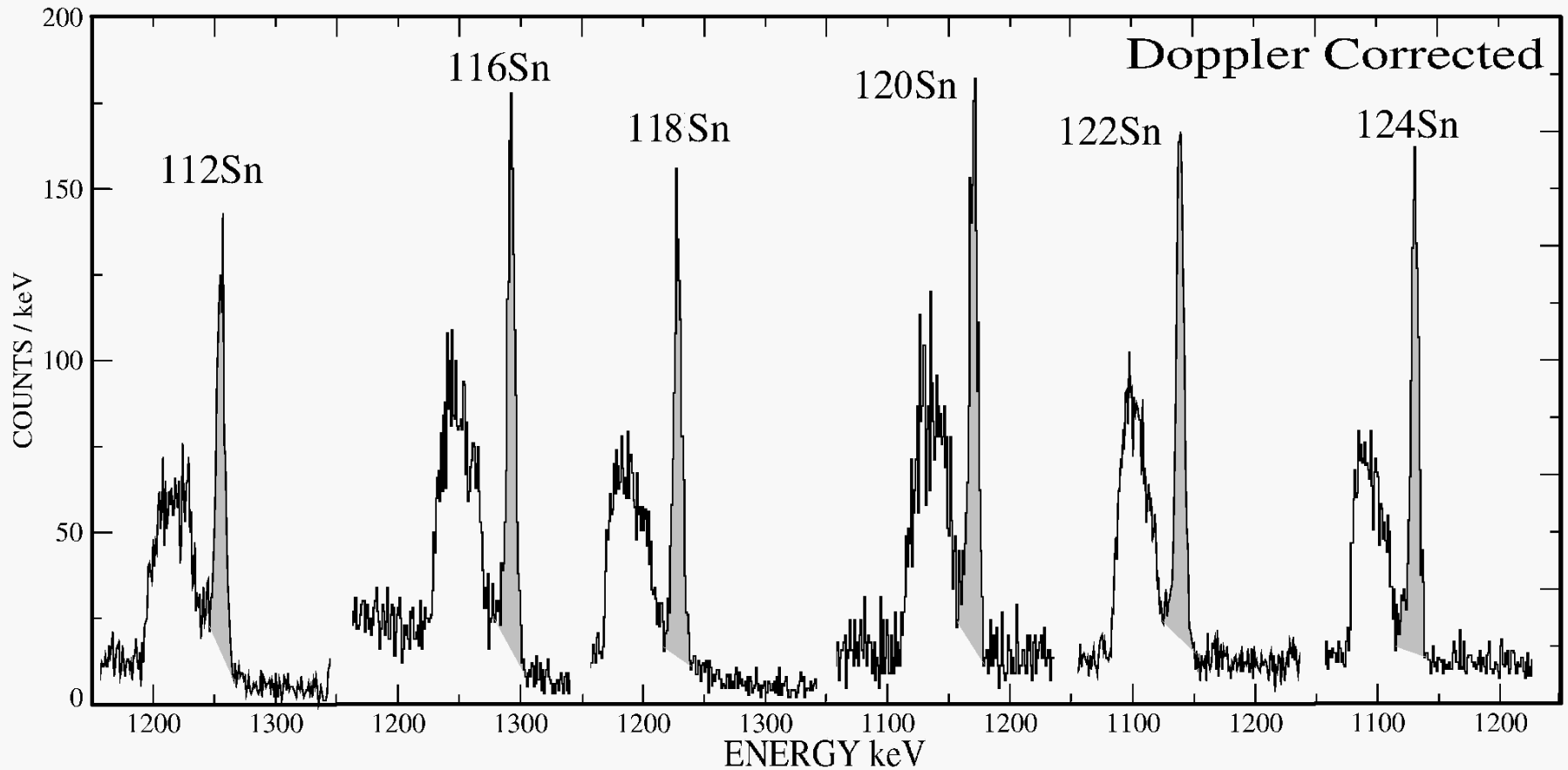


For distant collision ($22.1^\circ \leq \theta_{\text{cm}} \leq 64.6^\circ$) ^{58}Ni detected in PPAC,
The corrected ^{122}Sn spectra left and ^{58}Ni spectra right



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

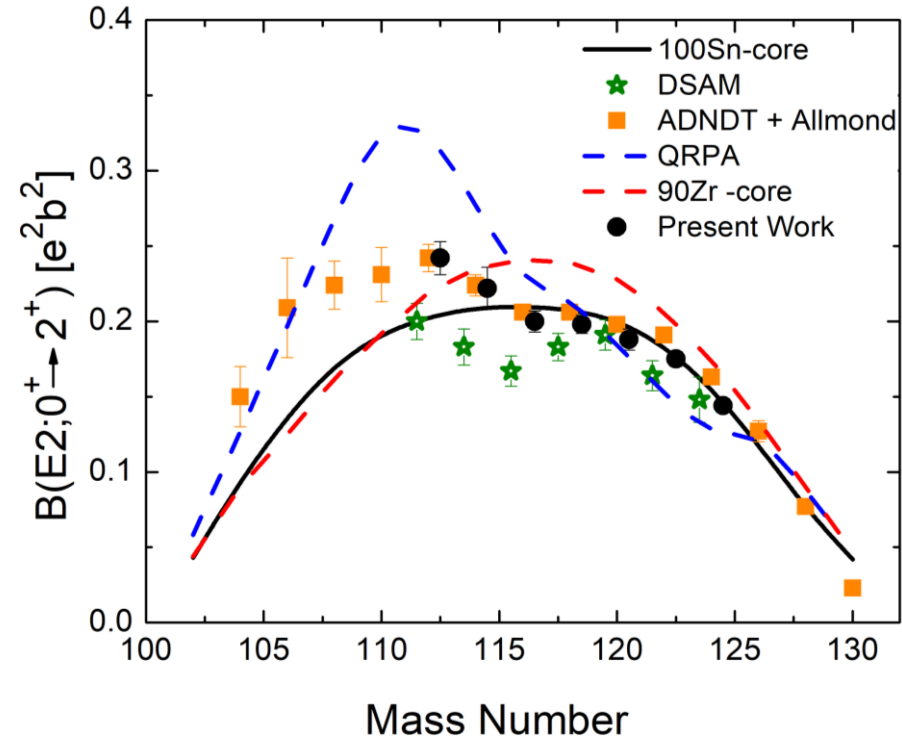
Energy Spectra from Sn Targets



Data from one Ge detector only (out of 16)

< Results >

Sn	B(E2;0 ⁺ → 2 ⁺) ADNDT+Allmond	B(E2;0 ⁺ → 2 ⁺) A. Jungclaus	B(E2;0 ⁺ → 2 ⁺) 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}Sc

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Summary

- Precise $B(E2; 0^+ \rightarrow 2^+)$ values -- stable ^{112}Sn , ^{114}Sn ----- relative to ^{116}Sn . $B(E2\uparrow)$ value increases upon going from ^{116}Sn to ^{112}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}Sn and ^{132}Sn are compared with theoretical predictions.

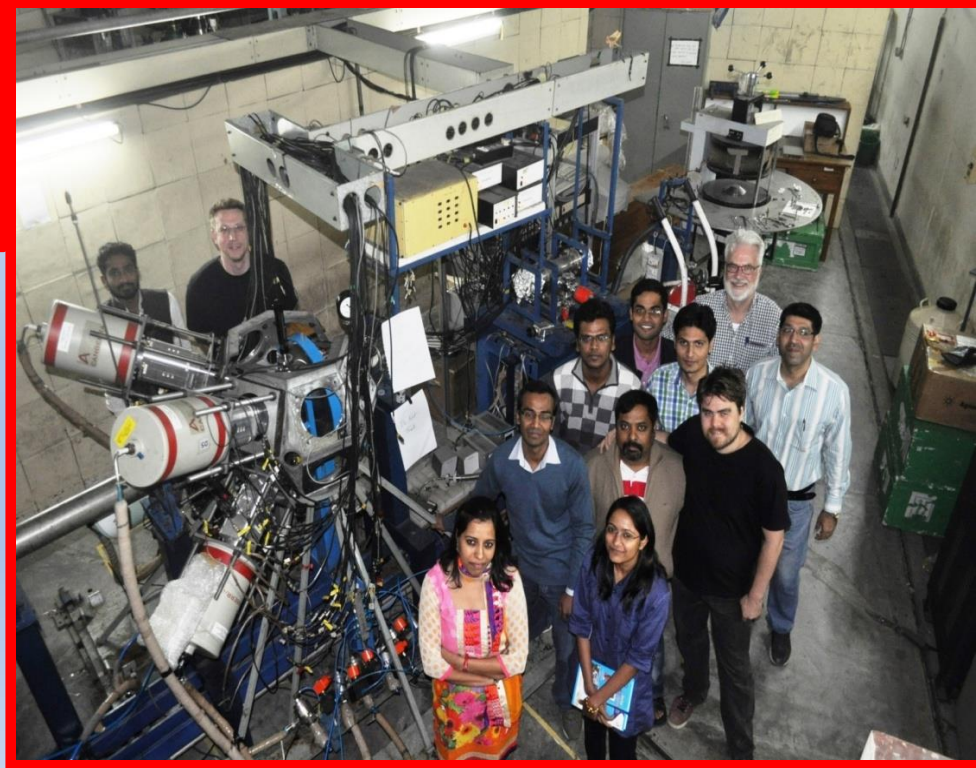
Thanks to Anna Stolarz for Targets



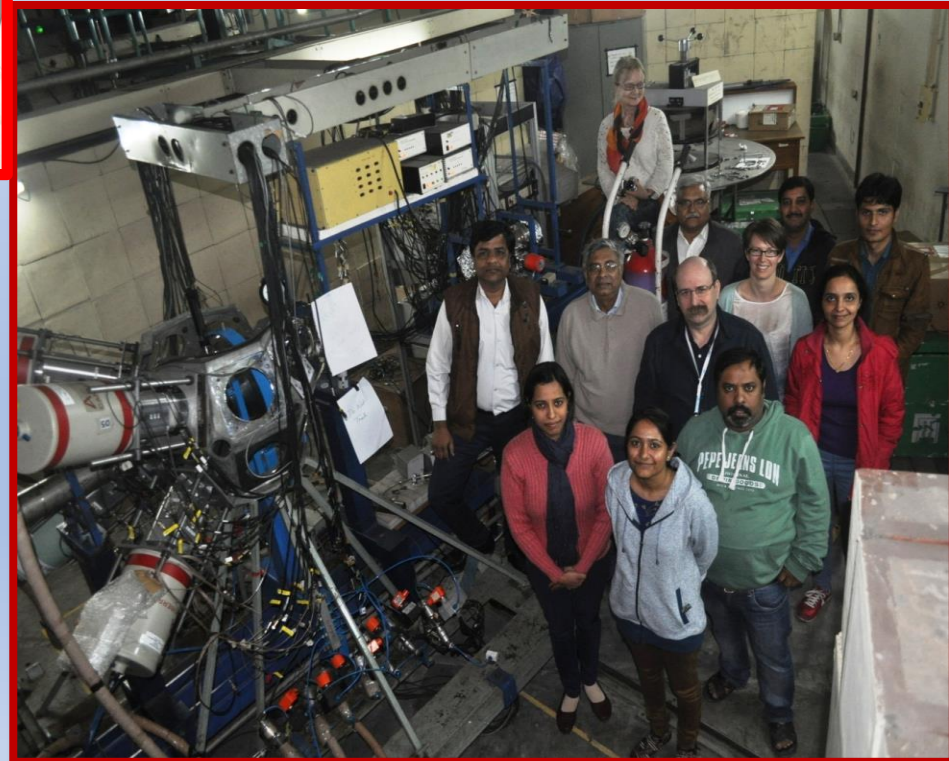
Te, Ba and Sc targets



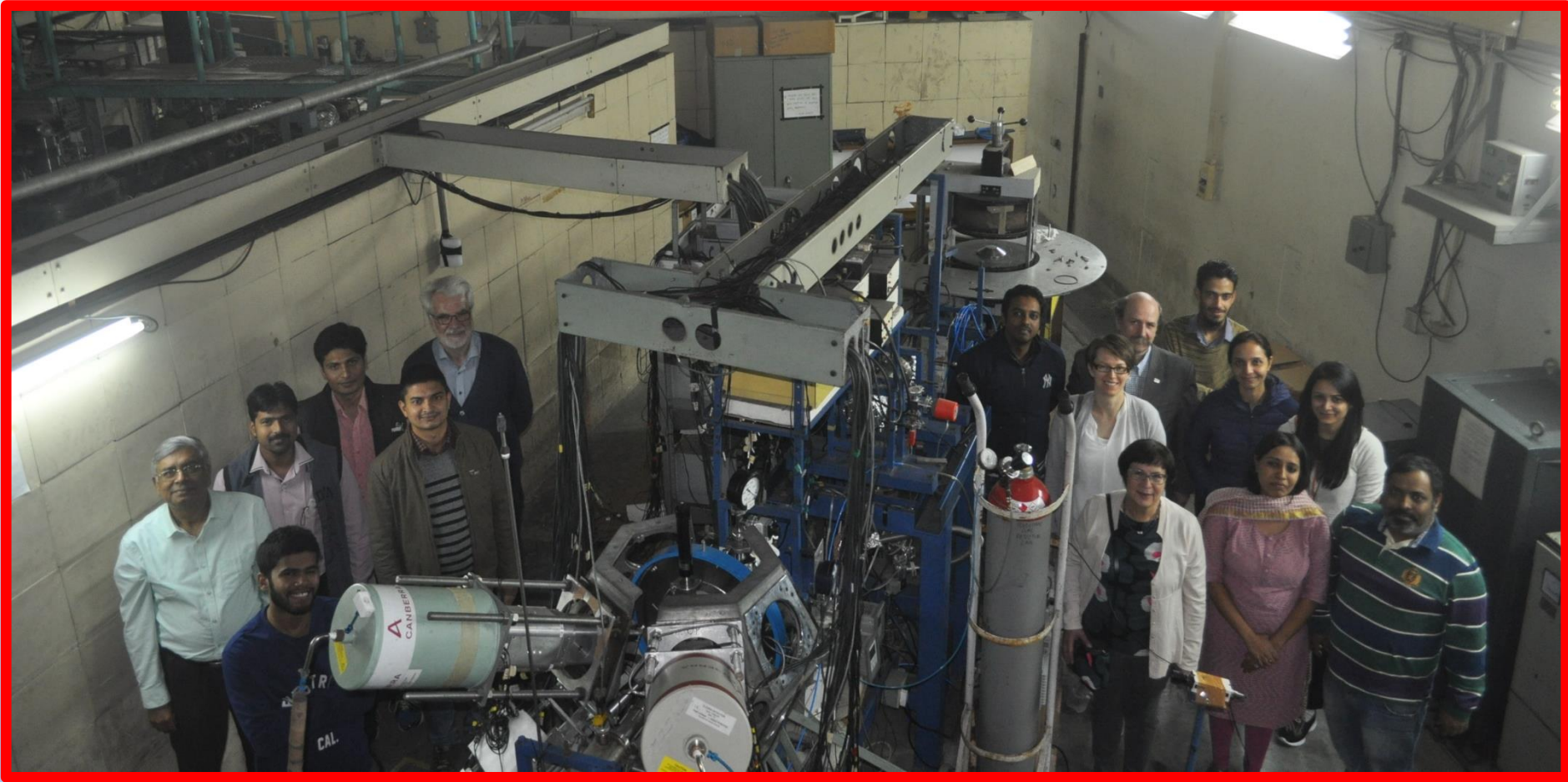
List of collaborators



Coulomb Excitation of ^{120}Te and ^{132}Ba at IUAC



Coulomb Excitation of ^{45}Sc at IUAC



From left: Dr. R.K. Bhowmik, Mr. C. Prakash, Mr. S. Kumar, Mr. S. Dutt, Mr. N.K. Rai, Prof. H-J. Wollersheim, Mr. M. Shuaib, Dr. M. Matejska-Minda, Dr. P.J. Napiorkowski, Prof. M. Kicińska-Habior, Mr. I. Ahmad, Dr. J. Kaur, Dr. M. Saxena, Ms. A. Sood, Dr. R. Kumar.

Prof. V. Nanal, Dr. R. Palit, Dr. A.K. Tyagi, Dr. A. Agarwal, Dr. T. Trivedi, Mr. D. Kumar.

*Thank you for your
kind attention*



Dziękuję

धन्यवाद

