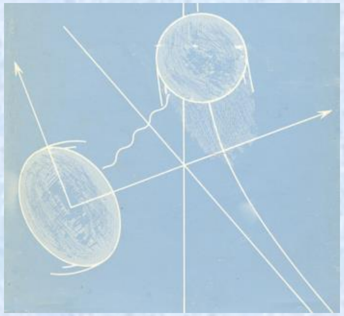
An Overview of Coulomb excitation activities at IUAC

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

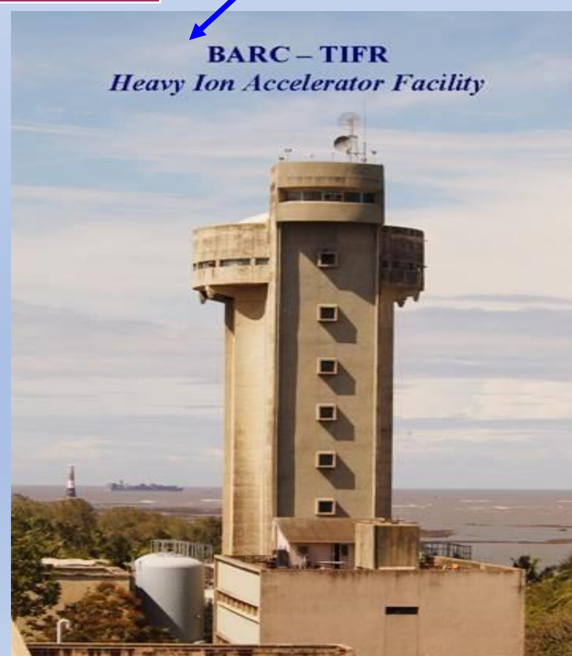


Rakesh Kumar

IUAC, New Delhi

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

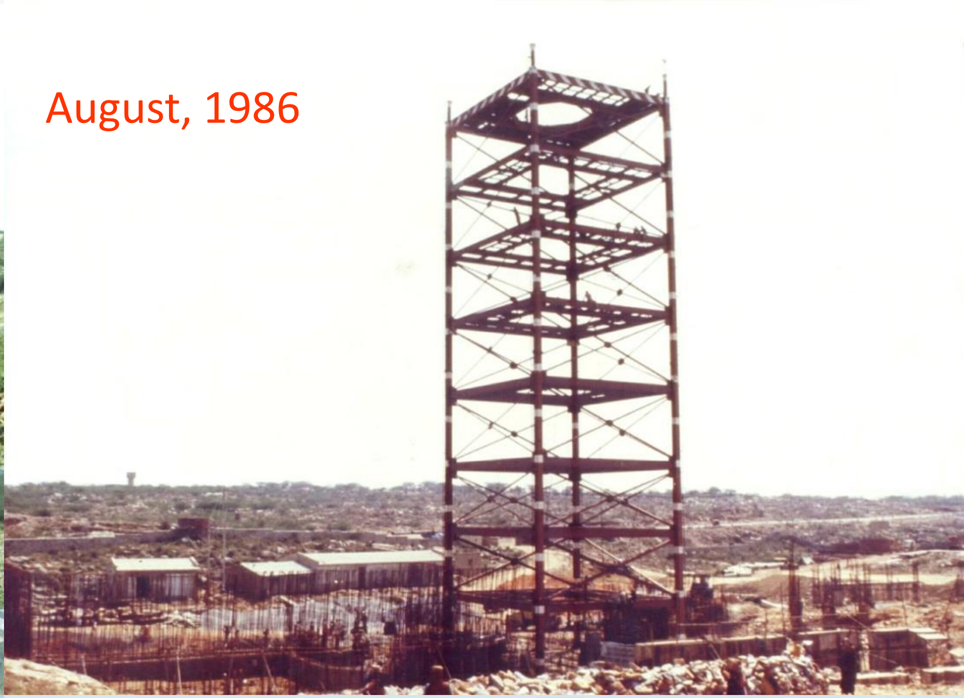
Inter University Accelerator Centre, New Delhi



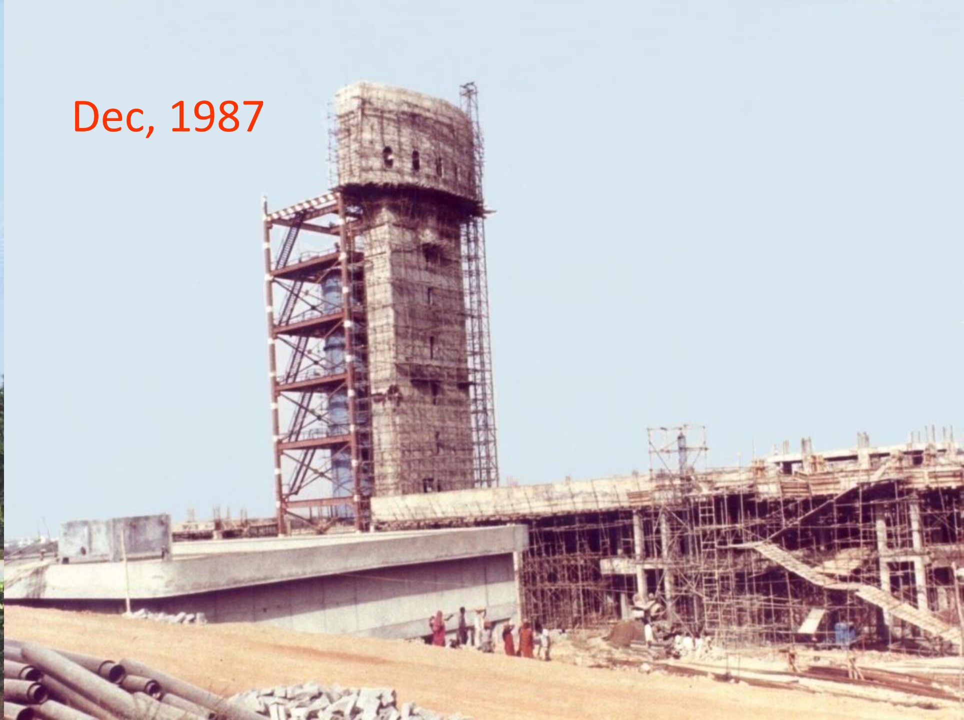
Variable Energy Cyclotron Centre

Kolkata

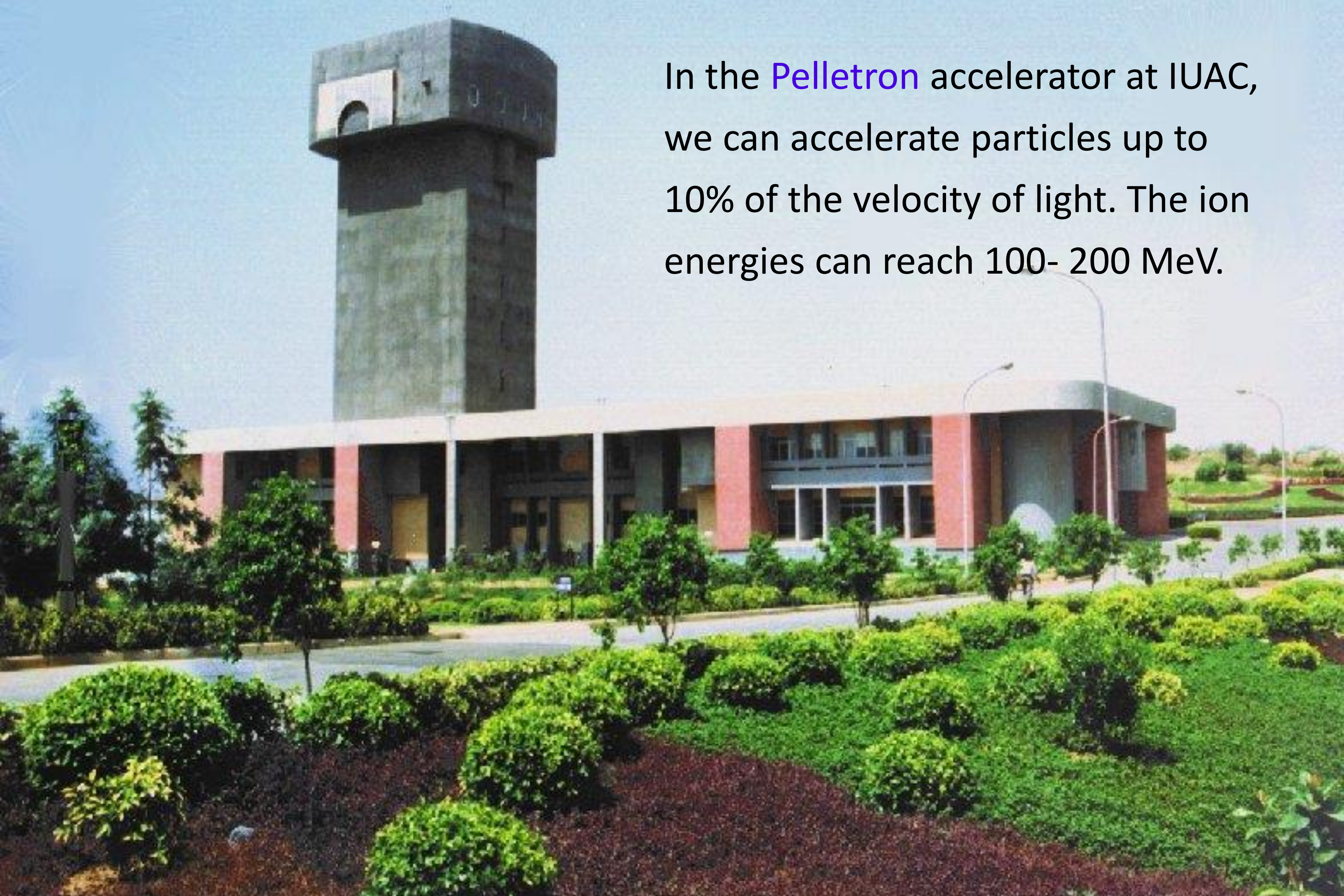

Before July, 1986


August, 1986


Nov, 1989

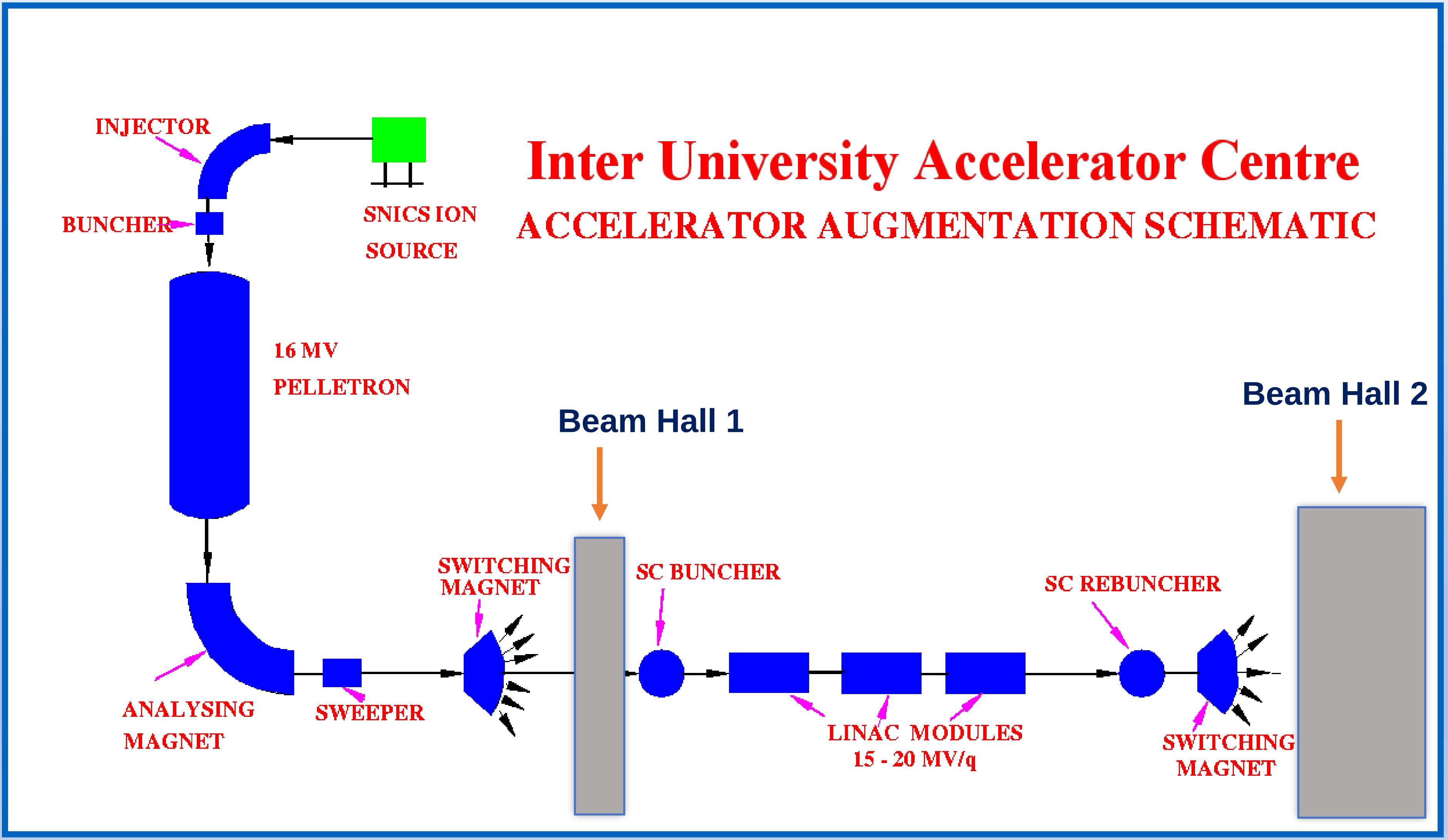

Dec, 1987

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



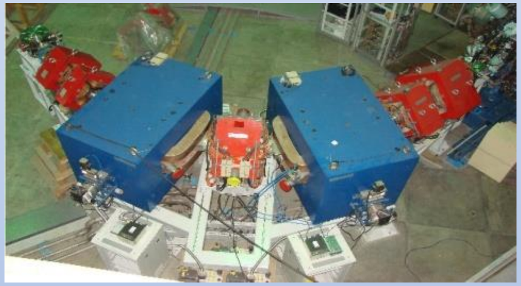
Major Nuclear Physics Facilities at IUAC

- **Gamma arrays**
  S. Muralithar (murali@iuac.res.in)

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

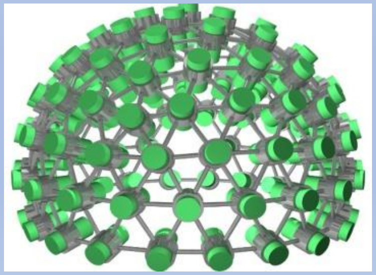

- **Recoil separators**
  N. Madhavan (madhavan@iuac.res.in)

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

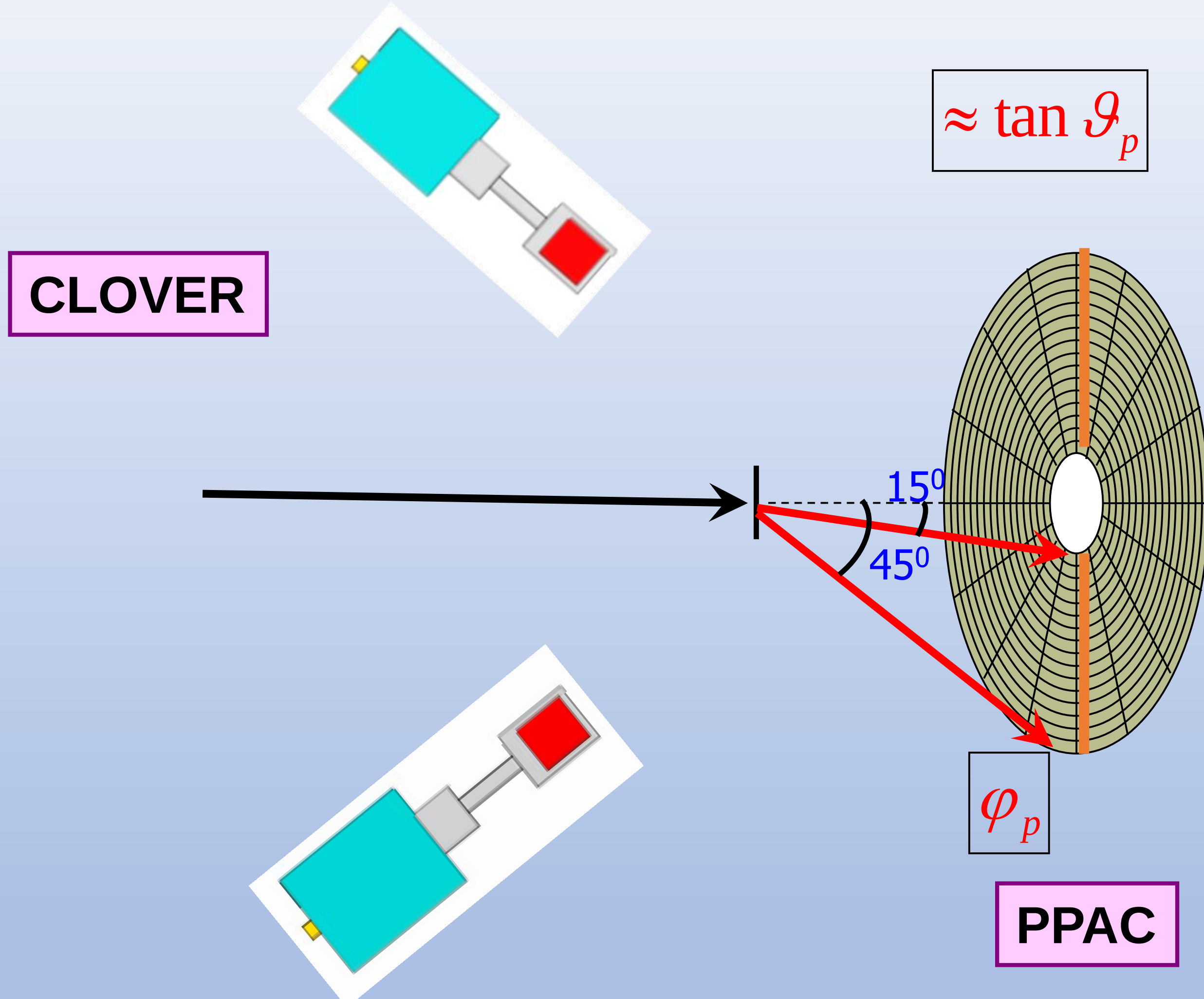
- **Scattering chamber / Neutron array**
  Dr. P. Sugathan (sugathan@iuac.res.in)

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

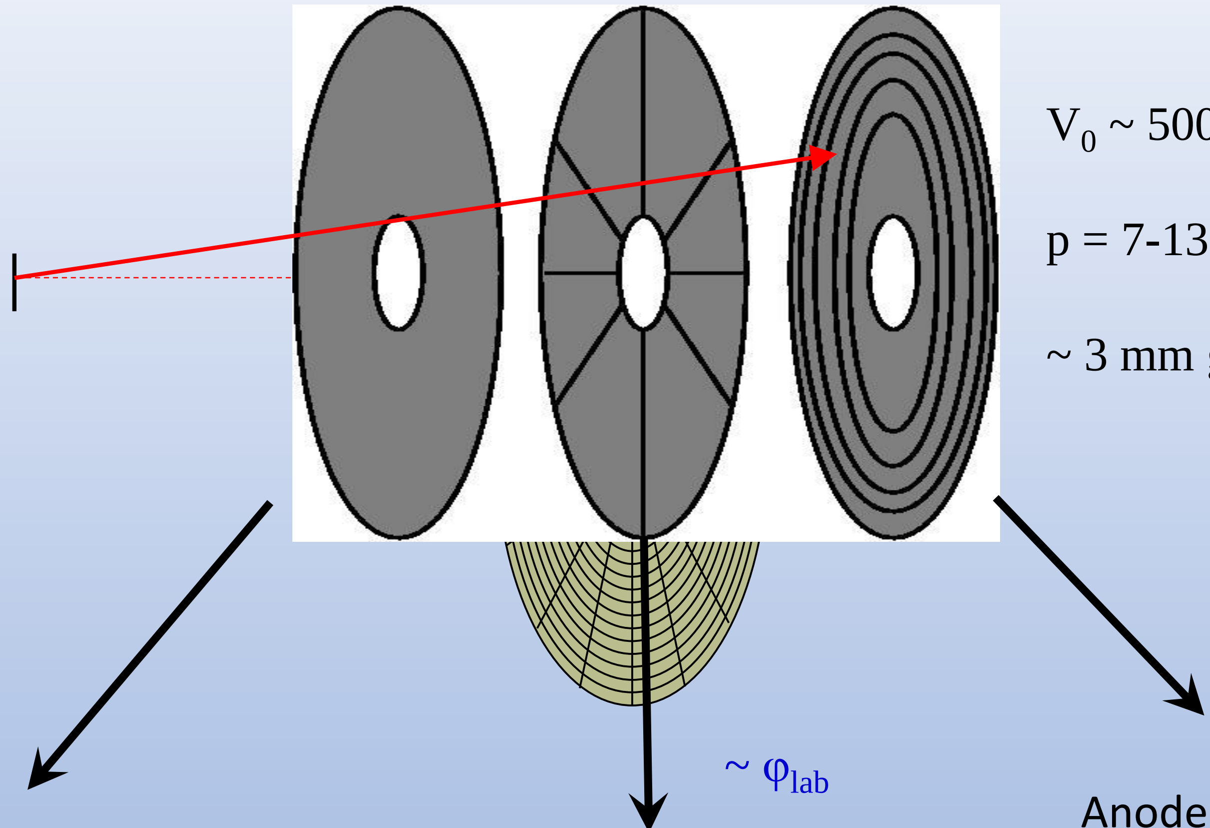



Coulomb excitation activities at IUAC

Present experimental set up at IUAC in GDA beam line



Proportional Counter



$V_0 \sim 500$ V

p = 7-13 mbar iso-butane gas

~ 3 mm gap cathode-anode

$\sim \varphi_{lab}$

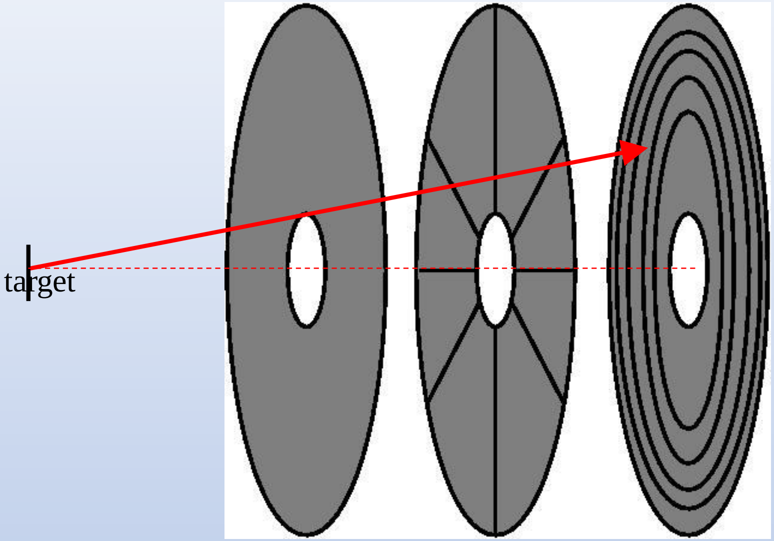
$\sim \vartheta_{lab}$

Detector is isolated from Vacuum through entrance window of 2um 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



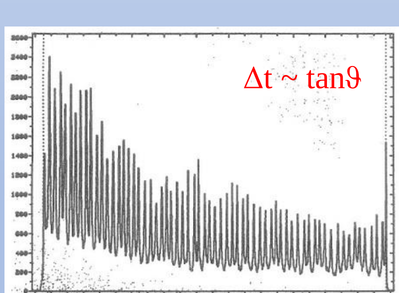
A. Jhingan et. al., DAE-BRNS Symp. on Nucl. Phys. 61 (2016) 966.

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

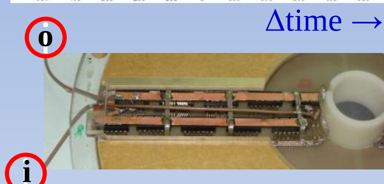
entrance window   ~ φ_{lab} ~ $\tan\vartheta_{lab}$

Front → ϕ-information

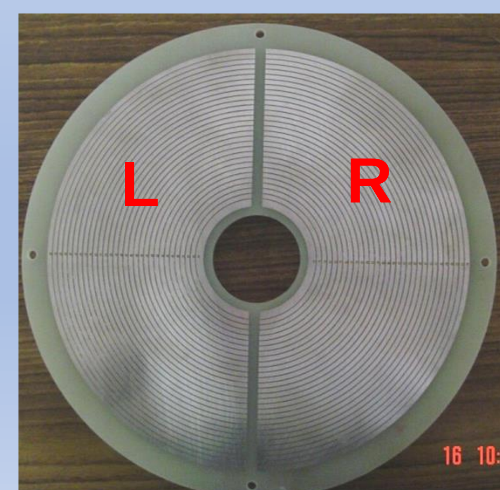
Back→ θ-information



Δtime →



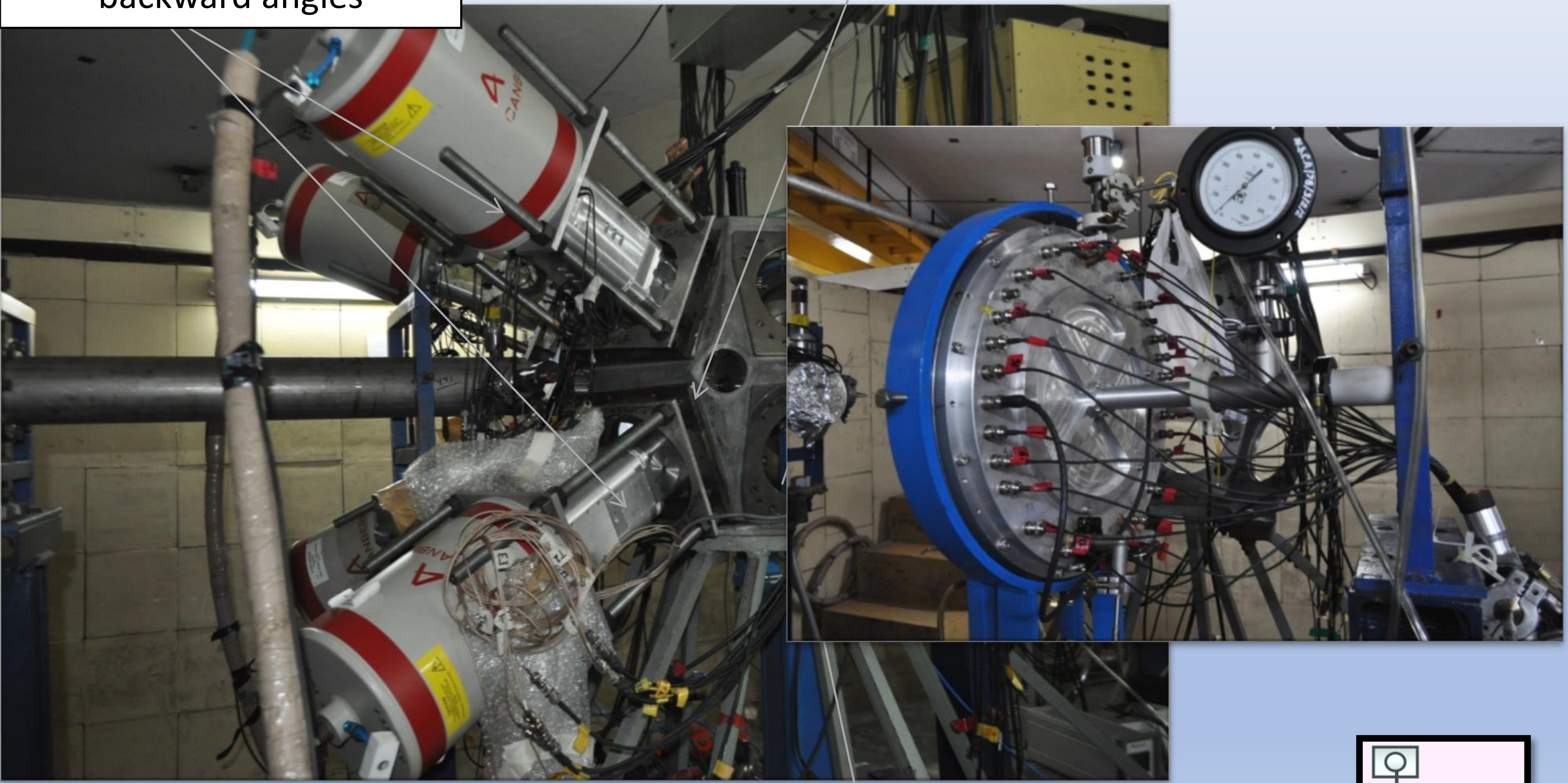
delay line



Experimental set up at IUAC

CLOVER DETECTORS
@
backward angles

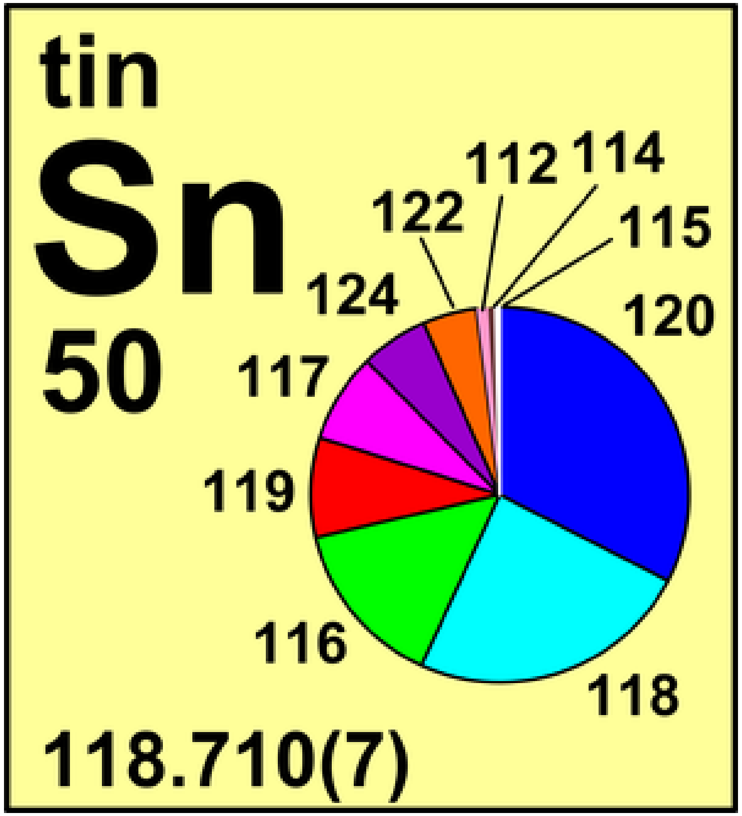
TARGET



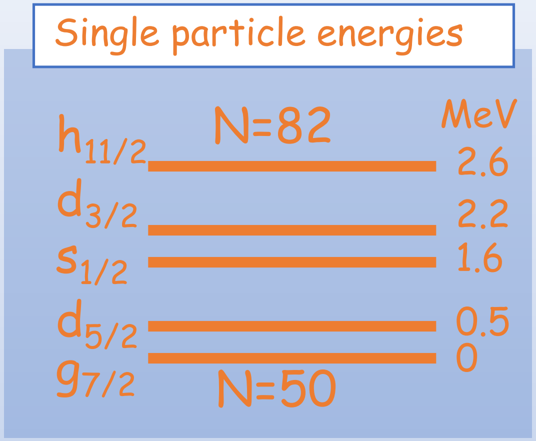
PPAC @ forward angle

Coulex Experiments
at
I.U.A.C

Brief Introduction to Sn Region



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



Z = 50

$g_{7/2}$ →

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

$d_{5/2}$ → $s_{1/2}$ → $d_{3/2}$ →

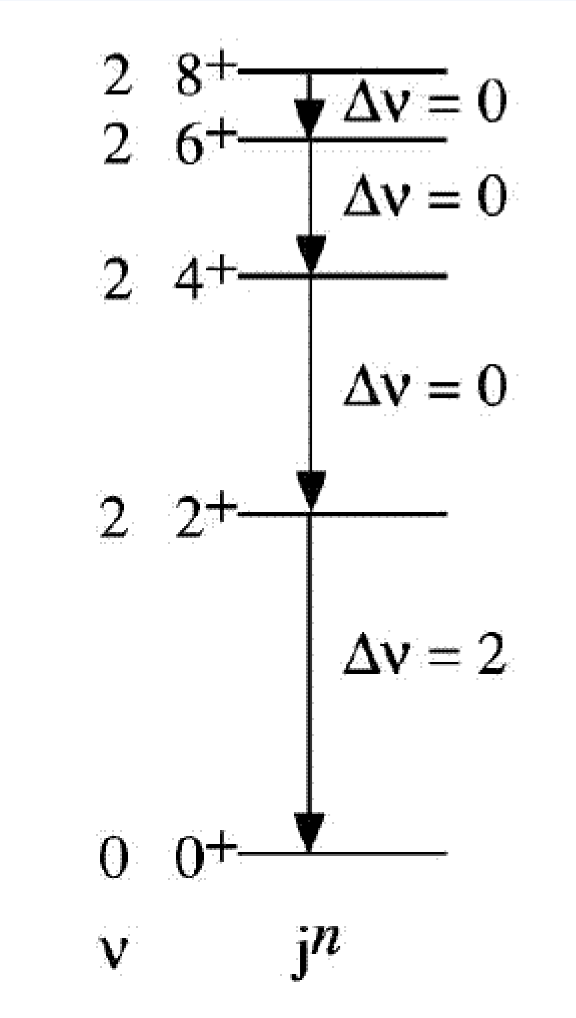
Sn112	Sn113	Sn114	Sn115	Sn116	Sn117	Sn118	Sn119	Sn120
	115.09 d							
0+	1/2+	0+	1/2+	0+	1/2+	0+	1/2+	0+
0.97	EC	0.65	0.34	14.53	7.68	24.23	8.59	32.59

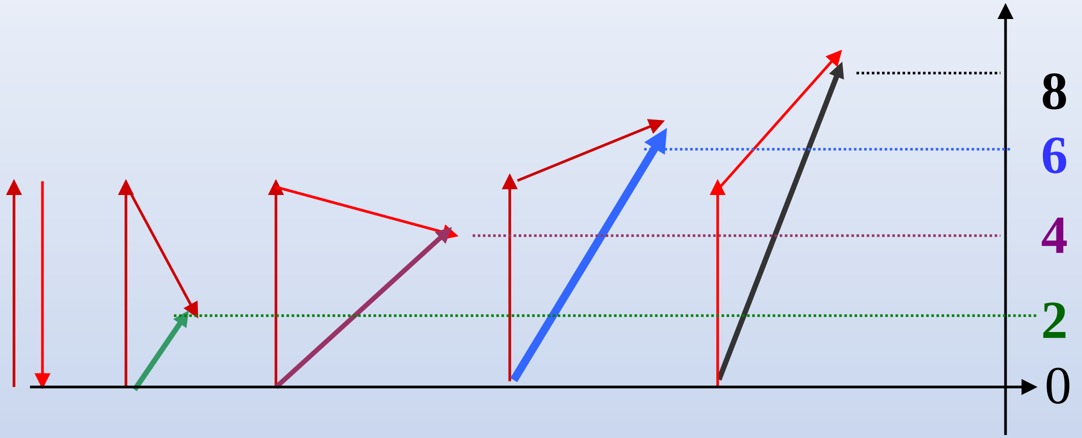
$h_{11/2}$ →

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

Naïve single particle filling

Seniority Scheme



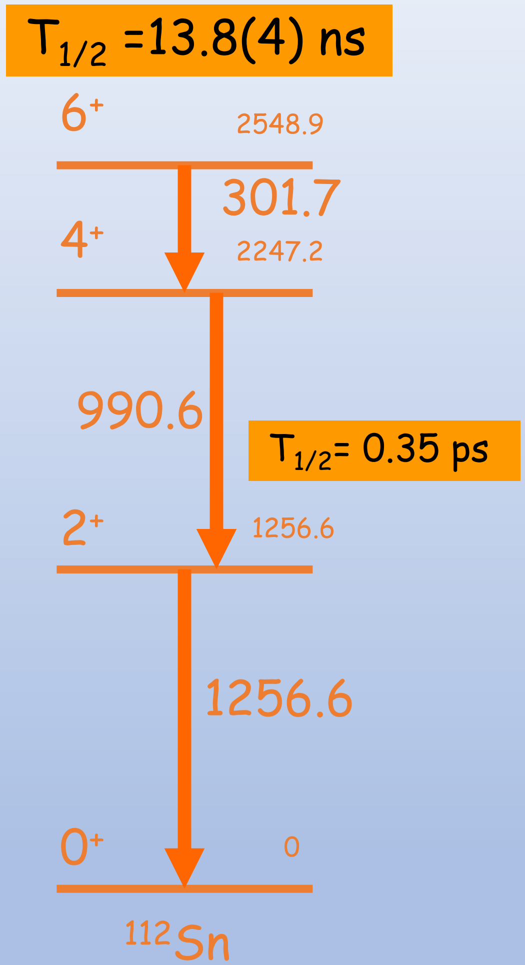


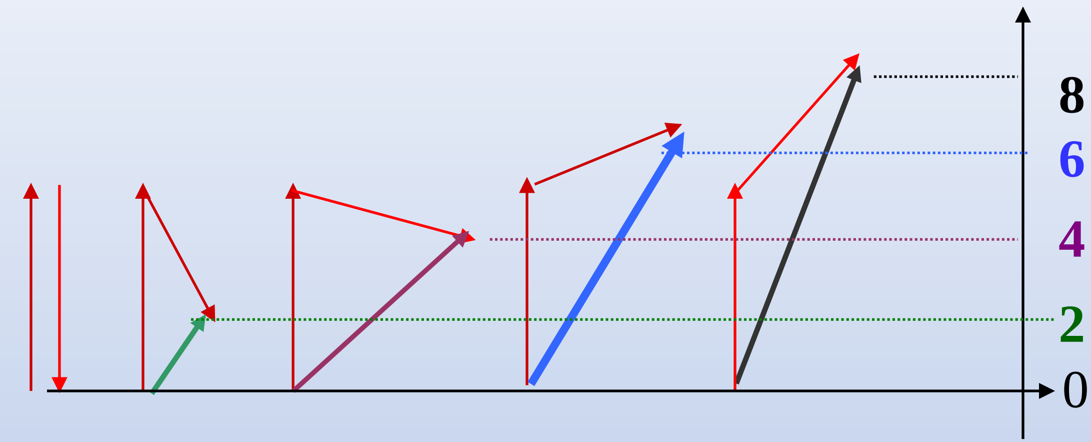
δ-interaction yields a simple geometrical expression for coupling of two particles

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

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

Generalized Seniority Scheme





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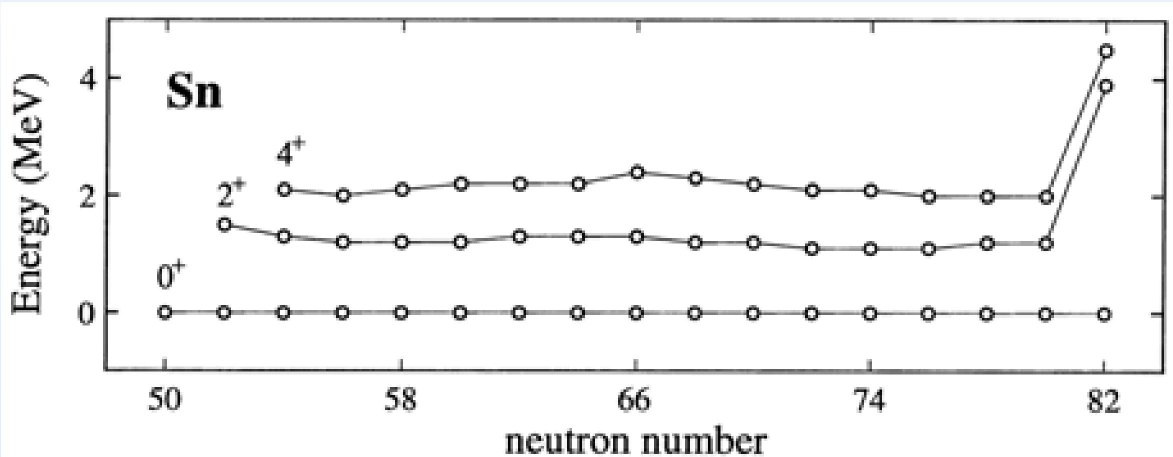
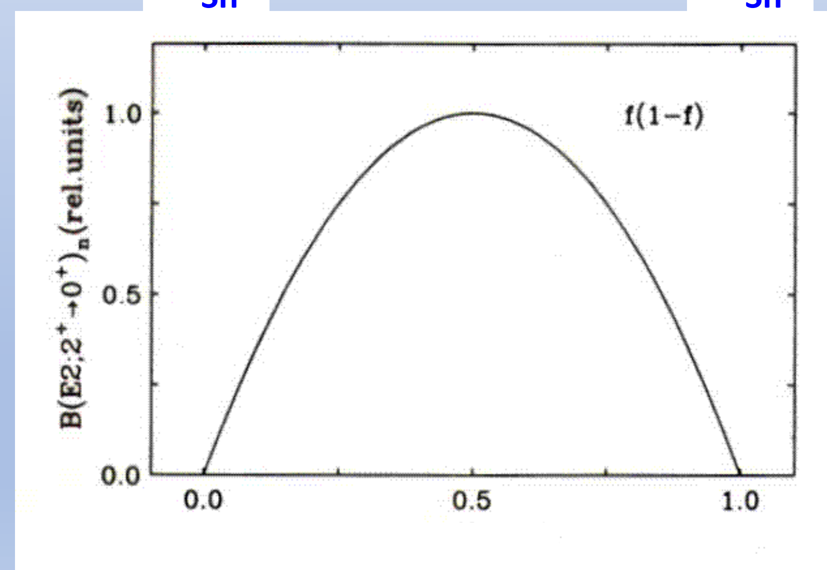
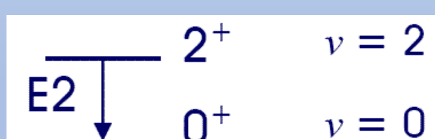


$B(E2; 2_1^+ \rightarrow 0_1^+) \approx f \cdot (1 - f)$

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

^{100}Sn ^{132}Sn

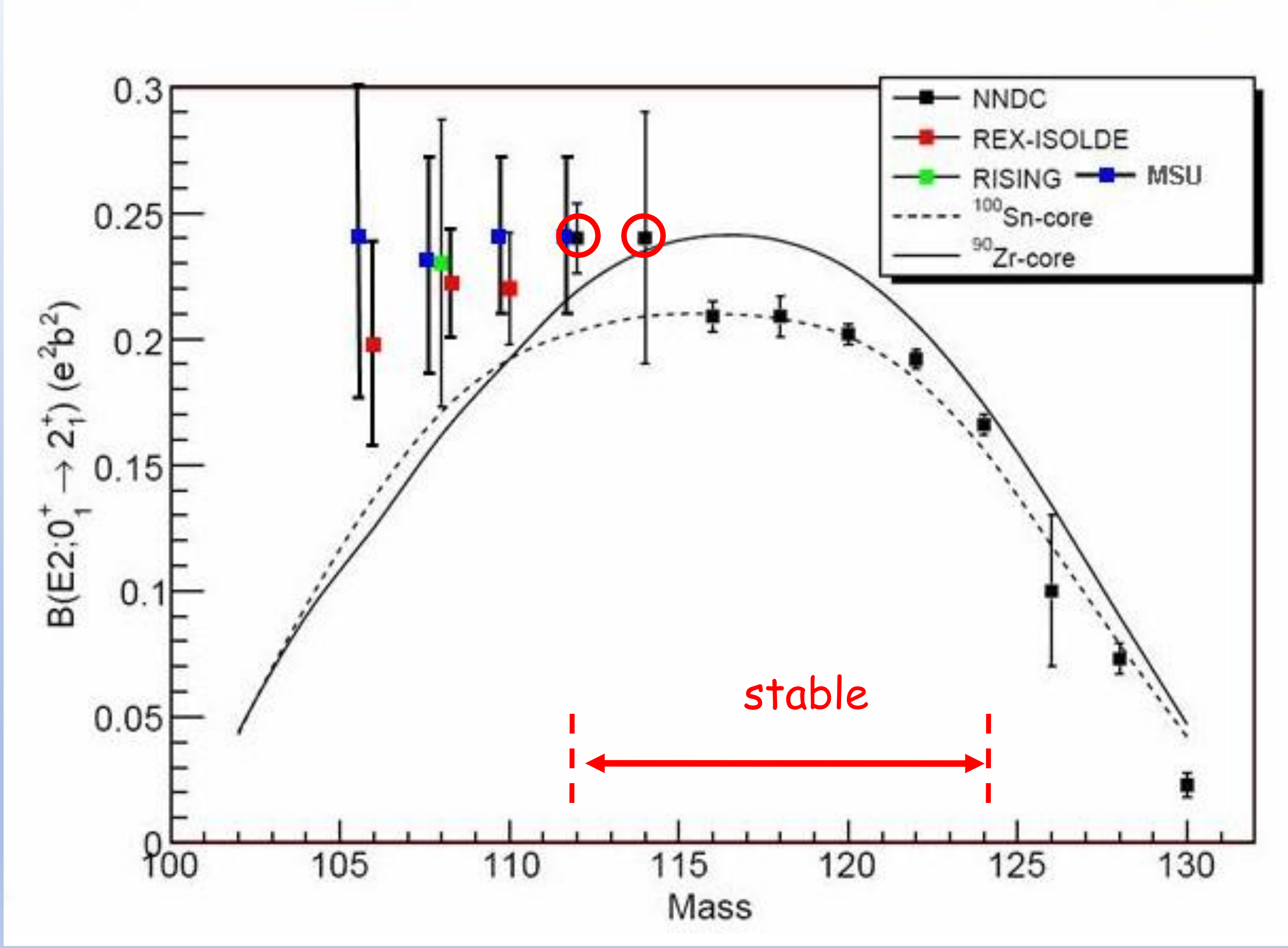




number of nucleons
between shell closures

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

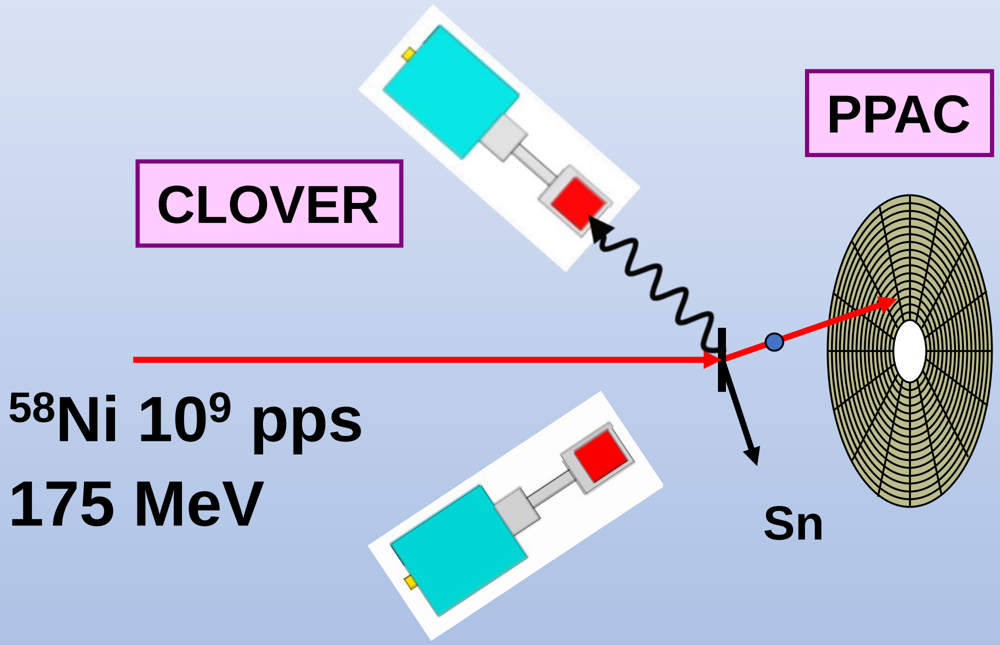
B (E2) values before our measurements



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

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

Experimental setup at IUAC



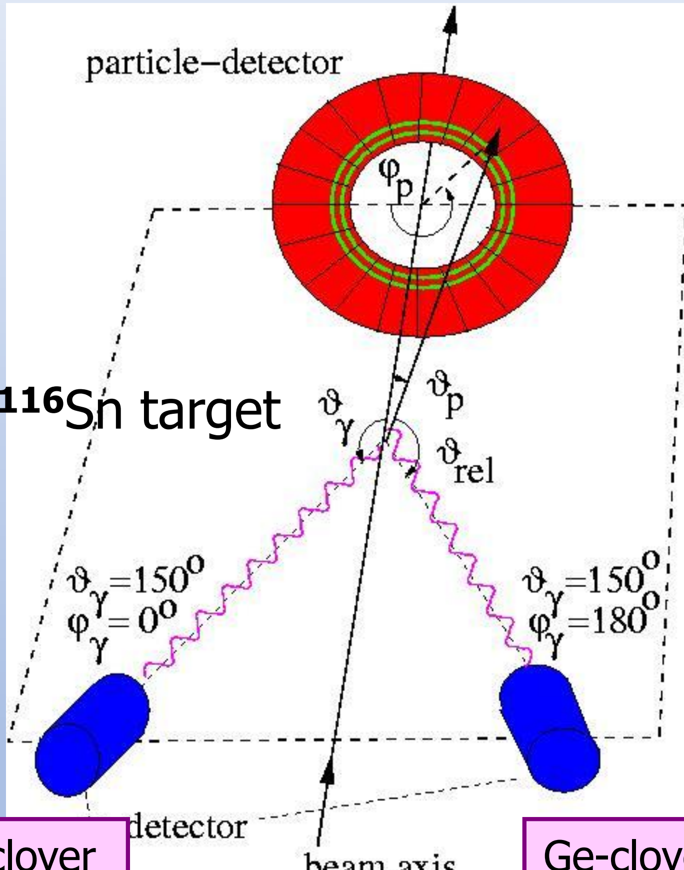
$^{58}Ni \rightarrow ^{112,116}Sn$ at 175MeV

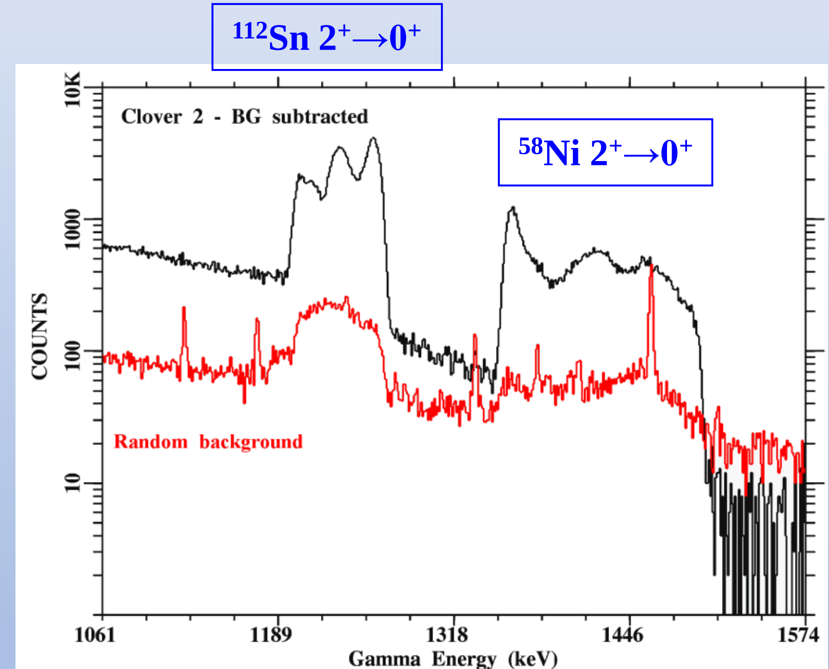
E_x=1257, 1294keV
B(E2)↑=0.24(2), 0.209(5)e^2b^2

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

E_x=1300, 1294keV
B(E2)↑=0.25(5), 0.209(5)e^2b^2

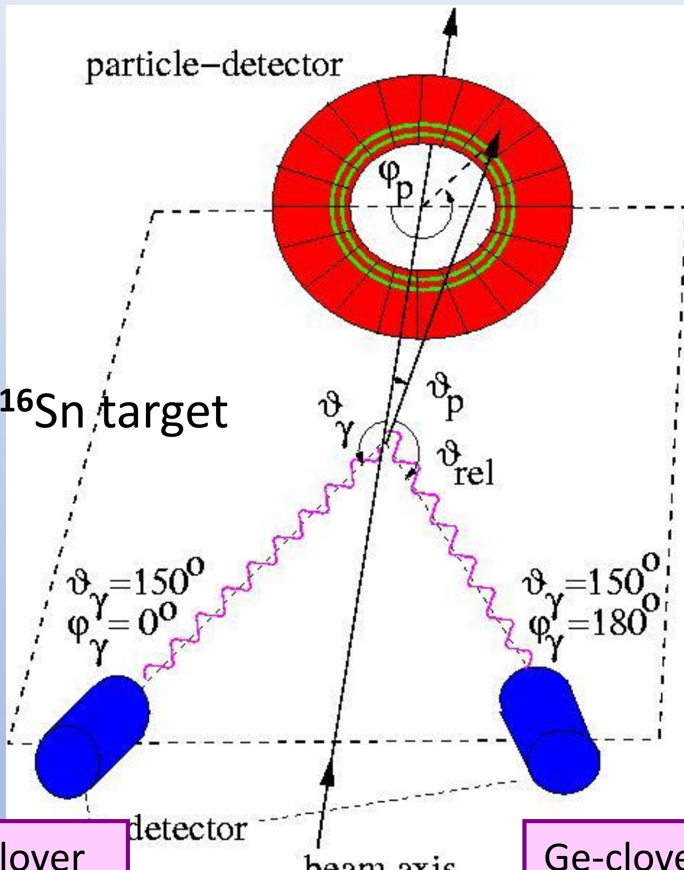
Coulomb Excitation of ^{112,114,116}Sn





Coulomb Excitation of ^{112,114,116}Sn

Doppler shift correction for Ni in PPAC

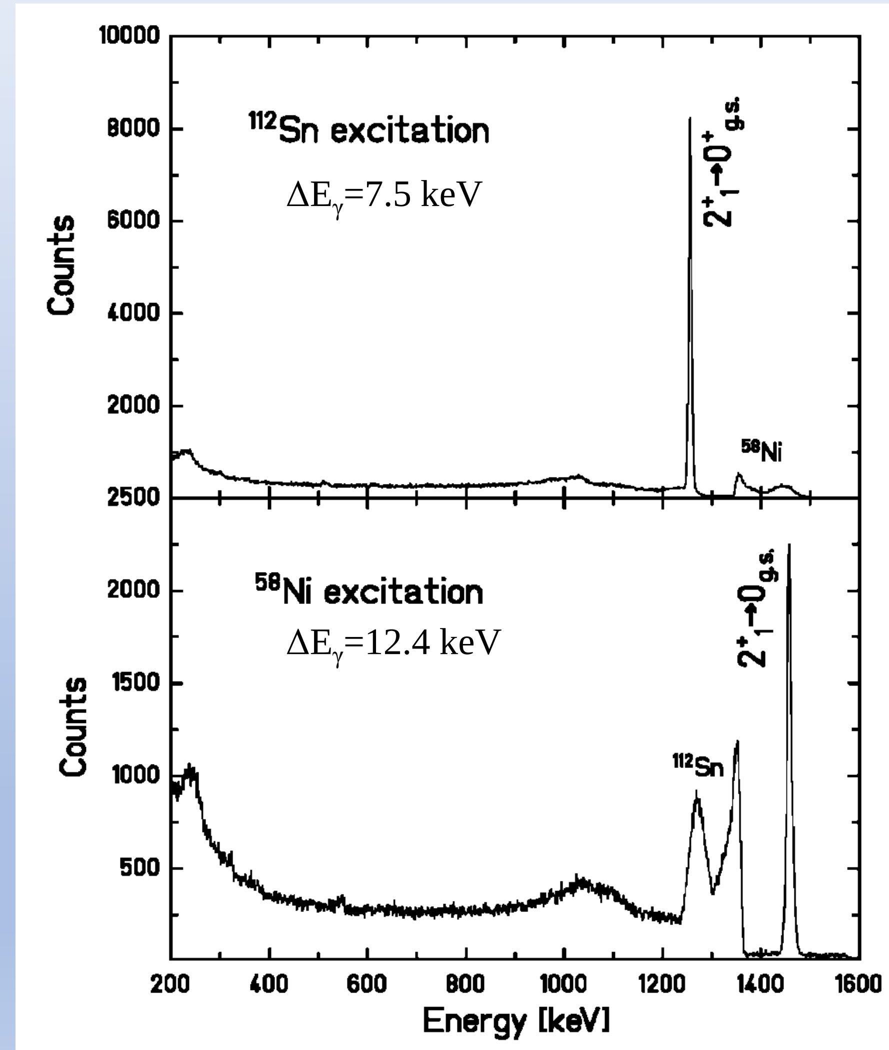


^{112,116}Sn target

Ge-clover

Ge-clover

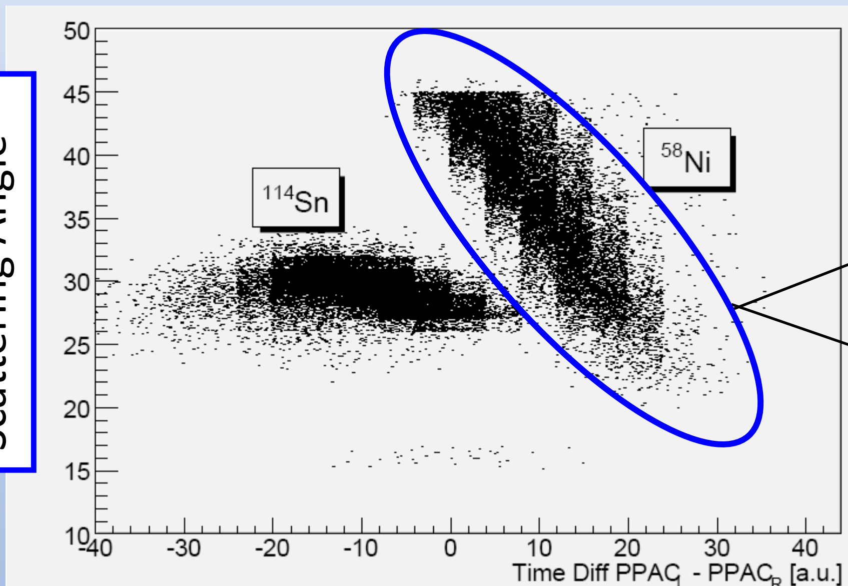
^{58}Ni beam



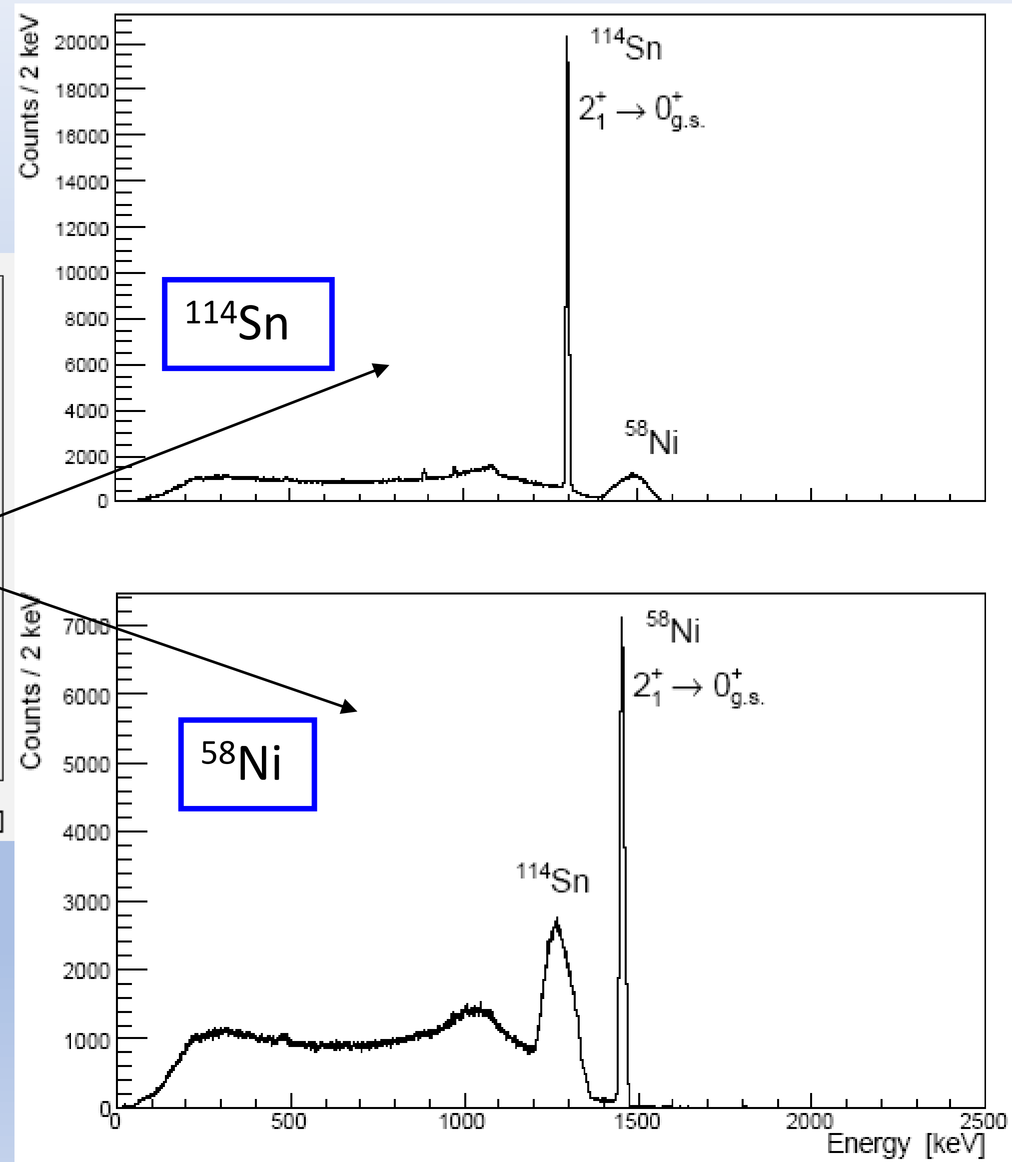
Particle Identification and Doppler correction at GSI

particle identification with PPAC
2 particles + γ-ray required

Scattering Angle



Time ($PPAC_L$-$PPAC_R$)



^{114}Sn

^{58}Ni

B(E2) value determination

- Literature value for ^{116}Sn B(E2↑) = 0.209(6) e^2b^2
- Literature value for ^{58}Ni B(E2↑) = 0.0493(7) e^2b^2

- Two possibilities to determine B(E2) of ^{112}Sn:

Relative to ^{58}Ni:

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

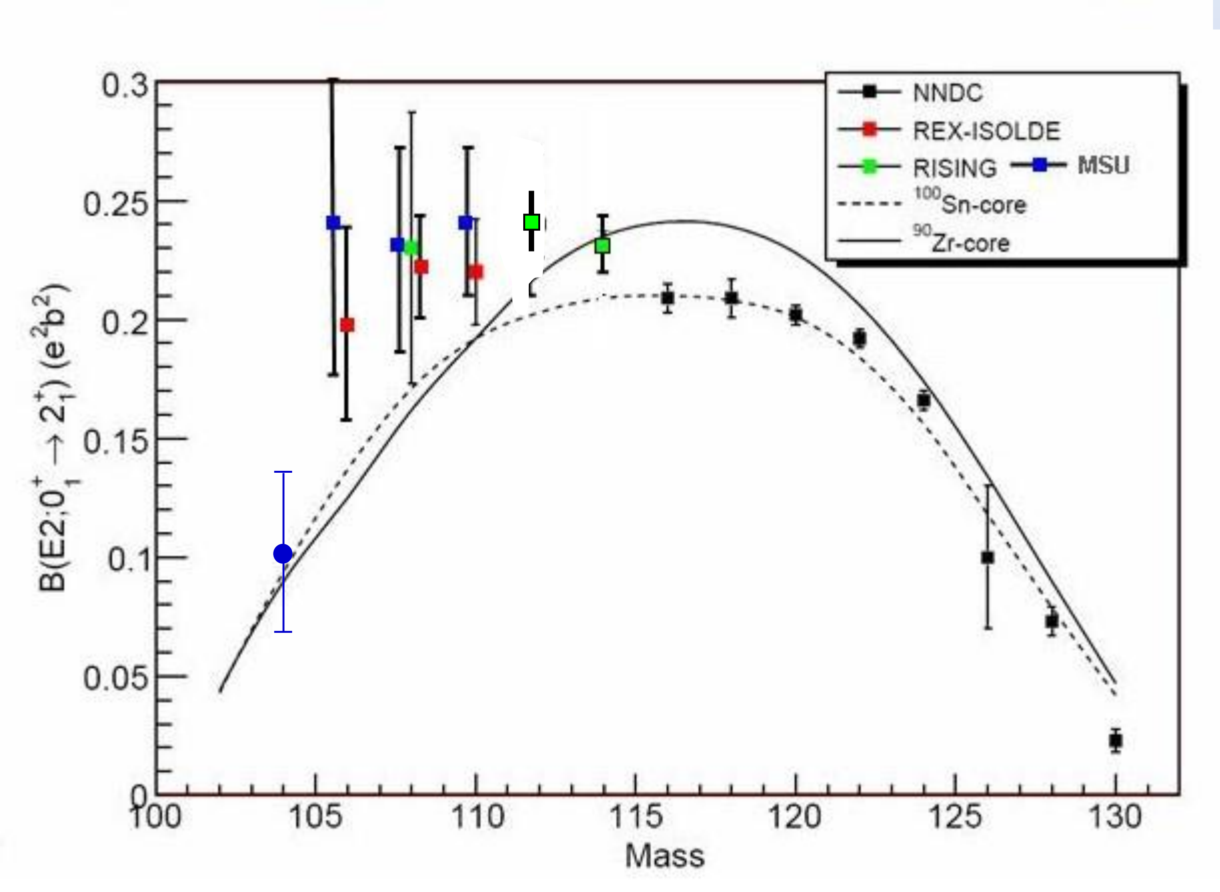
Relative to ^{116}Sn:

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

PHYSICAL REVIEW C **78**, 031303(R) (2008) **RAPID COMMUNICATIONS**

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. Singh[7]

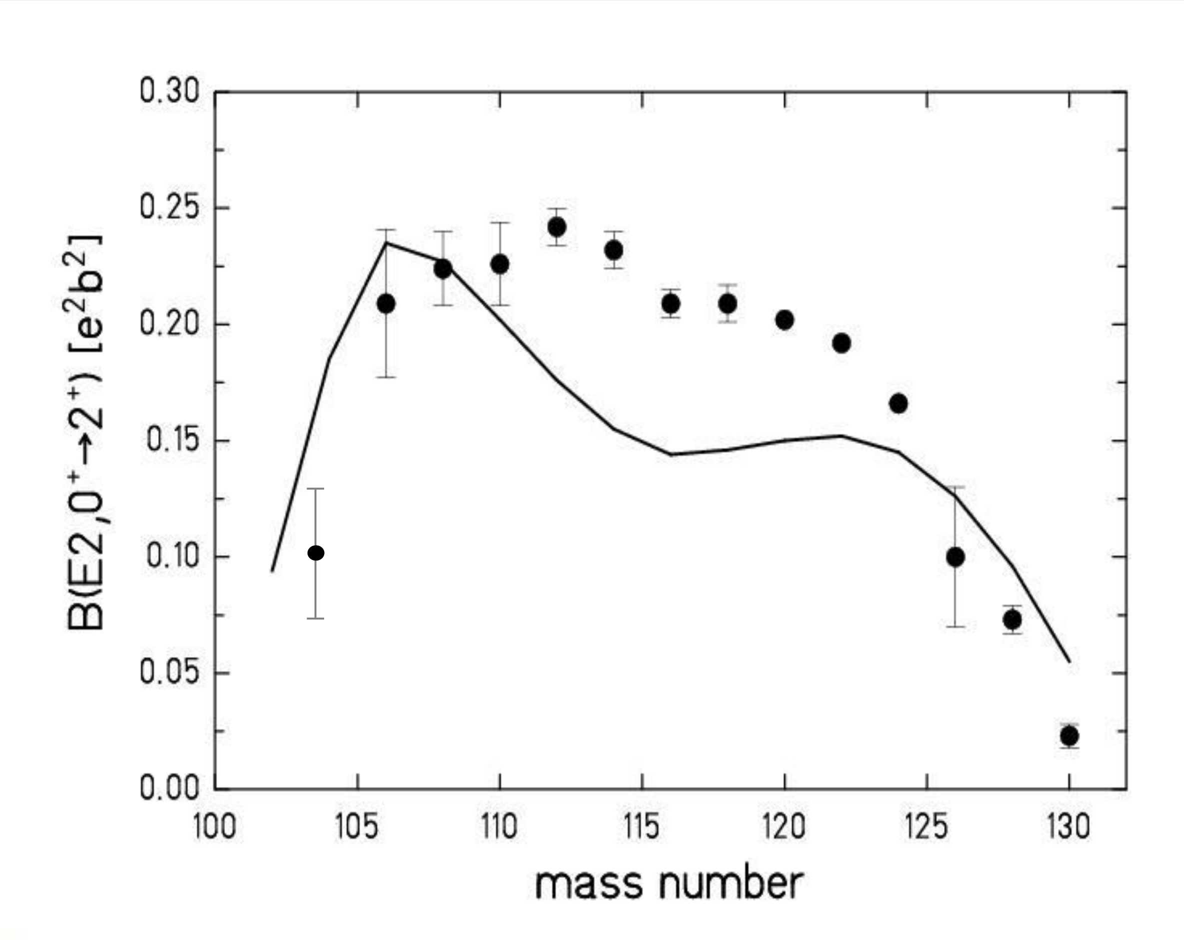


For ^{112}Sn we determined $B(E2;0^+ \rightarrow 2^+)=0.242(8)\ e^2b^2$

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

Comparison with RQRPA

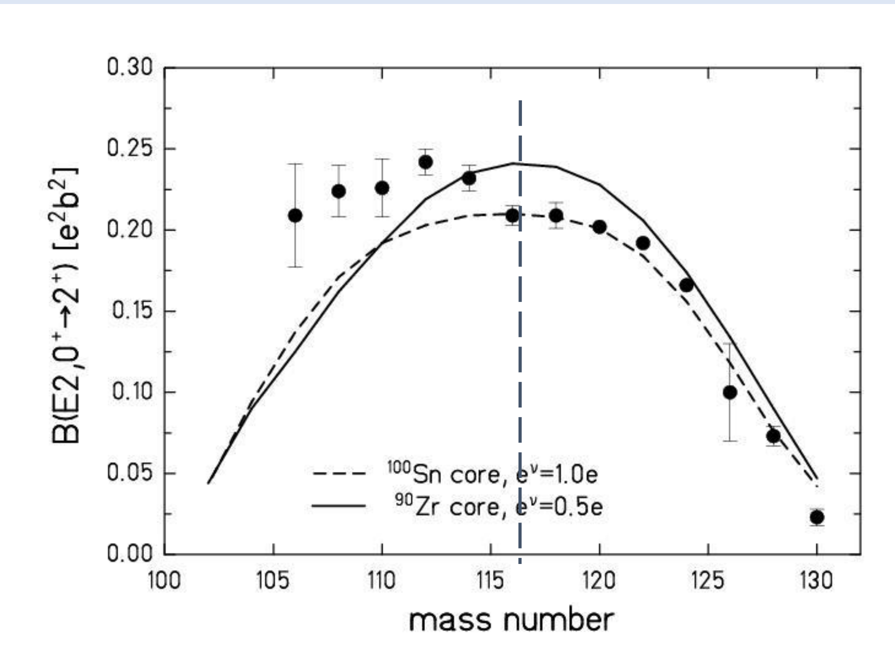
relativistic quasiparticle random-phase approximation calculation

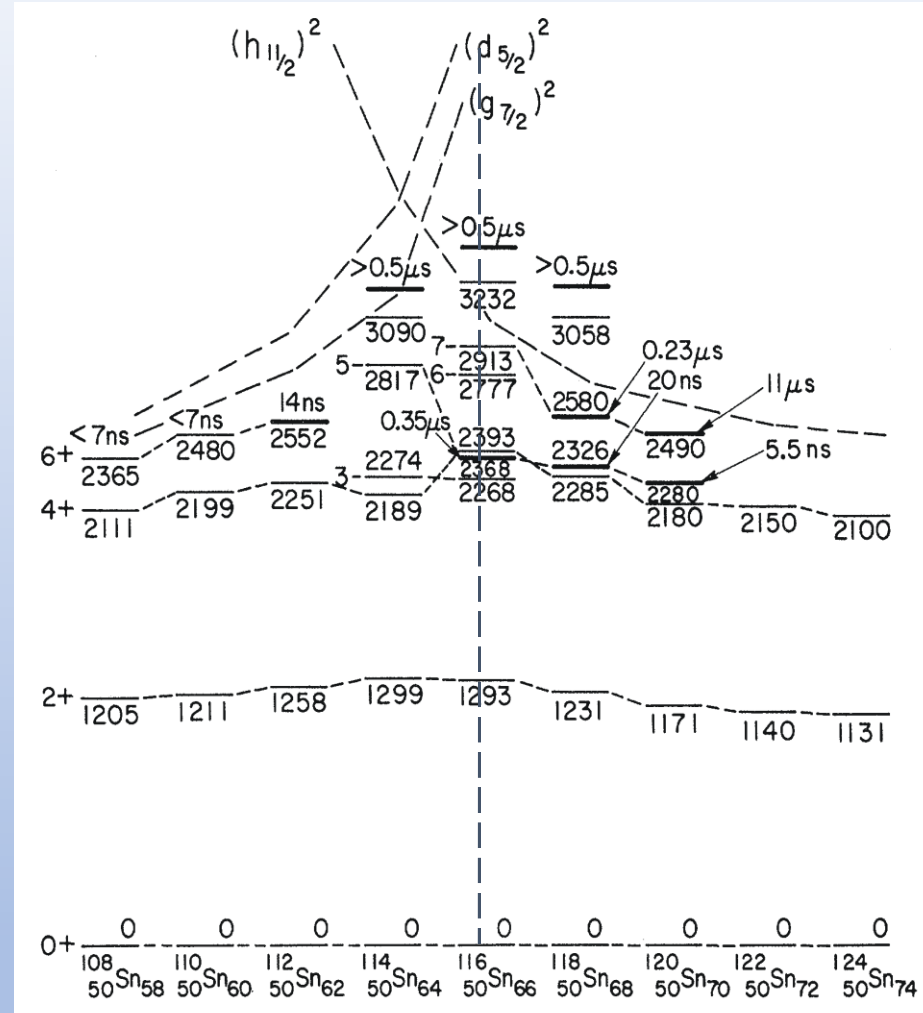


- no effective charges
- no core required
- satisfactory agreement also for the Ni and Pb isotopes

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

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





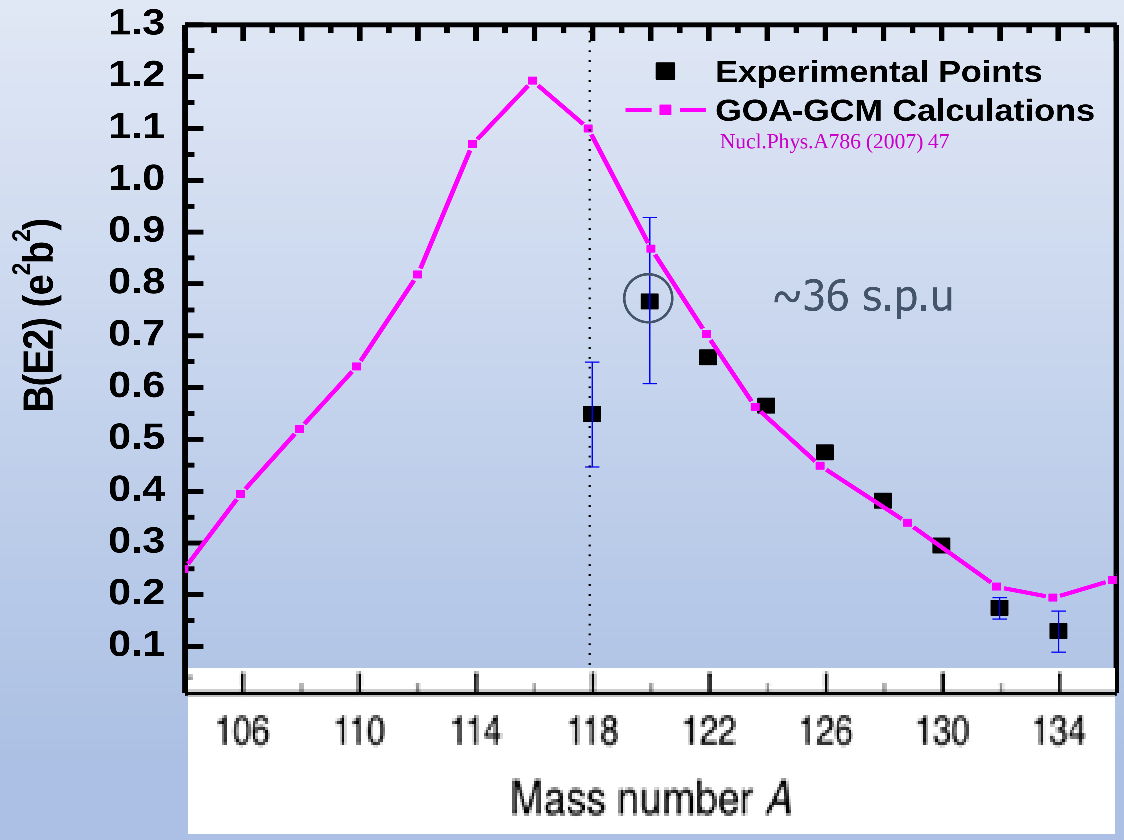
Coulomb Excitation of ^{120,122,124}Te isotopes

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

Mansi Saxena

HIL, Warsaw

Collectivity of the Te isotopes (Z=52)

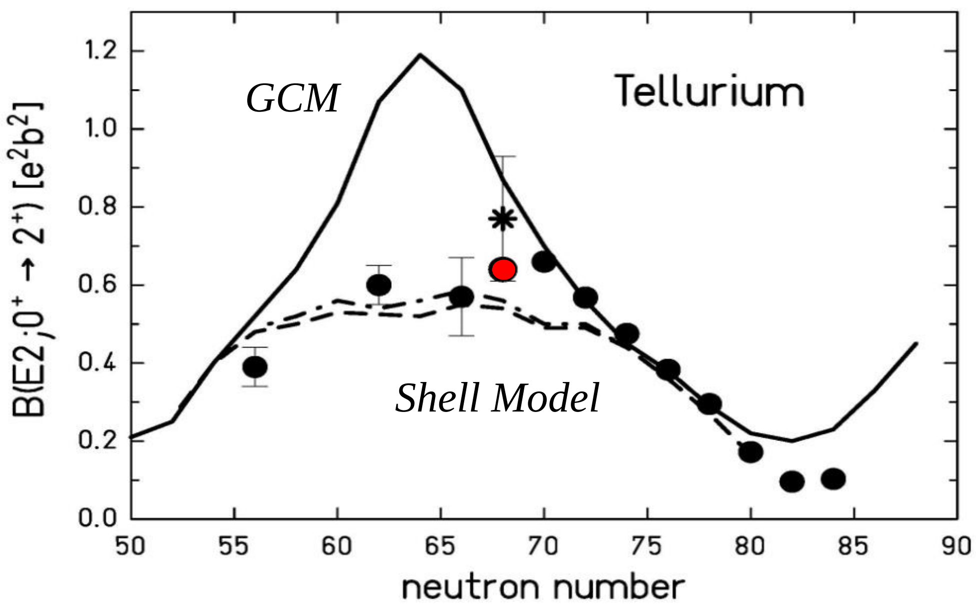


Remeasurement of B(E2) value in ^{120}Te using the double ratio method (^{122}Te is the reference nucleus)

PHYSICAL REVIEW C 90, 024316 (2014)

Rotational behavior of ^{120,122,124}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. Wollersheim[9]



Comparison with LSSM and GCM

B(E2)↑=0.666(20)

Effective charge used were $e_v = 0.8e$, $e_\pi = 1.5e$

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

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

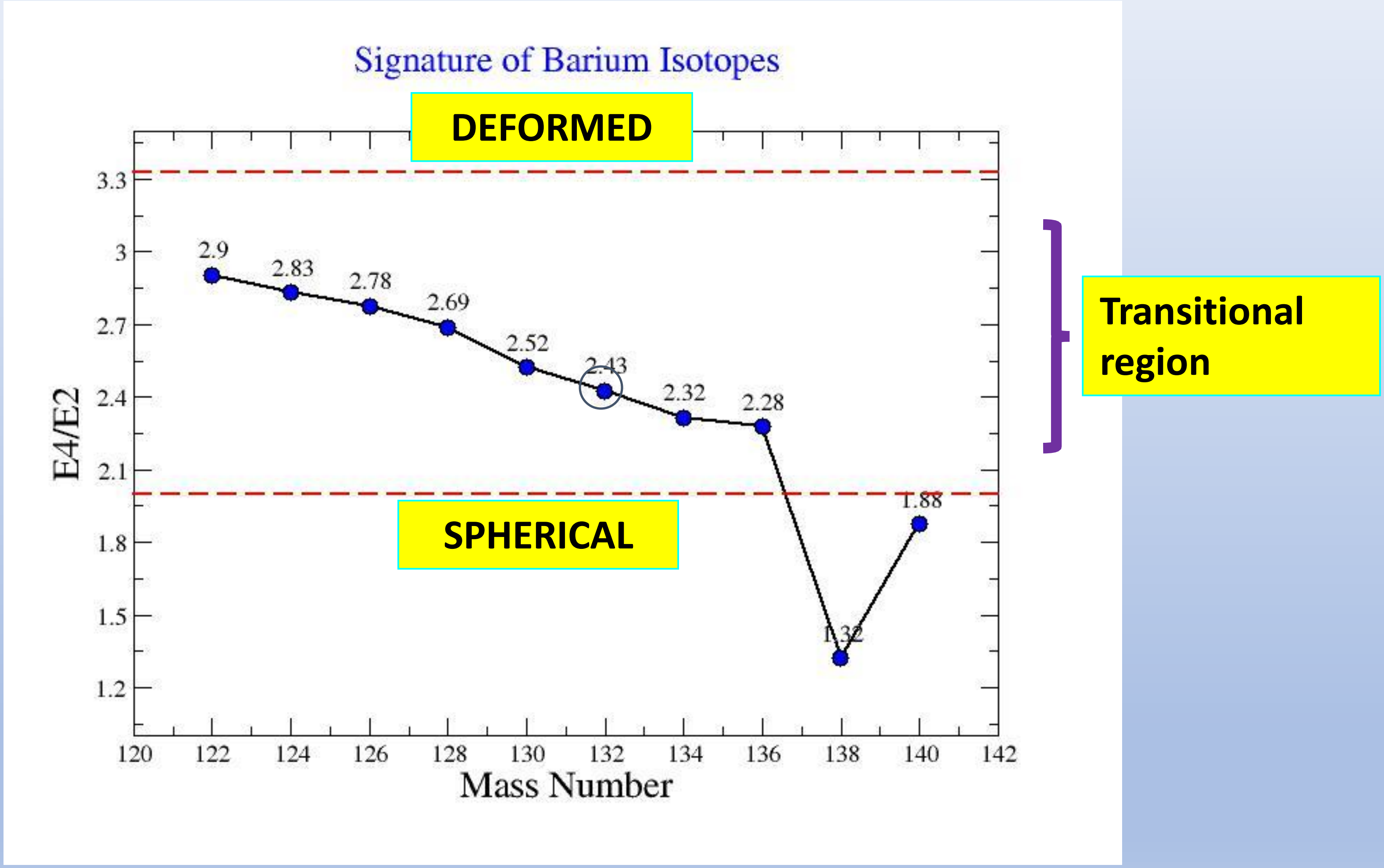
Guide:
Prof. I. A. Rizvi
A.M.U, India

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

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

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

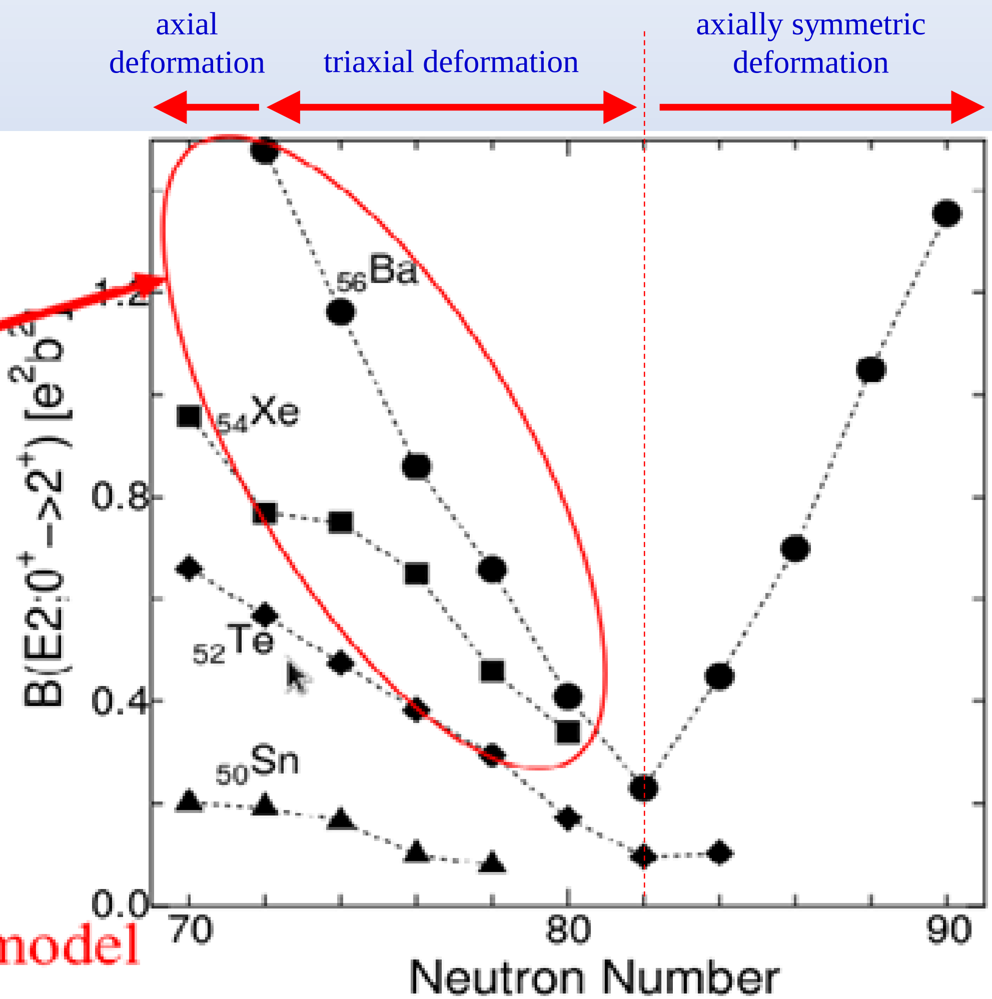
$^{132}_{56}Ba_{76}$

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

N = 82

B(E2) transition probabilities
of quadrupole collective states

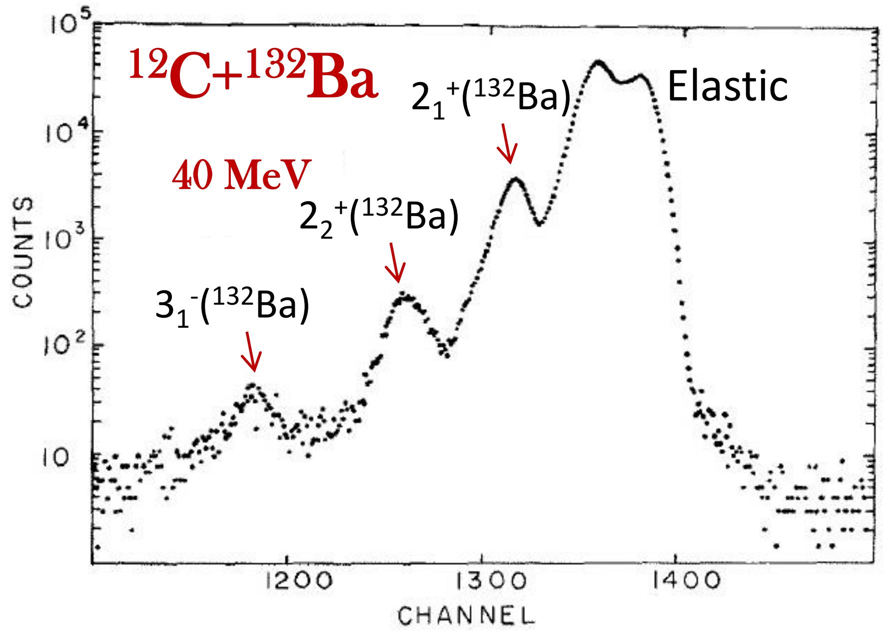
Transitional region between spherical vibrator and triaxially deformed rotor.



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



Position spectrum of $^{12}C^{6+}$ ions scattered from ^{132}Ba before subtraction of counts due to isotopic impurities.

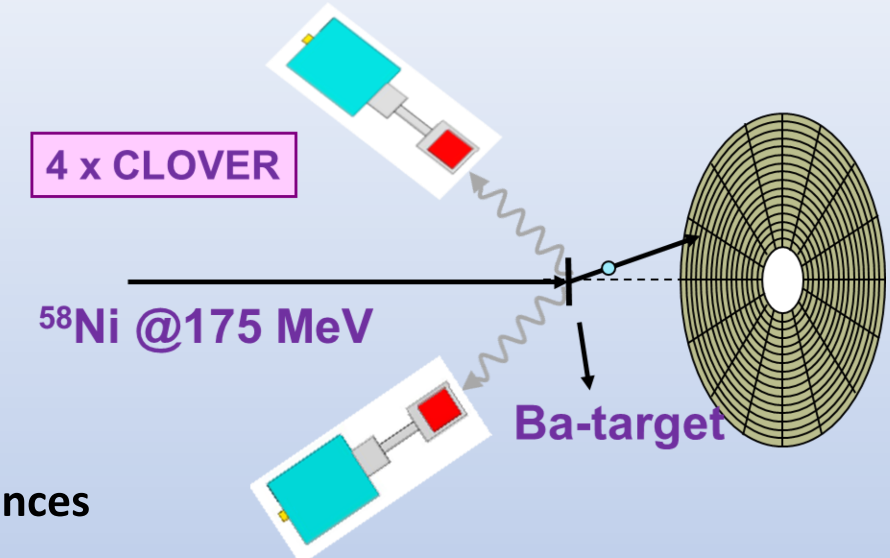
S.M.Burnett et al., Nucl. Phys. A 432(1985)514

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

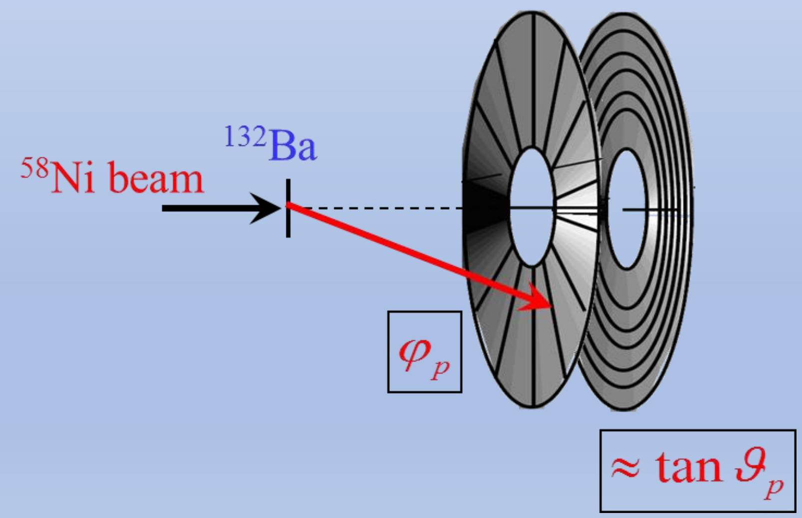
Enriched ^{132}Ba target ~ 550μg/cm^2
thickness on ~ 30 μg/cm^2 thick
Carbon backing



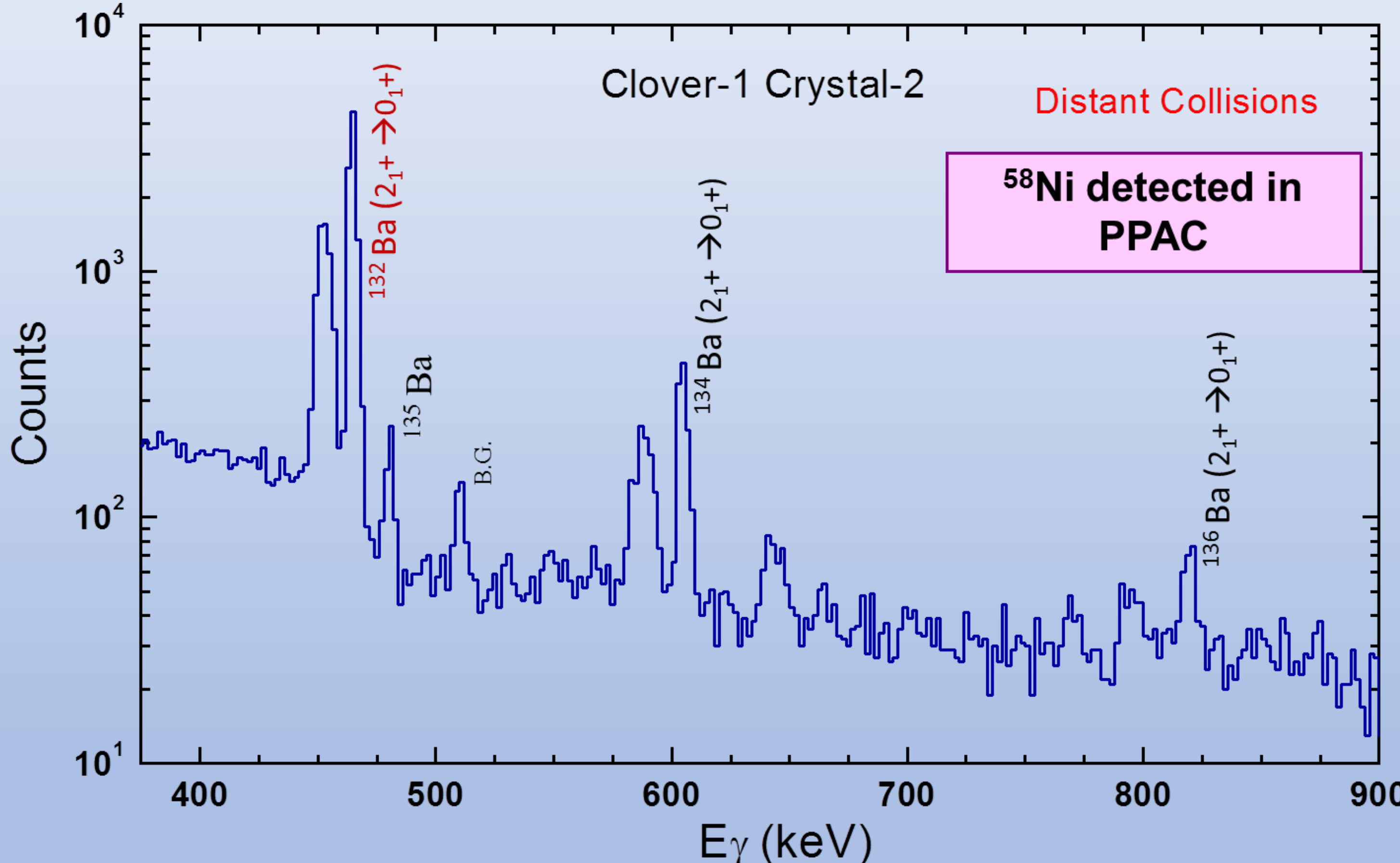
TRIGGER : Particle-Gamma Coincidences and Scale Down Particles

Doppler-Shift correction :

$$\frac{E_{\gamma 0}}{E_{\gamma}} = \frac{1-\upsilon_2 * \cos\theta_{\gamma 2}}{\sqrt{1-\upsilon_2^2}}$$

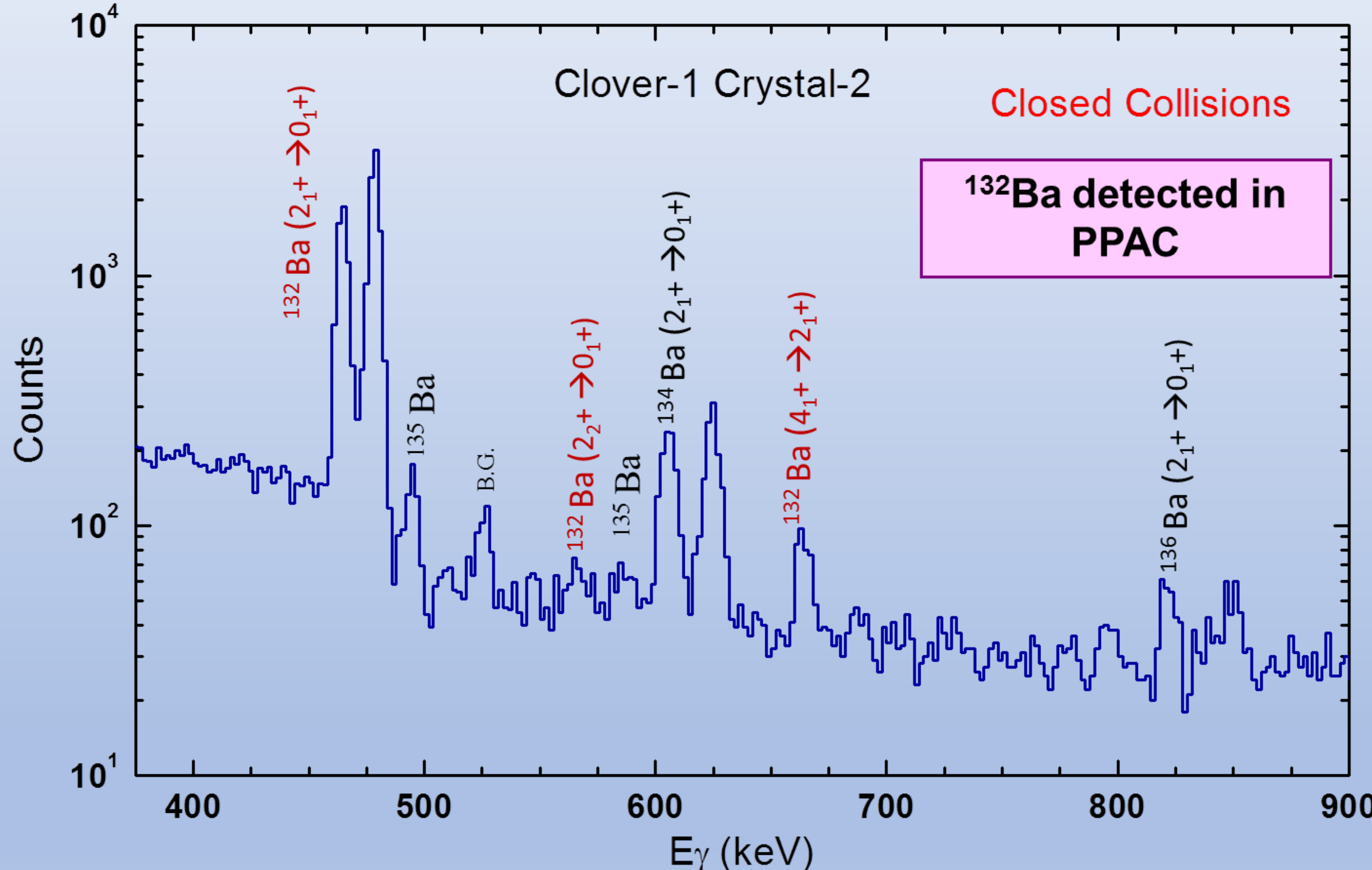


Doppler Shift Corrected γ-Ray Spectrum for $^{58}Ni + ^{132}Ba$



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}Ni + ^{132}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↑) 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↓) Present	B(E2↓) Ref-1	B(E2↓) Ref-2	B(E2↓) Ref-3 (β= 0.21 & γ=26.5º)
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.

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RE-MEASUREMENT OF REDUCED TRANSITION PROBABILITIES IN ^{132}Ba*

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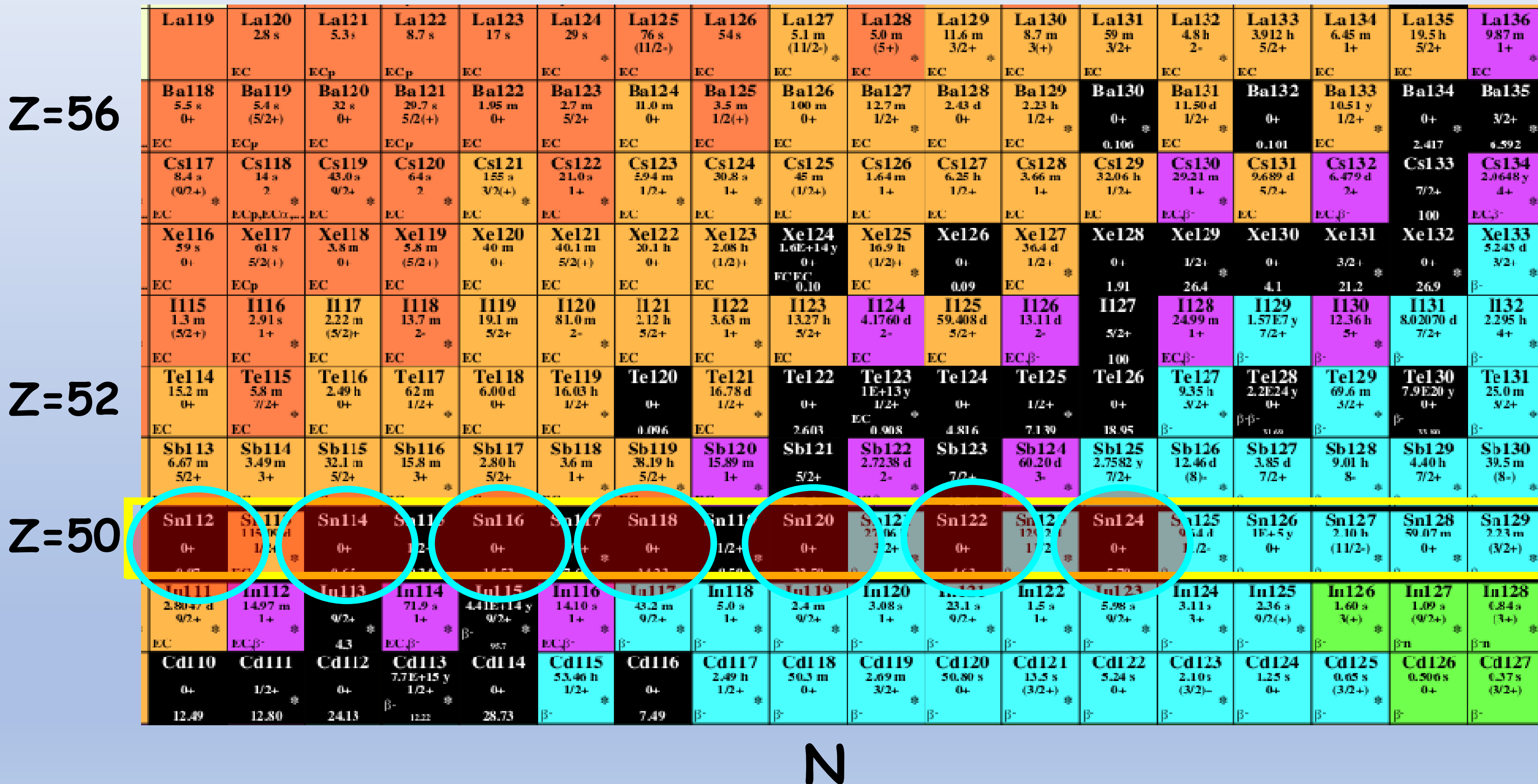
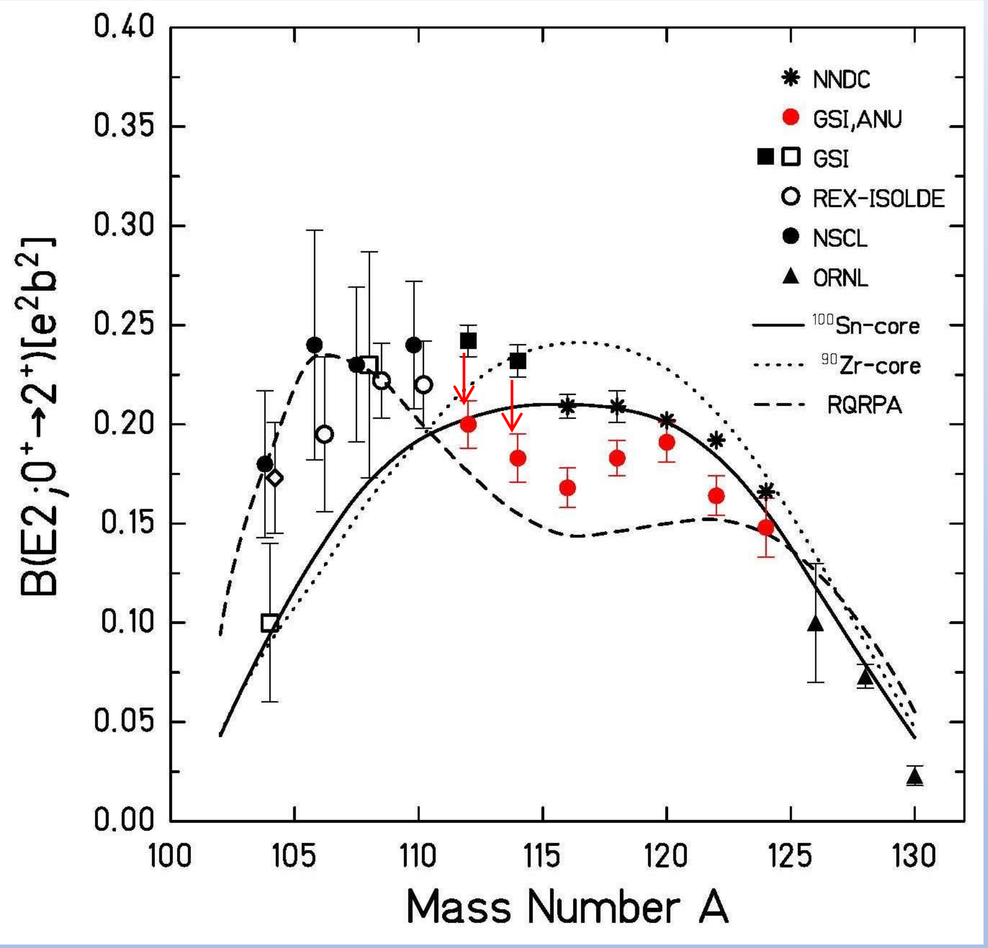
Re-measurement of Stable Sn-isotopes

Re-measurement of Stable Sn-isotopes



Evidence for reduced collectivity in Sn isotopes



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

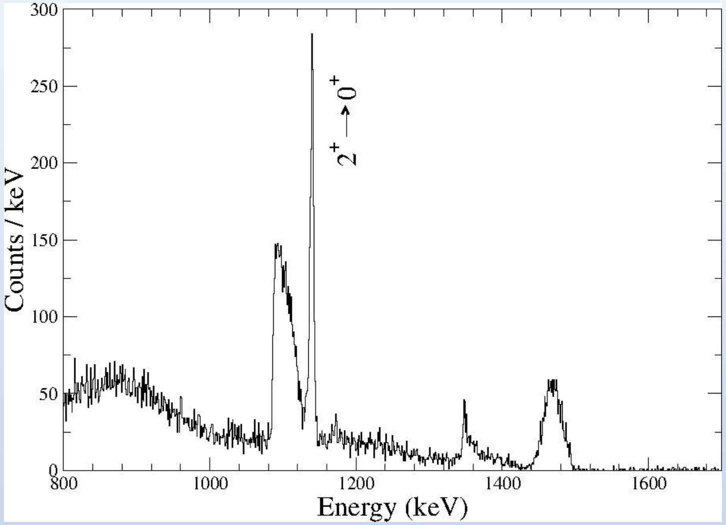
A recent Doppler Shift attenuation (DSA) measurement yield, however low B(E2↑) values (up to 20%) than previously found in the literature .

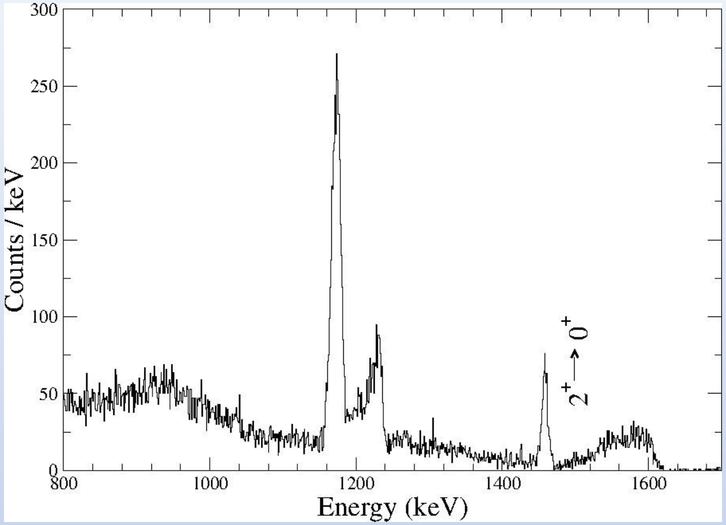
To draw firm conclusions on the B(E2↑) pattern for Sn isotopes, Coulomb excitation of all stable isotopes using a relatively heavy beam (e.g. ^{58}Ni) is necessary.

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

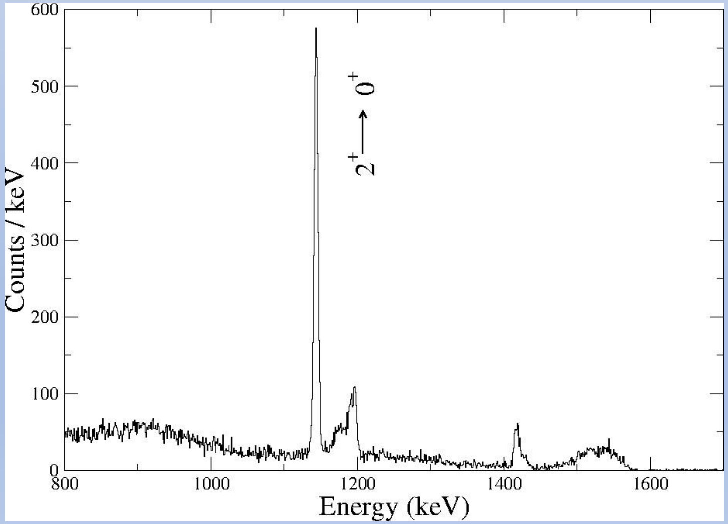
The stable beam facility of IUAC is perfect to settle the agreement or disagreement.

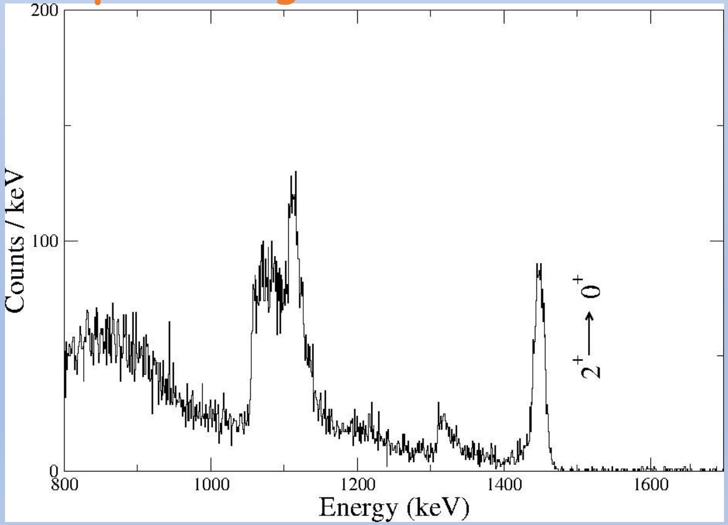
Doppler shift corrected γ-spectra emitted from the ^{122}Sn target nuclei and the ^{58}Ni projectiles at 175 MeV





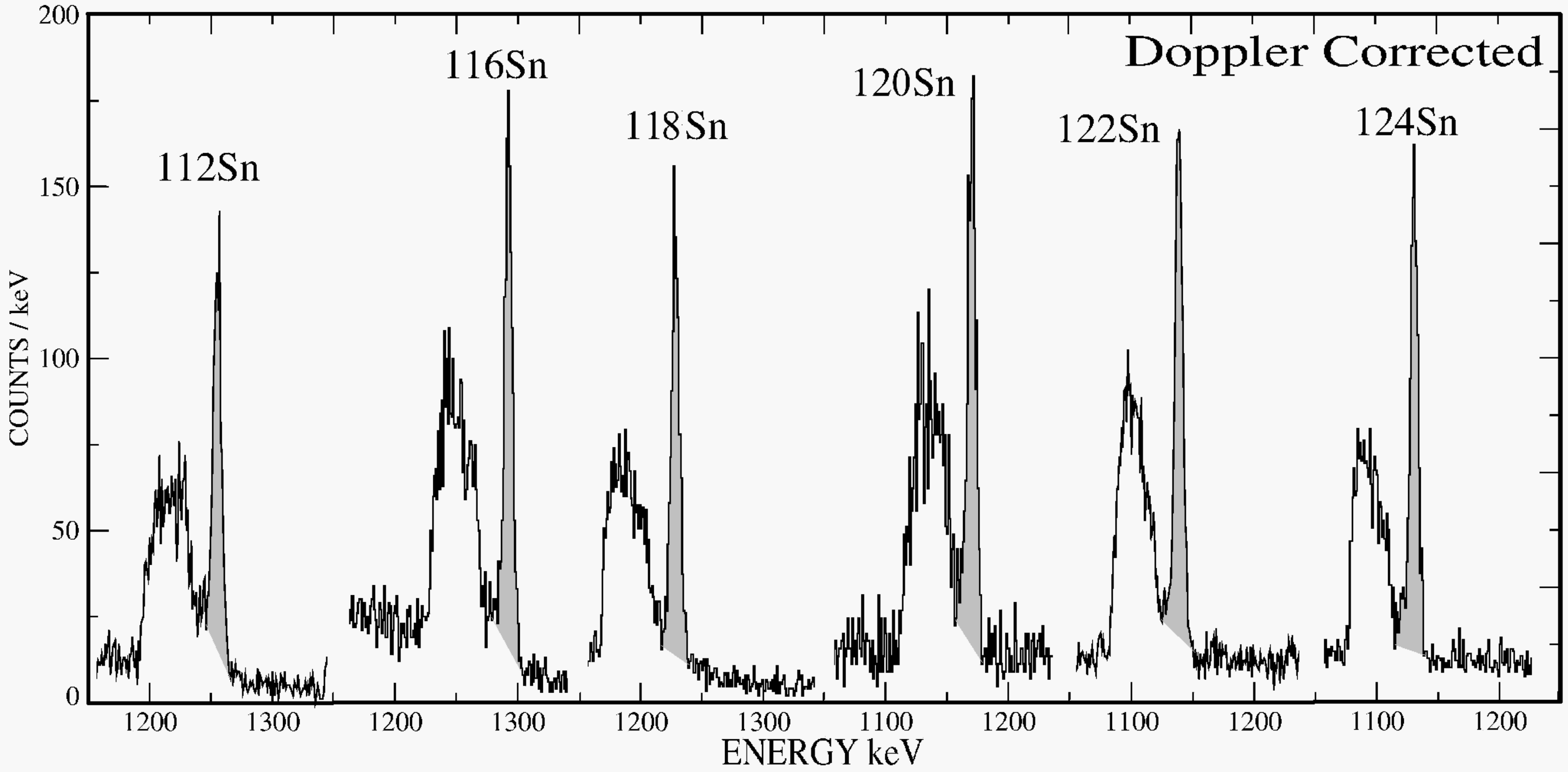
For distant collision ($22.1° \leq \theta_{cm} \leq 64.6°$) ^{58}Ni detected in PPAC,
The corrected ^{122}Sn spectra left and ^{58}Ni spectra right





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

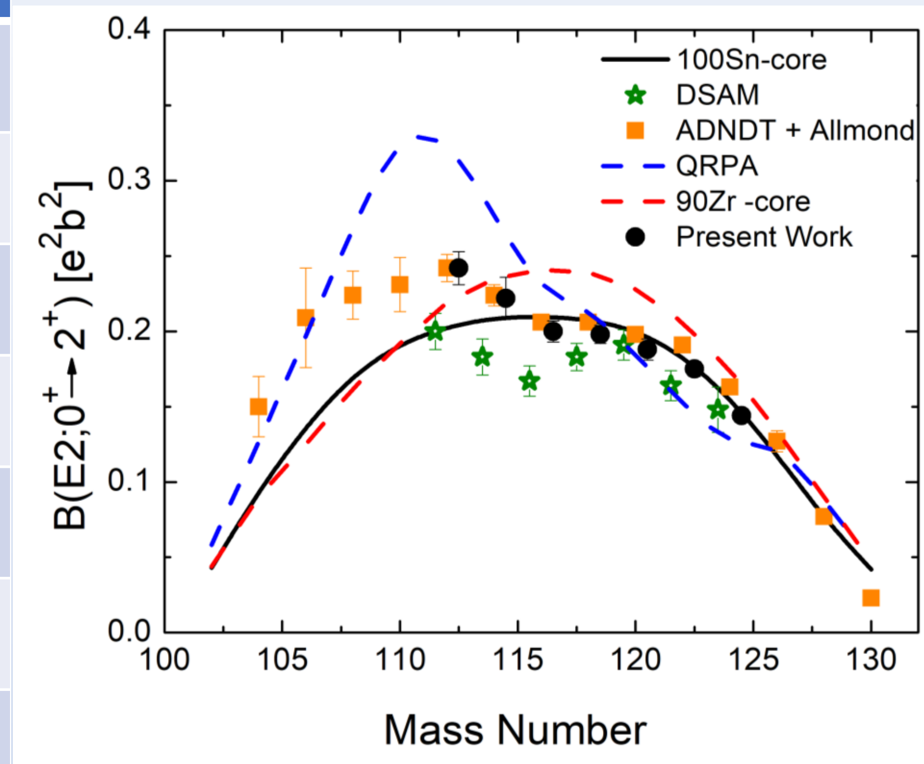
Energy Spectra from Sn Targets



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↑) value increases upon going from ^{116}Sn to ^{112}Sn, indicating failure of generalized seniority scheme for the B(E2↑) systematics for Sn isotopes.

  The experimental data --- compared with RQRPA calculations that predict the observed asymmetric behaviour of the B(E2↑) values with respect to the mid shell nucleus with N = 66.

- For the Te isotopes, the B(E2 ↑) values connecting higher-lying states, the nuclear structure of the ^{120,122,124}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 ± 4:3 W.u.

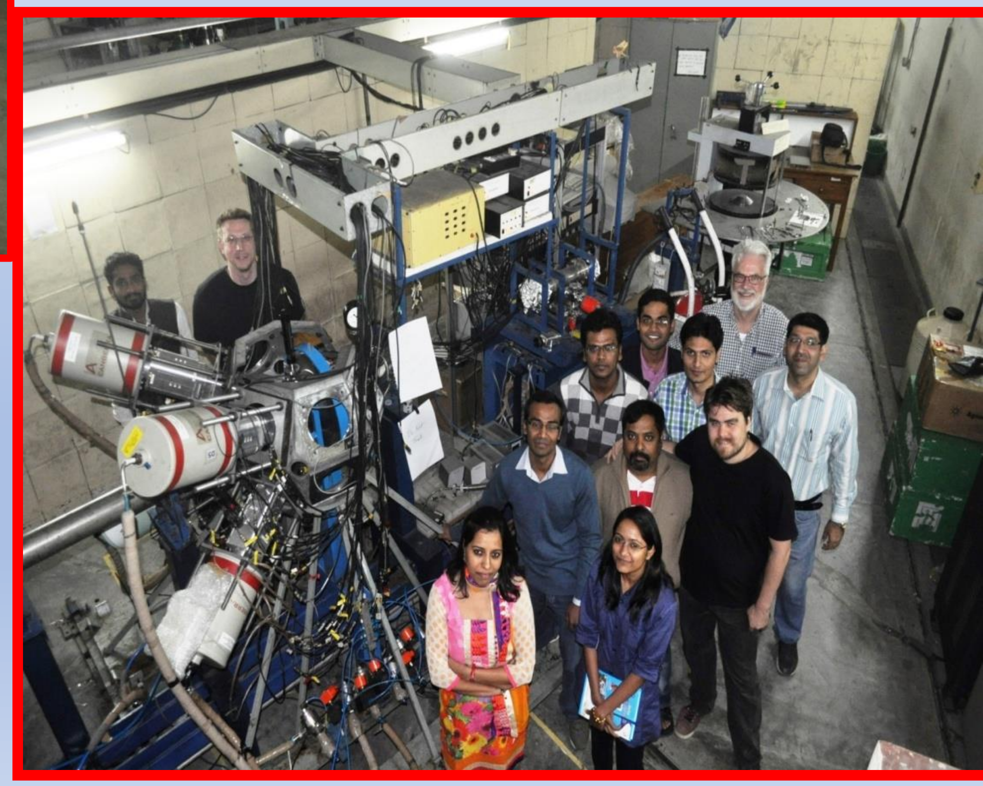
- Remeasured B(E2↑) values of stable Sn isotopes agree well with the recent Coulomb excitation result--confirming the disagreement with the DSA lifetime data.

  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.

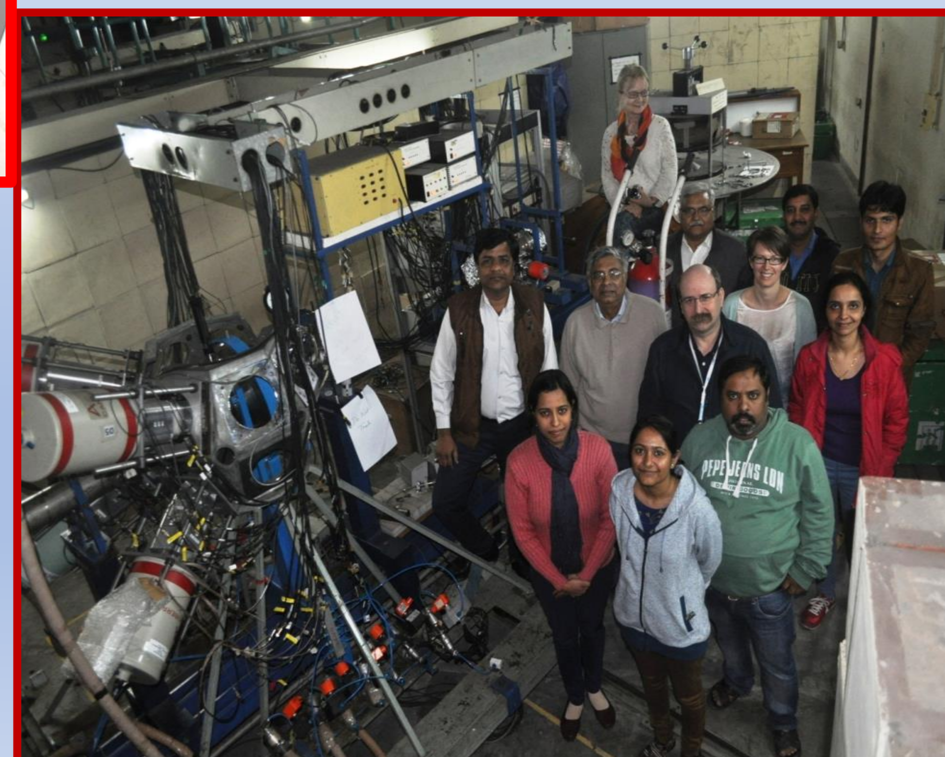
Thanks to Anna Stolarz for Targets

Te, Ba and Sc targets

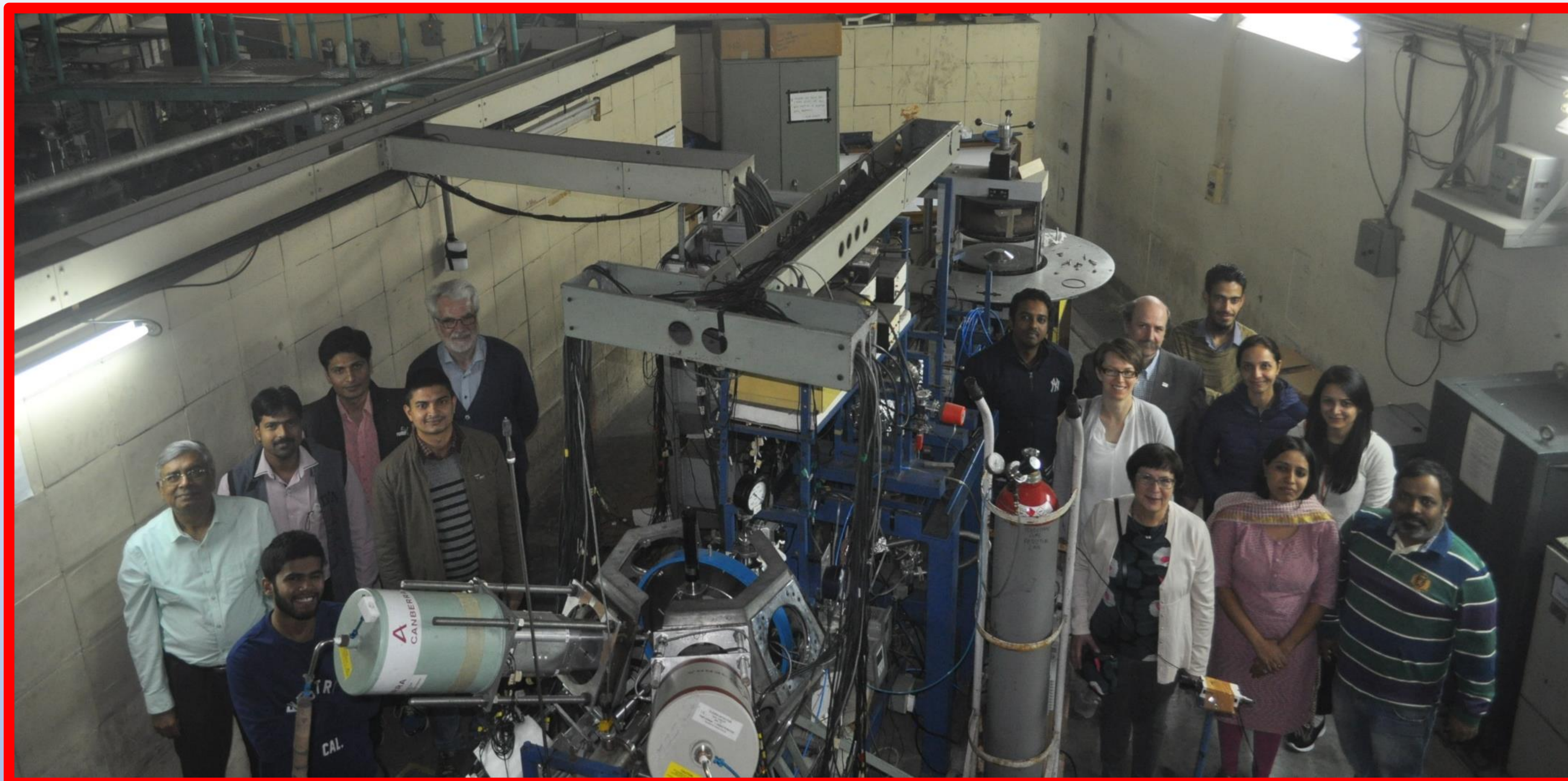
List of collaborators



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