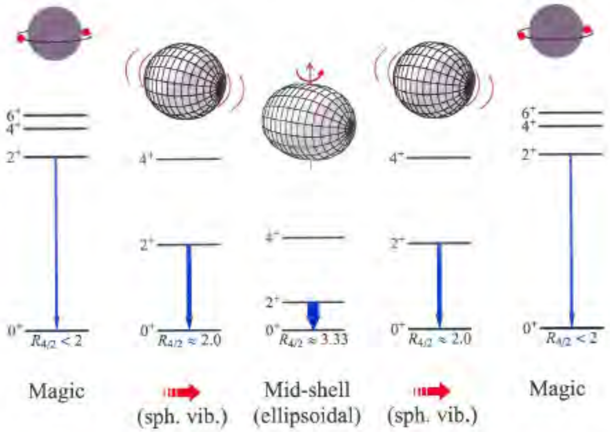
Chasing $B(E2)_{4_1^+/2_1^+}$ Anomaly

Bahadır Saygı

Ege University

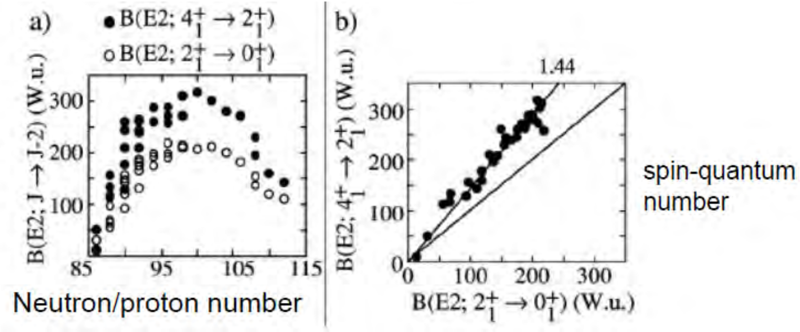
04/06/2021

- How the structure evolve as a function of
  - Spin-Quantum number ?
  - Proton/Neutron number or $N_p N_n$ Number ?



Which parameter we look in detail to deduce the structure of a nucleus of interest ?

- We measure B(E2) values - Reduced transition probability
  - A direct measure of deformation
  - Behavior of B(E2) values a function of spin-quantum or neutron/proton numbers play a key role to understand the nuclei of interest.



Cakirli, R. et al. Phys. Rev. C,70, 047302

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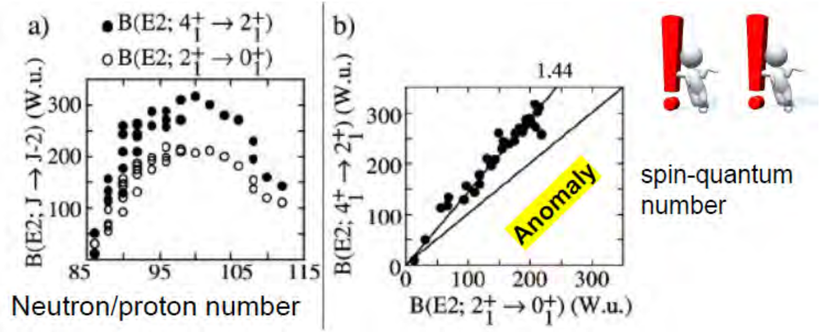
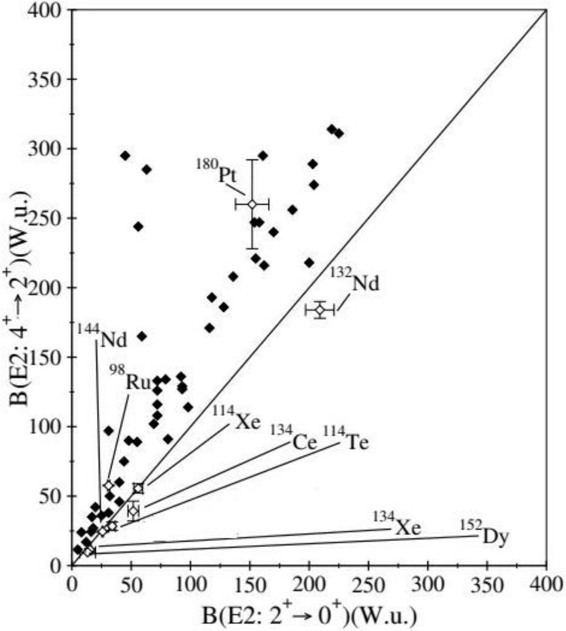
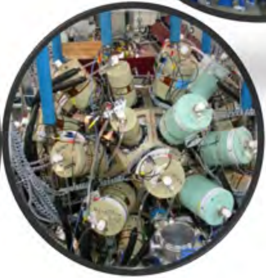


Cakirli, R. et al. Phys. Rev. C,70, 047302



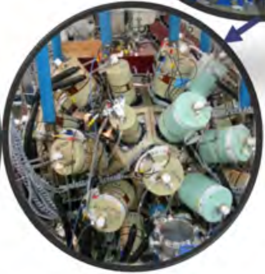
B(E2: 4+→2+)(W.u.)
B(E2: 2+→0+)(W.u.)
180Pt
132Nd
144Nd
98Ru
114Xe
134Ce
114Te
134Xe
152Dy

Set-Up



GREAT
Focal plane spectrometer

RITU
Gas-filled recoil separator



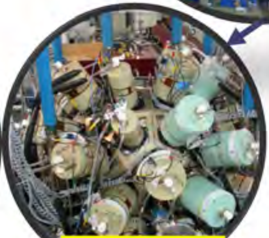
JUROGAM II Array

GREAT
Focal plane spectrometer

RITU
Gas-filled recoil separator

JUROGAM II Array

RITU
Gas-filled recoil separator,
transmission 20-50%



JUROGAM II
24+15 Ge+BGO
detectors, eff. 6%

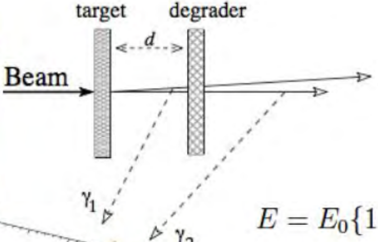
GREAT
Focal plane
spectrometer

RITU
Gas-filled recoil separator

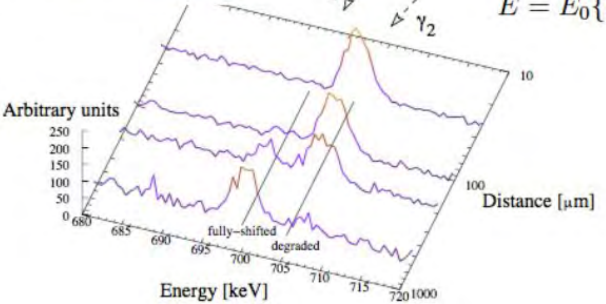
JUROGAM II Array

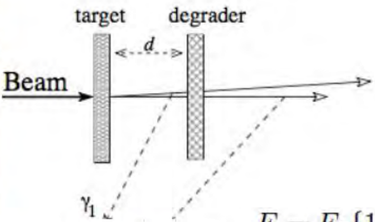
TDR
Total Data Readout, triggerless data
acquisition system with 10 ns time
stamping

Recoil Distance Doppler Shift Technique



$$E = E_0\{1 + \frac{v}{c}\cos\theta\}$$





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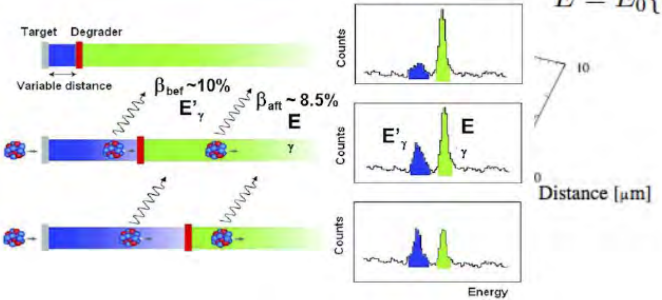
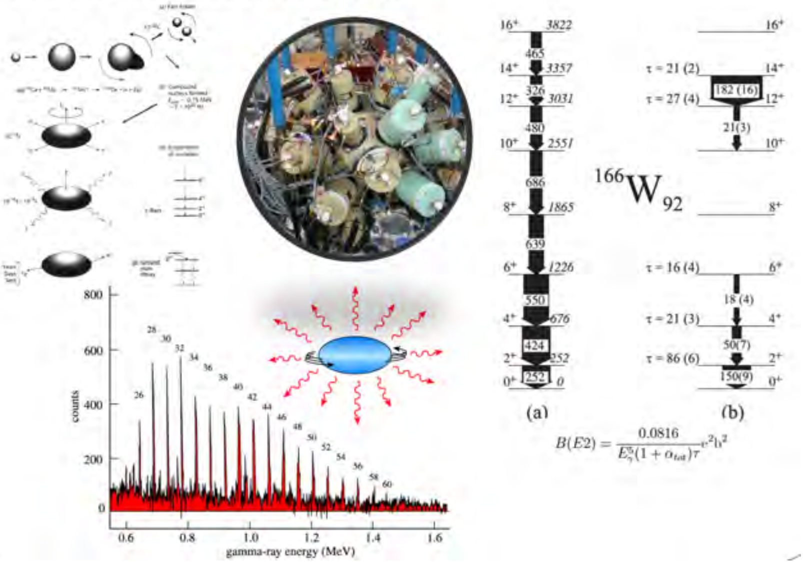


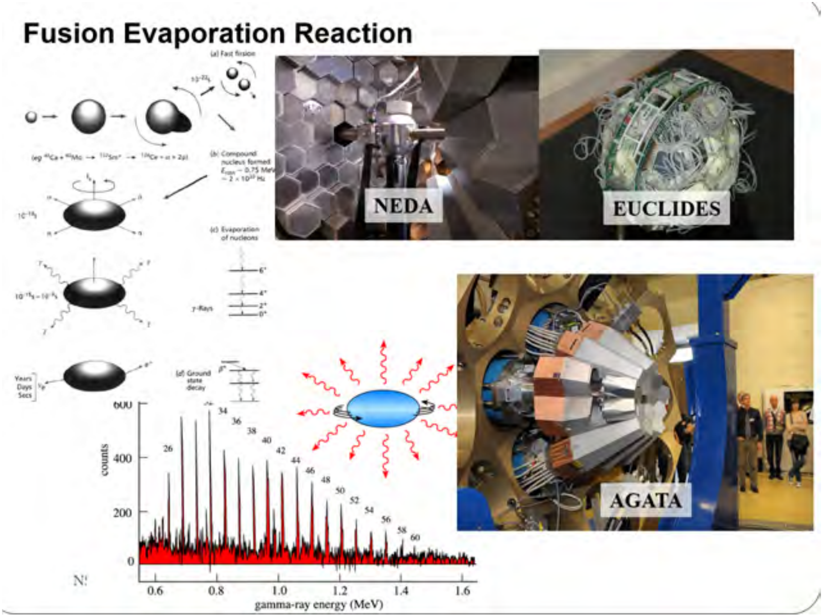
Reaction Mechanism

Fusion Evaporation Reaction



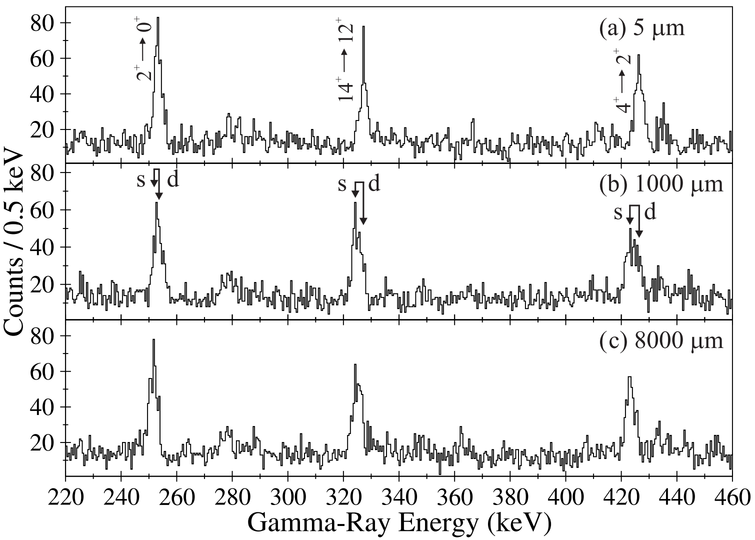
$$B(E2) = \frac{0.0816}{E_\gamma^5(1+\alpha_{tot})\tau} e^2b^2$$

Reaction Mechanism



^{166}W Case

- Excited states in ^{166}W were populated using the ^{92}Mo(^{78}Kr,4p) reaction.
- A 380 MeV $^{78}Kr^{15+}$ beam provided by the K130 cyclotron at the University of Jyväskylä Accelerator Laboratory bombarded a 0.6 mg/cm^2 ^{92}Mo target.
- A nominal beam intensity of 3 pnA was delivered to the target.



(a) 5 μm
$2^+ \rightarrow 0^+$
$14^+ \rightarrow 12^+$
$4^+ \rightarrow 2^+$
(b) 1000 μm
s d
s d
s d
(c) 8000 μm
Counts / 0.5 keV
Gamma-Ray Energy (keV)

Differential Decay Curve Method

$$\tau = \frac{Q^d_{\text{depop}}(x) - Q^d_{\text{feed}}(x)}{v\frac{d}{dx}[Q^s_{\text{depop}}(x)]},$$

where $Q^i_j(x) = I^i_j/(I^s_j + I^d_j)$ and $I^i_j(x)$ are the γ-ray intensities for the shifted ($i = s$) and degraded ($i = d$) components measured at the target-to-degrader distance x for the depopulating ($j =$ depop) and feeding ($j =$ feed) transitions, respectively.

A. Dewald et al. Prog in Part and Nucl Phys 67, 3, 2012, 786

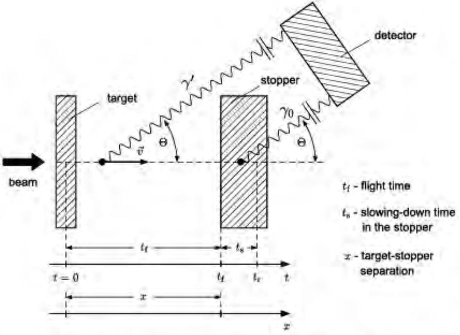
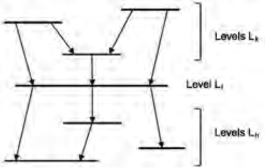
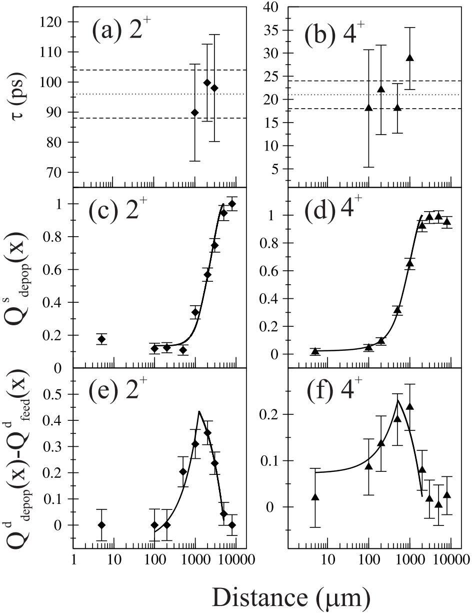


Fig. 1. Schematic description of the Recoil Distance Doppler-Shift method.





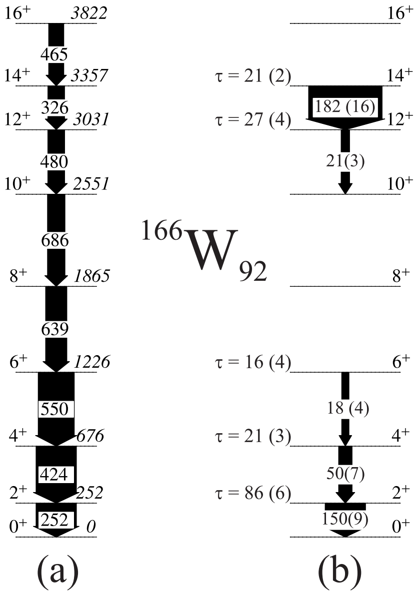
(a) 2+
(b) 4+
(c) 2+
(d) 4+
(e) 2+
(f) 4+
τ (ps)
Q^s_depop(x)
Q^d_depop(x)-Q^d_feed(x)
Distance (μm)
1
10
100
1000
10000

$$\mathrm{T}(E\lambda; i \to f) = \frac{1}{\tau} = \frac{8\pi}{\hbar} \frac{\lambda + 1}{\lambda[(2\lambda + 1)!!]^2} k^{2\lambda+1} B(\lambda; i \to f),$$

$$B(E\lambda; i \to f) = \frac{F_{\lambda}^{(E)}}{(E_{\gamma})^{2\lambda+1}\tau} e^2.b^{\lambda}$$

$$B(E2) = \frac{0.0816}{(E_{\gamma})^5 \tau (1 + \alpha_{\gamma})} e^2 b^2.$$

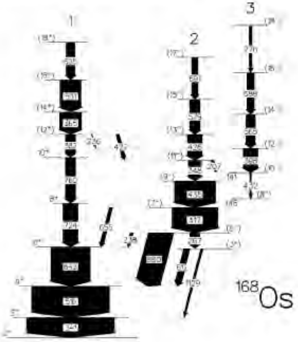
$$1W.u. = (5.94 \times 10^{-6}) A^{4/3} e^2 b^2 \ .$$

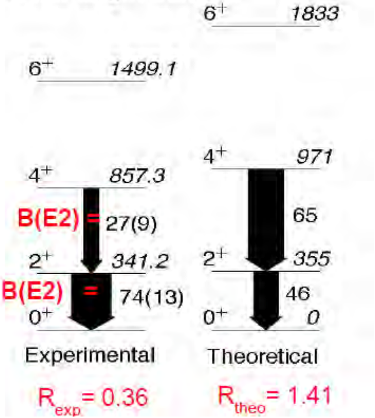


B. Saygı et al Phys. Rev. C, 96, 021301 (R).

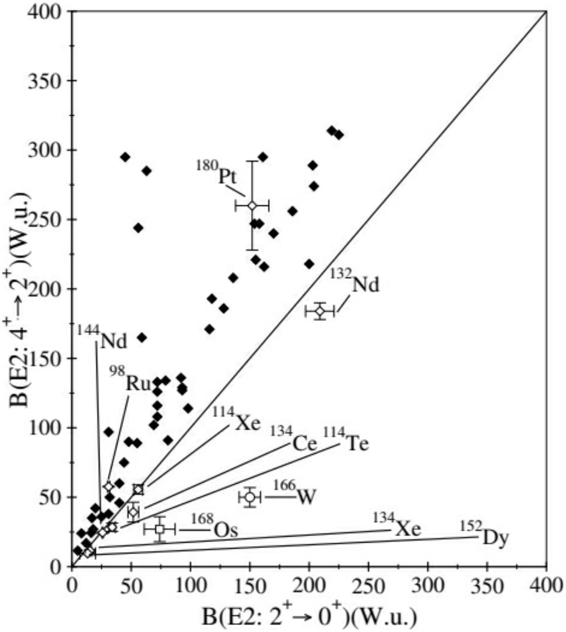
$B(E2)_{4_1^+/2_1^+} \approx$ f(P.N) ^{168}Os Case

- $^{78}Kr^{15+}$ + ^{92}Mo @345 using K130 2p exit channel
- Employed RDDS in junction with plunger in the target camber
- Measured τ values of 2^+ and 4^+

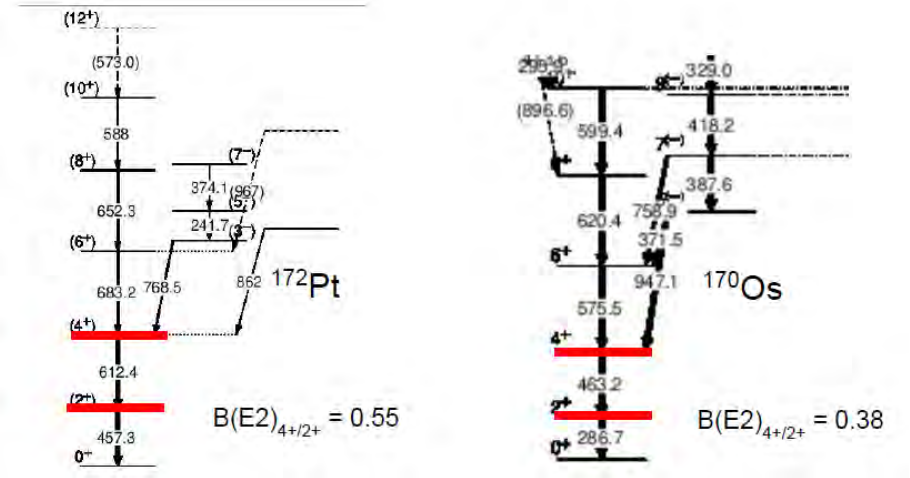




T. Grahn and B. Saygı et al. Phys. Rev. C,94, 044327

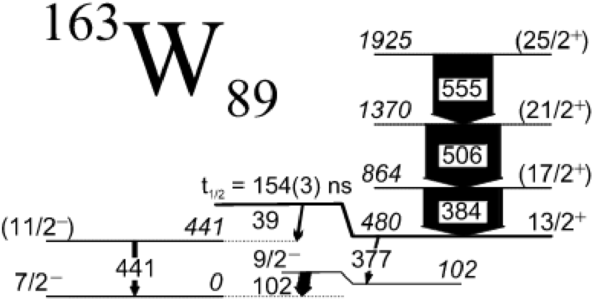

B(E2: 4+ → 2+)(W.u.)
B(E2: 2+ → 0+)(W.u.)
0
50
100
150
200
250
300
350
400
180Pt
132Nd
144Nd
98Ru
114Xe
134Ce
114Te
166W
168Os
134Xe
152Dy

$B(E2)_{4_1^+/2_1^+} \approx$ f(P.N)



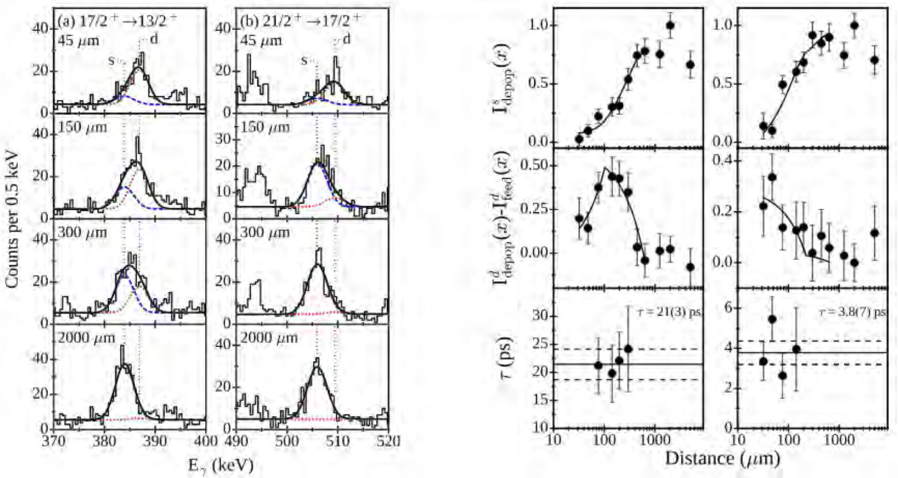
Cederwall, B. et al. Phys. Rev. Lett.,121, 022502.
Goasduff, A. et al. Phys. Rev. C,100,034302.

$B(E2)_{4_1^+/2_1^+} \approx$ f(N.N) ^{163}W Case



- ^{106}Cd(^{60}Ni,2pn)^{163}W
- DPUNS coupled to JUROGAM II
- 11 target-to-degrader distances

M.C. Lewis, D.T. Joss and B. Saygı et al. Phys. Lett. B 798 (2019) 134998

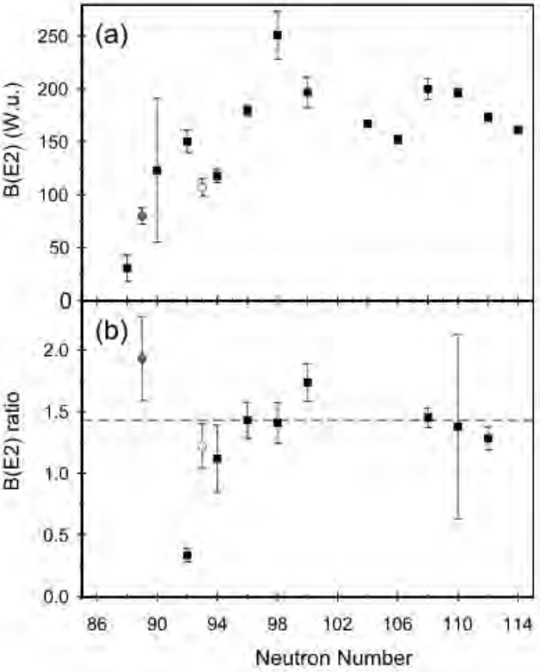


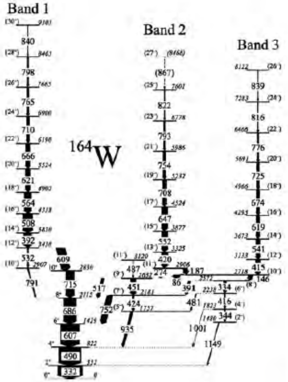
M.C. Lewis, D.T. Joss and B. Saygı et al. Phys. Lett. B 798 (2019) 134998

Table 1
Measured lifetimes and reduced transition probabilities for excited states in ^{163}W.

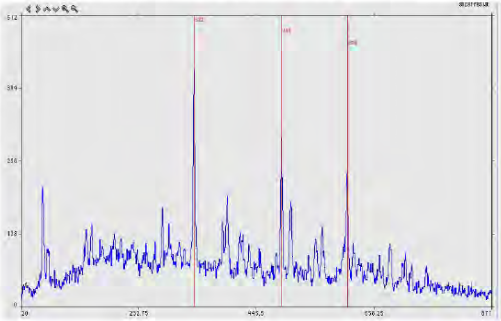
E_γ (keV)	$I_i^\pi \to I_f^\pi$ ($\hbar$)	Detector angle	Recoil-correlated γ-ray coincidences	Isomer-tagged singles	Average values	
			τ (ps)	τ (ps)	τ (ps)	$B(E2)\downarrow$ (W.u.)
384.1	$17/2^+ \to 13/2^+$	158°	21.3(30)			
		134°	21.4(30)			
		134°		26.5(50)		
					22(2)	80(8)
506.2	$21/2^+ \to 17/2^+$	158°	2.3(6)			
		134°	3.8(7)			
					3.0(4)	154(23)

M.C. Lewis, D.T. Joss and B. Saygı et al. Phys. Lett. B 798 (2019) 134998


(a)
(b)
B(E2) (W.u.)
B(E2) ratio
250
200
150
100
50
0
2.0
1.5
1.0
0.5
0.0
86
90
94
98
102
106
110
114
Neutron Number



- In the experiment searching ^{163,164}W isotopes;
- ^{106}Cd(^{60}Ni,2p)164W* at 270 MeV
- DPUNS coupled to JUROGAM II
- 11 Target-to-Degrader Distance used.



^{164}W has a similar $B(E2)_{4_1^+/2_1^+}$=0.56(13)

B. Saygı et al. To be Published Data from JR139

TABLE I. Spin and parities of the yrast states in ^{170}Os together with their excitation energies, lifetimes, and reduced electromagnetic transition probabilities (experimental and theoretical). The reported theoretical values are the ones obtained in this work using the symmetry-conserving configuration mixing method.

				$B(E2)\downarrow$ (e^2b^2)	
J^π	E (keV)	τ (ps)	$I_i^\pi \rightarrow I_f^\pi$	Expt.	Theor.
2_1^+	287	70_{-6}^{+6}	$2_1^+ \rightarrow 0_1^+$	$0.54_{-0.05}^{+0.05}$	0.53
4_1^+	750	18_{-4}^{+6}	$4_1^+ \rightarrow 2_1^+$	$0.21_{-0.04}^{+0.07}$	0.81

Goasduff, A. et al. Phys. Rev. C,100,034302.

- Symmetry conserving configuration mixing (SCCM) calculations were performed using the generator coordinate method framework with Hartree-Fock-Bogoliubov states found with variation after particle number projection (PN-VAP)
- The only benchmark situation in which $B(E2)_{4_1^+/2_1^+} < 1$ occurs where seniority is a good quantum number and from phenomenological point of view, a quantum phase transition from seniority-conserving structure to a collective regime as a function of neutron number around N $\approx$ 90 -94 has been proposed for these nuclei
- From theoretical point of view, the origin and the underlying structure giving rise to this anomalous behaviour remains unexplained up to date. These observations have not been reproduced so far by any type of state-of-the-art nuclear structure calculations, neither large-scale shell models nor beyond-mean-field models

Cederwall, B. et al. Phys. Rev. Lett.,121, 022502.

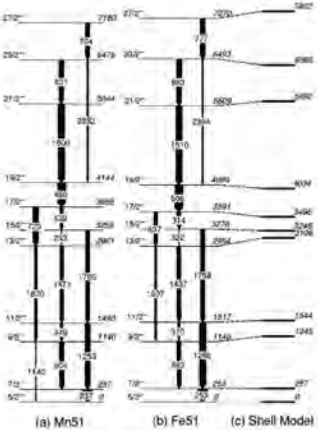
T. R. Rodríguez and J. L. Egido, Phys. Rev. C 84, 051307(R) (2011).

T. R. Rodríguez and J. L. Egido, Phys. Lett. B 705, 255 (2011).

$B(E2)_{4_1^+/2_1^+} \approx \mathbf{f}(N_p.N_n)$

NpNn Scheme

- NpNn scheme is introduced by Federman and Pittel and broadly used by Casten.
- Physics meaning of NpNn: a measure of integrated neutron-proton interaction.
- Symmetry of neutron-proton or related particle-hole arises from the isospin concept, which introduced by Heisenberg and states that neutron and proton and their related holes are different states of a nucleon.
- Experimental reflection of the isospin symmetry is quite well known.



M.A. Bentley, PRC, 62, 51303(R)

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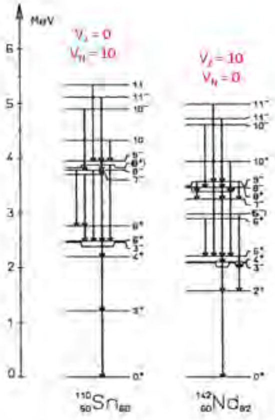

J. Yan et. al. PRC, 42, 743,1990

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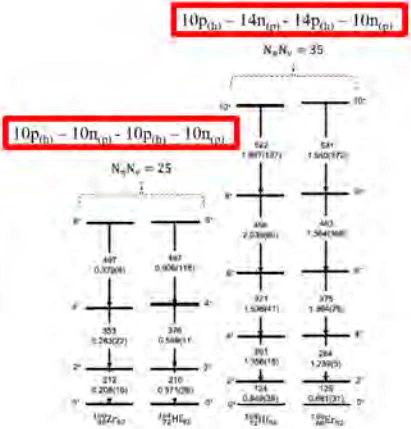
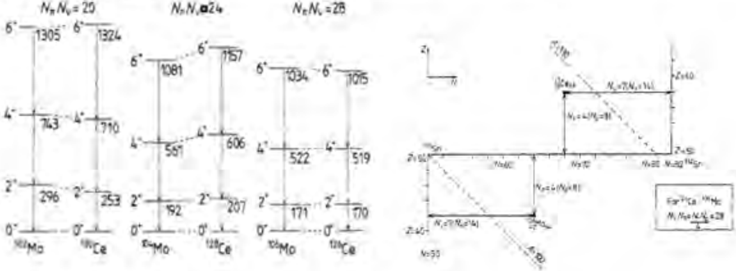


B. Saygı, Nuclear Physics A, 980 (2018) 15-20

Pseudo-mirror nuclei

Pseudo-mirror nuclei (PMN) have been introduced by Moscrop et.al for the first time through the end of 80's.



R. Moscrop et.al. J. of Physics G: Nucl. and Phys., vol. 14, pp. L189, 1989.

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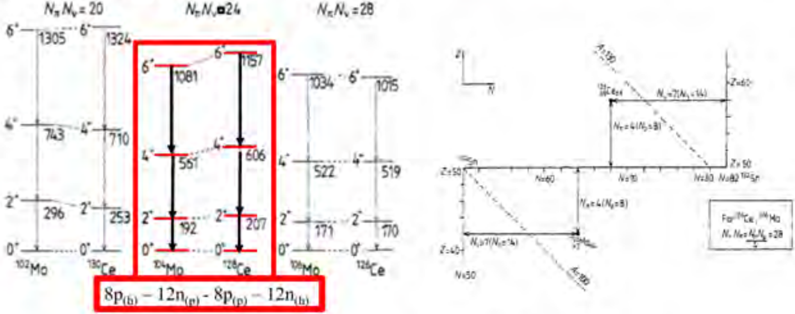


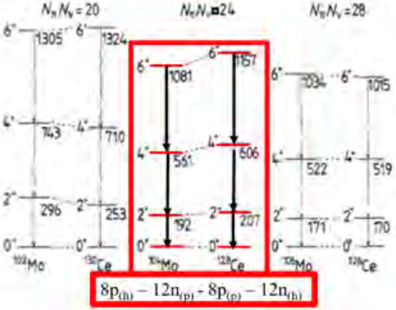
R. Moscrop et.al, J. of Physics G: Nucl. and Phys., vol. 14, pp. L189, 1989.

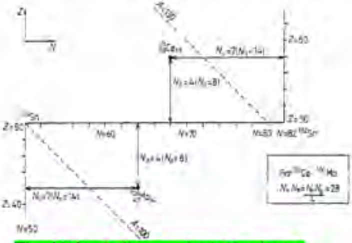
Pseudo-mirror nuclei

Proton/Neutron - midshell

Pseudo-mirror nuclei (PMN) have been introduced by Moscrop et.al for the first time through the end of 80's.

28 – 39 - Mo (42) - 50 50 - Ce (58) – 64 - 82
50 – Mo (62) – 64 - 82 50 – 64 - Ce (70) - 82





The NpNn is the product of valence neutrons (holes) and protons (holes) numbers.

R. Moscrop et.al, J. of Physics G: Nucl. and Phys., vol. 14, pp. L189, 1989.

Pseudo-mirror nuclei

Proton/Neutron - midshell

Pseudo-mirror nuclei (PMN) have been introduced by Moscrop et.al for the first time through the end of 80's over 12 nuclei

Pseudo-mirror nuclei (et.al for the first time
through the end of 80'

28 – 39 - Mo (42) - 50   50 - Ce (58) – 64 - 82
50 – Mo (62) – 64 - 82   50 – 64 - Ce (70) - 82

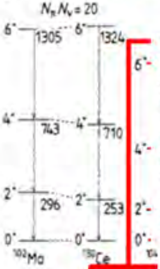
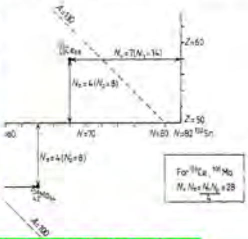


Table 1. New candidates for pseudo-mirror nuclei.

$N_\pi N_\nu$	Nuclei				
15	^{136}Nd	^{160}Hf			figure 1
16	^{132}Ce	^{164}W			figure 1
18	^{106}Ru	^{126}Ba			figure 1
21	^{108}Ru	^{124}Ba			figure 2
25	^{164}Hf				figure 3
30	^{166}Hf	^{162}Yb			figure 4
35	^{104}Zr	^{128}Nd	^{168}Hf	^{160}Er	figure 5

B. Saygı, J. of Physics G: Nucl. and Part. Phys. 45, 095104, 2018

$8p_{(h)} - 1$



n is the product of valence neutrons (holes) and protons (holes) numbers.

R. Moscrop et.al, J. of Physics G: Nucl. and Phys., vol. 14, pp. L189, 1989.

NpNn Scheme

- NpNn scheme is introduced by Federman and Pittel and broadly used by Casten.
- Physics meaning of NpNn: a measure of

Systematics between B(E2)'s

$B(E2; L^+ \rightarrow (L\text{-}2)^+)_{A \equiv 130} / B(E2; L^+ \rightarrow (L\text{-}2)^+)_{A \equiv 100} \equiv 2,$

$B(E2; L^+ \rightarrow (L\text{-}2)^+)_{A \equiv 160} / B(E2; L^+ \rightarrow (L\text{-}2)^+)_{A \equiv 100} \equiv 2,$

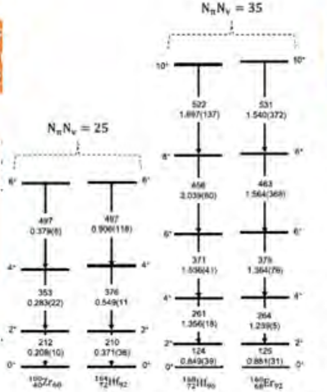
$B(E2; L^+ \rightarrow (L\text{-}2)^+)_{A \equiv 170} / B(E2; L^+ \rightarrow (L\text{-}2)^+)_{A \equiv 160} \equiv 1,$

$B(E2; L^+ \rightarrow (L\text{-}2)^+)_{A \equiv 170, 160} / B(E2; L^+ \rightarrow (L\text{-}2)^+)_{A \equiv 130} \equiv 1$

B. Saygı, J. of Physics G: Nucl. and Part. Phys. 45, 095104, 2018

nucleon.

- Experimental reflection of the isospin symmetry is quite well known.



B. Saygı, Nuclear Physics A, 980 (2018) 15-20

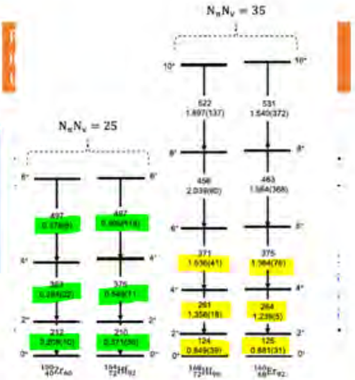
NpNn Scheme

- NpNn scheme is introduced by Federman and Pittel and broadly used by Casten.

- Systematics between B(E2)'s
- $B(E2; L^+ \rightarrow (L-2)^+)_{A \cong 130} / B(E2; L^+ \rightarrow (L-2)^+)_{A \cong 100} \equiv 2,$
- $B(E2; L^+ \rightarrow (L-2)^+)_{A \cong 160} / B(E2; L^+ \rightarrow (L-2)^+)_{A \cong 100} \equiv 2,$
- $B(E2; L^+ \rightarrow (L-2)^+)_{A \cong 170} / B(E2; L^+ \rightarrow (L-2)^+)_{A \cong 160} \equiv 1,$
- $B(E2; L^+ \rightarrow (L-2)^+)_{A \cong 170/160} / B(E2; L^+ \rightarrow (L-2)^+)_{A \cong 130} \equiv 1$
- B. Saygı, J. of Physics G: Nucl. and Part. Phys. 45, 095104, 2018

nucleon.

- Experimental reflection of the isospin symmetry is quite well known.



B. Saygı, Nuclear Physics A, 980 (2018) 15-20

Predictive pow

Nuclide	2^+	4^+	0^+
^{102}Zr		≈0.500	
^{106}Ru		≈0.250	
^{124}Ba		≈0.610	
^{128}Nd	≈0.800		
^{130}Nd		≈1.090	
^{164}W	≈0.400	≈0.820	

B. Saygı, J. of . Phys. G: Nucl. And 018

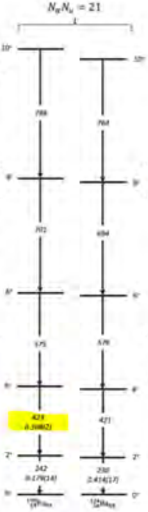


Table 1. Preliminary mean lifetimes and reduced electromagnetic transition probabilities in the yrast band of Ba derived in this work. The values shown in the table are the average from the results for forward and backward rings.

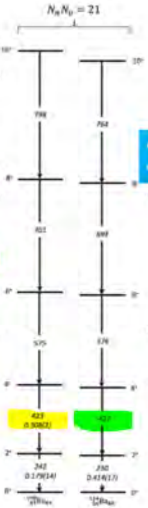
E_{lev} [keV]	I^π	E_γ [keV]	τ [ps]	$B(E2)$ [e^2b^2]
651.7	4^+	421.1	9.1 (8)	0.664 (58)
1228.4	6^+	576.5	2.1 (2)	0.6 (1)
1923.3	8^+	694.7	1.2 (4)	0.425 (148)

M. Trichkova, EPJ Web of Conferences 194, 03004 (2018)

Predictive pow

Nuclide	2^+	4^+
^{102}Zr		≈0.500
^{106}Ru		≈0.250
^{124}Ba		≈0.610
^{128}Nd	≈0.800	
^{130}Nd		≈1.090
^{164}W	≈0.400	≈0.820

B. Saygı, J. of . Phys. G: Nucl. And



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- Systematics between B(E2)'s
- $B(E2; L^+ \rightarrow (L-2)^+)_{A=130} / B(E2; L^+ \rightarrow (L-2)^+)_{A=100} \equiv 2$

Table 1. Preliminary mean lifetimes and reduced electromagnetic transition probabilities in the yrast band of ^{14}Ba derived in this work. The values shown in the table are the average from the results for forward and backward rings.

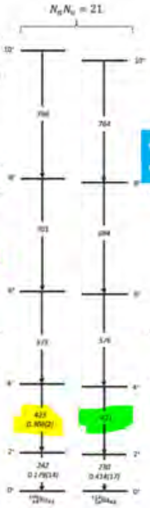
E_{lev} [keV]	I^π	E_γ [keV]	τ [ps]	$B(E2)$ [e^2b^2]
651.7	4^+	421.1	9.1 (8)	0.664 (58)
1228.4	6^+	576.5	2.1 (2)	0.6 (1)
1923.3	8^+	694.7	1.2 (4)	0.425 (148)

M. Trichkova, EPJ Web of Conferences 194, 03004 (2018)

Predictive pow

Nuclide	2^+	4^+
^{102}Zr		≈0.500
^{106}Ru		≈0.250
^{124}Ba		≈0.610
^{128}Nd	≈0.800	
^{130}Nd		≈1.090
^{164}W	≈0.400	≈0.820

B. Saygı, J. of . Phys. G: Nucl. And ... 018



- Systematics between B(E2)'s
- B(E2; $L^+ \rightarrow (L-2)^+)_{A=130}$/ B(E2; $L^+ \rightarrow (L-2)^+)_{A=100} \equiv 2$

Table 1. Preliminary mean lifetimes and reduced electromagnetic transition probabilities in the yrast band of ^{124}Ba derived in this work. The values shown in the table are the average from the results for forward and backward rings.

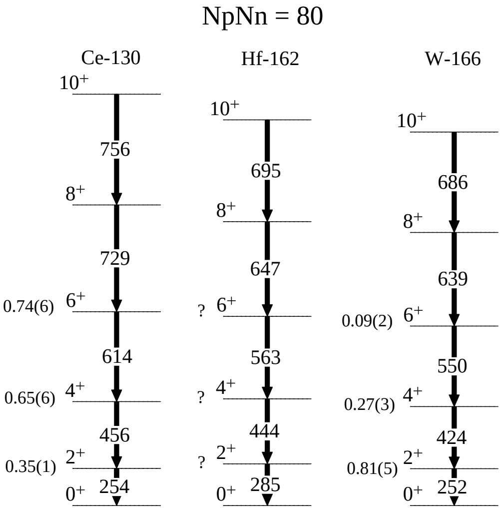
E_{lev} [keV]	I^π	E_γ [keV]	τ [ps]	$B(E2)$ [e^2b^2]
651.7	4^+	421.1	9.1 (8)	0.668 (58)
1228.4	6^+	576.5	2.1 (2)	0.6 (1)
1923.3	8^+	694.7	1.2 (4)	0.425 (148)

M. Trichkova, EPJ Web of Conferences 194, 03004 (2018)

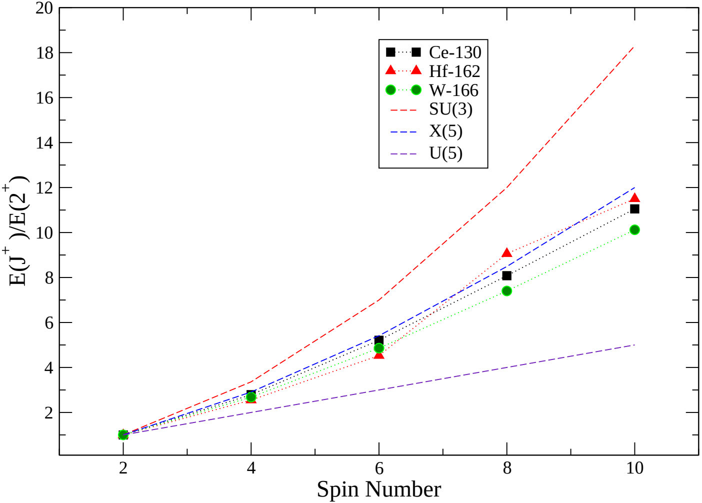
- Deformed mean field and self-consistent Hatree-Fock (SCHF) Hamiltonian
- $$\hat{H} = \hat{H}_0 + \frac{1}{2}\kappa_{nn}\hat{Q}_n\hat{Q}_n + \frac{1}{2}\kappa_{pp}\hat{Q}_p\hat{Q}_p + \kappa_{np}\hat{Q}_n\hat{Q}_p, \qquad (1)$$
- $\hat{H}_0$ is the spherical single-particle Hamiltonian
- κ's are the coupling constants.
- The relation of the κ's is that $\kappa_{np} \approx 5\kappa_{pp} \approx= 5\kappa_{nn}$
- Indicating that n-p ($\hat{Q}_n\hat{Q}_p$) interaction dominates while building the nuclear deformation.

J. Dobaczewskiet al., Phys. Rev. Lett. 60 (1988) 2254.

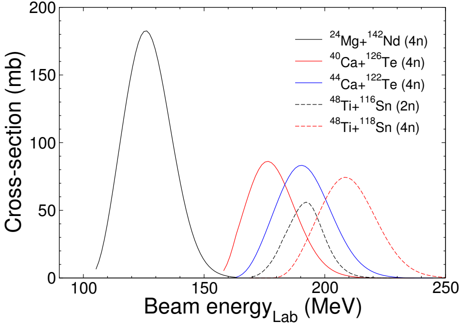
^{162}Hf Case



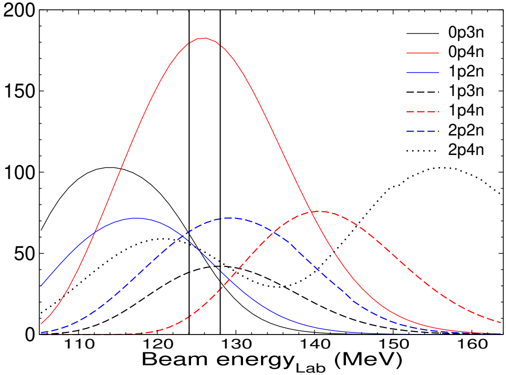
NpNn = 80
Ce-130
Hf-162
W-166
10+
756
8+
729
0.74(6)
6+
614
0.65(6)
4+
456
0.35(1)
2+
254
0+
10+
695
8+
647
?
6+
563
?
4+
444
?
2+
285
0+
10+
686
8+
639
0.09(2)
6+
550
0.27(3)
4+
424
0.81(5)
2+
252
0+



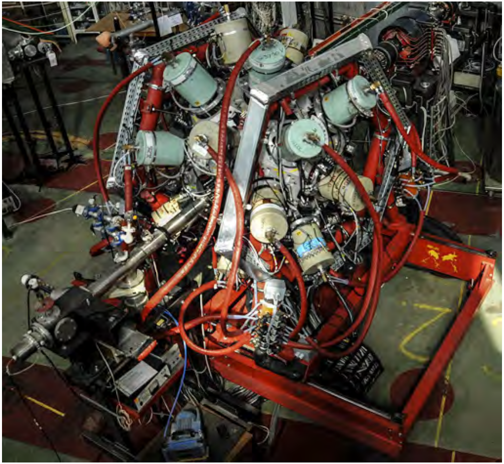
Systematics of excitation energies values in neutron-deficient even-even ^{130}Ce, ^{162}Hf and ^{166}W nuclie. Calculated ratio using the IBM in the SU(3), X(5) and U(5) limits are also reported. Excitation energy of the yrast state normalized to the $E(2_1^+)$



Comparison of reaction of interest with possible reactions to populate ^{162}Hf* reaction.



Comparison of reaction channels of interest with possible reaction channels in $^{142}Nd(^{24}Mg,4n)^{162}Hf^{*}$ reaction.



UNIVERSITY OF WARSAW | HIL

Heavy Ion Laboratory

Warsaw, 25.05.2020

Prof. Krzysztof Rusek
Director
Heavy Ion Laboratory
University of Warsaw
Warsaw, Poland

Dr. Bahadir SAYGI
Ege University
Science Faculty
Physics Department
Izmir, Turkey

Dear Spokesperson Dr. Saygi,

I would like to inform that your proposal entitled "Lifetime measurement of excited states in [illegible]Hf" has been accepted by the Heavy Ion Laboratory Program Advisory Committee meeting held on the 17th of December 2019. The PAC recommends that your experiment should be performed with the total number of requested 21 shifts. The code HIL092 has been assigned for your experiment. You will be notified about the beam-time schedule, when it is available.

For any additional information please do not hesitate to contact the PAC Secretary.

Best regards,

NEDA@HIL

- The NEutron Detector Array, NEDA, will form the next generation neutron detection system that has been designed to be operated in conjunction with γ-ray arrays, such as the tracking-array AGATA, to aid nuclear spectroscopy studies.
- NEDA has been designed to be a versatile device, with high-detection efficiency, excellent neutron- discrimination, and high rate capabilities.
- It will be employed in physics campaigns in order to maximise the scientific output, making use of the different stable and radioactive ion beams available in Europe.
- The first implementation of the neutron detector array NEDA with AGATA 1π was realised at GANIL. This manuscript reviews the various aspects of NEDA.

J.J. Valiente-Dobón, G. Jaworski, A. Goasduff, ..., B. Saygı et al.Nuclear Inst. and Methods in Physics Research, A 927 (2019) 81–8

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- Dr. G. Jaworski got a funding from The Polish Academy of Sciences in order to host NEDA at Heavy Ion Laboratory in Warsaw, Poland.
- As an international collaborator, we have contributed with 3 experimental idea in order to investigate $B(E2)_{4_1^+/2_1^+}$ and gather more experimental data for future theoretical calculations.
- EAGLE array will be employed in junction with NEDA and plunger
- Data is planned to be collected using RDDS technique
- Data is planned to be analysed with DDCM in coincidence mode.

Thank You

Core Collaboration

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United Kingdom

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