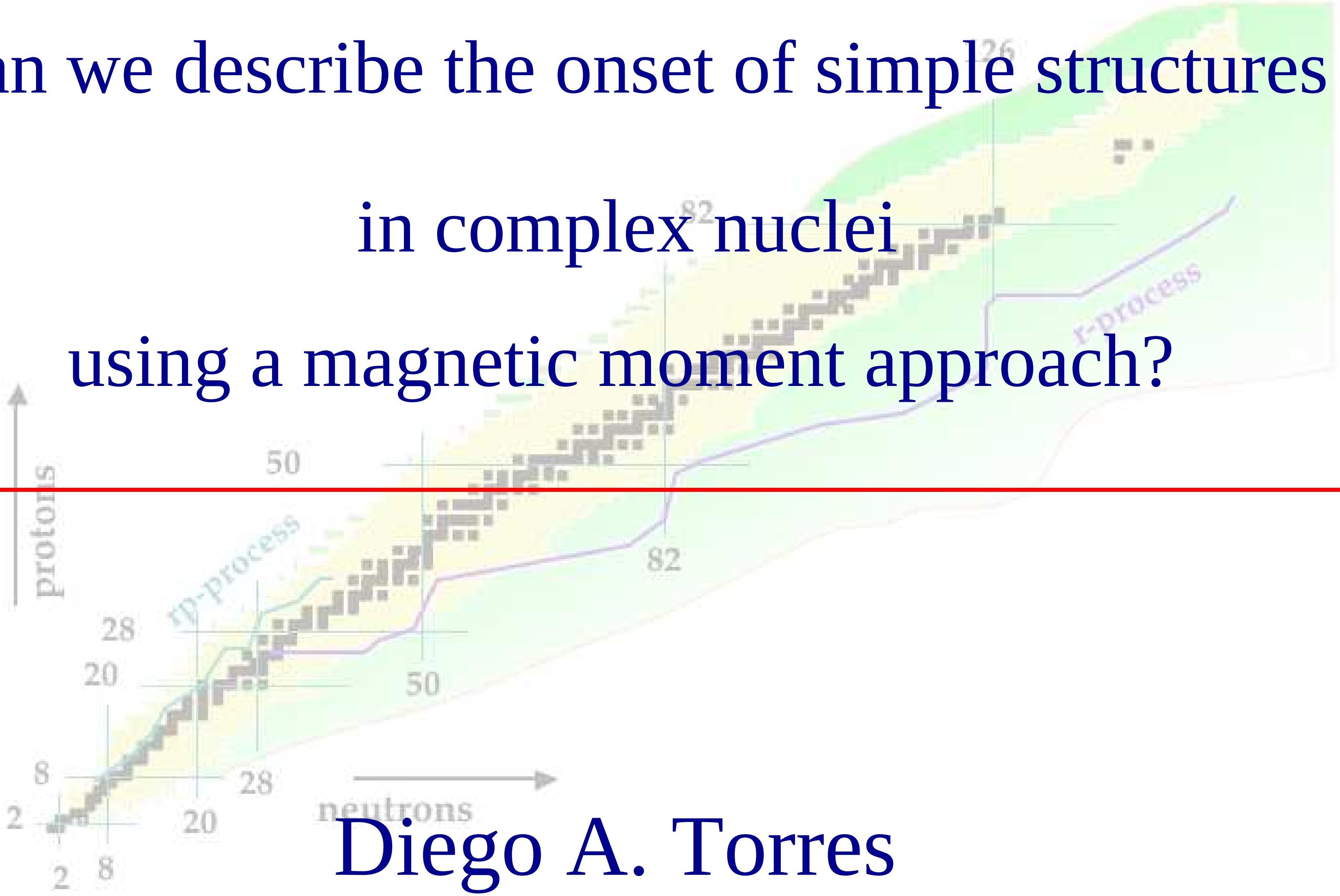
Can we describe the onset of simple structures in complex nuclei using a magnetic moment approach?



Diego A. Torres

Bogotá

Country side

Medellin

o A.

Villa de Leyva

What Questions Has Nuclear Physics Helped to Solve?

Is it possible to convert lead into gold?

R/ Yes we can!, BUT it is very expensive.

If the sun is a ball of fire where is the smoke?

R/ The sun is burning up using nuclear fusion reactions,

which are smoke−free reactions.

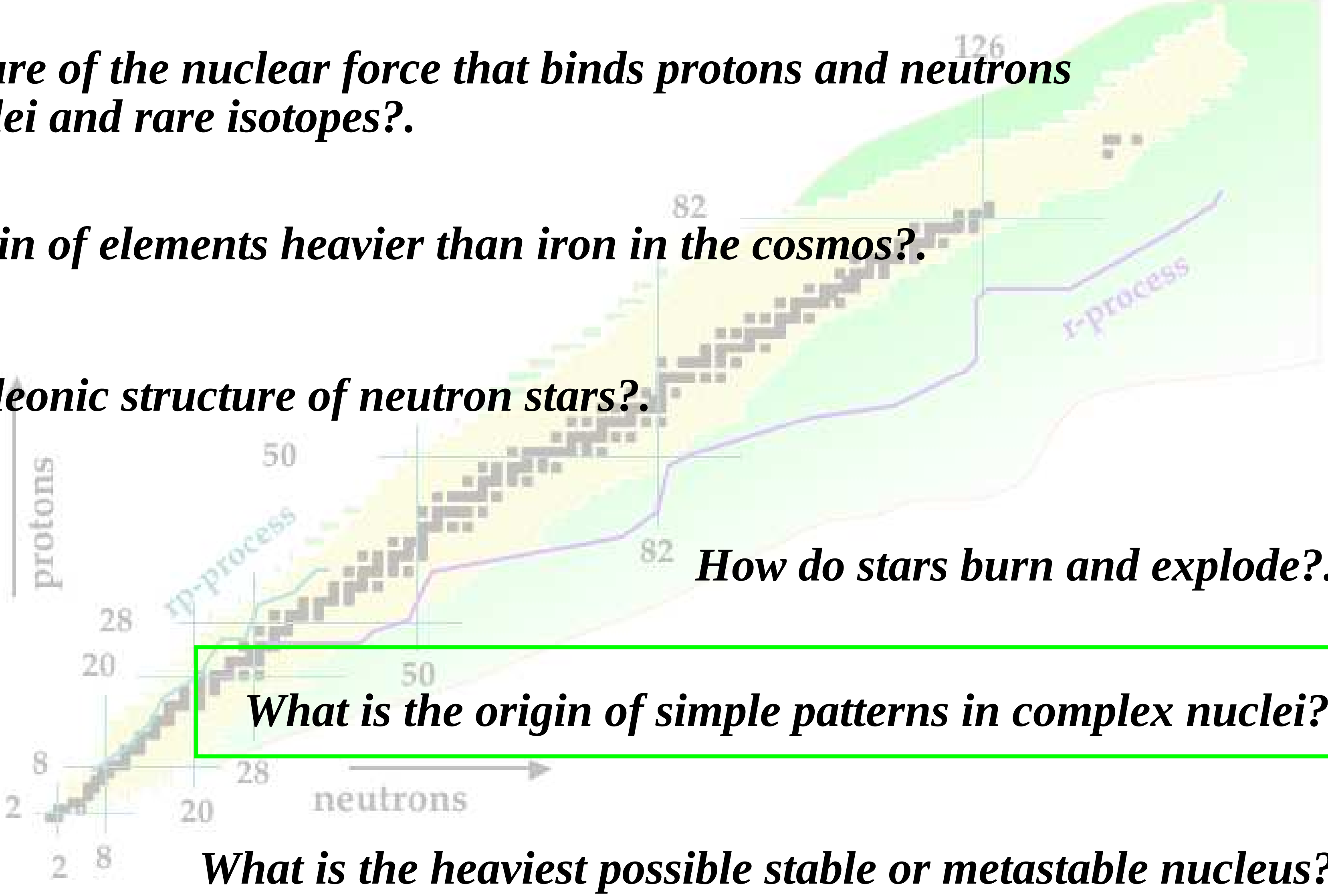
Which are the basic components of the universe we know presently?

R/ Quarks (Up, Down), electrons.

Are protons, neutrons and electrons composed by smaller particles?.

R/ Protons and neutrons are composed by quarks,
electrons are point−like particles.

Which are some of the questions that nuclear physics wants to solve?



What is the nature of the nuclear force that binds protons and neutrons into stable nuclei and rare isotopes?.

What is the origin of elements heavier than iron in the cosmos?.

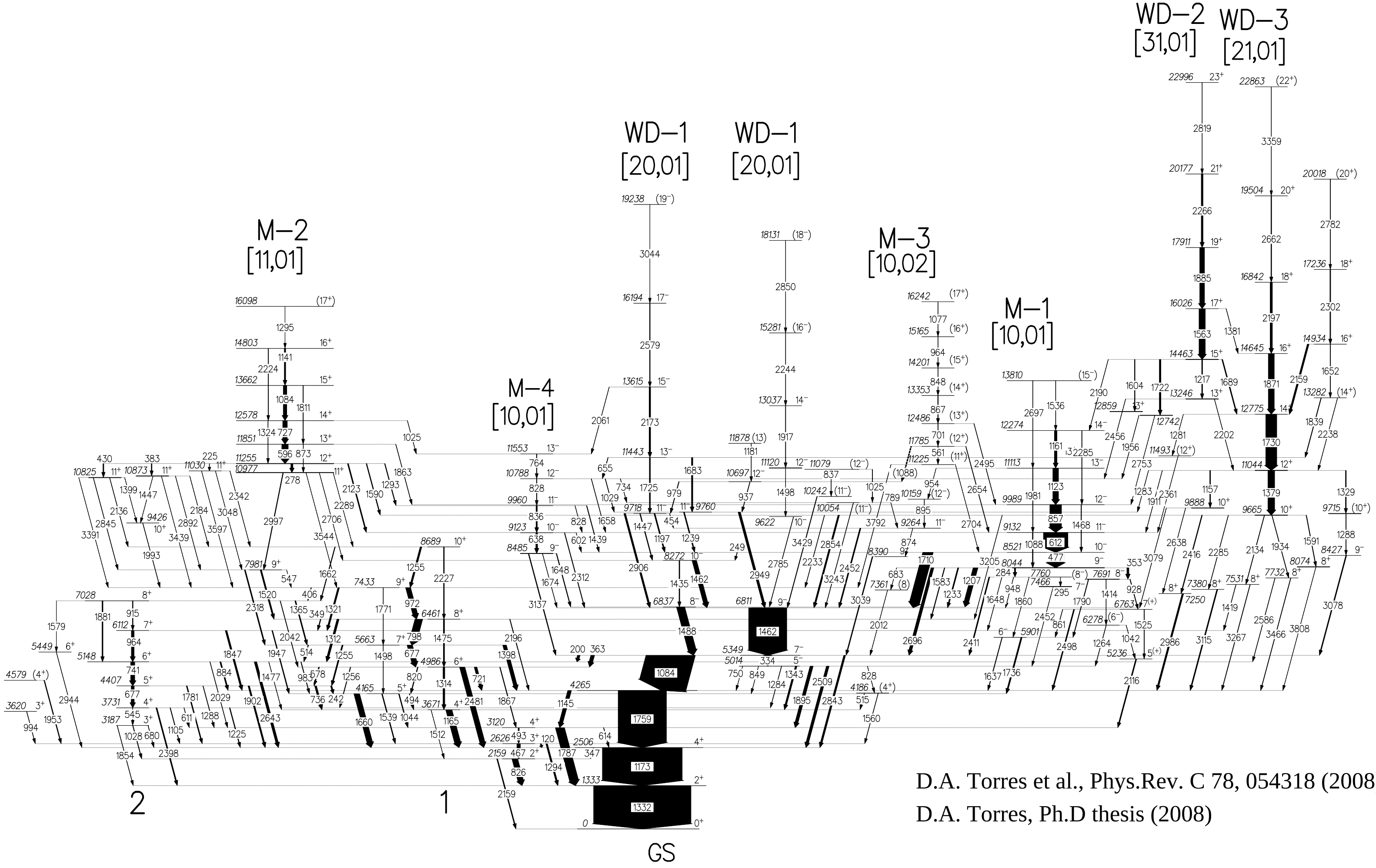
What is the nucleonic structure of neutron stars?.

How do stars burn and explode?.

What is the origin of simple patterns in complex nuclei?.

What is the heaviest possible stable or metastable nucleus?

What is the origin of simple patterns in complex nuclei?.



D.A. Torres et al., Phys.Rev. C 78, 054318 (2008)
D.A. Torres, Ph.D thesis (2008)

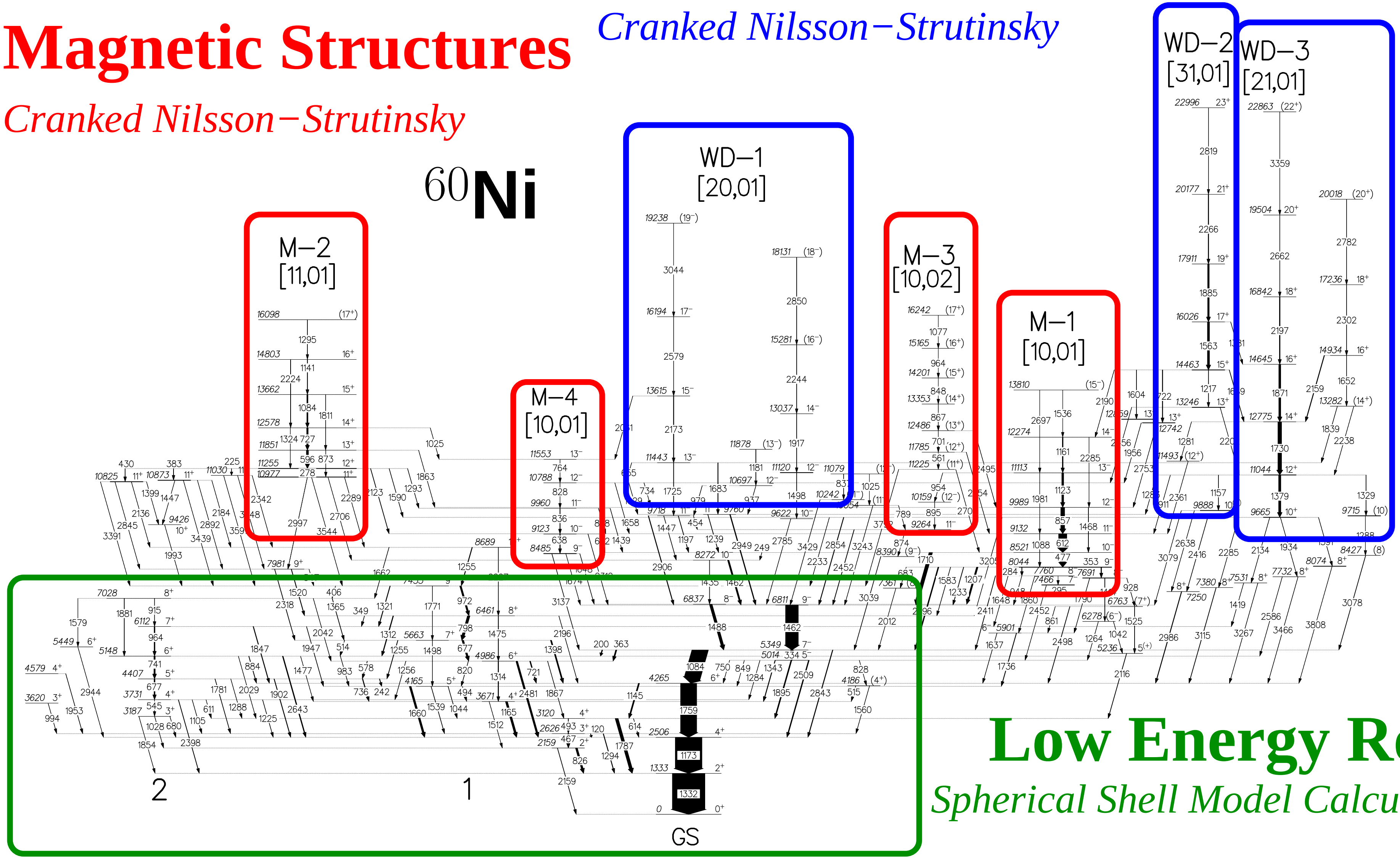
What is the origin of simple patterns in complex nuclei?.

Well Deformed Structures

Cranked Nilsson−Strutinsky

Magnetic Structures

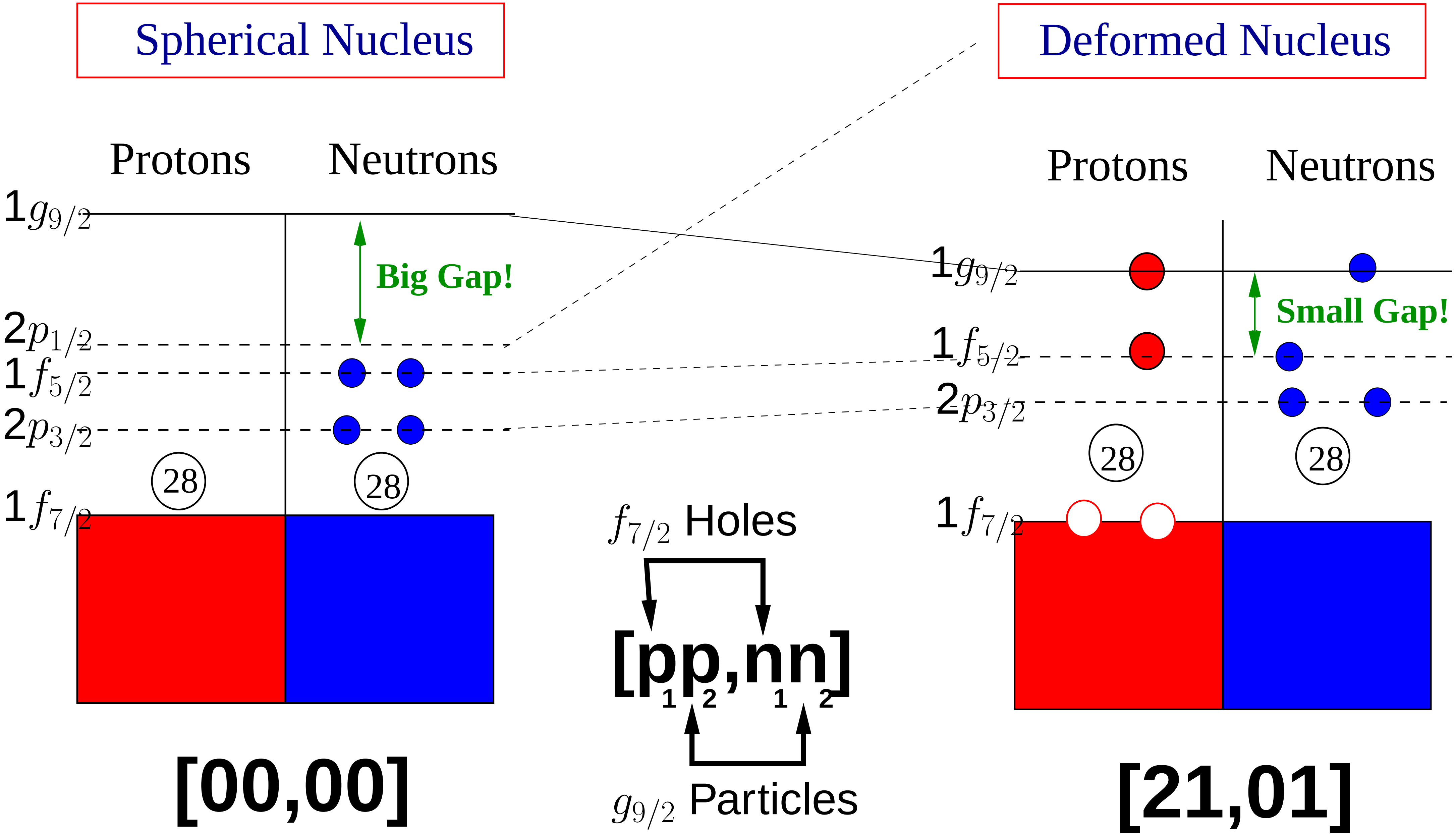
Cranked Nilsson−Strutinsky



Low Energy Region.

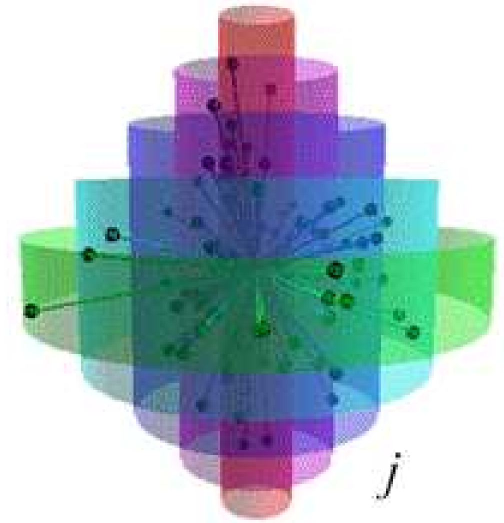
Spherical Shell Model Calculations

What is the origin of simple patterns in complex nuclei?.



What is the microscopic origin of "simple" collective structures in "complex" nuclei?.

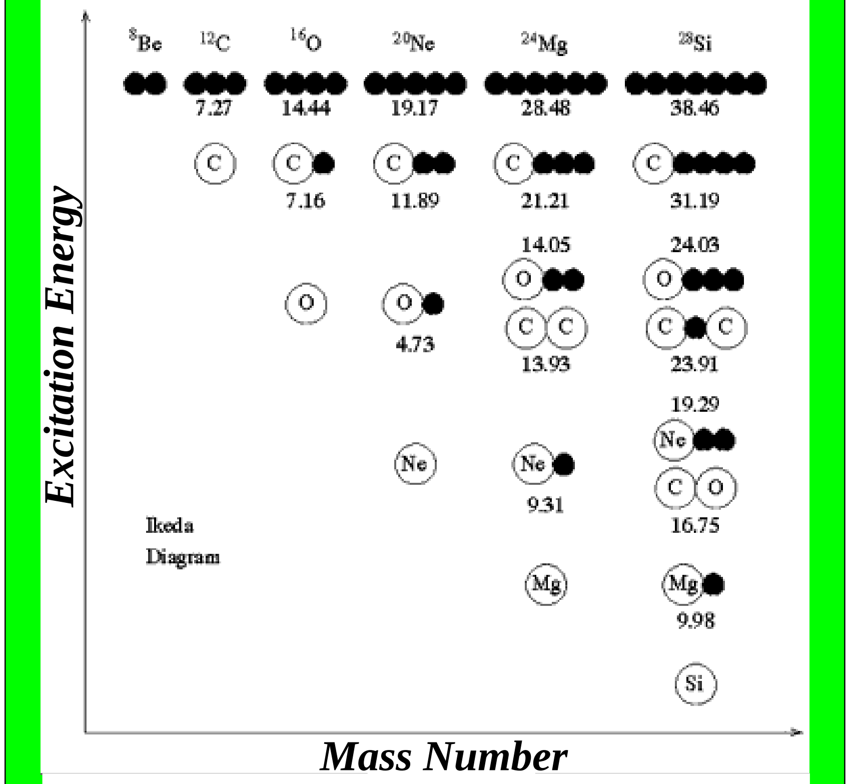
Which Nuclear Models Do We Have?



Nuclear Shell Model

(Gas)

Single Particle Model



Liquid Drop Model

(Liquid)

Vibrations, rotations, etc...

Collective Model

Cluster Model

(Molecular Model)

What Can We Measure in Nuclear Structure?

Nuclear Masses.

Excitation energies.

Parity of the States.

Lifetimes of excited and ground states.

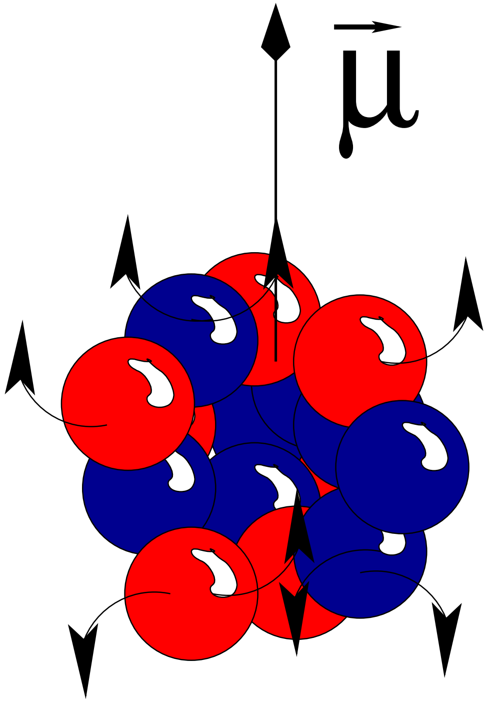
Magnetic Moments of the states.
(g factors)

⋮

What is the ‘g’ factor in the nucleus?

The nucleus is composed by moving protons and neutrons.

Current densities → Magnetic Moments.

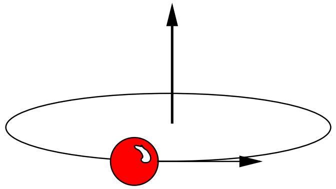


What is the ‘g’ factor in the nucleus?

The nucleus is composed by moving protons and neutrons.
Current densities → Magnetic Moments.

Orbital

$$\vec{\mu}_l = I\vec{A}$$



Classical Mechanics

$$\boxed{|\vec{\mu}_l| = \frac{e}{2m}|\vec{l}|}$$

Only protons have an orbital magnetic moment!

Quantum Mechanic

(Define a Z axis to measure)

$$\boxed{\hat{\mu}_{l_z} = \frac{e\hbar}{2m}\hat{l}_z}$$

Nuclear Magneton μ_N

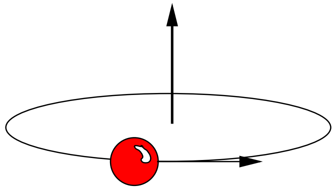
What is the ‘g’ factor in the nucleus?

The nucleus is composed by moving protons and neutrons.

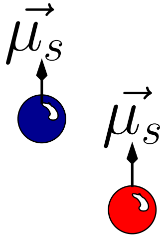
Current densities → Magnetic Moments.

Orbital

$$\vec{\mu}_l = I\vec{A}$$



Intrinsic



Classical Mechanics

$$|\vec{\mu}_l| = \frac{e}{2m}|\vec{l}|$$

Quantum Mechanic

(Define a Z axis to measure)

$$\hat{\mu}_{l_z} = \frac{e\hbar}{2m}\hat{l}_z$$

Nuclear Magneton μ_N

+

No Classical Mechanics Picture

Quantum Mechanic

$$\hat{\mu}_{s_z} = g_s\frac{e\hbar}{2m}\hat{s}_z$$

$$g_{s,\nu} = -3.8263$$

$$g_{s,\pi} = 5.5845$$

Protons and Neutrons have opposite signs in their intrinsic magnetic moments!

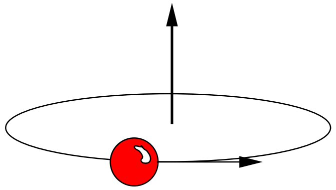
What is the 'g' factor in the nucleus?

The nucleus is composed by moving protons and neutrons.

Current densities → Magnetic Moments.

Orbital

$$\vec{\mu}_l = I\vec{A}$$



Classical Mechanics

$$\boxed{|\vec{\mu}_l| = \frac{e}{2m}|\vec{l}|}$$

Quantum Mechanic

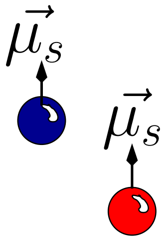
(Define a Z axis to measure)

$$\boxed{\hat{\mu}_{l_z} = \frac{e\hbar}{2m}\hat{l}_z}$$

Nuclear Magneton μ_N

+

Intrinsic



No Classical Mechanics Picture

Quantum Mechanic

$$\boxed{\hat{\mu}_{s_z} = g_s\frac{e\hbar}{2m}\hat{s}_z}$$

$$g_{s,\nu} = -3.8263$$

$$g_{s,\pi} = 5.5845$$

$\longrightarrow$

Nuclear Magnetic Moment

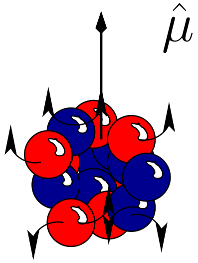
$$\hat{I} = \hat{l} + \hat{s}$$

$$\hat{I}_z = \hat{l}_z + \hat{s}_z$$

We define:

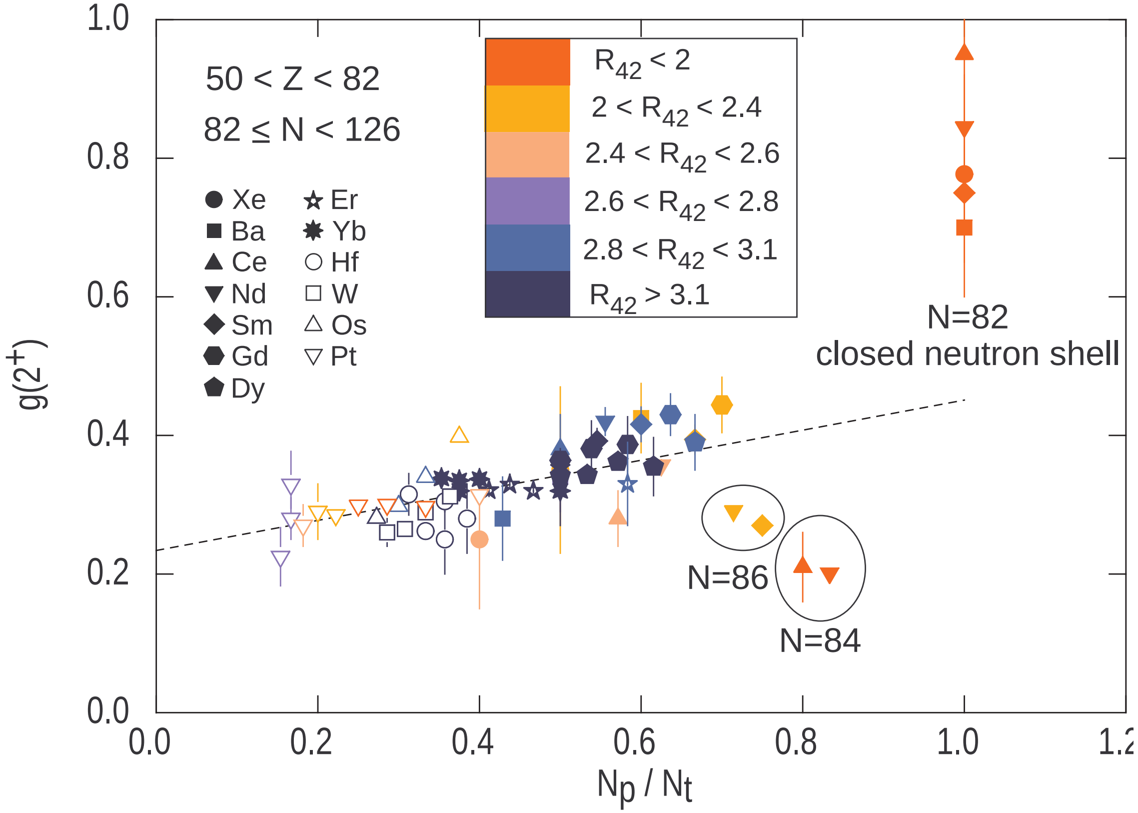
$$\hat{\mu}_{I_z} = \sum^{A}\hat{\mu}^i_{I_z} = \sum \hat{\mu}_{l_z}{}^i + \hat{\mu}^i_{s_z}$$

When $I_z = I$ (aligned)

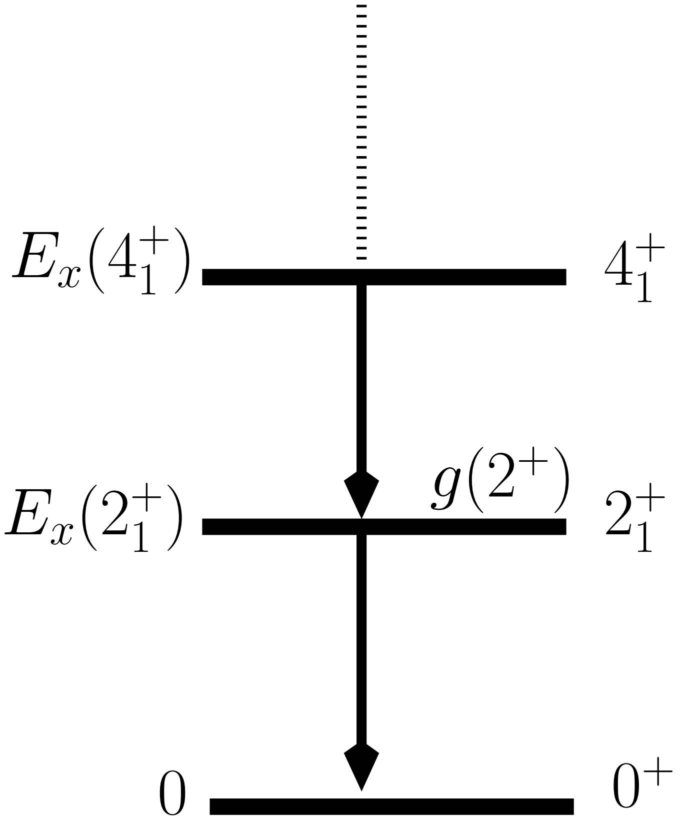


We measured: $\boxed{g = \frac{\mu/\mu_N}{I/\hbar}}$

The $50 \leq Z < 82$ and $82 \leq N < 126$ region



$$R_{42} = E_x(4_1^+)/E_x(2_1^+)$$



N_p; number of valence protons or proton holes relative to the nearest magic number.

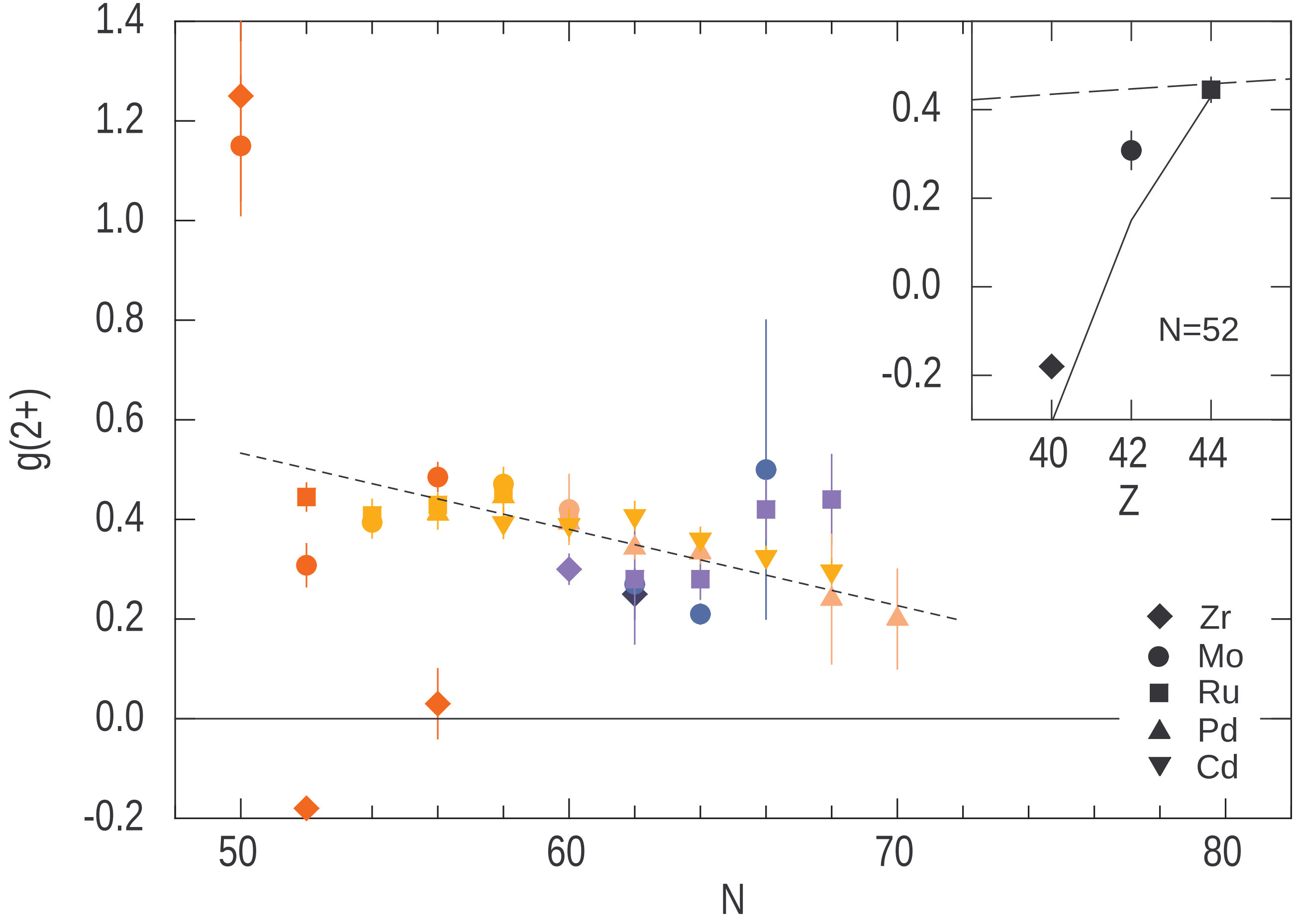
N_t; number of valence nucleons ($\pi + \nu$) relative to the nearest magic number.

…………………… $g_{IBM} = g_\nu + (g_\pi - g_\nu)(N_p/N_t)$ for $N_p/N_t < 0.7$ with $g_\nu = 0.23$ and $g_\pi = 0.45$.

$g(2_1^+)$ different from $g = Z/A$.

From Andrew E. Stuchberry, Journal of Physics: Conference series 266 (2012) 012042

The $40 \le Z \le 50$ **and** $50 \le N < 82$ **region**



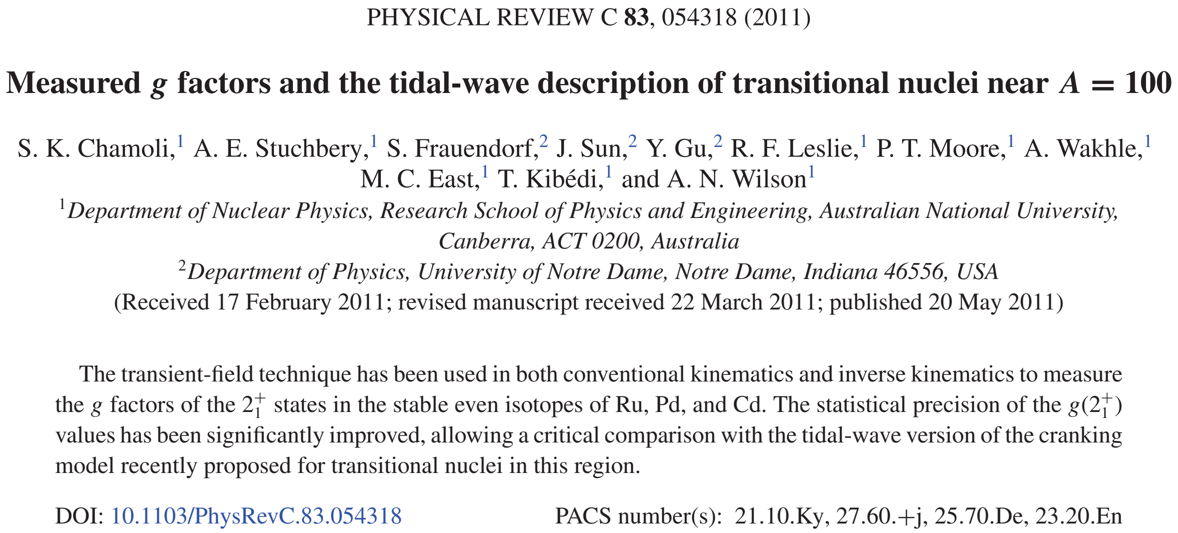
…… $g = Z/A$

In the region g factors are not well correlated with N_p/N_t.

Instead they decrease steadily as N increases!.

The Tidal−Wave Model by Frauendorf and collaborators

Description of the yrast states of transitional and deformed nuclei by means of the self-consistent cranking model.



PHYSICAL REVIEW C **83**, 054318 (2011)

Measured g factors and the tidal-wave description of transitional nuclei near $A = 100$

S. K. Chamoli,[1] A. E. Stuchbery,[1] S. Frauendorf,[2] J. Sun,[2] Y. Gu,[2] R. F. Leslie,[1] P. T. Moore,[1] A. Wakhle,[1]
M. C. East,[1] T. Kibédi,[1] and A. N. Wilson[1]
[1] *Department of Nuclear Physics, Research School of Physics and Engineering, Australian National University, Canberra, ACT 0200, Australia*
[2] *Department of Physics, University of Notre Dame, Notre Dame, Indiana 46556, USA*

(Received 17 February 2011; revised manuscript received 22 March 2011; published 20 May 2011)

The transient-field technique has been used in both conventional kinematics and inverse kinematics to measure the g factors of the 2_1^+ states in the stable even isotopes of Ru, Pd, and Cd. The statistical precision of the $g(2_1^+)$ values has been significantly improved, allowing a critical comparison with the tidal-wave version of the cranking model recently proposed for transitional nuclei in this region.

DOI: 10.1103/PhysRevC.83.054318 PACS number(s): 21.10.Ky, 27.60.+j, 25.70.De, 23.20.En

The model allows the calculation of the magnetic moment directly from the nucleonic currents.

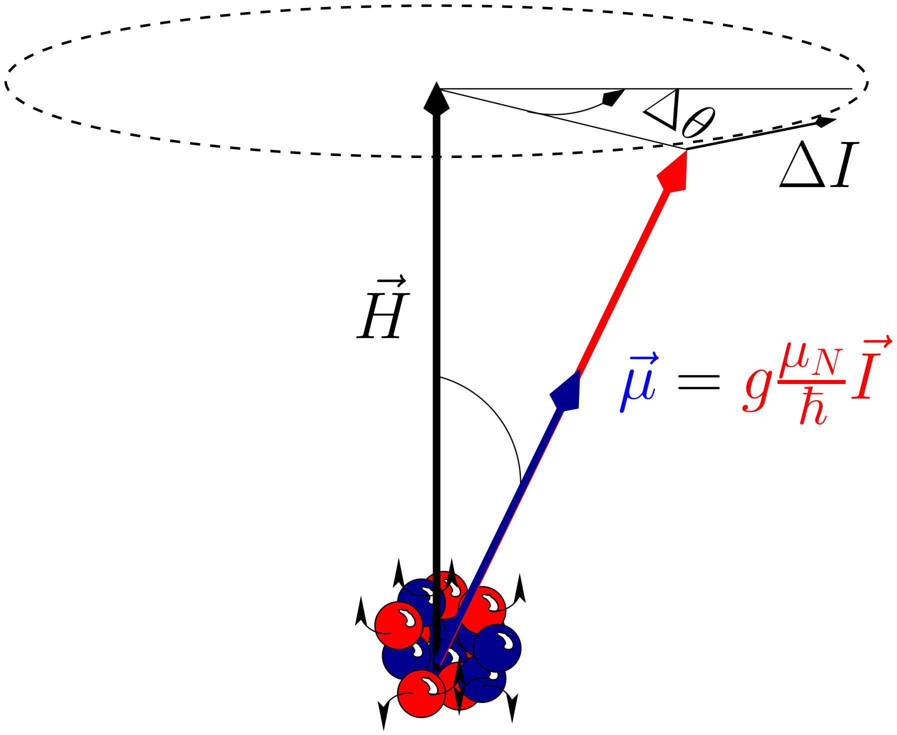
The model propose that the origin of the difference is contribution of the $h_{11/2}$ neutrons.

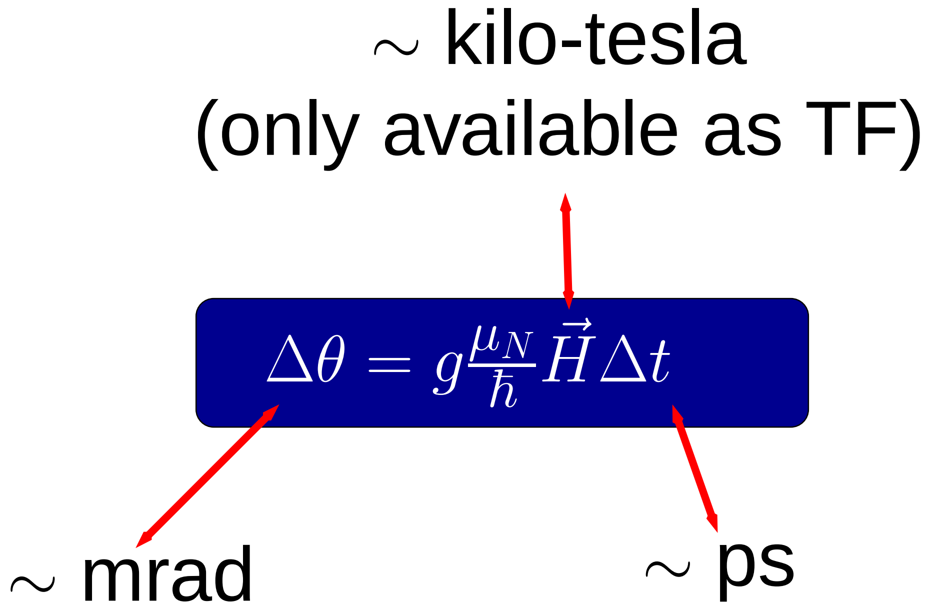
It predicts that $i_{11/2}$ and $j_{15/2}$ neutrons will reduce the g factor values of high-spin states below the Z/A.

How do we measure $\vec{\mu}$?

-) The interaction between $\vec{\mu}$ and $\vec{H}$ creates a torque:

$$\boxed{\vec{\tau} = \vec{\mu} \times \vec{H}}$$





$\sim$ kilo-tesla
(only available as TF)

$$\Delta\theta = g\frac{\mu_N}{\hbar}\vec{H}\Delta t$$

$\sim$ mrad

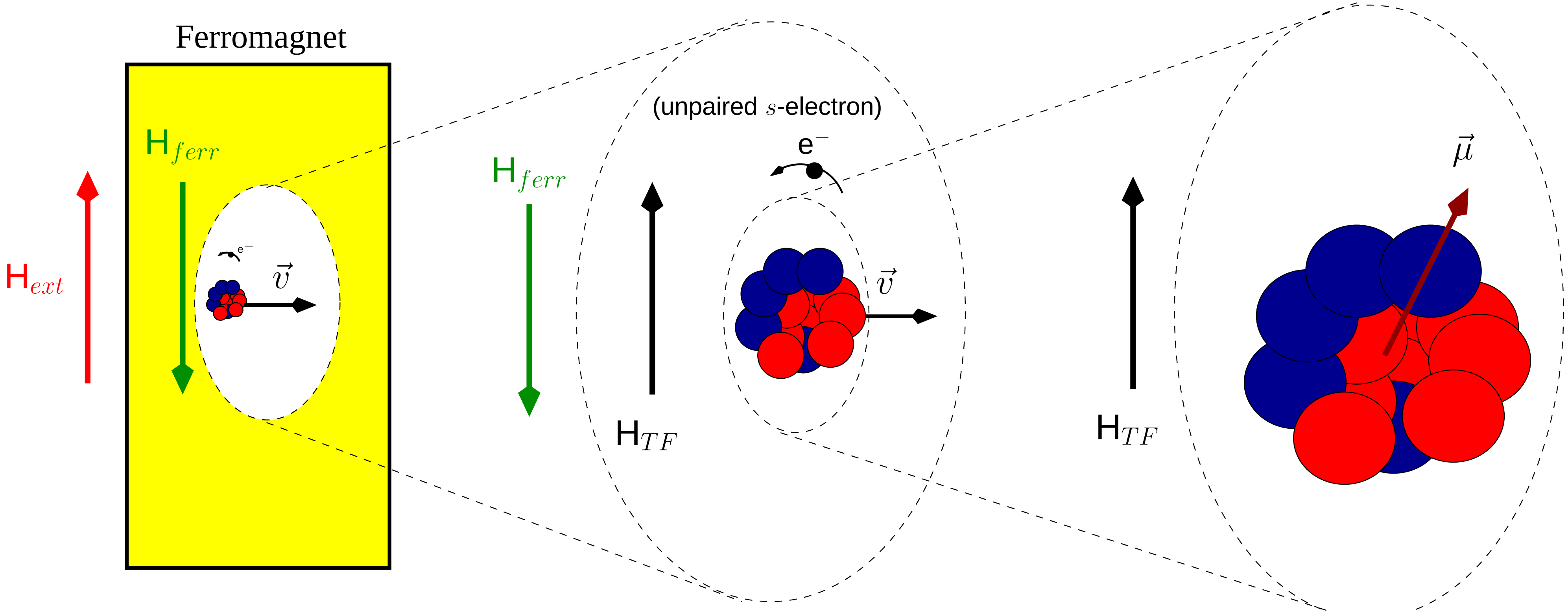
$\sim$ ps

Our goal is to measure $\Delta\theta$ to obtain a g factor.

The Transient Field (TF)

TF are experienced by nuclei when ions move through ferromagnetic materials.

They arise from the polarization of unpaired s electrons of the moving ion following spin exchange with the magnetized electrons of the ferromagnet.



The real picture is more complex and not totally understood, but there are some facts:

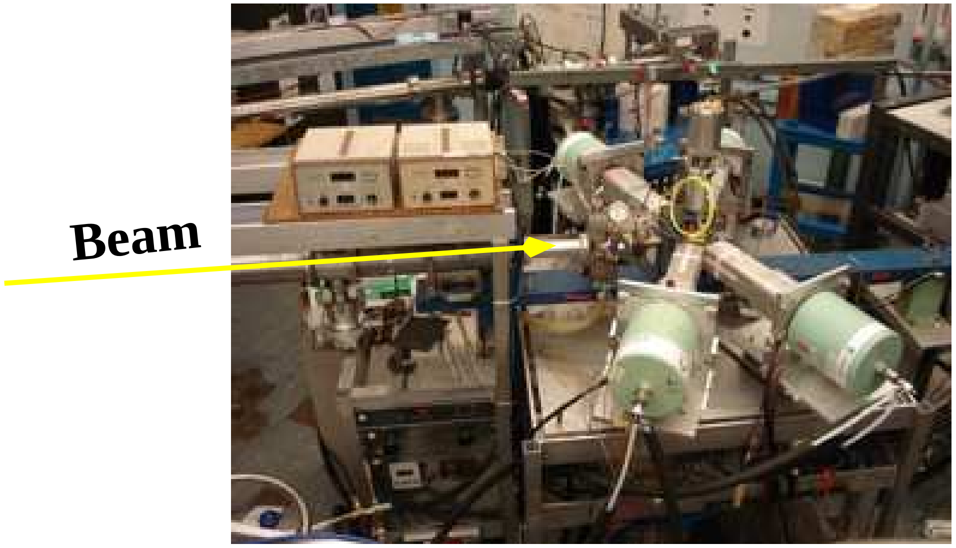
1) H_{TF} has the same direction of H_{ext}.

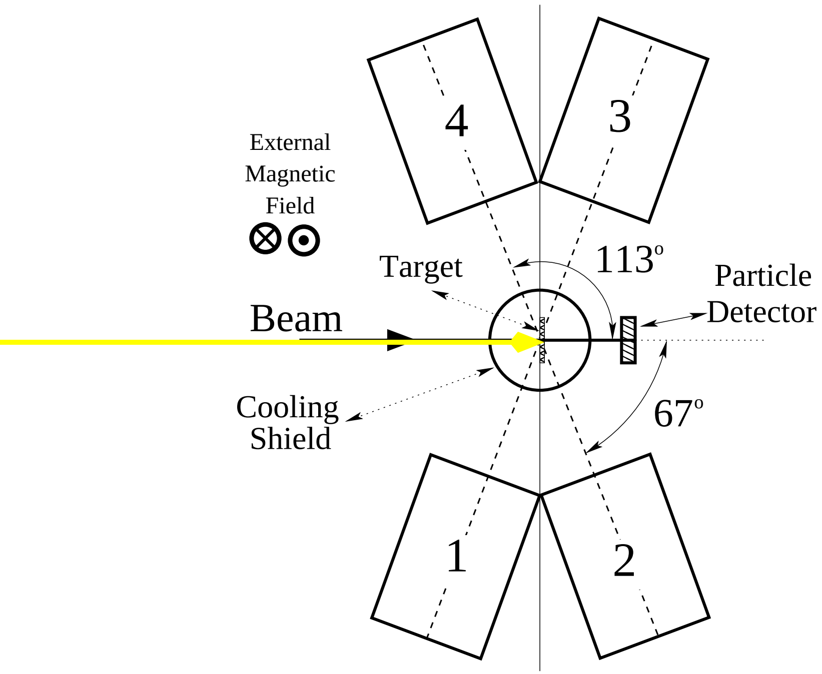
2) The strength of the TF is proportional to the velocity of the ion.
The maximun field strength is reached when $v = v_{Bohr}$ of the $1s$ electron state.

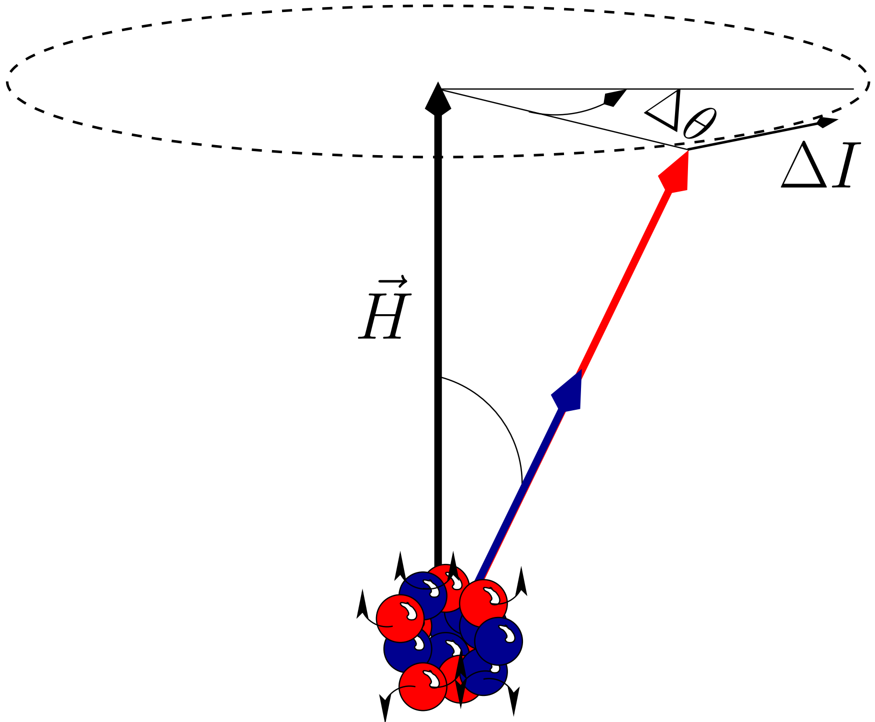
3) There is a dependence with the Z numbers of the ion and the ferromagnet.

4) A parametrisation must be use to obtain $H_{TF}(v_{ion}, Z_{ion}, Z_{target})$.

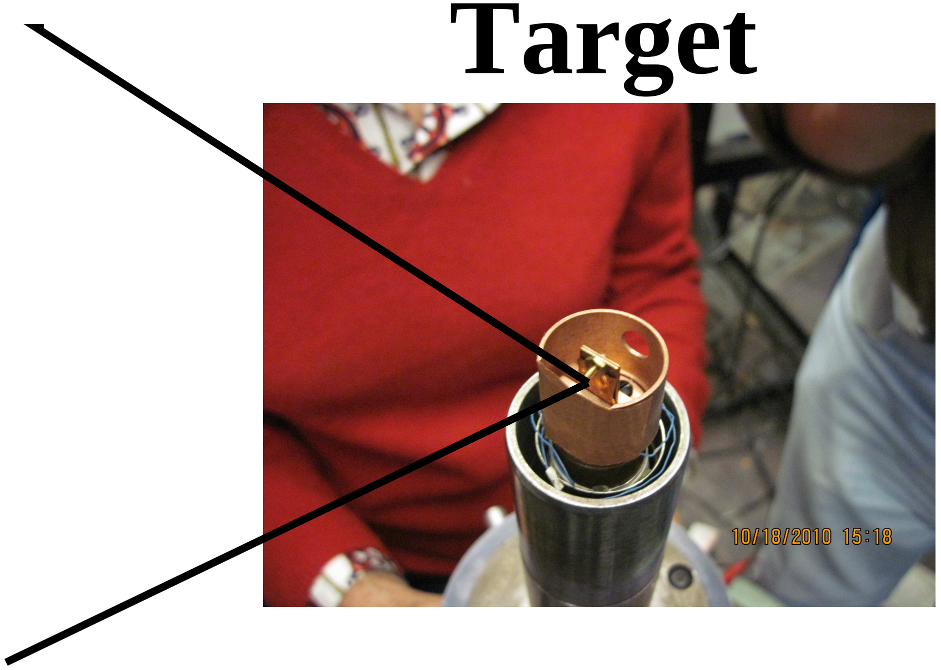
How do we measure $\vec{\mu}$?



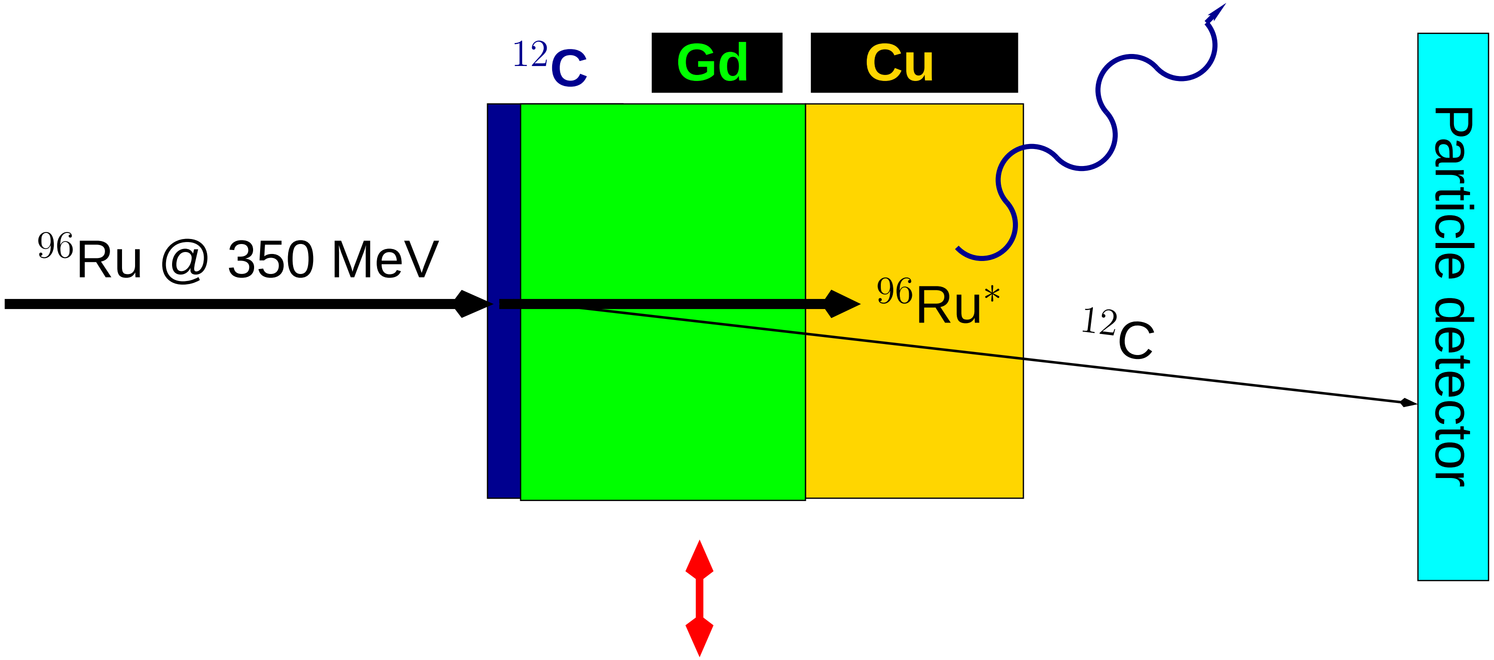




Target

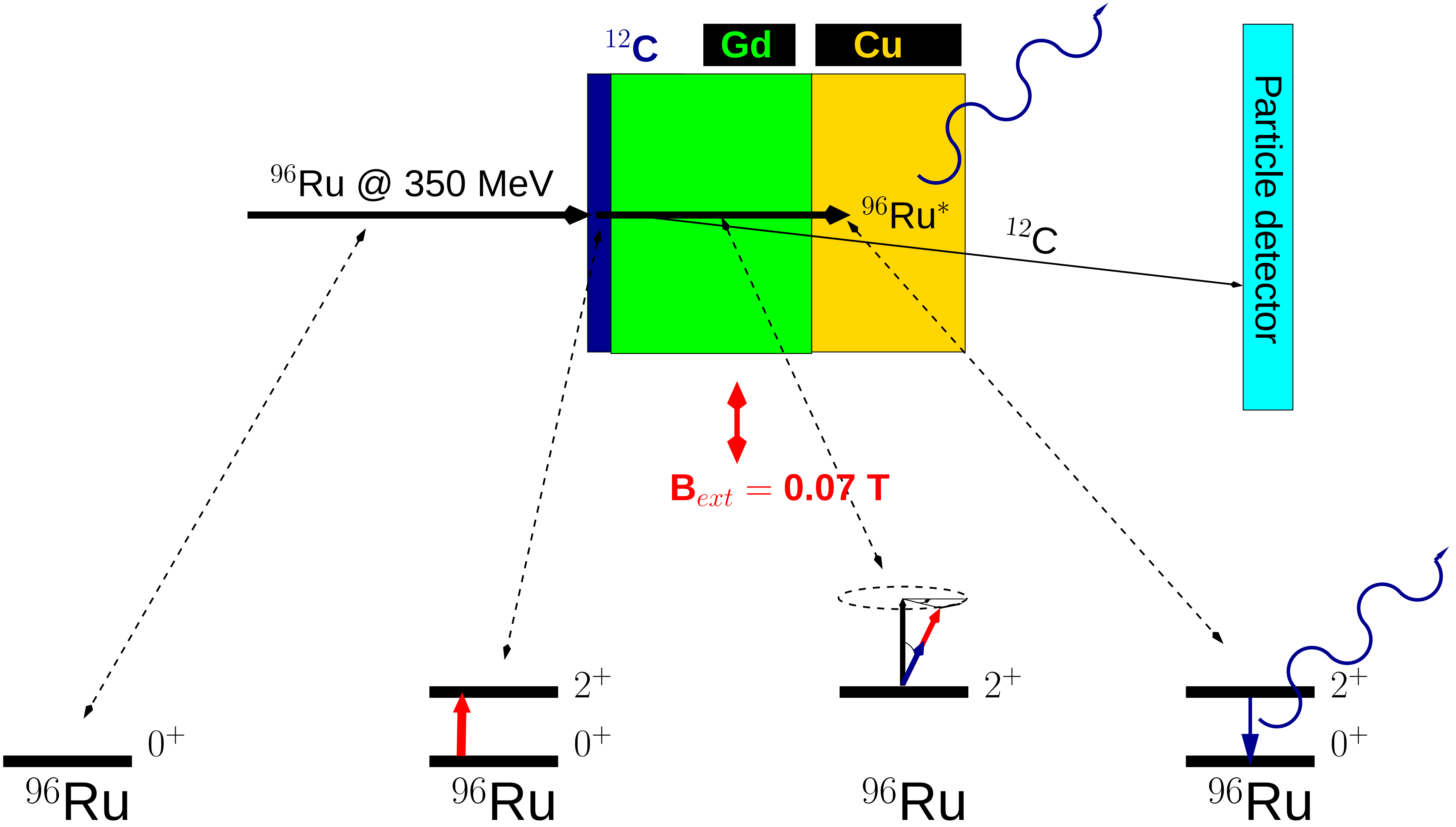


Coulomb Excitation Experiment: ^{12}C(^{96}Ru,^{12}C)^{96}Ru* @ 350 MeV

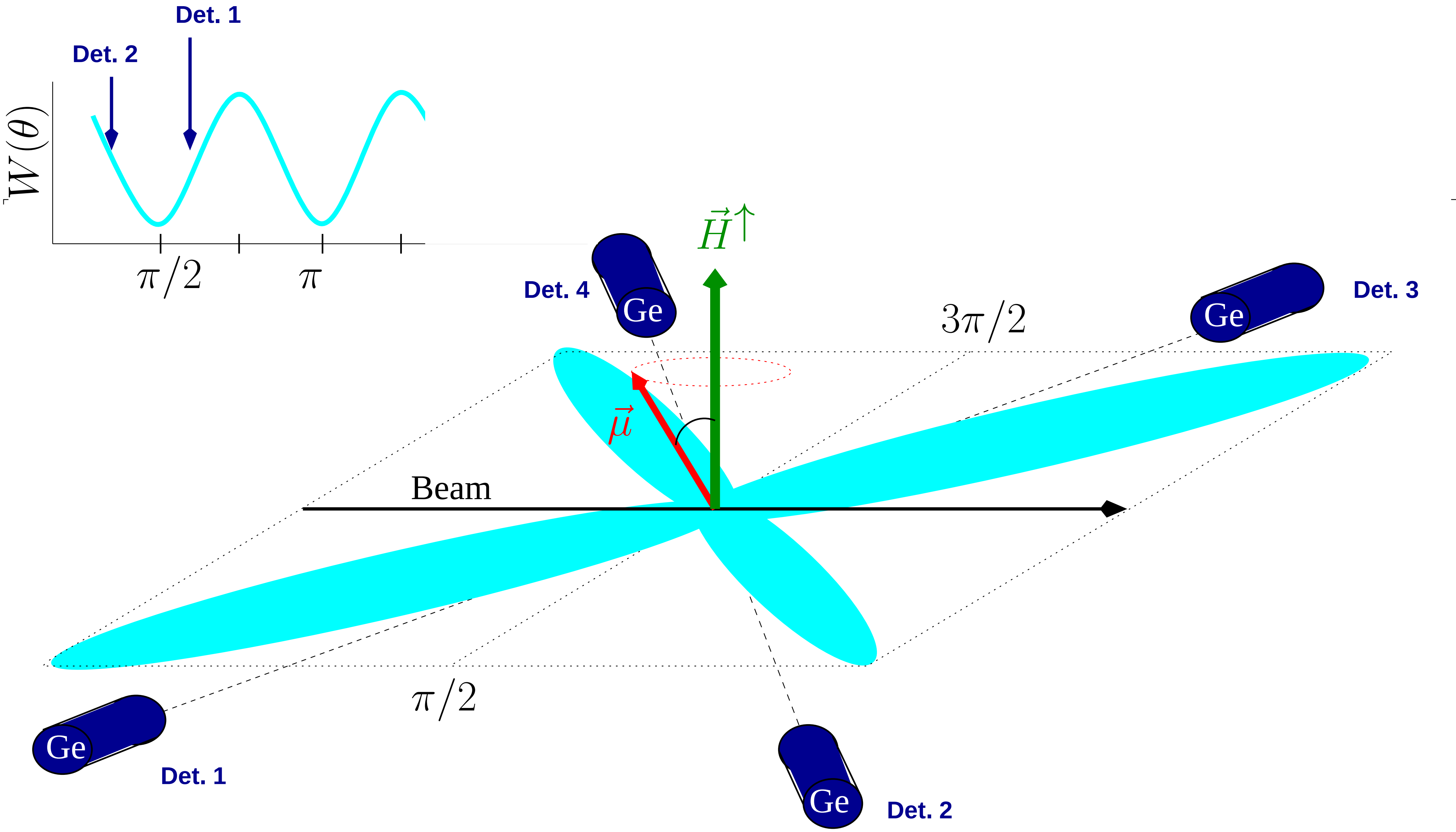


B$_{ext}$ = 0.07 T

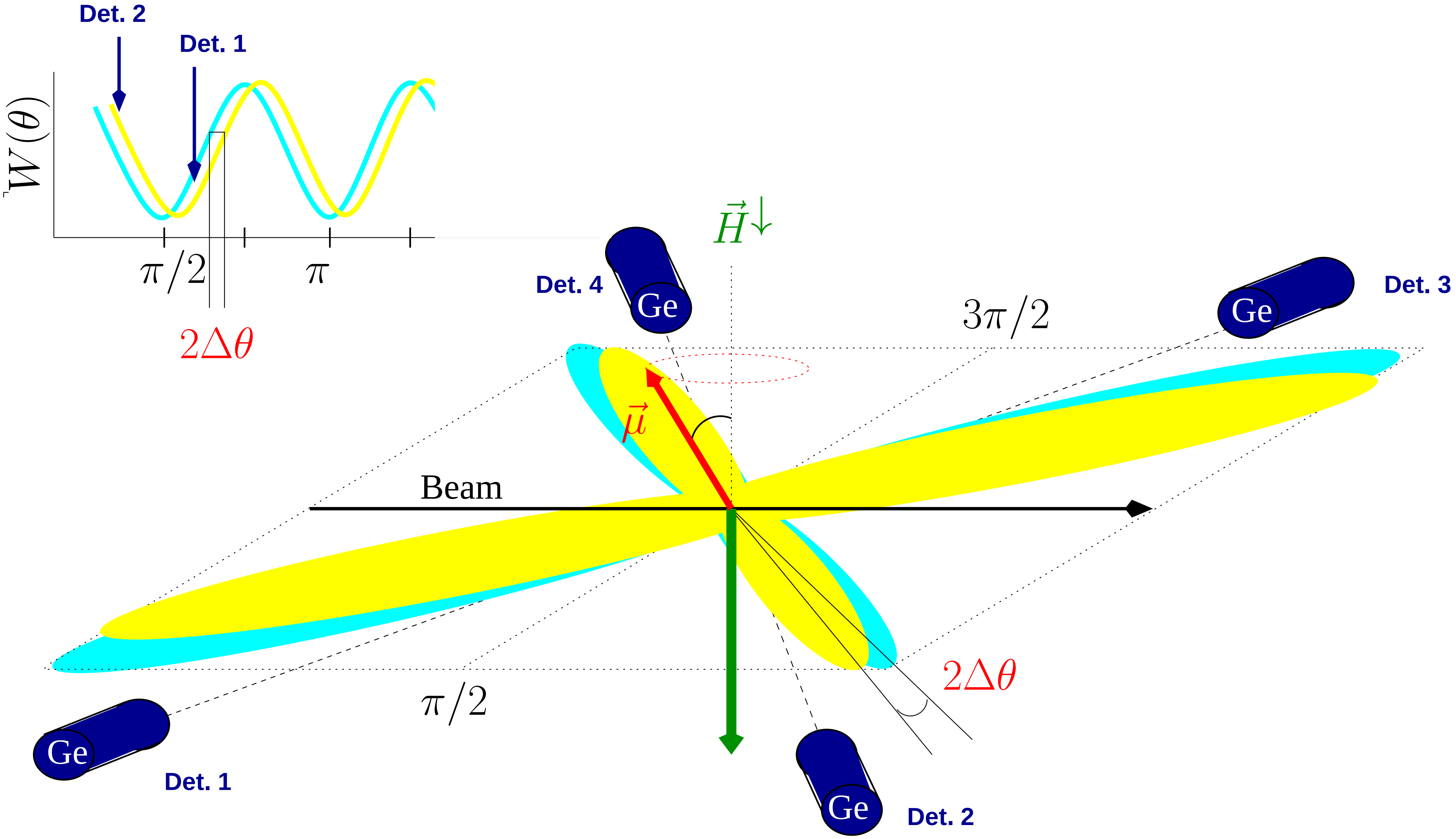
Coulomb Excitation Experiment: ^{12}C(^{96}Ru,^{12}C)^{96}Ru* @ 350 MeV



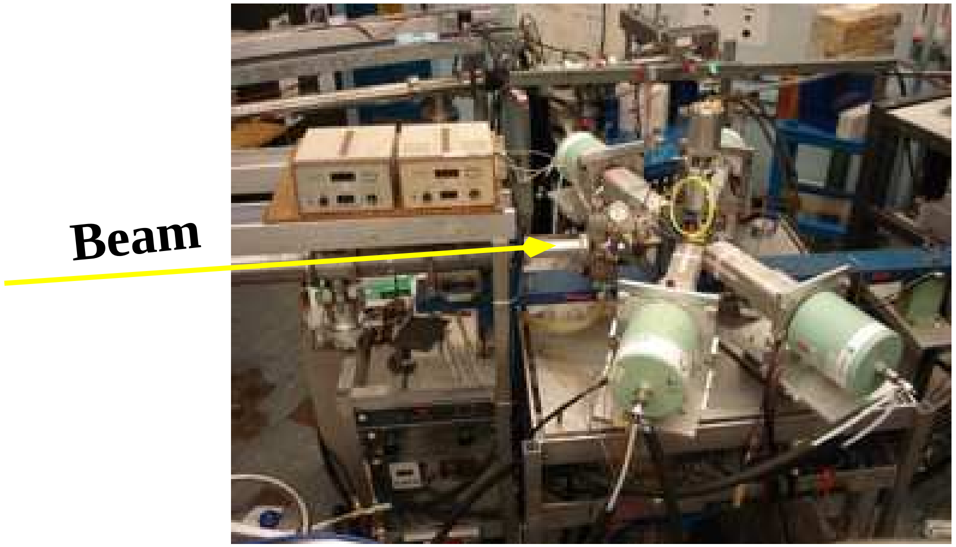
Quadrupolar emission from an oriented state $I_z = I$ with $\vec{H}\uparrow$

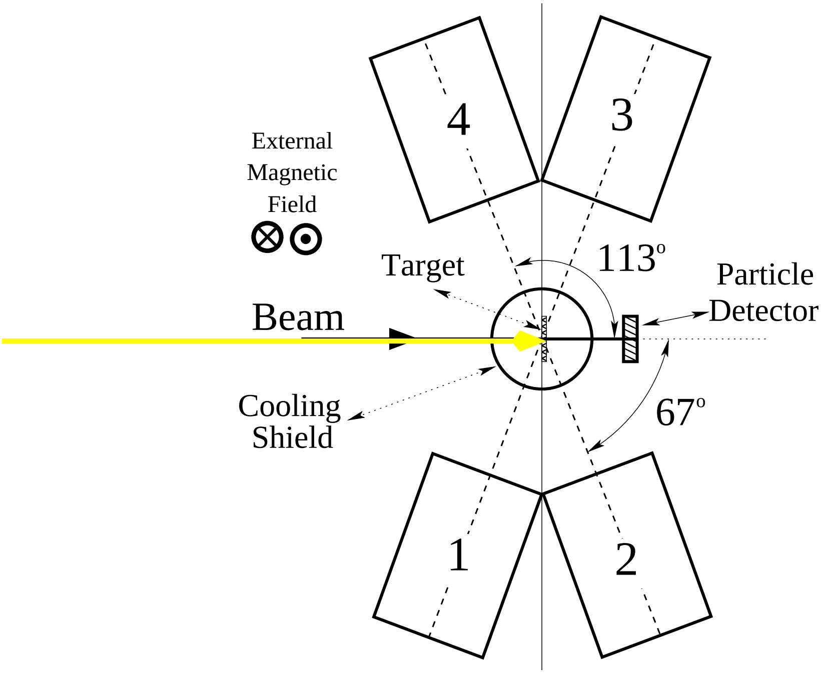


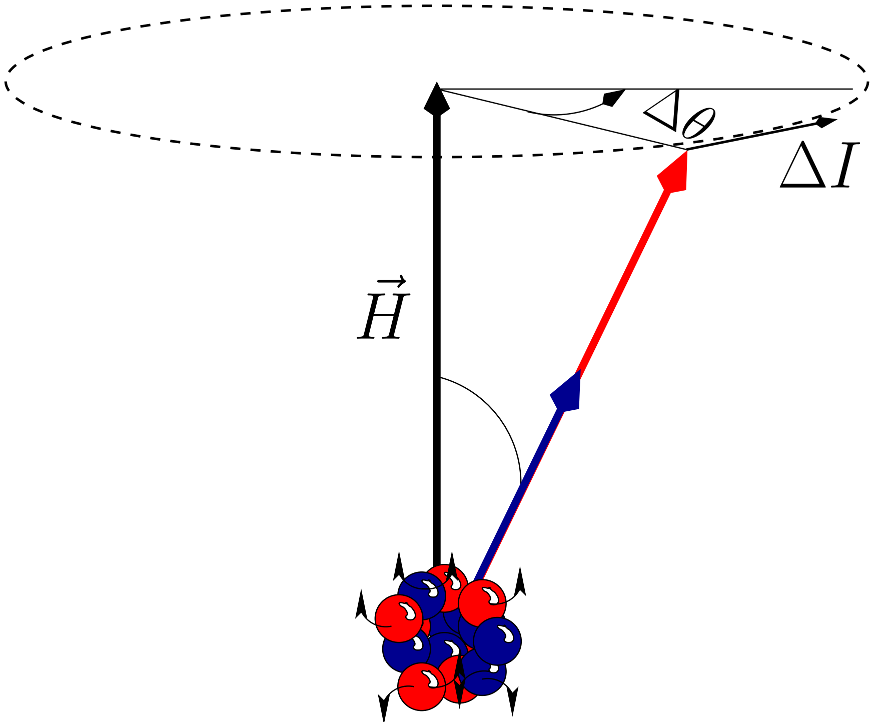
Quadrupolar emission from an oriented state $I_z = I$ with $\vec{H}\downarrow$



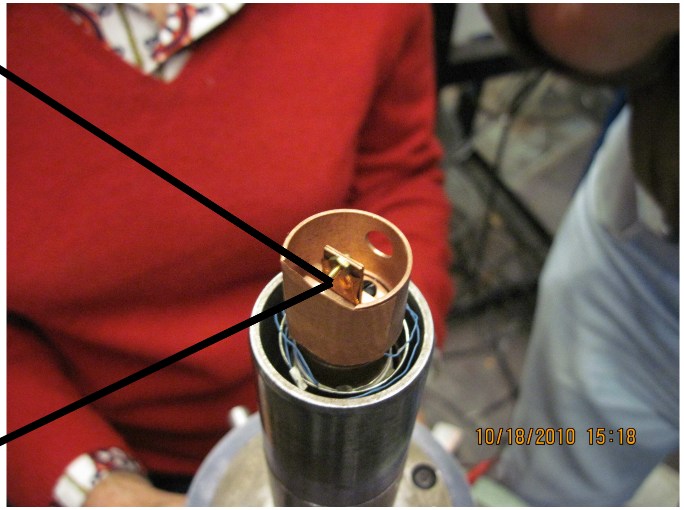
How do we measure $\vec{\mu}$?



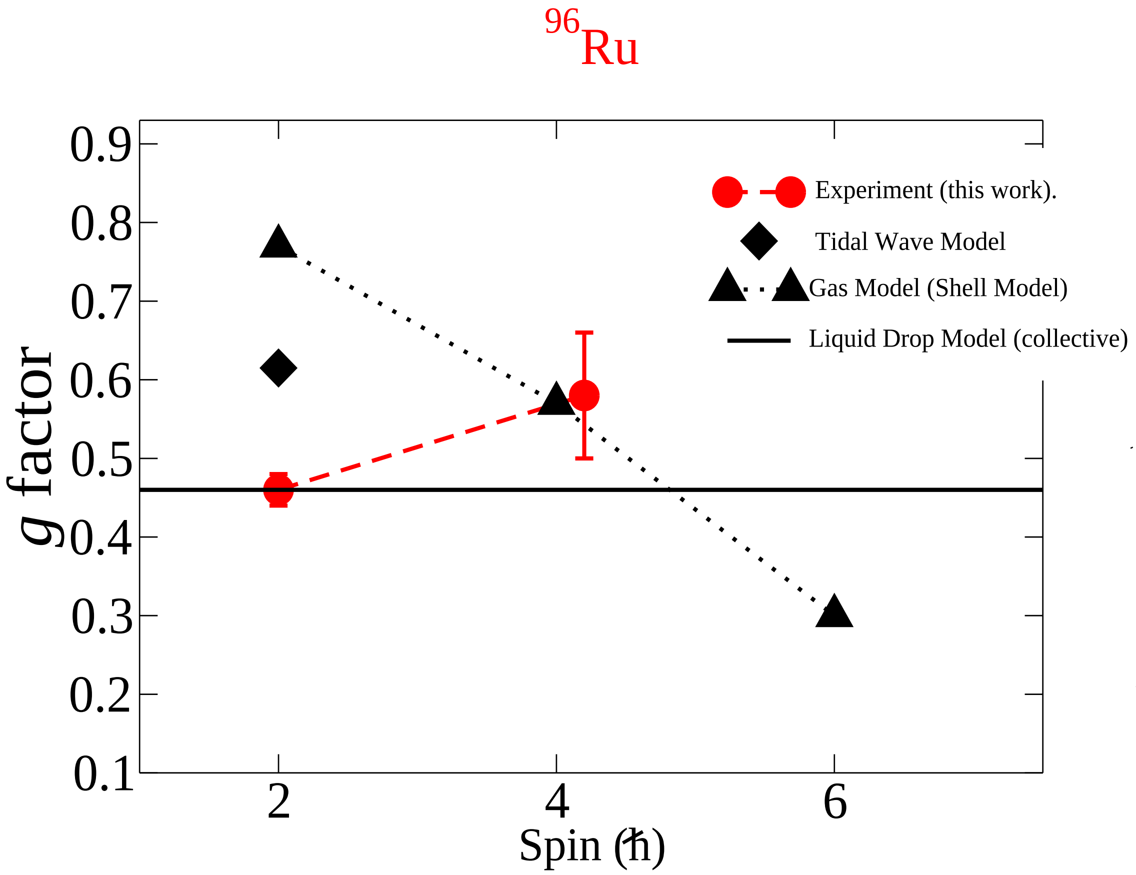


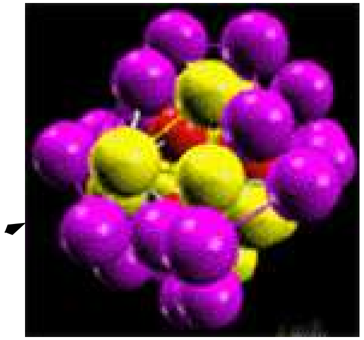


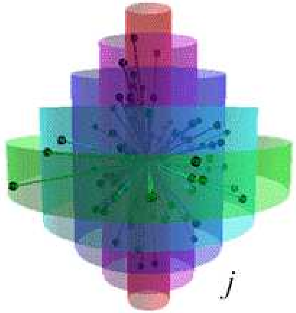
Target



Results for $^{96}_{44}$Ru

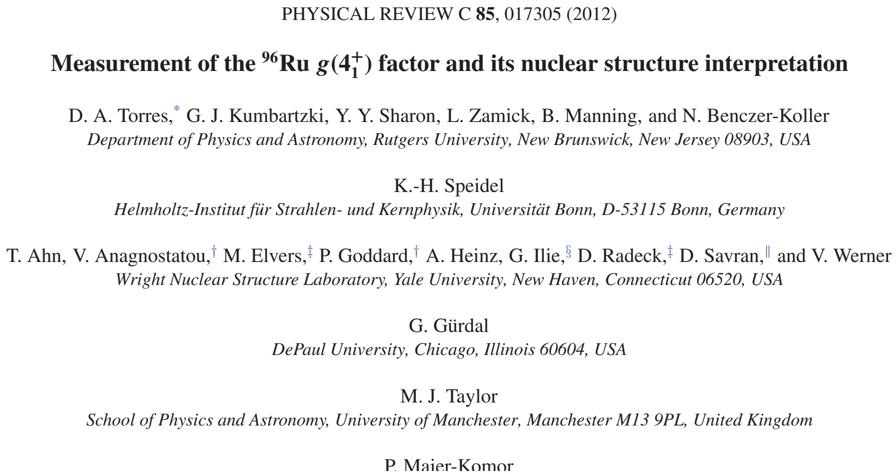






^{96}Ru

$$g(2_1^+) = +0.46(0.02)$$
$$g(4_1^+) = +0.58(0.08)$$



PHYSICAL REVIEW C **85**, 017305 (2012)

Measurement of the ^{96}Ru $g(4_1^+)$ factor and its nuclear structure interpretation

D. A. Torres,[*] G. J. Kumbartzki, Y. Y. Sharon, L. Zamick, B. Manning, and N. Benczer-Koller
Department of Physics and Astronomy, Rutgers University, New Brunswick, New Jersey 08903, USA

K.-H. Speidel
Helmholtz-Institut für Strahlen- und Kernphysik, Universität Bonn, D-53115 Bonn, Germany

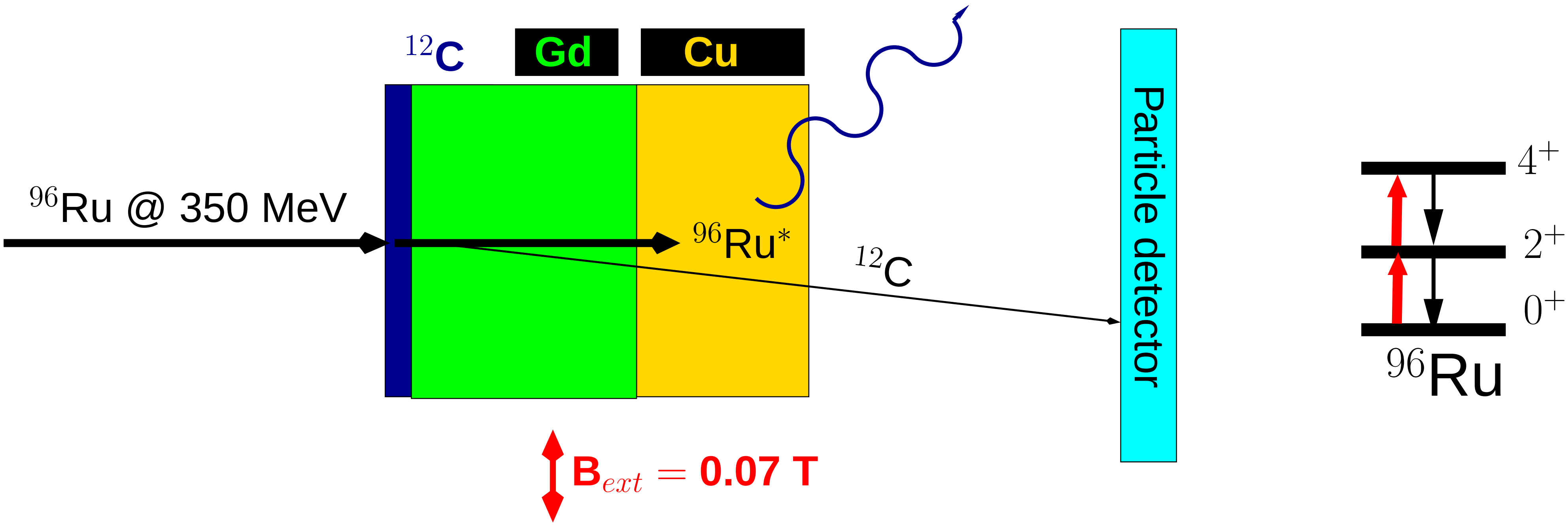
T. Ahn, V. Anagnostatou,[†] M. Elvers,[‡] P. Goddard,[†] A. Heinz, G. Ilie,[§] D. Radeck,[‡] D. Savran,[∥] and V. Werner
Wright Nuclear Structure Laboratory, Yale University, New Haven, Connecticut 06520, USA

G. Gürdal
DePaul University, Chicago, Illinois 60604, USA

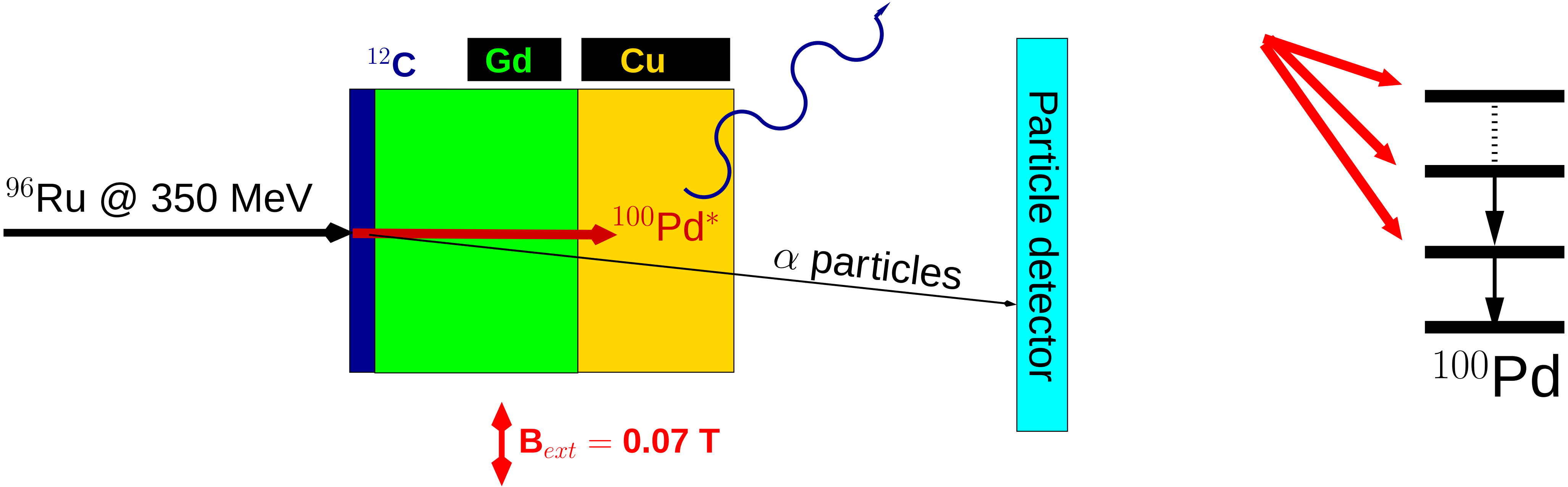
M. J. Taylor
School of Physics and Astronomy, University of Manchester, Manchester M13 9PL, United Kingdom

P. Maier-Komor

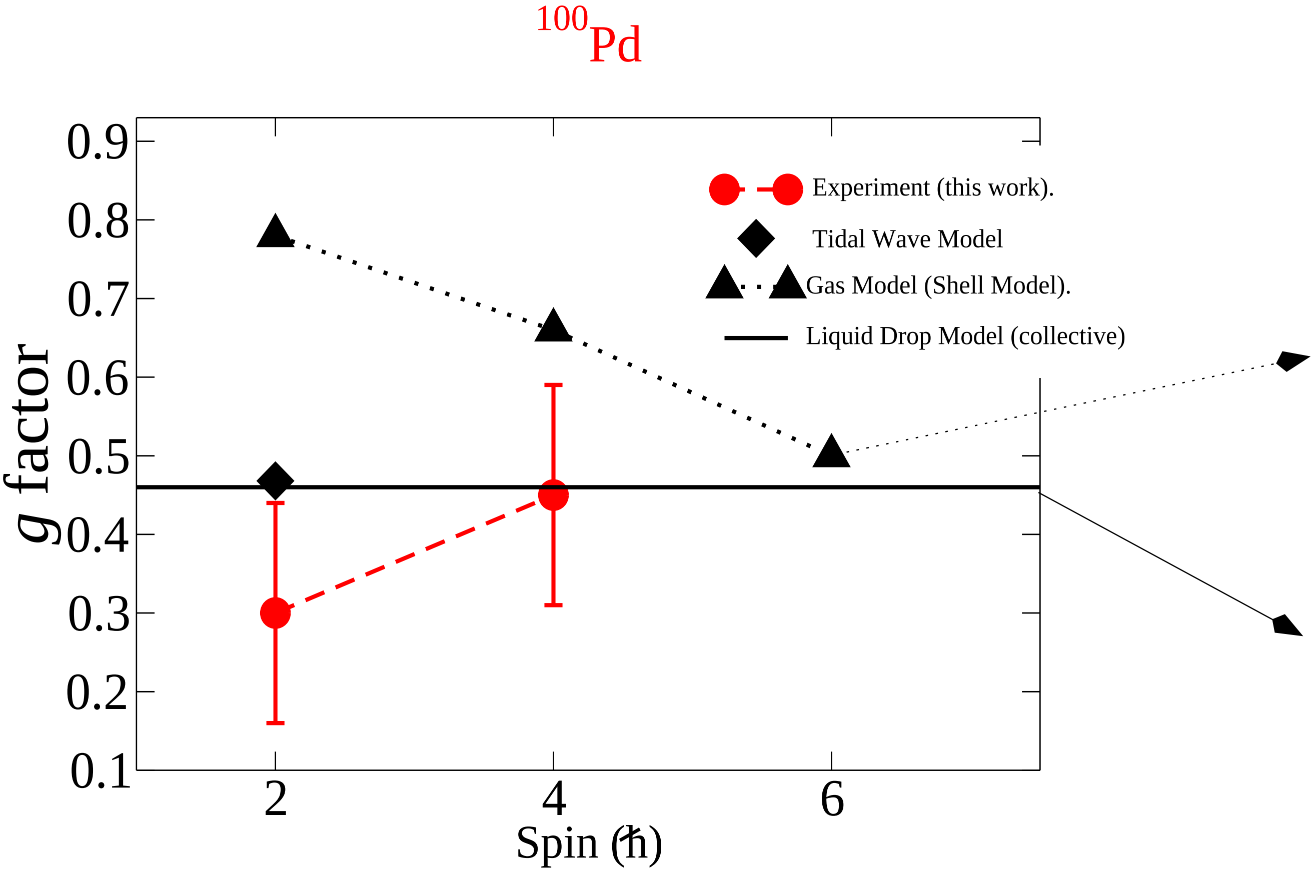
Coulomb Excitation Experiment: ^{12}C(^{96}Ru,^{12}C)^{96}Ru* @ 350 MeV

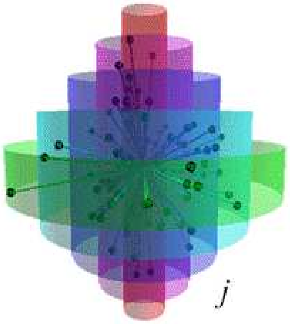


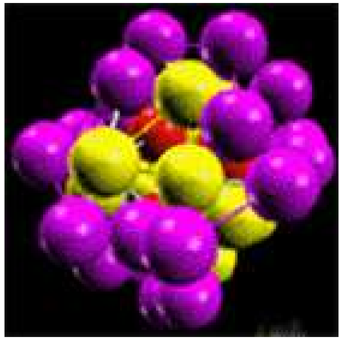
α-transfer experiment: ^{12}C(^{96}Ru,2α)^{100}Pd* @ 350 MeV



Results $^{100}_{46}$Pd

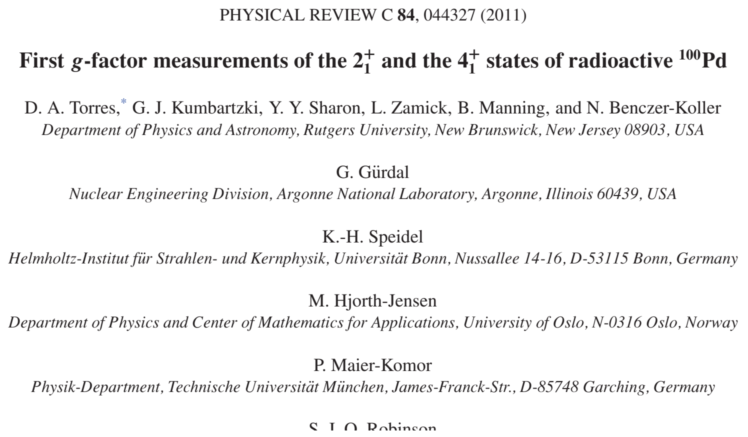






^{100}Pd

$$g(2_1^+) = +0.30(0.14)$$
$$g(4_1^+) = +0.45(0.14)$$



PHYSICAL REVIEW C **84**, 044327 (2011)

First g-factor measurements of the 2_1^+ and the 4_1^+ states of radioactive ^{100}Pd

D. A. Torres,* G. J. Kumbartzki, Y. Y. Sharon, L. Zamick, B. Manning, and N. Benczer-Koller
Department of Physics and Astronomy, Rutgers University, New Brunswick, New Jersey 08903, USA

G. Gürdal
Nuclear Engineering Division, Argonne National Laboratory, Argonne, Illinois 60439, USA

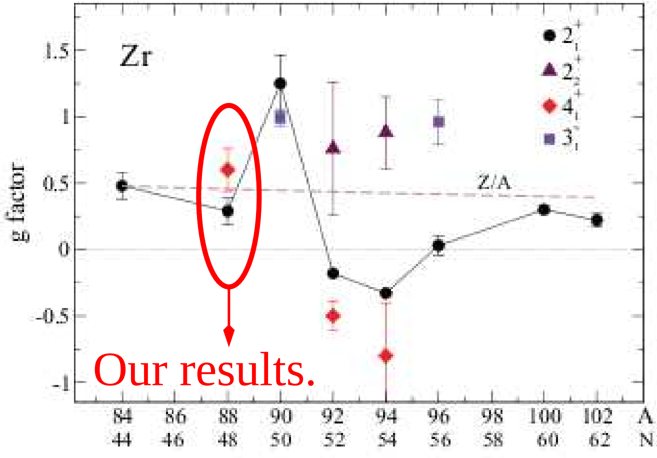
K.-H. Speidel
Helmholtz-Institut für Strahlen- und Kernphysik, Universität Bonn, Nussallee 14-16, D-53115 Bonn, Germany

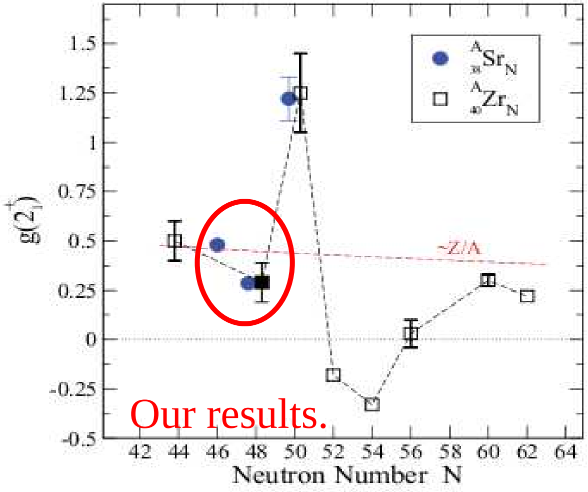
M. Hjorth-Jensen
Department of Physics and Center of Mathematics for Applications, University of Oslo, N-0316 Oslo, Norway

P. Maier-Komor
Physik-Department, Technische Universität München, James-Franck-Str., D-85748 Garching, Germany

S. J. Q. Robinson

Results for $^{88}_{40}$Zr and $^{84,86,88}_{38}$Sr

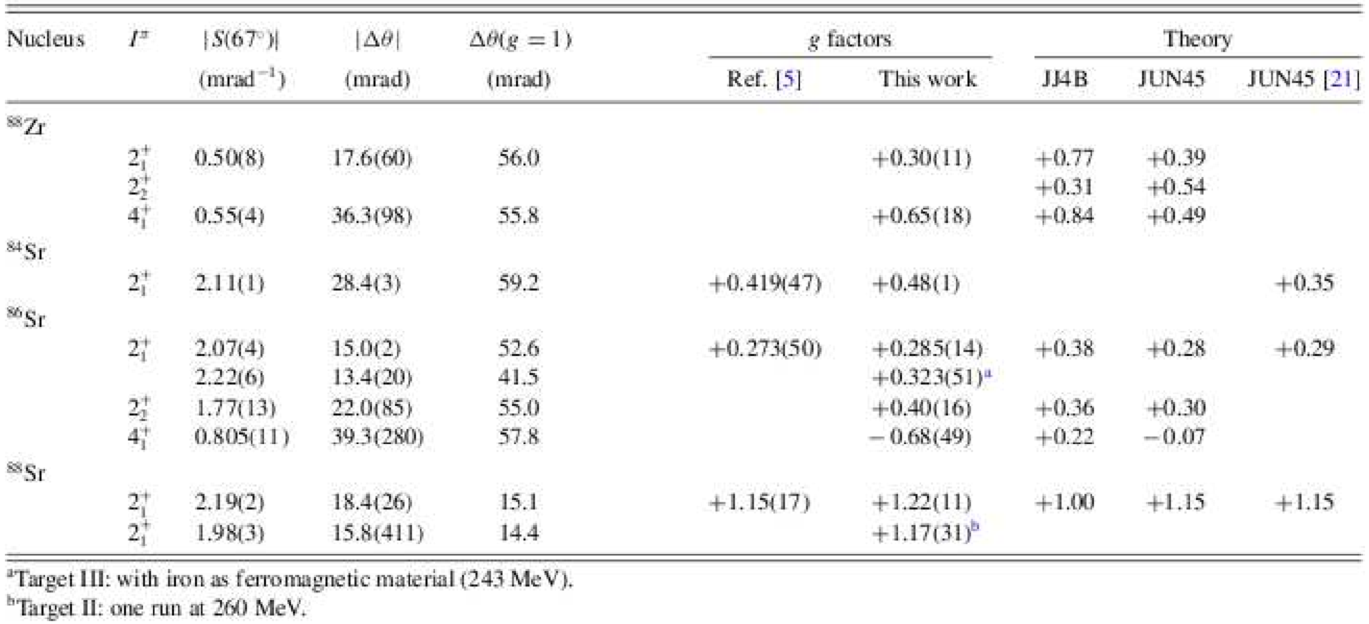




What produces the $g(4^+) = -0.68(49)$ (negative) value of ^{86}Sr?

*) $g(4^+) = +0.65(18)$ for ^{88}Zr!.

*) some Schmidt values: $g(p_{1/2})_\pi$=-0.529 (π particles), $g(g_{9/2})_\nu = -0.425$ and $g(p_{3/2}) = -1.275$ (ν holes).



Nucleus	I^π	$\|S(67^\circ)\|$	$\|\Delta\theta\|$	$\Delta\theta(g=1)$	g factors		Theory		
		(mrad^{-1})	(mrad)	(mrad)	Ref. [5]	This work	JJ4B	JUN45	JUN45 [21]
^{88}Zr									
	2_1^+	0.50(8)	17.6(60)	56.0		+0.30(11)	+0.77	+0.39	
	2_2^+						+0.31	+0.54	
	4_1^+	0.55(4)	36.3(98)	55.8		+0.65(18)	+0.84	+0.49	
^{84}Sr									
	2_1^+	2.11(1)	28.4(3)	59.2	+0.419(47)	+0.48(1)			+0.35
^{86}Sr									
	2_1^+	2.07(4)	15.0(2)	52.6	+0.273(50)	+0.285(14)	+0.38	+0.28	+0.29
		2.22(6)	13.4(20)	41.5		+0.323(51)[a]			
	2_2^+	1.77(13)	22.0(85)	55.0		+0.40(16)	+0.36	+0.30	
	4_1^+	0.805(11)	39.3(280)	57.8		− 0.68(49)	+0.22	−0.07	
^{88}Sr									
	2_1^+	2.19(2)	18.4(26)	15.1	+1.15(17)	+1.22(11)	+1.00	+1.15	+1.15
	2_1^+	1.98(3)	15.8(411)	14.4		+1.17(31)[b]			

[a] Target III: with iron as ferromagnetic material (243 MeV).

[b] Target II: one run at 260 MeV.

PHYSICAL REVIEW C **85**, 044322 (2012)

Structure of the Sr-Zr isotopes near and at the magic $N = 50$ shell from g-factor and lifetime measurements in $^{88}_{40}$Zr and $^{84,86,88}_{38}$Sr

G. J. Kumbartzki,[1] K.-H. Speidel,[2] N. Benczer-Koller,[1] D. A. Torres,[1,*] Y. Y. Sharon,[1] L. Zamick,[1] S. J. Q. Robinson,[3]
P. Maier-Komor,[4] T. Ahn,[5] V. Anagnostatou,[5] Ch. Bernards,[5,†] M. Elvers,[5,†] P. Goddard,[5] A. Heinz,[5] G. Ilie,[5] D. Radeck,[5,†]
D. Savran,[5,†] V. Werner,[5] and E. Williams[5]
[1] *Department of Physics and Astronomy, Rutgers University, New Brunswick, New Jersey 08903, USA*
[2] *Helmholtz-Institut für Strahlen- und Kernphysik, Universität Bonn, Bonn, Germany*
[3] *Physics Department, Millsaps College, Jackson, Mississippi 39210, USA*
[4] *Physik-Department, Technische Universität München, München, Germany*
[5] *Wright Nuclear Structure Laboratory, Yale University, New Haven, Connecticut 06520, USA*

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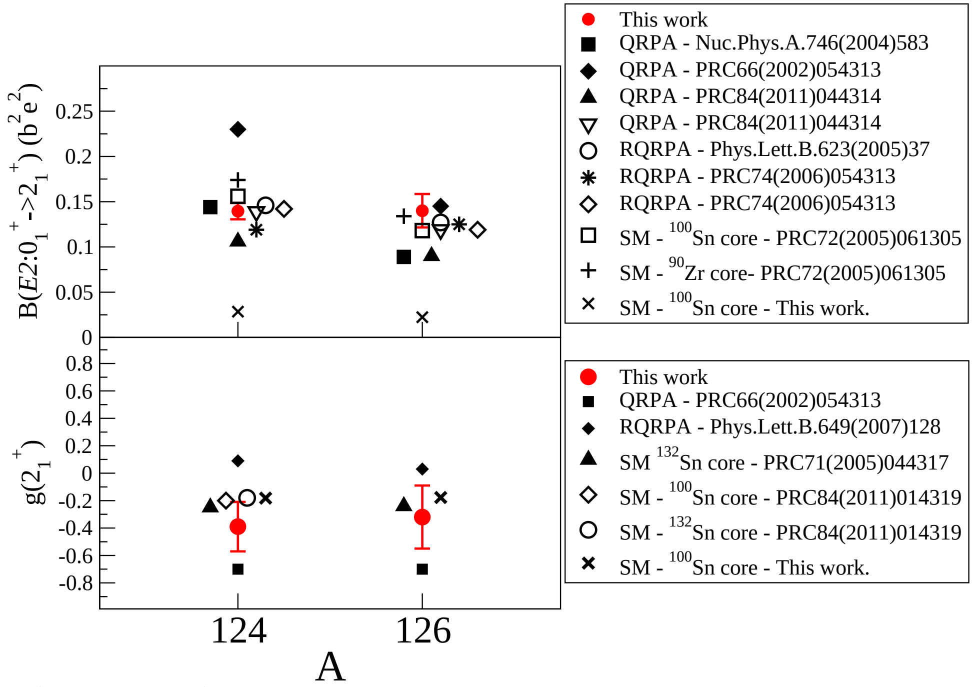
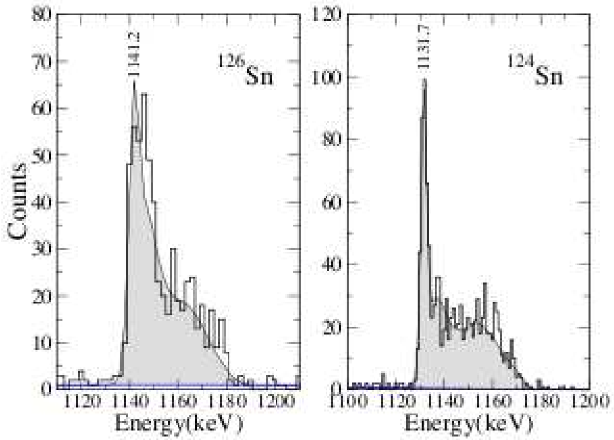
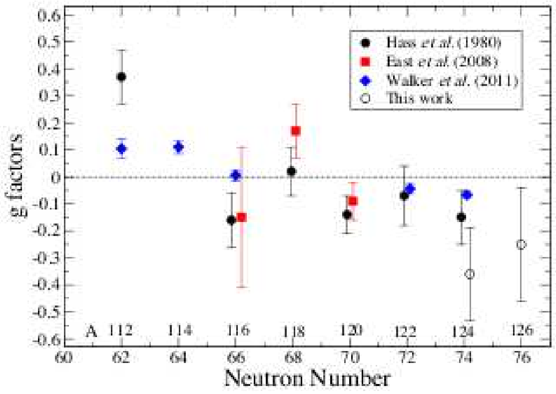
Results for $^{124,126}_{50}$Sn







$$g_{Schmidt}(\nu, h_{11/2}) = -0.35 \quad \rightarrow$$ neutron holes in the $h_{11/2}$

$g(^{124}\text{Sn};2_1^+)$ = -0.36(17)

$g(^{126}\text{Sn};2_1^+)$ = -0.25(21)

$\tau(^{124}\text{Sn};2_1^+)$ = 1.58(10) ps

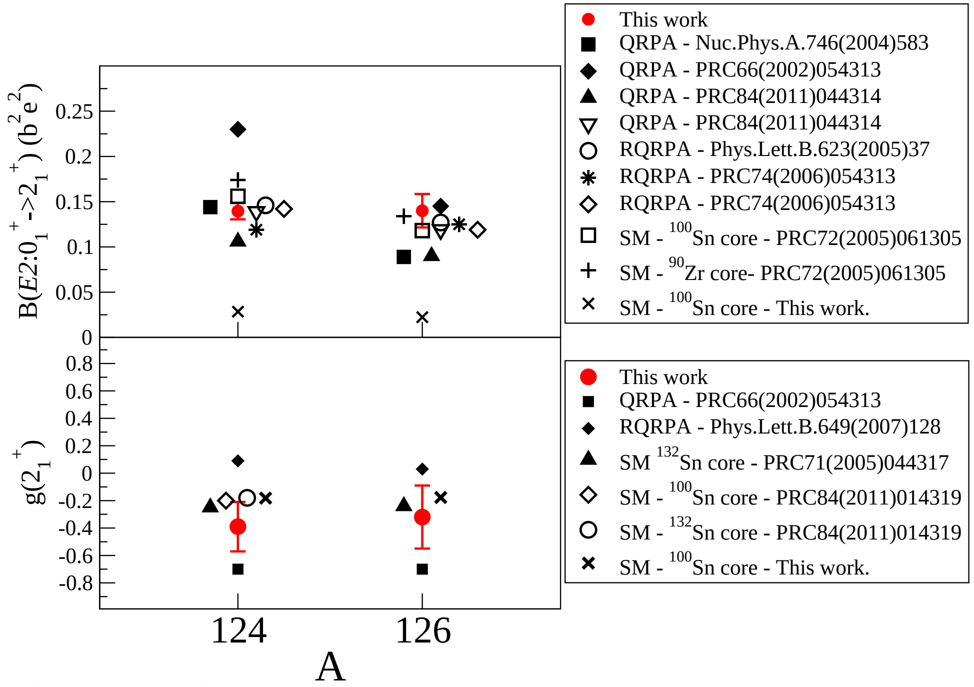
$\tau(^{126}\text{Sn};2_1^+)$ = 1.50(20)

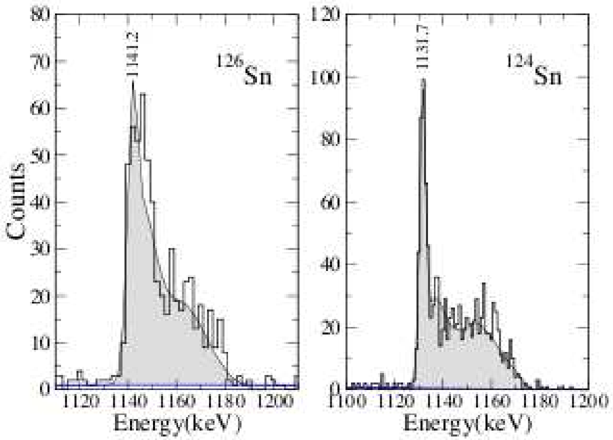
PHYSICAL REVIEW C **86**, 034319 (2012)

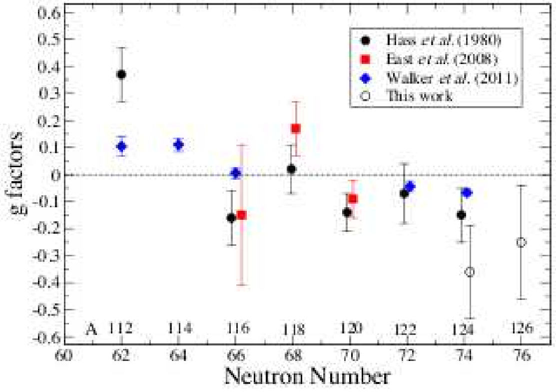
Transient field *g* factor and mean-life measurements with a rare isotope beam of ^{126}Sn

G. J. Kumbartzki,[*] N. Benczer-Koller, D. A. Torres,[†] B. Manning, P. D. O'Malley, Y. Y. Sharon, and L. Zamick
Department of Physics and Astronomy, Rutgers University, New Brunswick, New Jersey 08903, USA

Results for $^{124,126}_{50}$Sn







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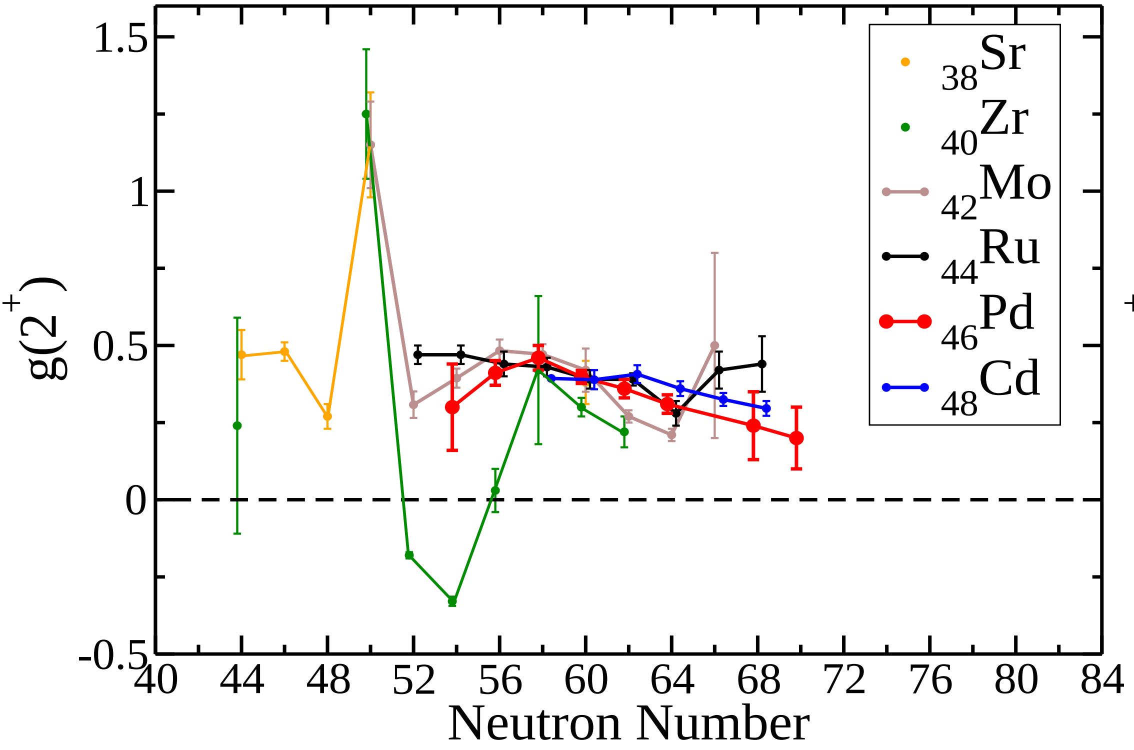
Department of Physics and Astronomy, Rutgers University, New Brunswick, New Jersey 08903, USA

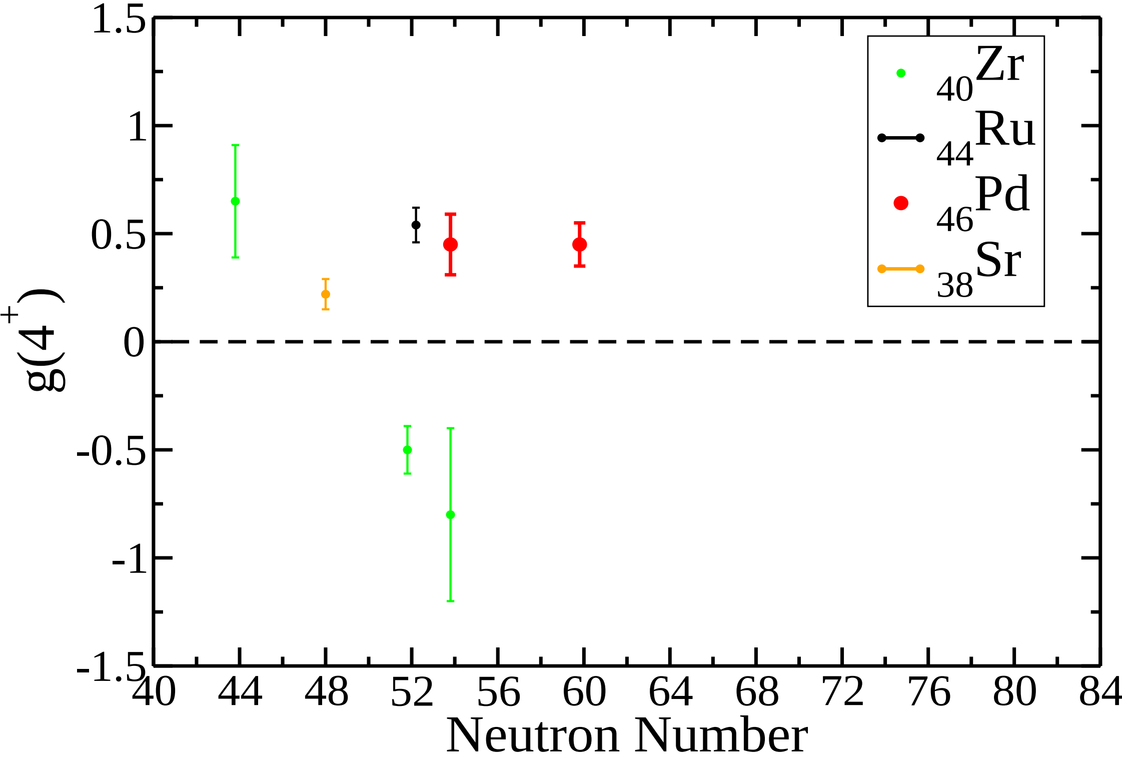
g−factor status (November 2012)

For the $40 \leq Z < 50$ and $50 \leq N < 82$ region

$g(2^+_1)$ values



$g(4^+_1)$ values



Remarks

1) Recent theoretical efforts have shown a possible path to describe the microscopic origin of simple pattern in complex nuclei.

2) The measurement of "g" factors for J>2 could be pivotal to test those nuclear models.

3) The α-transfer reactions allows measurements of magnetic moments using the TF on certain unstable nuclei, for which otherwise a radioactive beam is needed. (more reactions?)

4) Should experiments drive theory?, or the opposite?

Thank you!

Gracias!

Obrigado!