Collectivity in N=Z nuclei: Coulomb excitation of ^{60}Zn

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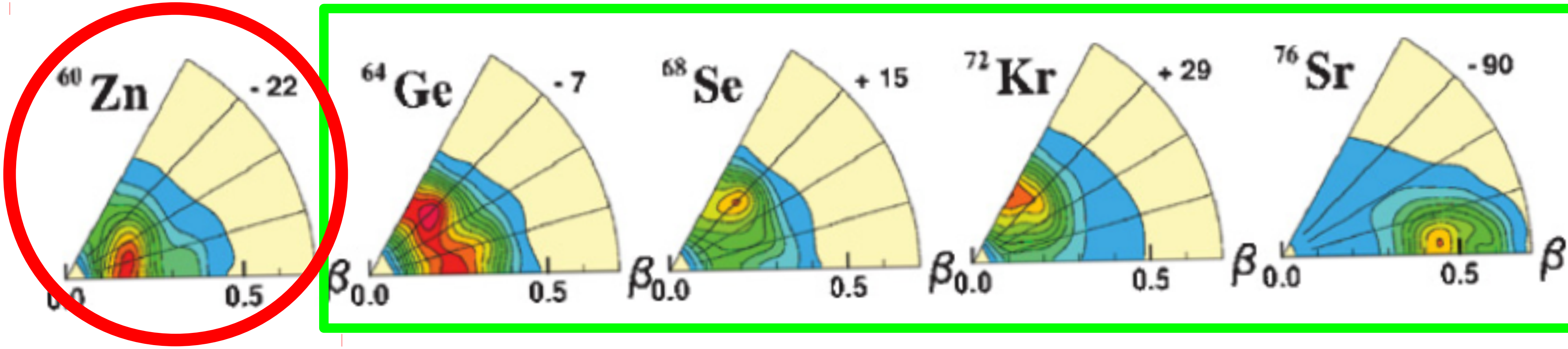
[4]CEA, Saclay, France

Self-conjugate nuclei beyond ^{56}Ni



- 58Zn – **spectroscopy**

C.Langer et al., PRL113, 032502 (2014). Spectroscopy via 57Cu (d,n) 58Zn reaction. MSU

- 64Ge, 68Se – **known BE2**

K.Starosta et al., PRL 99, 042503 (2007). Lifetime first and second 2+, ^{nat}C(65Ge,1n)64Ge

S.M.Fisher et al. PRL84, 4064 (2000). Evidence for oblate GS in 12Ca(58Ni,2n)68Se

A.Obertelli et al., PRC80, 031304(R) (2009). Interm. Coulex 68Se

- 72Kr

A.Gade et al., PRL95, 022502 (2005). Interm. Coulex after fragm of 78Kr

- 76Sr

A.Lemasson et al., PRC85(R), 141303 (2012). BE2 lineshape.

What is know in ^{60}Zn

PHYSICAL REVIEW C VOLUME 10, NUMBER 2

γ-ray transitions in ^{48}Cr and ^{60}Zn

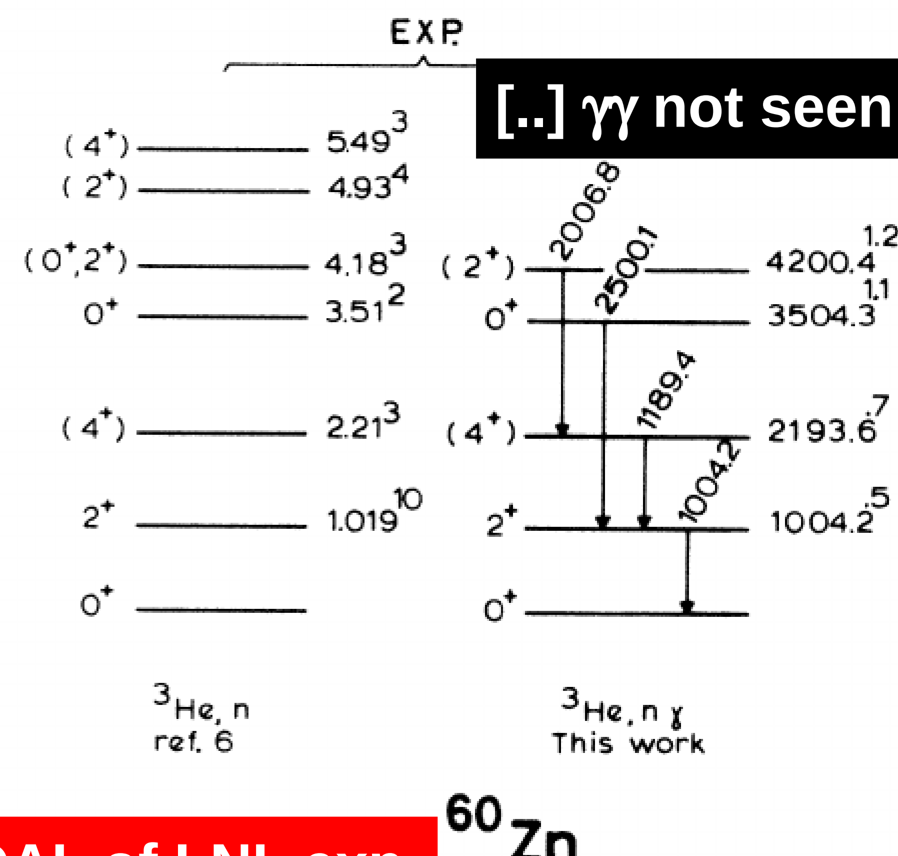
R. Kamermans, H. W. Jongsma, J. van der Spek, and H. Verheul
Natuurkundig Laboratorium der Vrije Universiteit, Amsterdam, The Netherlands

(Received 28 January 1974)

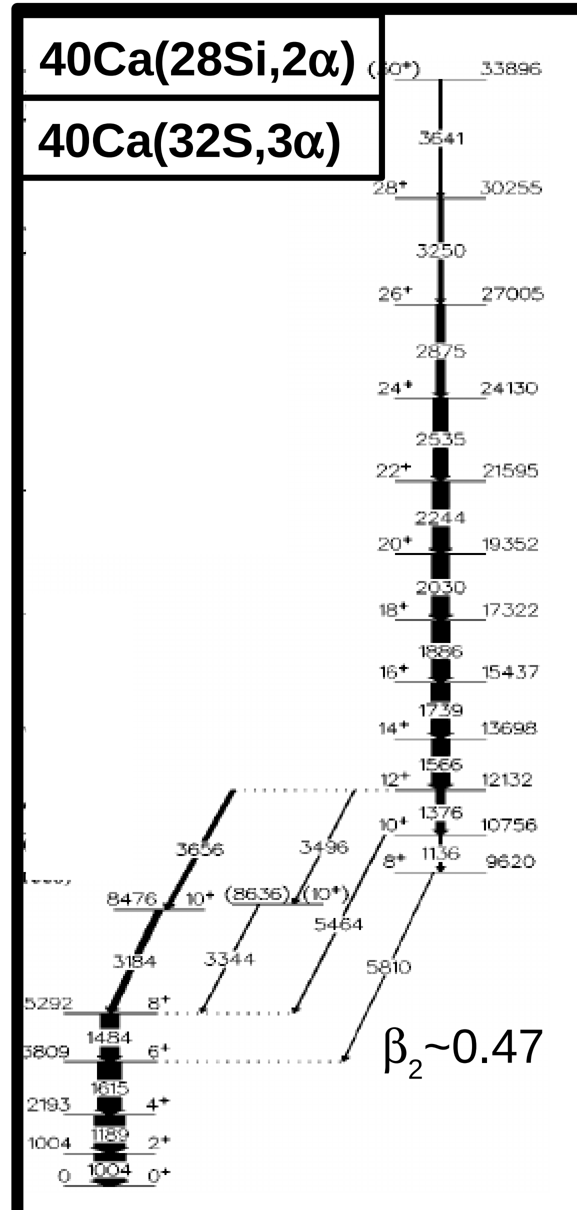
The level structure of the $N = Z$ = even nuclei ^{48}Cr and ^{60}Zn was investigated. The levels were excited in the (^{3}He, n) reaction. By measuring direct γ radiation in coincidence with the outgoing neutrons information about the γ decay of the levels was obtained.

SD band in ^{60}Zn

Side band in ^{60}Zn



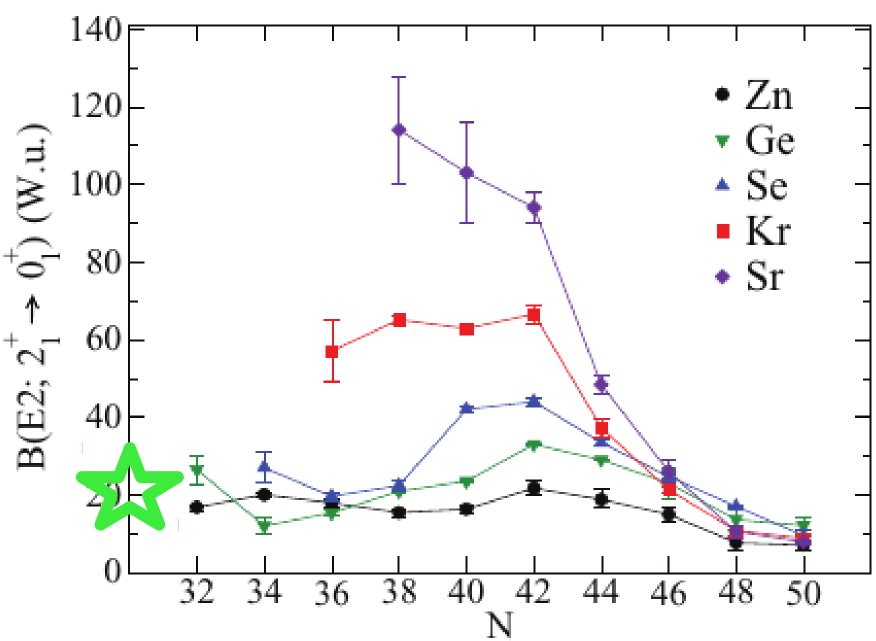
GOAL of LNL exp

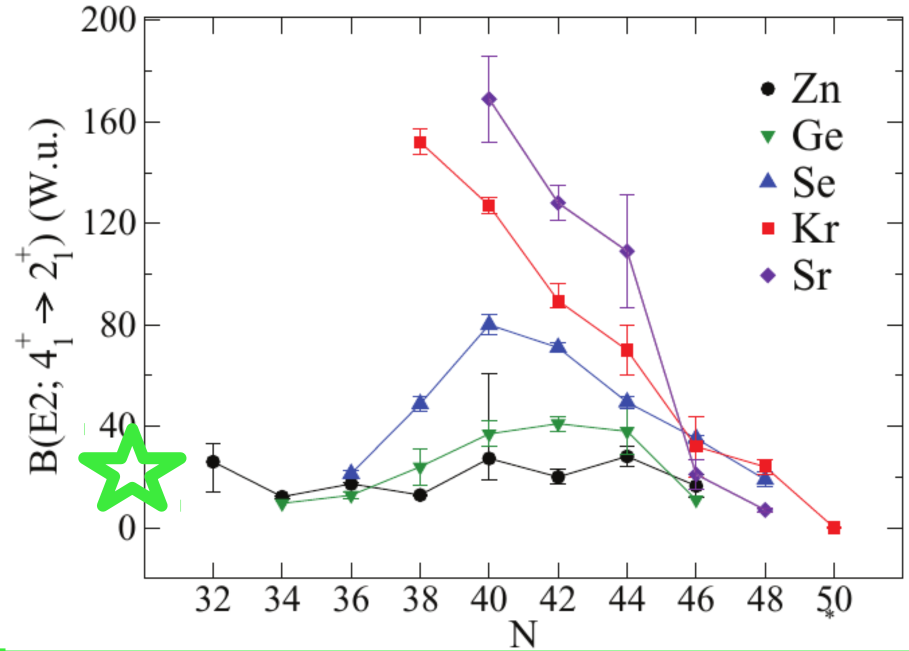


C.E.Svensson et al., PRL82,3400(1999)

BE2 systematics

S.Rice et al., PRC 88, 044334 (2013)





- ^{60}Zn is presently the most exotic Zn isotope in the region without measured lifetimes/BE2
- ISOLDE is presently a UNIQUE facility for low-energy Coulomb excitation measurement in this N=Z medium mass region (formerly N.Singh ^{72}Kr)

Calculations

(OBLATE)PROLATE

TRIAXIAL

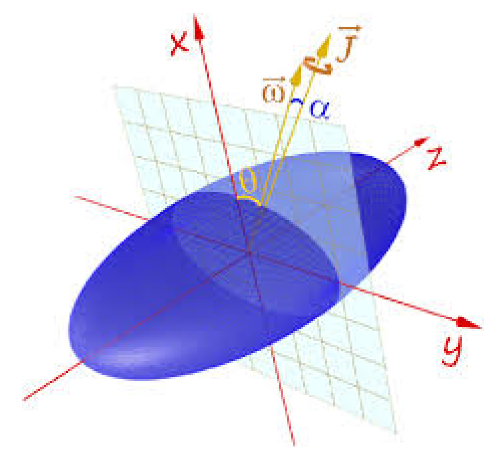
K.Kaneko et al., PRC70, 051301(R) (2004), SM

A.P.Zuker et al., PRC92, 024320 (2015), SM

D.Gambacurta and D.Lacroix, PRC 2015

T.Rodriguez, *priv.comm.*, EDF

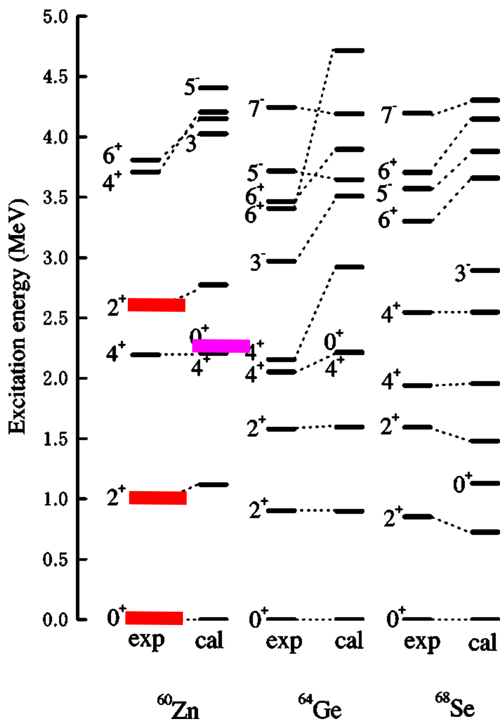
D.Vretenar, *priv.comm.*, EDF



^{60}Zn: SM

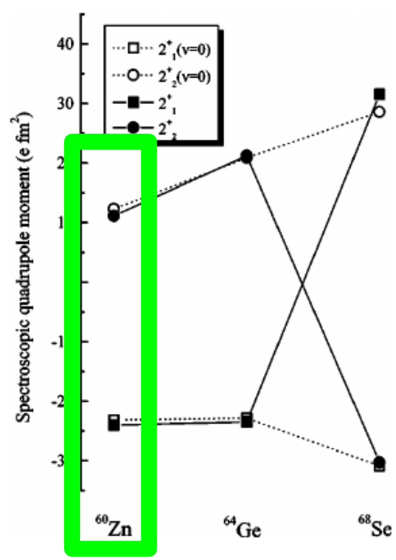
- **Prolate GS band**
- **Oblate side band**

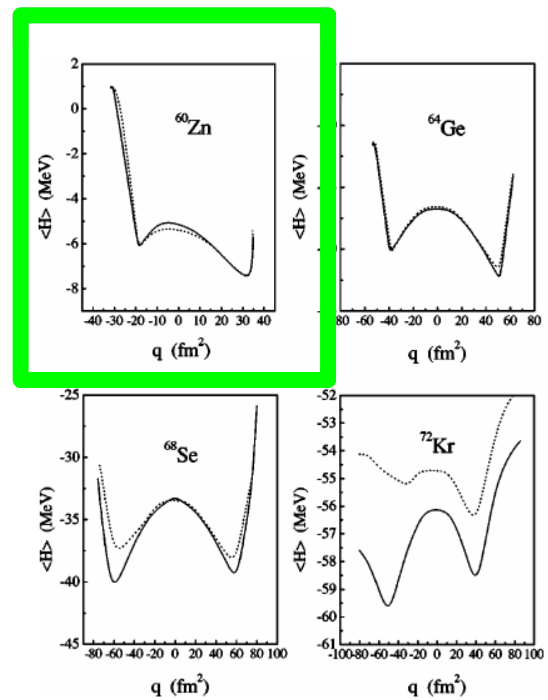
- ***fpg* model space, 56Ni core**
- **P+QQ eff int. + phen adj**
- **Canonical eff. Charges**
- **Oblate driving force $V_m(f_{5/2},p_{1/2};T=1)$**



Q_s

Q_s: -24 efm^2





K.Kaneko et al., PRC70, 051301(R) (2004), SM calc.

^{60}Zn: SM in the EEI scheme

"reliance on quadrupole degrees of freedom as the backbone of nuclear structure [..]"

- EEI *scheme (...NNN forces)*
- *qq force in* r_3^4 ($r_3 g$)
- 1.36, 0.46 effective charges

A.P.Zuker, A.Poves, F.Nowacki, and SM.Lenzi, PRC92, 024320 (2015)

J	E_{exp}	E_{qq}	E_{pf}	$Q_{0s,qq}$	$Q_{0s,pf}$	$Q_{0t,qq}$	$Q_{0t,pf}$
2^+	1.00	1.00	1.07	24	22	23	31
4^+	2.19	3.34	2.31	23	25	22	30
6^+	3.81	7.03	4.06	23	14	19	31

- **Prolate GS band**

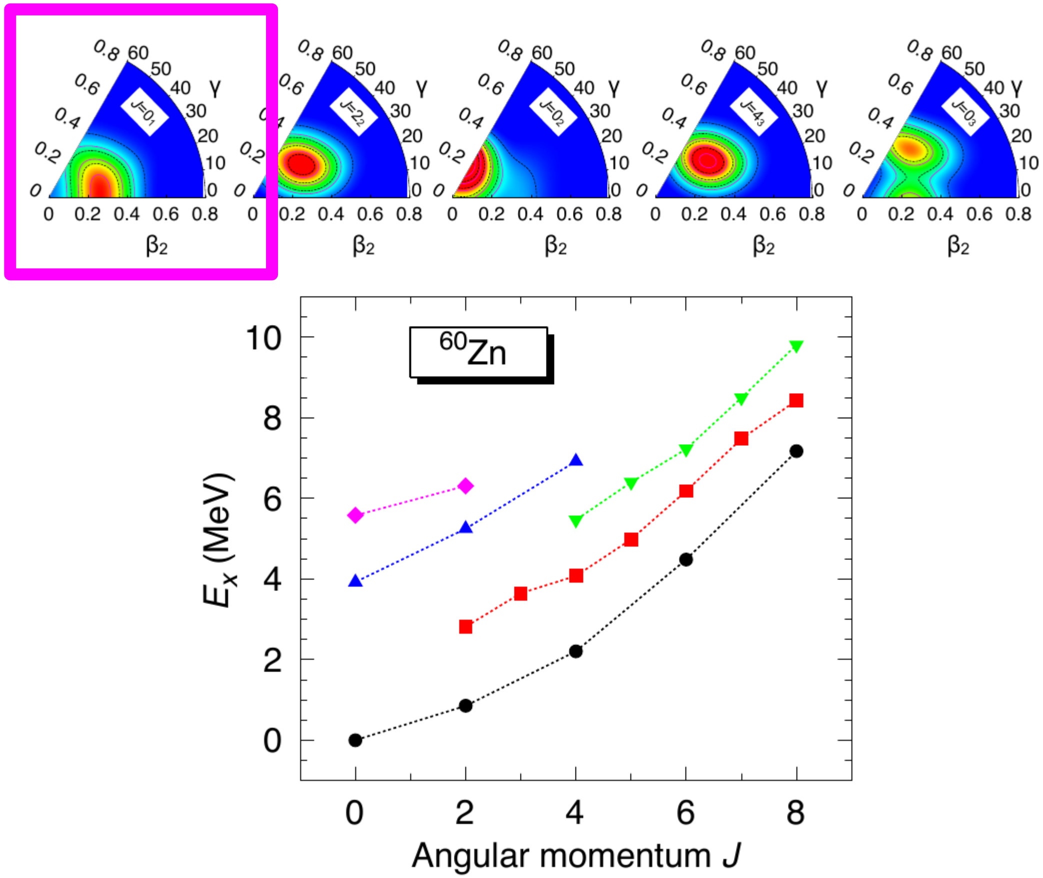
BE2: 352 e^2fm^4

Q_s: -26 efm^2

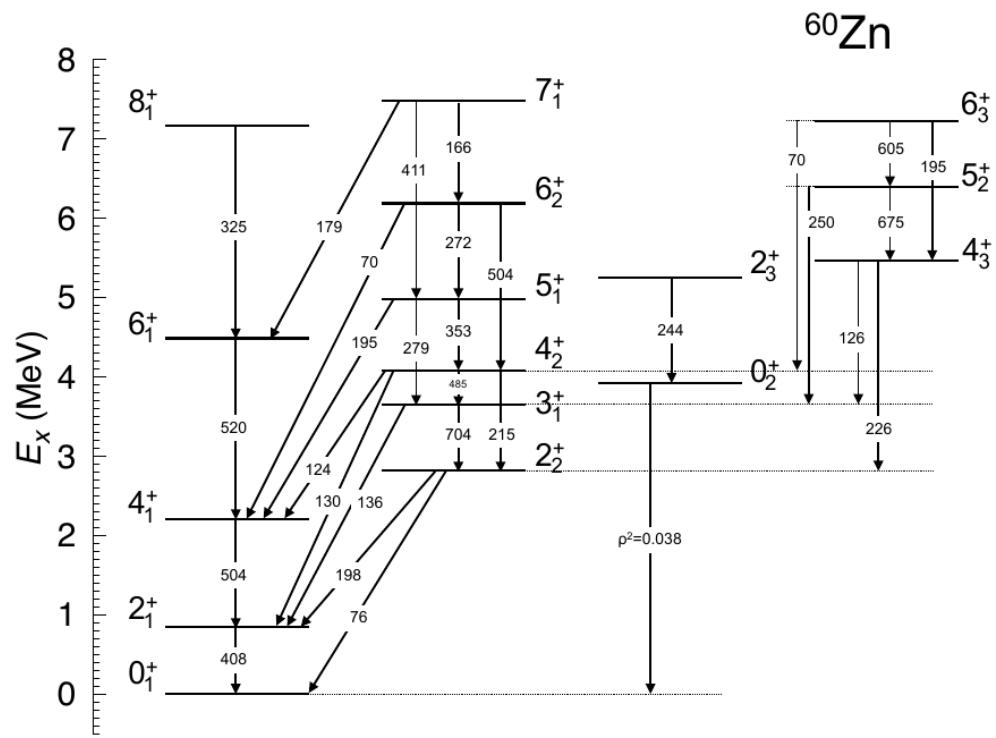
[..] Mild axial rotor equivalent to ^{20}Ne, $\mathbf{r_1^4}$

F.Nowacki and N.Houda, *private comm*

^{60}Zn: EDF



T.Rodriguez, *priv.comm.*

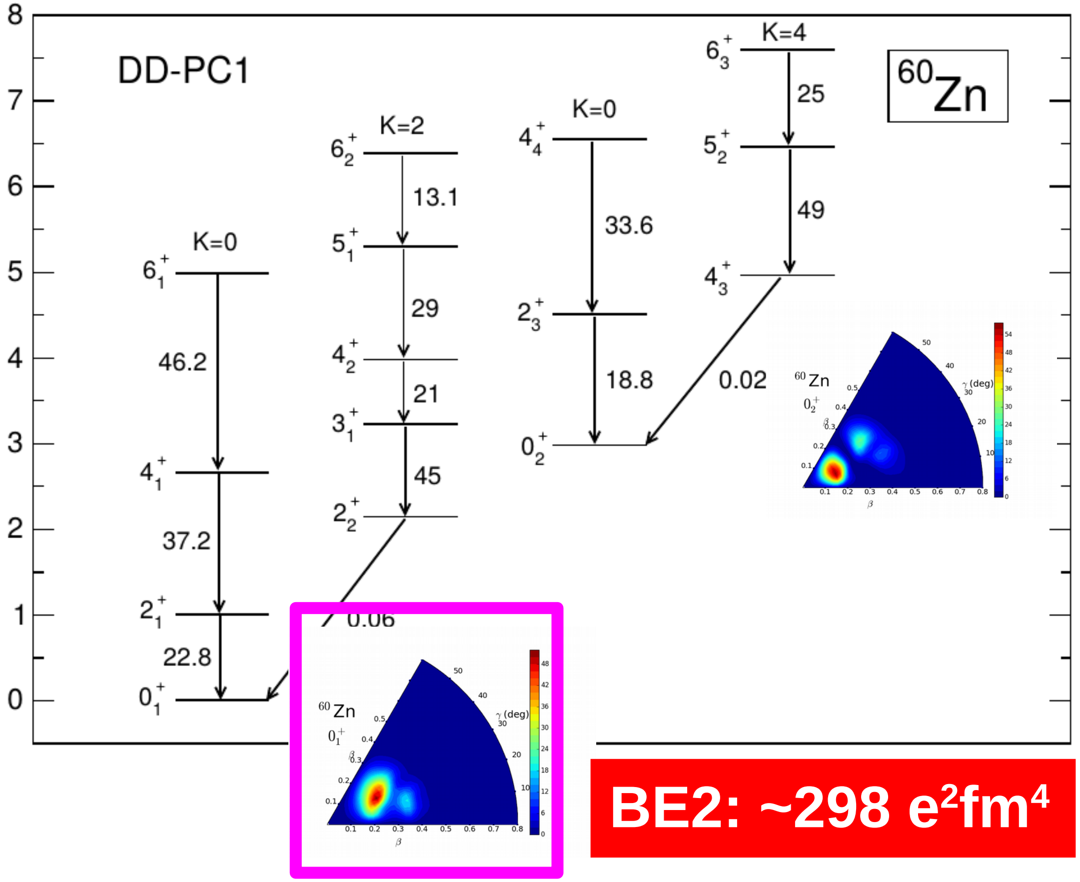


BE2: 408 e^2fm^4

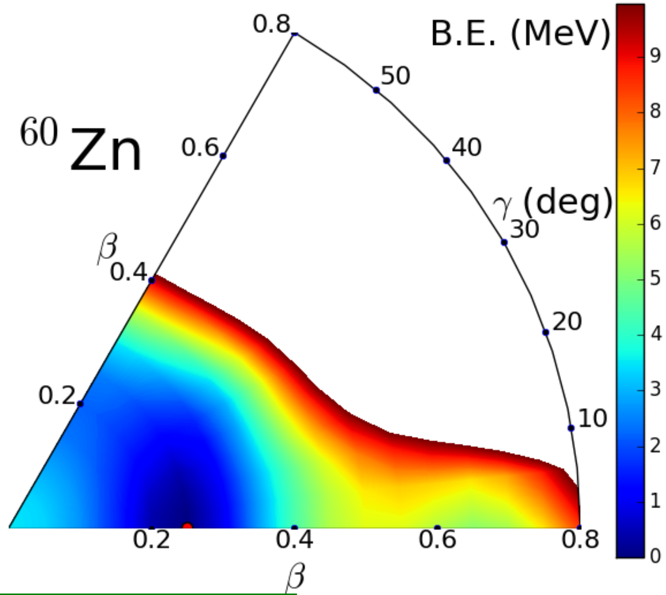
Q_s: -38 efm^2

- EDF calculation [Gogny – D1M]
- Axial rotor character: prolate GS, oblate SB

^{60}Zn: EDF



D.Vretenar, *priv.comm*.



BE2: ~298 e^2fm^4

Q_s: -9 efm^2

- EDF calculation [DD-PC1 potential]
- γ – soft character/triaxial

Goals

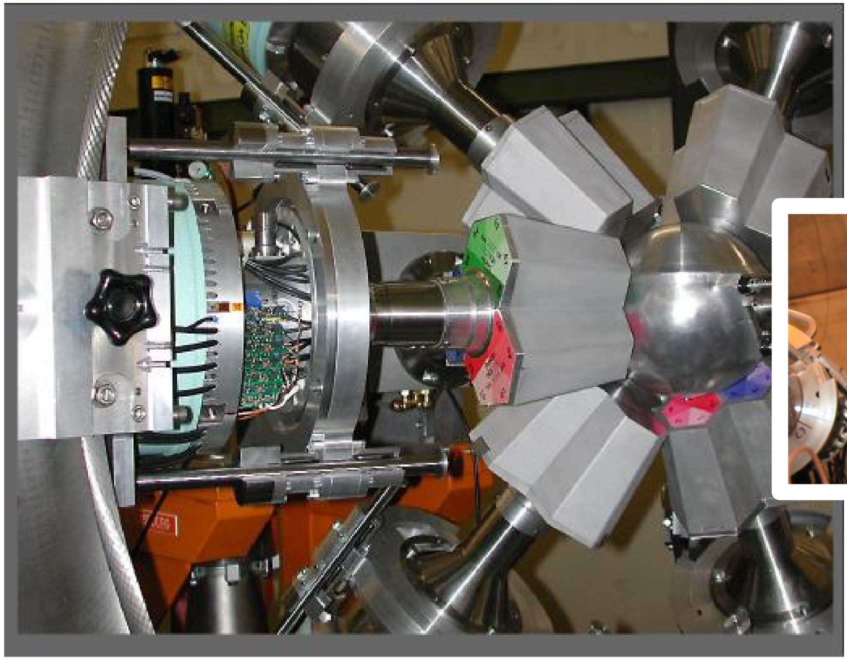
Objectives

I. Low-lying states collectivity via B(E2)

II. Oblate/prolate vs triaxial rotor via spectroscopic quadrupole moment

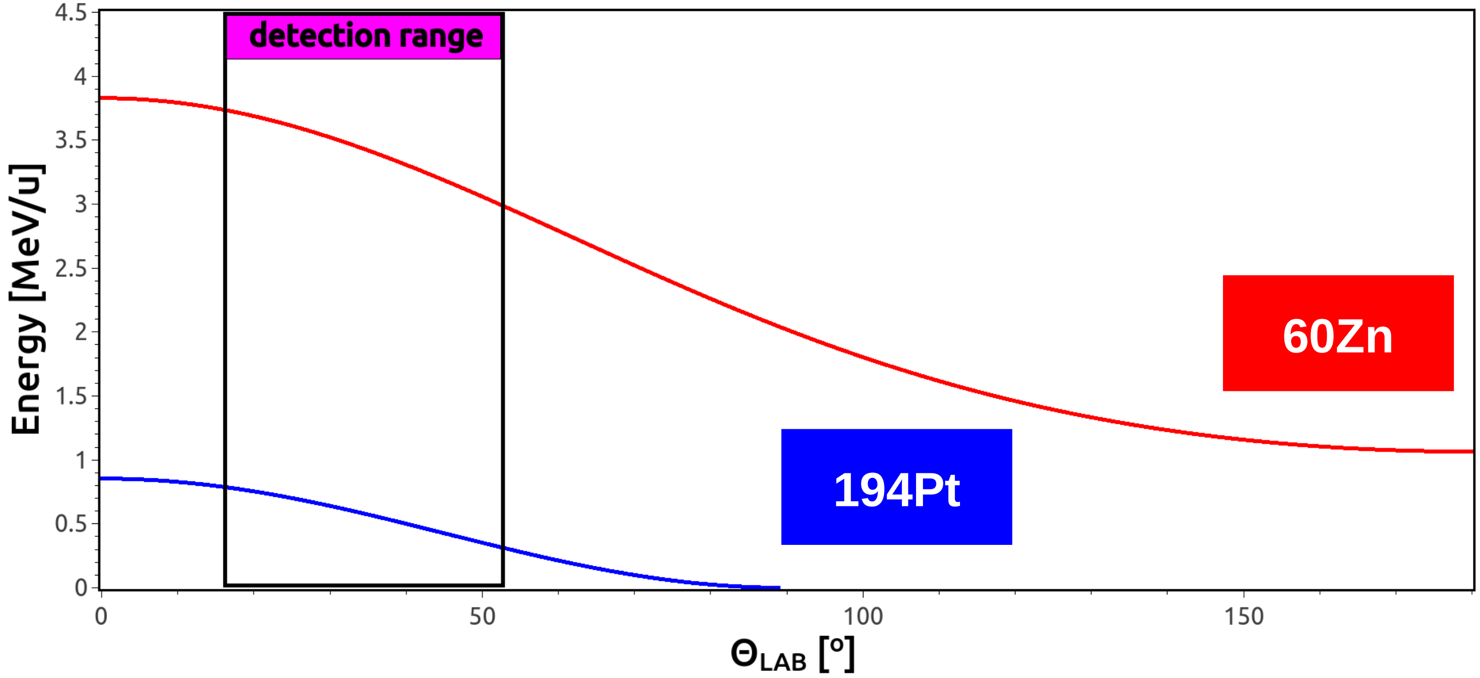
The experiment

Experimental setup



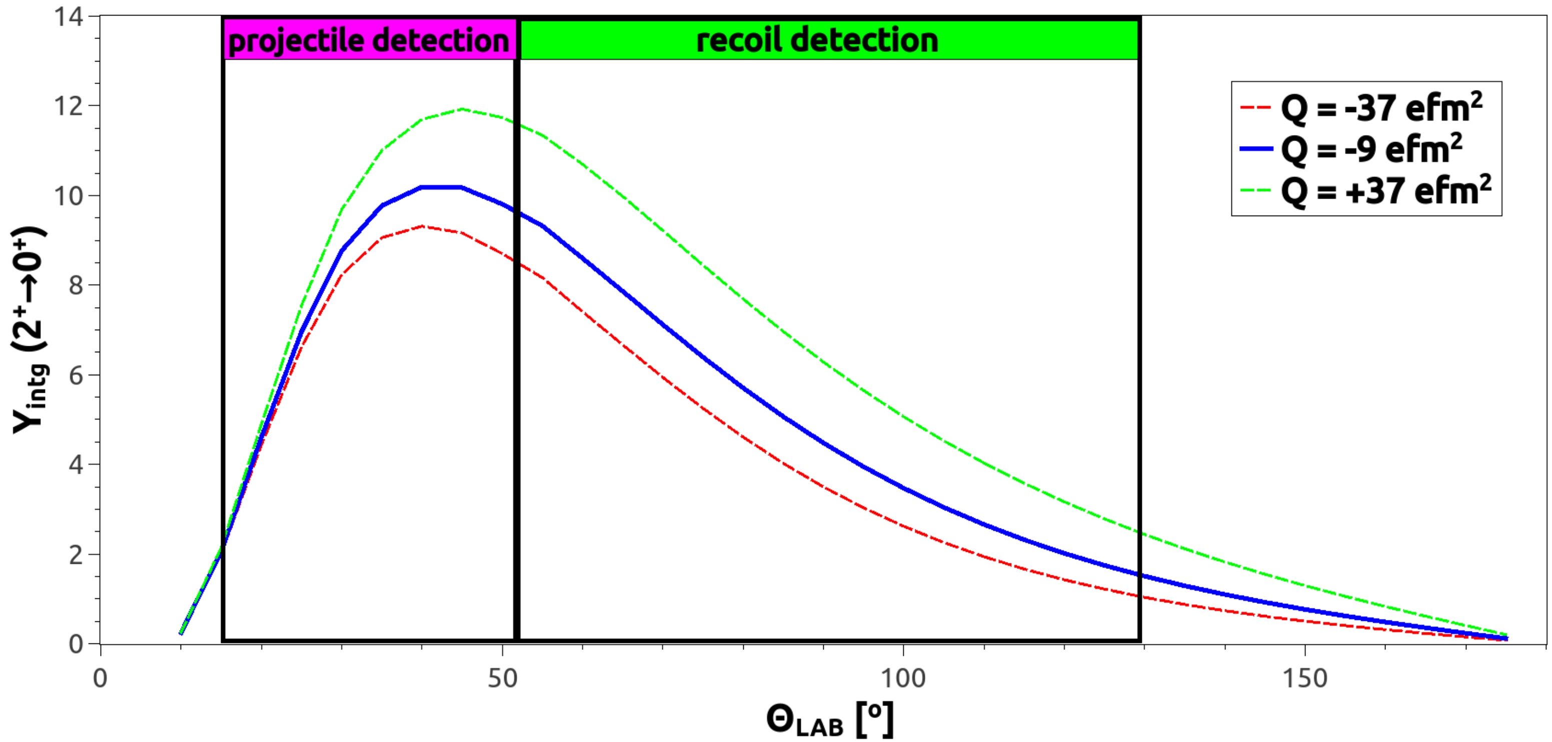

- Setup: MINIBALL+ DSSD
- Beam: ^{60}Zn (260 MeV), 4.2 x 10^4 pps [target]
- Target: ~2 mg/cm^2 ^{194}Pt

Reaction kinematics & detection efficiency



- Detection range: 16-53 degrees in the lab frame
- DSSD energy threshold 5-10 MeV
- Detection of Zn-proje and Pt-target ejectiles
- MINIBALL detection efficiency ~ 8% @1.3 MeV (8 triples)

BE2 and Qs



- Dependence of the excitation process on the scattering angle
- Angular ranges (4-5 subsets expected) : independent points *vs* statistics
- ^{44}Ar[§] similar case

[§] M.Zielinska et al., PRC80, 014317 (2009)

Calculated yields

GOSIA calculations assuming a BE2 from theory for 60Zn

Transition	Energy [keV]	Yield [counts/1day]	Yield [counts/6days]
Zn			
$2_1^+ \rightarrow 0_1^+$	1003	$\sim$1500	$\sim$10000
$4_1^+ \rightarrow 2_1^+$	1189	$\sim$15	$\sim$100
Pt			
$2_1^+ \rightarrow 0_1^+$	328	$\sim$9000	$\sim$54000
$4_1^+ \rightarrow 2_1^+$	482	$\sim$670	$\sim$4020

§10% relative error in BE2 and ~40% in Q_s was found in "similar" case

§M.Zielinska et al., PRC80, 014317 (2009)

Beam time request

18 (+3) shifts

15-20% contamination scenario is sustainable (TISD demanded)

Investigation of the collectivity in N=Z nuclei: Coulomb excitation in ^{60}Zn

October 13, 2015

D. Mengoni[1,2], K. Hadyńska-Klęk[3], E. Clement[4], M. Zielińska[5], F. Azaiez[6], D. Bazzacco[2], G. Benzoni[7], A. Boso [1,2], M.J.G. Borge[8,9], A. Bracco[7], F. Camera[7], F.C.L. Crespi[7], G. de Angelis[3], G. de France[4], H. De Witte [10], D. Doherty[11], C. Domingo-Pardo[12], S. Franchoo[6], A. Gadea[12], A. Goasduff[3], A. Görgen[13], L. Gaffney[14], A. Gottardo[6], M. Huyse[10], A. Illana Sison[10], G. Jaworski[3], D. Jenkins[11], P.R. John[1,2], Tz. Kokalova [15], M. Komorowska[16], S.M. Lenzi[1,2], S. Leoni[7], I. Matea[6], R. Menegazzo[1,2], C. Michelagnoli[4], B. Million[7], T. Mijatovic[17], V. Modamio[13], P. Napiorkowski[16], D.R. Napoli[3], S. Nara Singh[11], L. Olivier[6], R. Orlandi [18], F. Recchia[1,2], P. Reiter[19], E. Sahin[13], M. Siciliano[1,2], J. Smith[14], J. Srebrny[16], T. Stora[8], M. Scheck[14], S. Szilner[17], D. Testov[3], J.J. Valiente-Dobón[3], P. Van Duppen[10], D. Verney[6], D. Vretenar[20], N. Warr[19], O. Wieland[7], C. Wheldon[15], K. Wrzosek-Lipska[16]

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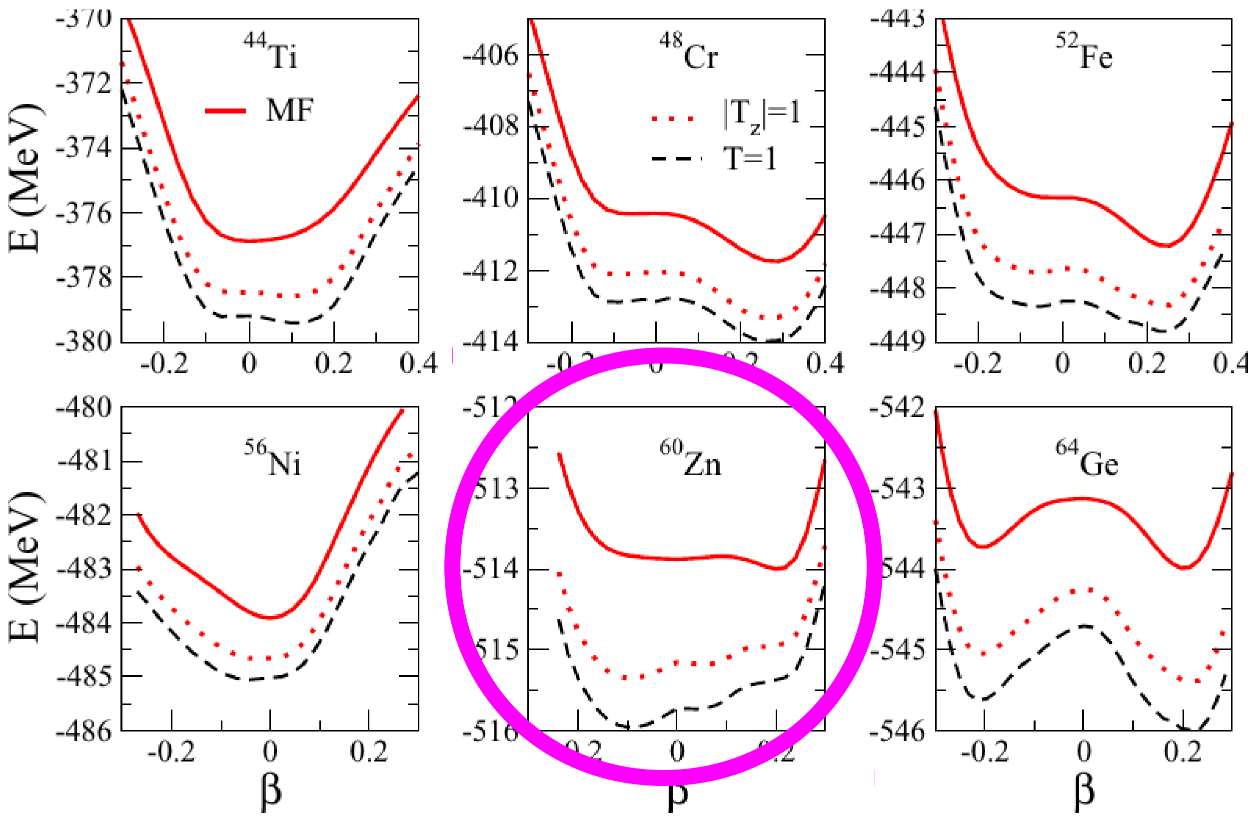
4 *GANIL, Caen, France*
5 *CEA Saclay, IRFU/SPhN, Gif-sur-Yvette, France*

backup

Contaminants

- ^{60}Zn from ZrO_2 using a W surface ion source and RILIS scheme
- ^{60}Ni (stable) and ^{60}Fe could be present
- No data presently available. In any case not exceeding $5x10^7$ pps
- Ion source, Release time and mass difference could lead to a reduction of factor 100 in contamination. A TISD test is needed
- 15-20% contamination scenario is sustainable

^{60}Zn: MF ⊗ SM



Shell Model Hamiltonian from self consistent mean-filed outputs

- **Skyrme HF+BCS**
- **Two-body pairing**

H:$H_{sp}+H_{10}+H_{01}$

- **Oblate GS band at variance with the Kaneko**

D.Gambacurta and D.Lacroix, *PRC91, 014308 (2015)* catkin2.02.xls – LibreOffice Calc

N73 =N72/O71

Target particle =		pt	194
	barrier =	277.800	MeV
	=	4.634	MeV/A

theta (degrees)	E(safe) (MeV)	E/A (safe) (MeV/A)
10	1226.948	20.449
20	664.811	11.080
30	478.407	7.973
40	385.956	6.433
50	331.109	5.518
60	295.088	4.918
70	269.853	4.498
80	251.388	4.190
90	237.469	3.958
100	226.766	3.779
110	218.441	3.641
120	211.942	3.532
130	206.894	3.448
140	203.038	3.384
150	200.195	3.337
160	198.243	3.304
170	197.101	3.285
180	196.725	3.279

or

Target particle =		Pb	208
	barrier =	288.009	MeV
	=	4.805	MeV/A

theta (degrees)	E(safe) (MeV)	E/A (safe) (MeV/A)
10	1277.193	21.287
20	692.035	11.534
30	497.998	8.300
40	401.761	6.696
50	344.668	5.744
60	307.172	5.120
70	280.904	4.682
80	261.682	4.361
90	247.193	4.120
100	236.052	3.934
110	227.387	3.790
120	220.621	3.677
130	215.366	3.589
140	211.353	3.523
150	208.393	3.473
160	206.361	3.439
170	205.173	3.420
180	204.781	3.413

Incident particle =	Zn	60
Incident energy =	210	MeV
	3.50	MeV/A
Target particle =	Pt	194
Sum of radii =	12.13	fm

theta (degrees)		d (closest) (fm)	
10	step	100.075	safe
20	10	54.225	safe
30		39.021	safe
40		31.480	safe
50		27.007	safe
60		24.069	safe
70		22.010	safe
80		20.504	safe
90		19.369	safe
100		18.496	safe
110		17.817	safe
120		17.287	safe
130		16.875	
140		16.561	
150		16.329	
160		16.169	
170		16.076	
180		16.046	

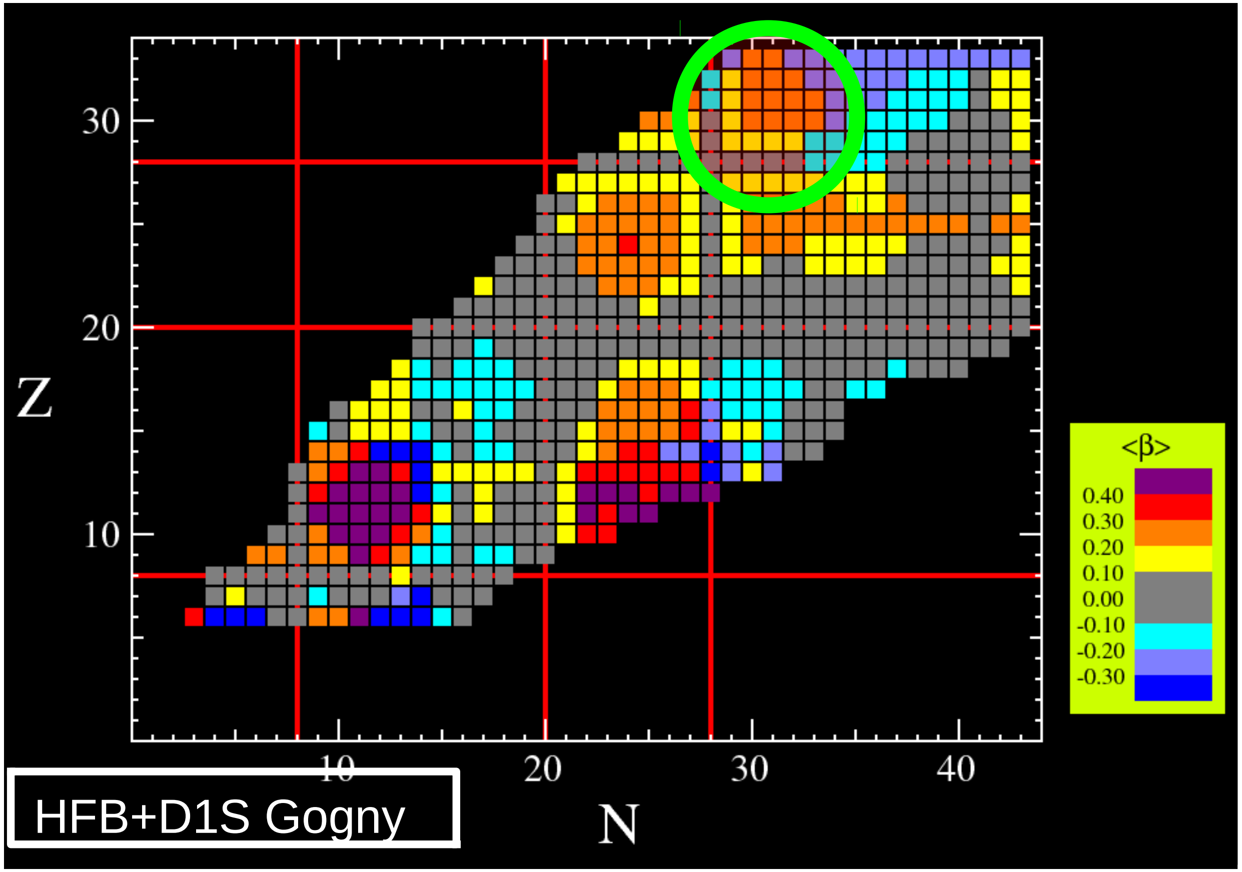
Breakup cones (non-relativistic)

Kinematic focussing of breakup particles at non-relativistic velocities

		Δ (MeV)	mass (u)
Incident particle =	c 12	0	12

Sheet 5 / 8 PageStyle_Calculator Sum=3.50 110%

Deformation beyond ^{56}Ni



Credits: S.Hilaire, M.Girod. CEA

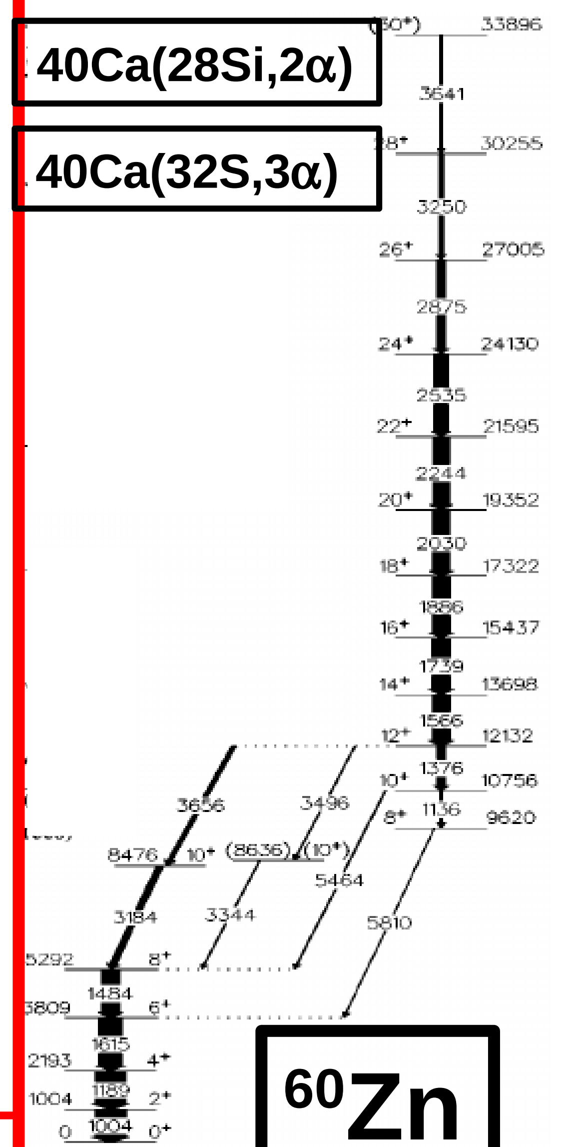
- HFB
- Gogny 1DS interaction
- Axial quadrupole deformation
- … shape coexistence
- … shape transition
- Stabilizing effects in the Nilsson diagrams

SD band in ^{60}Zn (and ^{62}Zn)

- $\beta_2 = 0.47 \pm 0.07$
- (Only) 37% to the GS
- Prompt particles?
- Partial decay to the other bands?

[…] configuration differ only by the movement of a pair of protons and a pair of neutrons from the $f_{7/2}$ to $g_{9/2}$

The oblate excited band has a larger fraction of g9/2 than the GS band. Should we expect a decay-out towards this band?



C.E.Svensson et al., PRL82,3400(1999)

PHYSICAL REVIEW C VOLUME 10, NUMBER 2 AUGUST 1974

γ-ray transitions in ^{48}Cr and ^{60}Zn

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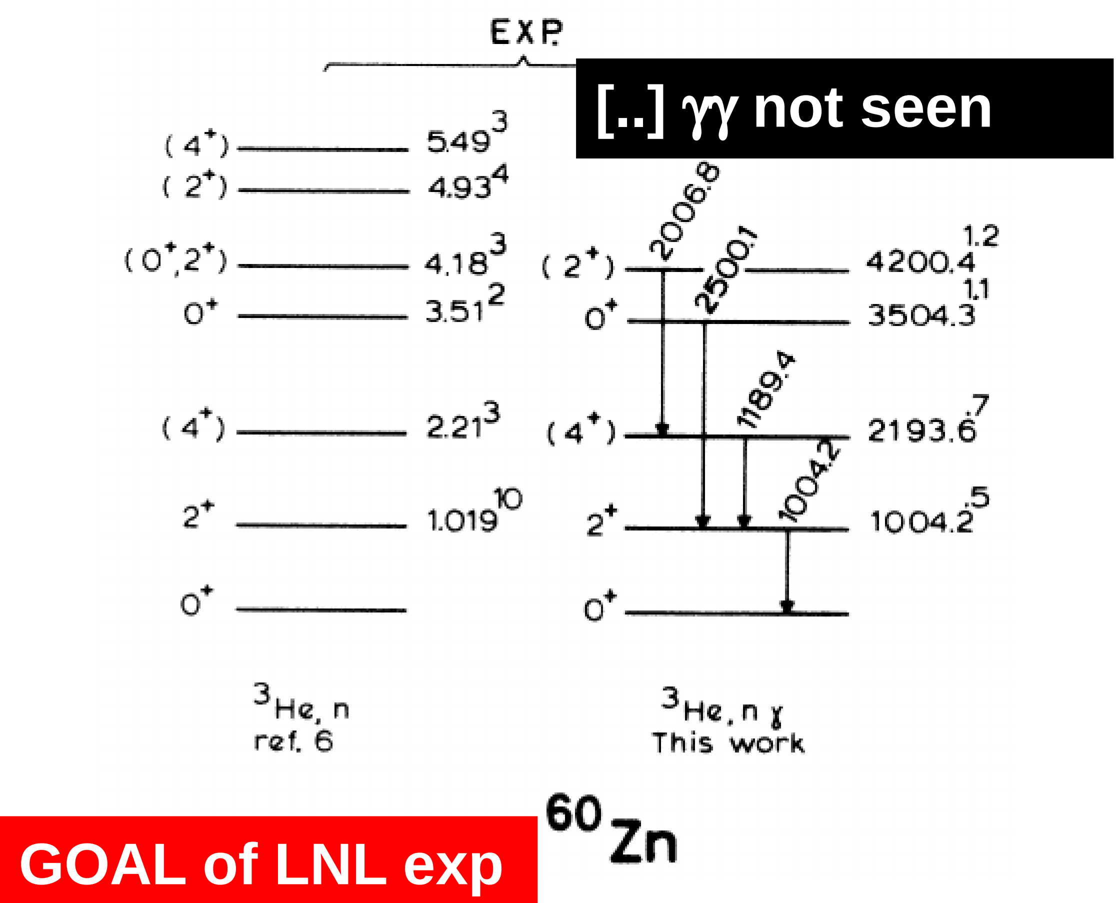
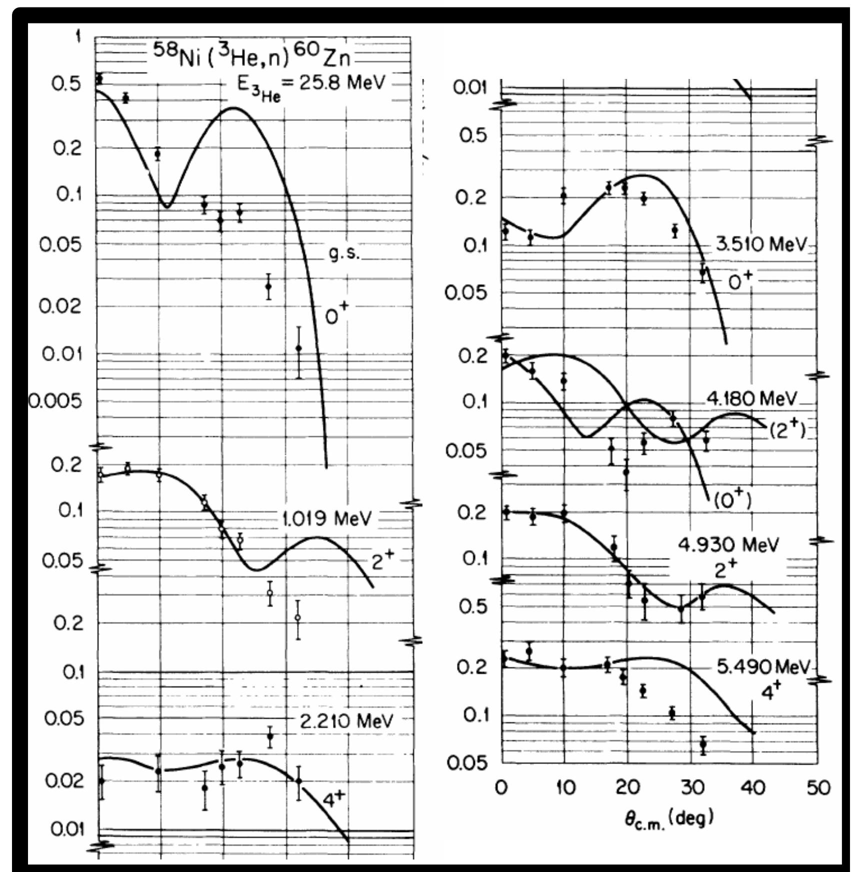
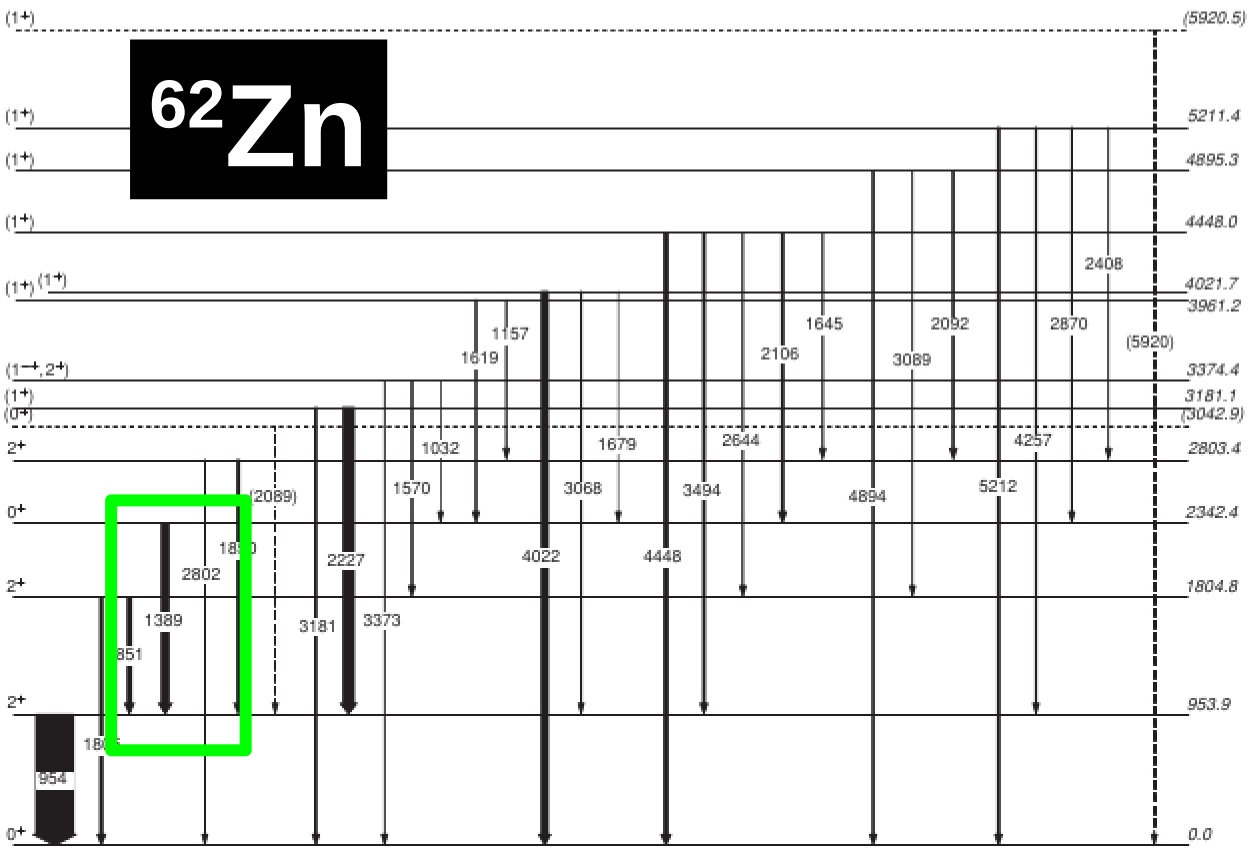




^{60}Zn lifetimes

- Lifetime $2_1 \rightarrow 0_1$: WU~20, 1MeV (2.9 ps)
- Lifetime $2_2 \rightarrow 0_1$: WU<1, 2.5 MeV (9 ps)
- Lifetime $2_2 \rightarrow 2_1$: (M1/E2)??
- Lifetime $0_2 \rightarrow 2_1$: WU?

0^+_2 in ^{62}Zn

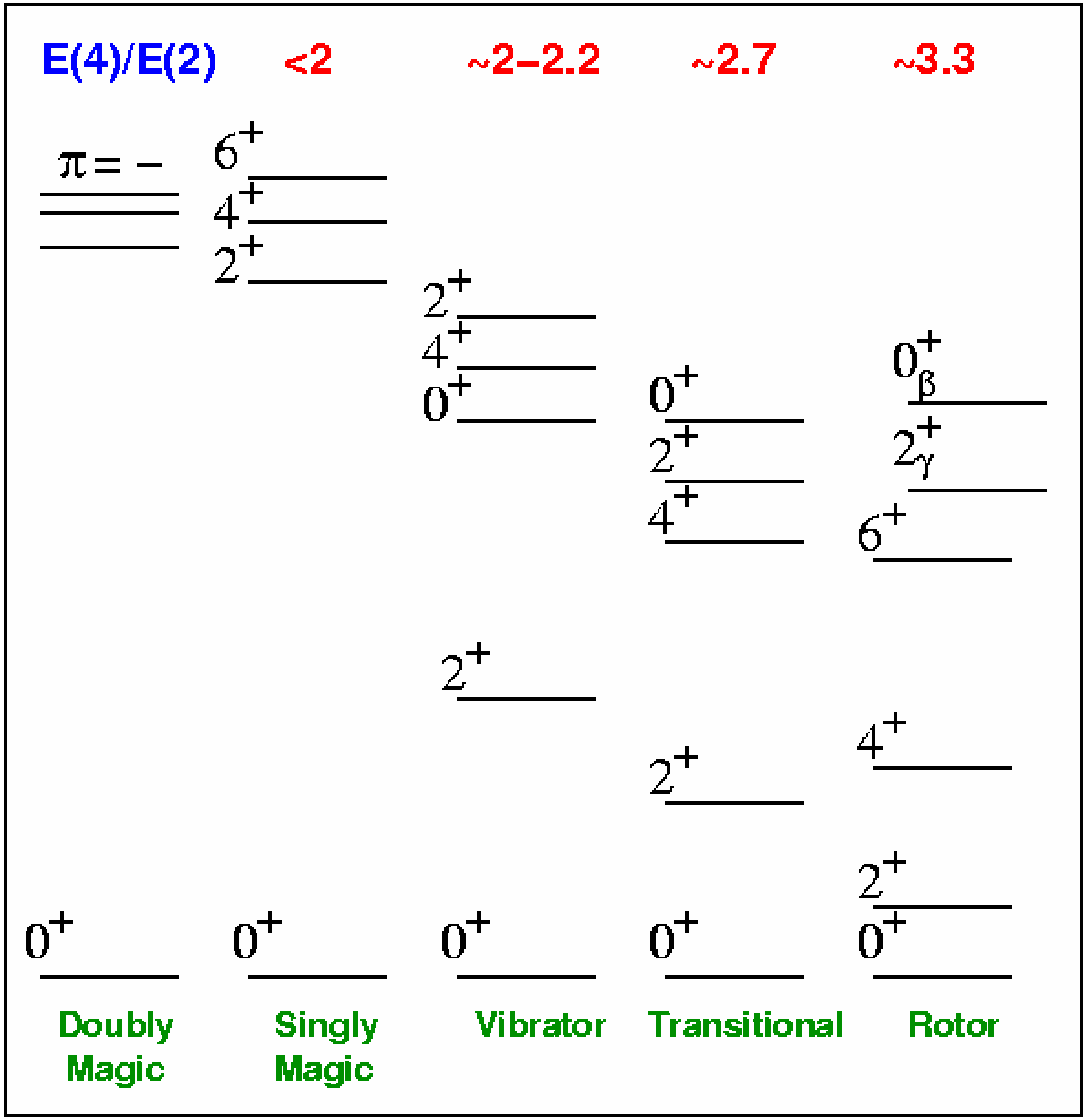


- 62Zn: 0^+_2 seen in β decay from ^{62}Ga: deexcites to 2^+_1
- Transfer reaction from 61Ni and γγ correlation confirm the 0^+_2

S.Finlay et al., PRC 78, 025502 (2008)

M.Albers et al., Nuclear Physics A 847 (2010) 180-206

Evolution of shell structure



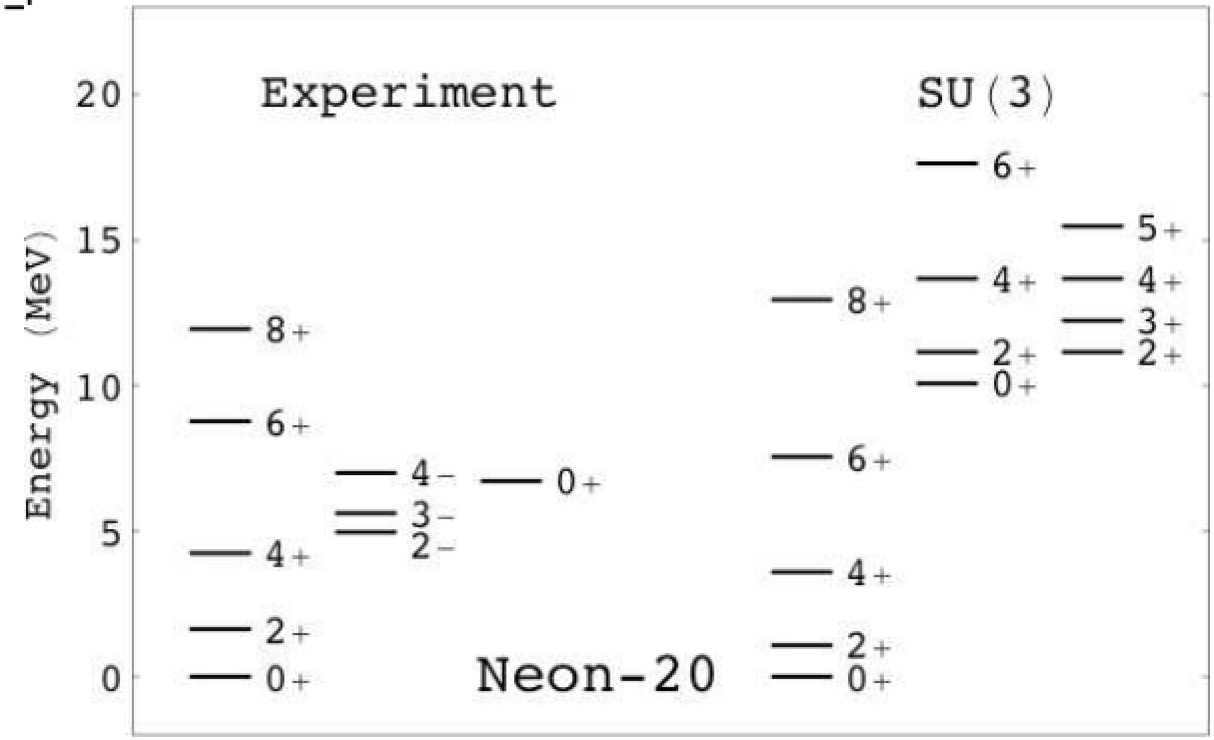
Elliott's SU(3) model of rotation

Harmonic oscillator mean field (*no* spin-orbit) with residual interaction of quadrupole type:

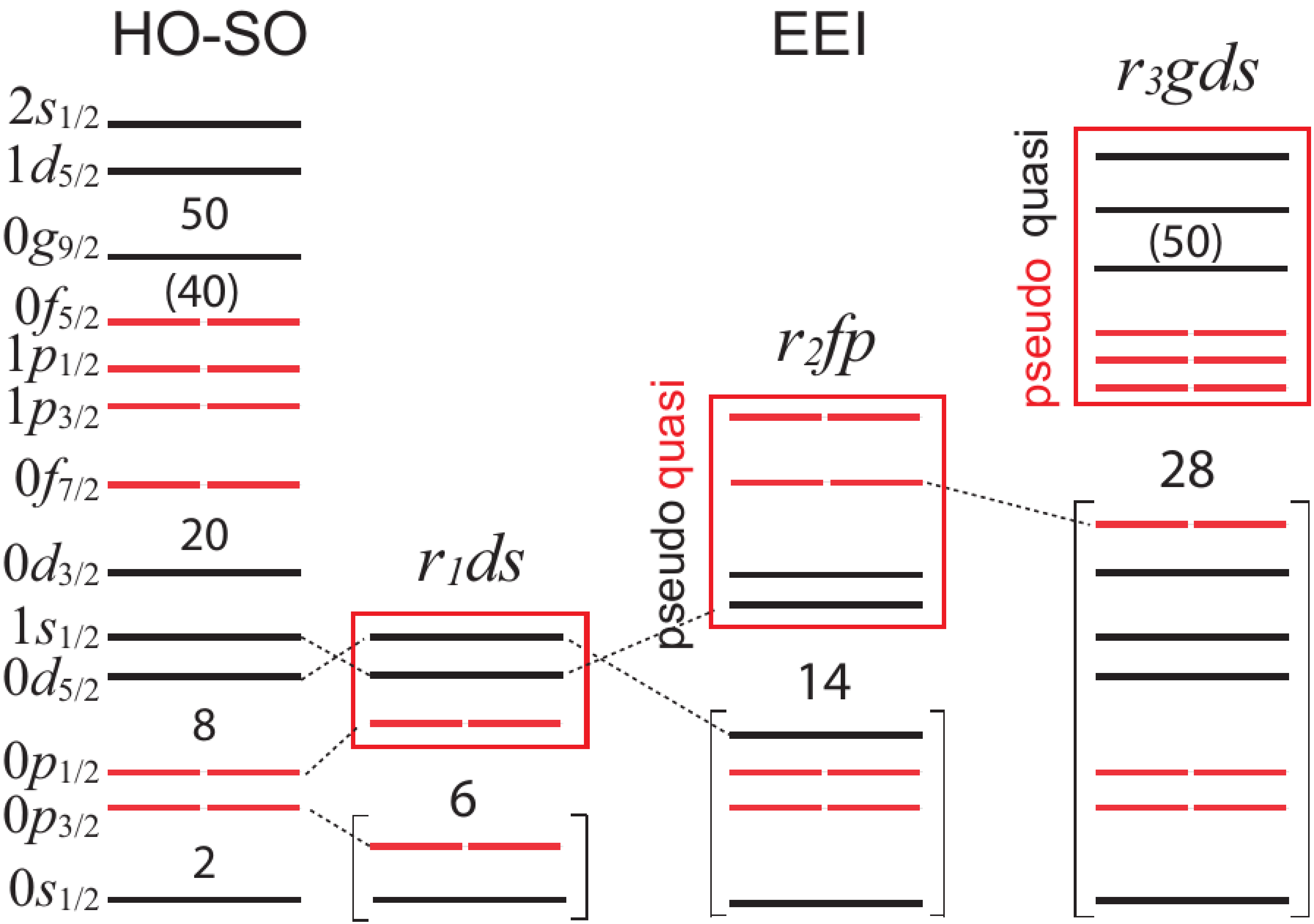
$$\hat{H} = \sum_{k=1}^{A} \left[\frac{p_k^2}{2m} + \frac{1}{2} m \omega^2 r_k^2 \right] - g_2 \hat{Q} \cdot \hat{Q},$$

$$\hat{Q}_\mu \propto \sum_{k=1}^{A} r_k^2 Y_{2\mu}(\hat{\boldsymbol{r}}_k)$$

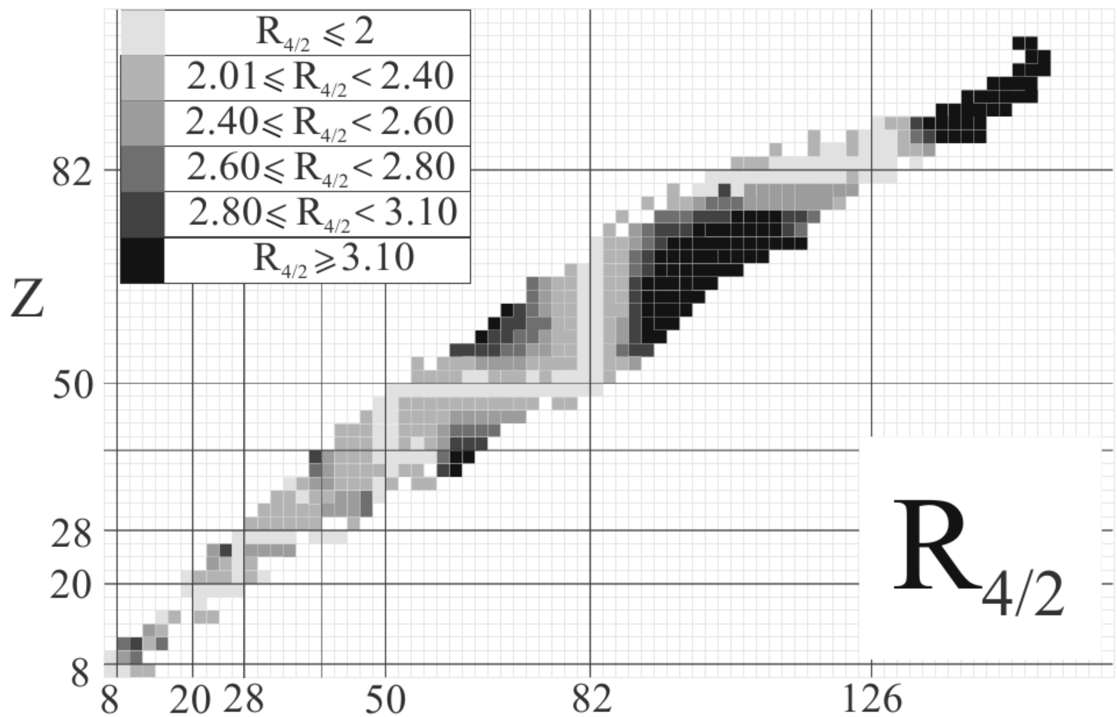
$$+ \sum_{k=1}^{A} p_k^2 Y_{2\mu}(\hat{\boldsymbol{p}}_k)$$



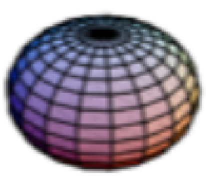
J.P. Elliott, Proc. Roy. Soc. A **245** (1958) 128; 562

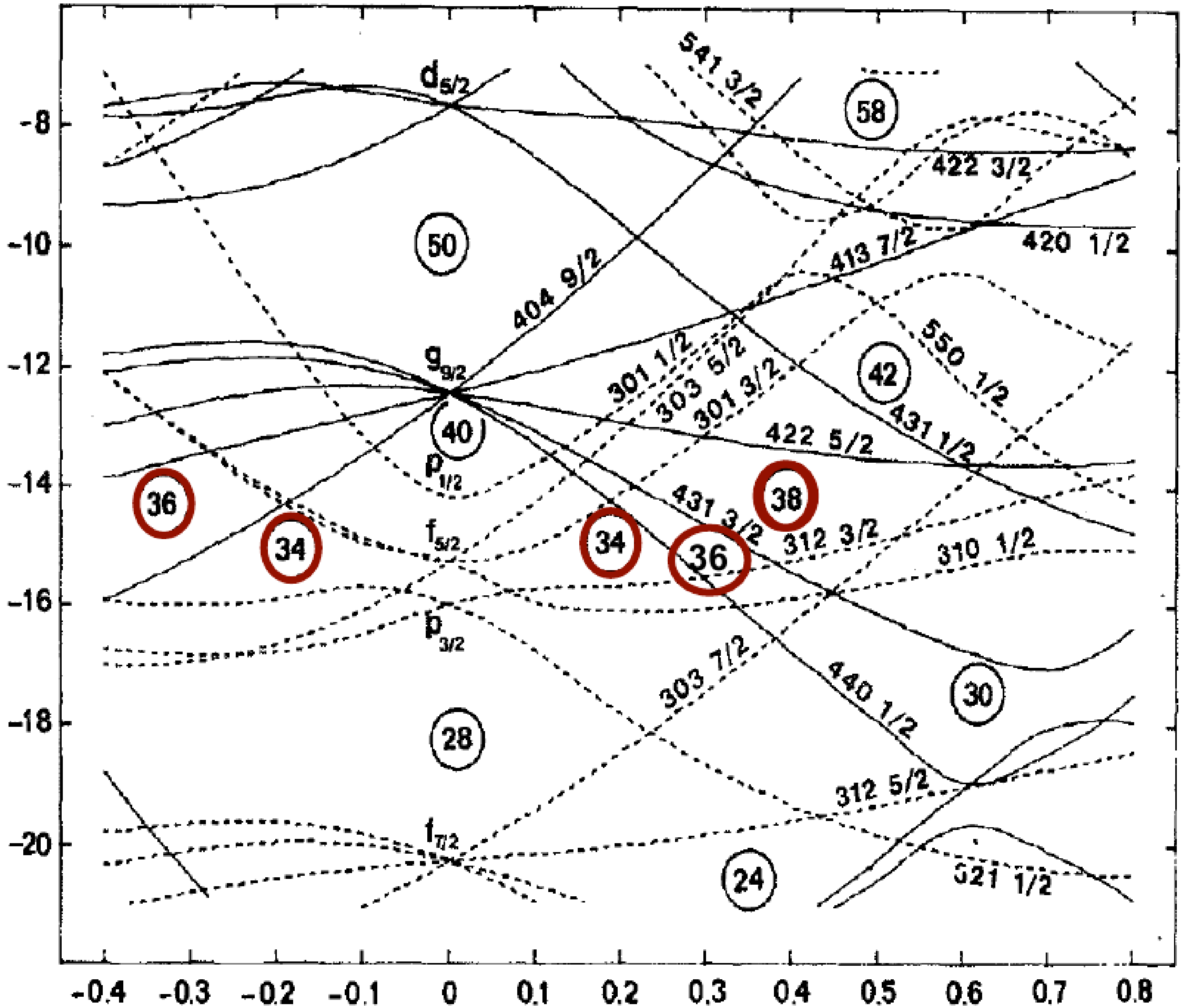


HO-SO
EEI
$2s_{1/2}$
$1d_{5/2}$
50
$0g_{9/2}$
(40)
$0f_{5/2}$
$1p_{1/2}$
$1p_{3/2}$
$0f_{7/2}$
20
$0d_{3/2}$
$1s_{1/2}$
$0d_{5/2}$
8
$0p_{1/2}$
$0p_{3/2}$
2
$0s_{1/2}$
r_1ds
6
r_2fp
pseudo quasi
14
r_3gds
pseudo quasi
(50)
28



$R_{4/2} \leqslant 2$
$2.01 \leqslant R_{4/2} < 2.40$
$2.40 \leqslant R_{4/2} < 2.60$
$2.60 \leqslant R_{4/2} < 2.80$
$2.80 \leqslant R_{4/2} < 3.10$
$R_{4/2} \geqslant 3.10$
Z
82
50
28
20
8
8
20
28
50
82
126
$R_{4/2}$





-8
-10
-12
-14
-16
-18
-20
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
d5/2
g9/2
p1/2
f5/2
p3/2
f7/2
50
40
28
58
42
30
24
36
34
34
36
38
541 3/2
422 3/2
420 1/2
413 7/2
404 9/2
550 1/2
301 1/2
303 5/2
301 3/2
422 5/2
431 1/2
431 3/2
312 3/2
310 1/2
303 7/2
440 1/2
312 5/2
321 1/2