Multiple Coulomb Excitation and Transfer Studies beyond N=40

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TRIUMF

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Changing Lives Improving Life

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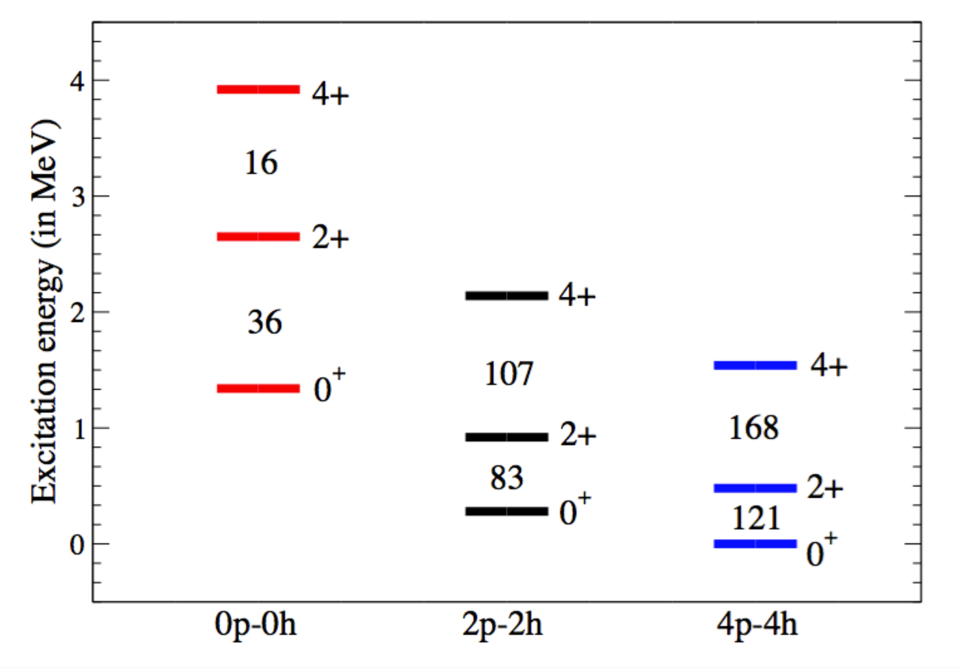
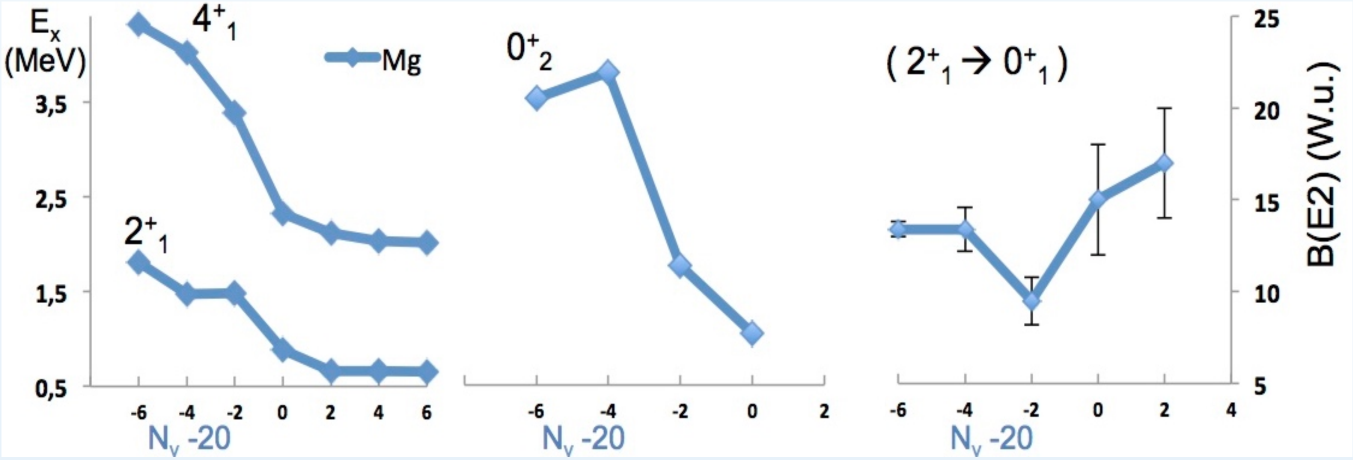


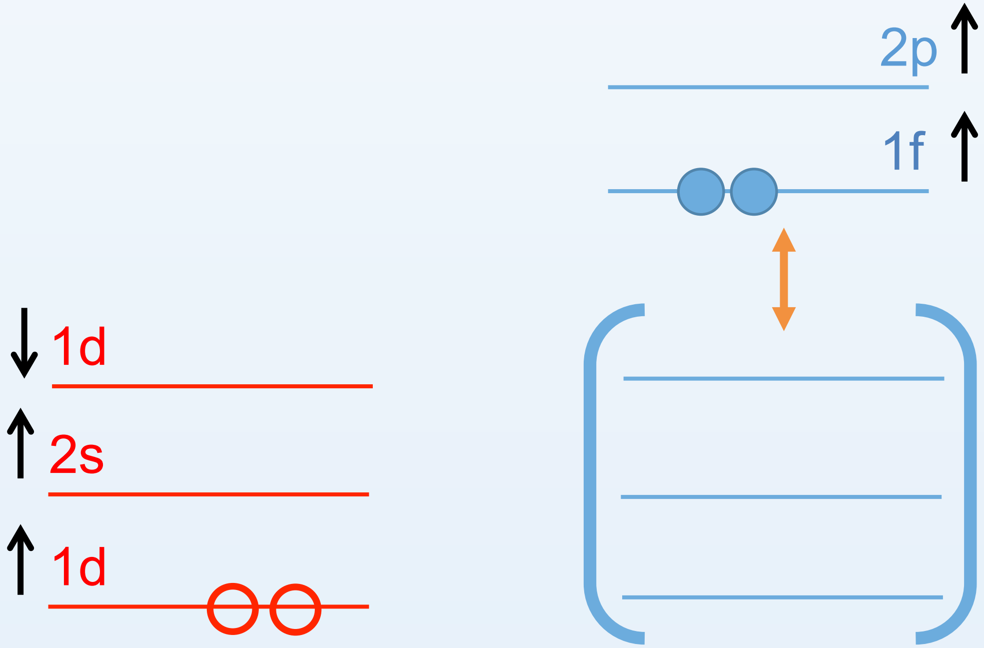
"Shape coexistence is the portal to deformation"(A. Poves)

$$|0_1^+\rangle = \quad \alpha\,|0\rangle + \beta\,|\uparrow\downarrow\rangle$$
$$|0_2^+\rangle = -\beta\,|0\rangle + \alpha\,|\uparrow\downarrow\rangle$$

shell model: $\alpha^2 \cong$ 10 %

two-neutron transfer: $\alpha^2 \cong$ 75 %





Z=8-20

N=8-20

K. Wimmer et al. PRL 105, 252501 (2010)

J. A. Lay et al., PRC **89**, 034618 (2014)

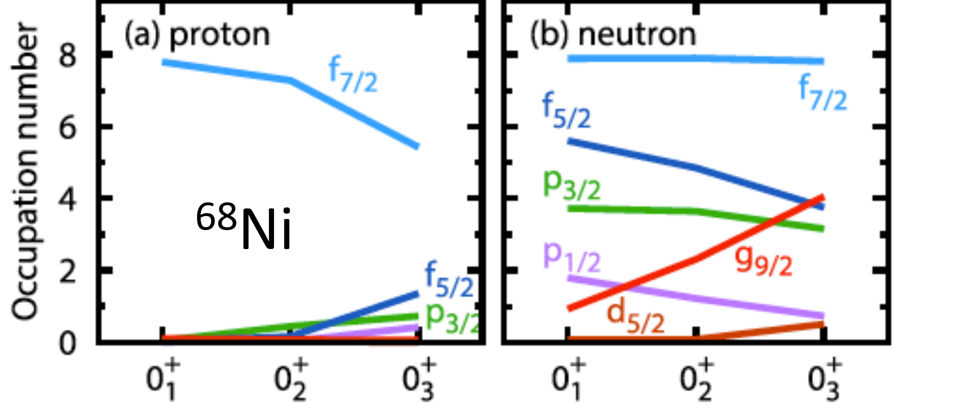
E. Caurier F. Nowacki and A. Poves, PRC **90**, 014302 (2014)

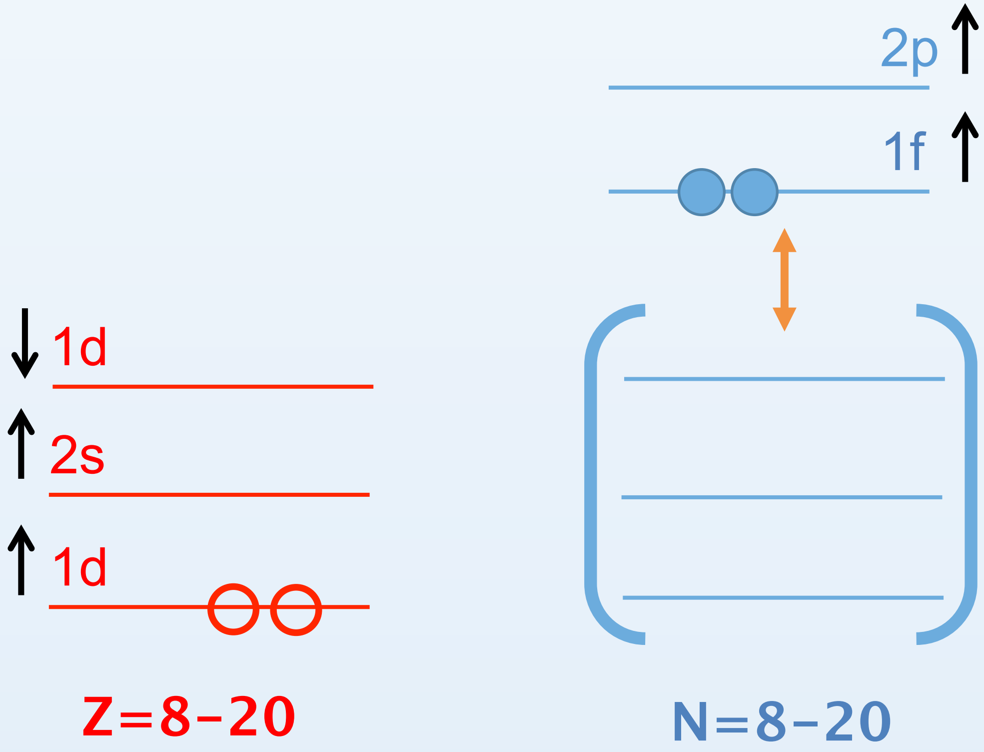
Z	66Zn STABLE 27.73%	67Zn STABLE 4.04%	68Zn STABLE 18.45%	69Zn 56.4 M β-: 100.00%	70Zn ≥2.3E+17 Y 0.61% 2β-	71Zn 2.45 M β-: 100.00%	72Zn 46.5 H β-: 100.00%	73Zn 23.5 S β-: 100.00%	74Zn 95.6 S β-: 100.00%
29	65Cu STABLE 30.85%	66Cu 5.120 M β-: 100.00%	67Cu 61.83 H β-: 100.00%	68Cu 30.9 S β-: 100.00%	69Cu 2.85 M β-: 100.00%	70Cu 44.5 S β-: 100.00%	71Cu 19.4 S β-: 100.00%	72Cu 6.63 S β-: 100.00%	73Cu 4.2 S β-: 100.00%
28	64Ni STABLE 0.9255%	65Ni 2.5175 H β-: 100.00%	66Ni 54.6 H β-: 100.00%	67Ni 21 S β-: 100.00%	68Ni 29 S β-: 100.00%	69Ni 11.2 S β-: 100.00%	70Ni 6.0 S β-: 100.00%	71Ni 2.56 S β-: 100.00%	72Ni 1.57 S β-: 100.00%
27	63Co 27.4 S β-: 100.00%	64Co 0.30 S β-: 100.00%	65Co 1.16 S β-: 100.00%	66Co 0.20 S β-: 100.00%	67Co 0.425 S β-: 100.00%	68Co 0.199 S β-: 100.00%	69Co 229 MS β-: 100.00%	70Co 108 MS β-: 100.00%	71Co 80 MS β-: 100.00% β-n≤ 6.00%
26	62Fe 68 S β-: 100.00%	63Fe 6.1 S β-: 100.00%	64Fe 2.0 S β-: 100.00%	65Fe 0.81 S β-: 100.00%	66Fe 440 MS β-: 100.00%	67Fe 0.40 S β-: 100.00%	68Fe 180 MS β-: 100.00%	69Fe 110 MS β-: 100.00%	70Fe 71 MS β-: 100.00%
	36	37	38	39	40	41	42	43	N

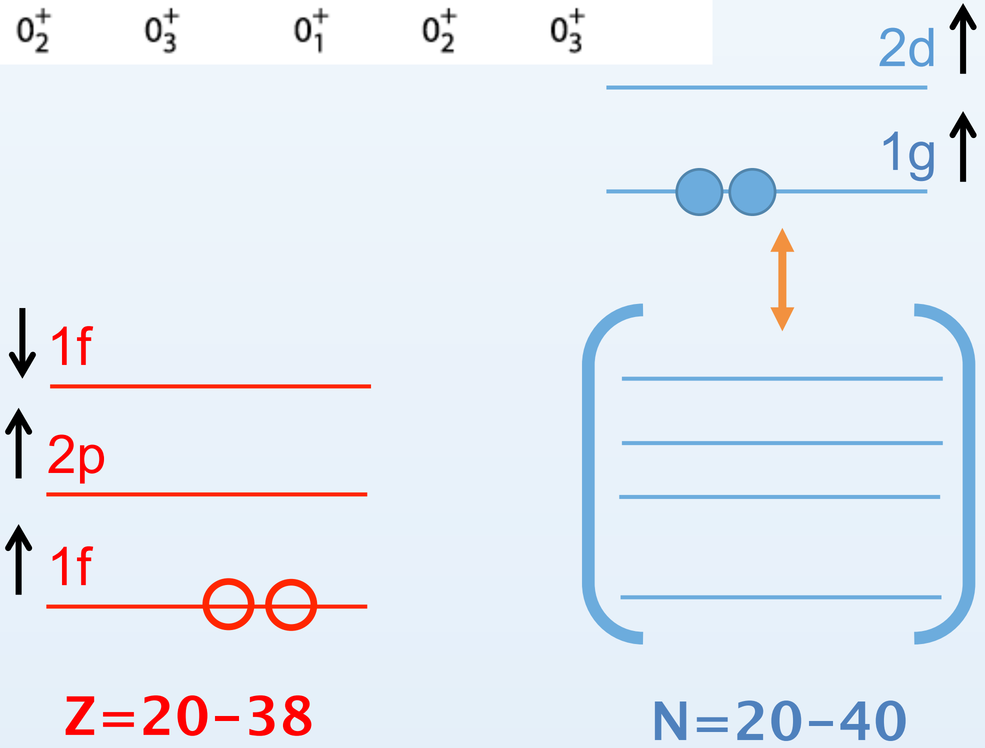
role of p($f_{7/2}$) – n($g_{9/2}$) in zinc isotopes around N=40:

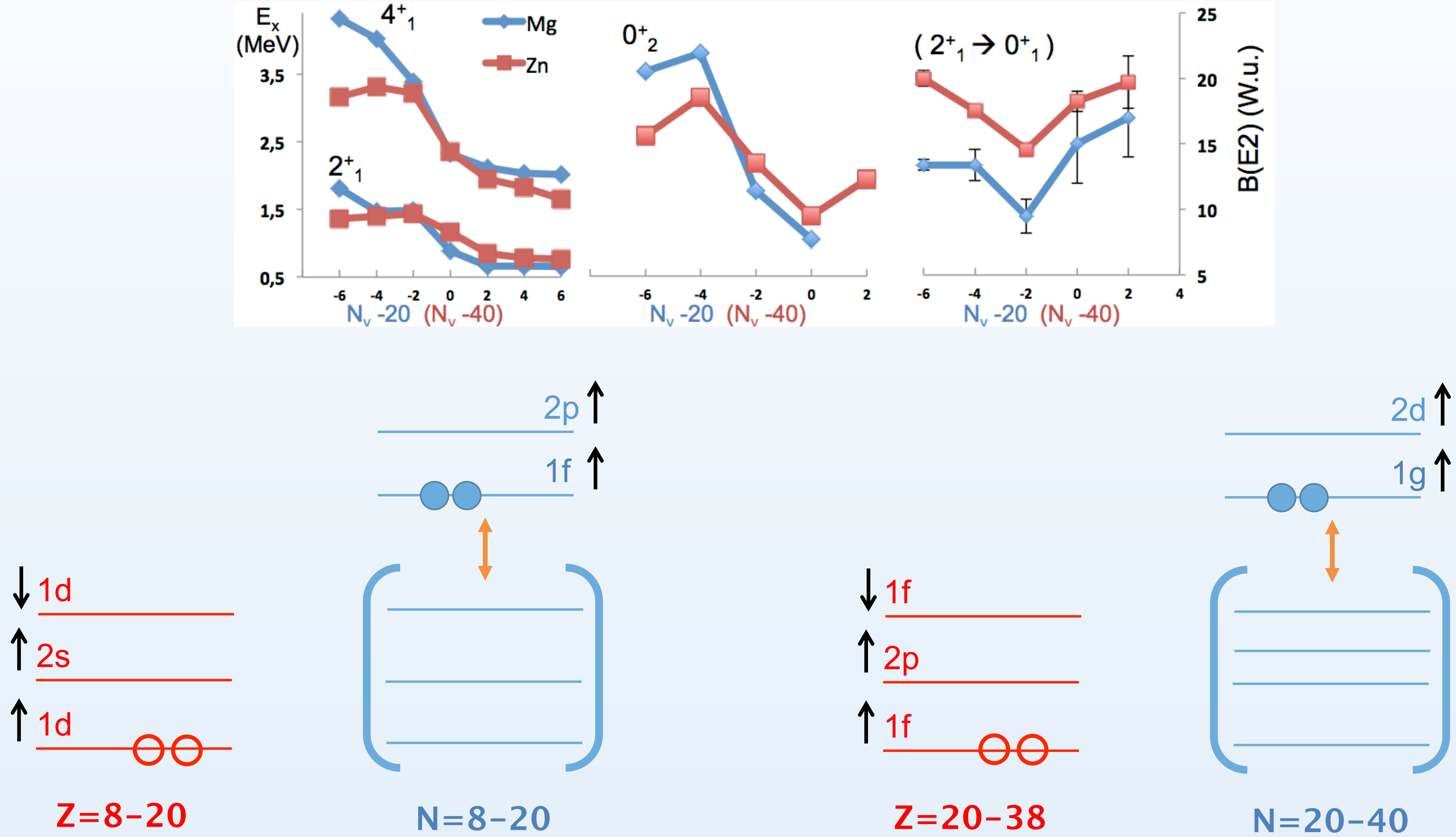
- A. Lisetskiy et al., PRC 70, 044314, 2004
- O. Sorlin et al. PRL 88, 092501, 2002
- D. Muecher at al. PRC 79, 054310, 2009

Y. Tsunoda, T. Otsuka, et al., Phys. Rev. C 89, 031301 (2014).

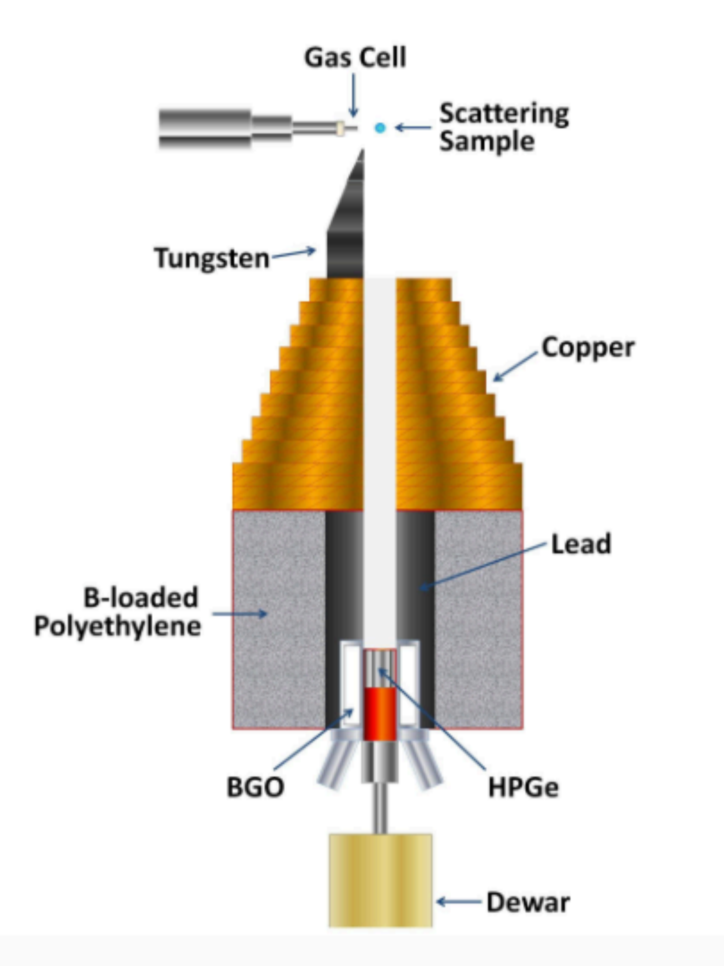




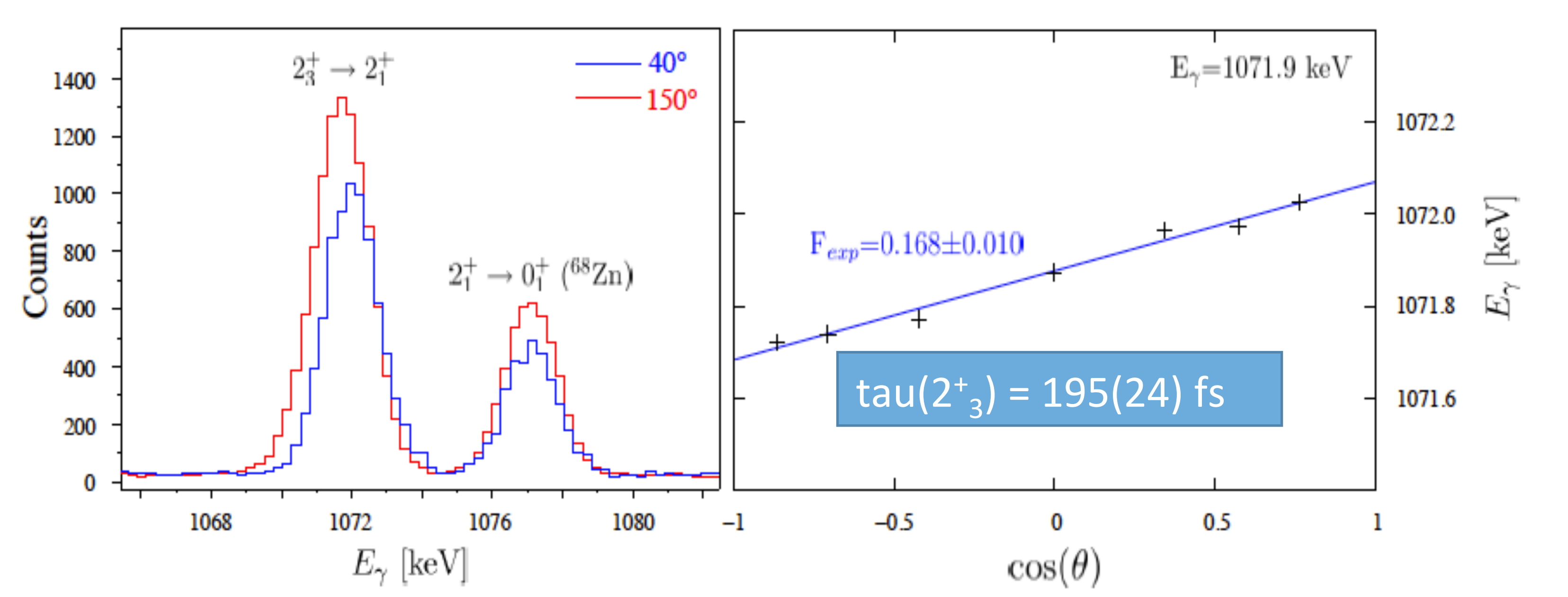



E$_x$ (MeV)
4$^+_1$
2$^+_1$
Mg
Zn
0$^+_2$
(2$^+_1$ → 0$^+_1$)
B(E2) (W.u.)
N$_\nu$ -20 (N$_\nu$ -40)
N$_\nu$ -20 (N$_\nu$ -40)
N$_\nu$ -20 (N$_\nu$ -40)
2p
1f
1d
2s
1d
2d
1g
1f
2p
1f
Z=8-20
N=8-20
Z=20-38
N=20-40

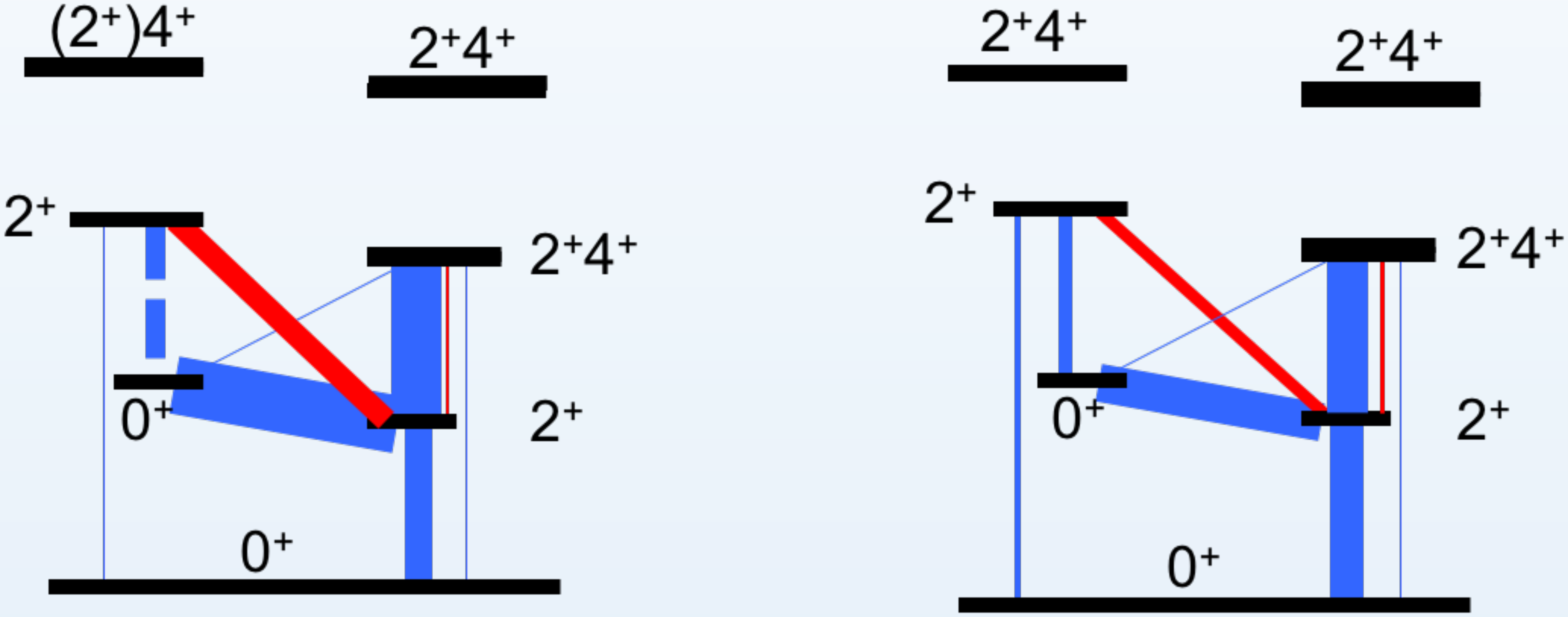
Inelastic Neutron Scattering, University of Kentucky



production of monoenergetic neutrons:
$^3H(p,n)\,^3He$
$0.5 < E_n < 5.5$ MeV 50 keV $< \Delta E_n < 100$ keV
neutron flux: 10^7 1/s
target: 12 g ZnO
angular disributions: E_n=2.5 MeV + E_n=3.6 MeV
excitation function: E_n=1.5–4 MeV (steps of 100 keV)



Shape Coexistence at the "Shore" of the Island of Inversion at N=40



exp. data

JJ4C shell model

NushellX @ UofG with new "JJ4C" effectie interaction: modified interaction of JJ4B: ^{56}Ni core and $p_{3/2}$, $f_{5/2}$, $p_{1/2}$, $g_{9/2}$
D. Muecher, E. Peters, B. A. Brown et al, to be published

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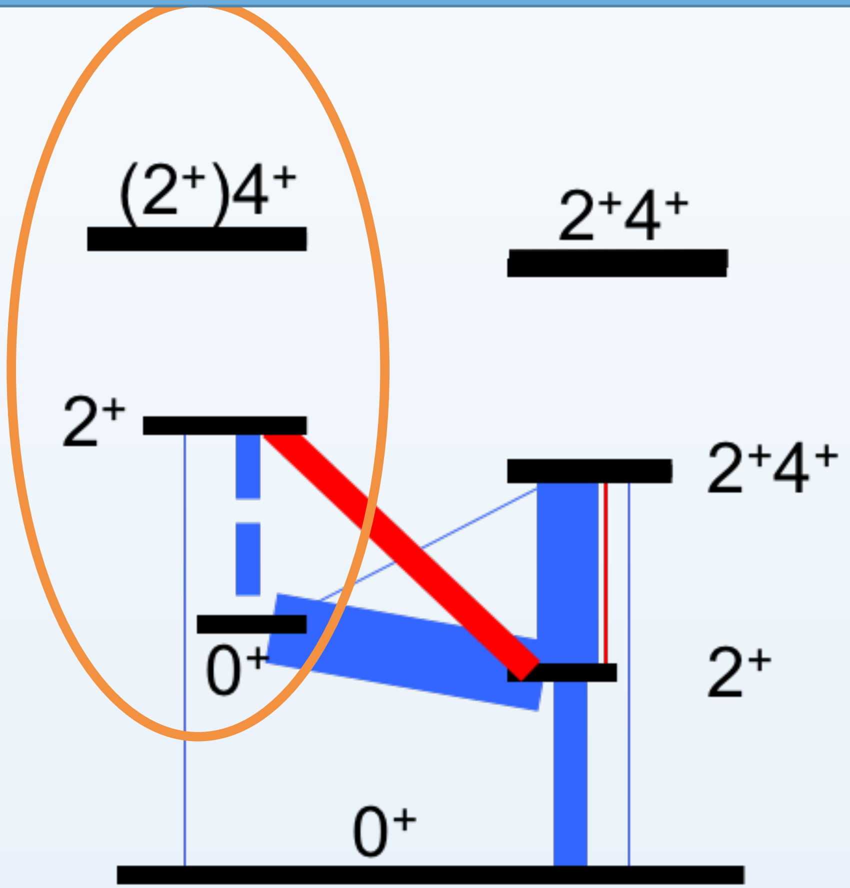
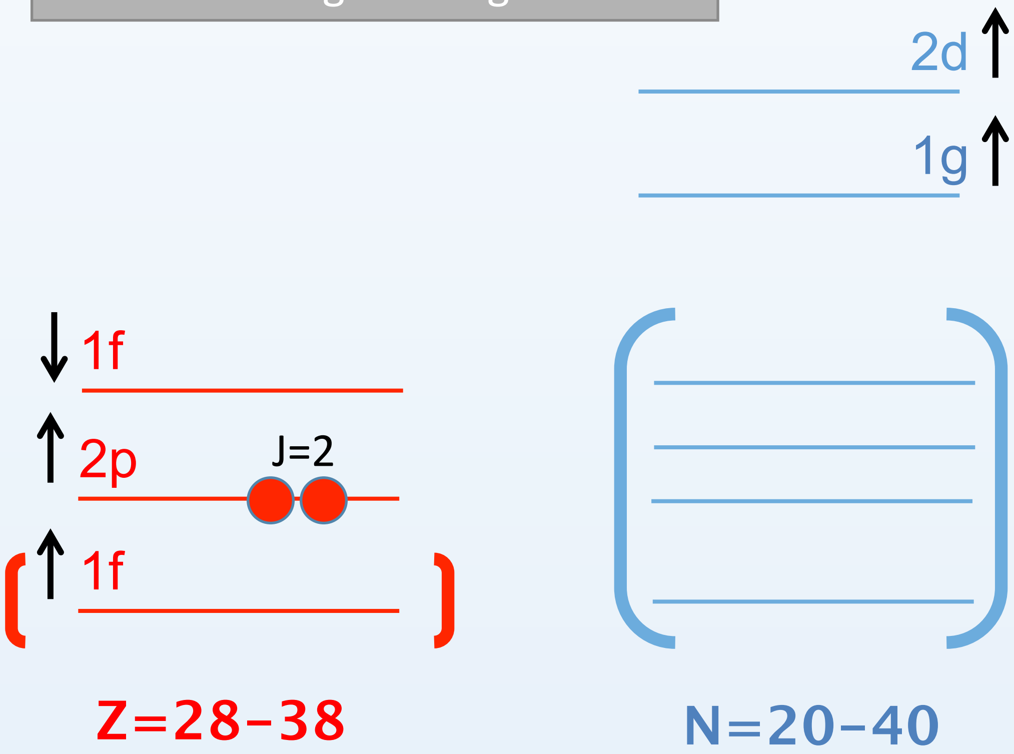


exp. data

$\mu(2^+_3) = 2.02\ \mu_N$
(shell model)

wavefunction for 2^+_3 state:
49% is this single configuration!

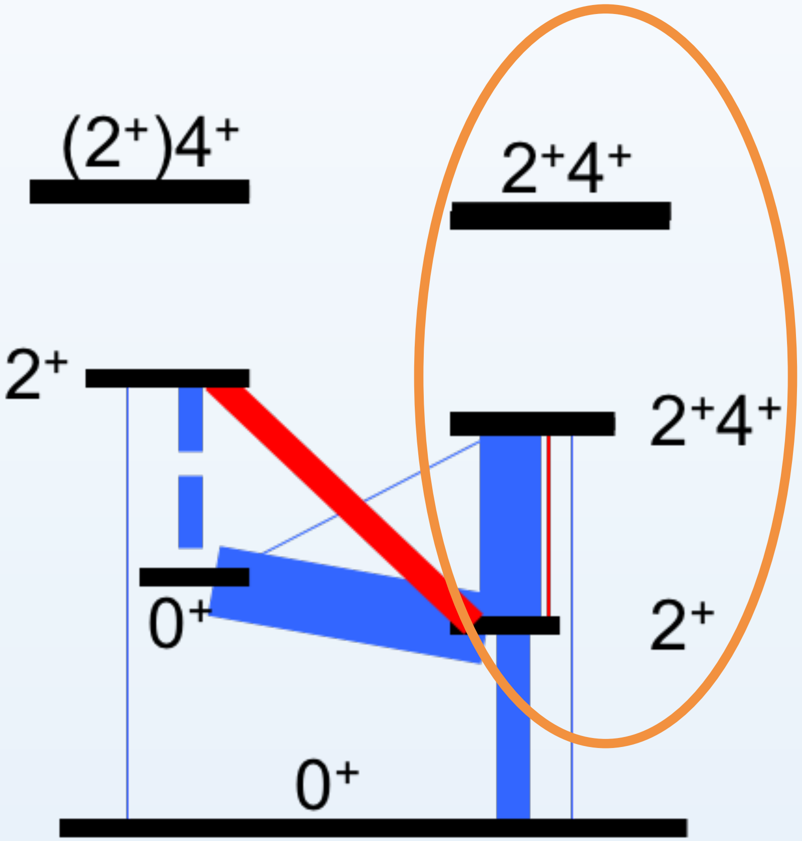


large magnetic moment and lack of configuration mixing for 2^+_3 state: strong M1 transition into 2^+_1 state

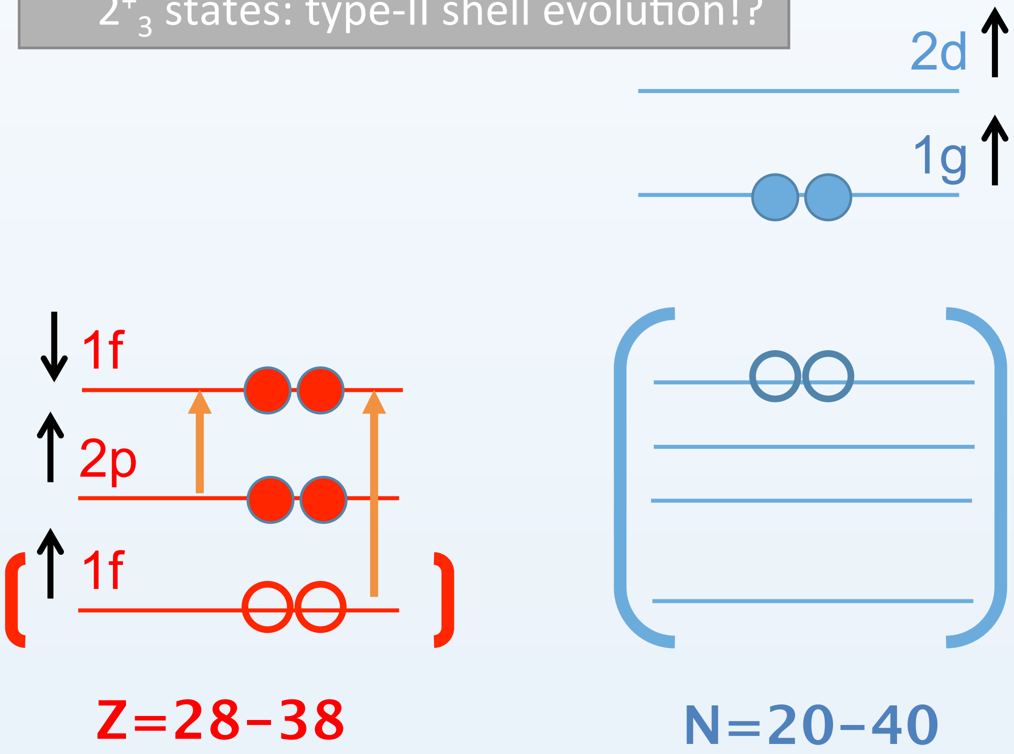
Shape Coexistence at the “Shore” of the Island of Inversion at N=40

Y-rast band:

- protons move to $1f_{5/2}$ and neutrons into $1g_{9/2}$
- $1f_{7/2}$ occupation highest for 0^+_2, 2^+_3 states: type-II shell evolution!?



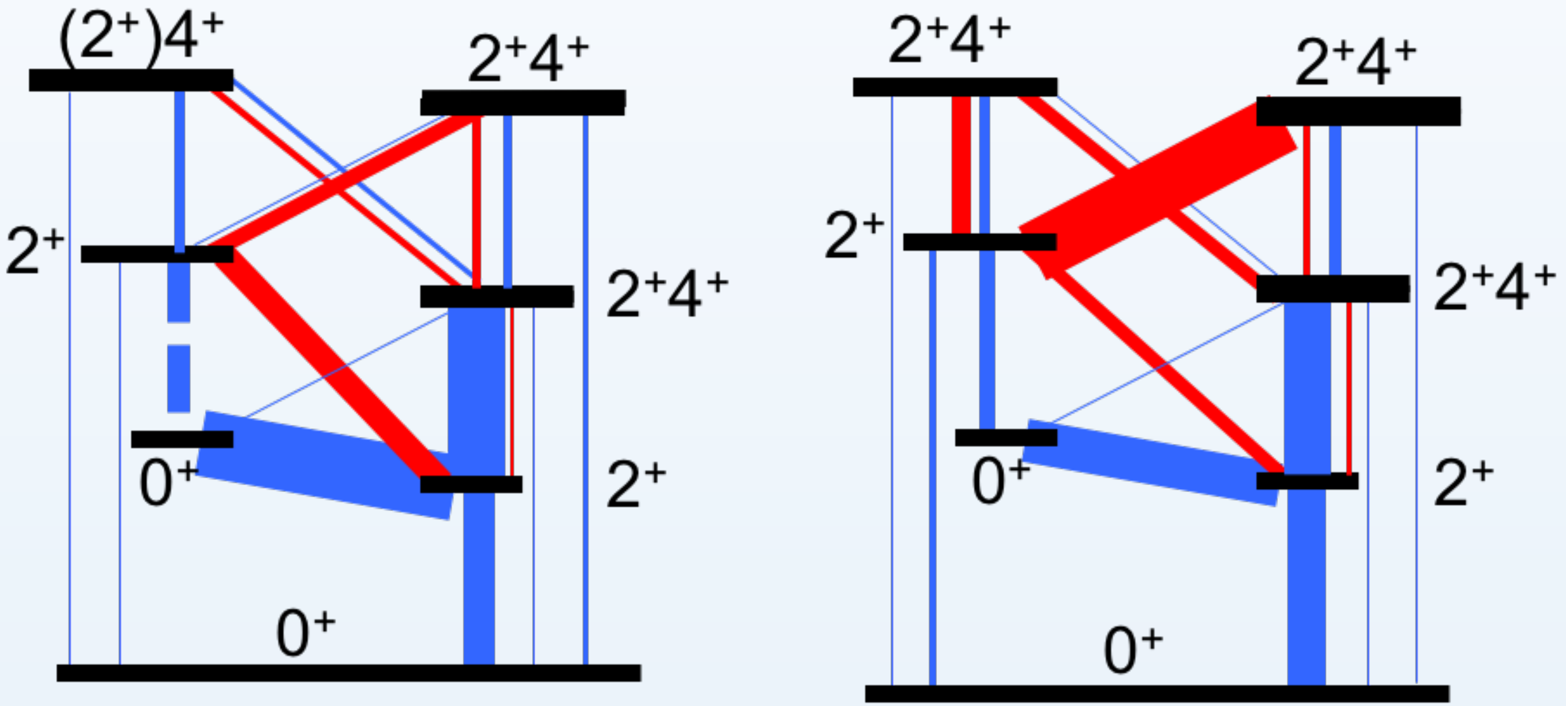
exp. data



large-scale SM using ^{48}Ca core and fpg interaction:
P. C. SRIVASTAVA, *Mod. Phys. Lett. A*, **27**, 1250061 (2012)

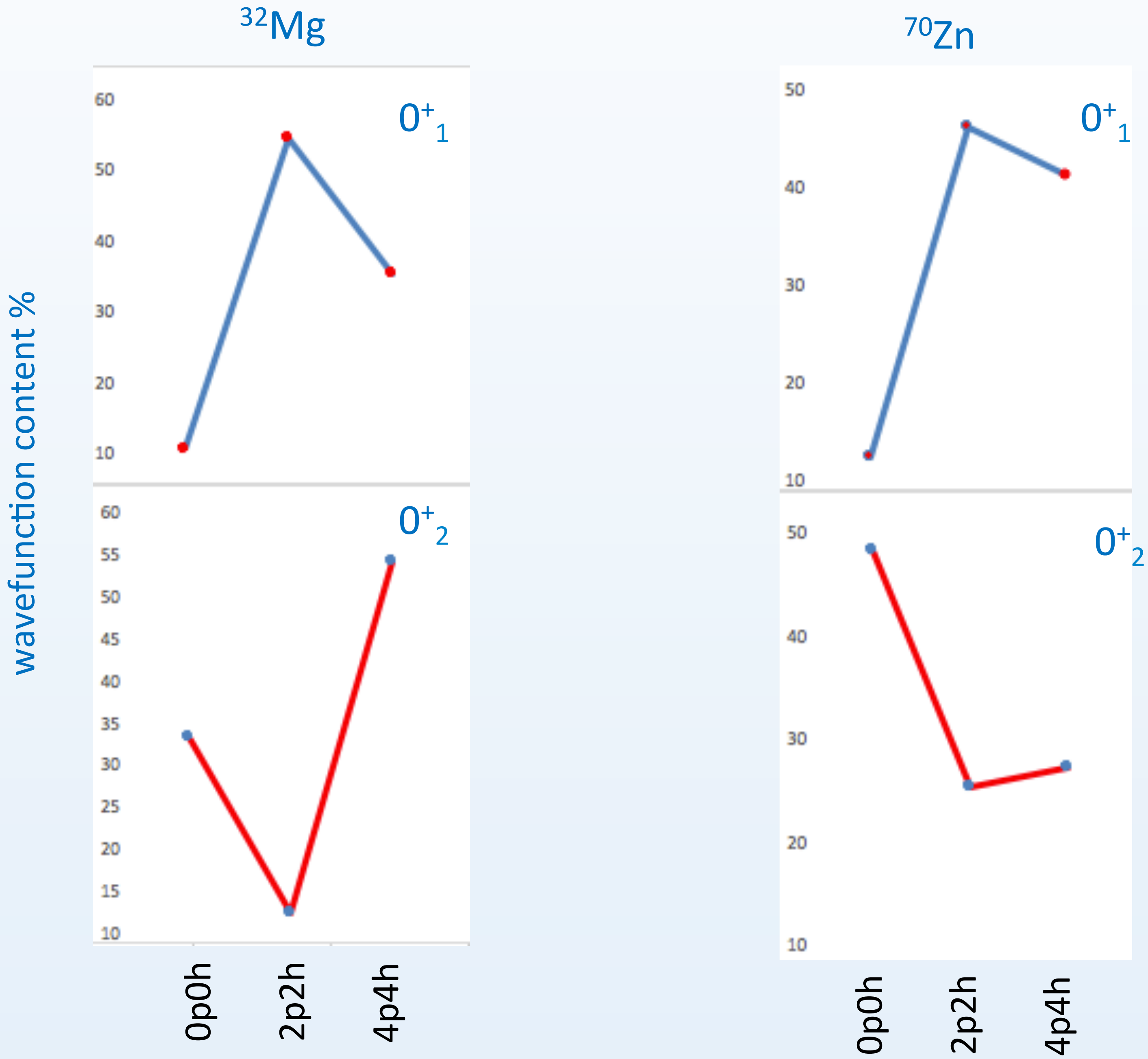
little mixing between 2^+_3 and 2^+_2 states: coherent change in proton and neutron configurations, driven by the strong T=0 pn tensor interaction $1f_{5/2} - 1g_{9/2}$

Shape Coexistence at the "Shore" of the Island of Inversion at N=40



- strong M1 transition $2^+_4 \rightarrow 2^+_3$ of the same origin: interband M1 transitions as a robust feature to trace shape coexistence at closed shell nuclei?
- more mixing for 4^+ states: protons have to go into $f_{5/2}$ to couple to J=4!

→ tensor-degree of freedom controls mixing of the two configurations at N=40


32Mg
70Zn
wavefunction content %
0+1
0+2
0p0h
2p2h
4p4h
60
50
40
30
20
10
55
45
35
25
15

Z									
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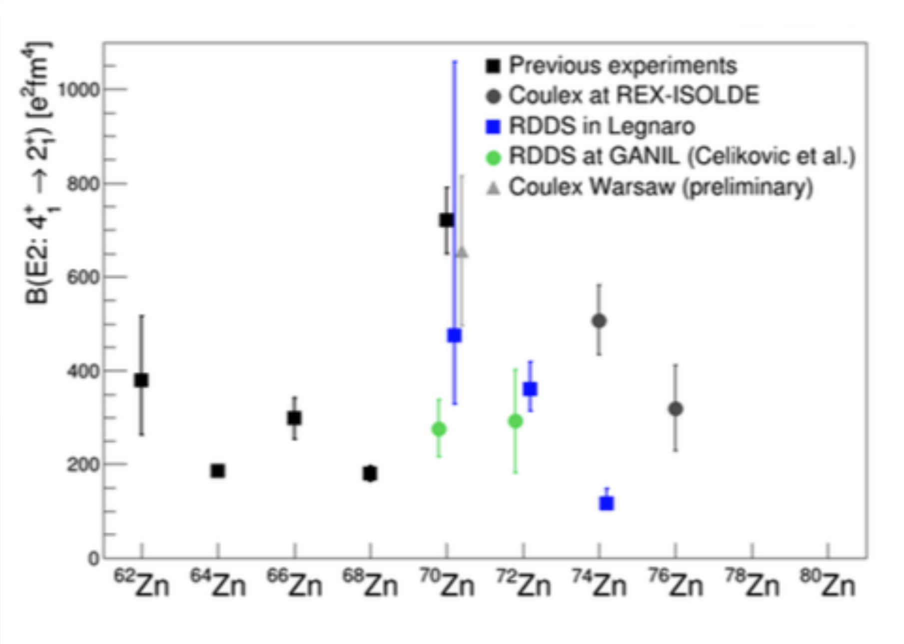
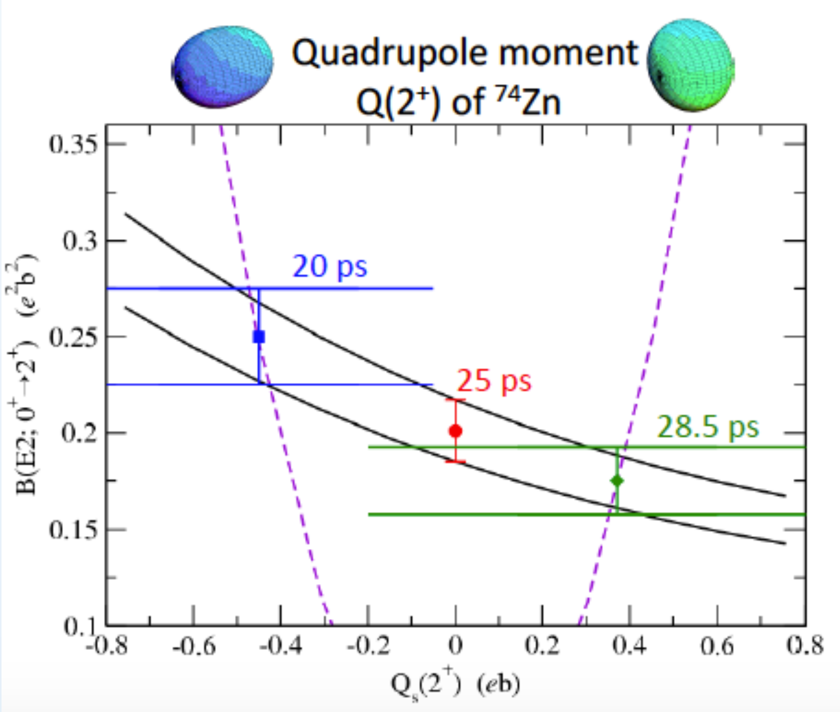
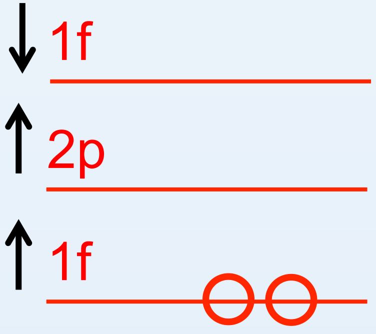
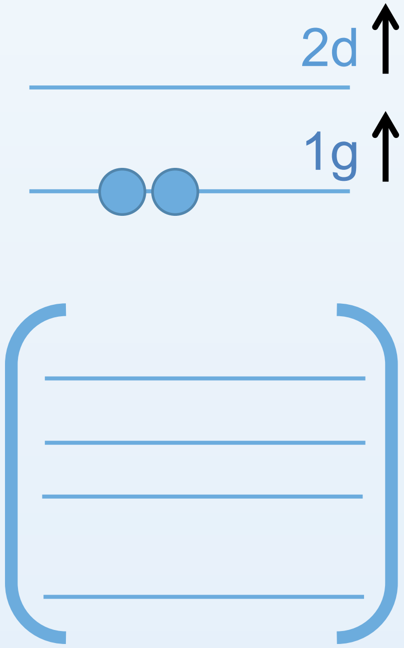




slide Wolfram
Korten, INPC 2016

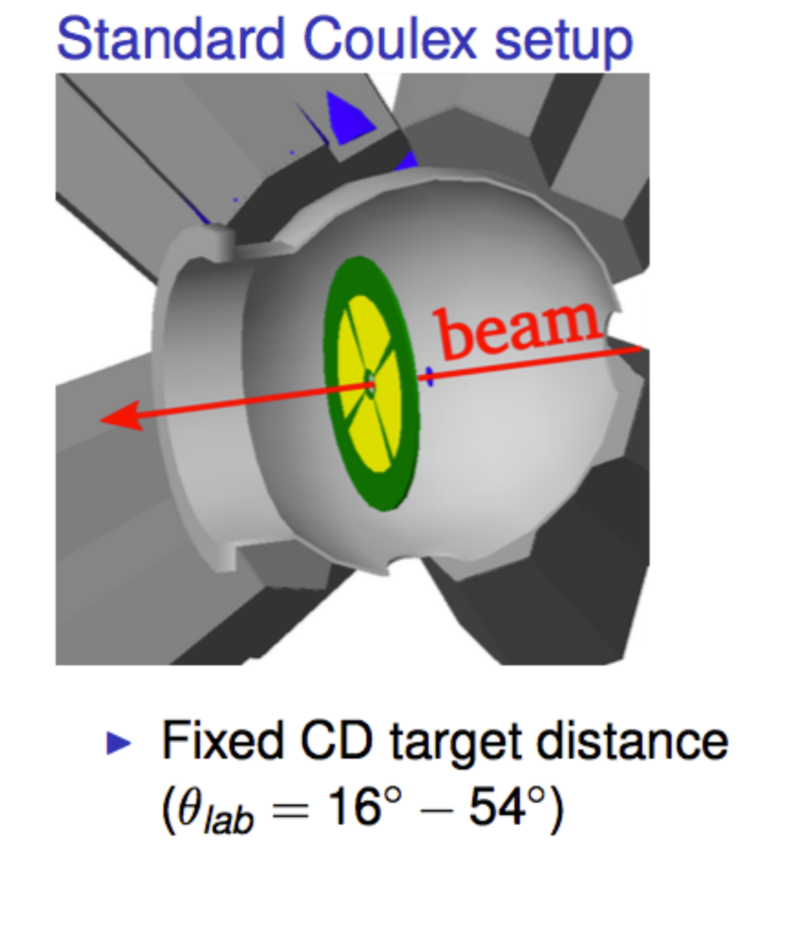


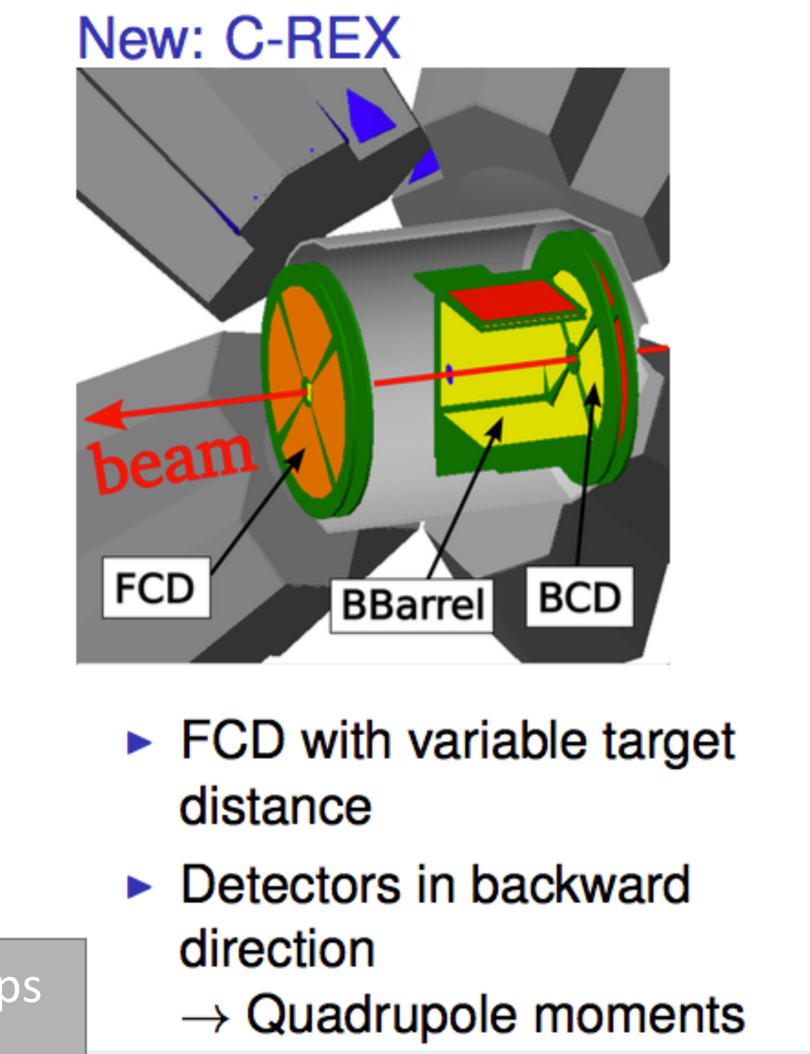
Z=20-38



N=20-40

Multiple Coulomb Excitation of ^{72}Zn with MINIBALL at ISOLDE



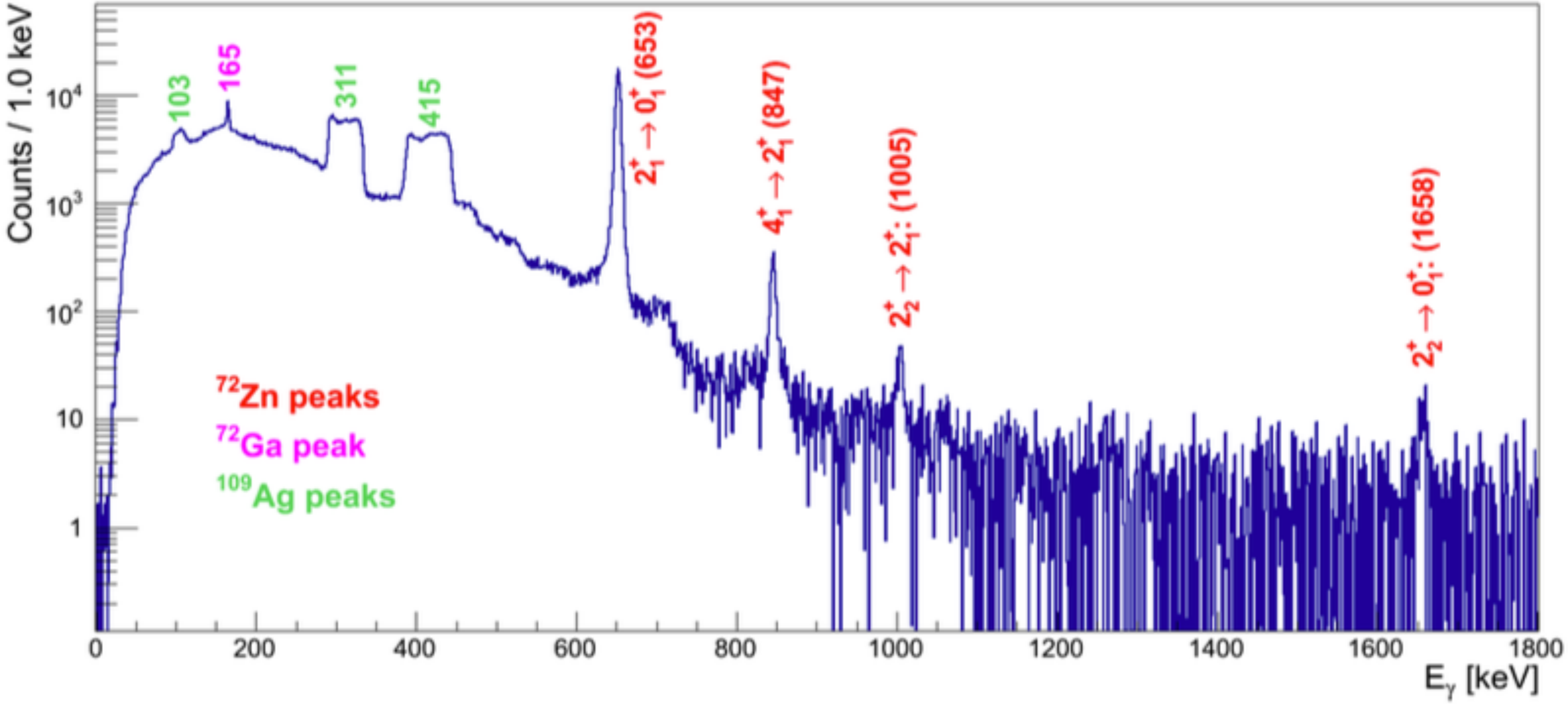


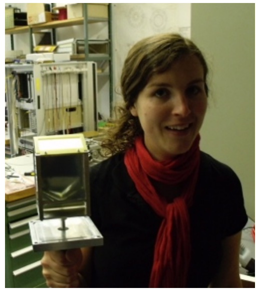
^{72}Zn mean beam intensity (MINIBALL): $(3.5 \pm 0.3) \cdot 10^7$ pps

Doppler Corrected γ-ray-Spectrum w.r.t. ^{72}Zn

Ph.D. thesis S. Hellgartner (TU Munich), Sep. 2015

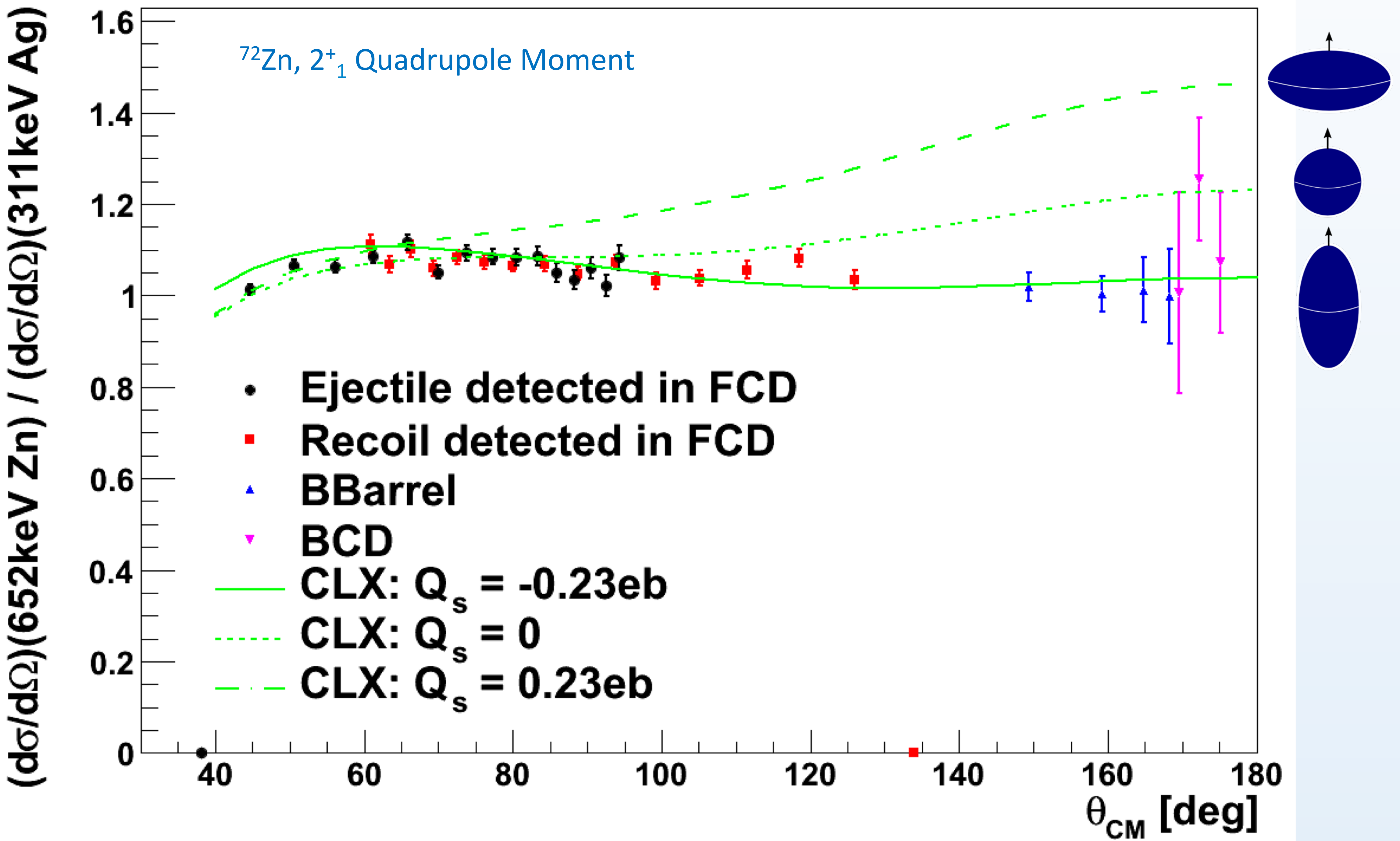
- ^{72}Zn detected in the Forward CD





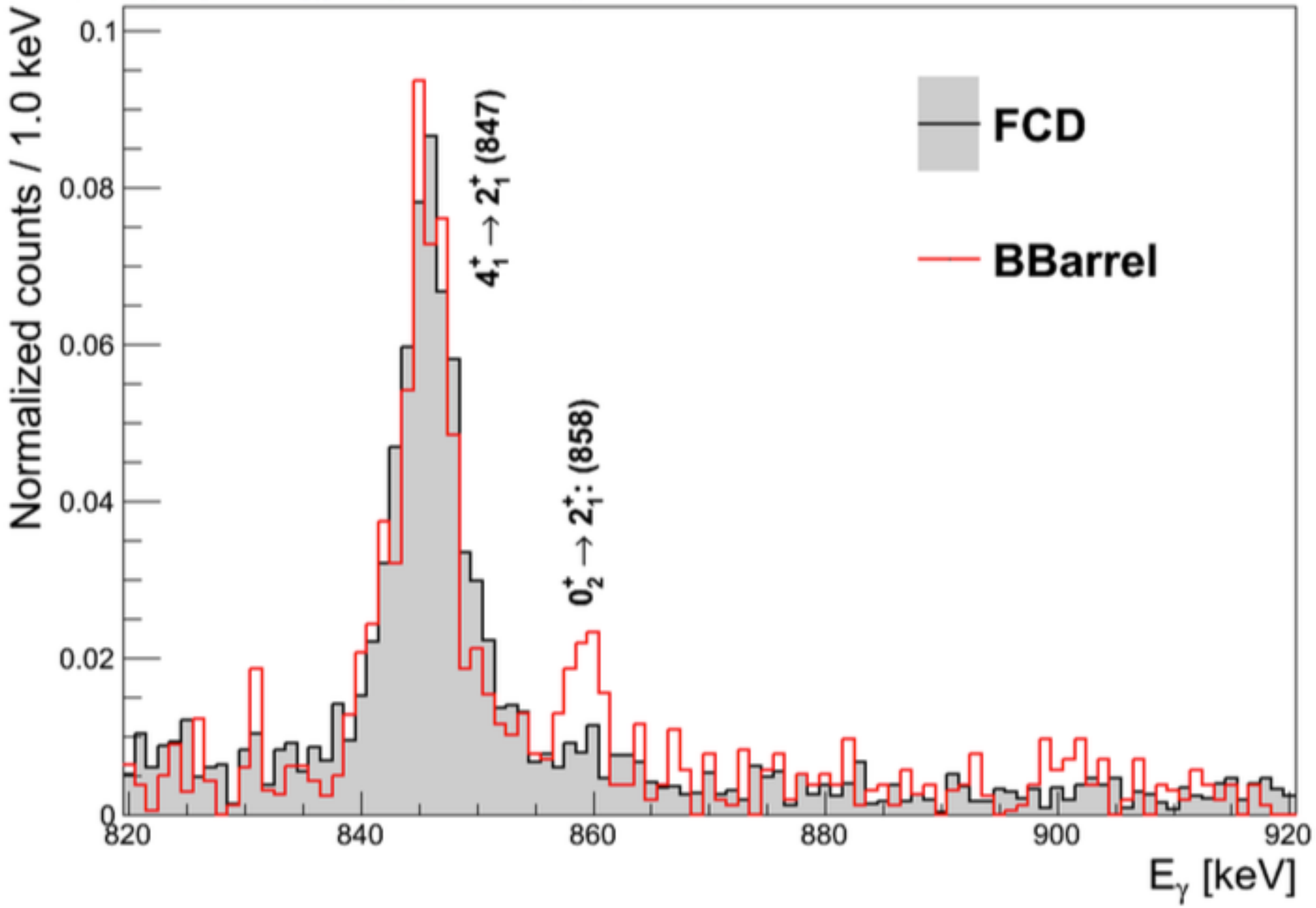
- Development of new data-driven calibration procedure

⇒ Unprecedented performance of the Doppler correction: $\Delta E = 6.4\,\text{keV}$ (FWHM) at $E_\gamma = 653\,\text{keV}$



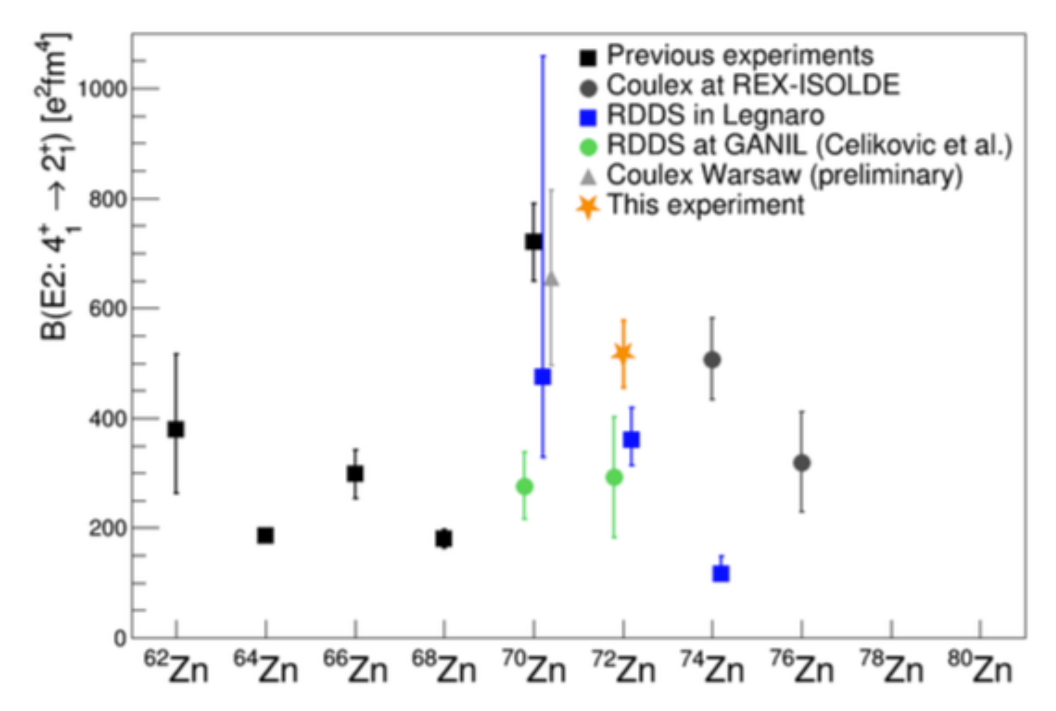
^{72}Zn, 2^+_1 Quadrupole Moment
(dσ/dΩ)(652keV Zn) / (dσ/dΩ)(311keV Ag)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
40
60
80
100
120
140
160
180
θ$_{CM}$ [deg]
Ejectile detected in FCD
Recoil detected in FCD
BBarrel
BCD
CLX: Q$_s$ = -0.23eb
CLX: Q$_s$ = 0
CLX: Q$_s$ = 0.23eb

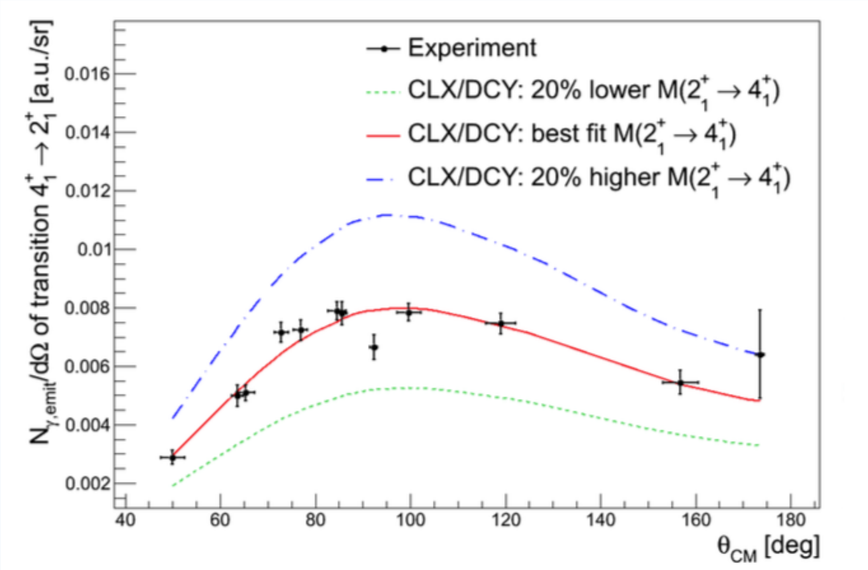
Doppler Corrected γ-ray-Spectrum w.r.t. ^{72}Zn



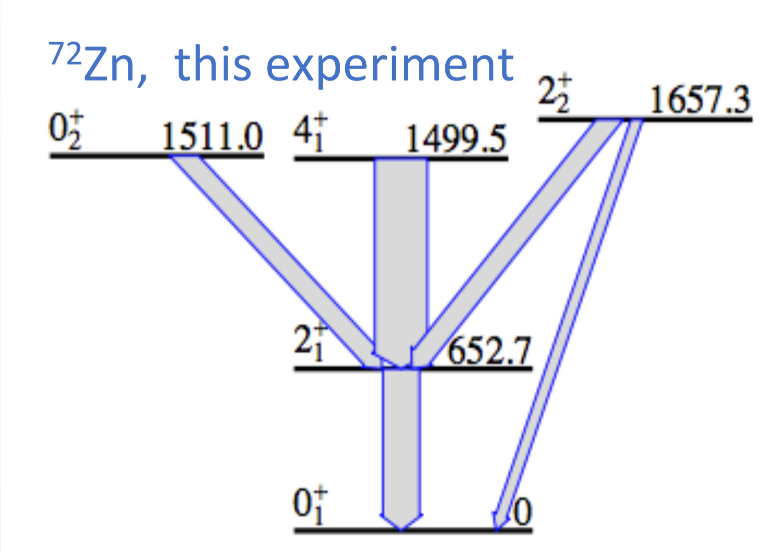
- $0_2^+ \to 2_1^+$ transition only visible in backward direction

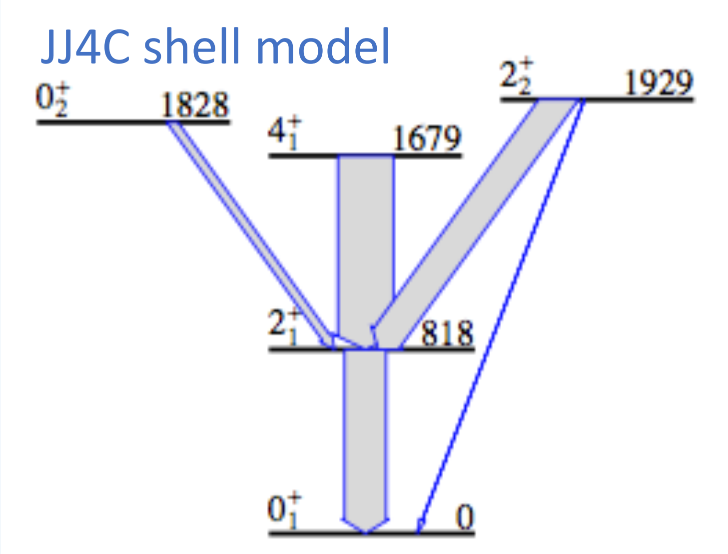
$\rightarrow$ Benefit of the new C-REX setup, no measurement with previous setup possible!

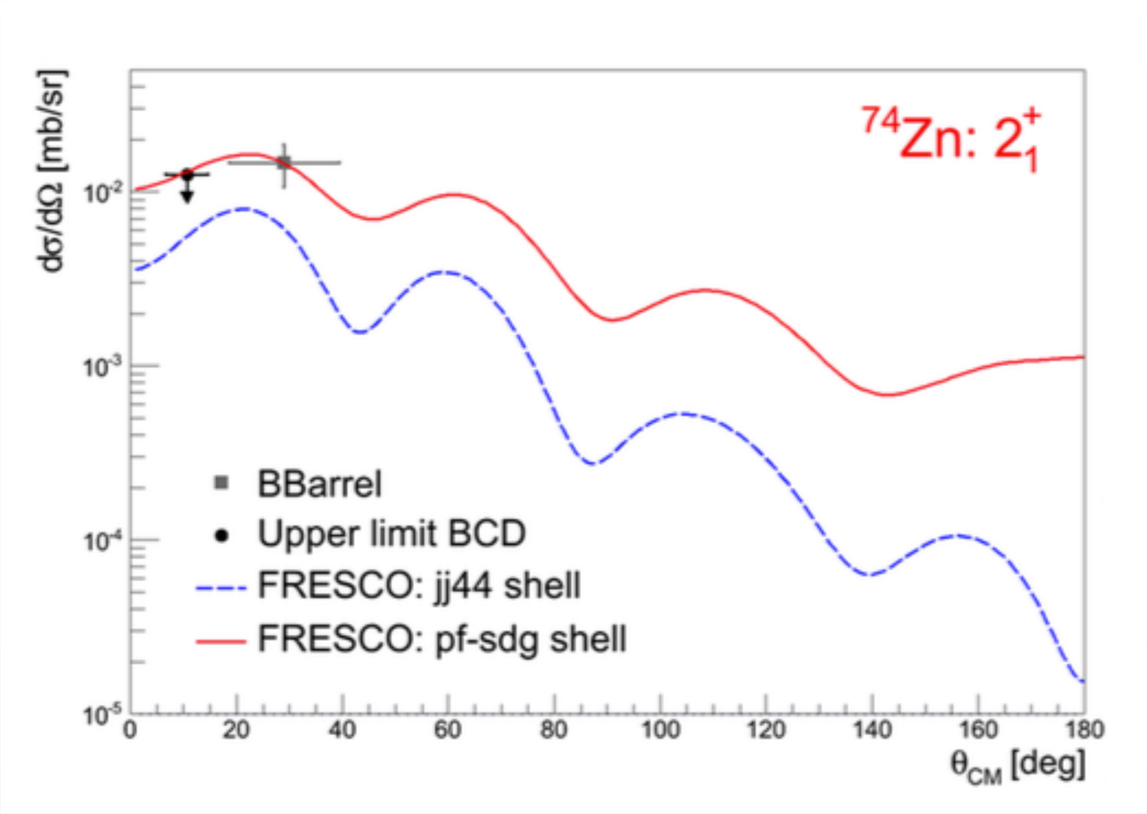




4$^+$ states gain collectivity in neutron-rich Zn isotopes due to interplay $p(f_{5/2}) - n(g_{9/2})$

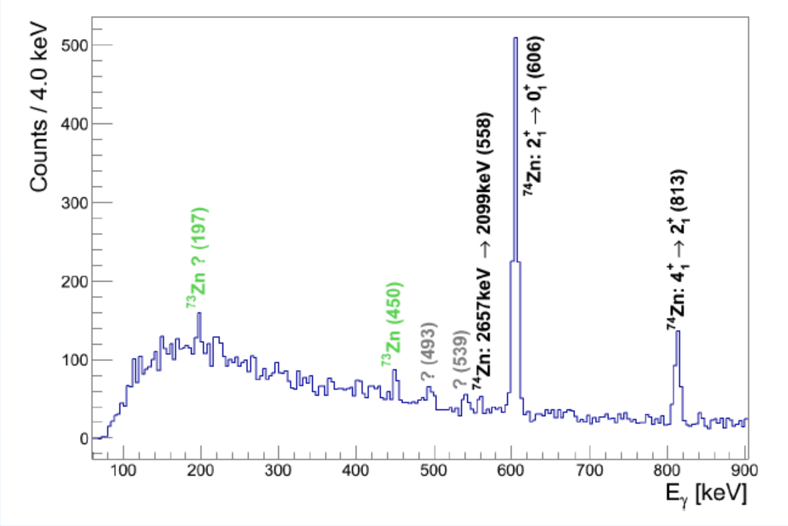


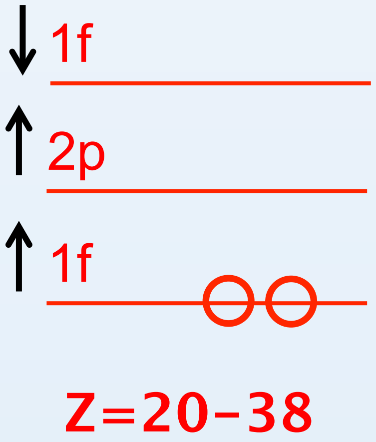


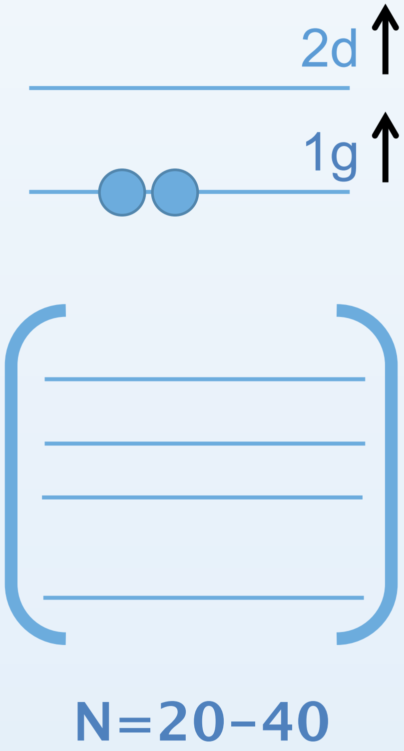


- inclusion of n($2d_{5/2}$) seems essential using a perturbation approximation(B.A. Brown, priv. com.)
- full calculation using ^{48}Ca core and pf-sdg on the way: P.C. Srivastava, Indian Institute of Technology, Roorkee

perturbation approach:
P . Decowski, W. Benenson, B.A. Brown and H. Nann Nuclear Physics A302 (1978) 186-204







Technical University of Munich:

- S. Hellgartner + K. Nowak: ISOLDE
- K. Wimmer, R. Gernhäuser, R. Krücken

University of Kentucky:

- E. Peters
- S. W. Yates and his team

NSCL, MSU:

- B. A. Brown

Indian Institute of Technology, Roorkee

- P.C. Srivastava

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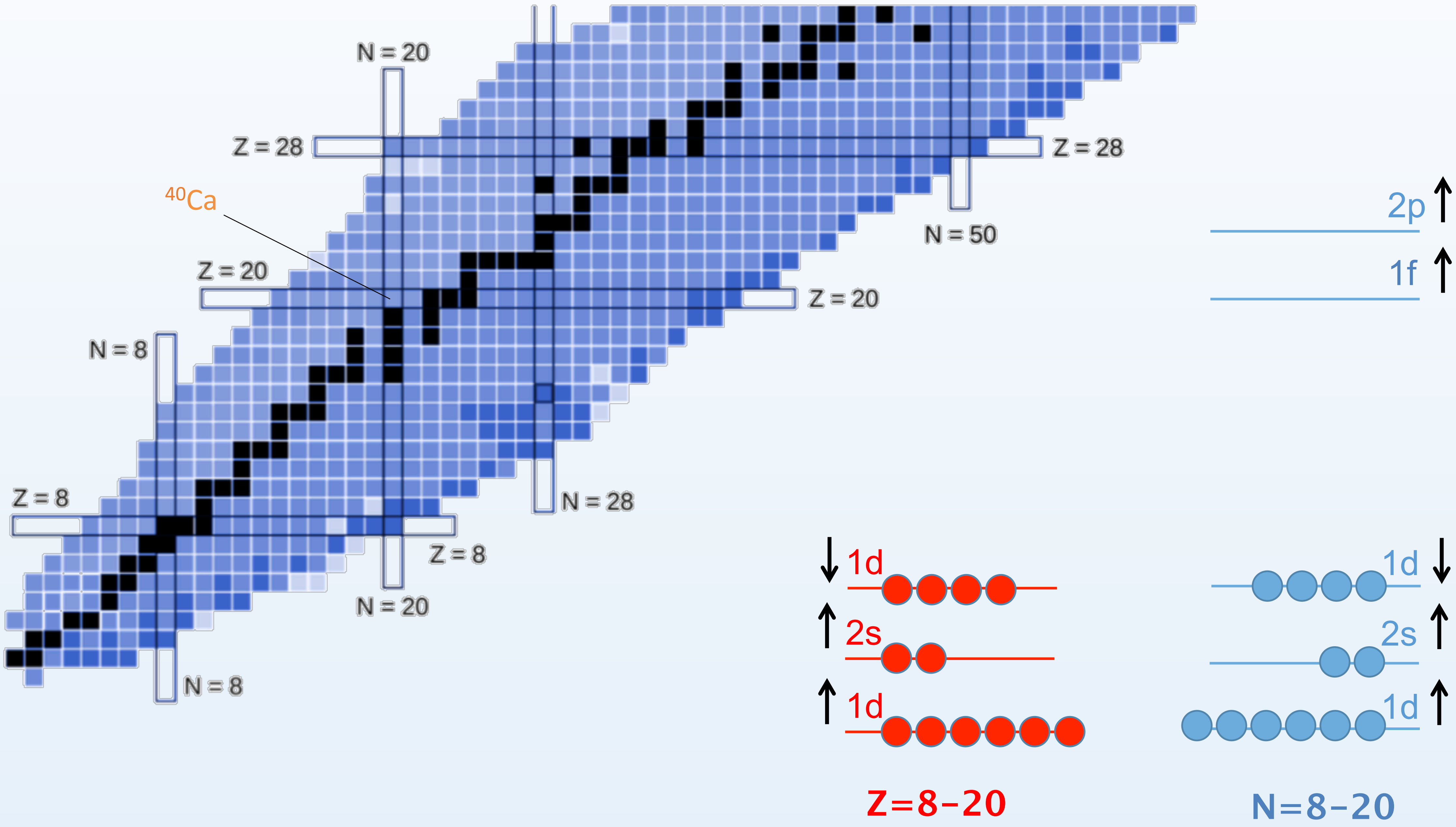
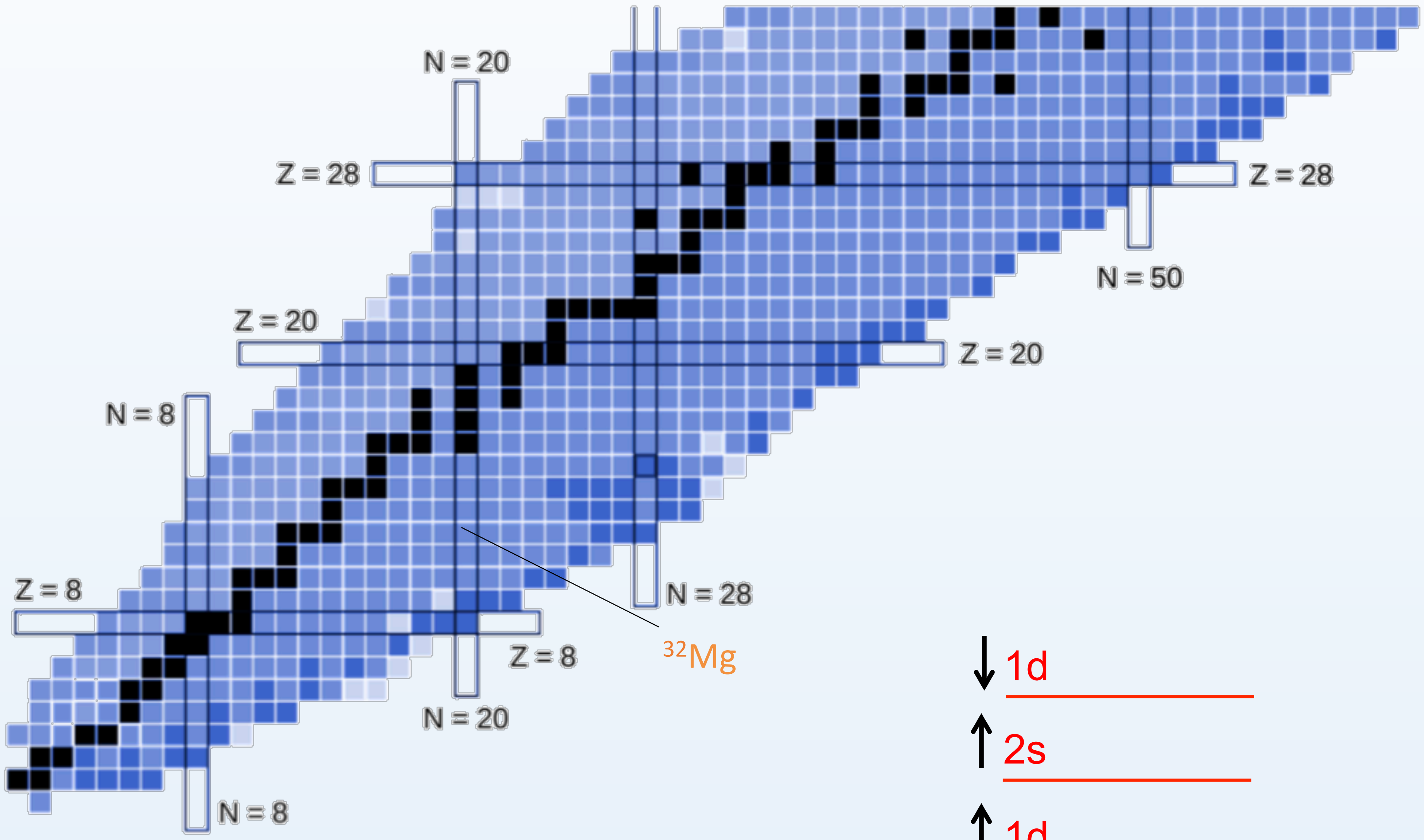
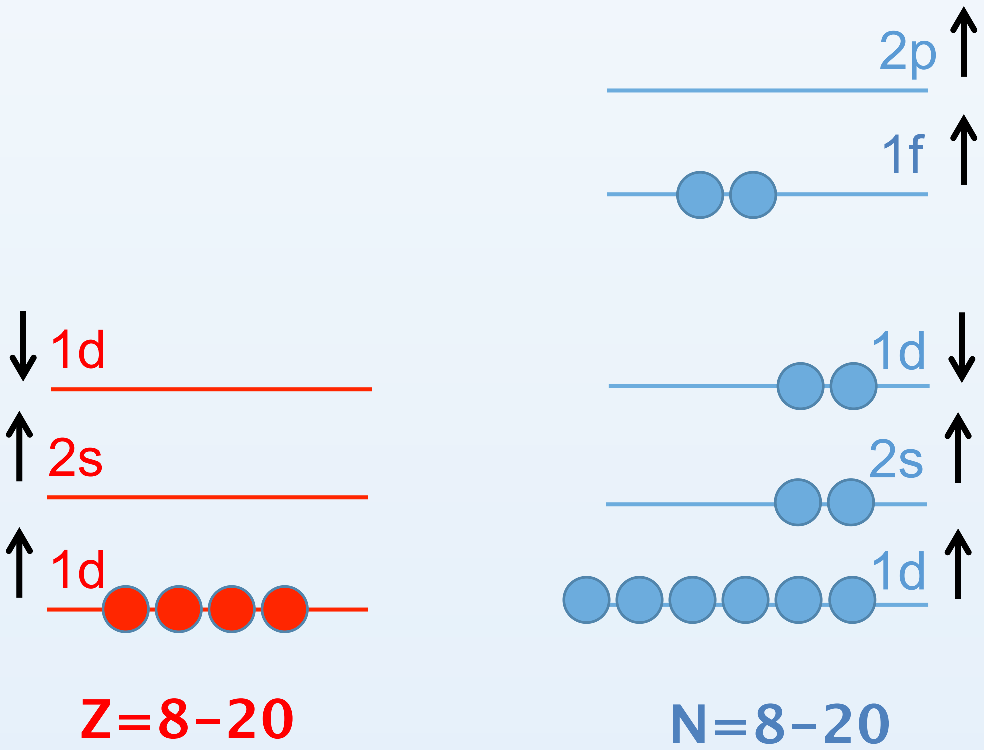
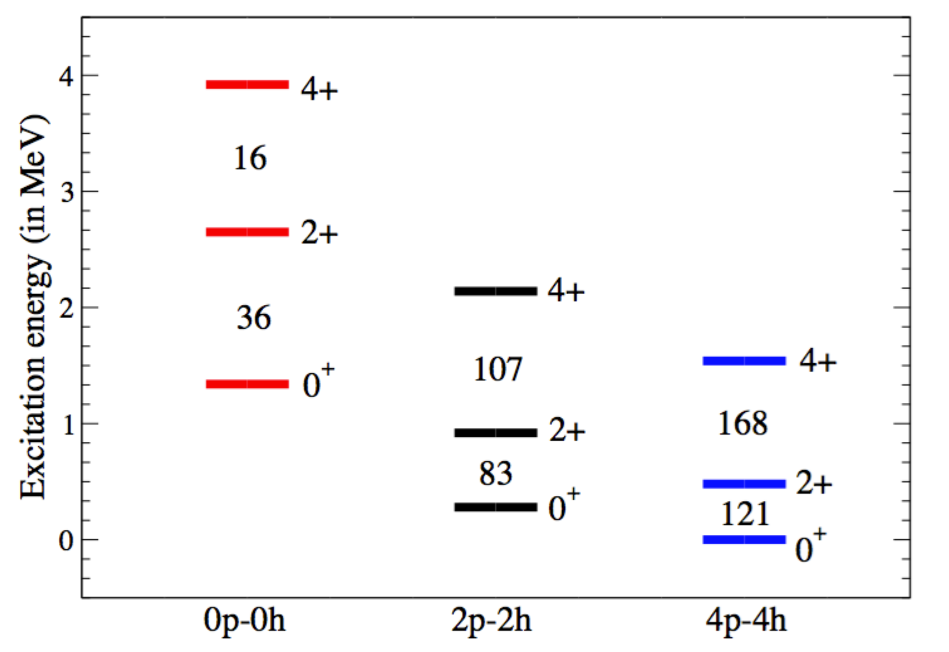


N = 20
Z = 28
Z = 28
40Ca
N = 50
Z = 20
Z = 20
N = 8
N = 28
Z = 8
Z = 8
N = 20
N = 8
2p
1f
1d
2s
1d
1d
2s
1d
Z=8-20
N=8-20


N = 20
Z = 28
Z = 28
N = 50
Z = 20
Z = 20
N = 8
N = 28
Z = 8
Z = 8
^{32}Mg
N = 20
N = 8

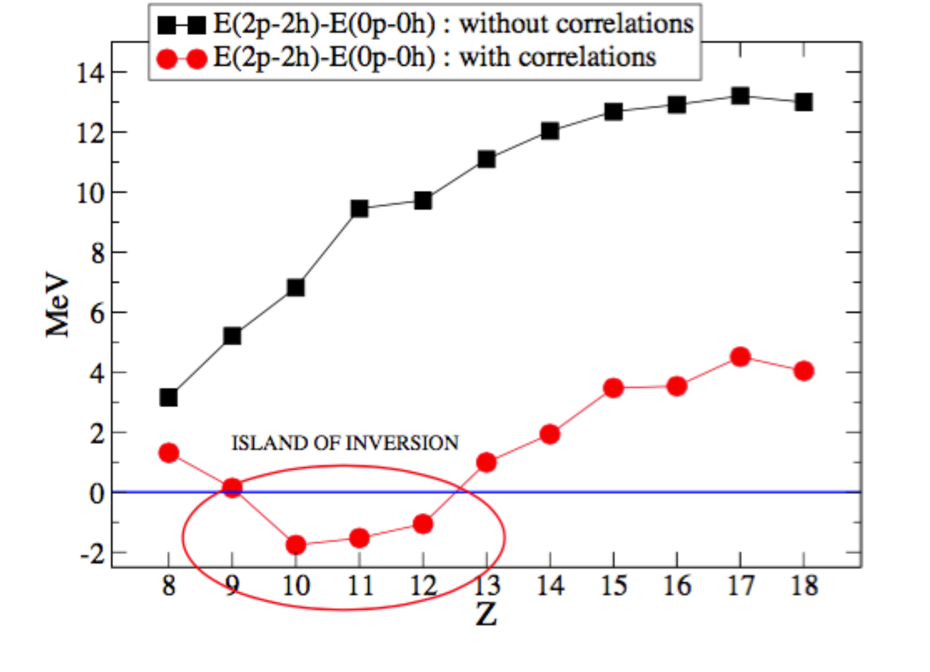

2p
1f
1d
1d
2s
2s
1d
1d
Z=8-20
N=8-20

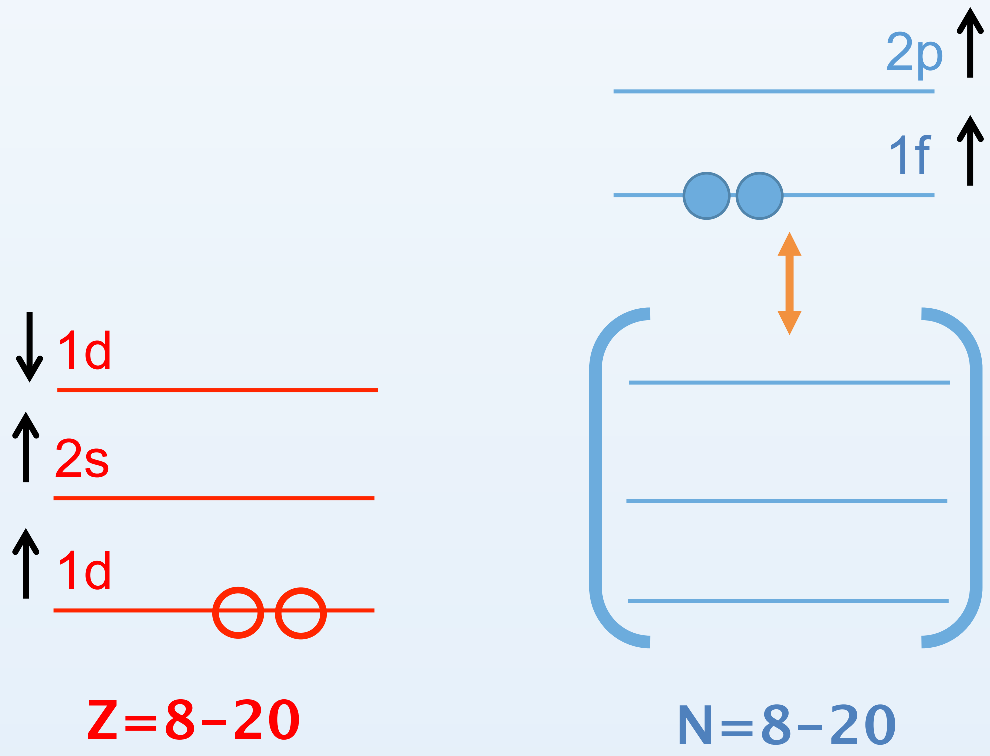
“Shape coexistence is the portal to deformation” (A. Poves)



$$|0_1^+\rangle = \quad \alpha\,|0\rangle + \beta\,|\uparrow\downarrow\rangle$$
$$|0_2^+\rangle = -\beta\,|0\rangle + \alpha\,|\uparrow\downarrow\rangle$$

shell model: $\alpha^2 \cong 10\,\%$





E. Caurier F. Nowacki and A. Poves, PRC **90**, 014302 (2014)

Shape coexistence and the role of the tensor force