The $f_{7/2}$ shell:
an optimum test bench

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R. A. Ricci, *et al.*
Aprile-Giugno 1969
Rivista del Nuovo Cimento
Serie I, Vol. 1, pag. 291-354

R. A. RICCI - P. R. MAURENZIG

The $1f_{7/2}$ Problem in Nuclear Spectroscopy.

"One of the main problems in low-energy nuclear physics is the derivation of the various properties of nuclei from the realistic forces deduced from the free nucleon-nucleon interaction"

BOLOGNA
TIPOGRAFIA COMPOSITORI
1969

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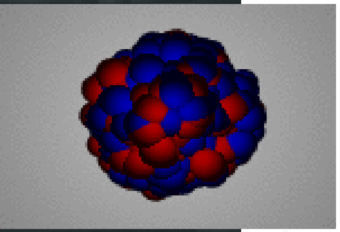
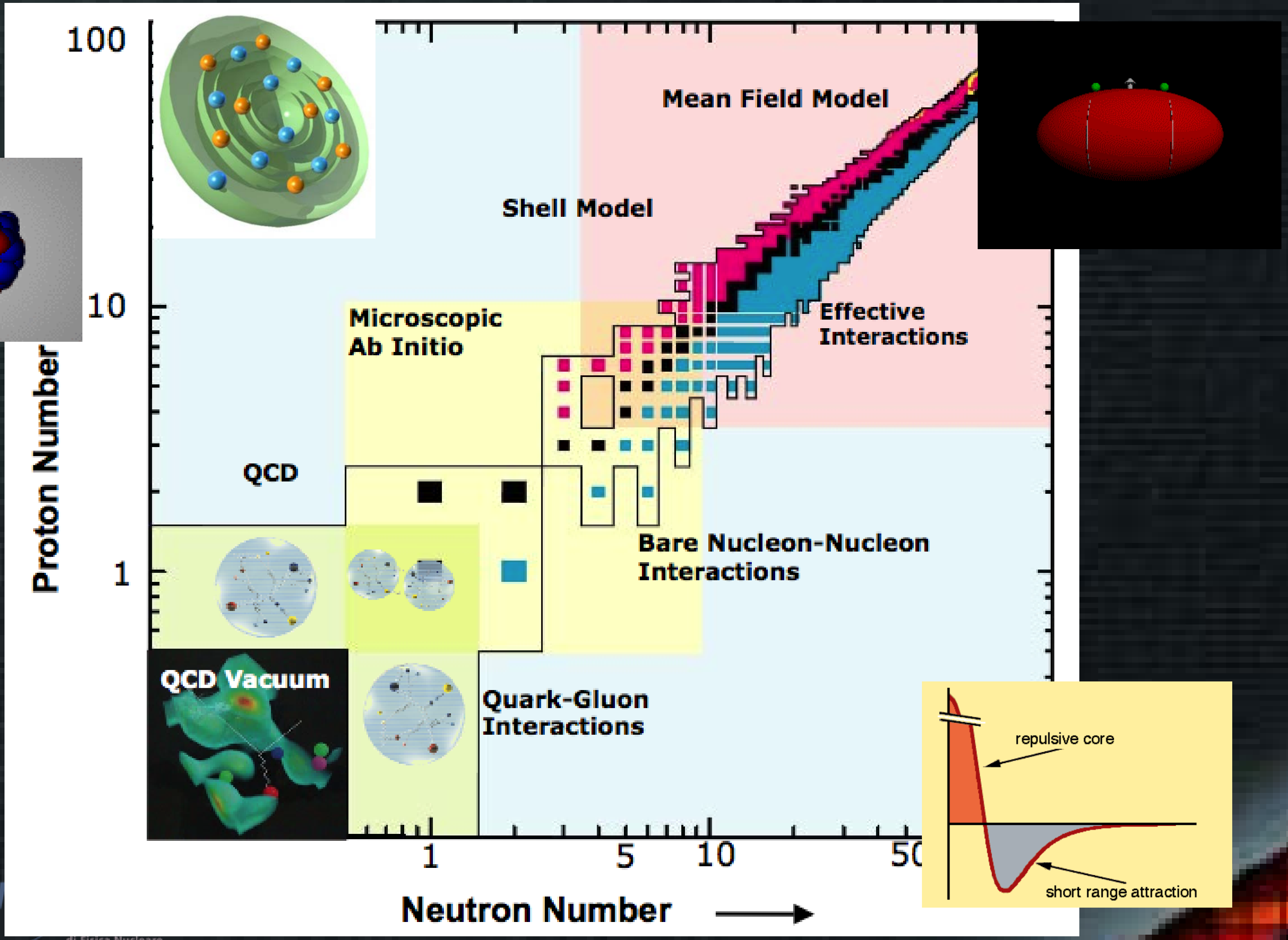
The nuclear models



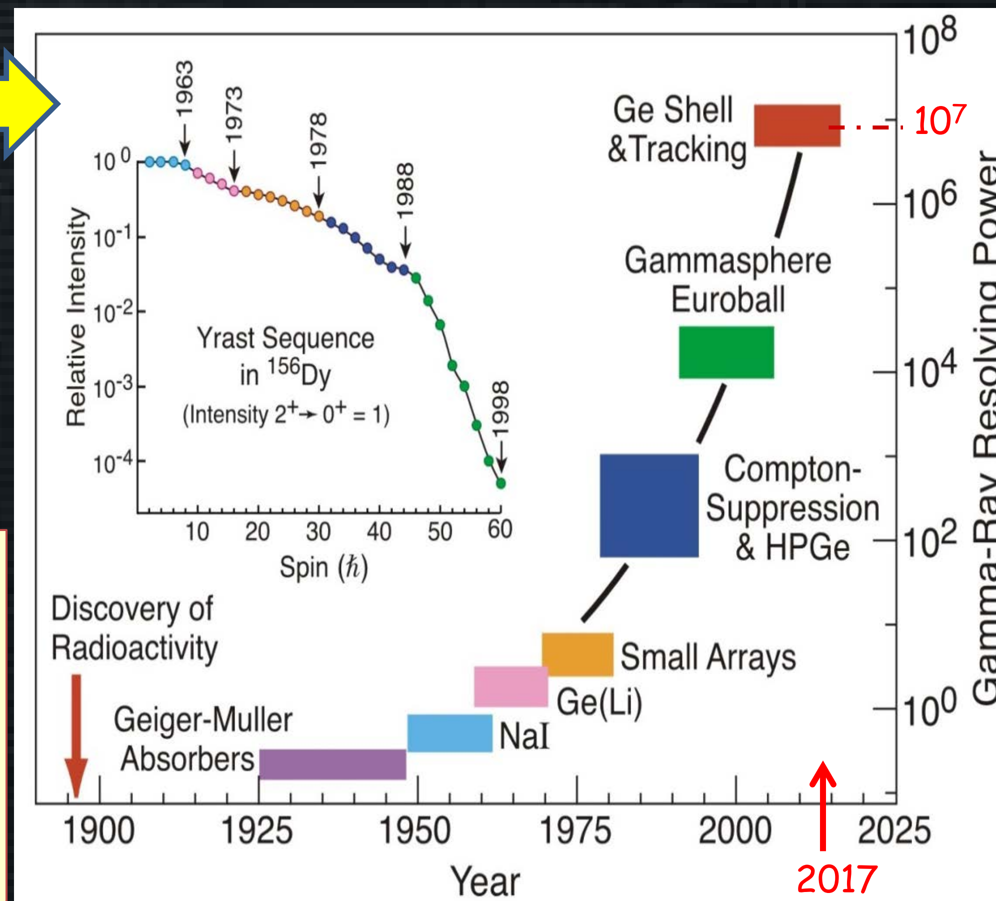


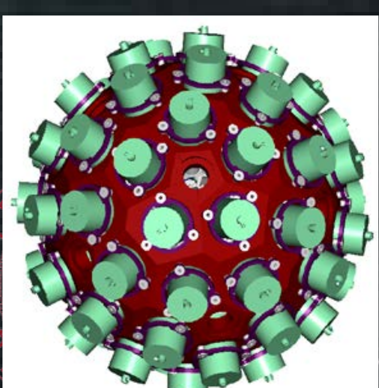
From the experimental side

A continuous development in gamma spectrscopy

- NaI(Tl) detectors in the 60's
- Ge detectors of the 70's
- HPGe arrays of the 80-90's
- the large spectrometers of the late 90's (EUROBALL, GAMMASPHERE)
- the tracking Ge-arrays (**AGATA, GRETA**) of present days

Development in terms of the evolution of the observational limit (the inverse of the resolving power).





Unprecedented performance due to:

- ❑ segmented detectors
- ❑ pulse-shape analysis
- ❑ tracking the g rays
- ❑ digital electronics

The $f_{7/2}$ shell
an optimum test bench

Isospin symmetry breaking in neutron-deficient nuclei

Development of deformation in neutron-rich nuclei

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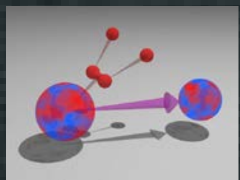
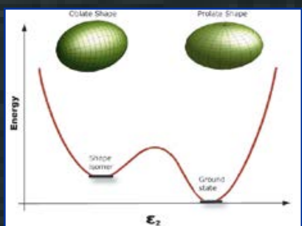
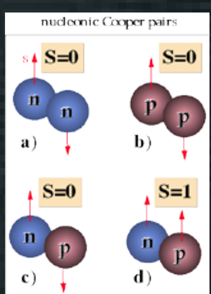
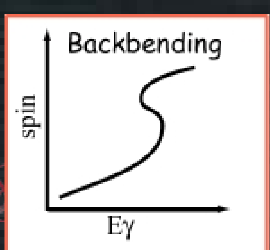
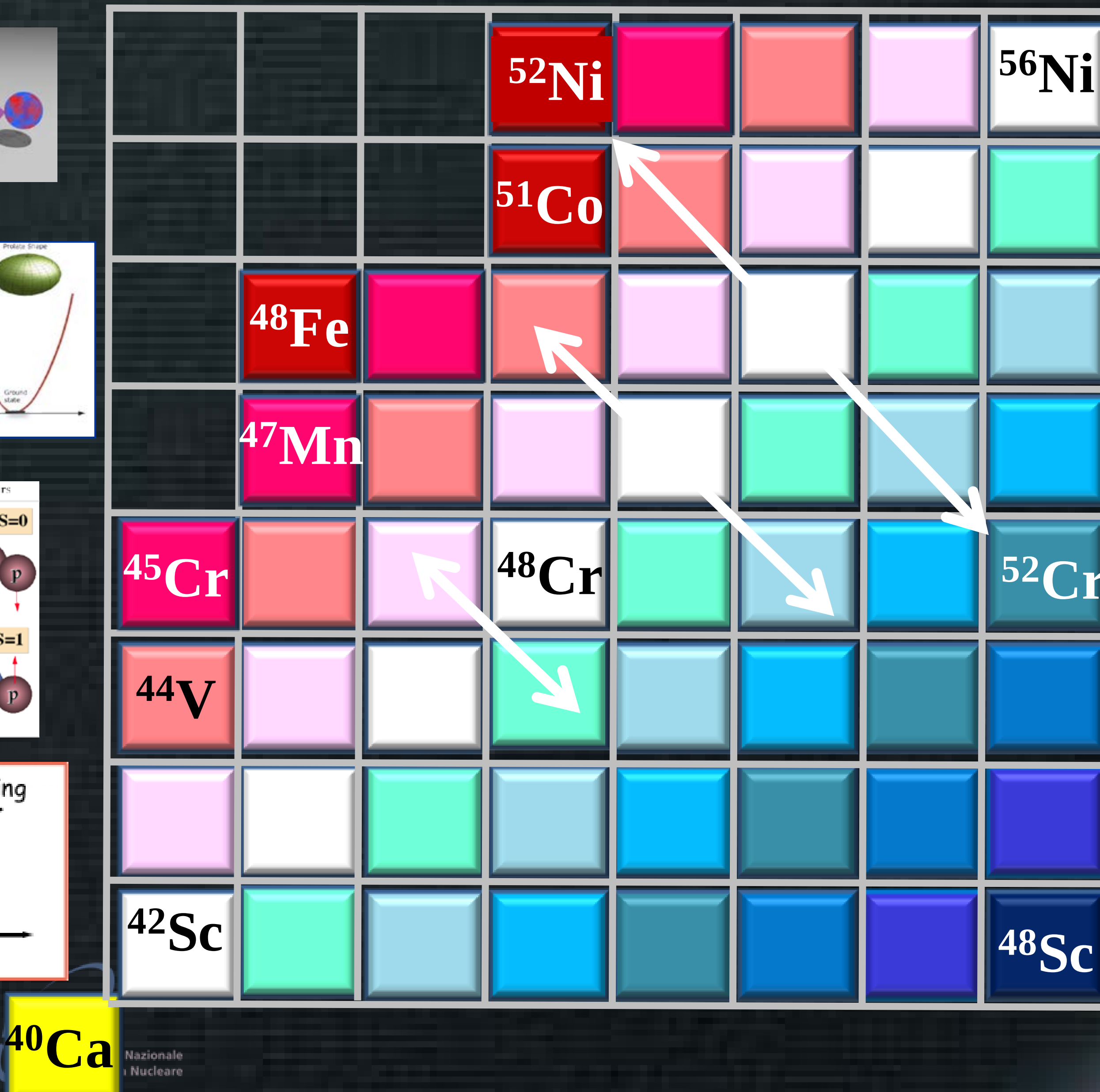
High spin states in $f_{7/2}$-shell nuclei

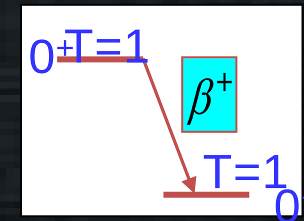


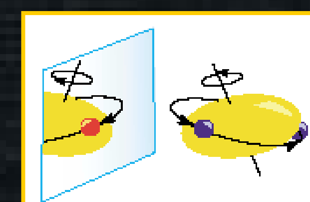


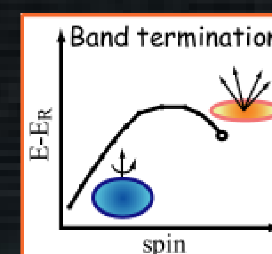










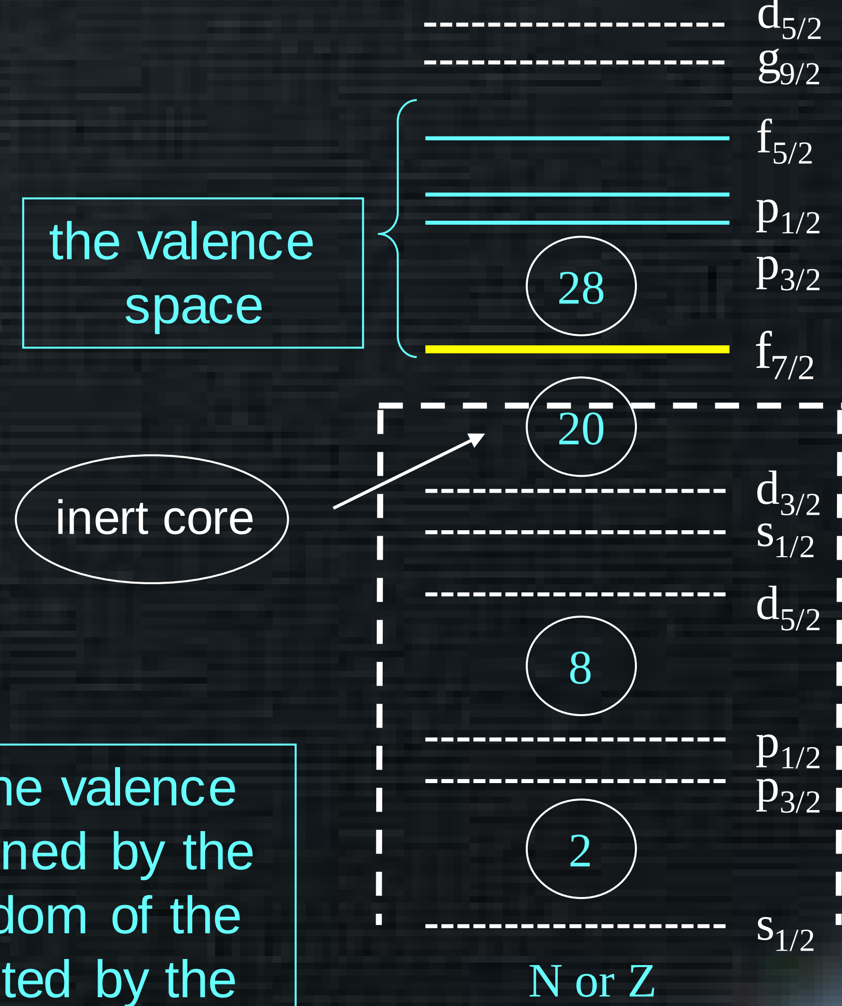


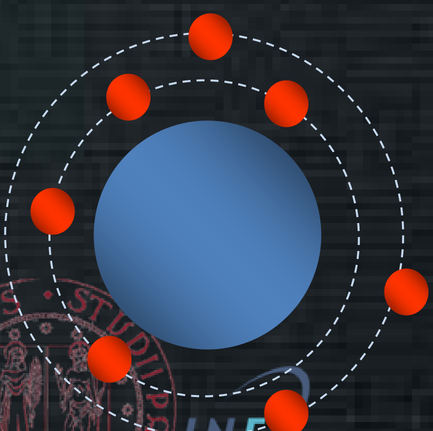
Ingredients for Shell Model calculations

1) an inert core
2) a valence space
3) an effective interaction that mocks up the general hamiltonian in the restricted basis

$$H_{\mathrm{eff}}\psi_\alpha = H_0 + V_{\mathrm{eff}}\psi_\alpha = E_\alpha\psi_\alpha$$

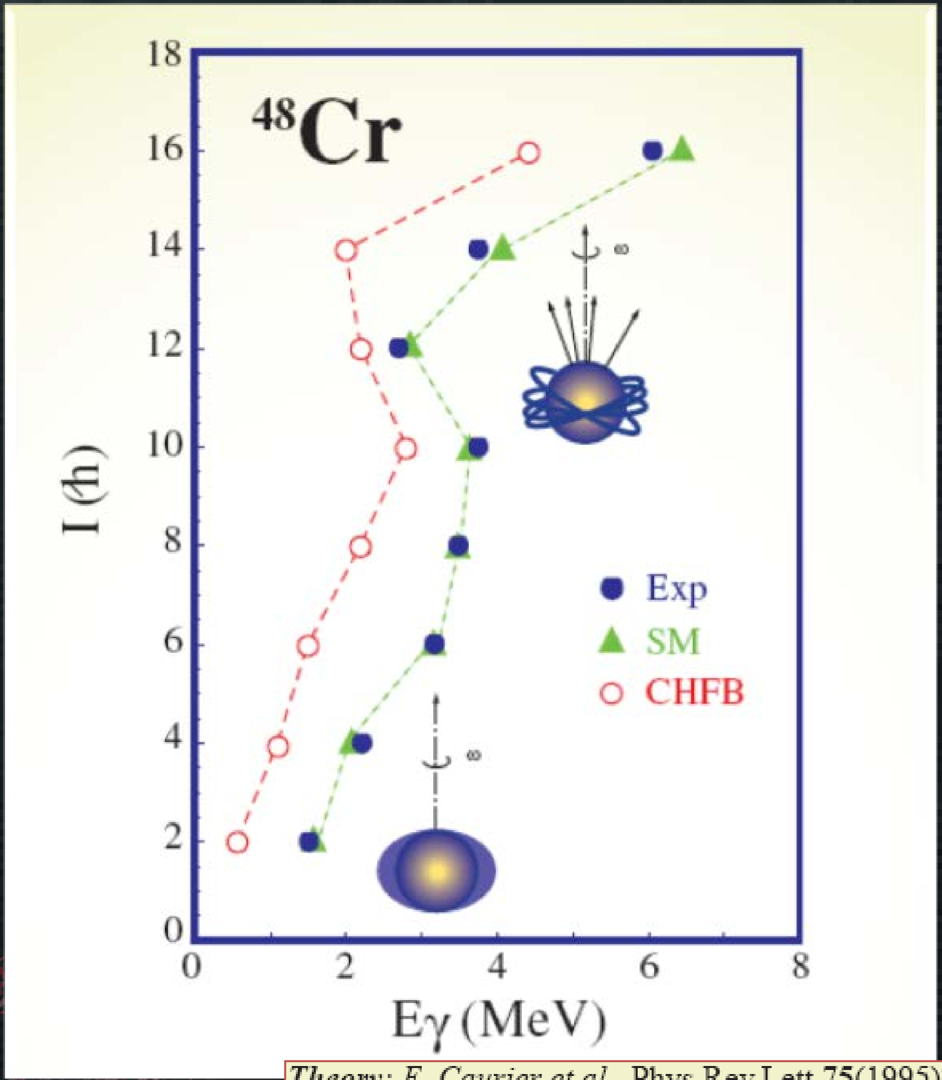
with $H_0 = T + U$



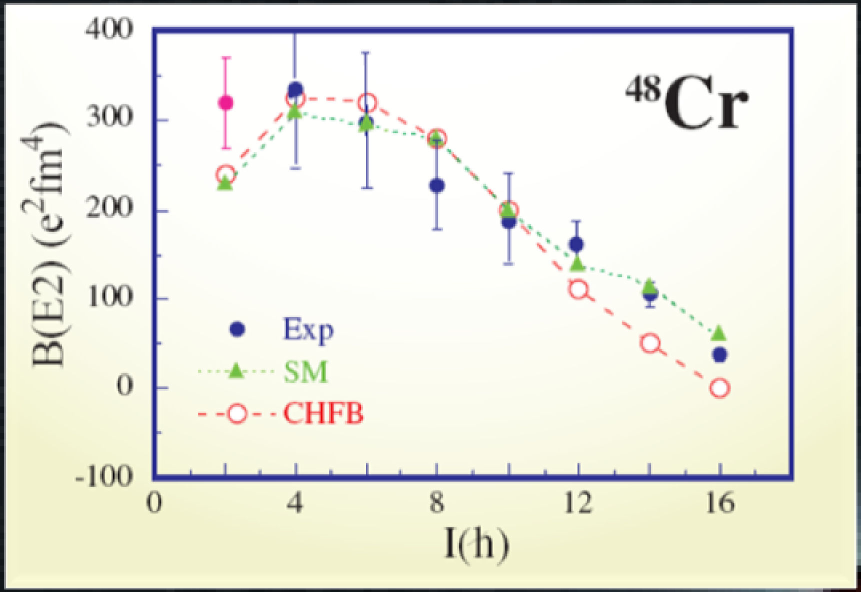


The choice of the valence space is determined by the degrees of freedom of the system and limited by the dimensions of the matrices to be diagonalized

Shell model and collective phenomena

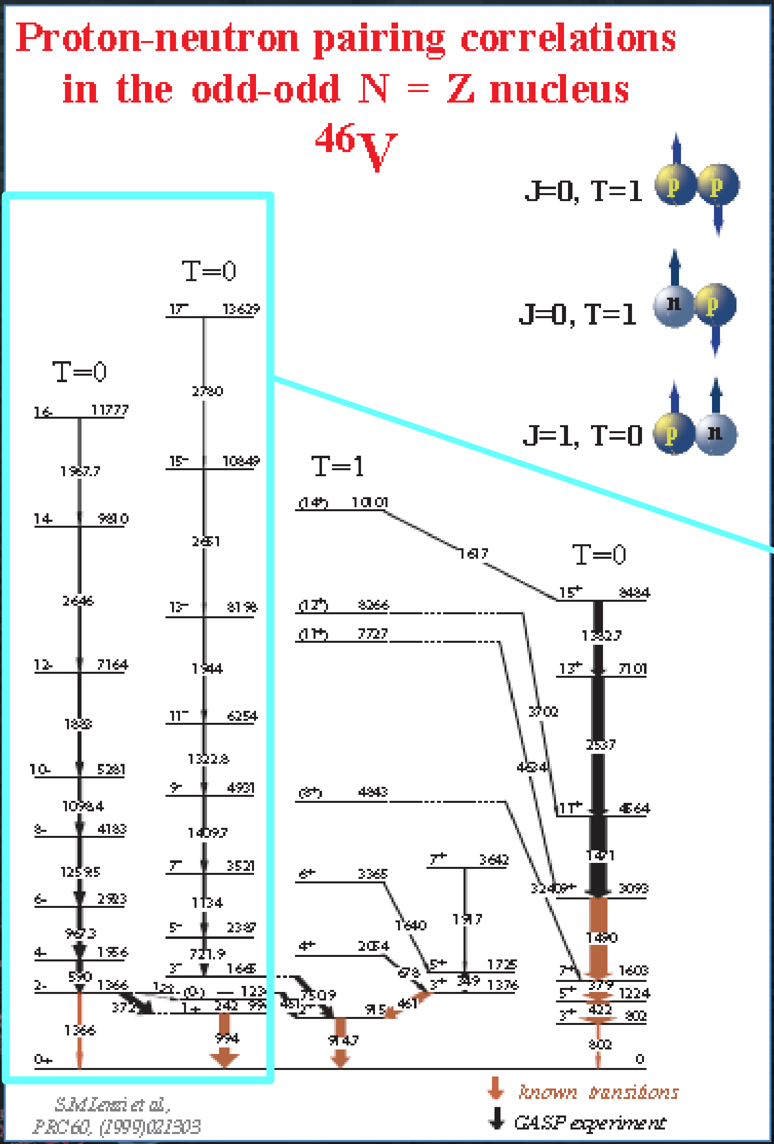


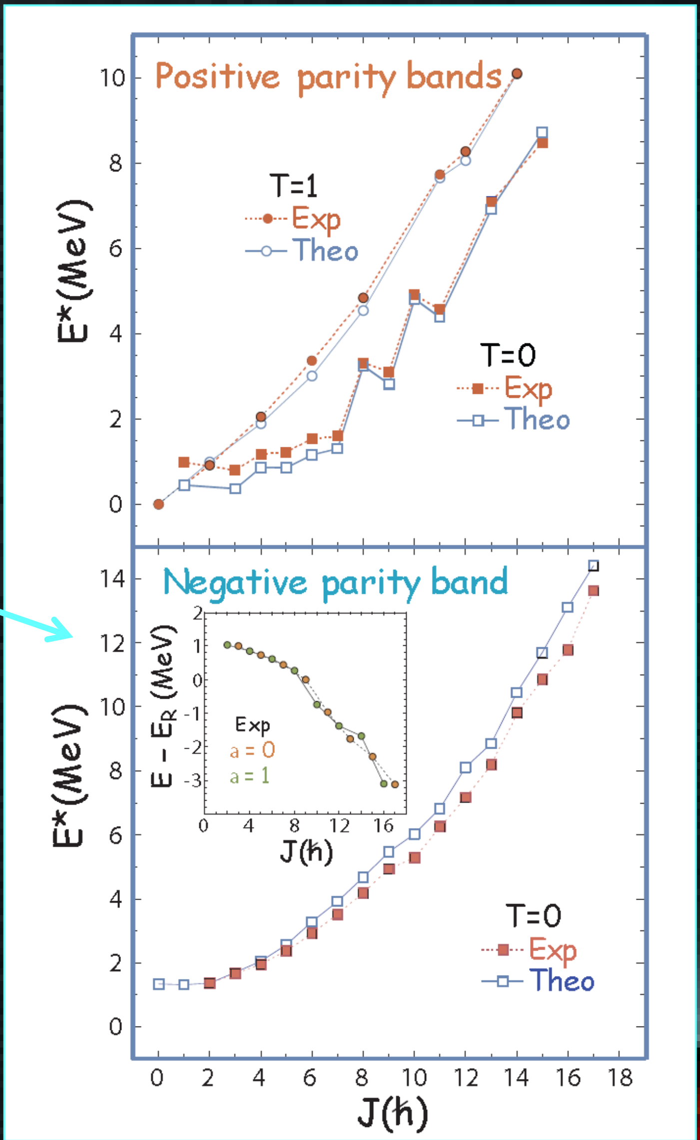
Shell model calculations in the full fp shell give an excellent description of the structure of collective rotations in nuclei of the $f_{7/2}$ shell



Theory: E. Caurier et al., Phys.Rev.Lett.75(1995)225
Experiments: S. M. Lenzi et al., Z.Phys.**A354**(1996)117 - *F. Brandolini et al.*, Nucl.Phys.**A642**(1998)387

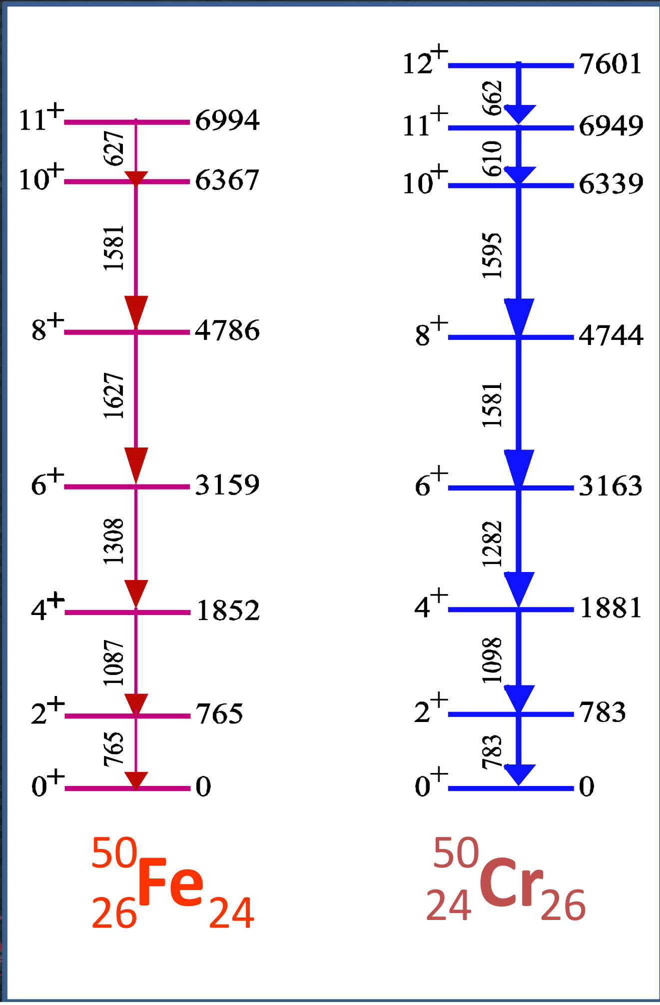
Shape coexistence in N=Z

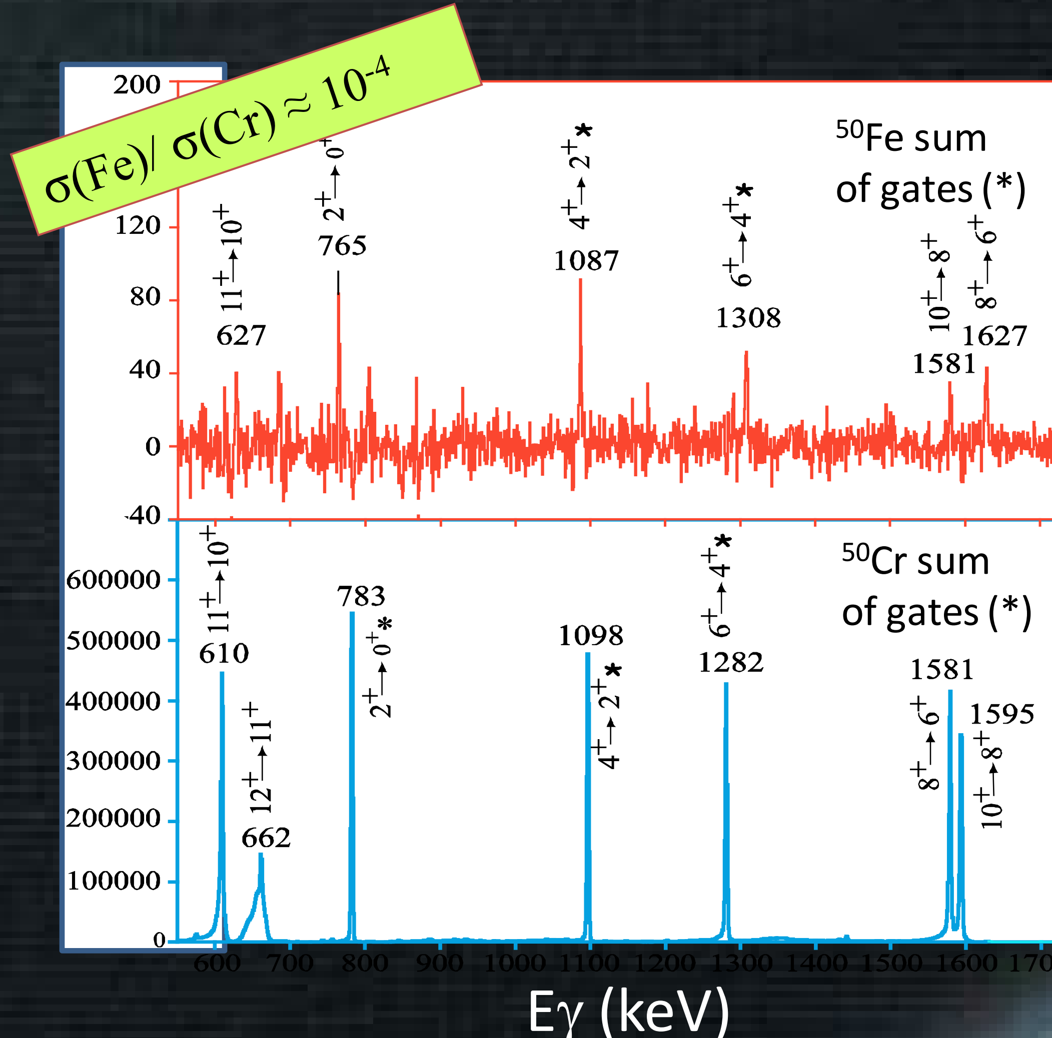




First observation of excited states in ^{50}Fe

The mirror pair A=50



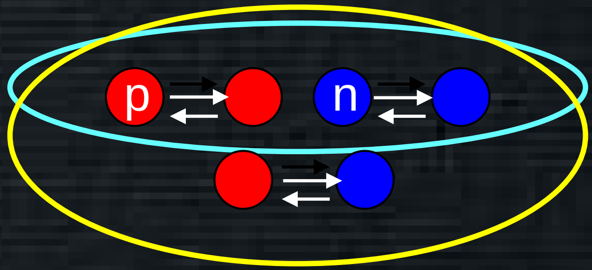


EUROBALL + EUCLIDES + NWALL

SML et al., Phys. Rev. Lett. 87, 122501 (2001)

Neutron-proton exchange symmetry

Charge symmetry : $V_{pp} = V_{nn}$

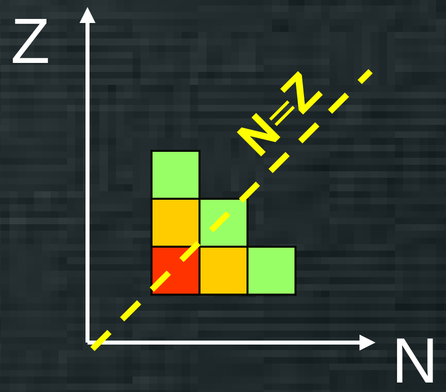


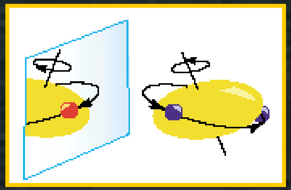
Charge independence: $(V_{pp} + V_{nn})/2 = V_{np}$

Deviations are small

Electromagnetic interactions lift the degeneracy of the analogue states, but do not generally affect the underlying symmetry.

Differences in analogue excited states

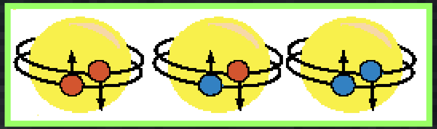




Mirror Energy Differences (MED)

$$\mathrm{MED}_J = \mathrm{E}x_{J,T_z=-T} - \mathrm{E}x_{J,T_z=+T}$$

Test the charge symmetry of the interaction



Triplet Energy Differences (TED)

$$\mathrm{TED}_J = \mathrm{E}x_{J,T_z=-T} + \mathrm{E}x_{J,T_z=+T} - 2\mathrm{E}x_{J,T_z=0}$$

Test the charge independency of the interaction

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Measuring MED and TED

Can we reproduce such small energy differences?
What can we learn from them?

They contain a richness of information
about spin-dependent structural phenomena

We measure nuclear structure features:

- How the nucleus generates its angular momentum
- Evolution of radii (deformation) along a rotational band
- Learn about the configuration of the states
- Isospin non-conserving terms of the interaction

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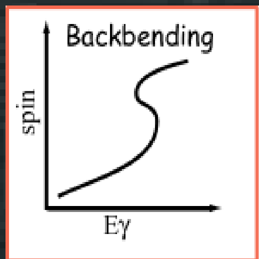
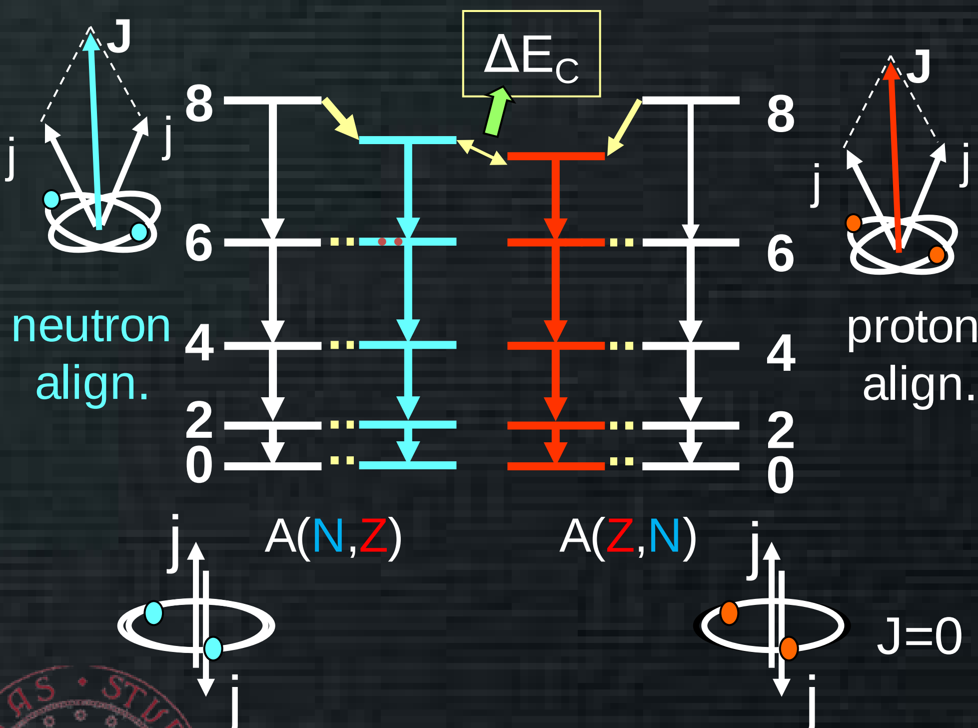
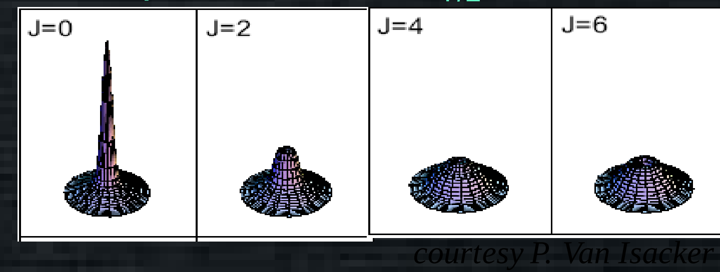
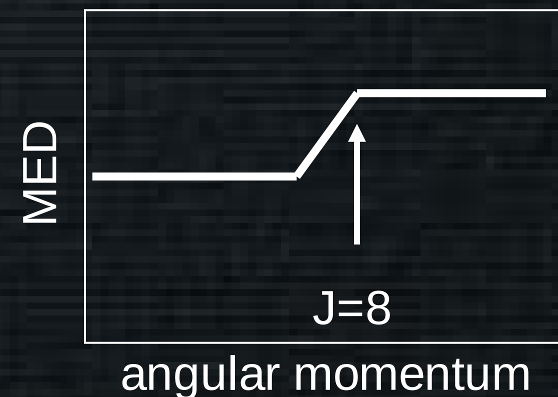
MED and nucleon spatial correlations





probability distribution for the relative distance of two like particles in the $f_{7/2}$ shell

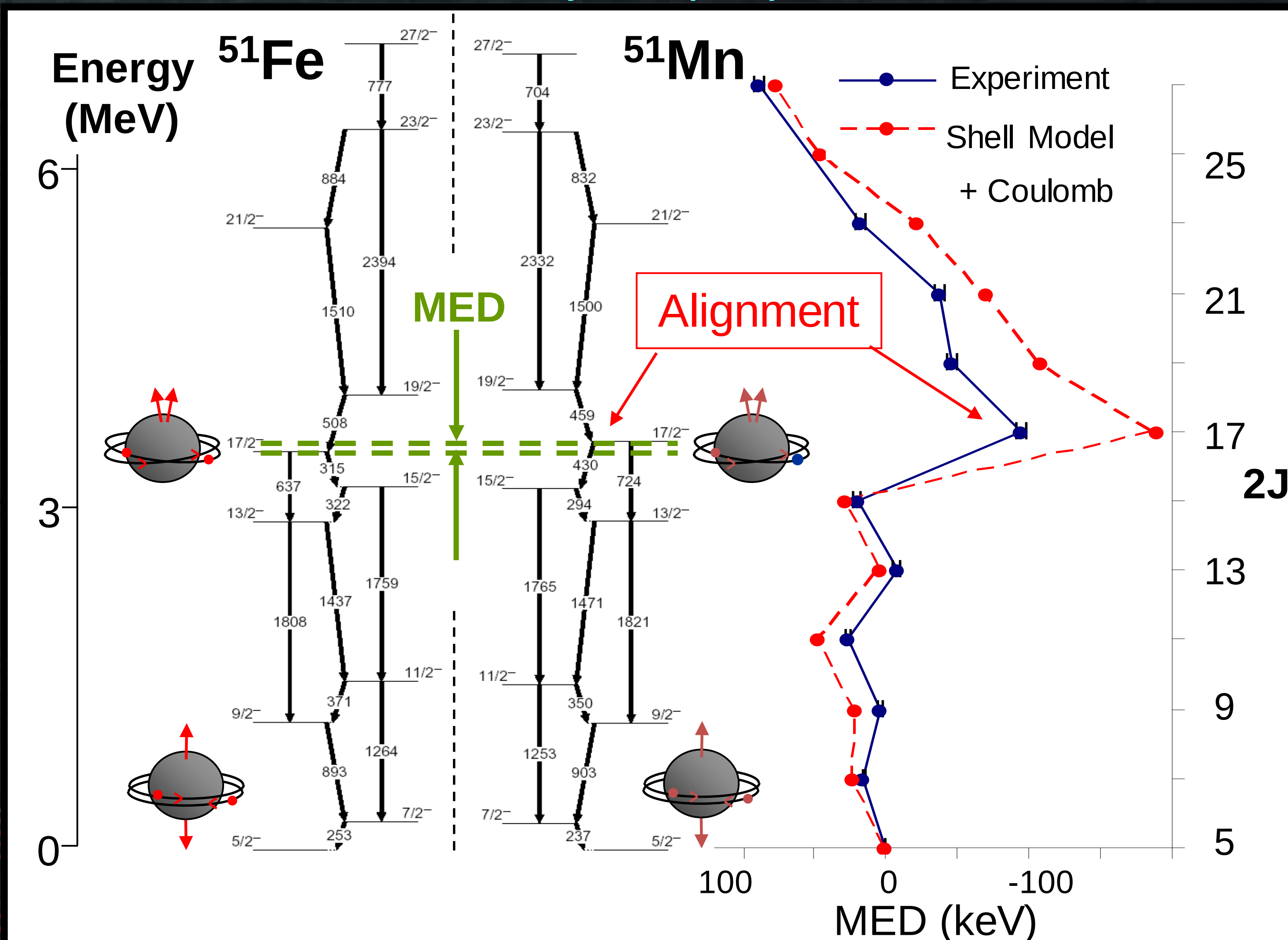




Shifts between the excitation energies of the mirror pair at the backbending indicate the type of nucleons that are aligning

MED and nucleon alignment

D.D. Warner, M.A. Bentley and P. Van Isacker, Nature Physics 2 (2006) 311



The effective interaction

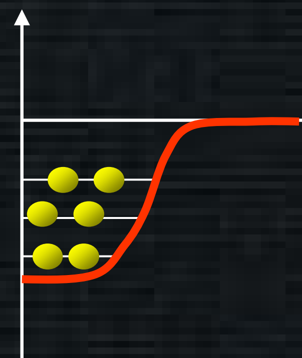
A multipole expansion

$$V = V_m + V_M$$

monopole Multipole

V_m

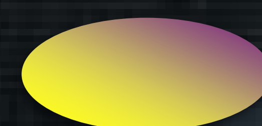
- represents a spherical mean field extracted from the interacting shell model
- determines the single particle energies or ESPE



V_M

- correlations
- energy gains

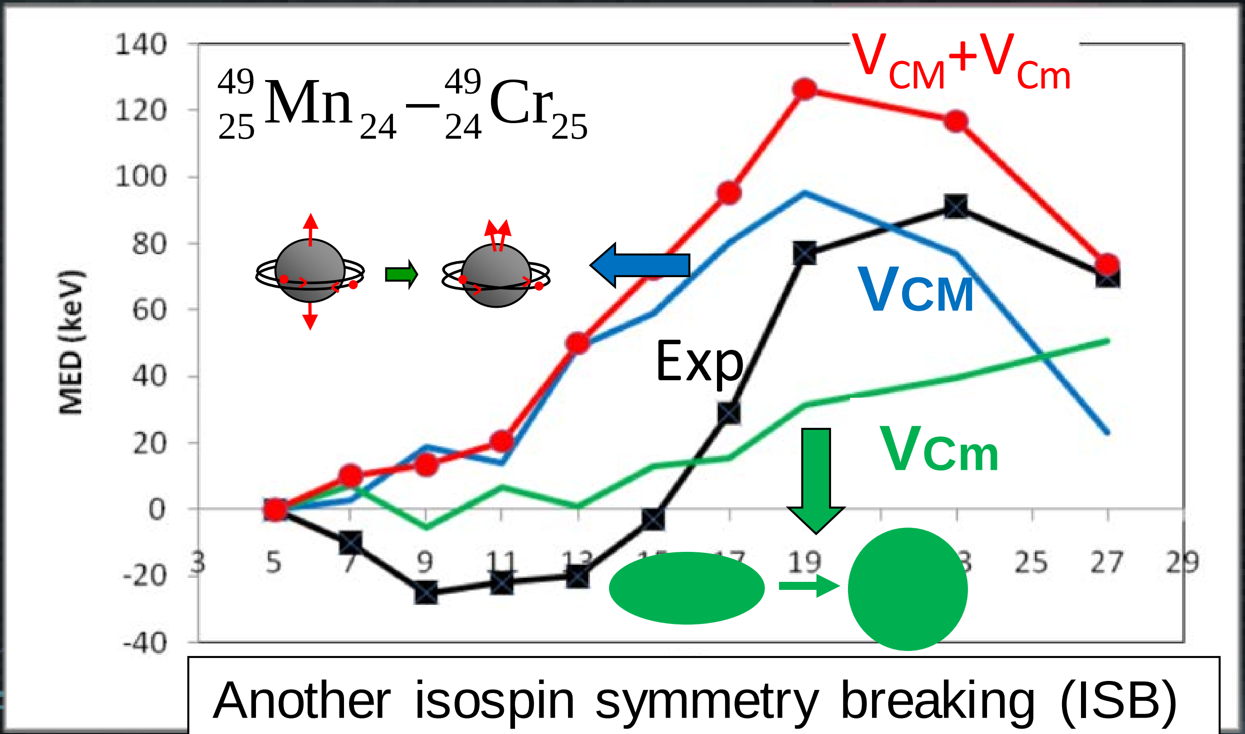
Deformation



Coulomb effects

V_{CM} Multipole term — between valence protons only — sensitive to nucleon recoupling

V_{Cm} Monopole term — $E_C = \frac{3}{5}\frac{e^2 Z(Z-1)}{R}$ — radial effect: radius changes with J



Another isospin symmetry breaking (ISB) term is needed and it has to be big!

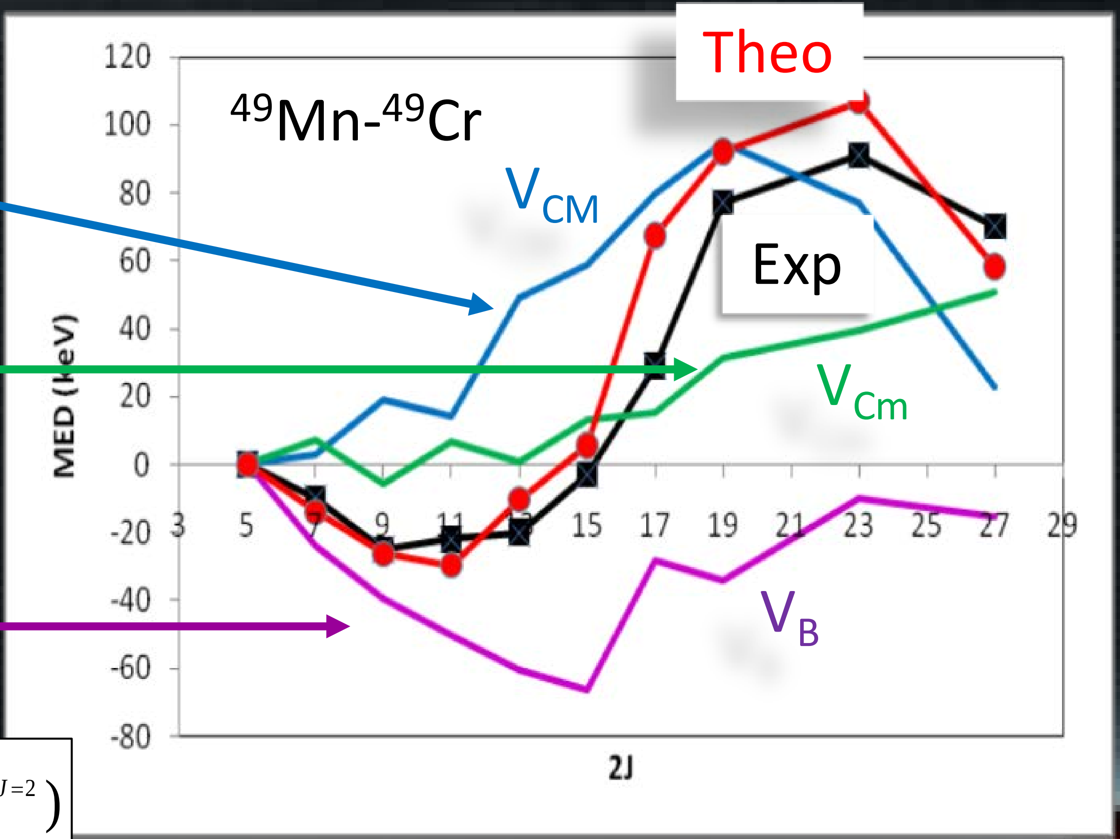
Calculating the MED with SM

$$MED_J^{theo} = \Delta\langle V_{Cm}\rangle_J + \Delta\langle V_{CM}\rangle_J + \Delta\langle V_B\rangle_J$$

VCM: gives information on the nucleon alignment or recoupling

VCm: gives information on changes in the nuclear radius

The ISB V_B term is of the same order as the Coulomb contributions



$$\Delta\langle V_B\rangle = +100\ \text{keV}\ (V_{\pi\pi}^{(f_{7/2}^2)_{J=2}} - V_{\nu\nu}^{(f_{7/2}^2)_{J=2}})$$

$V_{xx}^{(f_{7/2}^2)_{J=2}}$ interaction of one single unitary matrix element for two nucleons in the $f_{7/2}$ coupled to J=2

A. P. Zuker et al., PRL 89, 142502 (2002)

Calculating MED and TED

We rely on isospin-conserving shell model wave functions and obtain the energy differences in first order perturbation theory as sum of expectation values of the Coulomb (V_C) and ISB (V_B) interactions

$$MED_J^{\exp} = E_J^*(Z_>) - E_J^*(Z_>)$$

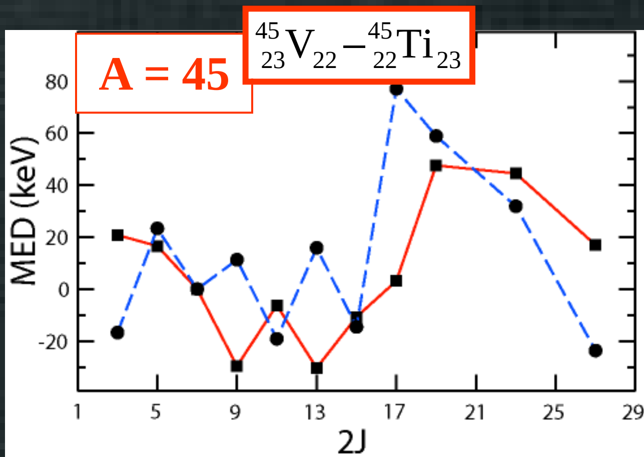
$$MED_J^{theo} = \Delta_M \langle V_{Cm} \rangle_J + \Delta_M \langle V_{CM} \rangle_J + \Delta_M \langle V_B^{(1)} \rangle_J$$

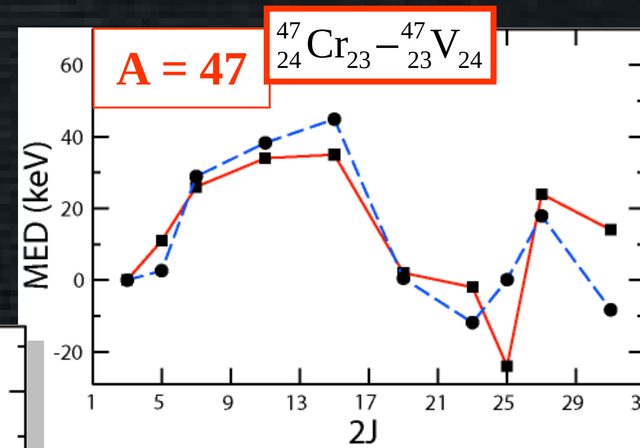
$$TED_J^{\exp} = E_J^*(Z_>) + E_J^*(Z_>) - 2E_J^*(N = Z)$$

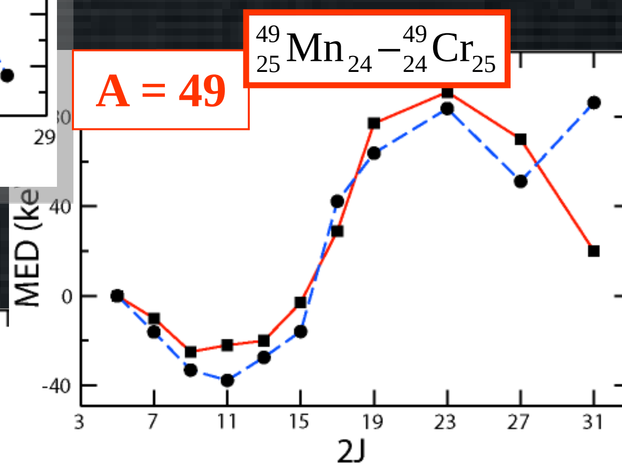
$$TED_J^{Theo} = \Delta_T \langle V_{CM} \rangle_J + \Delta_T \langle V_B^{(2)} \rangle_J$$

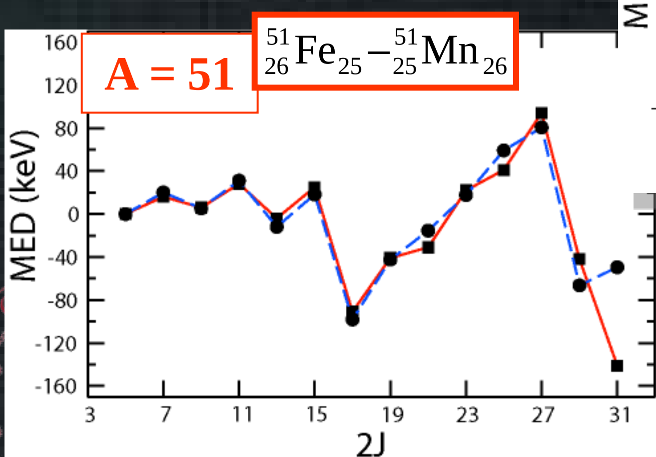
MED in T=1/2 states

Very good quantitative description of data without free parameters

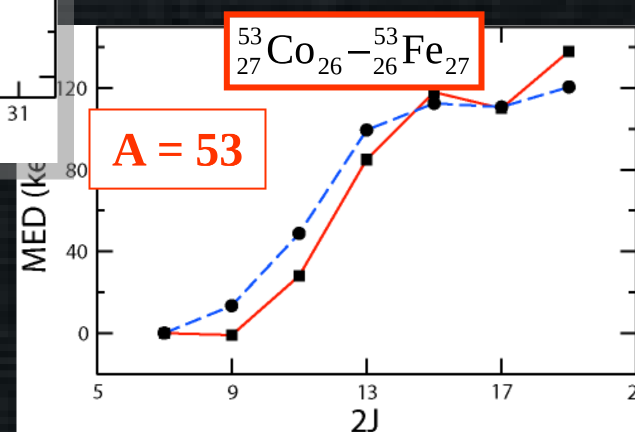




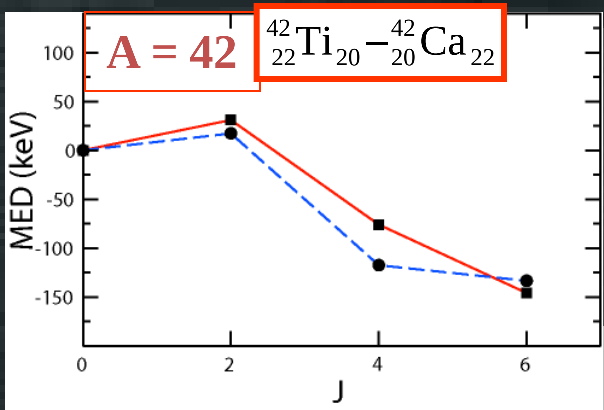


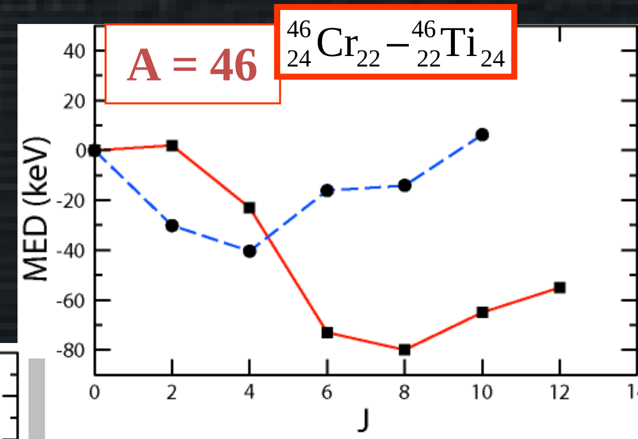


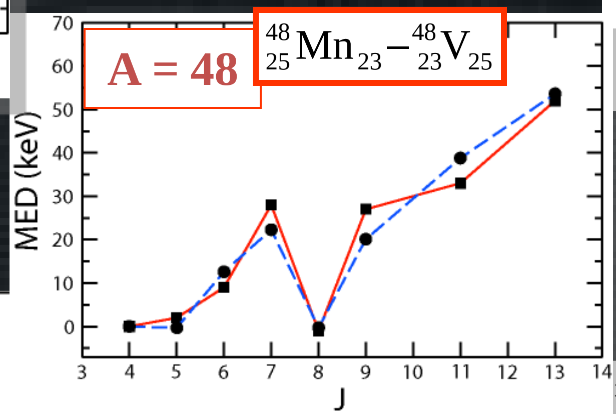
M.A. Bentley and SML, Prog. Part. Nucl. Phys. 59, 497-561 (2007)

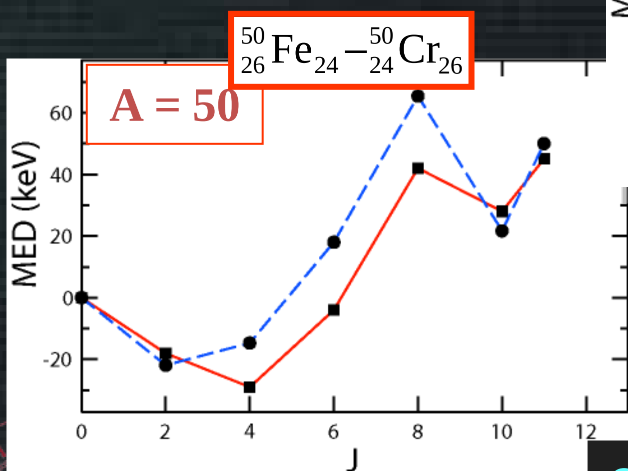


MED in T=1 states

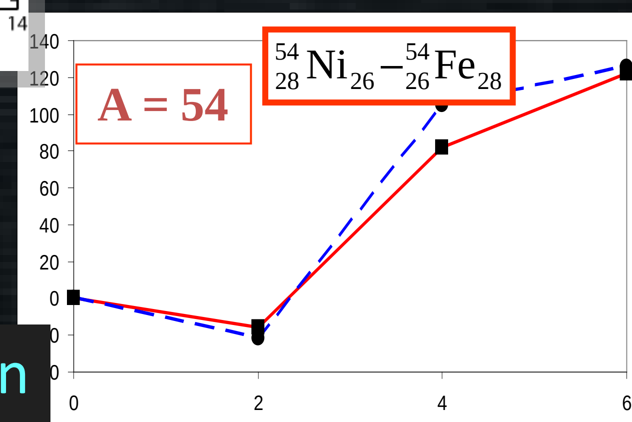






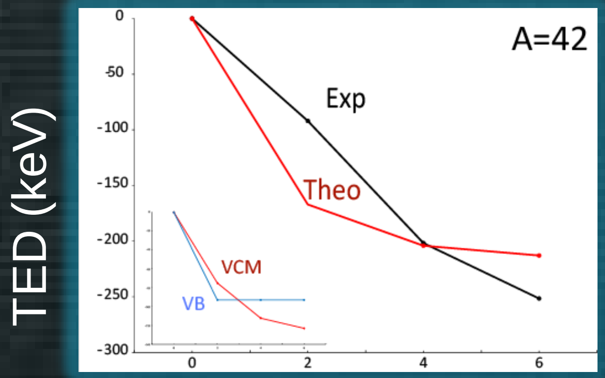


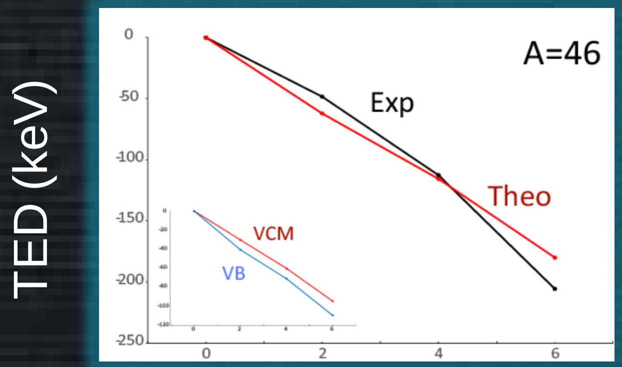
M.A. Bentley and SML, PPNP 59, 497(2007)

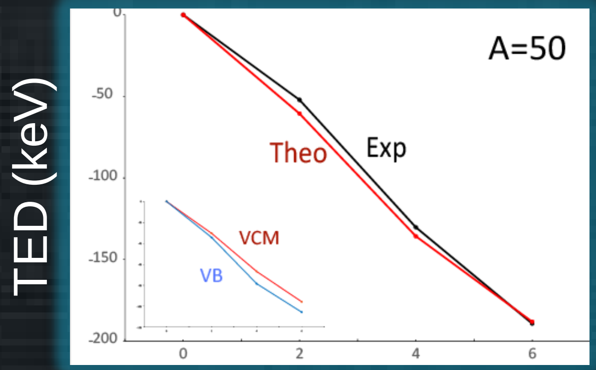


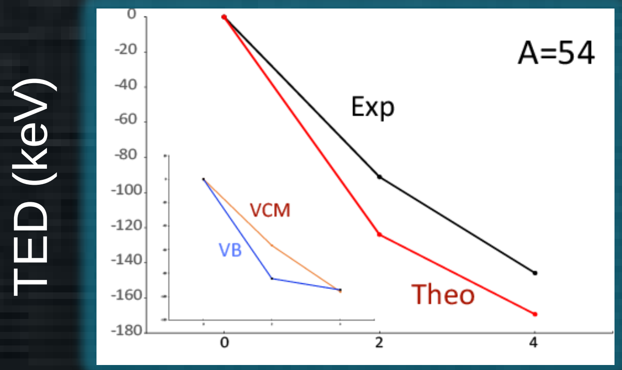
Same parameterization for the whole $f_{7/2}$ shell!

TED in the $f_{7/2}$ shell









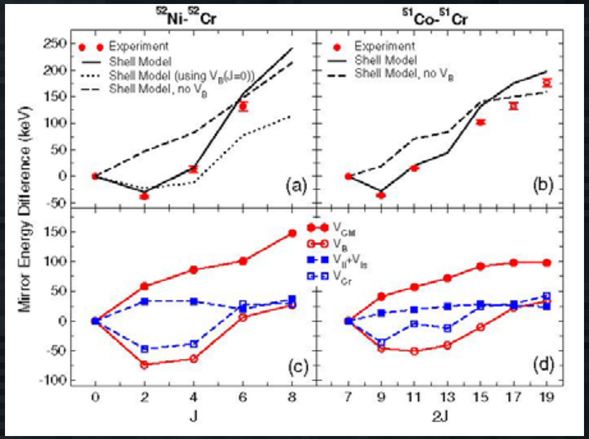
Only multipole effects are relevant.

The ISB term VB is of the same magnitude of the Multipole Coulomb term

Some questions arise…

What happens farther from stability
or at larger T in the $f_{7/2}$ shell?

The same prescription applies



Is the ISB VB term confined to the $f_{7/2}$ shell
or is a general feature?

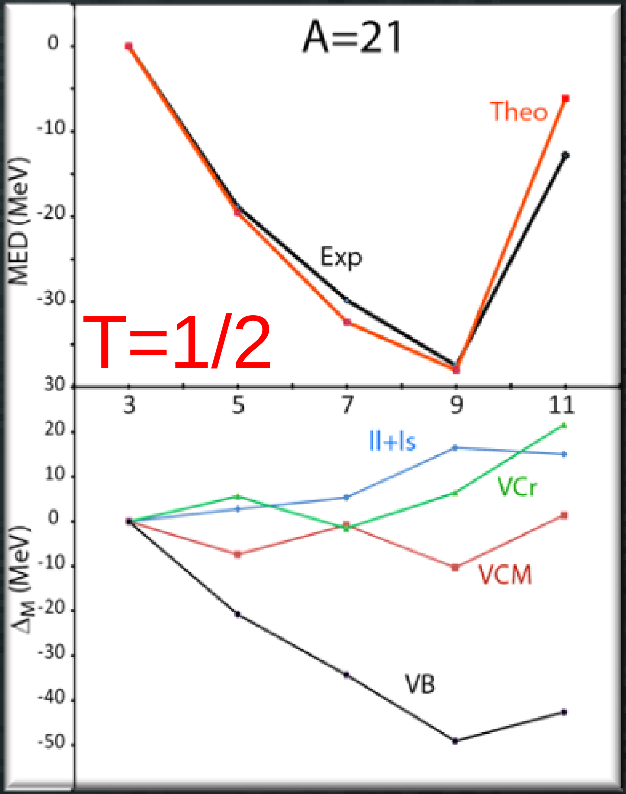
If so the same prescription should work

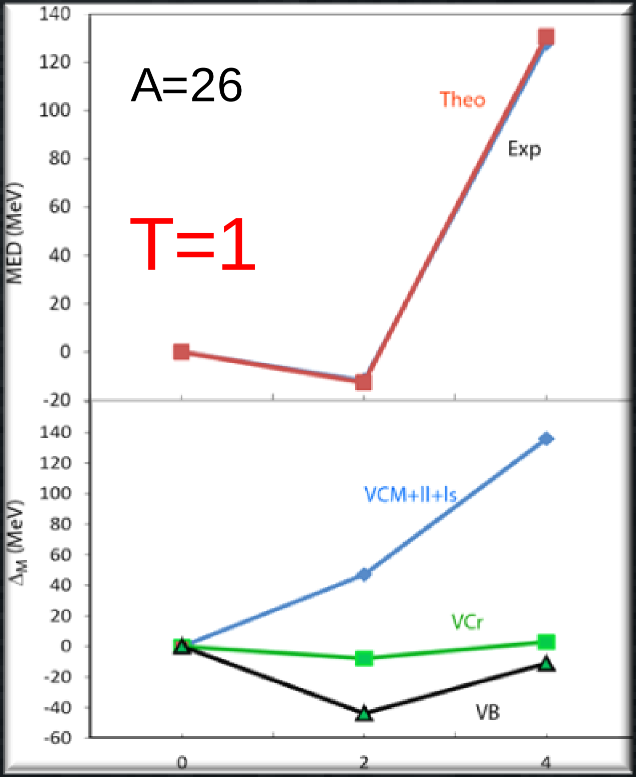
Can we understand the origin of the VB term?

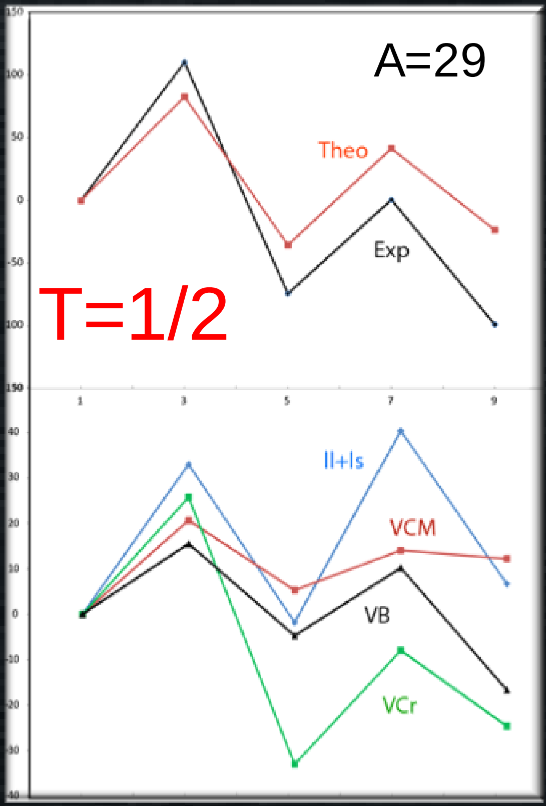
Work in progress…

A systematic analysis of MED and TED in the sd shell

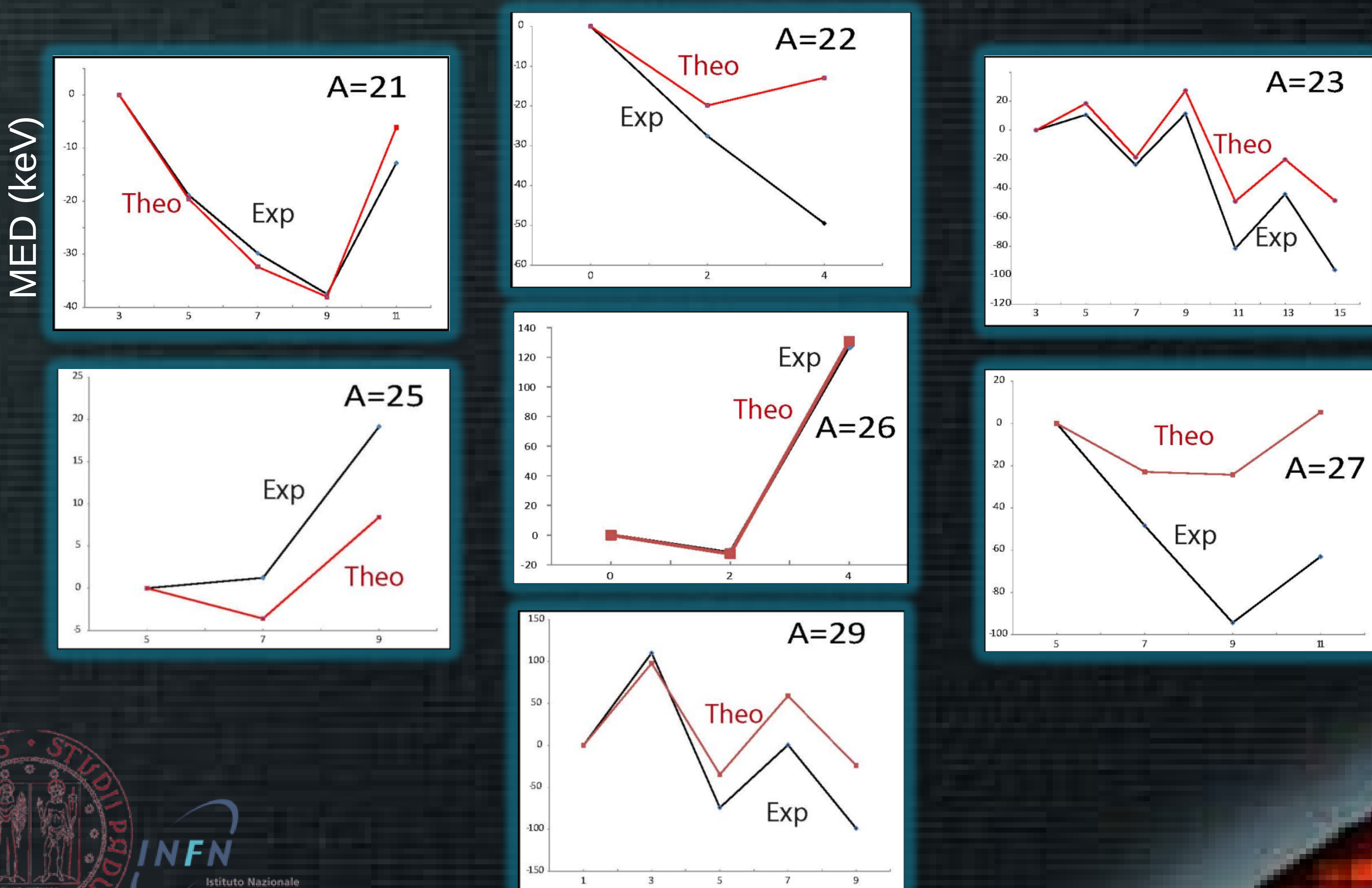
MED: different contributions



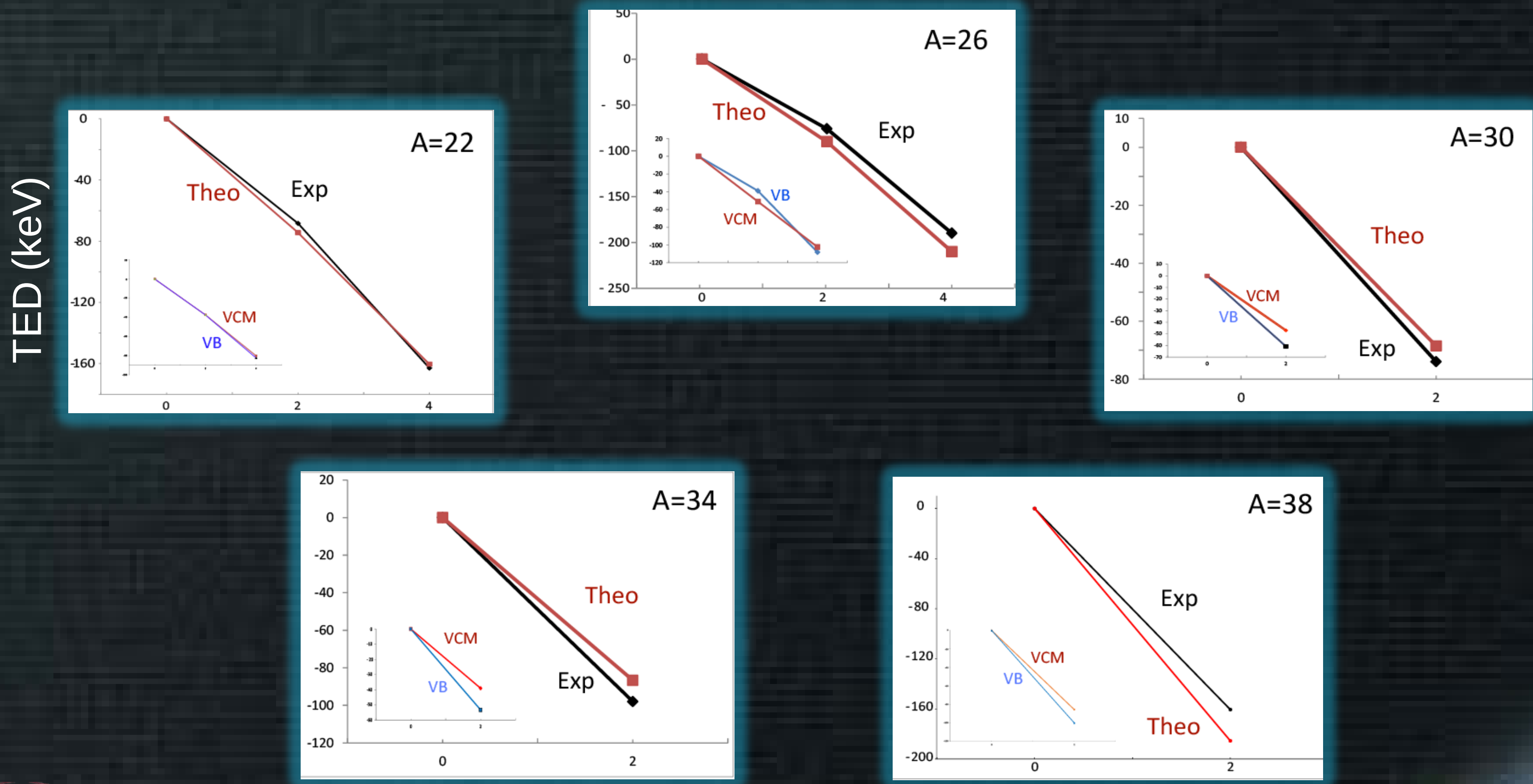




MED in the sd shell



TED in the sd shell



The prescription applies successfully also in the sd shell!

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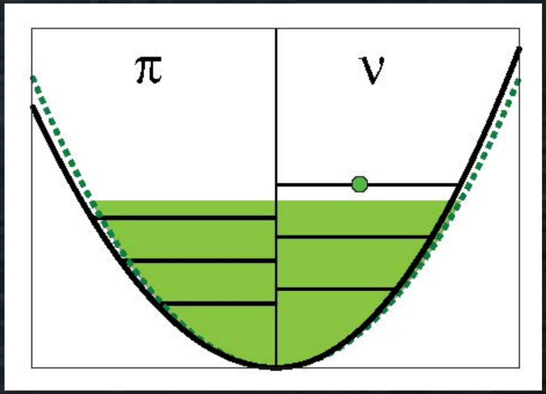
Understanding ISB

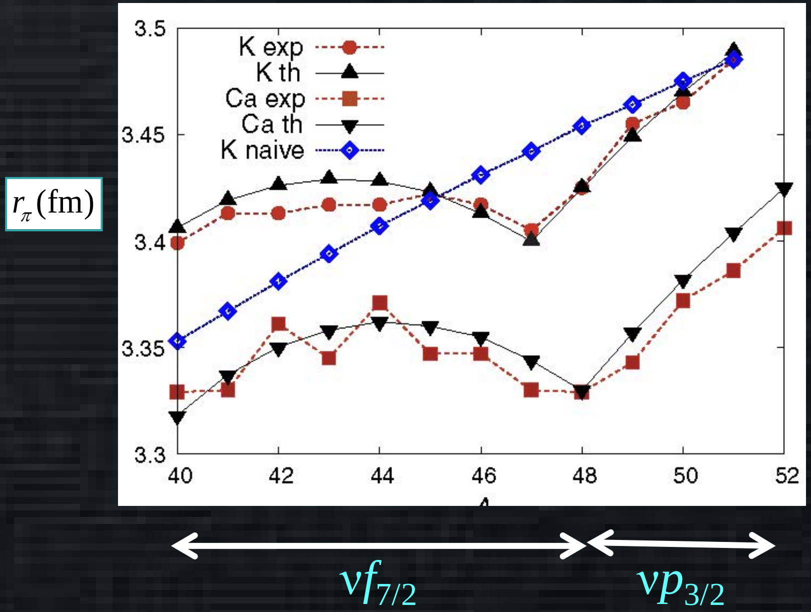
We have used a new interaction MCI deduced from the realistic nucleon-nucleon N3LO in a no-core approach, that includes both Coulomb and ISB nuclear interaction

An important effect to consider is the isovector polarizability



which induces changes in the potential wells of protons and neutrons

Charge radii in Ca and K isotopes

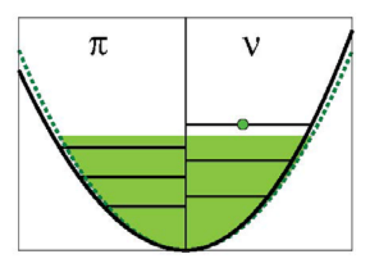


Proton radii increases when filling with neutrons the $p_{3/2}$ shell!

J. Bonnard et al., PRL 116, 212501 (2016)

Constructing the matrix elements

We need to determine the size of the potential wells where to calculate the matrix elements of the effective interaction, different for protons and neutrons!



How do we proceed? The well is directly related to the nuclear radius

We know the charge radius of the neutron-rich partner, which due to isospin symmetry is the same as the neutron radius of its mirror

measured!

$$r_{\pi}(N > Z) = r_{\nu}(N < Z)$$

We also know the difference in binding energy of the g.s. of the two mirrors

These two observables allow to obtain

$$r_{\pi}(N < Z) = r_{\nu}(N > Z)$$

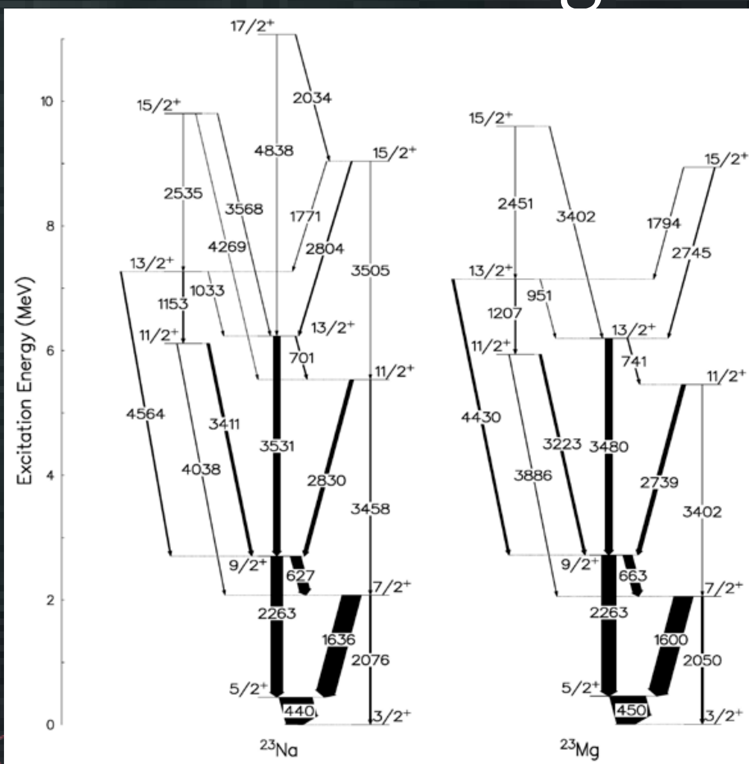
and thus the size of the two wells and the nuclear skin!

Once we have the interaction, using different wells for protons and neutrons in each nucleus, we can compute MED.

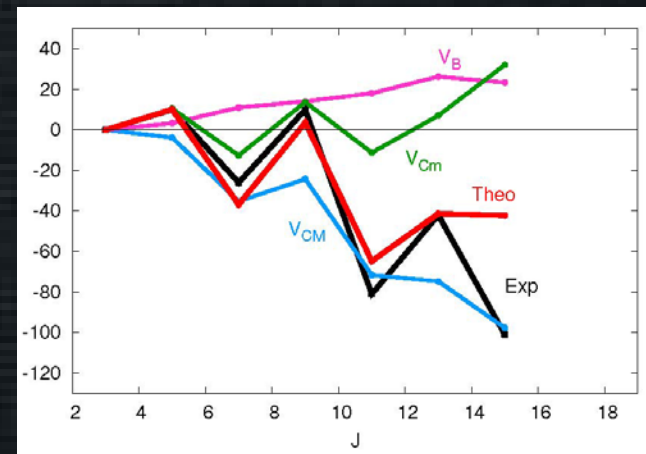
J. Bonnard et al., PRL 116, 212501 (2016)

Understanding the ISB: the mirror nuclei A=23

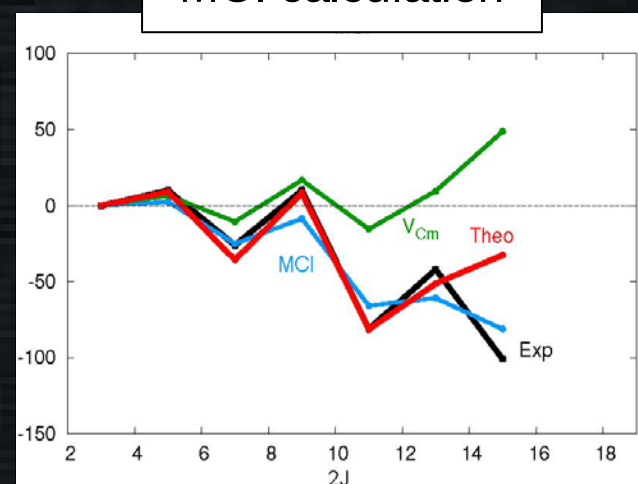
^{23}Na ^{23}Mg



Standard calculation

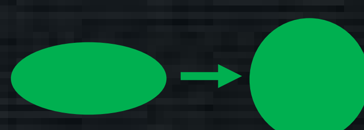


MCI calculation

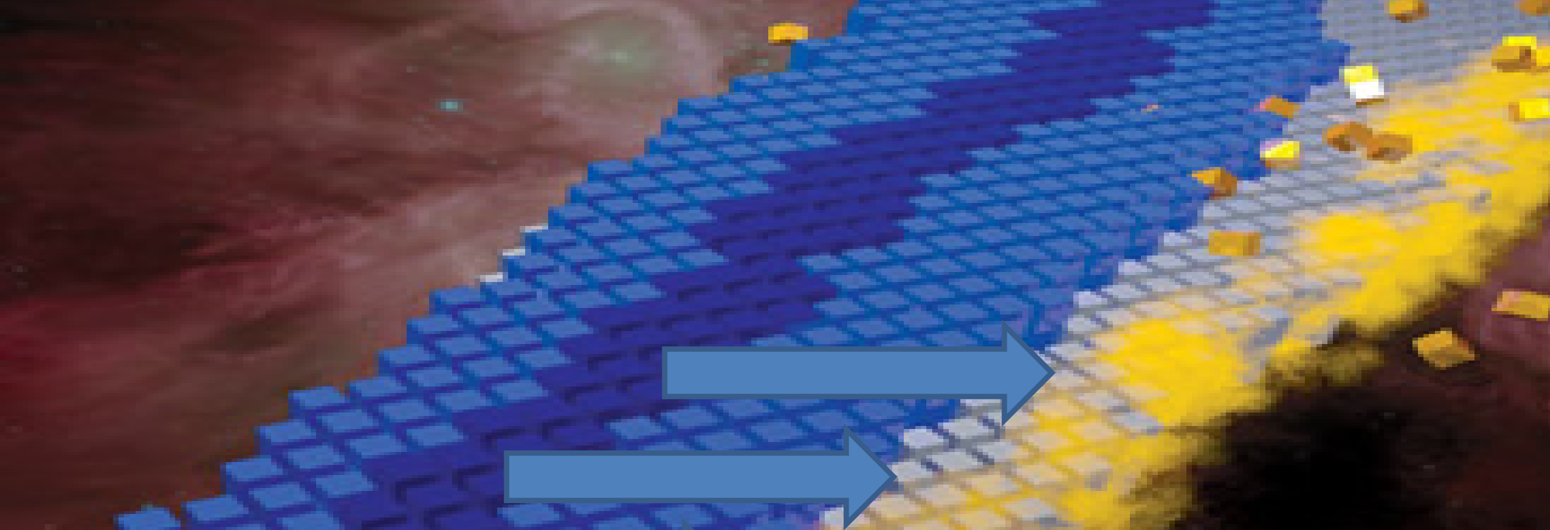


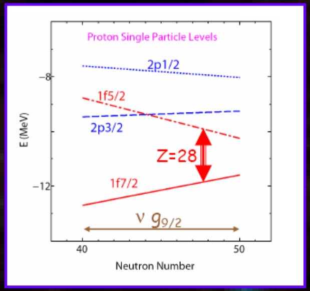
A.Boso et al., to be published

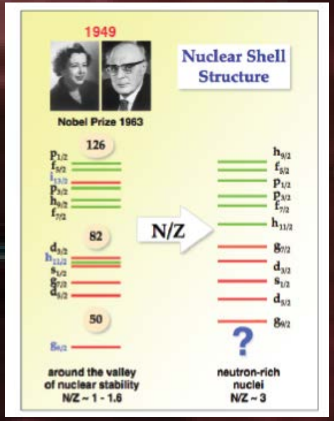
V_{Cm}



Moving far from stability towards neutron-rich







Shell evolution with γ spectroscopy

Among the most fascinating current problems in nuclear structure far from stability, the shell evolution and the development of new regions of deformation, the so-called Islands of Inversion (IoI) around proton and neutron numbers that are "magic" near stability have attracted the attention of many research communities.

Many efforts from the experimental and theoretical sides allow to compose the puzzle by using the most sophisticated techniques and methods in looking at different observables.

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Understanding shell evolution

In the last years the amount and quality of these investigations have allowed to understand some of these phenomena in detail.

In particular, in some mass regions that are accessible with the current experimental facilities and allow microscopic theoretical calculations

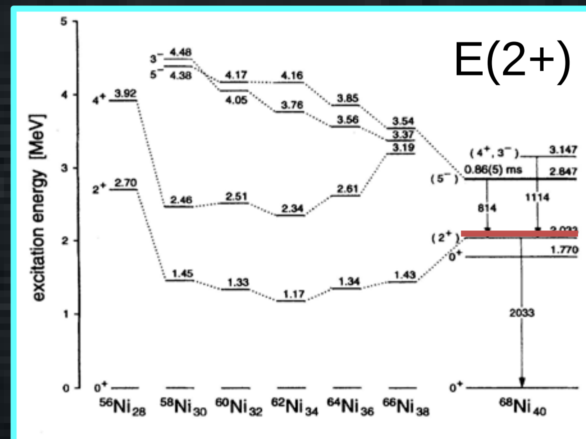
UNDERSTANDING SHELL EVOLUTION

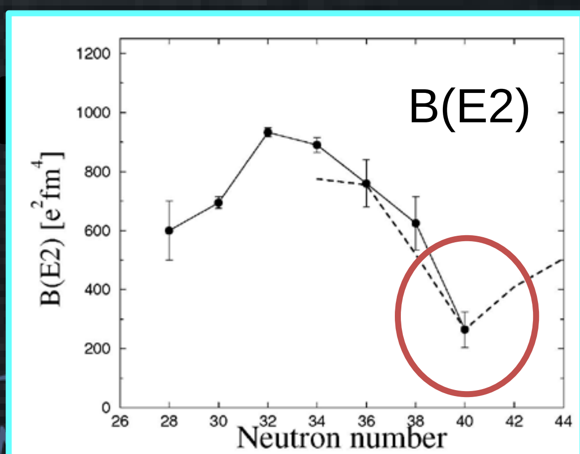
In this presentation I will focus on a particular mass region and the theoretical description with the shell model, but these phenomena are the ideal ground where several methods can be applied and compared between them and with experimental data.

A promenade south of ^{68}Ni

First hints of a doubly-closed shell structure in ^{68}Ni

R.Broda et al.,
PRL 74, 868 (1995)





O. Sorlin et al. PRL
88, 092501 (2002)

Deformation at N~40 in Cr isotopes

Approaching N=40 Cr isotopes show the development of deformation

Eur. Phys. J. A 16, 55–61 (2003)
DOI 10.1140/epja/i2002-10069-9

THE EUROPEAN PHYSICAL JOURNAL A

beta decay @ GANIL

New region of deformation in the neutron-rich $^{60}_{24}Cr_{36}$ and $^{62}_{24}Cr_{38}$

O. Sorlin[1,a], C. Donzaud[1], F. Nowacki[2], J.C. Angélique[3], F. Azaiez[1], C. Bourgeois[1], V. Chiste[1], Z. Dlouhy[4], S. Grévy[3], D. Guillemaud-Mueller[1], F. Ibrahim[1], K.-L Kratz[5], M. Lewitowicz[6], S.M. Lukyanov[7], J. Mrasek[4], Yu.-E. Penionzhkevich[7], F. de Oliveira Santos[6], B. Pfeiffer[5], F. Pougheon[1], A. Poves[8], M.G. Saint-Laurent[6], and M. Stanoiu[6]

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Physics Letters B 633 (2006) 696–700
PHYSICS LETTERS B
www.elsevier.com/locate/physletb

multinucleon transfer @ LNL

Shape transitions far from stability: The nucleus ^{58}Cr

N. Mărginean[a,e,*], S.M. Lenzi[b], A. Gadea[a], E. Farnea[b], S.J. Freeman[c], D.R. Napoli[a], D. Bazzacco[b],

PHYSICAL REVIEW C **74**, 064315 (2006)

deep-inelastic @ ANL

Level structure of the neutron-rich ^{56,58,60}Cr isotopes: Single-particle and collective aspects

S. Zhu,[1] A. N. Deacon,[2] S. J. Freeman,[2] R. V. F. Janssens,[1] B. Fornal,[3] M. Honma,[4] F. R. Xu,[5] R. Broda,[3] I. R. Calderin,[6]

PRL **102,** 012502 (2009) PHYSICAL REVIEW LETTERS week ending 9 JANUARY 2009

(p,p') @ RIKEN

Development of Large Deformation in ^{62}Cr

N. Aoi,[1] E. Takeshita,[1,2] H. Suzuki,[3] S. Takeuchi,[1] S. Ota,[4] H. Baba,[1] S. Bishop,[1] T. Fukui,[4] Y. Hashimoto,[5] H. J. Ong,[6]

RAPID COMMUNICATIONS

inelastic scattering @ NSCL (MSU)

PHYSICAL REVIEW C **81**, 051304(R) (2010)

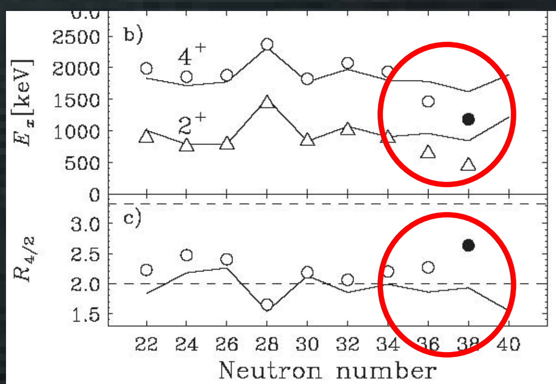
Collectivity at $N = 40$ in neutron-rich ^{64}Cr

A. Gade,[1,2] R. V. F. Janssens,[3] T. Baugher,[1,2] D. Bazin,[1] B. A. Brown,[1,2] M. P. Carpenter,[3] C. J. Chiara,[3,4] A. N. Deacon,[5] S. J. Freeman,[5] G. F. Grinyer,[1] C. R. Hoffman,[3] B. P. Kay,[3] F. G. Kondev,[6] T. Lauritsen,[3] S. McDaniel,[1,2] K. Meierbachtol,[1,7] A. Ratkiewicz,[1,2] S. R. Stroberg,[1,2] K. A. Walsh,[1,2] D. Weisshaar,[1] R. Winkler,[1] and S. Zhu[3]

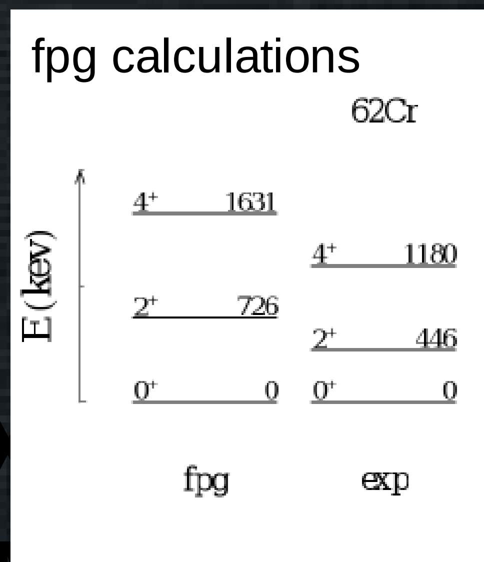
MCCXXII
INFN Istituto Nazionale di Fisica Nucleare

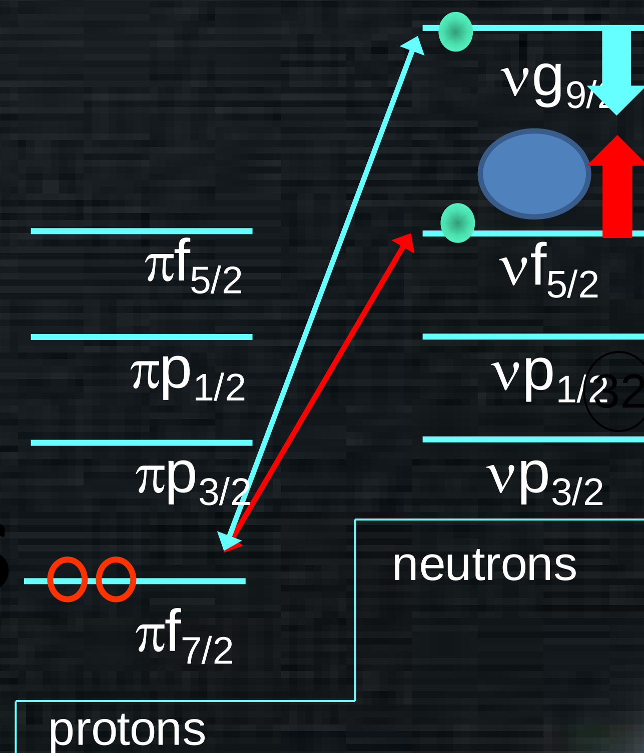
How to explain this phenomenon?

Different theoretical calculations and, in particular, the shell model failed to reproduce the data on $^{60-62}Cr$



N. Aoi et al., PRL 102, 012502 (2009)





These valence spaces do not include the quadrupole degrees of freedom of the systems

The monopole migration was not able to justify and reproduce the data

Development of deformation and Islands of Inversion

The effective interaction

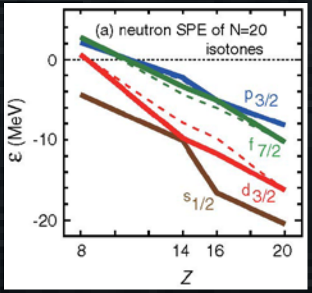
A multipole expansion

$$V_{eff} = V_m + V_M$$

monopole Multipole

V_m

- determines the single particle energies and the shell evolution
- main components: central, tensor and s.o.



V_M

- responsible for the correlations,
  main components **Pairing and Quadrupole**
- determines the energy gains and collective behavior

Deformation

It is the interplay of the monopole with the multipole terms what determines the different phenomena we observe.

Nuclear deformation: a simple model

Elliott's SU(3)

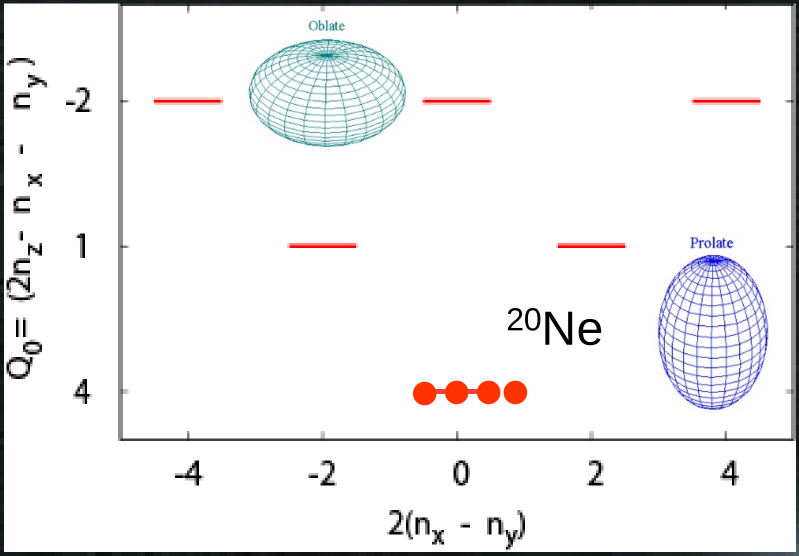
In the limit of degeneracy of the single-particle energies of a major shell and in the presence of an attractive Q.Q interaction among protons and neutrons, the ground state of the many-body nuclear system is maximally deformed.

The quadrupole moment of a nucleon is:

$$Q_0 = (2n_z - n_x - n_y)$$

where the principal quantum number $N = (n_x + n_y + n_z)$

$$Q_0 = 4, 1, -2$$



In the *sd* shell *N* = 2
there are 6 possible states:
(2,0,0) (0,2,0) (0,0,2)
(1,1,0)(1,0,1)(0,1,1)

Elliott's SU3 works well in the sd shell but fails for upper shells where the SO interaction introduces large energy shifts

SU3 approximate symmetries

Two variants of SU3 apply in specific spaces

Quasi SU3

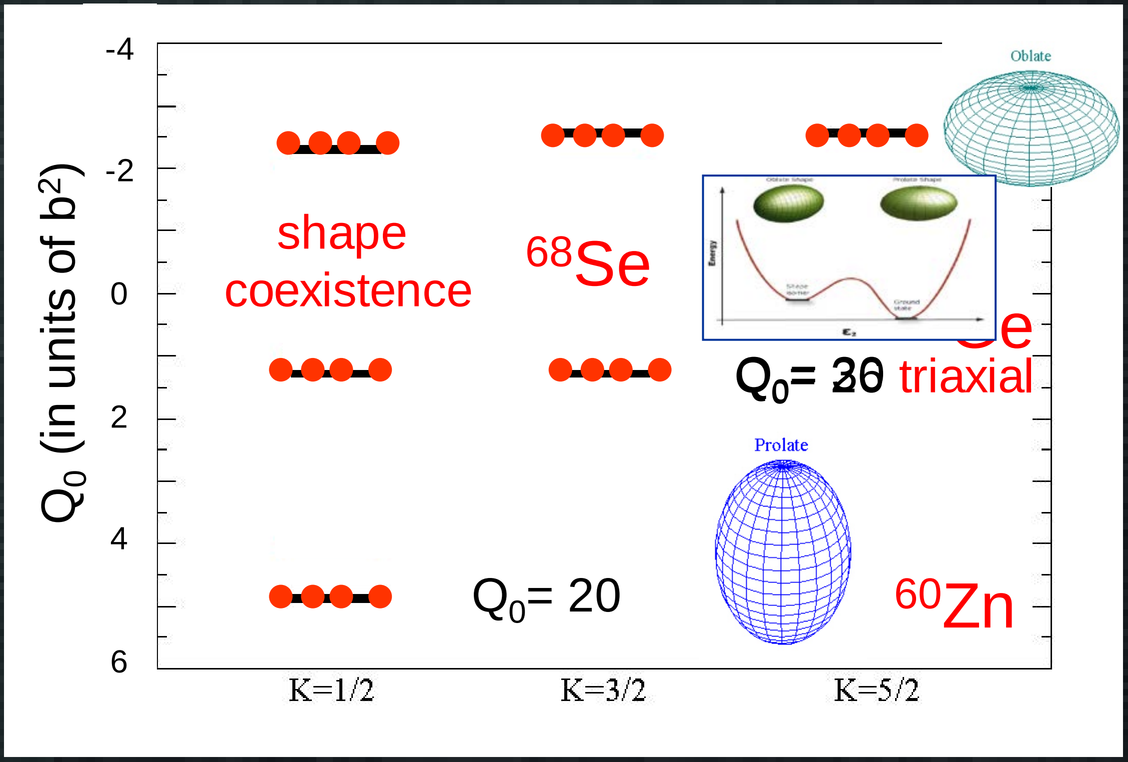
applies to the lowest $\Delta j = 2$, $\Delta \ell = 2$ orbits in a major HO shell

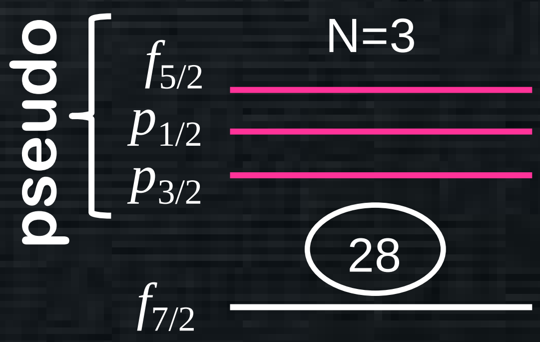
Pseudo SU3

applies to a HO space where the largest *j* orbit has been removed.

A.P. Zuker et al., PRC **52**, R1741 (1995).
Zuker, Poves, Nowacki, Lenzi, PRC 92, 024320 (2015)

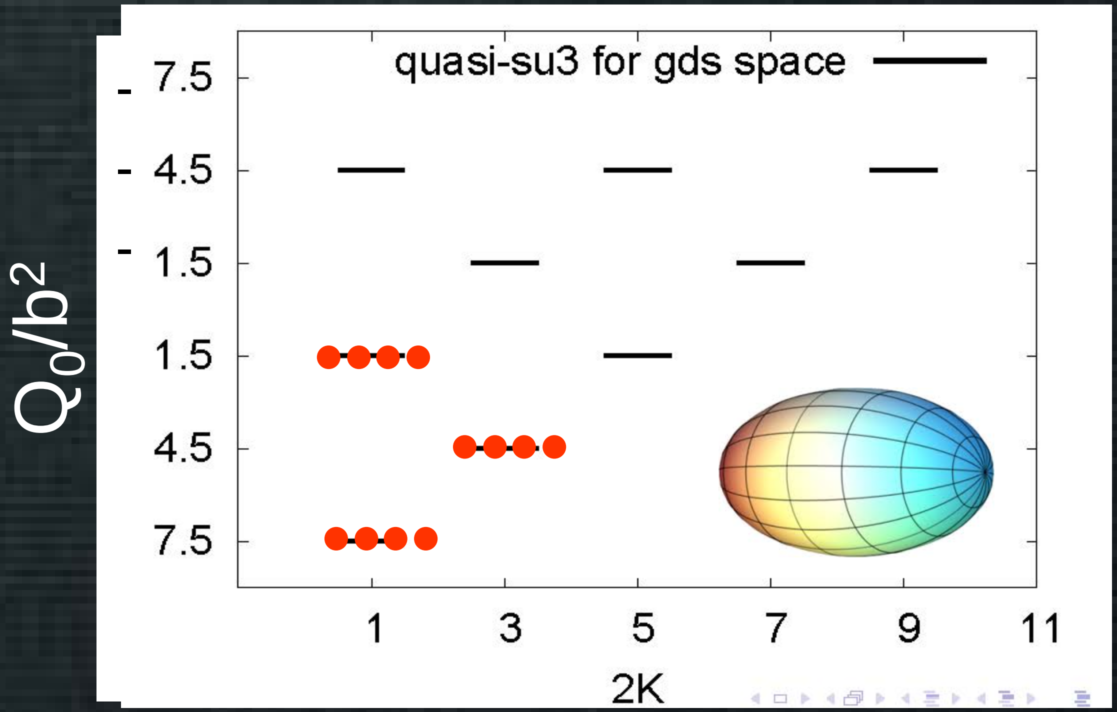
Quadrupole moments in Pseudo SU3





We obtain Q_0 by summing those of the single particles/holes in each "orbit"

Quadrupole moments in Quasi SU3

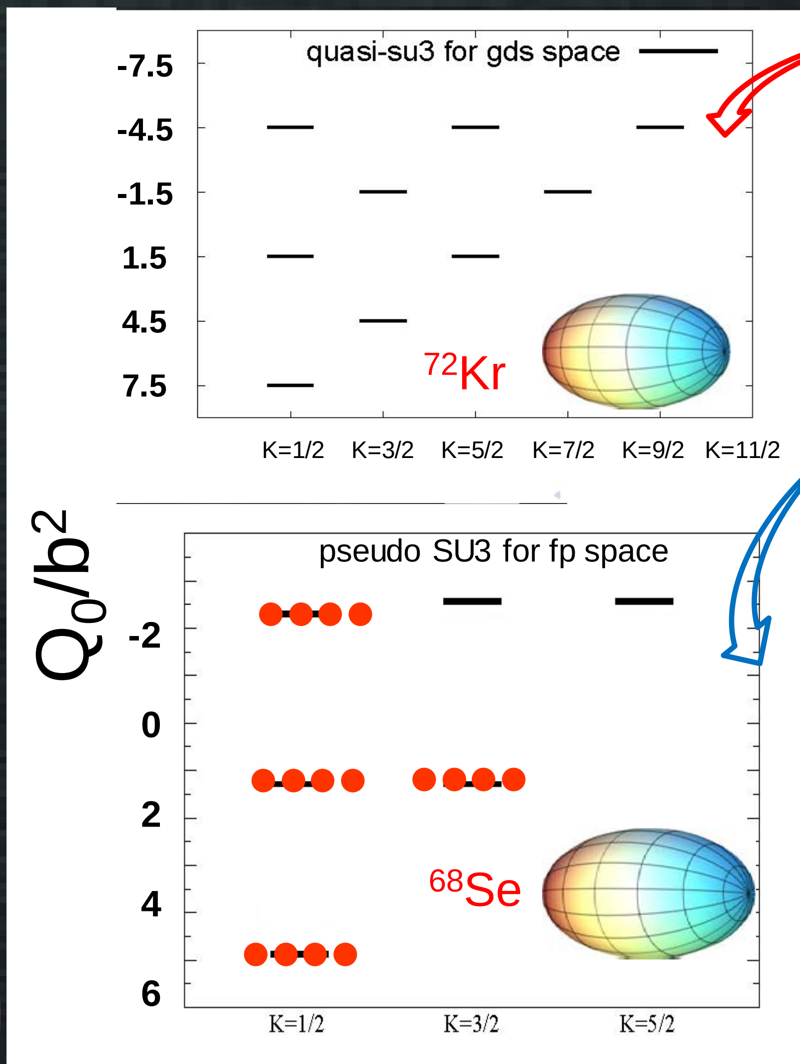


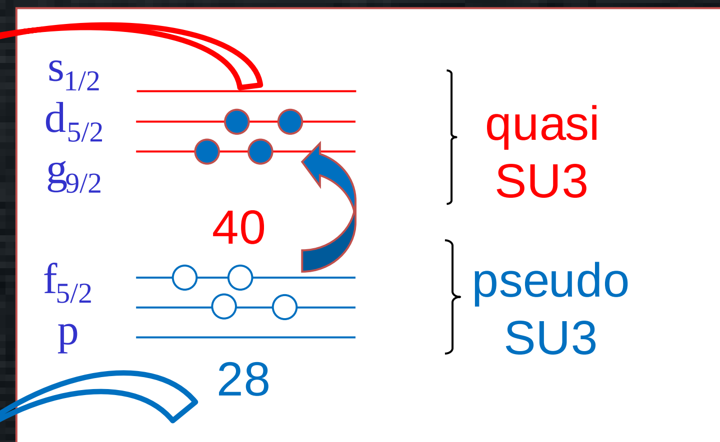
We obtain Q_0 by summing those of the single particles in each "orbit"

Maximizing quadrupole correlations

quasi

pseudo





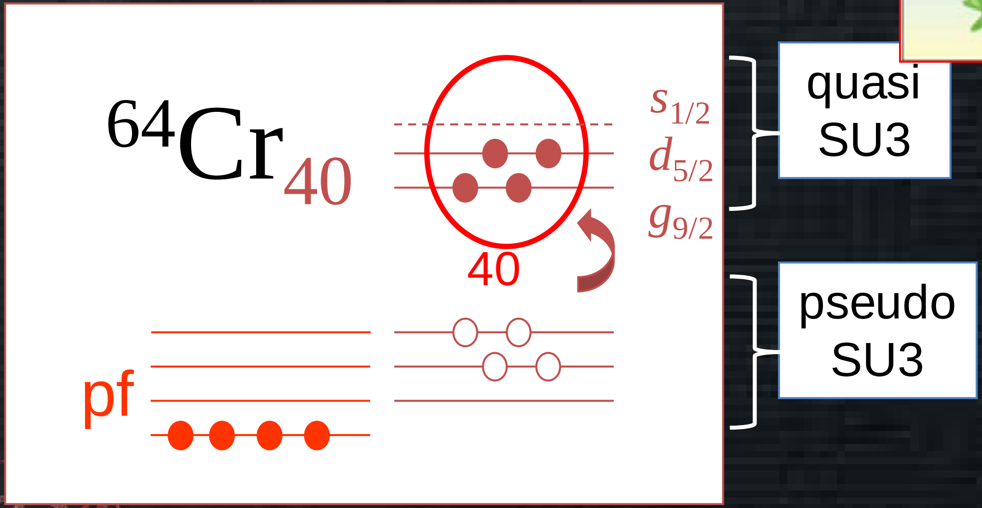
Particle-hole excitations in the pseudo + quasi space maximize the quadrupole moment.

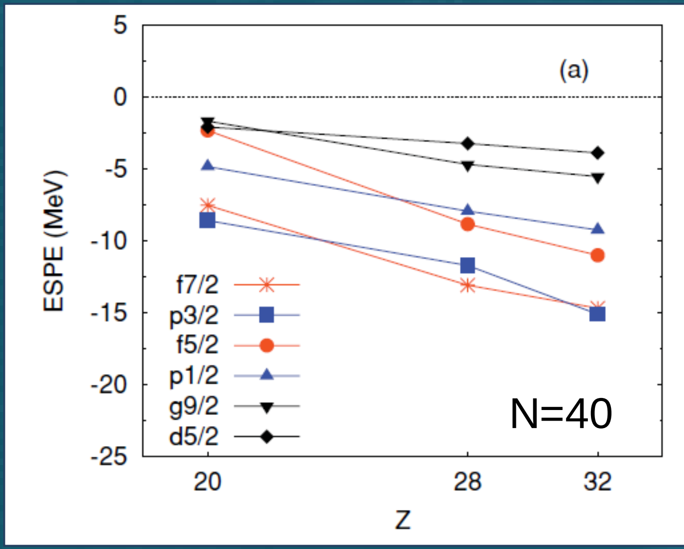
The quadrupole correlation energy results much larger than the energy cost to promote the particles

The model space that includes the quadrupole degrees of freedom

It is the interplay of the monopole terms of the interaction with multipole terms, like pairing and quadrupole, which determines the different phenomena we observe.

This explains the development of the Islands of inversion at the "traditional" magic numbers





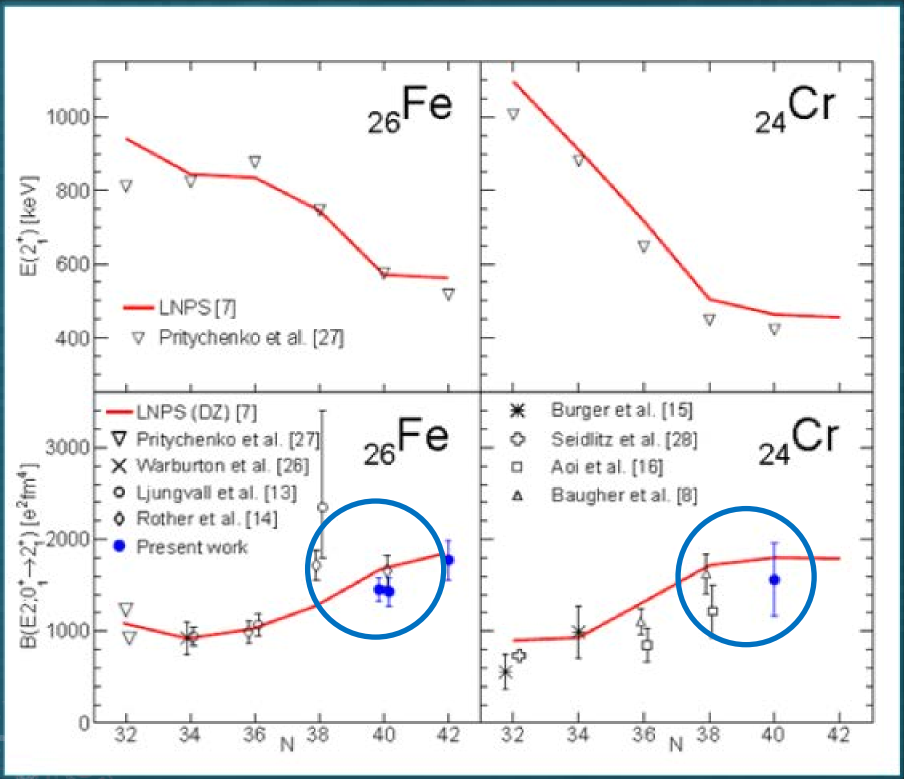
Lenzi, Nowacki, Poves, Sieja
(LNPS interaction)
PRC 82, 054301 (2010)

Other effective interactions:
$V_{low\ k}$: L. Coraggio et al., PRC 89, 024319 (2014).
A3DA: Tsunoda et al., PRC 89, 031301 (2014).

Continuing our promenade

Measurement of deformation with radioactive beams

Intermediate-energy Coulomb excitation measurements at NSCL-MSU



H. L. Crawford et al., PRL 110, 242701 (2013)
T. Baugher et al., PRC 86, 011305(R) (2012)

p-h excitations across Z=28 and N=40 in N=40 isotones

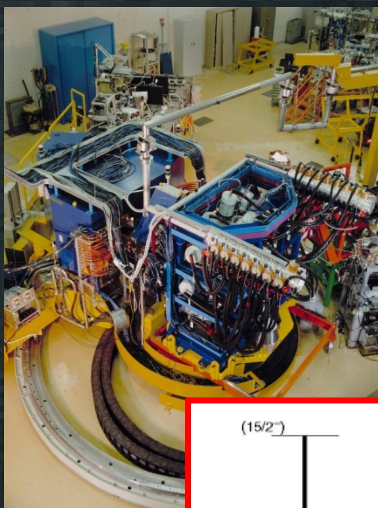
Nucleus	$\nu g_{9/2}$	$\nu d_{5/2}$	0p0h	2p2h	4p4h	6p6h	E_{corr}
^{68}Ni	0.98	0.10	55.5	35.5	8.5	0.5	−9.03
^{66}Fe	3.17	0.46	1	19	72	8	−23.96
^{64}Cr	3.41	0.76	0	9	73	18	−24.83
^{62}Ti	3.17	1.09	1	14	63	22	−19.62
^{60}Ca	2.55	1.52	1	18	59	22	−12.09

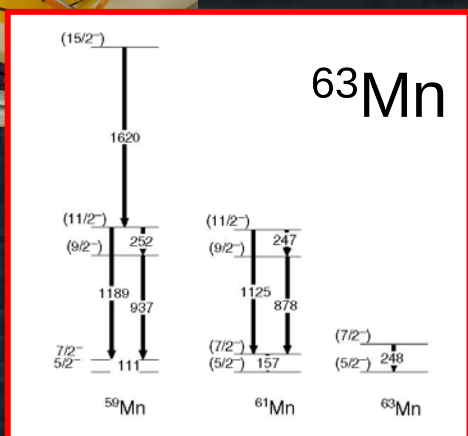
deformation $\beta \sim 0.3$

See also: $^{68-70}$Fe G. Benzoni et al., PLB 751 (2015) 107

Spectroscopy on heavy Mn

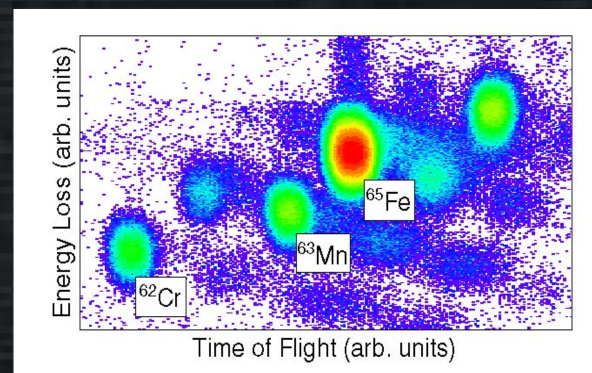
First level schemes from multi-nucleon transfer reactions using CLARA + PRISMA at LNL





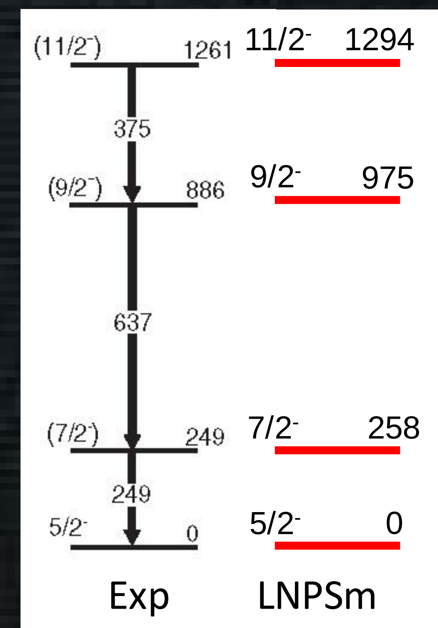
J.J. Valiente-Dobon et al., PRC **78**, 024302 (2008)

Inelastic scattering following fragmentation with SEGA @ MSU



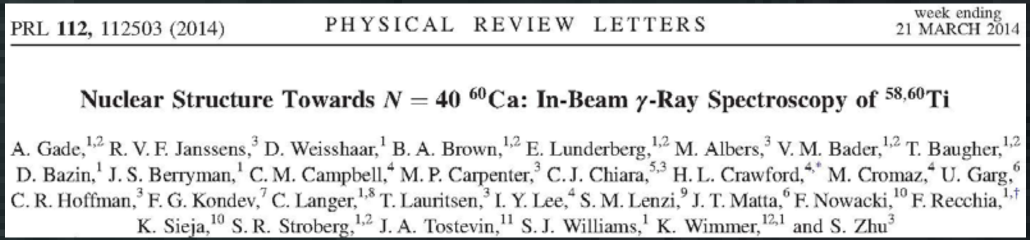
T. Baugher et al., PRC 93, 014313 (2016)

^{63}Mn



More data on heavier Mn isotopes coming soon from RIKEN.

Deformation in ^{58,60}Ti: towards ^{60}Ca

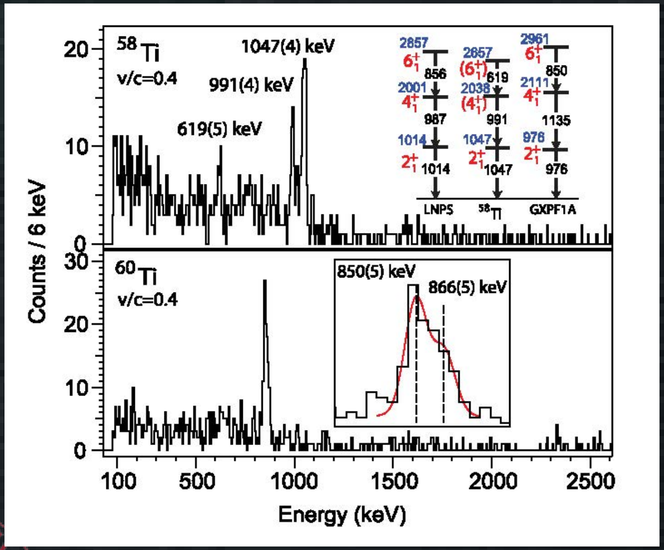

PRL **112,** 112503 (2014) PHYSICAL REVIEW LETTERS week ending 21 MARCH 2014

Nuclear Structure Towards $N = 40$ ^{60}Ca: In-Beam γ-Ray Spectroscopy of ^{58,60}Ti

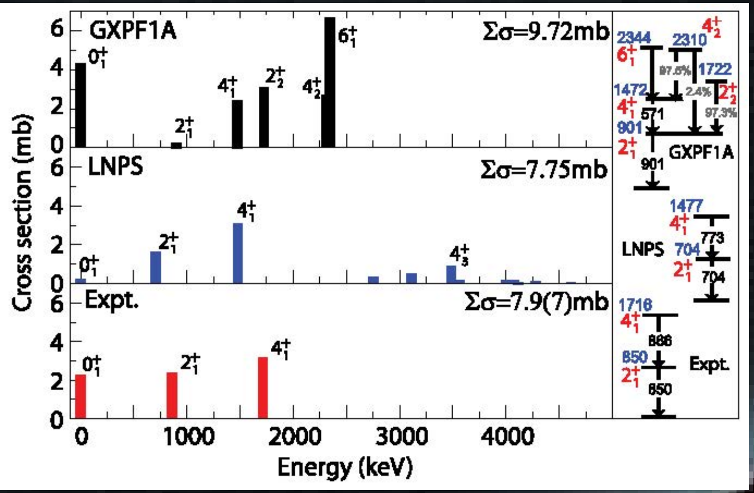
A. Gade,[1,2] R. V. F. Janssens,[3] D. Weisshaar,[1] B. A. Brown,[1,2] E. Lunderberg,[1,2] M. Albers,[3] V. M. Bader,[1,2] T. Baugher,[1,2] D. Bazin,[1] J. S. Berryman,[1] C. M. Campbell,[4] M. P. Carpenter,[3] C. J. Chiara,[5,3] H. L. Crawford,[4,*] M. Cromaz,[4] U. Garg,[6] C. R. Hoffman,[3] F. G. Kondev,[7] C. Langer,[1,8] T. Lauritsen,[3] I. Y. Lee,[4] S. M. Lenzi,[9] J. T. Matta,[6] F. Nowacki,[10] F. Recchia,[1,†] K. Sieja,[10] S. R. Stroberg,[1,2] J. A. Tostevin,[11] S. J. Williams,[1] K. Wimmer,[12,1] and S. Zhu[3]

GRETINA data from NSCL

A decrease of quadrupole deformation is observed at Z=22 indicating the smooth transition at the border of the Island of Inversion



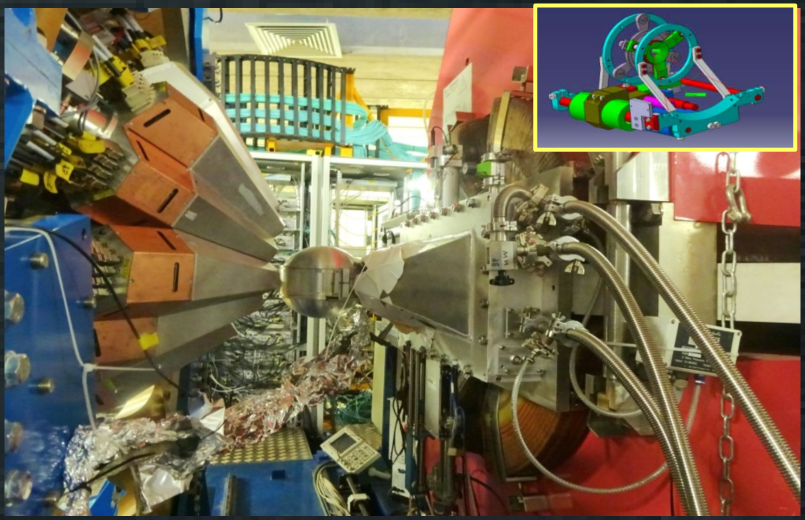
Knockout cross section obtained with SM spectroscopic factors



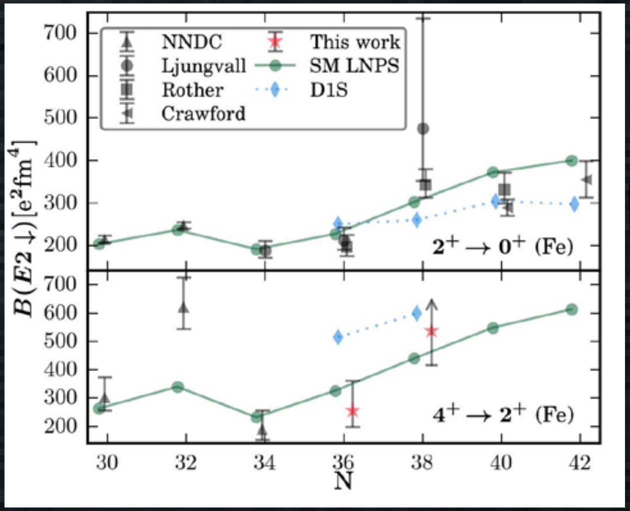
^{60}Ti represents an important benchmark from which to extrapolate towards ^{60}Ca and the location of the neutron drip line in the Ca isotopic chain.

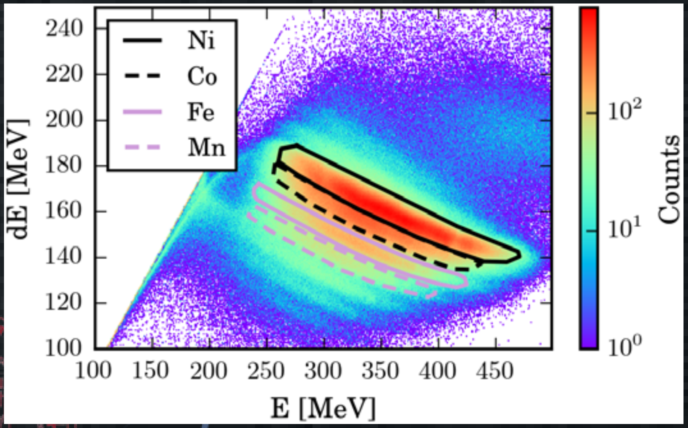
Lifetimes in Mn, Fe, Co and Ni

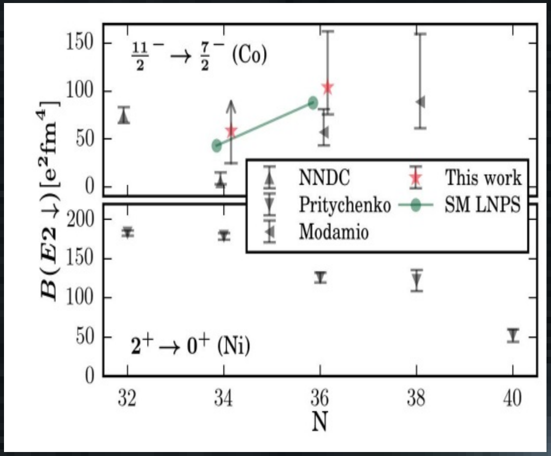
AGATA + VAMOS experiment



Multinucleon transfer+ punger

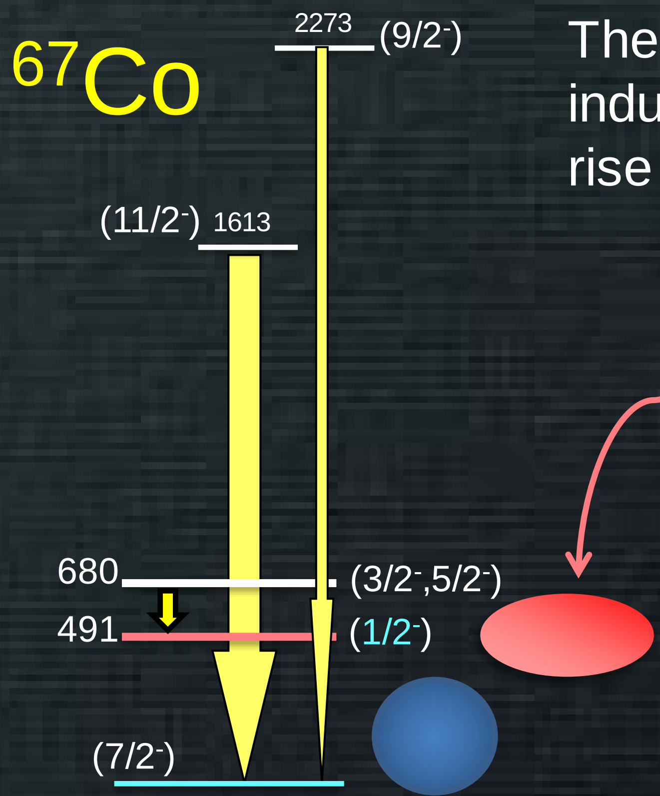




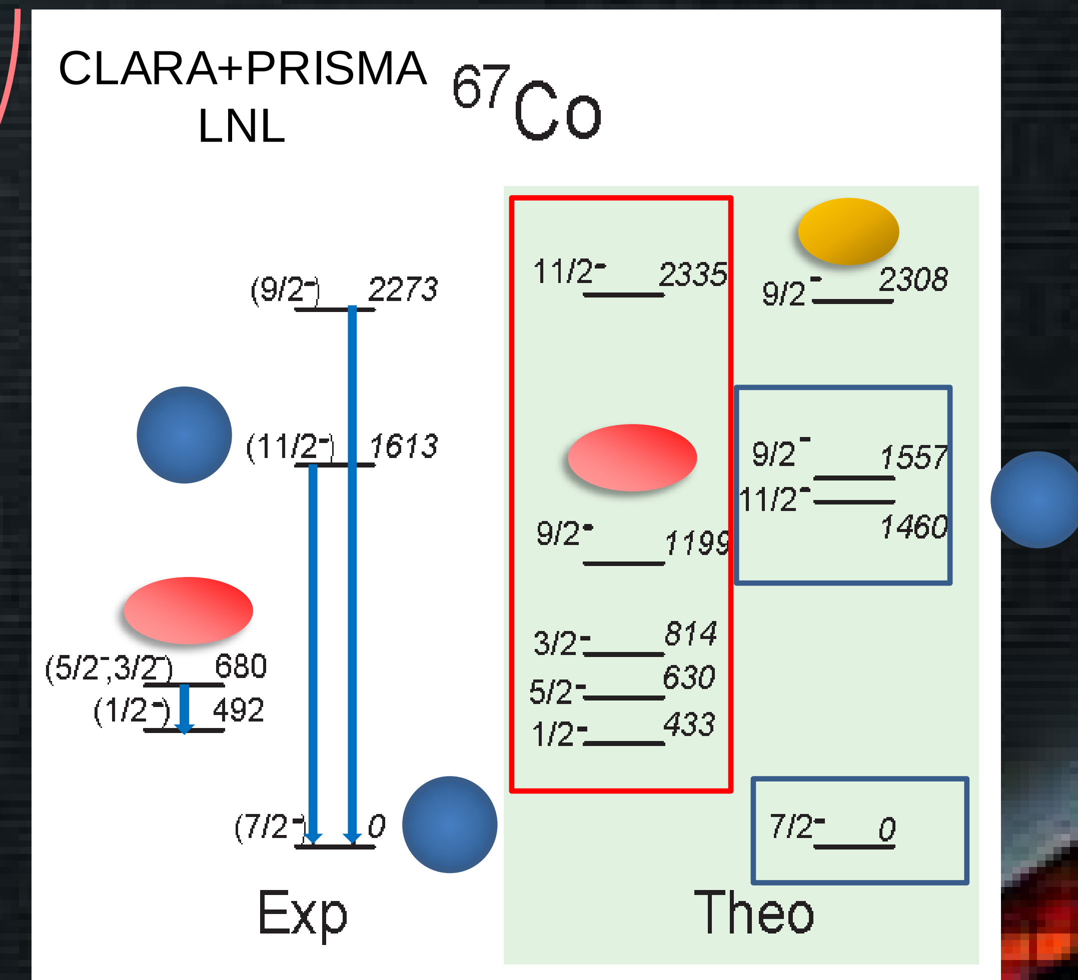


M. Klintefjord et al., PRC 95, 024312 (2017)

Shape coexistence in ^{67}Co



The deformation driven by the neutrons induces a reduction of the Z=28 gap and gives rise to a deformed low-lying 1/2- state

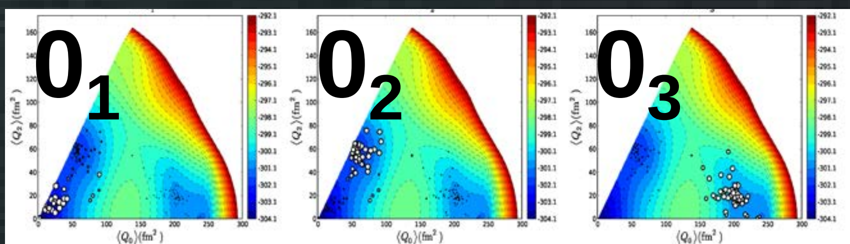


D. Pauwels et al., PRC 78, 041307 (2008) and PRC 79, 044309 (2009)

F. Recchia et al., PRC 85, 064305 (2012)

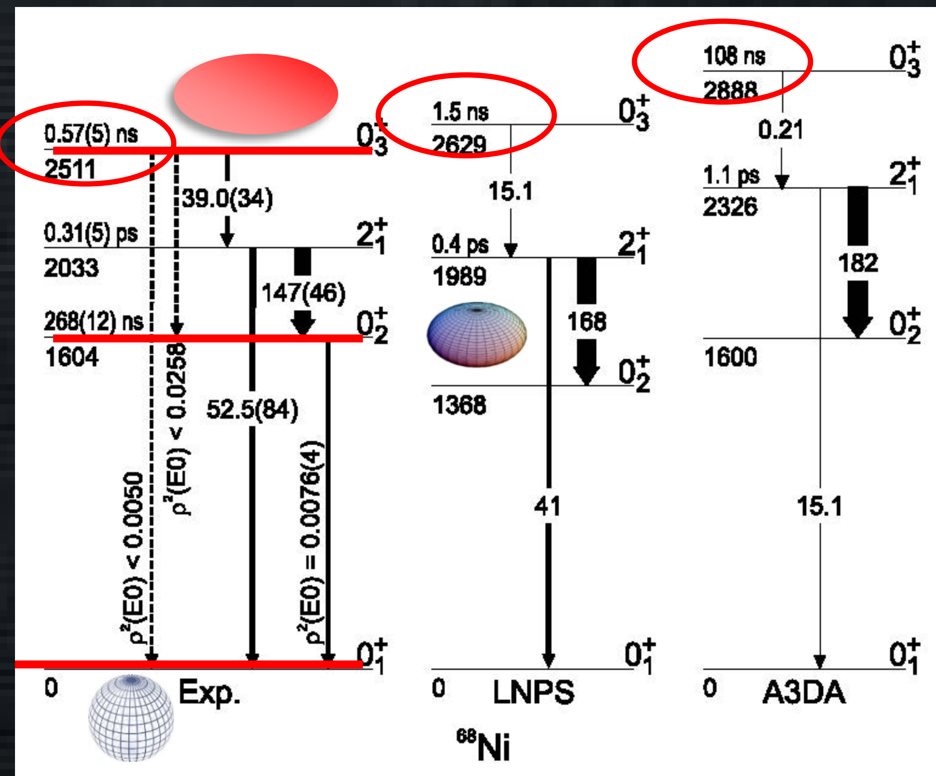
Triple shape coexistence in ^{68}Ni

The first three 0^+ states are predicted
to have different shapes by MCSM calculations



Y. Tsunoda et al., PRC 89, 024313(R) (2014)

In ^{68}Ni as in ^{40}Ca (super- deformed band at low excitation energy) the magic closures are probed by the action of the nuclear correlations, pairing and quadrupole, that favor the intruder configurations



F. Flavigny et al., PRC 91, 034310 (2015)

F. Recchia et al., PRC **88**, 041302(R) (2013)

B.P. Crider et al., PLB 763 (2016) 108
lifetime measurement beta-decay
NSCL with LaBr3(Ce) + SEGA

Doorway excited states in magic nuclei

Excited (intruder) states in doubly-closed shell nuclei act as precursors of what becomes the ground states of lighter isotones.

Valence spaces spanned by a single mayor shell do not contain the degrees of freedom necessary for the development of collectivity.

Two main shells have to be included, but just keeping the relevant orbitals where the Quadrupole Deformation develops. The choice is ruled by dynamical symmetries, variants of SU(3)

Approaching N=50

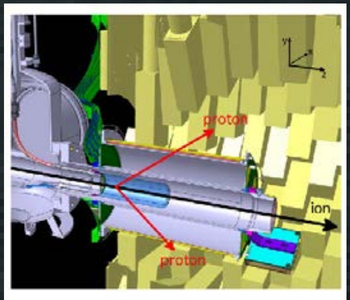
The N=40 IoI continues to N=50

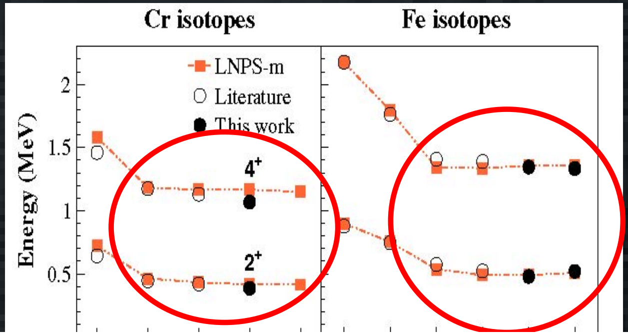
(p,2p) reactions at using DALI2 and MINOS

PRL **115**, 192501 (2015) PHYSICAL REVIEW LETTERS week ending 6 NOVEMBER 2015

Extension of the $N = 40$ Island of Inversion towards $N = 50$: Spectroscopy of ^{66}Cr, $^{70,72}Fe$

C. Santamaria,[1,2] C. Louchart,[3] A. Obertelli,[1,2] V. Werner,[3,4] P. Doornenbal,[2] F. Nowacki,[5] G. Authelet,[1] H. Baba,[2]





Nucleus	$n^{\nu}(g_{9/2}+d_{5/2})$		$0p0h$	$2p2h$	$4p4h$	$6p6h$	$\Delta E^{*}_{\text{Pairing}}$
	IPM	SM					
^{60}Cr	0	1.8	14	75	7	0	1.84
^{62}Cr	0	3.5	1	25	71	3	1.49
^{64}Cr	0	4.3	0	8	71	20	1.25
^{66}Cr	2	5.2	0	40	56	3	1.13
^{68}Cr	4	6.0	6	79	11	0	1.24

β-decay with EURICA

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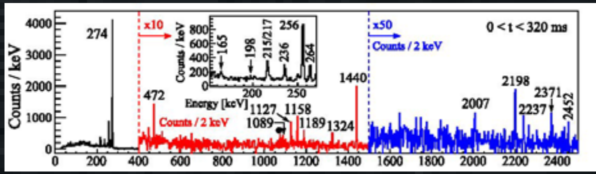
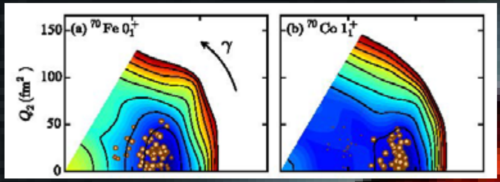
Type II shell evolution in $A = 70$ isobars from the $N \geq 40$ island of inversion

A.I. Morales[a,b,*], G. Benzoni[a], H. Watanabe[c,d], Y. Tsunoda[e], T. Otsuka[f,g,h], S. Nishimura



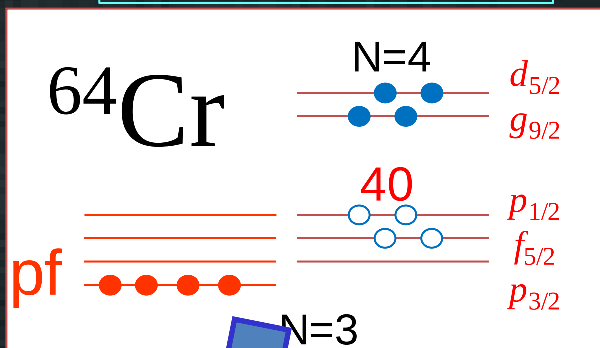
Low-lying state in ^{70}Co is deformed

$^{70}Fe \rightarrow ^{70}Co$			
J^{π}_{p}	J^{π}_{d}	$B(\text{GT})$	$\log ft$
0^+	1^+_1	4×10^{-5}	7.9
	1^+_2	3.7×10^{-2}	5.02
	1^+_3	1.8×10^{-1}	4.33

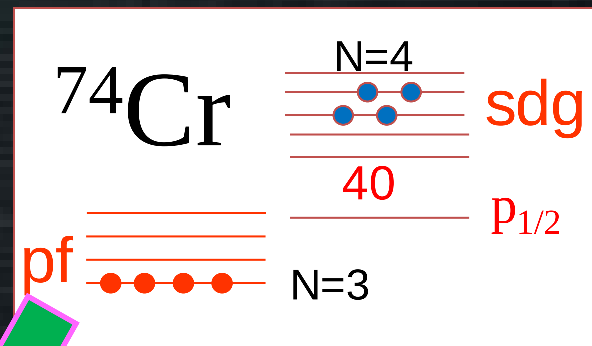


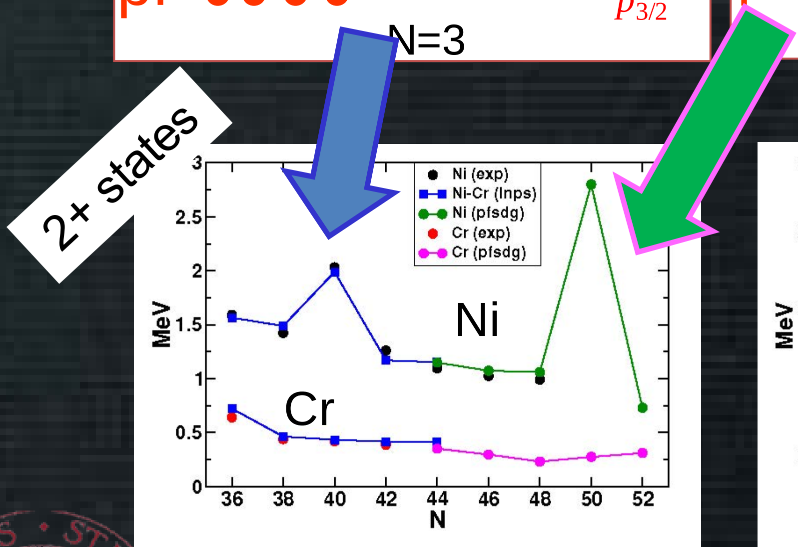
Extension of the IoI from N=40 to N=50

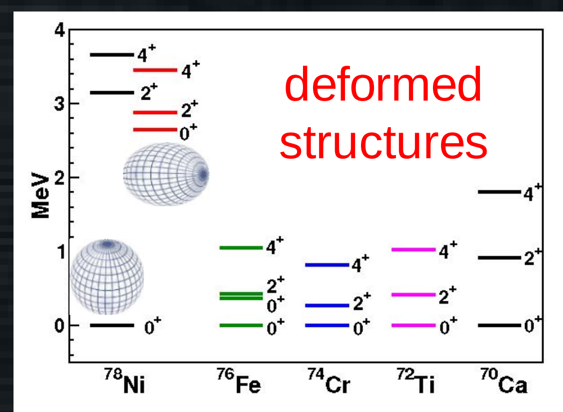
LNPS Model space

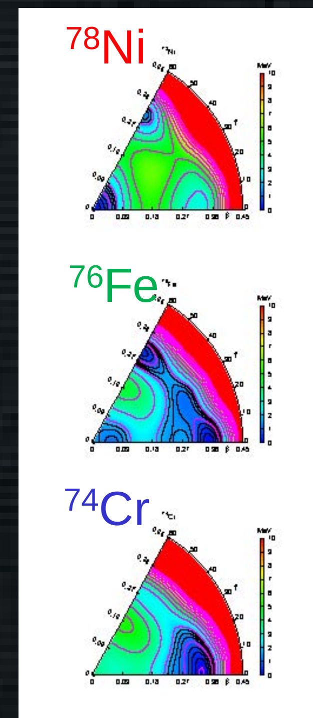


pf-sdg Model space



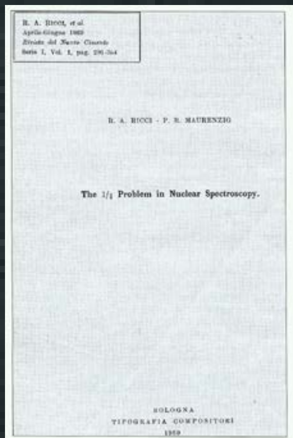






Merging the two islands of inversion:
F. Nowacki et al., Phys. Rev. Lett. 117, 272501 (2016)

Conclusions and perspectives



The $f_{7/2}$-shell nuclei are the ideal benchmark to understand nuclear structure properties such as:

- development of deformation
- shape coexistence
- proton-neutron pairing
- charge-symmetry broken
- islands of inversion far from stability

High-resolution gamma ray spectroscopy allows to get detailed insight into several nuclear properties by means of different experimental techniques and, therefore, to have a comprehensive picture of the nuclear dynamics and its evolution far from stability.

The subtle balance between correlations induced by the multipole interaction and the monopole field determines these phenomena. Dynamical symmetries help to choose the model spaces that contain the relevant degrees of freedom of the system.

Low-ℓ orbits play a very important role in determining different nuclear properties, as e.g. the Mirror Energy Differences.
More is coming!

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Thank you for your attention

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