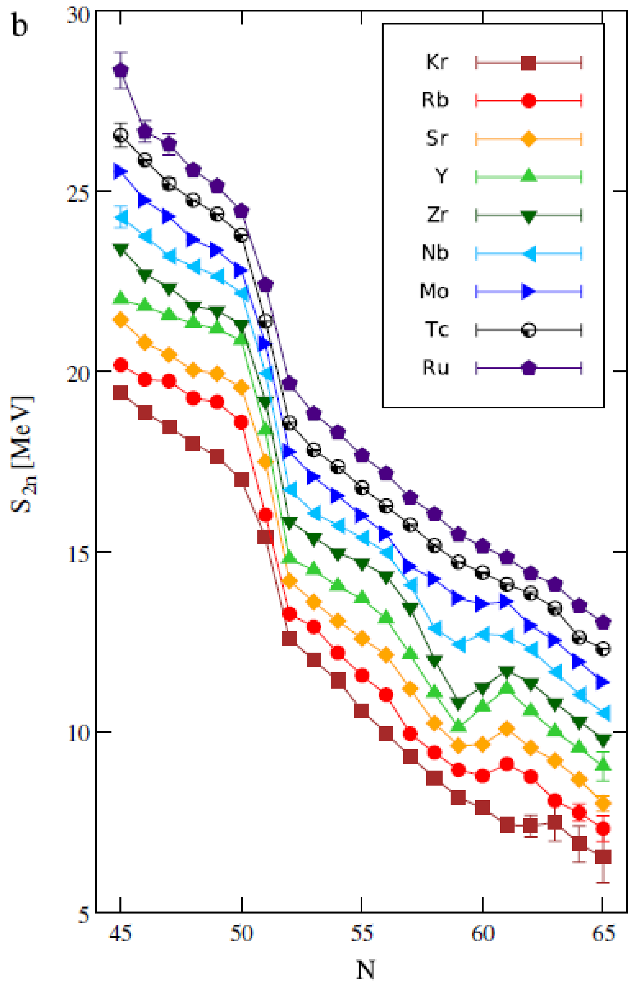
Spectroscopic Quadrupole Moment in ^{96,98}Sr : Shape coexistence at N=60

NUSPIN 2016 Workshop of the Nuclear Spectroscopy Instrumentation Network
San Servolo, Venice

E.Clément-GANIL

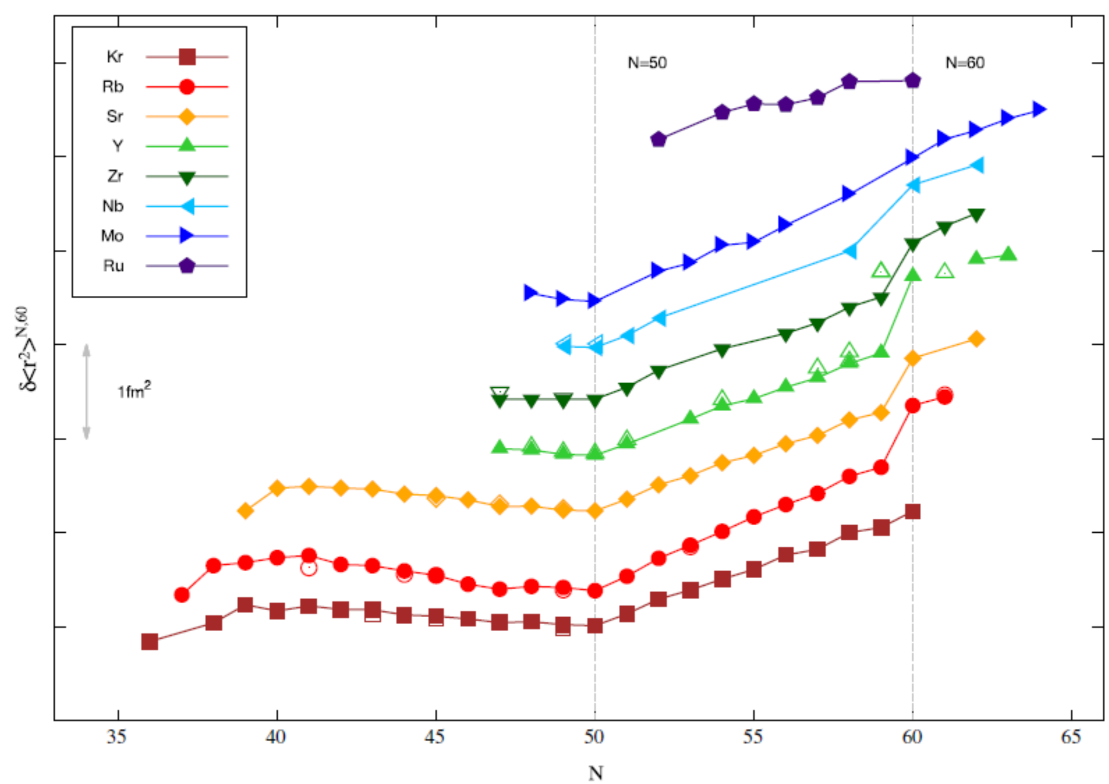
Shape Transition at N=60

P. Campbell, I.D. Moore, M.R. Pearson
Progress in Particle and Nuclear Physics 86 (2016) 127–180



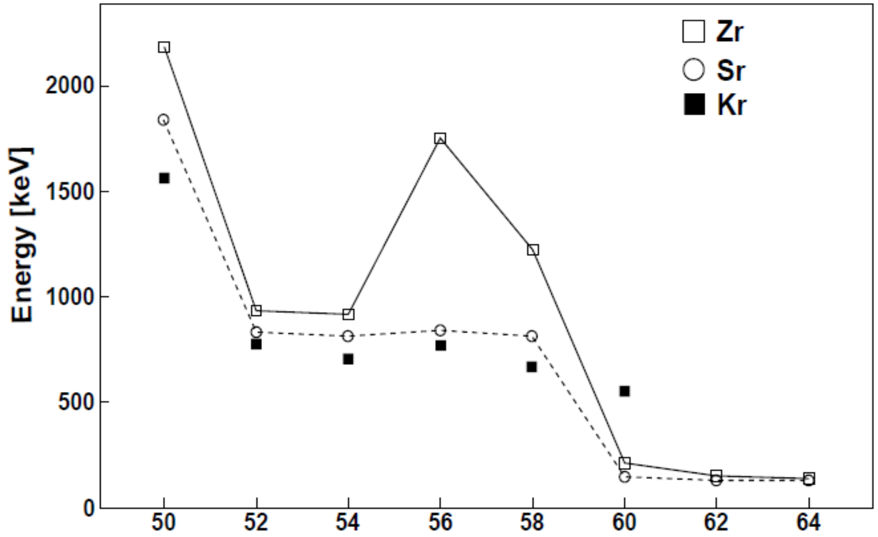
- ❑ The n-rich nuclei between Z=37 and Z=41 present at N=60 one of the most impressive deformation change in the nuclear chart
- ❑ Localized within the Z degree of freedom
  → Point to a specific π–ν interaction

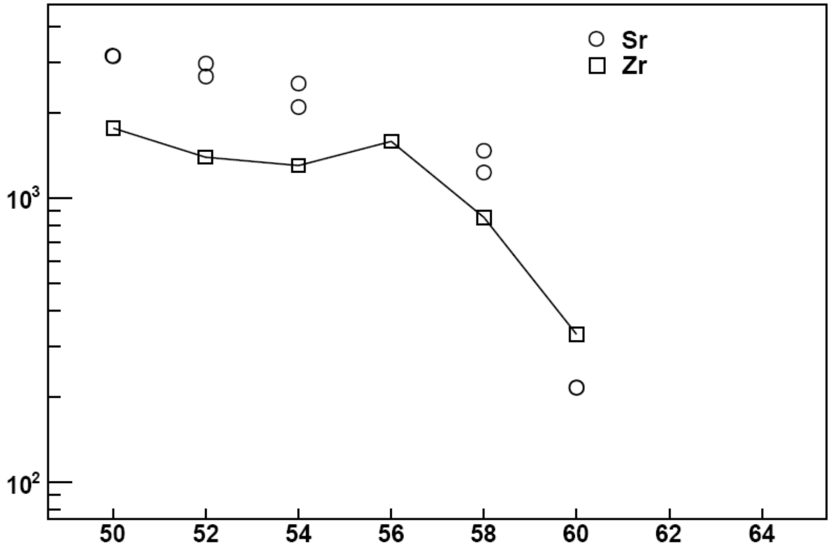
162 P. Campbell et al. / Progress in Particle and Nuclear Physics 86 (2016) 127–180



Shape Transition at N=60

M. Albers *et al.*, *Phys. Rev. Lett. 108, 062701 (2012)*



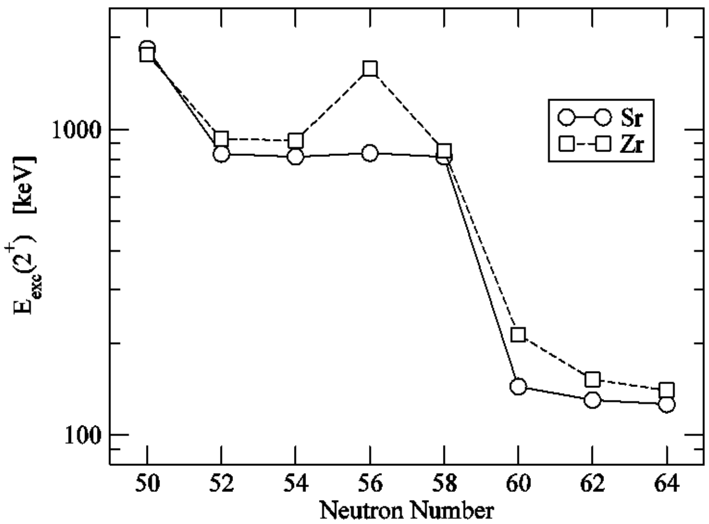


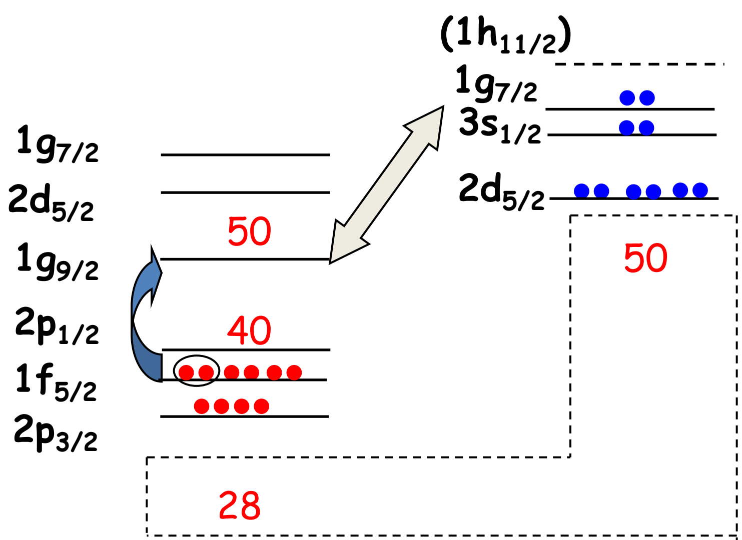
❖First spectroscopy (GS and 2^+_1) indicated a shape change from β ~0.1 to β~0.4

❖0^+_2 states are indication of shape coexistence
→ Shape inversion ?

❖Kr isotopes behave differently : smooth 2^+ change, delayed S_{2n} increase, no low lying 0^+_2

Shape Transition at N=60





The sharp transition and magnitude of the deformation remain still a challenge for theories (> 100 theoretical papers since the 70's)

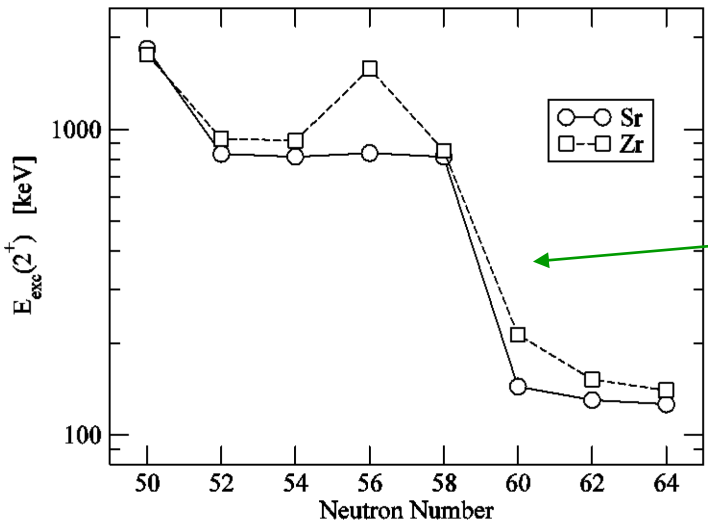
- ✓HFB + the generator coordinate method (GCM)
- ✓the macroscopic-microscopic method
- ✓the shell model
- ✓the Monte Carlo shell model
- ✓the interacting boson model (IBM) approximation
- ✓the VAMPIR model
- ✓covariant density functional (DF) theory (PC-PK1).

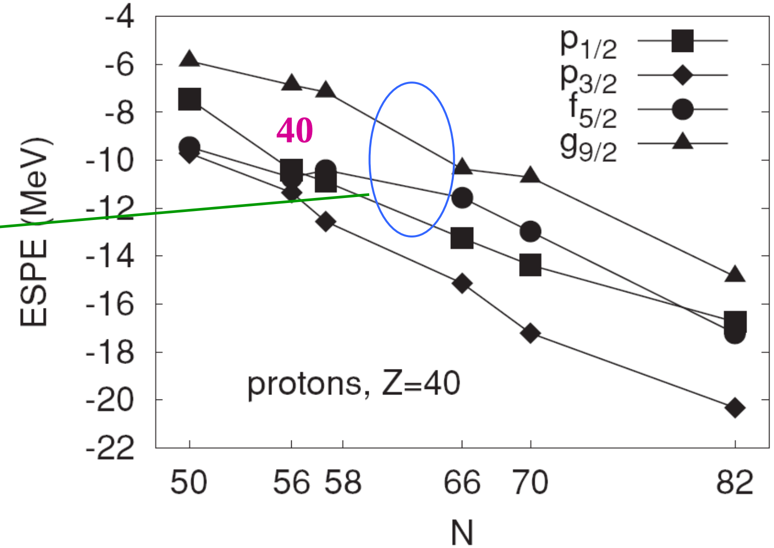
- ❑ 0^+_2 state created by 2p-2h excitation across Z=40
- ❑ Beyond N=60, $g_{7/2}$ is populated, the $\pi-\nu$ interaction participates to the lowering 0^+_2 state and to the high collectivity of 2^+_1 state.
- ❑ In BMF calculations, two minima appear in the PES

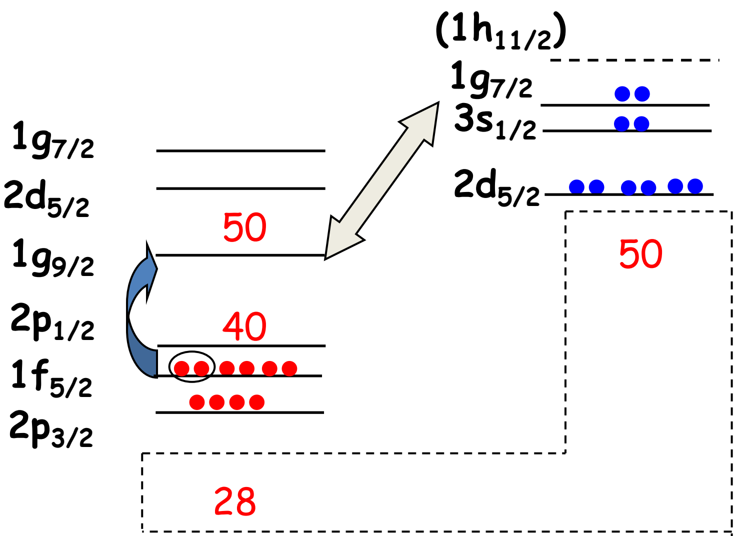
Mainly GS and level scheme are known and limit the comparison with theoretical models

K. Sieja et al PRC 79, 064310 (2009)
A. Petrovici PRC 85, 034337 (2012)

Shape Transition at N=60







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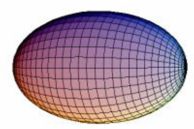
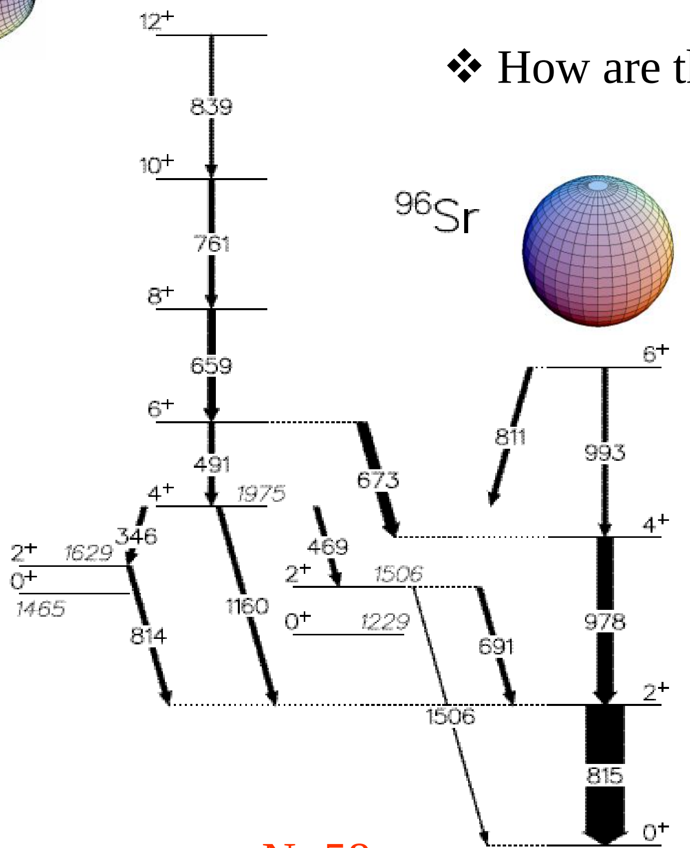
Shape Transition at N=60

laboratoire commun CEA/DSM CNRS/IN2P3

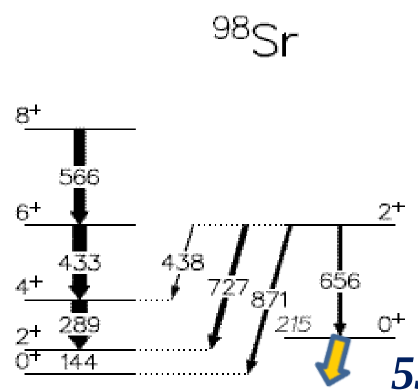
- What is the shape of the corresponding the 2^+ states ?
- How are the different configurations connected ?





N=58

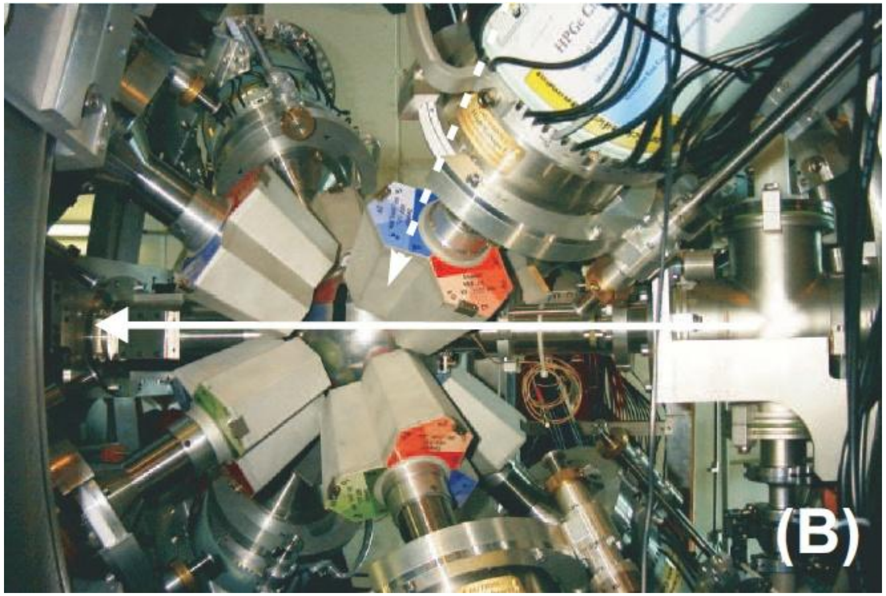
→ Coulomb excitation of RIB



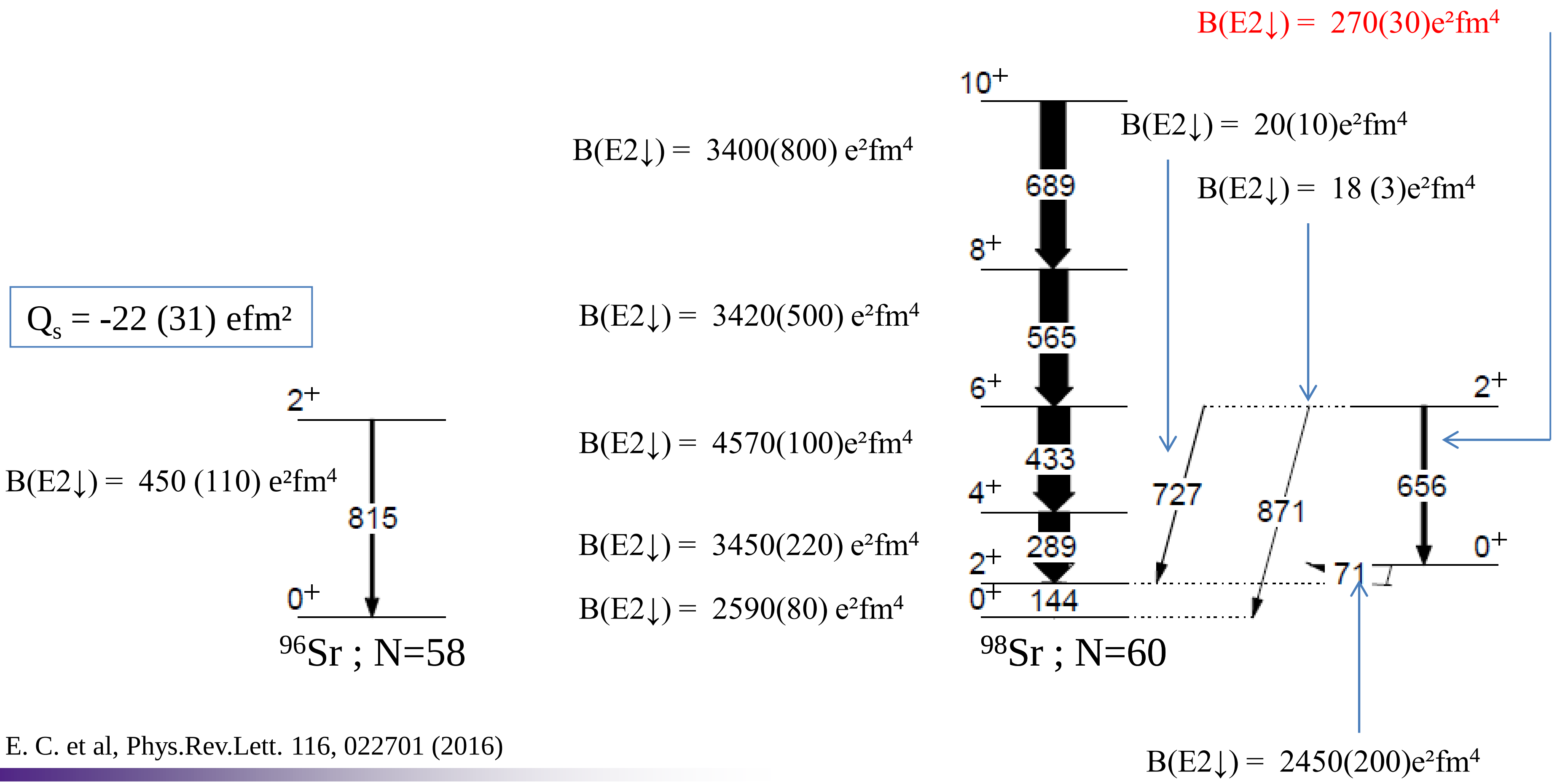
N=60

Safe Coulomb excitation of ^{96,98}Sr beams at REX-ISOLDE using the MINIBALL array

^{96}Sr $T_{1/2}$ =1.07 sec. 7000 pps   at 275 MeV
^{98}Sr $T_{1/2}$ =0.65 sec. 60000 pps at 276 MeV



Shape Coexistence in ^{96,98}Sr

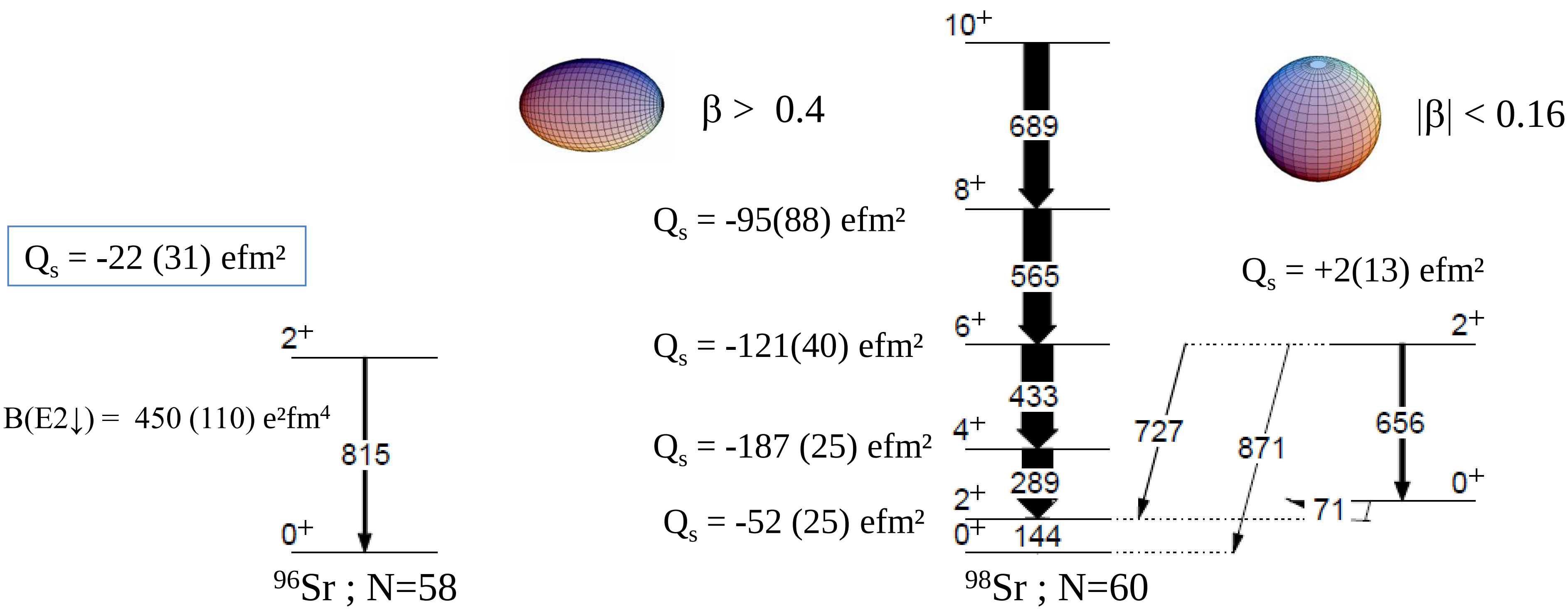


E. C. et al, Phys.Rev.Lett. 116, 022701 (2016)

Shape Coexistence in ^{96,98}Sr

The 2^+_1 in ^{96}Sr is weakly deformed
The ground state band in ^{98}Sr has a large prolate deformation and the 2^+_2 is similar to the ground state in ^{96}Sr

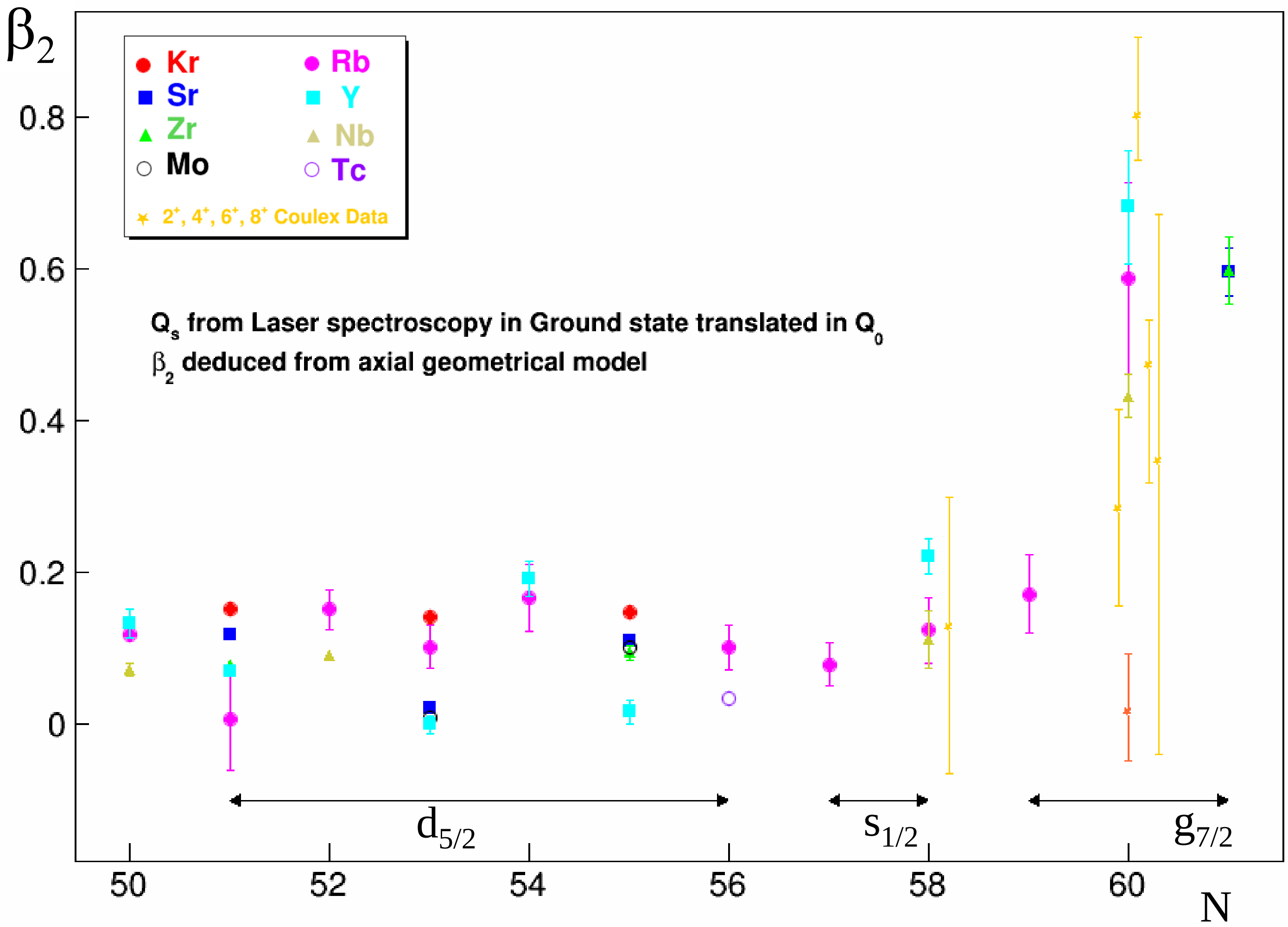
Shape coexistence in ^{98}Sr
Shape inversion at N=60



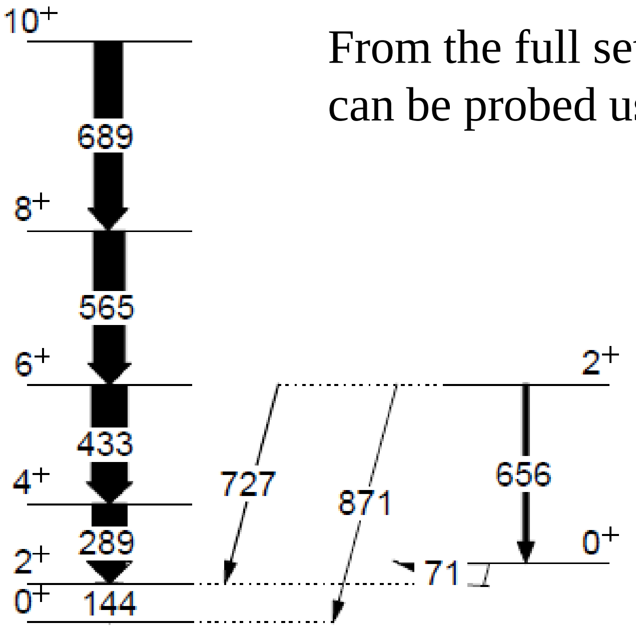
E. C. et al, Phys.Rev.Lett. 116, 022701 (2016)

Shape Coexistence at N=60

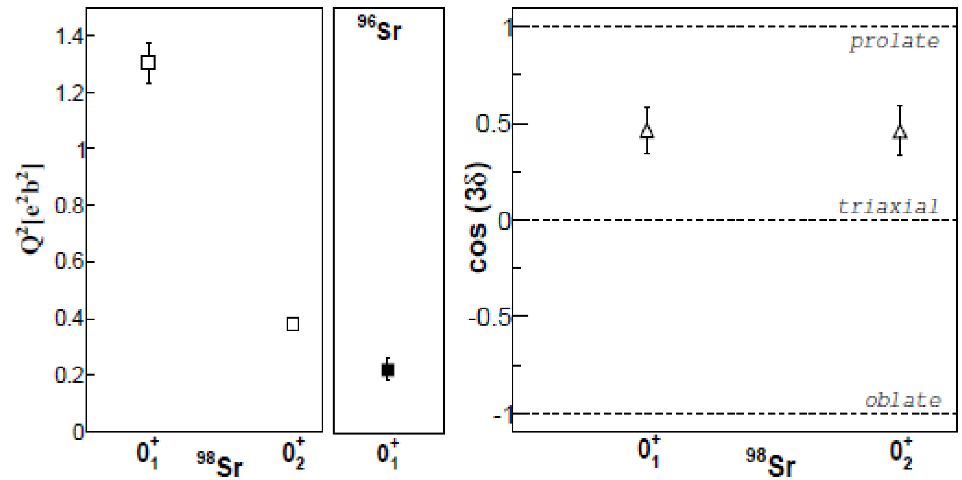
Comparison between Ground and Excited state Quadrupole moments



Shape Coexistence in ^{96,98}Sr



From the full set of E2 matrix elements, 0^+ states deformation can be probed using the QSR formalism



Shape coexistence in a two-state mixing model

$$|I_1\rangle = +\cos\theta_I|I_{\mathrm{pr}}\rangle + \sin\theta_I|I_{\mathrm{ob}}\rangle$$
$$|I_2\rangle = -\sin\theta_I|I_{\mathrm{pr}}\rangle + \cos\theta_I|I_{\mathrm{ob}}\rangle$$

Perturbed states

Pure states

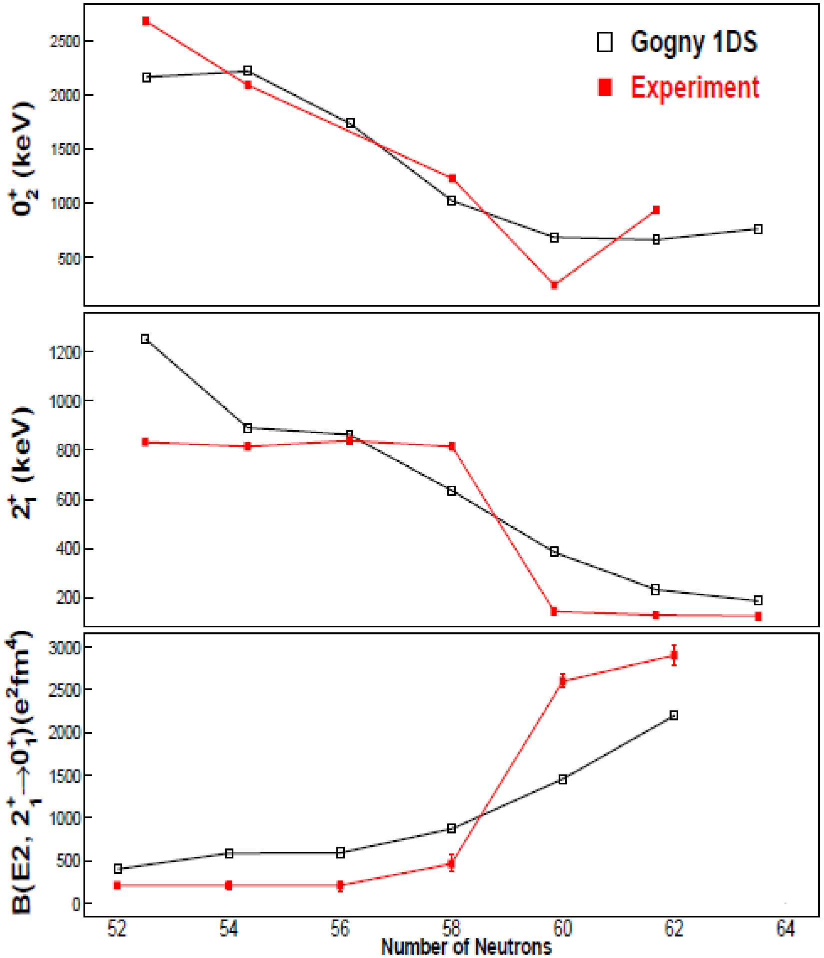
$\cos^2\theta_0 = 0.82(2)$
$\cos^2\theta_2 = 0.99(1)$

The sharp transition is related to the very weak mixing between competing configurations in contrast to the N~Z cases in Kr and Hg isotopes

E. C. et al, Phys.Rev.Lett. 116, 022701 (2016)

Collectivity around N=60

From a theoretical point of view



The onset of collectivity is reproduced

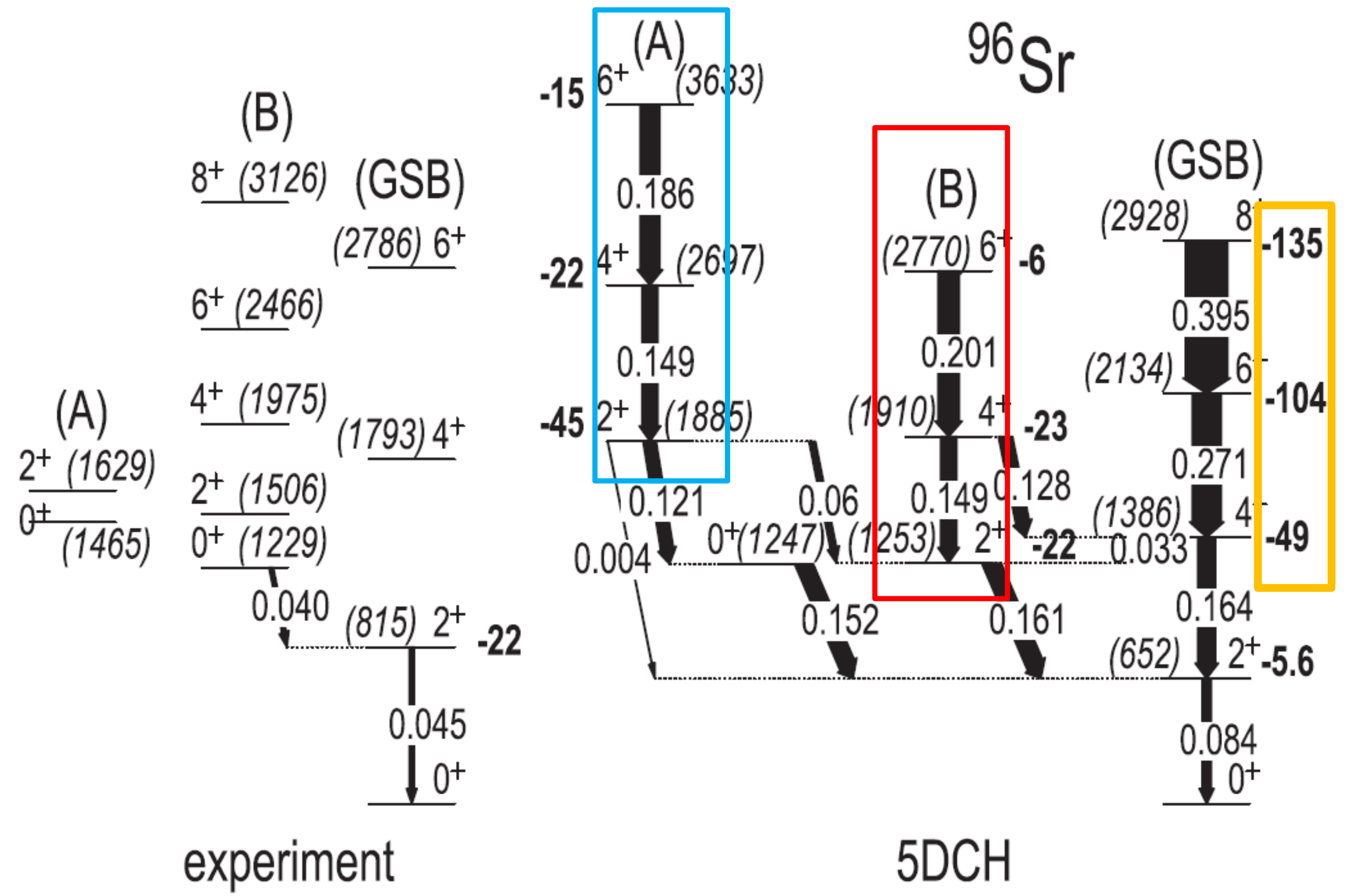
Not as sudden as in the experiment

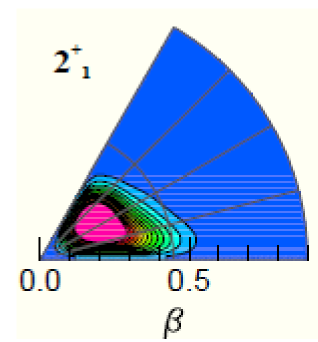
Collectivity around N=60

From a theoretical point of view

Larger B(E2), higher Qs K=0 ~70%

Large B(E2), low Qs K=0 < 50%

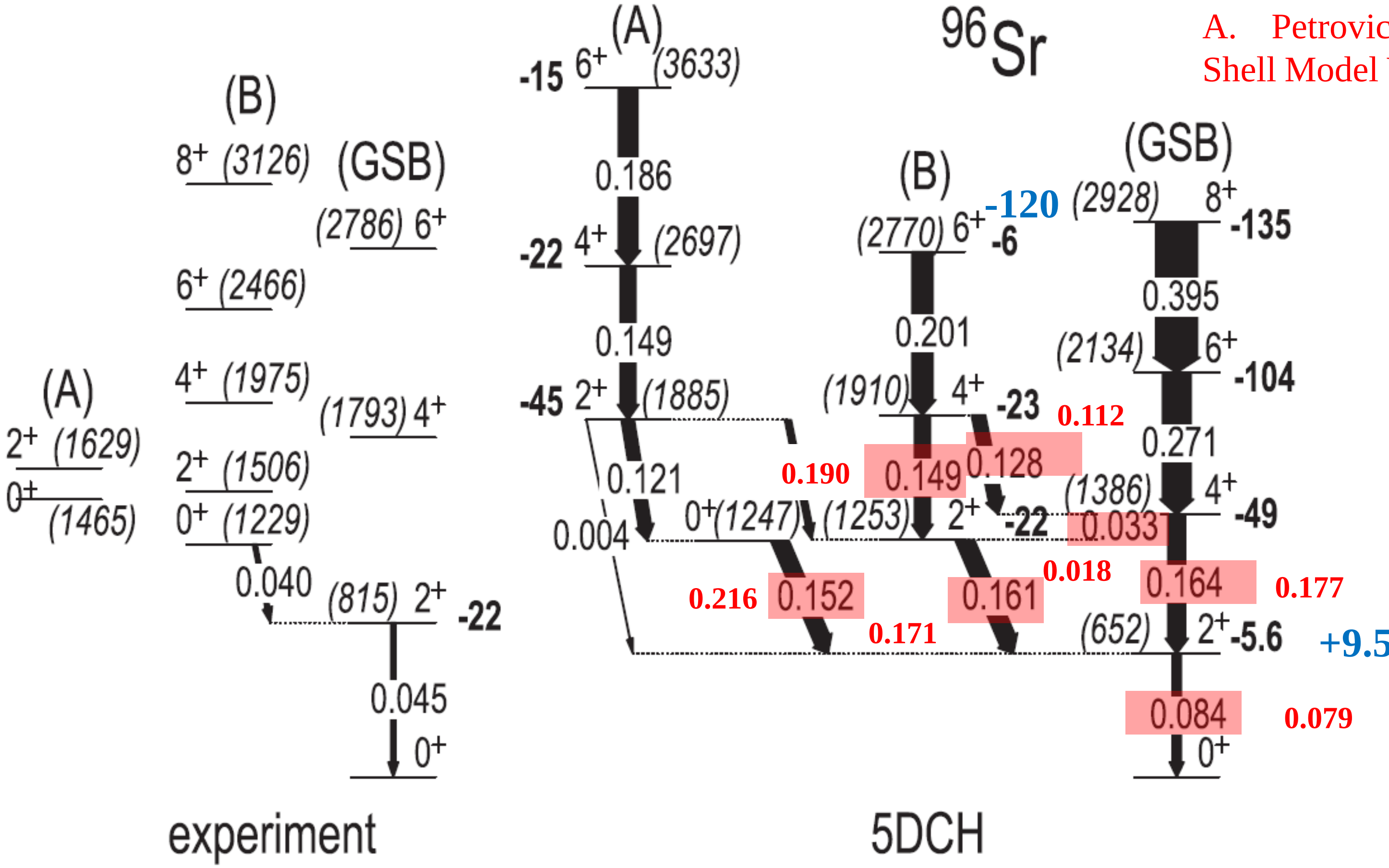




(30% K=2)

E. C. et al, Phys.Rev.Lett. 116, 022701 (2016)

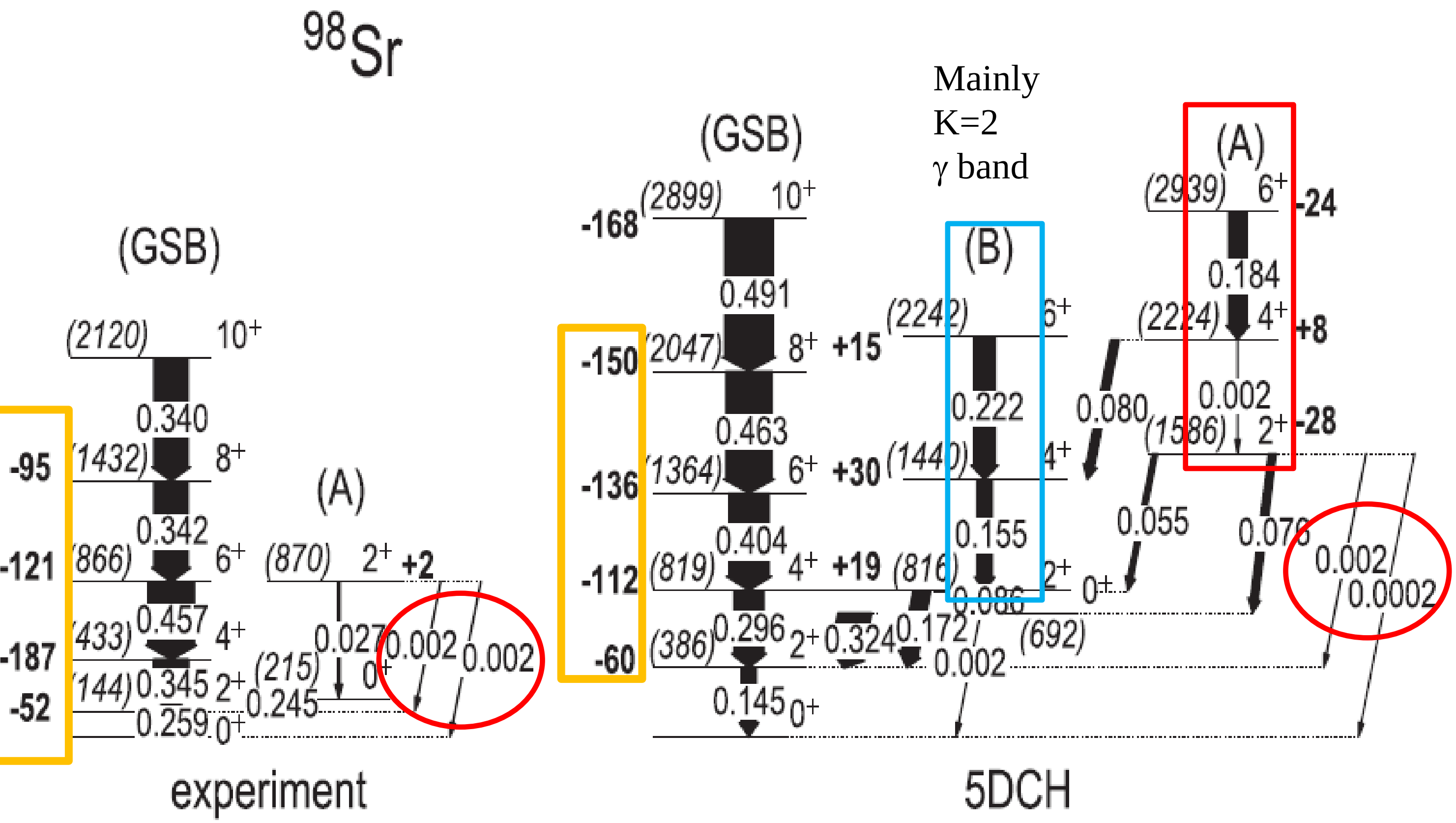
A. Petrovici PRC 85, 034337 (2012)
Shell Model VAMPIR



E. C. et al, Phys.Rev.C in prep.
E. C. et al, Phys.Rev.Lett. 116, 022701 (2016)

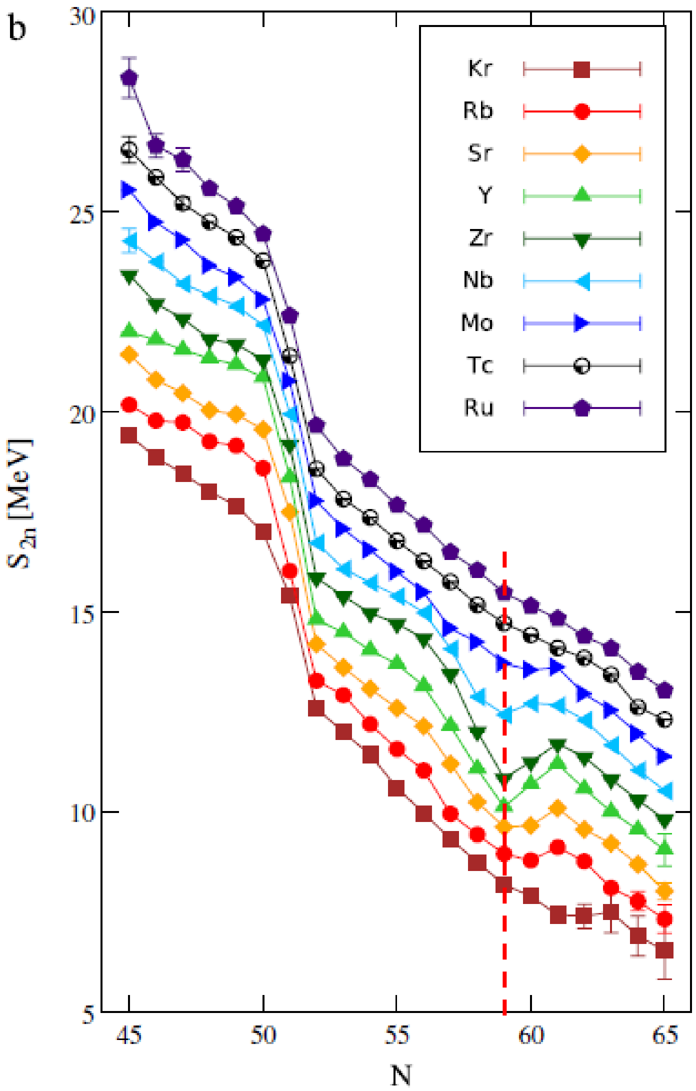
Collectivity around N=60

From a theoretical point of view



J. Xiang et al . Phys. Rev. C 93, 054324 (2016)
E. Clément, et PRL. 116, 022701 (2016)

Conclusions



❑ We investigated the collectivity and the deformation in ^{96,98}Sr at the shape transition using RIB and the Coulomb excitation technique at REX-ISOLDE, CERN

❑ E2 matrix elements have been extracted and establish shape coexistence between small and large prolate deformations that do not mix and give rise to a sharp transition at N=60

❑ *HFB+GCM Gogny force D1S* calculations reproduce the trend

❑Shell Model calculations show a nice agreement with BMF for B(E2) between low lying states

❑ But :
→Collectivity below Z = 38 ?
→Why Kr behave differently ?
Fission runs at AGATA@GANIL
(spectroscopy, plunger and Fast-Timing)
ISOL facilities beams

→Position of the proton orbital along N=58-60 down to Ni ?
→Confusing predictions for ^{96}Sr beyond the 2^+_1 ?
→ pseudo and quasi –SU(3) approach ?

Experimental results 3/3

The Coulomb excitation cross section is analysed using the least-squares fitting code GOSIA

T. Czosnyka, D. Cline, and C. Y. Wu, Bull. Am. Phys. Soc. **28,** 745 (1983).

Inputs:
*Level scheme
*Experimental setup
*Iγ (θ_{cm})
*known τ,BR,δ(Eλ/Mλ), g

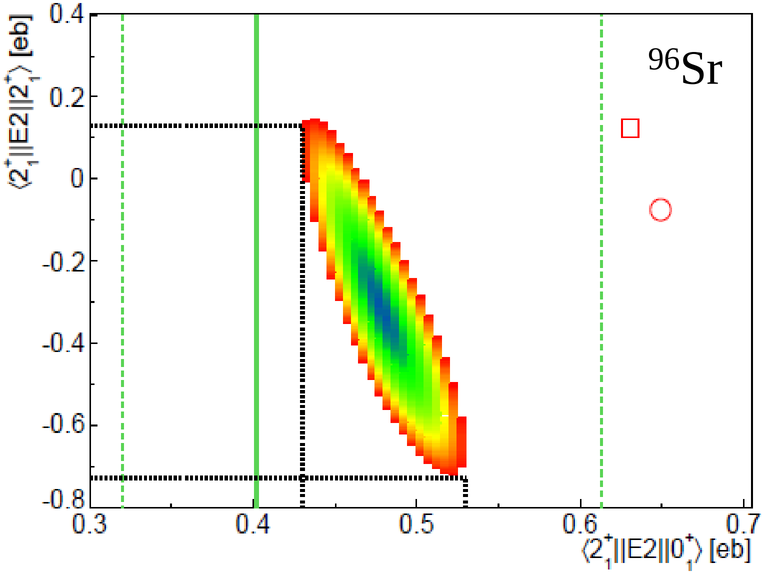
Electromagnetic Matrix Elements

Coulomb excitation cross section

χ^2 minimization

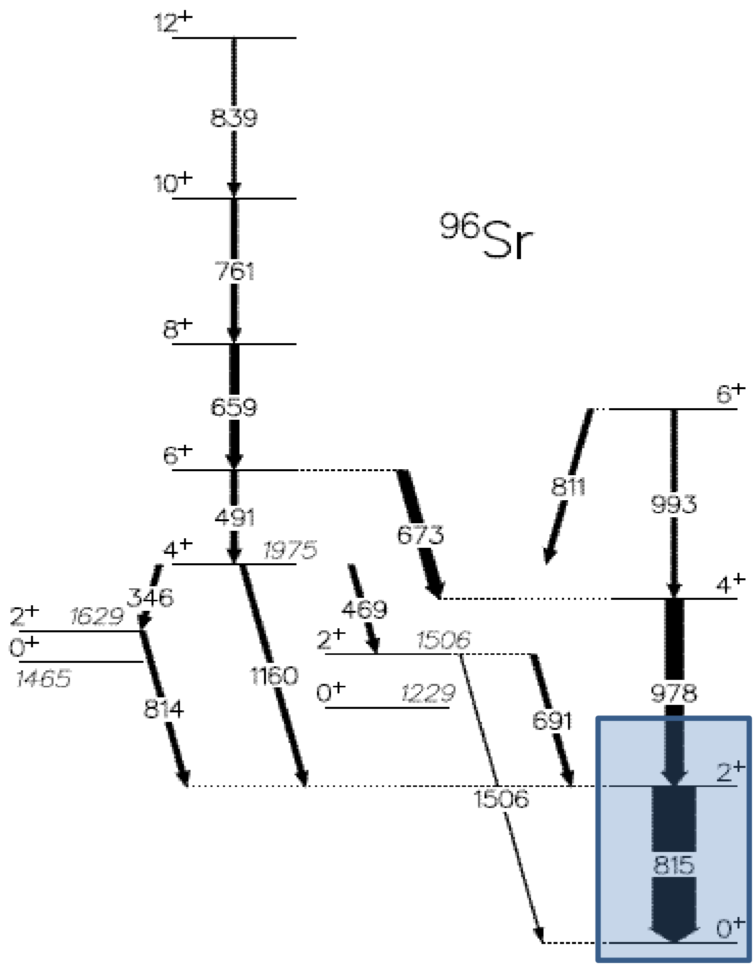
Calculated decay intensities
vs
Observed decay

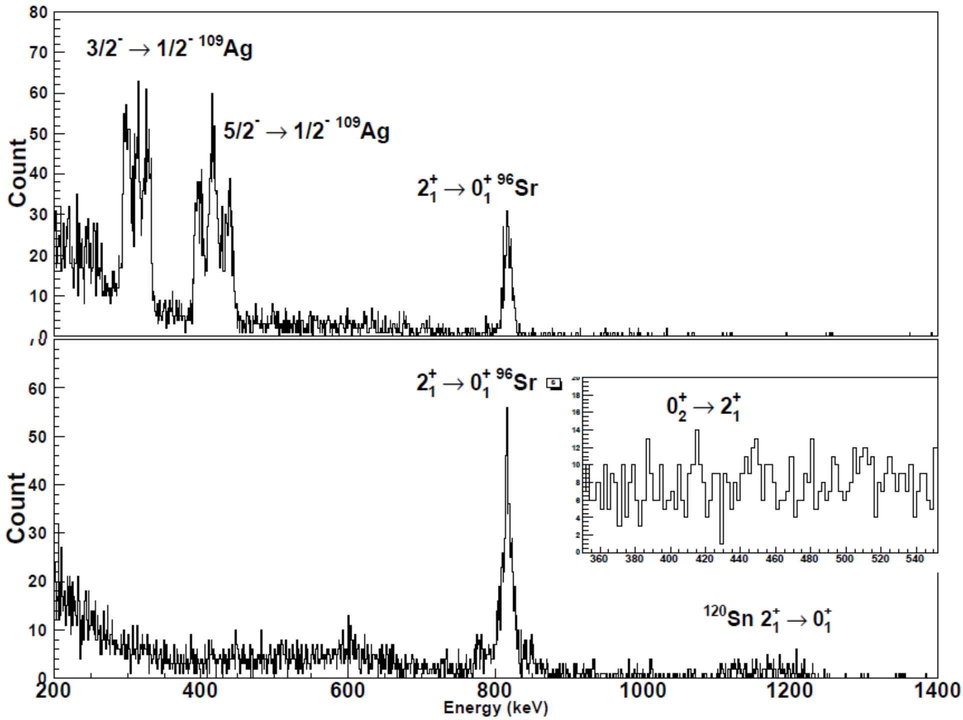
Complete set of Elect. Matrix Elements



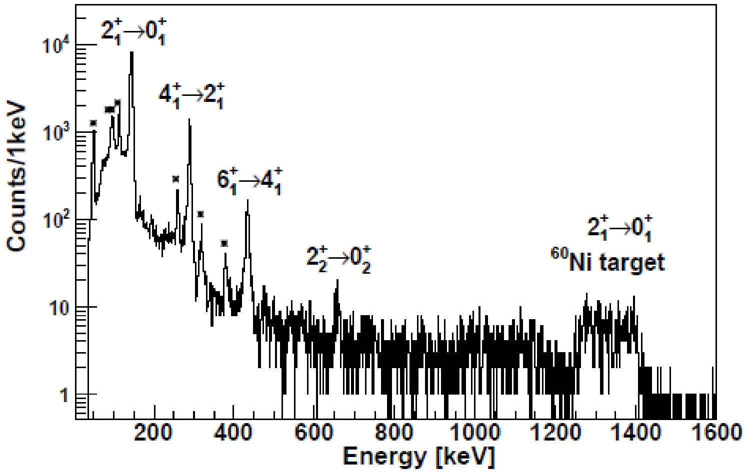
M. Zielinska et al Eur. Phys. J. A (2016) 52: 99

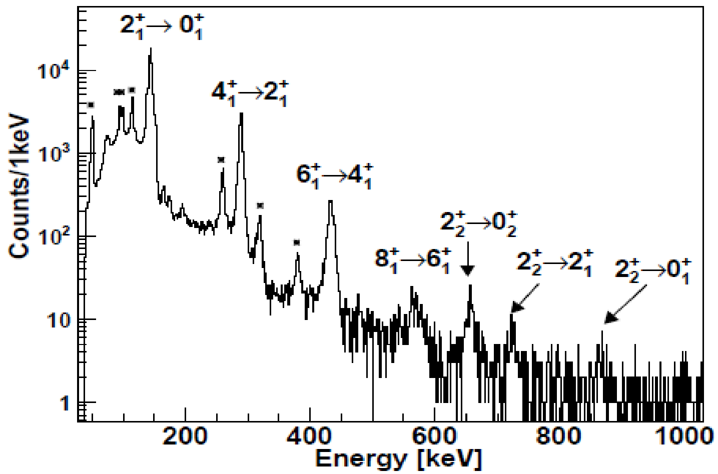
Experimental results 1/3

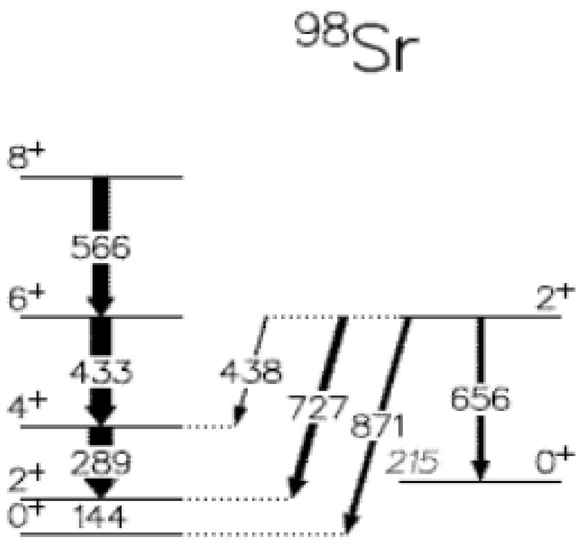




Experimental results 2/3

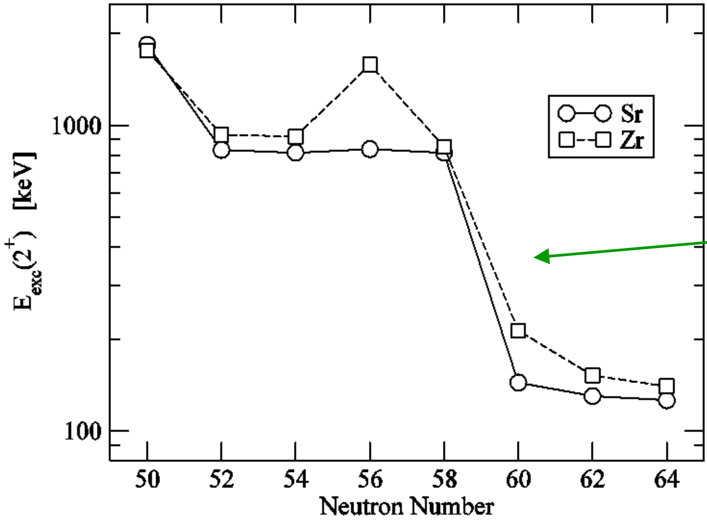


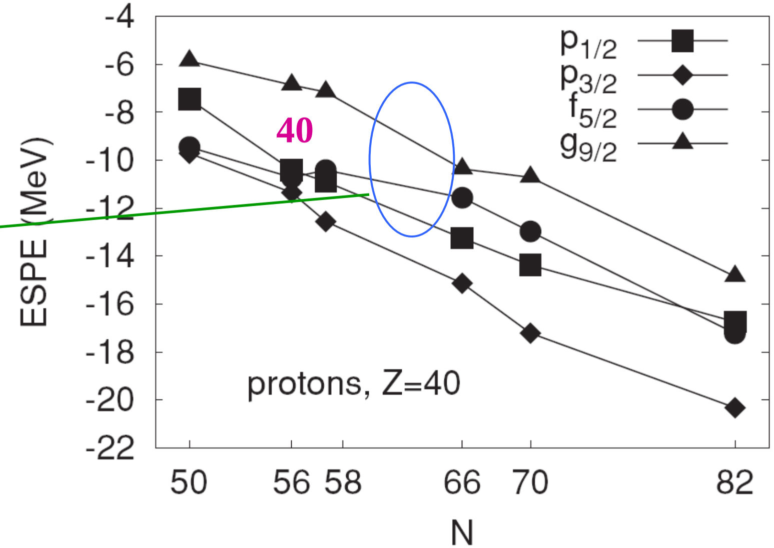


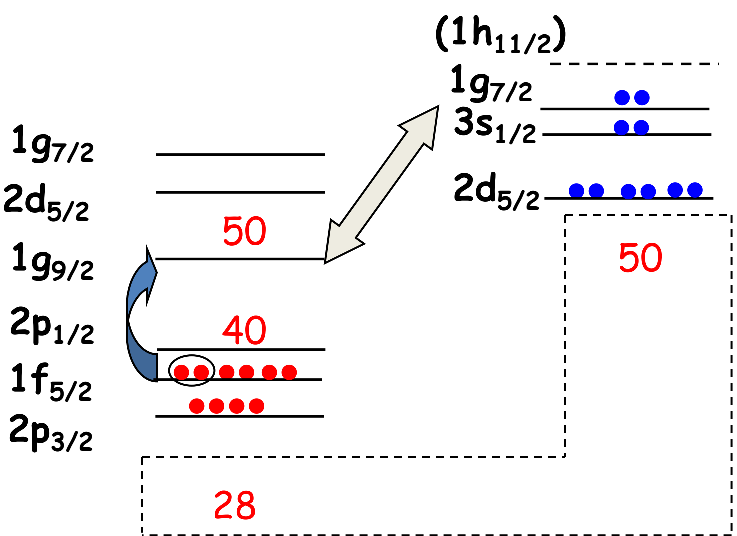


Shape Transition at N=60

50 years later, where are we ?







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K. Sieja et al PRC 79, 064310 (2009)
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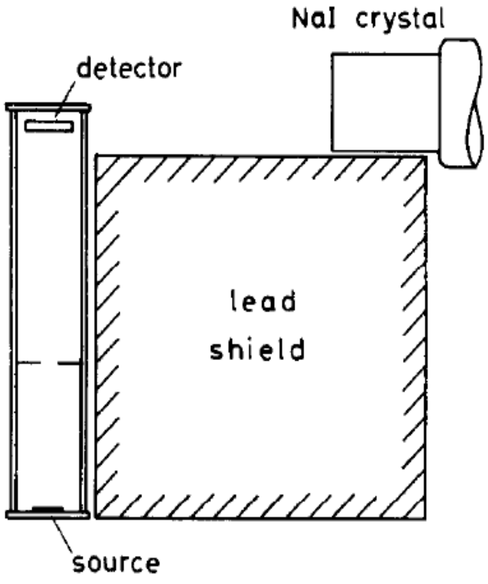
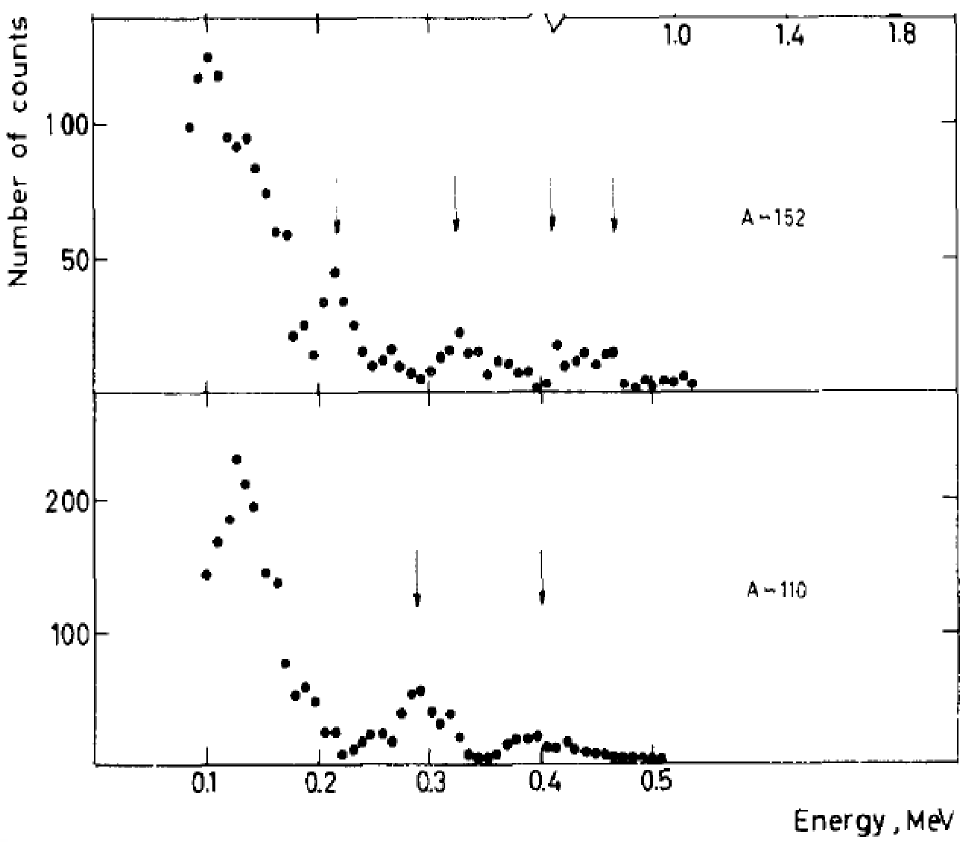
It has been established in the 60's that elements with A~ 110 belong to a new island of stable deformation similar to the rare earth region



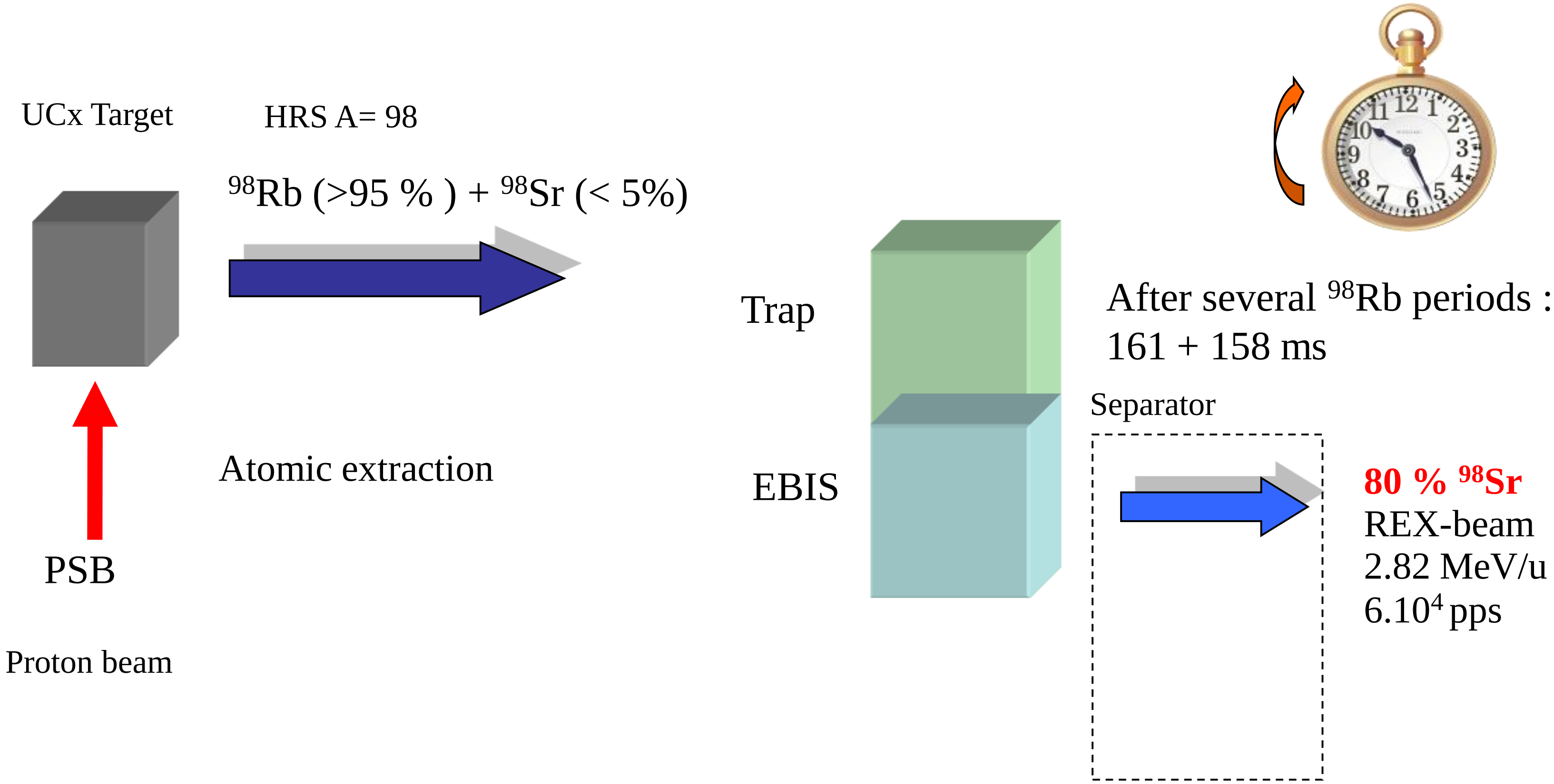
S. A. E. Johansson, Nucl. Phys. **64** (1965) 147

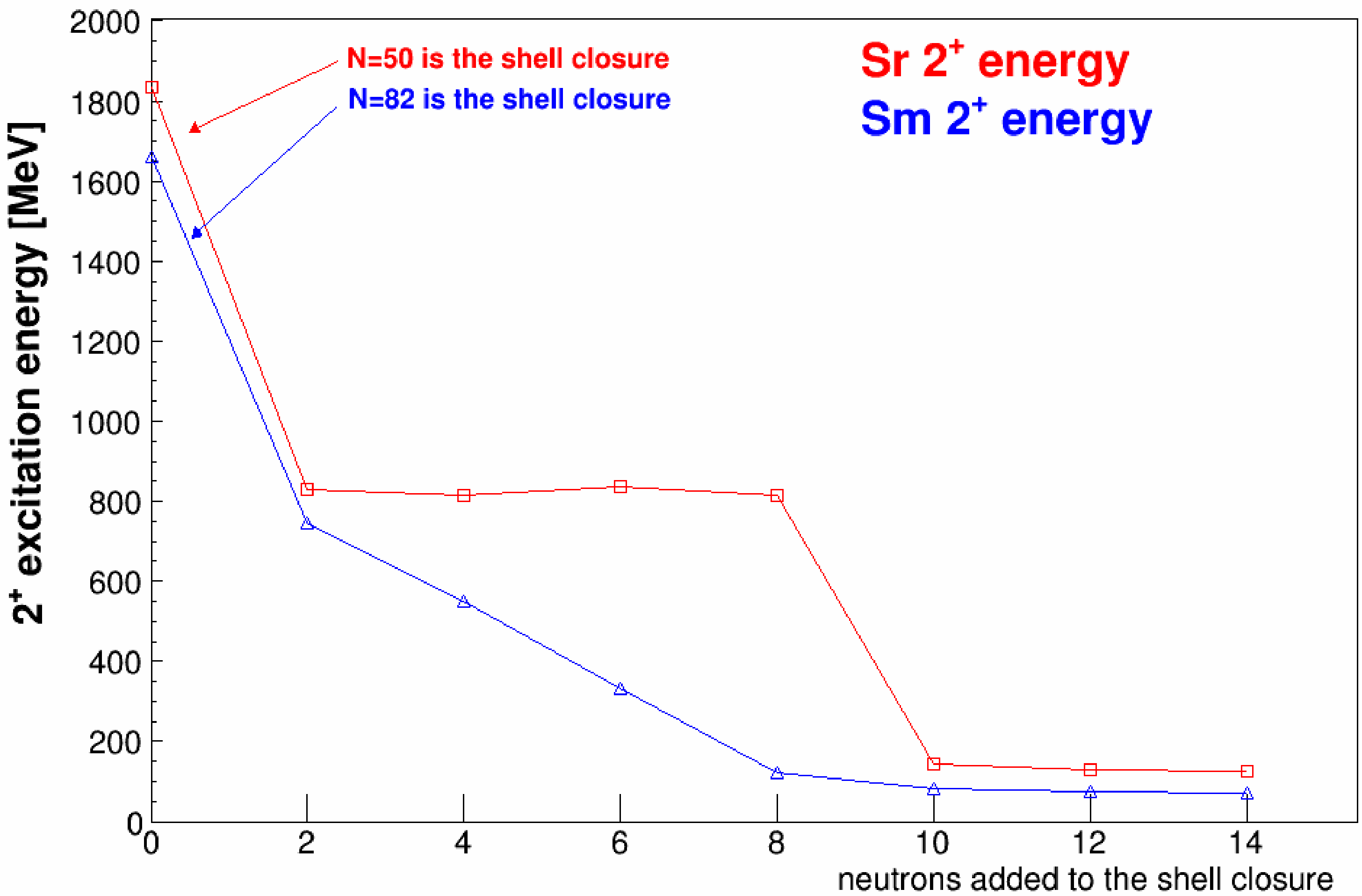


- Post-accelerated radioactive ^{96,98}Sr beam at REX-ISOLDE (2.8 MeV/A) ^{96}Sr $T_{1/2}$ = 1s, ^{98}Sr $T_{1/2}$ = 0.6 s
- Safe Coulomb excitation
- B(E2)'s and Q_0 extracted from the Coulomb excitation cross section

re $^{96}Sr^{23+}$ REX-
am
7 MeV/u
to 0.5 ~10^4 pps

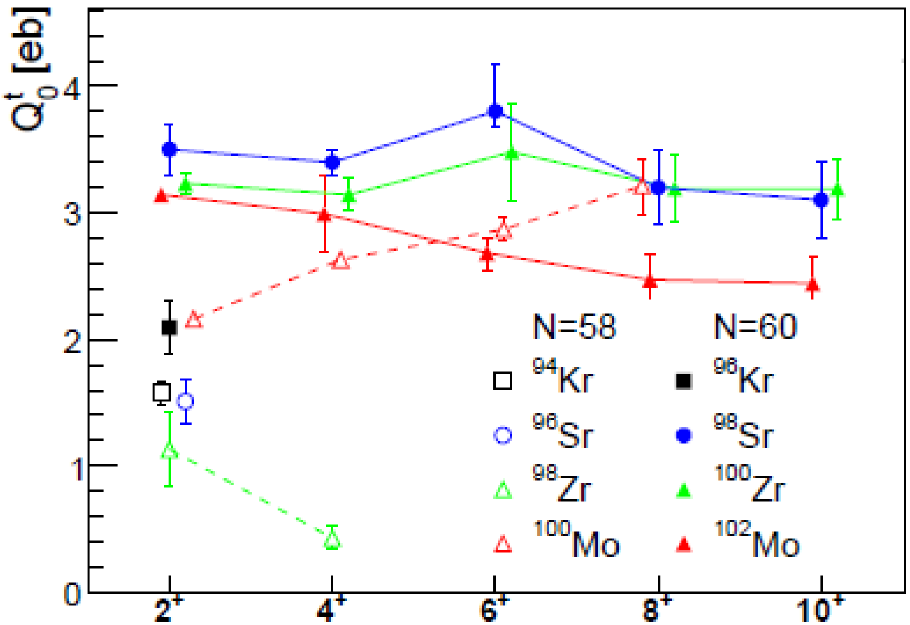
- Post-accelerated radioactive ^{96,98}Sr beam at REX-ISOLDE (2.8 MeV/A)
- Safe Coulomb excitation
- B(E2)’s and Q_0 extracted from the Coulomb excitation cross section

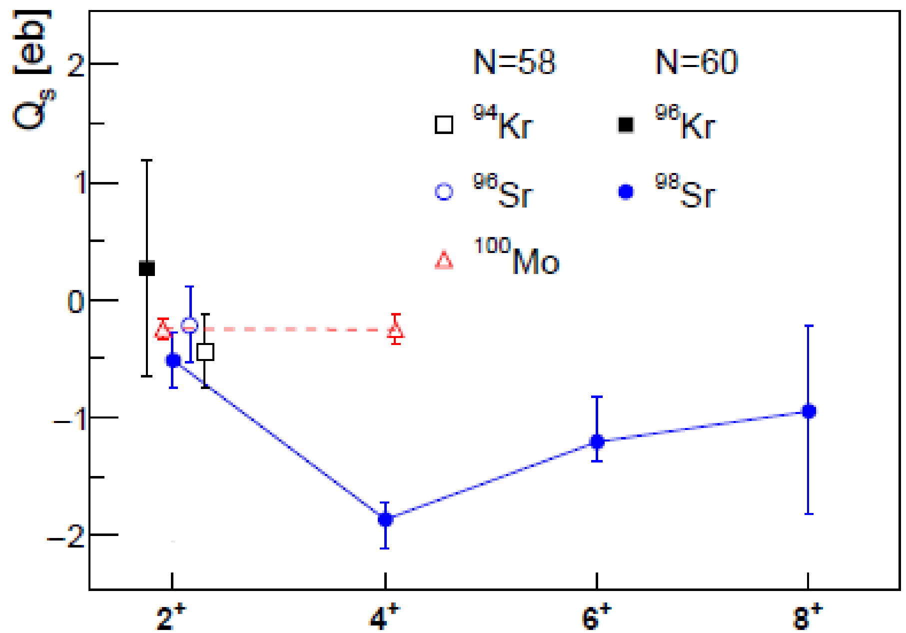




Sr 2+ energy
Sm 2+ energy
N=50 is the shell closure
N=82 is the shell closure
2+ excitation energy [MeV]
neutrons added to the shell closure
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
2
4
6
8
10
12
14

Collectivity around N=60

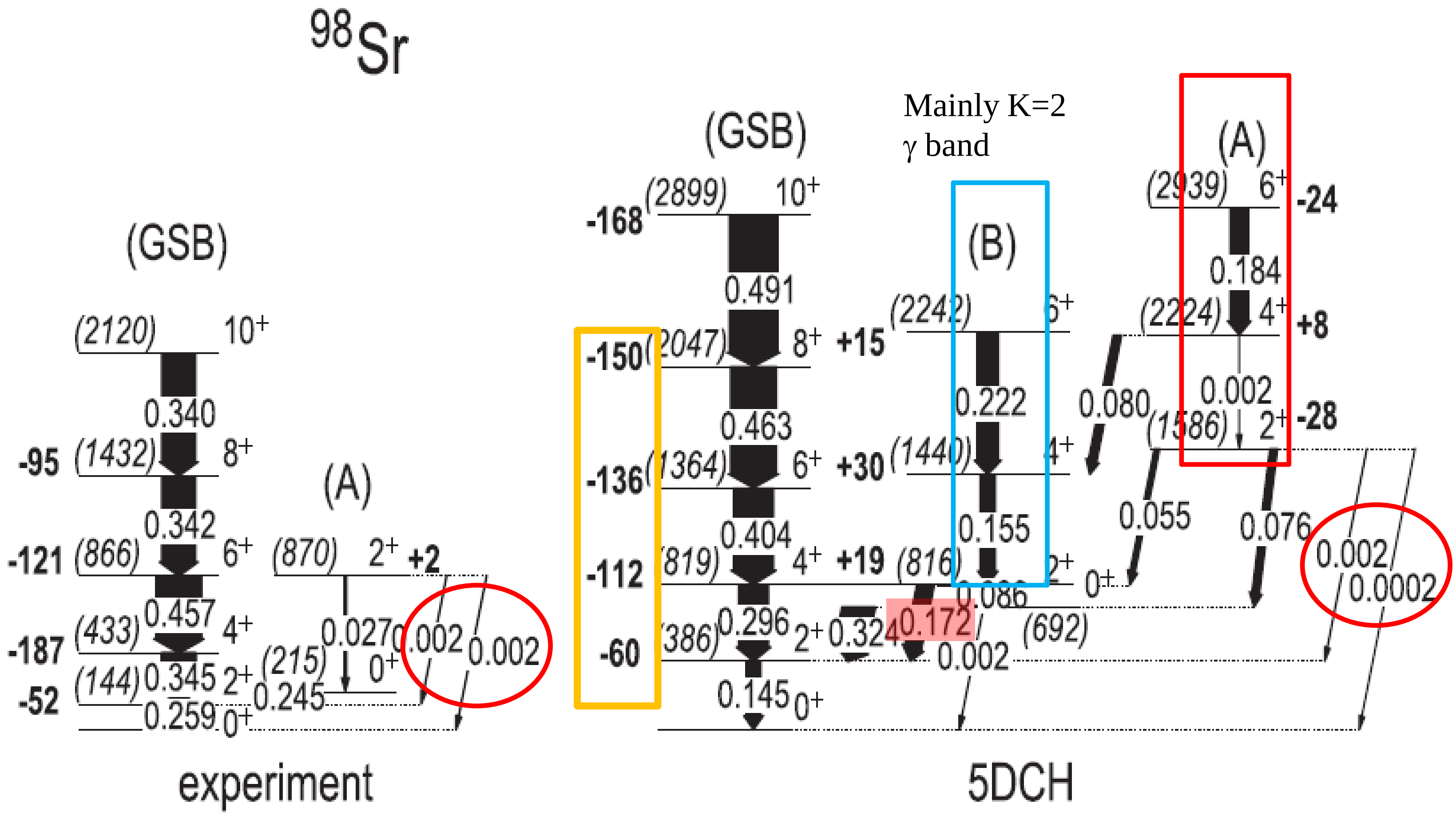




E. Clément, M. Zielinska et al, Phys.Rev.C in prep.

Collectivity around N=60

From a theoretical point of view



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