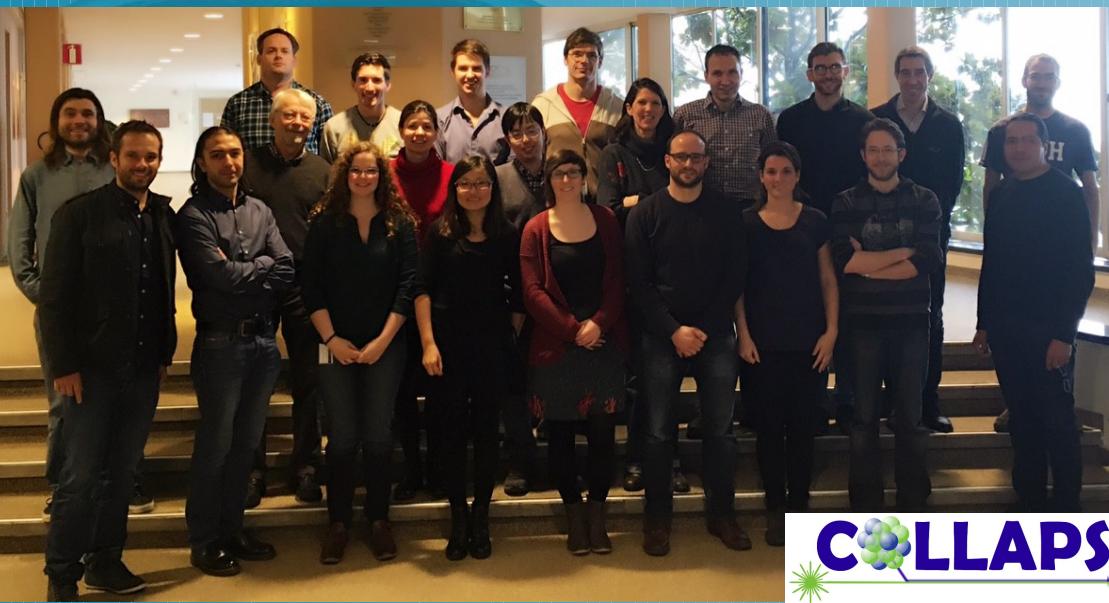


TOOL TO STUDY SHAPES AND SYMMETRIES



Gerda Neyens
KU Leuven, Belgium



with thanks to the
COLLAPS and CRIS
collaborations at
ISOLDE-CERN

Laser spectroscopy – observables, methods, applicability range

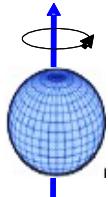
Zn ($Z=30$) – intruder isomer, shape coexistence in ^{79}Zn

Mn ($Z=25$) – deformation towards $N=40$

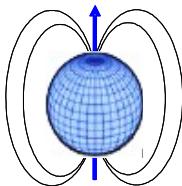
Cu ($Z=29$) – ^{78}Ni core polarization from moments towards ^{79}Cu

Collinear laser spectroscopy

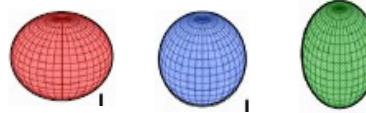
Measure nuclear ground state properties
(CLS)



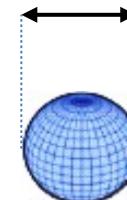
Spin I



Magnetic moment μ

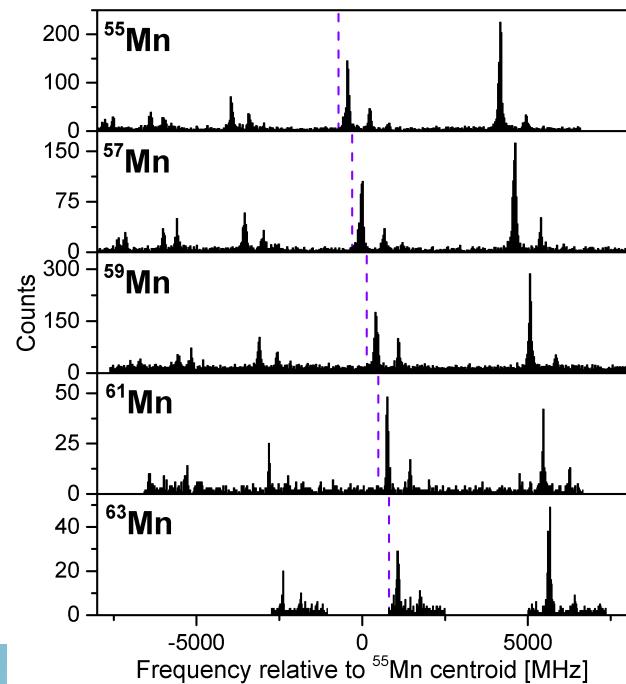
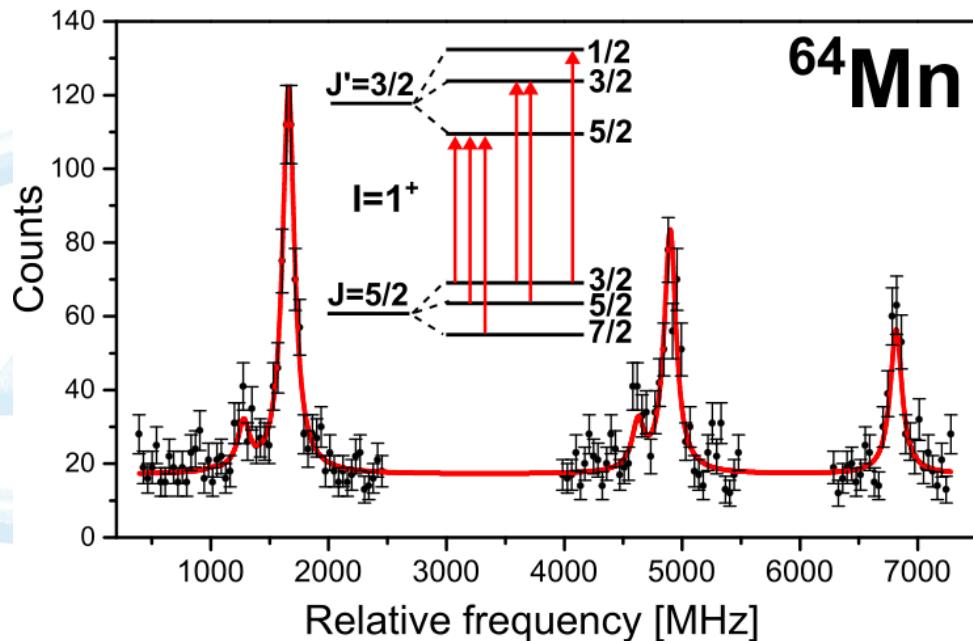


Quadrupole moment Q_s



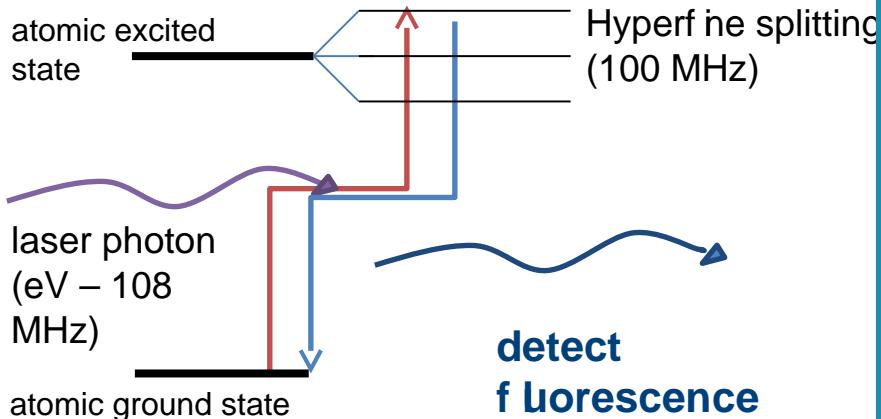
Charge radii r_{Fr2h}

Via atomic hyperfine splitting and isotope shifts

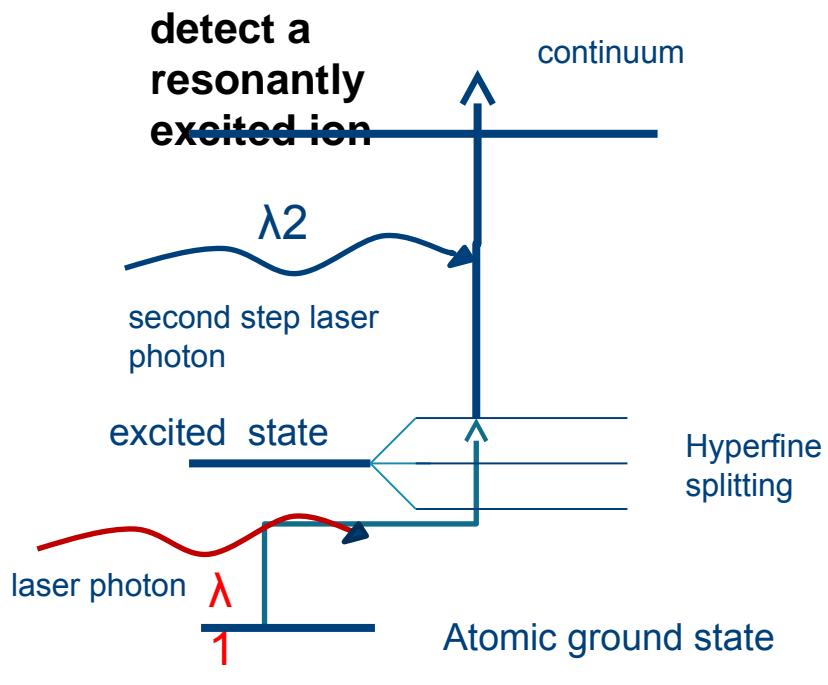


Collinear laser spectroscopy at ISOLDE-CERN

COLLAPS



CRIS



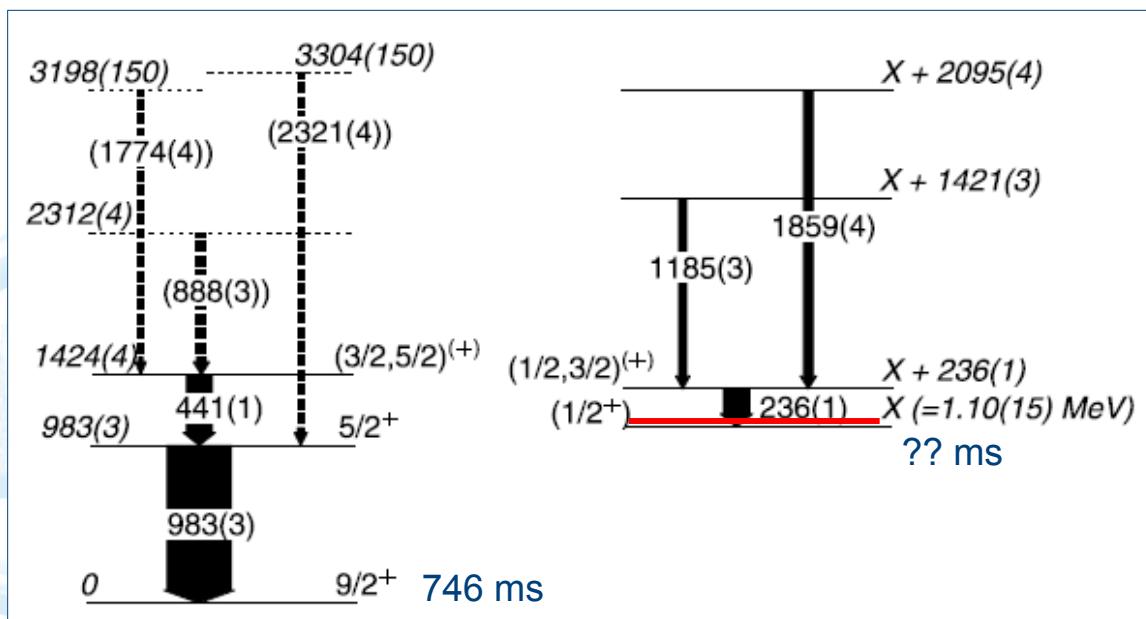
- low background (few /s) with bunched beams from the ISCOOL RFQ at the HRS
- moderate efficiency (0.01%)
- high resolution (\sim 40-60 MHz)
- **need few 1.000 ions/s** from ISOLDE

- ultra-low background (1 event /10 min)
- high efficiency (\sim 1-5 %)
- high resolution (\sim 15-60 MHz)
- **need about 10 ions/s** from ISOLDE

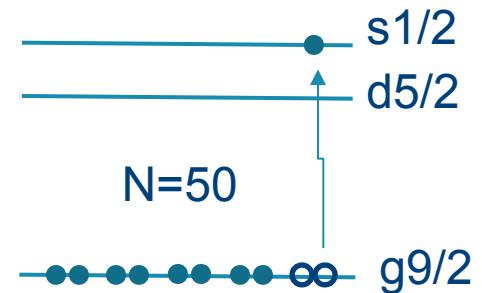
KU LEUVEN

^{79}Zn : intruder isomer and shape coexistence

R. Orlandi et al., PLB740, 298 (2015)
 $^{78}\text{Zn}(\text{d},\text{p})^{79}\text{Zn}$ at ISOLDE



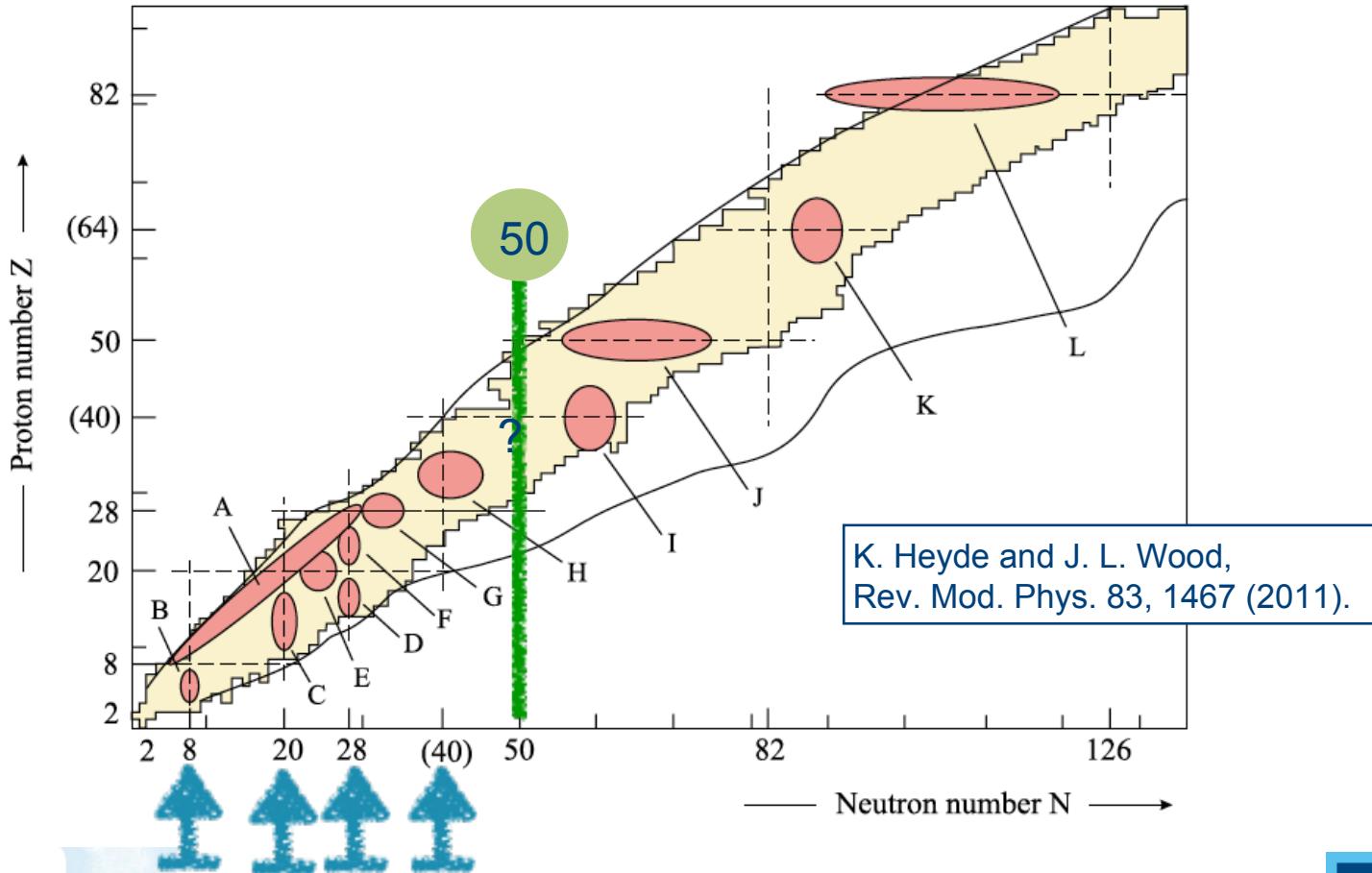
Isomer (unknown lifetime) observed; suggested $1/2^+$



Good candidate to be an intruder 1p-2h state → measure g-factor !

Shape coexistence in the chart of nuclei:

- States with different shapes at low energy
- Near one magic shell and one mid-shell for p and n (or vice-versa)



Fingerprints of coexistence

Heyde et al., Physics Reports 102, 291 (1983).



- **Static moments and isomer shift**
- **Band structure**
- **Retarded electromagnetic transitions**

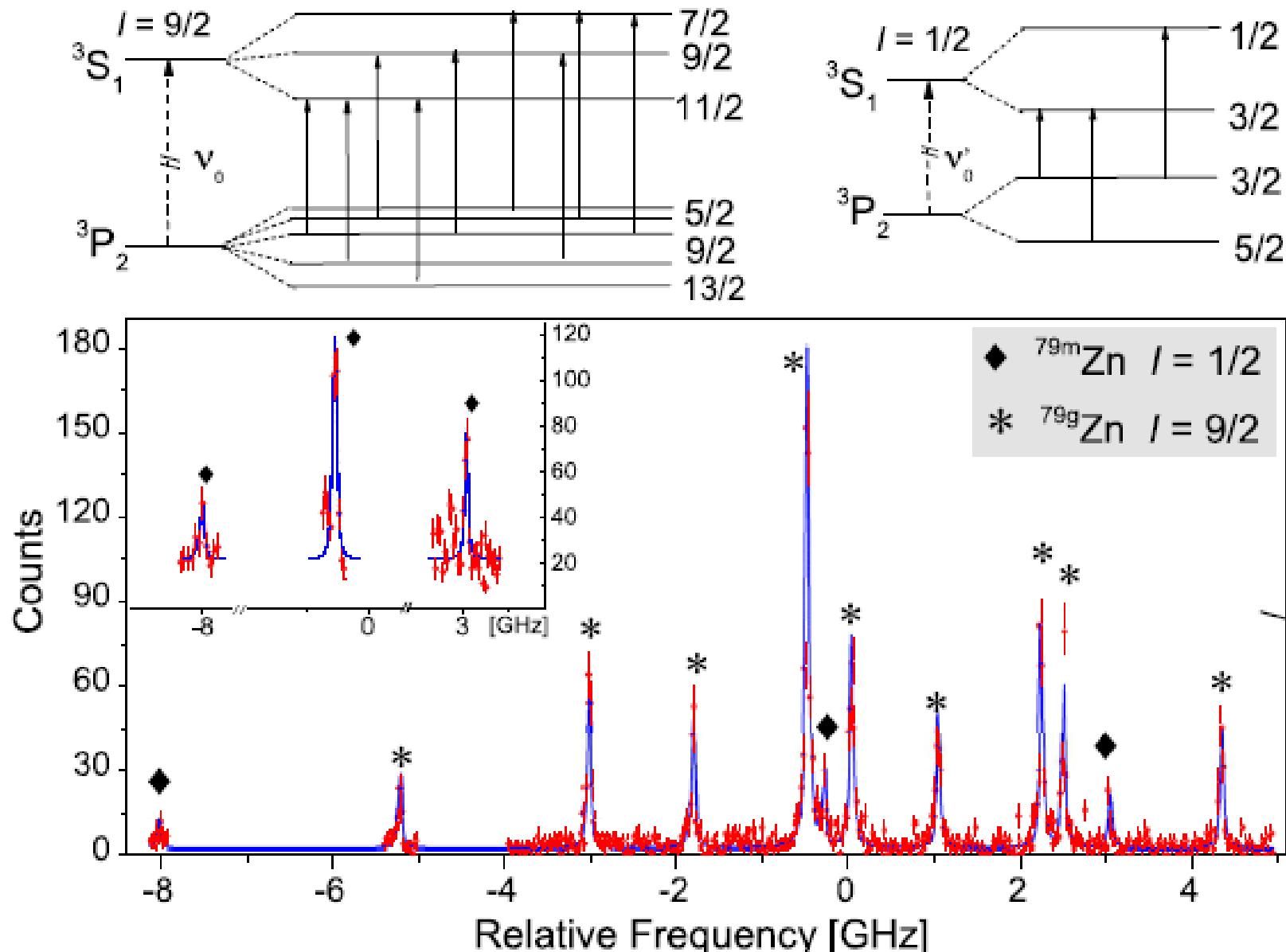
Three types of static moments are commonly measured for nuclear states: (i) the nuclear charge volume; (ii) the magnetic dipole moment; (iii) the electric quadrupole moment. The measurement, for a given excited state relative to the ground state, of the nuclear charge volume (isomer shift) provides definitive evidence of shape coexistence. Such evidence is similarly provided by electric quadrupole moment measurements. Magnetic dipole moment measurements reveal essentially the single-particle nature of a given nuclear state, and thus can fingerprint a shell-model intruder configuration.

Laser spectroscopy technique is a perfect tool

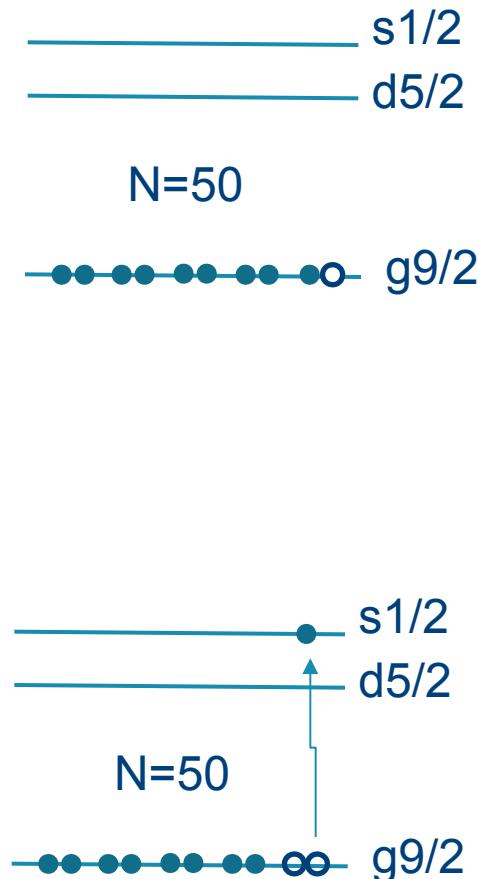
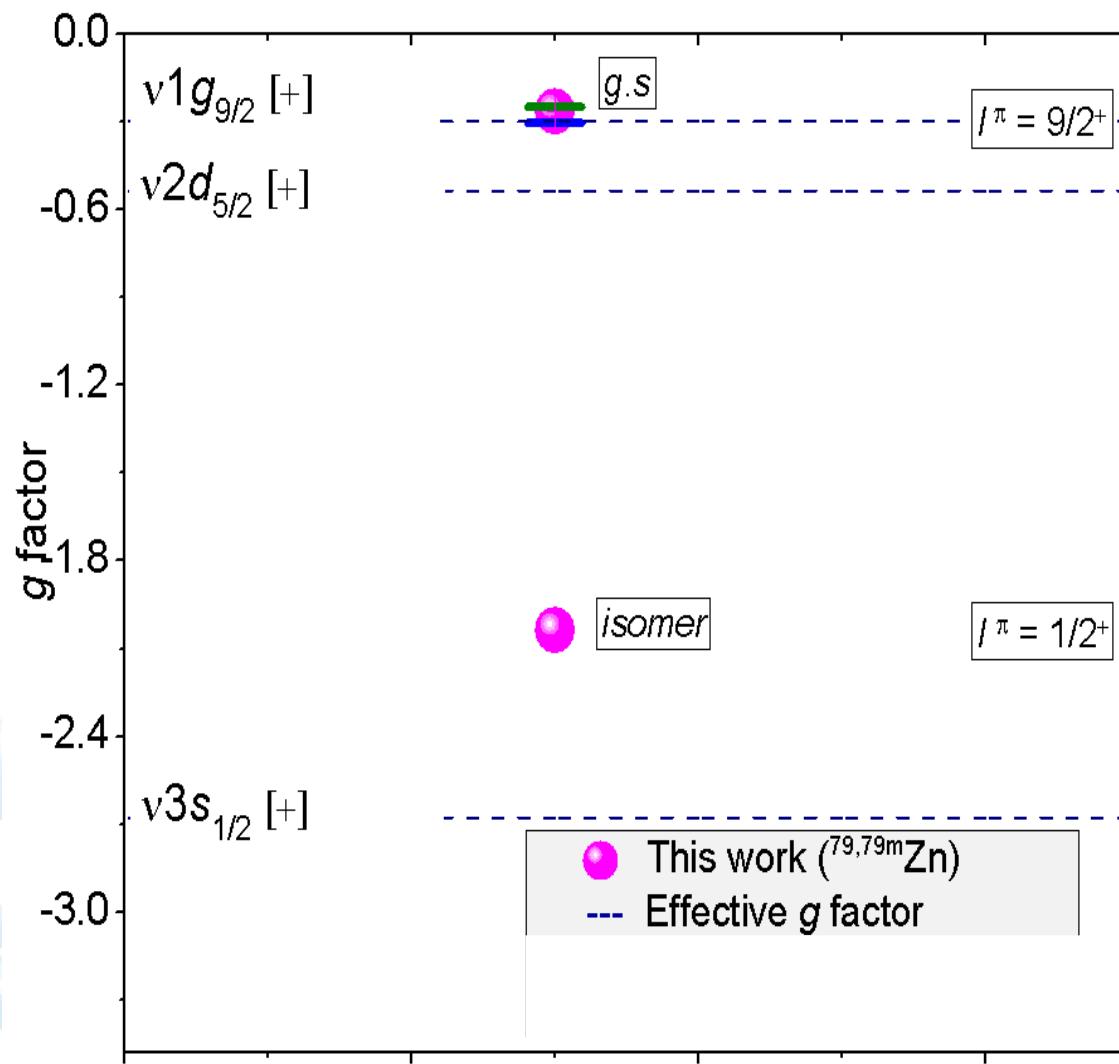
=> spins, magnetic and quadrupole moments, and charge radii

UVEN

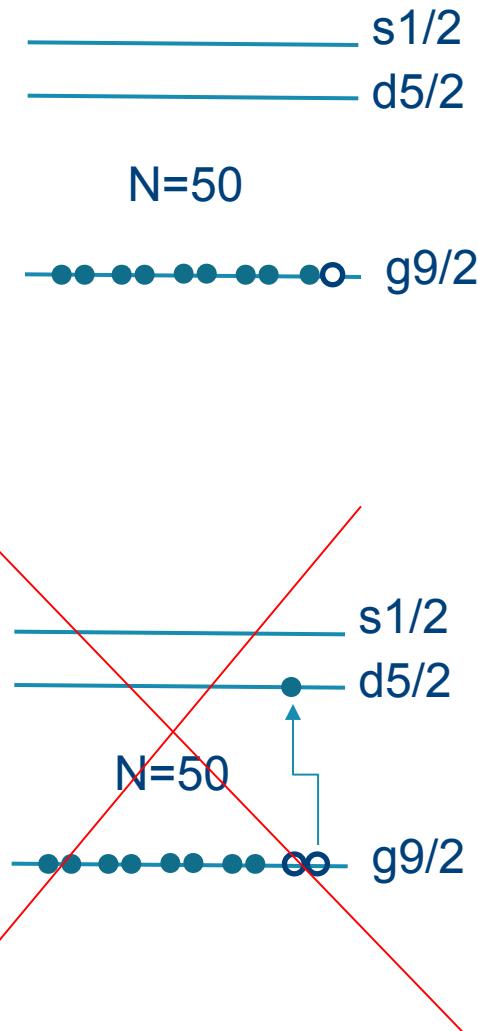
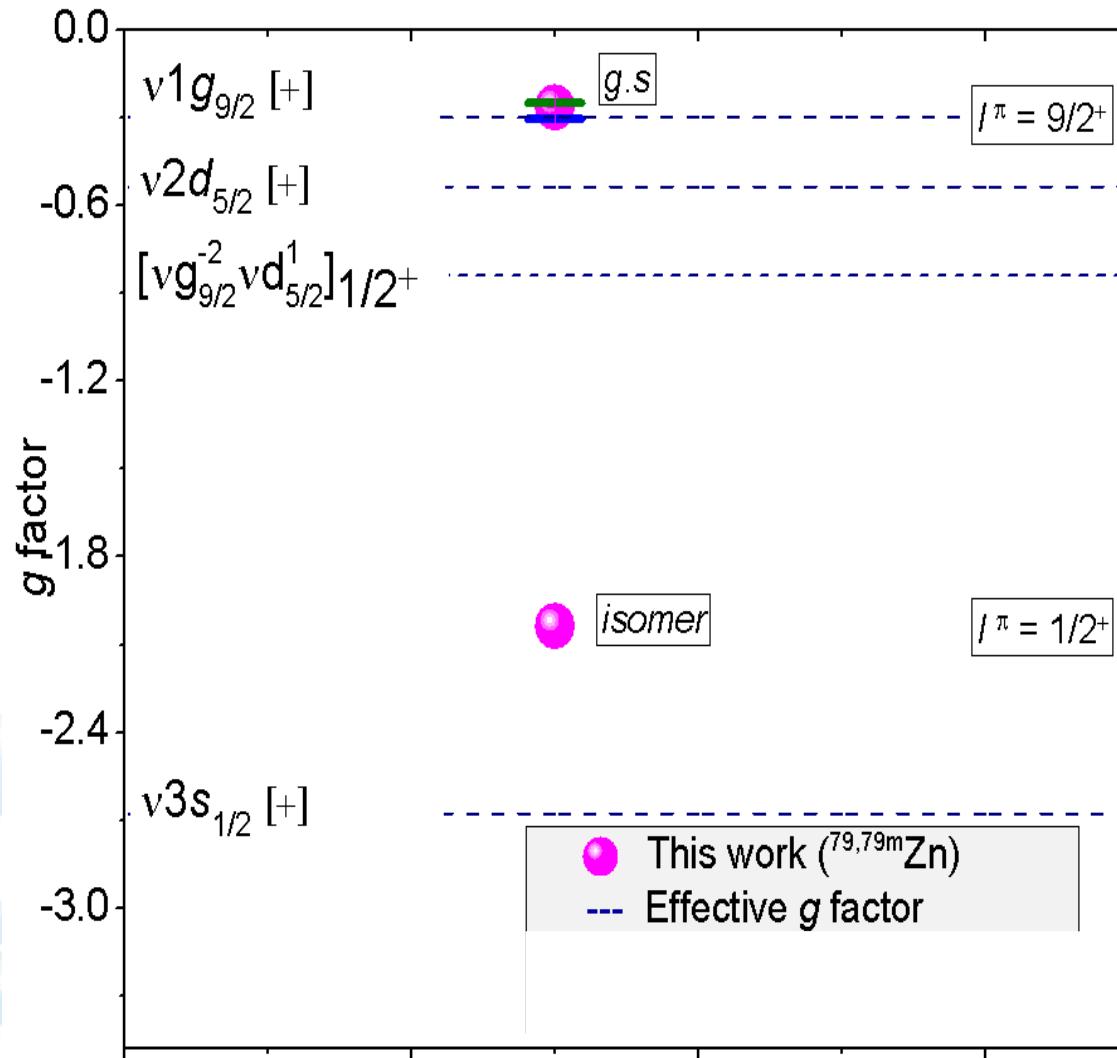
HFS spectra of $^{79}\text{g,mZn}$ $I = 9/2^+, 1/2^+$



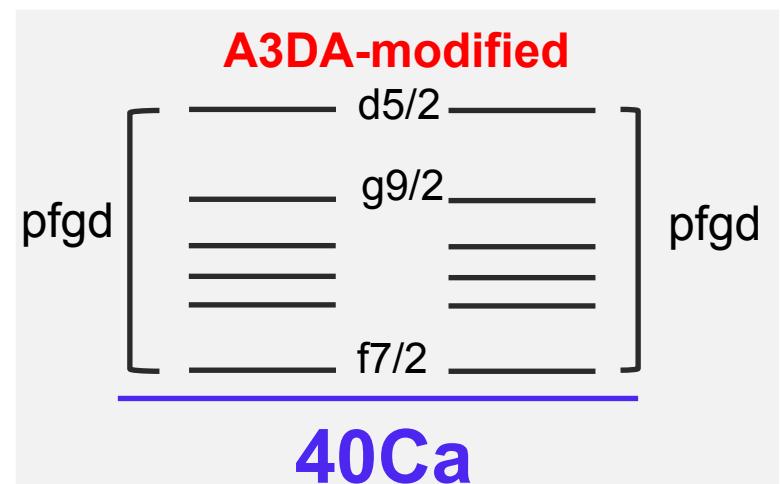
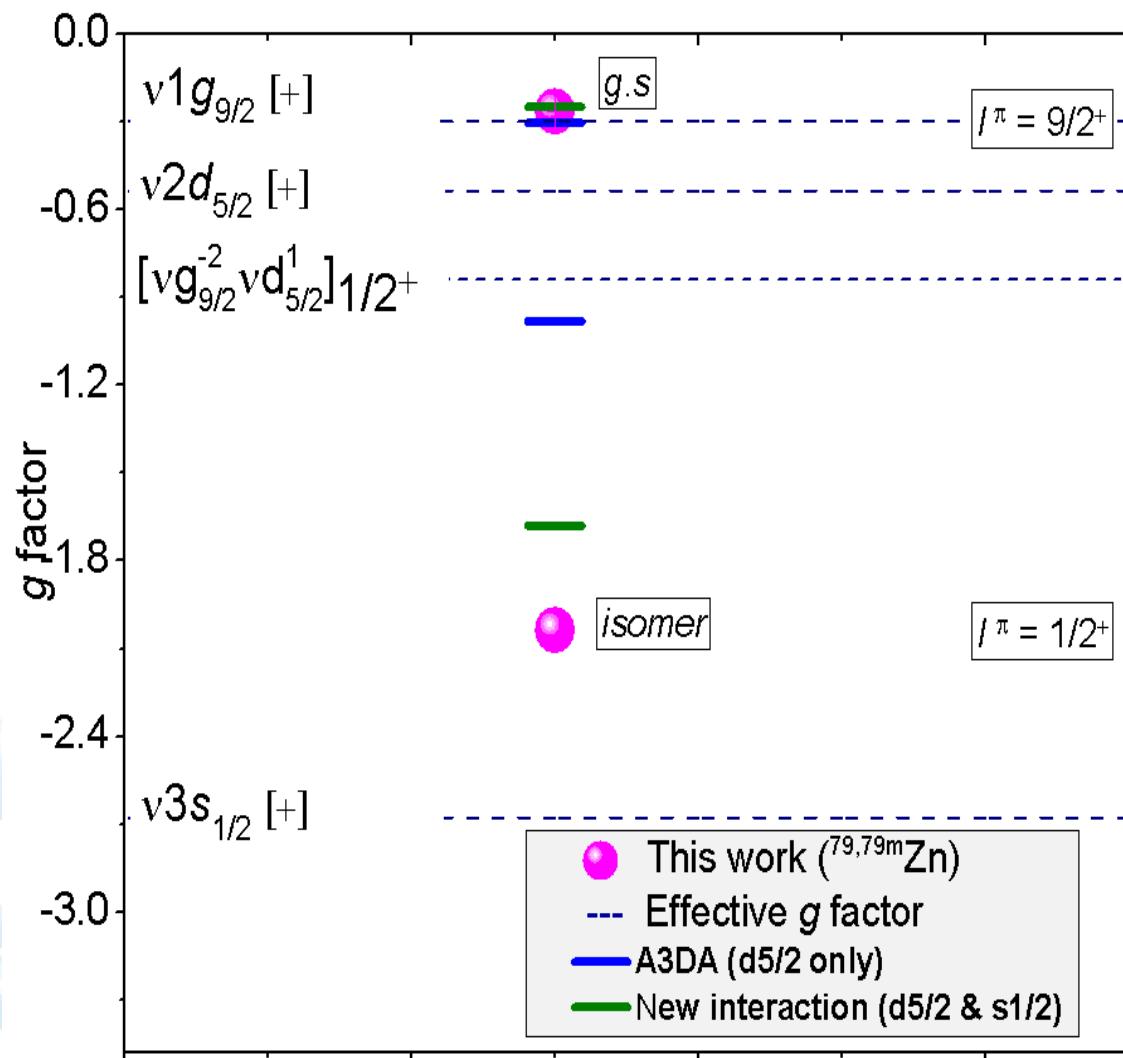
g-factor of 9/2 g.s. and 1/2 isomeric state in ^{79}Zn



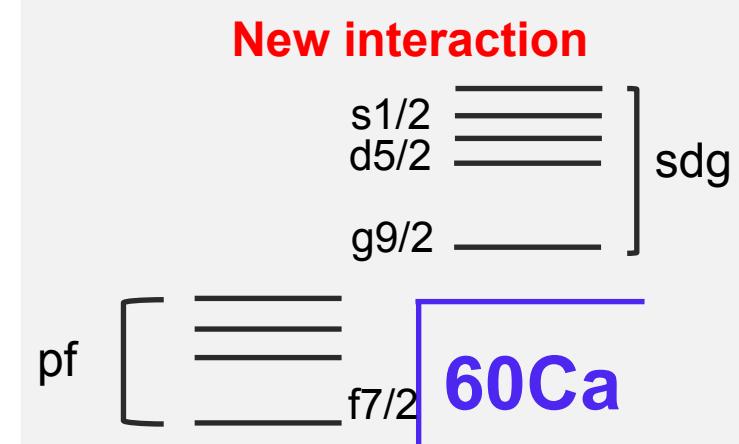
g-factor of 9/2 g.s. and 1/2 isomeric state in ^{79}Zn



g-factor of 9/2 g.s. and 1/2 isomeric state in ^{79}Zn

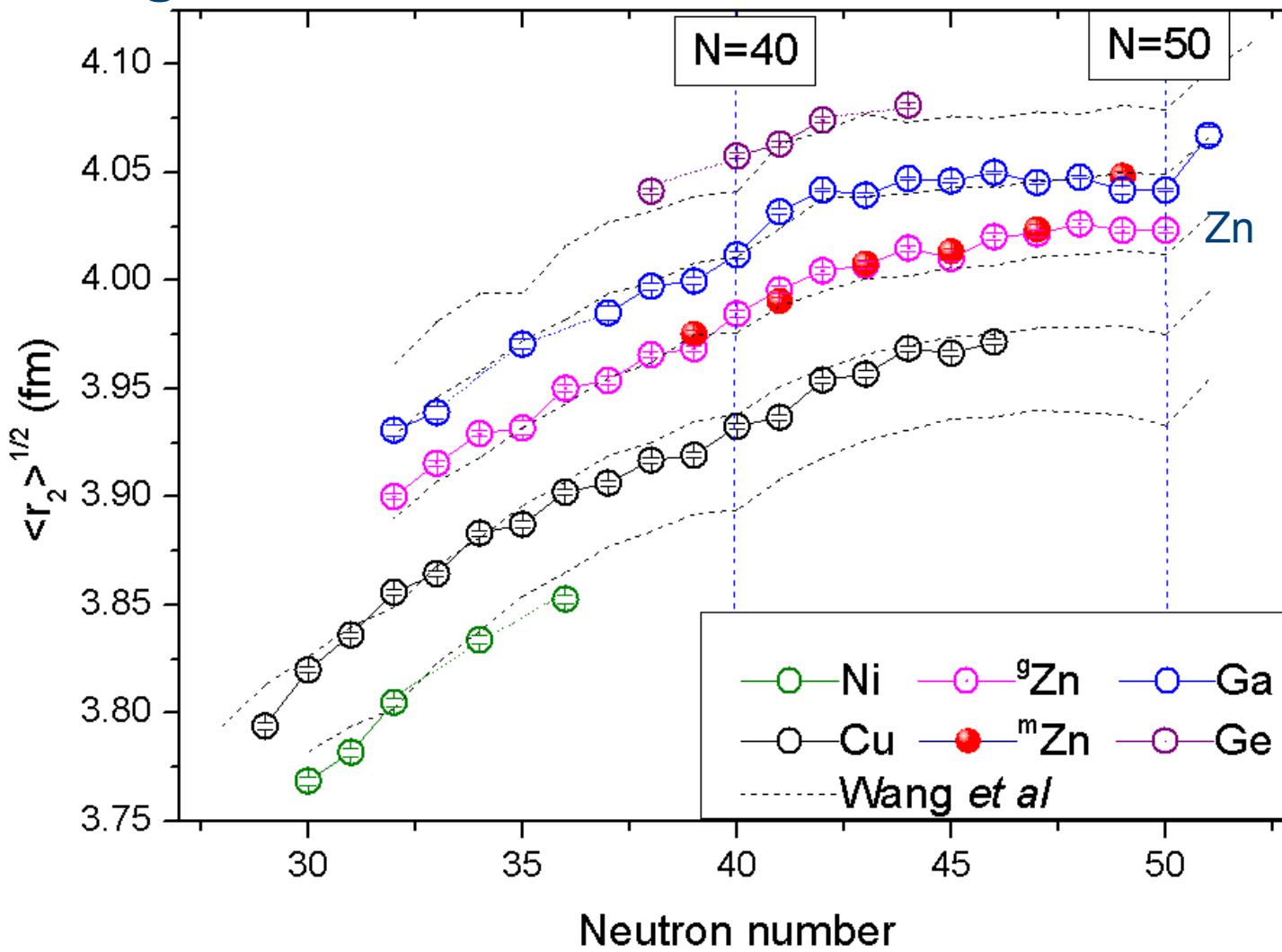


Y. Tsunoda et al., PRC 89, 031301(R) (2014)



F. Nowacki et al., Private communication

Charge radii of Zn



M. L. Bissell *et al.*, Phys. Rev. C **93**, 064318 (2016)

T. J. Procter *et al.*, Phys. Rev. C **86**, 034329 (2012)

Angeli and Marinova, At. Data Nucl. Data Tables **99**, 69 (2013) other radii

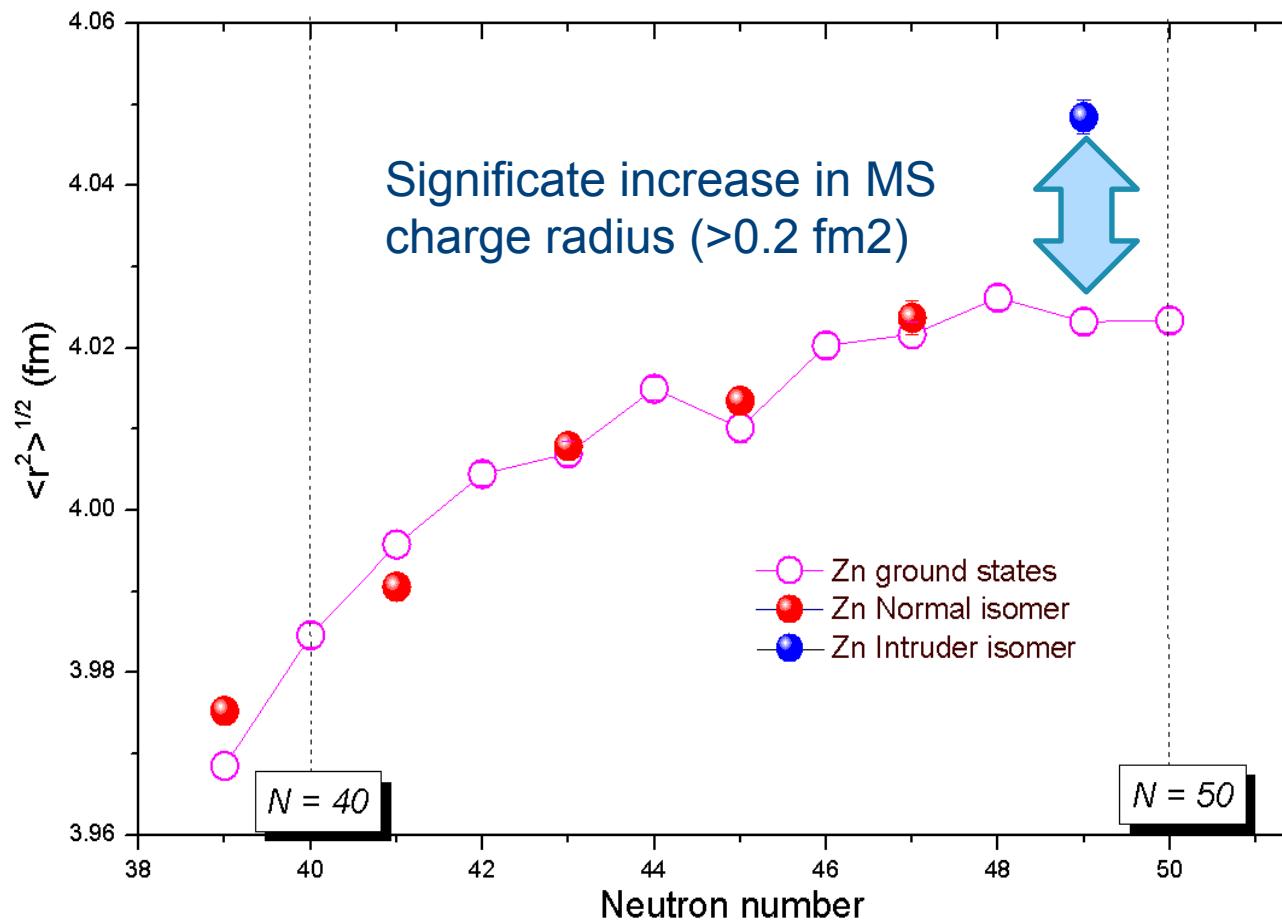
N. Wang and T. Li, Phys. Rev. C **88**, 011301 (2013)

Cu radii

Ga radii

KU LEUVEN

$^{79}\text{g,mZn}$ radii \rightarrow signature for shape coexistence



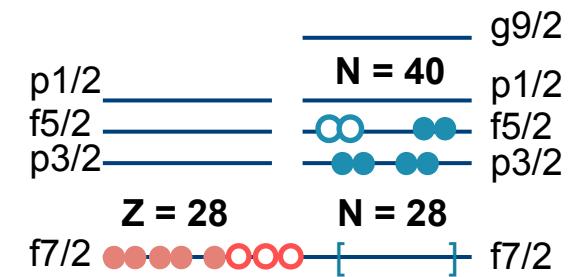
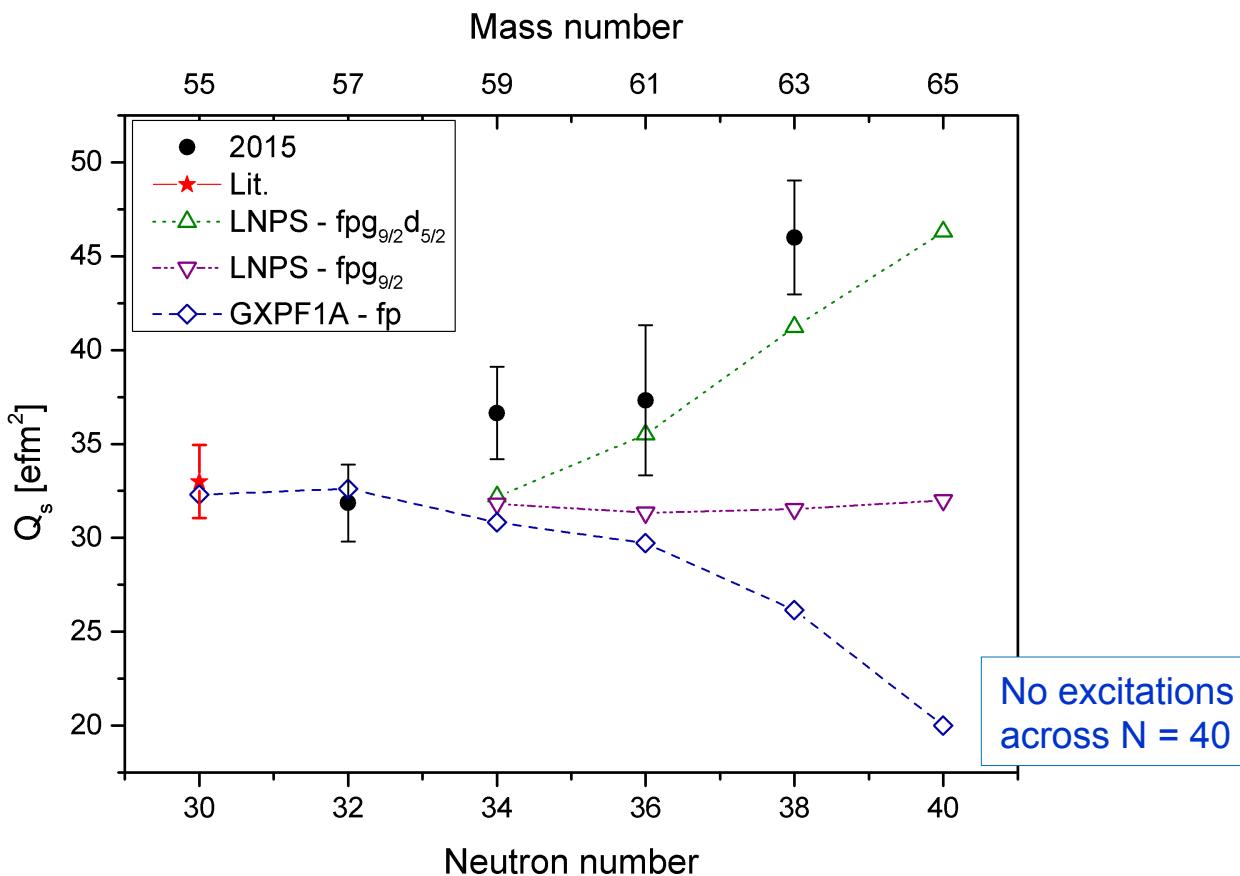
→ Confirm by performing COULEX on the isomeric beam to measure its deformation !

Mn isotopes ($Z=25$, middle of $M7/2$ orbit): evolution of deformation from radii and quadrupole moments



Quadrupole moments: sensitive to correlations and deformation

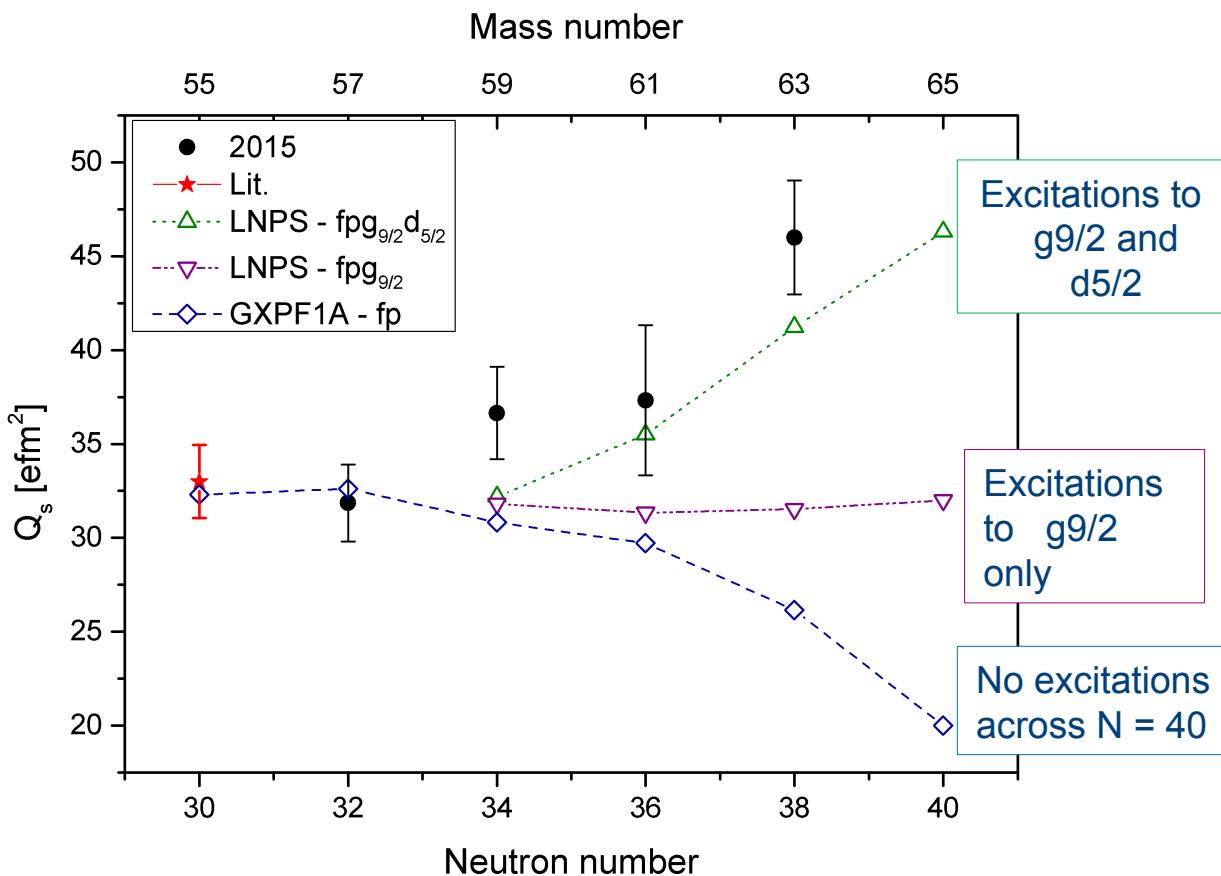
Mn isotopes ($Z=25$)



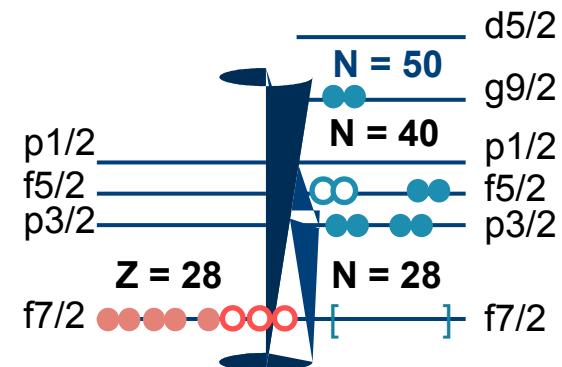
gxpf1a
Honma, PRC65 (2002);
40Ca core
Mand K in fp-shell

All isotopes have $I=5/2$
except 53Mn (at $N=28$) has normal $I=7/2$

Quadrupole moments: sensitive to correlations and deformation



Mn isotopes ($Z=25$)



gxpf1a

Honma, PRC65 (2002); Lenzi, PRC82 (2010)

Inps

40Ca core

^M fp-shell

K fp-shell

48Ca core

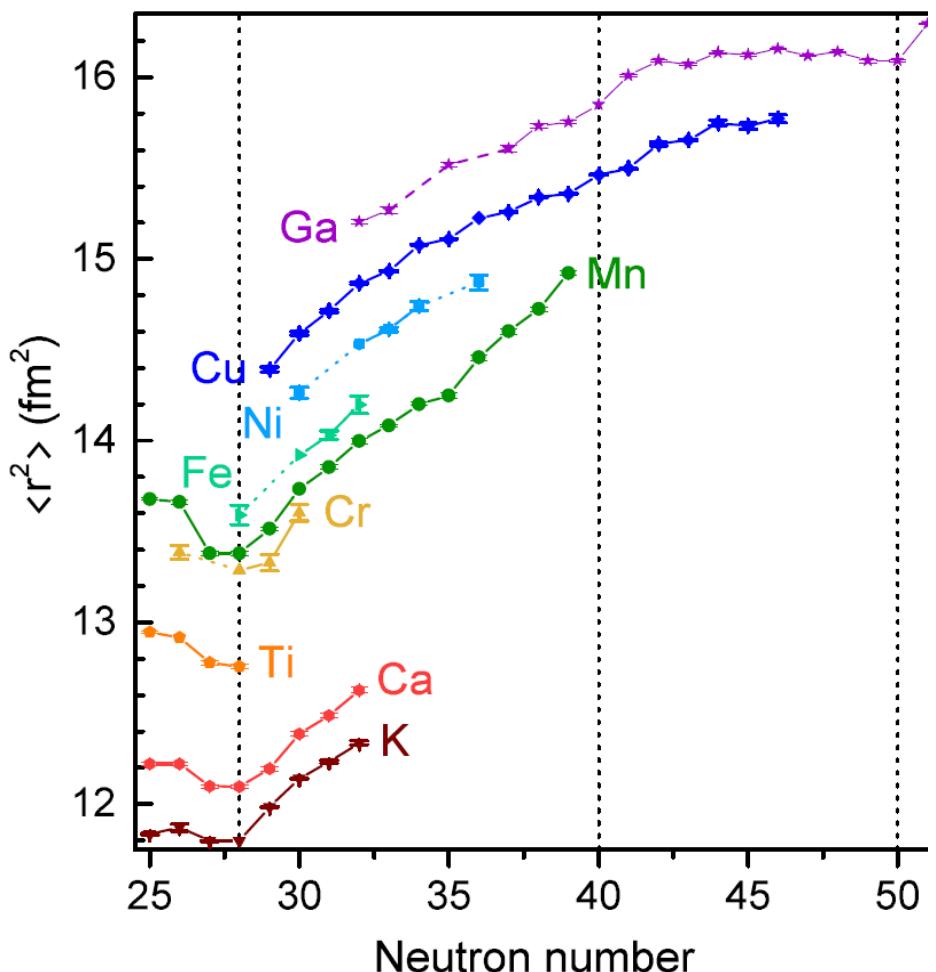
M fp-shell

K upper fp

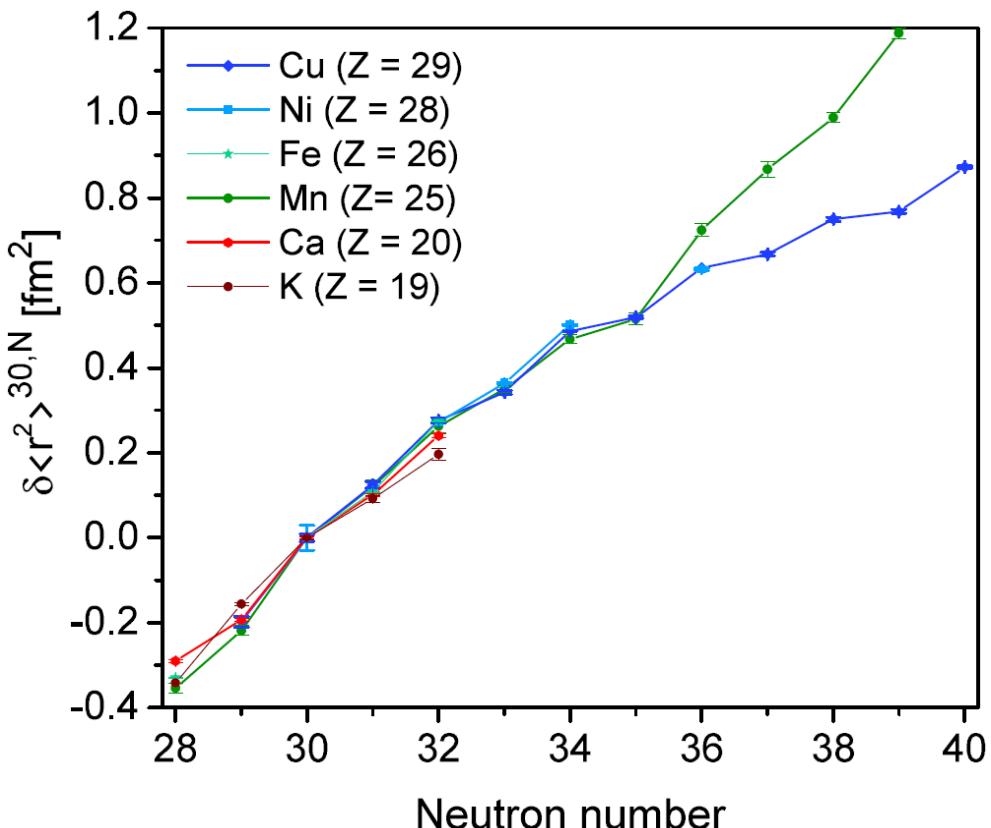
+ $\text{g}_{9/2}\text{d}_{5/2}$

- neutron excitations are needed from $N=36$ onwards, into $\text{Kg}_{9/2}$ and $\text{Kd}_{5/2}$!

Radii of Mn isotopes



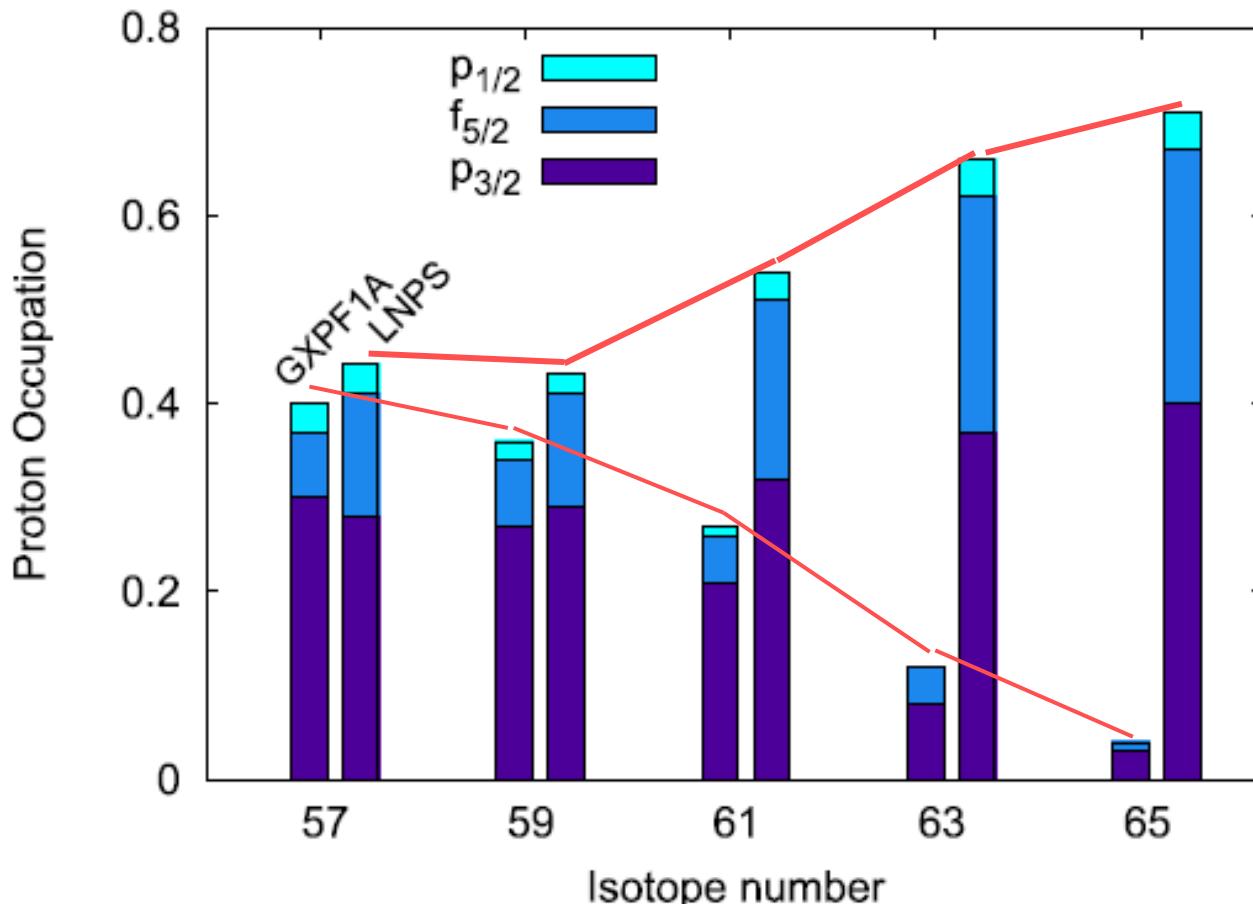
Consistent with conclusion
from Q-moments



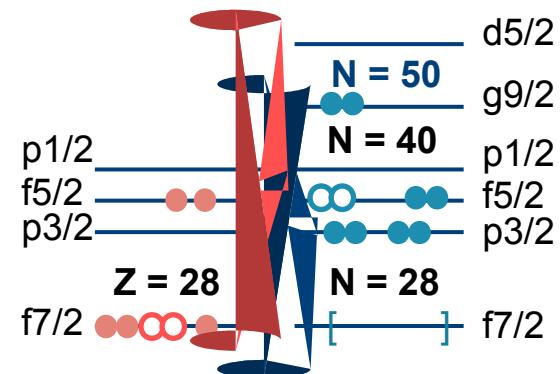
Onset of deformation from $N=36$ onwards

Moments: probing the wave function

LNPS reproduces the moments → correct wave function



Mn isotopes ($Z=25$)

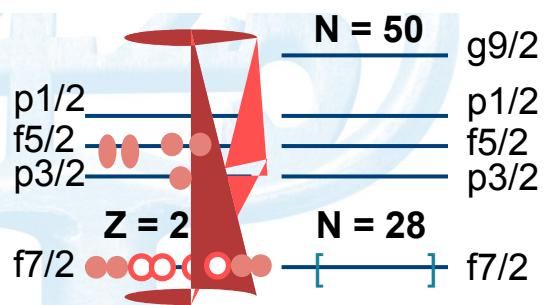
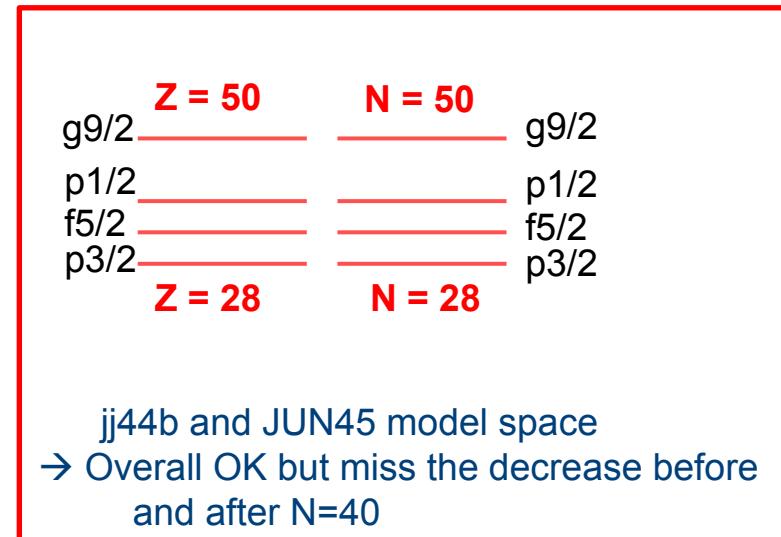
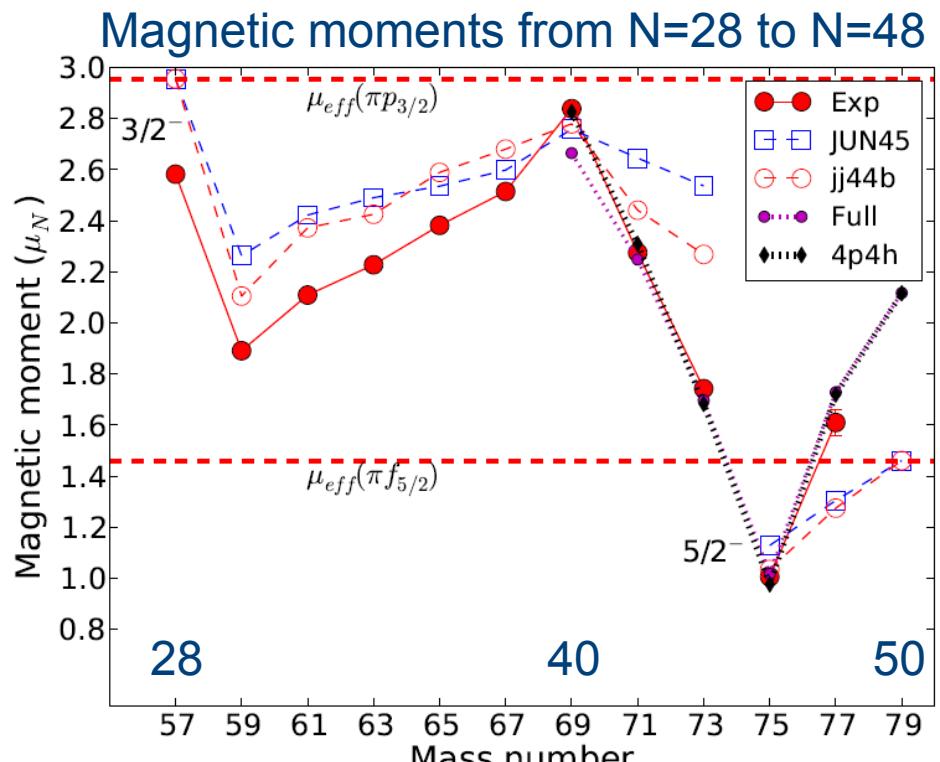


Excitations across $N = 40$ induce increase in proton excitations across $Z=28$ (type-II shell evolution
Tsunoda et al., PRC89, 2014)

Cu isotopes: Core polarization between N=28 and N=50



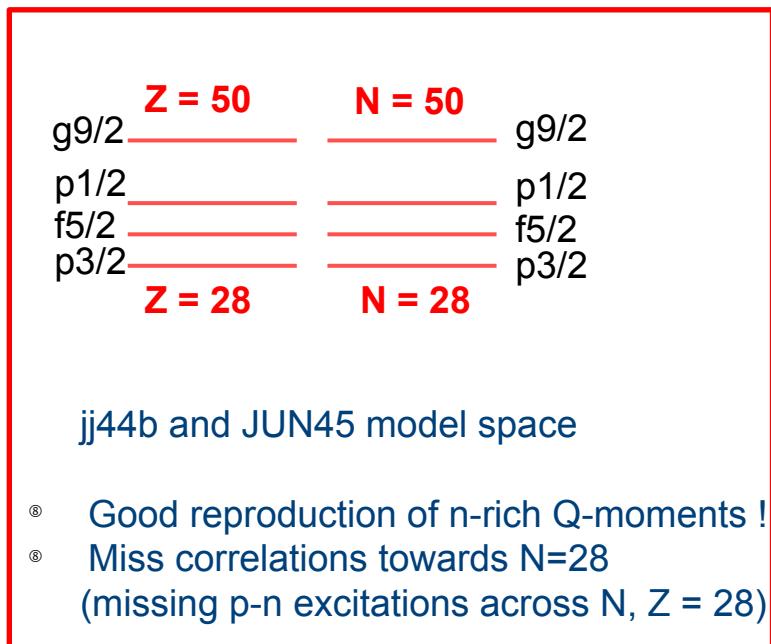
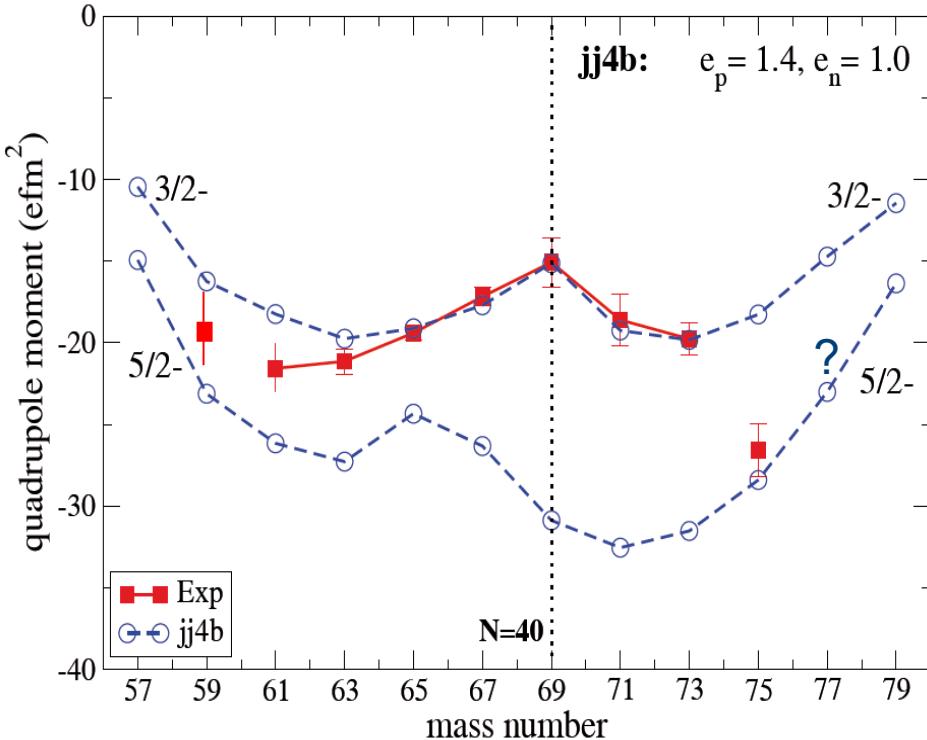
Magnetic and Quadrupole moments: probe different correlations (M1/E2)



Sieja et al., PRC81, 061303(R) (2010): include M7/2 in model space
Need 4p-4h proton excitations across Z=28
 to reproduce magnetic moments 71-77Cu
 (no calculations for n-deficient)

Magnetic and Quadrupole moments: probe different correlations

Quadrupole moments from N=28 to N=46

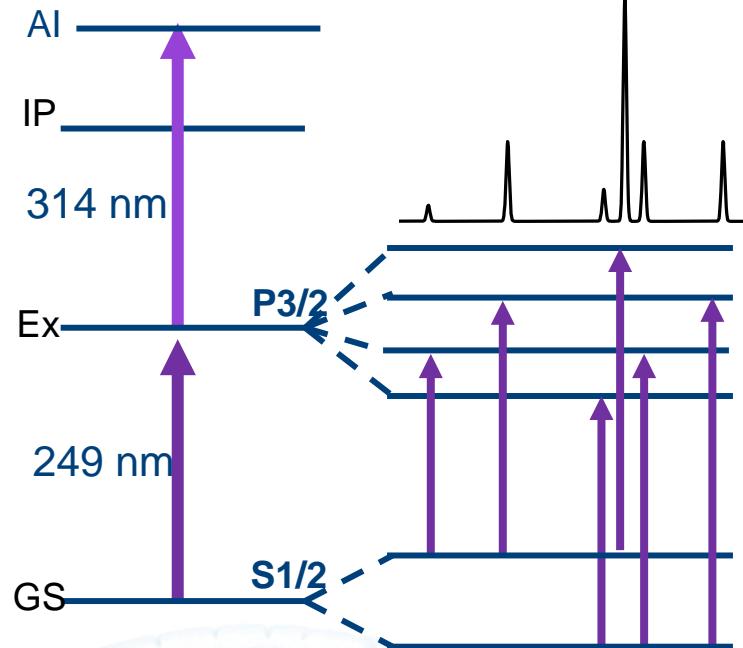


Sieja et al., PRC81, 061303(R) (2010): include M7/2 in model space

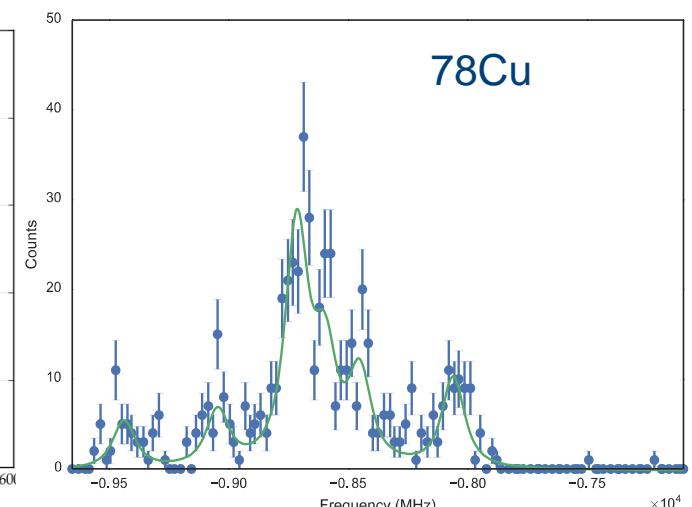
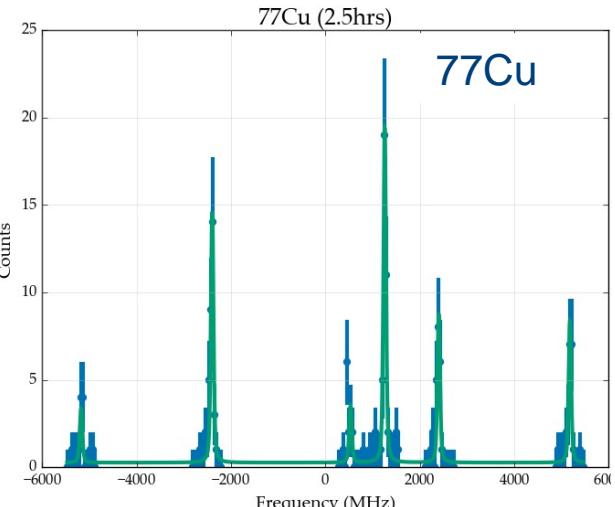
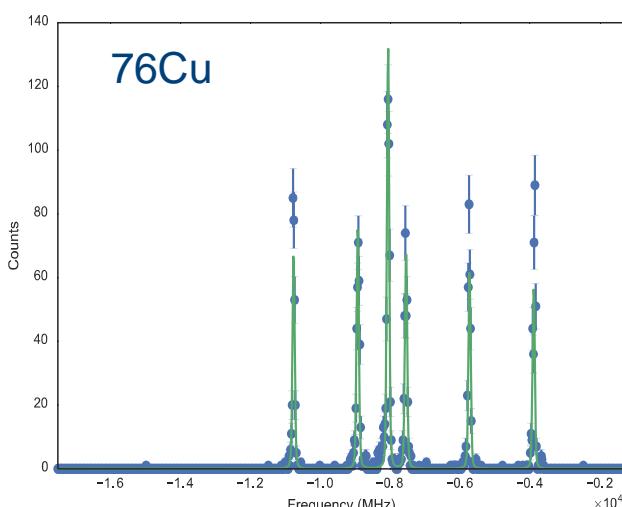
No quadrupole moments calculated for 71-79Cu

- ④ What if proton excitations are included ?
- ④ What about excitations across the N=50 shell gap ?

Injection seeded pulsed Ti:Sa laser for 249 nm (Tripled)

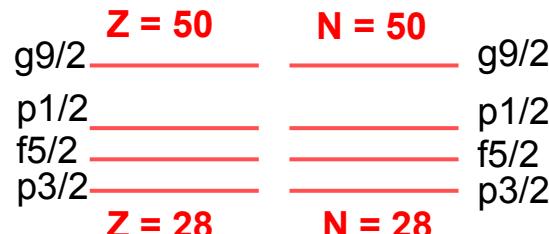
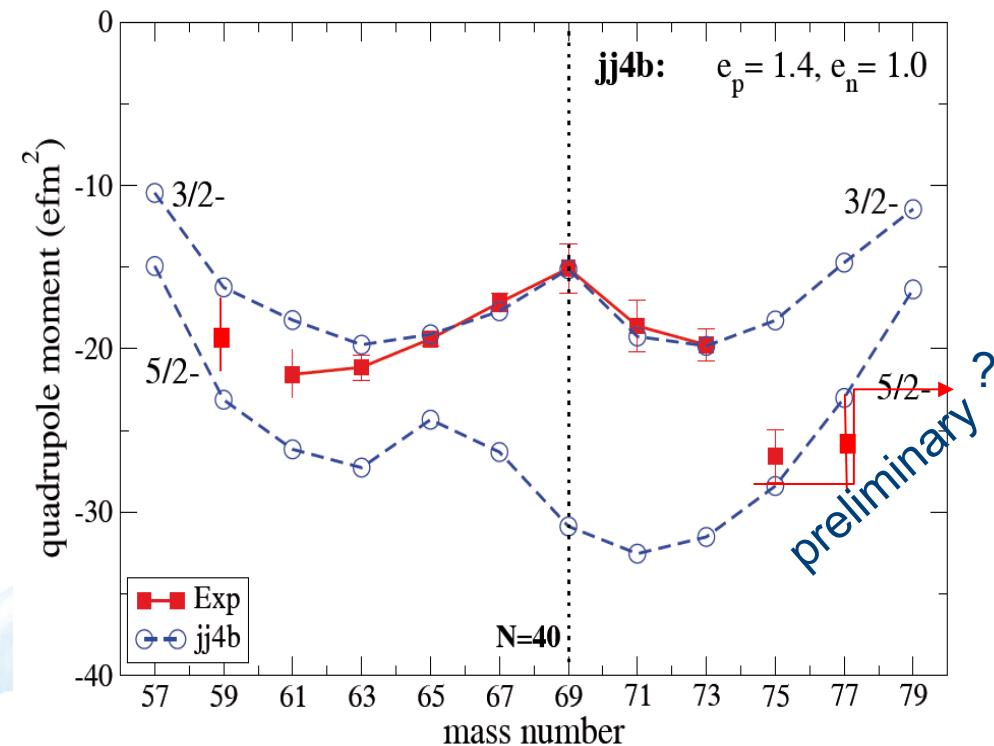


- 75Cu measured yield of 20,000 ions/s
- Estimated yield of 78Cu of < 20 ions/s



Magnetic and Quadrupole moments: probe different correlations

Quadrupole moments from N=28 to N=48



jj44b and JUN45 model space

- ④ Good reproduction of n-rich Q-moments !
- ④ Miss correlations towards N=50 ?

Calculated Q-moments for 71-77Cu in extended model spaces...
→ Only proton excitations sufficient ?
④ Weakening of N=50 shell gap ?
④ Calculations needed !

CONCLUSIONS

Nuclear moments and radii are complementary probes
to study nuclear structure far from stability

- moments: probing the single particle components and correlations in the wave function
- in combination with radii: establish deformation and shape coexistence



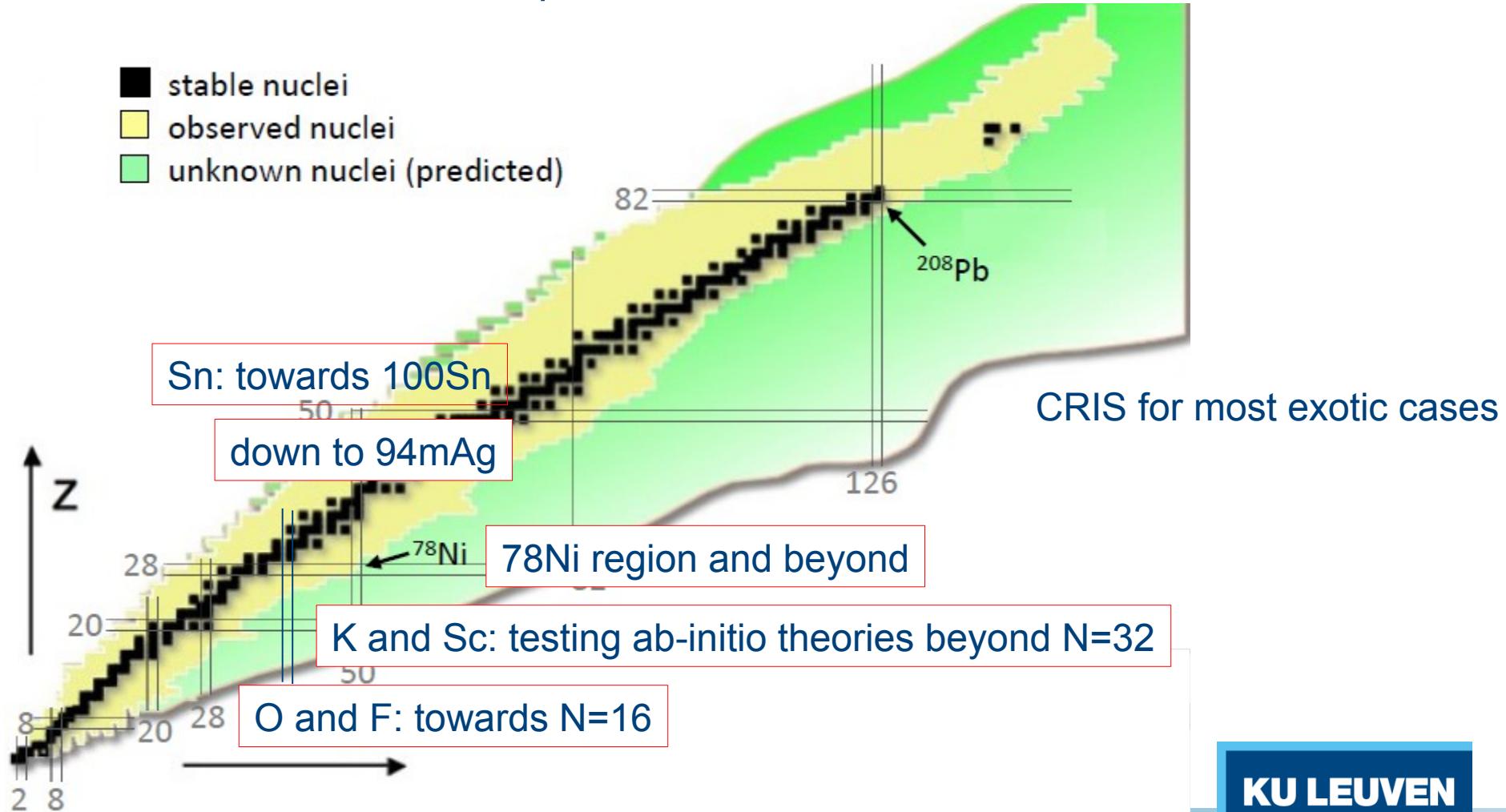
Collinear laser spectroscopy gives
spin, moments and radii from 1 measurement of HFS

BUT NEED SEVERAL METHODS TO COMPLEMENT THE PICTURE

Future cases

Main focus:

- transition regions between/towards closed shells
- towards exotic doubly-magic nuclei
- neutron-deficient proton emitters



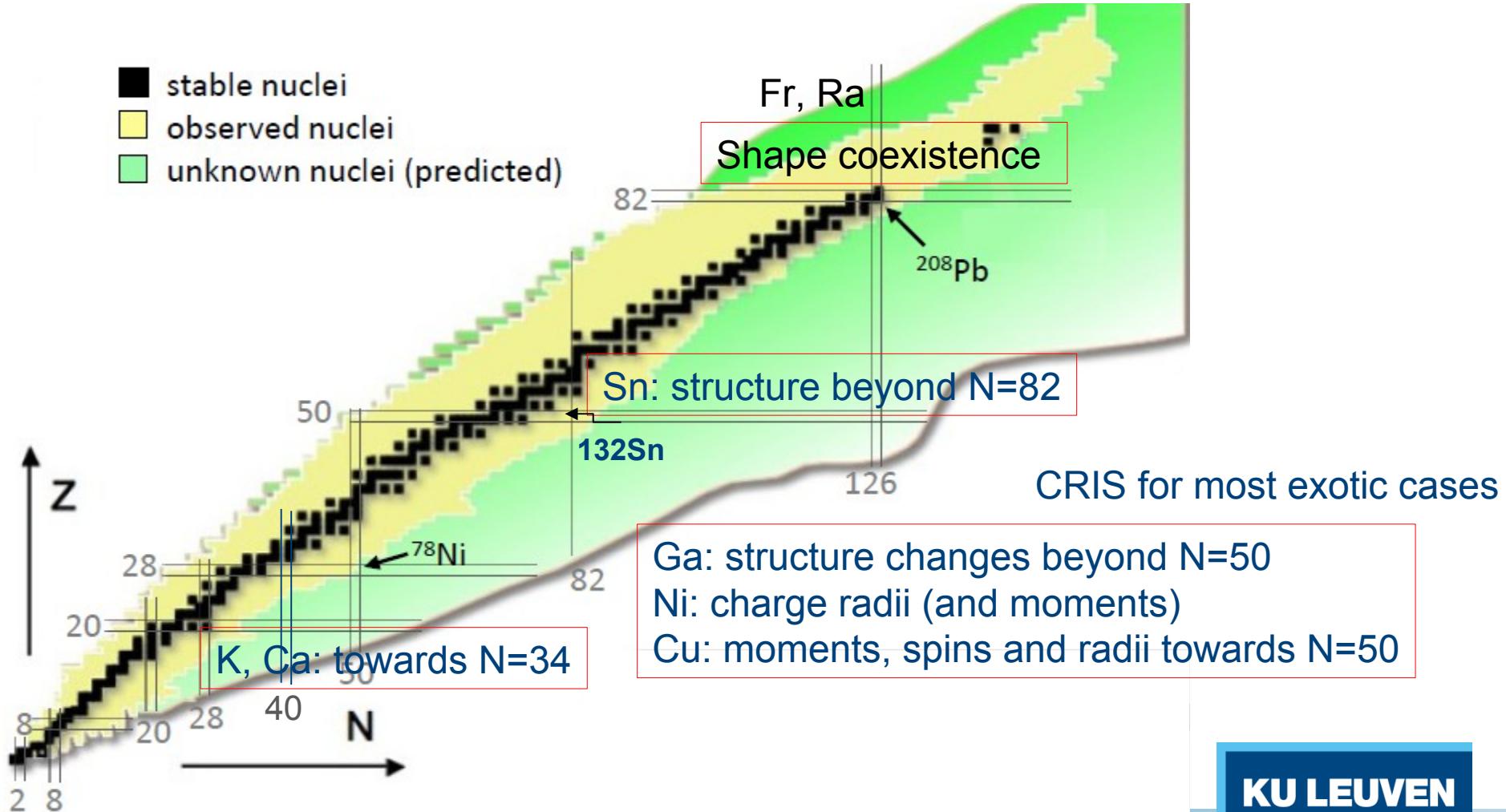


KU LEUVEN

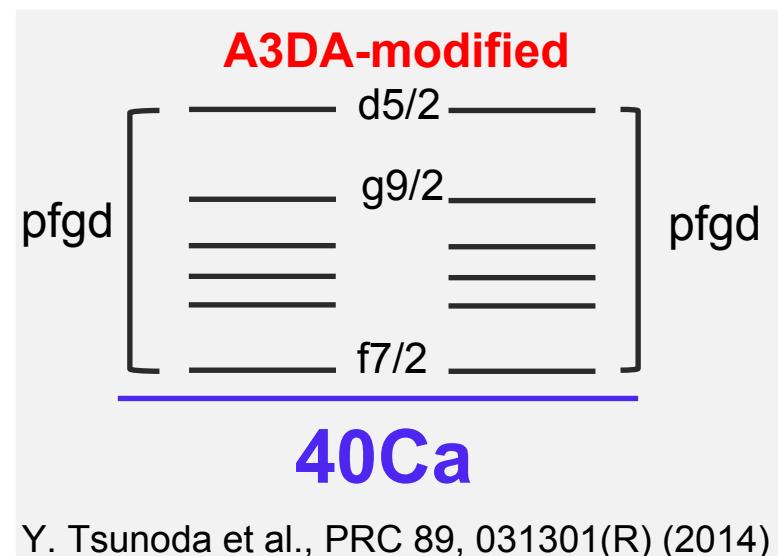
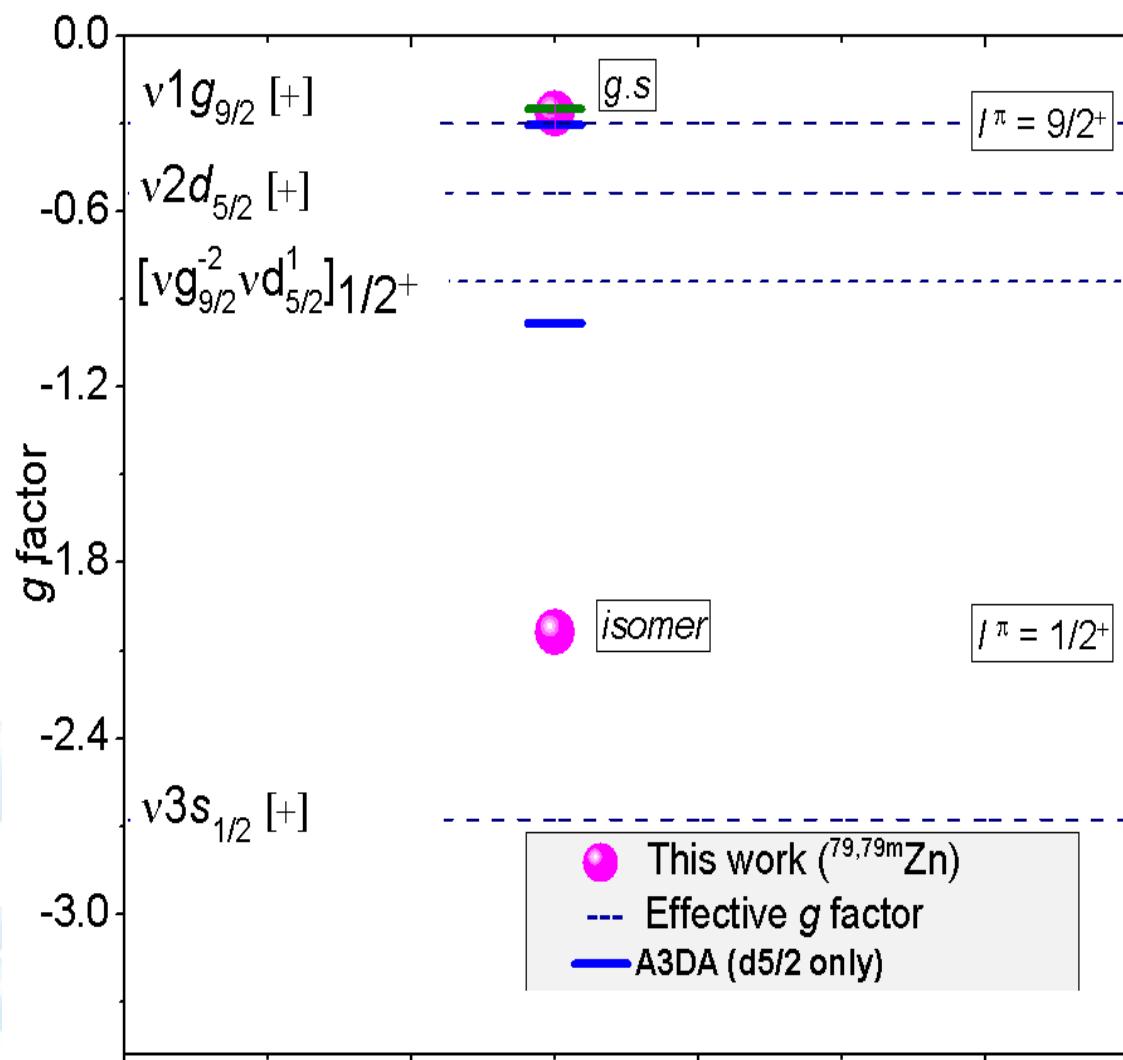
Current regions of interest

Main focus:

- transition regions between/towards closed shells
- towards exotic doubly-magic nuclei

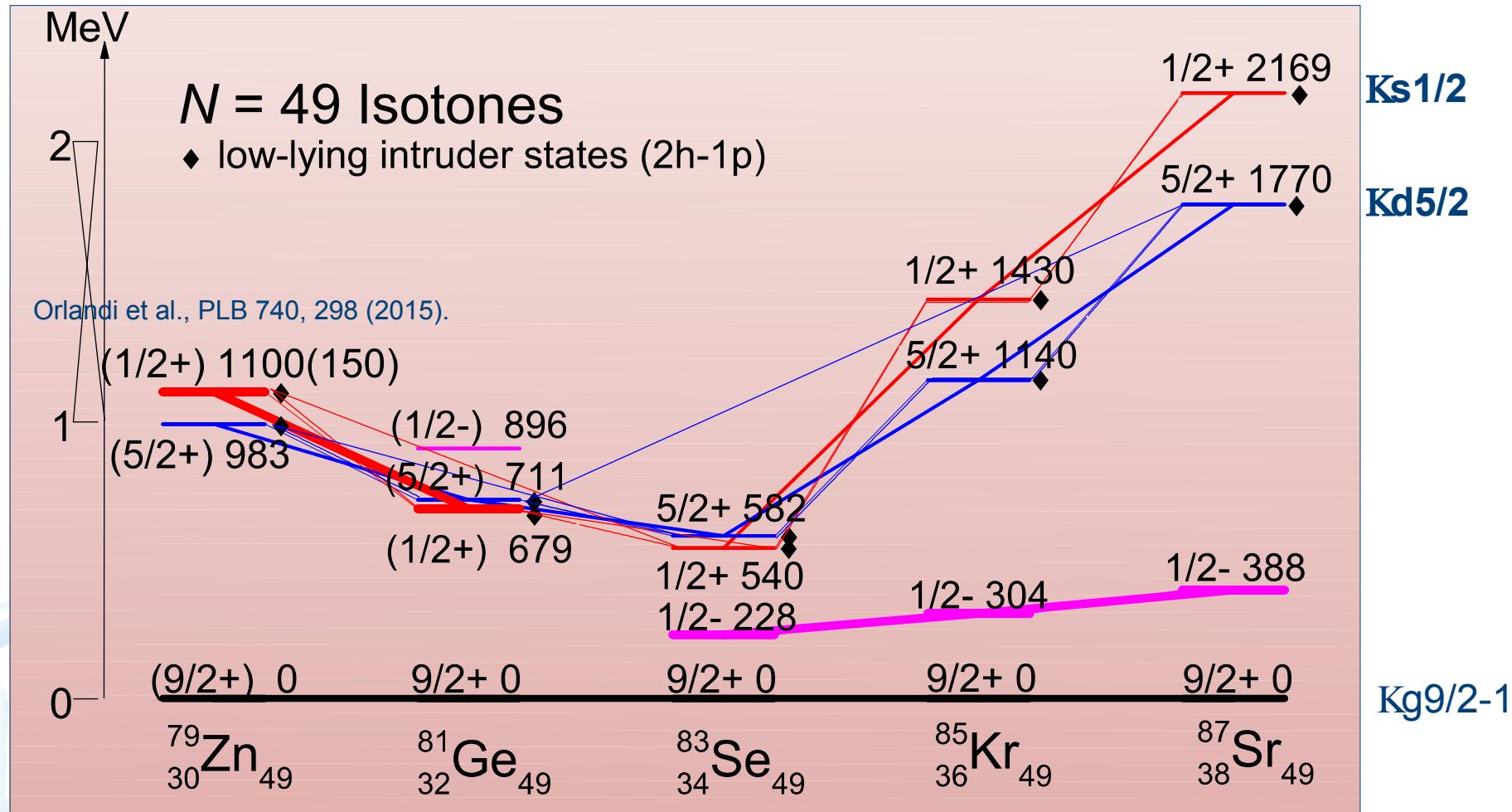


g-factor of 9/2 g.s. and 1/2 isomeric state in ^{79}Zn



Y. Tsunoda et al., PRC 89, 031301(R) (2014)

Shape coexistence around $N = 50$?



Intruder states confirmed for $N = 49$ isotones for more than 3 decades

K. Heyde et al., Physics Reports 102, 291 (1983)

Experimental evidence for shape coexistence is still missing!!