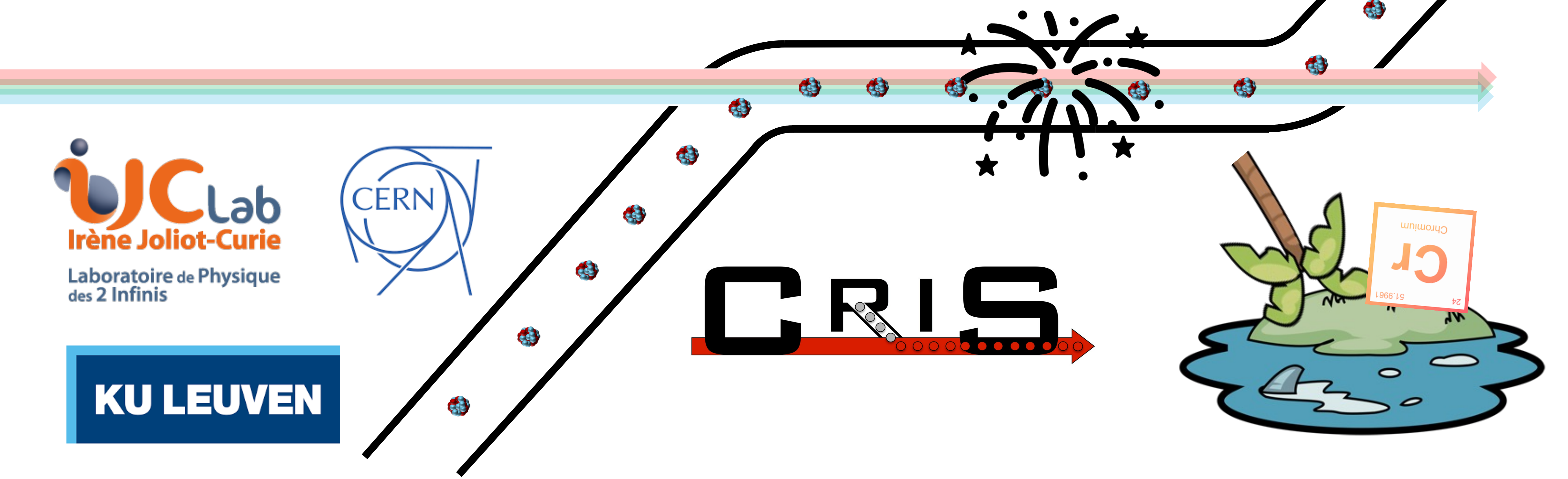
Evolution of ground state properties of Chromium isotopes from stability to the *N* = 40 Island of Inversion

Louis Lalanne IJCLab / CNRS



IJCLab Irène Joliot-Curie
Laboratoire de Physique des 2 Infinis
CERN
KU LEUVEN

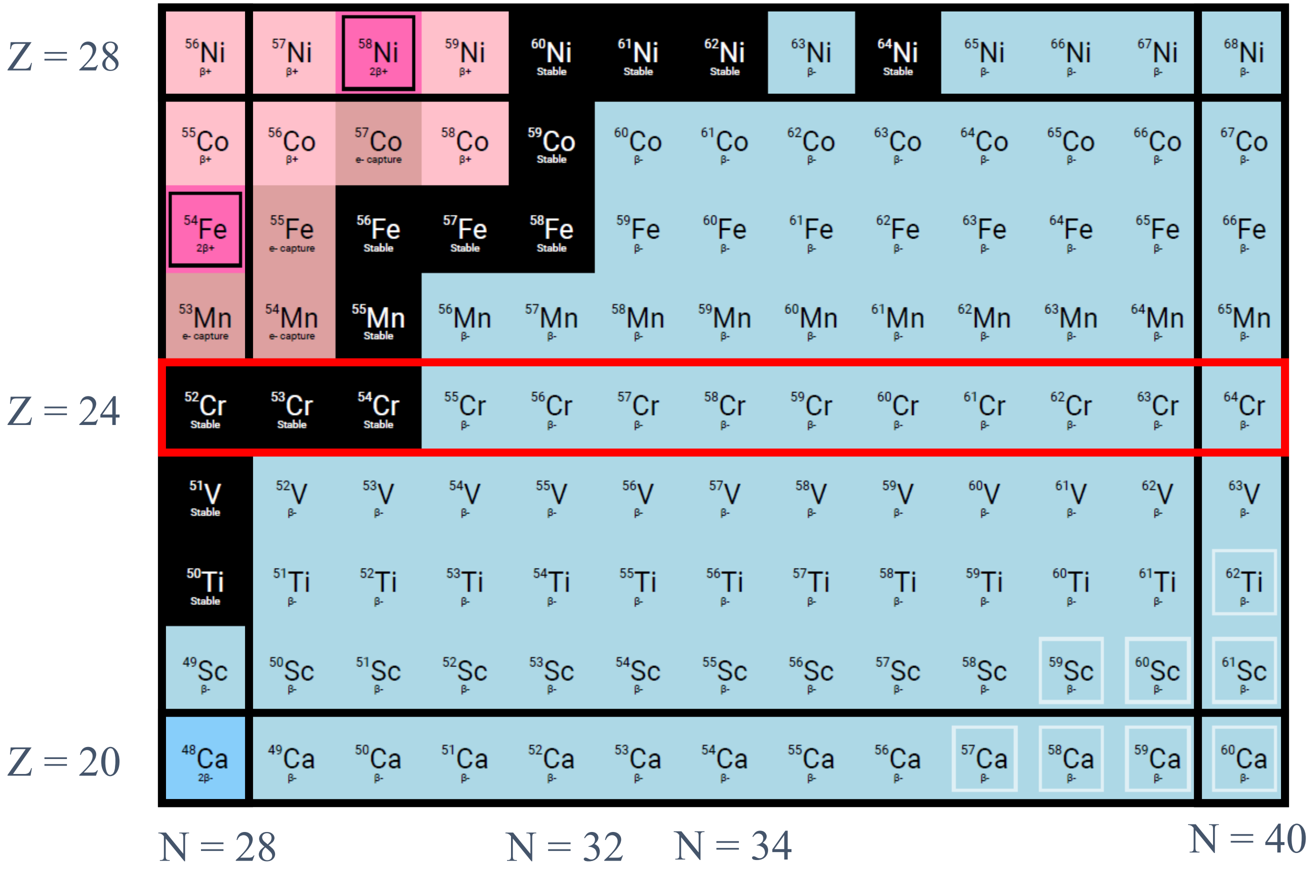
Introduction

The N=40 Island of Inversion

- Sign for a weak sub-shell closure at N=40 in ^{68}Ni
- Very collective ^{66}Fe and ^{64}Cr ground-states
- N=40 Island of Inversion (IoI) around ^{64}Cr (3)

The Cr isotopes:

- Half filled $f_{7/2}$ → strongest p-n collectivity
- Mass : gradual increase of collectivity and deformation from N=34 onward (1)
- Competing nuclear shapes in ^{62}Cr (2)



(1) M. Mougeot *et al.*, PRL **120**, 232501 (2018)
(2) A. Gade et al., Nature Physics **21**, 37-42 (2025)
(3) S. Lenzi et al., PRC **82**, 054301 (2010)

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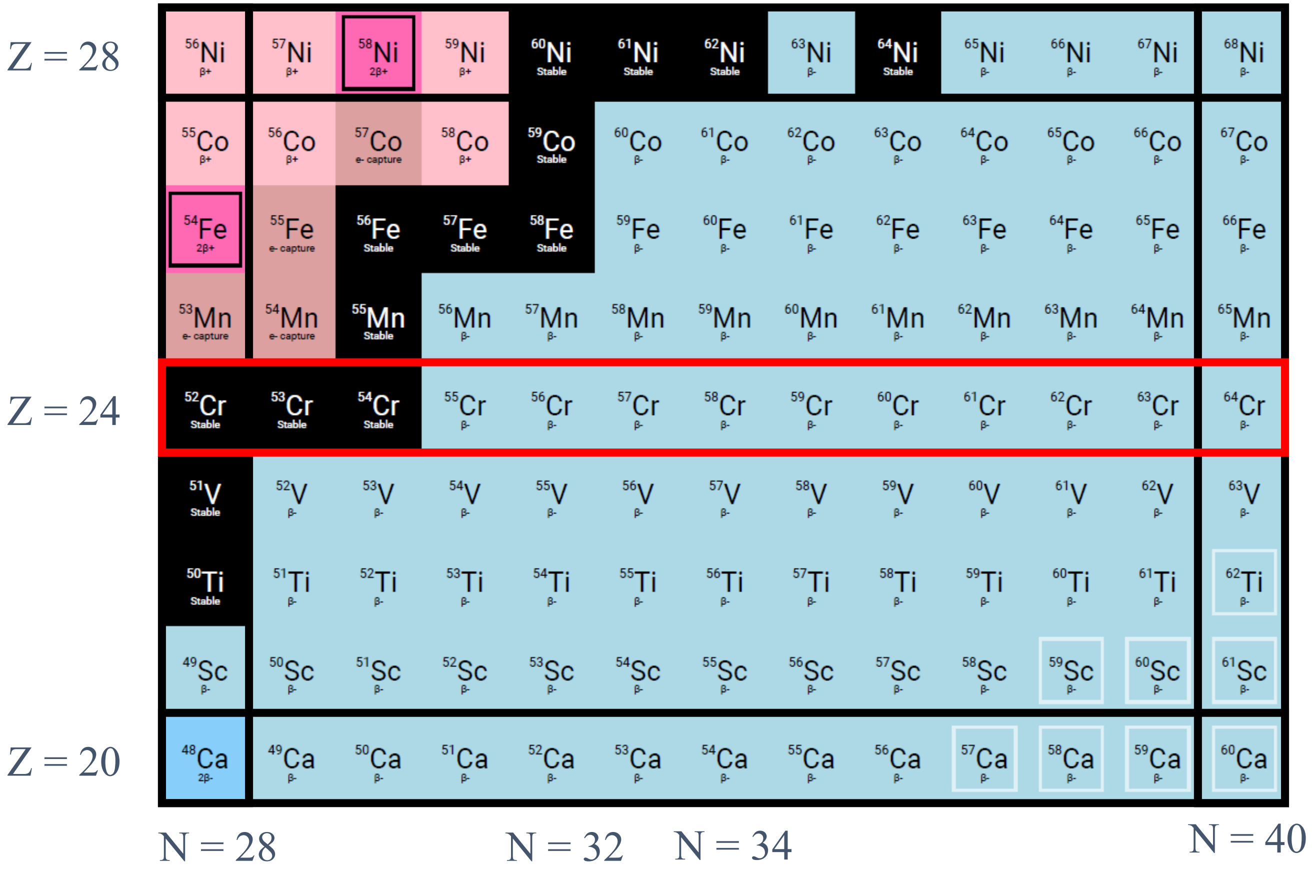
→ Location and nature of the transition into the IoI ?

→ Structure and shape of ground state ?



Goals of the experiment:

- ➢ First measurement of electromagnetic g.s. properties of neutron rich Cr outside stability
- ➢ Better understand the structure of the odd-A Cr ground states
- ➢ Investigate the structural changes along the chain and the formation of the N=40 IoI

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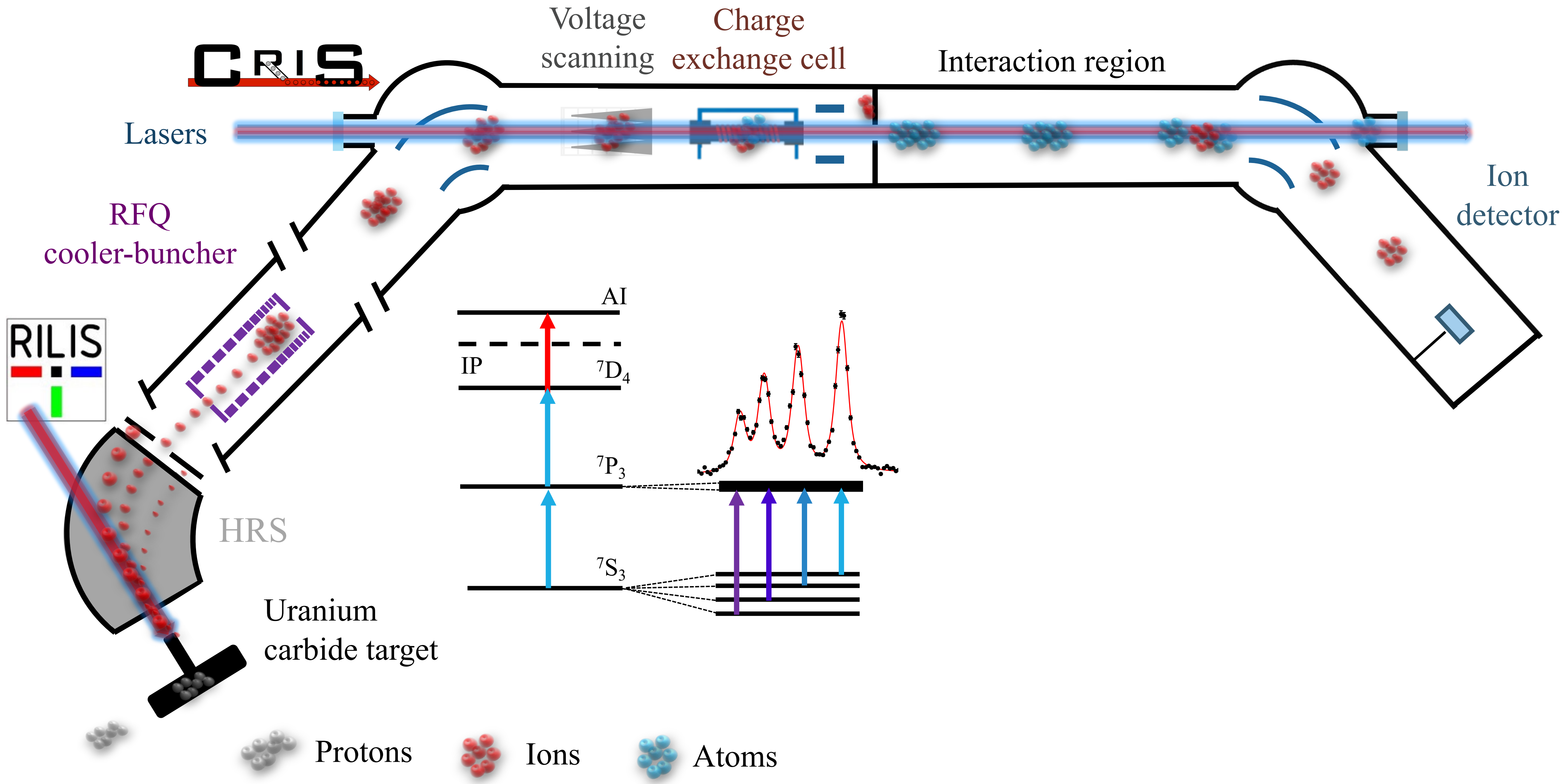
CRIS
Voltage scanning
Charge exchange cell
Interaction region
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RFQ cooler-buncher
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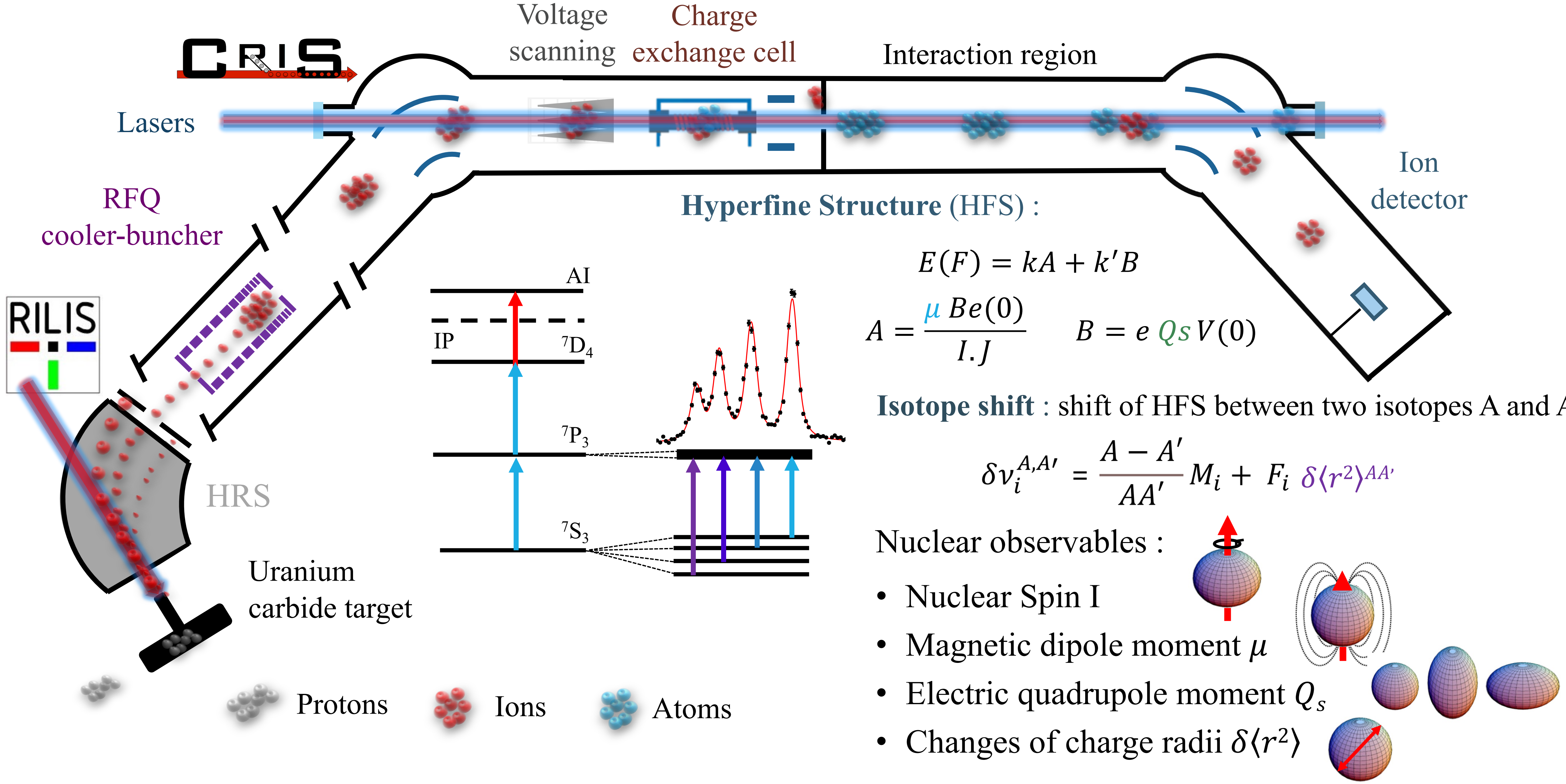


Hyperfine Structure (HFS) :

$$E(F) = kA + k'B$$

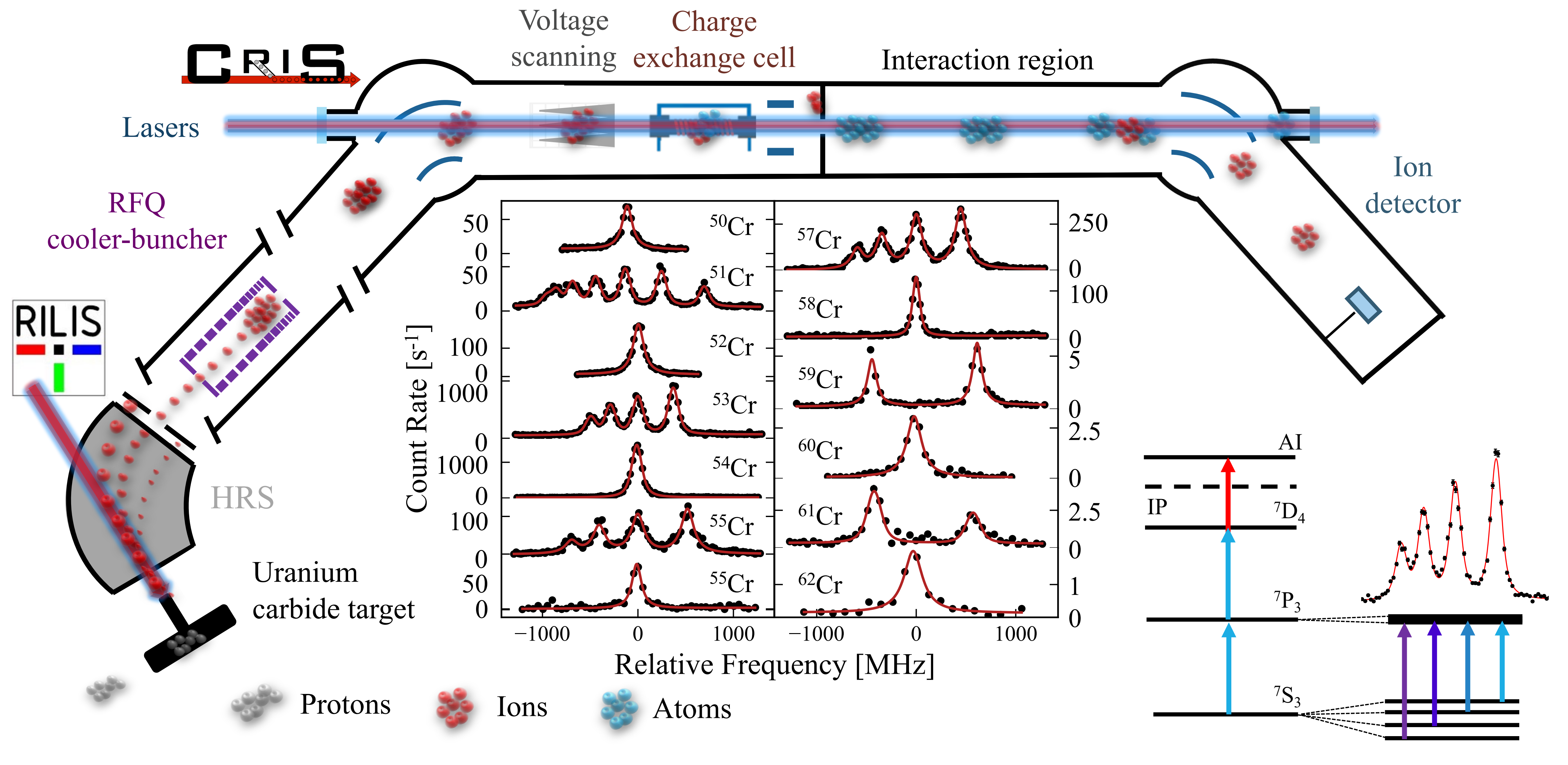
$$A = \frac{\mu\, Be(0)}{I.J} \qquad B = e\, Q_s V(0)$$

Isotope shift : shift of HFS between two isotopes A and A'

$$\delta\nu_i^{A,A'} = \frac{A - A'}{AA'} M_i + F_i\, \delta\langle r^2\rangle^{AA'}$$

Nuclear observables :

- Nuclear Spin I
- Magnetic dipole moment μ
- Electric quadrupole moment Q_s
- Changes of charge radii $\delta\langle r^2\rangle$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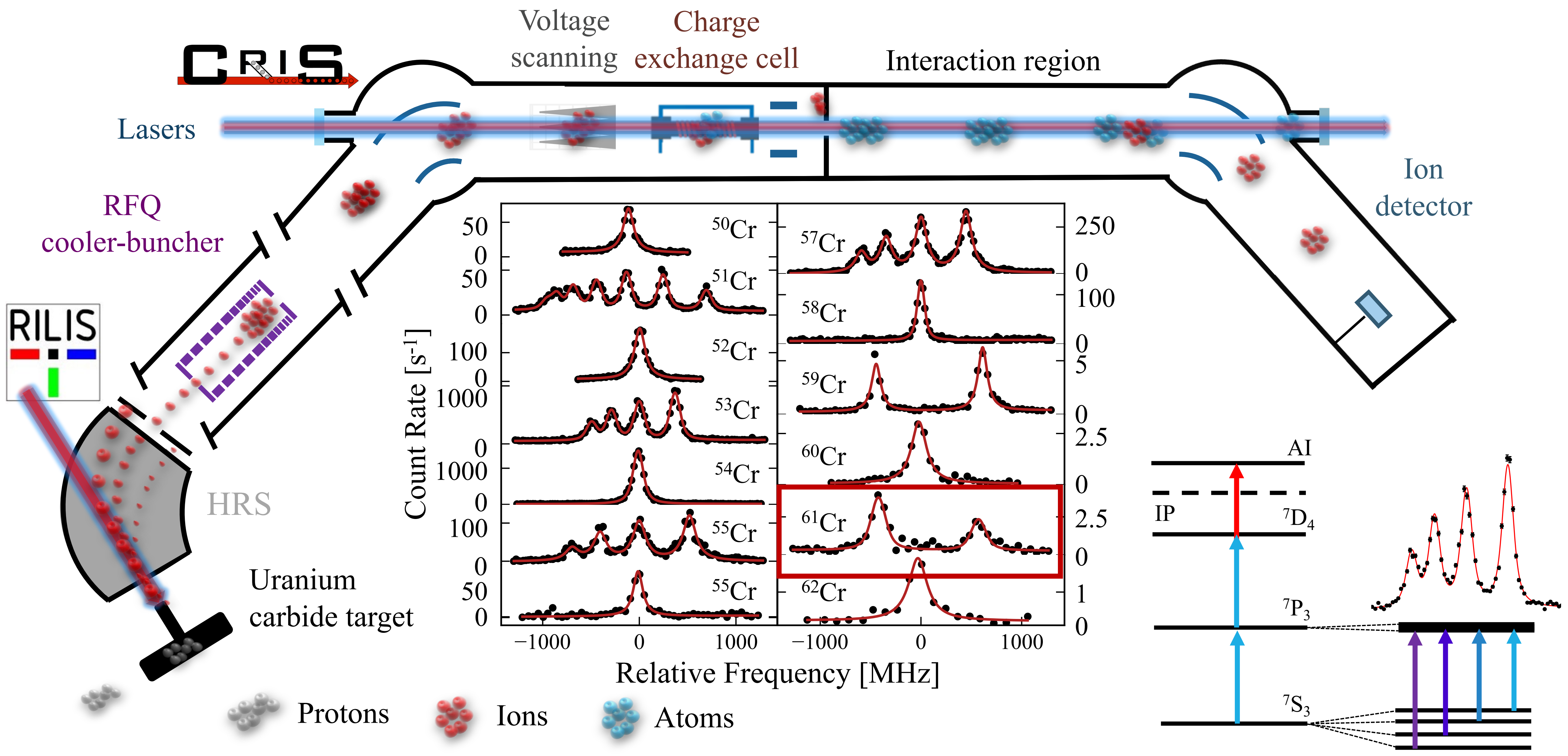
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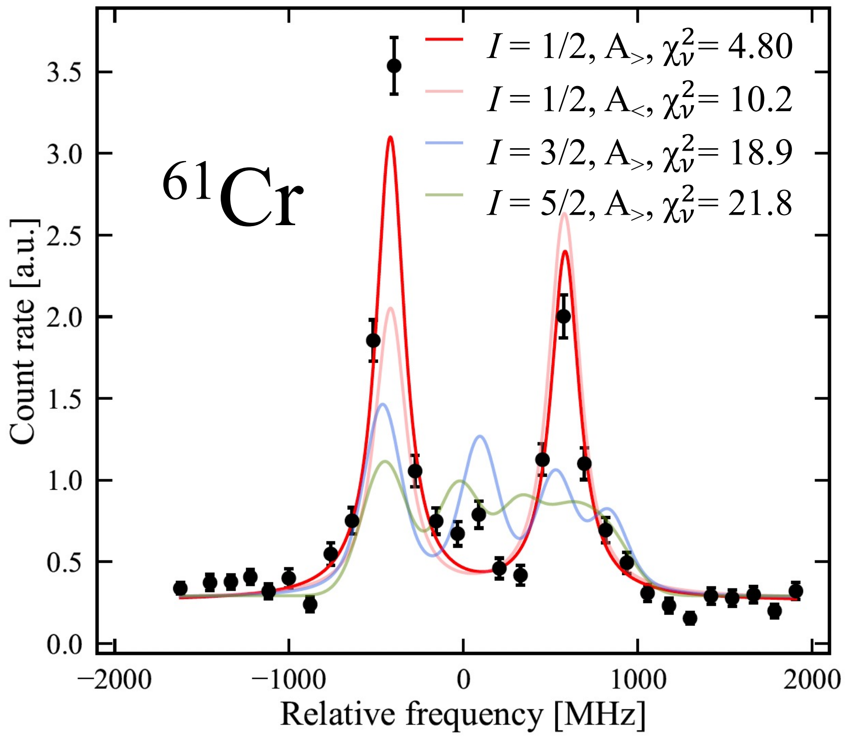
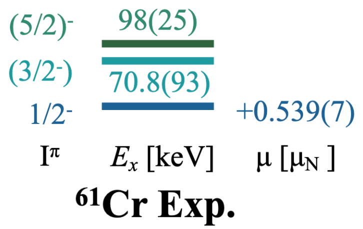
^{61}Cr as a Doorway to the N=40 Island Of Inversion

- Spin ^{61}Cr found to be 1/2 , disagrees with 5/2 assignment from literature :
  - Spin-parity assignment of first two ^{61}Cr excited state from multipol.[1]
  - Over estimation beta feeding in ^{61}Mn [2]





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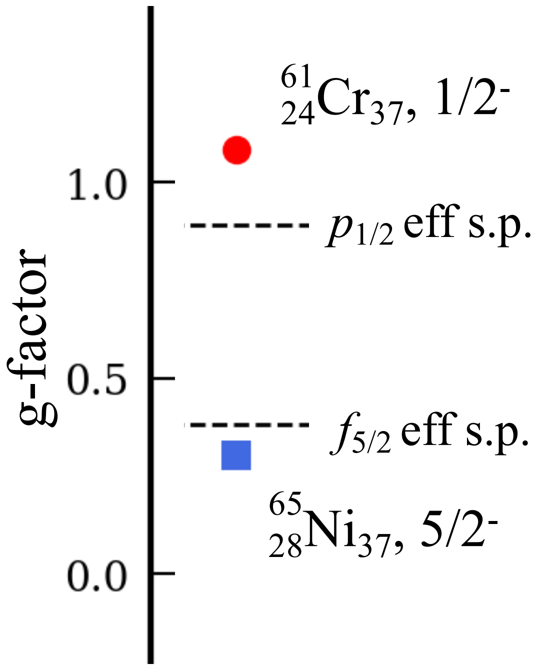

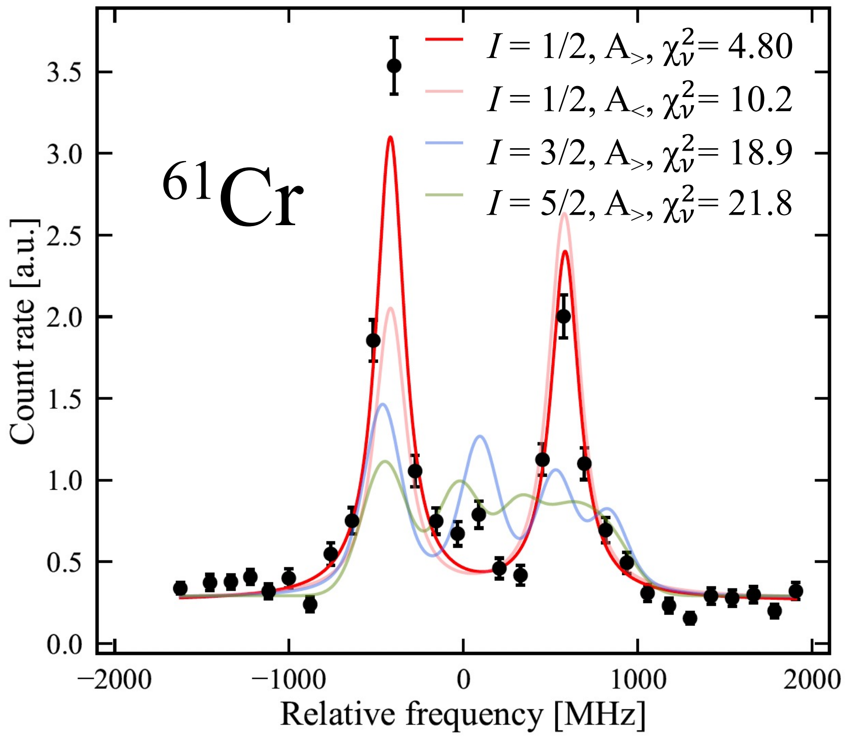

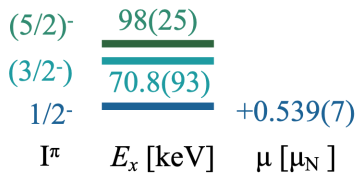

^{61}Cr Exp.

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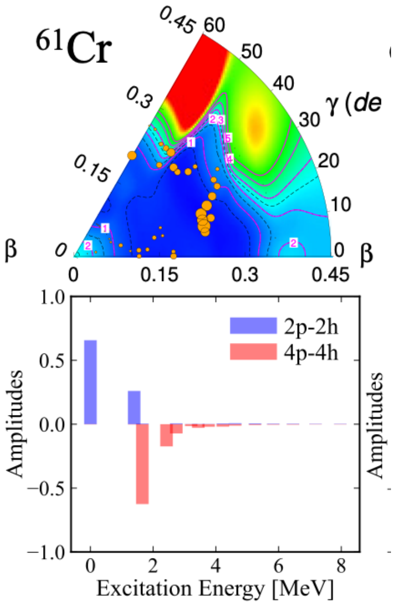

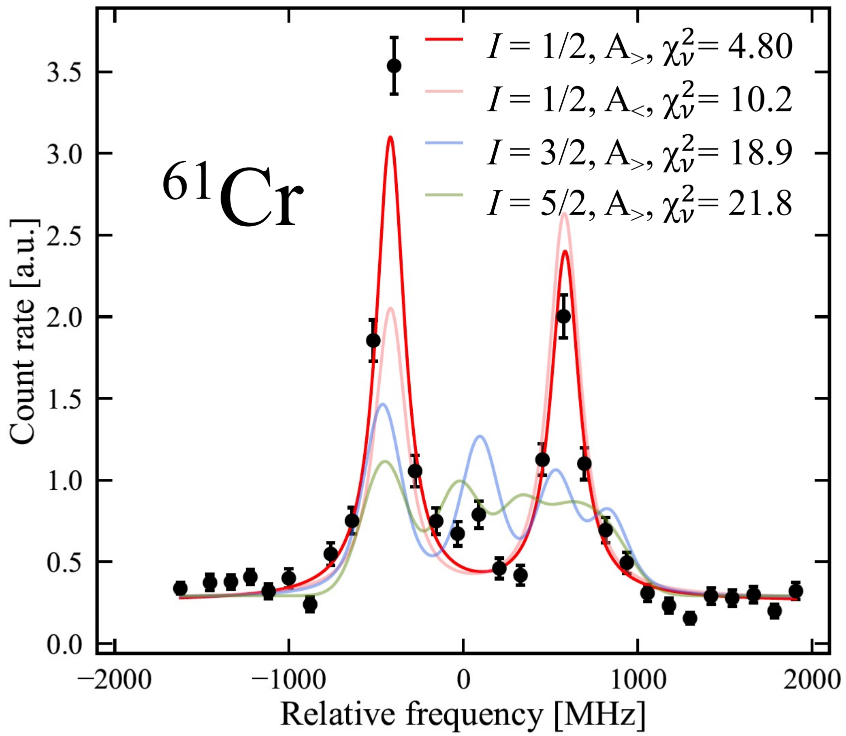

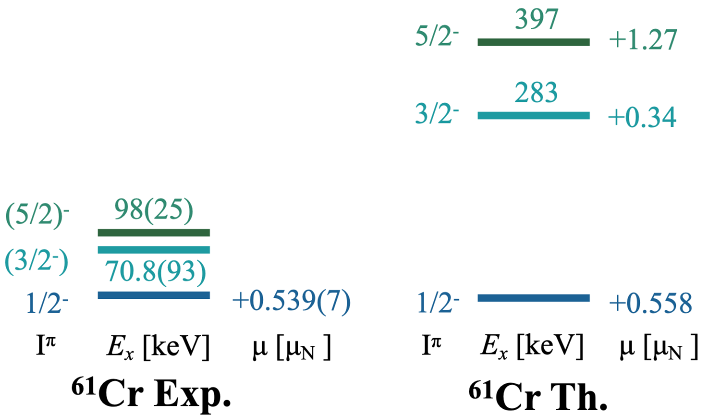

- ➢ *2p-2h* neutron intruder configuration with lonely $p_{1/2}$ neutron
- ➢ Triaxiality of ^{61}Cr ground state

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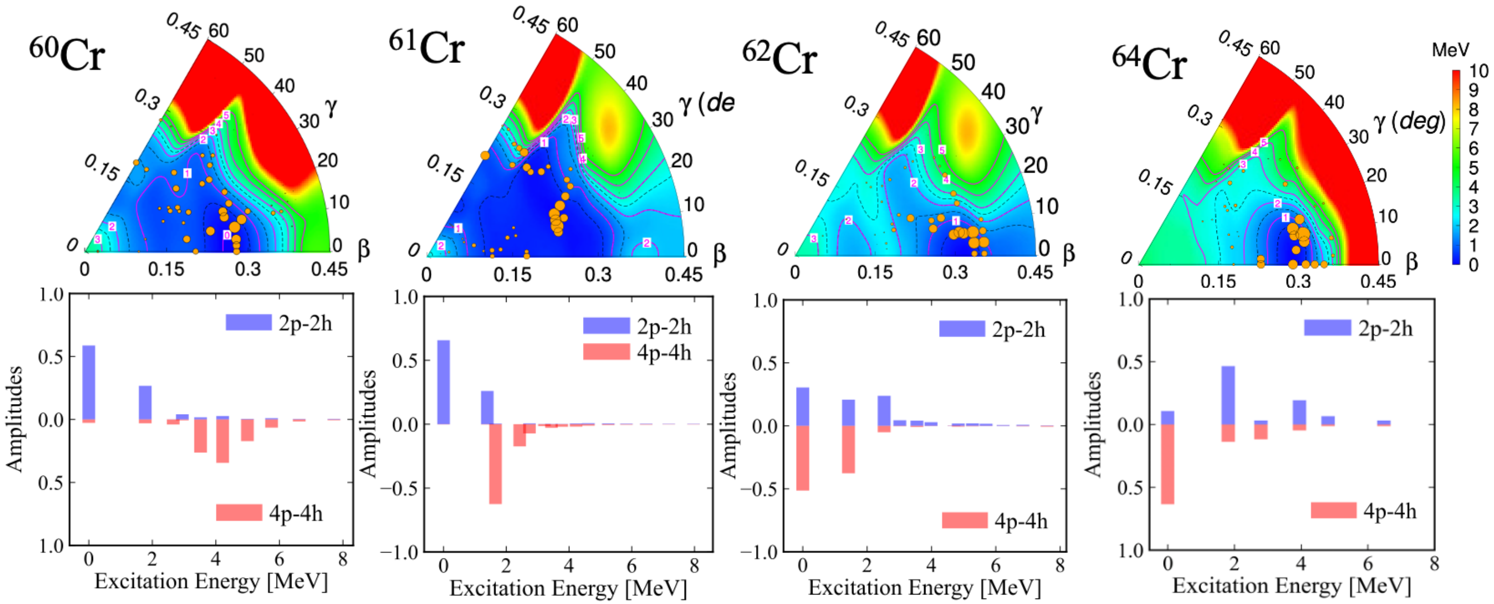

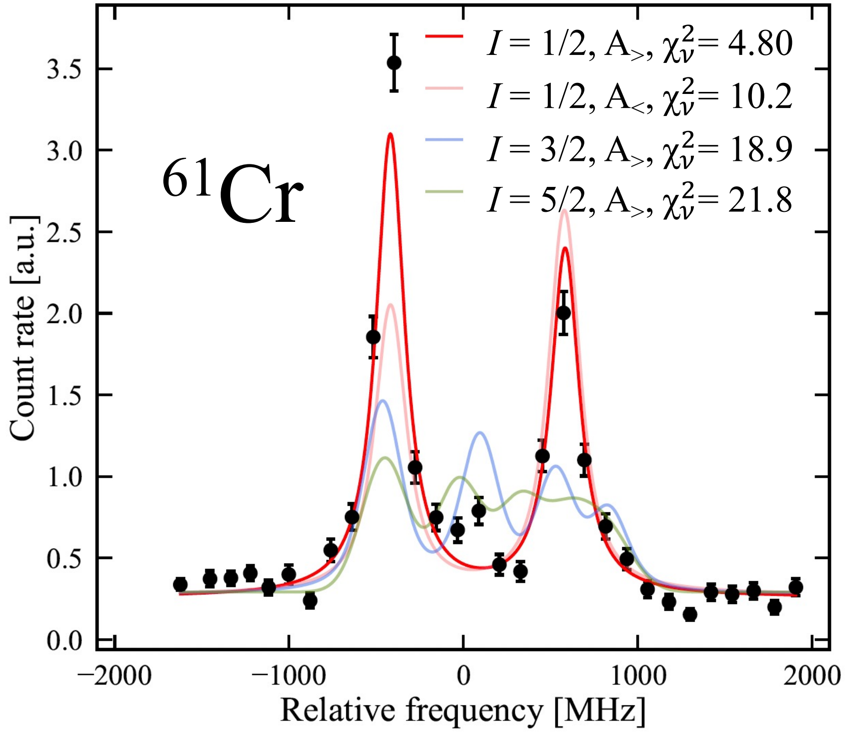

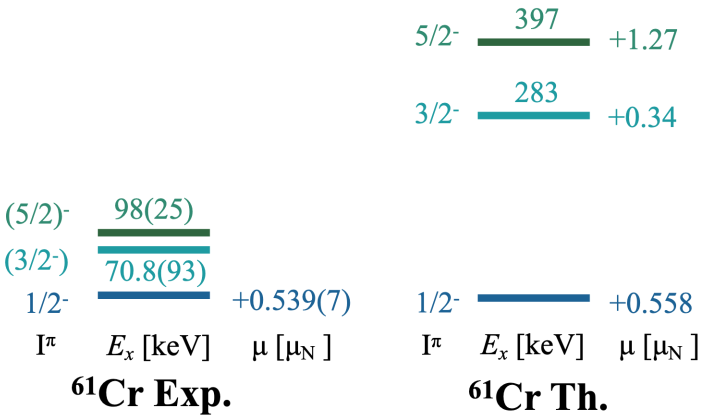

- ➢ *2p-2h* neutron intruder configuration with lonely $p_{1/2}$ neutron
- ➢ Triaxiality of ^{61}Cr ground state
- ➢ ^{61}Cr transition between the 2p-2h and the 4p-4h regime of the N=40 IoI
- ➢ 2nd order quantum phase transition at the entrance of the N=40 IoI

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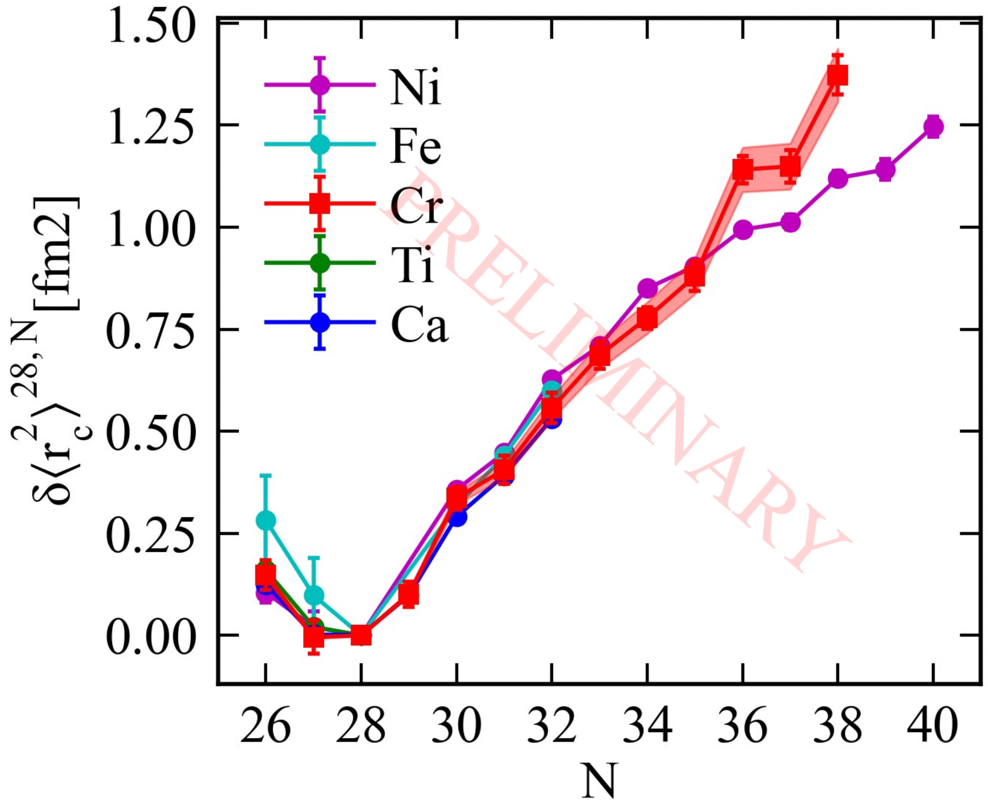
Charge radii of Cr isotopes



$$\delta\nu_i^{A,A'} = \frac{A-A'}{AA'} M_i + F_i\, \delta\langle r^2\rangle^{AA'}$$

- F and M determined from King plot using model independent absolute radii values [(a)] (muonic+e$^-$ scat.)

(a) J. W. Lightbody et al., PRC 27, 1 (1983)

- Strong kink at N=28, in good agreement with literature
- Steep increase of the Cr charge radii between N=28 and N=34
→ Interpreted in K and Ca from filling of neutron *p* halo orbits (b)
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- Clear jump at N=36

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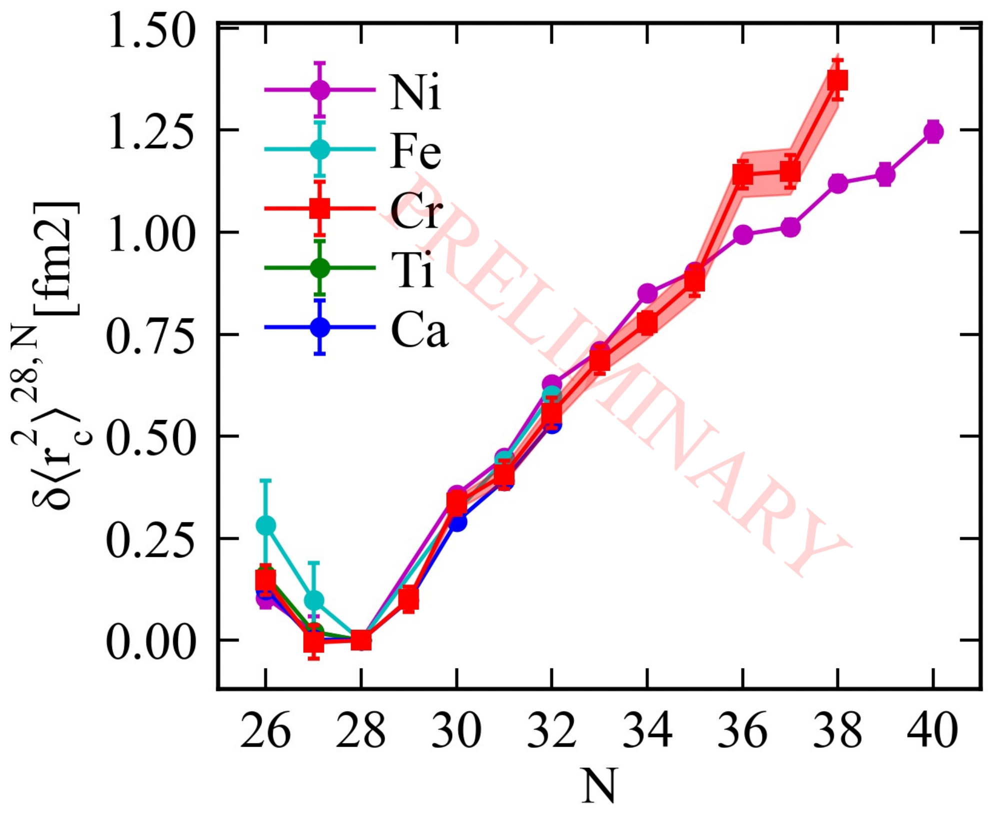

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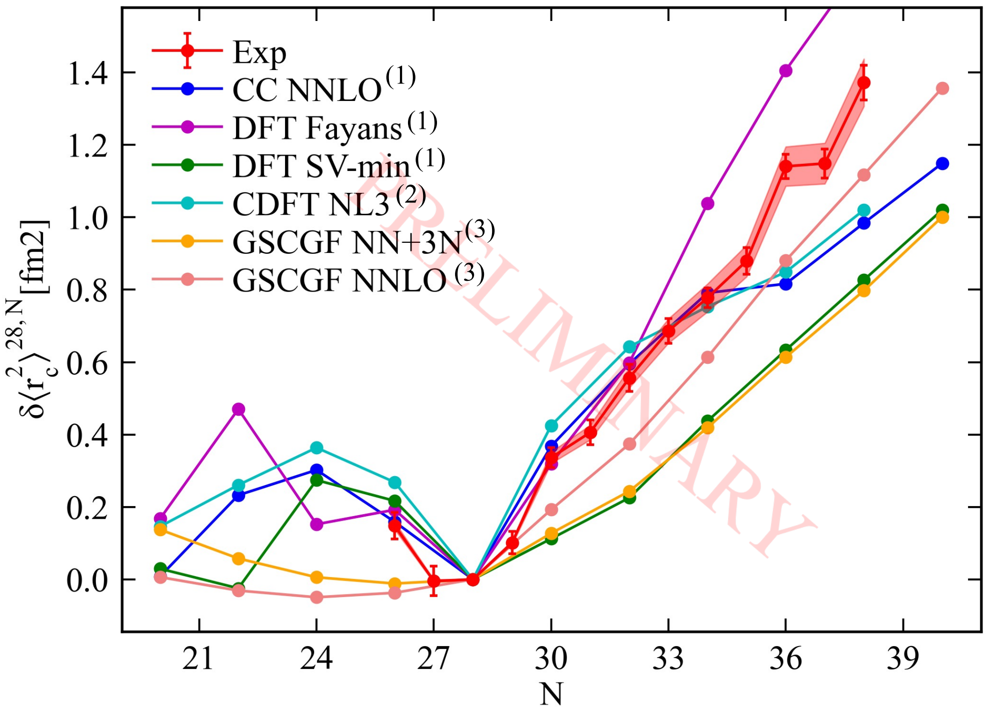

➢ Recent *ab-initio* (1,3) and DFT (1,2) calculations do not reproduce the evolution of Cr radii approaching the IoI

(1) M. Kortelainen, Z. Sun, G. Hagen, W. Nazarewicz, T. Papenbrock, and P.G. Reinhard , Phys. Rev. C **105**, L021303 (2022)
(2) U. C. Perera, A. V. Afanasjev, and P. Ring, PRC **104**, 064313 (2021)
(3) V. Somà, C. Barbieri, T. Duget & P. Navratil, EPJA 57, 135 (2021)

Charge radii of Cr isotopes

DZ : $$\rho_\pi^{sc} = \rho_\pi + \mathcal{D}, \qquad \mathcal{D} = \lambda S_\pi S_\nu + \mu Q_\pi Q_\nu .$$

$$\sqrt{\langle r_\pi^2 \rangle} \approx \rho_\pi = A^{1/3}\left(\rho_0 - \frac{\zeta}{2}\frac{t}{A^\sigma} - \frac{\upsilon}{2}\left(\frac{t}{A}\right)^2 \right) e^{(g/A)}$$

Phenomenological macroscopic formula from :
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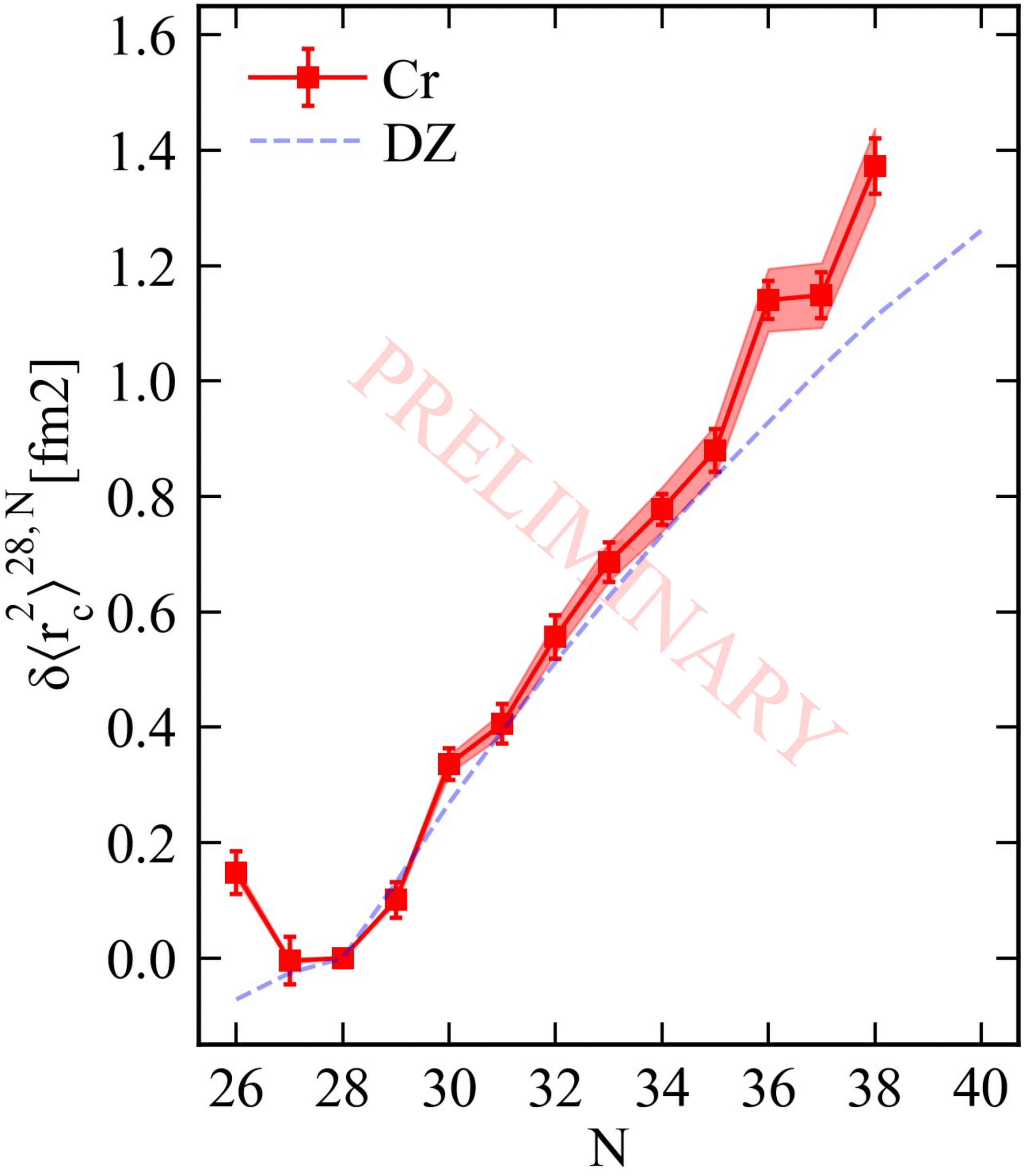

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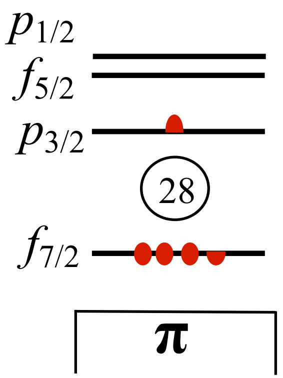
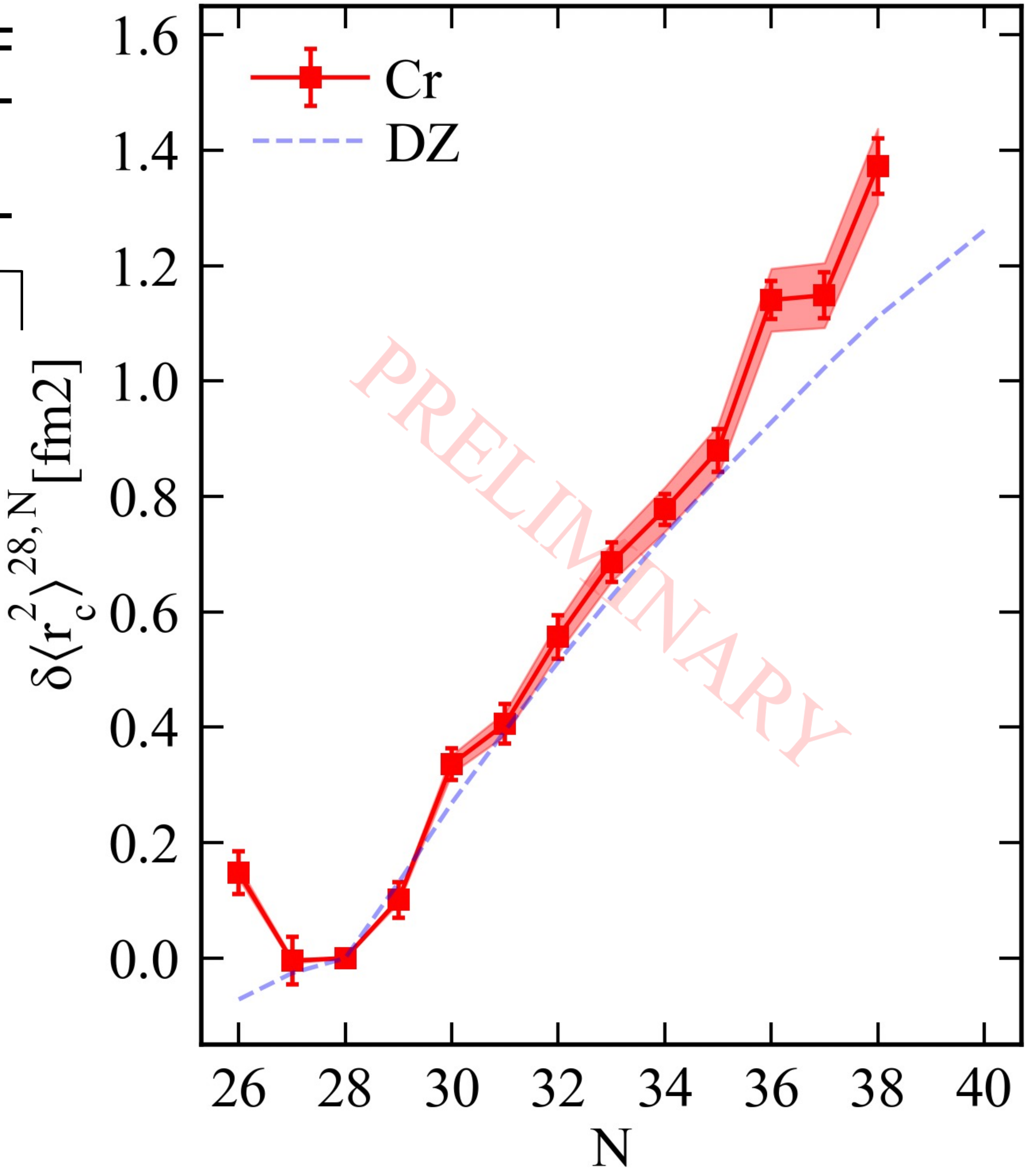


SM = DZ + Δ [$occ_p(A)$ - $occ_p(28)$]   where : $\Delta = \langle r_f^2\rangle - \langle r_p^2\rangle$



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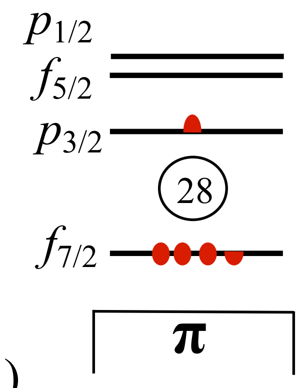

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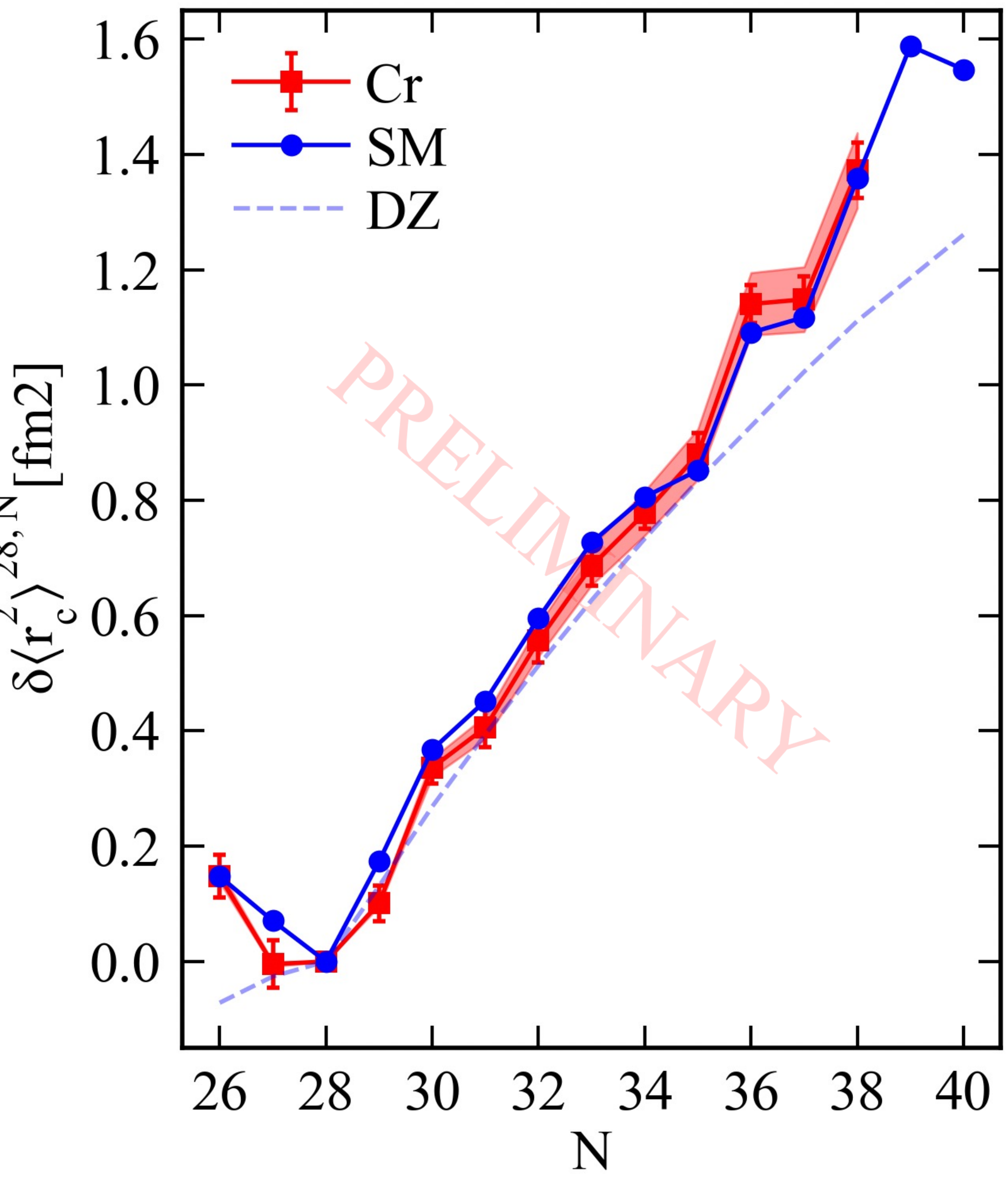
→ Add one parameter to DZ, proportional to the proton *p* orbits occupancies, reproduces exp. data very well
→ Deviation from DZ at N ≥ 36, where deformation arise

Interpretation :

- stronger deformation → stronger quadrupole correlation → stronger mixing between $\Delta l = 2$ protons *f* and *p* orbits.
- If true: radii jump shouldn't be present in Ni



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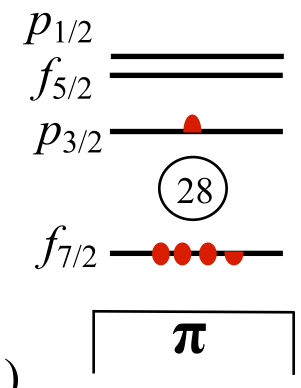

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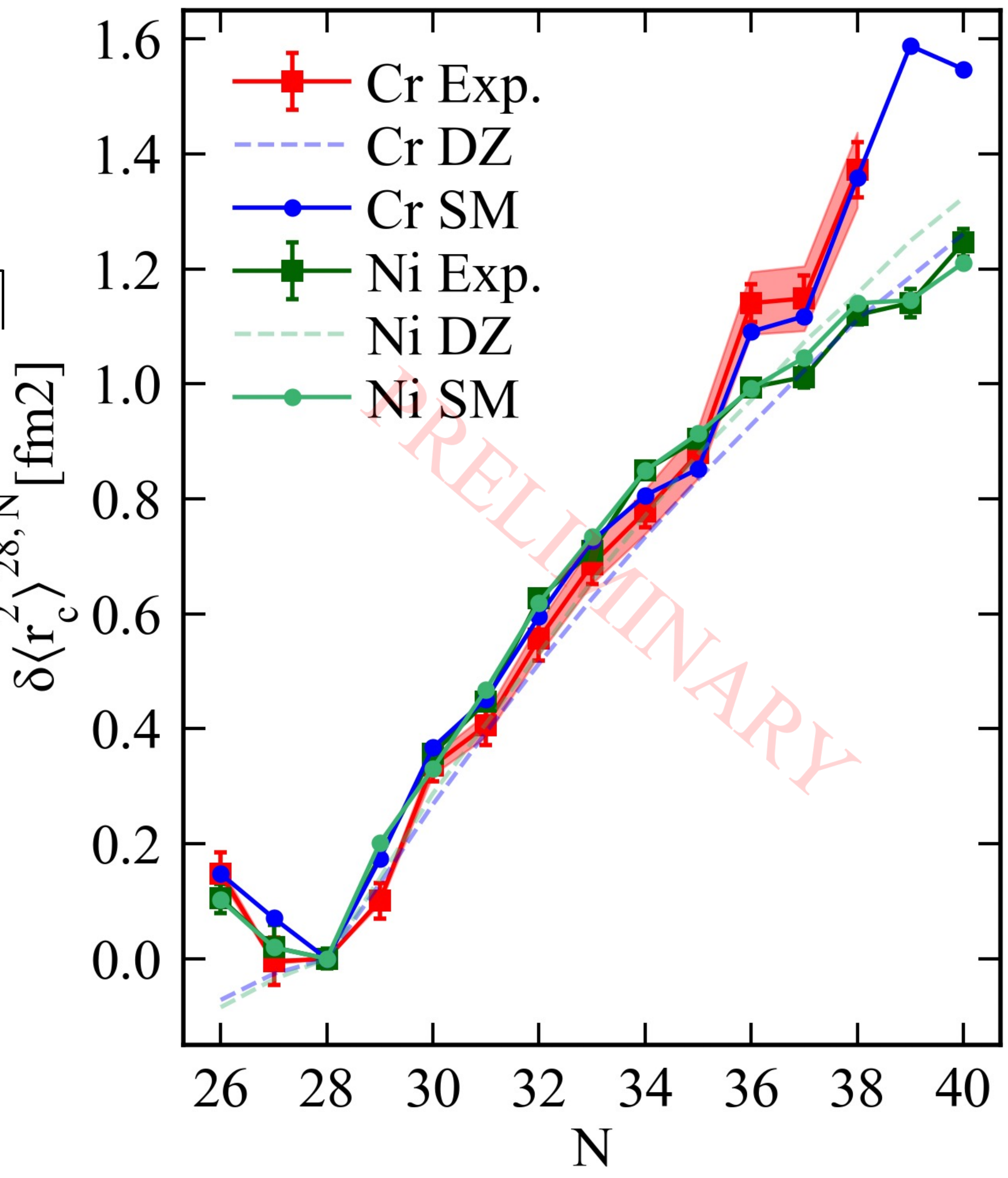
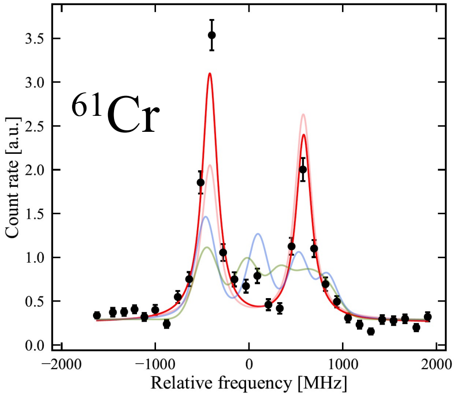
Small mixing difference due to deformation are seen in the charge radii thanks to the halo character of the *p* orbits

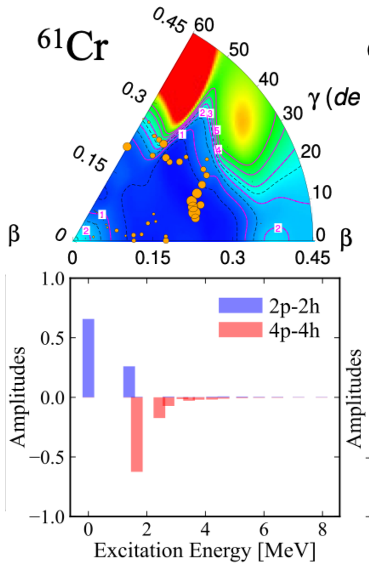


Conclusion

- $^{50\text{-}62}$Cr studied by laser spectroscopy with CRIS at ISOLDE

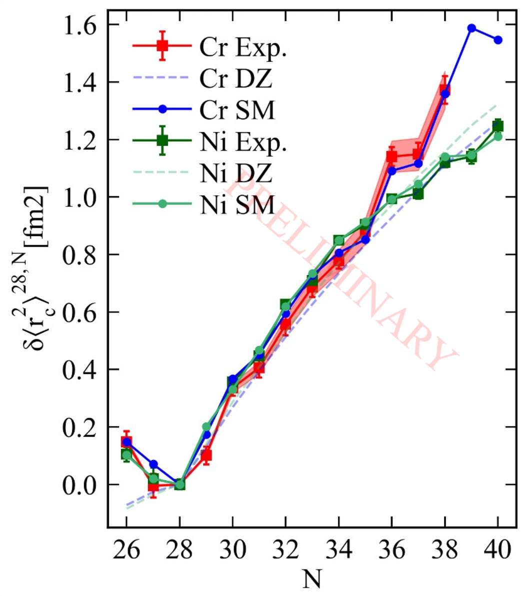
- First firm spin assignment of neutron rich odd-A Cr isotopes:
  → ^{57,59}Cr literature values confirmed
  → ^{61}Cr spin found to be 1/2, large impact on decay data





- ^{61}Cr as a doorway to the N=40 Island Of Inversion:
  → ^{61}Cr dominated by 2p-2h intruder structure and triaxial shape
  → Quantum Phase transition at the entrance of the *N*=40 IoI

- First measurement of changes in rms charge radii of neutron rich Cr outside stability:
  → Signature of rising deformation entering the N=40 Island of Inversion
  → Microscopic interpretation of radii within IoI with SM calculations
  → Sign for halo proton *p* orbits



The collaboration

L. Lalanne,[1,2,3,*] M. Athanasakis-Kaklamanakis,[1,2] D.D. Dao,[3] Á. Koszorús,[1] Y. C. Liu,[4] R. Mancheva,[2,1] F. Nowacki,[3] J. Reilly,[5] C. Bernerd,[2] K. Chrysalidis,[2] T. E. Cocolios,[1] R. P. de Groote,[1] K. T. Flanagan,[5] R. F. Garcia Ruiz,[6] D. Hanstorp,[7] R. Heinke,[1] M. Heines,[1] P. Lassegues,[1] K. Mack,[5] B. A. Marsh,[2] A. McGlone,[5] K. M. Lynch,[5] G. Neyens,[1] B. van den Borne,[1] R. Van Duyse,[1] X. F. Yang,[4] and J. Wessolek[5,2]

THANK YOU FOR YOUR ATTENTION