Collinear resonance ionization spectroscopy of chromium isotopes between $N = 28$ and $N = 40$

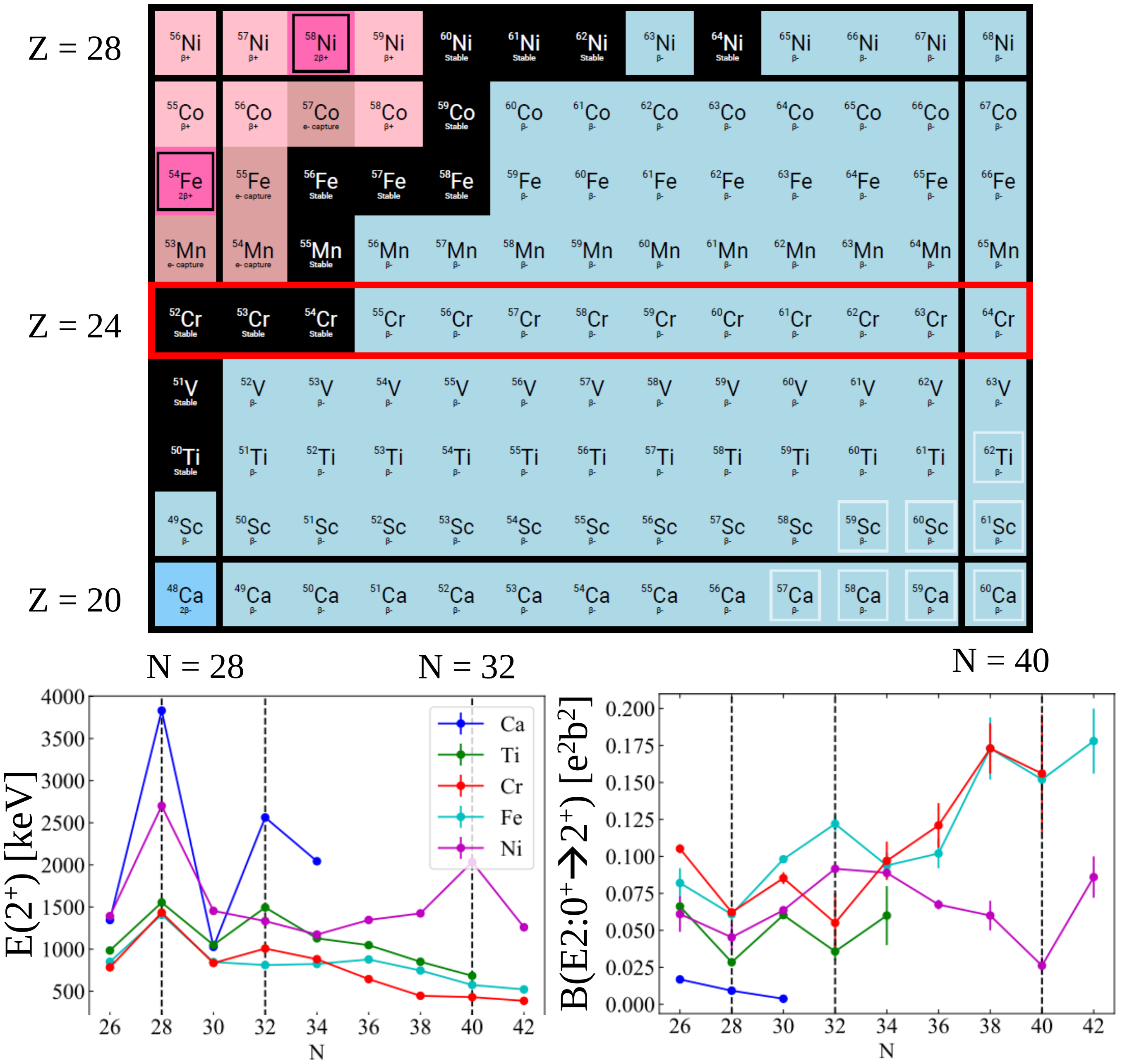
Louis Lalanne, Ágota Koszorús
and the CRIS collaboration

INTC Meeting
22/06/2022

Introduction

Shell evolution between Ca and Ni:

- Sub-shell closure at N=32 around ^{52}Ca
- Sign for a weak sub-shell closure at N=40 in ^{68}Ni
- N=40 Island of Inversion (IoI) around ^{64}Cr



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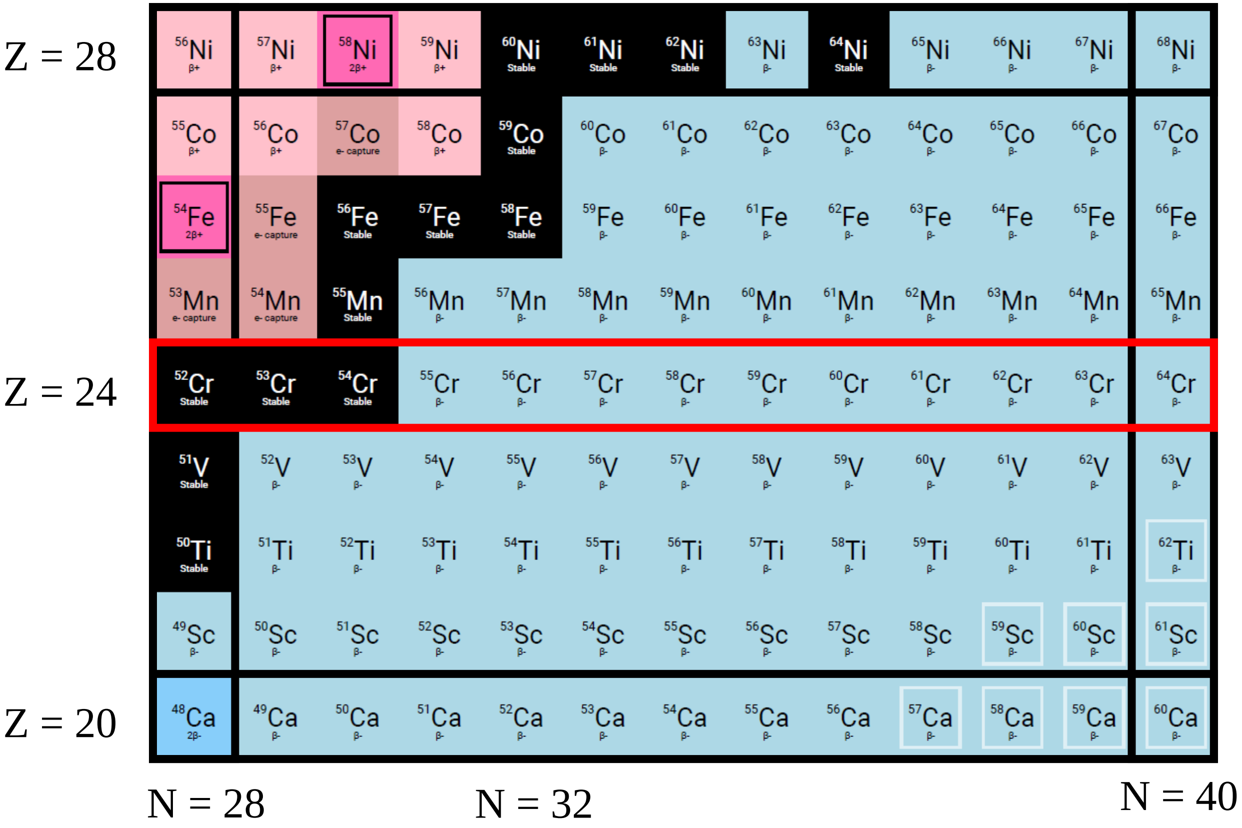
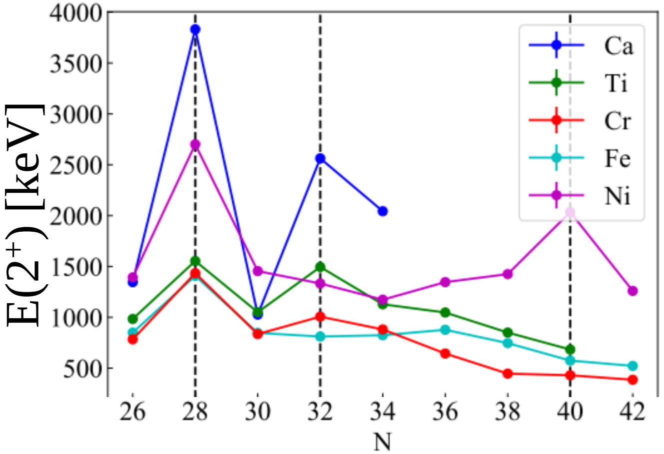
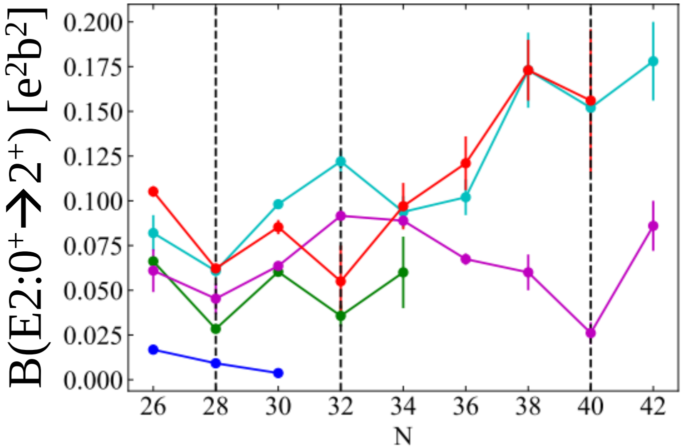
The Cr isotopes:

- Half filled $f_{7/2}$ → strongest *p*-*n* collectivity
- Highest Z for which a sign of N=32 is observed
- Fast increase of collectivity and deformation from N=32 onward
- ^{64}Cr is the predicted center of the N=40 IoI







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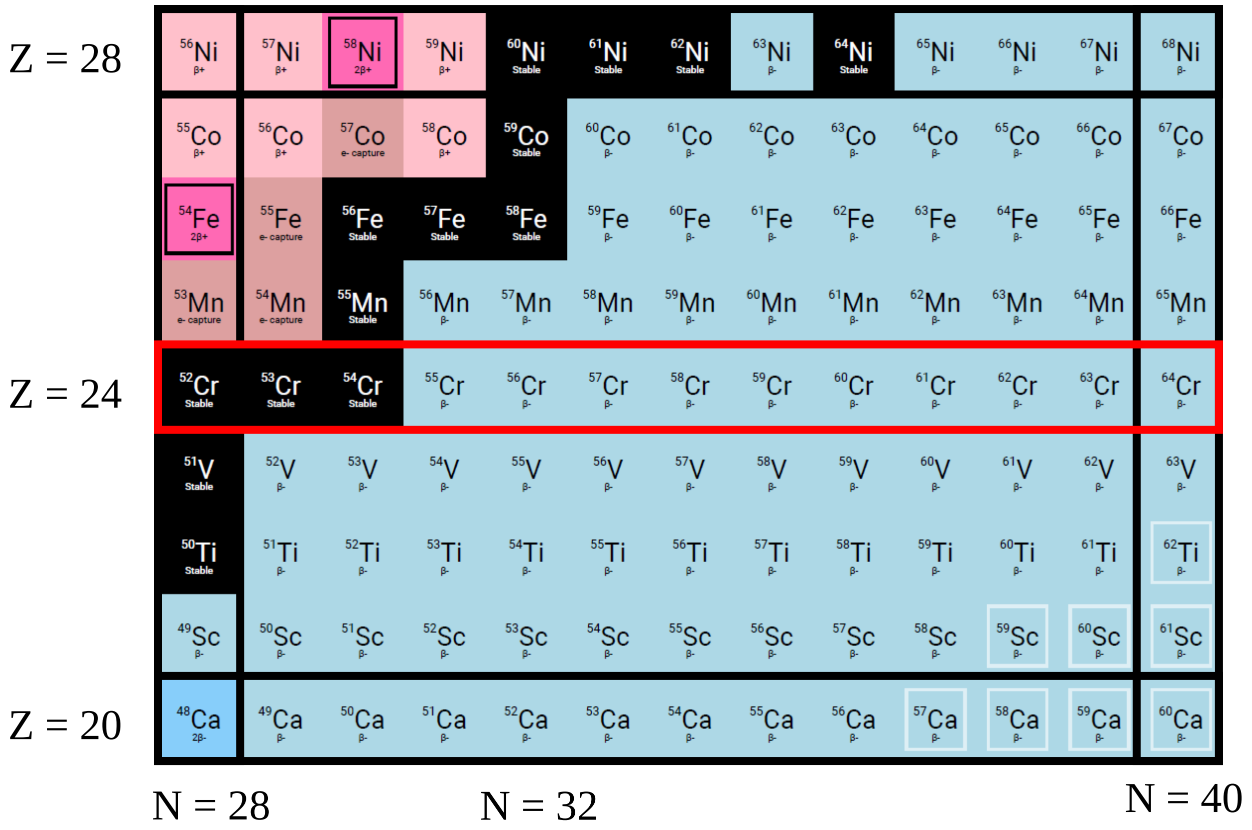
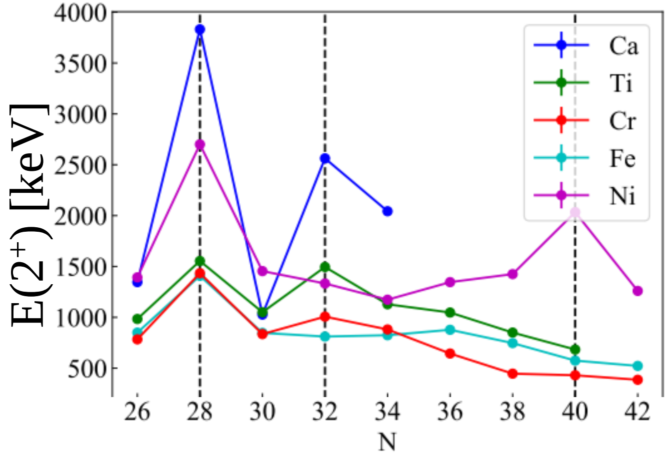
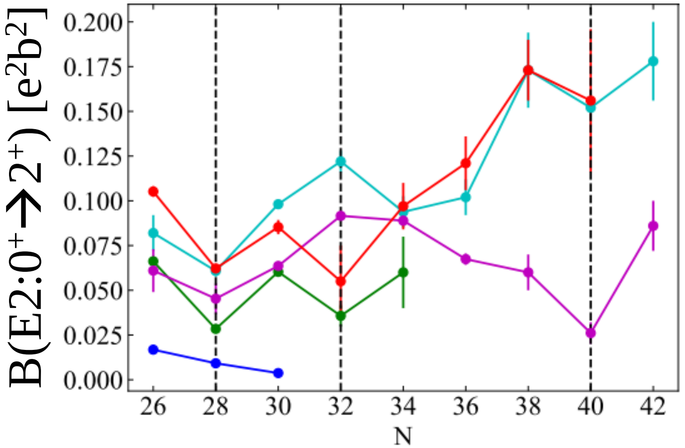


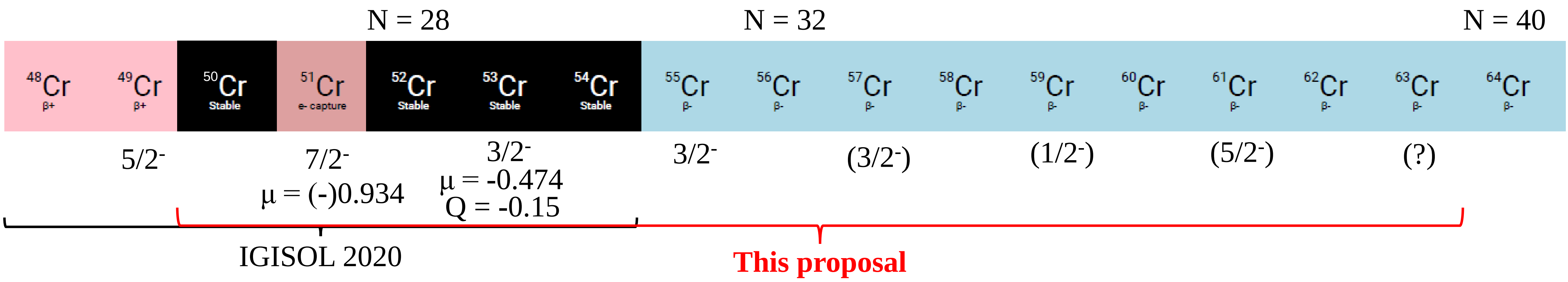
Drastic structural changes observed, driven by a complex interplay of single particle and collective behaviors that poses challenges to indirect methods and to nuclear theories





→ Need detail study of *g.s.* spins, moments and radii

Spins and Moments of odd-A Cr



Spins and Moments of odd-A Cr

N = 28 N = 32 N = 40

^{48}Cr	^{49}Cr	^{50}Cr	^{51}Cr	^{52}Cr	^{53}Cr	^{54}Cr	^{55}Cr	^{56}Cr	^{57}Cr	^{58}Cr	^{59}Cr	^{60}Cr	^{61}Cr	^{62}Cr	^{63}Cr	^{64}Cr
β+	β+	Stable	e- capture	Stable	Stable	Stable	β-	β-	β-	β-	β-	β-	β-	β-	β-	β-
	$5/2^-$		$7/2^-$ $\mu = (-)0.934$		$3/2^-$ $\mu = -0.474$ $Q = -0.15$		$3/2^-$		$(3/2^-)$		$(1/2^-)$		$(5/2^-)$		(?)	

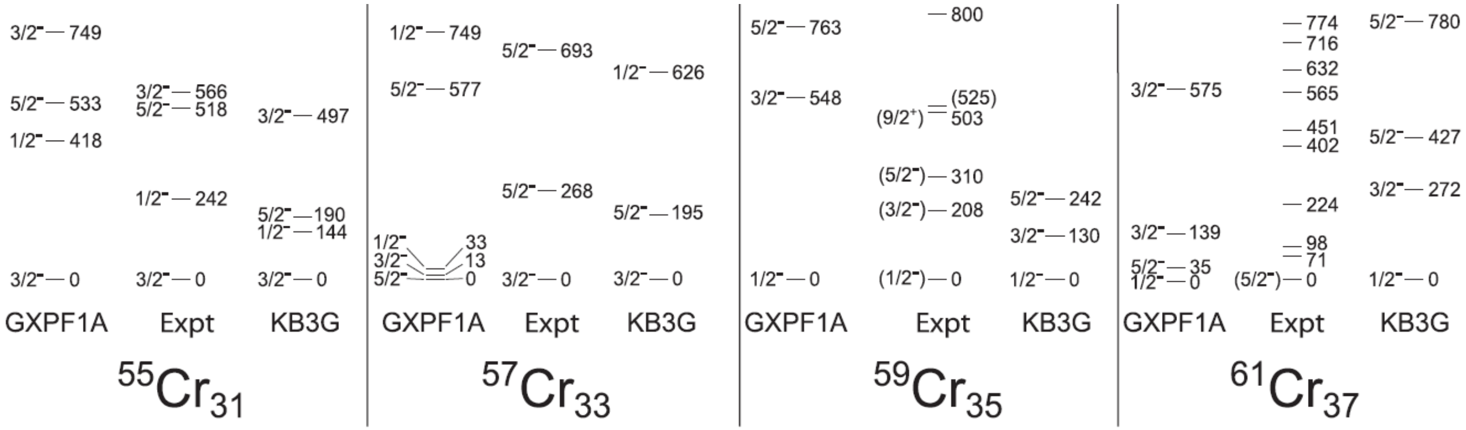
IGISOL 2020

This proposal

Spins of odd-*A* Cr isotopes:

- **No *g.s.* spin firmly assigned beyond *N*=32**
- High density of low-lying states makes spin assignment very challenging for indirect method and for nuclear theory

S. Suchyta *et al.*, Phys. Rev. C 89, 034317 (2014)



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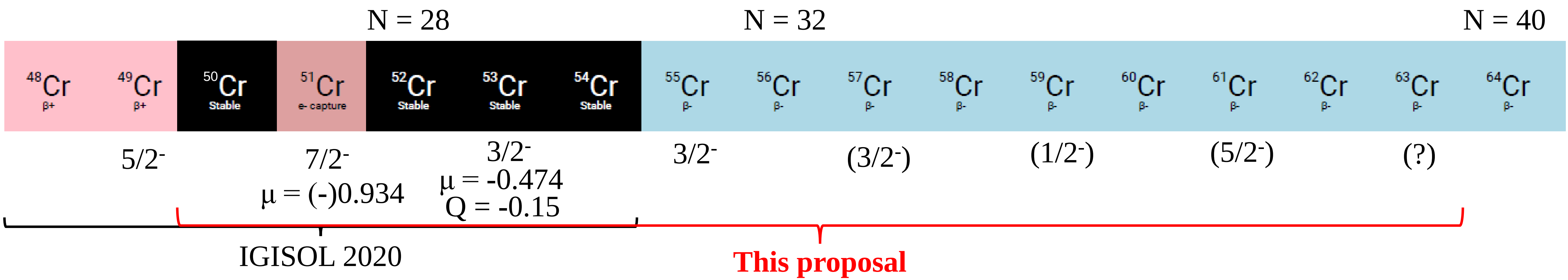

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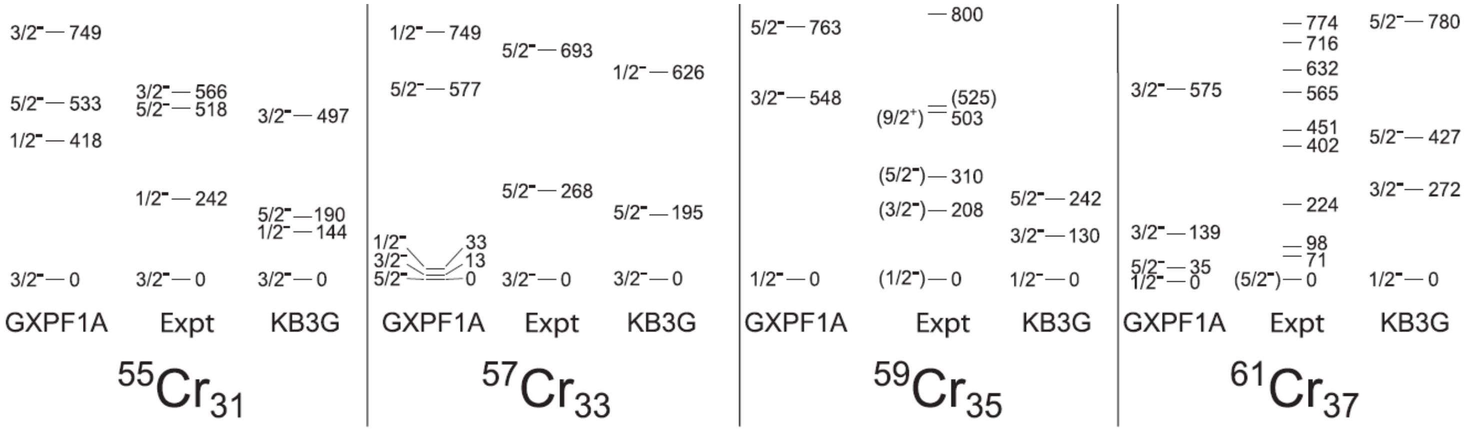
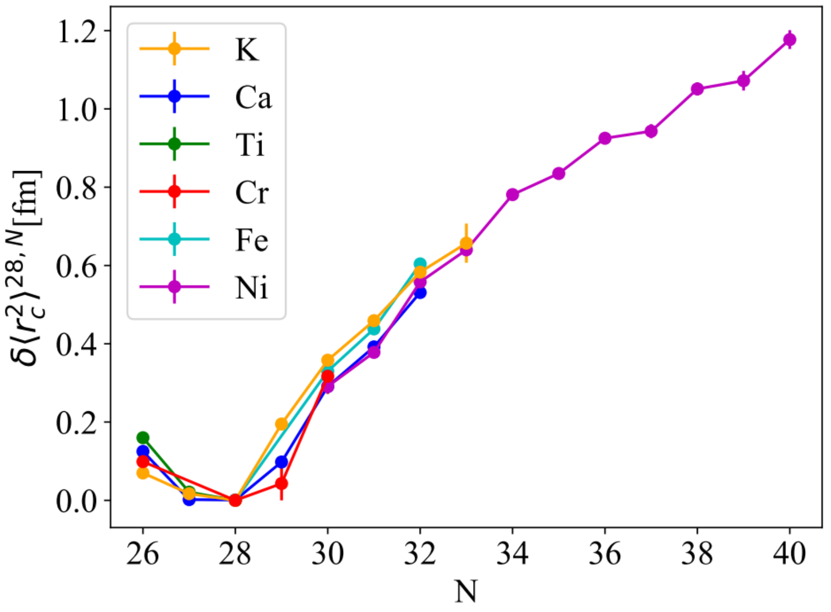
Moments of odd-*A* Cr isotopes :

- **No moments known outside stability**
- *g.s.* wf is expected to be very mixed
- Transition from spherical to deformed

→ Very challenging case for nuclear theory



Charge Radii of Neutron Rich Cr

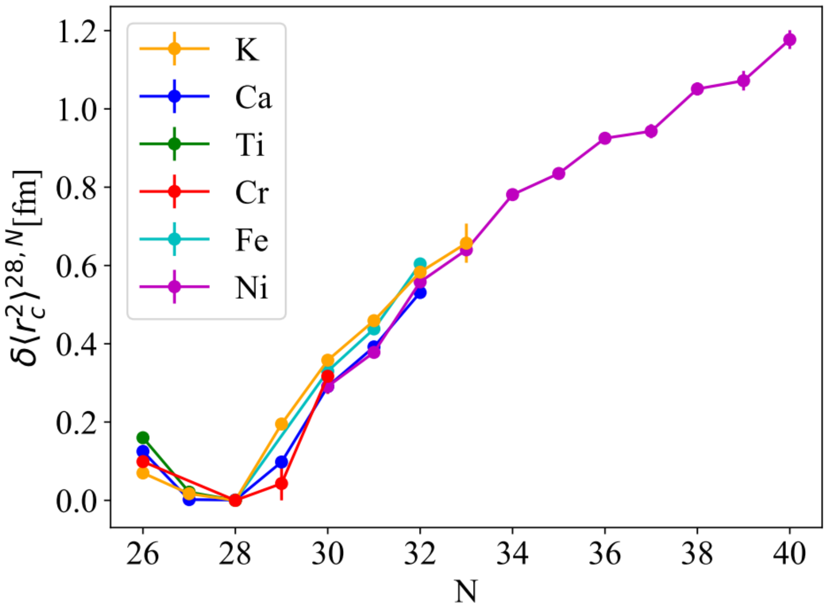


Charge Radii of Neutron Rich Cr

Steep increase beyond *N*=28:

- Intriguing Z independent behavior
- Lack of data beyond N=32 for even Z isotopes
- Cr has the highest level of collectivity

→ Best candidate to observe a faster increase



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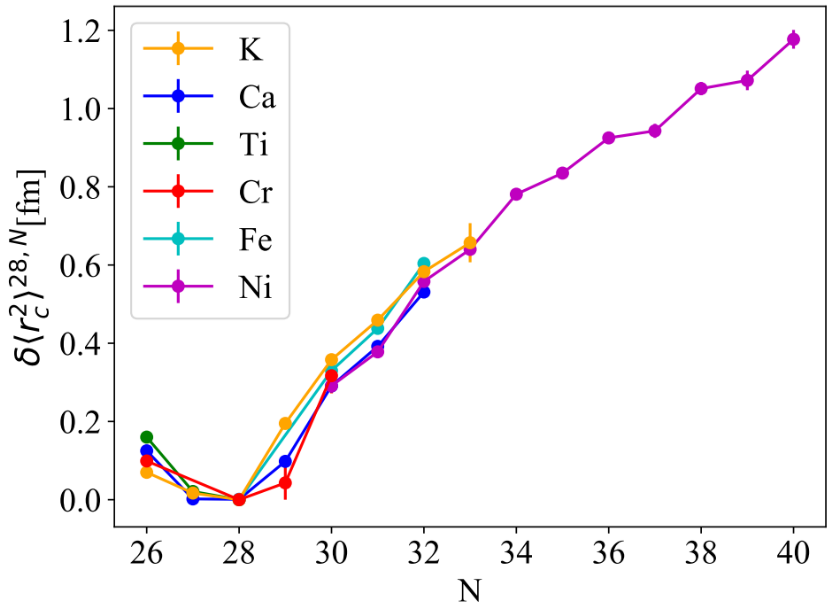
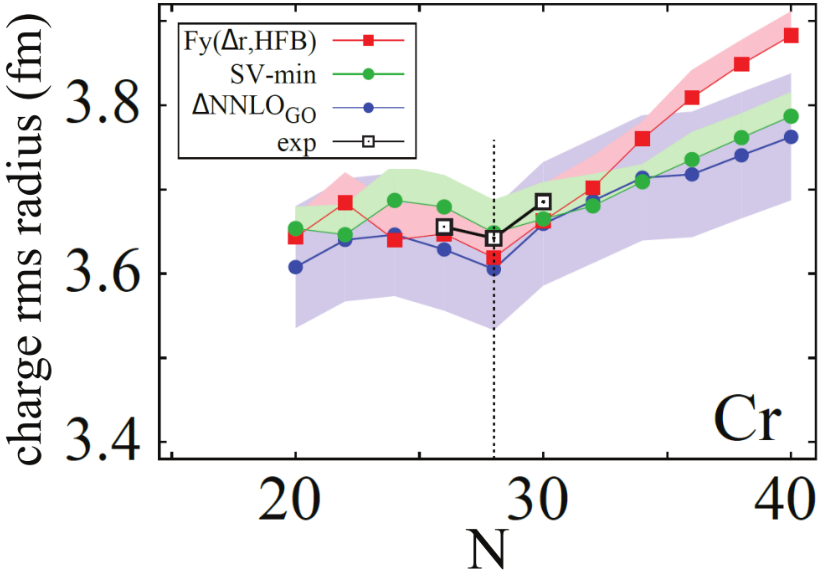
Comparison to theory:
- Z independency investigated by theory
- Discrepancy btw state-of-the-art ab-initio CC and Fayans DFT

→ **Theory calls for Cr data**





M. Kortelainen *et al.*, Phys. Rev. C 105, L021303 (2022)

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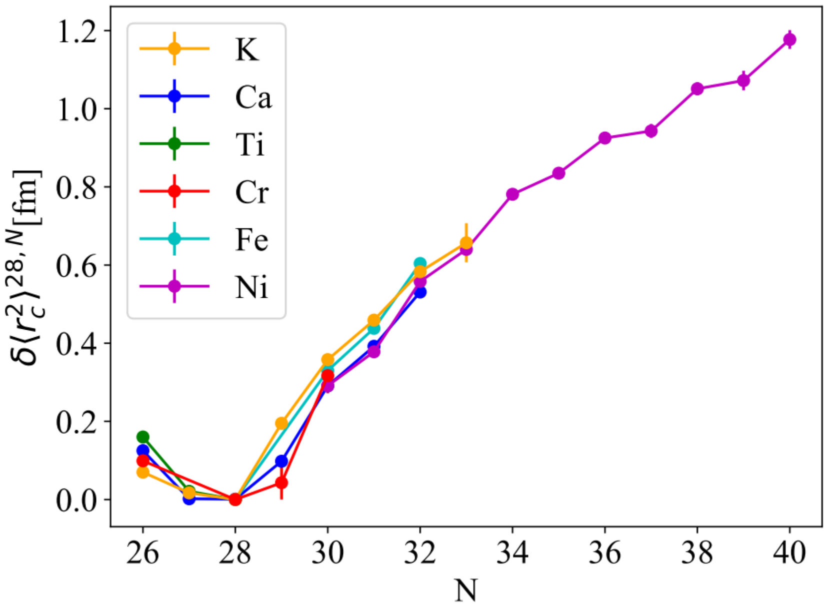
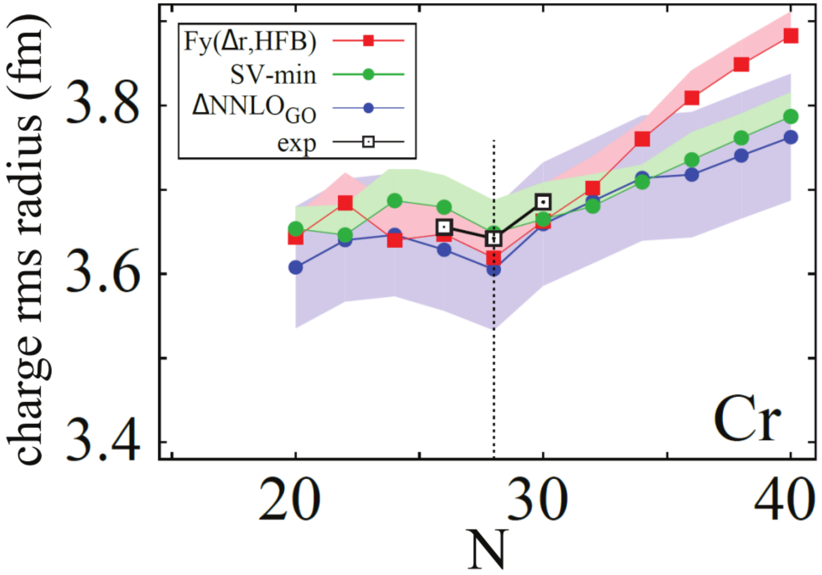
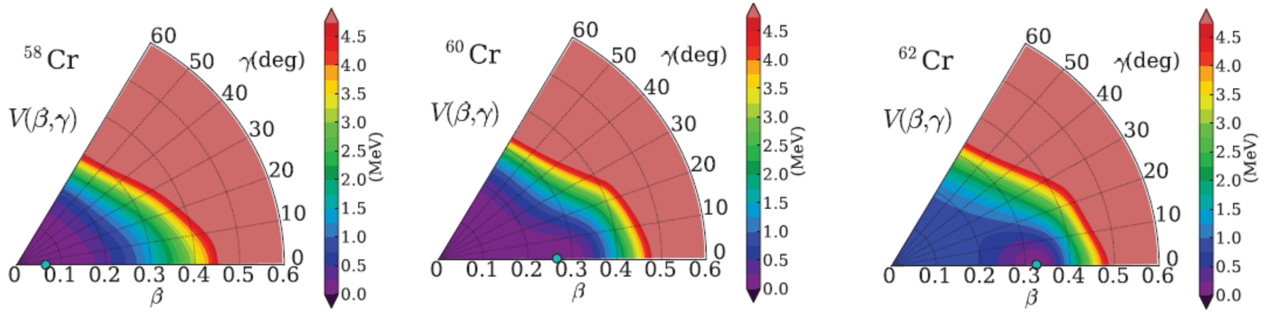
Effect of shape transition on charge radii:
- Shape transition from spherical to prolate around ^{58}Cr
- Sign of triaxiality in Mn (1)

→ Large irregularities are expected in the Cr charge radii





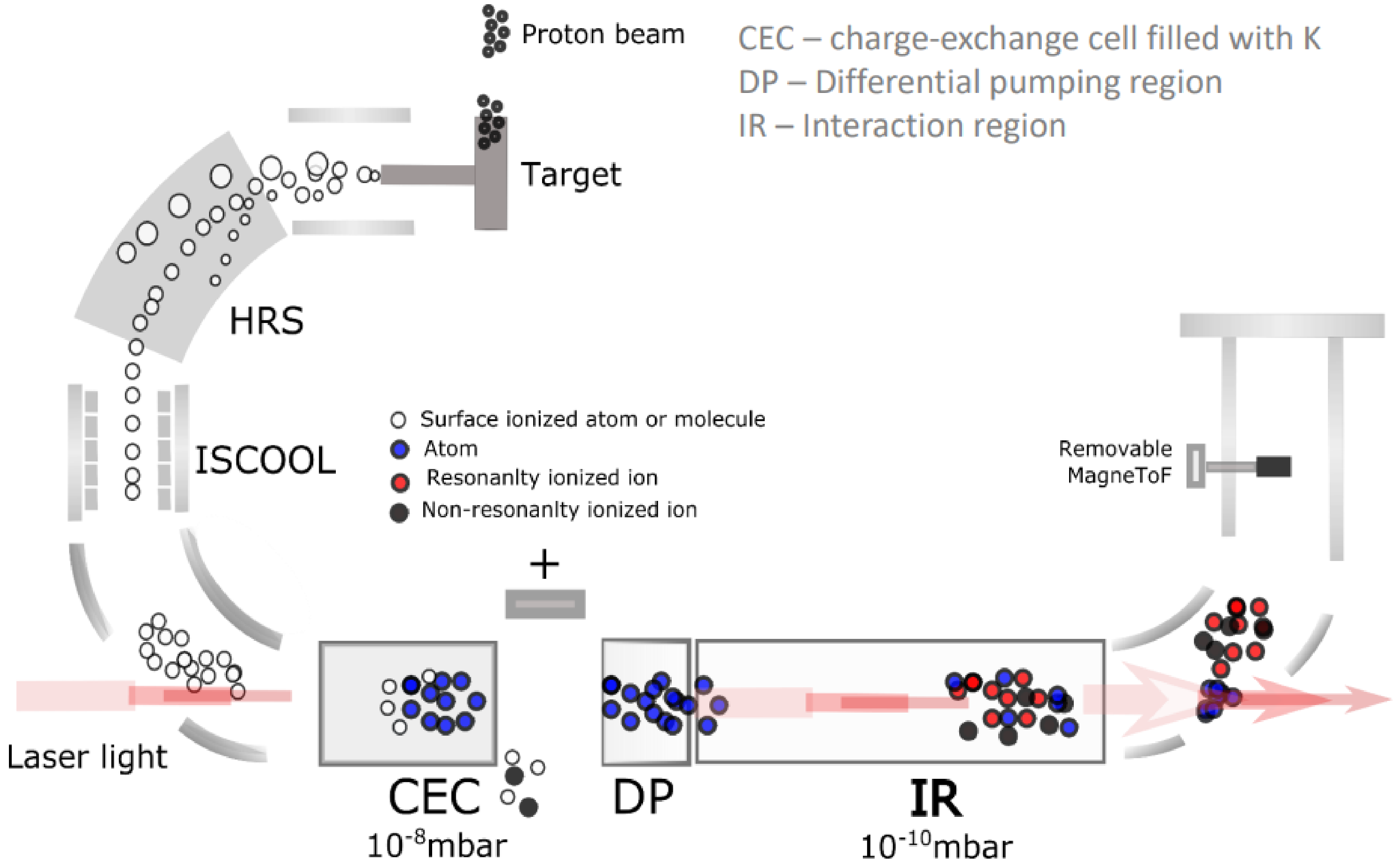


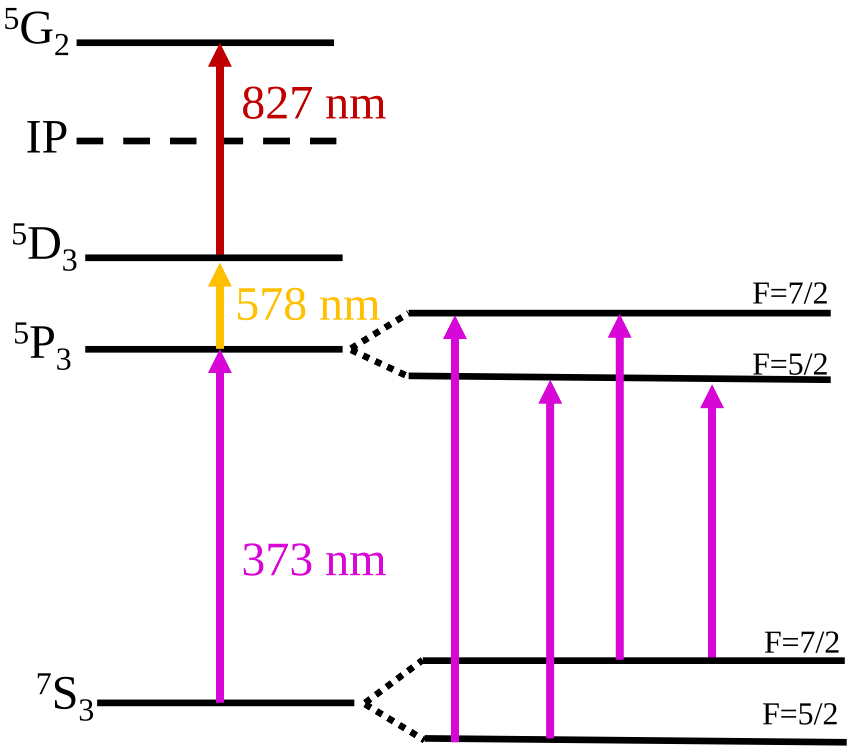
K. Sato *et al.*, Phys. Rev. C 86, 024316 (2012)

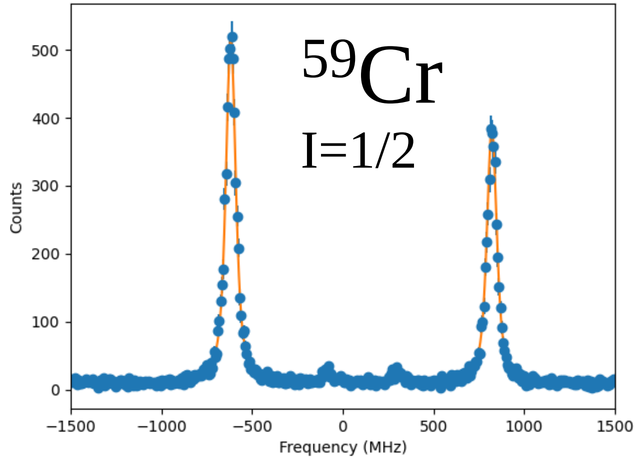
(1) H. Heylen et al., Phys. Rev. C 94, 054321 (2016)

M. Kortelainen *et al.*, Phys. Rev. C 105, L021303 (2022)

The CRIS experiment







Shift Request

Cr Beam :

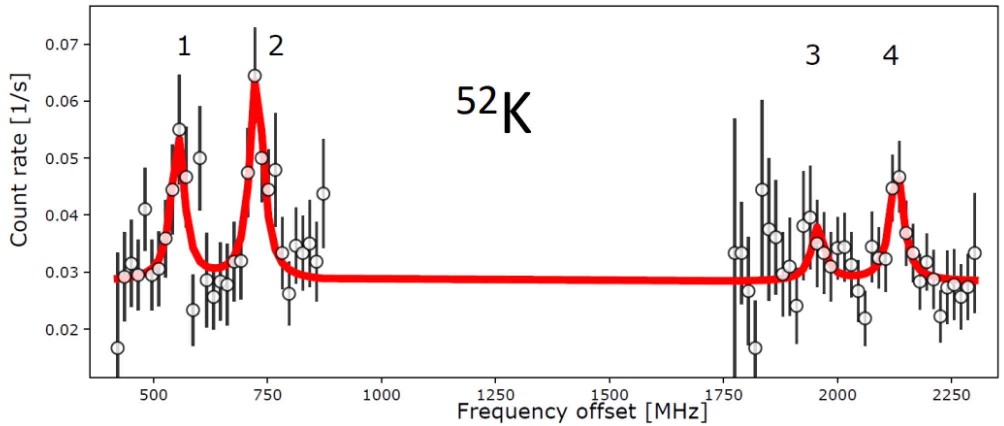
- UCx + RILIS: yields from ISOLTRAP [(1)]
- > 10^4 pps up to ^{60}Cr
- Measurement feasible up to ^{63}Cr

[(1)]M. Mougeot *et al.*, Phys. Rev. L 120, 232501 (2018)

Isotope	N	Yields UC_x + RILIS [ions/s]	Half-life	shifts
$^{50-59}$Cr	26-35	$> 10^5$	> 1 s	3.8
^{60}Cr	36	2×10^4	490(10) ms	0.2
^{61}Cr	37	2×10^3	243(9) ms	1
^{62}Cr	38	3×10^2	206(12) ms	2
^{63}Cr	39	3×10^1	129(2) ms	8
^{52,53}Cr		Reference isotopes		3
Stable		Optimization of the experimental set-up		2
Total :				20

Shift request :

- Re-measurement of $^{50-54}$Cr for field-mass shift factor calibration and benchmark meas. for moments
- Yields for $^{50-60}$Cr > 10^4 pps → 4 shifts
- ^{52}K: yield ~ 300 pps, T ~ 110 ms, 3 shifts
- Regular Ref. measurement on ^{52,53}Cr to monitor drifts



A. Koszorús et al., Nature Physics 17 439–443 (2021)

TAC comments: The TAC does not foresee any serious issues with this proposal.

Conclusion

		N = 28				N = 32								N = 40
^{50}Cr	^{51}Cr	^{52}Cr	^{53}Cr	^{54}Cr	^{55}Cr	^{56}Cr	^{57}Cr	^{58}Cr	^{59}Cr	^{60}Cr	^{61}Cr	^{62}Cr	^{63}Cr	^{64}Cr
2β+	e- capture	Stable	Stable	Stable	β-	β-	β-	β-	β-	β-	β-	β-	β-	β-
	$7/2^-$		$3/2^-$		$3/2^-$		$(3/2^-)$		$(1/2^-)$		$(5/2^-)$		(?)	

This proposal :

Laser spectroscopy of $^{50-63}$Cr (Z = 24, N = 26 − 39)

Scientific goals:

- *g.s* spin indispensable to construct reliable level schemes
  → First firm spin assignment of the *g.s.* of the odd-*A* isotopes
- Determine *g.s.* wf composition, map the *N*=40 IoI and provide stringent test for nuclear theories
  → First measurement of nuclear moments
- Investigate the various structural changes and compare to state-of-the-art *ab-initio* and DFT calculations
  → First measurement of charge radii

Method:

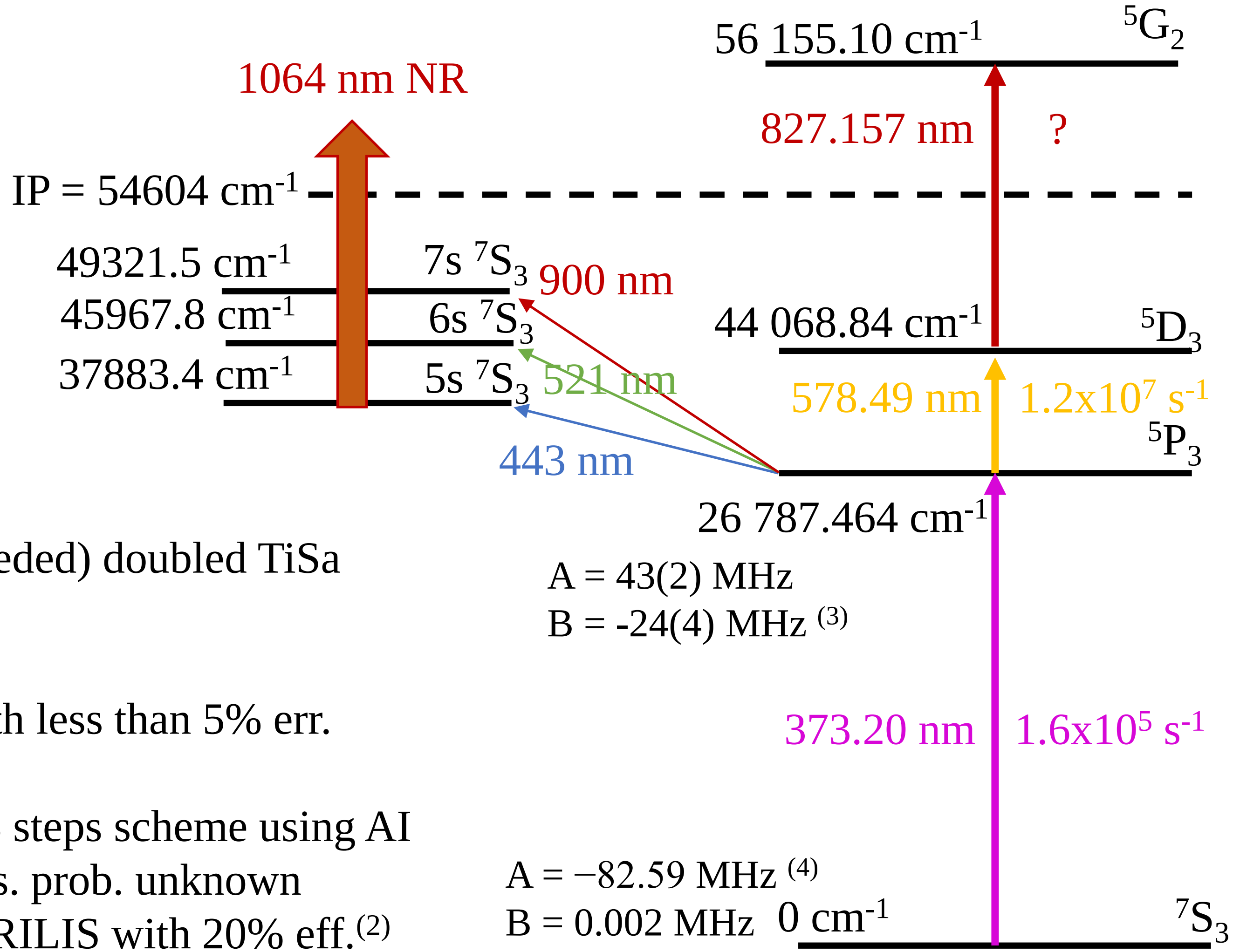
- Collinear resonance ionization spectroscopy at CRIS

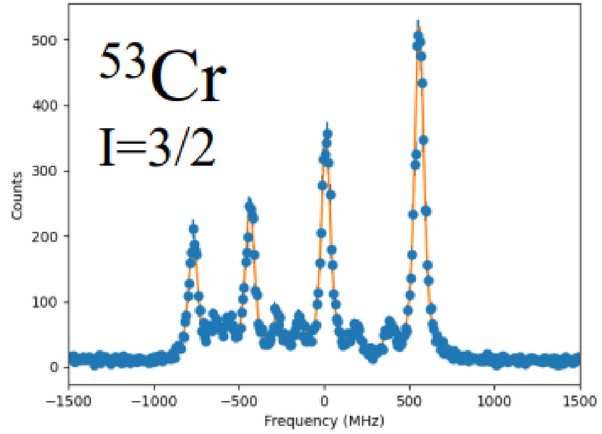
Requested shifts:

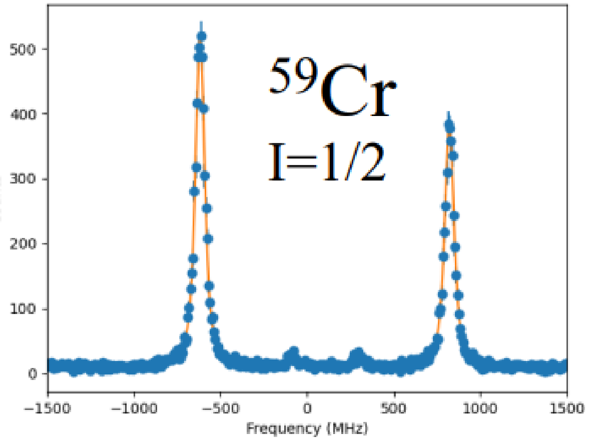
- 2+18 shifts on a UCx target + RILIS

THANK YOU FOR YOUR ATTENTION

Ionization Scheme







Spec. step : $^7S_3 \rightarrow {}^5P_3$

- Chopped (or injection seeded) doubled TiSa
- *sp* transition
- Good sensitivity to A
- Need large stat. for B with less than 5% err.

Large CaF^+ and TiO^+ [(1)] → 3 steps scheme using AI

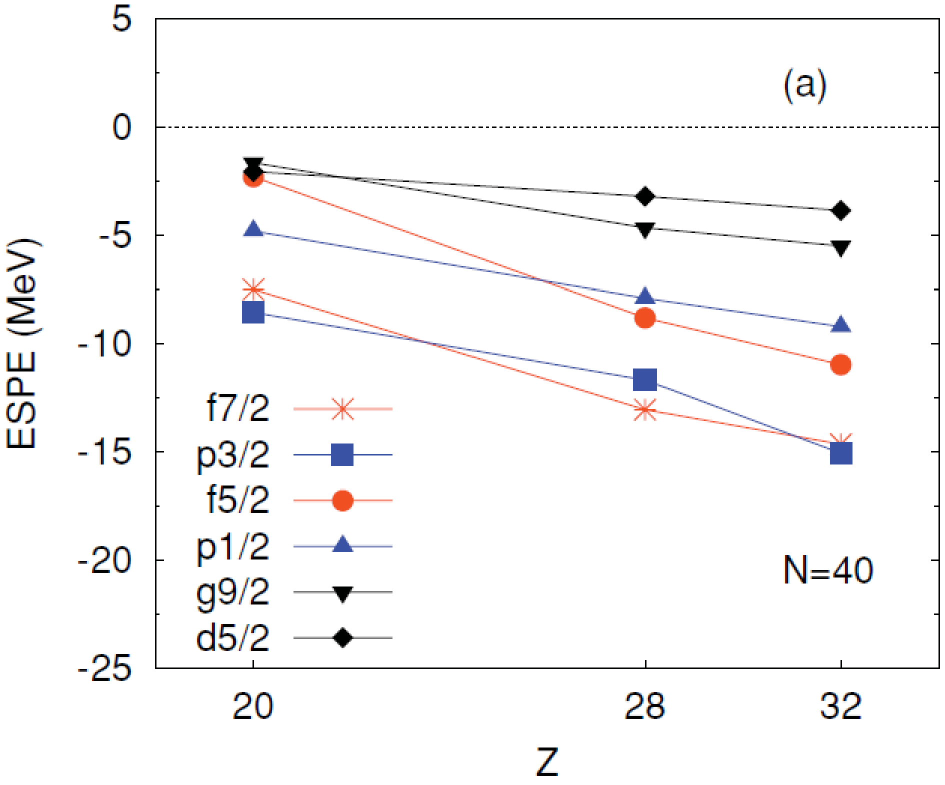
- Some AI known but trans. prob. unknown
- Similar scheme used by RILIS with 20% eff.[(2)]
- Offline work for eff. test and eventually AI search
- β-tagging setup with tape

(1) M. Mougeot *et al.*, Phys. Rev. L 120, 232501 (2018) (2) T. Day Goodrace *et al.*, Spec. Acta B 129, 58-63 (2017)

(3) W. Ertmer *et al. Z. Phys.* A **309** 1 (1982)

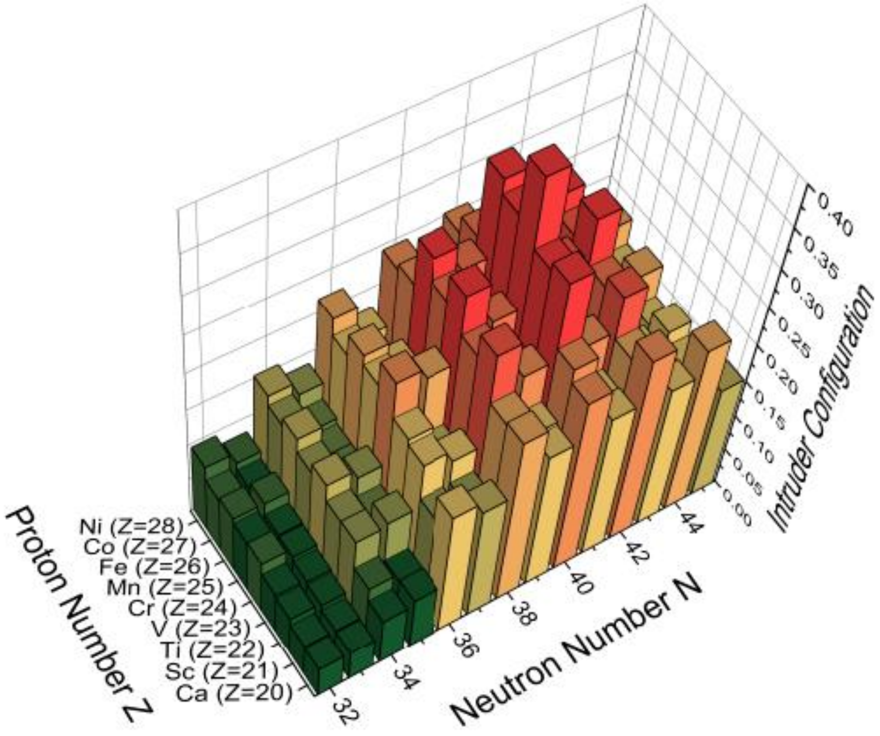
(4) T. Reinhardt *et al.*, Z. Phys. D 34, 87-90 (1995)

The *N*=40 Island of Inversion



Neutron effective single-particle energies obtained with (a) the LNPS interaction at $N = 40$

S. M. Lenzi *et al.*, Phys. Rev. C, vol. 82, p. 054301 (2010)

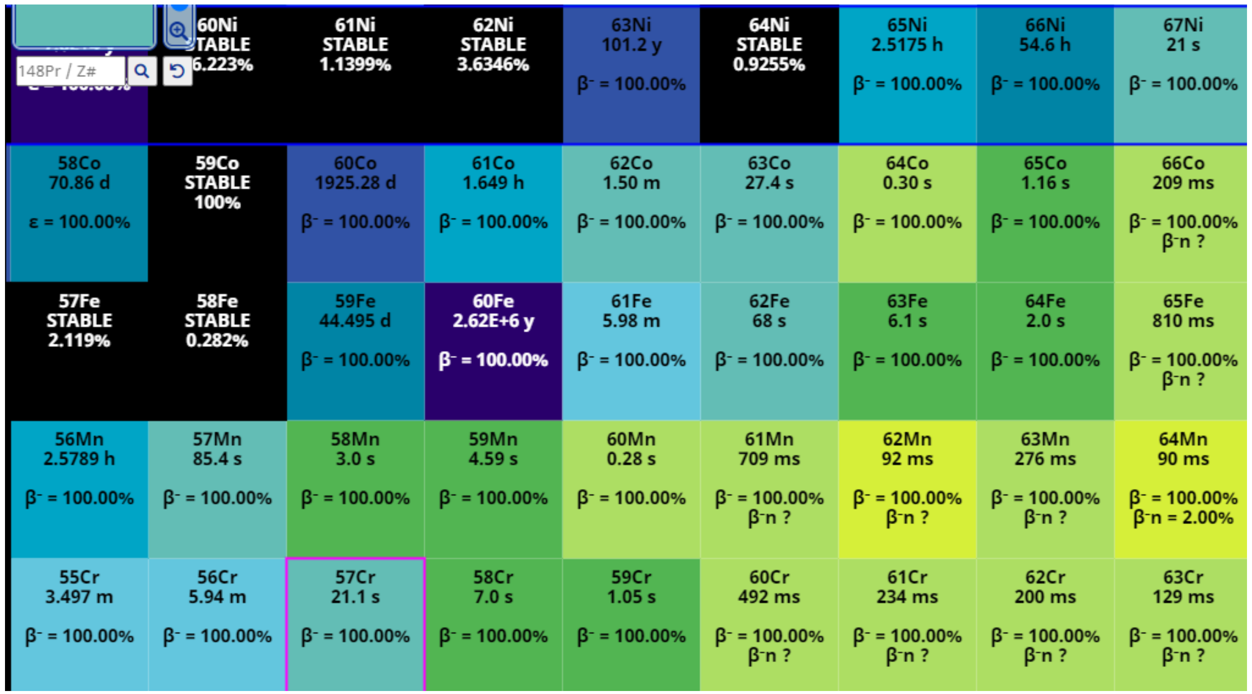


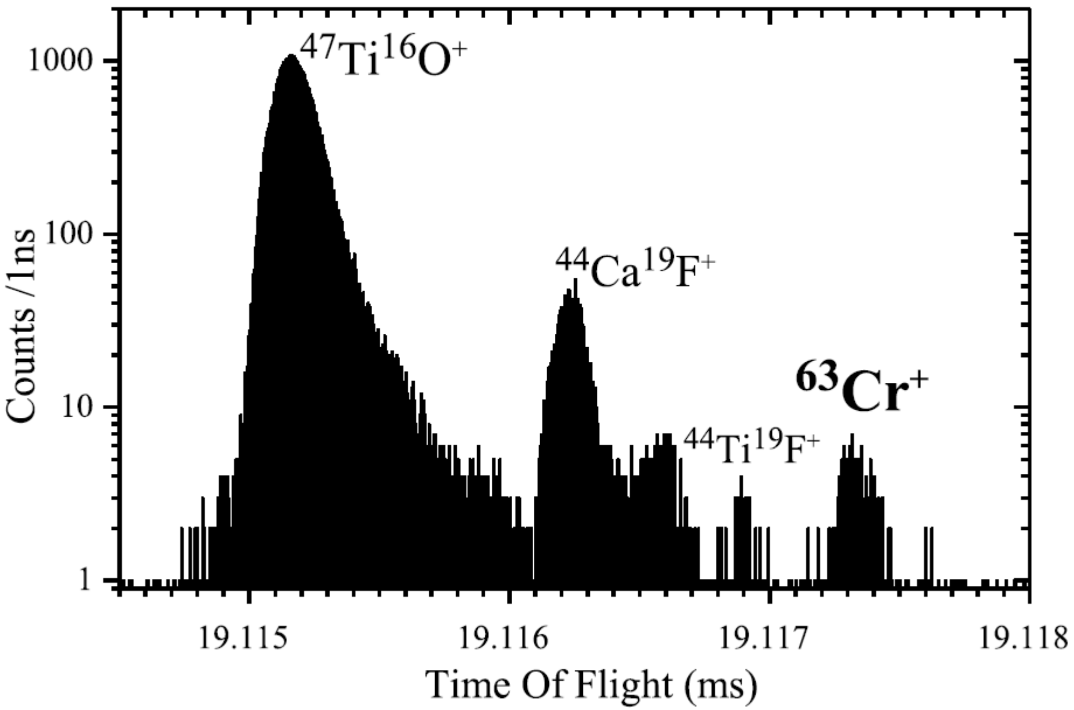
The intruder contribution of the calculated ground-state wave function for the elements Ca (Z=20) through Ni(Z=28), computed by the VS-IMSRG(2) within the proton *pf* neutron *pf*-$g_{9/2}$ valence space.

R.Silwal *et al.*, arXiv:2204.09566v1 (2022)

Contaminants

$T_{1/2}$





M. Mougeot *et al.*, Phys. Rev. L 120, 232501 (2018)

TiO and CaF contaminant from mass 59 to 63

→ Beta taging setup to remove stable contaminants