2023 at CRIS

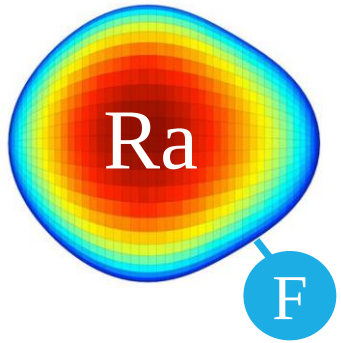
Louis Lalanne

CERN / ISOLDE

on behalf of the CRIS collaboration

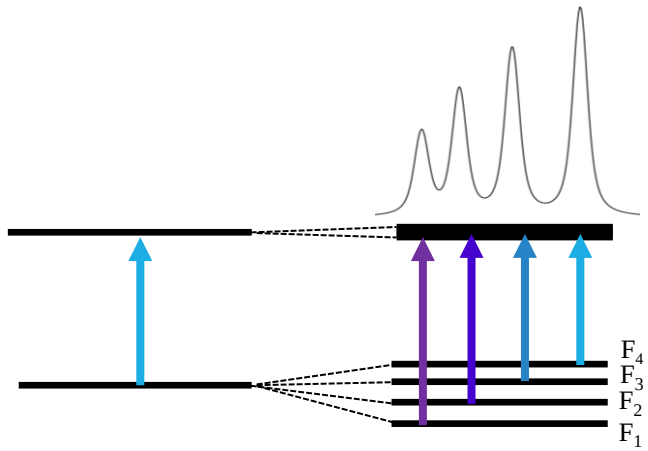
ISOLDE Workshop

30/11/2023



CRIS : Collinear Resonance Ionization Spectroscopy

Hyperfine Structure (HFS) :



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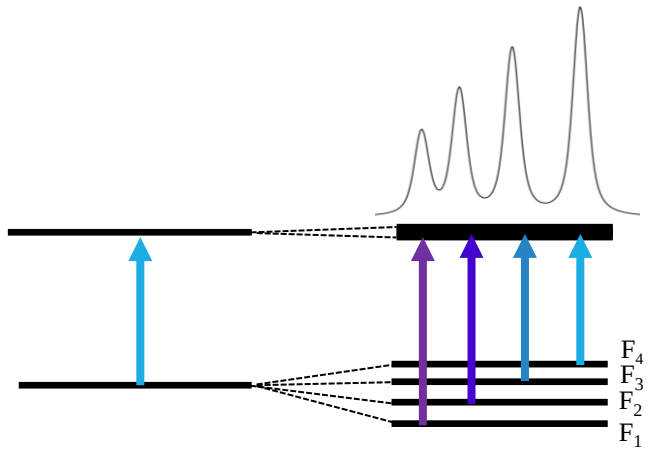

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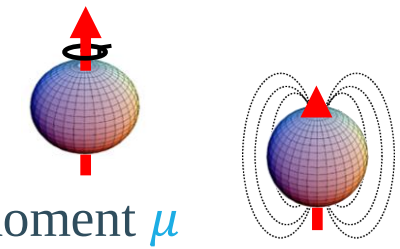

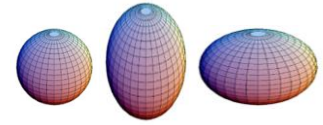

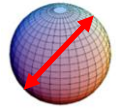

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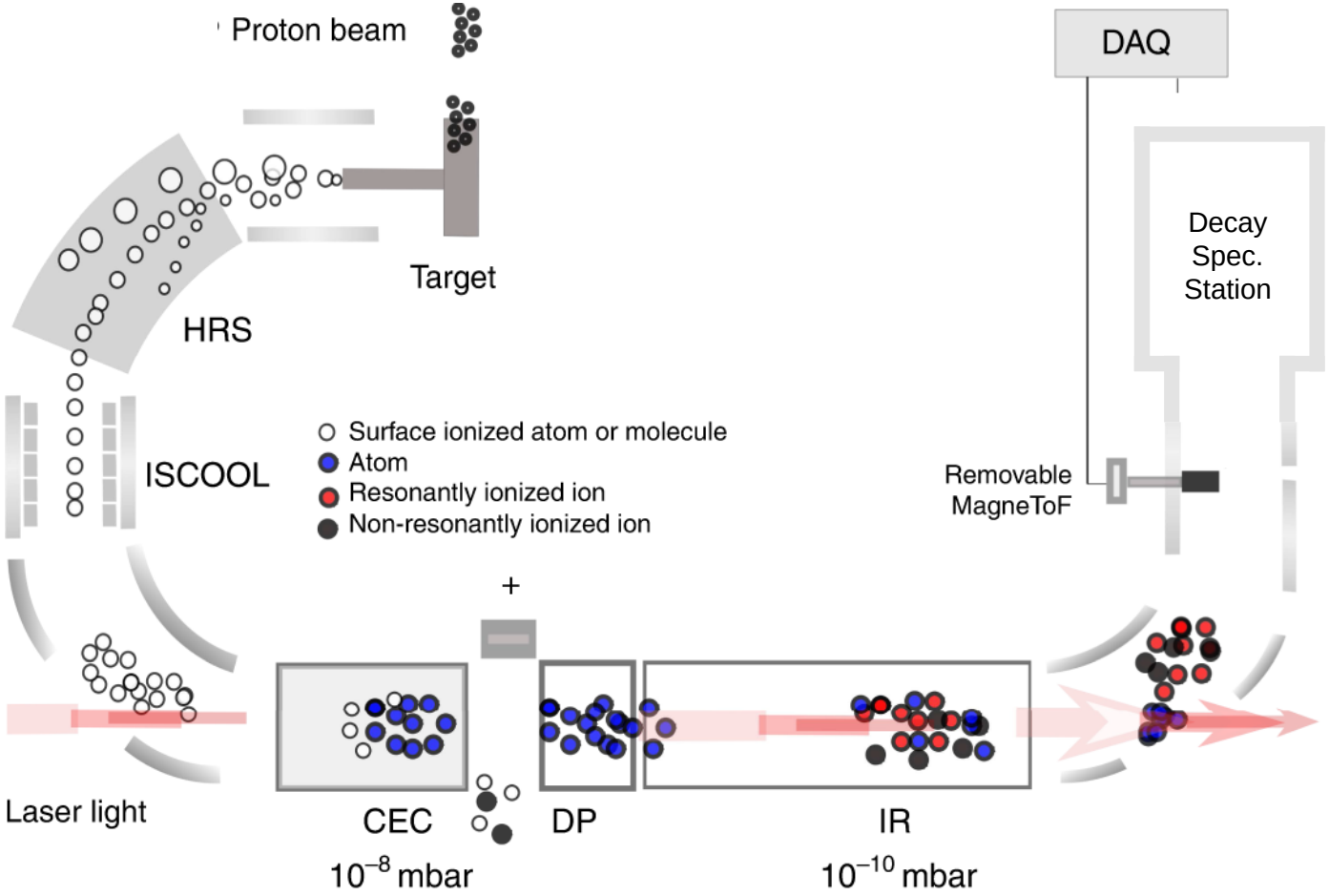

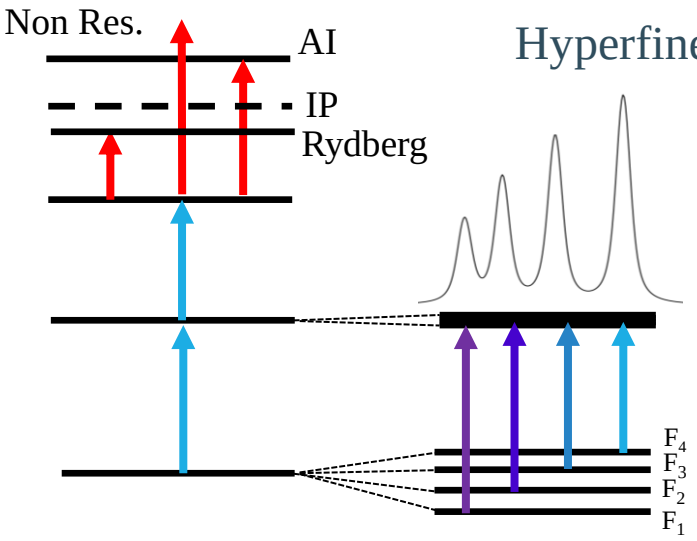

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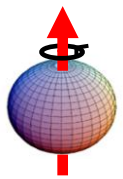

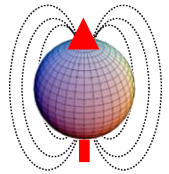

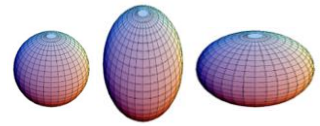

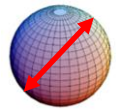

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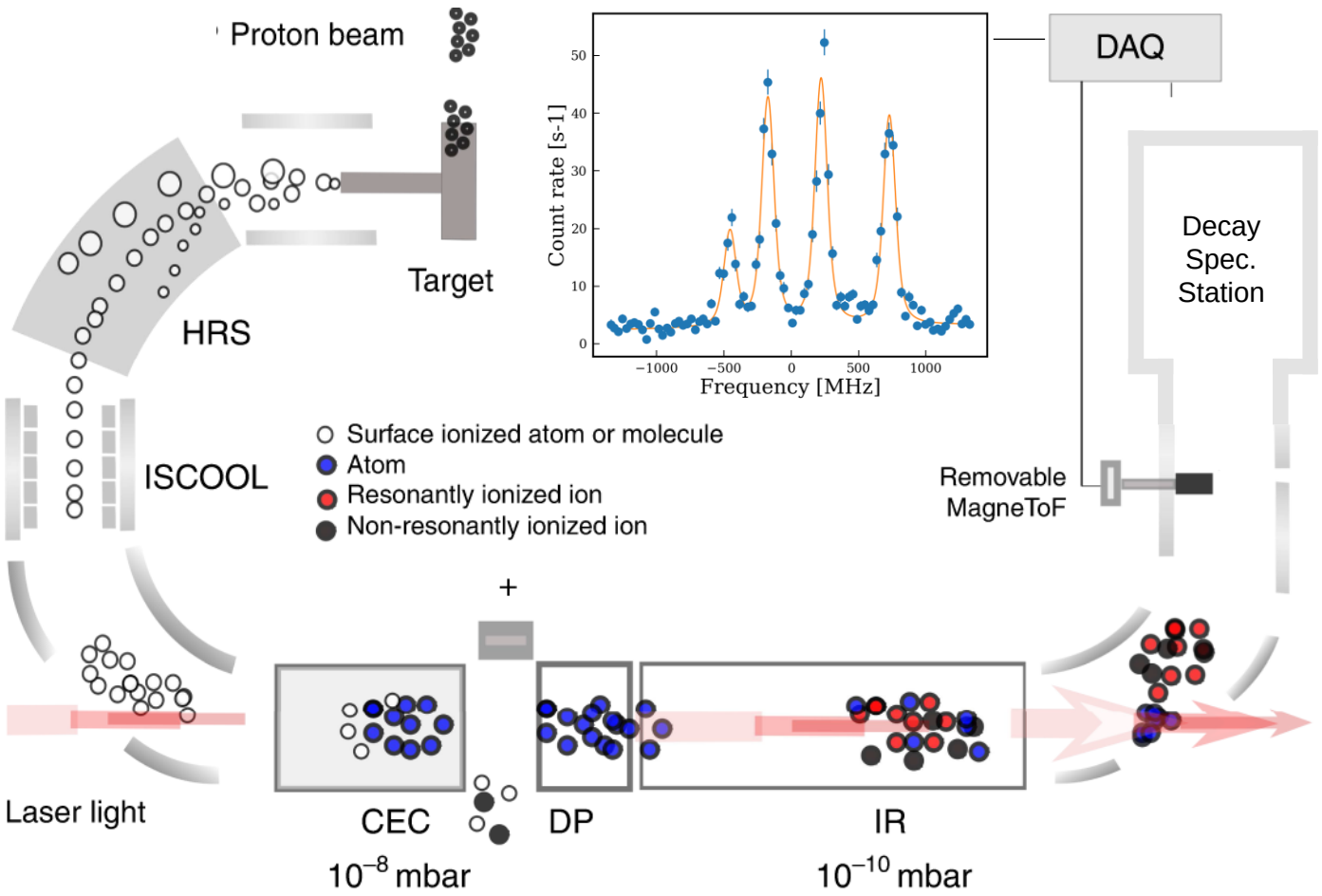
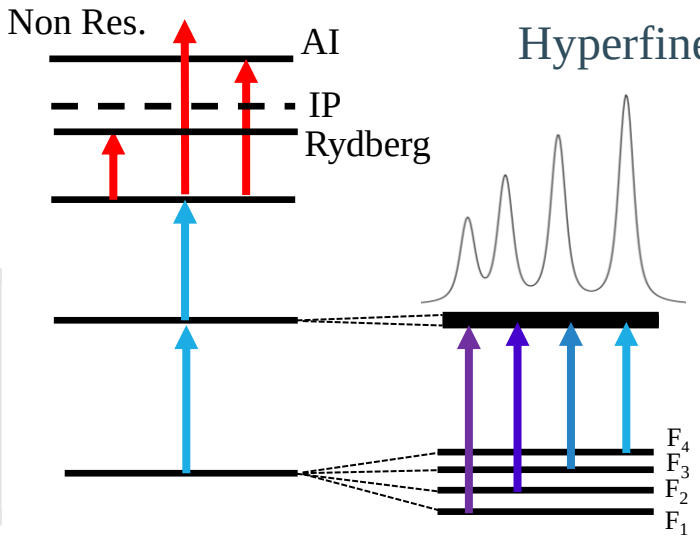


✓ High sensitivity : > few 10 ions/s ✓ High resolution : > 20 MHz

✓ High versality



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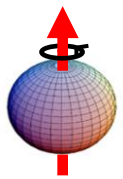
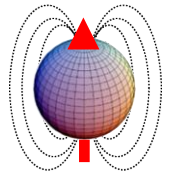
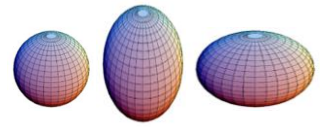
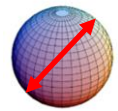


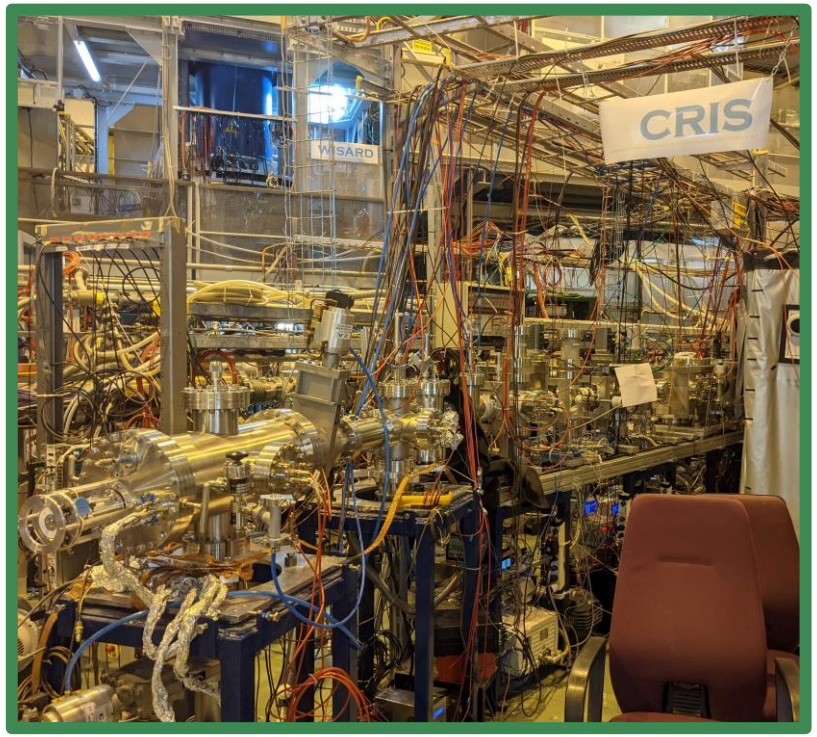






2023 CRIS upgrade: New End of the Beam Line

Decembre 2022



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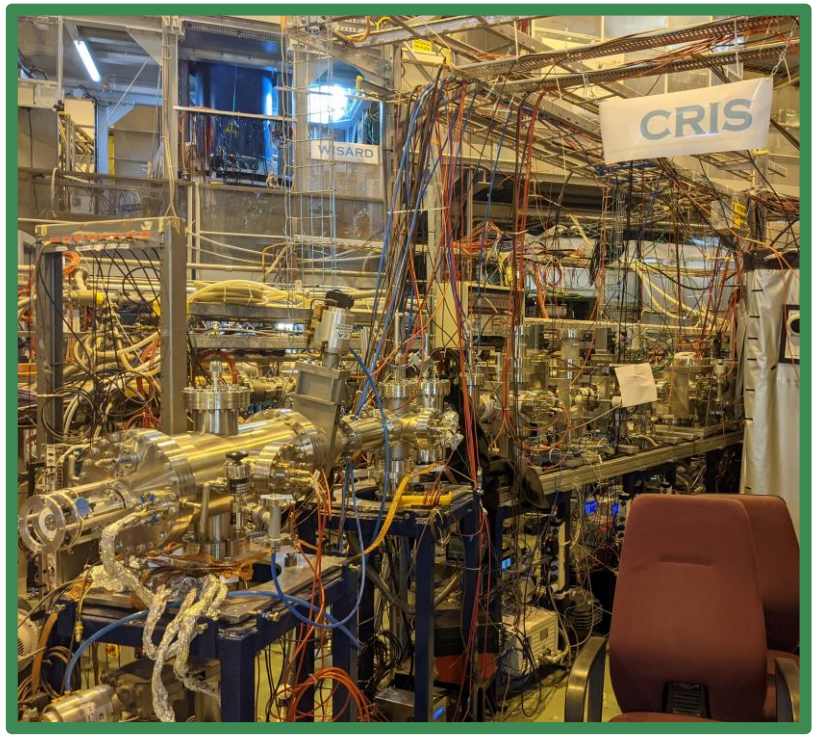

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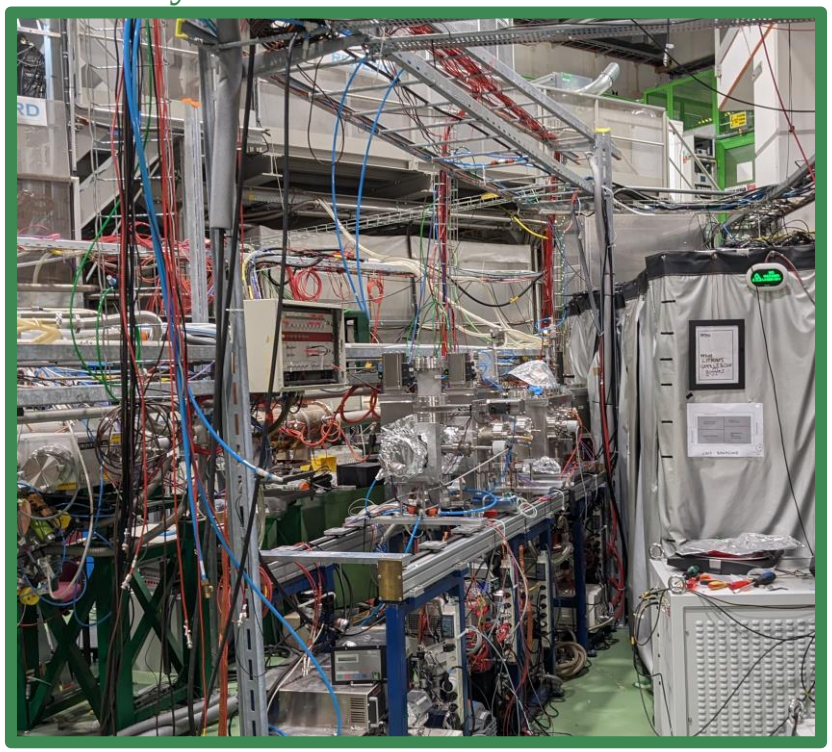

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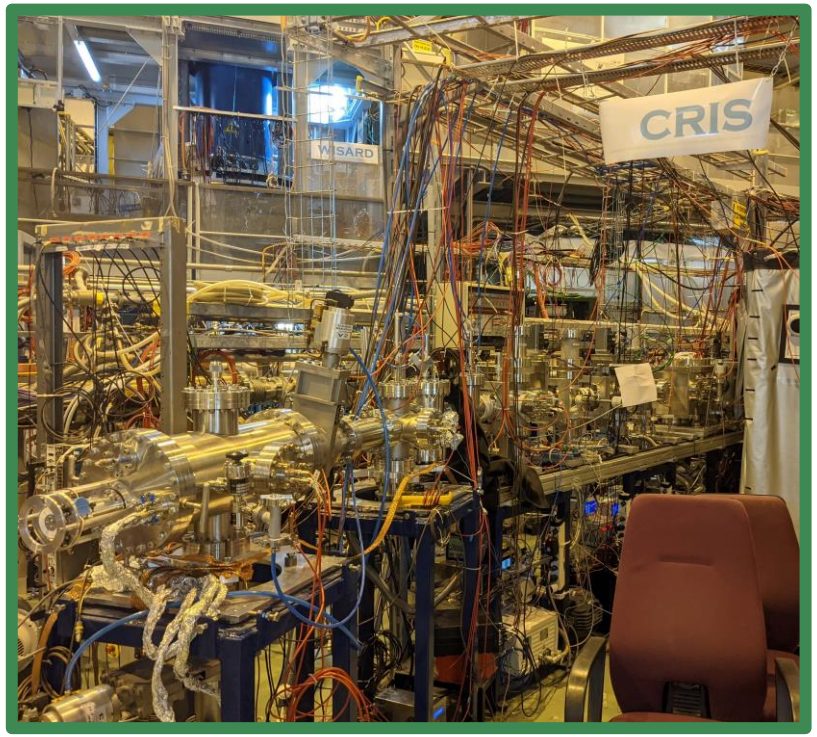

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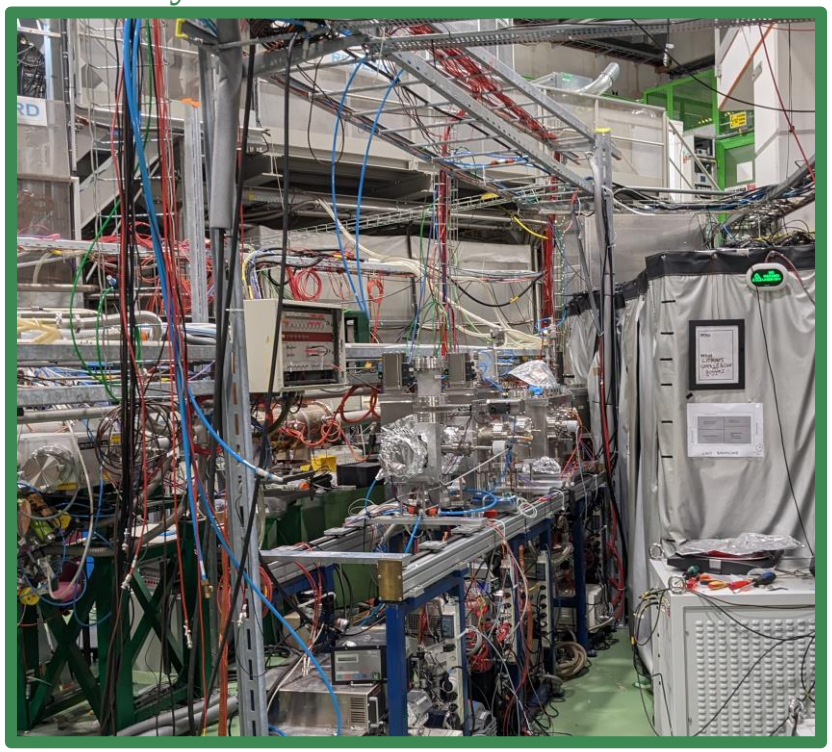

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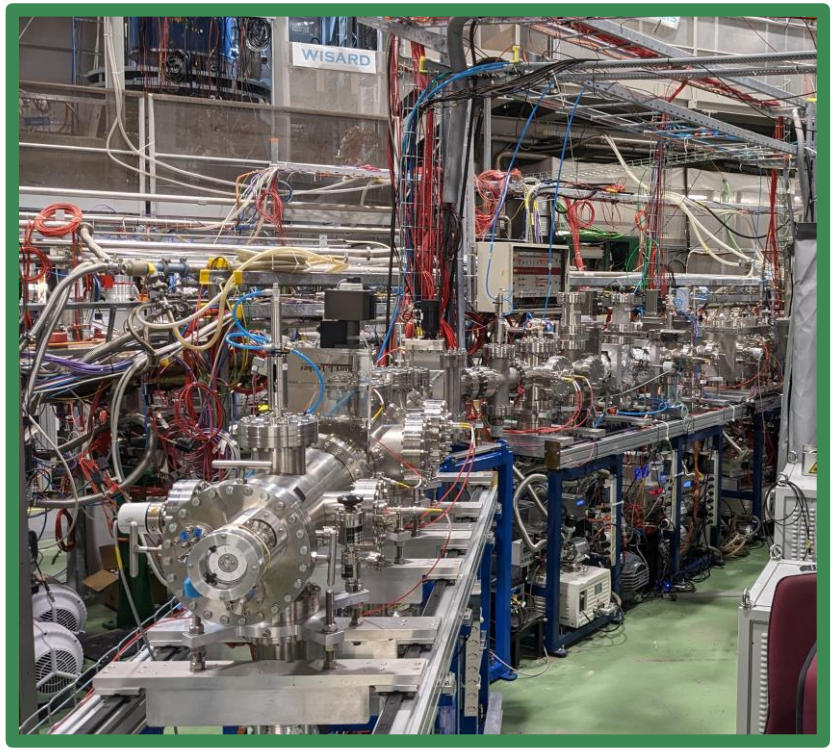

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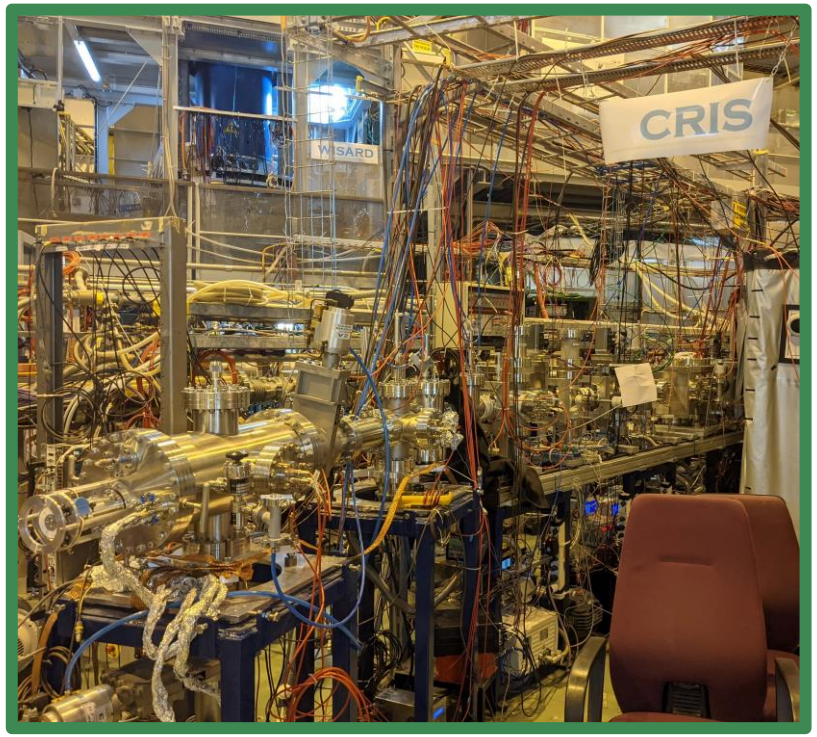

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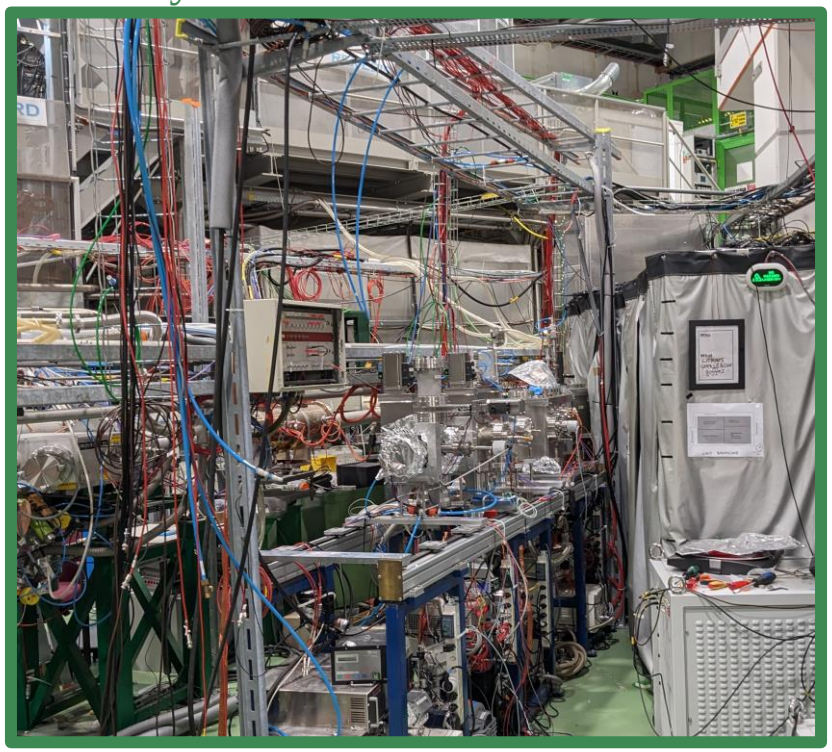

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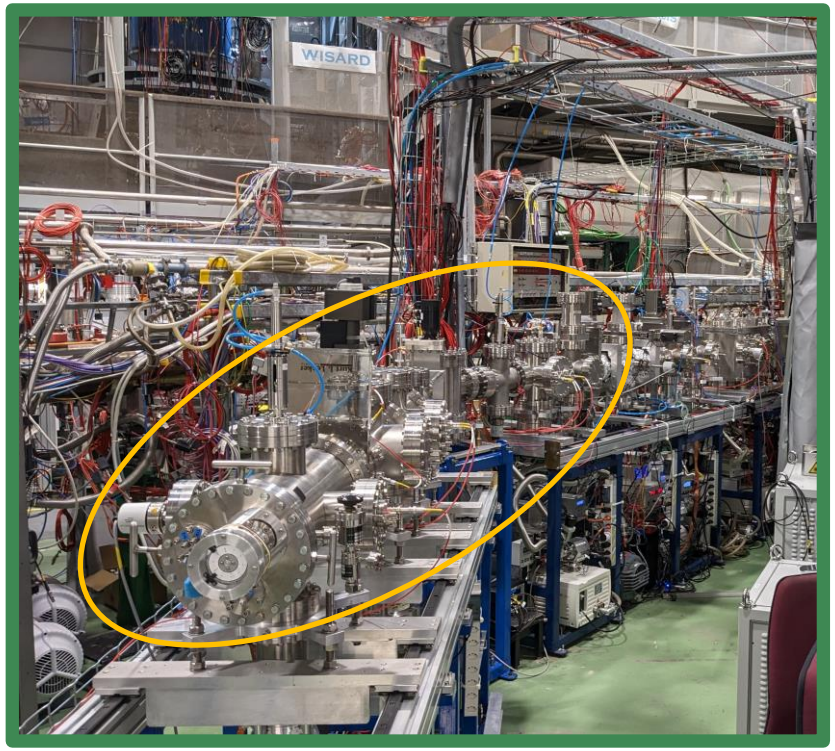

New end of the beam line:

- New field ionization unit
- New bender
- New beam optics

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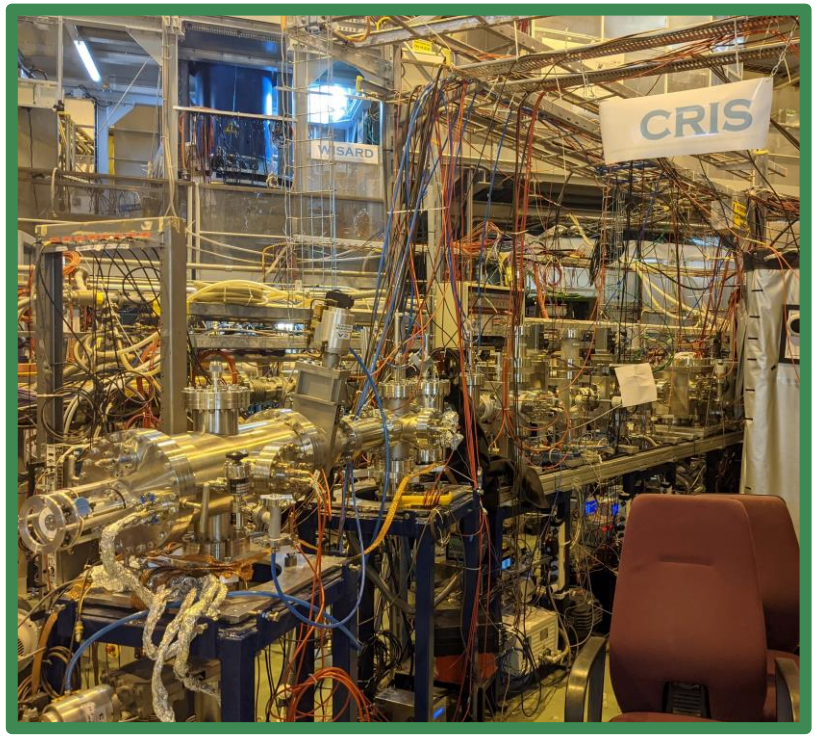

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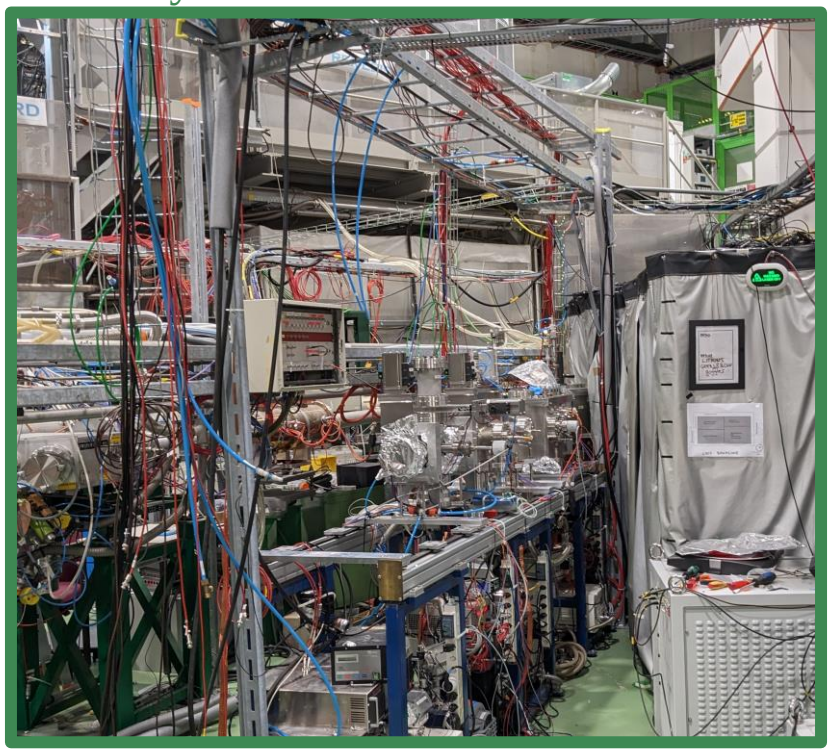

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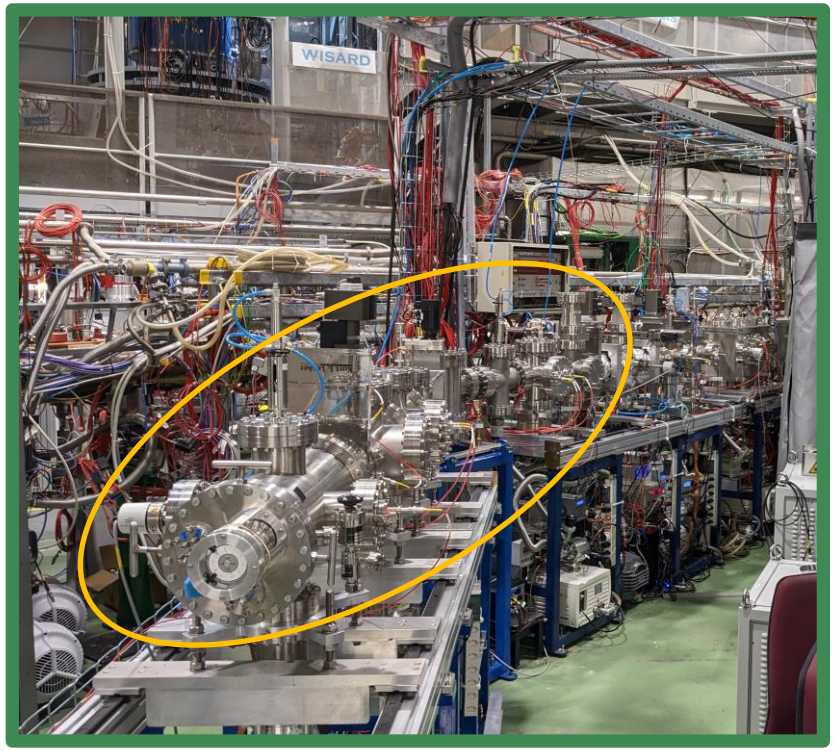


New end of the beam line:

- New field ionization unit
- New bender
- New beam optics

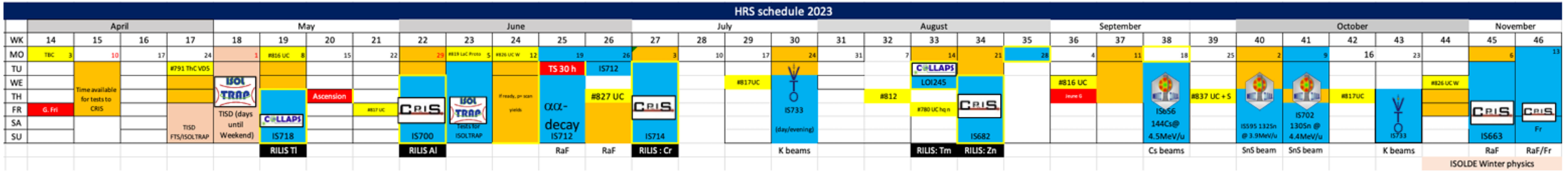
→ Allows Rydberg ionization scheme

→ Beam transport efficiency toward ion detector and decay spectroscopy station improved from 30% to 100%

→ Enable upgrade of the DSS toward a tape system

See talk of Yongchao Liu !

The 2023 experimental campaign



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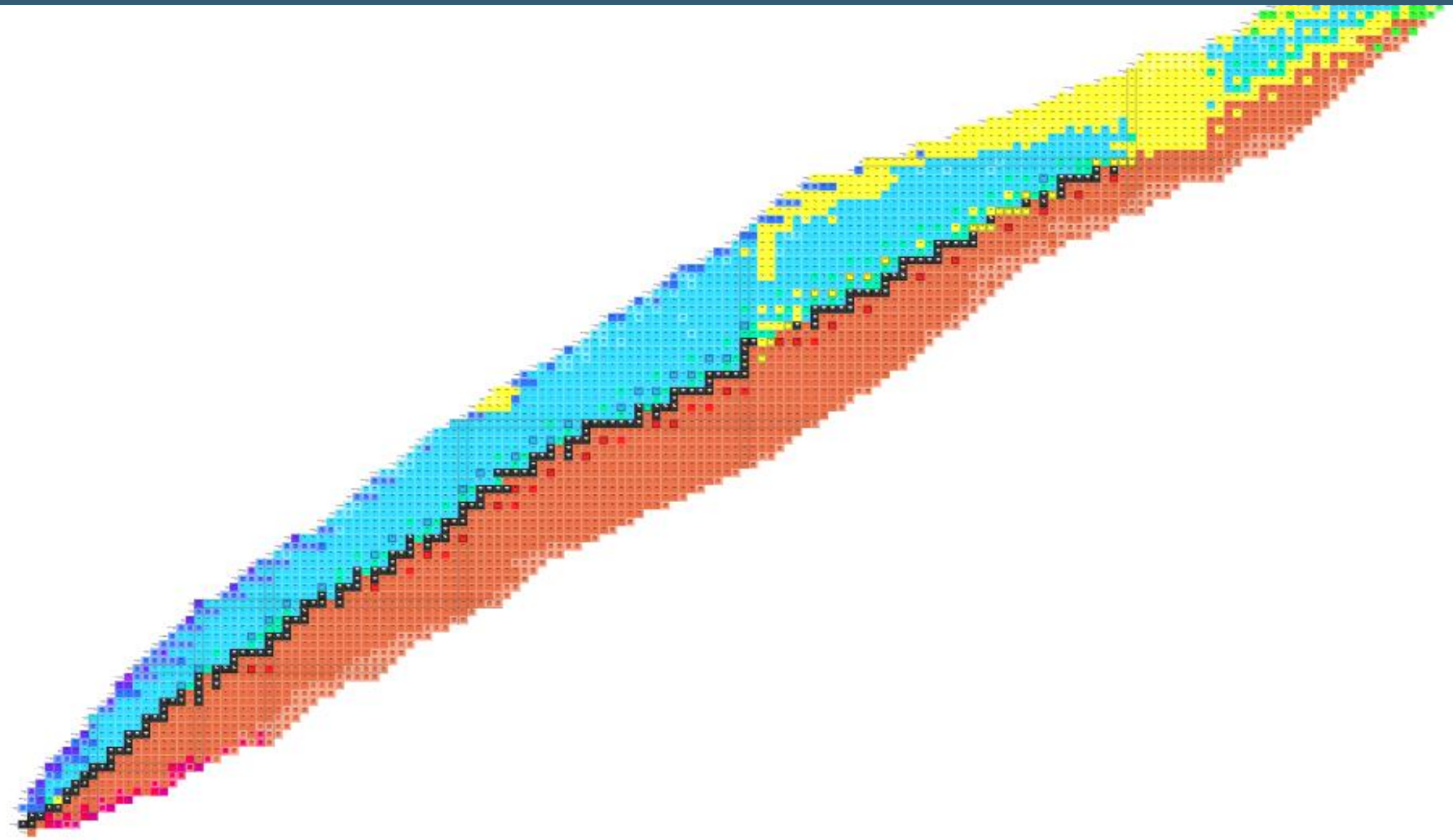

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MO	TBC		17	24	1	#816 UC 8	15	22	29	#819 LoC Proto 5	#826 UC W 12	19	26	3	10	17	24	31	7	14	21	28	4	11	18	25	2	9	16	23		6	13
TU				#791 ThC VDS								TS 30 h	IS712							COLLAPS													
WE		Time available for tests to CRIS			ISOLTRAP											#817UC			#812	LOI245			#816 UC			#837 UC + S			#817UC		#826 UC W		
TH							Ascension		CRIS	ISOLTRAP	If ready, pr scan yields	αα-decay	#827 UC	CRIS			IS733			#780 UC hq n	CRIS		Jeune G		ISb56 144Cs@ 4.5MeV/u		IS595 132Sn @ 3.9MeV/u	IS702 130Sn @ 4.4MeV/u		IS733		CRIS	CRIS	
FR	G. Fri			TISD FTS/ISOLTRAP	TISD (days until Weekend)			#817 UC		Tests for							(day/evening)																Fr
SA						COLLAPS																											
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						RILIS Tl			RILIS Al			RaF	RaF	RILIS : Cr			K beams			RILIS: Tm	RILIS: Zn				Cs beams		SnS beam	SnS beam		K beams		RaF	RaF/Fr
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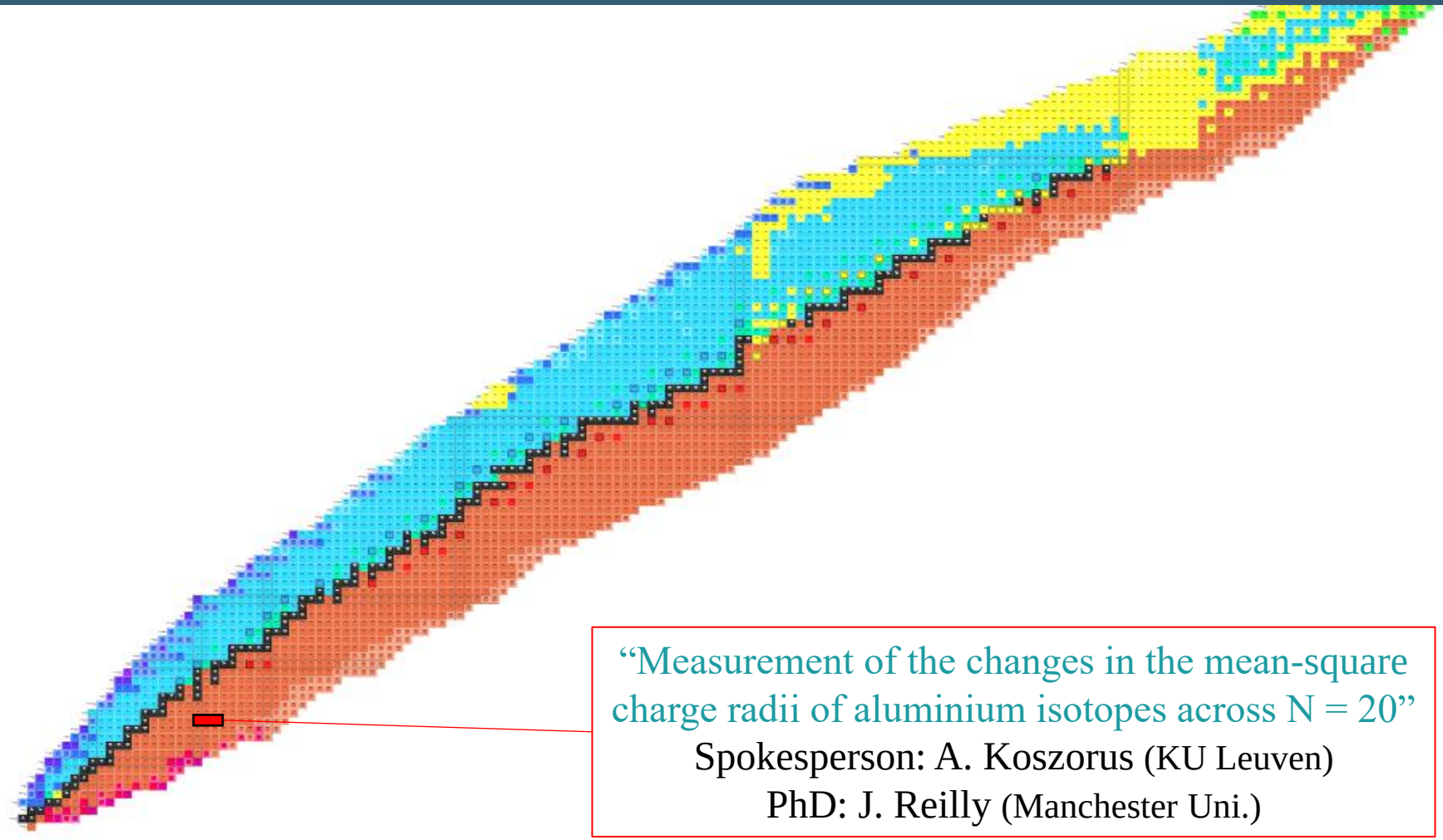

"Measurement of the changes in the mean-square charge radii of aluminium isotopes across N = 20"

Spokesperson: A. Koszorus (KU Leuven)

PhD: J. Reilly (Manchester Uni.)

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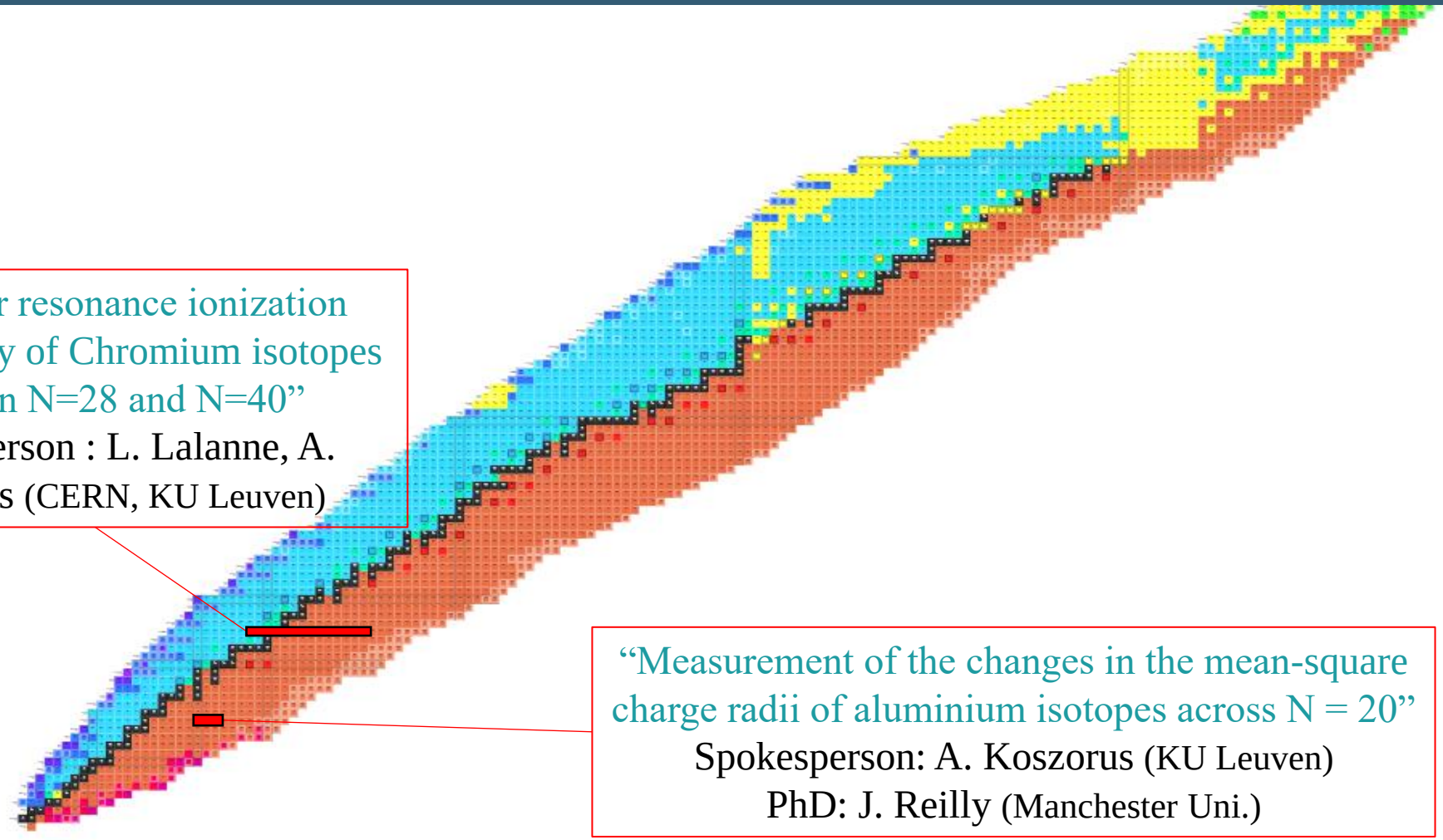

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Spokesperson : L. Lalanne, A. Koszorus (CERN, KU Leuven)

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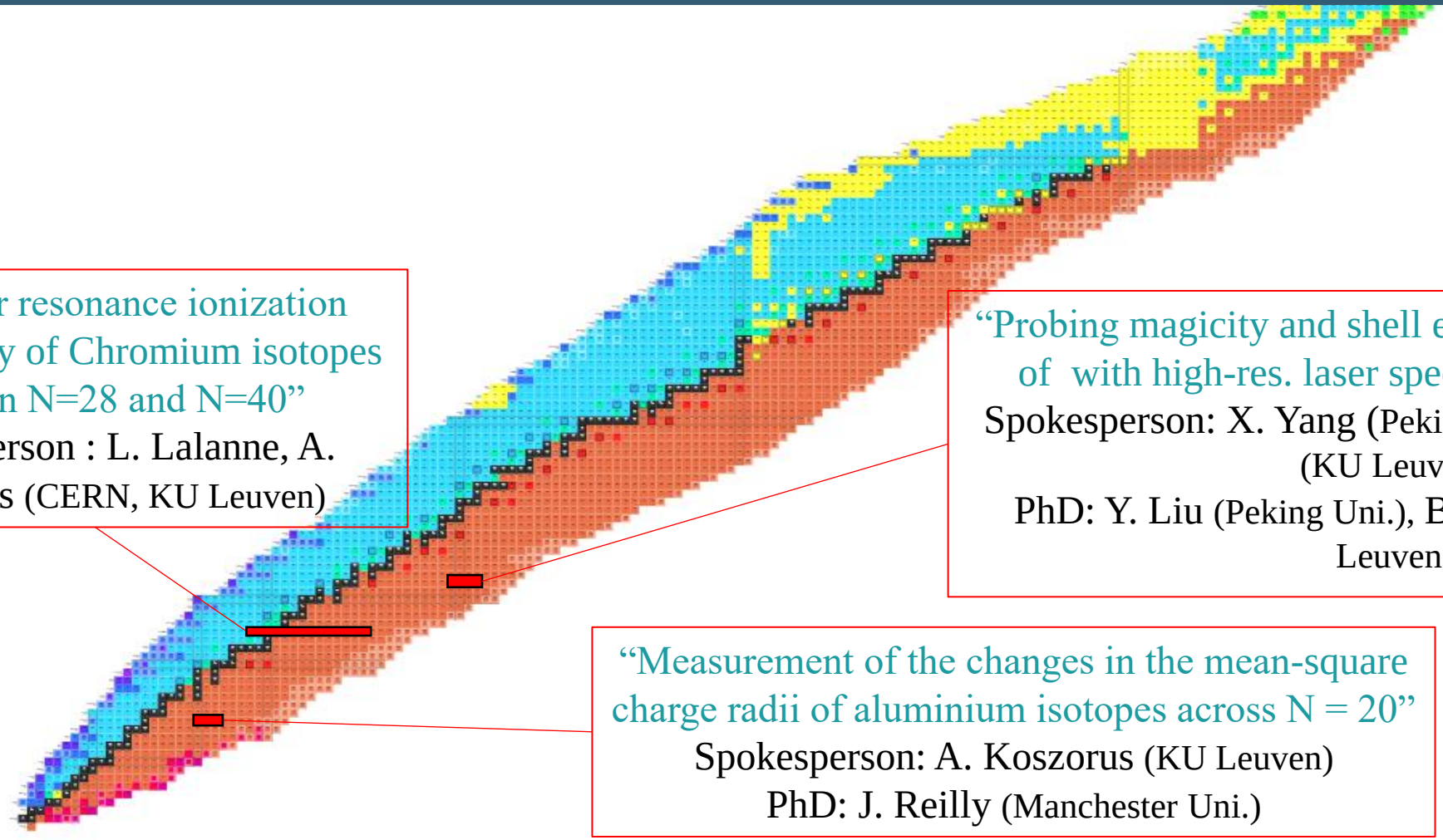

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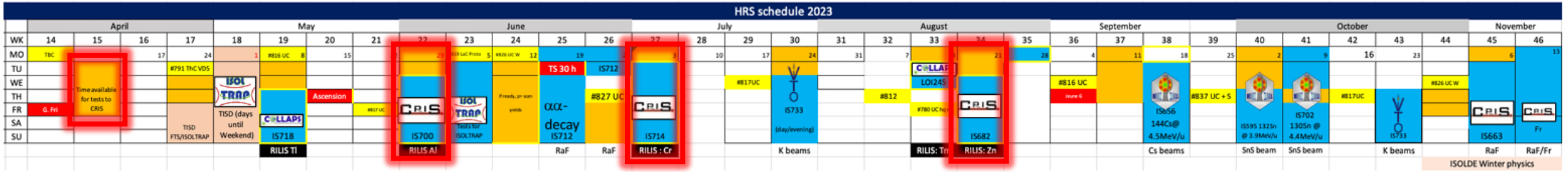

The 2023 experimental campaign

"Rotational and hyperfine structure of RaF molecules"
Spokesperson: M. Athanasakis-Kaklamanakis (KU Leuven, CERN), S. Wilkins, R. Garzia-Riuz (MIT)
PhD: Carlos Fajardo-Zambrano (KU Leuven)

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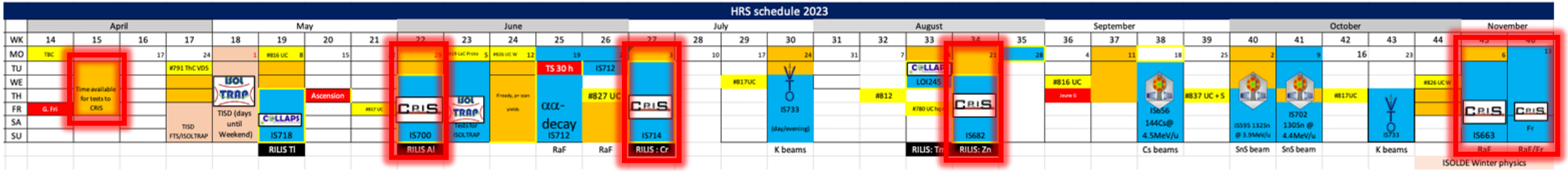

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"Rotational and hyperfine structure of RaF molecules"
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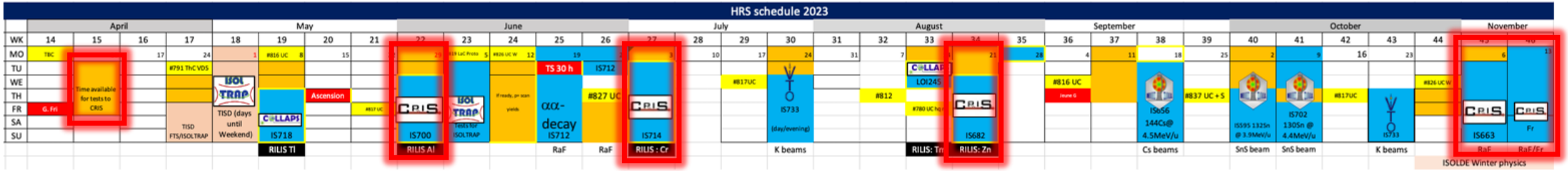

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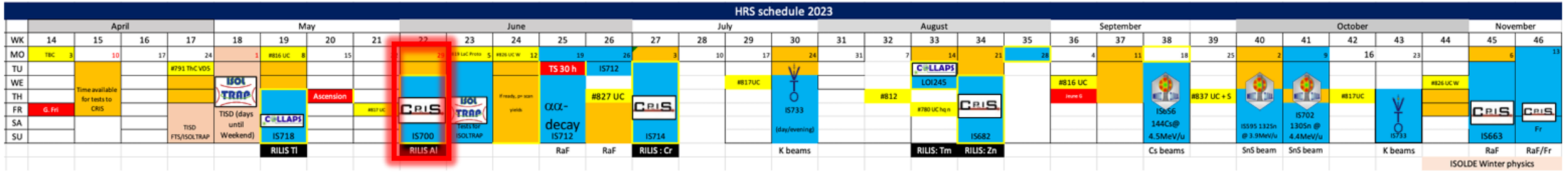
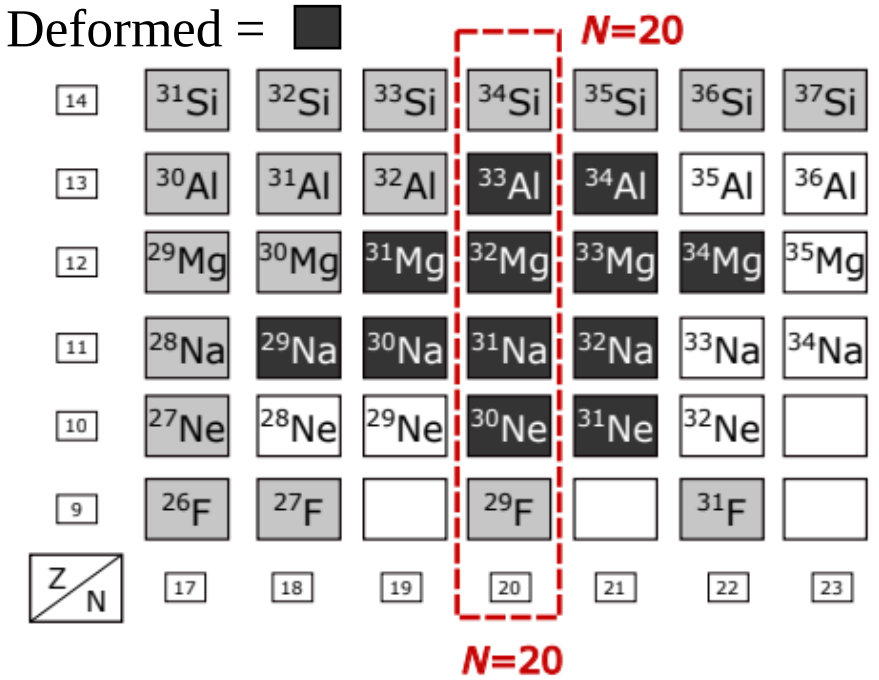


Charge radii of Aluminium isotopes across N = 20

- N=20 Island of Inversion: Strongly mixed and deformed ground state configuration around ^{32}Mg
- ^{33}Al located between strongly deformed ^{32}Mg and spherical ^{34}Si
- Evidence for ^{33}Al g.s. deformation from quadrupole moment [1] - Transition into the Island of inversion?



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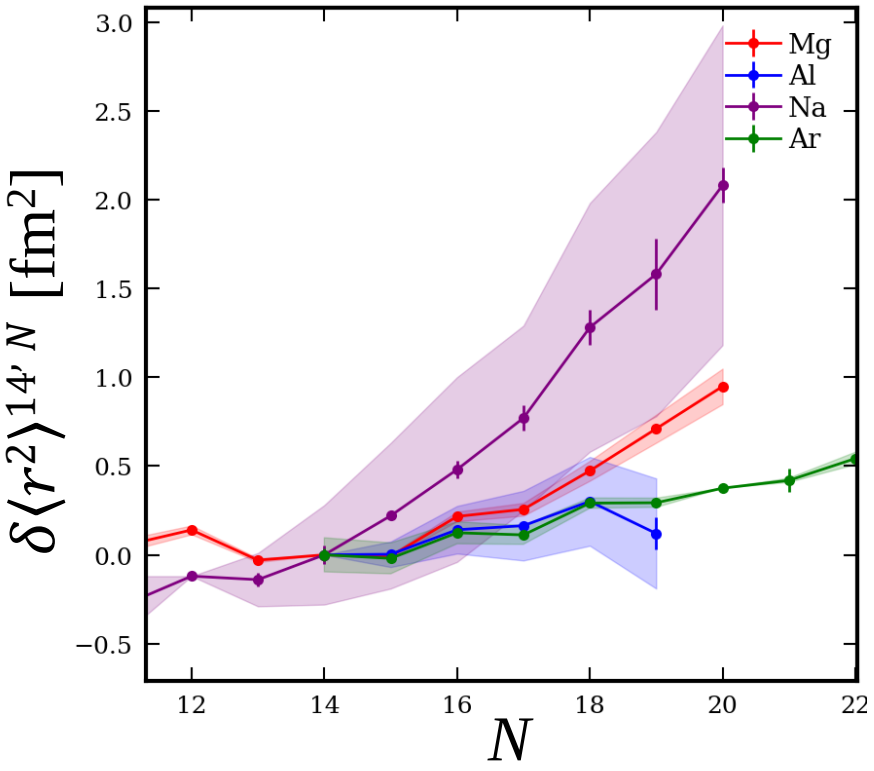

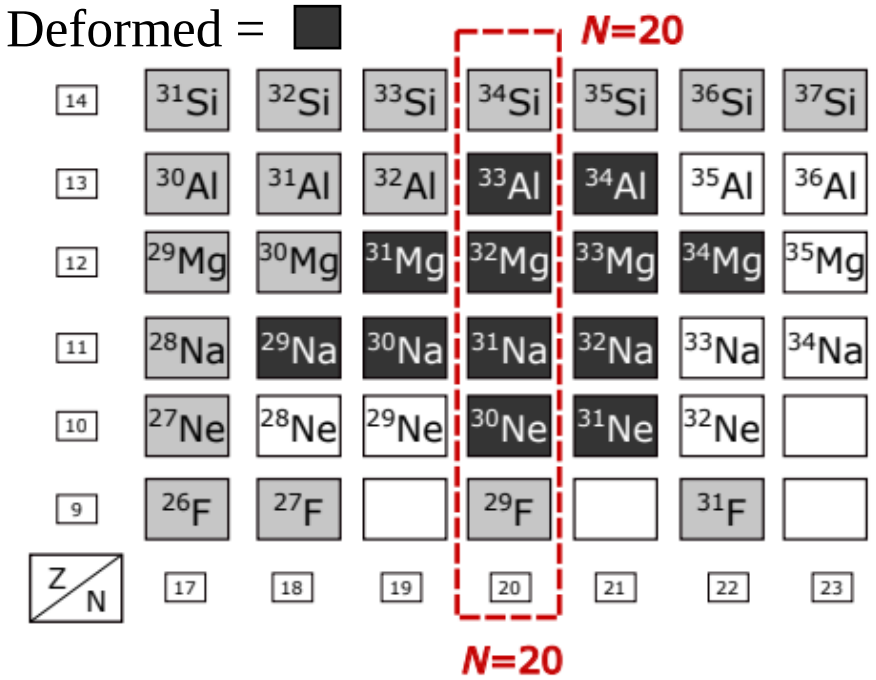

- Large increase in charge radii towards the N = 20 shell closure is observed for **Na** and **Mg**
- Previous measurements of Al radii display an unexpected decrease in $\delta\langle r^2\rangle$ between ^{31}Al and ^{32}Al [2]

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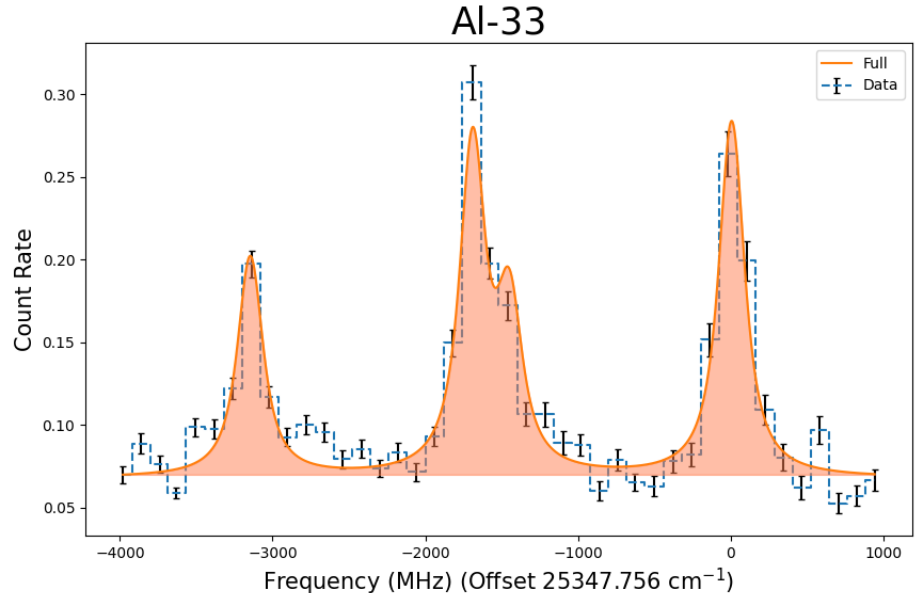
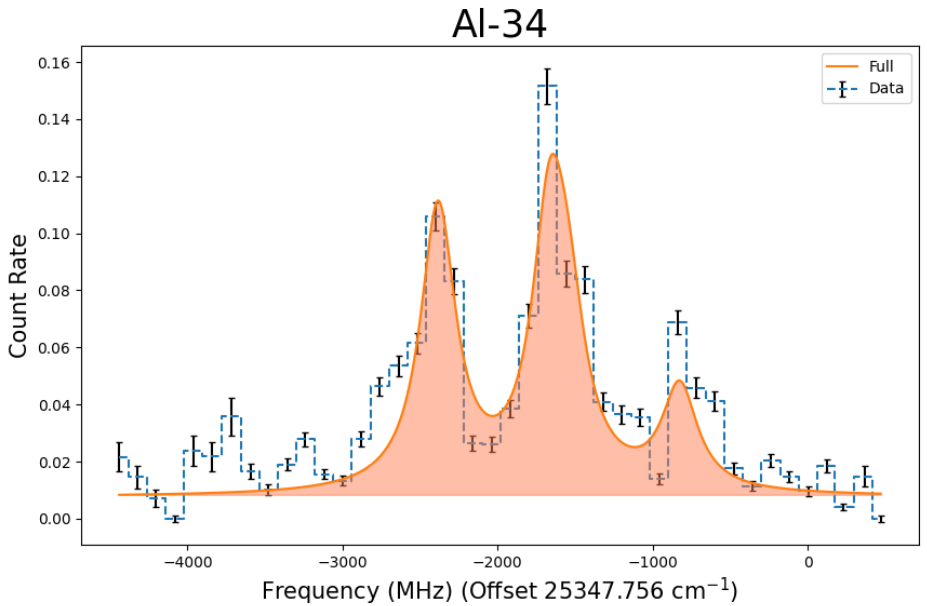
[2] Heylen et al., PHYSICAL REVIEW C **103**, 014318 (2021)

Charge radii of Aluminium isotopes across N = 20

- Two runs: 2022 ($^{27\text{-}32}$Al) and 2023 ($^{33\text{-}34}$Al)
- First laser spectroscopy measurement of Al across N=20
- Ongoing analysis to extract radii

Analysis and plots from Jordan Reilly





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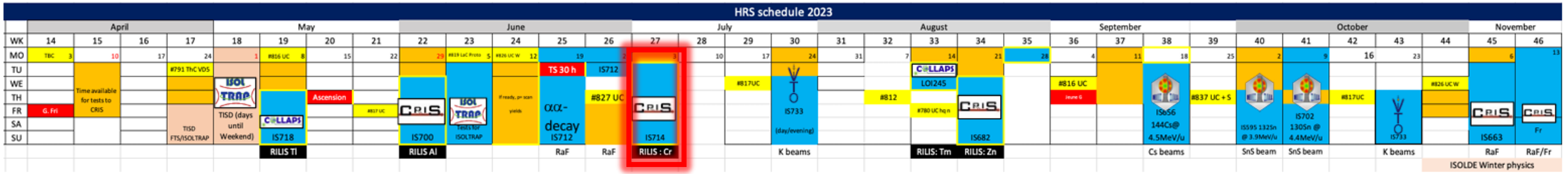
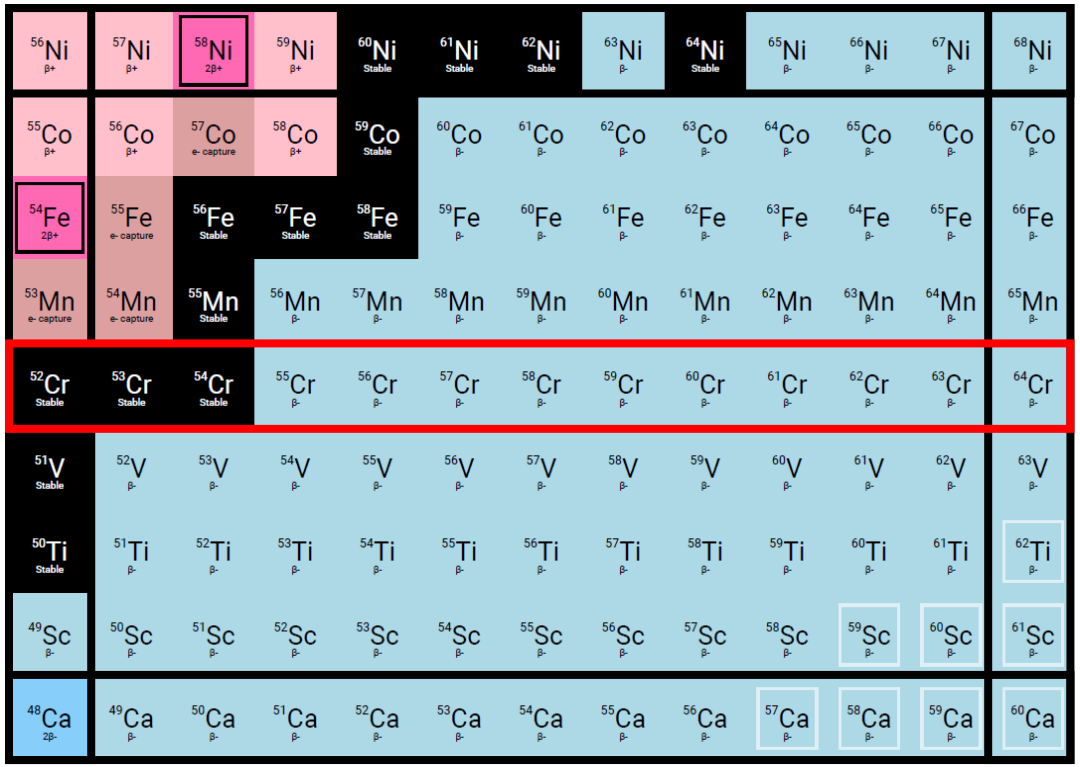
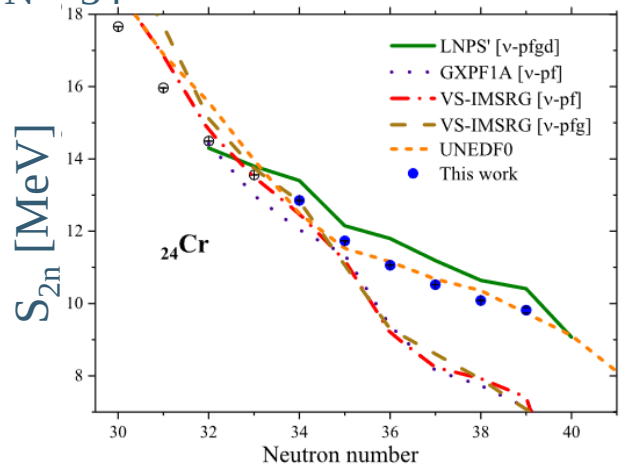


The N=40 Island of Inversion and the Cr isotopes

The Cr isotopes:

- Half filled $f_{7/2}$ → strongest *p-n* collectivity
- Mass : gradual increase of collectivity and deformation from *N*=34 onward [1]
- Radii of Mn (*Z*=25): suggested onset of deformation around *N*=35 [2]
- ^{64}Cr is the predicted center of the *N*=40 Island of Inv.
- No firm assignment of g.s. spins
- No radii or moments known outside stability





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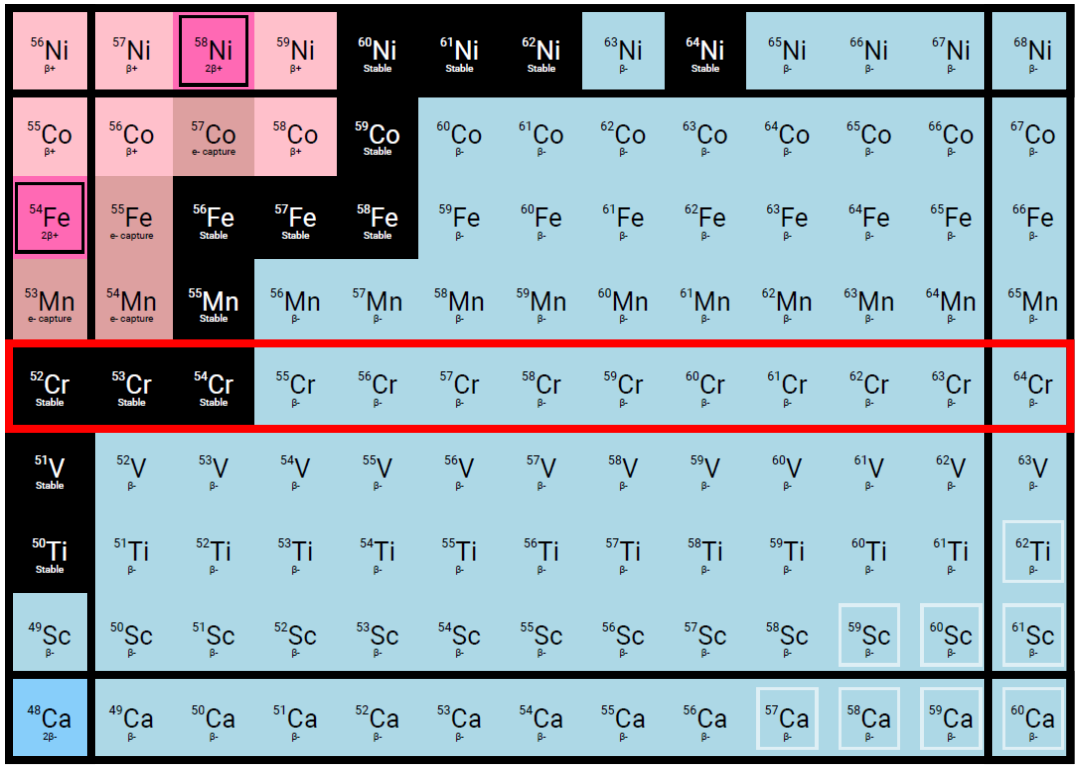
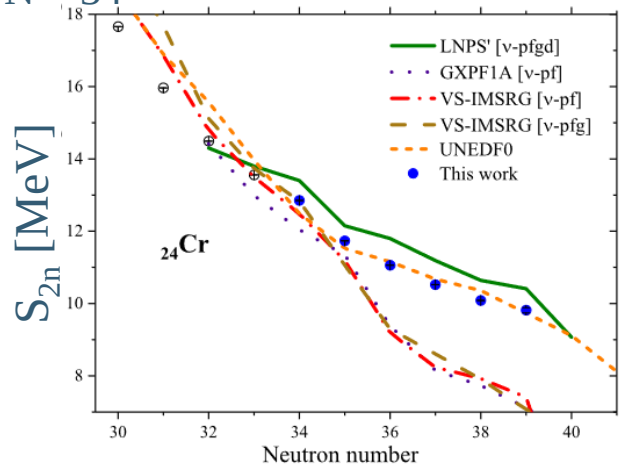


Goals:

- Firm spin assignment 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

→ Laser RIS scheme developed by RILIS



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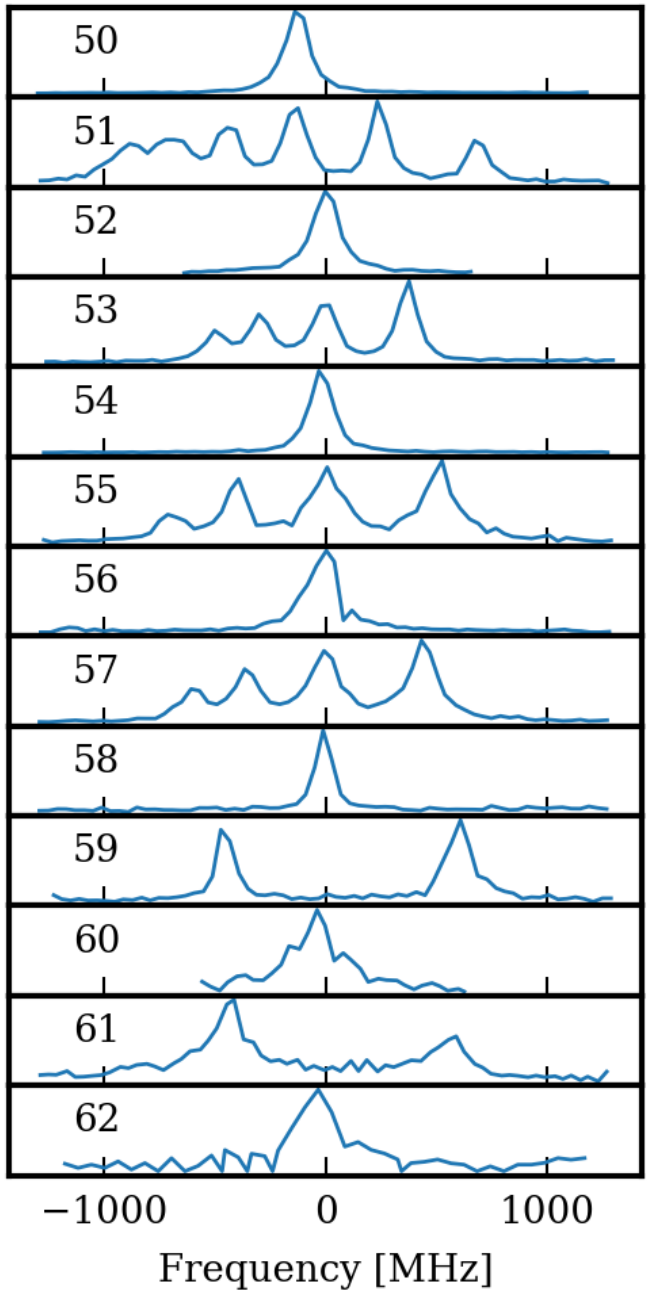
Cr Results: spins of odd-*A* Cr isotopes



I Lit:

7/2-

3/2-

3/2-

(3/2)-

(1/2)-

(5/2)-

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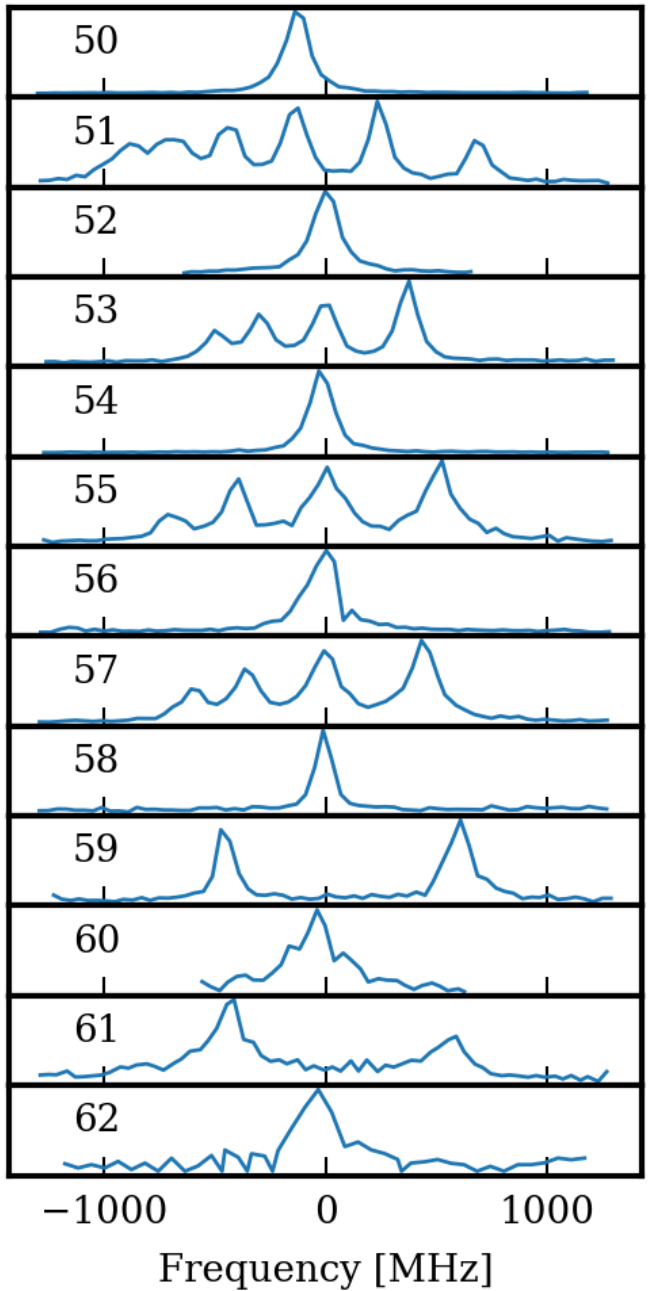

I Lit:	*I* CRIS:
$7/2^-$	$7/2^-$
$3/2^-$	$3/2^-$
$3/2^-$	$3/2^-$
$(3/2)^-$	$3/2^-$
$(1/2)^-$	$1/2^-$
$(5/2)^-$	$1/2^-$

- First firm spin assignment of ^{57,59,61}Cr
- ^{57}Cr and ^{59}Cr spins confirmed to be 3/2 and 1/2, respectively

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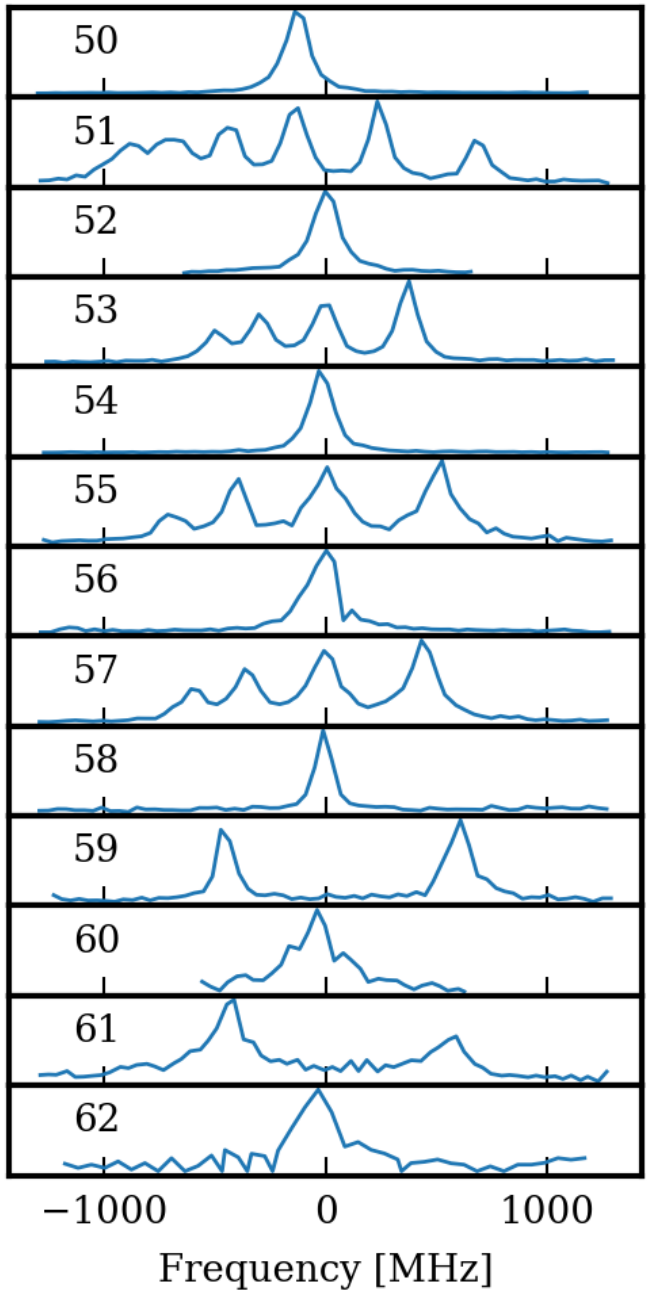

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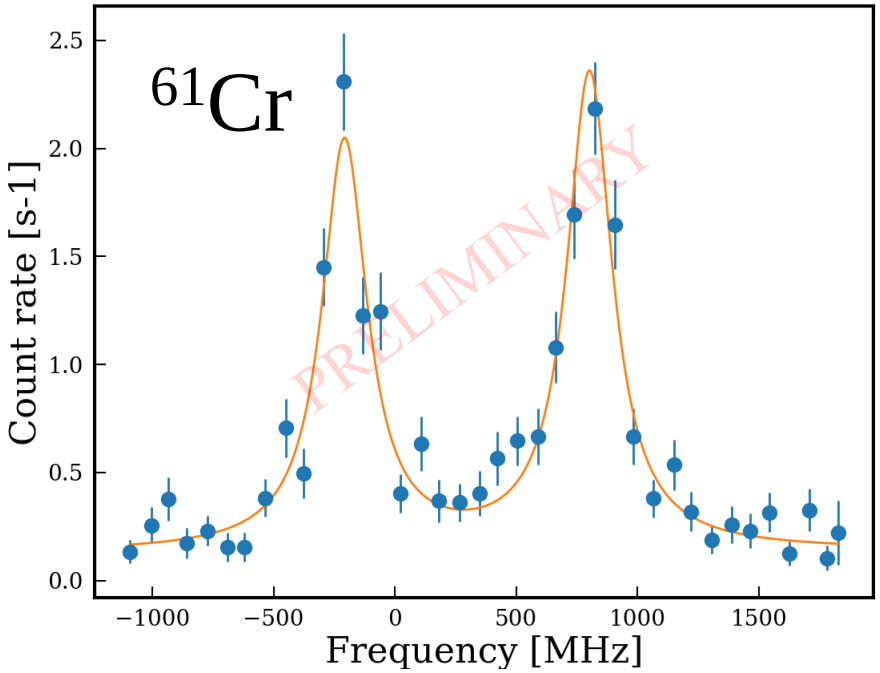

- First firm spin assignment of ^{57,59,61}Cr
- ^{57}Cr and ^{59}Cr spins confirmed to be 3/2 and 1/2, respectively
- ^{61}Cr found to be 1/2 , in disagreement with 5/2 assignment from beta decay experiments

→ Large consequences on the interpretation of beta decay data and on the ^{61}Cr and ^{61}Mn level schemes

Results: g factors of odd-*A* Cr isotopes

g-factor : $$g = \frac{\mu}{I\mu_N}$$

→ Very sensitive to which orbitals are occupied by the valence particles

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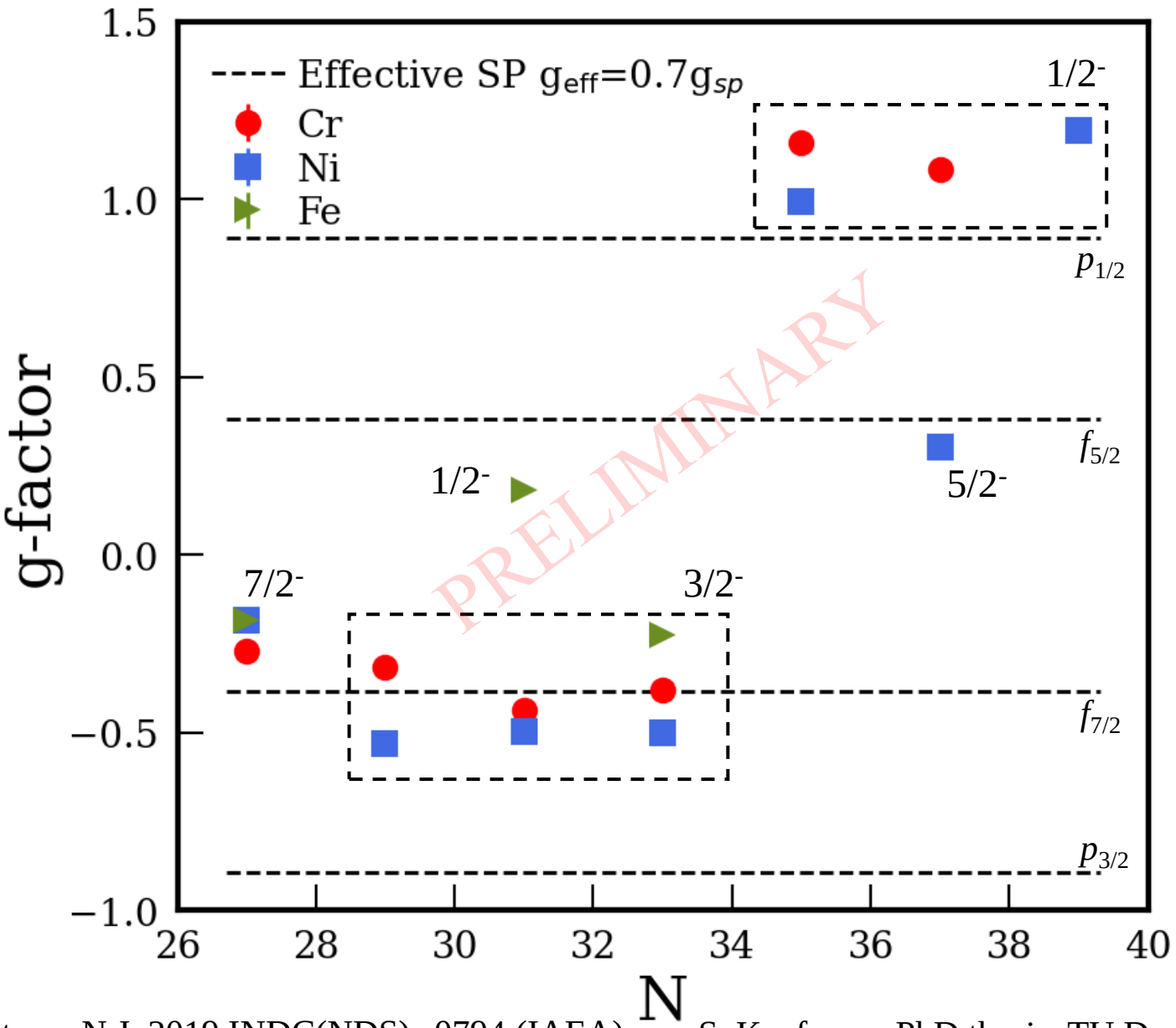

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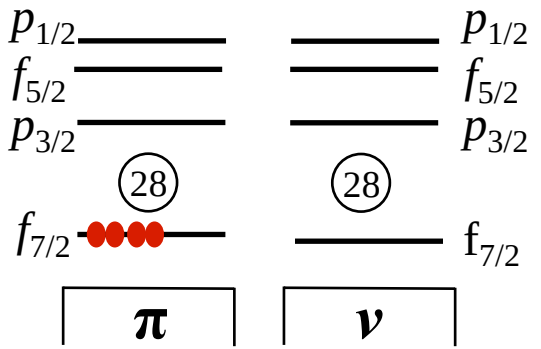

Cr valence space

Stone, N.J. 2019 INDC(NDS)--0794 (IAEA)

S. Kaufmann PhD thesis, TU Darmstadt

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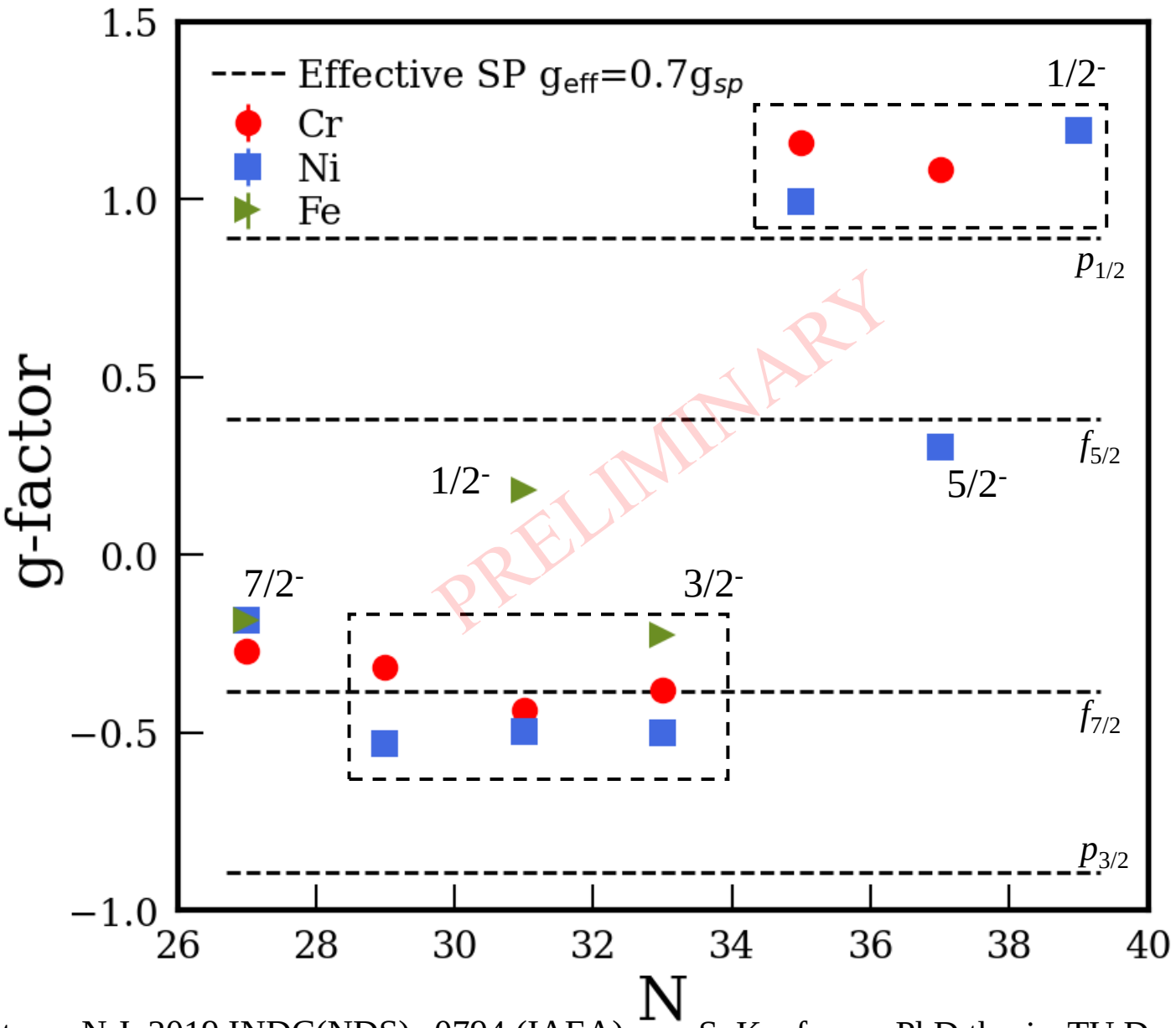

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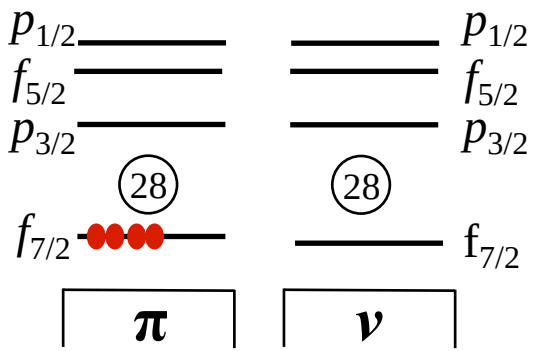

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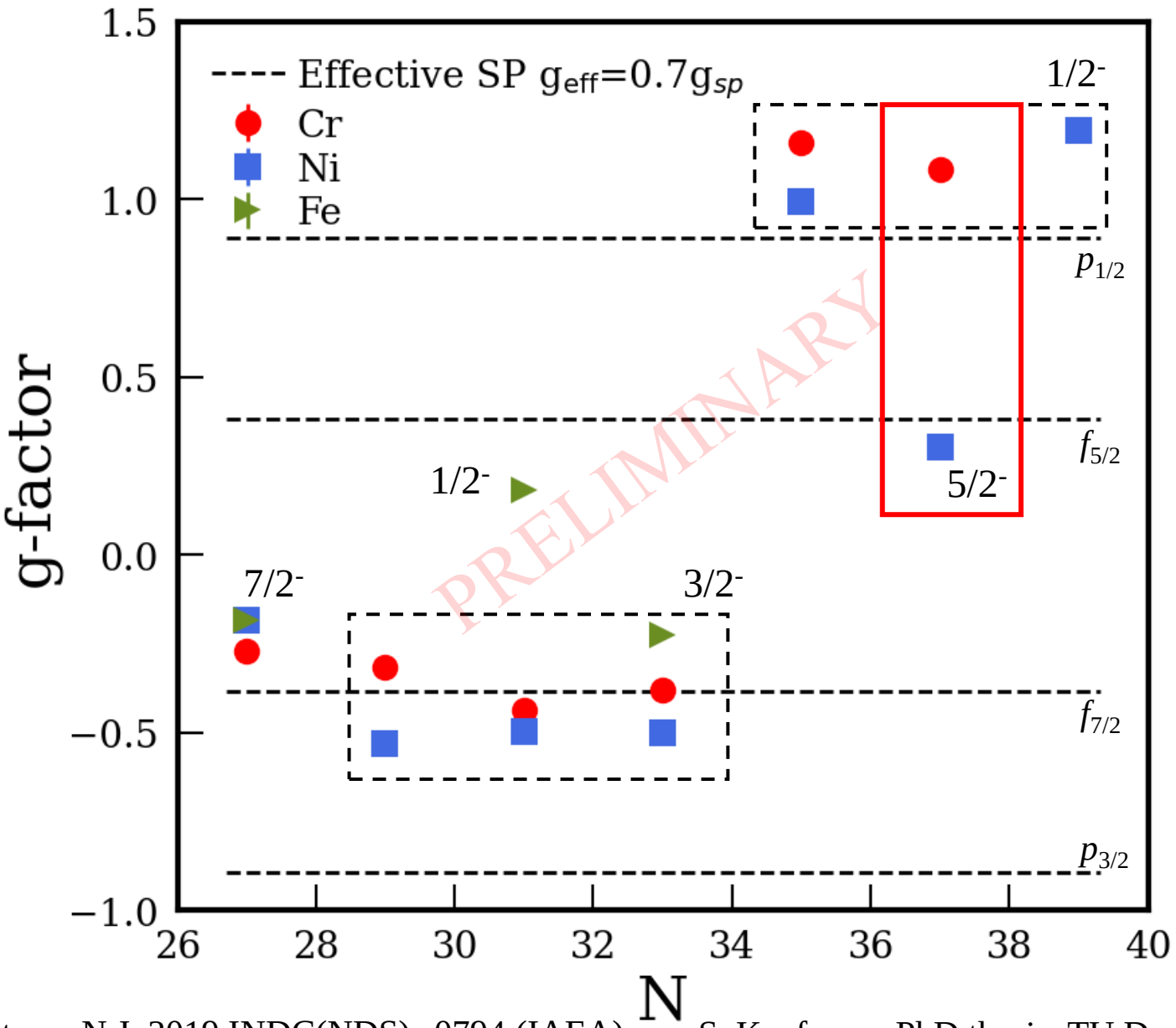

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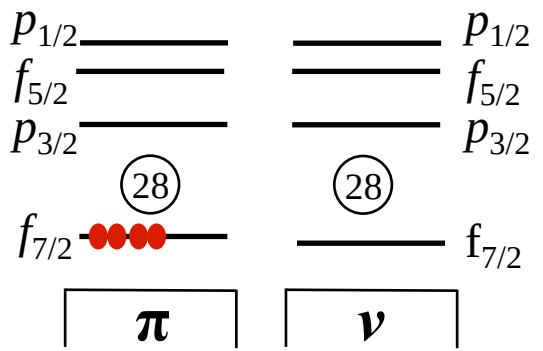

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N=37 config. moving from ν $f_{5/2}$ in Ni (Z=28) to ν $p_{1/2}$ in Cr (Z=24)

→ Monopole drift of the ν $f_{5/2}$ orbital?

Stone, N.J. 2019 INDC(NDS)--0794 (IAEA)

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Cr Results: 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 [1] (muonic+e^- scat.)

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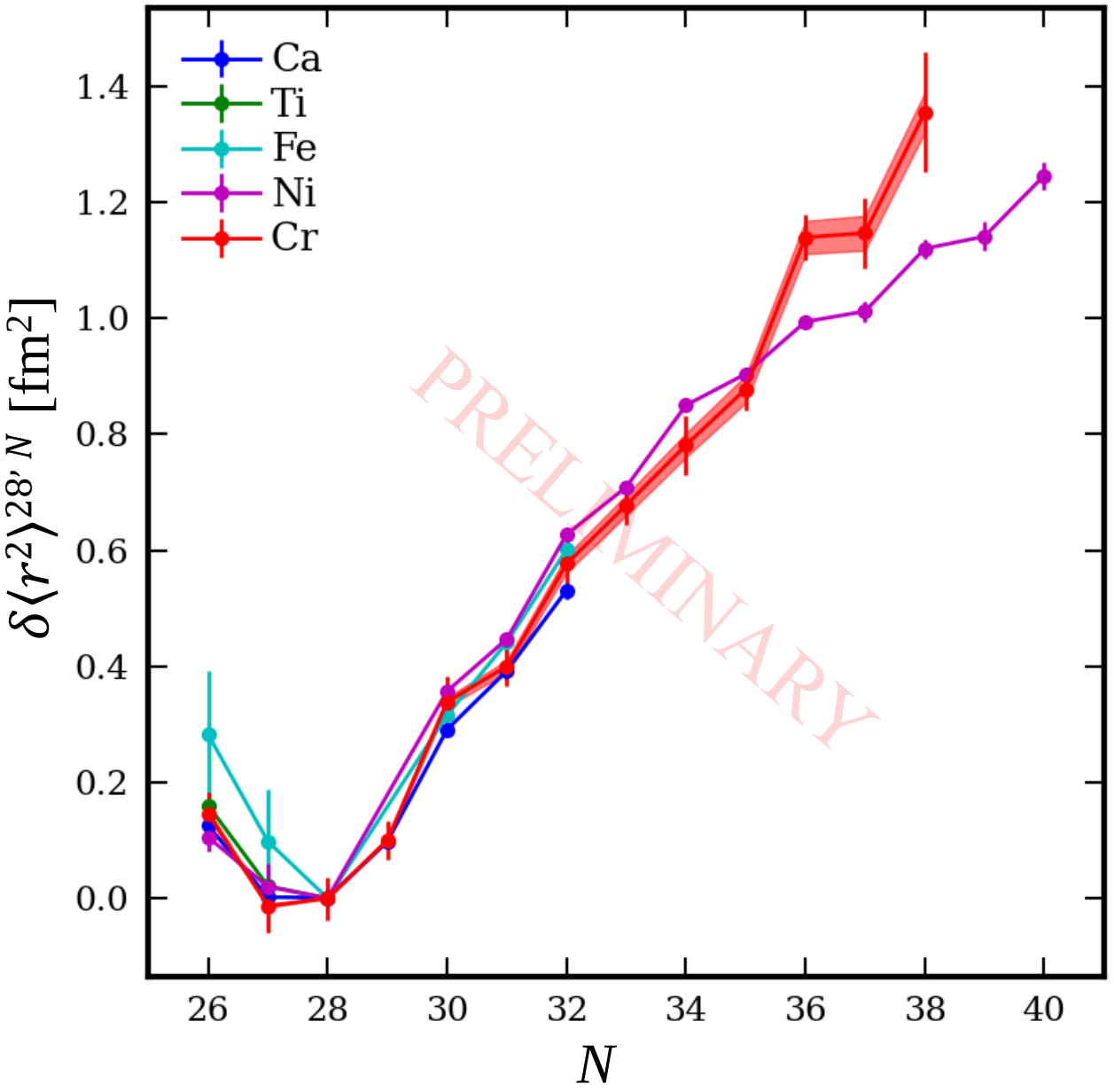

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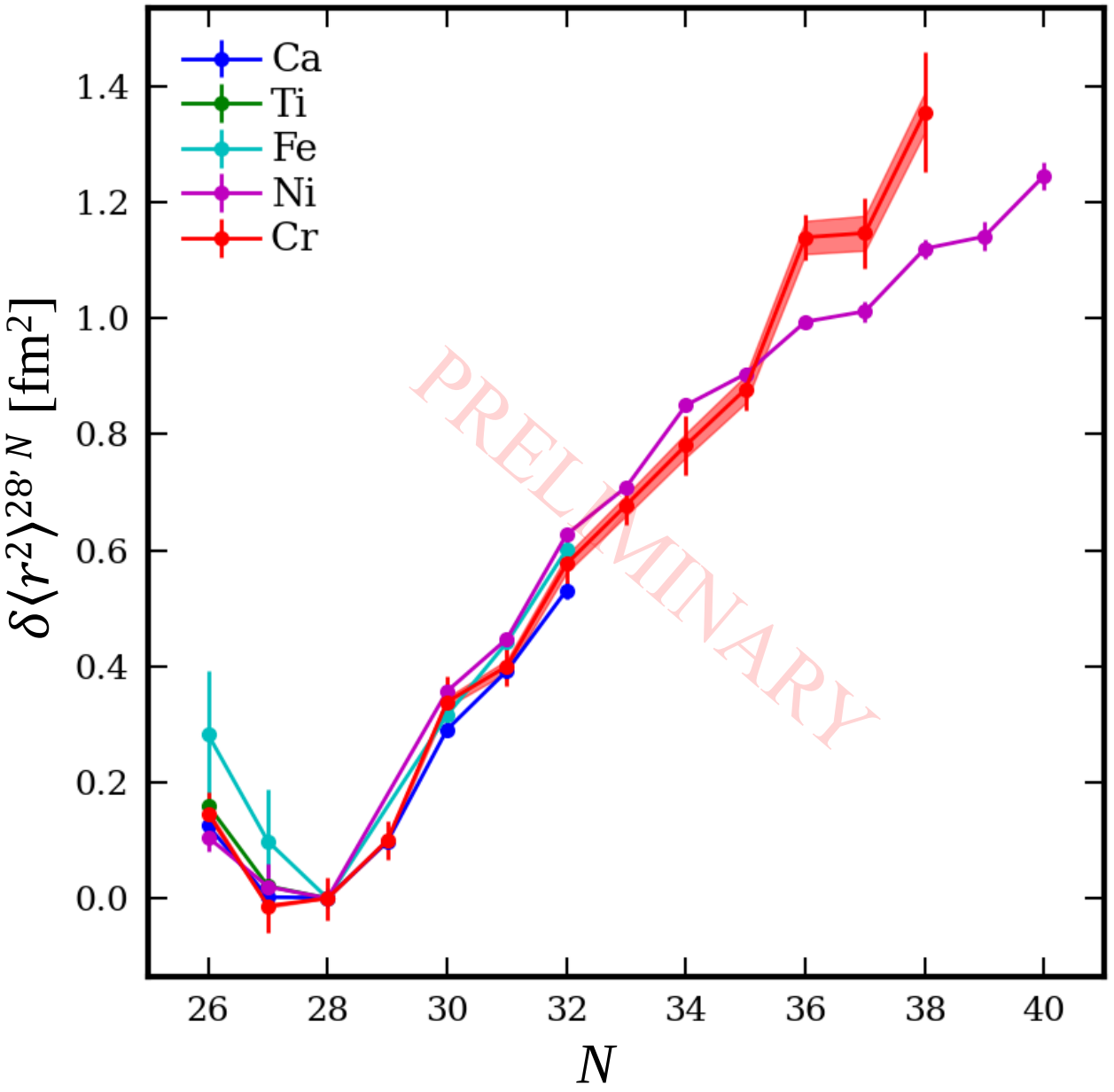

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- Clear change of slope at N=34 between deformed Cr, and spherical Ni
- Strong odd-even staggering of the Cr radii for N>34

Signature of the beginning of the N=40 Island of Inversion

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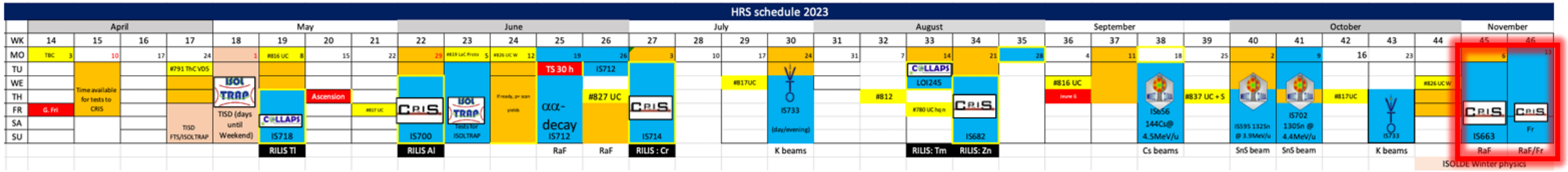

RaF for *P,T* violation searches

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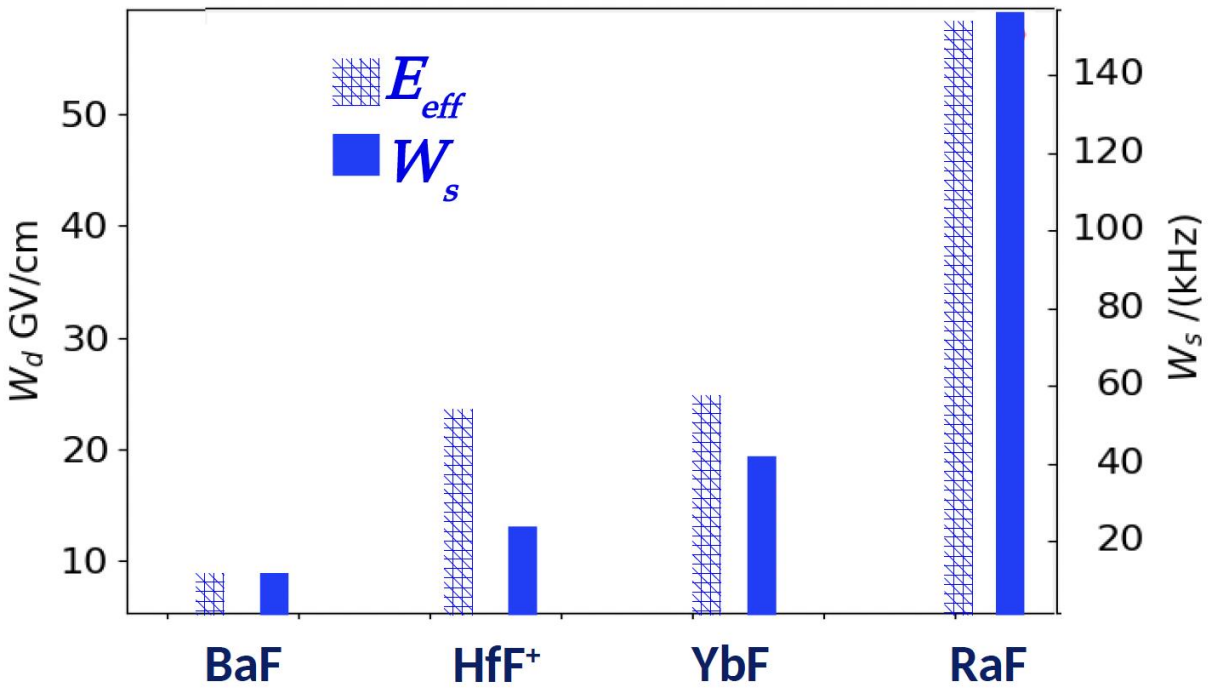

Plot courtesy of R. F. Garcia Ruiz and S. G. Wilkins (MIT)

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Exceptionally sensitive to P,T-violating moments
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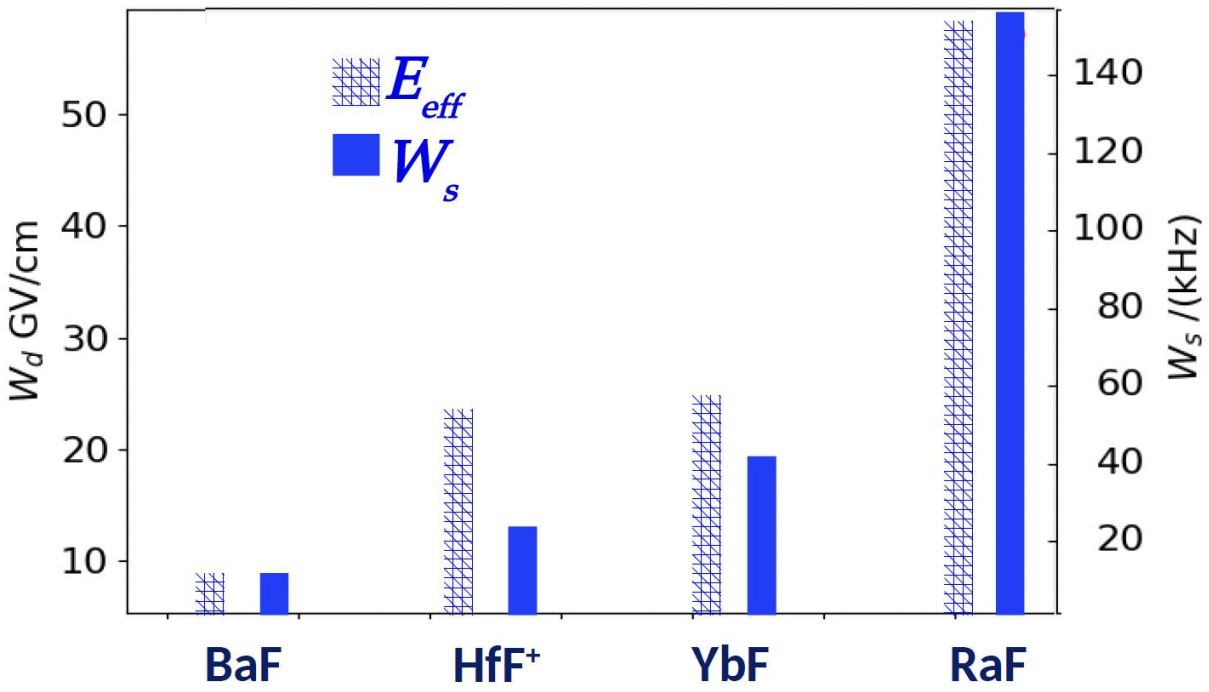

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Very long coherence time τ
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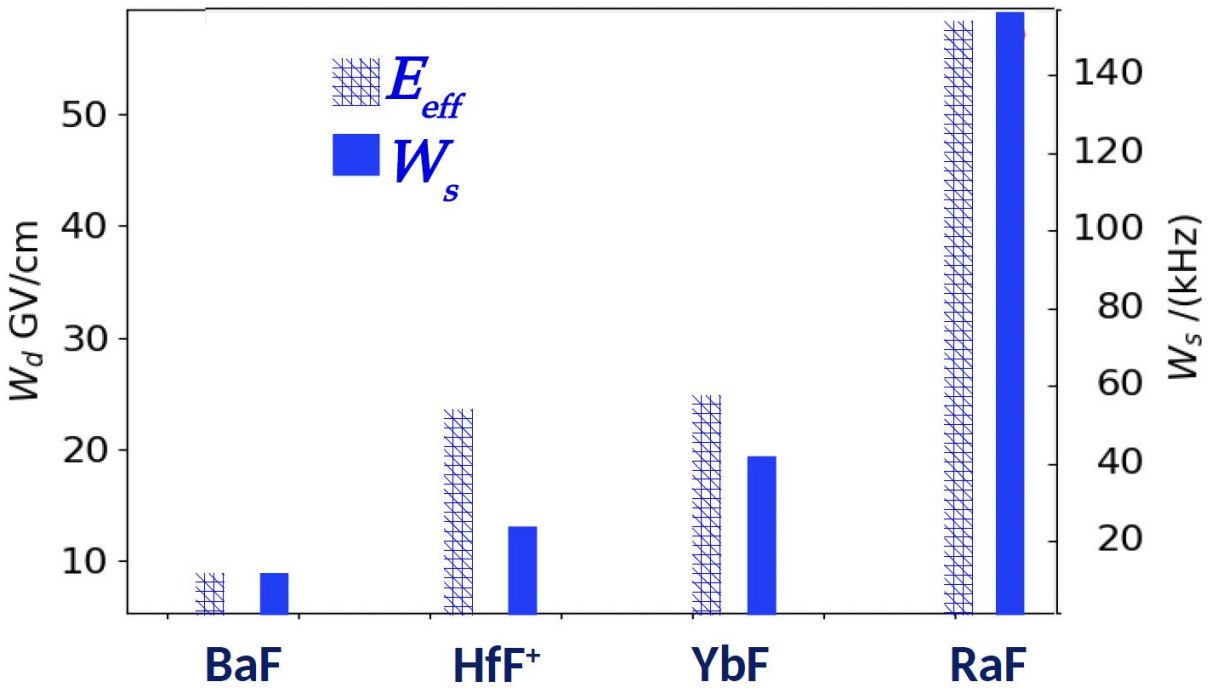

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➔ RaF is one of the most promising system for *P,T* violation searches

The Hamiltonian of RaF:

$$\hat{H}^{\mathrm{RaF}} = \hat{H}_{\mathrm{el}} + \hat{H}_{\mathrm{vib}} + \hat{H}_{\mathrm{rot}} + \hat{H}_{\mathrm{hfs}} + \cdots + \hat{H}_{P,T}$$

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Electronic and vibrational structure

CRIS 2018

Nature 581, 396 (2020)

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Electronic and vibrational structure
CRIS 2018

Nature 581, 396 (2020)

Rotational structure
CRIS 2021

Nature Physics, accepted (2023)

PRL 127, 033001 (2021)

Magnetic dipole interaction
CRIS 2021

arXiv:2311.04121, submitted (2023)

arXiv:2308.14862, submitted (2023)

See poster of Carlos Fajardo-Zambrano!

High-resolution spectroscopy of RaF

The Hamiltonian of RaF:

$$\hat{H}^{\mathrm{RaF}} = \hat{H}_{\mathrm{el}} + \hat{H}_{\mathrm{vib}} + \hat{H}_{\mathrm{rot}} + \hat{H}_{\mathrm{hfs}} + \cdots + \hat{H}_{P,T}$$

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Magnetic dipole interaction
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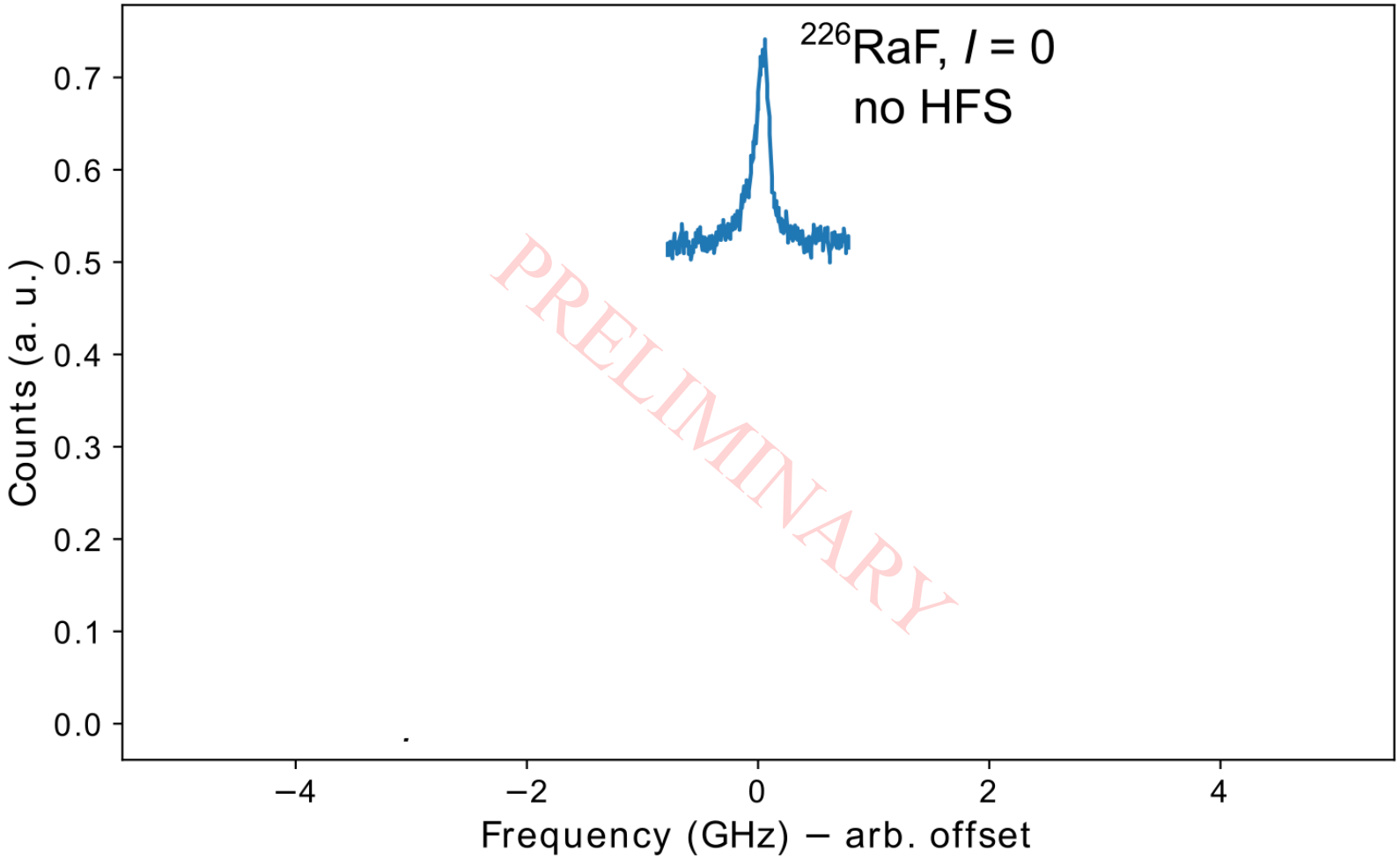
Electric quadrupole interaction
CRIS 2023

See poster of Carlos Fajardo-Zambrano!

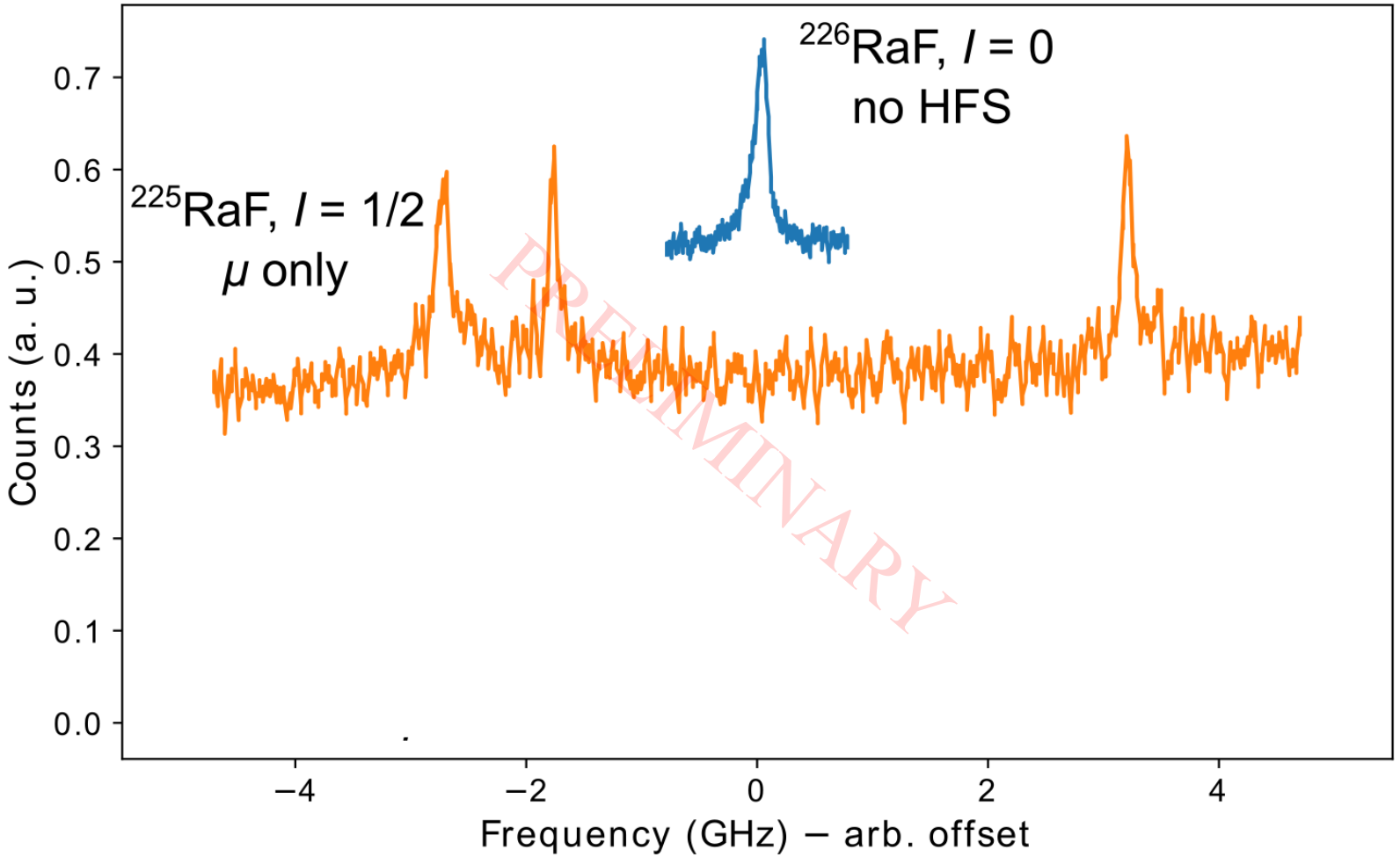
High-resolution spectroscopy of RaF



2023 RaF:

- High res. spec. of ^{226}RaF

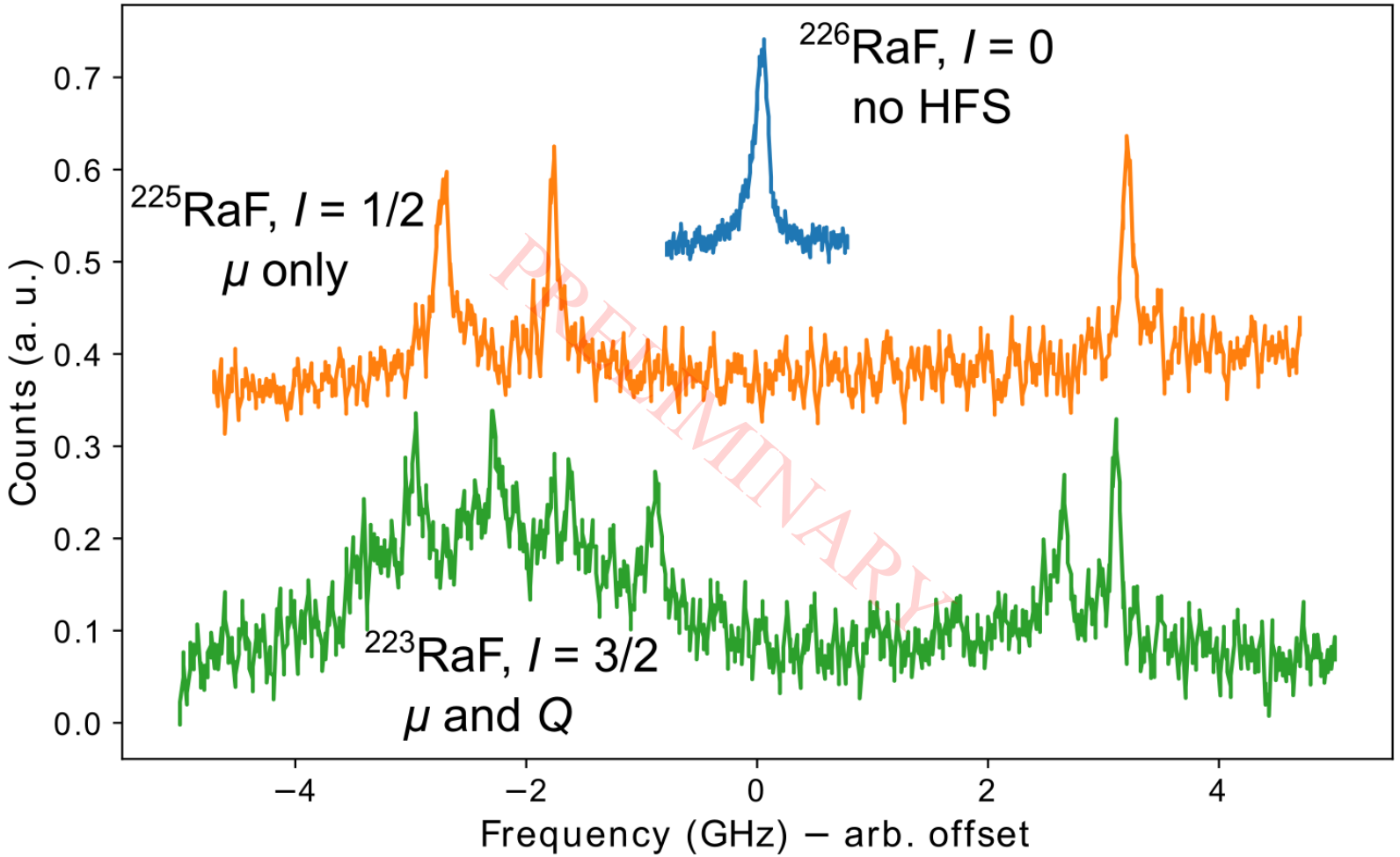
High-resolution spectroscopy of RaF



2023 RaF:

- High res. spec. of ^{226,225}RaF

High-resolution spectroscopy of RaF



2023 RaF:

- High res. spec. of ^{226,225,223}RaF
- First measurement of the hyperfine structure of ^{223}RaF

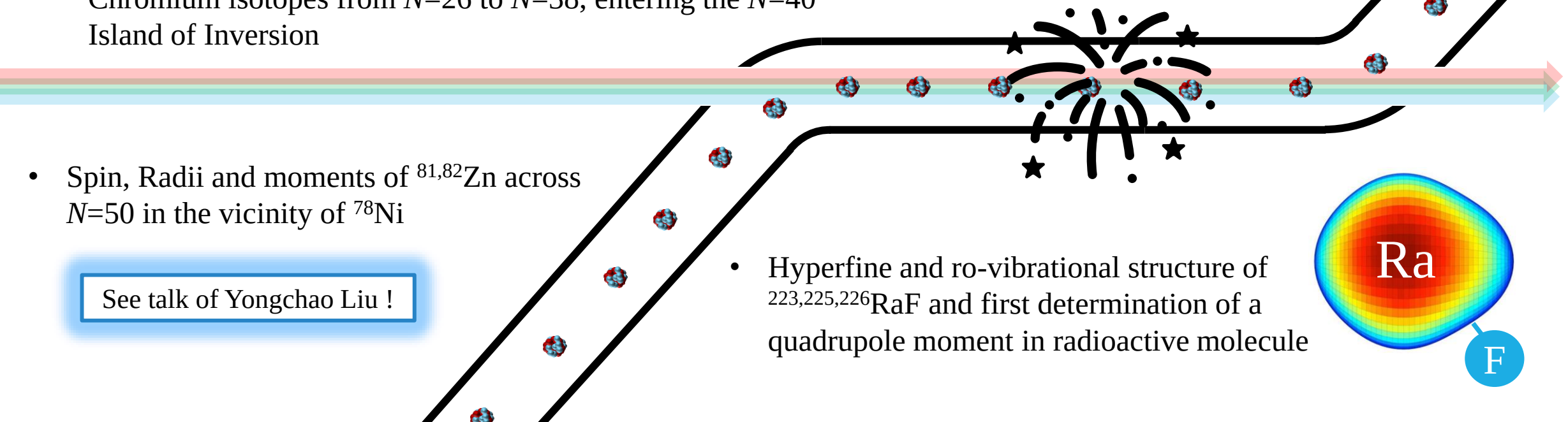
→ Analysis ongoing for the first measurement of an electric quadrupole moment in a radioactive molecule

Analysis and slides from Michail Athanasakis-Kaklamanakis

Conclusion

2023 @ CRIS

- Two major upgrades: New end of the beam line and new Decay spectroscopy station succesfully commisioned
- Charge radii of neutron rich Aluminium isotopes across *N*=20 in the Island of inversion
- Spin, radii and magnetic dipole moment of neutron rich Chromium isotopes from *N*=26 to *N*=38, entering the *N*=40 Island of Inversion



- Spin, Radii and moments of ^{81,82}Zn across *N*=50 in the vicinity of ^{78}Ni

See talk of Yongchao Liu !

- Hyperfine and ro-vibrational structure of ^{223,225,226}RaF and first determination of a quadrupole moment in radioactive molecule

The 2023 CRIS Collaboration

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THANK YOU FOR
YOUR
ATTENTION