2023 at CRIS

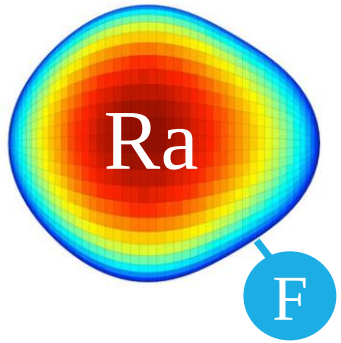
Louis Lalanne

CERN / ISOLDE

on behalf of the CRIS collaboration

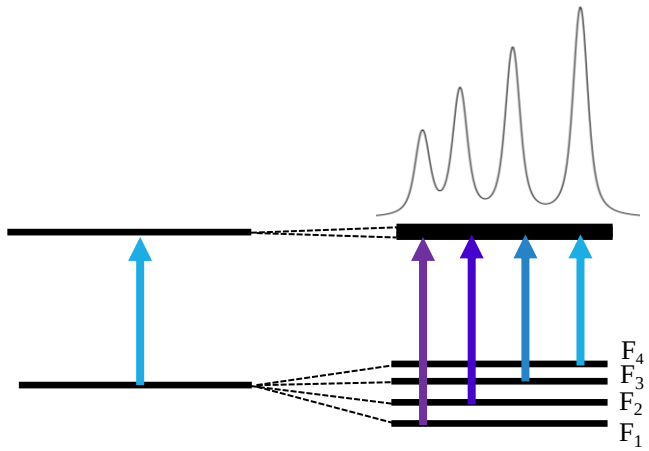
ISOLDE Workshop

30/11/2023



CRIS : Collinear Resonance Ionization Spectroscopy

Hyperfine Structure (HFS) :



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

$$A = \frac{\mu\, Be(0)}{I.J}$$

$$B = e\, Qs\, V(0)$$

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

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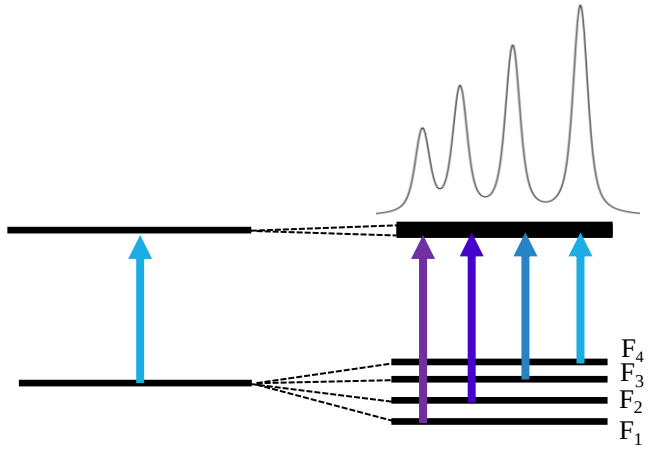

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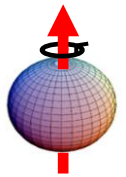
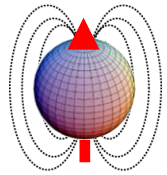
Measuring the HFS :

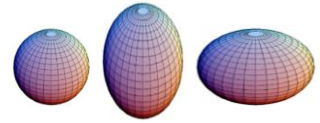
- Nuclear Spin I



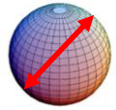
- Magnetic dipole moment μ



- Electric quadrupole moment Q_s



- Changes of charge radii $\delta\langle r^2\rangle$



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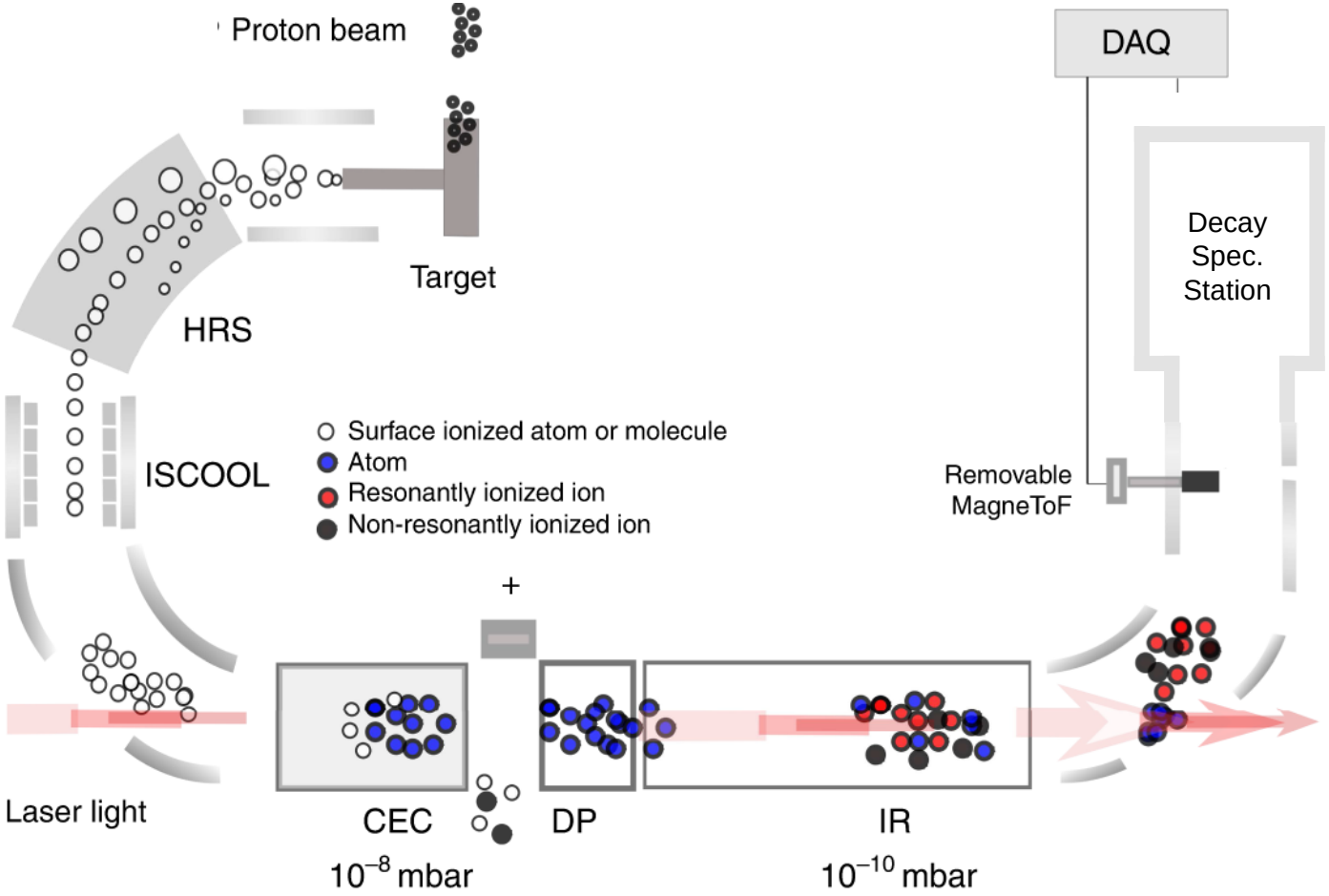

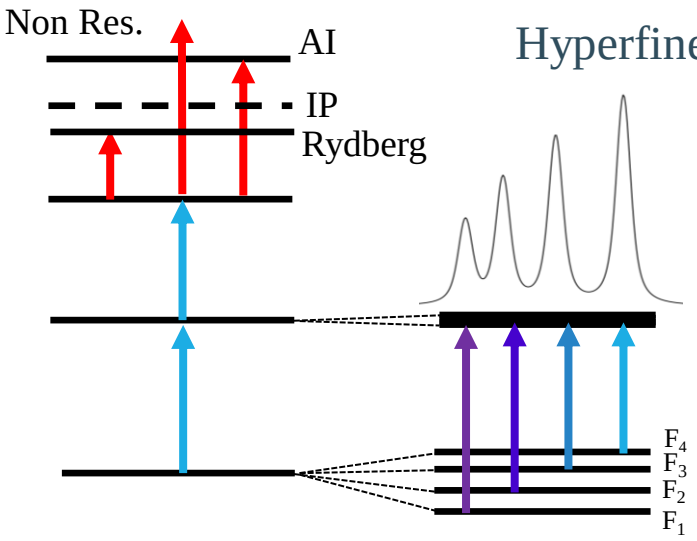

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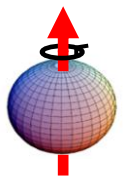

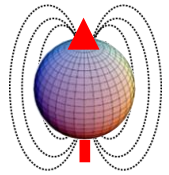

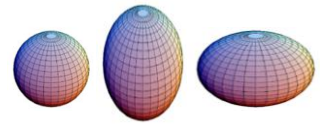

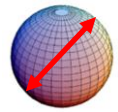

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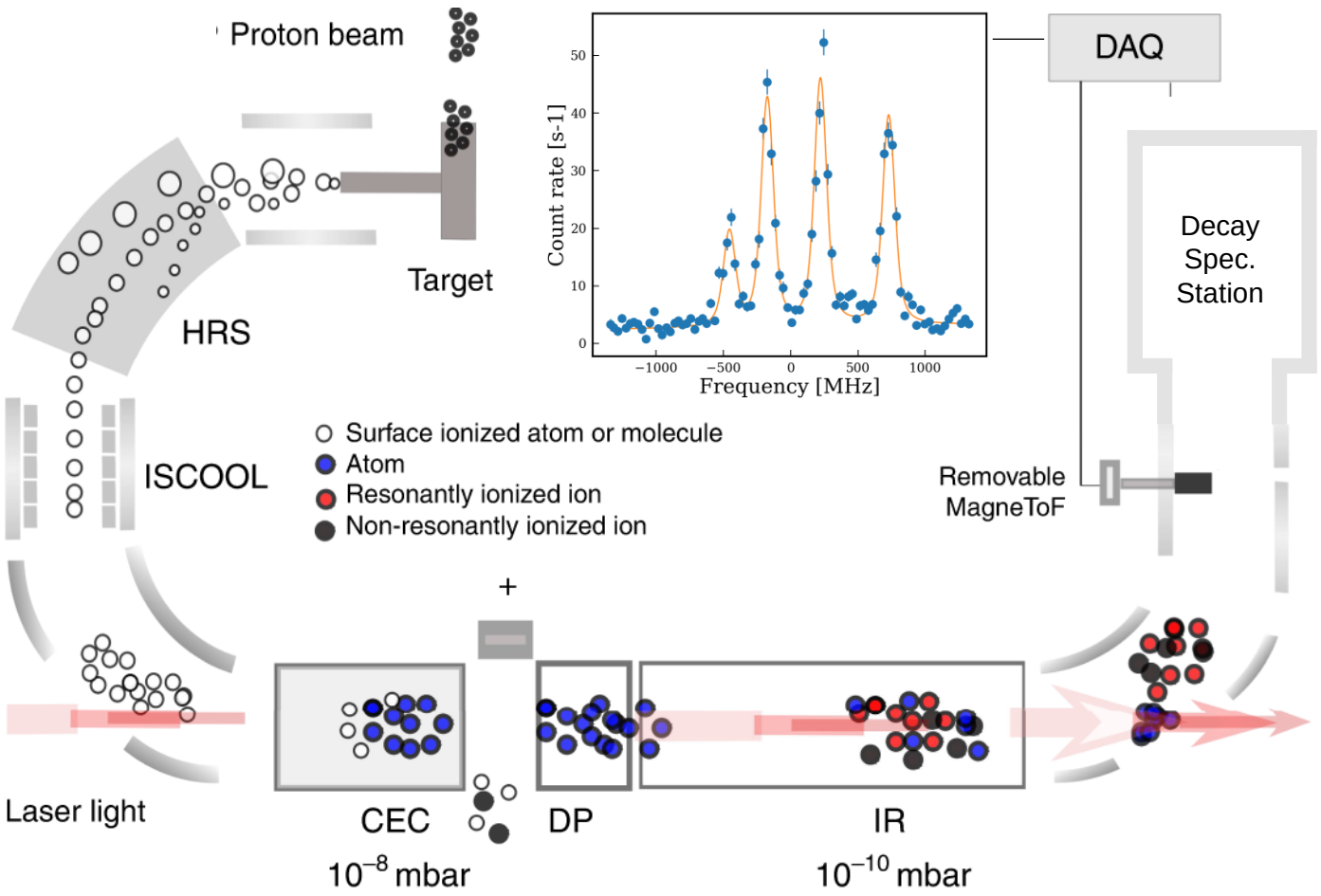
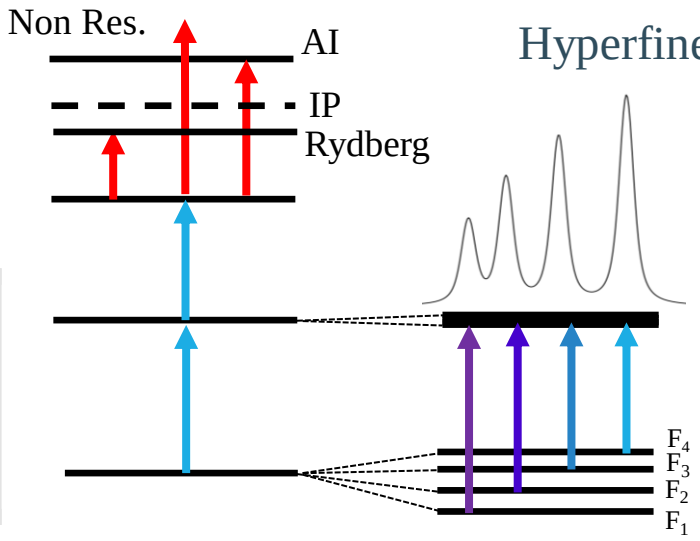


✓ High sensitivity : > few 10 ions/s ✓ High resolution : > 20 MHz

✓ High versality



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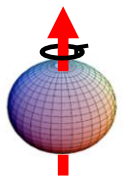
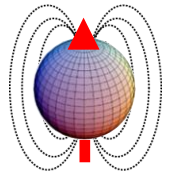
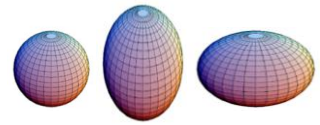
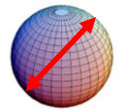


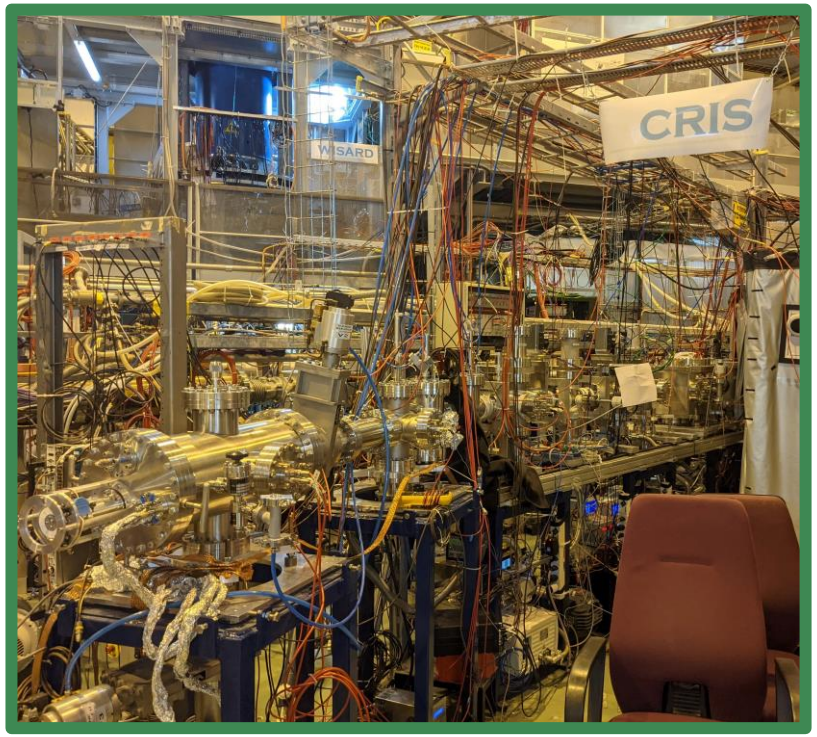






2023 CRIS upgrade: New End of the Beam Line

Decembre 2022



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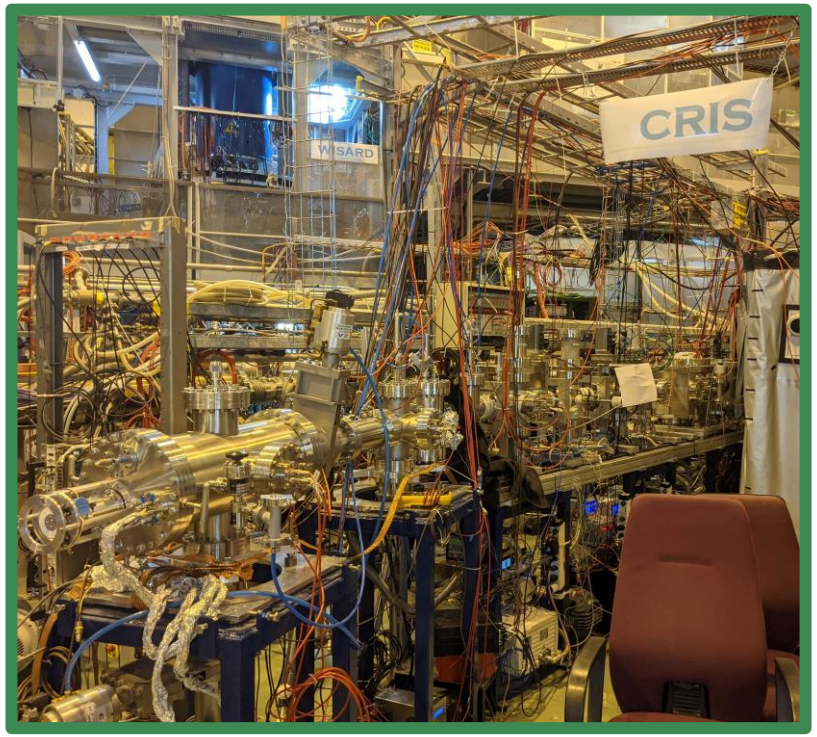
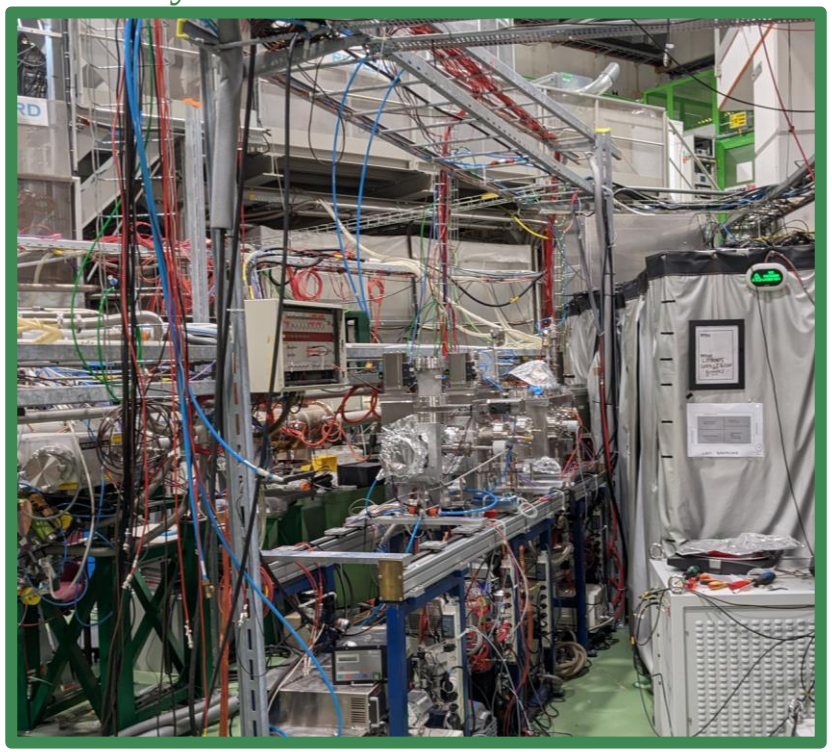


January 2023



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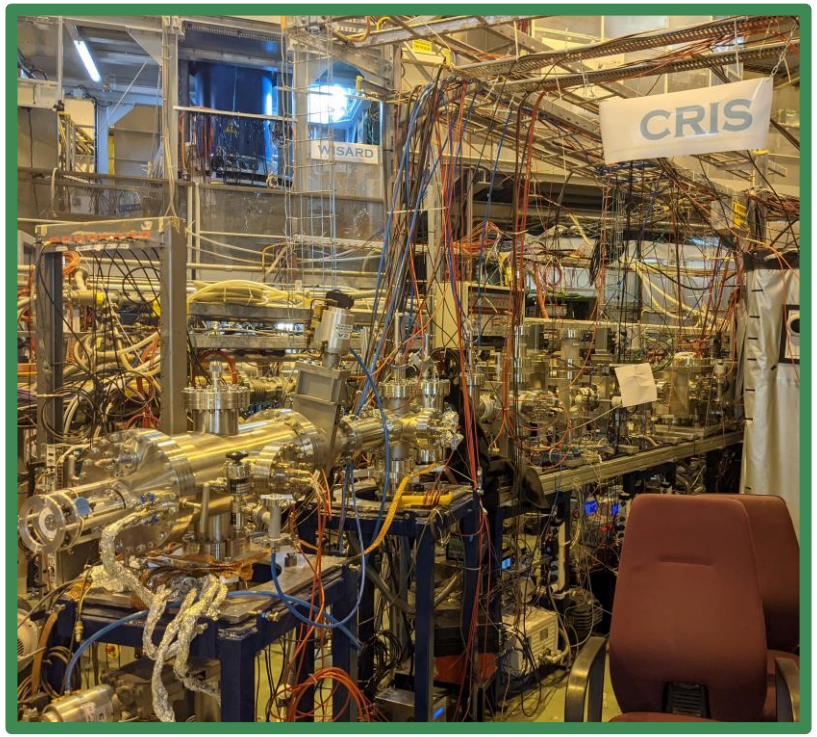

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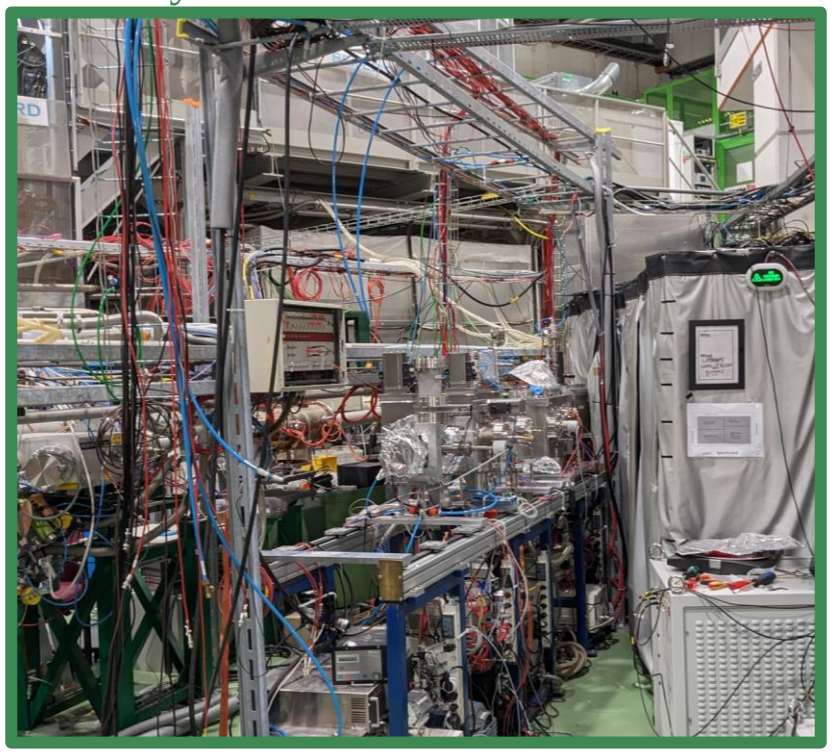
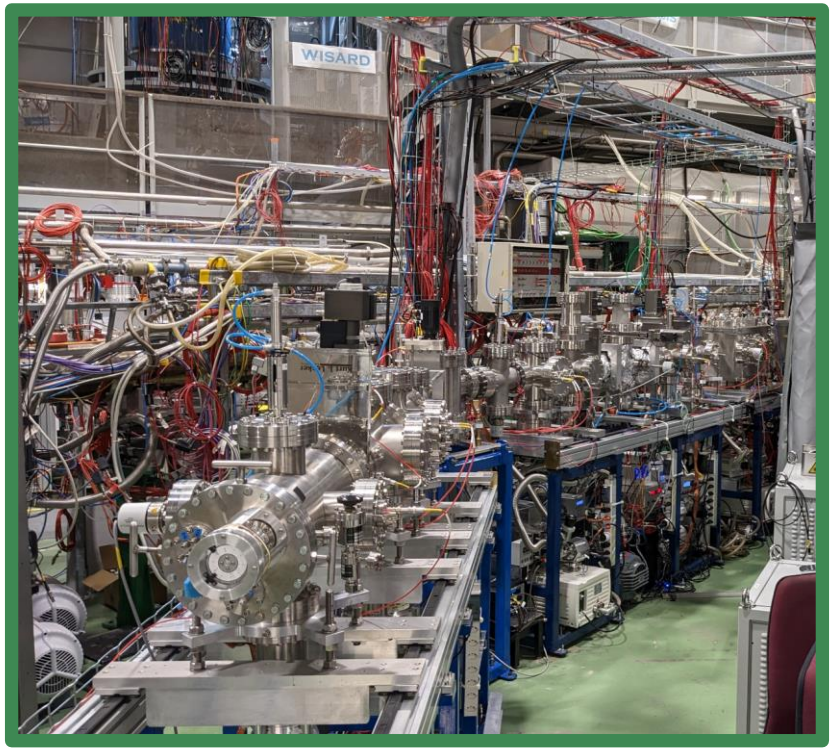


March 2023



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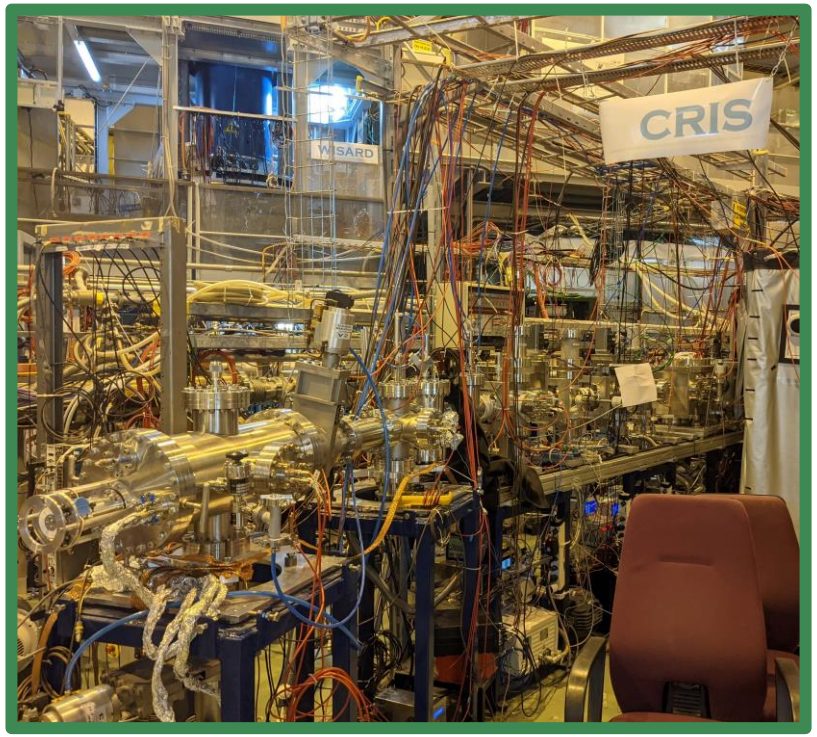

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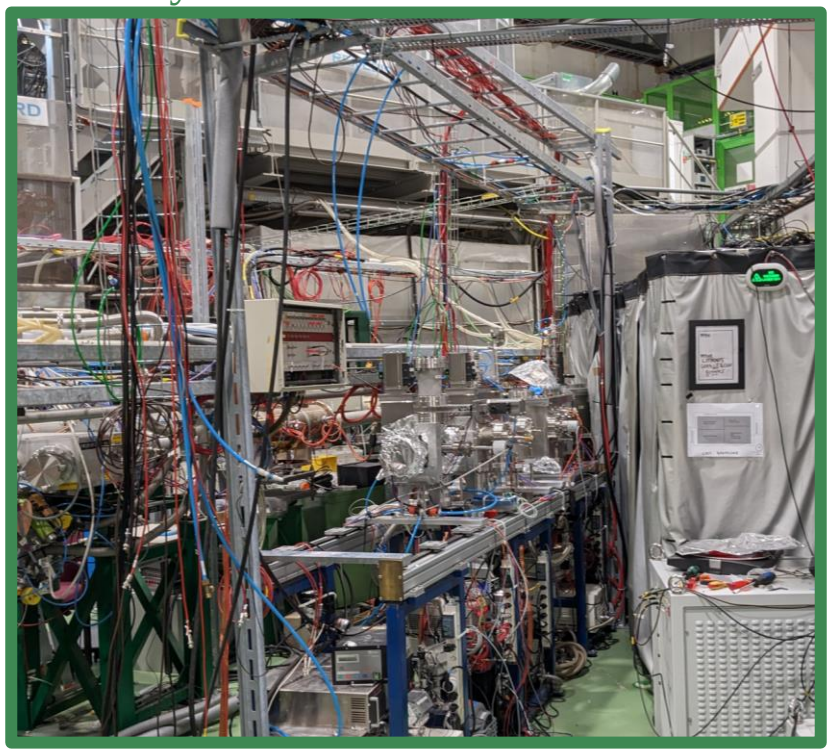

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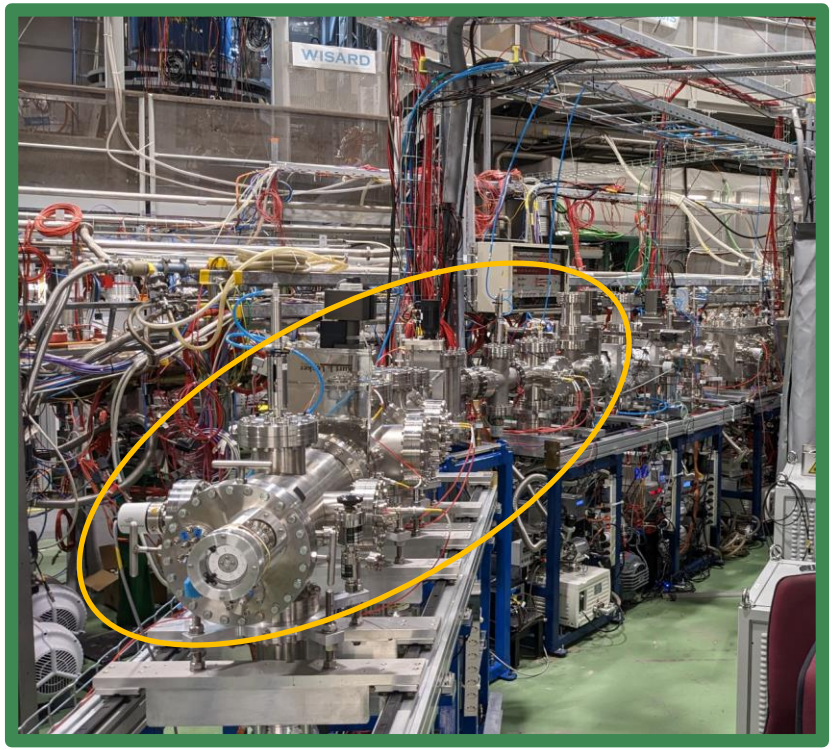

New end of the beam line:

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

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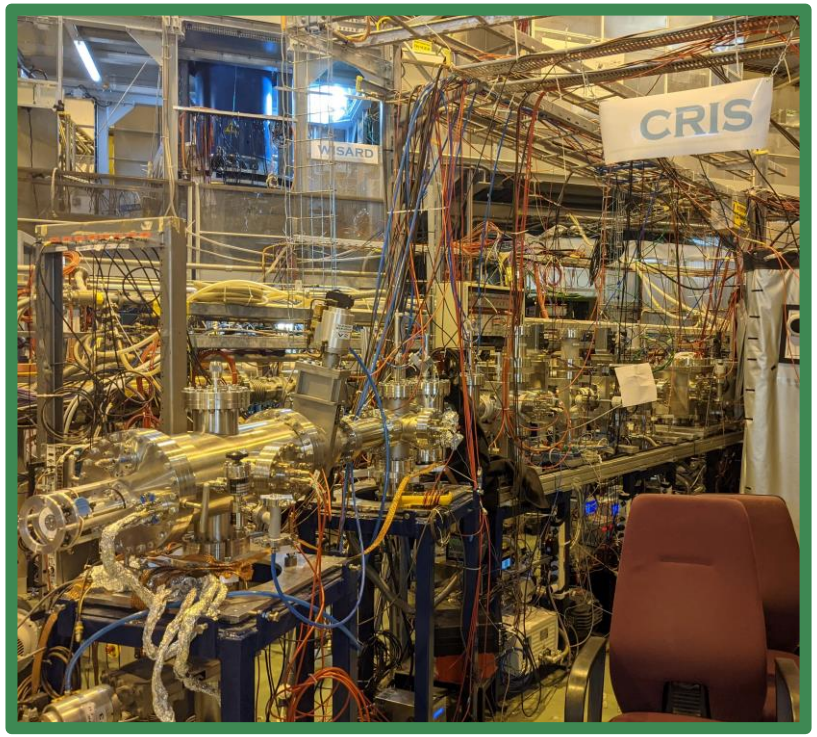

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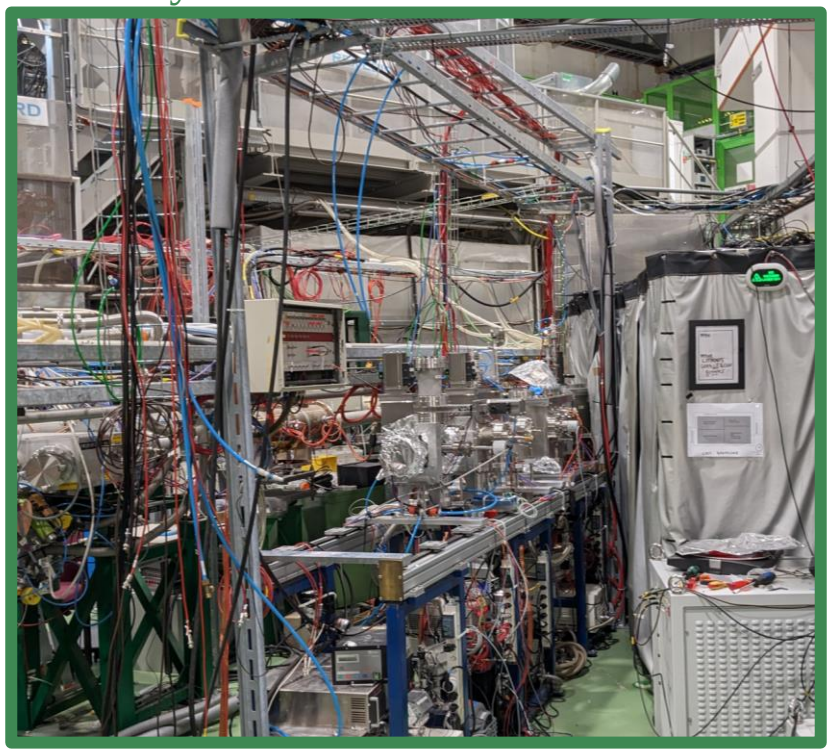

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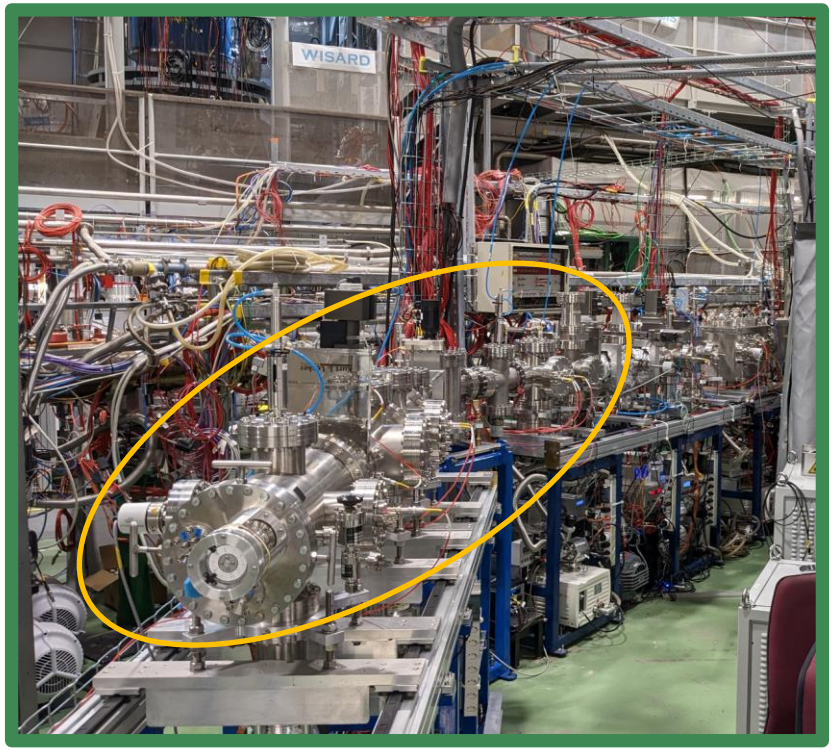


New end of the beam line:

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

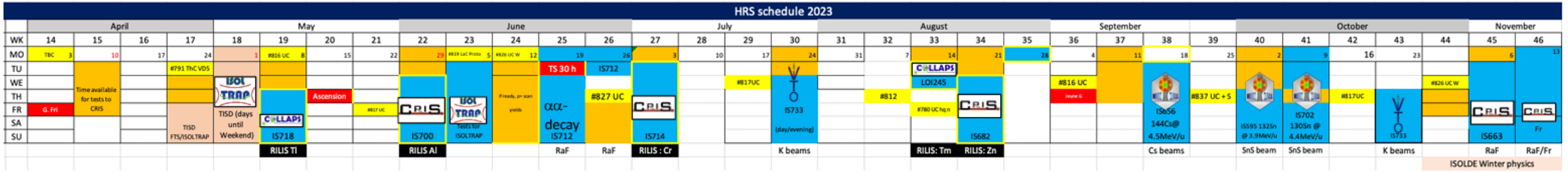
→ Allows Rydberg ionization scheme

→ 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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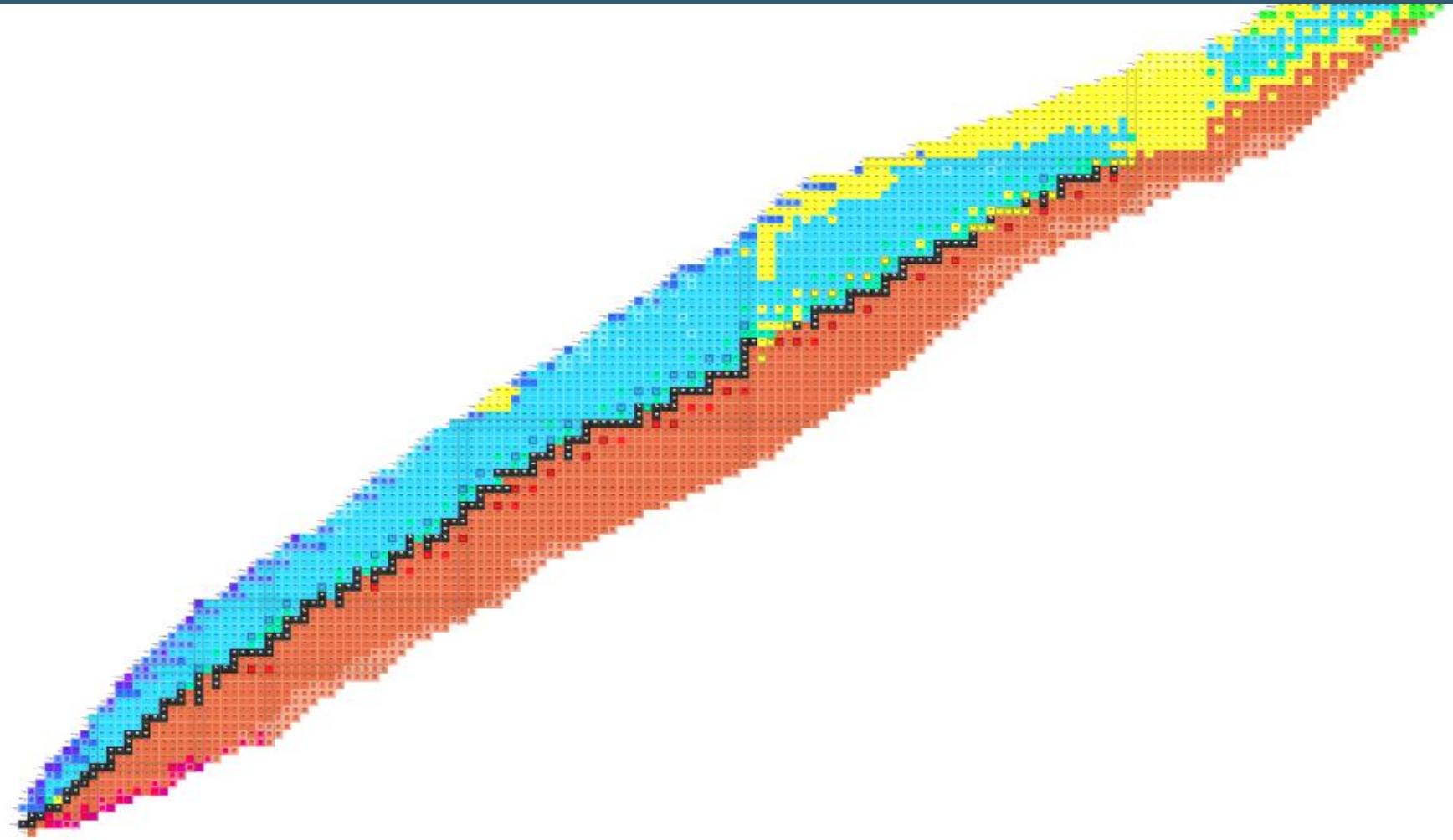

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	April				May				June					July				August					September				October					November	
WK	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
MO	TBC		17	24	1	#816 UC 8	15	22	29	#819 LoC Proto 5	#826 UC W 12	19	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 ISOLTRAP				IS714			(day/evening)				IS682										IS663	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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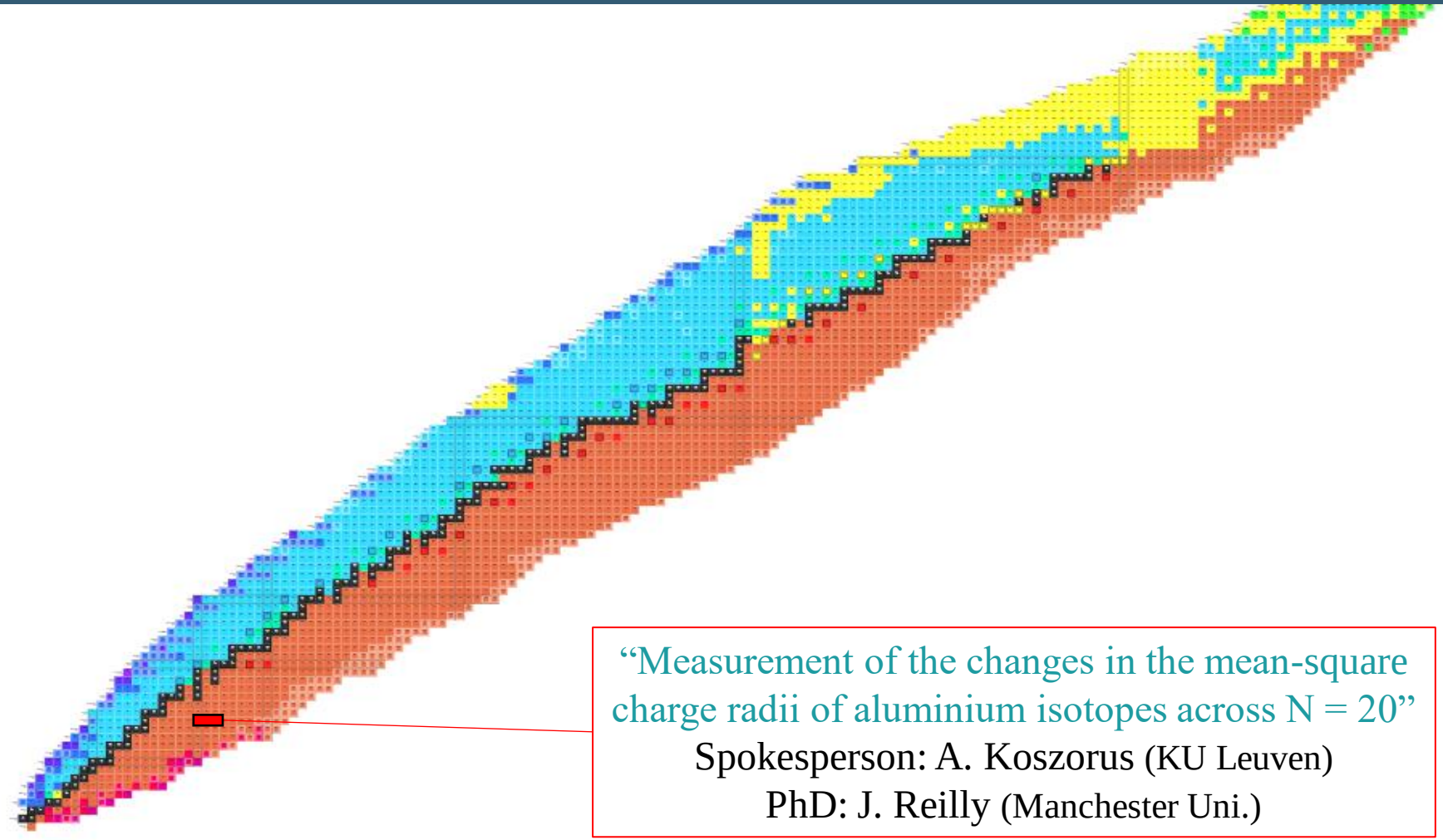

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Spokesperson: A. Koszorus (KU Leuven)

PhD: J. Reilly (Manchester Uni.)

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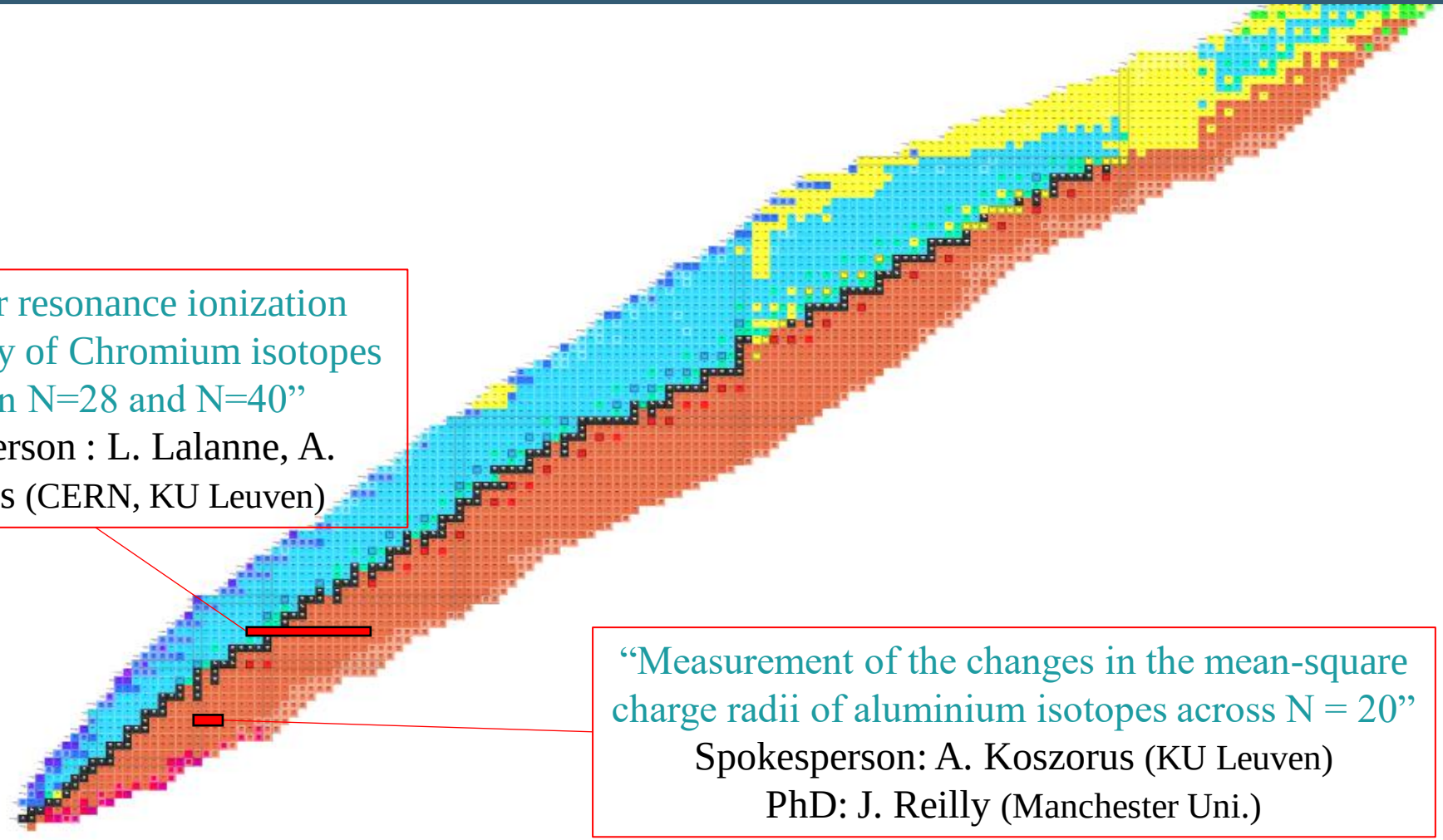

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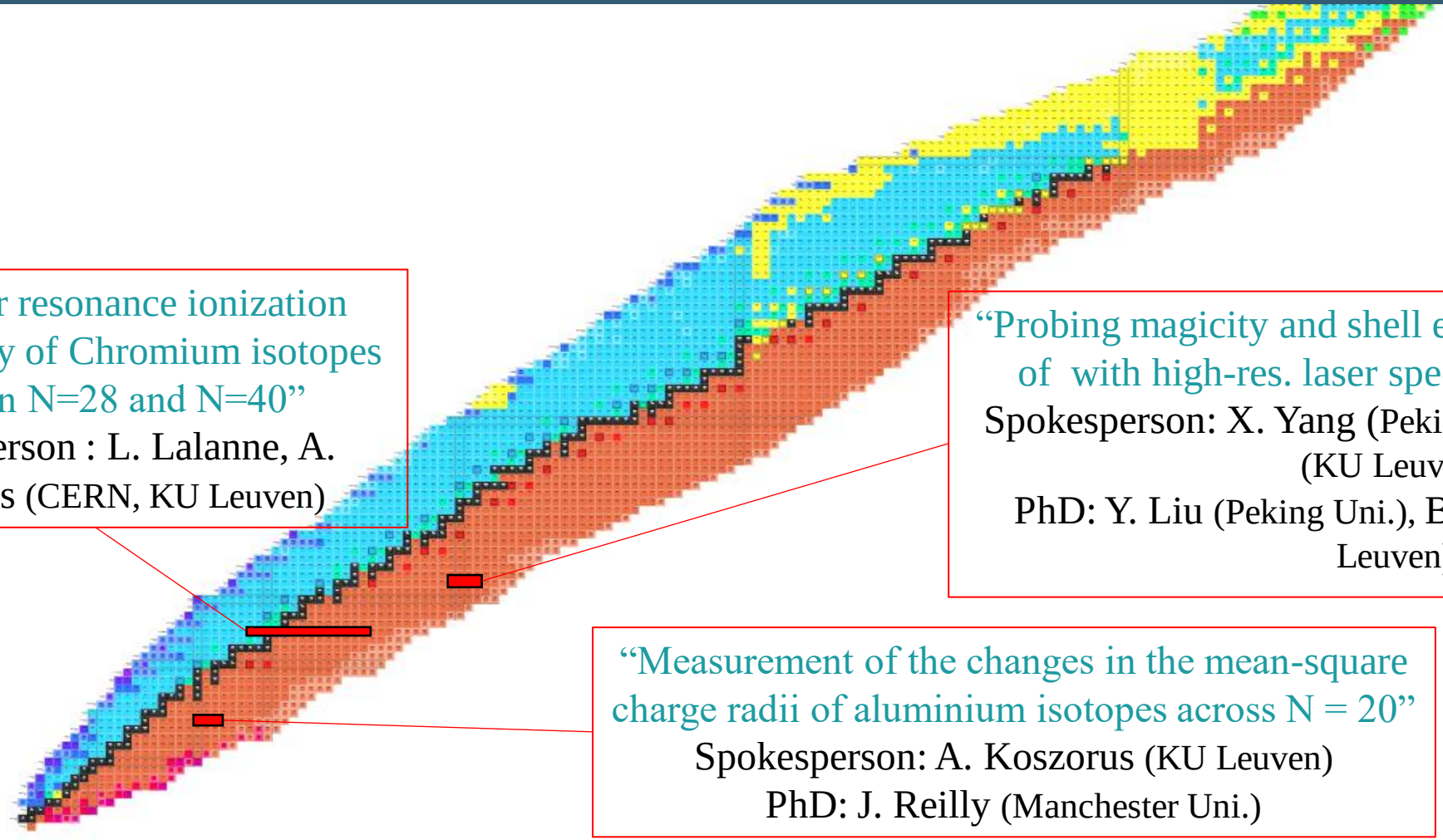

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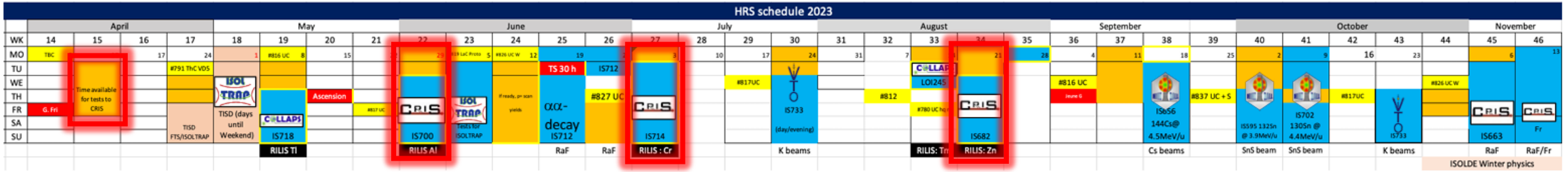

The 2023 experimental campaign

"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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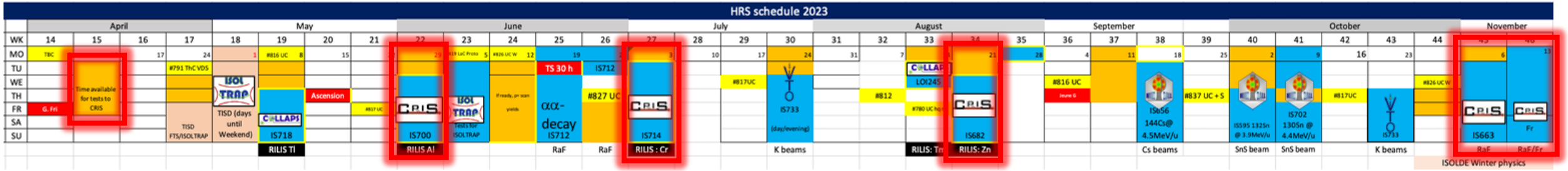

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Spokesperson: M. Athanasakis-Kaklamanakis (KU Leuven, CERN), S. Wilkins, R. Garzia-Riuz (MIT)
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"Collinear resonance ionization spectroscopy of Chromium isotopes between N=28 and N=40"
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See talk of Yongchao Liu !

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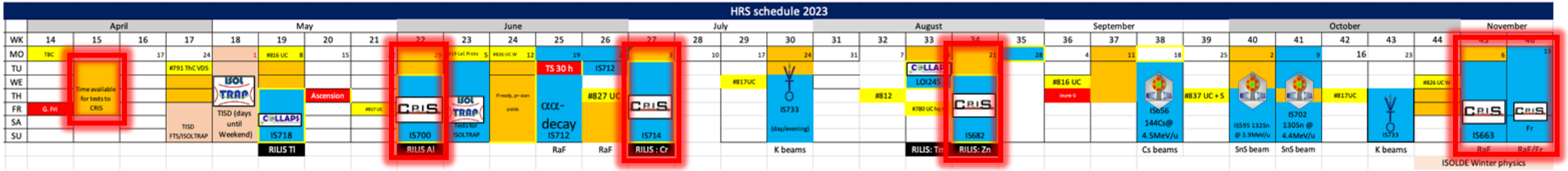

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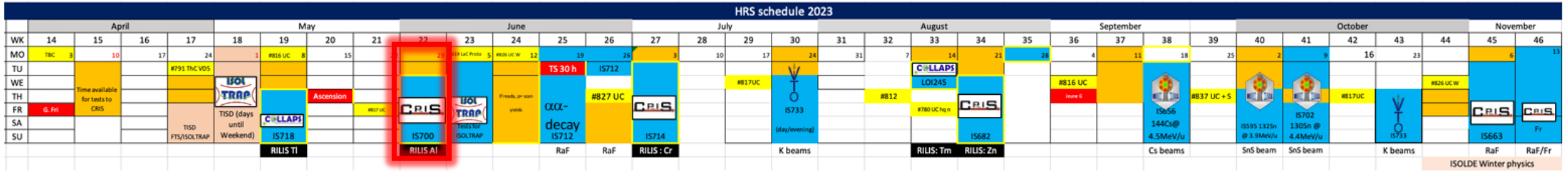
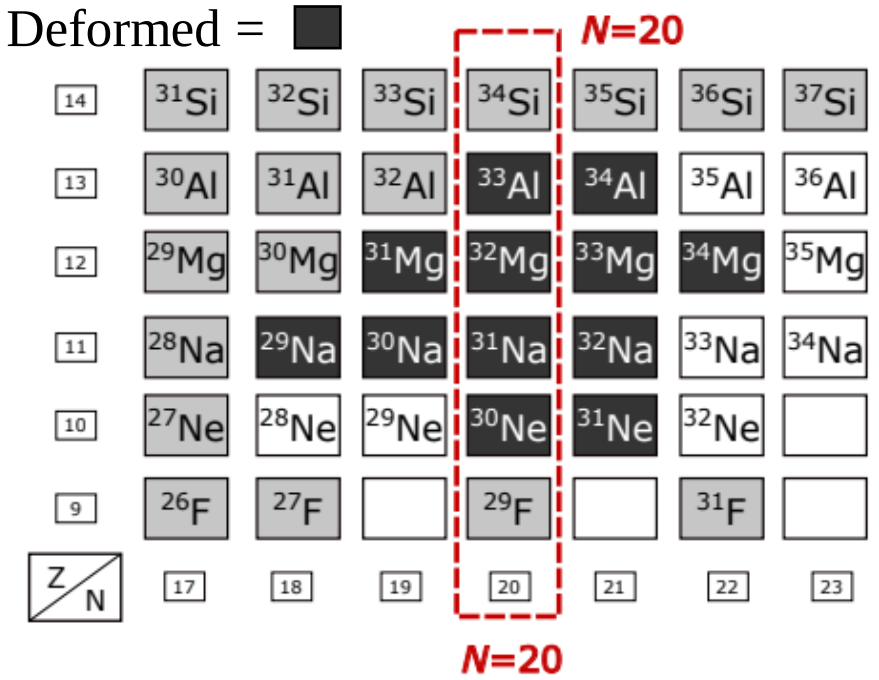


Charge radii of Aluminium isotopes across N = 20

- 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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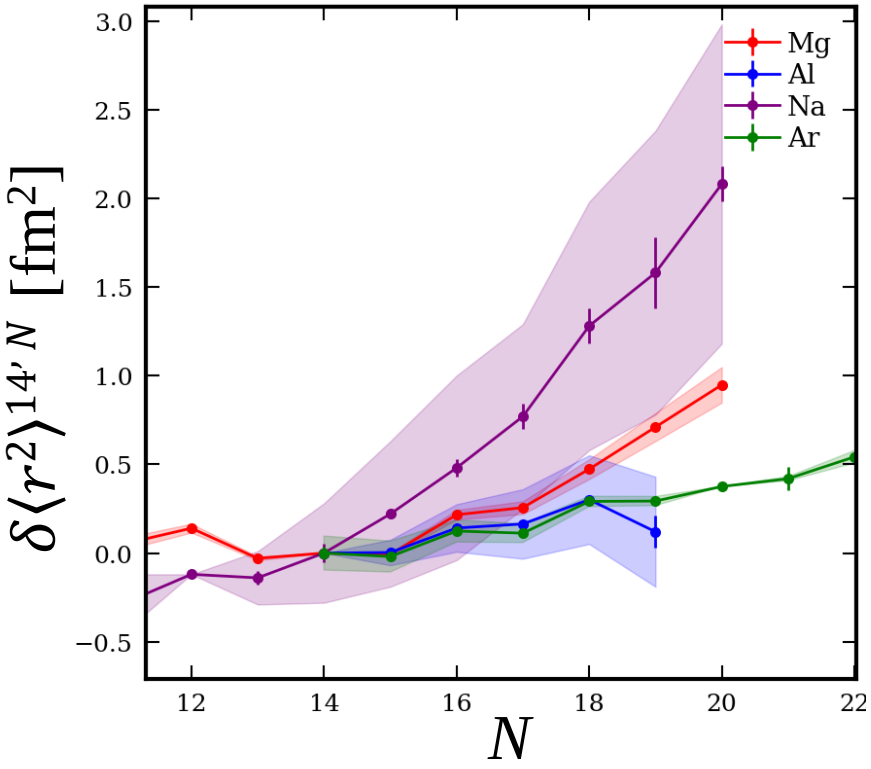

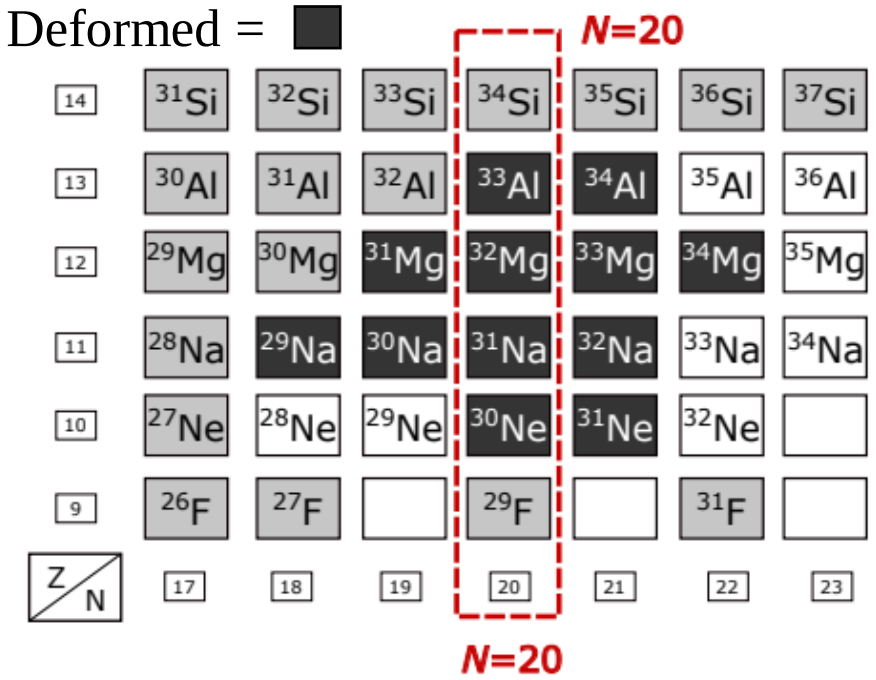

- Large increase in charge radii towards the N = 20 shell closure is observed for **Na** and **Mg**
- Previous measurements of Al radii display an unexpected decrease in $\delta\langle r^2\rangle$ between ^{31}Al and ^{32}Al [2]

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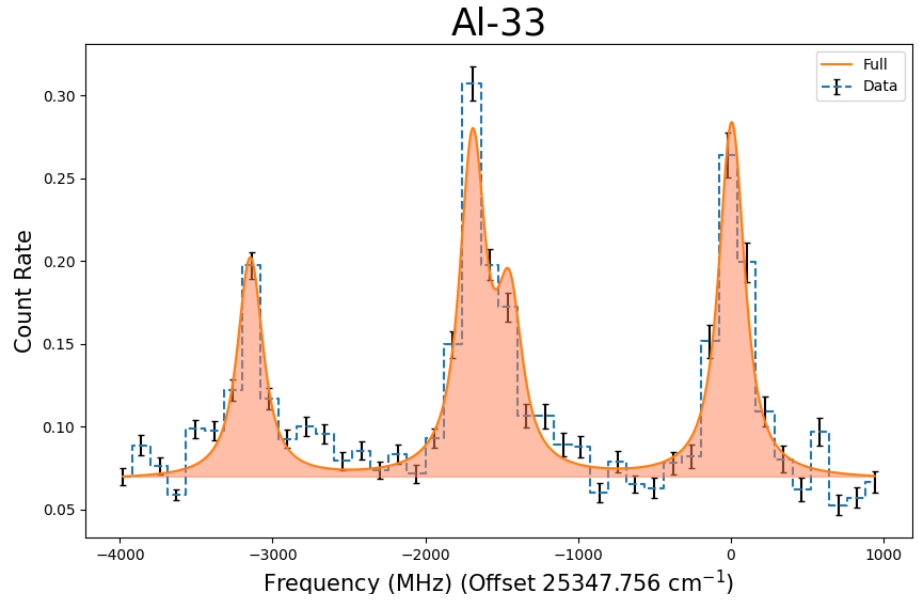
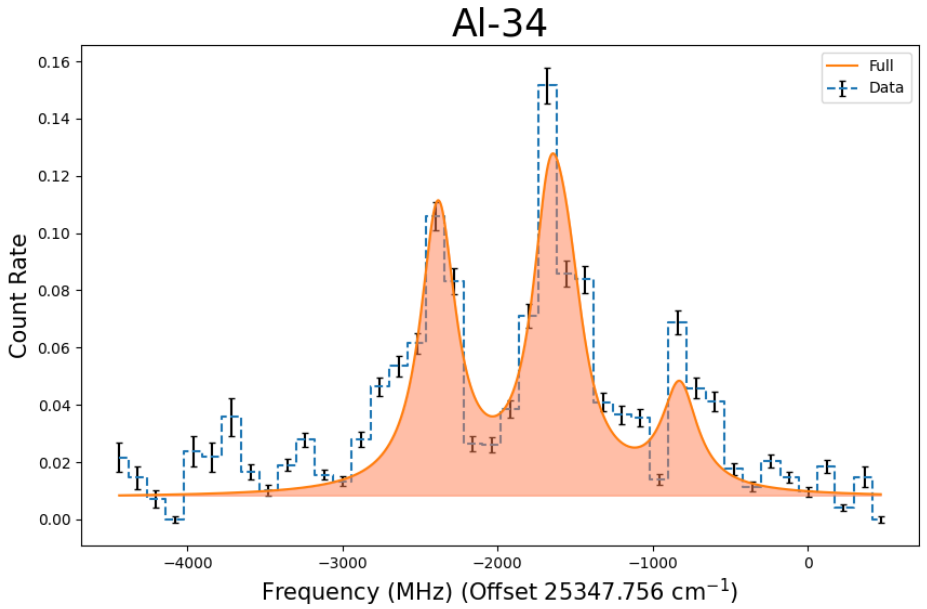
[2] Heylen et al., PHYSICAL REVIEW C **103**, 014318 (2021)

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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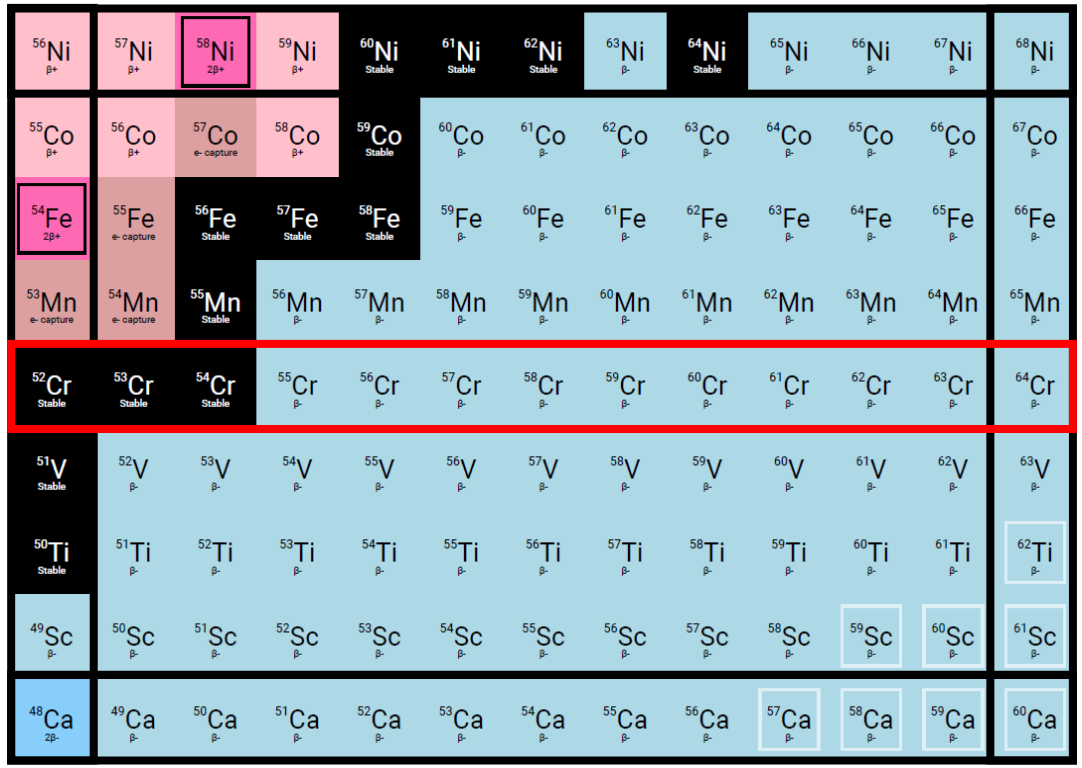
HRS schedule 2023

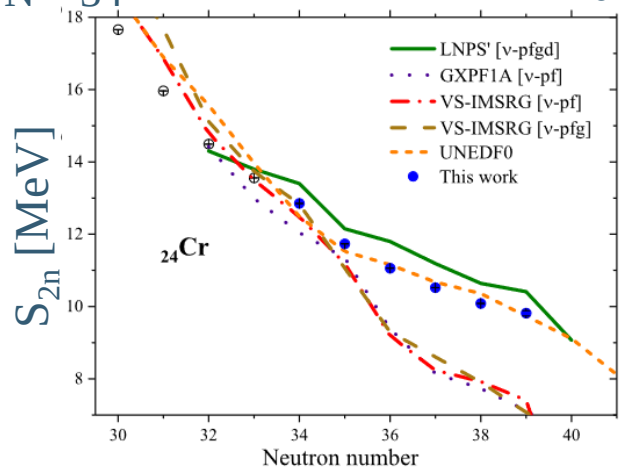
	April				May				June					July				August					September				October					November	
WK	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
MO	TBC					#816 UC				#819 LoC Proto	#826 UC W	TS 30 h	IS712							COLLAPS													
TU				#791 ThC VDS																LOI245													
WE		Time available for tests to CRIS			ISOLTRAP		Ascension						#827 UC			#817UC			#812				#816 UC			#837 UC + S			#817UC		#826 UC W		
TH									CRIS	ISOLTRAP		αα-decay IS712		CRIS			IS733			#780 UC hg n	CRIS											
FR	G. Fri			TISD FTS/ISOLTRAP	TISD (days until Weekend)	COLLAPS IS718		#817 UC	IS700	Tests for ISOLTRAP	If ready, pr scan yields			IS714			(day/evening)				IS682			IS56 144Cs@ 4.5MeV/u		IS595 132Sn @ 3.9MeV/u	IS702 130Sn @ 4.4MeV/u		IS733		CRIS IS663	CRIS Fr	
SA																																	
SU																																	
						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
																																ISOLDE Winter physics	

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





[1] M. Mougeot *et al.*, PRL **120**, 232501 (2018)

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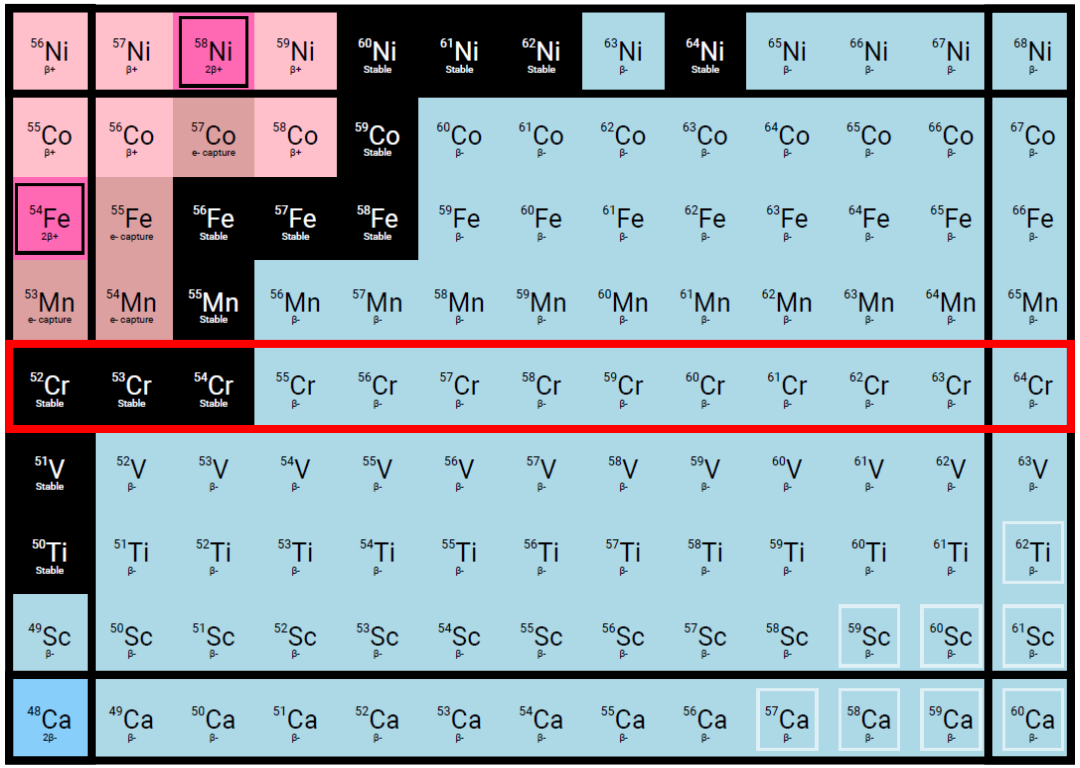
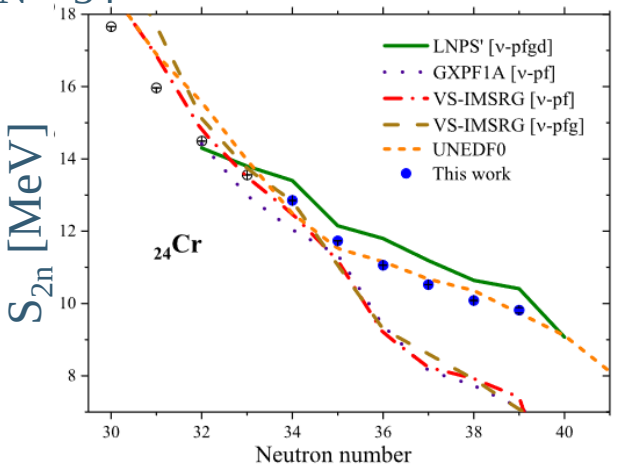


Goals:

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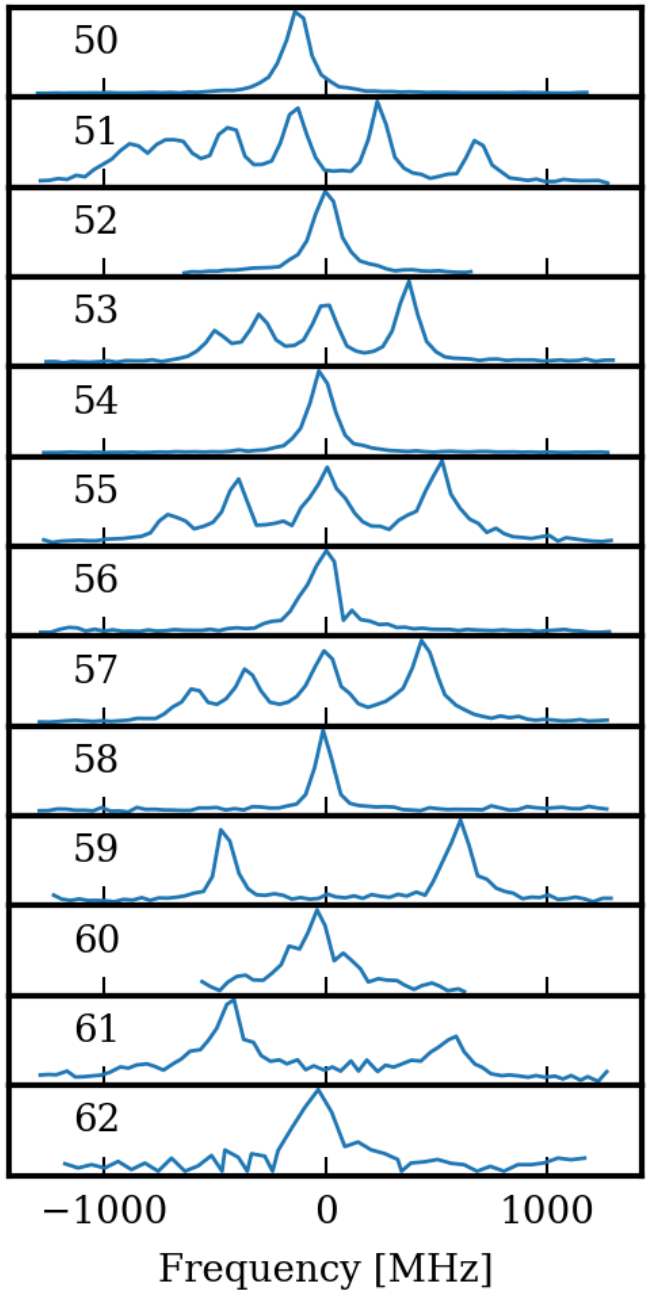
Cr Results: spins of odd-*A* Cr isotopes



I Lit:

7/2-

3/2-

3/2-

(3/2)-

(1/2)-

(5/2)-

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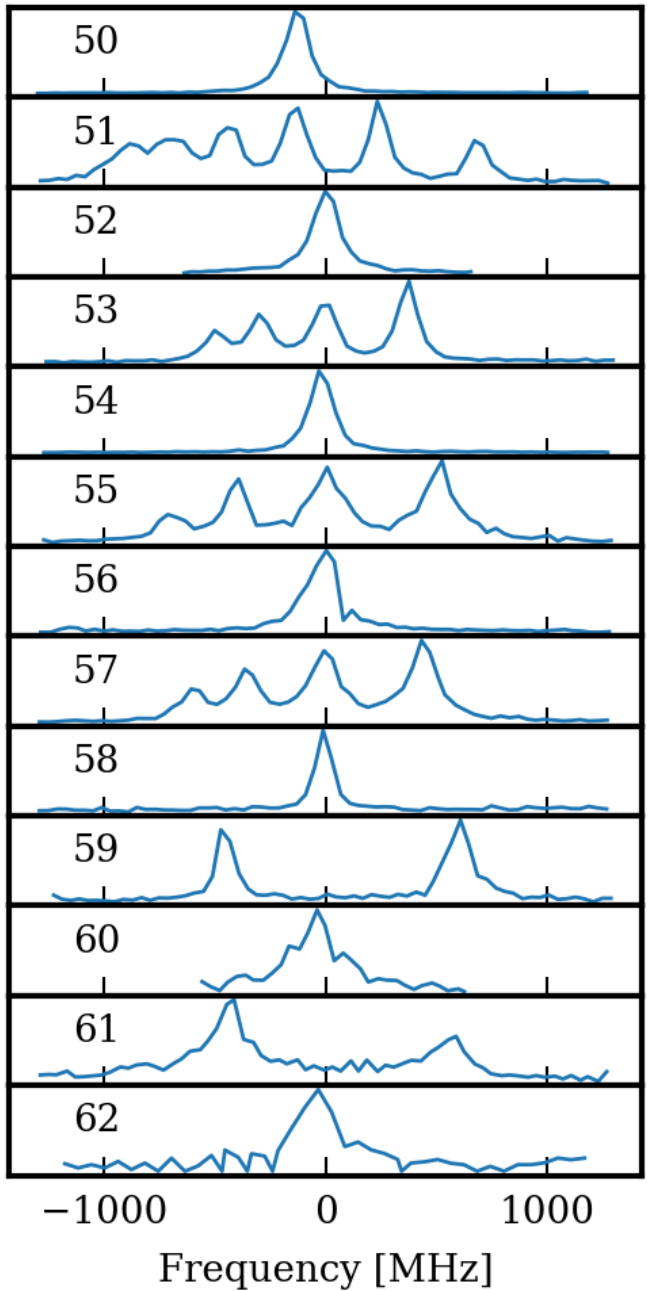

I Lit:	*I* CRIS:
$7/2^-$	$7/2^-$
$3/2^-$	$3/2^-$
$3/2^-$	$3/2^-$
$(3/2)^-$	$3/2^-$
$(1/2)^-$	$1/2^-$
$(5/2)^-$	$1/2^-$

- 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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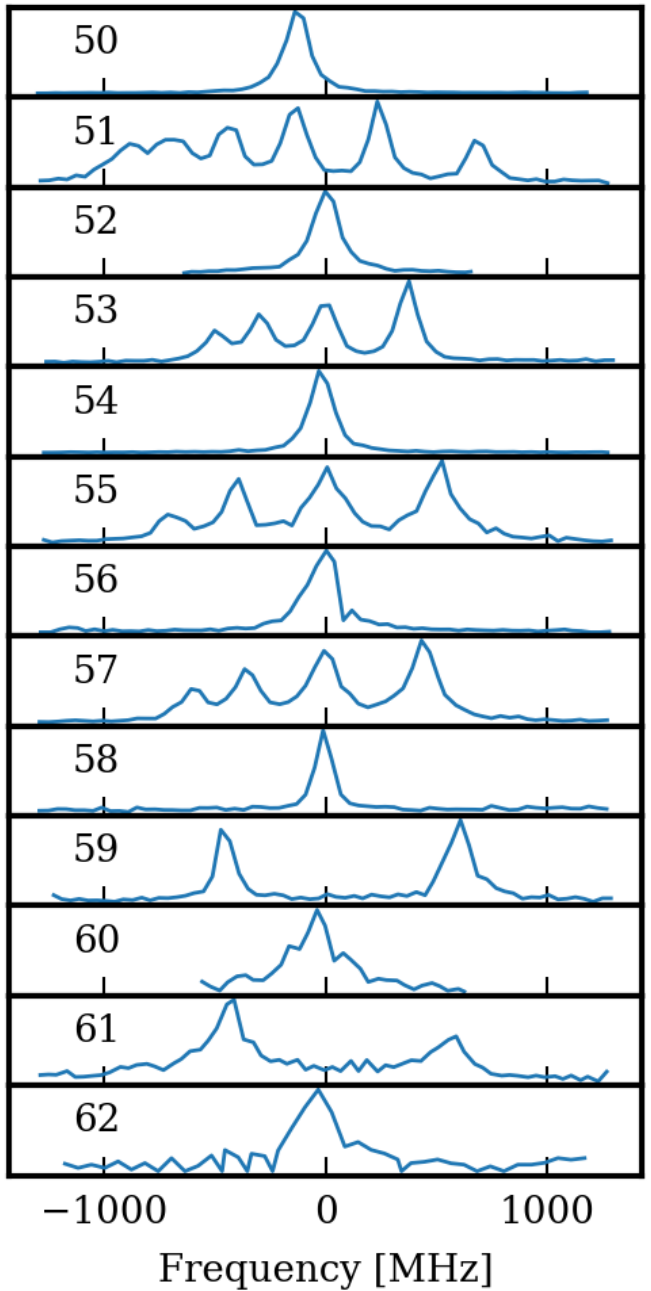

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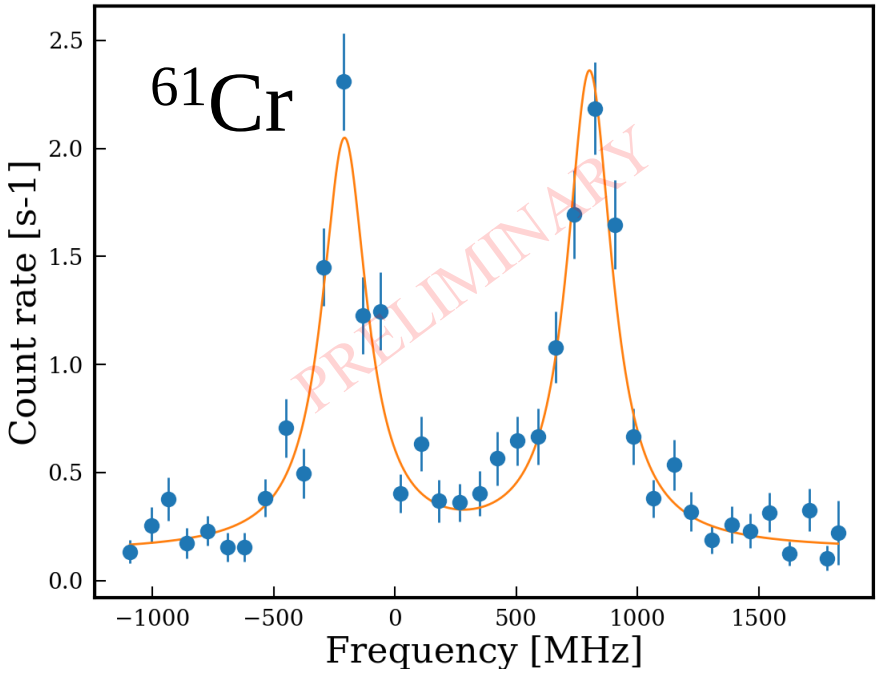

- First firm spin assignment of ^{57,59,61}Cr
- ^{57}Cr and ^{59}Cr spins confirmed to be 3/2 and 1/2, respectively
- ^{61}Cr found to be 1/2 , in disagreement with 5/2 assignment from beta decay experiments

→ 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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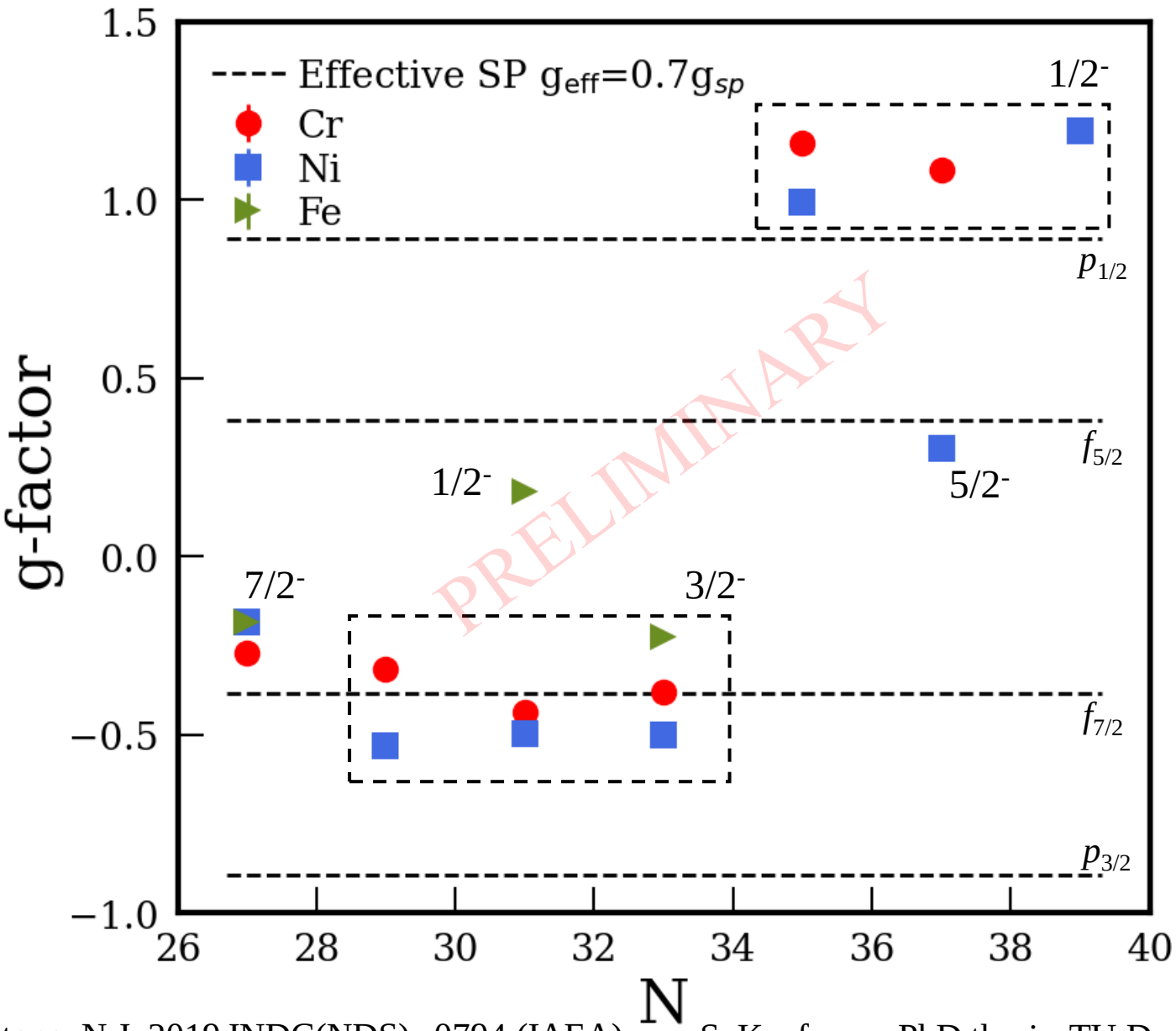

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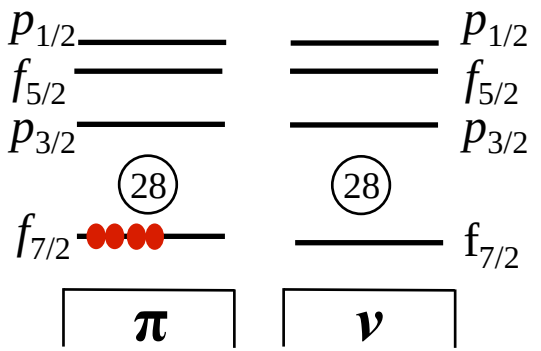

Cr valence space

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

S. Kaufmann PhD thesis, TU Darmstadt

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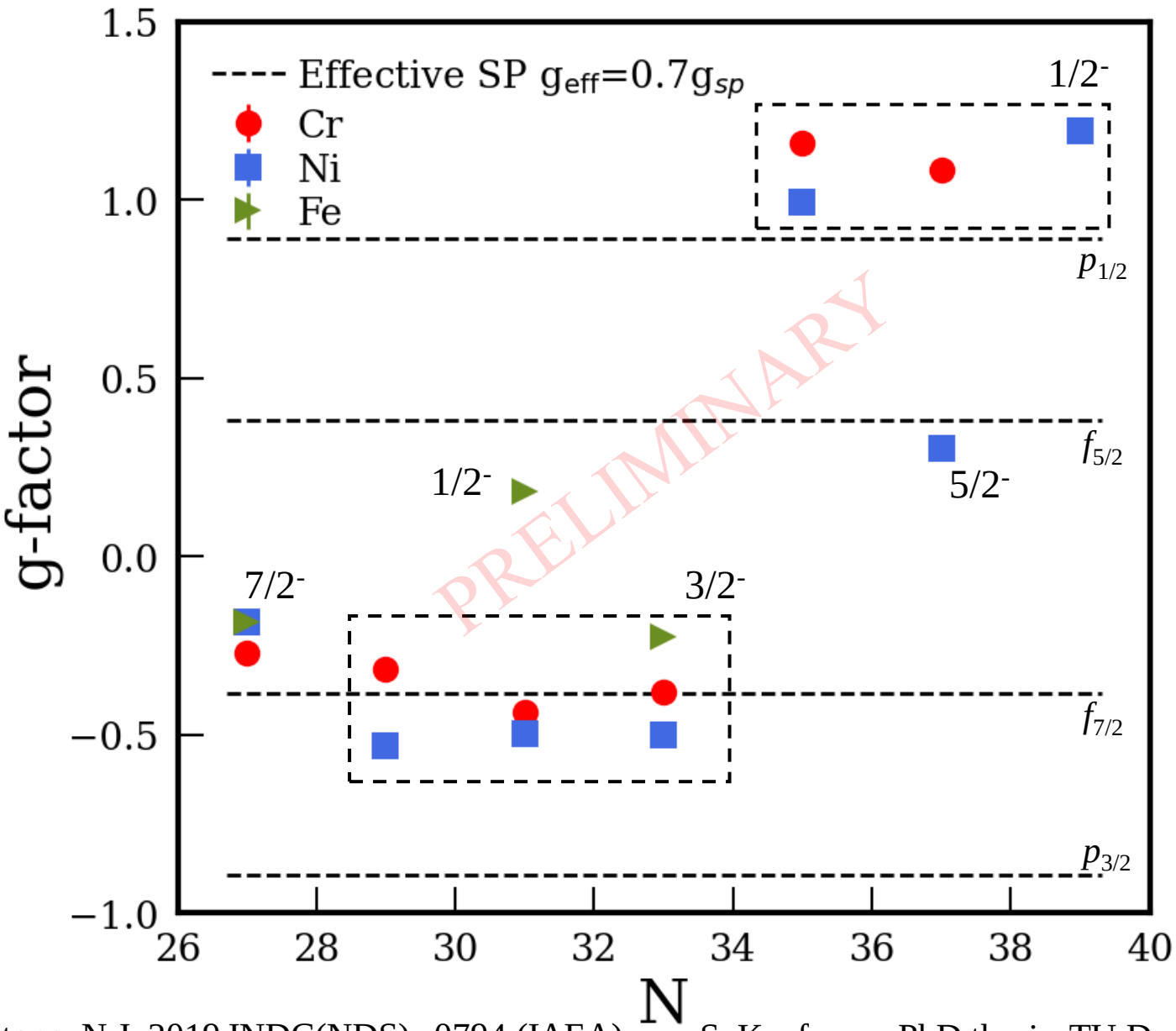

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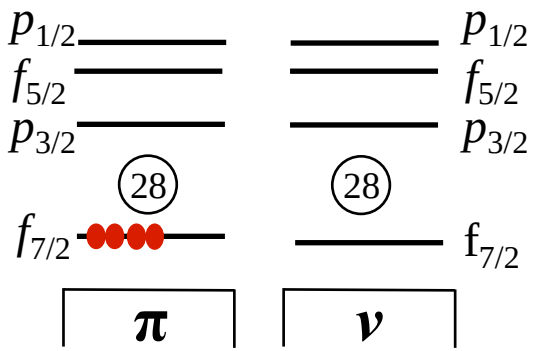

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- ^{51}Cr (N=27) → ν $f_{7/2}$ configuration
- ^{53,55,57}Cr (N=29, 31, 33) → ν $p_{3/2}$ configuration
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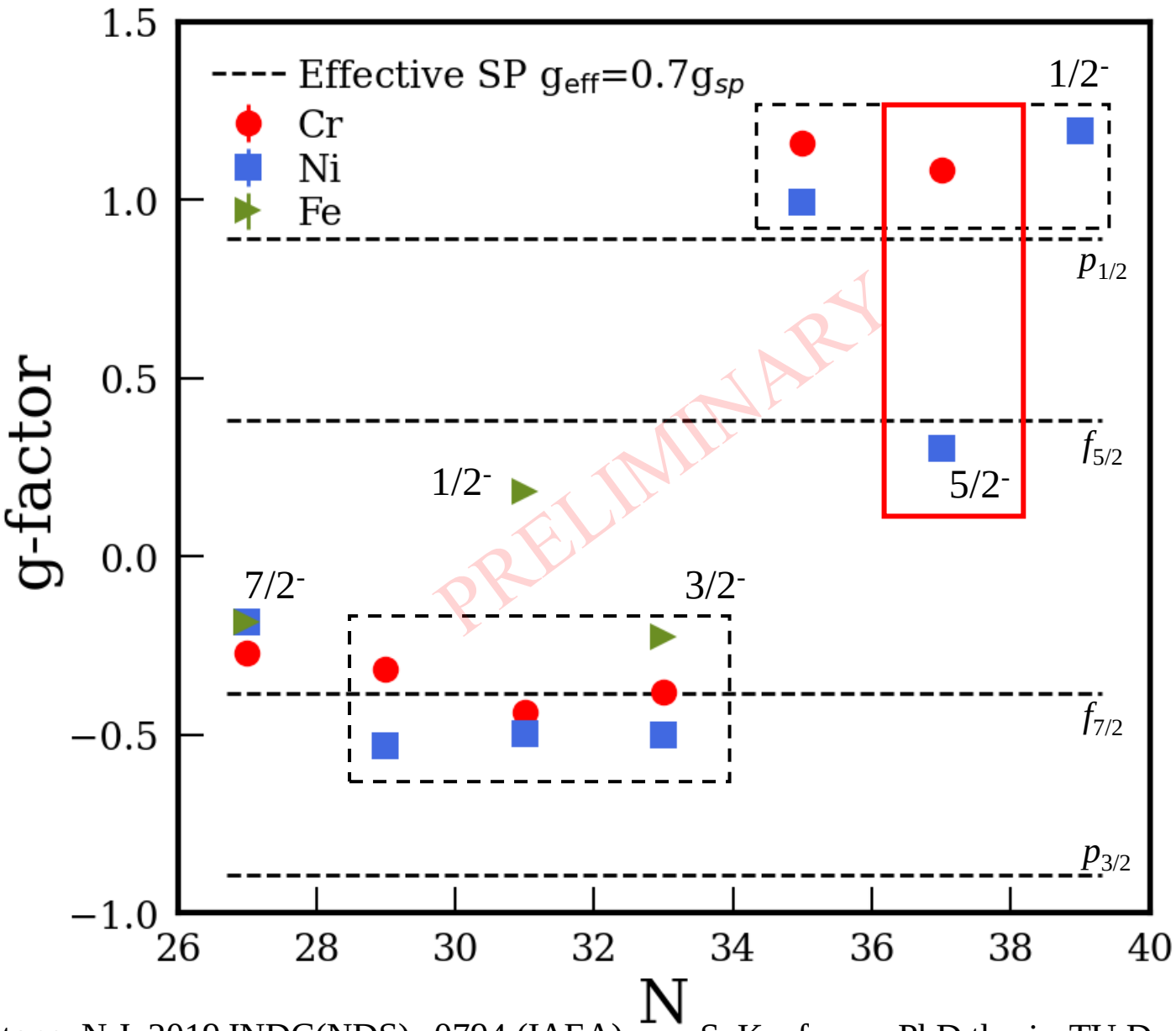

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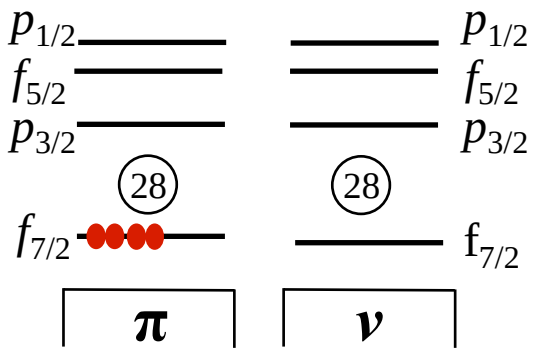

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N=37 config. moving from ν $f_{5/2}$ in Ni (Z=28) to ν $p_{1/2}$ in Cr (Z=24)

→ 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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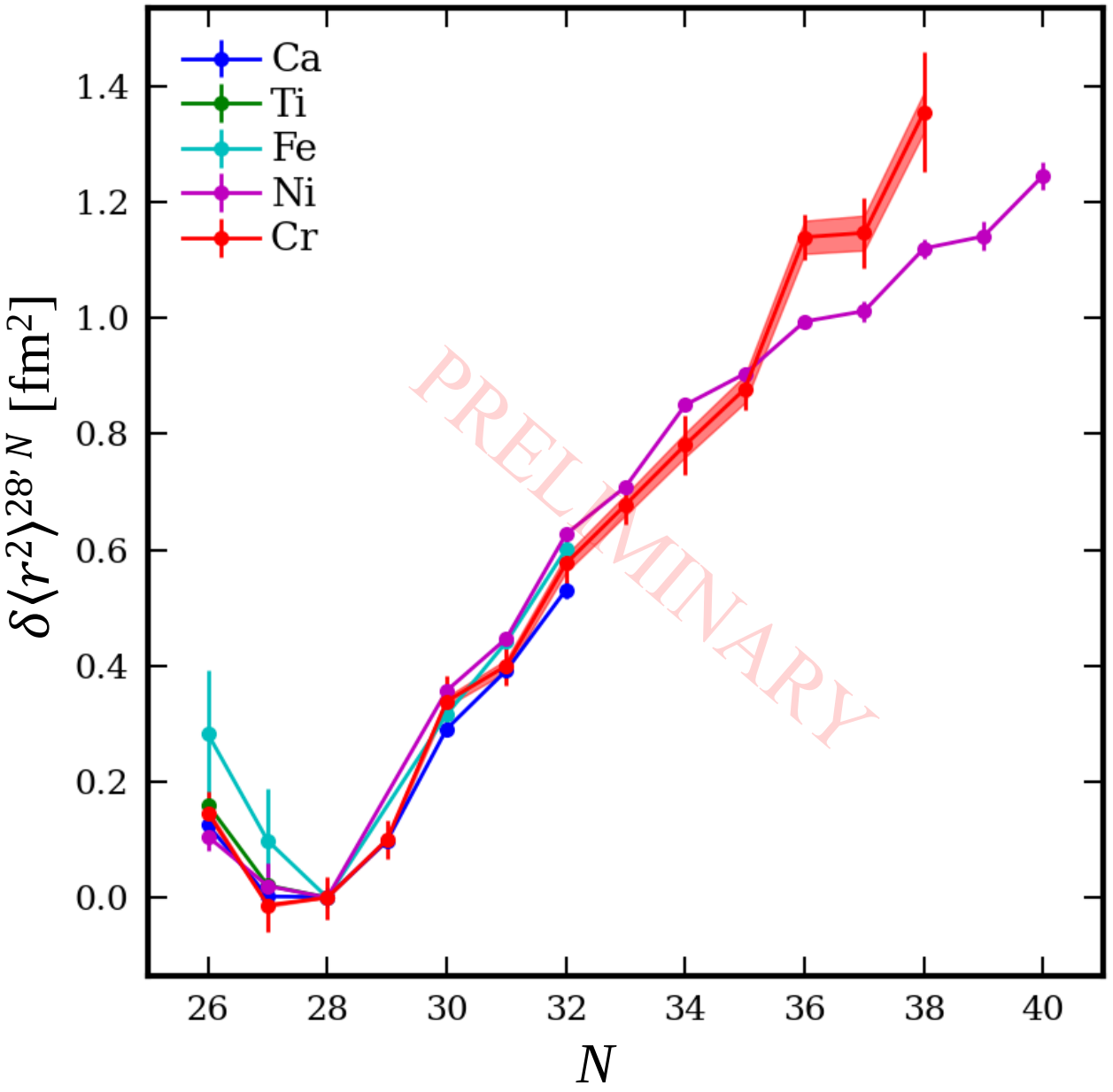

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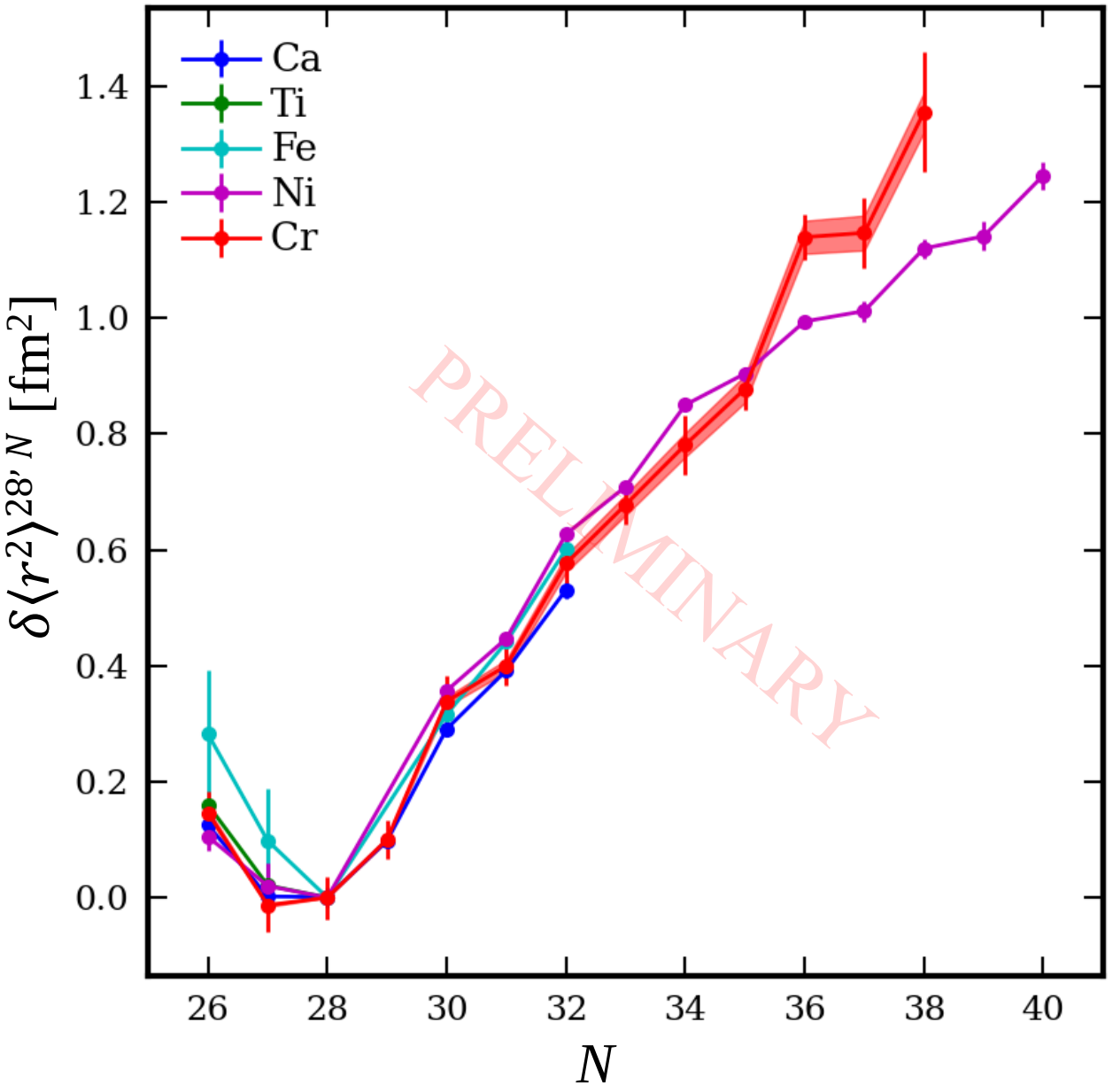

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  → Z independent behaviour
- Clear change of slope at N=34 between deformed Cr, and spherical Ni
- Strong odd-even staggering of the Cr radii for N>34

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

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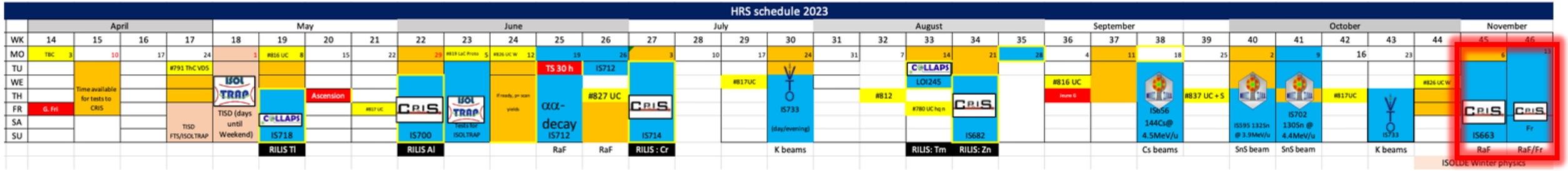

RaF for *P,T* violation searches

- electron electric dipole moment (eEDM) : asymmetric charge distribution along electron's spin axis
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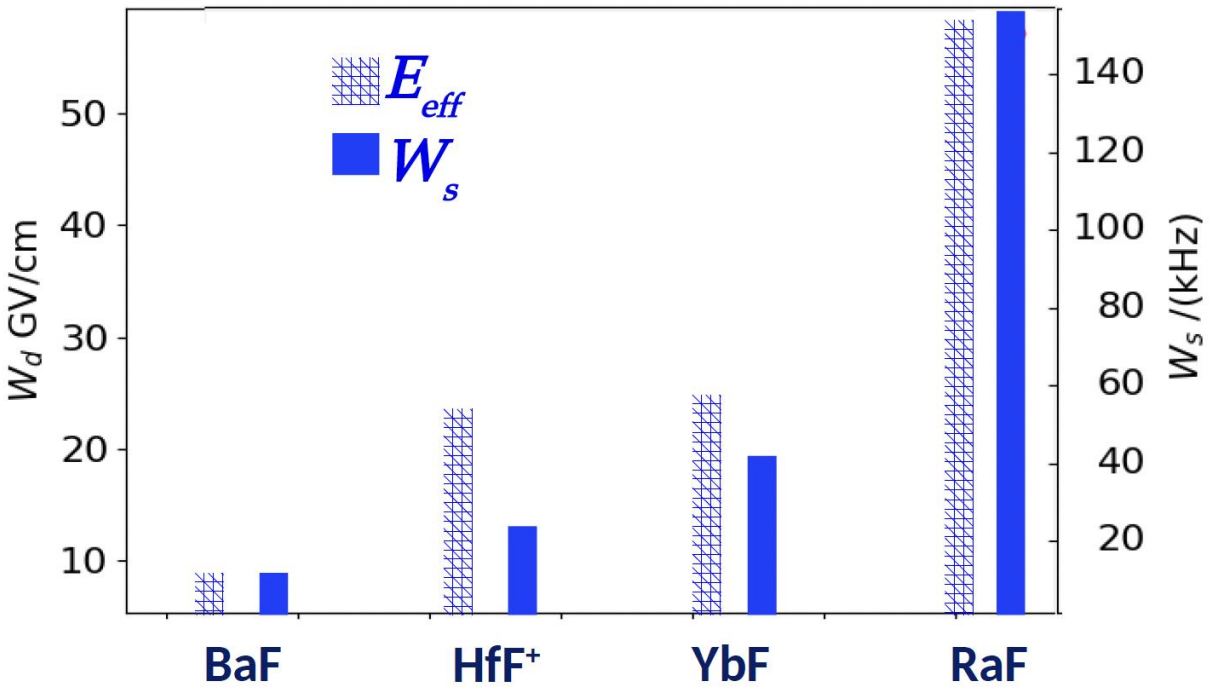

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Radioactive molecules:
Exceptionally sensitive to P,T-violating moments
$>10^5$ times more sensitive than stable atoms

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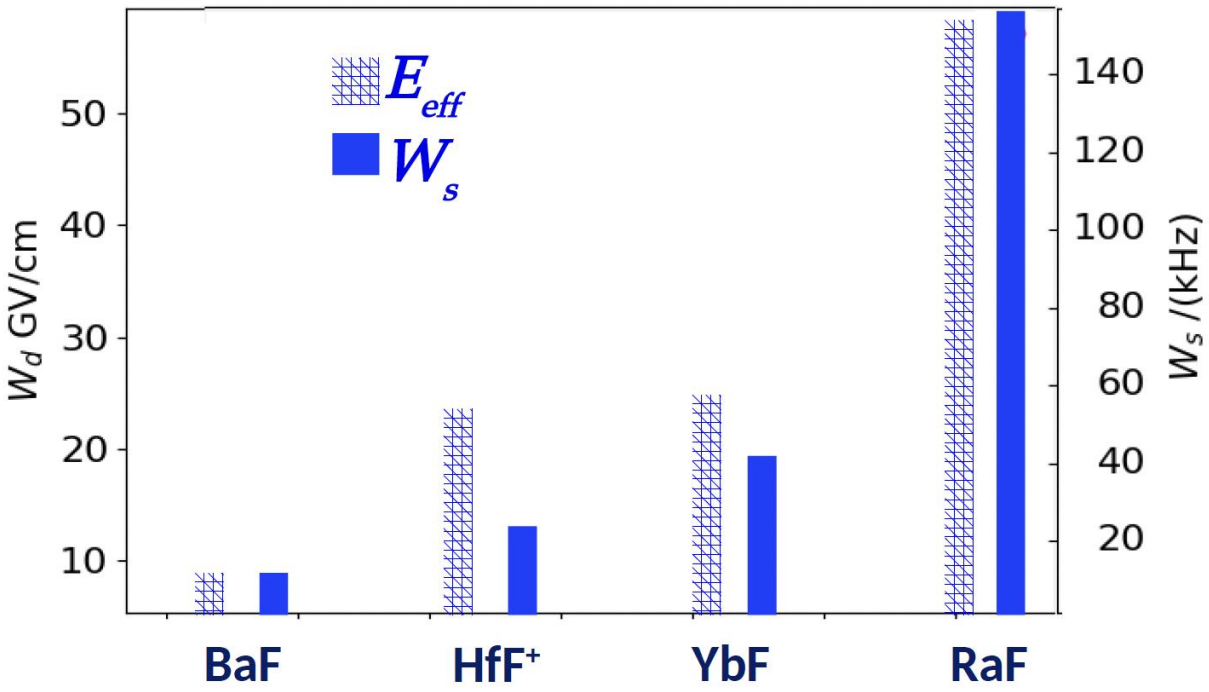

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Very long coherence time τ
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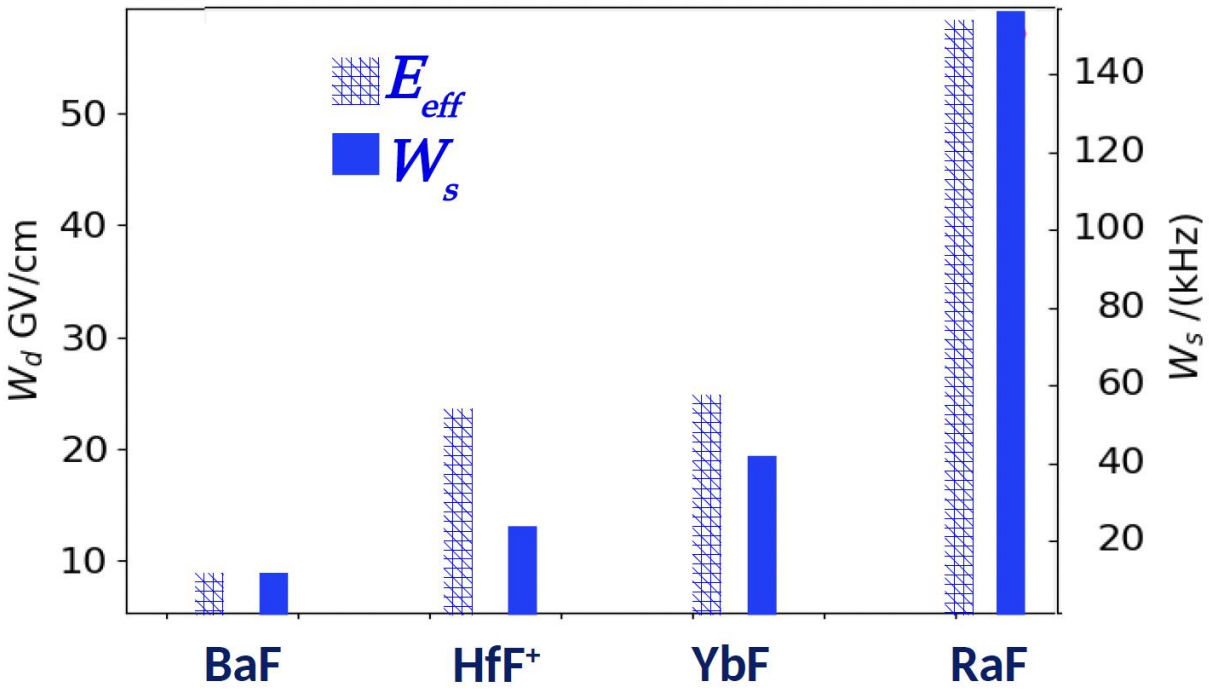

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➔ RaF is one of the most promising system for *P,T* violation searches

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

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Rotational structure
CRIS 2021

Nature Physics, accepted (2023)

PRL 127, 033001 (2021)

Magnetic dipole interaction
CRIS 2021

arXiv:2311.04121, submitted (2023)

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See poster of Carlos Fajardo-Zambrano!

High-resolution spectroscopy of RaF

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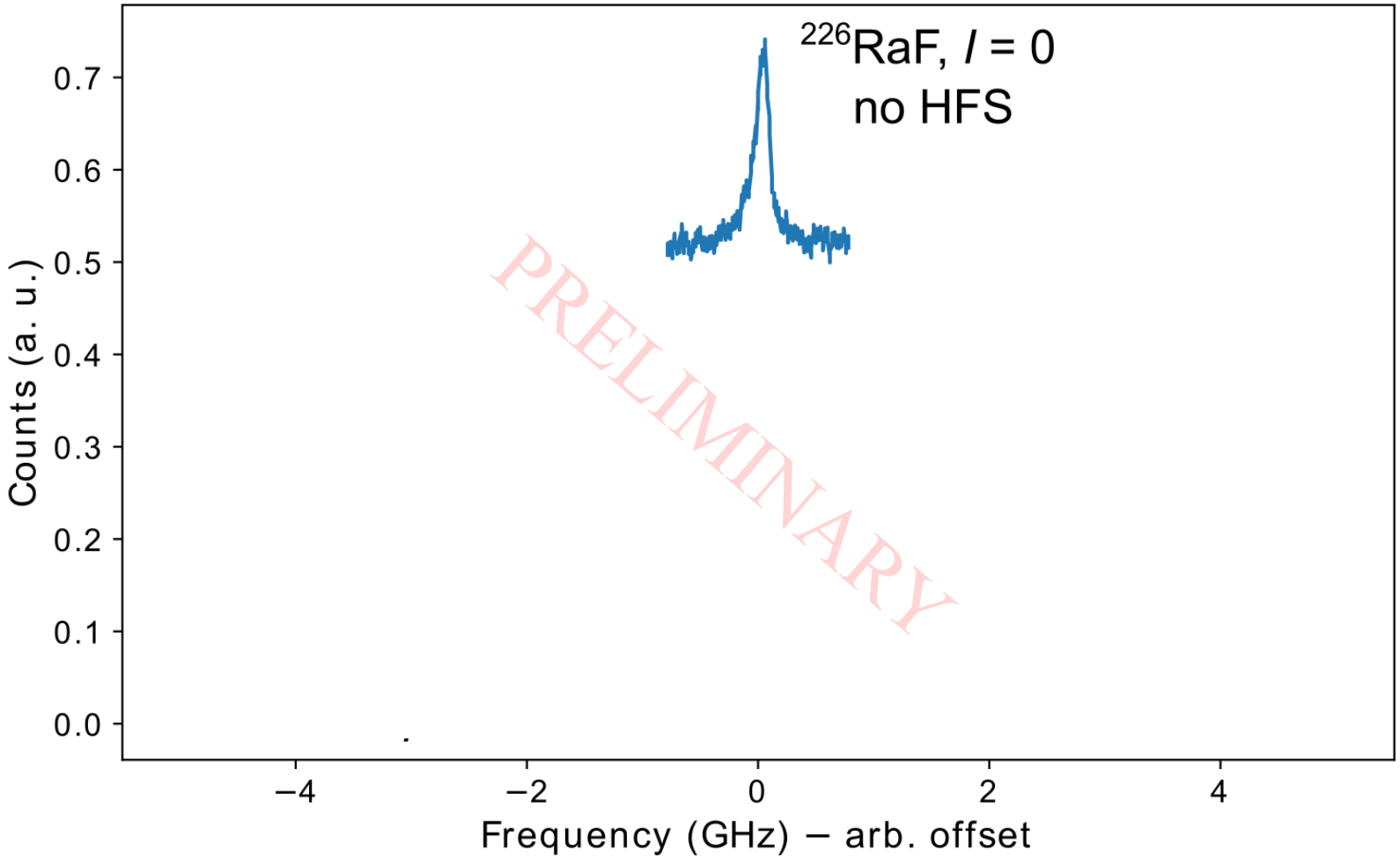
Electric quadrupole interaction
CRIS 2023

See poster of Carlos Fajardo-Zambrano!

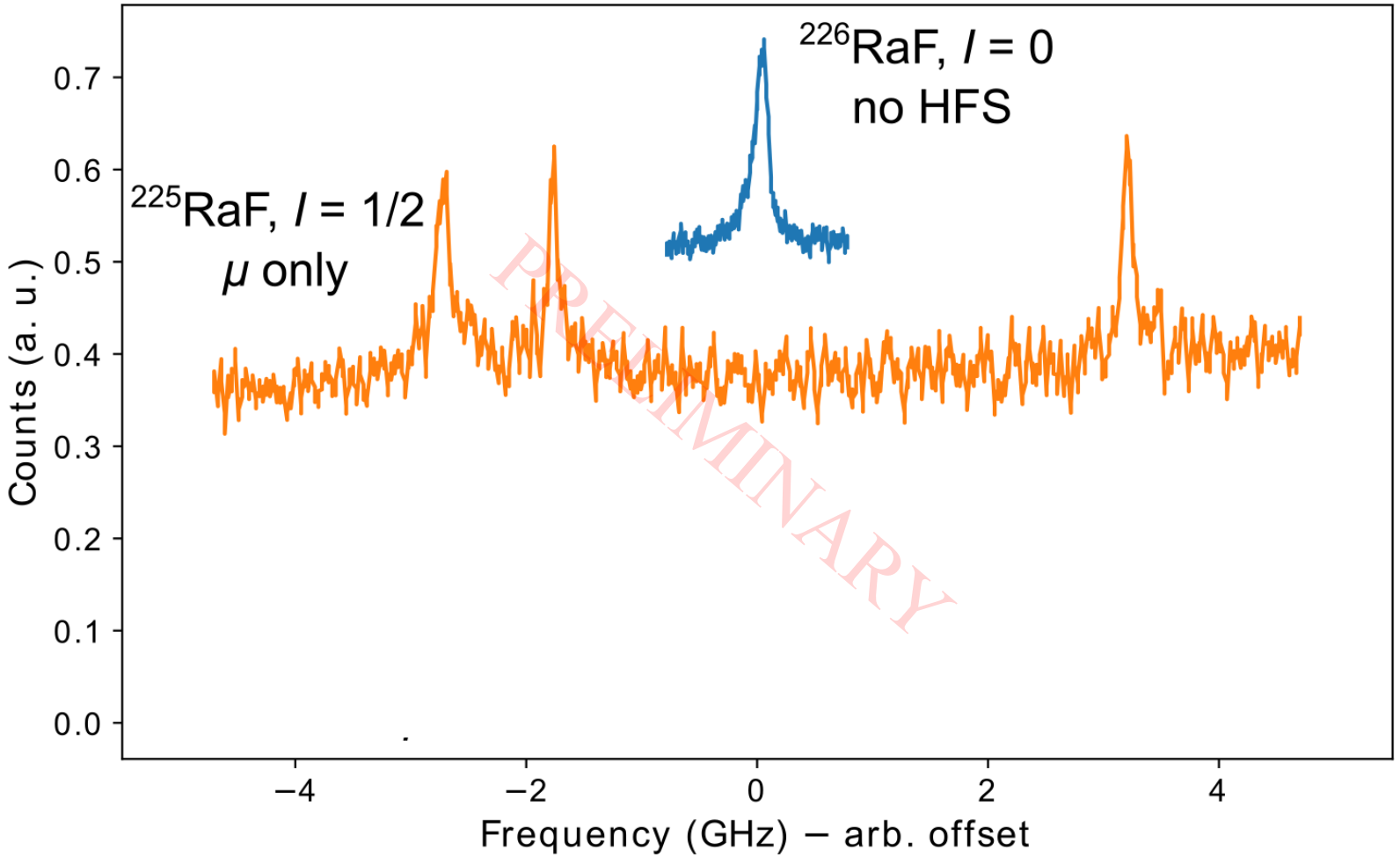
High-resolution spectroscopy of RaF



2023 RaF:

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

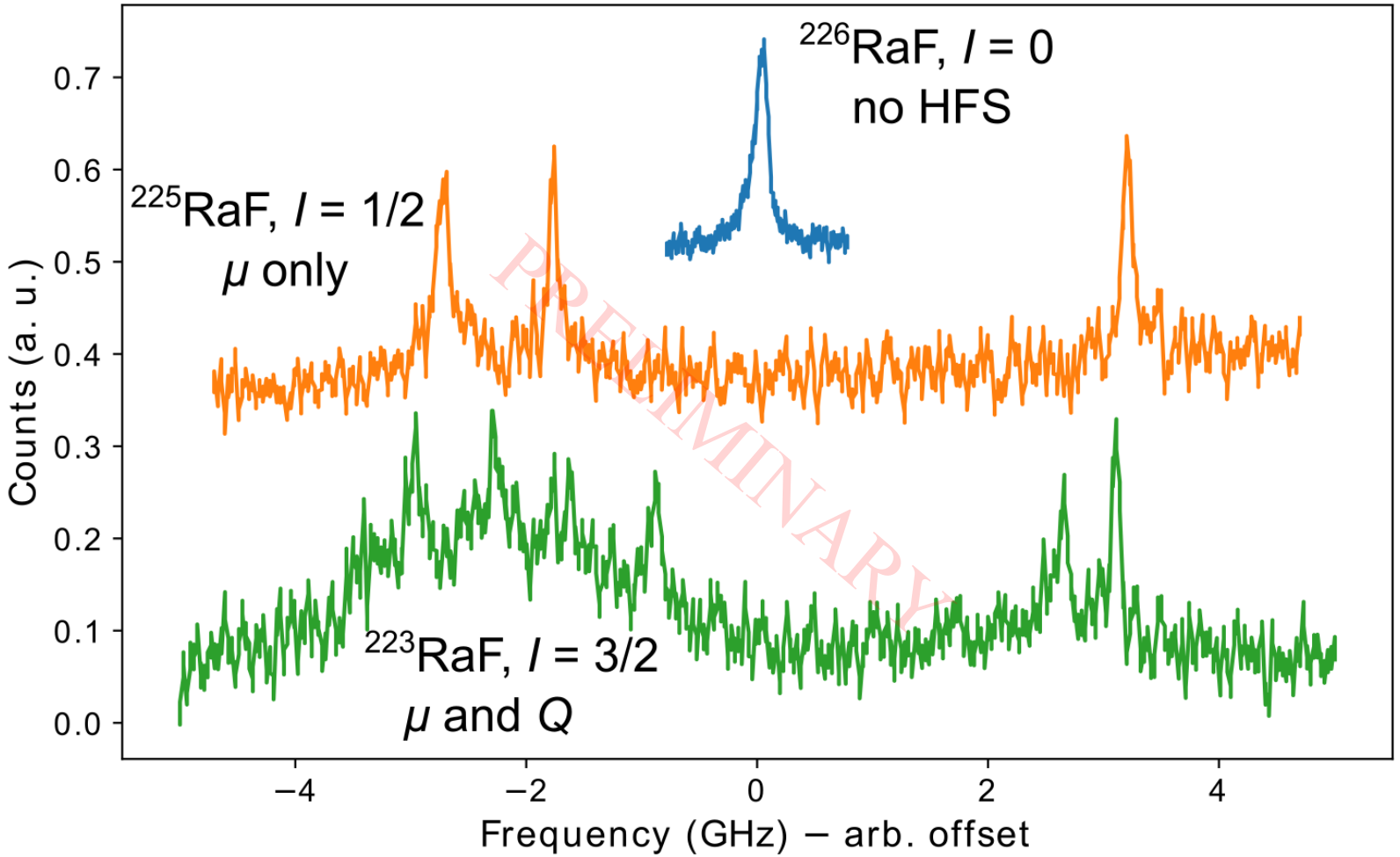
High-resolution spectroscopy of RaF



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

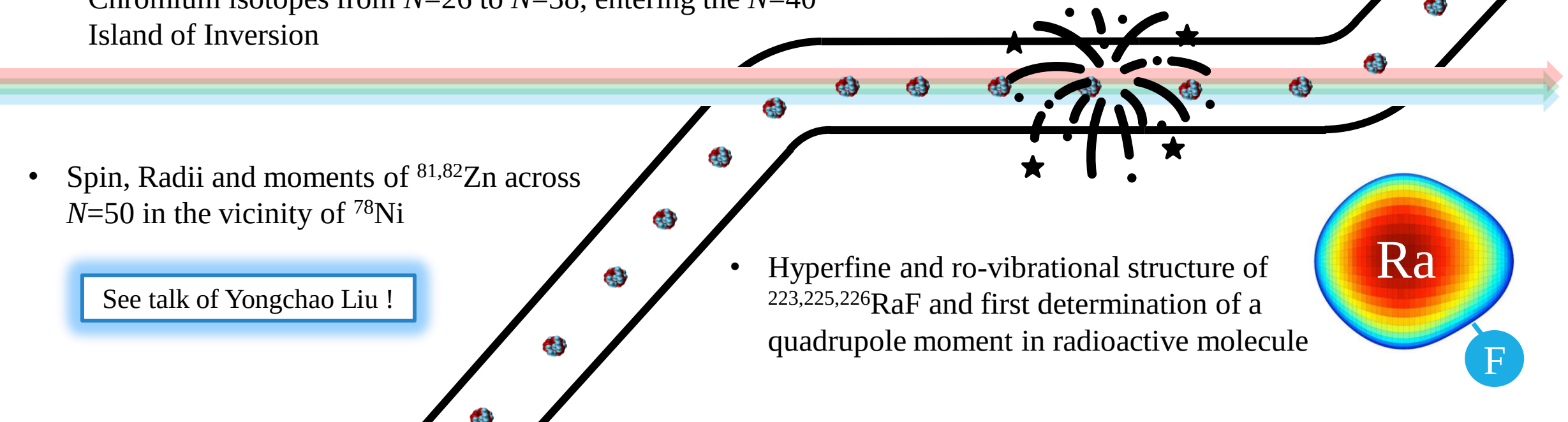
→ Analysis ongoing for the first measurement of an electric quadrupole moment in a radioactive molecule

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