JYVÄSKYLÄN YLIOPISTO
UNIVERSITY OF JYVÄSKYLÄ

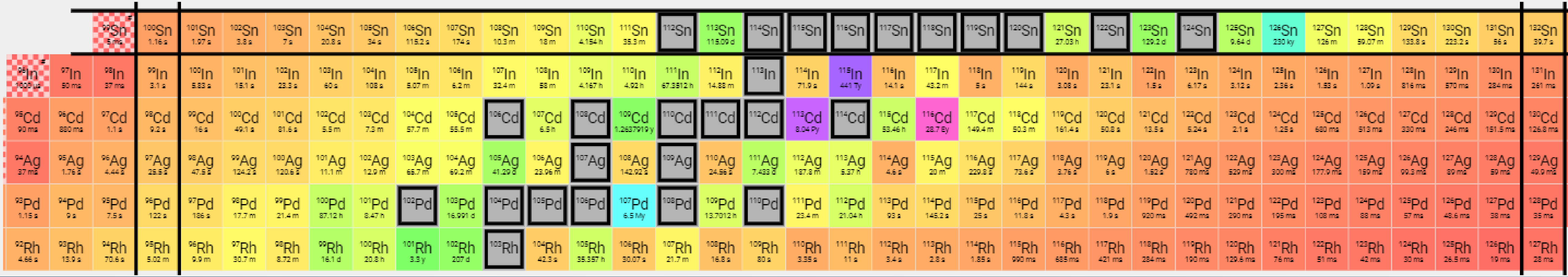
Collinear resonance ionization spectroscopy of silver between *N*=50 and *N*=82

Ruben P. de Groote, University of Jyväskylä and Helsinki Institute of Physics, Finland
on behalf of the CRIS collaboration

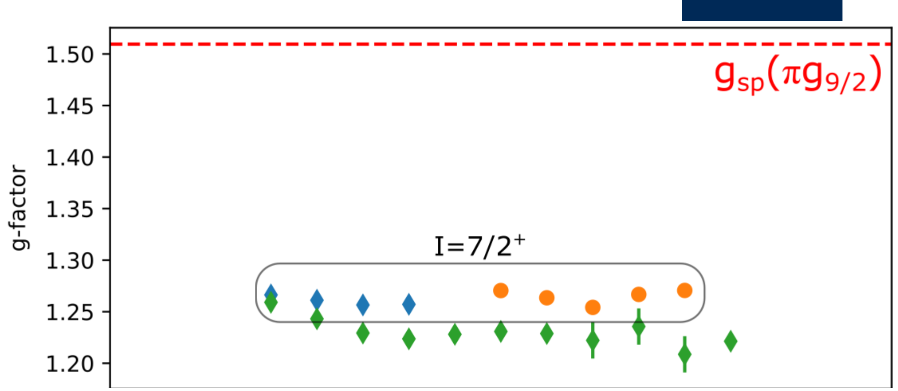
INTC meeting June 2020

Outline

- Physics case
- Experimental setup
- Beamtime request
  - TAC comments



Physics case



Magnetic moments: shell structure and nuclear configurations

- Dipole moments
  - Strength of shell closures, ordering of shell model orbits
  - Establish leading configuration (esp. for odd-odd)
  - Comparison with indium: role of collectivity

In data:
C. Binnersley, A. Vernon, PhD Thesis, and in preparation for publication

Ag data:
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U. Dinger Nucl. Phys. A 503 2, 1989, Pages 331-348
deGroote2020: data obtained at IGISOL, in preparation

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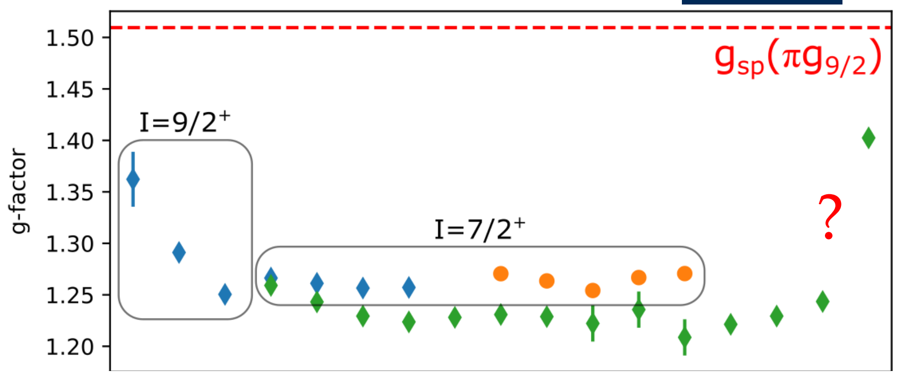

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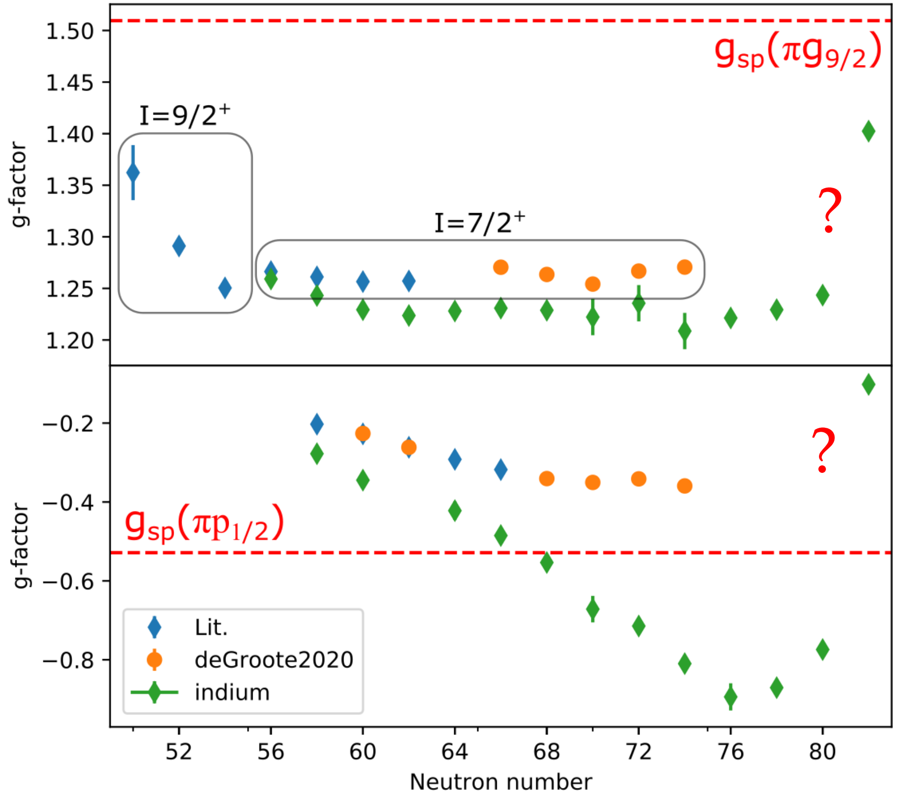

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  - / Comparison with indium: role of collectivity
- Quadrupole moments
  - / Reflect collectivity in neutron mid-shell
  - / Decrease towards N=50, N=82: investigate strength of shell closure

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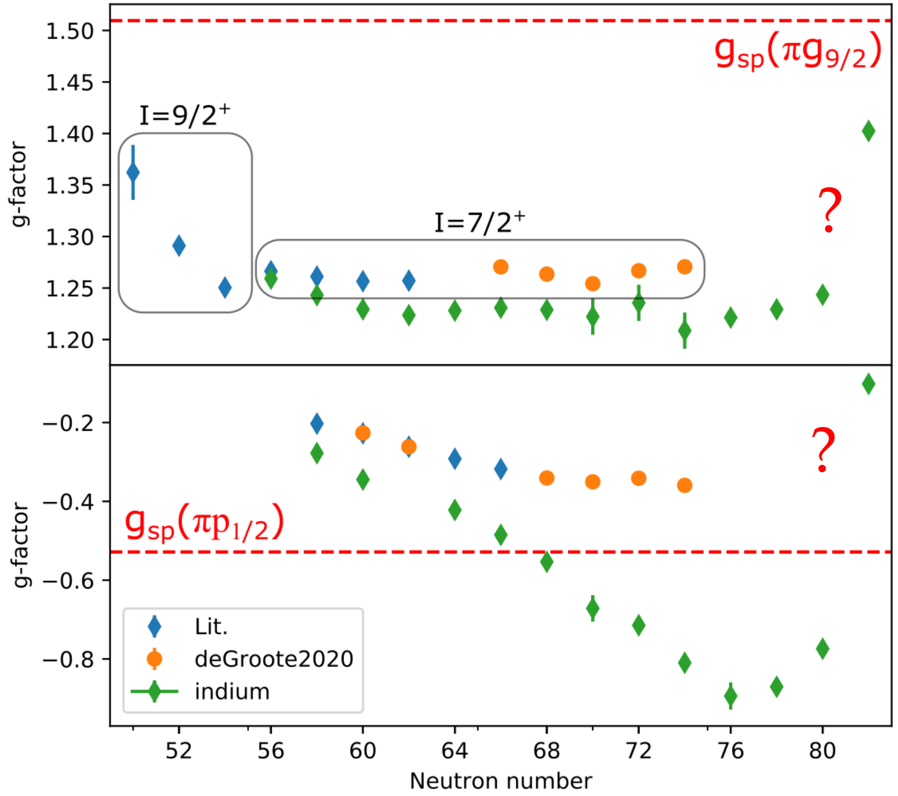
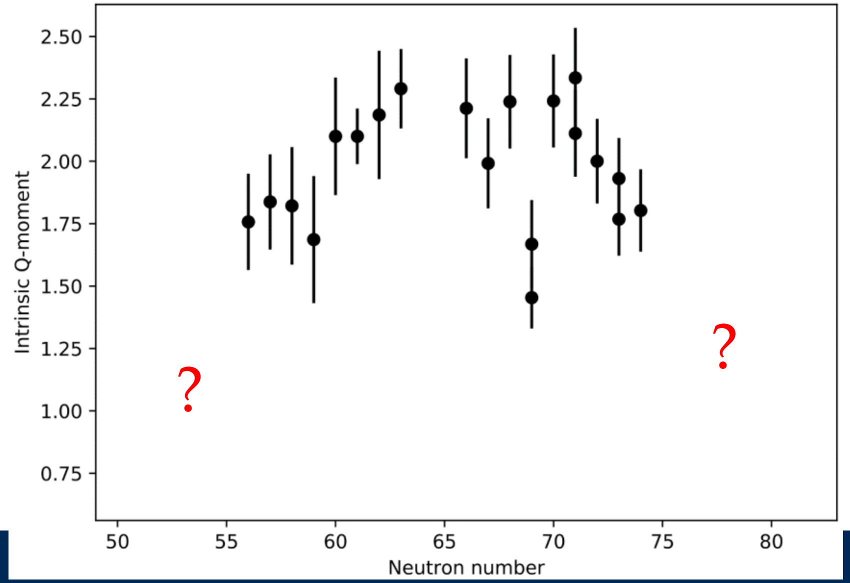
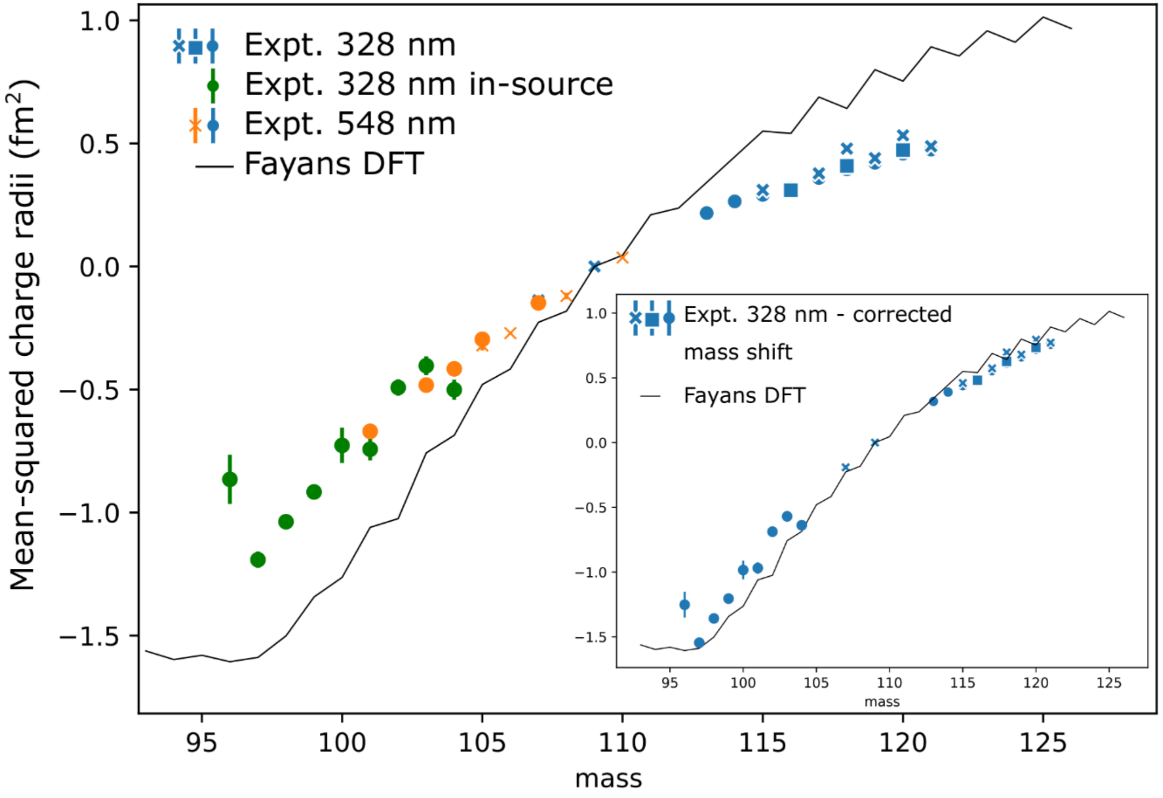




Charge radii: deformation, shell closures, many-body correlations, …

- Dipole moments
- Quadrupole moments
- Nuclear charge radii
  - Complimentary information on nuclear deformation, strength of shell closures
  - Odd-even staggering: requires every isotope and long-lived state to be measured; contains information on many-body correlations and local structure effects [1]
  - Existing data obtained with various methods and optical transitions: systematics need to be tied together in a consistent way!



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[1] R. P. de Groote, et al. Nat. Phys. 16, 620–624 - 2020

Charge radii: shell closures and deformation

- Dipole moments
- Quadrupole moments
- Nuclear charge radii
- Nuclear spins and unambiguous state identification, info on configuration…
  - Especially for neutron-rich odd-odd isotopes, rich landscape of isomers with high spins
  - Recent measurements at IGISOL found new isomers and erroneous spin assignments in literature
- Sets the stage also for future work towards ^{94}Ag

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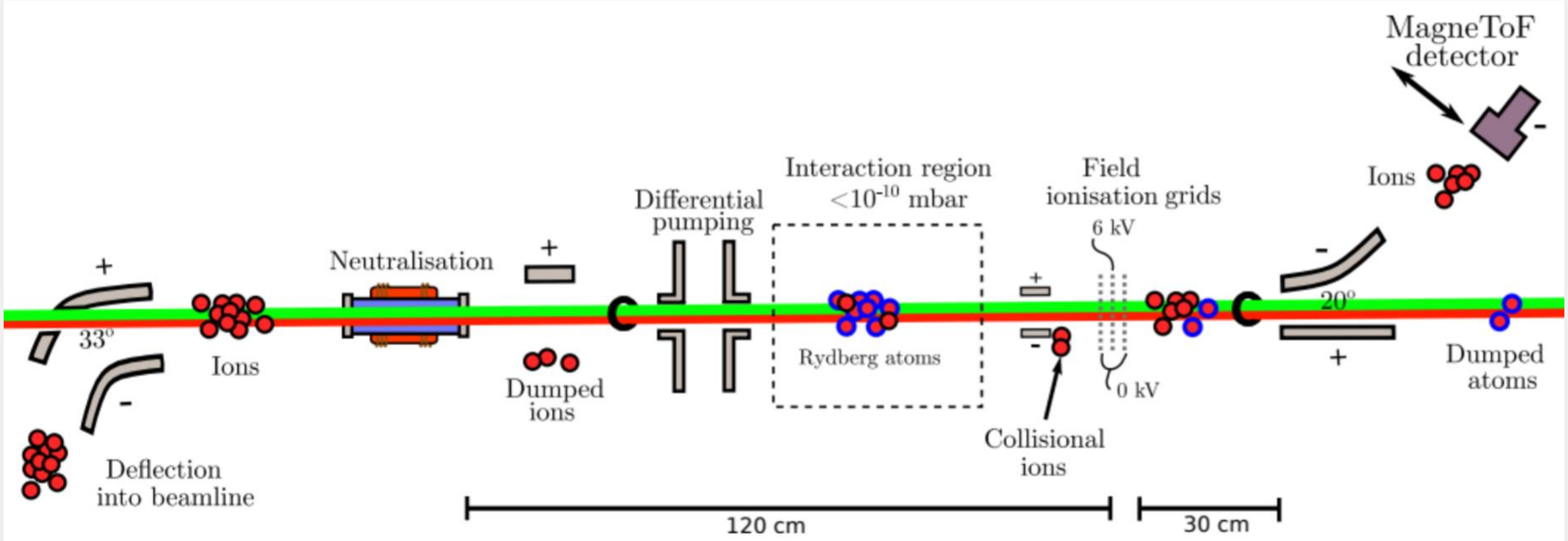
In general, these observables are good probes for nuclear structure and serve to test nuclear theory!

Chiral effective field theory, and density functional theory, large-scale shell model, …

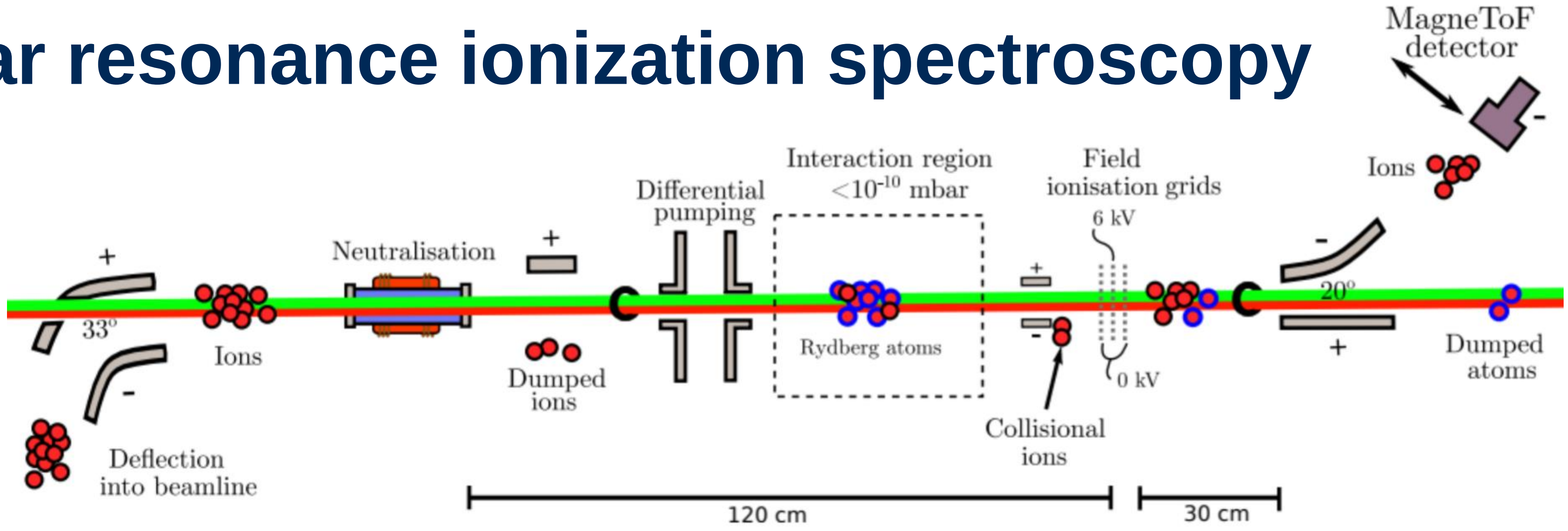
We propose to measure these properties for 31 isotopes, ~70 nuclear states

Note on 'remeasurements': not all observables/all states studied in literature!



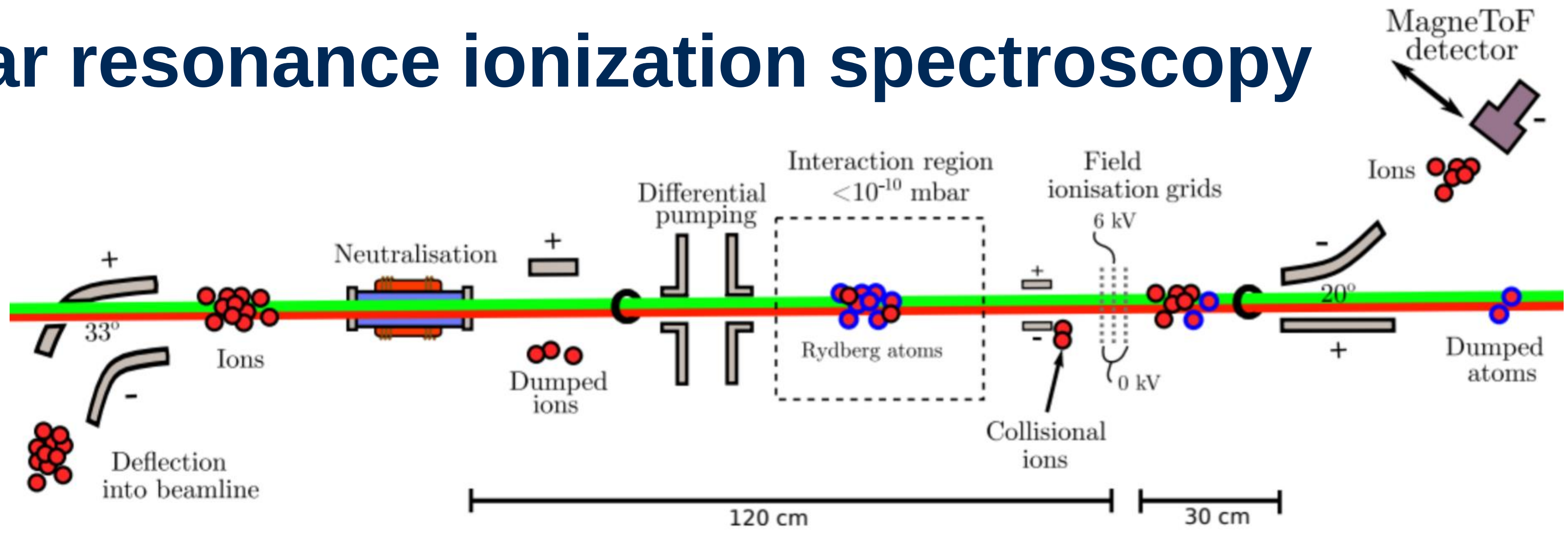
Experimental setup

Collinear resonance ionization spectroscopy



- High spectral resolution: precise and accurate
- High efficiency
- High suppression of background events
- Very flexible choice of atomic transitions

Collinear resonance ionization spectroscopy



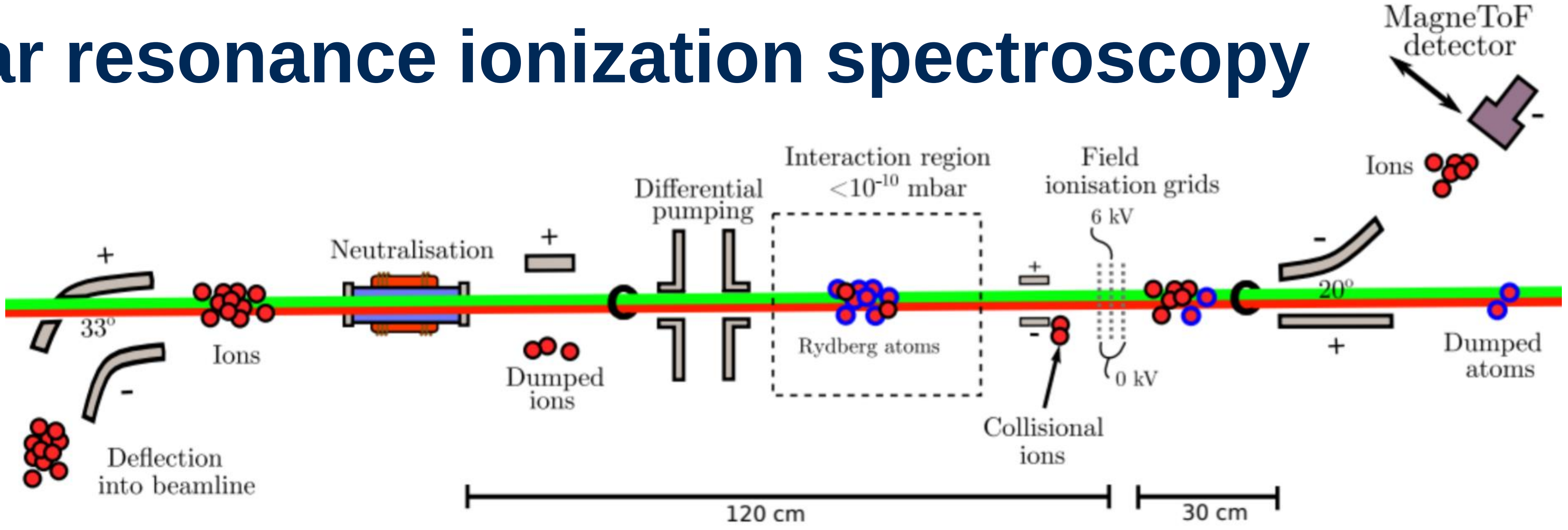
- High spectral resolution: precise and accurate
- High efficiency
- High suppression of background events
- Very flexible choice of atomic transitions

28 Ni	29 Cu	30 Zn	31 Ga
46 Pd	47 Ag	48 Cd	49 In
78 Pt	79 Au	80 Hg	81 Tl

- Copper homologue (similar atomic structure)
- down to 20 pps production rate

R. P. de Groote, et al. Nat. Phys. 16, 620–624 - 2020

Collinear resonance ionization spectroscopy



- High spectral resolution: precise and accurate
- High efficiency
- High suppression of background events
- Very flexible choice of atomic transitions

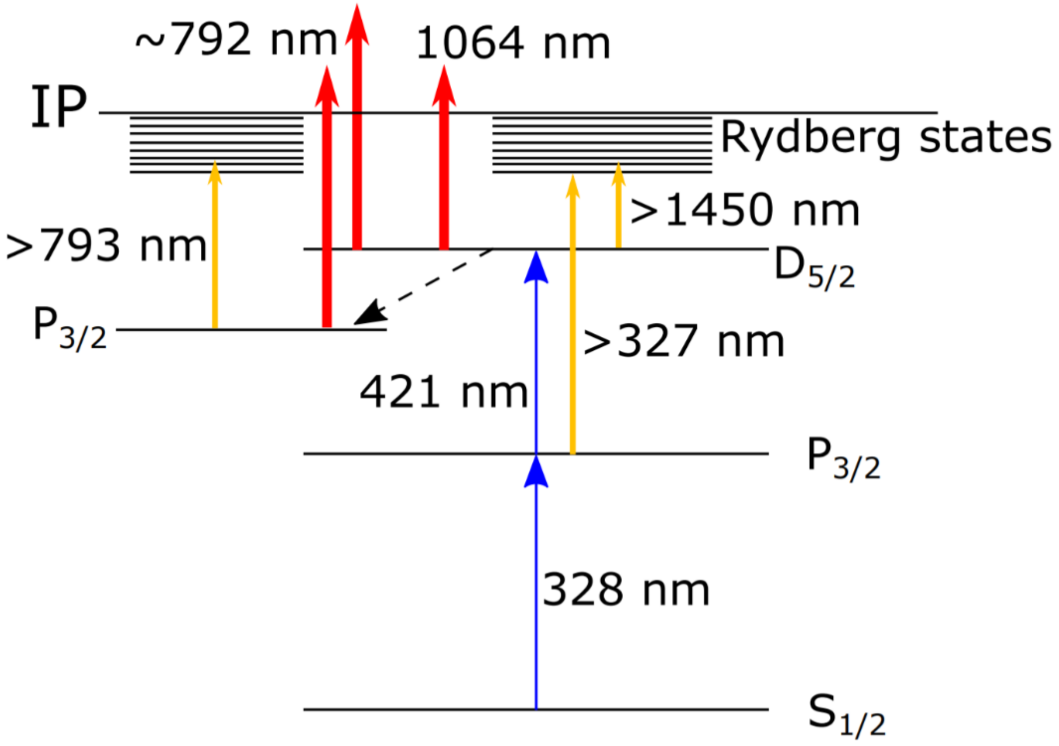
28 Ni	29 Cu	30 Zn	31 Ga
46 Pd	47 Ag	48 Cd	49 In
78 Pt	79 Au	80 Hg	81 Tl

- Indium: similar mass range, target, ion source, so same contaminants
- $^{101-131}$In studied successfully

BK Sahoo, et al., New Journal of Physics 22 (1), 012001

Laser ionization schemes for silver

- Silver has been very well studied over the years
  - RILIS element
  - In-gas-cell @ Louvain-la-Neuve
  - In-source spectroscopy @ IGISOL
- Specific case of CRIS:
  - 328 + 421 + 1064: easily saturated, high efficiency.



Beamtime request

Beamtime request

- Shaded cases: new data can be obtained!
- For high-yield (>10^5 pps), request is not statistica limited
  - Given rich isomerism and large hyperfine structure, 0.5 shifts per mass estimated on average (3 scans per isoto
  - This includes time for reference measurements as well
- For lower yields, request based on previous experience at CRIS
  - Efficient laser ionization
  - Background well understood from indium expts.

A	Nr. of states	ABRABLA calc	Expt.	Predicted yield	Shifts
94	3	-		< 0.1	-
95	4	-		< 1	-
96	2	-		< 10	-
97	2	$8.4 \cdot 10^2$		80	-
98	2	$1.6 \cdot 10^4$		$1.5 \cdot 10^3$	2
99	2	$2.8 \cdot 10^5$		$2.8 \cdot 10^4$	1
100	2	$1.5 \cdot 10^6$		$1.5 \cdot 10^5$	0.5
101	2	$1.0 \cdot 10^7$	$2.0 \cdot 10^5$	$1.0 \cdot 10^6$	0.5
102	2	$4.5 \cdot 10^7$		$4.5 \cdot 10^6$	0.5
103	2	$2.0 \cdot 10^8$	$1.6 \cdot 10^6$	$2.0 \cdot 10^7$	0.5
104	2	$5.9 \cdot 10^8$		$5.9 \cdot 10^7$	0.5
105	2	$1.3 \cdot 10^9$	$7.0 \cdot 10^7$	$1.3 \cdot 10^8$	0.5
106	2	$1.8 \cdot 10^9$	$7.0 \cdot 10^7$	$1.8 \cdot 10^8$	0.5
107	2	$3.4 \cdot 10^9$		$3.4 \cdot 10^8$	0.5
108	2	$3.5 \cdot 10^9$		$3.5 \cdot 10^8$	0.5
109	2	$5.4 \cdot 10^9$	$6.0 \cdot 10^8$	$5.4 \cdot 10^8$	0.5
110	2	$4.7 \cdot 10^9$		$4.7 \cdot 10^8$	0.5
111	2	$6.4 \cdot 10^9$	$4.0 \cdot 10^9$	$6.4 \cdot 10^8$	0.5
112	1	$4.7 \cdot 10^9$	$2.3 \cdot 10^9$	$4.7 \cdot 10^8$	0.5
113	2	$6.3 \cdot 10^9$	$2.0 \cdot 10^9$	$6.3 \cdot 10^8$	0.5
114	2	$4.6 \cdot 10^9$	$1.0 \cdot 10^9$	$4.6 \cdot 10^8$	0.5
115	2	$5.4 \cdot 10^9$	$1.8 \cdot 10^8$	$5.4 \cdot 10^8$	0.5
116	3	$3.6 \cdot 10^9$		$3.6 \cdot 10^8$	0.5
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118	3	$1.9 \cdot 10^9$		$1.7 \cdot 10^8$	0.5
119	2	$1.6 \cdot 10^9$		$1.5 \cdot 10^8$	0.5
120	3	$5.6 \cdot 10^8$		$4.3 \cdot 10^7$	0.5
121	2	$3.1 \cdot 10^8$	$3.0 \cdot 10^7$	$2.1 \cdot 10^7$	0.5
122	3	$7.6 \cdot 10^7$		$4.3 \cdot 10^6$	0.5
123	2	$3.5 \cdot 10^7$		$1.2 \cdot 10^6$	0.5
124	2-3?	$8.5 \cdot 10^6$		$1.4 \cdot 10^5$	0.5
125	2	$6.1 \cdot 10^6$		$1.0 \cdot 10^5$	0.5
126	2-3?	$1.5 \cdot 10^6$		$6.4 \cdot 10^2$	4
127	2	$6.5 \cdot 10^5$		$1.4 \cdot 10^3$	3
128	1-3?	$1.1 \cdot 10^5$		62	5
129	2	$1.3 \cdot 10^4$	1	1	7
				Total	35

Table 1: Calculated in-target, experimental and predicted yields per μC using a UC_x target. Also listed is the number of states with a lifetime > 1 ms. No shifts are requested for $A < 98$ since those isotopes are likely easier to study using a La_x target.

Beamtime request

- In summary: two experiments, both with fresh UC_x
  - Run 1: explore exotic isotopes and cover wide mass range: check internal systematics and tie data in with all literature datasets
  - Run 2: dedicated to most challenging cases, with overlap with run 1 for systematics
    Measurements on less exotic cases are required to define the experimental uncertainties and evaluate systematics!
- Neutron-deficient isotopes: yields for deficient isotopes would be better with LaC_x, BUT:
  - For all except 98,99 shift request is not statistically limited anyway
  - Two UC_x runs in any case required
  - Future proposal/addendum: as n-deficient as possible + a few overlapping cases for systematics

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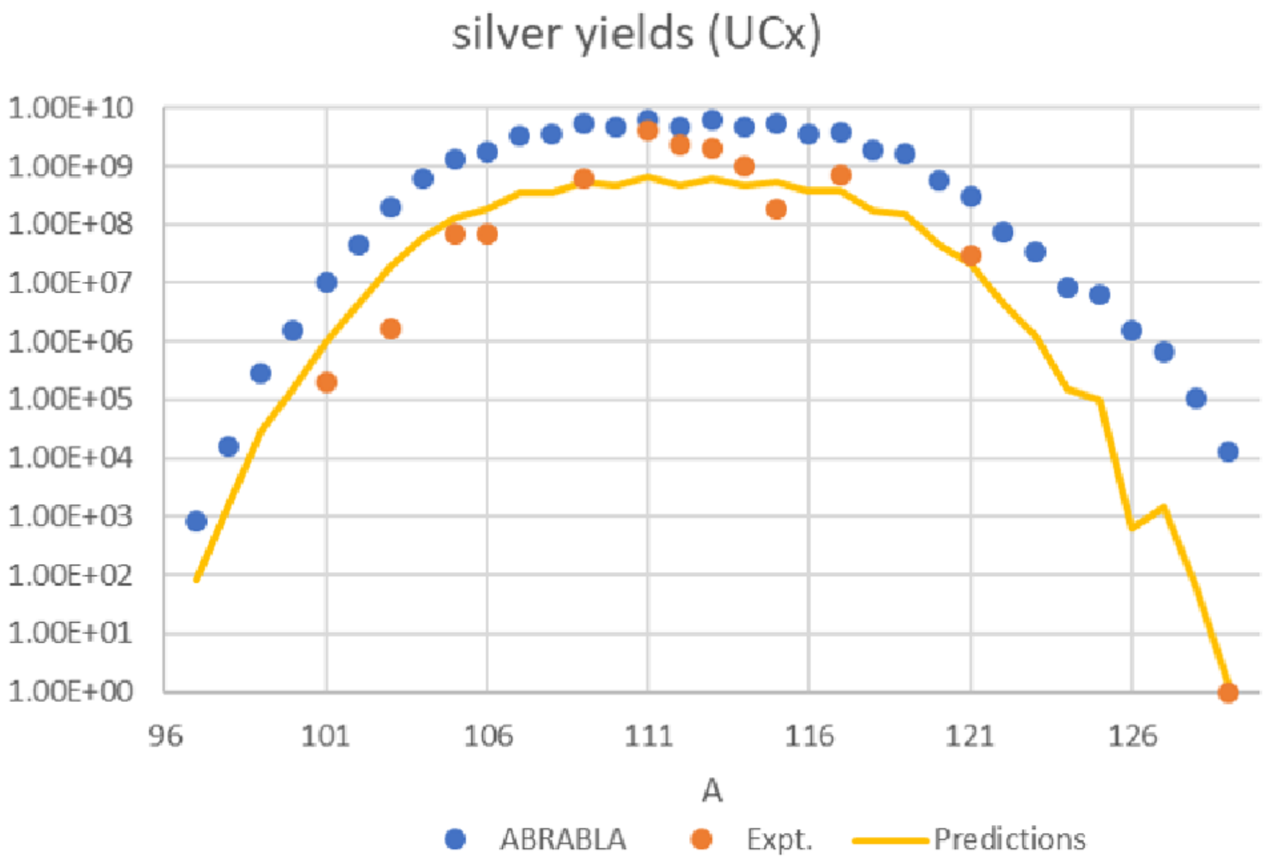
TAC comments

- RILIS required for the experiment
  - Different laser settings required for GS/isomers; we suggest dynamic changing of settings as CRIS measurements progress
  - Same atomic transition is used for CRIS which will simplify this
  - Previously, good experience for e.g. indium and radium proves this feasible
- Intensity of beams with high dose rates would be reduced to minimize contamination
  - Intensity would be reduced to ~10^5 pps (also to mitigate cooler and DAQ saturation)
- Priorities and UC_x/LaC_x: addressed in previous slides
  - 2x UC_x required
  - In any case a third experiment would be needed for the n-deficient isotopes A<98

Some additional slides

Yield estimates

- Quoting TAC: “The yield estimate has been well prepared for the Ag chain from a UCx unit.”



Data in literature

- $^{96-104}$Ag: only one out of two states have all moments and radii
- $^{104-110}$Ag: either very imprecise/not all states/not all observables

New physics to extract; all masses should be measured again

- $^{115-121}$Ag: all states and all observables measured in literature

- At least three required for good systematic check (=> 3/6 shifts in any case required)
- Furthermore, several odd-odd where spin assignment requires much higher statistics
- Odd-even staggering requires all states and all masses to be measured consistently
- Even better control over internal systematics of CRIS measurements

Charge radii: shell closures and deformation

- Dipole moments
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- Quadrupole moments
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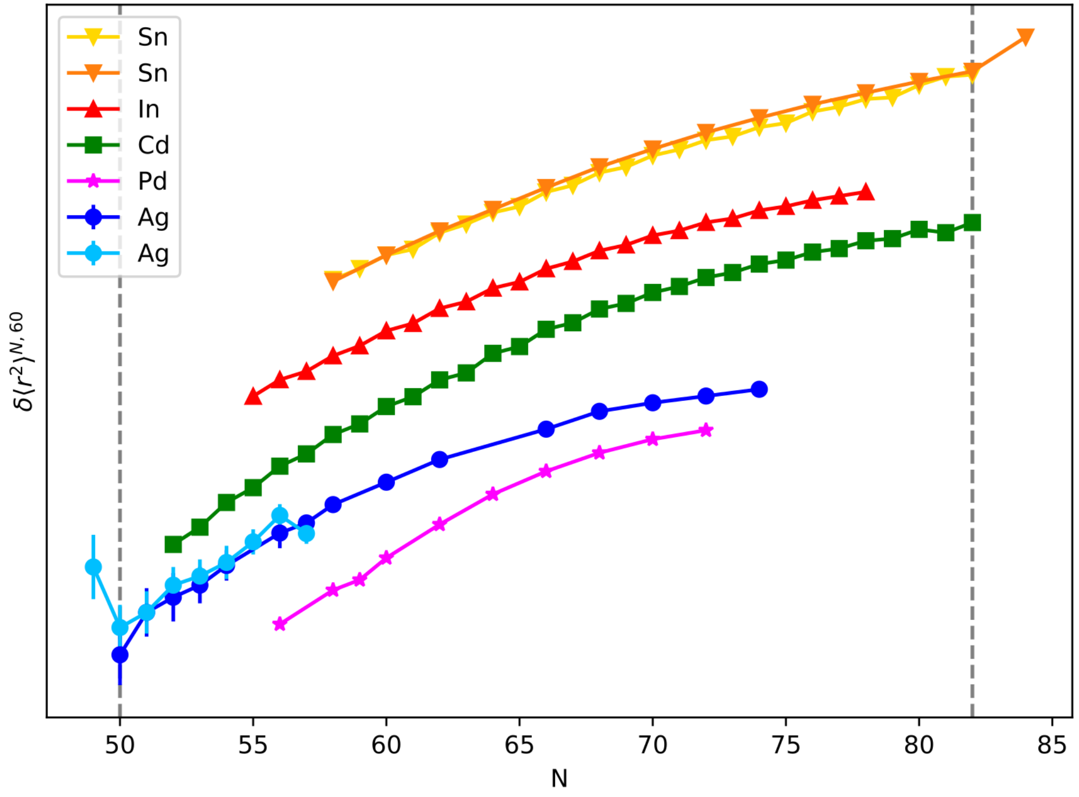
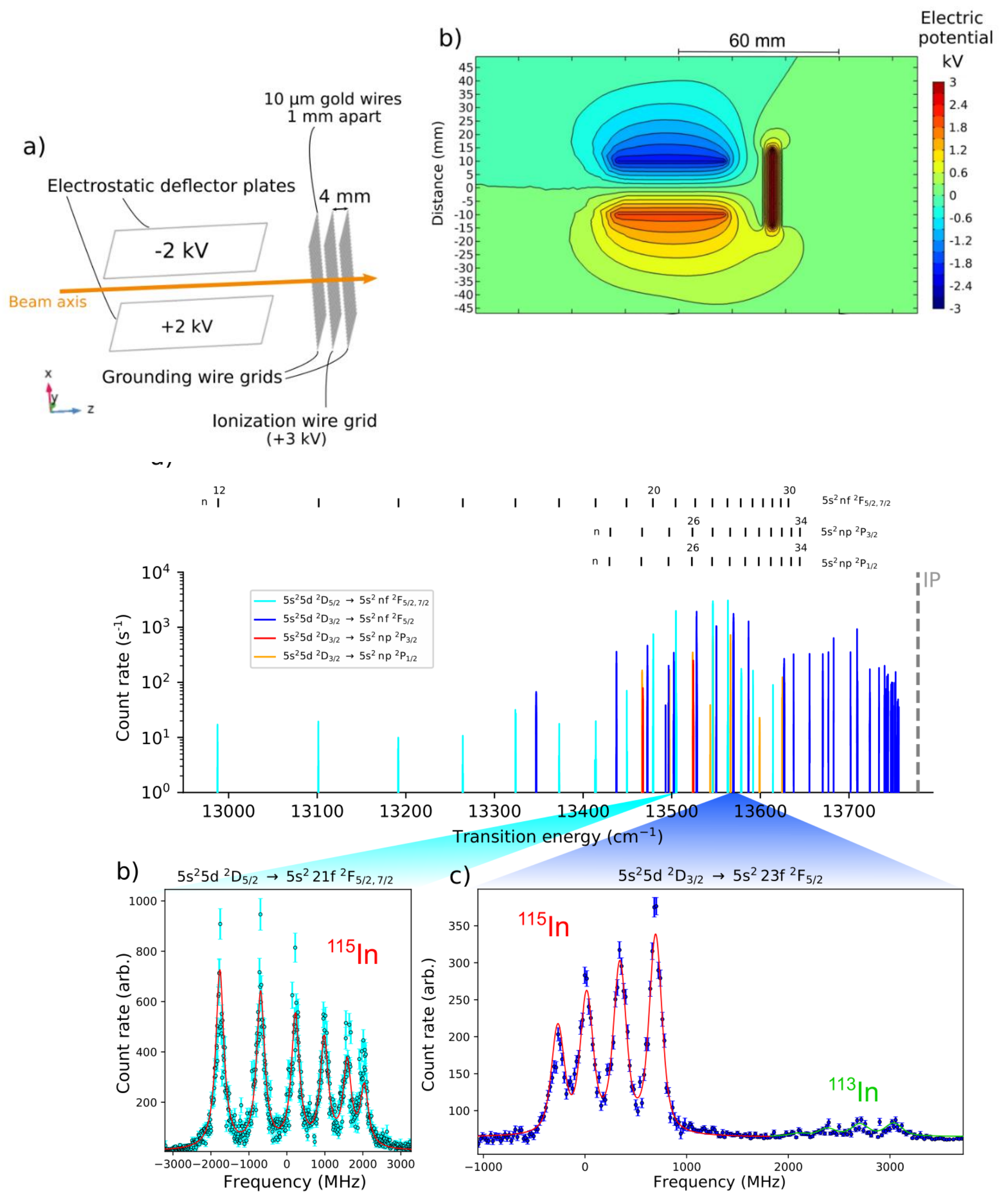
- Nuclear charge radii
  - Complimentary information on nuclear deformation
  - Strength of shell closures



Field ionization at CRIS

- Rather than use high-power nonresonant step, excite to high-lying atomic state (Rydberg state)
- Strong E-field can then ionize the atom
- Advantage:
  - / No laser-induced background*
  - / Smaller ionization volume reduces collisional background
  - / Total: factor 5 obtained offline; further improvement up to a few 100 will be pursued



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- Advantage:
  - No laser-induced background*
  - Smaller ionization volume reduces collisional background
  - Total: factor 5 obtained offline; further improvement up to a few 100 will be pursued
- First steps already made offline @ IGISOL

* Previous campaigns on indium with 1064 nm laser not limited by this background, and for silver we go for lower mass numbers