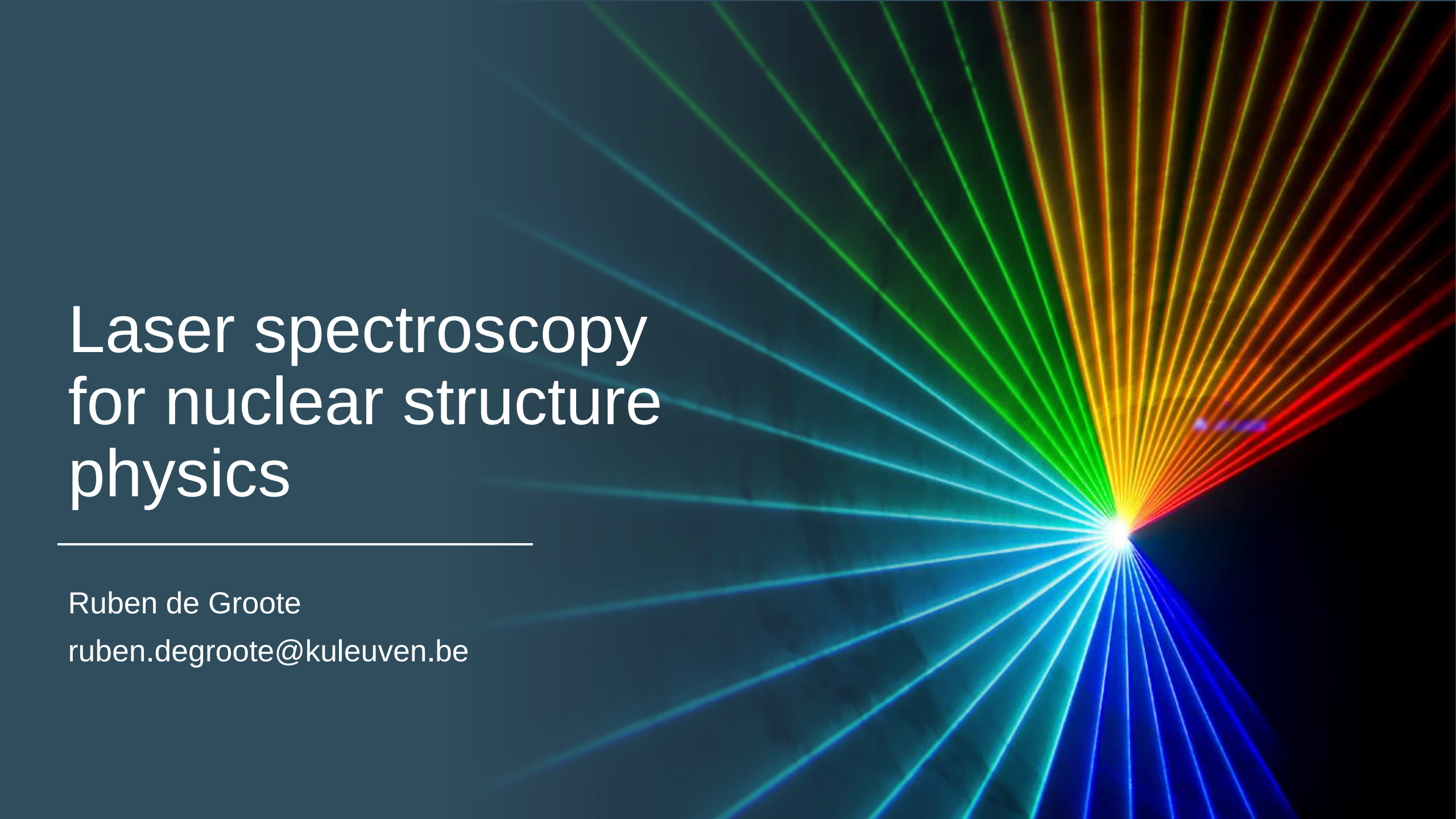
Laser spectroscopy for nuclear structure physics

Ruben de Groote
ruben.degroote@kuleuven.be



Outline

- Lecture 1: History, nuclear fingerprints, shapes and radii
- Lecture 2: Optical spectroscopy, laser ionization, Doppler-free approaches, …

- Lecture 3: Magnetic moments as probes of nuclear structure: a case study

- Lecture 4: Super efficient, super precise: two examples!
  - Here we can talk about all the higher order things that Iain has been building up suspense for

Let’s revise some of the basics…

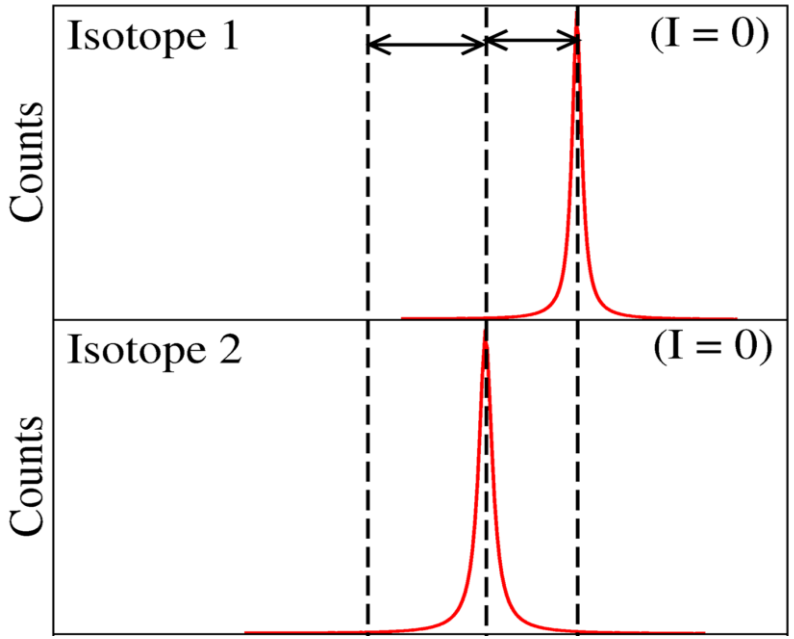
- Precision measurements of atomic excitations allow us to learn about nuclear structure
- Shift of a line from one isotope to the next
  = isotope shift

$$\delta\langle r^2\rangle = \frac{1}{F}\left[\nu^{AA'} - (K_{\mathrm{NMS}} + K_{\mathrm{SMS}})\frac{m_A - m_{A'}}{(m_A + m_e)m_{A'}}\right]$$

Nuclear

Measured

Atomic



Let's revise some of the basics…

- Precision measurements of atomic excitations allow us to learn about nuclear structure
- Shift of a line from one isotope to the next
  = isotope shift

$$\delta\langle r^2\rangle = \frac{1}{F}[\nu^{AA'} - (K_{\mathrm{NMS}} + K_{\mathrm{SMS}})\frac{m_A - m_{A'}}{(m_A + m_e)m_{A'}}]$$

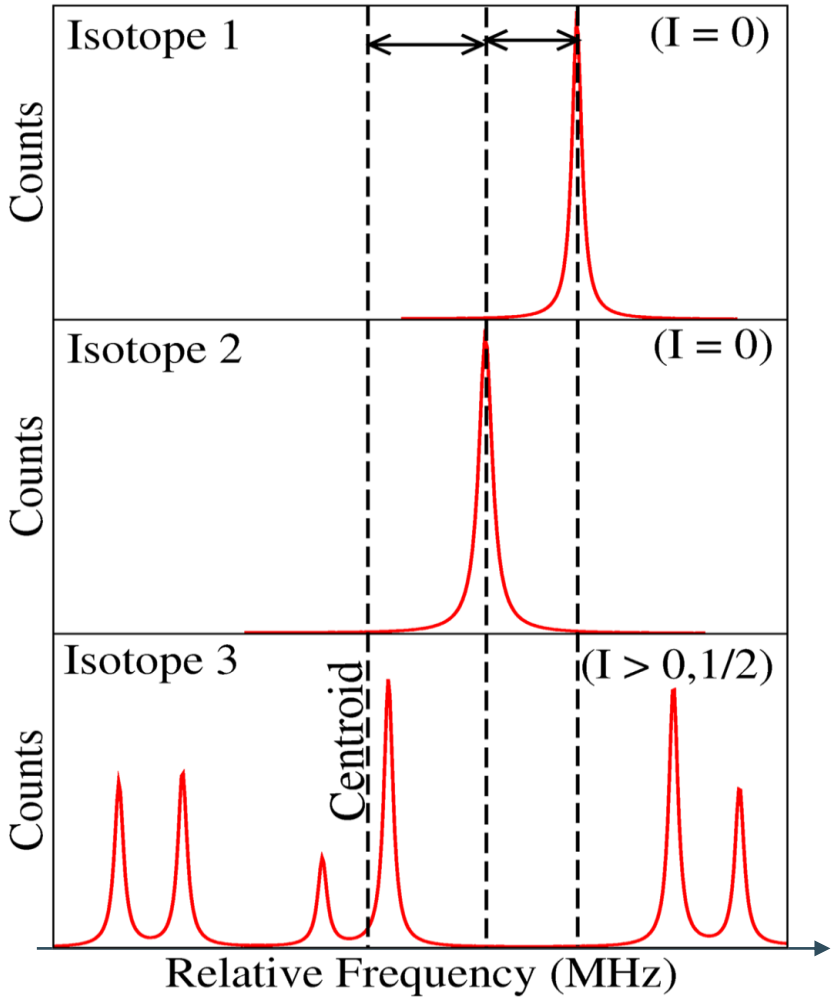
- Hyperfine interaction:

$$E(F) = \frac{A}{2}C + B\frac{\frac{3}{4}C(C+1) - I(I+1)J(J+1)}{2(2I-1)(2J-1)I\cdot J}$$

where $C = F(F+1) - I(I+1) - J(J+1)$

Measured

Nuclear * atomic



For a nucleus with I>0: possible values of F = I + J:
I+J, |I+J-1| … |I-J|

Let's revise some of the basics…

- Precision measurements of atomic excitations allow us to learn about nuclear structure
- Shift of a line from one isotope to the next
  = isotope shift

$$\delta\langle r^2\rangle = \frac{1}{F}\left[\nu^{AA'} - (K_{\mathrm{NMS}} + K_{\mathrm{SMS}})\frac{m_A - m_{A'}}{(m_A + m_e)m_{A'}}\right]$$

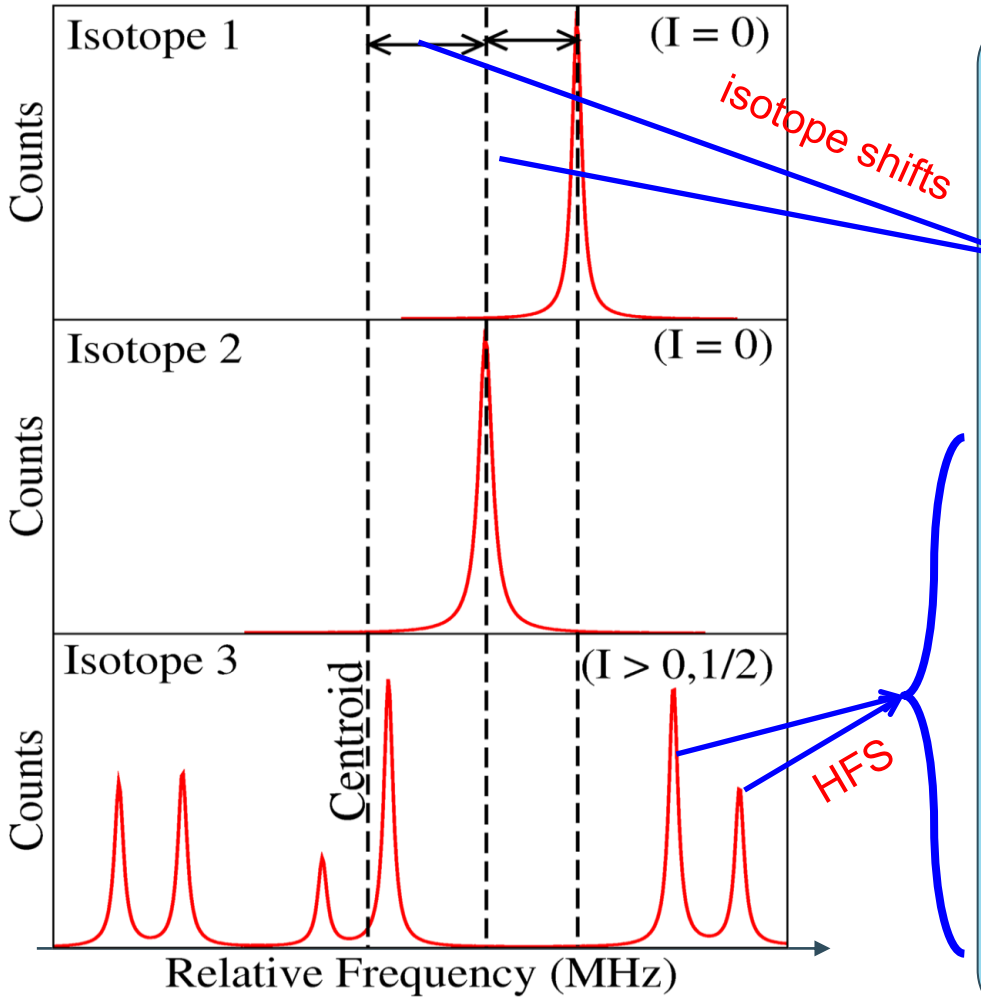
- Hyperfine interaction:

$$E(F) = \frac{A}{2}C + B\frac{\frac{3}{4}C(C+1) - I(I+1)J(J+1)}{2(2I-1)(2J-1)I\cdot J}$$

where $C = F(F+1) - I(I+1) - J(J+1)$

Measured

Nuclear * atomic



Model Independent
(measured)

Sizes

Q_s

Spins

μ

Unit conversions…

Optical transitions: 100's of THz, a few eV, 10000s of cm^{-1}, 100s of nm

Hyperfine splitting: 100's of MHz, a few μeV, ~0.01 cm^{-1}

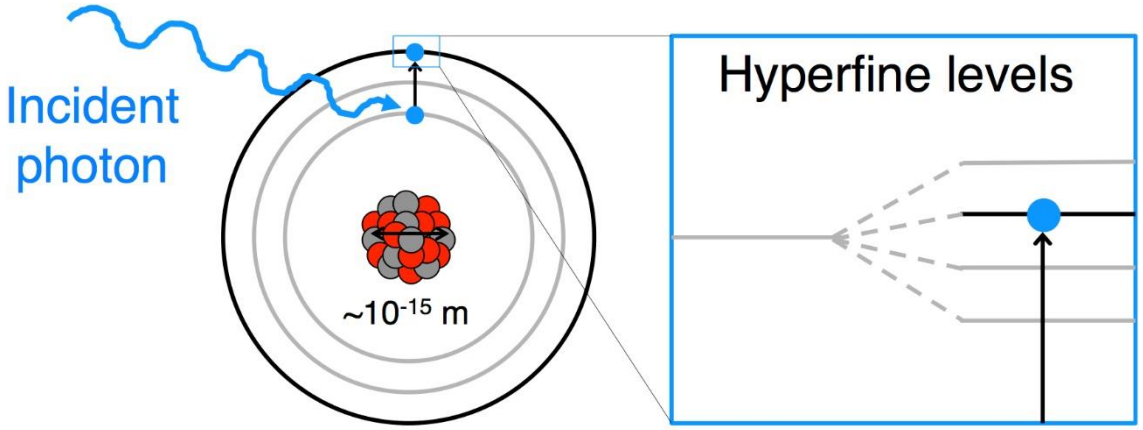
Optical linewidth: 100's of MHz, a few μeV, ~0.01 cm^{-1}

1 cm^{-1}: ~ 30000 MHz

1eV: ~ 8000 cm^{-1}

Let’s revise some of the basics…

- Laser spectroscopy techniques
  - use a laser to excite atoms or ions,
  - ideally with sufficient resolution to resolve the hyperfine structure and/or isotope shift,
- They differ in
  - how these optical excitations are detected
  - the conditions the atoms or ions find themselves in



In-source techniques

- Excitation is converted into *ionization* by adding additional lasers
- Close to the site of radioactive isotope production – environment strongly affects spectroscopy!

Collinear techniques

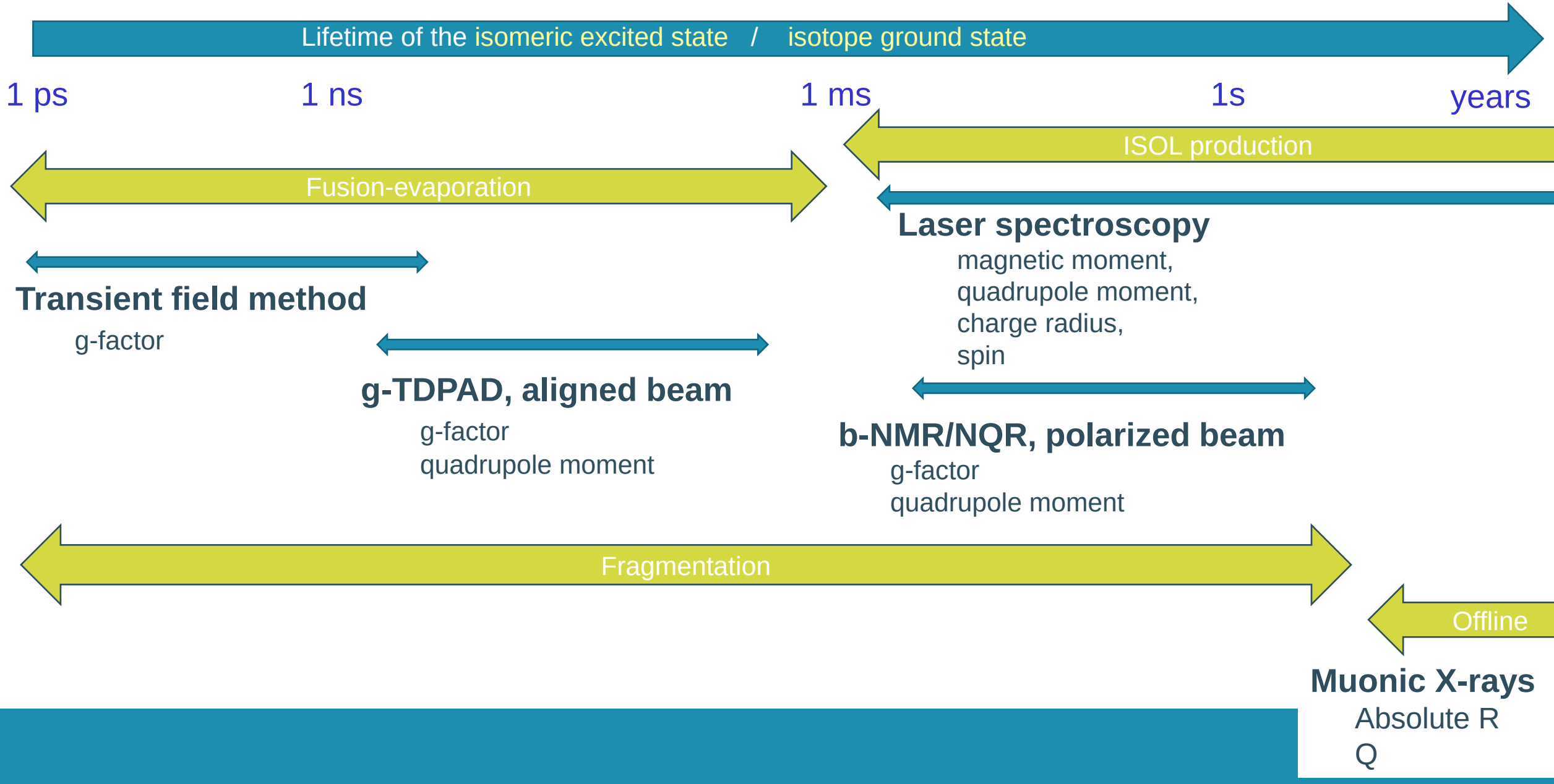
- Isotopes are accelerated prior to the measurement to a few keV energy – doppler-free!
- Many variants exist, e.g. fluorescence detected, CRIS, using laser polarization, …

Trap-based techniques

- Isotopes are carefully manipulated and held ‘still’ inside an atom or ion trap
- At RIB facilities: predominantly used for precision experiments (parity violation, weak interaction studies, …)

Methods to measure moments, radii, spins:

lifetime dependence / production method



Magnetic moments – what can they tell us?

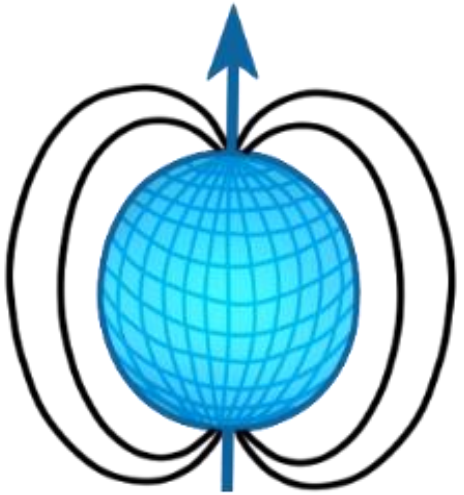
From the definition:

$$\bar{\mu}^{\pi} = g_L^{\pi}\bar{L}_{\pi} + g_S^{\pi}\bar{S}_{\pi} = g^{\pi}\bar{I}_{\pi}$$

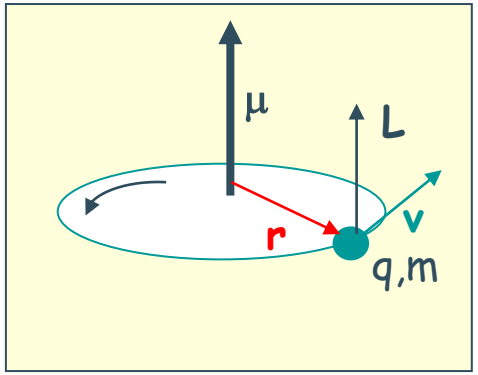
We can see that the magnetic moment depends on the orbital and spin angular momentum.

Protons:	$g_l = +1$	$g_s = +5.586$
Neutrons:	$g_l = 0$	$g_s = -3.826$
(These are values for a *free* proton/neutron)		

Measuring a magnetic moment is an excellent way to learn more about the wavefunction/configuration of the nucleus.



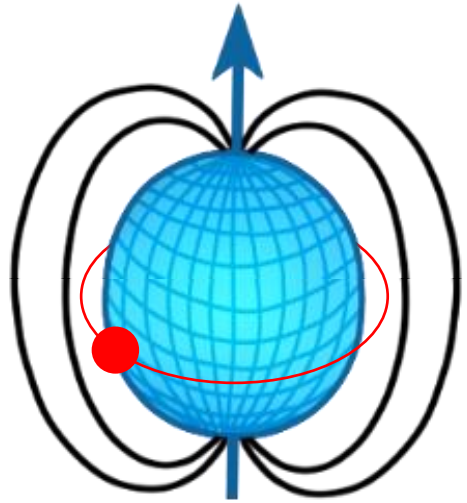
μ



Magnetic dipole

Magnetic moments – what can they tell us?

Assume a single, unpaired nucleon outside of a core that it does not interact with at all.



μ

All nucleons inside the nucleus neatly pair up to spin zero, thus not contributing to the magnetic moment, and we find:

$$\mu_{\mathrm{sp}} = \mu_{\mathrm{N}}\left[g_l j + \tfrac{1}{2}(g_s - g_l)\right] \qquad \text{for } j = l + \tfrac{1}{2}$$

$$\mu_{\mathrm{sp}} = \mu_{\mathrm{N}}\left[g_l j - (g_s - g_l)\frac{j}{2j+2}\right] \qquad \text{for } j = l - \tfrac{1}{2}$$

These expressions summarize the so-called **Schmidt moments**.

Magnetic moments – what can they tell us?

For protons:

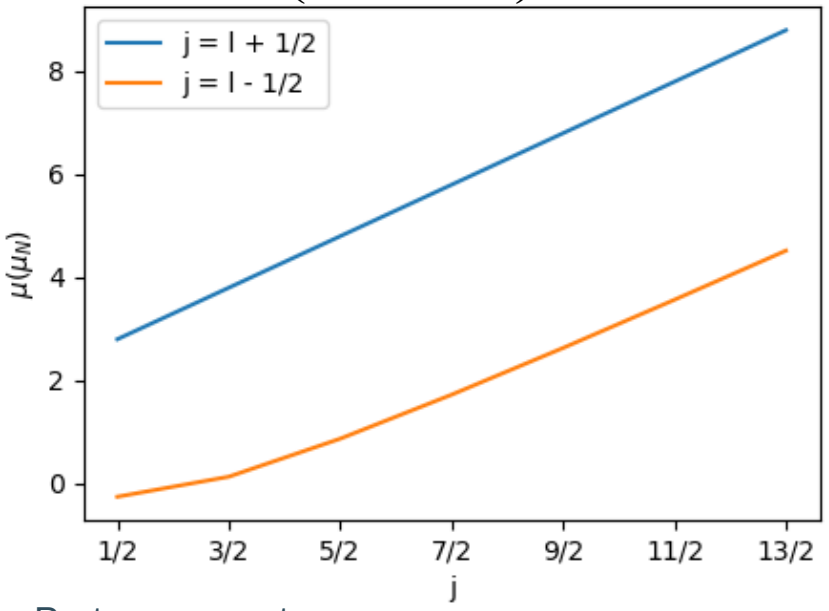
$$\mu = j - \frac{1}{2} + \frac{g_s^{\pi}}{2} \qquad \text{for } j = l + \frac{1}{2}$$

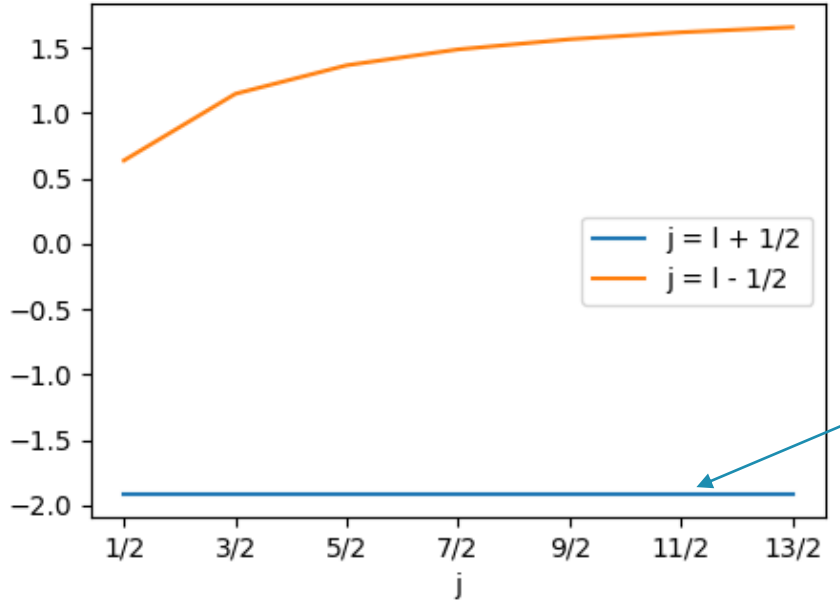
$$\mu = \frac{j}{j+1}\left(j + \frac{3}{2} - \frac{g_s^{\pi}}{2} \right) \qquad \text{for } j = l - \frac{1}{2}$$

For neutrons:

$$\mu = \frac{g_s^{\nu}}{2} = -1.913 \qquad \text{for } j = l + \frac{1}{2}$$

$$\mu = -\frac{j}{j+1}\frac{g_s^{\nu}}{2} \qquad \text{for } j = l - \frac{1}{2}$$





neutron has no charge
=> no orbital contribution

Proton moments
- → increase with j
- → only $\pi p_{1/2}$ negative !

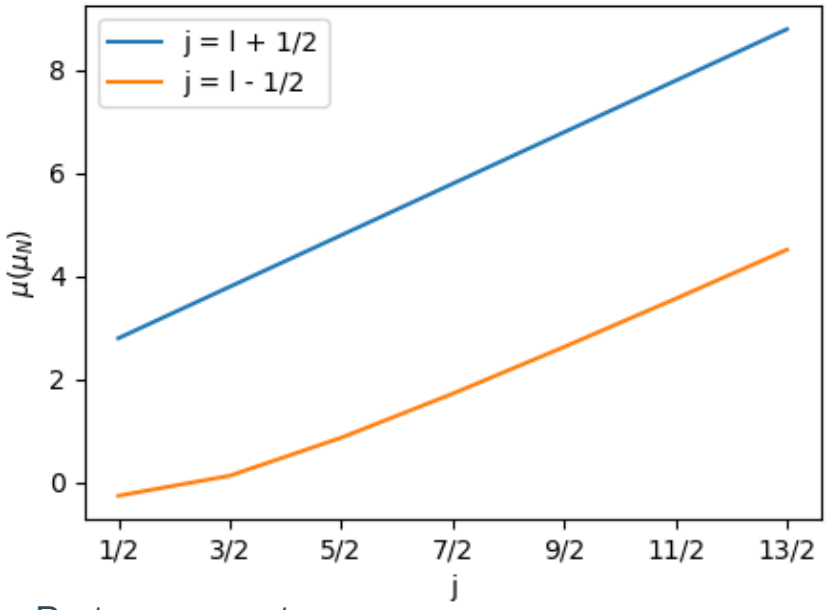
Neutron moments
- → constant negative value for neutron in a l+1/2 orbit
- → (small) positive values for l-1/2 orbits

Magnetic moments – what can they tell us?

For protons:

$$\mu = j - \frac{1}{2} + \frac{g_s^{\pi}}{2} \qquad \text{for } j = l + \frac{1}{2}$$

$$\mu = \frac{j}{j+1}\left(j + \frac{3}{2} - \frac{g_s^{\pi}}{2} \right) \qquad \text{for } j = l - \frac{1}{2}$$

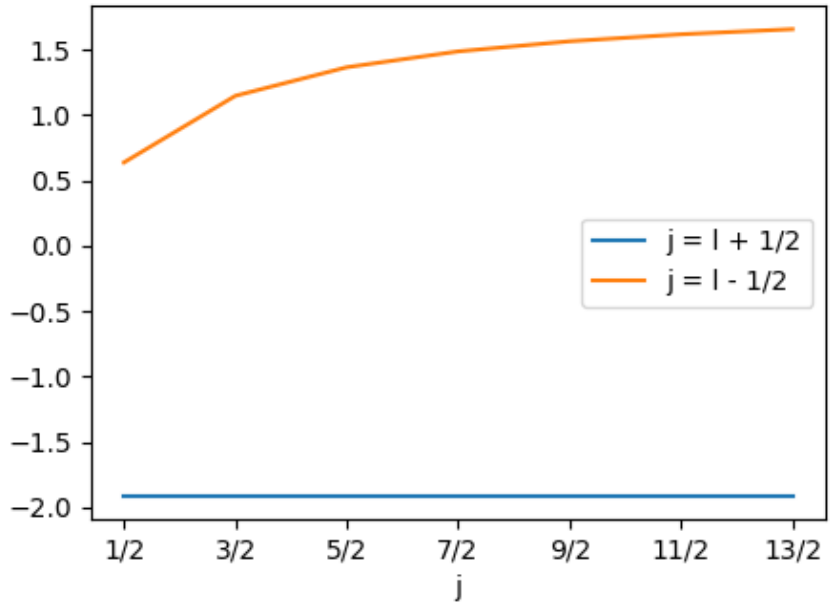


Proton moments
- → increase with j
- → only $\pi p_{1/2}$ negative !

For neutrons:

$$\mu = \frac{g_s^{\nu}}{2} = -1.913 \qquad \text{for } j = l + \frac{1}{2}$$

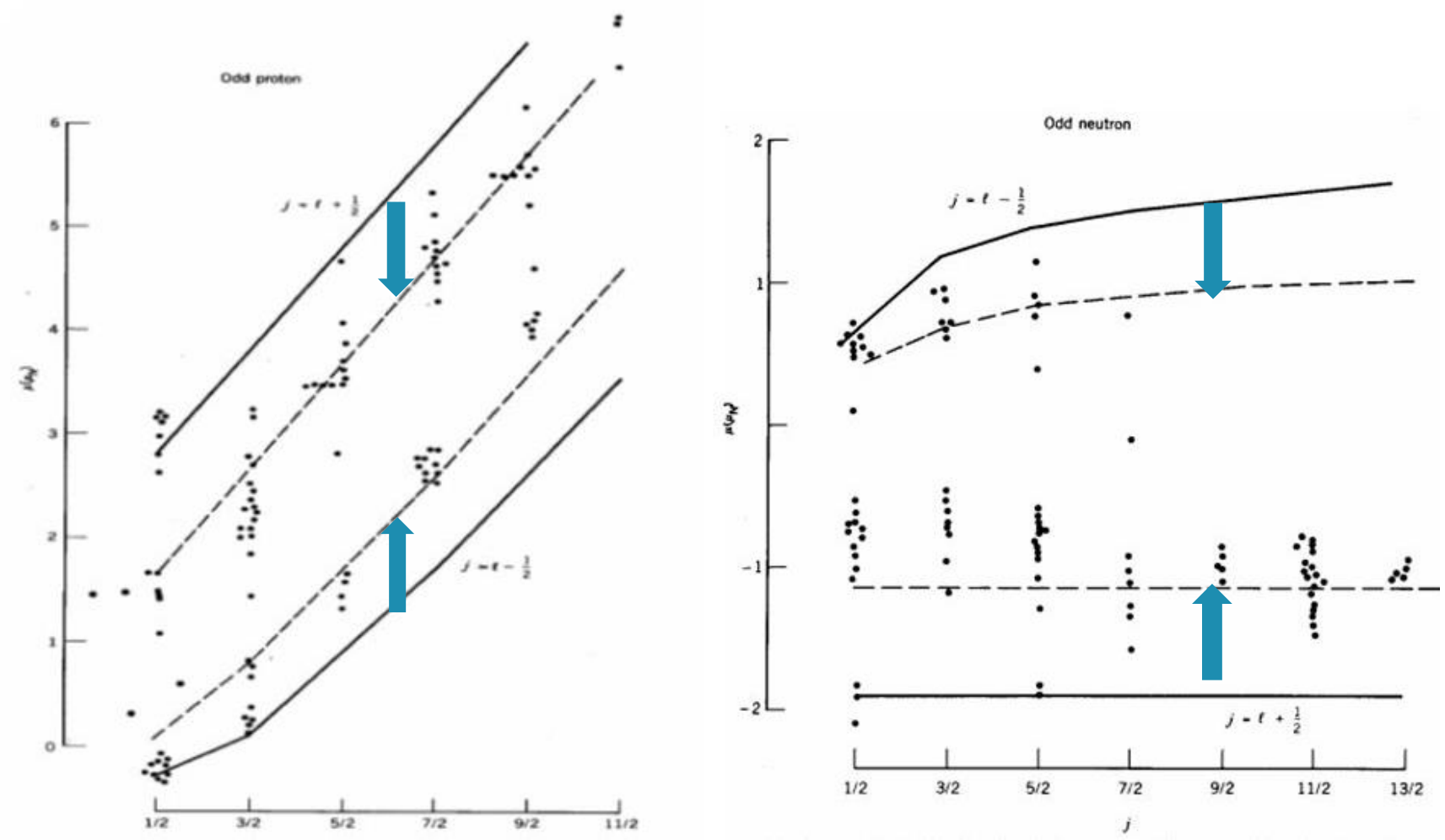
$$\mu = -\frac{j}{j+1}\frac{g_s^{\nu}}{2} \qquad \text{for } j = l - \frac{1}{2}$$



Neutron moments
- → constant negative value for neutron in a l+1/2 orbit
- → (small) positive values for l-1/2 orbits

Note:
- Protons: larger values
- Moment depends very strongly on the relative alignment of spin and orbital moment!
- Relative to our experimental accuracy (to be discussed next), these are **very large** differences in μ for a given configuration

Magnetic moments – what can they tell us?



- Experimentally, we find the general trend is correct, but there is a consistent deviation from Schmidt lines
- **$g_s = 0.7\ g_{s,free}$**
- Cause?
  - Nucleons are not free but are embedded in nuclear medium
  - Configuration mixing: our assumption of a perfect single-particle behaviour is imperfect.

Case study – zinc isotopes
0. atomic structure

- Zinc has 30 protons
- Singly-charged Zn: difficult wavelengths
- Neutral zinc therefore has 30 electrons
- Atomic structure: https://physics.nist.gov/PhysRefData/ASD/levels_form.html
  - Filled atomic d-shell
  - Two valence electrons can be placed in 4s, 4p, 5s, 5p, … to form lowest-energy atomic states

Configuration	Term	J	Level (cm^{-1})	Uncertainty (cm^{-1})
$3d^{10}4s^2$	^1S	0	0.0000	0.0019
$3d^{10}4s4p$	$^3P°$	0	32 311.3176	0.0010
		1	32 501.3990	0.0000
		2	32 890.3267	0.0009
$3d^{10}4s4p$	$^1P°$	1	46 745.4032	0.0024
$3d^{10}4s5s$	^3S	1	53 672.2398	0.0008
$3d^{10}4s5s$	^1S	0	55 789.216	0.003
$3d^{10}4s5p$	$^3P°$	0	61 247.866	0.005
		1	61 274.419	0.004
		2	61 330.845	0.003

Case study – zinc isotopes
0. atomic structure

Spectroscopy from ground state?

- Ground state: J=0
  => no sensitivity to nuclear moments:
  there is no hyperfine splitting!

Configuration	Term	J	Level (cm^{-1})	Uncertainty (cm^{-1})
$3d^{10}4s^2$	^1S	0	0.0000	0.0019
$3d^{10}4s4p$	$^3P°$	0	32 311.3176	0.0010
		1	32 501.3990	0.0000
		2	32 890.3267	0.0009
$3d^{10}4s4p$	$^1P°$	1	46 745.4032	0.0024
$3d^{10}4s5s$	^3S	1	53 672.2398	0.0008
$3d^{10}4s5s$	^1S	0	55 789.216	0.003
$3d^{10}4s5p$	$^3P°$	0	61 247.866	0.005
		1	61 274.419	0.004
		2	61 330.845	0.003

Case study – zinc isotopes
0. atomic structure

Spectroscopy from ground state?

- Ground state: J=0
  => no sensitivity to nuclear moments
- Only option is a transition to J = 1*
  => J = 1: hyperfine structure will only contain three peaks, not enough to get isotope shift, A, B and nuclear spin
  (4 parameters with only three measurable frequencies)

- So: not ideal.

Configuration	Term	J	Level (cm^{-1})	Uncertainty (cm^{-1})
$3d^{10}4s^2$	^1S	0	0.0000	0.0019
$3d^{10}4s4p$	$^3P°$	0	32 311.3176	0.0010
		1	32 501.3990	0.0000
		2	32 890.3267	0.0009
$3d^{10}4s4p$	$^1P°$	1	46 745.4032	0.0024
$3d^{10}4s5s$	^3S	1	53 672.2398	0.0008
$3d^{10}4s5s$	^1S	0	55 789.216	0.003
$3d^{10}4s5p$	$^3P°$	0	61 247.866	0.005
		1	61 274.419	0.004
		2	61 330.845	0.003

*J=0 to J=0 is very weak, only because of mixing not totally forbidden

Case study – zinc isotopes
0. atomic structure

Spectroscopy from ground state?

- Not ideal.

Luckily, there is a long-lived metastable state!

Configuration	Term	J	Level (cm^{-1})	Uncertainty (cm^{-1})
$3d^{10}4s^2$	^1S	0	0.0000	0.0019
$3d^{10}4s4p$	$^3P°$	0	32 311.3176	0.0010
		1	32 501.3990	0.0009
		2	32 890.3267	0.0009
$3d^{10}4s4p$	$^1P°$	1	46 745.4032	0.0024
$3d^{10}4s5s$	^3S	1	53 672.2398	0.0008
$3d^{10}4s5s$	^1S	0	55 789.216	0.003
$3d^{10}4s5p$	$^3P°$	0	61 247.866	0.005
		1	61 274.419	0.004
		2	61 330.845	0.003

Case study – zinc isotopes
0. atomic structure

Luckily, there is a long-lived metastable state!

Furthermore, convenient optical transition

$$4s\ 4p\ {}^3P^0 \rightarrow 4s\ 5s\ {}^3S_1$$

Pro:

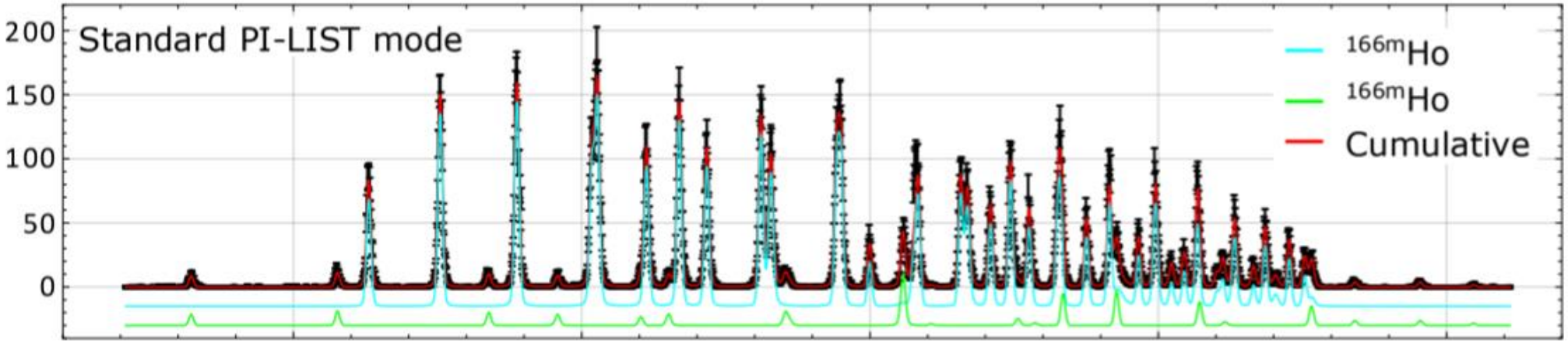
- 418 nm: easy wavelength with modern Ti:sapphire laser systems
- J = 2 to J = 1: measuring all observables a priori possible
- Transition excites a 4p electron to 5s: expect large field shift

Con:

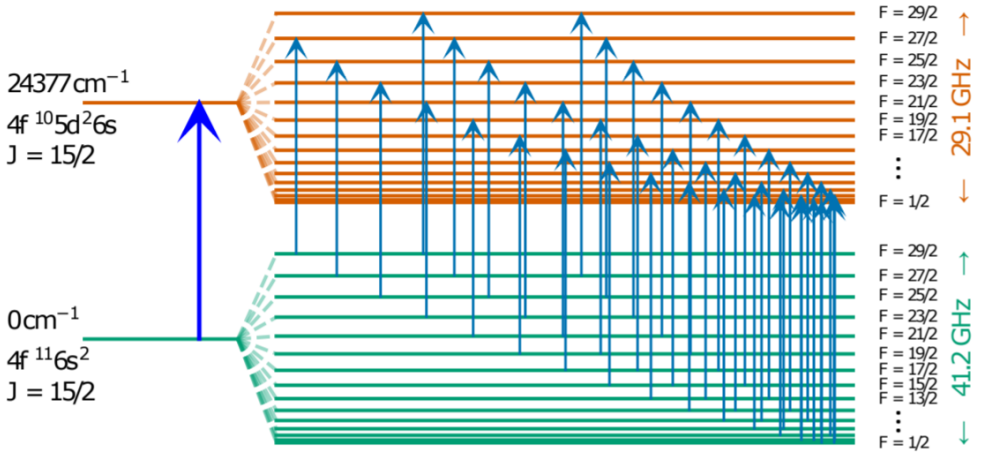
- Producing atoms in a metastable state?

Configuration	Term	J	Level (cm^{-1})	Uncertainty (cm^{-1})
$3d^{10}4s^2$	^1S	0	0.0000	0.0019
$3d^{10}4s4p$	$^3P°$	0	32 311.3176	0.0010
		1	32 501.3990	0.0000
		2	32 890.3267	0.0009
$3d^{10}4s4p$	$^1P°$	1	46 745.4032	0.0024
$3d^{10}4s5s$	^3S	1	53 672.2398	0.0008
$3d^{10}4s5s$	^1S	0	55 789.216	0.003
$3d^{10}4s5p$	$^3P°$	0	61 247.866	0.005
		1	61 274.419	0.004
		2	61 330.845	0.003

A note on high angular momenta…

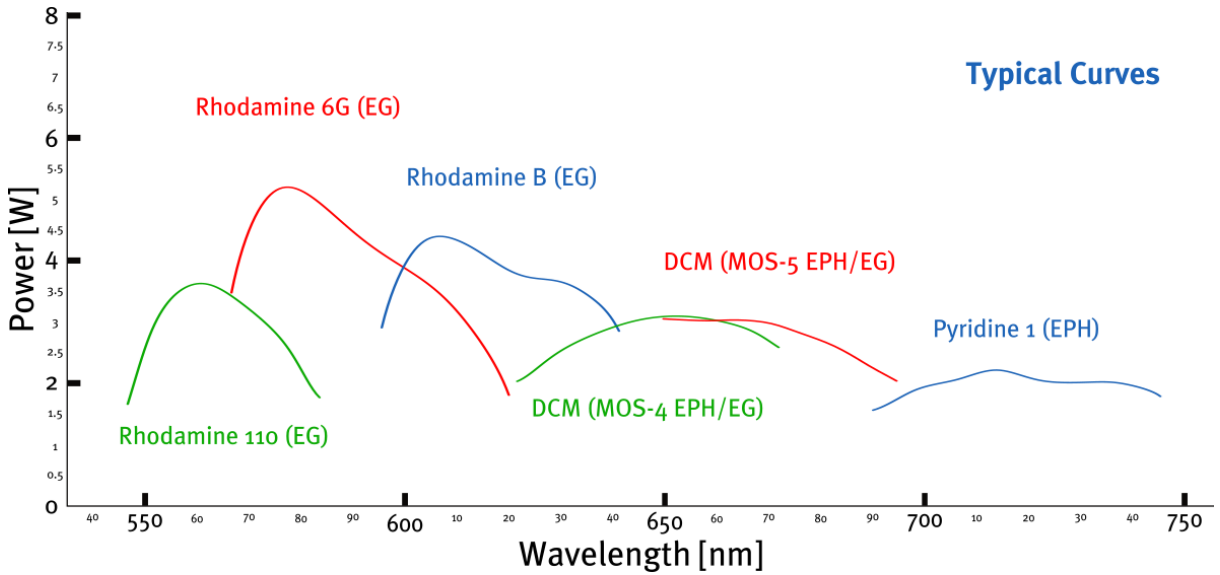


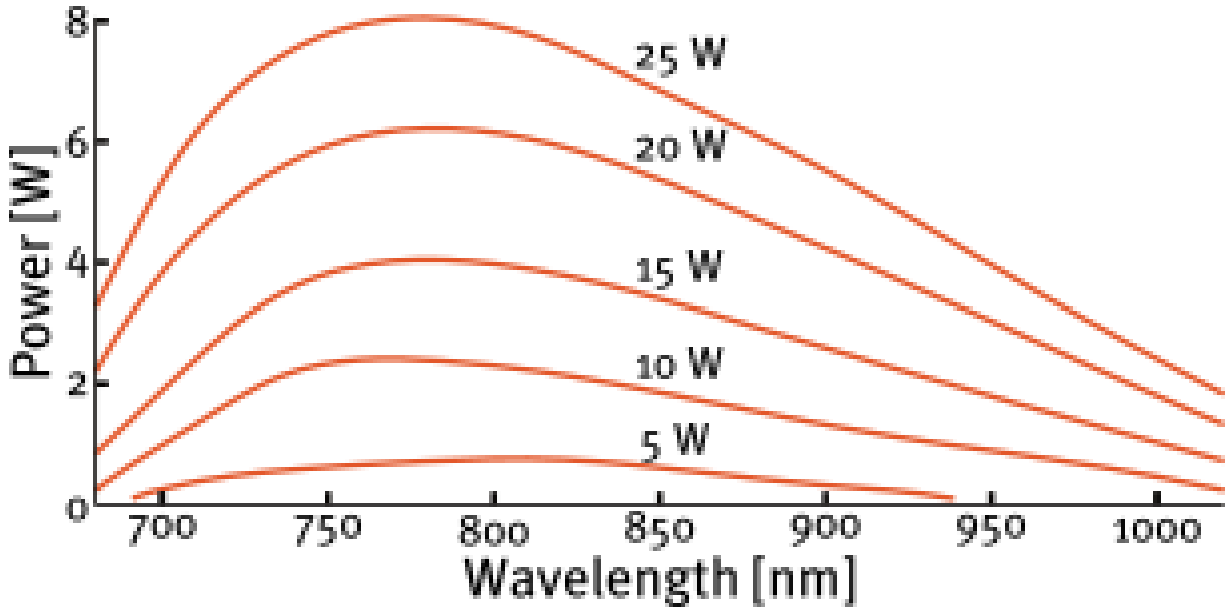
- A transition involving high angular momenta is good for sensitivity to spins and moments
- But it comes at a cost! Signal strength is spread over many peaks.
- Even with super high production rates, these kinds of measurements on radioactive isotopes are simply not feasible.



R. Heinke, PhD thesis Mainz (2019)

Brief aside about tunable cw lasers…





- We want to match the Doppler width of the resonance (few MHz), so we use lasers with a similar bandwidth (<MHz for ring cavity continuous-wave lasers)
- Depending on the wavelength we need different laser gain mediums
- Frequency doubling and even quadrupling is used to make blue and UV wavelengths as well

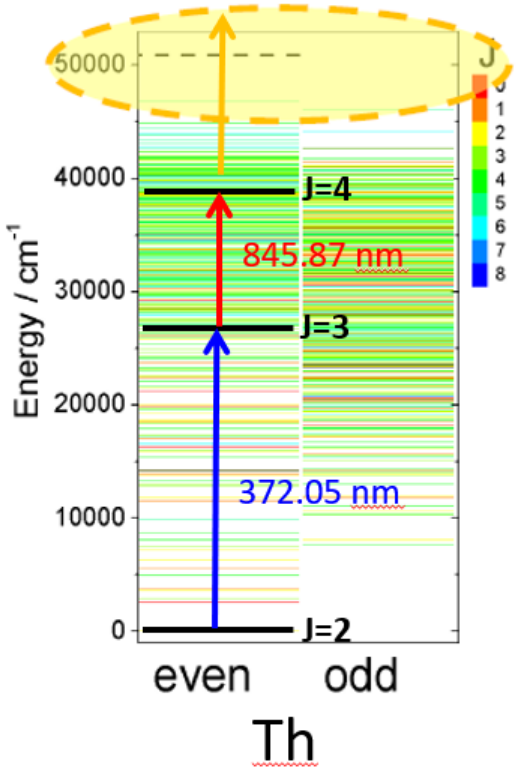
How do we develop the ionization scheme

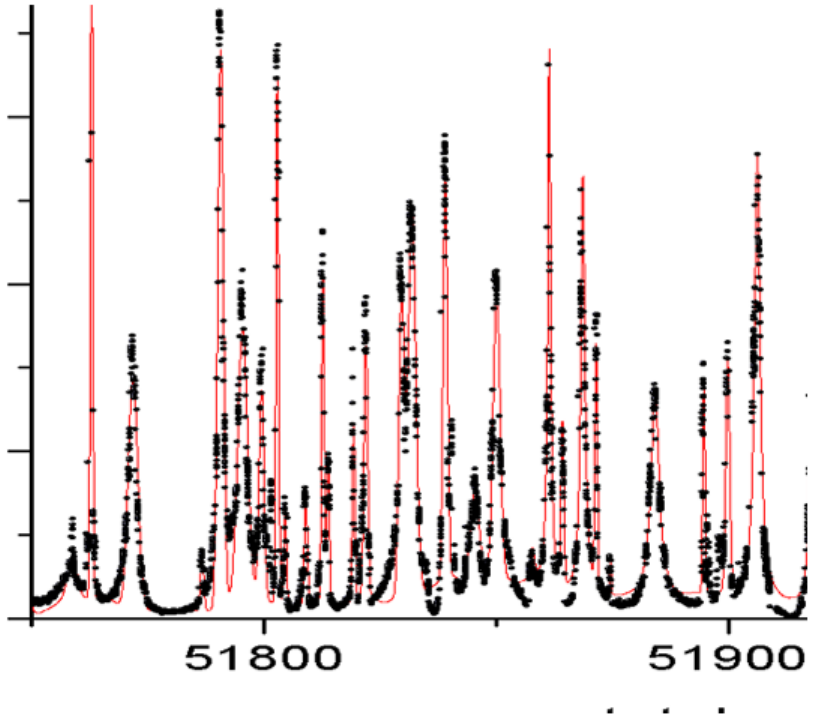
UNIVERSITY OF JYVÄSKYLÄ

Literature Search

On-line atomic spectral line databases, published spectroscopy work.

- R.L. Kurucz' CD-ROM 23 Atomic Line Database: http://www.pmp.uni-hannover.de/cgi-bin/ssi/test/kurucz/sekur.html
- NIST atomic spectral line database: http://www.nist.gov/pml/data/asd.cfm
- Blaise and Wyart (actinides): http://web2.lac.u-psud.fr/lac/Database/Contents.html



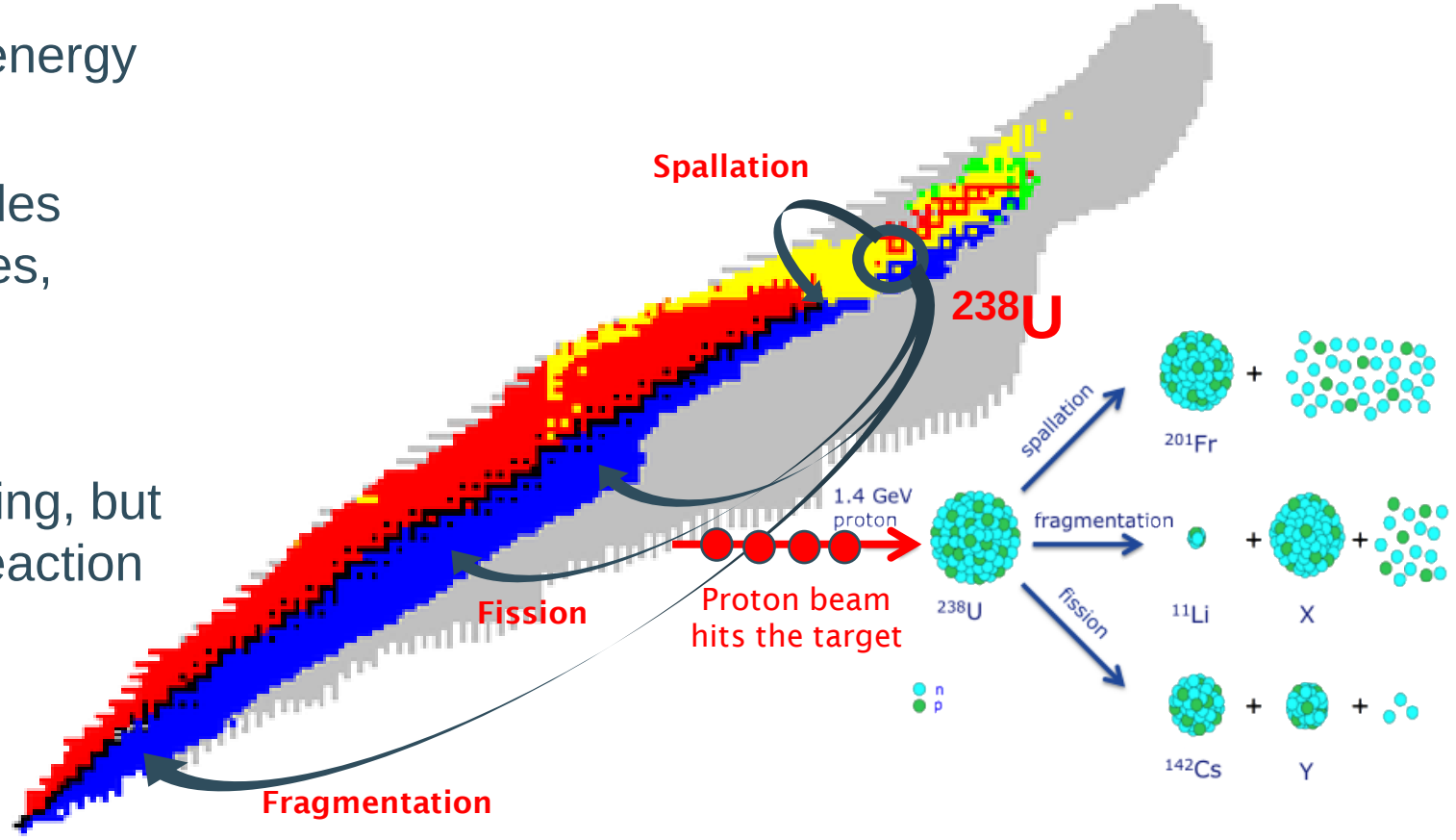


V. Sonnenschein, I.D. Moore et al., EPJ A 48 (2012) 52

Case study – zinc isotopes
1. production

- Nuclear reactions induced by high-energy beam hitting a target
- Fission of uranium or thorium provides access to many neutron-rich isotopes, including e.g. Zn!

- Picking a suitable reaction is one thing, but the next issue is how to get those reaction products from the target to the experimental setup quickly

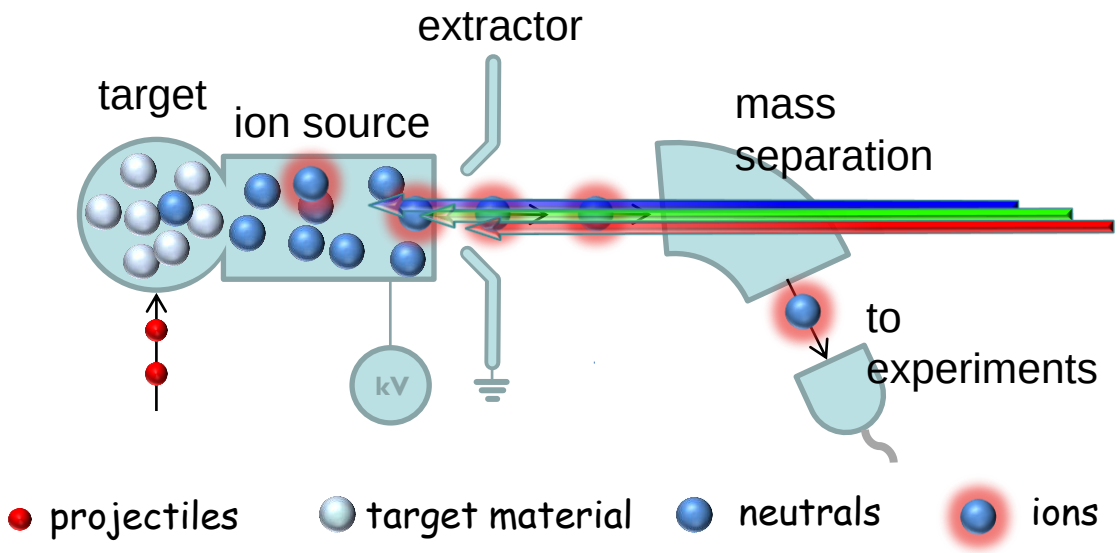


KU LEUVEN

Case study – zinc isotopes
1. production

- Nuclear reactions induced by high-energy beam hitting a target
- Fission of uranium or thorium provides access to many neutron-rich isotopes, including e.g. Zn!

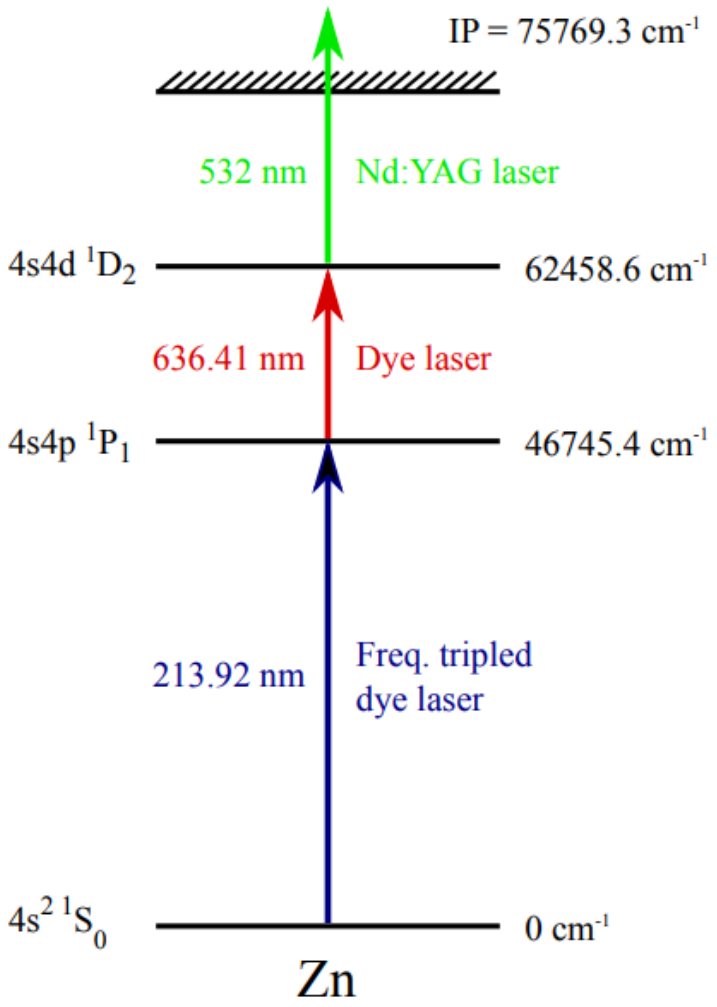
- Laser ionization and mass separation is used to only select the isotope of interest, and reduce the amount of unwanted isotopes, molecules,… in the beam



Case study – zinc isotopes
1. production

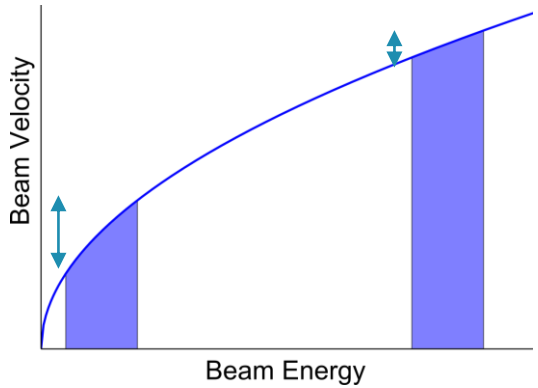
- Nuclear reactions induced by high-energy beam hitting a target
- Fission of uranium or thorium provides access to many neutron-rich isotopes, including e.g. Zn!

- Laser ionization and mass separation is used to only select the isotope of interest, and reduce the amount of unwanted isotopes, molecules,… in the beam
- Laser ionization is an important tool in an RIB lab's toolbox



KU LEUVEN

Case study – zinc isotopes
2. spectroscopy

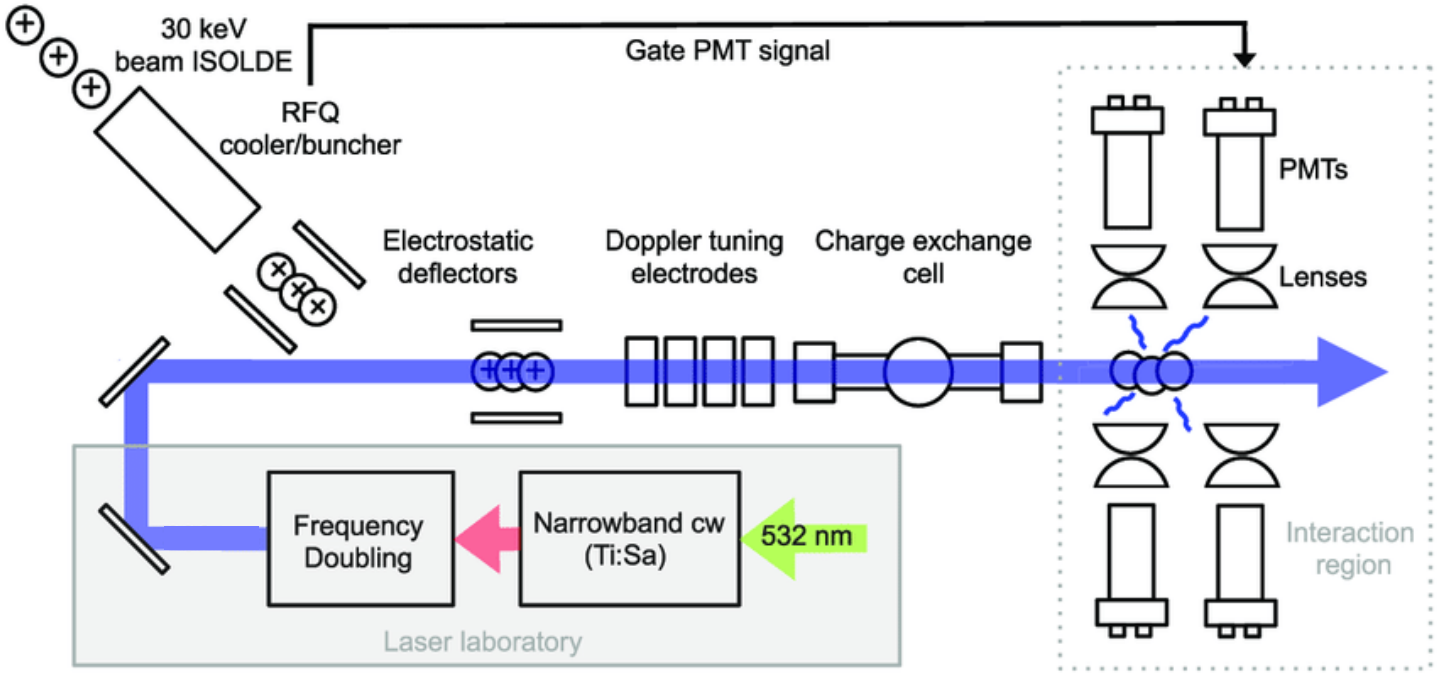


- Collinear laser spectroscopy

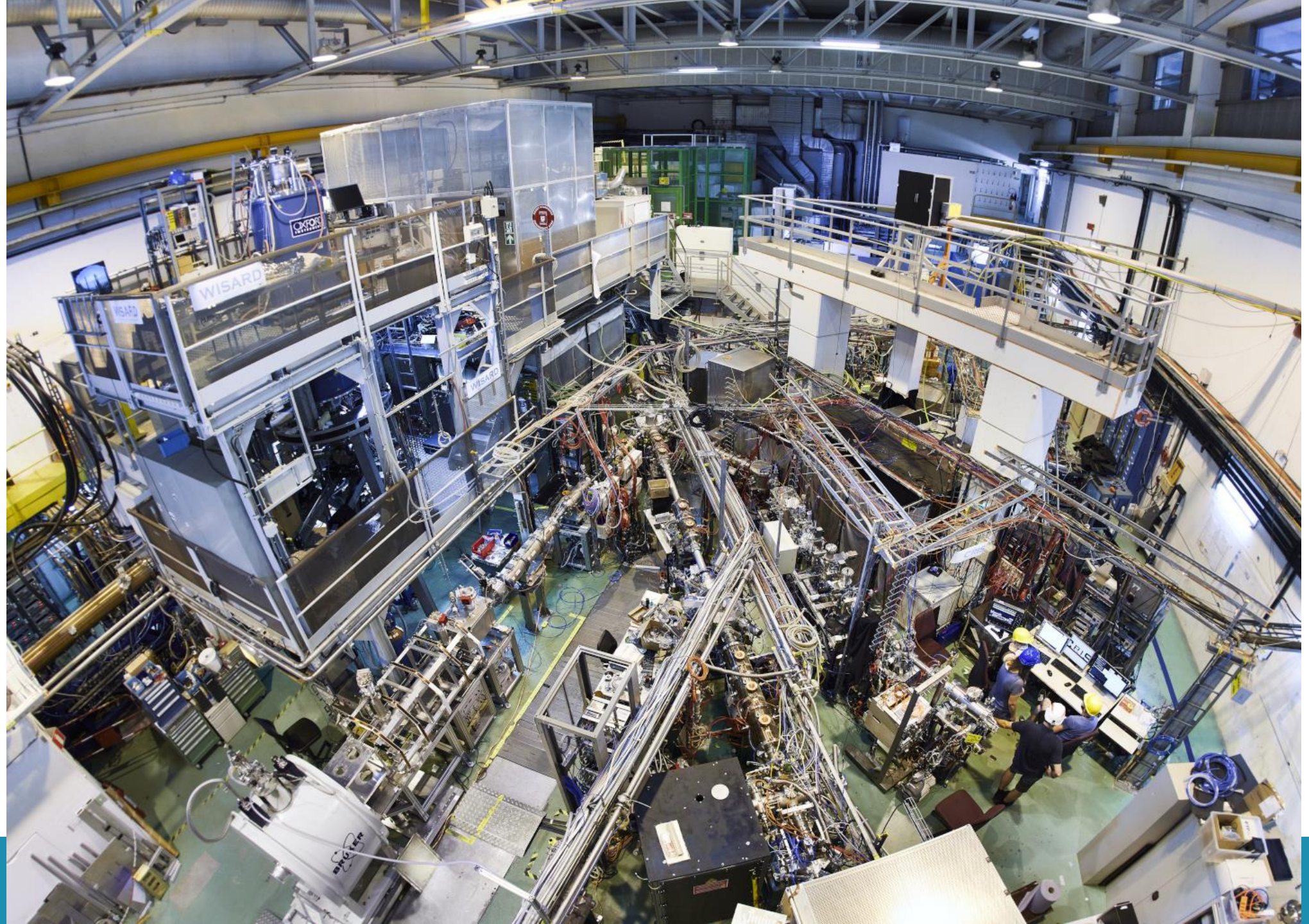
- Charge exchange:
  cell which is filled with e.g. sodium and heated to produce a vapour

- At beam energies of a few keV, large cross section for:

$Zn^+ + Na \rightarrow Zn + Na^+$



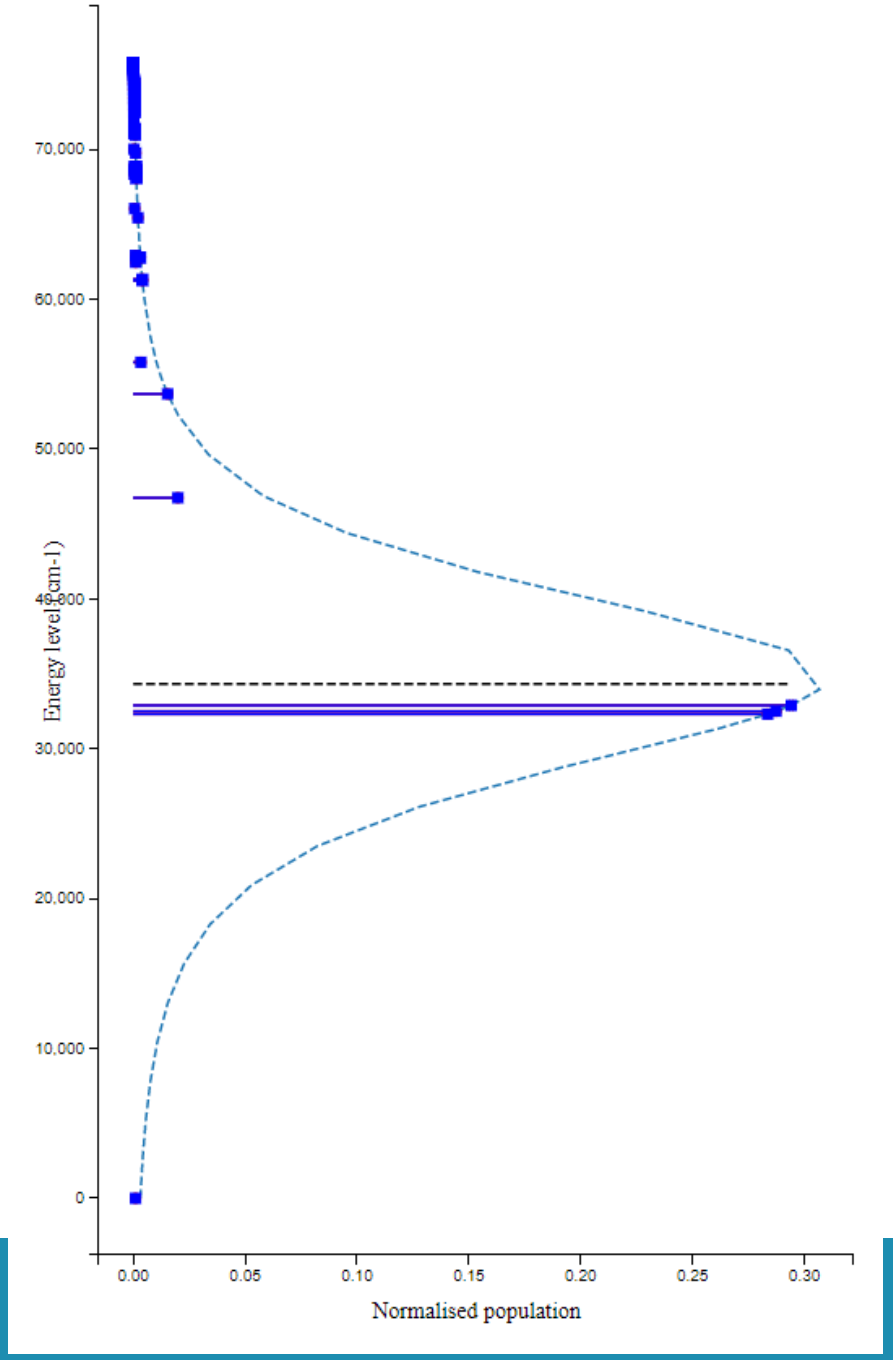
KU LEUVEN


WISARD
WISARD
WISARD

Case study – zinc isotopes 2. spectroscopy

- Collinear laser spectroscopy
- Charge exchange:
  cell which is filled with e.g. sodium and heated to produce a vapour
- At beam energies of a few keV, large cross section for:

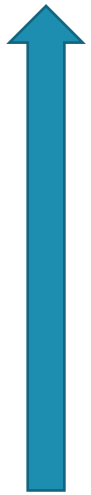
$Zn^+ + Na \rightarrow Zn + Na^+$



Case study – zinc isotopes
2. spectroscopy

I = 9/2

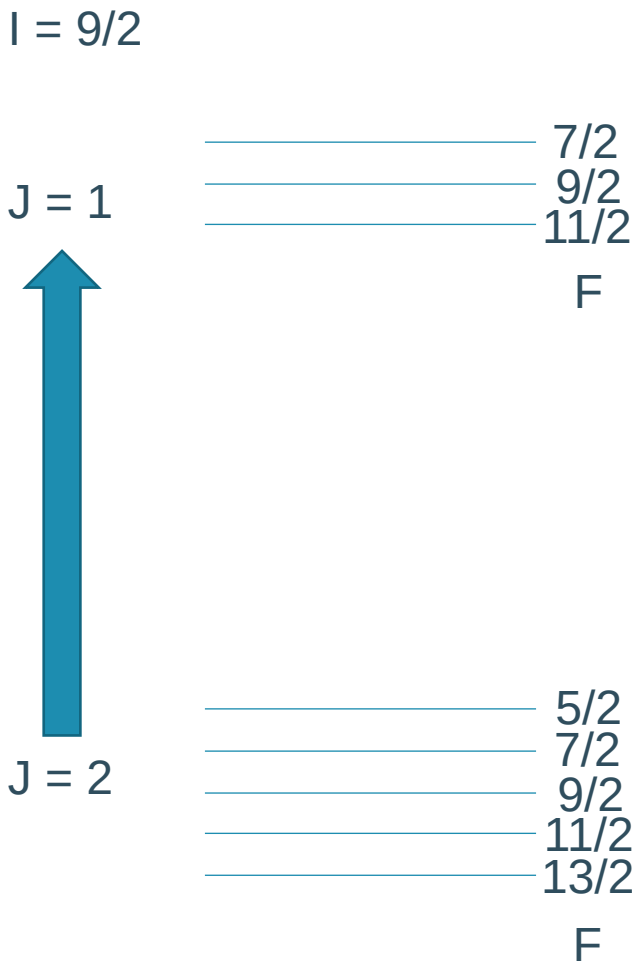
J = 1



J = 2

C. Wraith et al. / Physics Letters B 771 (2017) 385–391

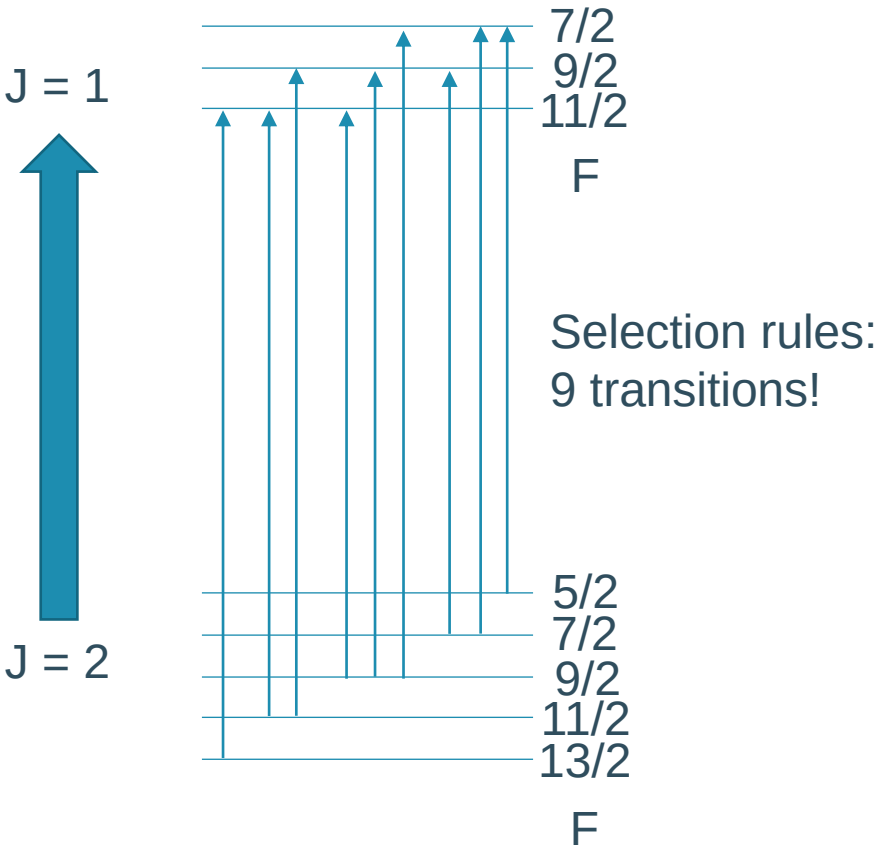
Case study – zinc isotopes
2. spectroscopy



C. Wraith et al. / Physics Letters B 771 (2017) 385–391

Case study – zinc isotopes
2. spectroscopy

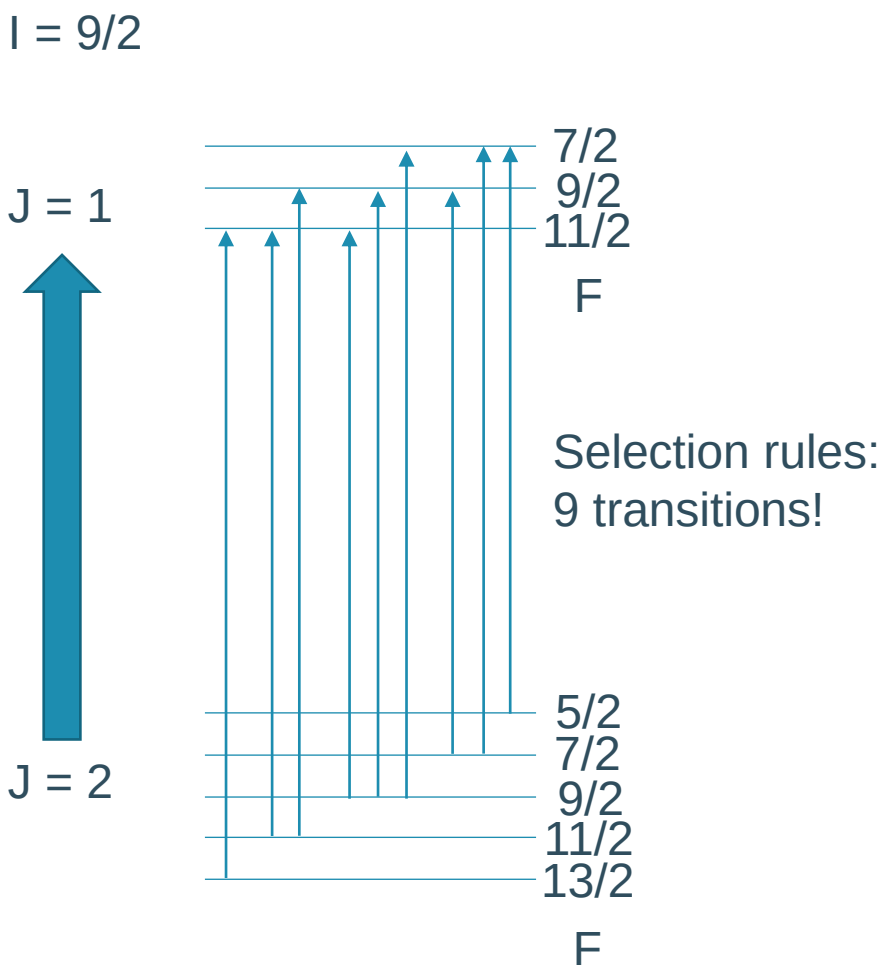
I = 9/2



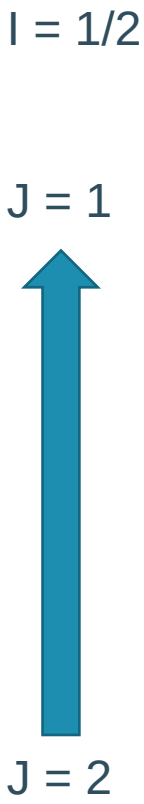
Selection rules:
9 transitions!

C. Wraith et al. / Physics Letters B 771 (2017) 385–391

Case study – zinc isotopes
2. spectroscopy



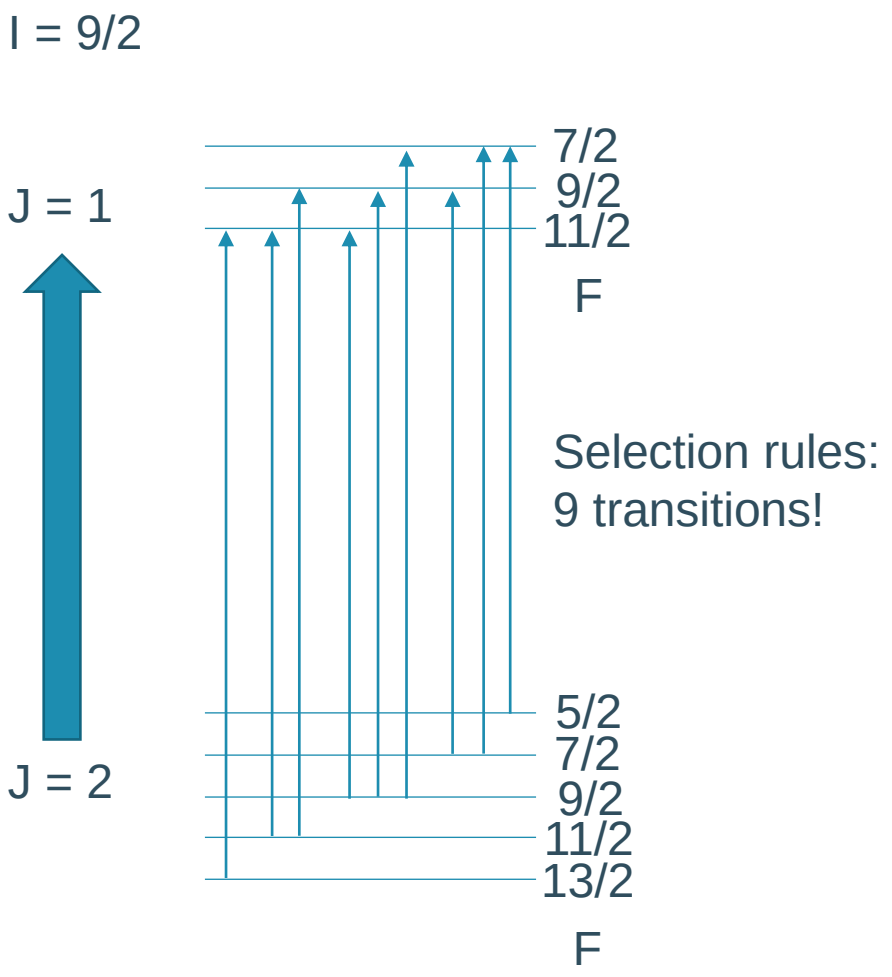
Selection rules:
9 transitions!

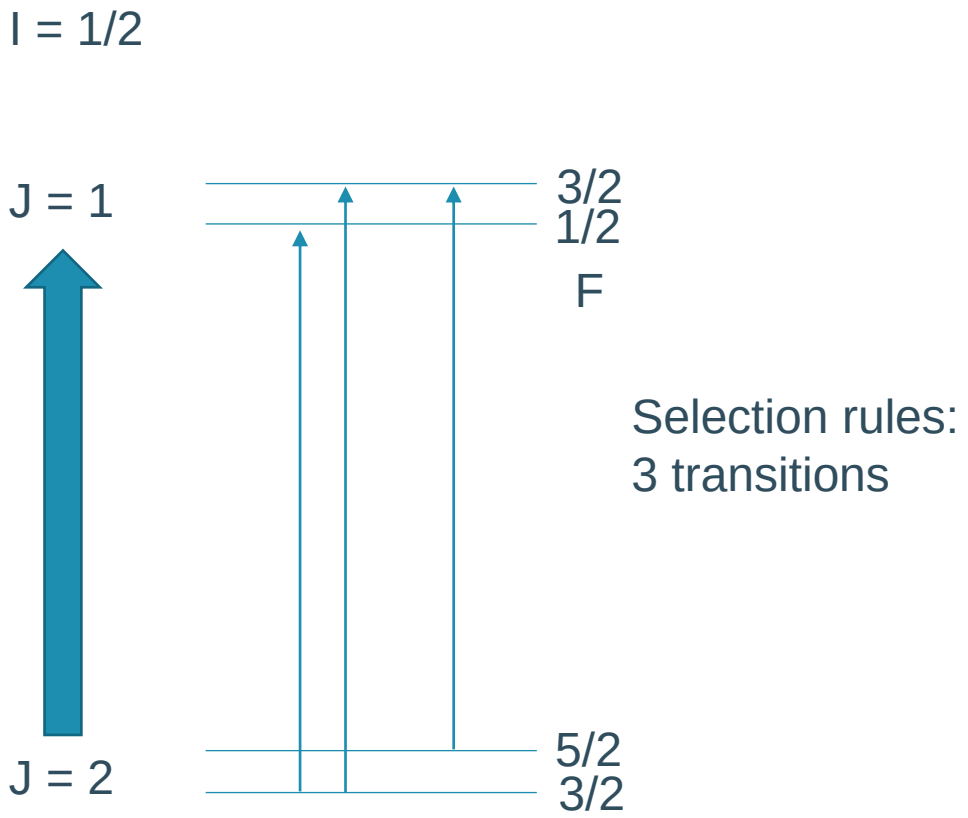


How many transitions are there in this case?

C. Wraith et al. / Physics Letters B 771 (2017) 385–391

Case study – zinc isotopes
2. spectroscopy

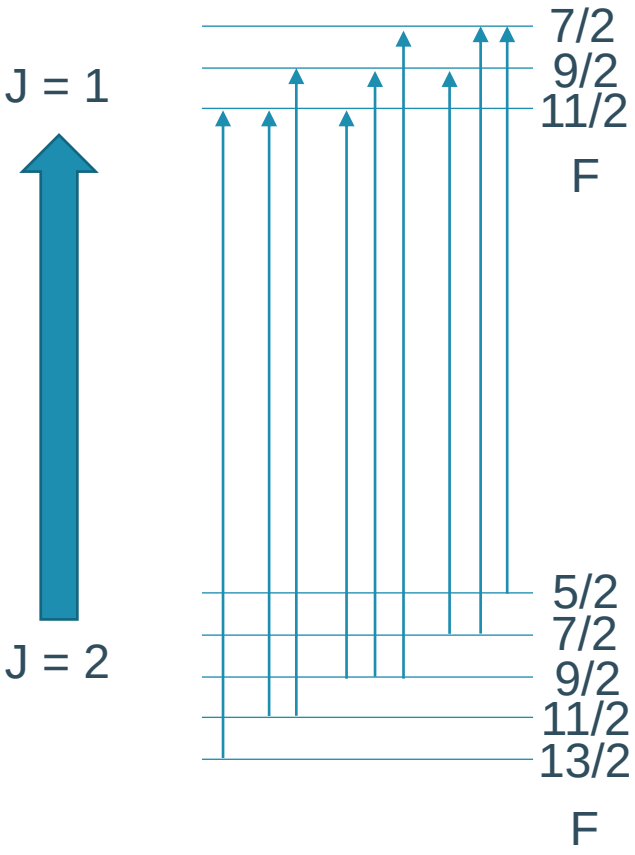


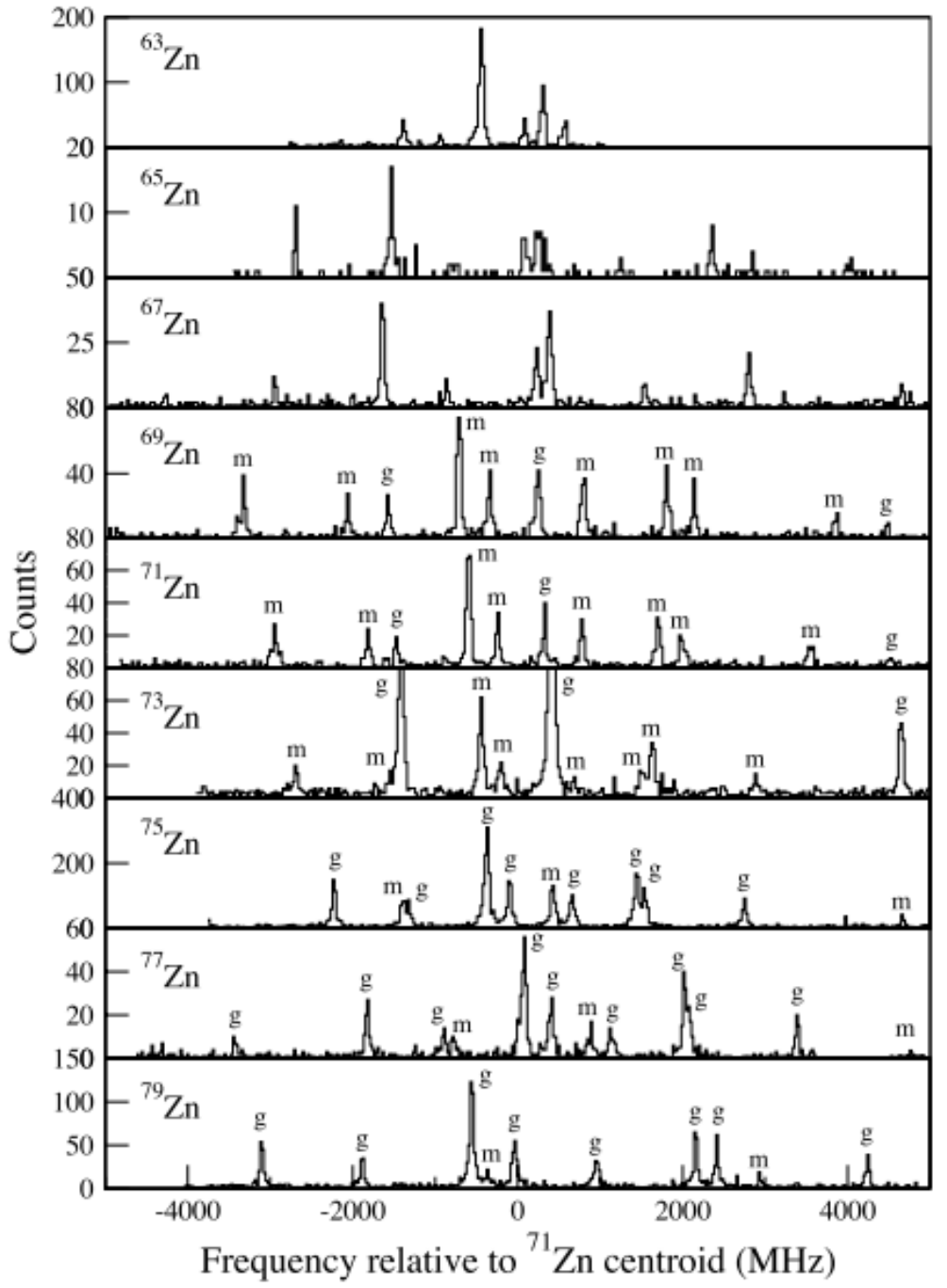


C. Wraith et al. / Physics Letters B 771 (2017) 385–391

Case study – zinc isotopes
2. spectroscopy

I = 9/2

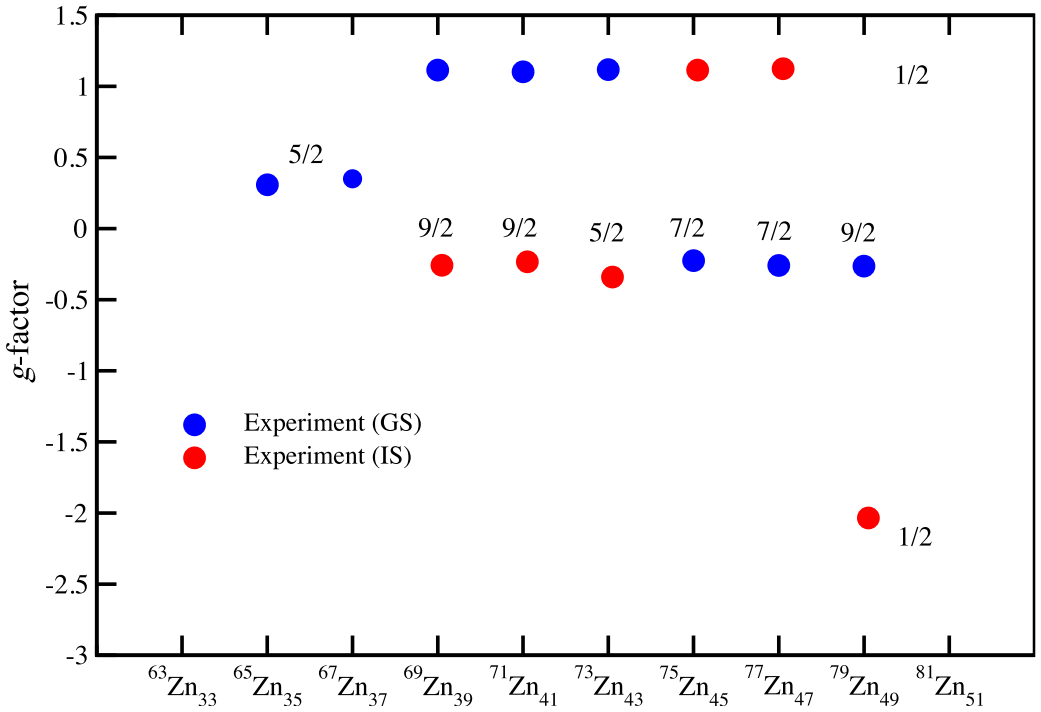




C. Wraith et al. / Physics Letters B 771 (2017) 385–391

Case study – zinc isotopes
3. physics discussion

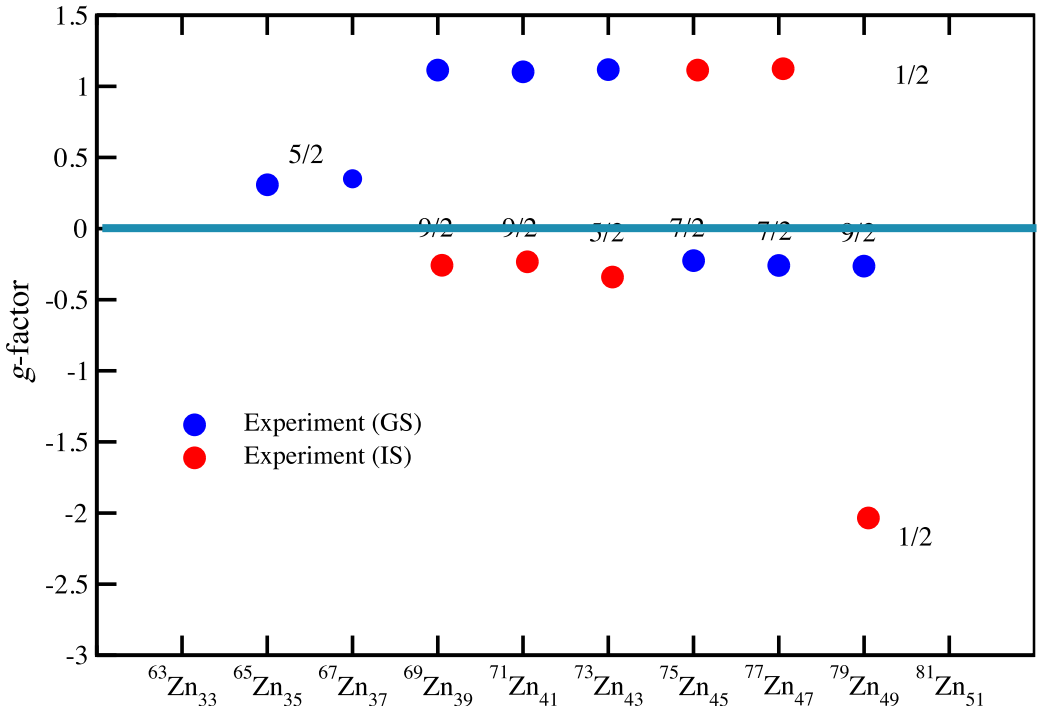
- In nearly all isotopes, two long-lived states were found in the spectra
  - Recall: laser spectroscopy is possible down to lifetimes of a few ms
- The plot on the right summarizes the g-factors
  $g = \mu/I$
  and the nuclear spins
- Observations?



C. Wraith et al. / Physics Letters B 771 (2017) 385–391

Case study – zinc isotopes
3. physics discussion

- In nearly all isotopes, two long-lived states were found in the spectra
  - Recall: laser spectroscopy is possible down to lifetimes of a few ms
- The plot on the right summarizes the g-factors
  $g = \mu/I$
  and the nuclear spins
- Observations?



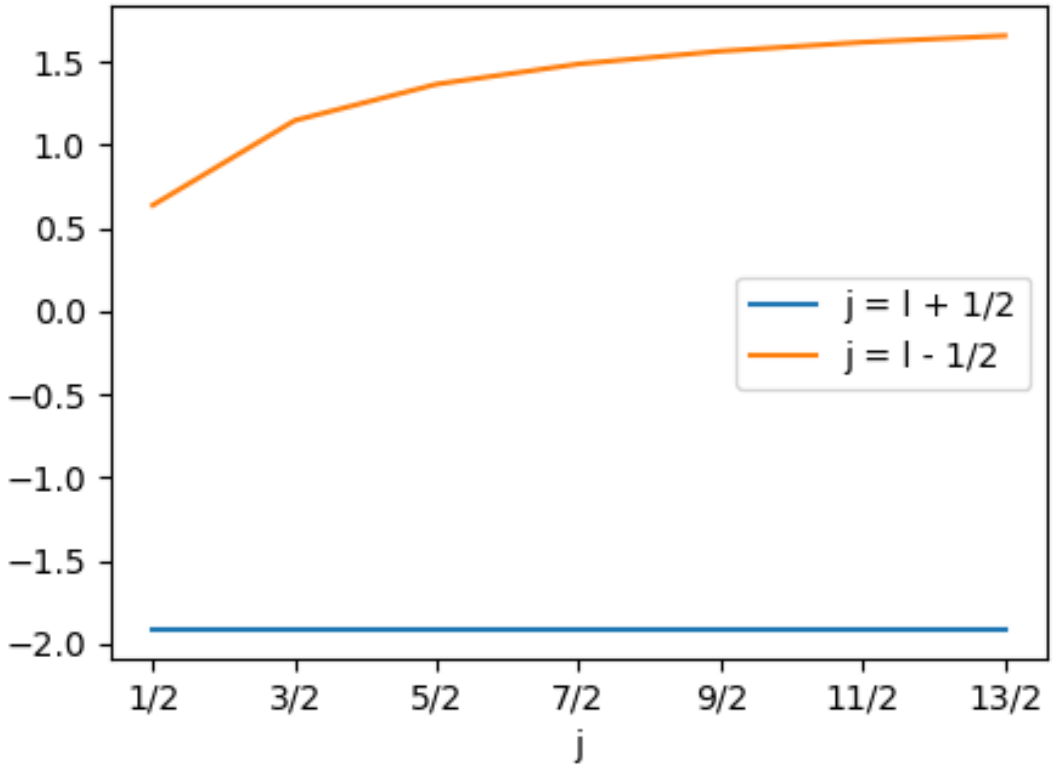
C. Wraith et al. / Physics Letters B 771 (2017) 385–391

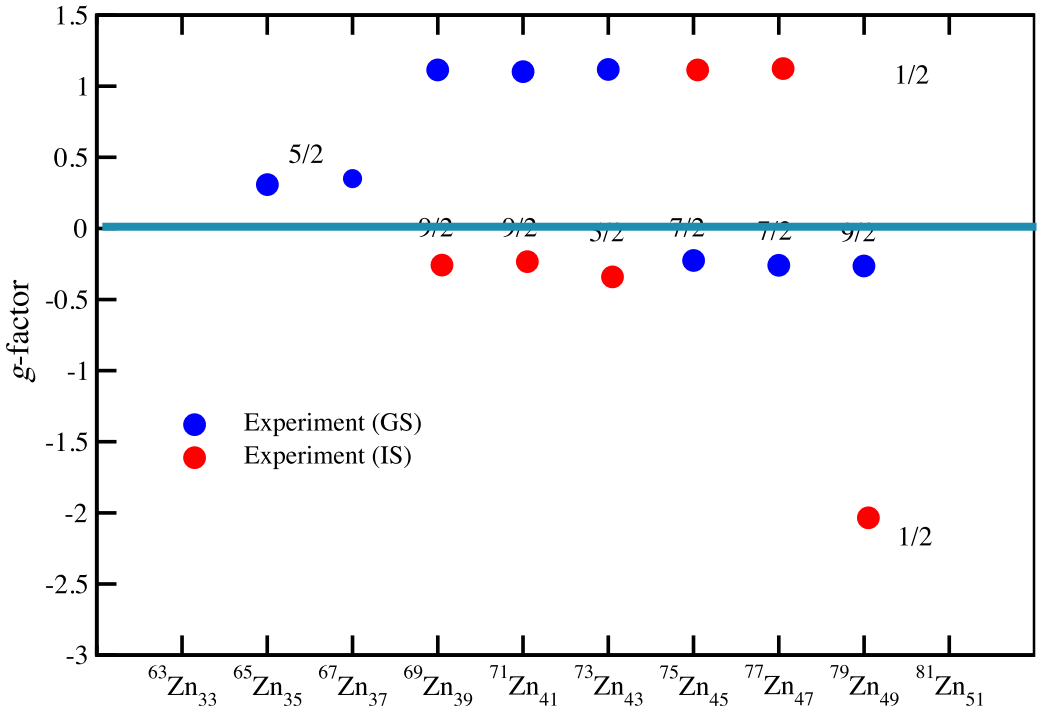
Case study – zinc isotopes
3. physics discussion

Observations?

- Some g-factors positive, some negative

  => relative alignment of l and s





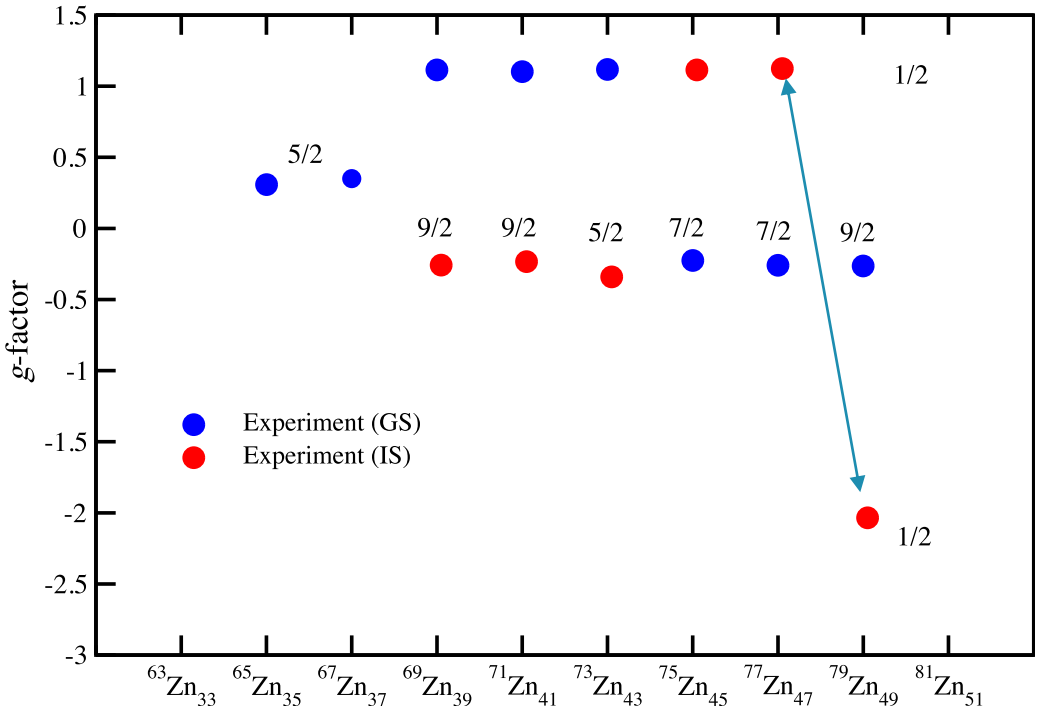
KU LEUVEN

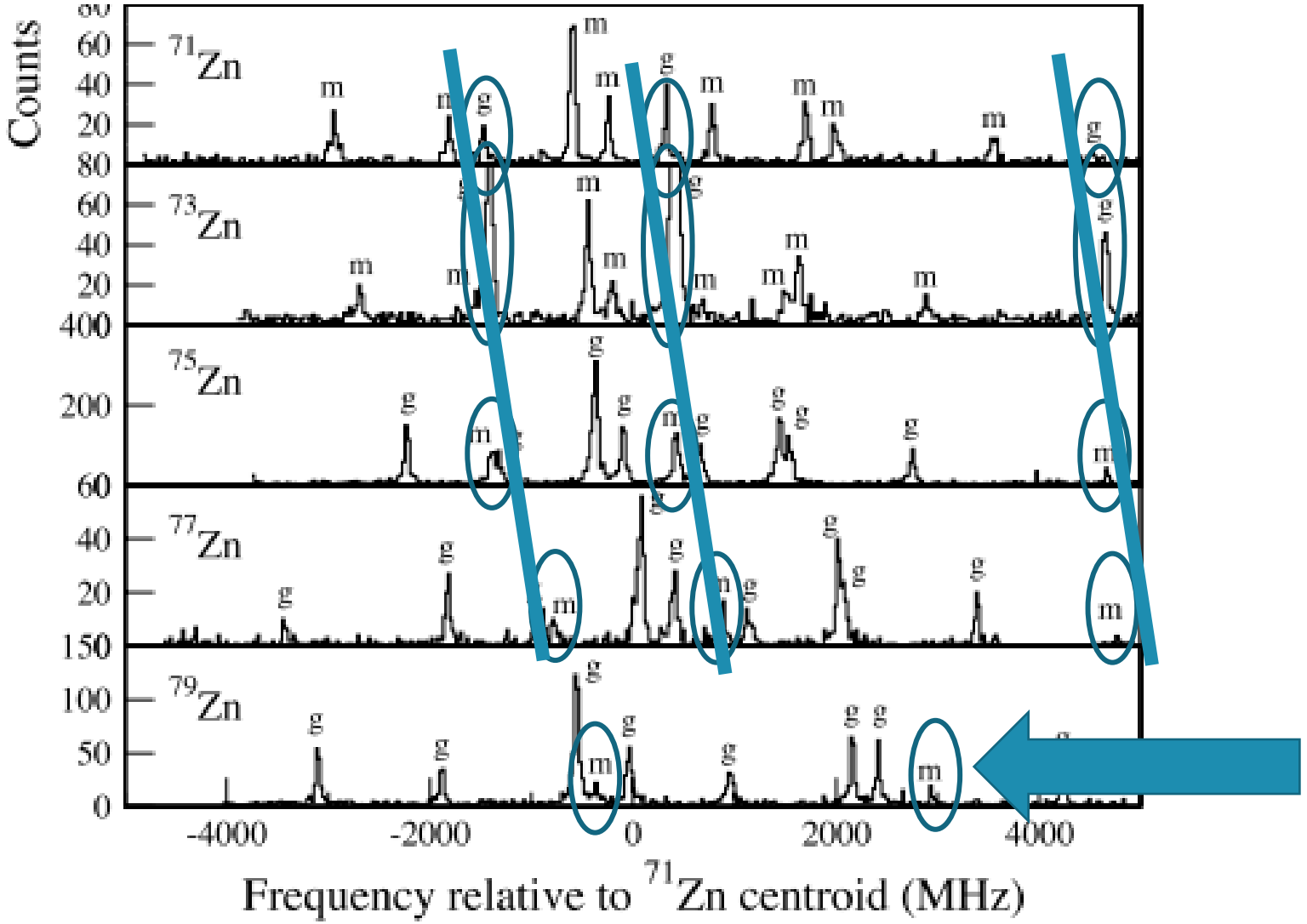
Case study – zinc isotopes
3. physics discussion

Observations?

- Some g-factors positive, some negative

  => relative alignment of l and s
- Two I=1/2 states have very different g-factor



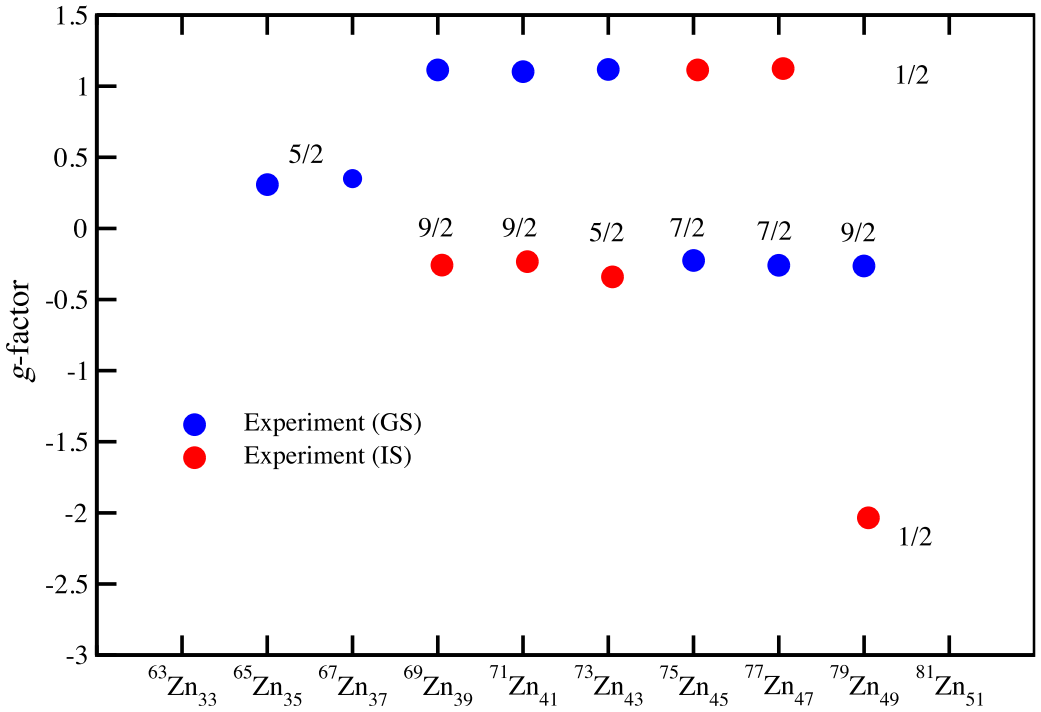

Counts
^{71}Zn
^{73}Zn
^{75}Zn
^{77}Zn
^{79}Zn
-4000
-2000
0
2000
4000
Frequency relative to ^{71}Zn centroid (MHz)

Case study – zinc isotopes
3. physics discussion

Observations?

- Some g-factors positive, some negative

  => relative alignment of l and s
- Two I=1/2 states have very different g-factor
- g-factors line up very nicely $^{69\text{-}79}$Zn



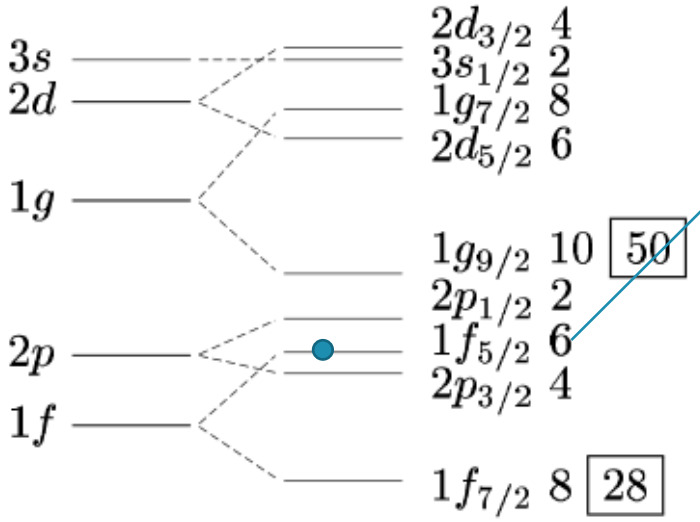
Case study – zinc isotopes
3. physics discussion

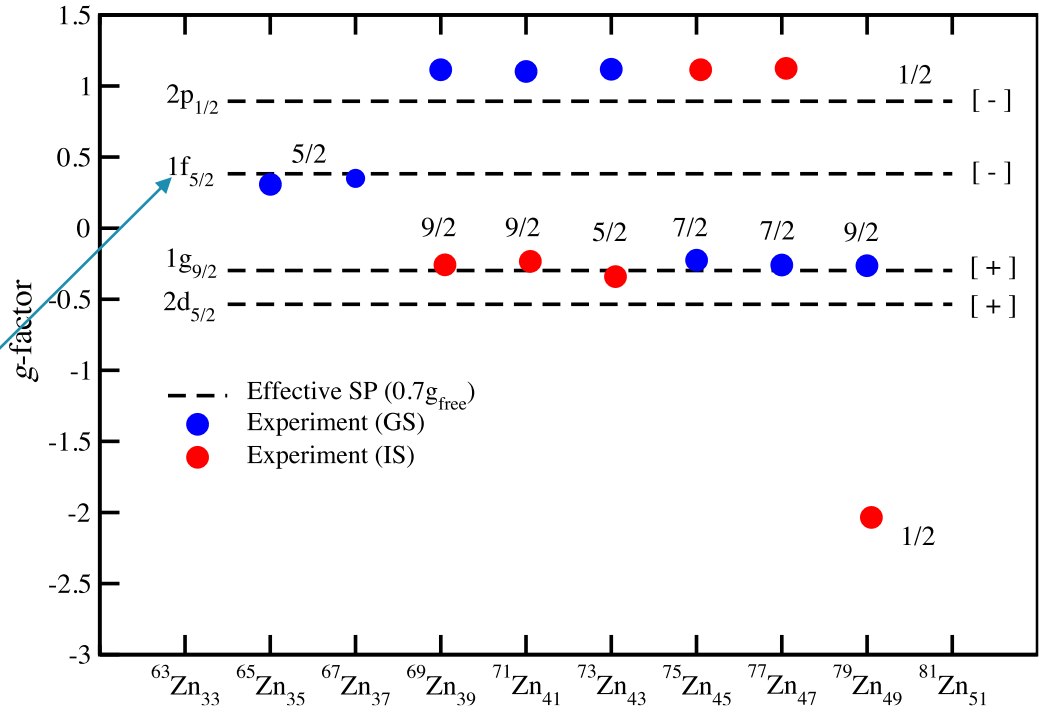
Observations?

- Some g-factors positive, some negative

  => relative alignment of l and s
- Two I=1/2 states have very different g-factor
- g-factors line up very nicely $^{69\text{-}79}$Zn

- We can now easily suggest some configurations





dashed line: single-particle magnetic moment with $g_s = 0.7 g_{s,free}$

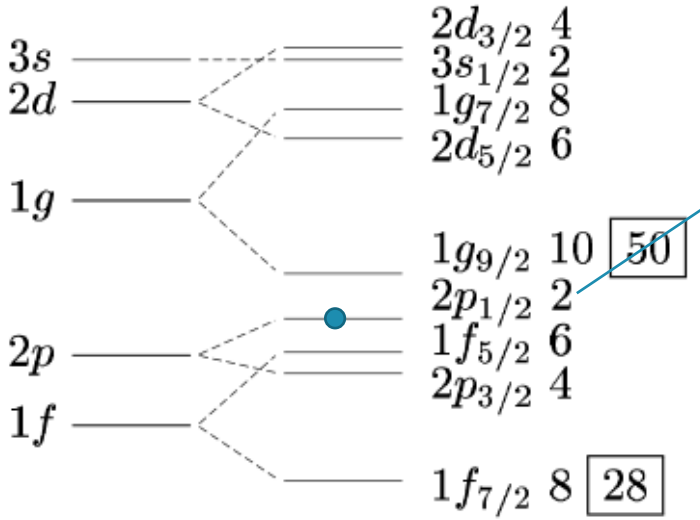
Case study – zinc isotopes
3. physics discussion

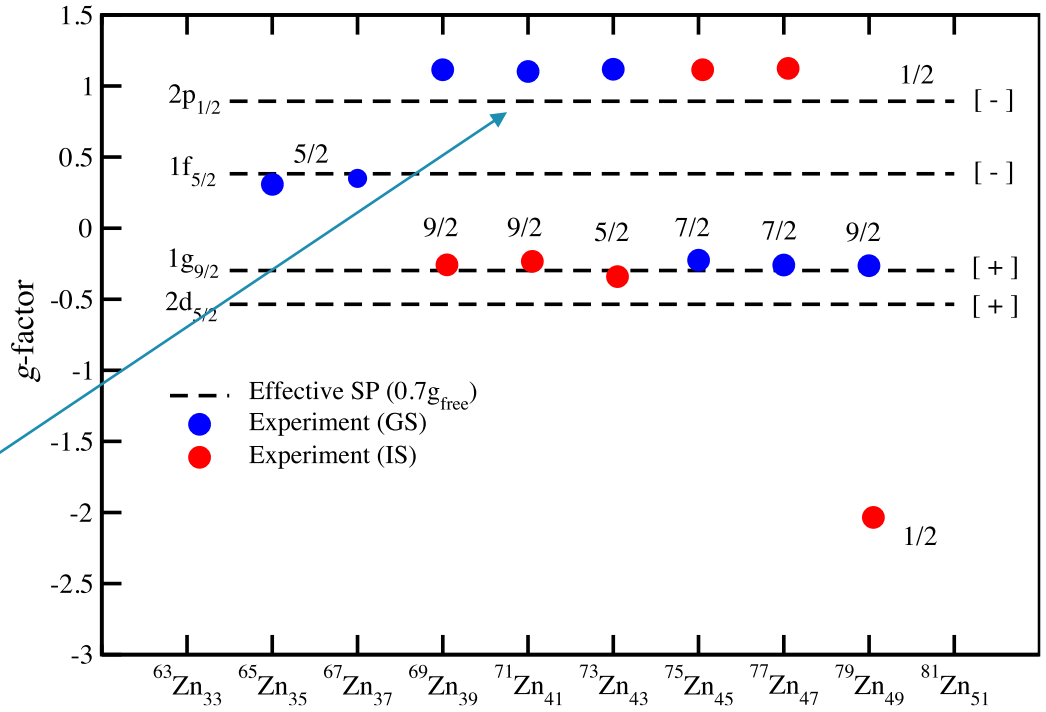
Observations?

- Some g-factors positive, some negative

  => relative alignment of l and s
- g-factors line up very nicely $^{69\text{-}79}$Zn
- Two I=1/2 states have very different g-factor

- What configurations would you suggest?





dashed line: single-particle magnetic moment with $g_s = 0.7 g_{s,free}$

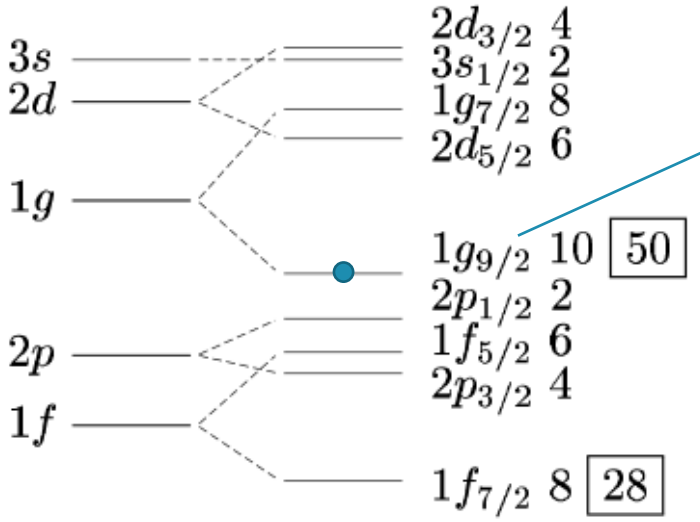
Case study – zinc isotopes
3. physics discussion

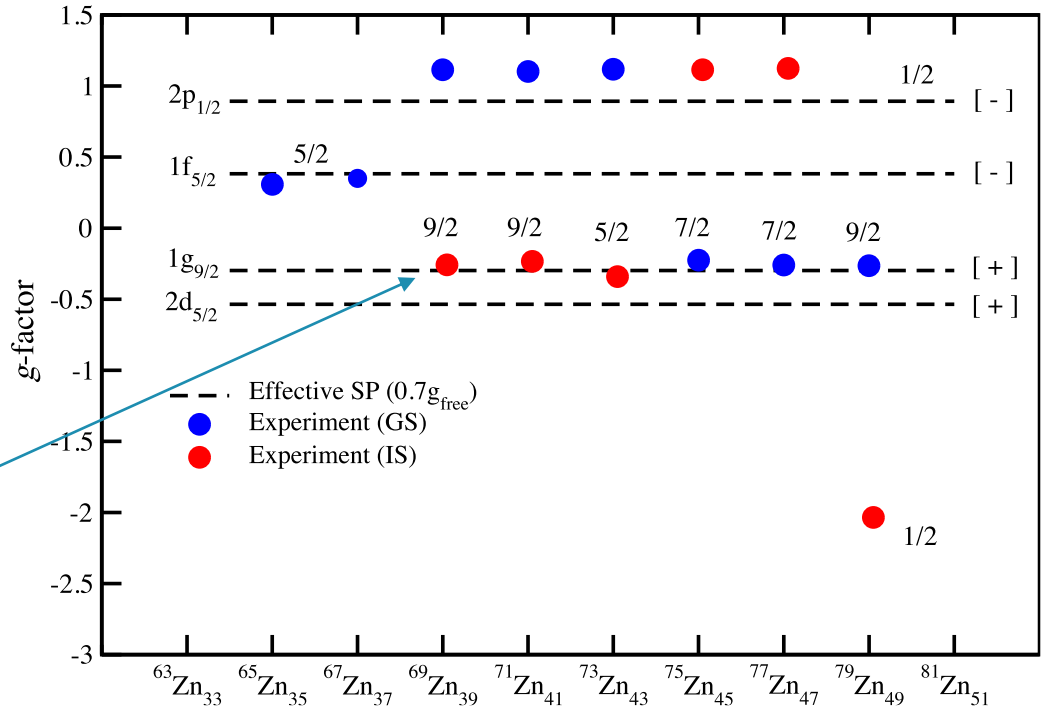
Observations?

- Some g-factors positive, some negative

  => relative alignment of l and s
- g-factors line up very nicely $^{69\text{-}79}$Zn
- Two I=1/2 states have very different g-factor

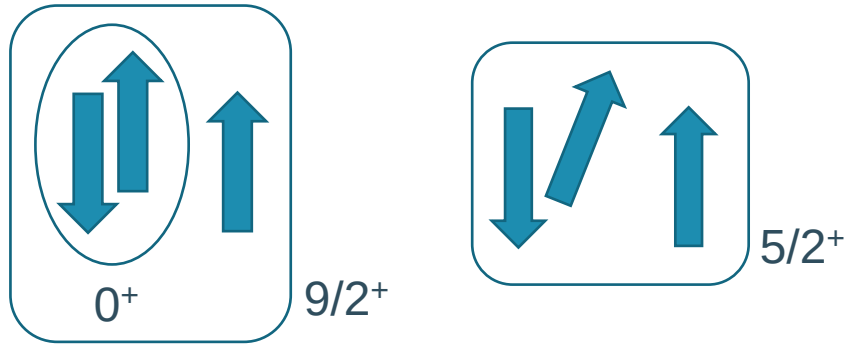
- What configurations would you suggest?





dashed line: single-particle magnetic moment with $g_s = 0.7 g_{s,free}$

Case study – zinc isotopes
3. physics discussion

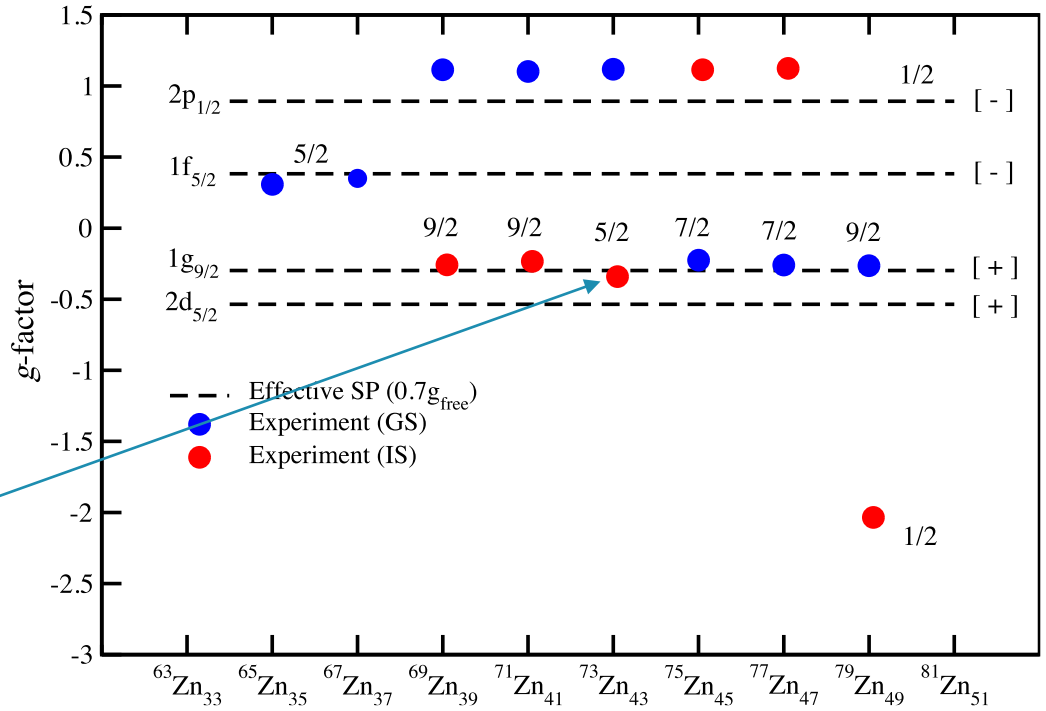


Observations?

- Some g-factors positive, some negative

  => relative alignment of l and s
- g-factors line up very nicely $^{69\text{-}79}$Zn
- Two I=1/2 states have very different g-factor

- What configurations would you suggest?
- Note that **g((j^n) I) = g(j)**
- Thus, suggestion is that e.g. ^{73m}Zn has a $(g_{9/2})^{-3}{}_{5/2}$ configuration



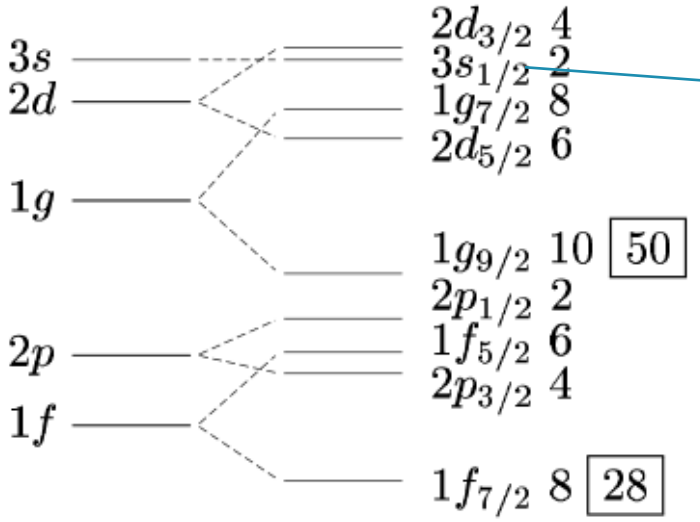
dashed line: single-particle magnetic moment with $g_s = 0.7g_{s,free}$

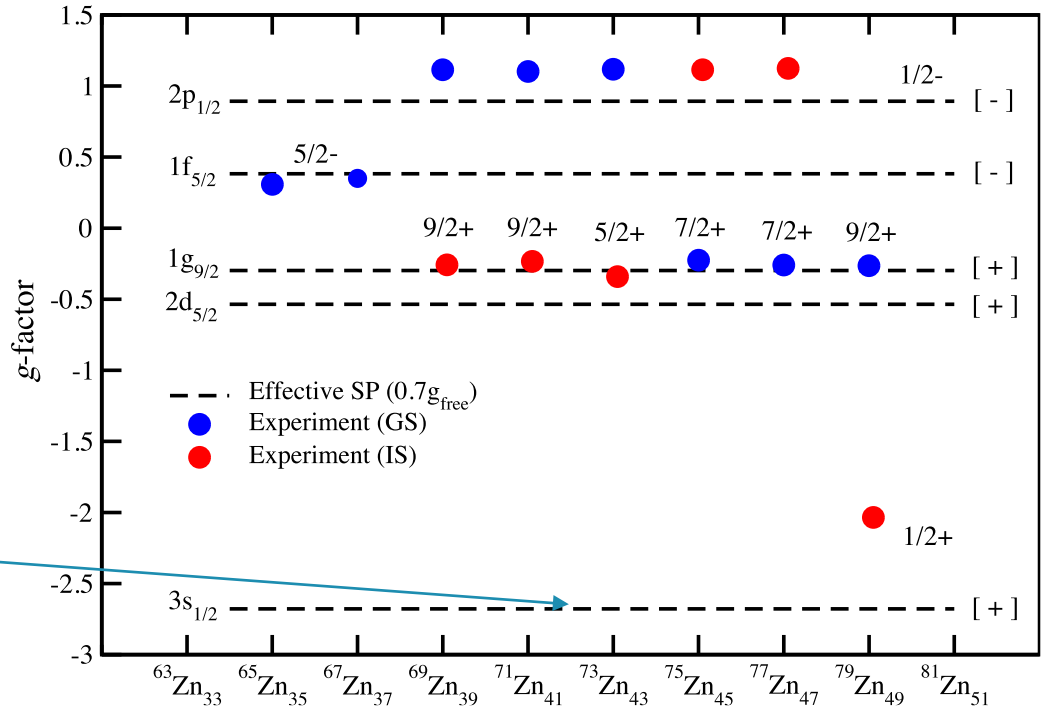
C. Wraith et al. / Physics Letters B 771 (2017) 385–391

Case study – zinc isotopes
3. physics discussion

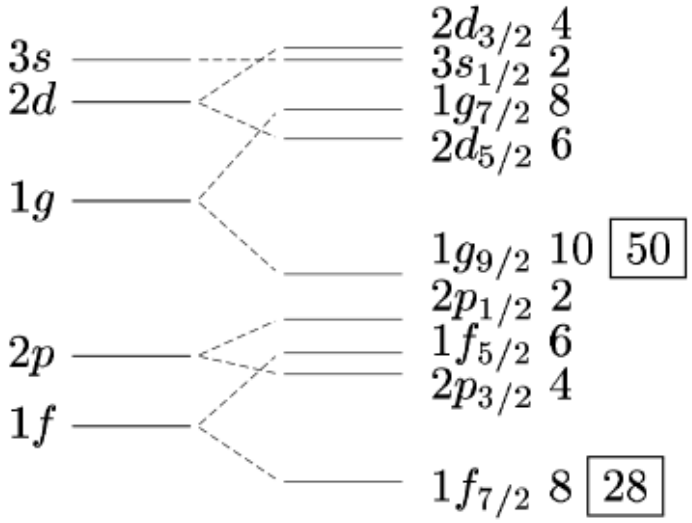
Observations?

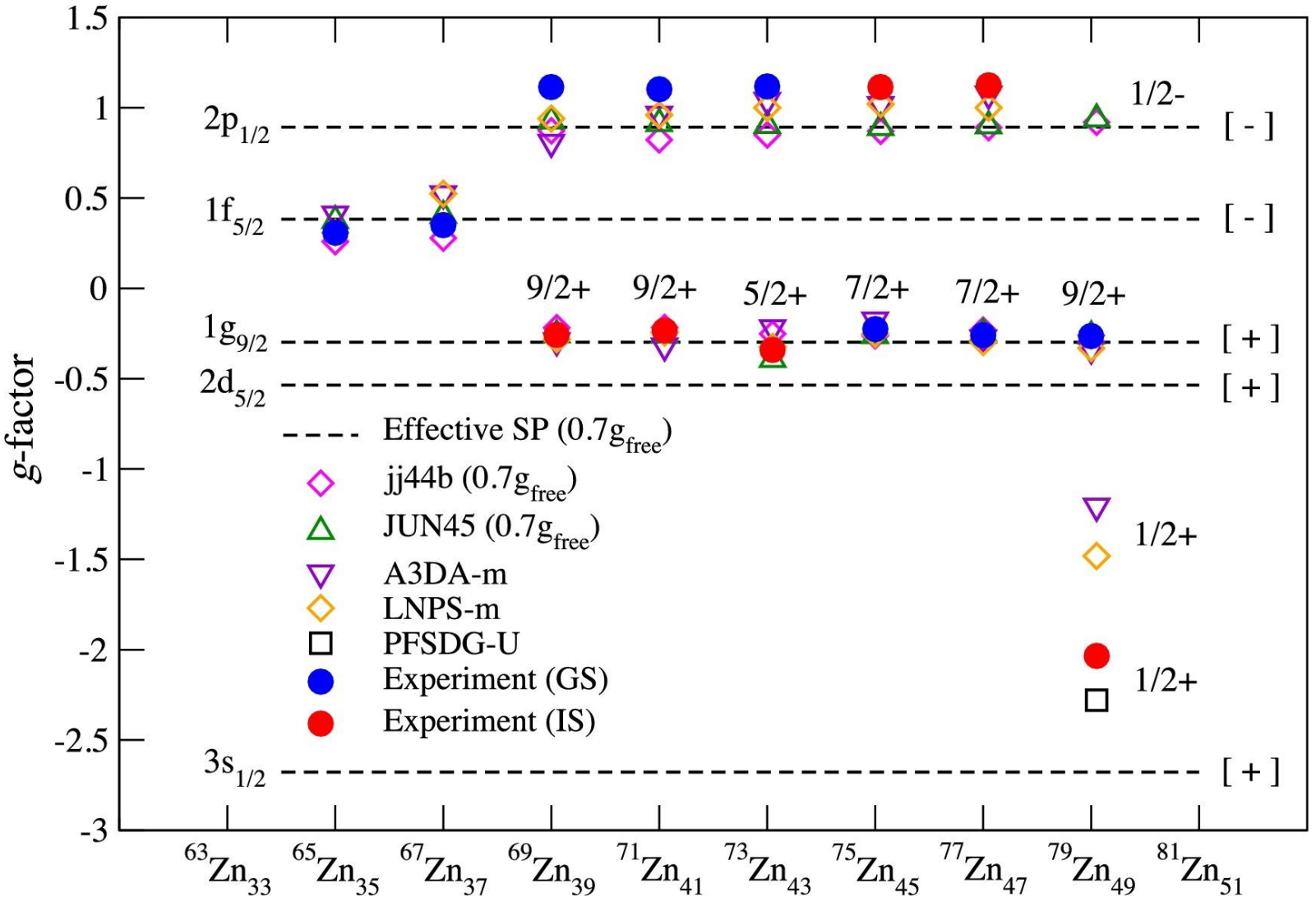
- Two I=1/2 states have very different g-factor
- g-factors line up very nicely $^{69\text{-}79}$Zn
- What configurations would you suggest?



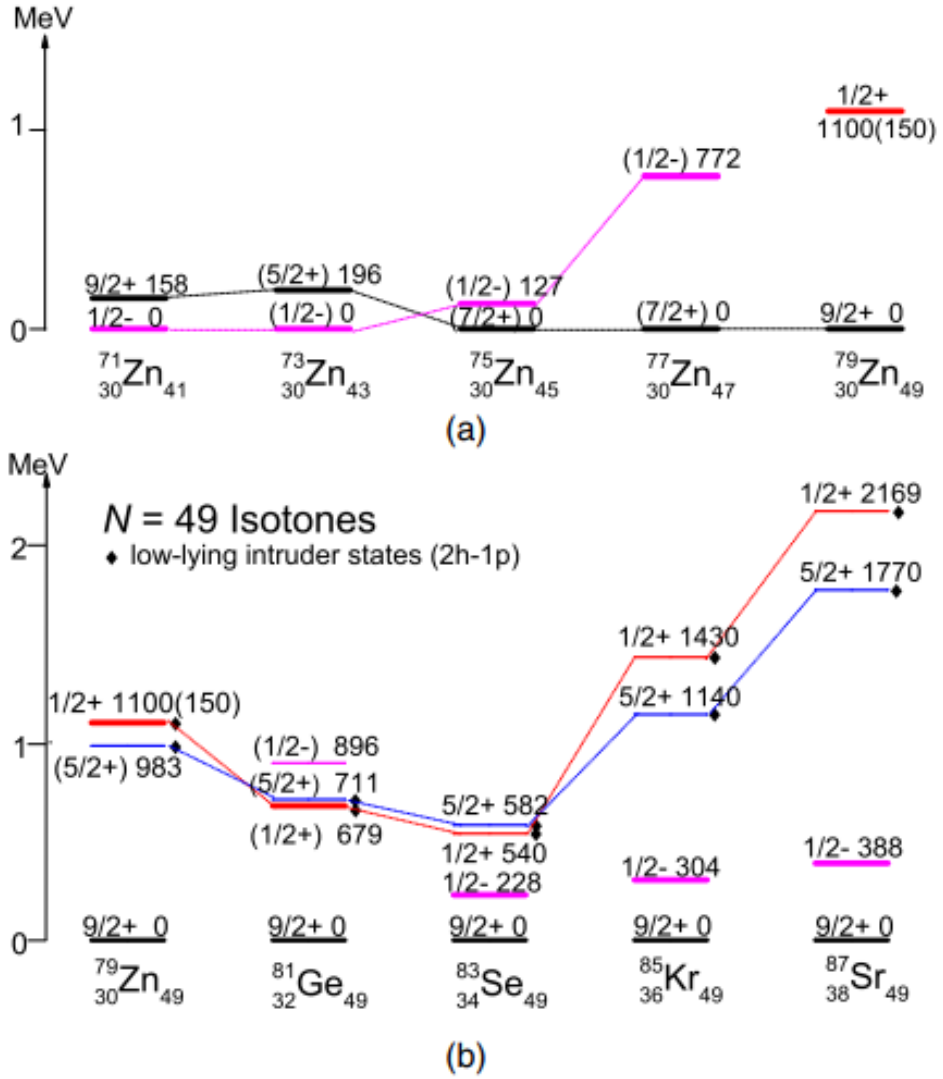


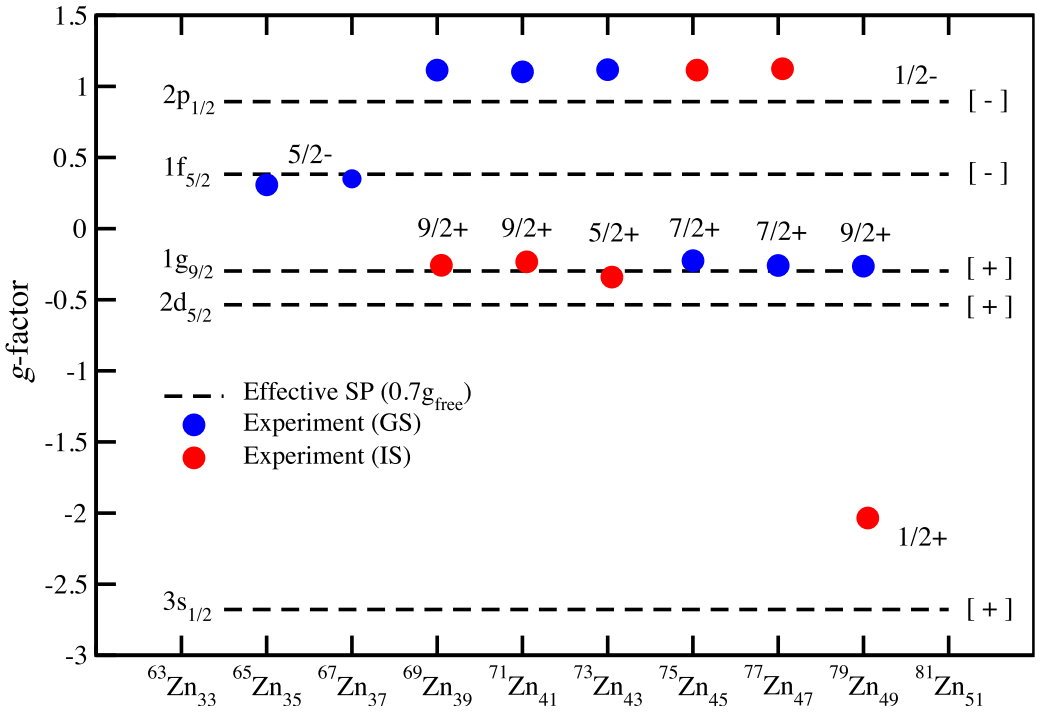
dashed line: single-particle magnetic moment with $g_s = 0.7g_{s,free}$

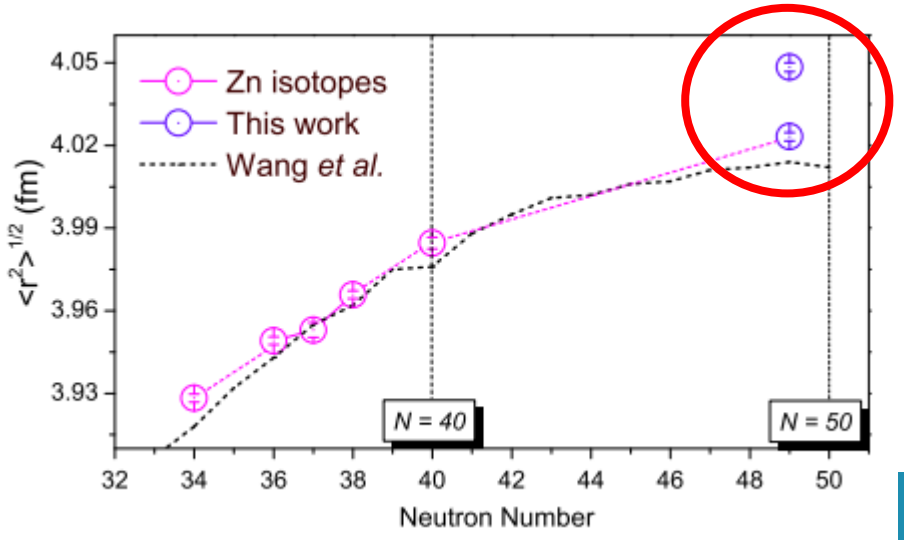

3s
2d
1g
2p
1f
2d3/2 4
3s1/2 2
1g7/2 8
2d5/2 6
1g9/2 10
50
2p1/2 2
1f5/2 6
2p3/2 4
1f7/2 8
28


g-factor
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
2p1/2
1f5/2
1g9/2
2d5/2
3s1/2
1/2-
[-]
[-]
[+]
[+]
[+]
9/2+
9/2+
5/2+
7/2+
7/2+
9/2+
Effective SP (0.7gfree)
jj44b (0.7gfree)
JUN45 (0.7gfree)
A3DA-m
LNPS-m
PFSDG-U
Experiment (GS)
Experiment (IS)
1/2+
1/2+
63Zn33
65Zn35
67Zn37
69Zn39
71Zn41
73Zn43
75Zn45
77Zn47
79Zn49
81Zn51

Case study – zinc isotopes
3. physics discussion



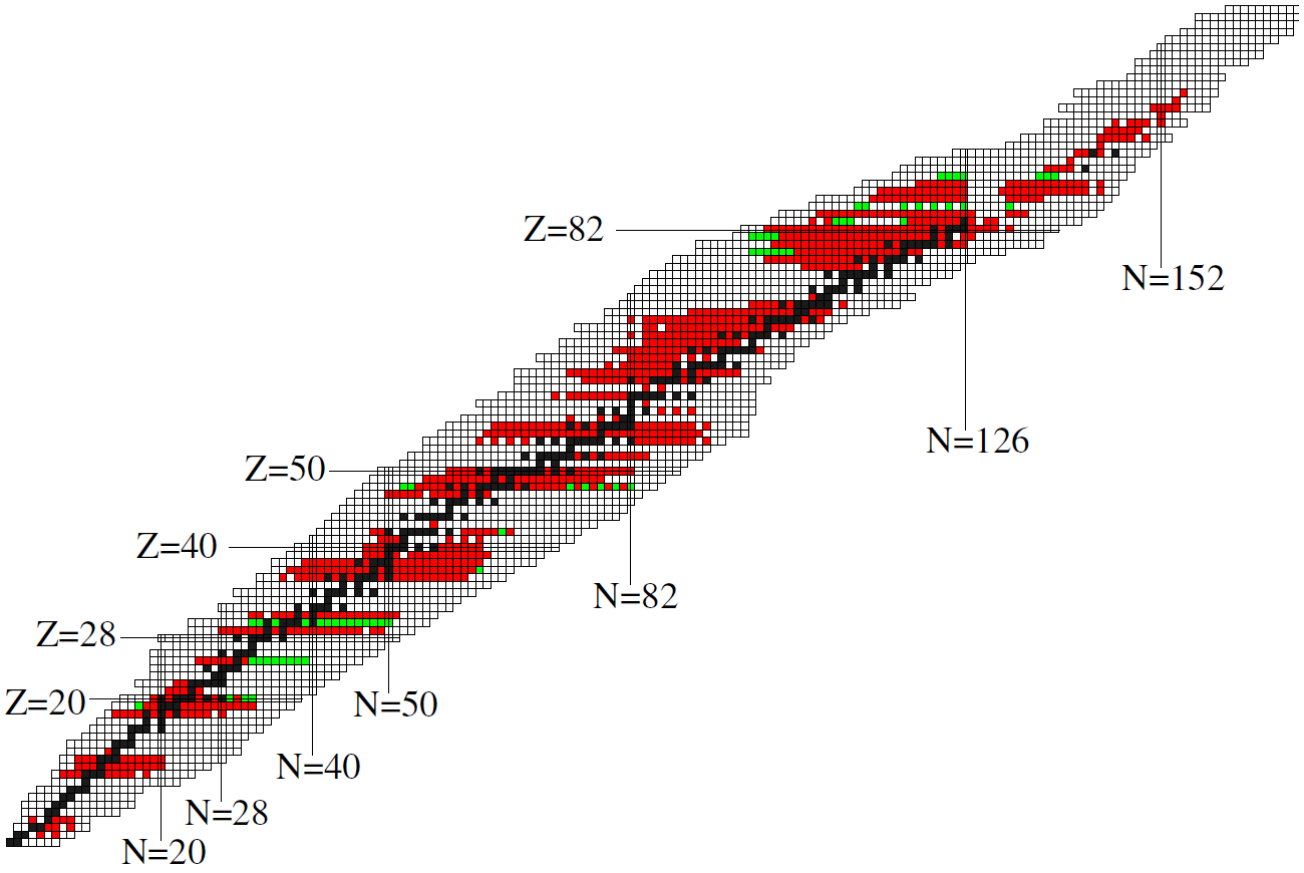




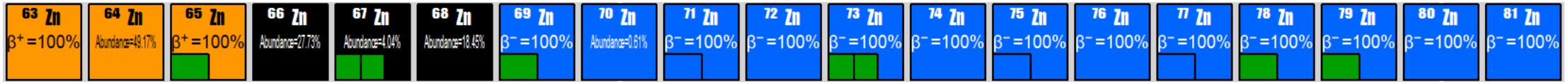
KU LEUVEN

What did we learn here?

- Magnetic moments are very sensitive to the configuration of unpaired nucleons
  - They can be used to identify ordering of single particle levels
  - More in-depth comparisons with nuclear theory can be used to learn more about rigidity of shell closures, role of collective excitations, …
- BUT! be careful when dealing with strongly deformed systems. In this case the assumptions made to derive the simple Schmidt limit are absolutely not valid.
- Laser spectroscopy is one of the few techniques that can be used to measure magnetic moments close to stability as well as for very exotic isotopes.

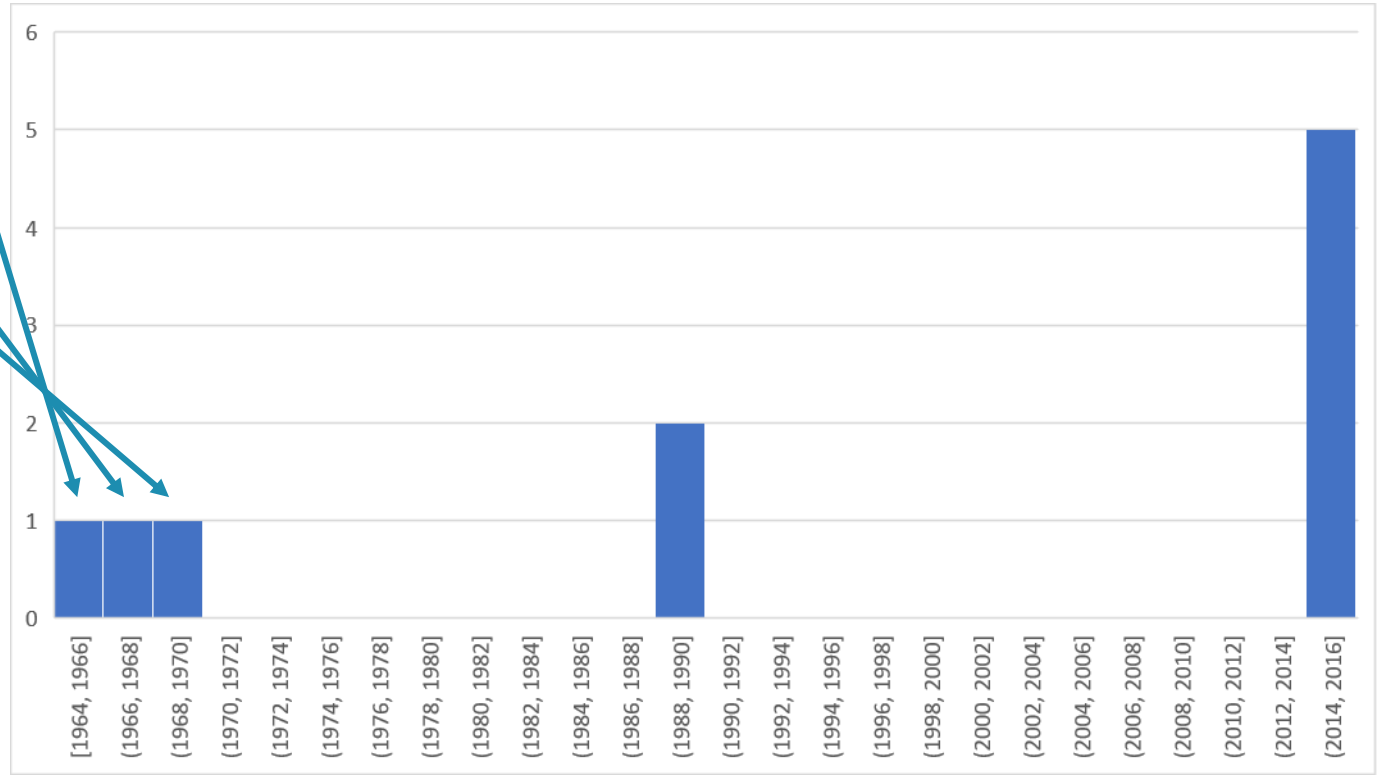


Example for zinc



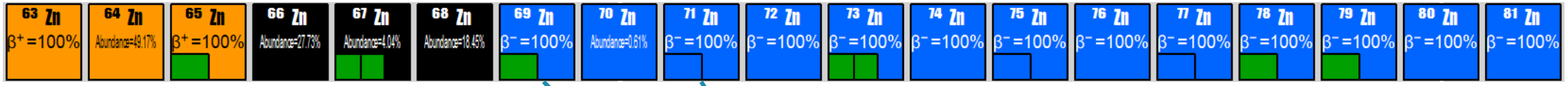
‘Offline’ measurements

- Stable isotopes, long-lived
- ^{63}Zn: 38 min half life, 8 Curie source was made…..!



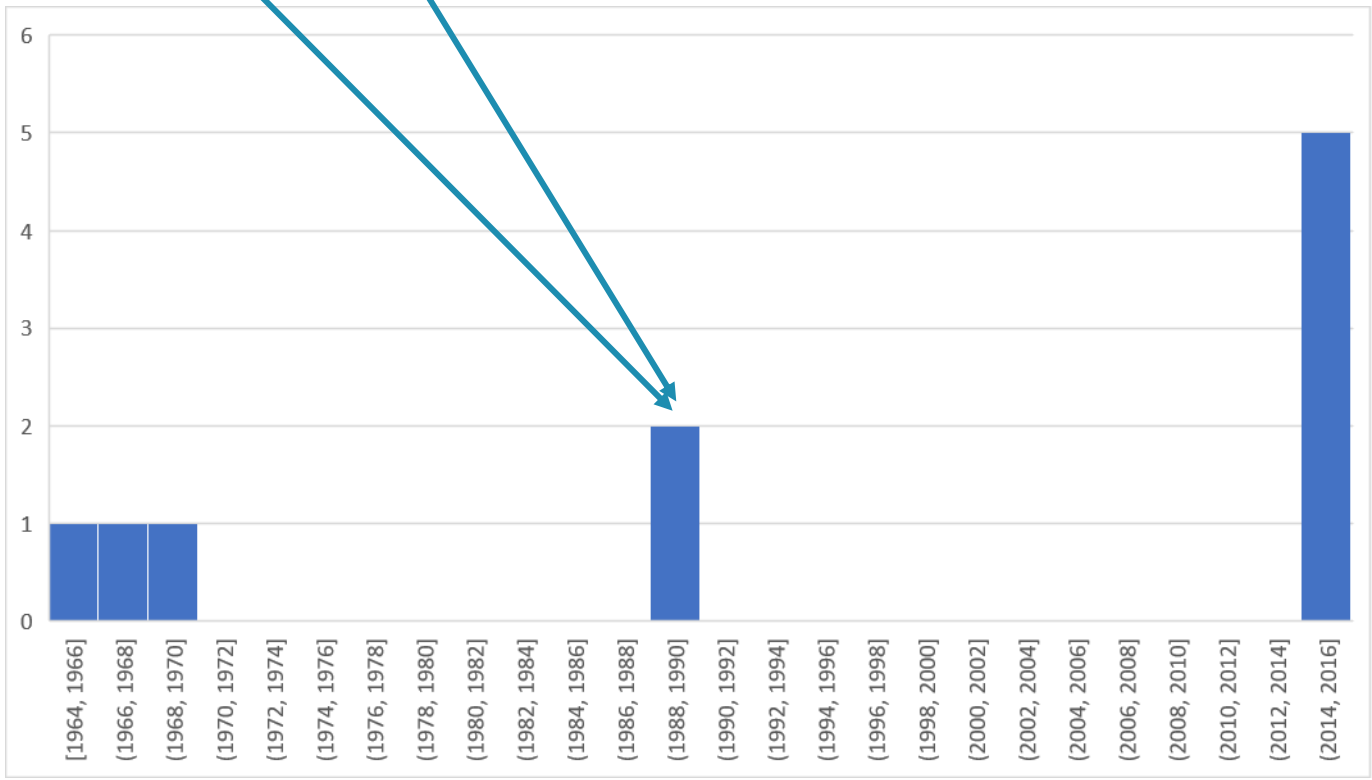
KU LEUVEN

Example for zinc



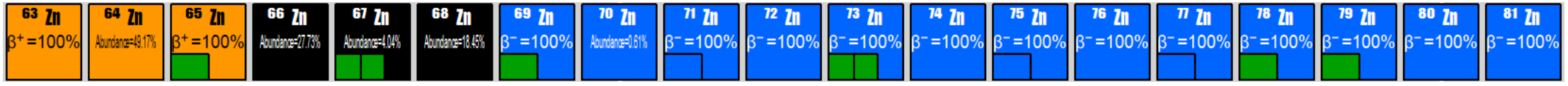
‘Online’ measurements

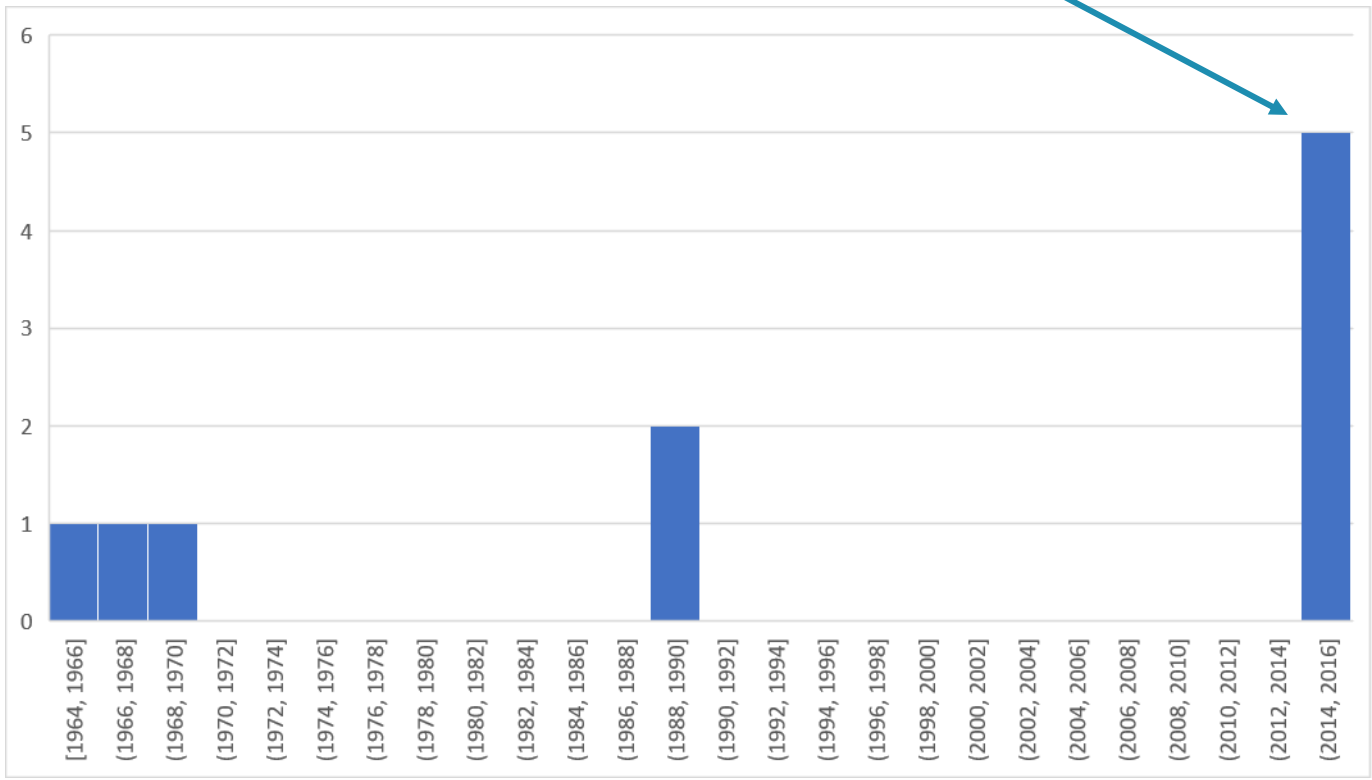
- Shorter half-lives become possible
- Non-laser technique



KU LEUVEN

Example for zinc





‘Online’ measurements
- Shorter half-lives become possible
- Laser spectroscopy technique

=> suddenly a lot of isotopes can be studied in a few days!
Lifetimes << 1s

KU LEUVEN

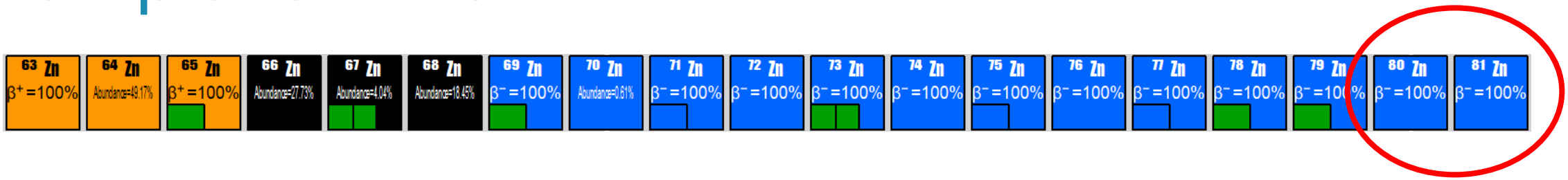
In summary…

- Magnetic moments are very sensitive to the configuration of unpaired nucleons
  - They can be used to identify ordering of single particle levels
  - More in-depth comparisons with nuclear theory can be used to learn more about rigidity of shell closures, role of collective excitations, …
- Laser spectroscopy techniques provide a convenient way to measure magnetic moments, as well as the other observables discussed by Iain

- We studied the Zn isotopic chain as an example, but the lessons generalize to isotopic chains throughout the chart

- In particular: we leverage the richness of atomic structure to optimize our experiments so we can study the most exotic and short-lived isotopes
- It is at this interface of atomic physics, nuclear physics and ever-evolving technology that we perform our work!

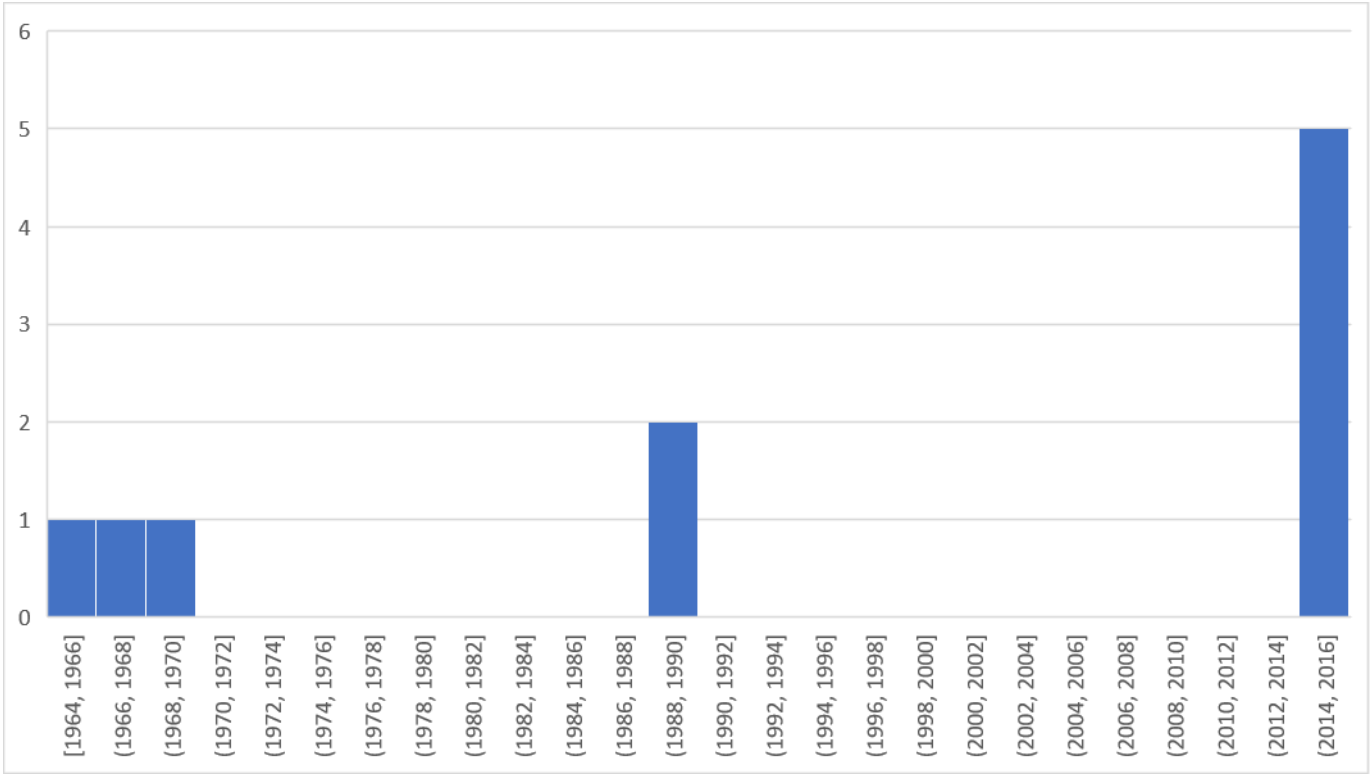
Example for zinc



Accepted proposal!

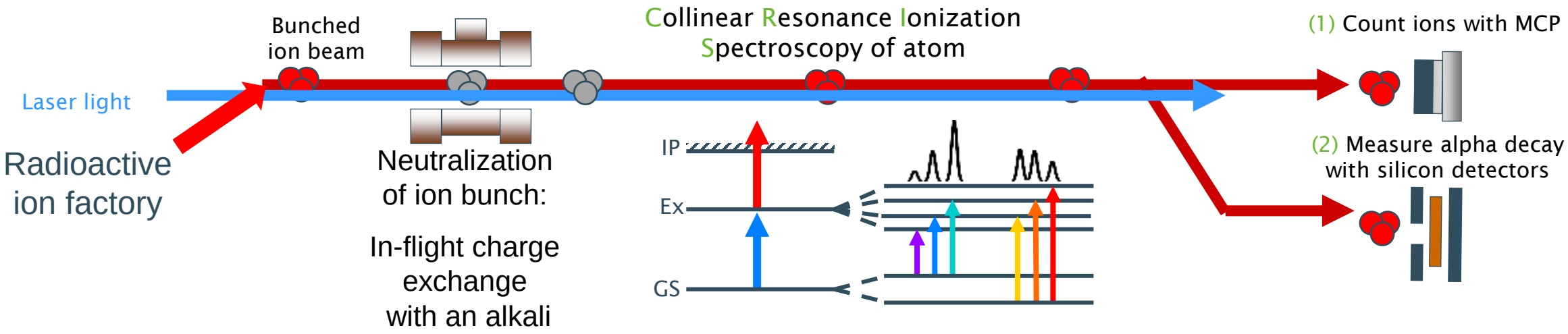
‘Online’ measurements
- Shorter half-lives become possible
- Laser spectroscopy technique

=> suddenly a lot of isotopes can be studied in a few days!
Lifetimes << 1s



KU LEUVEN

Collinear resonance ionization spectroscopy



- Use of laser ionization enables measurements with lower backgrounds and higher efficiency

- Since the atoms get ionized, we can send them to a decay station for further spectroscopy
  - !!! We can produce isomerically pure beams!
  - Thus, we can gather complimentary decay data to really help understand e.g. ^{79m}Zn and the isotopes N=50, 51