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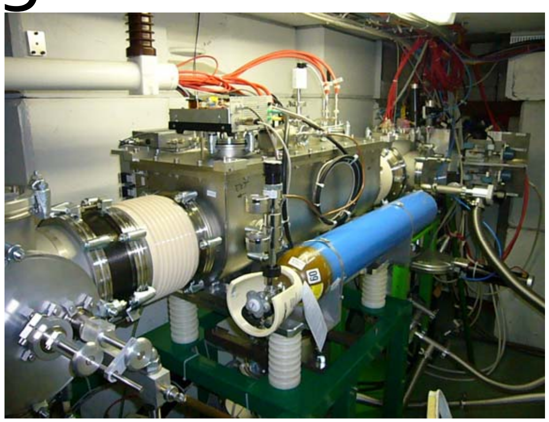
Collinear resonant ionization laser spectroscopy of rare francium isotopes

The first dedicated ISCOOL experiment

- This proposal aims at pushing the limits of laser spectroscopy sensitivity.
- To measure for the first time cases with yields of only 1 atom per second.
- ISCOOL is essential to realize this project, by providing bunched ions beams.



Outline of proposal

- New innovation in laser spectroscopy.
- Ultra-high sensitivity and efficiency combined with high resolution.
- New semi permanent beam-line.
- New pulsed laser laboratory.
- New versatile method of producing clean beams for decay spectroscopy.
- Capability to study single atom yields even with large isobaric contamination

Physics Motivation:Francium

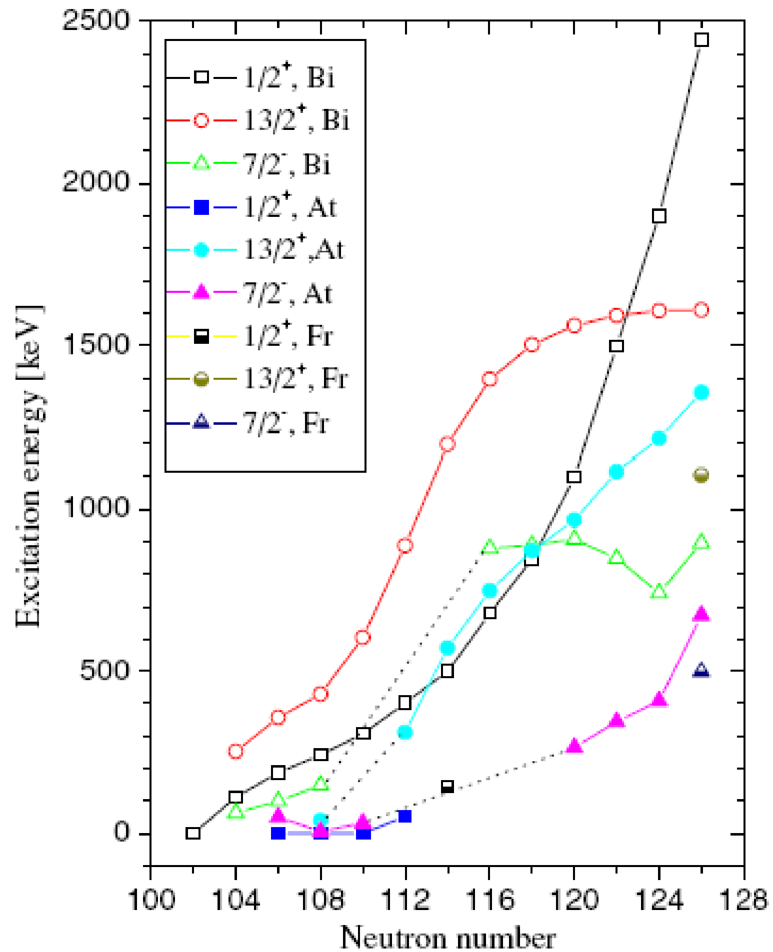
- Initial case which forms part of larger study of this region of the nuclear chart.
- Deformed (oblate) intruder $\pi(s_{1/2})$ state believed to be ground state of ^{199}Fr, and isomeric state in ^{201,203}Fr.
- ^{218,219}Fr border of region of reflection asymmetry, yielding important information on the transition from spherical to octupole-quadrupole deformed nuclear structure.

Intruder levels and large deformation in neutron deficient francium

Systematic reduction in energy of the
Deformed *π(1/2+)* in isotopes in
This region of the chart

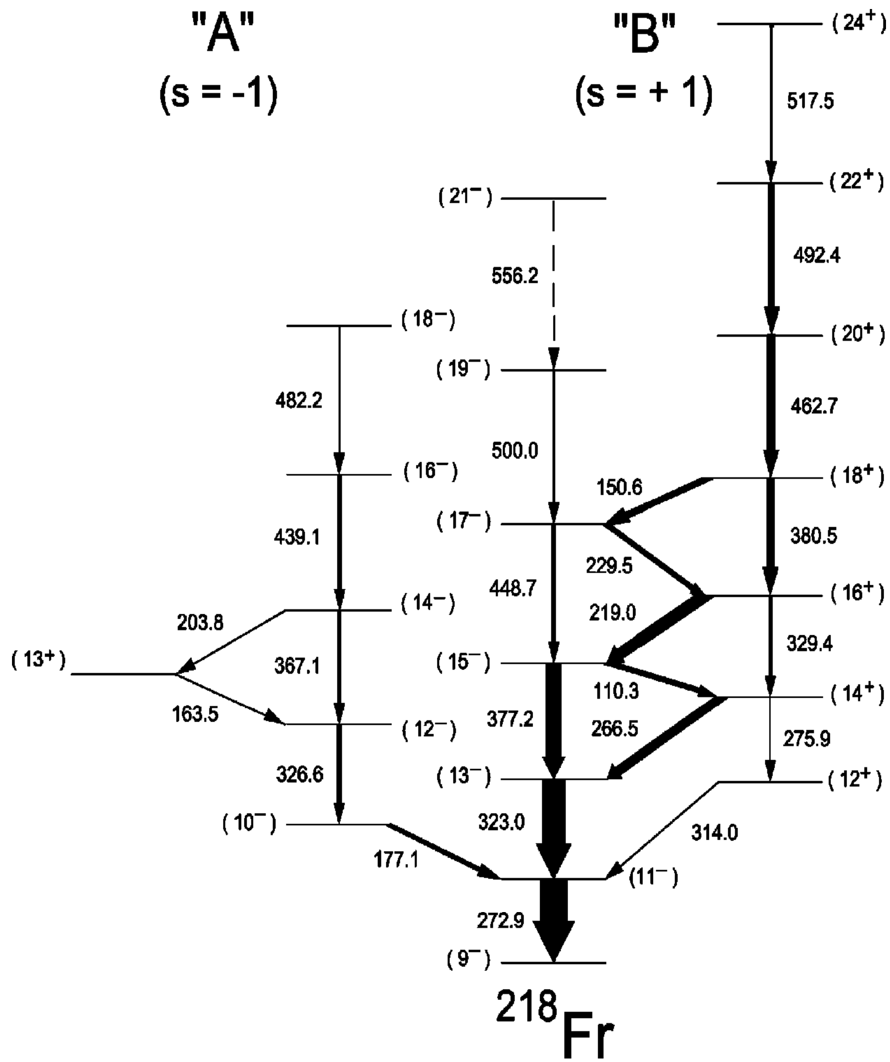
π(1/2+) proton intruder state becomes the ground state in 195At and 185Bi

The isomer shifts of ^{201,203}Fr
And their magnetic moments will provide important information to better understand the evolution of nuclear structure in this region.

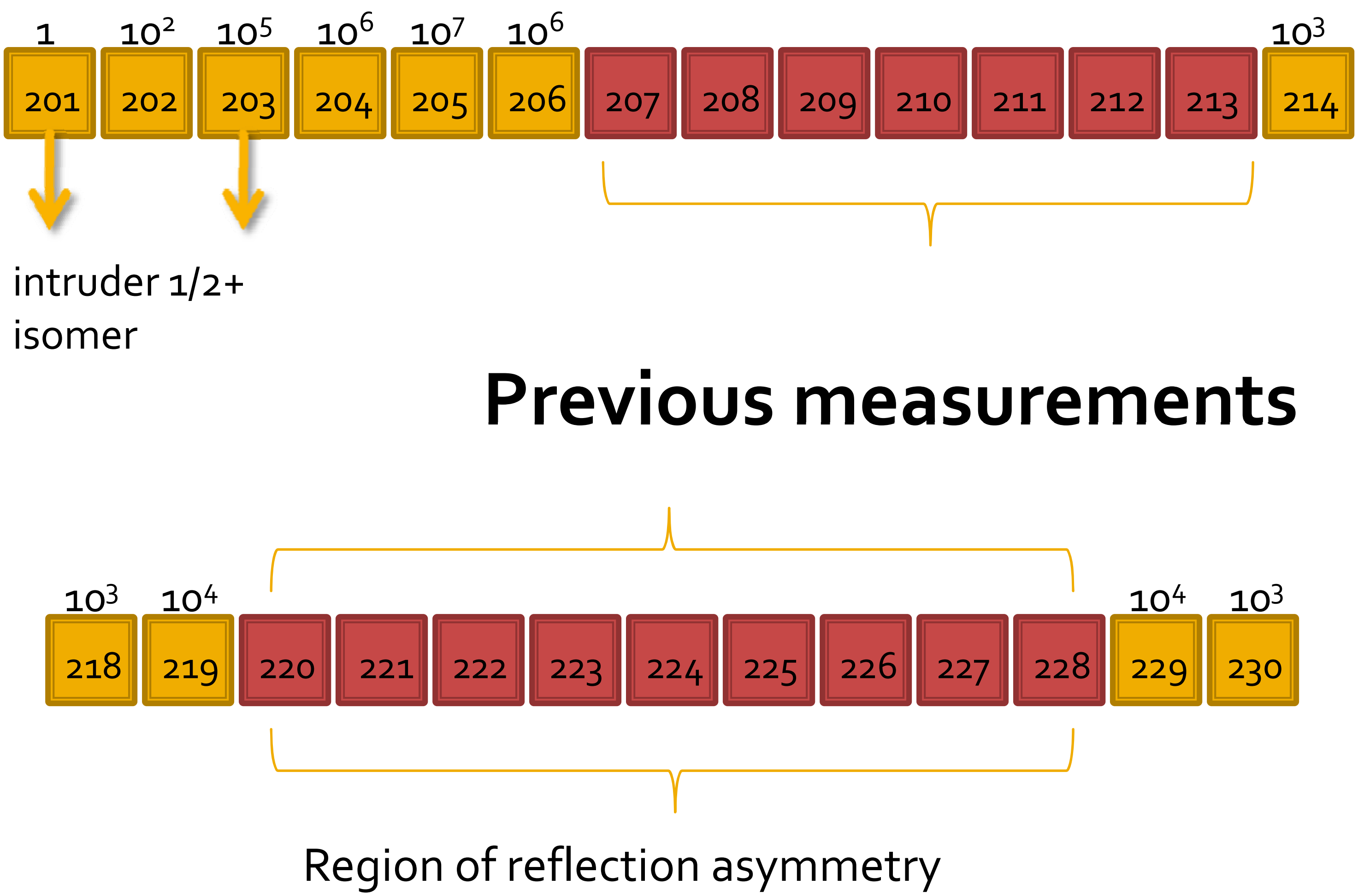


Boarder of the region of reflection asymmetry

- Region characterised by reversal in odd-even staggering, which is attributed to presence of octupole-quadrupole deformation.
- Also characterised in the interleaving alternating band structure connected by enhance E1 transitions



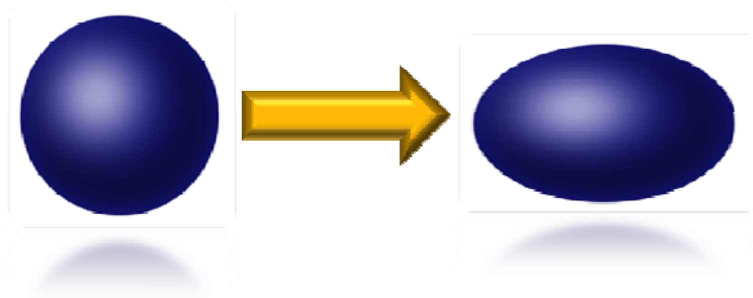
Previous and proposed isotopes



Beyond francium

- Surrounding isotones Ra and Rn to complete the description of the $\pi(1/2)^+$ level and border of region of reflection asymmetry.
- Bi isotope chain out to ^{218}Bi (yield of 10^3) and possibly even further from N=126.
- Quadrupole moments and spin assignment in neutron deficient Po, Bi and Pb isotopes. Providing a full description of the shape evolution in this region.

Shape transitions beyond N=126

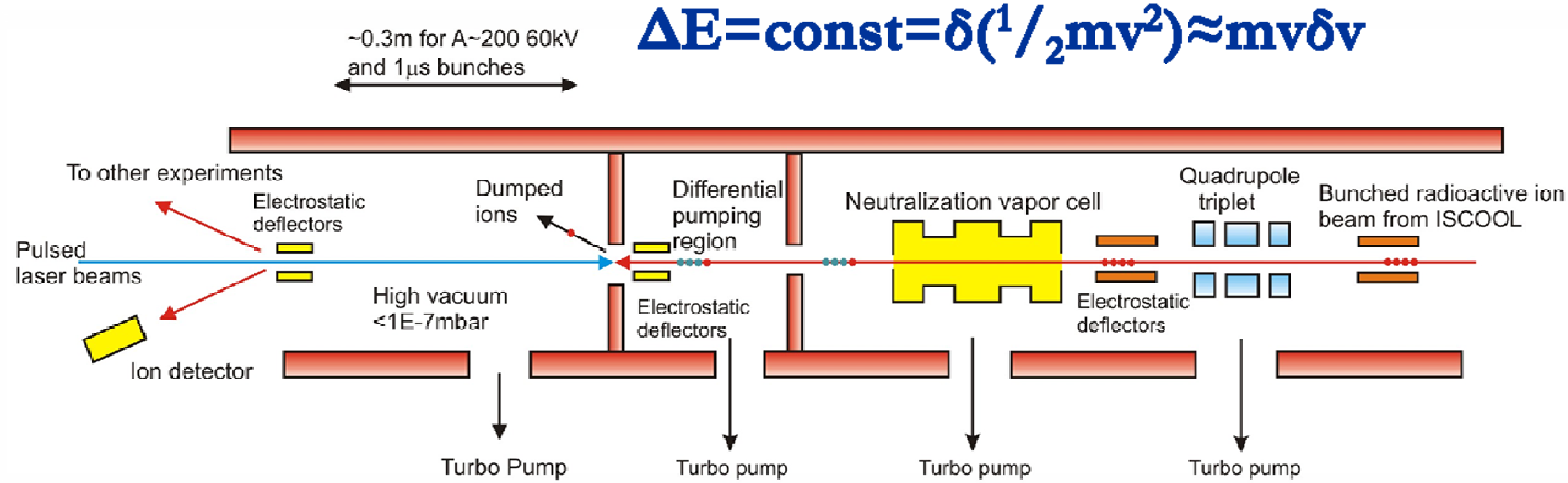


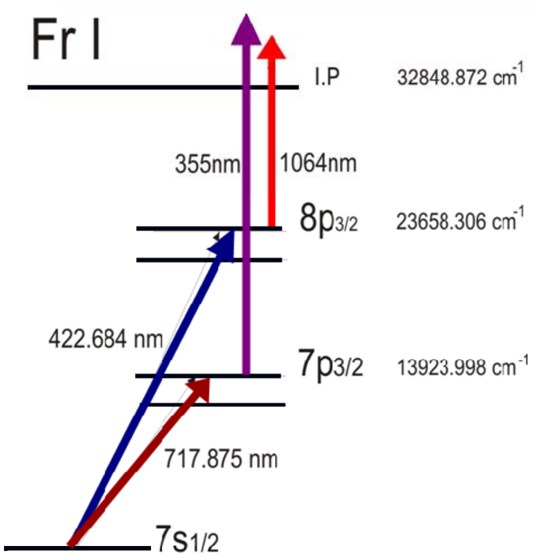
Nuclear Information from laser spectroscopy

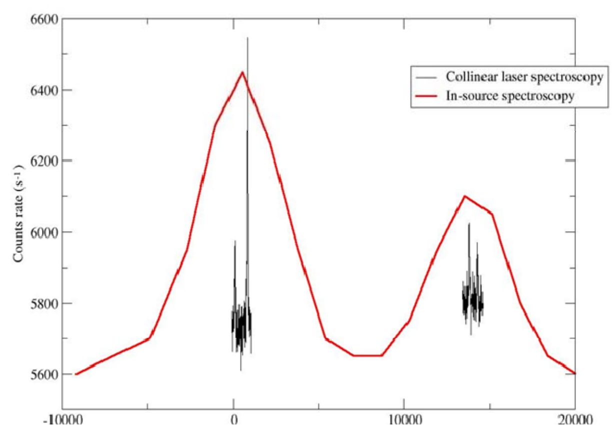
- Coupling of nuclear and atomic total angular momentum vectors giving rise to a hyperfine splitting of the atomic transitions.
- It is possible to extract nuclear observables from these measurements without introducing nuclear model dependence.
- Unambiguous assignment of the nuclear spin, nuclear moments and changes in charge radius across an isotope chain.
- High resolution laser spectroscopy techniques are required to resolve the full structure.

CRIS beam line and method

$$\Delta E = const = \delta(^1/_2 m v^2) \approx m v \delta v$$







Relative Frequency (MHz)

Combining high resolution nature of collinear beams method with high sensitivity of in-source spectroscopy. Allowing extraction of B factors and quadrupole moments.

Collinear resonant ionization laser spectroscopy (CRIS)

- RIS performed on a fast atomic bunched beam.
- Pulsed Amplified CW laser has a resolution which is Fourier limited to π/t (dye).
- Background events are due to non-resonant collisonal ionization, which is directly related to the vacuum
- Very high total experimental efficiency
  - Neutralization 50-90%
  - Ionization efficiency 50-100% (no HFS)
  - Detection efficiency almost 100%
  - Transport through ISCOOL 70-80%
  - Transport to experiment 80-90%

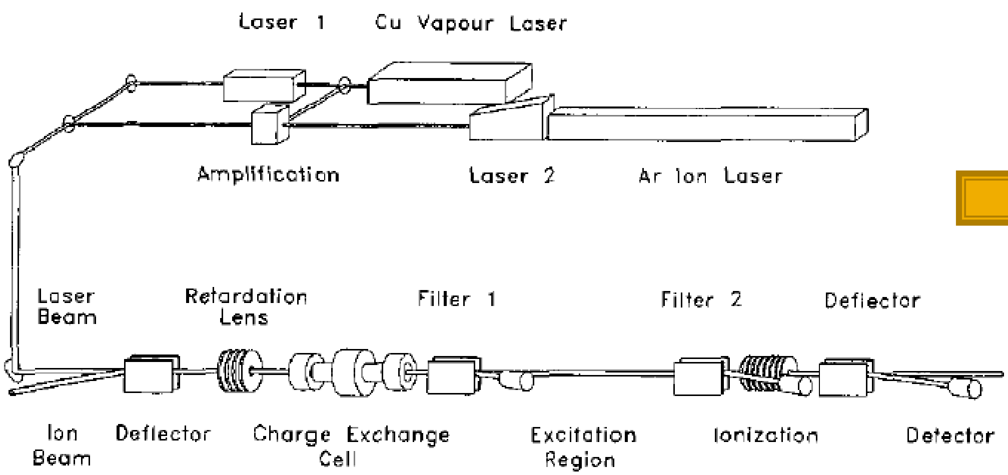
1:30 From Jyvaskyla off-line tests
(K. Flanagan, PhD)

→ Up to 50% efficiency possible

Previous CRIS of Yb at ISOLDE

Ch. Schulz *et al.*, J. Phys. B, **24** (1991) 4831

- Charge exchange efficiency into meta stable states
- Below saturation on second step
- CW beam and duty cycle losses due to lasers



Total efficiency
1:100 000

Previous work limited to yields greater than 10^7 ions/μC

Limiting factors: Efficiency and isobaric contamination

- From the ISCOOL tests in November a limit of 10^8pps were trapped and measured on an MCP.
- Conservative efficiency of 1:30 (number from Jyvaskyla work) and a pressure of 10^{-9} mbar and a high isobaric contamination of 10^7 (expect much lower).

Background suppression:
Pressure 10^{-9} mbar = 1:200 000
Detection of secondary electrons by MCP

→ Limited to > 100pps

Alpha decay detection allows removal of all isobaric contamination (50-100cts/s)

→ Limited >5pps

With 50% efficiency and signal limited noise regime = 0.3pps

This underlines the importance of improving beam purity for future HIE-ISOLDE and ISCOOL work

Logistical planning 2008-2009

- Finalize technical design and commence construction of beam line components March/April 2008
- Purchasing and shipping of equipment to CERN Summer 2008
- Installation of equipment winter shutdown 2008
- Initial off-line optimization March/April 2009

Break down of beam time request

Year	Run	Isotopes	Number of shifts	Preparation requirements
2009	1	206-203	11	1 shift for Tl/Fr optimization
2010	2	218,219	9	
2010	3	202,201	12	

Total of 33 shifts requested over 2 year period.
Run 1. will work with ground state yields between 10^7-10^5pps

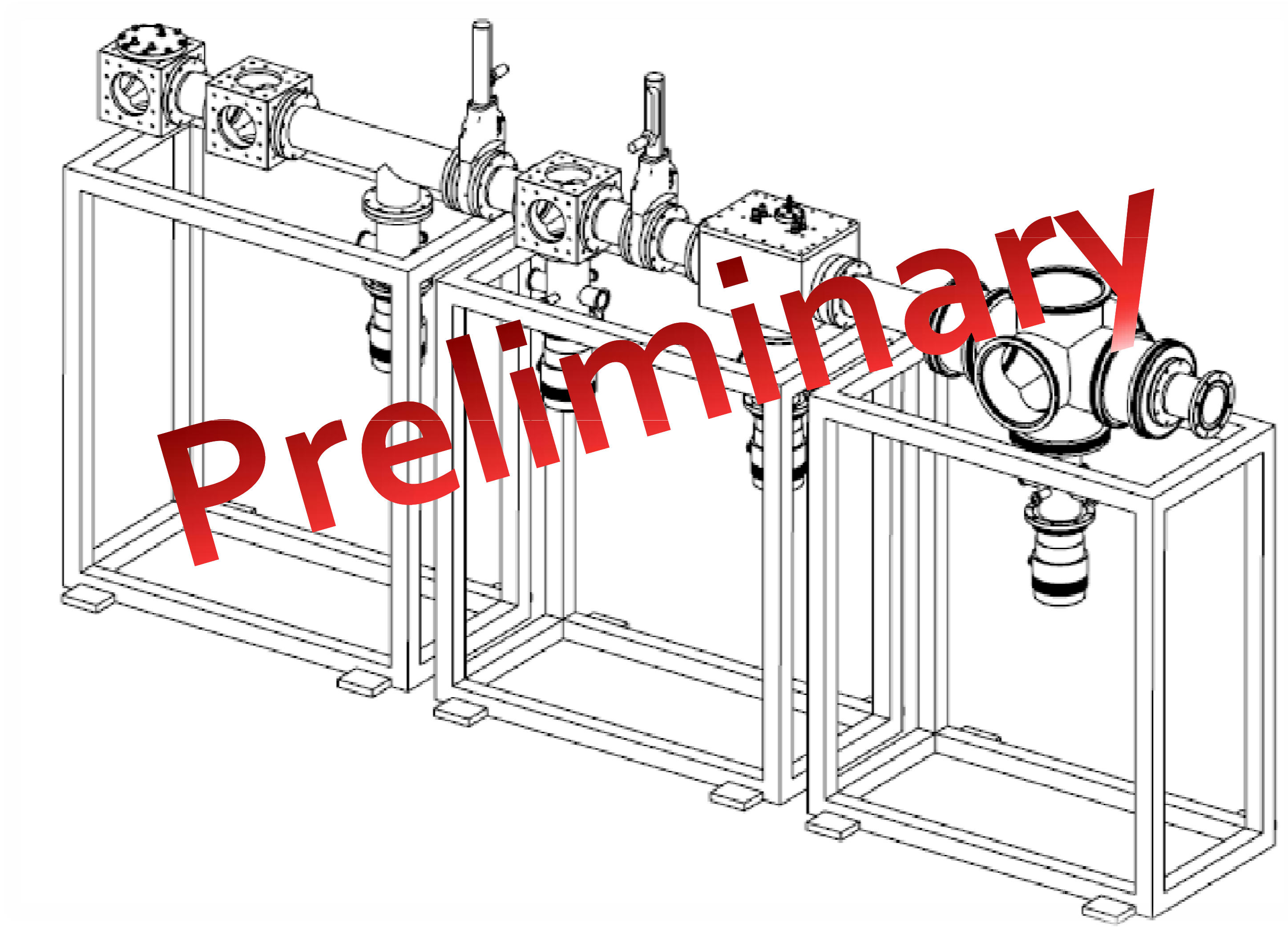
Thank you for your attention

Available resources

- Manchester: 2 Academics, 1 postdoc, 2 PhD students, 2 Technical staff.
- Leuven: 1 Academic, 2 postdocs, 2 PhD students.
- Orsay:2 Academic, 1 postdoc, 1 PhD student.
- Birmingham: 1 Academic, 1 postdoc, 2 PhD students.

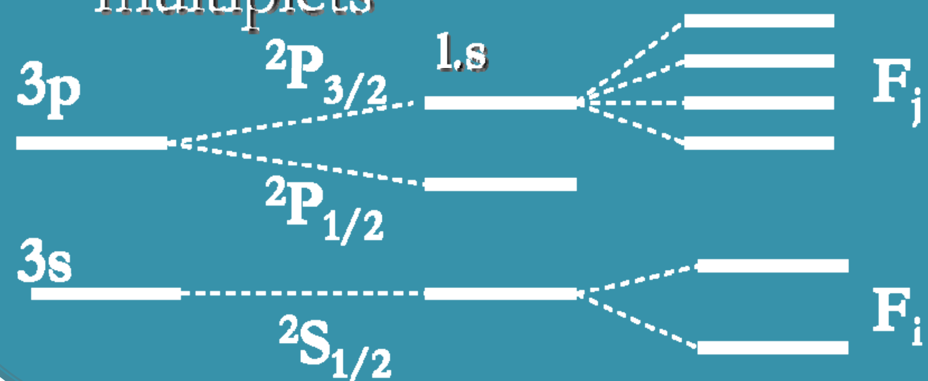
Total of 20 people

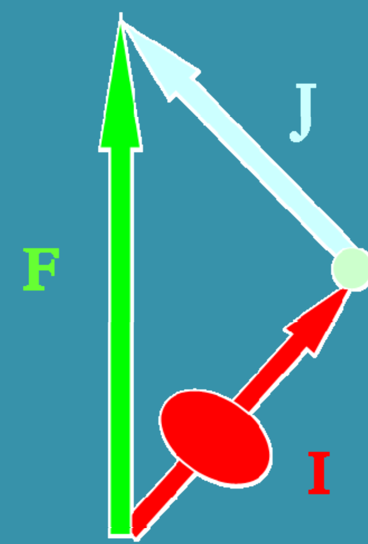
Technical Drawings



Hyperfine interaction of the atom (ion)

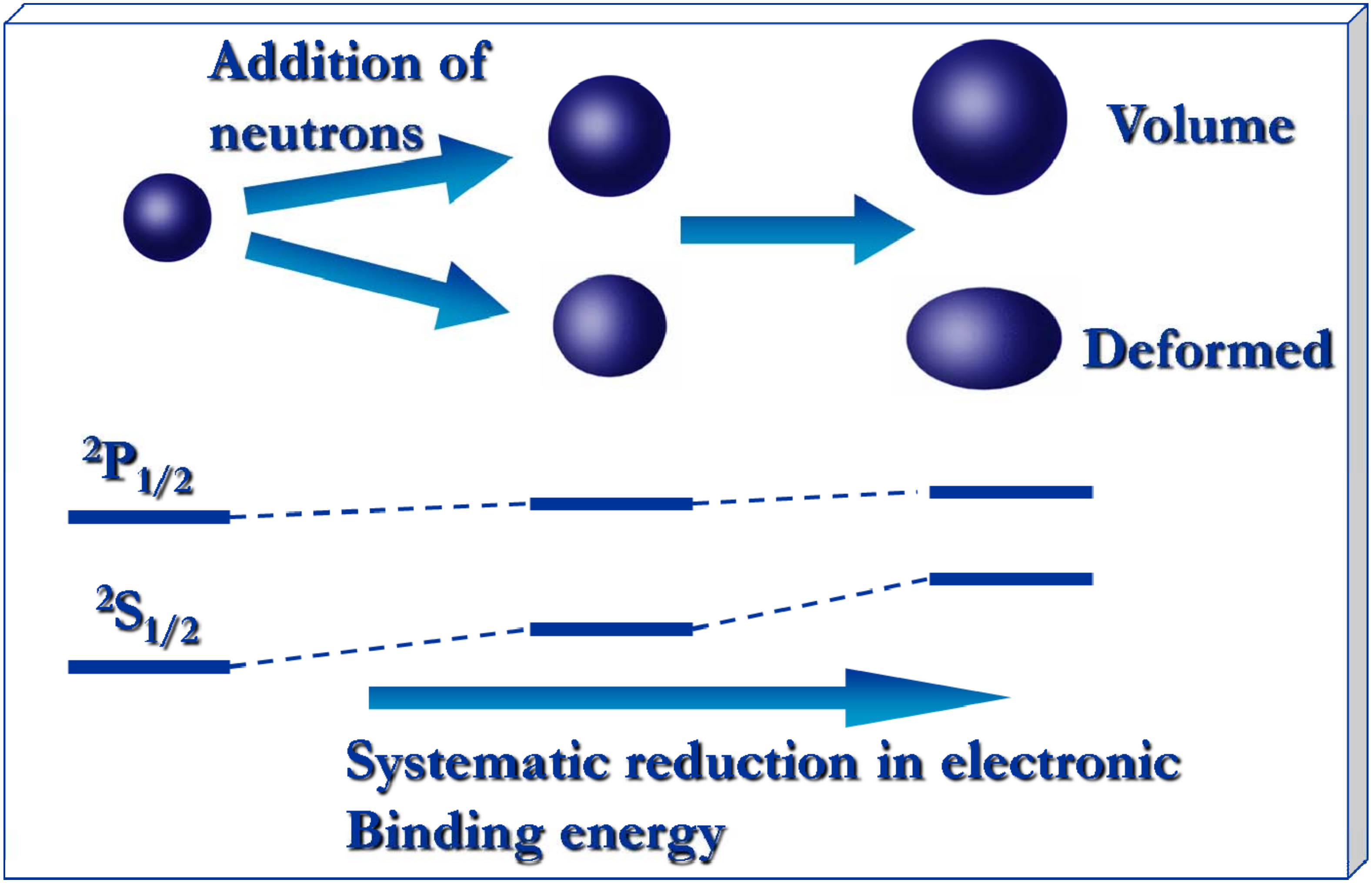
- Coupling of the nuclear spin with electronic
- New quantum number F=I+J
- The nuclear electromagnetic moments break the degeneracy.
- Atomic (ionic) states are split into multiplets





Hyperfine Structure

Isotope Shift



Signal to noise: Limits of detection

- Signal Noise Ratio (SNR) > 5 for total confidence in laser spectroscopy.
- SNR =$(S/\sqrt{(S+B)})*\sqrt{t}$ where S is the signal rate, B is the background rate and t is the time in seconds
- By eliminating the background the SNR reduces to $\sqrt{(S*t)}$ which presents the ultimate limit on the time it takes to collect data.