The Collinear Resonant Ionization Spectroscopy (CRIS) experimental setup at CERN-ISOLDE

H.H. Al Suradi, J. Billowes, I. Budinčević, **T.E. Cocolios**, R. de Groote, S. De Schepper, K.T. Flanagan, S. Franchoo, R.F. Garcia Ruiz, H. Heylen, F. Le Blanc, K.M. Lynch, B.A. Marsh, P.J. Mason, G. Neyens, J. Papuga, T.J. Procter, M.M. Rajabali, S. Rothe, G. Simpson, A.J. Smith, I. Strashnov, H.H. Stroke, D. Verney, P.M. Walker, K.D.A. Wendt, R.T. Wood

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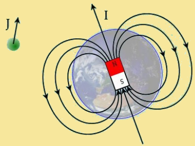
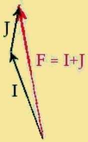
EMIS Conference
Matsue, Japan

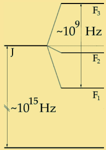
The nuclear observables of interest

Spin, moments, ...

Nuclear magnetic dipole







- each nucleon is like a small magnet;
- the nucleus can then exert a magnetic field;
- the electrons orbiting the nucleus are perturbed by this magnetic field.

$$\Delta E = \frac{A}{2} \cdot \Big(F(F+1) - I(I+1) - J(J+1)\Big) \cdot h$$

The nuclear observables of interest

Radii, . . .

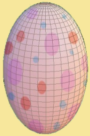
A variety of sizes and shapes

oblate

pancake-like

spherical

Ferrero Rocher-like



prolate

Easter egg-like

- s and $p_{1/2}$ electrons encounter the nucleus;
- the size of the nucleus affects the transitions;
- deformation (oblate/prolate) averages out to a bigger radius.

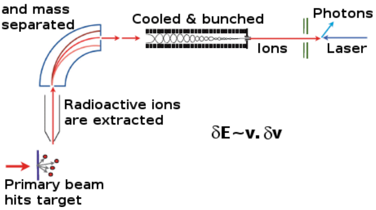
$$\delta\nu = \frac{A' - A}{A \cdot A'} \cdot (m_e \nu + K_{SMS}) + F \cdot \delta\langle r^2 \rangle$$

Collinear laser spectroscopy

Probing the nucleus with atomic levels

High-resolution spectroscopy

- The isotopes of interest are produced, separated, and delivered to the setup in bunches;
- The bunches are manipulated (Doppler tuning, neutralization, optical pumping, . . .) and overlapped with the laser beam;
- Photons are recorded by a photomultiplier.



B. Cheal, T.E. Cocolios, S. Fritzsche, PRA 86(2012)042501

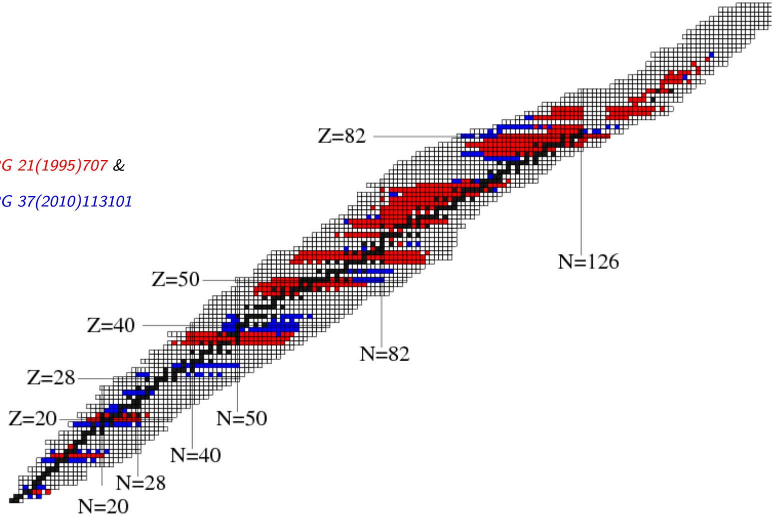
The resolution of this technique reaches down to the natural linewidth of the transition, which is sufficient to measure most of the ground-state properties of interest.

The reach of laser spectroscopy

Survey of the nuclear chart

JPG 21(1995)707 &

JPG 37(2010)113101

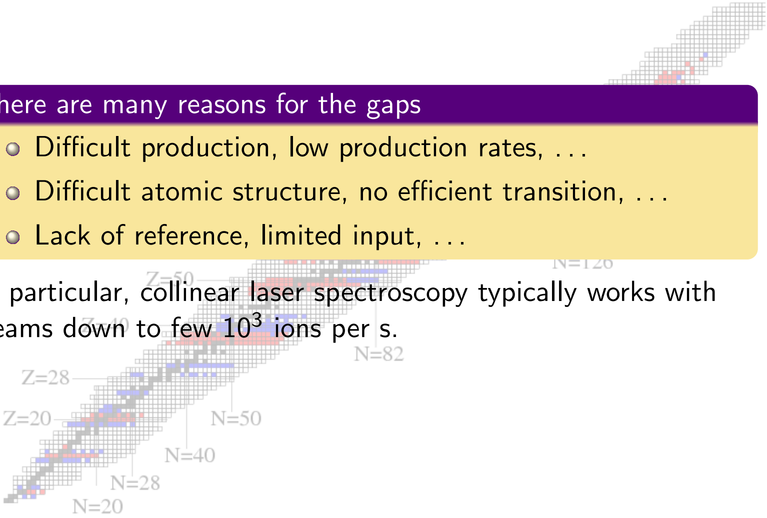


The reach of laser spectroscopy
Survey of the nuclear chart

There are many reasons for the gaps

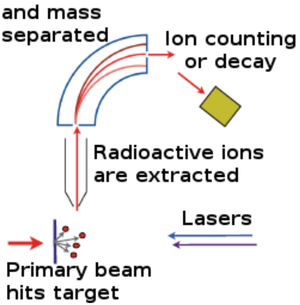
- Difficult production, low production rates, . . .
- Difficult atomic structure, no efficient transition, . . .
- Lack of reference, limited input, . . .

In particular, collinear laser spectroscopy typically works with beams down to few 10^3 ions per s.



In-source laser spectroscopy

Overcoming the low-production limit at a price



High-efficiency spectroscopy

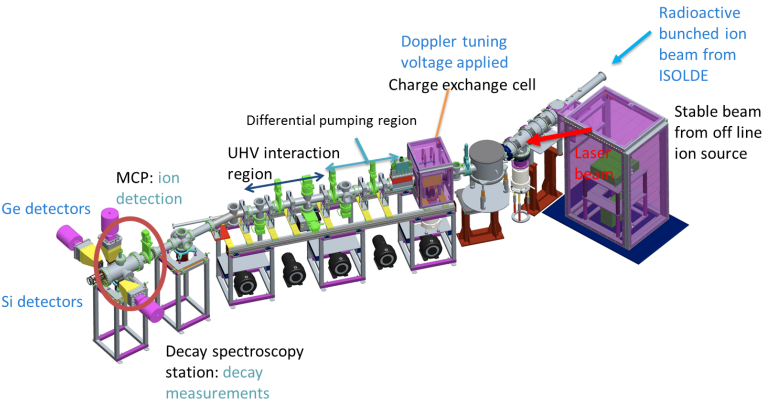
- The lasers are shown into the ion source, one of which is being scanned across the atomic resonance of interest;
- The ions are mass separated and counted, either directly or via their characteristic decay pattern.

Spectra with less than 1 ion per second have been recorded with this method! The resolution is however 100 to 1000 times worse than with the collinear technique due to broadening effect in the ion source (high T, high pressure, . . .).

H. De Witte et al., PRL 98(2007)112502

T.E. Cocolios et al., PRL 106(2011)052503

CRIS@ISOLDE
The beam line



CRIS@ISOLDE

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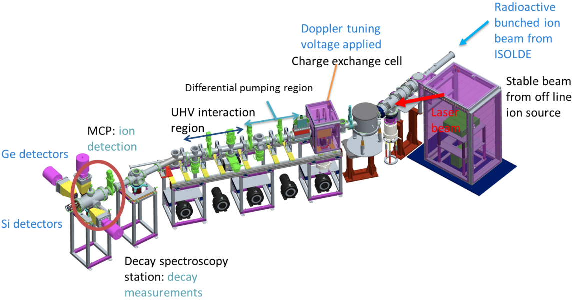
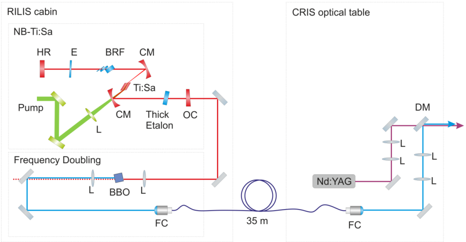
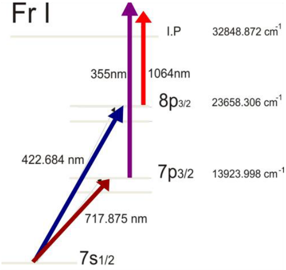


Layout of the CRIS beam line

- Bunches are delivered from the ISOLDE HRS ISCOOL at 30 to 50 keV;
- Ions are (Doppler-tuned and) neutralized in a K charge exchange cell operated at 10^{-6} mbar;
- Non-neutralized ions are deflected away while the atoms drift through the interaction region, maintained at $< 10^{-9}$ mbar;
- Lasers are sent through the interaction region;
- Re-ionized isotopes are deflected towards an MCP or an α-decay station.

CRIS@ISOLDE
The laser system





See posters 129-R.E. Rossel & 131-S. Rothe

RILIS + CRIS

- 10kHz 422nm light from the RILIS Ti:Sa laser system with a bandwidth of $\sim$ 1GHz is fiber-coupled to the CRIS experiment;
- 30Hz 1064nm light from a Nd:YAG laser is mixed with the blue light at the CRIS experiment and is delivered to the beam line.

CRIS@ISOLDE

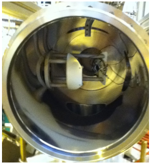
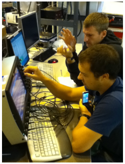
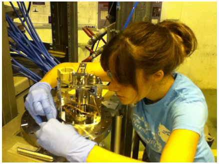
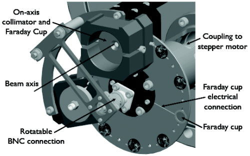
Counting ions

MCP counting

- The ions are sent onto a biased copper plate;
- Secondary electrons are guided to an MCP and recorded;
- The MCP signal is processed in a digital scope, triggered by the Nd:YAG laser in order to accept signals in sync with the ion bunch passing through the experiment.

α counting

- The ions are implanted in 1 of 9 C foil (20μg/cm^2);
- 2 Si detectors surround the C foil;
- up to 3 Ge detectors can be placed around the DSS.
- To identify the respective components of mixed hyperfine structures;
- To perform decay spectroscopy on ultra-pure samples.

CRIS@ISOLDE
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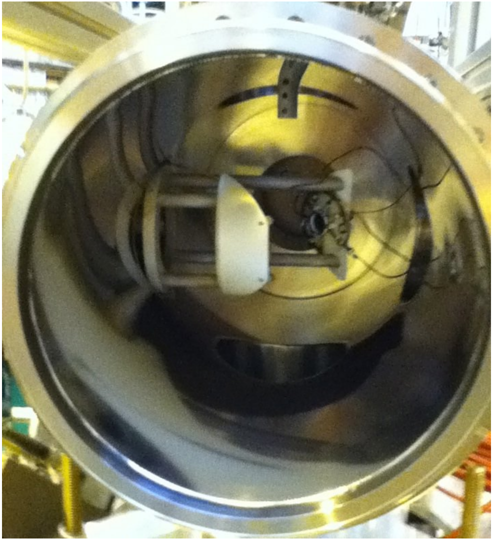

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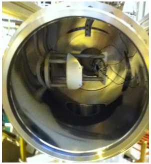
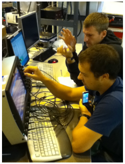
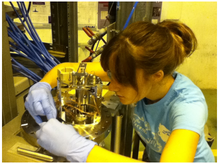
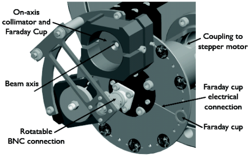
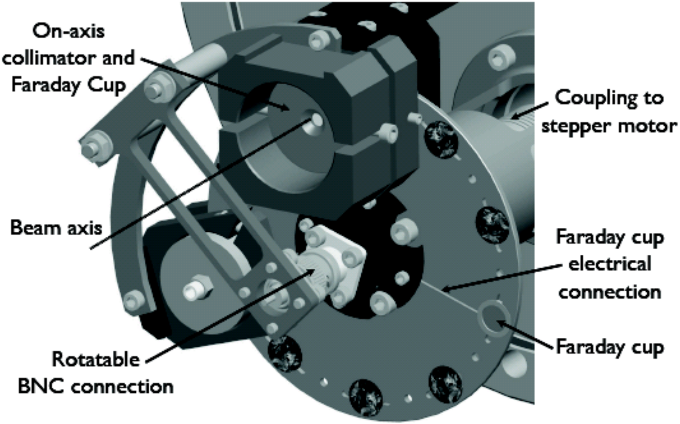





CRIS@ISOLDE
Counting ions



CRIS@ISOLDE

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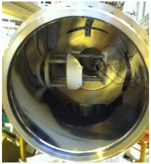
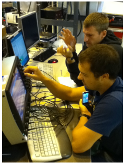
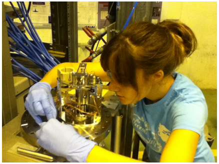
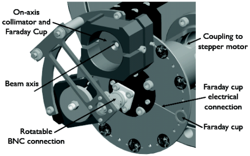








2012 experimental campaign

Study of the francium isotopic chain

One successful test beam time (Aug'12) and one successful beam time (Oct'12) have allowed to study 17 hyperfine structures, including 9 new isotopes and 4 isomers.

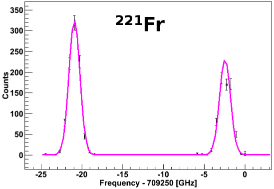
High efficiency

- Neutralization efficiency of 1:2;
- Total efficiency for resonant ions of 1:60 has been reached in Fr;
- ^{202}Fr has been effortlessly measured with 100 ions per second.

High purity

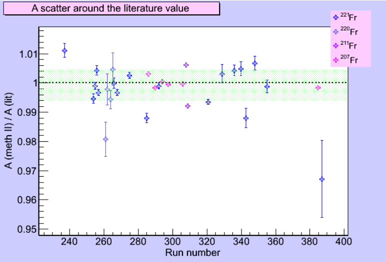
- Total collisional background efficiency of 1:300 000 at a pressure of $8 \cdot 10^{9}$mbar;
- Background-free measurement in the most exotic cases (e.g. ^{202}Fr);

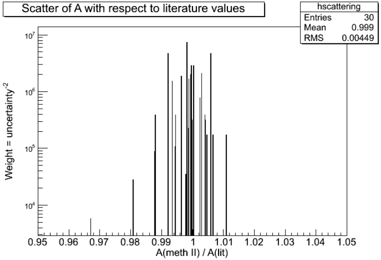
⇒ 99.98% purity on isomer selection.



Systematic study

Testing the confidence in the technique



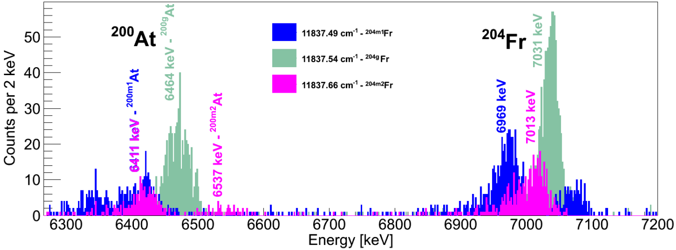


Chasing the systematic effects

- A full description of the line profile is not yet available (ionization process is non-Hermitian, possible coherent effects, . . .) - *M.Sc. thesis R. de Groote, KULeuven*;
- The resolution is still limited (1GHz);
- The scatter of the reference isotopes around the literature values is consistent with an uncertainty of 0.5%.

α tagging

Identifying hyperfine components with the DSS



Isomeric beams

- Scans on the MCP revealed many components;
- Each component was sent to the DSS to observe the respective α decay;
- The peaks in the hyperfine structure can then be associated with their respective states.
- Additionnally, purified beams of isomer corresponding with a mass resolving power $M/\Delta M \sim 5 \cdot 10^6$ have been produced.

Conclusions

CRIS

- CRIS provides ground-state properties of radioactive isotopes with low production rates at high resolution.
- First successful operation of CRIS@ISOLDE on the francium isotopic chain.
- Demonstration of beam purification and isomeric beam production.

Francium

- An efficiency of 1:60 for resonant ionization against 1:300 000 for non-resonant ionization has been achievevd.
- The preliminary analysis of the francium isotopes has shown that the measurements are consistent with the literature.
- α tagging at the DSS allows for unambiguous identification of isomers.

Outlook

- Improve resolution (CW laser operation, Doppler tuning, ...)
- Improve vacuum (Getter material, more differential pumping sections, ...)
- Expand range of applicability (3-step schemes, field ionization, ion ionization, ...)
- Apply the technique in other fields (beam manipulation and purification, trace analysis, ...)

Arigato gozaimasu!

Thank you for your attention!