Collinear Resonant Ionization Spectroscopy (CRIS) of exotic isotopes at ISOLDE, CERN

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Collinear Resonant Ionization Spectroscopy (CRIS)

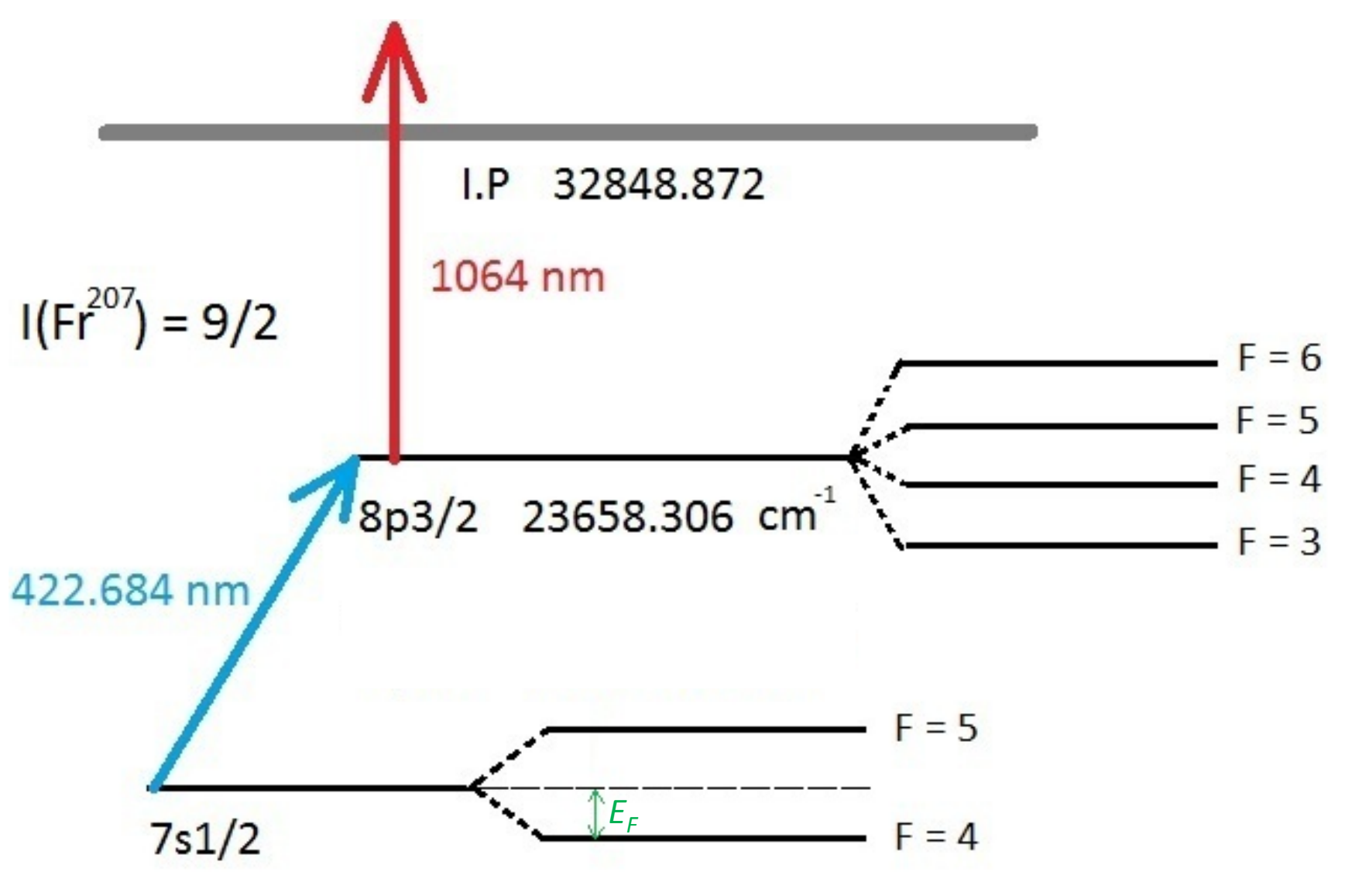
The CRIS technique combines the high resolution of a collinear laser-atomic beam geometry with the high efficiency of ion detection from resonant ionization.

- Stepwise excitation of atoms into the ionization continuum via resonant interaction with laser light.
- By scanning the laser frequency and measuring the number of ions produced, it is possible to measure the atomic hyperfine structure.

- Electrostatic acceleration of an ion ensemble

$$\delta E = const = \delta\left(\frac{1}{2}mv^2\right) = mv\delta v.$$

- Small Doppler width enables high resolution measurements to be performed.



Fr ionization scheme

The hyperfine structure levels F are related to the nuclear spin I and the angular momentum J by:

$$\mathbf{F} = \mathbf{I} + \mathbf{J} \qquad |I-J| \le F \le |I+J|$$

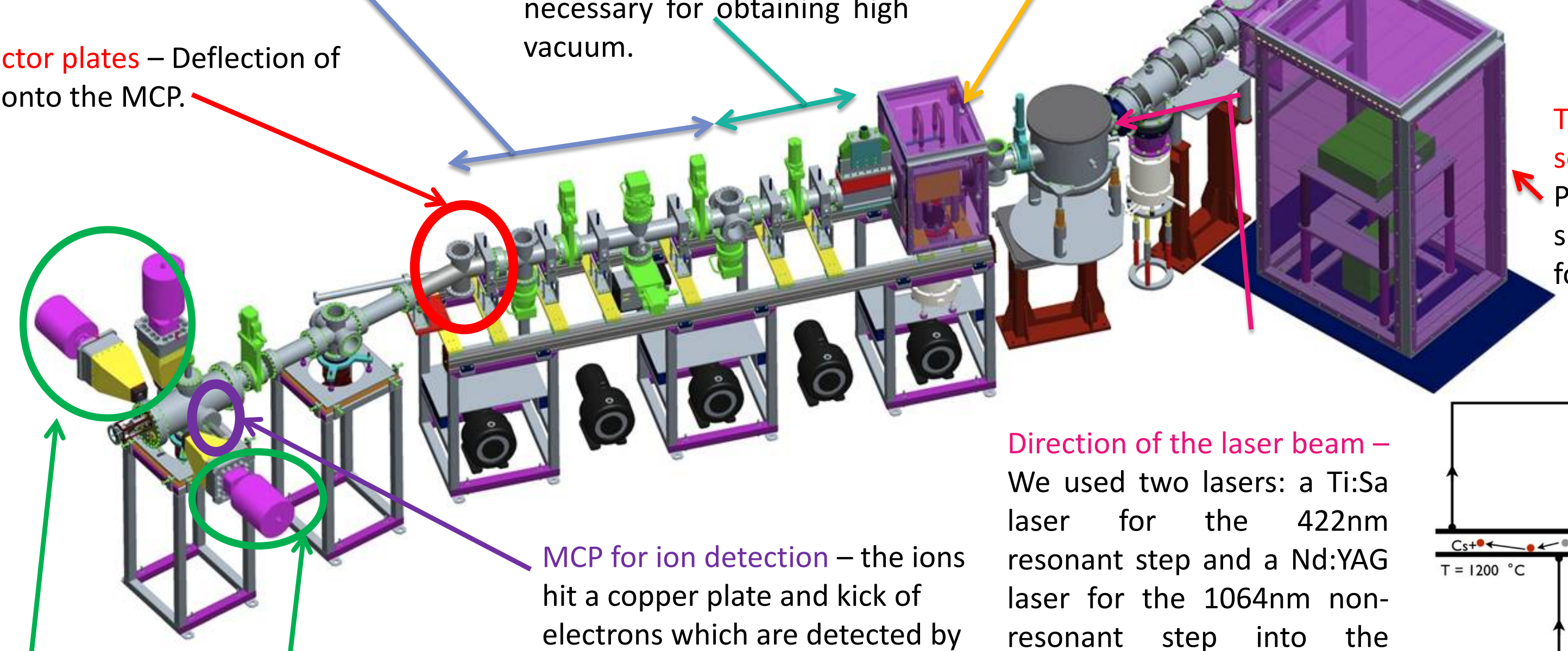
The hyperfine energy levels E_F are given by:

$$E_F = \frac{1}{2}AC + B\frac{\frac{3}{4}C(C+1) - I(I+1)J(J+1)}{2I(2I-1)J(2J-1)}, \qquad C = F(F+1) - I(I+1) - J(J+1)$$

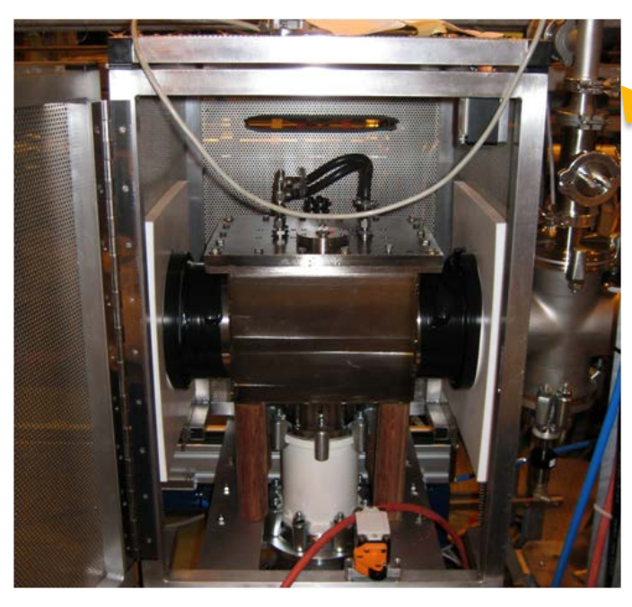
$$A = \frac{\mu_I B_J}{IJ} \qquad B = eQ_s V_{zz}$$

Where μ_I is the magnetic dipole moment and Q_s is the spectroscopic quadrupole moment of the nucleus. [1]

The CRIS beam line

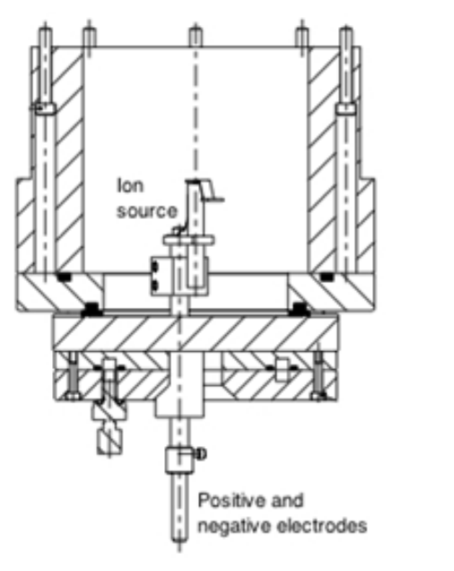


The Ultra High Vacuum interaction region (UHV) – where the laser light interacts with the neutralized atomic beam and resonantly ionizes it. The pressure in the region was bellow 5·10^{-9} mbar.



The charge exchange cell – The ion bunch is neutralized via collisions with an alkali vapor.

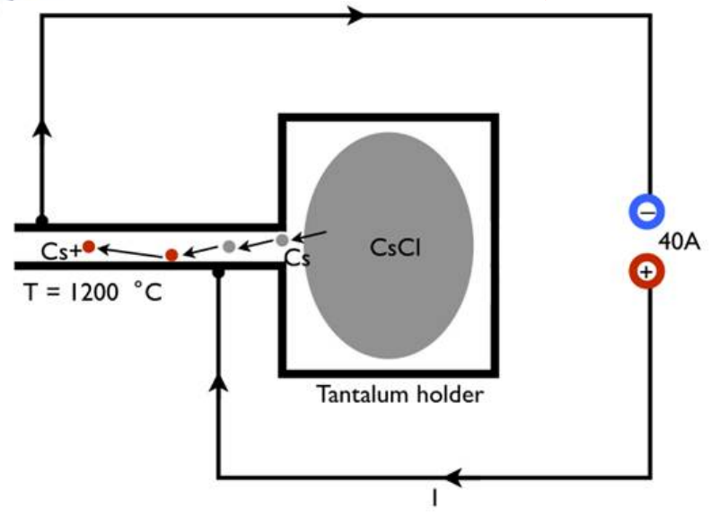
Bunched ion beam from ISOLDE



Differential pumping region – necessary for obtaining high vacuum.

Deflector plates – Deflection of ions onto the MCP.

The CRIS off-line ion source: CRISIS – Provides ions via surface ionization for off-line tests.

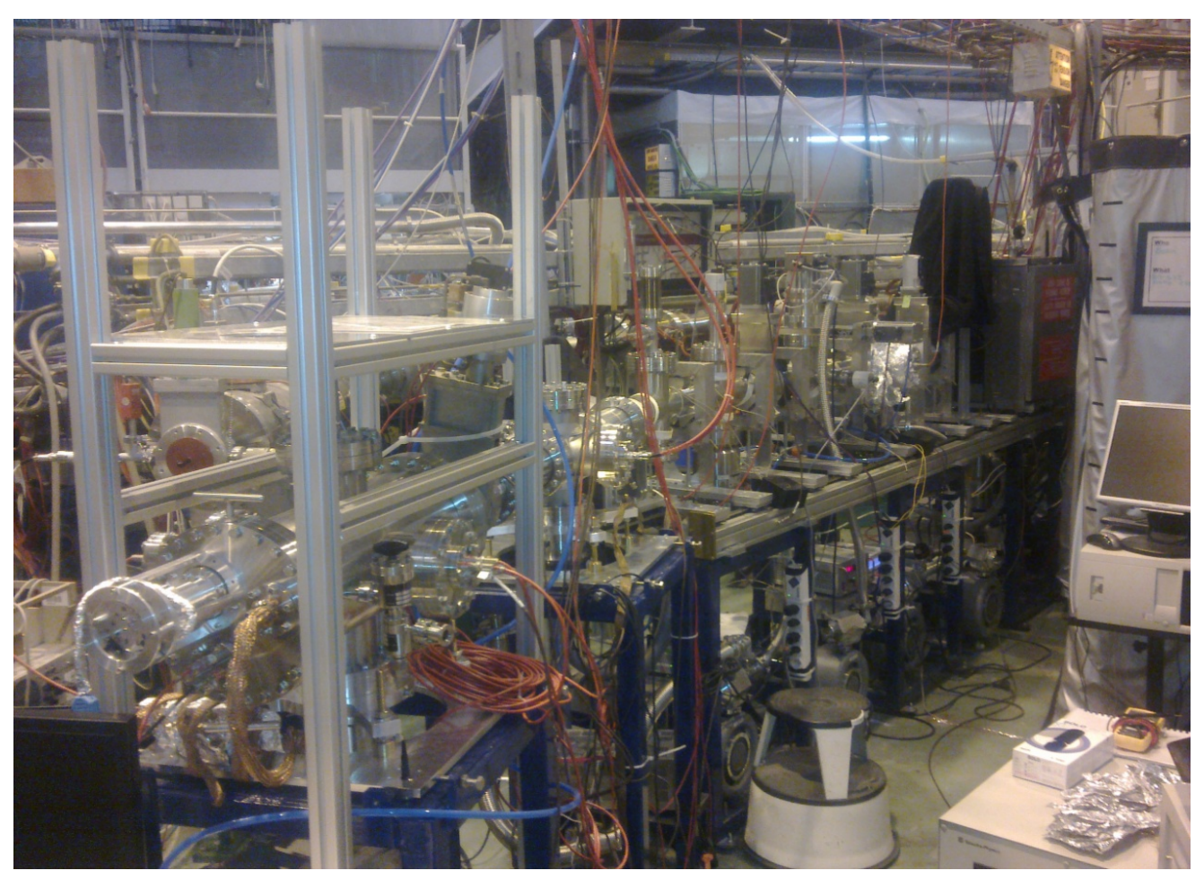


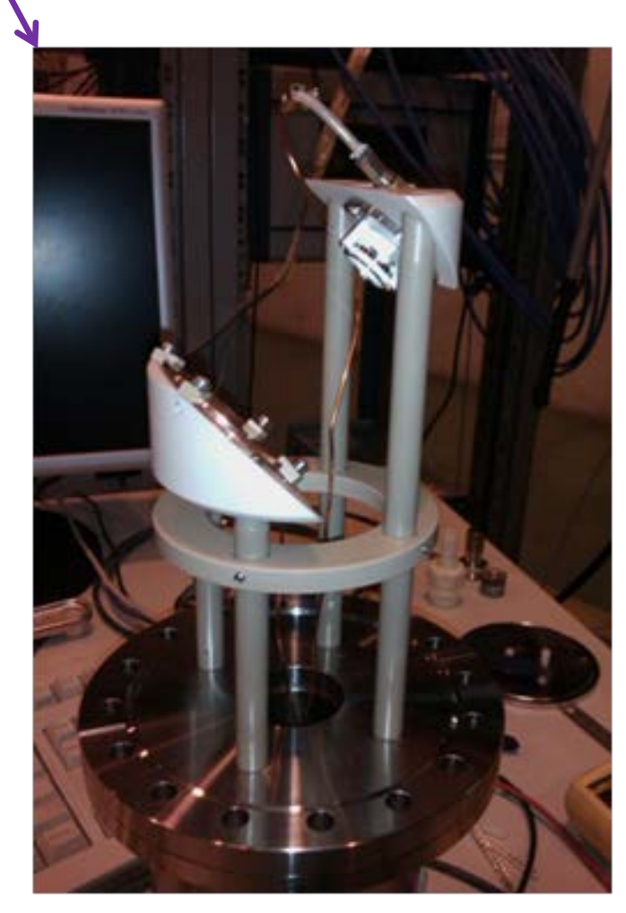
Direction of the laser beam – We used two lasers: a Ti:Sa laser for the 422nm resonant step and a Nd:YAG laser for the 1064nm non-resonant step into the ionization continuum.

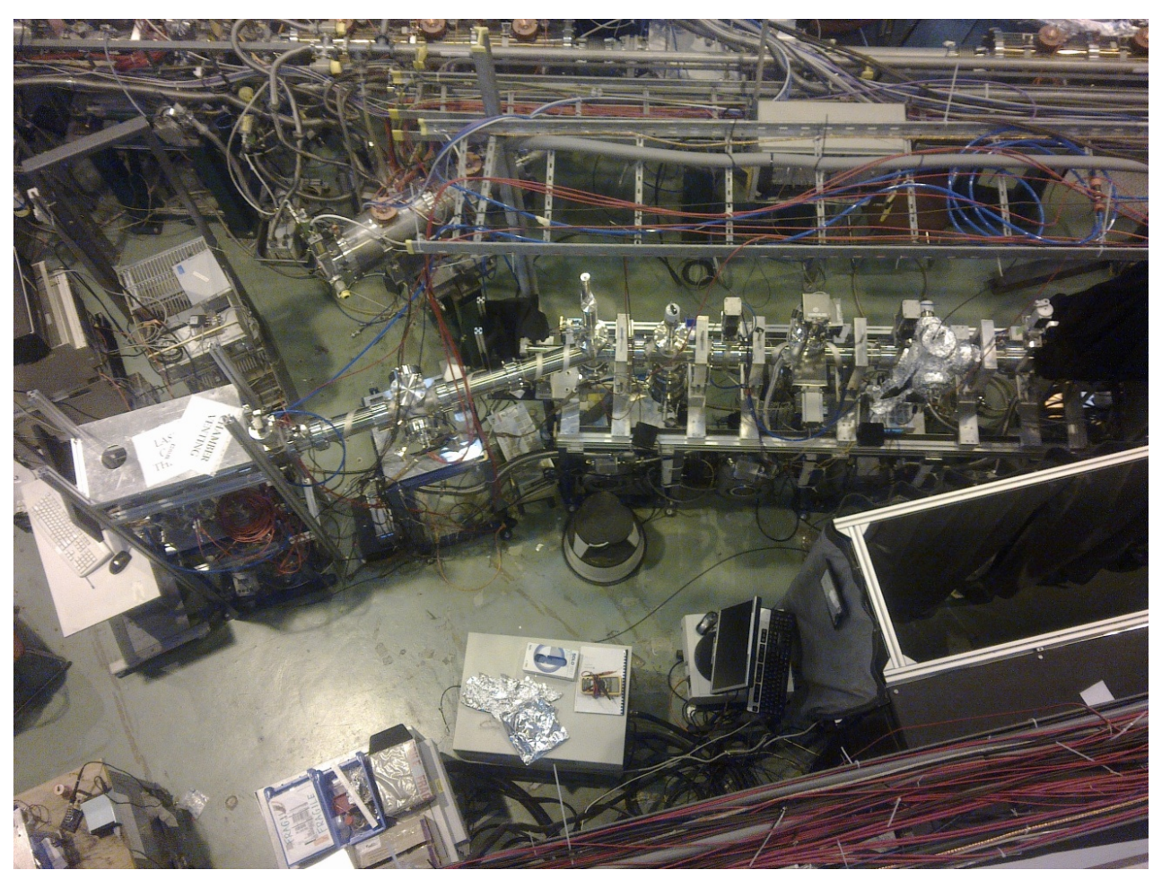
MCP for ion detection – the ions hit a copper plate and kick of electrons which are detected by the Multi-channel plate (MCP).

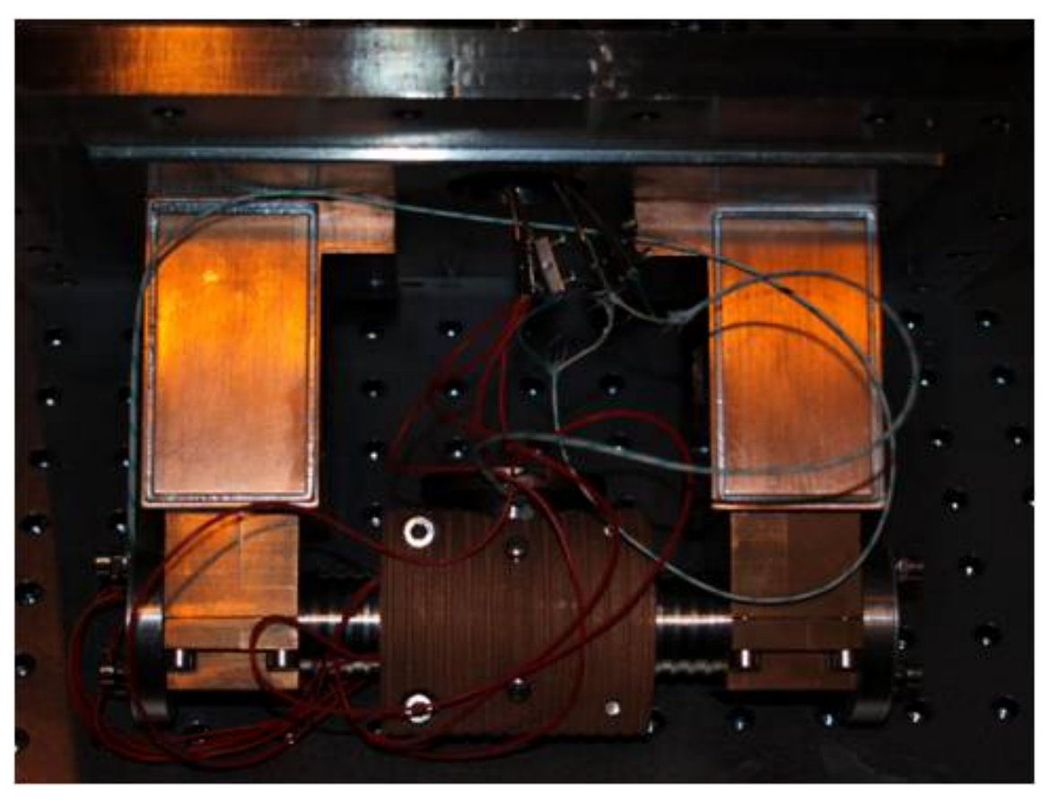
Si and Ge detectors - The Decay Spectroscopy Station (DSS) provides complementary decay spectroscopy measurements while taking advantage of the high selectivity of resonant laser ionization.

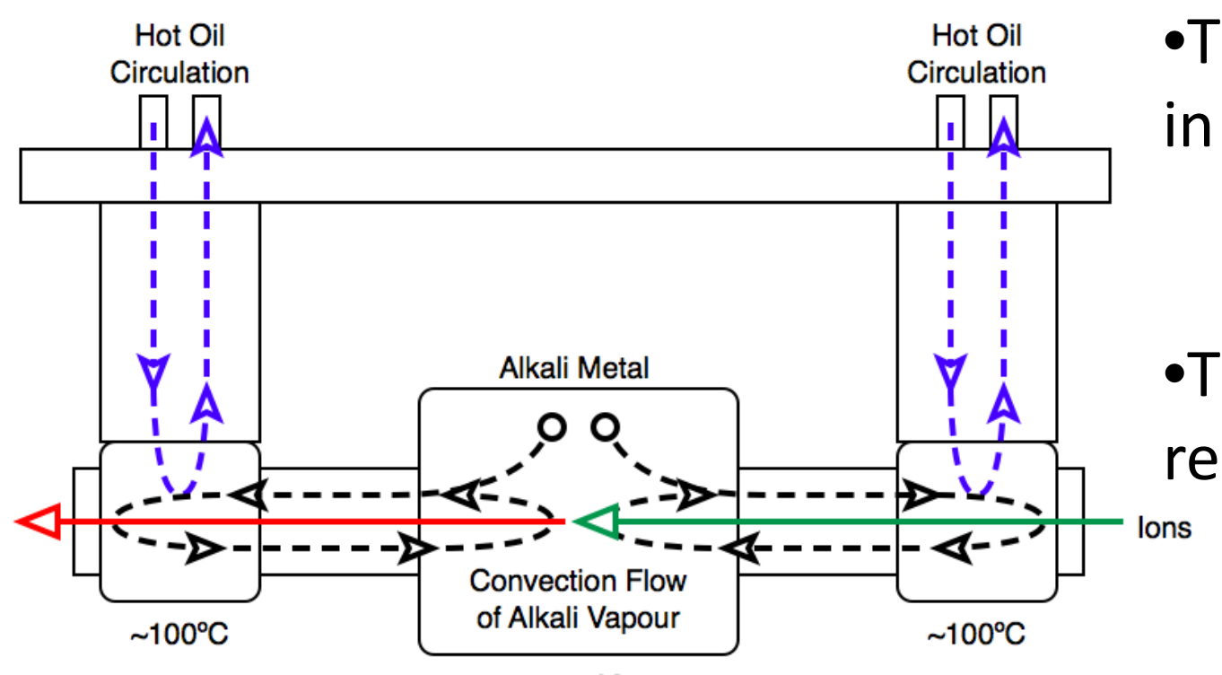
•Total transmission efficiencies of ~70% from the beginning of the beam line onto the MCP have been achieved during stable beam tests.











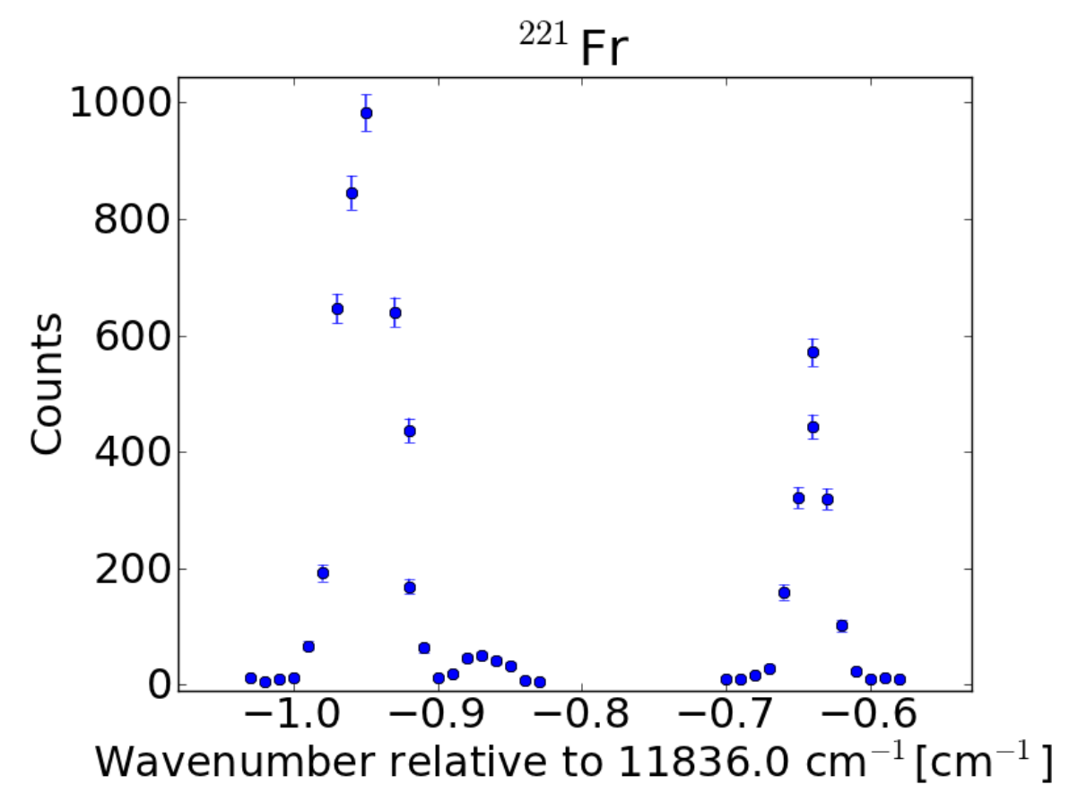
- The Charge Exchange Cell (CEC) had a neutralization efficiency of ~50% during the run in which we measured the low-mass Fr isotopes.
- After the CEC, there are plates which deflect the ions that have not been neutralized, since these ions would constitute a background in our measurements.

•The hot oil circulates around the outer edges of the CEC in order to increase the length of the vapour flow region.

•The CEC operated at between 147 – 157 °C in the middle region and at ~103 °C in the outer region of the cylinder.

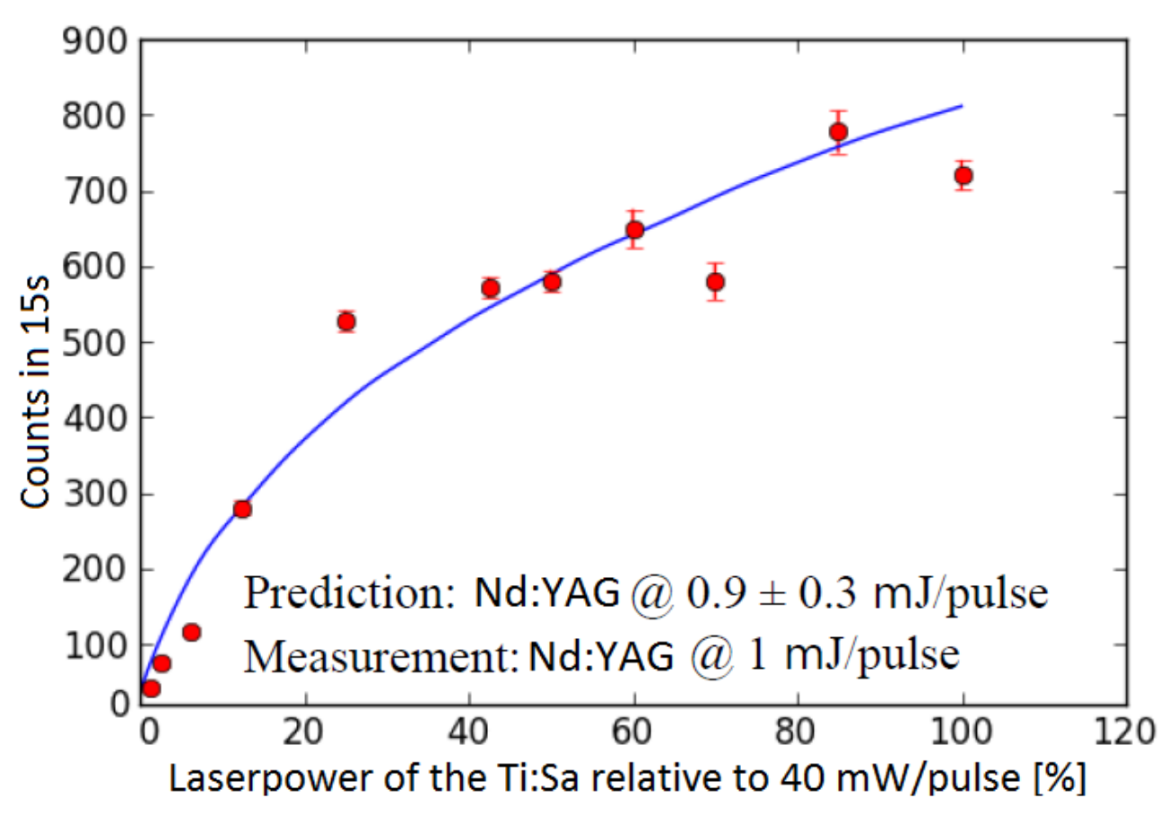
Newest results on low-mass Fr isotopes

- First successful on-line run measured the isotopes: ^{202,203,204,205,206,207,221}Fr.



- The background signal comes from collisional ionization and ions that have not been neutralized by the CEC.
- Due to the very low pressure in the UHV interaction region and the non-neutralized ions being deflected after the CEC, a background suppression of between 1·10^{-5}–5 ·10^{-5} was observed.

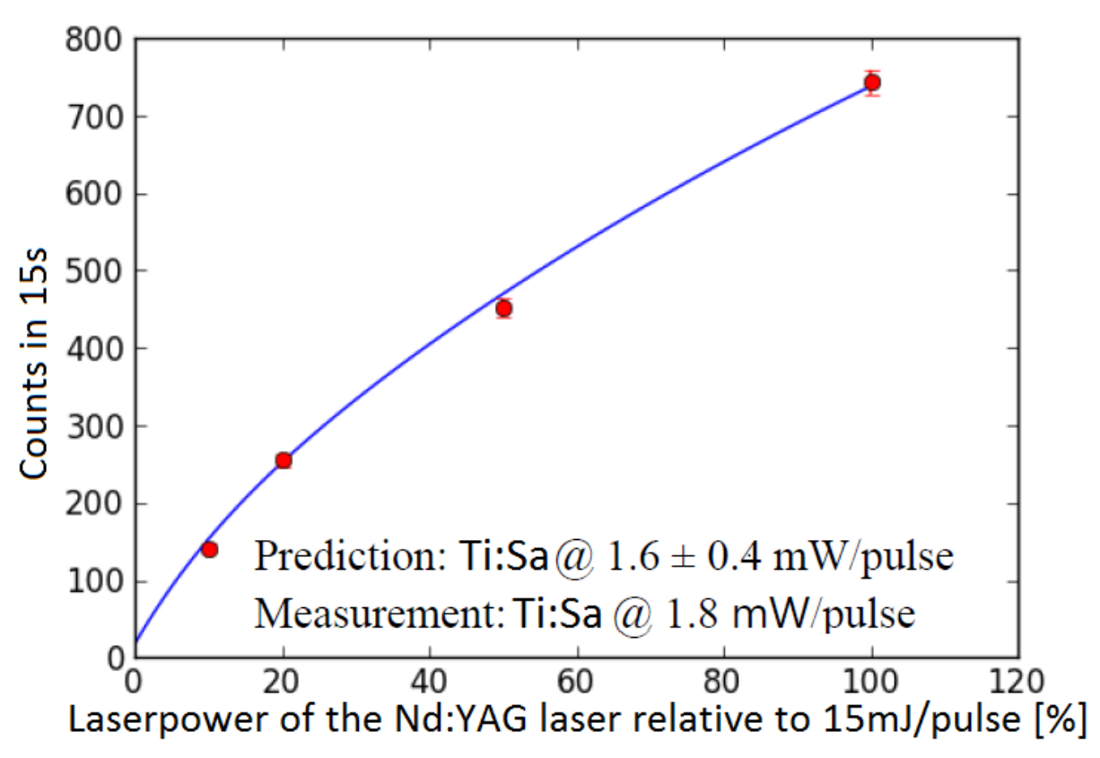
Saturation curve for the 422 nm Ti:Sa laser



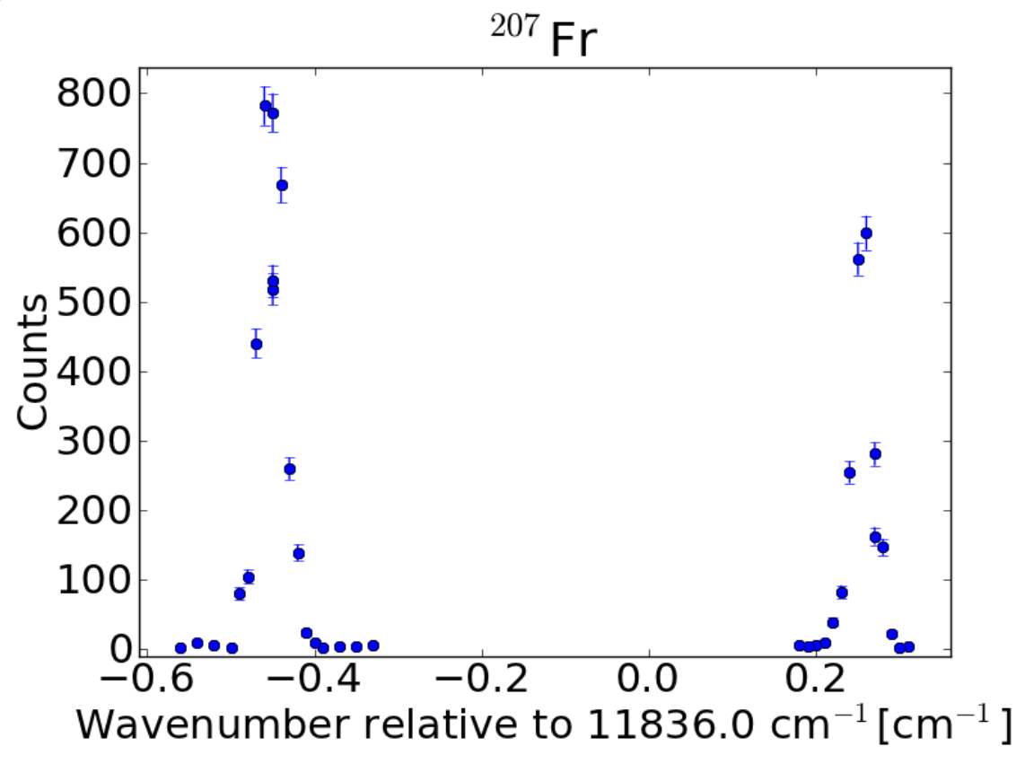
- The measured saturation curves for both of the lasers compare very well with the dressed-state theoretical model predictions [2].

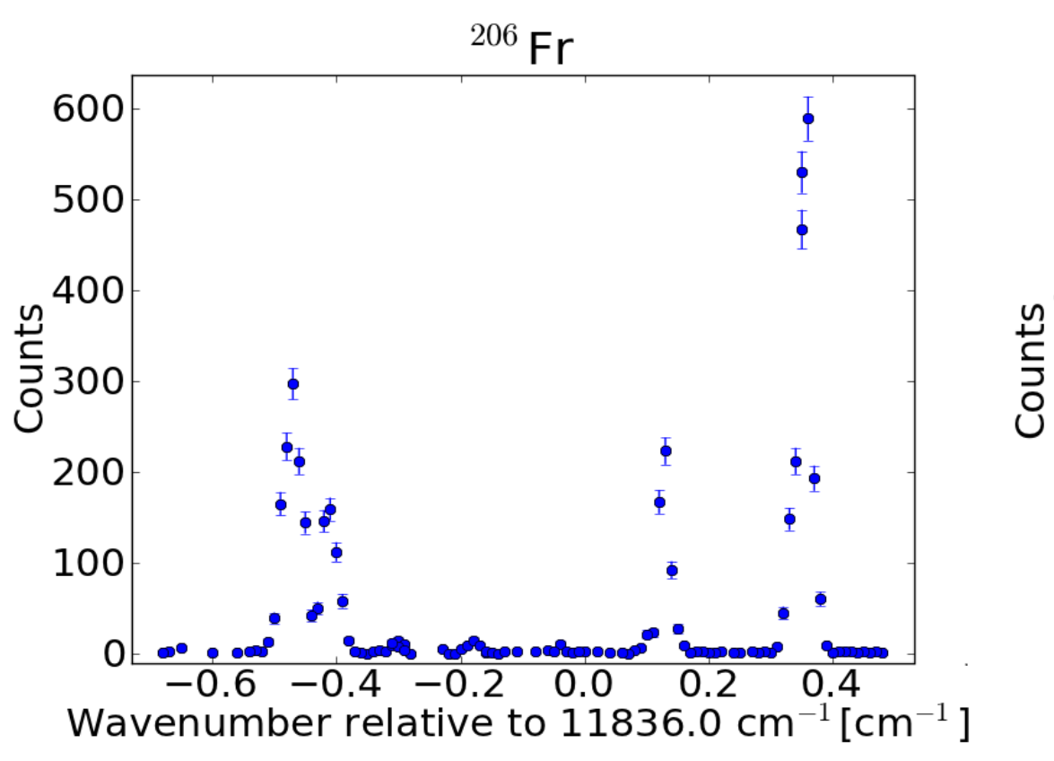
- We were able to saturate the 7s1/2 → 8p3/2 transition with about 40mW of the 422nm Ti:Sa laser light.
- The Ti:Sa repetition rate is 10kHz and the pulse length is 50ns, which translates to 80W of continuous power.

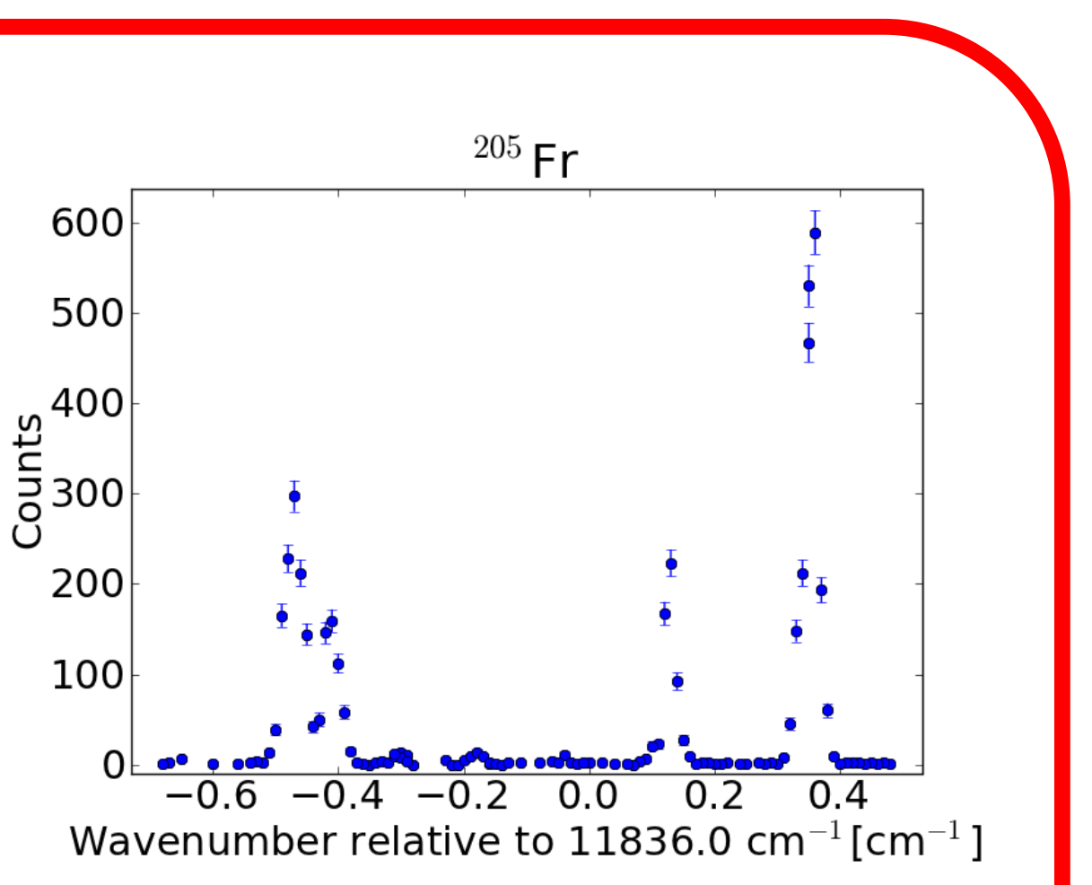
Saturation curve for the 1064nm Nd:YAG laser



- Since the linewidth of the Ti:Sa was 1GHz and the natural linewidth of the 7s1/2 → 8p3/2 transition is of the order of 5MHz, there was a loss factor of ~200 for the laser power. This would bring the power requirement for a narrow-band continuous wave (cw) laser down to the order of ~0.4W (assuming a linewidth of ≤ 5MHz for the cw laser light) .

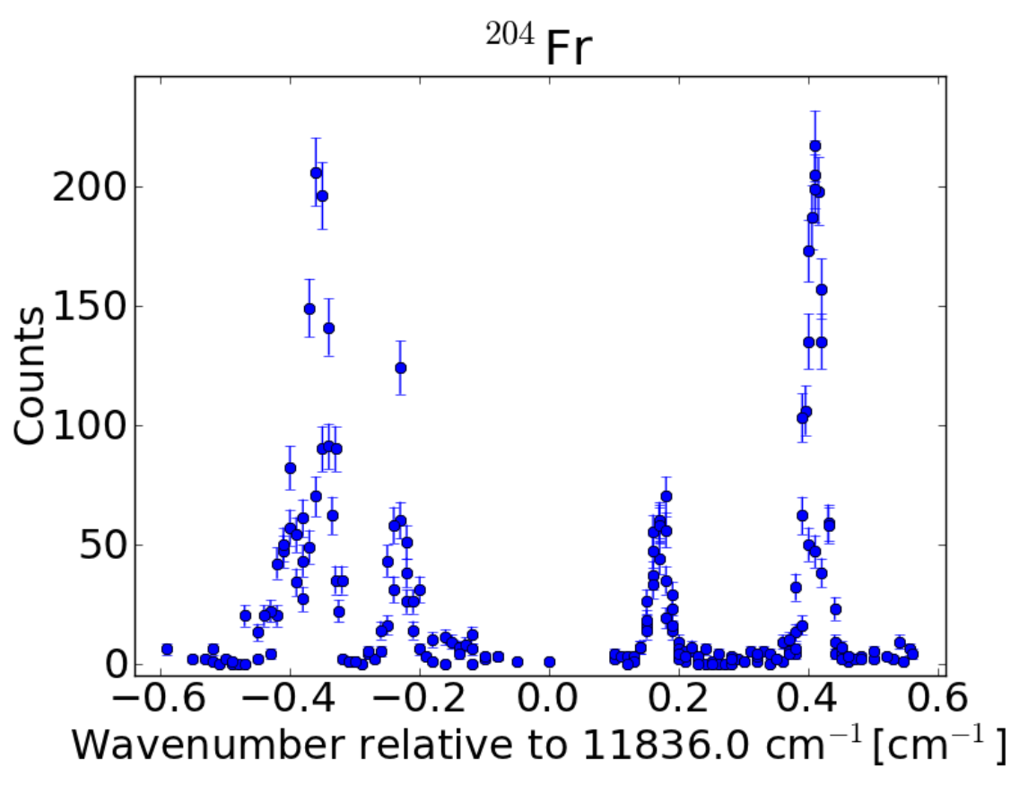


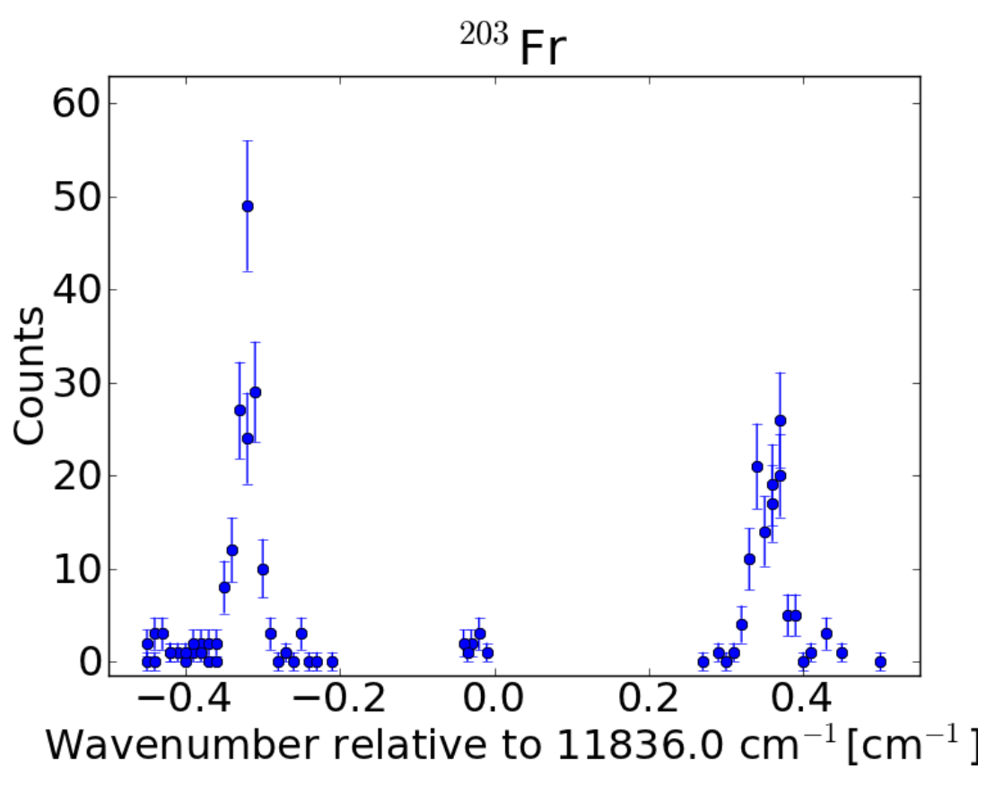


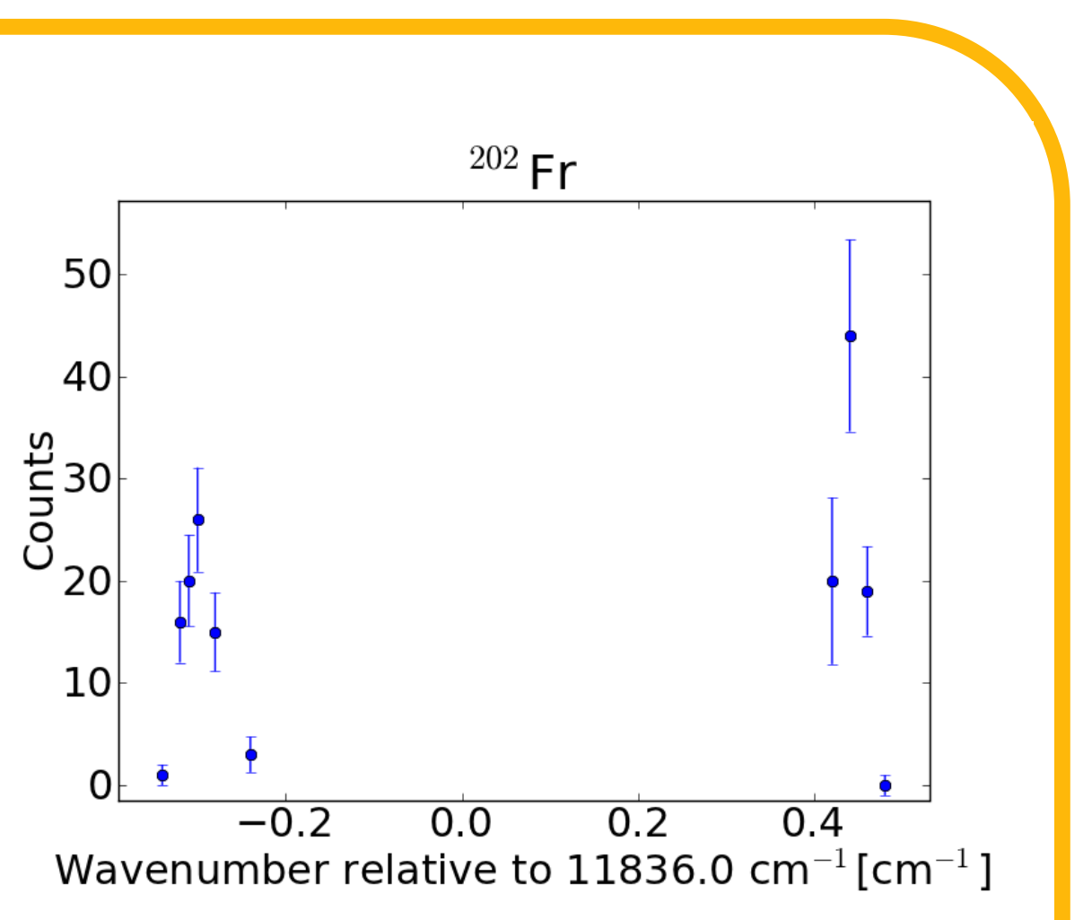


- The linewidth of the 422nm Ti:Sa laser used for the resonant step was around 1GHz.
- Using a continuous wave narrow-band laser will improve our spectral resolution.

•The total experimental efficiency was of the order of 1:400, owing to the high efficiency of ion detection, the high ionization efficiency and the fact that we had a bunched ion beam from ISOLDE, which meant that we didn't experience any losses due to the duty cycle of our laser system.







- Investigation of the onset of deformation in the region above the Z = 82 shell closure and around N = 112.[3]

Conclusions and Outlook

- From this data it will be possible to deduce the nuclear magnetic dipole moments μ_I and isotope shifts $\delta\nu_I$ of the investigated isotopes.

•The very high background suppression allows us to measure isotopes with very low yields like ^{202}Fr which had an estimated yield of 71 atoms/μC. [3]

- The presence of multiple peaks in the spectra of ^{204,206}Fr is already an indication of the presence of isomeric states, some of which have already been measured by other authors [4].
- Performing complementary measurements on the isotopes ^{204,206}Fr with the Decay Spectroscopy Station will help identify each hyperfine structure component.
- For future planned experiments such as Cu[5] and Po[6], we are planning on using a narrow-band laser with which we will be able to resolve the full hyperfine splitting, giving us access to the study of nuclear electric quadrupole moments.

References

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