# Status of the Project TRAPSENSOR: Weighing Nuclei With Photons

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# Outline

- Motivation
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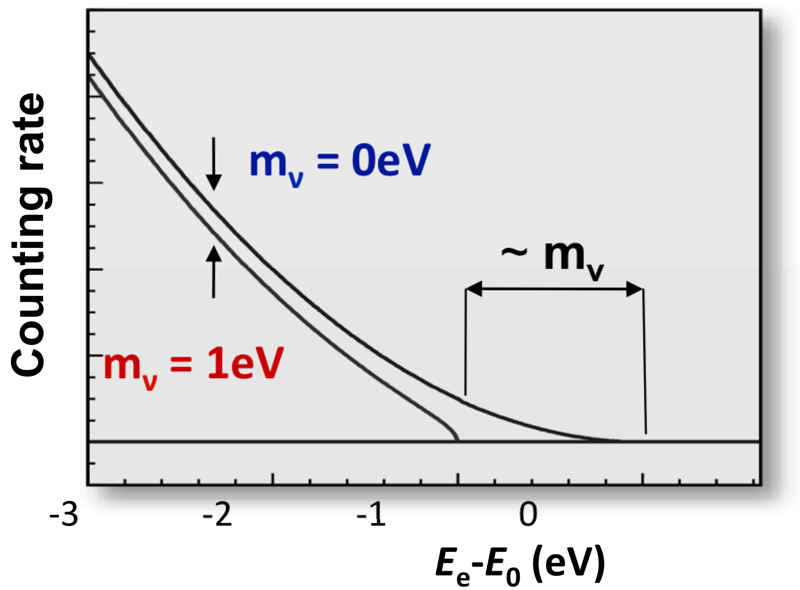
    - The mass of the electron antineutrino
- Present status in Penning trap mass spectrometry
- The TRAPSENSOR project: a new concept in mass spectrometry
- Implementation of the project
    - The full setup and the lab
- Status and results
    - The ion source and the transfer section
    - The superconducting magnet and the Penning traps
    - The Paul trap for laser cooling
- Summary & perspectives

# Motivation
# What is the mass of the electron antineutrino?

- Direct measurement of the mass by analyzing the end of the β-decay spectrum independent whether the neutrino is a Majorana or a Dirac particle

$$\frac{dN}{dE} = k \times F(E,Z) \times p \times E_{total} \times (E_0 - E_e)^2 \times \left[ (E_0 - E_e)^2 - m_\nu^2 \right]^{1/2}$$




$$F(\delta E) = \int_{-\delta E}^{0} N(E_\beta)\, dE \approx 2\left(\frac{\delta E}{E_0}\right)^3$$

- **The best candidates will be decaying nuclei with low *end-point energies***
- **Tritium:** $T_2 \rightarrow ({}^3\mathbf{HeT})^+ + e^- + \bar{\nu}_e$

  $Q = 18.6\ \mathbf{keV}$ $T_{1/2} = 12.3\ \mathbf{y}$

- **$^{187}$Re:** ${}^{187}\mathrm{Re} \rightarrow {}^{187}\mathbf{Os} + e^- + \bar{\nu}_e$

  $Q = 2.5\ \mathbf{keV}$ $T_{1/2} = 43.2 \times 10^9\ \mathbf{y}$

***Q*** **has to be unambiguously determined (with δ*m*/*m* of at least $10^{-11}$) from the mass difference $^{187}$Re-$^{187}$Os using a Penning trap**

# Present status in Penning trap mass spectrometry:
# The two presently applied techniques

## Existing techniques

1. **Time-of-flight resonance technique** allows for $\delta m/m \sim 10^{-8}$, for singly charged ions, and up to $\delta m/m \sim 10^{-10}$ for highly charged ions.

- Drawback: one needs several ions in a reasonable time interval in the trap, e.g. **48 ions in 93 hours for $^{256}Lr^{++}$** (previous talk by M .Block)**.**

2. **Induced image-current detection technique** allows for $\delta m/m \sim 10^{-11}$ for singly or multiply-charged ions and subatomic particles, even for antiprotons.

- Drawback: It has been used for low or medium mass-to-charge ratios.

## Proposed technique

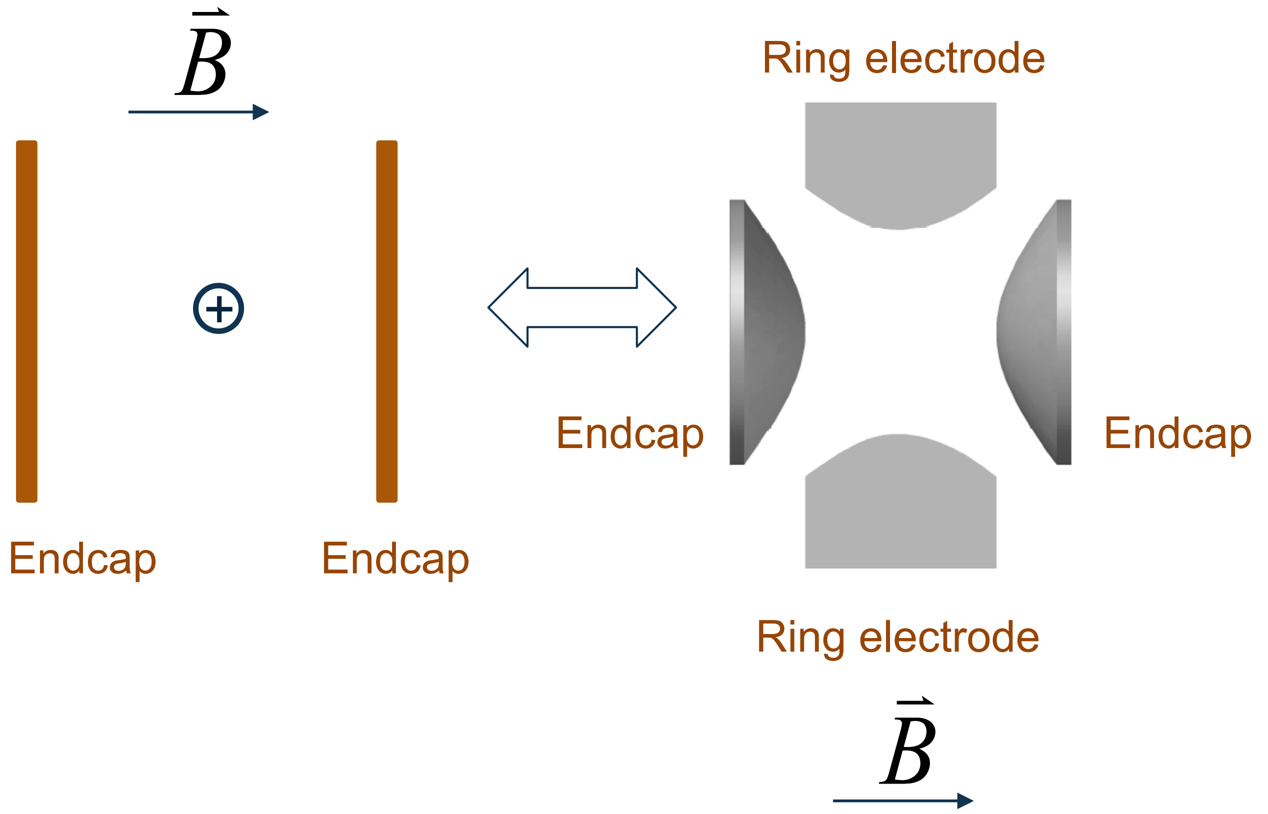
The excellent performance is not yet sufficient for investigating elements with $Z$>103 at GSI, nor for the pair $^{187}$Re-$^{187}$Os.

**It will yield the highest sensitivity.**

The signal-to-noise ratio decreases with increasing mass-to-charge ratio. Mass measurements on very heavy isotopes were not carried out up to now.

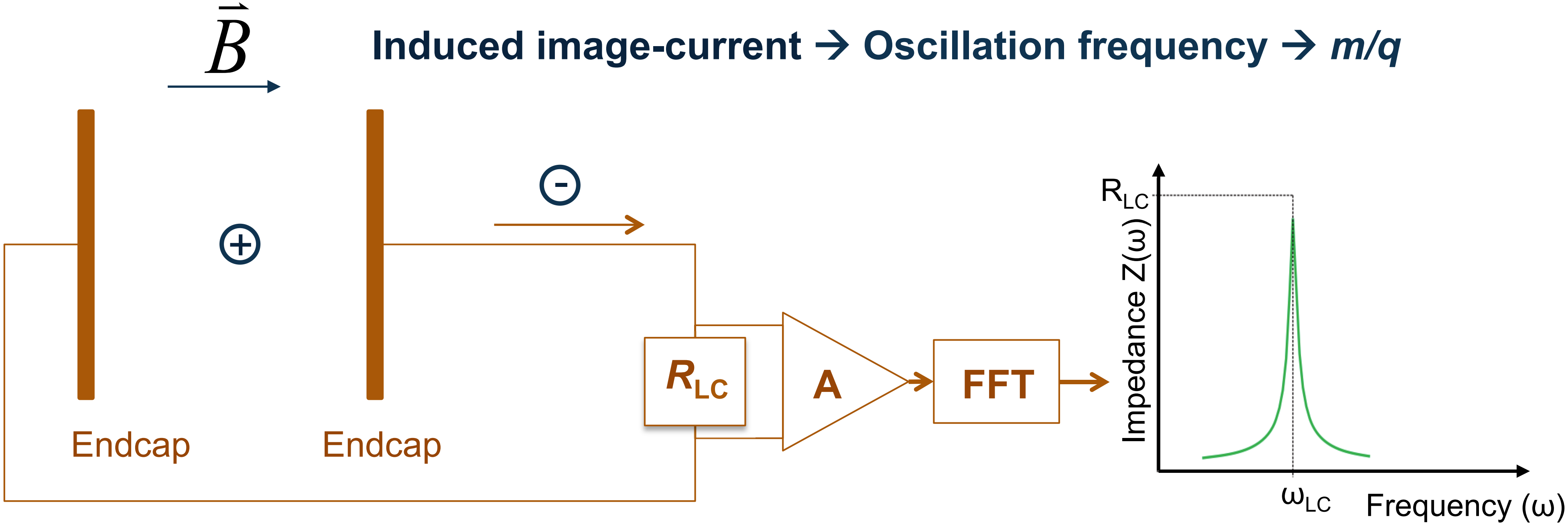
**It is not dependent on the mass-to-charge ratio.**

# The TRAPSENSOR project
## A new concept in mass spectrometry



# The TRAPSENSOR project
# A new concept in mass spectrometry

**Induced image-current → Oscillation frequency → *m/q***




$$I_{induced} \propto q \cdot \frac{\nu_z}{z_0} \cdot \rho_z$$

$$\frac{S}{N} \propto q \cdot \frac{\rho_z}{z_0} \cdot \sqrt{\frac{\nu_z}{\Delta\nu}} \cdot \sqrt{\frac{Q}{TC_T}}$$

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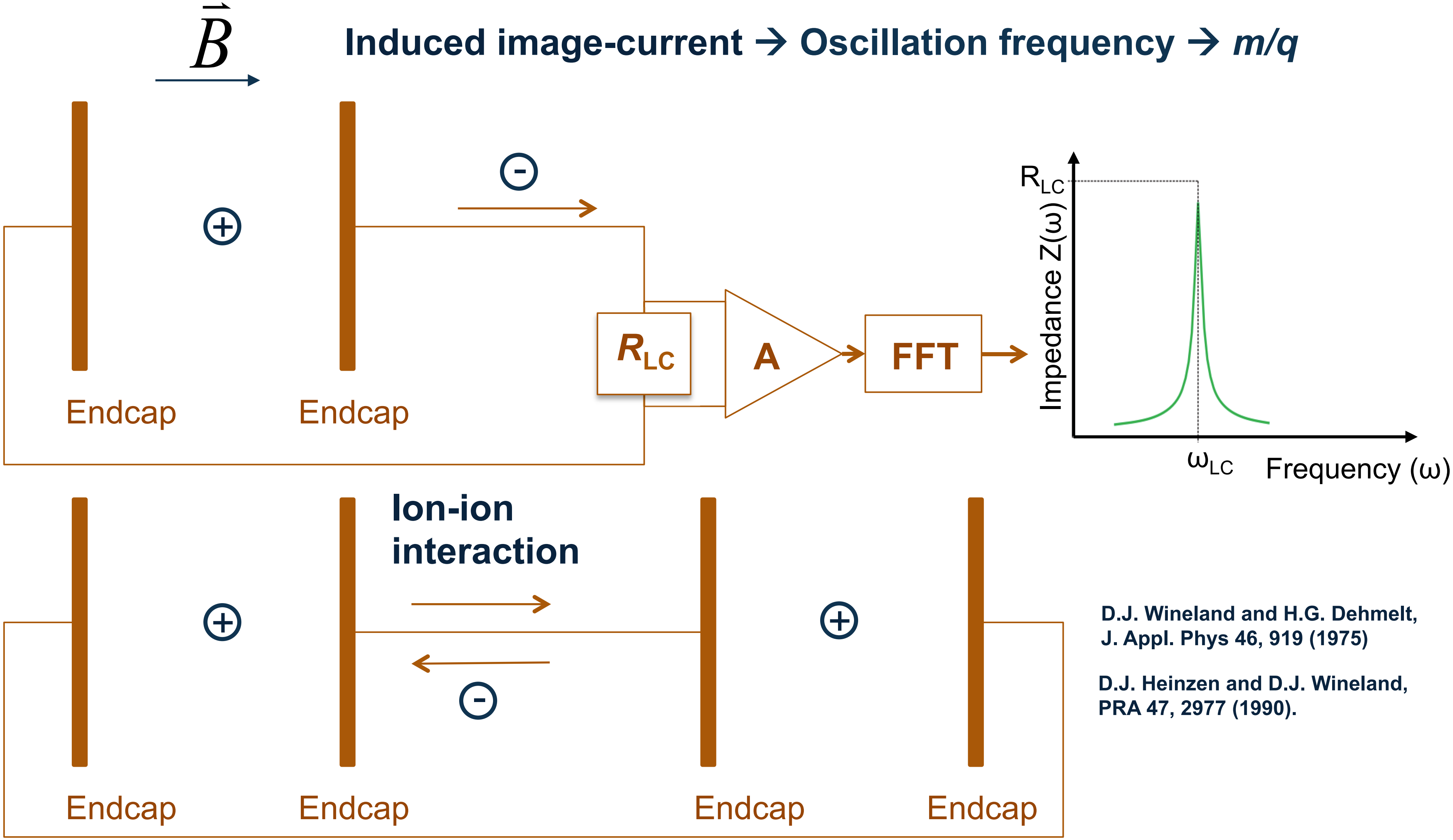


**D.J. Wineland and H.G. Dehmelt, J. Appl. Phys 46, 919 (1975)**

**D.J. Heinzen and D.J. Wineland, PRA 47, 2977 (1990).**

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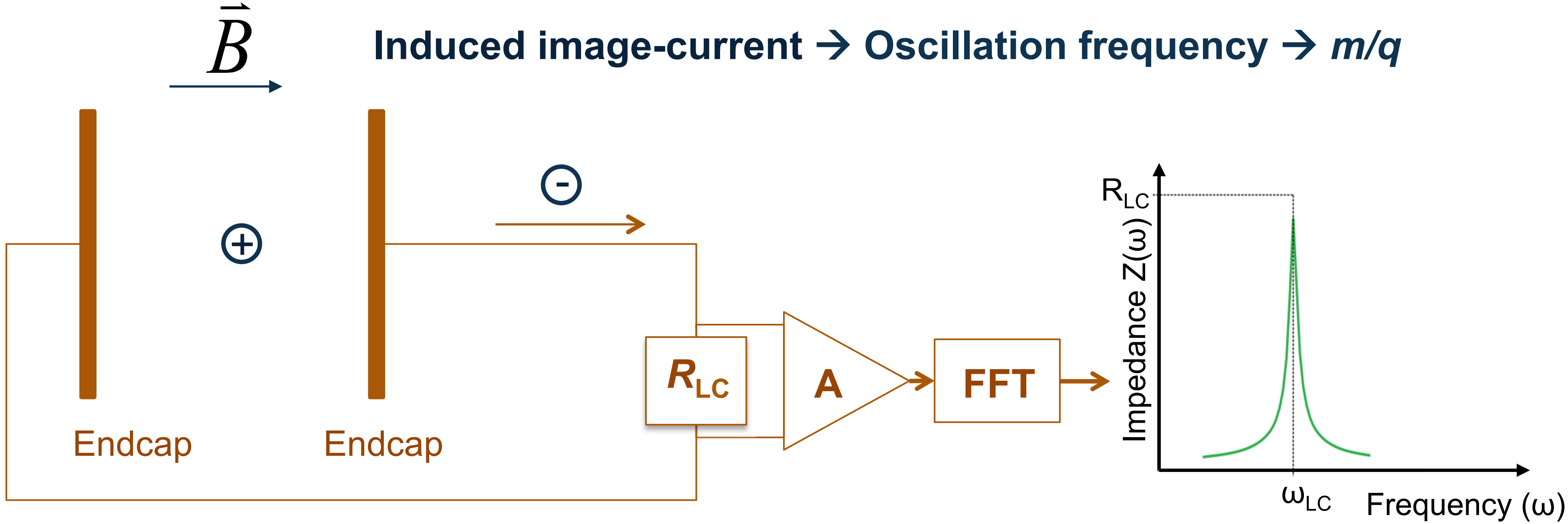
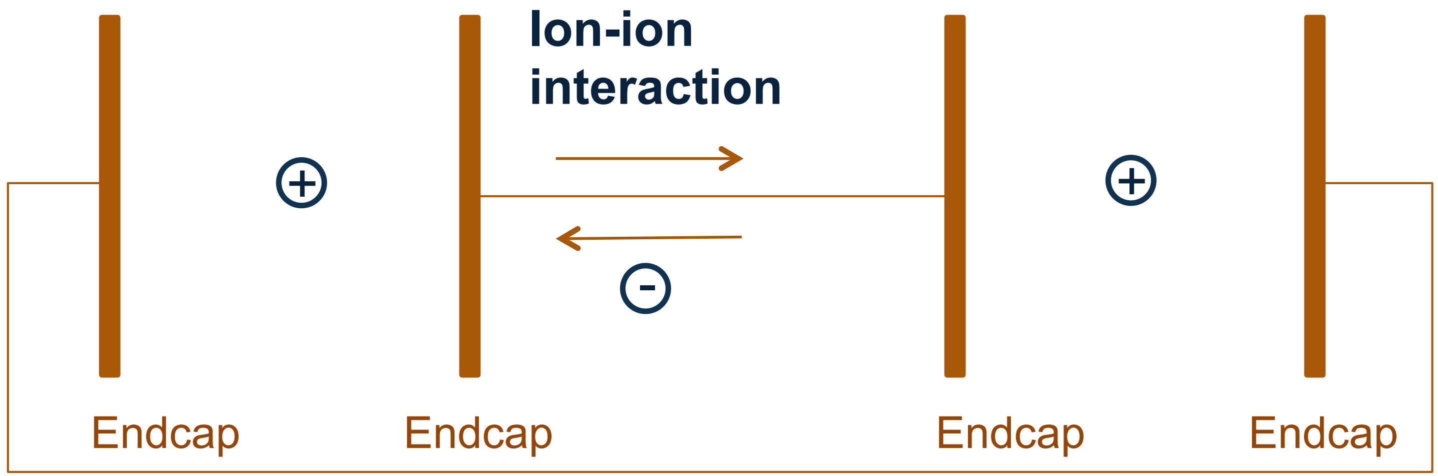
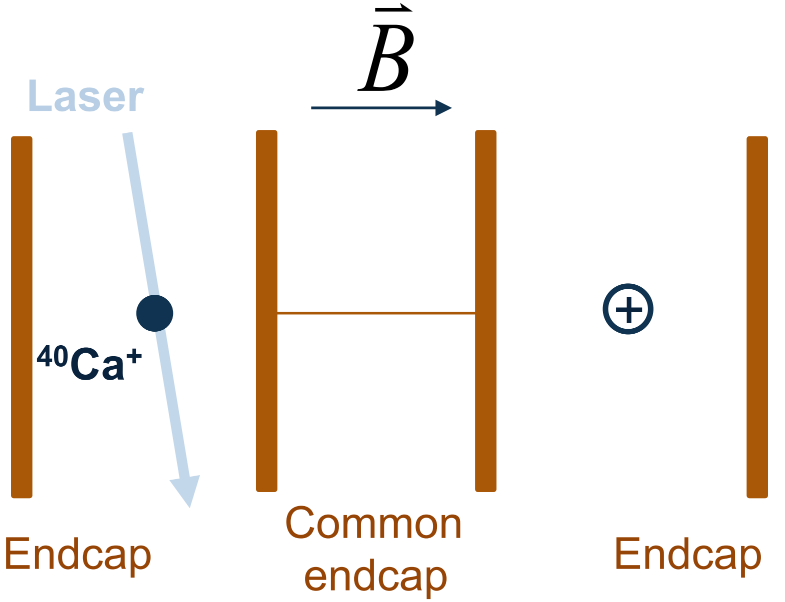


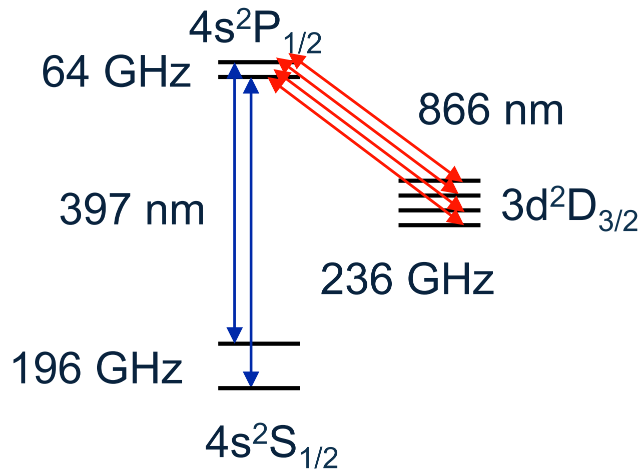




**How to detect the energy exchange?**

# The TRAPSENSOR project
## A new concept in mass spectrometry




**Level scheme for a $^{40}Ca^{+}$ ion in a 7 T magnetic field (Doppler cooling)**



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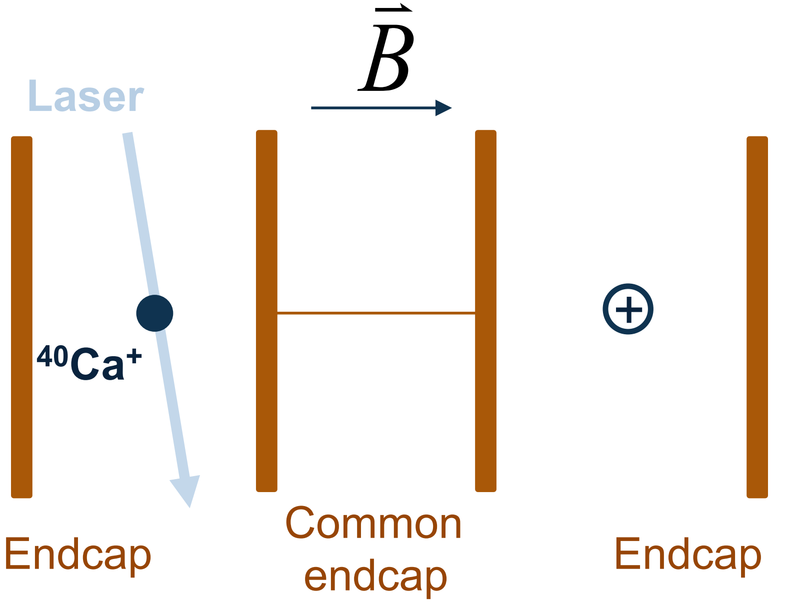


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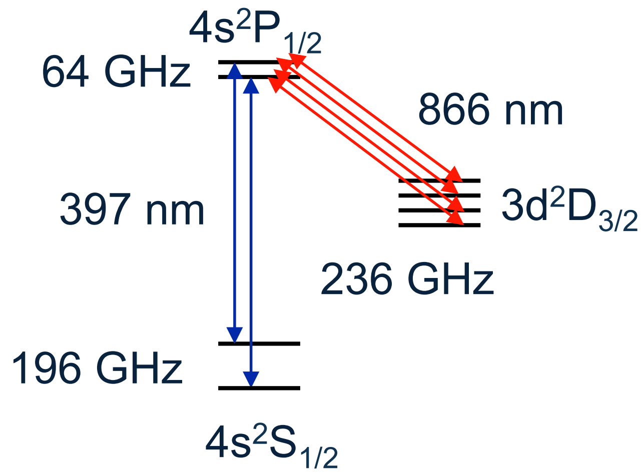


1. Stop excitation of any motional frequency
2. Convert to axial motion
3. Laser OFF → energy transfer

$$t_{exc} = 2\pi^2 \nu_z \sqrt{L_{i_1} L_{i_2}} C_T$$

**D.J. Heinzen and D. J. Wineland, Phys. Rev A 42, 2977 (1990)**

4. Laser ON with strong focus
5. Observation of the ion motion through fluorescence photons→ motional frequency

# The TRAPSENSOR project
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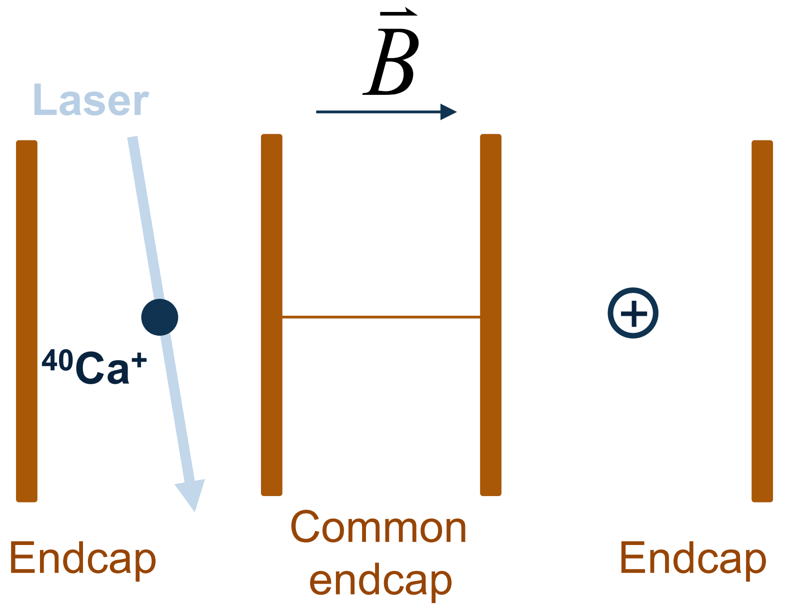
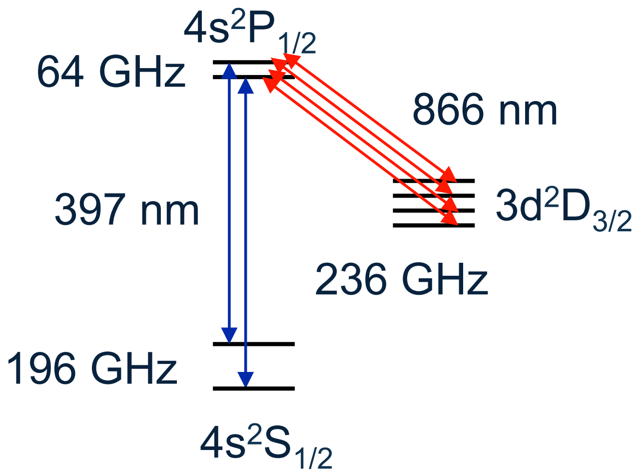



Level scheme for a $^{40}Ca^{+}$ ion in a 7 T magnetic field (Doppler cooling)

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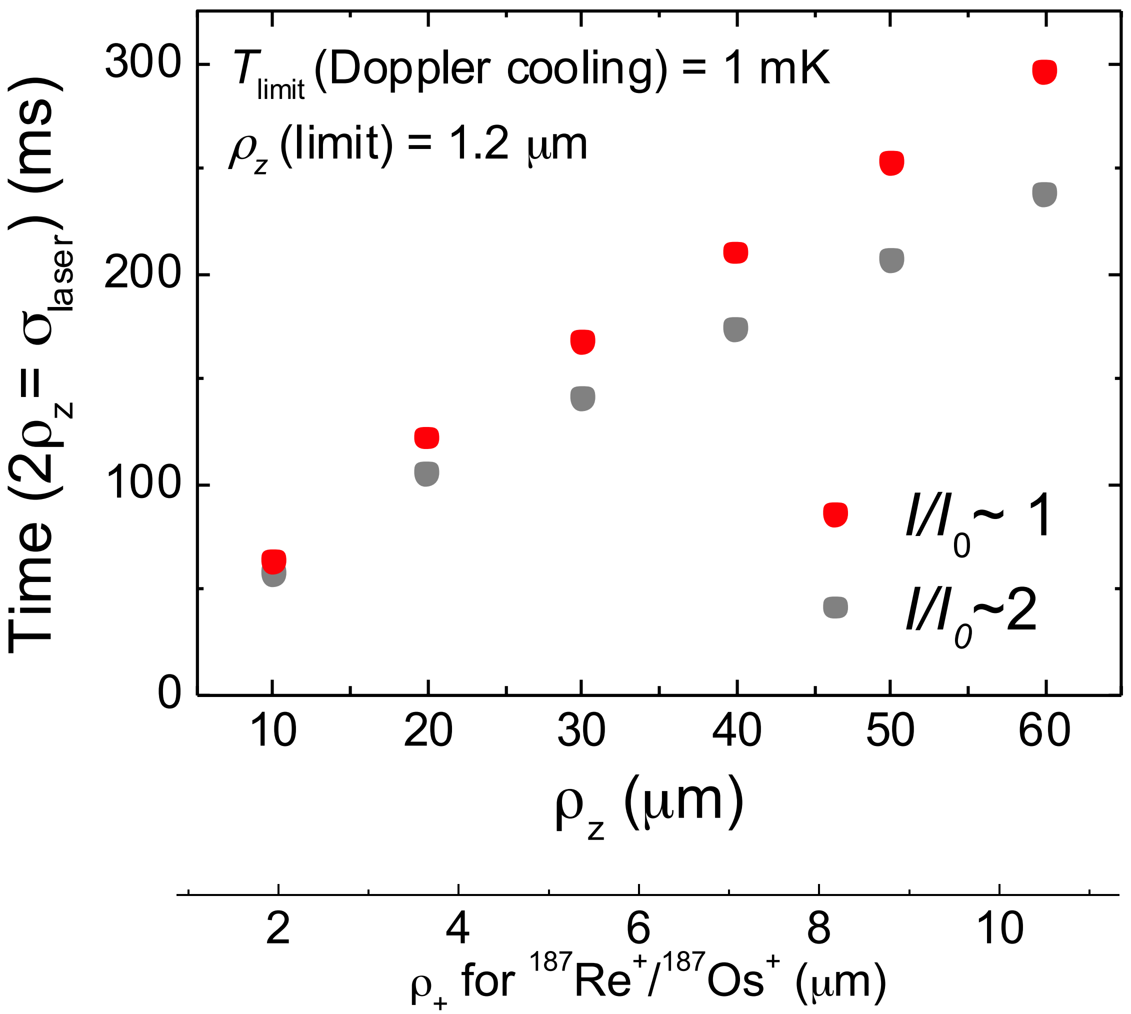
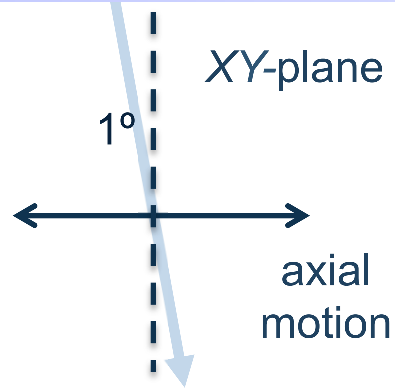
4. Laser ON with strong focus
5. Observation of the ion motion through fluorescence photons→ motional frequency

1. The ion motion in the RF regime will be detected by photons.
2. This signal is only depending on the excitation amplitude and not on the mass or the charge of the ion.
3. Small excitation amplitudes can already yield observable signals reducing that way systematic effects due to electric field imperfections.

## A new concept in mass spectrometry



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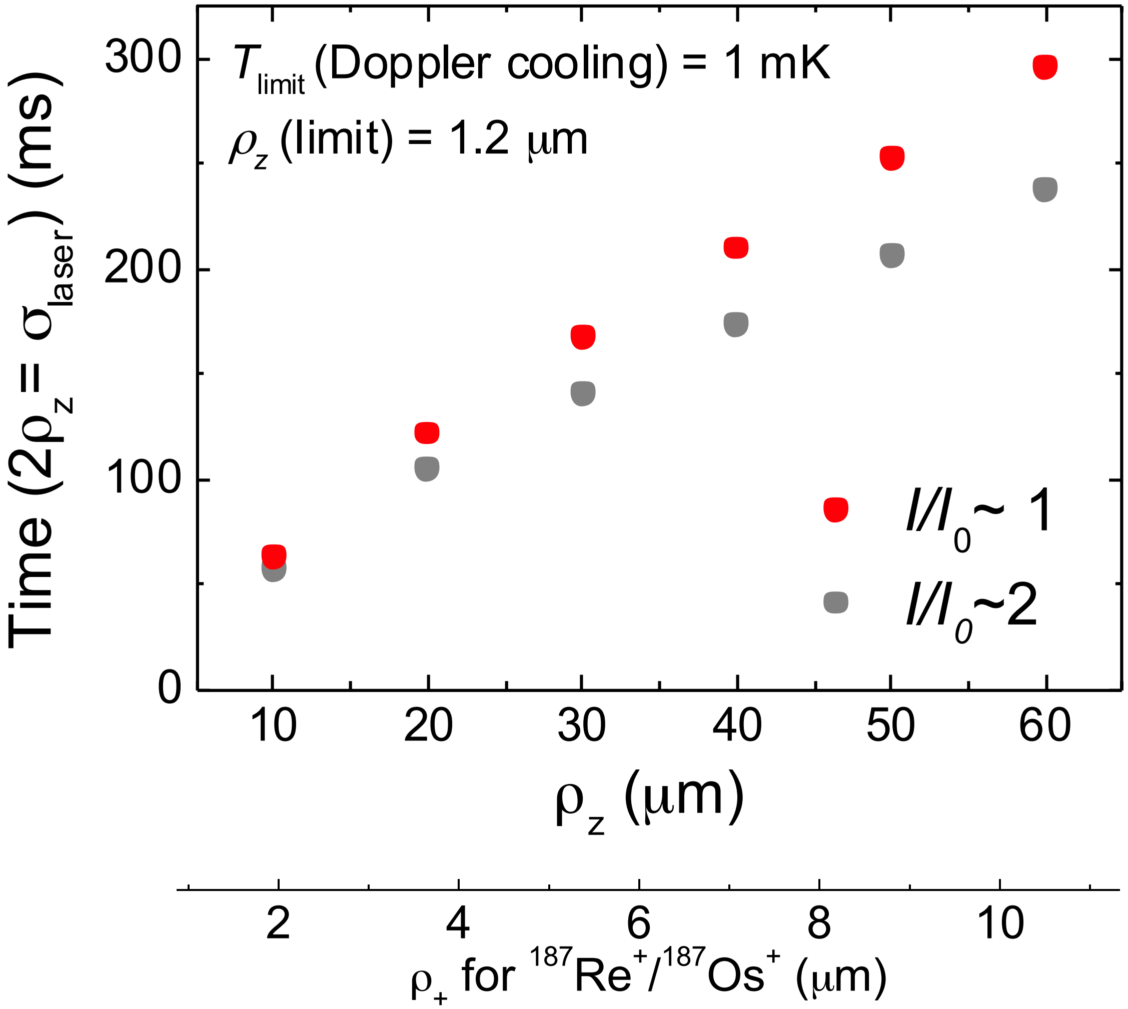
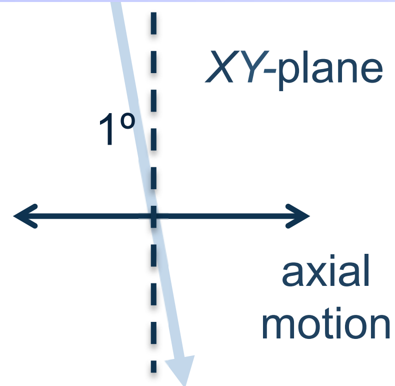
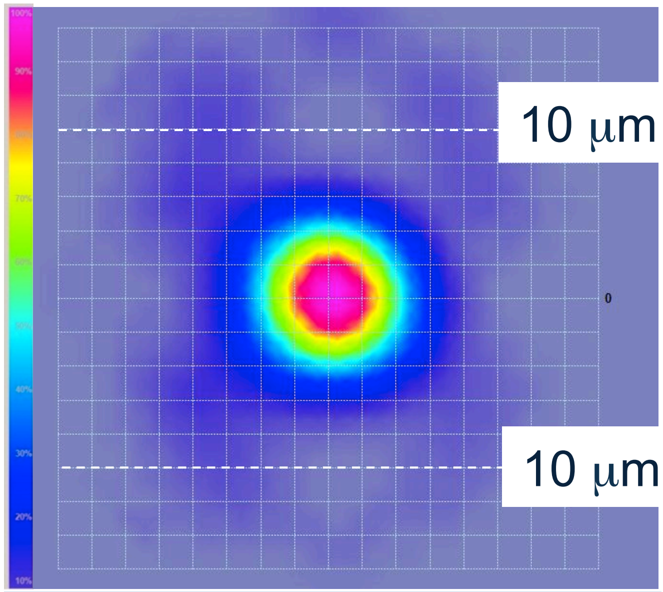
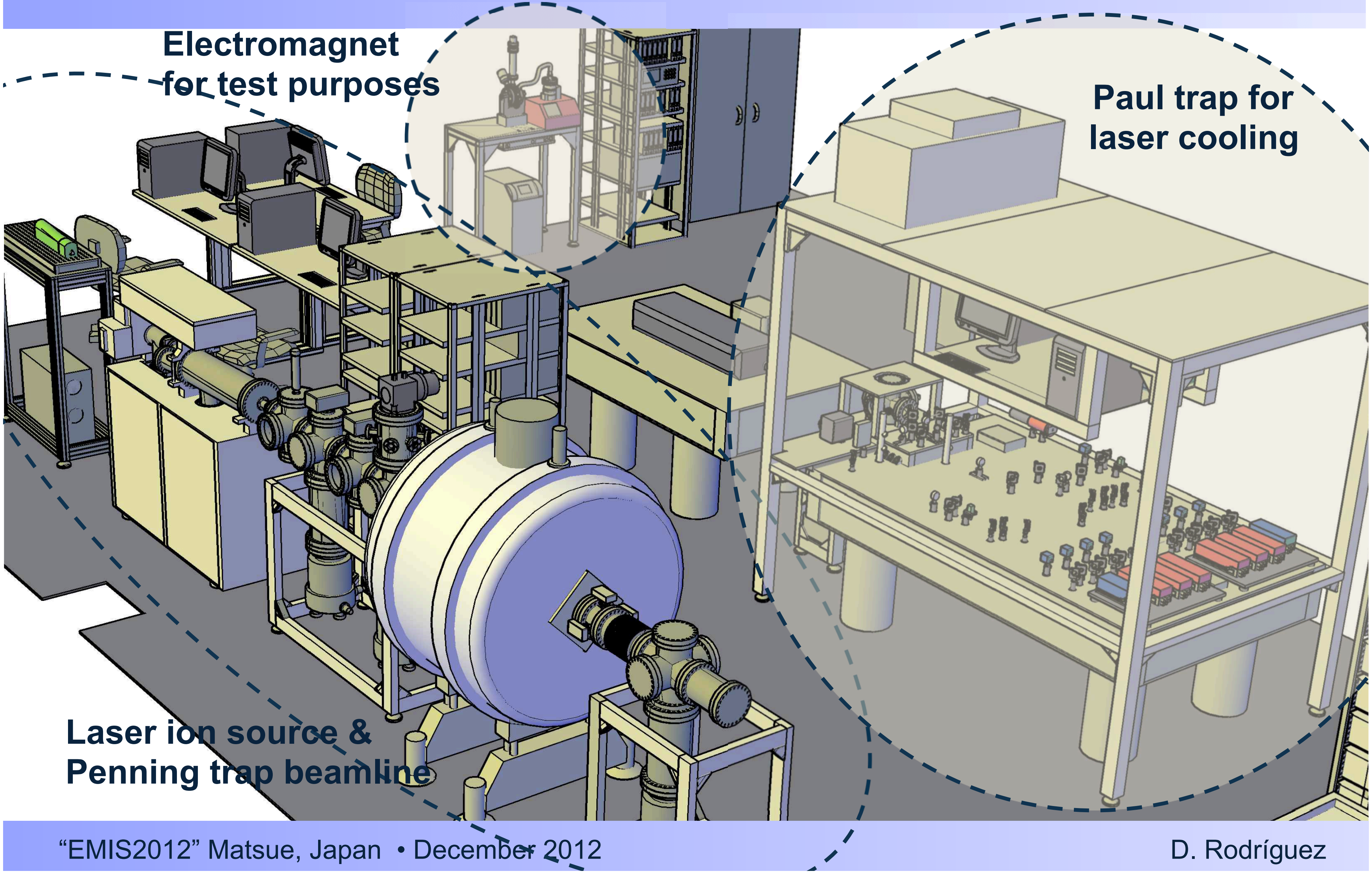



Laser-profile measurement
(397 nm laser)

# Implementation of the project
## The full setup

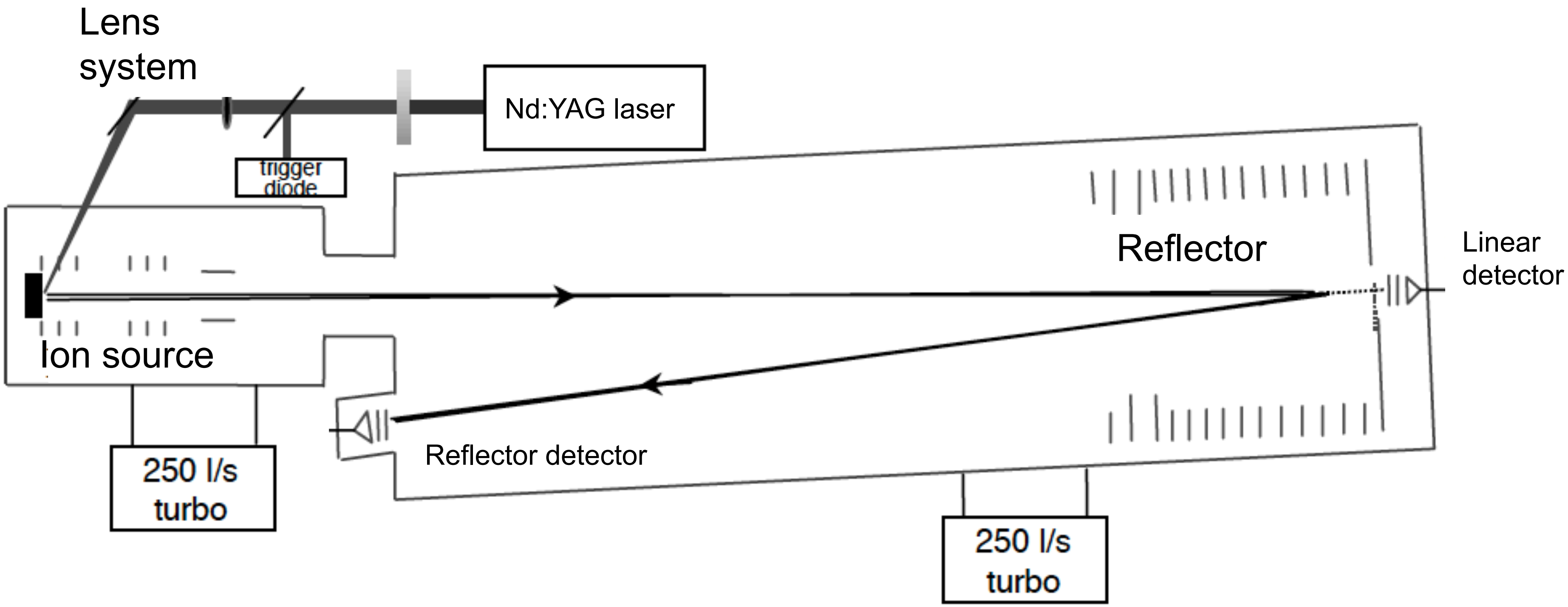


# Implementation of the project
## The lab


**February 2012**

# Implementation of the project
## The lab

## Status and results
# The ion source and the transfer section



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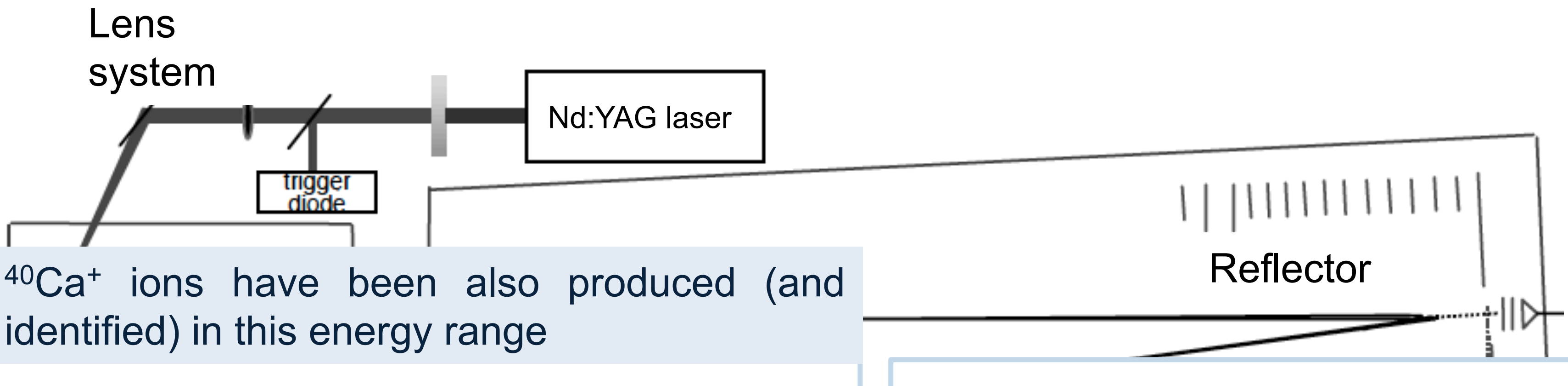
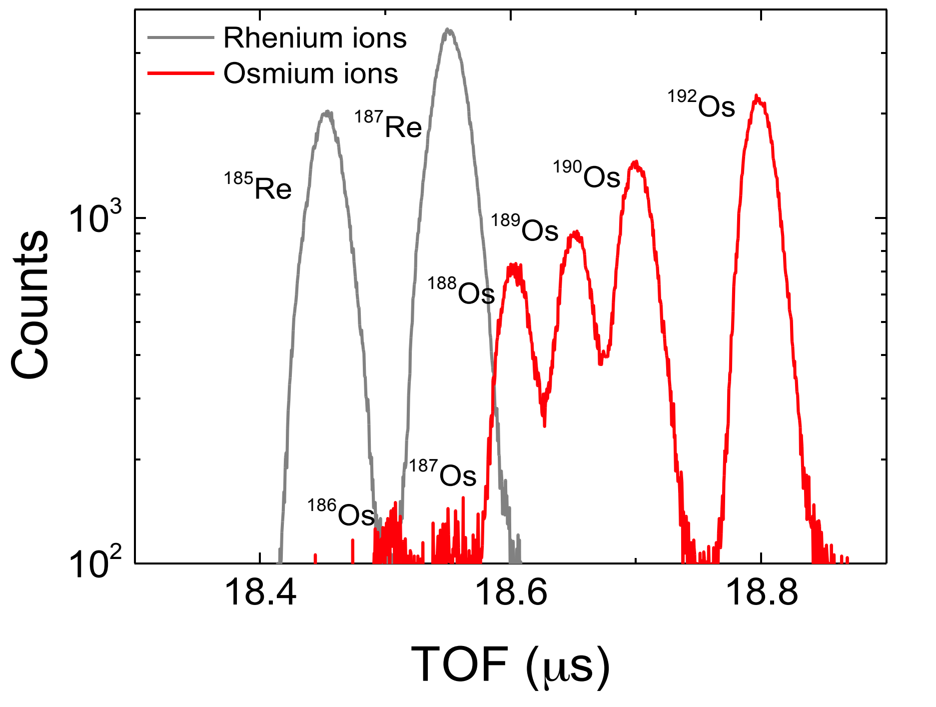
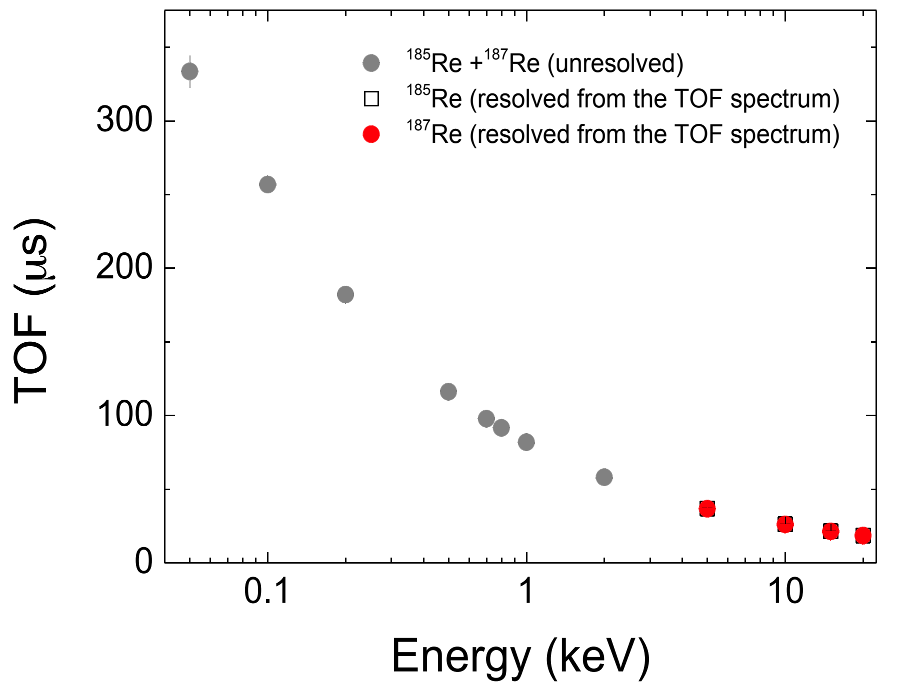



$^{40}Ca^{+}$ ions have been also produced (and identified) in this energy range

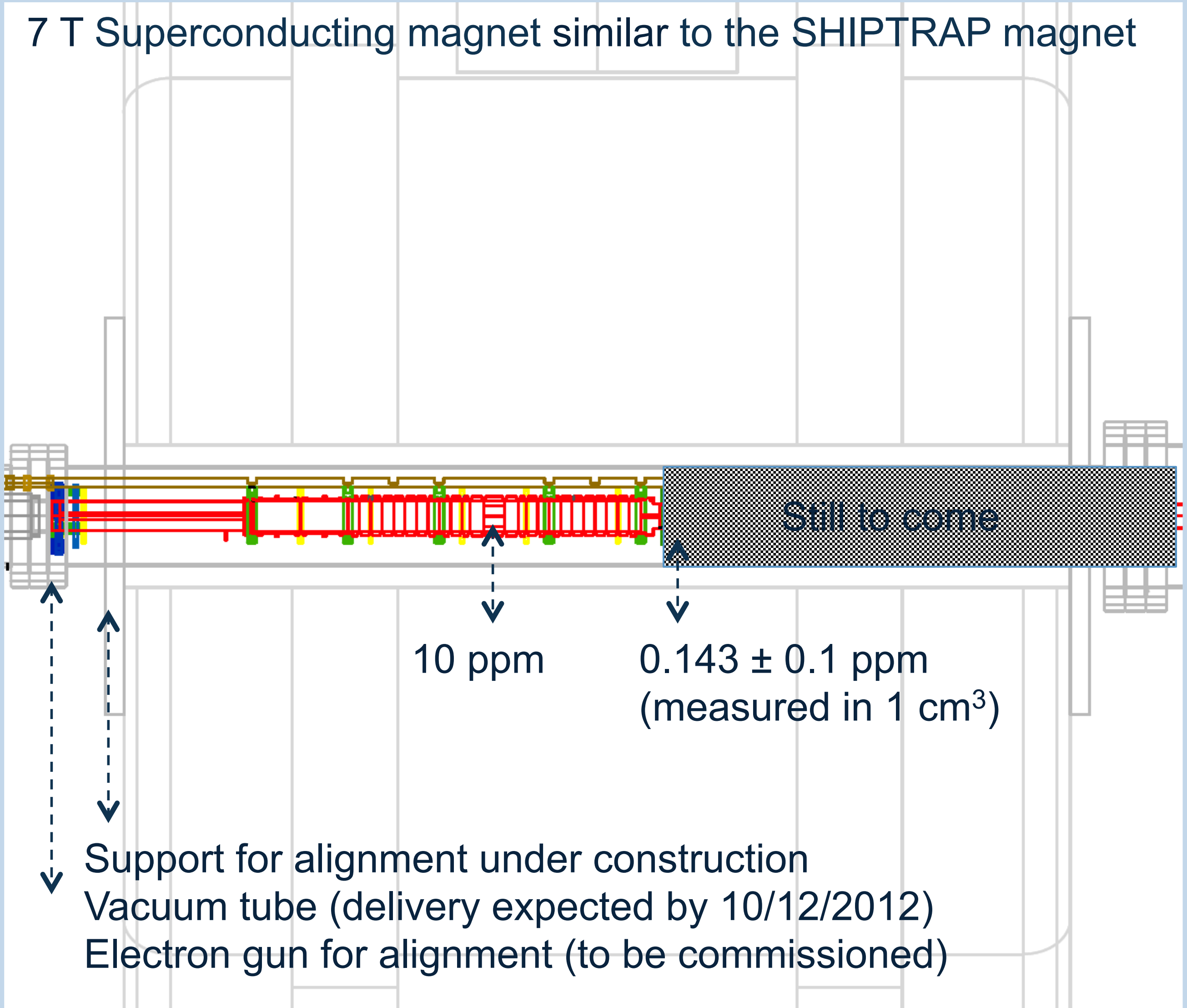


## Status and results

# The superconducting magnet and the Penning traps

7 T Superconducting magnet similar to the SHIPTRAP magnet




Support for alignment under construction
Vacuum tube (delivery expected by 10/12/2012)
Electron gun for alignment (to be commissioned)

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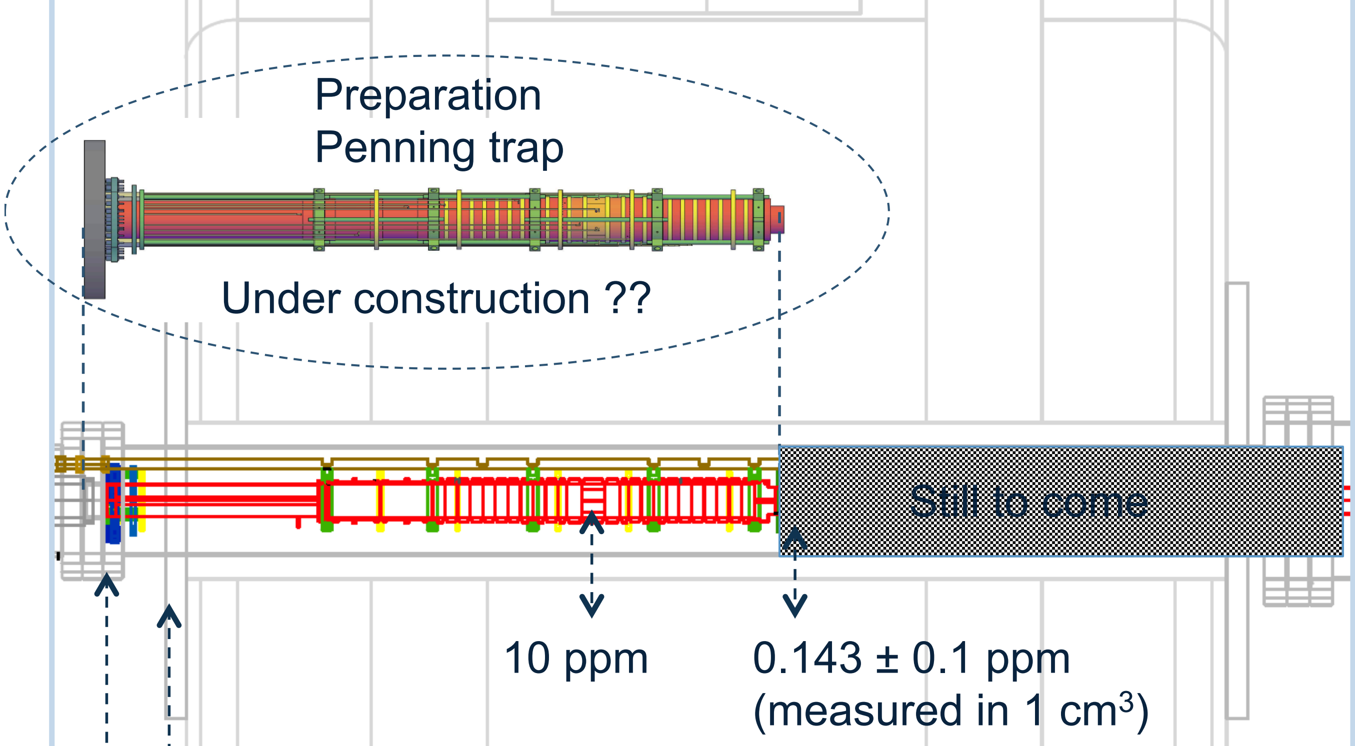


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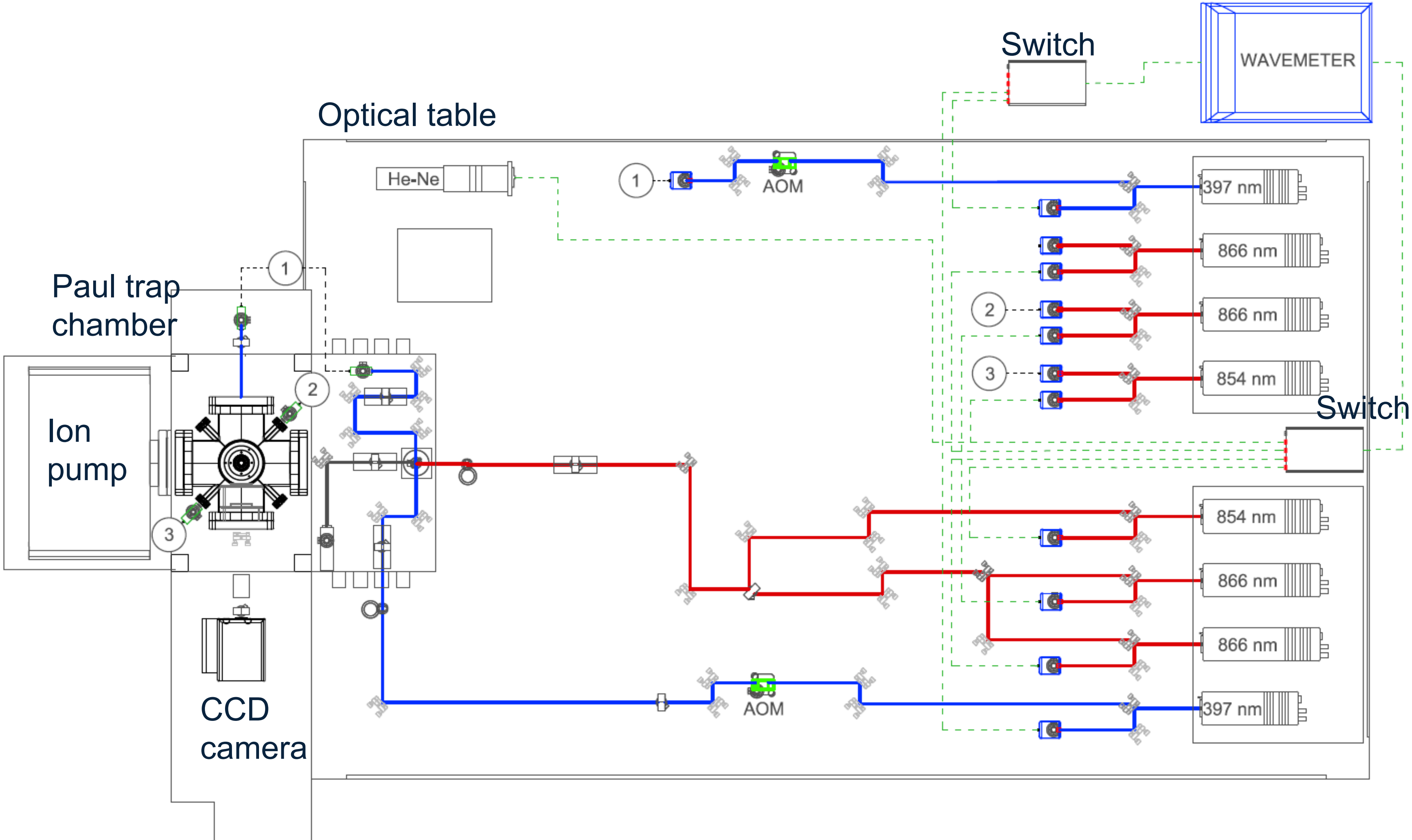

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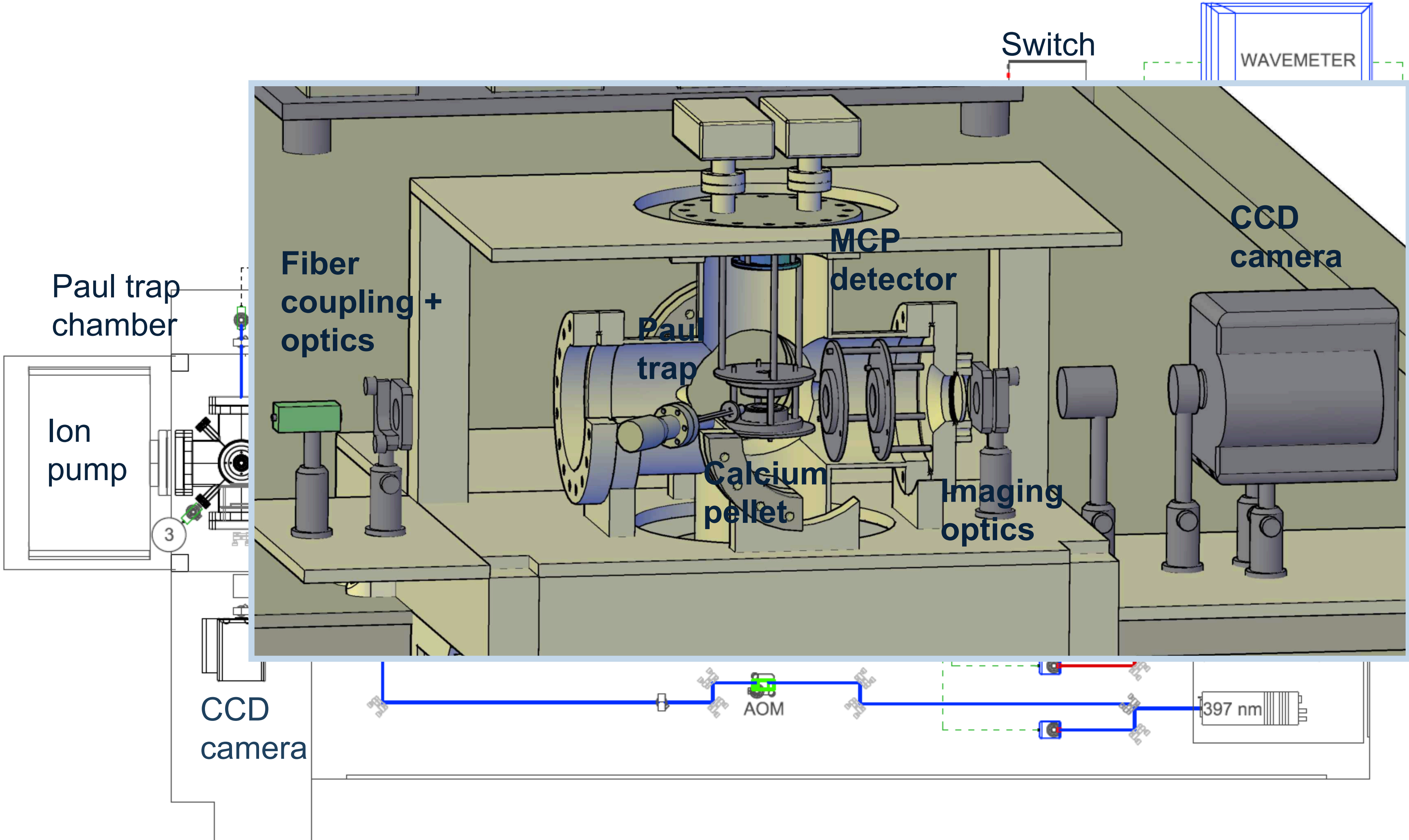
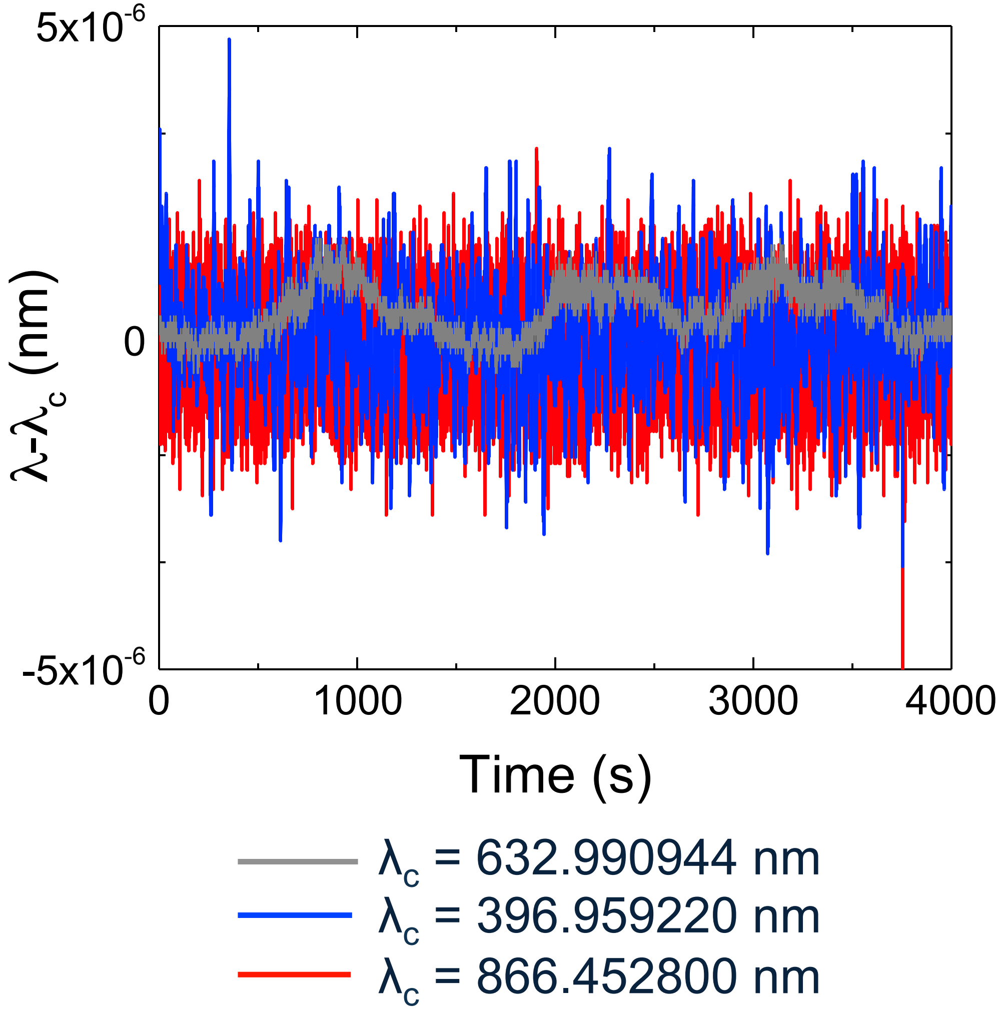
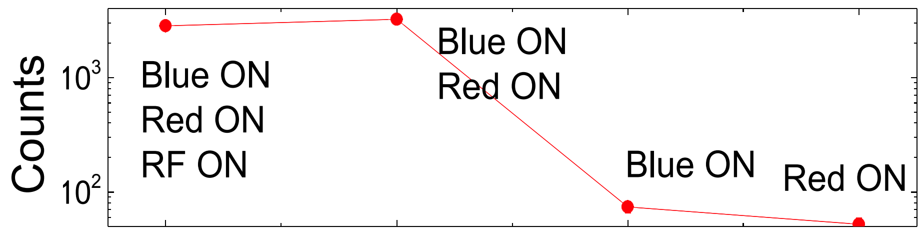


# Implementation of the project
## The Paul trap for laser cooling

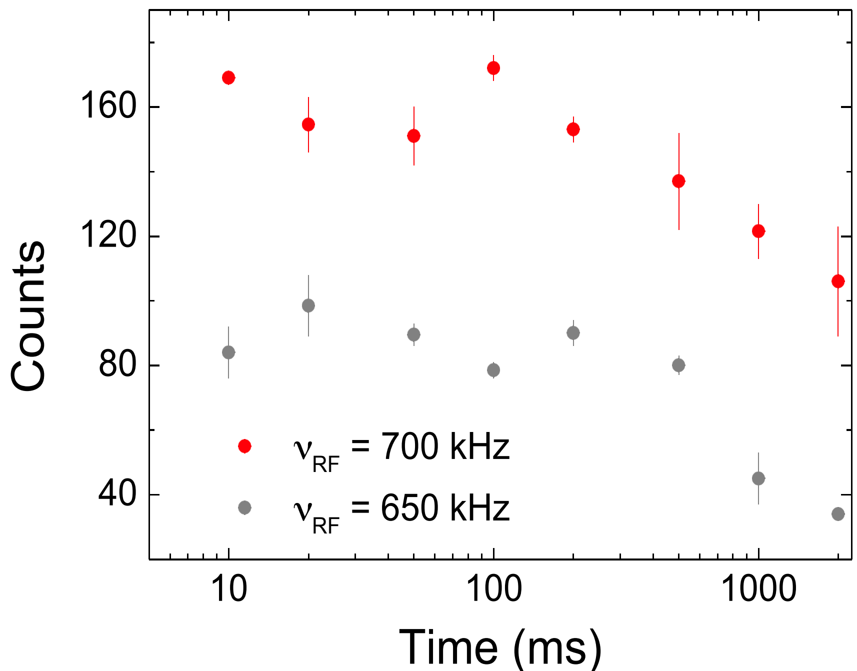
### Lasers-frequency locking




### Fluorescence measurement




### Storage time measurement



# Summary & perspectives

- A new concept for mass measurement using Penning traps is under construction aiming at improving sensitivity and accuracy.
- In the first stage of the project, two setups are under development:

1. A Paul trap setup for laser cooling which is almost completed. Laser cooling on the sensor ion should be accomplished soon.
2. The ion source & the Penning traps. The source is in operation and the preparation trap is under construction. Wishes are to have it in the magnet bore by March 2013. We intend to have a precision trap for TOF mass measurements using the full beamline by end of 2013.

- Discussions on issues related to the design of the sensor trap already started. The trap should be firstly operated as an RF trap in the setup presented here by mid of 2013.
- Tests of the sensor RF-trap should be completed by end of 2014 to start the completion of the sensor Penning-trap.
- If we manage with this, we are in the time line of the project to carry out mass measurements by 2015 (second stage of the project).

# People

**Universidad de Granada**
Juan Manuel Cornejo (PhD Student)
Antonio Lorenzo (Master Student)
Daniel Rodríguez

**Collaborators/Guests**
Michael Block (GSI)
Dennis Neidherr (GSI)
Dennis Renisch (Univ. Mainz)
Rodolfo Sánchez (GSI)

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Norbert Trautman (Univ. Mainz)
Klaus Wendt (Univ. Mainz)

Thank you your attention