# Status of the anion source CERN, 17 Dec 2024

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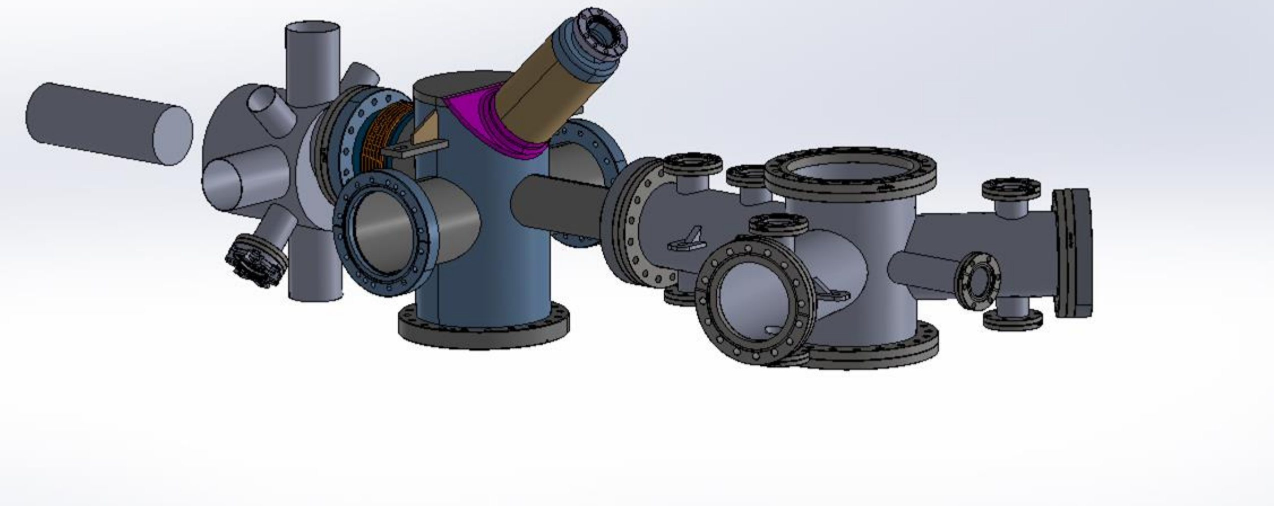
# Our goal

- A source of negatively charged ions
  - Controlled composition of the ion ensemble
  - Controlled energy, time characteristics, and geometry of the pulse
  - Long-lasting source
  - Compatible with the AEgIS main apparatus
  - compact
- The ions can be co-trapped with antiprotons (the same sign of the electric charge), and later be used for production of antiprotonic atoms



# The device works!

- We can produce pulses of about 60 000 iodine anions in several-minute intervals
- We still can do better!
- Stable, long lasting source
- Repeatable results

# Positive vs negative ions

**cation**

- Relatively easy to produce:

$$A + e^- \rightarrow A^+ + 2e^-$$

$$A + h\nu \rightarrow A^+ + e^-$$

- May be cooled optically, for example in a Doppler scheme

**anion**

- Attachment of an electron forbidden by the Energy and momentum conservation

$$A + e^- \rightarrow A^-$$

- Only one bound state – optical cooling impossible
- 3-body interactions improbable due to vacuum conditions
- Electron dissociative attachment may be used:

$$AB + e^- \rightarrow A^- + B$$

# A brief summary of the technique used

- Electron dissociative attachment inside a multi-segment linear Paul trap

$$I_2 + e \rightarrow I + I^-$$

$$I_2 + e \rightarrow I^+ + I^- + e$$

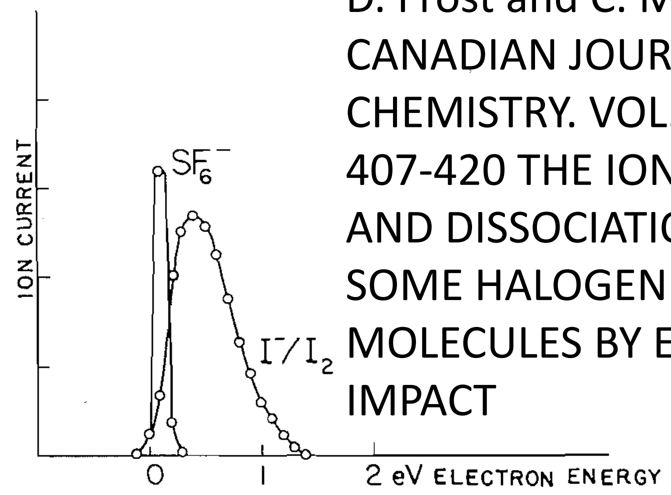



FIG. 14. The resonance capture peak for the formation of $I^-$ from iodine by electron impact.

D. Frost and C. McDowell, CANADIAN JOURNAL OF CHEMISTRY. VOL. 38. 1960, 407-420 THE IONIZATION AND DISSOCIATION OF SOME HALOGEN MOLECULES BY ELECTRON IMPACT

- Iodine:
  - Mass 127 a.m.u. (only one natural isotope)
  - Electron affinity 3.06 eV
  - The heaviest 2-atomic, homonuclear molecule
  - Solid at room temperature

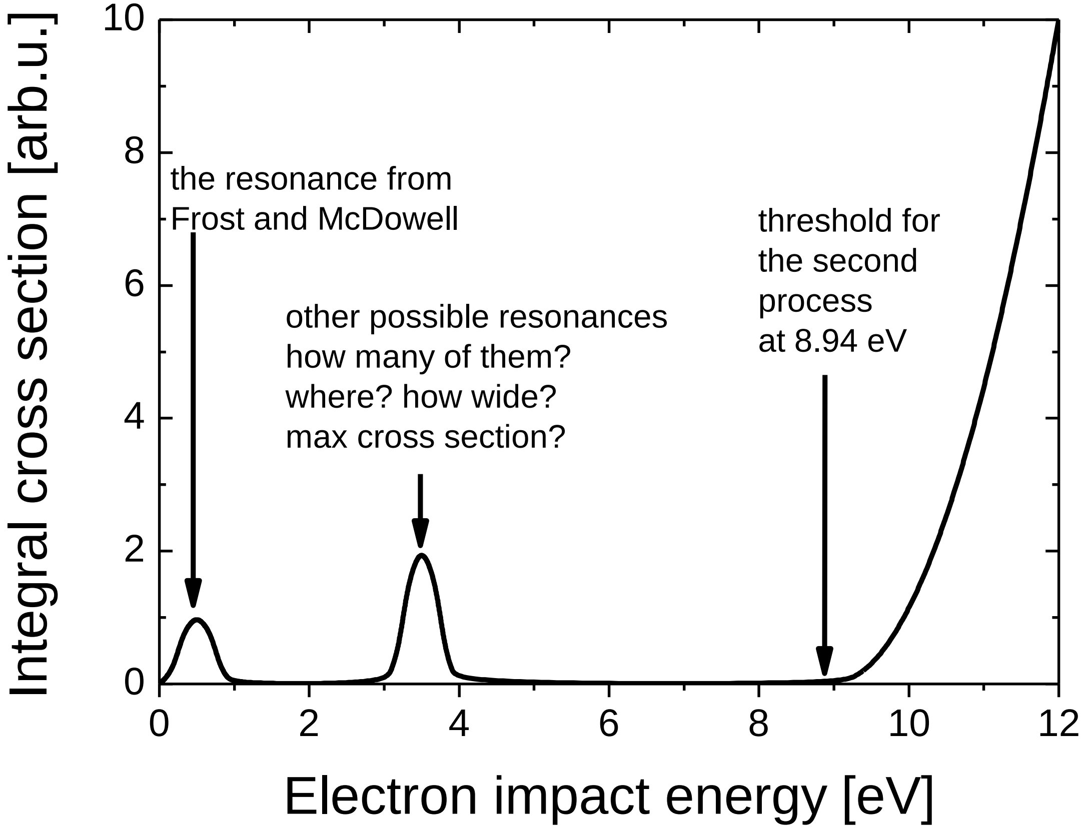
# Expected cross sections and final kinetic energies

$$I_2 + e \rightarrow I + I^-$$

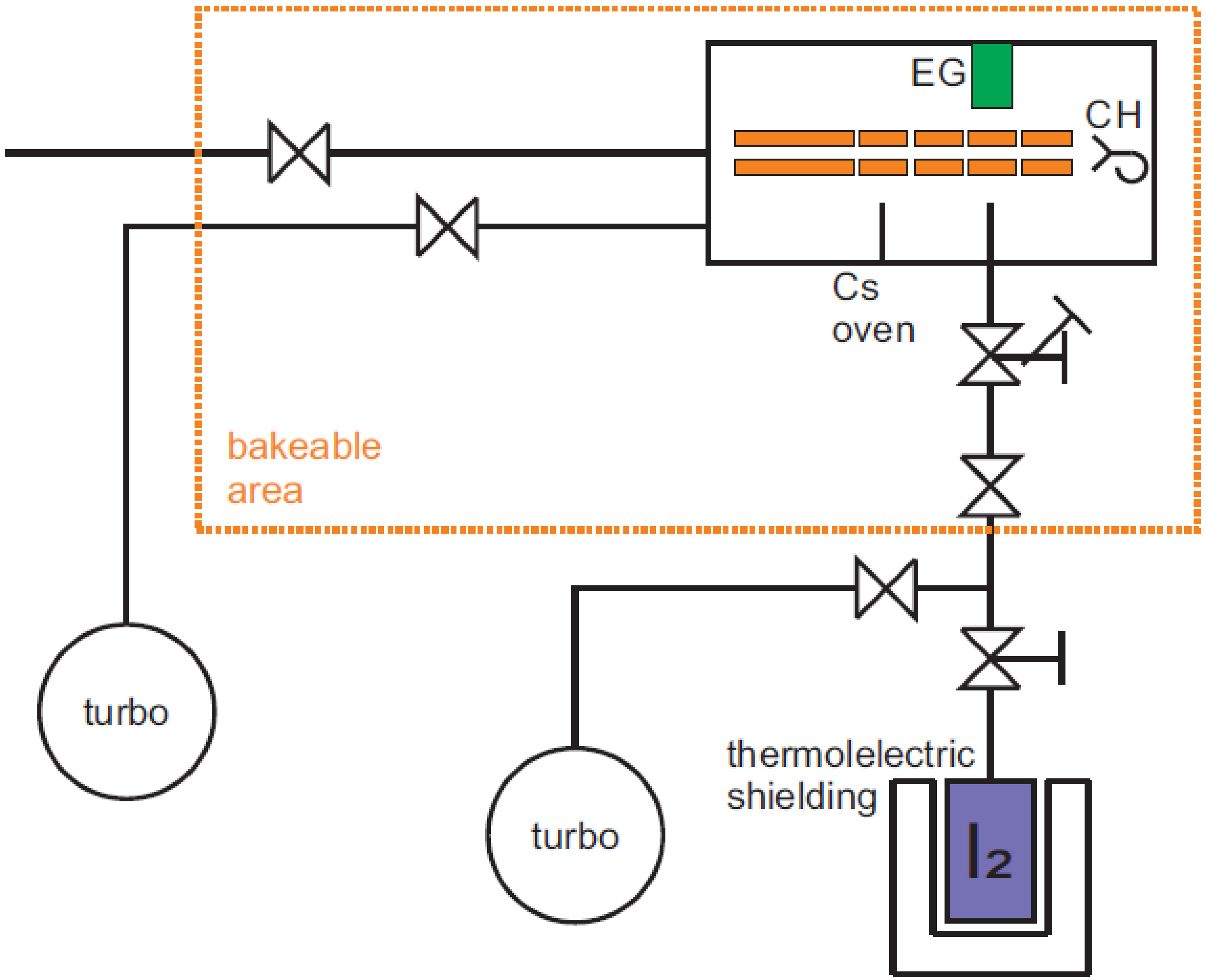
$$E_{anion} = \frac{E_{electron}}{2} + 0.76eV$$

$$I_2 + e \rightarrow I^+ + I^- + e$$

$$E_{anion} \leq \frac{E_{electron}}{2} - 4.47eV$$

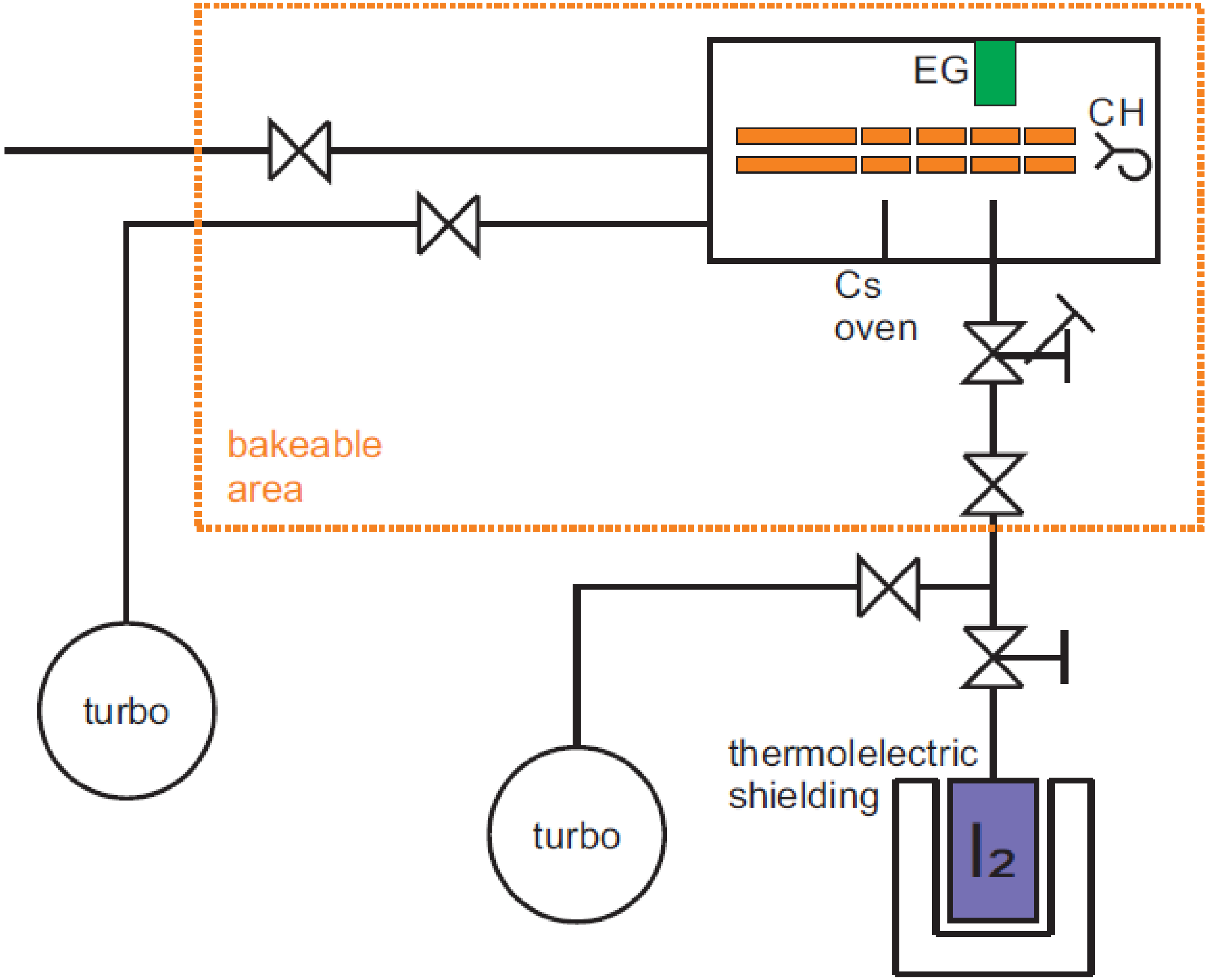


# The first idea of the source (2021)




| temperature [°C] | pressure [mbar] | temperature [°C] | pressure [mbar] |
|---|---|---|---|
| -90 | $6.68 \cdot 10^{-23}$ | 10 | $5.58 \cdot 10^{-2}$ |
| -80 | $9.42 \cdot 10^{-17}$ | 20 | $1.85 \cdot 10^{-1}$ |
| -70 | $8.77 \cdot 10^{-13}$ | 30 | $5.25 \cdot 10^{-1}$ |
| -60 | $5.21 \cdot 10^{-10}$ | 40 | $1.32 \cdot 10^{0}$ |
| -50 | $5.82 \cdot 10^{-8}$ | 50 | $2.98 \cdot 10^{0}$ |
| -40 | $2.18 \cdot 10^{-6}$ | 60 | $6.16 \cdot 10^{0}$ |
| -30 | $3.85 \cdot 10^{-5}$ | 70 | $1.18 \cdot 10^{1}$ |
| -20 | $3.97 \cdot 10^{-4}$ | 80 | $2.14 \cdot 10^{1}$ |
| -10 | $2.74 \cdot 10^{-3}$ | 90 | $3.65 \cdot 10^{1}$ |
| 0 | $1.39 \cdot 10^{-2}$ | 100 | $5.95 \cdot 10^{1}$ |

# Further idea: iodoform instead of iodine for safety reasons




$$I_2 + e \rightarrow I + I^-$$

$$I_2 + e \rightarrow I^+ + I^- + e$$

$$CHI_3 + e \rightarrow CHI_2 + I^-$$

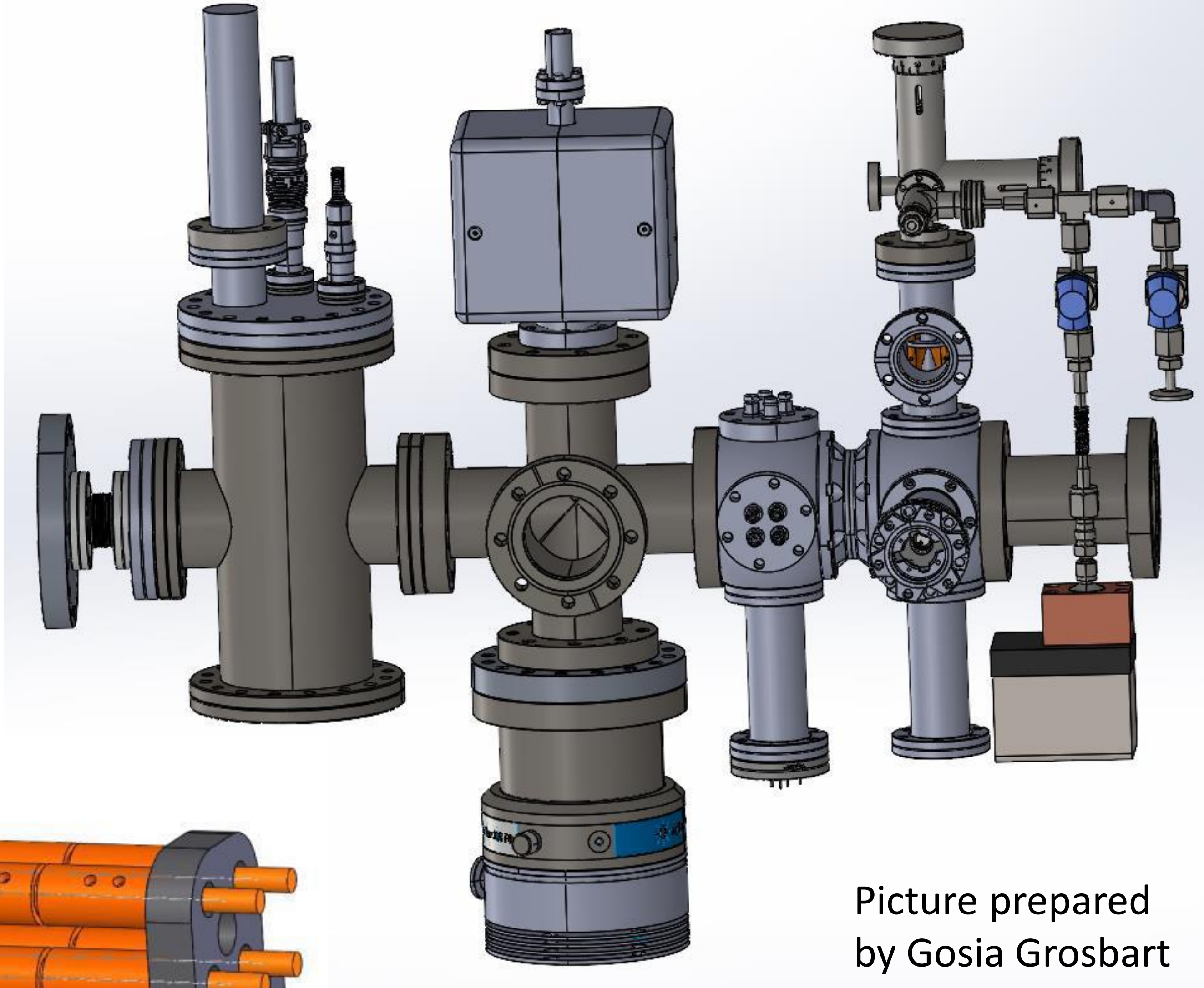
$$CHI_3 + e \rightarrow CHI + I + I^-$$

$$CHI_3 + e \rightarrow CH + I_2 + I^-$$

$$CHI_3 + e \rightarrow CH + 2I + I^-$$

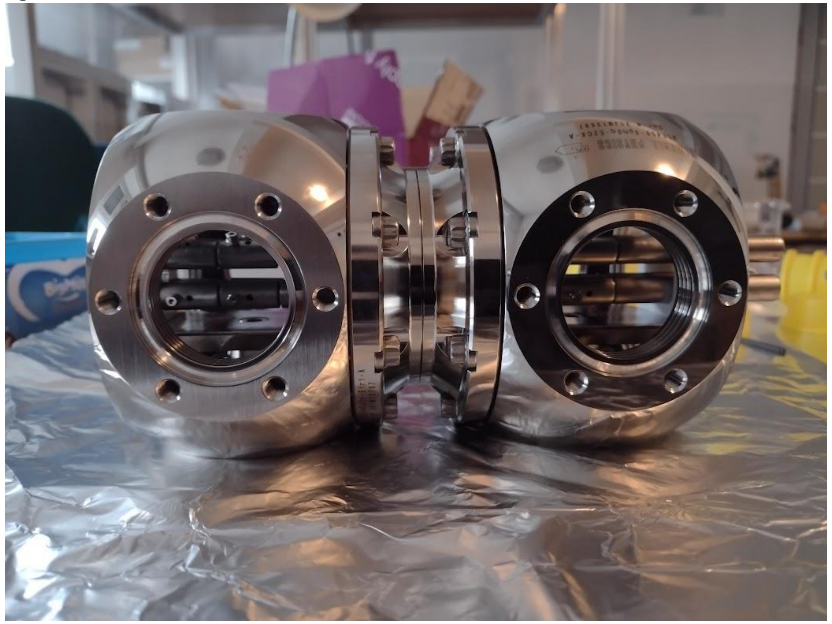
...

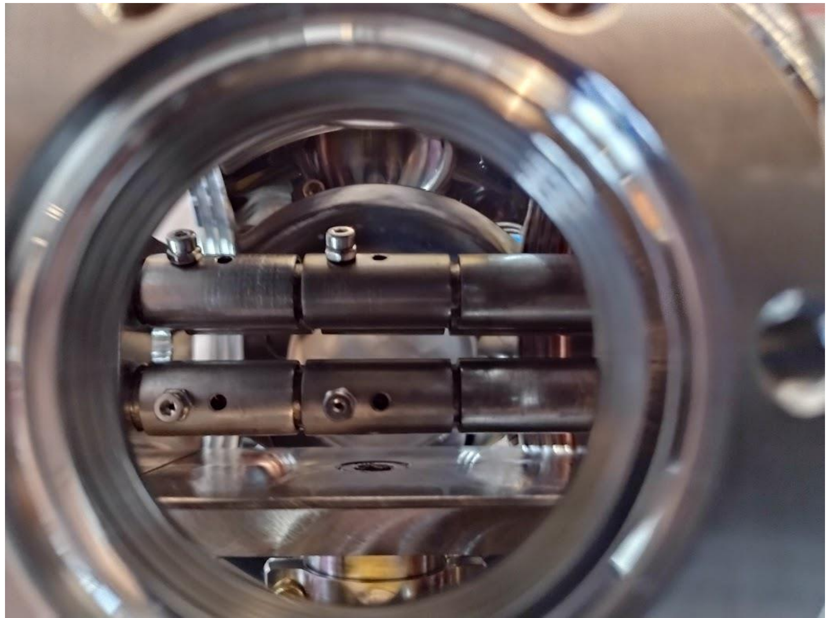
# Design of the device

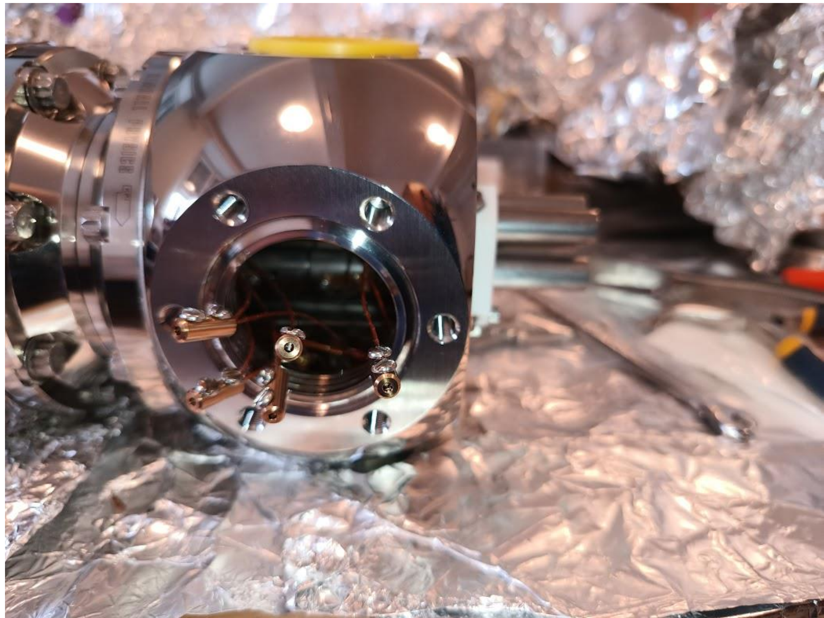


Picture prepared by Gosia Grosbart

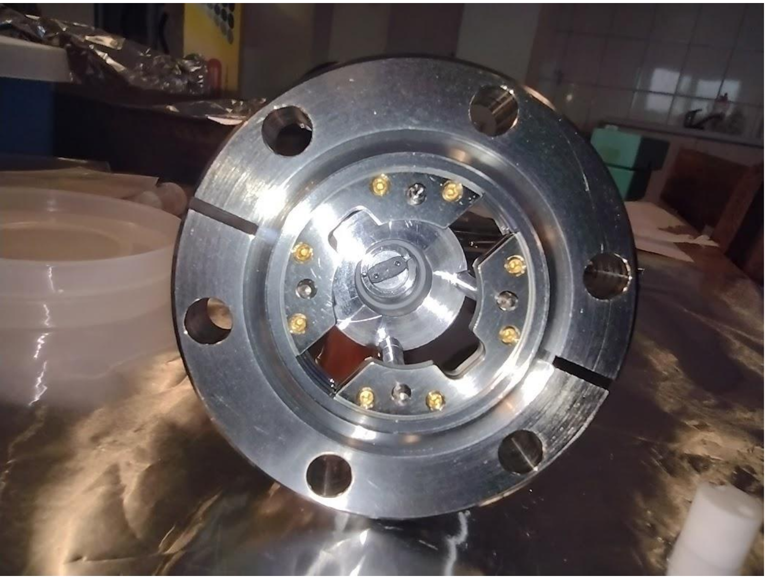
# The linear Paul trap

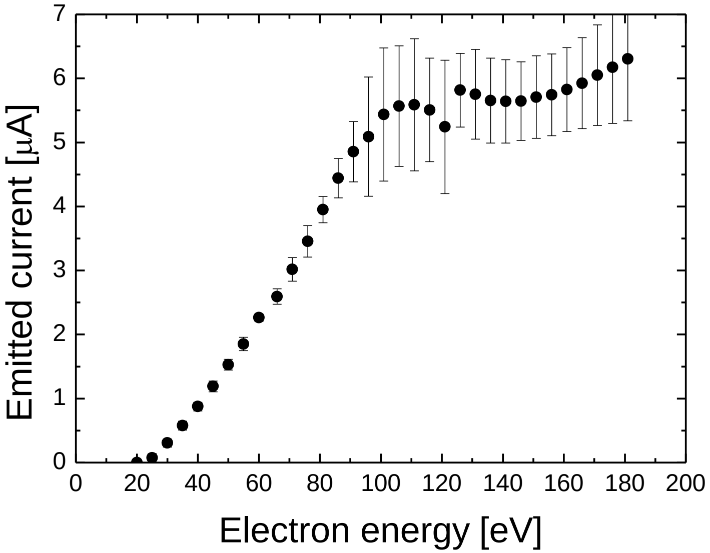


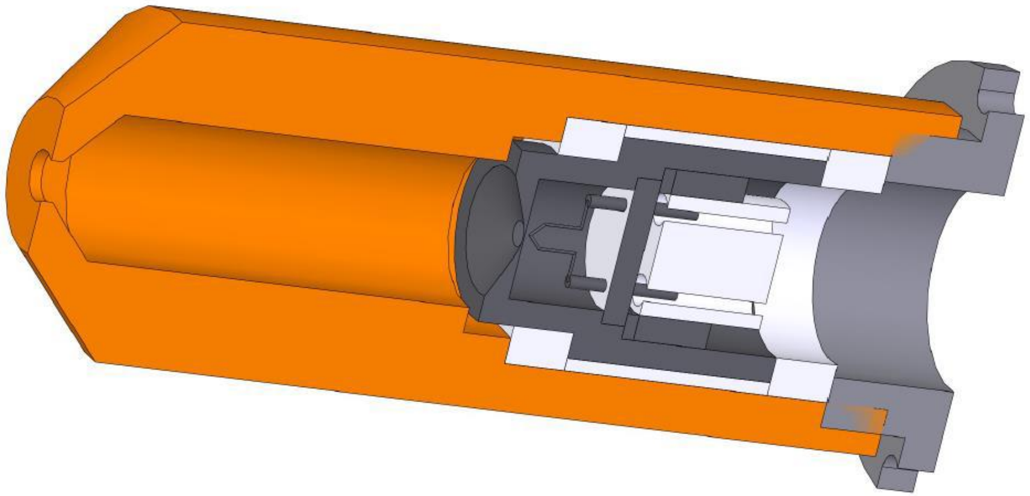




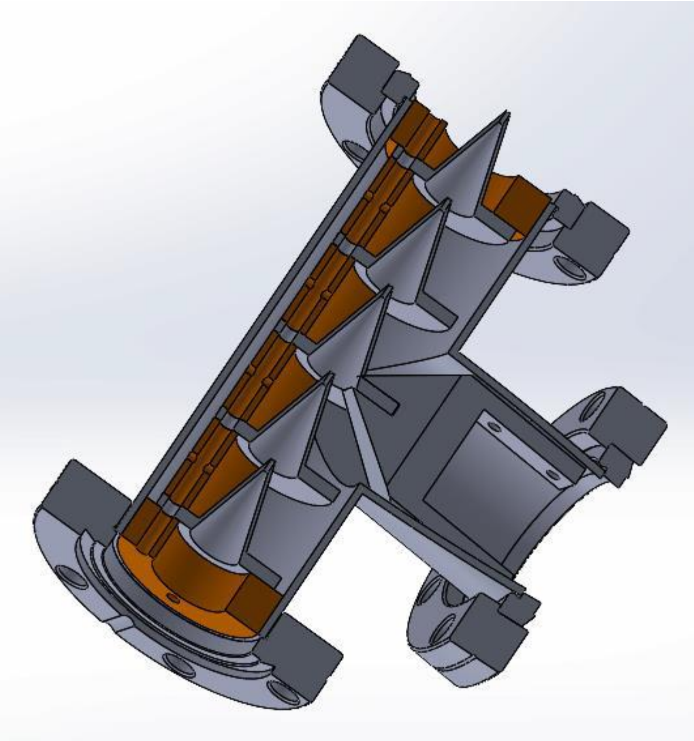
# Electron gun

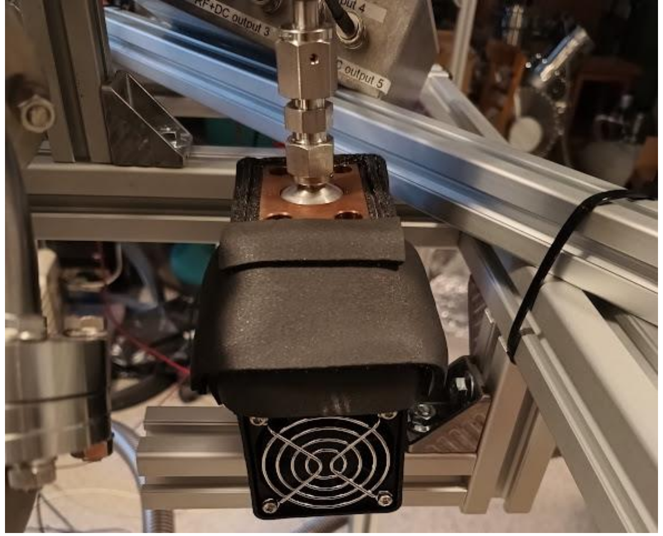




# Molecular beam source





Thermal shielding for the reservoir designed and built by Adam Linek (the driver not presented in the picture)

Silver mesh absorber of the iodine

# Anion detector (spiraltron)

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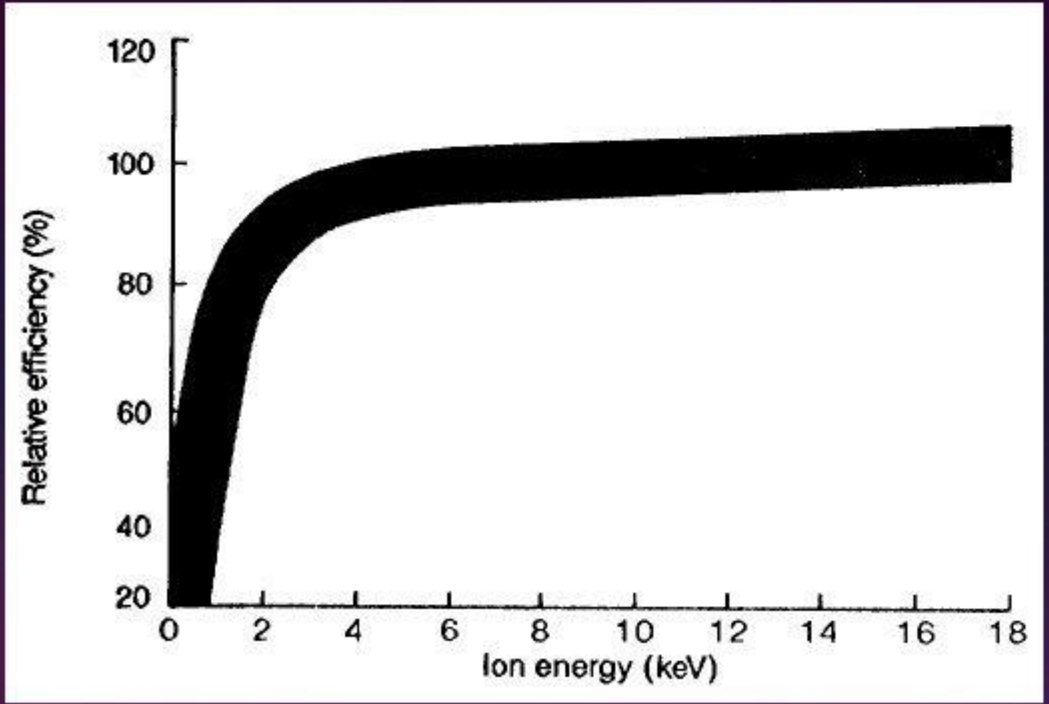
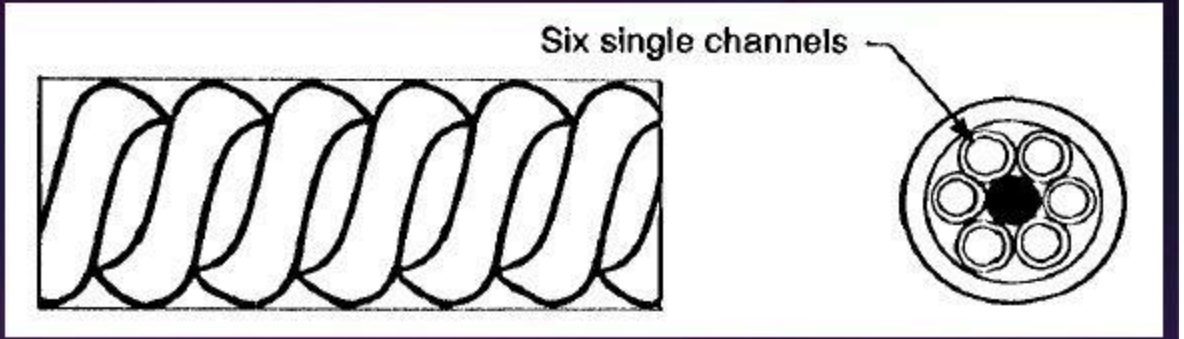
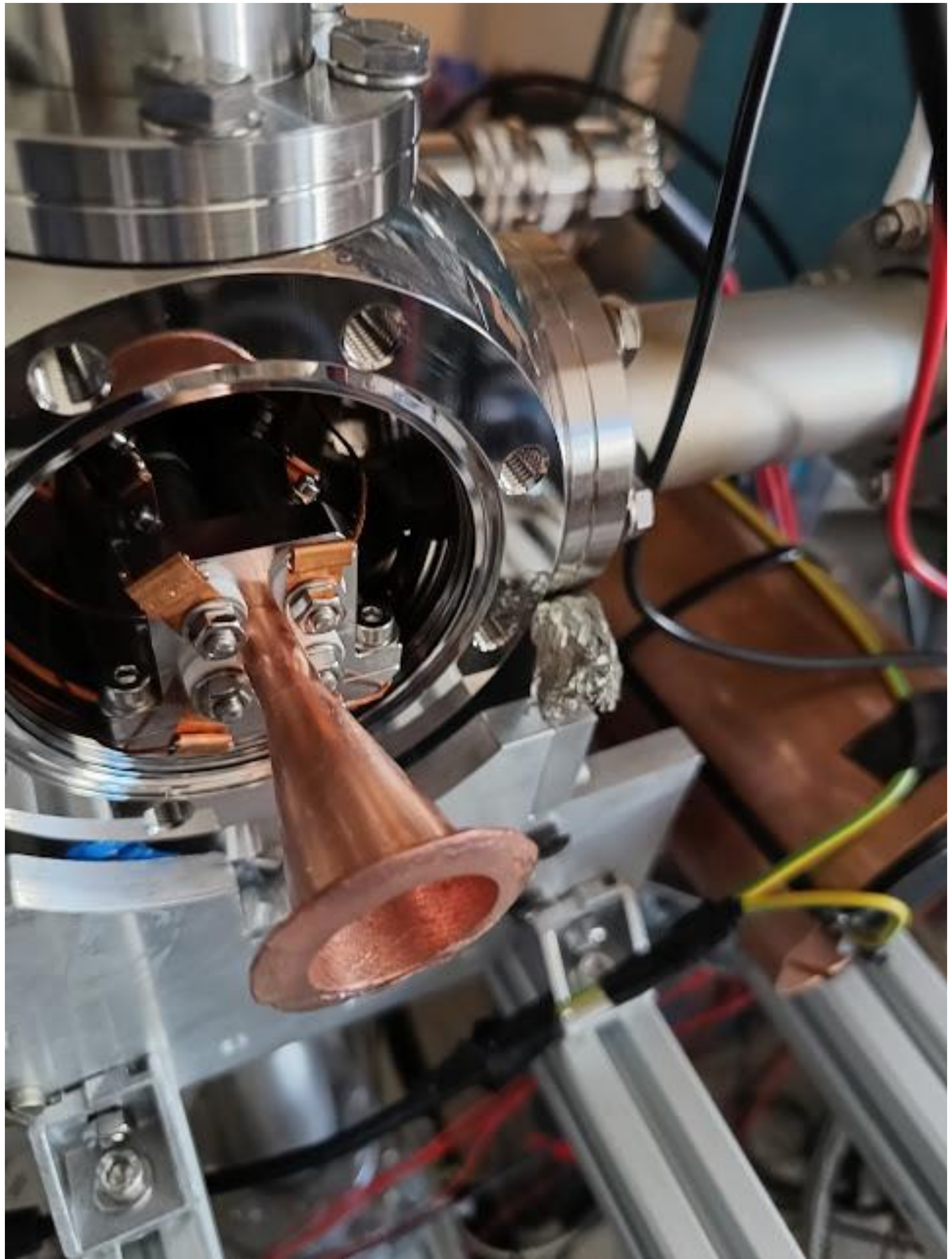


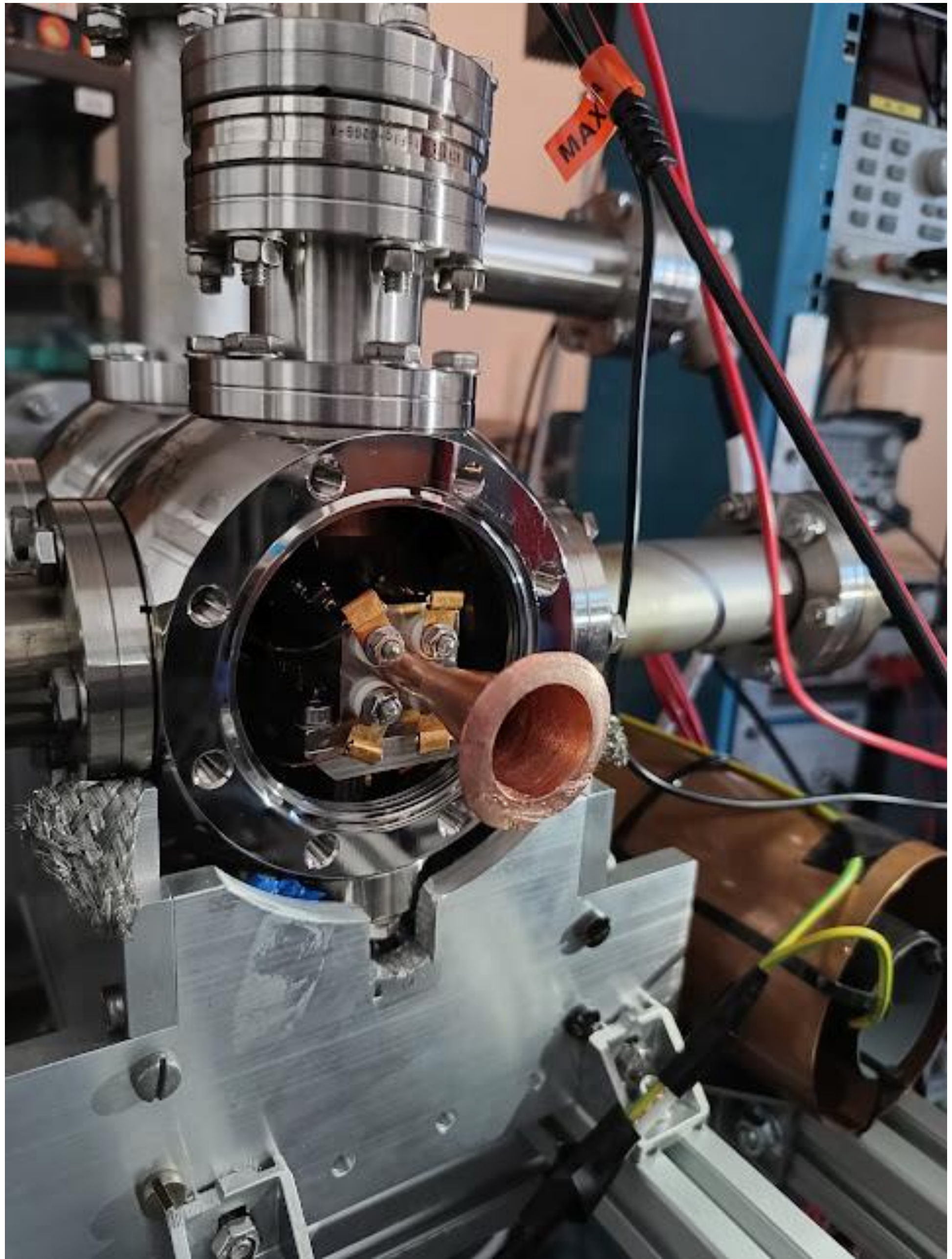

Relative ion detection efficiency curve



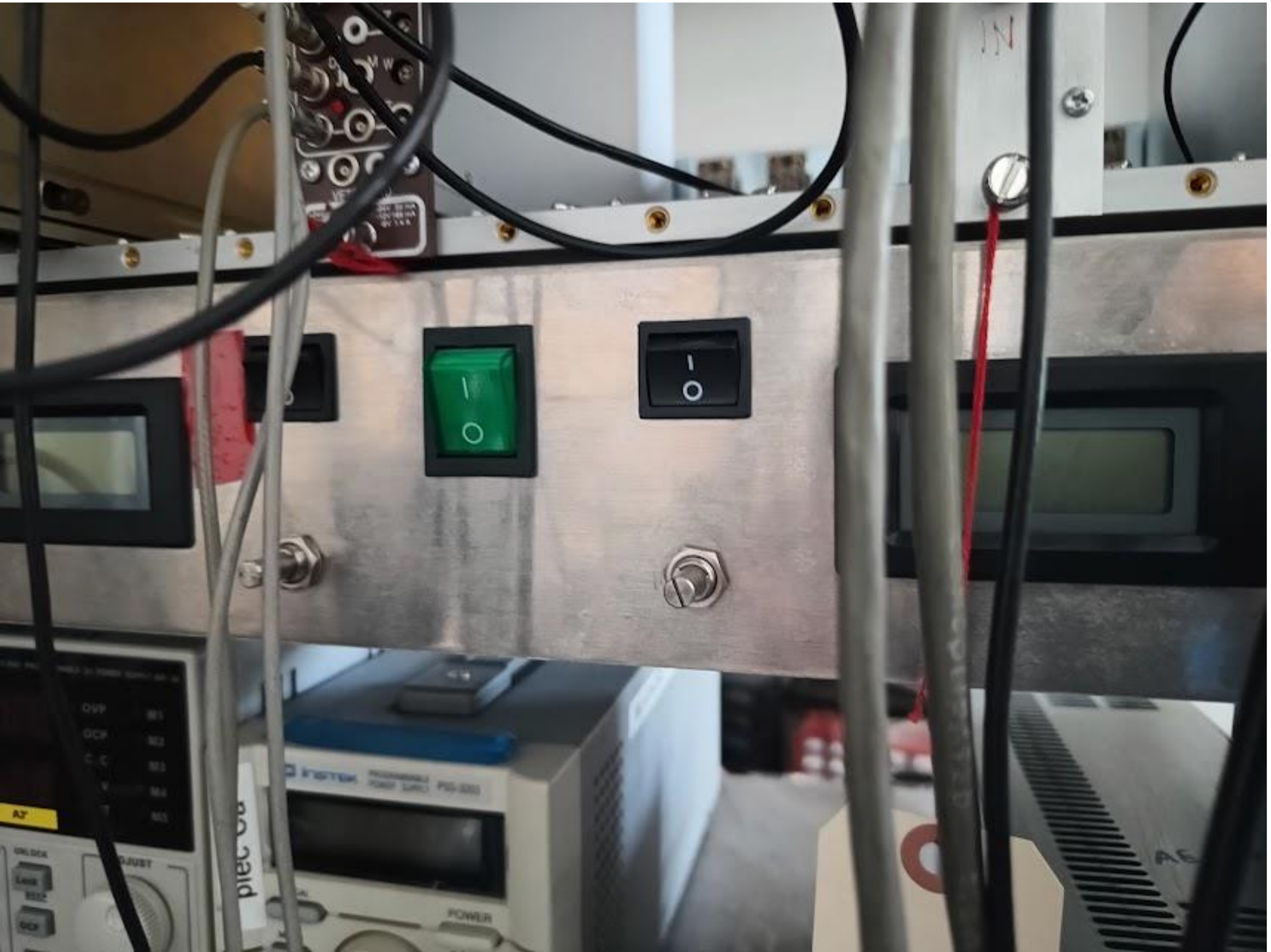

The structure of spiraltron

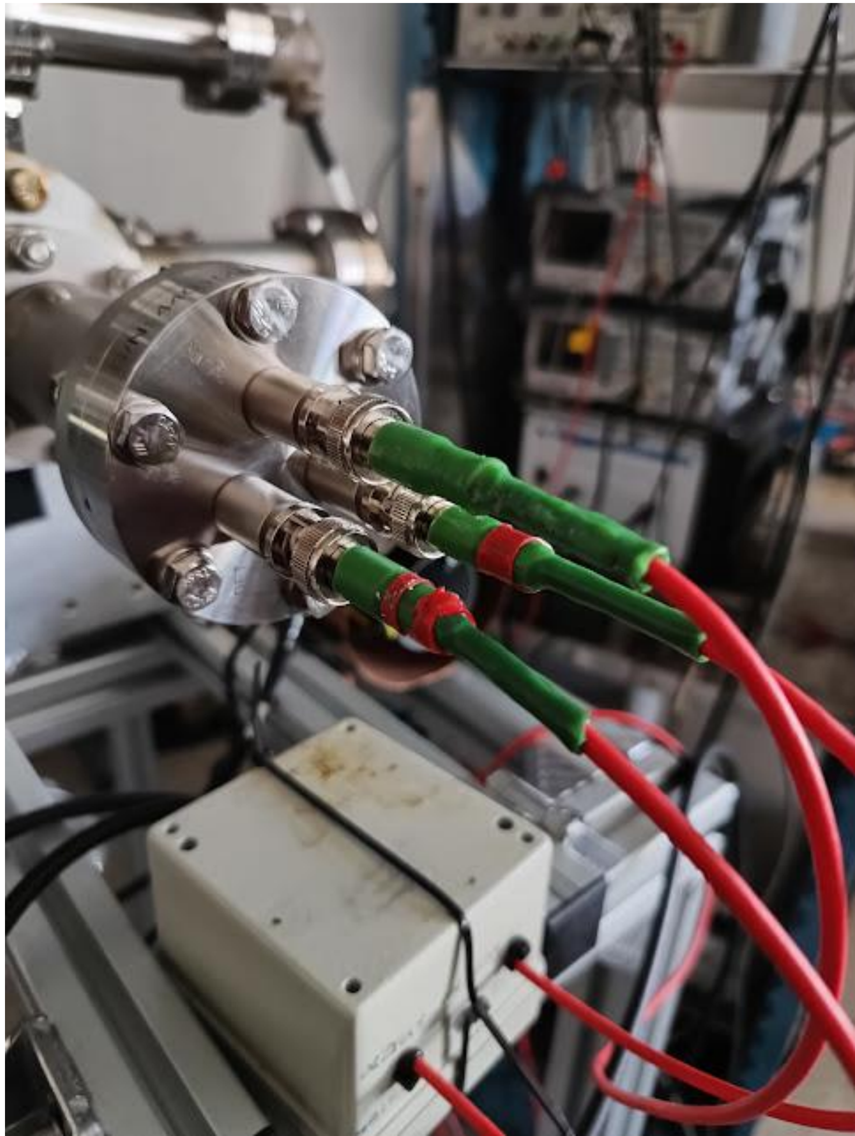
# Modifications: stray electron shielding

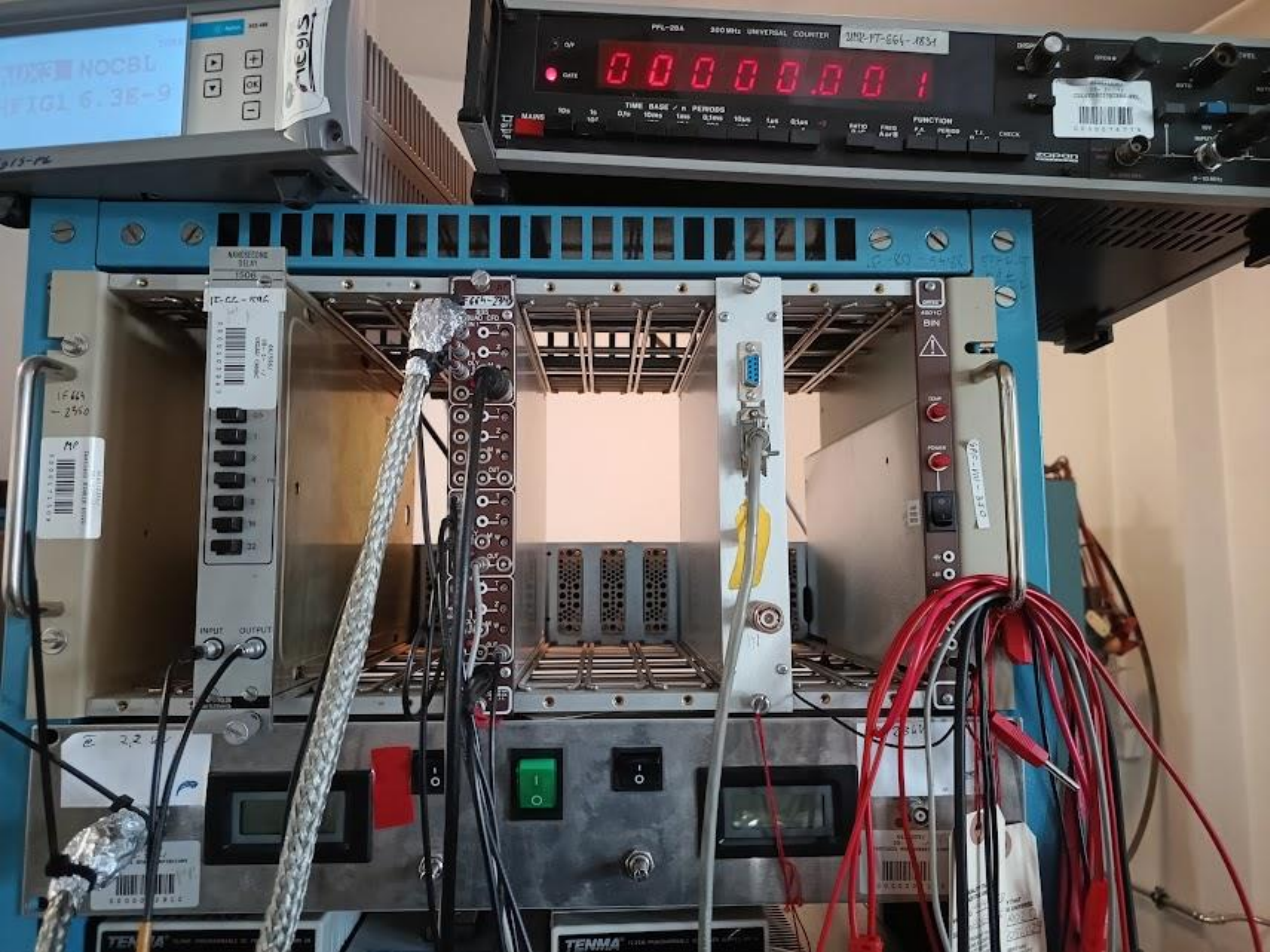




# Custom-made HV power supplies

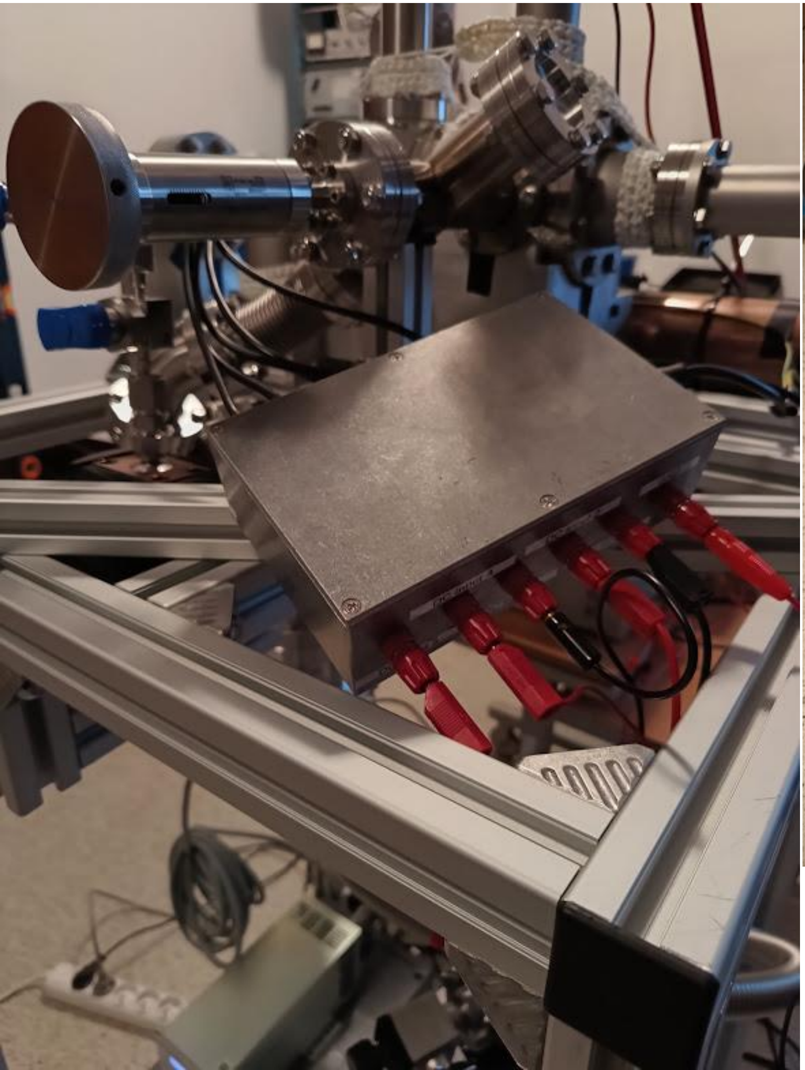


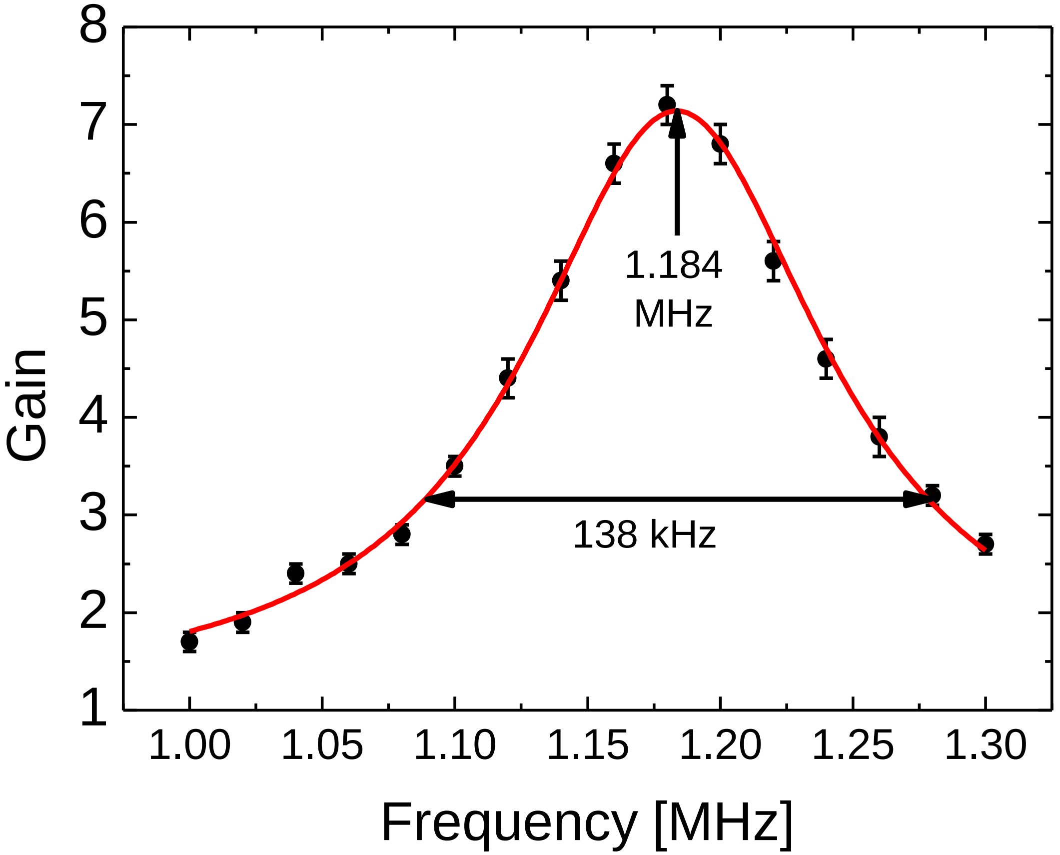





Pulsed electronics (Ortec) – borrowed from another experimental setup

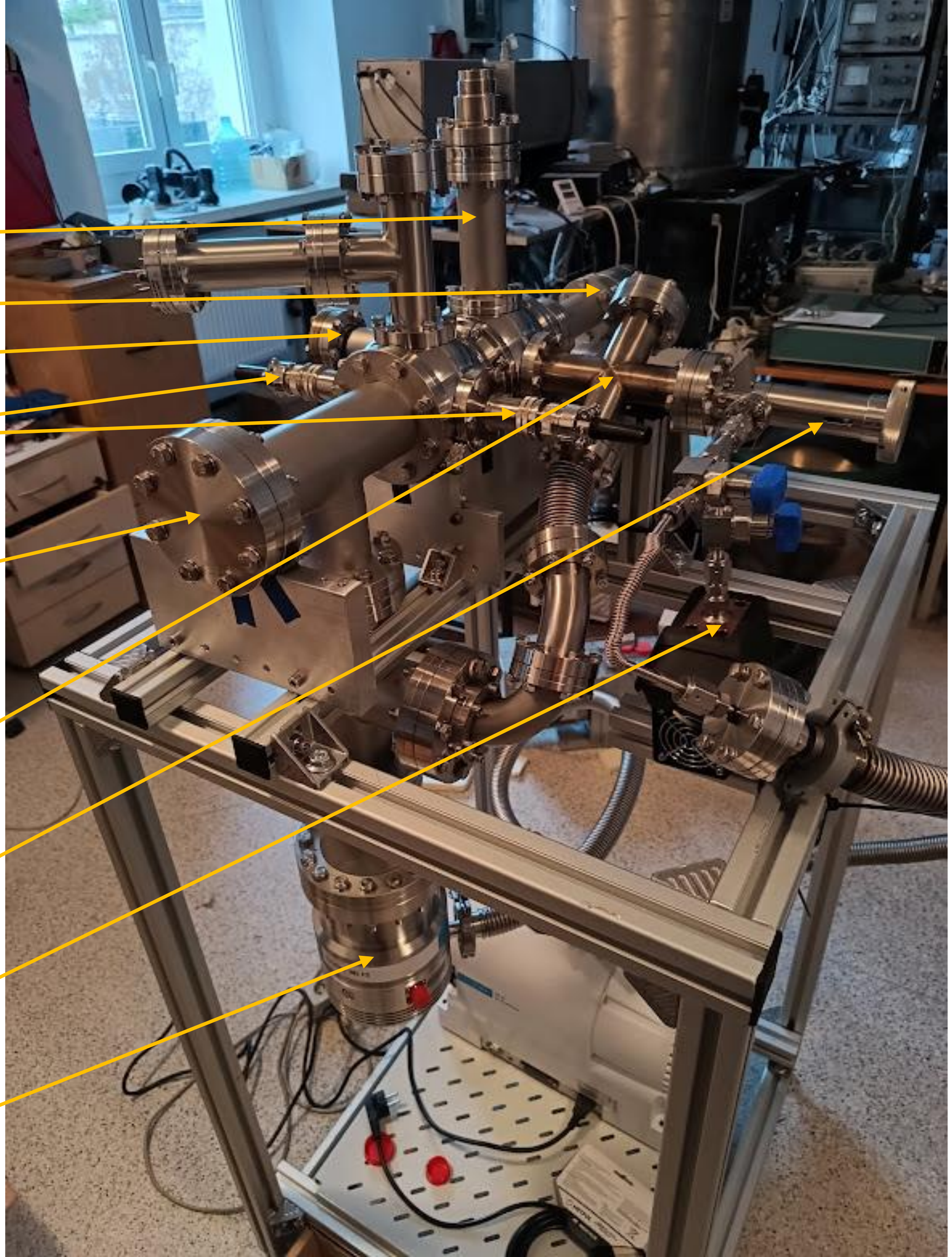
# Temporary voltage supply system






At this frequency, the amplitude of about 280 V is necessary.
At Q=7, we need to provide 40 V from the function generator.

# The device assembled together



Electron gun

channeltron

Silver absorber

Feedthrouhs of the trap

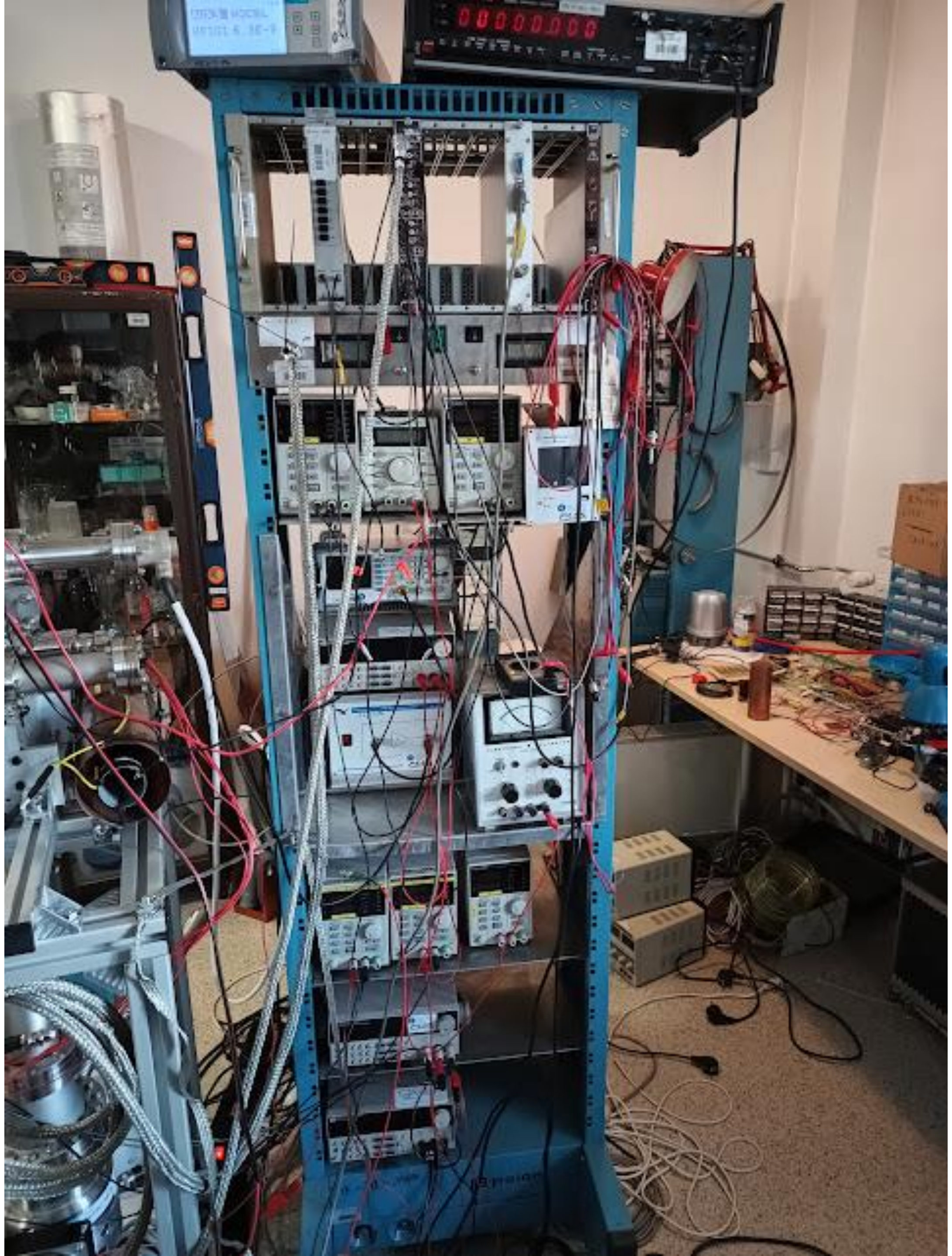
To the diagnostic cross and further to the AEgIS main apparatus

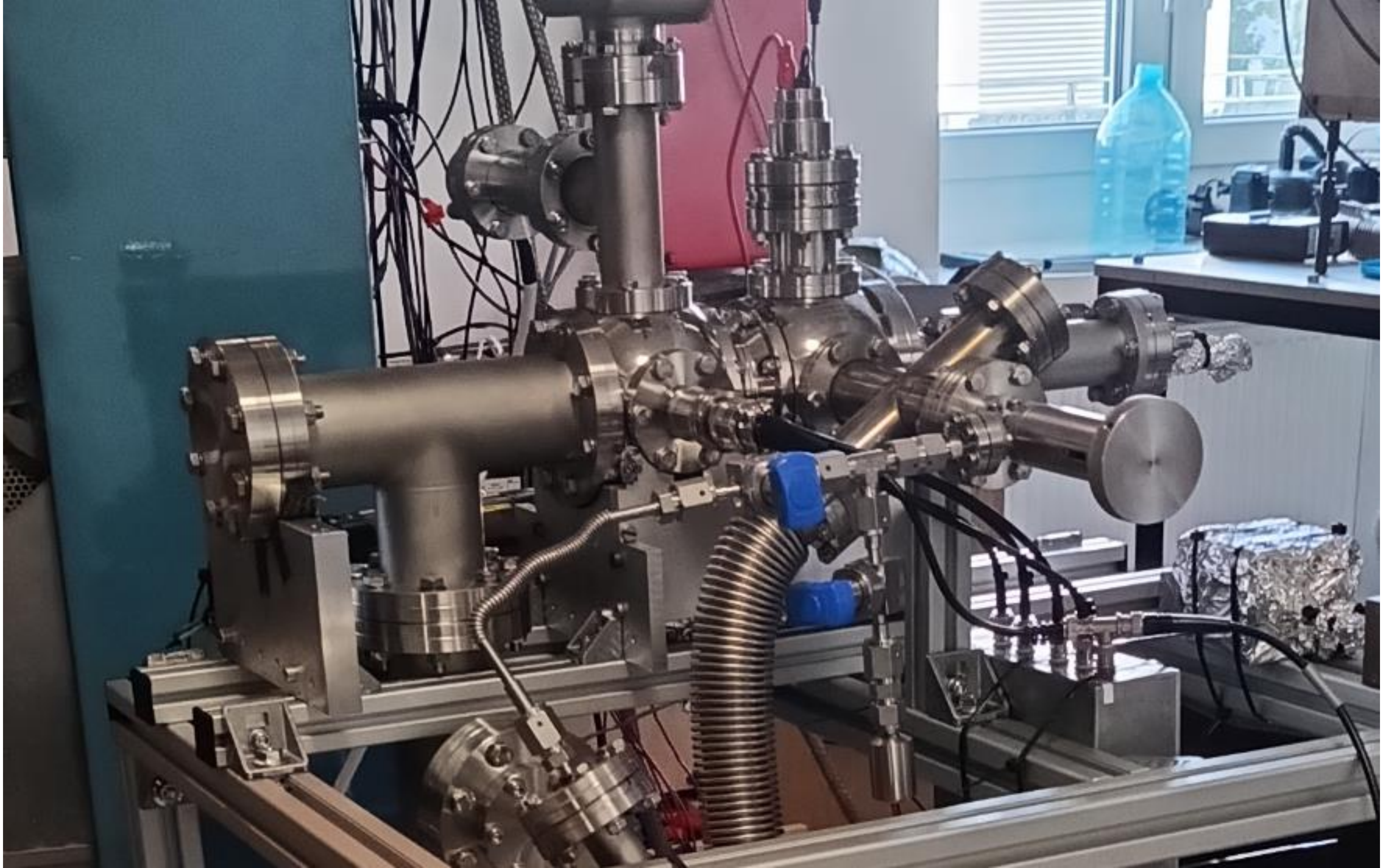
skimmers

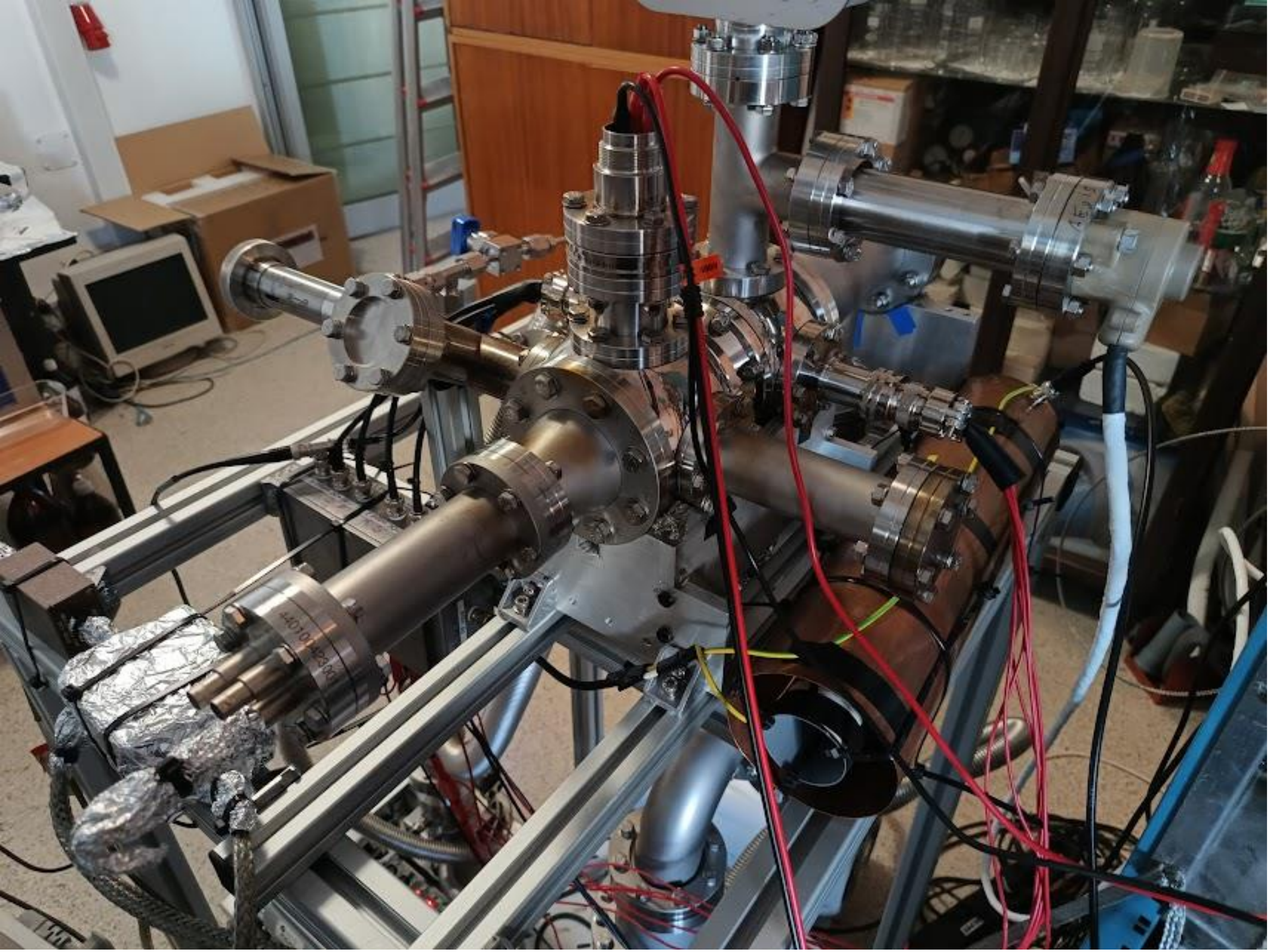
Leak valve

Iodine reservoir

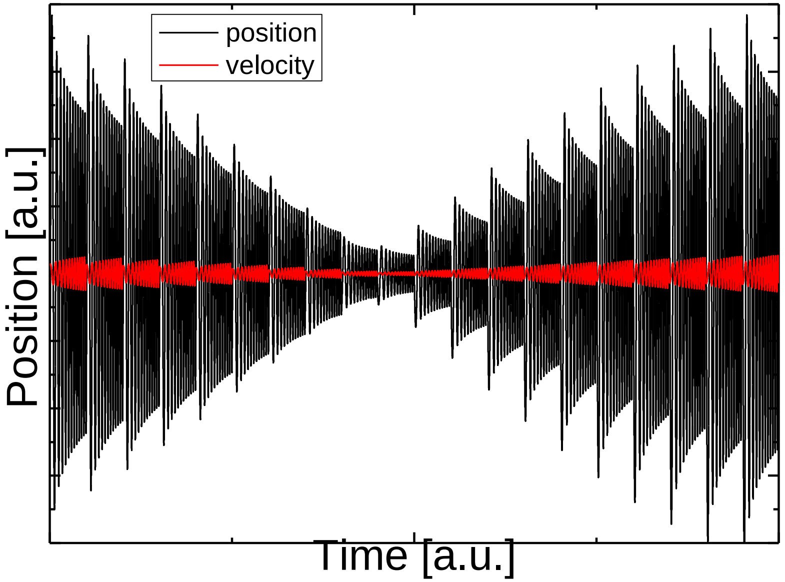
Turbo pump



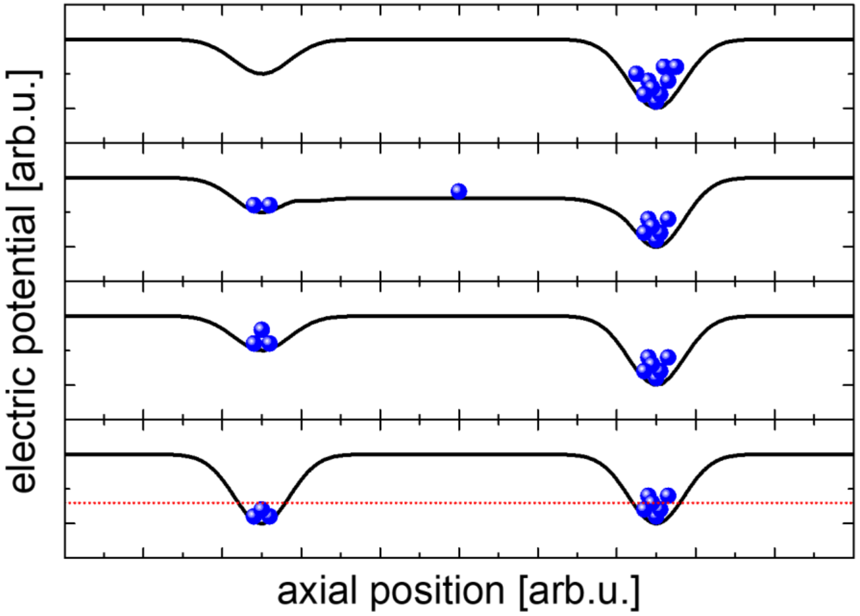


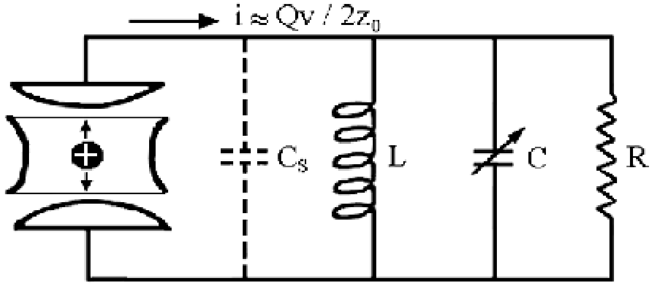


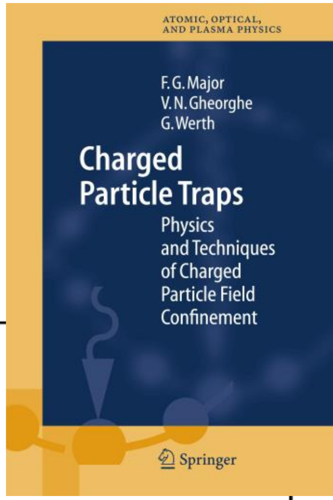
# Cooling problem (no optical access to the anion)

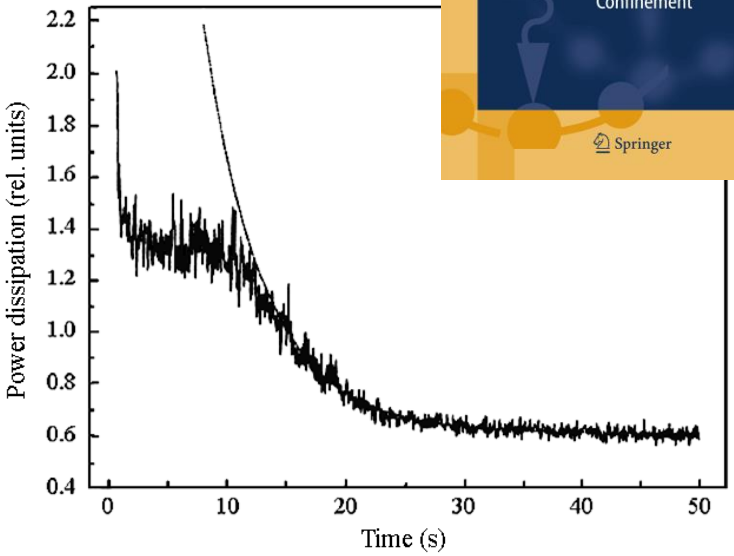




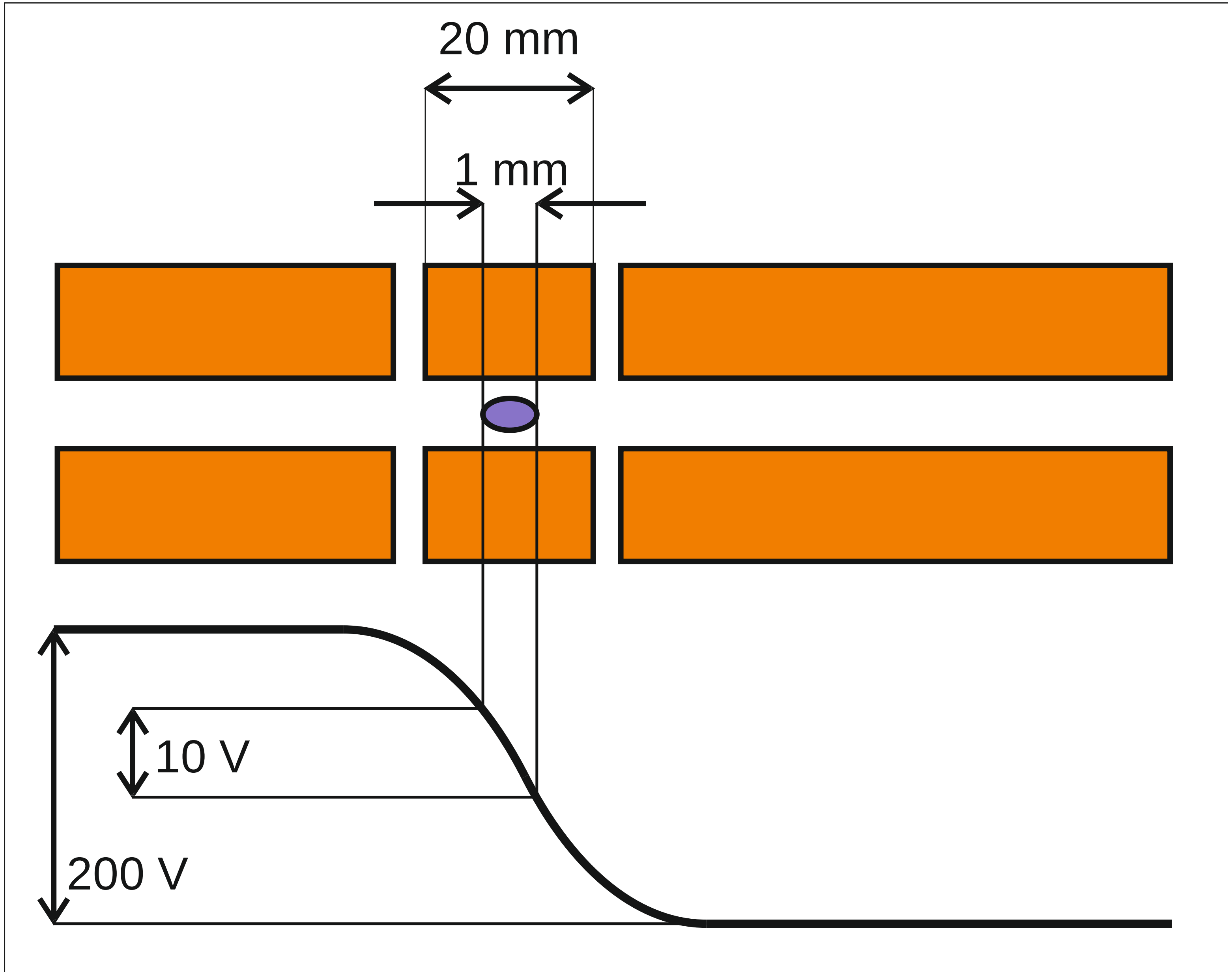


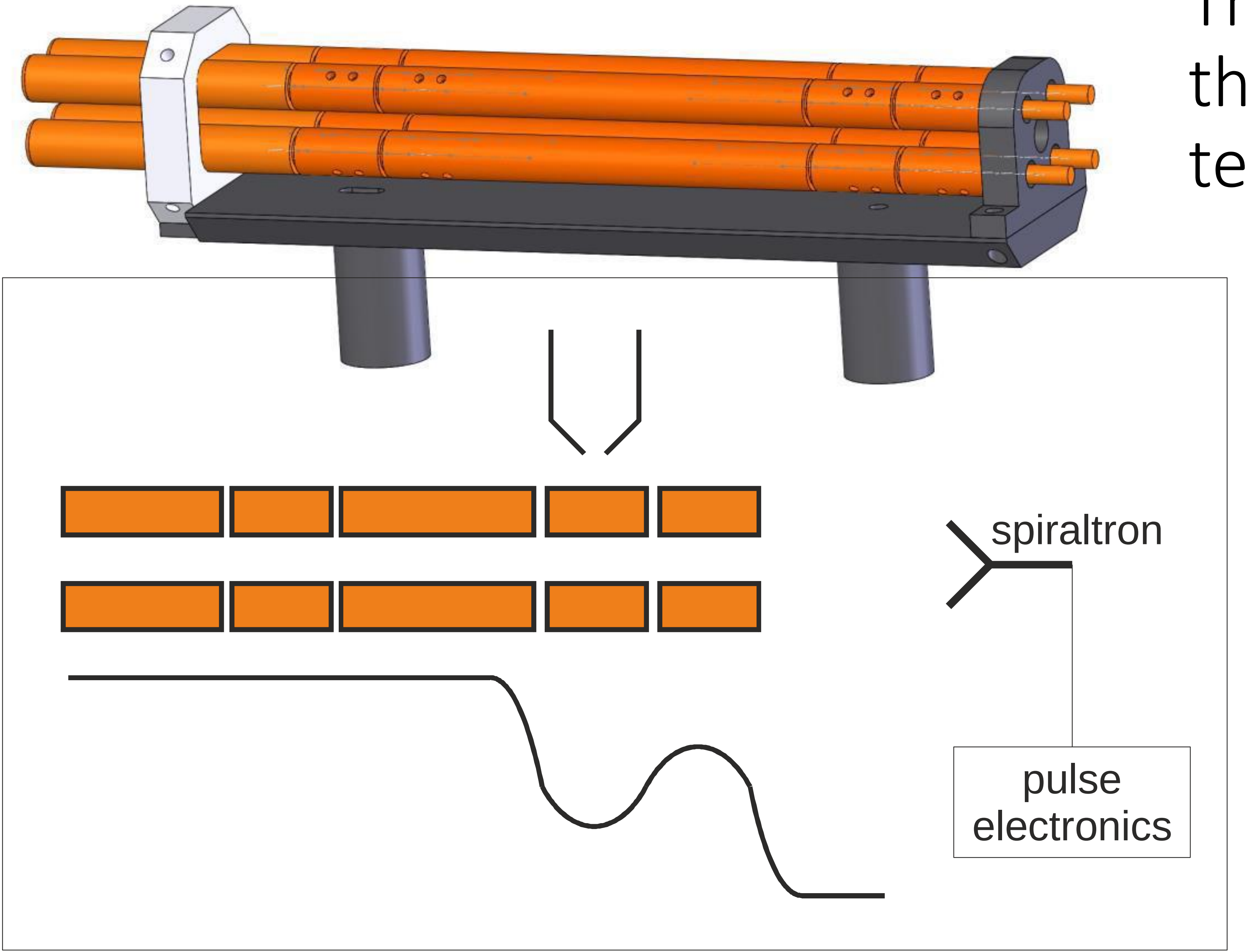



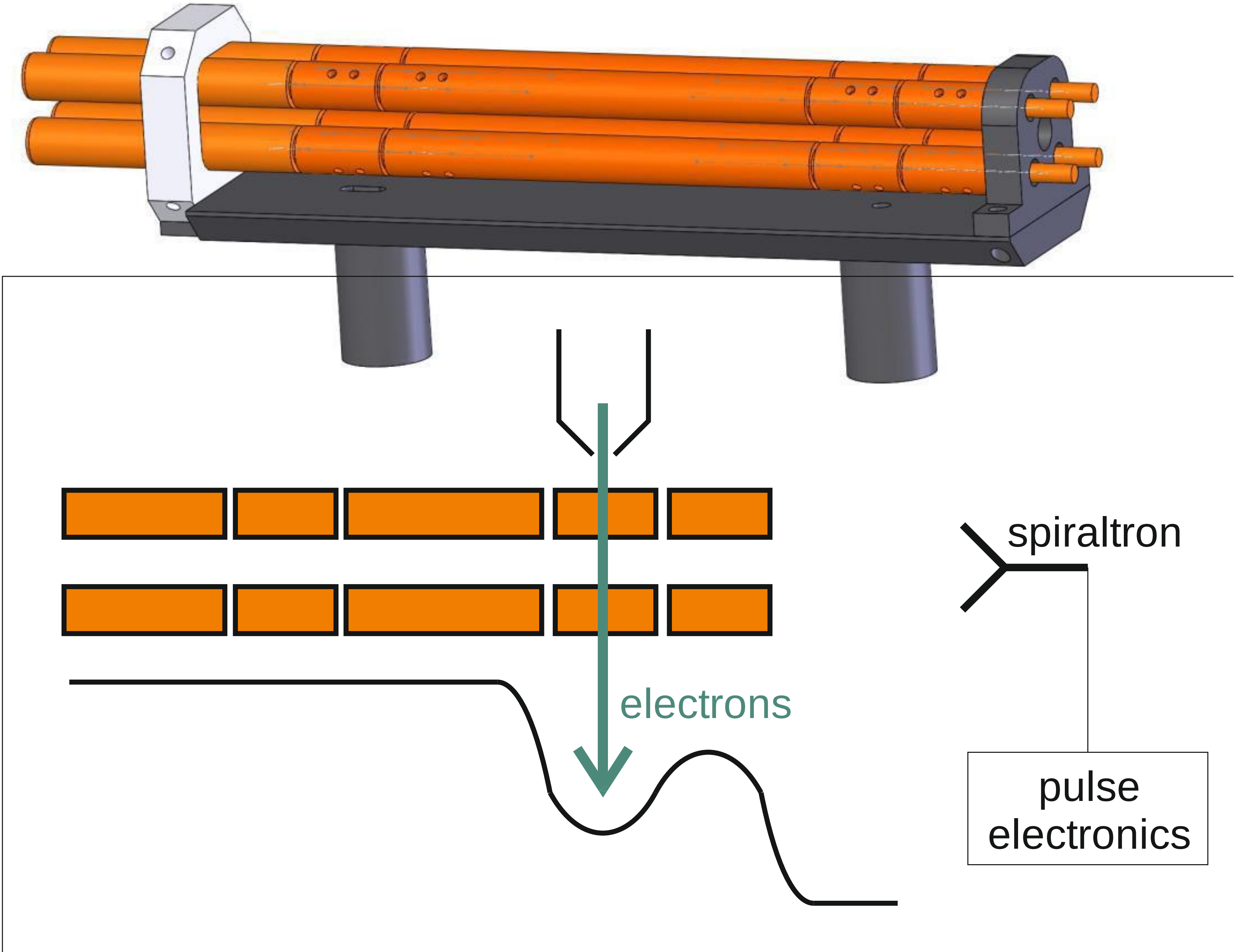



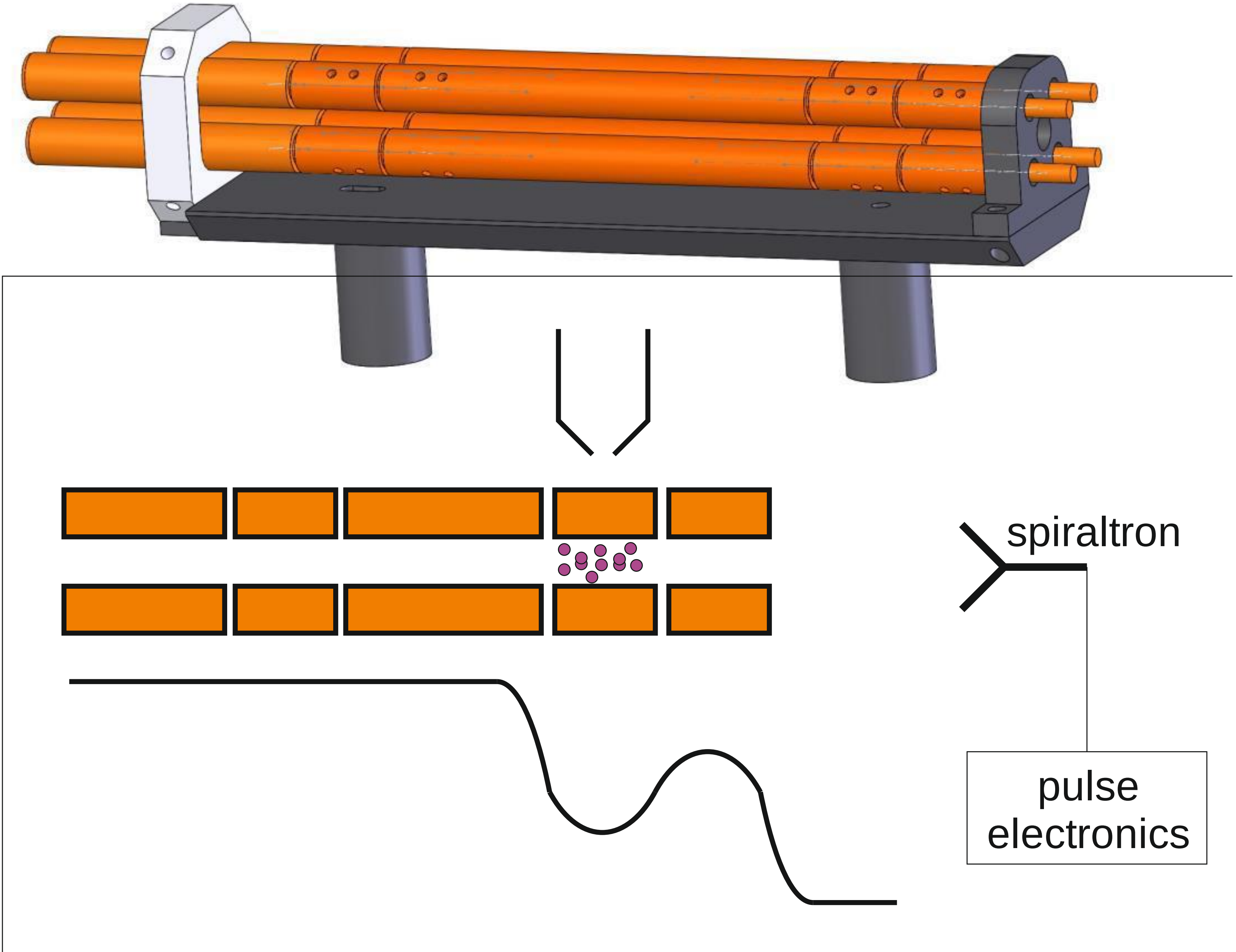
# Solution for the cooling problem



# The procedure of the ion source testing

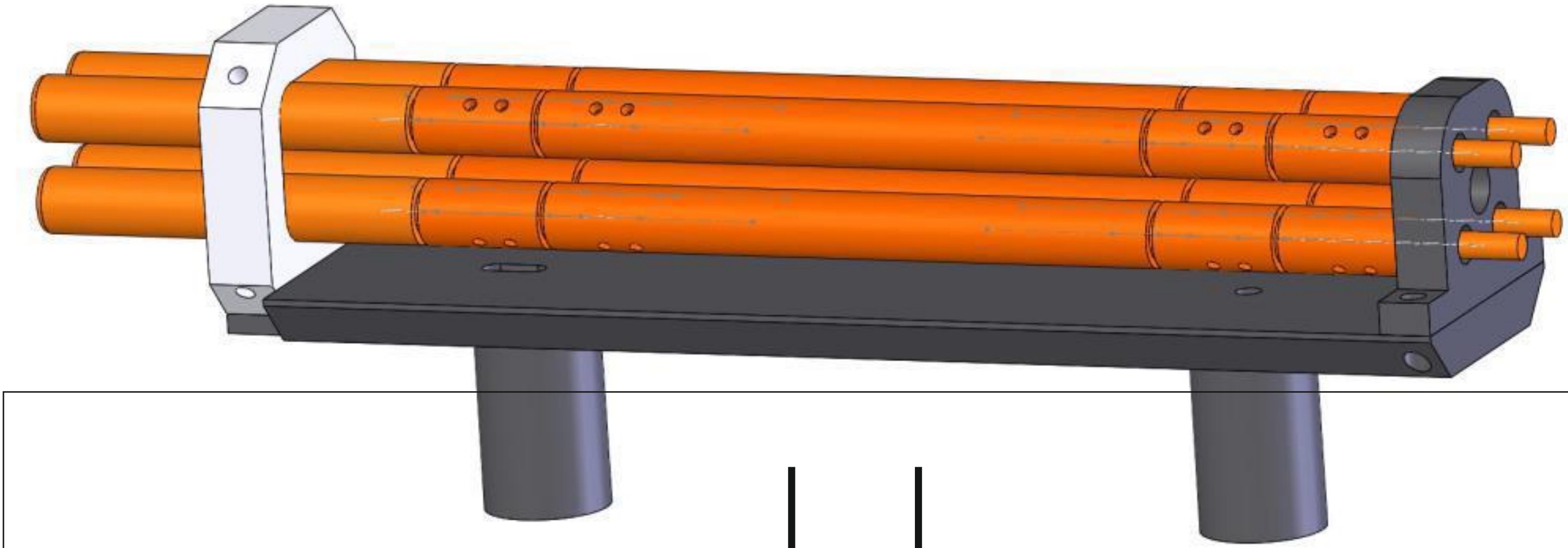


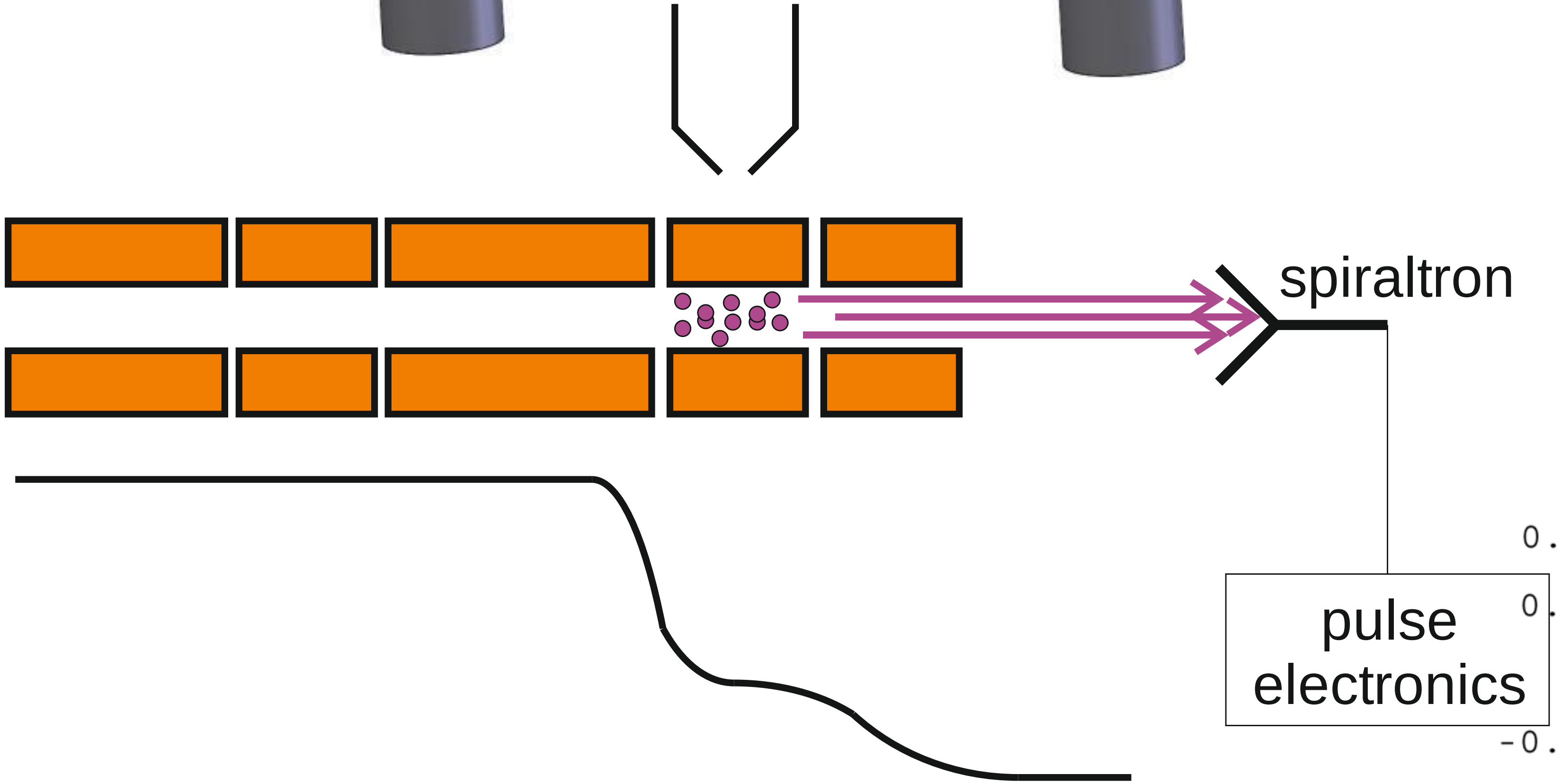

spiraltron
electrons
pulse
electronics


spiraltron
pulse
electronics

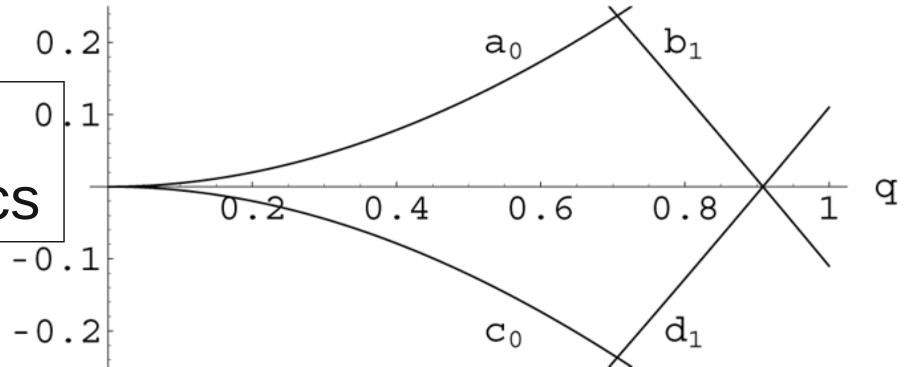
The pulses counted come from an object, which has:

- Negative electric charge
- Mass to charge ratio above 72 amu/e

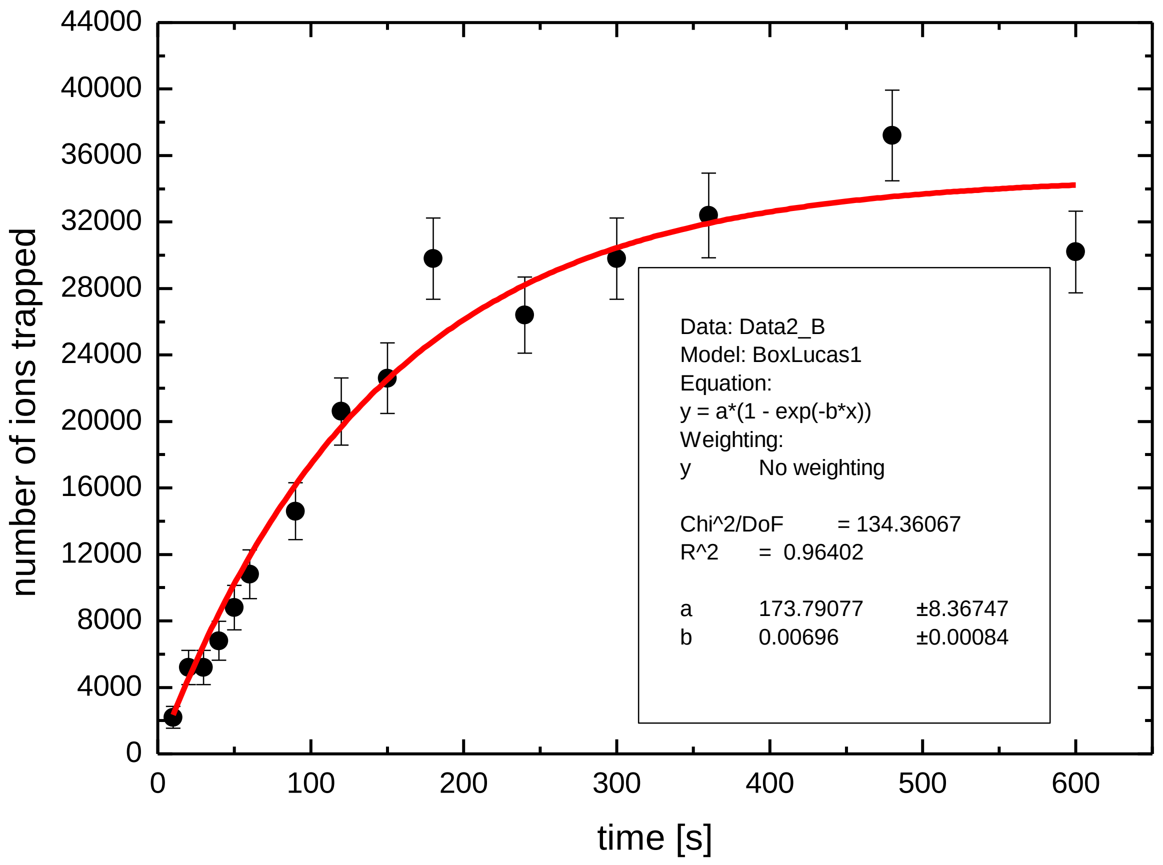


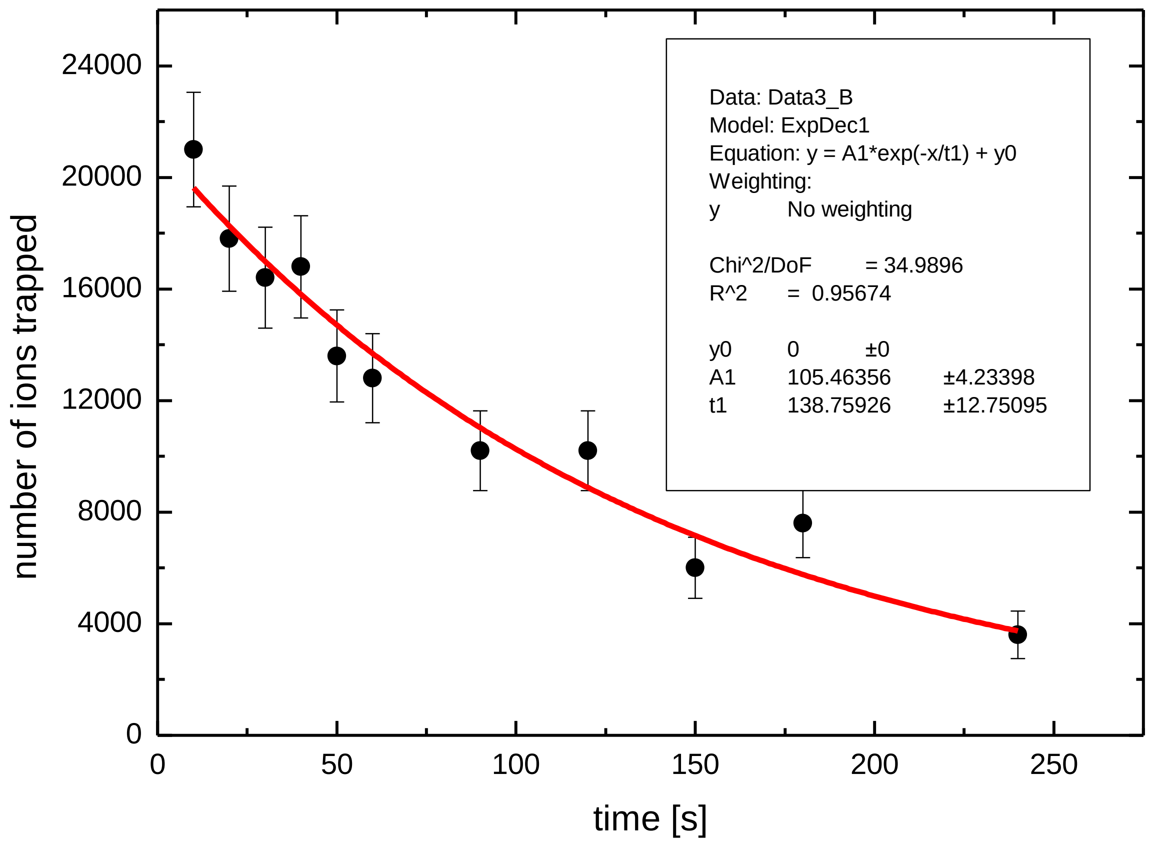



$$q = 2\frac{QV_0}{Md^2\Omega^2}$$

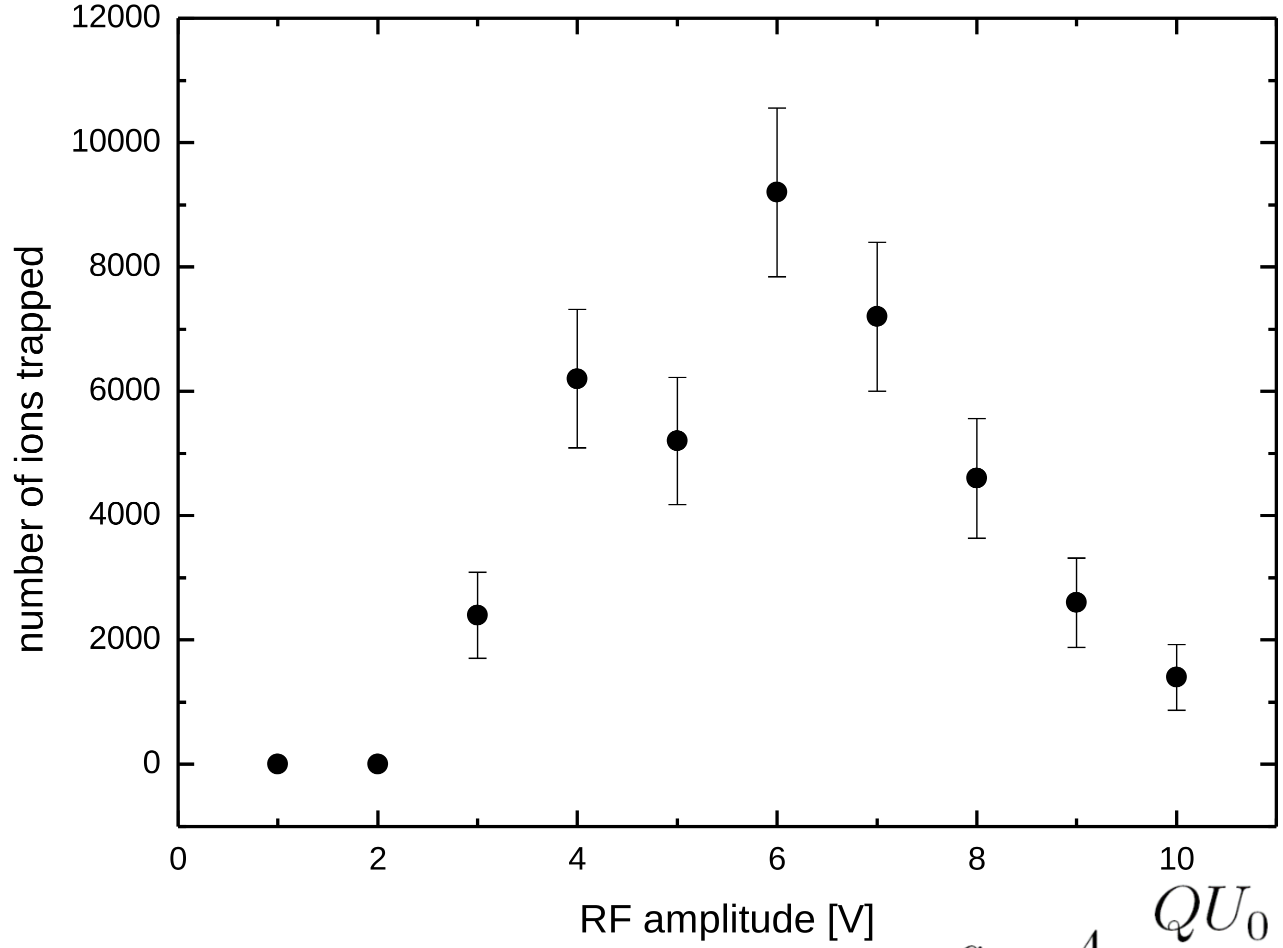


# Loading and unloading the trap



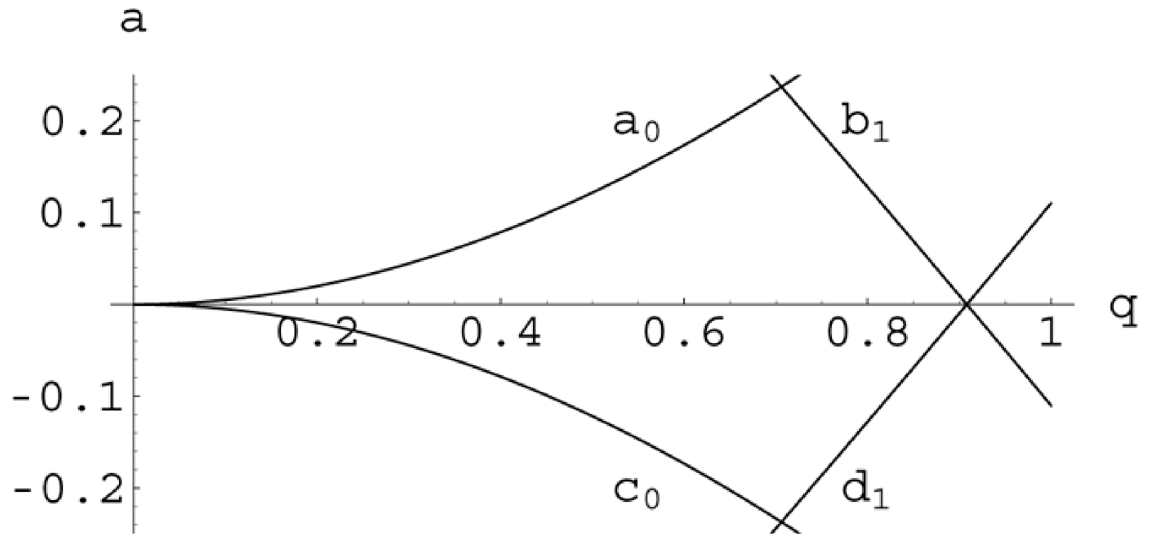
# Trap settings



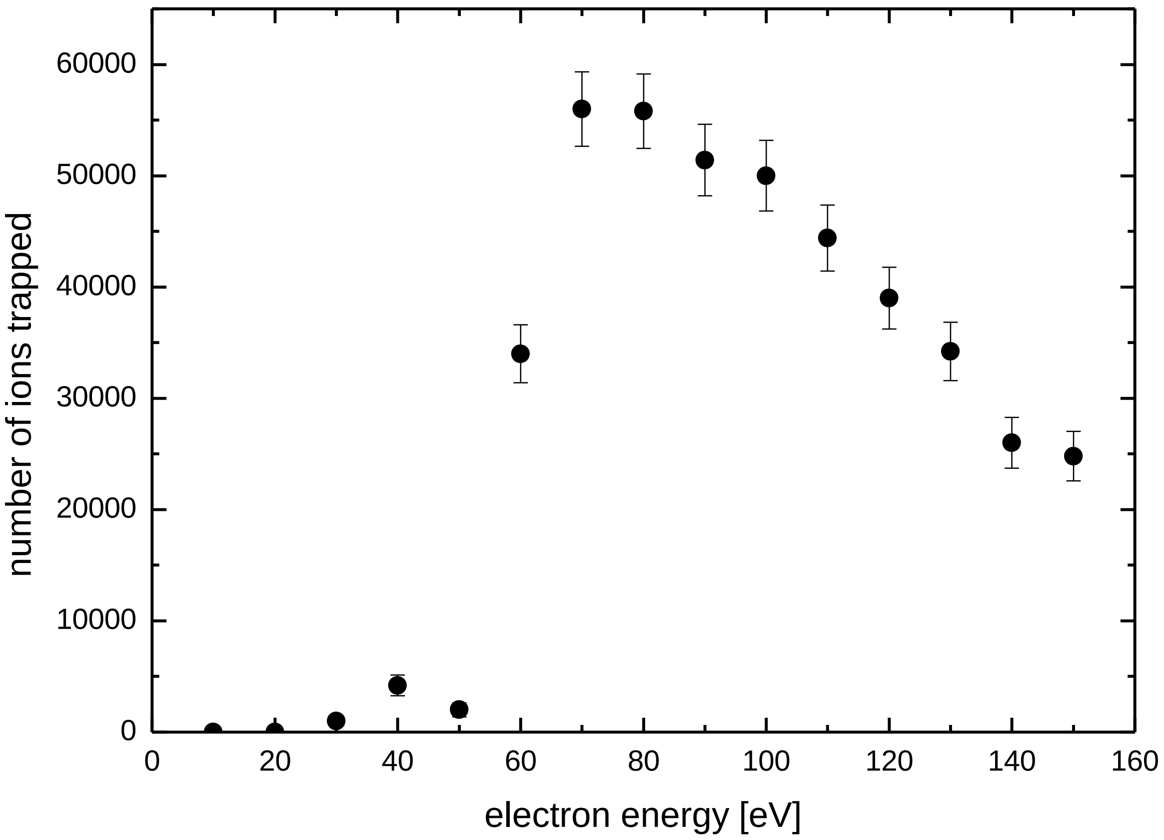

At 6V from the generator, we have 270 V at the trap’s electrodes.
For iodine ions it translates to the „q” stability parameter equal 0.3, which is the cue that $I^-$ are the dominating component in the ion ensemble.

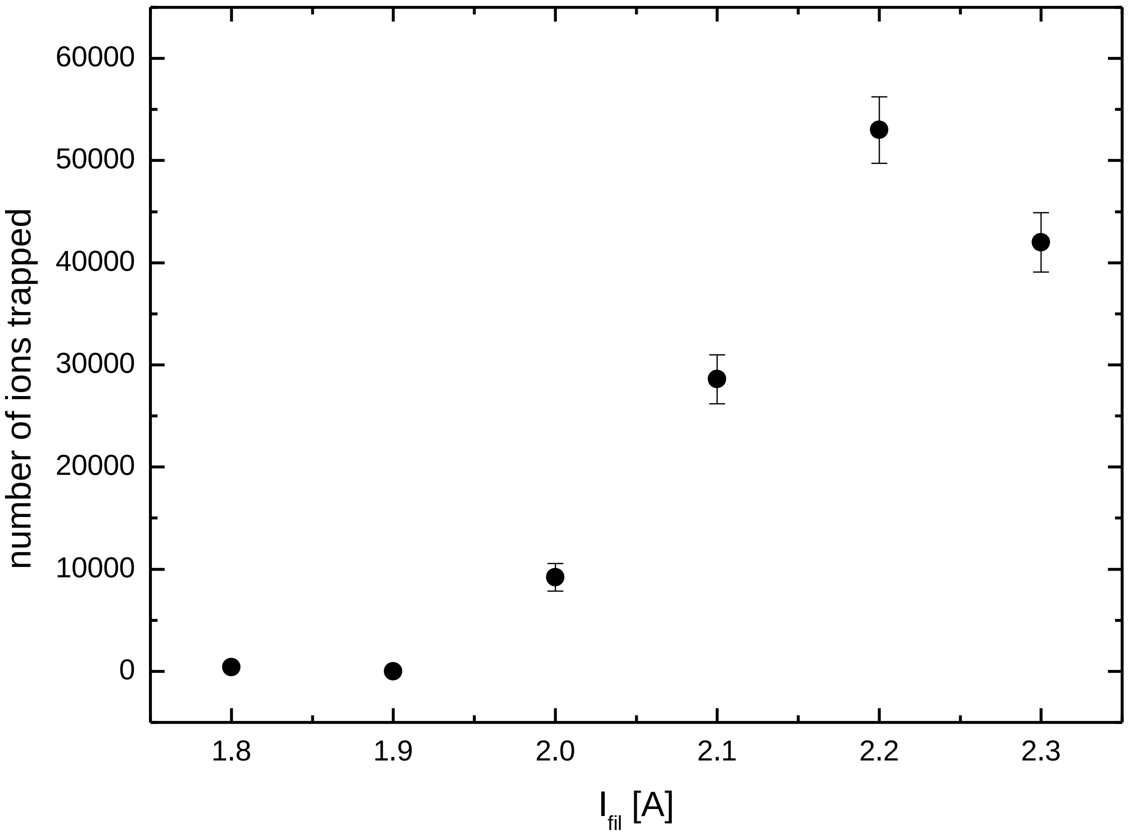
$$a = 4\frac{QU_0}{Md^2\Omega^2}$$

$$q = 2\frac{QV_0}{Md^2\Omega^2}$$

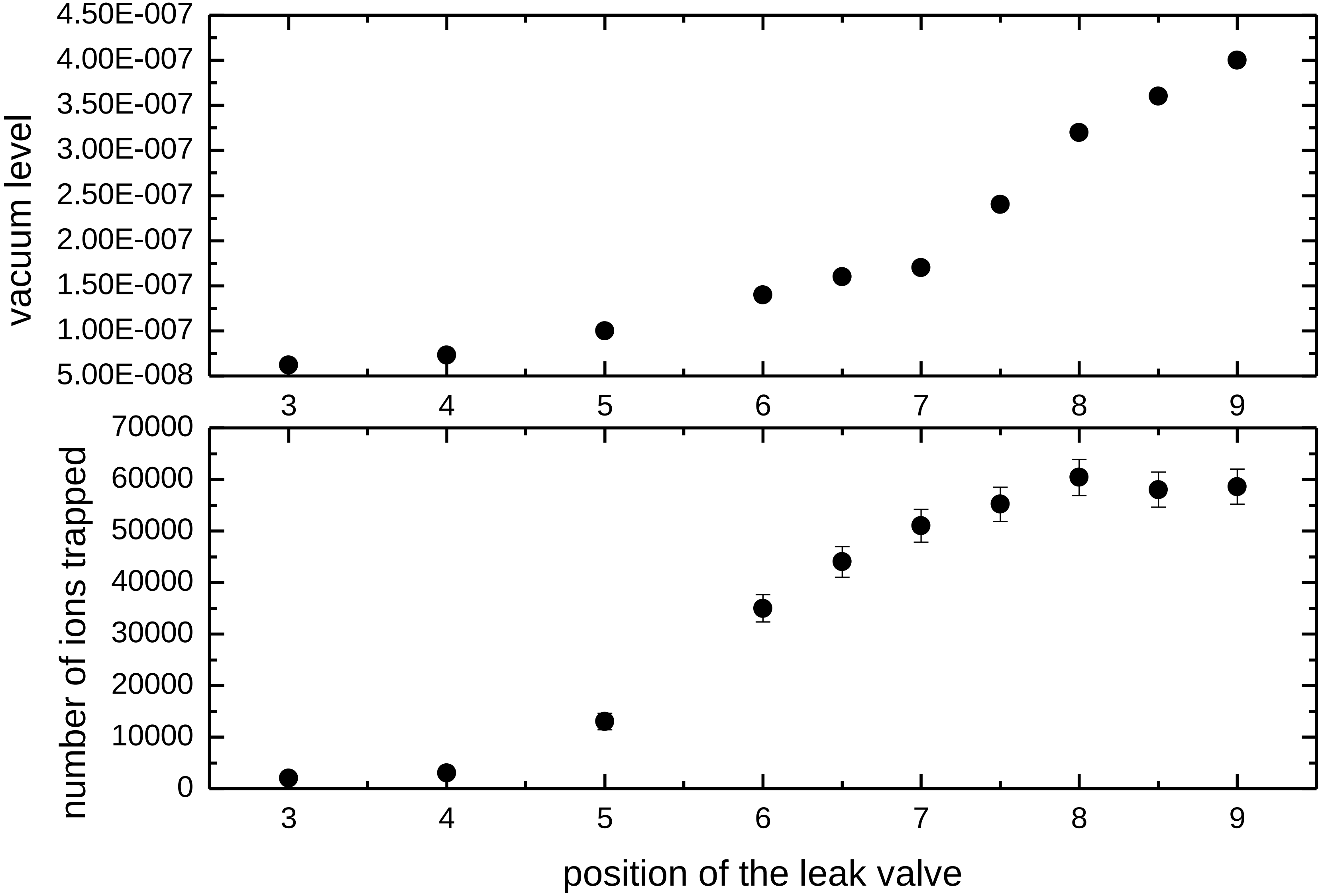


# Electron gun efficiency

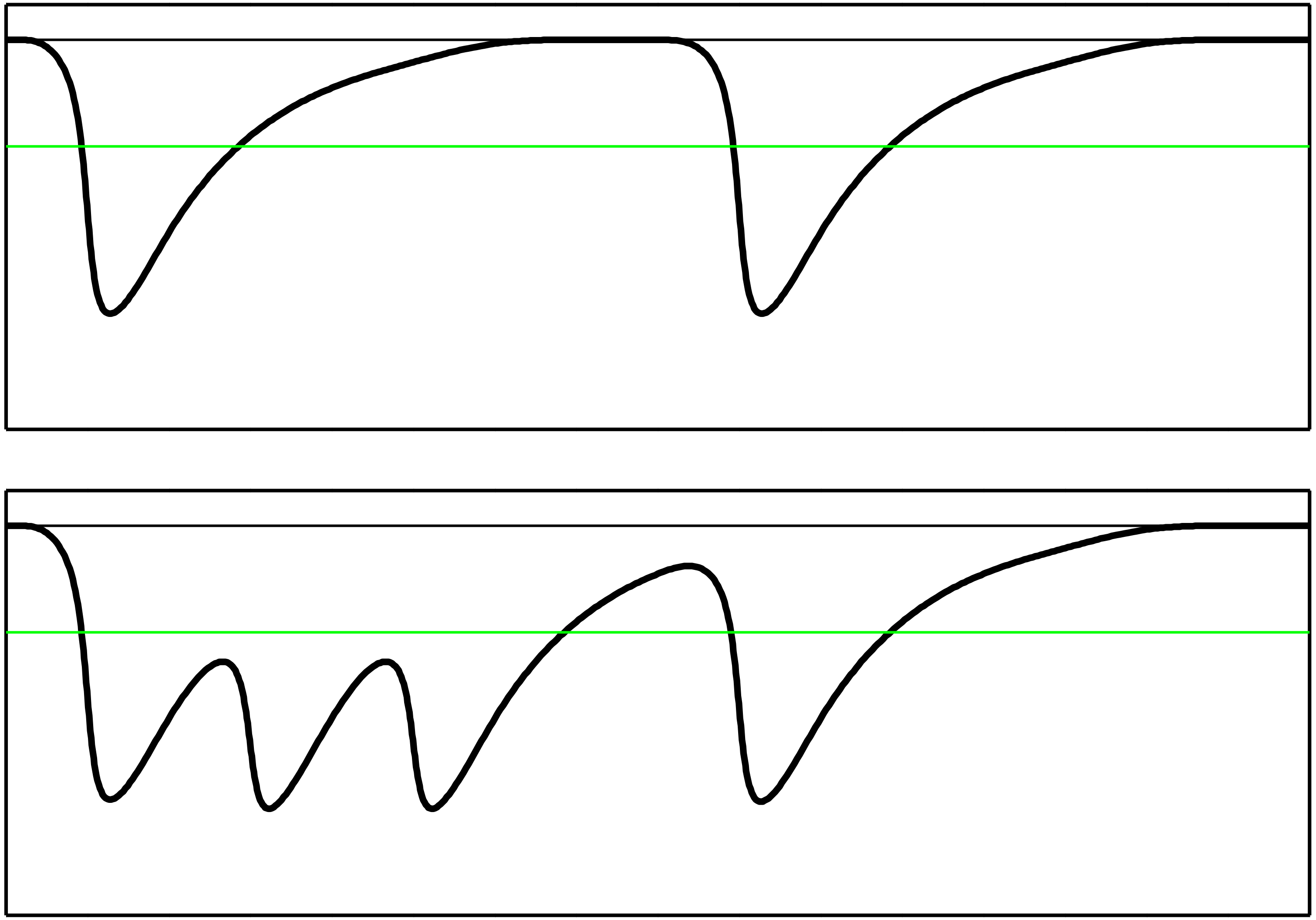


# Molecular beam intensity



# Time resolution of the detection system



Conclusion:
Our ion ensemble is squeezed to approximately 10 microseconds.
This leads to estimation of our ions’ temperature at at 6000 K (0.5 eV).
This is not very exact estimation, but the order of magnitude should be correct.

# Summary

- The device works
- By now, iodoform is used instead of iodine
- Temporary voltage supply system is used – to be replaced by SINARA
- Transport to CERN: anytime we find it conveneient