# Status of the AISHa ion source at INFN-LNS


**L. Celona, G. Castro, F. Chines, S. Gammino, O. Leonardi, G. Calabrese, G. Manno, D. Mascali, A. Massara, S.Passarello, D. Siliato, G. Torrisi**

*Istituto Nazionale di Fisica Nucleare – Laboratori Nazionali del Sud*

**C. Maugeri, F. Russo**

*CNAO Foundation – Pavia*

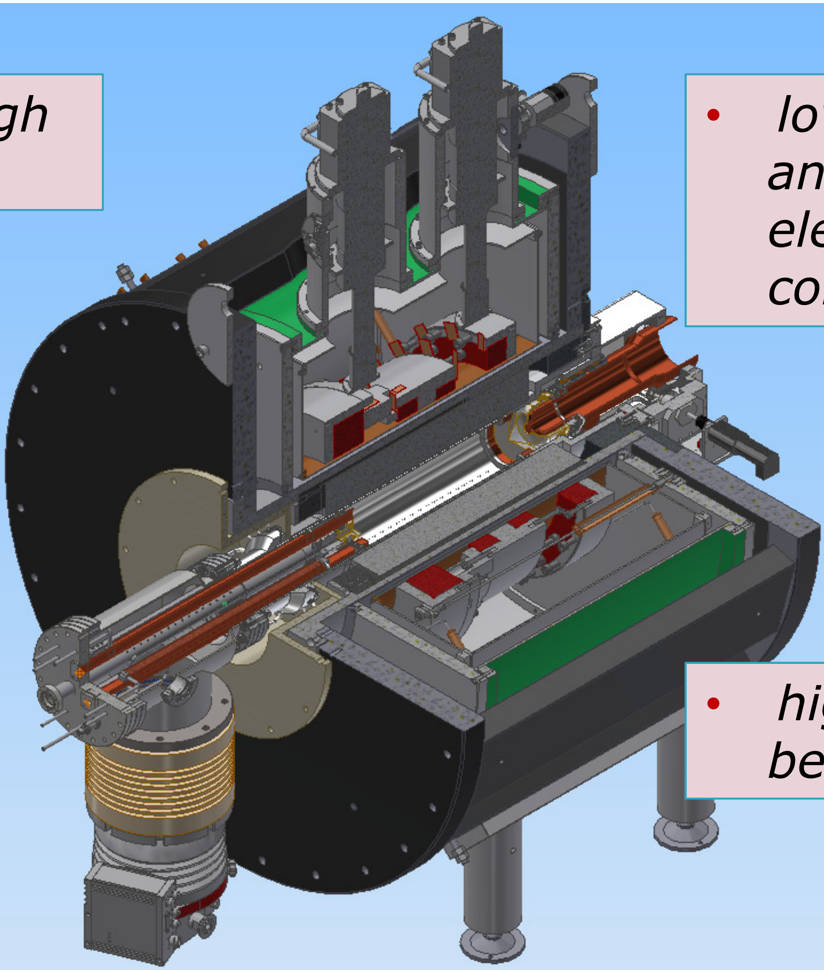


24th International Workshop on ECR Ion Sources (ECRIS'20)

# AISHA requirements

## Advanced Ion Source for HAdrontherapy

- high stability and high reproducibility
- low space occupation and minimization of electrical consumption



- low maintenance time
- highly charged ion beams with low ripple

**State-of-art strategies on magnetic field/RF tuning needed!**

# FINE TUNING OF ECRIS PARAMETERS ( B , *f* )

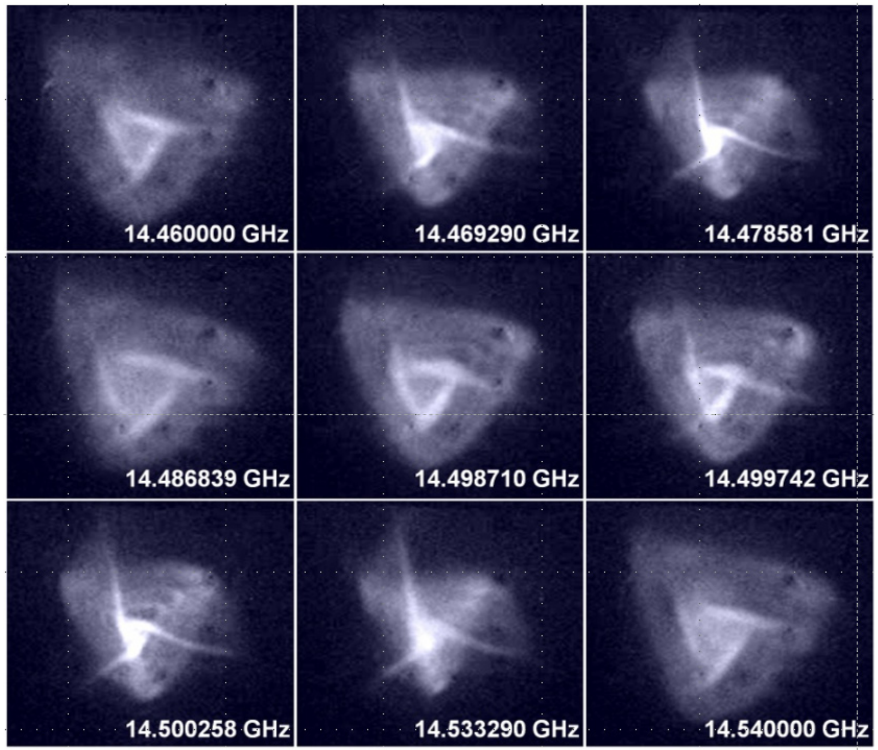
The CSD, the plasma density and the Electron Energy Distribution Function can be tuned by the magnetic field and pumping wave frequency adjustments.

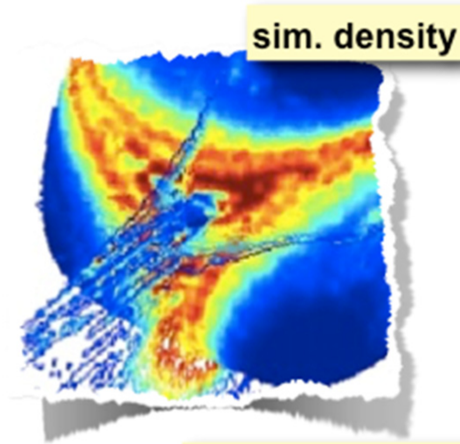
- **The tuning of the magnetic field changes the distribution of the charge states and the temperature of the hot component of the plasma;**

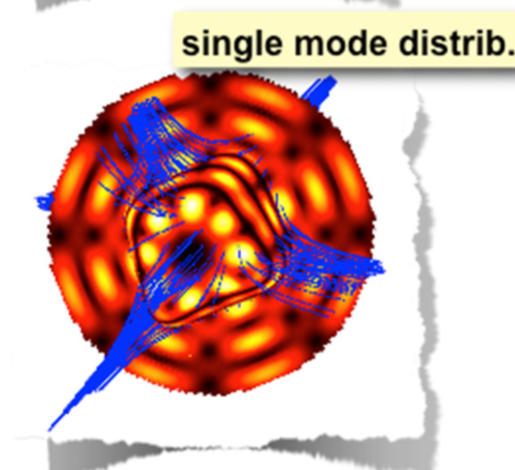
**[S. Gammino, D. Mascali, L. Celona and G.Ciavola, *Plasma Sources Science & Technol.* 18 045016 (2009)]**

- **Evidence of plasma structure changes for slight variations of microwave frequency**

# Evidence of plasma structure changes for slight variations of microwave frequency in modal dominated cavities ($\lambda \approx L$).




INTERPLAY between plasma structure and beam parameters (current, shape, brightness, emittance)


[L. Celona, G. Ciavo[illegible] S. Gammino, F. Maimone, D. Mascali, Review of Scientific Instrument 79, 023305 (2008)]
[L. Celona, S. Gammino, G. [illegible]vola, F. Maimone and D. Mascali, Review of Scientific Instrument 81, 02A332 (2010)]
[D. Mascali et al., Review of Scie[illegible] Instrument 87, 02A510 (02/2016)]

# THE MAIN CLUE

**The beam structure depends on the plasma structure**

- **Maximum flexibility on the frequency**

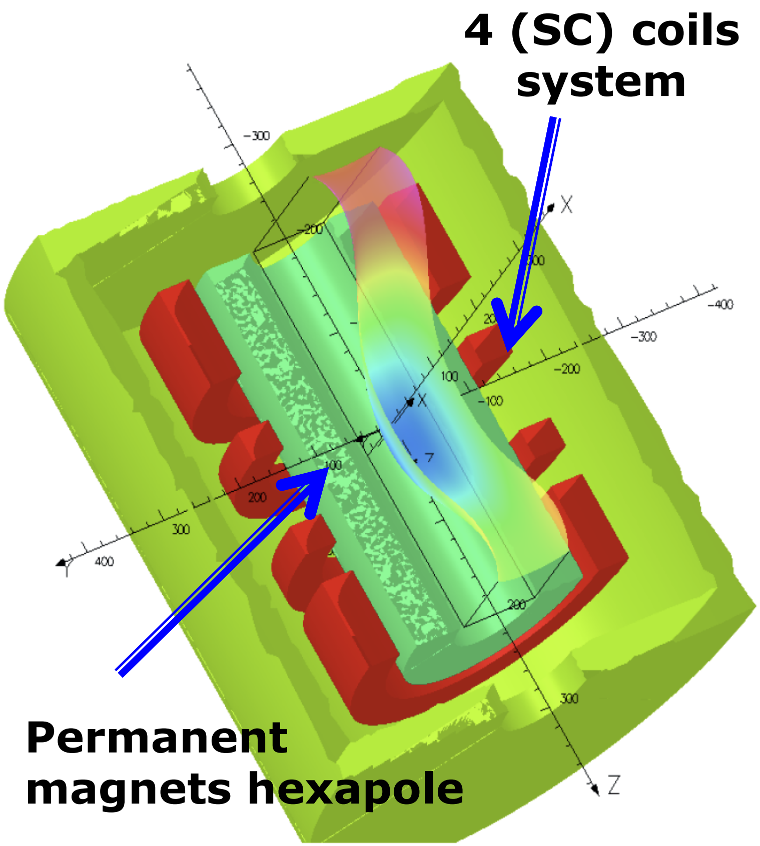
  *(the plasma structure changes with the cavity frequency)*

- **Maximum flexibility on the axial B-field**

  *(no matter about the radial one, it is less influent)*

# AISHA

## Advanced Ion Source for HAdrontherapy

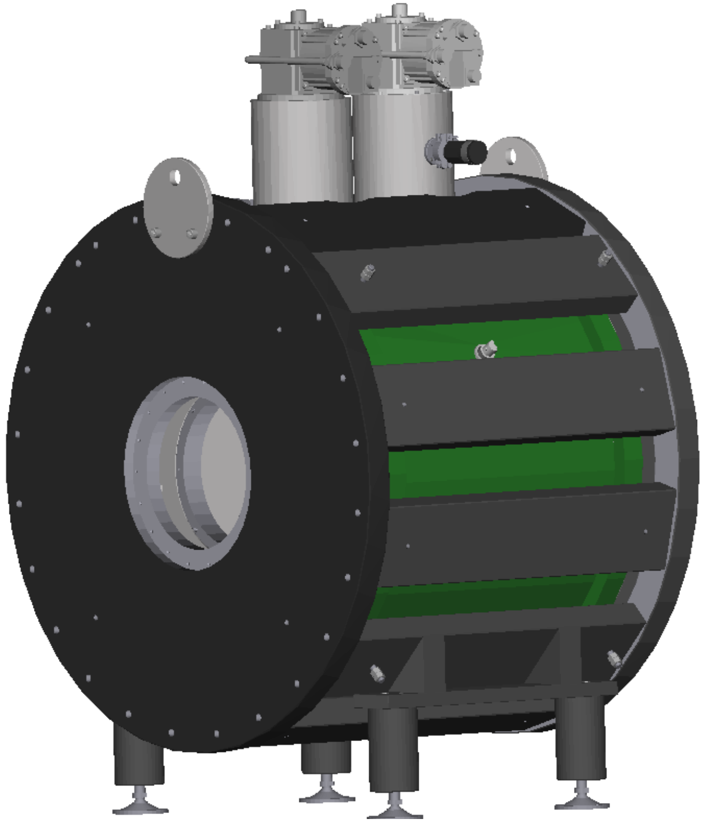


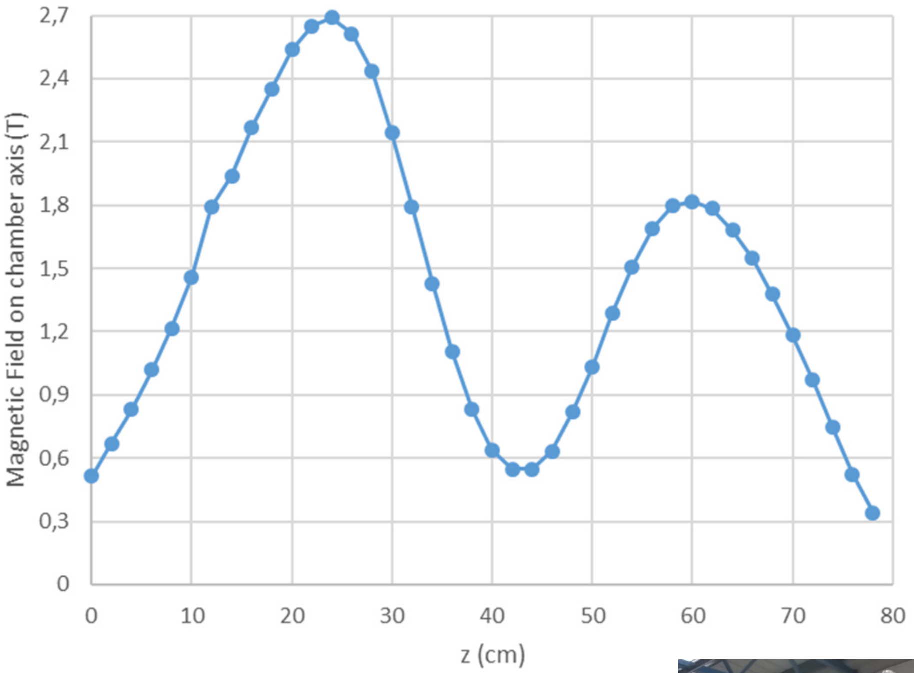

AISHA is a hybrid ECRIS: the radial confining field is obtained by means of a permanent magnet hexapole, while the axial field is obtained with a **Helium-free superconducting system.**

The **operating frequency of 18 GHz will permit** to maximize the plasma density by employing commercial microwave tubes meeting the **needs of the installation in hospital** environments.

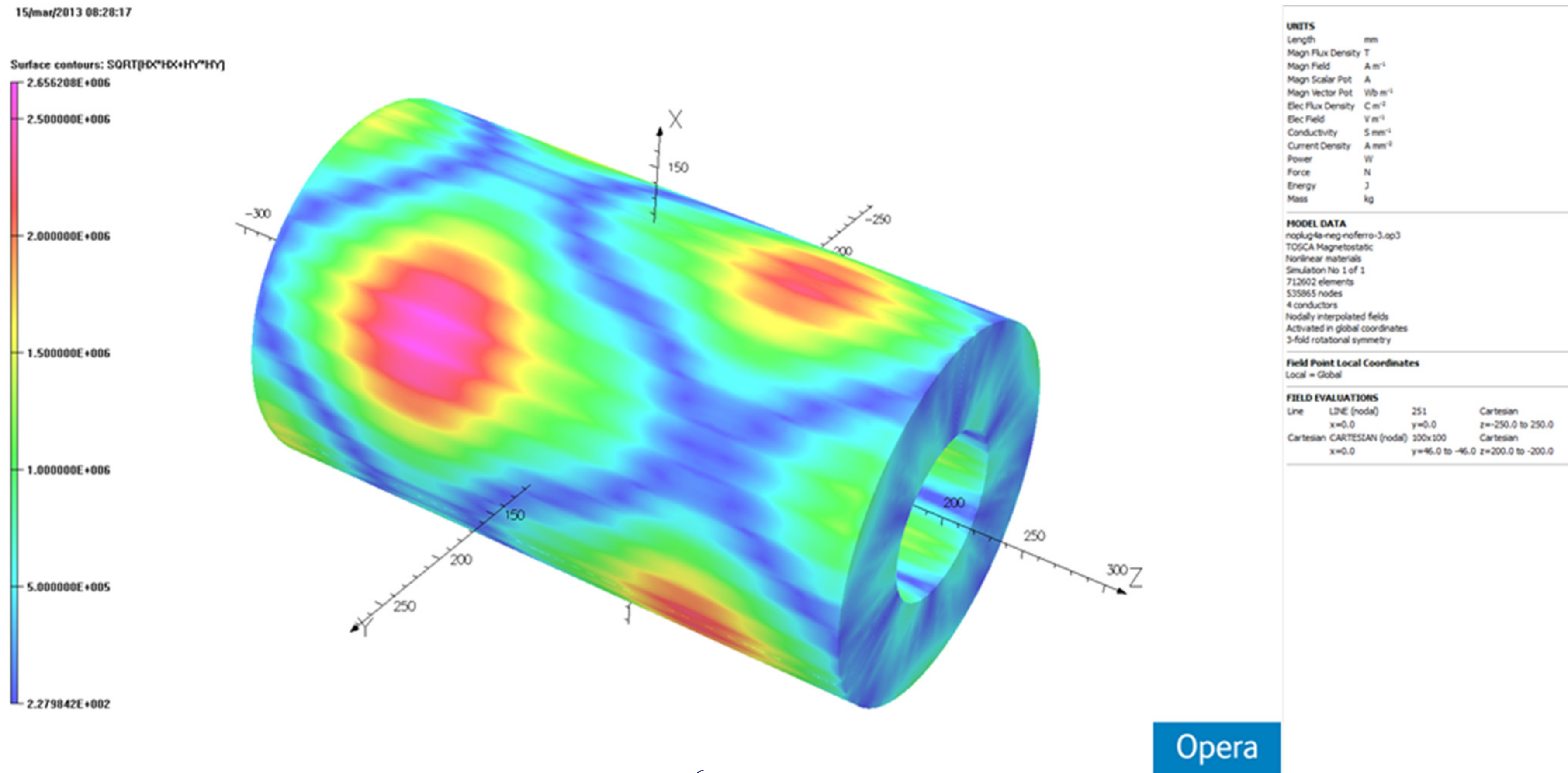
| | |
|---|---|
| Radial field | 1.3 T |
| Axial field | 2.7 T - 0.4 T - 1.6 T |
| Operating frequencies | 18 GHz – 21 GHz |
| Operating power | 1.5 + 1.5 kW (max) |
| Extraction voltage | 40 kV (max) |
| Chamber diameter / length | Ø 92 mm / 360 mm |
| LHe | Free |
| Warm bore diameter | 274 mm |
| Source weight | 1400 kg |

# SC magnetic system assemby





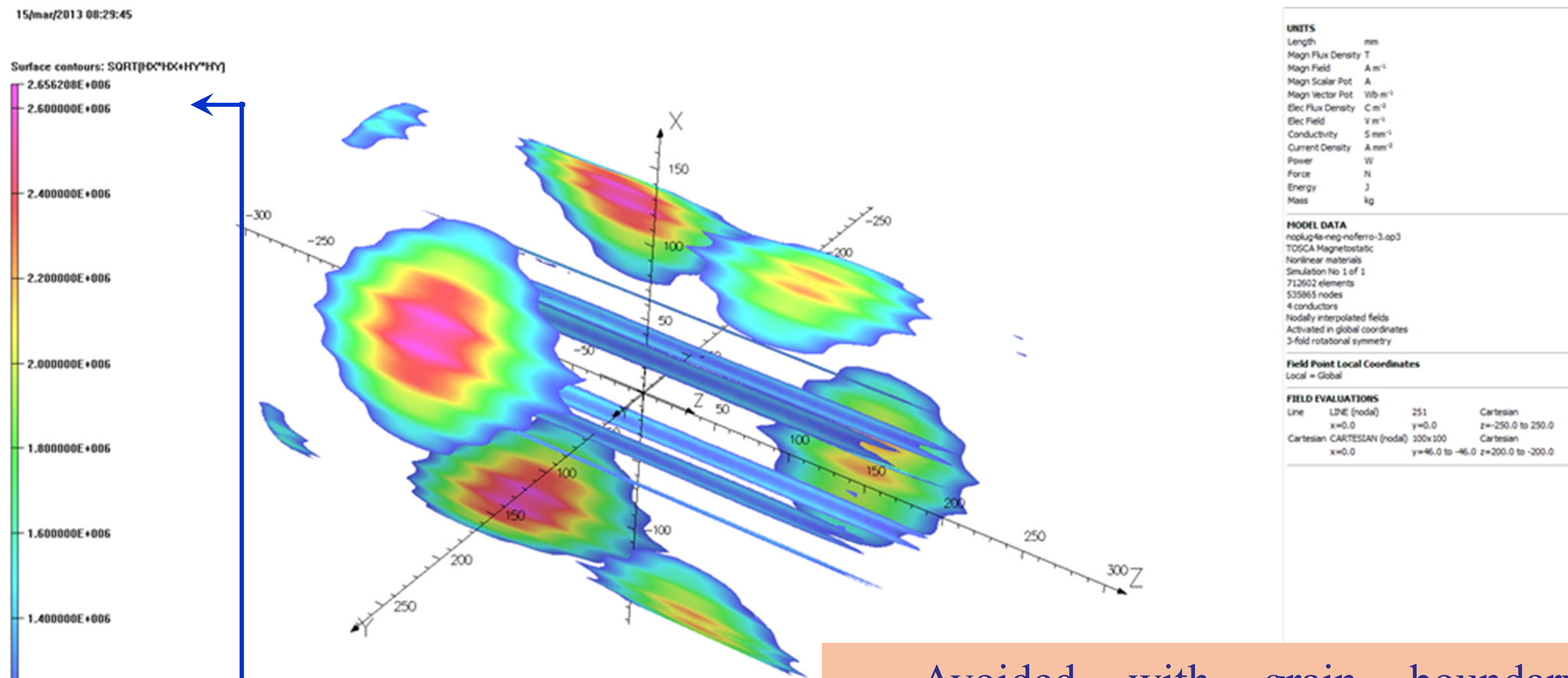

# Radial magnetic confinement
# Demagnetization issues




VAC745HR coercitivity $1.195 \times 10^6$ A/m

VAC677HR coercitivity $2.465 \times 10^6$ A/m

# Radial magnetic confinement
# Demagnetization issues



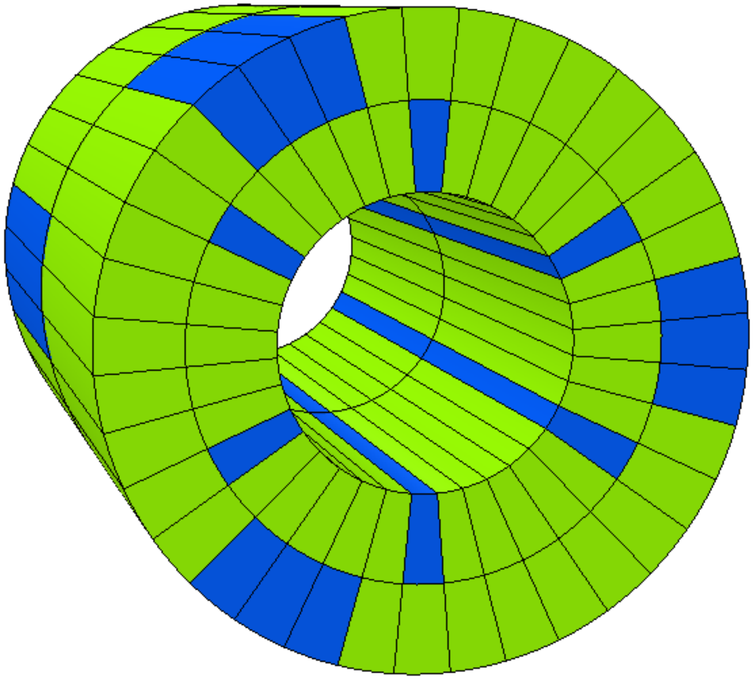

VAC745HR coercitivity $1.195 \times 10^6$ A/m

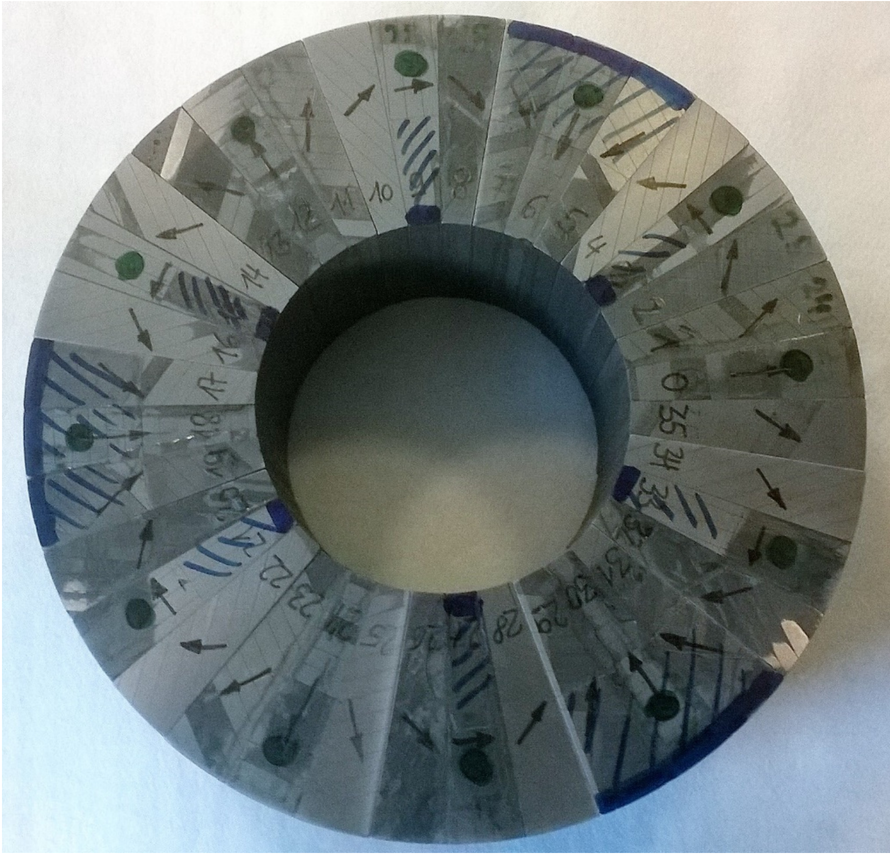
VAC677HR coercitivity $2.465 \times 10^6$ A/m

Avoided with grain boundary diffusion process!

Temperature of external part of plasma chamber MUST be kept low to avoid demagnetization

# AISHa hexapole

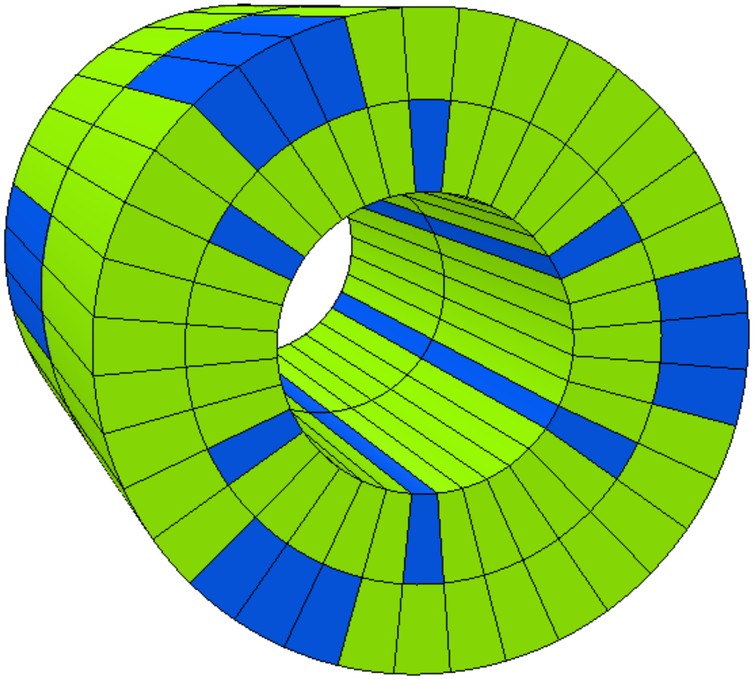


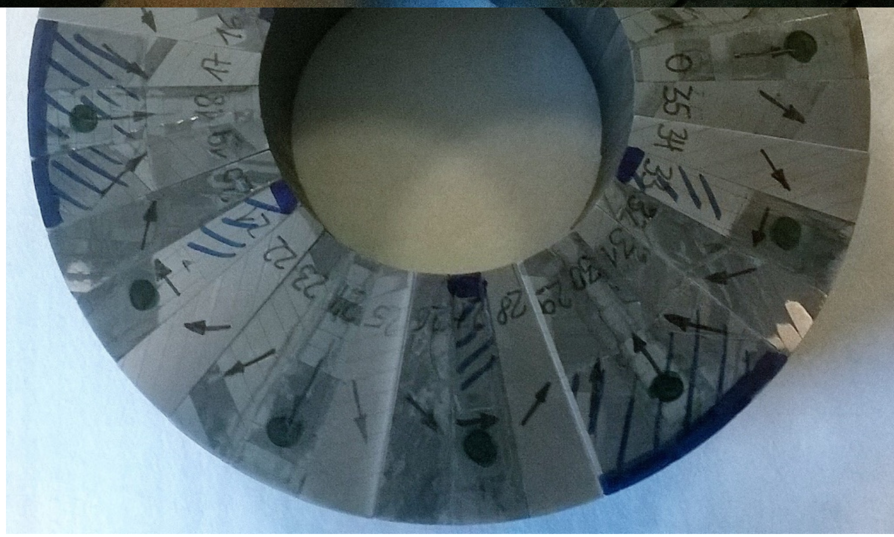


**Grain boundary diffusion process to enhance coercitivity on both materials to avoid demagnetization issues**

**Green= VAC 745 HR**
**Blue= VAC677 HR**

# AISHa hexapole



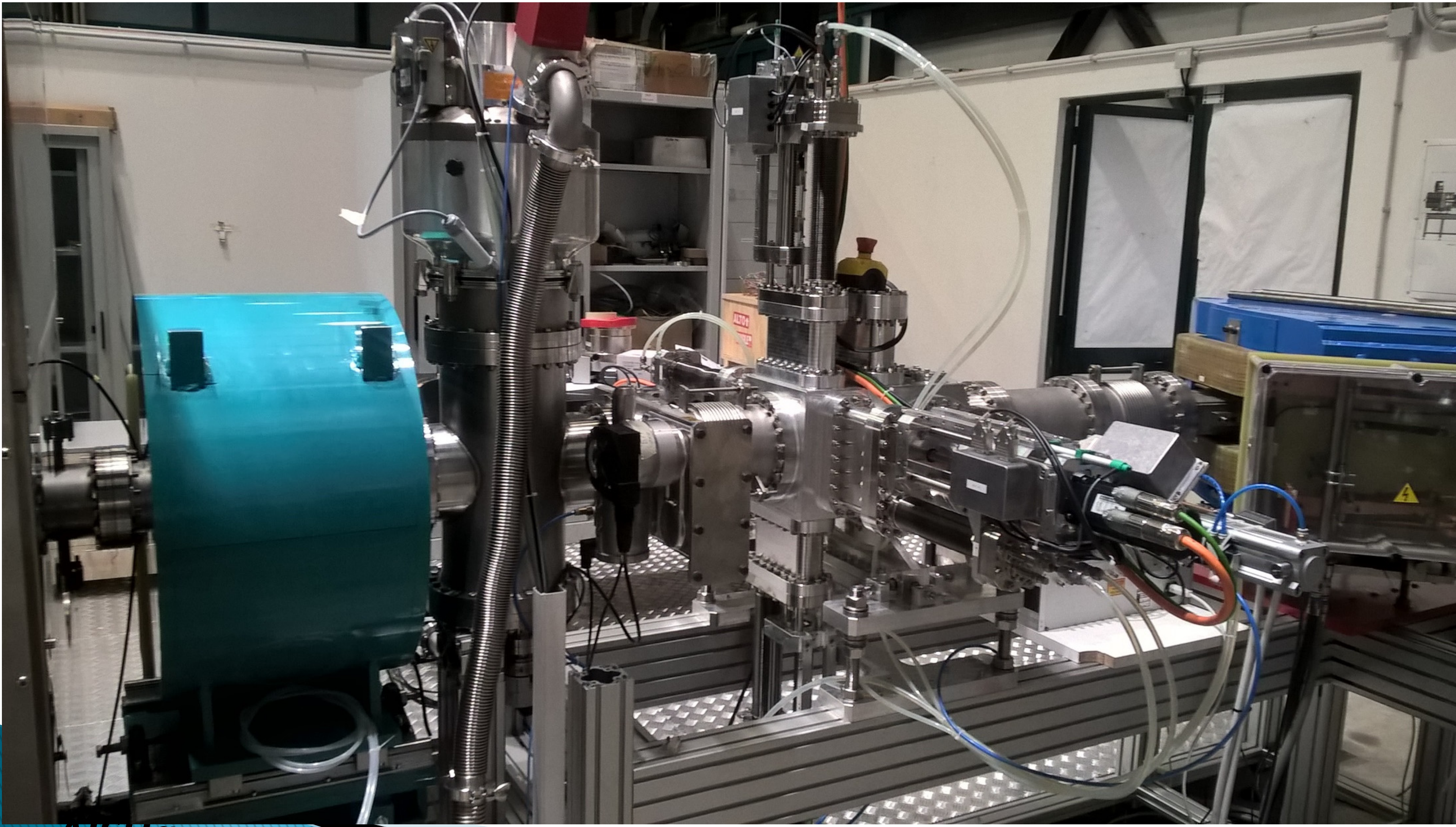


**Grain boundary diffusion process to enhance coercitivity on both materials to avoid demagnetization issues**

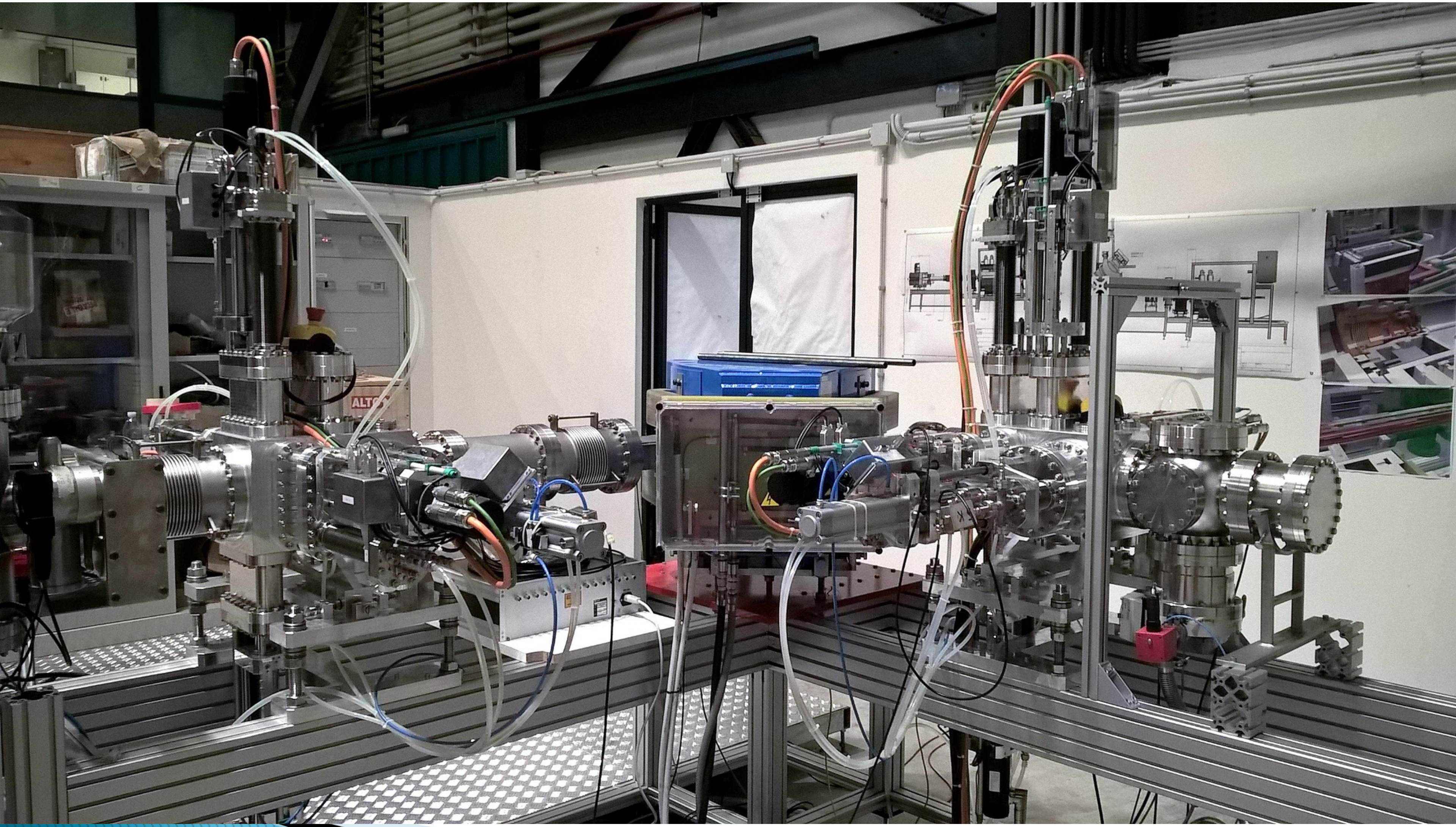
**Green= VAC 745 HR**
**Blue= VAC677 HR**

# Experimental setup

# Experimental setup

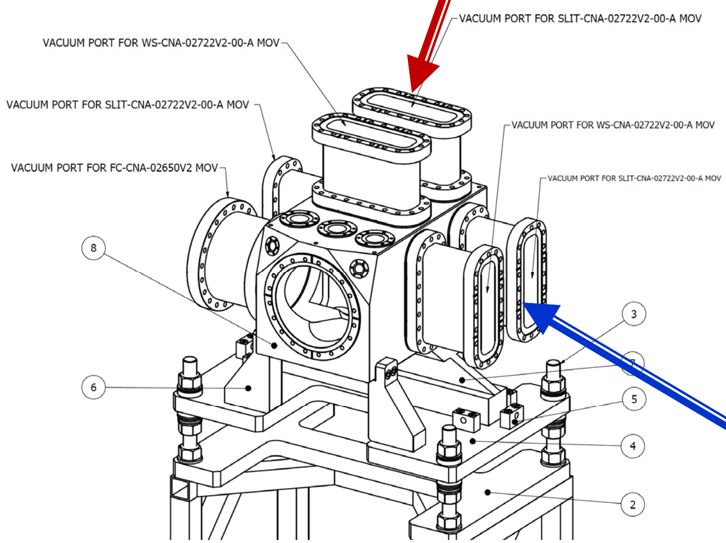


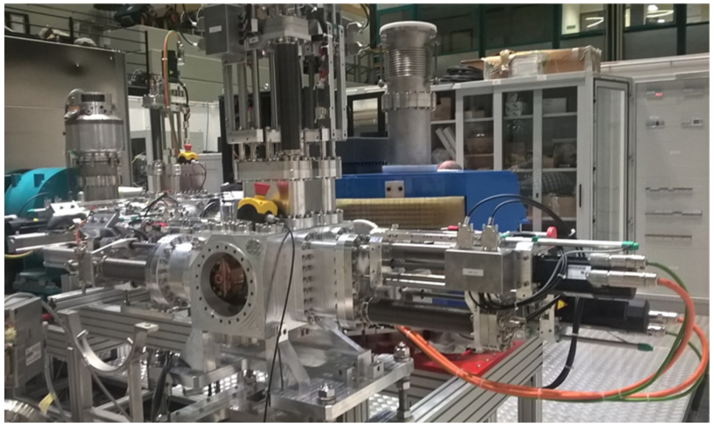
# Experimental setup



# Emittance measurements setup

Vertical slit and BWS



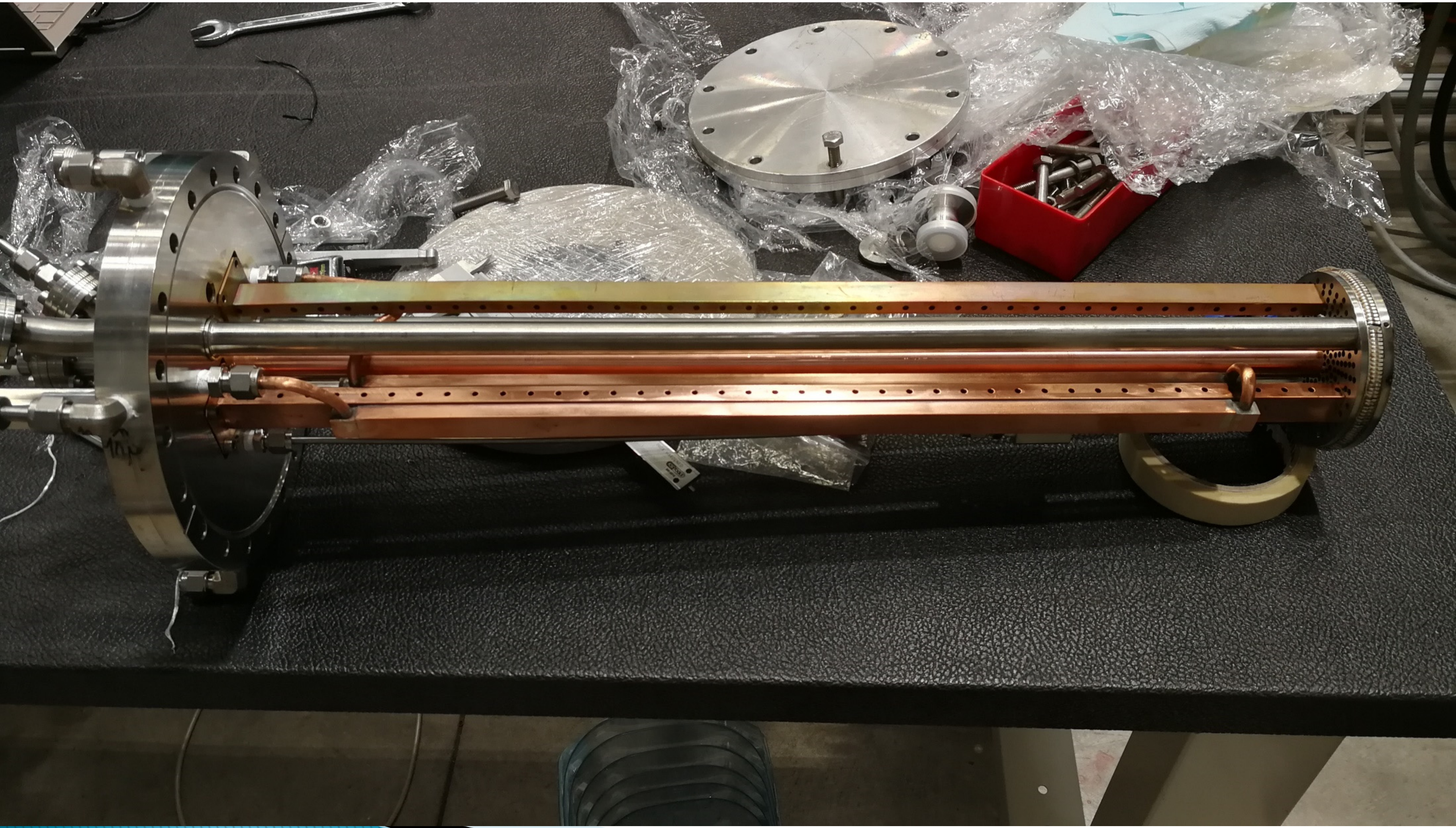
Horizontal slit and BWS

Distance between Horizontal slit and BWS = 133 mm
Distance between Vertical slit and BWS = 138 mm

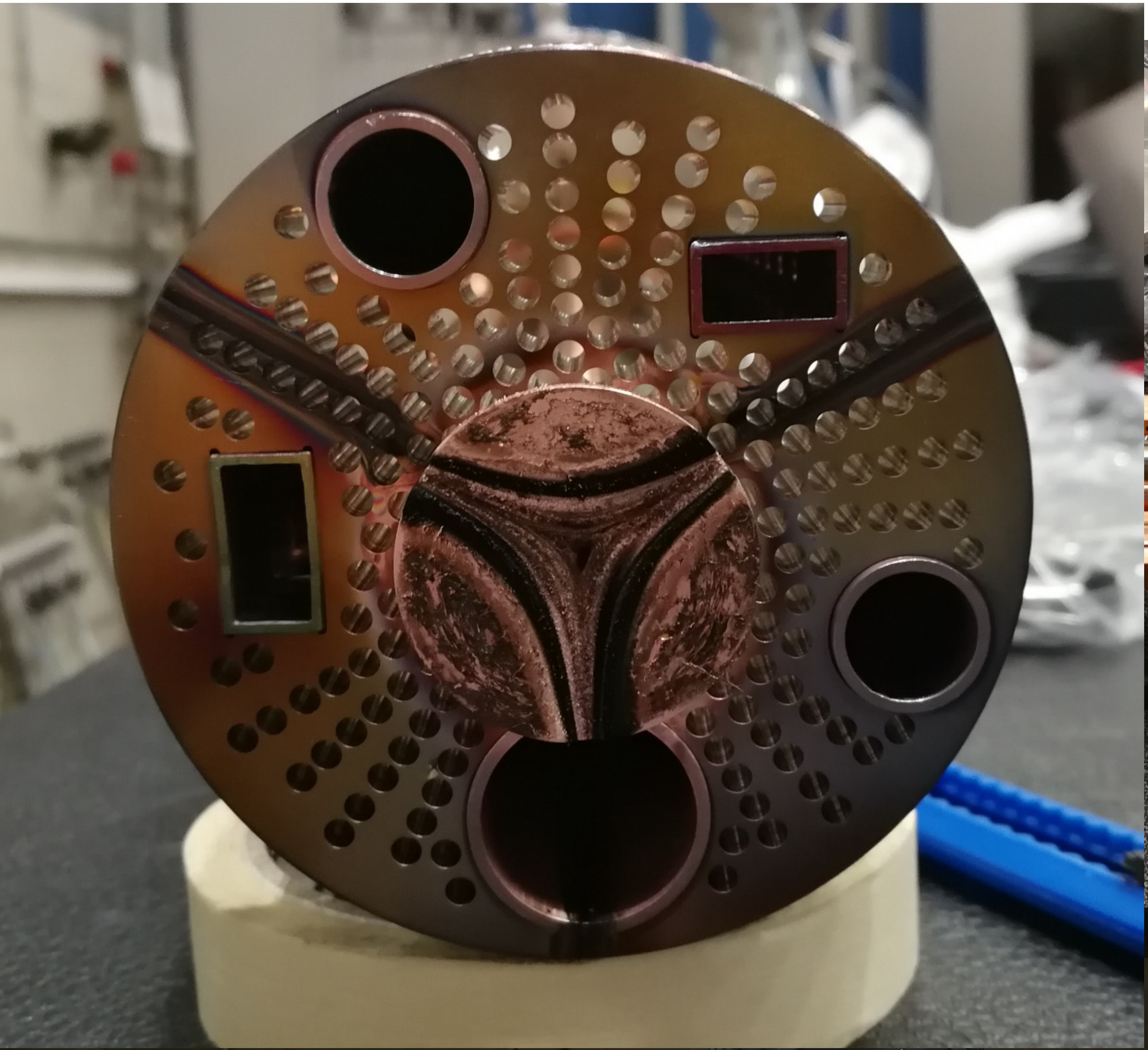
Slit aperture: 0.5 mm
BWS speed: 1-100 mm/s (between 10-20 mm/s normally used)
Max sampling rate: 100kHz on 2 channels (1 sample each 0.1 mm normally used)

Displacement of 0.1 mm after 130 mm means 0.7 mrad divergence.

# AISHa mechanics 1.5

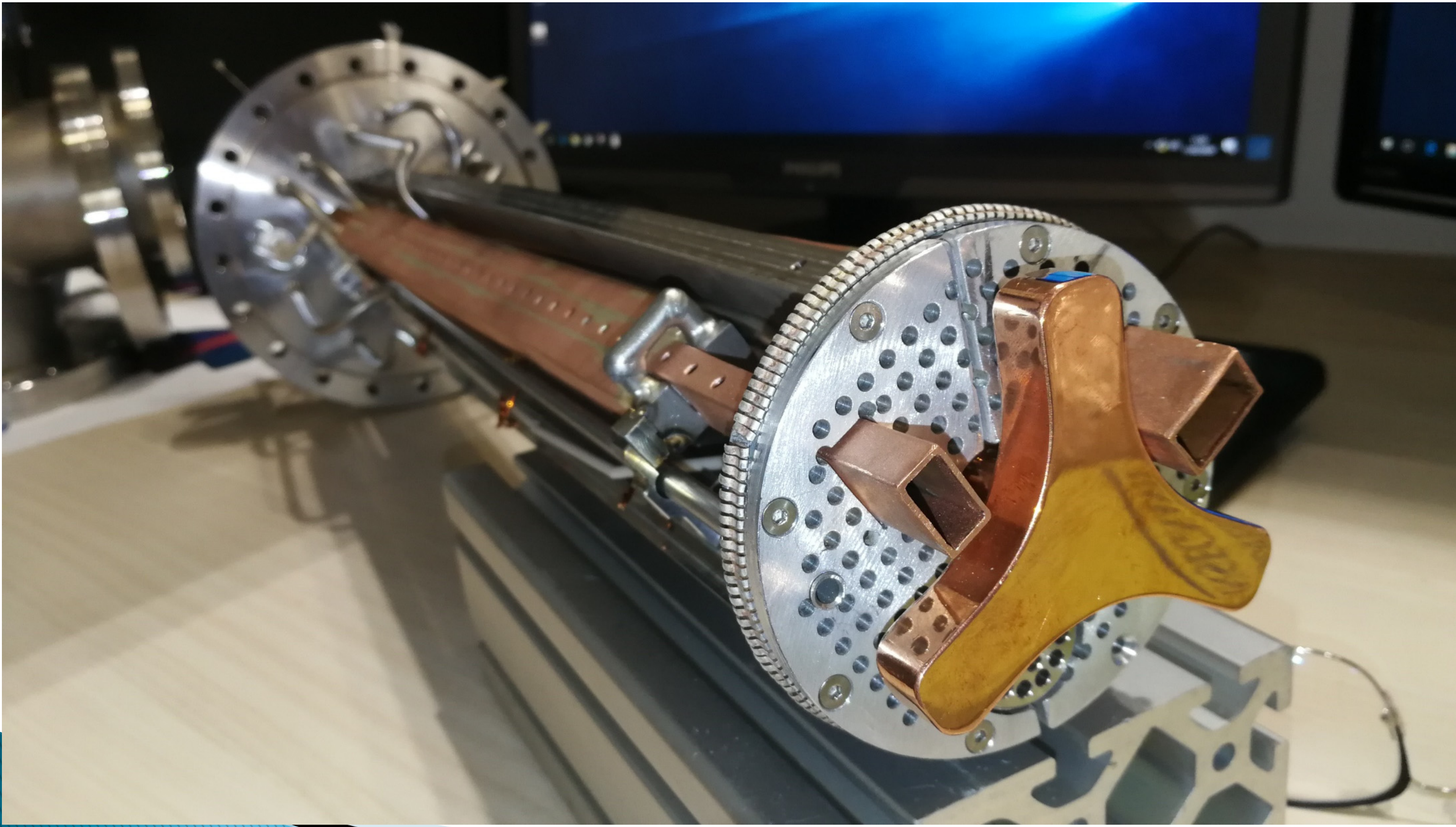


# AISHa mechanics 1.5

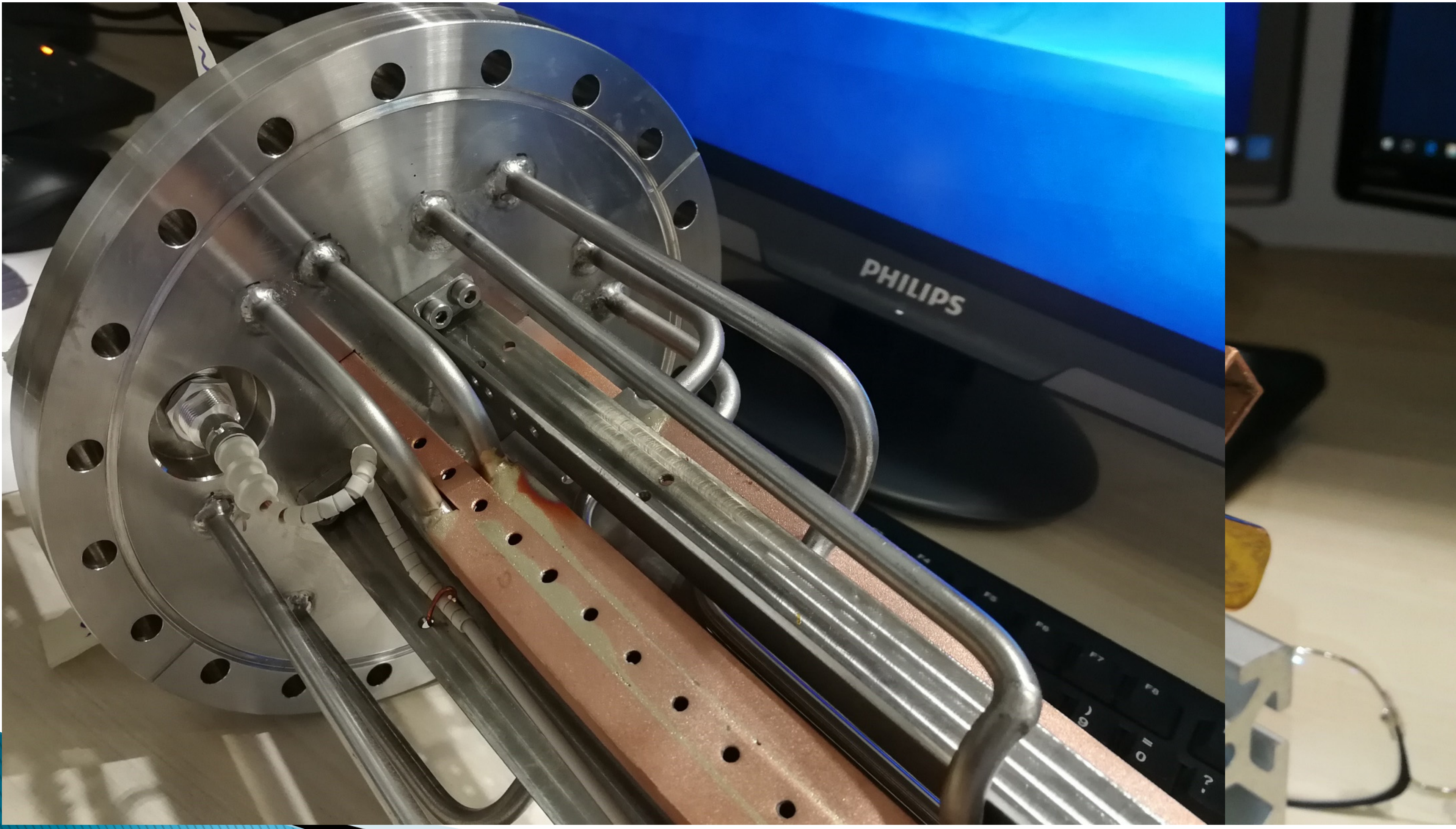


# AISHa mechanics 1.5

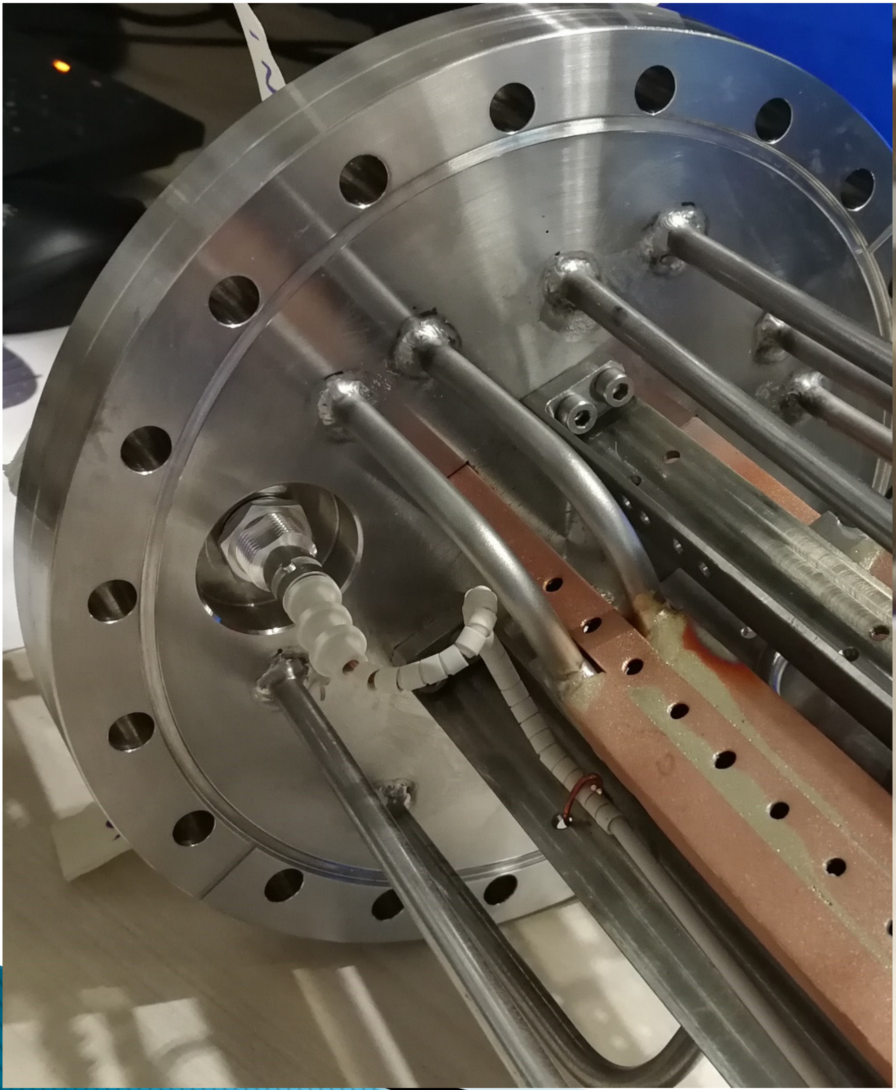
# AISHa improved mechanics

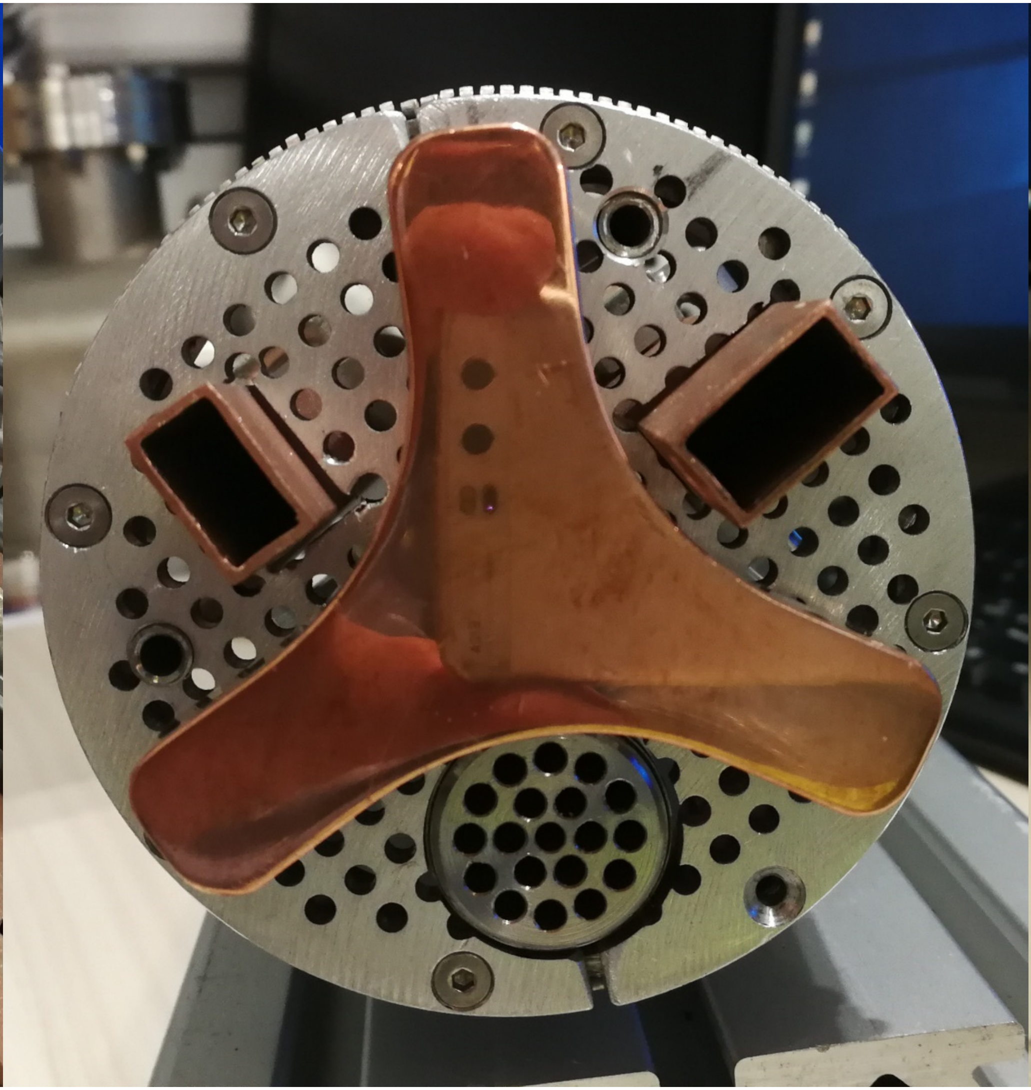


# AISHa improved mechanics

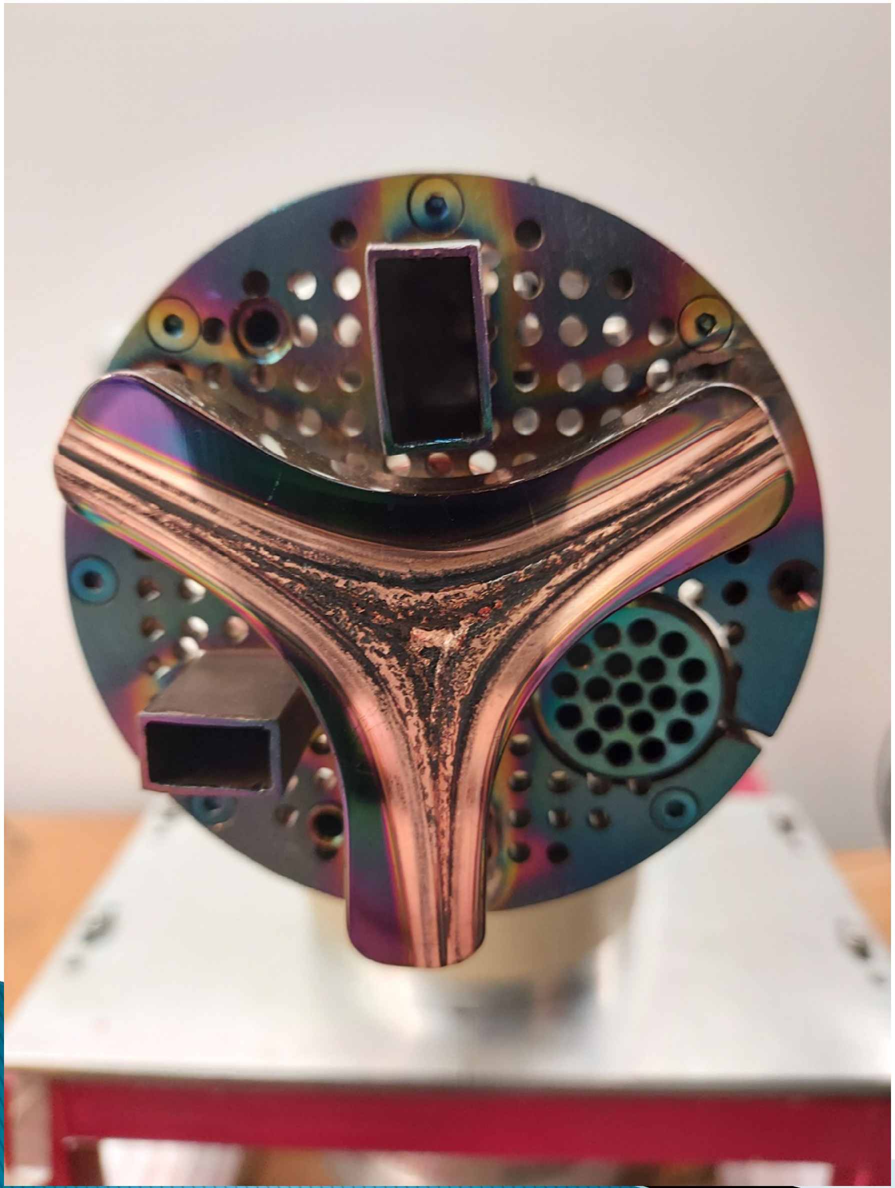


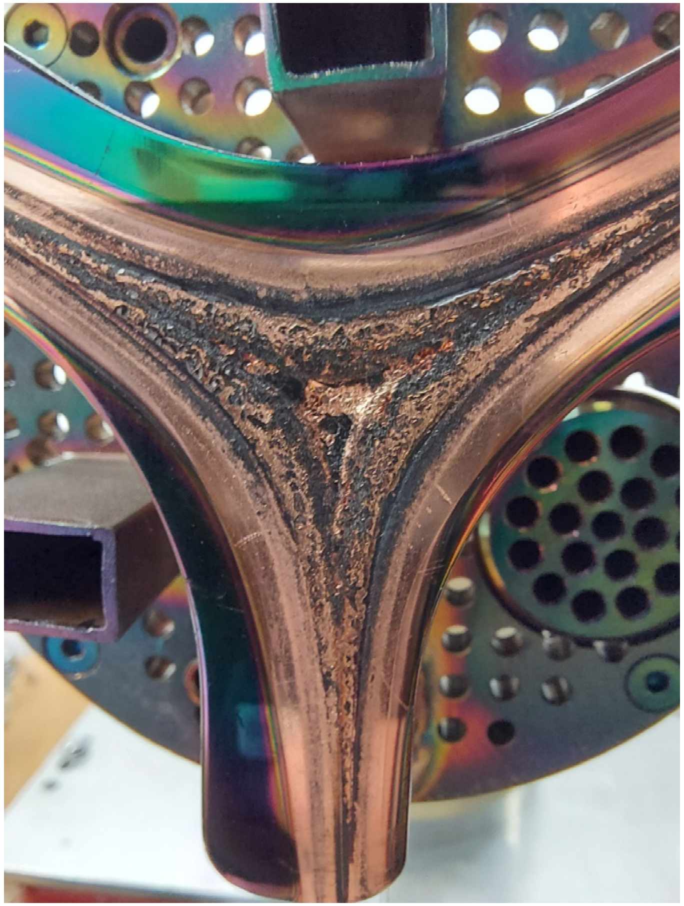
# AISHa improved mechanics





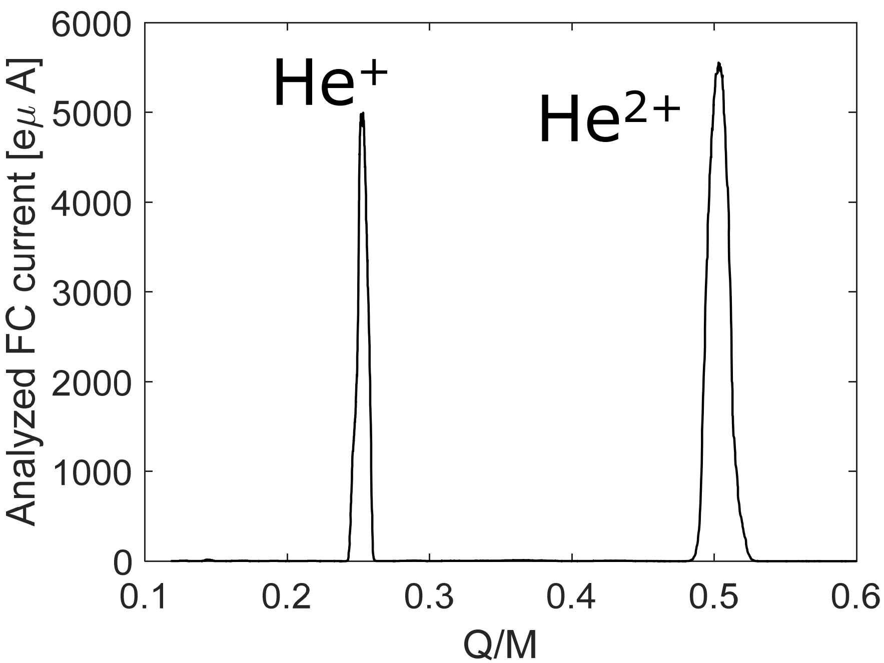
# AISHa improved mechanics





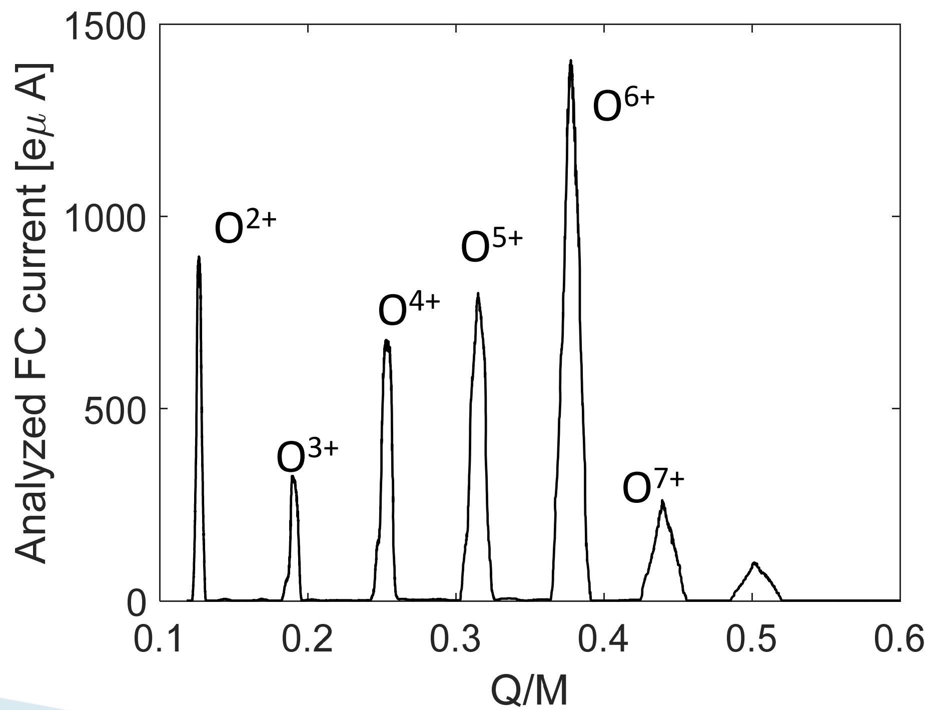
# AISHa Helium and Oxygen
# SFH (17.3-18.4 GHz – 1.5 kW max)

Helium

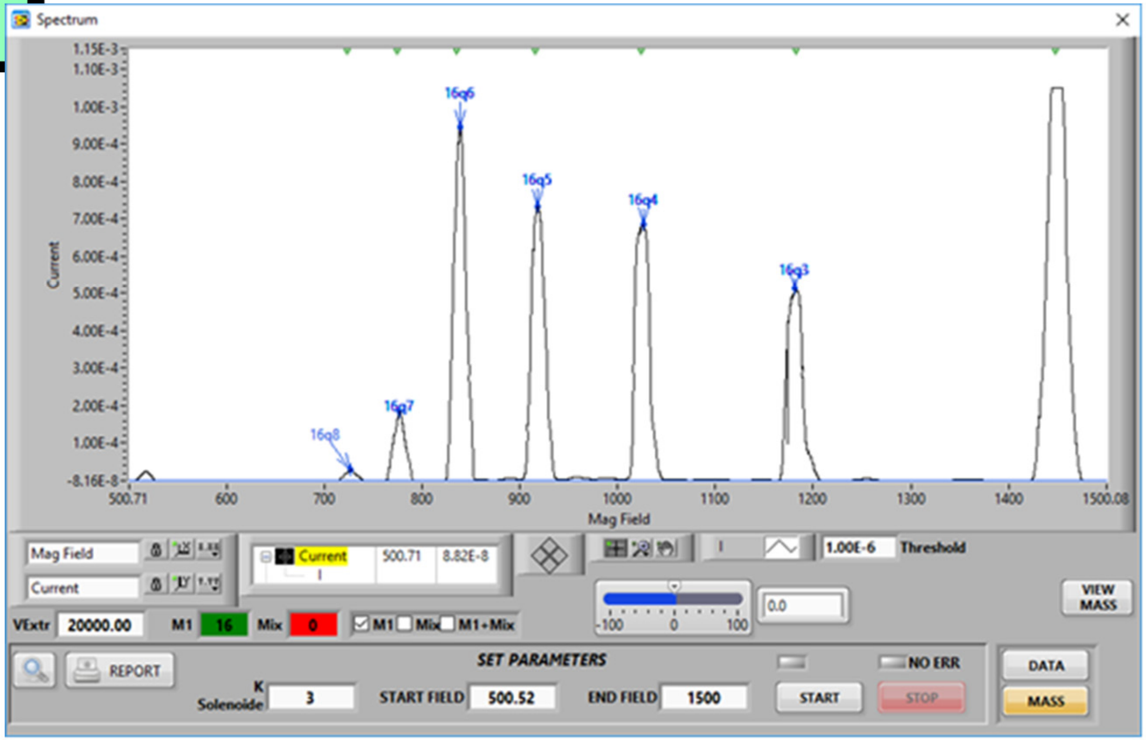



$O^{6+}$ > 1.6 emA
$O^{7+}$ > 0.35 emA
$O^{8+}$ > 0.1 emA

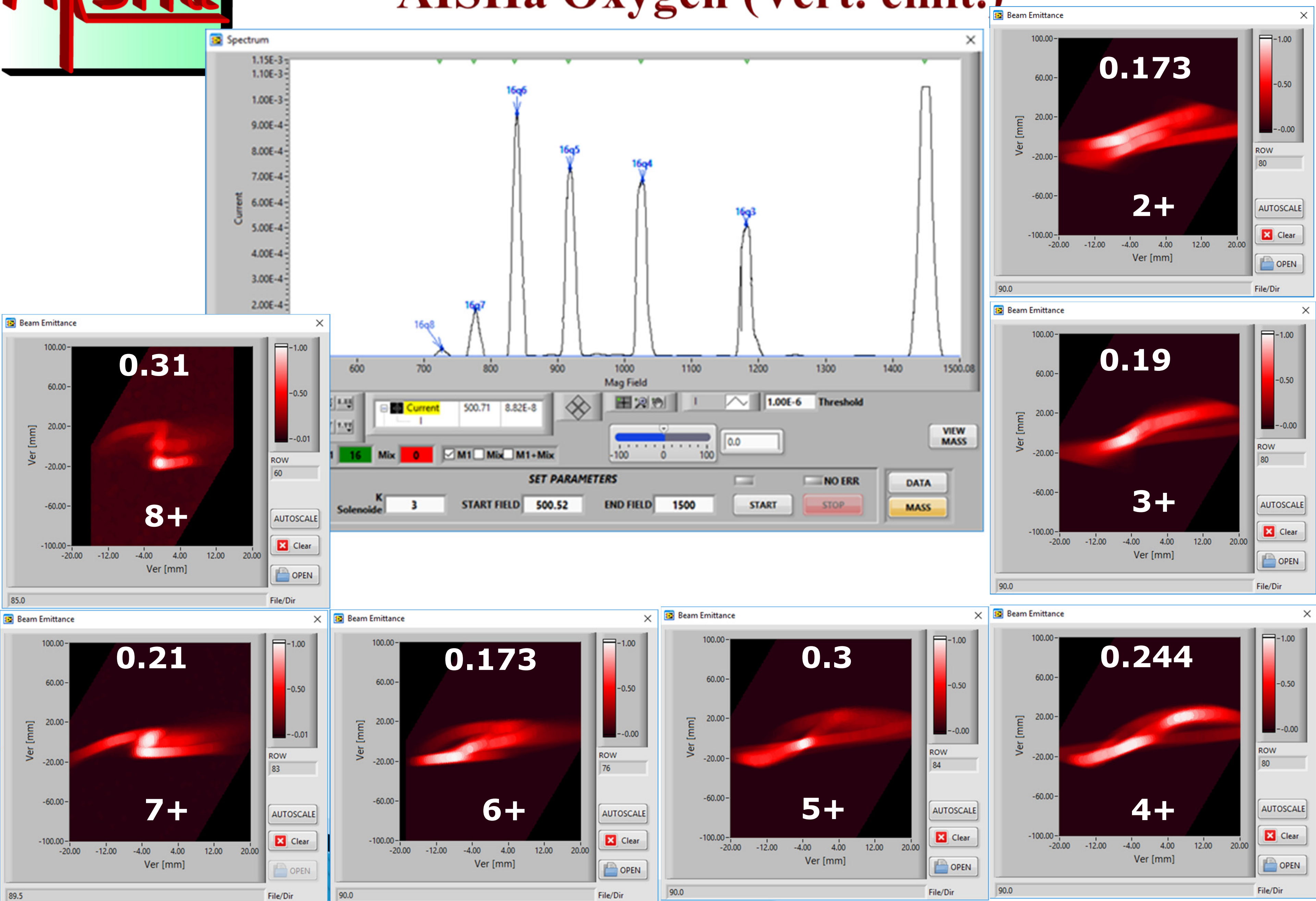
$O^2$ + He (4:1)



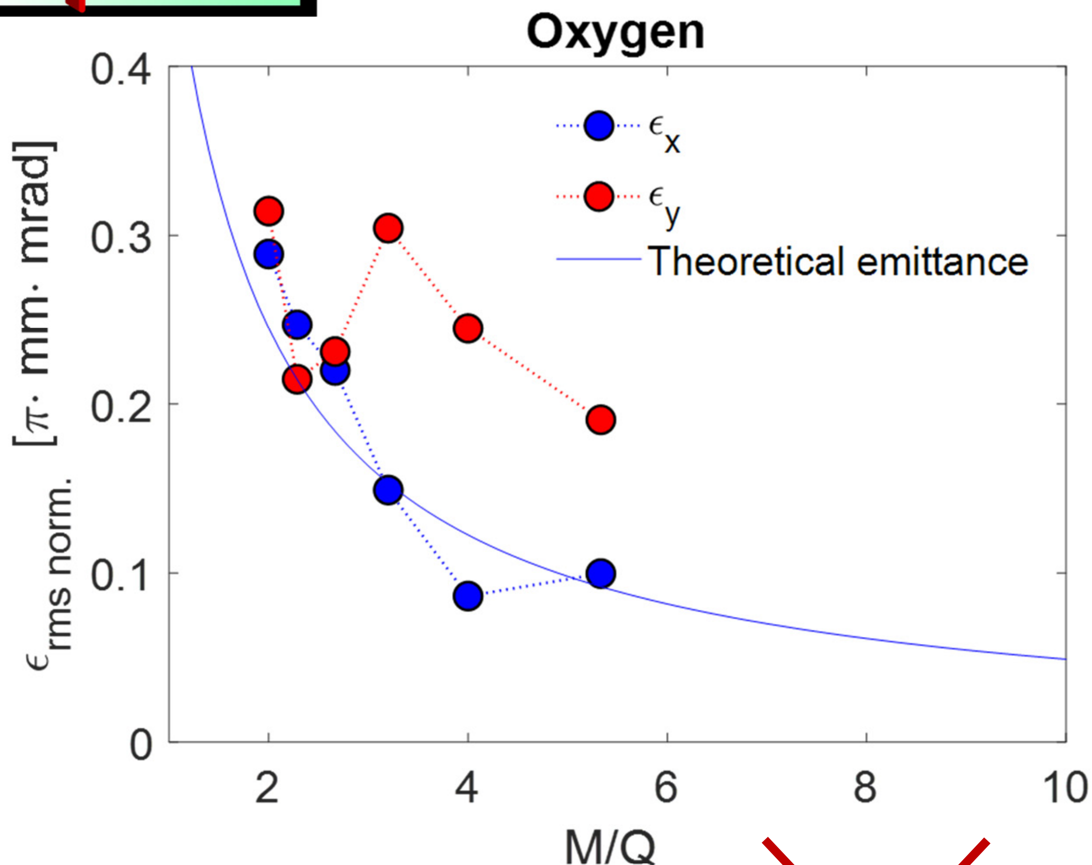
# AISHa Oxygen (Vert. emit.)



# AISHa Oxygen (Vert. emit.)



# AISHa Oxygen




$$\varepsilon^{theor.}_{rms.norm} = 0.032\mathrm{r}^2 \frac{B_{extr}}{M/Q} + \cancel{0.016r\sqrt{\frac{T_i}{M/Q}}}$$

**neglected term**

Source stability is a close synonym of good beam quality produced (almost one-to-one corrispondence)

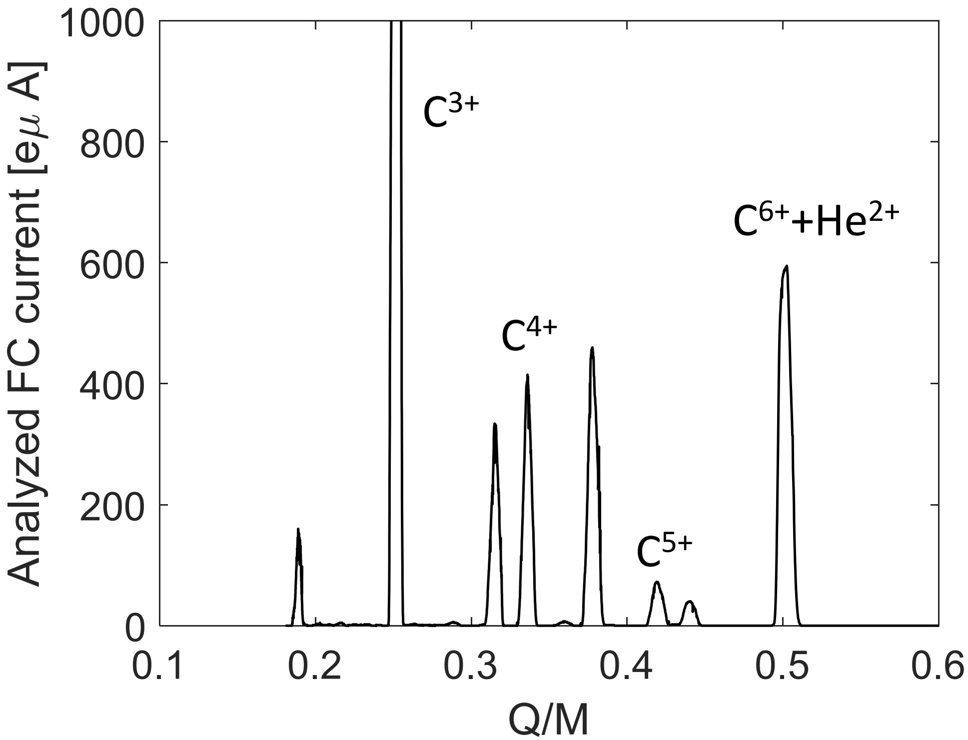
Beam ripple was the reference during our measurements

A key role is played by the amount of neutrals injected into the chamber (fine control of such flux and its stability make the difference)

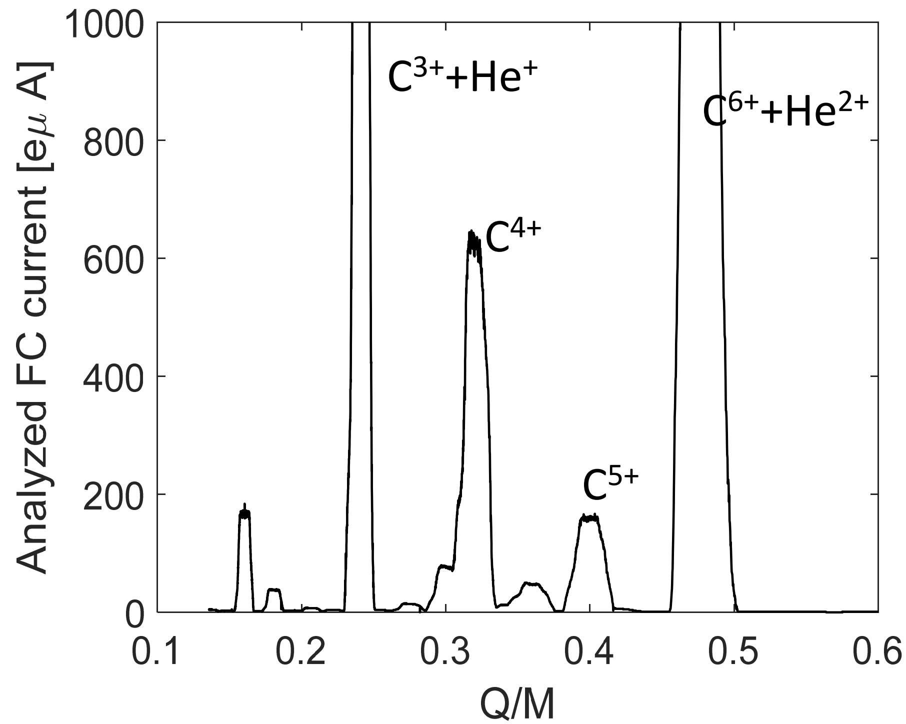
**MFC** 0.01-0.7 sccm

# AISHa Carbon

$CO^2$+He (~1: 1)

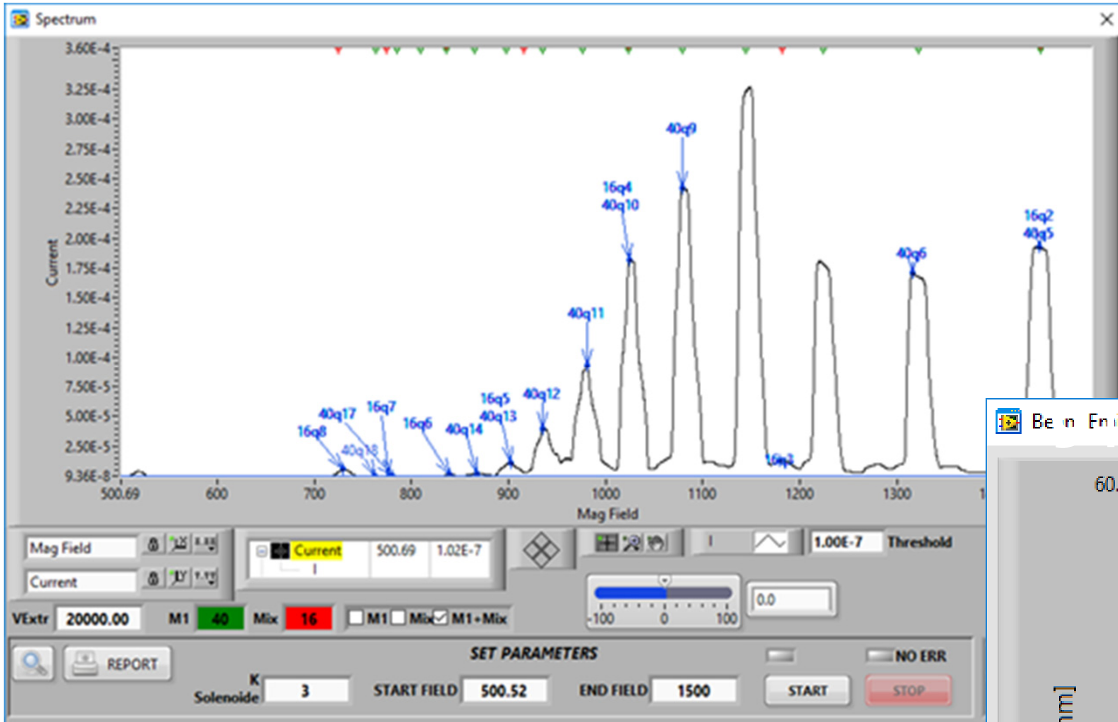



$CH^4$+He (~10: 1)

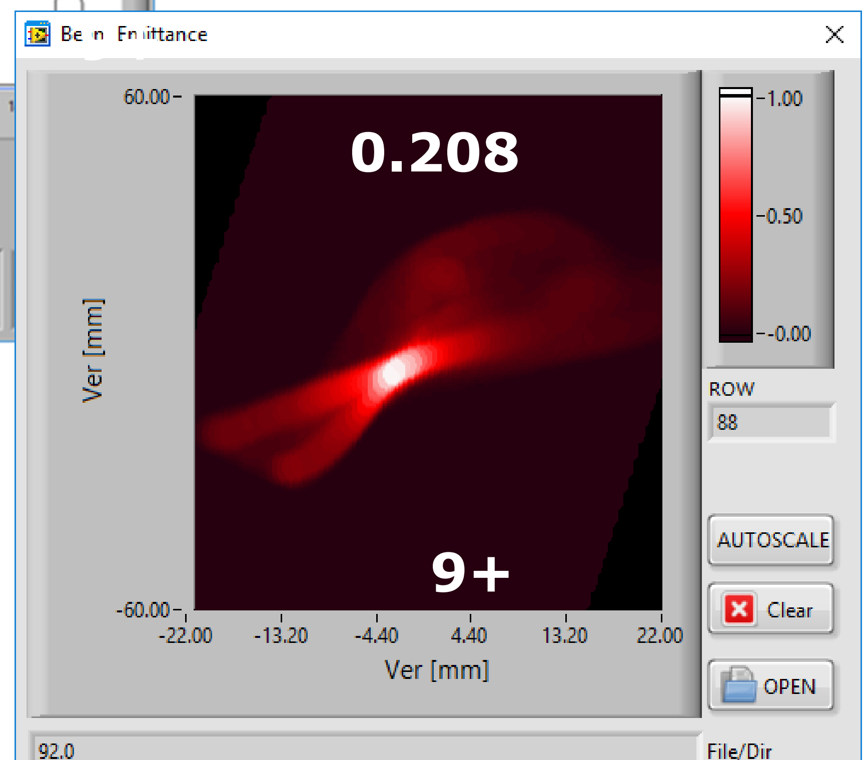



**Very high drain current (up to 18 mA) with more than 10 mA between Helium and Hydrogen.**

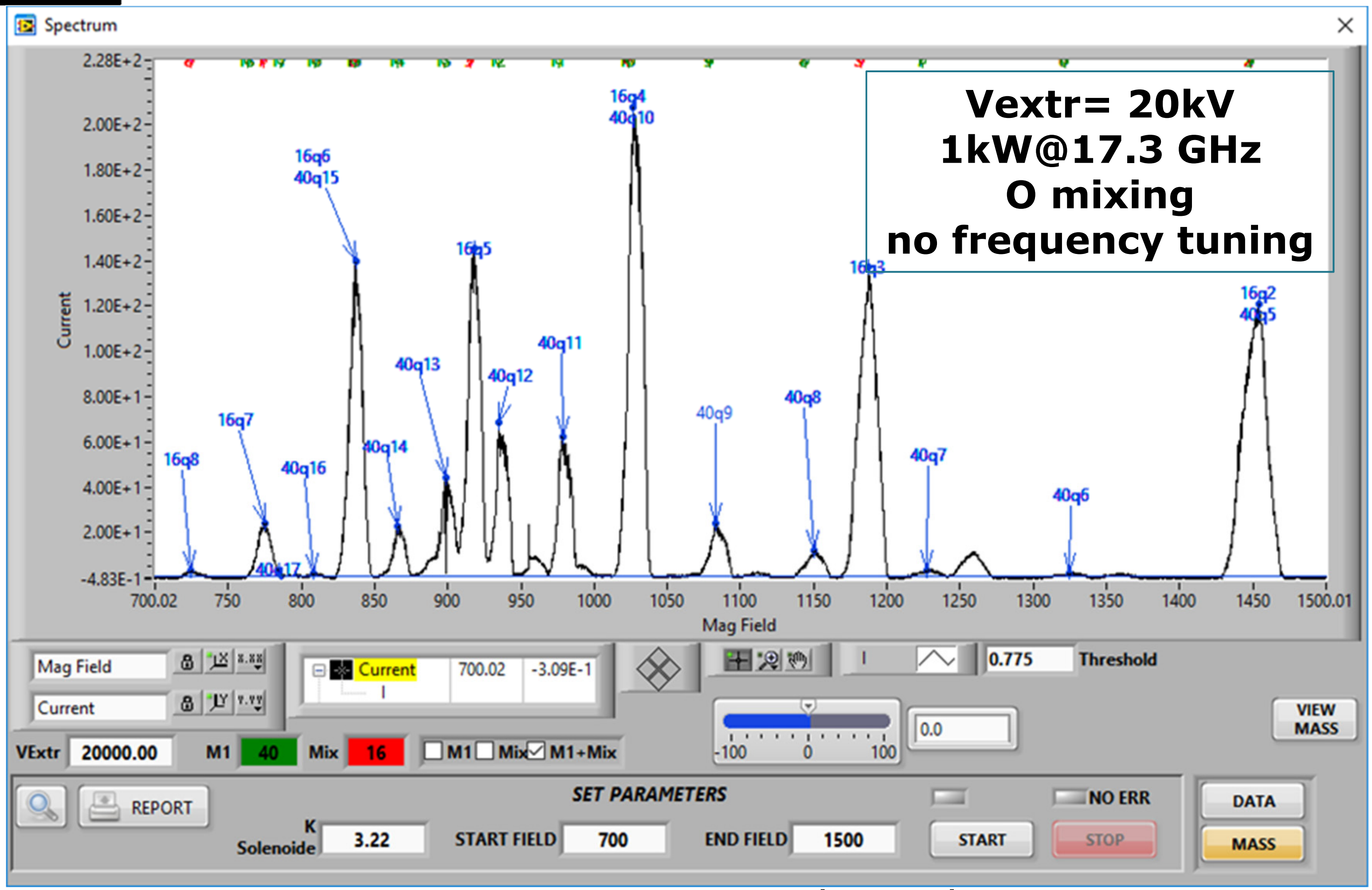
# Charge State Distribution for Argon ions (07/20)




Very high stability, but flux was vey close to the lower limit of MFC.



# Charge State Distribution for Argon ions (06/18)

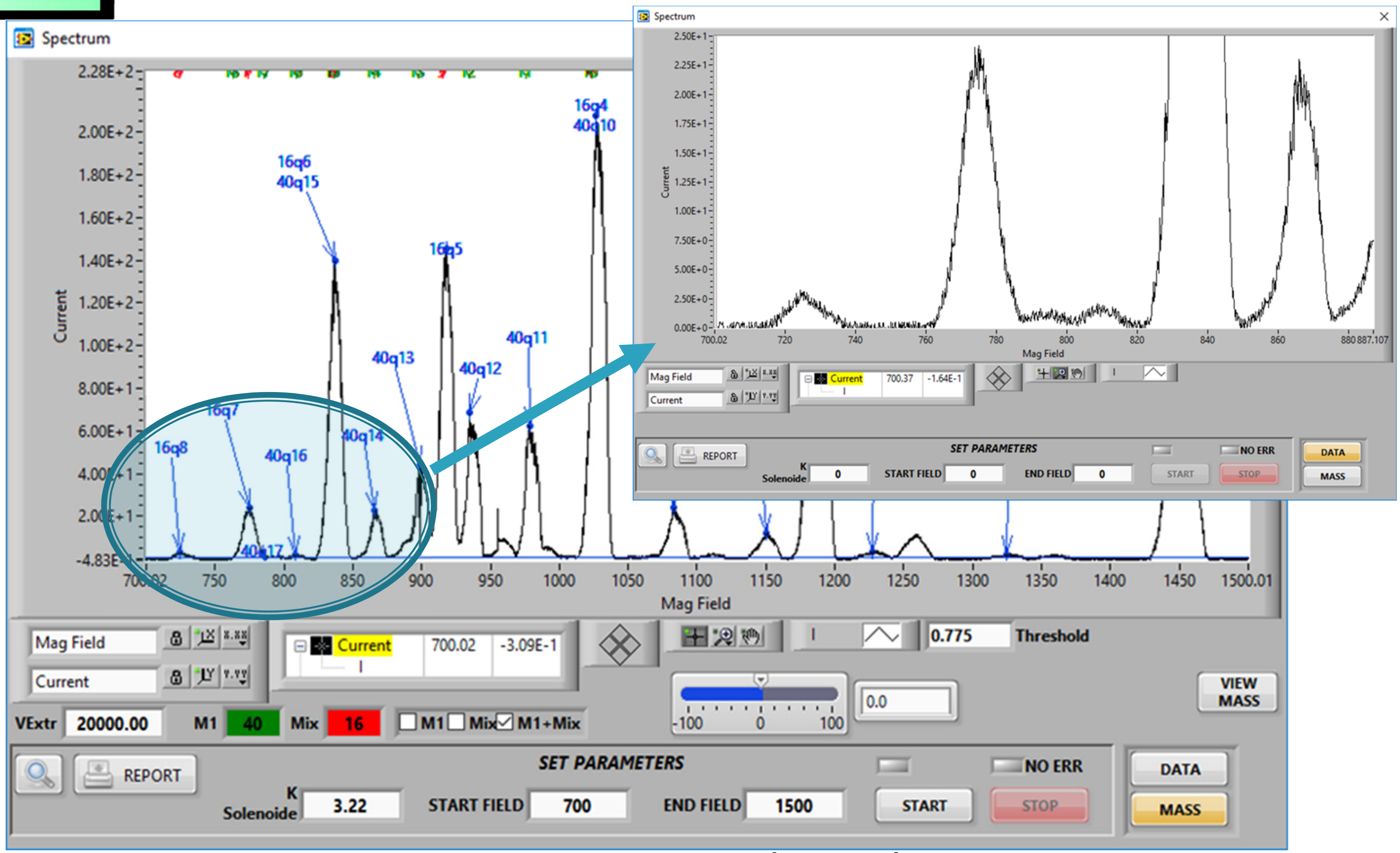



Max currents achieved:

$Ar^{11+}$ 190 uA - $Ar^{13+}$ 80 uA - $Ar^{16+}$ 2 uA

$Ar^{12+}$ 140 uA - $Ar^{14+}$ 40 uA

# Charge State Distribution for Argon ions (06/18)



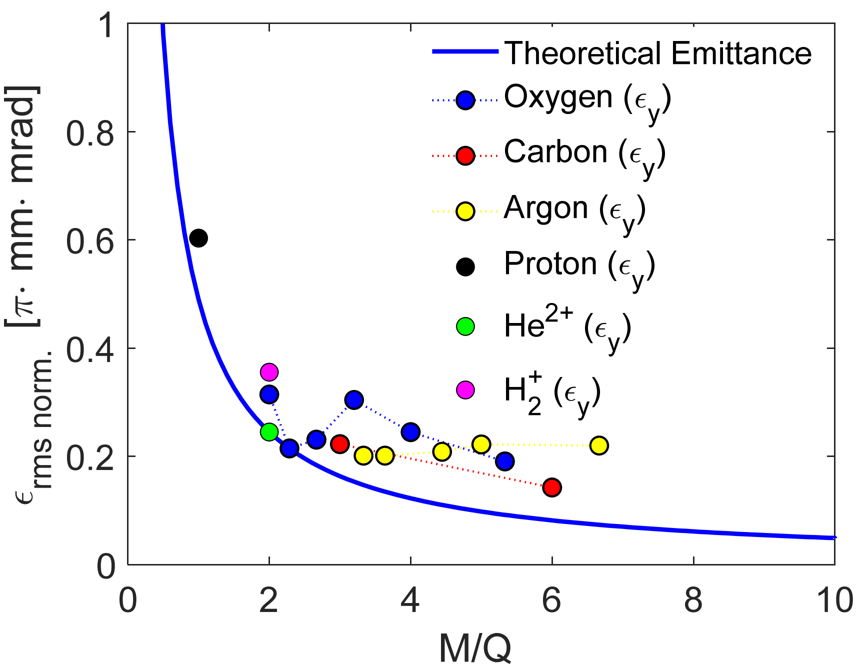

Max currents achieved:

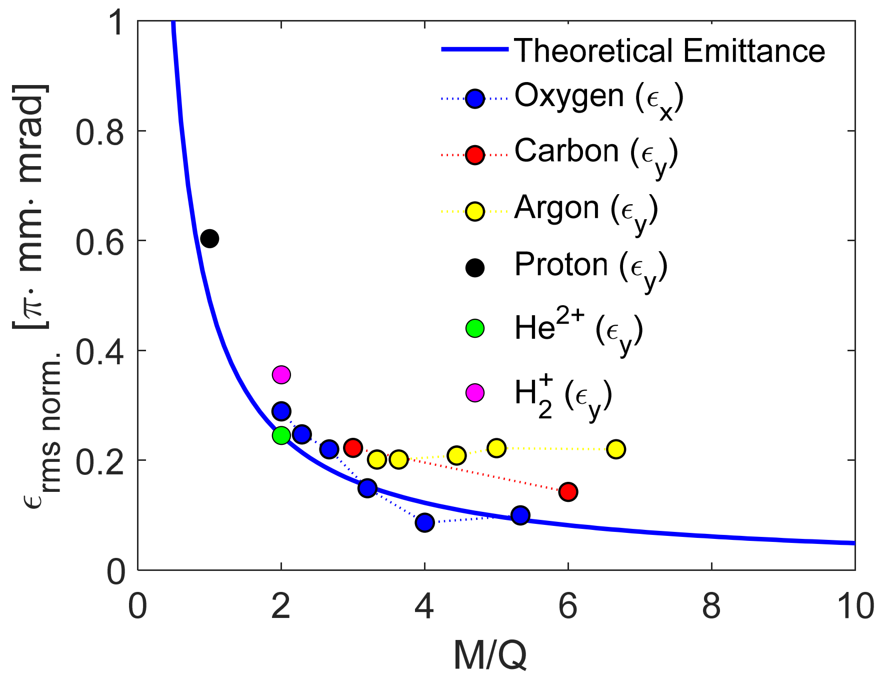
$Ar^{11+}$ 190 uA - $Ar^{13+}$ 80 uA - $Ar^{16+}$ 2 uA

$Ar^{12+}$ 140 uA - $Ar^{14+}$ 40 uA

AISHa

# Emittance measurements




$$\varepsilon_{rms.norm}^{theor.} = 0.032\mathrm{r}^2 \frac{B_{extr}}{M/Q} + \cancel{0.016\mathrm{r}\sqrt{\frac{T_i}{M/Q}}}$$

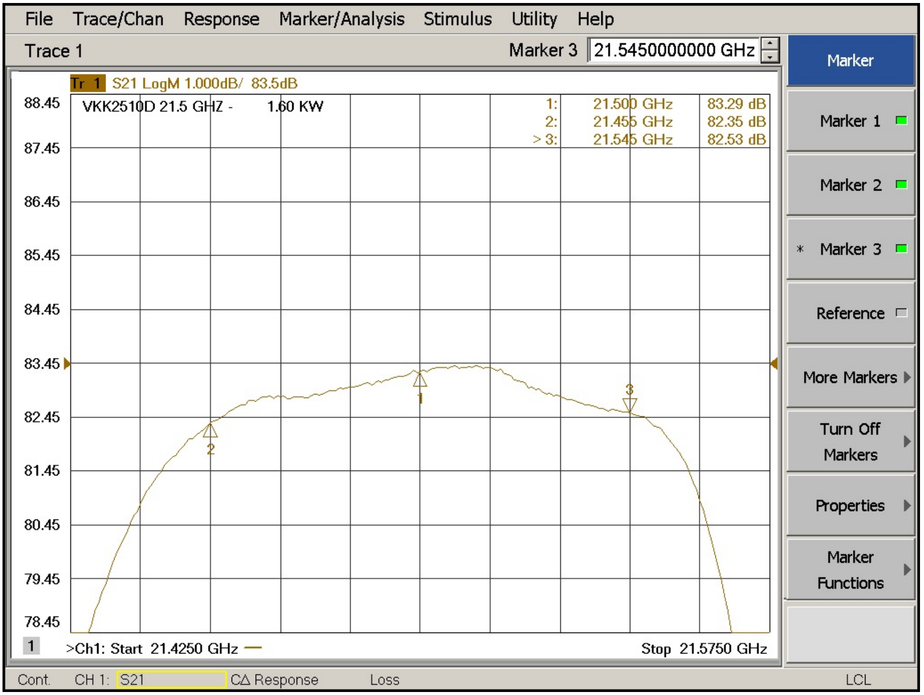
**neglected term**

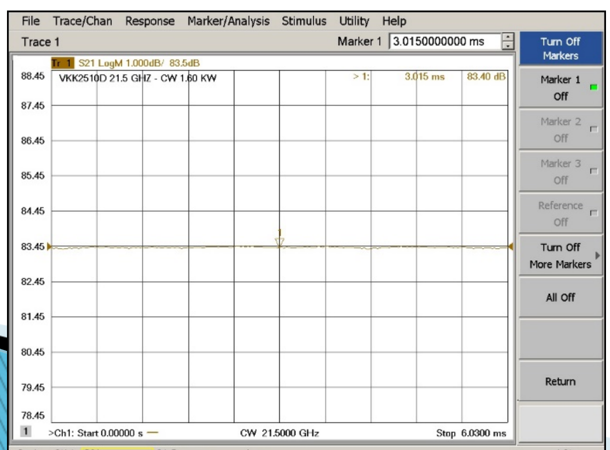
# AISHa performances
# SFH (17.3-18.4 GHz) – 1.5 kW max

| Charge state | Beam intensity [e$\mu$A] | $\varepsilon_{rms.norm}$ [$\pi \cdot mm \cdot mrad$] |
|---|---|---|
| $^{16}O^{6+}$ | 1400 | 0.2198 |
| $^{16}O^{6+}$ | 225 | 0.115 |
| $^{16}O^{7+}$ | 350 | 0.247 |
| $^{12}C^{4+}$ | 650 | 0.272 |
| $^{12}C^{4+}$ | 150 | 0.222 |
| $^{12}C^{5+}$ | 165 | --- |
| $^{40}Ar^{11+}$ | 155 | 0.201 |
| $^{40}Ar^{12+}$ | 140 | 0.201 |
| $He^{2+}$ | 5400 | 0.418 |
| $He^{2+}$ | 700 | 0.245 |

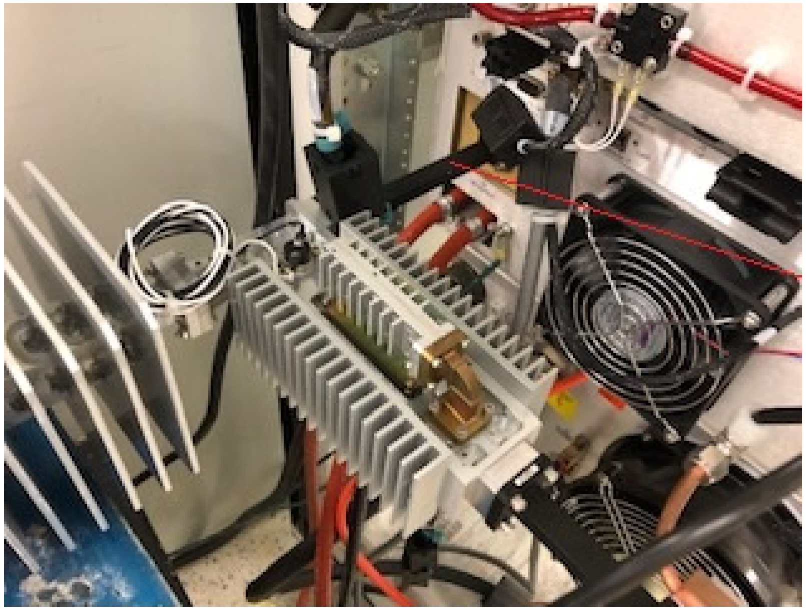
**Data analysis in progress**

# 21 GHz upgrading

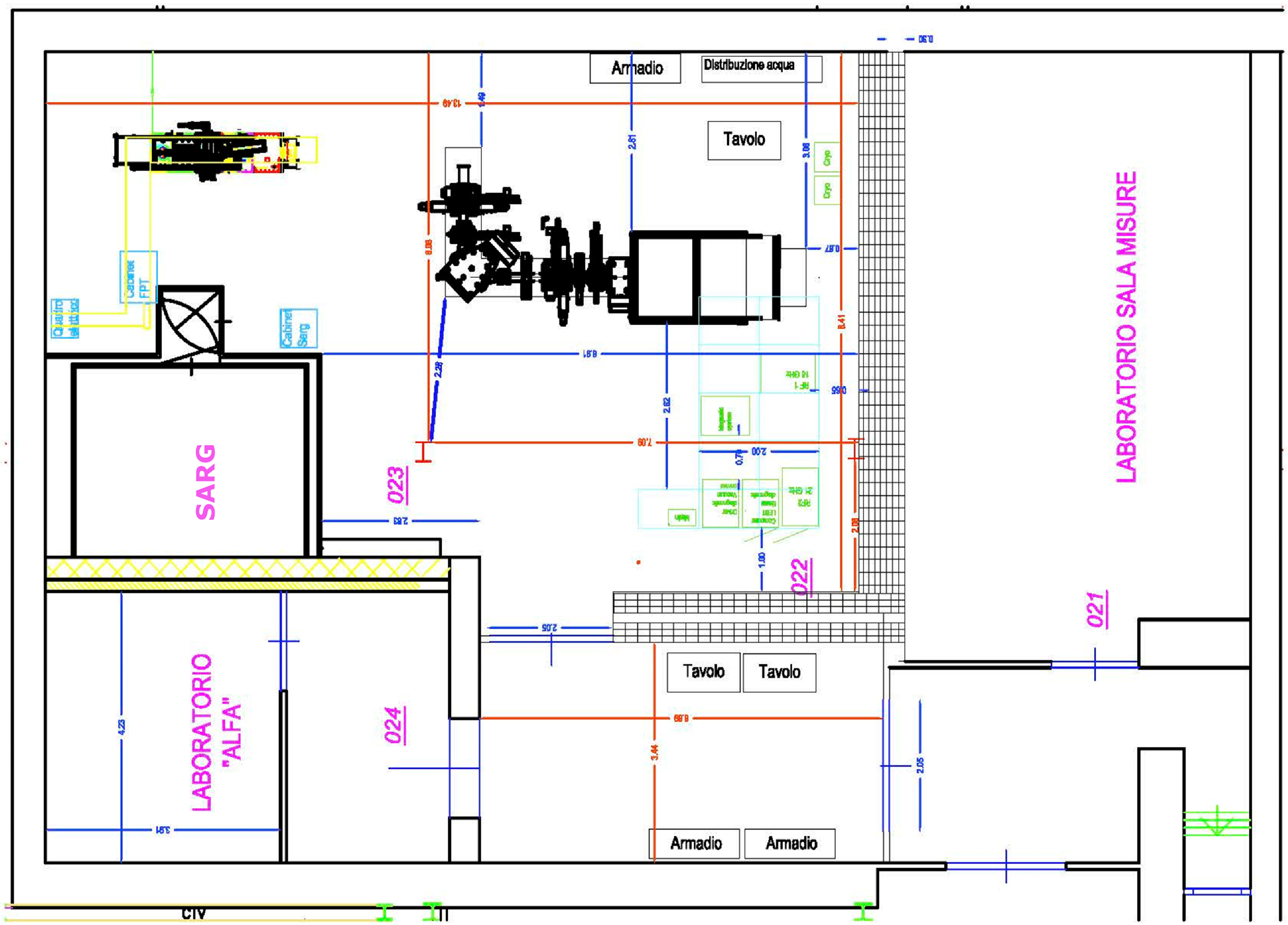



- 21 GHz klystron is ready and it passed the tests at CPI factory in Georgetown (Canada)
- Delivery is expected before the fall of the year.



# New AISHa room@INFN-LNS



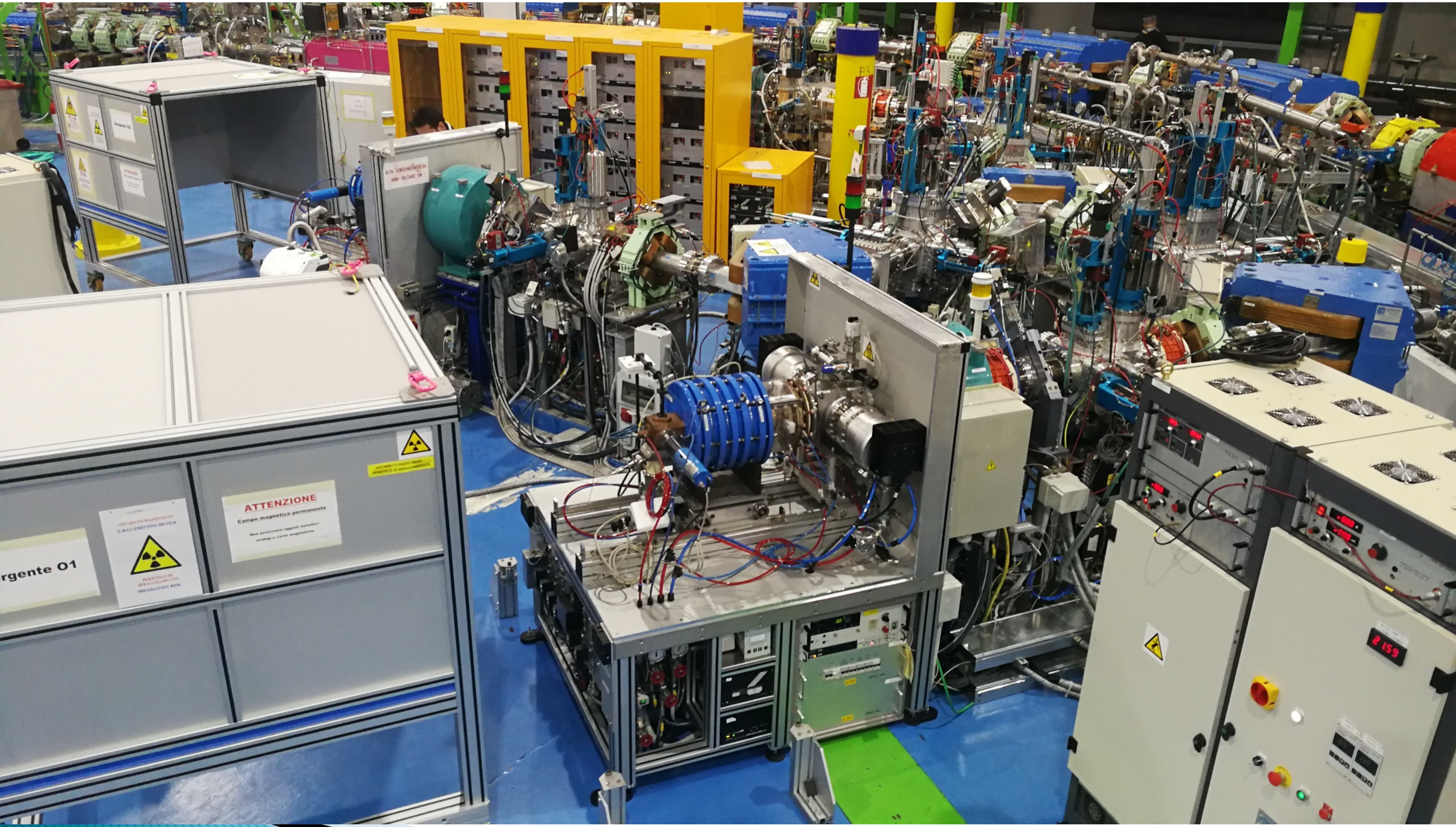
# New AISHa room@INFN-LNS

# New AISHa room@INFN-LNS

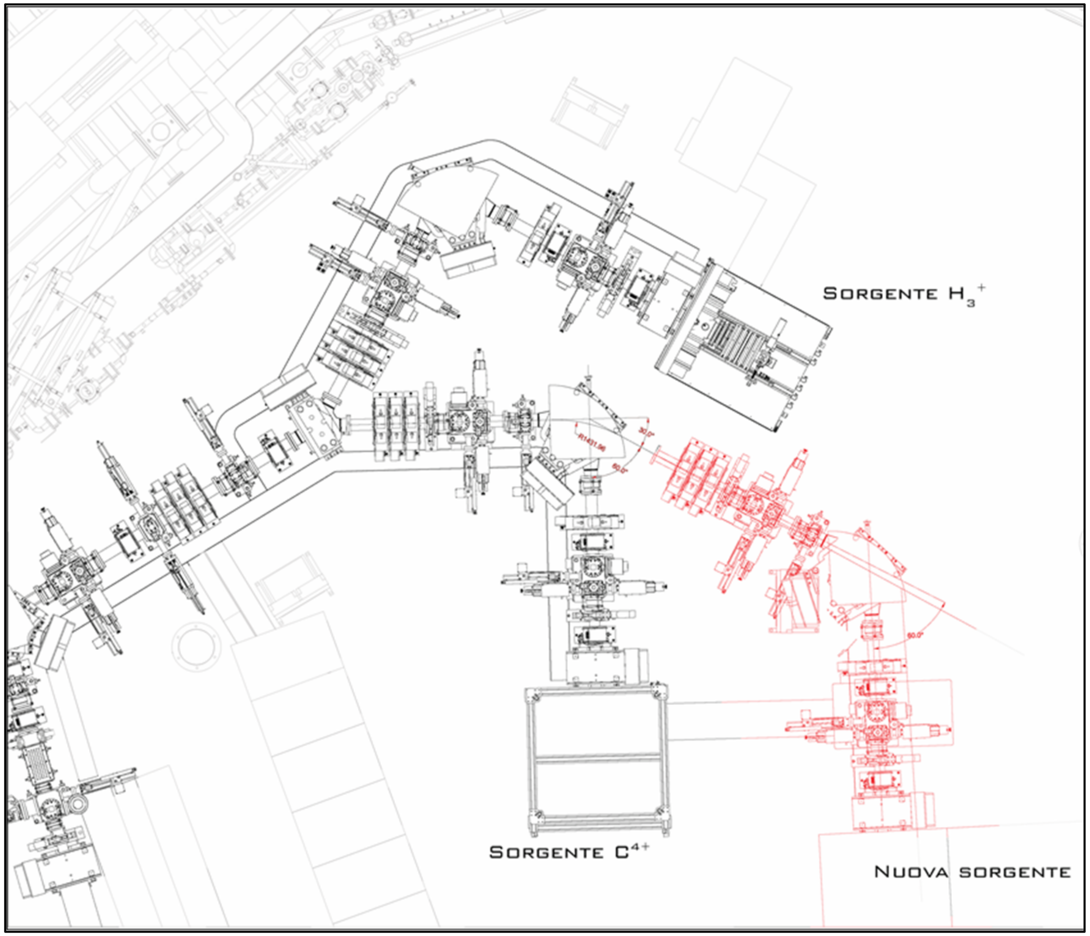
# AISHa-2@CNAO

- In the frame of IRPT, the italian national grant for hadrontherapy, it is planned to install a second AISHa source @CNAO.
- The He-free SC system and permanent magnet hexapole were already purchased and the source is going to be completed and assembled in the CNAO synchrotron room in the frame of INSPIRIT project.
- Beam development requested: $^{56}Fe^{19+}$, $^{7}Li^{3+}$. GSI STO oven will be used.

# AISHa-2 @CNAO



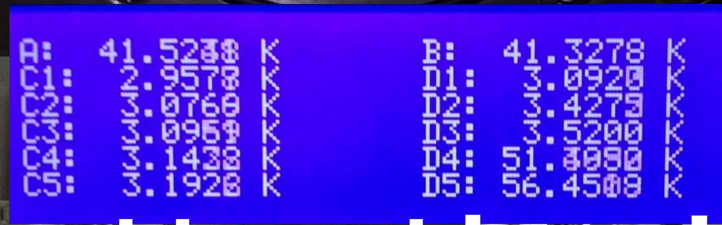
# AISHa-2 @CNAO




- Integration within synchro room in progress.
- Source and ancillary equipment will be preassembled in INFN-PV from June 2021 and then deployed into synchro room in several time windows allotted for synchro general maintenance.
- Commissioning is planned to start from Feb. 2022 and will envisage night shifts as already carried out for O1 and O2.
- Procedures for CE marking (conformity with health, safety, and environmental protection standards) are under progress.

# Conclusions and Perspectives

- **LHe free compact high performance ECR ion source adapted to work in hospital environment;**
- Compact source design with high degree of freedom for fine tuning of (B, f);
- AISHa already fulfills the requests of the new NUMEN facility@LNS envisaging cyclotron operation up to 10 kW and the realization of a third further optimized source is planned.
- Transfer to the new room in progress, restart of operations planned in January 2021
- Coupling with SARG and UV spectrometer (70-400 nm) planned within 2021 within the LAPSUS experiment funded by Italian Space Agency.
- Integration with GSI STO oven in progress: test of Fe and Li planned for March 2021.
- Integration of AISHa2 with synchro room in progress




# Thanks for your attention!