Commissioning of the AISHA Ion Source at INFN-LNS

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Istituto Nazionale di Fisica Nucleare
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ICIS GENEVA 2017

17th International Conference on Ion Sources
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CERN - CICG - Geneva

AISHA motivations
Advanced Ion Source for HAdrontherapy

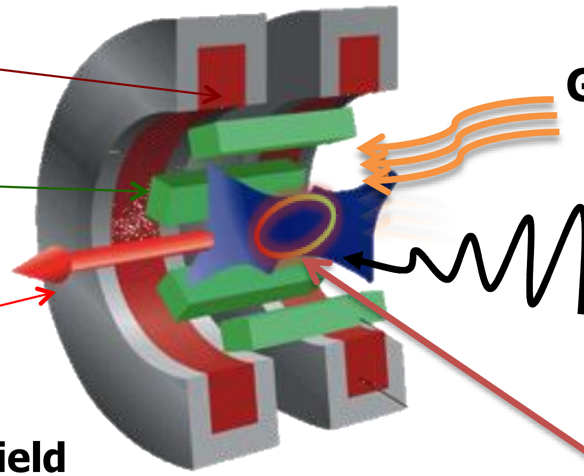
- **Most of the existing Clinical Centers for Hadrontherapy are based on proton beams;**
- **However, new frontiers are now being explored such as the use of heavier species like Li or C;**
- **Versatile ion sources for production of high currents of light ions are requested;**
- **AISHa is a ECR Ion Source prototype suitable for operations in hospital facilities, but ensuring high performances both in terms of currents and charge states that may be applied to nuclear physics facilities, etc;**

Multicharged Ions' production in a minimum-|B|trap : no news after HBM (are we sure ?)

Solenoids for
Axial confinement

Hexapole for
radial confinement

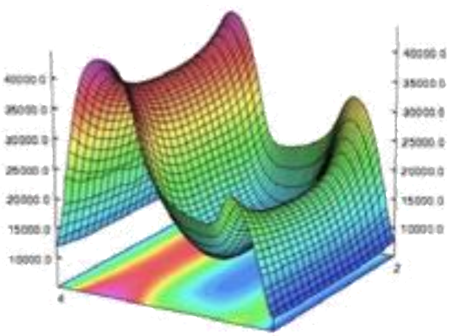
Extraction system



Gas injection system

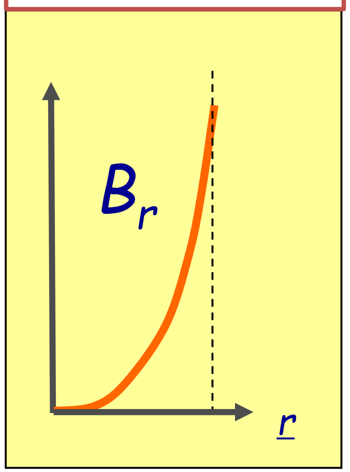
Incident microwaves
few **kW** at **tens GHz**

"B_minimum" Magnetic Field structure



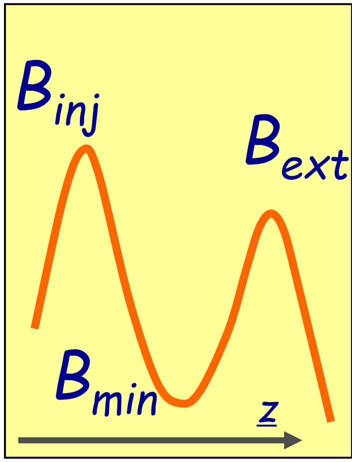
ECR Plasma
$n_e \sim 10^{12}$ cm^{-3}
$T_e \sim$ keV
$\tau_{ion} \sim$ ms

ECR Surface
$B_{ECR} = \omega_{RF} m_e/e$



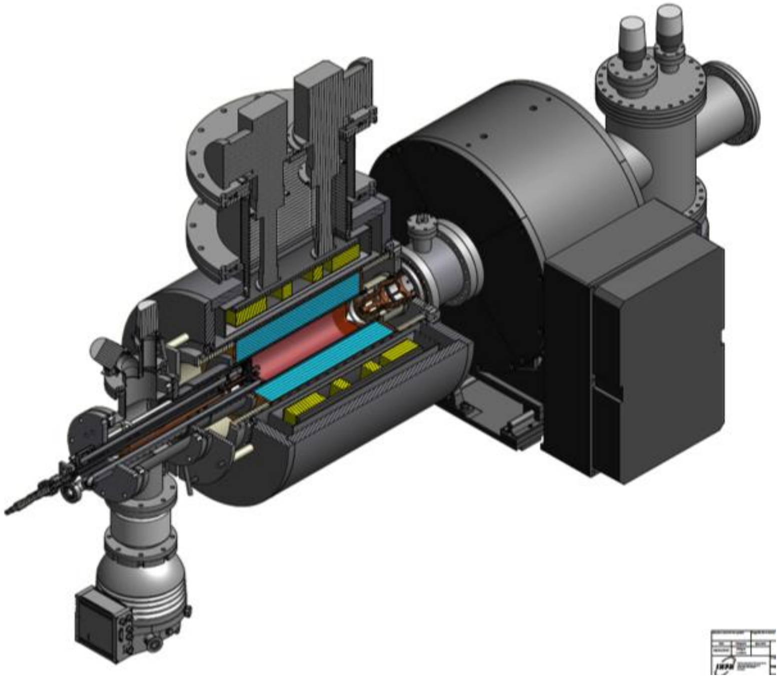
Radial Confinement

Axial Confinement



AISHA: Design Strategy

Advanced Ion Source for HAdrontherapy



- *high stability and high reproducibility*
- *low maintenance time*
- *low space occupation and minimization of electrical consumption*
- *highly charged ion beams with low ripple*

… we wanted to keep the performances as high as possible…

Implementation of state-of-art strategies on magnetic field/RF coupling optimisation

Foreground

FINE TUNING OF ECRIS PARAMETERS ($\mathbf{B}$, f)

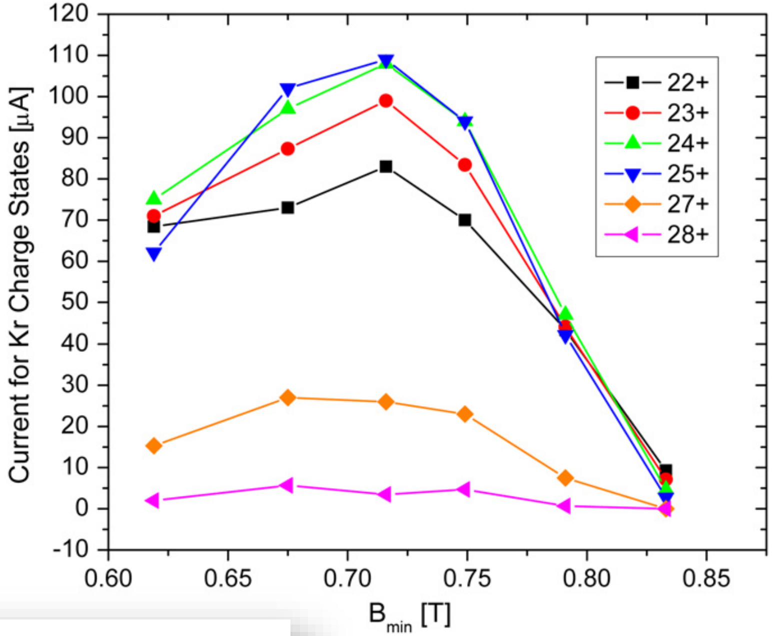
How does the pumping wave frequency and magnetic field influence the plasma heating?

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

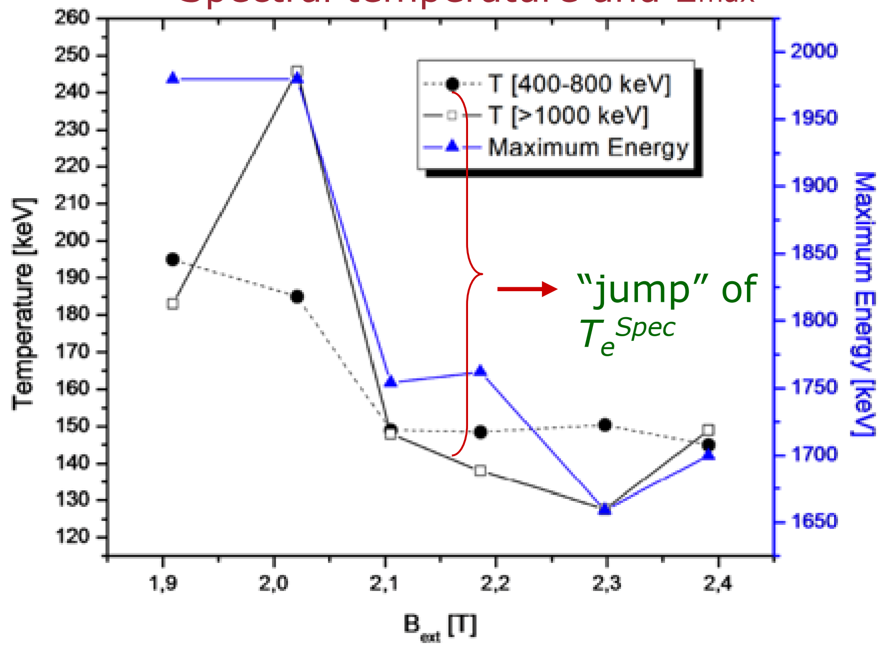
Additionally the availability of diagnostics for monitoring the EEDF reinforced the flexibility of tuning: in some conditions of magnets' tuning we observed the presence of X with maximum energy up to 1 MeV, in other cases much lower (200 keV): in the second case, the stability of the beam was better.
This was observed at INFN-LNS, GSI,JYFL,LBNL,MSU, etc. but only recently a cause-effect relation is partially understood.

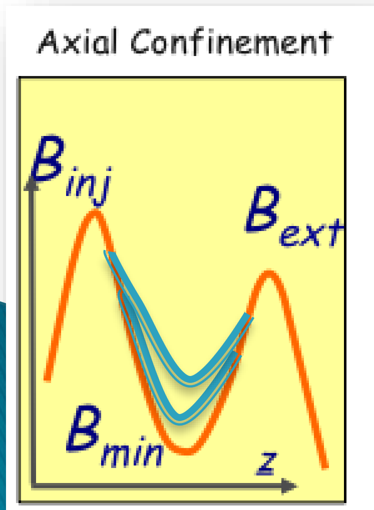
Evidence of hot electrons generation for slight variations of the mirror ratio.

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



Spectral temperature and Emax

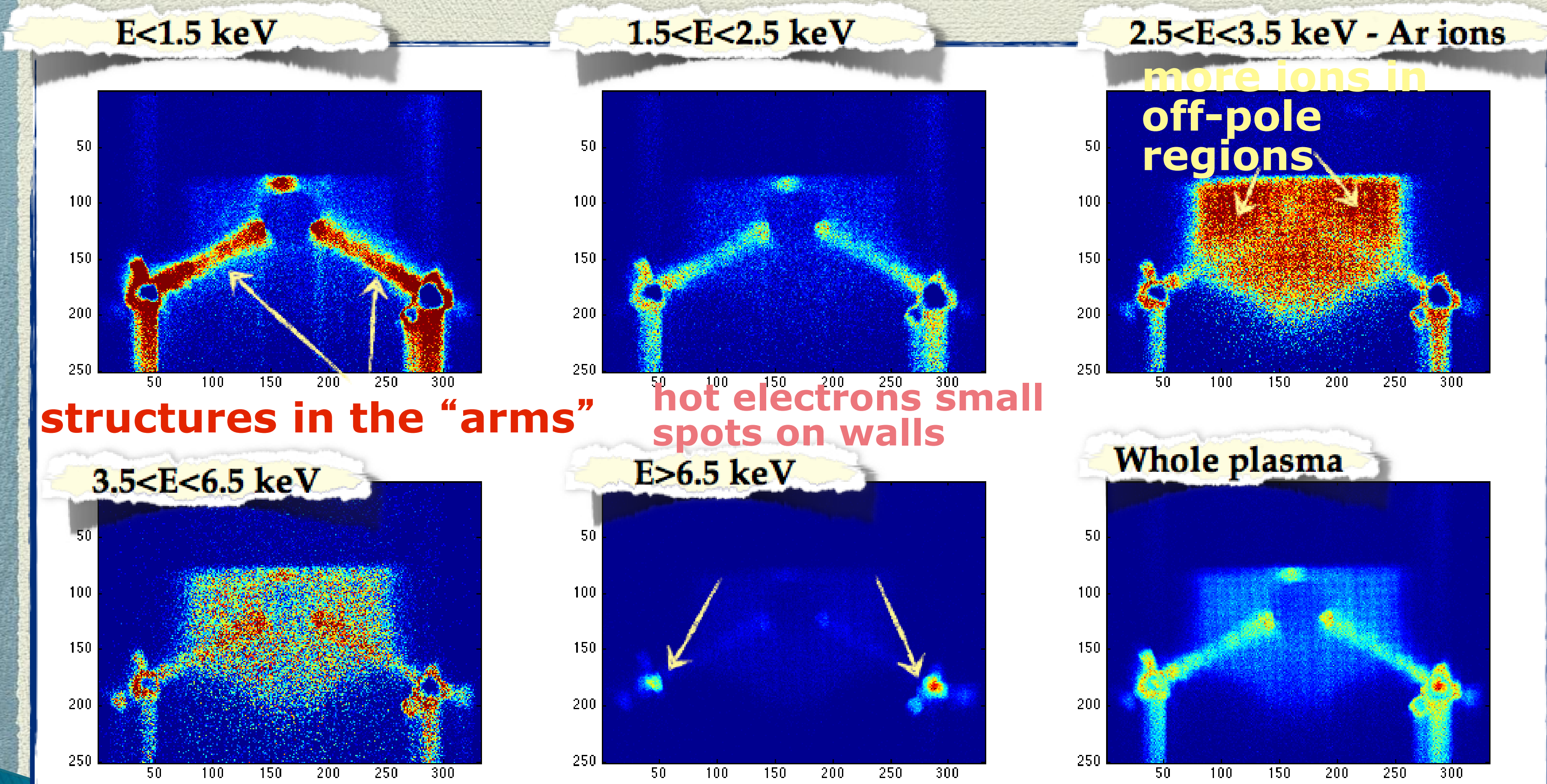


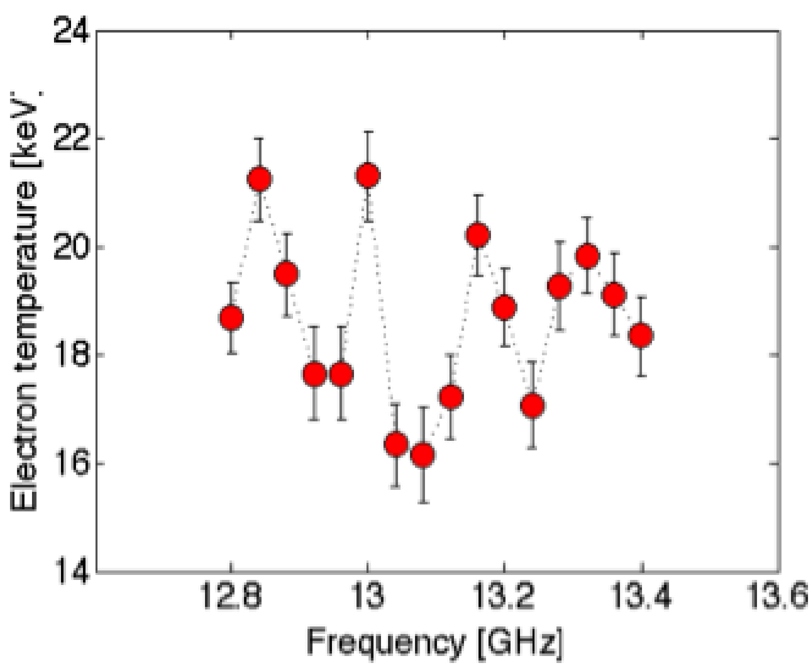


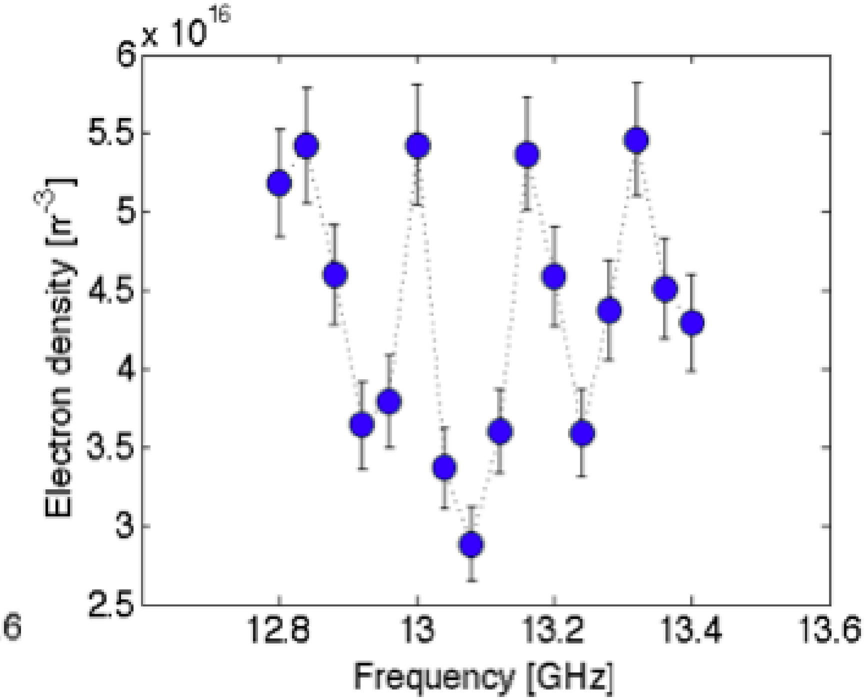
The tuning of the magnetic field changes the distribution of the charge states and the temperature of the hot component of the plasma!!

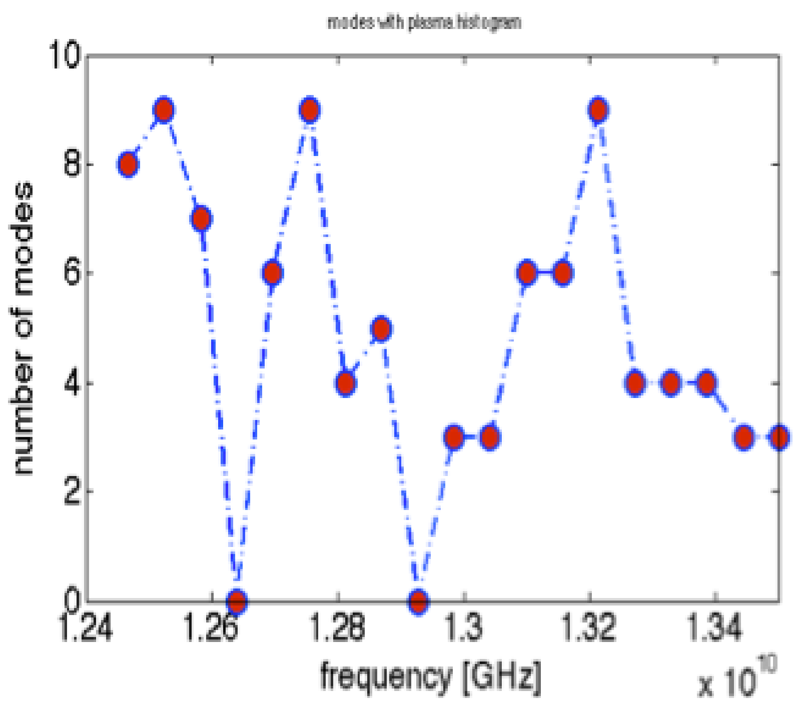
Low magnetic gradients at the resonance boost the production of very high energy electrons: up to 2 MeV of γ–rays emitted in last generation ECRIS.

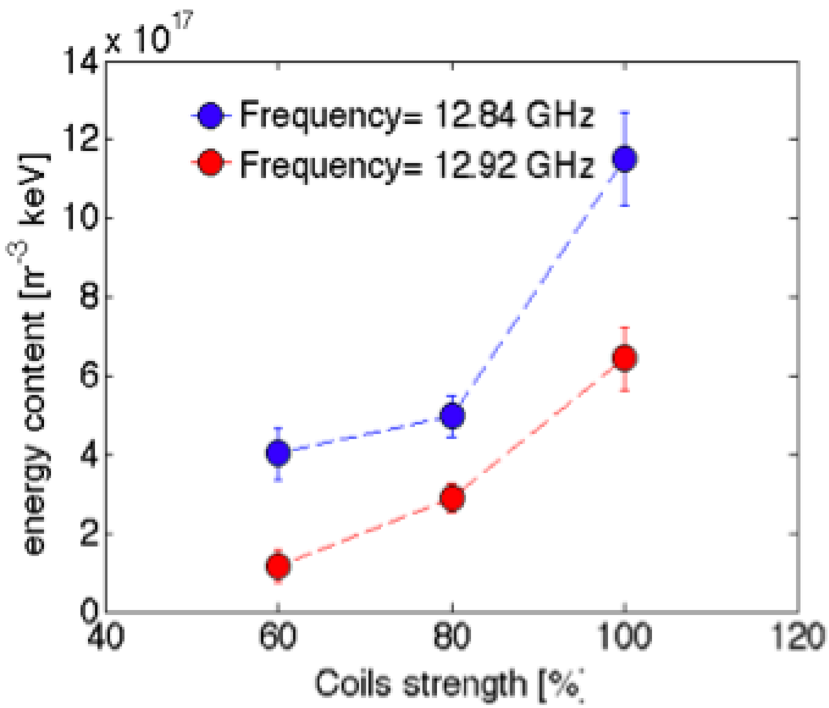
12.84 GHz - distribution at different energies (INFN-ATOMKI collaboration, 2015)




Electron temperature [keV]
24
22
20
18
16
14
12.8
13
13.2
13.4
13.6
Frequency [GHz]


x 10^16
6
5.5
5
4.5
4
3.5
3
2.5
Electron density [m^-3]
12.8
13
13.2
13.4
13.6
Frequency [GHz]


modes with plasma histogram
10
8
6
4
2
0
number of modes
1.24
1.26
1.28
1.3
1.32
1.34
frequency [GHz]
x 10^10


x 10^17
14
12
10
8
6
4
2
0
energy content [m^-3 keV]
Frequency= 12.84 GHz
Frequency= 12.92 GHz
40
60
80
100
120
Coils strength [%]

The main clues…

- The beam structure depends on the plasma structure

- X-ray imaging confirms this dependence

- **Maximum flexibility on the frequency** is required *(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) is requested

POR – U.E. funds for regional development

UNIONE EUROPEA

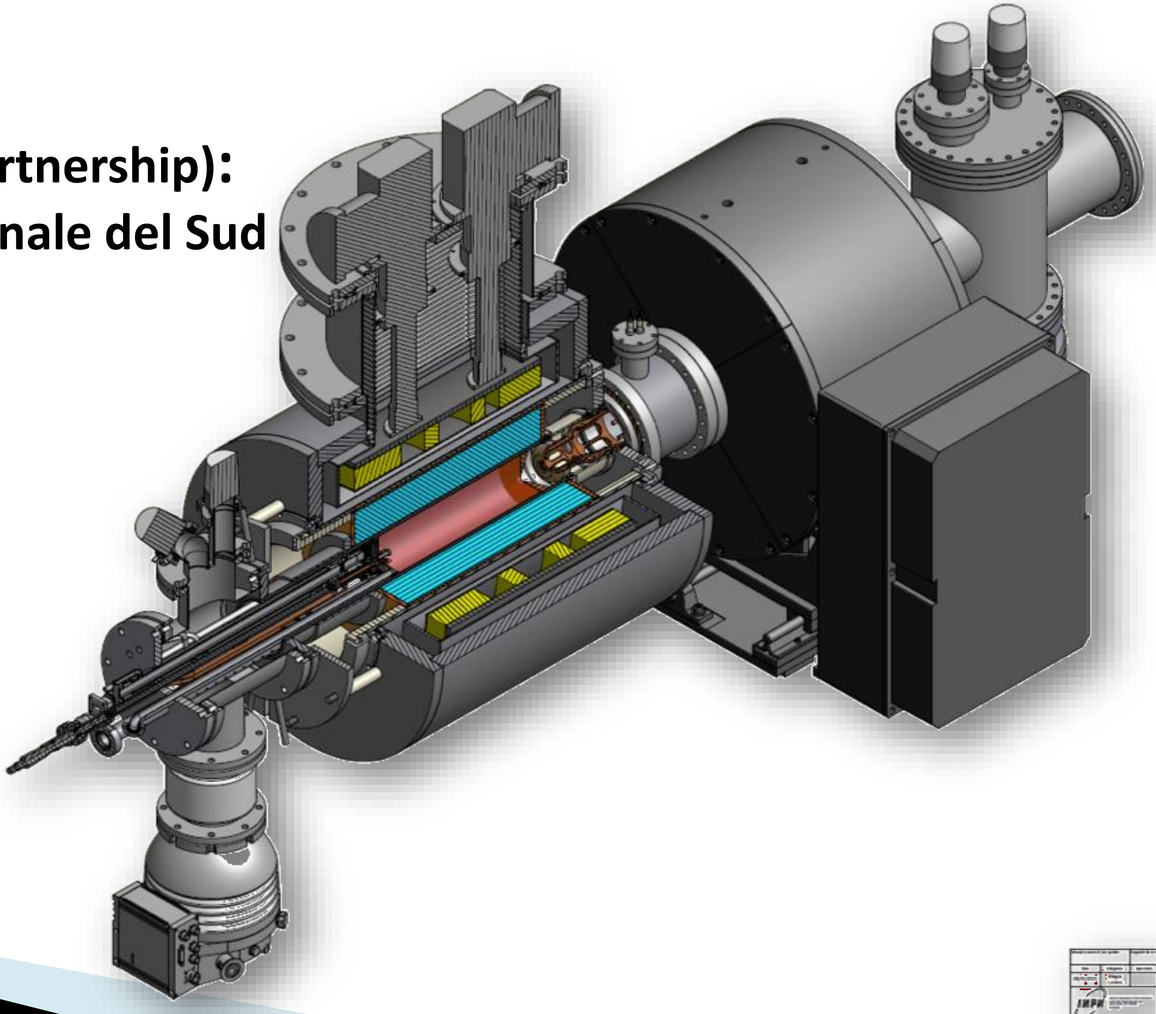
Regione Siciliana

PO FESR Sicilia 2007/2013

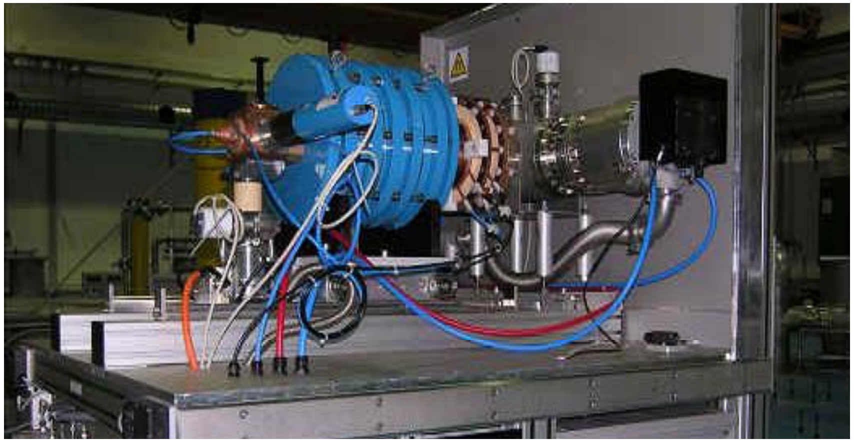
Topics: Health and Life Sciences

Proponents (public-private partnership):

- **INFN-Laboratori Nazionale del Sud**
- **Hitec2000 srl**
- **C3SL srl**
- **Unico srl**



The GOAL: make a step forward w.r.t. PK-SUPERNANOGAN for CNAO and other hadron therapy facilities

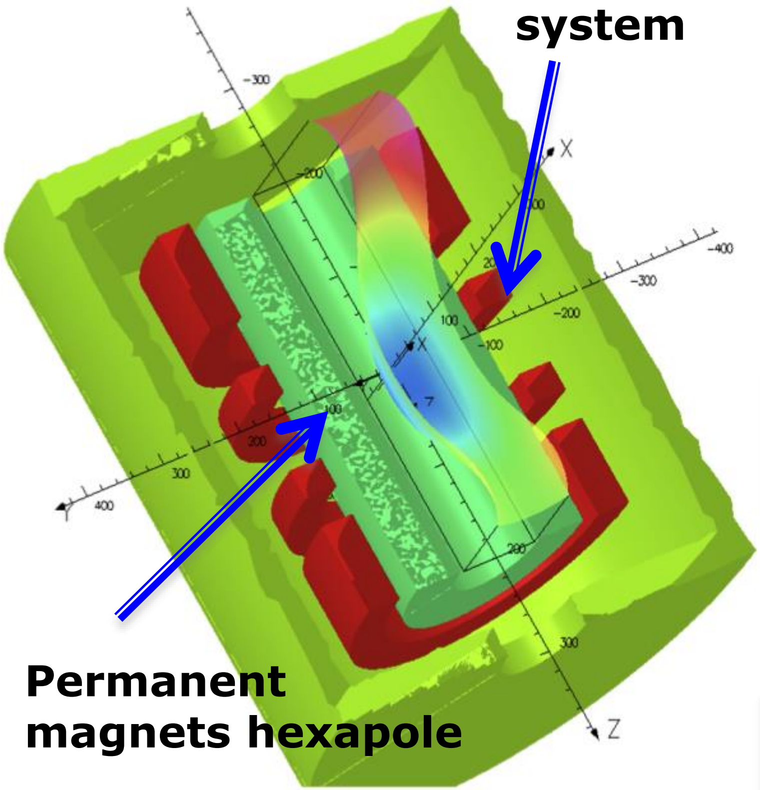


Measured performances

Ions	Current (request) [μA]	Current (avail.) [μA]	After improvements by INFN-LNS [μA]	Emittance (request) π mm.mrad	Emittance (new extractor) π mm.mrad	Stability [99,8%]
C^{4+}	200	200	250	0.75	0.56	36 h
H_2^+	1000	1000		0.75	0.42	2 h
H_3^+	700	600	1000	0.75	0.67	8 h
He^+	500	500		0.75	0.60	2 h

Significant improvements have been provided by INFN-LNS: frequency tuning effect, gas control, extractor reliability, etc. but further improvements are not possible and different set of requirements are done for the treatments by therapy experts.

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	17.3 GHz – 21.5 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

AISHA
Advanced Ion Source for HAdrontherapy

- The set of four superconducting coils independently energized realize a ***flexible magnetic trap***, which is fundamental to test alternative heating schemes based on Bernstein waves excitation and heating in sub-harmonics.

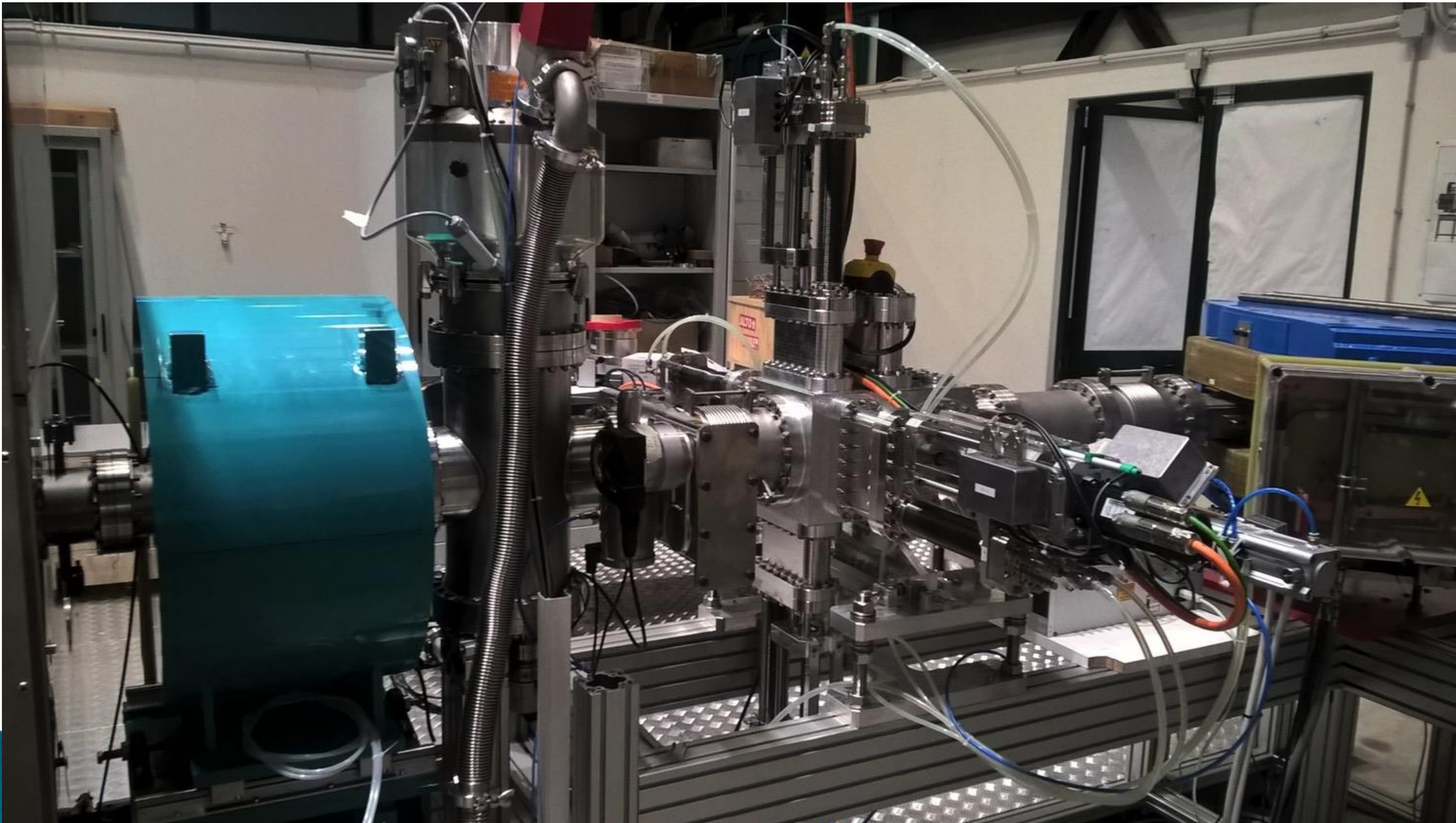
- The use of a ***broadband microwave generator*** able to provide signal with complex spectrum content, will permit to efficiently tune the frequency increasing the electron density and therefore the performance in terms of current and average charge state produced.

- The chamber dimension and the injection system are designed in order to ***optimize the microwave coupling*** to the plasma chamber taking into account the need of space to house the ***oven for metallic ion*** beam production.

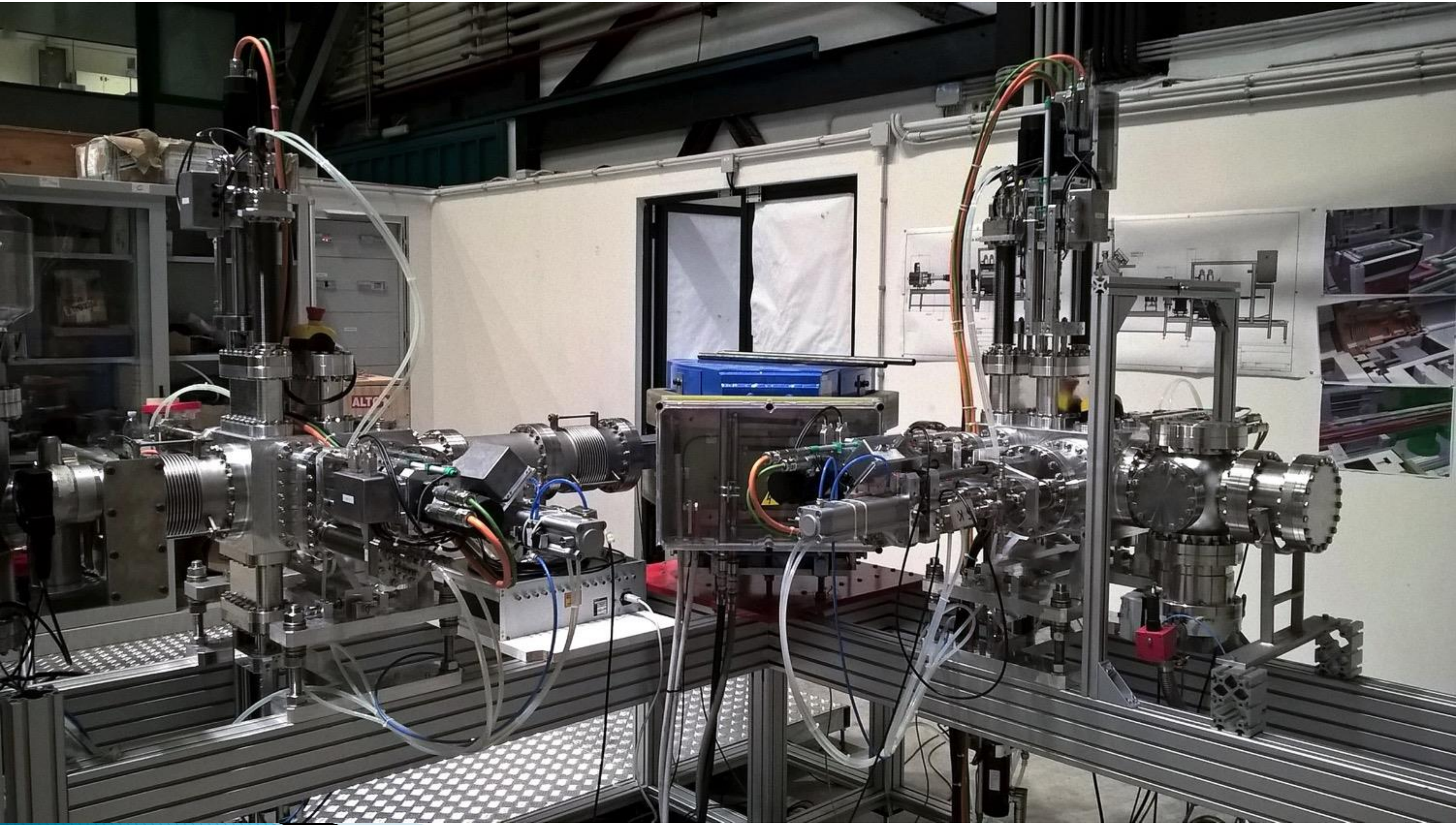
- An adequate study of the ***extraction system*** has been carried out taking into account the production of high current and high charge states.

Experimental setup

Experimental setup

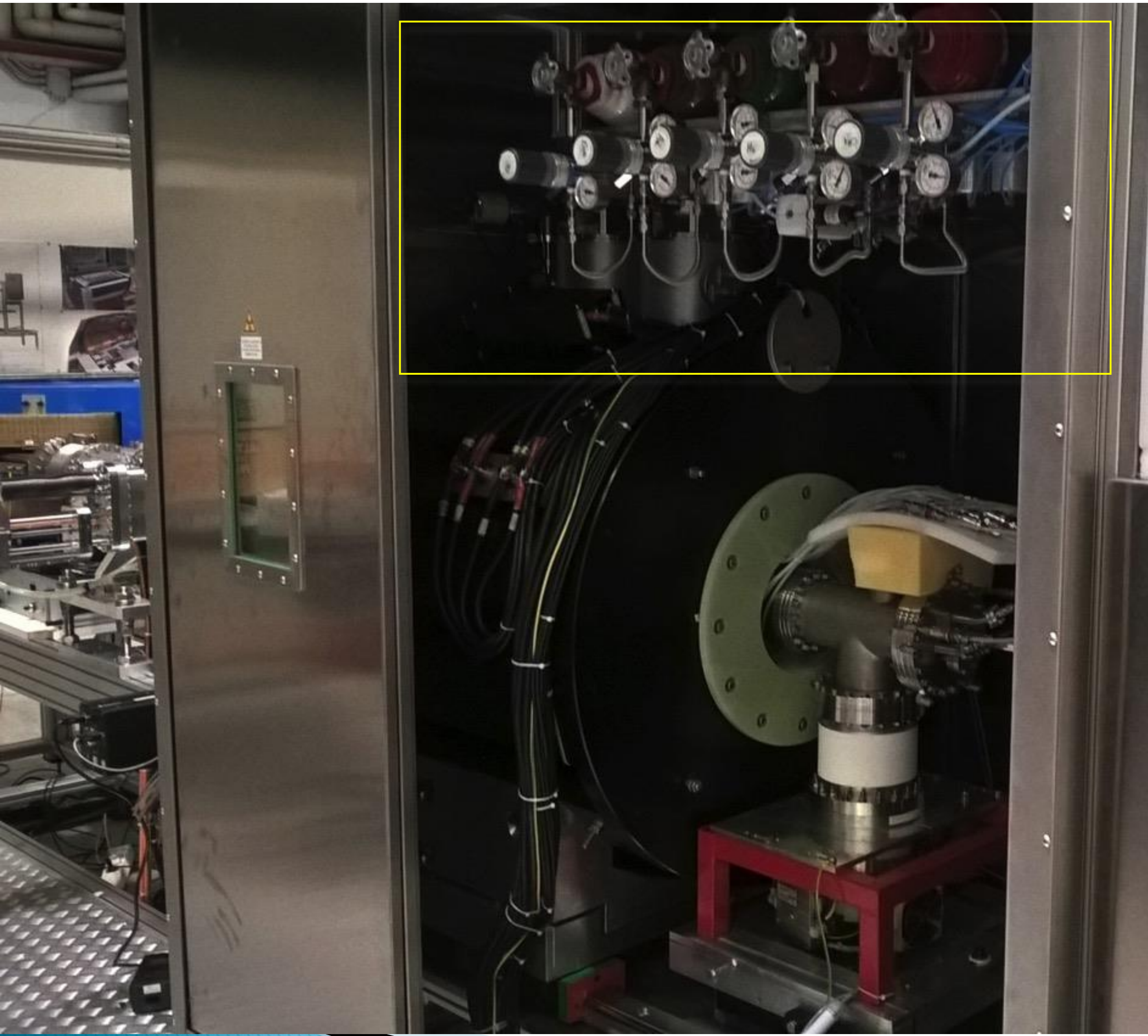


Experimental setup



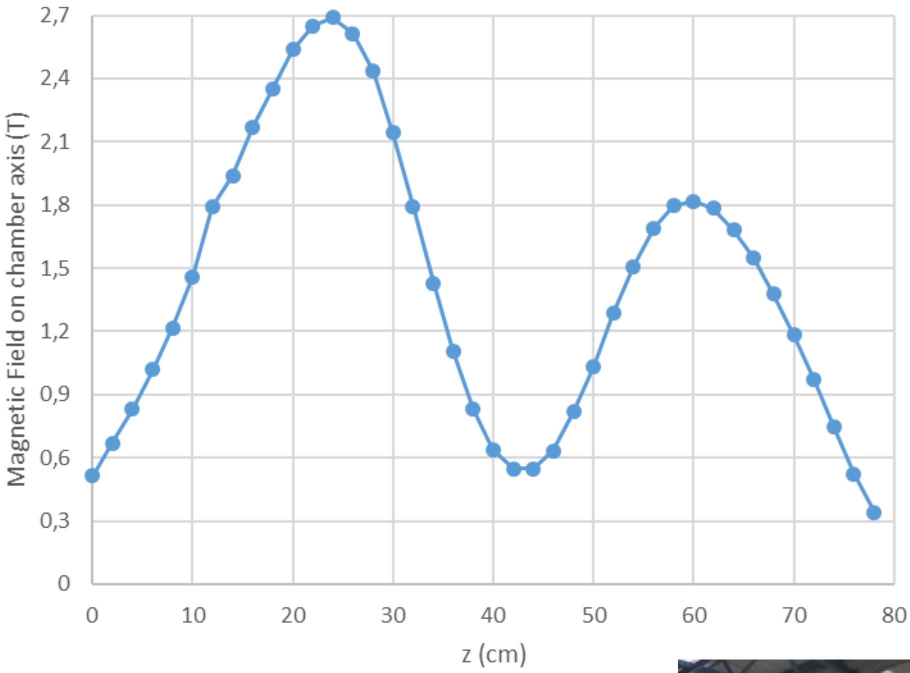
Ion source platform

Ion source platform

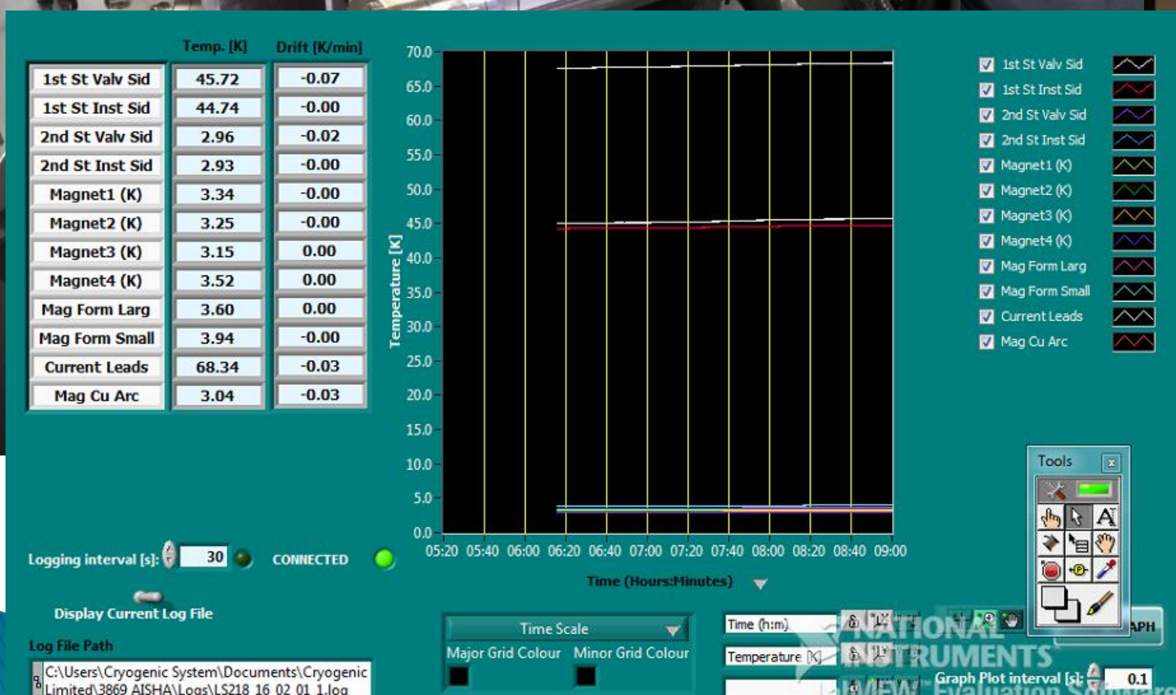


New gas-box for fast tuning/switching of species during source's operations

SC magnetic system assemby

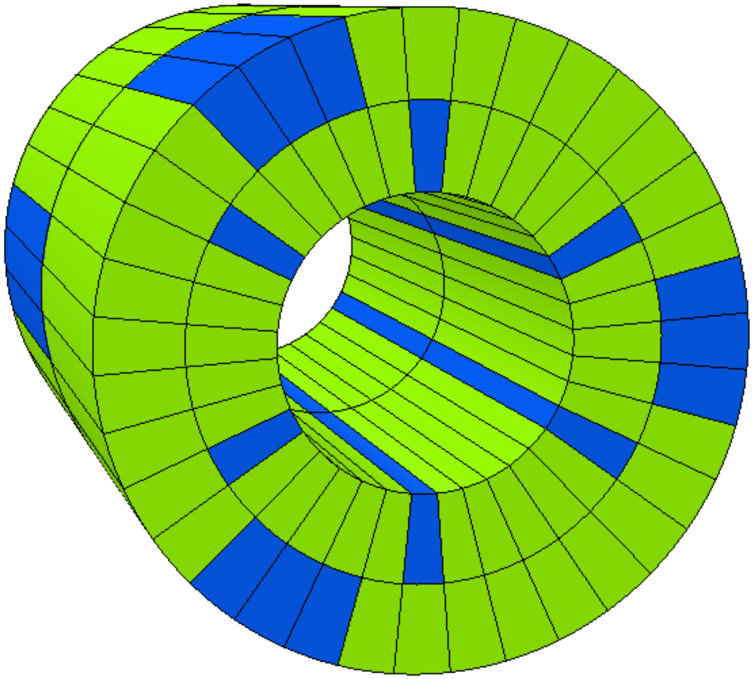


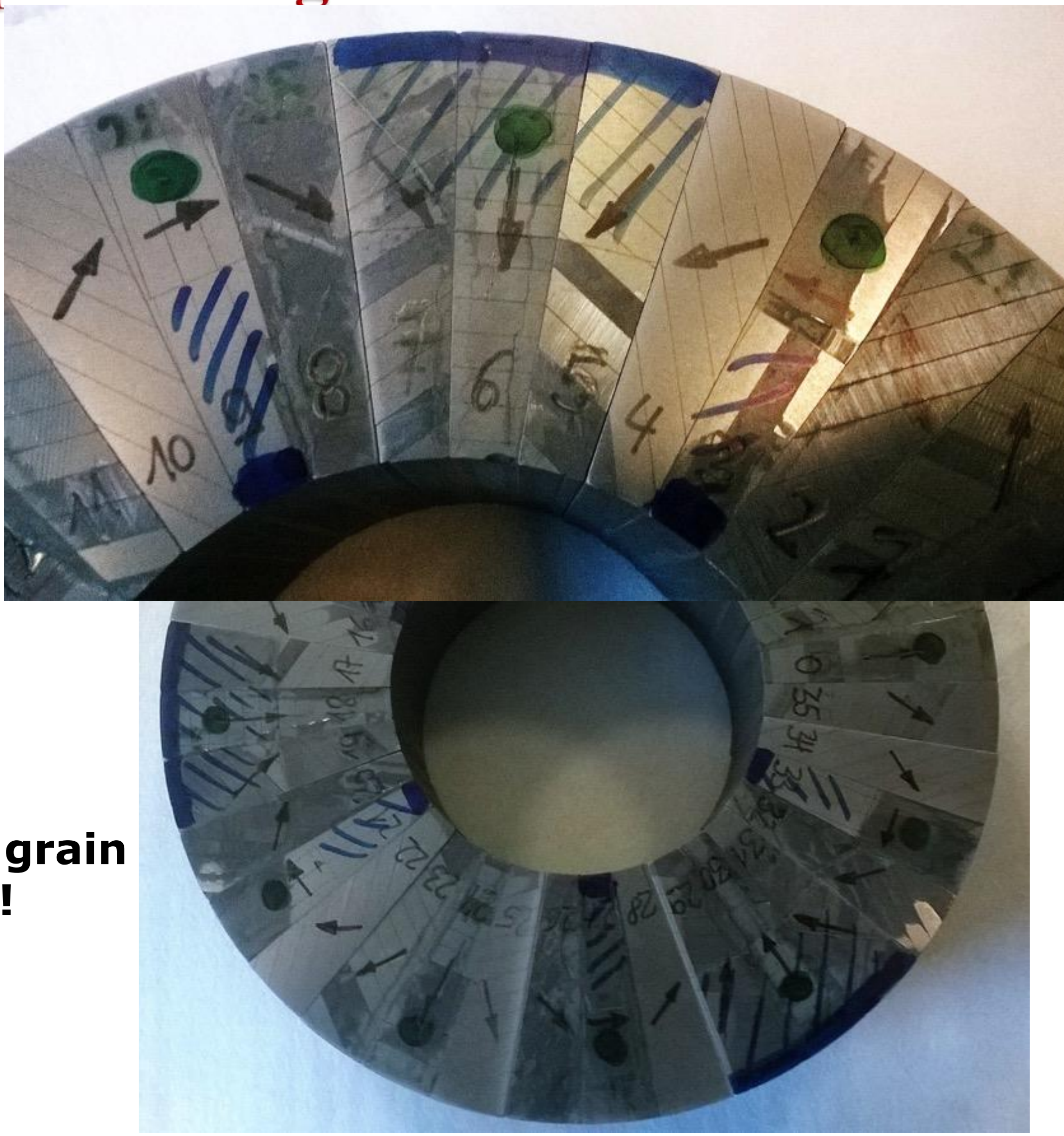
Magnetic system



AISHa

Final hexapole configuration

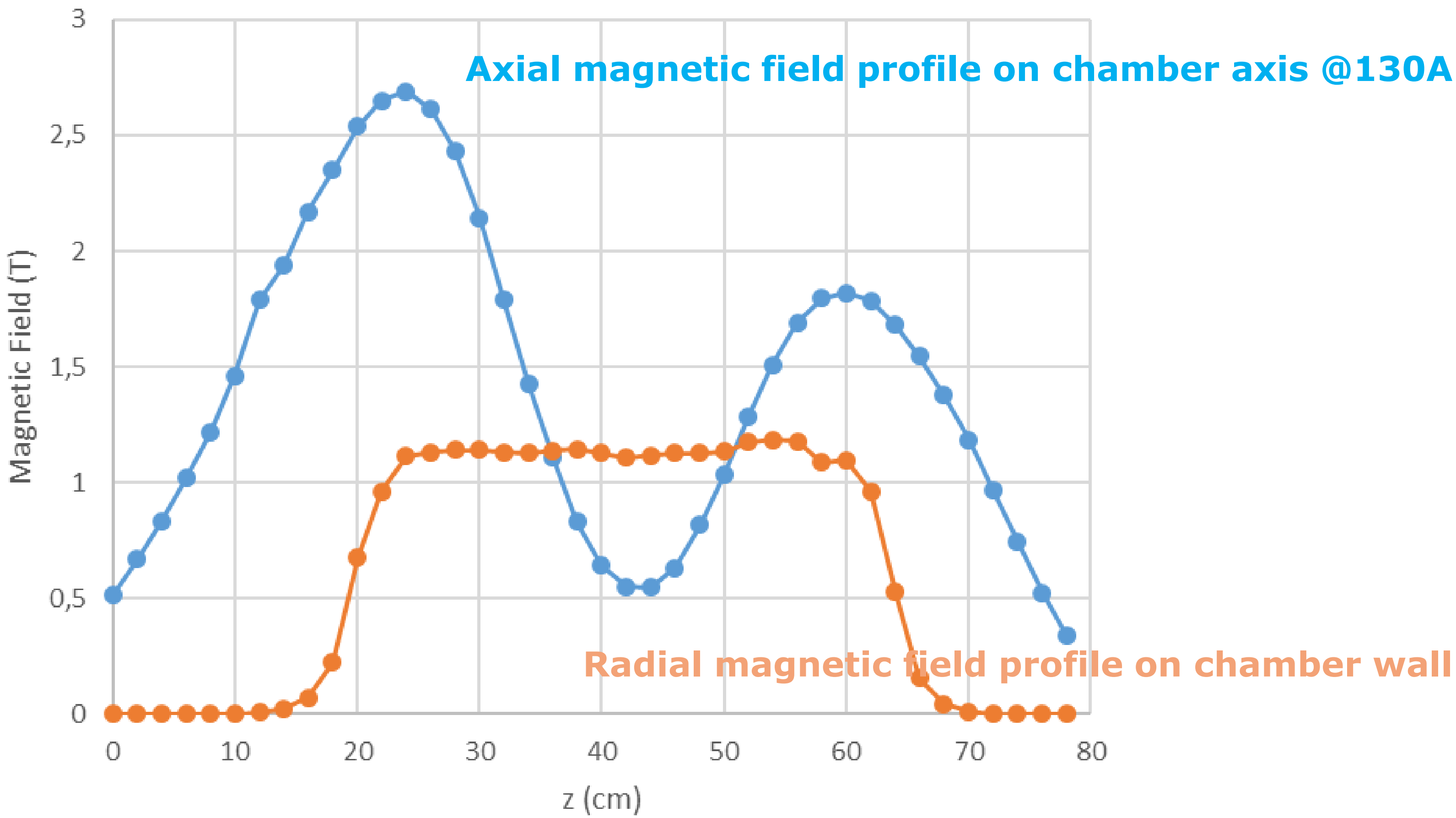




Only 2 materials needed with the grain boundary diffusion (Tb) process!!!

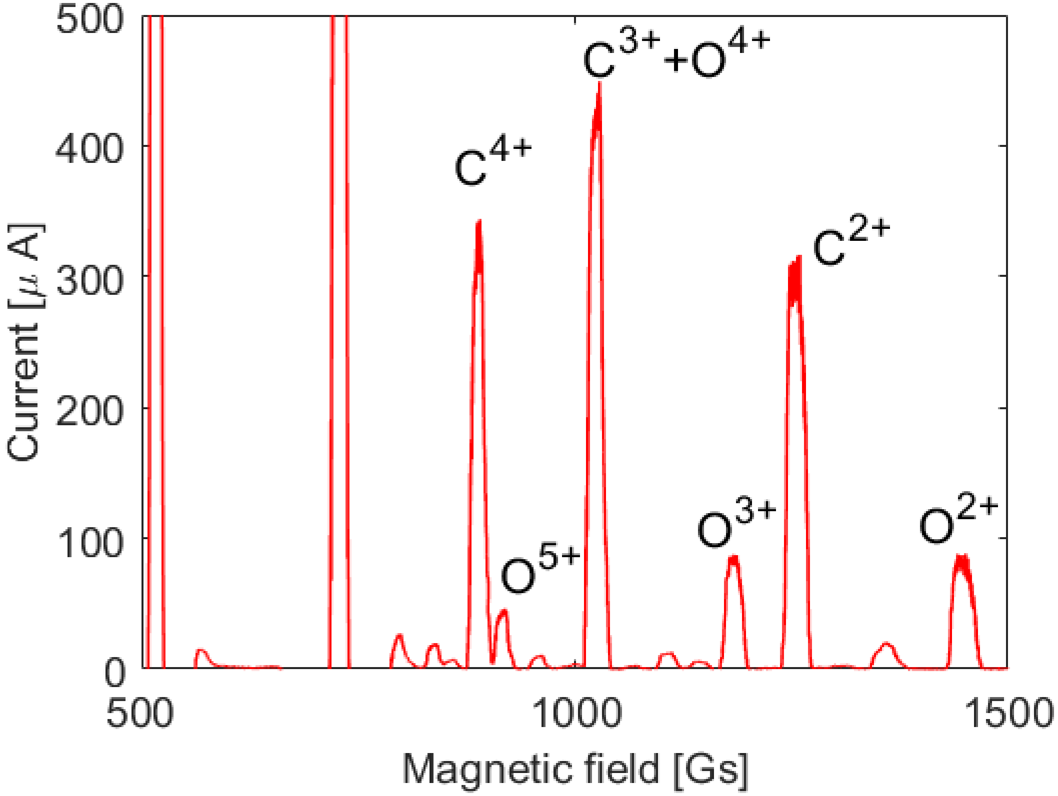
Green= VAC 745 HR
Blue= VAC677 HR

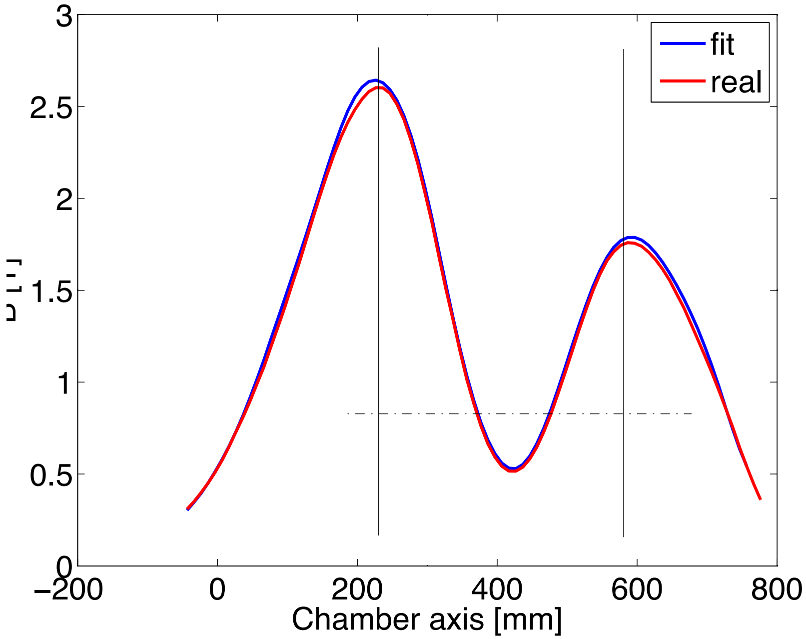
Magnetic measurements



Preliminary tests: first beam of C^{4+} extracted in May 2017

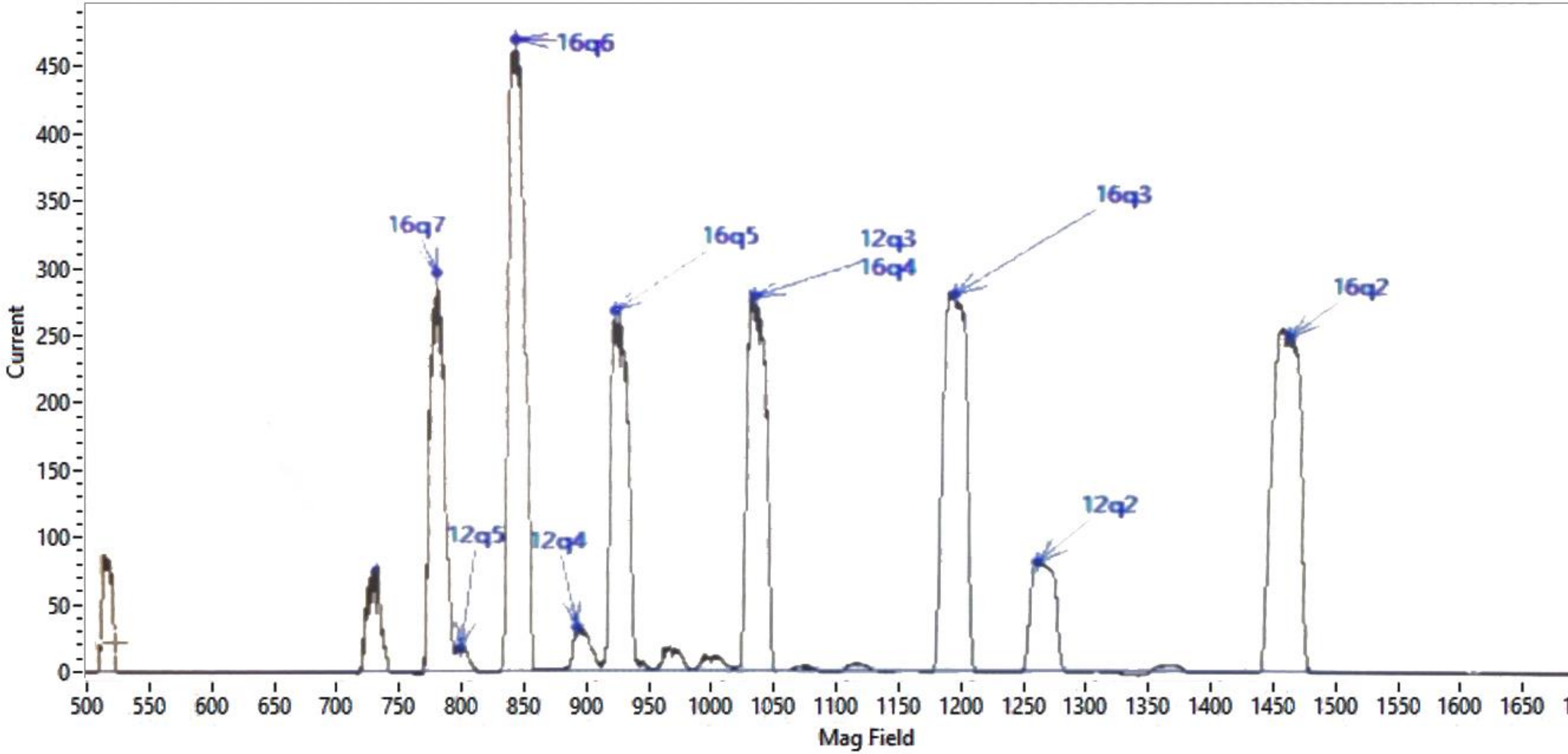
Charge State Distribution for Carbon ions





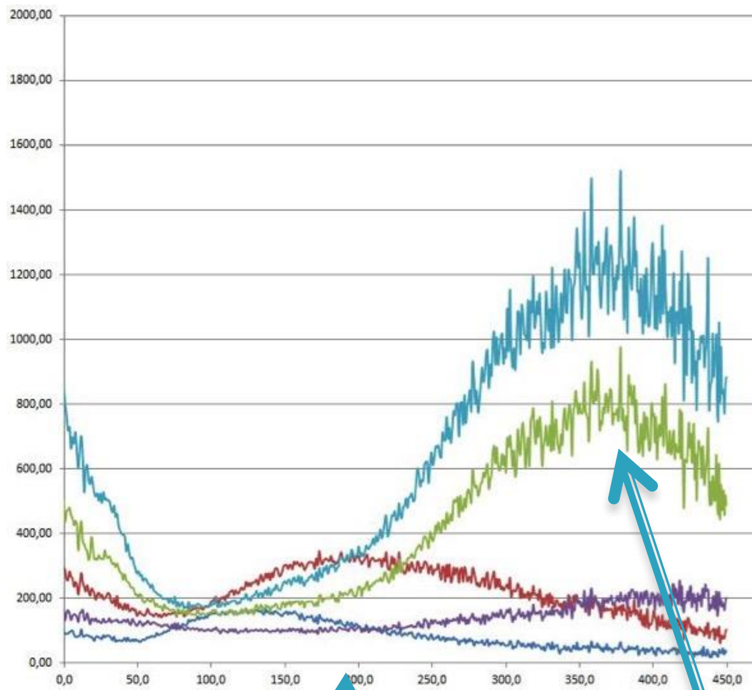
The magnetic field profile was optimized for maximizing C^{4+} production

Charge State Distribution for Oxygen ions



Next tests

X measurements

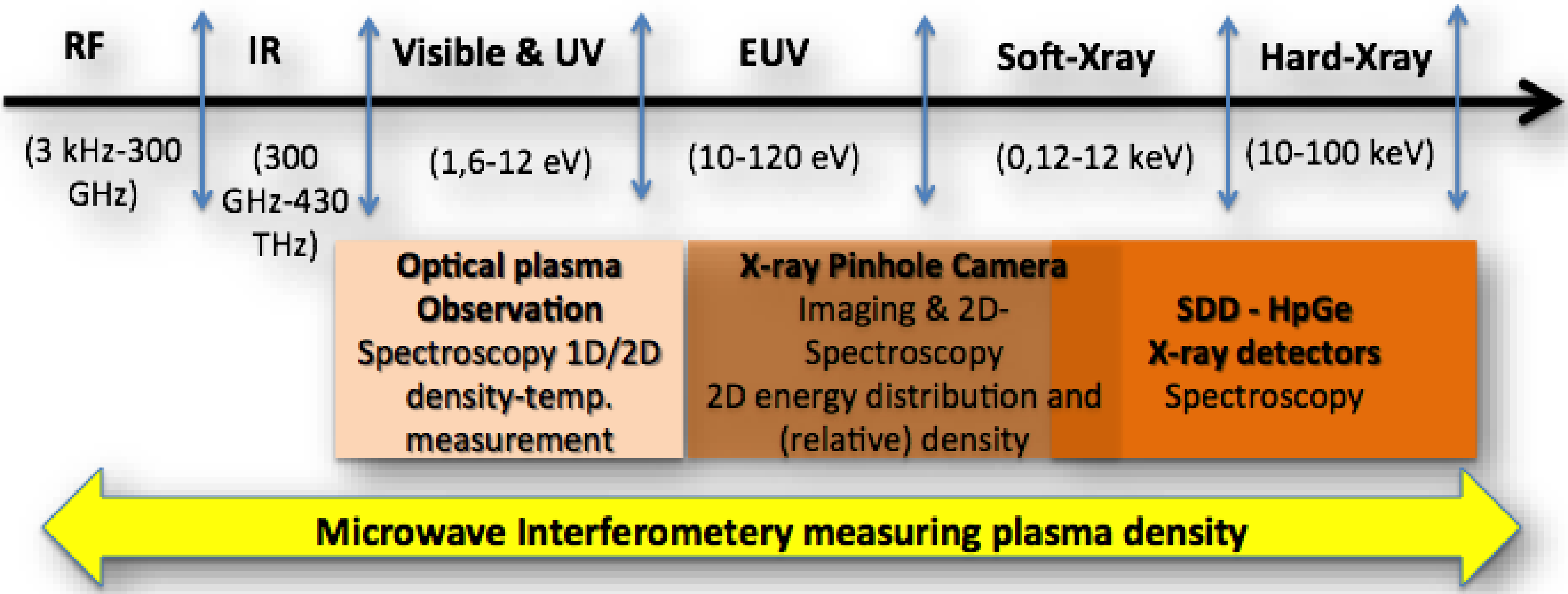


Stable configurations

High beam ripple

1. *Biased disk*
2. *Gas mixing*
3. *Frequency tuning (used to optimize, but far from the full characterizion)*
4. *Two frequency heating*
5. *Evaluation of the power density in W/cm^3 that allows a stable operation in different configurations and for different species*
6. *X ray studies for EEDF optimization*
7. *Use of RF signals with complex spectrum content*
8. *Exploitation of the available diagnostics*

Multi-diagnostics approach



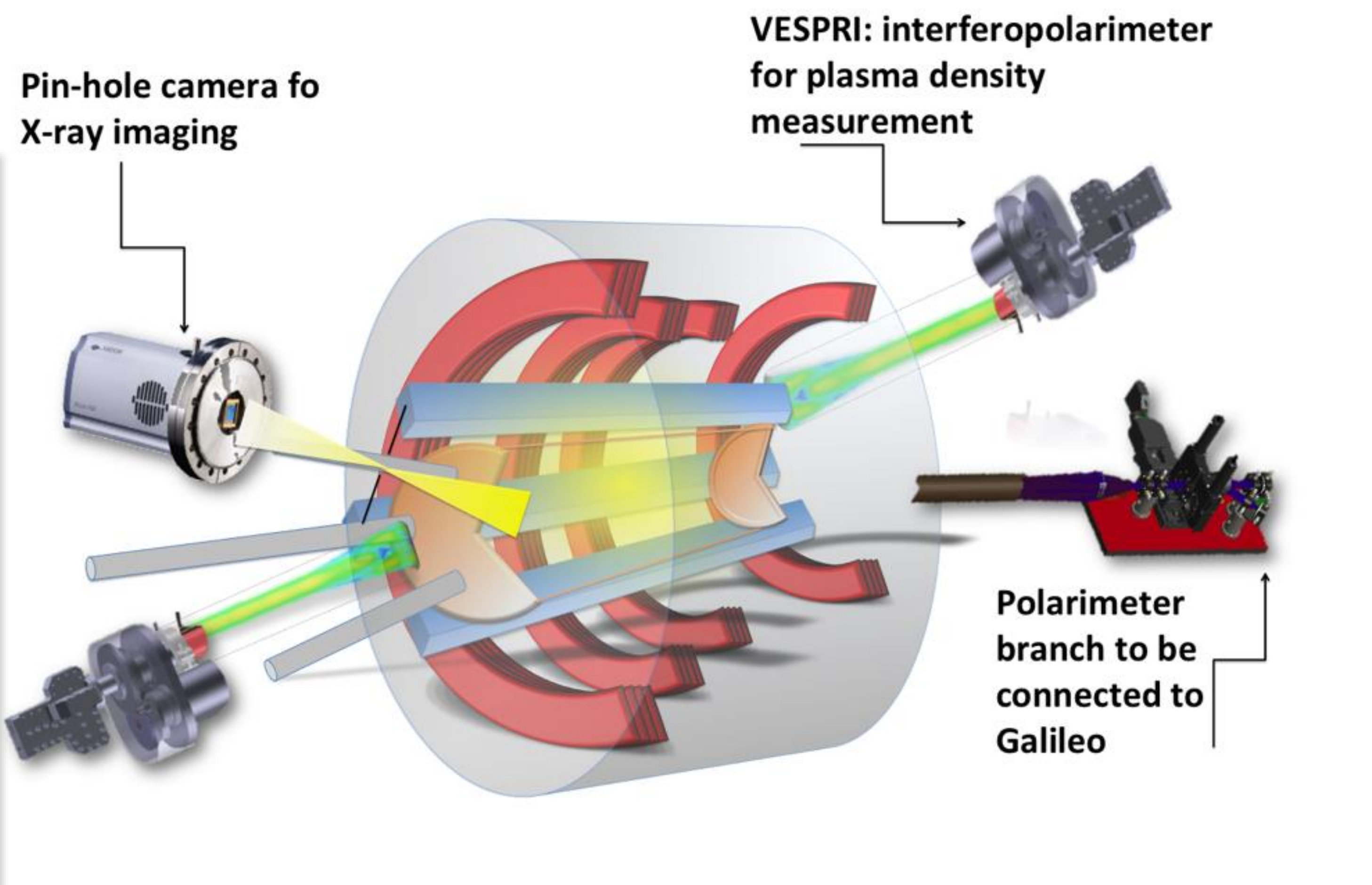
Due to the flexibility of AISHa magnetic and RF system, AISHa will be explored with a multi-diagnostics approach, by taking profit from the techniques developed at LNS since 2010 (recently also in cooperation with ATOMKI, MPI-IPP and INAF) for the whole characterization of the EEDF

Multi-diagnostics approach

The plasma properties under the **influence of single/double frequency heating (18+22 GHz), variation of Mirror Ratios (B_{inj}/B_{min} – B_{min}/B_{ECR}, B_{ext}/B_{ECR}) and magnetic gradients** in multidiagnostics approach

FIRST RUN in MD-Mode

- **Interferometry** *long. Density profile*
- **Polarimetry** *total density*
- **OES** *cold electrons density and temperature*
- **SR-XRS** *warm electrons energy, density, displacement*



AISHa-2 in the frame of IRPT, the italian national grant for hadrontherapy

- He-free SC system already purchased and delivered
- Permanent magnet hexapole: delivery expected for Dec. 2017
- Mechanics: cost effectiveness analysis in progress

The AISHa-2 is expected to become the new injector of the CNAO-Pavia (the Italian National hadrontherapy Center)

Conclusions and Perspectives

- AISHa: **First LHe free compact high performance ECR ion source** commissioning was not completely successful up to now because we have not reached our goal in terms of currents for the beam of interest for hadron therapy.
- Compact source design with higher degree of freedom with respect to SERSE or other II-III generation ECRIS (4 solenoids).
- **First operations already demonstrate the flexibility is a key for fast tuning and performances optimisation**; beam stability is not satisfactory in all the configurations and the use of electron donors seems necessary.
- A number of procedure will be implemented soon to operate in a better condition (bias disk, two-frequency heating and additional tools for diagnostics and tuning);
- **Interest of both labs and hospitals is growing** and AISHa will be soon duplicated.

Thanks for your attention