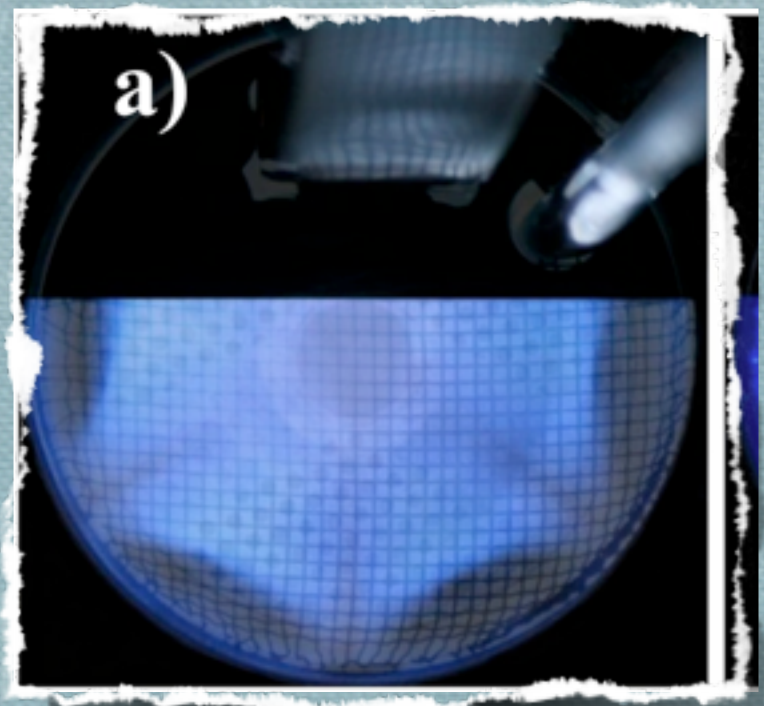
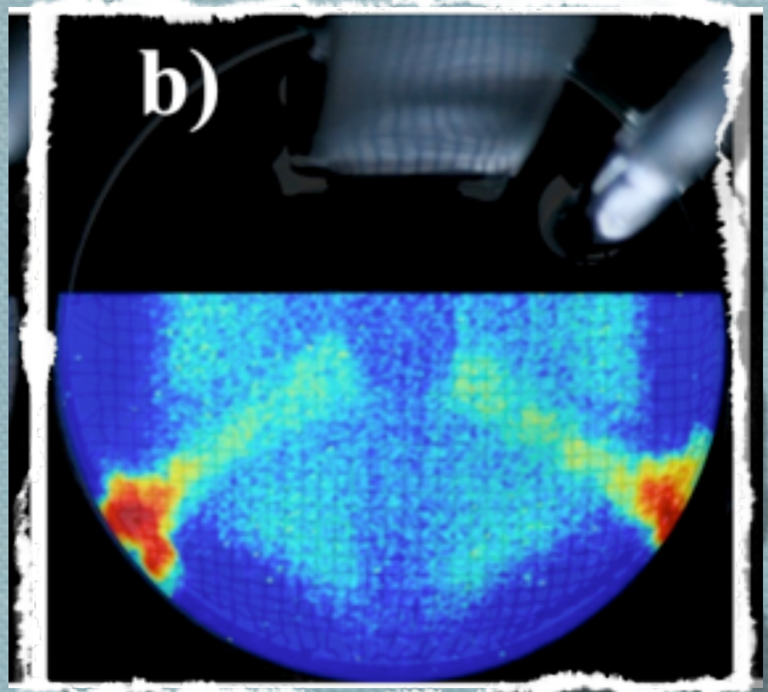
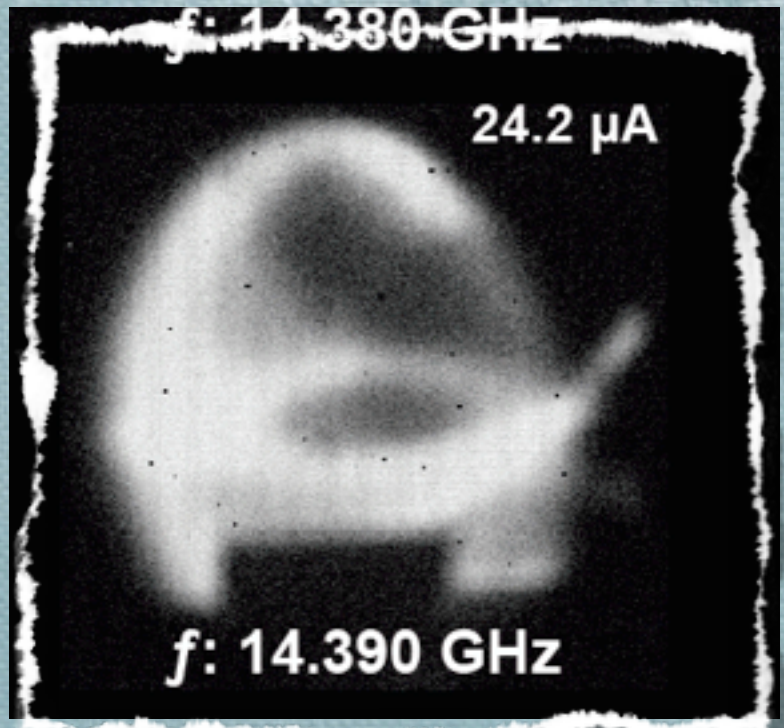






David Mascali, INFN-LNS

Catania - December 15th, 2015

Perspectives about Ion Sources development @ INFN-LNS

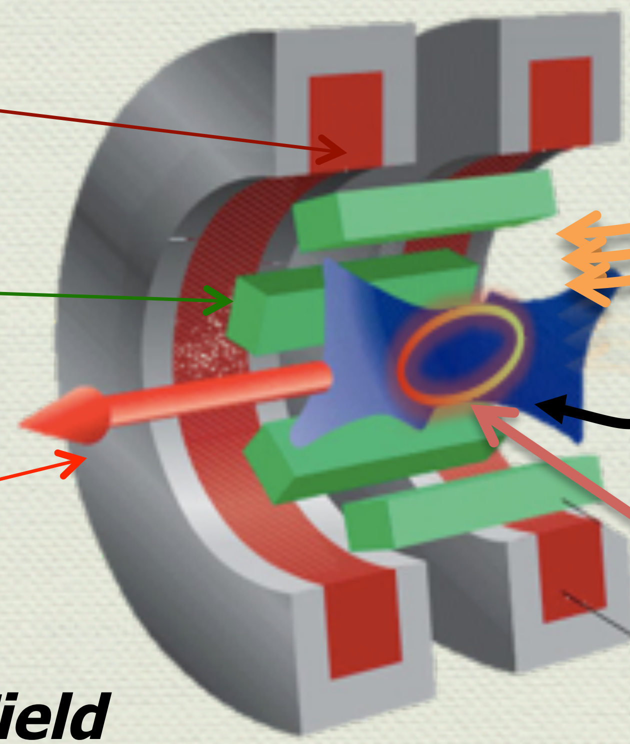
The ECRIS configuration

high intensity of multiply charged ions

***Solenoids** for*
Axial confinement

***Hexapole** for*
radial confinement

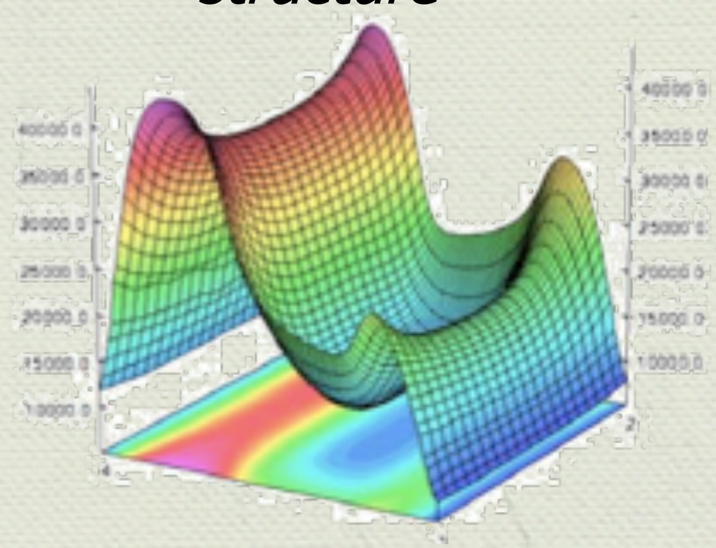
Extraction system



Gas injection system

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

"B_minimum" Magnetic Field
structure



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

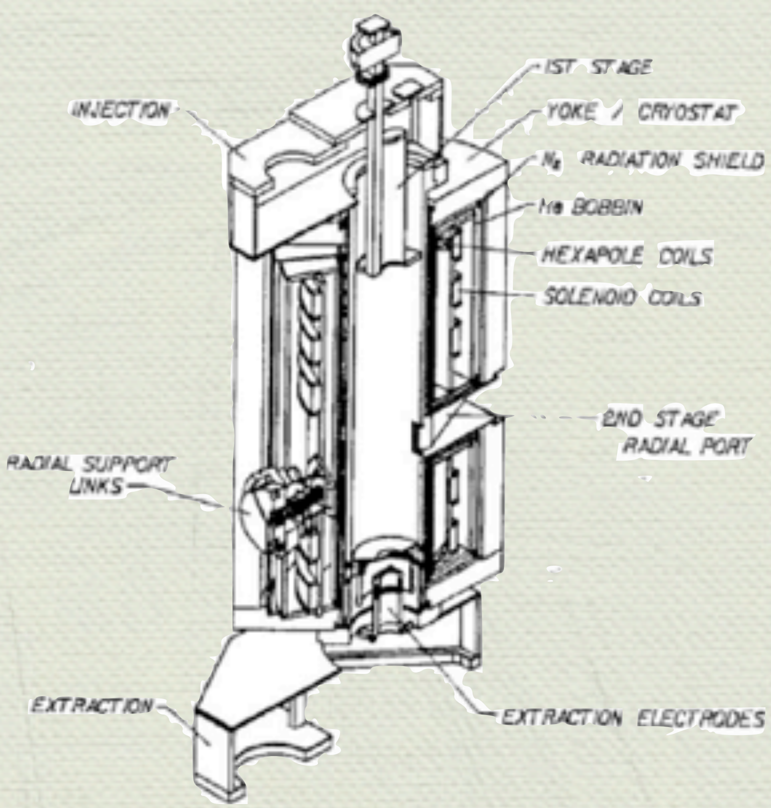
ECR Surface
$B_{ECR} = \omega_{RF} m_e / e$

ECRIS: classification in terms of "generations"

1st generation:
f=6-14 GHz, P=0.5 kW, I<mA, q=6-12 for Ar

2nd generation:
f=14-18 GHz, P=1-2 kW, I=1-2 mA, q=8-16 for Ar

3rd generation:
f=24-28 GHz, P=5-10 kW, I=20-40 mA, q=14-18 for Ar



SC-ECRIS, MSU-NSCL

SERSE, INFN-LNS

CAESAR, INFN-LNS

VENUS, LNBL-USA

LNS - Ion Source main beams

Frequency	18 GHz + 14.5 GHz
Type of launching	WR62, off-axis
Axial maxima distance	490 mm
B_{max} (injection side)	2.7 T
B_{min}	0.3 to 0.6 T
B_{max} (extraction side)	1.6 T
Resonance zone length	< 100 mm
Hexapole length	700 mm
B_{rad} (at chamber wall)	1.55 T maximum
Biased disk	300 to 600 V, 1 to 2 A mA
ϕ plasma electrode	8 mm
ϕ puller	12 mm
Extraction voltage	30 kV max

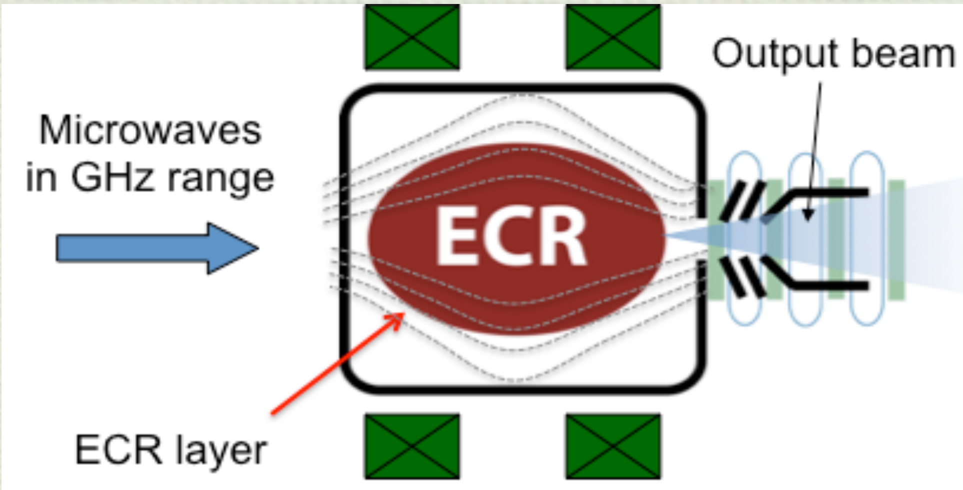
Beams from SERSE

	14.5 GHz	18 GHz	14+18	A.I.E.	optimum
O^{7+}	200		208		
O^{8+}	40		55		
Ar^{14+}	80		84		
Ar^{16+}	17		21		
Ar^{17+}	1		2.6		
Ar^{18+}	0.05		0.4		
Kr^{22+}	46	66			
Kr^{25+}	20	35			
Kr^{27+}	4.5	7.8			
Xe^{30+}	12	17	21.2	27	38.5
Xe^{31+}	7.6	10.3	14.7	18.3	23.5
Xe^{33+}	1.5	3.3	6	7.2	9.1
Xe^{34+}	1	1.6	3	4.1	5.2
Xe^{36+}	0.4	0.9	1.3		2

Major faults especially in the SERSE LHe - cryostat stopped further developments.

Now restarting operations

Overcoming the current limits of ECRIS



$$\boxed{\omega_p^2 < \omega^2} \rightarrow \boxed{n_e < \frac{\epsilon_0 m_e}{e^2}\omega^2 = n_{cutoff}}$$

Beam characteristics

$$\boxed{\langle q \rangle \propto n_e}$$

$$\boxed{I \propto n_e}$$

ECRIS STD MODEL

$$\boxed{n_e \propto \omega_{RF}^2}$$ → ***INTRINSIC Density limitation***

1. **High Frequency Generators to increase the plasma density**;
2. **High Magnetic Fields to make longer the ions confining time**;

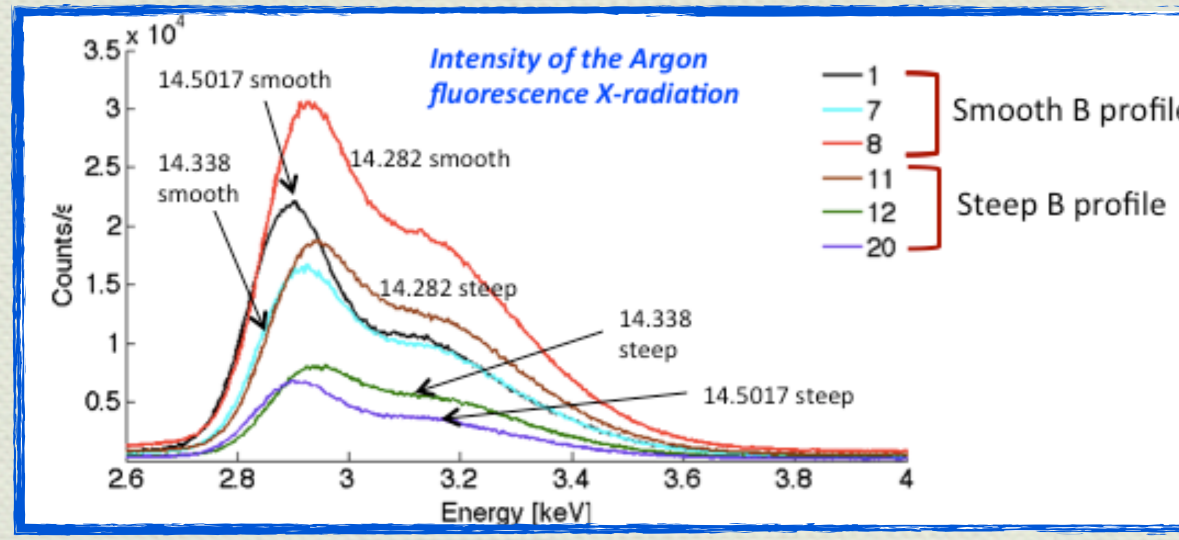
Brute force cannot be anymore used because of technological reasons (magnets, hot electrons generations, plasma overheating, cooling, ...)

Alternative heating schemes → **Development of advanced diagnostics tools to make a step forward in understanding heating and confinement mechanism**

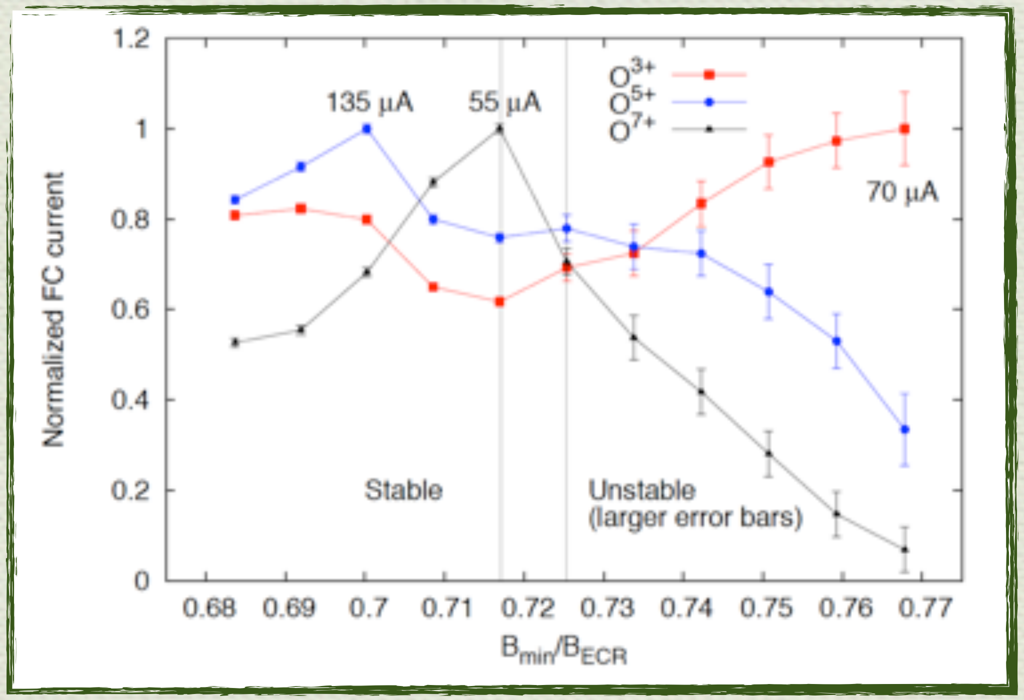
Some questions....

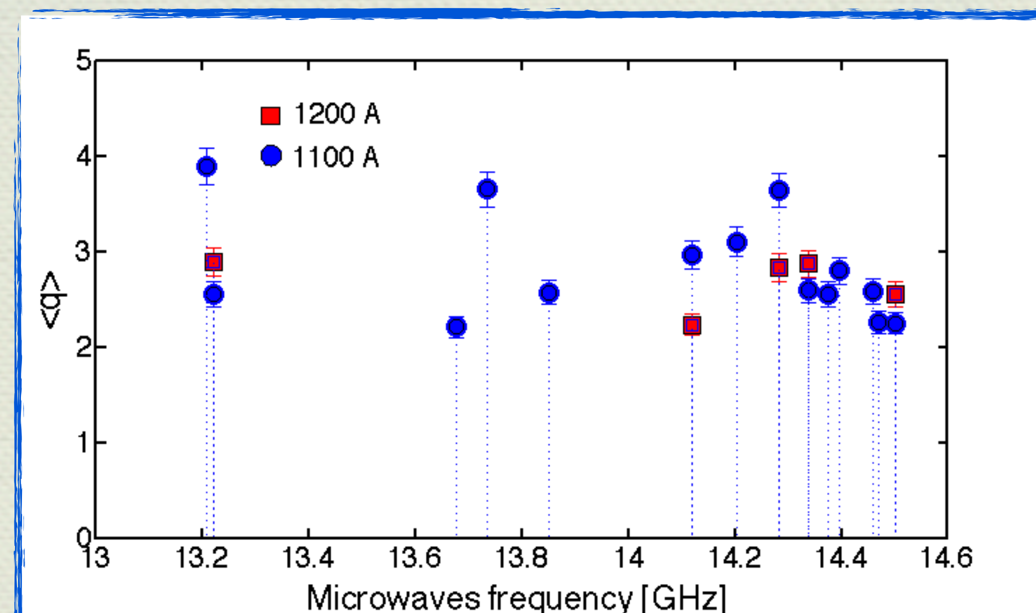
- Does exist an "ECRIS fine structure" with respect to magnetic field and RF frequency tuning?

D. Mascali et al., Rev. Sci. Instrum. 2014



O. Tarvainen et al. Plasma Sour. Sci. Tech. 2014



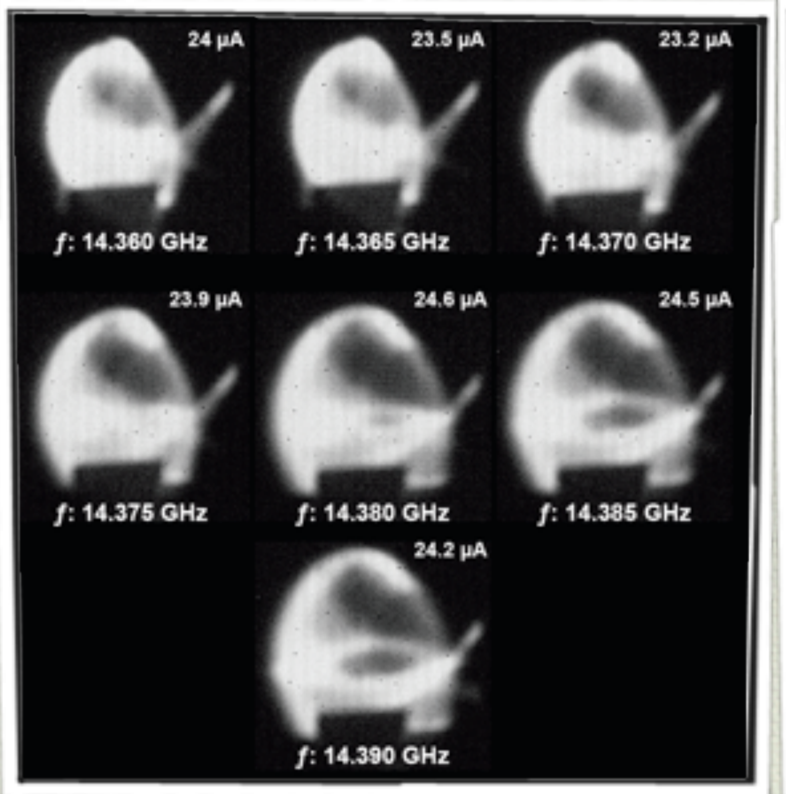


Evidences of plasma instabilities when tuning B

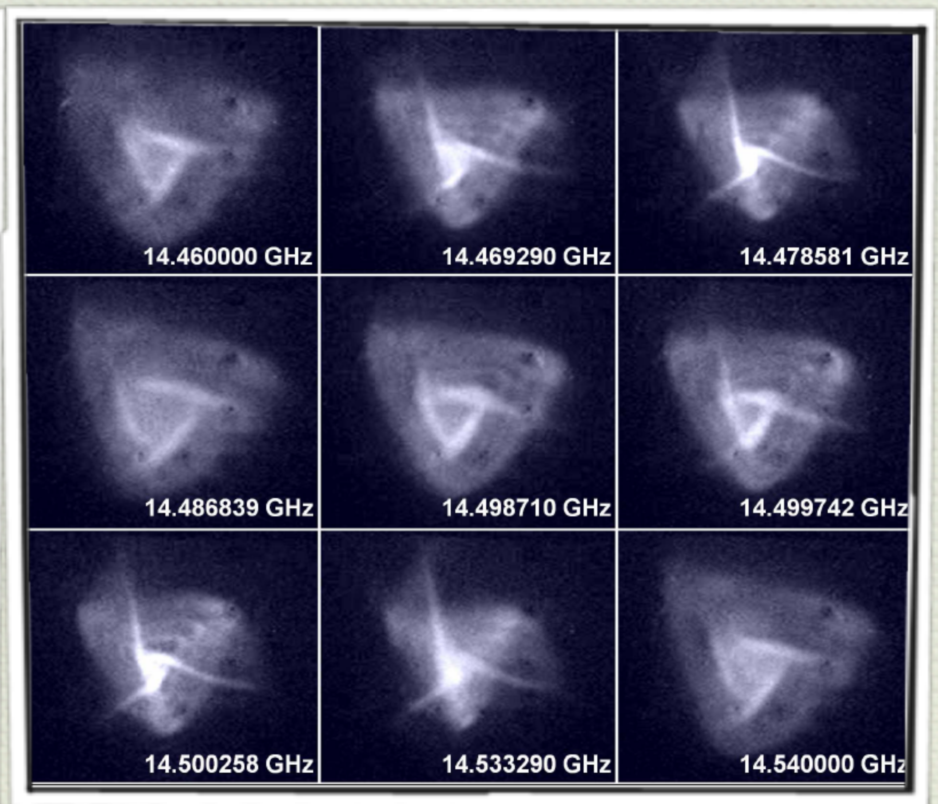
Evidences of strong fluctuations with the RF frequency correlated to X-ray emission

Some questions....

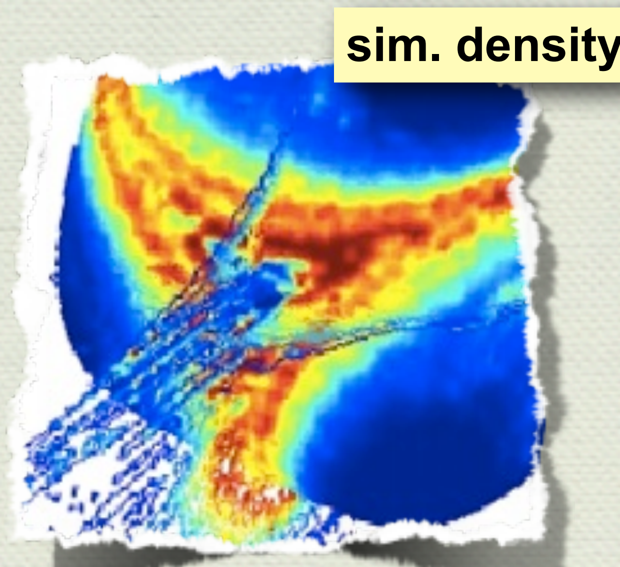
- Does exist an INTERPLAY between the plasma structure and the beam shape, brightness, emittance?

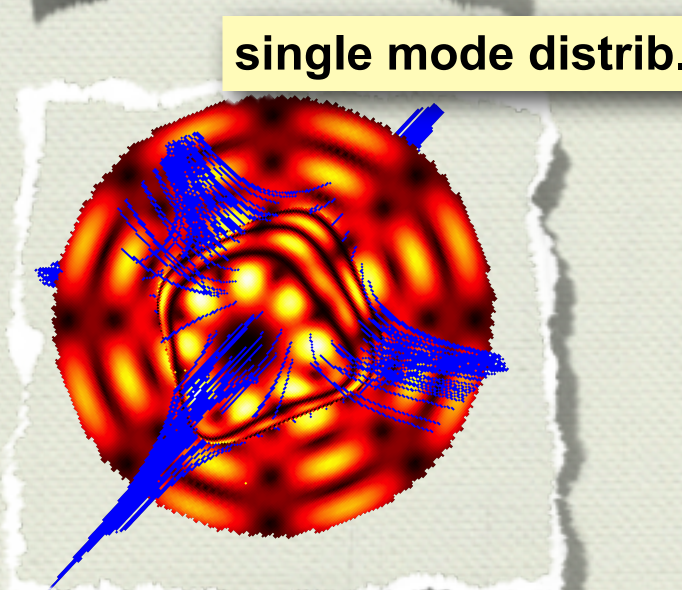


D. Nicolosi et al. ICIS-15, New York City



L. Celona et al., Rev. Sci. Instrum. 2008

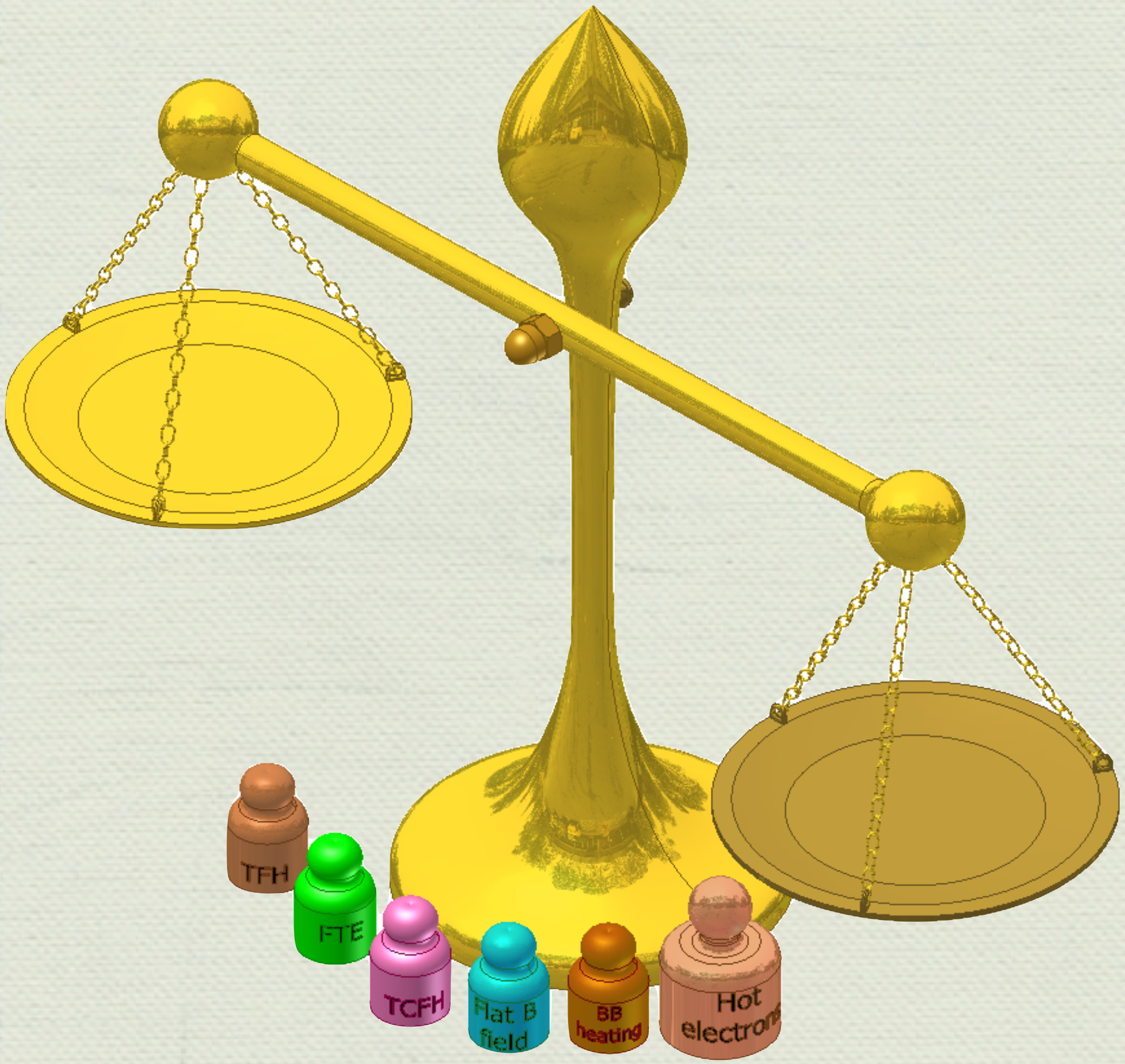




- Does the plasma distribute uniformly?

- Are electrons of different energy domains merged each other or not?

Applying alternative heating schemes



1. Frequency tuning
2. Two Frequency Heating
3. Two Closed Frequency Heating
4. “Flat B Field” heating
5. “Broadband” heating

Efforts on plasma diagnostics methods development, studies about the impact of new techniques on the beam properties, etc.

Strategies for improving LNS-ECRIS efficiency

6-18 months

Improving beam transport/handling

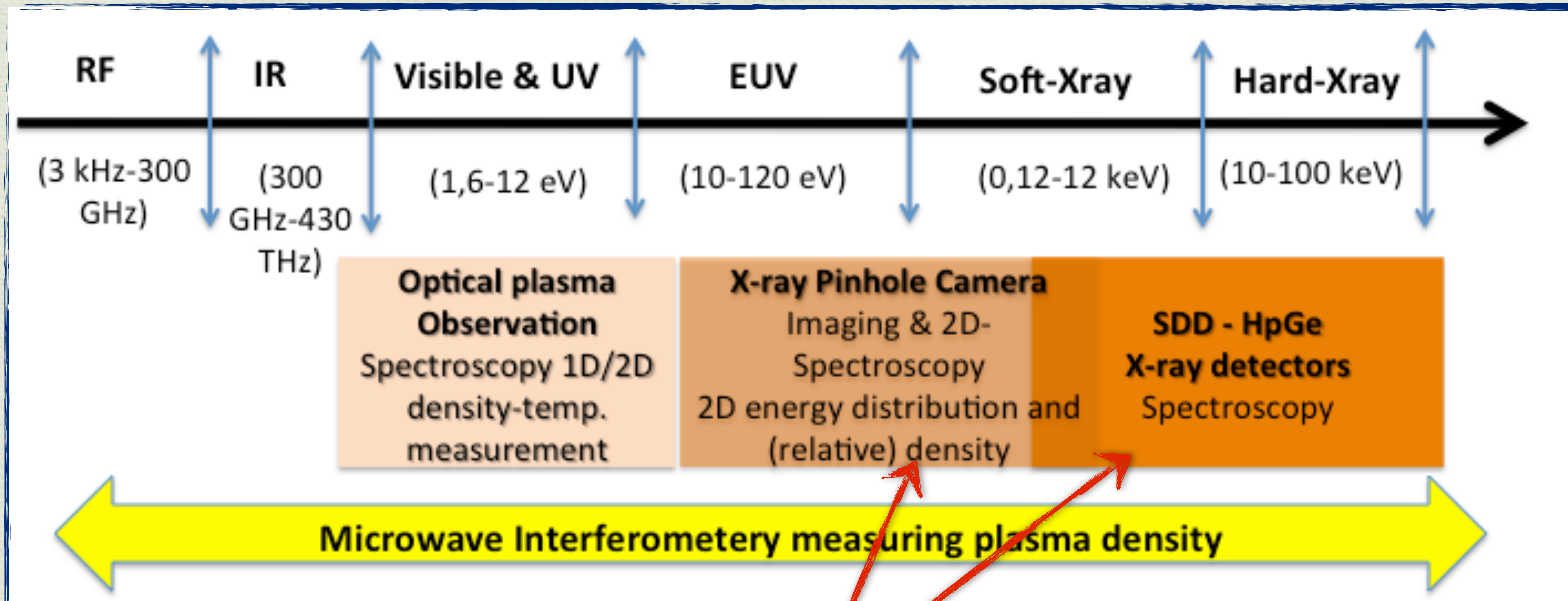
0-18 months

Implementing new plasma heating methods

18-36 months

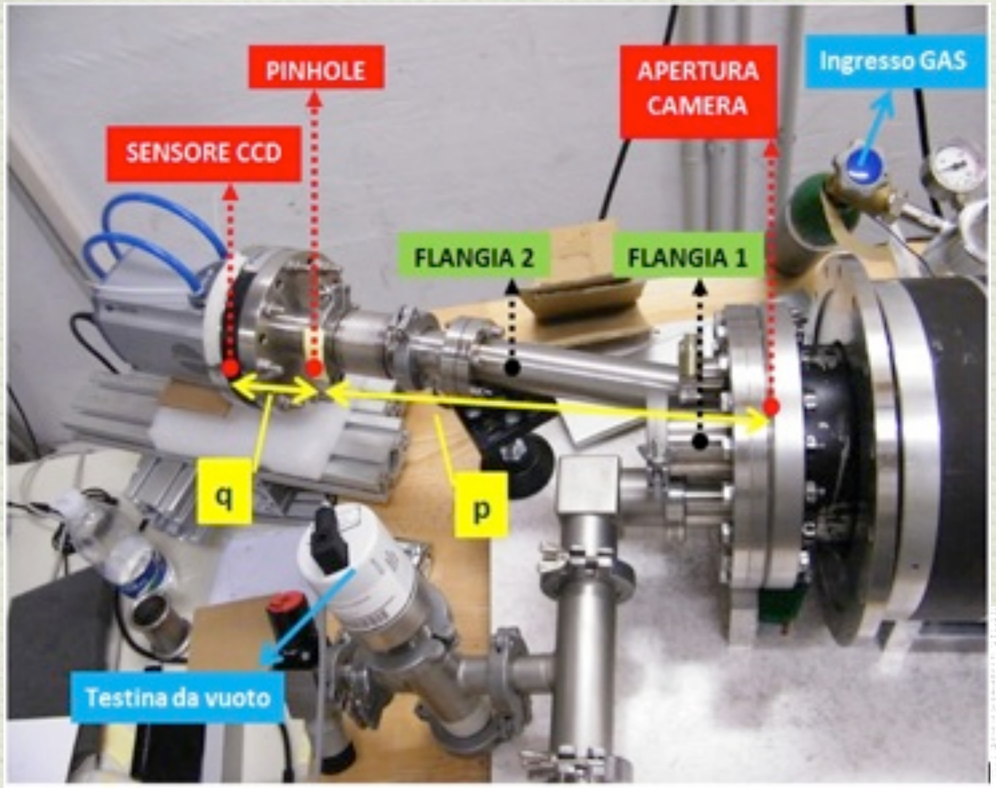
A Big Jump ---> installing a 21 GHz machine (**AISHa**) for very-high intensities

Non-intrusive plasma diagnostics methods



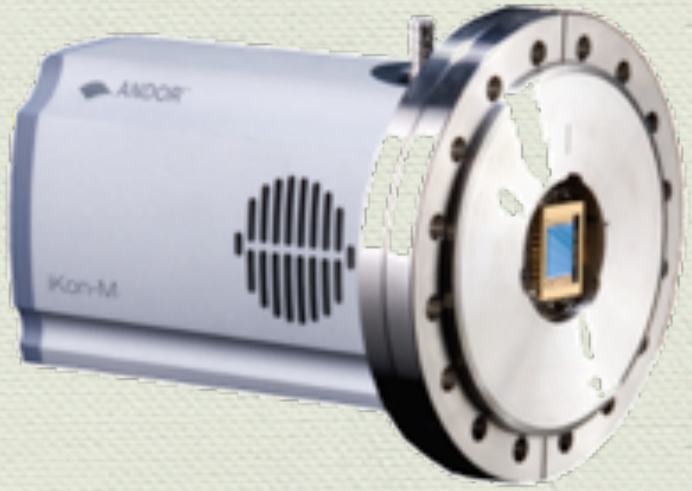
Measuring the plasma density in different energy regimes: density, temperature and plasma structure evaluation under different operative parameters

Advanced techniques of plasma diagnostics have been implemented: the X-ray pin-hole camera

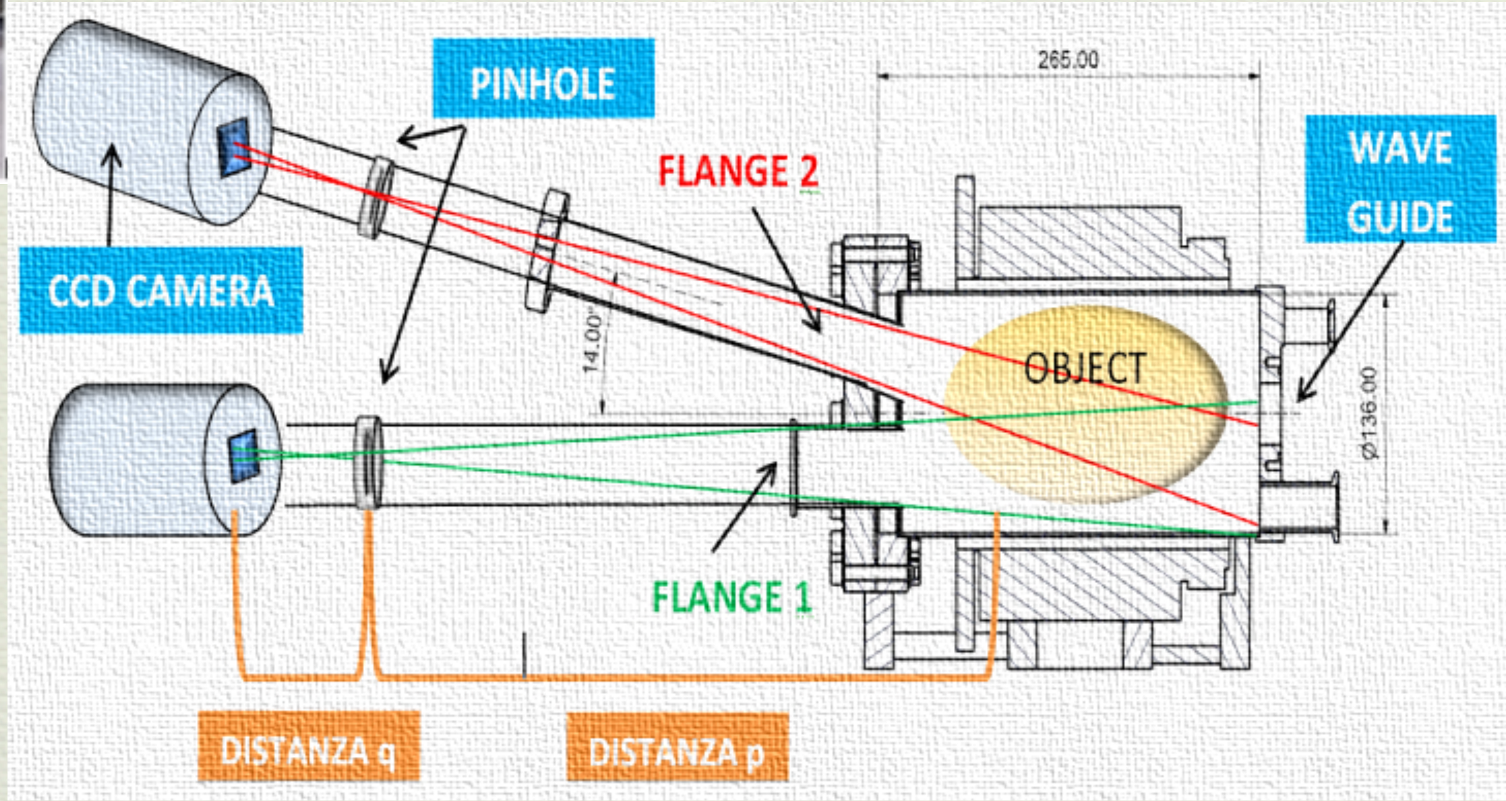


X-ray imaging can be performed with a pin-hole camera technique

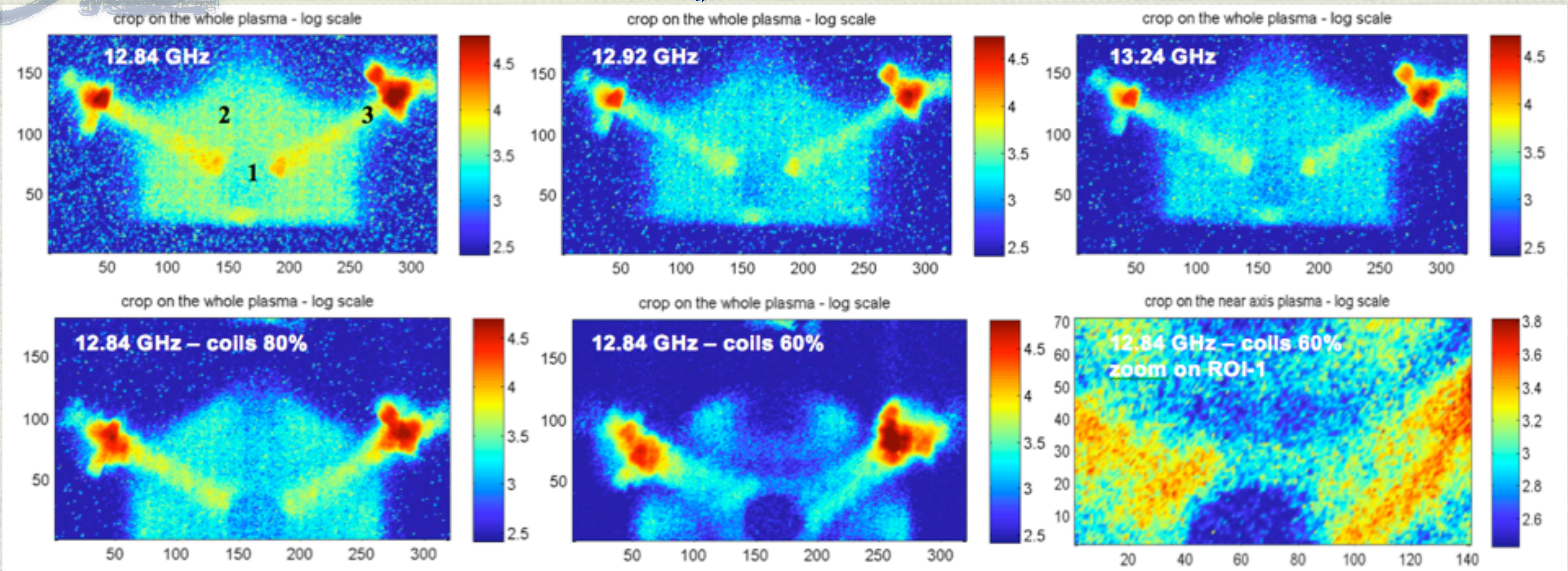
The pin-hole is mounted between the plasma and a X-ray sensitive CCD camera having 1024x1024 pixels in the 0.5-15 keV energy domain

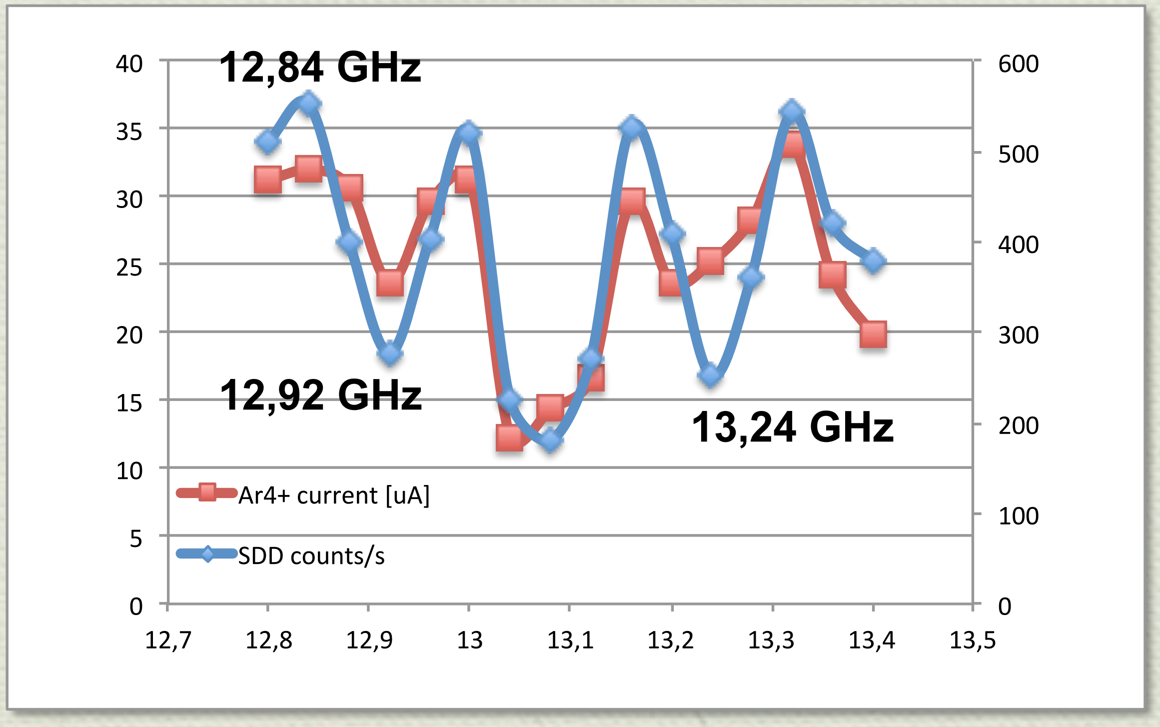


X-ray sensitive CCD - camera



X-ray imaging



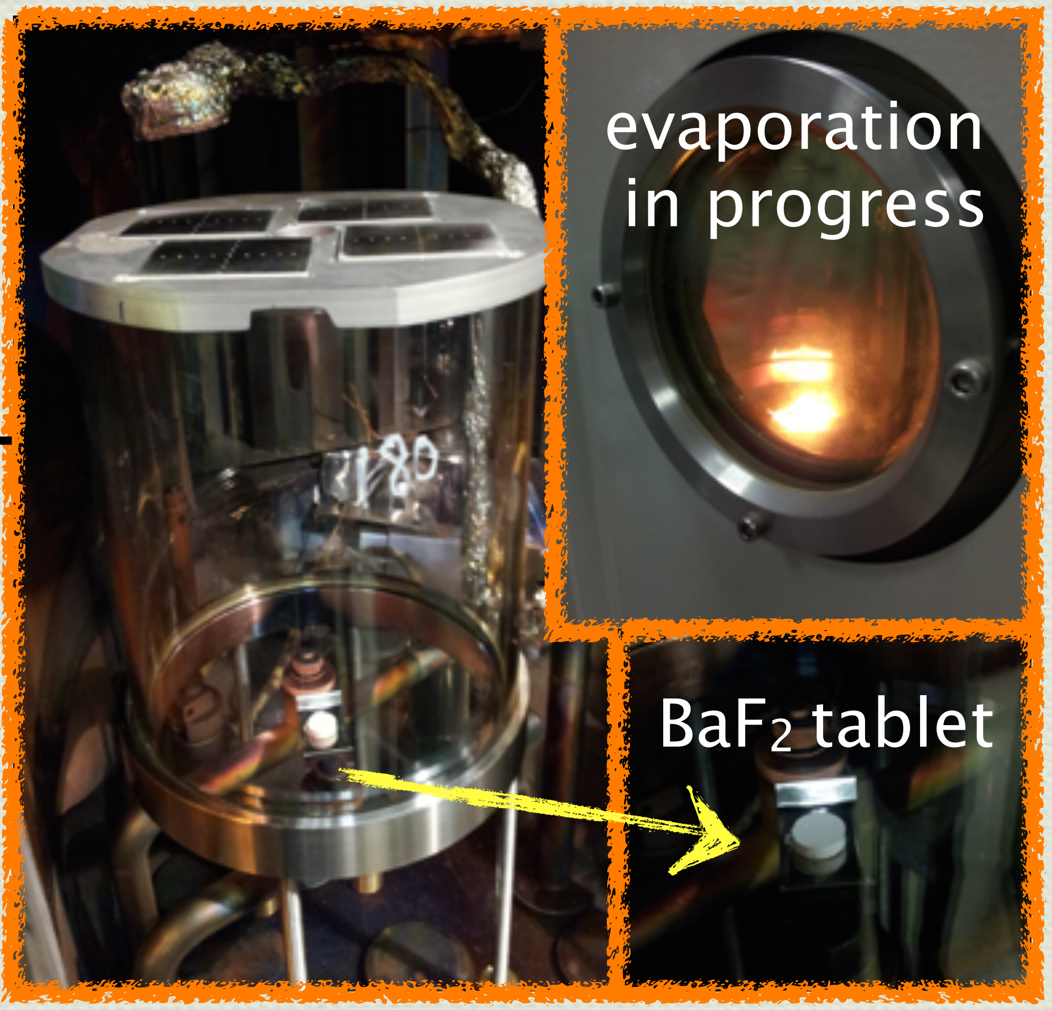


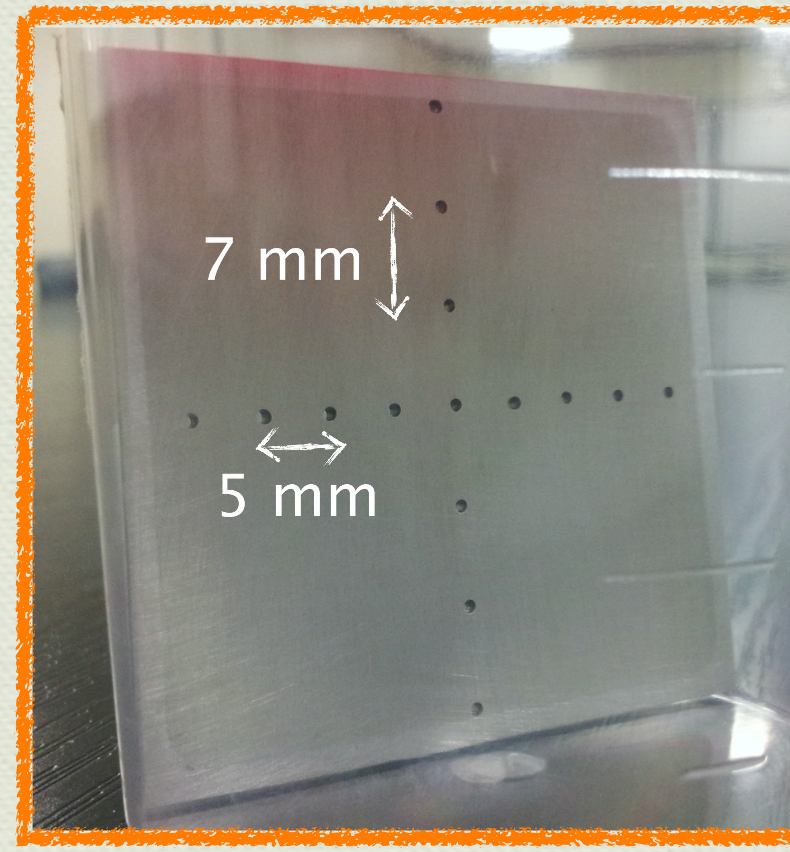
From a general inspection of the pictures, it is clearly visible the structure of the plasma:

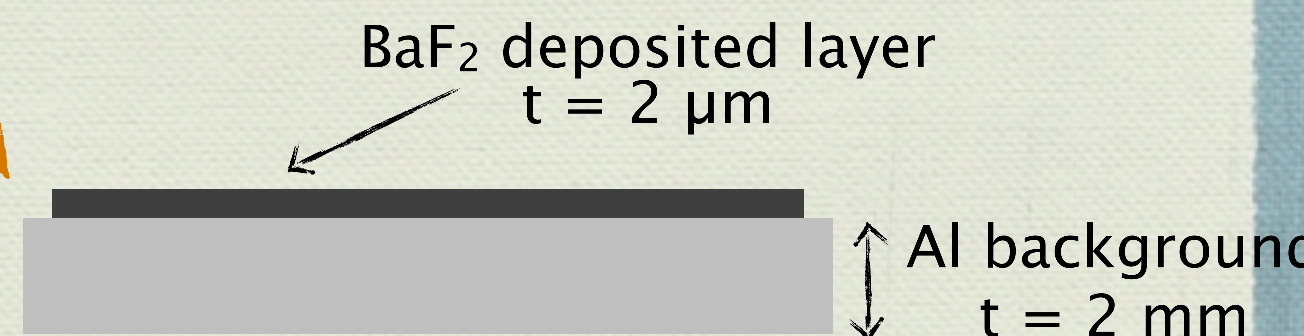
- the hole in the near axis region
- the branches due to the electrons escaping from the confinement
- he hot spots due to lost electrons producing bremsstrahlung radiation when impinging on the chamber walls.

Mastering beam transport and source-to-CS matching

LNS Evaporator



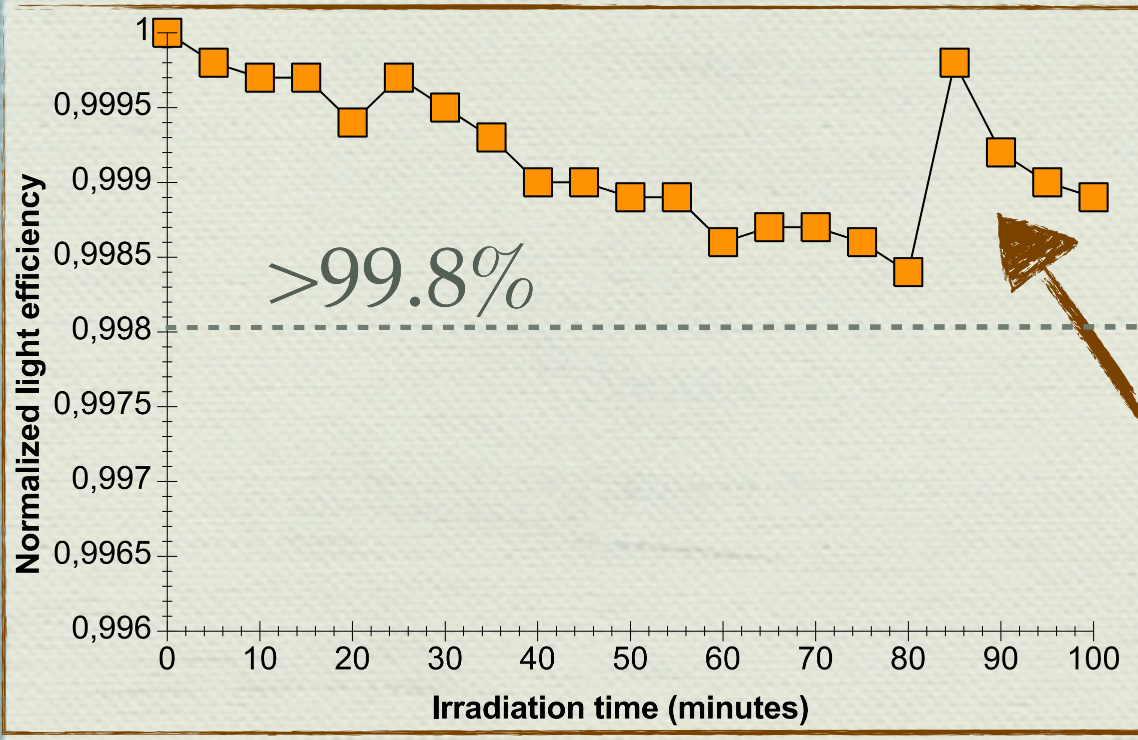


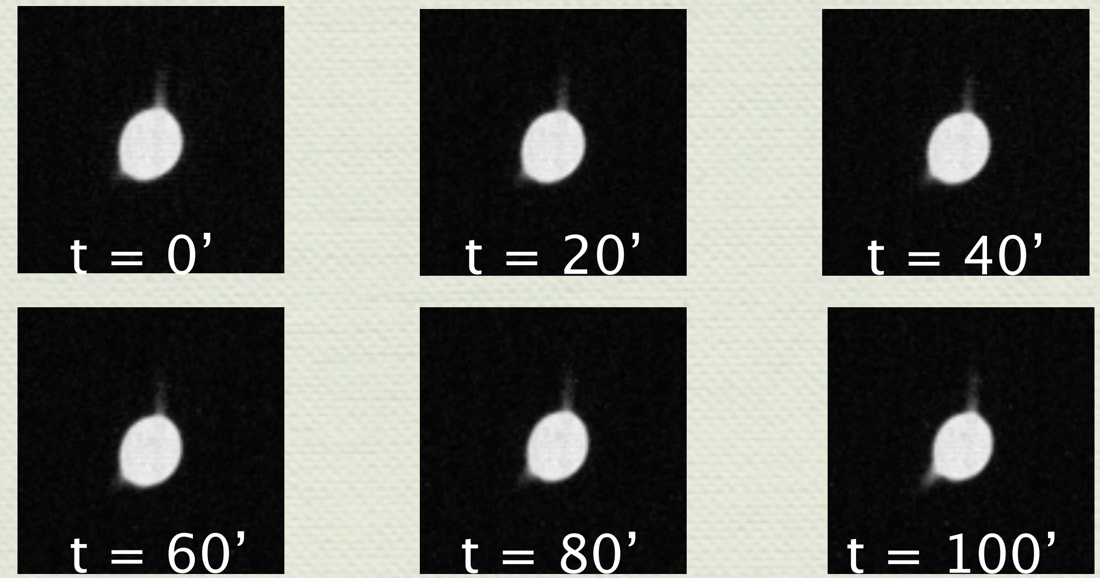


BaF_2 screen irradiation

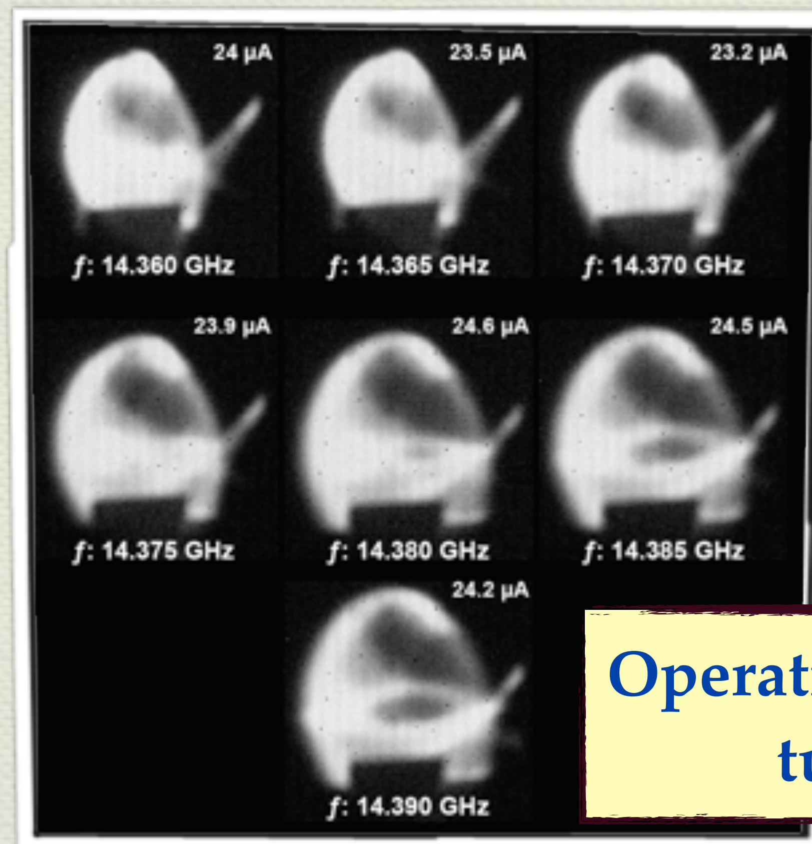
Selection of materials

$^{40}Ar^{8+}$ ions I_{beam} = 9.5 μA V_{extr} = 20 kV E = 160 keV Deposited power





20 minutes stop (source operation)

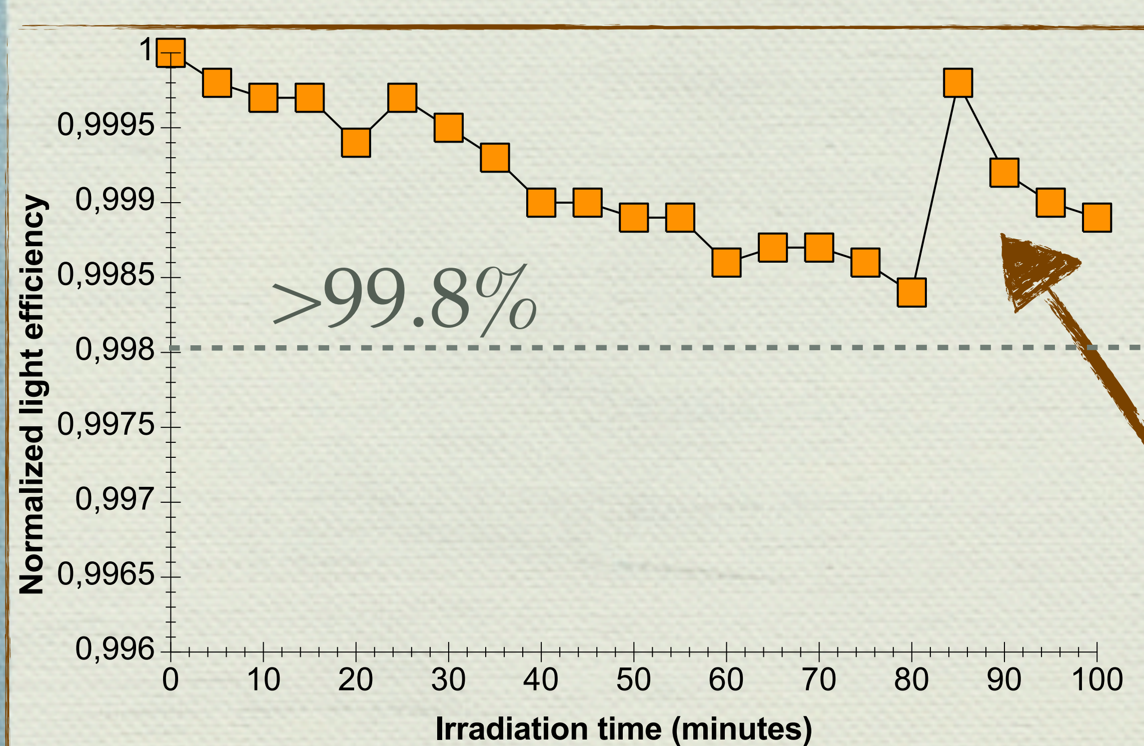


Operations in frequency tuning mode

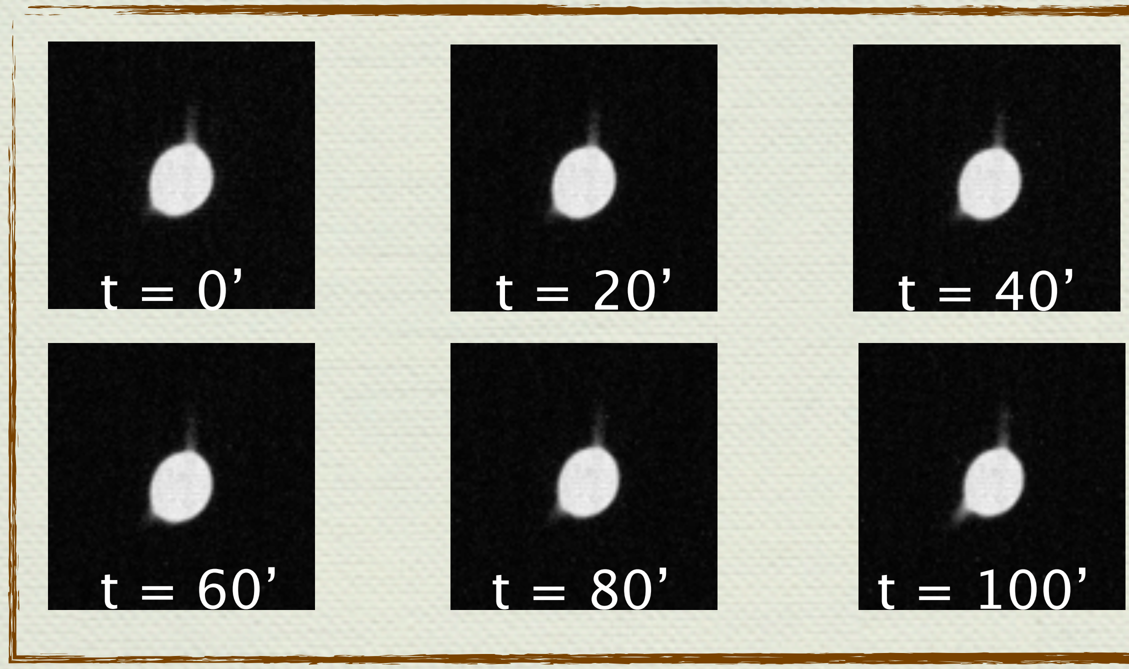
BaF$_2$ screen irradiation

Selection of materials

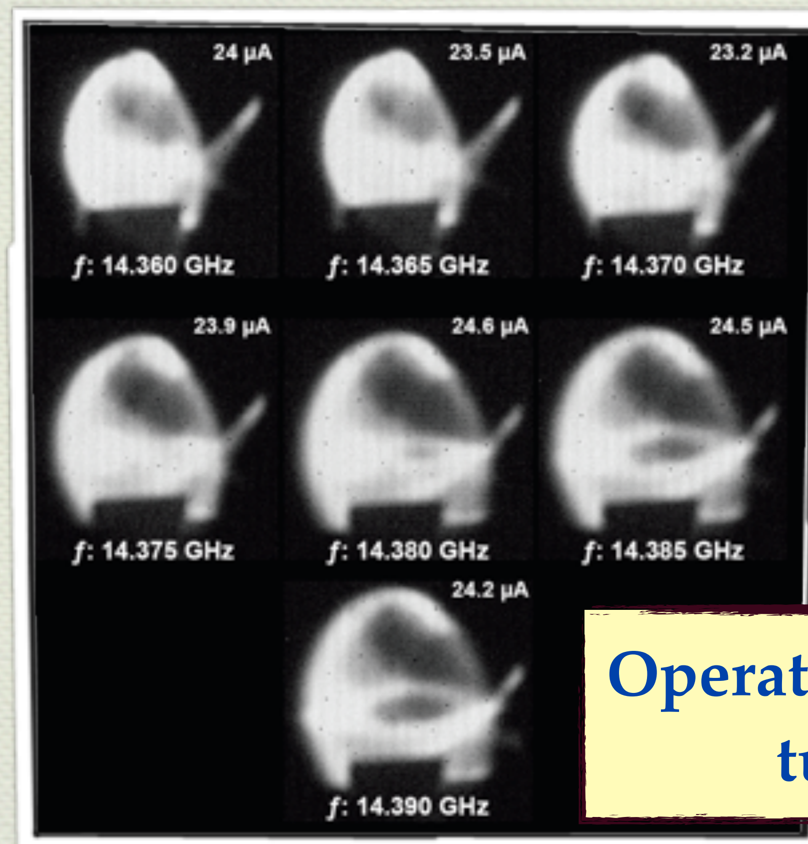
$^{40}Ar^{8+}$ ions I_{beam} = 9.5 μA V_{extr} = 20 kV E = 160 keV Deposited power



20 minutes stop
(source operation)



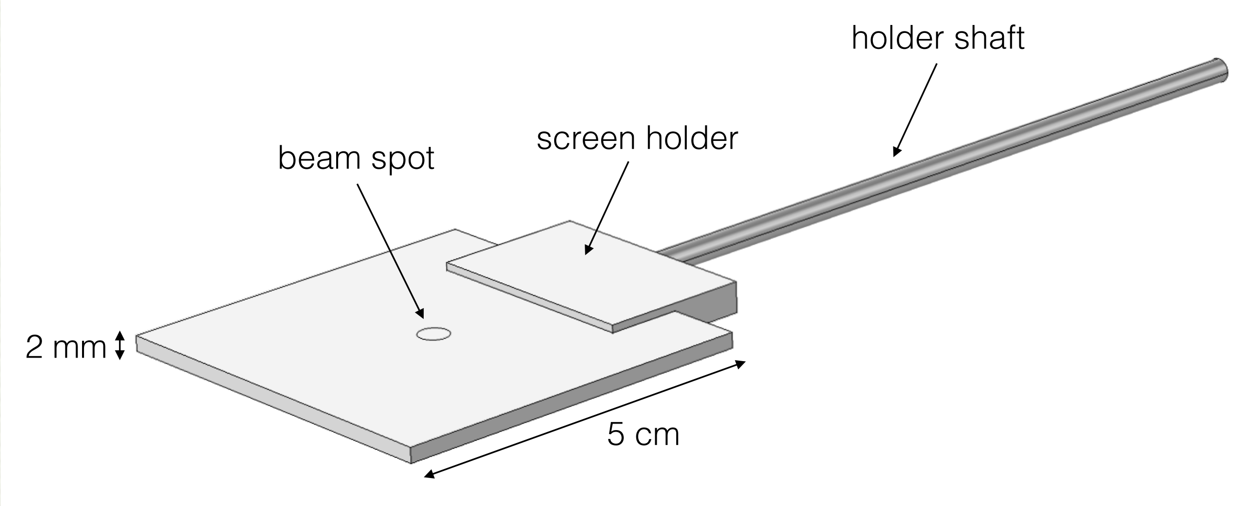
The BaF$_2$ screen does not suffer for beam irradiation in a significant way
No remarkable degradation observed



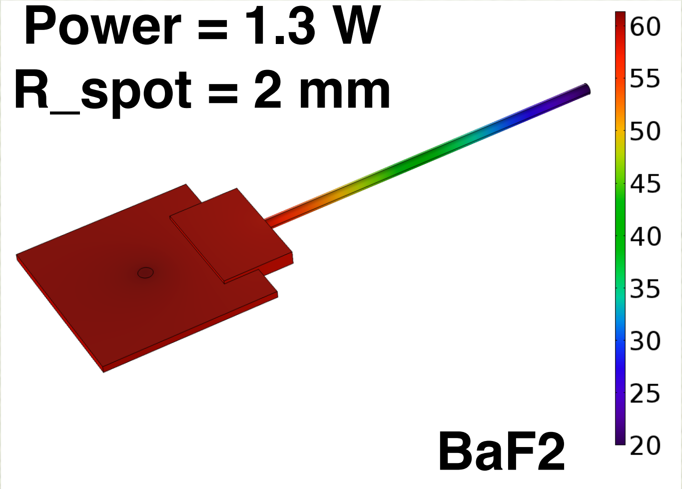
Operations in frequency tuning mode

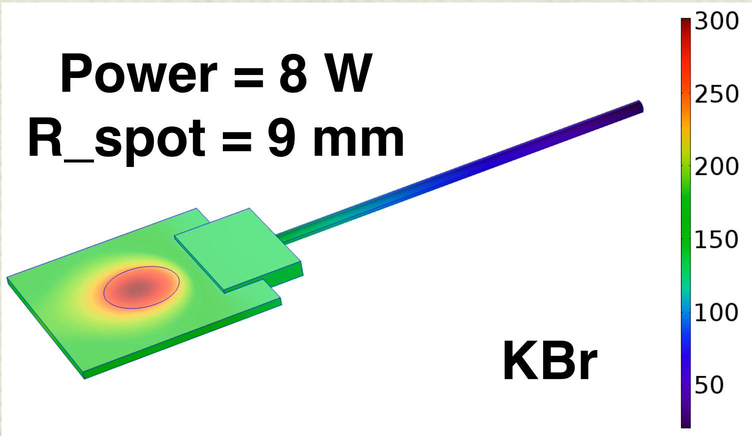
Steps toward high intensity beams monitoring

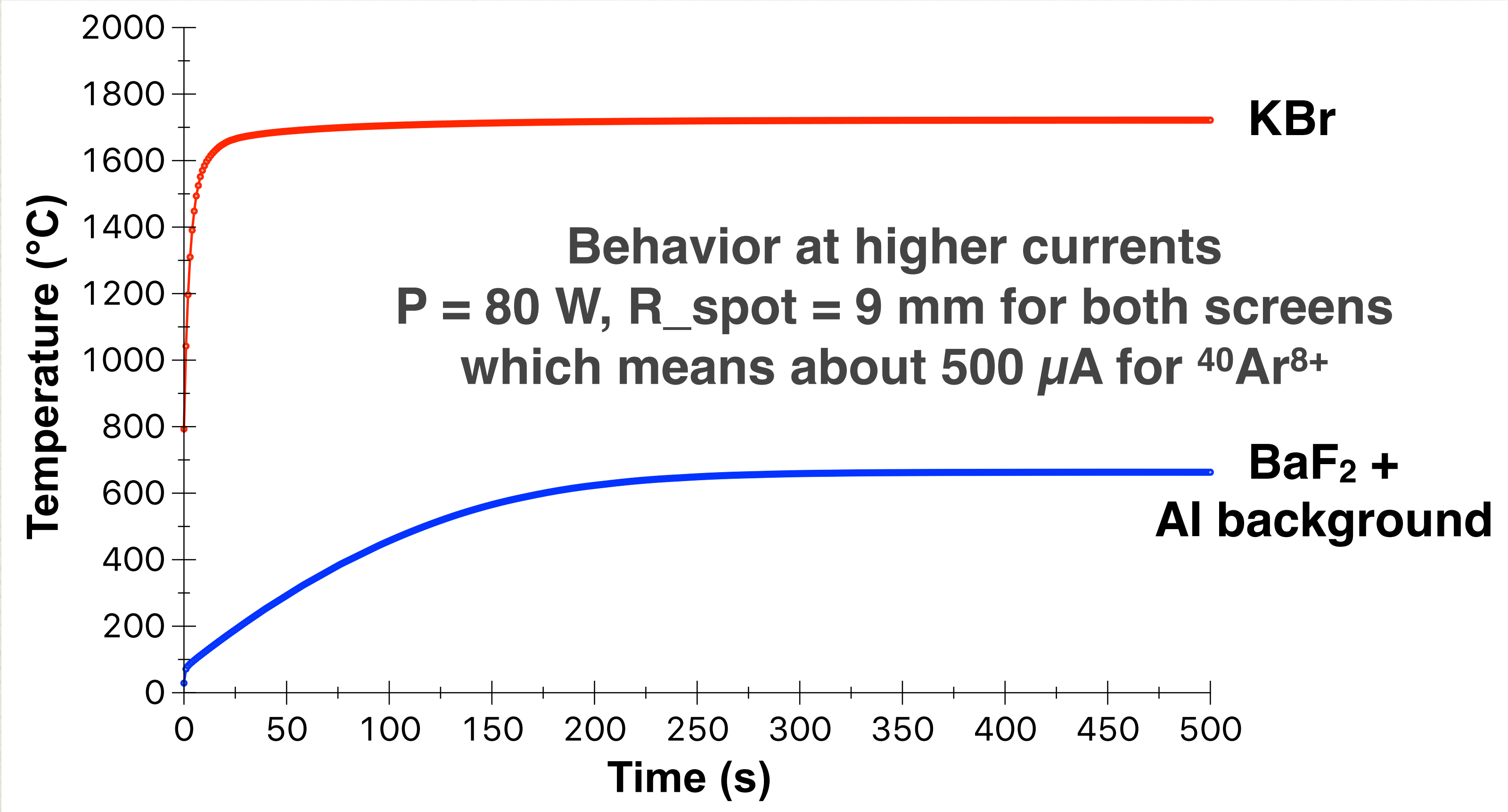
Thermal Simulations



simulation time 6000 s
simulation conditions = experimental ones







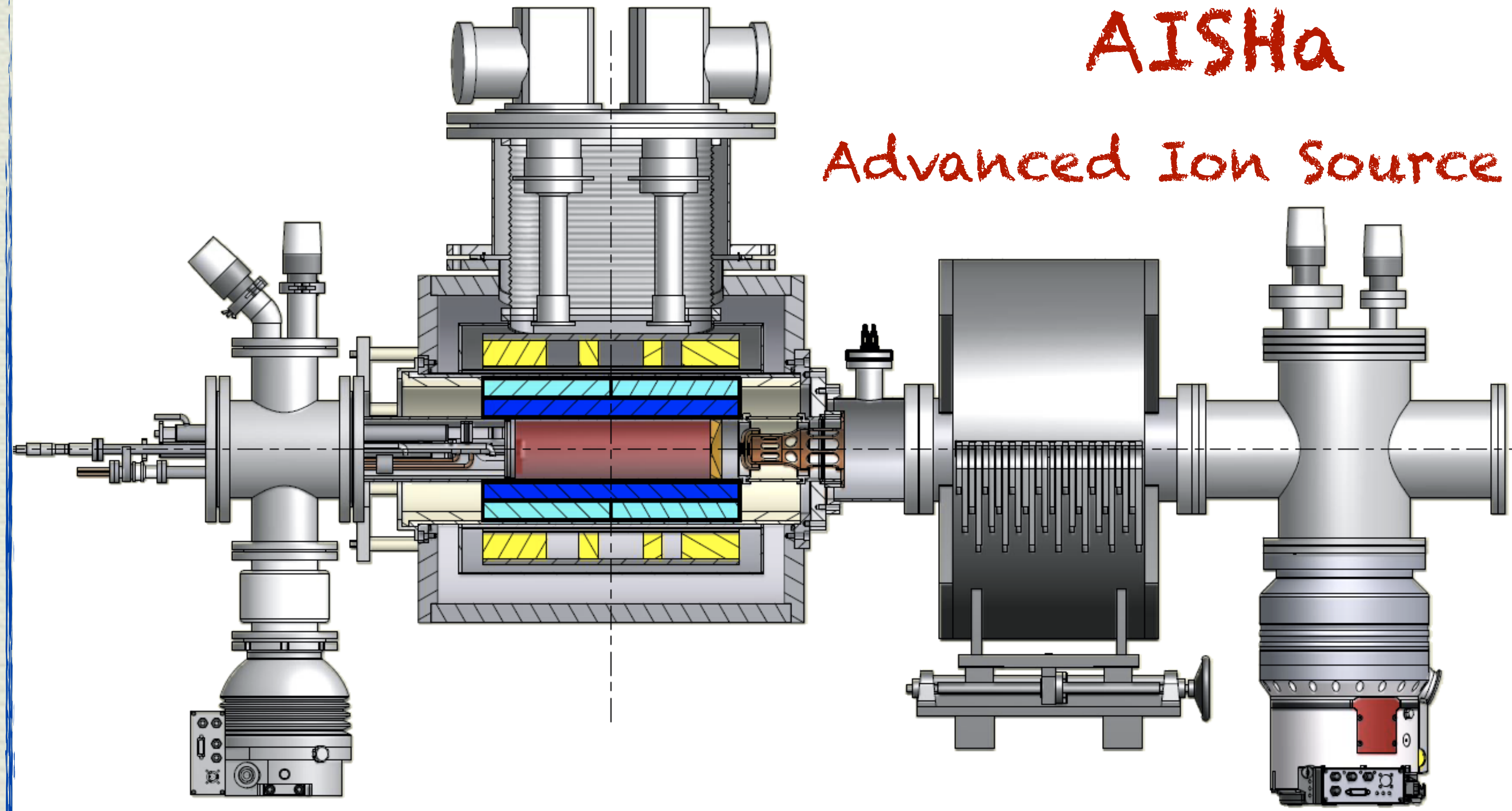
Our BaF2 screens is suitable also for high current beams —-> AISHa beams

Short/mid/Long term strategies

	Goal	Action
Short (0-6 months)	Broaden the beams availability in the perspective of high intensity	• R&D on vaporization techniques (oven, sputtering, innovative methods); • Fast and reliable tunings of the Sources
Short/Mid (0-12 months)	Improving the primary currents and <q>	Implementation of Alternative plasma heating methods (TCFH)
Short/Mid (6-18 months)	Improving the IS-CS beam matching	Diagnostics and beam transport modelling and optimization
Mid/Long (18-36 months)	Boost of primary beam currents + Testbench	The AISHa replace CAESAR. CAESAR becomes a Testbench.

AISHa

Advanced Ion Source for Hadrontherapy



- Reliability
- **High flexibility (RF +B field)**
- High Performances
- Compactness
- Easy-to-tune
- Low maintenance

Radial field	**1.3 T**
Axial field	**2.6 T - 0.4 T - 1.5 T**
Operating frequencies	**18 GHz (TFH)**
Operating power	**1kW**
Extraction voltage	**40 kV**
Chamber diameter / length	**Ø 92 mm / 300 mm**
LHe	**Free**
Iron yoke diameter/length	**42 cm / 60 cm**
Source weight estimation	**480 kg**

Ion	Expected currents (eμA)
C^{4+}	800
O^{6+}	1000
O^{7+}	400
Ne^{7+}	500
Ar^{14+}	150
Kr^{22+}	100
Xe^{27+}	100
Au^{30+}	50

A partial List of Actions already scheduled

- Low temperature oven for SERSE;
- New control system for SERSE (ready for CAESAR);
- Motorized stage for extraction optics (repeller+ground electrodes) ---> SERSE (already done for CAESAR);
- Beam pipes alignement;
- Installation of beam diagnostics tools (Allison Scanner + beam viewers, almost ready);
- Beam transport simulations;
- X-ray and RF passive diagnostics helping sources tuning;
- New plasma chamber for SERSE and injection flange;

Assets and criticalities

Criticalities

- Long time elapsed from last systematics;
- Time needed for implementing all the actions;
- no test-bench available (very short time available for off-line experiments and tests); ---> AISHa will serve as testbench during 2016

Assets

- Motivated technical manpower with valuable skills;
- Well-established know-how gained by the RD group (recognized international leadership in Ion Sources science and technology);
- INFN-LNS management supporting new synergies and strategies for revamp of LNS machines.