Non-Conventional Microwave Coupling of RF Power in ECRIS Plasmas

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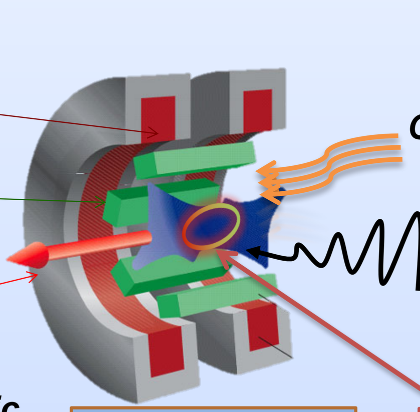
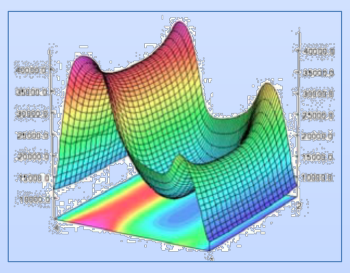


"B_minimum" Magnetic Field structure



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

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

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

ECRIS STD MODEL

Beam characteristics: $\langle q \rangle \propto n_e$, $I \propto n_e$ → $n_e \propto \omega_{RF}^2$ → INTRINSIC Density limitation

- Increasing **efficiency** of **ECR** heating mandatory to increase the **accelerator performance**
- Investigation of **alternative heating mechanism**
- Explaining the experimentally observed technique known as "**frequency tuning effect**"

Abstract

X-ray imaging and numerical simulations demonstrate that the **RF power deposition** in ECRIS plasmas **is not concentrated in the near-axis region**, as it would be desirable in order to maximize the ion beam brilliance. There are different arguments to explain this occurrence as due to the symmetry of the plasma chamber. In this **aperture coupled cylindrical cavity resonator**, in fact, any eigenmode solution of Maxwell equations prefers **off-axial concentration of the electromagnetic field**. The aperture-coupling of the rectangular waveguides with the cylindrical chambers (as it is normally for ECRIS) also suffers of an intrinsic, **geometrical impedance mismatch**. Both these issues suggest that a major optimization of RF coupling efficiency to ECRIS plasmas is still possible, provided that the overall geometry is changed.

A reshaping of both the plasma chamber and related RF launching system

in a plasma microwave absorption oriented scenario is considered as a possible solution, as well as the design of optimized launchers (taking inspiration from tools adopted in the thermonuclear-fusion) enabling single-pass power deposition, i.e. not being affected by cavity walls effects.

During the last 30 years ECRIS development allowed to increase the accelerators' performance

Highly charged ions $\frac{E}{A} \propto \frac{q^2}{m}$ **Higher energy for cyclotron beams**

Geller's scaling laws

$$I \propto f_{RF}^2$$
$$q \propto \log B^{3/2}$$

...near the technology limits...

Overcoming a "brute force" empirical towards a "Microwave Absorption Optimization-oriented" design in order to: Developing the next generation ECRIS

$L_B, L_T, L_n \approx \lambda$

TYPICAL WAVELENGTHS AND SIZES OF COMPACT ION SOURCES

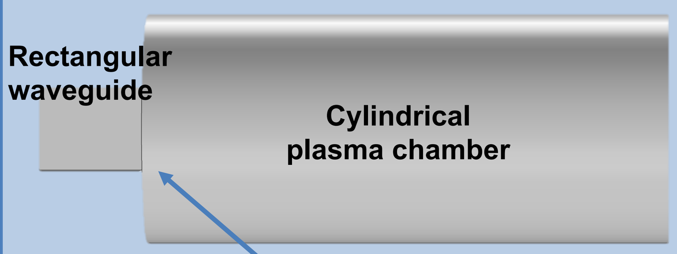
λ_{RF} Launching [mm]	λ_{RF} Diagnostics [mm]	L_c[mm]
10-120	7-15	250

in the ECRIS, ray-traving approximation is not applicable, and the full-wave calculations have to be applied to simulate the wave behaviour in the plasma

Reshaping of both the plasma chamber and related RF launching system

RF launching reshaping

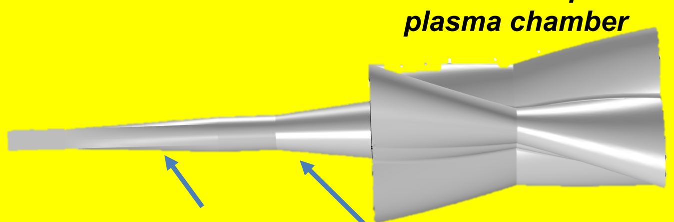
Aperture coupled cylindrical cavity



geometrical impedance mismatch

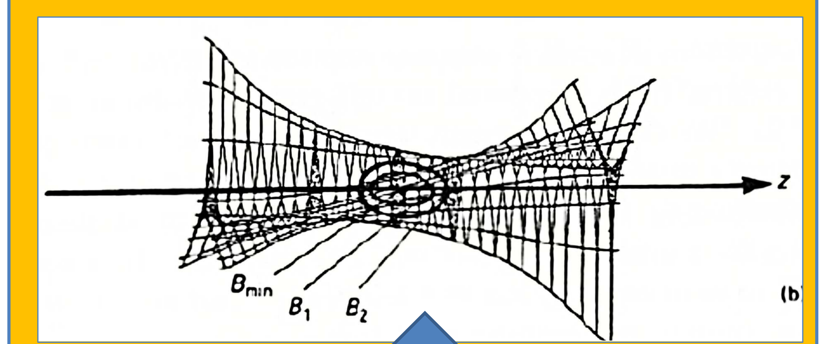
Reshaping of both the plasma chamber and related RF launching system

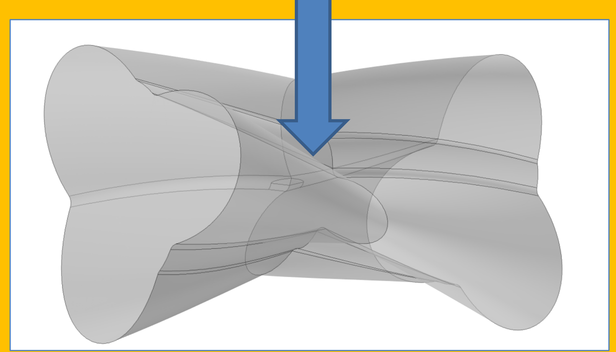
Plasma-shape plasma chamber



Cavity Geometry reshaping

Magnetic field structure obtained by the superposition of the field produced by two solenoids and an hexapole (minimum-B field)



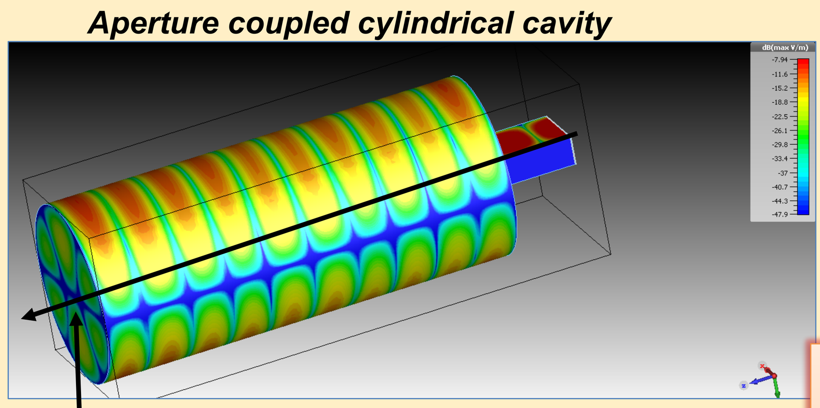


Plasma-shape plasma chamber following Magnetic field structure

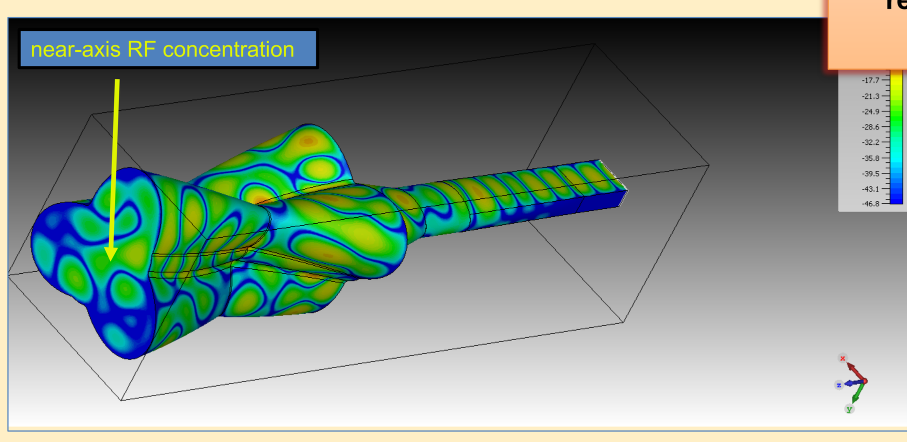
CST MW Studio Numerical results

Electric field |E| @ 10.3 GHz (logscale)

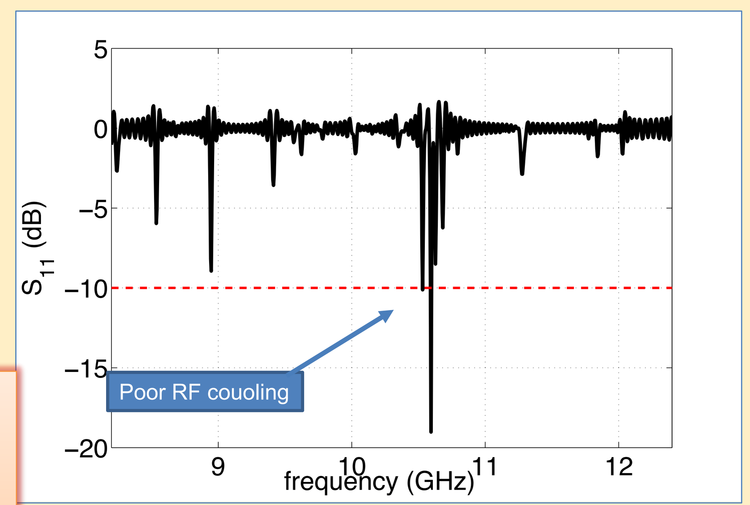
Aperture coupled cylindrical cavity



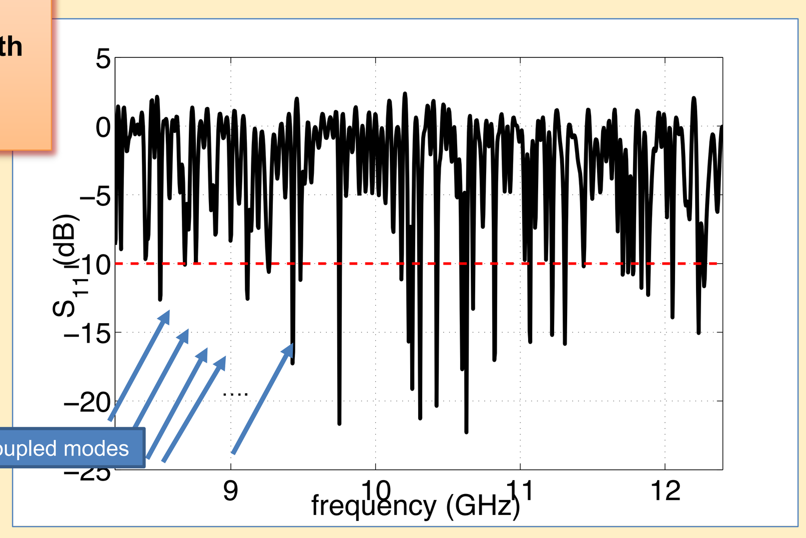
Plasma-shape plasma chamber



Reflection coefficient S_{11}



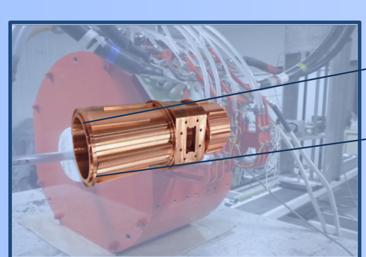
Numerical results show that the proposed plasma chamber and launching system can achieve a reflection coefficient $|S11| \leq -10$ dB for a very larger number of frequencies with respect to the classical plasma chamber

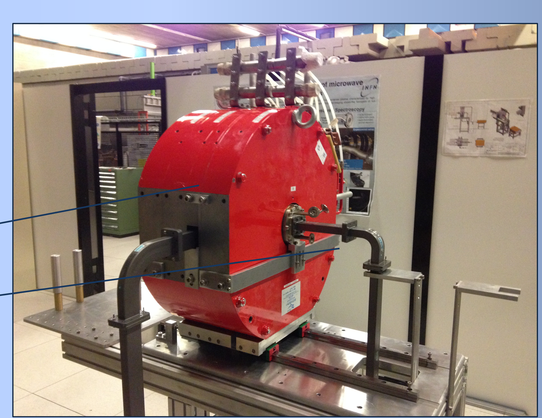


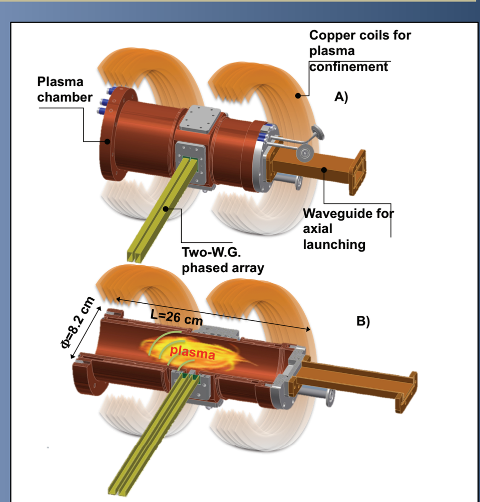
Alternative microwave plasma heating in a modal-conversion scenario, by multiple-launching at different frequencies, controllable angles and polarization

Microwave launcher design for the Flexible Plama Trap (FPT) to trigger Bernstein waves in Overdense plasma

- Magnetic field up to 0.5 T
- RF Frequency 3÷14 GHz
- RF injection // and perp to B_0

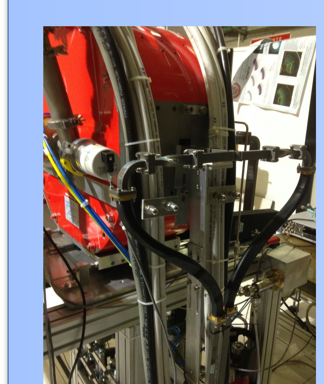


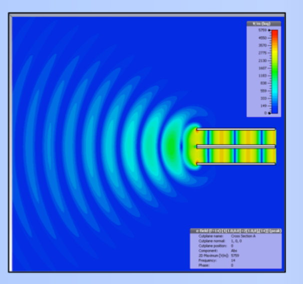


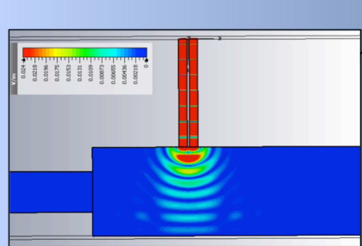


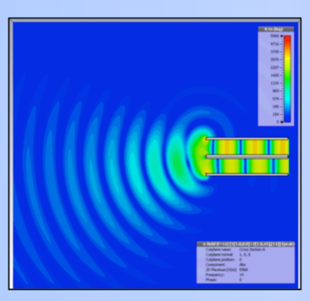
Phased waveguide array of two elements: using a relative phase shift for scanning the radiated beam

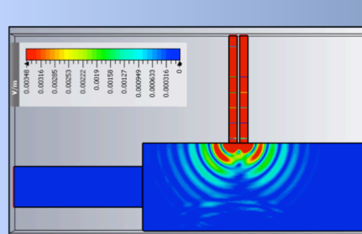
ARRAY of two waveguides for ECRIS





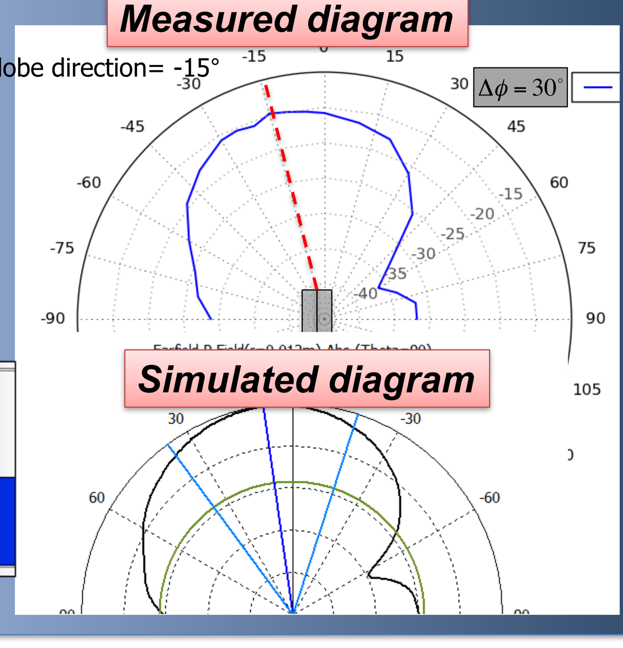






Measured diagram

Simulated diagram

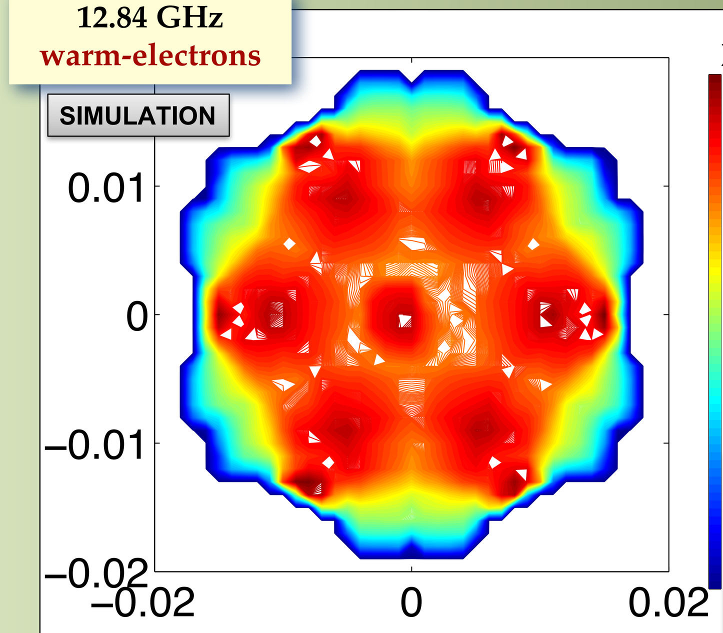


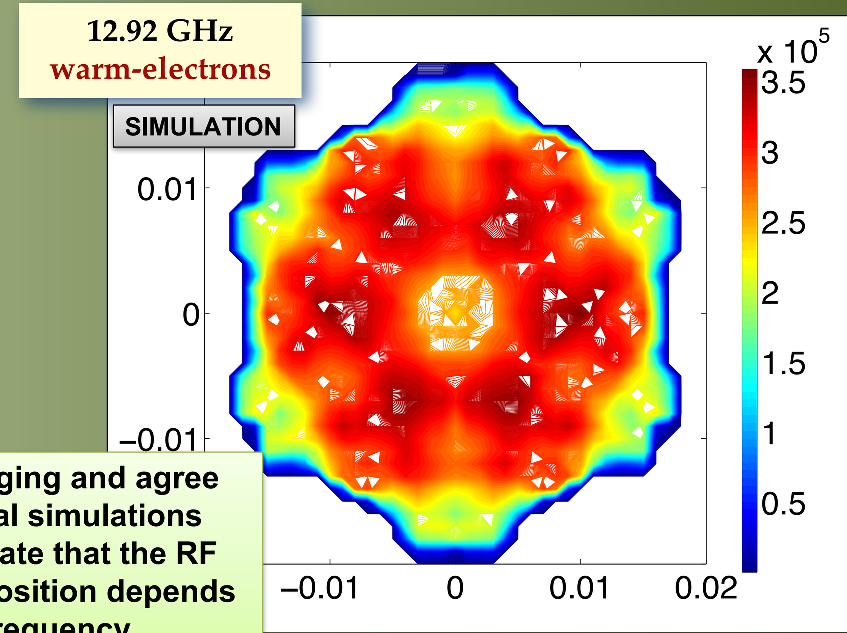
X-ray imaging experiment Comparison to self-consistent simulations 12.84 + 12.92 GHz

X-ray imaging and numerical simulations often demonstrate that the RF power deposition in ECRIS plasmas is not concentrated in the near-axis region

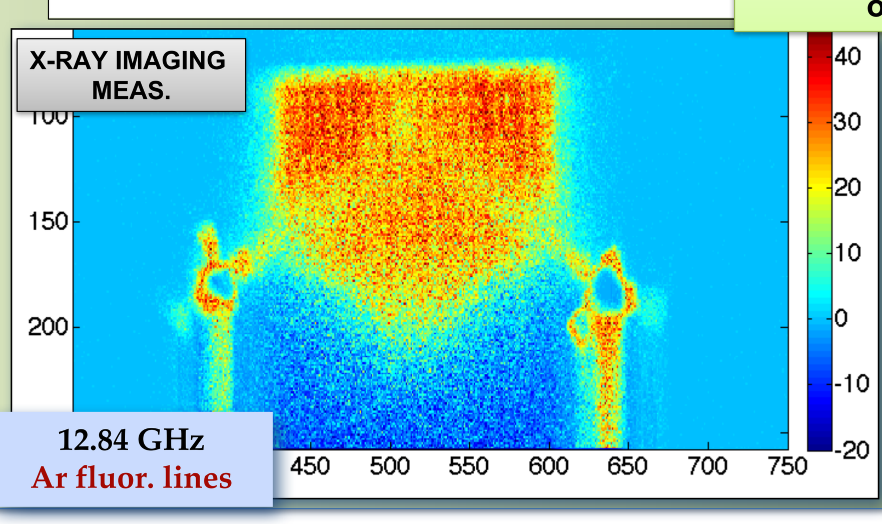
Energy density in 2-12 keV range on xy plane z=0 @12,84 GHz

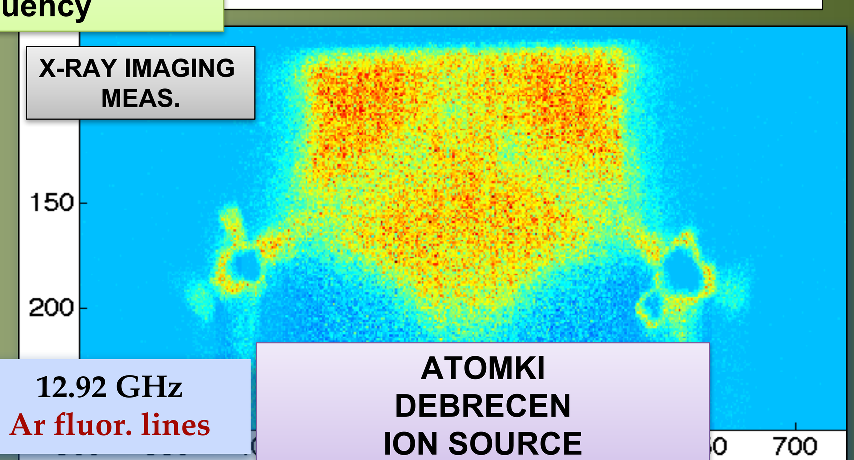
Energy density in 2-12 keV range on xy plane z=0 @12,92 GHz





X-ray imaging and agree numerical simulations demonstrate that the RF power deposition depends of frequency





ATOMKI DEBRECEN ION SOURCE SETUP