CHARACTERIZATION OF THE MICROWAVE COUPLING TO THE PLASMA CHAMBER OF THE LBL ECR ION SOURCE

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LBNL and Jyväskylä Collaboration

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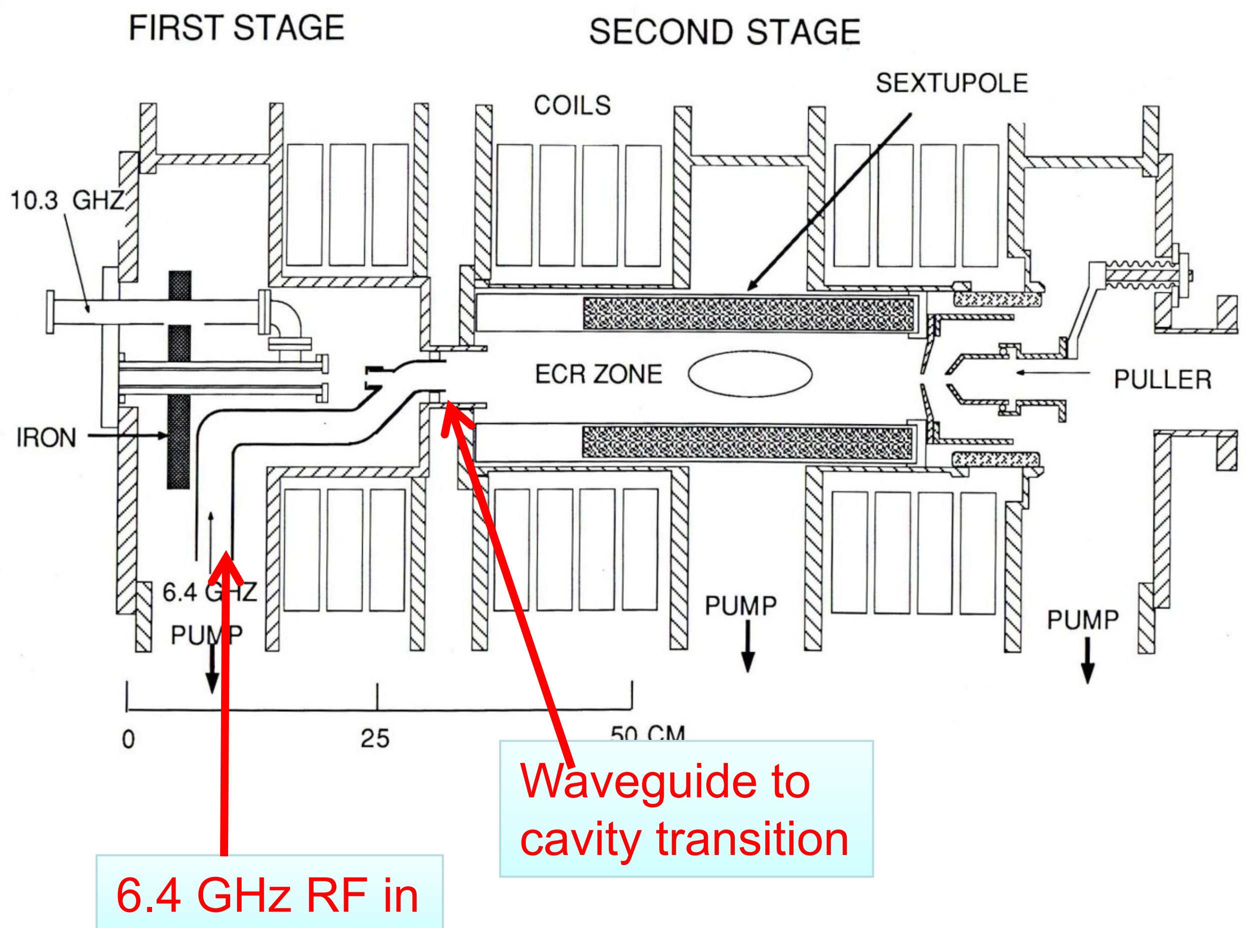
- Markus Strohmeier
- Jonathan Noland

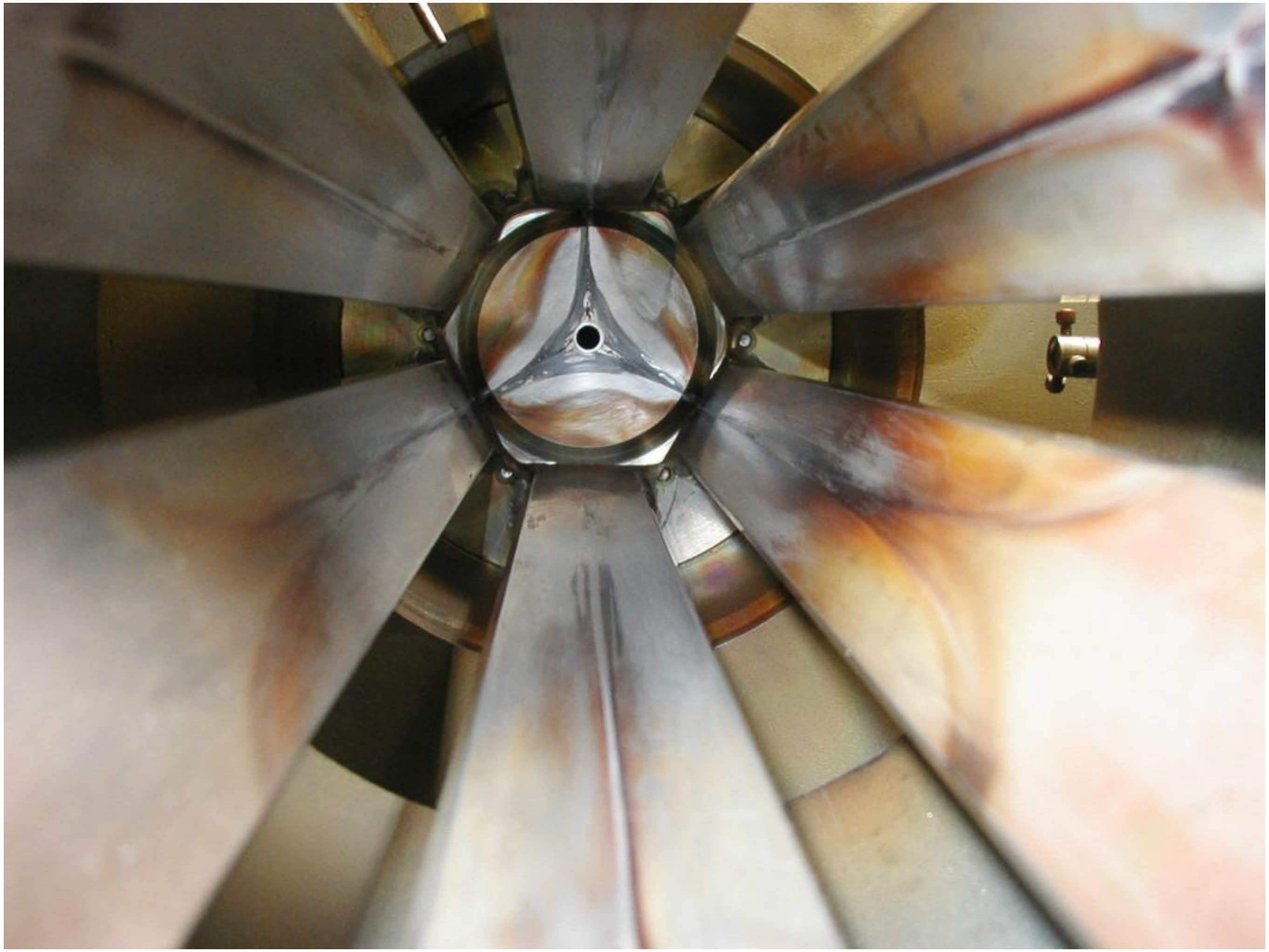
The LBL ECR then and now

6th ECR Ion Source Workshop Berkeley 1985

LBL ECR


FIRST STAGE
SECOND STAGE
SEXTUPOLE
COILS
10.3 GHZ
ECR ZONE
PULLER
IRON
6.4 GHZ
PUMP
PUMP
PUMP
0
25
50 CM
Waveguide to cavity transition
6.4 GHz RF in

LBL ECR "Cavity"



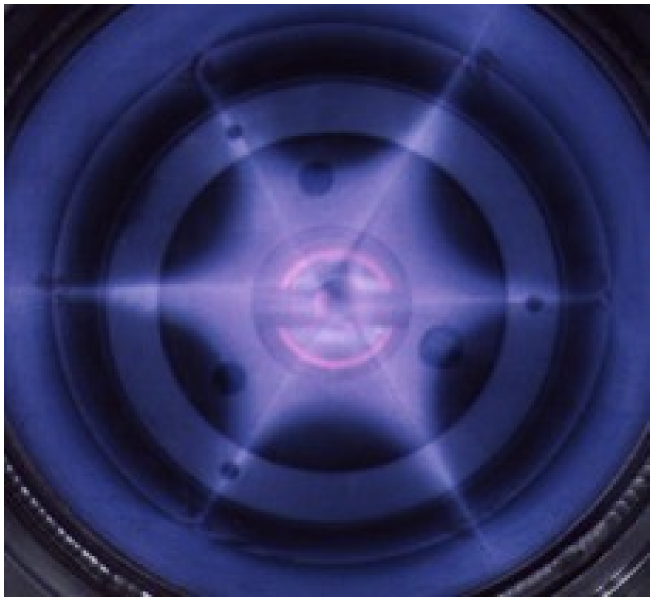
Cavity Modes in the LBL ECR

Mode	Frequency in GHz
$TM_{0,1,16}$	6.236
$TE_{4,1,9}$	6.317
$TM_{0,2,8}$	6.325
$TE_{1,2,9}$	6.330
$TE_{3,1,13}$	6.339
$TE_{2,1,10}$	6.353
$TE_{0,1,14}$	6.362
$TM_{1,1,14}$	6.362
$TE1_{,1,17}$	6.374
$TM_{0,2,9}$	6.496
$TE_{4,1,10}$	6.507

$D/\lambda = 2$

Approximate mode spacing 10 MHz

ECR Plasma Properties



ECR plasma

- Partially or fully ionized gas consisting of free electrons and free ions as well as neutral atoms and molecules
- Plasma frequency scales as the square root of density
- $\omega_p = \text{sqrt}\{n_e e^2/\varepsilon_o m\}$ where
  - □ ω_p plasma frequency
  - – n_e plasma density
  - – e electron charge
  - – m electron mass

$$\omega^2 - \omega_p^2 = k^2 c^2$$

ω is resonant frequency

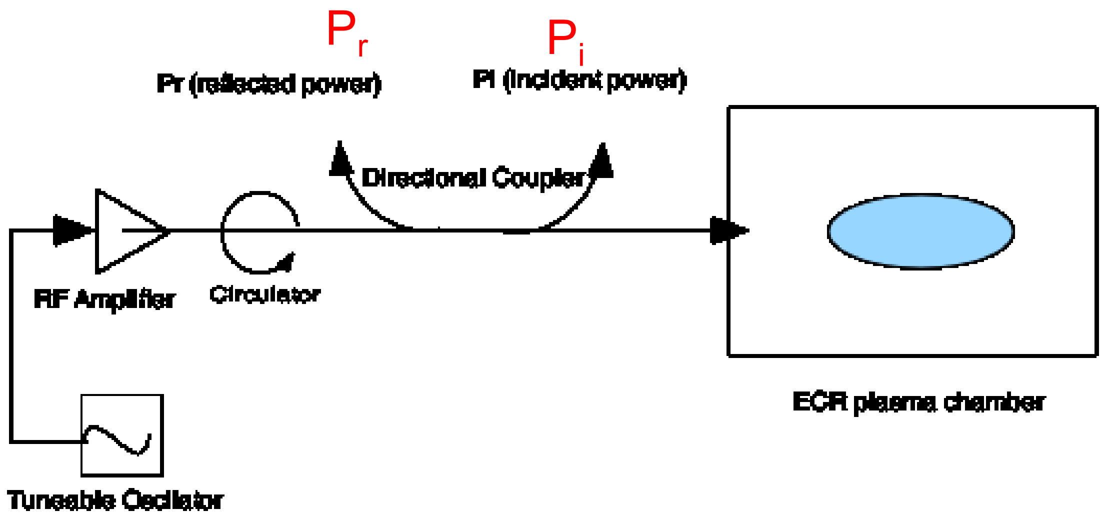
k is the wave number (1/wavelength)

c speed of light

Critical density when $\omega_{rf} = \omega_p$

ECR as a single port microwave cavity

Measured quatities Pi,Pr, f



$$U = \frac{Q_0 P_a}{\omega}$$

Stored EM energy

$$\beta = \frac{Q_0}{Q_{ext}}$$

Coupling coefficient

$$\beta = \frac{\sqrt{P_i} \mp \sqrt{P_r}}{\sqrt{P_i} \pm \sqrt{P_r}}$$

$$\frac{U_t}{U_{t=0}} = \frac{\beta_t \left(1 - \left(\frac{P_r}{P_i}\right)_t\right)}{\beta_{t=0} \left(1 - \left(\frac{P_r}{P_i}\right)_{t=0}\right)}$$

Stored EM energy ratio

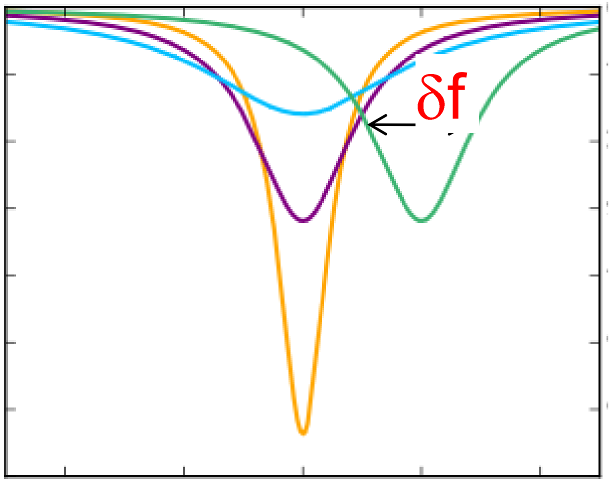
Q_L =f/δf where δf is full width at half max

- For an ideal network and a single mode the ratio of reflected to incident power should be a Lorentzian line shape

The steady-state frequency response of a cavity resonator can also be used to determine the parameters of the cavity and coupling system. For the steady-state case the power reflected as a function of fequency $P_r(\Delta f)$ is given by[17]

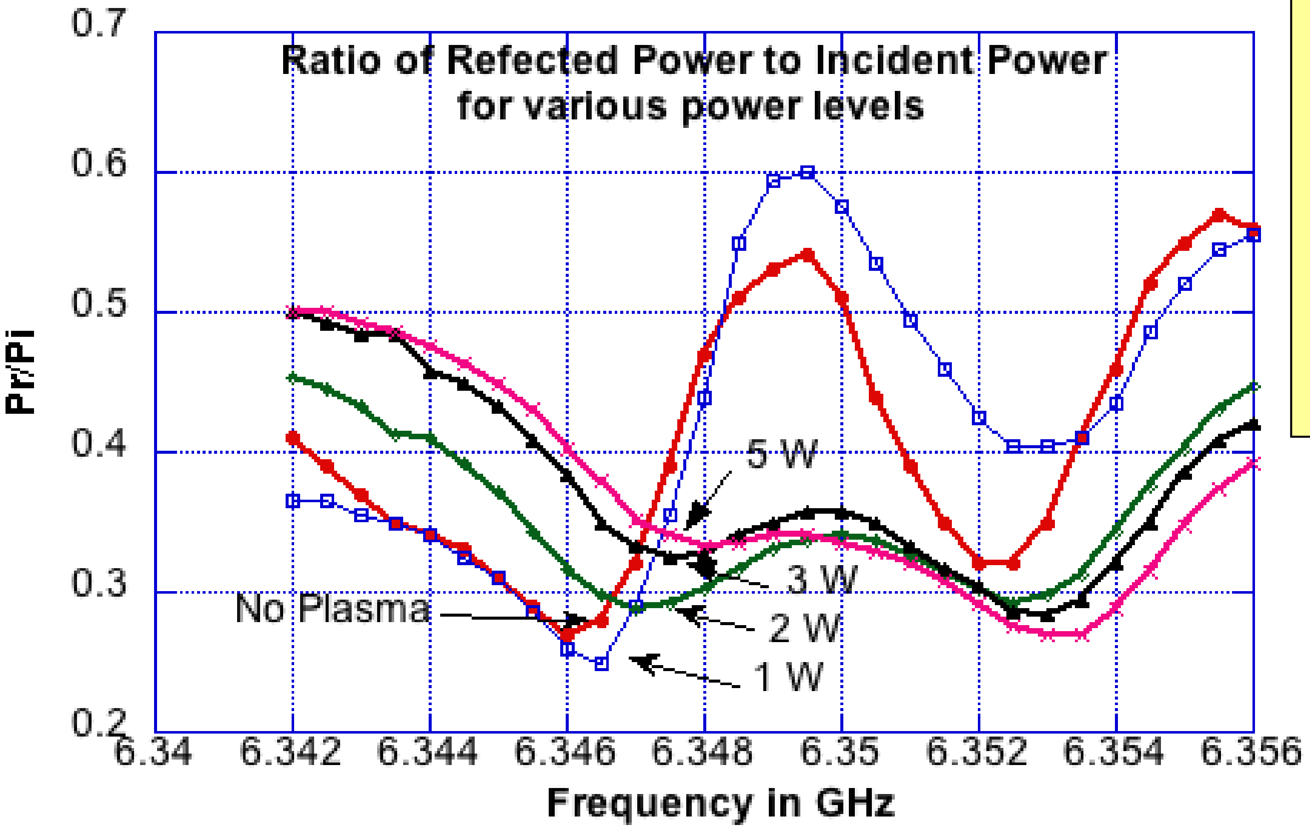
$$P_r(\Delta f) = P_i \left[1 - \frac{4\beta}{(1+\beta)^2} \left(\frac{1}{1 + \left(\frac{2Q_L \Delta f}{f_o} \right)^2} \right) \right] , \qquad (2.20)$$

where f_o is the resonant frequency, f is the incident frequency and $\Delta f = f - f_o$. The details of the procedure used to invert Eq. (2.20) and thereby determine Q_L, f_o, and β are discussed later in this chapter.



Ideal Loretzians

Low power reflected power measurements



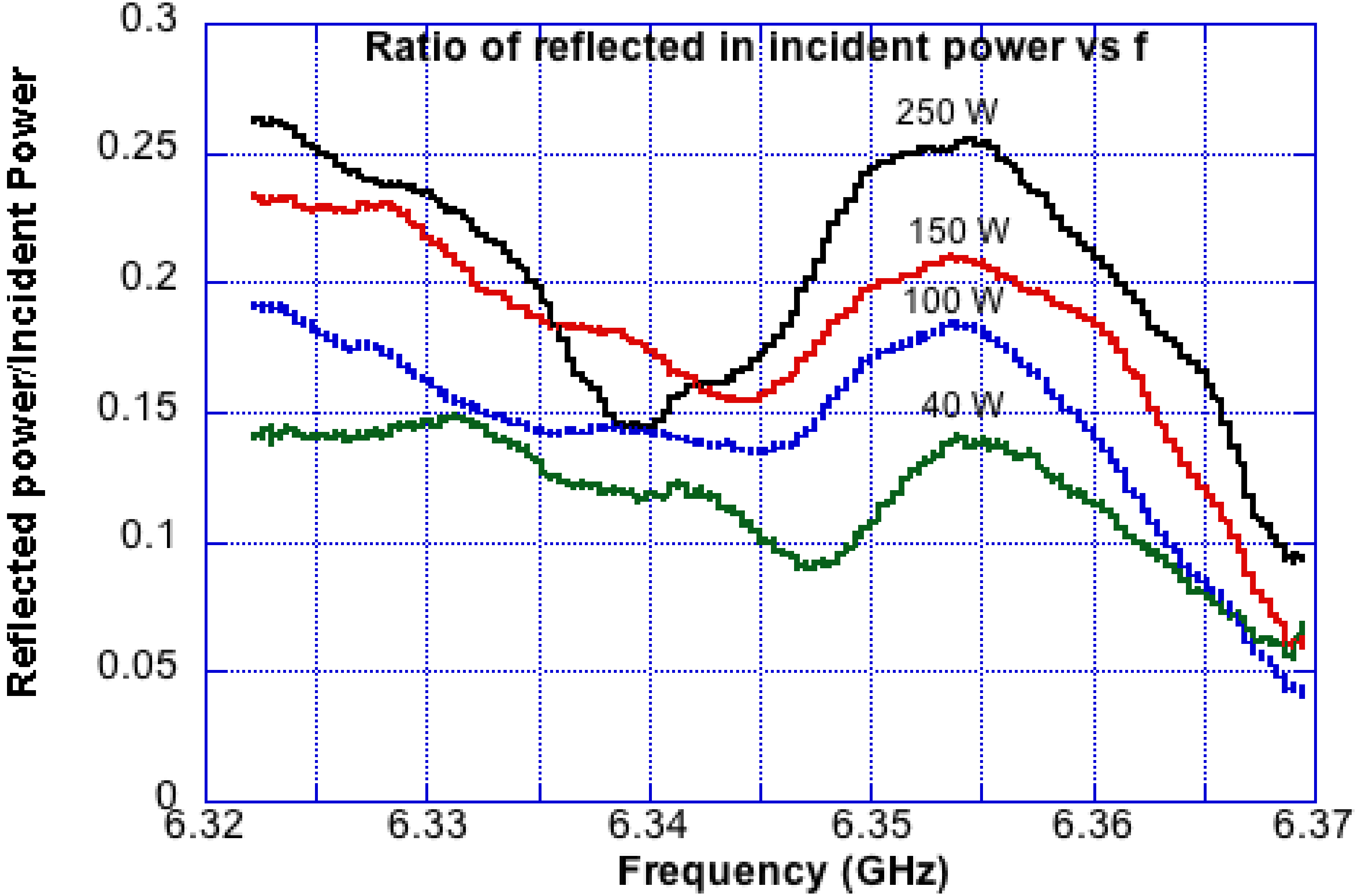
As the power is increased

β goes over to under coupled

Center frequency increases with power

Full width half max increases with power

Reflected power 40 to 250 W



Normalized beam currents for argon charge states

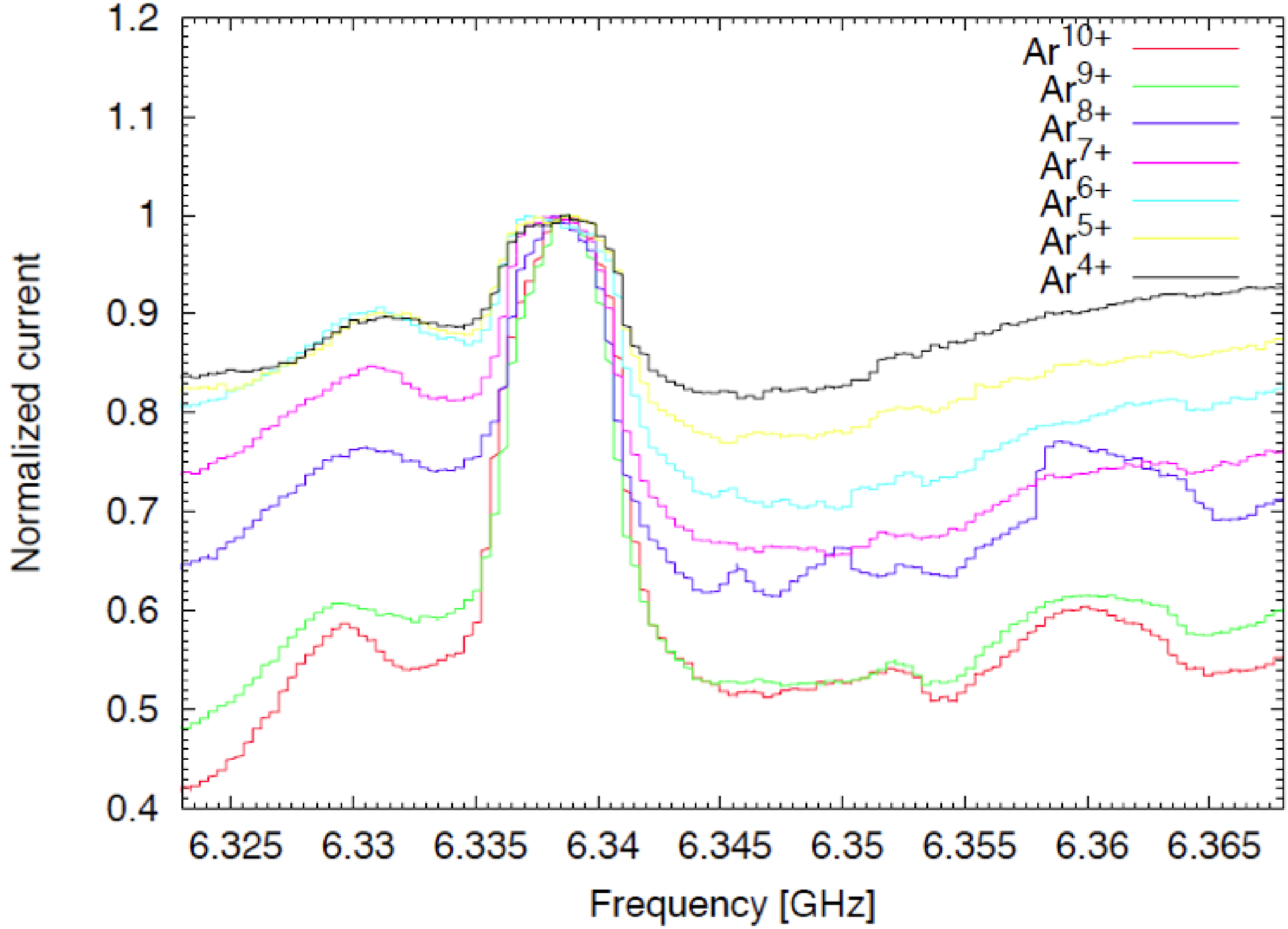
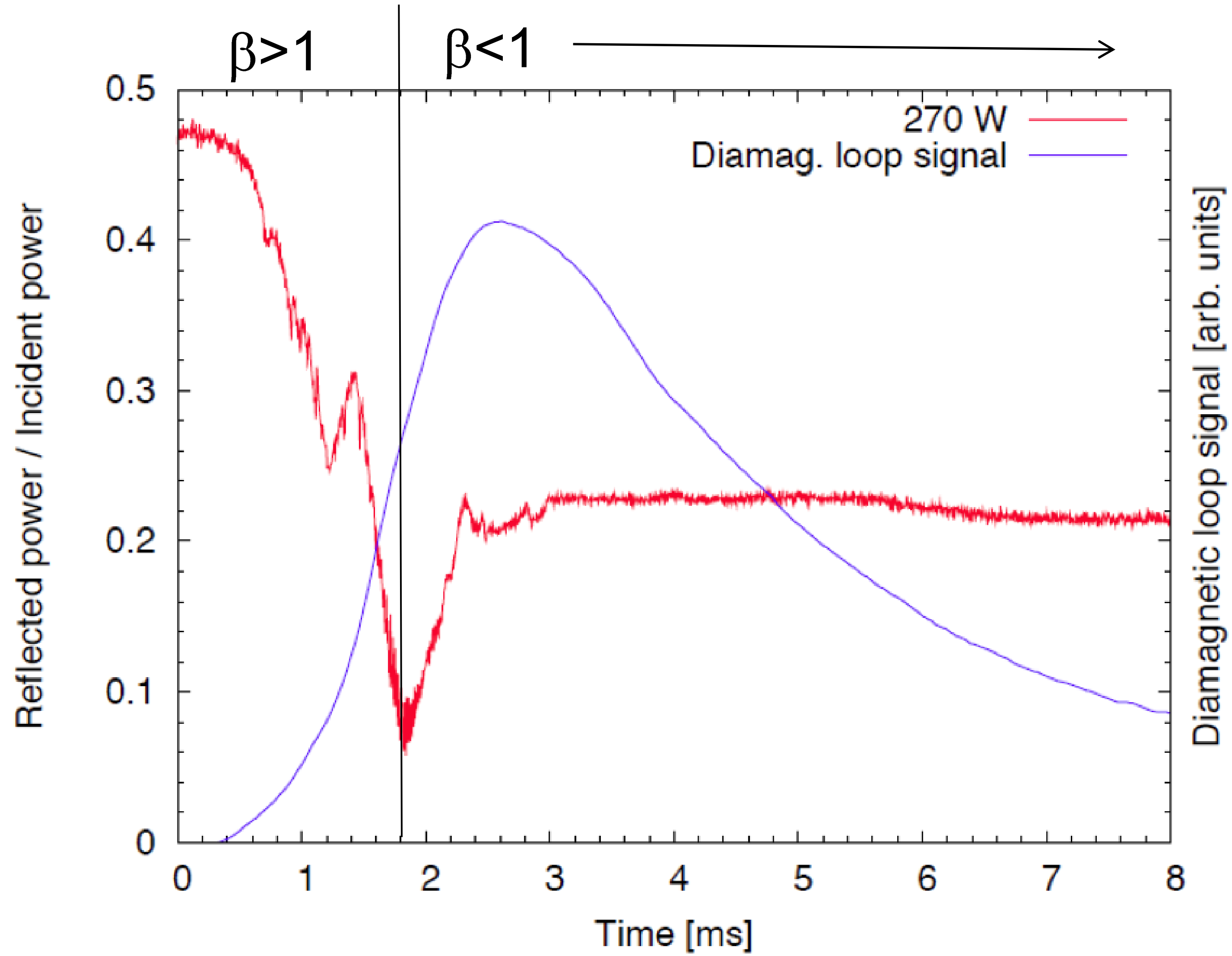
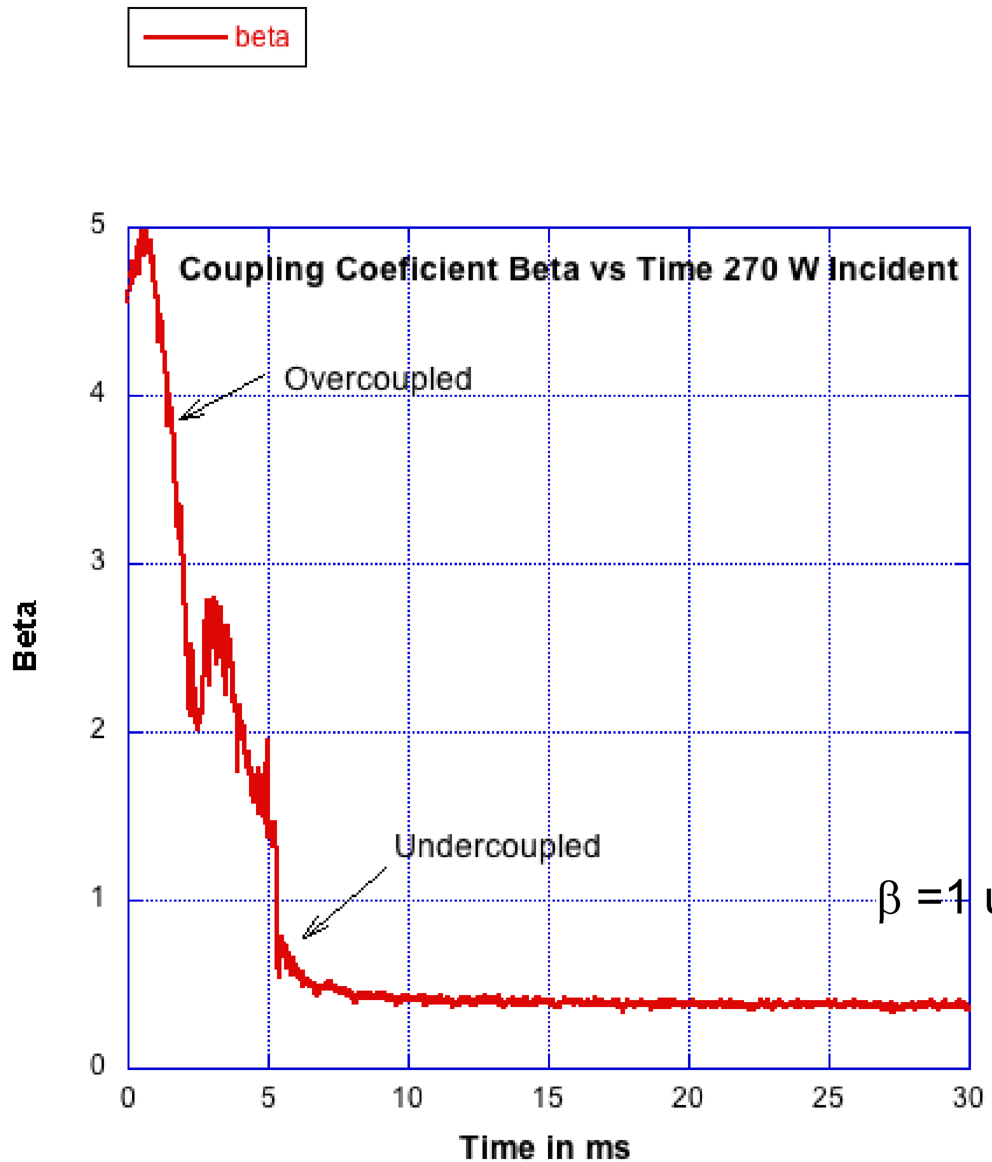


Figure 3: Normalized beam currents of argon at 250 W. The ion source tuned for Ar^{9+} at 6.343 GHz.

Reflected power and diamagnetic loop signal vs time



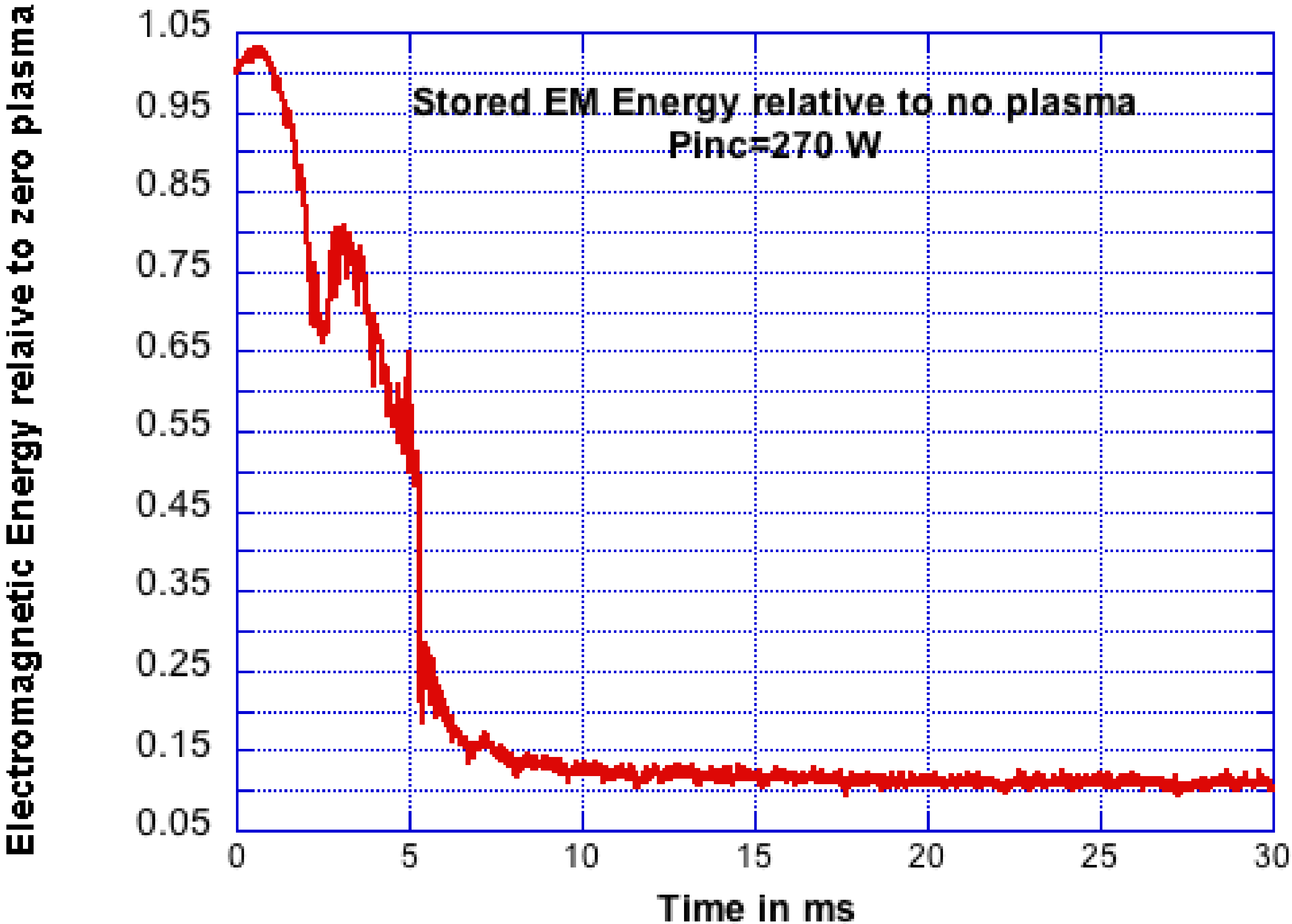
β vs time



$$\beta = \frac{Q_0}{Q_{ext}}$$

β =1 unity coupling

Relative electromagnetic stored energy vs time



- At low plasma densities the mode spacing in the LBL ECR is wide enough to study individual modes.

- For the 6.347 GHz mode, it moves to higher frequency and lower Q's as the plasma density increases.

- The ECR loading is strong enough to reduce the natural Q of the cavity by a factor of 10 even for this relatively low density plasma

- We expect in higher frequency, high density ECR sources to see much stronger loading, lower Q's and hence relatively low RF electric fields—(Beware of electron heating models requiring high RF electromagnetic fields)

- The RF coupling and ECR performance of the LBL ECR could be improved by using coupling similar to the AECR-U (waveguide inserted directly)

Possible Extensions

- Use cavity bead measurements to identify the modes
- Use “Microwave Studio” for more accurately calculation of the mode structure
- Use a second RF coupling port to directly measure the stored energy
- Search for other frequencies where high charge states are produced well
- Rebuild the RF coupling system of the LBL ECR to improve source performance