28 GHz Gyrotron ECRH Upgrade for LDX

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ABSTRACT - A 10 kW, CW, 28 GHz gyrotron is being implemented on LDX to increase the plasma density and to more fully explore the potential of high beta plasma stability in a dipole magnetic configuration. Higher density increases the heating of ions by thermal equilibration and allows for improved wave propagation in planned ICRH experiments. This represents over a 50% increase over the present 17 kW ECRH from sources at 2.45, 6.4, and 10.5 GHz. The higher frequency will also make possible access to plasma densities of up to 10^{13} cm^{-3}. The 1 Tesla resonances are located above and below the floating coil near the dipole axial region. The gyrotron beam will be transmitted in TE01 mode in 32.5 mm diameter guide using one 90° bend and a short < 5 m straight waveguide run. A Vlasov launch antenna in LDX will direct the beam to the upper 1 Tesla resonance region. A layout of the planned system is presented.

Motivation

Advance to more fusion relevant plasmas

- **10 kW ECRH power increase**
  - *> 50 % increase over present ECRH (17 kW)*
- **Increase plasma density**
  - *10^{13} cm^{-3} density cut off limit (tokamak regime)*

Enable new physics investigations

- **Higher density will increase β and improve thermal equilibration with ions**
- **Higher density will improve wave propagation for planned ICRH experiments**

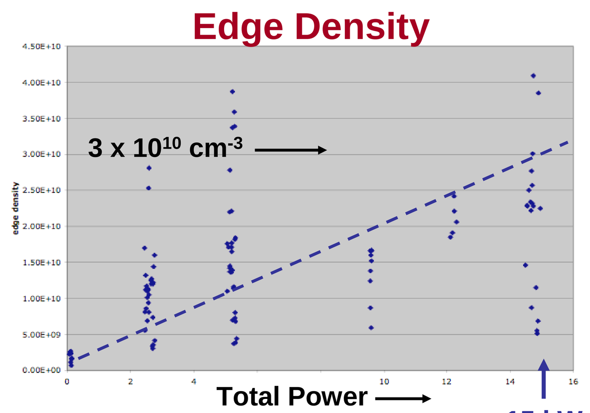
Current ECRH heating capability is a maximum of 17 kW

- 2.45 GHz magnetrons, 2.5 & 1.9 kW
- 6.4 GHz klystron, 2.5 kW
- 10.5 GHz klystron, 10 kW

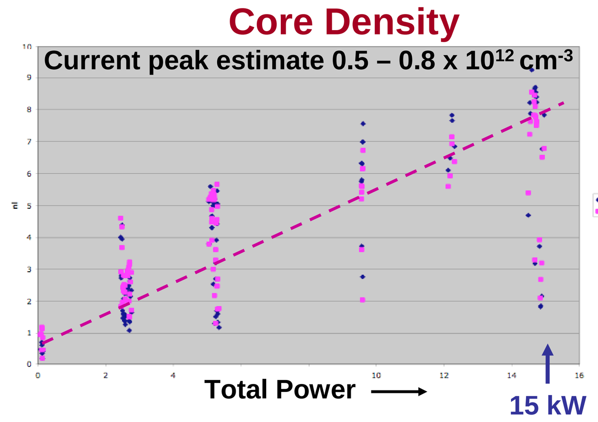
Density Increases with ECRH Power

Data to date shows electron density increasing linearly with ECRH power

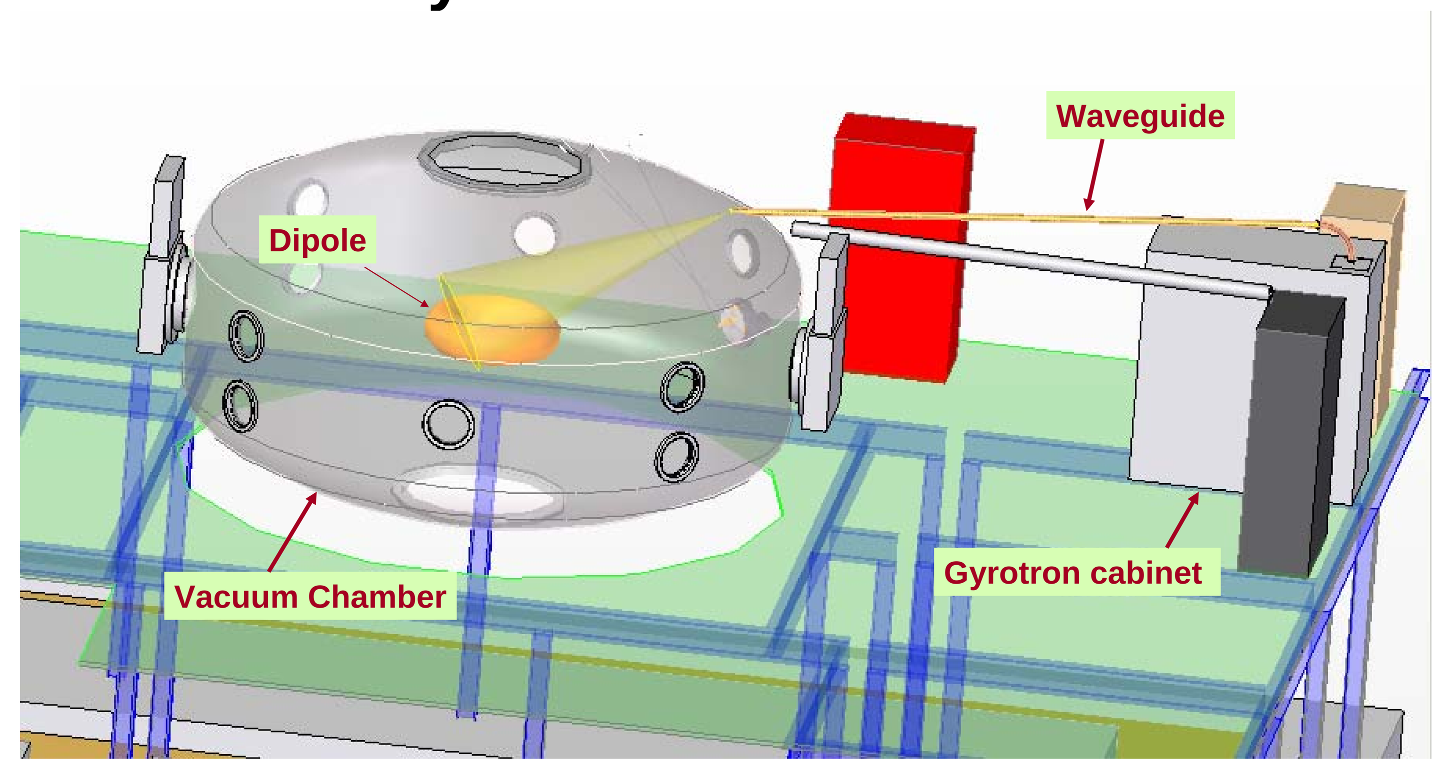
Edge Density



Core Density



28 GHz Gyrotron Installation at LDX

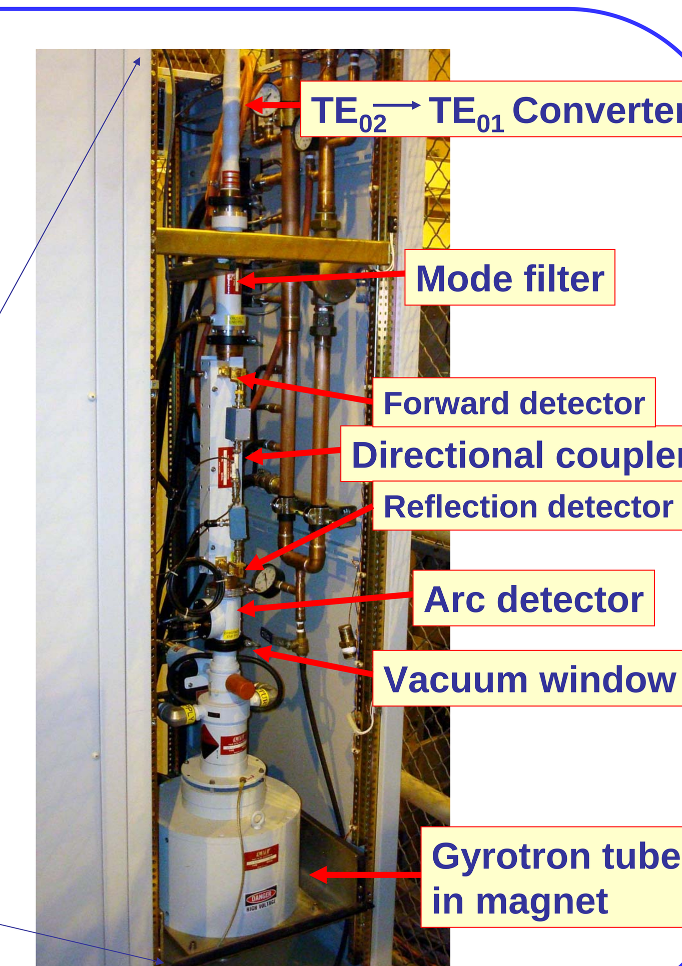


28 GHz system layout at LDX for ECRH in the high field plasma region

Gyrotron

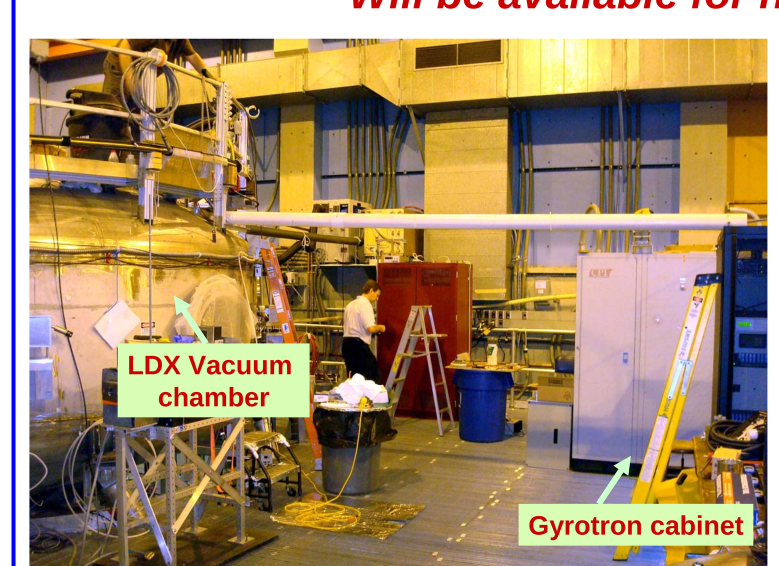
Complete turn key system
CPI HeatWave Model VIA-301

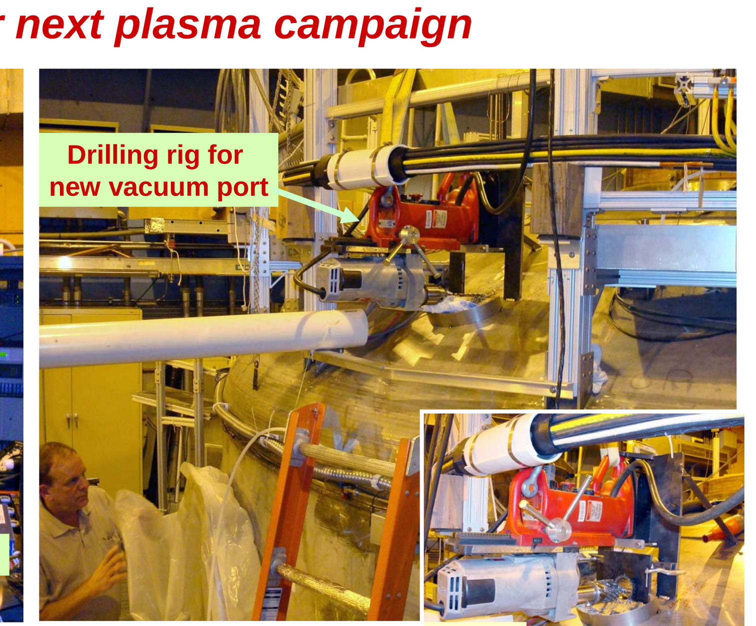
- **Frequency:** 28 GHz
- **Power:** 10 kW, min.
- **Duty:** Continuous
- **Transmitted mode:** Circular TE_{01}



New Vacuum Port Installation

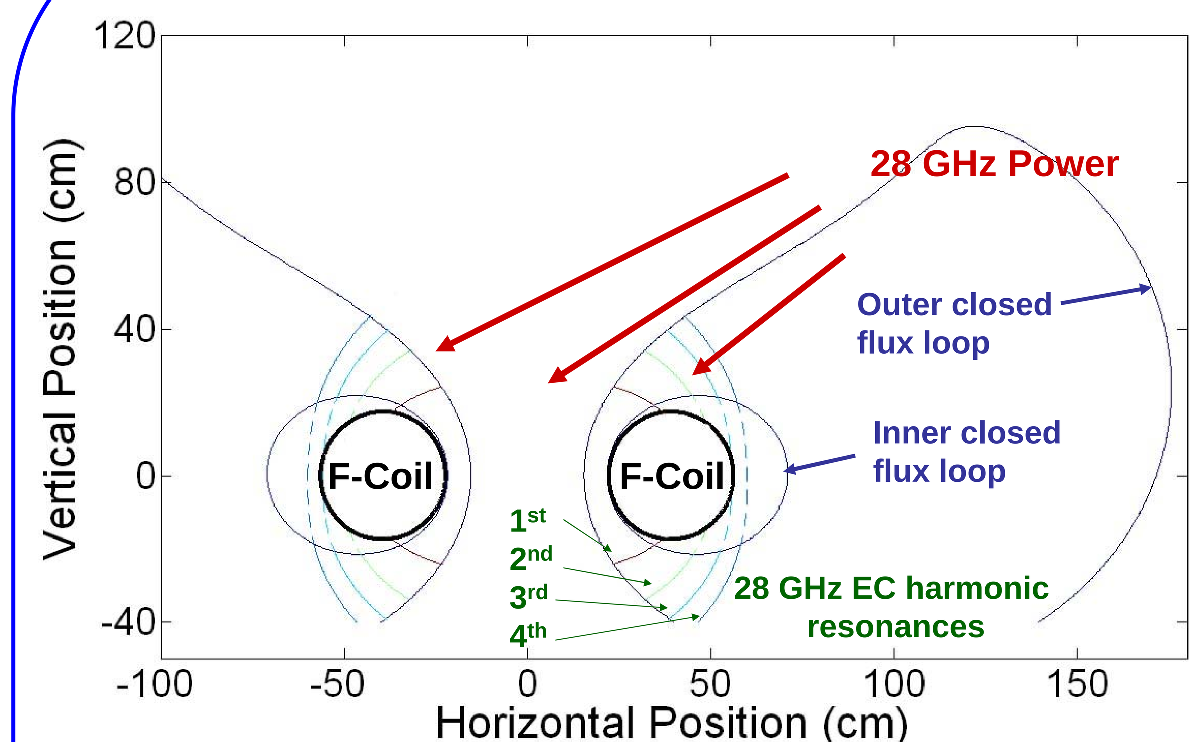
28 GHz ECRH system is being rapidly implemented on LDX
Will be available for next plasma campaign





Views of recent 28 GHz ECRH system installation activity at LDX

28 GHz EC Resonances in LDX



- A diverging 28 GHz beam will be launched by a Vlasov antenna
- The beam will be incident on the upper dipole plasma region
- The incident beam will be linearly polarized and mostly at oblique angles to the magnetic field direction
- Reflections and propagation down the donut hole should distribute the 28 GHz absorption around and above/below the dipole

Circular TE_{01} Transmission Line

- The gyrotron cabinet location and LDX vacuum port entry have been chosen to simplify the transmission line as much as possible
  - LDX stray field at the gyrotron < 2 Gauss oriented vertically
- The TE_{01} mode 28 GHz beam will be guided to LDX in 32.5 mm diameter waveguide
  - One TE_{01} corrugated bend
  - Aprox. 5 m straight waveguide length to LDX port
  - Water cooled fused quartz window
  - Vlasov antenna inside LDX
- Ideal straight copper waveguide transmission losses ~0.005 dB/m
- Main transmission losses due to:
  - Tilt and offset errors
  - Waveguide bend
  - Window

32.5 mm internal diameter and 10 mm wall copper bus bar tubing for straight waveguide run and Vlasov antenna.

Tilt and Offset Losses

Waveguide overmoding is small, D/λ = 3.2, with good tolerance for imperfections

Tilt mode conversion to TE_{11}, TE_{12}, TM_{11}

$$\frac{P}{P_o} = (0.63\theta)^2$$

[θ in radians]

1° tilt corresponds to 0.4% loss

Offset mode conversion to TE_{02}

$$\frac{P}{P_o} = \left(1.57\frac{\Delta r}{a}\right)^2$$

0.02 inch change corresponds to 0.06% loss

Commercial (CPI) corrugated TE_{01}bend. A properly built bend without mode conversion would have losses corresponding straight TE_{01} waveguide.

28 GHz Vacuum Window

Fused quartz brazed in standard flange

Resonant Thickness
(5.596 mm thick window m = 2 chosen)

$$h[mm] = 2.798m$$

m =1, 2, 3, …

44 mm diameter (2a)

Rupture Safety Factor

$$S.F. = 395\left(\frac{h}{a}\right)^2 = 24$$

28 GHz Absorption

< 1%, or < 100 Watts at 10 kW beam power

Waveguide Gap Losses, TE_{01} Mode

$$\frac{P}{P_o} = 4.5\frac{h^{3/2}}{a^3}$$

1.4% or 140 Watts at 10 kW with fused quartz gap

Water cooling will be implement to allow continuous plasma operation > 1 min.

Valsov Launcher

$$\alpha = \sin^{-1}\left(\frac{k_{cn}}{k}\right)$$

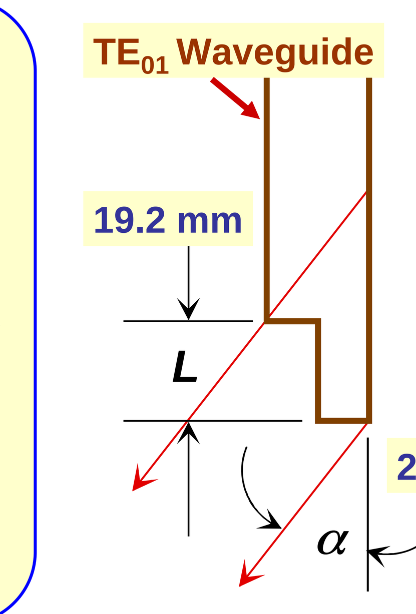
$$L = 2a\cos\alpha$$

$$k_{cn} = \nu'_{0n}/a \qquad k = 2\pi/\lambda$$

ν'_{0n} root of $J'_0(\nu)=0$

for TE_{01}, $\nu'_{01} = 3.832$

a =16.25 mm waveguide radius



Beam Dump Water Load

A beam dump will be implemented for testing and calibration between LDX plasma campaigns