Helicon Plasma Cell

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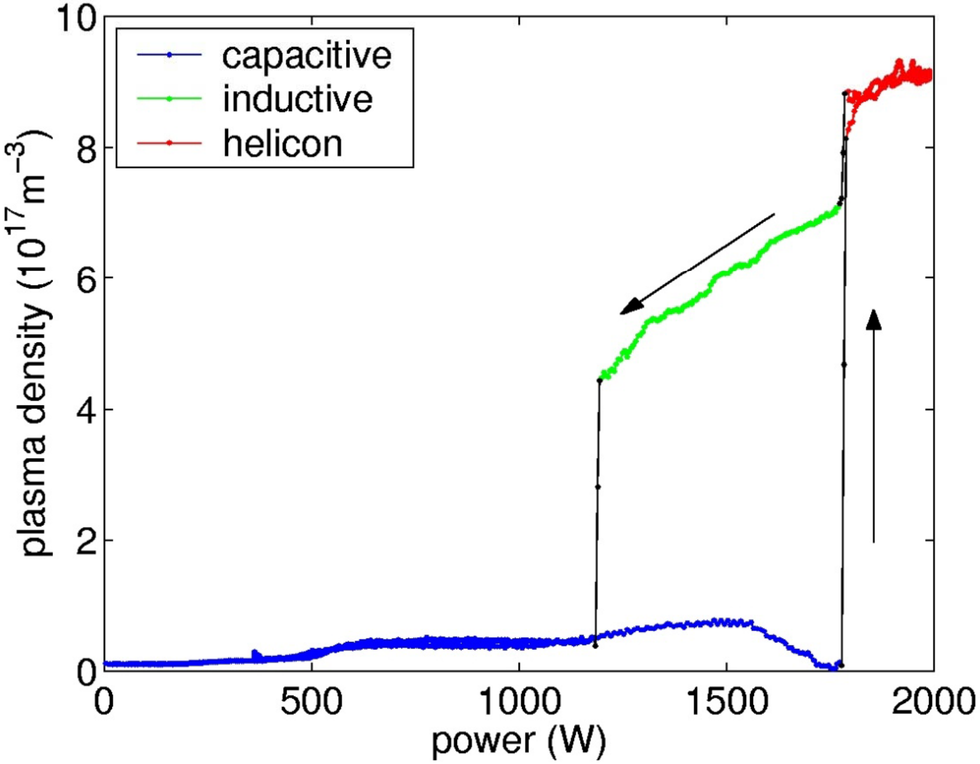
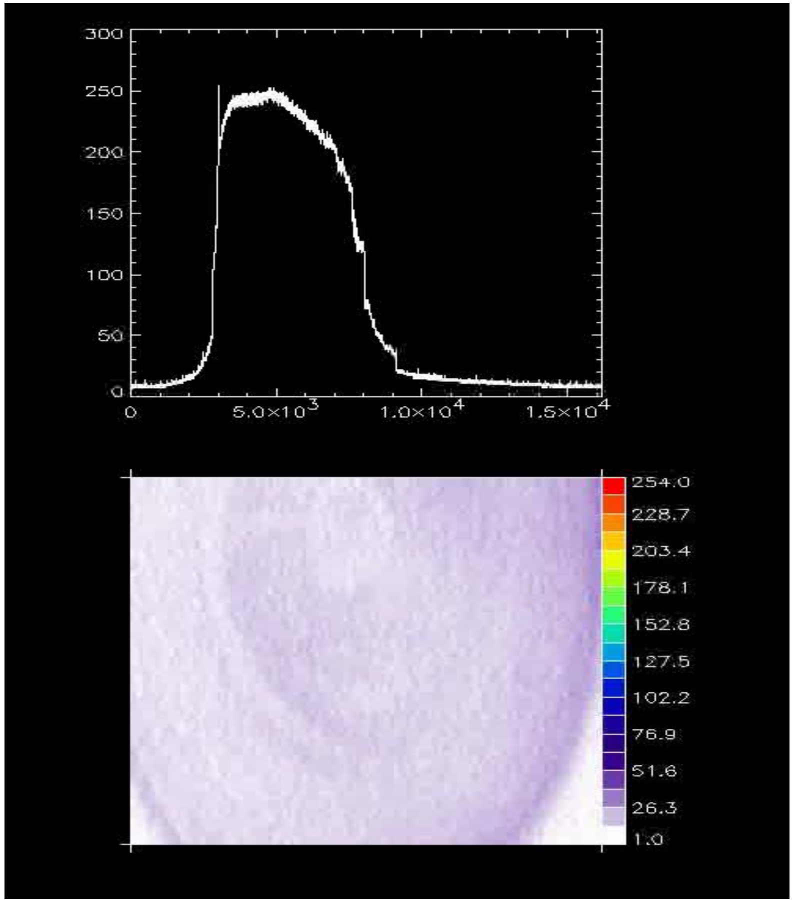
Greifswald

helicon discharge: rf discharge

transition between rf discharge modes



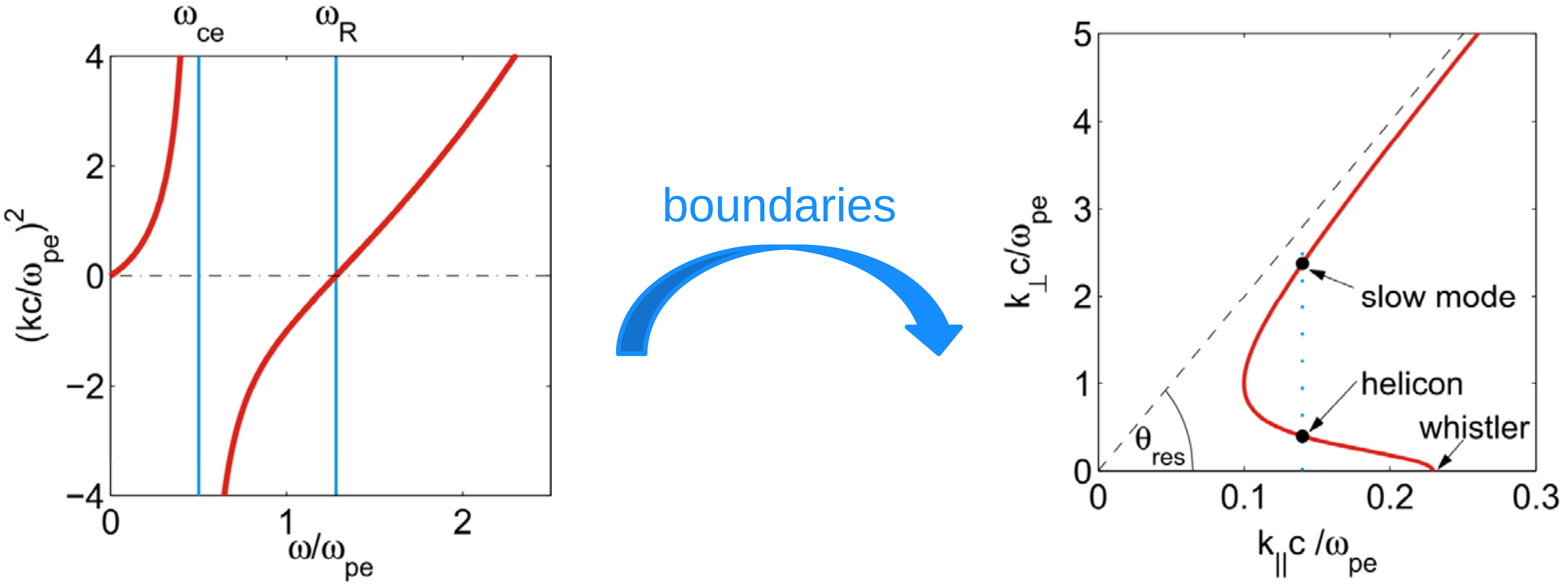


helicon wave basics

- electromagnetic, right-hand polarized wave
- propagation mainly parallel to ambient magnetic field
- non-resonant helicon plasma heating

R-wave dispersion
(oblique propagation)

$$k^2c^2 = \omega^2 - \frac{\omega\omega_{pe}^2}{\omega - \omega_{ce}\cos\theta}$$



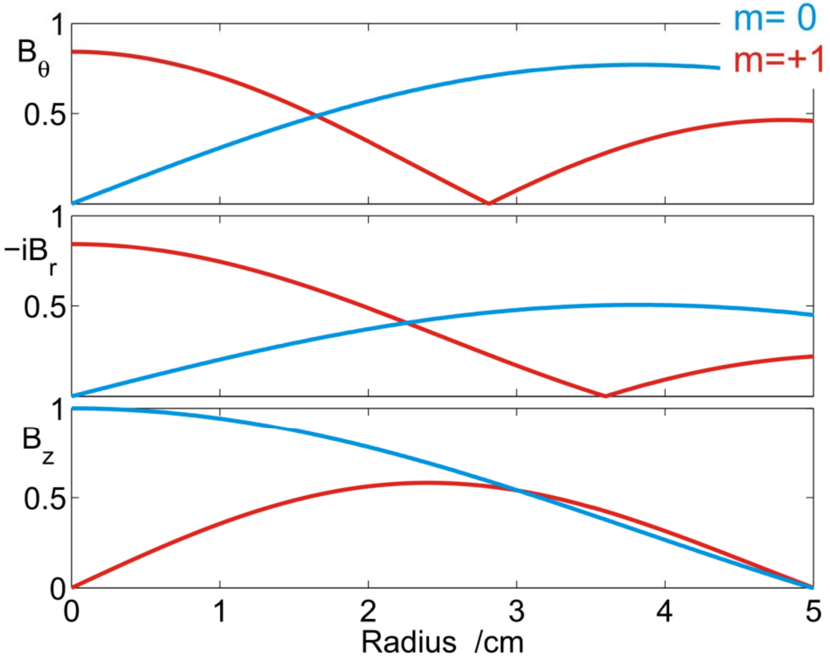
boundaries

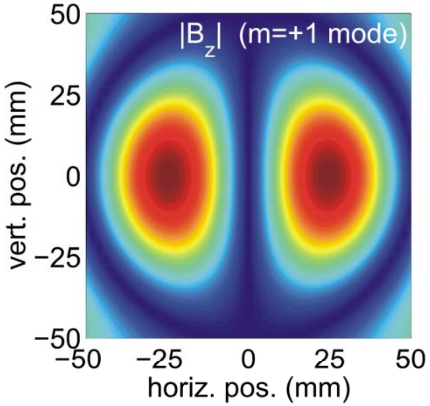
helicon wave basics cont.

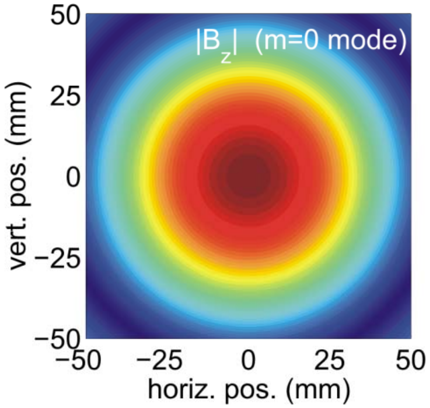
$$B_r = \mathrm{i}\frac{C}{2k_\perp}\left[(k + k_\parallel)J_{m-1}(k_\perp r) + (k - k_\parallel)J_{m+1}(k_\perp r)\right]$$

$$B_\theta = -\frac{C}{2k_\perp}\left[(k + k_\parallel)J_{m-1}(k_\perp r) - (k - k_\parallel)J_{m+1}(k_\perp r)\right]$$

$$B_z = C J_m(k_\perp r).$$







helicon wave dispersion

- frequency range: limited by cyclotron frequencies

$$\omega_{ci} \ll \omega \ll \omega_{ce}, \omega_p$$

- helicon wave dispersion (low-frequency limit)

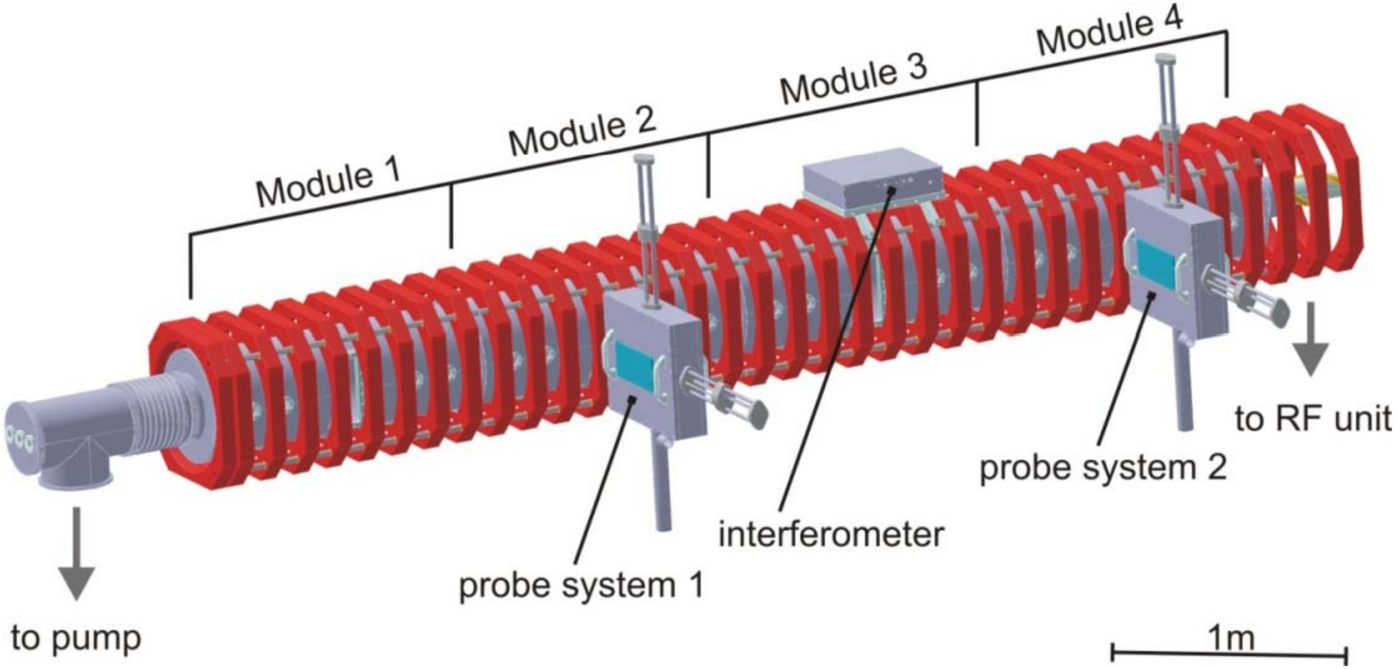
$$\frac{k_{\|} k}{\omega} = \frac{e \mu_0 n}{B}$$

wave parameters

operational parameters

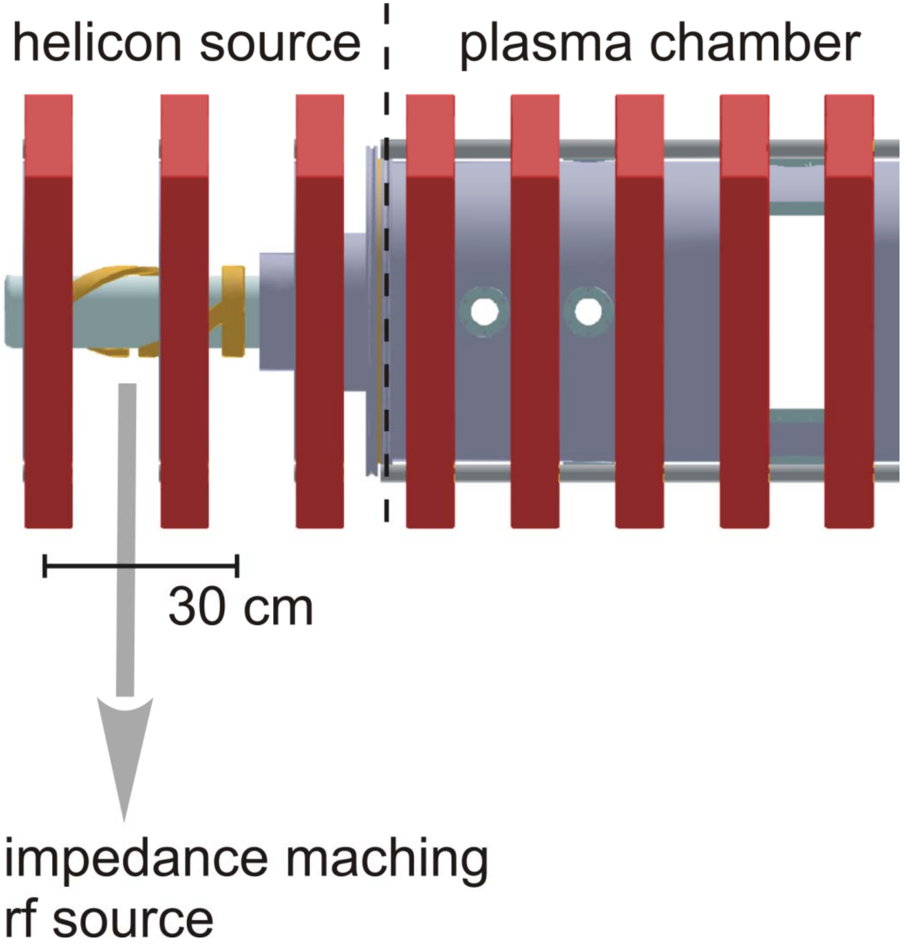
wave parameters determine evolution of plasma density

VINETA experiment



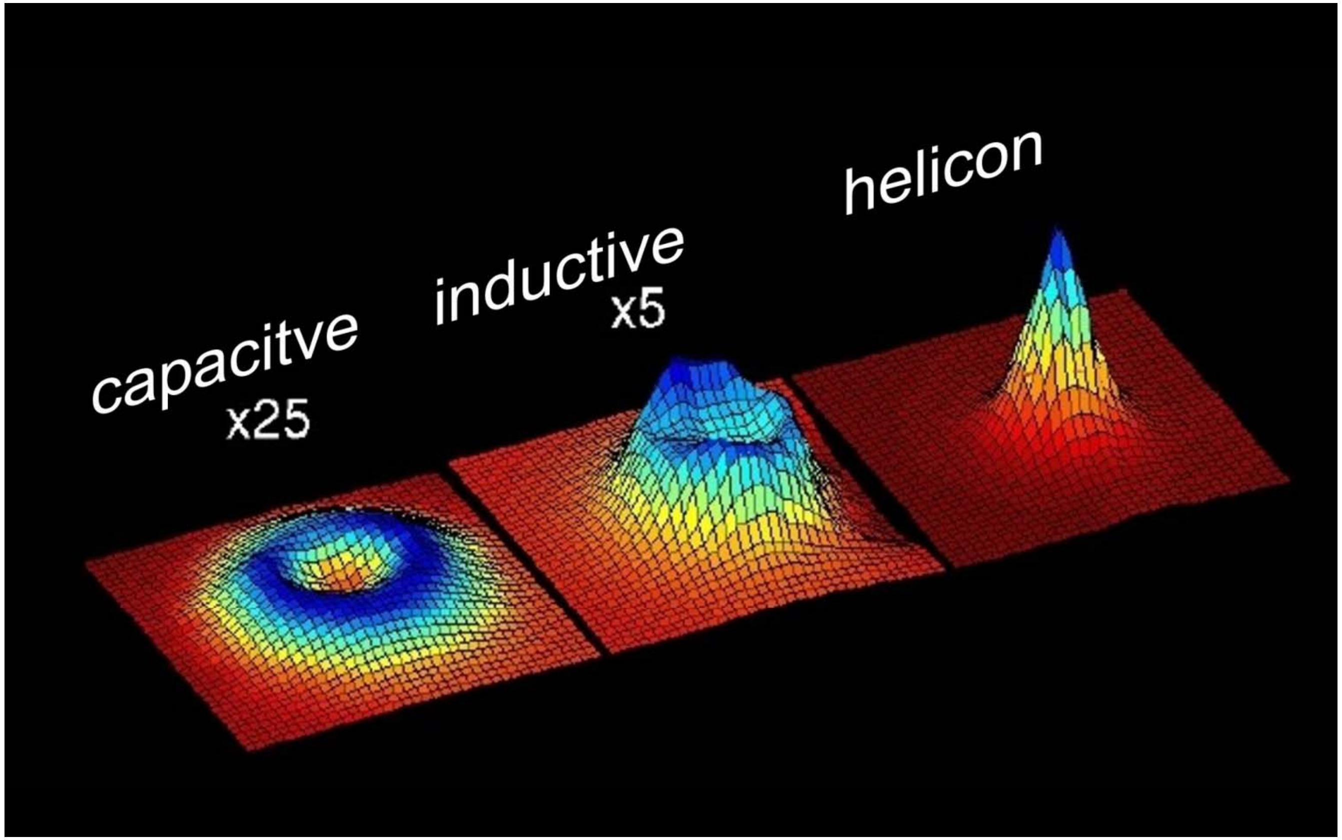
magnetic field	$B \leq 100\,\mathrm{mT}$	helicon antenna	$m = +1$
plasma density	$n \leq 2 \cdot 10^{19}\,\mathrm{m}^{-3}$	rf frequency	$f_{rf} = 13.56\,\mathrm{MHz}$
electron temperature	$T_e \cong 2\mathrm{eV}$	rf power	$P_{rf} \leq 4.5\,\mathrm{kW}$
working gas:	Argon	source diameter:	$r = 10\,\mathrm{cm}$

VINETA helicon source



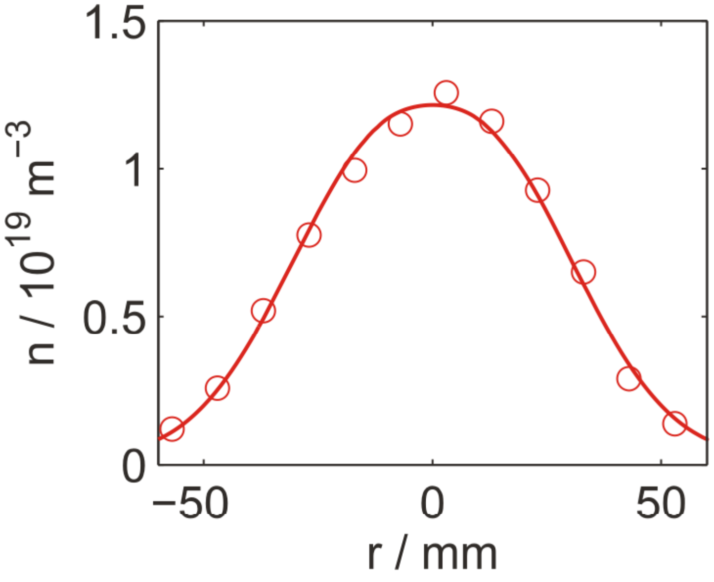
- antenna shaped to excite specific helicon mode (m=+1)
- antenna outside vacuum around dielectric (glas)
- here: transition from insulated to conducting boundary
- need of magnetic field, could be inhomogeneous

helicon plasma profiles

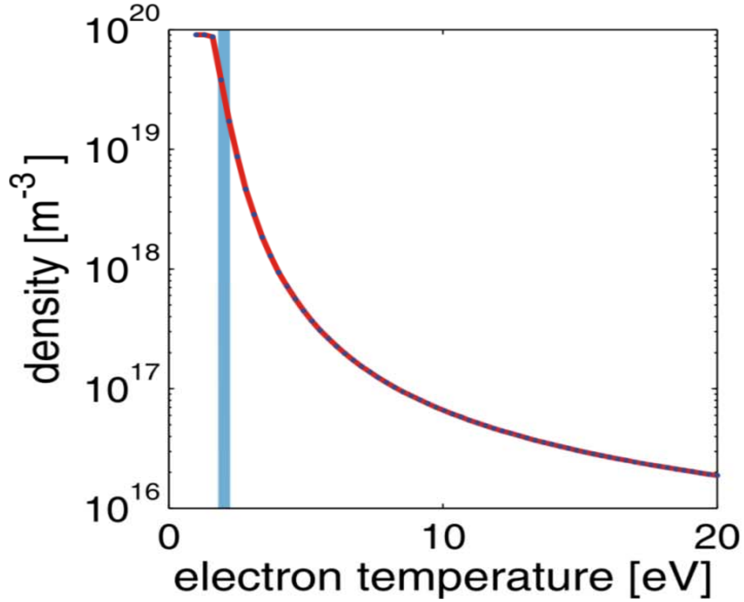


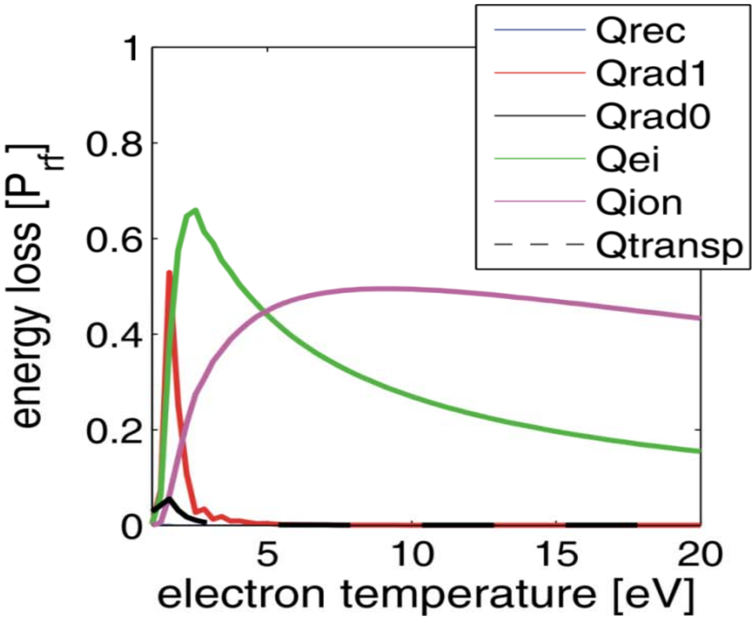
increase of rf power

radial helicon plasma profile and power balance

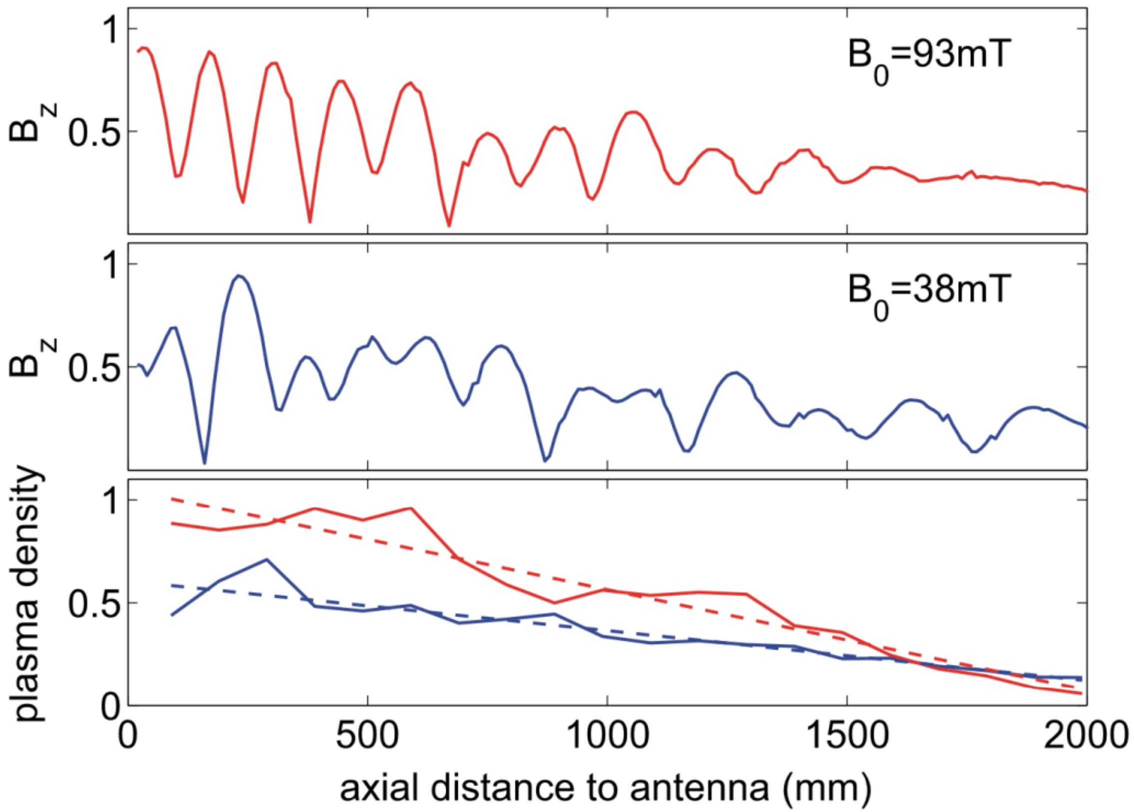


- radial profiles ~ Gaussian shape
- profile width = antenna diameter (+transport)
- operation can be cw or pulsed (thermal load)
- always: small electron temperature



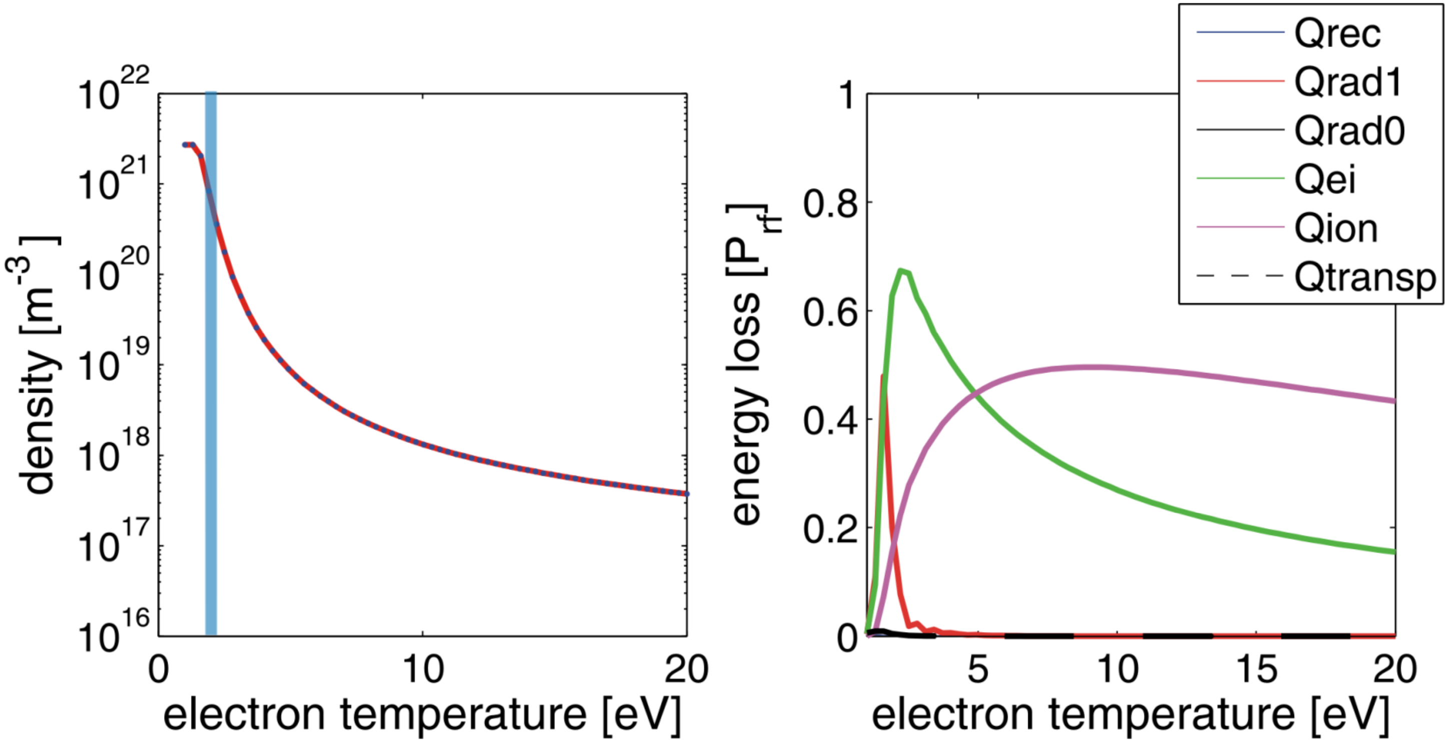


axial helicon plasma profile



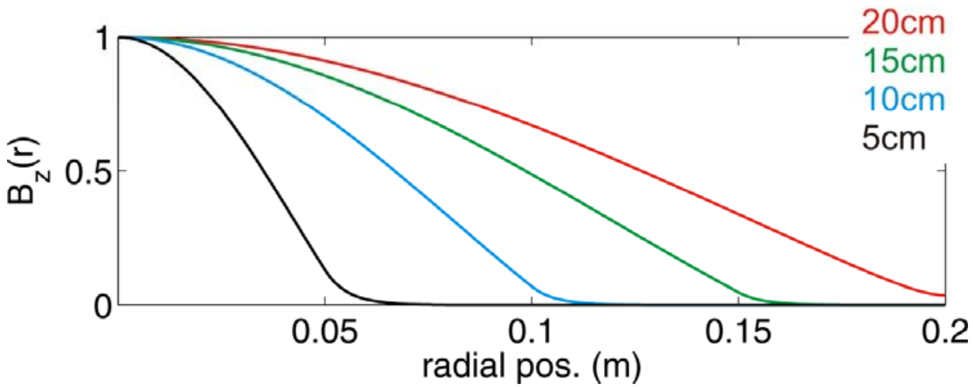
- wavefield damped along field
- scaling of density with magnetic field
- axial density gradient due to transport (high collisionality)

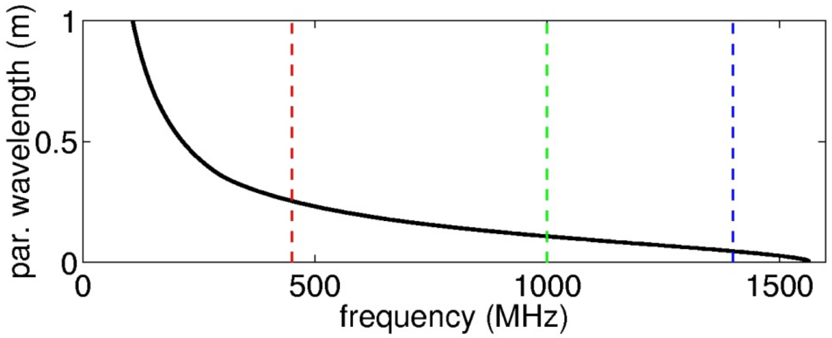
power balance (1m cell)



- assumed Gausian radial density profile (r~3cm)
- Argon gas pressure p=15Pa (~100mT)
- rf input power P_{rf}=100kW

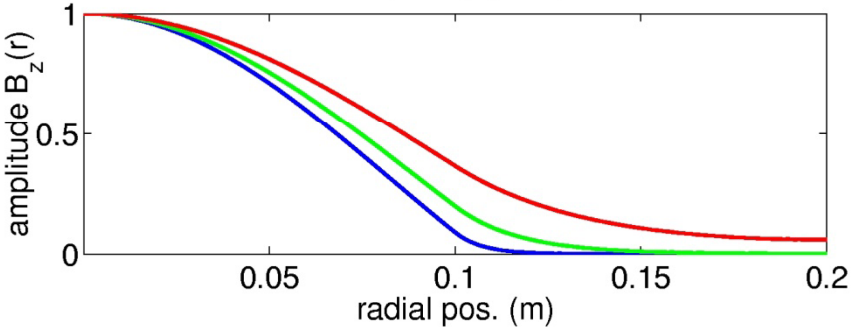
helicon wave dispersion





dispersion relation:

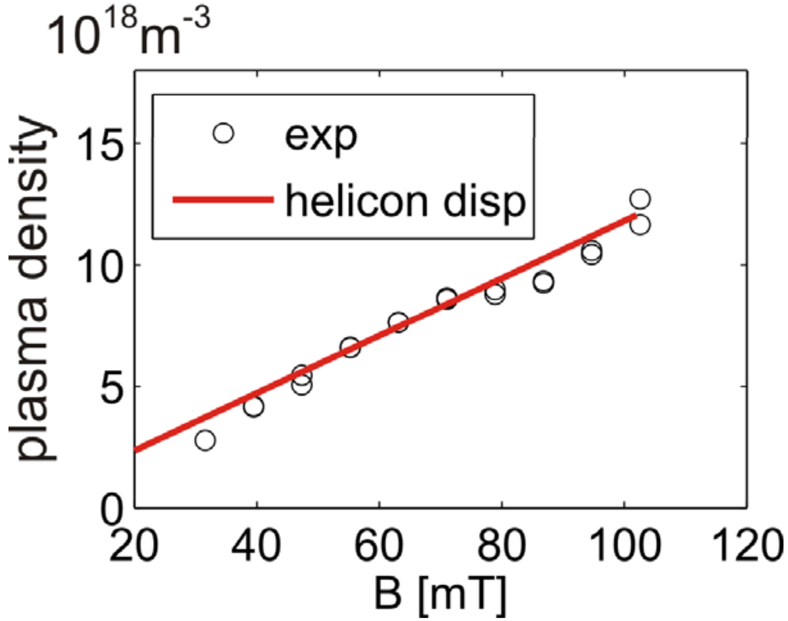
$$\frac{k_{\|}k}{\omega} = \frac{e\mu_0 n}{B}$$



- radial wave field $k_\perp$ determined by plasma radius
- second order effect: $k_\perp$ variation with frequency
- axial wave field $k_{\|}$ imposed by antenna geometry

helicon wave dispersion cont.

dispersion relation:
$$\frac{k_{\|}k}{\omega} = \frac{e\mu_0 n}{B}$$



- linear scaling of density with ambient magnetic field
- however: $\omega_{ci} \ll \omega \ll \omega_{ce}$

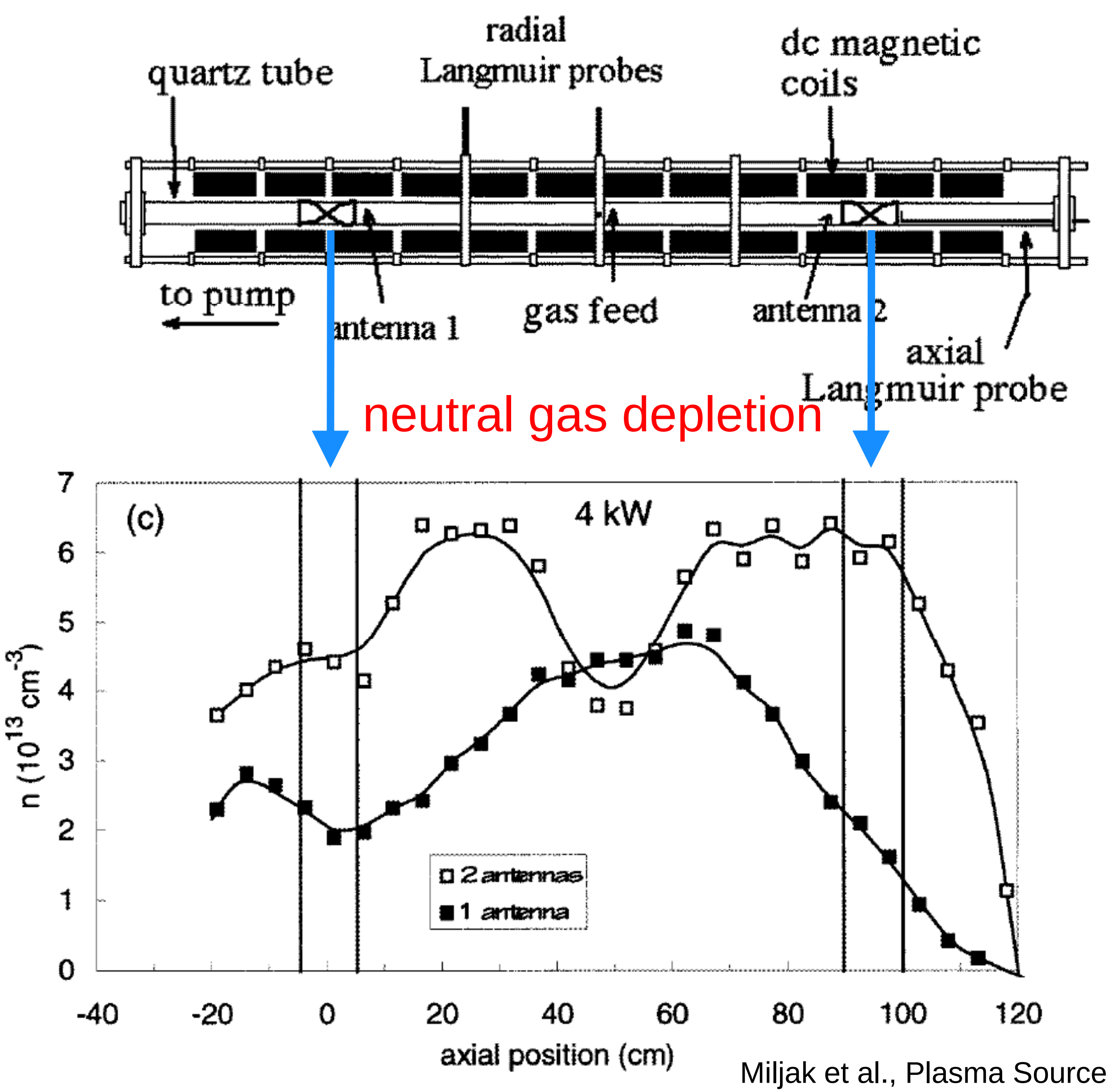
R&D issues

- coupling of rf-power to plasma (antenna, matching, heat load)
- shaping of the density profile (homogeneous axial density)
- multi-antenna quasi-cw operation (no transient effects)
- shaping of the helicon wave field (boundary conditions)
- helicon discharge in (strongly) inhomogeneous magnetic field

  (quadrupole magnetic field for actual proton bunch experiments)
- control of neutral gas density

etc……..

central neutral gas depletion



neutral gas depletion

Miljak et al., Plasma Sources Sci. Technol. **7** (1998)

design parameters

- glas vacuum tube
- multiple m=1 helicon antennas, distributed along discharge
- density $n \leq 1 \cdot 10^{22}$ m^{-3} ⇨ $n \leq 1 \cdot 10^{21}$ m^{-3} reported without neutral gas control Sakawa et al., Appl. Phys. Lett. **69** (1996)
- magnetic guide field ~0.5-1T ⇨ $f_{rf} \approx 100$ MHz

$$\omega_{ce} \ll \omega_p$$

$$\beta < 1\%$$

- distributed capillary neutral gas feeding (heavy ions)
- diagnostics: interferometry, probes, spectroscopy