Beam Probe Imaging Method for Edge Plasma Modeling in CHS

H. Iguchi [1)], K. Nakamura [1)], J. Schweinzer [2)] and CHS Group

[1)] National institute for Fusion Science, Toki-shi, 509-5292 Japan

[2)] Max-Planck-Institut fur Plasmaphysik, D-4086 Garching bei Munchen, Germany

---

A neutral lithium beam probe with variable beam injection angle has been developed for the CHS (2D-LiBP).

An image of 2D plasma structure is obtained by changing the beam injection angle shot by shot, showing **an asymmetric plasma structure** in the edge chaotic layer of CHS.

Plasma Diagnostics Using a LiBP

Edge Plasma Diagnostics with High Spatial Resolution

(1) Beam Emission Intensity・・・ n_e , $\tilde{n}_e$

Emission intensity is proportional to electron density
density reconstruction based on collisional-radiative model

(2) Polarization of Spectral Line・・・ B, J

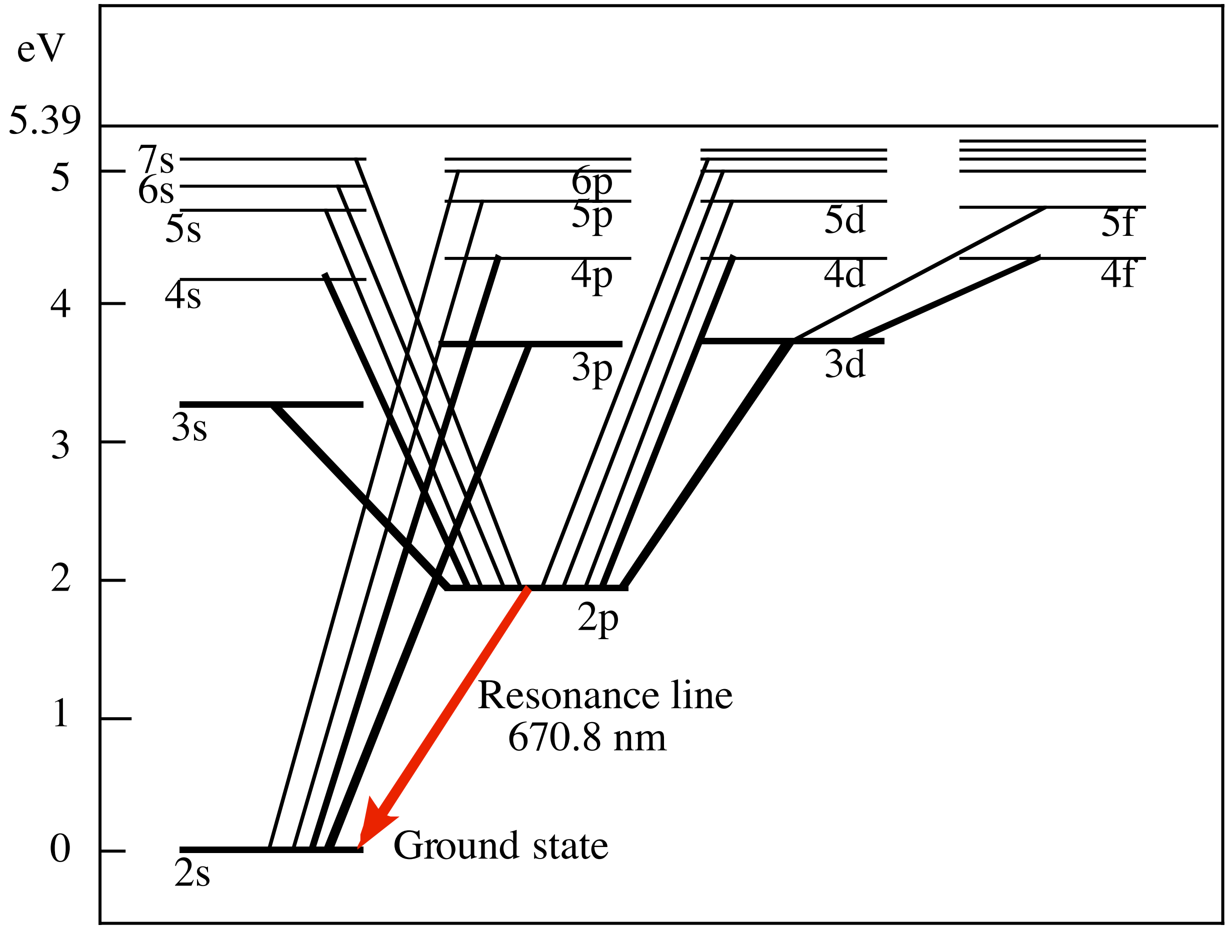
Polarization of Zeeman splitted line
π-component is parallel to B、σ-component is perpendicular to B

(3) Charge Exchange Recombination Spectroscopy ・・T_z, n_z

Doppler broadening of impurity spectral line
Large charge exchange cross section

Lithium Neutral Beam Probe (LiBP)

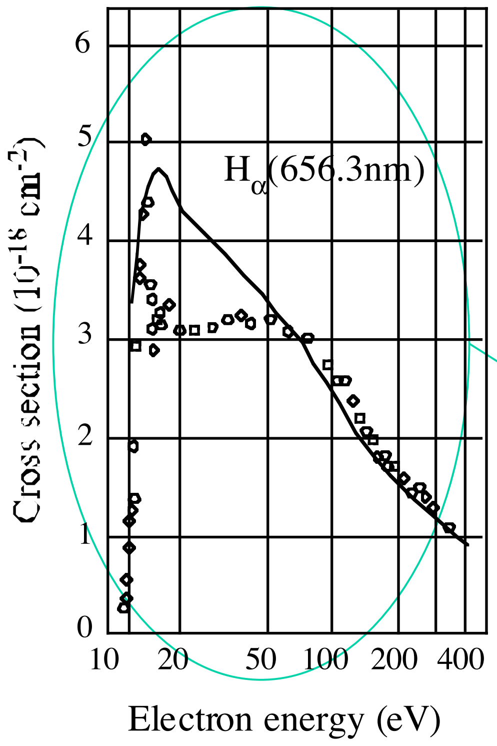
Energy level of the lithium atom



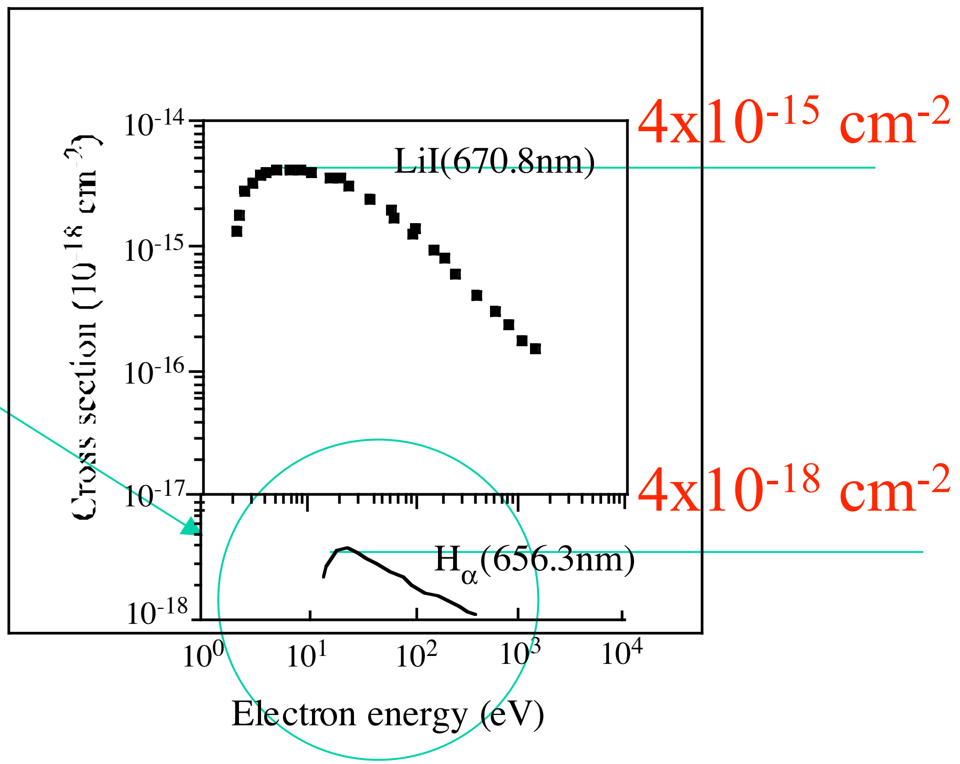
Lithium Neutral Beam Probe (LiBP)

Excitation cross-sections by electron impact collisons

H_α emission



Li(I) emission



Beam Transport in a Plasma

Beam attenuation due to electron impact ionization

$$\frac{dn_b(z)}{dz} = -n_b(z)n_e(z)\frac{<\sigma_{ion}v_r>_e}{v_b}$$

Electron density

Beam density in the plasma

$$n_b(z) = n_b(0)\exp\left\{-\int_0^z n_e(z)\frac{<\sigma_{ion}v_r>_e}{v_b}dz\right\} = n_b(0)F_{att}^e(z)$$

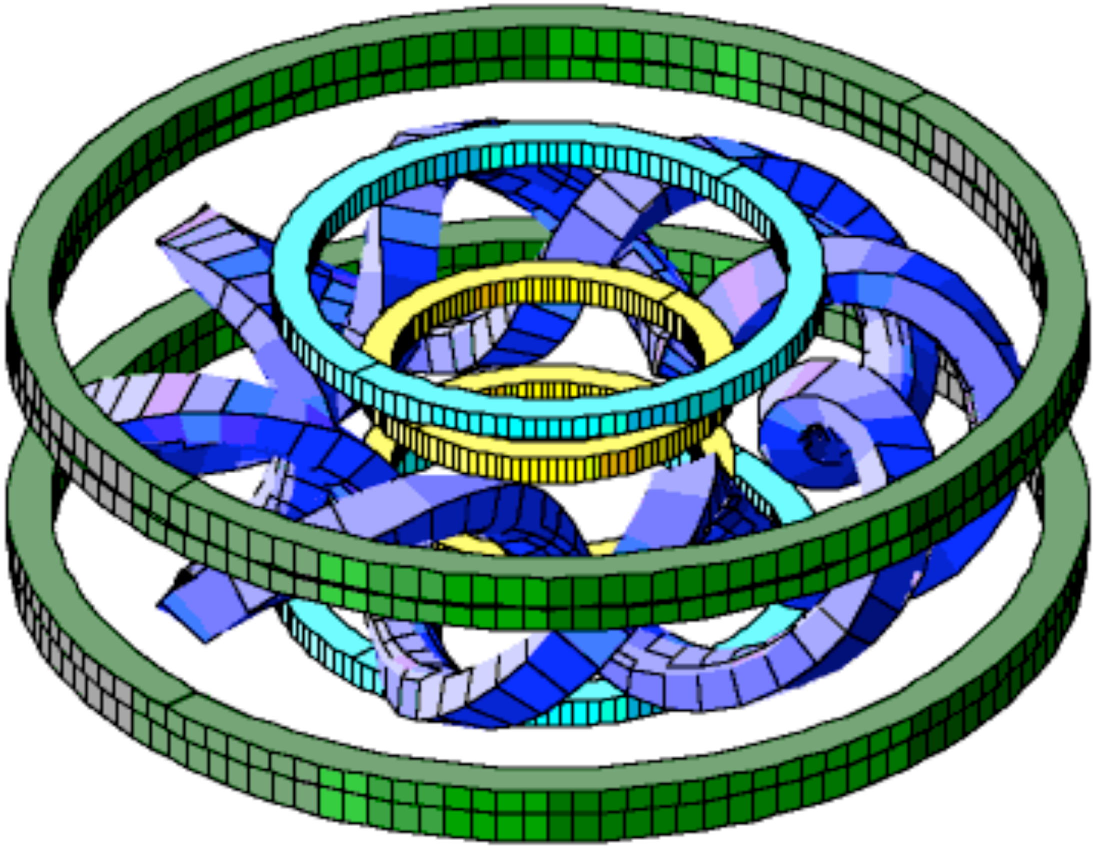
Total attenuation factor

Effective cross section (T_e)

$$F_{att}^{total}(z) = \exp\left\{-\int_0^z \sum_{k,j} n_j(z)\frac{<\sigma_k v_r>}{v_b}dz\right\}$$

k: kind of interaction *j*: plasma particle species

Compact Helical System (CHS)



Major Radius:

R = 1.0 m

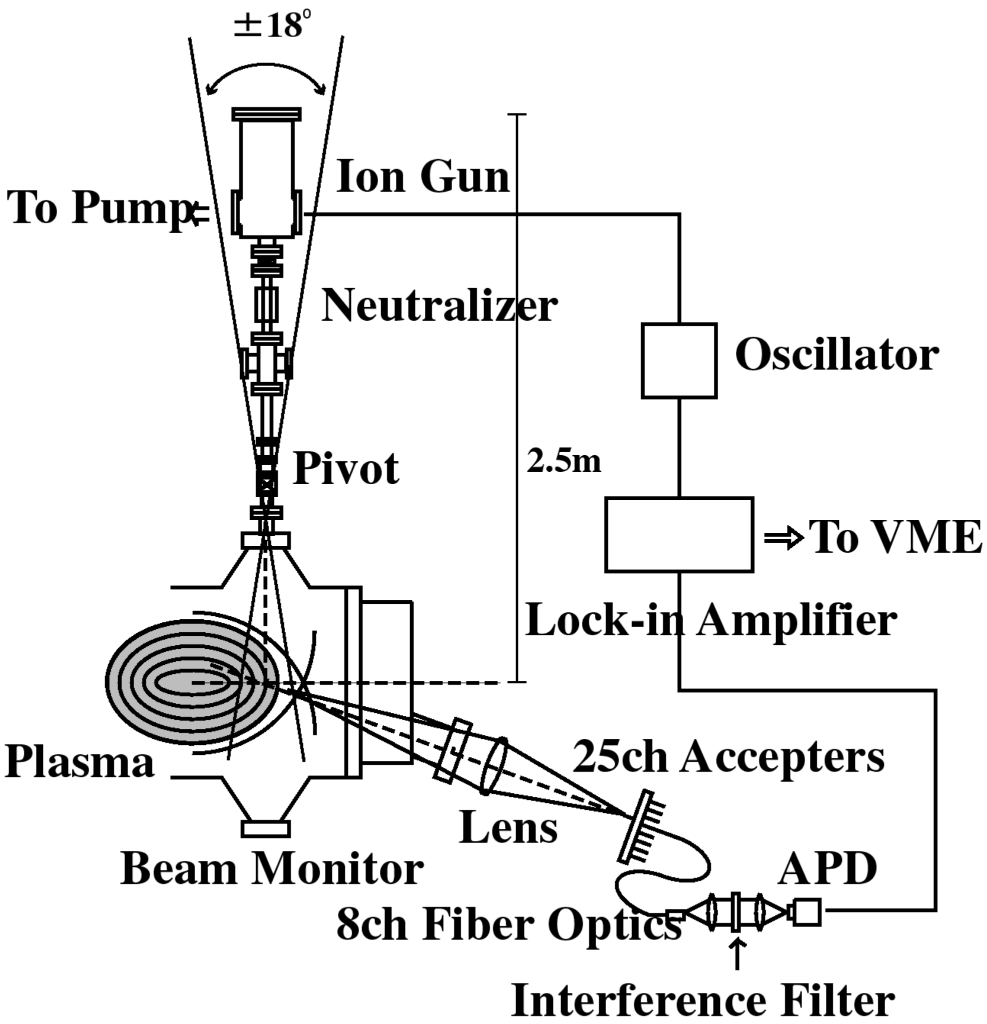
Minor Radius:

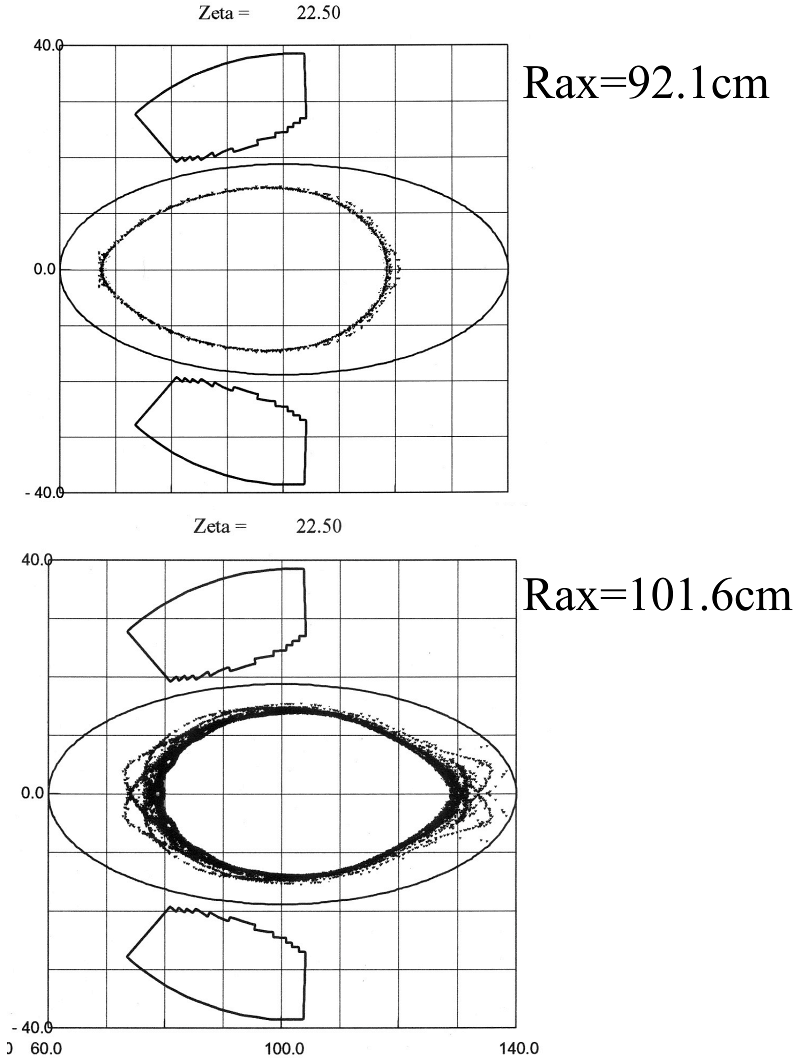
a = 0.2 m

Magnetic Field:

B = 1.8 T

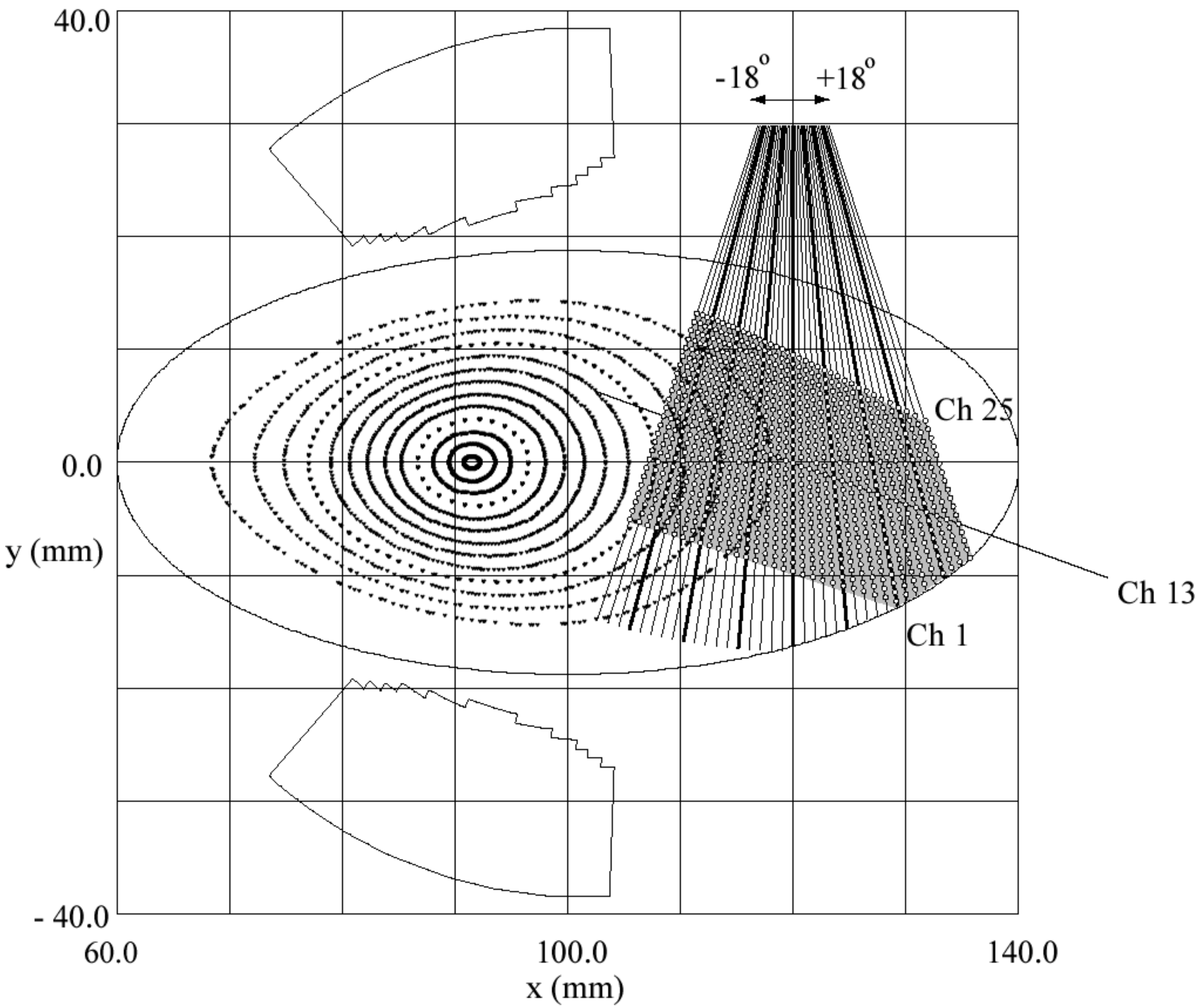
Example : 15 kV LiBP for CHS



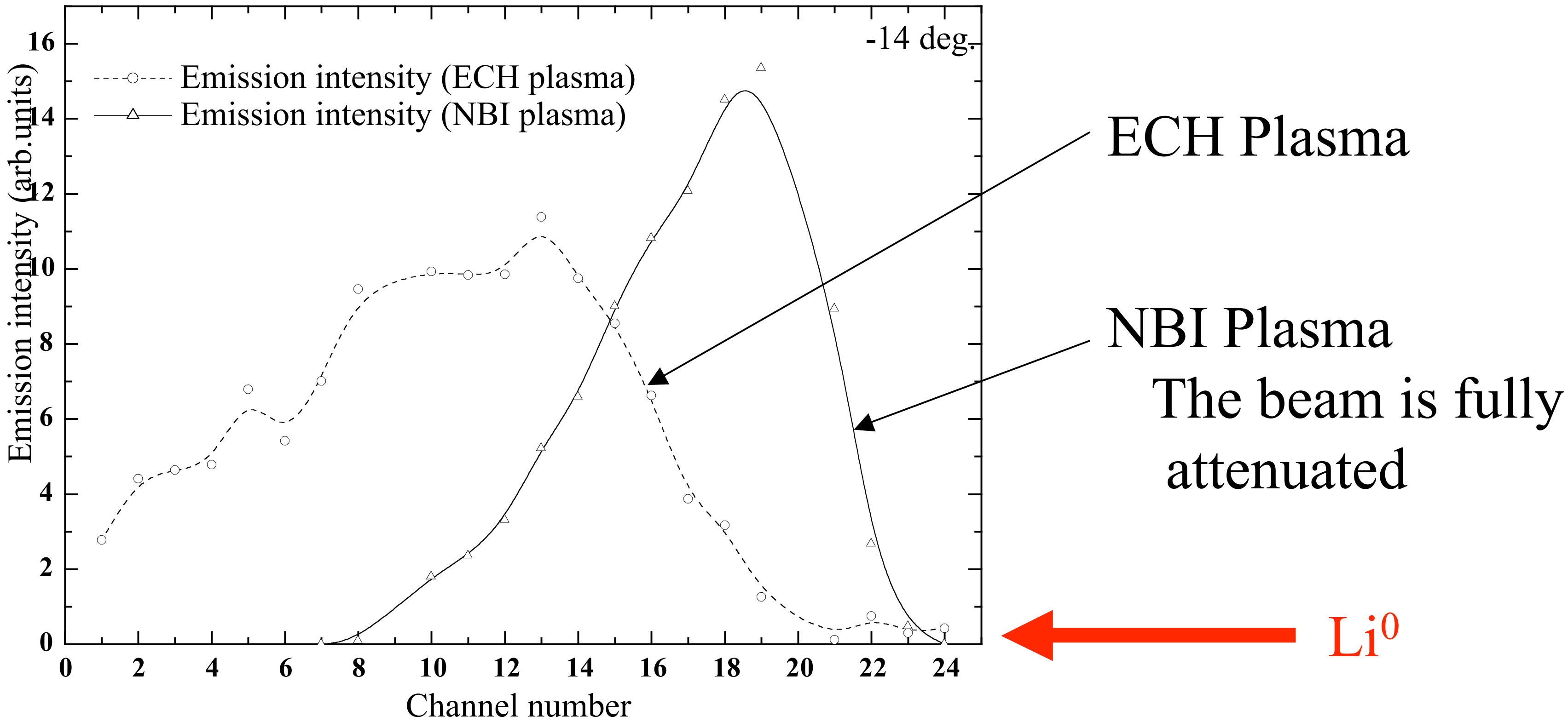


K. Nakamura, H. Iguchi, et al., Rev. Sci. Instrum, 76, (2005) 013504.

Observation Area



Beam Emission Intensity



Electron Density Profile Reconstruction

Method I : Gas Calibration Method

$$I_v^{gas} = n_b n_{gas} \sigma_{em}^{gas} v_b S l_{sv} \Omega / 4\pi$$

$$n_e(z) = n_{gas} \frac{I_v(z)}{I_v^{gas}(z)} \frac{n_{b0}}{n_b(z)} \frac{\sigma_{em}^{gas} v_b}{< \sigma_{em} v_r >_{eff}}$$

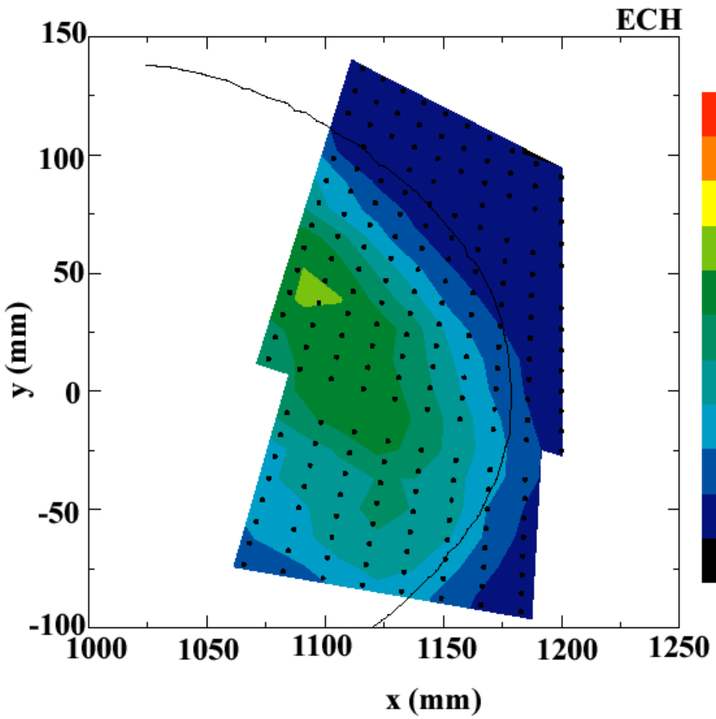
Method II : Beam Attenuation Method

$$\frac{1}{n_b(z)} \frac{dn_b(z)}{dz} = -n_b(z) \frac{< \sigma_{ion} v_r >_{eff}}{v_b}$$

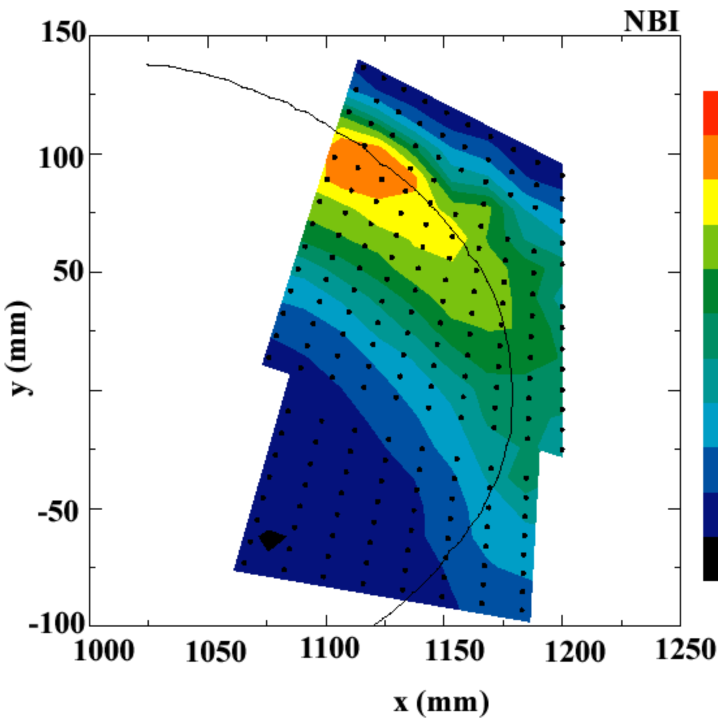
$$n_e(z) = \frac{I_v(z) v_b}{< \sigma_{em} v_r >_{eff}} / \int_z^{z1} I_v(\xi) \frac{< \sigma_{ion} v_r >_{eff}}{< \sigma_{em} v_r >_{eff}} d\xi$$

2-D Beam Emission Intensity

R_{ax} = 92.1 cm



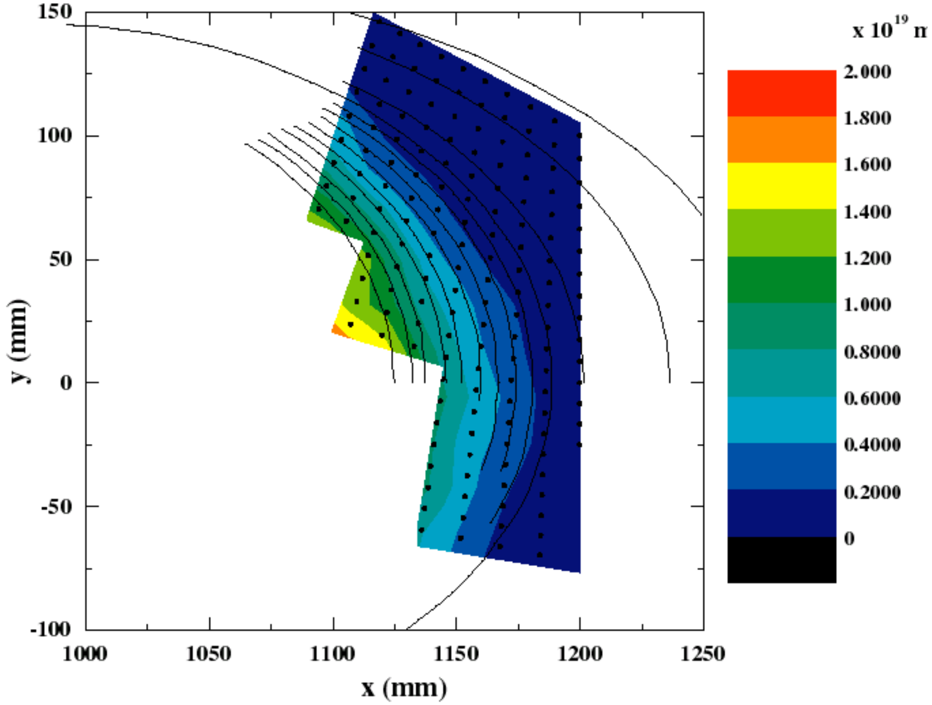
ECH plasma



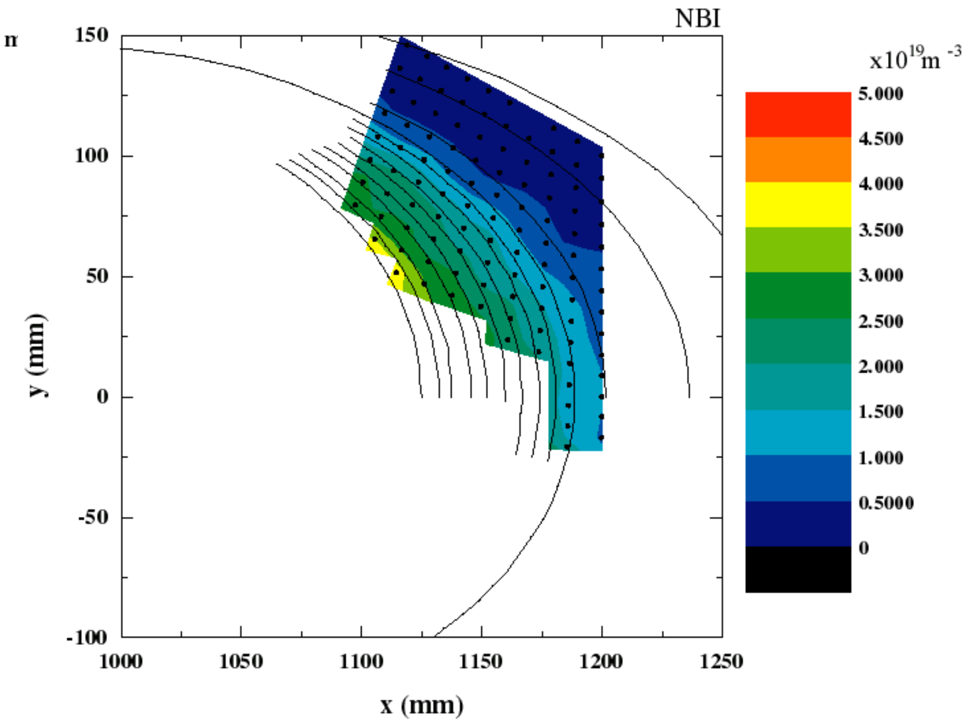
NBI plasma

Reconstructed Density Profiles

R_{ax} = 92.1 cm



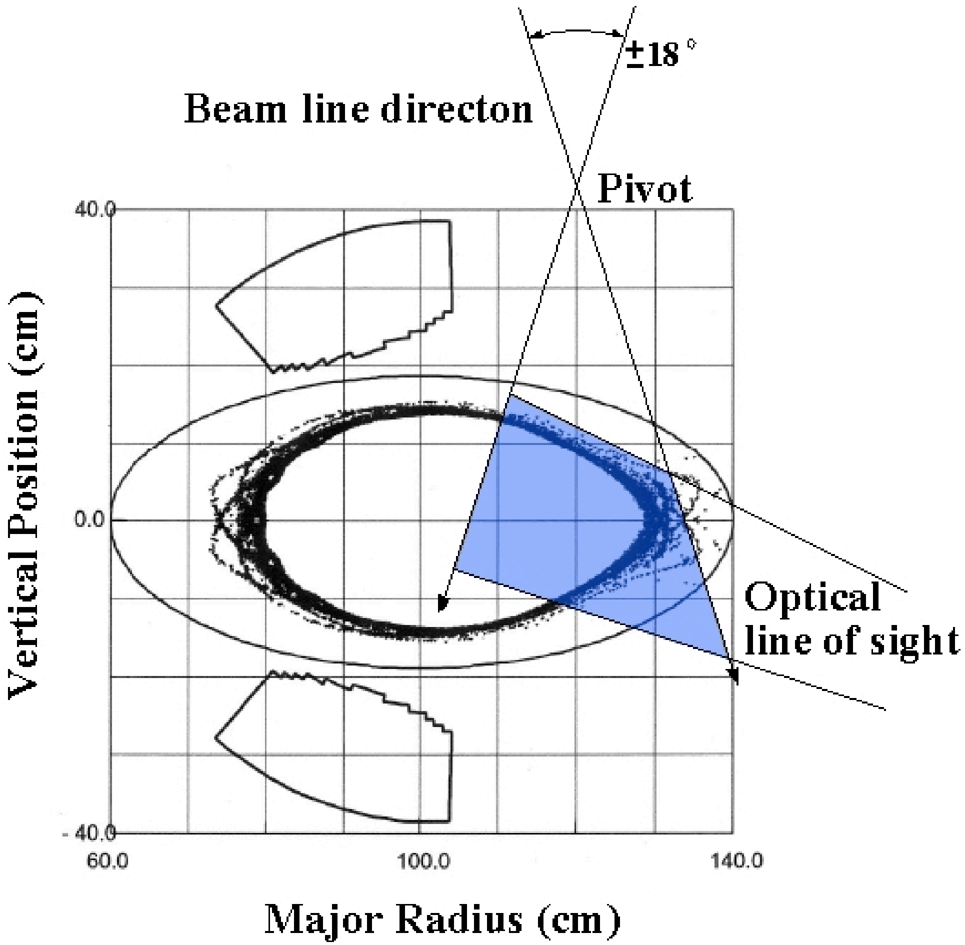
ECH plasma



NBI plasma

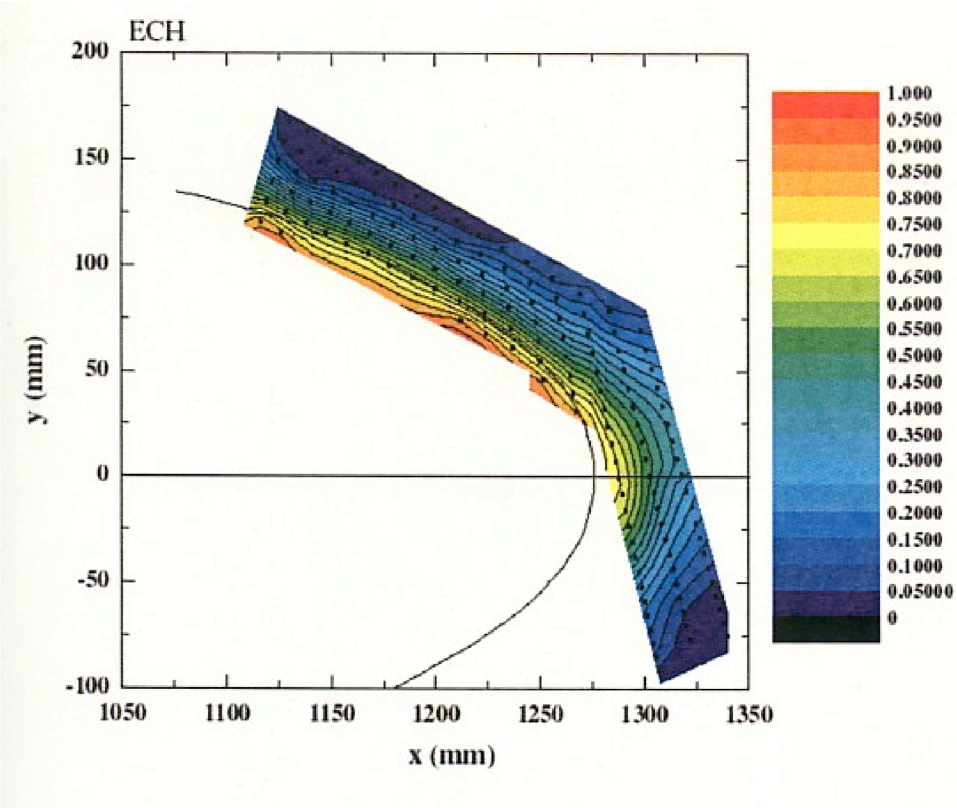
Discharge for Magnetic Divertor Configuration

R_{ax} = 101.6 cm (Normal B / CCW)

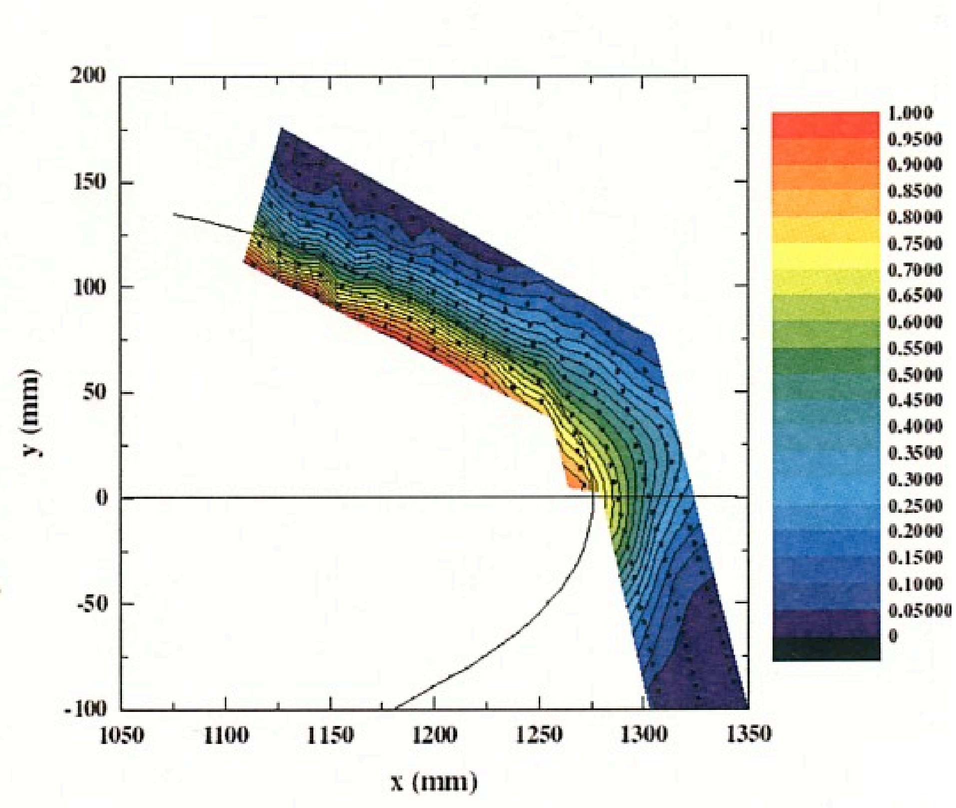


Reconstructed Density Profiles

R_{ax} = 101.6 cm (Normal B / CCW)



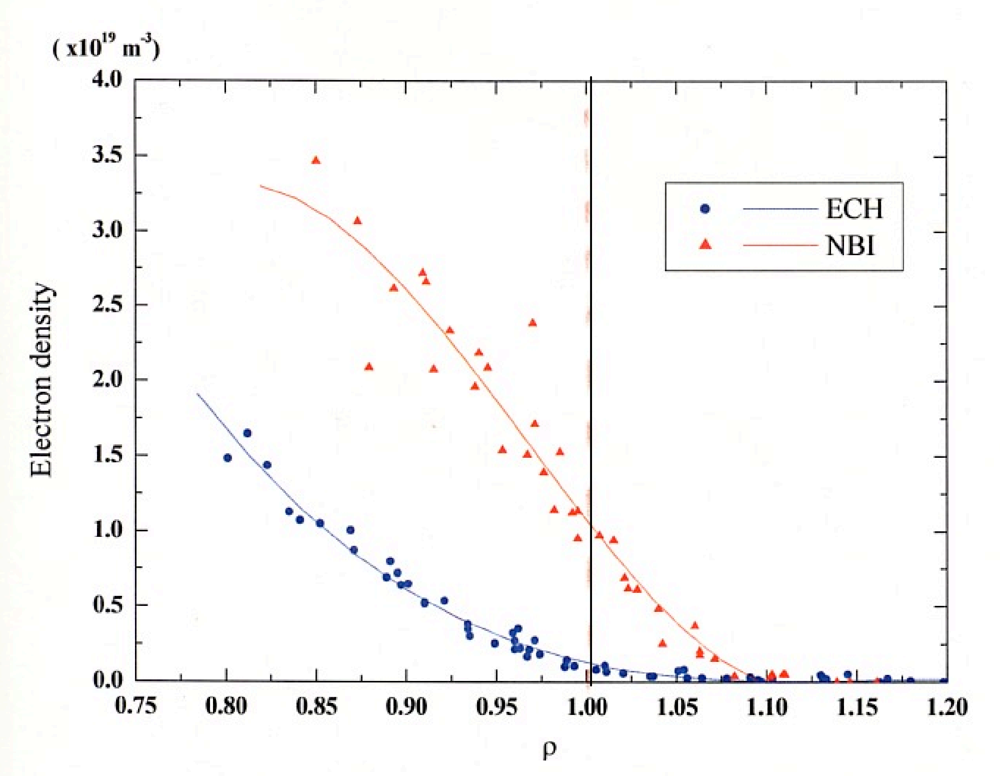
ECH plasma



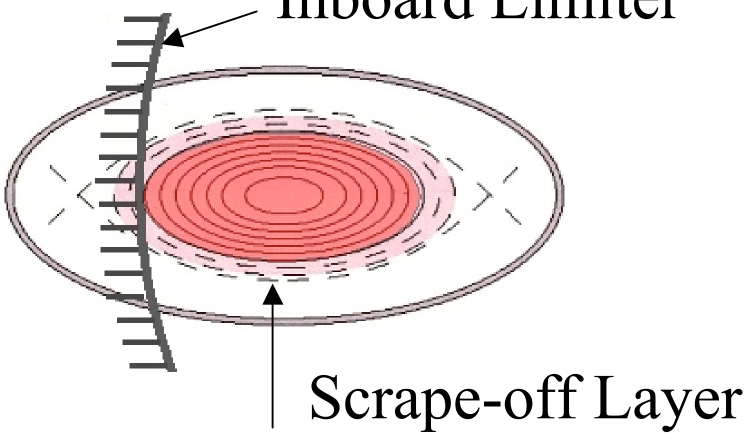
NBI plasma

Modeling of CHS Edge Plasma

Inboard Limiter Configuration (1)



Electron density is a function of magnetic flux even outside the LCFS. (Data points are taken at different poloidal location (different beam injection angle)



Field line connection length

$$L_{||} = 2\pi R$$

Parallel confinement time

$$\tau_{||} = L_{||} / c_s$$

Mean free path for Frank-Condon neutral

$$l_{FC} = v_{FC} / n_e < \sigma v >_i$$

Modeling of CHS Edge Plasma

Inboard Limiter Configuration (2)

Particle flux balance (cylindrical model)

$$\nabla \cdot \vec{\Gamma} = \Gamma_r + \Gamma_z = n_e n_0 < \sigma v >_i$$

$$\Gamma_r = -D_\perp \frac{\partial n_e}{\partial r} \qquad \Gamma_z = n_e c_s$$

$$-D_\perp \left(\frac{\partial^2 n_e}{\partial r^2} + \frac{1}{r}\frac{\partial n_e}{\partial r}\right) + n_e \frac{c_s}{L_\parallel} - n_e n_0 < \sigma v >_i = 0$$

$$\frac{\partial^2 n_e}{\partial r^2} + \frac{1}{r}\frac{\partial n_e}{\partial r} - n_e \left[\frac{c_s / L_\parallel - n_0 < \sigma v >_i}{D_\perp}\right] = 0$$

(Bessel's Differential Equation)

Slab model approximation

$$\frac{\partial^2 n_e}{\partial r^2} - n_e \left[\frac{c_s / L_\parallel - n_0 < \sigma v >_i}{D_\perp}\right] = 0$$

Assuming the density profile as

$$n_e \equiv n_a \exp\left[-(r-a)/\lambda_n\right]$$

Density gradient scale length in the scrap off layer is

$$\lambda_n = \left[\frac{D_\perp}{c_s / L_\parallel - n_0 < \sigma v >_i}\right]$$

In CHS

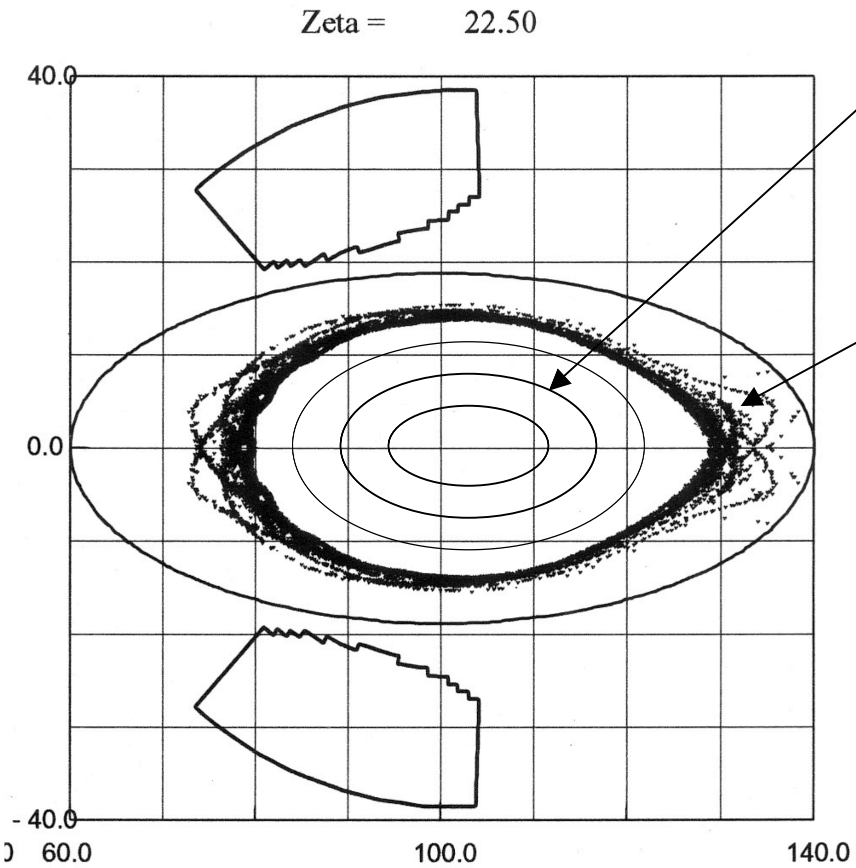
$$c_s / L_\parallel \gg n_0 < \sigma v >_i$$

Then

$$\lambda_n = \left[\frac{D_\perp}{c_s / L_\parallel}\right]$$

Modeling of CHS Edge Plasma

Magnetic Divertor Configuration



Equilibrium in the core plasma

$$\nabla p = J \times B$$

Equilibrium in the chaotic layer ?

<u>Perpendicular</u>

<u>Parallel</u>

Summary

- A LiBP has been extended to a two-dimensional imaging diagnostic (2D-LiBP) in CHS : Beam Probe Imaging.

- The 2D image has shown asymmetric plasma structure in the chaotic magnetic field region, which suggests the necessity of new edge plasma modeling in the ergodized magnetic field layer.