Electron Bernstein wave heating in overdense Stellarator plasmas

H.P. Laqua, Y.Podoba, J. Lingertat,W7-AS Team, Wega Team, ECRH-Group*
Max-Planck-Institut für Plasmaphysik, EURATOM Ass.D-17491 Greifswald, Germany,
**Institut für Plasmaforschung, Univ. Stuttgart, D-70569 Stuttgart, Germany*

Introduction

Stellarators seemed to have no density limit based upon stability. Therefore they are an attractive test-bed for overdense plasma heating with electron Bernstein waves (EBW).
In comparison with electromagnetic electron cyclotron waves, the absorption of EBW´s is much higher. Therefor they can efficiently heat plasmas even at the higher harmonics or at low temperature efficiently. In this paper we describe heating experiments with 140 GHz at the Wendelstein7-AS and with 2.45 GHz at the Wega stellarator.

Experiments at Wendelstein7-AS

One key issue for commercial fusion reactors is the stability at high beta values. High beta experiments are preferably performed at low the magnetic field. For a fixed ECRH-frequency (140 GHz) this requires heating at a higher harmonic resonance. In the last experimental campaign of Wendelstein7-AS we have concentrated on high harmonic heating. The EBW´s were generated by the OXB- mode conversion process [1], [2], which requires an optimal parallel component for the launched wave with ordinary polarisation. In addition the plasma density has to expire the cut-off density of the ordinary wave. Therefore the target plasma was sustained by strong NBI-heating (up to 3 MW) at a density of above 3 $10^{20}m^{-3}$. The available ECRH power in the right polarisation and launch direction was about 1.1 MW. Due to the power degradation of the confinement the total increase of plasma energy or normalised pressure (beta) was rather low, but the efficiency seemed comparable with that of NBI. In a magnetic field scan the largest increase of beta was found at 1.11 T as shown in Fig.1. The power was mainly deposited at half the plasma radius. Central power deposition was not possible due to the appearance the next harmonic resonance at the plasma edge. This was confirmed by the tomographic reconstruction of the change of the SX-emission at the ECRH switch-off shown in Fig. 2. With the ECRH stray radiation diagnostic the total efficiency of OX- coupling could be estimated. An example is shown for the fourth harmonic EBW-heating in Fig 3. The maximum stray radiation was found near the cut-off density. Assuming that no power is coupled to the plasma in that case, a reduction of the stray radiation down to 10% with increasing density indicates that 90% of the ECRH radiation has been absorbed in the plasma. Of course some part of the ECRH power may be absorbed at the plasma edge and did not contribute to the much to the increase of plasma energy.

Experiments at Wega stellarator

At the Wega Stellarator in Greifswald experiments with 2.4 GHz were performed. The Wega is a classical stellarator (l=2, n=5) with a major radius of 0.72 m and a minor radius of 10 cm. The Vacuum wavelength of the 2.45 GHz frequency is with about 12 cm larger than the typical density gradient scale length at Wega. Therefore the WKB-approximation fails here and full wave calculations are required. Nevertheless the OXB-mode conversion process can still take place if the appropriate $N_{||}$-vector is chosen. This was confirmed by Nakajima in a full wave calculation for similar plasma parameter [3]. Since the small port diameter does not allow an oblique launch via an oblique wave guide, a mono-mode HE11 waveguide antenna was equipped with a double-cut to provide an antenna pattern with the optimal $N_{||}$ value as shown in Fig.4. The Polarisation was set to a direction parallel to the magnetic field; such that mainly O-wave were ecxited. The plasma was generated by ECRH at a resonant field B_{ce} of 0.087 T. Then density was rised up by increasing the neutral background pressure and the magnetic field was reduced to get central EBW absorption. The typical discharge length was 100 s. During this time the neutral gas pressure was ramped up to find the maximum line density measured by a microwave interferometer. At the time point of maximum density a fast movable Langmuir probe measured density and the temperature profile. This procedure was performed for different magnetic fields and iota-values. As shown in Fig. 5 the highest density was found at a magnetic field of 0.65-0.7 B_{ce}. The profiles are shown in Fig.6 and Fig. 7. At the optimum field the density profile is peaked and the temperature profile is flat, what indicates a rather good power coupling into the dense plasma center. In case of magnetic field near B_{ce} or 0.5 B_{ce} the profiles become hollow, which is probably due to a strong absorption at the antenna front. Even though the densities measured by the probe differed from the interferometer measurement systematically by a factor of two, the plasma density exceeded 2 10^{18} m^{-3}. This could be confirmed by spectroscopic measurement additionally.

Summary and discussion

ECRH with EBW´s is an efficient method to heat high-beta and high-density fusion plasmas. This was successfully demonstrated at Wendelstein7-AS with 140 GHz microwaves at the fourth harmonic resonance. Here the wavelength was small compared with the plasma dimensions; therefore the WKB-approximation is valid.

At the Wega stellarator the wavelength was comparable with the plasma dimension and much larger than the typical gradient length. Nevertheless strongly overdense plasmas could be generated with ECRH only.

At such a high density and at a magnetic field below the cyclotron resonance no cyclotron wave can propagate into the dense plasma except of the electron Bernstein wave. Due to the oblique launch, the magnetic curvature and shear, the EBW´s can achieve large $N_{||}$ components, which cause the Doppler-shifted absorption at 0.7 B_{ce}. In comparison with a perpendicular X- and O-mode launch, the heating efficiency could be strongly improved by the double-cut antenna, which provides an oblique launch scenario. This is a hint that the EBW´s were generated by the OXB-mode conversion mechanism.

References

[1] Preinhaelter, J. and Kopecky,´ , V., J. Plasma Phys. 10 (1973) 1;
[2] H.P.Laqua et al., PRL 78, 18 (1997);
[3] Nakjima S., Abe H. :in Physics Letters A, Vol. 124, No. 4-5, p. 295-298 (1987)

Figures

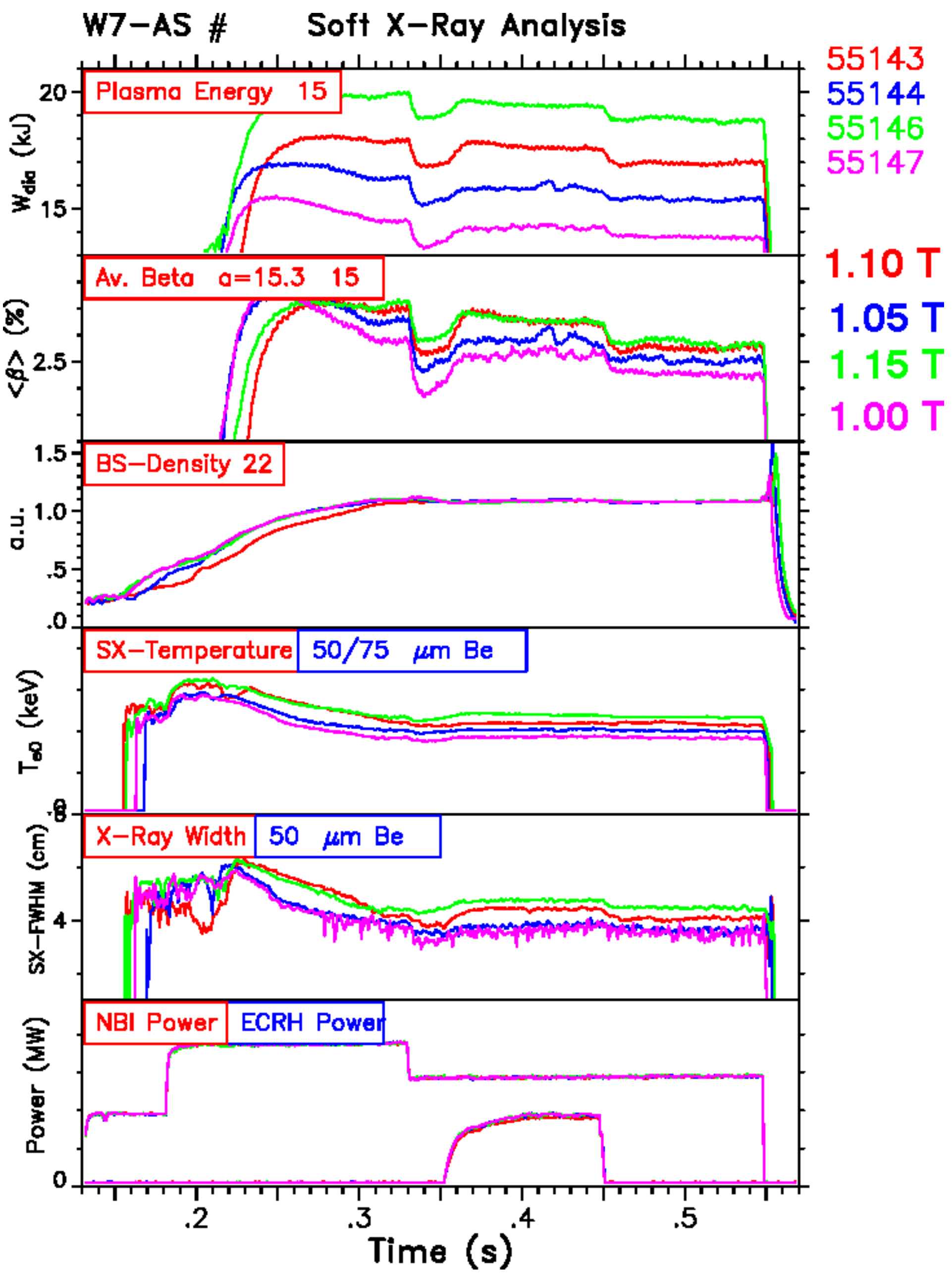

Fig.1 Plasma parameter for a magnetic field scan. It should be noted that, due to technical limitations only about 70% of the total ECRH power was launched with the optimal polarisation and launch angle.

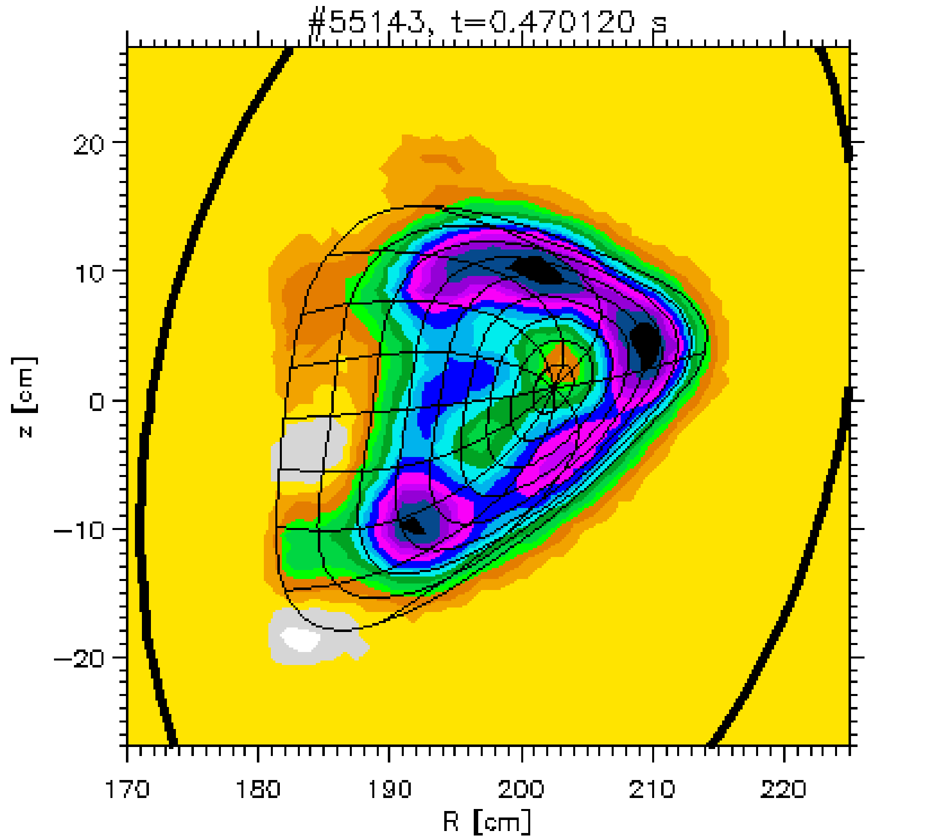

Fig. 2 Change of SoftX emission after ECRH switch-off.

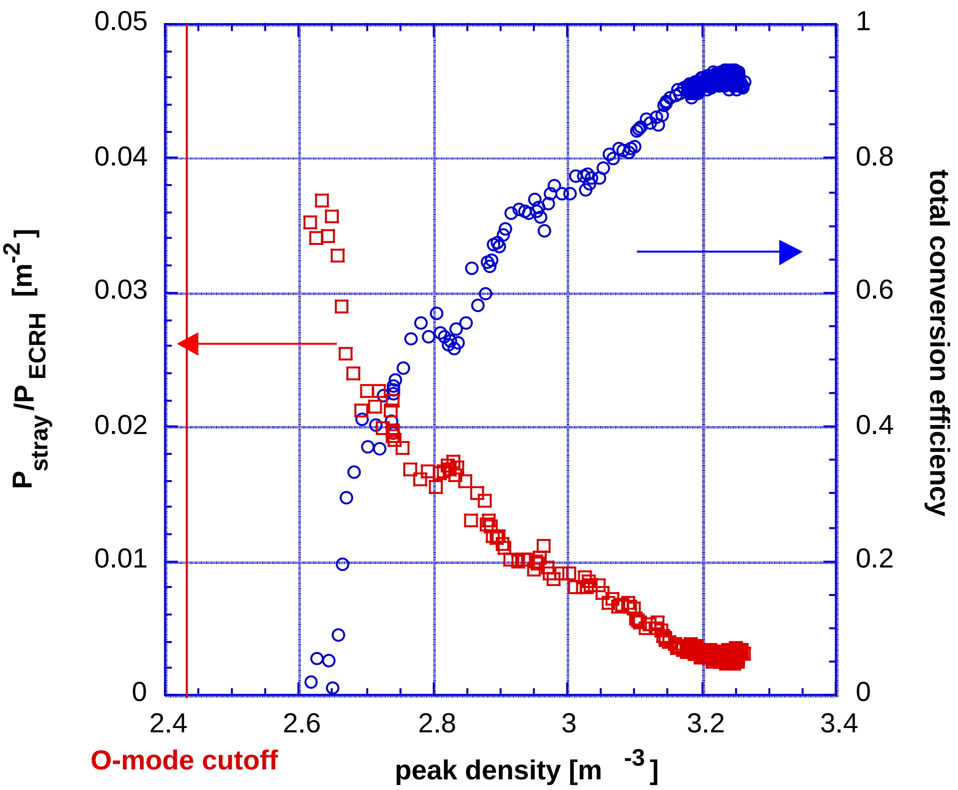

Fig. 3 red: 140 GHz stray radiation measured at a position opposite to the ECRH launch.
blue: absorbed power.

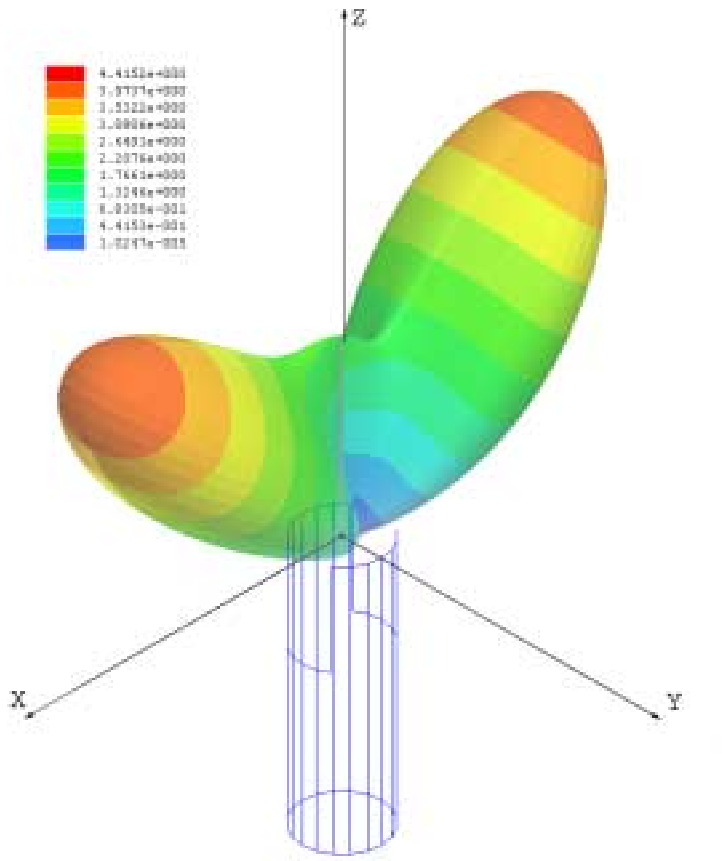

Fig. 4 Double-cut antenna with antenna pattern.

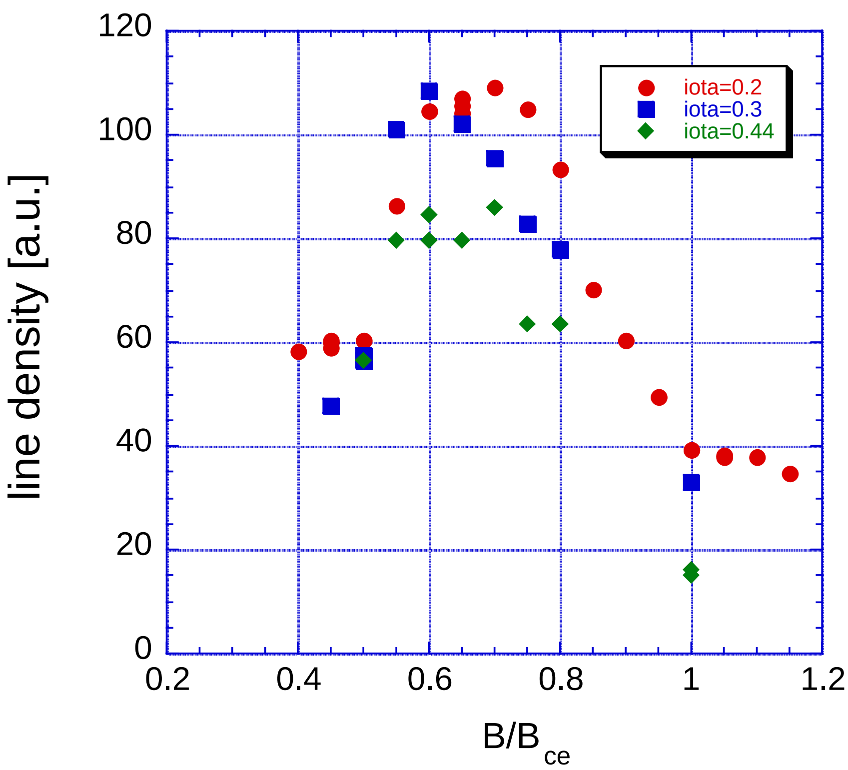

Fig. 5 Maximum density as a versus the magnetic field for different iota values.

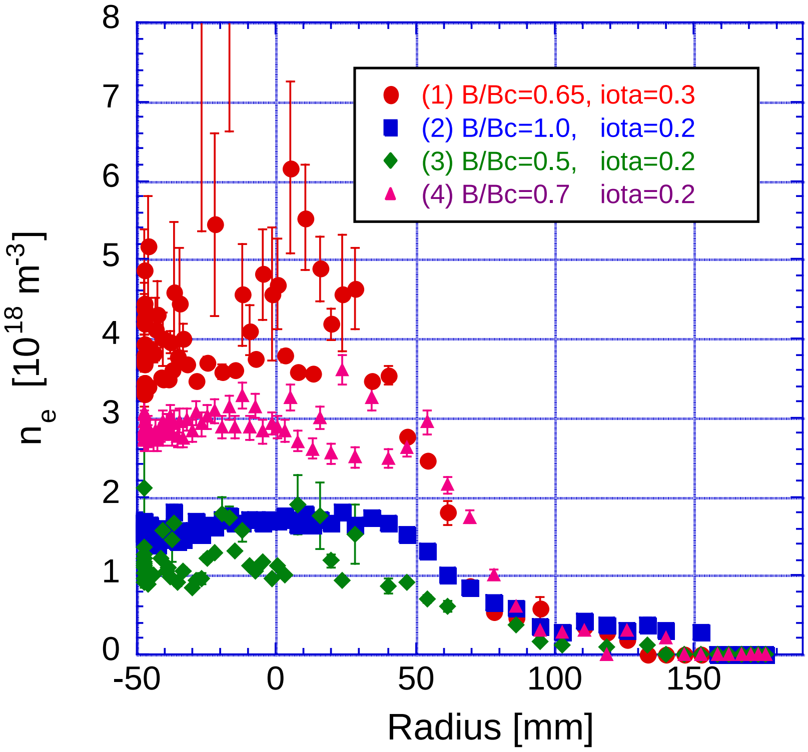

Fig. 6 Density profiles measured by a fast scan Langmuir probe for the different magnetic fields and iota values.

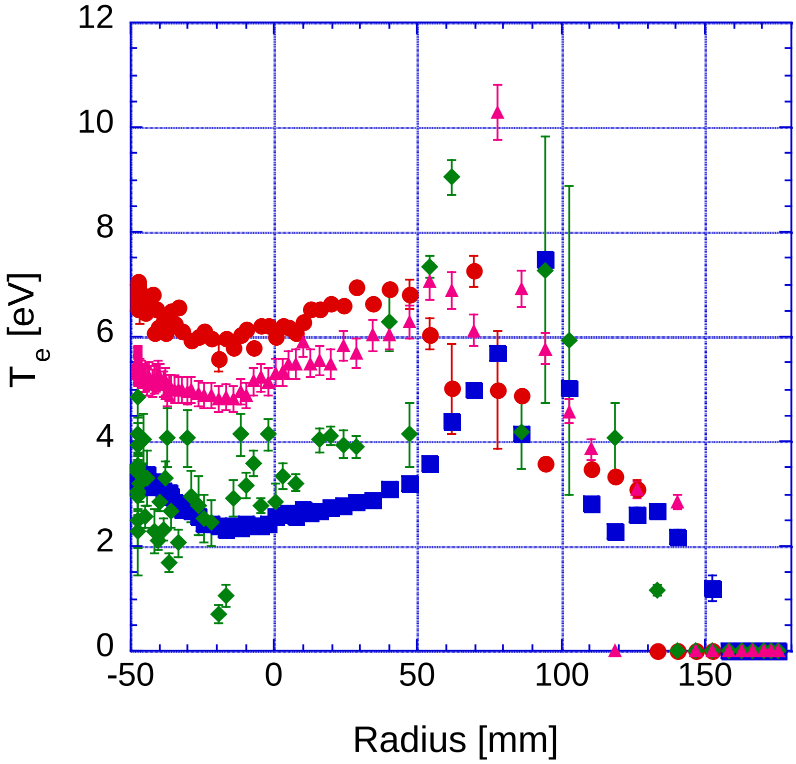

Fig. 7 Temperatue profiles measured by a fast scan Langmuir probe for the different magnetic fields and iota values.