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Interpretation of EBW simulation and comparison with NSTX

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Abstract. Electron Bernstein wave emission (EBWE) is strongly coupled to the magnetic equilibrium. Simulation results for different EFIT equilibria available for National Spherical Torus Experiment (NSTX) are compared. The EBWE intensity is dependent on which version of EFIT is used, whereas the conversion efficiency remains almost unaffected. Simulations indicate that during flat top current discharges the optimal angles for the aiming of the NSTX antennae are quite rugged and basically independent of time.

ECE and electron Bernstein waves on NSTX. The low magnetic fields and high plasma densities in spherical tokamaks lead to overdense plasma from which one cannot observe the standard O and X mode radiation emitted from the first several electron cyclotron harmonics. Hence, any measured electron cyclotron emission (ECE) cannot be simply interpreted. On the other hand, electrostatic electron Bernstein waves (EBW) are not subject to a density limit and are strongly emitted/absorbed near the electron cyclotron harmonics. On mode converting to electromagnetic waves near the upper hybrid resonance, the emitted cyclotron radiation can be attributable to electron Bernstein wave emission (EBWE) and hence to a local temperature near the cyclotron harmonic. On NSTX, there are two new remotely steered antennas [1], which can scan the frequency ranges 8-18 GHz and 18-40 GHz, respectively, as well as in directional angles. The significance of determining the frequency dependence of EBWE is that it provides important information on optimal parameters for proposed EBW heating and current drive experiments.

EBWE simulations using different equilibrium models. The EBWE simulation model, described in detail in [2, 3], uses the magnetic configuration determined by an EFIT code. We consider three different EFIT versions [4, 5] for NSTX. The 'Basic' EFIT01 uses only the external magnetic measurements and simple models for plasma current and pressure. The 'Partial kinetic' EFIT02 adds weak pressure constraints, allowing for edge currents and using higher order pressure and current approximations. The more advanced EFIT03 incorporates, in addition to EFIT02, the internal pitch angle constraints from the motional Stark effect measurements. The main differences in these equilibria are in the pressure profiles dependence on ψ and in the radial toroidal current profiles, but EBWE is sensitive mainly to the changes in the radial profiles of the magnitude of the magnetic field (Fig. 1). In the conversion region (usually near the LCFS), however, these magnetic field changes are minimal and thus the conversion efficiency is independent of the equilibrium model (see Fig. 2).

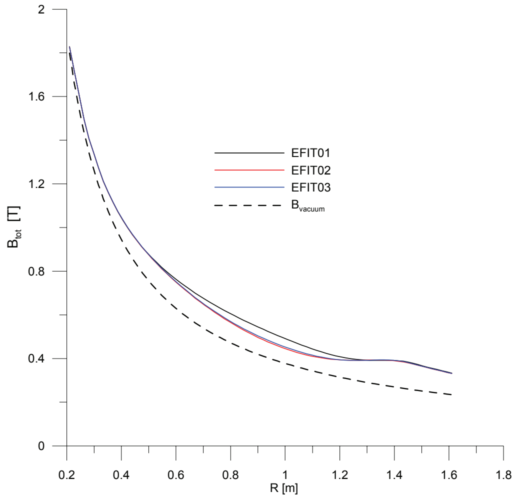

Fig. 1. Magnitude of total magnetic field vs. R in the equatorial plane #119685, t=0.348 s.

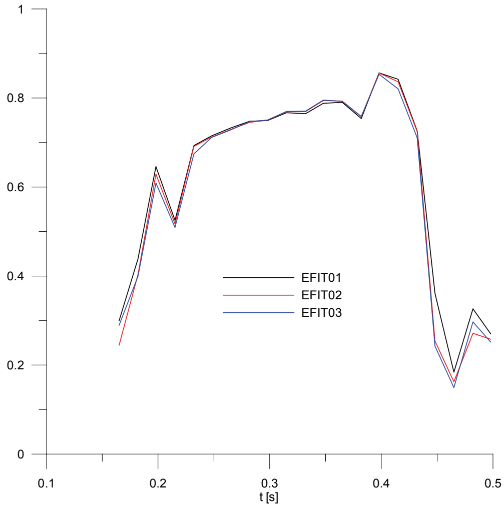

Fig 2. Conversion efficiency (summed for both polarizations), #119685, of whole beam, *f* =29 GHz, $\varphi_{pol} = 22^o$, $\varphi_{tor} = 18^o$.

On other hand, the radiative temperature depends on the equilibrium model, with EBWs being radiated from the electron cyclotron harmonics in the plasma centre which are shifted in the different magnetic equilibrium models. This is clearly seen in the frequency spectrum, Fig. 3, where the EBWE intensity from the third harmonic differs by more than 20% depending on whether one uses EFIT01 or EFIT02/03. The profiles of the electron cyclo-

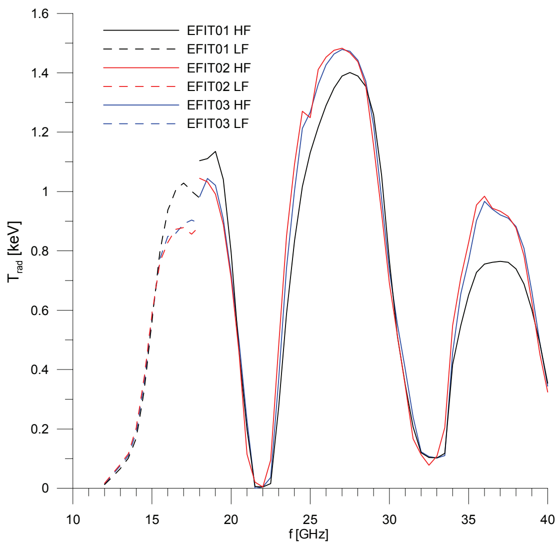

Fig. 3. EBWE, spectrum at *t*=0.365 s, #119685. Dotted lines correspond to the LF antenna ($\varphi_{pol} = -24^o$, $\varphi_{tor} = -22^o$), full lines correspond to the HF antenna ($\varphi_{pol} = 22^o$, $\varphi_{tor} = 18^o$).

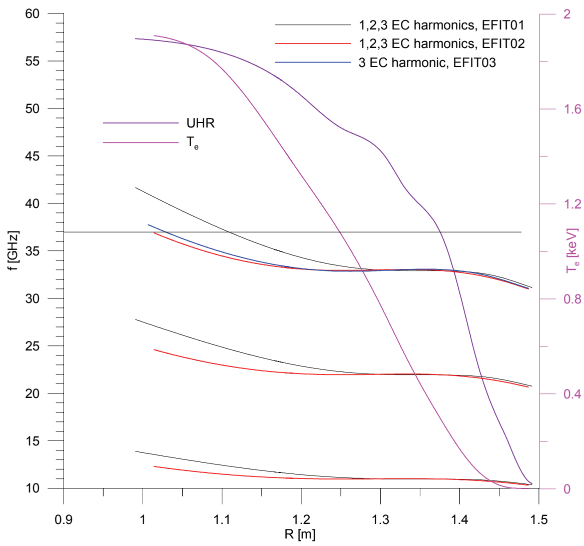

Fig. 4. Radial profiles of the characteristic resonances and the electron temperature for different models of magnetic equilibria.

tron harmonics for the different EFITs are shown in Fig 4. The higher intensity of the 37 GHz wave (3rd harmonic emission) corresponds to the lower magnetic field predicted by

EFIT02/03, so the EBWs are emitted closer to the plasma centre where the temperature is higher. On the other hand, the 16 GHz wave (1st harmonic emission) intensity is weaker for EFIT02/03 because they are emitted away from the plasma centre.

Antennae aiming optimization. Proper antennae aiming angles are crucial in EBW experiments. We have performed simulations for L-mode 800kA helium shots to estimate optimal antennae aiming. It was found that the most important parameter, which determines the optimum angles for the most intensive EBWE, is the EBW-X-O conversion efficiency.

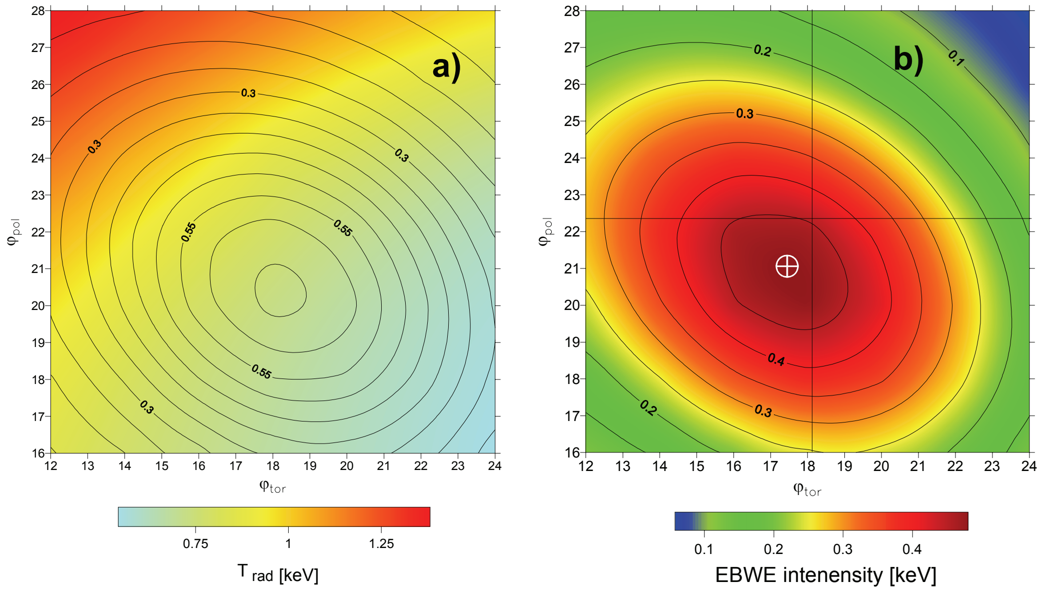

Fig. 5. a) Angular dependence of the antenna beam conversion efficiency (contours) and the EBW beam radiative temperature (colour). b) Angular dependence of the simulated EBWE signal of the high frequency antenna. Both figures for shot 120278, *t*=0.382, *f*=29GHz, EFIT02.

In Fig. 5, we compare the angular dependence of the beam conversion efficiency and the beam radiative temperature ($C_{EBW-X-O}=1$) with the angular dependence of the simulated

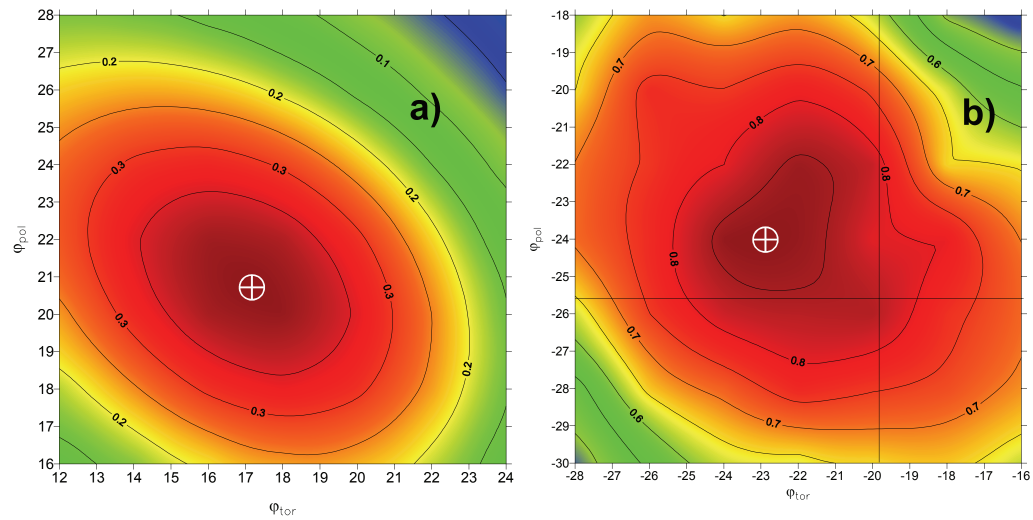

Fig. 6. a) Angular dependence of the simulated EBWE signal of the high frequency antenna. Shot 120271, *t*=0.398 s, *f*=29 GHz, EFIT01. b) Same as Fig. 5b for 16 GHz, low frequency antenna.

EBWE intensity for the high frequency antenna. The radiative temperature of the EBWs increases with angles aimed near the equatorial plane, whereas the conversion efficiency peaks at those optimum angles determined by the magnetic field direction in the conversion region. For the tested L-modes during the flat top current phase, the optimal angles are the same (see Fig. 6a) and do not even depend on the magnetic equilibrium model. The optimum for the low frequency antenna is given in Fig. 6b. The negative angles correspond to the low frequency antenna (which is above the equatorial plane) while the positive angles correspond to the high frequency antenna (below the equatorial plane). The optimal poloidal and toroidal angles $\left(\varphi_{pol},\varphi_{tor}\right)$ for the low and high frequency antennae are $\left(-24^{o},-22^{o}\right)$ and $\left(+21^{o},+17.5^{o}\right)$, respectively. For the shot #120278, these correspond well with the $N_{||}$ at the O-X mode conversion at the plasma resonance: $N_{||}=0.6$ for 16 GHz and $N_{||}=0.5$ for 29 GHz and the pitch angle to the magnetic field of about 45^{o}, where $N_{||}=ck_{||}/\omega$ and $||$ is parallel to the local magnetic field. The actual experimental antenna orientation for shot #120278 with intensive EBWE was close to the optimal simulation angles (the intersection of the axis cross hairs in Fig. 5b and 6b).

Conclusions. EBWE simulations are sensitive to the magnetic equilibrium model. The basic EFIT01 predicts usually higher magnetic fields than the more sophisticated EFIT02 and EFIT03 which have greater flexibility in modelling the diamagnetic effects of the poloidal current. As a consequence, predicted EBWE intensities are different, particularly for the 3rd harmonic. However there are insignificant differences at the EBW-X-O conversion region, so the conversion efficiency does not depend on the EFIT version. Thus, the antenna aiming studies can be performed with any of the tested equilibria. Comparison to experimental results will be available in the near future. We expect better agreement with EFIT02 or EFIT03 for EBWE.

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