Simulation of the time development of EBW emission from NSTX

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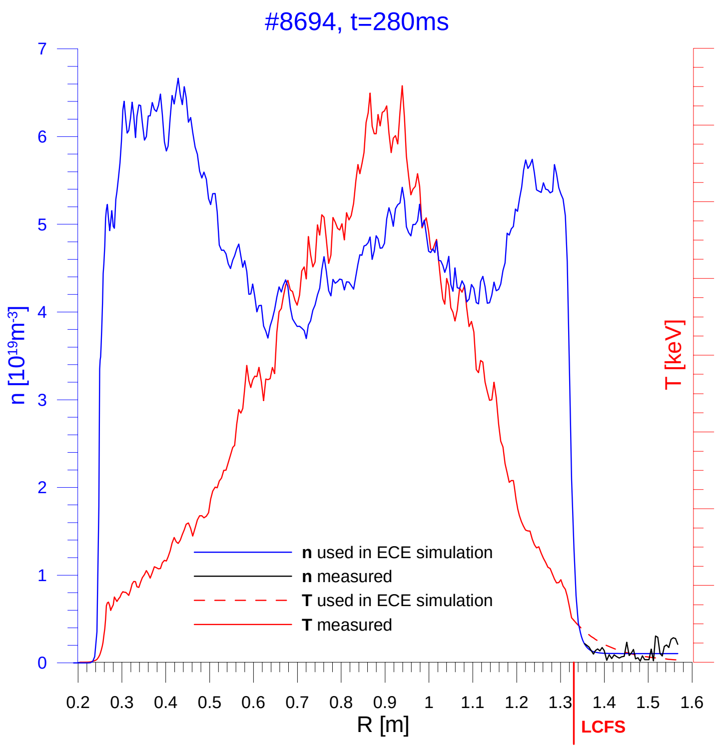
The time development of the frequency spectra of EBW emission from the new NSTX antenna is simulated.

For the shots (#117970-#117982), the most intense radiation occurs at f = 25GHz. In this case EBW starts at the plasma center and is radiated mainly from the second harmonic.

3D spherical tokamak plasma model

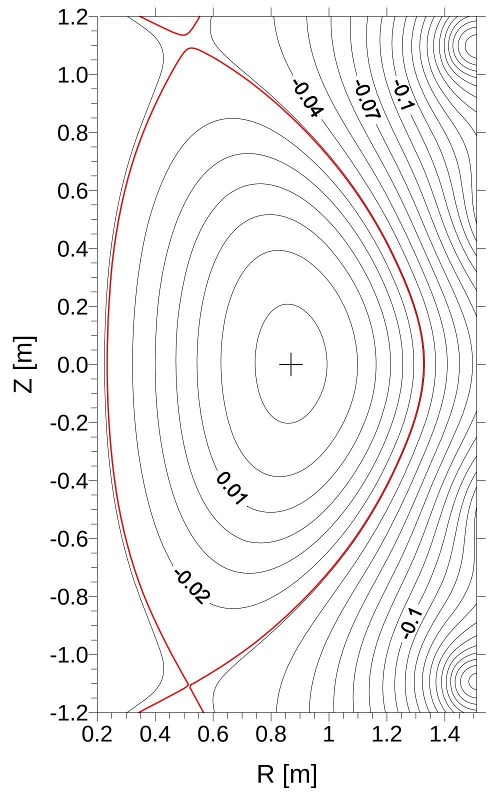
- A realistic 3D model of the MAST and NSTX plasma has been developed for the simulation.
- The magnetic field is reconstructed by splining the two potentials determined from the EFIT code, assuming toroidal symmetry.
- The temperature and density profile are obtained from the Thomson scattering measurements, and beyond the LCFS exponentially decaying profiles are used.



← density, electron temperature profiles

magnetic surfaces ψ(R,Z) →

MAST shot #8694, t= 280ms



ECE intensity

- The intensity of ECE detected by the antenna can be expressed as

$$I_{ECE} = const \times \iint \mathrm{d}S\, W_{Gauss} C_{EBW-X-O} \omega^2 T_{rad} C_{window} V_{relat}$$

where

$W_{Gauss} = e^{-\left(2r^2/w_0^2\right)}$ - Gaussian weight (*w_0* is the waist radius)

$C_{EBW-X-O}$ - conversion efficiency

$\omega^2 T$ - Rayleigh-Jeans black body radiation law

C_{window} - power transmission coefficient of the MAST window

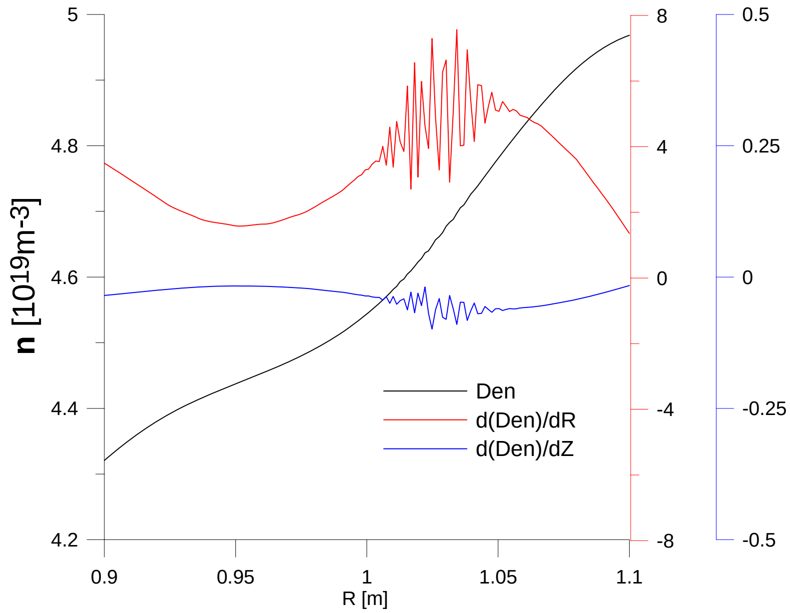
$V_{relat} = w^2 / w_0^2$ - relative visible area (*w* is the Gaussian beam radius at the plasma surface)

- The integration is taken over the intersection of the waist and the projection of the vessel window rim

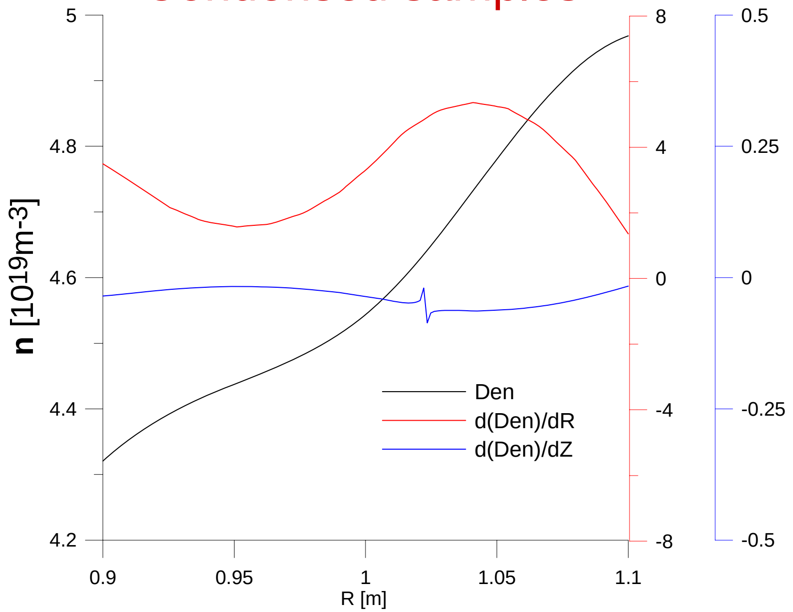
Improved density and temperature mapping in the plasma centre

- The plasma center in H-mode shots is shifted from the equatorial plane, so we first determine the exact position of minimum of $\psi(R,Z)$.
- Further, to determine $R_{LFS}(\psi)$ and $R_{HFS}(\psi)$ near ψ_{min} with high precision we use highly condensed samples in the R, ψ splining near $\psi_{min.}$. We thus suppress artificial oscillations in the derivatives of density and temperature, and avoid EBW ray propagation problems.

Equidistant samples



Condensed samples



New 18-40 GHz EBW antenna on NSTX

position of waists and their sizes as a function of frequency

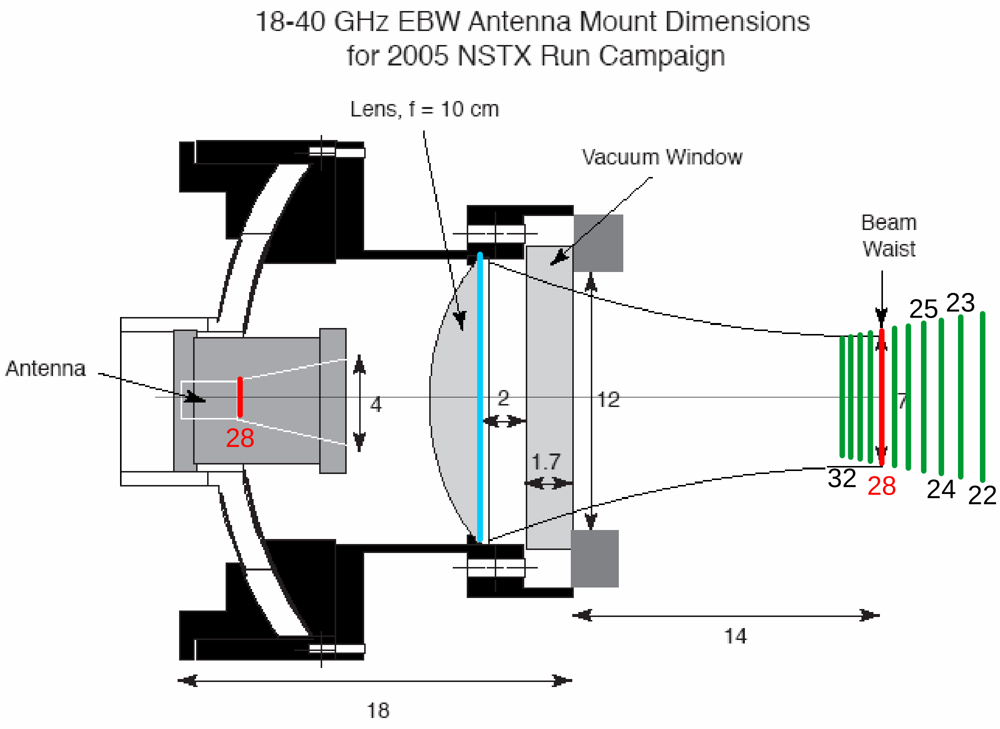
Field pattern in front of the antenna was measured by J. Caughman (16th RF Power in Plasmas in Utah) and the position of the waist of the Gaussian beam was determined for 28GHz

Using simple formulas for Gaussian beam transformation for thin lens

$$\frac{L_{w_{02}}}{f_{lens}} = 1 + \frac{\frac{L_{w_{01}}}{f_{lens}} - 1}{\left(\frac{L_{w_{01}}}{f_{lens}} - 1\right)^2 + \left(\frac{\pi w_{01}^2}{\lambda f_{lens}}\right)^2}$$

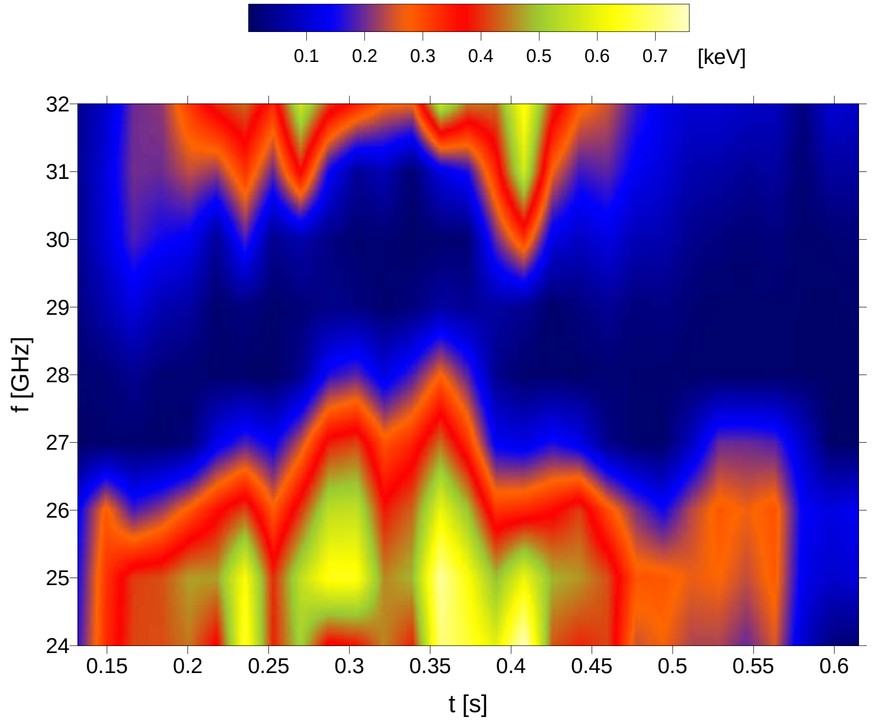
$$\left(\frac{w_{02}}{w_{01}}\right)^2 = \frac{1}{\left(\frac{L_{w_{01}}}{f_{lens}} - 1\right)^2 + \left(\frac{\pi w_{01}^2}{\lambda f_{lens}}\right)^2}$$

we determined the position of the input waist in the horn for 28GHz and then determine the position of waists and their radii for frequencies in the range 22-32GHZ

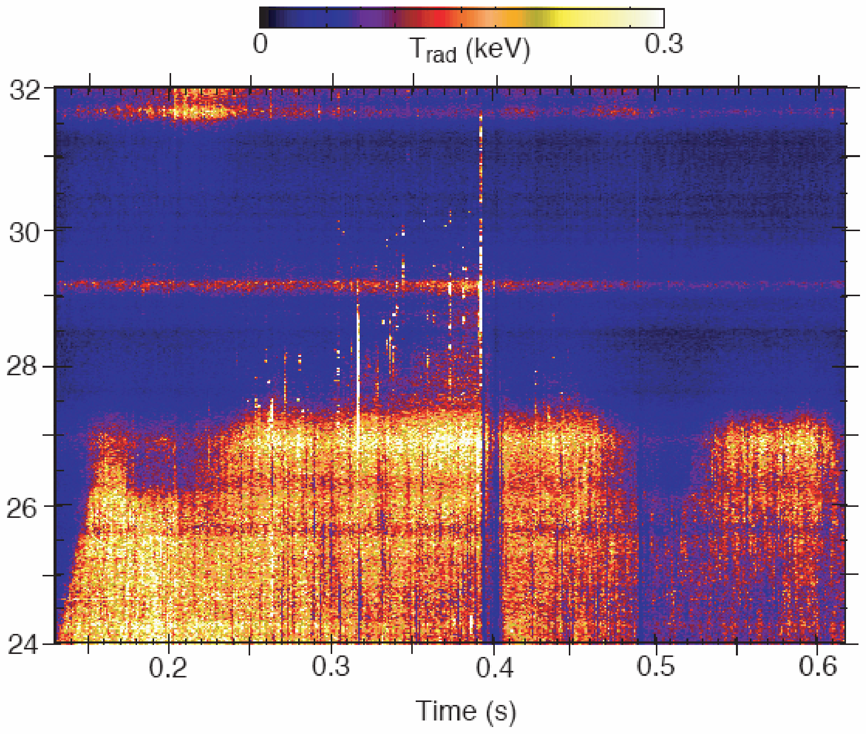


The time development of the frequency spectrum of ECE intensity from NSTX for #117970

Simulation



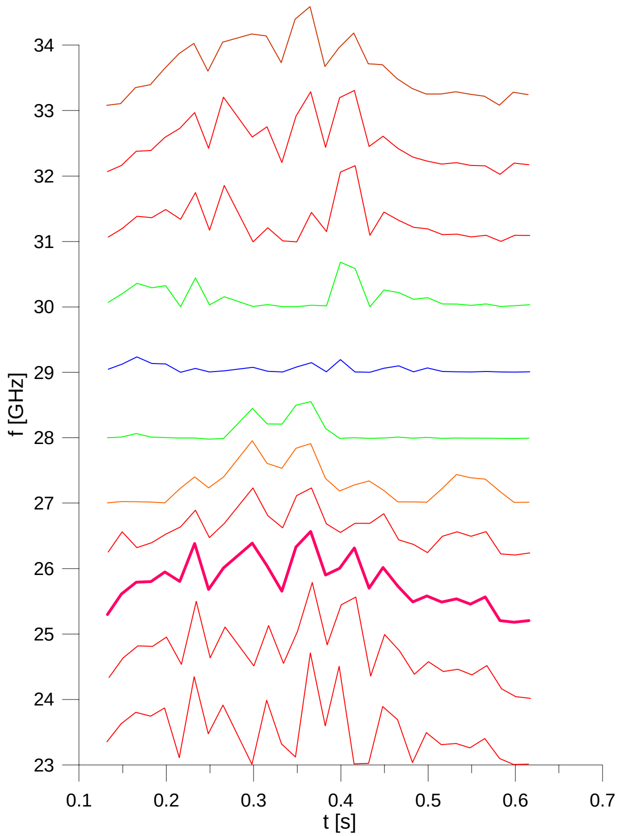
Experiment



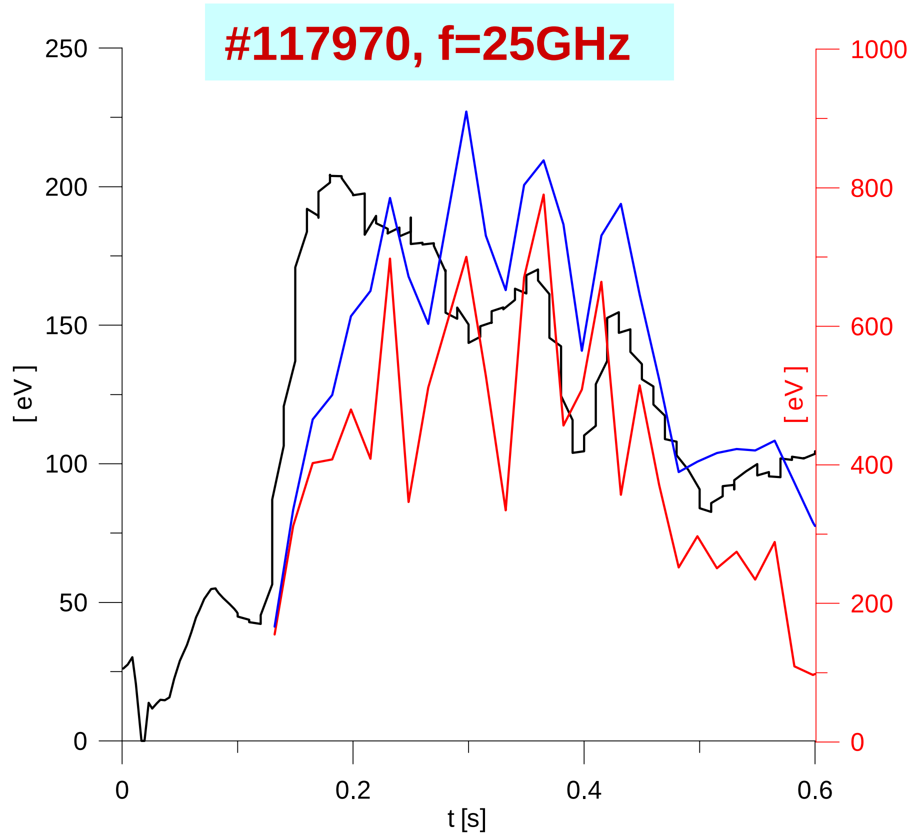
The 25 GHz EBW has the most intense emission during this shot

Collisional damping in the mode conversion region produces a rugged profile of the simulated signal (red). To eliminate collisions, set Z_{eff} =0 (blue).

Simulated intensity of EBE in the range 23-33GHZ

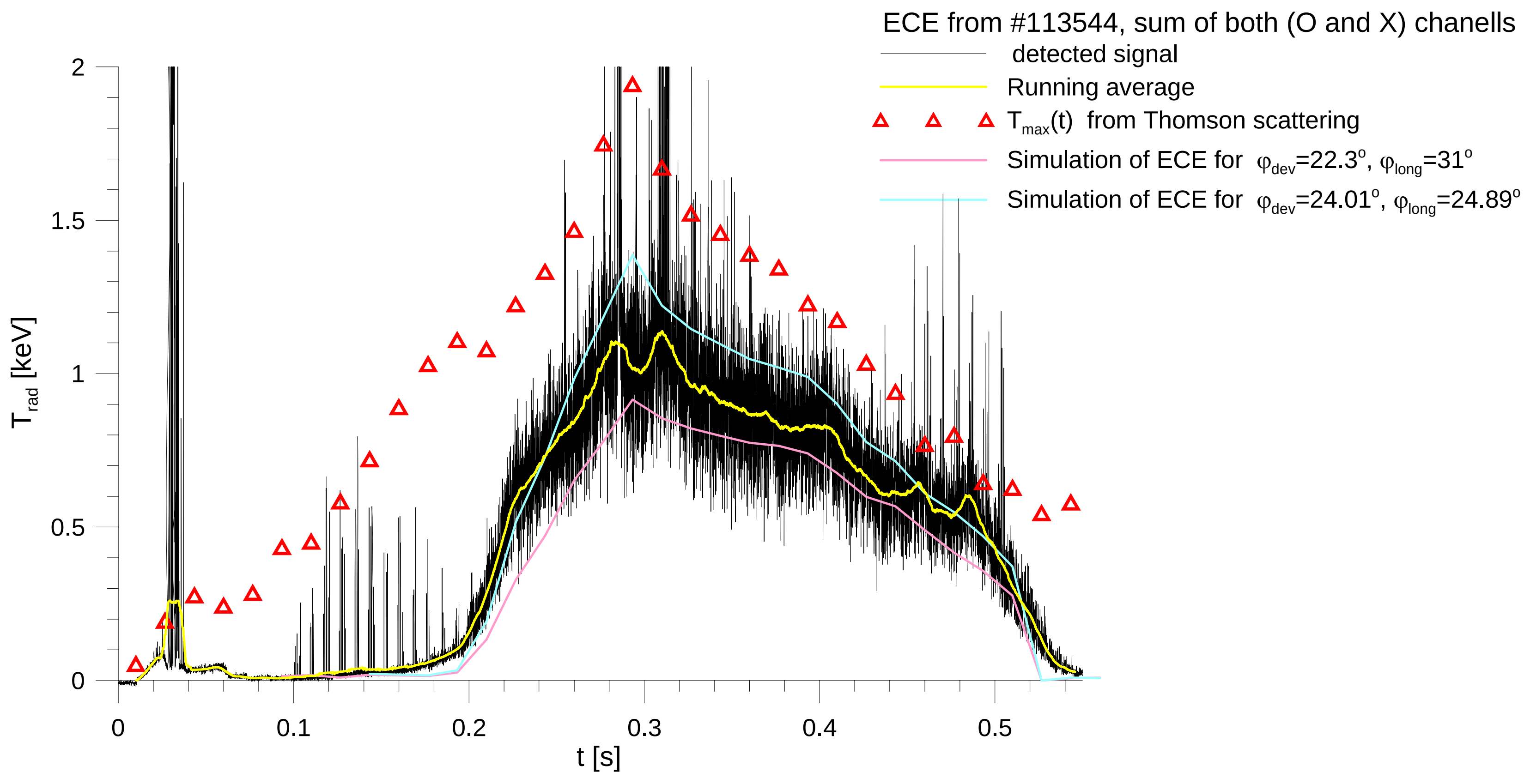


Comparison of measured EBE signal (black) with simulation (red - Z_{eff}=1.34, blue- Z_{eff}=0)



Present modeling is predicting 2-3 times higher T_{rad} than we measure and we are trying to understand why this is

- We reach excellent fit between simulated and the EBW signal detected by NSTX (EBW signal is noisy due to fluctuation of density in the conversion region – no fluctuation are included in the simulation)

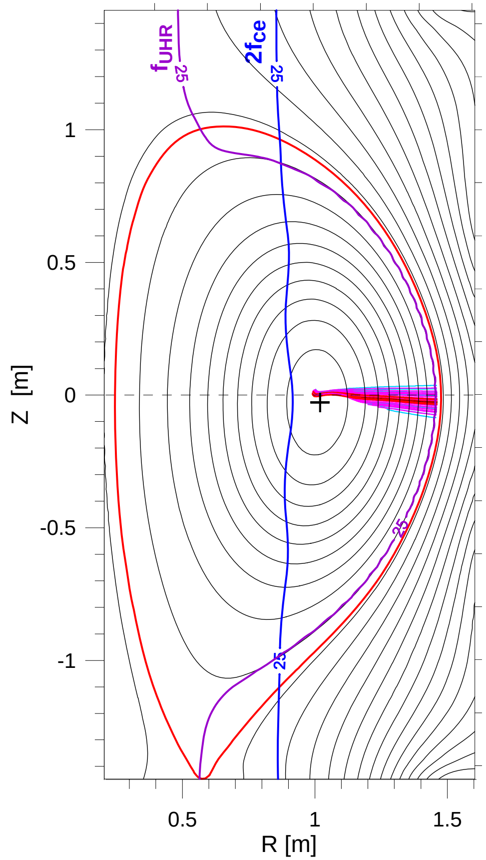


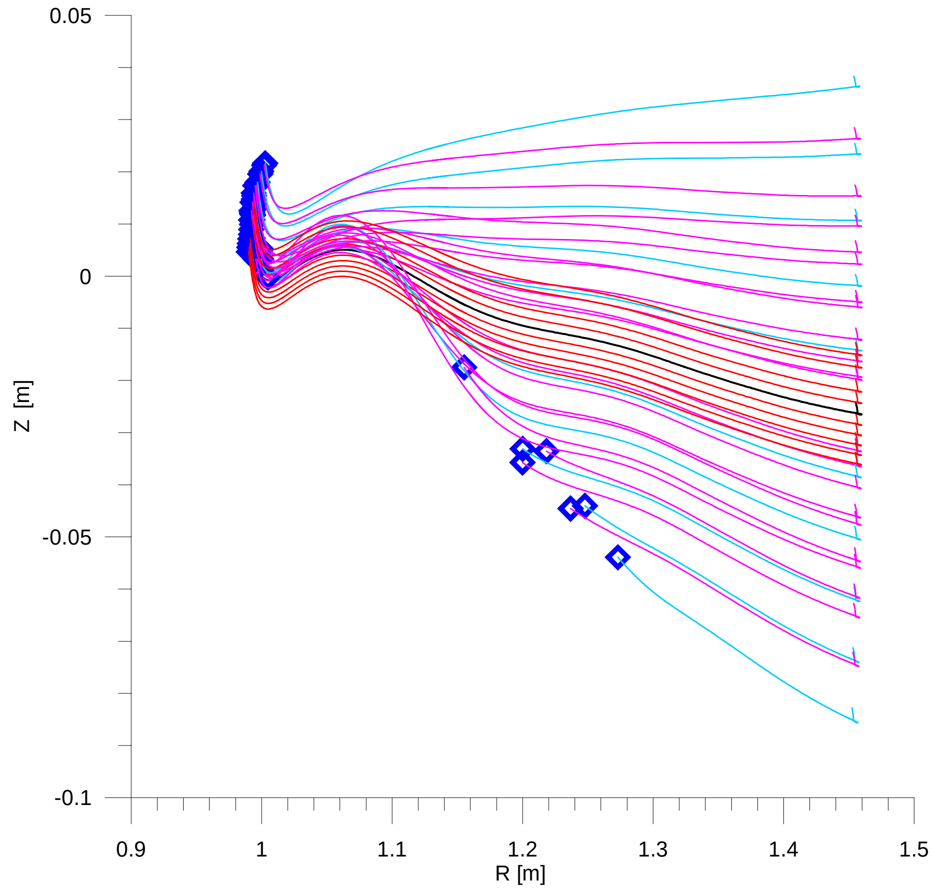
Peak in simulated signal at t=0.298s, f=25GHz

Practically all the rays penetrate to the plasma center and are absorbed (or emitted) from the 2nd harmonics.

Several rays emitted below the equatorial plane are absorbed at the 3rd harmonic, half way between the plasma boundary and the plasma center

Typical scenario before development of magnetic well



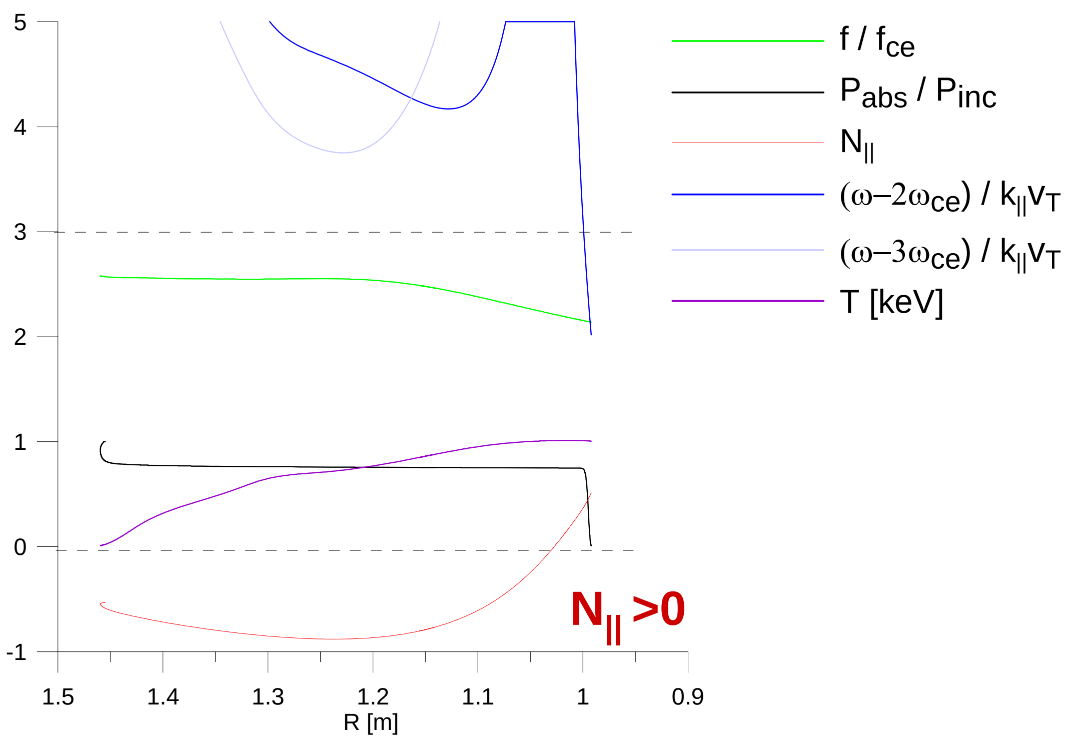


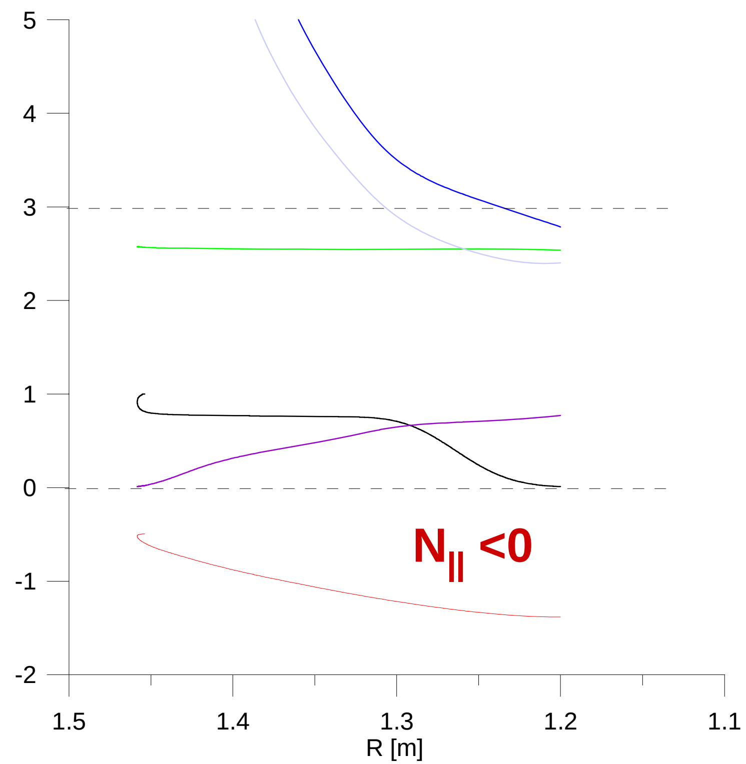
Radial profiles of individual rays

#117970, t=298ms, Z_{eff}=1.362,   f=25GHz, , $\varphi_{dev}=21^o$, $\varphi_{long}=20^o$

The central ray is absorbed at the 2nd harmonic near the plasma center. $N_{||}$ usually oscillates for equatorial rays

Rays launched below the equatorial plane are absorbed at the 3rd harmonic, near the plasma periphery

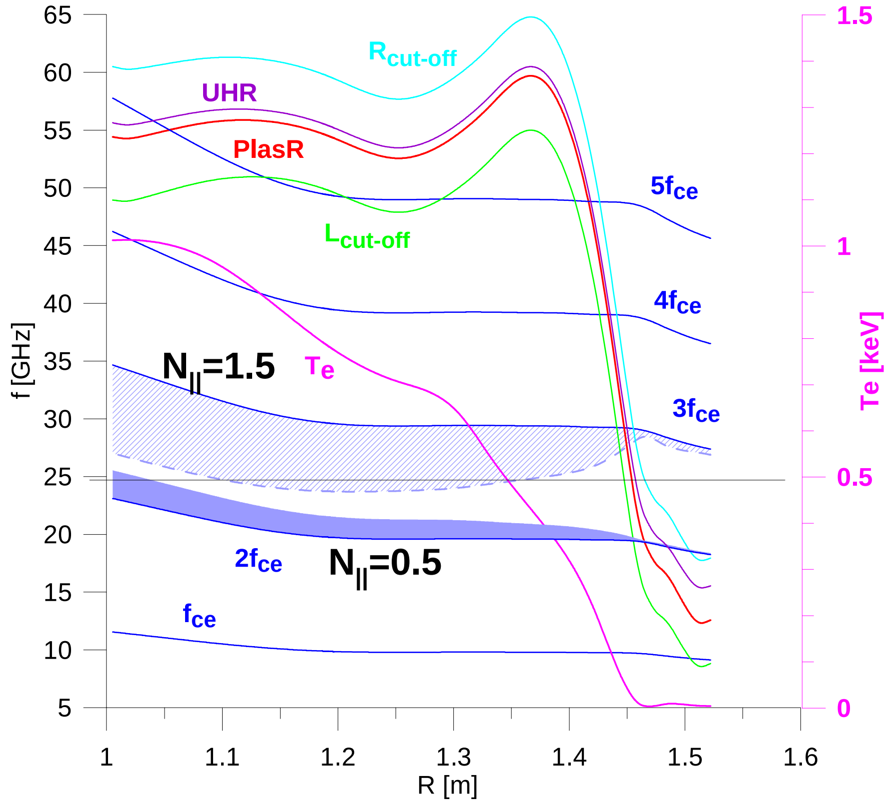


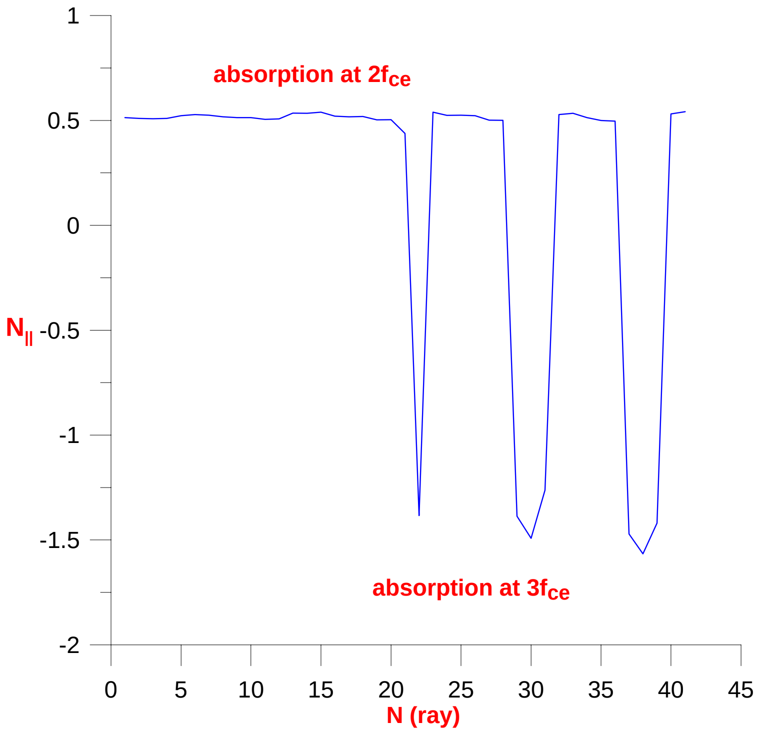


Profiles of characteristic resonances and cut-offs

$N_{||}$ at the absorption position for 41 different rays

#117970, t=0.298s, f=25GHz, $\varphi_{dev}=21^o$, $\varphi_{long}=20^o$





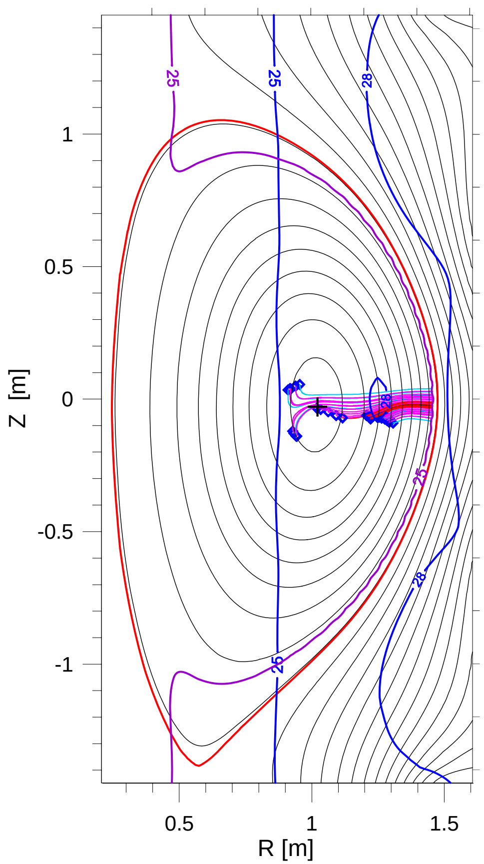
EBW emission can start only from the shadded regions and not from the EC harmonics.
Broadening of $n\omega_{ce}$ is given by the factor $1/(1\pm 3N_{||}v_T/c)$

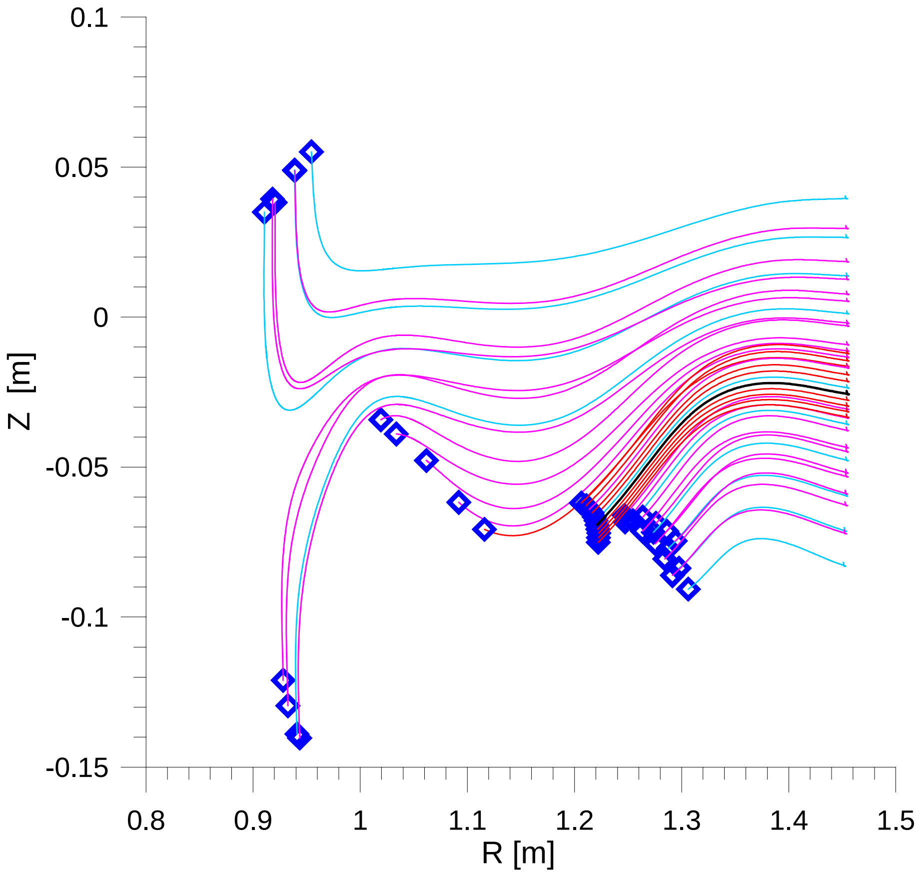
The sign of $N_{||}$ determines the direction of the generated current

Main peak in simulated signal at t = 0.365 s, f = 25 GHz

The plasma temperature reaches its maximum and the magnetic well is formed half way between the plasma boundary and the plasma center

Most of the rays are absorbed (or emitted) at the 3rd harmonic - at the rim of the magnetic well. Several rays emitted above the equatorial plane are absorbed at the 2nd harmonic near the plasma center.



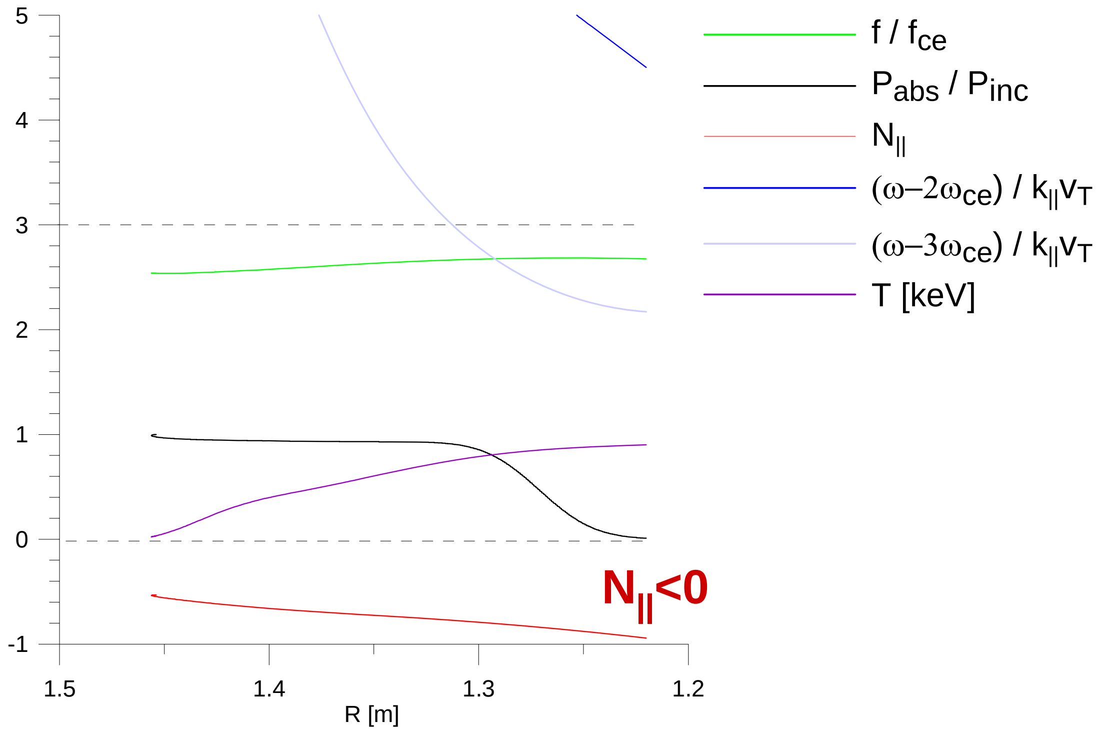


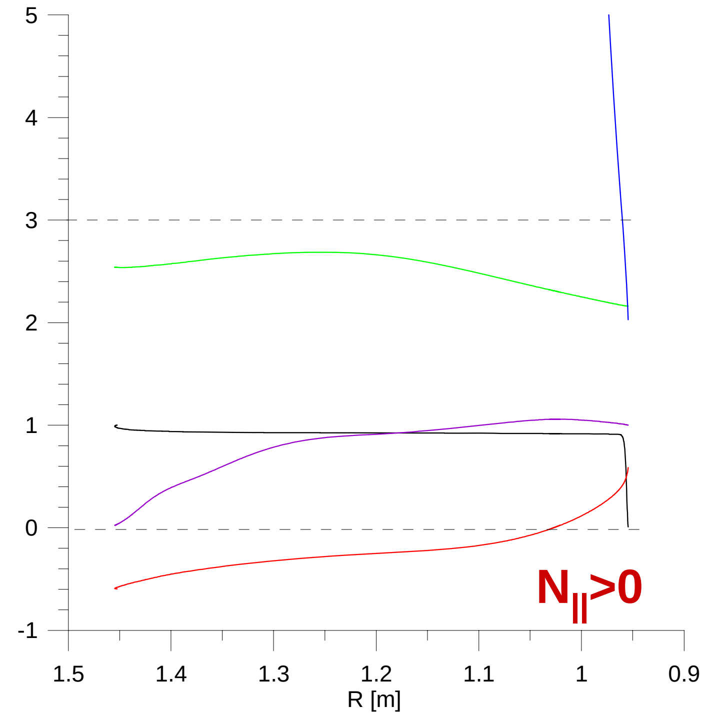
Radial profiles of individual rays

#117970, t=0.365 s, Z_{eff}=1.362, f=25 GHz, , $\varphi_{dev}=21^o$, $\varphi_{long}=20^o$

Central ray is absorbed at the 3rd harmonic at the rim of the magnetic well

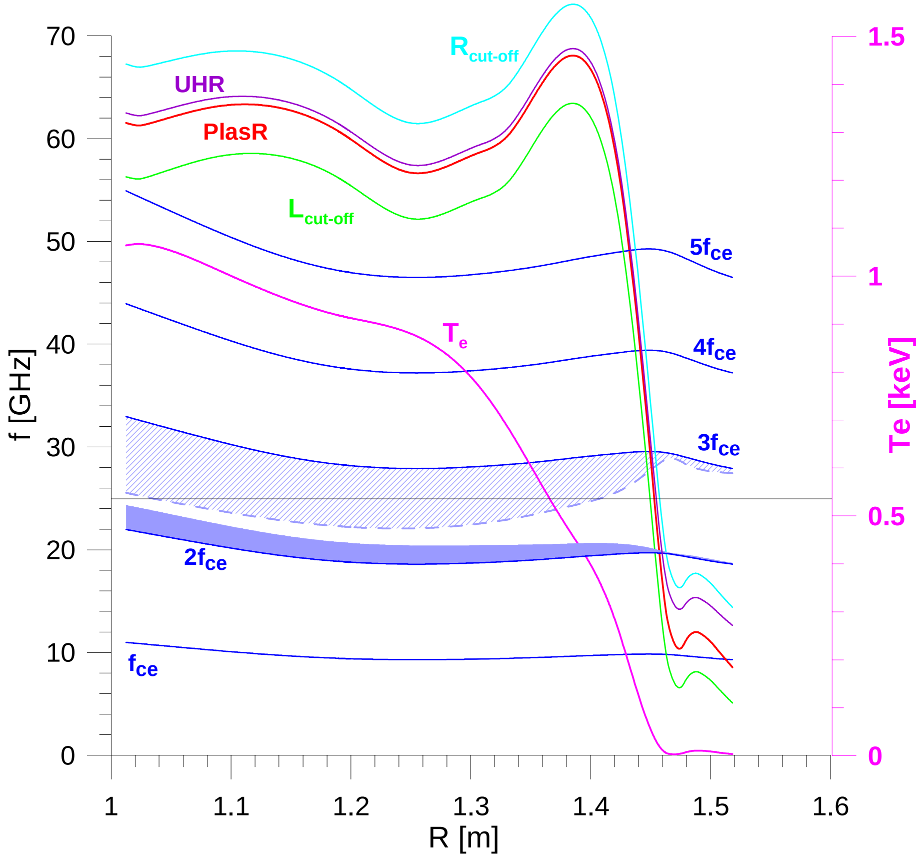
Rays launched below the equatorial plane are absorbed at the 2nd harmonic near the plasma center





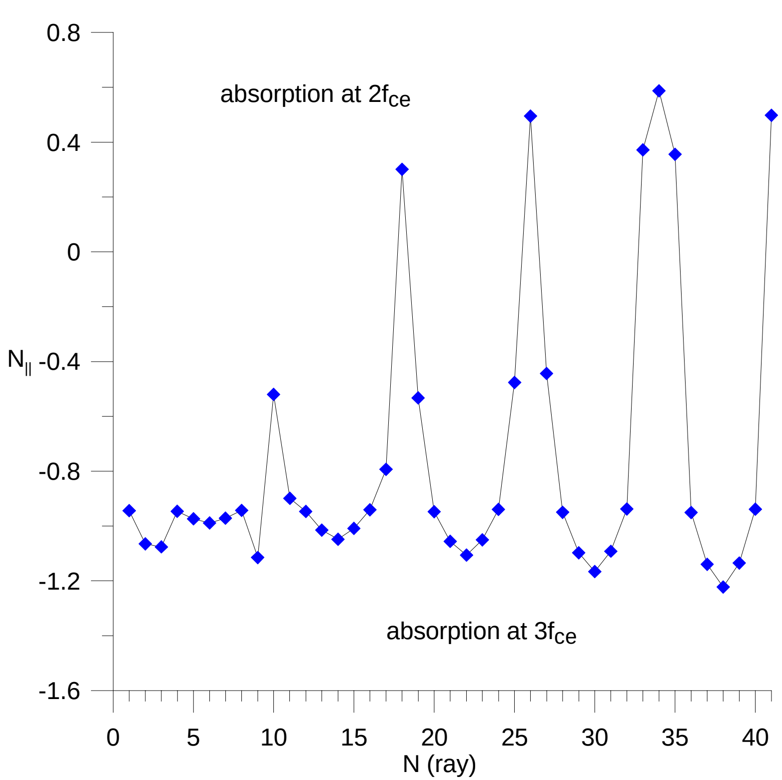
Profiles of characteristic resonances and cut-offs (t = 0.365 s)

Magnetic well prevents the emission of EBW from the plasma center



$N_{||}$ at the absorption position for different rays (t = 0.365 s)

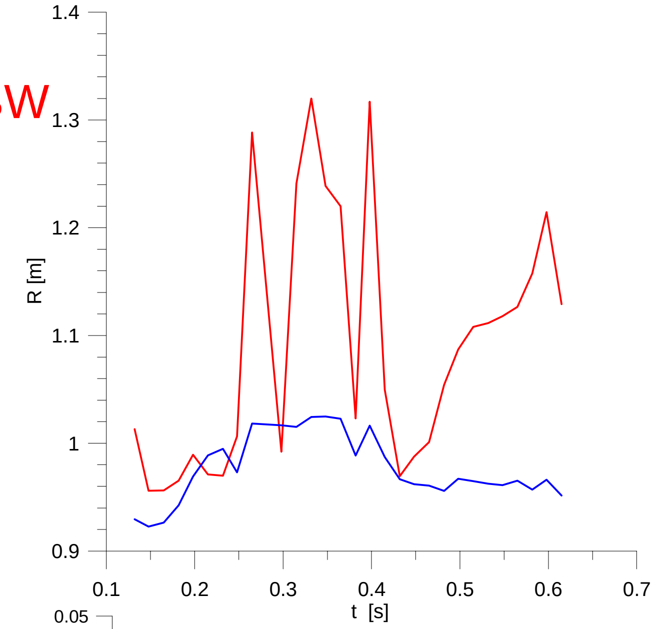
In the case of wave absorption the current will be generated in the opposite direction to that at t = 0.298 s



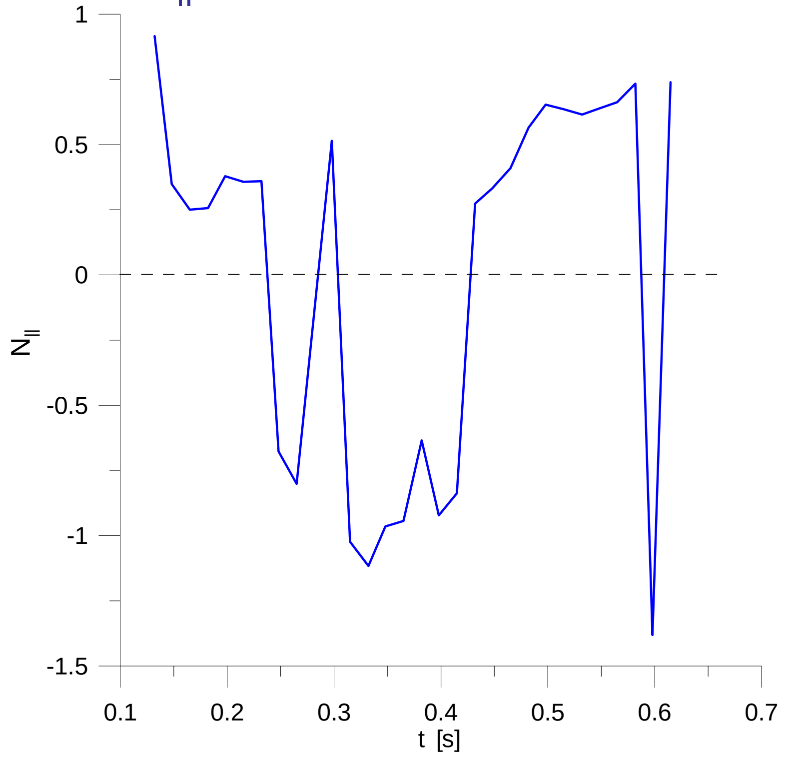
Time development of the global characteristic of discharge and EBW emission (or absorption)

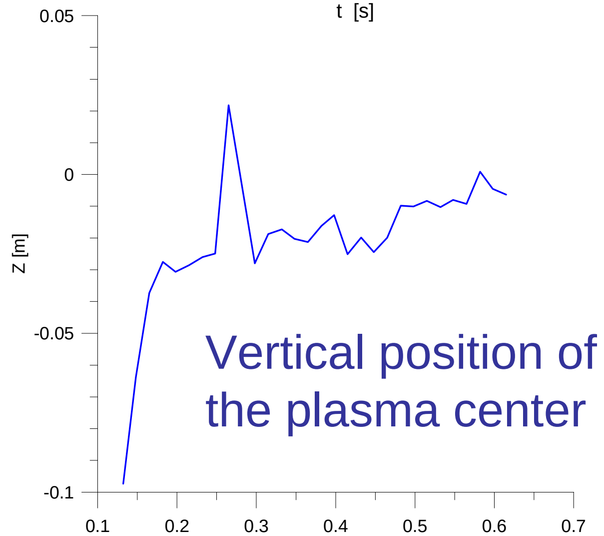
Radial position of EBW absorption

Vertical position of the plasma center



$N_{||}$ at EBW absorption





Conclusions

- **EBW emission from the H-mode is a complicated process.**
  We find the plasma center moves from the equatorial plane (t = 0.248 s) and a magnetic well (t = 0.365 s) is formed between the LFS plasma boundary and the plasma center.

- Both these processes typically switch the emission from the 2nd to the 3rd Harmonic -- i.e., from the plasma center to the plasma periphery.

- Because $N_{||}$ oscillates, for rays launched in the equatorial plane these transitions are accompanied by a change in sign of $N_{||}$ at the position of absorption.

- Thus the absorbed wave would generate currents which at these different times will have opposite directions and driven at different radial positions.
  Off mid plane launch for EBWCD on NSTX is prepared.

• Our simulations are sensitive to the level of collisional damping in the mode conversion region. This sensitivity is not apparent from preliminary experimental data

[Possible exception: there is a drop-off in EBW emission at t = 0.382 s, when after a disruption there is a substantial drop in the plasma temperature and the UHR is in front of the LCFS]

Thomson scattering Te data radial resolution is typically 1-2 cm near the UHR and few data points are near the UHR resulting in large uncertainties when modeling the EBW coupling physics. There are additional radial data near the UHR from Thomson scattering for these plasmas from the August experiment that may be calibrated and available later this year. This additional data may allow better modeling of the EBW coupling.

In the simulation code, the effect of collisions can be switched off by setting $Z_{eff} = 0$.