# High-field-side ECE diagnostic for W7-X: some features and advantages

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# Why it should be interesting

- W7-X is based on the concept of optimised confinement. ECCD will be used for feedback control of the total plasma current. The possibility to perform this control is already being investigated with the help of a newly developed predictive transport code [Yu.A. Turkin, EPS-2004, P1-198].

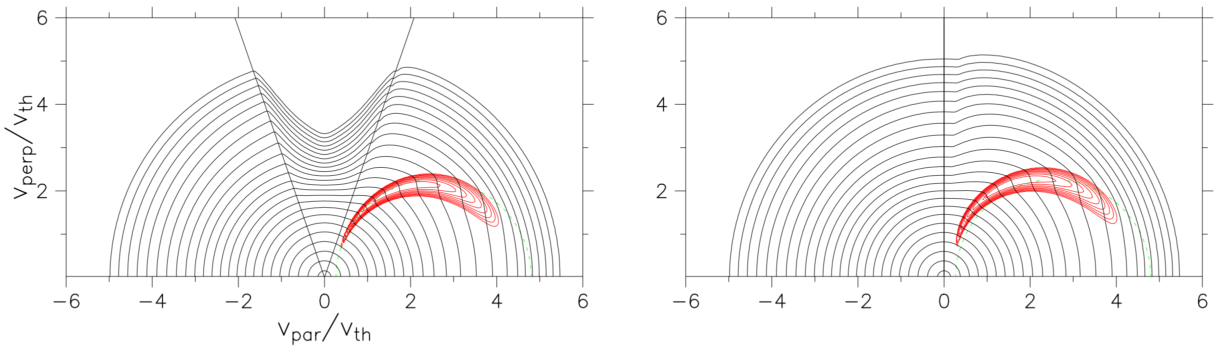
- The ECRH system is designed for continuous operation with $P_{\rm RF} \lesssim$ 10 MW at the frequency 140 GHz.

- The scenario we analyse is a high power ECCD case (X2-mode) with the deposition profile highly peaked near the axis within $\Delta \approx$ 5 cm.
  Plasma parameters expected for the initial stage of W7-X operation:
  $n_e \simeq 3.0 \cdot 10^{19}$ m$^{-3}$, $T_e \simeq 4$ keV, and $B$ = 2.54 T on axis.

- For $p_{\rm RF} \lesssim$ 30 MW/m$^3$ $\kappa = p_{RF}/n_e T_e \nu_{ee} \simeq 5 \cdot 10^{-4} p_{RF} \sqrt{T_e}/n_{20}^2 \simeq 0.35$, which is large enough to expect a significant disturbance of the electron distribution function.

# Why it should be interesting (continue)

- FP simulations with the neoclassical (stellarator-specific) loss model also demonstrate a significant deviation of the distribution function from the Maxwellian in the heated region.




- Population of suprathermal electrons, which appears in the deposition region, can significantly affect the ECE spectrum.

- Apart from the standard $T_e$ diagnostic tools, i.e. LFS ECE measurements and Thomson scattering, the informativity of the HFS ECE measurements needs to be checked.

- The HFS observations provide general information about the suprathermal fraction, but their interpretation is not trivial and requests special attention.

# ECE simulations (sketch)

- The ECE spectrum is obtained from the radiative transport equation

$$I_\omega(s) = I_\omega^{inc}(\pm a)\,\mathrm{e}^{-(\tau_\omega(s)-\tau_\omega(s_0))} + \int_{s_0}^{s} \mathrm{d}s'\,\eta_\omega(s')\,\mathrm{e}^{-\left(\tau_\omega(s)-\tau_\omega(s')\right)} \qquad (1)$$

with optical depth $\tau_\omega(s) = \int^s \mathrm{d}s'\alpha_\omega(s')$, and absorption coefficient $\alpha_\omega$ and emissivity $\eta_\omega$

$$\alpha_\omega^X = \frac{\omega}{cN_\perp^X}|1 - \frac{i\varepsilon_{12}}{\varepsilon_{11}}|^2\,\varepsilon''_{11}, \qquad \eta_\omega^X = \frac{4\pi^2\omega^2}{c^3N_\perp^X}|1 - \frac{i\varepsilon_{12}}{\varepsilon_{11}}|^2\,G_{11}. \qquad (2)$$

The requested components of the microscopic current correlation tensor, $G_{11}$, and of the anti-hermitian part of dielectric tensor, $\varepsilon_{11}$, are

$$G_{11} = \frac{\omega T_e}{(2\pi)^5}\frac{\pi(\omega_p^2/\omega^2)}{2^{2n}(n-1)!^2}\left(\frac{N_\perp^X\omega}{\sqrt{\mu}\,\omega_c}\right)^{2(n-1)}\int \mathrm{d}\mathbf{u}\,\frac{u_\perp^{2n}}{\gamma}\,f(u_\perp,u_\parallel)\,\delta\left(\gamma - \frac{n\omega_c}{\omega}\right), \qquad (3)$$

$$\varepsilon''_{11} = -\frac{\pi(\omega_p^2/\omega^2)}{2^{2n}(n-1)!^2}\left(\frac{N_\perp^X\omega}{\sqrt{\mu}\,\omega_c}\right)^{2(n-1)}\int \mathrm{d}\mathbf{u}\,u_\perp^{2n-1}\,\frac{\partial f}{\partial u_\perp}\,\delta\left(\gamma - \frac{n\omega_c}{\omega}\right), \qquad (4)$$

with $f(u_\perp, u_\parallel)$ obtained from FP simulation.

# ECE simulations (continue)

- For a Maxwellian distribution function we have $\eta_\omega = \omega^2/8\pi^3 c^2 \cdot T_e \cdot \alpha_\omega$, and, for optically thick plasma,

$$I_\omega(a) \simeq \mathrm{Const} \ \cdot T_e(s_*) \tag{5}$$

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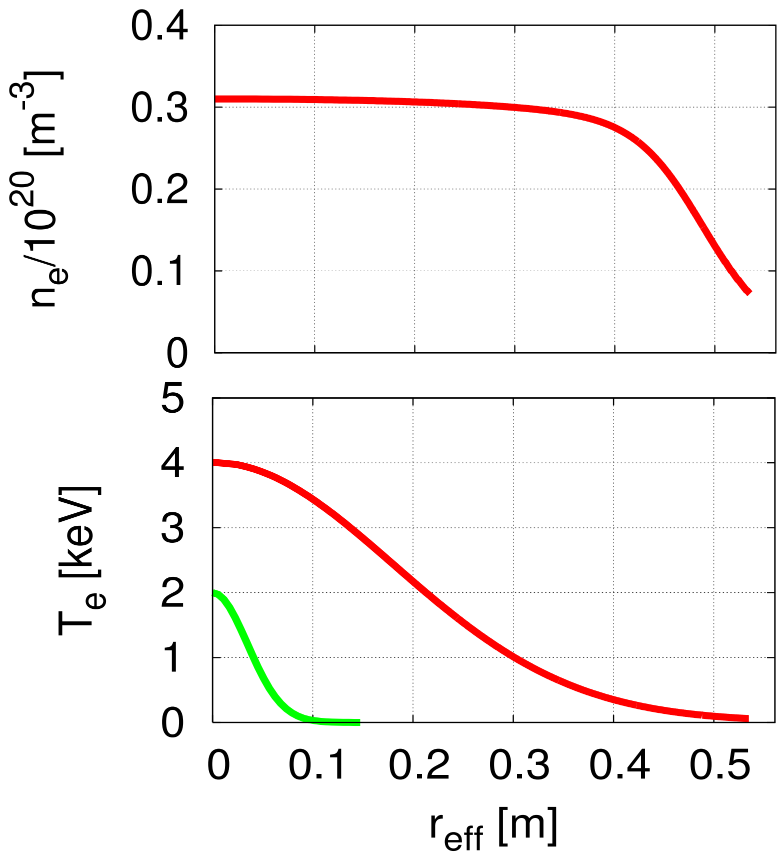
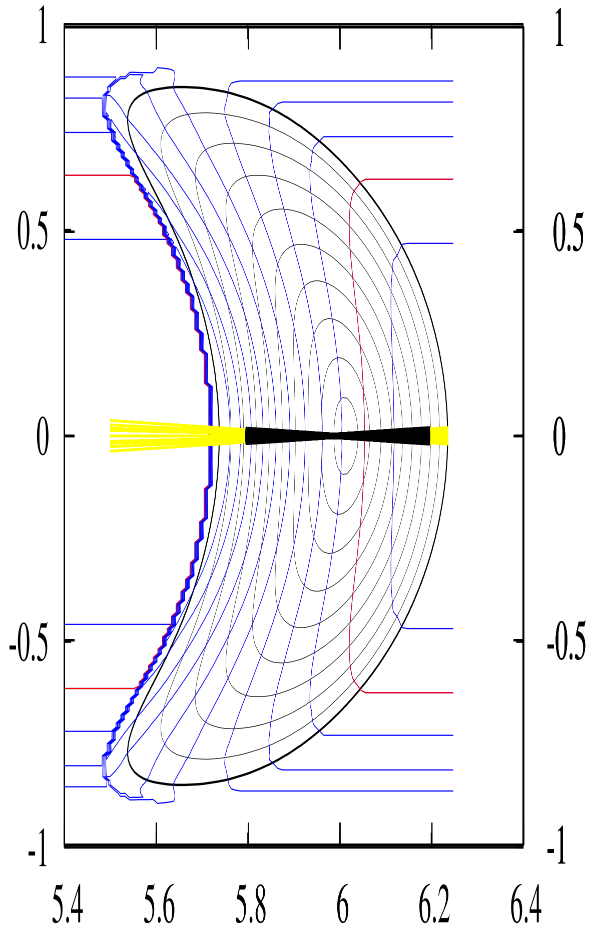
- We check the frequency range 115 GHz to 160 GHz, which more than covers the standard range of X2 observation for $B$ = 2.5 T, i.e. 135 GHz to 160 GHz.

- From the point of view of analysing suprathermal effects, the low frequencies, which correspond to the cold resonances situated outside of the plasma, are most interesting for HFS ECE measurements.

# ECE simulations (continue)

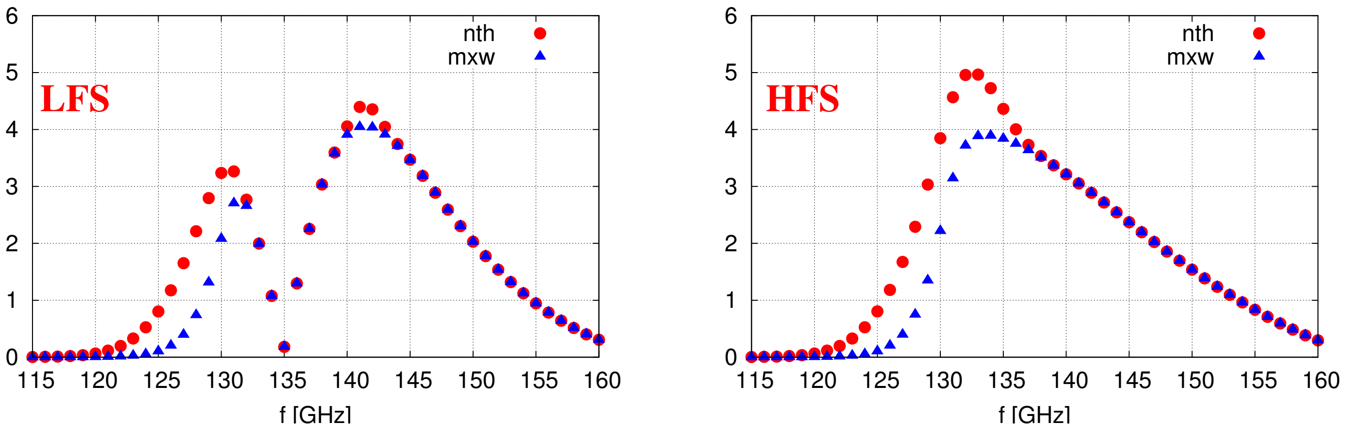
- Density and temperature profiles, deposition profile, and the rays seen by radiometer:



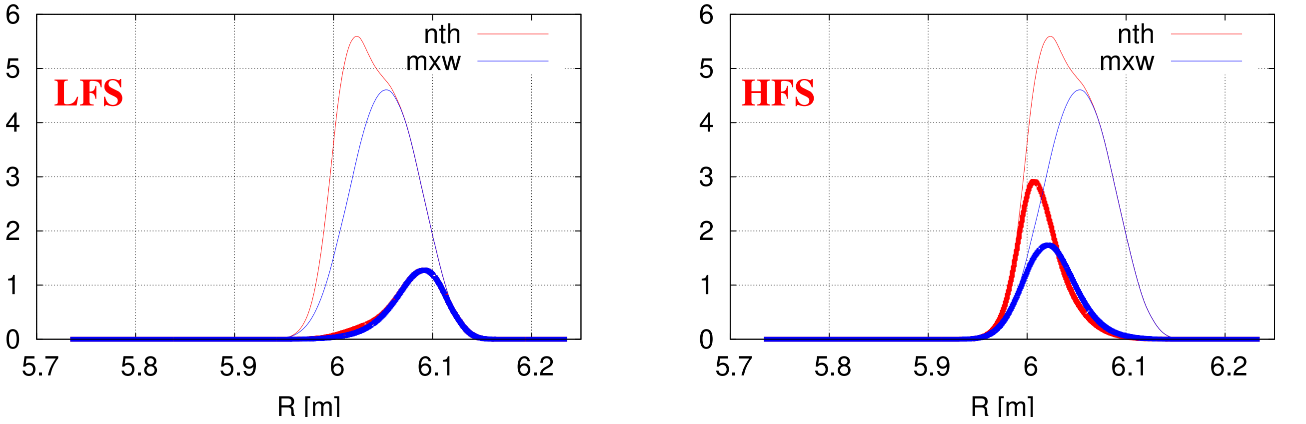



# ECE simulations (continue)

◇ ECE spectrum for LFS (left) and the same for HFS (right) observations.




◇ 132 GHz: emissivity with (thick lines) and without (thin lines) reabsorption ($R_{cy} \simeq 6.3$ m).



# ECE simulations (discussion)

- FP simulations show that the main disturbance of the distribution function is located at energies of 25 - 45 keV.

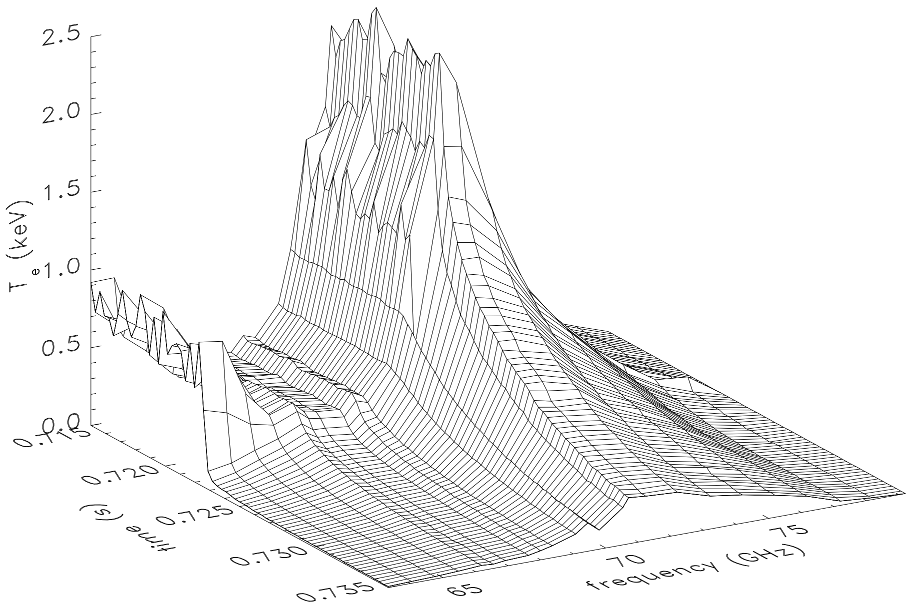
- The main contribution to the emission:
  HFS - (25 - 45) keV, i.e. $\Delta E \sim (6 - 12) \cdot T_{e0}$,
  LFS - (15 - 30) keV, i.e. $\Delta E \sim (15 - 30) \cdot T_{e,\mathrm{per}}$, respectively.

- However, the weights of (measured/simulated) $f_e$-disturbances are quite different: being maximal on axis, from where the HFS emission is originates, it is almost nothing on the periphery (LFS case).

- Usually the low frequency channels do not show so big spectral “hump” as predicted for the LFS observation, if an existance of the suprathermal populations is not expected. The time scale for the neoclassical transport in the $1/\nu$-regime is $\tau_{tr} \propto T_e^{5/2}/n_e$, and the ratio $\tau_{tr}/\tau_{ee} \propto T_e$ shows that on the periphery only bulk electrons should be Maxwellian.

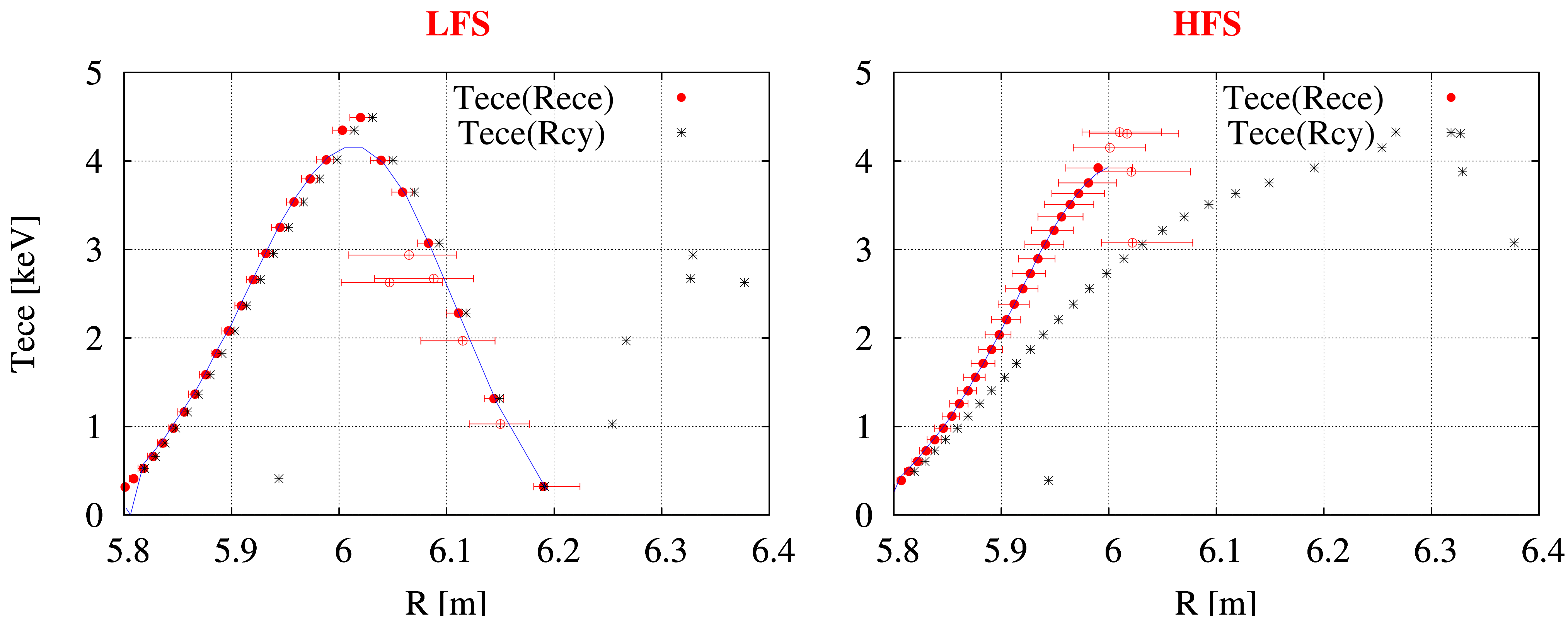
# ECE measurements (discussion)

- The (old) LFS ECE measurement results obtained at W7-AS during the ECRH experiments [M.Romè at al., PPCF **39** 117 (1997)]. The “nonthermal” feature at low frequencies decays much faster than the bulk temperature after the power is switched off.



# ECE simulations (discussion)

◇ Radial $T_{ECE}$ profiles and the spatial resolution of ECE measurements:



# Summary

- Despite poor localisation of the emission, the HFS diagnostic can be used for a rough estimation of the deposition profile.

- Due to the possibility to observe the heated region from the HFS, the power modulation experiments should also be more informative in comparison with the LFS

- While the HFS measurements always contain the information about the suprathermal electrons in the heated region, the "hump" at low frequencies of the LFS spectrum is expected to be supressed due to the optimised confinement;