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Impact of an Electron-Cyclotron source on tokamak turbulence

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Abstract

An electron-cyclotron (EC) source can induce an enhanced electron transport even far from the power deposition area. This transport is attributed to an increase of turbulent transport induced by the interaction between the EC wave and the plasma. This claim is supported by different indirect evidences pointing in the same direction. On the experimental side, the detailed analysis of TCV plasmas heated by a power-modulated electron-cyclotron suggests an increased transport of suprathermal electrons proportional to the applied power. This is associated with a modest but non negligible increase of the fluctuation level. The increase of particle transport when the electron-cyclotron heating source is applied is also supported by simulations of these TCV shots performed with the Fokker-Planck code LUKE, and is also suggested by global gyrokinetic simulations performed with the ORB5 code.

Context

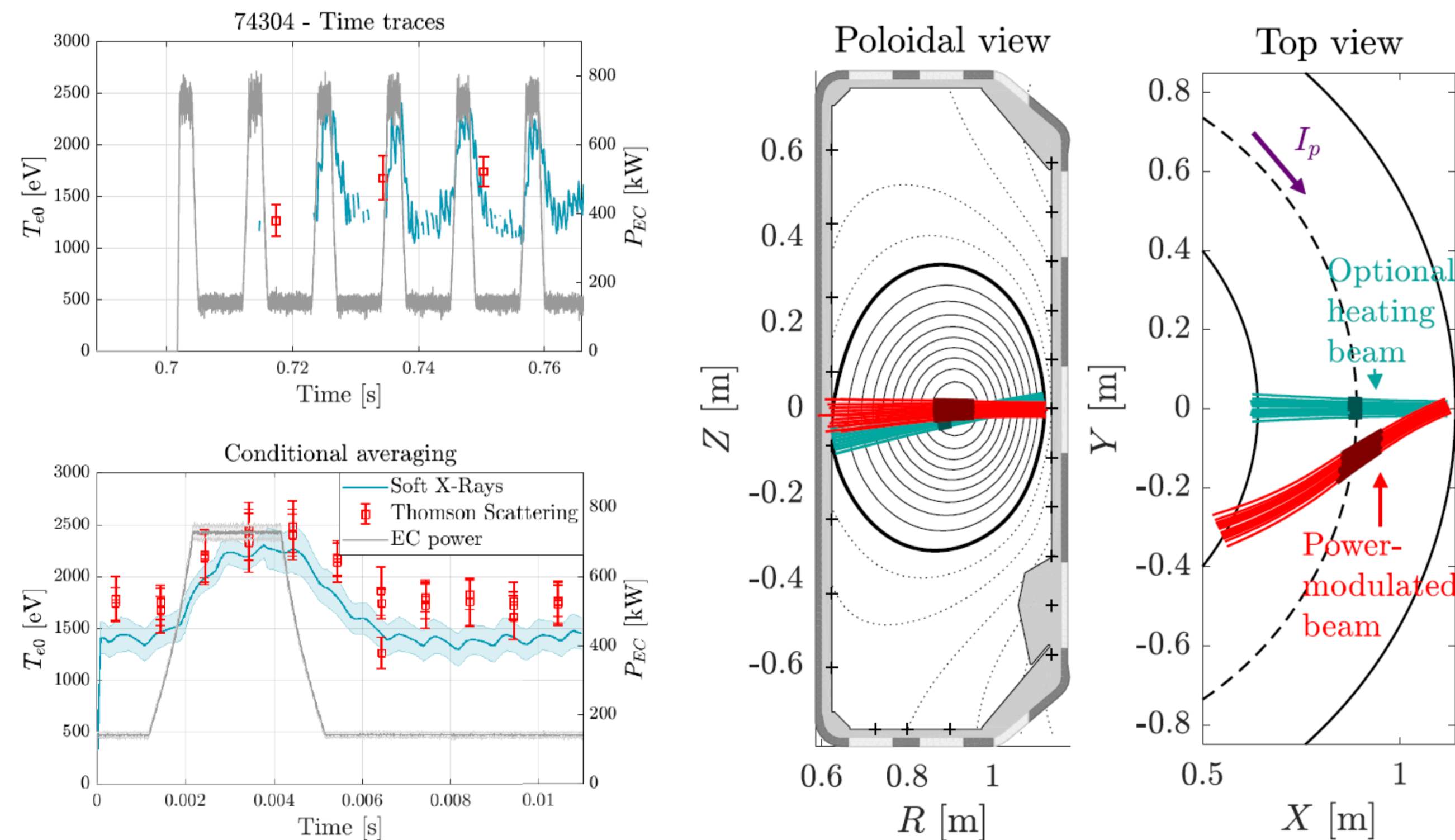
- EC source can be used for heating and current generation
- The high spatial localization of power deposition make it an interesting option for MHD control scheme [1]
- But some experimental observations suggest that suprathermal electrons can be observed far from the theoretically predicted deposition area. Two mechanisms are proposed:
 - Scattering of the EC beam by turbulent fluctuations
 - Increase of turbulence by the EC power deposition, leading to an efficient transport of suprathermal electrons (this presentation)
- All the results presented here are coming from a recent publication [2]

Experimental observations

❖ Experimental setup

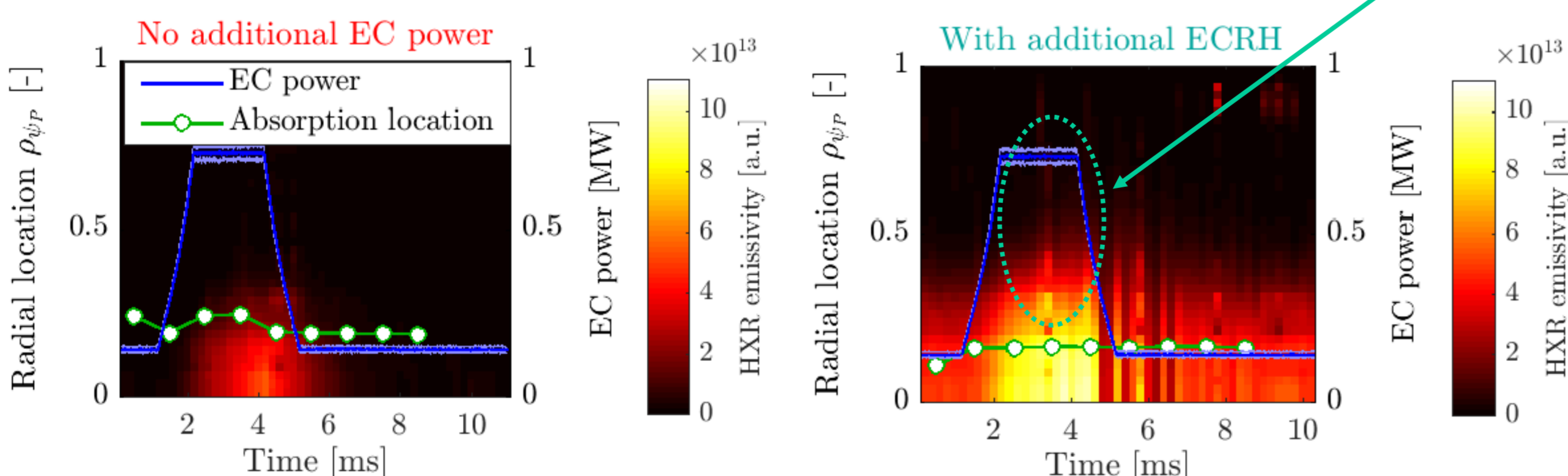
A set of four limited plasmas were done in TCV. These plasmas are heated by two EC beams

- One in ECCD configuration (2 angles scanned) whose power is modulated in time (red beam). This modulation allows to increase the statistics by conditional averaging.
- An optional beam in pure ECRH configuration with fixed power.



❖ Evaluation of suprathermal electron transport

HXR signal coming from suprathermal electrons, Suprathermal electrons detected far from the deposition area.



Effective suprathermal electron diffusion computed via emissivity cross-correlation

$$c_{\times}(r, \tau_d(r)) = \max_{\tau} (c_{\times}(r, \tau)) \quad \text{where} \quad c_{\times}(r, \tau) = \int_{-\infty}^{\infty} \bar{\epsilon}_{HXR}(r^{abs}, t) \bar{\epsilon}_{HXR}(r, t - \tau) dt$$

Exponential decay length of the perturbation:

$$F^{fit}(r) = -\lambda_d^{-1} r + F_0^{fit} \quad \text{where} \quad F(r) = \ln[\epsilon_{HXR}(r, \tau_d(r))]$$

Radial phase velocity:

$$\tau_d^{fit}(r) = v_{\phi,d}^{-1}(r - r^{abs})$$

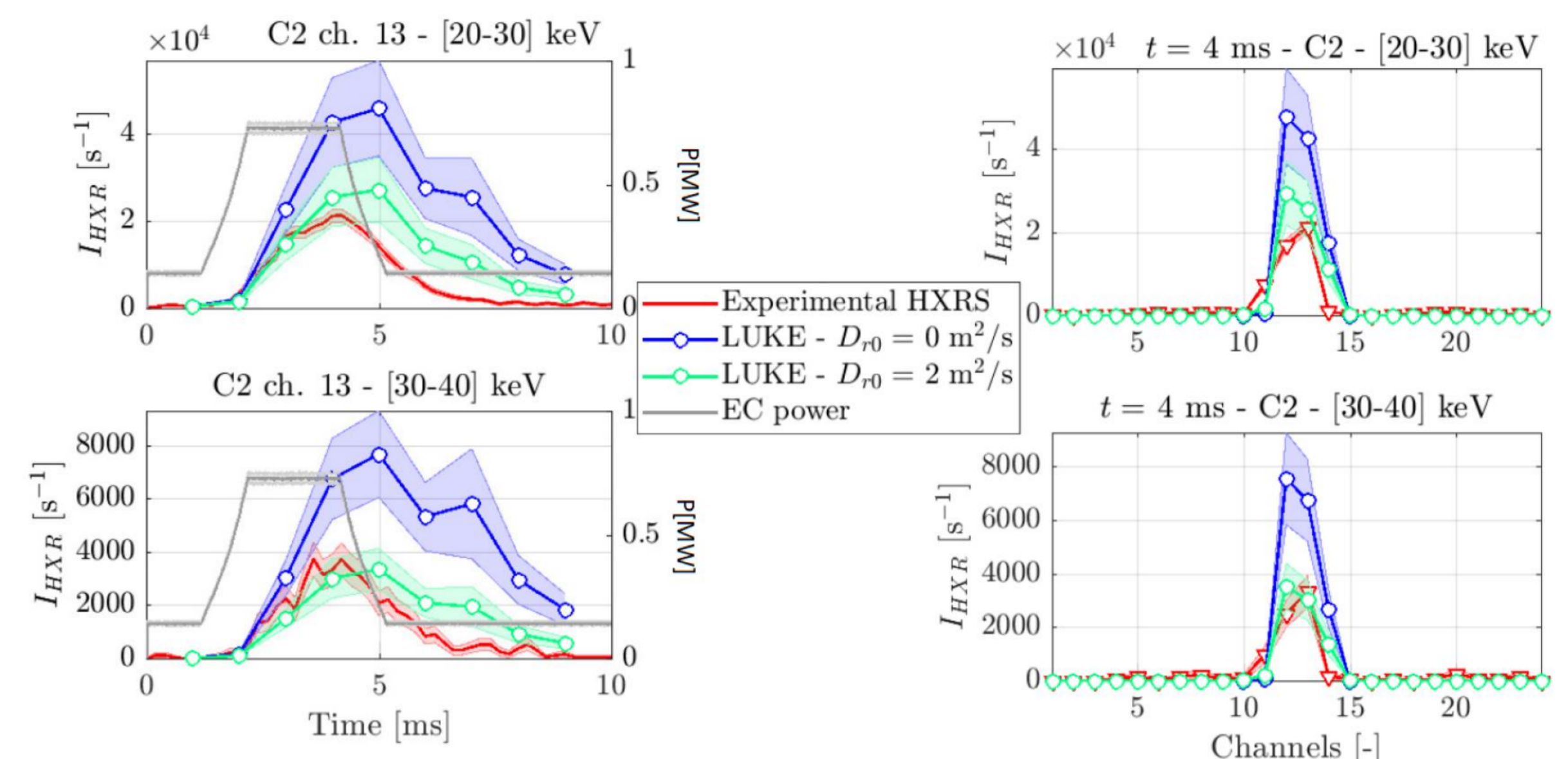
Suprathermal electron diffusion [3]:

$$D_r^{exp} = \lambda_d v_{\phi,d} / 2$$

Simulation

❖ Need for an ad-hoc transport to match experimental observations code LUKE

LUKE code solves the evolution of the bounce averaged electron distribution function in presence of an EC source.



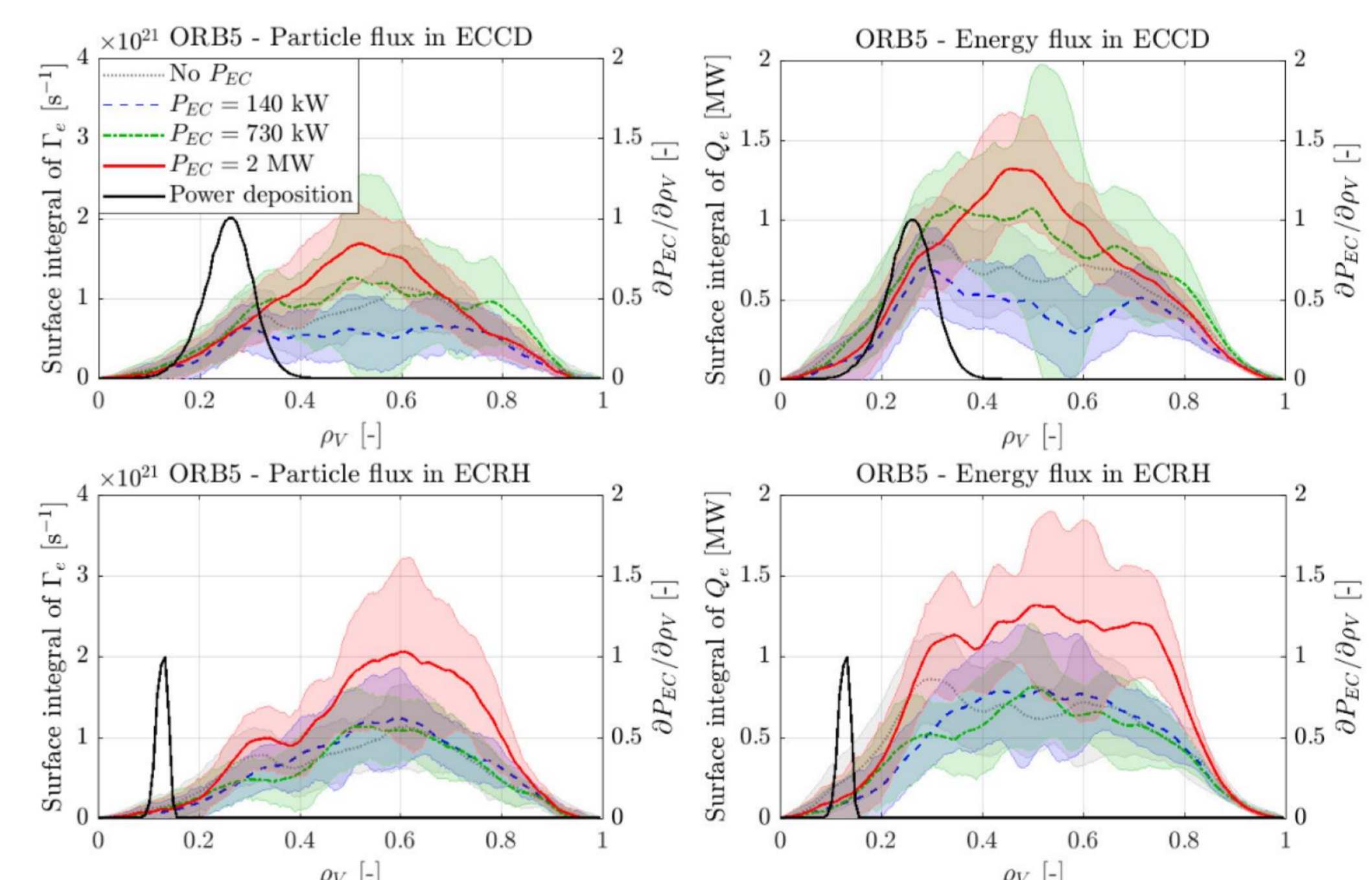
An ad-hoc radial diffusion coefficient [4] need to be added to match experimental data. The intensity of this transport is similar to the one observed experimentally.

θ_0^{abs}	P_{EC}	D_r^{exp} [m ² /s]	D_r^{LUKE} [m ² /s]
57°	-	0.9 ± 0.4	2
65°	-	0.6 ± 0.2	2
57°	794 kW	5 ± 3	4
65°	794 kW	6 ± 4	4

❖ Gyrokinetic simulations: modification of turbulent electron flux in presence of an EC source

- A realistic EC source [5,6] has recently been derived and implemented in the gyrokinetic code ORB5 [7].
- A power scan, for two injection angles (pure ECRH or ECCD) was performed
- The simulation time is short enough to consider that the background profiles did not evolve, but long enough to have turbulence saturation.

An increase electron transport is found when increasing the input power, in qualitative agreement with experimental observations



Conclusion

- Experimental observations and numerical simulations show that the electron transport increases with the power of the EC source.
- This transport is associated with increased turbulent fluctuations [2] (not shown here).

Perspectives

- Longer gyrokinetic simulations with more realistic profiles to confirm the trend observed
- Improvement of the ad hoc radial transport model used in LUKE thanks to gyrokinetic simulations
- On the experimental side: try to get closer to a pure ECRH case for the power modulated beam to test the higher impact observed in gyrokinetic simulation. But difficulty for HXR measurements

Acknowledgement

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