The transport of NTM-controlling EC wave due to density fluctuations in European DEMO

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Key Take-Aways

- First study of EC propagation including density fluctuations for European DEMO
- Significant broadening of beam, depending on the launch configuration
- Estimation of power requirement for NTM mitigation shows:
  - Configuration with lowest broadening not necessarily the best candidate
  - Ability to drive large absolute current is important
  - For final assessment, beam broadening AND absolute current should be considered

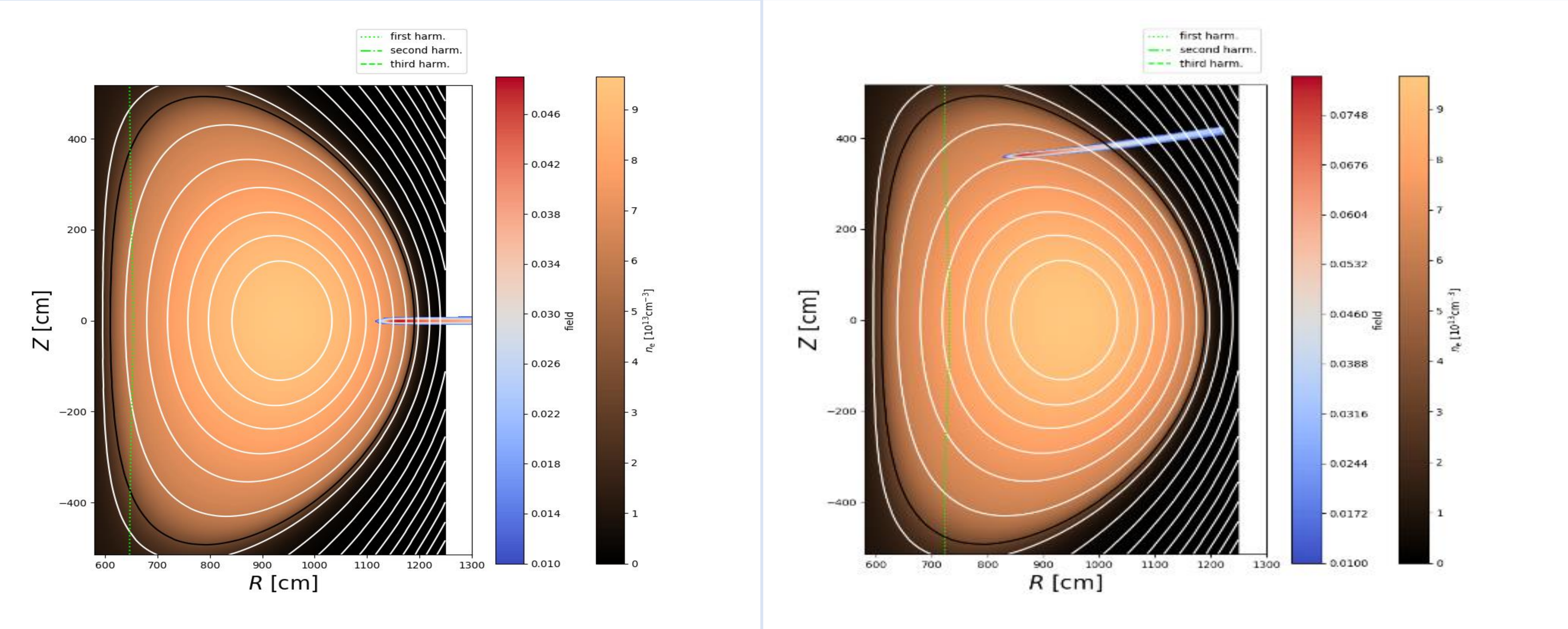

Figure 1: EC antenna positions at the equatorial port (EP, left) and the upper port (UP, right).

BACKGROUND AND SIMULATION SET-UP

- EC beams propagate through turbulent plasma, density fluctuations act as random lenses and could potentially diffuse the beam
- Neoclassical tearing mode (NTM) mitigation requires ECCD inside the mode
- Earlier work [1] estimated beam broadened by a factor of two for ITER
- European DEMO design considered with four different EC configurations (see Figure 1)
  - Pos 1: Equatorial port (EP), low toroidal injection angle (170 GHz)
  - Pos 2: Upper port (UP), optimal toroidal injection angle (170 GHz)
  - Pos 3: EP, optimal toroidal injection angle (170 GHz)
  - Pos 4: EP, low field side absorption (with 146 GHz reduced frequency)
  - Positions not necessarily feasible engineering-wise, selection not extensive -> academic physics study rather than extensive engineering design
- Simulations using WKBeam [2] and TORBEAM codes [3]
- Assumptions for turbulence identical as for ITER study [1] (see Figure 2)

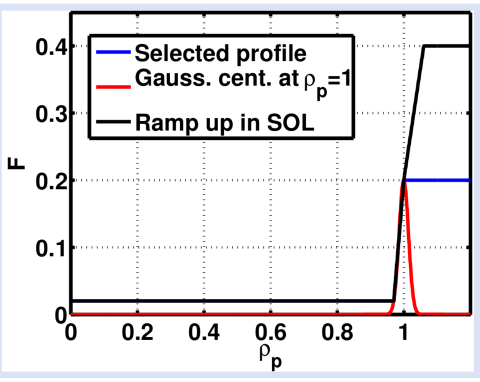

Figure 2: Profile of the fluctuation amplitude $F=\delta n_e/n_e$ as a function of the radial coordinate. The blue profile is used in all simulations. Note that the amplitude of the core turbulence plays a minor role in these simulations.

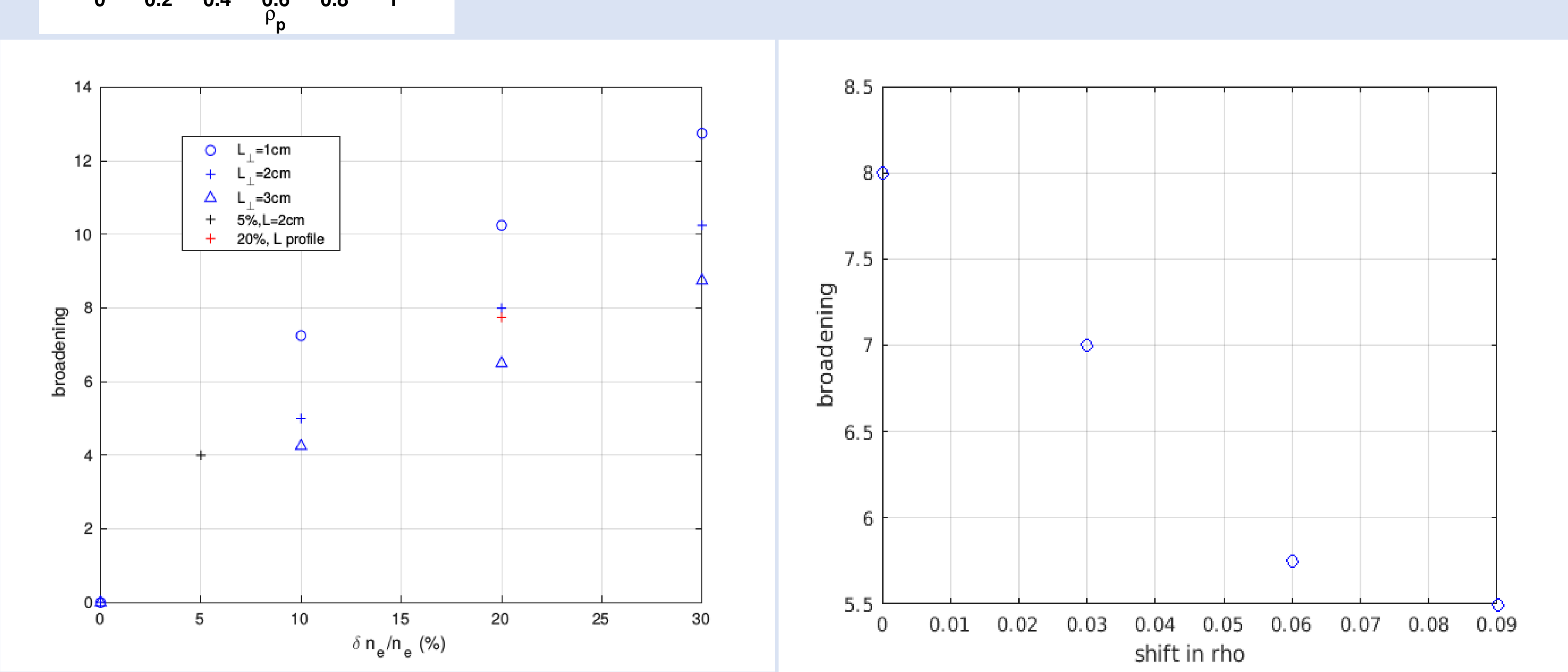

Figure 3: Broadening of the EC beam as a function of the fluctuation amplitude and correlation length for the position 1 (left). Broadening as a function of a shift of electron density profile (right).

Results: scans and broadening studies

- Scan for position 1 for fluctuation amplitude and correlation length (Figure 2, left)
  - Similar scaling as for ITER [1], larger broadening
  - Explanation: distance between the fluctuation layer and deposition larger in European DEMO
  - Broadening = relative increase of power deposition profile FWHM (vs. no fluct.)
- Scan for electron density profile shift
  - Sensitivity study for the electron perturbation/density profile
  - Shifting electron density profile radially inwards
  - Even with unphysically large shift of 0.09 in poloidal normalized flux, broadening still by a factor of 5.5 (Figure 2, right)

Results: lost driven current and power requirements

- From broadening to the lost driven current
  - Integrate current inside the marginal island size (~5.5cm)
  - Calculate relative decrease vs. quiescent case
  - Repeat analysis for all launching positions (Figure 3)
  - Significant difference observed between the configurations
- Estimation of the power required to mitigate (2,1) NTMs
  - Based on solution of modified Rutherford equation
  - TORBEAM simulations of current density and broadening by WKBeam included
  - From these, position 3 turns out to be a favorable compromise
- Tracking of NTM dynamics in the presence of realistic control scheme
  - Reference scenario without turbulence mitigated using 19MW of EC power
  - Case with broadening by a factor of two mitigated only using 30MW of EC power

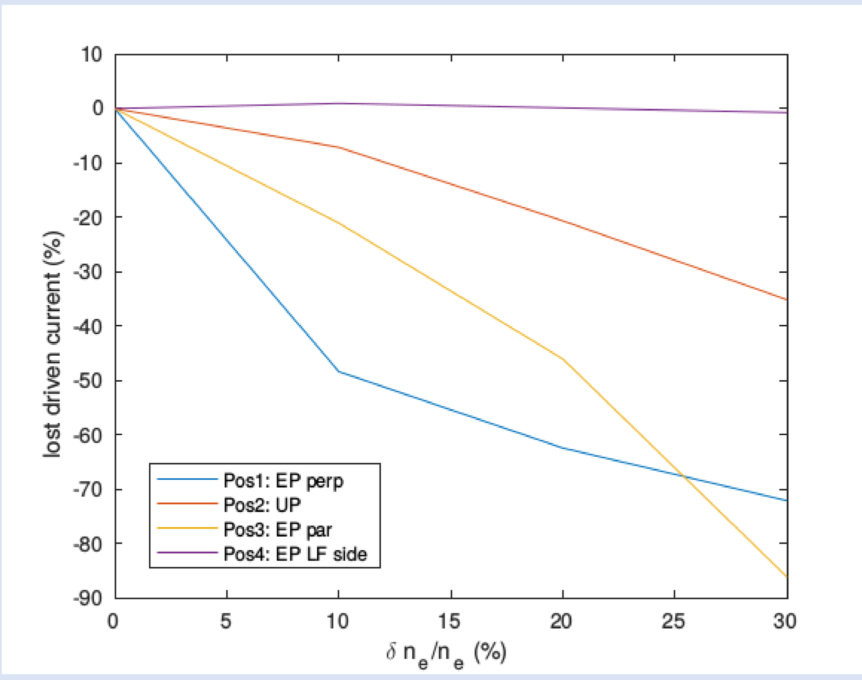

Figure 4: Lost driven current (relative to quiescent case) as a function of the perturbation amplitude. Large variations between launching configurations are observed.

Table 1: Power requirement necessary to mitigate (2,1) NTM for different launch configurations. Current peak corresponds to 1MW power.

Pos	Freq (GHz)	Cur peak (MA/m^2)	Broadening (x w_0)	P_{EC} (MW)
1	170	1.8e-3	6	>150
2	170	5.3e-3	3	42
3	170	7.8e-3	3	27
4	146	3.0e-3	1	60

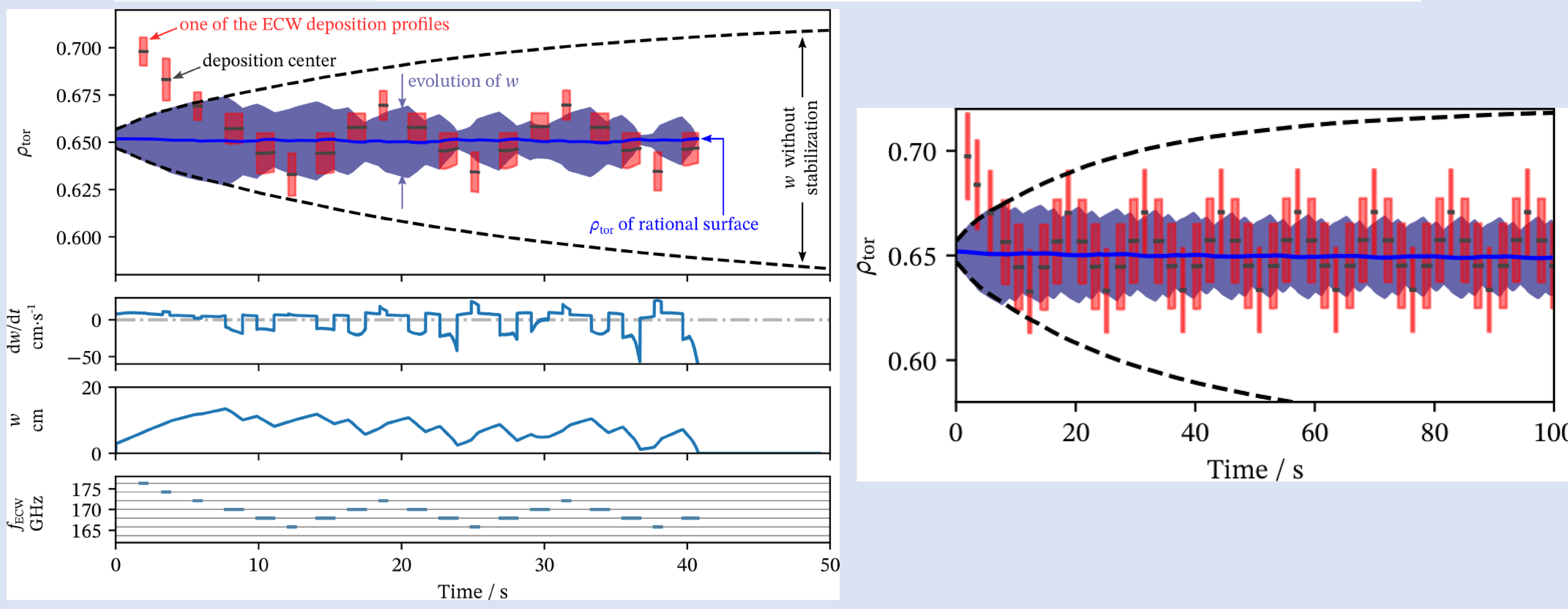

Figure 5: Mitigation of a NTM in the quiescent scenario (left) and the same assuming broadening by a factor of two, and power increase by x1.58 (19MW->30MW). Figure courtesy from Chuanren Wu.

CONCLUSIONS

- European DEMO prone to EC deterioration due to density fluctuations
- Launching configurations differ dramatically
- Optimal beam launching configuration a compromise between the broadening effects and "classical" beam performance

ACKNOWLEDGEMENTS / REFERENCES

[1] A. Snicker et al., Nucl. Fusion 58 016002 (2018);
[2] Weber et al., EPJ Web of conf. 87 (2015);
[3] E. Poli et al., Comp. Phys. Comm. 225 (2018)

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