Parallel Dispersion in ICRF Modelling of Travelling Wave Antenna Concept in DEMO-Like Plasmas

BJÖRN ZAAR[1], LUKAS BÄHNER[1], ROBERTO BILATO[2], THOMAS JOHNSON[1], RICCARDO RAGONA[3], PABLO VALLEJOS[4]

[1]KTH Royal Institute of Technology, Stockholm, SE-114 28, Sweden
[2]Max-Planck-Institut für Plasmaphysik, Garching, D-85748, Germany
Contact: bzaar@kth.se
[3]Technical University of Denmark, Kgs. Lyngby, DK-2800, Denmark
[4]FOI Swedish Defence Research Agency, Norra Sorunda, SE-137 94, Sweden

Ion Cyclotron Heating in DEMO

- ICRF waves can provide both ion heating and current drive (CD) in DEMO [1, 2]
- **Main scenarios**:
  - ^{3}He minority for ramp-up and landing
  - 2nd harmonic T heating/CD for flat top
- Ion heating degrades at medium to high temperatures
- Travelling wave antenna (TWA) concept:
  - Narrow directive toroidal spectrum
  - Appropriate for large wall-to-plasma
  - Small effect on tritium breed ratio
- Unexplored possibilities for TWA fed through upper port – up/downshifted parallel wave spectrum
- **Objective:** Explore scenario in DEMO with waves launched from upper port and quantify importance of shift in $k_\parallel$

Theory and Modelling

- To resolve small scale structures in large devices, local discretization techniques such as FEM are very efficient
- FEM enables modelling of complex geometries
- Wave equation is non-local integro-differential equation, difficult to treat using FEM
- Parallel dispersion (non-local effect) can impact propagation and absorption of RF waves in fusions plasmas
- **Idea:**
  i. Split dielectric tensor into two parts: dispersive and non-dispersive
  ii. Solve wave equation with non-dispersive plasma response using FEM
  iii. Evaluate integral operator spectrally and add iteratively [3-5]
- Iterative method implemented in the wave solver FEMIC, employing Anderson acceleration [6]
- Operator splitting [5]

$$\tilde{\chi}_j(k_\parallel) = \chi_j + \delta\tilde{\chi}_j(k_\parallel)$$

(Non-dispersive contribution: χ_j; Dispersive contribution: $\delta\tilde{\chi}_j(k_\parallel)$)

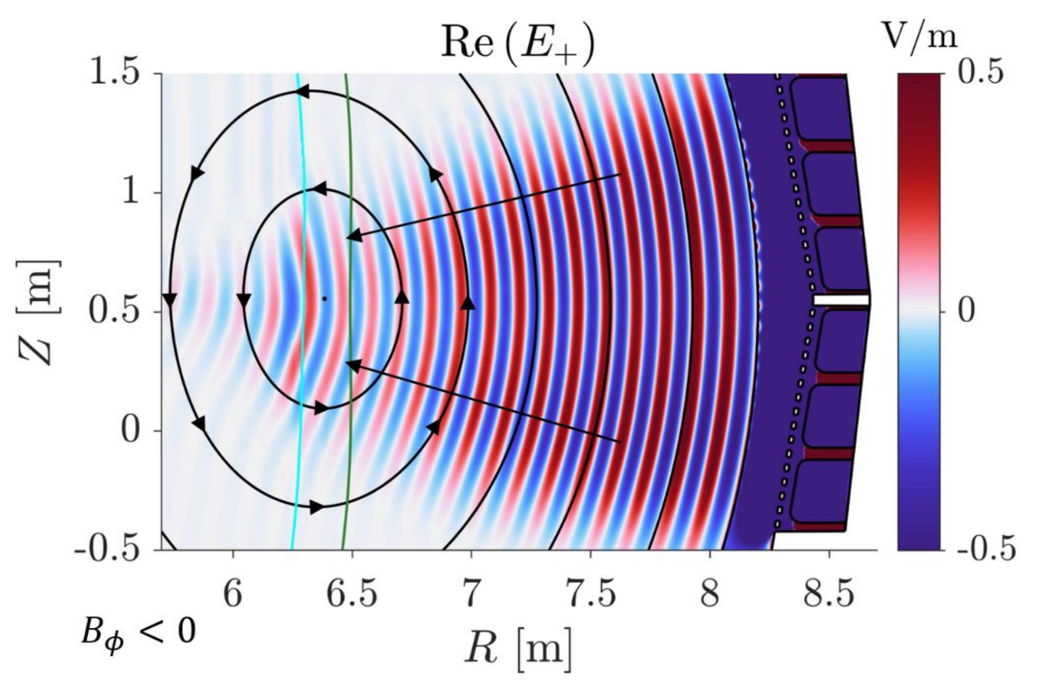
- Express dispersive contribution as an external source current and iterate:

$$E_A^k = A[E^k, E^{k-1}, \dots, E^1] \quad \text{(Anderson acceleration)}$$

$$\delta J_{ind}^k(E_A^k) = -i\omega\varepsilon_0 \sum_{\text{spec. } j} \delta\tilde{\chi}_j E_A^k$$

$$\nabla \times (\nabla \times E^{k+1}) - \frac{\omega^2}{c^2} K \cdot E^{k+1} = -i\omega\mu_0 (J_{ant} + \delta J_{ind}^k)$$

- Direction of wave front relative to poloidal fields causes local up- and downshift in $k_\parallel$



References

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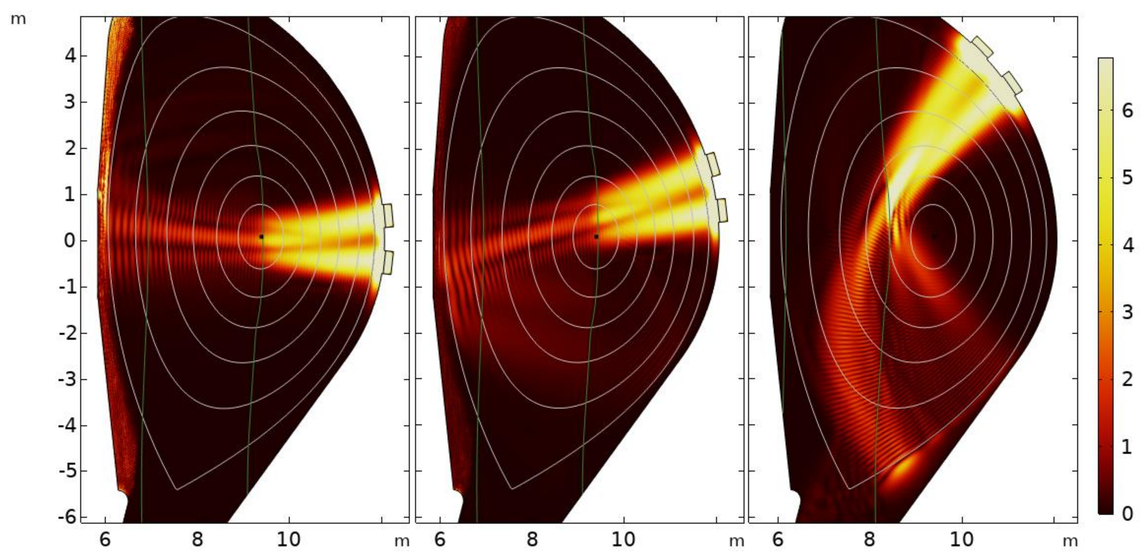
Launch Positions

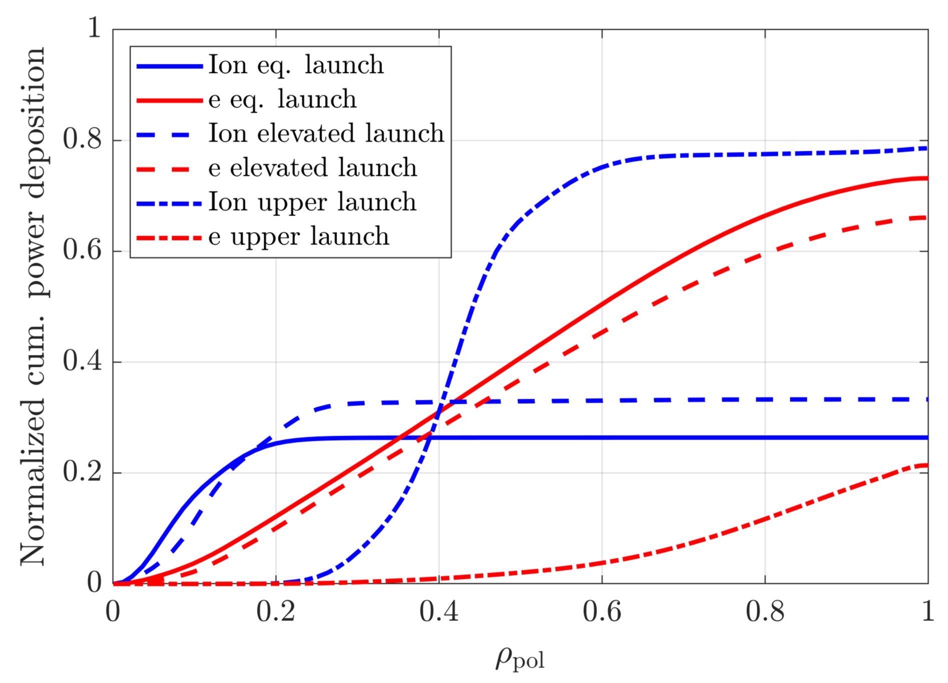
- Evaluate three different antenna positions
  - Equatorial launch (baseline)
  - Elevated launch
  - Upper launch (from upper port)



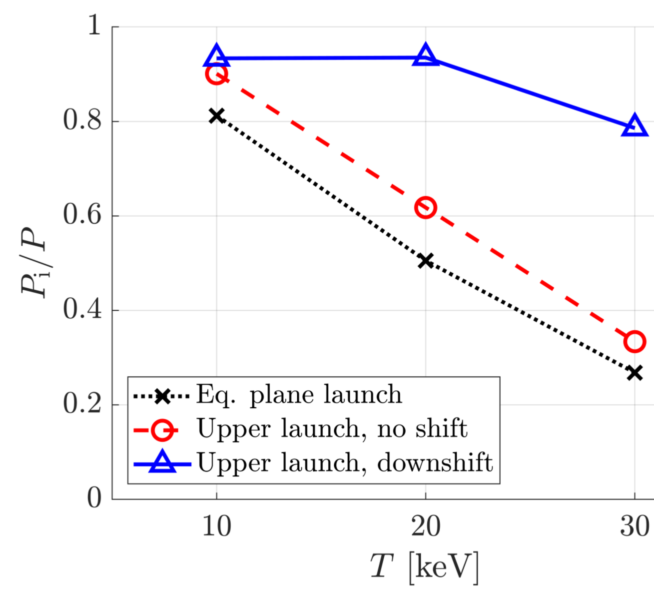
$|E|$ For different antenna positions

- Downshift in $k_\parallel$ has strong impact on power partition for asymmetric launch (w.r.t. equatorial plane)

Launch position	P_i/P (no shift)	P_i/P (downshift)
Equatorial plane	26%	26%
Elevated	26%	33%
Upper	33%	79%



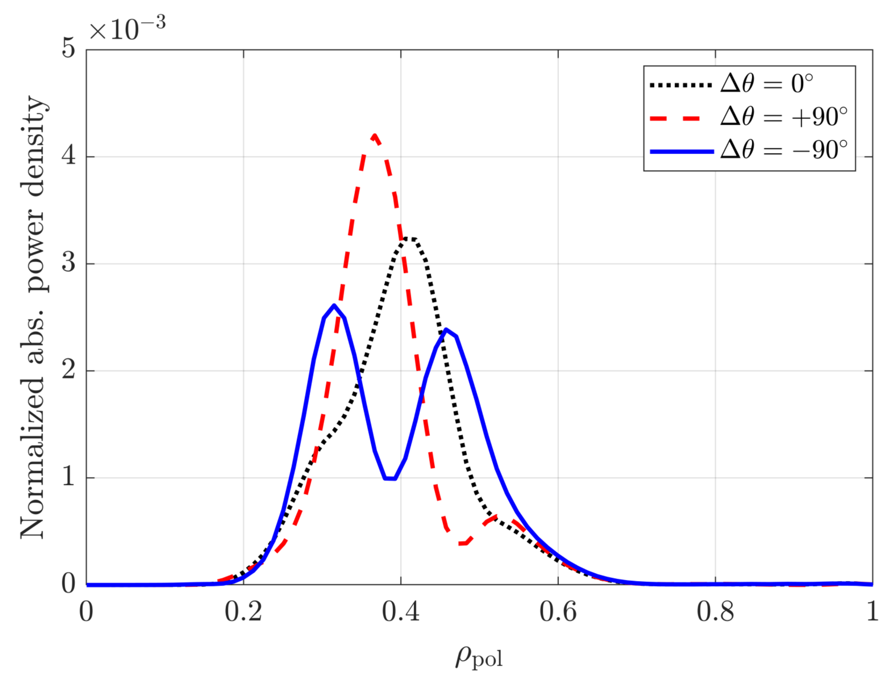
Ramp-up



- Difference in ion absorption is small for low temperatures
- Upper launch permits good ion absorption also for medium to high temperatures
  - Downshift (parallel dispersion) reduces electron damping

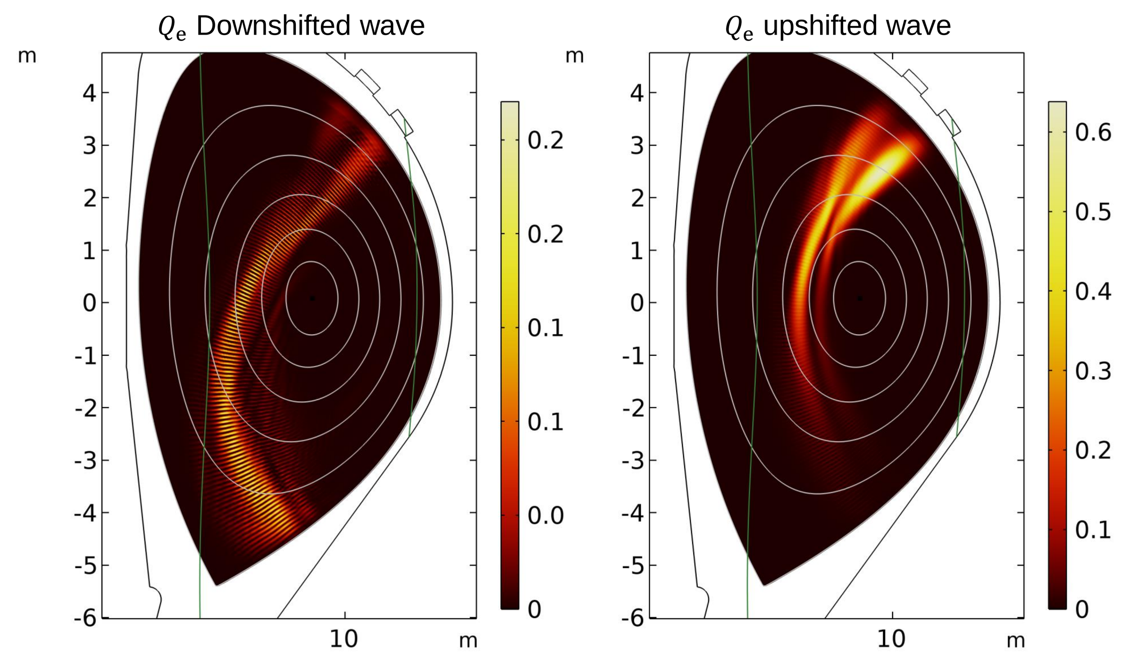
Poloidal Phasing

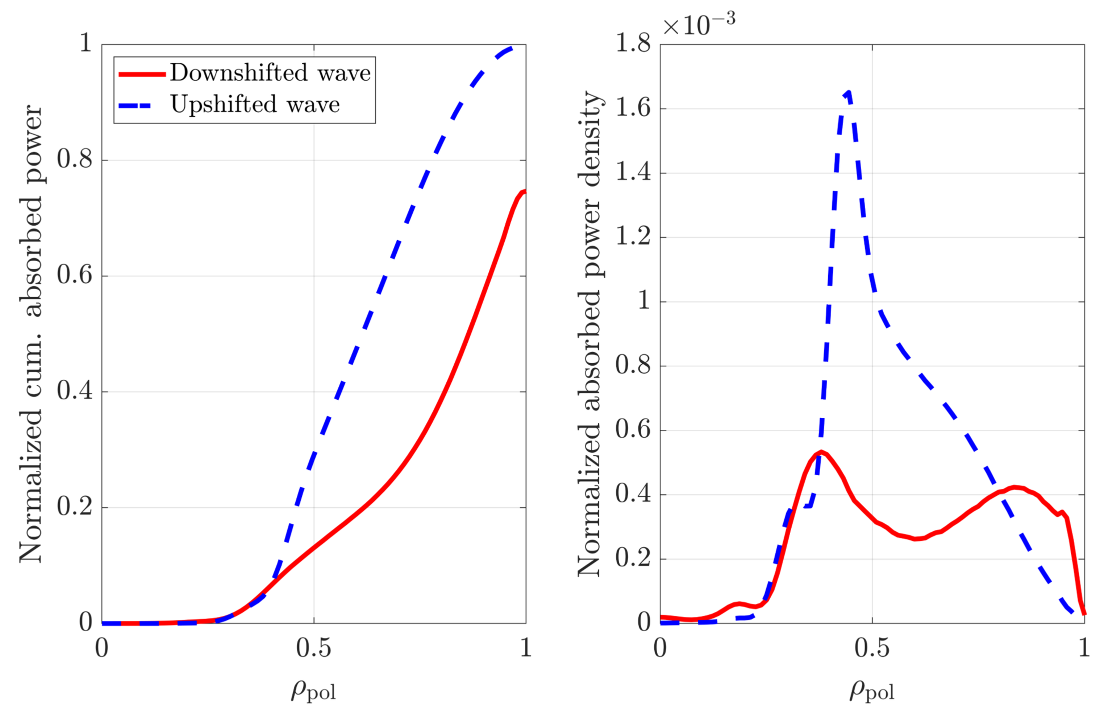
- Phasing of poloidal straps permits tweaking of absorption profiles, but destructive interference reduces coupled power
  - 5% reduction for $\Delta\theta = +90°$
  - 15% reduction for $\Delta\theta = -90°$



Current Drive Prospects

- Top launched CD can provide higher efficiency compared to launch from equatorial plane [2]
- Narrow and directed TWA spectrum ideal for current drive
- Downshift in $k_\parallel$ beneficial for both ion heating and CD efficiency
- Upshift in $k_\parallel$ yields high electron absorption, but lower CD efficiency [2]

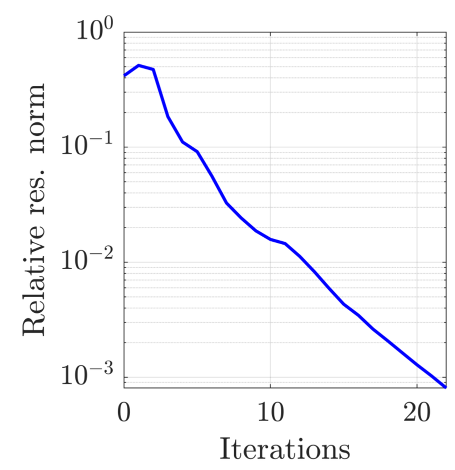




Launch	$k_\parallel \cdot I_\phi$	Rev. ∇B	Resulting shift	Appropriate for
Upper	+	Yes	Downshift	Ion heating
Upper	-	Yes	Upshift	Reduced CD
Upper	+	No	Upshift	-
Upper	-	No	Downshift	Ion heating/CD
Lower	+	Yes	Upshift	-
Lower	-	Yes	Downshift	Ion heating/CD
Lower	+	No	Downshift	Ion heating
Lower	-	No	Upshift	Reduced CD

Convergence

- Anderson acceleration enables robust convergence
- Fixed point iterations do not converge
- Fast convergence even for large up/downshift



Discussion and Conclusions

- New method to iteratively add dispersive effects to FEM models
- Opens up for modelling of advanced wave physics in complex wall and antenna geometries
- Applied to DEMO scenario with travelling wave antenna mounted in upper port
- Strong downshift allows for larger fraction of ion damping from low to high temperatures
- Launch from upper port is also beneficial for current drive

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