3D magnetic fields and plasma flow in helical RFX-mod equilibria

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Background: self-organized helical equilibria

- RFX-mod is exploring for the first time high plasma currents up to 2MA
- At high current a helical equilibrium with an electron internal transport barrier spontaneously forms [R. Lorenzini et al. 2009 Nature Phys. 5 570]

Flux surfaces from constant-$p_e$ contours

![Flux surfaces](image1.png)

ITB in electron temperature

![ITB graph](image2.png)
Outline

- Helical RFP equilibria sustained by external 3D magnetic fields
- Helical flow and possible effects on ITB
- 3D magnetic fields as a knob to change the flow profile
- Conclusions and future work

192 active coils independently controlled
An almost stationary helical equilibrium can be sustained by imposing a finite $m=1/n=-7$ $B_r(a)$ at the edge through magnetic feedback.

Important for helical divertor operation [E. Martines et al. 2010 NF 50 035014]
Flow measurements in helical states

- Multi-chord passive Doppler spectroscopy of CV and BV ions was used to determine the $m=1$ helical flow pattern.
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The local $1/-7$ $B_r = b_{r,1,-7} \cos(\theta_d - 7\phi_d + \Phi_{1,-7})$ correlates with the $m=1$ flow
Flow measurements in helical states

- Multi-chord passive Doppler spectroscopy of CV and BV ions was used to determine the $m=1$ helical flow pattern.
A global helical flow forms

- 2D m=1 flow pattern reconstructed on a poloidal cross-section by fitting all lines of sight
- 2D $m=1$ flow pattern reconstructed on a poloidal cross-section by fitting all lines of sight
- The flow pattern resembles that obtained in nonlinear MHD simulations of single helicity states (SpeCyl code)
ITBs form where $q$ and the flow shear ($10^4$-$10^5$s$^{-1}$) are maximum, with strong similarity with tokamak and stellarator results.

[M. Gobbin et al., submitted to PRL]
Nonlinear MHD simulations with external 3D fields

- Also in nonlinear MHD simulations the shear flow peaks near the $q$ maximum
- and moves outward as the $1/-7 b_r(a)$ is increased
- External 3D magnetic fields may be used to improve ITBs
External 3D fields affect the flow profile

- External 3D magnetic fields modify the flow profile also in the experiment.
- A 50% increase in the $m=1$ flow inside the ITB is observed.
- Possible beneficial effects on ITB, dynamo, error field screening, to be tested in near future experiments.
Conclusions and future work

- External 3D magnetic fields allow to sustain and control helical RFP equilibria
- A global helical flow forms, which has probably an effect on ITB formation
- 3D magnetic fields can be used to modify the flow profile
- … and possibly to optimize ITBs in near future experiments

- Role of ambipolar electric fields being investigated with ORBIT and DKES+PENTA codes [M. Gobbin’s invited talk on Monday]
- Including MHD and ambipolar effects in a single simulation is a challenging work, but it could be important to understand and optimize this schenario