Magnetic perturbation as a viable tool for edge flow and turbulence modifications

presented by N. Vianello
Consorzio RFX, Padova, Italy

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On behalf of

M. Agostini, L. Carraro, R. Cavazzana, G. De Masi, P. Innocente, L. Marrelli, E. Martines, A. Mazzi[1], B. Momo, M.E. Puiatti, C. Rea, G. Spizzo, P. Scarin, M. Spolaore, D. Terranova, P. Zanca, M. Zuin and the RFX-mod team

Consorzio RFX, Padova, Italy

[1] *Dipartimento di Fisica Università degli studi di Trento, Italy*

Rationale and motivation

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- A complete 3D description of the magnetic field is unavoidable in present and future fusion devices
- The presence of a ripple/resonant perturbation at the edge modulates indeed all the plasma properties in the external region (Chapman *et al.* 2014a,b)

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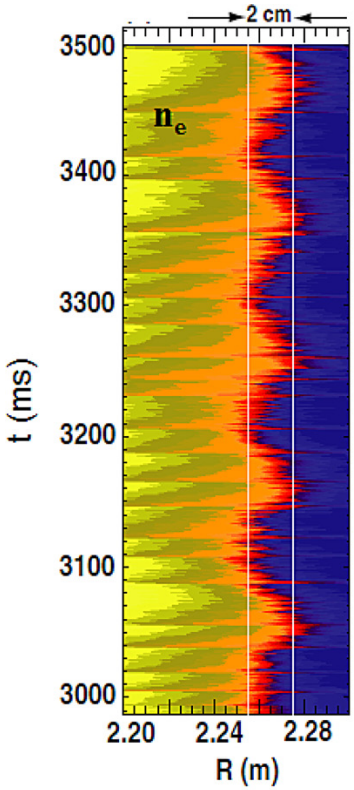
- It was clearly recognized in rotating RMP experiments (Moyer *et al.* 2012)



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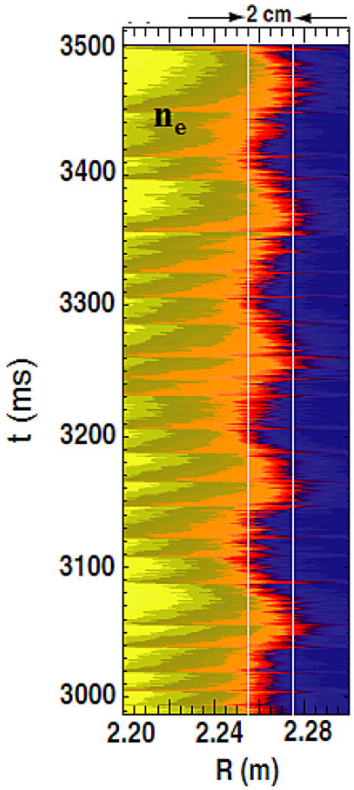
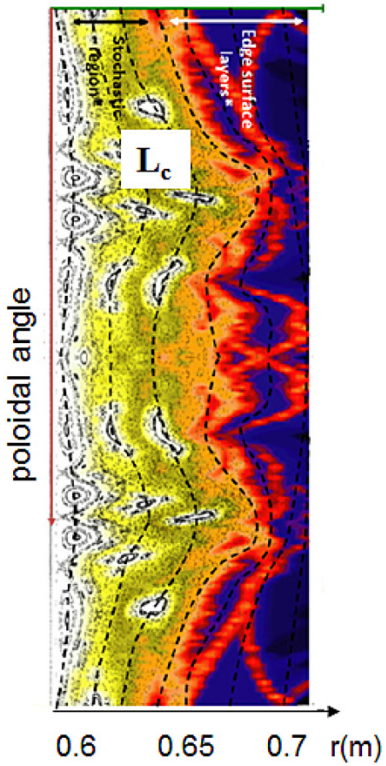
- Well known in magnetic-island divertor for stellarators (Feng *et al.* 2011)





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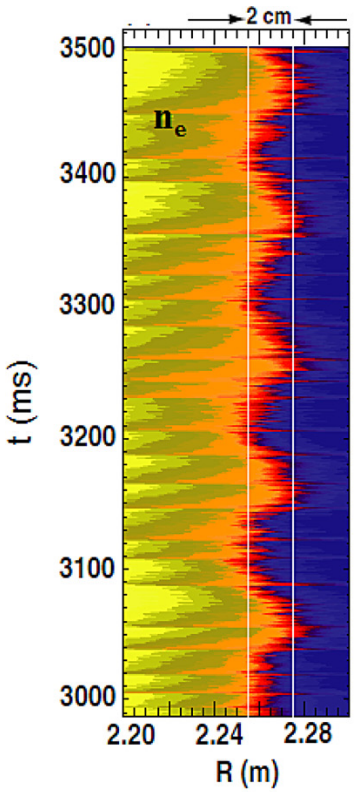
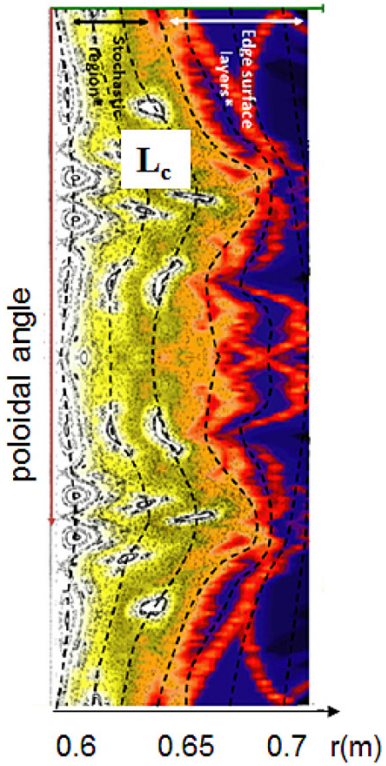
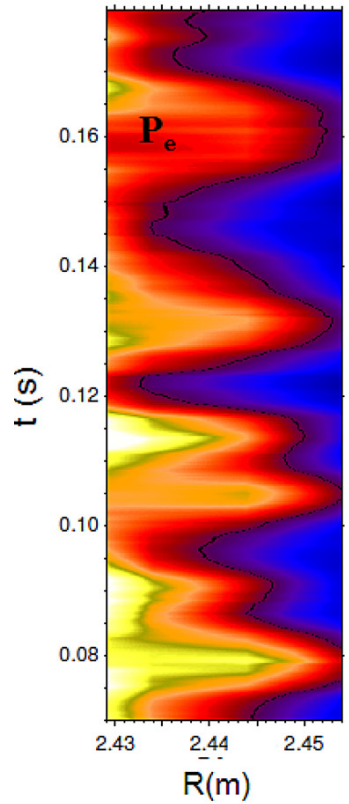
- The presence of a ripple/resonant perturbation at the edge modulates indeed all the plasma properties in the external region (Chapman *et al.* 2014a,b)
- Observed in helically-shaped Reversed Field Pinch discharges (Vianello *et al.* 2013)







Rationale and motivation /2

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  2. Which is the mechanism determining the operational space in term of collisionality/density?
  3. Is small scale turbulence/blobs affected by a non axy-symmetric field?
- We will try to provide some additional piece of information by detailed comparison of effects of a magnetic perturbation on the edge region of RFX-mod exploiting the versatility of the device and operating both as a Tokamak and as a Reversed Field Pinch

RFX-mod operational space

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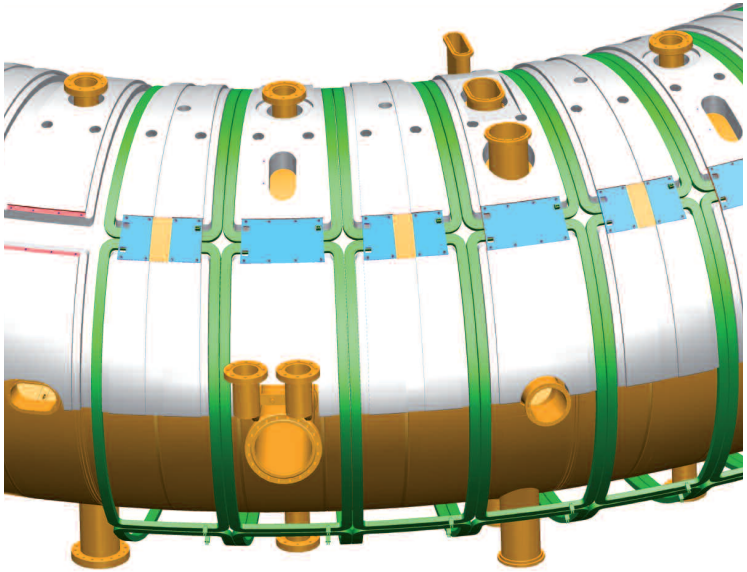
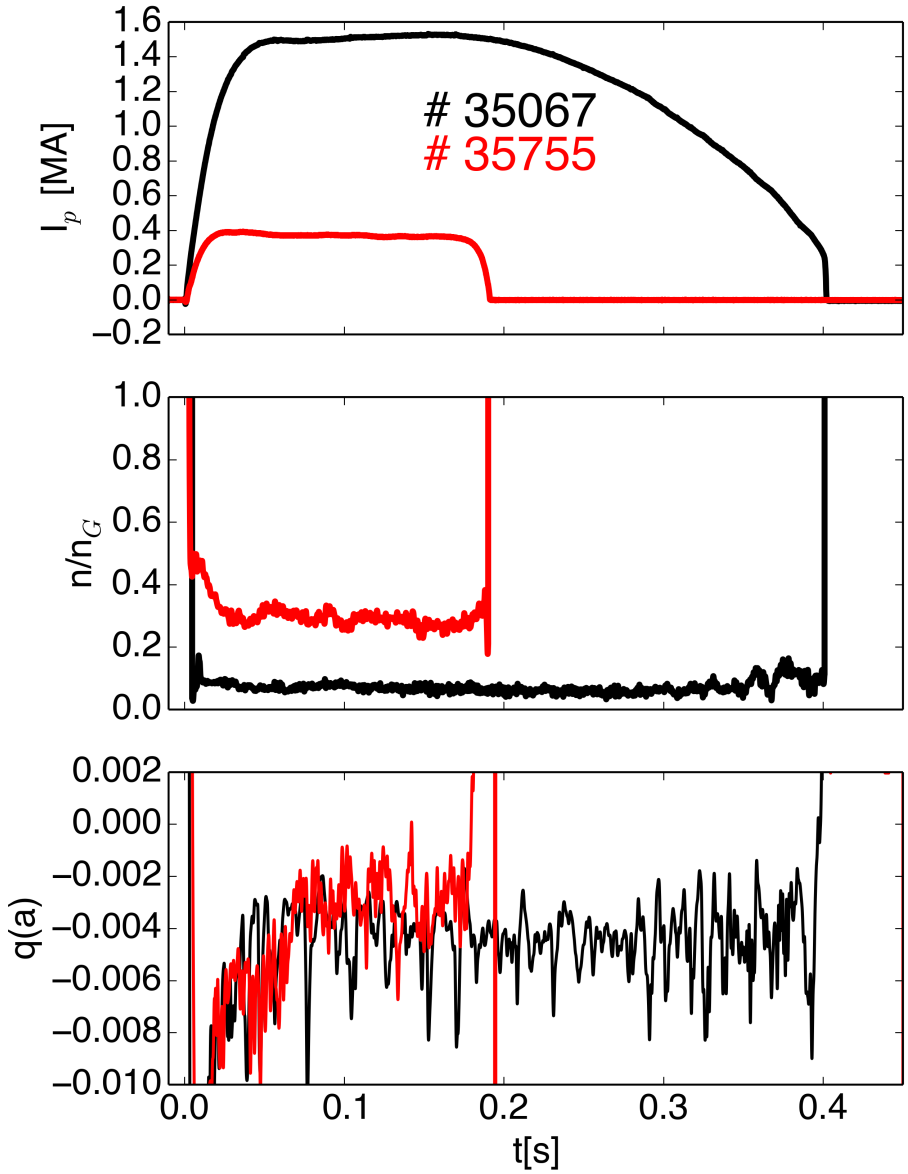
RFX-mod ($R = 2, a = 0.459$ m) is equipped with state of the art MHD control system with 192 independently fed saddle-coil. It can operate as an RFP with spontaneous and imposed helical boundary





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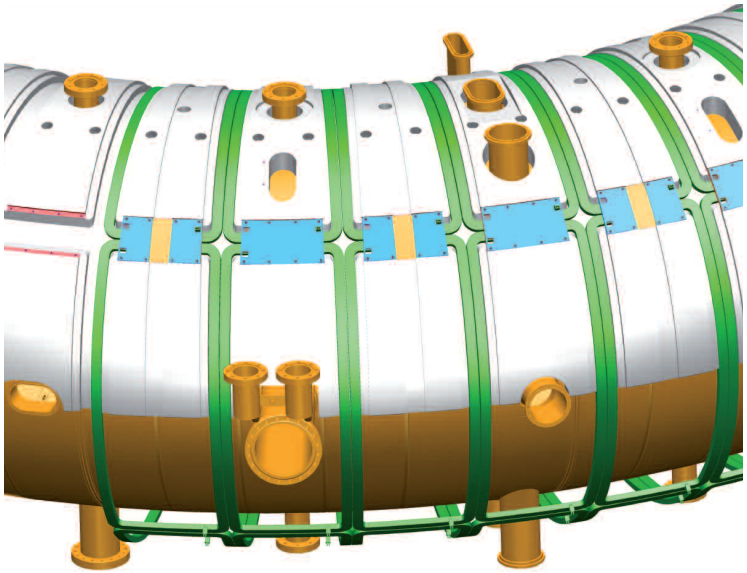

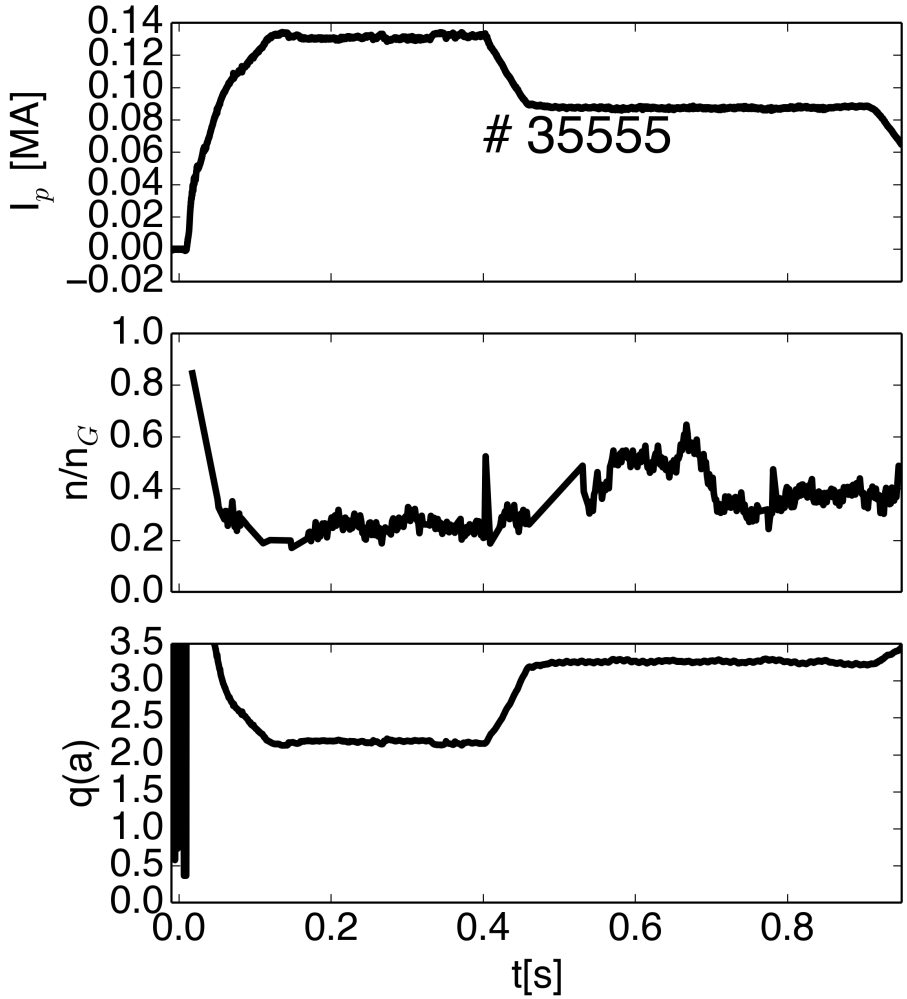

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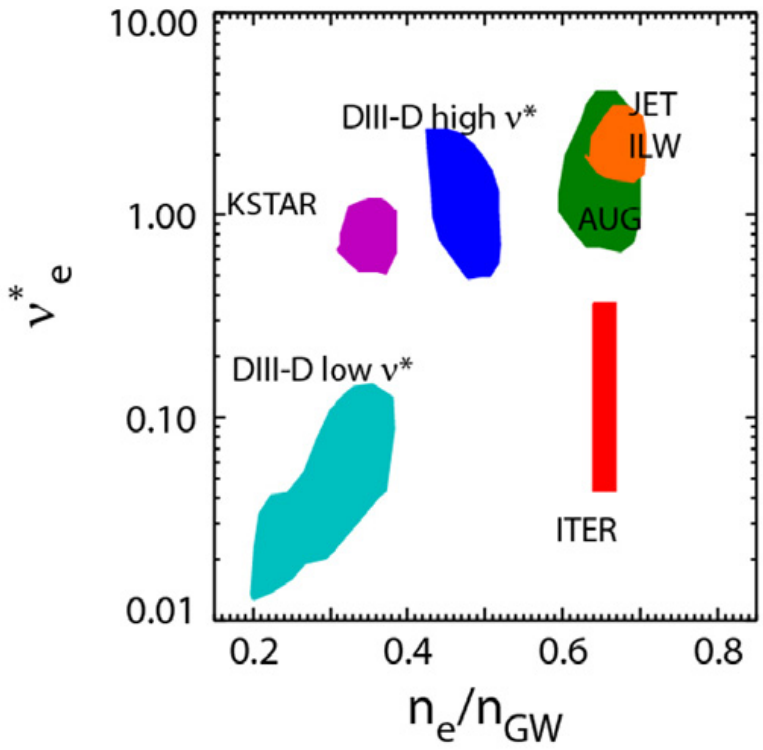

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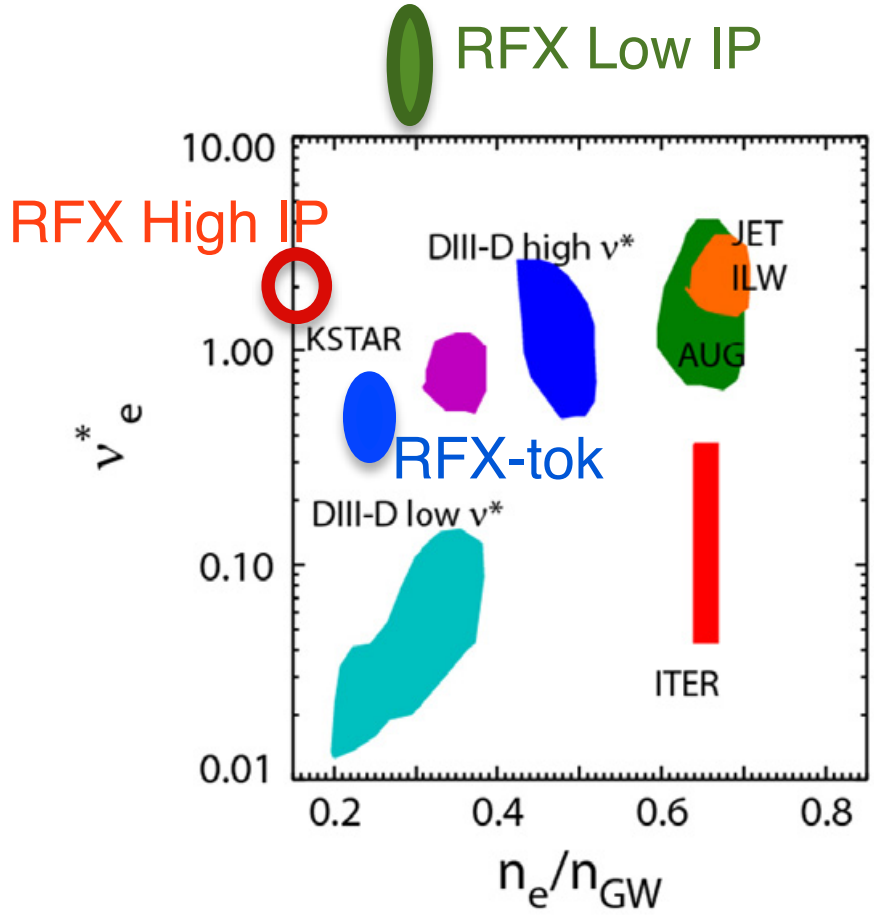
In the operational space used to describe ELM suppression (Kirk *et al.* 2013) we are well situated



RFP spontaneous helical plasmas 1/

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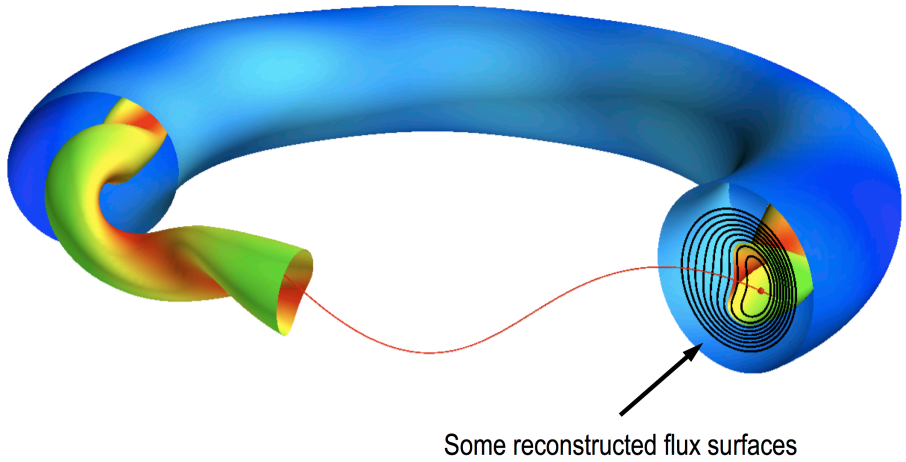

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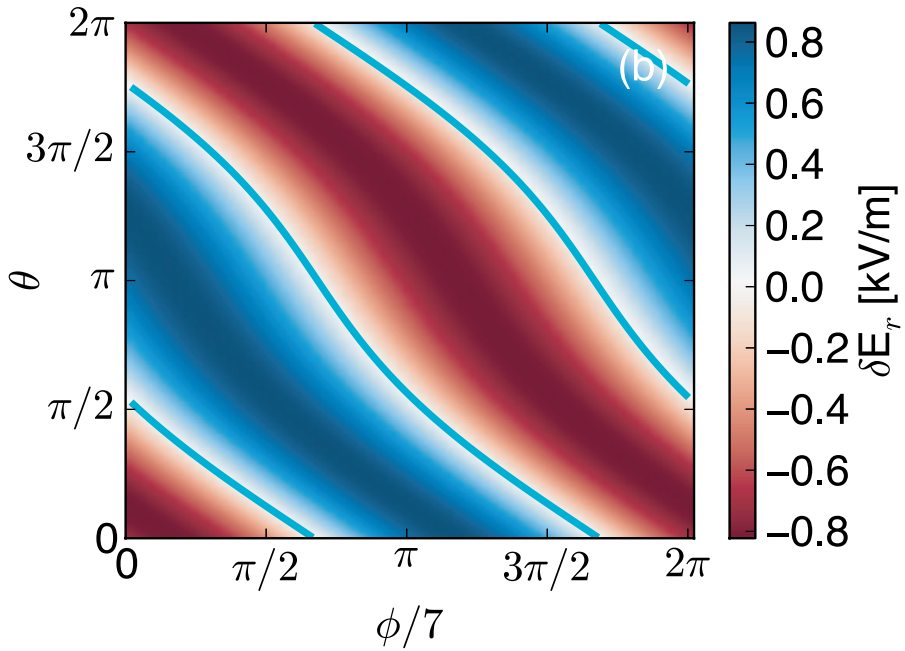

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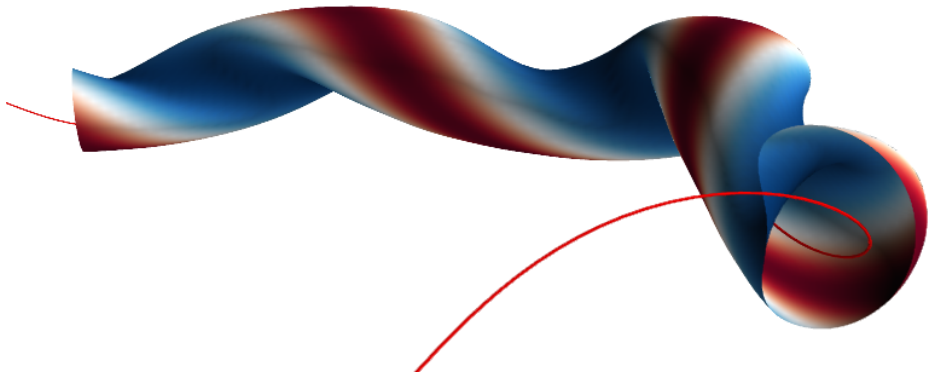

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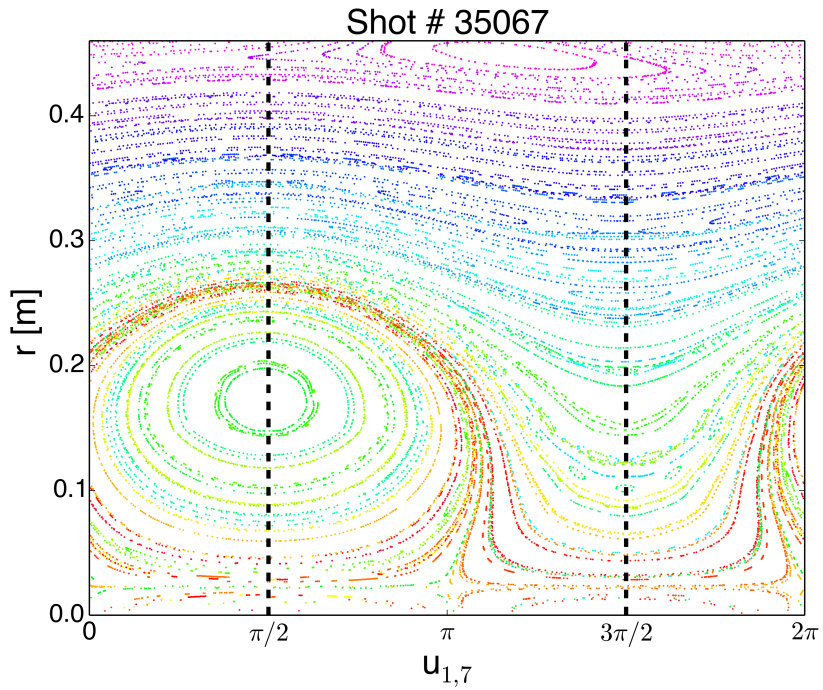
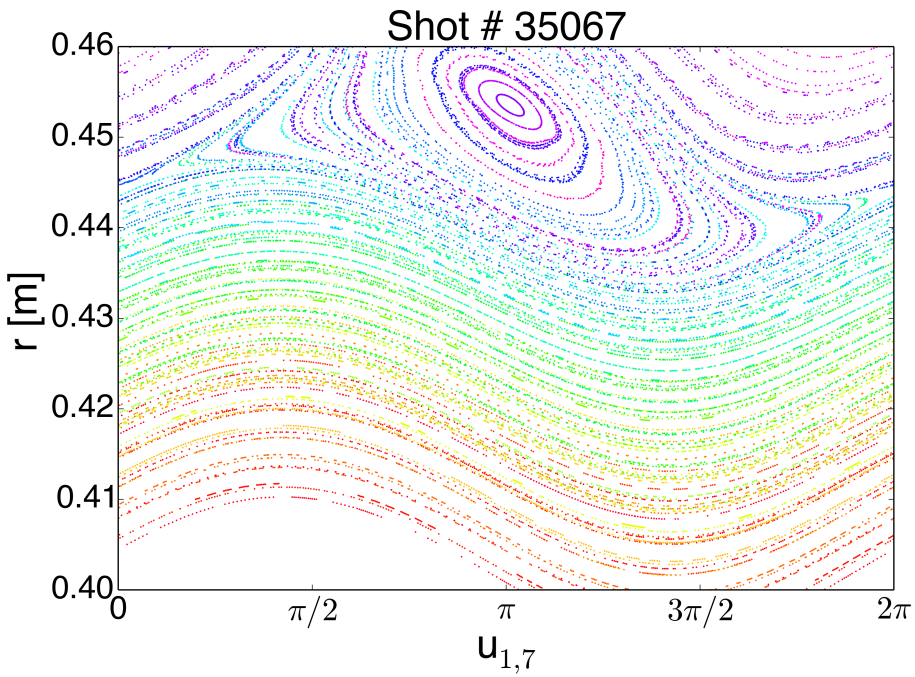
- Proper phase relation to mode structure recovered using the helical angle (Vianello *et al.* 2013)



$$u_{m,n} = m\theta - n\phi + \varphi_{m,n}$$

RFP spontaneous helical plasmas 2/

- Complex edge topology in an RFP. Combination of ripple induced by a saturated internal mode (resembling tokamak snake) (Chapman *et al.* 2014b) plus resonance close to the wall due to toroidal coupling (resembling RMPs)



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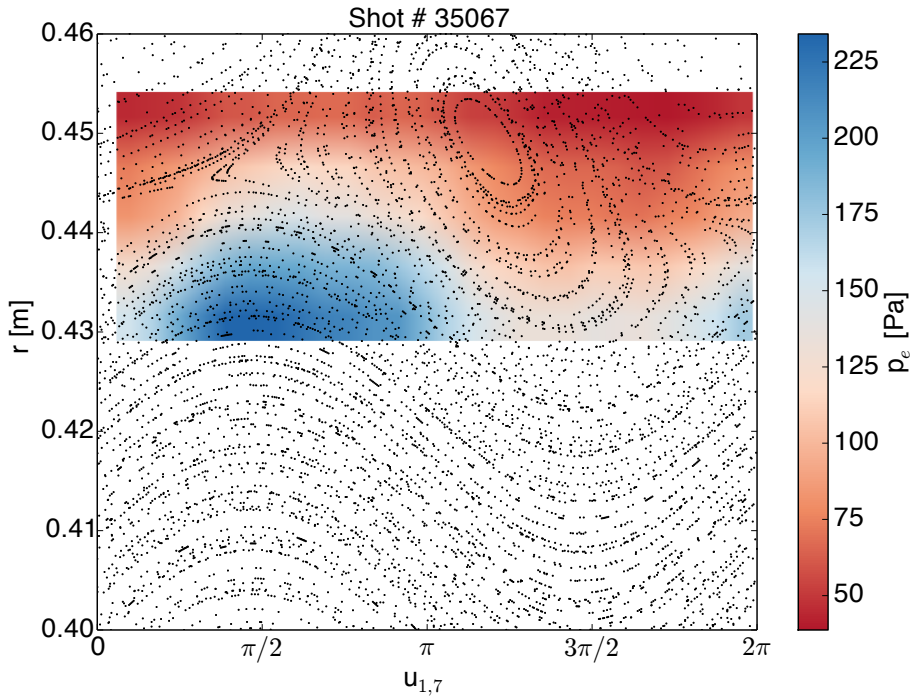

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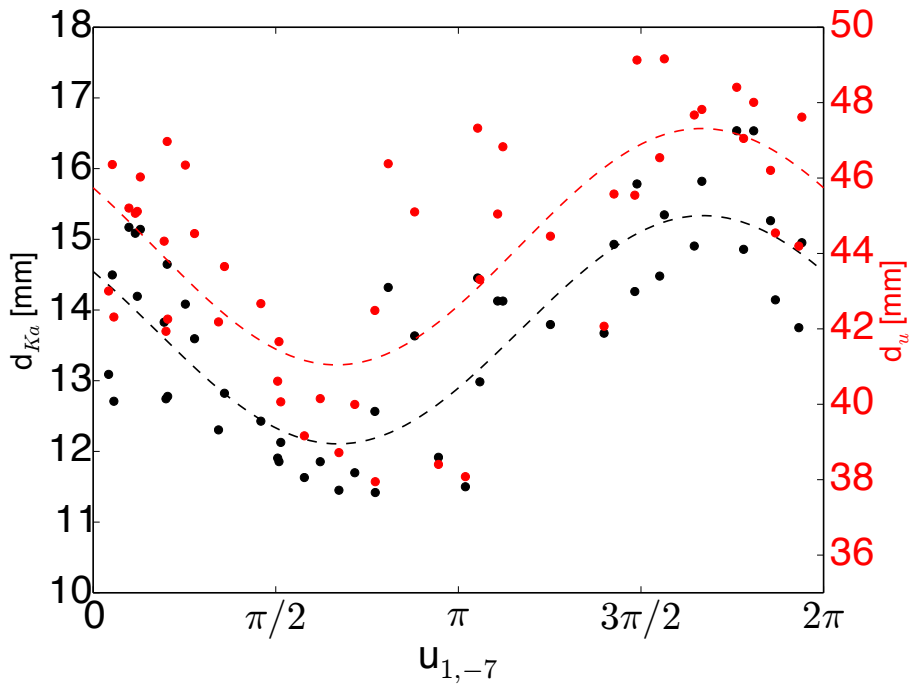
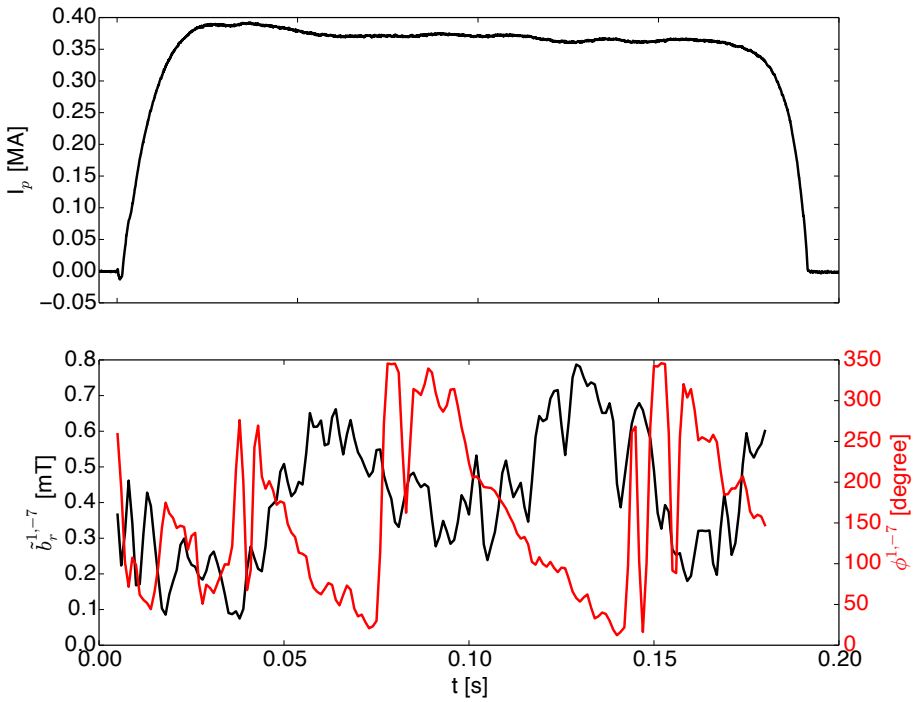
- Microwave reflectometer confirms that the modulation observed is essentially due to density oscillations (De Masi *et al.* 2011)



RFP low current helical boundary

- To have detailed localized information helical plasma at low current with applied helical boundary $(m, n) = (1, -7)$



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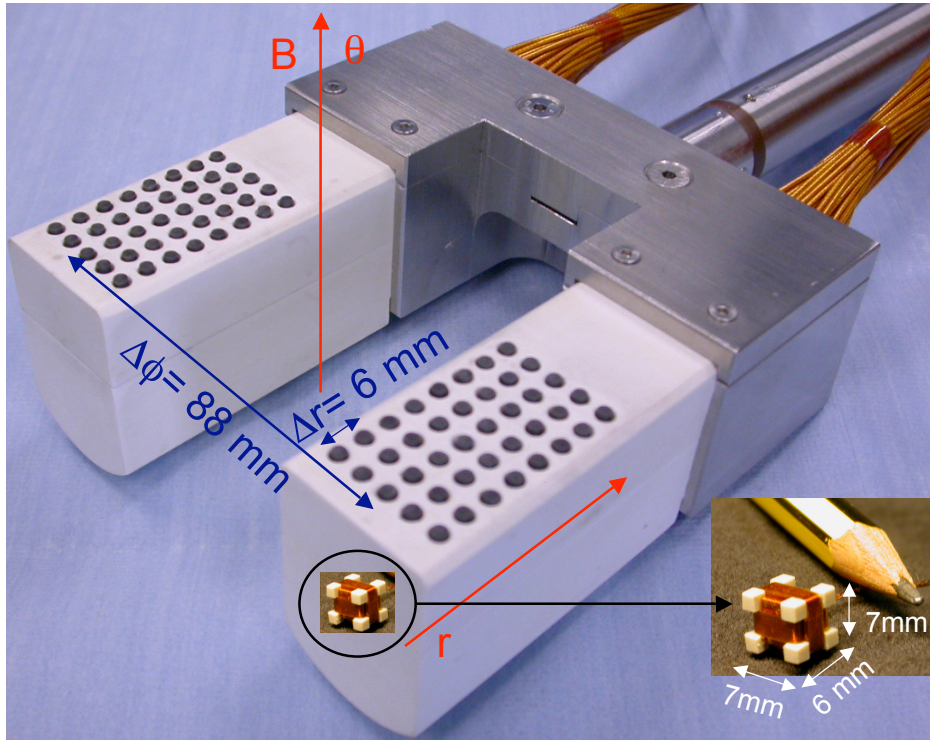
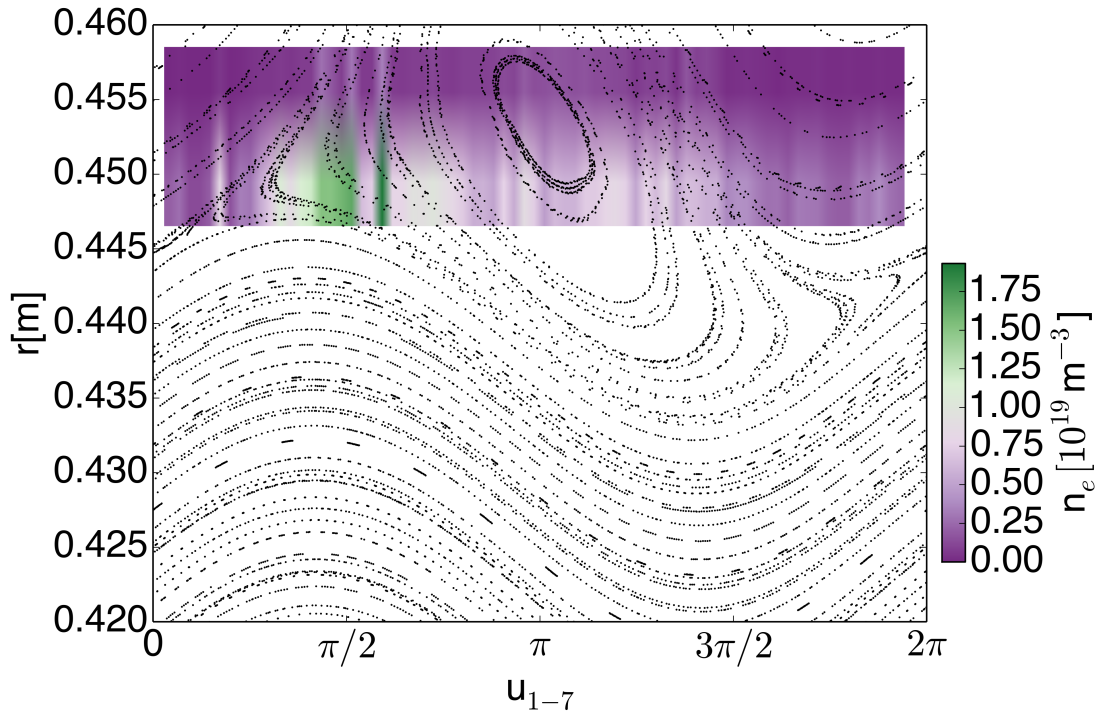
- This allow insertion of the probe which allows for estimate of $n_e, p_e, v_r, v_\phi, \omega = \nabla_\perp V_f, \tilde{J}_\parallel = \nabla \times \tilde{\mathbf{b}}/\mu_0$



Flow around magnetic island

- Local measurement from probe confirm accumulation of density around $\pi/2$



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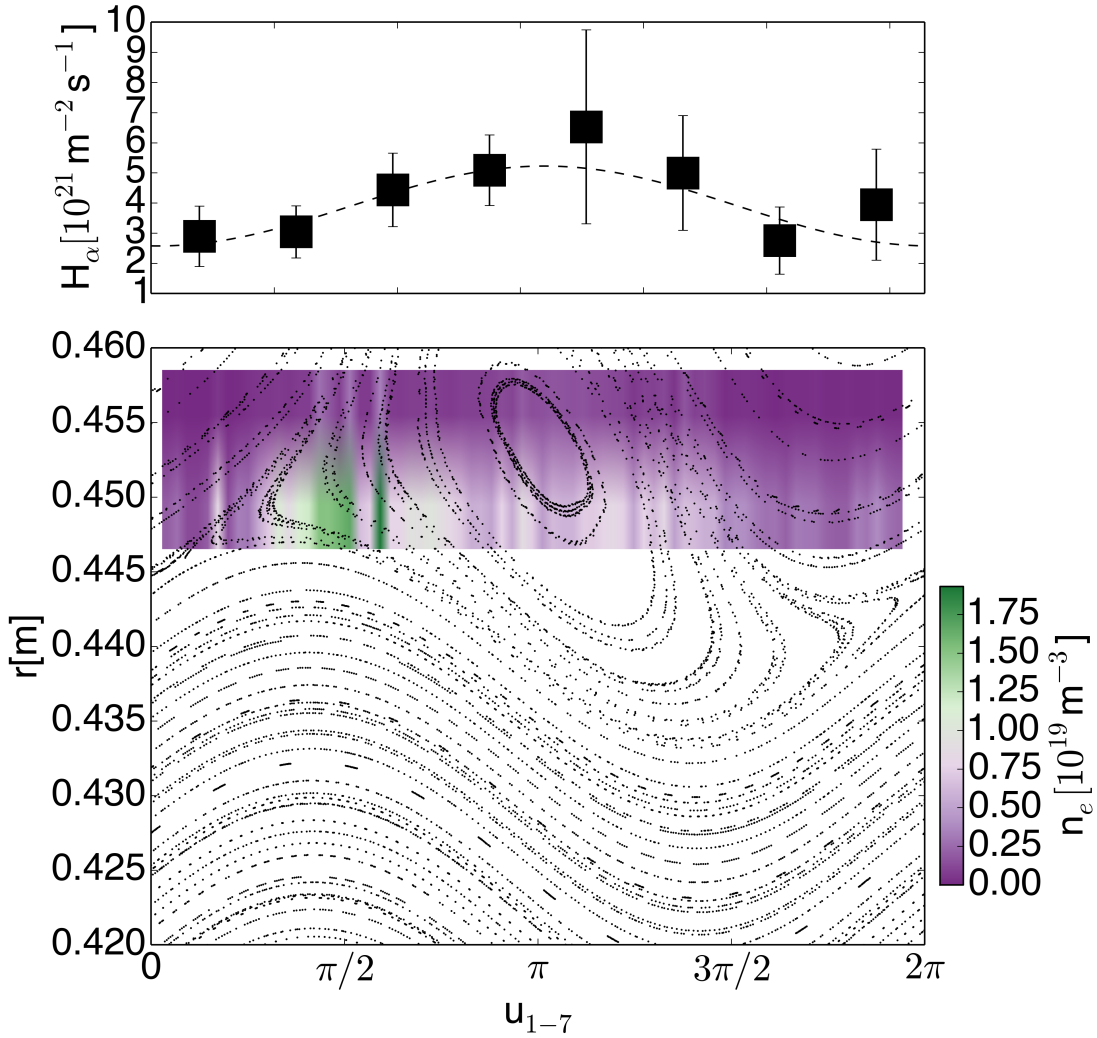

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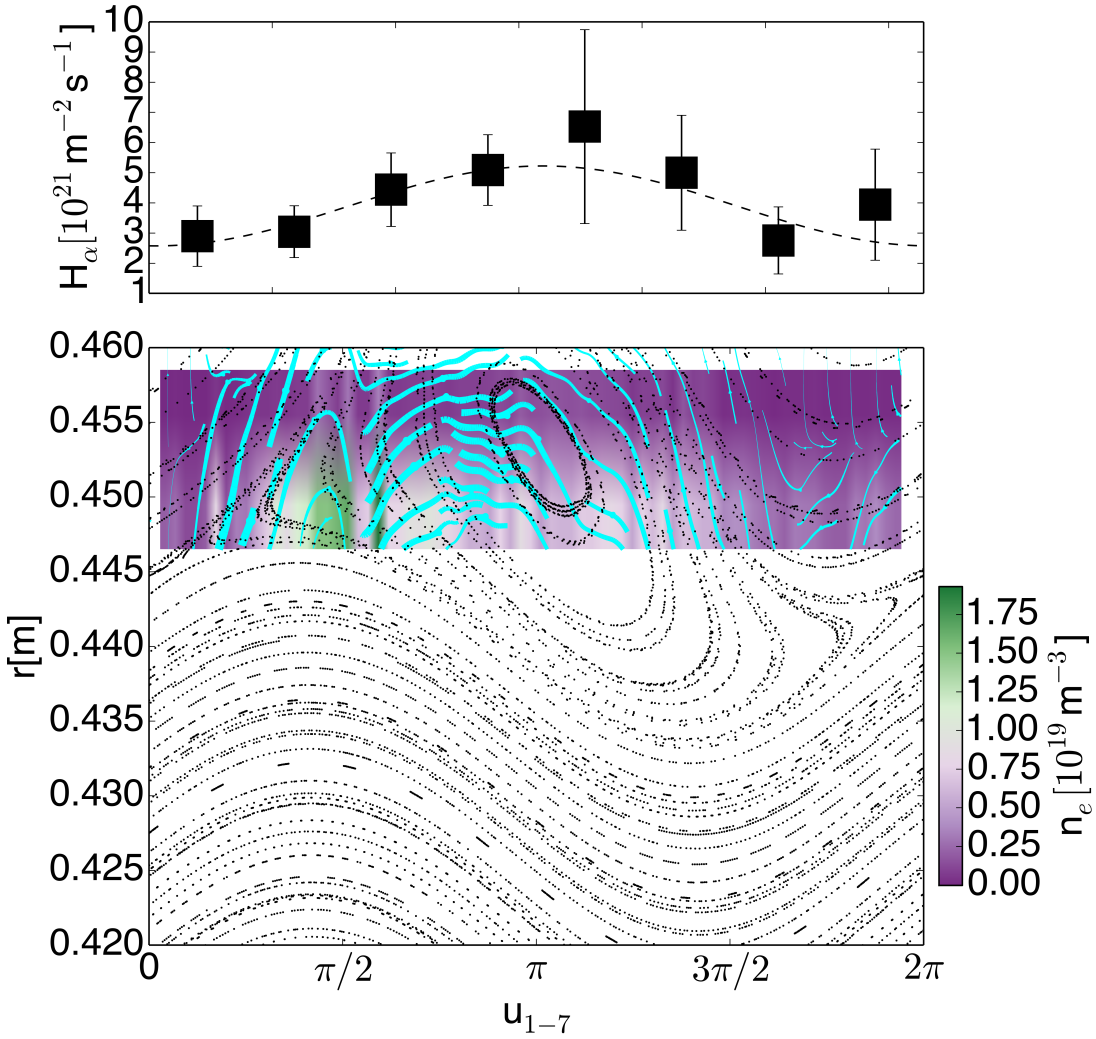

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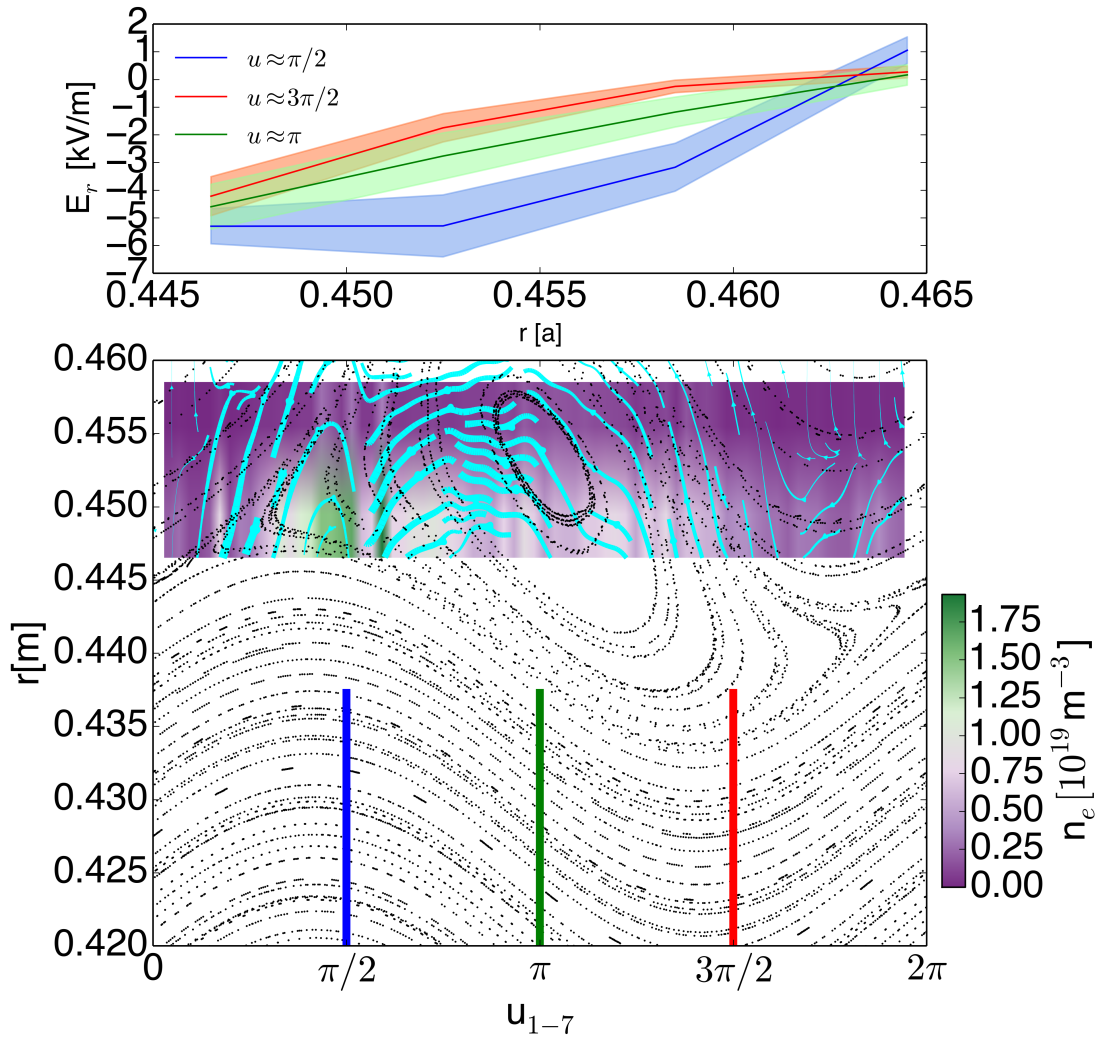

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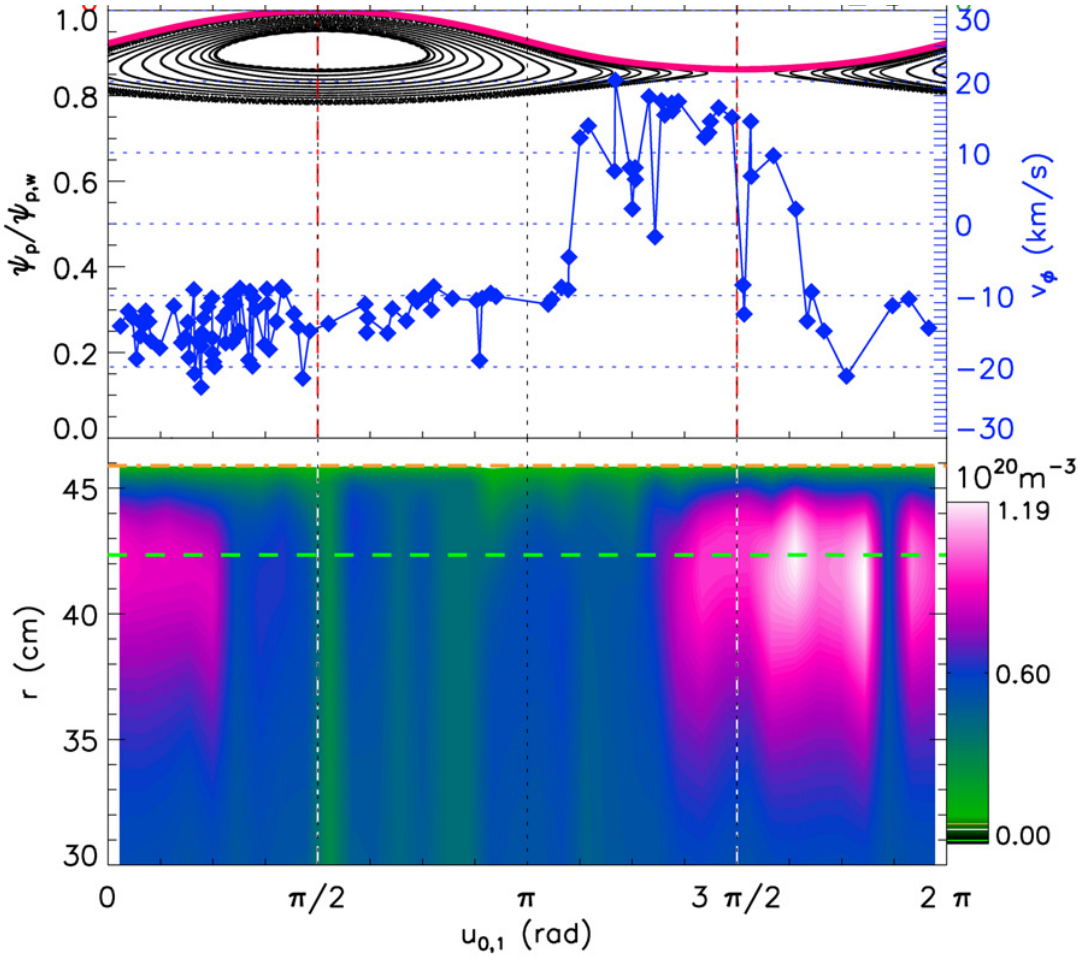
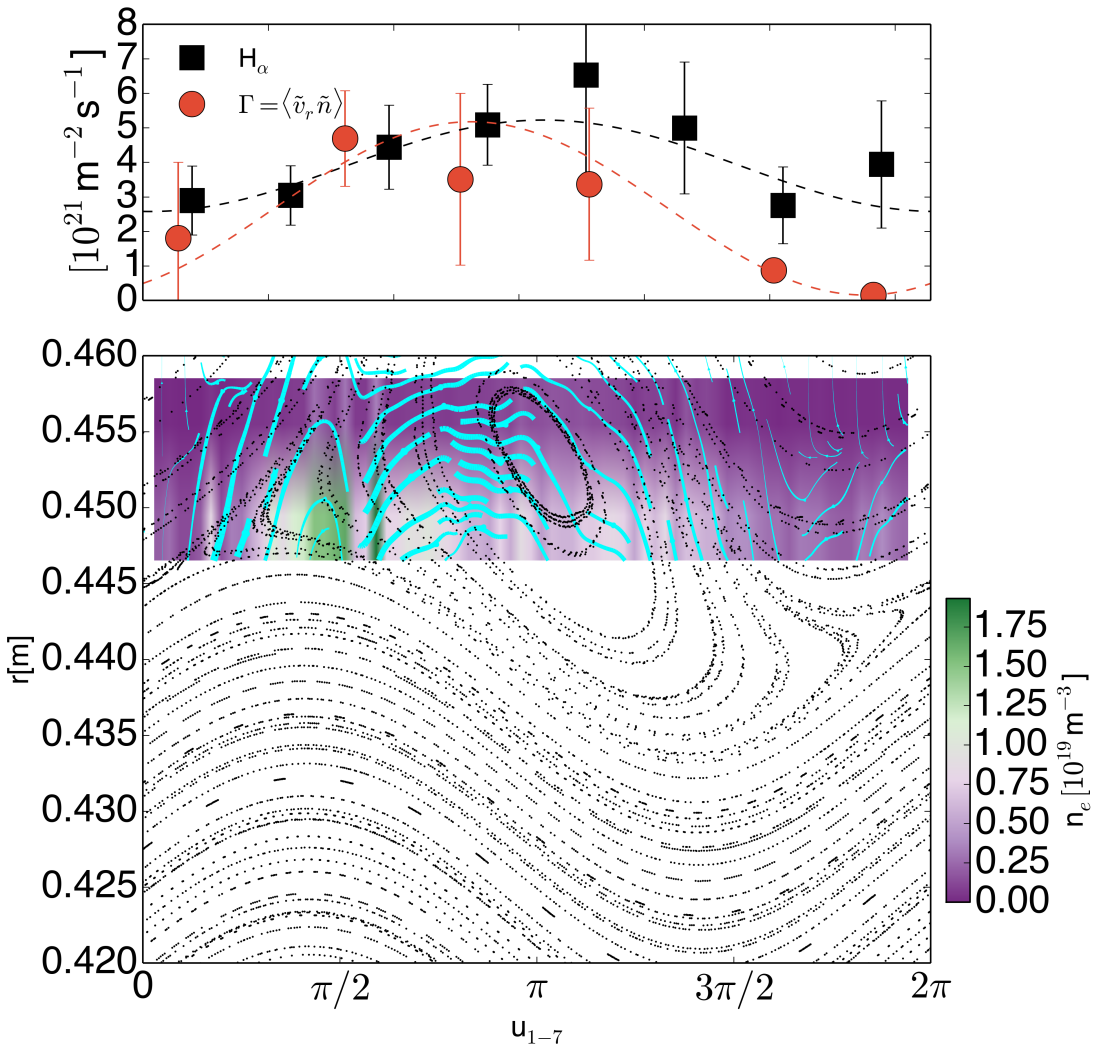
- 2D evaluation of $\mathbf{E} \times \mathbf{B}$ flow suggests a process of density accumulation through a convective-cell mechanism (De Masi *et al.* 2013)
- Clear modulation of the radial electric field
- Similar to what observed in high-density radiative collapse (Spizzo *et al.* 2012)



Turbulent flux around an island

- Probe is equipped to provide particle fluxes calculates as $\Gamma_{es} = \langle \tilde{n}\tilde{v}_r \rangle$ with fluctuating velocity coming from local estimate of $\mathbf{E} \times \mathbf{B}$ components
- Electrostatic particle fluxes is major contribution to out flux. It exhibits the same periodicity



Fluxes and blobs

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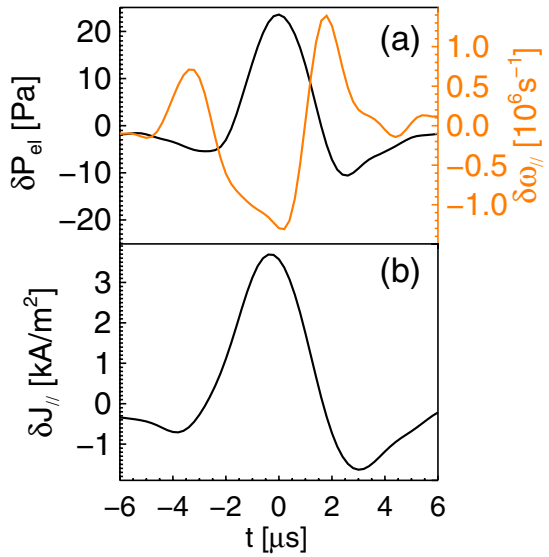

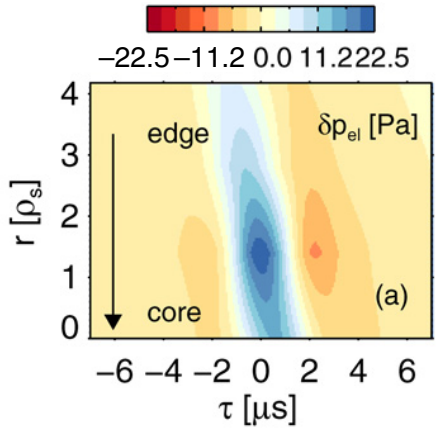

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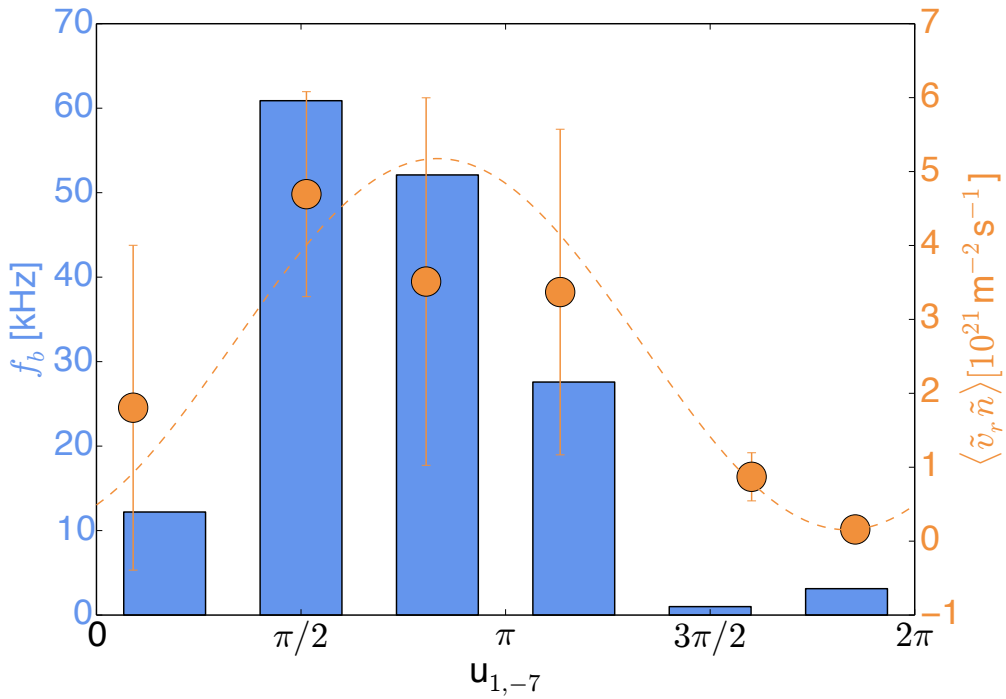
- Plotting the frequency of blobs as a function of the magnetic perturbation reveal a periodicity with the same symmetry



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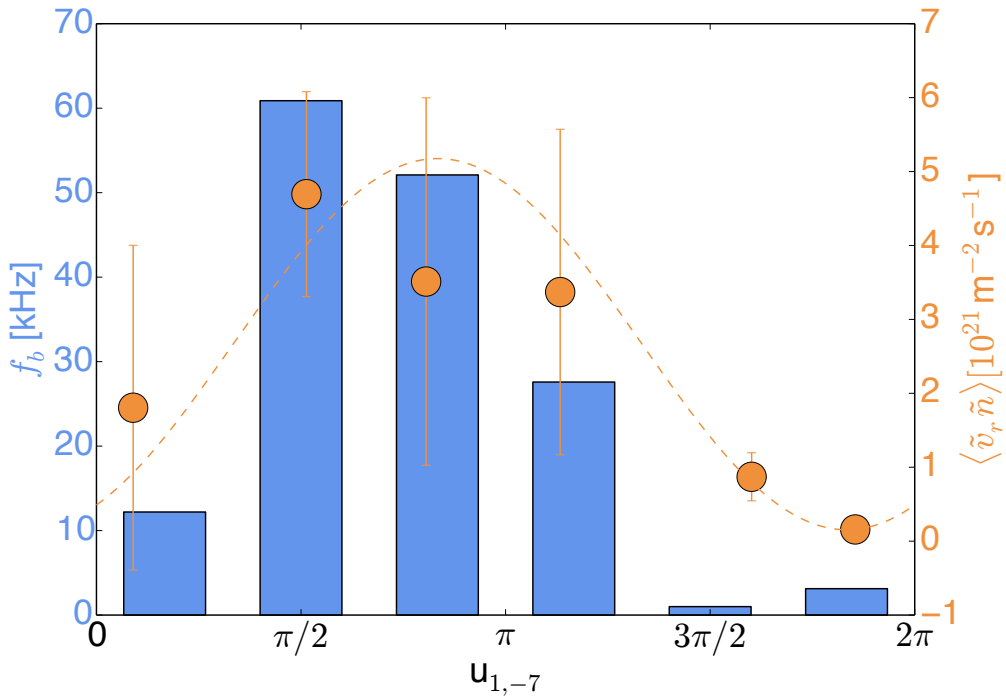

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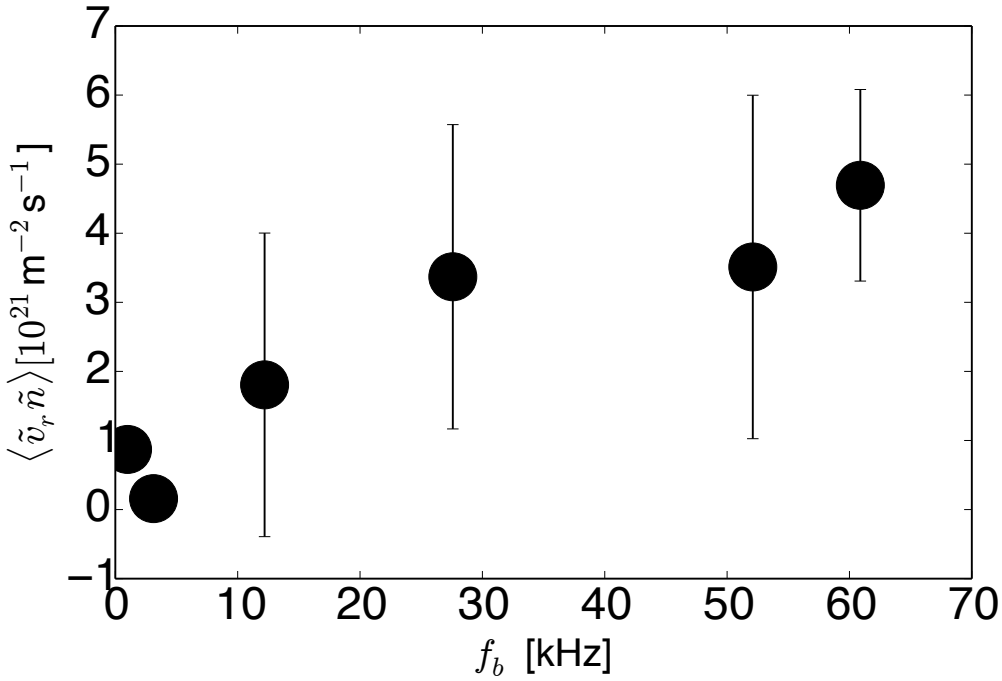
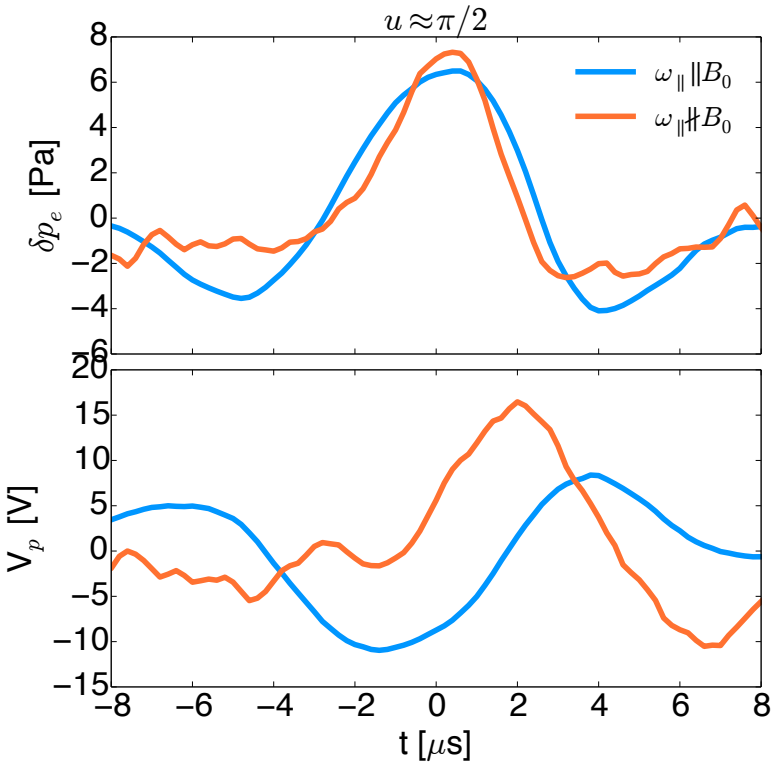
- Plotting the frequency of blobs as a function of the magnetic perturbation reveal a periodicity with the same symmetry
- Consistently, fluxes are peaked where the frequency of the blob increases
- A clear linear relation between fluxes and blobs confirm intermittent transport dominates particle losses



Shear and blob modulation

- Blobs with opposite vorticity ($\parallel$, $\nparallel$ to B_0) coexist with different abundance



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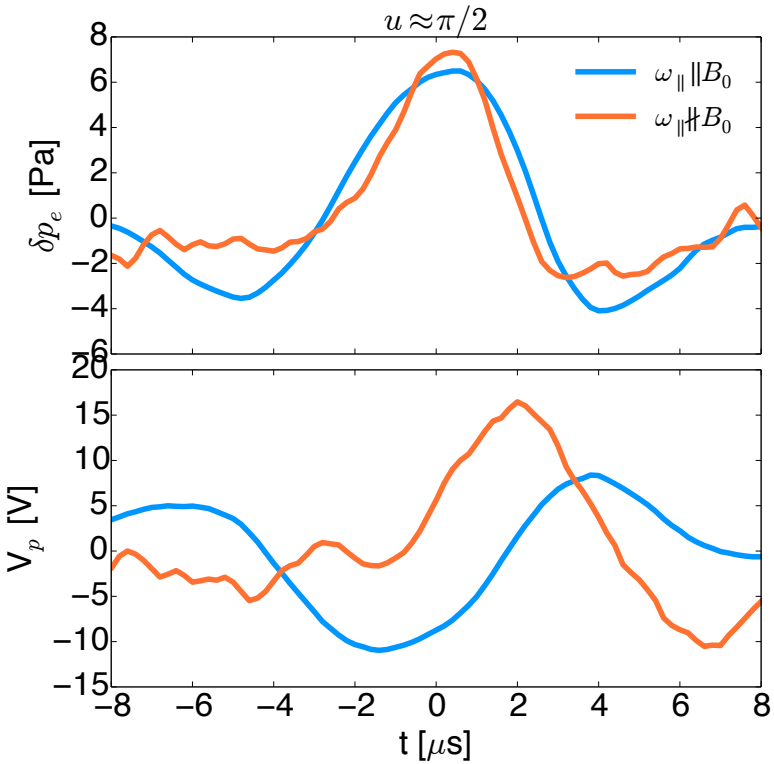

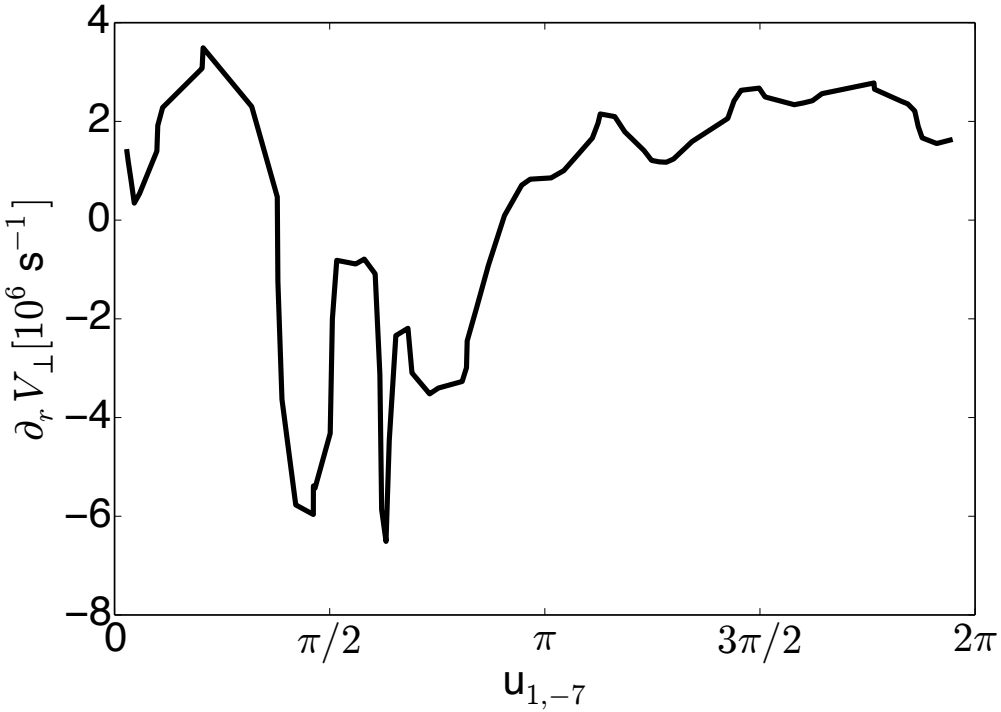

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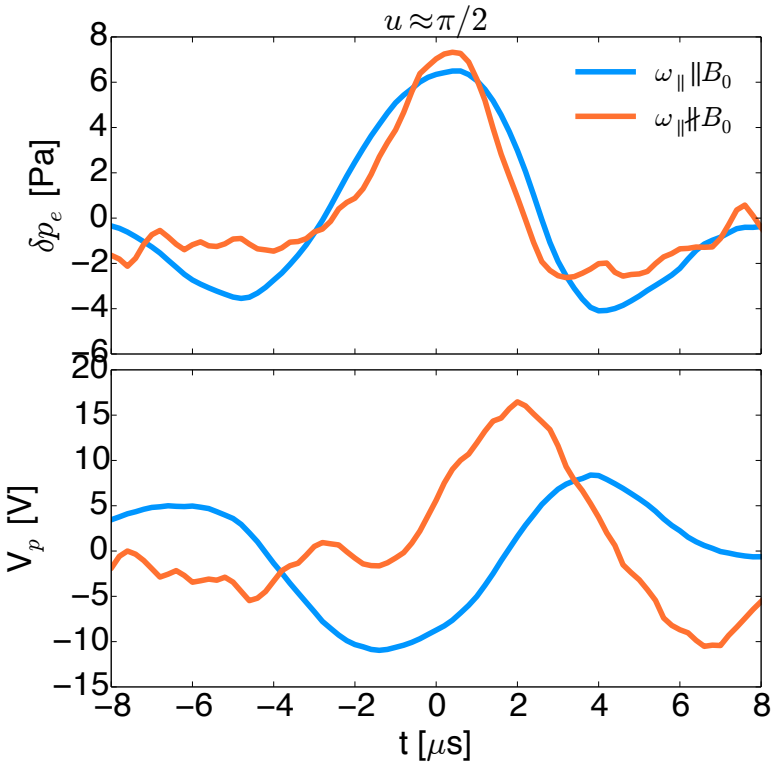
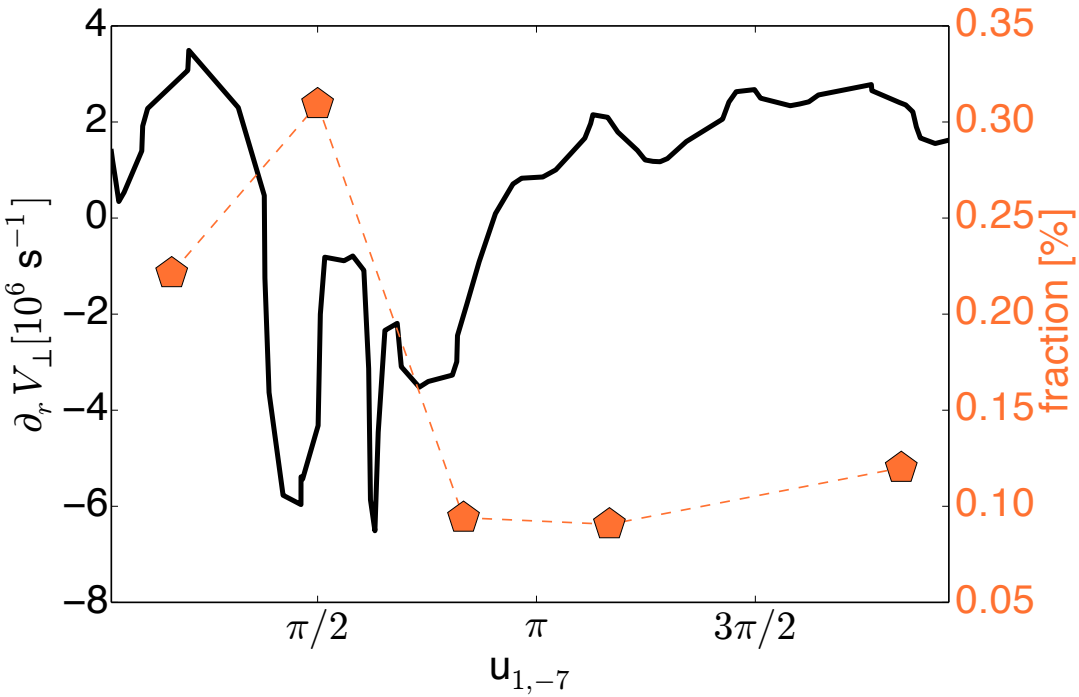
- $\mathbf{E} \times \mathbf{B}$ Shear modulated by the underlying magnetic topology
- The modulation of the shear modified the ratio between structures with opposite vorticity ($f = \#(\omega \nparallel B_0)/\#$ Total)





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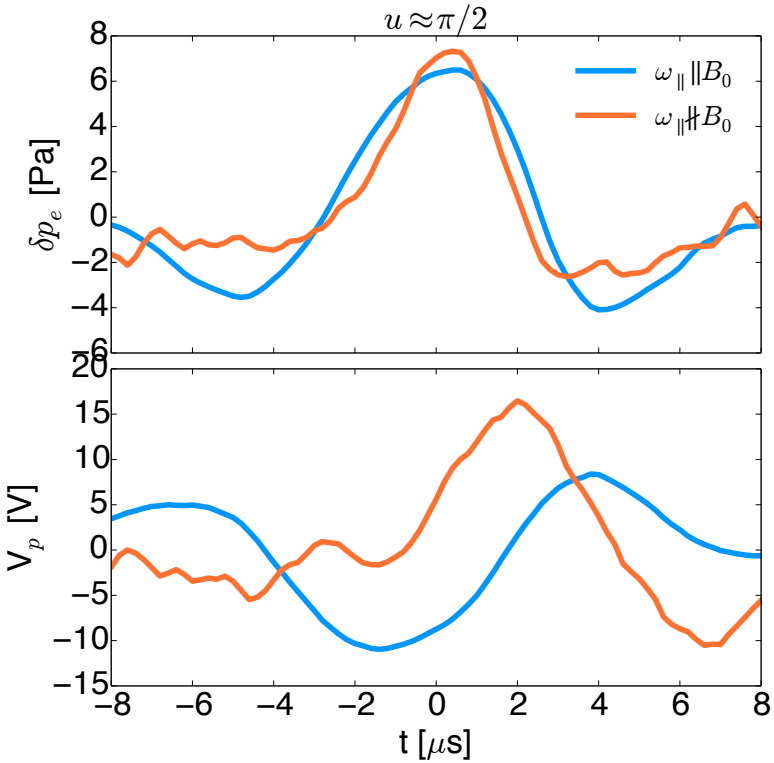
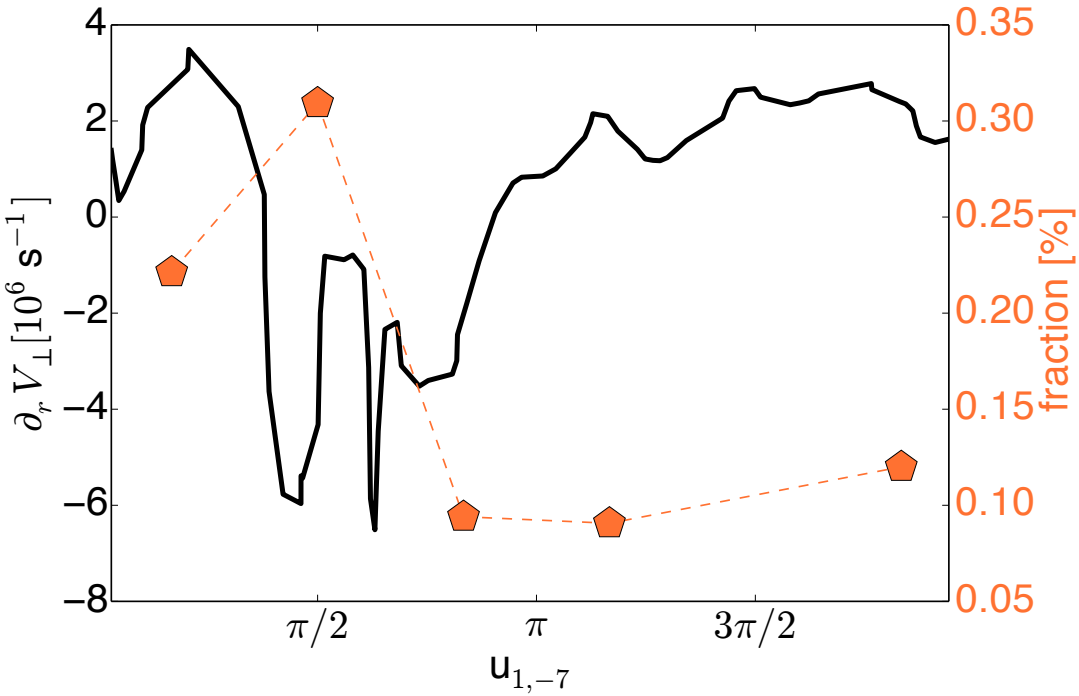
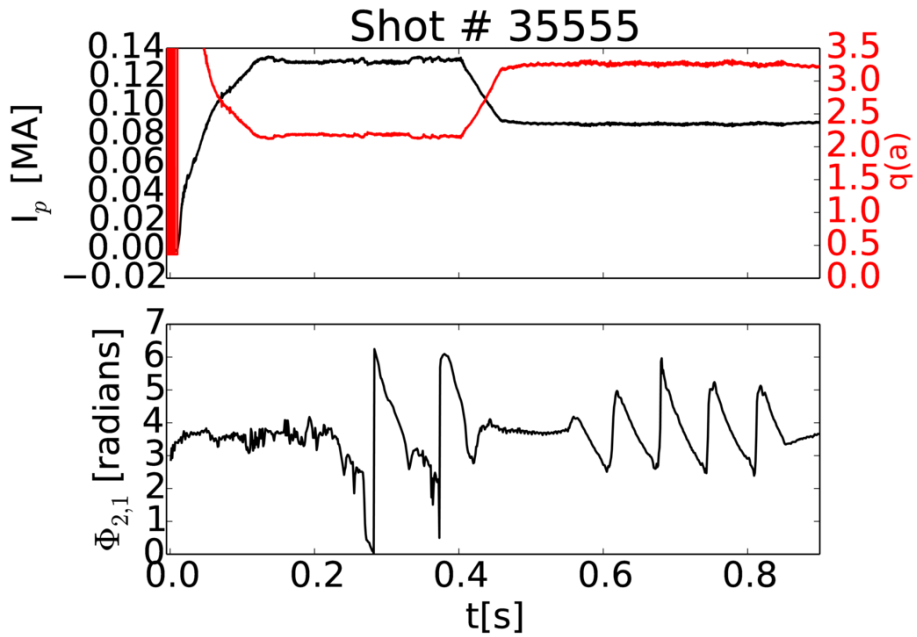
- The modulation of the shear modified the ratio between structures with opposite vorticity ($f = \#(\omega \nparallel B_0)/\#$ Total)
- Flux reduction does not depend on the absolute value of the shear





Is this Reversed Field Pinch effects only?

- Tokamak discharges performed dynamically varying the $q(a)$ through I_p control



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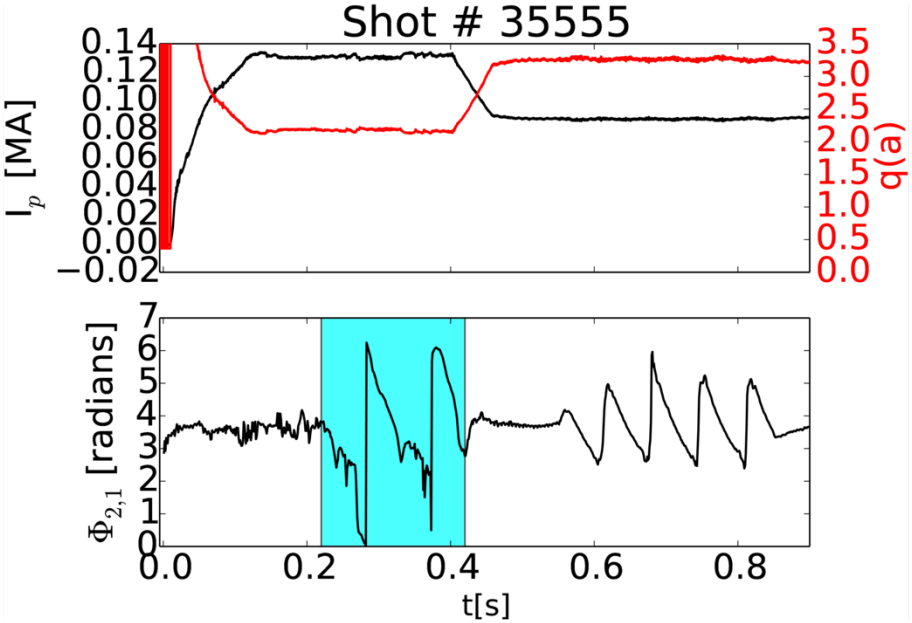

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- Tokamak discharges performed dynamically varying the $q(a)$ through I_p control
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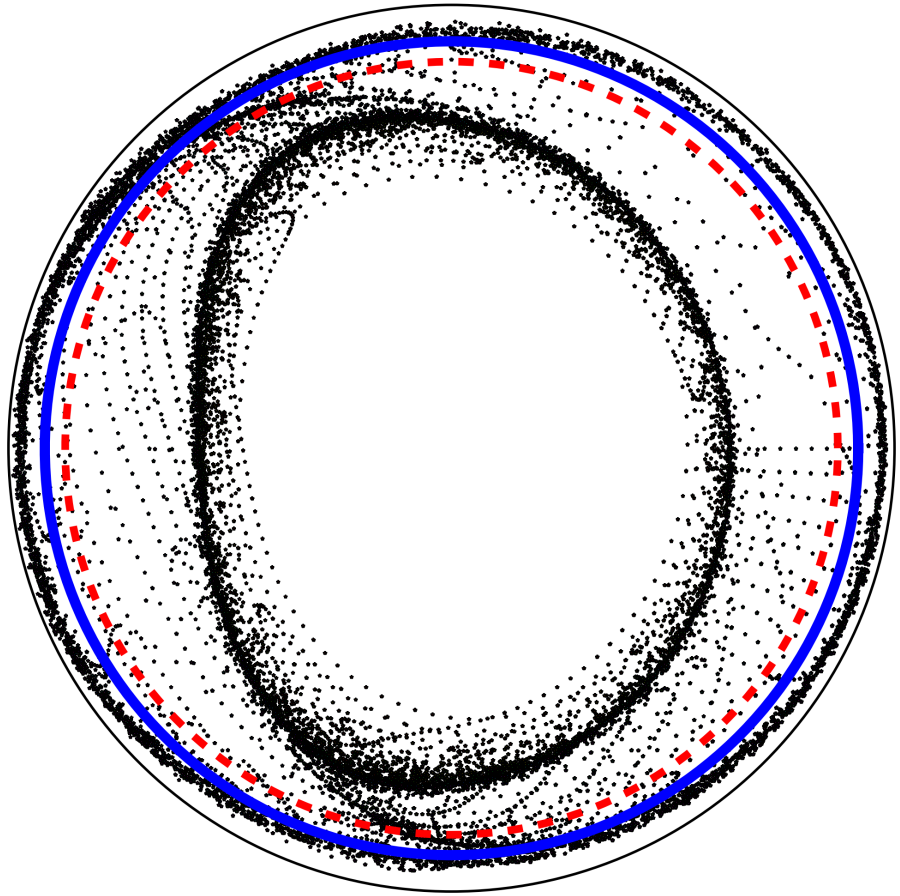
Shot # 35555 @ 0. 3 s, ϕ= 247



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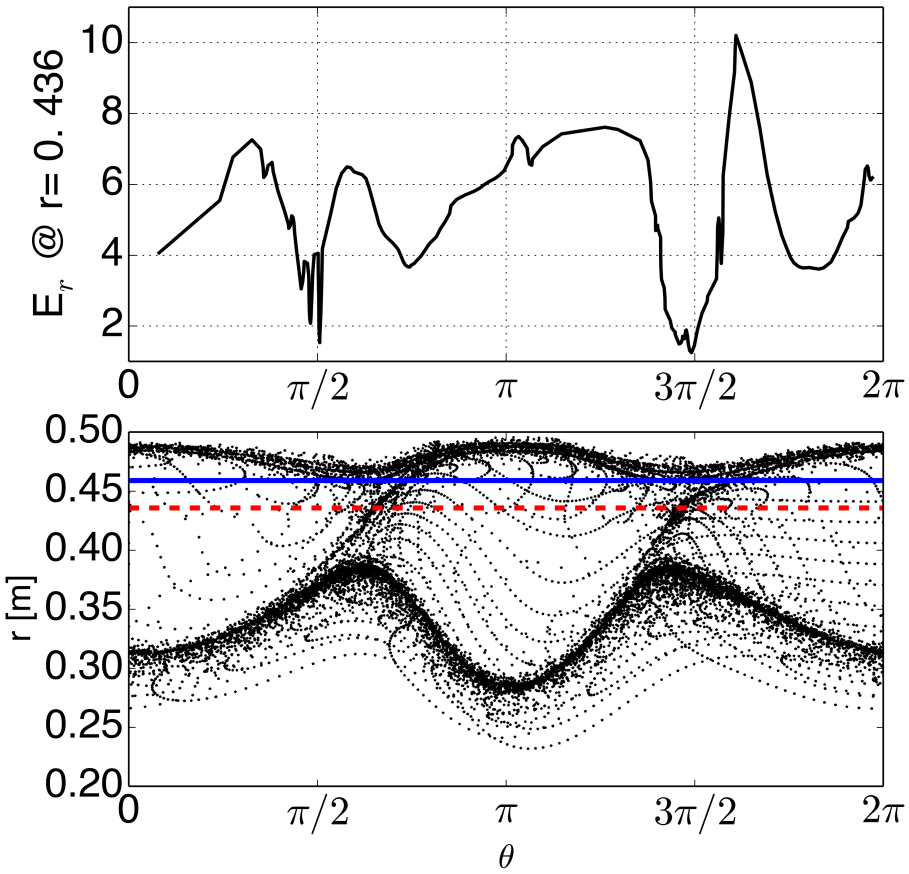

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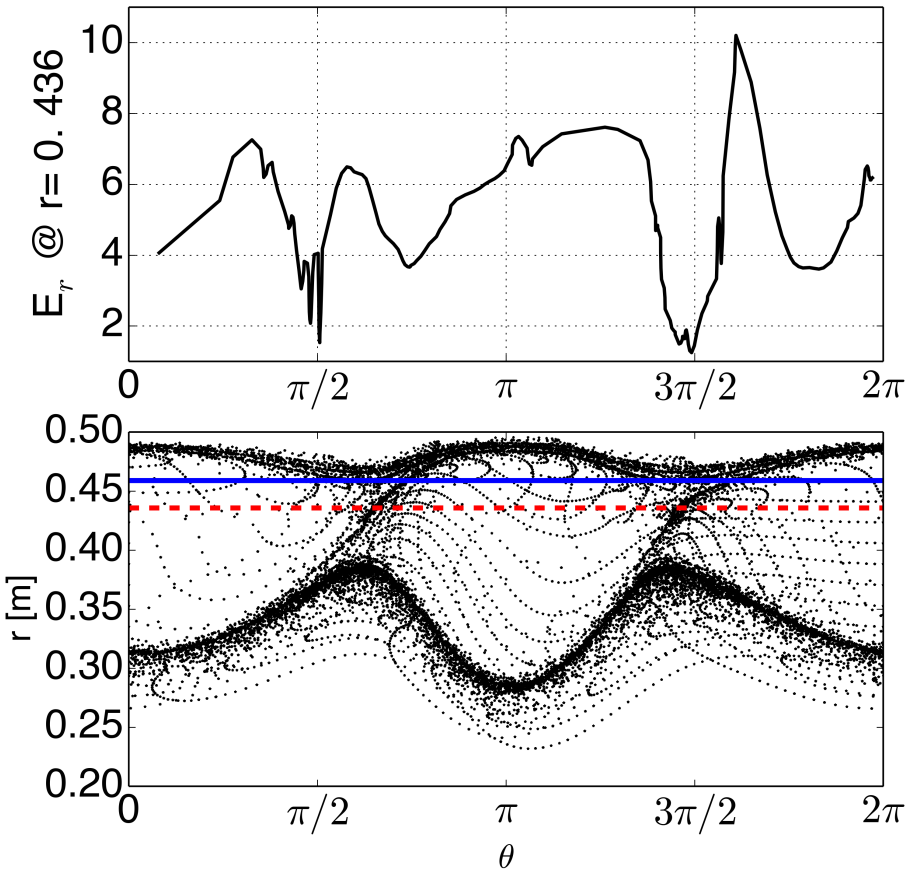
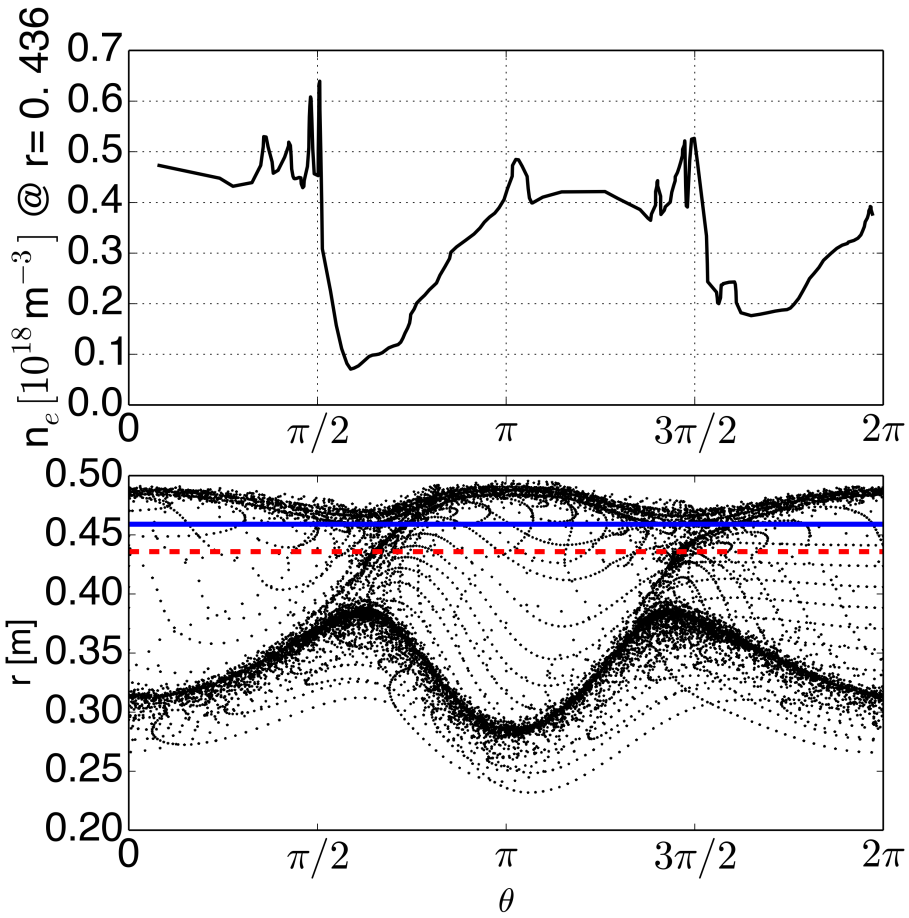
- Clearly modulated by the presence of the mode



Transport effects

- Also edge electron density is modulated by presence of the mode
- Density seems to be reduce where the electric field becomes more positive, with abrupt variations close the separatrix
- It seems consistent with the observation in RFPs



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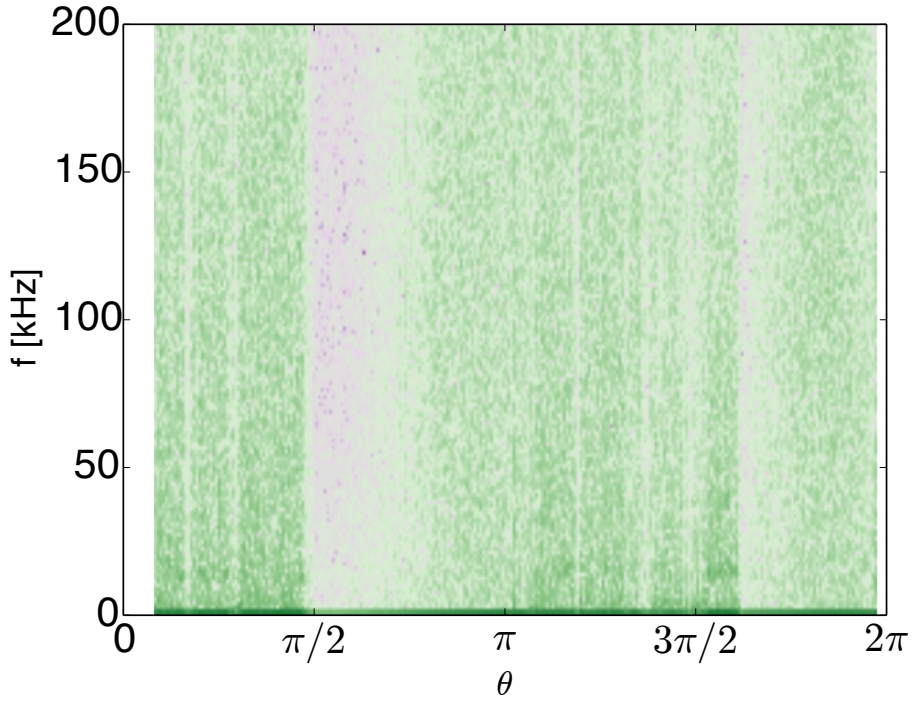

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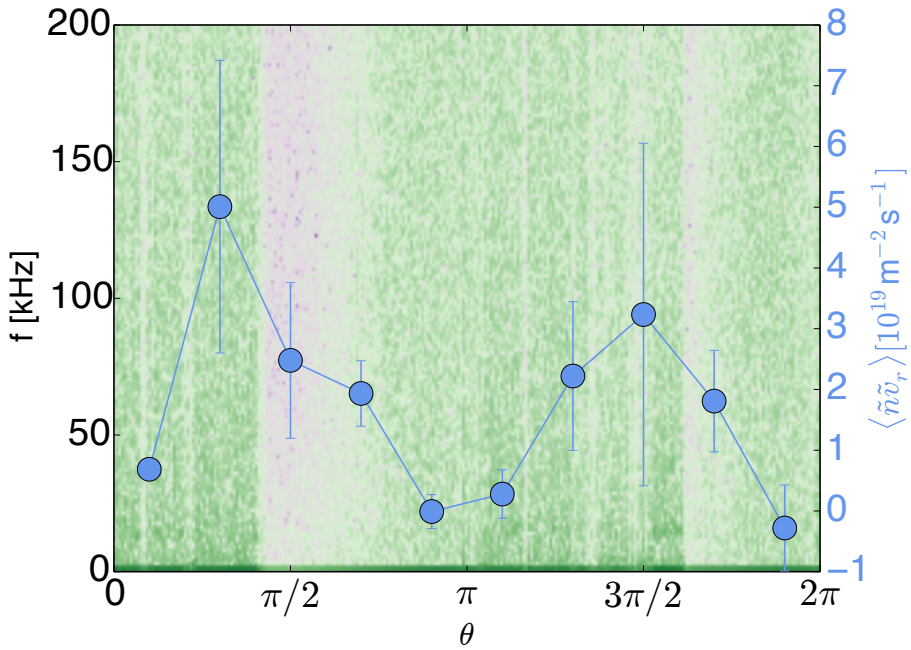
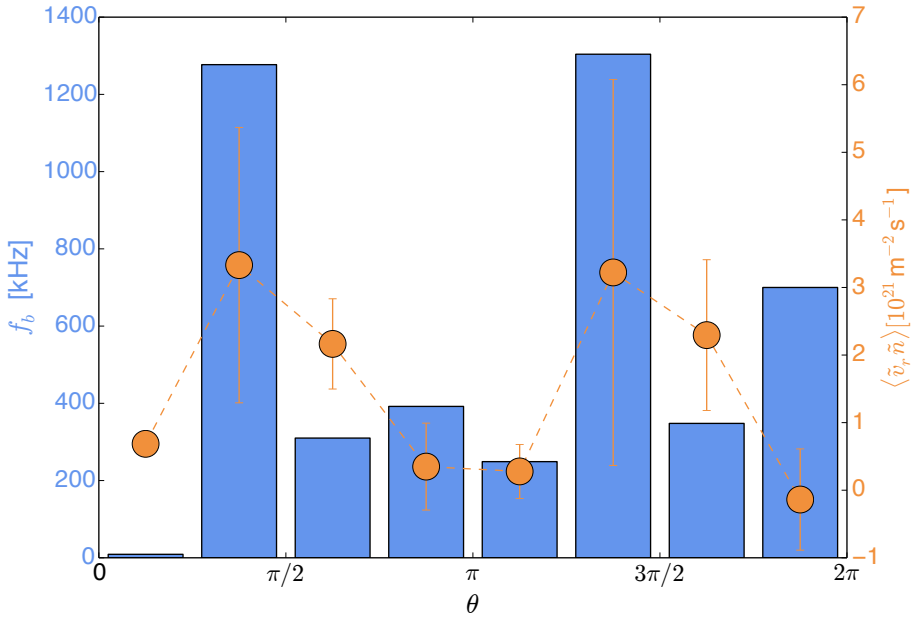
- Correspondingly turbulent particle transport is reduced whereas it peaks around π



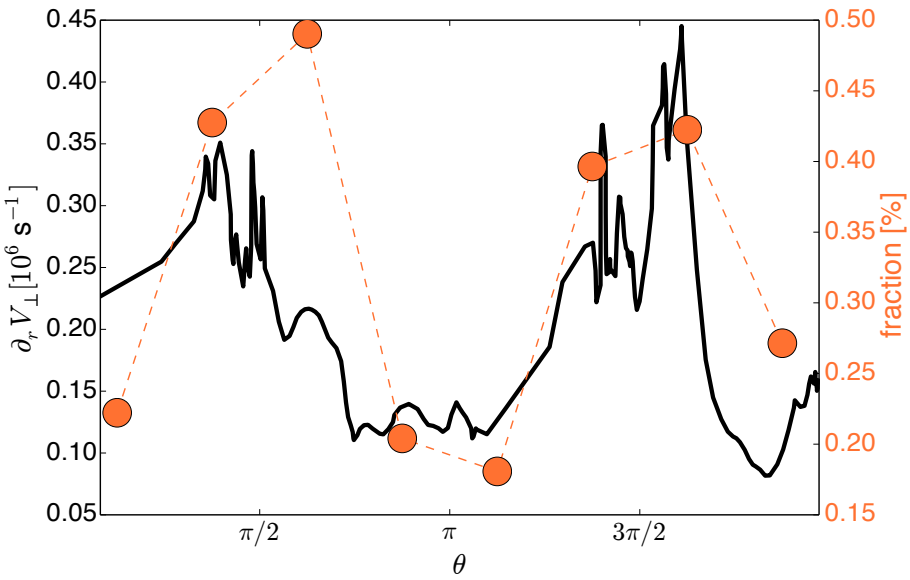
Transport and blobs

- In analogy to what observed in RFPs, particle losses increases in the region where the frequency of the blob increases



Transport and blobs

- In analogy to what observed in RFPs, particle losses increases in the region where the frequency of the blob increases
- In analogy to RFPs the spatial variation of the shear increases the number of structure with vorticity $\nparallel$ to guiding field. This seems to increase local transport



Common physical interpretation

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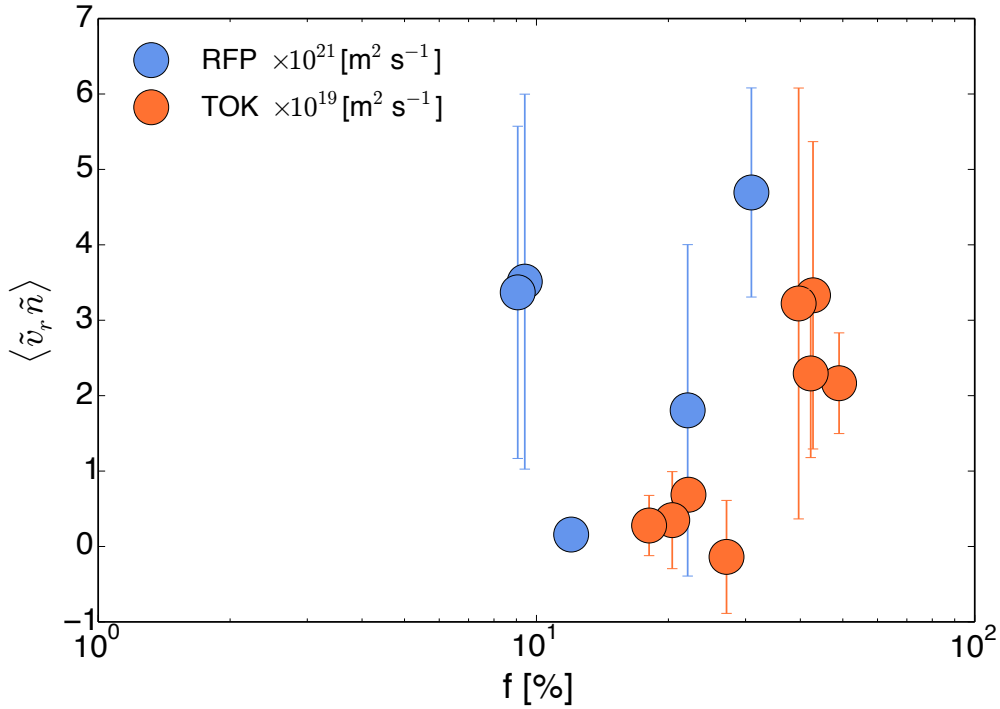
- Modification of $\mathbf{E} \times \mathbf{B}$ shear due to the presence of magnetic island close to the wall confirmed in both RFPs and Tokamak
- Variation of the shear modifies intrinsic rotation of blobs and population of vortices with vorticity parallel and anti-parallel with respect to B_0
- Both the configuration suggest an enhancement of transport whenever population of anti-parallel vortices increases



Conclusion

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5. Shear is modulated as well acting on local vorticity of turbulent eddies. Suggestion of enhanced transport due to different ratio between vortices parallel/anti-parallel to B_0

Poster and talks from RFX-mod team I

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1. D. Terranova *et al.*, *Equilibrium reconstruction for shaped tokamak discharges in RFX-mod*, P5.039
2. G. Marchiori *et al.*, *Model based feedback control system of plasma shape in RFX-mod Tokamak discharges*, P5.049
3. O. Kudlacek *et al.*, *Real time plasma boundary reconstruction in RFX-mod tokamak discharges*, P5.062
4. L. Pigatto *et al.*, *MHD control system optimization to RFX-mod real passive boundary*, P5.080
5. M. Gobbin *et al.*, *Characterization of eITBs in high current deuterium and hydrogen helical shaped plasmas*, P5.074
6. L. Carraro *et al.*, *Impurity screening in RFX-mod RFP plasmas*, P5.078
7. F. Auriemma *et al.*, *Spontaneous mitigation of anomalous transport in RFX-mod helical regimes*, P5.079
8. T. Bolzonella *et al.*, *Physics and control of multiple external kink instabilities with realistic 3D boundaries: recent understandings from experiment and modelling*, O4.132

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