CONSORZIO RFX

Ricerca Formazione Innovazione

3D Effects on RFX-mod helical boundary region

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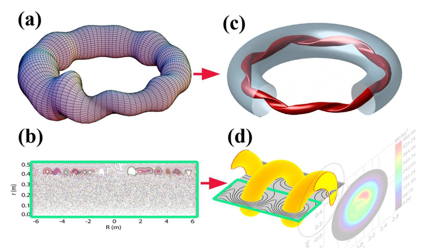
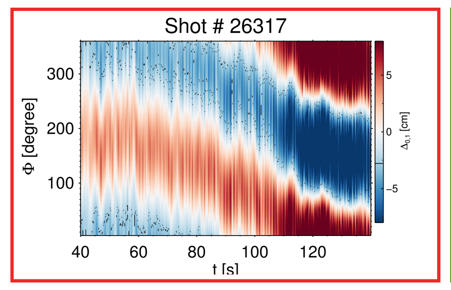
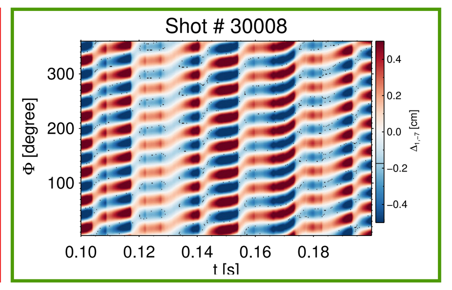
(i) The RFX-mod Reversed Field Pinch experiment

1. Toroidal axisymmetric configuration sustained mainly by internal current
2. Toroidal field reversed at the edge with *safety factor* $q<1$ always below unity
3. RFX-mod: R =2 m, a=0.46 m
4. Data obtained at high current $I_p \geq 1.5$ MA and edge parameter $n_e = 1-2\times 10^{19}\mathrm{m}^{-3}$ $T_e = 20-100$ eV
5. RFP exhibits bifurcation from chaotic regimes to helical states (Escande et al. 2000; Lorenzini et al. 2009)
6. Plasma moving from topology dominated by an $(m,n)=(0,1)$ perturbation to a $(m,n)=(1,-7)$ helicity

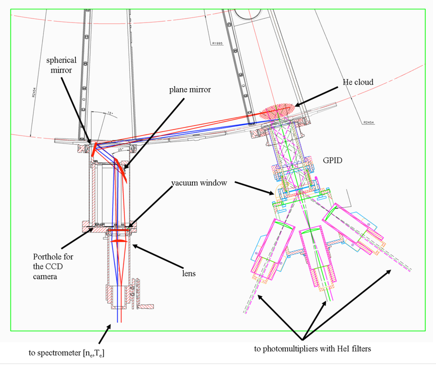


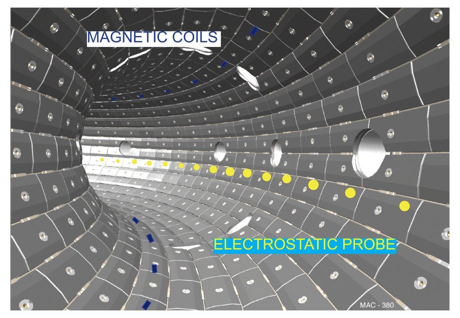




(ii) Experimental setup

- Edge density and temperature measured through a Thermal Helium Beam diagnostic (Agostini, Scarin, et al. 2010)
- The same helium gas cloud used for the Gas Puff Imaging diagnostic which provide information on fluctuations and perpendicular flow

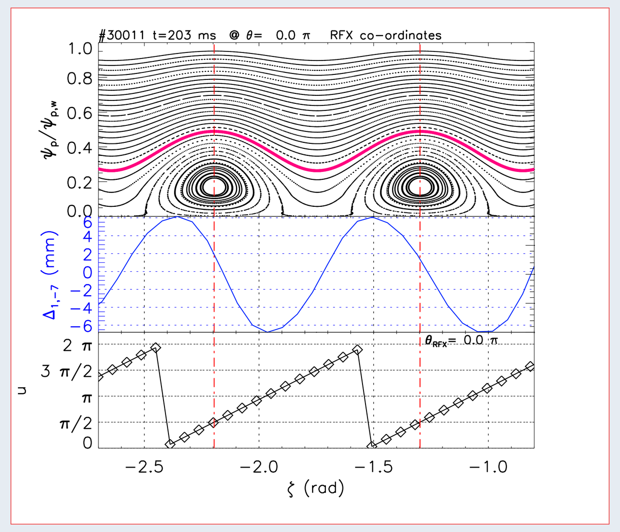




- Internal sensor of integrated signals (ISIS) constitute by a toroidal array of floating potential measurements with 5 degree spatial resolution
- Through correlation measurement the toroidal map of the toroidal flow is computed

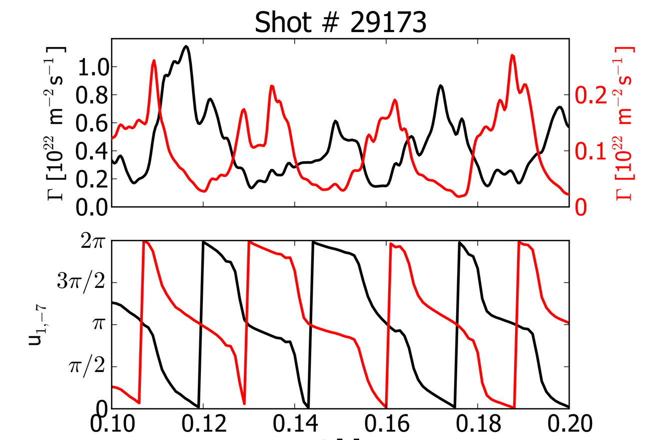
(iii) The helical angle

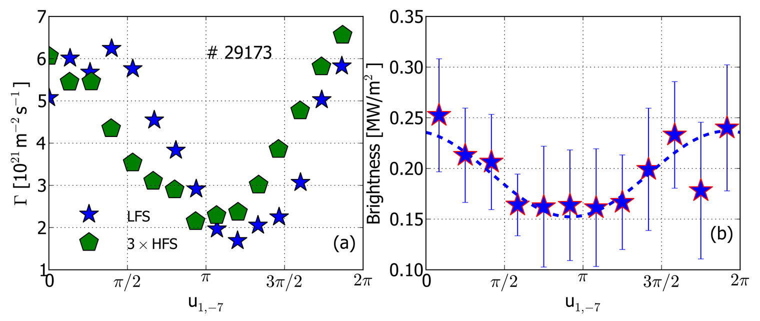
- Standard definition of the toroidal flux for a single mode
$$\psi(r,\theta,\phi)=\psi^0(r)+(m/nB_\phi+B_\theta)\alpha_{m,n}(r)\sin u$$
- $\delta\mathbf{A}=\alpha_{m,n}(r)\mathbf{B}$
- u being the *helical angle* defined as
$$u_{m,n}(t)=m\theta-n\phi+\varphi_{mn}(t)$$
- Maximum radial displacement $\Delta_r^{1,-7}$ is in the direction of $\nabla\psi$ (pink line) and by construction at $u=\pi/2$
- At the edge at $u\approx 0$ due to the toroidal coupling with $(m,n)=(0,7)$ mode (Zanca et al. 2004)



(iv) Helical Plasma wall interaction

- In Helically shaped plasma particle influx as estimated from H_α exhibits an helical deformation, seen as non-axysimmetric oscillations (HFS/LFS out of phase)

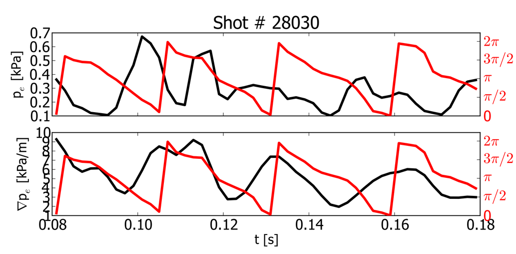


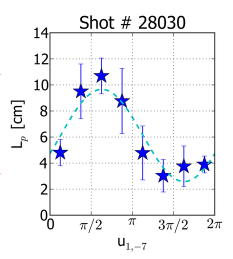


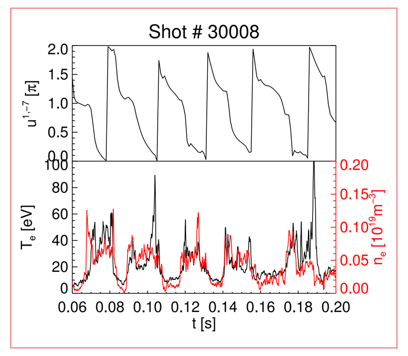
- The influx has a cos u behavior as a function of u (panel(a))
- Also P_{rad} radiation exhibits an helical deformation with decreasing radiation around $u\approx\pi$ panel (b))

(v) Pressure and pressure profile

- Density, Temperature and Pressure and relative gradient obtained through THB diagnostic (Agostini, Scarin, et al. 2010)
- Pressure and entire profile oscillate in time with higher values around $u\approx 0$
- $L_p=\left(\frac{\nabla p_e}{p_e}\right)^{-1}$ as a function of u exhibits a minimum around $u\approx 3\pi/2$
- Similar information obtained through Langmuir probe at $r/a=1$ with density and temperature oscillating in phase

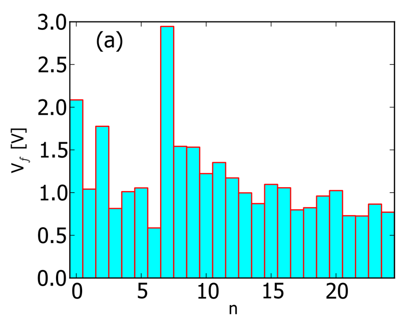


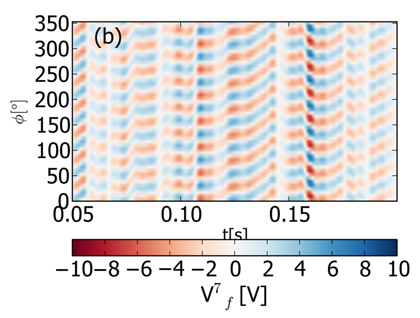


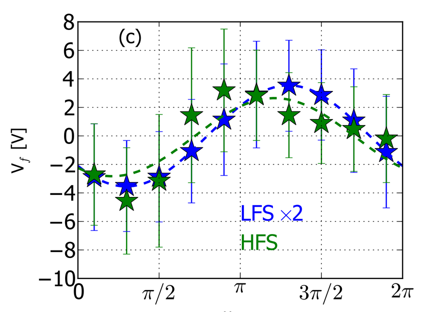


(vi) Floating potential

- Floating potential toroidal spectra (panel (a)) reveals a peak at the mode of the dominant perturbation
- Resolved as a function of u floating potential oscillations are negative around $u\approx\pi/2$. and positive around $u\approx 3\pi/2$
- **HFS** and **LFS** signals as a function of u collapse into a single shape sinusoidal pattern

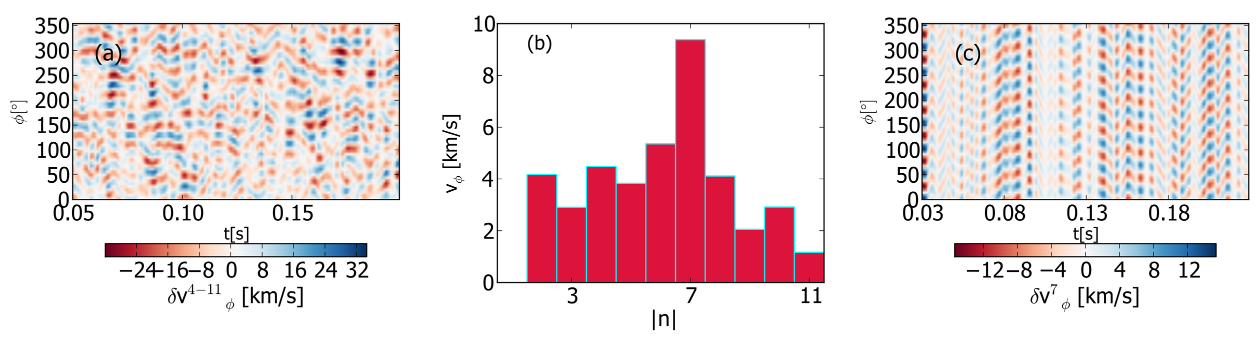




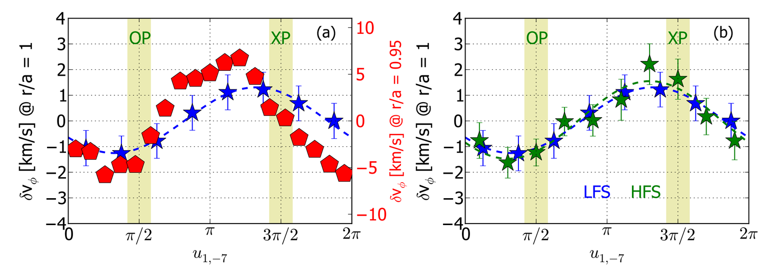


(vii) Plasma flow

- At the edge of RFP, $B_\theta \simeq B_\theta$ & $q\simeq 0$
- Toroidal map of toroidal flow at $r/a=1$ reconstructed through correlation analysis (panel (a))
- The Spectrum reveals a peak at the same helicity of dominant perturbation (panel(b))

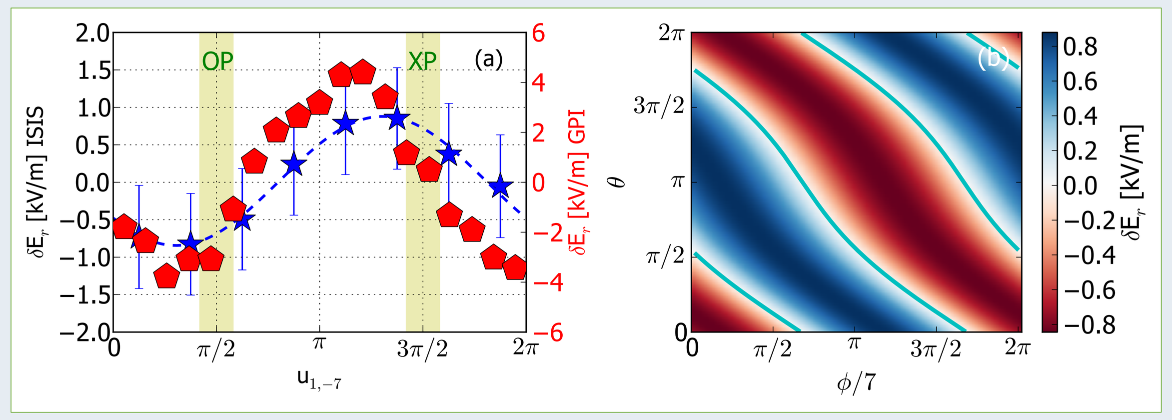


- The same information obtained also in a different radial position (see panel (a))
- HFS and LFS measurements of the flow collapse in a single sinusoidal shape (panel (b))



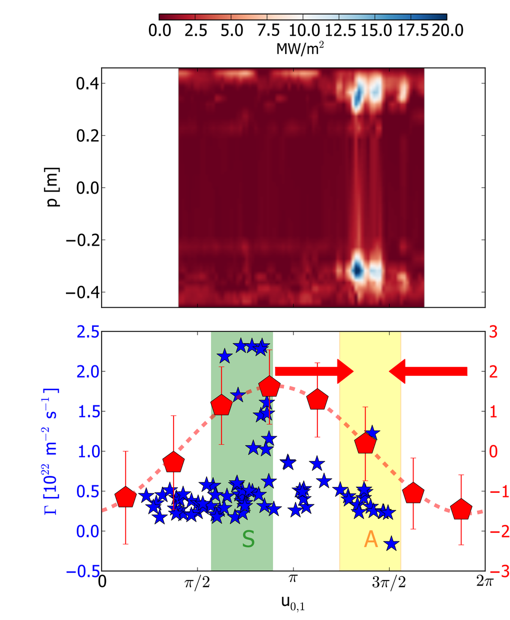
(viii) The radial electric field

- Diamagnetic contribution to the plasma flow at the edge of an RFP is negligible (Spizzo et al. 2012).
- **Radial electric Field** may be consequently directly computed from plasma flow
- At the edge, radial electric field is constant on helical surface and helical ripple on δE_r appears with maximum close to the location of the X-point of the island

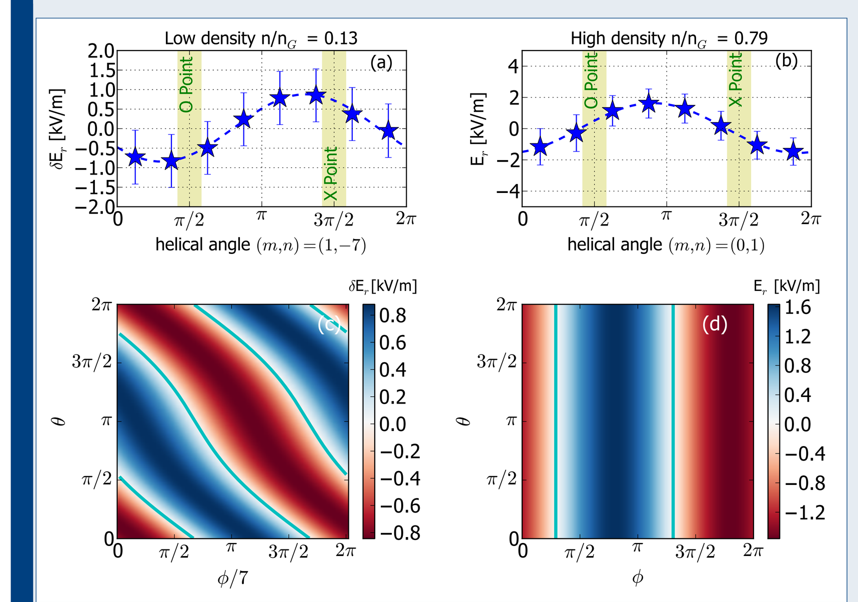


(ix) Radial electric field in MH case: the MARFE in an RFP

- High density operation in RFPs dominated by Multiple Helical (MH) regimes, with a broad spectrum of MHD modes.
- The modes are phase and wall locked and distortion may be described in a $(m,n)=(0,1)$ geometry
- Approaching $n/n_G\approx 1$ radiative collapse due to appearance of localized poloidally symmetric regions of enhanced radiation (Puiatti et al. 2009; Spizzo et al. 2012)
- Particle coming from source (**S**) are toroidally convected from both side towards an accumulation point (**A**) corresponding to the X-point of the (0,1) island

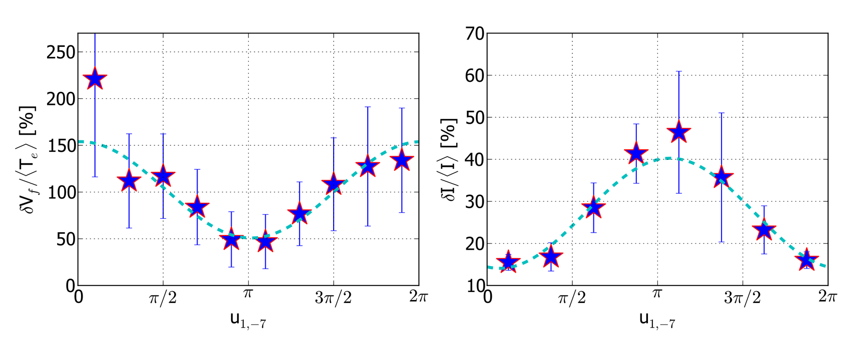


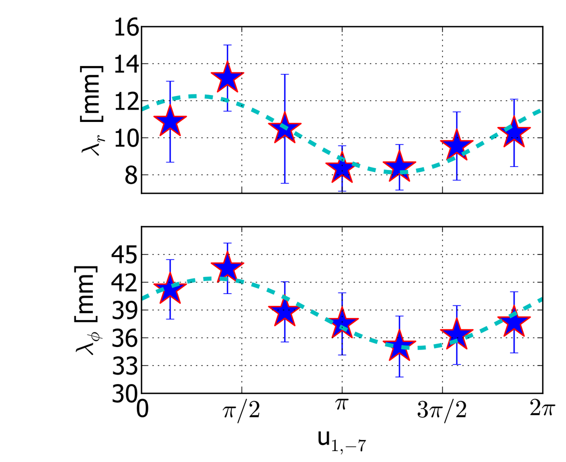
(x) Comparing the topologies



- Comparing two perturbations with different helicity at different Greenwald normalized density (i.e. Different collisionality)
- Radial electric field at the edge responds with a ripple consistent with the applied helicity
- Phase relation with respect to the perturbation different at different collisionality

(xi) Helical modulation of turbulence properties





- Turbulence properties modulated by helical deformation (Agostini, Scaggion, et al. 2012)
- Density fluctuations higher at $u\approx\pi$ at the minimum of Δ_r
- Potential fluctuation exhibits opposite behavior: $\Longrightarrow$ reduction in the region of reduction of the flow
- Radial and perpendicular correlation lengths (proportional to blobs dimension) higher around $u\approx\pi/2$
- Consistent picture of blobs generated at $u\approx 0$ and convected in the region where they accumulates $u\approx\pi$

Conclusion

- Plasma edge properties modulated by spontaneous helically deformed plasma
- Plasma wall interaction helically deformed and maximum at the maximum radial edge displacement
- Plasma pressure and pressure profile modulated with reduction of L_p for helical angle $u\approx 3\pi/2$.
- Edge flow, resulting from ambipolar electric field is found constant on constant helical surface
- Helical modulation of the radial electric field is found to follow helicity of the dominant perturbation
- Phase relation between electric field ambipolar response and magnetic perturbation is not constant at different n/n_G

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