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FACULTY OF ENGINEERING AND ARCHITECTURE

Experimental characterization of the ExB staircase in Tore Supra

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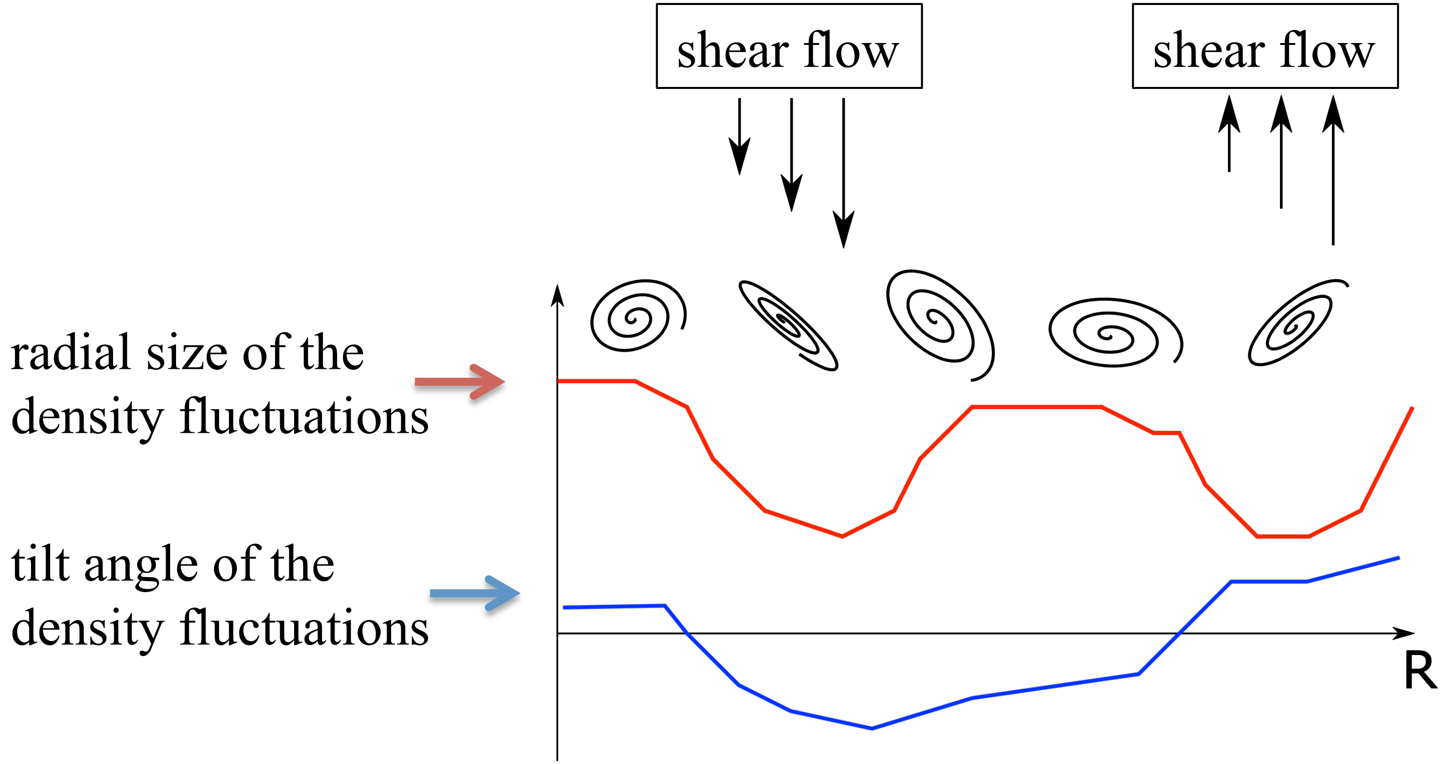
ExB staircase : set of regularly spaced shears flow which produce a specific pattern on the properties of the fluctuations

- ExB staircase was discovered in numerical simulations *Dif-Pradalier, PRE, 2010*

➢ 2-4 distinct flows on the radial profile ➢ radial extent of the flow ~ 1 cm



Expected signatures of the staircase:

➢ local minima of the fluctuations size

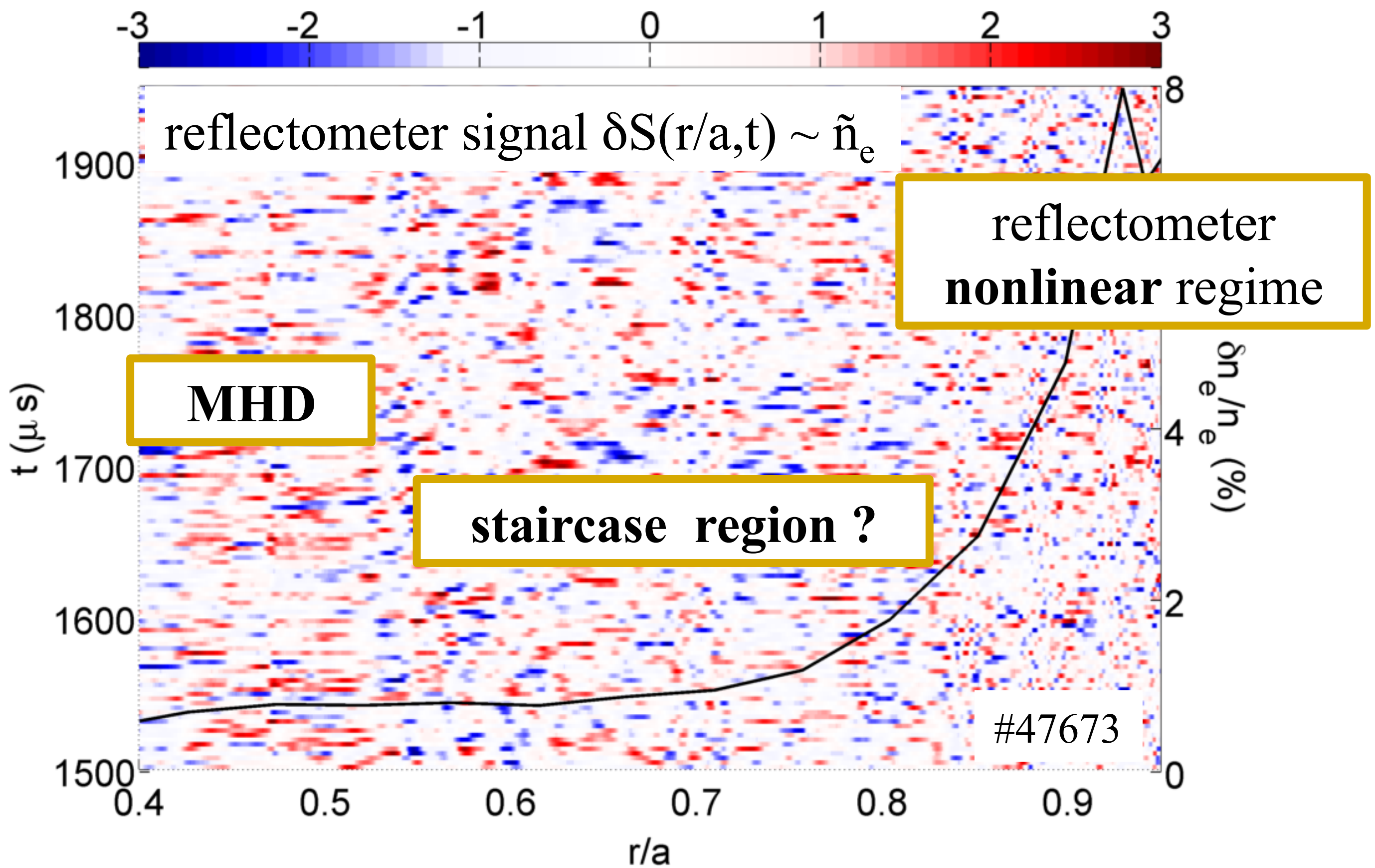
➢ sudden variation of the tilt angle

Shesterikov, PRL, 2013

Investigated by ultrafast sweeping reflectometry

Clairet, RSI, 2010

Moderate fluctuation level and MHD-free plasmas are optimal conditions for the observation of the staircase



How to evaluate the radial variation of the:

- size of the fluctuations?
- tilt of the fluctuations?

The coherence quantifies the size of the fluctuations, the correlation quantifies the tilt of the fluctuations

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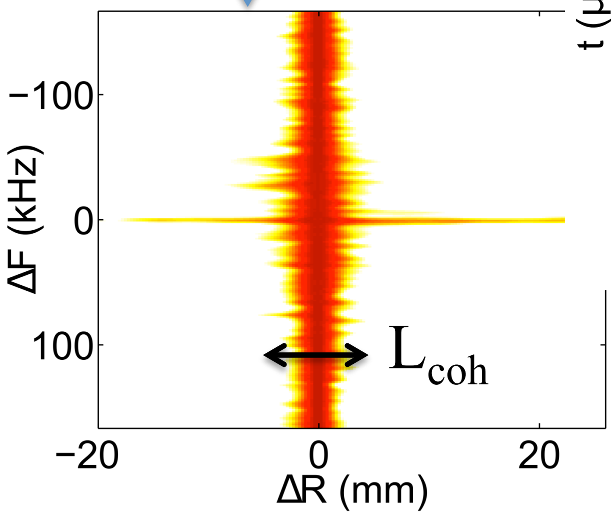
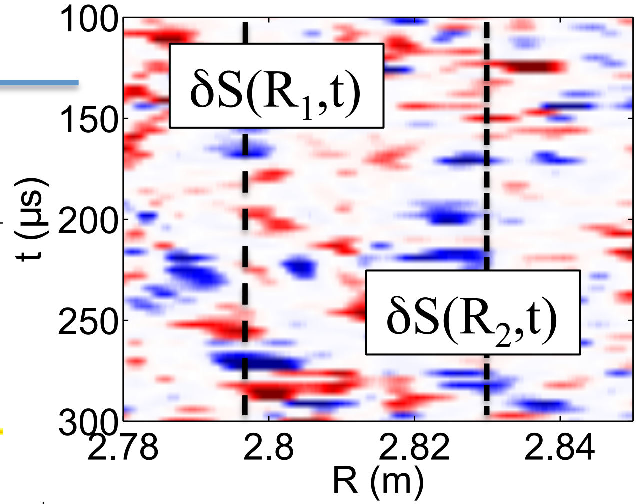
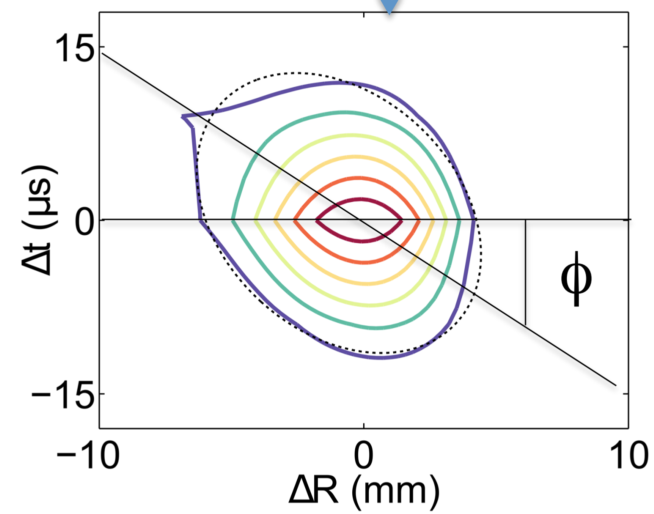
coherence





correlation



L_{coh}: proxy for the size of the fluctuations

- defined as the FWHM of the coherence
- only turbulent frequencies are considered |F| > 15 kHz

(Hornung, PPCF, 2013)

ϕ: proxy for the tilt of the fluctuations

- obtained by fitting an ellipse to the contour of the correlation function

(Pinzon, IRW12, 2015)

Local reduction of the coherence lengths observed in several plasma discharges

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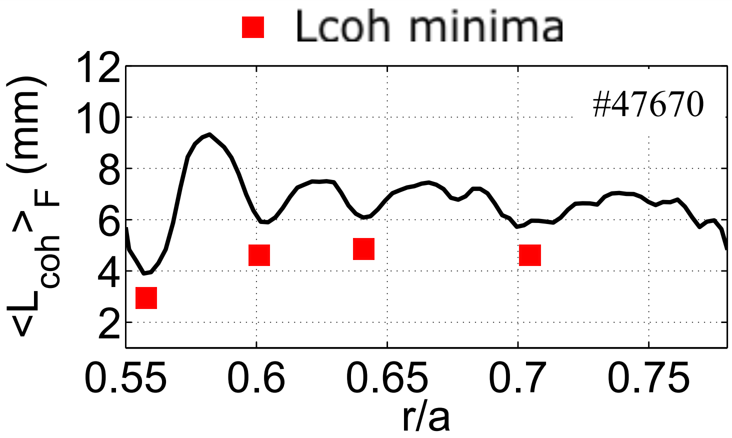
- Experimental conditions:
  Ip=0.7MA, $<n_e>$ =1.47 $10^{19}m^{-3}$,
  B_t=3.85T, Ohmic plasmas

- L_{coh}: proxy for the fluctuations size

- L_{coh} mimima are quasi regularly spaced along the radial direction

➢ consistent with Gysela observations
  (Dif-Pradalier, PRL, 2015)



Local reduction of the coherence lengths observed in several plasma discharges

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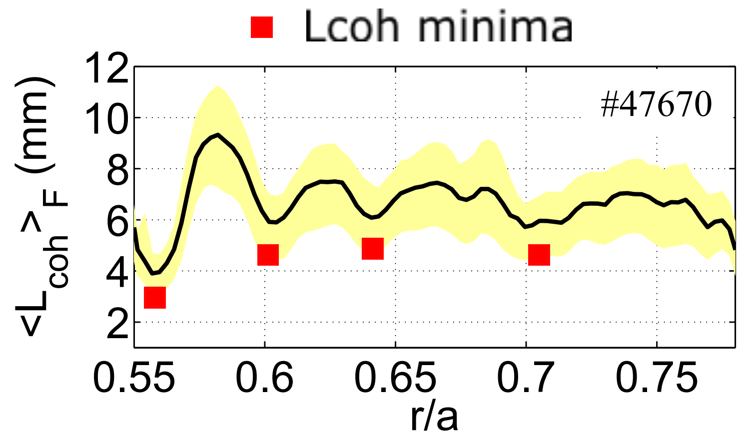

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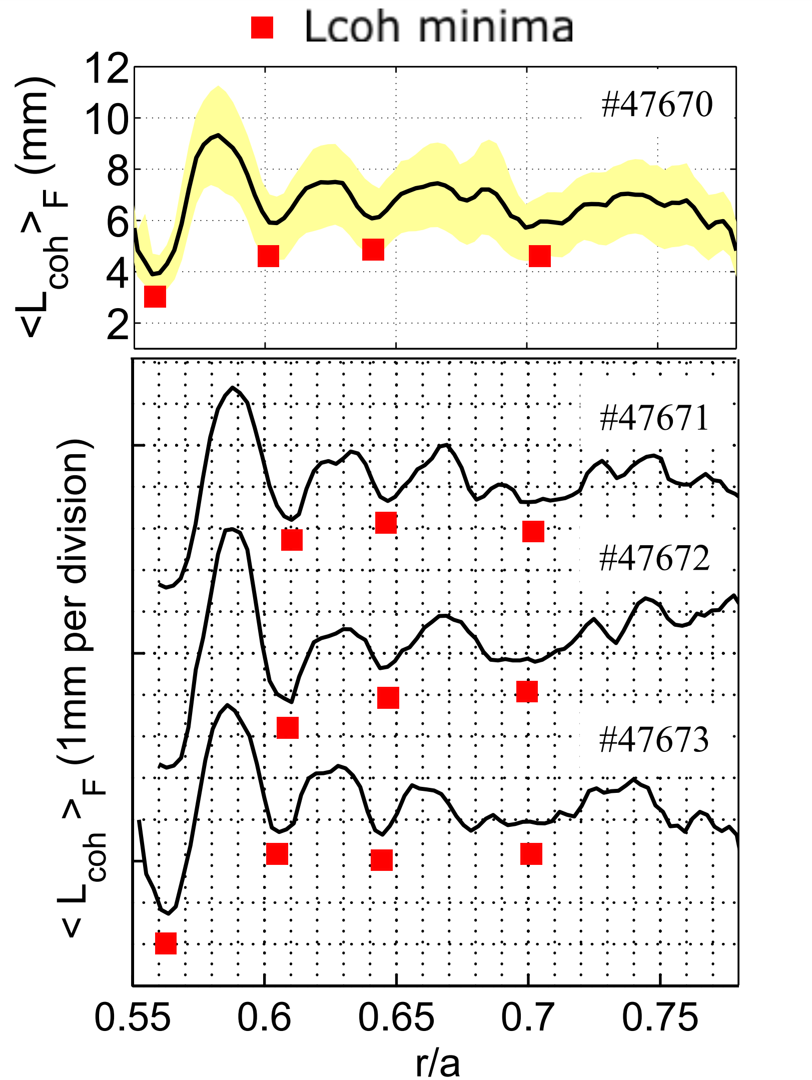
- L_{coh}: proxy for the fluctuations size

- L_{coh} mimima are quasi regularly spaced along the radial direction
  - ➢ consistent with Gysela observations *(Dif-Pradalier, PRL, 2015)*

- Reproducibility of the minima
  - ➢ not a random phenomena
  - ➢ robust w.r.t. the definition of L_{coh}



The tilt of the fluctuations changes sign around the radial position of L_{coh} minima

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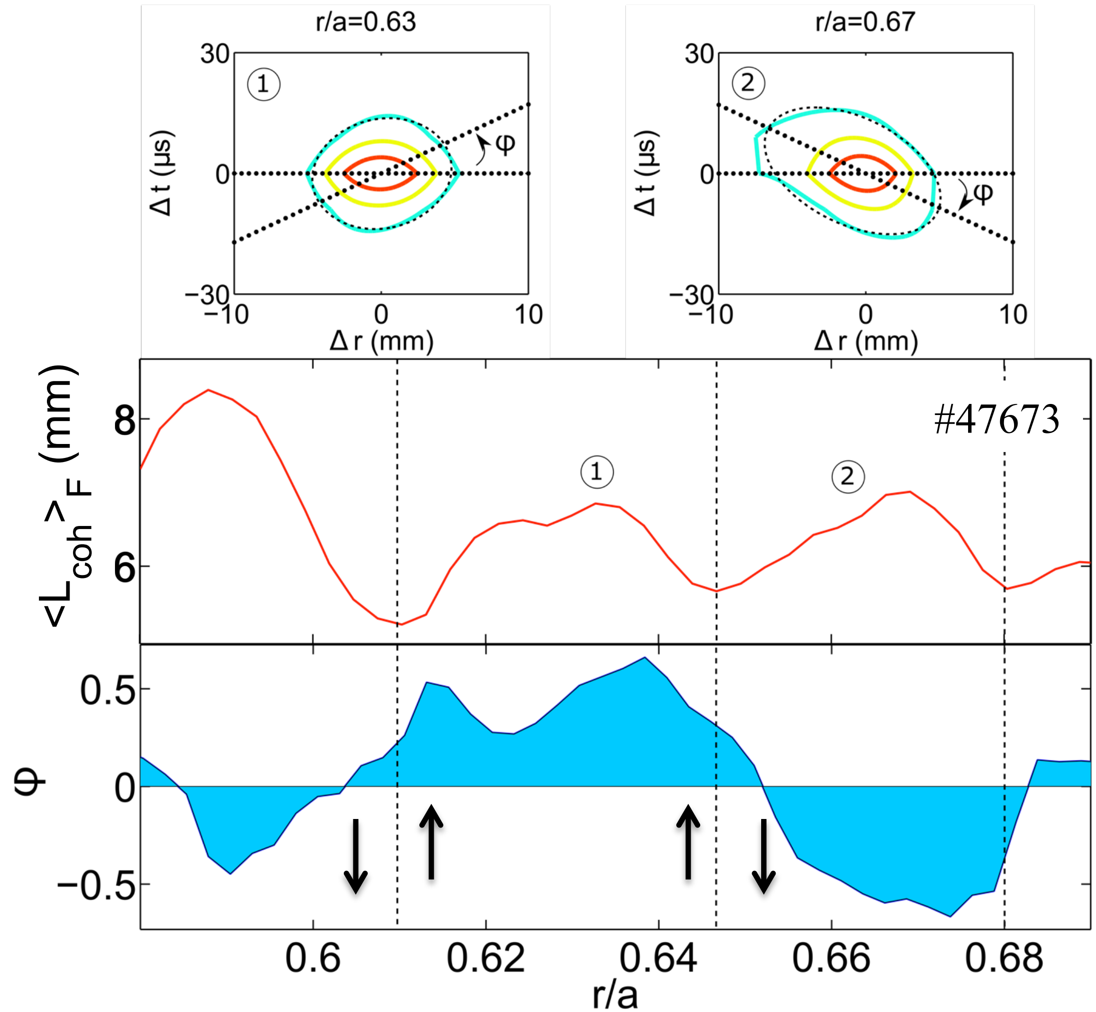
- ϕ: proxy for the tilt of the density fluctuations

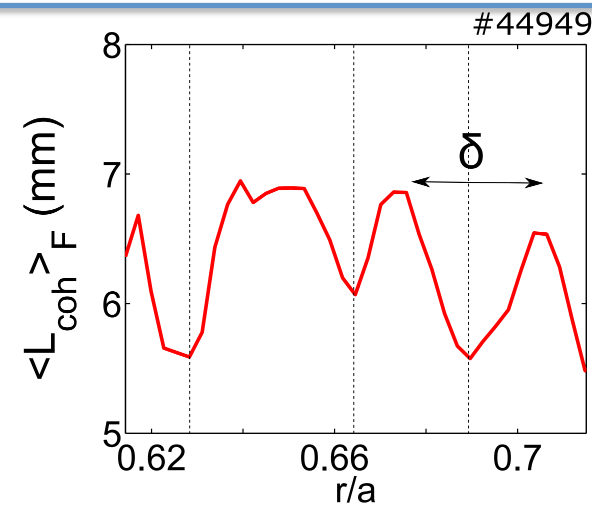
- Eddies may also be tilted by the magnetic shear but this effect is small in the equatorial plane *(Fedorczak, PPCF, 2013)*

The profile of ϕ is consistent with the presence of shear flow around the minima of L_{coh}



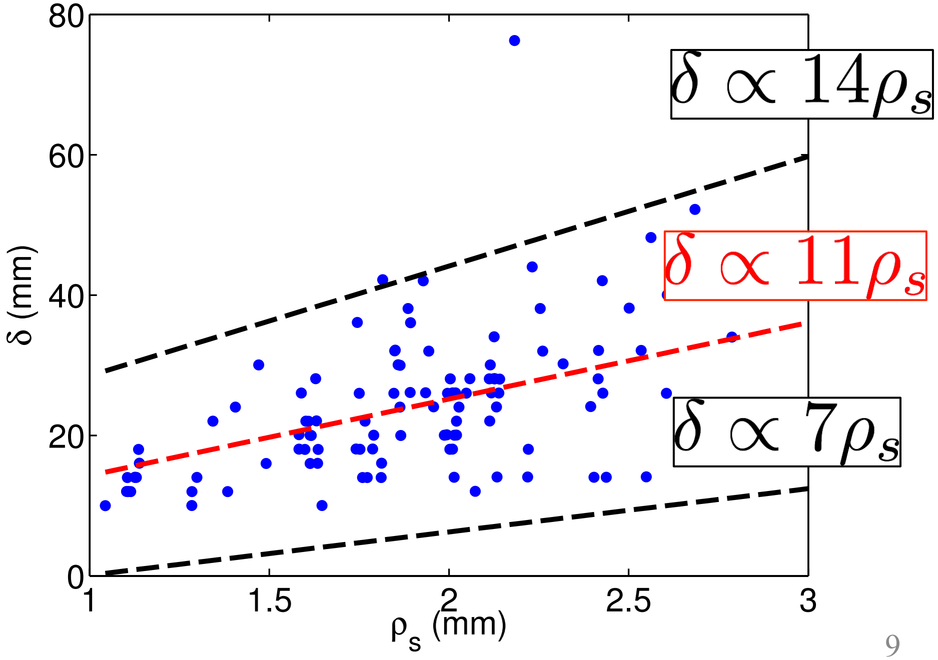
The widths of the local minima increase with ρ_s

- The local minima of L_{coh} are characterized by their width δ
- ρ_s is evaluated at the position of the local minima
- 179 local minima identified so far in our data base



Assuming δ ~ radial scale of a shear flow, then $\delta \sim 11\ \rho_s$

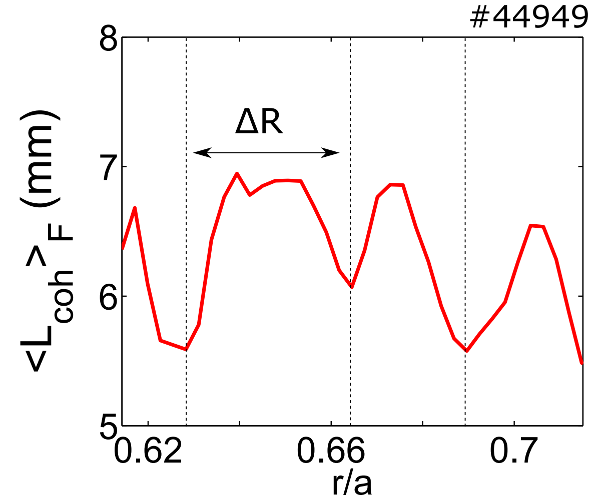
- ➢ consistent with the radial extent of zonal flows (m=0,n=0)
  Fujisawa, Nuc. Fus., 2009
- ➢ support Gysela observations
  Dif-Pradalier, PRL., 2015

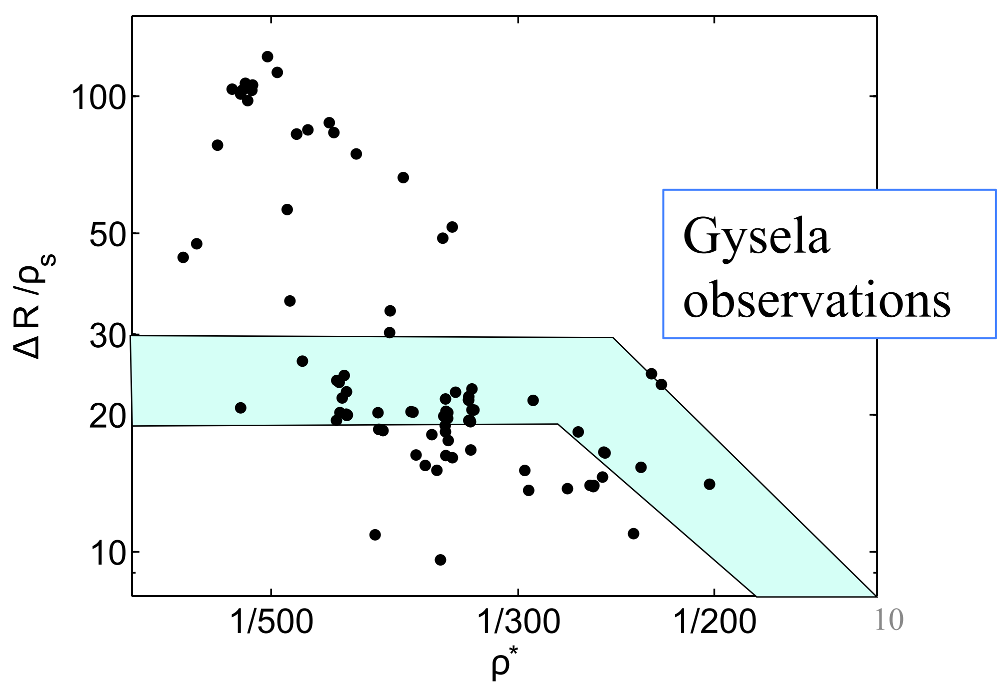


The spacing between two successive local minima decreases slightly with $1/\rho^*$

- The step ΔR is defined as the radial spacing between two successive minima

- Interpreting ΔR as a measure of the outer scale of the avalanches:
  - the avalanches propagate on a distance ~ 20 ρ_s
  - long distance propagation observed in low ρ^* discharges?

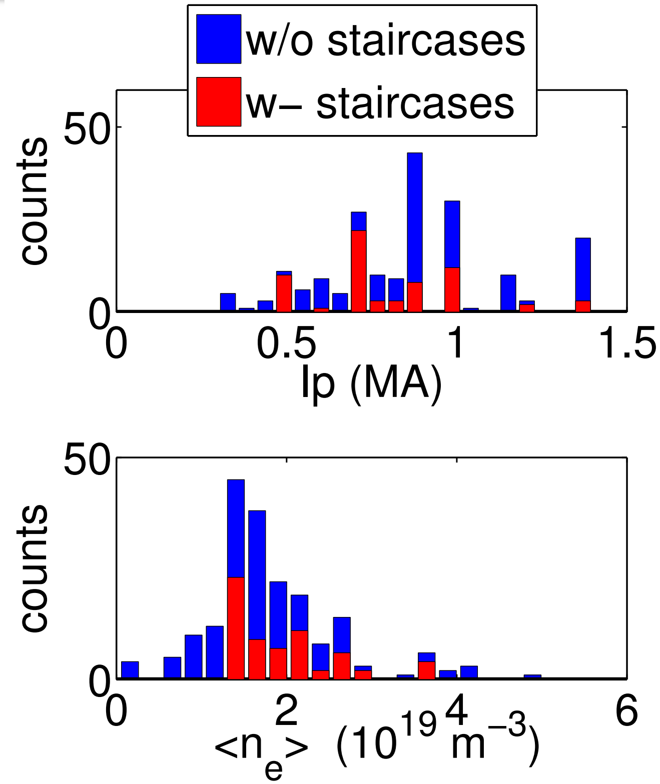




The staircases are identified for a Greenwald fraction ~ 0.3-0.5

Taken individually, Ip and $\langle n_e \rangle$ cannot be used effectively to distinguish cases containing staircase

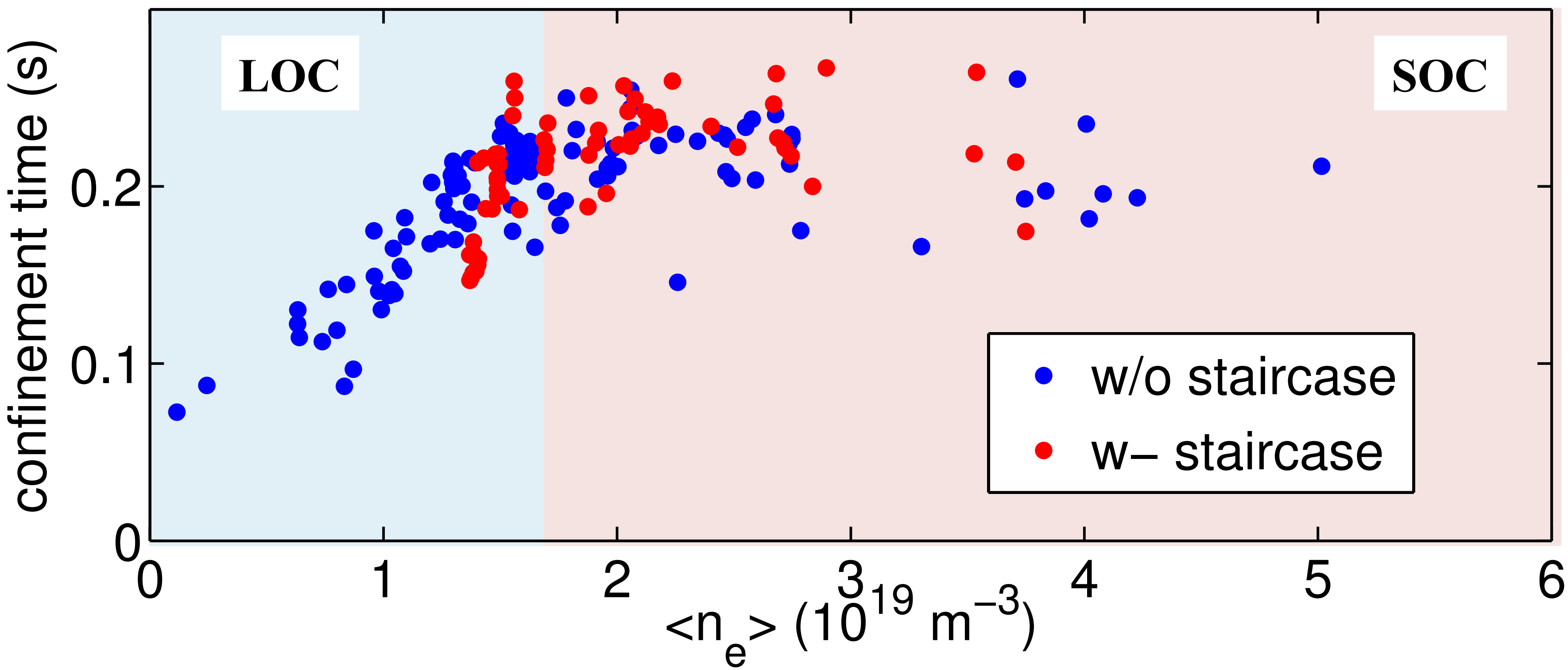
The Greenwald fraction $f_{GW} \sim \langle n_e \rangle / Ip^2$ allows us to discriminate each case more efficiently:
- staircases are not observed for $f_{GW} \leq 0.25$
- mostly, staircases are observed for $f_{GW} \sim 0.4$



Interestingly, the Shimomura density predicts a transition from LOC to SOC regime for $n_S/n_{GW} \sim 0.5$ *(Shimomura, JEARI, 85)*

Is the apparition of the staircases correlated with the LOC/SOC transition?

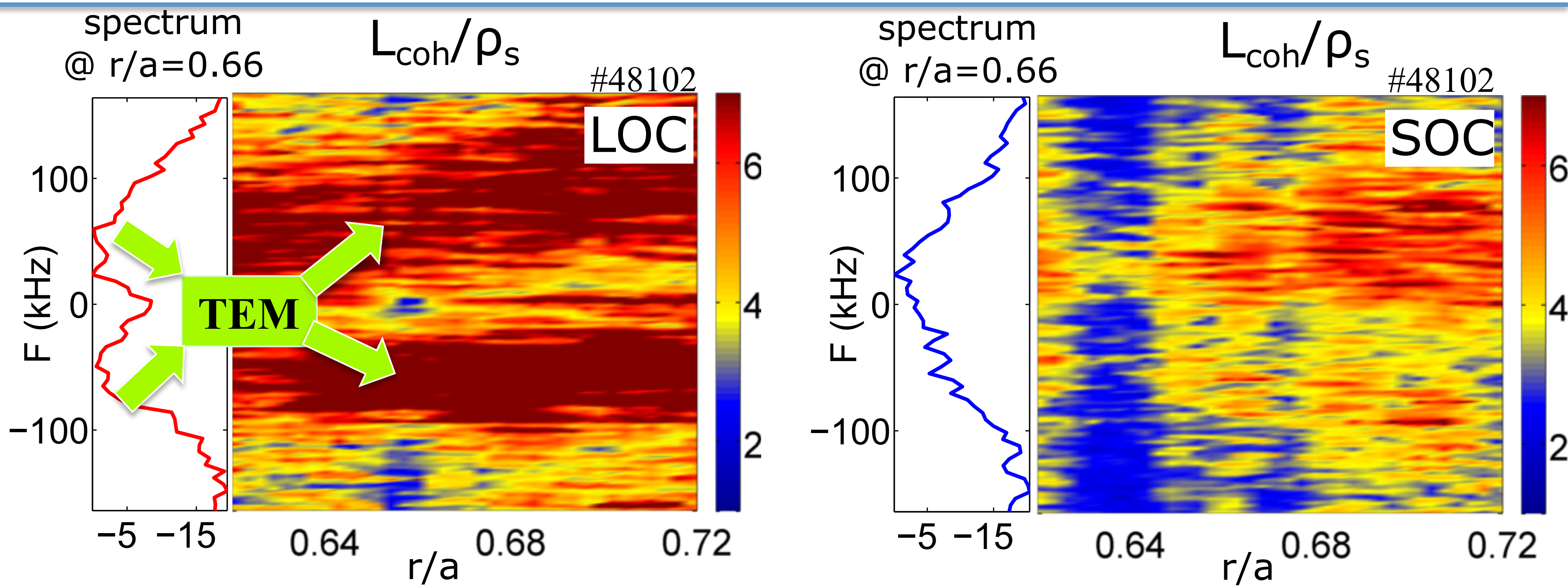
The staircases are abundantly observed at the transition between LOC and SOC regimes



- ➢ Relation with the TEM-ITG transition ?

  (Conway, Nuc.Fus, 2006; Rice, PRL, 2011; Angioni, PRL, 2011)

Staircase not observed in LOC regime as the underlying ExB flows barely affect TEM turbulence



LOC: quasi-coherent (QC) modes

- TEMs are dominant
  Arnichand, Nuc. Fus., 2014
- TEM's frequencies almost not affected by ExB flows

SOC: broad band turbulence

- ITGs are dominant
  Arnichand, Nuc. Fus., 2014
- strong reduction of L_{coh} for all frequencies @ r/a ~ 0.64

✧ consistent with GENE observations: TEM's saturation does not primarily occur via shear flows *(Merz, PRL, 2008; Vernay, PPCF, 2014)*

Conclusions: experimental observations are consistent with the presence of ExB staircase in Tore Supra plasmas

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Footprints of the staircase

- quasi regularly spaced local minima of L_{coh}
- rapid variation of the eddies tilt around L_{coh} minima

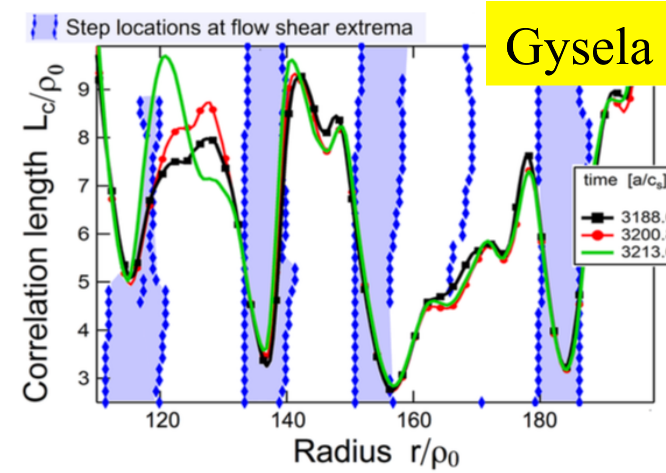
Characterization of the staircase

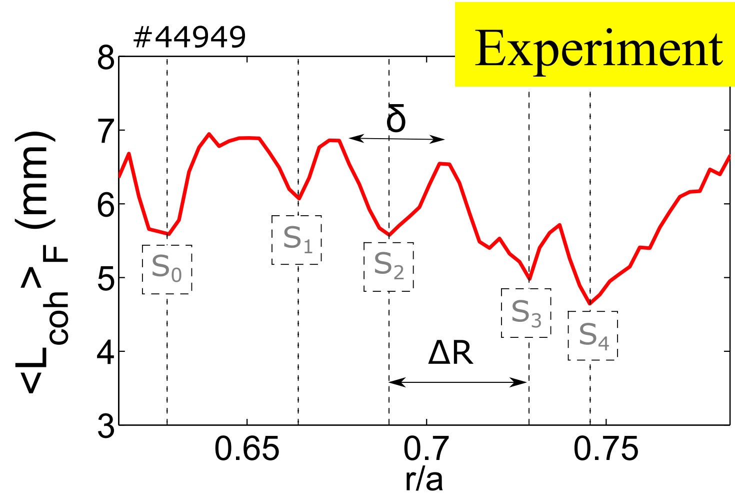
- $\delta \sim 11\ \rho_s$: characteristics radial extent of shear flows
- $\Delta R \sim 20\ \rho_s$: outer scales of the avalanches

Parameter space of the staircase

- L_{coh} minima observed independently of the local values of q, in banana regime ($\nu^* \sim 10^{-2}$-1) and for moderate turbulent drive ($\eta = L_n/L_T \sim 2$-3)
- ExB staircase is difficult to observe in LOC, consistent with the fact that the underlying shear flows barely affect the TEMs

Dif-Pradalier, PRL., 2015





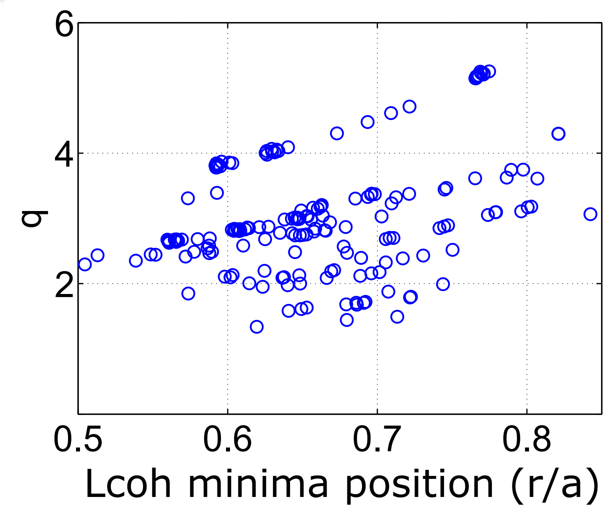
Backup

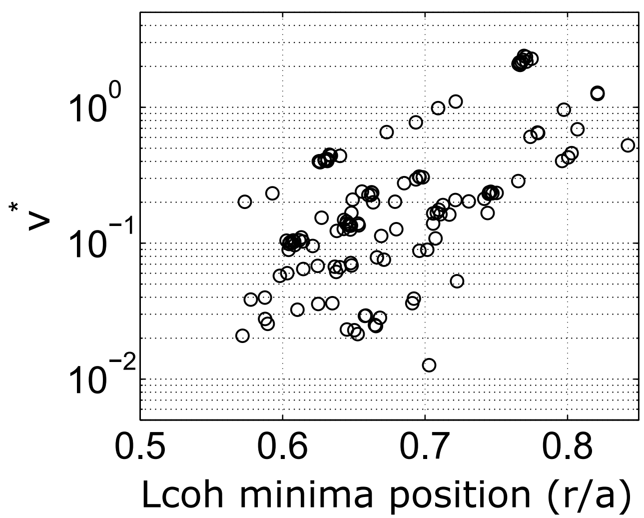
L_{coh} minima were observed for a significant range of plasma parameters

- 85 out of the 243 analysed data set contain local minima of L_{coh}
  - ➢ 179 L_{coh} minima identified

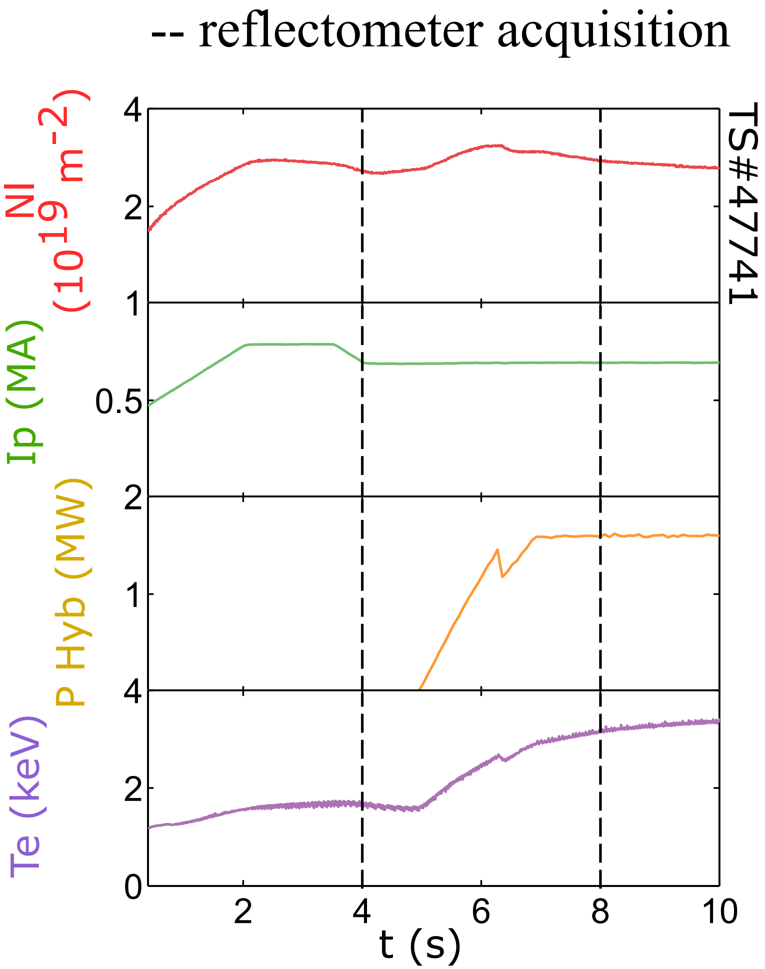
L_{coh} minima were observed:

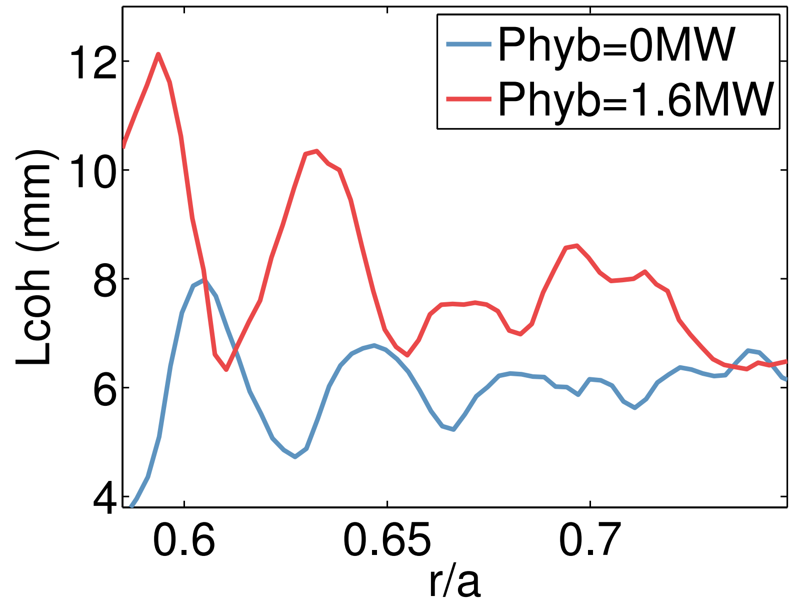
- uncorrelated with the rationale q surfaces
  - ➢ suggests a minor role of the MHD
- for weak collisionality $\nu^* \sim 10^{-2} - 1$ (banana regime)
- at moderate turbulent drive $\eta = L_n/L_T \sim 2\text{-}3$ (assuming $T_i = T_e$)





The hybrid heating amplifies the corrugated patterns observed on the coherence lengths





- Coherence length patterns are very similar in Ohmic and hybrid phases
- Overall increase of the coherence lengths when heating is turned on
- The local minima drift radially inward

The reduction of the coherence length is robust against the defnition of L_{coh}