Laboratorio Nacional Fusión

Long-range correlations during plasma transitions in the TJ-II stellarator

M. A. Pedrosa

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MOTIVATION

Understanding the physical mechanisms governing the H-mode transition

Transport bifurcation to an improved confinement regime is directly related to the formation of sheared flows that can stabilize the turbulence

Small-scale fluctuations → Larmor radius size

Long-scale instabilities → Up to system size

Zonal flows (turbulence generated low frequency potential structures) have been suggested to explain the Low to High transition (L-H) in magnetic confinement devices

P. Diamond, S-I. Itoh, K. Itoh, and T.S. Hahm, Plasma Phys. Control. Fusion **47** (2005) R35

A. Fujisawa, Nucl. Fusion **49** (2009) 013001

The characterization of the emergence of sheared flows and the quantification of the degree of long-range correlation can provide relevant information on the mechanisms involved in the transition to improved confinement regimes.

OUTLINE

- Confinement bifurcations in TJ-II:
  - Experimental set-up
  - Spontaneous low density transitions
  - Biasing induced transitions
  - NBI regime transitions (H-mode)
- Long-range correlations at TJ-II
  - Long-range correlation measurements
  - Multi-scale correlation properties
  - Interplay between different frequency ranges
- Comparison with fast camera measurements
- Comparison with Zonal Flows model
- Summary
- Actions under way

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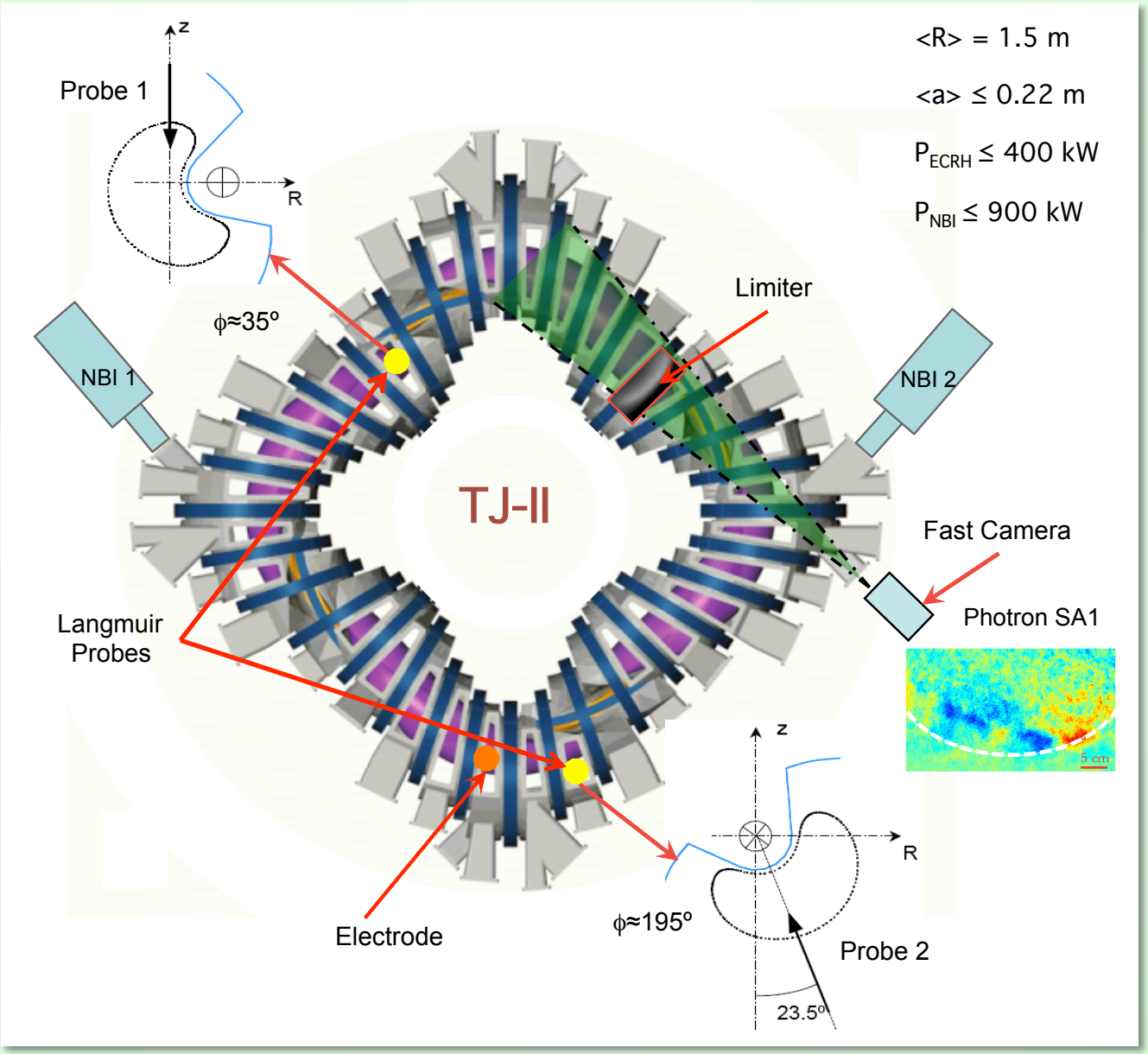
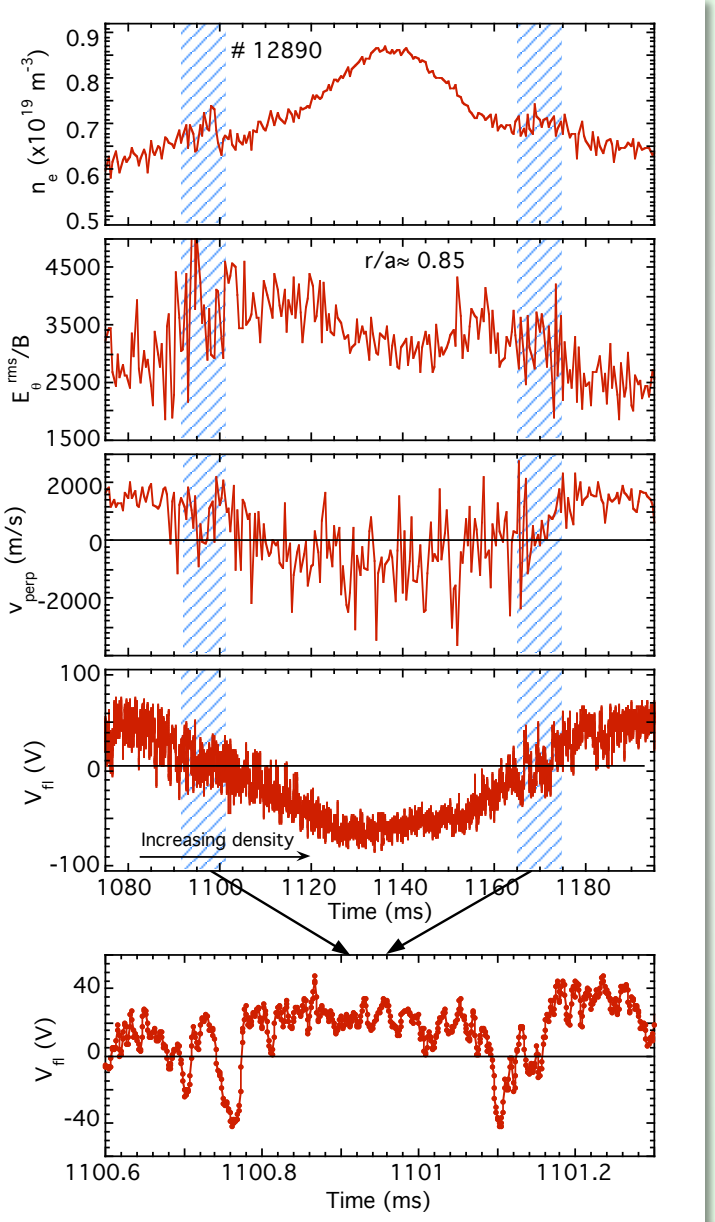
Experimental set-up



Spontaneous ECRH phase transitions



Under some conditions a transition to an improved confinement mode has been observed in TJ-II.

F. L. Tabarés, B. Brañas et al., Plasma Phys. Control. Fusion **43** (2001) 1023

I. García-Cortés et al., Plasma Phys. Control. Fusion **44** (2002) 1639

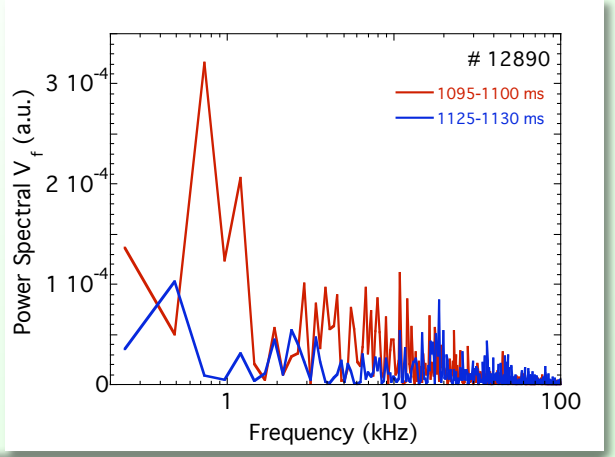
V. I. Vargas et al., Informes Técnicos Ciemat 1162 (2009)

Above a critical density (or gradient) the naturally occurring velocity shear layer appears in the proximity of the LCFS.

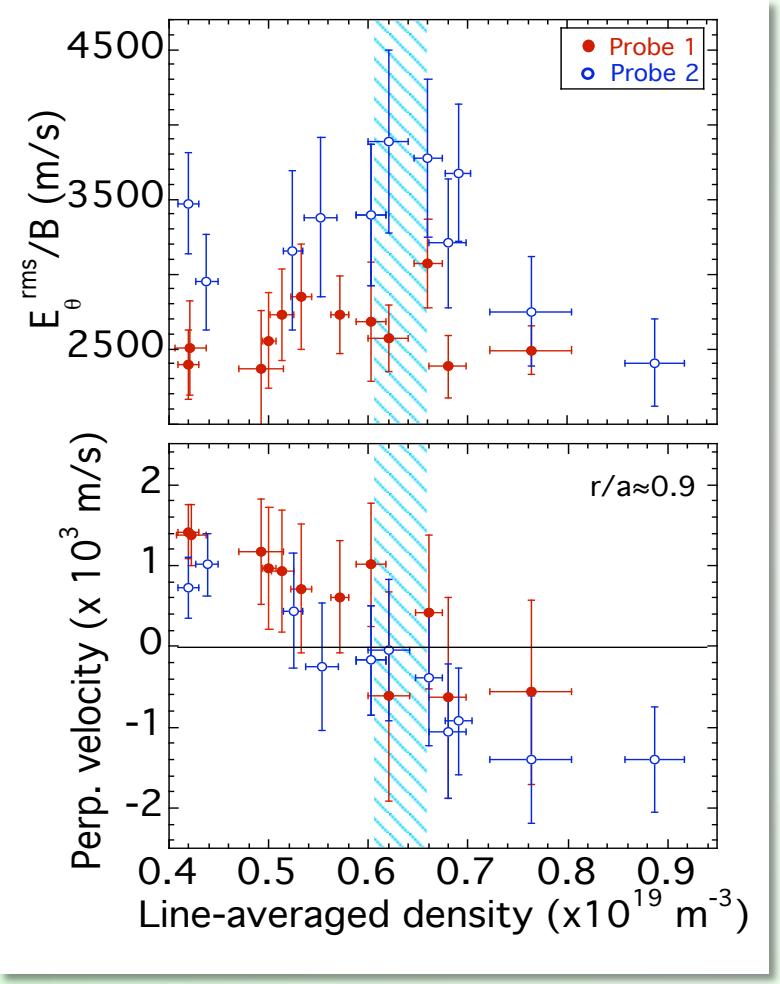
Transient events appear in the proximity of the TJ-II threshold density to trigger edge sheared flows.

M.A. Pedrosa, C. Hidalgo et al., Plasma Phys. Control. Fusion, **47** (2005) 777

C. Hidalgo, M.A. Pedrosa et al., Plasma Phys. Control. Fusion, **48** (2006) S169



Shear development



Edge sheared flows are developed at the same threshold density in the two toroidal positions.

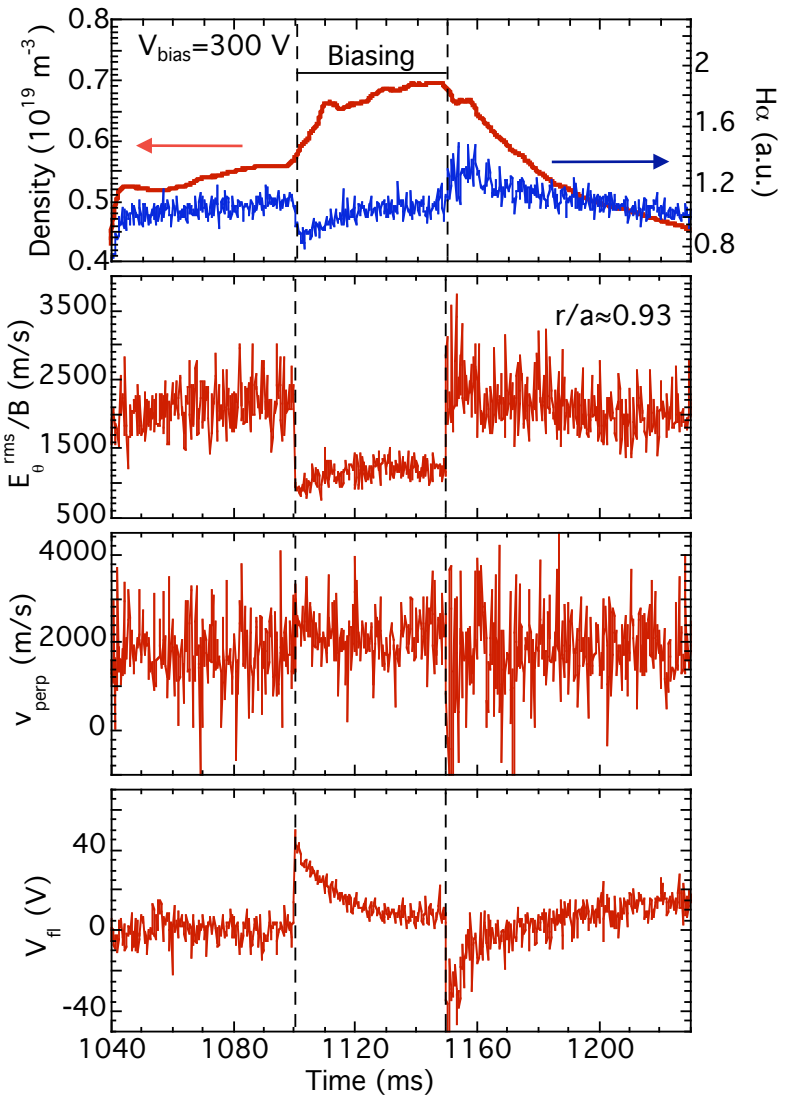
Sheared flows and fluctuations appear to be organized near marginal stability.

C. Hidalgo, M.A. Pedrosa et al., Phys. Rev. E **70** (2004) 067402

The experimental results for the emergence of the plasma edge shear flow layer in TJ-II have been explained using a simple model for a second-order transition.

B.A. Carreras, L. García et al., Phys. Plasmas **13** (2006) 122509

Biasing induced transition



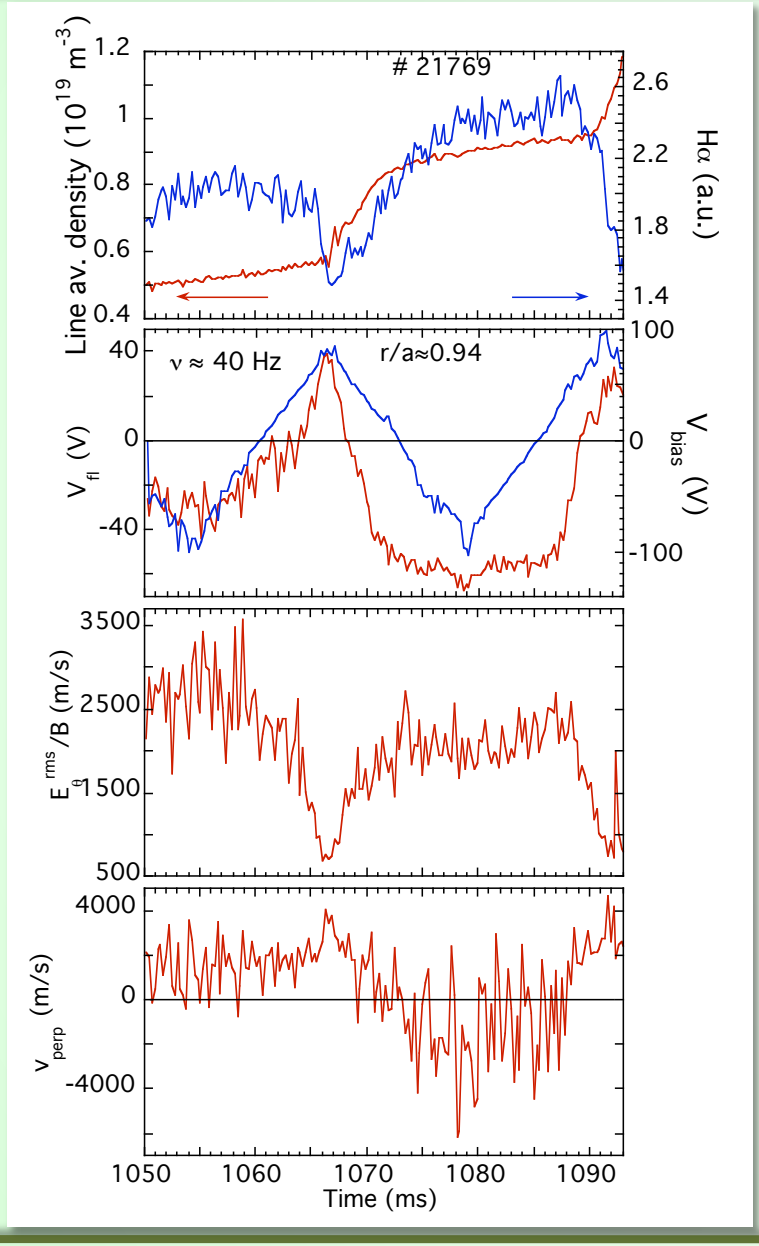
Global confinement and edge plasma parameters have been modified inducing external electric fields.

- Gradient increase in the edge density profiles
- Development of electric fields
- Reduction of edge turbulence

C. Hidalgo, M.A. Pedrosa et al., Plasma Phys. Control. Fusion **46** (2004) 287

C. Silva, B. Gonçalves et al., Czech. J. Phys. **55** (2005) 1589

Dynamic biasing transitions

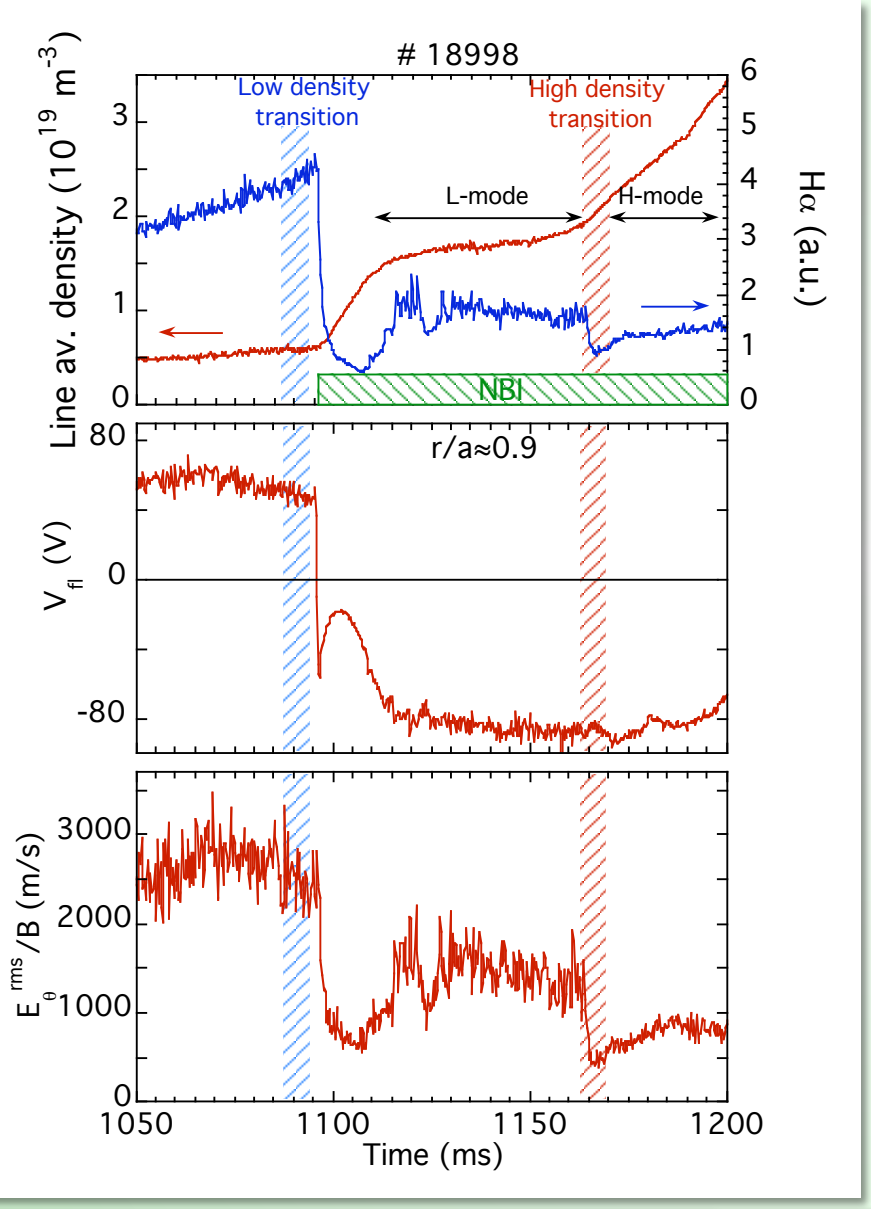


Preliminary results with dynamic biasing shows modulation of plasma density, Hα, edge electric field and fluctuations depending on the plasma density and on the frequency of applied voltage.

Results strongly depend on the plasma density and on the applied voltage and its frequency.

Density effects for shear flow development can compete with biasing effects.

NBI regime transitions



Spontaneous bifurcations observed in TJ-II plasmas with Li-coating and NBI heating with H-mode characteristics.

J. Sánchez et al., Nucl. Fusion **49** (2009) 104018

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- Reduction in Hα emission.
- Reduction of broadband fluctuations level.

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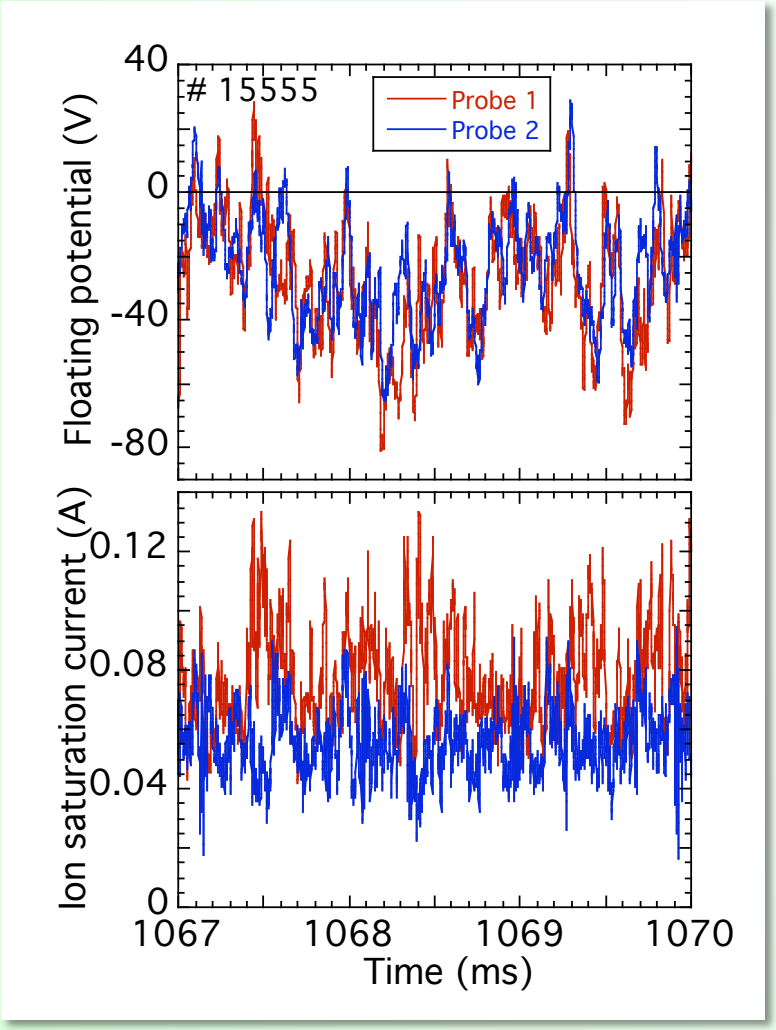
Long-range correlations at TJ-II plasma edge

PROBES TOROIDALY APART



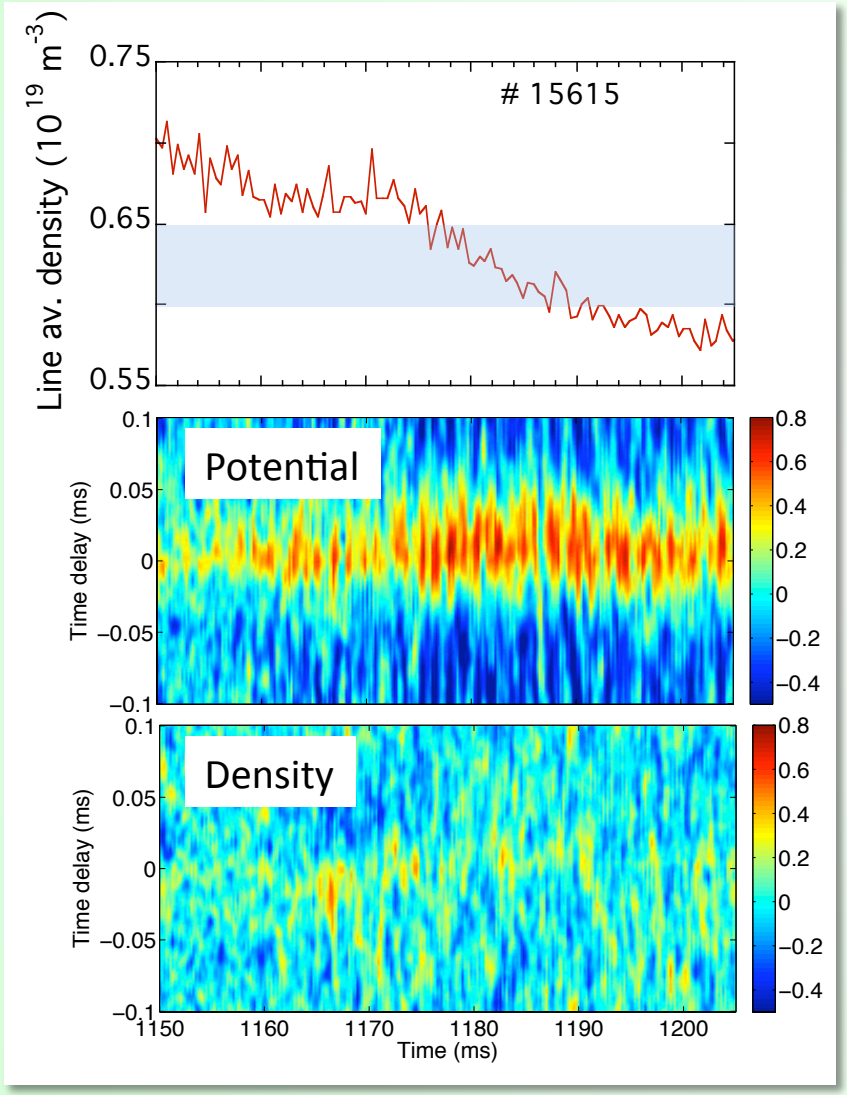
Floating potential signals measured at both toroidal locations show a striking similarity, contrary to that observed in the ion saturation current signals.

The similarity in the floating potential signals is observed in shorter time scales, particularly in the fast events that appear as sheared flows develop.

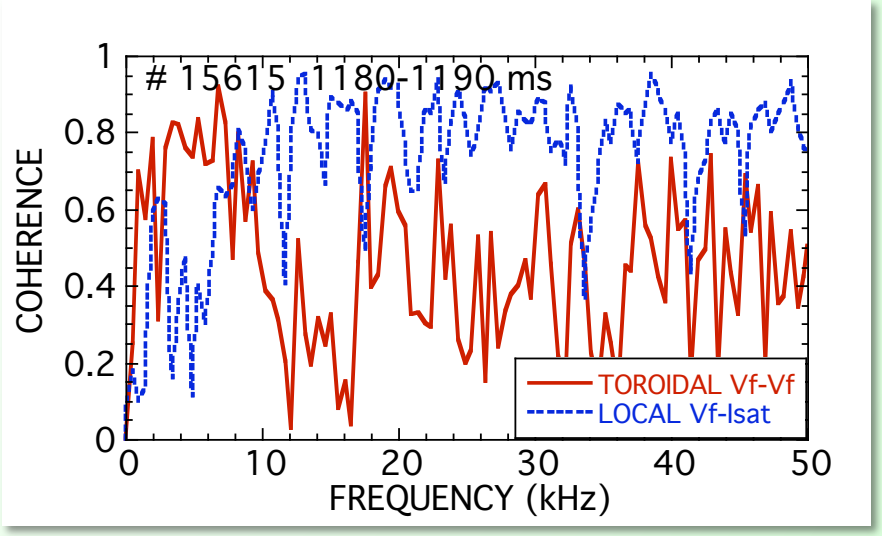
Long-range correlation has been computed for different TJ-II plasma conditions (plasma density scan, electrode bias experiments and NBI heated plasmas).

$$\gamma_{xy}(\tau) = \frac{E\left\{\left[x(t+\tau)-\bar{x}\right]\left[y(t)-\bar{y}\right]\right\}}{\sqrt{E\left\{\left[x(t)-\bar{x}\right]^2\right\}E\left\{\left[y(t)-\bar{y}\right]^2\right\}}}$$

Long-range correlation: density induced transition

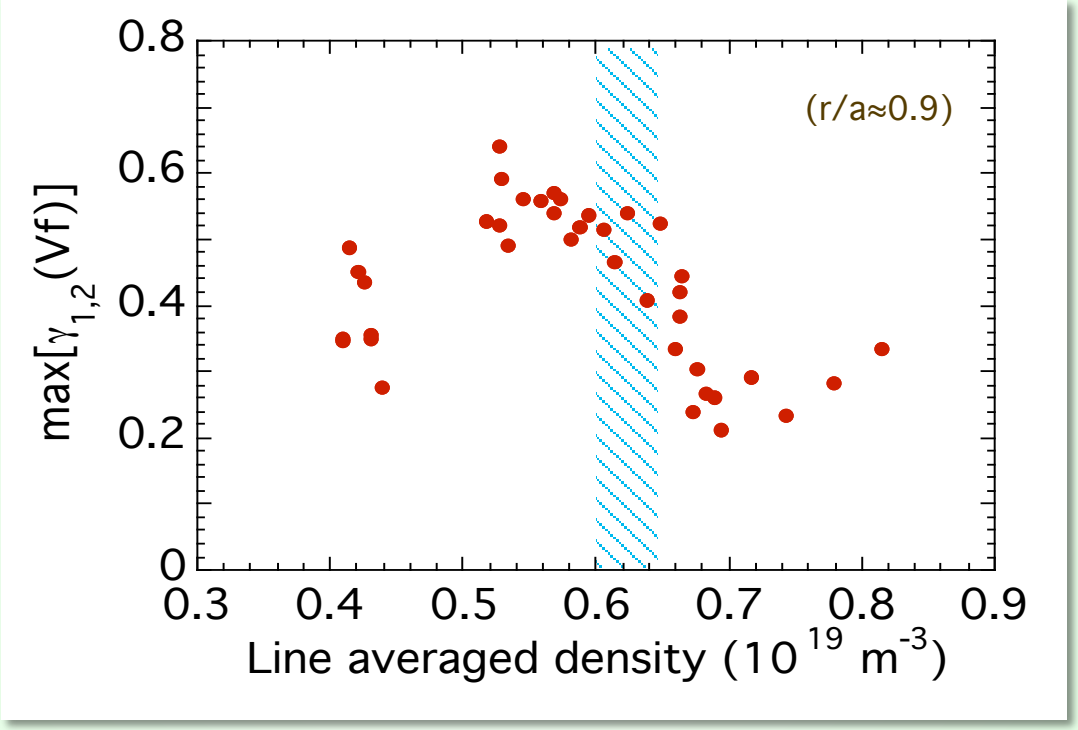


Increase in the toroidal coherence (between floating potential signals) simultaneous to a decrease in the local density-potential (flux related) coherence.



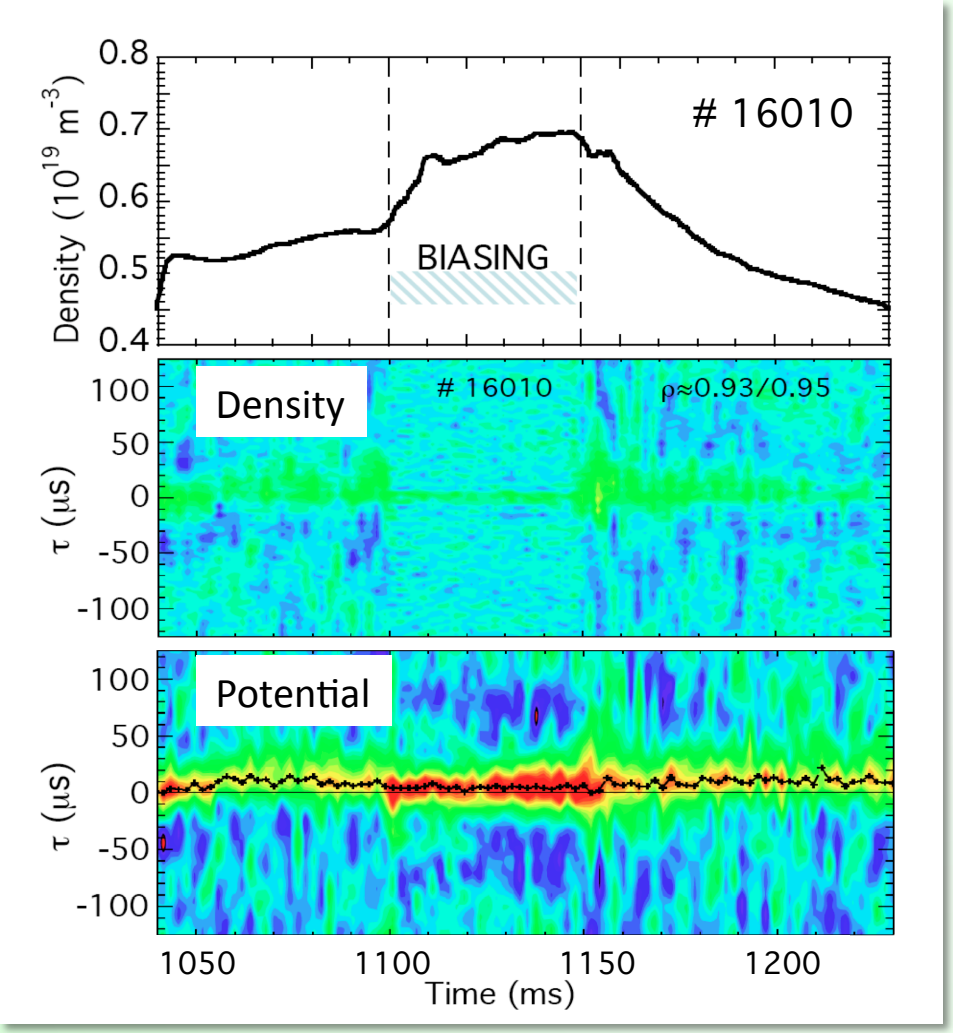
Long-range correlation: density induced transition

Toroidal floating potential correlation strongly depends on the plasma density (or gradient) being larger as density increases up to the threshold value for shear flows development.



M.A. Pedrosa, C. Silva, C. Hidalgo, et al. Phys. Rev. Letters **100** (2008) 215003

Long-range correlation: biasing induced transition



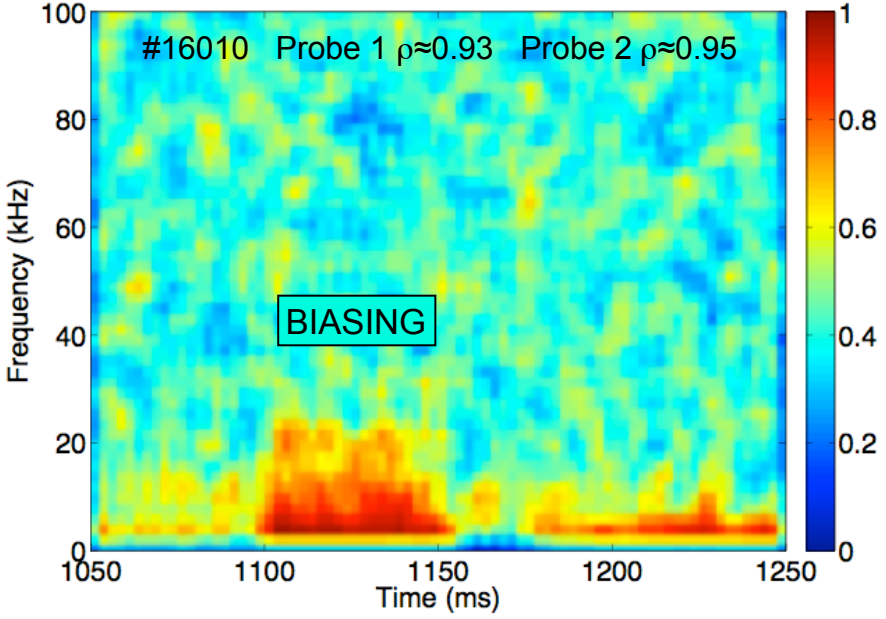
Potential correlation increases during bias phase and is coupled to the radial electric field and not to the plasma density (fast decay time).

M.A. Pedrosa, C. Silva, C. Hidalgo, et al. Phys. Rev. Letters **100** (2008) 215003

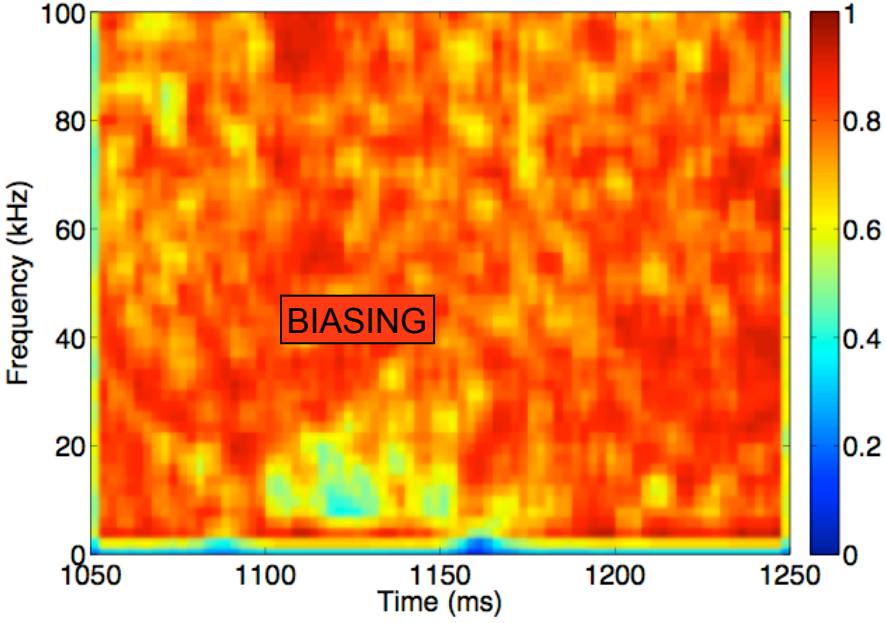
Long-range correlation: biasing induced transition

- Long-range coherence shows a strong increase at low frequencies (below 20 kHz) during the transition to improved confinement regimes (biasing experiments).
- Local density-potential (flux-related) coherence is reduced at low frequencies (below 20 kHz) during the transition to improved confinement regimes.
- Results suggest transport regulation by long-range flows.

Long-distance coherence (potential fluctuations)



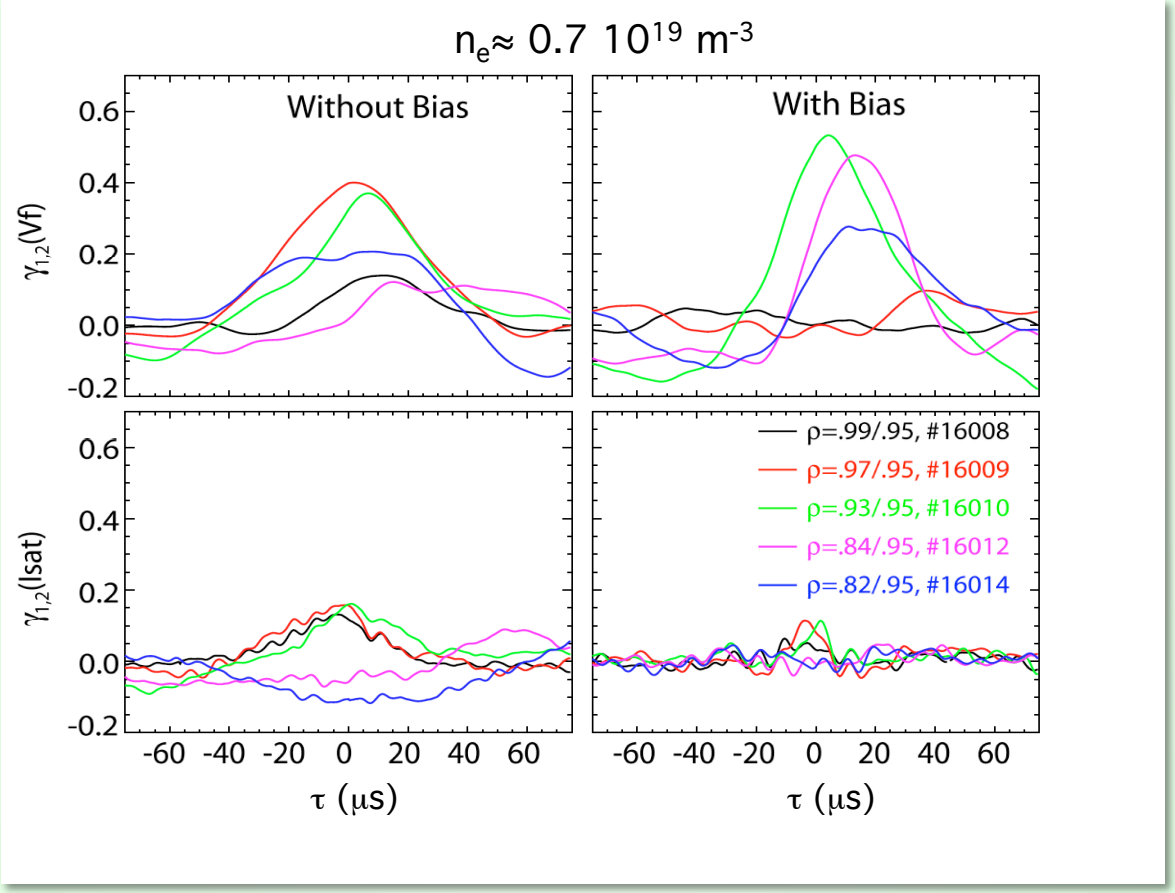
Local coherence (density-potential)



Long-range correlation: probe position effects

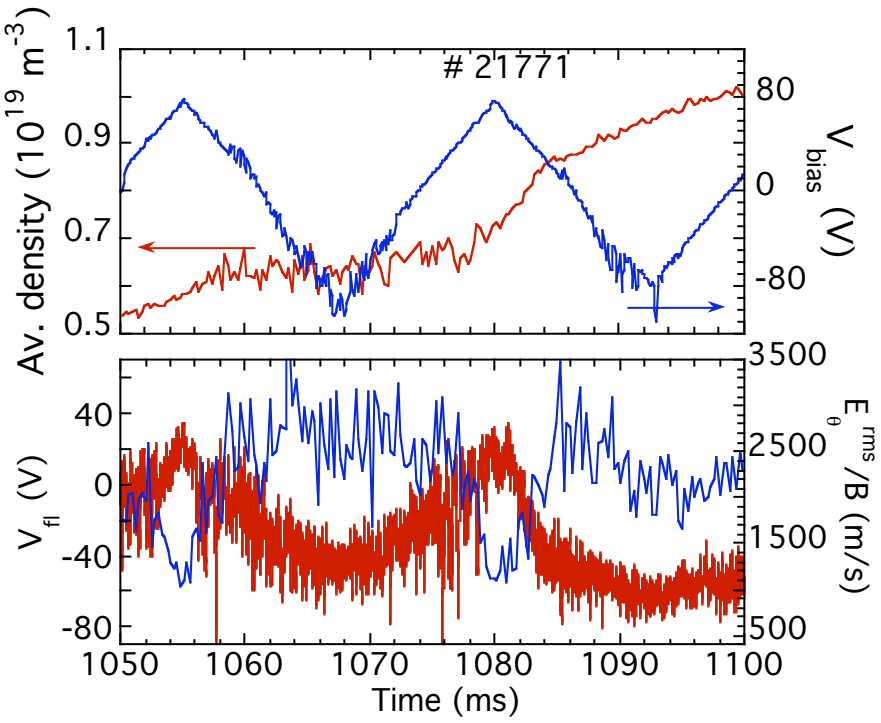
Multi-scale physics mechanisms are amplified by electric fields.

In the framework of second-order phase transition long-range correlation is expected in the order parameter (shearing rate) related with the electric field.



M.A. Pedrosa, C. Silva, C. Hidalgo, et al. Phys. Rev. Letters **100** (2008) 215003

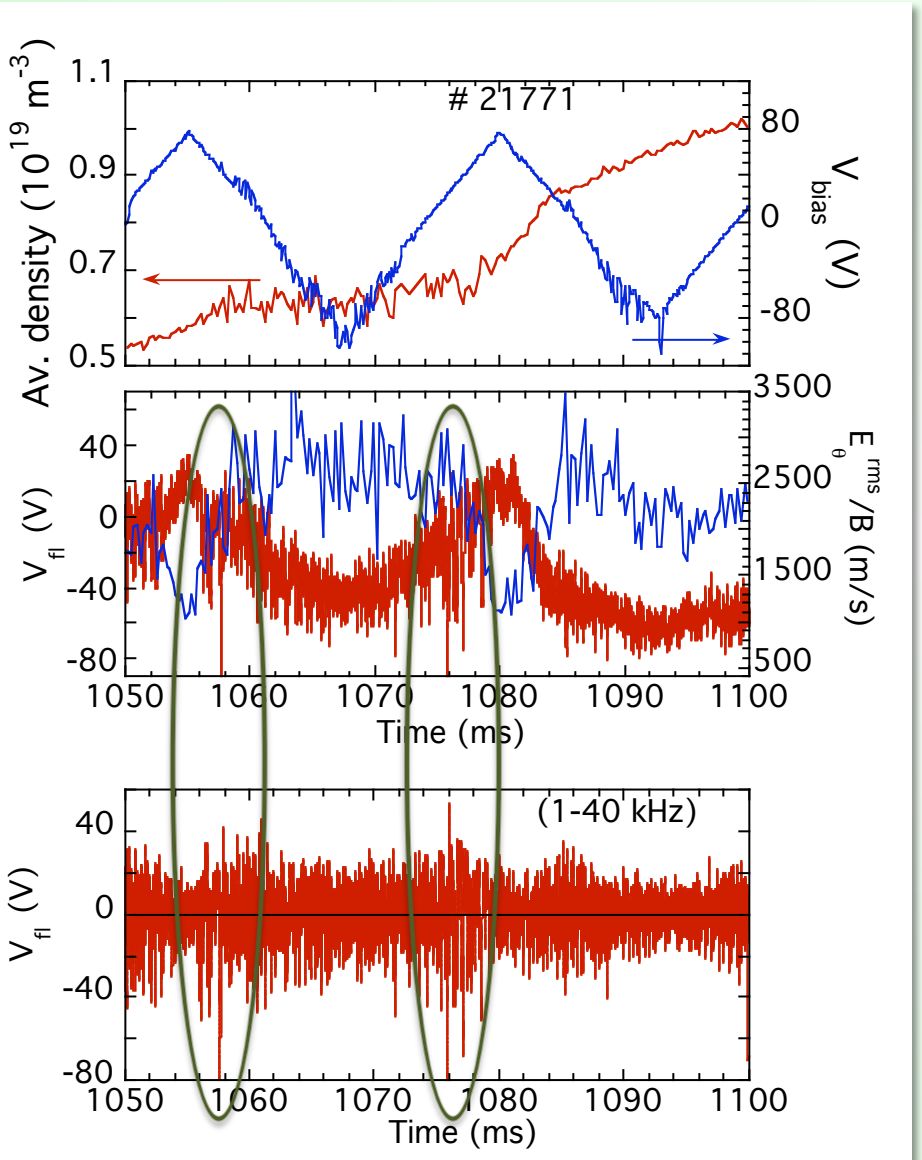
Long-range correlation: dynamic biasing transition



Dynamic biasing induces modulated changes in global and edge plasma parameters with the biasing frequency.

Fast transient events are seen approaching the transition and the reduction of fluctuations level.

Long-range correlation: dynamic biasing transition



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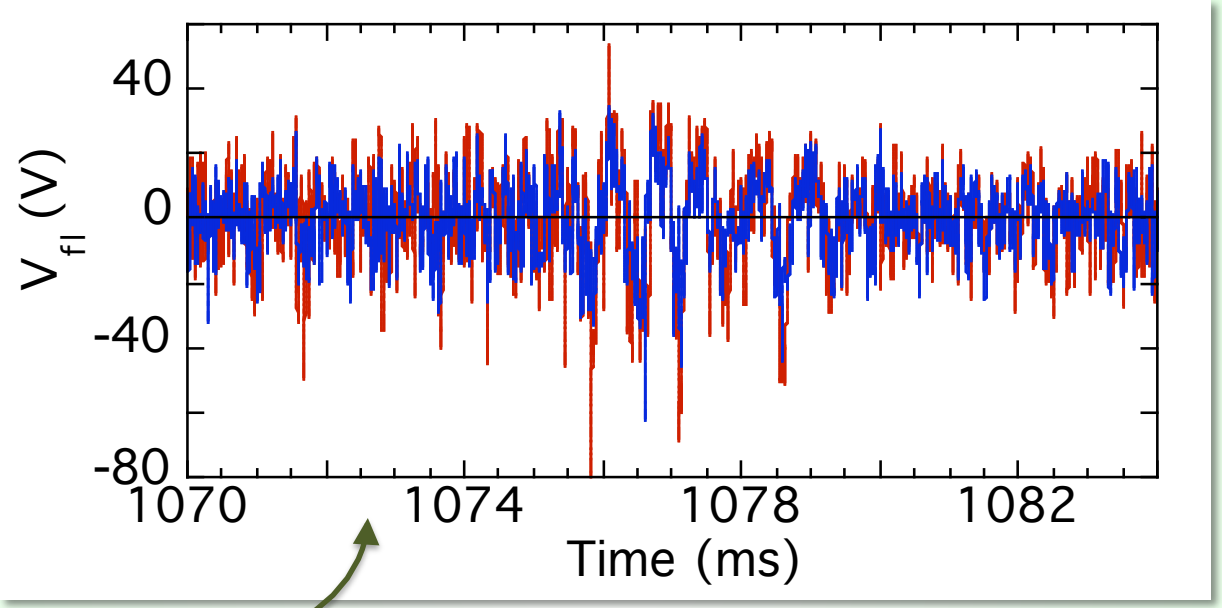
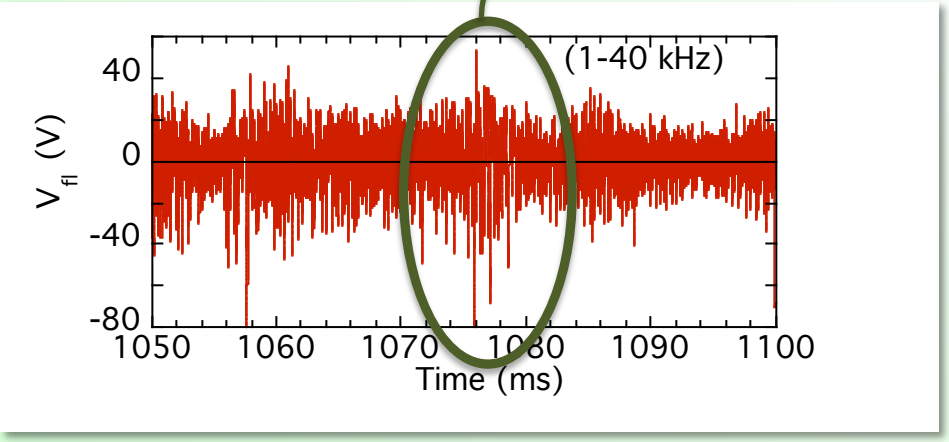
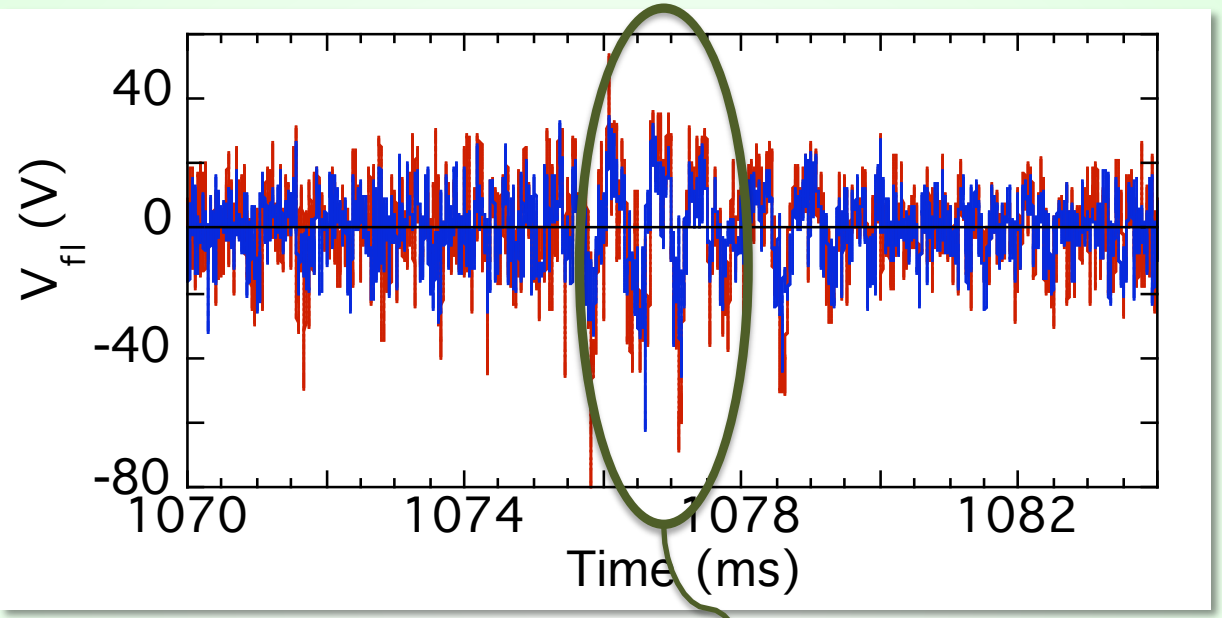
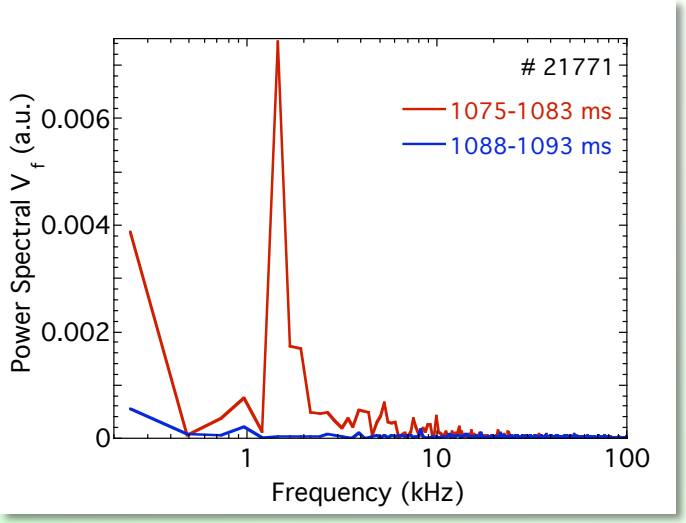


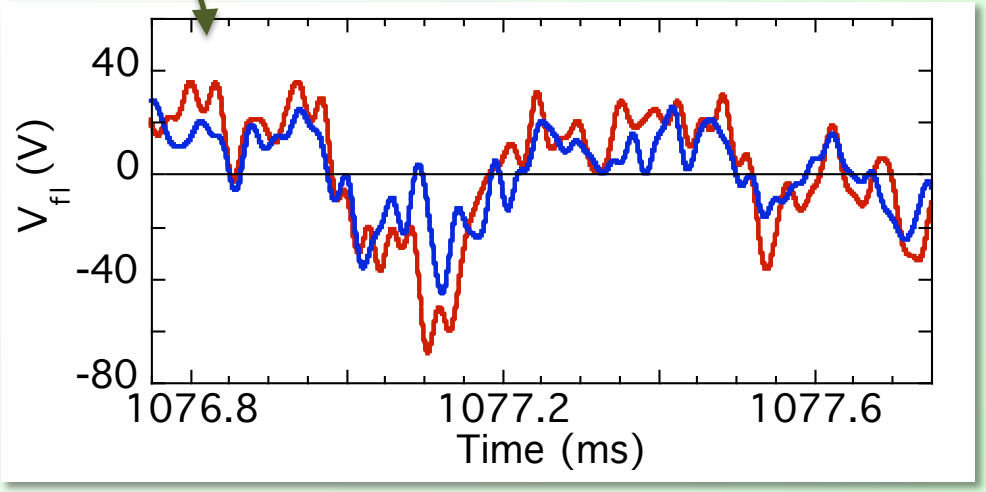


Fast transient events appear simultaneously in the two toroidaly apart positions.

Long-range correlation: dynamic biasing transition

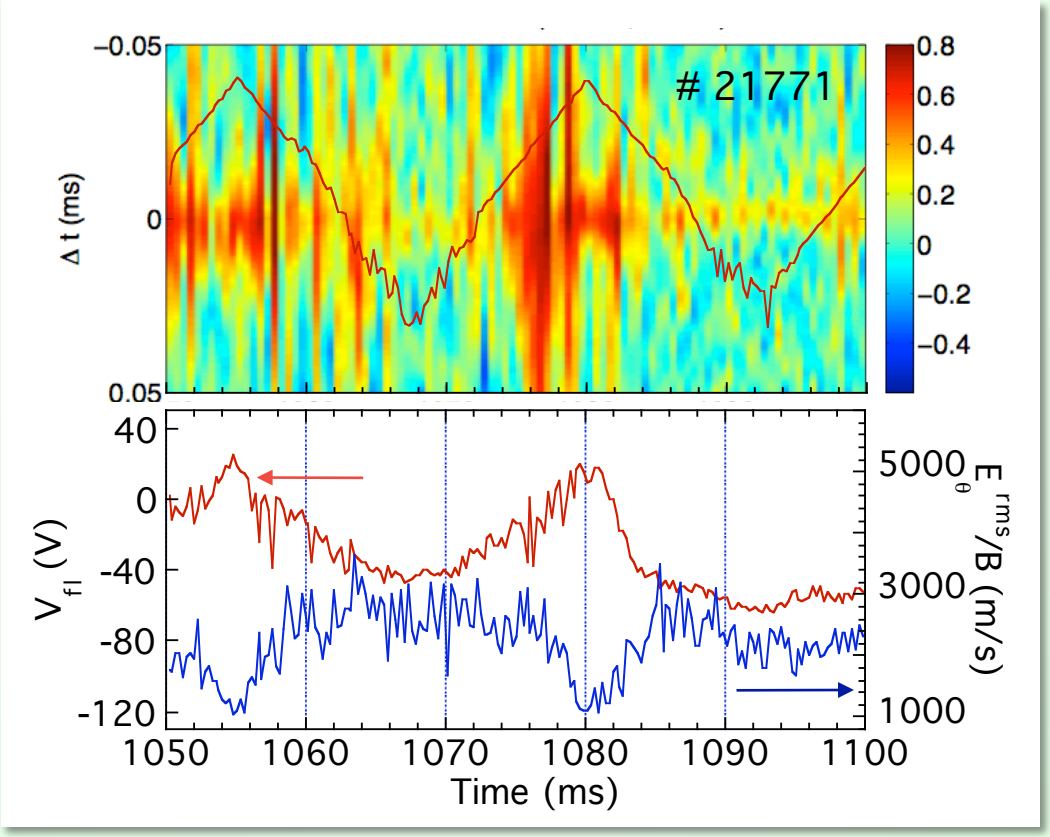




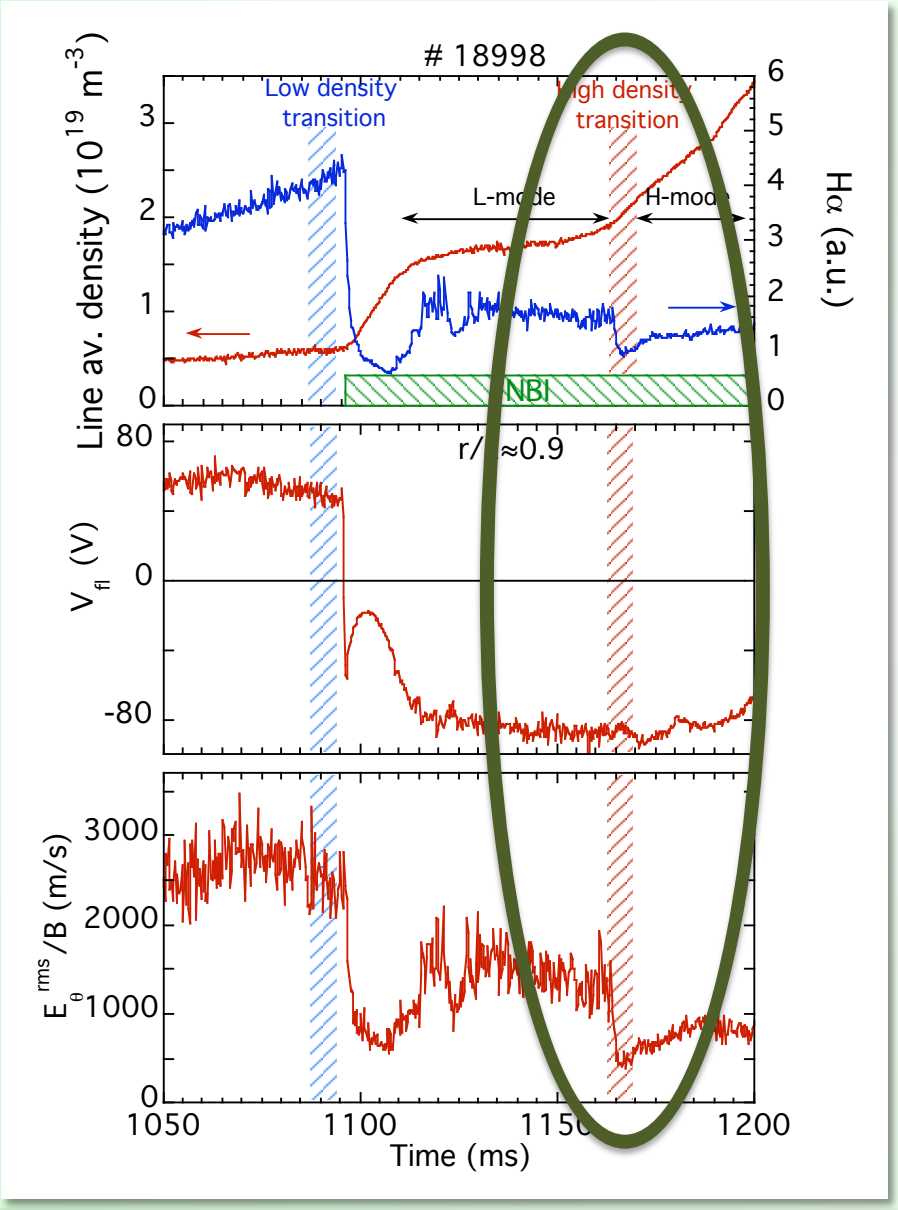


Long-range correlation: fluctuations relation

Maximum correlation between floating potential signals increases approaching the improving confinement regime where fluctuations decrease showing maximum values during transient events.



Long-range correlation: NBI transition



Spontaneous bifurcations observed in TJ-II plasmas with Li-coating and NBI heating with H-mode characteristics.

J. Sánchez et al., Nucl. Fusion **49** (2009) 104018

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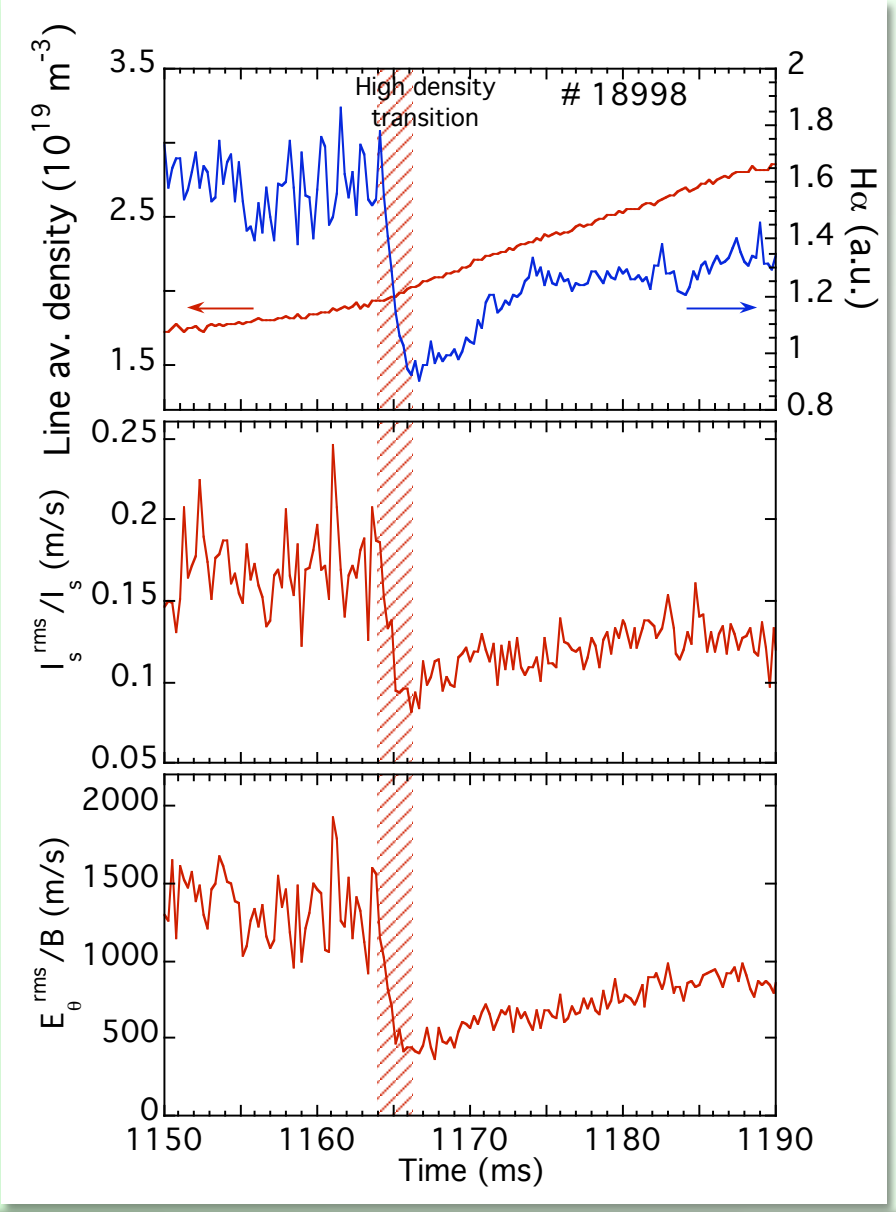

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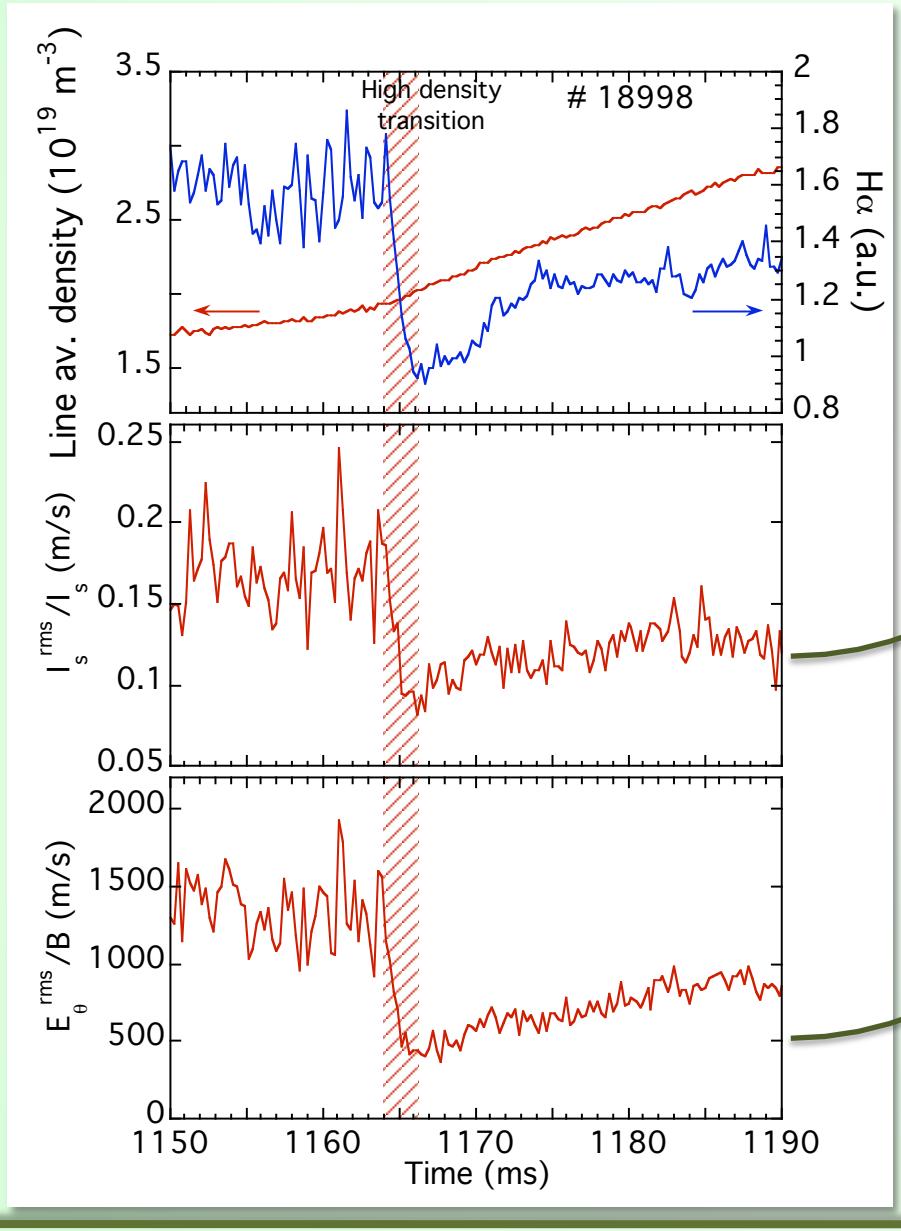
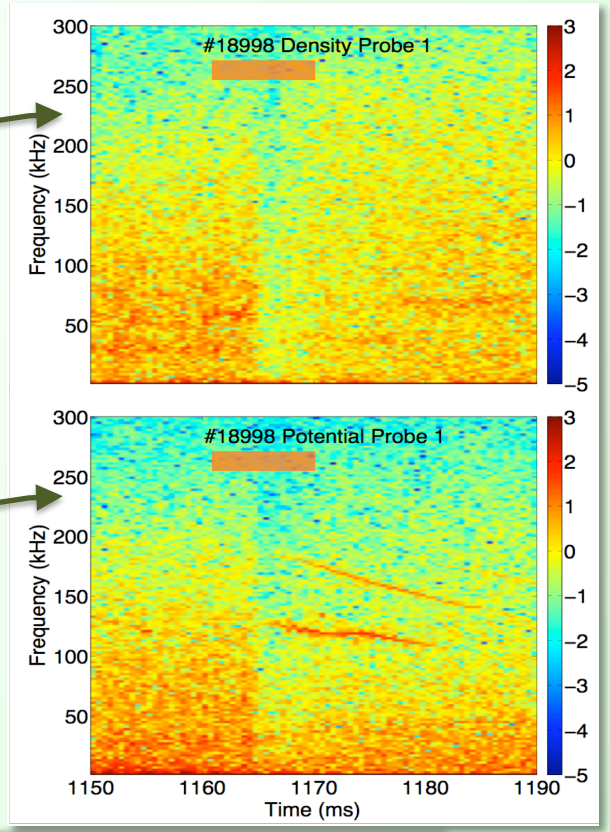
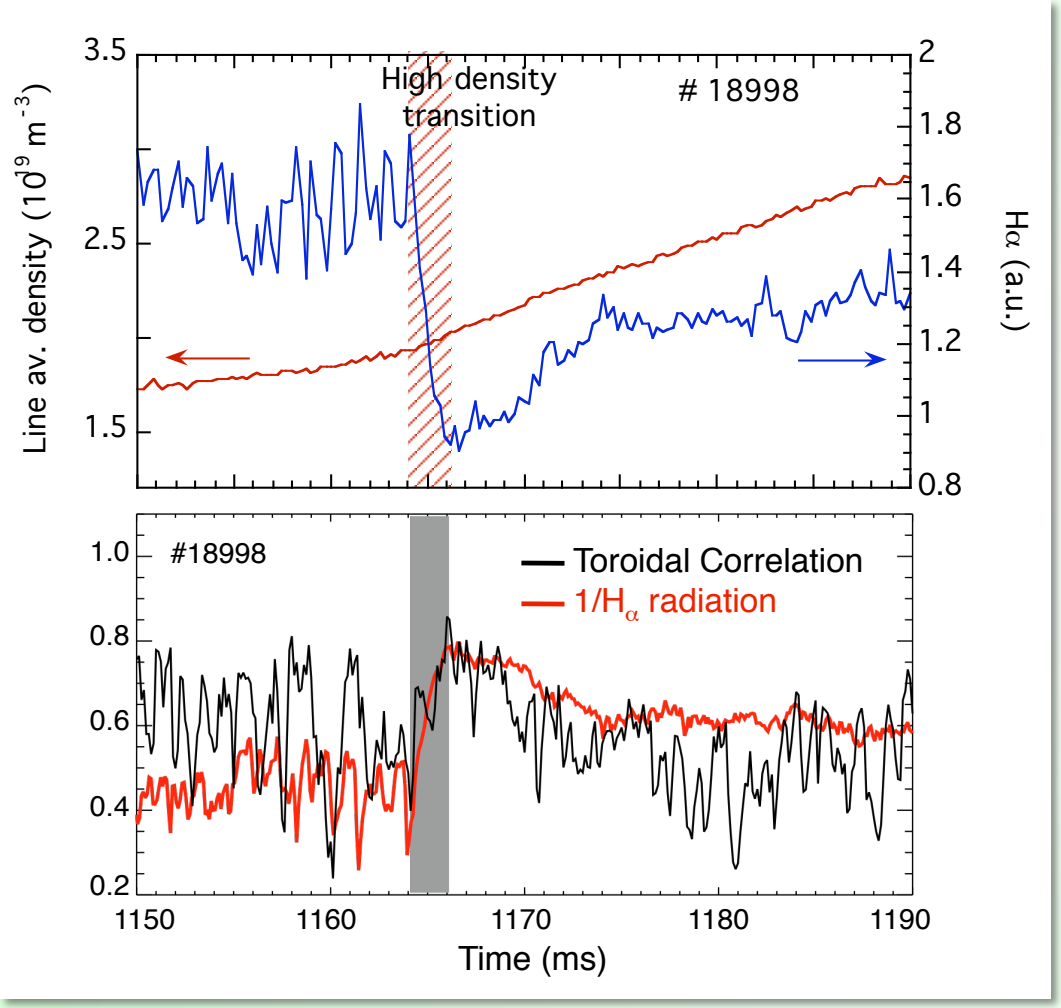


Density fluctuations are reduced over a wide range.

Low frequency fluctuations in the potential measurements (below 40 kHz) are not significantly reduced at the transition.



Long-range correlation: NBI transition

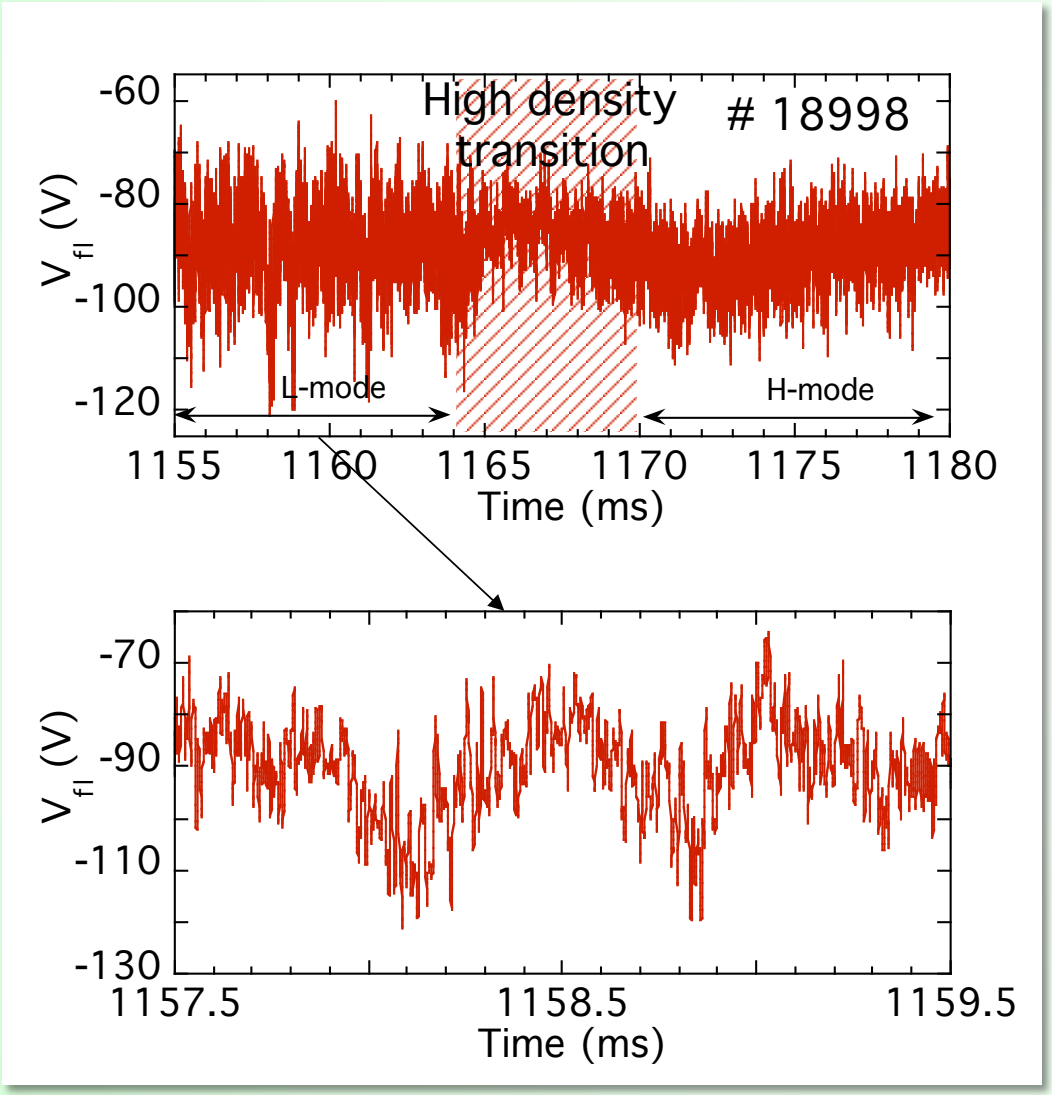


Degree of long-range coupling for potential fluctuations:

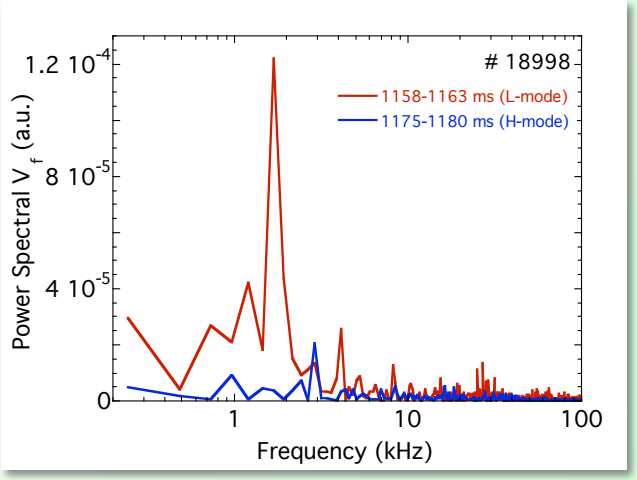
- is significant and intermittent in the low confinement regime.
- increases at the bifurcation point.
- matches the 1/Hα evolution.

C. Hidalgo, M.A. Pedrosa et al., Eur. Phys. Lett. **87** (2009) 55002

Long-range correlation: NBI transition



Transient events appear when plasma conditions are close to the ones needed for the transition (similar and with similar frequency than in ECRH and biasing regimes).



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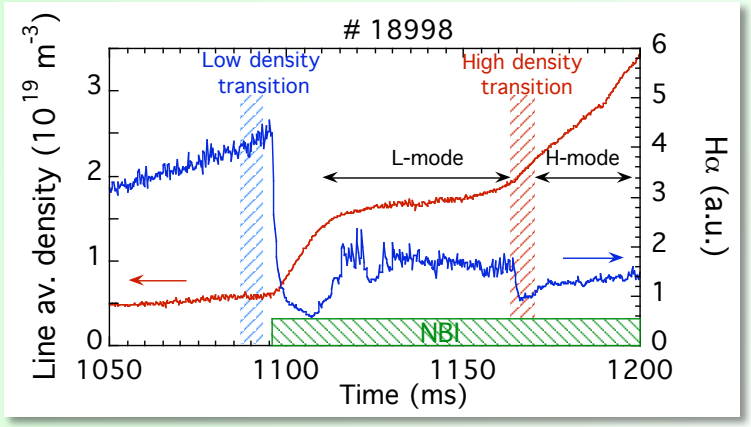
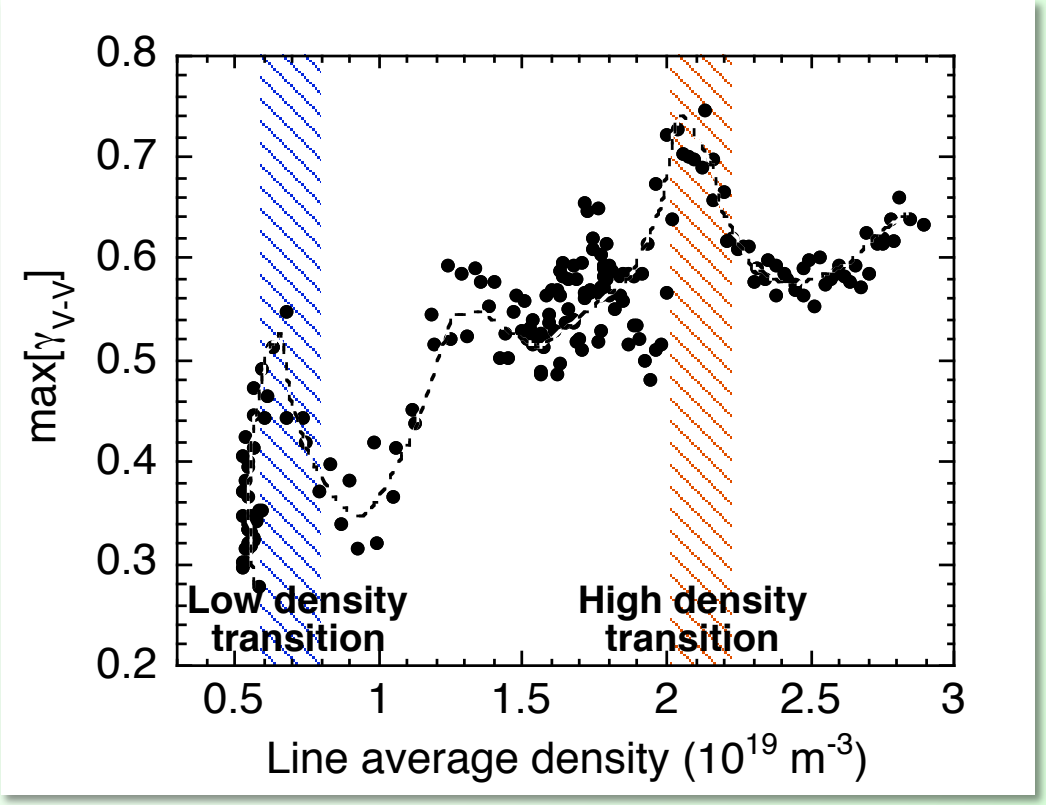


The degree of long-range (toroidal) correlations increases as approaching the plasma conditions where the L-H transition is developed.



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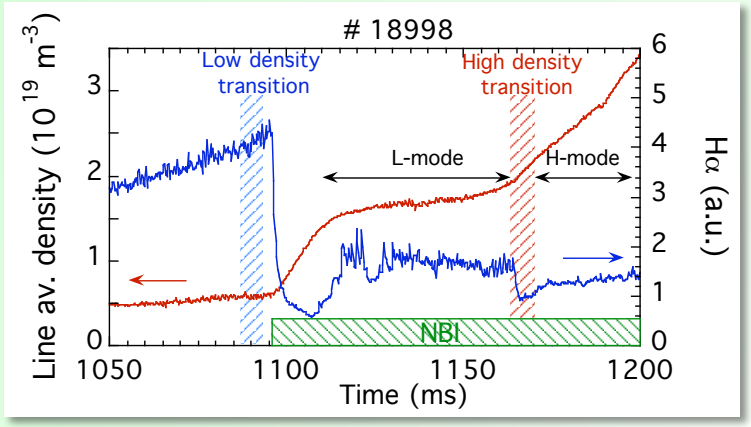

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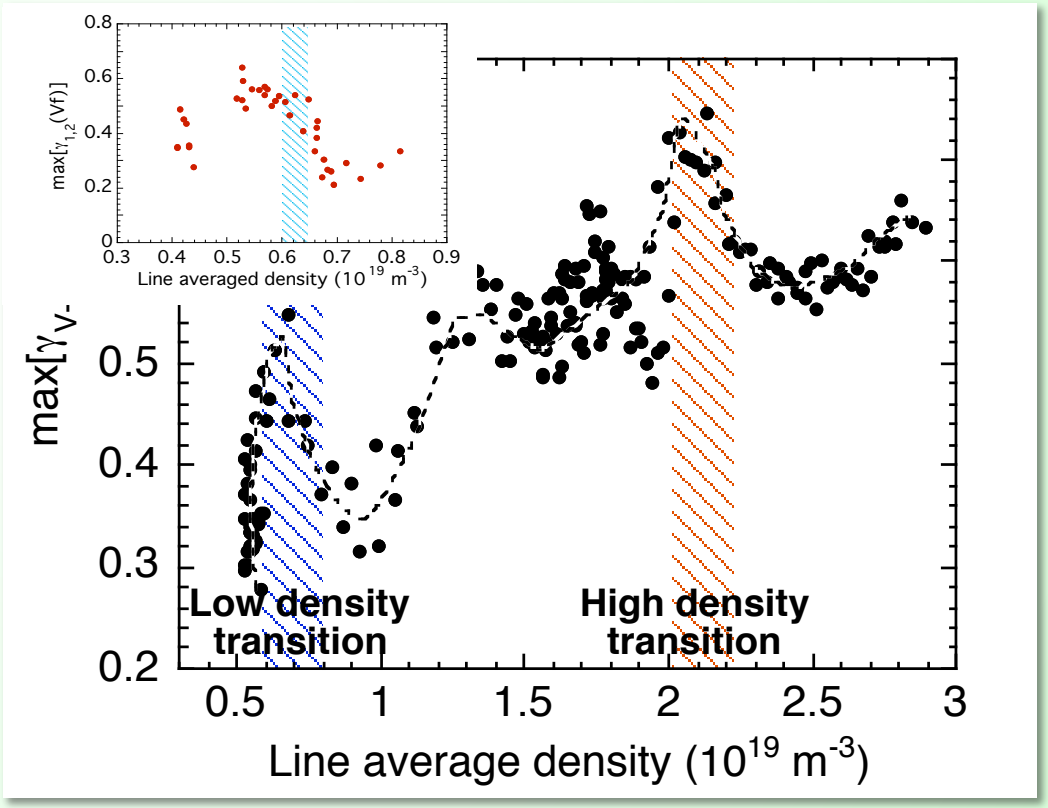
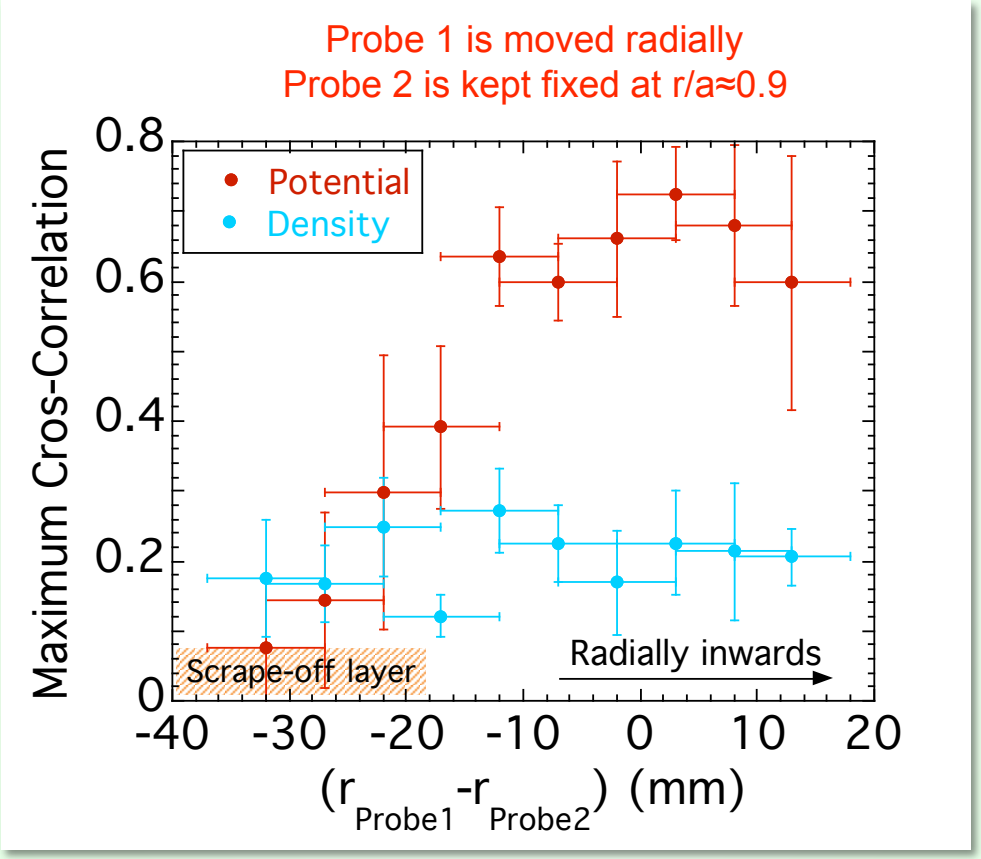


C. Hidalgo, M.A. Pedrosa et al., Eur. Phys. Lett. **87** (2009) 55002

Radial dependence of long-range correlations

The maximum correlation of the floating potential signals is observed when probes are approximately at the same radial location in the plasma edge.

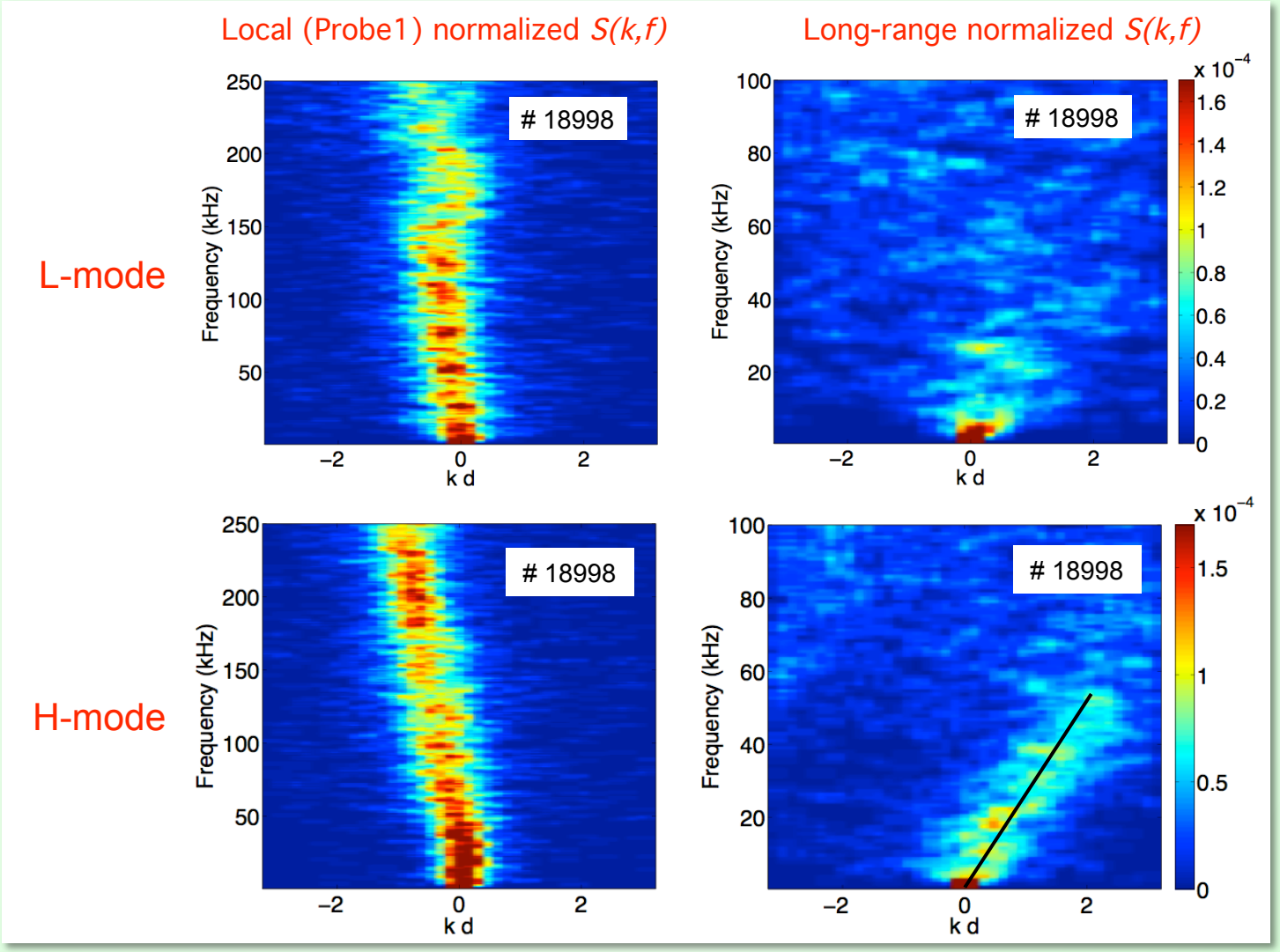


C. Hidalgo, M.A. Pedrosa et al., Eur. Phys. Lett. **87** (2009) 55002

Multi-scale correlations properties

S(k,f) analysed using a standard two-points correlation technique.

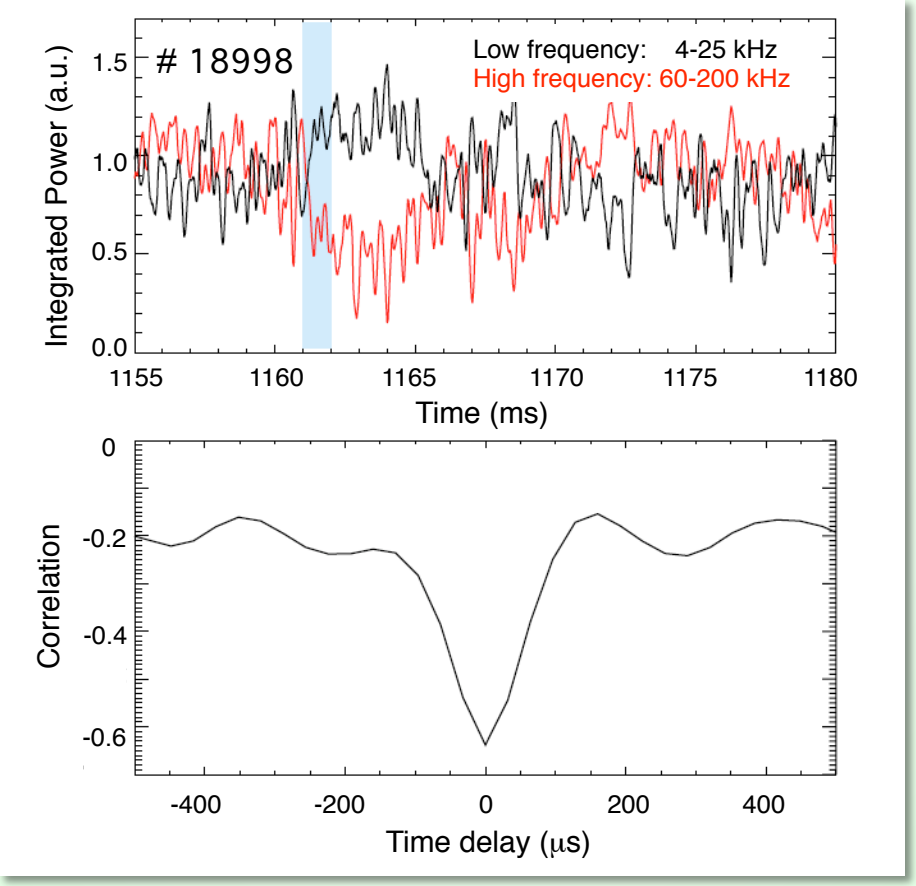
Long range *S(k,f)* spectrum in H-mode indicates propagation (that can be radial).



Interplay between different frequency ranges

The integrated potential power spectra in the low and high frequency ranges are approximately anti-correlated.

This result is consistent with energy transfer between broadband turbulence and low frequencies fluctuations (i.e. between different plasma scales).



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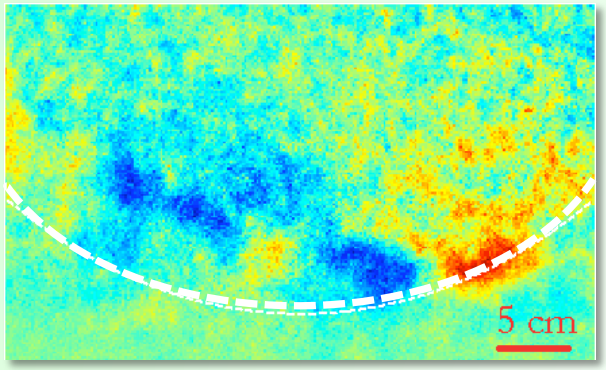
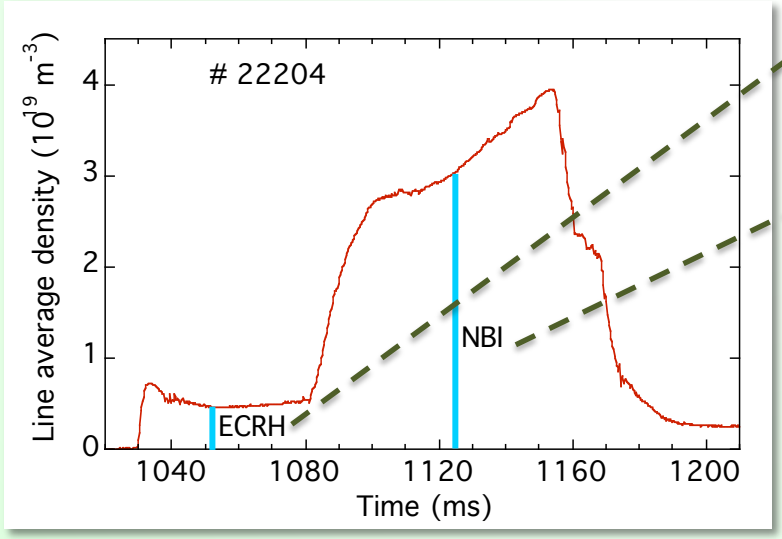
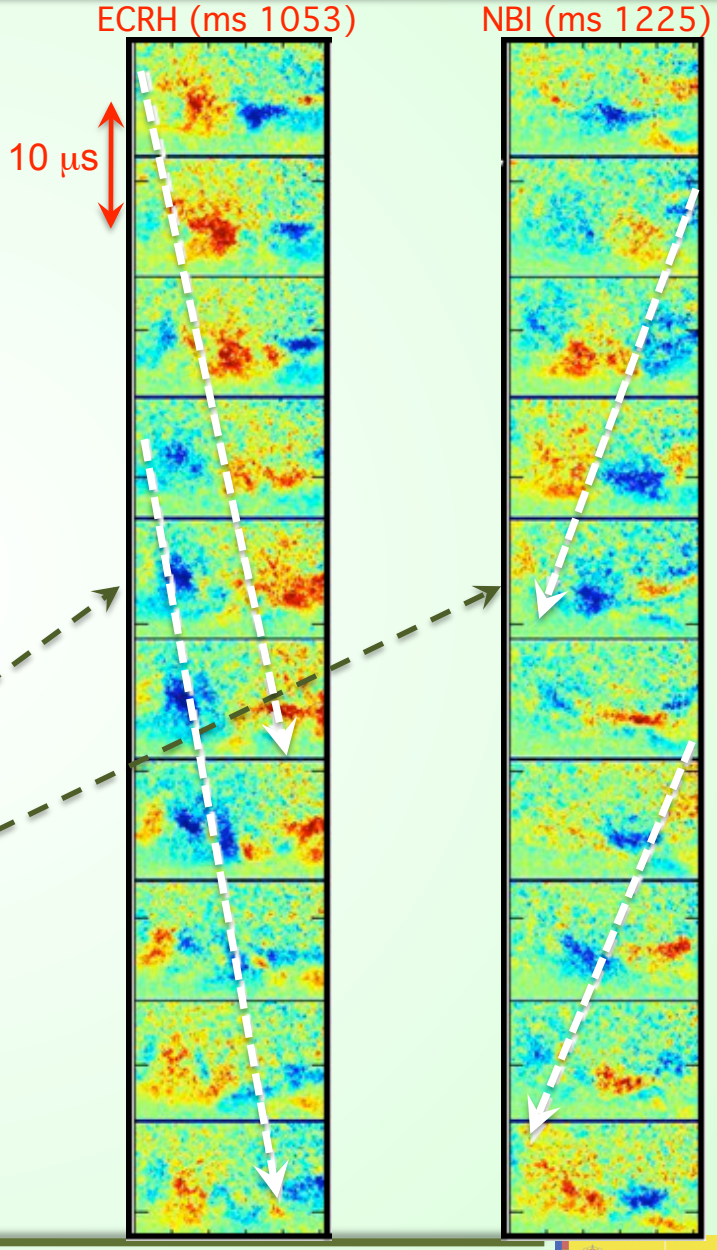
Comparison with fast camera measurements

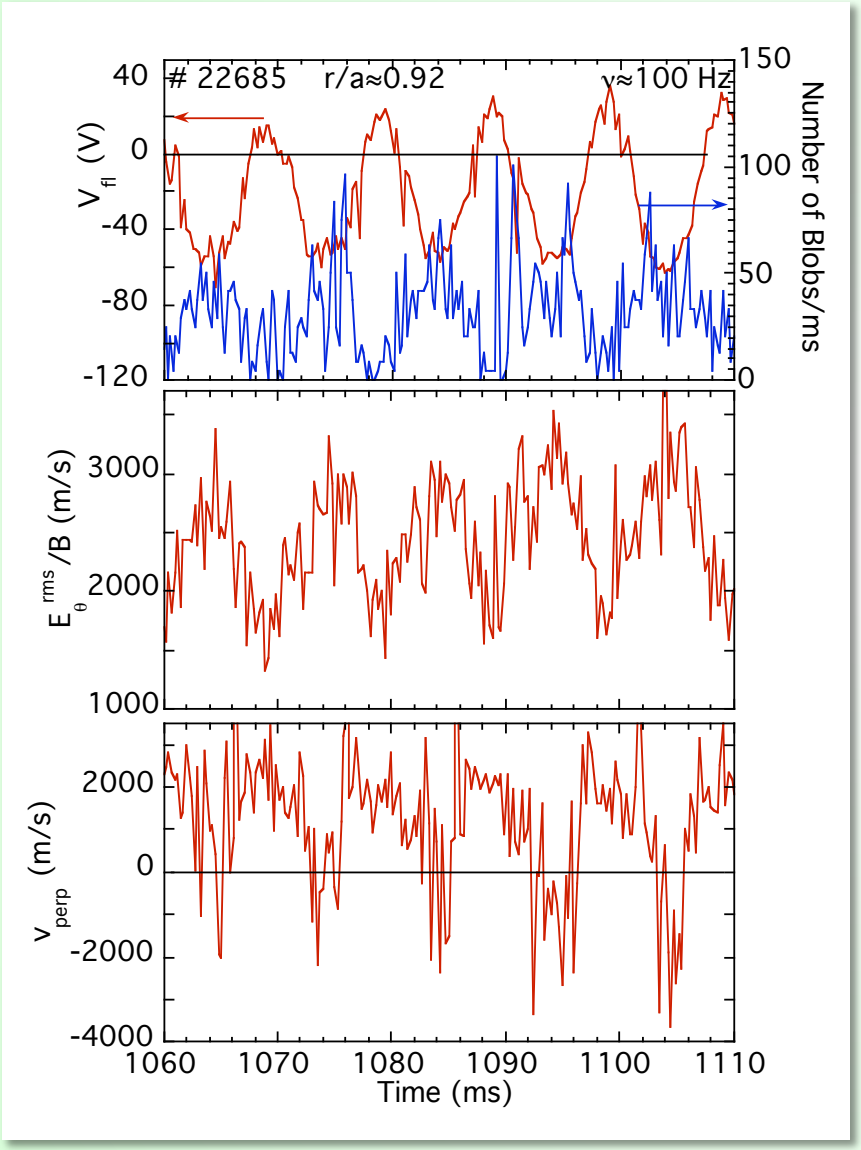


Fast camera experiments have shown the capability to detect the 2-D structure of plasma fluctuations in different plasma regimes.





Comparison with fast camera measurements



The evolution of the blobs velocity detected by the camera is in a good agreement with the evolution of the poloidal phase velocity of fluctuations measured by probes.

The evolution of the rms fluctuation levels (as measured with probes) is strongly correlated with the number of blobs (above a size threshold) detected by fast camera measurements.

OUTLINE

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  - Experimental set-up
  - Spontaneous low density transitions
  - Biasing induced transitions
  - NBI regime transitions (H-mode)
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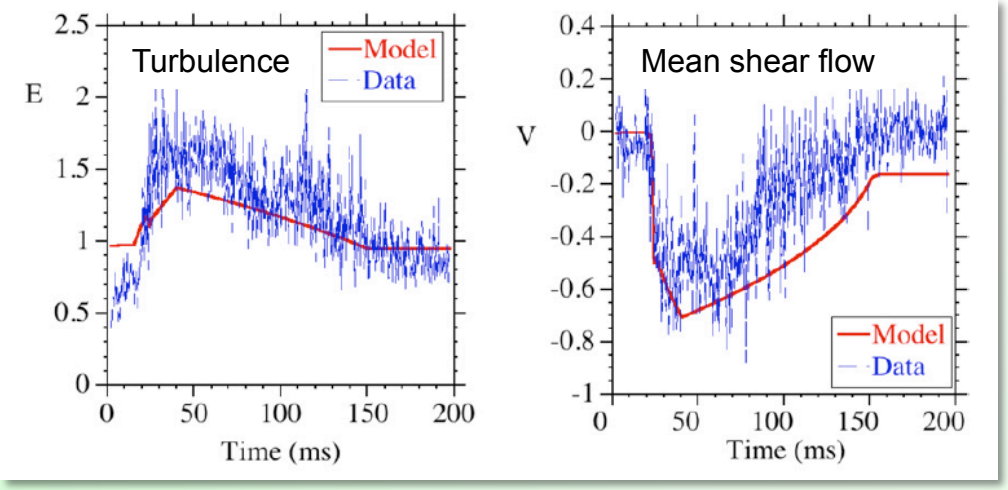
Comparison with Zonal Flows models

The experimentally observed correlations can be understood in the framework of simple transition models including the contribution of zonal flows in an appropriately way .

Numerical calculations include a flux ramp traversing the critical point, going from a low to an improved confinement state.

The model is able to capture the essential features of the experimental observations.



$$\frac{dE}{dt} = N^{2/3}E - N^{-1/2}E^2 - N^{-1/3}E(V^2 + V_{ZF}^2),$$

$$\frac{dV}{dt} = a_1 N^{-4/3}E^2 V + a_2 N^{-2/3}V_{ZF}^2 V - bV,$$

$$\frac{dV_{ZF}}{dt} = \frac{a_1}{1 + N^{-1}V^2} N^{-4/3}E^2 V_{ZF} + a_3 N^{-4/3}E^2 V - bV_{ZF},$$

$$\frac{dN}{dt} = \Gamma - DEN,$$

E, amplitude of turbulence

V, mean flow shear

V_{ZF}, zonal flow shear

N, (minus) pressure gradient

μ, toroidal correlation

I. Calvo et al., Plasma Phys. Control. Fusion **51** (2009) 065007

Laboratorio Nacional Fusión

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Summary

- ✓ High long-range correlations (in potential fluctuations) have been found in the TJ-II plasma edge.
- ✓ Long-range correlations are amplified by the presence of radial electric fields (transitions to improved confinement regimes).
- ✓ It remains as an open question to clarify which mechanisms can provide such long-range correlations in plasma potential but not in density fluctuations.
- ✓ The experimental measurements and the good agreement obtained with the model results suggest that the phenomenon of the long-range correlations is an indication of the development of zonal flows during the transition.

TJ-II findings show the important role of long distance correlation as a first step in the transition to improved confinement regimes and the key role of electric fields to amplify them.

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Actions under way

Priority research area of the EFDA Transport Topical Group

✓TJ-II experiments:

Radial characteristics of the toroidal structures
Improvement of dynamic biasing experiments
Measurement of Reynolds stress components
……

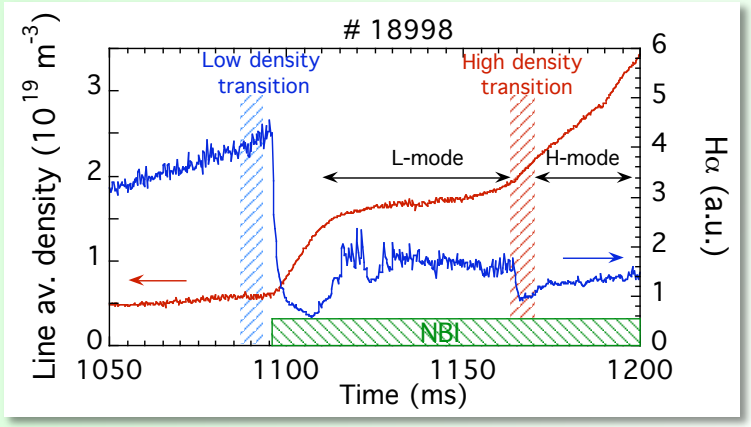
✓Diagnostics development to characterize simultaneously the structure of sheared flows at different plasma locations.

✓Comparative studies in different geometry devices and during L-H transition.

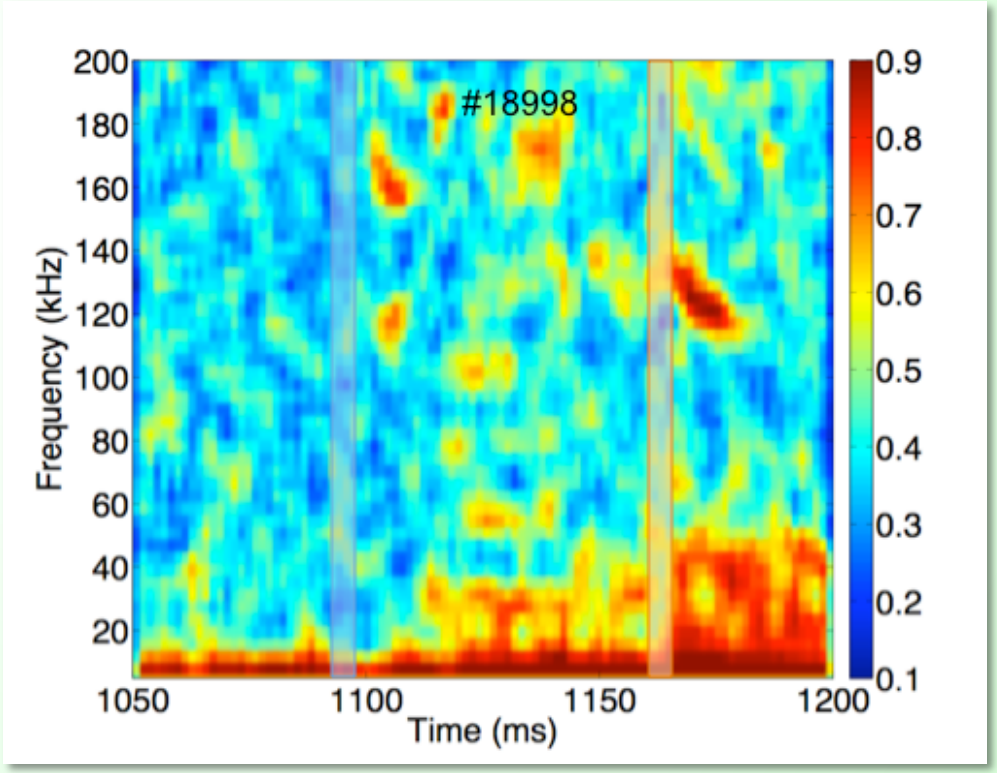
Results from: TJ-K (P. Manz et al., Phys. Plasmas **16**, 042309 (2009))
TEXTOR (Y. Xu et al., submitted to Phys. Plasmas (2009))
ISSTOK (C. Silva et al., Plasma Phys. Control. Fusion **51**, 085009 (2009))
HL-2A (K. J. Zhao et al., to be published)
……..

✓Link with modelling and theory activities.

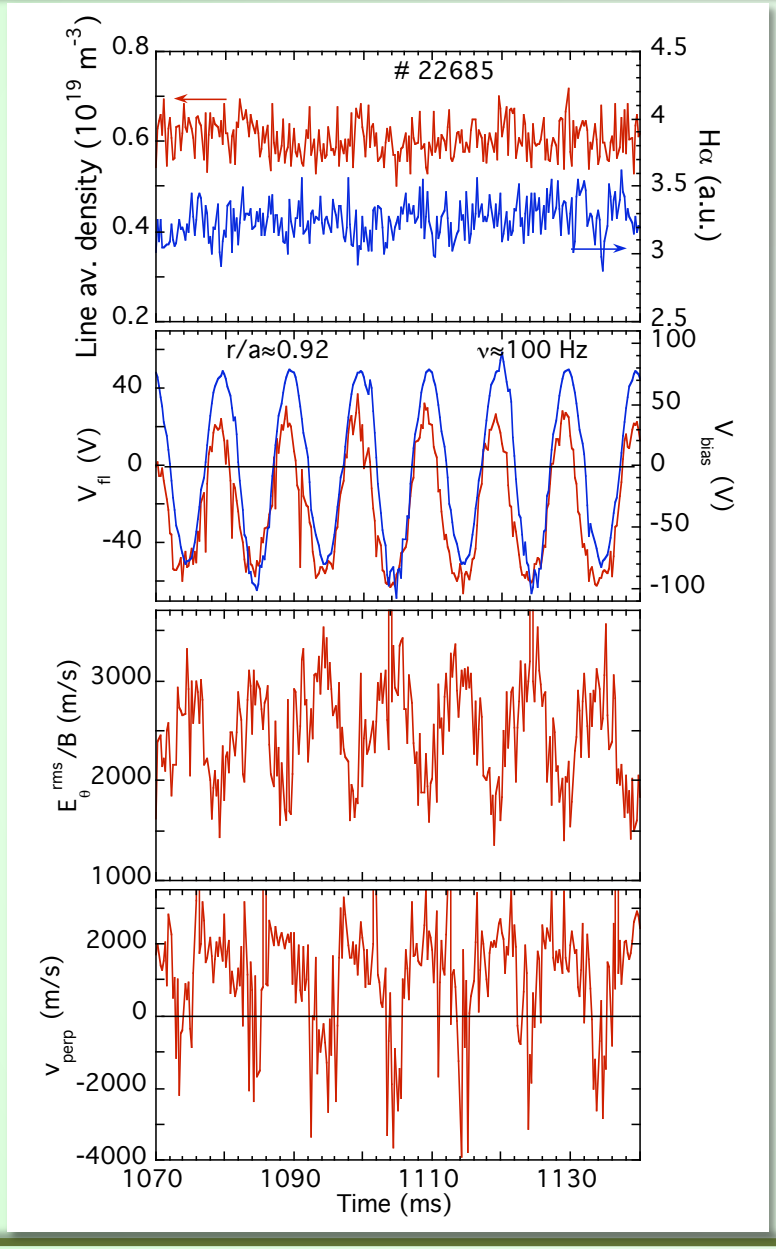
Long-range correlation: NBI transition



The frequency resolved coherence of floating potential signals is dominated by frequencies below 40 kHz.



Dynamic biasing transitions



Preliminary results with dynamic biasing shows modulation of plasma density, Hα, edge electric field and fluctuations depending on the plasma density and on the frequency of applied voltage.

Results strongly depend on the plasma density and on the applied voltage and its frequency.

Density effects for spontaneous shear development can compete with biasing effects.