L-H transition experiments in TJ-II

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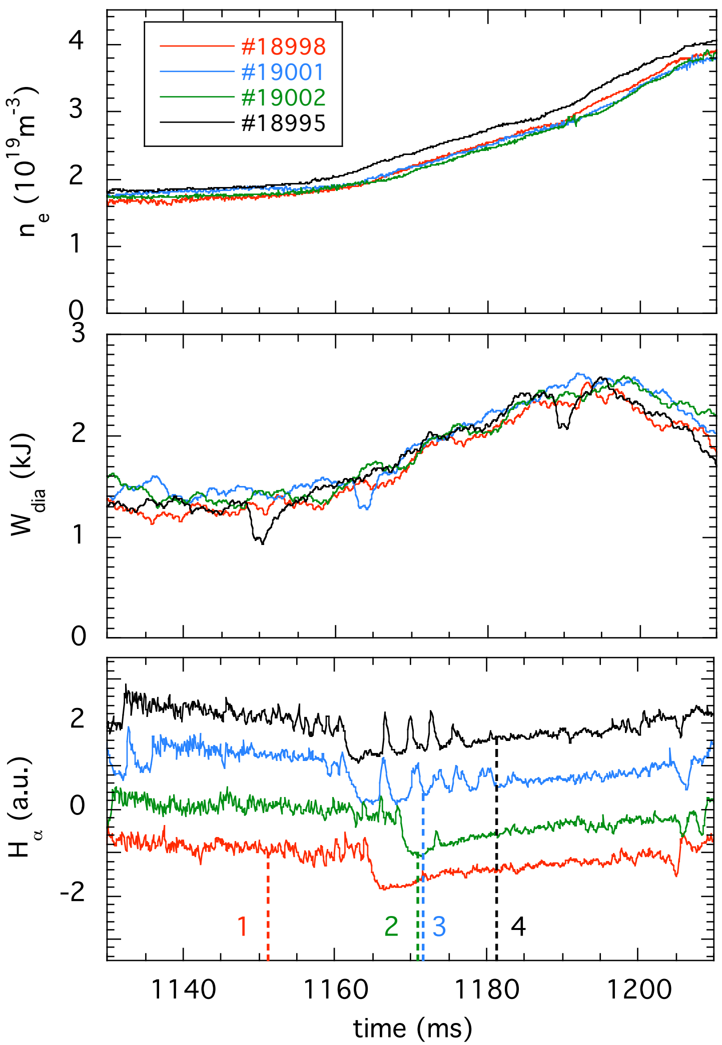
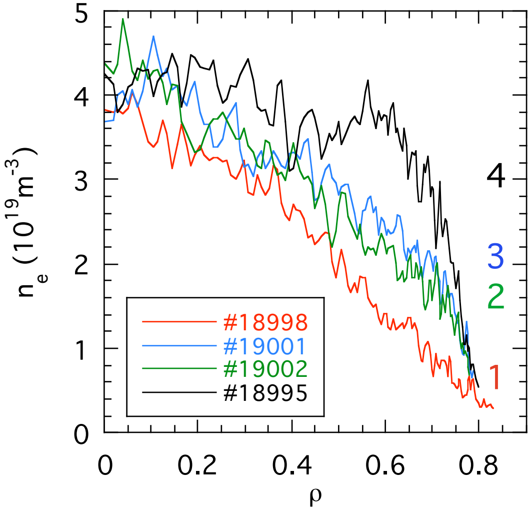
Energéticas, Medioambientales
y Tecnológicas

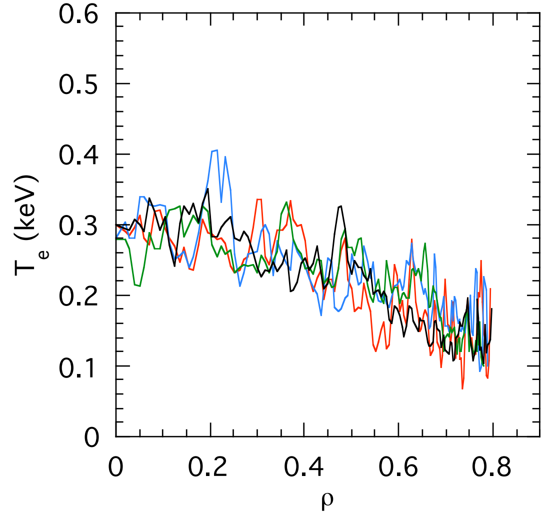
First L-H transitions in TJ-II *(spring 2008)*

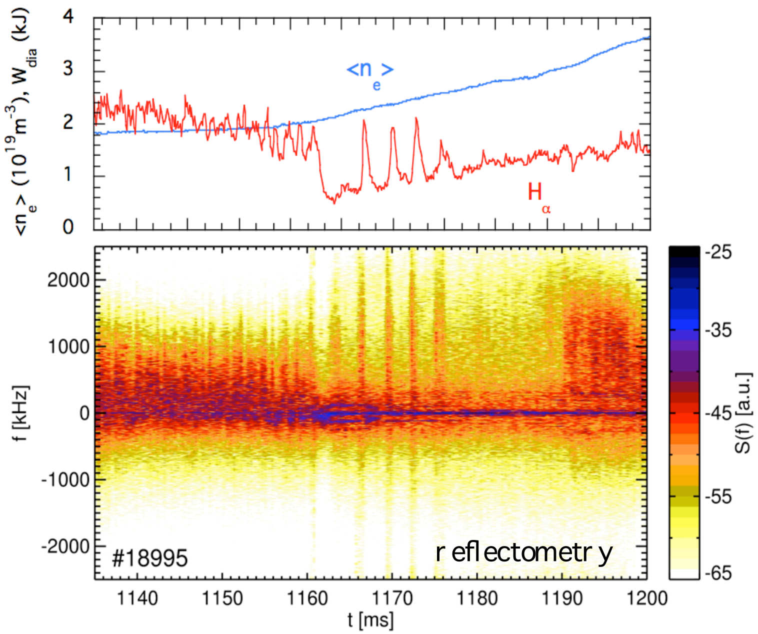
NBI heated plasmas, with one or two injectors J. Sánchez *et al.*, NF **49** (2009) 104018

Li coated wall: low recycling, improved density control and confinement F.L. Tabarés *al.*, PPCF **50** (2008) 124051









Outline

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TJ-II capabilities

L-H transitions studies

- Low NBI input power (≈ 400 kW)
  - magnetic configuration dependences
  - fine magnetic configuration scan
  - influence of low order rational surfaces
- High NBI input power (≈ 900 kW)
  - dynamics of radial electric field and turbulence

Conclusions

TJ-II plasma heating capabilities

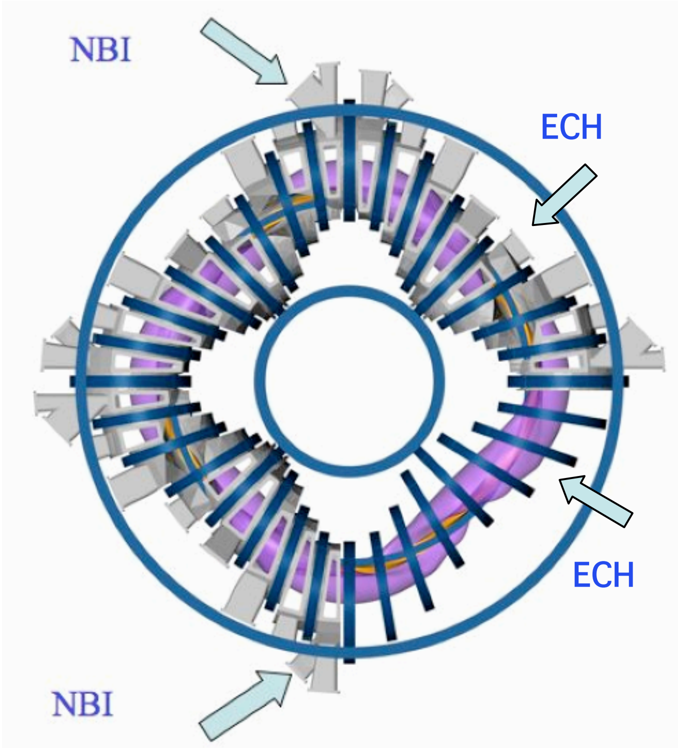
ECH

Two gyrotrons, f = 53.2 GHz, 300 kW each

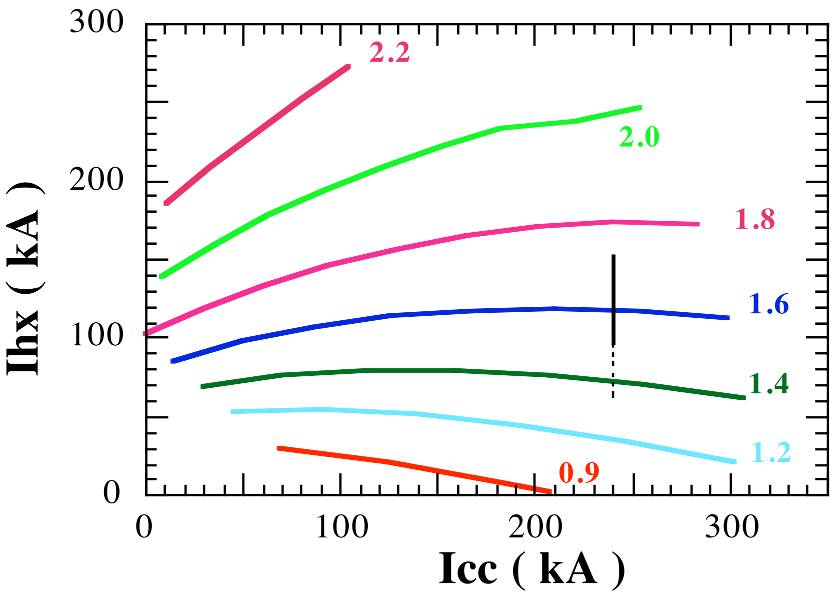
Maximum plasma density: 1.7 10^{19} m^{-3}

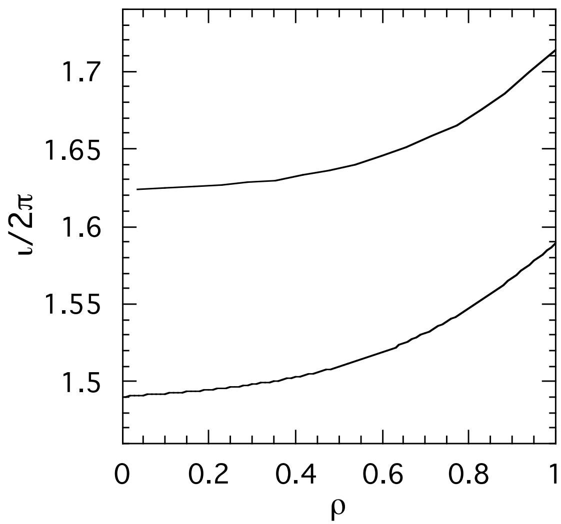
NBI

Two injectors, co and counter, up to 500 kW port-through each (32 kV, 60 A)



TJ-II magnetic configuration flexibility





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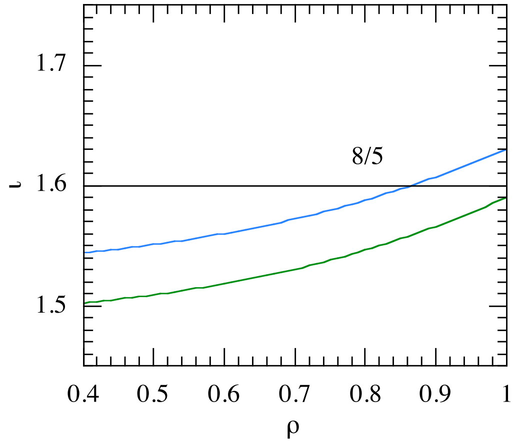
Conclusions

L-H transitions

co-NBI heated plasmas: 400 kW port-through

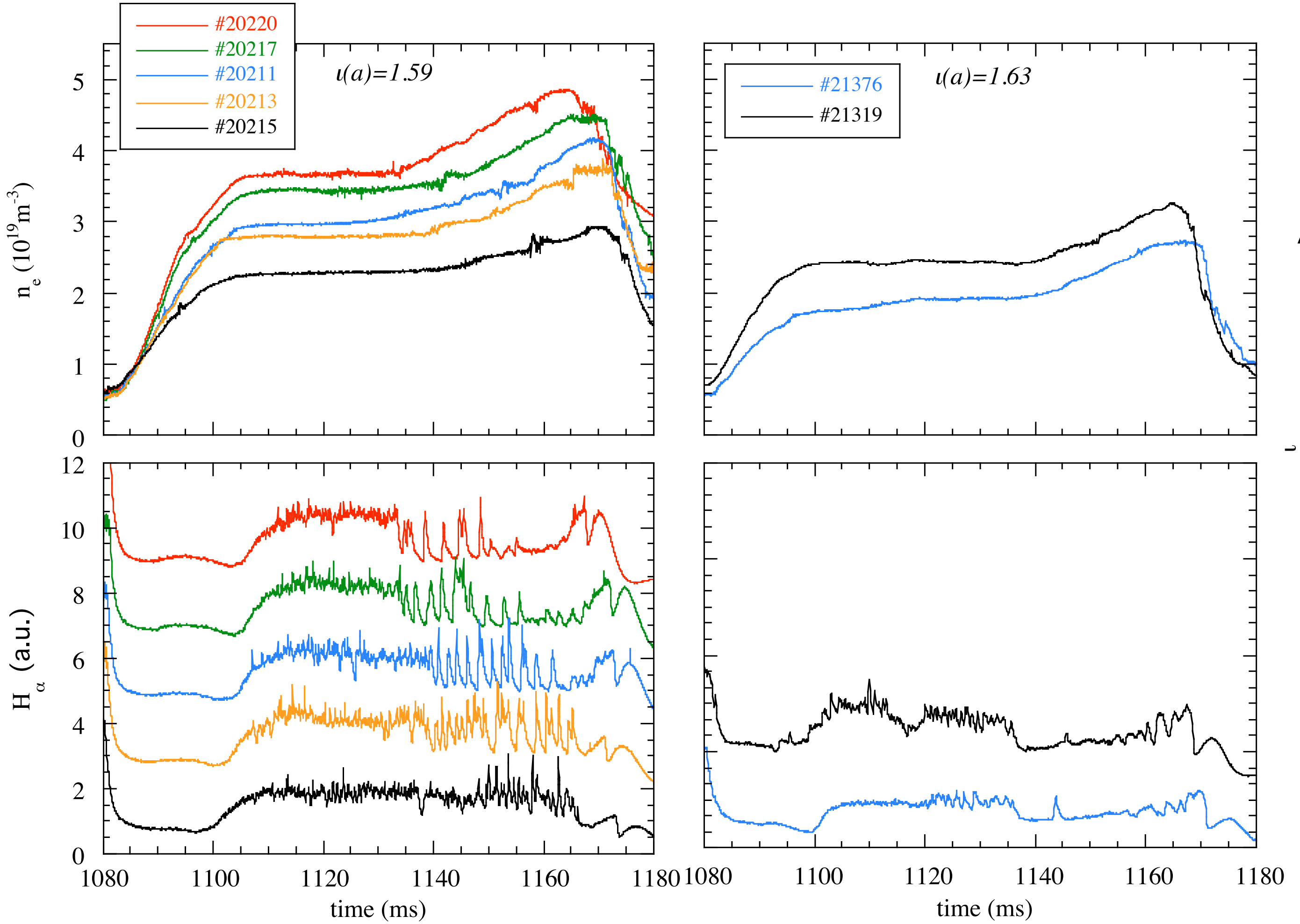
Plasma current < +1 kA

$\Delta\iota(a) \leq 7.5\ 10^{-3}\ I_p < 0.007$



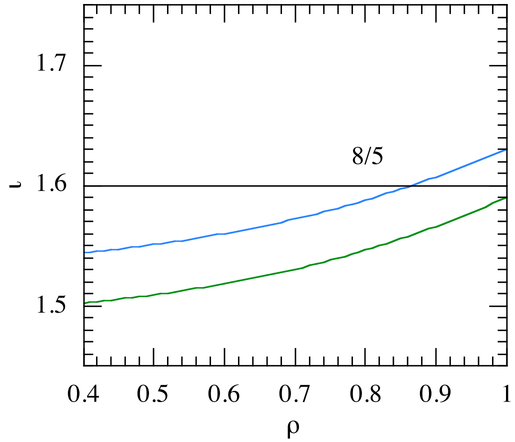
L-H transitions

co-NBI heated plasmas: 400 kW port-through



Plasma current ≈ +0.3 kA

$\Delta\iota(a) \leq 7.5\ 10^{-3}\ I_p \approx 0.002$



Confinement enhancement factor: $\tau_{E\,exp}$ / $\tau_{E\,ISS04}$

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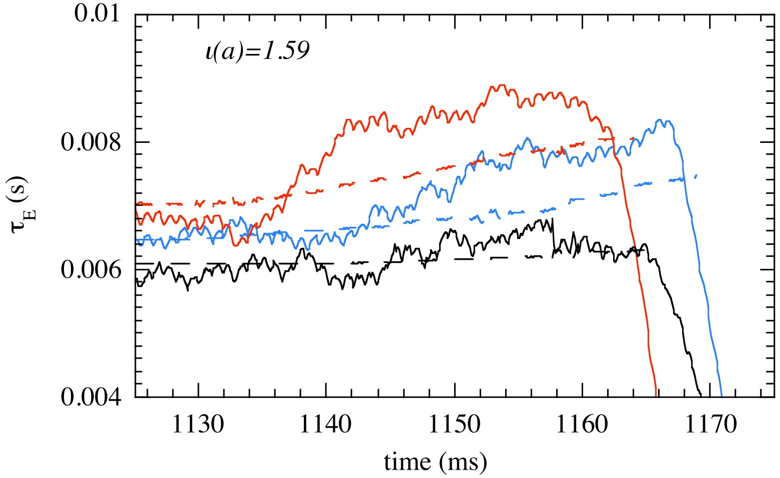
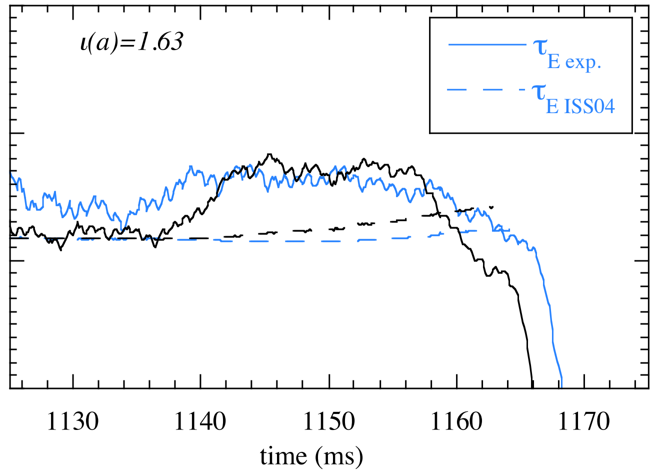
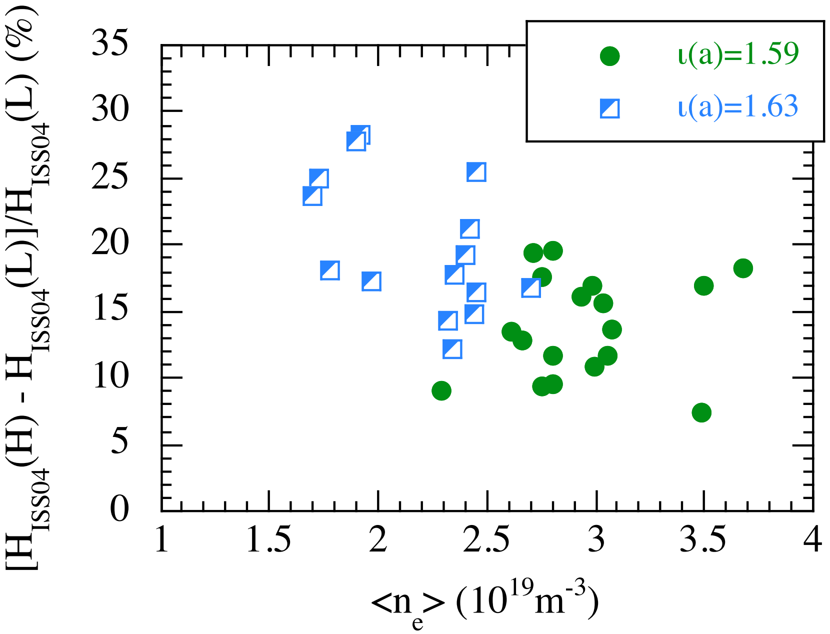
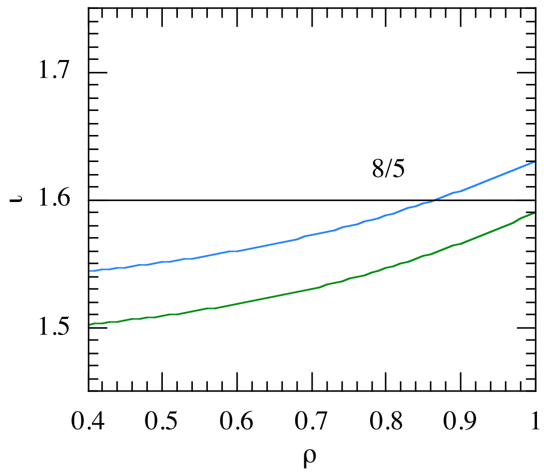


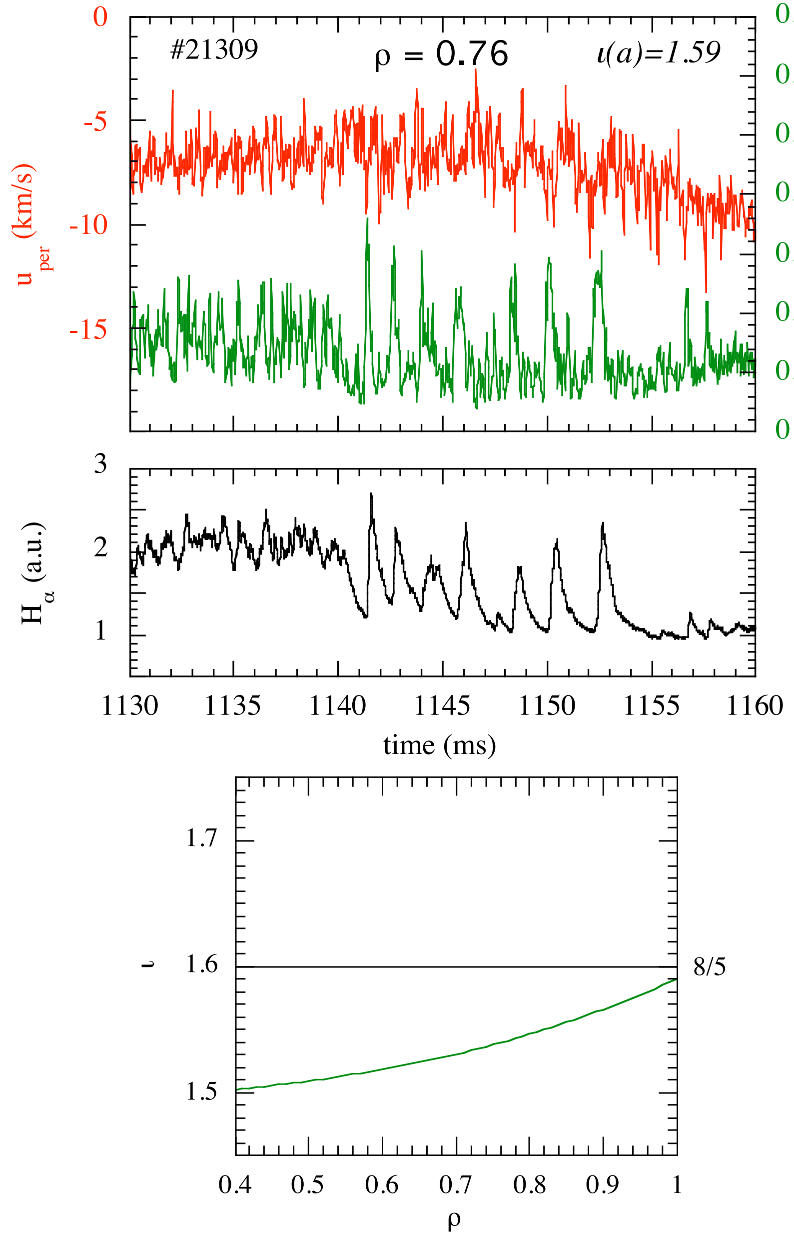


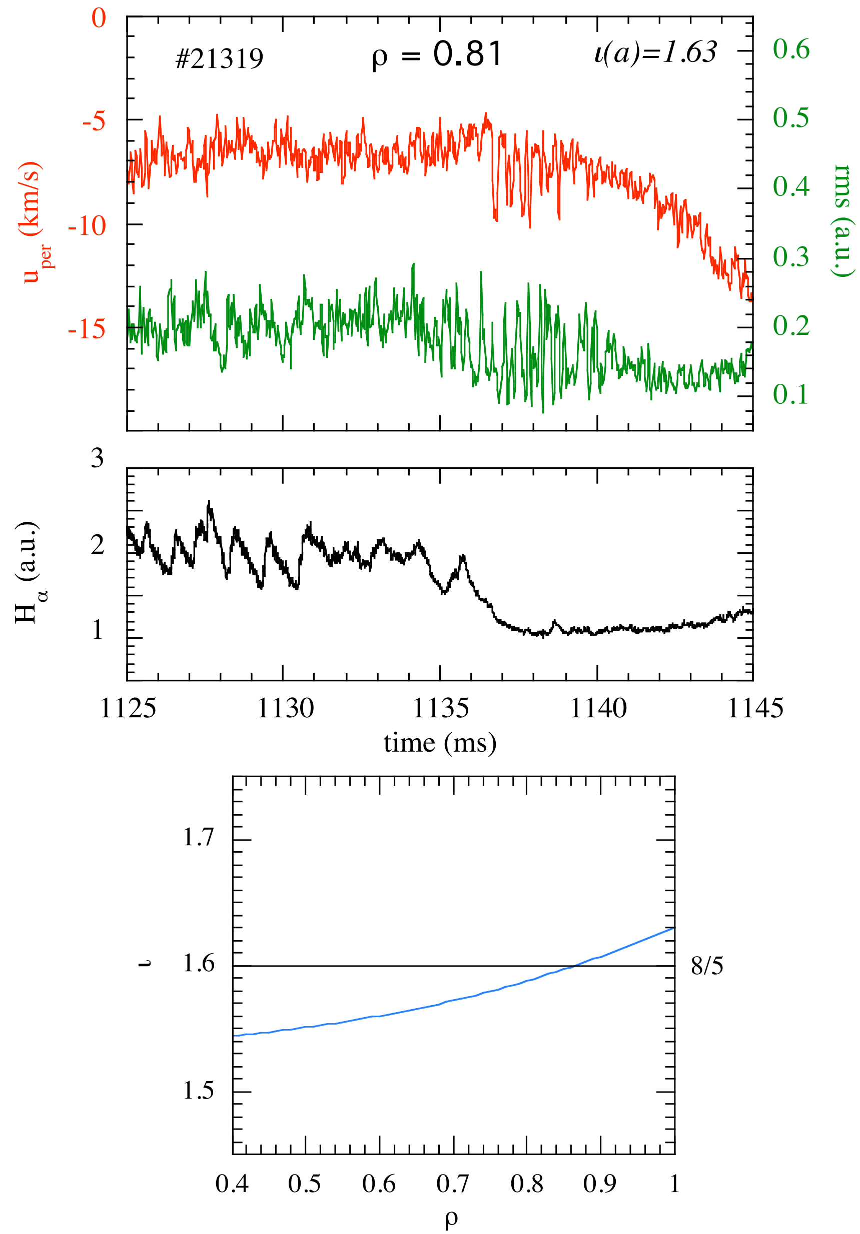




ISS04: H. Yamada, *et al.*, NF **45** (2005) 1684

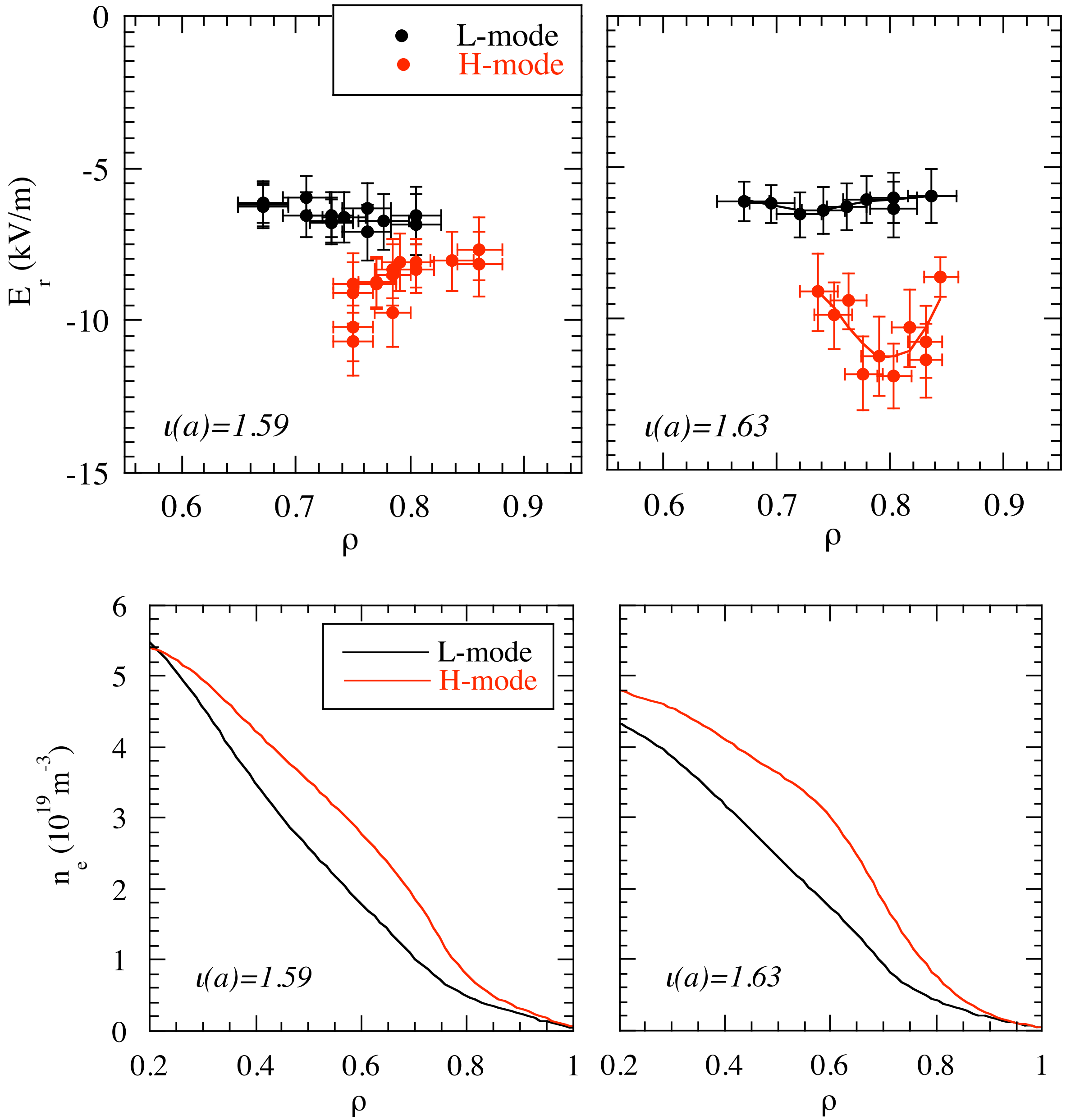
$u_\perp$ and density fluctuations





Doppler reflect.: T. Happel *et al.*, RSI **80** (2009) 073502

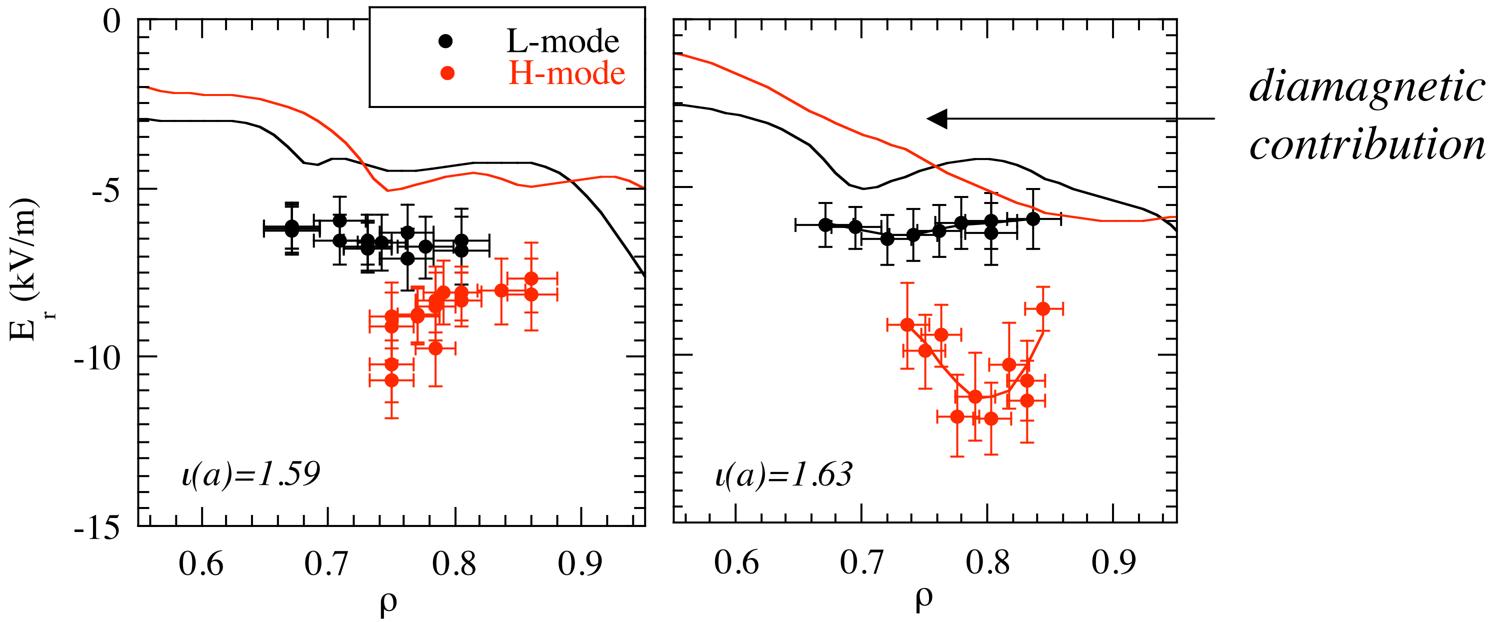
radial electric field and density profiles



Er profiles measured by Doppler reflect.

Density profiles measured by Thomson scattering + AM reflect.

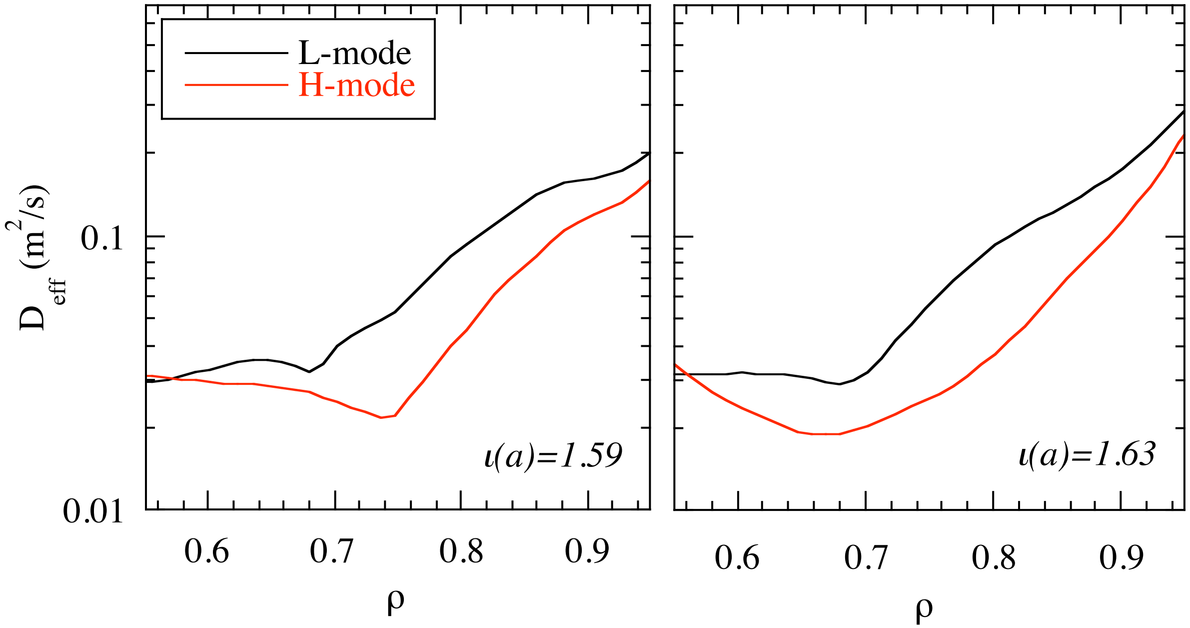
radial electric field profiles



Diamagnetic term close to Er profile in L-mode; a ***v*** x ***B*** contribution appears in H-mode also observed in W7-AS: F. Wagner *et al.*, PPCF **48** (2006) A217

Transport analysis

Transport analysis done with the ASTRA system



Energy confinement time changes from about 7 to 8 ms in agreement with the experimental one

Particle confinement time:

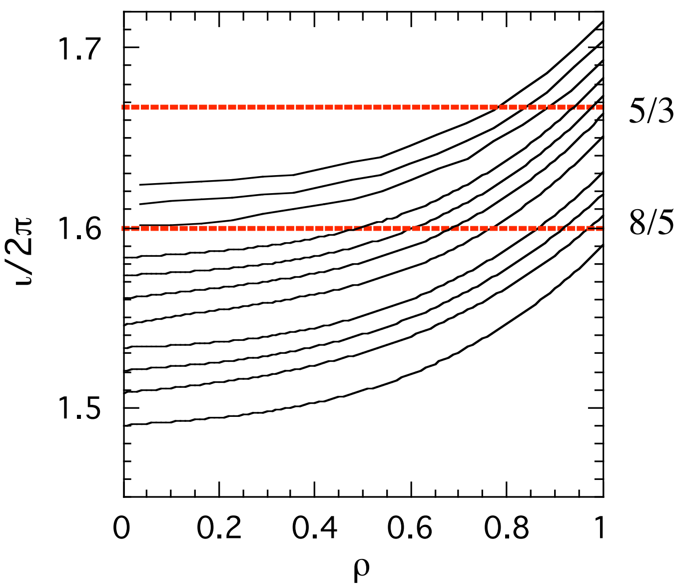
L-mode: $\tau_p \approx 55$ ms

H-mode: +25% in *ι(a)=1.59* configuration

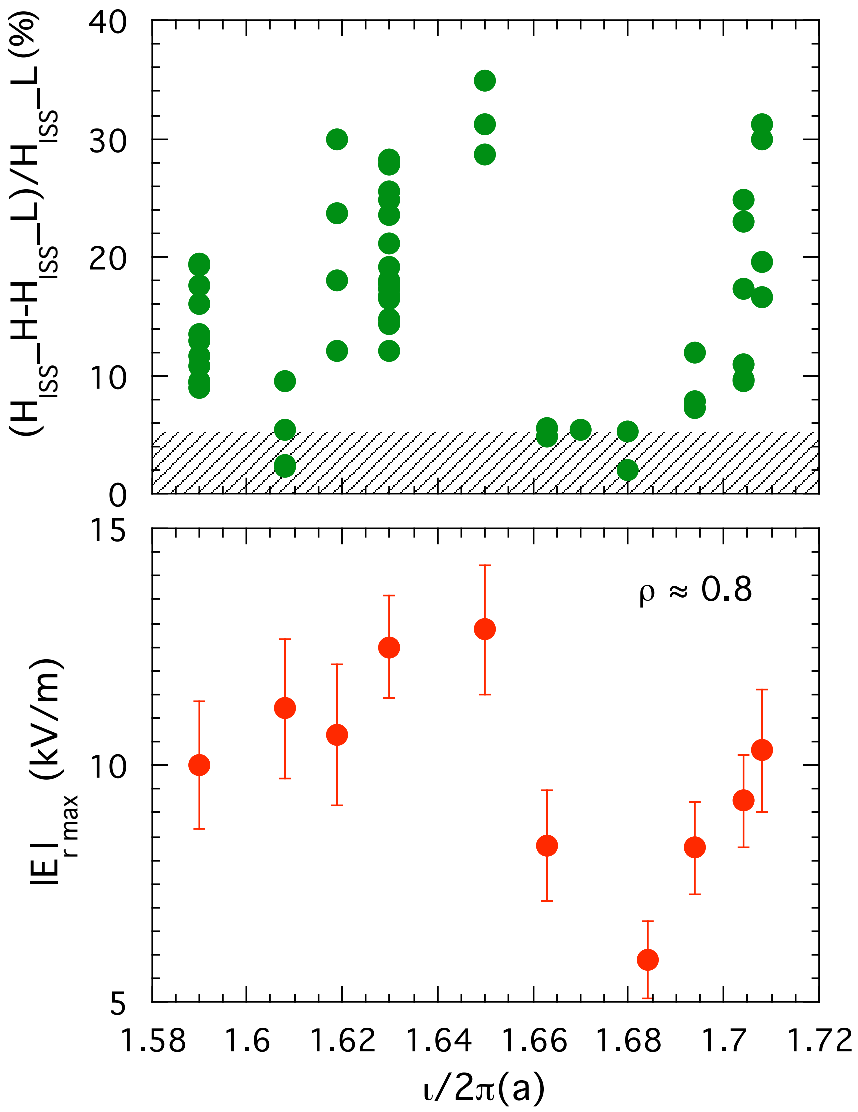
+35% in *ι(a)=1.63* configuration

ASTRA: G.V. Pereverzev, *et al.*, IPP 5/98, Garching (2002)

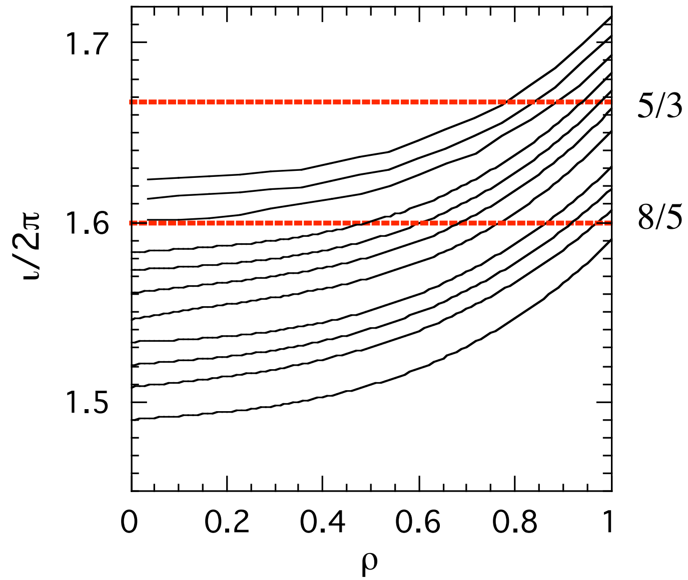
Magnetic configuration scan



Magnetic configuration scan



co-NBI heated plasmas:
370-400 kW port-through

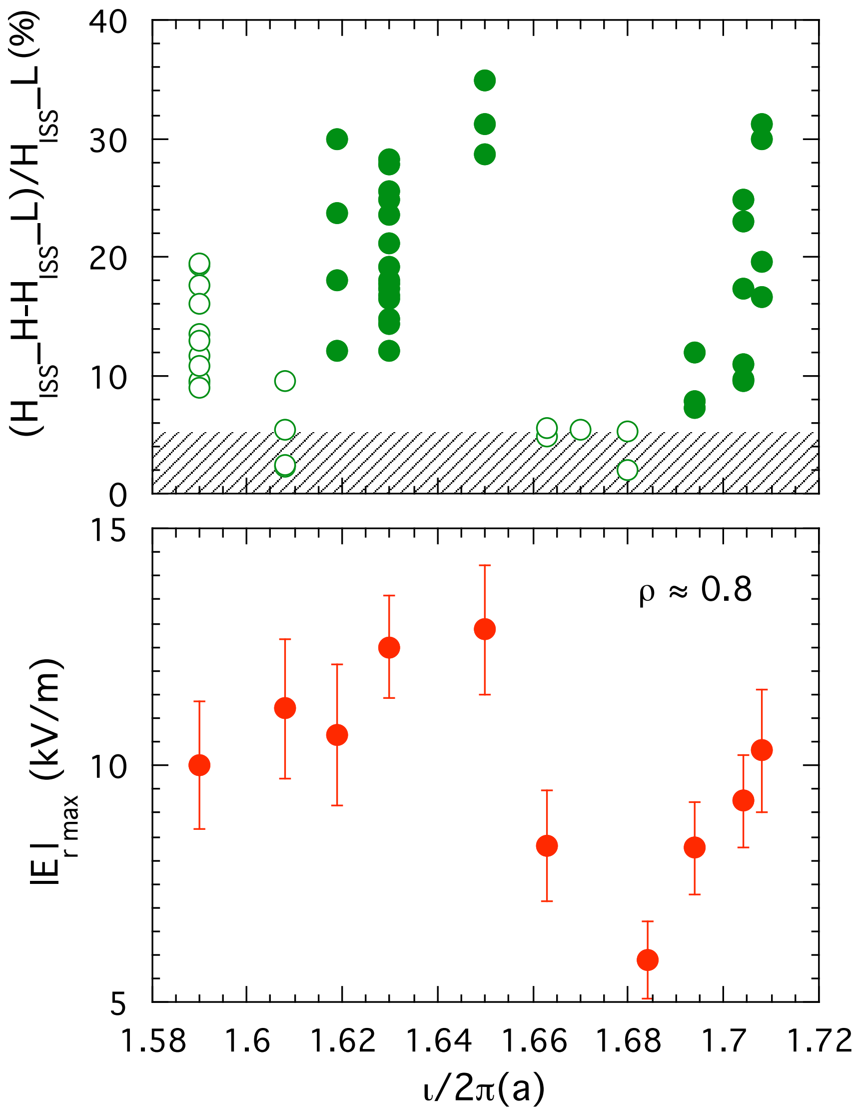


Iota dependence of L-H transitions in stellarators:

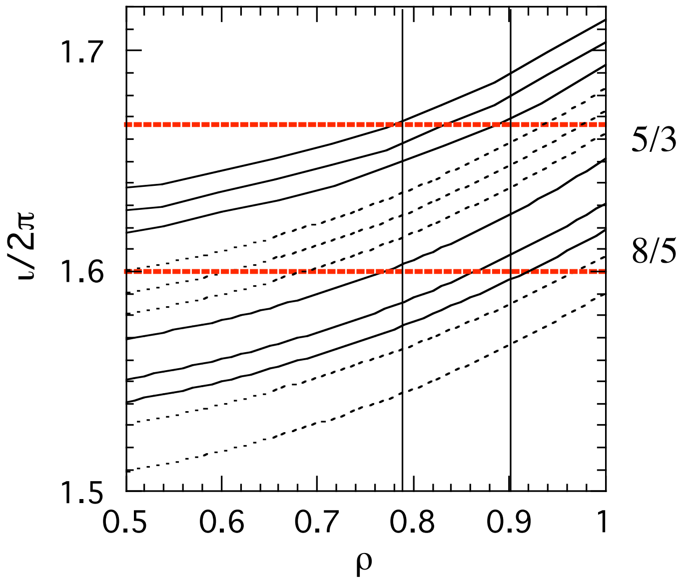
F. Wagner. PPCF **49** (2007) B1

F. Sano, *et al.*, NF **45** (2005) 1557

Magnetic configuration scan

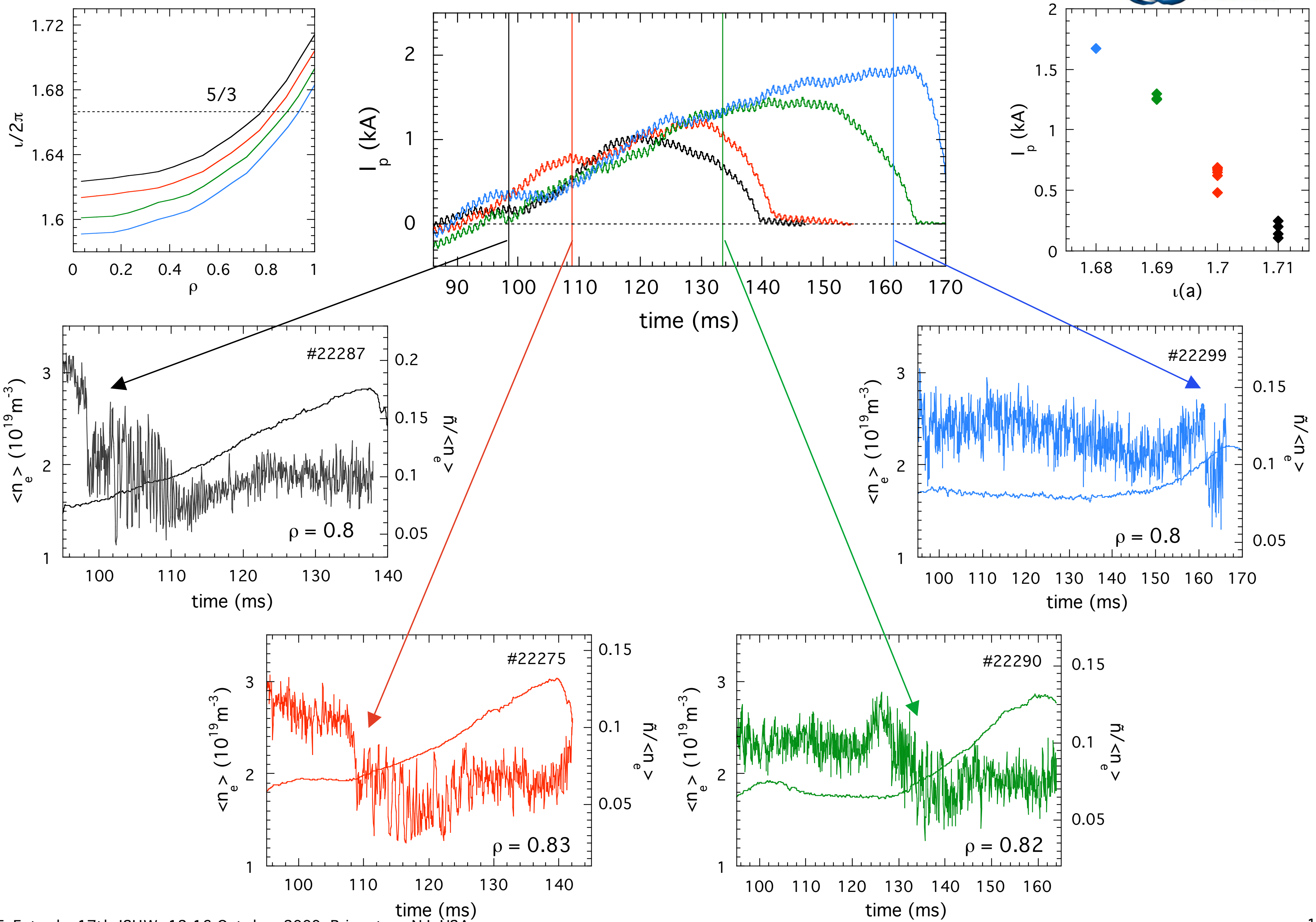


co-NBI heated plasmas:
370-400 kW port-through

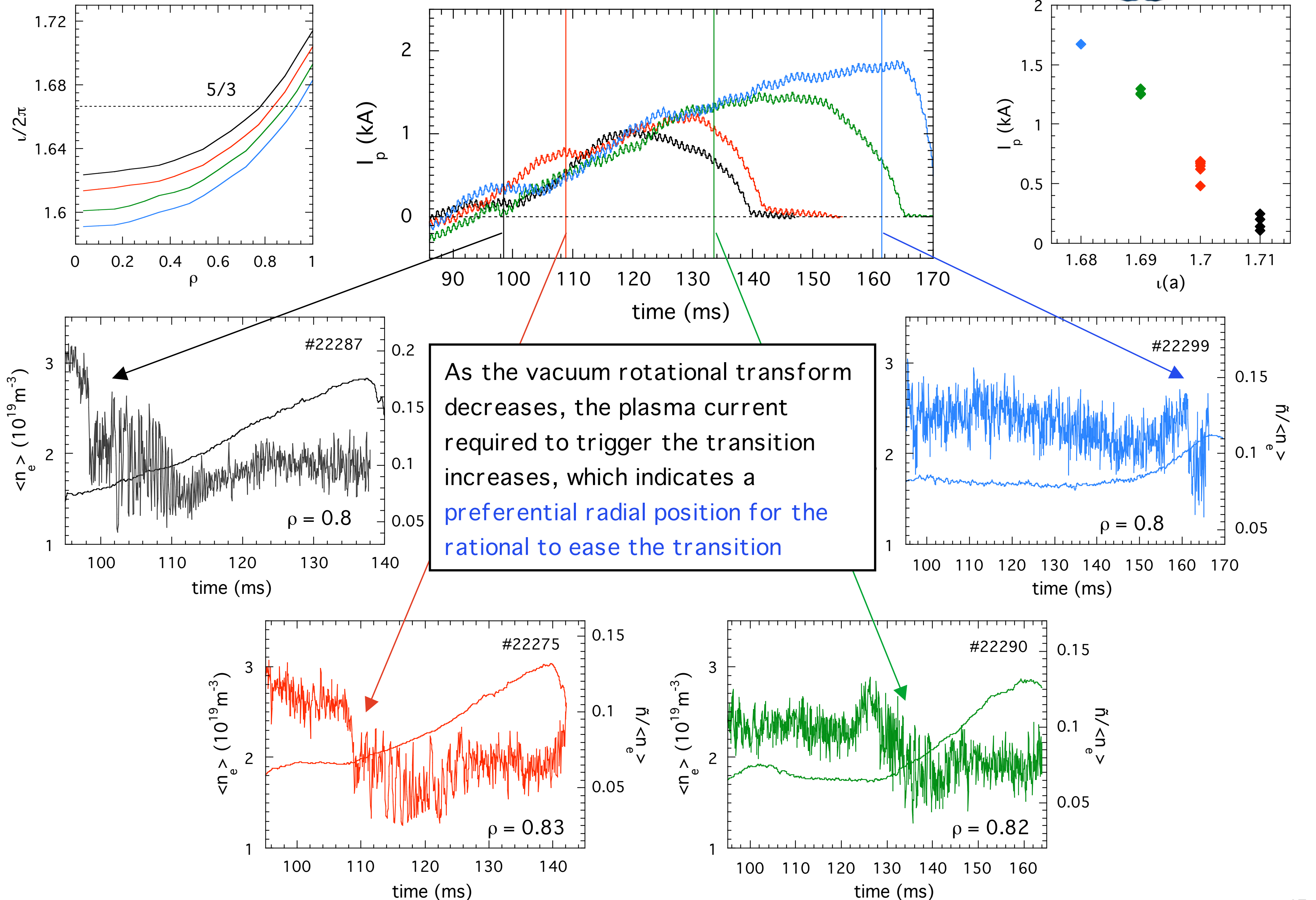


iota-dependence suggests a positive influence of low order rationals close to the plasma edge ($\rho \approx$ 0.8-0.9)

Fine rotational transform scan



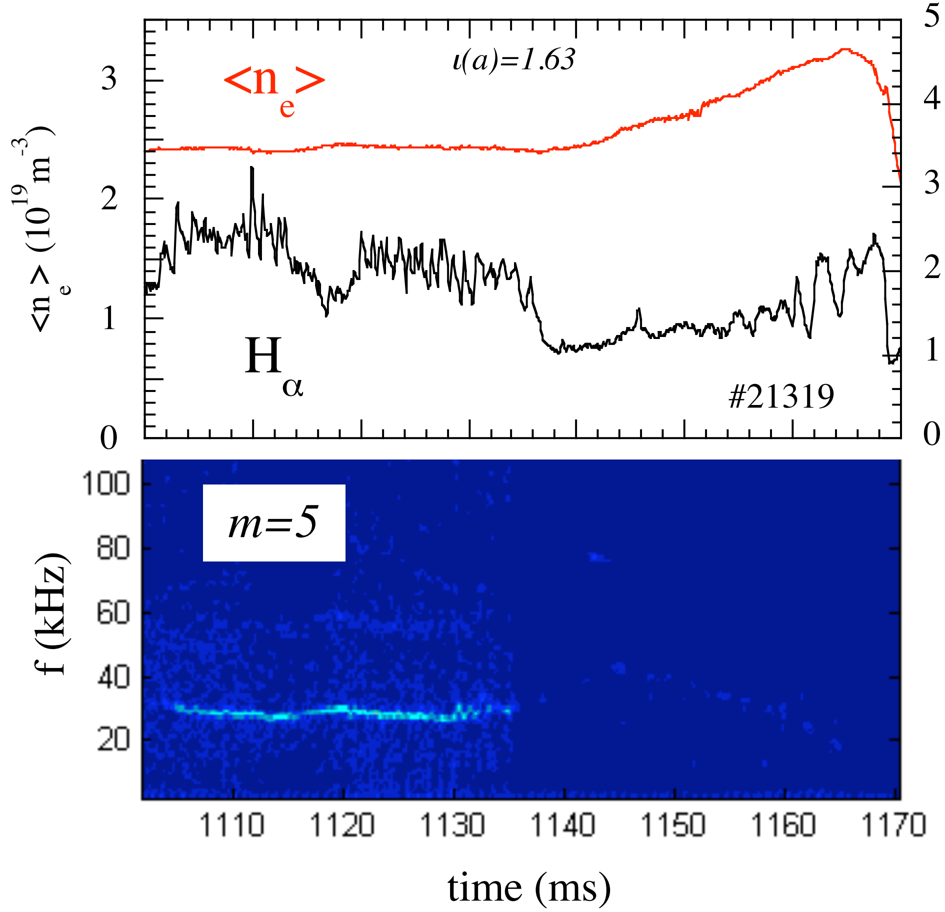
Fine rotational transform scan

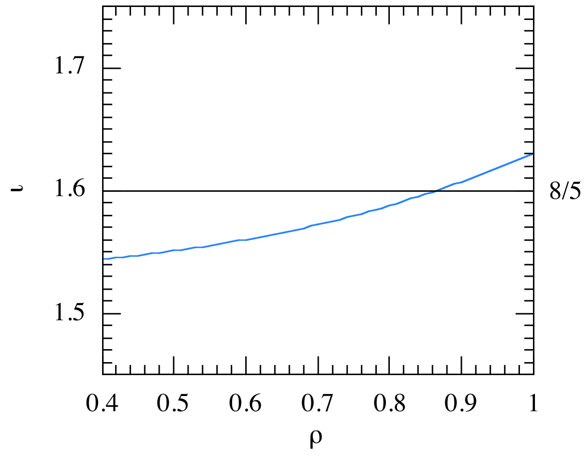


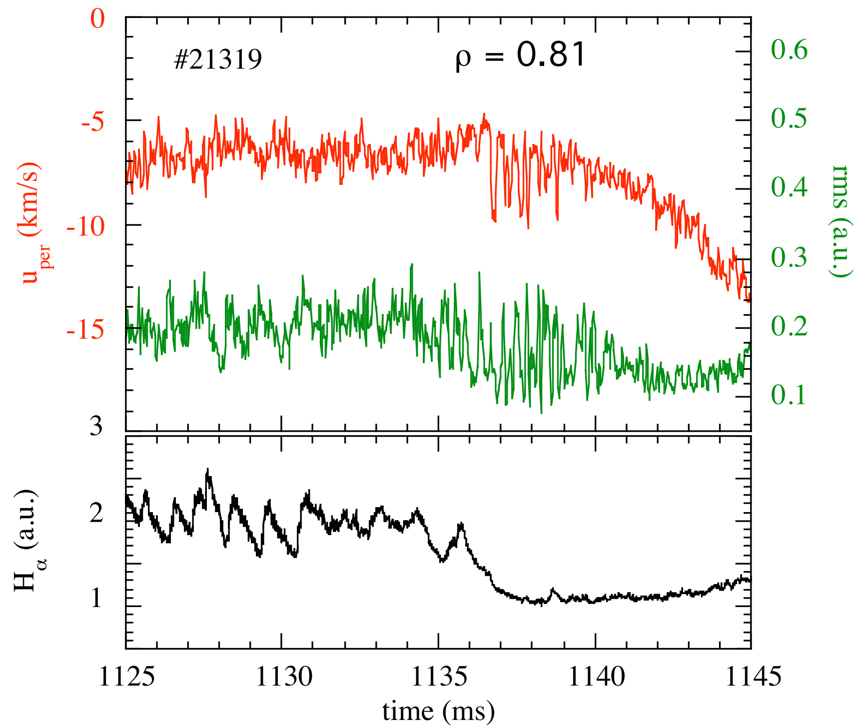
As the vacuum rotational transform decreases, the plasma current required to trigger the transition increases, which indicates a preferential radial position for the rational to ease the transition

Influence of low order rational surfaces: 8/5

co-NBI: 400 kW, configuration $\iota(a)=1.63$







Rational surface can trigger sheared *E*x*B* flows:

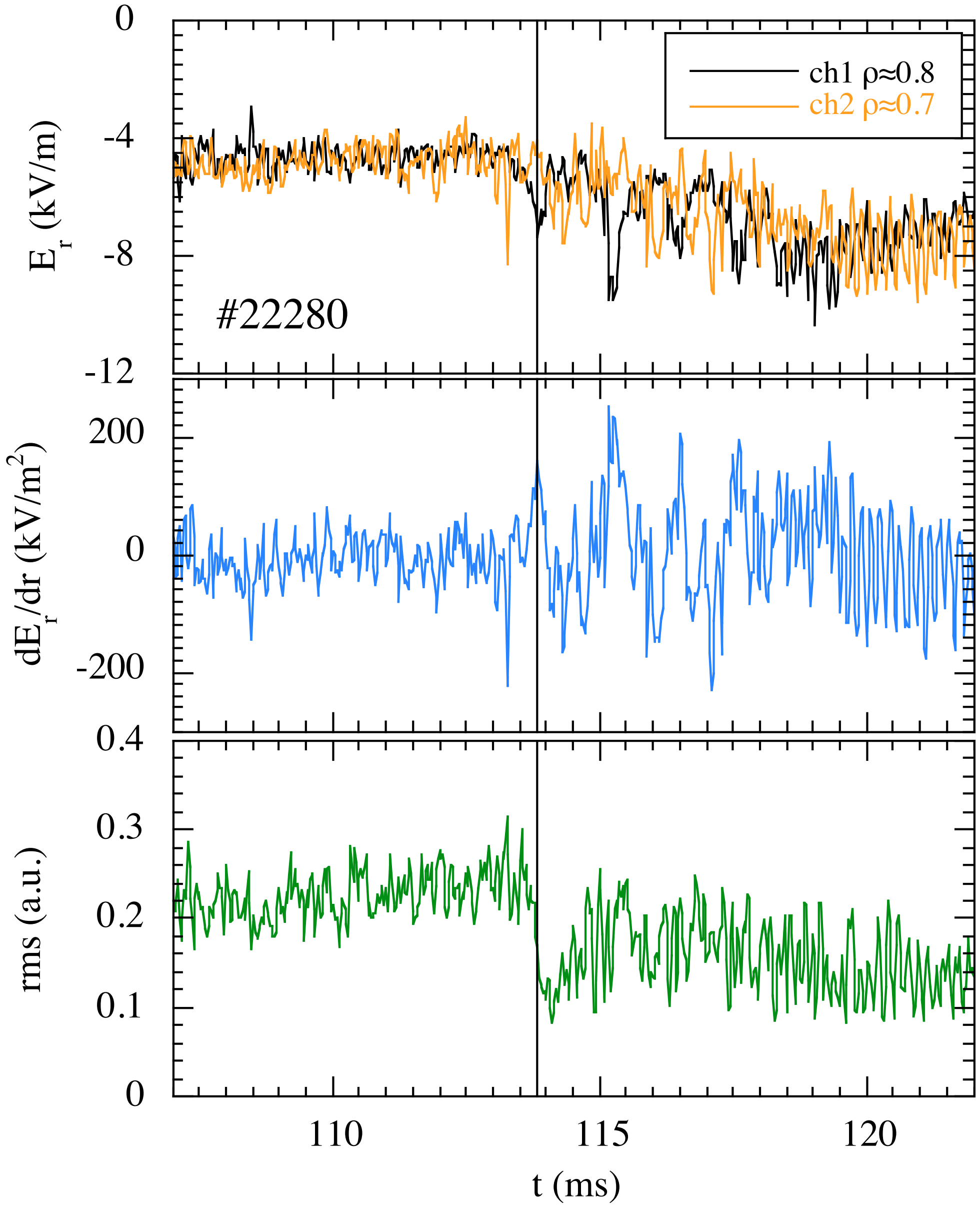
C. Hidalgo, *et al*., PPCF **42** (2000) A153

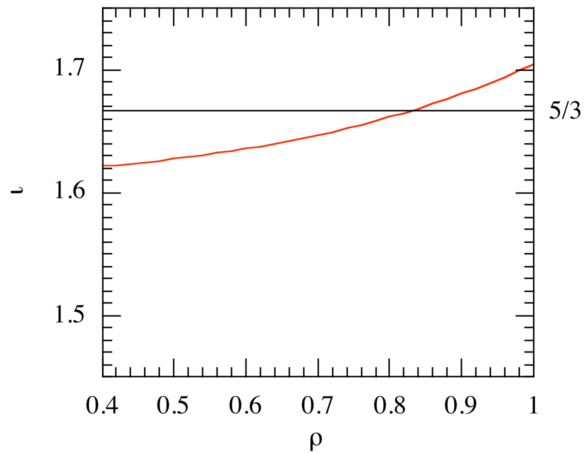
L. García, *et al*., PoP **8** (2001) 4111

K. Ida, *et al*., PRL **88** (2002) 015002

Influence of low order rational surfaces: 5/3

co-NBI: 400 kW, configuration $\iota(a)=1.7$



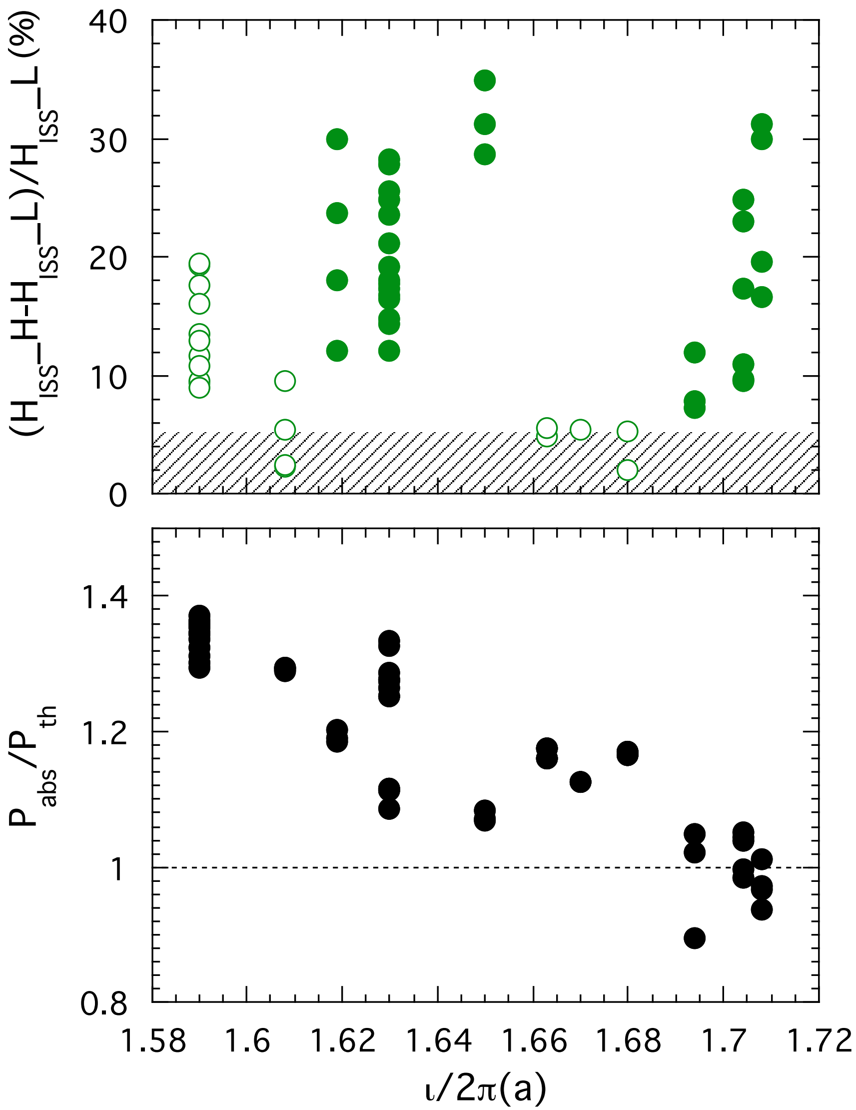


→ *shearing rate ≈ 2 10^5 s^{-1}*

These results can be interpreted in terms of local changes in the Er field shear induced by the rational surface facilitating the transition

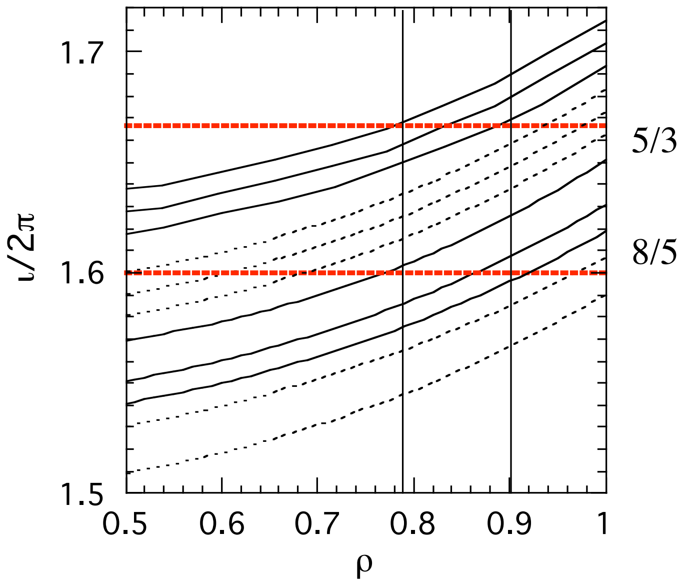
T. Estrada *et al.*, PPCF **51** (2009) *In press*

Magnetic configuration scan



ITER physics basis 2007: $P_{th} = 0.042\, n_{20}^{0.73}\, B_T^{0.74}\, S^{0.98}$

co-NBI heated plasmas:
370-400 kW port-through



scan performed at low NBI input power: a reduction in the "effective" power threshold due to the rational surface could explain the pronounced iota-dependence

--> *high NBI power experiments*

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  fine magnetic configuration scan

  influence of low order rational surfaces

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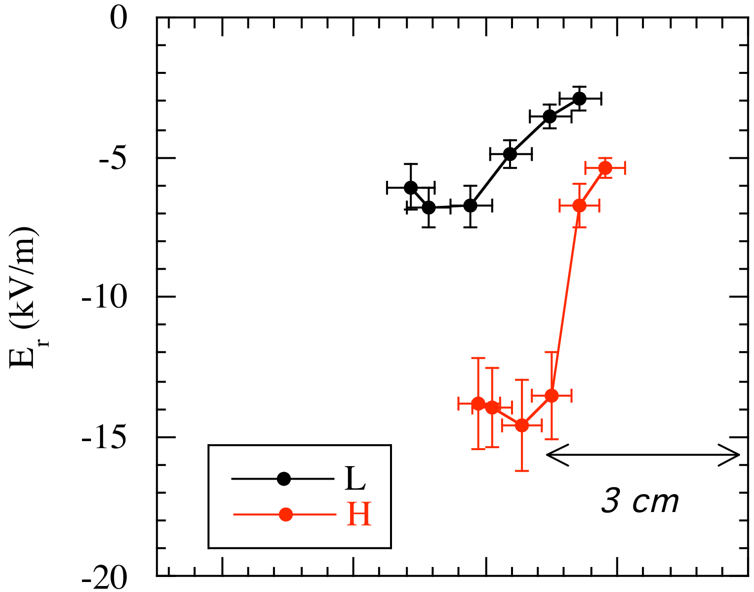
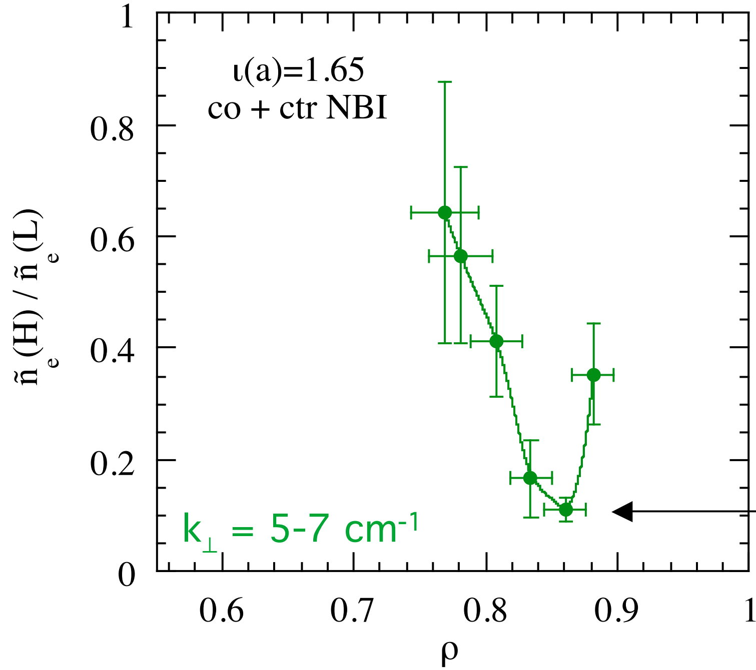
  dynamics of radial electric field and turbulence

Conclusions

higher NBI power



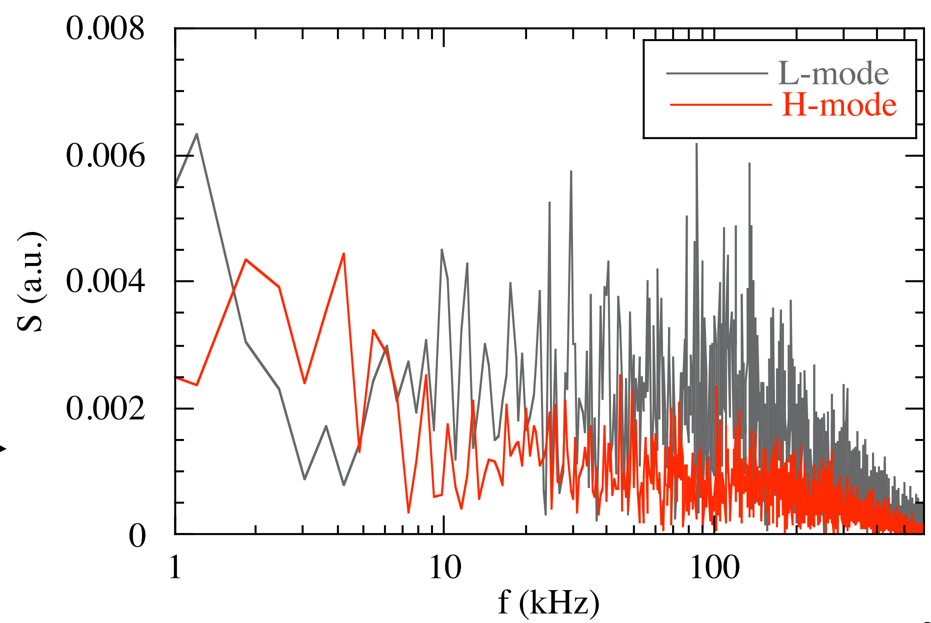


balanced-NBI: 900 kW port-through

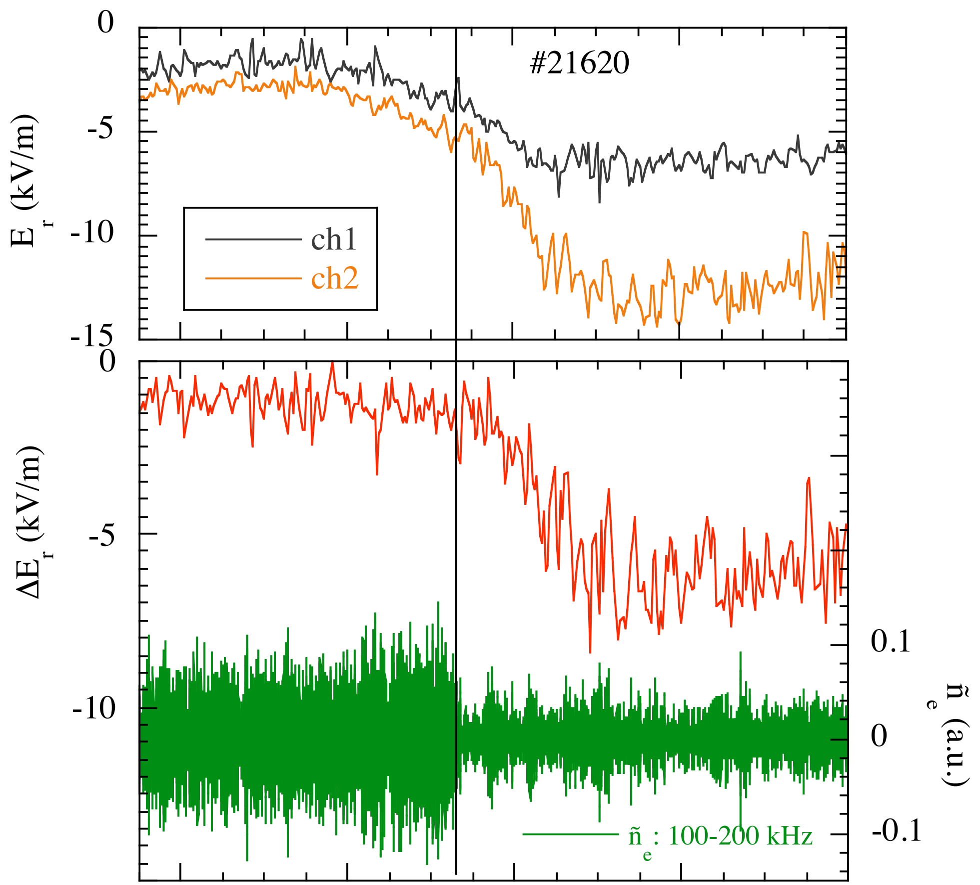
standard configuration: *ι(a)=1.65*

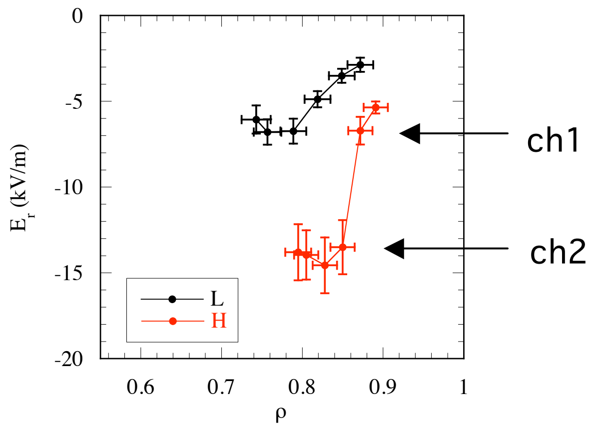
H_{ISS04}: 1.3 - 1.5

density fluctuations

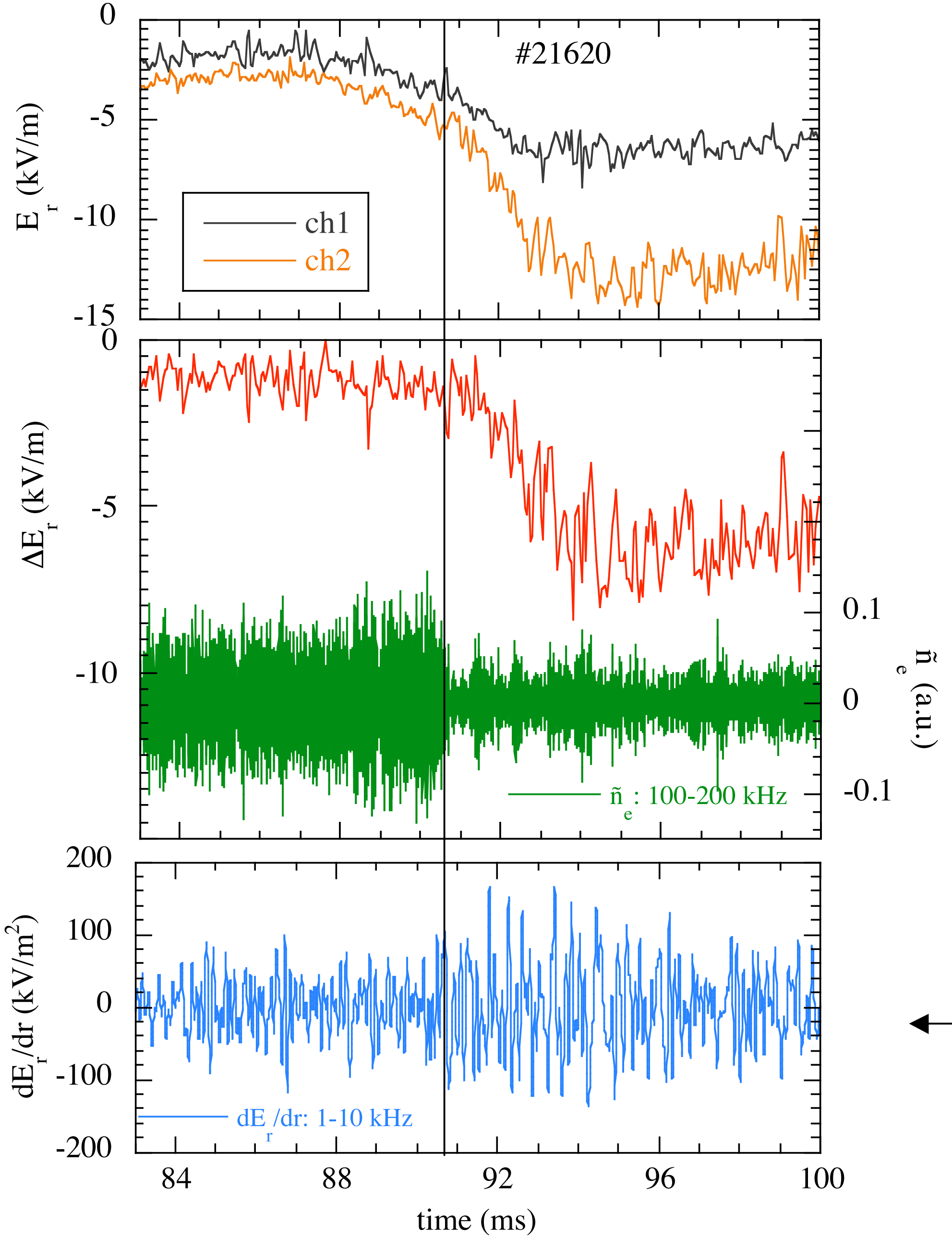


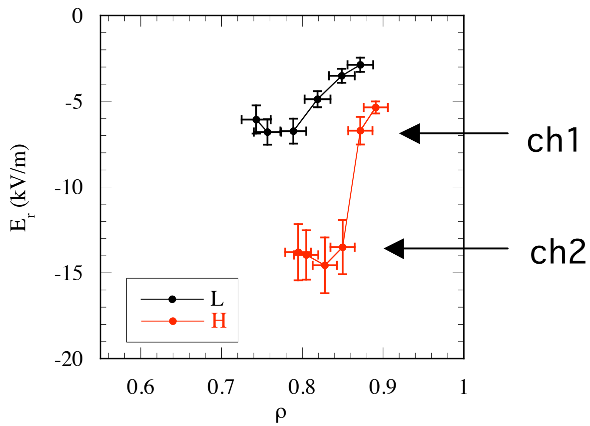
Dynamics of Er and turbulence

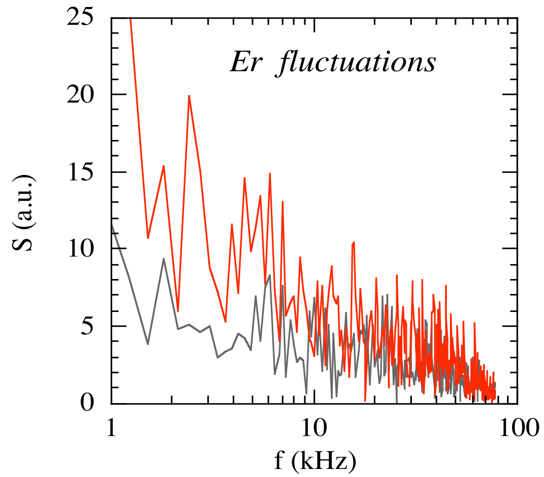




Dynamics of Er and turbulence







High temporal and spatial resolution measurements indicate that the turbulence reduction precedes the increase in the mean sheared flow, but it is simultaneous with the increase in the low frequency oscillating sheared flow

mean sheared flow is not the unique element to explain the suppression of turbulence at the transition, oscillating sheared flow has to be also considered

This observation may be an indicator, albeit insufficient, of the existence of zonal flows:

---> long-distance correlation measurements have been carried out using Langmuir probes   M.A. Pedrosa *et al.*, *invited talk* I27

Conclusions

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At the L-H transition, H_{ISS04} and $|E_r|$ field increase in an amount that depends on magnetic configuration and heating power. A reduction in the density fluctuation level is measured, stronger at the position of maximum Er shear

"Low" P_{NBI} : A rotational transform dependence is found that could be related to the presence of a low order rational close to the plasma edge

Low order rational surfaces close to the plasma edge can induce local changes in the radial electric that could facilitate the L-H transition

pronounced iota-dependence due to $P_{abs} \approx P_{th}$*?*

---> further experiments at higher P_{NBI}

"High" P_{NBI} : High temporal and spatial resolution measurements indicate that the turbulence reduction precedes the increase in the mean sheared flow, but it is simultaneous with the increase in the low frequency oscillating sheared flow

These results may be an indicator of the existence of zonal flows triggering the transitions

Diagnostics: Doppler reflectometer (I)

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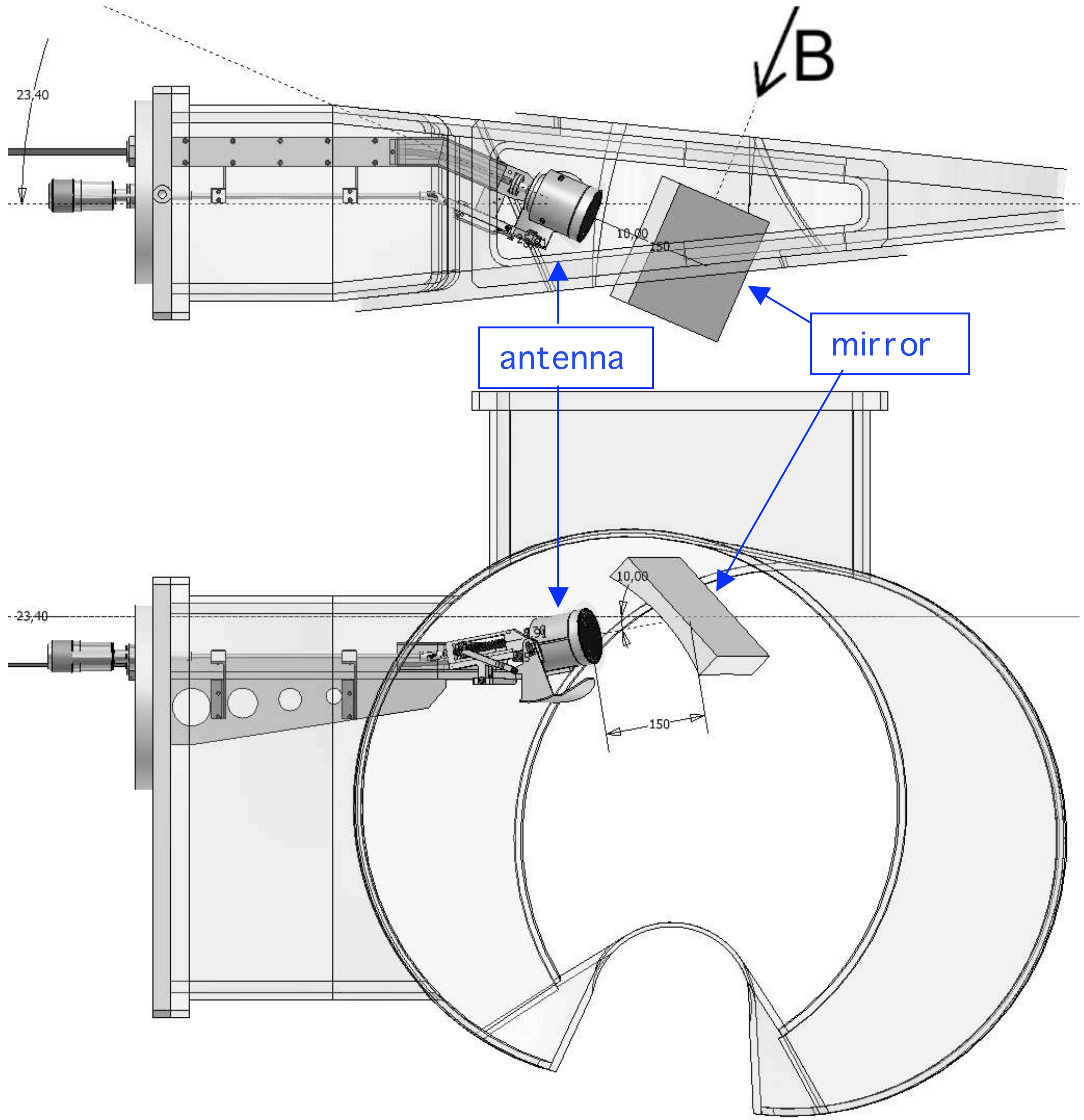
Perpendicular rotation velocity of the turbulence and density fluctuations



n_e: 0.3 - 1.5 10^{19} m^{-3}

$k_\perp$: 4 - 15 cm^{-1}

T. Happel *et al.*, RSI **80** (2009) 073502

Diagnostics: Doppler reflectometer (II)

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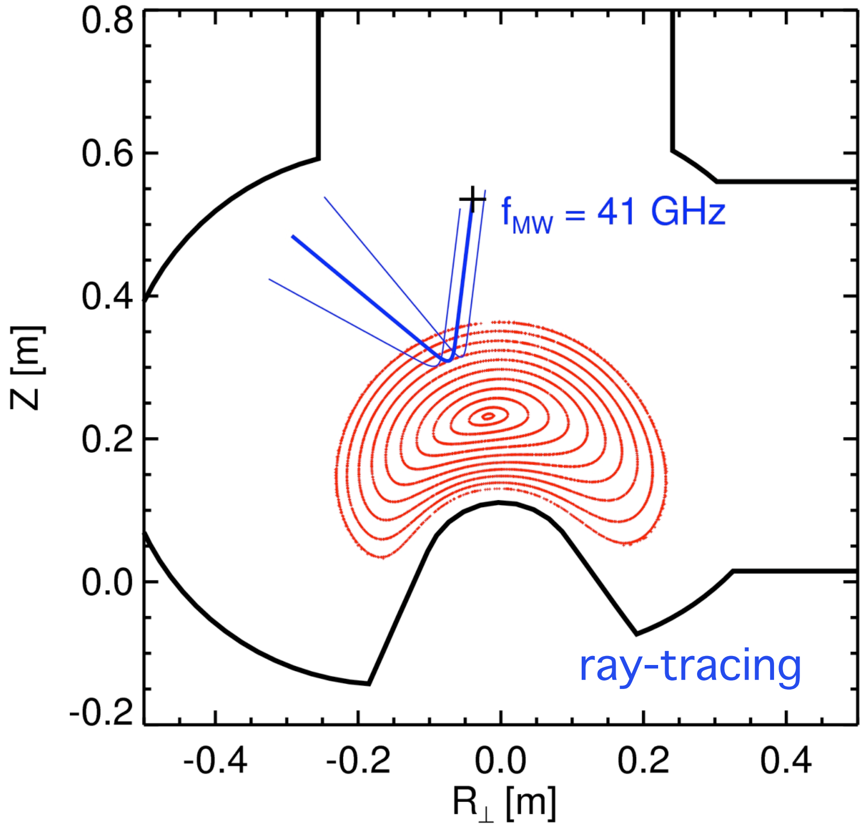
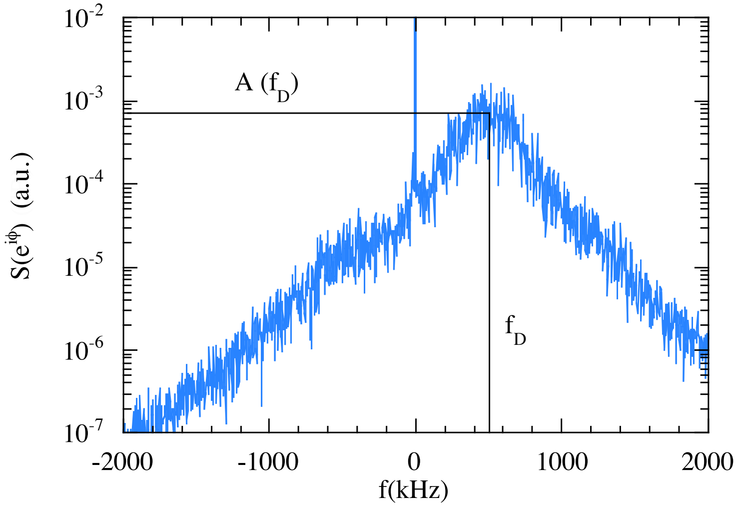




$u_\perp = \omega_D / k_\perp$

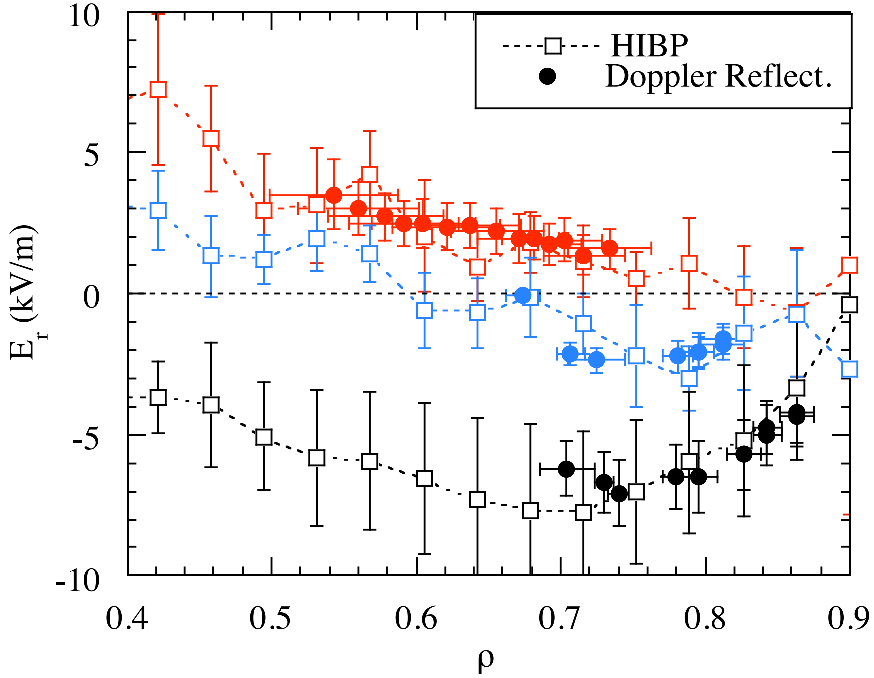
$u_\perp = v_{ExB} + v_{ph}$

if $v_{ph} << v_{ExB}$ --> $E_r = u_\perp B$

Perpendicular rotation velocity of the turbulence and density fluctuations at two radial positions simultaneously with good temporal and spatial resolution

dynamics of Er field, Er field shear and $\tilde{n}_e$

HIBP-Doppler reflect. comparison



Doppler reflectometry: $u_\perp = v_{ExB} + v_{ph}$

if $v_{ph} << v_{ExB}$ --> $E_r = u_\perp B$