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Influence of the magnetic topology on transport and radial electric fields in the TJ-II stellarator

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Outline

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- Introduction and description of the problem.
- Low order rationals in the core.
- Kinetic effects and transport.
- Low order rationals close to the edge.
- Conclusions.

Introduction and description of the problem

Low order rational surfaces:

*Break the magnetic topology of nested flux surfaces.

*Introduce magnetic islands and ergodic zones.

Transport, Turbulence and Electric fields are affected.

The effect of low order rationals was controversial:
Degrade confinement (Some works [1]).

But

Transport barriers can be triggered in tokamak and stellarators:
ITB. Tokamaks [2] and stellarators [3]
ETB. Tokamaks [4] and stellarators [5]

[1] Brakel, NF 42 (2002) 903

[2] Lopes-Cardoso et al. PPCF 39 (1997) B303

[3] Fujisawa. PPCF 45 (2003) R1

[4] Wolf. PPCF 45 (2003) R1

[5] Hidalgo et al. PPCF 42 (2000) A153

Introduction and description of the problem

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Two different explanations for Transport Barriers:

Generation of electric fields:
1) ExB sheared flows reduce turbulent transport [6].
2) Neoclassical Transport Barriers [7]

Rarefaction of resonant surfaces in proximity of low order rationals [9,10].
Reduction of anomalous transport.

In TJ-II, low order rational surfaces can trigger electron heat Transport Barriers (eITB) in the core and positive sheared electric fields appear in the edge.

[6] Terry. Rev. Modern Phys. 72 (2000) 109
[7] Minami et al. NF 44 (2004) 342
[9] Wobig et al. 11th IAEA, 1986
[10] Romanelli et al. PhF B 5 (1993) 4081

The Flexible Heliac TJ-II

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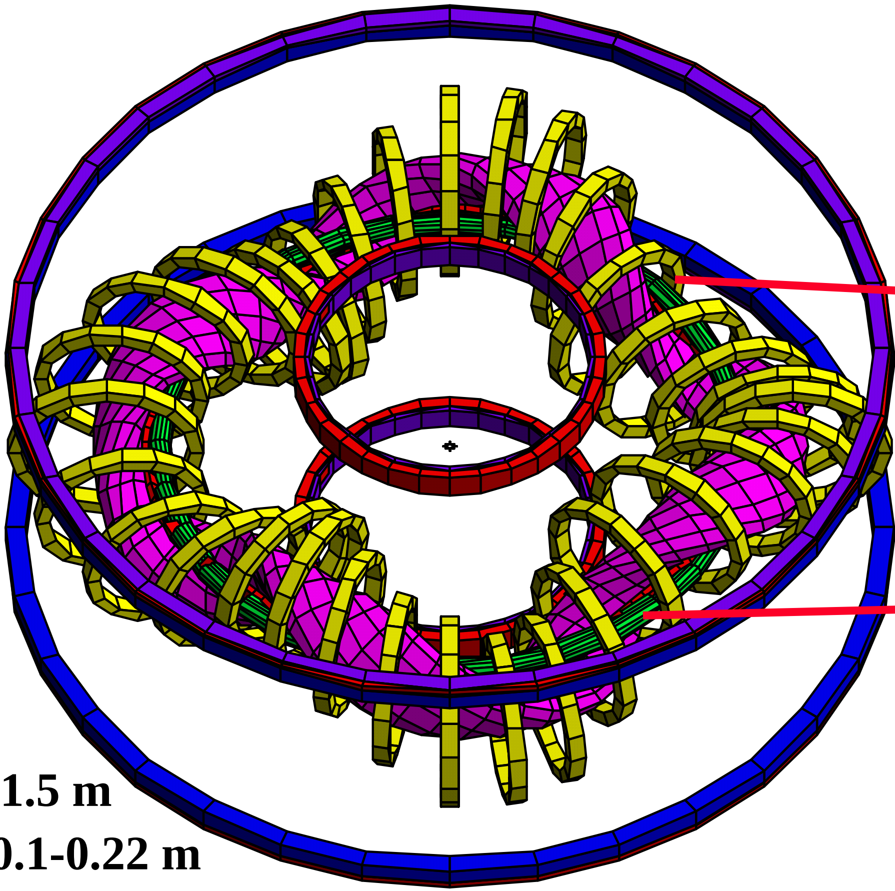
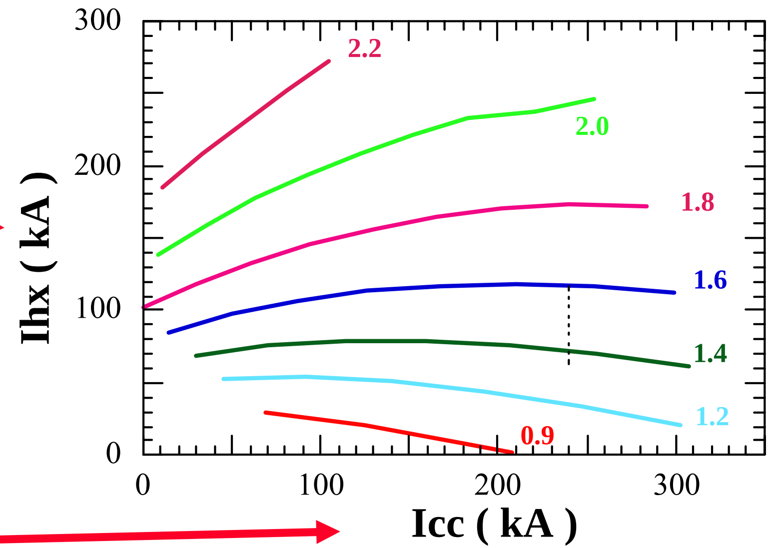


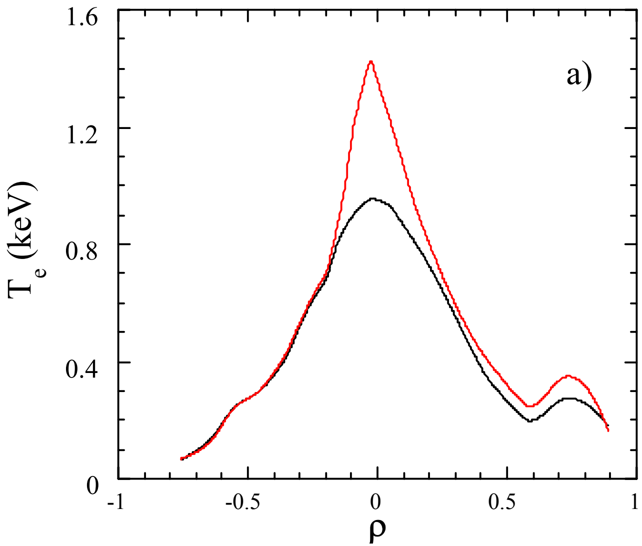
- **R=1.5 m**
- **a=0.1-0.22 m**
- **B<1.2 T**

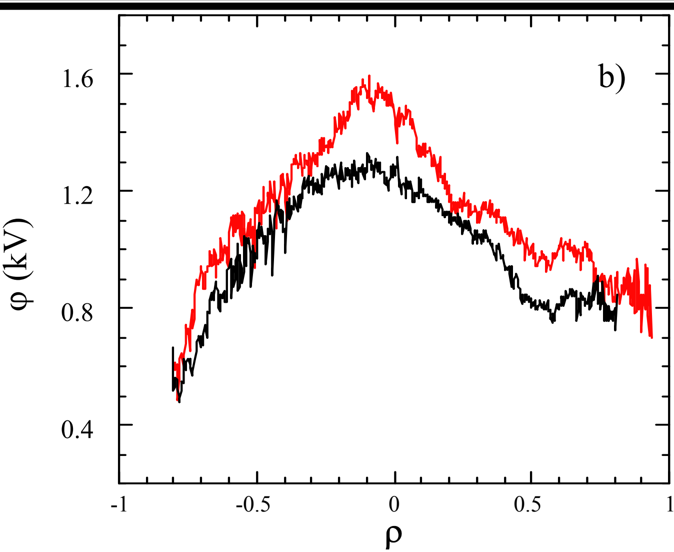
Magnetic configuration flexibility:

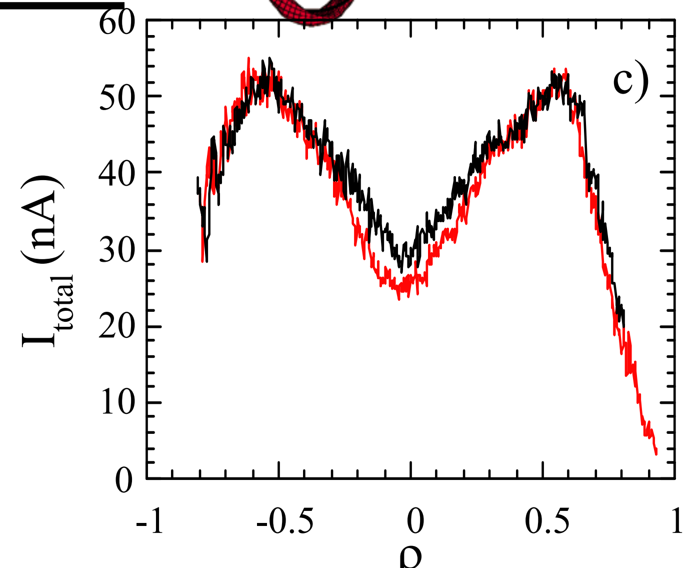


- High rotational transform flexibility
- Low magnetic shear
- Allow the control of low order rationals within the ι-profile

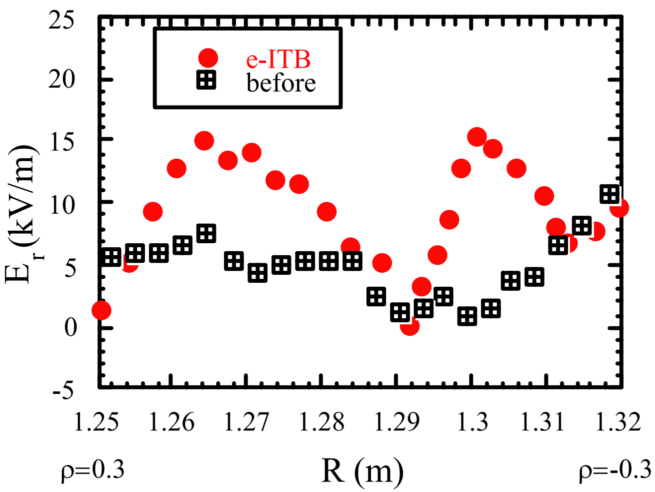
Plasma core: eITB signatures







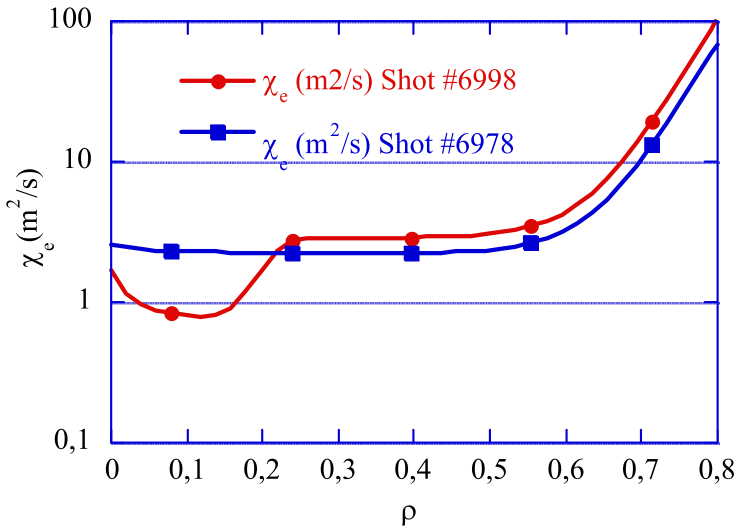
Te profile, plasma potential and beam intensity (proportional to density) with (red) and without (black) eITB

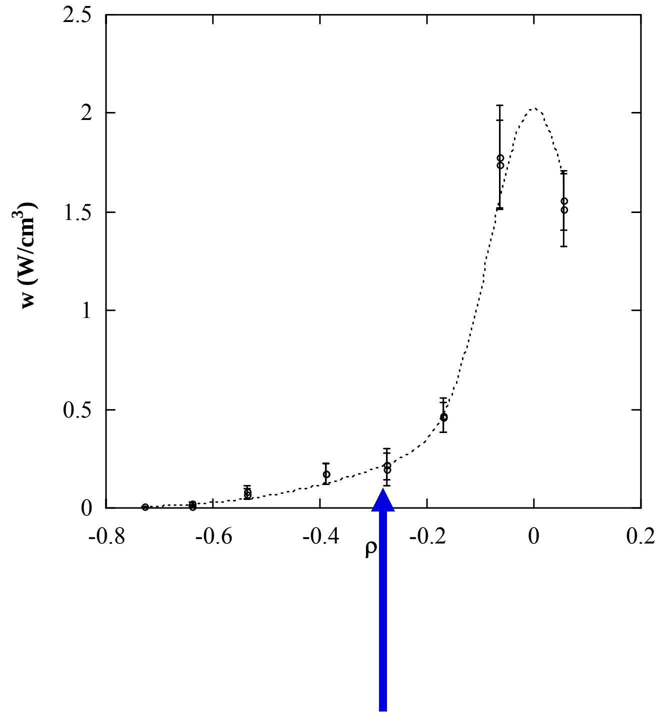


Te profile is steeper, plasma potential is more positive, (strong electric field appears, and central density falls).

Core heat confinement is improved.

eITB signatures (2)

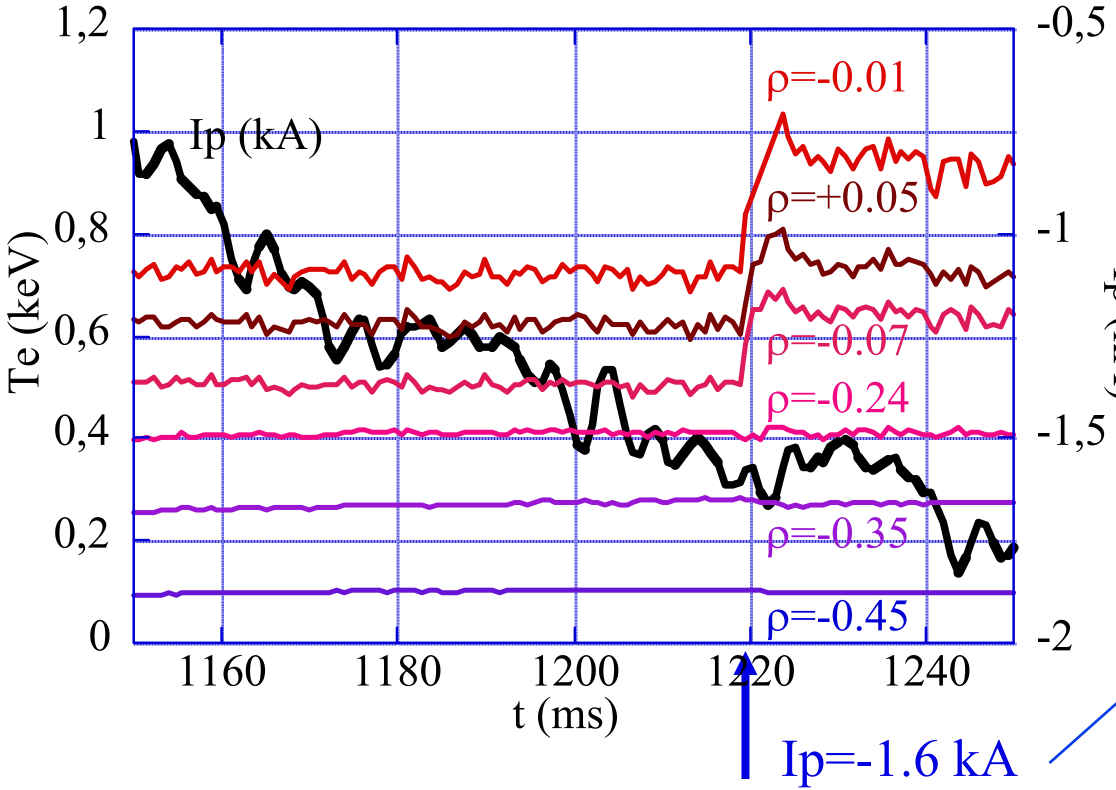


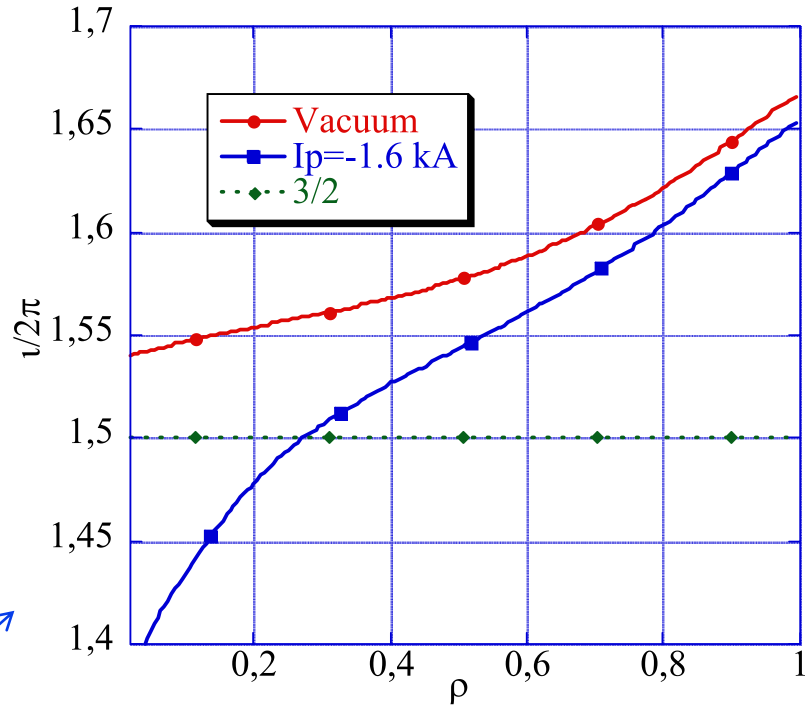


Heat conductivity with eITB is reduced in a factor two in plasma core.

eITB appears when rational is overlapping the power deposition region.

Positioning Rationals: Ohmic current (1)





Central electron temperature suddenly increases when 3/2 surface is close to plasma core.

Positioning Rationals: Ohmic current (2)

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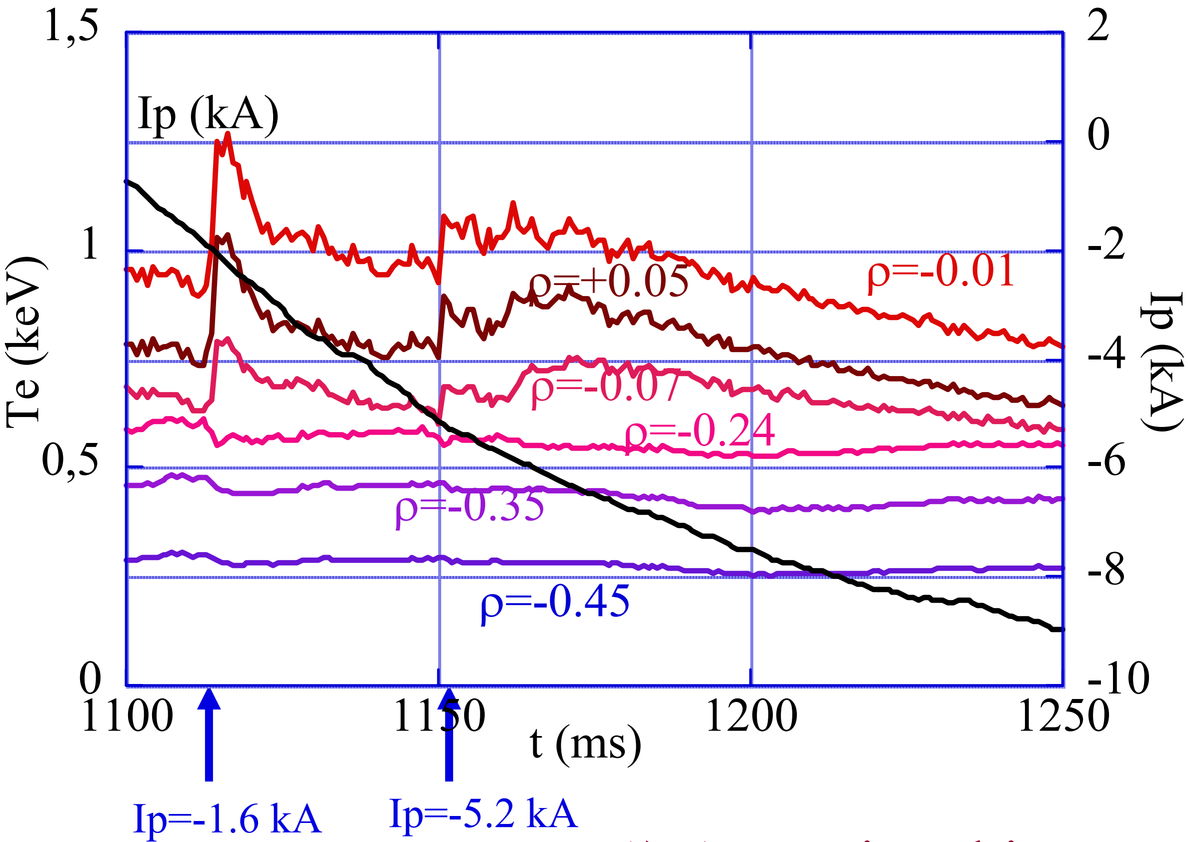

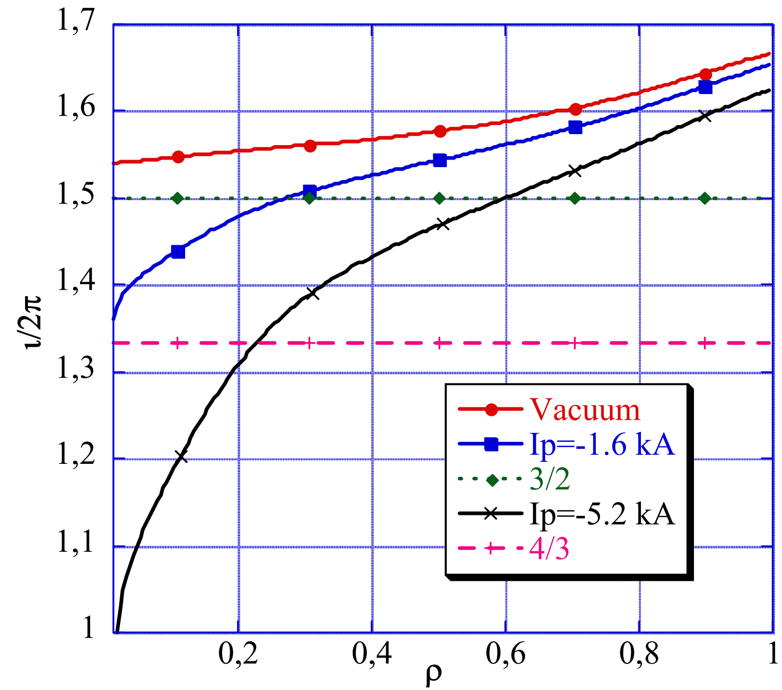

1) As Rational is moved outwards, eITB disappears.

2) eITB only appears for low order Rationals.

Positioning Rationals: Ohmic current (3)

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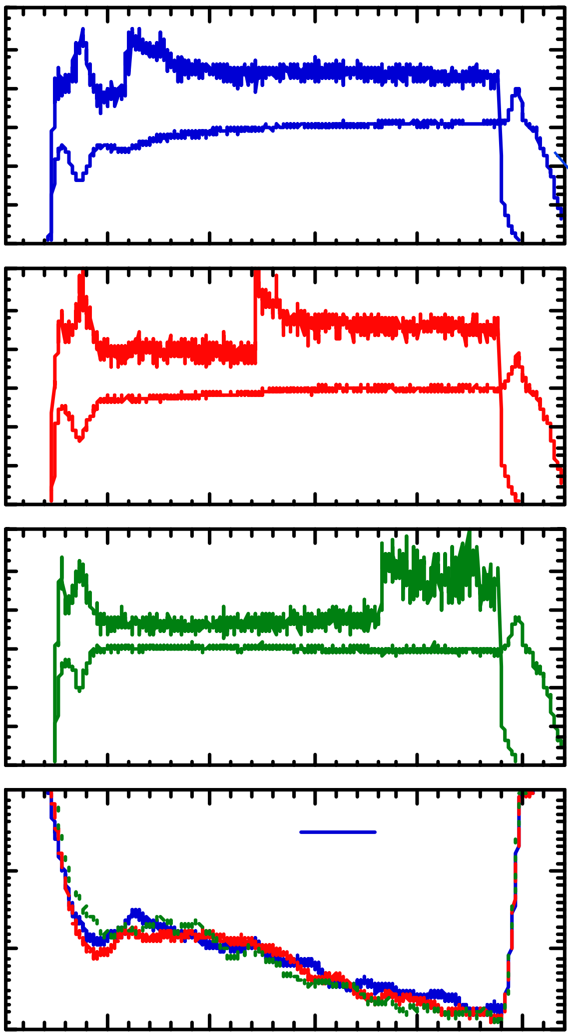

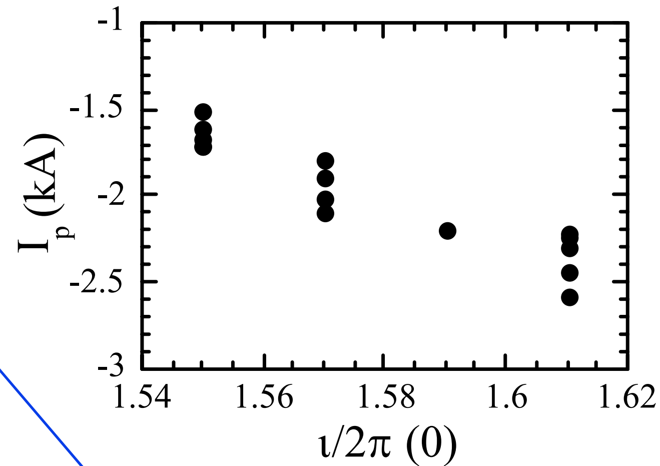

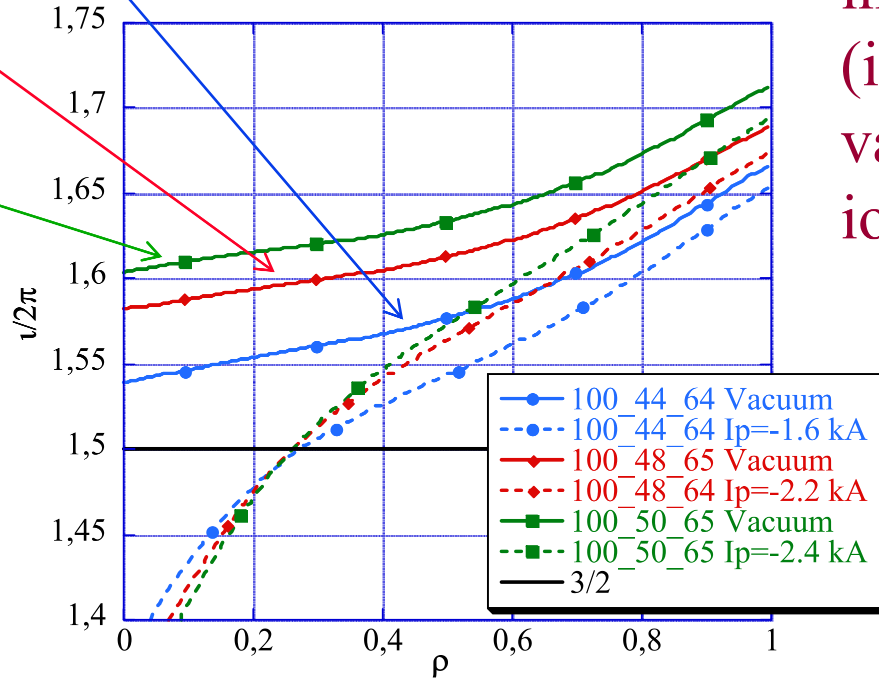

The Current needed to position the Rational at r≈0.2 - 0.3 increases (in absolute value) with iota.

Suprathermal electrons with eITB

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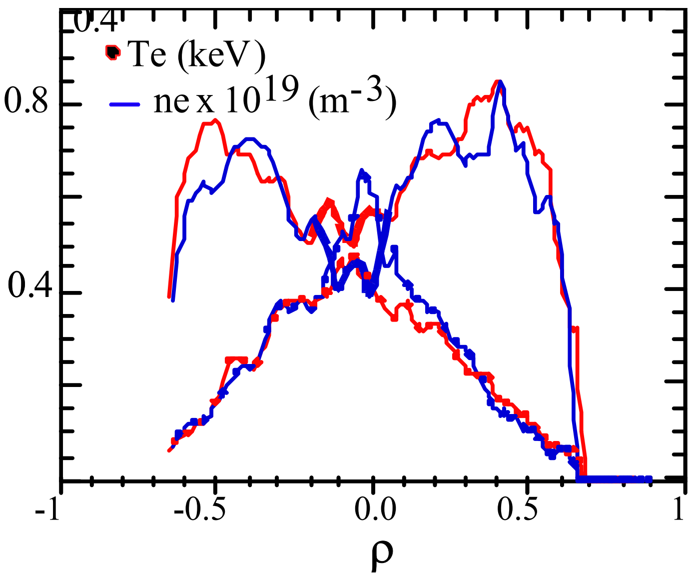
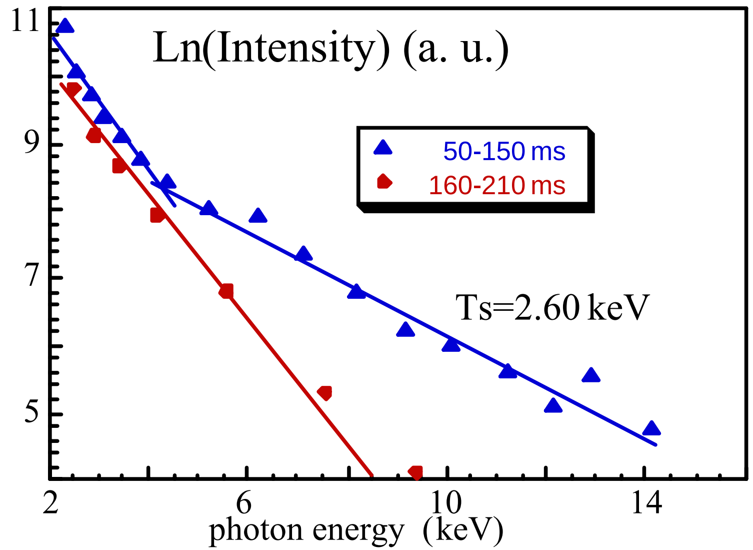


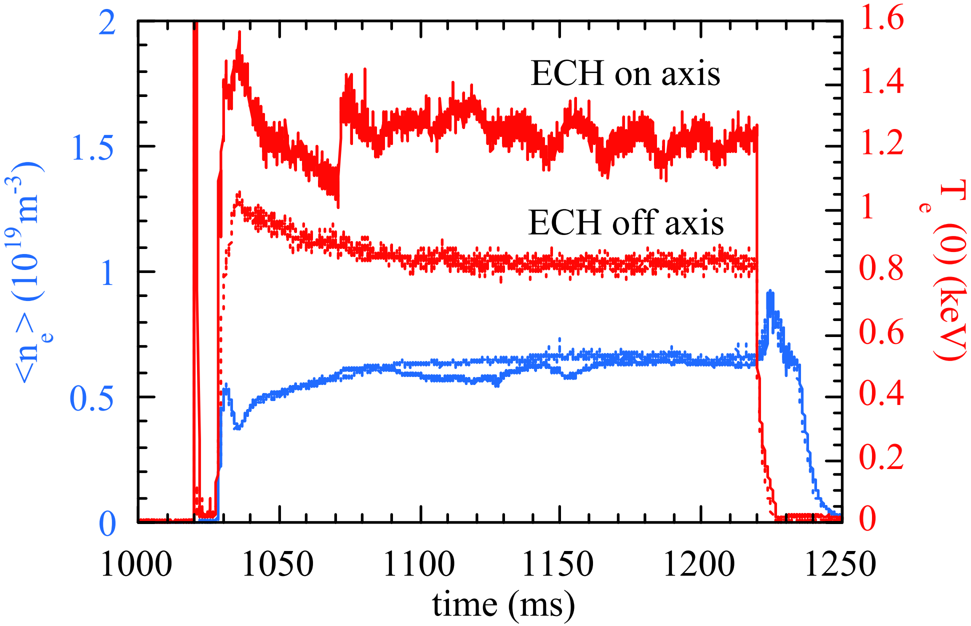


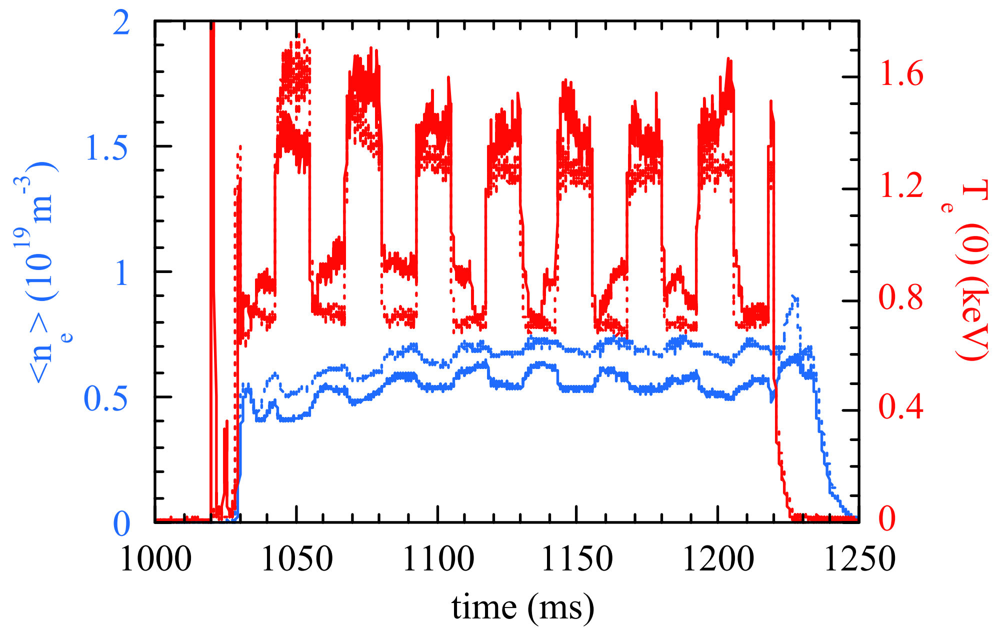
Temperature and density profiles, SXR spectra (100_44_64. Vacuum ι(0)/2π=1.51) with (blue) and without (red) eITBs.

When steep temperature gradient is present and the density profile is more hollow (left), the population of suprathermal electrons is larger (right).

The role of power density

Further proofs of the role played by kinetic effects:

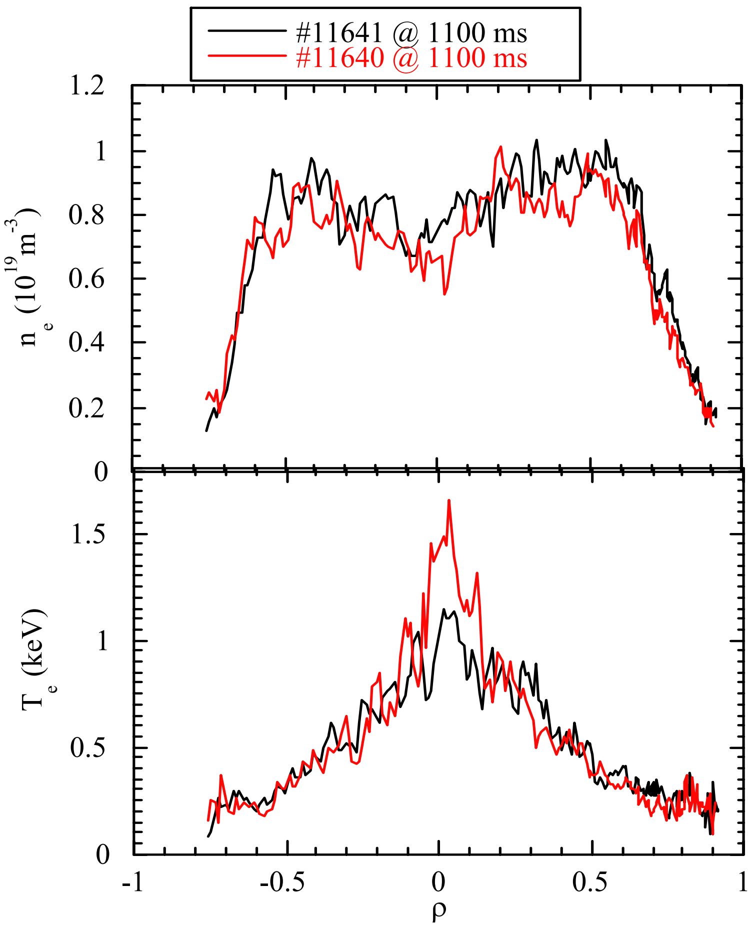


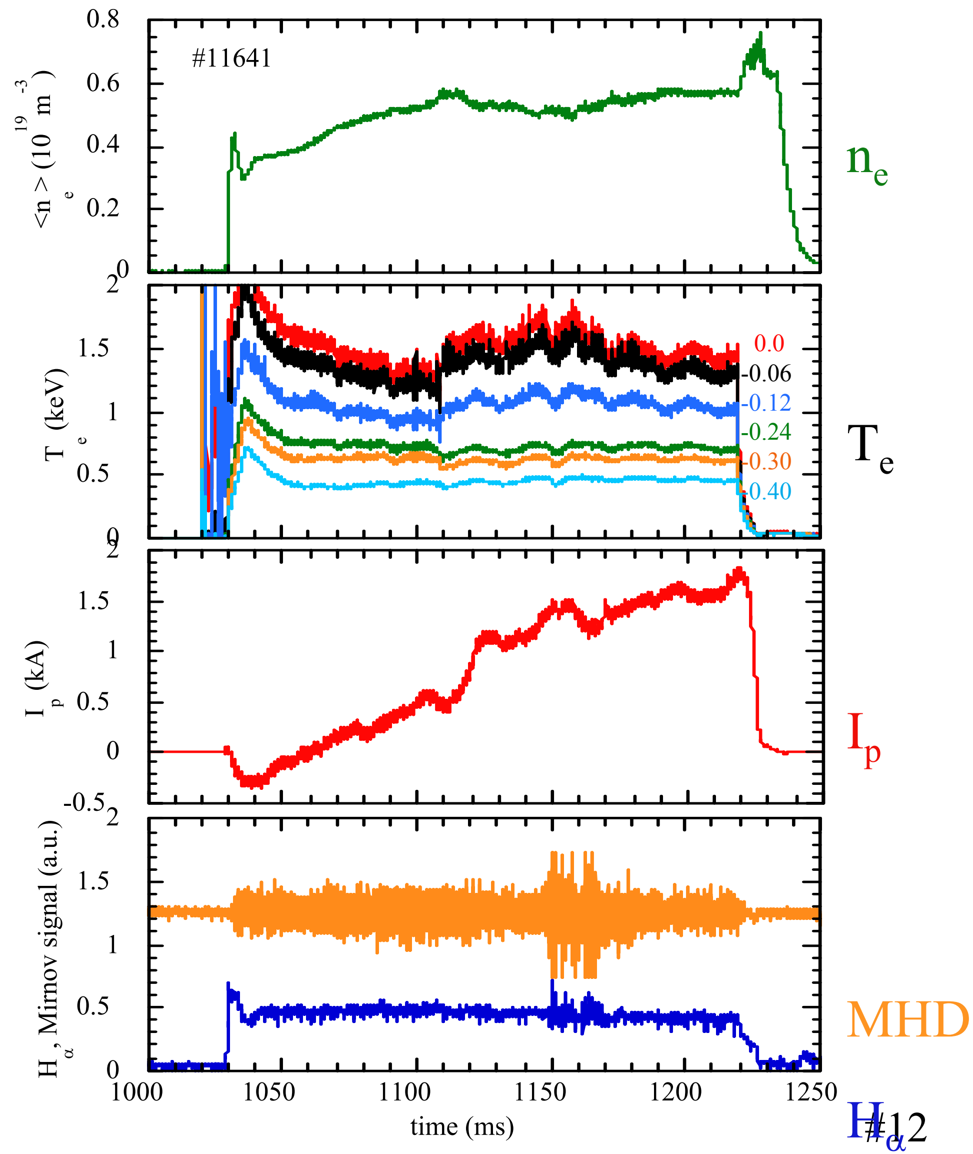


For the same density and magnetic configuration (close to n/m=3/2), the eITB appears in the high absorbed power case.

Magnetic configuration close to 3/2. 300 kECH power modulation is enough to trigger eITB.

eITB with positive magnetic shear





Kinetic effects and Transport

The total electron flux is: neoclassical + ExB turbulent + ECH-induced + RS-induced.

$$\Gamma^{e}(E_r) = \Gamma^{e}_{NC}(E_r) + \Gamma^{e}_{TURB}(E_r) + \Gamma^{e}_{ECH}(E_r) + \Gamma^{e}_{RS}(E_r)$$

Neglecting ion flux and assuming that the main contribution is due to the rational surface, the electric field in the steady state is:

$$E_r \approx (T/e)\left(n'/n - T'/2T\right) \approx \left(-T'/2e\right)$$

Therefore, central temperature and potential profiles evolve in a similar way, opposite to density (as observed experimentally in modulation experiments)

Measured potential: 15 kV (HIBP), similar to the obtained using this expression, 12 kV.

Kinetic effects and Transport

$$\frac{\partial u_i}{\partial t} = F_i(\vec{u}) + D_{ik}(\vec{u})\xi_k, \quad i,k = \perp, //$$

Deterministic

Stochastic

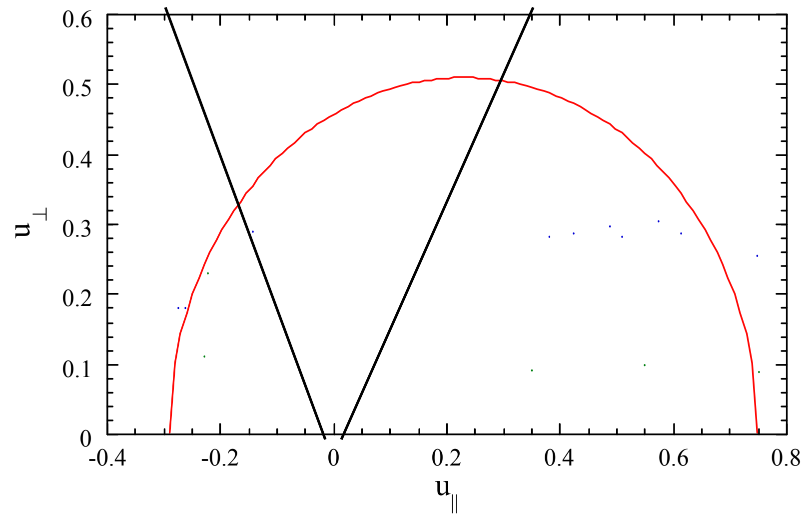
Power Density

$$F \propto D_{cy} = \int dN_{//}\Gamma(N_{//})\,\delta(\gamma - Y_s - u_{//}N_{//})\frac{w}{\gamma}\left|\hat{e}\cdot\vec{\Pi}\right|^2$$

$$\int dN_{//}\Gamma(N_{//}) = 1$$

$$\vec{\Pi} = \left(\frac{sJ_s(\rho)}{\rho}, iJ'(\rho), \frac{u_{//}}{u_\perp}J_s(\rho)\right) \qquad D \propto D_{cy}^{1/2}$$

$$\rho = N_\perp u_\perp \omega_c / \omega$$



Resonant Quasi-Linear Diffusion pushes particles inside loss cone.

An enhanced outwards particle flux is produced.

Kinetic effects and Transport

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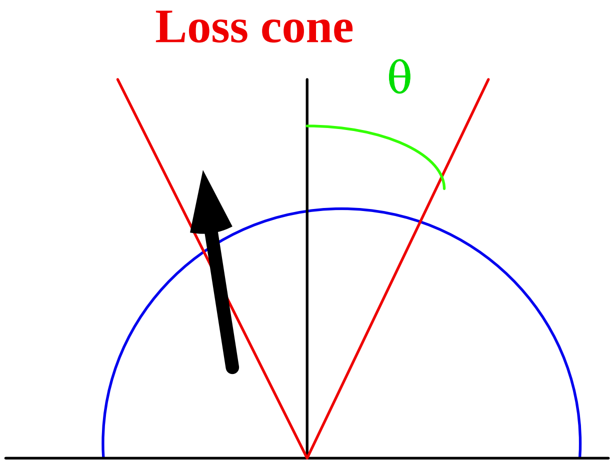
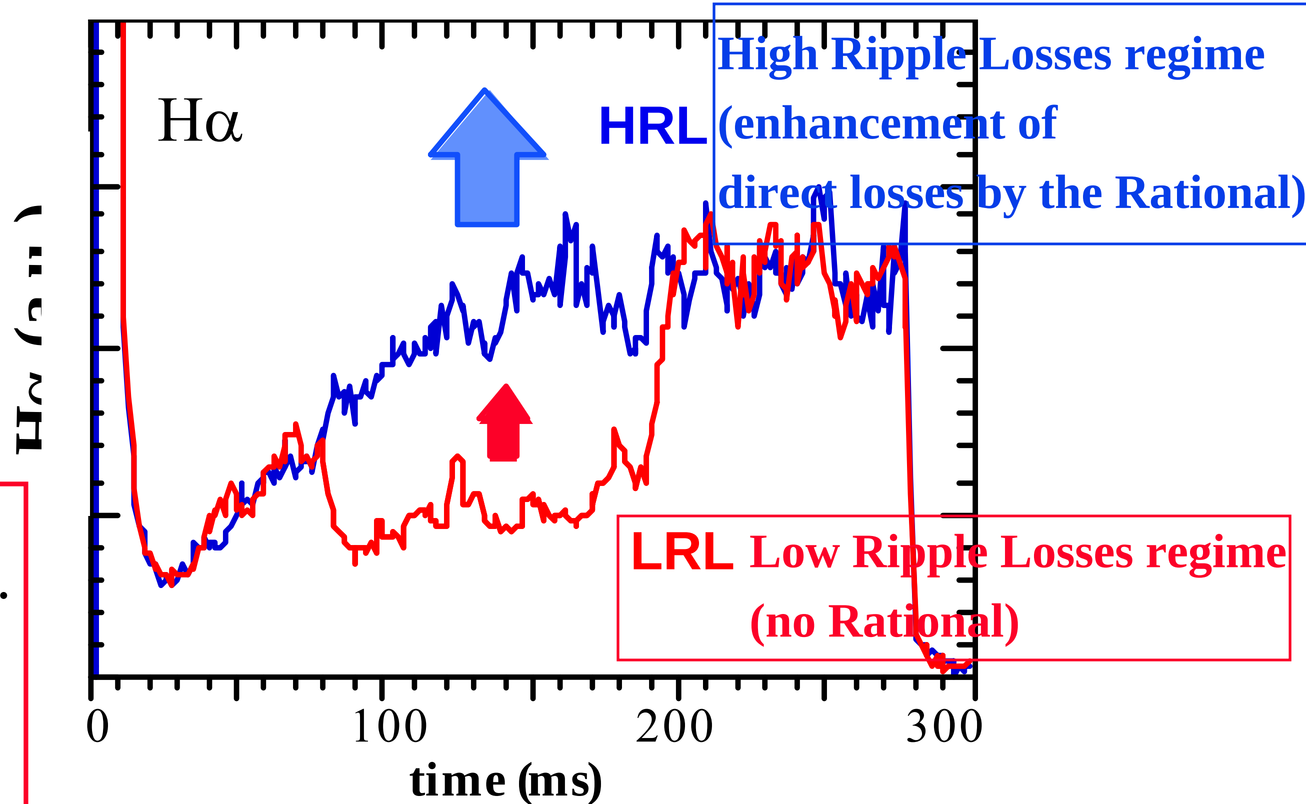


Γ^{ECH} is directed outwards.

$$\Gamma^{ECH} = 1/r \int r'\,dr' \left(\nabla \Gamma^{ECH}\right)$$

Particle flux in loss cone:

$$\vec{\nabla} \cdot \vec{\Gamma}_e^{ECH} = \left(\frac{\partial n}{\partial t}\right)_{ECH} = \int_{\delta} f(\vec{u}) \frac{d\vec{u}}{dt} \cdot d\vec{S}$$



Further needed developments of flux calculation:

1) Modification of distribution function.

2) Loss cone reduction due to Electric field.

3) Inclusion of RS.

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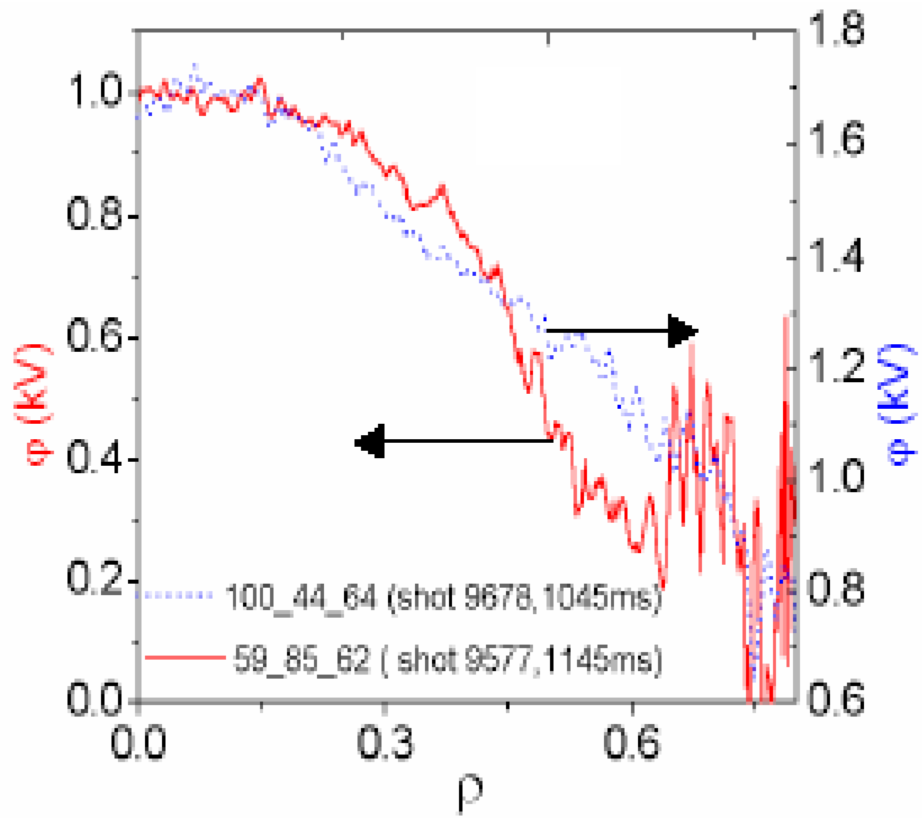
Electric field with low order rational in plasma edge

Sheared electric field appears in the inner part of rational surface n=4/m=2, as measured by HIBP.

Influence on transport?



Electric potential profiles in presence of n=4, m=2 resonance in the plasma periphery (red) and without low order resonances (blue).

Low order rationals in TJ-II plasma edge

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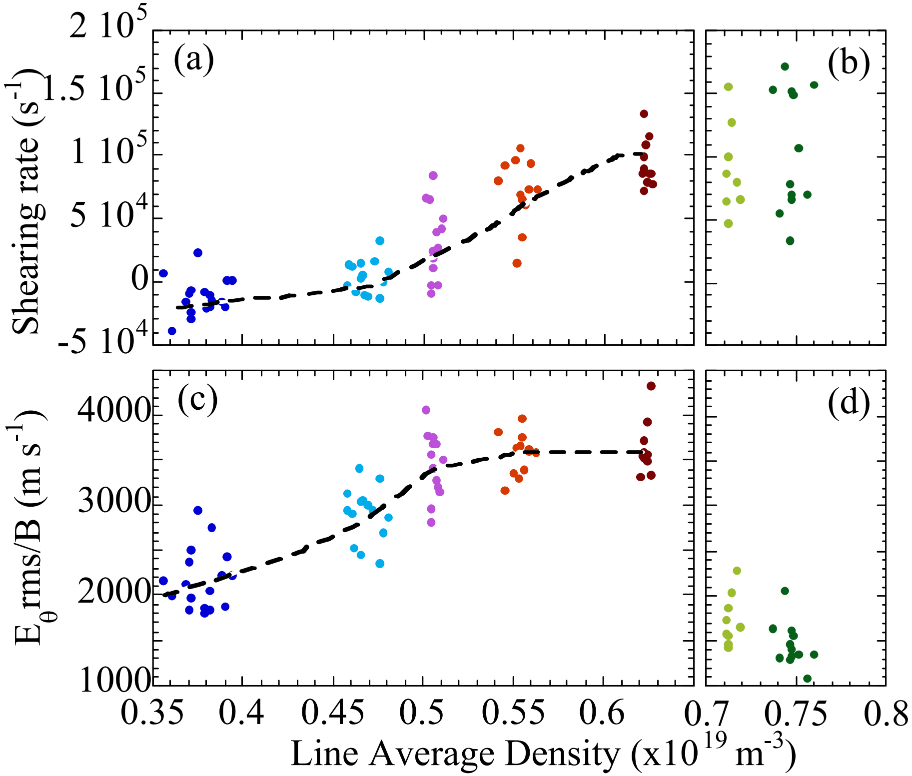

Shearing rate vs. line density without (a) and with (b) polarised electrode and their corresponding turbulence levels (c,d).

Electrode polarization experiments:

Plasma is kept in a marginal stability state (The shear flow tends to reduce turbulence and improve confinement).

The shear flow generation could be due to the turbulence (e. g. via Reynolds stress).

Sheared flow can be enhanced by:

- Positioning a low order Rational.
- Introducing a polarised electrode

Summary and Conclusions

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- eITB are triggered in ECRH plasmas when low order rationals are positioned close to plasma core ($\rho < 0.3$) in TJ-II.

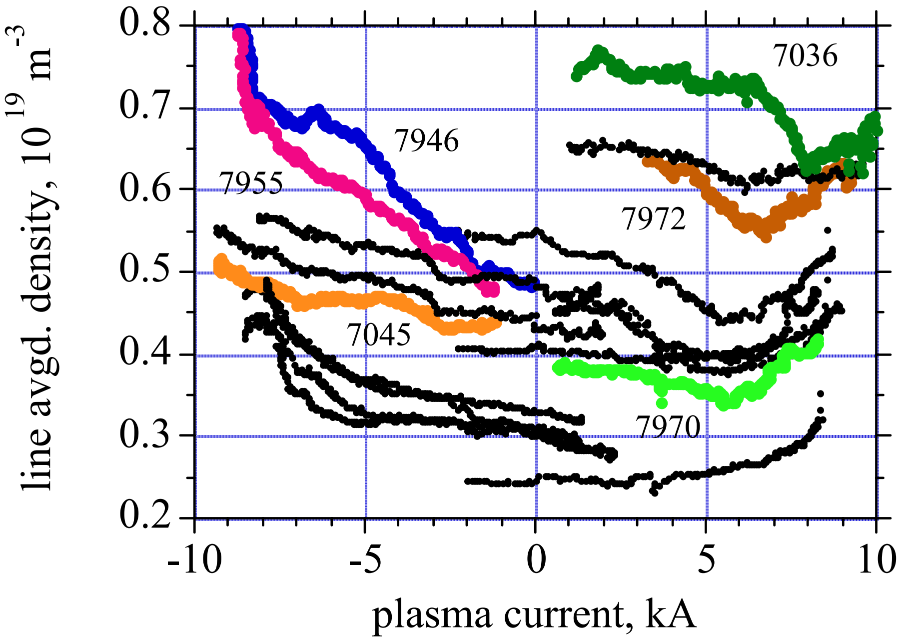
- eITB are not found in TJ-II when positioning low order rational surfaces in the confinement region ($0.4 < \rho < 0.7$) for the present experiments, with low magnetic shear.

- Sheared electric fields appear in presence of low order rational surface in the edge. Polarized electrode experiments show that the created sheared flow can overcome the turbulence level and, hence, to reduce the anomalous transport.

- TJ-II results offer valuable information on the multiple mechanisms based on neoclassical/turbulent bifurcations and kinetic effects to explain the effect of magnetic topology on radial electric fields and confinement.

Thank you!

Low order rationals in the confinement zone



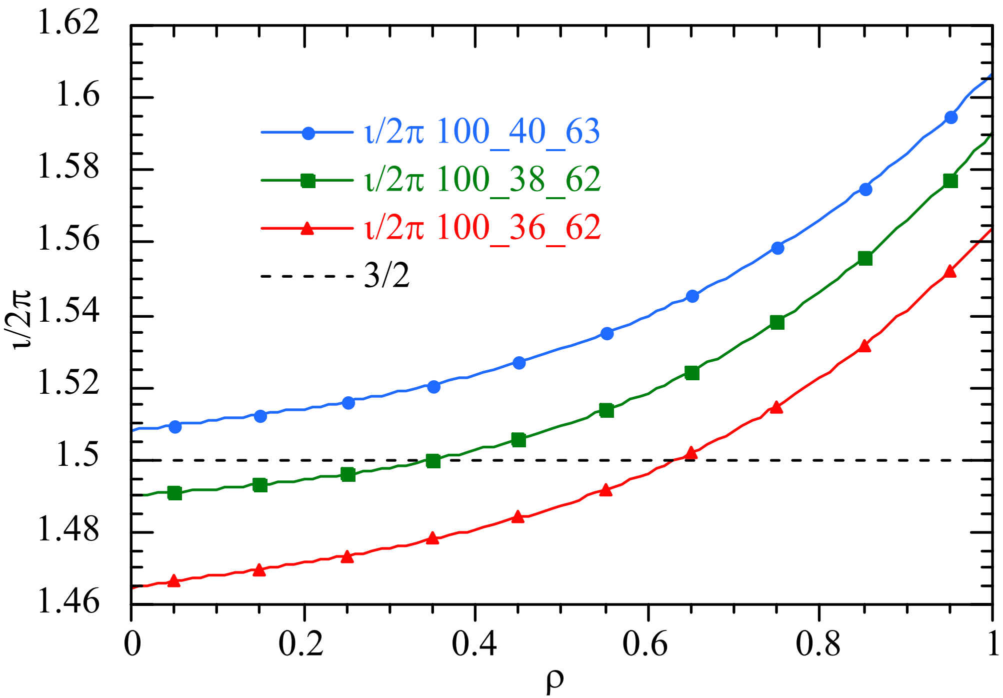
Para ver esta película, debe disponer de QuickTime™ y de un descompresor TIFF (LZW).

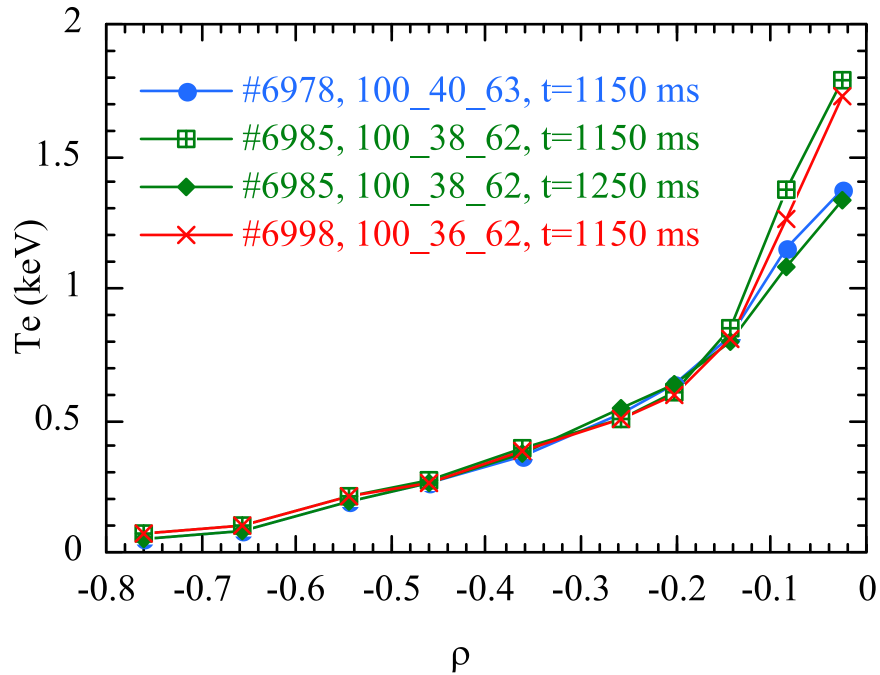
OH current is induced in a single shot.

Confinement evolves monotonically with current and, hence, with magnetic shear from Ip=-10 kA up to 5 kA. For higher plasma currents the confinement is restored again.

Jumps in line density, as well as in thermal signals show the presence and influence of low order rationals.

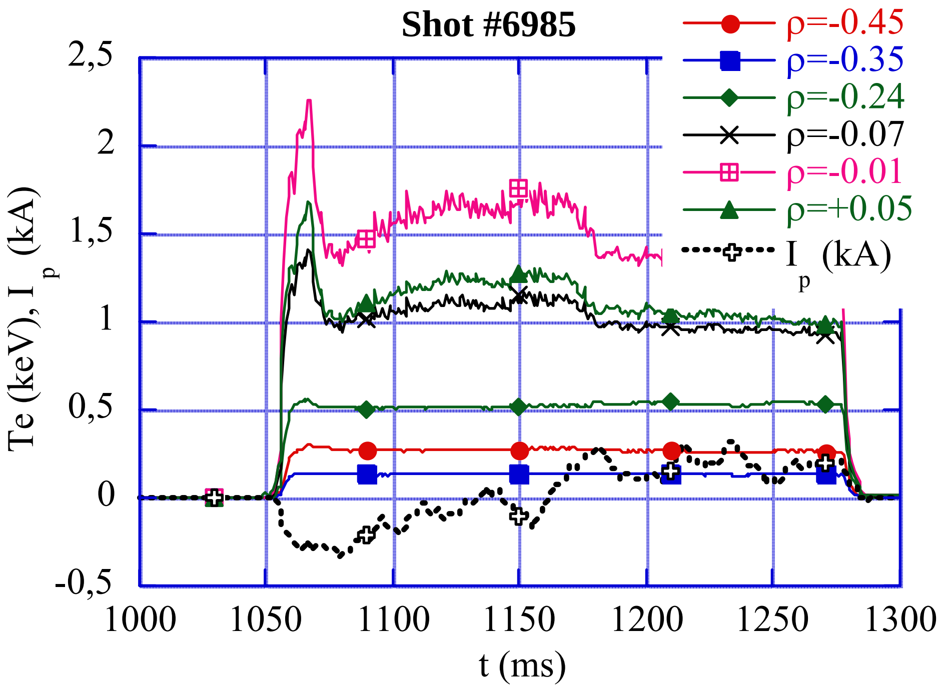
Positioning RS: magnetic scan

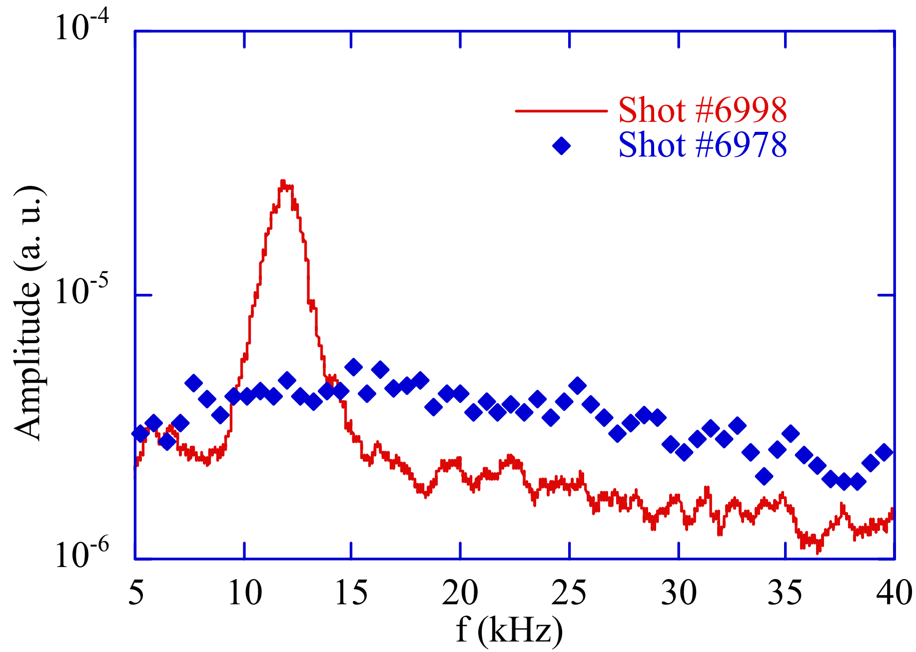




eITB, intermediate case, and no eITB.

Positioning RS: magnetic scan (2)





Intermediate case: eITB appears or disappears depending on bootstrap current.

Coherent mode detected by Mirnov coils in the case with eITB.