Effects of the finite beam size of the ECE diagnostic in Tore Supra tokamak

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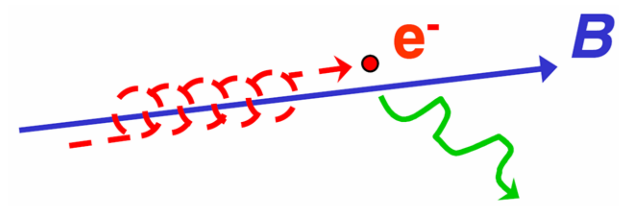
I - Introduction

- The Electron Cyclotron Emission (ECE) diagnostic {I.1} is used to measure the electronic temperature and its fluctuations in magnetically confined plasmas like in the French tokamak Tore Supra {I.2}.
- The ECE is a powerful tool to study the electronic temperature oscillations induced by MHD modes {I.3}.
- From the radial profiles of the induced temperature oscillations at the equatorial plane it is possible to define the poloidal parity (odd or even) and the type (a kink or a magnetic island) of the mode {I.4}.

I.1 - The ECE diagnostic



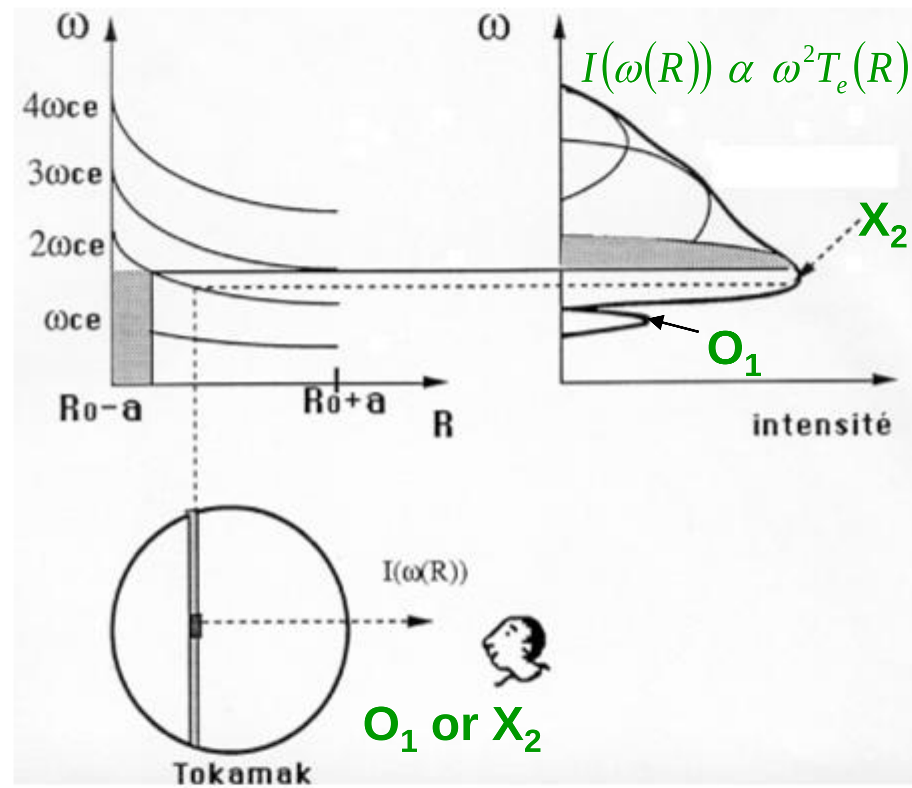
In a magnetically confined plasma, electrons gyrate on a spiral path around the magnetic field lines, emitting electromagnetic radiation called **electron cyclotron emission (ECE)**

For optically thick plasma:

$$I_{ECE}(\omega) = (8\,\pi^3\,c^2)^{-1}\,\omega^2\,T_e$$

$$\omega_{ce} = e\,B\,/\,m_e$$

$$B = B_0\,\left(R_0/R\right)$$



- **ω(R) is given by *B(R)***
- ***$I_{ECE}(\omega)$*** is measured by **a multi-band radiometer** providing measurement of **the radial profile Te(R)**

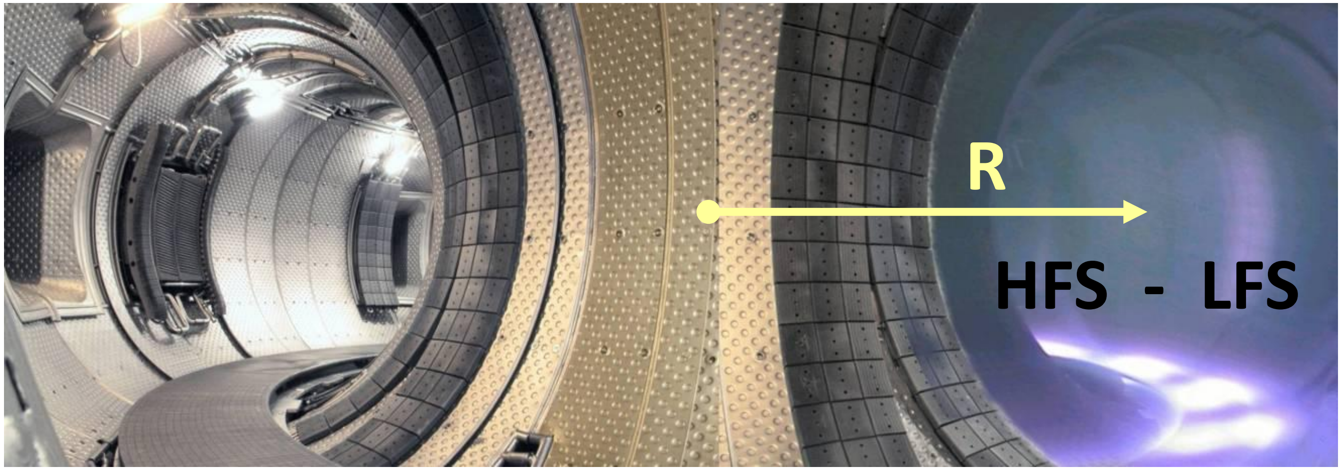
I.2 - Tore Supra Tokamak

Tore Supra is the largest tokamak with superconductor coils in operation nowadays

- Major radius R ≈ 2.4 m, minor radius a ≈ 0.7 m, circular cross section
- Central toroidal magnetic field B_T up to 4 T
- Able to perform long pulse discharges (up to 6 min)

ECE diagnostic in Tore Supra

- The ECE antenna (~15cm wide) is placed at the equatorial plane
- Profiles of electronic temperature with 32 channels (radial resolution ~3cm)
- Two acquisition rates: the slow mode (1kHz) which records data during all shot and the fast mode (1MHz) used to study MHD instabilities



I.3 - T_e oscillations induced by MHD modes

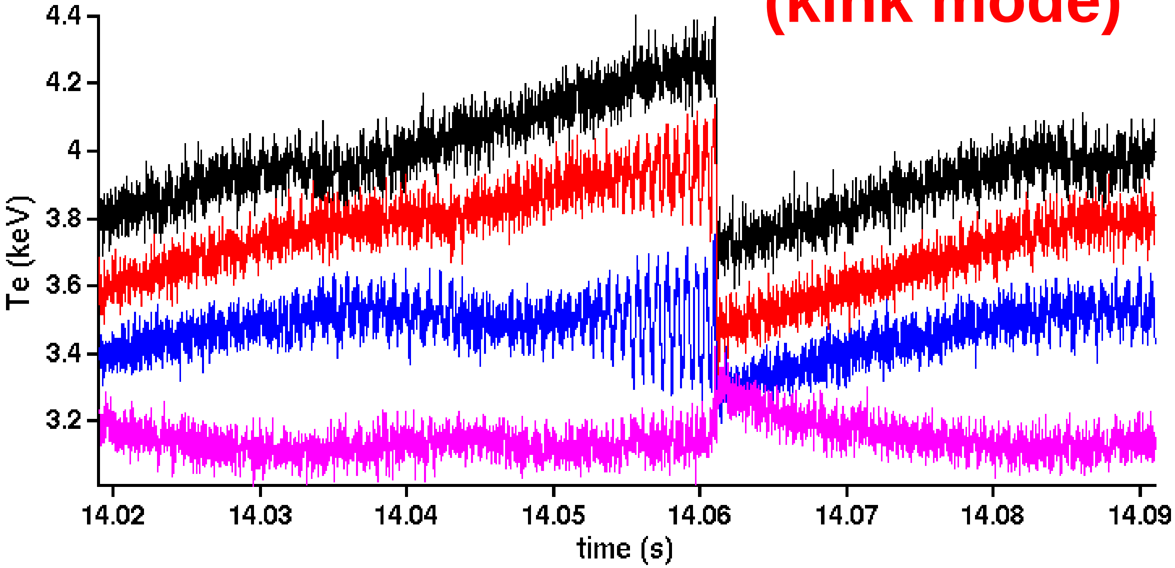
Radial displacement of the magnetic field lines induced by MHD modes:

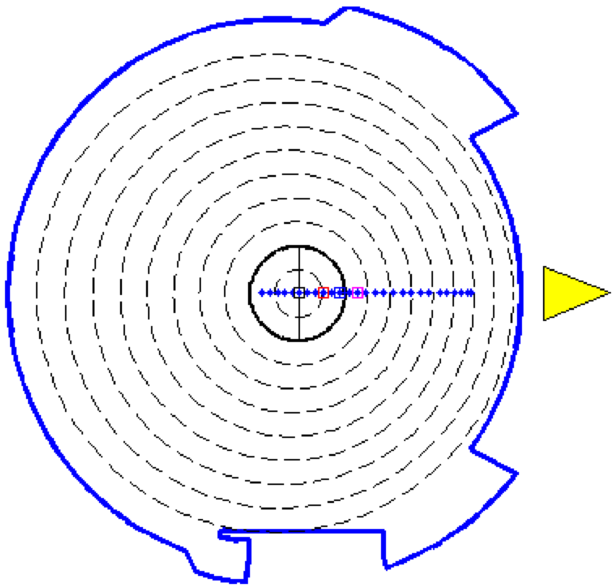
$$\xi = \xi_0 . e^{i(n.\varphi - m.\theta - \omega.t)}$$

The induced T_e oscillations:

$$\tilde{T}_e \cong \xi . \nabla T_e$$

Example: ECE measurements of a sawtooth precursor (kink mode)

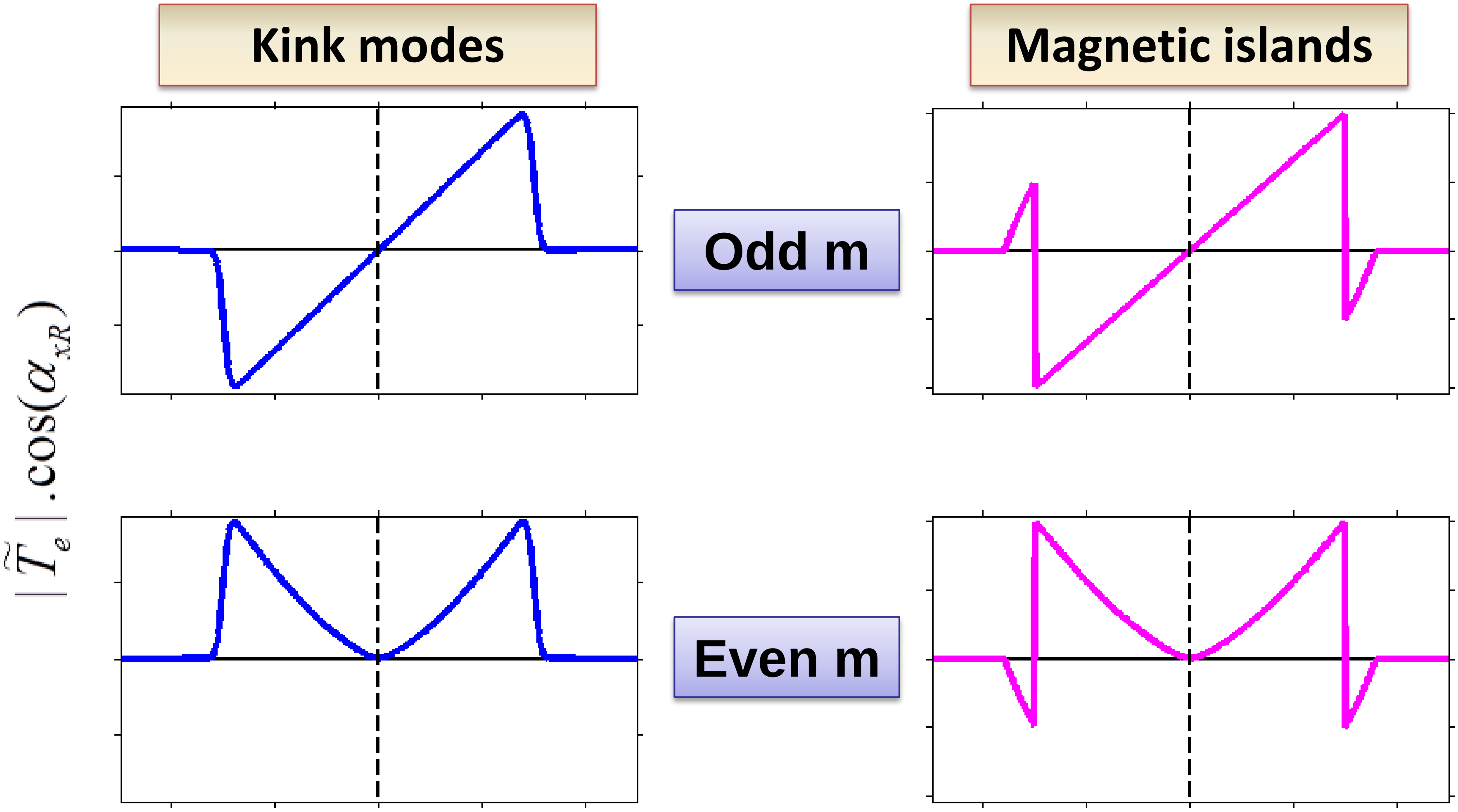




ρ=0.01 **ρ=0.11** **ρ=0.18** **ρ=0.25**

I.4 – Radial profile of the induced T_e oscillations

Expected radial structure of the induced Te oscillations according to the type of instability and the poloidal parity

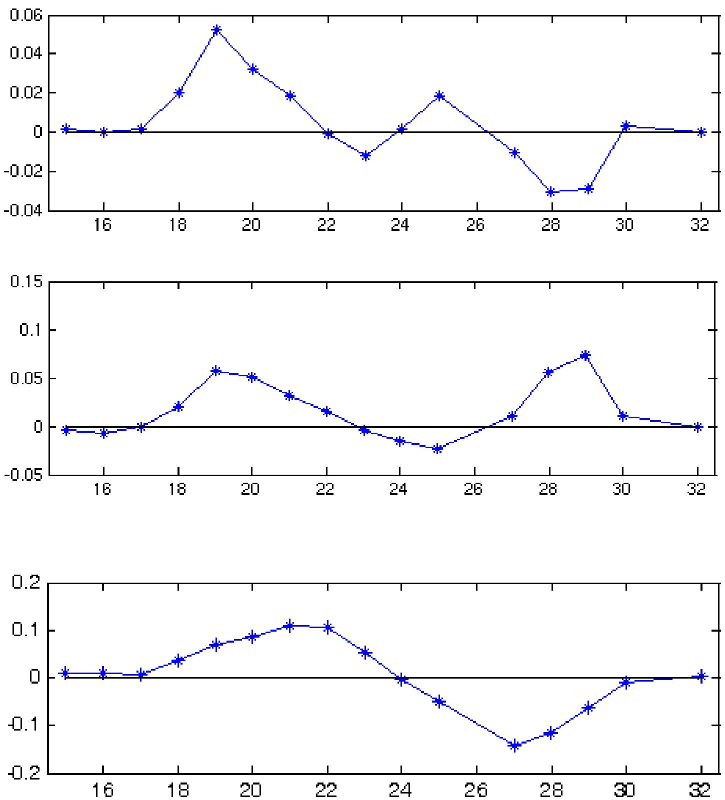


II – Complex radial structure of ECE measurements

- The ECE radial profiles of the core MHD modes often display {II.1-2} a radial structure more complex than the expected one {I.4}.
- The complex structures only depend on the poloidal mode number (m): similar structures are observed on kink modes in LHCD {II.1} and ICRH {II.2} shots, as well as on core magnetic islands in ohmic shots.
- The effect of the finite beam size explains the origin of the complex structures {II.3-4}. The simulated signals agree well with the experimental ones {III.1}.

II.1 – Radial profiles of kink modes in LHCD shots

$$|\tilde{T}_e|.\cos(\alpha_{xR})$$

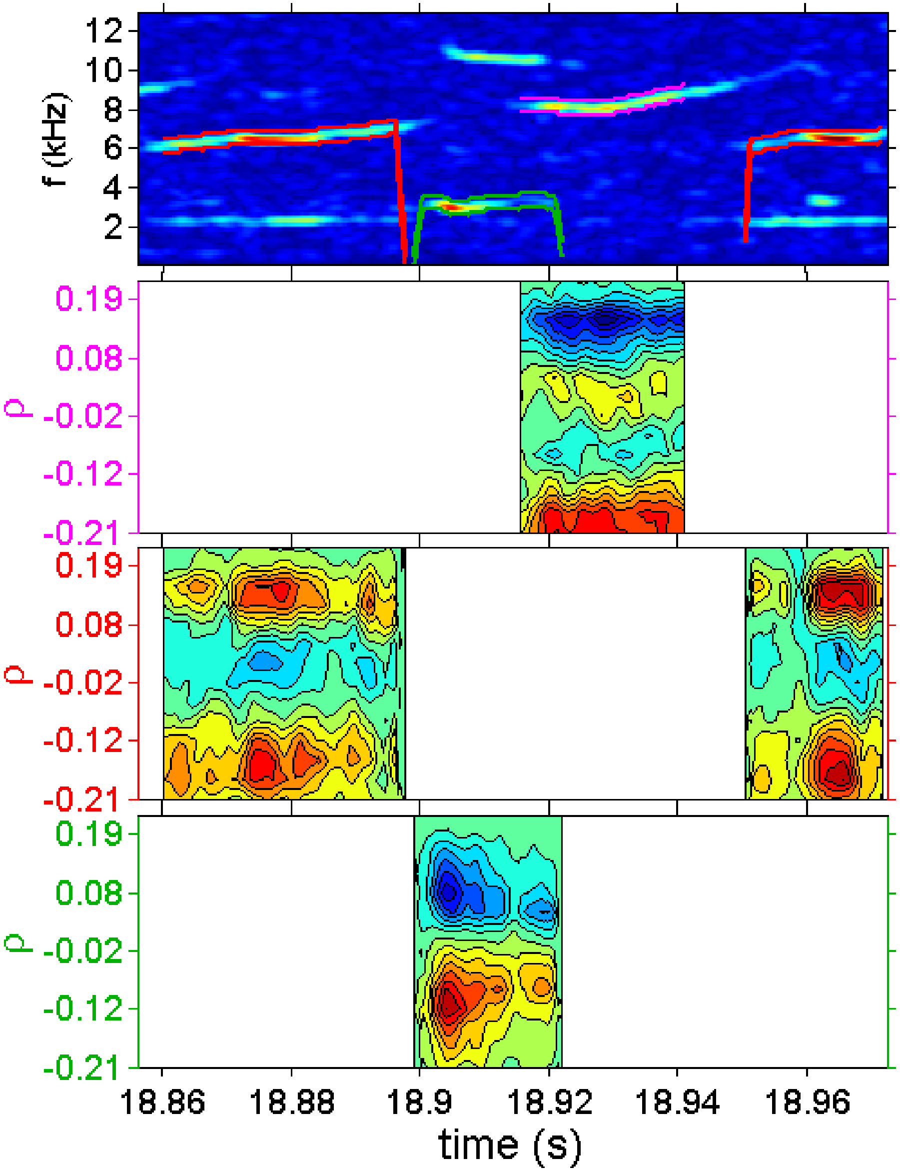


ECE channel

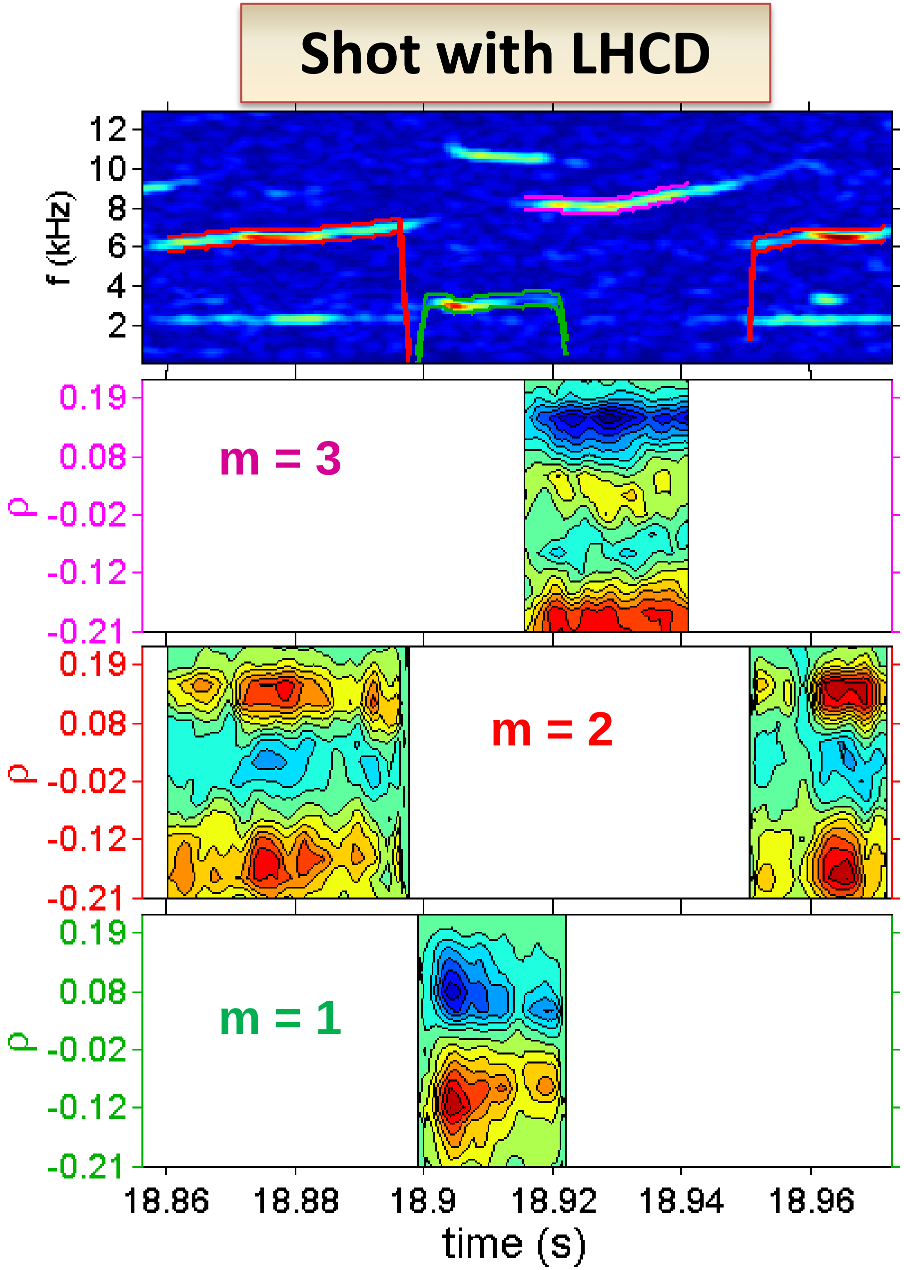
9 kHz
m = 3

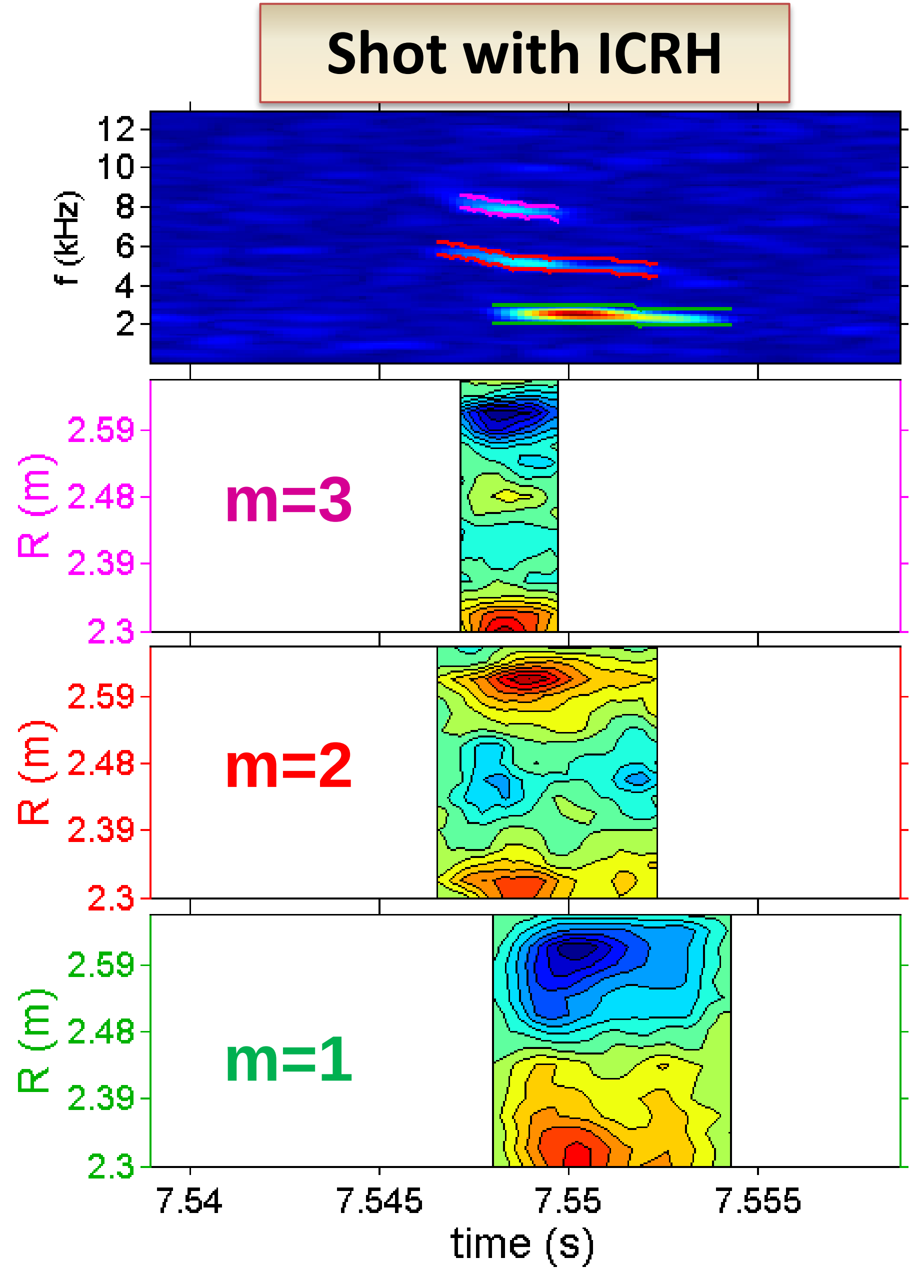
6 kHz
m = 2

3 kHz
m = 1



II.2 – The same structures in different regimes





II.3 - The numerical ECE

Simplified model for the ECE signals considering the finite beam size

- The real Te oscillations induced by the modes are simulated by

$$\dot{\tilde{T}}_e = -\xi_0 . \nabla T_e . \cos(m.\theta + w.t)$$

where ξ_0 is the MHD displacement.

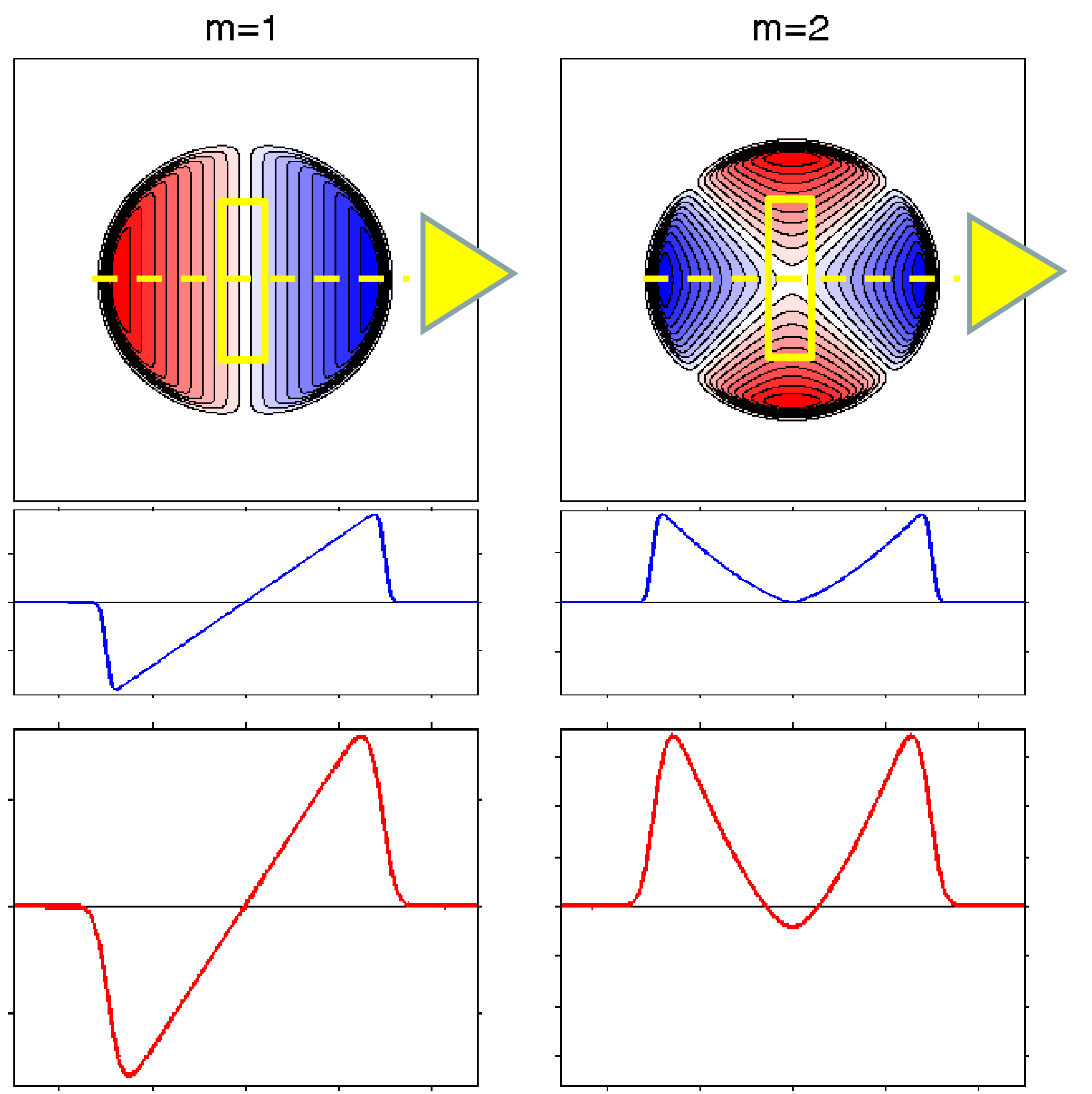
- The measured signal is simulated by averaging the real Te oscillations inside the probed region (δ_R~3cm and δ_Z~10cm)

II.4 - The effect of the finite size of the probed region on the experimental profiles

Te oscillations induced by m=1 and m=2 kink modes

Te oscillations at the equatorial plane

Observed Te oscillations by ECE

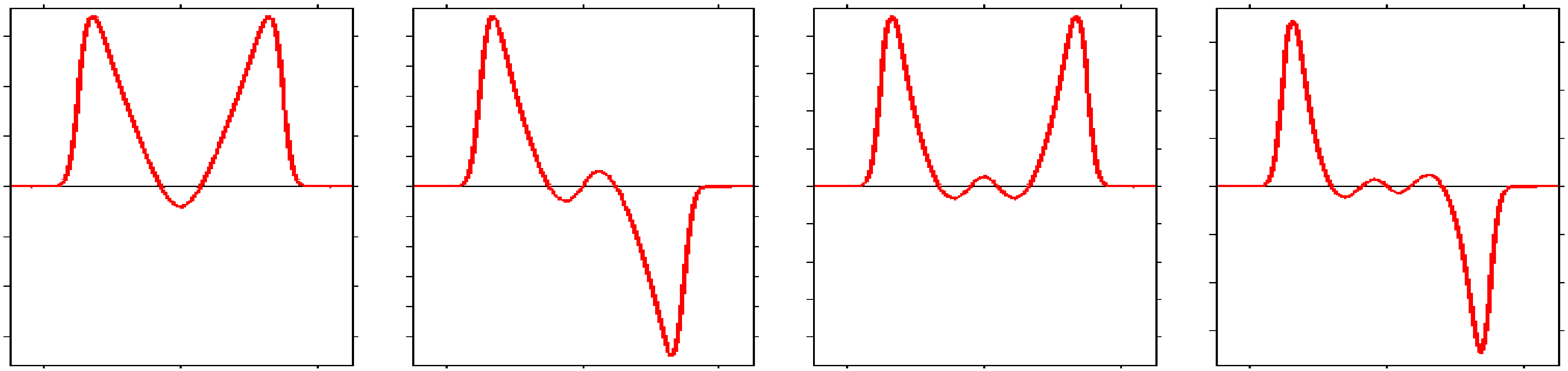


III – Consequences of the finite size of ECE beam

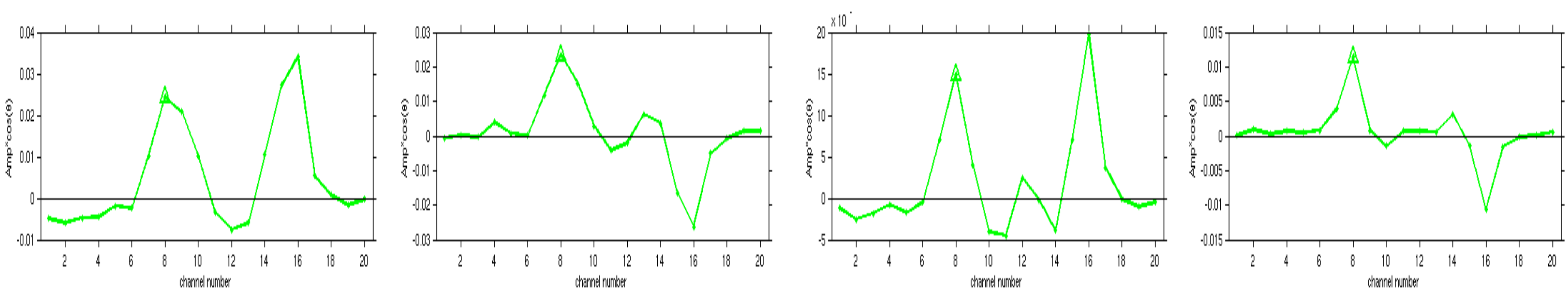
- The poloidal mode numbers can be inferred from the ECE measurements by comparing the radial profiles of the ECE measurements with the simulated ones {III.1}.
- The core channels of the ECE measurements can even be in opposition of phase with respect to the real Te oscillations {III.1}.
- Due to it, spurious structures appear in tomographic reconstructions of modes with m bigger than 1 {III.2}.
- On top of that, even a small vertical shift of the ECE LoS can affect the poloidal parity determination {III.3}.

III.1 - Comparison between simulated and experimental profiles

Simulated profiles from Numerical ECE



m=2 **m=3** **m=4** **m=5**

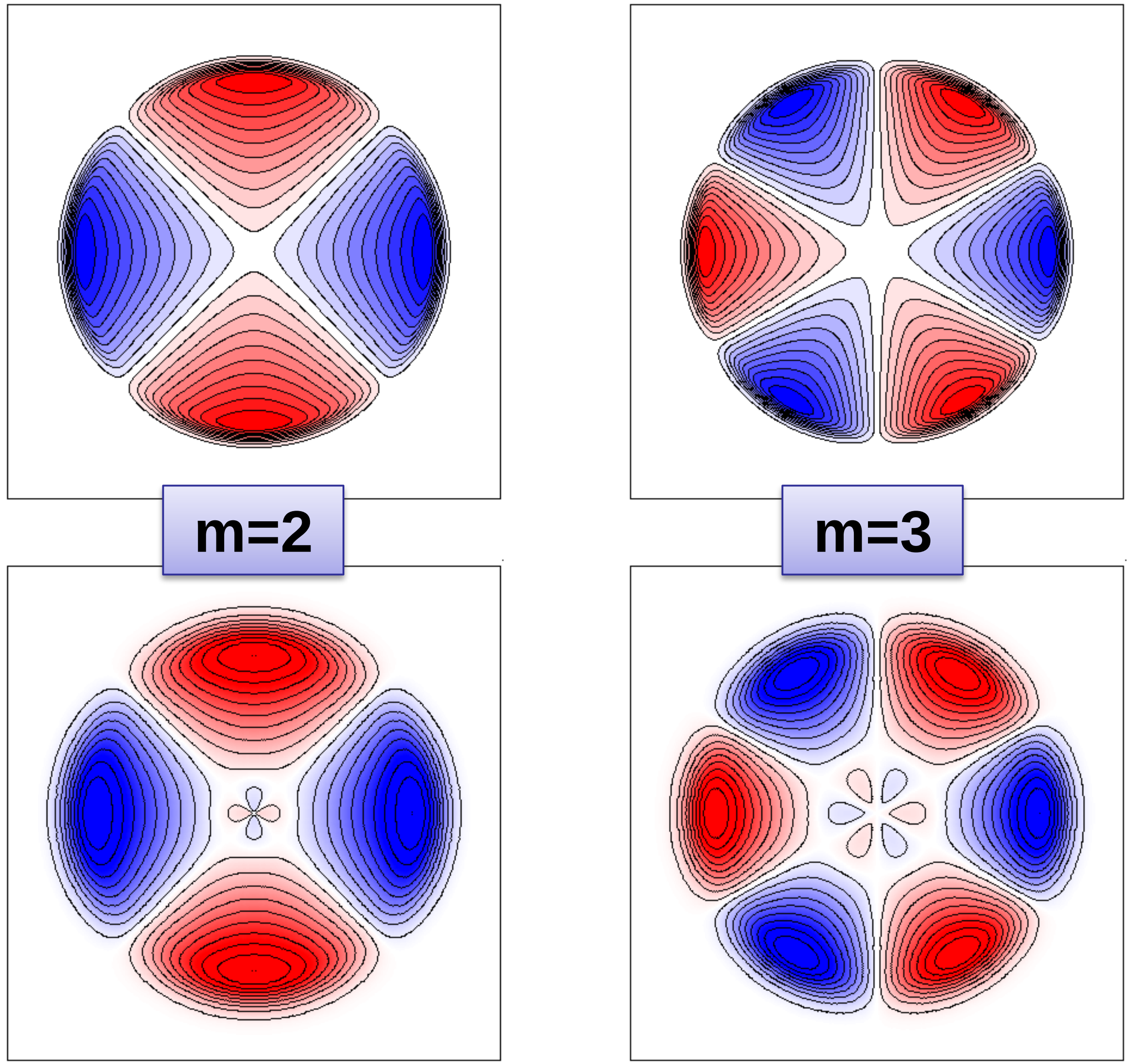


Experimental ECE profiles

III.2 – Spurious structures in tomographic reconstructions

Te oscillations induced by m=2 and m=3 kink modes

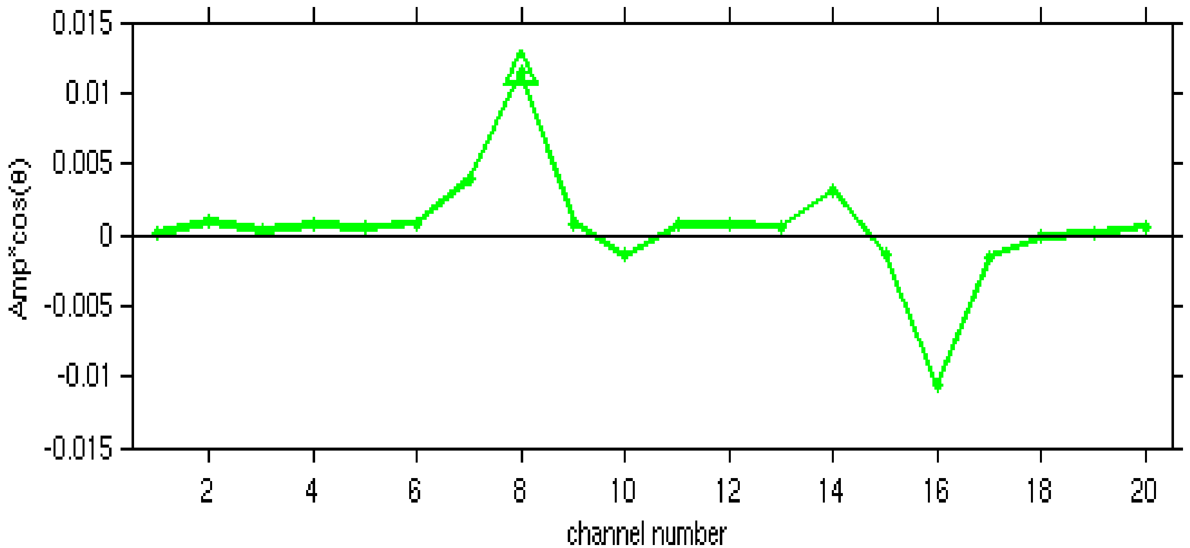
Tomographic reconstructions from ECE



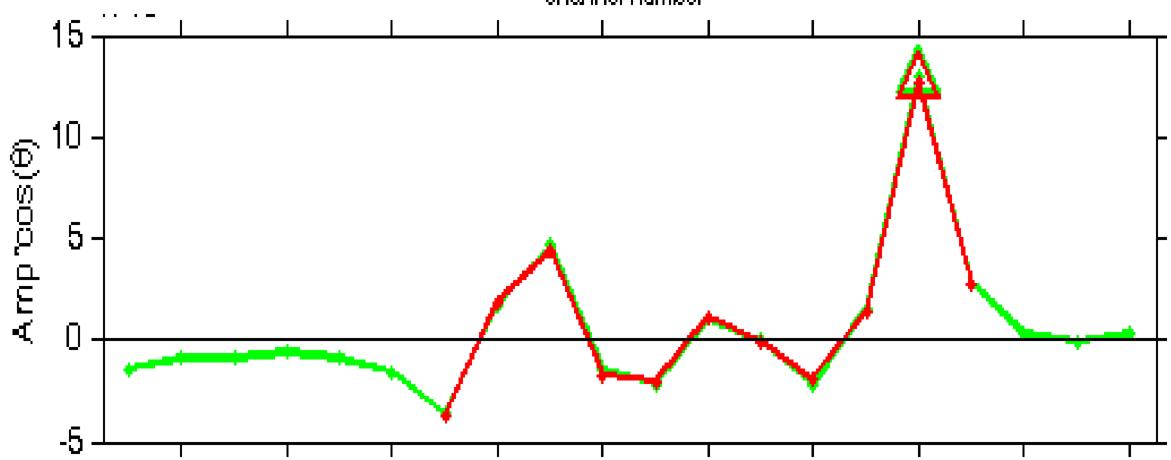
III.3 - Effect of a small vertical shift of the ECE Line of Sight on the observable poloidal parity

Experimental ECE profiles of an m=5 mode

Non shifted plasmas (clear odd poloidal parity)



Δz=+2 cm (suggests an even poloidal parity)



IV - Conclusions

- The radial profiles of the ECE measurements of core MHD modes in Tore Supra are more complex than the real Te oscillations due to the finite beam size.
- The poloidal mode numbers can be determined from the ECE measurements thanks to these structures.
- Advanced uses of the ECE data, however, may be affected by this effect, for instance when determining the phase shift with other diagnostics or when performing tomographic reconstructions.

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