Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

Impact of ECRH on the NBI-driven Alfvén activity in the TJ-II stellarator: experiments and data analysis

Á. Cappa, E. Ascasíbar, M. Liniers
S. Baojun, F. Castejón, T.Estrada
J.M. Fontdecaba, J.L. Velasco, M. Ochando (LNF-CIEMAT)

K. Nagaoka, S. Yamamoto
T. Ido, S. Ohshima (NIFS)

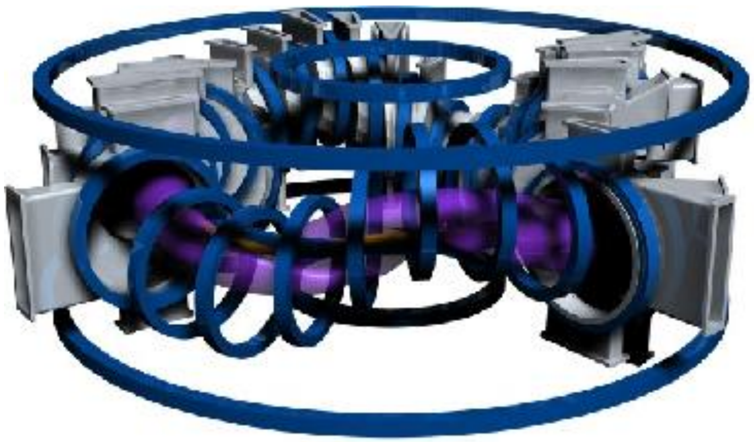
Laboratorio Nacional de Fusión
National Fusion Laboratory

Motivation

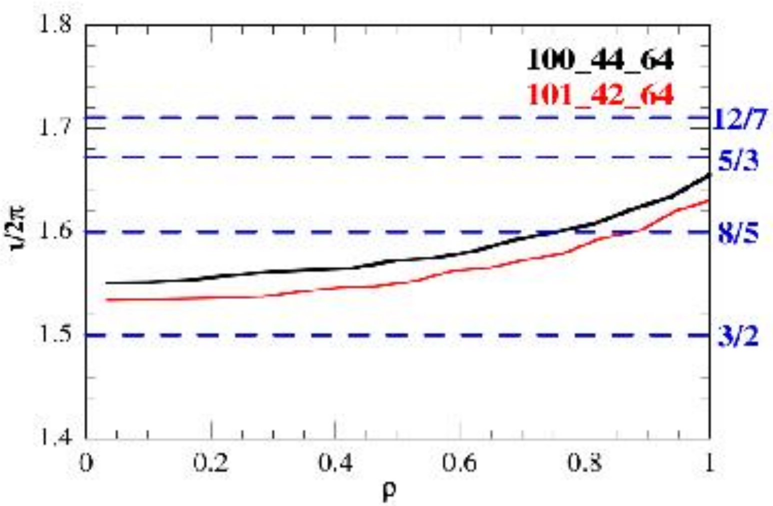
- Controlling the amplitude of Afvén eigenmodes is an open issue in fusion plasmas.
- Fast ion losses associated to these modes may decrease the plasma performance and damage plasma facing components.
- Stabilization of **R**everse **S**hear **A**lfvén **E**igenmodes associated to a minimum in q(r) profile by means of ECRH has been investigated in the D-IIID tokamak [M.A. Van Zeeland, *Nucl. Fusion* **49** 065003 (2209)].
- ECRH mechanism still not well understood (probably a combination of both):

  a. ECRH specific effect (e.g. changes in trapped fraction electrons affecting the damping of AE's).

  b. Changes in plasma current, density, temperature and Z_{eff} profiles when ECRH/ECCD is applied (e.g. modifying the slowing down of NBI ions and its distribution function or changing iota profile).
- Experiments in the TJ-II stelllarator have shown strong impact of ECRH on the AE's properties measured by magnetics diagnostics [K. Nagaoka, Nucl. Fusion **53** 072004, 2013 / A.Cappa, 25th IAEA, St Petersburg.].
- Ongoing data analysis and interpretation of results.

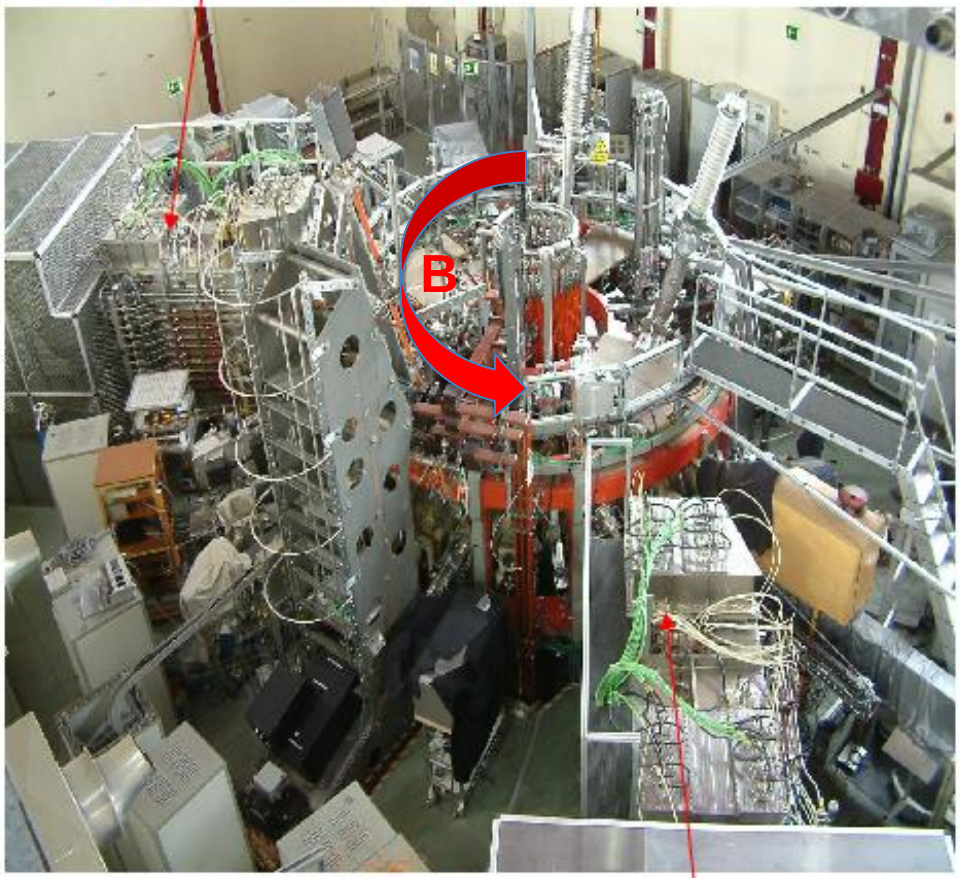


- R_0 = 1.5 m
- M = 4
- B_0 = 0.95 T
- ι = 0.96-2.5
- $V_p < 1.2$ m^3
- $\langle a \rangle \leq 0.22$ m



Counter B

NB Injector 2 (Counter-)



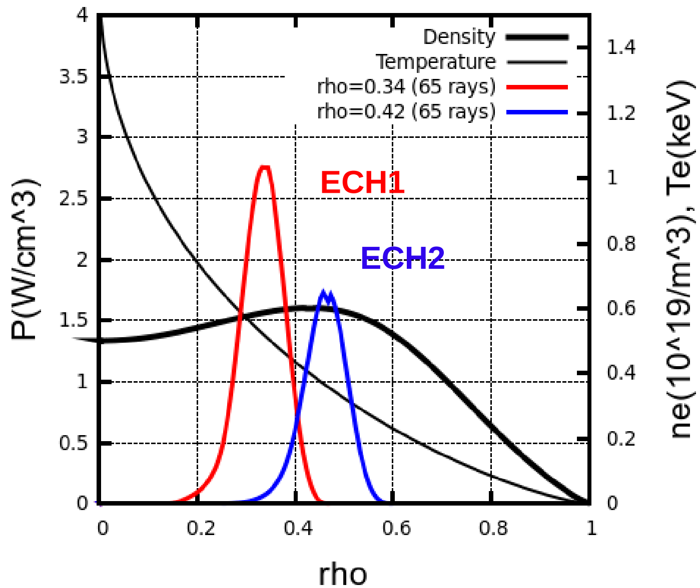
32 keV / 0.5 MW / H^0

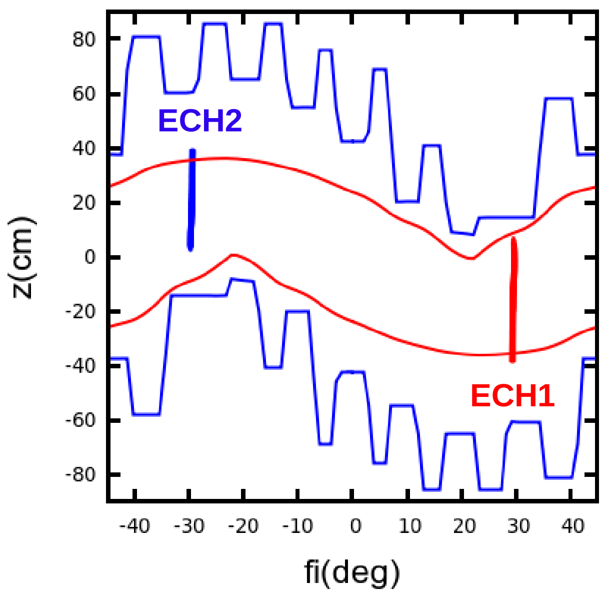
$v_b = 2.5 \times 10^6$ m/s

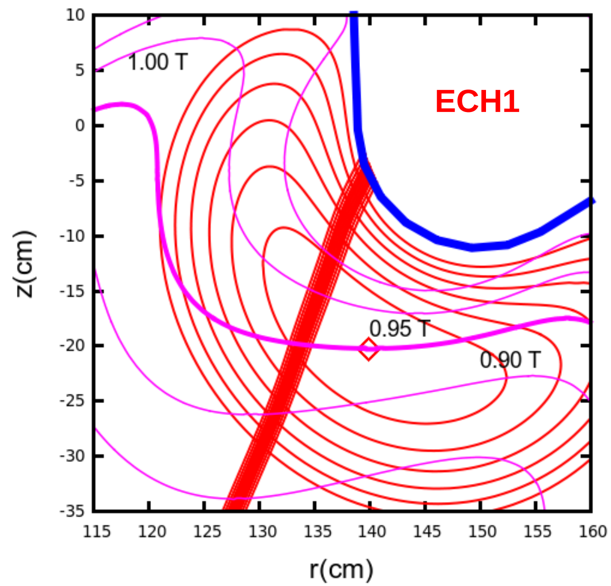
NB Injector 1 (Co-)

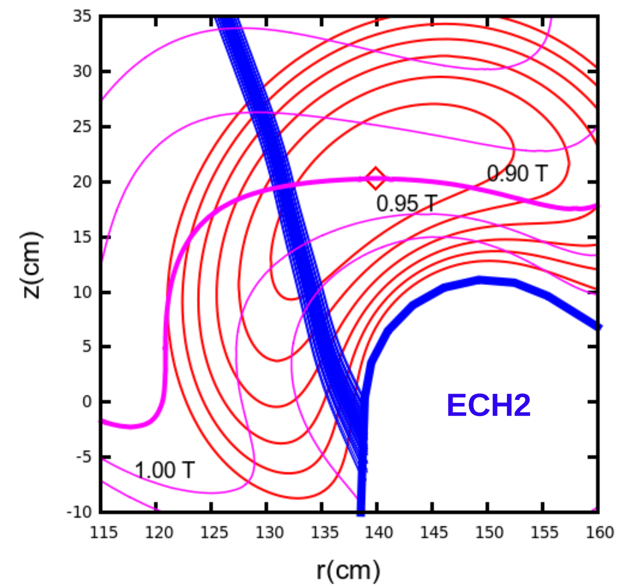
ECRH system

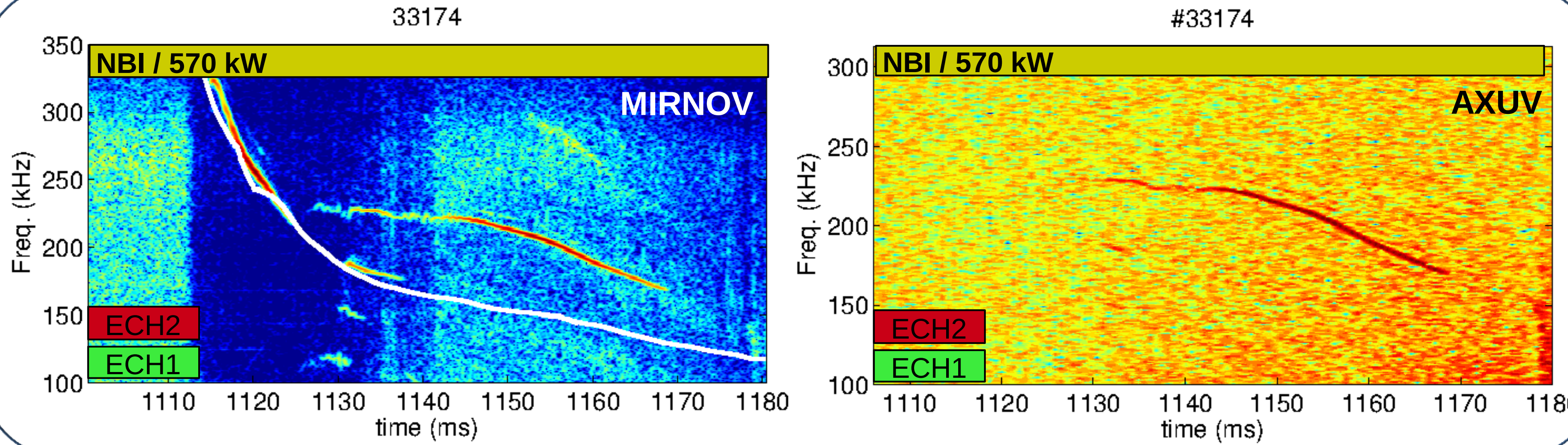
- ✓ two GYCOM 300 kW gyrotrons 2nd harm. X-mode
- ✓ QO transmission (no waveguides)
- ✓ located at stellarator symmetric positions
- ✓ steerable in horizontal and vertical direction
- ✓ beam size on axis $w_0 \cong$ 1-2 cm (strongly focused)
- ✓ all experiments were accomplished with $N_{||} \cong 0$









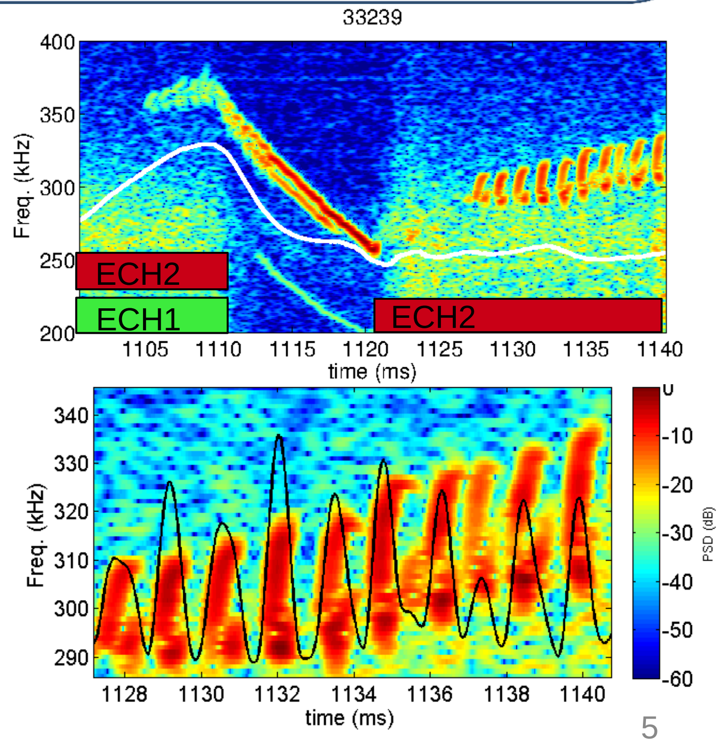


When ECRH is applied during the NBI phase two main effects are observed:

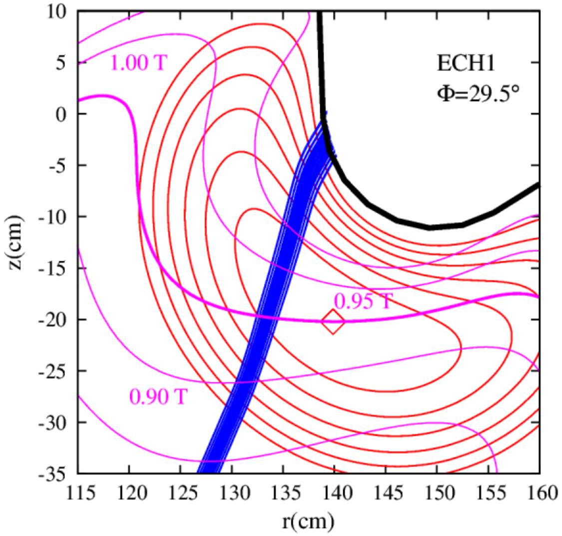
✓ Generation of frequency chirping, always coincident with positive plasma current.

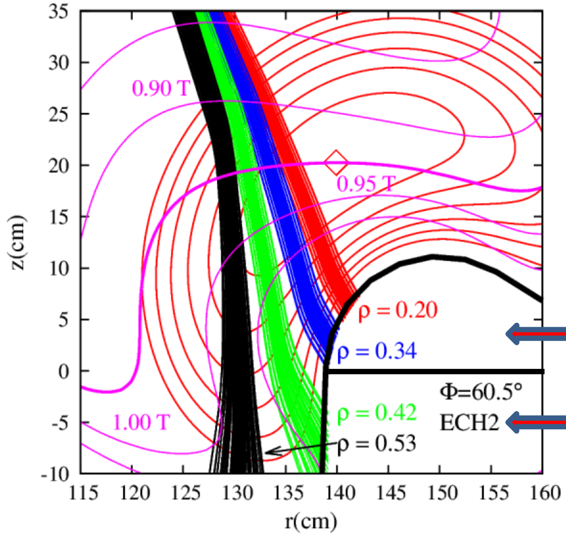
✓ Changes in mode amplitude (in both cases, steady & chirping mode).

$$\delta B(t) \cong \beta \frac{\sigma_{Mirnov}(t)}{2\pi f_A(t)}$$

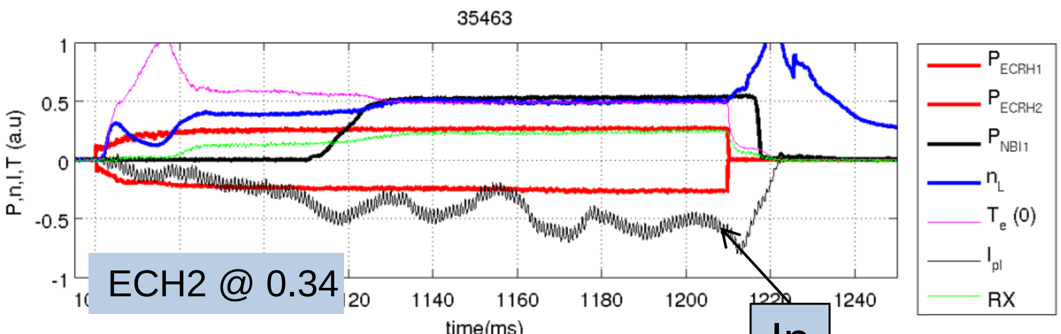


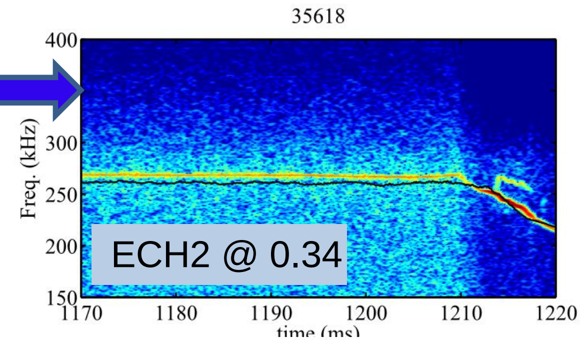
NBI driven AE's + ECRH: relation with plasma current

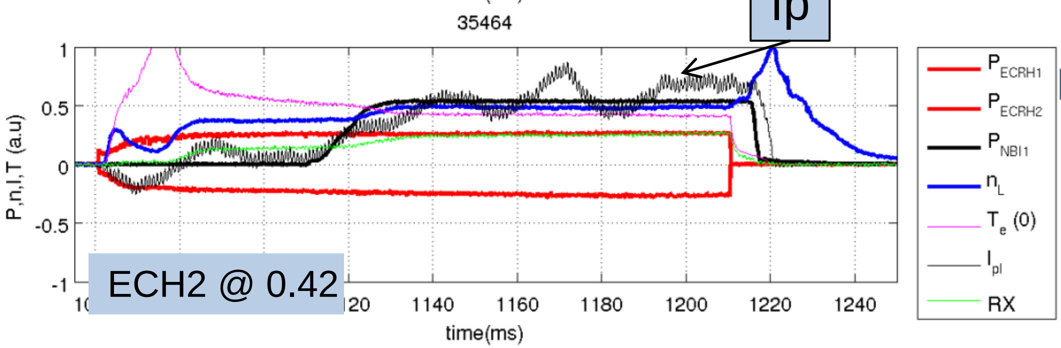


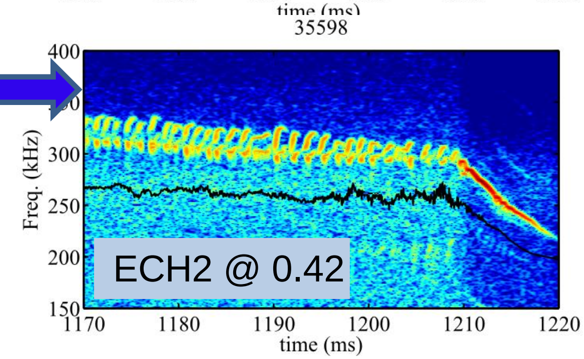


- ✓ In principle, $N_{||} = 0$ but…
- ✓ Changing injection direction modifies total plasma current !! (plasma current profile → iota).
- ✓ Ip < 0 steady mode
- ✓ Ip > 0 frequency chirping

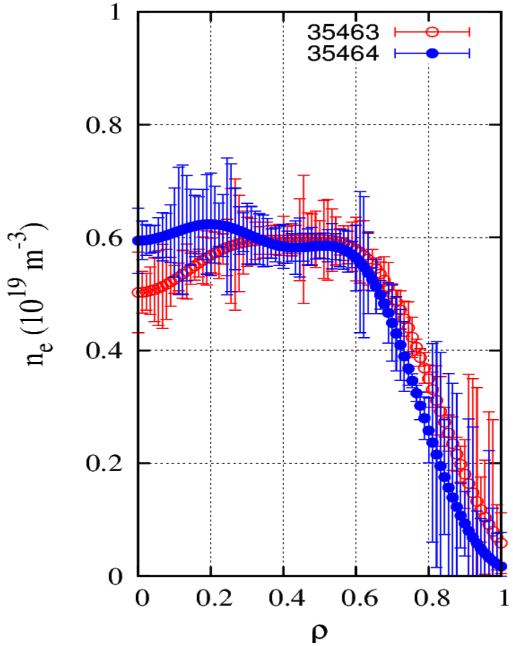


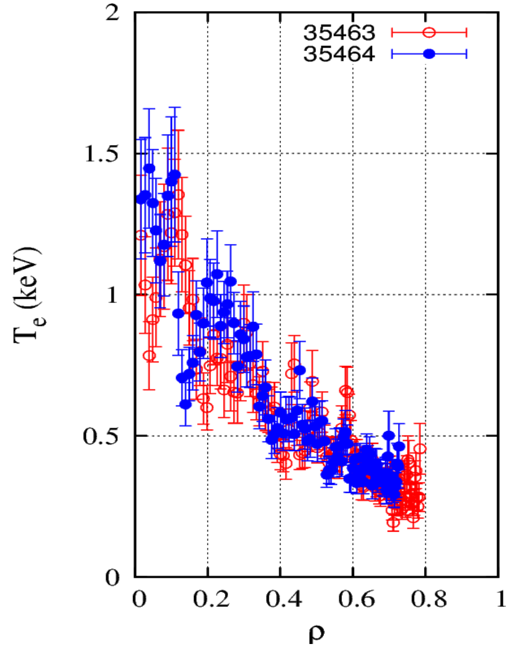


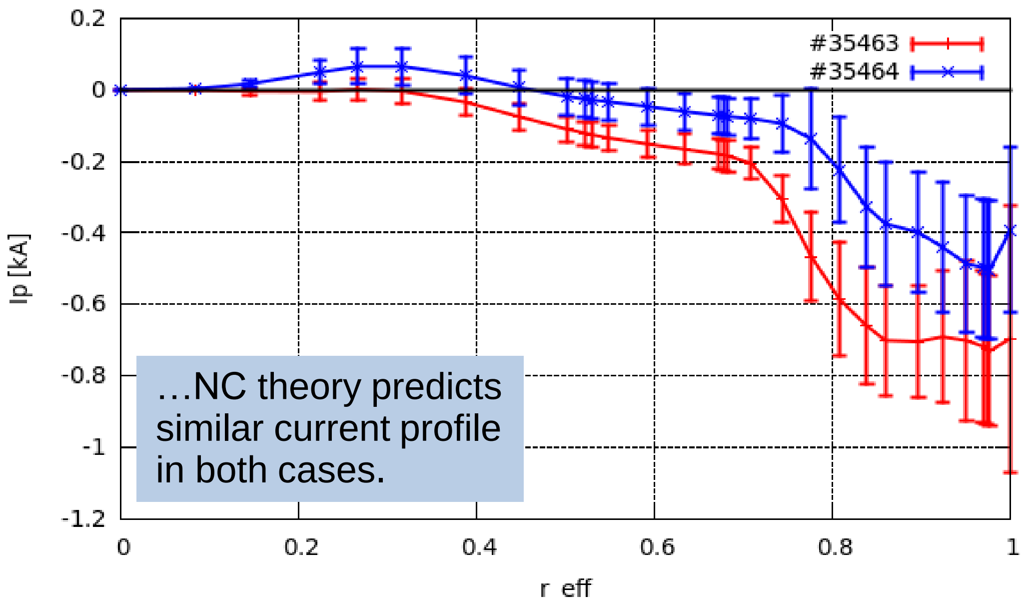




NBI driven AE's + ECRH: relation with plasma current





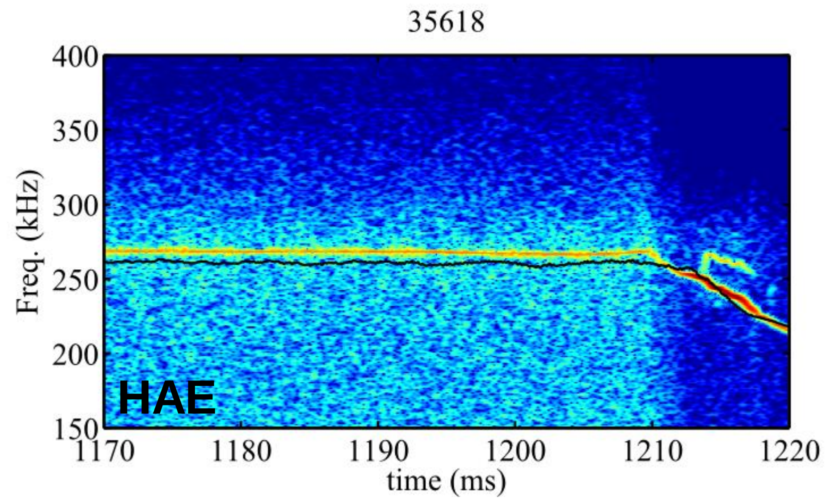


…NC theory predicts similar current profile in both cases.

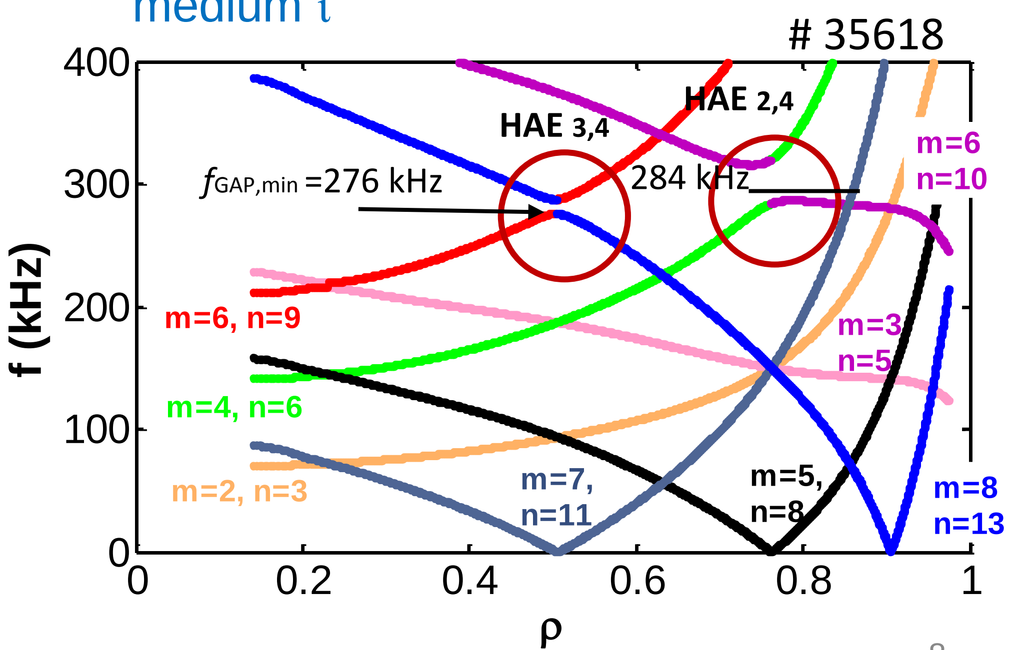
- ✓ Plasma current reversal can not be explained by changes in the plasma profiles.
- ✓ Bootstrap current calculation shows almos no difference.
- ✓ ECCD?
- ✓ ECRH system alignment?
- ✓ Low single pass absorption & beam reflection?
- ✓ Off-axis heating changes trapped particle fraction?

STELLGAP (vacuum iota profile, steady mode, I_p<0, Thomson nT profiles)

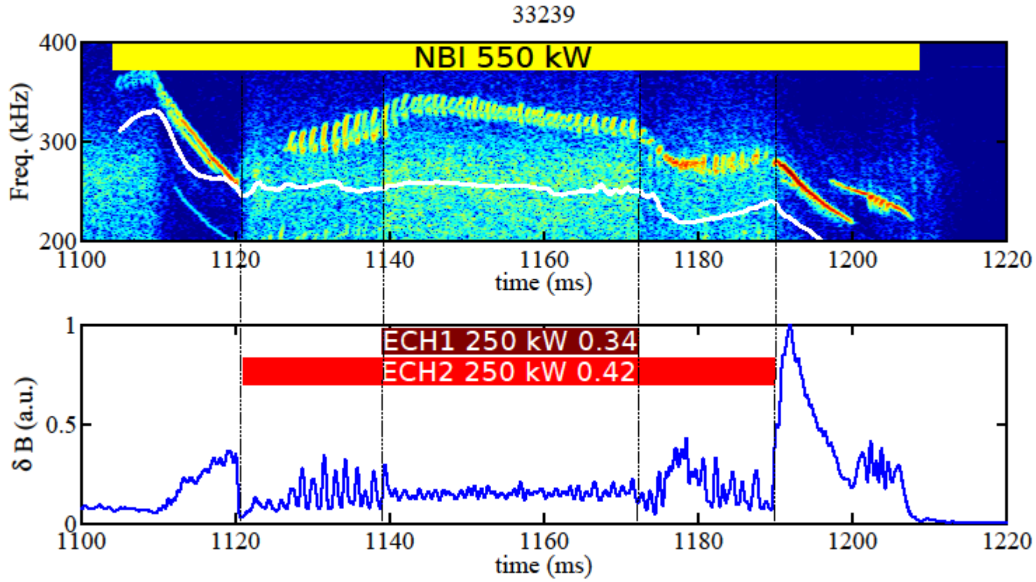
- Highly coherent Alfvén wave → gap mode
- Effective mass 1.2 × m_p
- Calculation limited to low mode number frequency spectrum (m ≤ 8)
- $HAE_{M,N}$, where M & N corresponding to magnetic helical component
- $f_{GAP,min}$ → minimum boundary of the gap frequency.
- Result is strongly modified if a positive current contribution is added → a minimum in iota profile appears?
- Relation with chirping mode?
- Ongoing poloidal mode number analysis with Mirnov coils array.

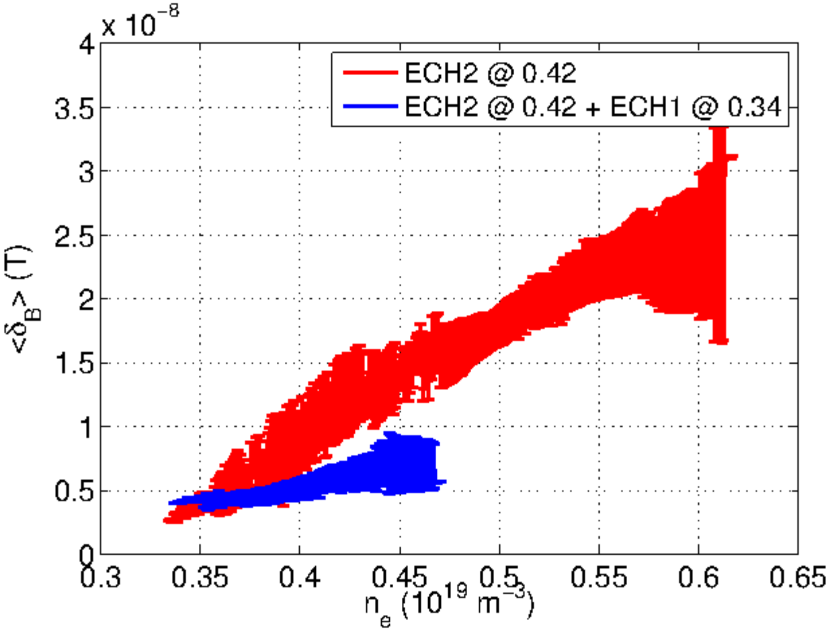


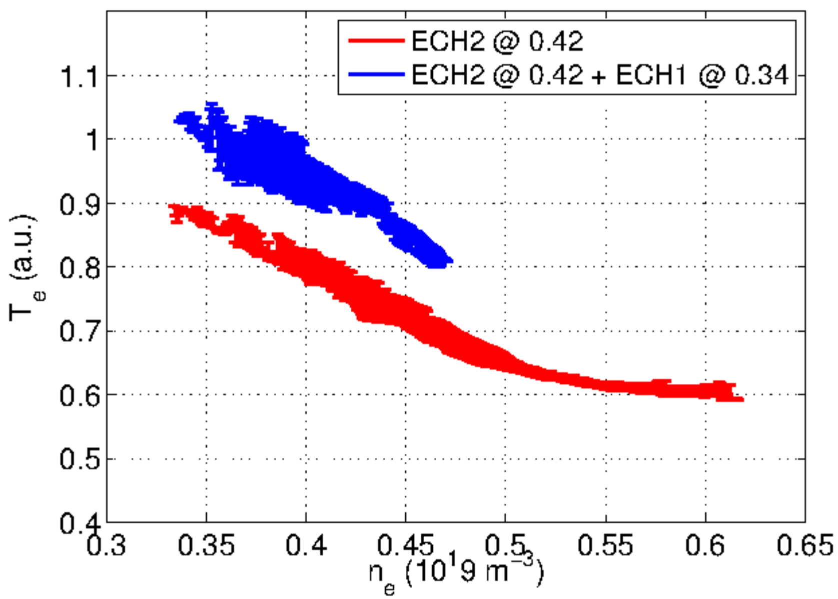
medium ι



- ✓ Amplitude of the chirping mode produced by ECH2 (ρ=0.42) is reduced when ECH1 (ρ= 0.34) is applied.
- ✓ Strong chirping mode amplitude reduction.
- ✓ Most likely caused by changes in plasma profiles.

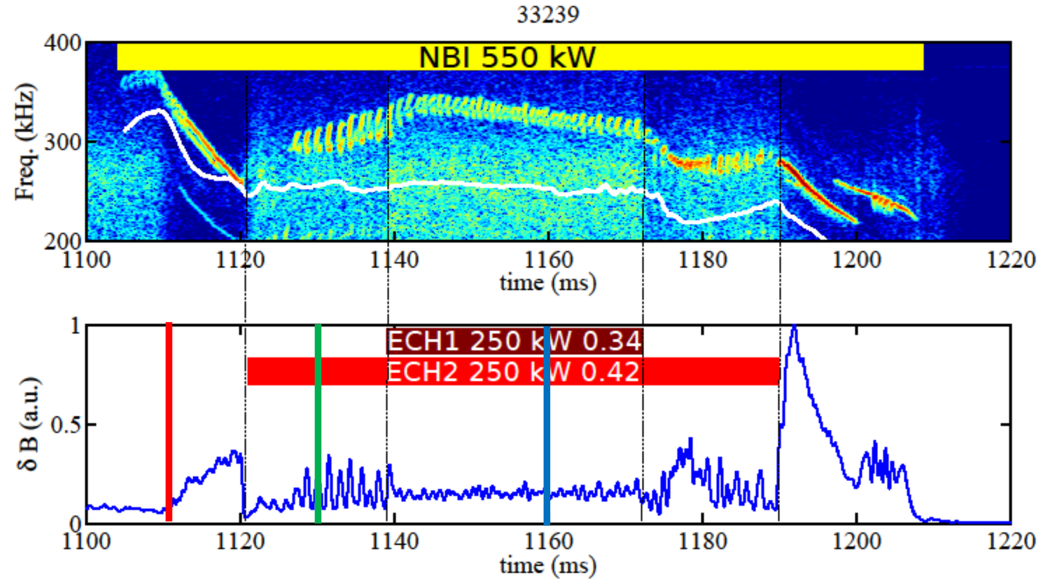


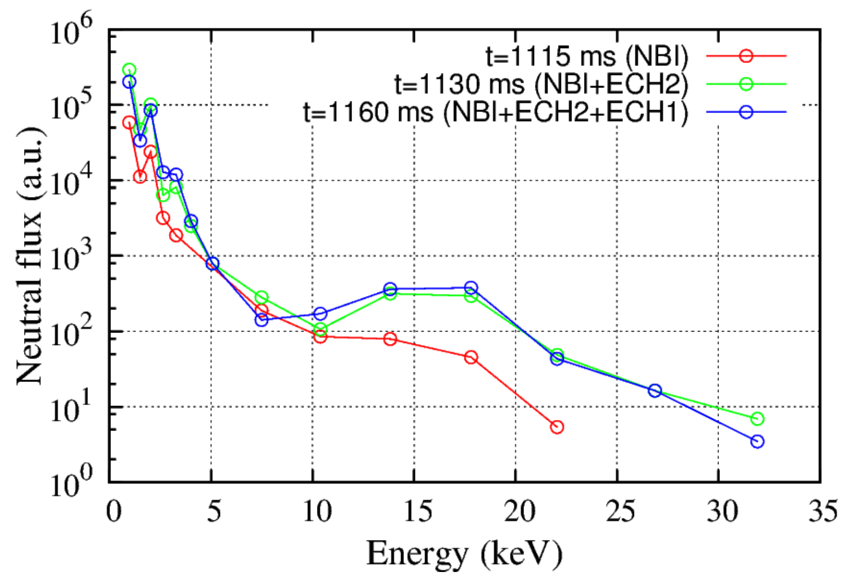




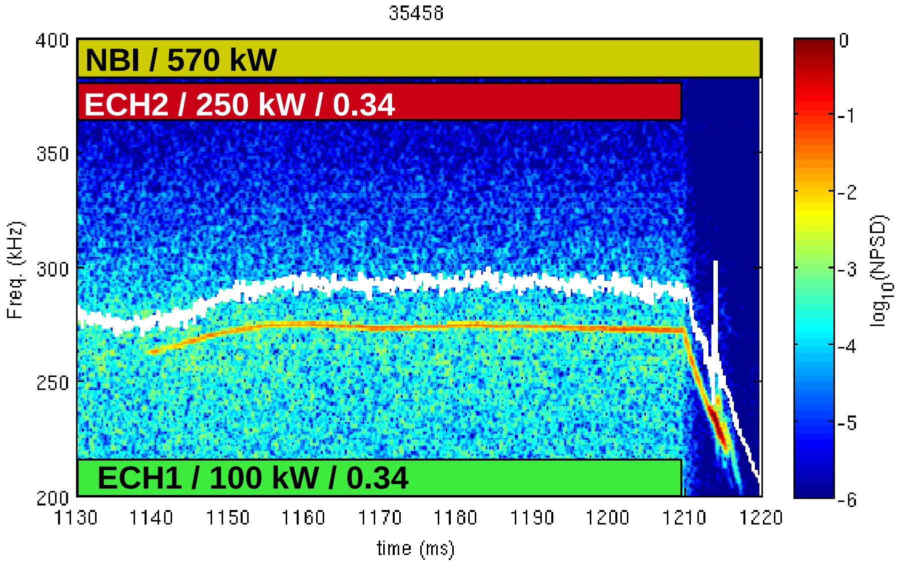
NBI driven AE's + ECRH: CNPA data

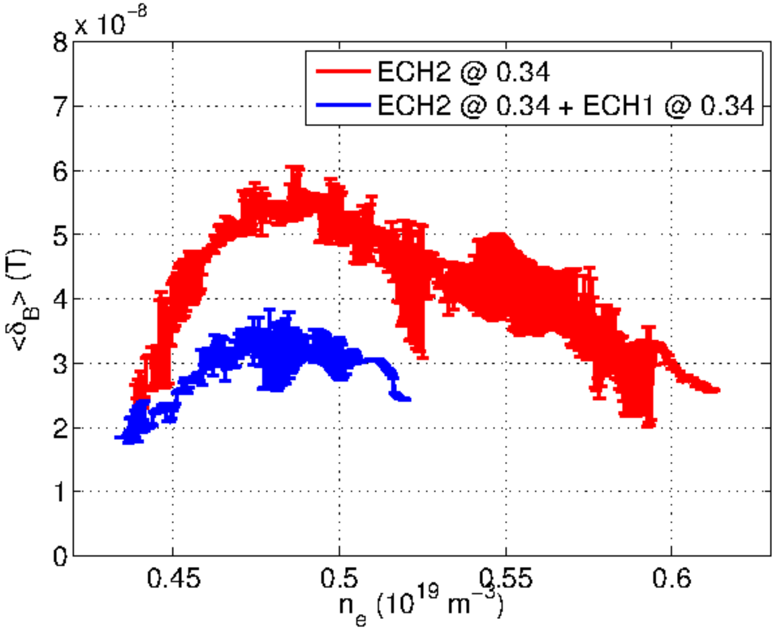
- ✓ Effect of ECH on fast ion population & relation with mode amplitude.
- ✓ CNPA signal is proportional to the density of confined fast ions and low energy neutrals.
- ✓ Steady neutral flux is enhanced when ECH2 is applied (for energies above one third of the nominal beam energy, 32 keV).
- ✓ Consistent with an increase (better confinement) of the fast ion population during the ECH+NBI phase as compared to the only-NBI phase?.
- ✓ However, no large difference in spectrum between ECH2 and ECH2+ECH1.

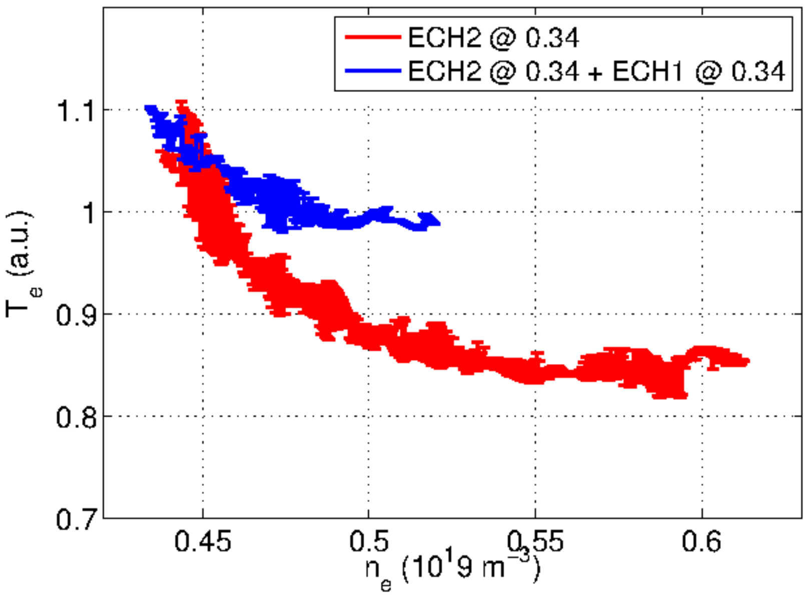


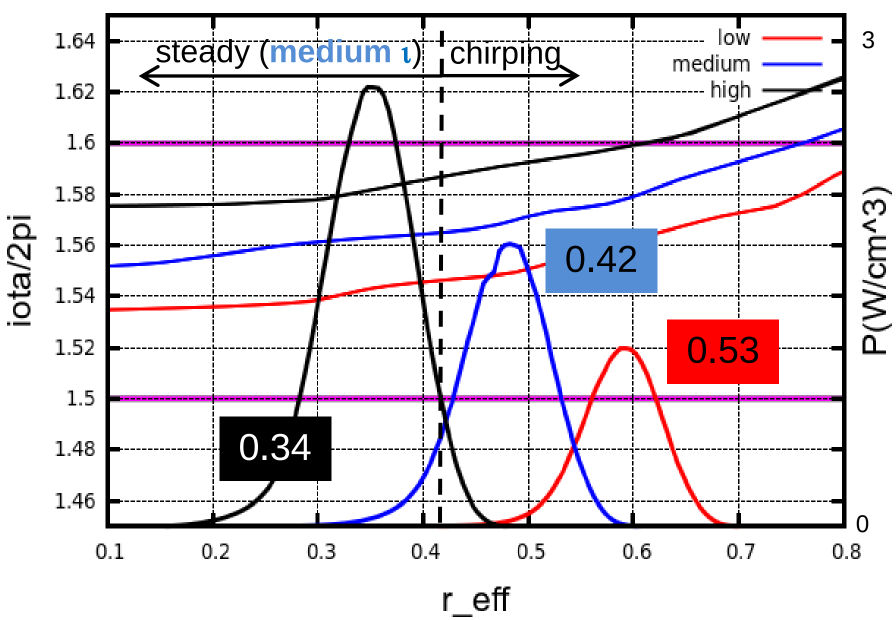


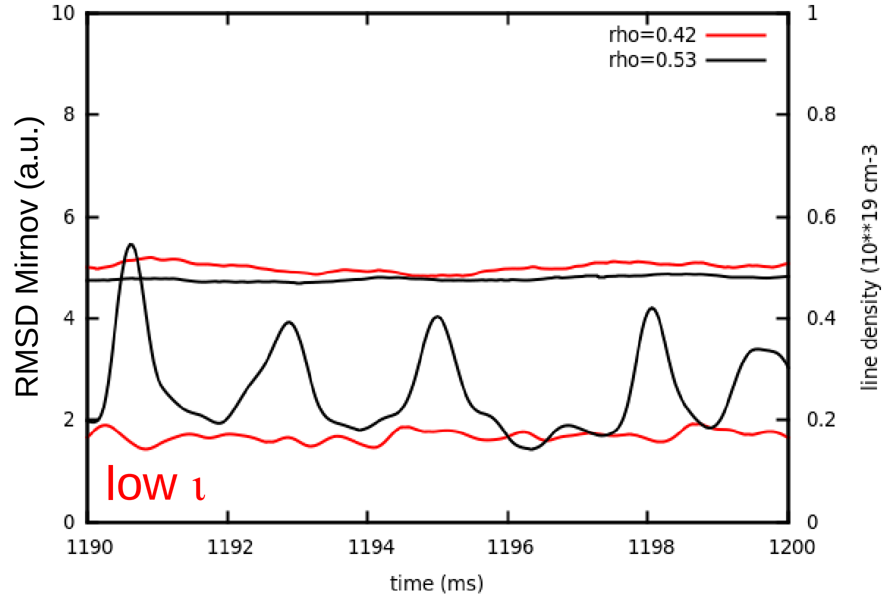
- ✓ Amplitude of the steady mode observed with ECH2 at ρ=0.34 or ρ=0.20 is reduced when ECH1 (ρ= 0.34) is applied.
- ✓ Again, amplitude reduction is most likely caused by changes in plasma profiles.

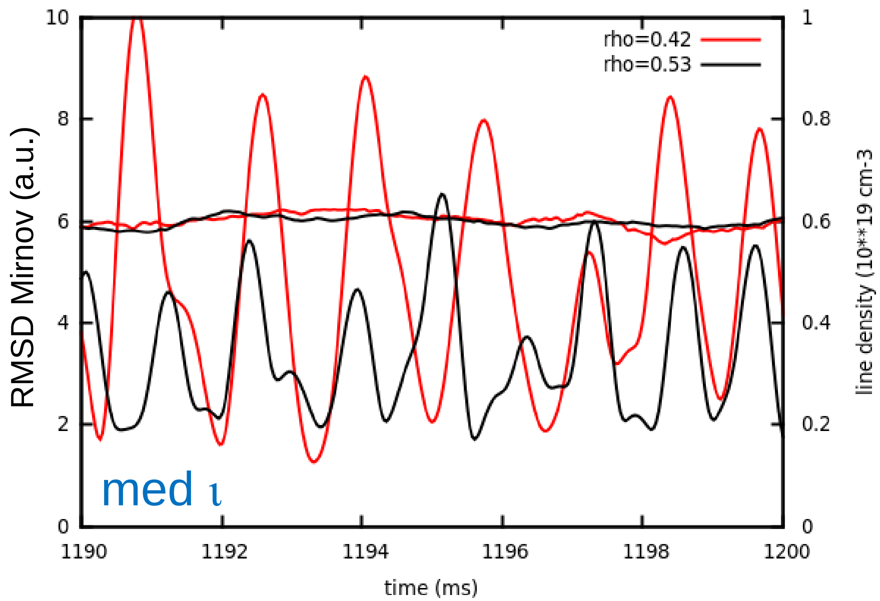






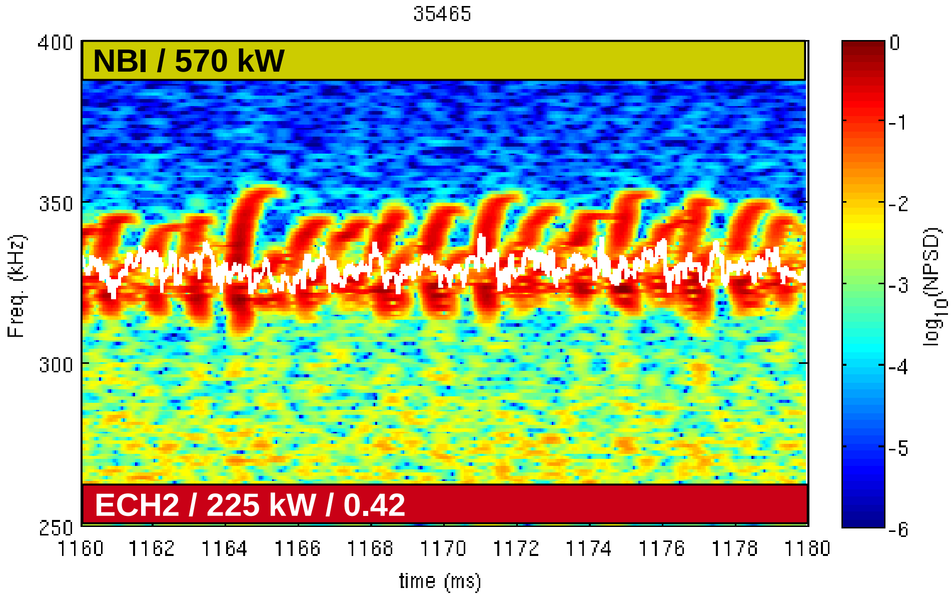


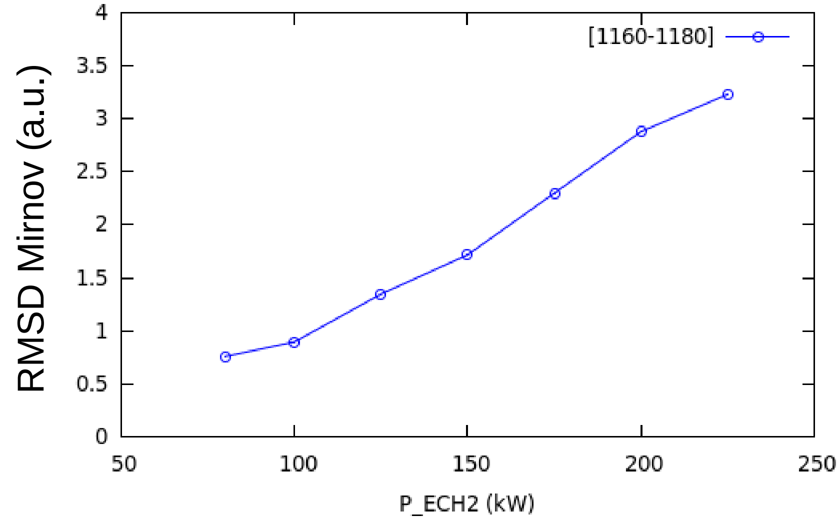


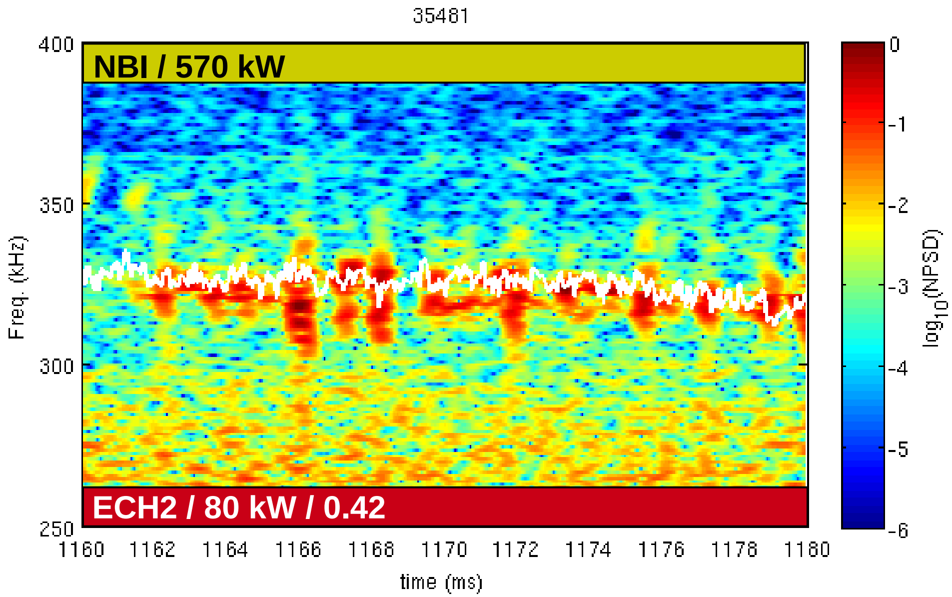


- ✓ Strongest chirping occurs at different positions for different configurations.
- ✓ Current reversal ($\rho \cong 0.34 \leftrightarrow \rho \cong 0.42$) occurs always independently of the studied configurations.

- ECH2 @ ρ≅ 0.42







- ECH2 Power: 80 kW - 225 kW
- Chirping mode amplitude increases with power.
- Regular chirps at high power.
- But: very low line density ($\cong 0.35\times10^{19}$ m^{-3})
- Check profiles!!

- ✓ Steady AE (NBI) ↔ chirping mode (ECH2 @ ρ =0.42, medium iota conf.): related with a change in current profile.
- ✓ Chirping mode (ECH2 @ ρ=0.42) ↔ attenuated chirping mode (ECH2 @ ρ=0.42 & ECH1@ ρ=0.34): plasma profiles effect.
- ✓ In the studied range,chirping mode amplitude increases with density and power.
- ✓ CNPA measurements consistent with better confinement of fast ions in the ECH phases.
- ✓ Chirping mode shows up only for power deposition off-axis $\rho > 0.34$ (ECH2).
- ✓ Lauching direction for which strongest chirping occurs depends on iota.