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High Harmonic Ion Cyclotron Heating in DIII-D: III. Excitation of Alfven Instabilities[1] S. BERNABEI, E.D. FREDRICKSON, Princeton Plasma Physics Laboratory, J.S. DEGRASSIE, C.C. PETTY, R.I. PINSKER, General Atomics, N. GORELENKOV , Triniti-Russia, W.W. HEIDBRINK, University of California, Irvine, E.A. LAZARUS, Oak Ridge National Laboratory — Sawtooth stabilization with ICRF heating is due to the buildup of a strong fast ion population inside $r(q = 1)$. In DIII–D the fast ions are generated by acceleration of beam injected ions: the 3rd, 4th, and 5th harmonics of deuterium are present in the plasma at a typical B_{T} in DIII–D. Stabilization of the sawteeth for up to 0.25 s is always accompanied by Alfvén instabilities. Since the first pass damping is rather weak, all harmonics contribute to the global power absorption. With the 4th harmonic of deuterium near the magnetic axis, small changes in B_{T} cause either the 3rd or the 5th harmonic to approach the center and contribute to the damping, creating fast ions outside $r(q = 1)$. We attempt to reconstruct the fast ion pressure profile to identify the power deposition and to identify the MHD modes responsible for the giant crash: evidence from other experiments indicates that they are Energetic Particle Modes.

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☐ Prefer Oral Session
☒ Prefer Poster Session

Special instructions: DIII-D Poster Session 2, immediately following WW Heidbrink

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[JP1.19] High Harmonic Ion Cyclotron Heating in DIII-D:
III. Excitation of Alfven Instabilities

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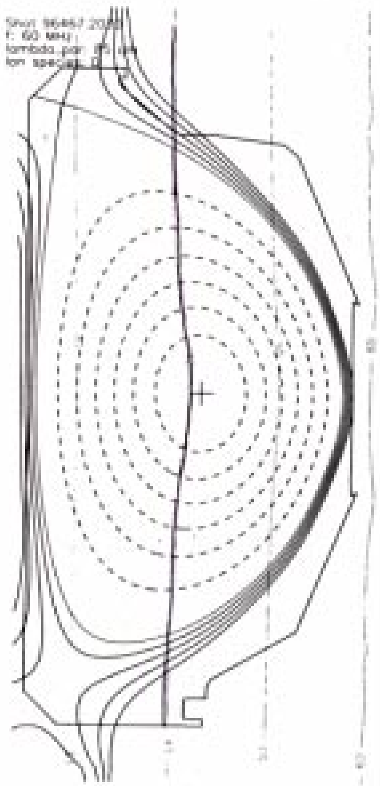
Sawtooth stabilization with ICRF heating is due to the buildup of a strong fast ion population inside r(q=1). In DIII--D the fast ions are generated by acceleration of beam injected ions: the 3rd, 4th, and 5th harmonics of deuterium are present in the plasma at a typical B_T in DIII--D. Stabilization of the sawteeth for up to 0.25~s is always accompanied by Alfvén instabilities. Since the first pass damping is rather weak, all harmonics contribute to the global power absorption. With the 4th harmonic of deuterium near the magnetic axis, small changes in B_T cause either the 3rd or the 5th harmonic to approach the center and contribute to the damping, creating fast ions outside r(q=1). We attempt to reconstruct the fast ion pressure profile to identify the power deposition and to identify the MHD modes responsible for the giant crash: evidence from other experiments indicates that they are Energetic Particle Modes.

Upon application of ICRF power to an NBI-heated discharge, it has been found that the Deuterium beam ions can be accelerated and monster sawteeth formed. *[See posters JP1.17 and JP1.18]*

The conditions for monster sawtooth formation depend critically on the location of the $4\Omega_D$ resonance.

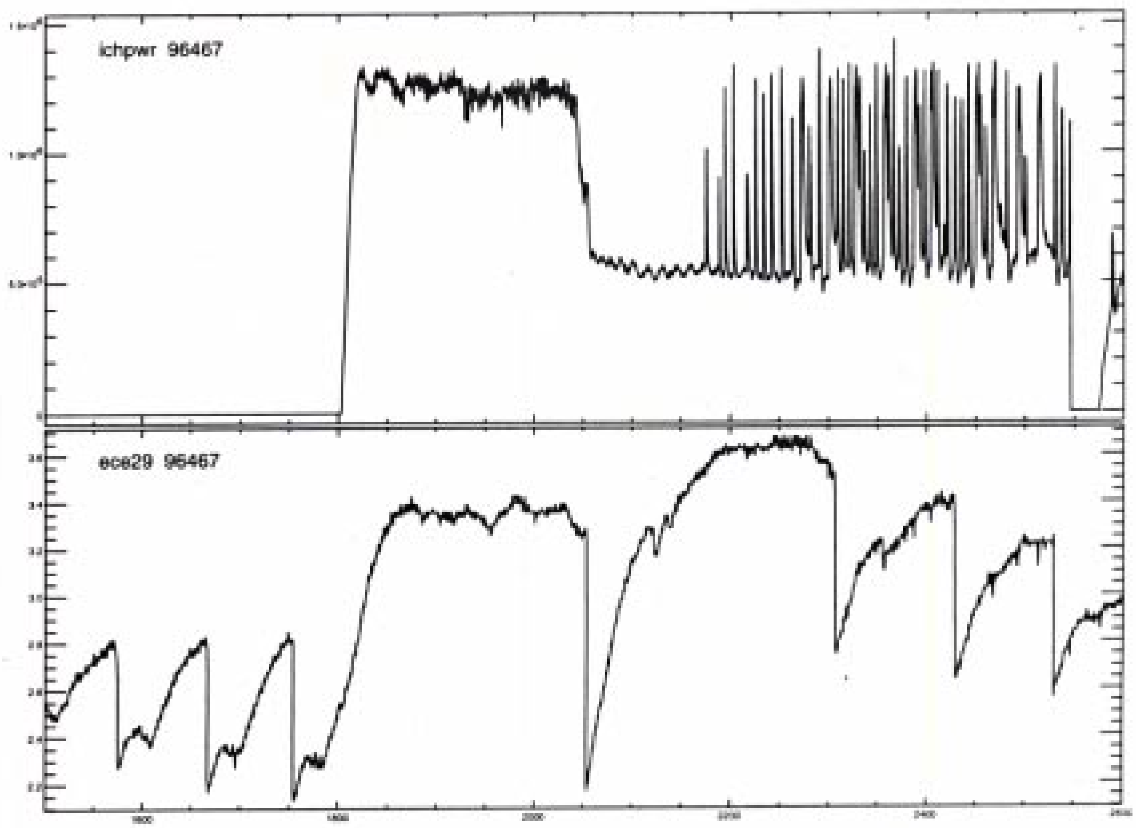
Also the $3\Omega_D$ and the $5\Omega_D$ are present and contribute to the damping, which being rather weak requires several passes of the waves through the plasma.

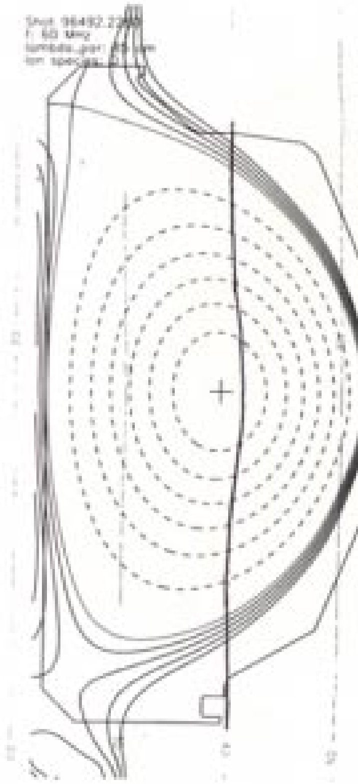
Additional power is deposited in electrons, in the Hydrogen minority and very likely some more is dissipated on the walls.
[*see T. K Mau, Proc. 13th RF conference, Annapolis Md. (April 1999, p 148]*



DIII-D

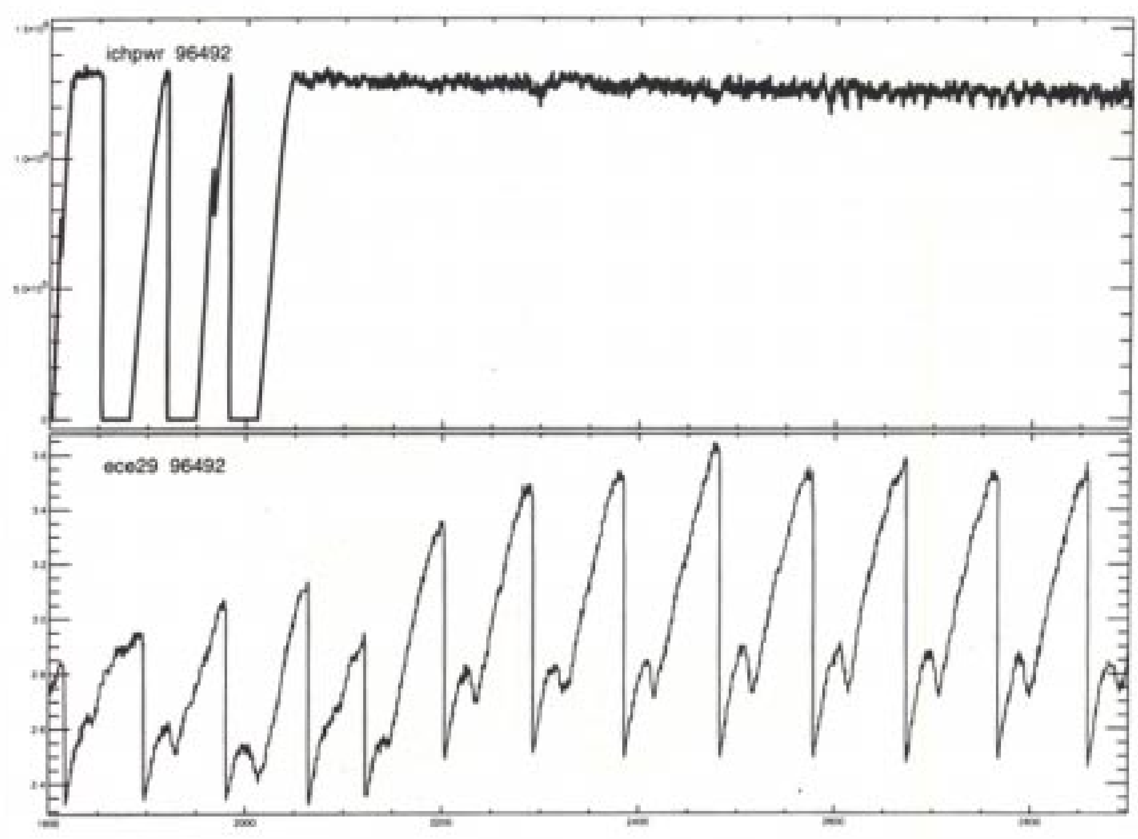
When the $4\Omega_D$ resonance is placed on the high-field-side of the magnetic axis, monster sawteeth can be formed.

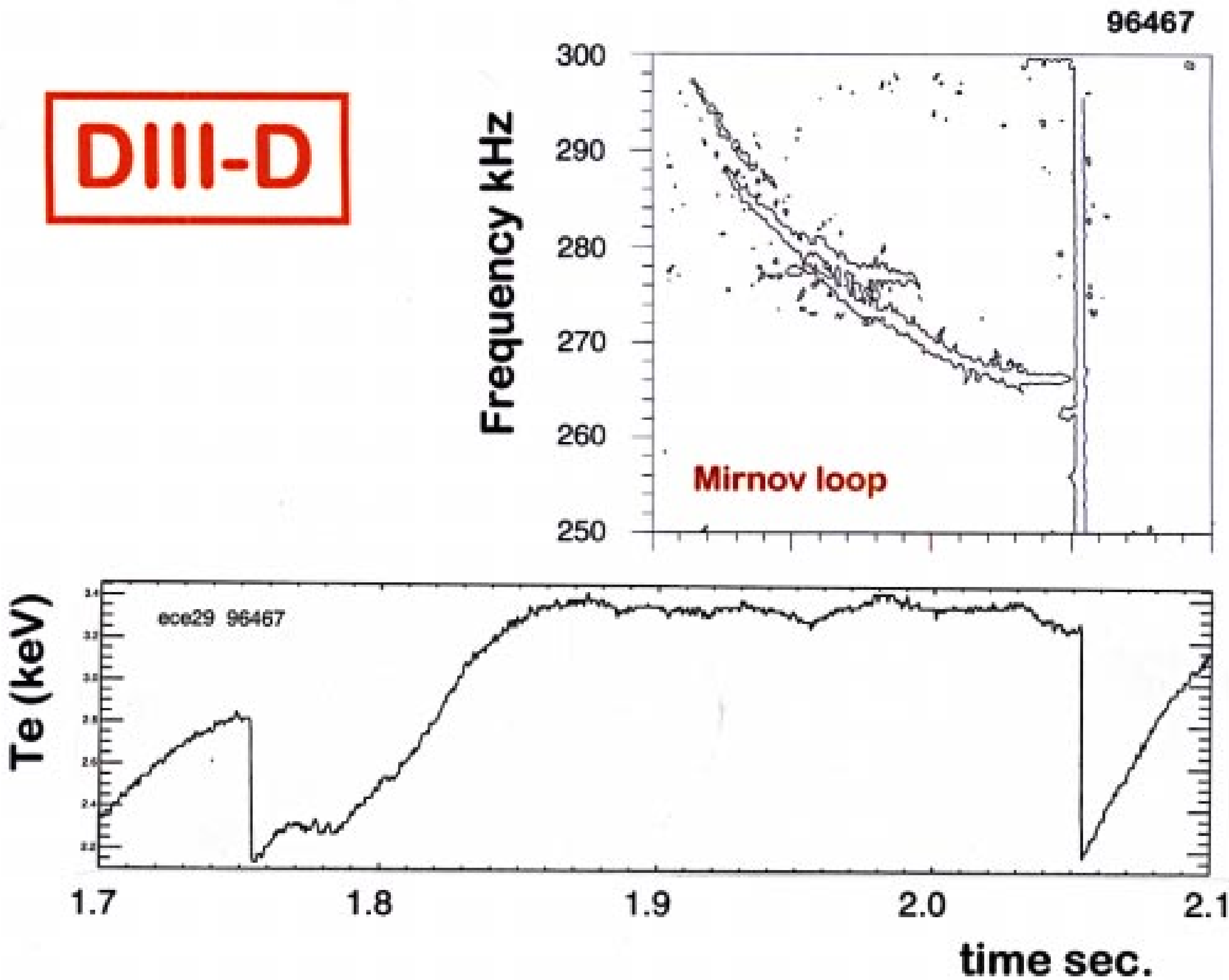




DIII-D

Shifting the $4\Omega_D$ resonance in either direction, causes the loss of the monster sawtooth.

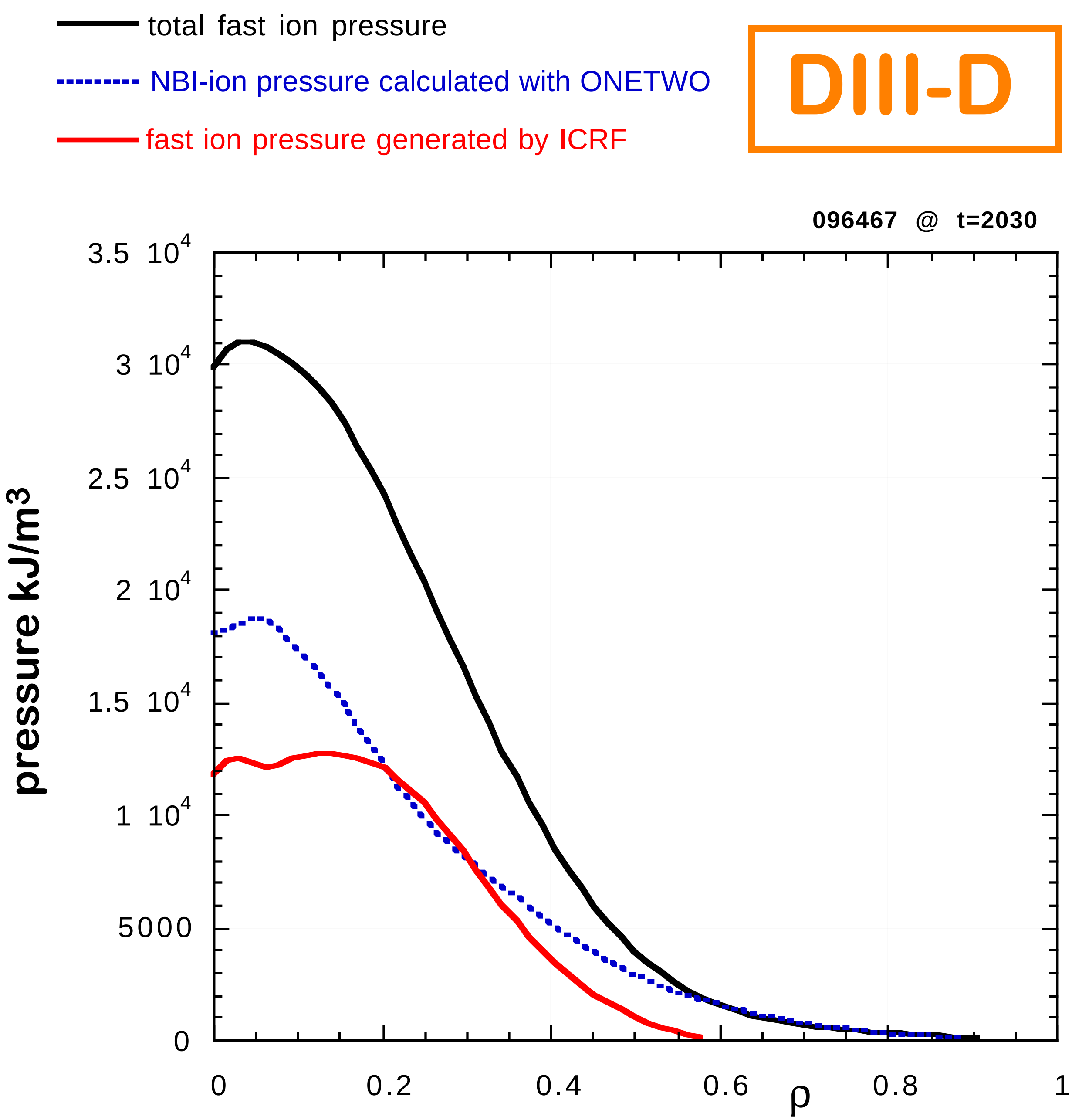




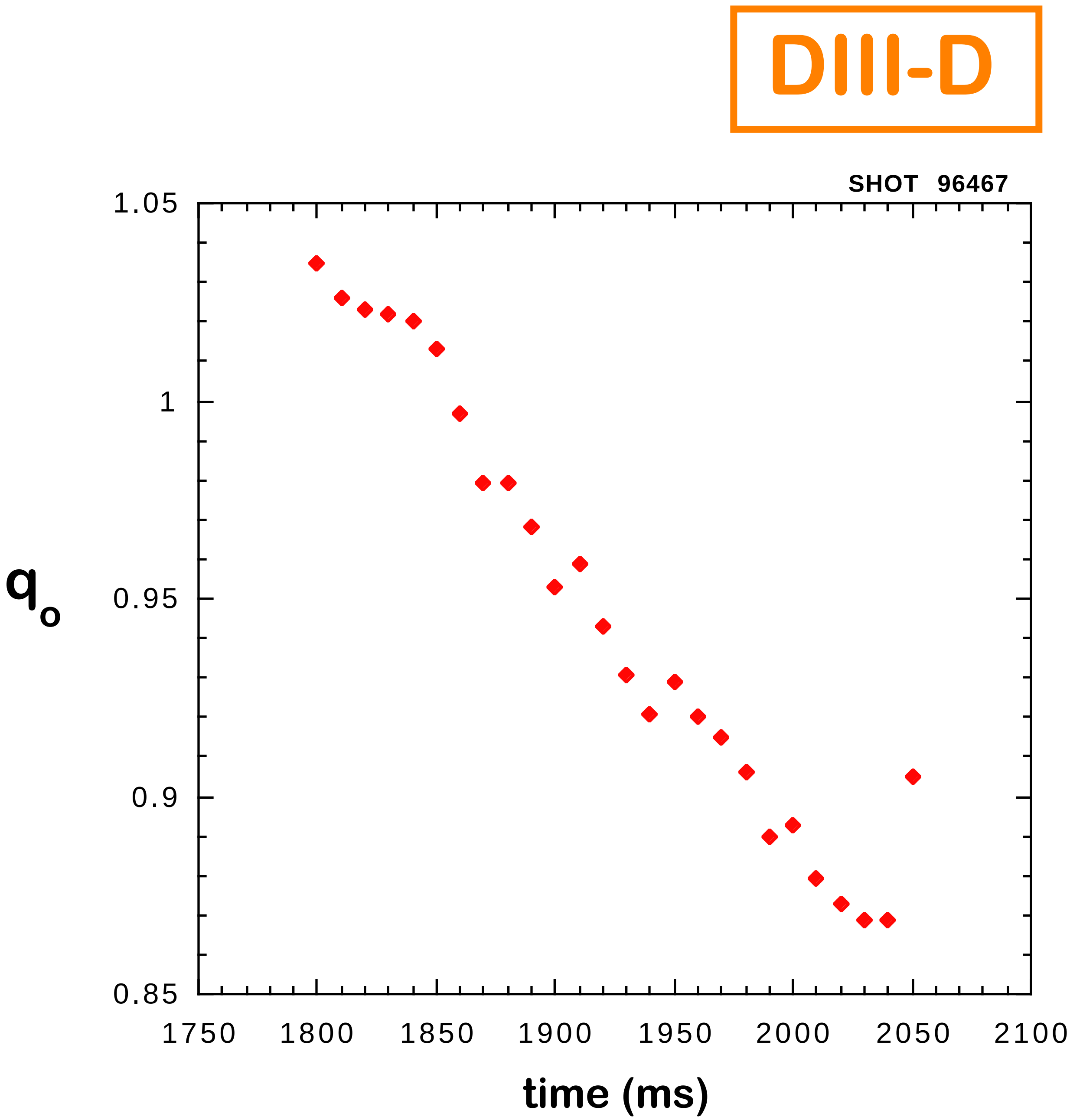
Alfvén instabilities excited by the fast ion pressure gradient f=60 MHz P_{ICRF} =1.2 MW

The modes cause saturation of the electron temperature.

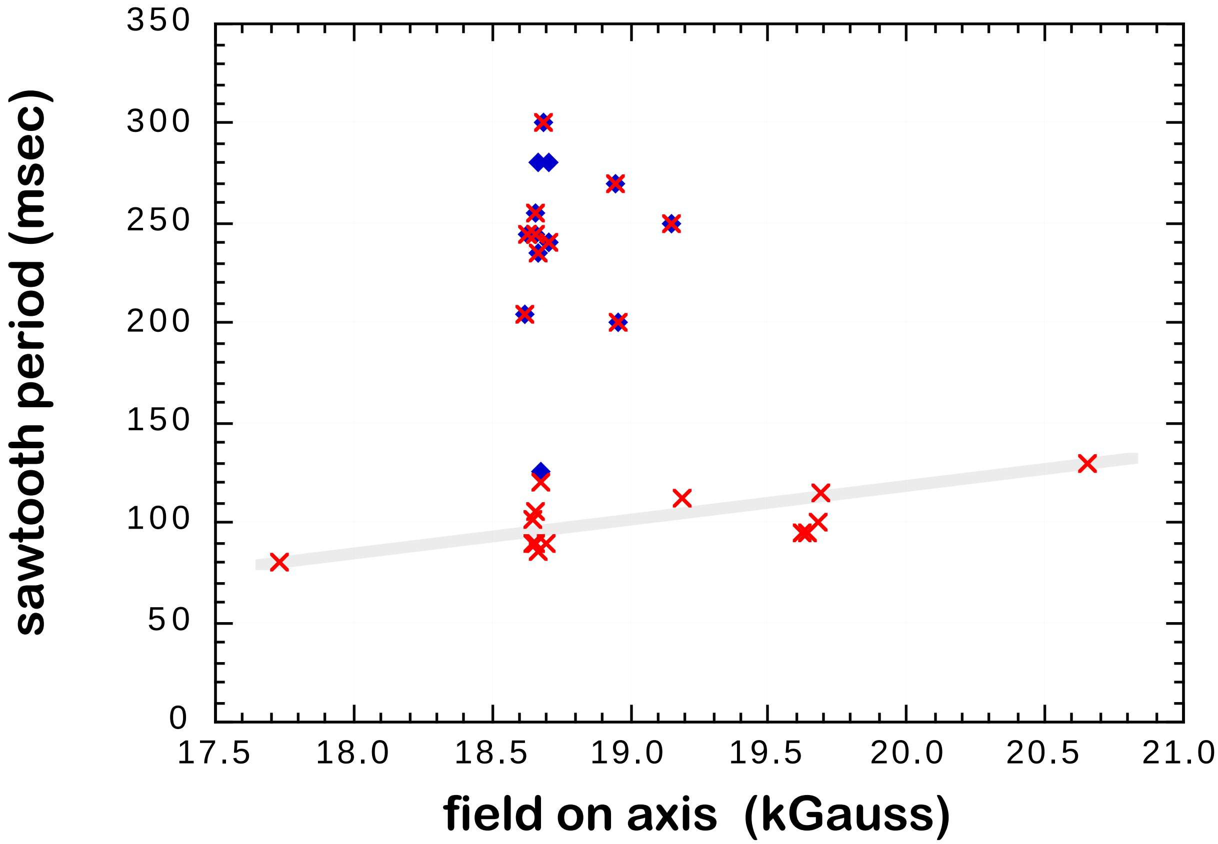
The monster sawtooth crash is caused by the depletion of fast ion from inside q=1 by the modes.



The fast ion pressure due to ICRF acceleration of NBI deuterium ions is determined subtracting the beam ion pressure (calculated from ONETWO) from the total ion pressure from a magnetic equilibrium reconstruction with MSE data.



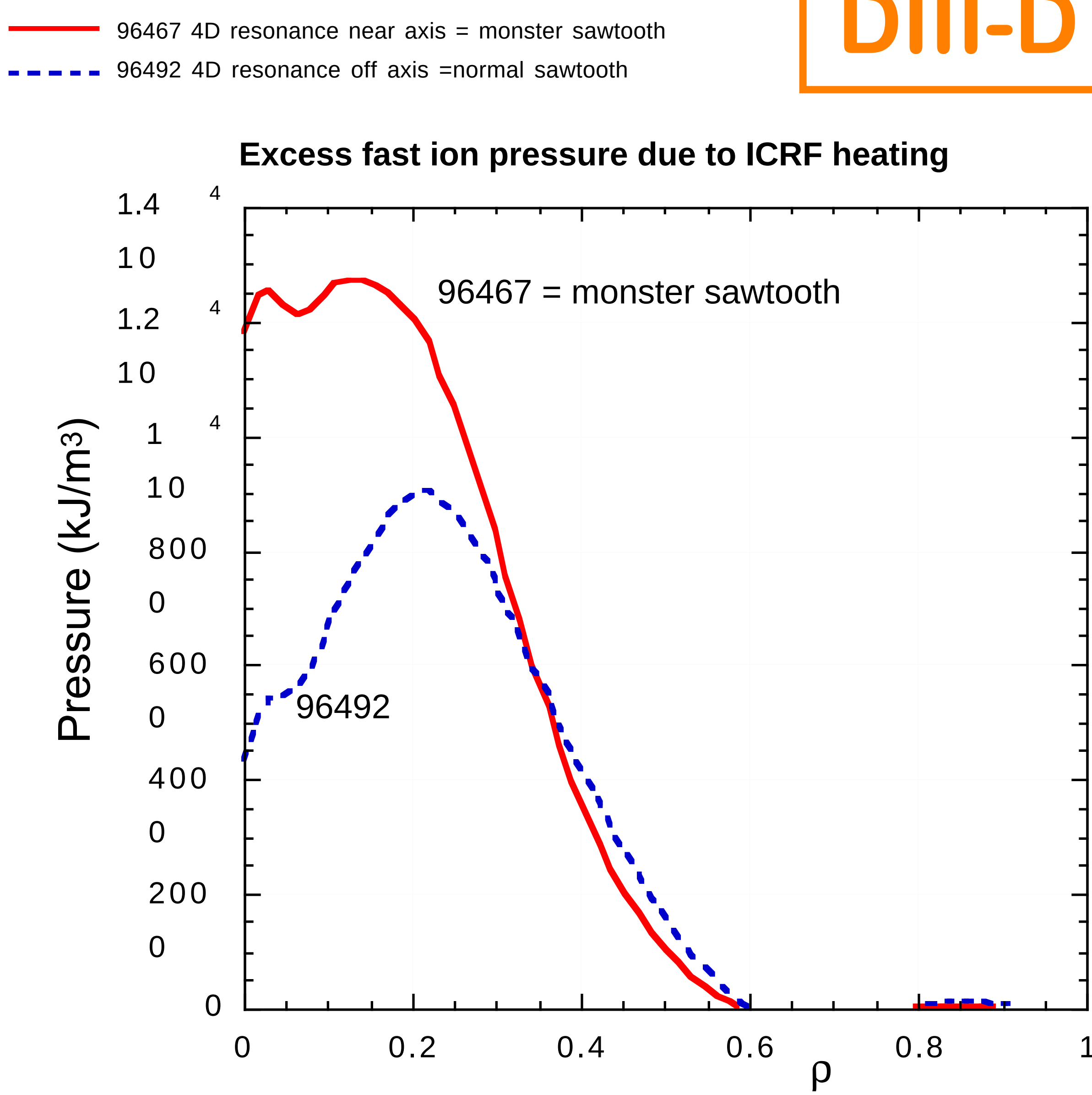
During the monster sawtooth, q_o decreases.



Monster sawteeth can be formed only in a narrow range of magnetic field.

They are usually accompanied by Alfvén instabilities (blue diamonds).

The amplitude of the modes appear to be just above threshold (only few chirping modes, no TAEs, like in TFTR)



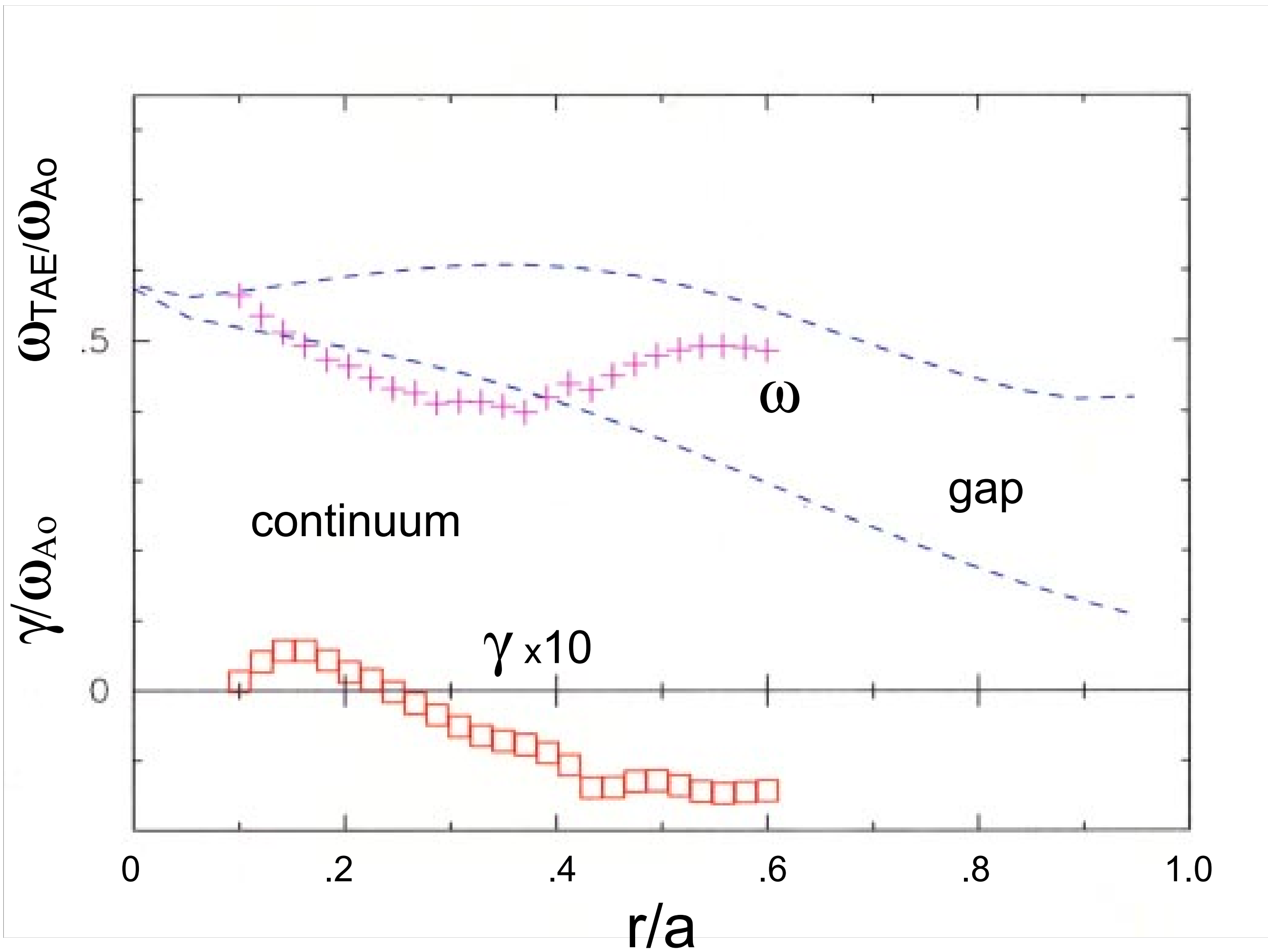
The excess fast ion pressure in shot 96467 is more peaked in the center than in shot 96492.

This provides more fast ions inside q=1 to stabilize the sawtooth.

In addition, the steeper gradient destabilizes EPMs.

HINST

For shot DIII-D # 96467 HINST code finds a strong drive for the chirping mode of figure 5 inside the Alfvén continuum, corresponding to an Energetic Particle Mode (EPM).



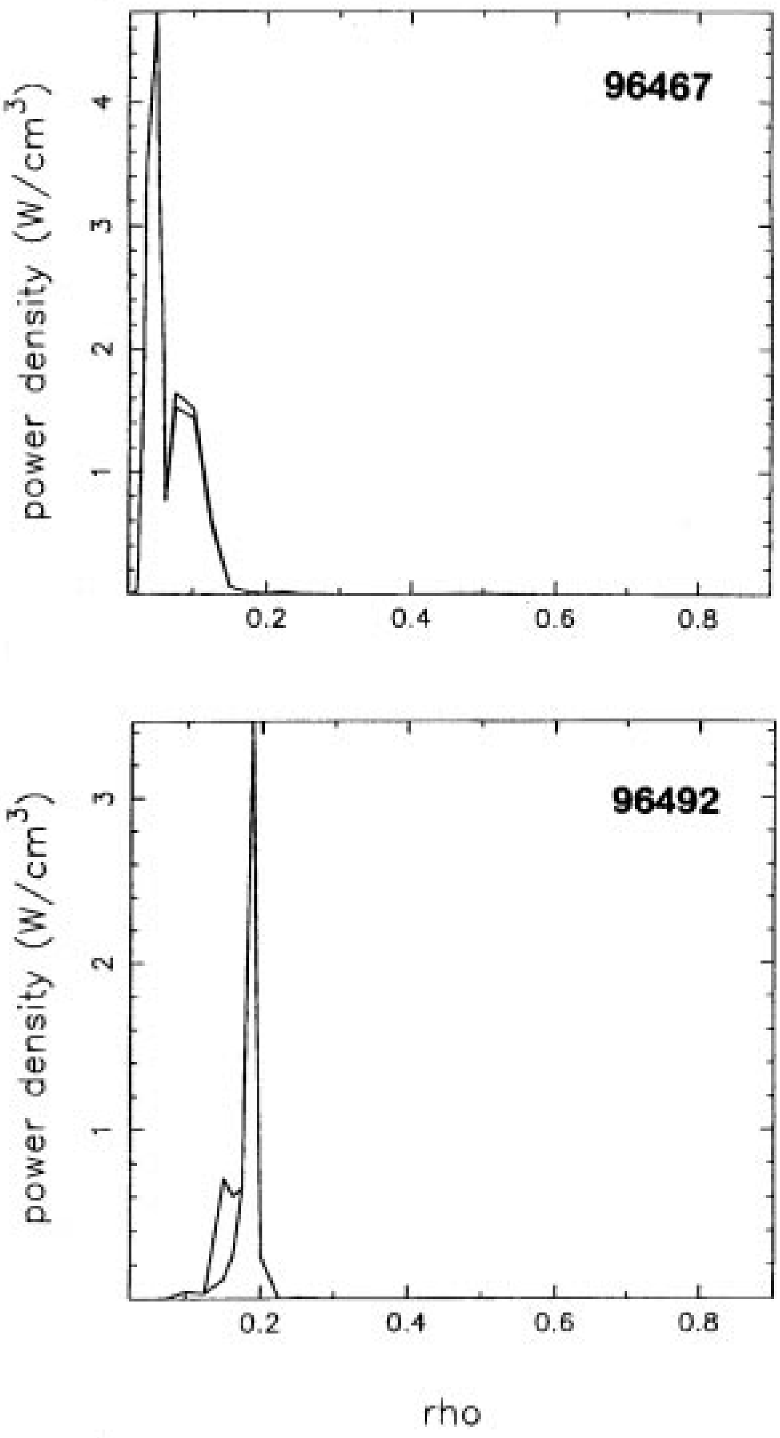
Frequency (ω) and growth rate (γ) of the EPM normalized to the Alfvén frequency in the center.

CQL3D is used to calculate the damping of ICRF waves by the Deuterium injected ions, the Hydrogen minority and electrons.

CQL3D calculates the damping over 5 passes through the plasma, for 42 rays.
The power absorbed is:

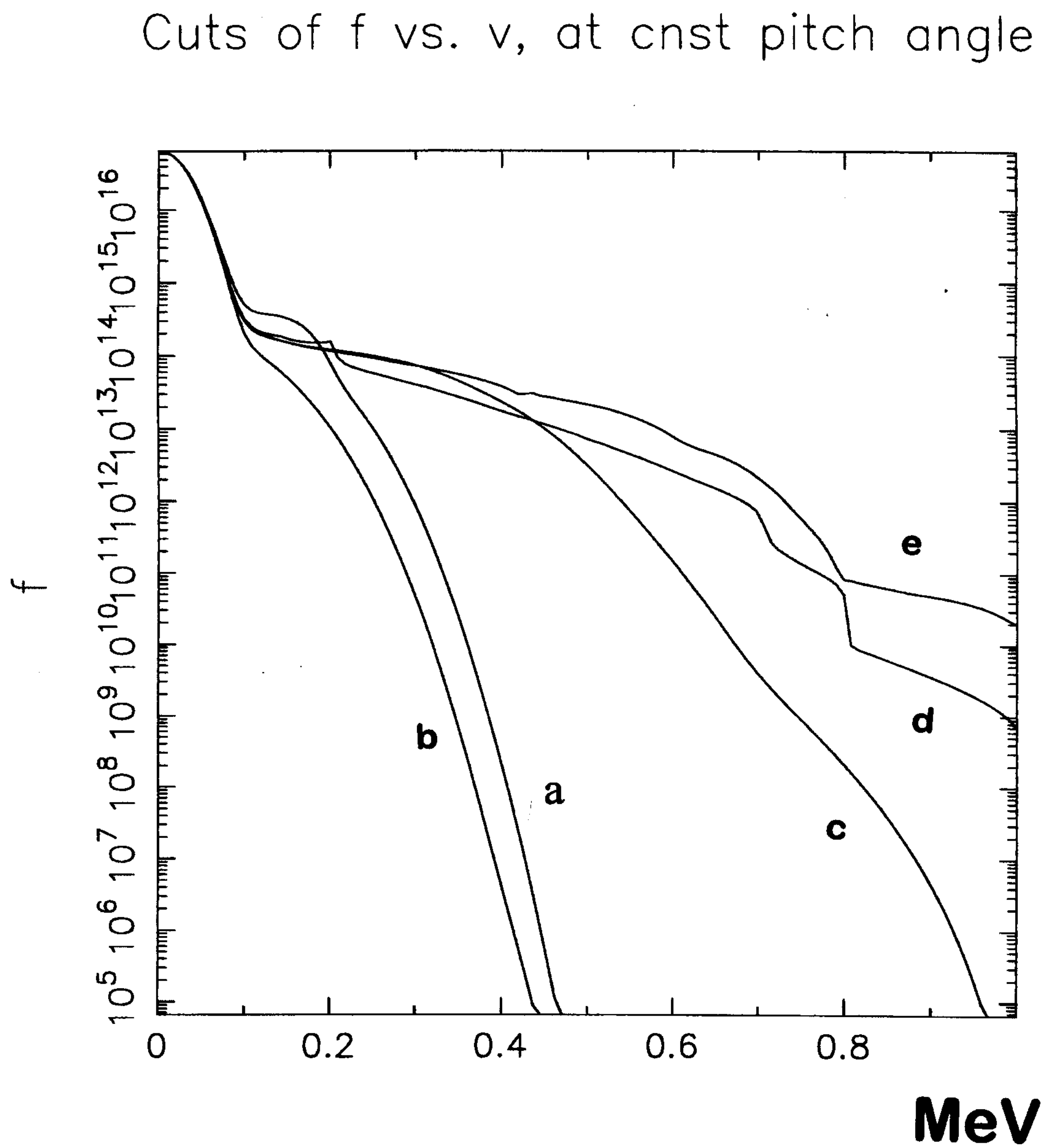
	shot 96467 → monster sawtooth	shot 96492
$3\Omega_D$	~0kW	9kW
$4\Omega_D$	700kW	713kW
$5\Omega_D$	26kW	~0kW
electrons	68kW	75kW

Very likely some power is lost to the walls, but it is not included in the calculation for the time being.



CQL3D

In shot 96467 all the power is deposited in the core, inside q=1 and the fast ions stabilize the sawtooth.

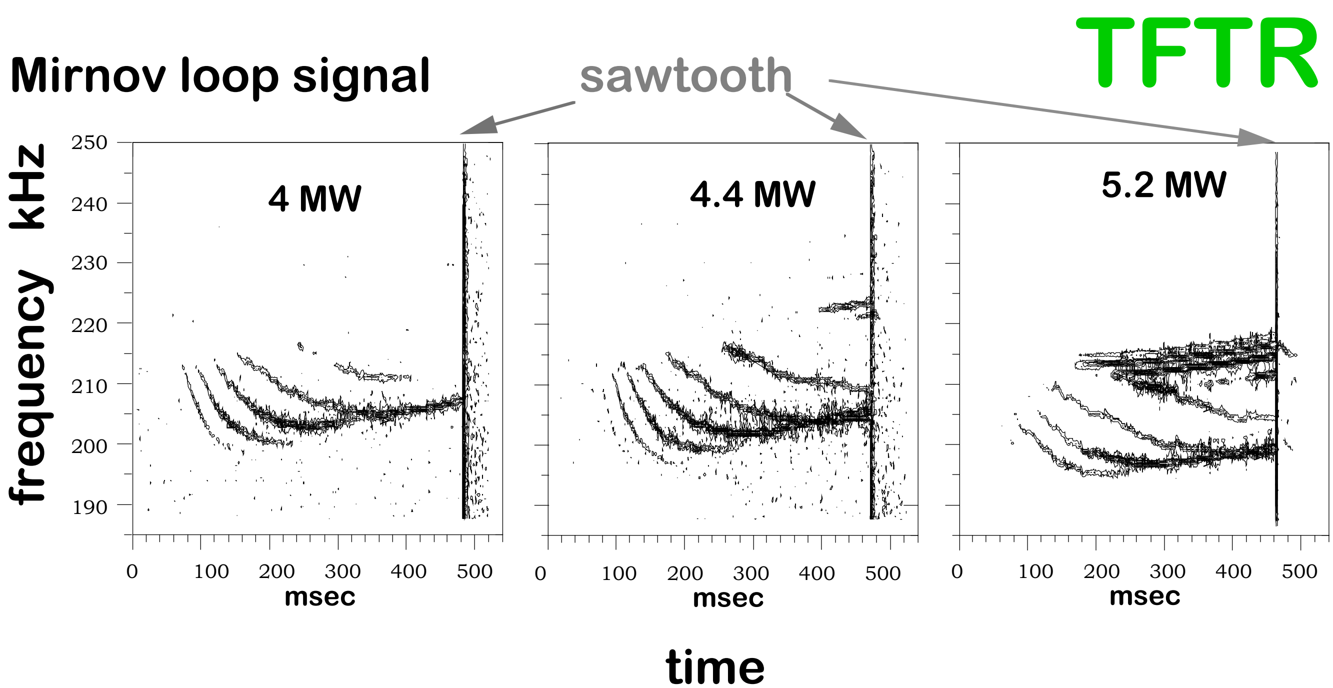


CQL3D

Ion distribution function for shot 96467 at r=4.27 cm

a parallel
b antiparallel
c perpendicular
d at the trapping boundary
e average

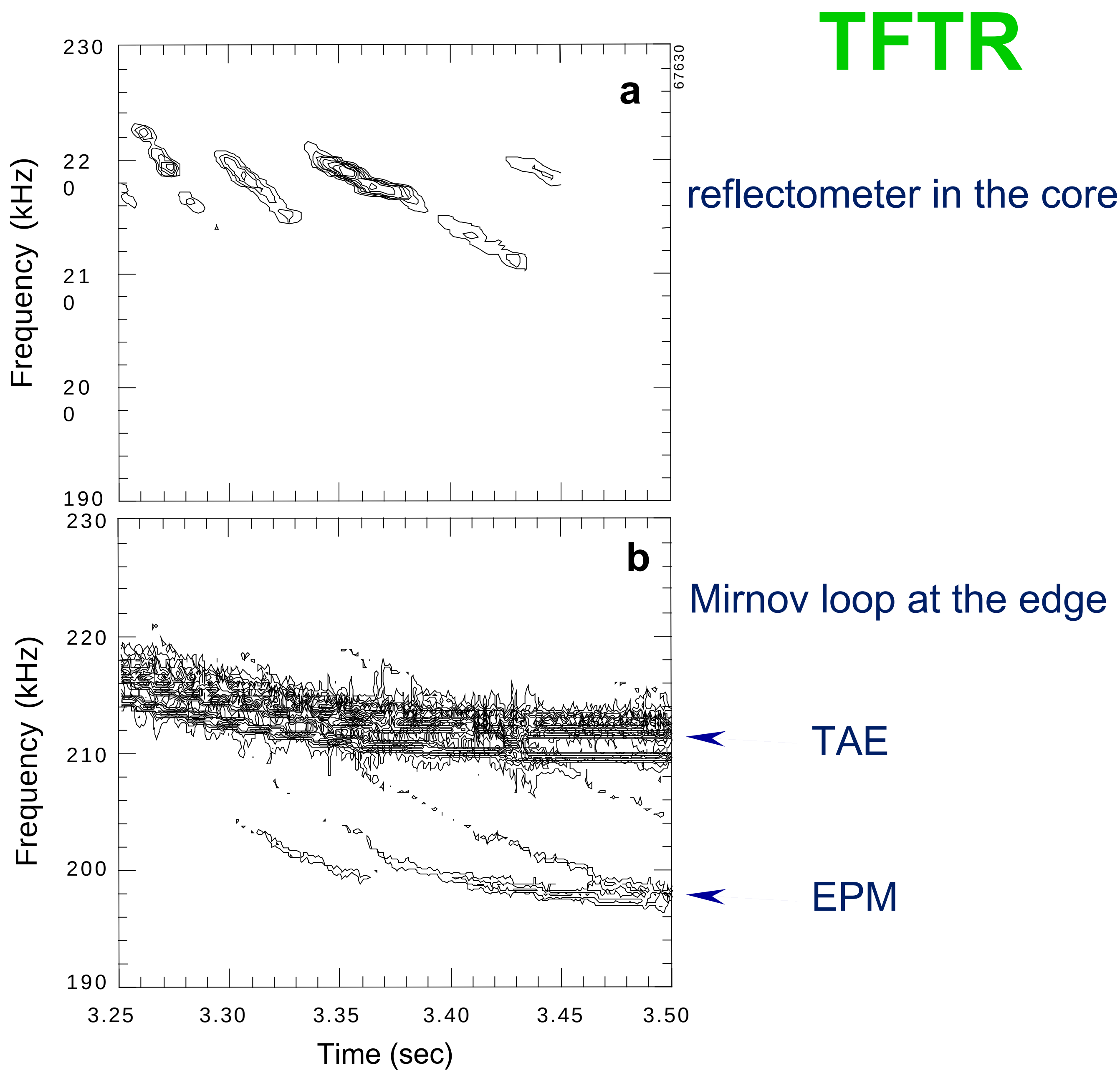
A very similar effect of combination of sawteeth and Alfvén instabilities has been observed and studied in TFTR during ICRF minority heating



EPM (chirping modes) are destabilized before the TAE, even if their threshold is higher.

The TAE, located near the edge, are excited by the fast ions expelled from the core by the EPM. They diffuse the fast ions outside the plasma.

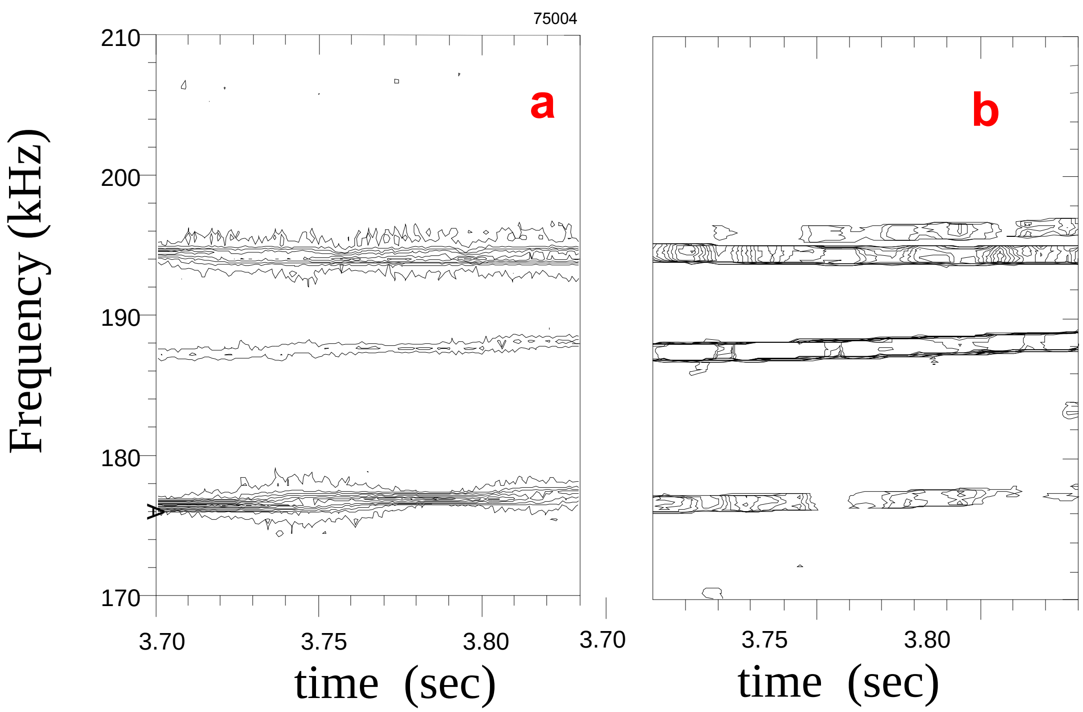
The depletion of fast ions from inside q=1 causes the monster sawtooth crash.



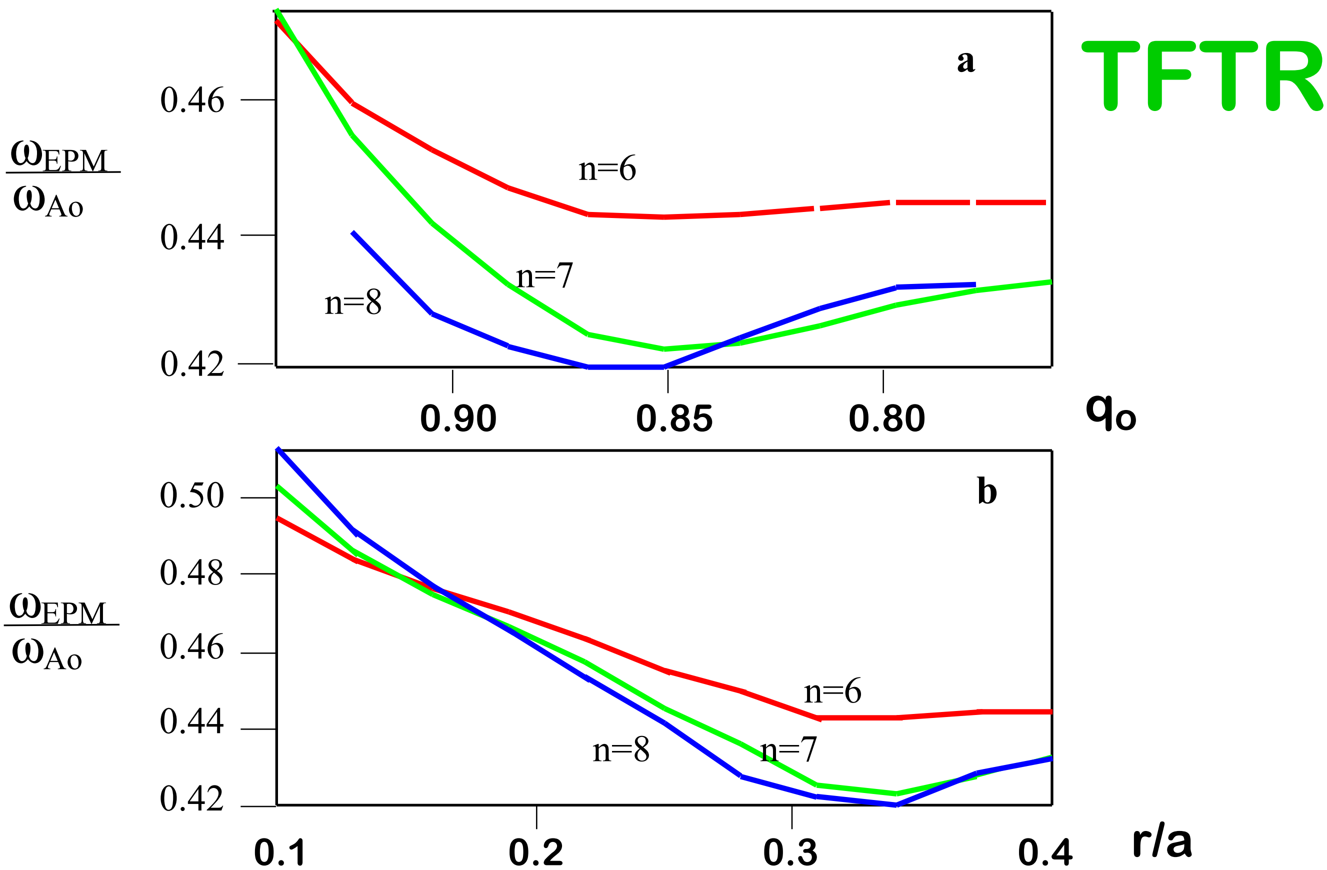
a. A reflectometer detects EPMs near the core of the plasma before the Mirnov loop sees them: the same reflectometer does <u>**not**</u> detect TAEs.

b. As the EPMs location moves toward the edge, they are detected by the Mirnov loop, together with TAEs.

TFTR



At high q_a (≥ 4), only TAEs are detected in the core both by the reflectometer (a) and at the edge (by the Mirnov loop (b).



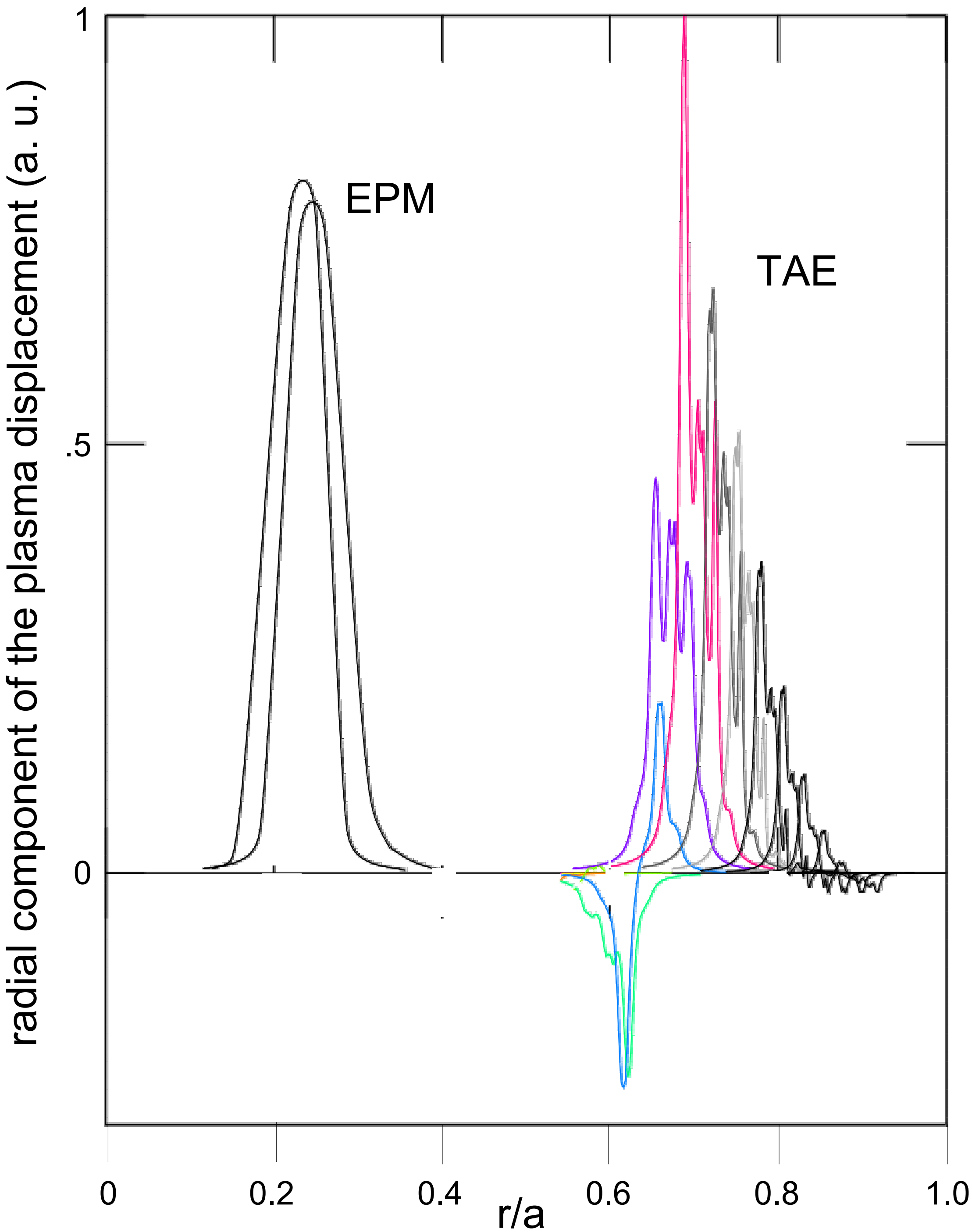
HINST code finds a branch of unstable shear Alfvén waves corresponding to the Energetic Particle Modes (EPM).

These modes are core localized and reside inside the Alfvén continuum.

HINST predicts that the modes move radially outward as q_o decreases.

The modes are destabilized in decreasing n-number.

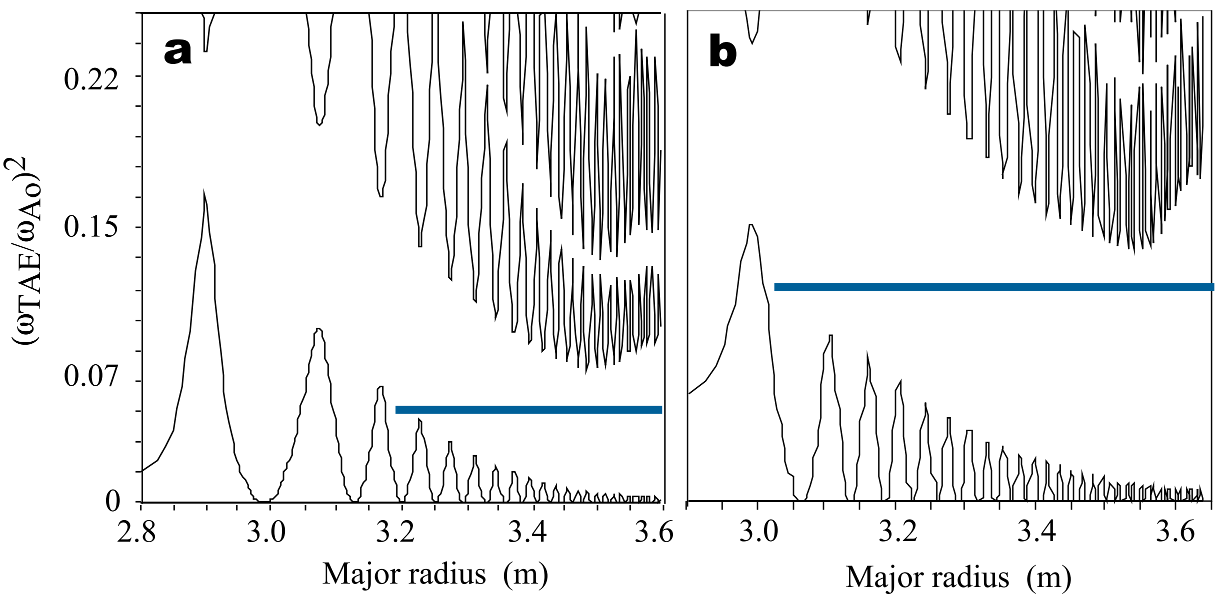
TFTR: q_a=3.2



Reconstruction by NOVA-K and HINST of the eigenfunctions. Te EPMs are localized in the core, while the TAE are confined in the outer half of the plasma.

TFTR

Alfvén frequency gap

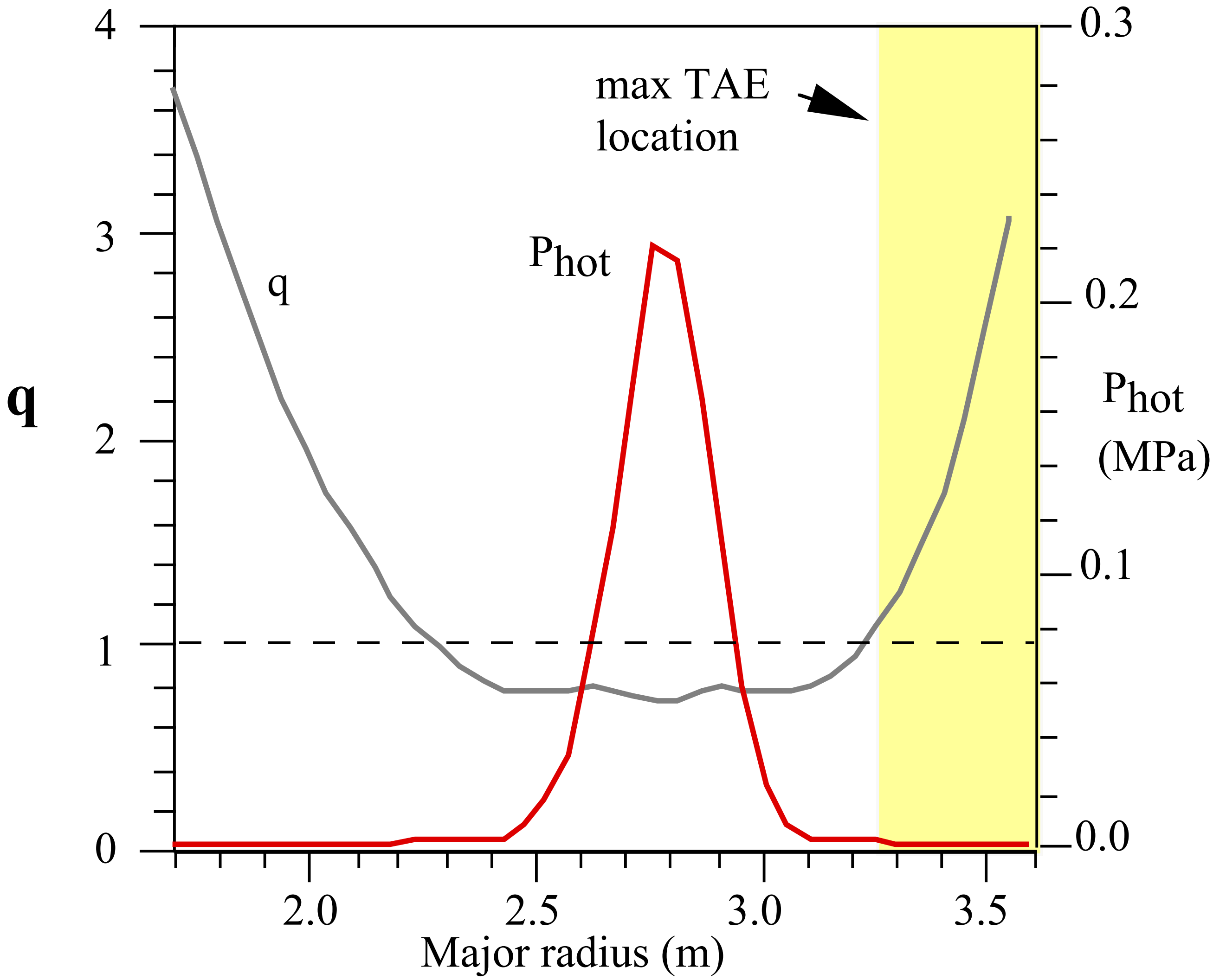


$q_a = 3.2$ $q_a = 4.5$

Because of the toroidal geometry, the Alfvén gap is located near the edge of the plasma.

In high q_a discharges, the Alfvén gap is widened by the steeper q-profile

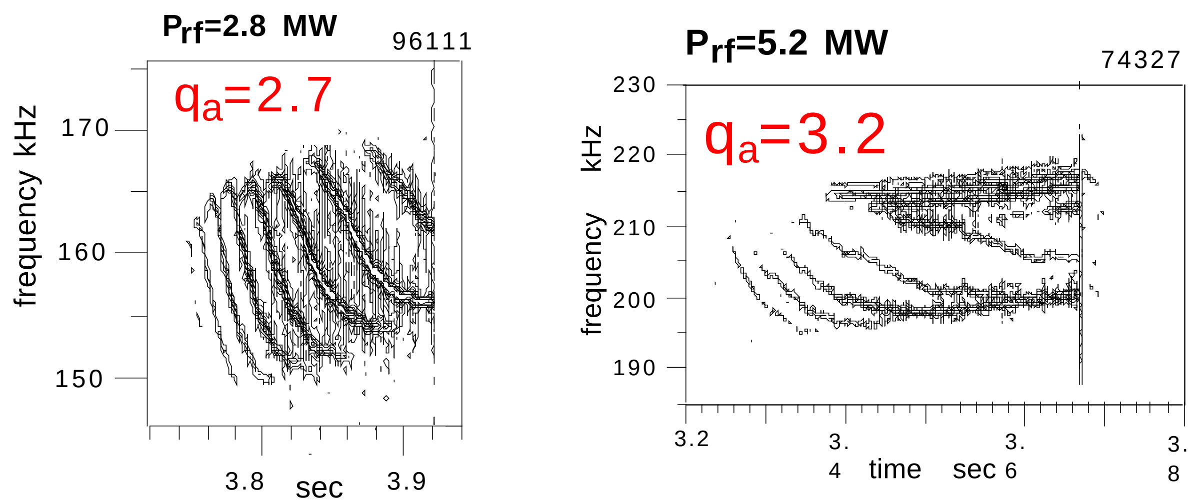
TFTR



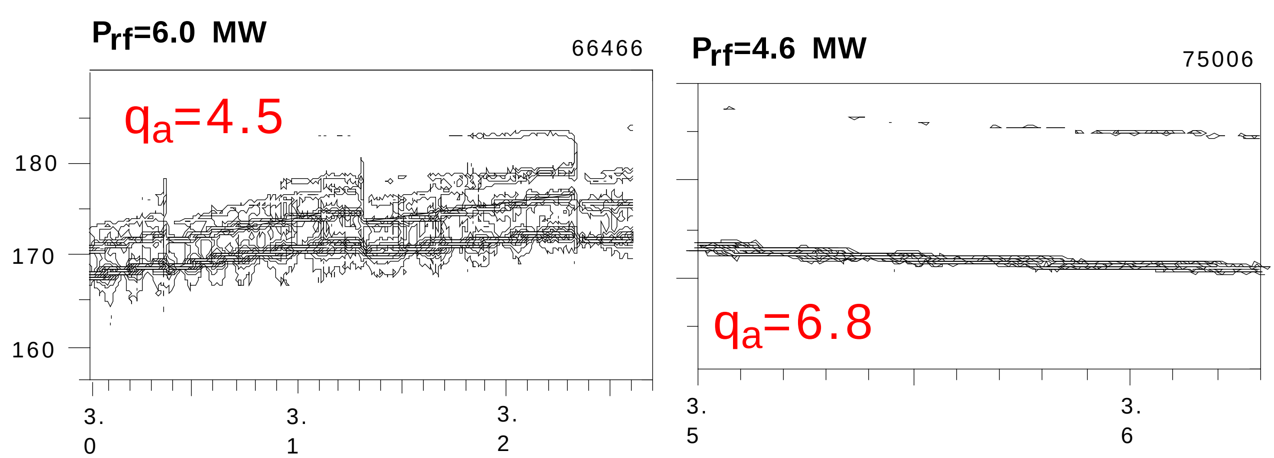
TRANSP calculation of the q-profile and of the hot ion pressure generated by ICRF. The fast ion pressure is not in contact with the TAE, therefore a strong distribution can be formed.

q_a=3.2 P_{RF}=6.2 MW

EPMs are observed only at low q_a



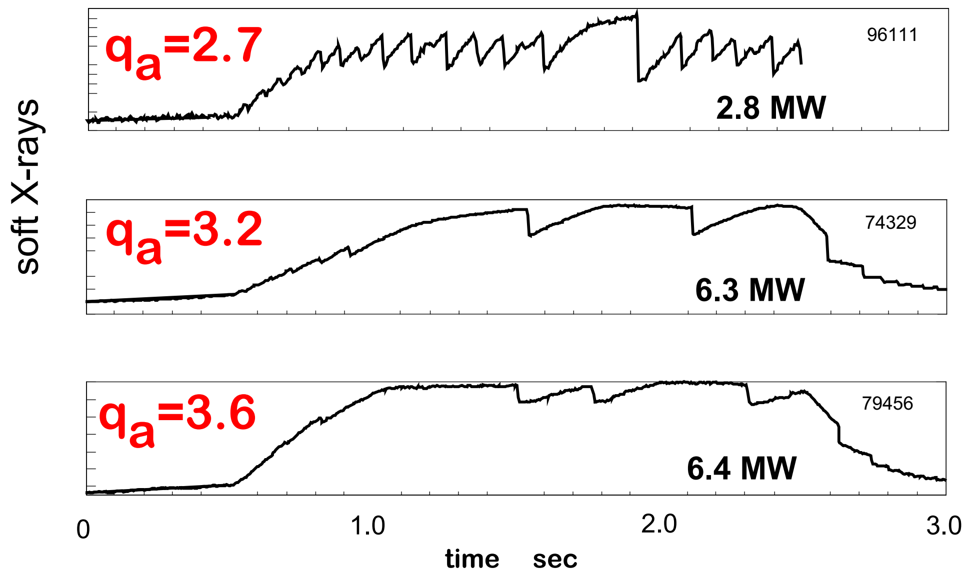
At $q_a \leq 3.6$ there are two kinds of Alfvén modes: one with a chirping frequency and one with a steady frequency.



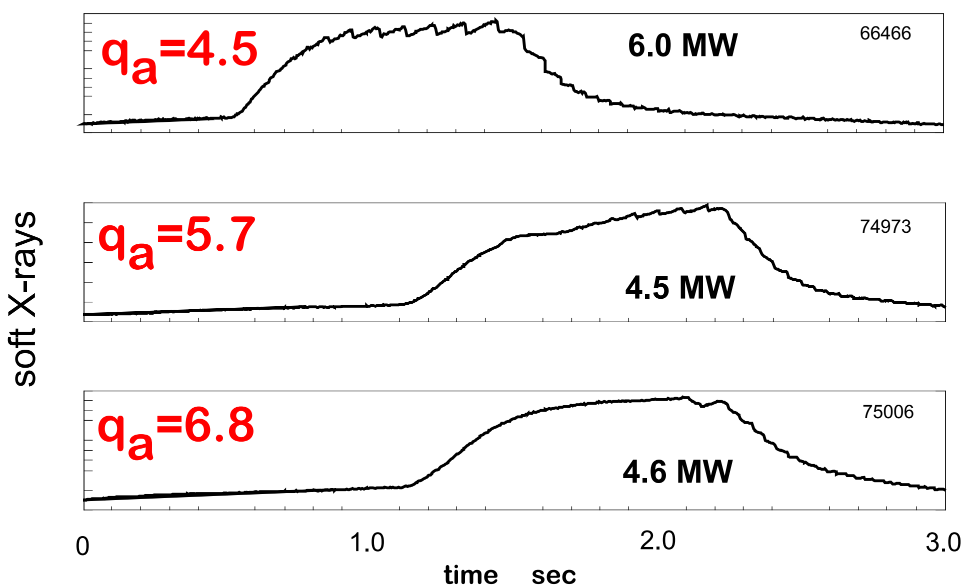
At higher q_a, only the steady modes are observed.

TFTR

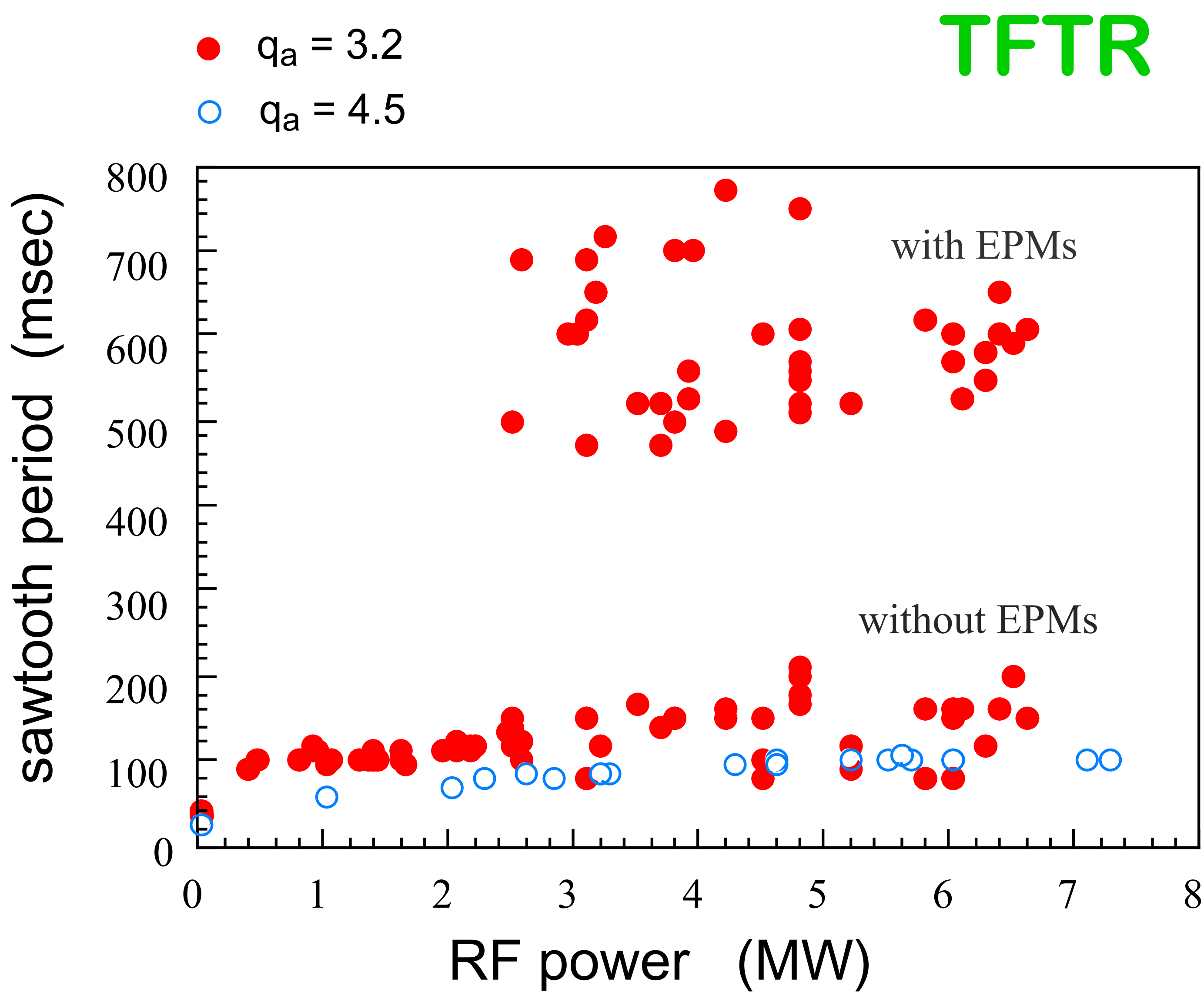
monster sawteeth



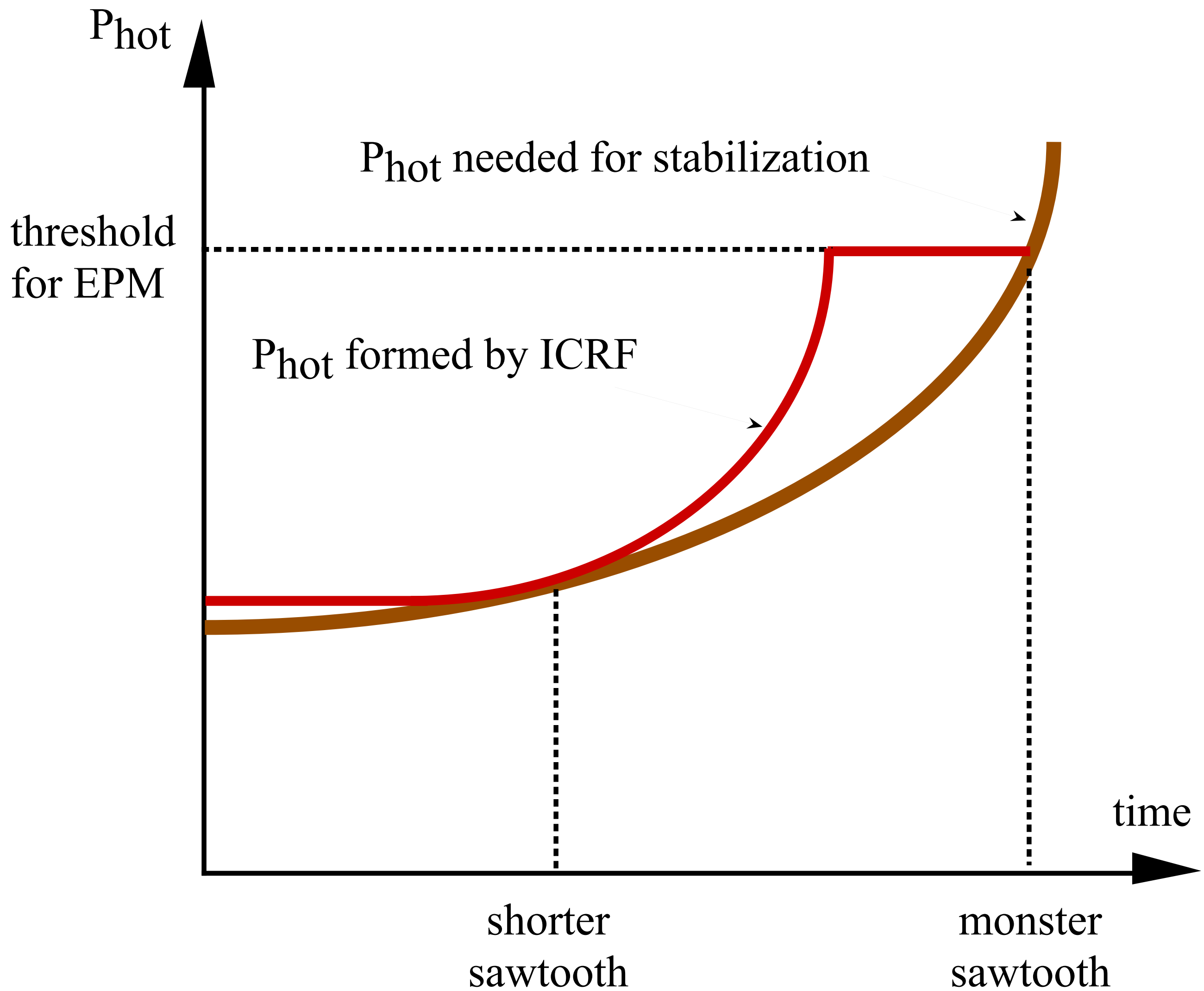
no monster sawteeth



Monster sawteeth are observed always in conjunction with EPM, only at low q_a



There is a bifurcation in the sawtooth period: the very long ones (monsters) are always accompanied by EPMs.



Proposed scenario:

1 initially, while the fast ion population is increased, the q=1 surface broadens, creating the possibility of the sawtooth crash.

2 If the critical point is passed, then the fast ion population increases faster than the q=1 surface and a good degree of stability is obtained: this is indicated by the fact that <u>large</u> fast ion losses are observed for up to ~200 msec before the crash.

Conclusions

Fast ions, either generated by ICRF minority heating or by acceleration of NBI ions, can transiently stabilize the sawteeth.

The lack of a loss mechanism in the core allows the formation of a strong fast ion population, which can destabilize Energetic Particle Modes.

These EPMs are core localized, but propagate radially outward as q_o decreases, carrying fast ions with them.

The combination of q=1 broadening and the destabilization of EPMs in the core, causes the sawtooth crash.

PROPOSAL: since it is the decrease in q_o that ultimately causes the radial diffusion of the fast ions, it would be interesting to see if a sawtooth free discharge can be maintained by applying either ECCD counter current drive or off-axis CD to keep $r_{q=1}$ fixed.