Alfvén Eigenmode evolution in NBI-heated plasmas with dynamic magnetic configuration in the TJ-II stellarator

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INTRODUCTION

Alfvén Eigenmodes (AEs) were studied in the low magnetic shear flexible heliac TJ-II (B_0=1 T, <R>=1.5 m, <a>=0.22 m).
The AE-modes were excited by hydrogen co-NBI in L-mode hydrogen plasmas ($P_{NBI} \leq 0.56$ MW, E_{NBI}=32 keV), and were diagnosed by HIBP [1], MPs and bolometers.
Taking advantage of the unique TJ-II capabilities, a dynamic magnetic configuration experiment with iota variation during discharge was performed via inducing the net plasma current I_{pl}.
Experiment has shown a strong effect of the iota value on the mode frequency. A drastic frequency change from ~50 to ~250 kHz was observed for some AEs, when plasma current as low as ±2 kA was induced by small (≤10%) changes in the vertical field (VF).
On top of the conventional linear link between f_{AE} and I_{pl}, which could explain the local extrema of f_{AE} coinciding with the extrema of I_{pl} via $k_{//}$, a new type of f_{AE} dependence on I_{pl} has been observed.

EXPERIMENTAL SET-UP

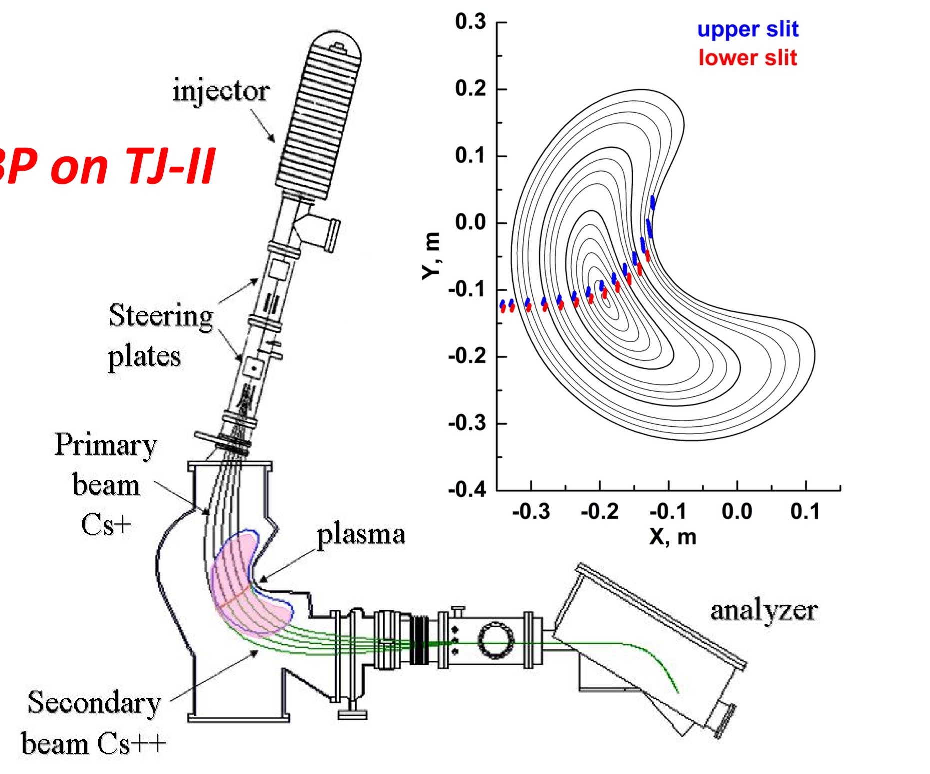
Beam characteristics	Plasma parameters
Energy ΔE_{beam}	$\varphi \rightarrow E_r$
Beam current ~I_{beam}	~n_e
Displacement ~Z_d	~B_{pol}

Poloidal orientation of sample volumes:

$E_p = (\varphi_1 - \varphi_2)/x$, x~1 cm $k_\theta < 3$ cm^{-1}

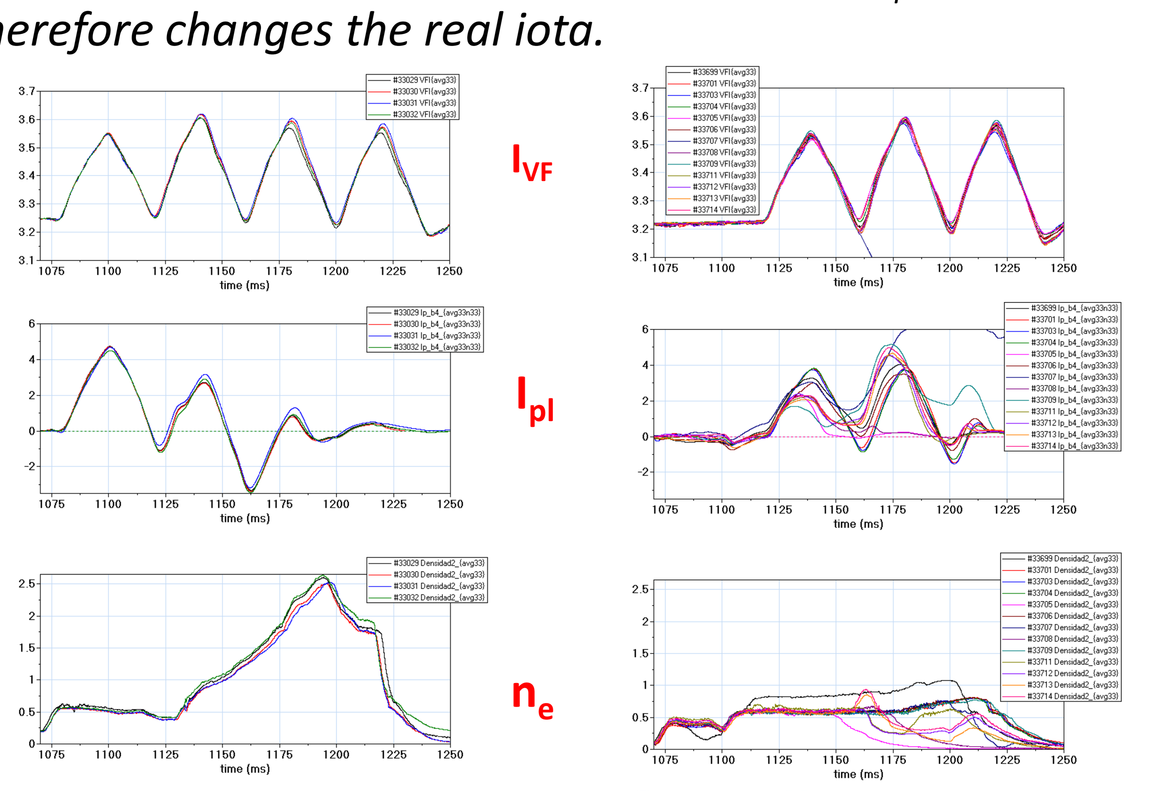
Turbulent particle flux
$\Gamma_r = \Gamma_{EpolxBtor} = \langle n_e\sim v_r\sim \rangle = \Gamma_{ExB}$
Poloidal mode number
$m = Lk_\theta/2\pi$
Poloidal propagation velocity
$V_\theta = Lf/m$

HIBP on TJ-II



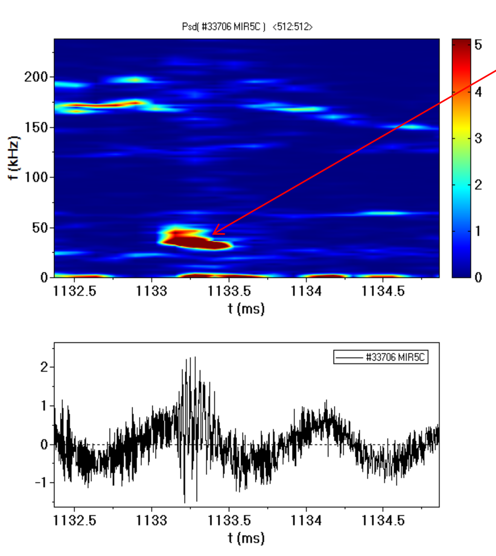
SCENARIO: Variable Magnetic Configuration

Vertical Field (VF) Modulation keeps vacuum iota the same, but causes the change of the plasma current I_{pl} and therefore changes the real iota.



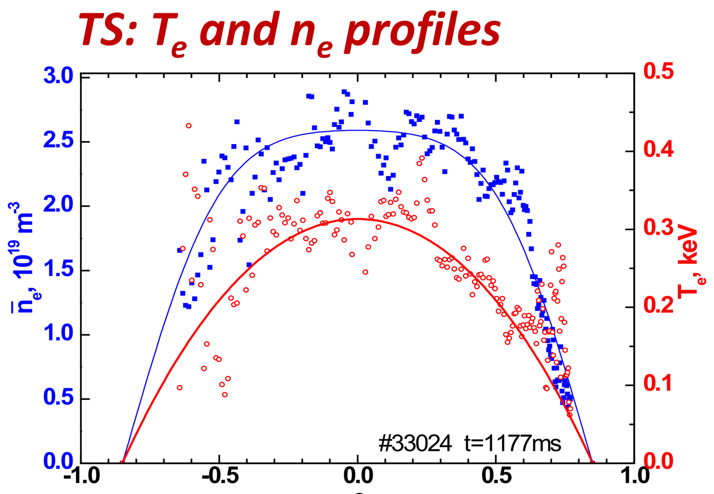
Group I ***Group II (OH compensation)***

Extrema of type II are reproducible and robust phenomenon.
They are accompanied by splash of the frequencies 35-45 kHz and higher up to 300 kHz.



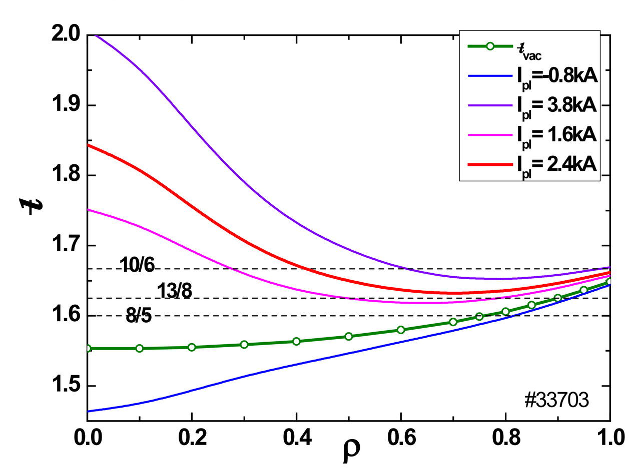
PROFILES

TS: T_e and n_e profiles



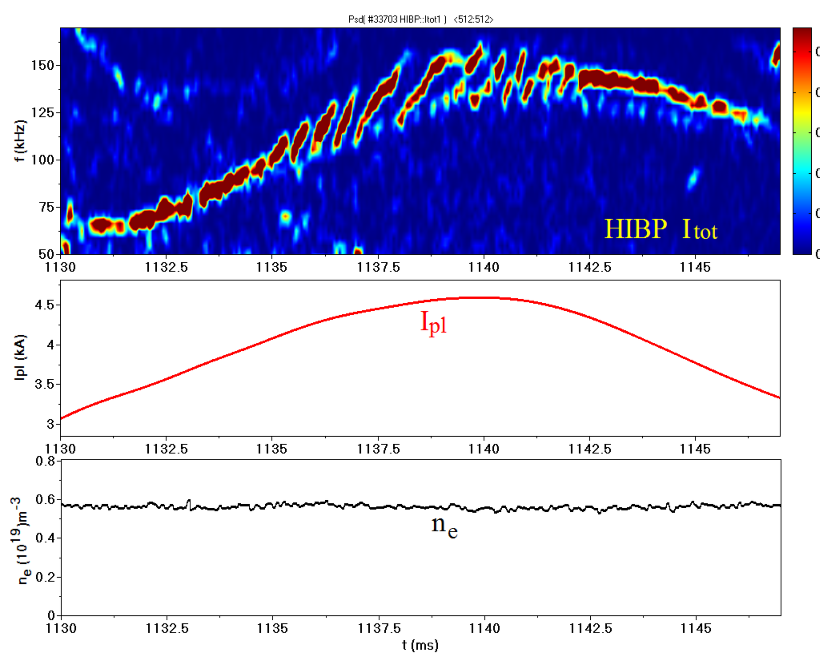
P_{NBI1} = 560 kW, U_{NBI1} =31.5 kV

iota profiles at various currents



STEADY TO CHIRPING TRANSITION

Transformation due to I_{pl} variation caused by VF

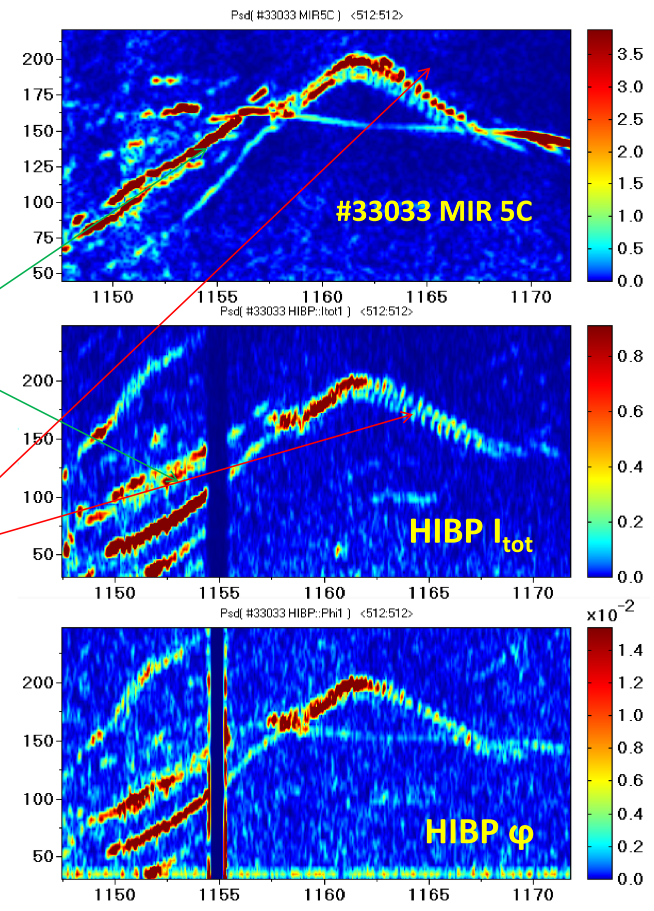


n_e and T_e are permanent, collisionality (slowing-down time) remains.
How does iota cause the transformation?

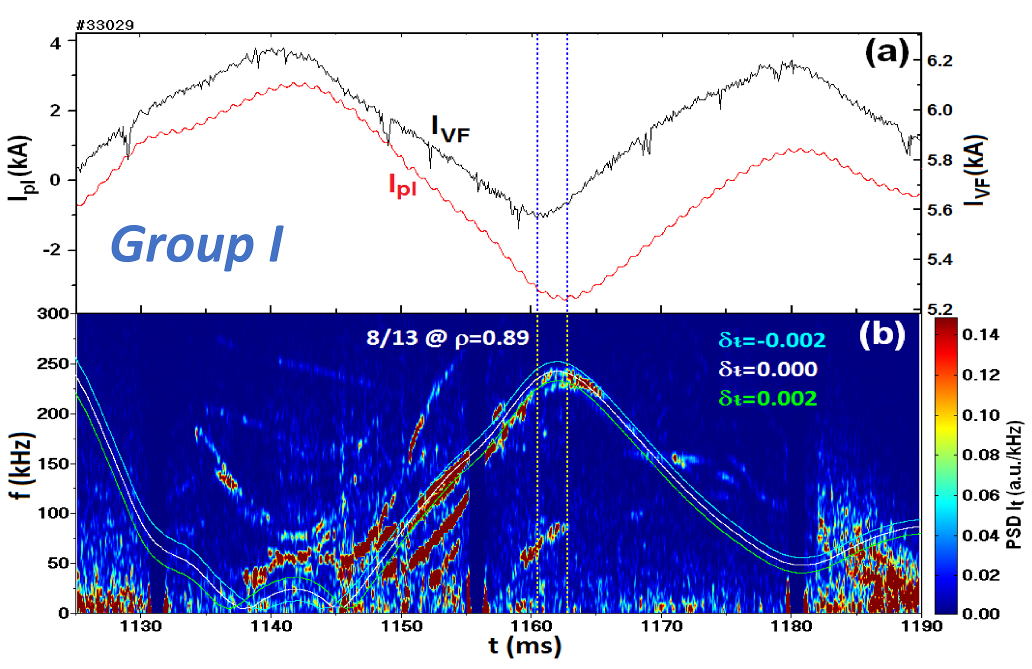
Transformation due to change sign of I_{pl} time-derivative

I_{pl} decreases - steady frequency mode

I_{pl} increases - chirping mode



EXPERIMENT: Extrema of Type I



Minima and maxima of AE frequency correspond to the extrema of I_{pl}

Modelling

AE frequency follows the formula [2]

$$f_{AE}(\rho_{AE}) = \frac{1}{2\pi} k_{\parallel} V_A$$

$$k_{\parallel} = \frac{1}{R}|m\iota - n|$$

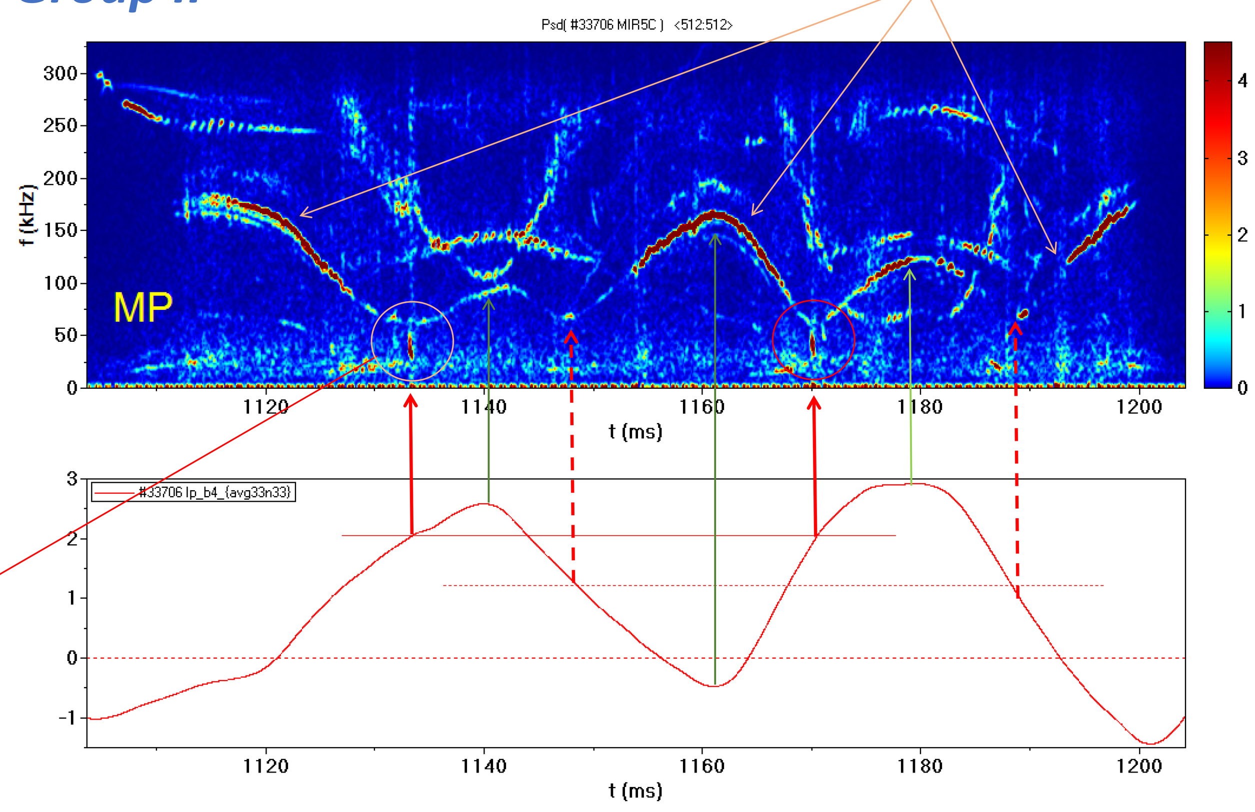
$$\iota(\rho_{AE}, t) = \iota_{vac}(\rho_{AE}, t) + C(\rho_{AE})\, I_{pl}(t)$$

The first group of shots is characterized by:
1) **Lifetime of AE is below a period of VF variation.**
2) **AE frequency minima and maxima corresponds to extrema of actual iota caused by I_{pl} .**

EXPERIMENT: Extrema of Type II

Group II

Mode under study lives as long as two periods of I_{pl} modulation – long-living mode (90 ms) , very rare case for TJ-II



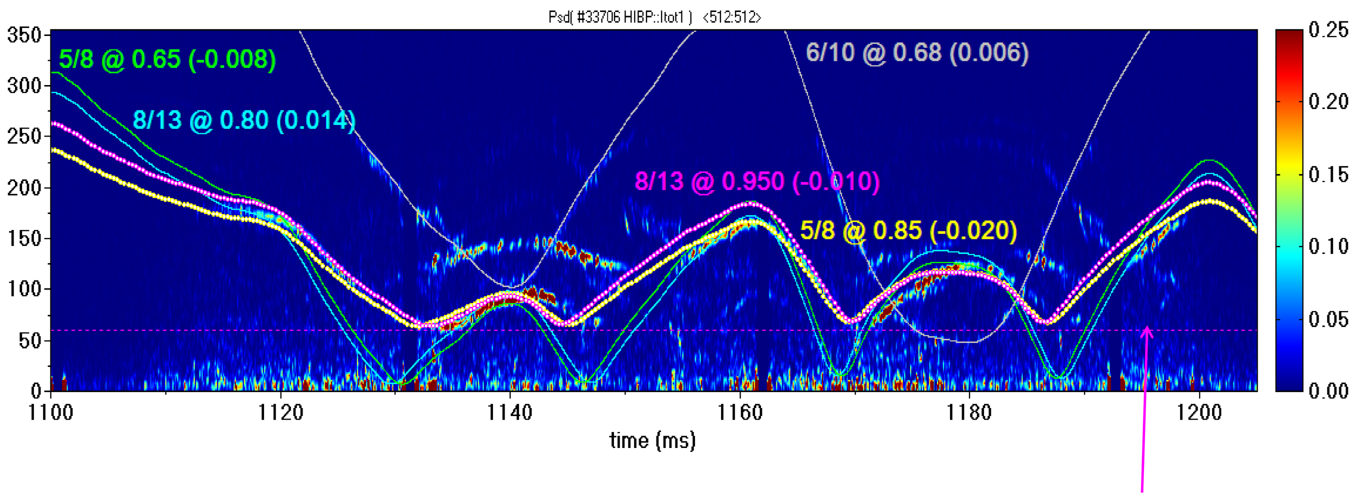
For the selected mode:

1) Local maxima of f_{AE} happen at the time of local extrema (maxima or minima) of I_{pl} - extrema of type I.

2) There are local minima of f_{AE}, which are located inside the intervals of linear I_{pl} growth/decay - extrema of type II.

AE frequency minima of type II: I_{pl} doesn’t have extrema in these points.
There is the experimental lower limit for f_{AE}: f_{AE} > 50 kHz.
A theory predicts $f_{AE} > f_{GAM}$

MODELLING: Modified model



Minima of type II appear, when $k_{\parallel} = 1/R \cdot |n - m\iota|$ becomes zero and term $(n - m\iota)$ changes its sign.
The old model [2] predicts that f_{AE} should reflect from zero.

Minima of type II are visible, when I_{pl} increases, and much less visible, when I_{pl} decreases, because AE disappears.

Modified model: $f^*(t) = f_{model}(I_{pl}(t)) + f_0$, $f_0 = f_{min}$ = const

If we shift f_{model} on f_{min} = const, we can obtain the curve $f^*(t)$ very close to the experimental $f^{AE}(t)$.
Minima of type II in this case are result of change of sign of |n-ιm| in $k_{||}$ = 1/R*|n-ιm|.

Minima of type II are smooth due to the iota smoothing. They should be sharp due to the modulus dependence in |n - ιm|.

SUMMARY

- The global minimum value for f_{AE} was observed, no AE exists with $f_{AE} < f_{min}$
- On top of conventional linear link between f_{AE} and plasma current I_{pl}, a new type of f_{AE} dependence on I_{pl} has been observed in TJ-II: when ι = n/m for specific mode, f_{AE} reaches f_{min}, then changes direction of evolution (decrease to raise).
- The evolution of AE from steady frequency mode to chirping mode and back takes place, when the plasma current reaches certain values or changes direction of evolution (raise to decrease).

ACKNOWLEDGEMENTS / REFERENCES

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[1] A.V. Melnikov *et al*, Nuclear Fusion **57** (2017) 072004
[2] A.V. Melnikov *et al*, Nuclear Fusion **54** (2014) 123002