26th IAEA Fusion Energy Conference
Kyoto, Japan, 17-22 October 2016

IAEA-CN-234/EX/3-4

Global stabilization effect of Shafranov shift on the edge pedestal plasmas in JET and JT-60U

H. Urano[1], S. Saarelma[2], L. Frassinetti[3], N. Aiba[4], C.F. Maggi[2], I.T. Chapman[2], I. Lupelli[2], C. Challis[2], M. Leyland[5], M. Beurskens[6], K. Kamiya[1], C. Giroud[2], S. Pamela[2], JT-60 Team[1] and JET Contributors*

EUROfusion Consortium, JET, Culham Science Centre, Abingdon, OX14 3DB, UK
[1] National Institutes for Quantum Radiological Science and Technology, Naka, Ibaraki 311-0193, Japan
[2] Culham Centre for Fusion Energy, Culham Science Centre, Abingdon OX14 3DB, UK
[3] Division of Fusion Plasma Physics, KTH Royal Institute of Technology, Stockholm, Sweden
[4] National Institutes for Quantum Radiological Science and Technology, Rokkasho, Aomori 039-3212, Japan
[5] York Plasma Institute, University of York, Heslington, York, YO10 5DD, UK
[6] Max-Planck-Institut für Plasmaphysik, Wendelsteinstr. 1, D-17491, Greifswald, Germany
*See the author list of "Overview of the JET results in support to ITER" by X. Litaudon et al. to be published in Nuclear Fusion Special issue: overview and summary reports from the 26th Fusion Energy Conference (Kyoto, Japan, 17-22 October 2016)

Background

In the present understanding, H-mode confinement is determined by the edge and core interplay.

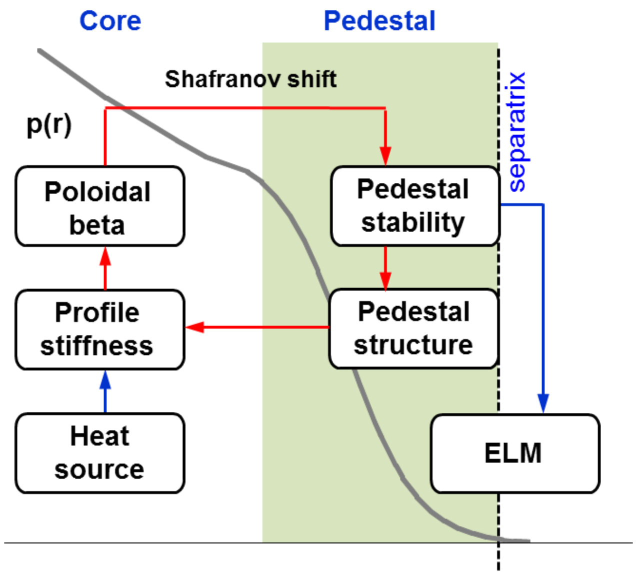
1. Pedestal structure is determined by the edge stability. The pedestal plays a role as a boundary condition determining the core confinement through profile stiffness.

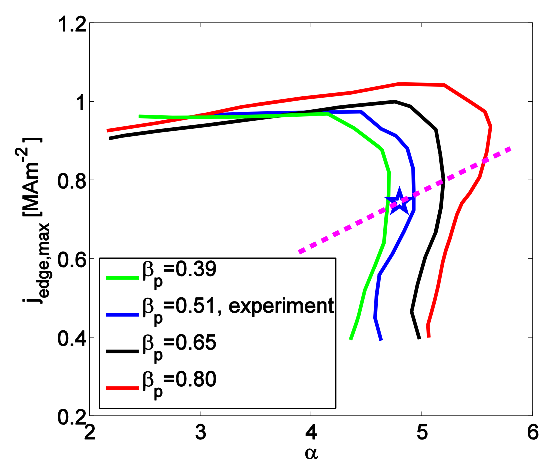
2. The increased poloidal beta can stabilize the pedestal plasma.

The effect of Shafranov shift on the pedestal has been examined by the stability analysis.

However, it is still unknown how effectively this global stabilization works on the pedestal depending on the plasma shape.

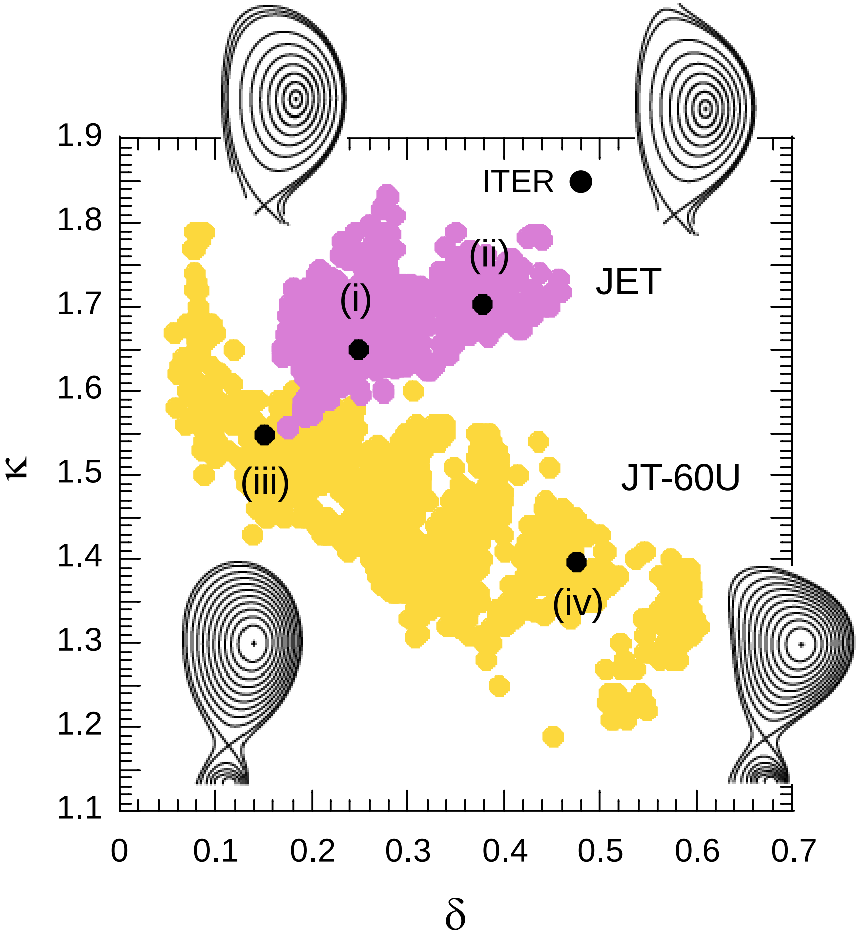
Examine the effect of the Shafranov shift on the pedestal in the variation of the plasma shape using JET and JT-60U.





S. Saarelma, H-mode WS 2013
I.T. Chapman, NF2015, this conference

Operational area of plasma shape in JET and JT-60U



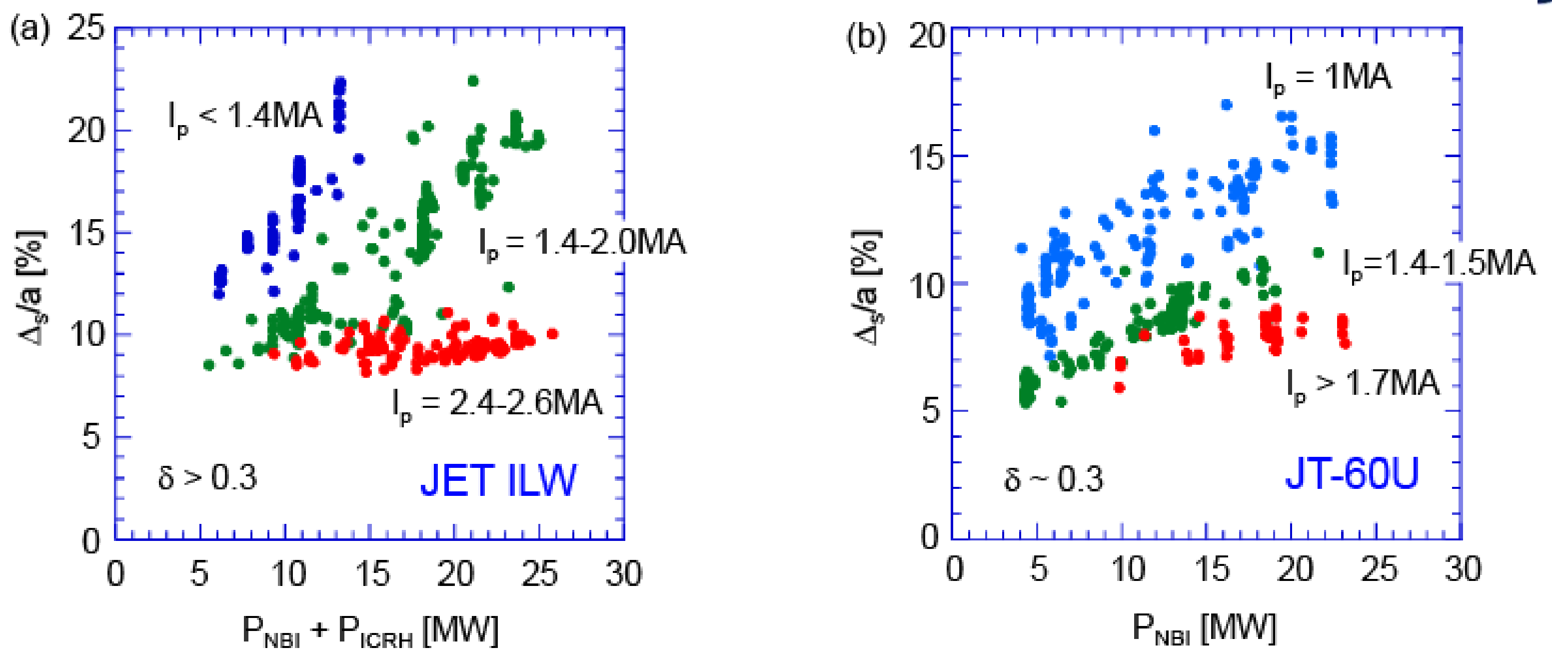
A large difference in the operational plasma shape between JET and JT-60U.

JET: δ=0.15-0.45 at high κ
JT-60U: wide variation of δ (=0.05-0.6) at relatively low κ. Anti-correlation between δ and κ.

The increased Shafranov shift stabilizes mainly the PBM ballooning component at the pedestal.

In the main operational regime of JET and JT-60U, the edge pedestal plasmas become generally unstable in this region.

Dependence of the Shafranov shift on the heating power



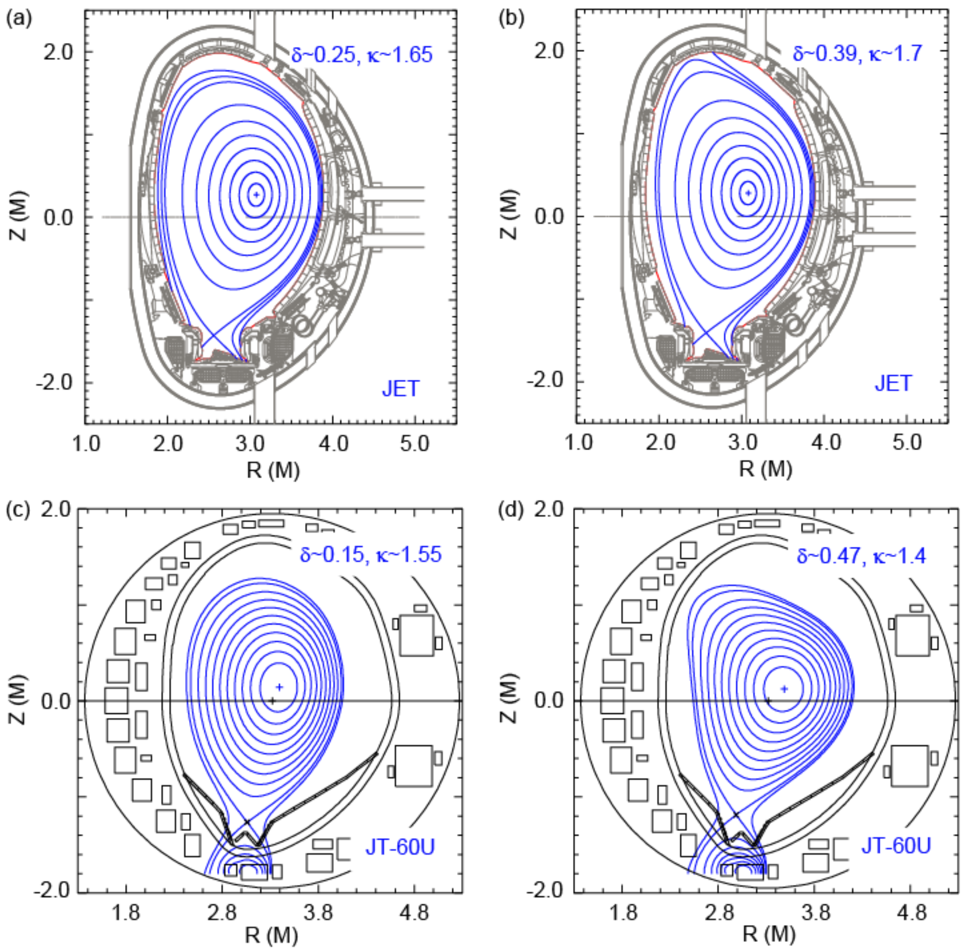
Shafranov shift can more easily be increased at lower I_p, whereas it is increased only very weakly at high I_p with increasing power.

$$\beta_p \sim \langle p \rangle / {I_p}^2$$

In order to keep a wide variation of the Shafranov shift or β_p, it is better to choose the experimental condition at relatively low I_p.

Employed the dataset of H-mode experiments at relatively low I_p with a wide variation of the heating power to change β_p.

Four types of plasma shape employed in this study



Four configurations were employed with wide variation of β_p.

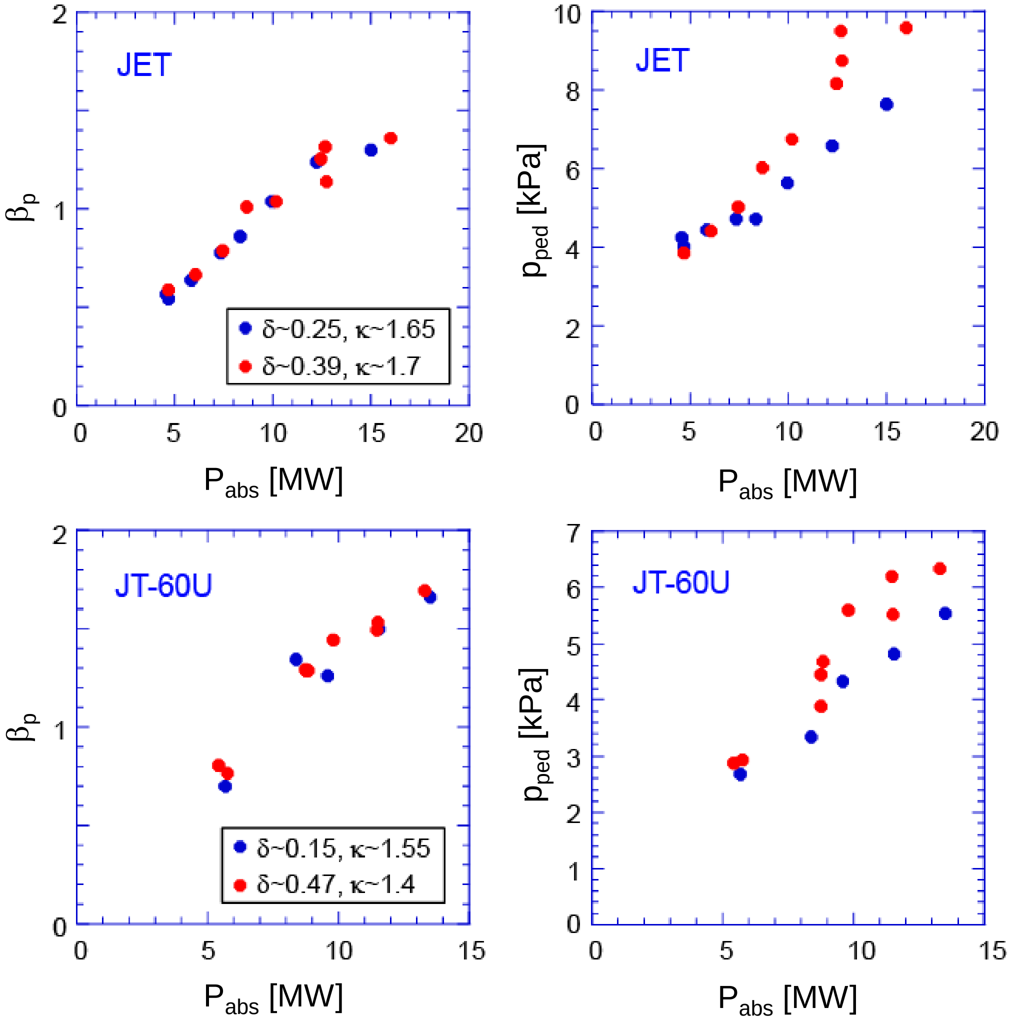
JET-ILW: 1.4MA/1.7T, q_{95} ~ 3.9
R~2.9m, a~0.92m, P_{NBI} = 5-16MW

Low and high δ at high κ
[Challis, NF2015, Garcia, NF2015]

JT-60U:
1.0MA/2.1T, q_{95} ~ 3.7
R~3.3m, a~0.8m, P_{NBI} = 6-15MW

Low δ at medium κ and high δ at low κ
[Kamada, IAEA2002]

Edge pedestal characteristics with increased β_p in JET and JT-60U

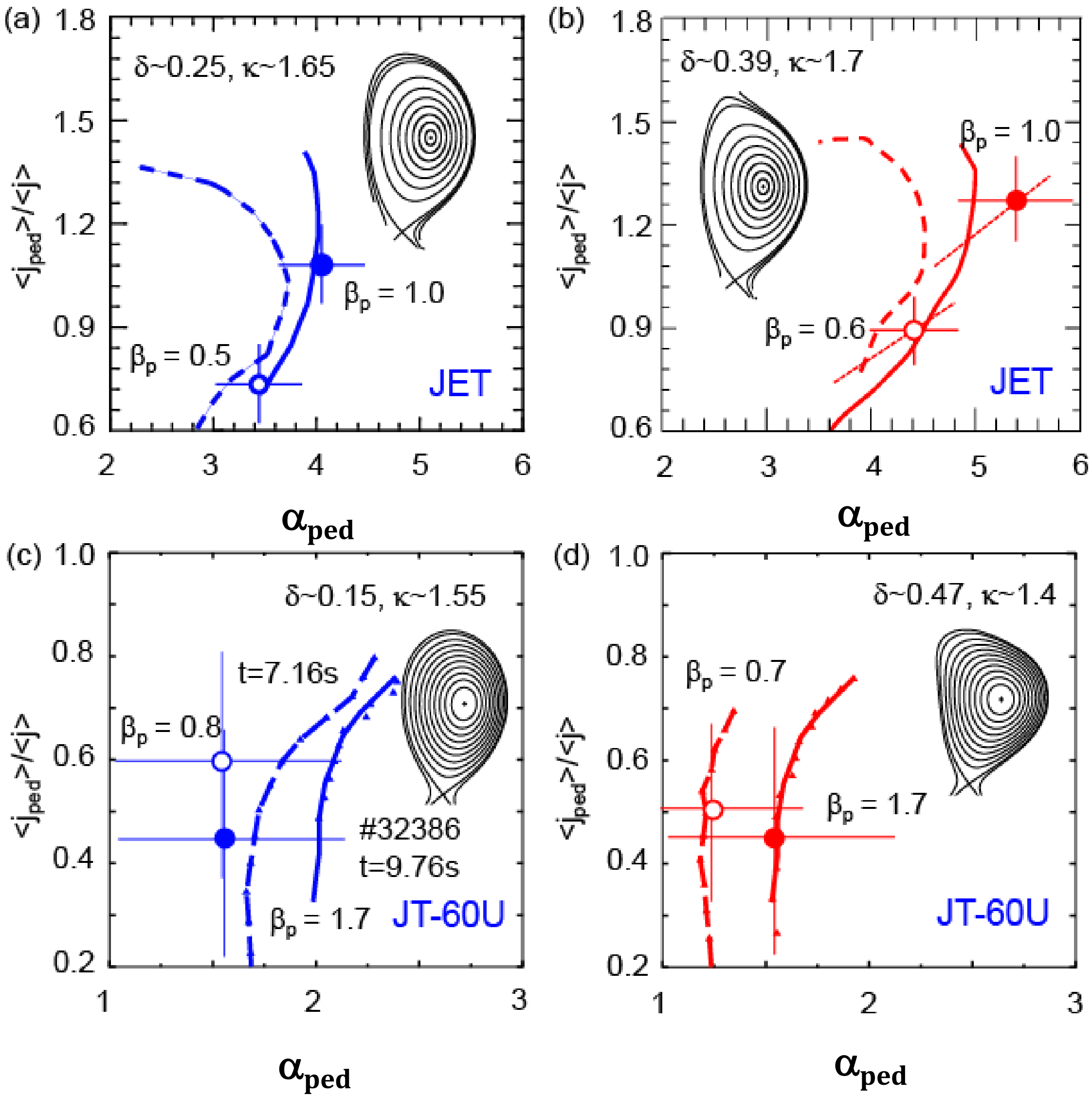


Global β_p increases with heating power for both low and high δ.

The pedestal pressure becomes larger at high δ in both devices, independently of κ.

The difference in pedestal pressure between low and high δ becomes larger with increased power.

Pedestal stability limit extends with the increased β_p for all types of plasma shape



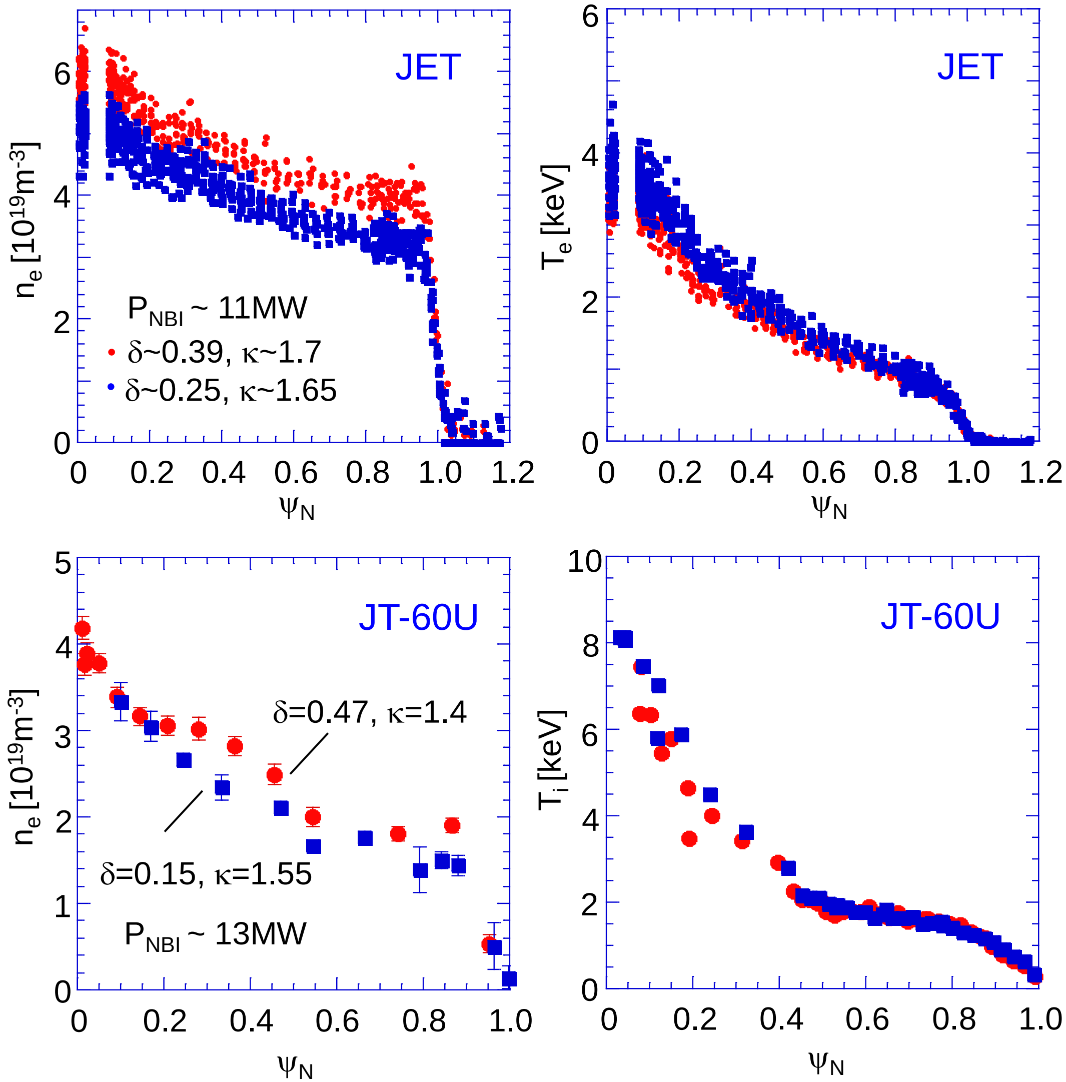
The PBM stability boundaries are compared between low and high power cases.

Global β_p changes roughly twice.

The stability limit of $(\mathrm{d}p/\mathrm{d}\psi)_{\mathrm{ped}}$ is raised by increased β_p for all types of plasma shape consistently with the experimental result.

The experimental $(\mathrm{d}p/\mathrm{d}\psi)_{\mathrm{ped}}$ is raised more strongly at high δ and high κ.

Density is raised by high δ configuration



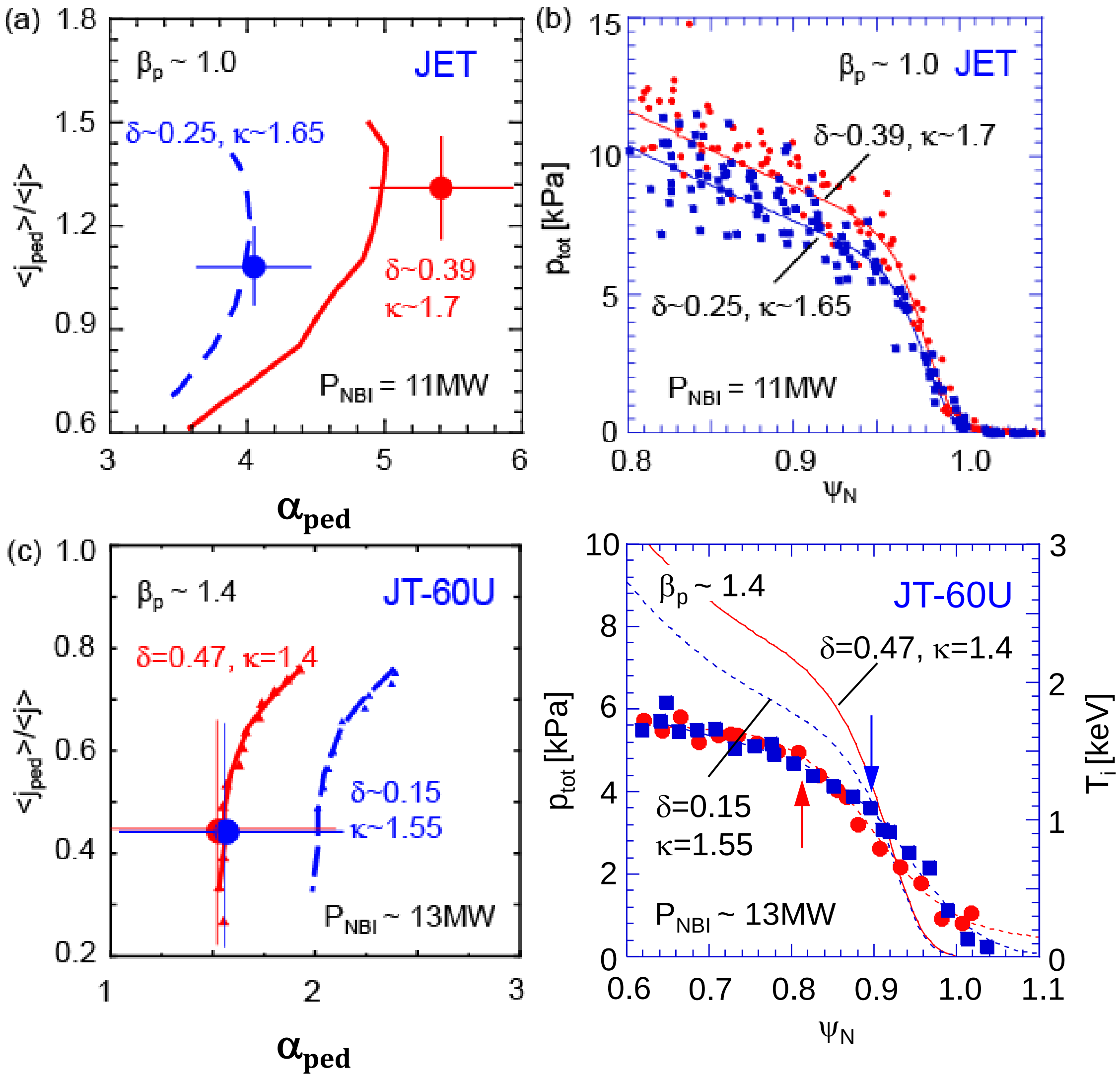
Density and temperature profiles are compared between low and high δ plasmas at fixed condition.

High δ configuration leads to high density throughout the minor radius, independently of κ.

Temperature profile does not change significantly or the core temperature becomes lower at high δ.

The increased pedestal pressure at high δ is mainly attributed to the increased density.

Pedestal is stabilized by high δ at fixed β_p whereas it is destabilized by low κ even at high δ



Global β_p is nearly the same at for low and high δ in each device.

Even at fixed β_p, larger $(dp/d\psi)_{ped}$ is obtained at higher δ due to the expanded stable region.

Nearly the same pedestal width between low and high δ.

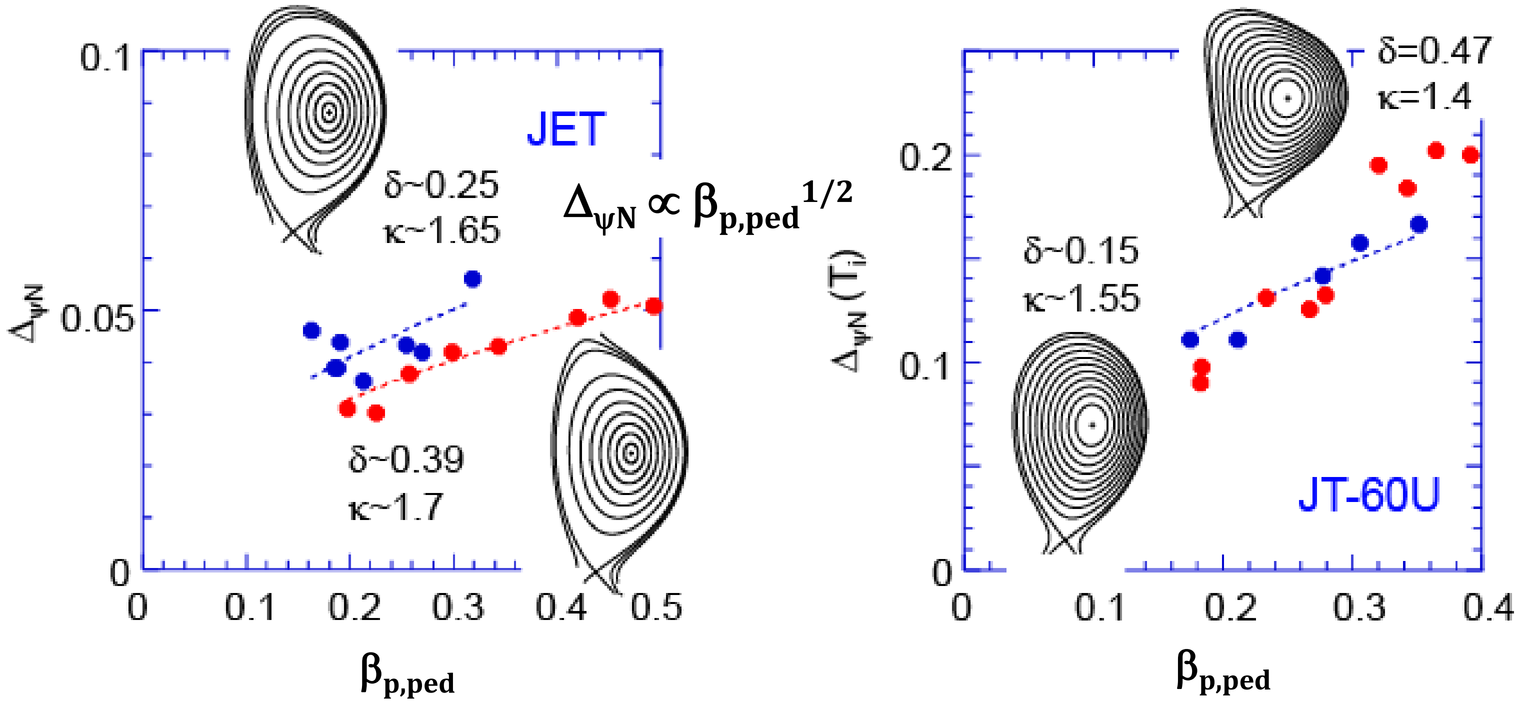
The stability limit for $(dp/d\psi)_{ped}$ is reduced at high δ in JT-60U.

Reduced κ makes the PBM unstable at high mode number.

[Aiba, NF2012]

Wider pedestal is obtained although $(dp/d\psi)_{ped}$ is not raised, so that the pedestal pressure is kept high.

Pedestal width at high δ / low κ in JT-60U increased more strongly than the conventional scaling

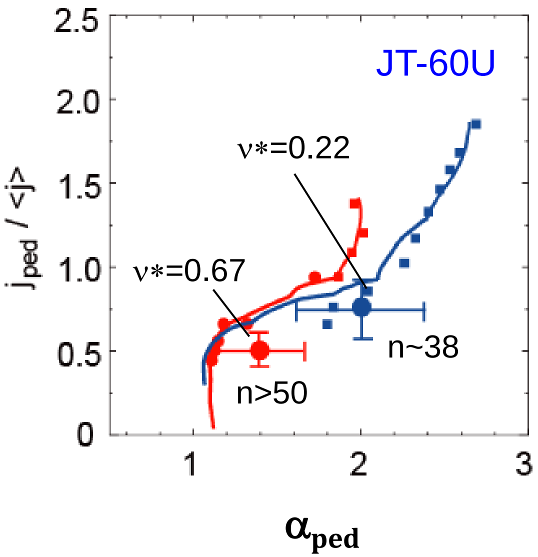


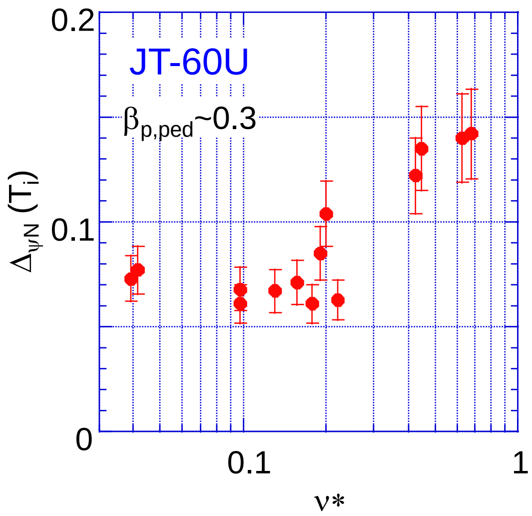
In JET, pedestal expands along the conventional scaling for both low and high δ. Relatively wide pedestal is formed for the low δ case at given $\beta_{p,ped}$.

In JT-60U, pedestal width is increased along $\Delta_{\psi N} \propto \beta_{p,ped}^{1/2}$ for the low δ case.

At high δ and low κ, pedestal width is increased more strongly than the $\beta_{p,ped}^{1/2}$ scaling. Pedestal expands largely when high power is applied.

Discussion: Pedestal widening is also observed by increased ν*

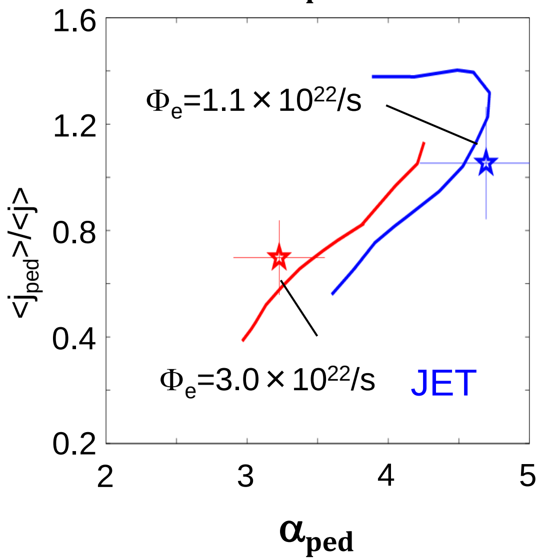


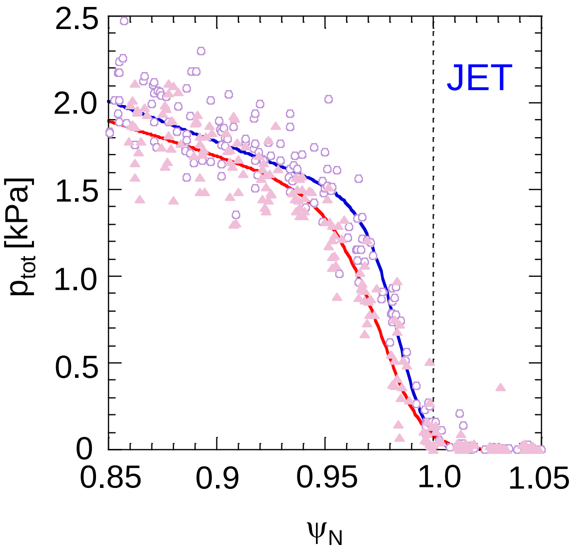


Pedestal widening has also been observed when the edge ν* is raised.

When ν* is raised in JT-60U, high n ballooning mode becomes unstable and $(dp/d\psi)_{ped}$ is reduced. The pedestal expands with increasing ν*.

[Urano, NF2015]





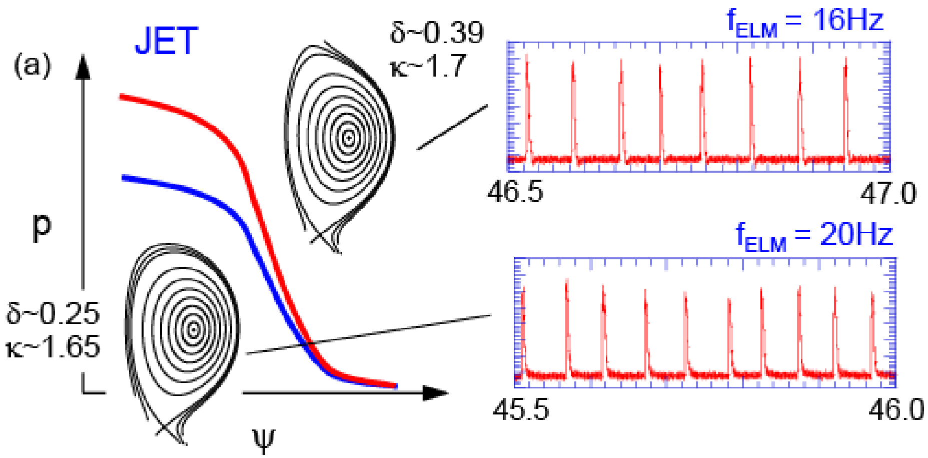
In JET, $(dp/d\psi)_{ped}$ is reduced with increased gas puff along the stability boundary.

Pedestal expands whereas the pedestal pressure remains constant.

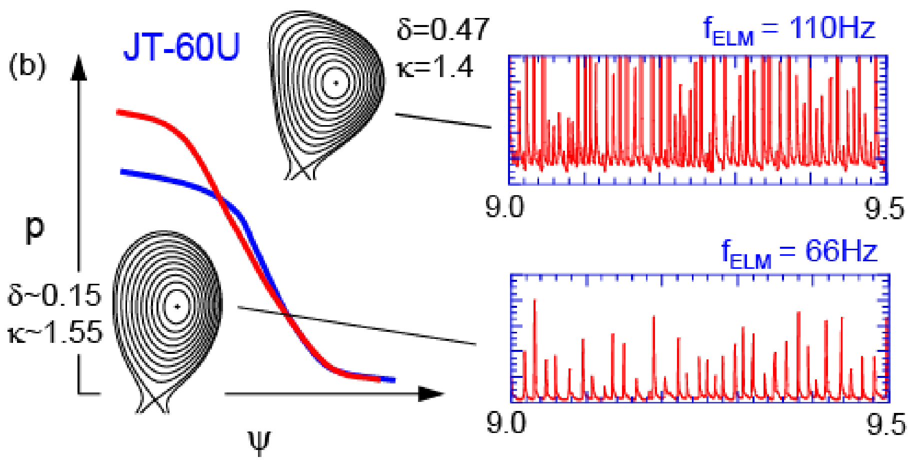
[Leyland, NF2015, Frassinetti, NF2016, Maggi, this conference]

Discussion:
Pedestal structure in the variation of plasma shape at high β_p

Low δ to high δ at high κ (JET)



Low δ / mid κ to high δ / low κ (JT-60U)



When δ is raised at fixed κ, $(dp/d\psi)_{ped}$ is raised due to the stability improvement accompanied by reduced f_{ELM}.

When δ is raised together with reduced κ, $(dp/d\psi)_{ped}$ is not raised because the pedestal is destabilized by high n ballooning mode due to reduced κ.

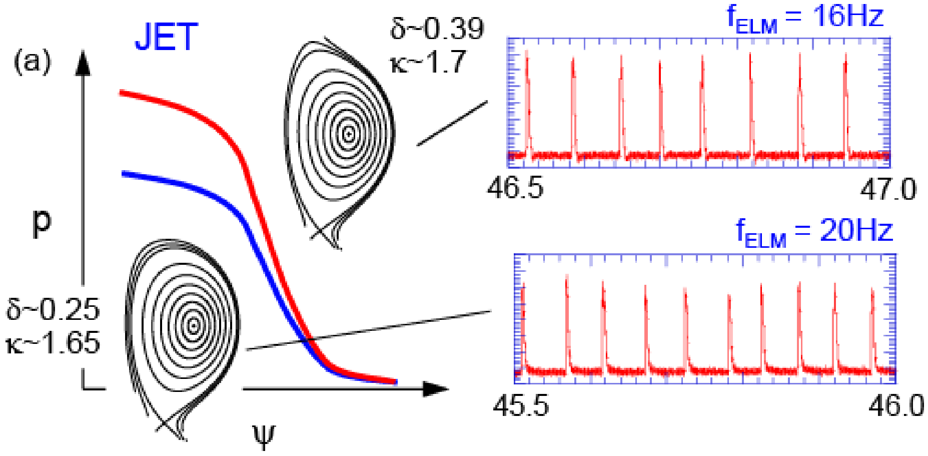
Pedestal pressure can be kept high because of the broadening pedestal.

Consistent with largely increased f_{ELM}.

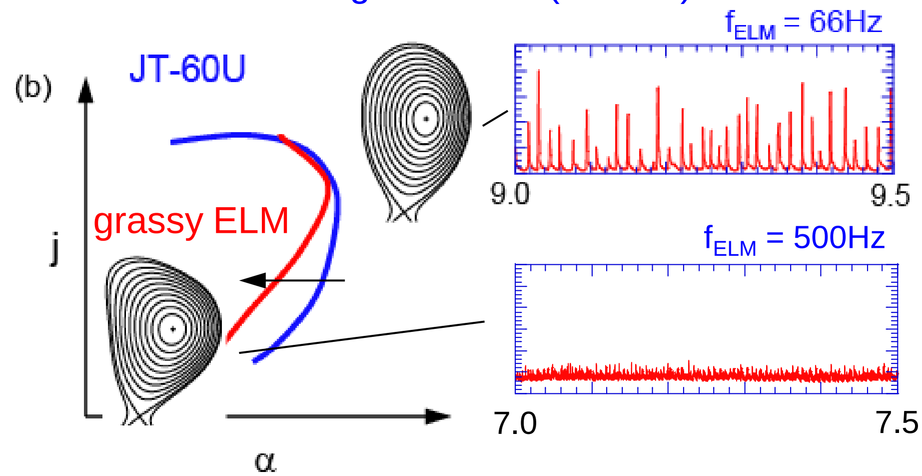
The condition of high δ and high q_{95} brings the pedestal close to grassy ELM regime, the pedestal in which is also destabilized by high n ballooning mode.

Discussion:
Pedestal structure in the variation of plasma shape at high β_p

Low δ to high δ at high κ (JET)



Low δ / mid κ to high δ / low κ (JT-60U)



When δ is raised at fixed κ, $(dp/d\psi)_{ped}$ is raised due to the stability improvement accompanied by reduced f_{ELM}.

When δ is raised together with reduced κ, $(dp/d\psi)_{ped}$ is not raised because the pedestal is destabilized by high n ballooning mode due to reduced κ.

Pedestal pressure can be kept high because of the broadening pedestal.

Consistent with largely increased f_{ELM}.

The condition of high δ and high q_{95} brings the pedestal close to grassy ELM regime, the pedestal in which is also destabilized by high n ballooning mode.

Summary

The effect of increased Shafranov shift on the pedestal structure was examined in the variation of the plasma shape using JET and JT-60U.

1) **With increased β_p, the stability boundary expands for all types of plasma shape. The edge pressure gradient is raised the most largely at high δ and high κ.**

2) **When κ is reduced at fixed β_p, the stability limit of the edge pressure gradient is reduced whereas the pedestal expands more largely than the conventional scaling.**

3) **Reduction of κ makes the high n ballooning mode unstable at the pedestal. The operation at low κ and high δ leads to wide pedestal, moderate edge pressure gradient and small ELMs close to grassy ELM regime.**