Numerical analysis of peeling-ballooning stability at various triangularities in Globus-M2

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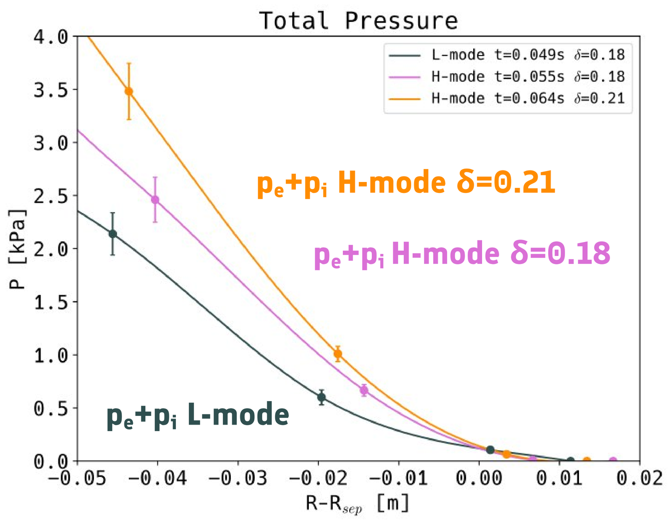
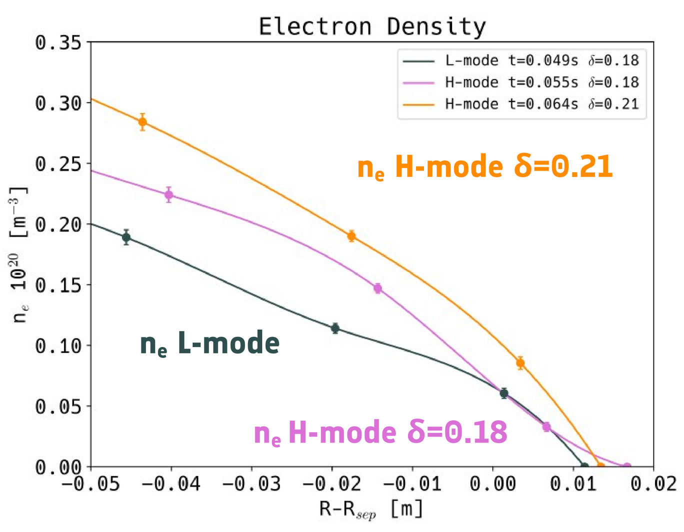
INTRODUCTION

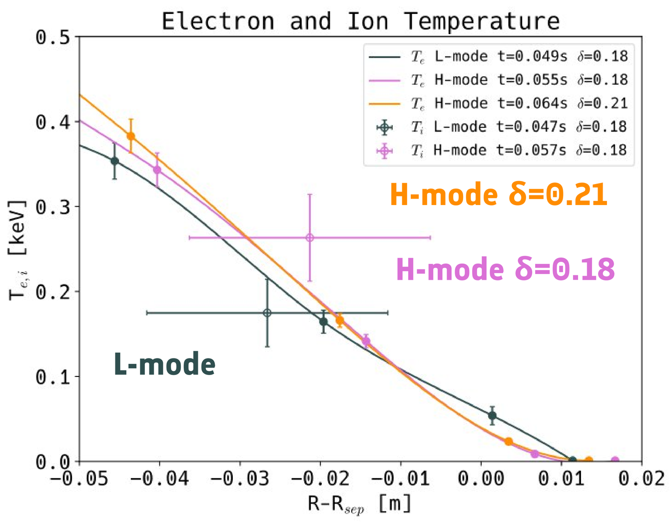
The formation of the reduced transport region during the high confinement mode operation (H-mode) implies steep density and temperature profiles, which drive the development of edge localized modes (ELMs). The compact spherical tokamak Globus-M2 [1] was shown to be able to achieve hot-ion H-mode with remarkably high ion temperature and moderate electron temperature and density. In H-mode pulses with high value of triangularity (δ) around 0.4 and elongation (κ) around 1.9, ELMs with type-V traits were observed at pedestal pressures higher than p_{ped}= 4 kPa [2].

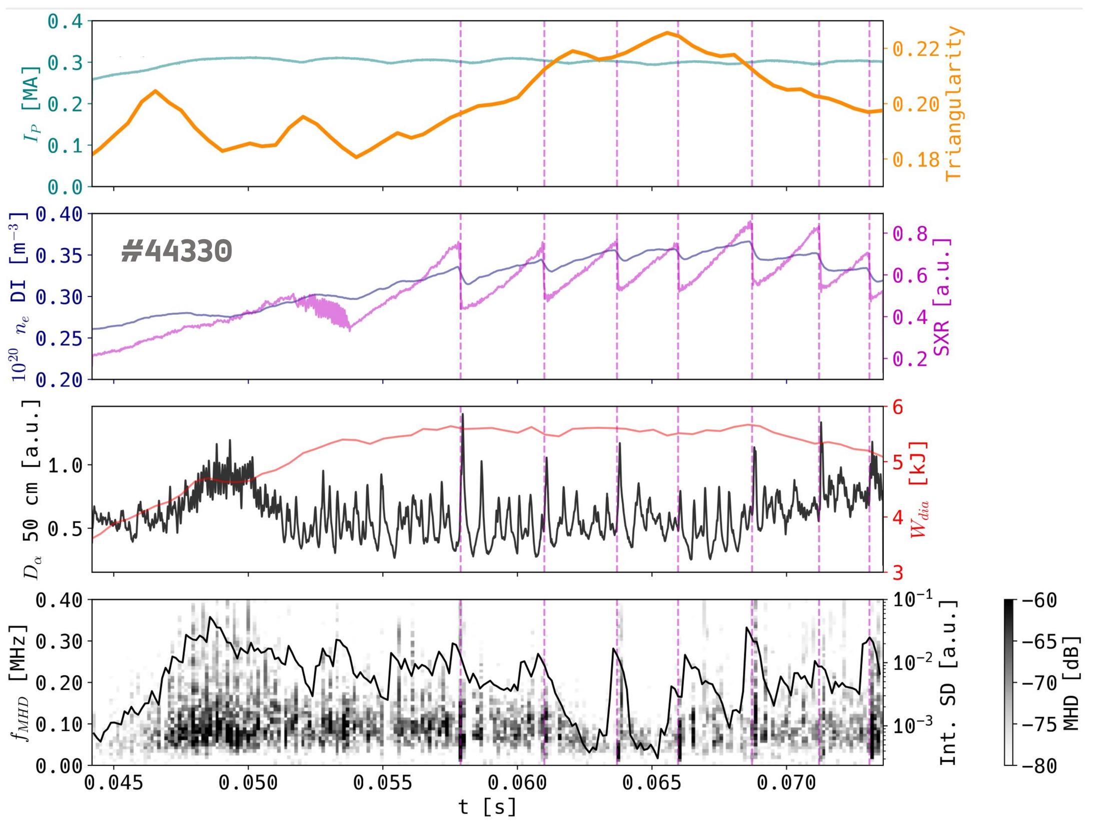
Experiments with medium triangularity values (δ=0.3) showed the presence of ELMs at p_{ped}= 2 kPa. The recent observation [3] of the shaping influence on the peeling-ballooning destabilization exhibited ELMs onsets at low pressure (p_{ped}= 1.2 kPa) in magnetic configuration with triangularity around 0.2 and the elongation around 1.9.

Low triangularity discharges in comparison with high triangularity discharges were having 20% lower magnetic shear values at virtually the same value of safety factor. The H-mode discharge with variable triangularity from 0.18 to 0.21 has shown the 20% increase in critical pedestal pressure corresponding to the type-V ELMy phase.



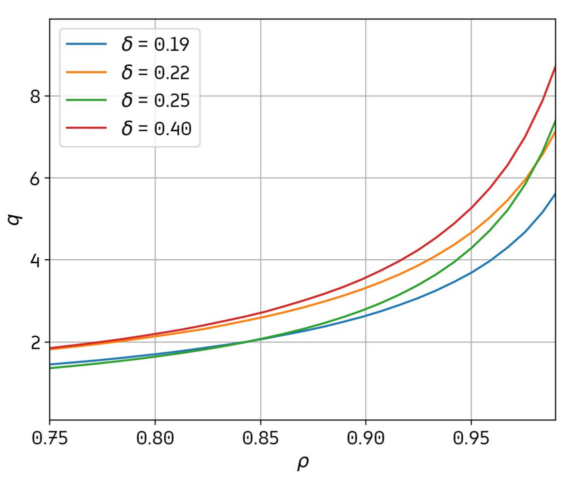


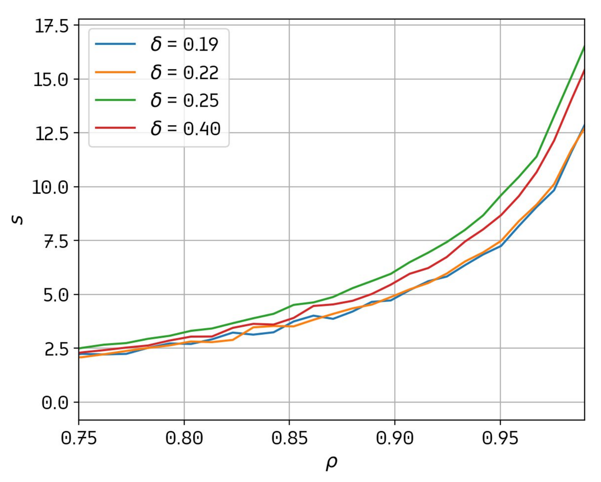


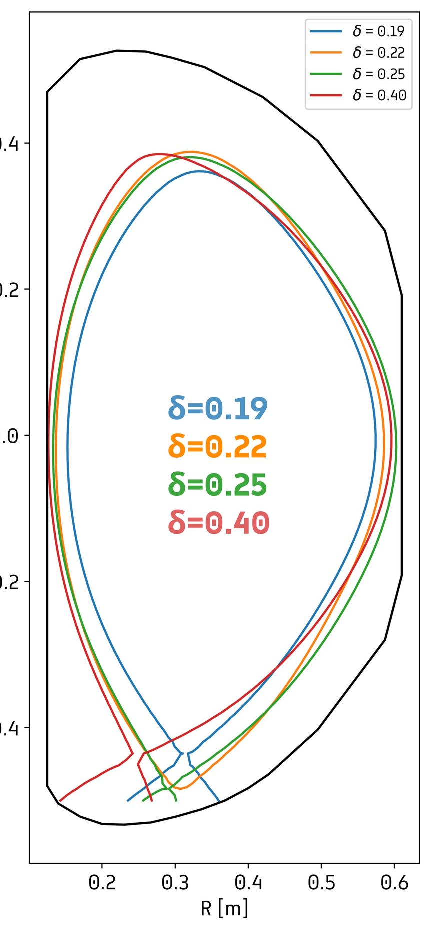


EQUILIBRIUM RECONSTRUCTION/BOUT++ SETUP

The investigation of peeling-ballooning stability was performed on a set of magnetic equilibria provided by free-boundary plasma equilibrium codes pyGSS [4] and PET [5] for Globus-M2 configurations with triangularities ranging from 0.19 to 0.40.







The quantitative estimations of the peeling-ballooning stability of Globus-M2 edge tokamak plasmas were carried out by the BOUT++ code [6]. The three-field model was used with the inclusion of the diamagnetic effect. The linear calculations were done with a Lundquist number of S=10^8. In the poloidal direction, the 0.75-0.97 normalized flux span was covered by the 64×64 mesh.

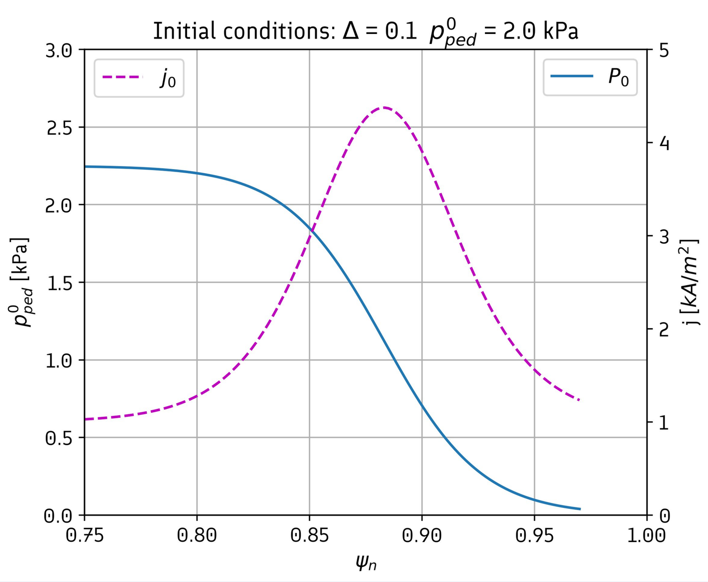
$$\rho\frac{dU}{dt} = B^2\vec{b}\cdot\nabla\left(\frac{J_{||}}{B}\right) + 2\vec{b}\times\vec{\kappa}\cdot\nabla P$$

$$\frac{\partial\psi}{\partial t} = -\frac{1}{B_0}\nabla_{||}\phi$$

$$\frac{\partial P}{\partial t} = -\frac{1}{B_0}\vec{b}_0\times\nabla\phi\cdot\nabla P$$

$$U = \frac{1}{B_0}\nabla_{\perp}^2\left(\phi + \frac{P}{en}\right)$$

$$J_{||} = J_{||0} - \frac{1}{\mu_0}B_0\nabla_{\perp}^2\psi$$



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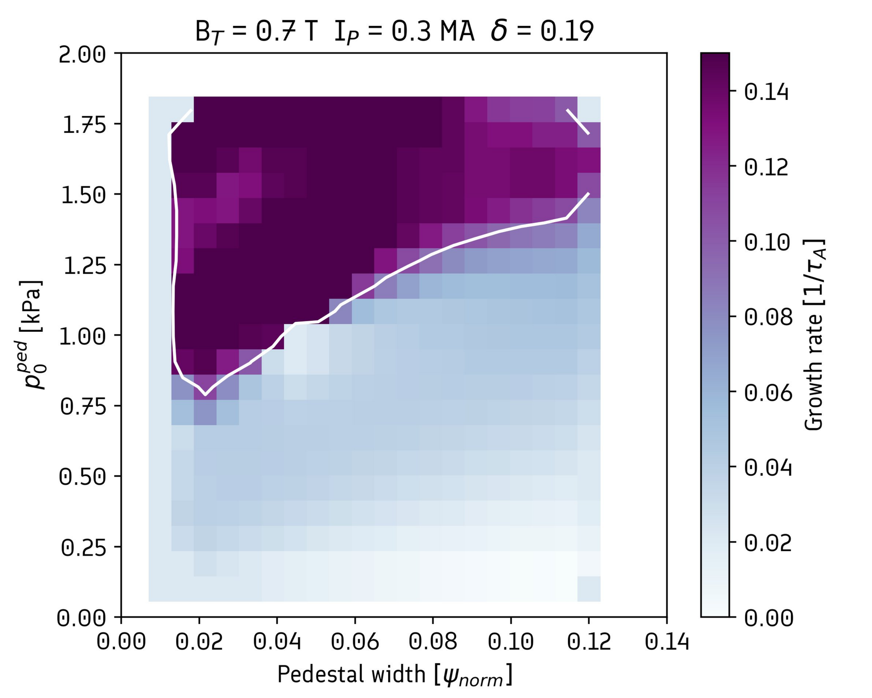
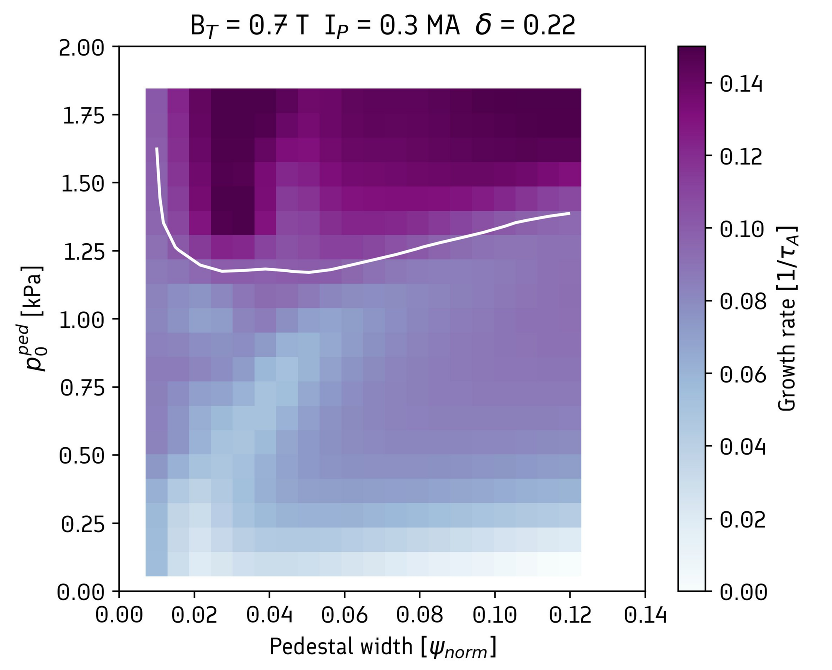
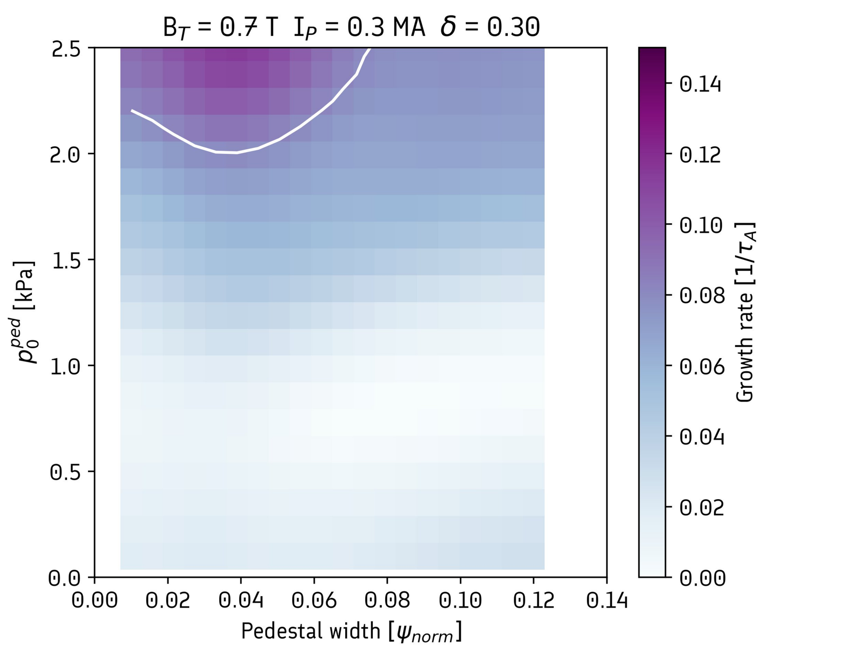
SIMULATION RESULTS

Peeling-ballooning stability calculations for low triangularity equilibrium corresponding to the toroidal magnetic field B_T = 0.7 T, plasma current I_P = 0.3 MA and triangularity δ = 0.19 shows, that for experimental values of the pedestal width around 0.08, the critical pressure is around 1 kPa. The widening of the pedestal does not allow increasing height beyond 1.25 kPa levels.

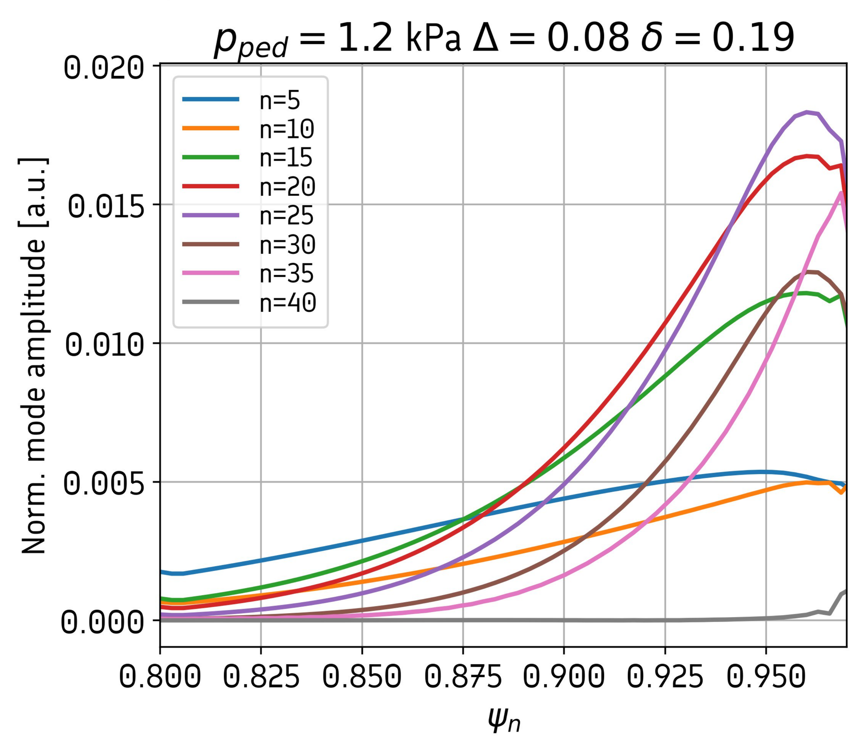
The 10% raise in triangularity up to δ = 0.22 leads to a significant flattening of the marginal stability boundary. The further increase in triangularity leads to a raise of the peeling-ballooning stability boundary. The case with medium triangularity δ = 0.30 shows up to 3 times higher critical pressures; for the experimentally relevant pedestal width, the critical pressure was found to be 2.3 kPa, which is consistent with the experimental results. The medium triangularity marginal stability boundary exhibits the steep shape, indicating more pronounced ballooning-type behavior.

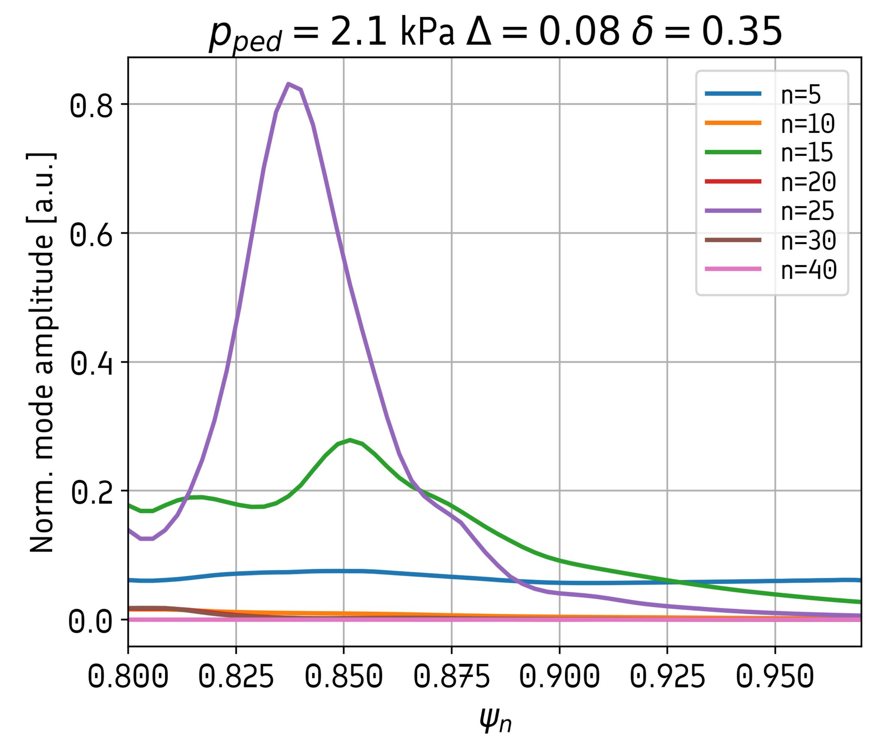






The spatial mode structure for the low triangularity case demonstrated the mode localization in the vicinity of the separatrix with mostly intermediate toroidal mode numbers. It indicates that reduced shear might have caused the significant peeling mode destabilization. At the same time, structure significantly span inside the pedestal and intermediate toroidal mode numbers marks a perceptible ballooning mode contribution.





The spatial mode structure for the medium triangularity case exhibits highly notable ballooning properties, as the one mode with n=25 is dominating in the simulations. Increased values of the magnetic shear in the medium triangularity case were enough to stabilize the peeling mode branch, and it requires the additional pressure gradient to destabilize the ballooning branch of the peeling-ballooning mode despite the increased values of the safety factor.

CONCLUSION

- Globus-M2 experiments with low triangularity (δ = 0.2) exhibited type-V ELMs at pedestal pressure around 1 kPa. The 10% increase in triangularity leads to 20% growth in pedestal pressure.
- BOUT++ simulations of low triangularity pulses demonstrated the critical pressure for peeling-ballooning destabilization at 1 kPa, indicating significant peeling contribution.
- The medium triangularity (δ = 0.3) case was characterized by a significantly steeper marginal stability boundary at approximately 2.5 kPa, indicating the ballooning properties of the mode and explaining experimentally observable differences in critical pressure.

ACKNOWLEDGEMENTS

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