Mode Penetration Thresholds in KSTAR

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R. Fitzpatrick, S.-K. Kim, and J. Lee, Phys. Plasmas **28**, 082511 (2021).

Central Hypothesis

- ELM are caused by peeling-ballooning modes/kinetic ballooning modes driven by pedestal pressure and current gradients.[1]
- Externally applied RMPs ($n = 1$, 2, or 3) do not directly interact with ELMs ($n \sim 10 - 15$) in plasma.[2]
- Rather, RMPs drive low-n magnetic island chains in pedestal that reduce pressure gradient, and, thereby, move pedestal further from ELM stability threshold.
- How can we test this hypothesis?

[1] P.B. Snyder, et al., PoP **19**, 056115 (2012).
[2] Q.M. Hu, et al., PRL **125**, 045001 (2020).

Description of EPEC Code - I

- EPEC (Extended Perturbed Equilibrium Code) code implements asymptotic matching approach.[3]
- Homogeneous toroidal tearing mode dispersion relation calculated by EPEC code using high-q approximation.
- Inhomogeneous components of toroidal tearing mode dispersion relation (which pertain to ideal response of plasma to applied RMP) calculated by GPEC code.[4]
- EPEC takes both poloidal and toroidal plasma rotation into account.
- EPEC incorporates accurate neoclassical model, that includes both impurities and neutrals, in order to determine correct neoclassical poloidal rotation, neoclassical poloidal flow damping rate, and neoclassical resistivity.

[3] R. Fitzpatrick, and A.O. Nelson, PoP **27**, 072501 (2020); R. Fitzpatrick, PoP **27**, 102511 (2020); R. Fitzpatrick, PoP **28**, 022503 (2021).

[4] J.-K. Park, and N.C. Logan, PoP **24**, 032505 (2017).

Description of EPEC Code - II

- In inner region, EPEC interpolates smoothly between appropriate linear (semi-collisional)[5] and nonlinear (Rutherford) constant-ψ response regimes.
- EPEC island-induced density and temperature flattening model takes into account fact that parallel transport is *convective* rather than *diffusive* in nature.[6]
- EPEC uses experimental plasma equilibrium (gfile), experimental profiles (pfile), and perpendicular energy/particle/momentum diffusivities determined by TRANSP code.
- EPEC ignores all resonant surfaces beyond $\Psi_N = 0.995$ (because GPEC does not give reliable results beyond this surface).

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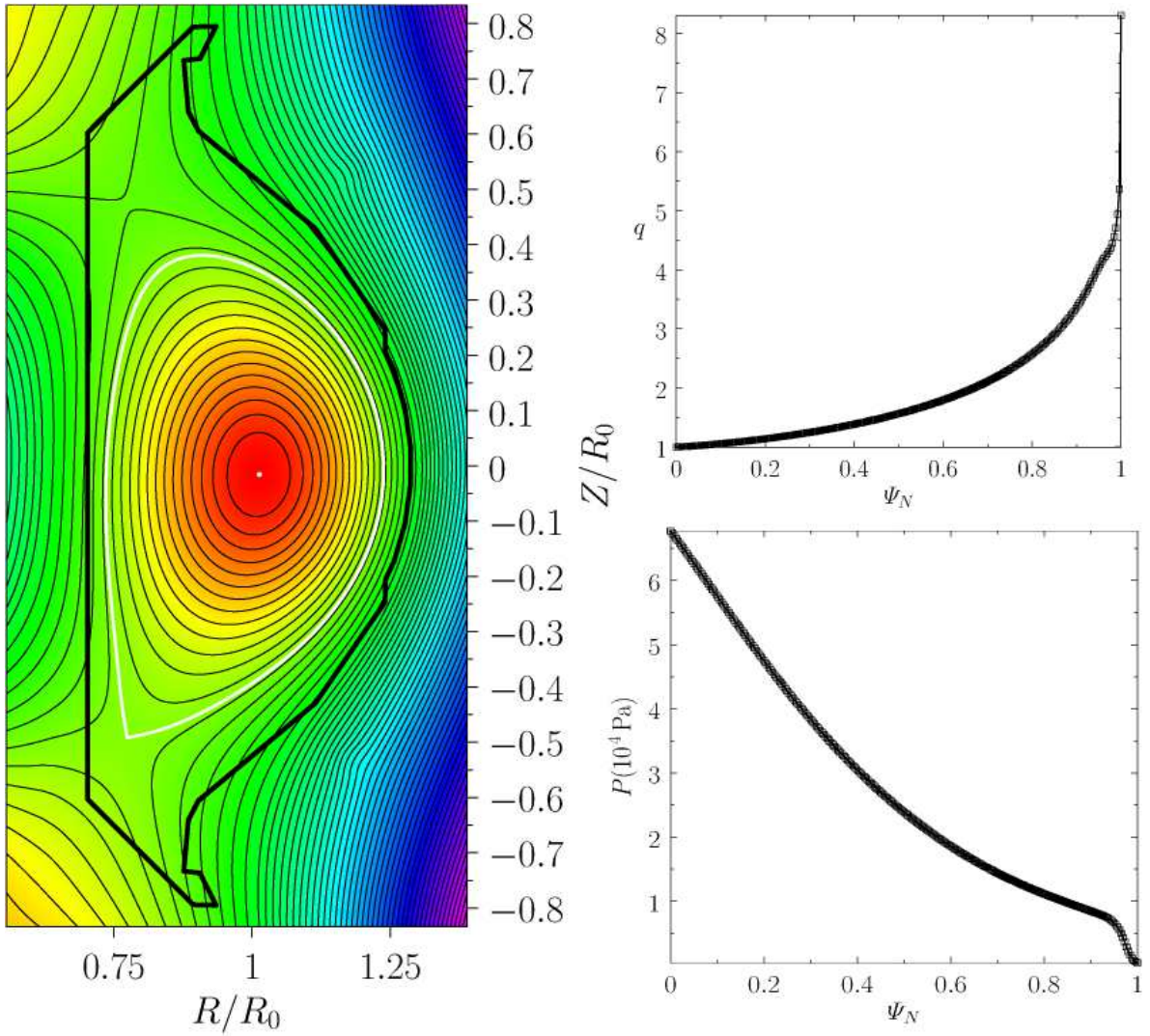
[5] A. Cole, and R. Fitzpatrick, PoP **13**, 032503 (2006).

[6] R. Fitzpatrick, PoP **2**, 825 (1995). N.N. Gorelenkov, et al., PoP **3**, 3379 (1996).

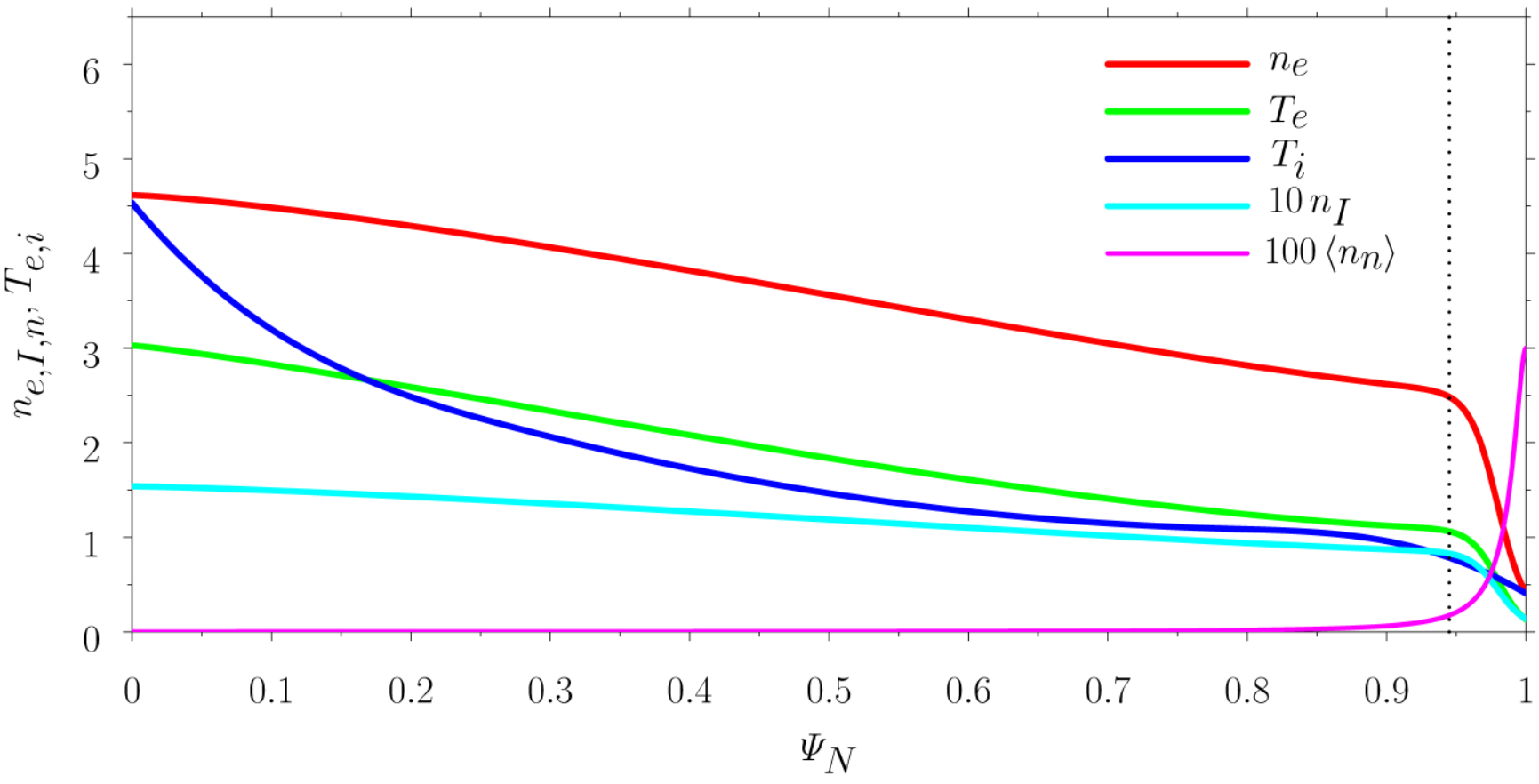
KSTAR Discharge #18594 - Plasma Equilibrium

- In KSTAR H-mode discharge #18594 an $n = 2$ RMP is used to suppress ELMs.[7]

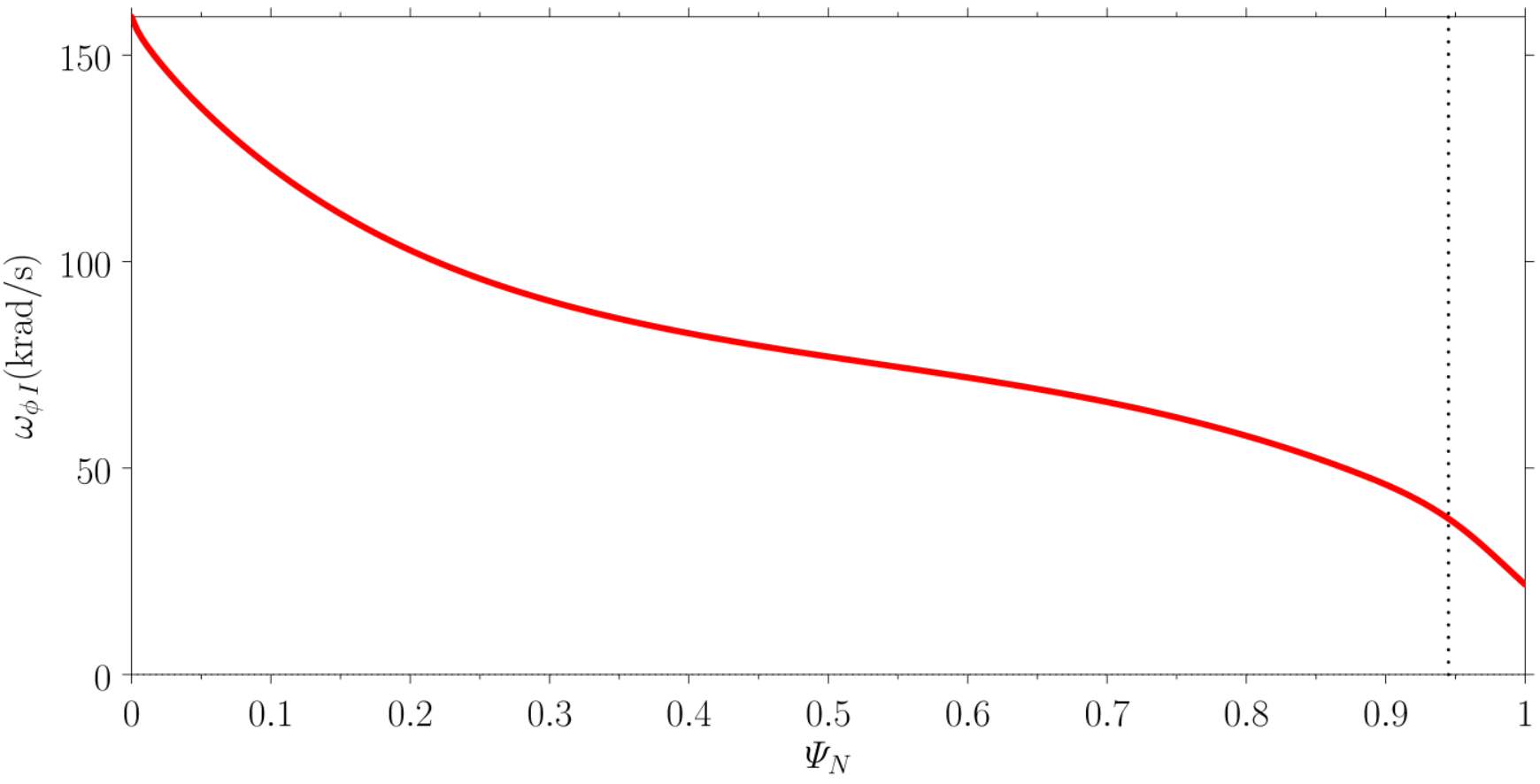


[7] J. Lee et al., NF **50**, 066022 (2010)

KSTAR Discharge #18594 - Plasma Profiles - I



KSTAR Discharge #18594 - Plasma Profiles - II



KSTAR Discharge #18594 - Plasma Profiles - IV

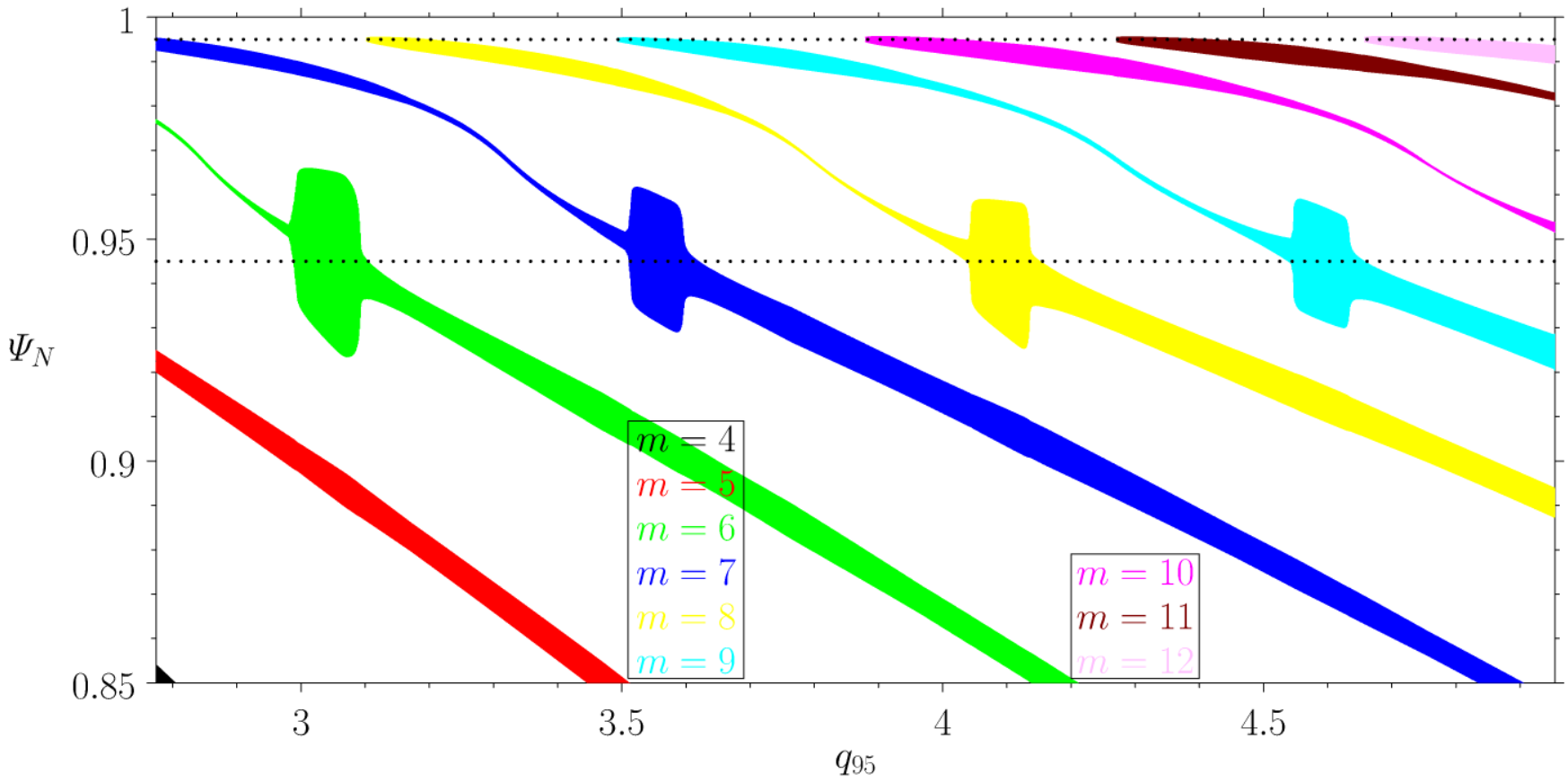
- Impurities are Carbon-VI.
- $Z_{\rm eff}$ assumed to take uniform value 2 across plasma.
- Energy, momentum, and particle diffusivities given plausible values $1\,{\rm m}^2/{\rm s}$, $1\,{\rm m}^2/{\rm s}$, $1/3\,{\rm m}^2/{\rm s}$, respectively.
- Neutral particle density guessed (based on previous DIII-D measurement).[8]
- No useable poloidal rotation data, so $\mathbf{E}\times\mathbf{B}$ profile determined from measured toroidal rotation data combined with neoclassical theory.

[8] P. Monier-Garbet, et al., NF **37**, 403 (1997).

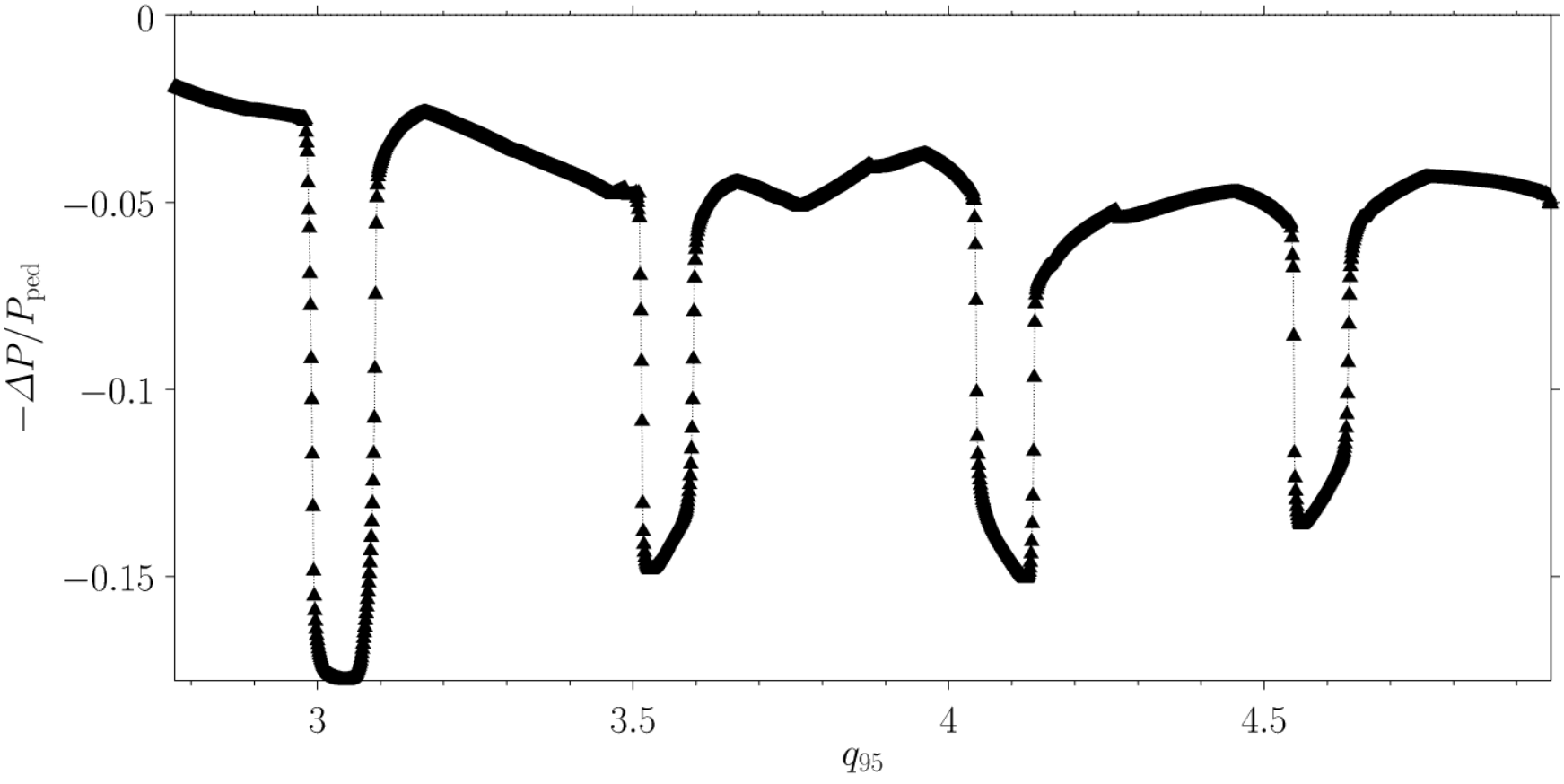
KSTAR Discharge #18594 - Rescaling of Equilibrium

- Rescale experimental equilibrium such that toroidal plasma current is modified while vacuum toroidal field-strength kept constant.
- Rescaling process leads to set of self-similar plasma equilibria with a range of different q_{95} values.
- EPEC performs simulation, based on rescaled equilibria, in which RMP coil current held fixed while q_{95} is scanned over 2 second timescale.

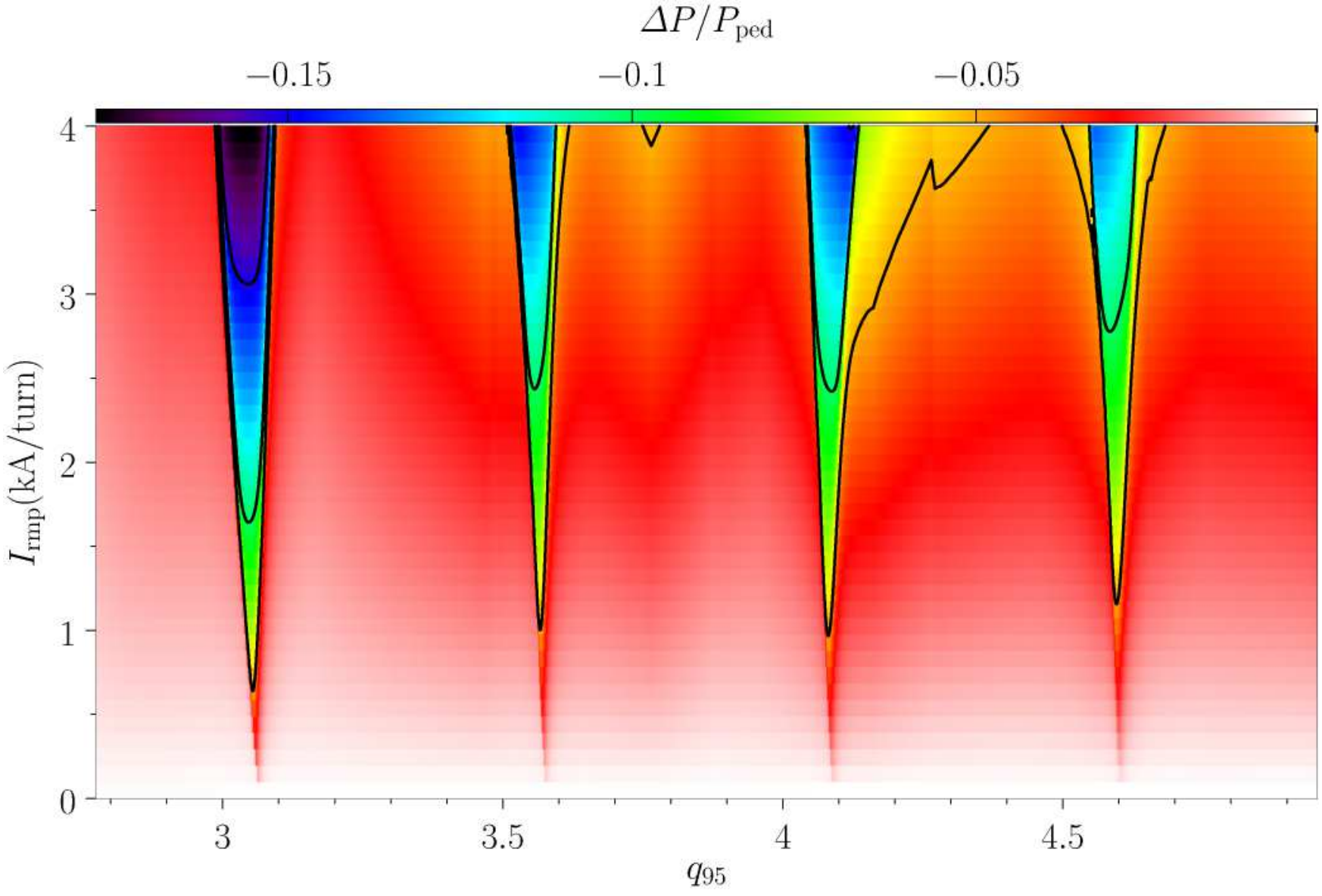
KSTAR EPEC Simulation - Driven Island Widths



KSTAR EPEC Simulation - Pedestal Pressure Decrease



KSTAR EPEC Simulation - q_{95} ELM Suppression Windows



KSTAR EPEC Simulation - Conclusions

- EPEC $n = 2$ ELM suppression windows are shifted upward in q_{95}, compared to those seen experimentally,[9] by 0.2.
- However, KSTAR experiments use "magnetic equilibria" whereas EPEC utilizes "kinetic equilibria" (i.e., equilibria that take strong current and pressures gradients in pedestal into account). q_{95} values from magnetic equilibria are about 0.2 smaller than those from corresponding kinetic equilibria.
- Overall, there is very good agreement between the EPEC simulations of $n = 2$ RMP-induced ELM suppression in KSTAR H-mode discharges and the experimental data.
- EPEC simulations confirm earlier results obtained by TM1 code.[10]

[9] Y. In, et al., NF **59**, 126045 (2019); Y. In, et al., NF **59**, 056009 (2019).
[10] Q. Hu, et al., APS-DPP Invited Talk 2020.