Flux driven pedestal formation in tokamaks: Turbulence simulations validated against the isotope effect

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Ingredients for realistic L mode edge modelling

Key players for realistic L mode edge [Bourdelle NF2020]:

- Turbulence drive resistive Drift Waves on which larger β has a destabilizing impact [Bonanomi NF2019, De Dominici NF2019]
- $\vec{E} \times \vec{B}$ shear, key in formation of the edge transport barrier [Burrell PoP 2020], incl. neoclassical friction and realistic SOL E_r or at least realistic LCFS value for E_r

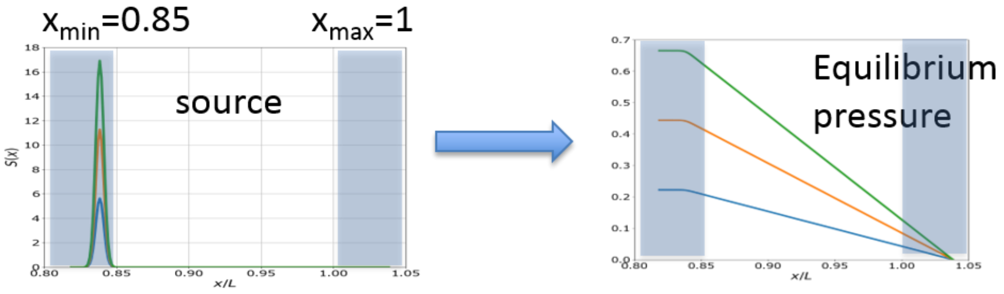
First self-consistent pedestal formation in 3D non-linear fluid flux-driven simulation including the following critical physical ingredients:

1) **resistive electromagnetic** Drift Waves and ballooning modes
2) **E_r accounting for neoclassical friction on $V_\theta(\nu^*)$** with realistic L mode edge ν^* from banana to Pfirsch-Schlüter regimes

As in experiments, the pedestal forms above a certain power threshold. As in experiments, this power threshold is lower for Tritium plasmas than for Deuterium plasmas.

So far, flux driven pedestal formation in electrostatic: EMEDGE3D [Chôné PoP2014] and BOUT++ [Park PoP2015] and here electromagnetic EMEDGE3D [DeDominici, ArXiv2019]. **More flux driven fluid codes should explore!!**

Fluid flux driven concentric circular torii without SOL



EMEDGE 3D [Fuhr PRL2008, De Dominici NF 2019]
Charge and energy conservation,
Pressure ∝ T, i.e. iso-density
Ohm's law
including electromagnetic and diamagnetic effects
E_r such that 0 at LCFS and with neoclassical friction on V_θ

Er force balance, role of V_θ in L mode edge

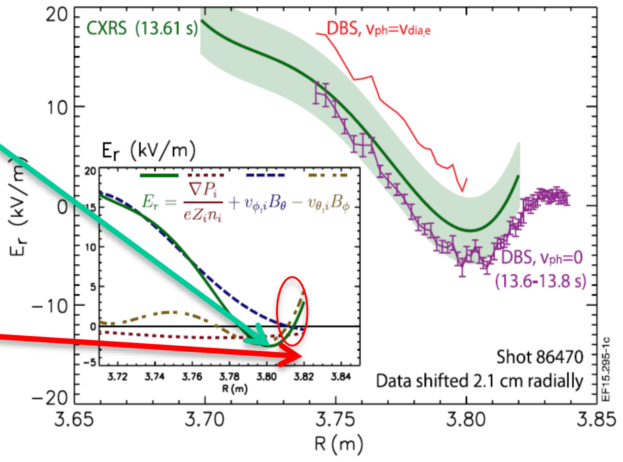
Example at JET [Hillensheim PRL 2016]

$\frac{\nabla P_i}{Z_i n_i}$ a good proxy for min(E_r) see AUG [CavedonNF2020]

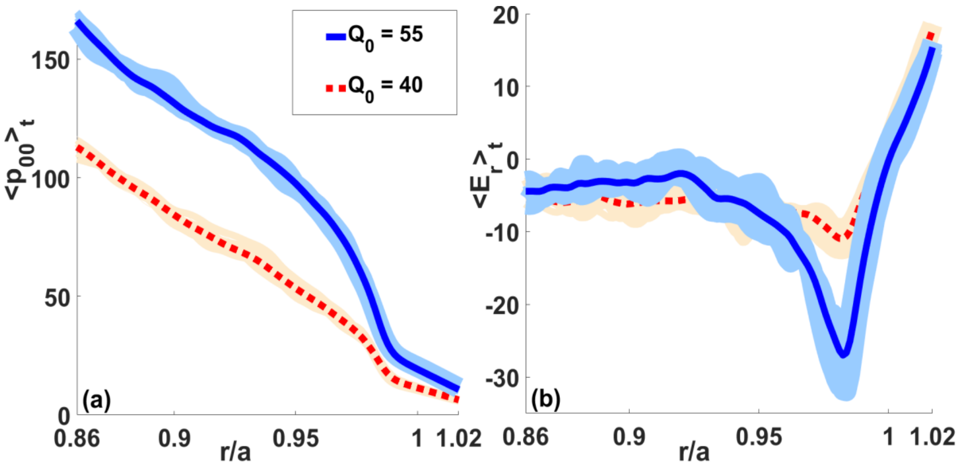
But… from min(E_r) to the LCFS $V_\theta(\nu^*)$ with ν^* from banana to P-S!

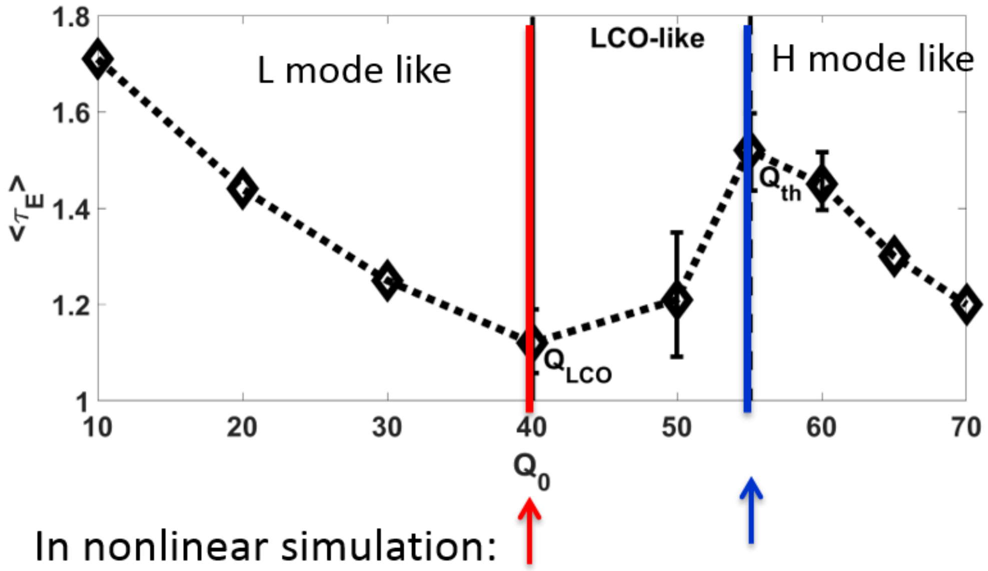
$$v_{\theta i} = k_i \frac{\nabla_r T_i}{eB_\varphi}.$$

$$k_i = \left(\frac{1.17 - 0.35\,\nu_{i,*}^{1/2}}{1 + 0.7\,\nu_{i,*}^{1/2}} - 2.1\,\nu_{i,*}^2 \epsilon^3 \right) \frac{1}{1 + \nu_{i,*}^2 \epsilon^3}$$



Flux driven pedestal formation above a certain source





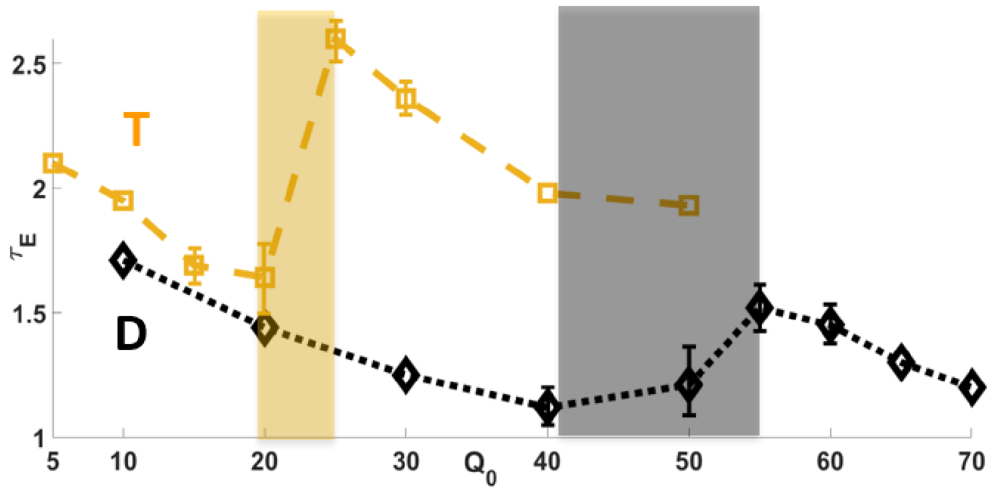
In nonlinear simulation:

$\tau_{E\times B} > \tau_{turb}$ i.e. $\gamma_E < \gamma_{turb}$ $\gamma_E > \gamma_{turb}$

T_{e0} (eV)	$n_0(m^{-3})$	B_0 (T)	$\frac{R}{L_p}$	q
50	$2{,}5 \cdot 10^{19}$	1	58	2.5 → 3.5

[DeDominici, ArXiv2019]

flux driven pedestal formation captures isotopic effect



A lower power threshold in T compared to D

$Q_{th} \sim \frac{1}{A^\alpha}$ with $\alpha \approx 1{,}8 \pm 0{,}6$ [DeDominici, ArXiv2019]

D to T: correlation length λ_{turb} similar

Correlation time τ_{turb} higher in T vs D due to higher mass

Hence weaker turbulence drive in T