Microturbulence at Extreme Flux-Surface Triangularity

DIFFER

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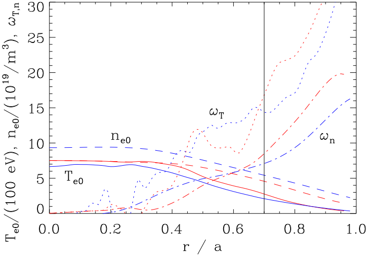
Pushing δ at TCV: Profiles

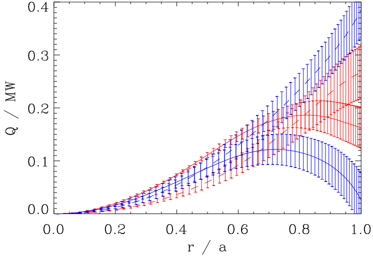
RT07 campaign at TCV: *how negative/positive can we go in δ?*

Well-matched parameters between PT, NT discharges

Profiles ($\omega_A = R/L_A$):



ASTRA modeling (— e, - - i):

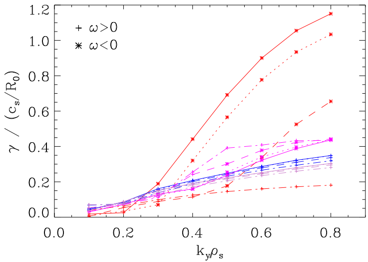


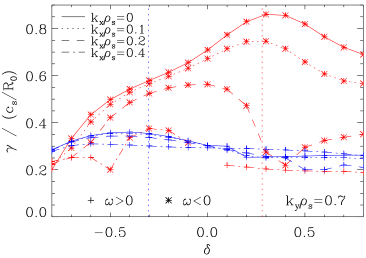
Note: at mode boundary $\Rightarrow$ moderate difference in ω_T means
PT discharge is TEM-dominated, NT is ITG-dominated

Pushing δ at TCV: Linear

RT07 TCV campaign: only $\delta \approx \pm 0.3$ achievable at $r/a = 0.7$
$\Rightarrow$ extrapolate using Miller (ignores edge-$\delta \approx 0.6$, ρ^* effects)

CHEASE geometry PT,NT Miller geometry





- at experimental gradients, stiff TEM, ITG growth
- ITG: finite-k_x contribution at $\delta > 0$
- TEM: $\gamma(\delta < 0)$ insensitive to k_x like ITG,
  $\delta > 0$ TEM dominated by $k_x \approx 0$

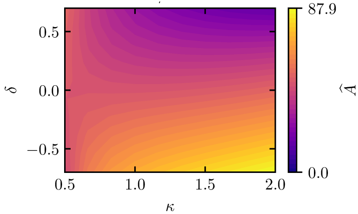
Available-Energy Analysis

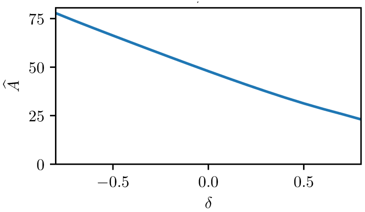
Mackenbach PRL 2022: **Available Energy** measures how strongly TEMs *can* be driven for given profiles/geometry

$$\hat{A} = \int \mathrm{d}z\mathrm{d}\lambda \sum_{\substack{\text{trapping}\\\text{wells}}} z^{5/2}\mathrm{e}^{-z}\left[\hat{\omega}_\alpha^2\left(\frac{\hat{\omega}_*^T}{\hat{\omega}_\alpha} - 1 + \hat{F}\right) + \hat{\omega}_\psi^2(\hat{F}-1)\right]\hat{G}^{1/2}$$

($\hat{F}$: ground state, $\hat{G}^{1/2}$: Jacobian; $\beta, \zeta, \hat{s}_\zeta = 0$, only electrons)

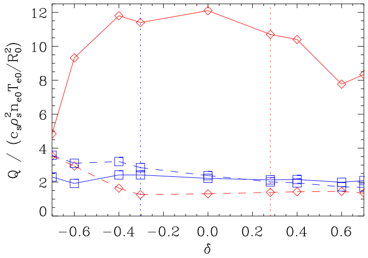
Apply to TCV TEM case = PT profiles (*work in progress*):

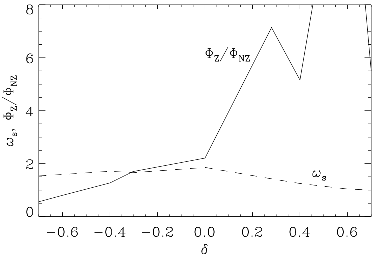




⇒ NT prevents access to substantial energy for instability drive
Could be exploited for stellarator optimization!

Pushing δ at TCV: Nonlinear





- near ITG/TEM thresholds; approx. matches Q_e^{exp}
- **extreme δ can but need not be beneficial**; too low $|\delta|$ in TCV core
- zonal flows change scale, $\delta < 0$: higher NL efficiency $\leftrightarrow$ weak k_x dependence
- quasilinear modeling: need to include finite k_x?

Quasilinear across δ

Common assumption in **QL modeling**: **need only** $k_x = 0$

QL weight ($\Phi \times T$ phase)

growth rate of mode j

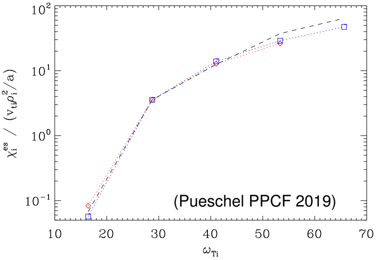
$$Q^{\mathrm{es}} = \omega_T \sum_{j,k_y} C(k_y) \frac{\gamma(j,k_y) w(j,k_y)}{\langle k_\perp(k_y,j)^2 \rangle}$$

$-R(\nabla T)/T = R/L_T$

model constant

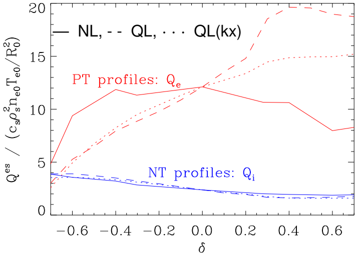
$\int_{-3\pi}^{3\pi} k_\perp^2 \Phi^2 \mathrm{d}\theta \,/\, \int_{-3\pi}^{3\pi} \Phi^2 \mathrm{d}\theta$

Strong ITG turbulence:



$\Rightarrow$ QL works w/o $k_x \neq 0$

TCV TEM δ scan:



$\Rightarrow$ need $k_x \neq 0$, more?

GENE ECCD Implementation

Before we return to TCV and triangularity, a little detour...

ECCD: electron heating & current drive $\Rightarrow$ impacts $\omega_{T\mathrm{e}}$

However, turbulence also impacts ECCD via beam broadening; **is turbulence affected directly** via δT_e, $\delta\Phi$?

resonance width $= 0.3 v_\mathrm{Te}$

deposition power $\sim 10^{-3}$

GENE ECCD:
$$\frac{\partial g_\mathrm{e}}{\partial t} = \mathcal{L} + \mathcal{N} + p_\mathrm{EC} \frac{\sqrt{2}}{\pi^{3/2}} \frac{\mu B_0 - 1}{m_\mathrm{e}} \left(\frac{2v_\Delta^2 + 1}{v_\Delta^2} \right)^{1/2} \times \exp\left(-\frac{2v_\Delta^2 + 1}{v_\Delta^2} (v_\| - v_\mathrm{res})^2 \right) \exp(-\mu B_0)$$

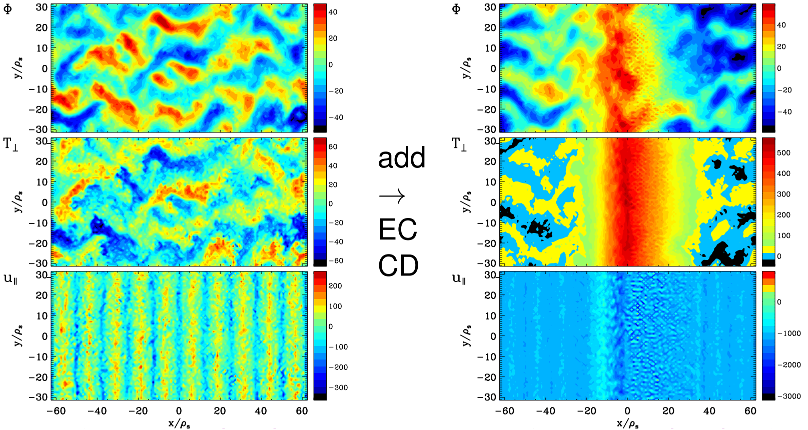
resonant velocity $= 2v_\mathrm{Te}$

with Gaussian localization in x, y, z

(see Westerhof PoP 2014; implementation: Skyllas & Claassen)

Circular TEM Case I

Add ECCD into ∇T-TEM case (Merz NF 2010 but with $m_{\mathrm{i}} = m_{\mathrm{H}}$)

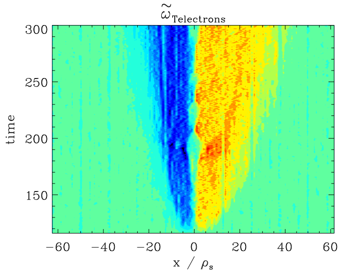


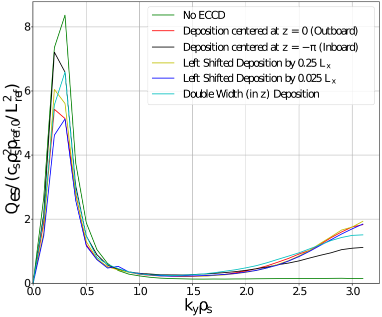
Beam equilibrates on flux surface: **zonal temperature & flows**

negative current: Okhawa effect (trapped e^-; outboard ECCD)

ETG-like streamers in right half of deposition region

Circular TEM Case II





local tripling of ω_{Te}

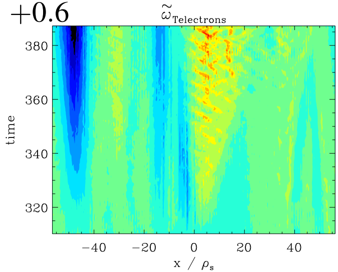
⇒ **locally destabilizes** (near-marginal) **ETG**

Nonlinearly, **TEM suppressed** by ZF (despite tertiary increase)

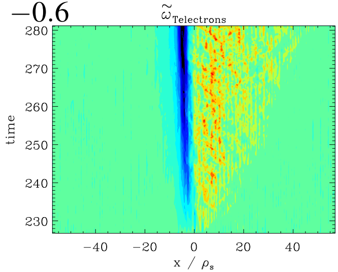
Note: **Asymmetry** in zonal T_e likely **due to TEM**, not ETG

ECCD in TCV Extreme δ

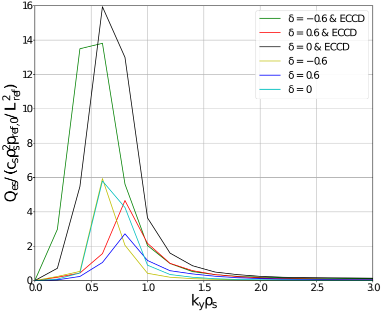
$\delta = +0.6$



$\delta = -0.6$



TCV case: TEM+ITG at NT, no marginal ETG, high ν_{ei}



NT, $\delta = 0$: increased TEM flux

PT: only little increase, non-local T_{e} effect $\leftrightarrow$ ZFs?

Summary

- **extreme triangularity** $|\delta| \gtrsim 0.6$ **promising** from turbulence standpoint, *but is it realistic in reactors?*
- PT-NT difference in zonal-flow scales **challenging for QL**
- **new ECCD implementation** in GENE
- ECCD destabilizing for TEM & ETG (tertiary), but **ZFs strengthened** $\Rightarrow$ **can lower flux**

Plans going forward:

- *add saturation efficiency* τ *to QL for PT vs. NT*
- *further tests of ECCD; explain PT asymmetry; multiscale?*

EUROfusion

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