MULTI-DEVICE DIMENSIONLESS SCALING OF NEOCLASSICAL TEARING MODE BETA LIMIT

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in collaboration with
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DIII–D NATIONAL FUSION FACILITY

ASDEX Upgrade

JET

UKAEA Fusion

315–99

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Sorting Category: 5.1.1.2 (Experimental)

Multi-Device Dimensionless Scaling of Neoclassical Tearing Mode Beta Limit[1] R.J. LA HAYE, General Atomics, R.J. BUTTERY, H.R. WILSON, Euratom/UKAEA Fusion Association Culham, S. GUENTER, MPI f. Plasmaphysik, G.T.A HUYSMANS, Jet Joint Undertaking (now at CEA, Cadarache) — To extrapolate the neoclassical tearing mode (NTM) beta limit to reactor grade tokamaks, a multi-device database has been compiled from Asdex-Upgrade, DIII-D, and JET. The key issue in predicting the NTM beta limit is the relative scaling of the "seed" island $w_{\rm s}$ to the threshold island $w_{\rm th}$. For sawtooth induced $m/n = 3/2$ NTM, the relative threshold island width is taken from the polarization/inertial model[2] as $w_{\rm th}/r \propto \rho_{\rm i*} g^{1/2}(\epsilon, \nu)$ where g is a function of collisionality $\nu = \nu_{\rm i}/\epsilon\omega_{\rm e*}$ that increases from 1 at low ν to $\epsilon^{-3/2} \gg 1$ at high ν. The relative seed island scaling, allowing for the dynamics of geometrically coupled perturbations as a function of magnetic Reynolds number S,[3] is taken as $w_{\rm s}/r \propto \beta_\theta^\gamma S^{-\alpha} \propto \rho_{\rm i*}^{3\alpha} \nu^\alpha$ for $\gamma \equiv \alpha/2$. Thus the scaling of $w_{\rm s}/w_{\rm th} \propto \rho_{\rm i*}^{3\alpha-1} \nu^\alpha$ with $\rho_{\rm i*}$ depends critically on whether $\alpha \lesseqgtr 1/3$. Best fits of experimental data will be presented.

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[2]H.R. Wilson *et al.*, Phys. Plasmas **3** (1996) 248.
[3]C.C. Hegna *et al.*, Phys. Plasmas **6** (1999) 130.

☒ Prefer Oral Session
☐ Prefer Poster Session

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General Atomics

Special instructions: DIII-D Contributed Oral Session, immediately following M Okabayashi

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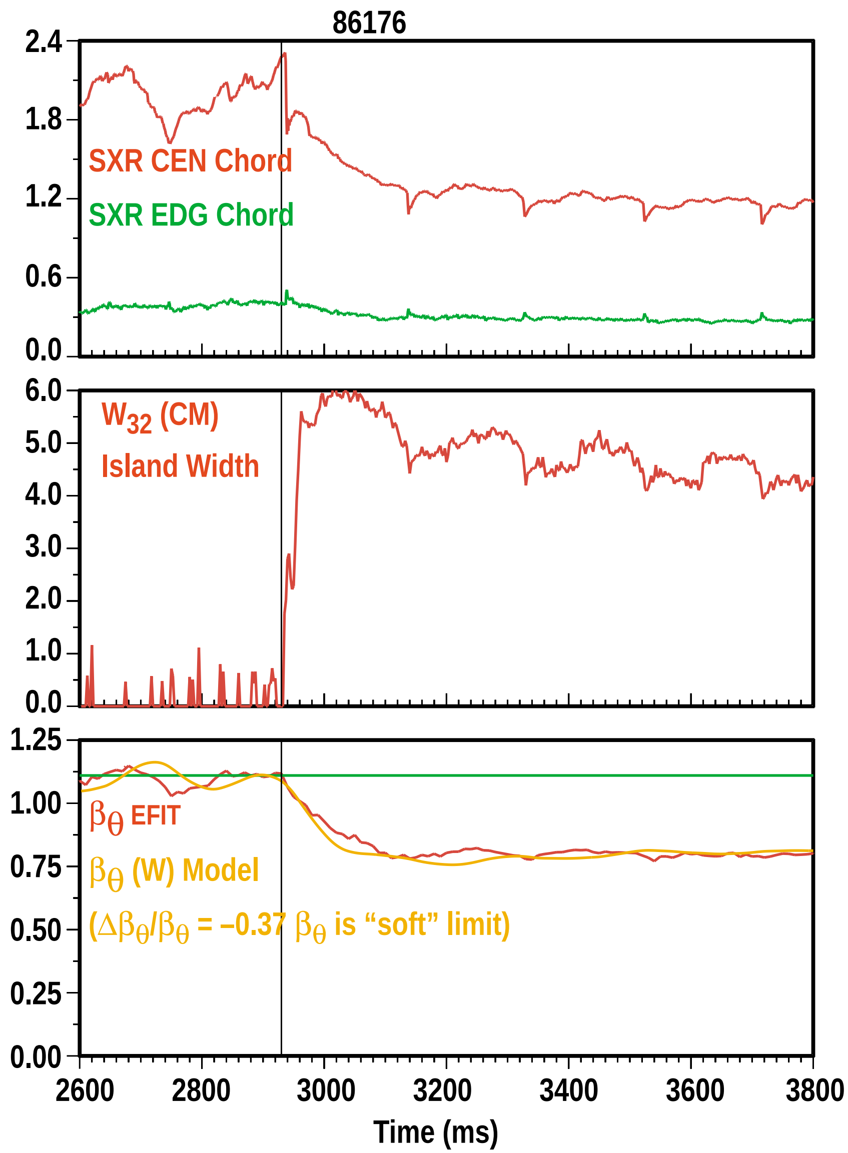
OFTEN THE FIRST LIMIT ON BETA IN HIGH CONFINEMENT ELMING H–MODE

- q = 1 sawtooth induced m/n = 3/2 NTM; beta decreases by up to 30%



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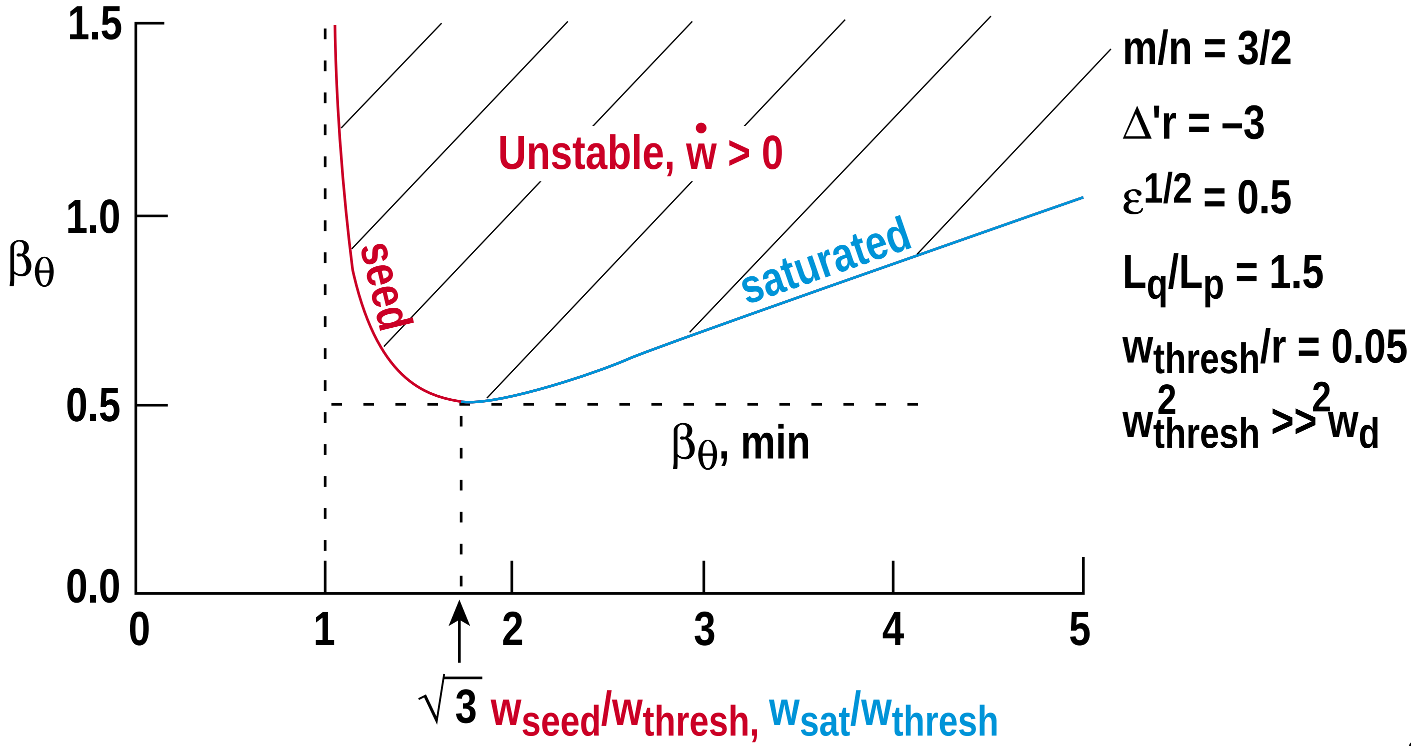
HELICALLY PERTURBED BOOTSTRAP CURRENT CAN EXCITE NEOCLASSICAL TEARING MODE

- $$\frac{\tau_R}{r^2}\frac{dw}{dt} = \Delta' + \varepsilon^{1/2}\left(L_q/L_p\right)\beta_\theta\left(\frac{w}{w^2+w_d^2} - \frac{w_{thresh}^2}{w^3}\right)$$
  - ★ Modified Rutherford Eq. with $w_{thresh} \approx \varepsilon^{1/2}\rho_{\theta i}$ the ion banana width
- $$\beta_{\theta,\,crit} \approx [-\Delta' r/(\varepsilon^{1/2}L_q/L_p]\left(\frac{w_{thresh}}{r}\right)\left[\frac{w_{seed}/w_{thresh}}{1-(w_{thresh}/w_{seed})^2}\right],\quad w_{thresh}^2 >> w_d^2$$
  - ★ if $w_{seed}/w_{thresh} \equiv$ constant > 1, $\beta_{\theta,\,crit} \propto w_{thresh}/r \propto \rho_{i*}$
  - ★ if w_{seed}/w_{thresh} < 1, $\beta_{\theta,\,crit} \rightarrow \infty$, i.e. plasma remains metastable



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DIMENSIONLESS SCALING MODEL

- w_{thresh} from polarization/inertial model (Wilson, et al., 1996)

  ★ $w_{thresh}/r \propto \rho_{i*}\, g^{1/2}(\nu,\varepsilon)$ with $g = (1+C_2\nu)/(1+C_3\nu)$ for $\nu \equiv \nu_i/\varepsilon\omega_{e*}$ and $C_2/C_3 \approx \varepsilon^{-3/2}$

  — $w_d/r \propto (\chi_\perp/\chi_{||})^{1/4} \propto \rho_{i*}^{1/3}$ for $\chi_\perp \propto \chi_{BOHM}$ and $\chi_{||} \propto C_s w^{-1}$
  . . . Fitzpatrick et al., incomplete pressure flattening

- w_{seed} from dynamical coupling model (Hegna et al., 1999)

  ★ $$\frac{w_{seed}}{r} \propto \left(\frac{\psi}{\psi_0}\right)^{1/2} * f\left(\frac{r_1}{R}, \frac{r_{3/2}}{R}, \Lambda\right) * S^{-\alpha} \propto \beta_\theta^\gamma S^{-\alpha},\ \alpha \text{ tbd}$$

rel. sawtooth amp. a function of S?	geometric m±1 coupling	dynamic shielding at q = 3/2 skin layer increases with mag. Reynold's no.

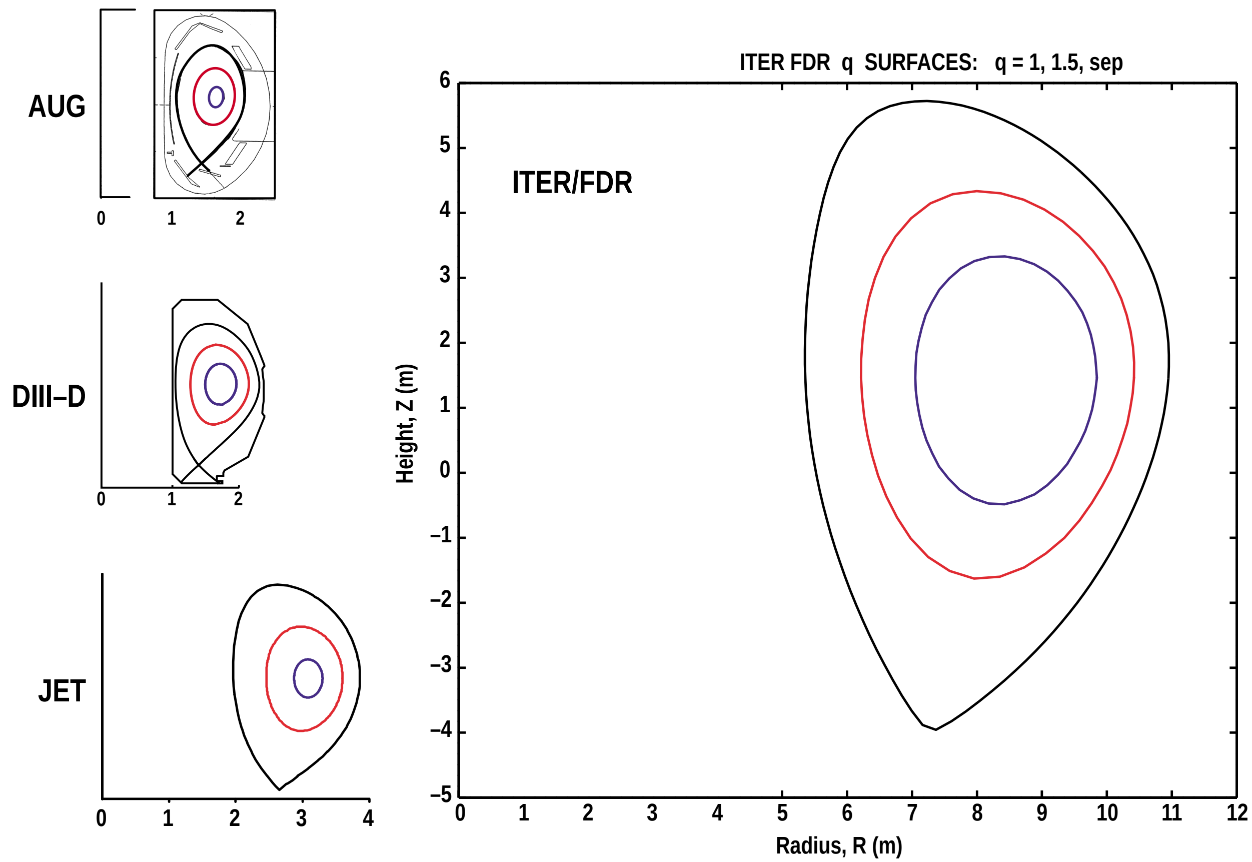
  — $S \propto \beta^{1/2}/\rho_{i*}^3\, \nu \Rightarrow w_{seed}/r \propto \rho_{i*}^{3\alpha}\nu^\alpha$ for $\gamma \equiv \alpha/2$

- $$\frac{w_{seed}}{w_{thresh}} \propto \rho_{i*}^{3\alpha-1}\,\nu^{\alpha}/g^{1/2}(\nu)$$ ≈ constant for $\alpha = 1/3$ and fixed ν

  – $\alpha > 1/3$ would be favorable for a reactor-grade tokamak

EXAMINE DIMENSIONLESS SCALING IN AUG, DIII–D AND JET

- LSND, ELMing H–mode, q95 ≳ 3
- Sawtooth induced 3/2 NTM database
- Extrapolate to proposed ITER/FDR



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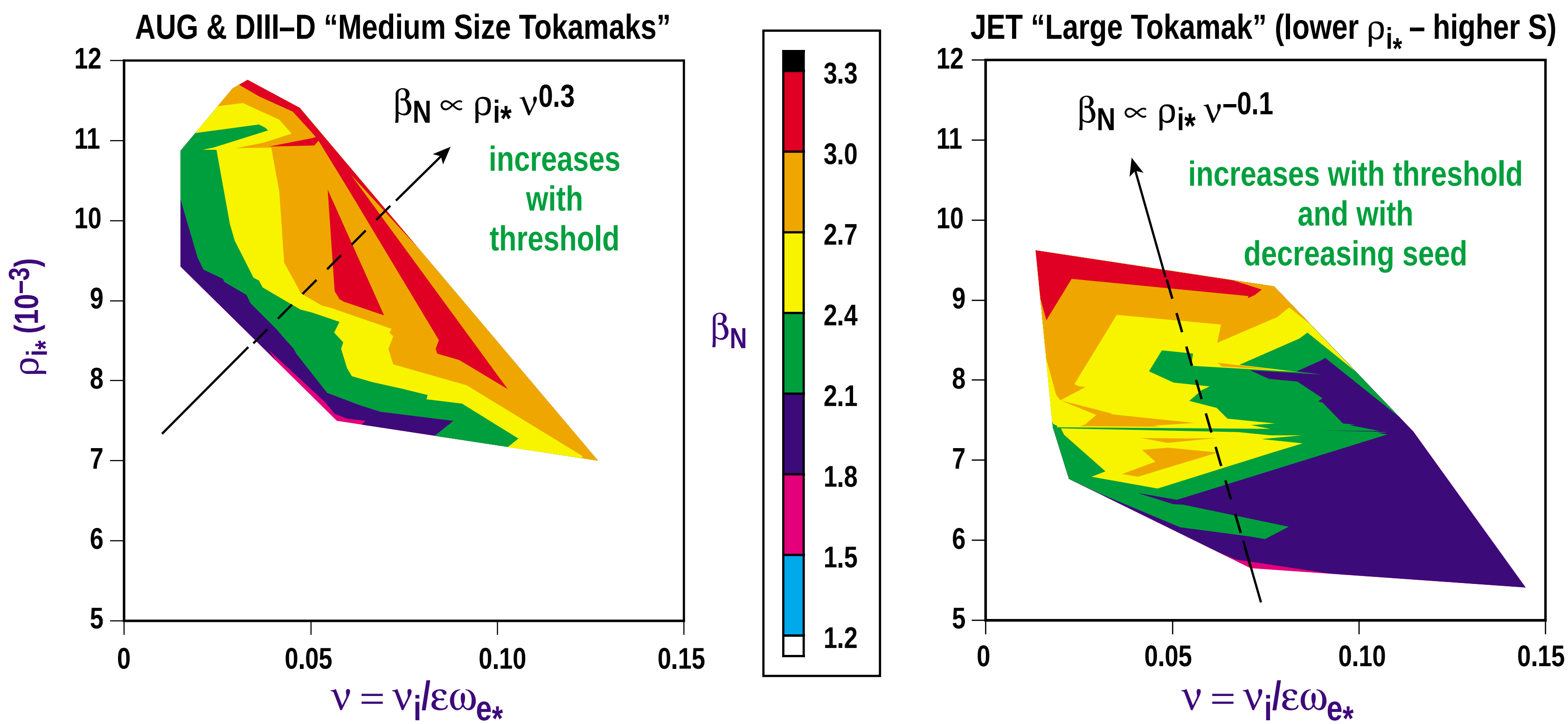
CONTOUR PLOTS OF DATABASE FOR SAWTOOTH INDUCED 3/2 NTM

- A common separable power law of form $\beta_{NC} \propto \rho_{i*}^{x} (\nu_i/\varepsilon\omega_{e*})^{y}$
  - Does not represent the scaling, thus $\alpha \neq 1/3$
- $\beta_N \propto \rho_{i*}$ is support for polarization/inertial threshold model



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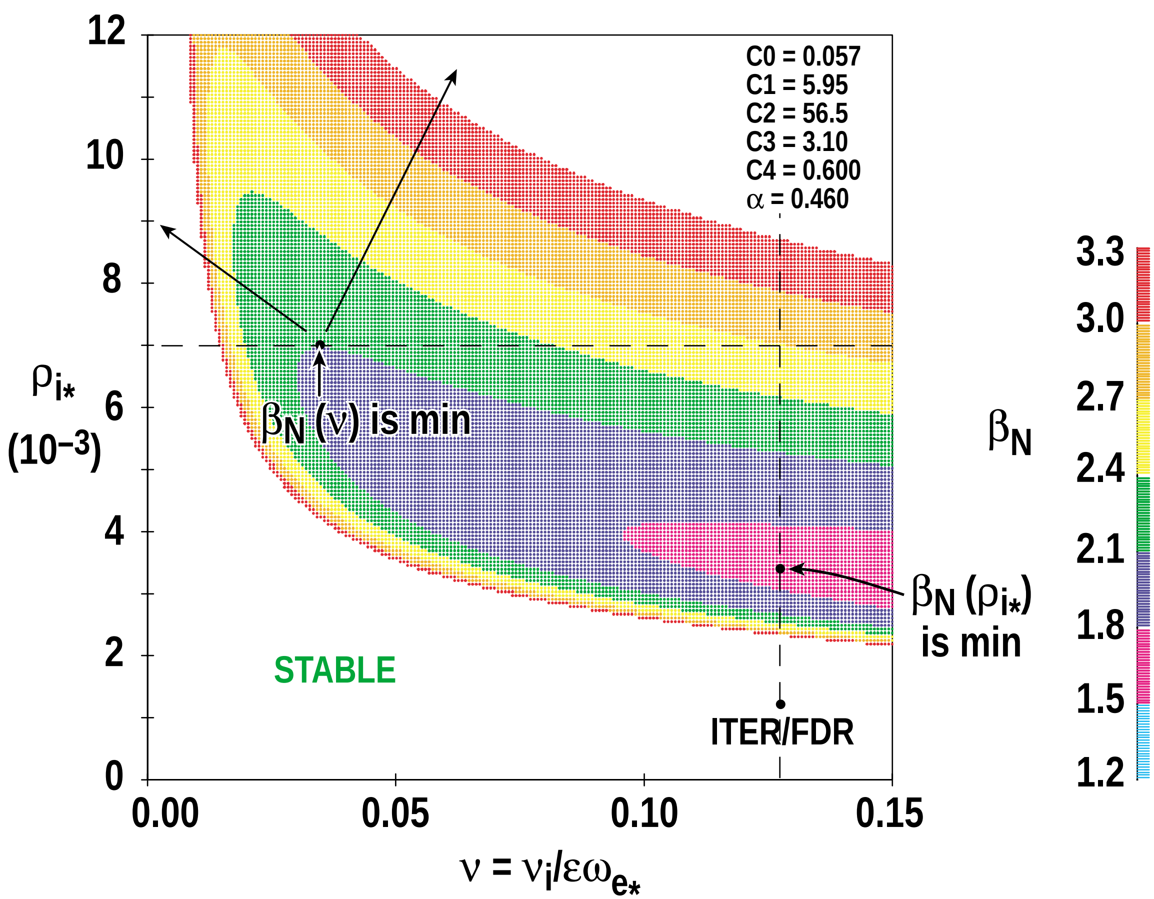
BEST FIT OF DATABASE TO PHYSICS MODEL HAS $\alpha \approx 4/9$

- $$\frac{\beta_{NC}}{C_0 \rho_{i*}} = \frac{C_1 \rho_{i*}^{3\alpha-1} \nu^{\alpha}}{\dfrac{1}{1+C_4^2 \rho_{i*}^{2/3-6\alpha} \nu^{-2\alpha}} - \dfrac{(1+C_2\nu)/(1+C_3\nu)}{C_1^2 \rho_{i*}^{6\alpha-2} \nu^{2\alpha}}}$$

★ Seed island decreases faster with ρ_{i*} than threshold for $\alpha \approx 4/9$

— stabilizes at very low ρ_{i*}, high S, i.e. $w_{seed}/w_{thresh} < 1$

. . . nom op pt is stable for ITER/FDR



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CRITICAL BETA FOR NTM DEPENDS ON RELATIVE SCALING OF w_{seed} TO $w_{threshold}$

- w_{seed}/r decreases in dynamic shielding model at higher S
  - $w_{seed}/r \propto S^{-4/9} \propto \rho_{i*}^{4/3}$ (at fixed ν)

- $w_{thresh}/r \propto \rho_{i*}$ from polarization/inertial model

- $w_{seed}/w_{thresh} \propto \rho_{i*}^{1/3}$ (at fixed ν)
  - Favorable for ITER-FDR, i.e. at small ρ_{i*}

★ Seed may be too small to excite NTM

. . . but depends on the difference of large extrapolations