QH configuration WISTA_15
Beta dependency of the bootstrap current and ideal MHD ballooning stability limits

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Outline

- WISTA_15
  - Stability, Well depth, Mercier
  - Bootstrap current
    - Constant P with varying N/T profiles: Effects of collisionality and Er
    - BOOTSJ
    - SFINCS
  - Ideal MHD ballooning stability

COILSET: WISTA_15

- Derived from FOCUS, T. Kruger
- Last closed flux surface was refined based on Poincaré maps, DESCUR and/or vacuum VMEC runs
- Magnetic well exists; Becomes deeper with increasing beta
- Ideal MHD ballooning growth rates calculated with COBRAVMEC

- Bootstrap current varies with collisionality, radial electric field
  - Ignoring these effect results in an underestimate of the total bootstrap current for this QH configuration
  - Consequences for modeling with BOOTSJ

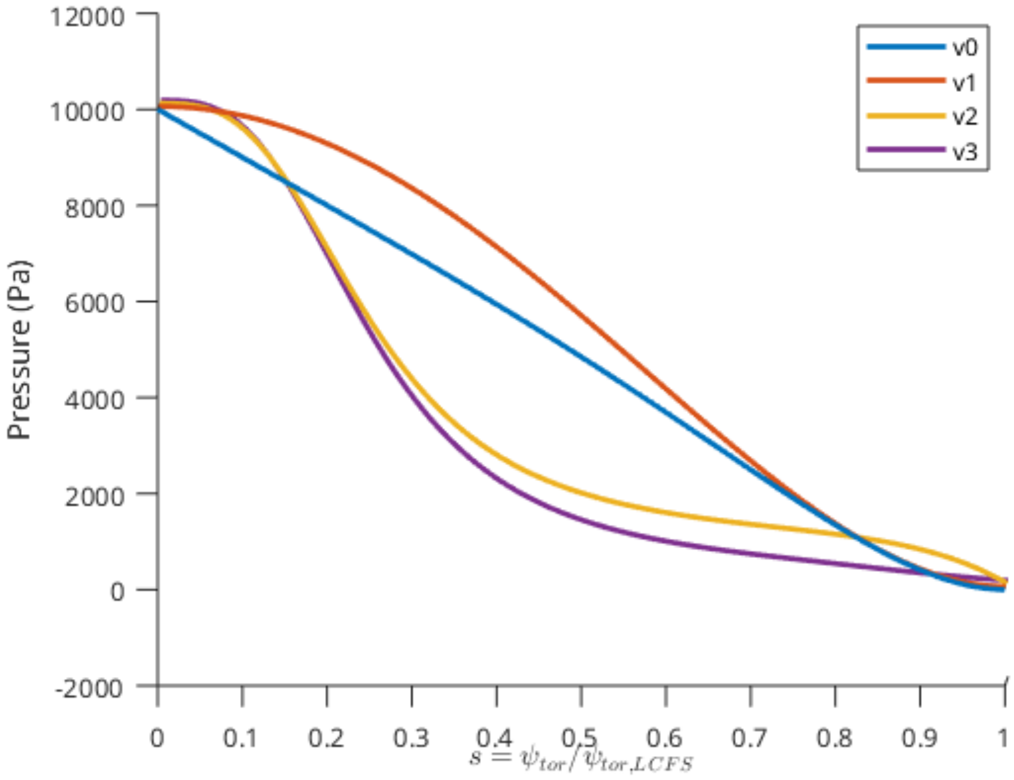
Mostly peaked pressure profiles are checked

- Most of the work assumes:
  - $T \sim T_0 * (1 - s)$
  - $N \sim N_0 * (1 - s^5)$

  - $\rightarrow P \sim P_0 (1 - s - s^5 + s^6)$
    - v0 in the figure

- Later on, a variety of pressure profiles are checked

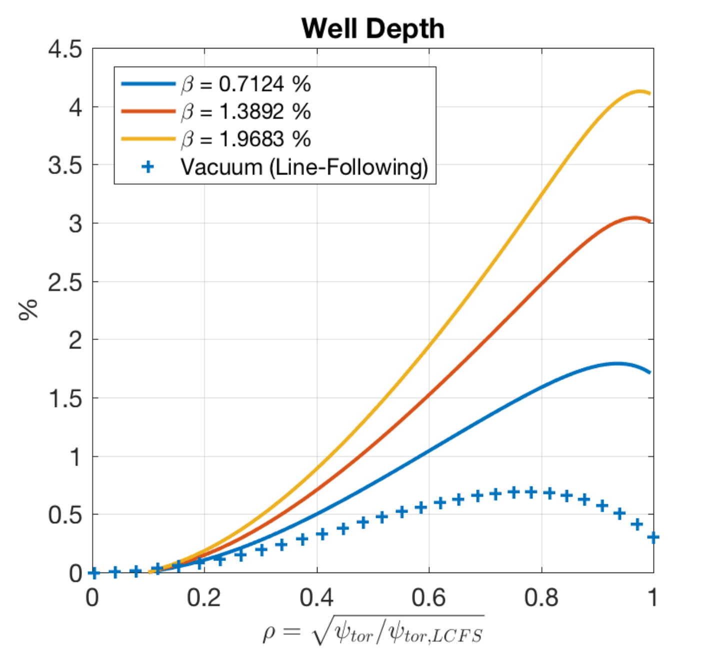
- Might add some flatter/broader profile selections

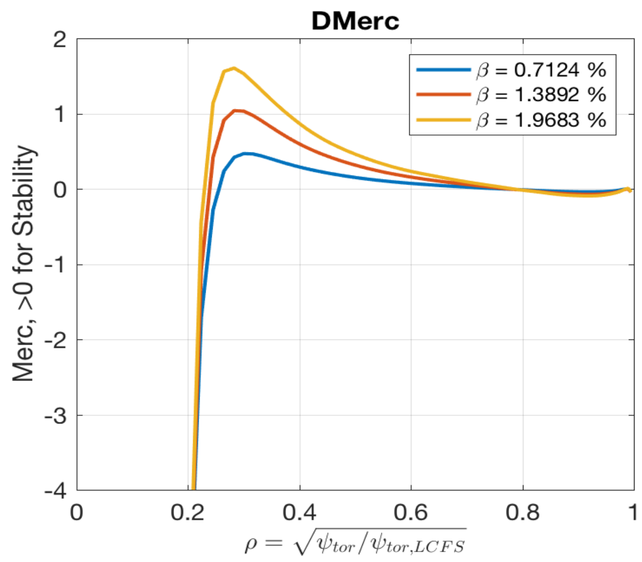


- Well Depth $= \dfrac{\left(\left.\dfrac{dV}{d\psi}\right|_{\rho=0} - \dfrac{dV}{d\psi}\right)}{\left.\dfrac{dV}{d\psi}\right|_{\rho=0}}$

- Well depth improves with pressure

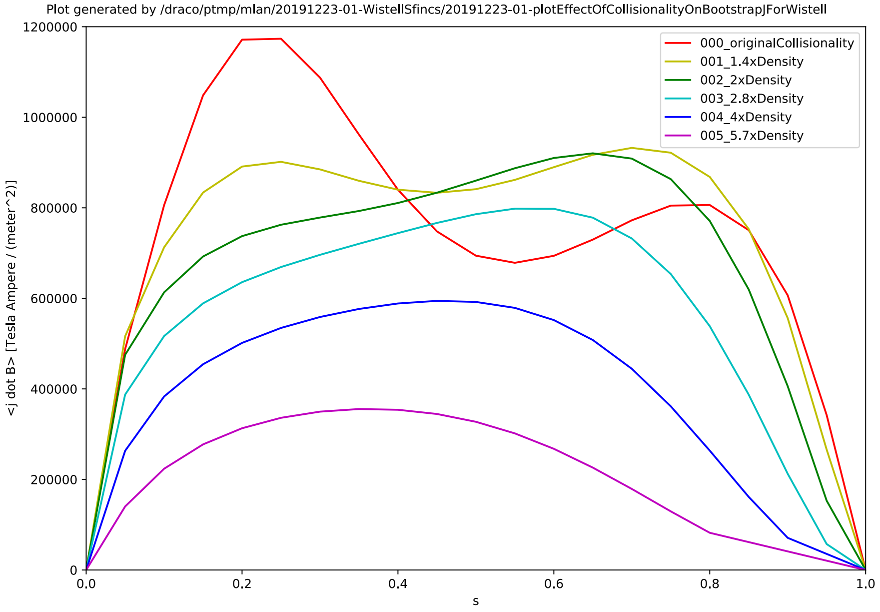
- Mercier stability (near mid-radius) improves (not certain about on-axis or edge behavior)

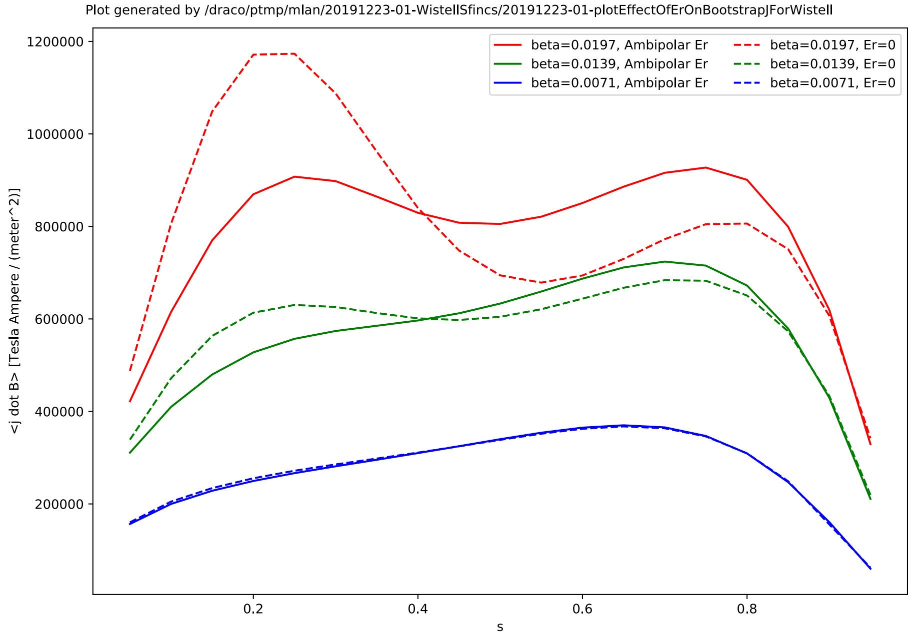




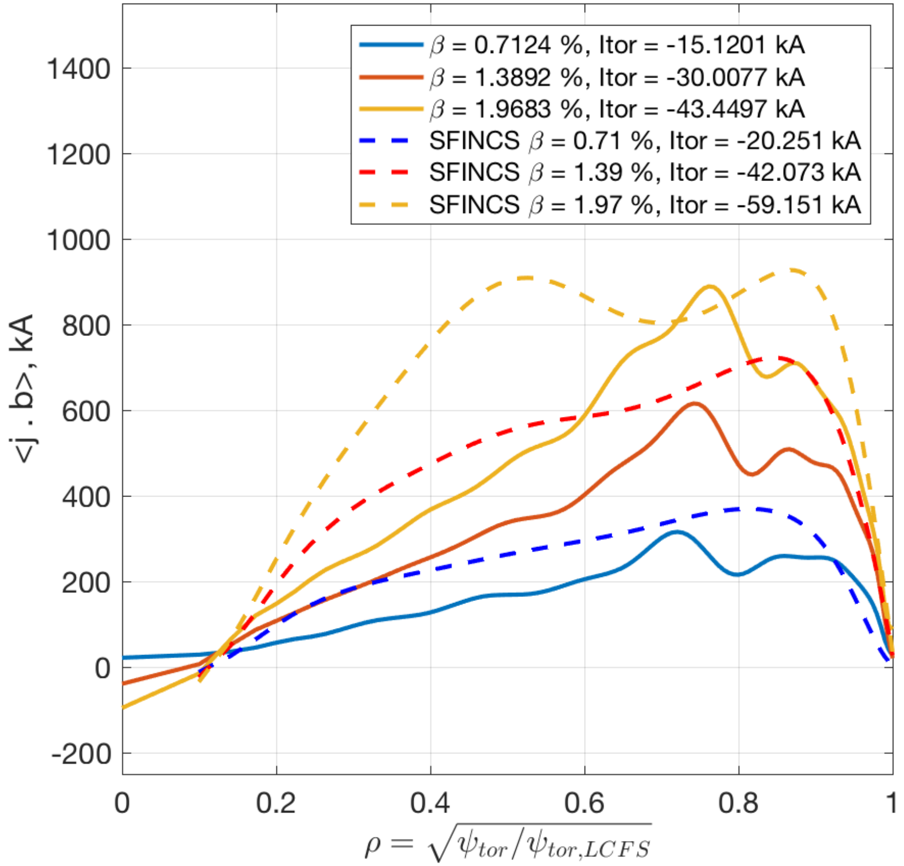
Bootstrap current: Importance of Er and collisionality

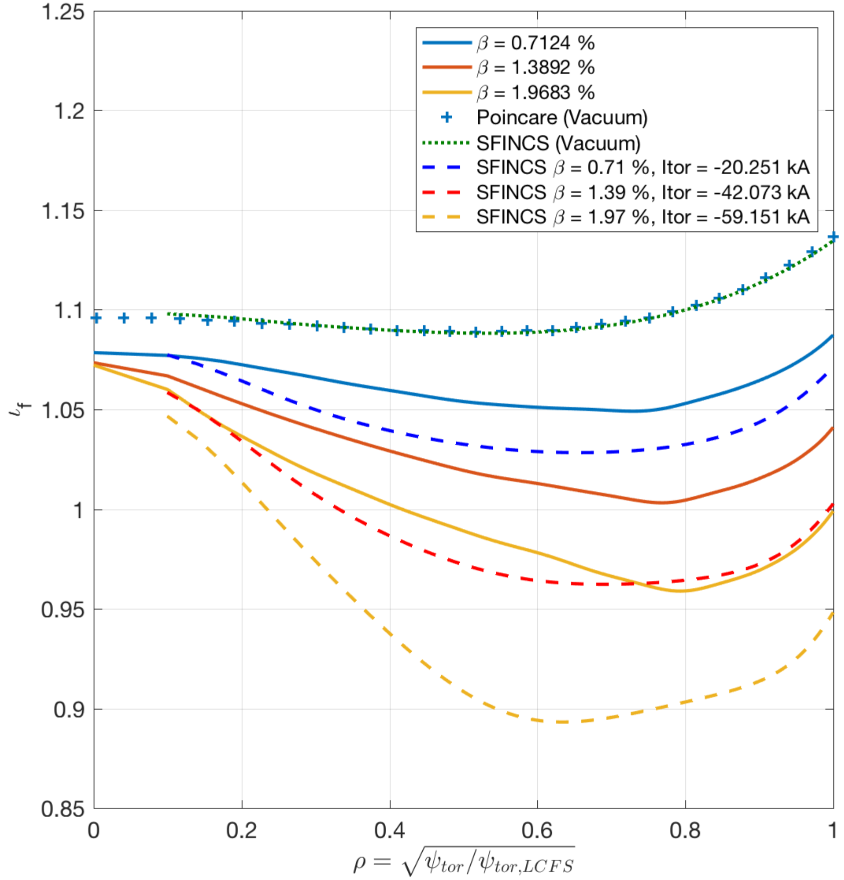
- SFINCS (M. Landerman)
- Left: <J.B> decreases with collisionality (at constant beta)
- Right: Effect of Ambipol Er vs Er=0 (for several cases of beta)





SFINCS vs BOOTSJ: BOOTSJ underestimates the total current density by 30%-40%





Seen before with NEO2, DKES

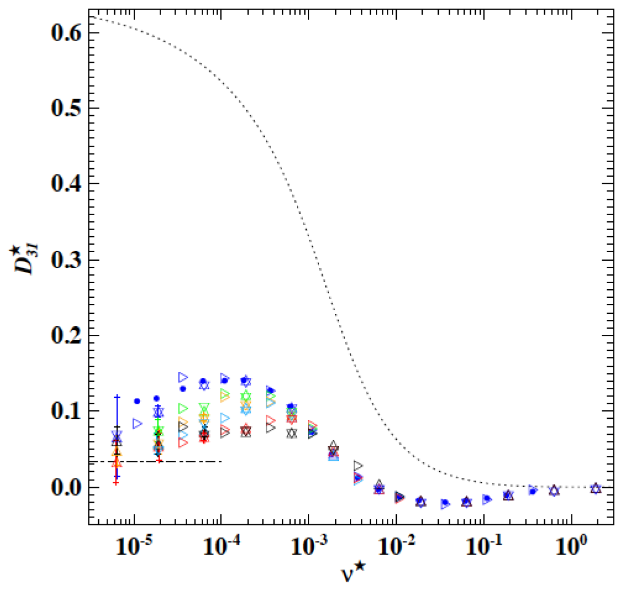


Figure 26. Normalised mono-energetic bootstrap current coefficient as a function of collisionality for $v_E^\star = 3 \times 10^{-3}, 1 \times 10^{-3}, 3 \times 10^{-4}, 1 \times 10^{-4}, 3 \times 10^{-5}$ and zero for the W7-X standard configuration at $\rho = 0.5$. Numerical results from NEO-2 are depicted as small filled-in circles (•) and those from DKES as triangles (△) with upper and lower variational bounds indicated when these lie outside the symbol. The results from VENUS+δf are plotted as upside-down triangles (▽) and those from a second Monte Carlo code [15] are indicated by right-pointing triangles (▷). For comparison, results for the equivalent axisymmetric tokamak ($r = 0.2555$ m, $R_0 = 5.5267$ m, $\iota = 0.8701$, $b_{1,0} = -0.0190$) are shown by the dotted line for $E_r = 0$. The collisionless asymptote [79,80] for W7-X has been evaluated by numerical integration and is shown by the dot-dash line.

Beidler, Nuclear Fusion (2011)

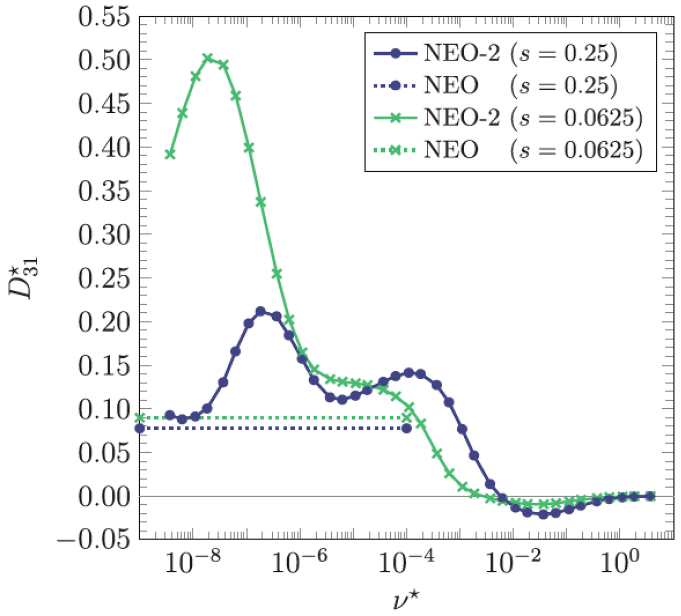
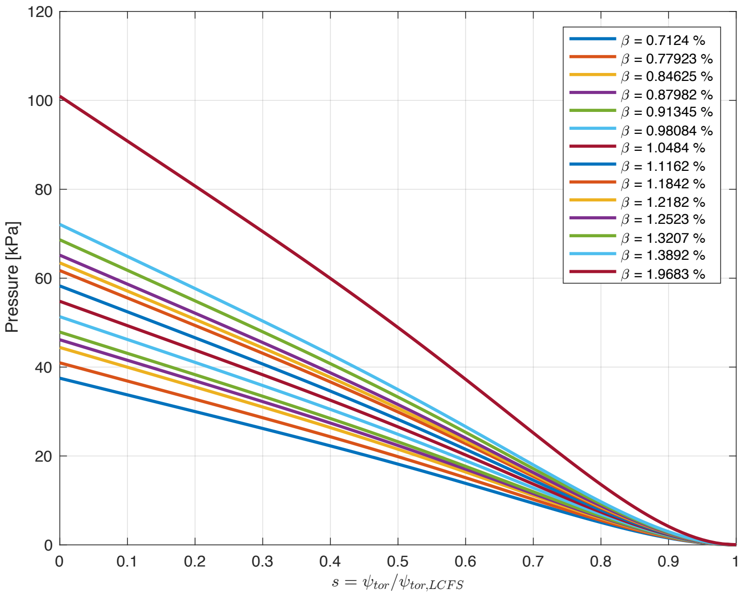


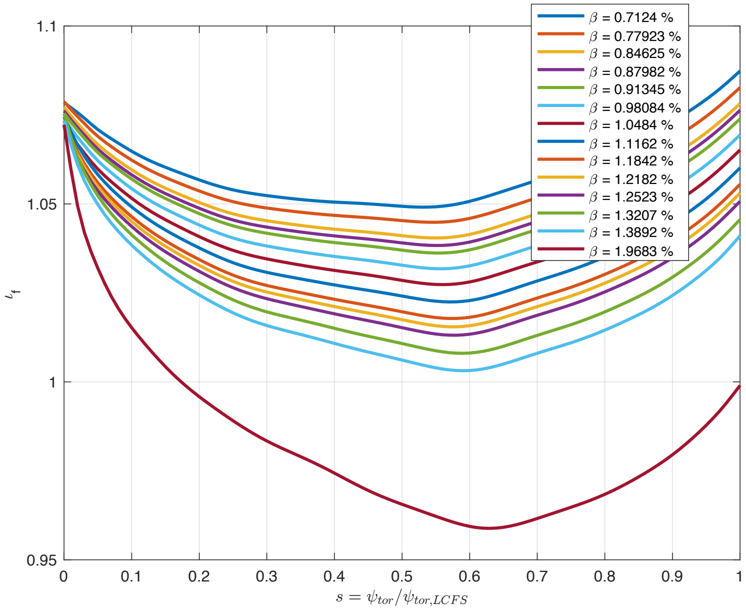
Figure 3. Normalized mono-energetic radial transport coefficient *D*11 (left) and normalized mono-energetic bootstrap current coefficient

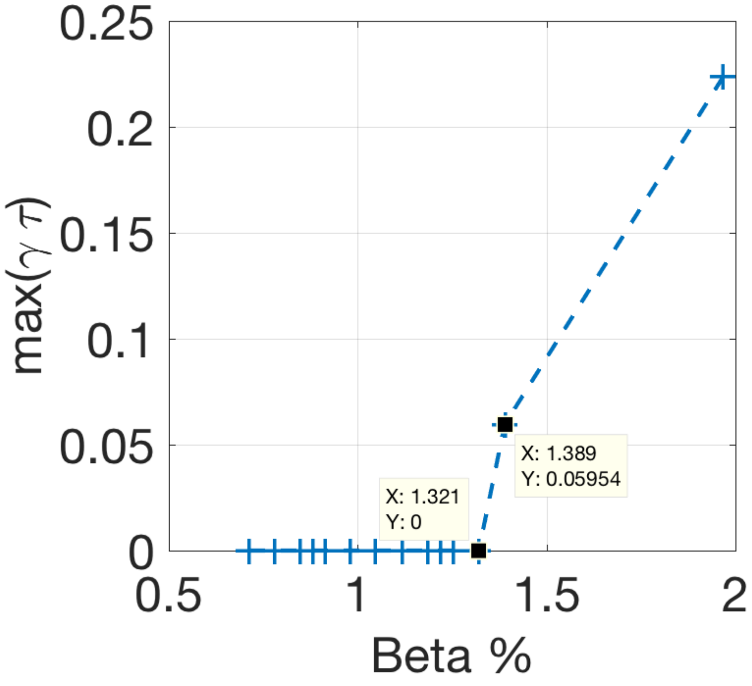
* (right) as a function of collisionality computed by NEO-2 (solid) for finite collisionalities and by NEO (dotted) for the collisionless limit at half radius $s = 0.25$ (circles) and quarter radius $s = 0.0625$ (crosses). Markers on the solid lines correspond to results of NEO-2 runs at given collisionalities.

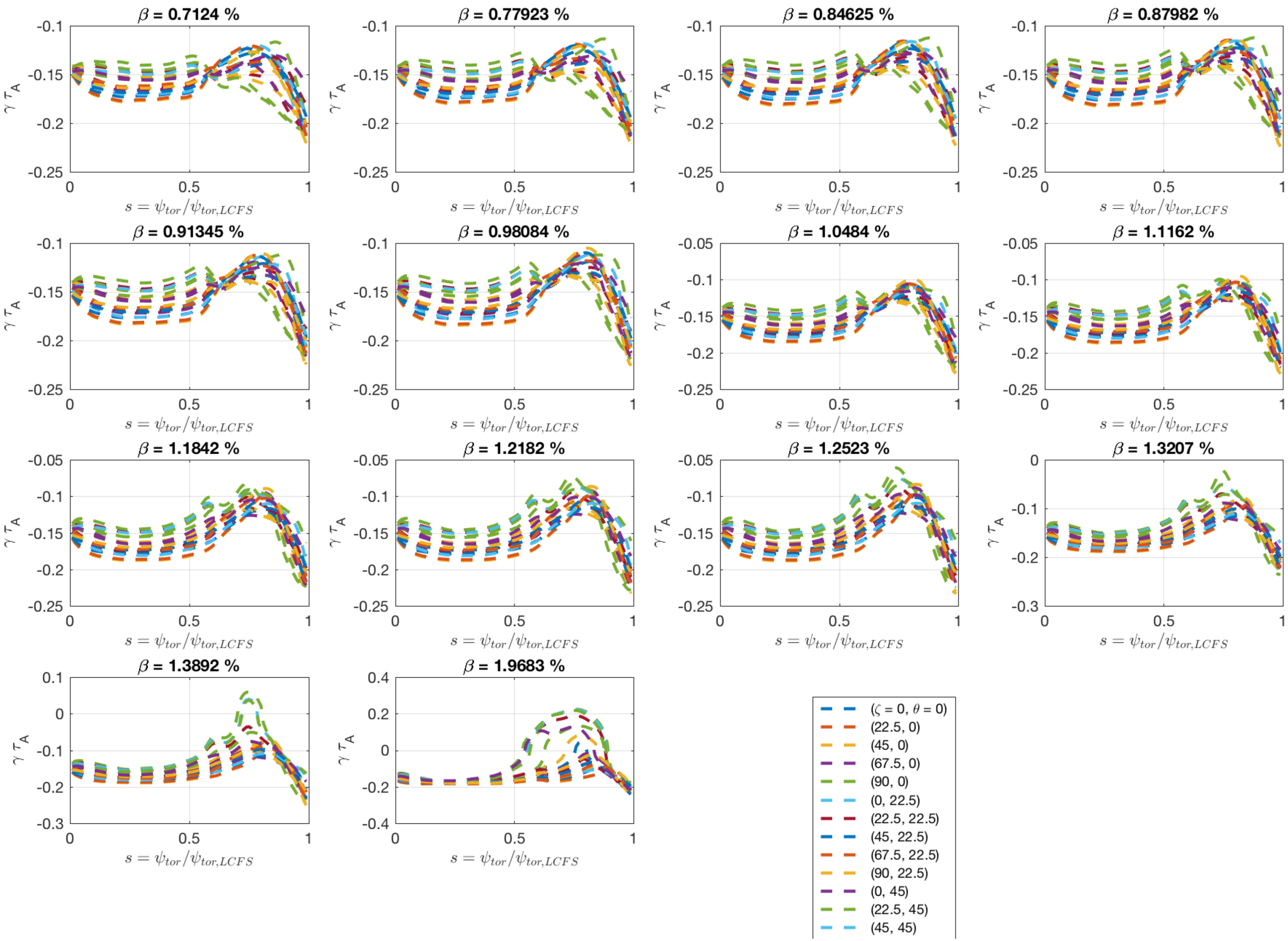
Kernbichler, PPCF (2016)

Beta Scan with ‘v0’ profile



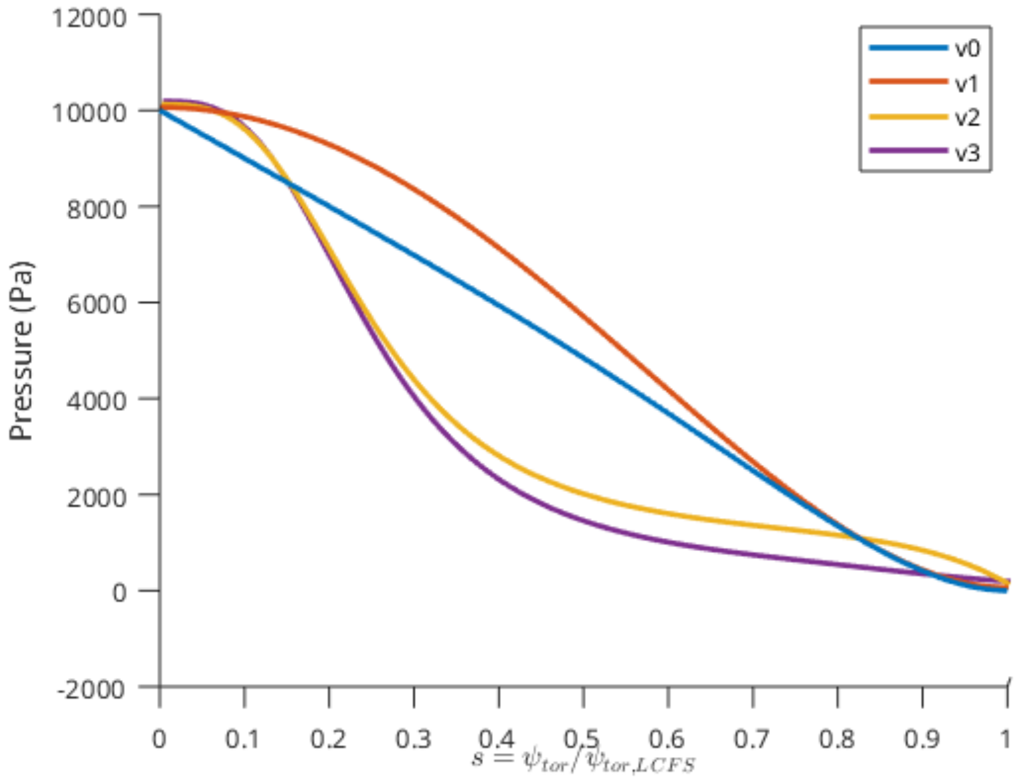


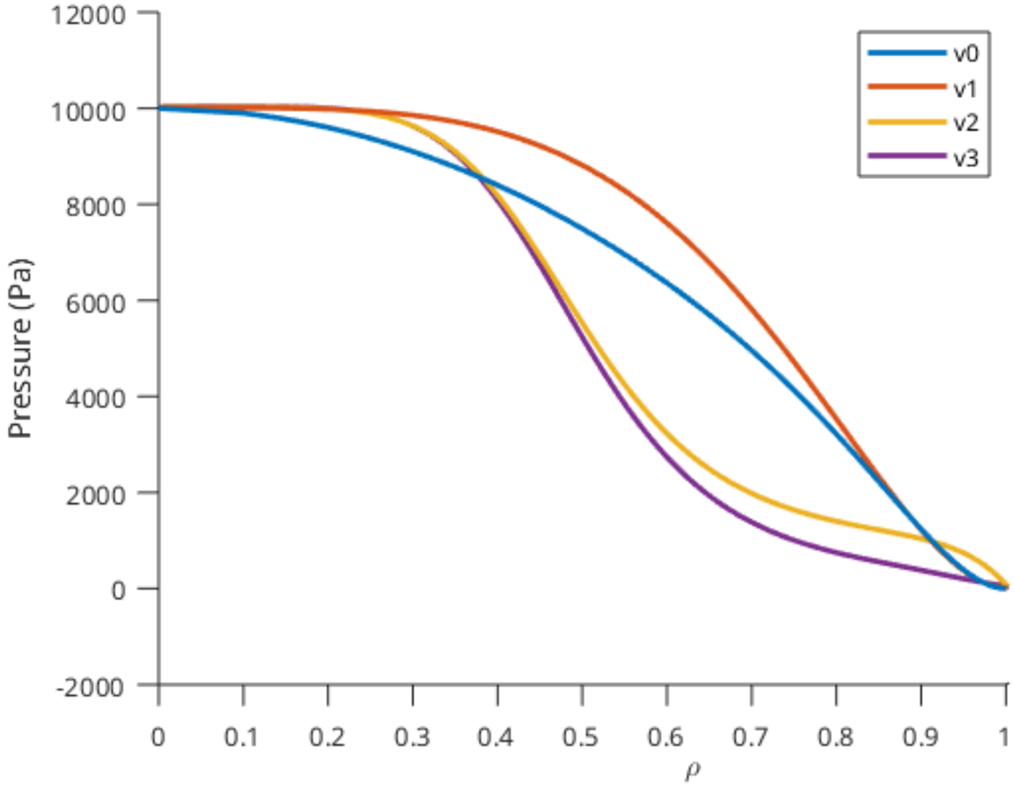




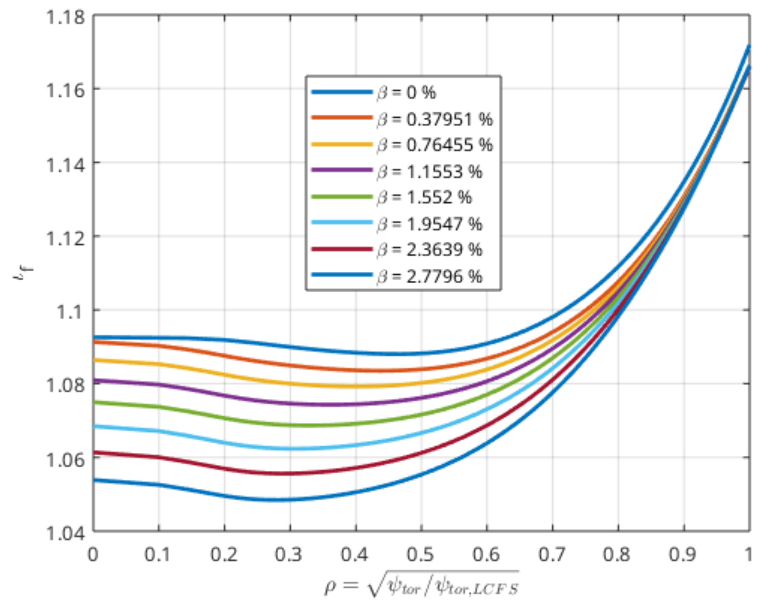
β = 0.7124 %
β = 0.77923 %
β = 0.84625 %
β = 0.87982 %
β = 0.91345 %
β = 0.98084 %
β = 1.0484 %
β = 1.1162 %
β = 1.1842 %
β = 1.2182 %
β = 1.2523 %
β = 1.3207 %
β = 1.3892 %
β = 1.9683 %
γ τ_A
s = ψ_tor/ψ_tor,LCFS
(ζ = 0, θ = 0)
(22.5, 0)
(45, 0)
(67.5, 0)
(90, 0)
(0, 22.5)
(22.5, 22.5)
(45, 22.5)
(67.5, 22.5)
(90, 22.5)
(0, 45)
(22.5, 45)
(45, 45)

The next few scan did NOT use bootstrap current. Considering the effect of pressure profile shape only. (if any)

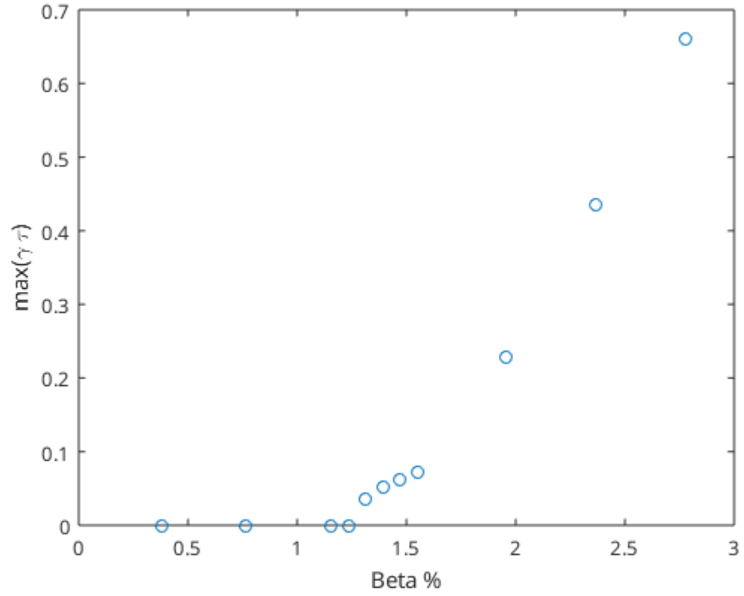




v1

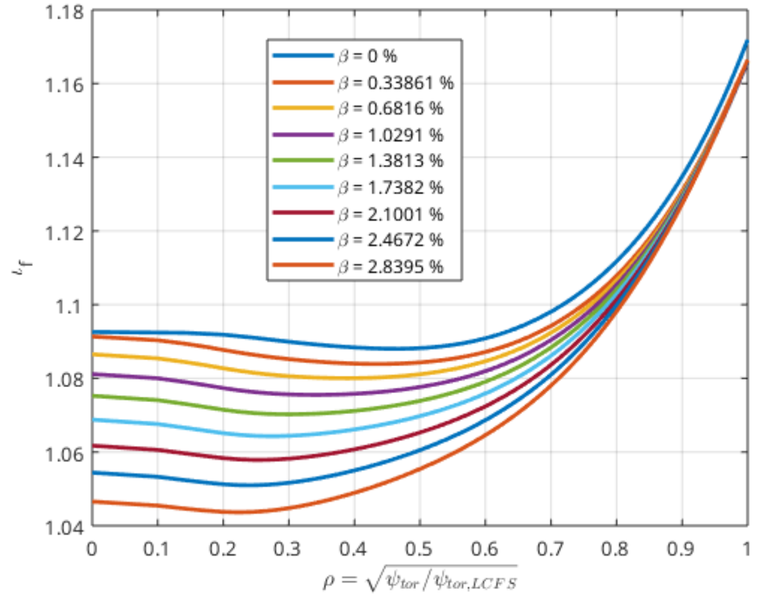


β = 0 %
β = 0.37951 %
β = 0.76455 %
β = 1.1553 %
β = 1.552 %
β = 1.9547 %
β = 2.3639 %
β = 2.7796 %
ι_f
$\rho = \sqrt{\psi_{tor}/\psi_{tor,LCFS}}$

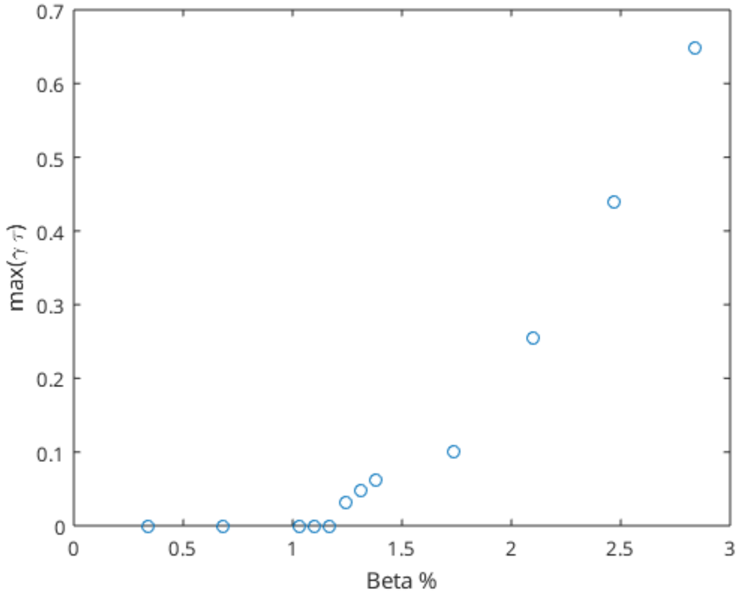


max($\gamma\tau$)
Beta %

v0

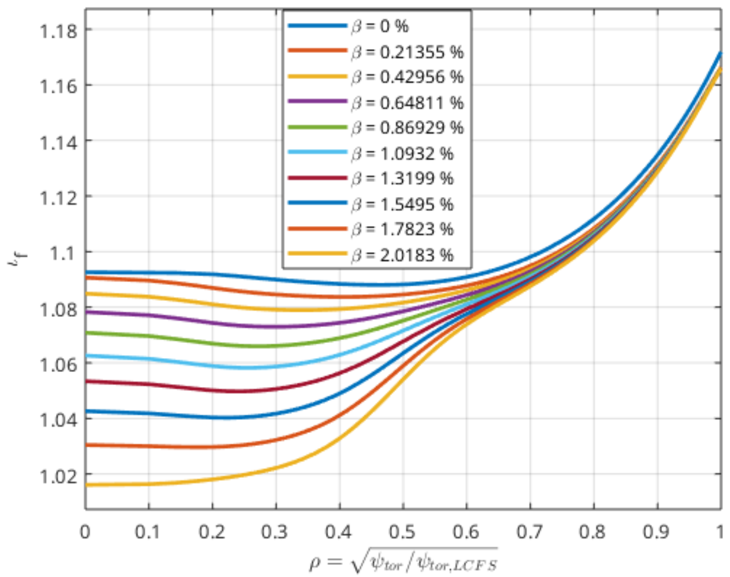


β = 0 %
β = 0.33861 %
β = 0.6816 %
β = 1.0291 %
β = 1.3813 %
β = 1.7382 %
β = 2.1001 %
β = 2.4672 %
β = 2.8395 %
ι_f
$\rho = \sqrt{\psi_{tor}/\psi_{tor,LCFS}}$

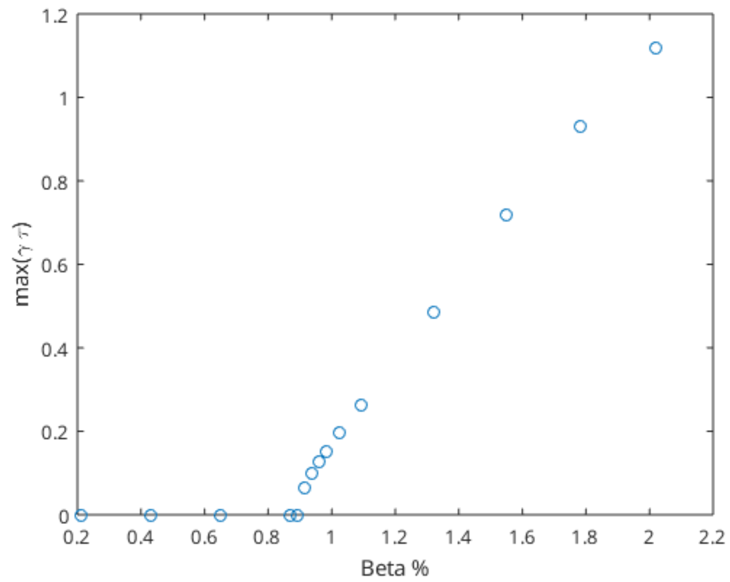


max($\gamma\tau$)
Beta %

v3

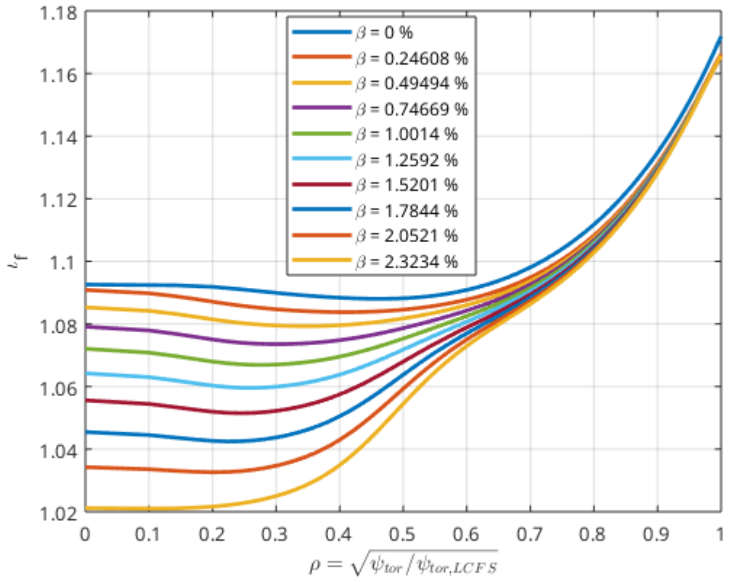


β = 0 %
β = 0.21355 %
β = 0.42956 %
β = 0.64811 %
β = 0.86929 %
β = 1.0932 %
β = 1.3199 %
β = 1.5495 %
β = 1.7823 %
β = 2.0183 %
ι_f
$\rho = \sqrt{\psi_{tor}/\psi_{tor,LCFS}}$

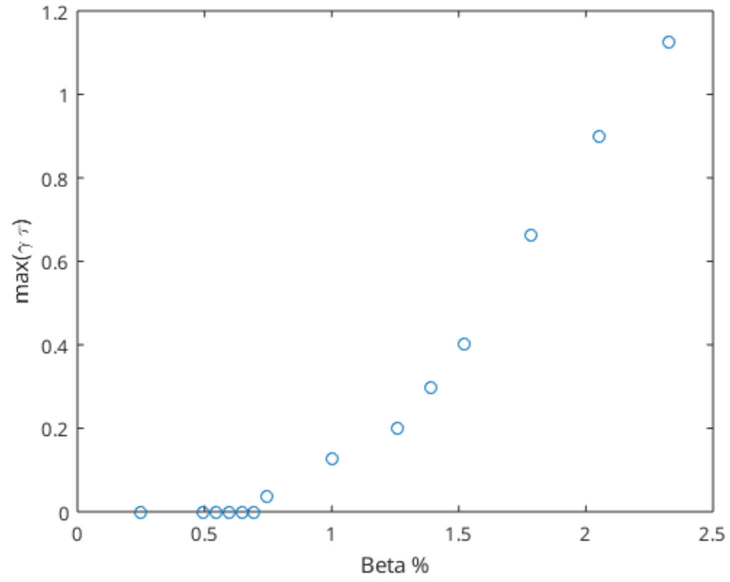


max($\gamma\tau$)
Beta %

v2



β = 0 %
β = 0.24608 %
β = 0.49494 %
β = 0.74669 %
β = 1.0014 %
β = 1.2592 %
β = 1.5201 %
β = 1.7844 %
β = 2.0521 %
β = 2.3234 %
ι_f
$\rho = \sqrt{\psi_{tor}/\psi_{tor,LCFS}}$



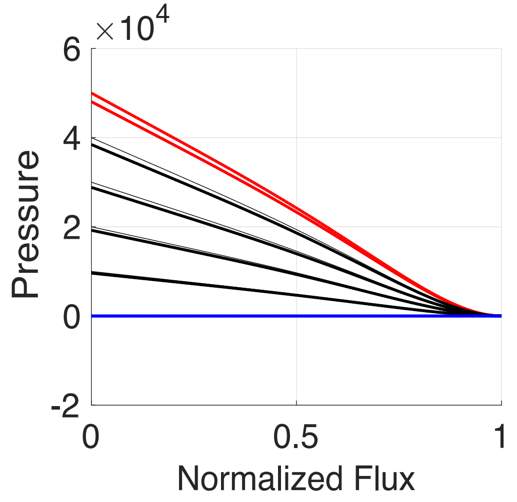
max($\gamma\tau$)
Beta %

- Profiles that are more ‘peaked’ tend to have lower stability limits (when ignoring bootstrap current)

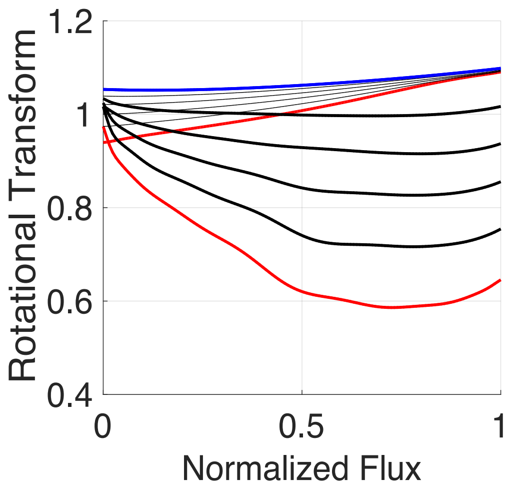
- Next steps
  - Stellopt: Use sfincs instead of bootsj: Better model of bootstrap current for spatially varying T/N profiles.
    - Need robust set of operating parameters
    - Meaningful/Reasonable profiles for T/N

HSX examples

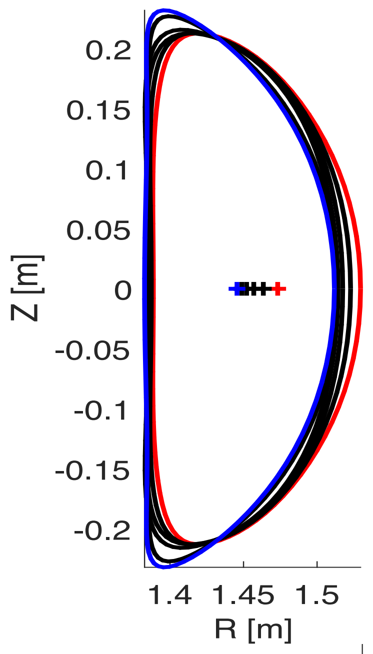
QHS



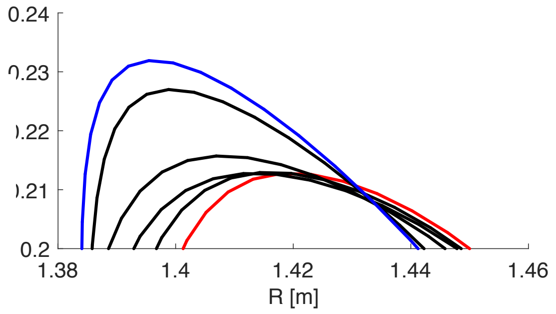
Pressure
×10^4
6
4
2
0
-2
0
0.5
1
Normalized Flux



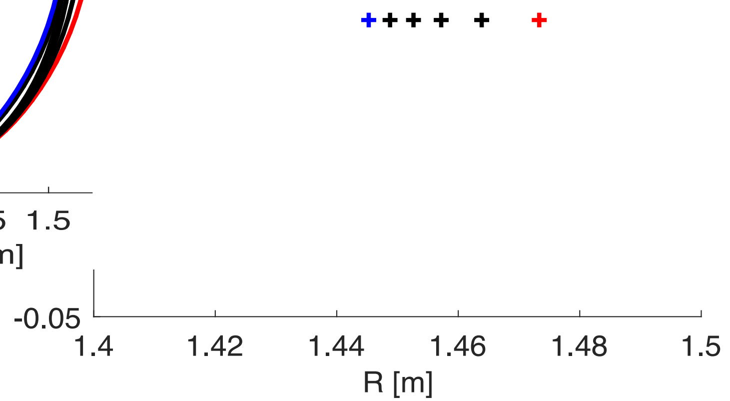
Rotational Transform
1.2
1
0.8
0.6
0.4
0
0.5
1
Normalized Flux



Z [m]
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
1.4
1.45
1.5
R [m]

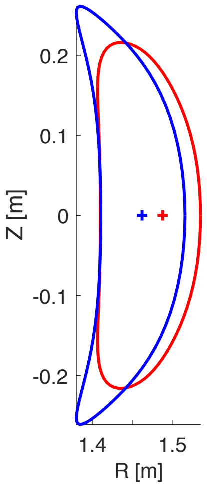


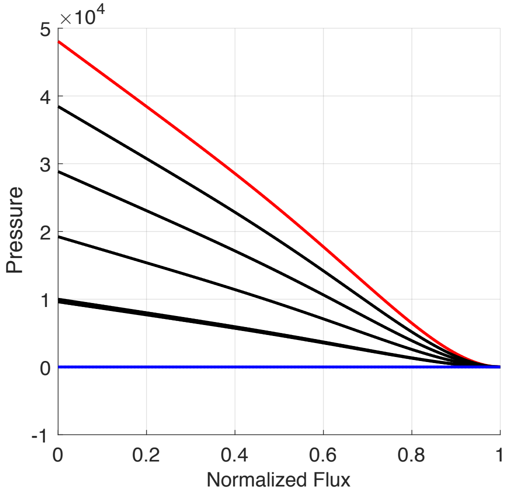
0.24
0.2
1.38
1.4
1.42
1.44
1.46
R [m]

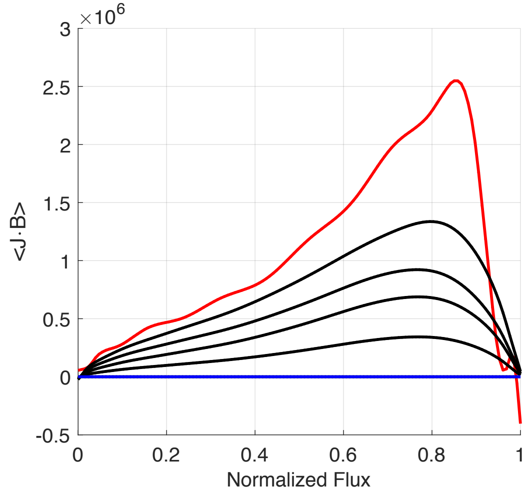


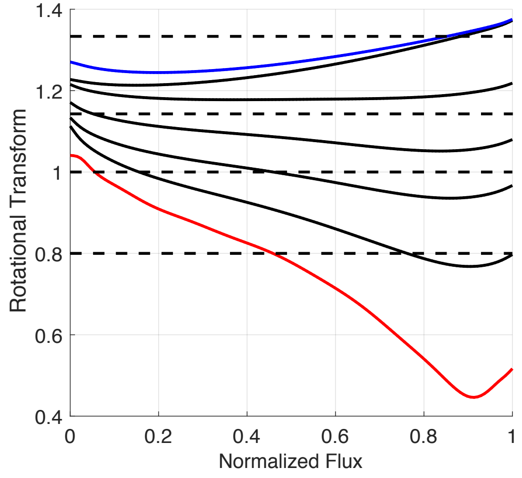
-0.05
1.4
1.42
1.44
1.46
1.48
1.5
R [m]

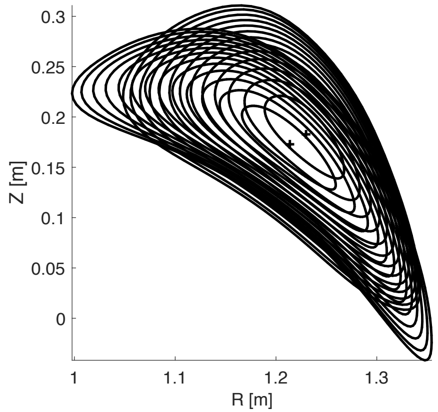
Well 10%

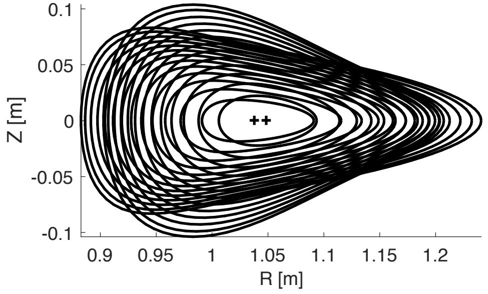

0.2
0.1
0
-0.1
-0.2
Z [m]
1.4
1.5
R [m]


×10^4
5
4
3
2
1
0
-1
Pressure
0
0.2
0.4
0.6
0.8
1
Normalized Flux

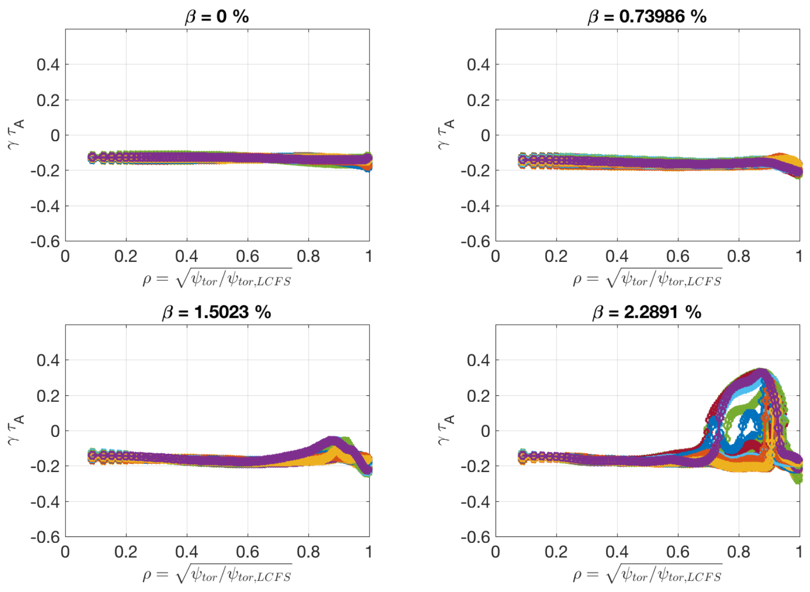

×10^6
3
2.5
2
1.5
1
0.5
0
-0.5
<J·B>
0
0.2
0.4
0.6
0.8
1
Normalized Flux


1.4
1.2
1
0.8
0.6
0.4
Rotational Transform
0
0.2
0.4
0.6
0.8
1
Normalized Flux

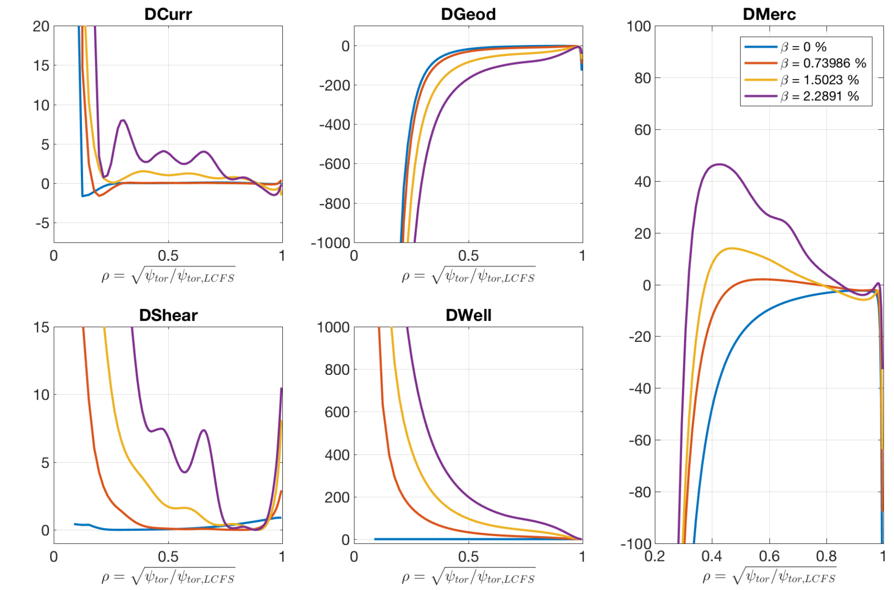

0.3
0.25
0.2
0.15
0.1
0.05
0
Z [m]
1
1.1
1.2
1.3
R [m]


0.1
0.05
0
-0.05
-0.1
Z [m]
0.9
0.95
1
1.05
1.1
1.15
1.2
R [m]

QHS

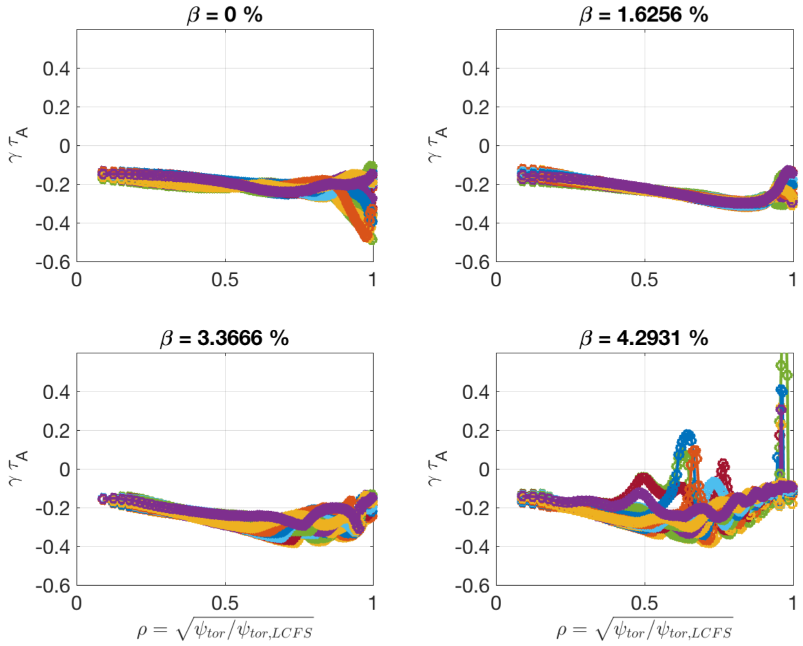


β = 0 %
β = 0.73986 %
β = 1.5023 %
β = 2.2891 %
γ τ_A
ρ = √(ψ_tor/ψ_tor,LCFS)

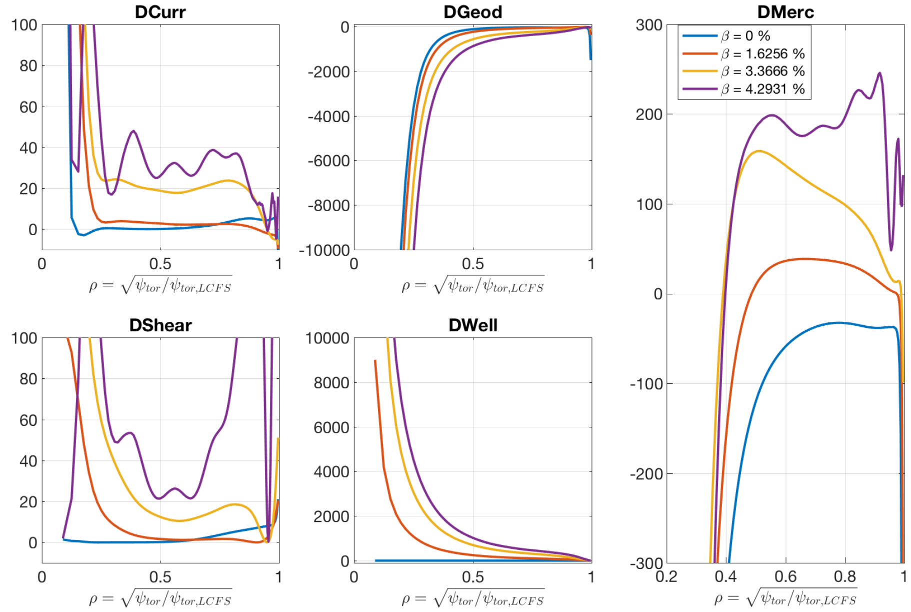


DCurr
DGeod
DMerc
DShear
DWell
β = 0 %
β = 0.73986 %
β = 1.5023 %
β = 2.2891 %
ρ = √(ψ_tor/ψ_tor,LCFS)

Well 10%



β = 0 %
β = 1.6256 %
β = 3.3666 %
β = 4.2931 %
γ τ_A
ρ = √(ψ_tor/ψ_tor,LCFS)



DCurr
DGeod
DMerc
DShear
DWell
β = 0 %
β = 1.6256 %
β = 3.3666 %
β = 4.2931 %
ρ = √(ψ_tor/ψ_tor,LCFS)