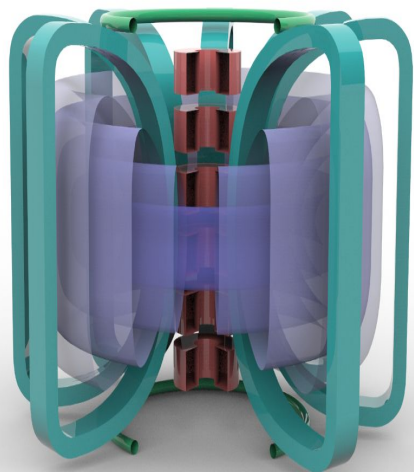




Initial Simulations of Negative Triangularity Plasmas on MAST-U

**A.O. Nelson, S. Freiberger,
H. Wilson, L. Rondini, C. Paz-Soldan**

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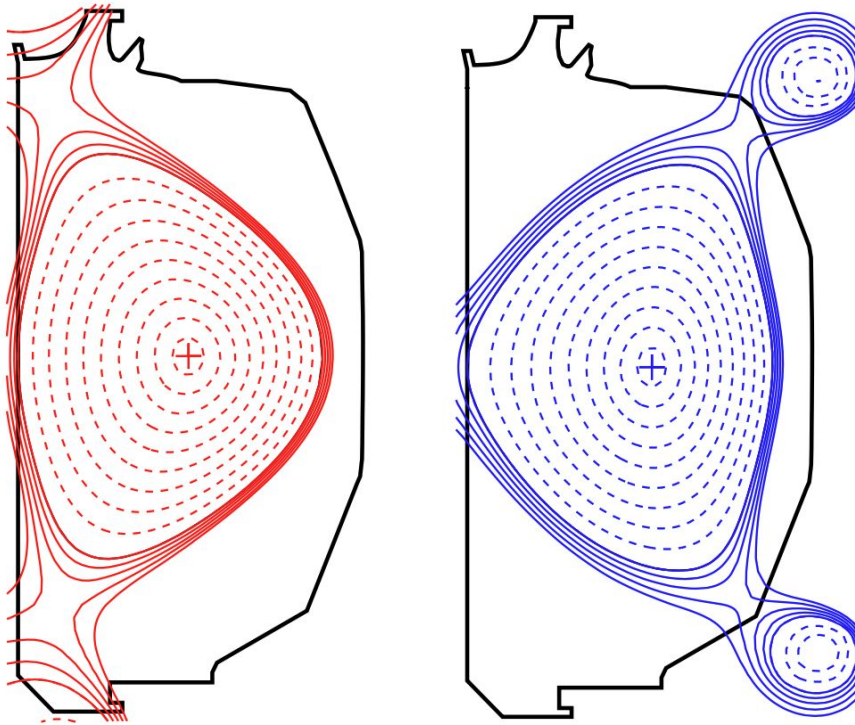
November 2nd, 2022
International Spherical Tokamak Workshop
Remotely from San Diego, CA



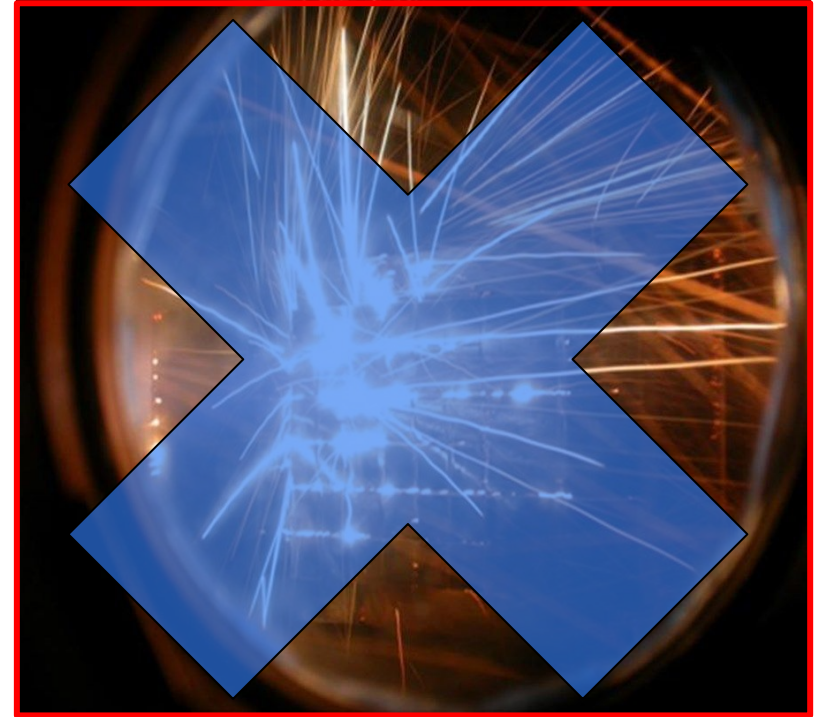
Introduction to Negative Triangularity

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Neg-D: L-modes with H-mode like confinement



Austin, et. al. PRL (2019)



<https://www.iter.org/newsline/166/628>

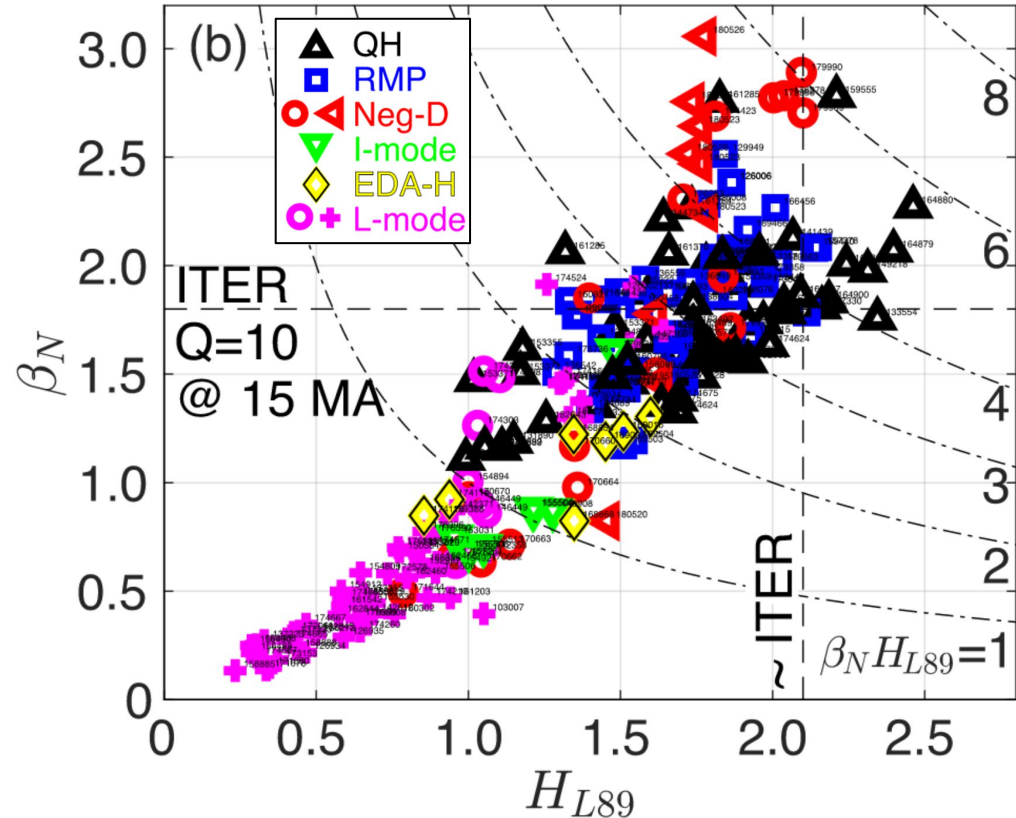
DIII-D Neg-D compares well with other no-ELM scenarios

Core:

- High pressure and confinement due to turbulence reduction
- Vertical stability is generally worse

Edge:

- Exhaust integration could be alleviated
- H-mode and ELMs avoided through MHD?

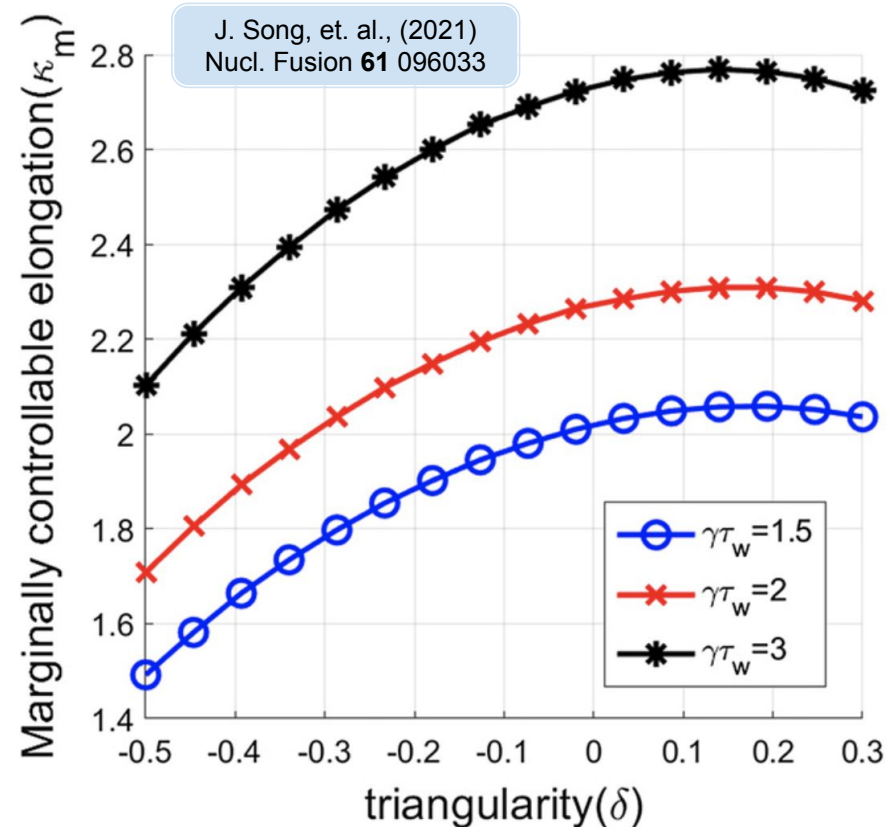


NT plasmas often more unstable to n=0 RWM

- Increasing elongation (κ) is highly desirable, since

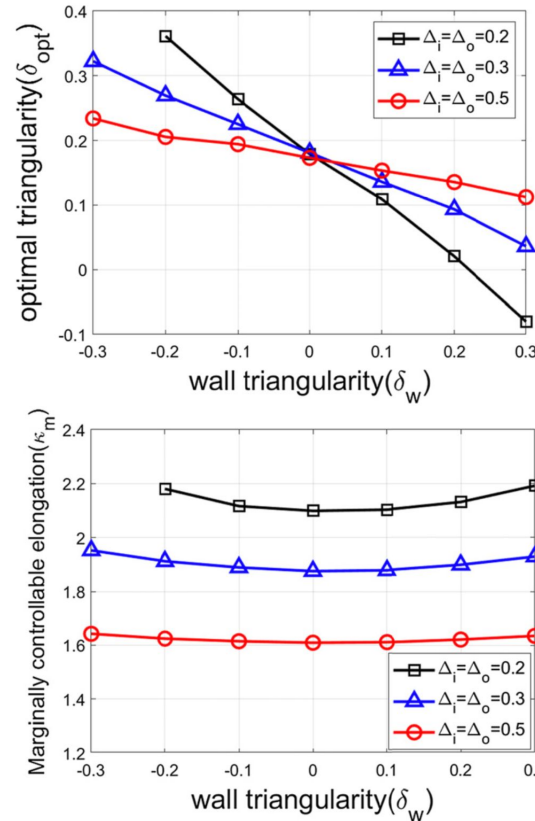
$$\tau_E = \kappa^{0.7}$$

- AVSTAB shows lower marginal elongation for $\delta < 0$
 - true for various $\gamma\tau_E$
- Plasma characteristics (β_p , I_i) and geometric effects also impact instability

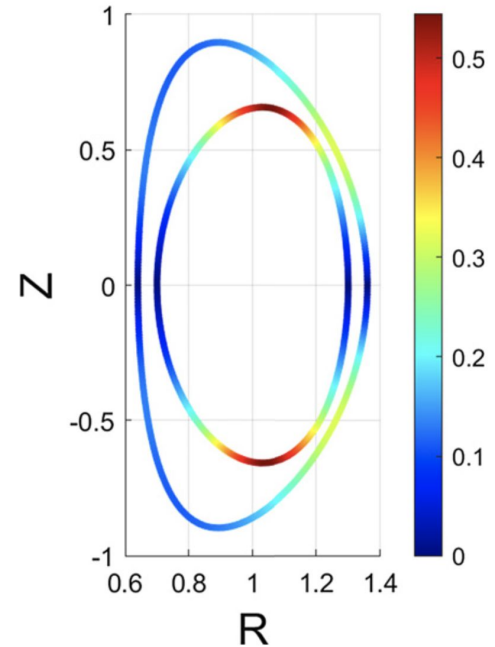


Non-conformal wall changes simple picture

- Tendency for opposite δ between wall and plasma to stabilize NT
- Highly dependent on gap distances ($\Delta_{i,o}$)
- Perturbed flux is significant at the poloidal sections when gap is small

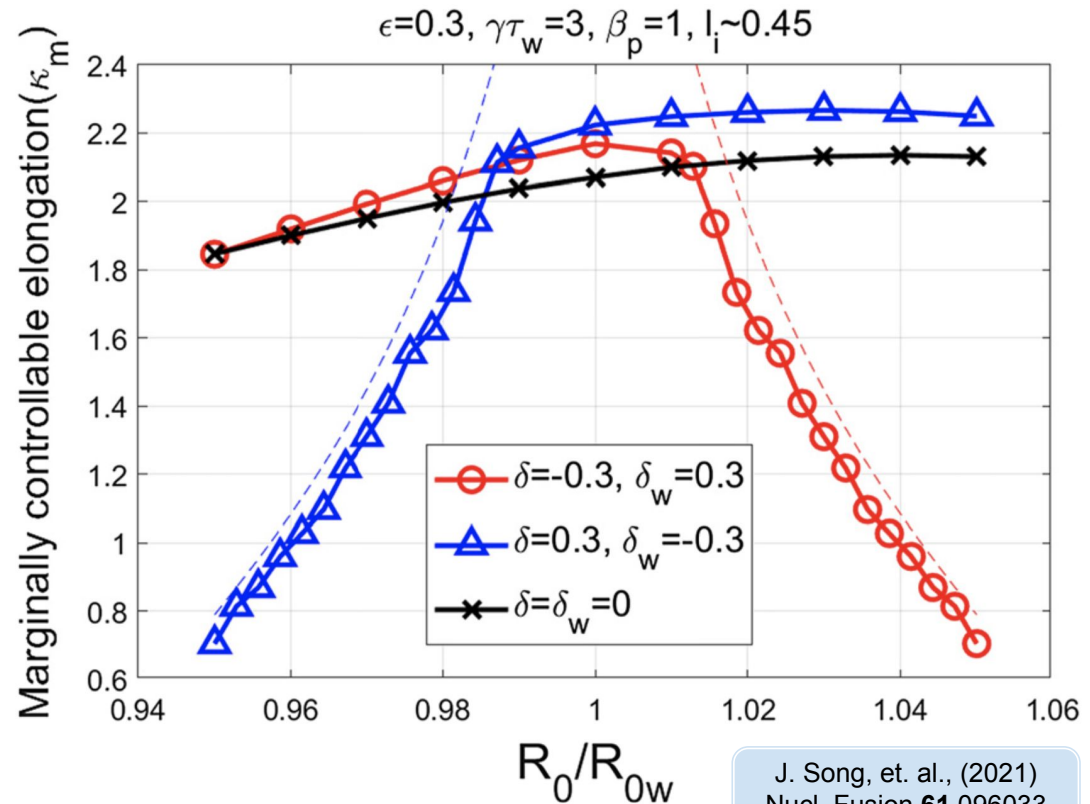


J. Song, et. al., (2021)
Nucl. Fusion **61** 096033

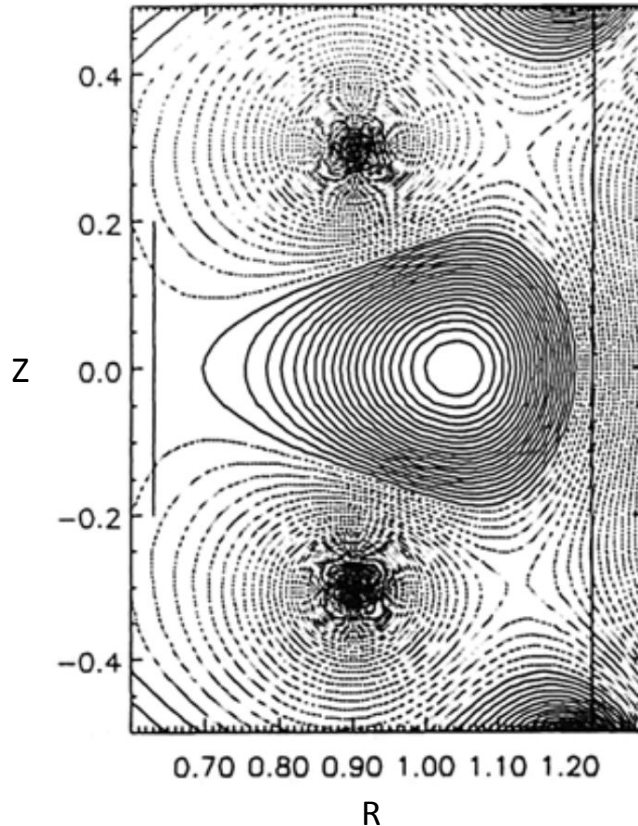


Movement towards the LFS increases $\max(\kappa)$

- A small move toward the LFS results in more stabilization
- Unless the plasma is too close to resistive wall
 - significant decrease of the vacuum δW contribution
- $\gamma_{PT} \sim \gamma_{NT}$ possible!



“Comet” cross-sections also well-suited for STs

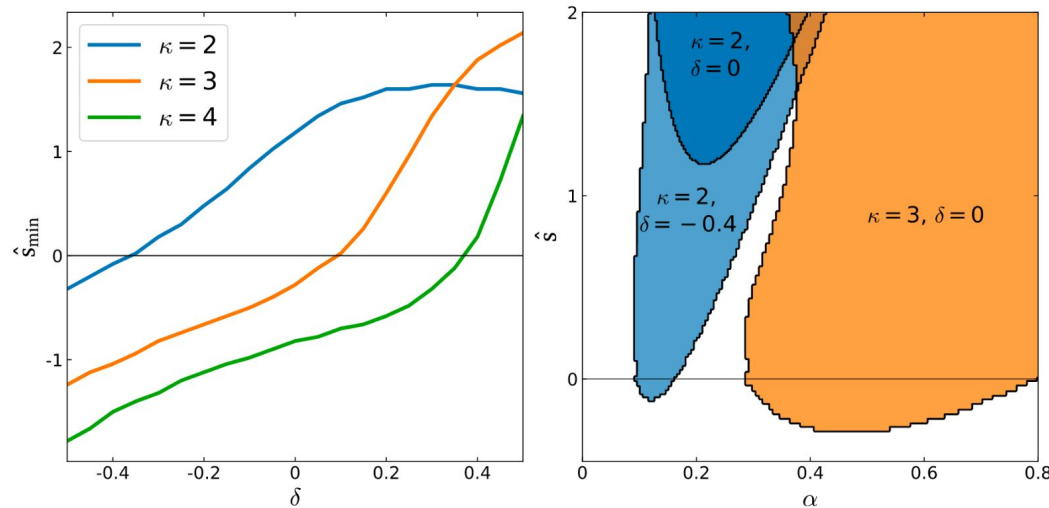


- “Comet” = oblate cross section + Neg-D
- Expected to:
 - **reduce trapping** of particles in the bad curvature region
 - **improve confinement**
 - **improve stability** to Mercier modes
 - allow for reactor configurations with **lower plasma current**

J. Kesner, et. al., (1995)
Journal of Fusion Energy, **14** 4

In single gyrokinetic study, KBMs limit NT ST performance

- In NT, **second stability window DNE** → core is ballooning unstable
 - Strong KBMs that limit transport → **reduced β limit!**
- Turbulence challenges reduced at high field

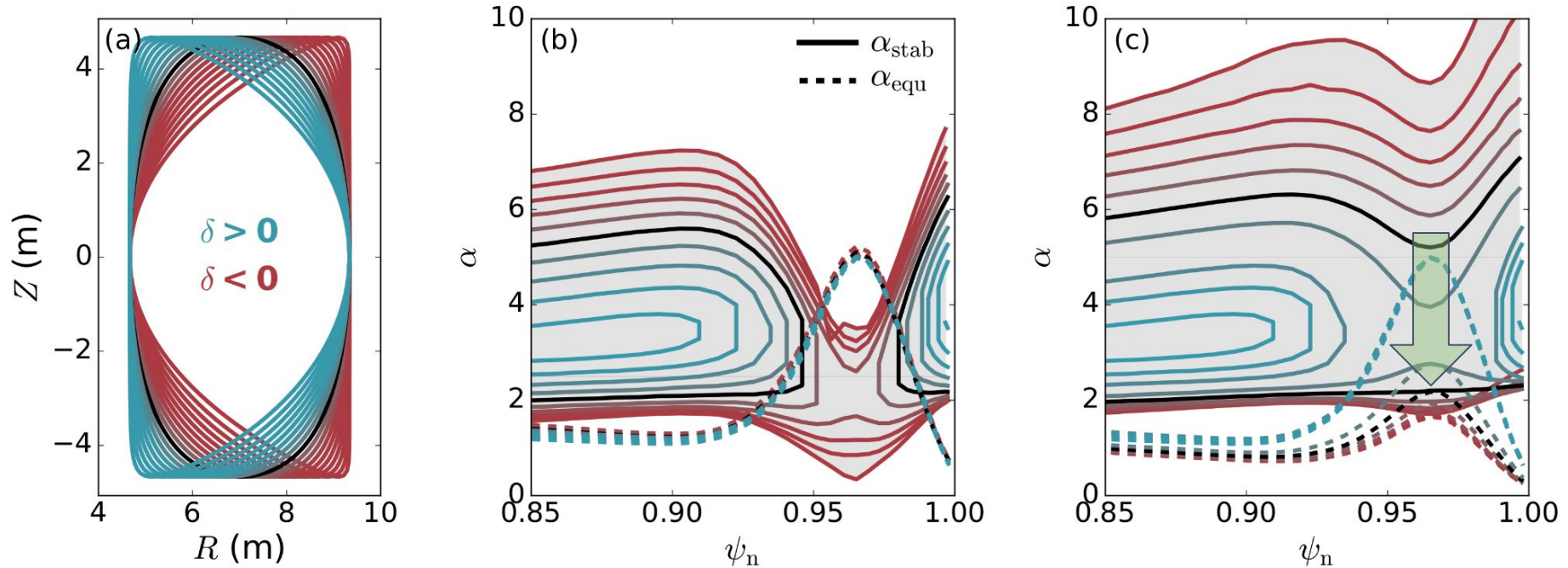


R. Davies, et. al., (2022)
PPCF, **64** 105001

Figure 5. Left: dependence of second stability access window ($\hat{s}_{\min}$) on elongation (κ) and triangularity (δ) for the $\psi_N = 0.5$ surface of ‘-ve tri’ equilibrium. Right: IBM unstable regions for $(\kappa, \delta) = (2, -0.4)$ (light blue), $(2, 0)$ (dark blue), $(3, 0)$ (orange).

Ballooning modes already limit edge pressure gradient

A. O. Nelson et. al., (2022)
Nucl. Fusion **62** 096020

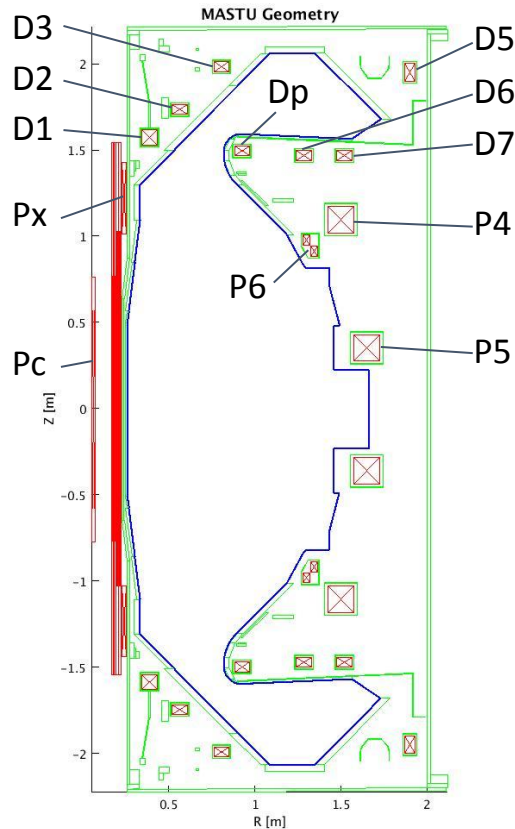




Capabilities of the MAST-U Machine

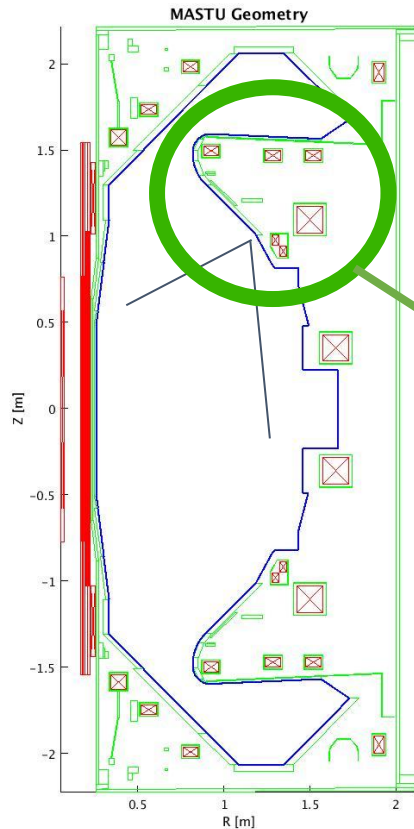

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MAST-U system available in toksys environment

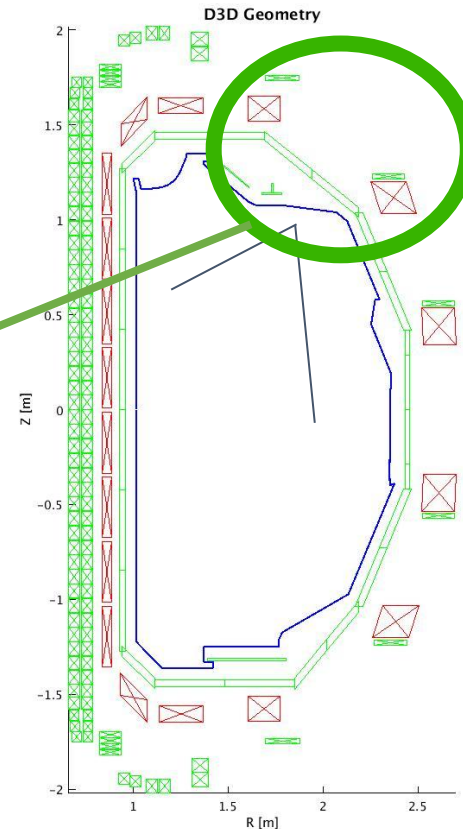


Coil	Current Limit (kA)	I^2t Limit ([kA] ² s)	F_z (kN)
Px	±8	500	±110kN
Pc	±5	90	±30
D1	±6.4	90	± 456
D2	±6.4	90	± 301
D3	±6.4	90	± 266
Dp	±6.4	110	± 239
D5	±4	50	± 183
D6	±3.2	50	± 172
D7	±4.8	50	± 347
P4	±14.4	288	- 1231 + 270
P5	±14.4	288	± 465
P6	±5	150	± 250

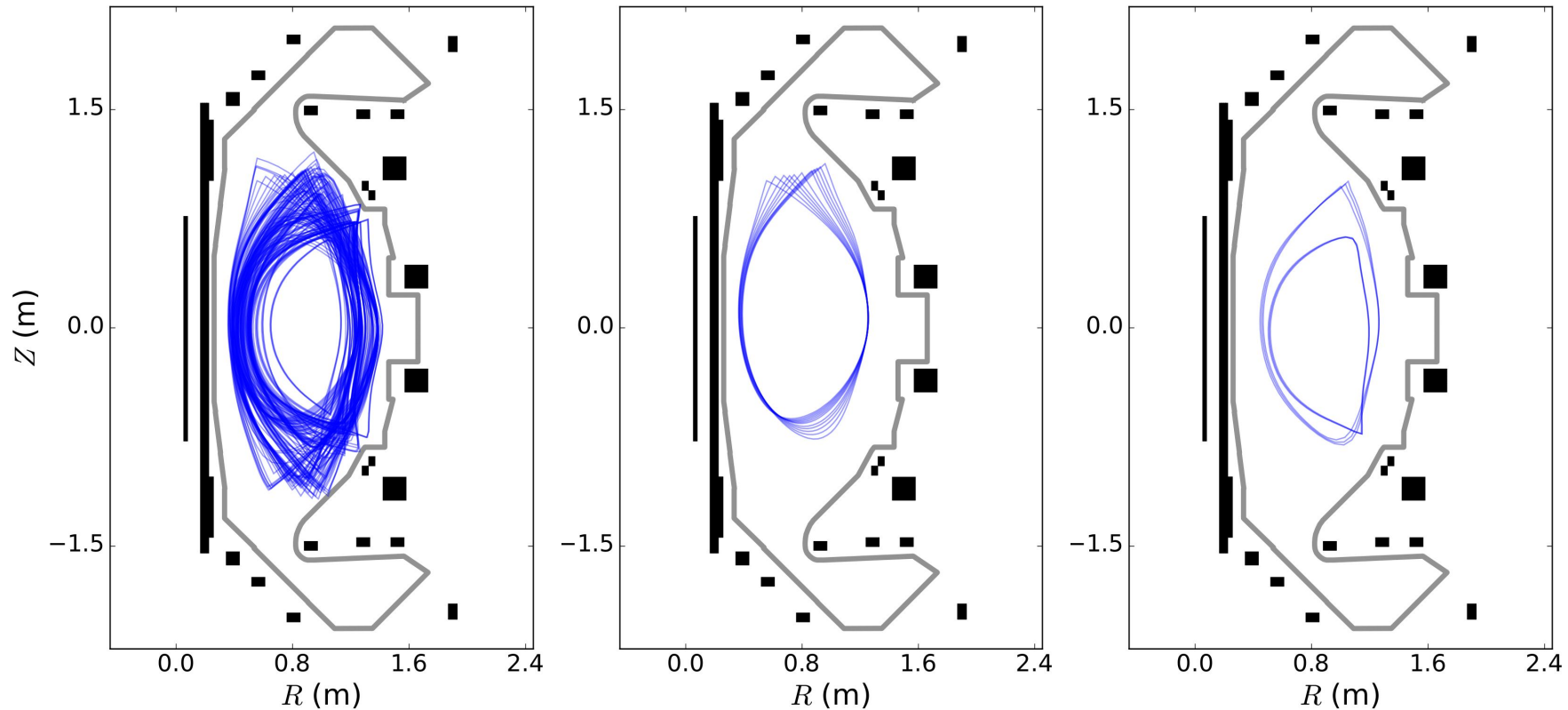
More NT pulling coils on MAST-U than DIII-D



potential
coils for
NT x-point

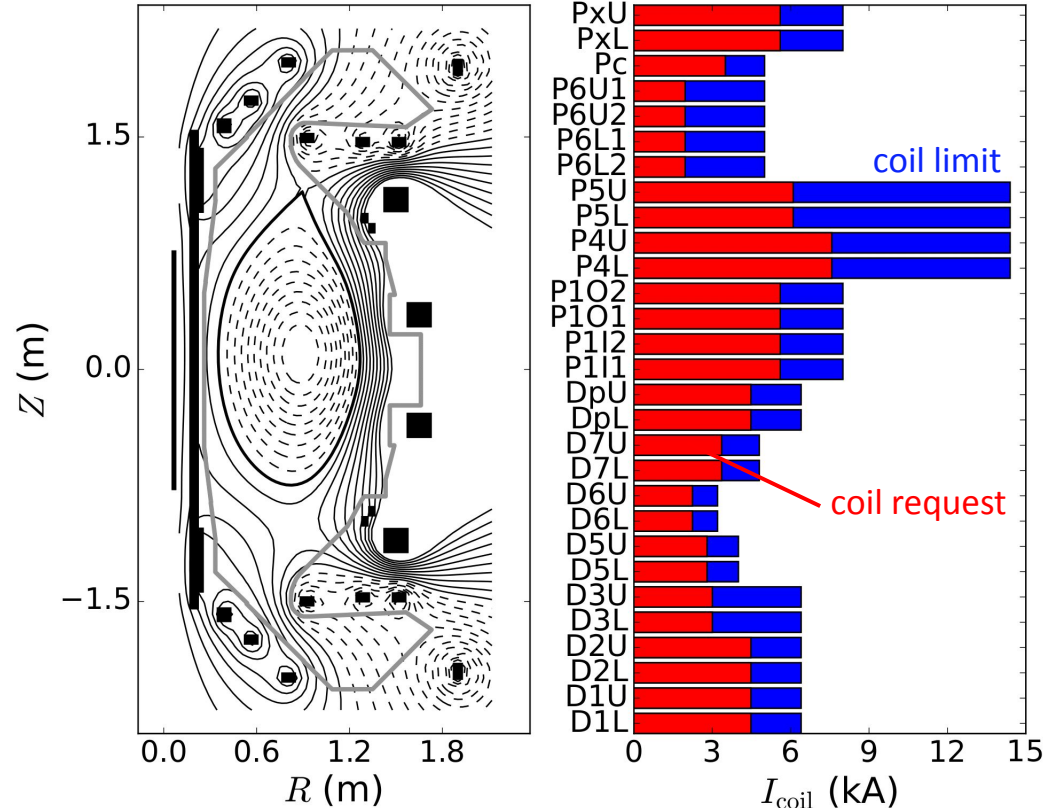


GSdesign: many flexible NT shapes found on MAST-U



MAST-U coli constraints satisfied during NT operation

- Conservative options available with reduced current limits
- On right:
 - $I_p = 0.6$ MA
 - $\delta = -0.1$
 - no coil at more than 70% of real limit
- Further optimization for initial test possible



Additional machine assessment still required

- Assistance needed from MAST-U team to:
 - Understand **dynamic control** capabilities
 - Understand **divertor placement** limitations
 - Assess **startup feasibility**
 - Assess prospects for **vertical control**
- Work will proceed with the MAST-U control team



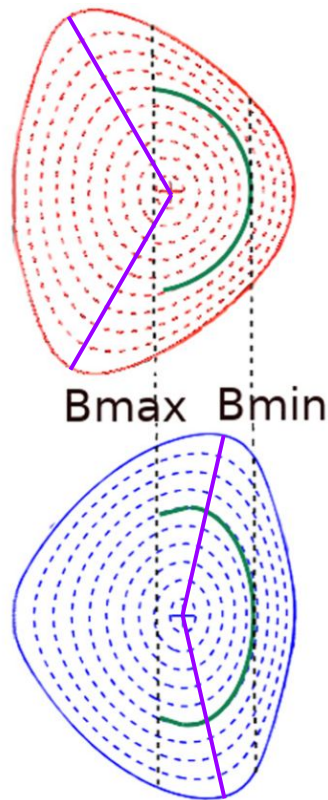
Assessment of Bounce Orbits in MAST-U NT

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Negative Triangularity reduces bad curvature region

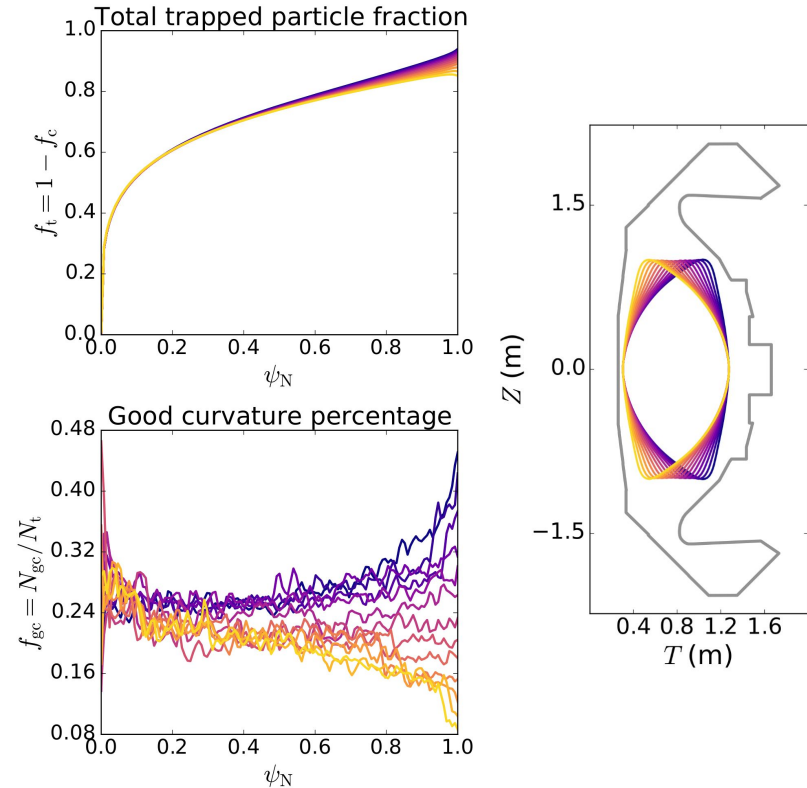
- Negative triangularity allows particles to bounce in the **good curvature region**
 - increases time spent in favorable curvature
 - Effect maximized by “comet-like” ST
- Increased “good curvature trapped fraction” associated with less destabilizing effect on turbulence

A. Marinoni , et. al., (2021)
Nucl. Fus., **61** 116010



Guiding orbit approximation → enhanced f_{gc} in NT

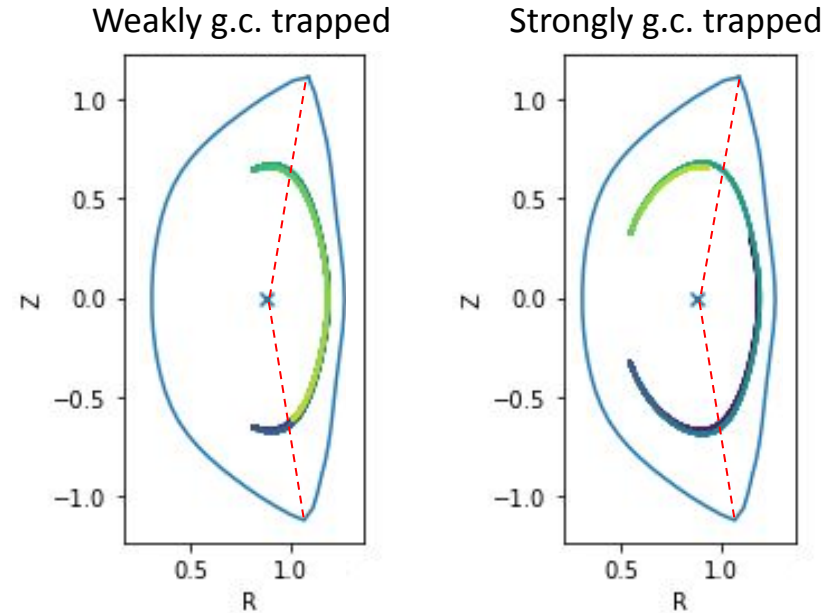
- Simple equilibrium calculations show:
 - small enhancement in $f_{trapped}$ with NT
 - large enhancement in $f_{g.c.}$ with NT
- Effect strongest at edge: almost 40% g.c. trapped!



Full orbit calculations ongoing to confirm effect

- NT in ST subject to sharp changes in B fields
 - full orbit picture can confirm particle trajectories
- Banana width reduced in NT!
- Full distribution analysis ongoing

Full orbit tracking:
2keV particle starting at $R = 1.15\text{m}$



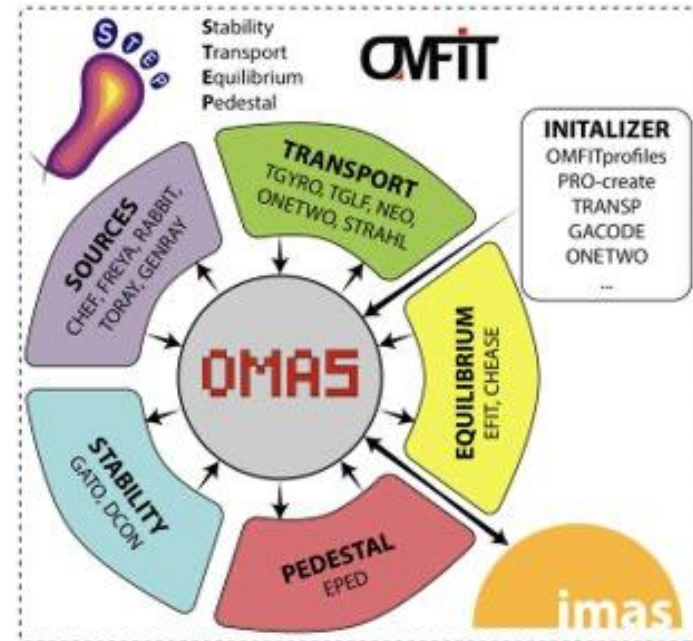


Performance Predictions for NT on MAST-U

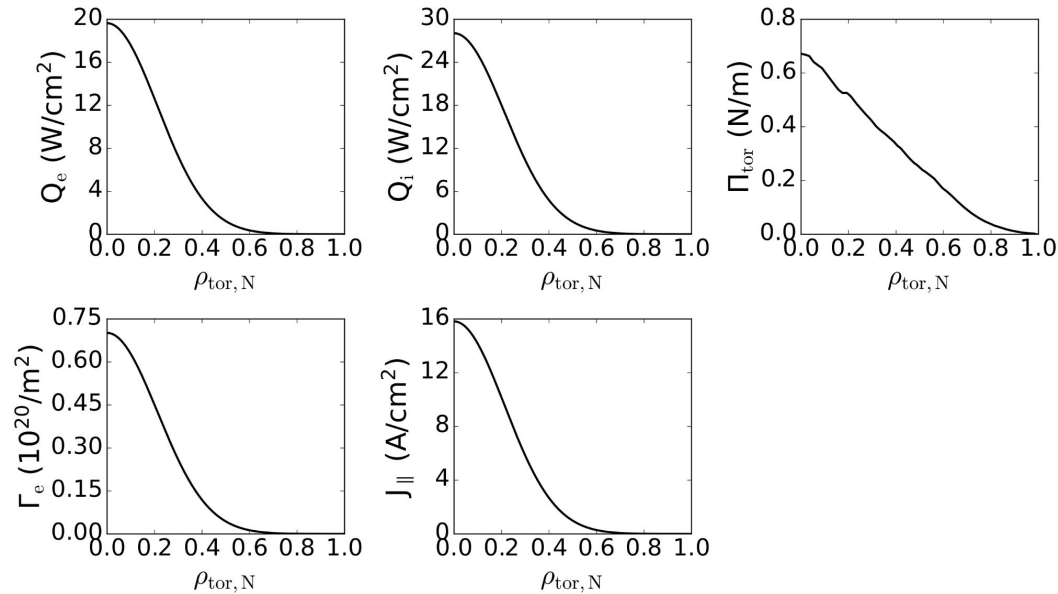
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STEP code used to predict performance on MAST-U

- STEP allows for integrated modeling of arbitrary devices by connecting utility codes:
 - CHEF: heating and current drive
 - CHEASE: equilibria
 - TGYRO: transport and profiles (here we use SATO only)
- Edge not yet modeled! (here we force L-mode)

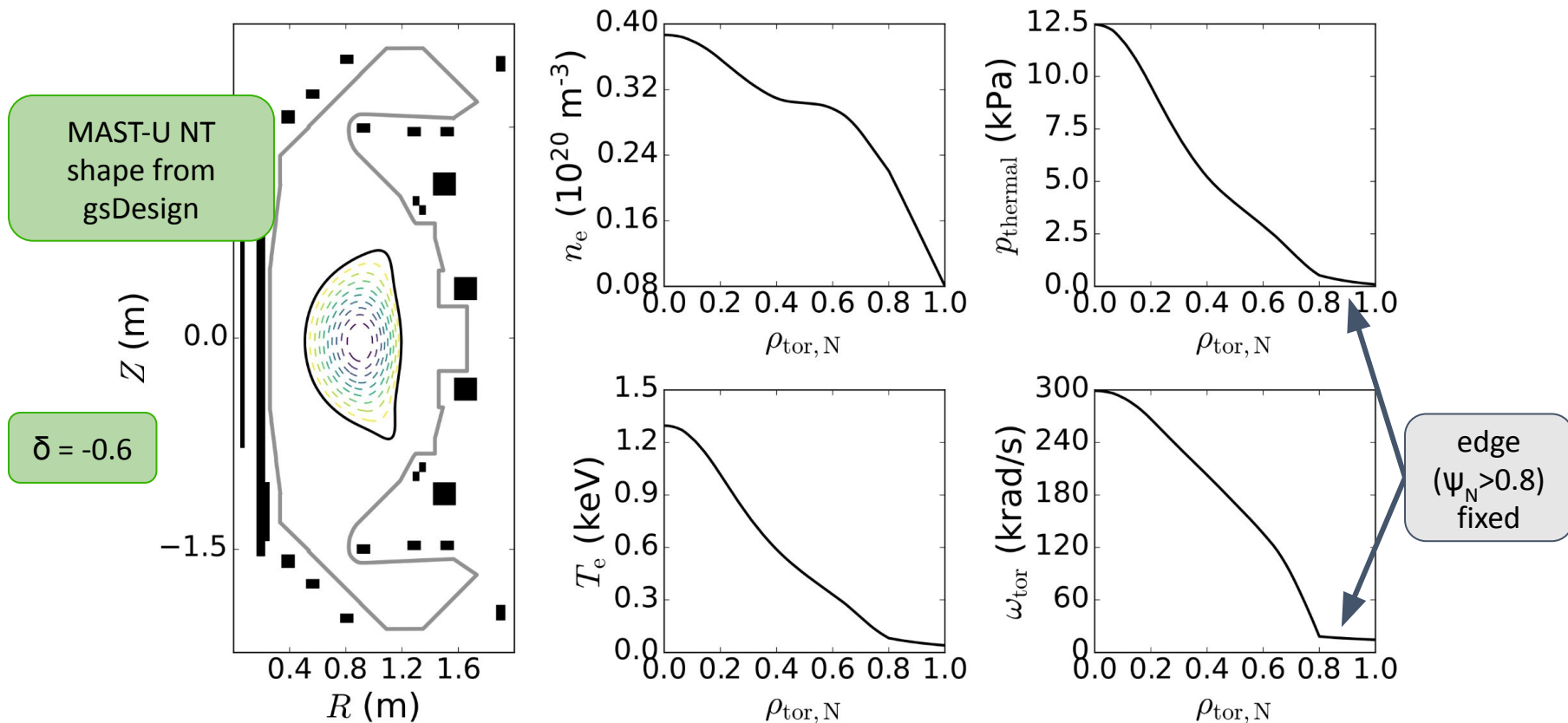


Heating contributions chosen to model NBI source

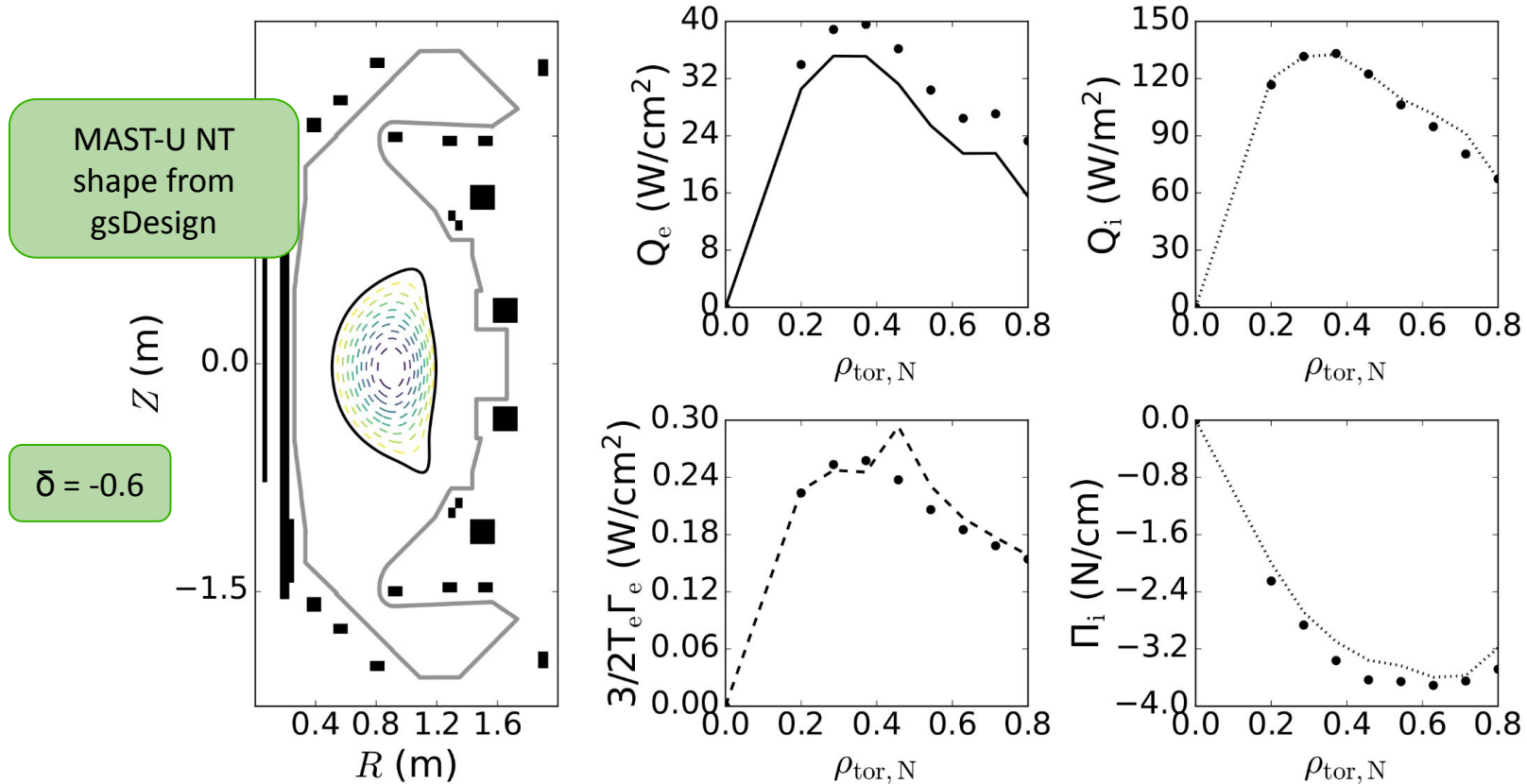


- Arbitrary heating profiles creating in CHEF to mimic ST NBI
- Heating amplitude adjusted to reach convergence with TGYRO

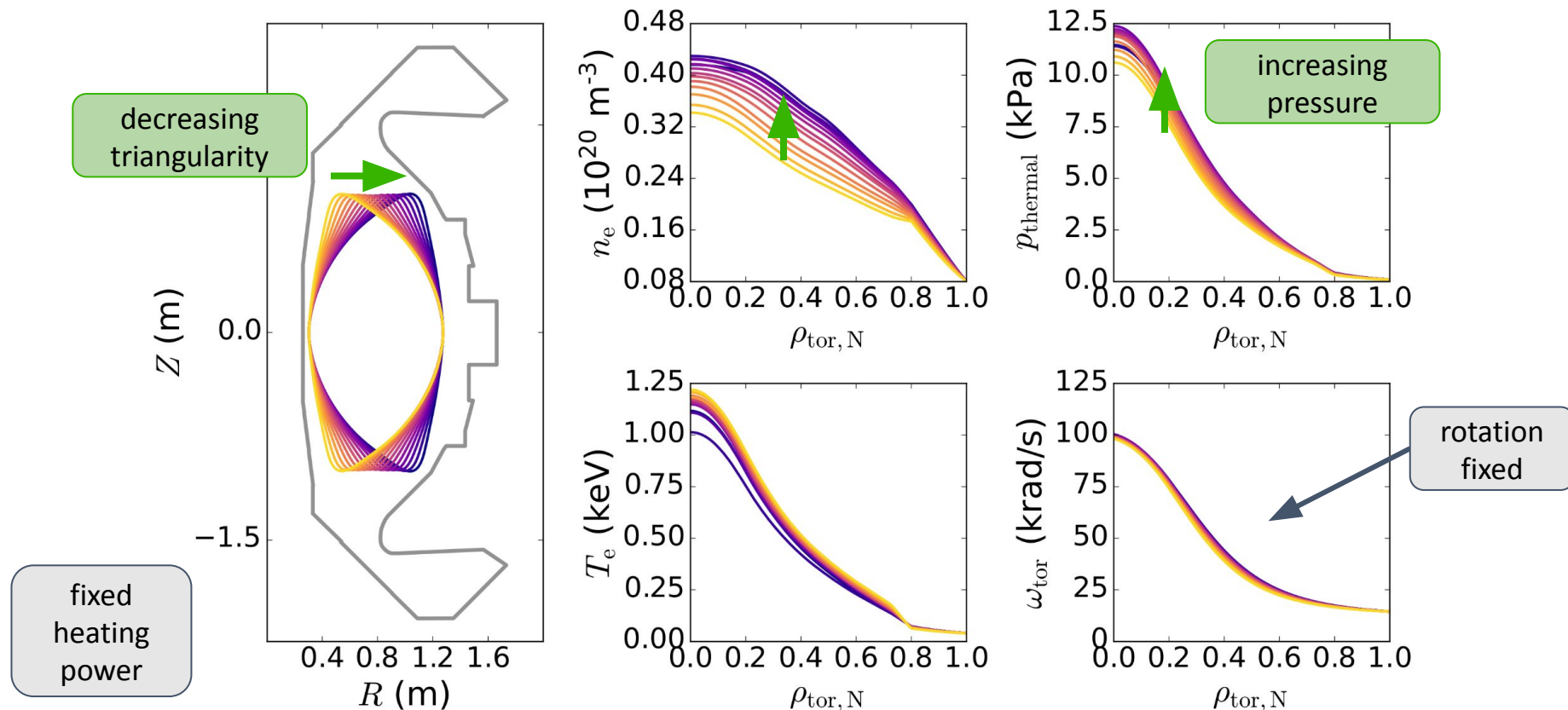
STEP can predict core profiles for realistic MAST-U NT



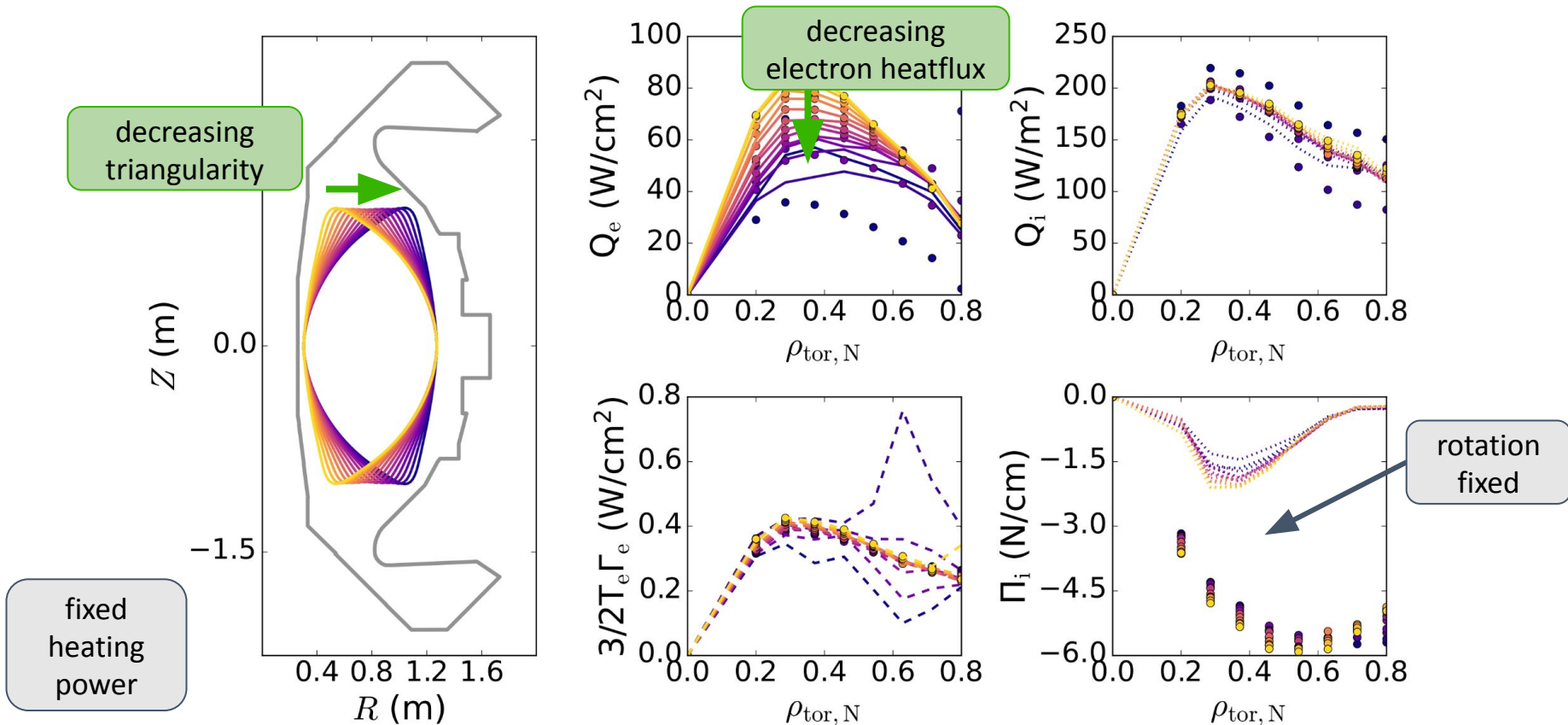
STEP model well converged inside of $\rho = 0.8$



Triangularity scan shows increasing performance in NT



Difficult to converge TGYRO on stronger NT shapes

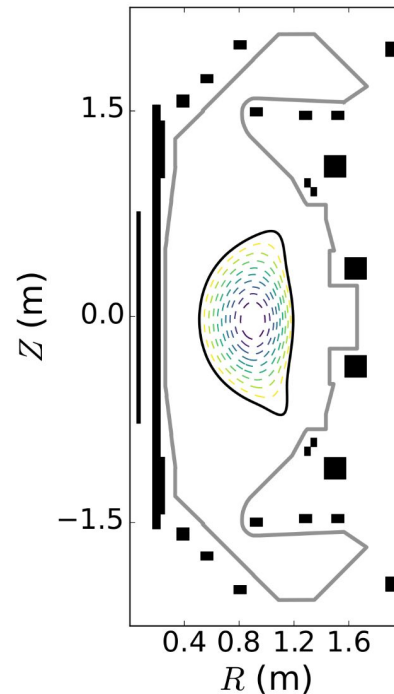


Additional work ongoing to validate STEP on MAST-U

- Realistic heating profiles
- Momentum / rotation evolution
- Exploration of various SAT rules to match MAST-U experiment
- Scans of triangularity and elongation within MAST-U coil constraints
- Addition of edge profile constraint (BALOO + EPED)

Conclusions and outlook

- Initial investigations into the feasibility of achieving **negative triangularity on MAST-U** demonstrate that:
 - Various NT configurations **realizable with existing coil sets**
 - TGRYO predictions indicate **performance enhancement** with NT
- Ongoing work to collaborate with the MAST-U team to explore experimental opportunities





Backup Slides



DIII-D NT armor incoming → establish new shapes!

