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FÜR PLASMAPHYSIK

A semi-automated algorithm for designing stellarator divertor plates and its application to HSX

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EUROfusion

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Motivation / Goals

Overall goal: automate/optimise divertor design for stellarators

- What should the magnetic field look like?
- What should divertor plates & other plasma-facing components (PFCs) look like?

- Commercially viable stellarator divertor requirements include:
  - Sufficiently low ***heat loads*** on PFCs
  - Acceptable ***tritium inventory***
  - Sufficiently good exhaust of ***He ash & impurities***
  - . . . whilst maximising ***performance of confined plasma***
  - ….

- Goal of this work: **semi-automated design** for **divertor plates** for given magnetic field(s), to achieve sufficiently low PFC **heat loads**

EMC3-Lite [1]: Edge Monte Carlo 3D (-Lite)

- Solves a (simplified) anisotropic heat diffusion equation (1) with Bohm target boundary condition (2), to predict heat loads on plasma-facing components

$$\frac{\kappa_e}{n_e}\nabla_{\|}^2 T + \chi \nabla_{\perp}^2 T = 0, \quad (1)$$

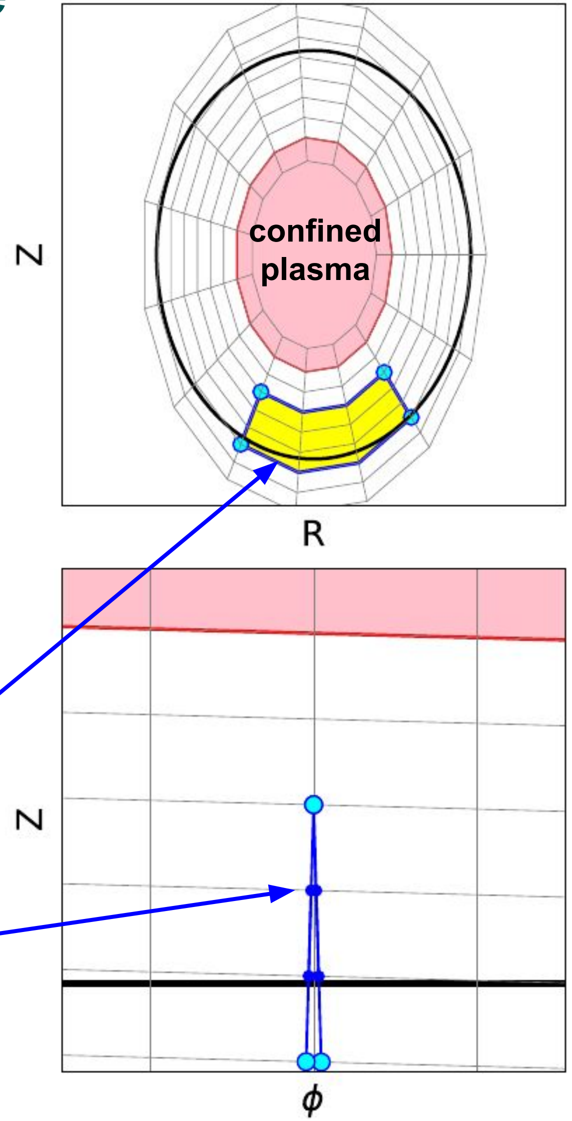
$$Q_{\|,\mathrm{PFC}} = -\kappa_e \nabla_{\|} T_{\mathrm{PFC}} = n c_s \gamma T_{\mathrm{PFC}}, \quad (2)$$

- A Monte-Carlo code, with heat “particles“ diffusing parallel & perpendicular to magnetic field
- Recently upgraded (Y. Feng) to simulate arbitrary stellarators
- Simulation inputs:
  - magnetic geometry
  - Wall geometry
  - Assumed parallel/perpendicular diffusivity (κ_e / ($n_e \chi_{\perp}$))

[1] Y. Feng *et al*. *Plasma Physics and Controlled Fusion* 64.12 (2022): 125012

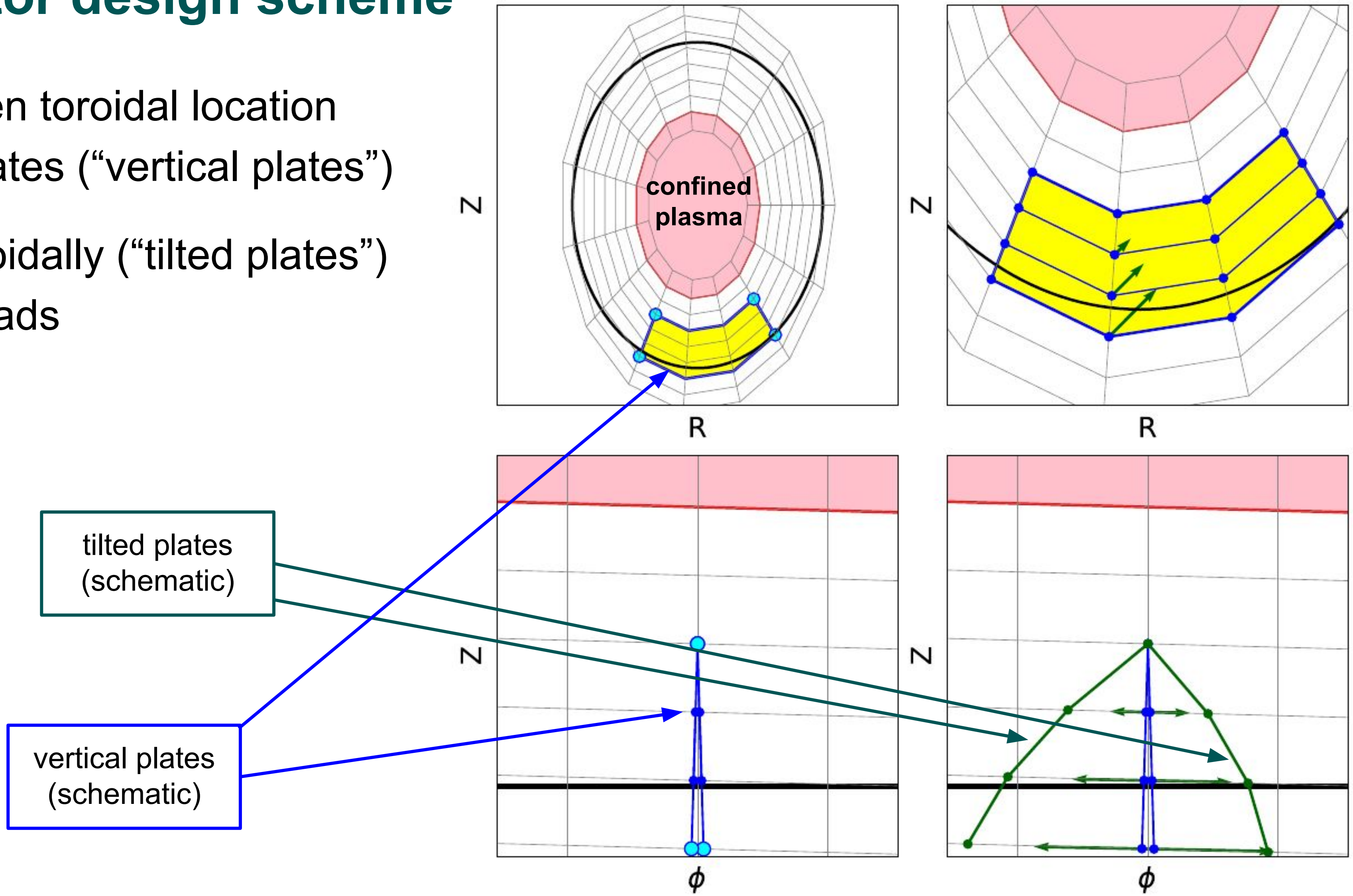
Semi-automated divertor design scheme

- **Step 1**: catch heat at given toroidal location using vertically inclined plates (“vertical plates”)

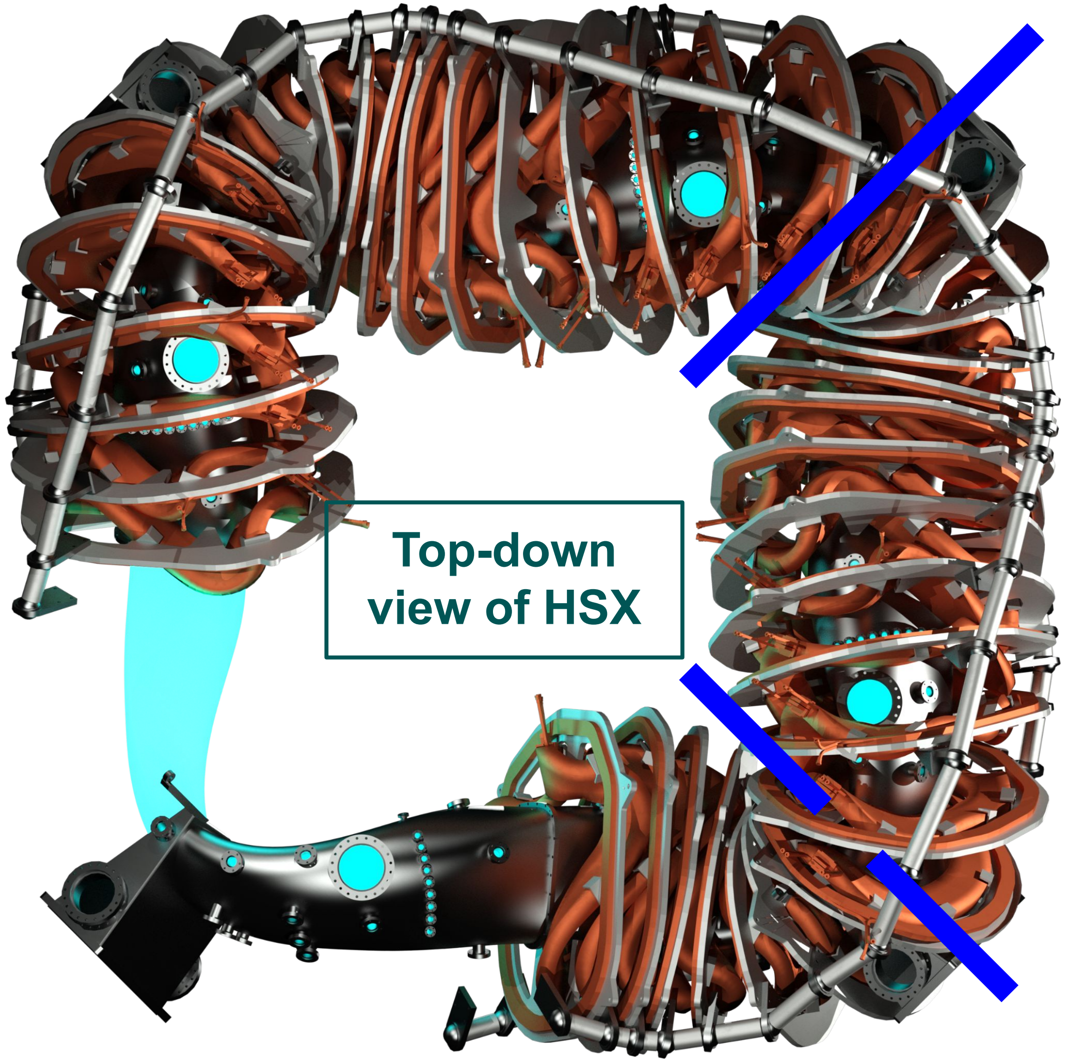


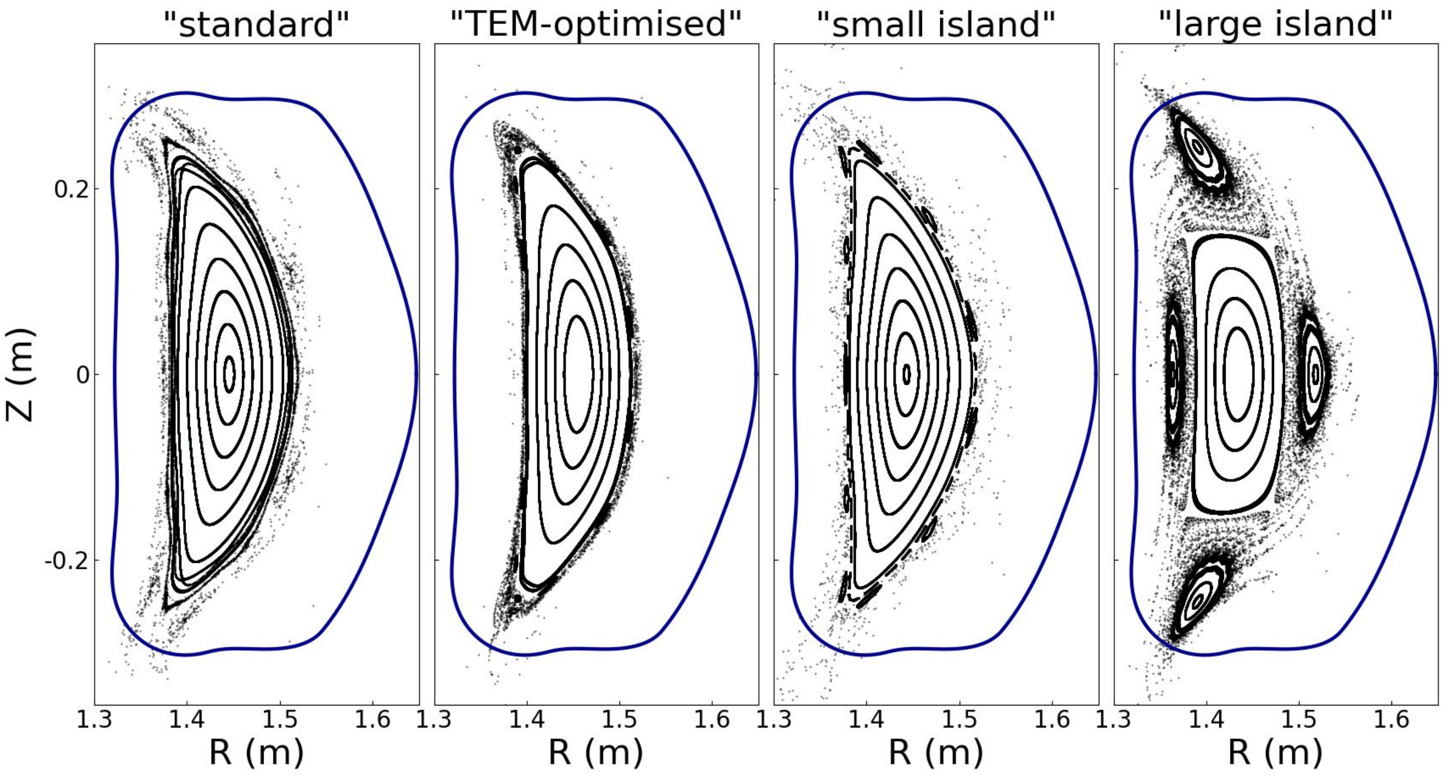
Semi-automated divertor design scheme

- **Step 1**: catch heat at given toroidal location using vertically inclined plates (“vertical plates”)
- **Step 2**: Tilt the plates toroidally (“tilted plates”) to ↑ wetted area, ↓ heat loads



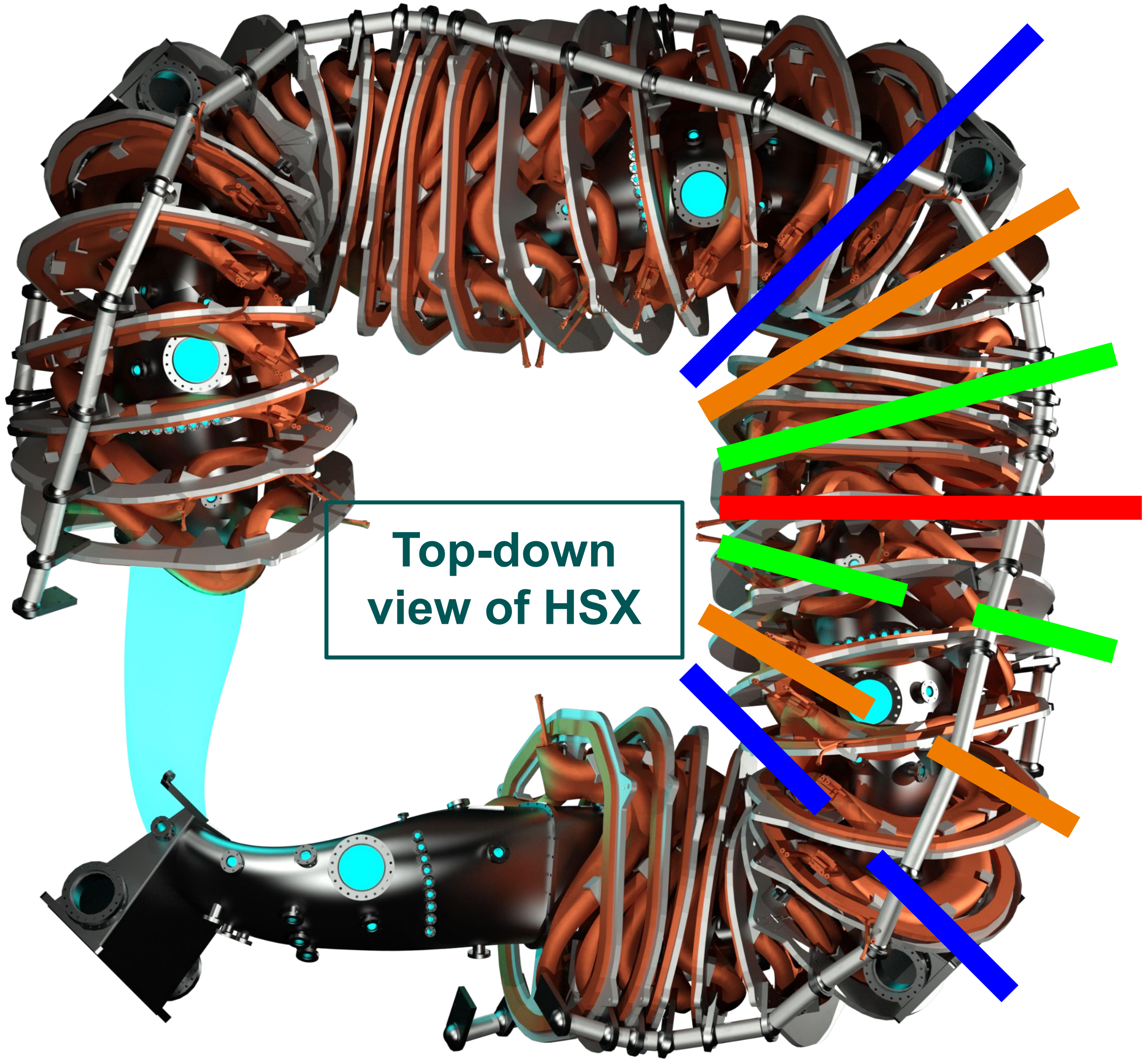
The HSX stellarator

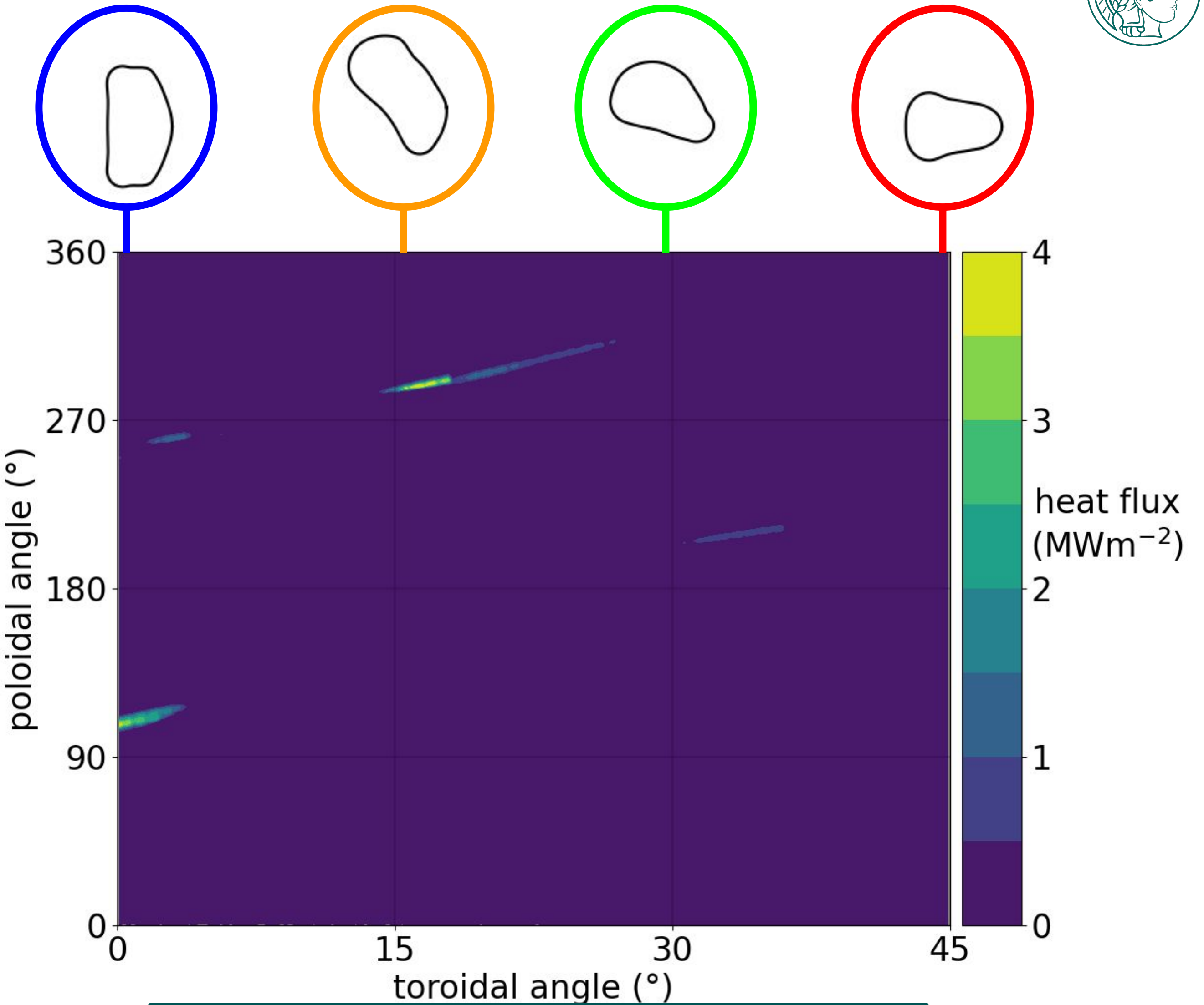




Poincaré sections of selected HSX configurations (φ=0°)

HSX: Heat load on bare wall



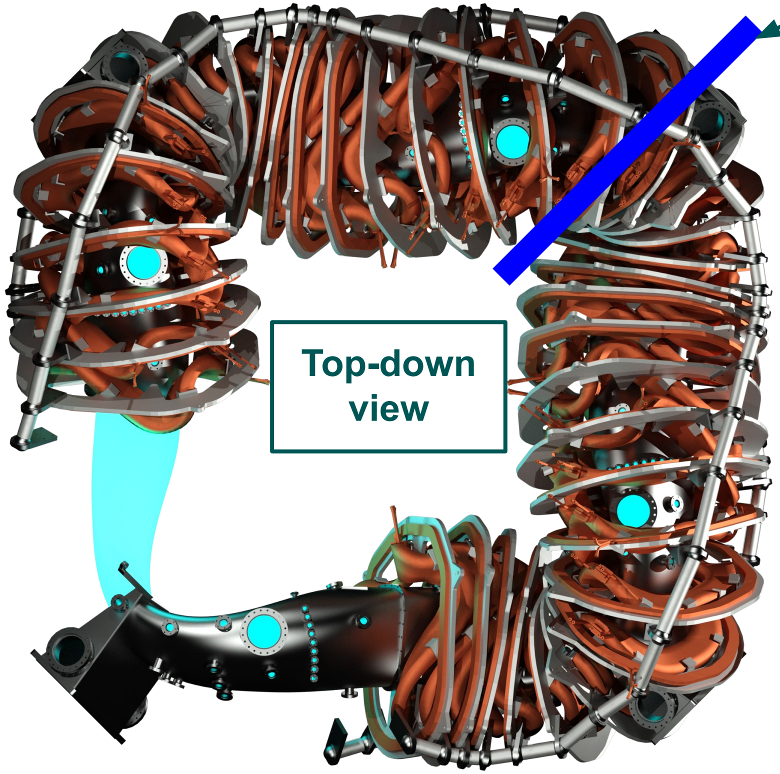


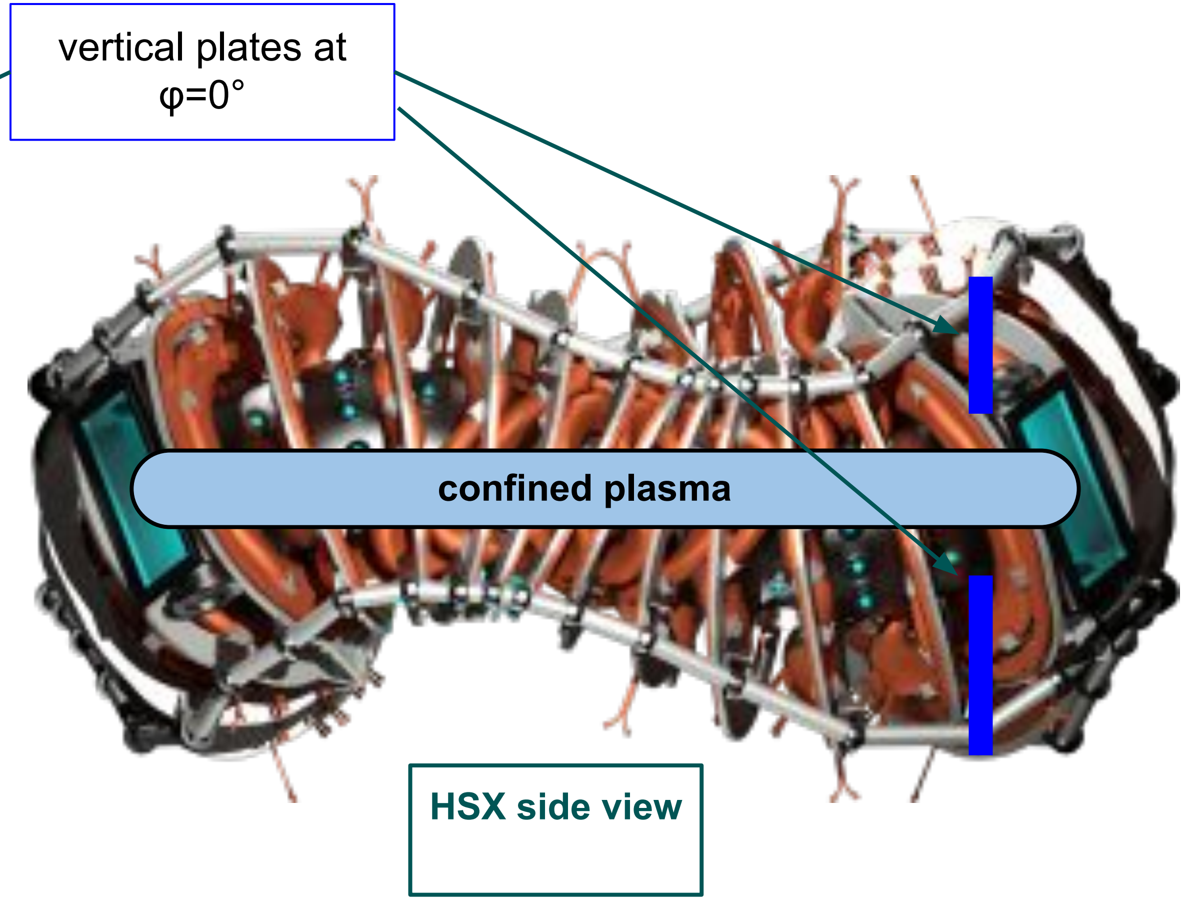
Simulated heat load on HSX “bare wall”

HSX “TEM-optimised” equilibrium
PSOL = 200kW (25kW per half field period)

Divertor design for HSX

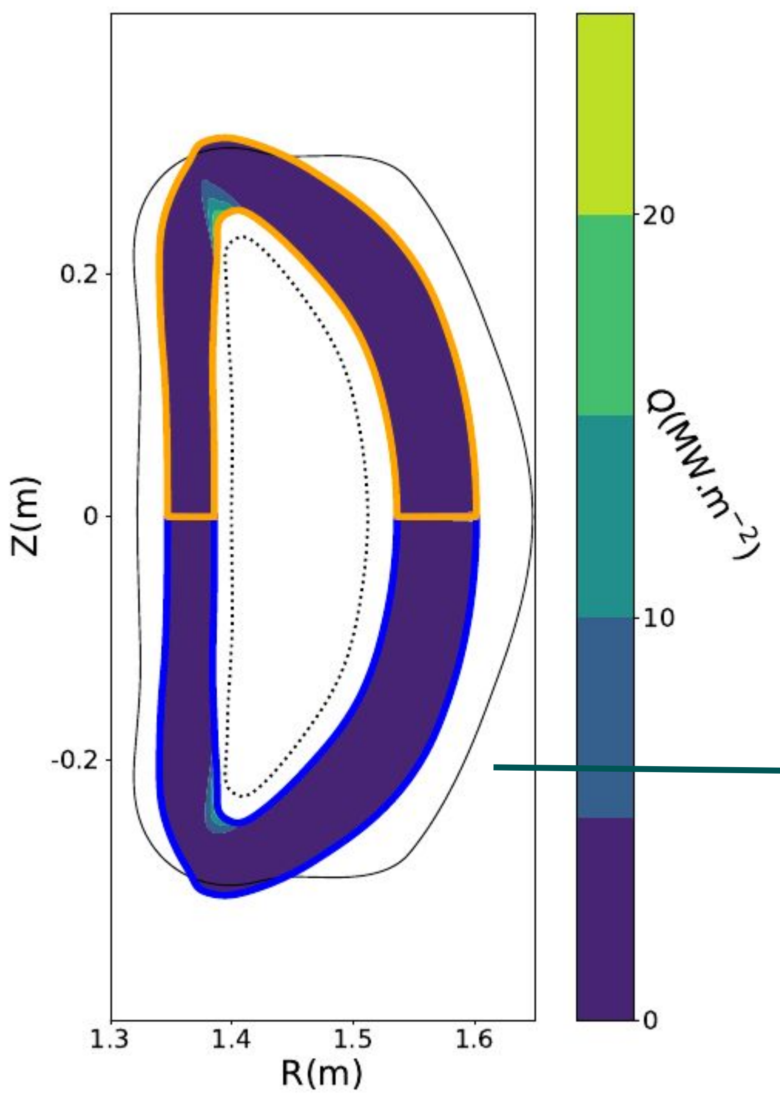
- **Step 1**: catch heat load at on “vertical plates”
- Example: use the φ=0° plane

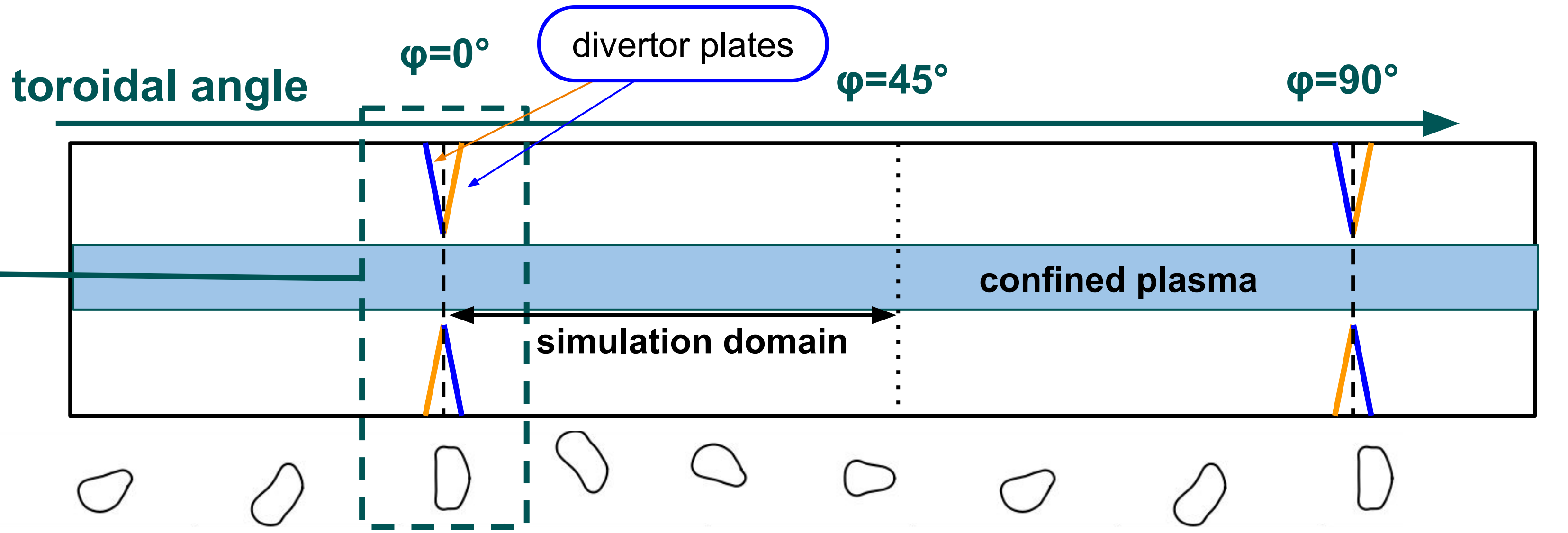




Divertor design for HSX

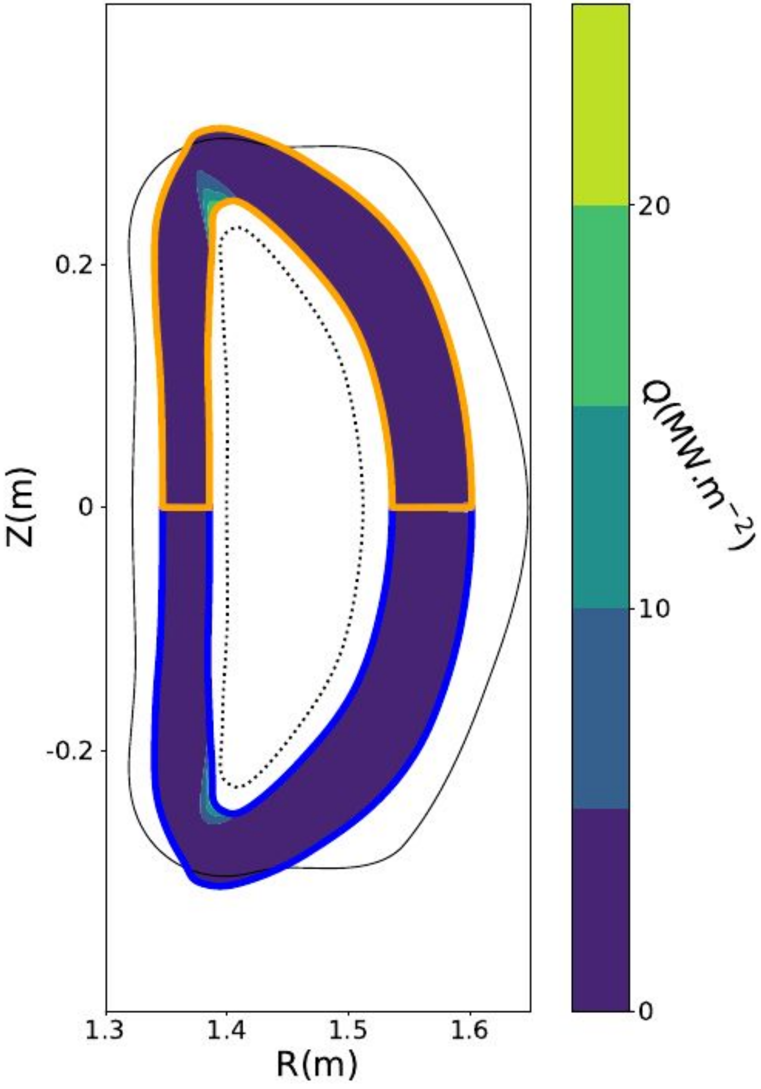
- Example: use the φ=0° plane
- Plate consists of 2 faces, which “see” different incoming flux tubes



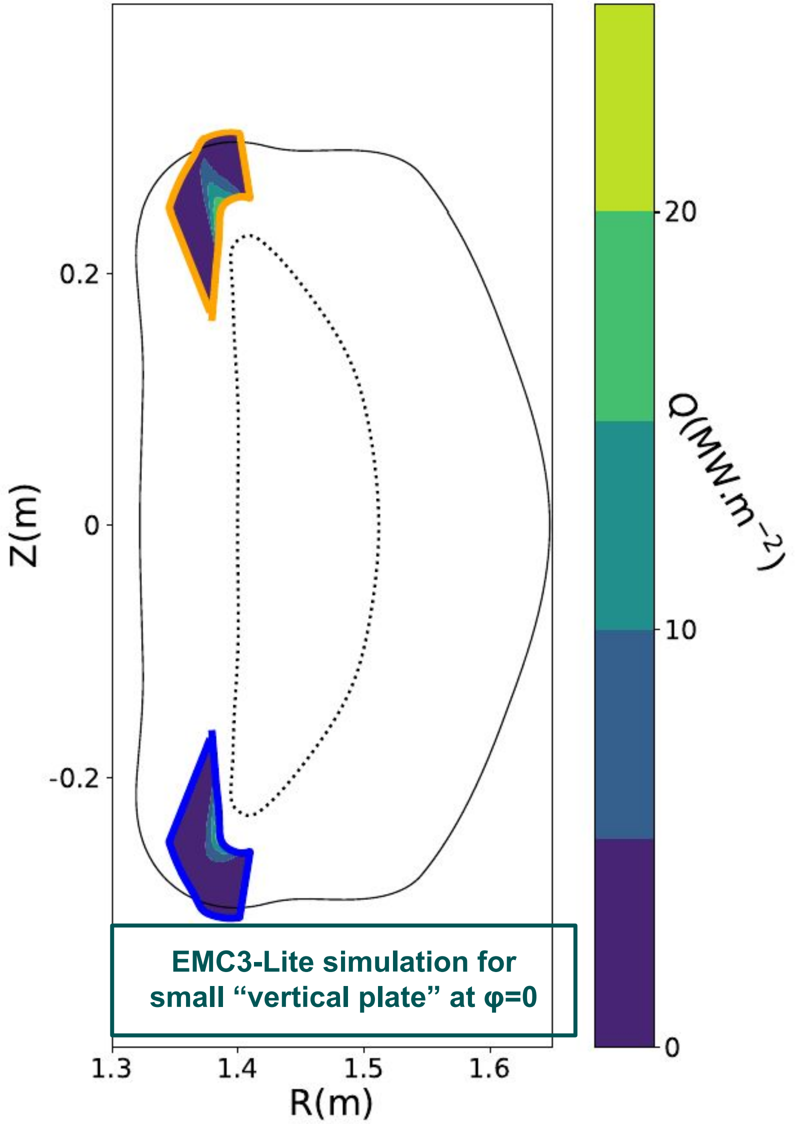


HSX “TEM-optimised” equilibrium
PSOL = 200kW (25kW per half field period)

Divertor design for HSX



Reducing vertical plate size

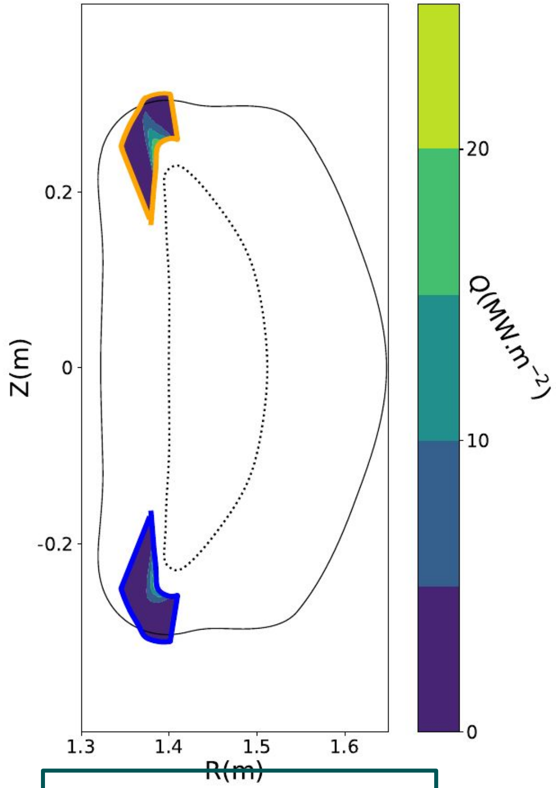


EMC3-Lite simulation for small “vertical plate” at φ=0

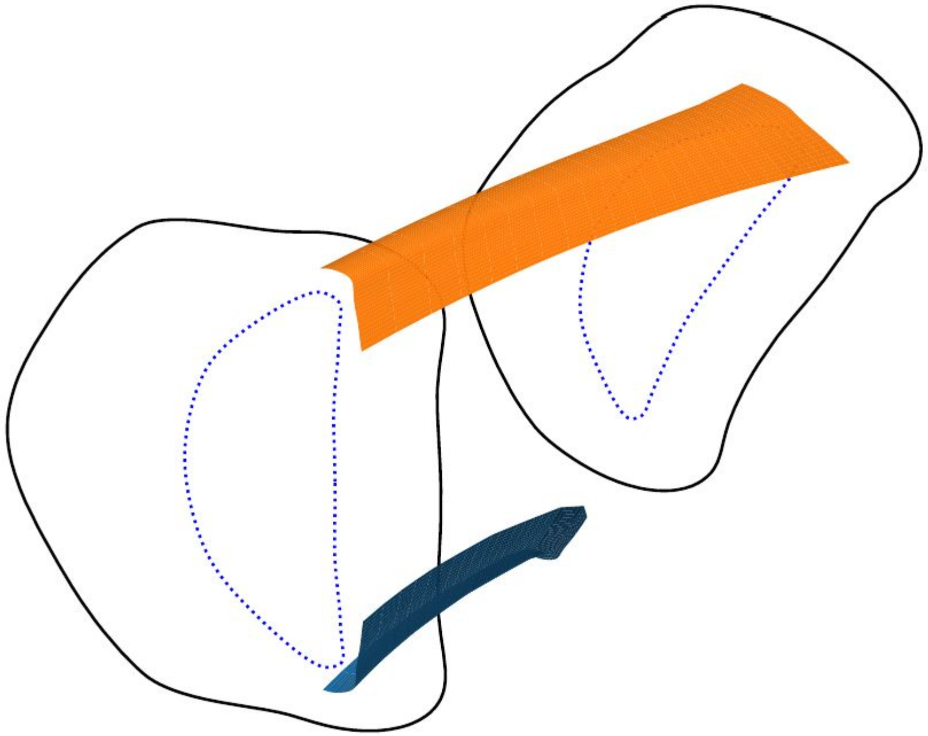
HSX “TEM-optimised” equilibrium
PSOL = 200kW (25kW per half field period)

Divertor design for HSX

- **Step 2**: Tilt plate toroidally (following the magnetic field) to ↑ wetted area, ↓ heat loads

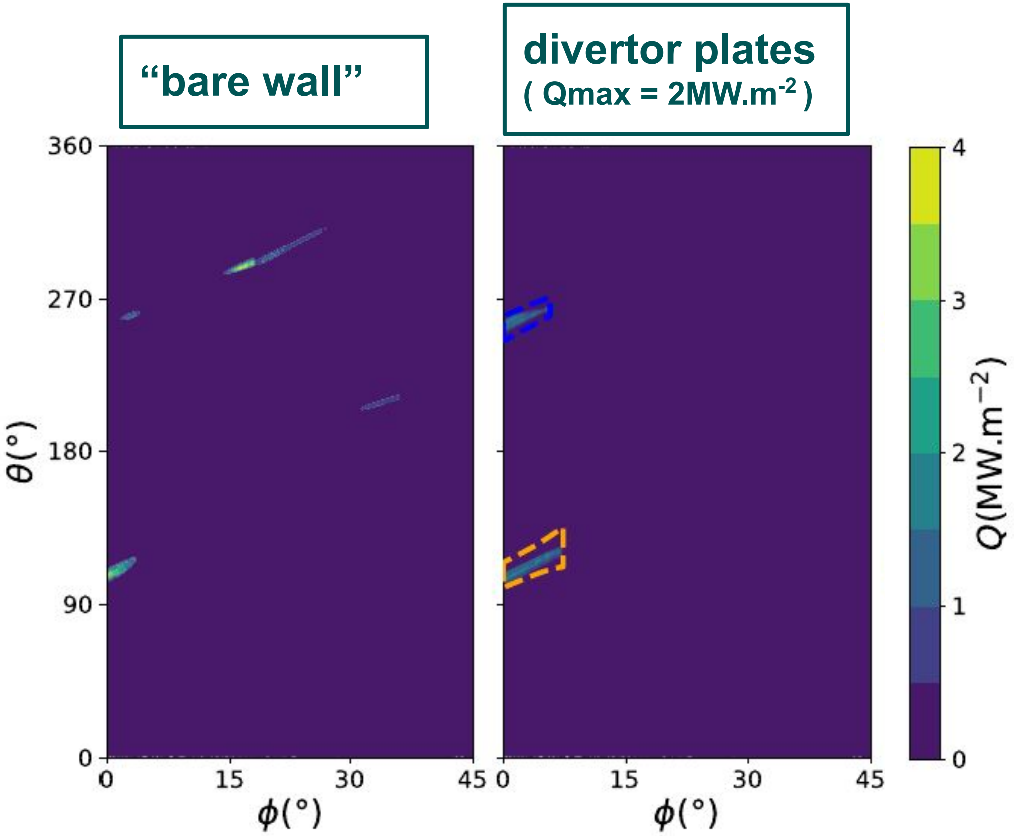


small vertical plate at φ=0

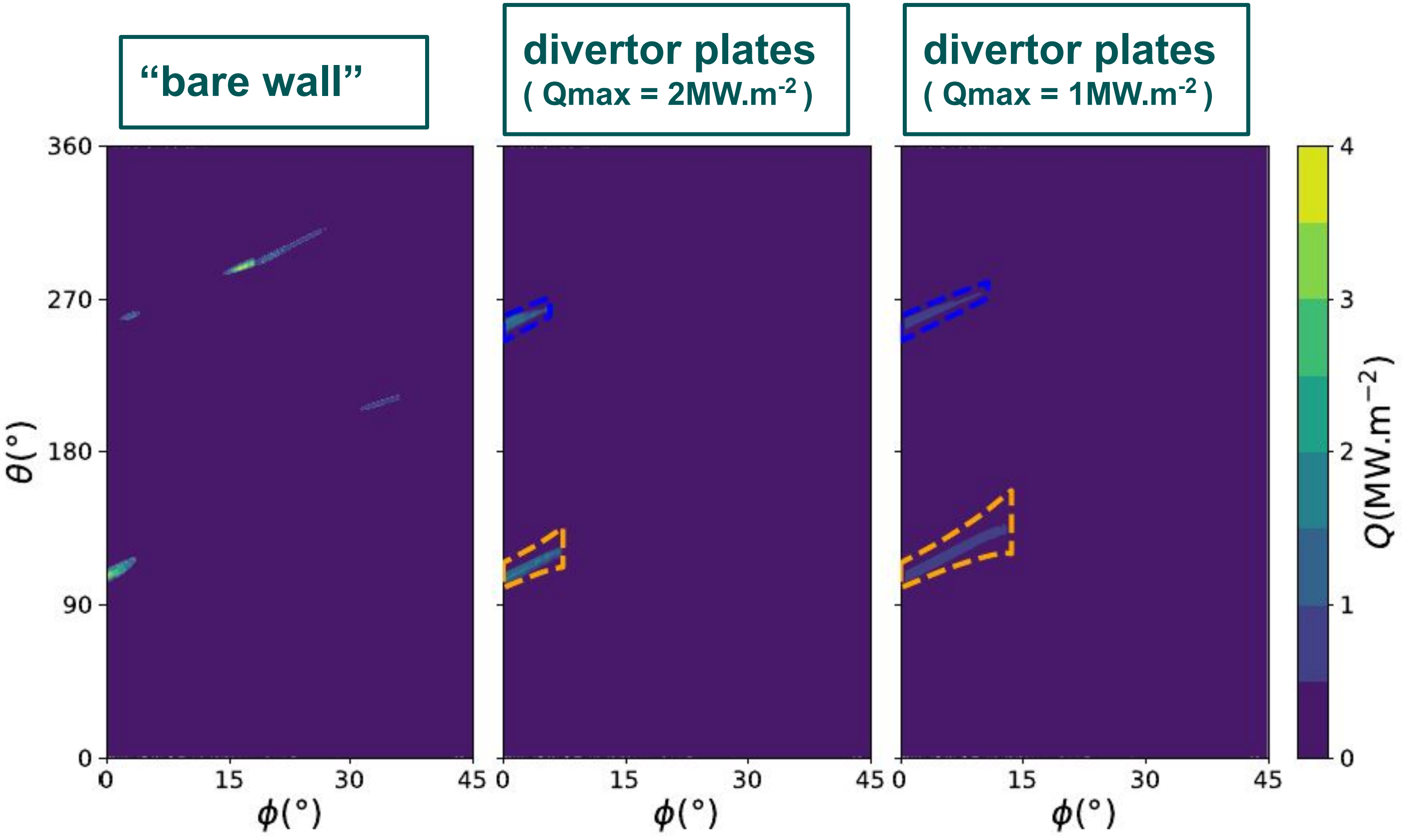


Toroidally tilted plates. NB (x,y,z) axes not to scale

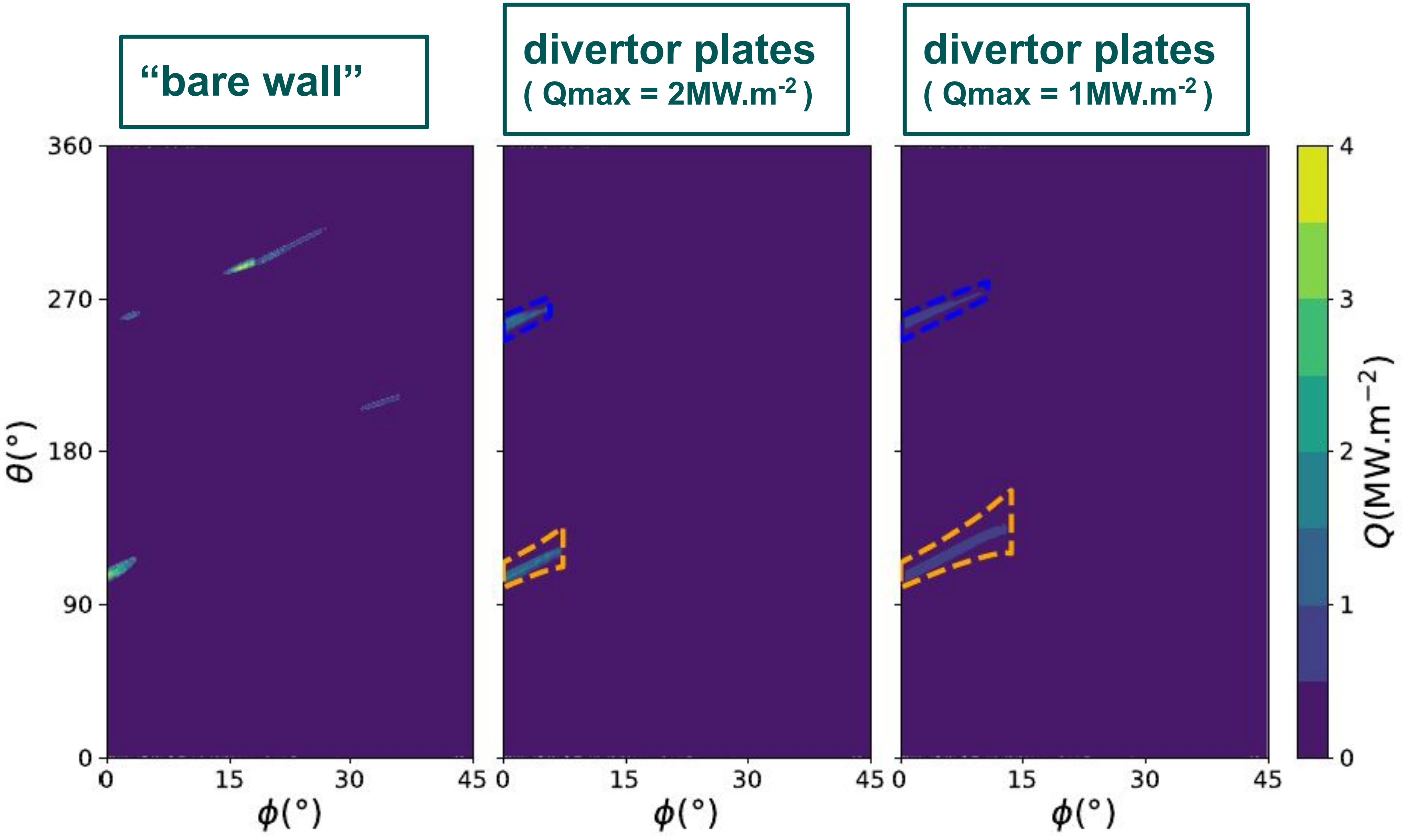
Divertor design for HSX



Divertor design for HSX



Divertor design for HSX



Additional topics addressed in this work:

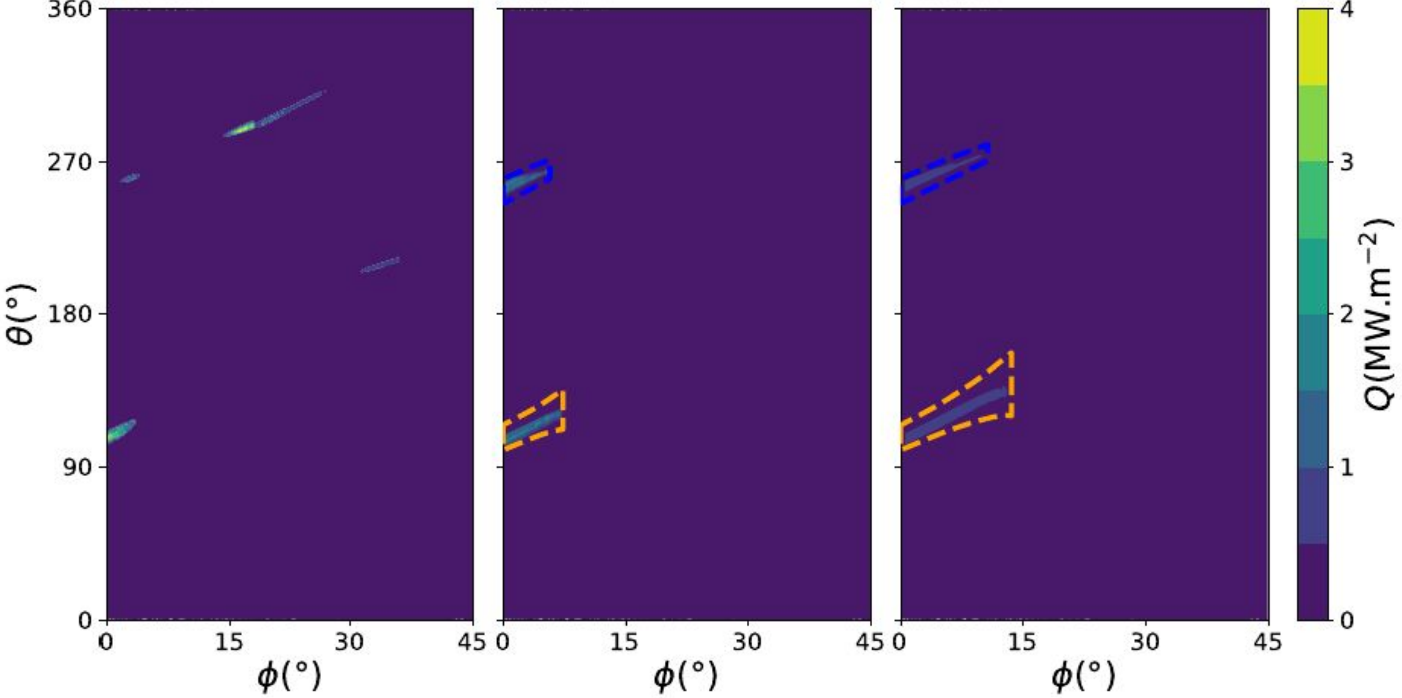
- Different toroidal plate locations
- Multi-plate divertor design
- Multi-configuration plate design

Divertor design for HSX

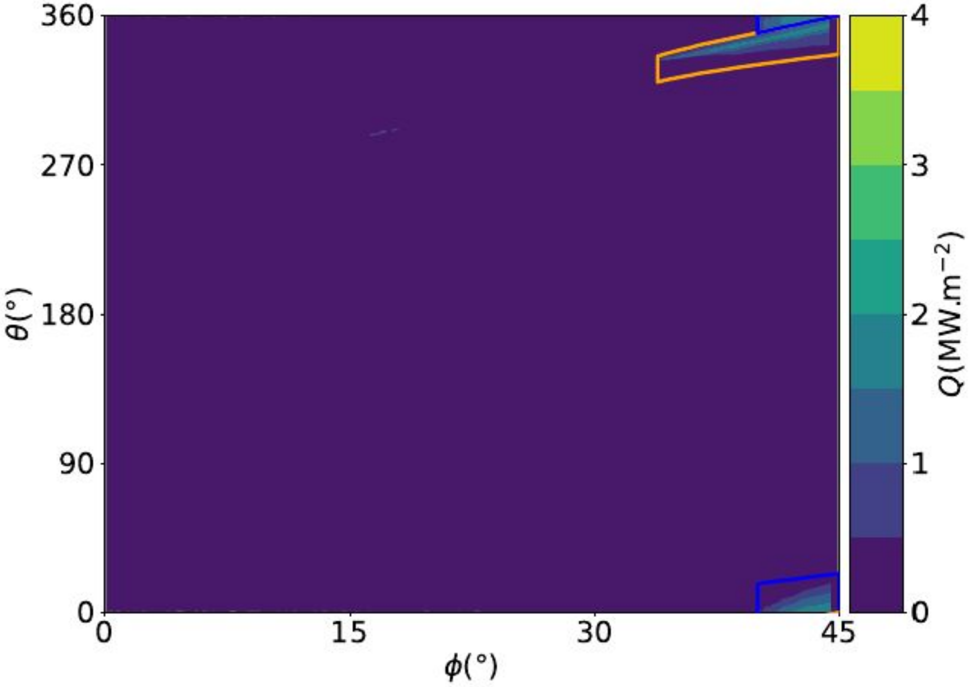
“bare wall”

divertor plates
(Qmax = 2MW.m^{-2})

divertor plates
(Qmax = 1MW.m^{-2})

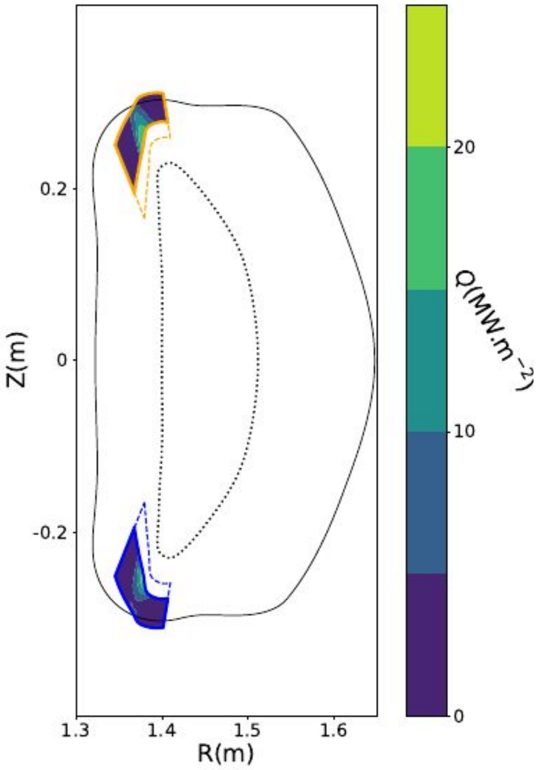


divertor plates
(Qmax = 2MW.m^{-2})

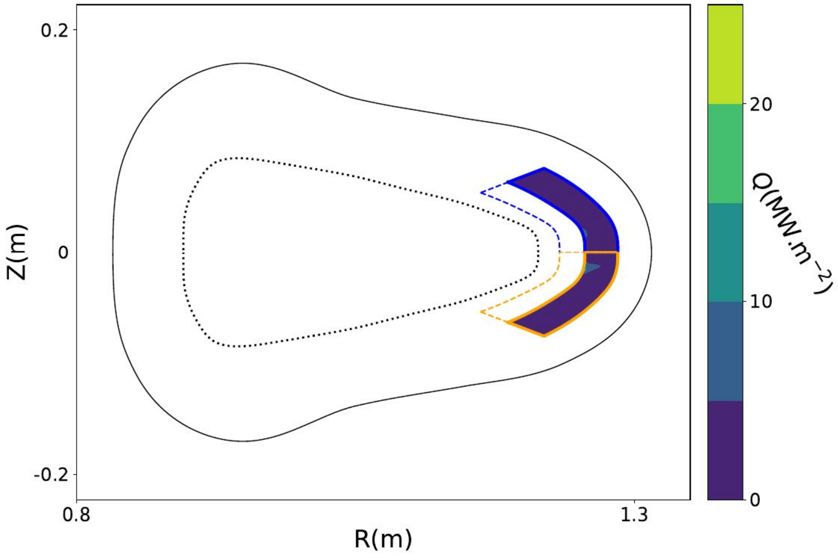


Divertor design for HSX - multi-plate designs

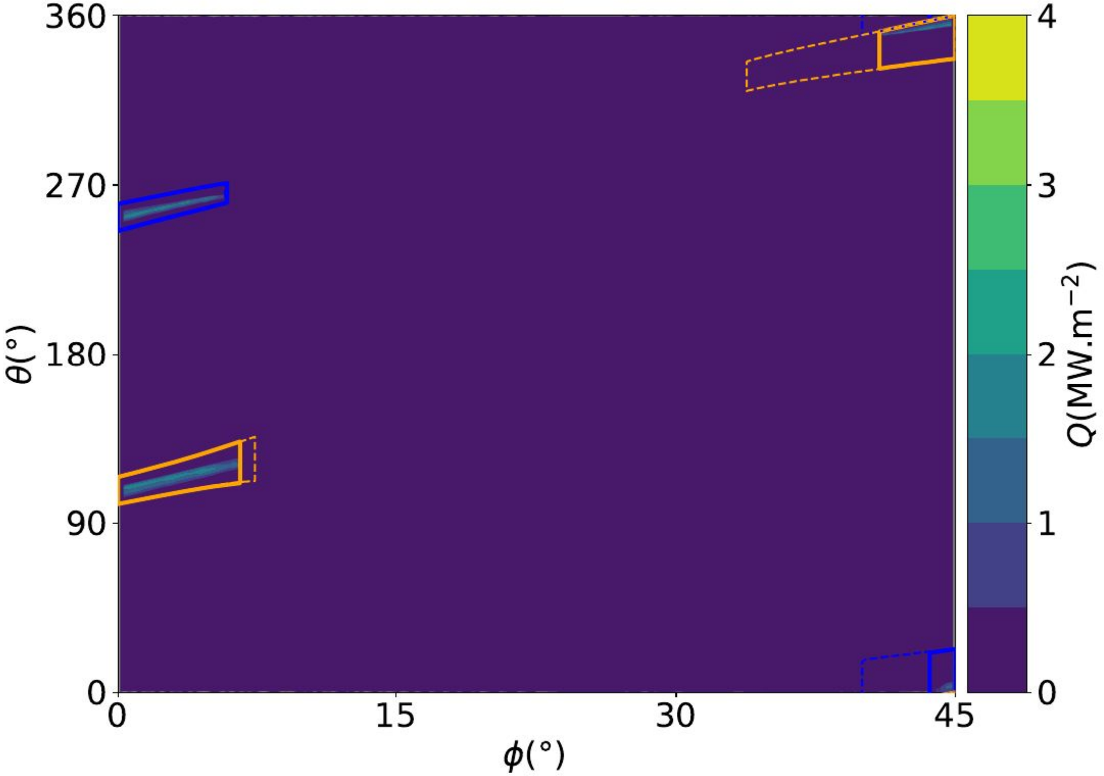
Vertical plates



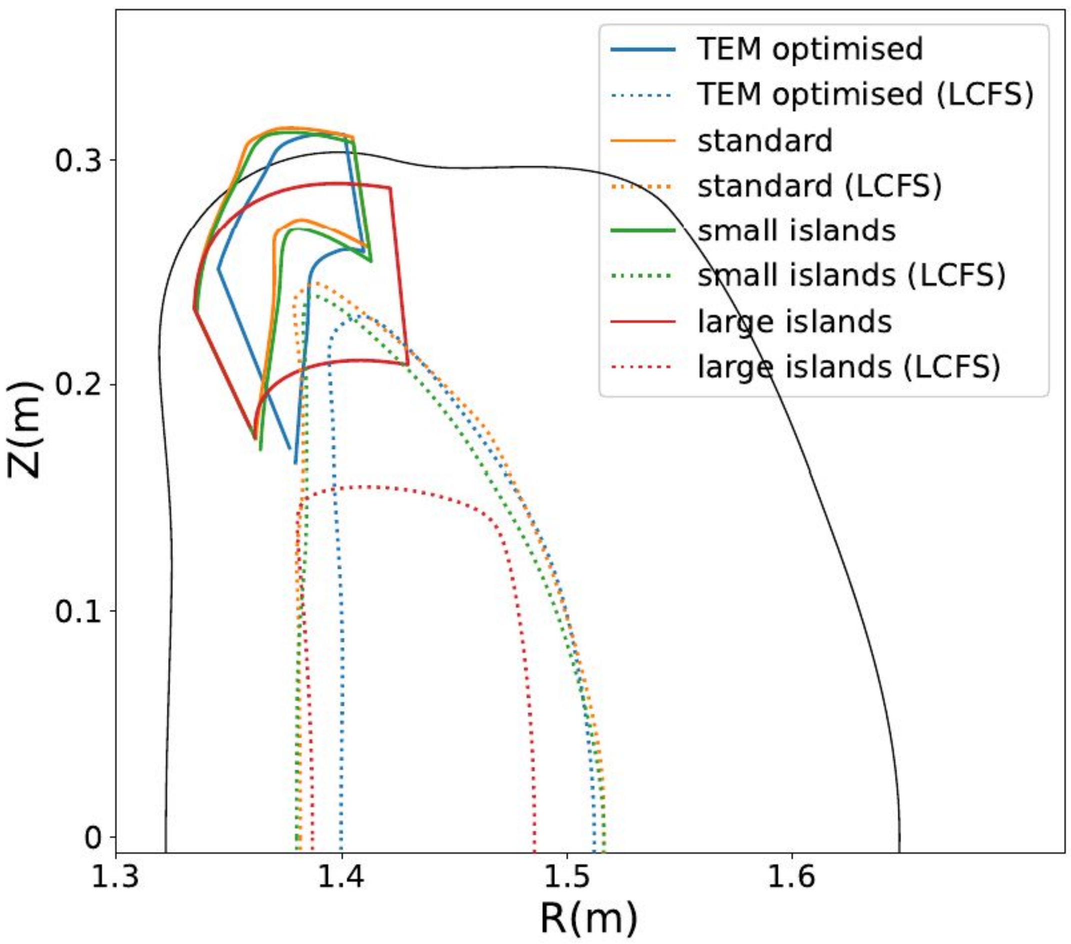
Vertical plates

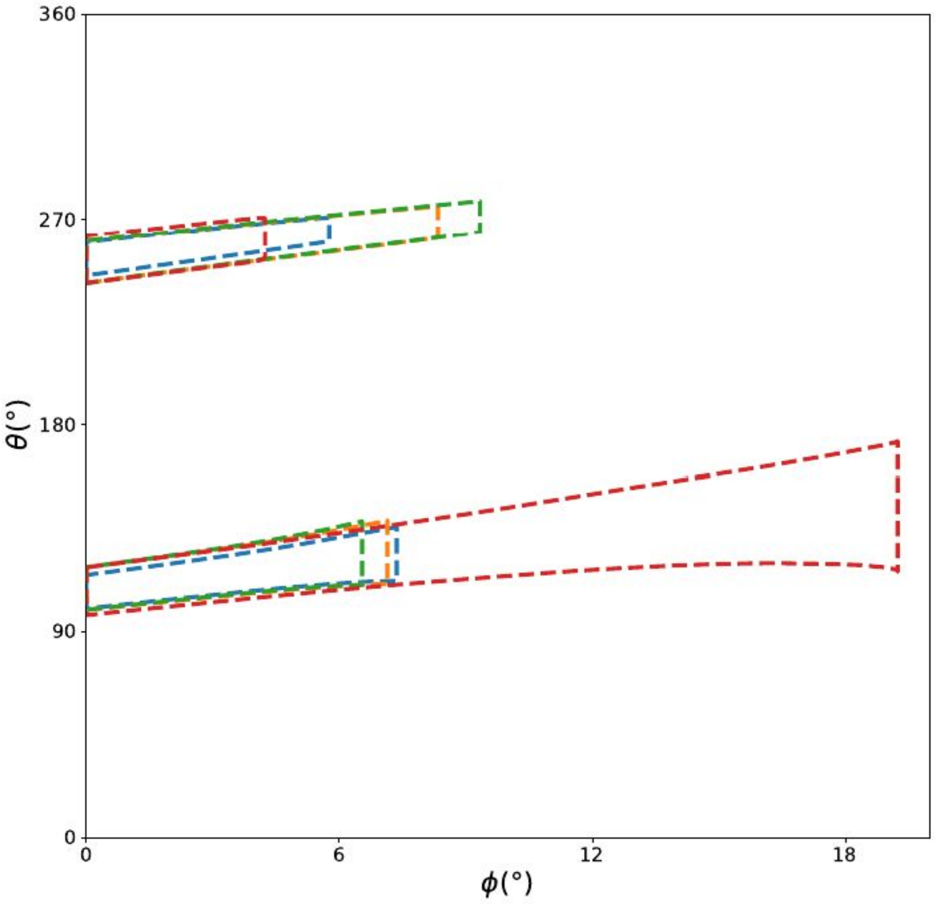


Tilted plates
(Qmax = 2MW.m^{-2})

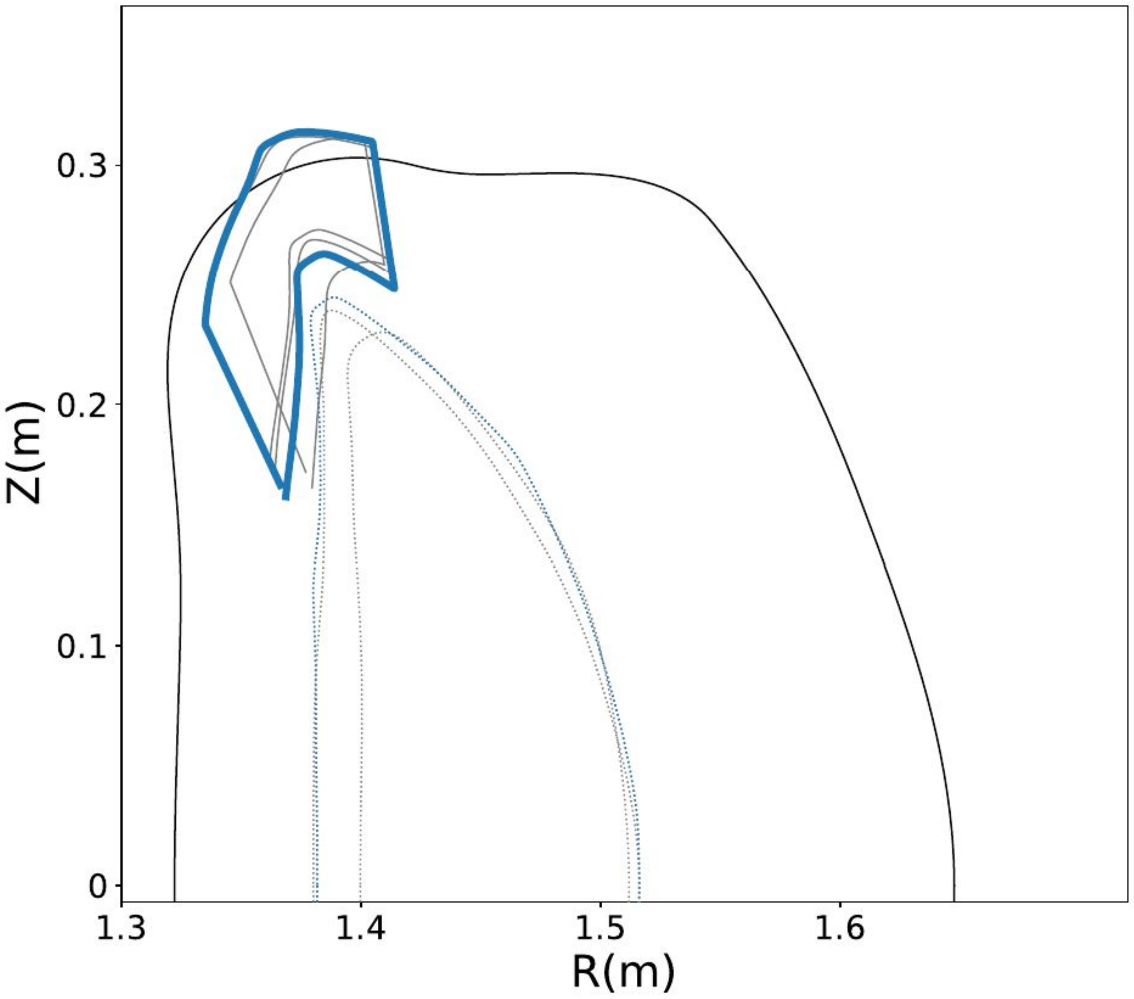


Divertor design for HSX - multi-configuration designs

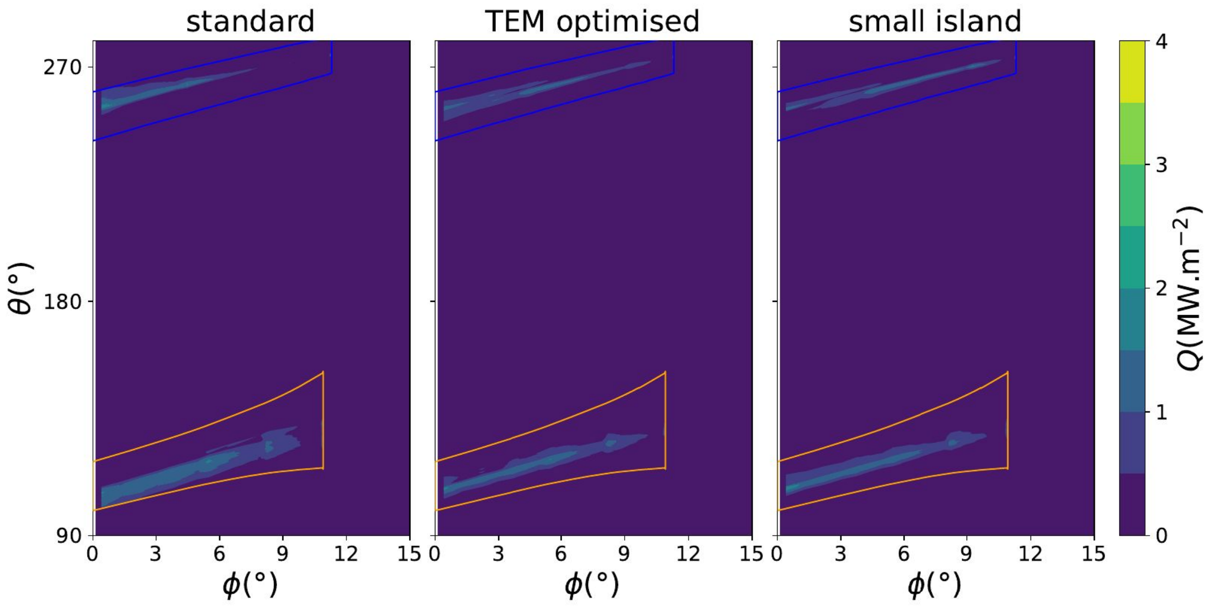




Divertor design for HSX - multi-configuration designs



Tilted plates
(Qmax = 2MW.m^{-2})



Conclusions & future work

- We have presented a **semi-automated design** for **divertor plates** for given magnetic field(s), to achieve sufficiently low PFC **heat loads,** in 2 steps:
  - Step 1: Catch heat on “Vertical Plates”
  - Step 2: Spread the heat on “Tilted Plates”

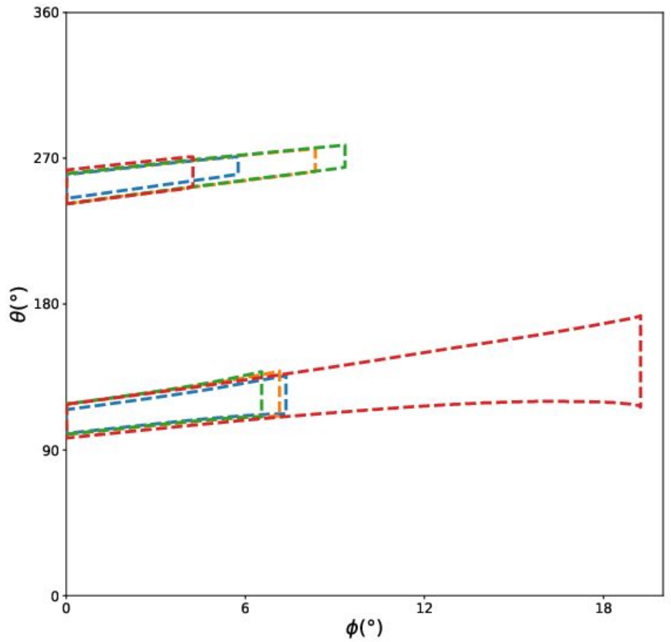
- We are able to design plates for HSX with <90% heat deposited on plates and heat loads < 2MW.m^{-2} for several magnetic configurations

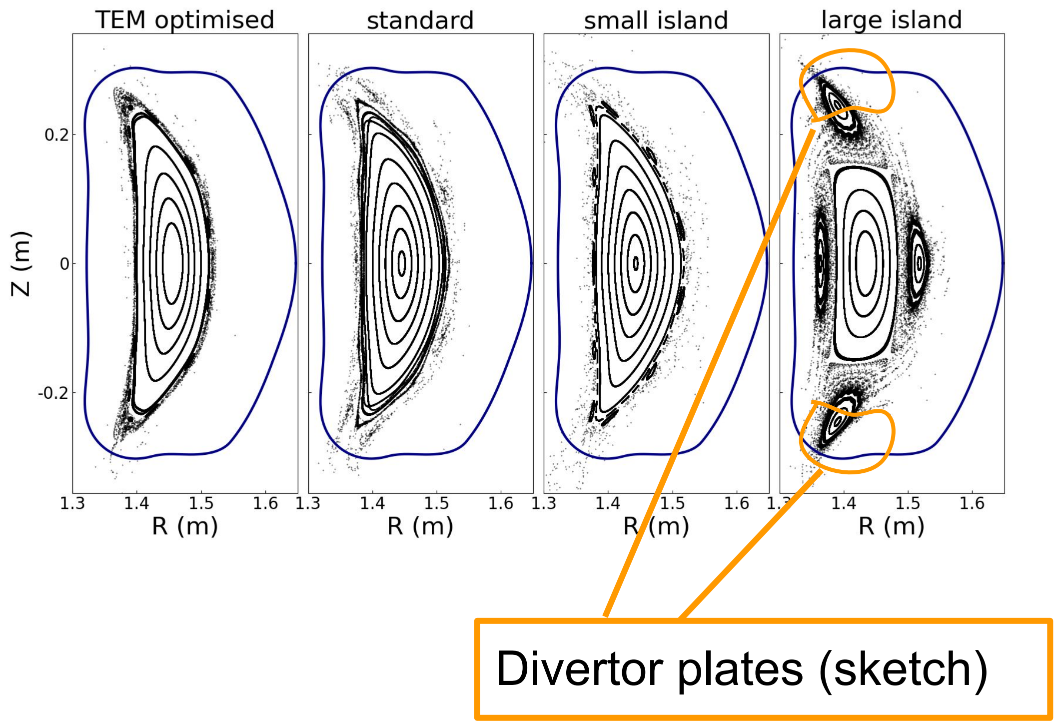
- Future work: First-flight neutral model -> divertors designed for heat loads & neutral exhaust

- **Open question:** *Is there a “general representation” of a divertor plate? (with O(100) controllable parameters?)*
  - … could be used in “black box” optimisation schemes

APPENDIX

A note on “large island” HSX configuration

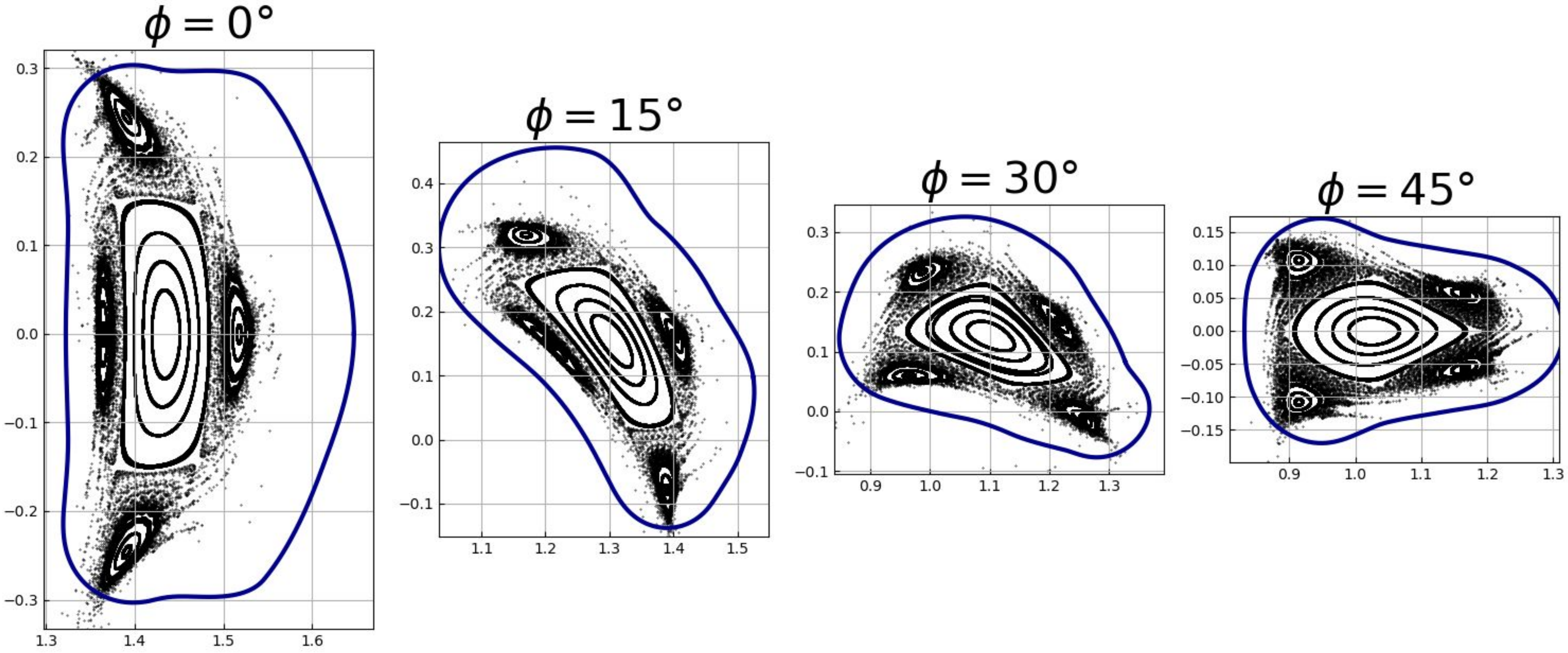




Red = large island.

- One side of vertical plate (the front side of the upper plate) takes much more heat than the other side (76% vs 22%), requires more tilting.
  - (Stellarator symmetry: the heat falling on the **front** side of the **upper** plate is identical to the the heat falling on the **back** side of the **lower** plate)
- Idea: heat loads island on **inboard side** which creates the imbalance.
- Plan: test this theory (look at how the islands move) and comment on this

A note on “large island” HSX configuration



A note on "large island" HSX configuration