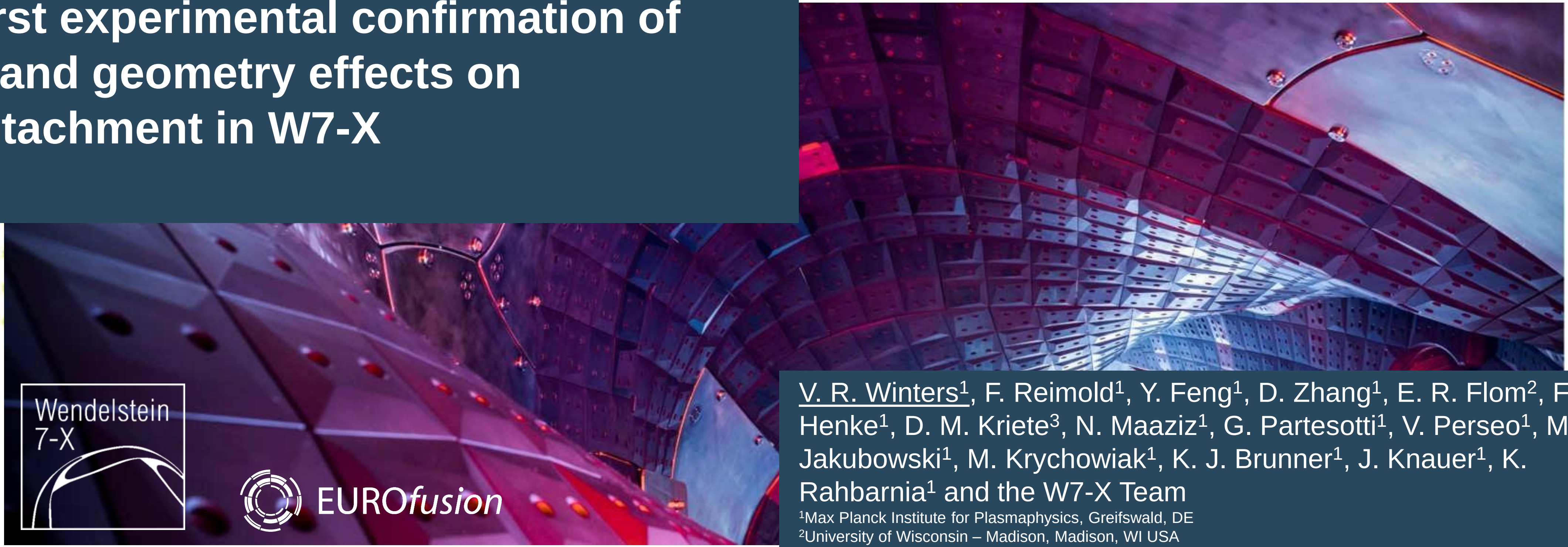
MAX-PLANCK-INSTITUT
FÜR PLASMAPHYSIK

First experimental confirmation of island geometry effects on detachment in W7-X



V. R. Winters[1], F. Reimold[1], Y. Feng[1], D. Zhang[1], E. R. Flom[2], F. Henke[1], D. M. Kriete[3], N. Maaziz[1], G. Partesotti[1], V. Perseo[1], M. Jakubowski[1], M. Krychowiak[1], K. J. Brunner[1], J. Knauer[1], K. Rahbarnia[1] and the W7-X Team
[1]Max Planck Institute for Plasmaphysics, Greifswald, DE
[2]University of Wisconsin – Madison, Madison, WI USA
[3]Auburn University, Auburn, AL USA

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

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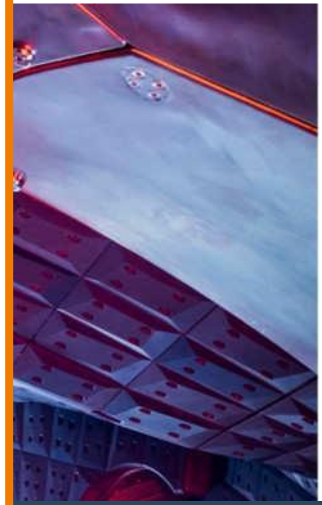
Special Note to W7-X team:

If desired, please send me your W7-X-related oral/poster number, which I can add to the final slide of my talk.

I could not find these on the conference website. Thanks!



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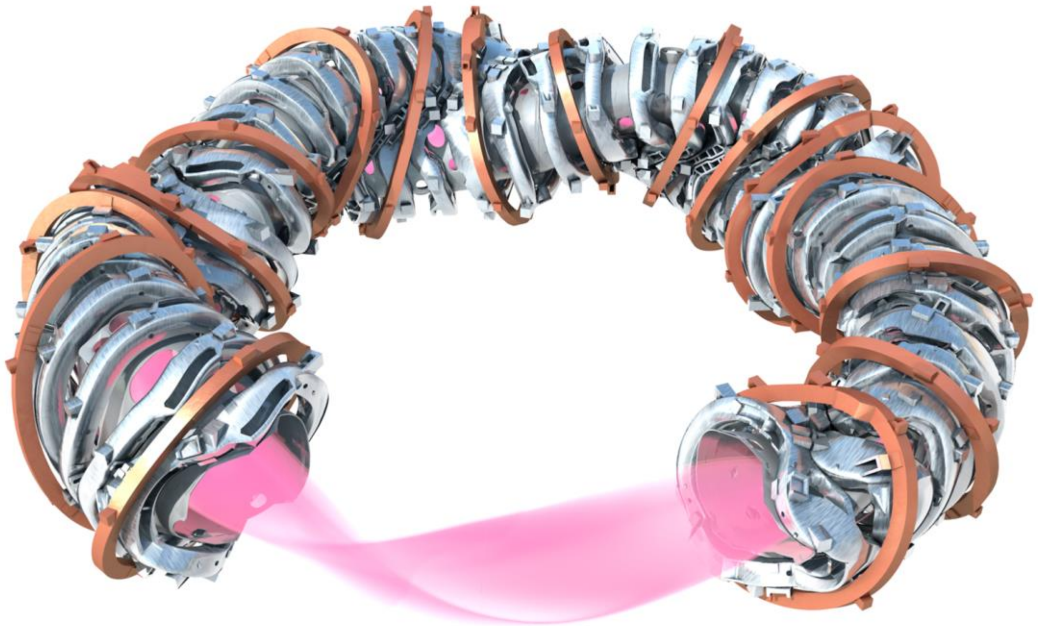
- 5-fold symmetric, quasi-isodynamic stellarator, carbon PFCs
- Coil system designed for high magnetic flexibility:



Machine Parameters	
R	$= 5.5$ m
a	≈ 0.5 m
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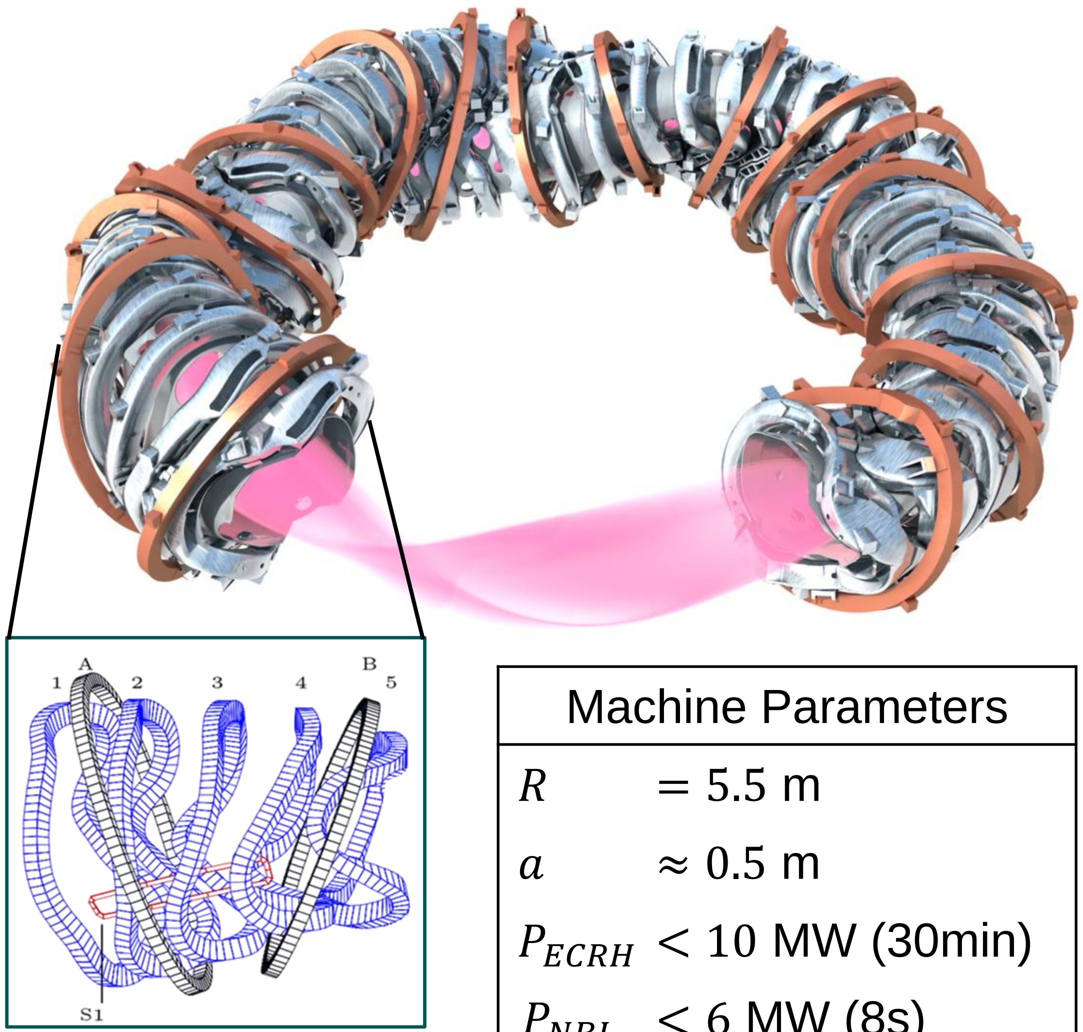

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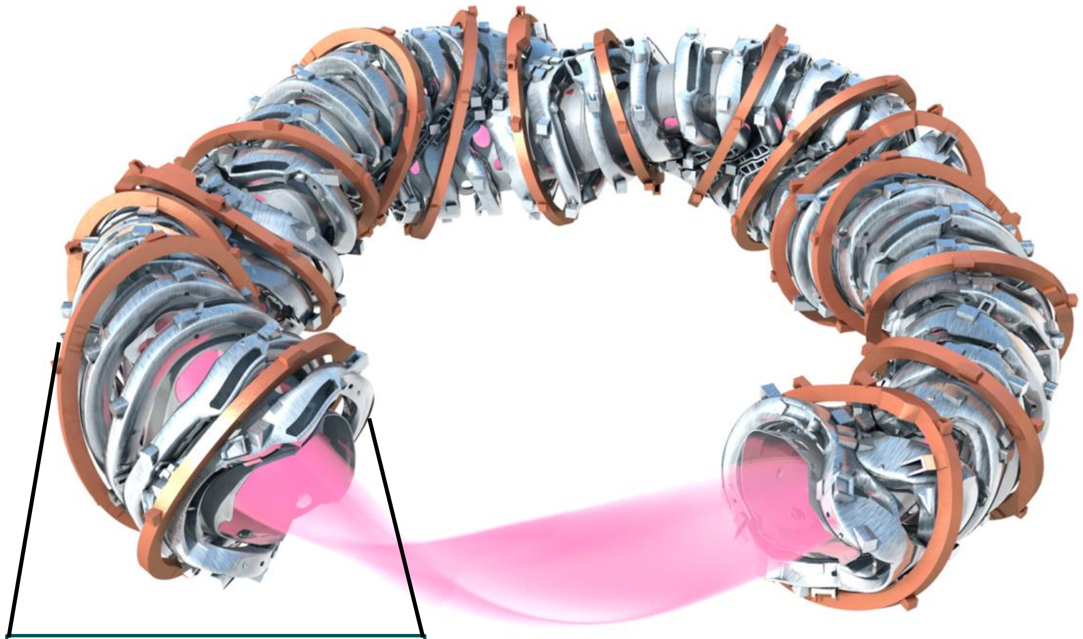

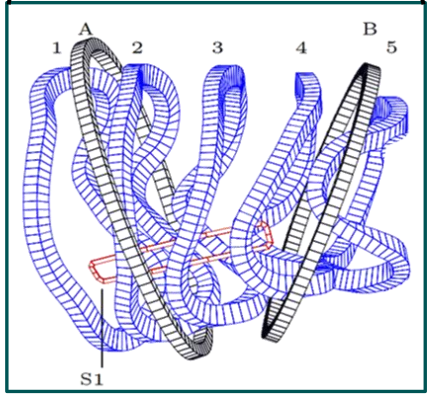

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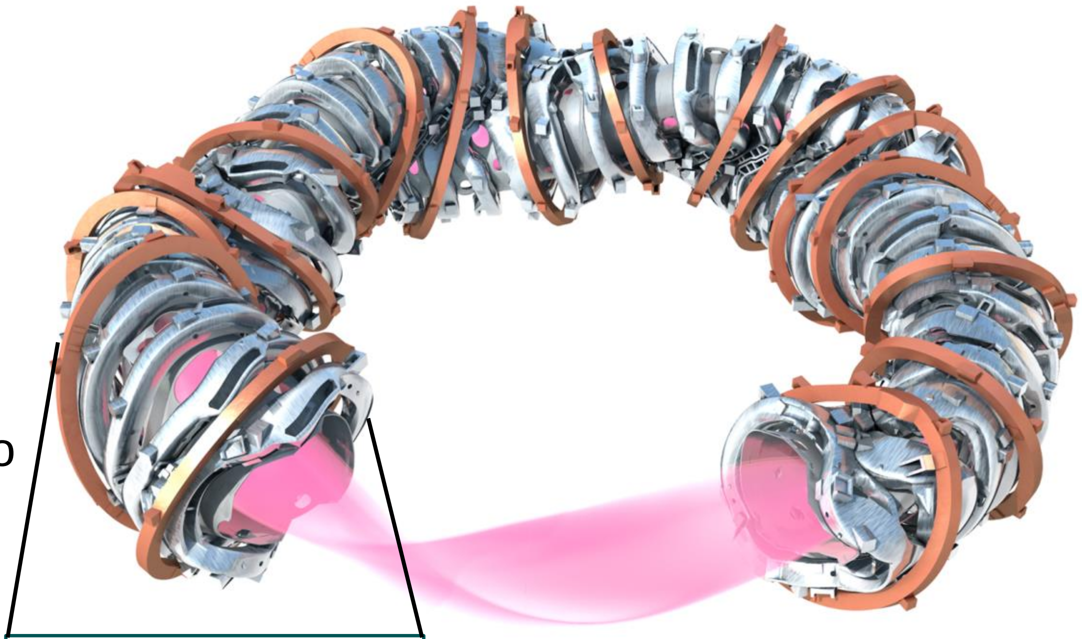

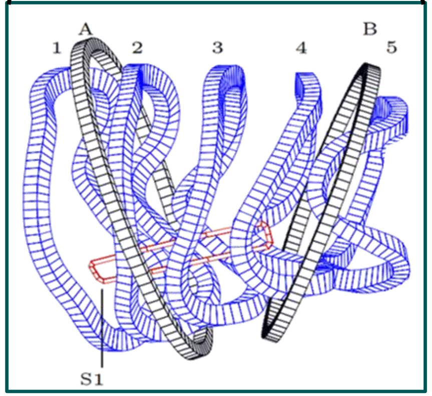

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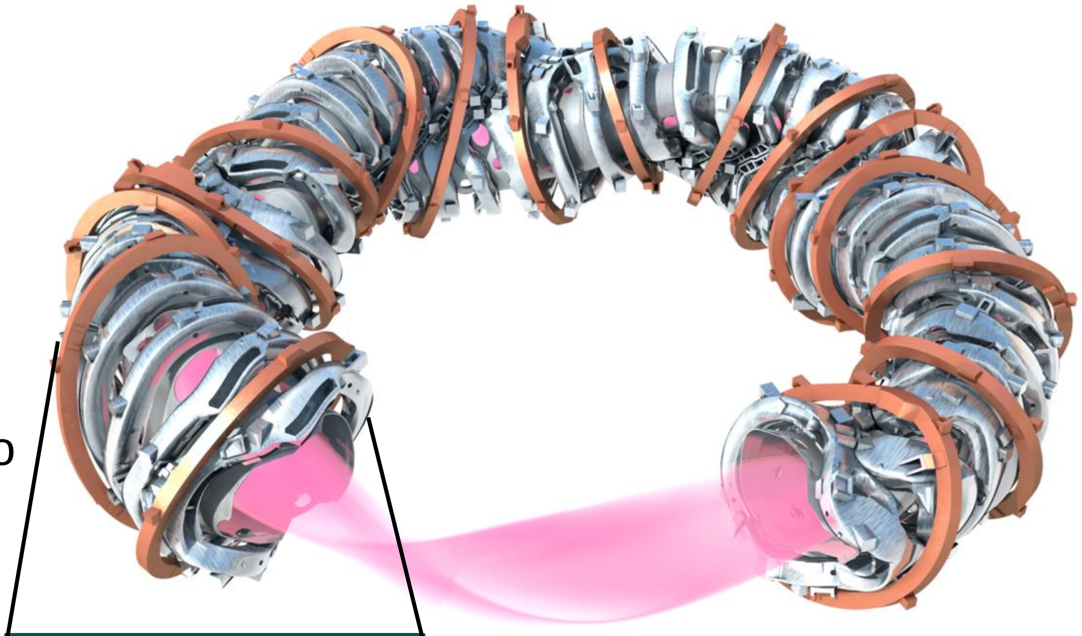

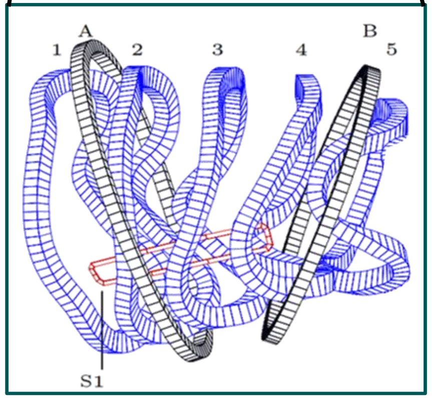

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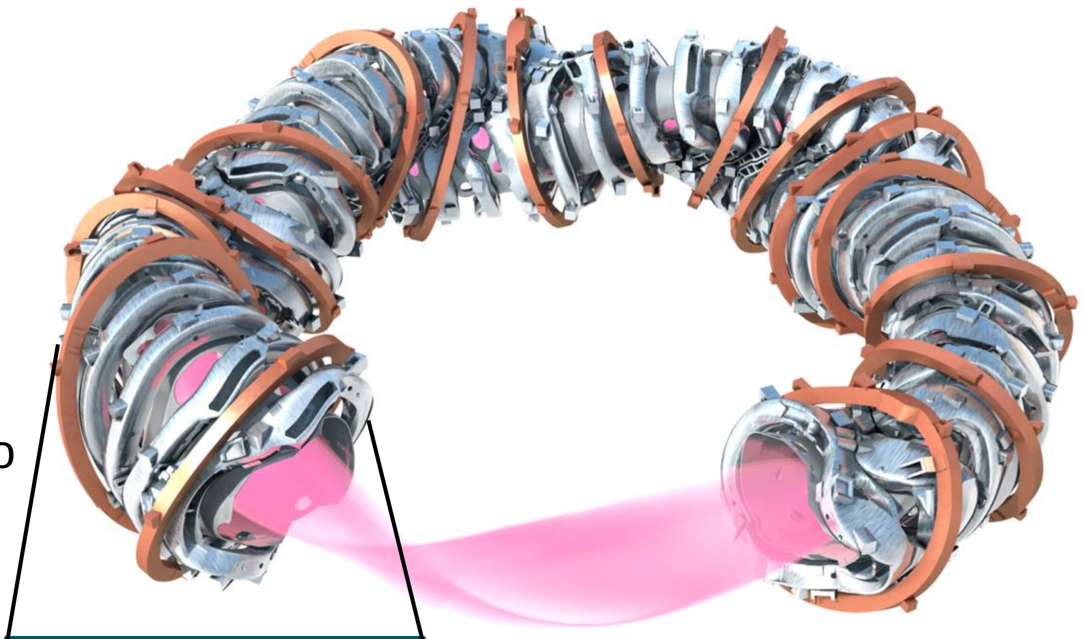
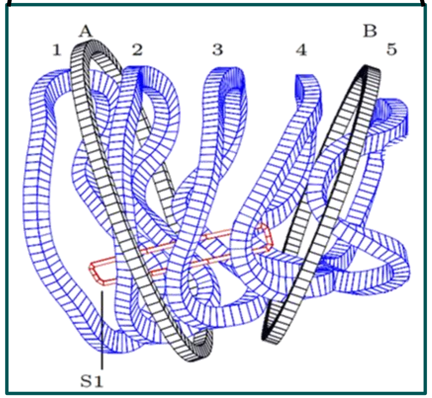
W7-X utilizes the *island divertor* concept.
What does this look like?





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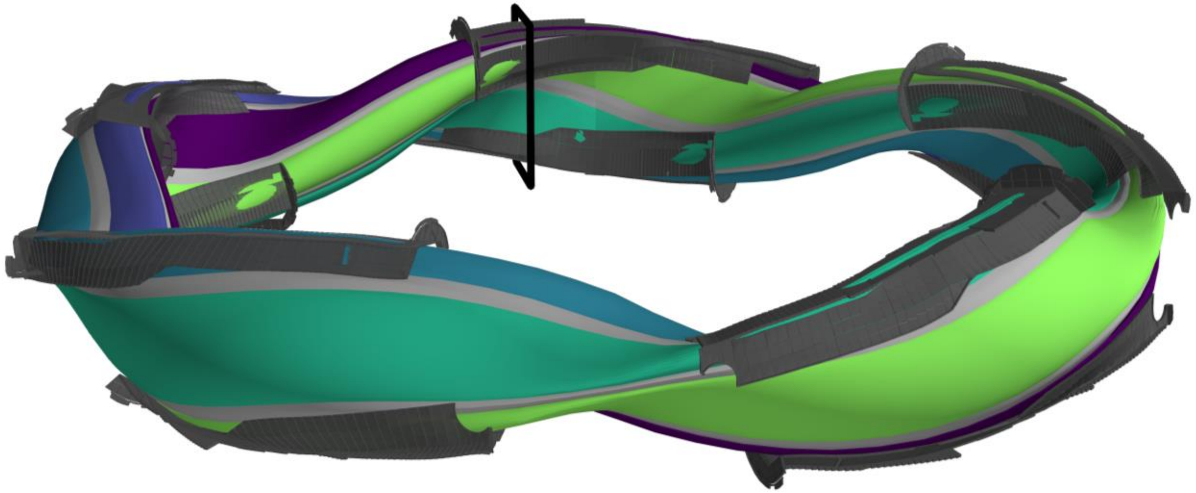
What does the SOL geometry look like for the island divertor?



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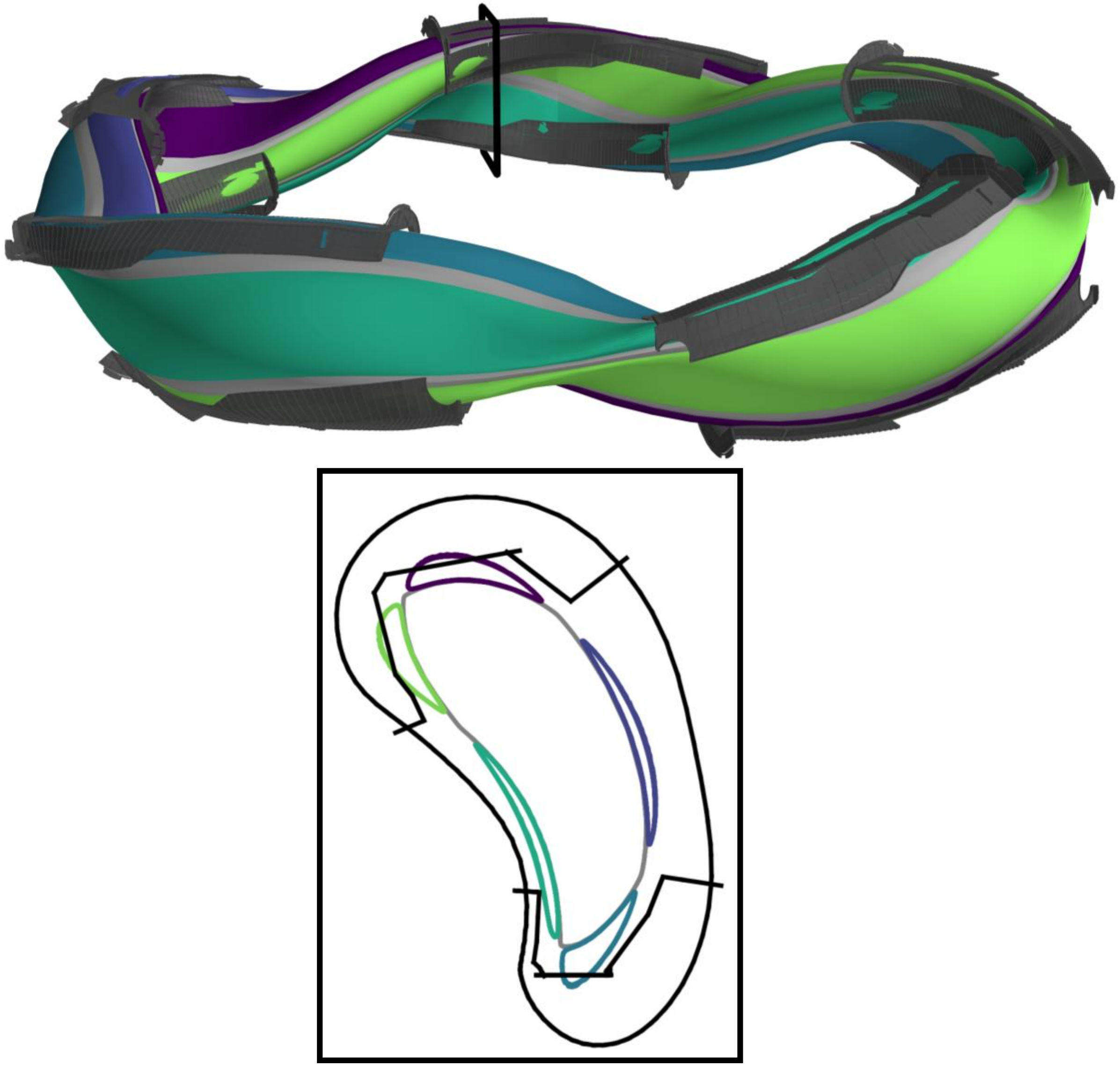

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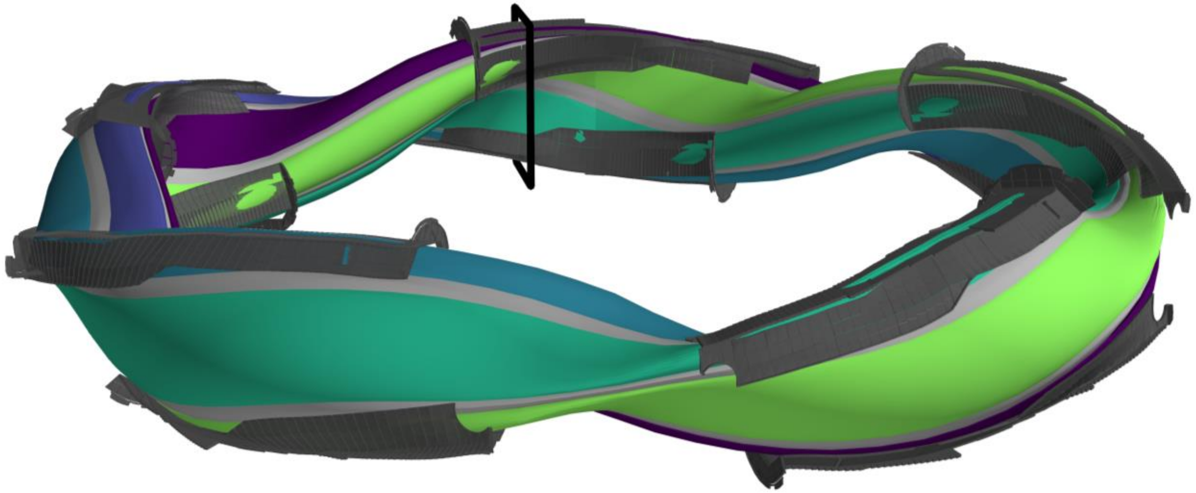
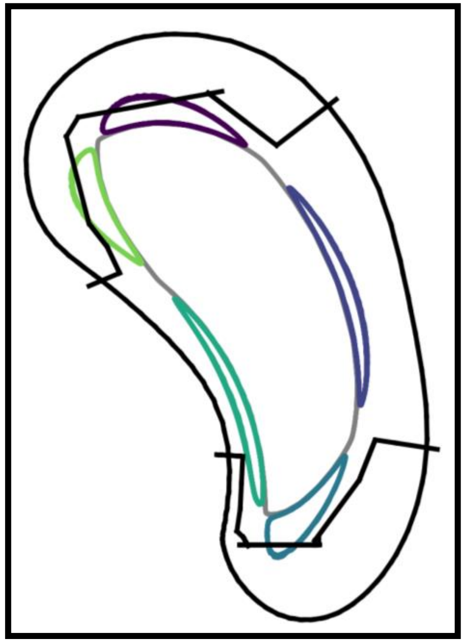
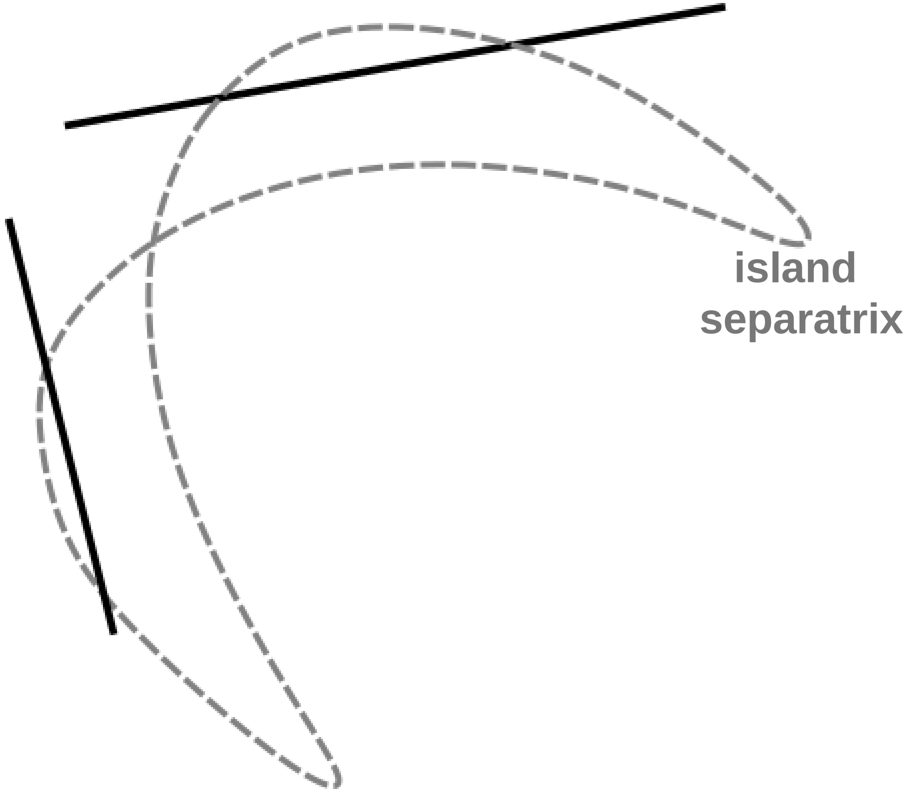




Standard Configuration (5 islands)



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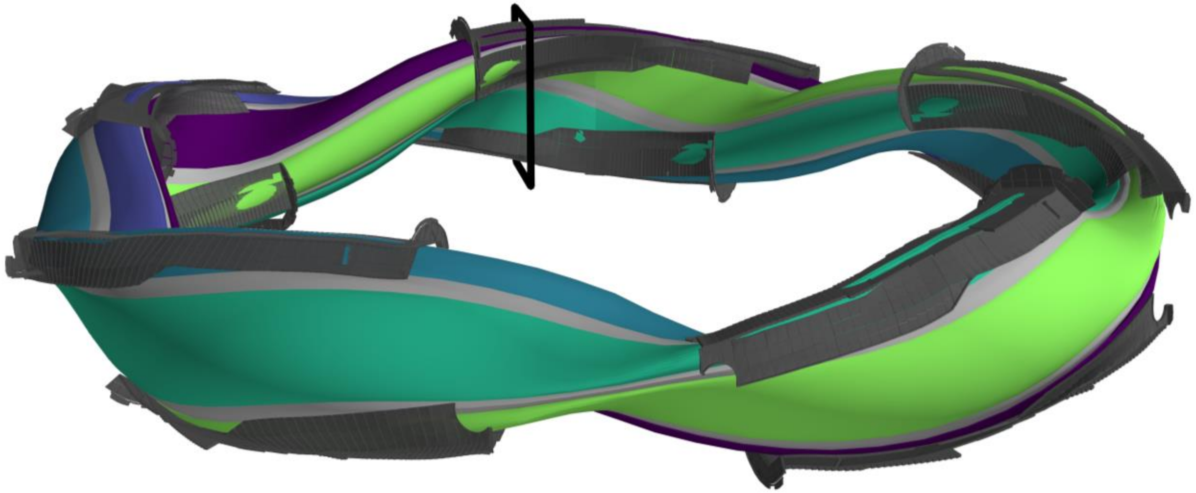

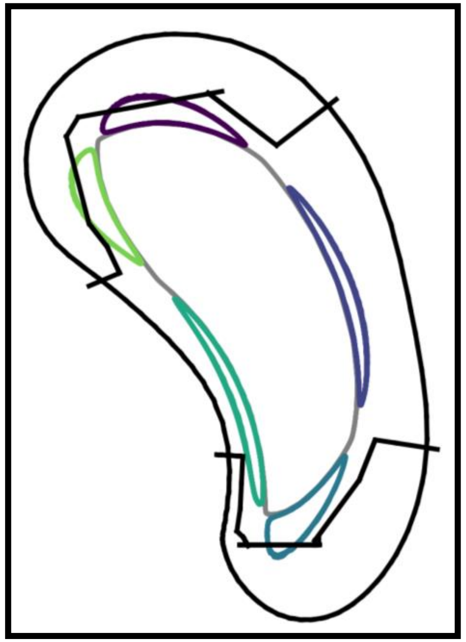

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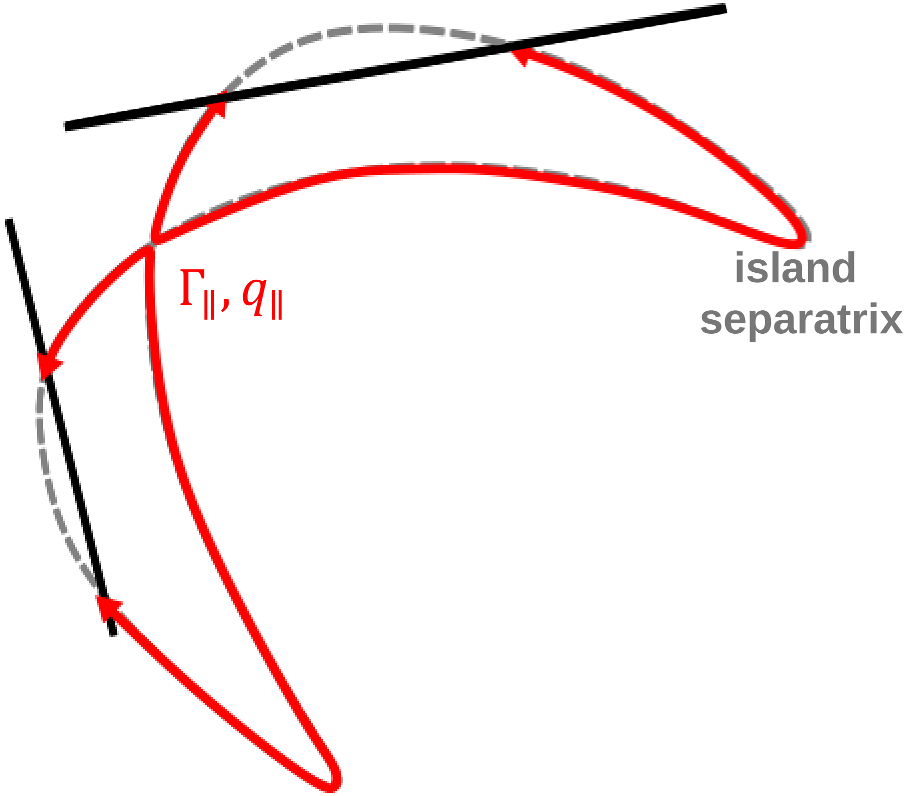

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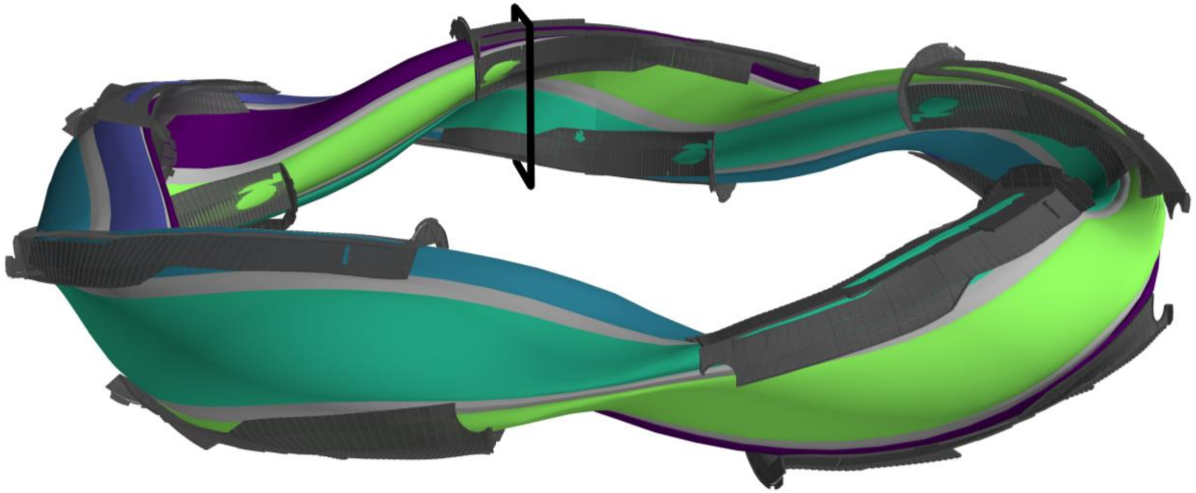

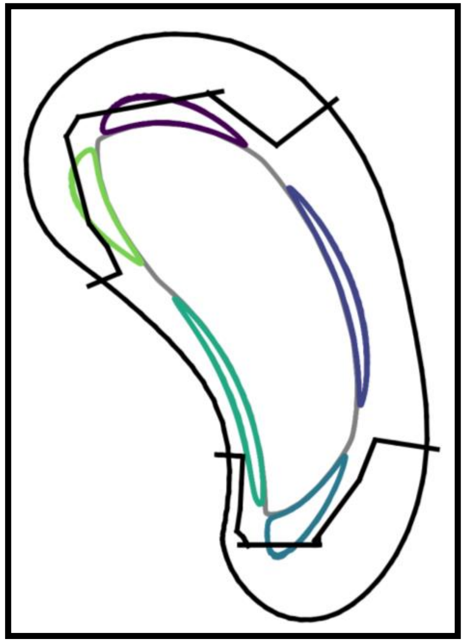

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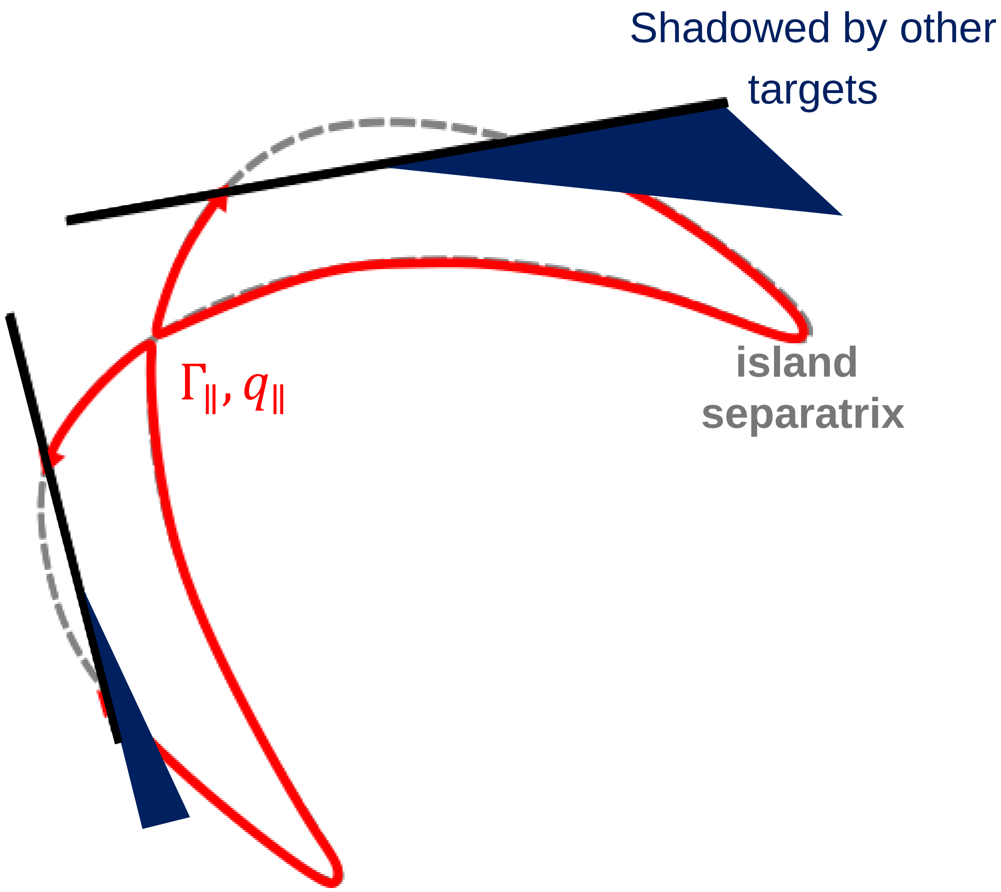

Shadowed by other targets

$\Gamma_{\parallel}, q_{\parallel}$

island separatrix

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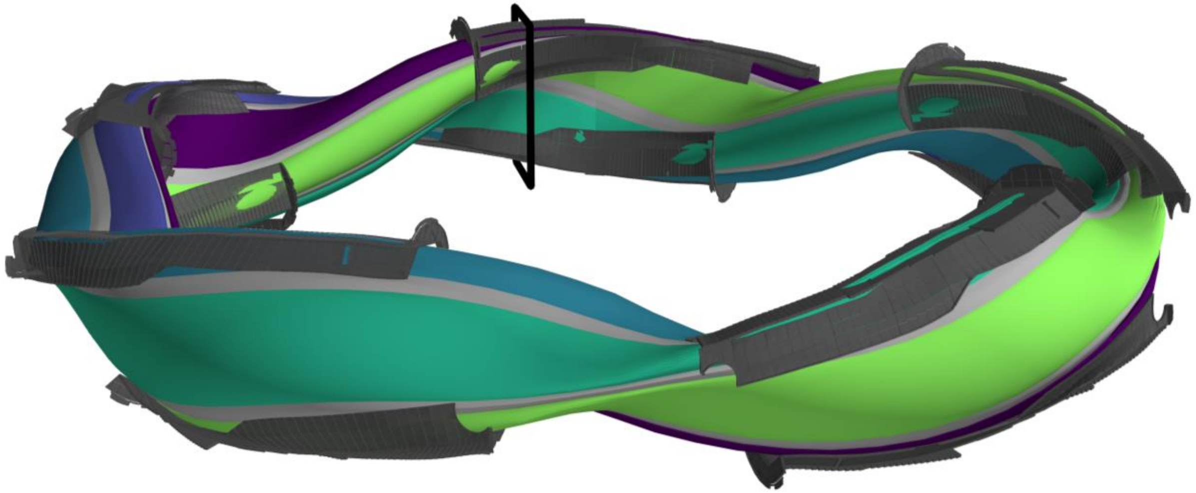

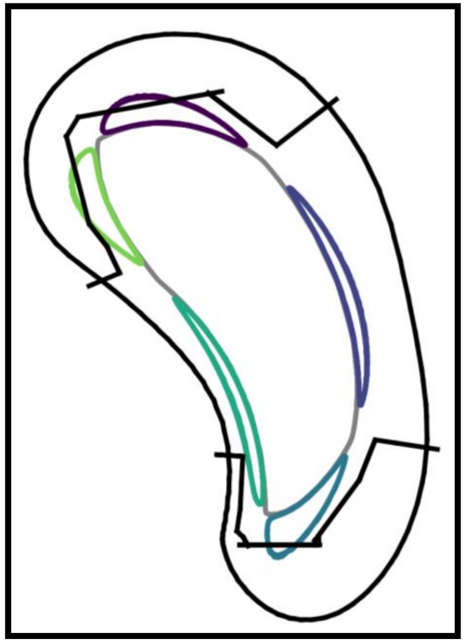

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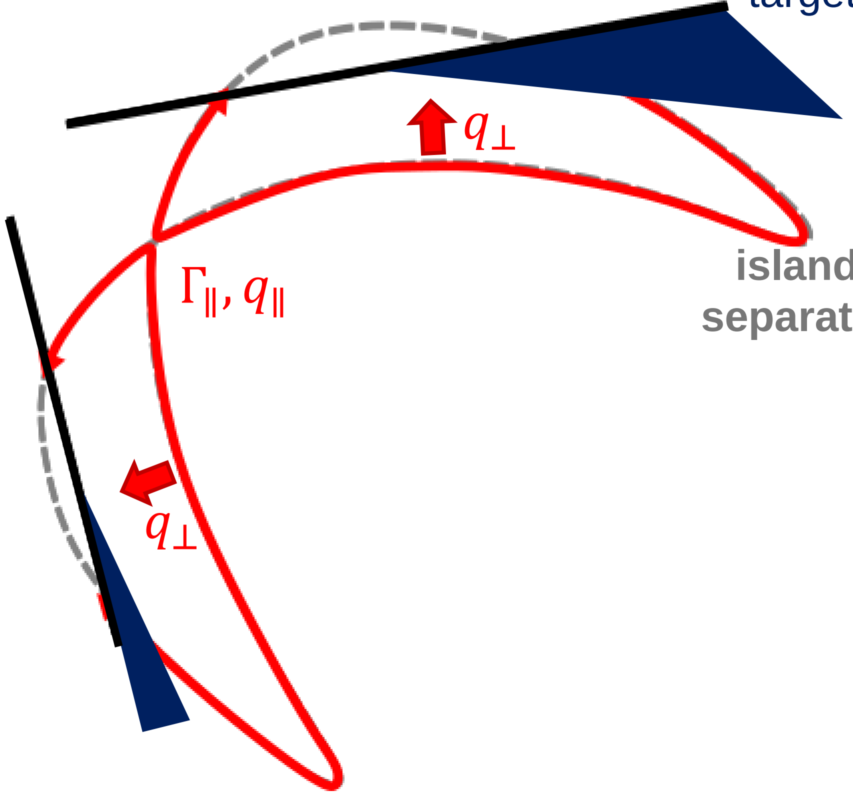

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$q_\perp$

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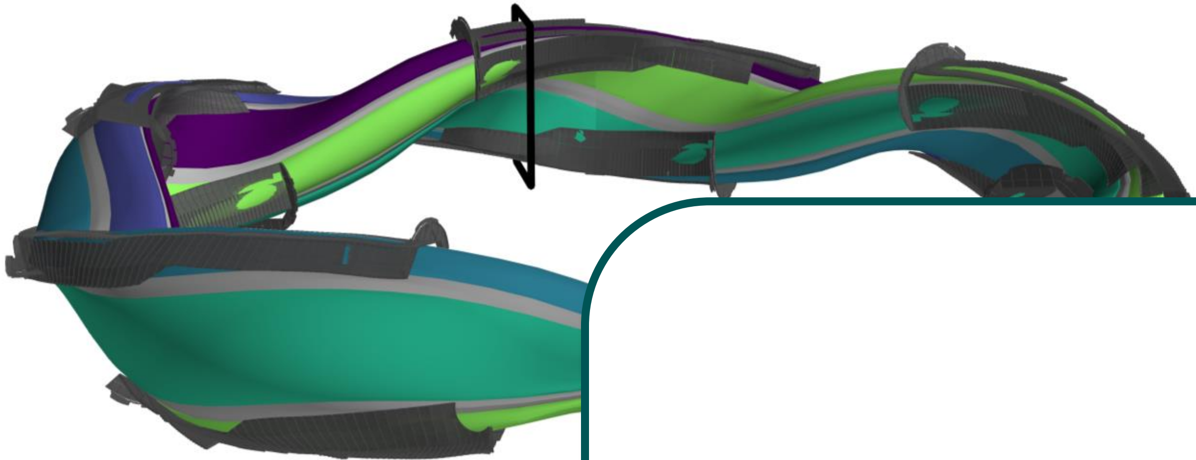

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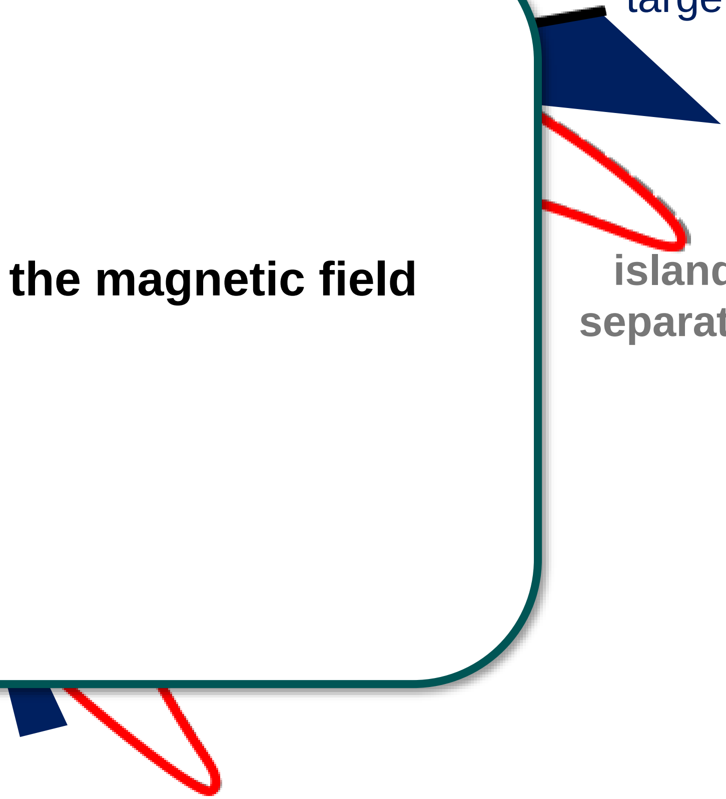
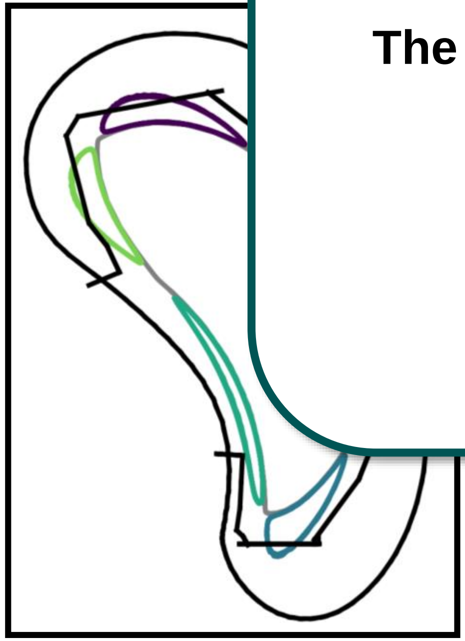


The details of this geometry depend on the magnetic field configuration!



Island geometry believed to play a critical role in SOL transport

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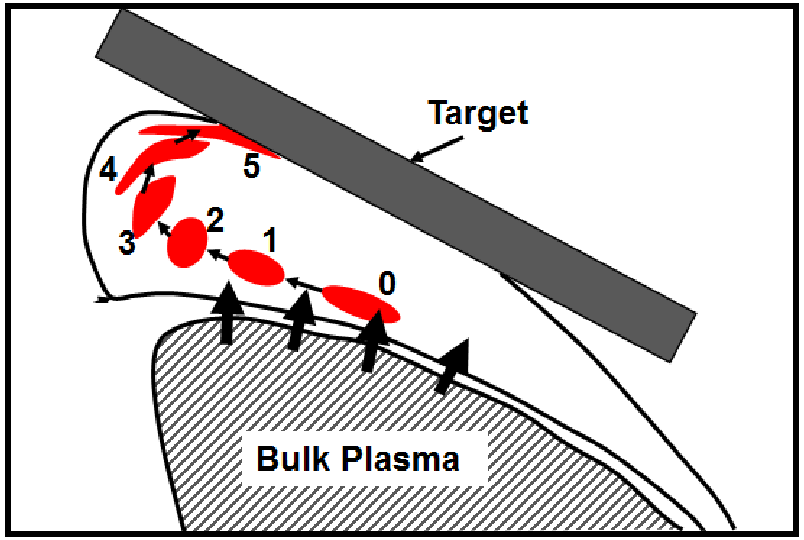

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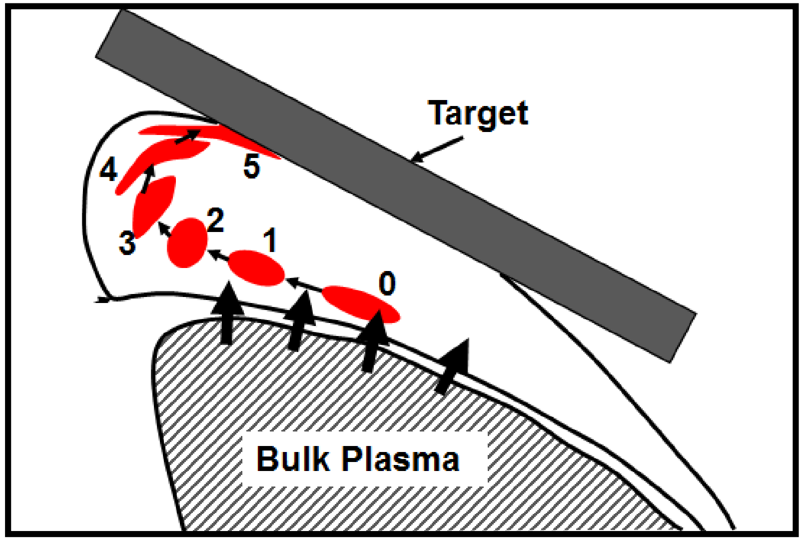

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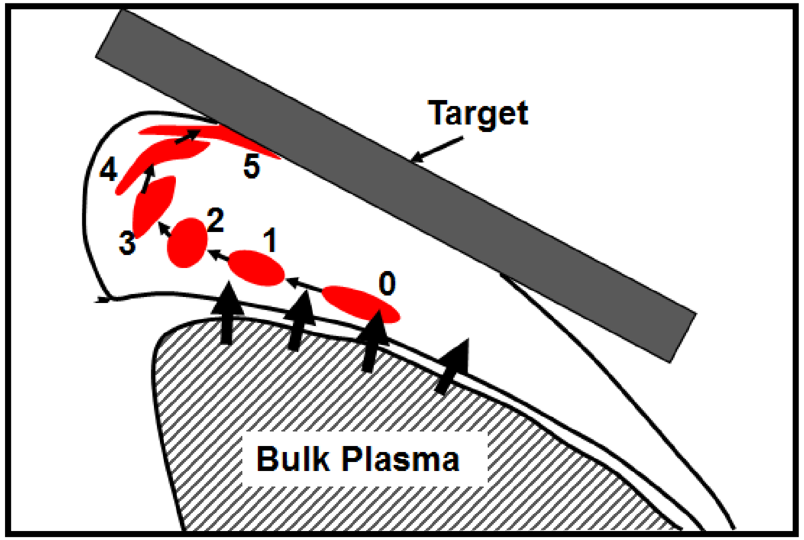

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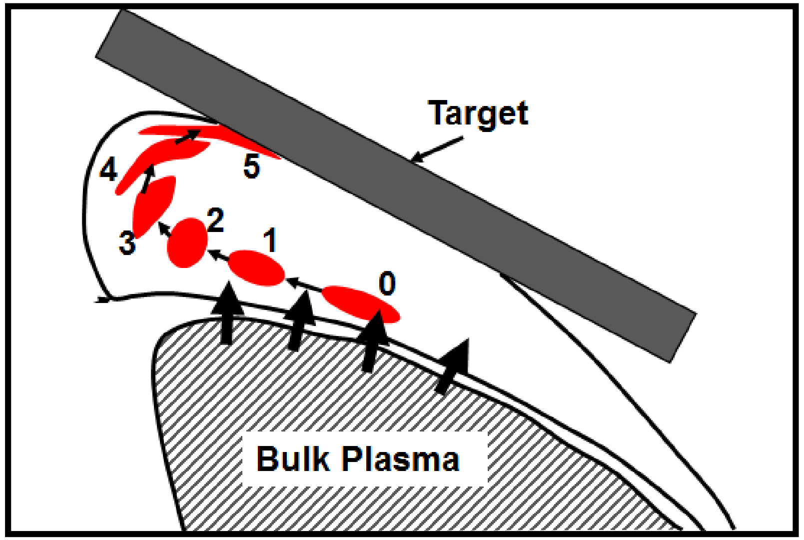
shear at resonant surface



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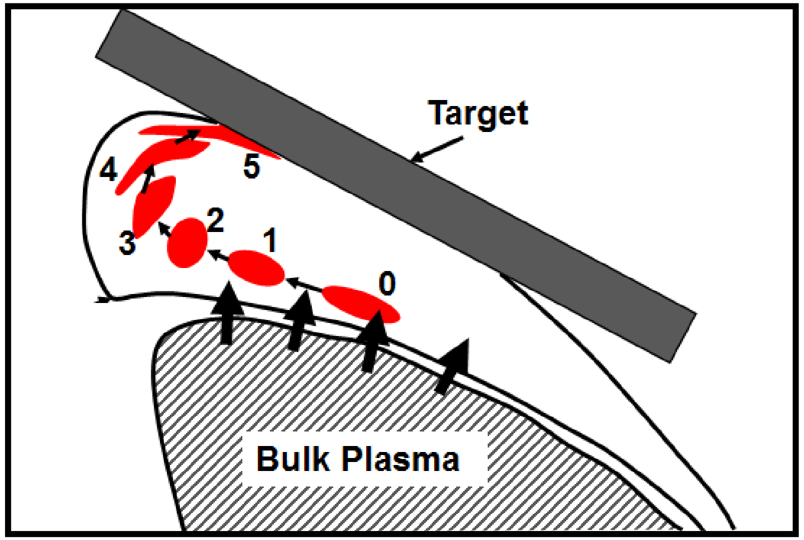

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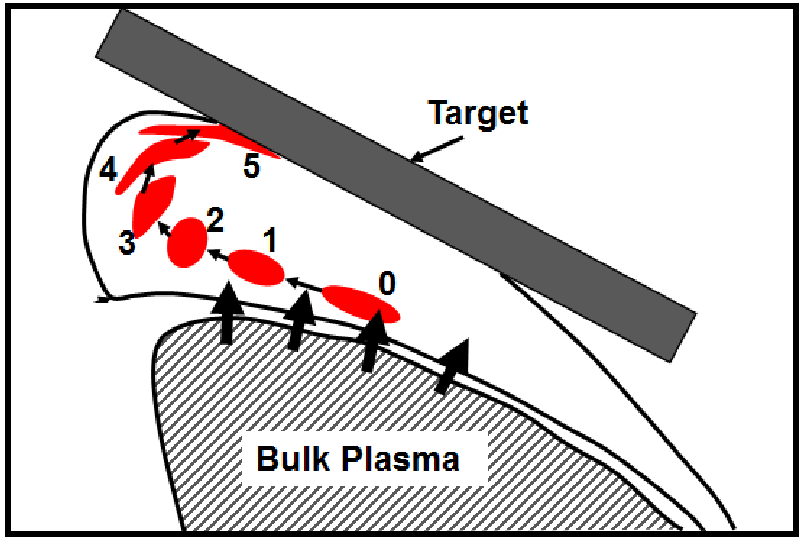

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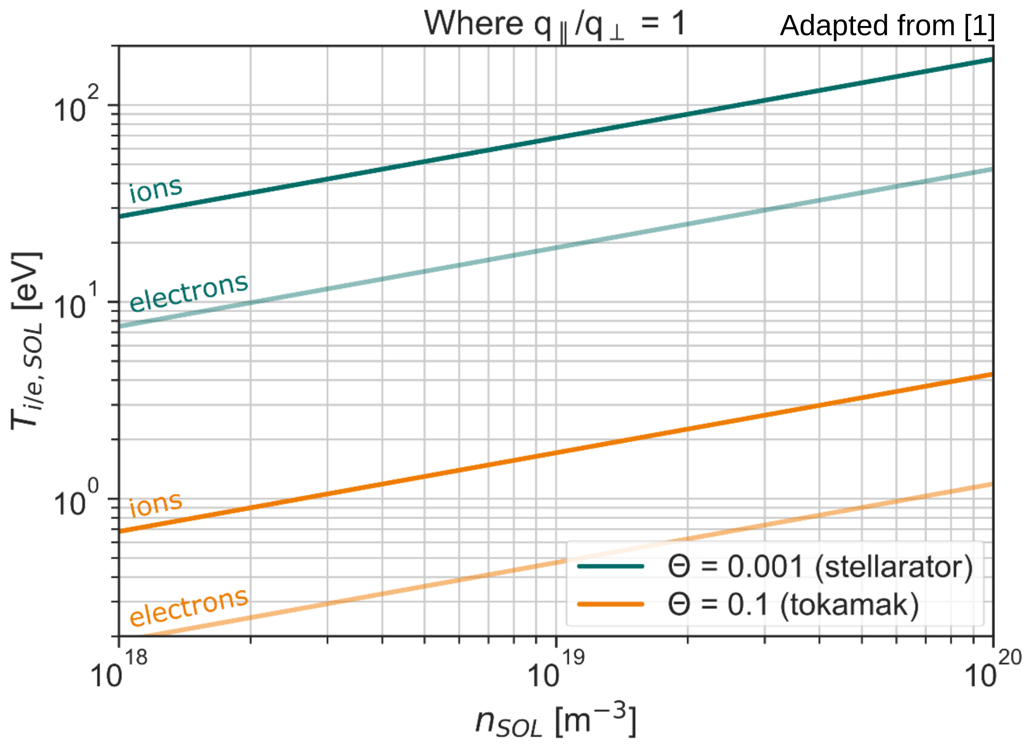

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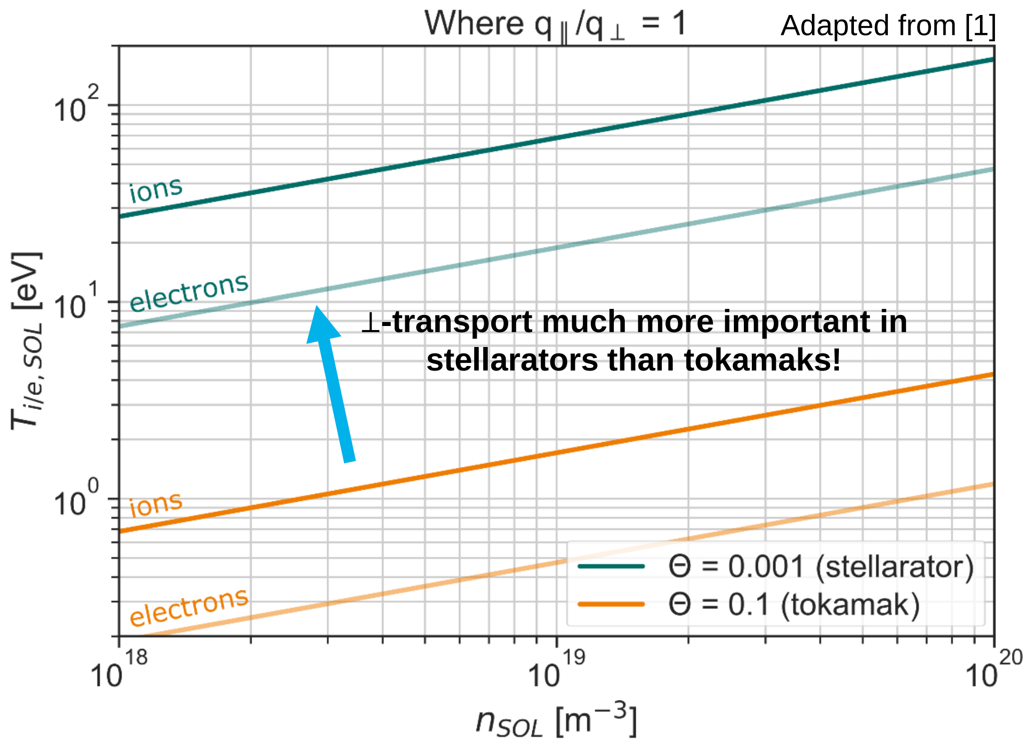

⊥-transport much more important in stellarators than tokamaks!

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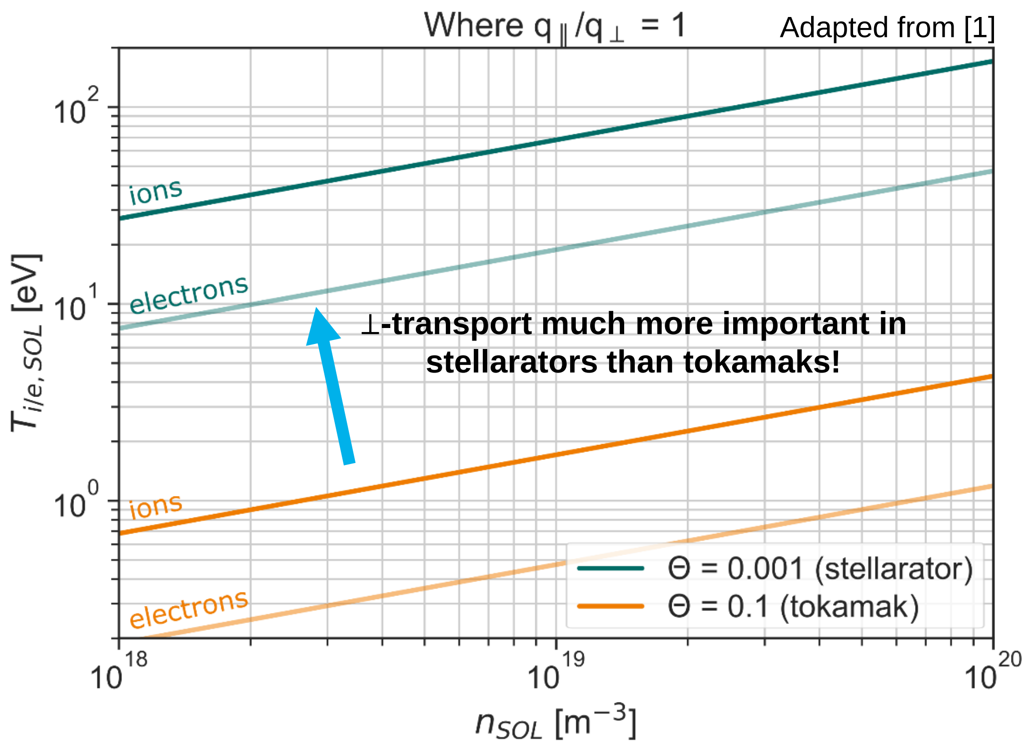
How do we test this sensitivity experimentally in W7-X?



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Experimental flexibility in W7-X → Modification of field line pitch

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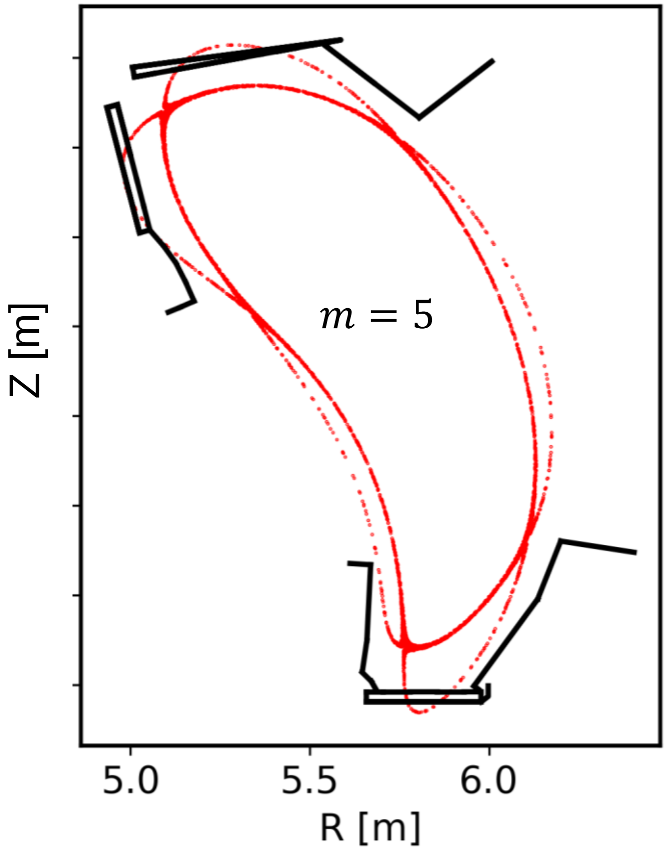
Method 1: Modify shear and/or poloidal number of islands



„Standard“

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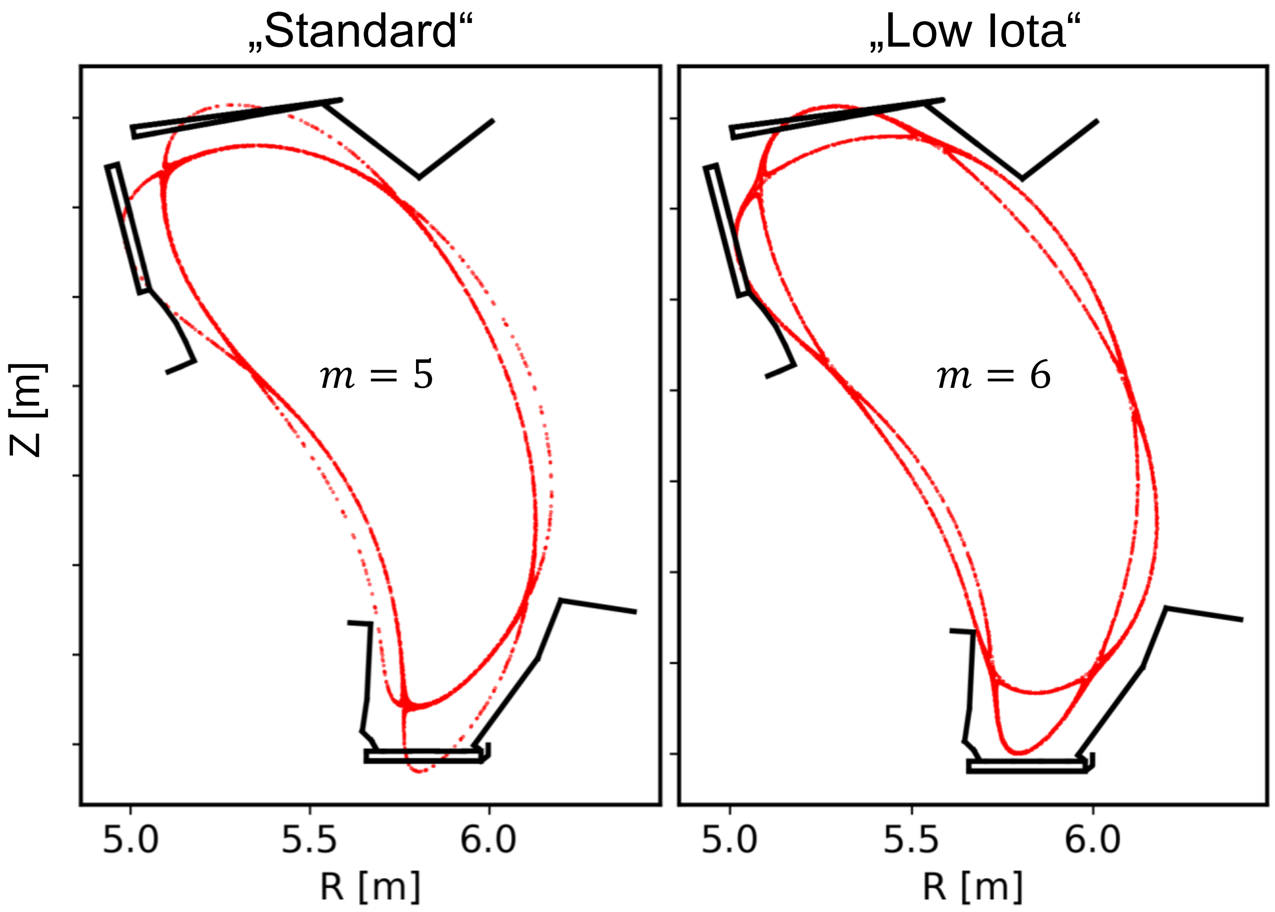

Experimental flexibility in W7-X → Modification of field line pitch

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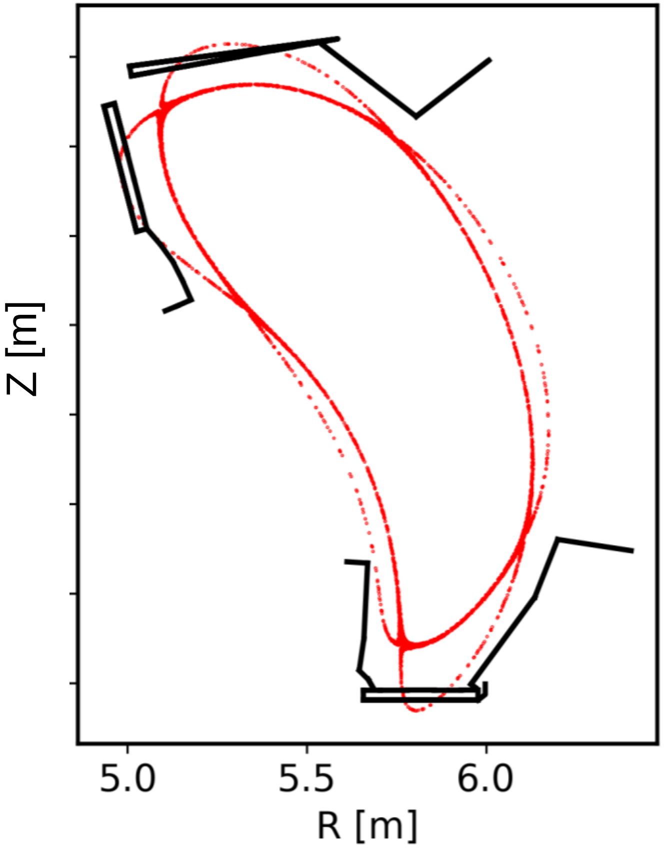
Method 2: Radial resonant field component

„Standard“



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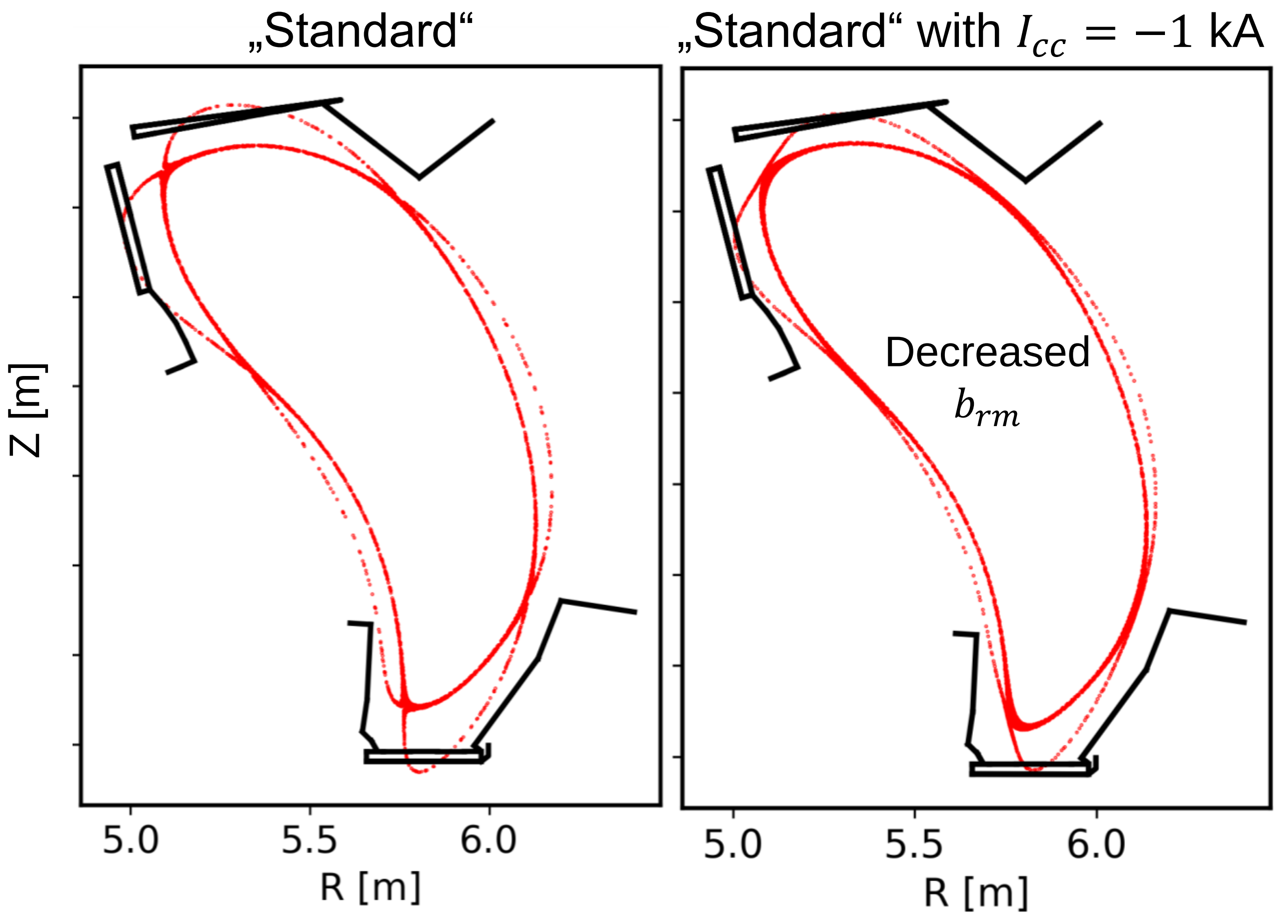

Experimental flexibility in W7-X → Modification of field line pitch

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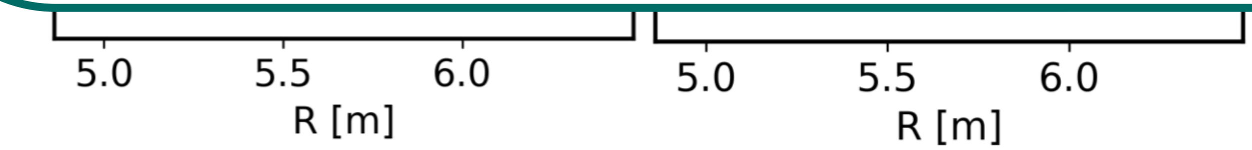
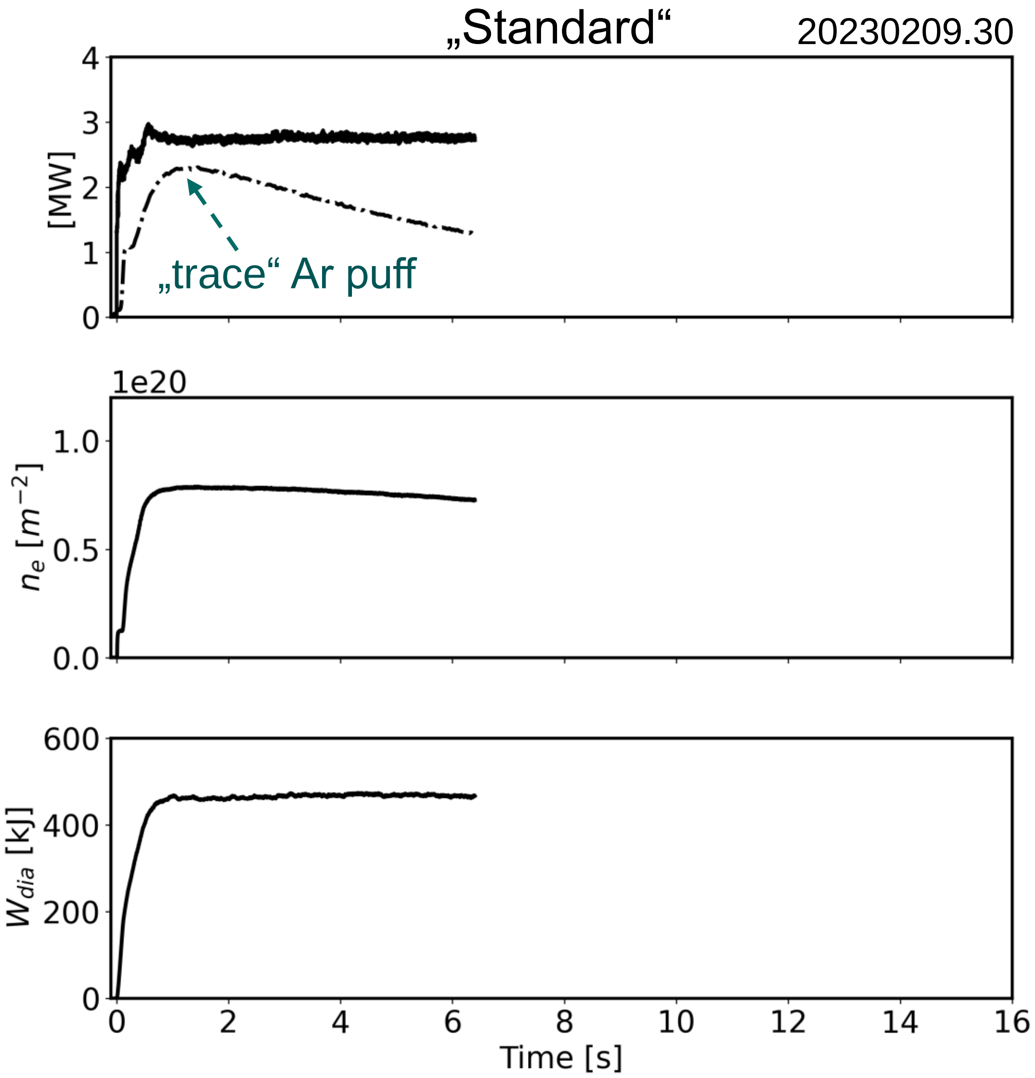
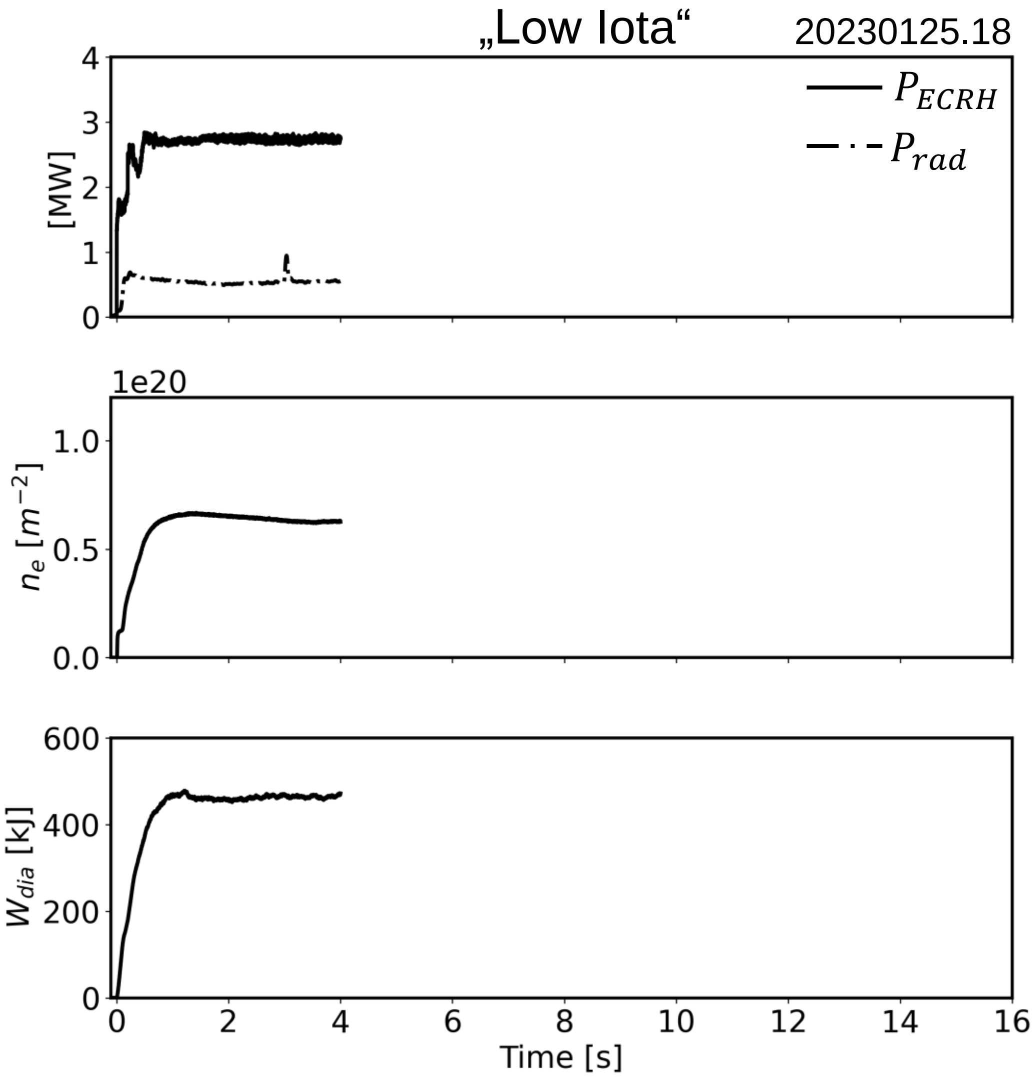
Both methods here are believed to *increase* the weight of ⊥-transport.

Do we see any effects experimentally?



Experimentally, we see fundamentally different radiation behavior between standard and low iota configurations


„Standard“ 20230209.30


„Low Iota“ 20230125.18

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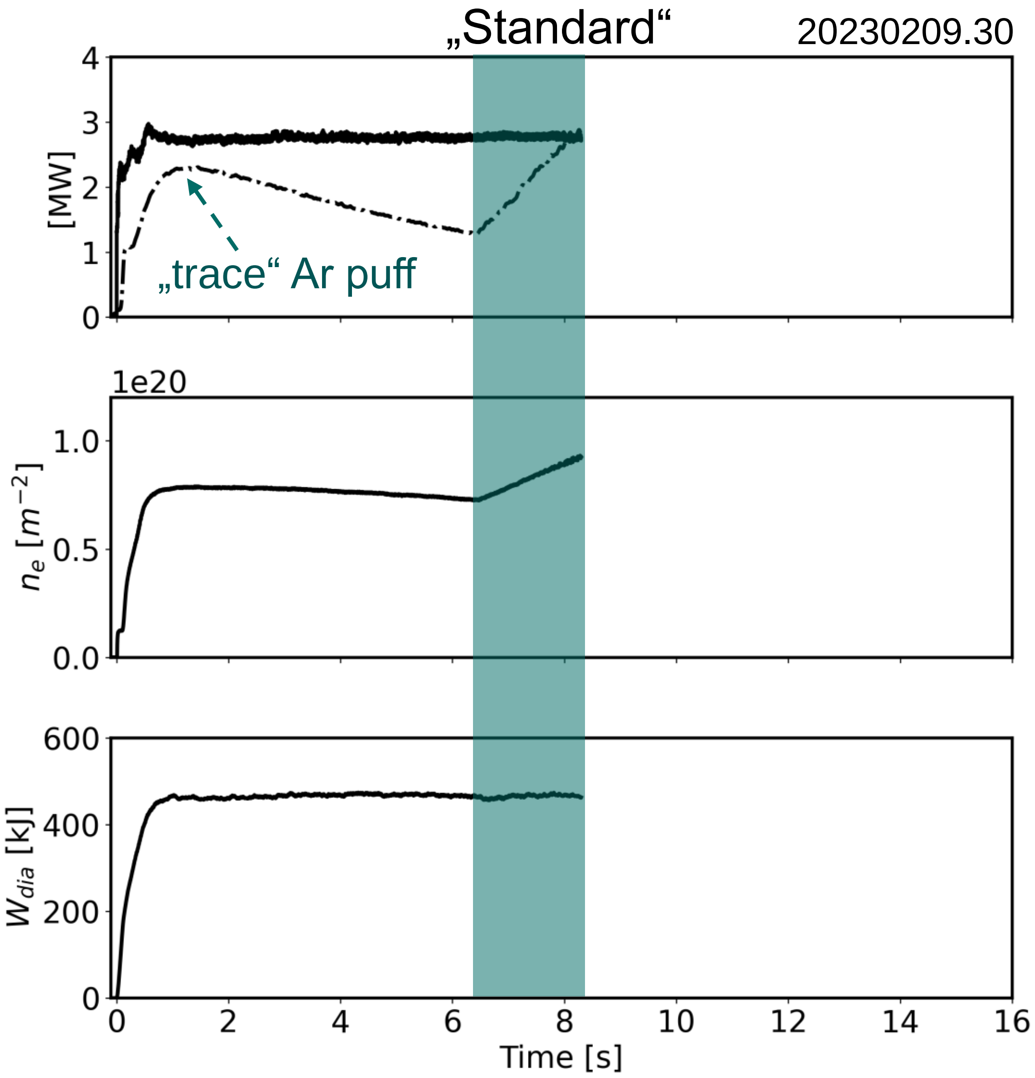

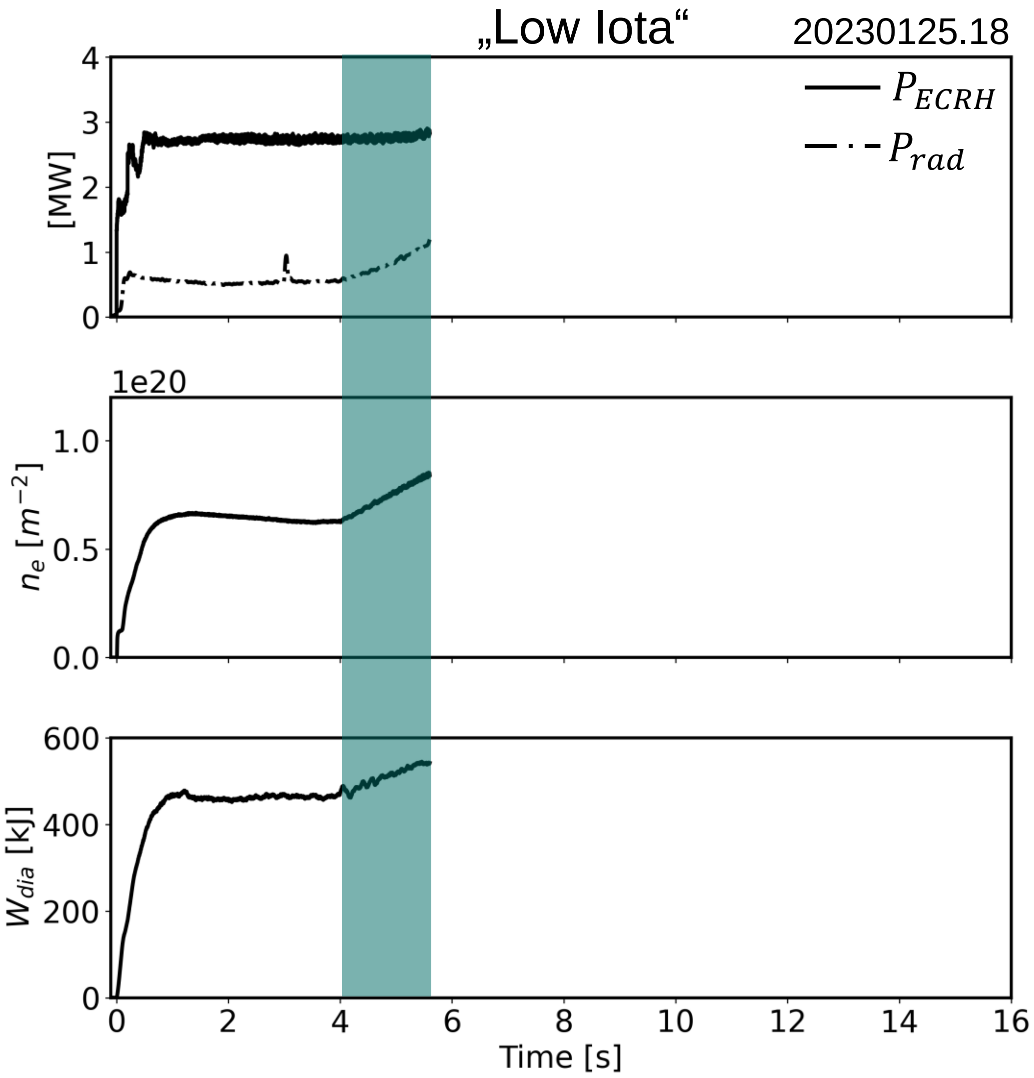

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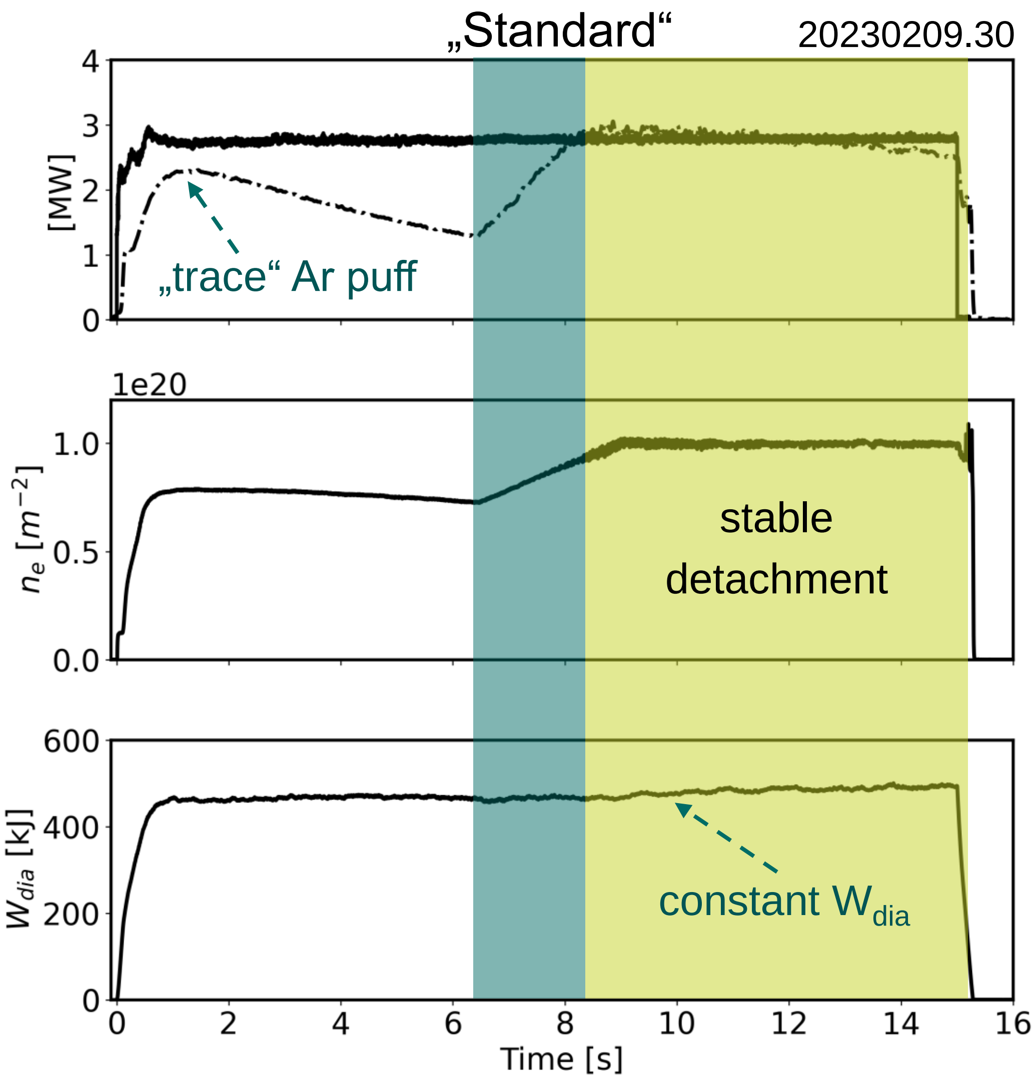
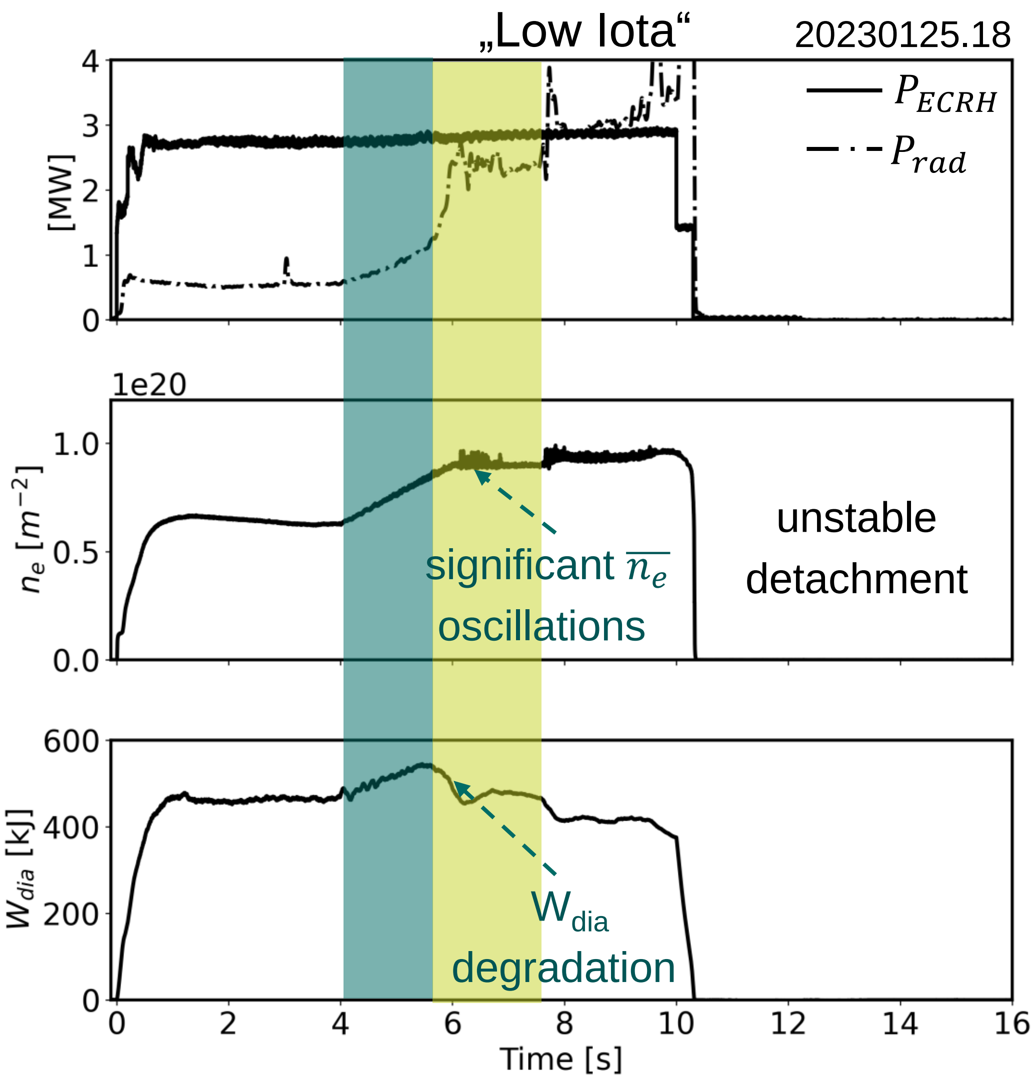


„trace“ Ar puff

stable detachment

constant W_{dia}



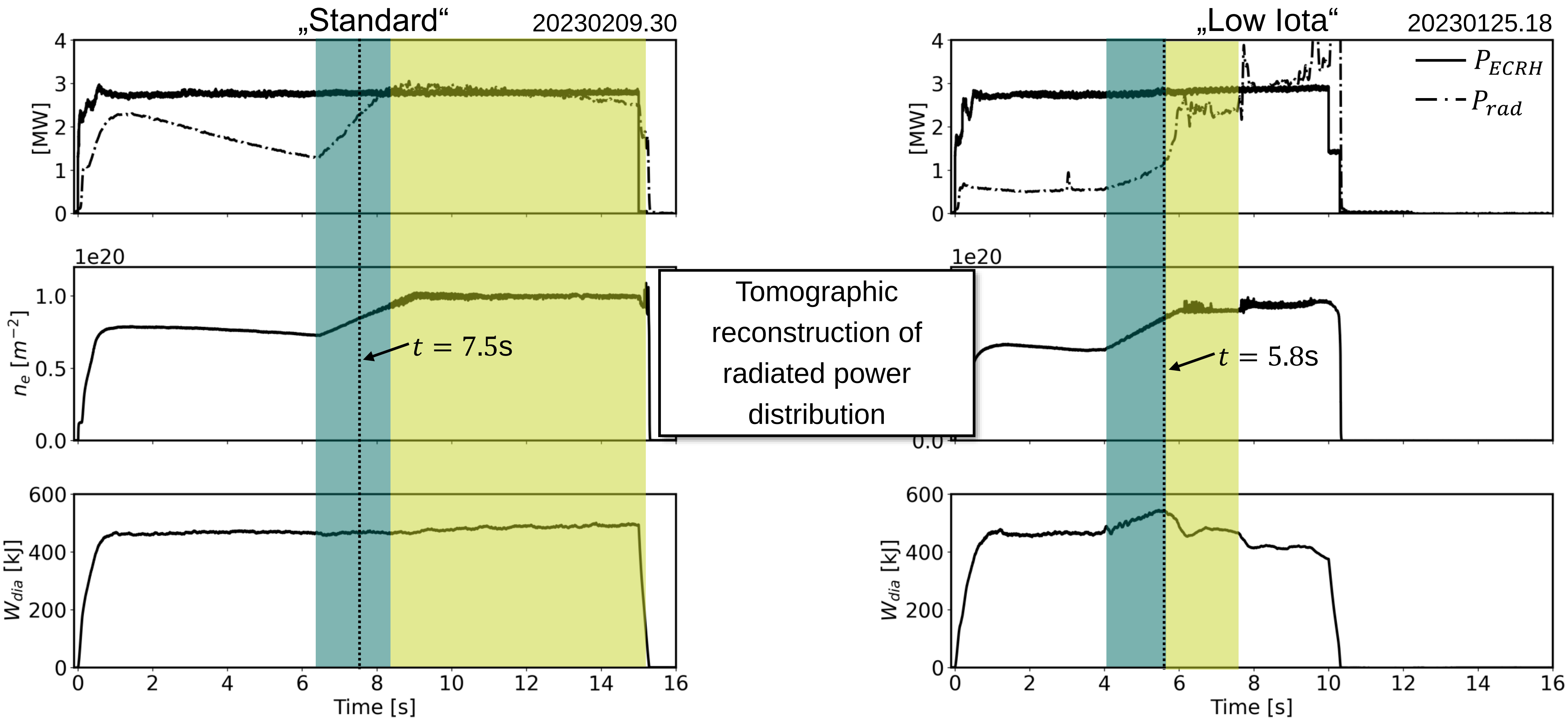
significant $\overline{n_e}$ oscillations

unstable detachment

W_{dia} degradation

Experimentally, we see fundamentally different radiation behavior between standard and low iota configurations

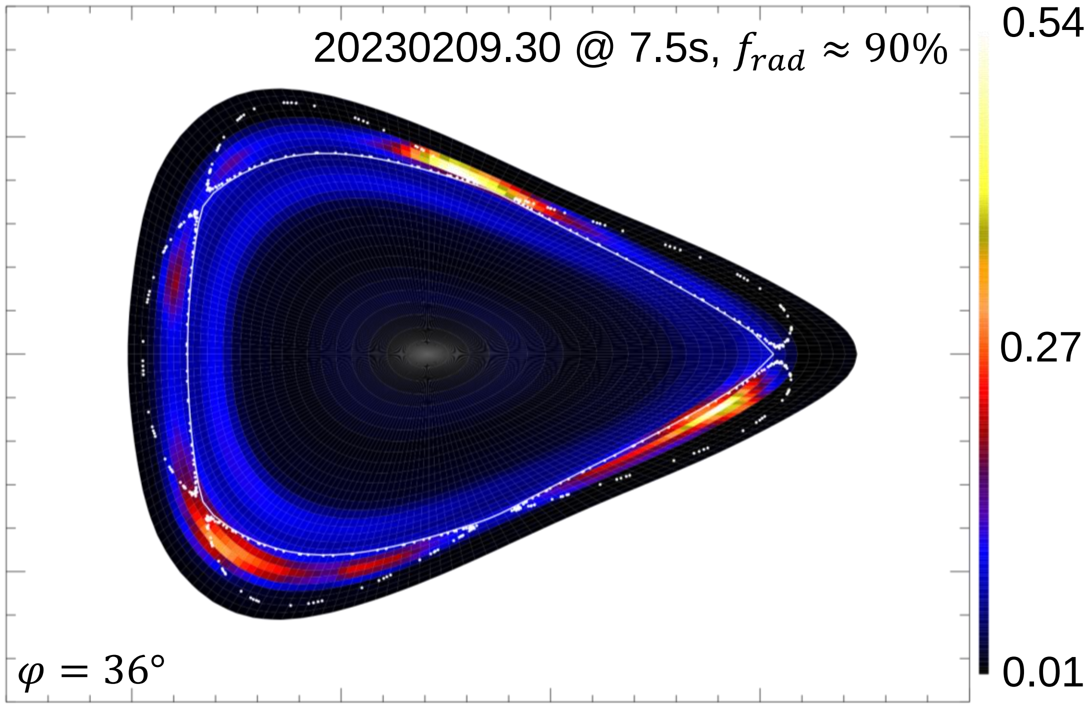
Further studies power exhaust →
F. Reimold (Invited, Friday)



Tomographic reconstruction of radiated power distribution

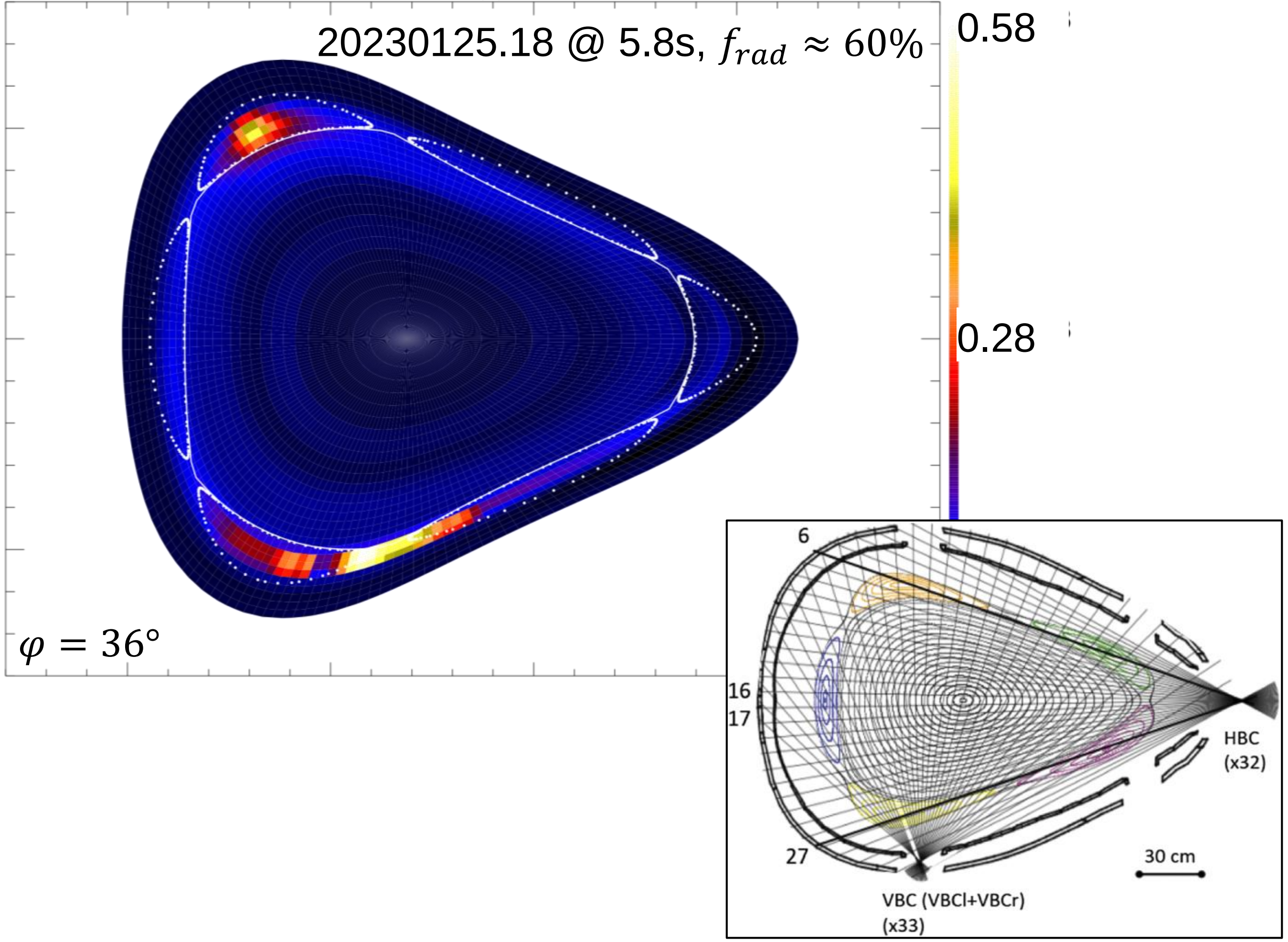
Tomographic reconstructions show differing radiated power distributions between standard and low iota

„Standard“ P_{rad} Distribution



Zhang et al, *Nucl. Fusion* **61** (2021)

„Low Iota“ P_{rad} Distribution



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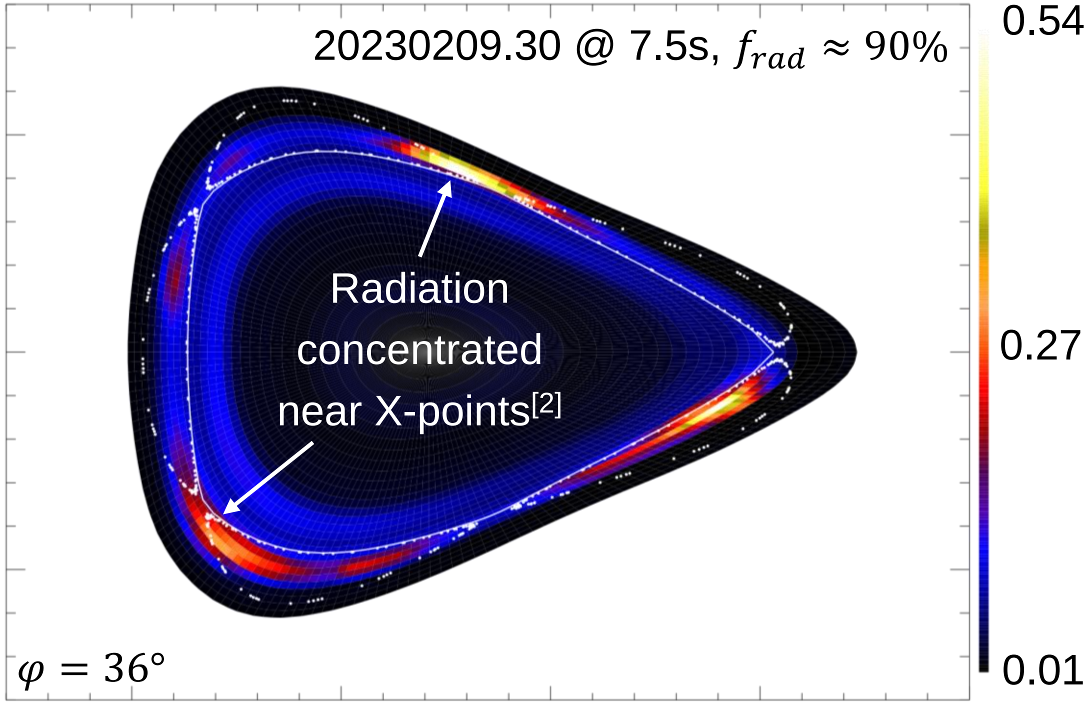
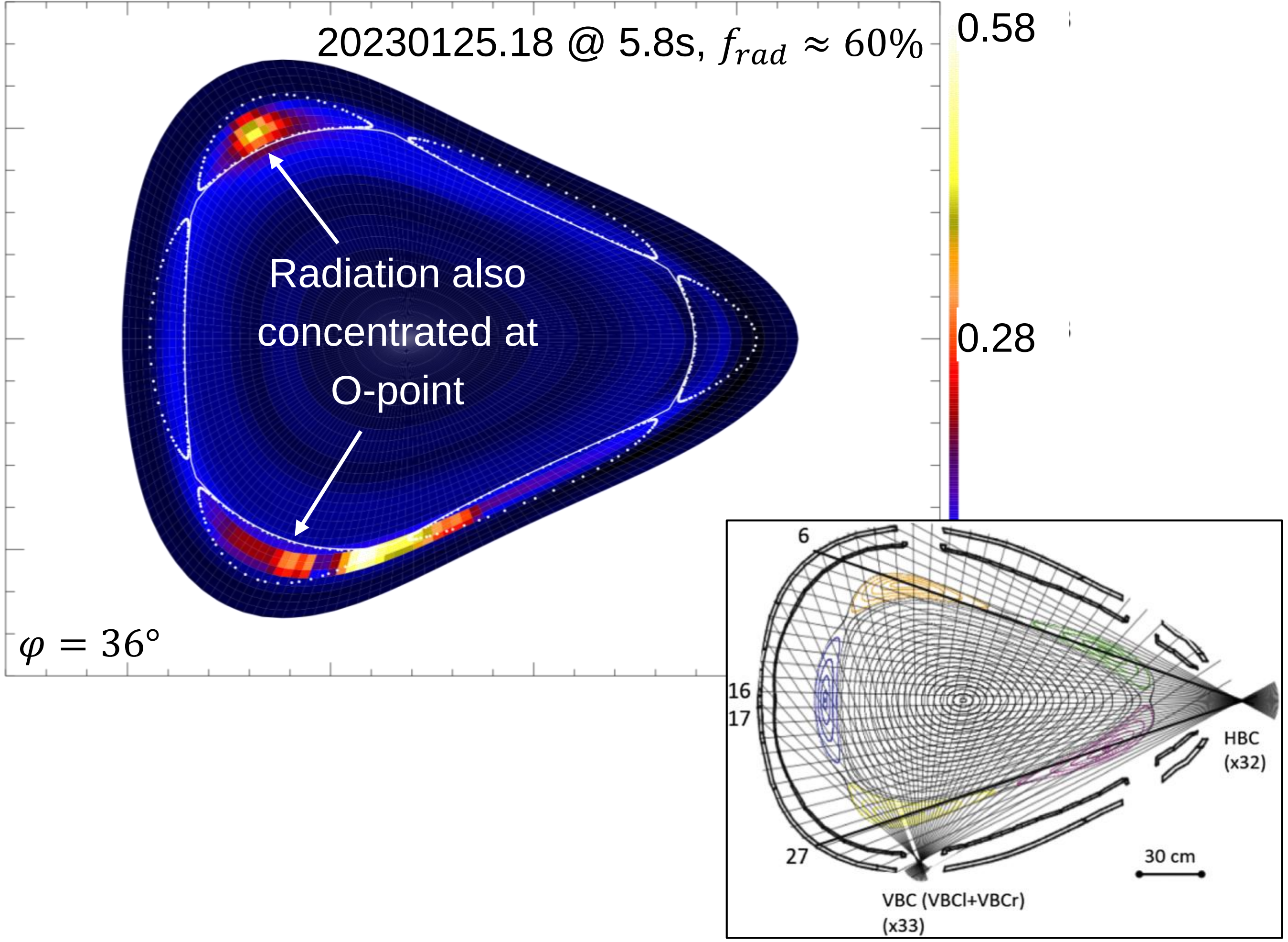


20230209.30 @ 7.5s, $f_{rad} \approx 90\%$

Radiation concentrated near X-points[2]

Zhang et al, *Nucl. Fusion* **61** (2021)

„Low Iota“ P_{rad} Distribution



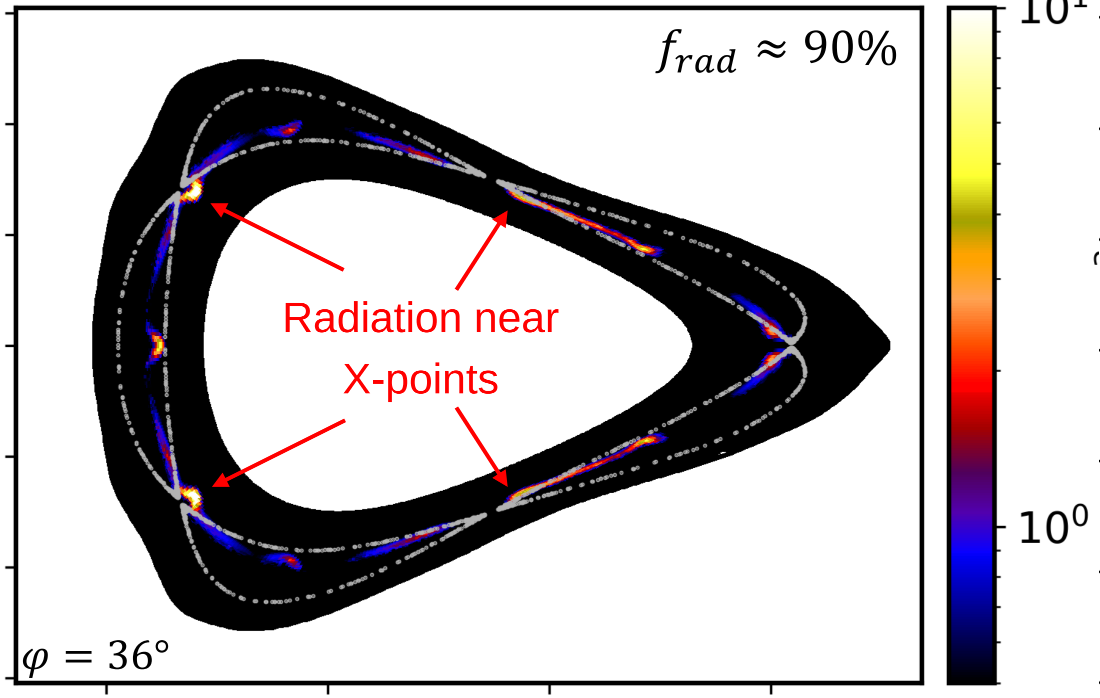
20230125.18 @ 5.8s, $f_{rad} \approx 60\%$

Radiation also concentrated at O-point

[2] Y. Feng et al, *Nucl. Fusion* **61** (2021)

EMC3-Eirene modeling of standard and low iota configurations show qualitatively similar trends in radiation patterns

„Standard" P_{rad} Distribution (EMC3-Eirene)



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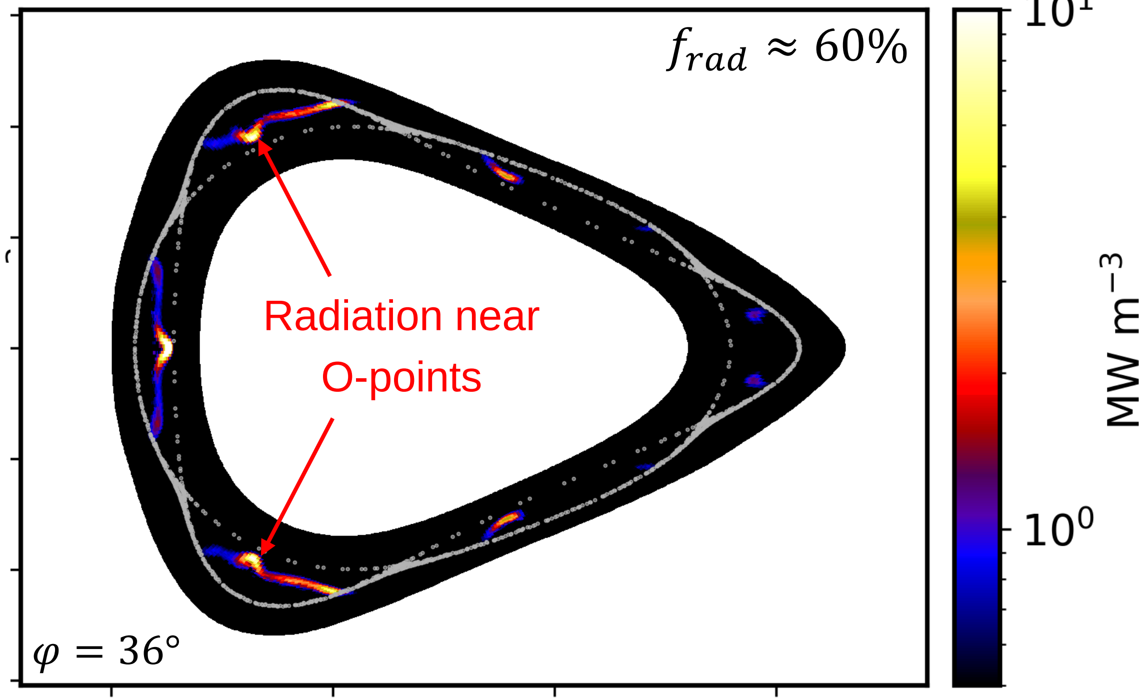
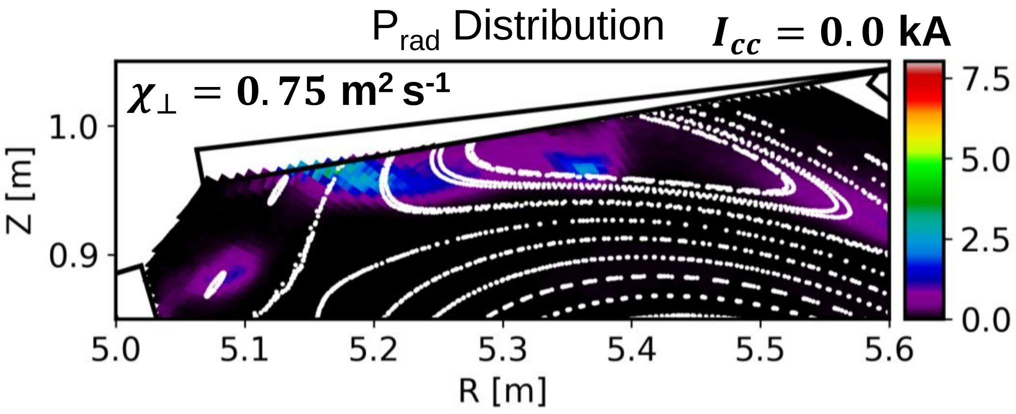


- Generally, Radiation in low iota configuration more concentrated on inboard side islands as compared to standard (both experiment and modeling)

[V. R. Winters et al, *Nucl. Fusion* (submitted)]

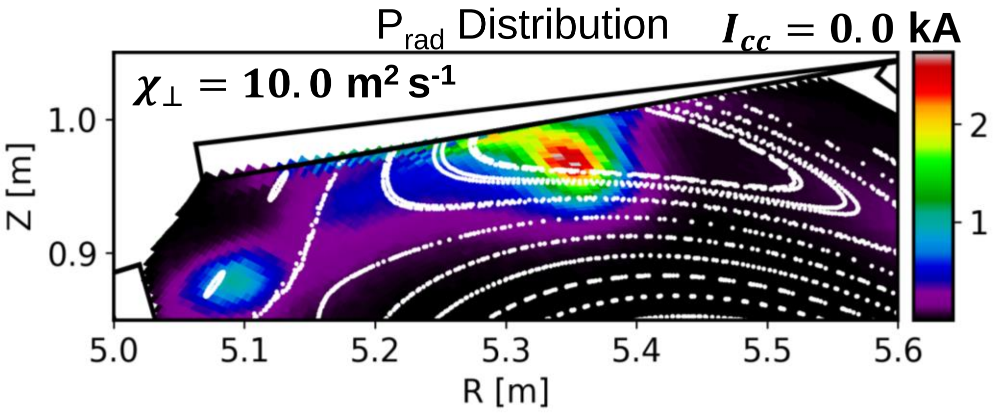
EMC3-Eirene modeling reveals that different radiation pattern indeed arises from island geometry effects

- We use the „standard“ configuration to understand why O-point radiation increases in „low iota“
- „low iota“ has a smaller Θ than „standard“ (increased weight $\perp$-transport)
- In simulation, 2 ways of increasing weight of $\perp$-transport:
    1. Increase $\chi_\perp$ in the simulation
    2. Decrease internal island field line pitch: $\Theta = 2a\sqrt{\frac{\iota' b_{rm}}{Rm}}$


P$_{rad}$ Distribution $\boldsymbol{I_{cc} = 0.0}$ **kA**

$\chi_\perp = \mathbf{0.75}$ **m^2 s^{-1}**

Increasing $\chi_\perp$


P$_{rad}$ Distribution $\boldsymbol{I_{cc} = 0.0}$ **kA**

$\chi_\perp = \mathbf{10.0}$ **m^2 s^{-1}**

[V. R. Winters et al, *Nucl. Fusion* (submitted)]

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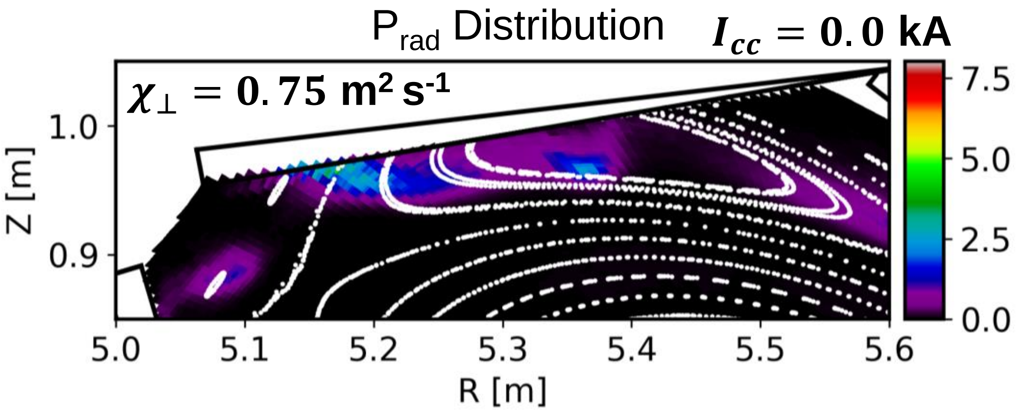
P_{rad} Distribution $\boldsymbol{I_{cc} = 0.0}$ **kA**

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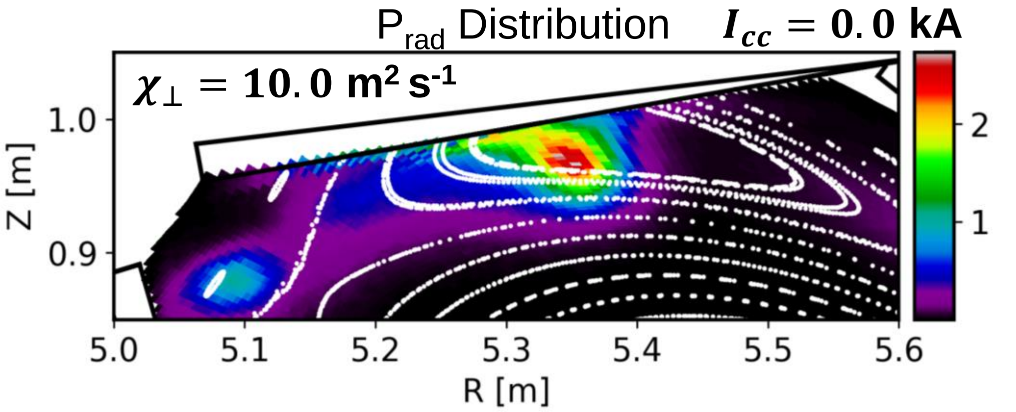
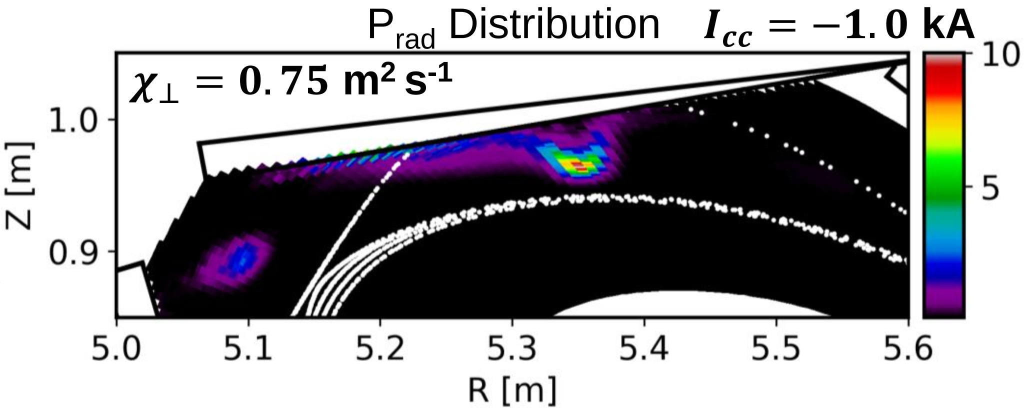

P_{rad} Distribution $\boldsymbol{I_{cc} = 0.0}$ **kA**

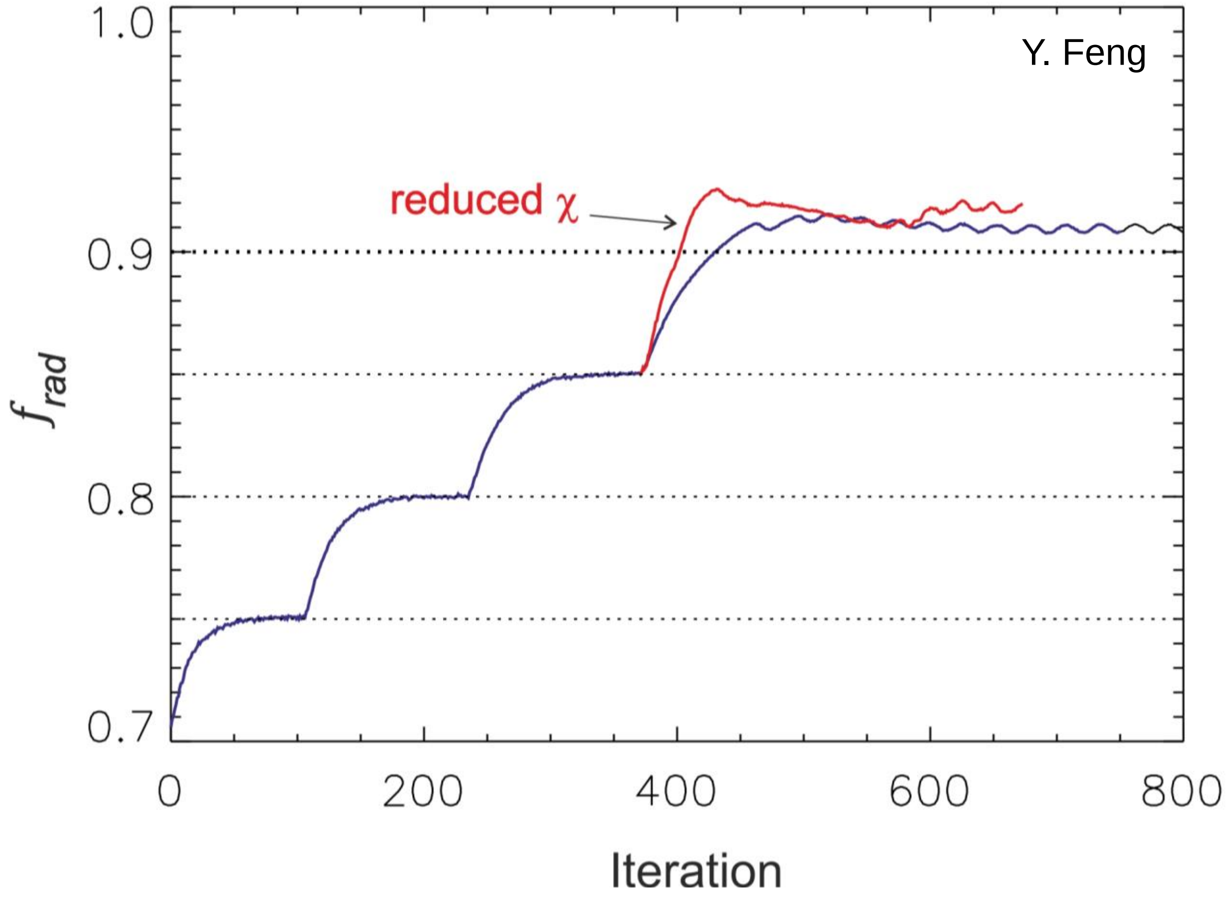
Decreasing b_{rm}


P_{rad} Distribution $\boldsymbol{I_{cc} = -1.0}$ **kA**

[V. R. Winters et al, *Nucl. Fusion* (submitted)]

Using a simplified impurity model in EMC3-Eirene indicates radiation bifurcation in the low iota configuration

- No self-consistent solution in EMC3-Eirene exists in „low iota“ at f_{rad}=90%, using impurity transport
- Solutions do exist, however, if one replaces impurity transport with a constant impurity concentration



[Y. Feng et al, *Nucl. Fusion* **64** (2024) 086027]

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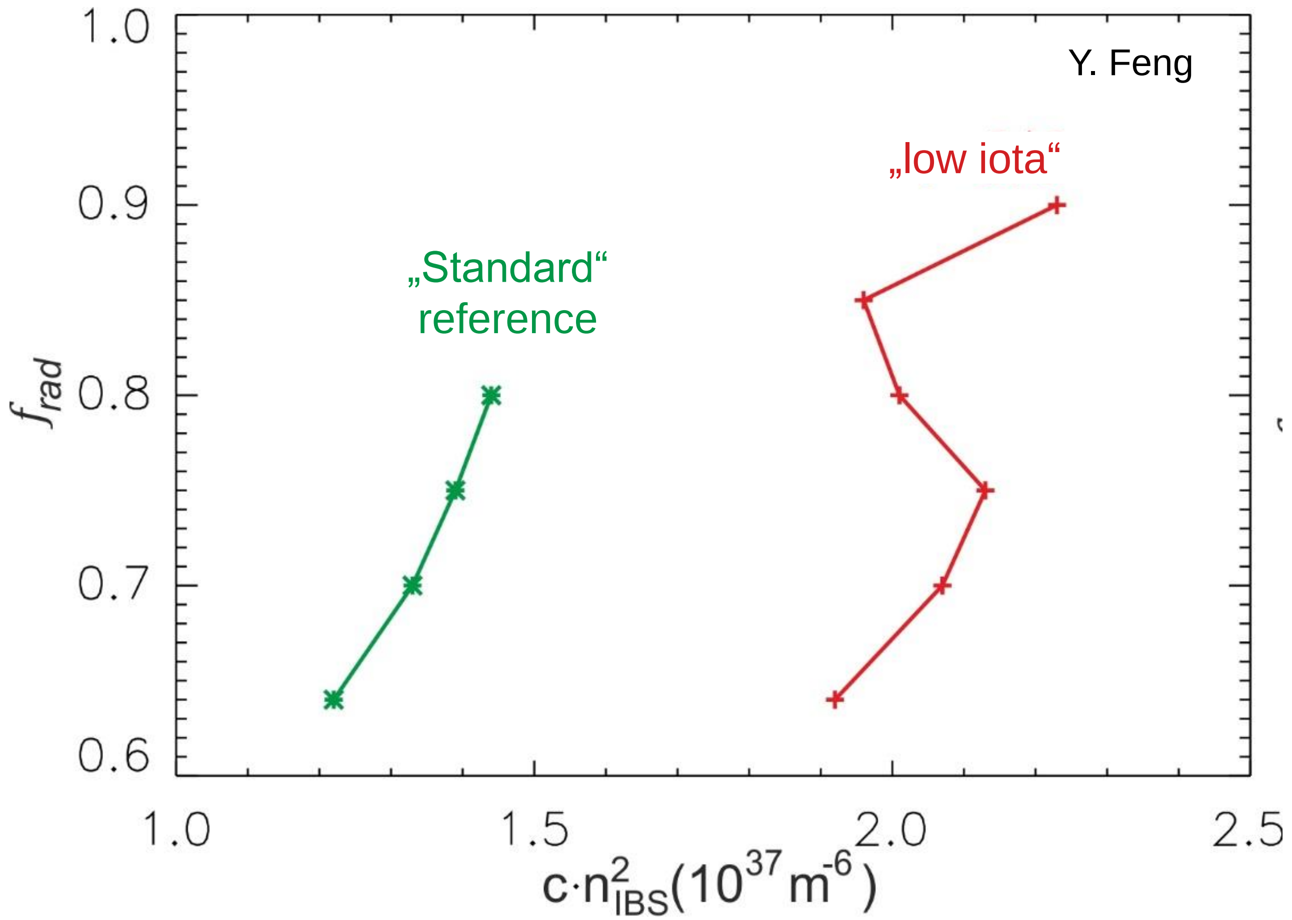

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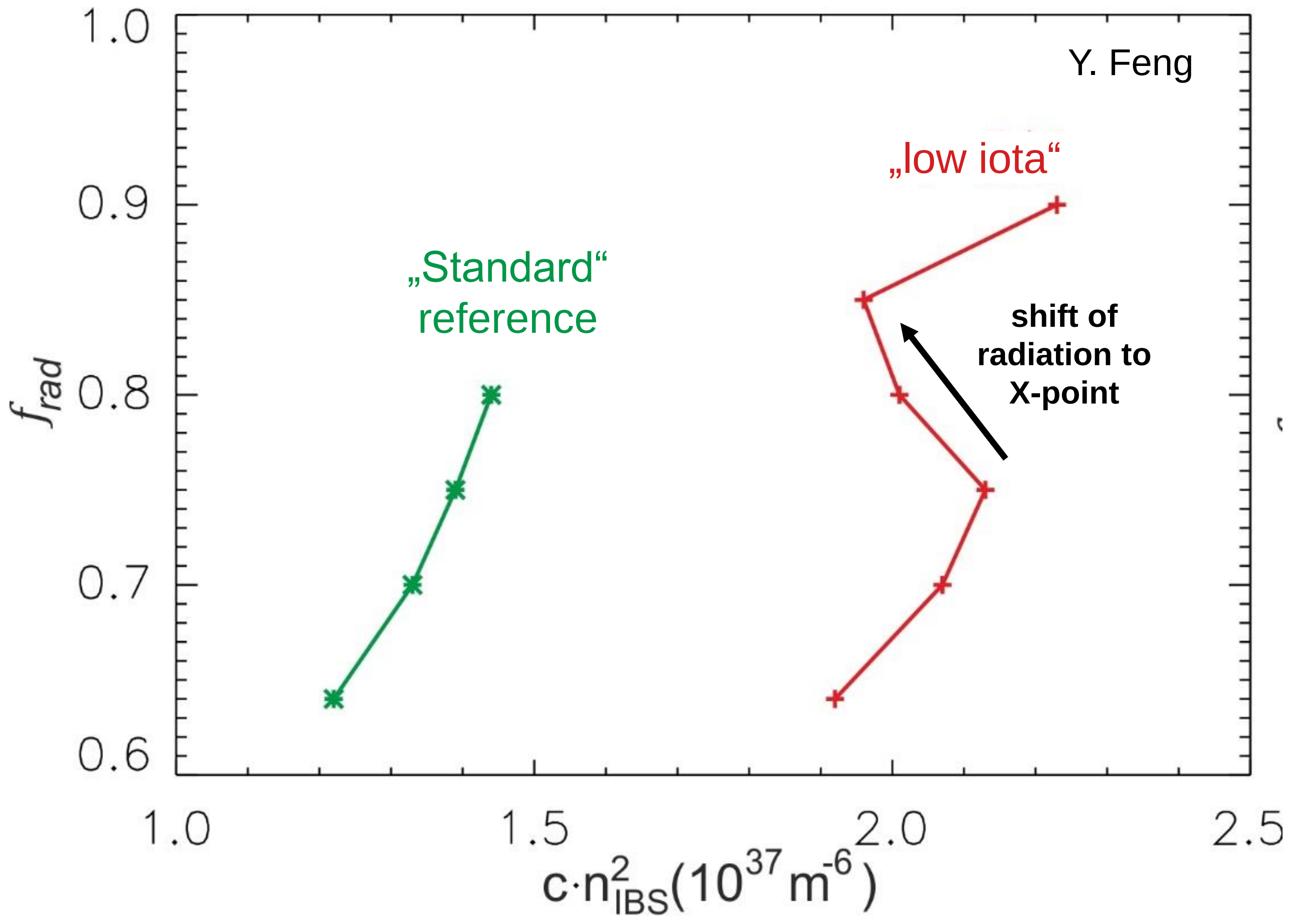
  - Results from shift of radiation location to X-point as it crosses the LCFS



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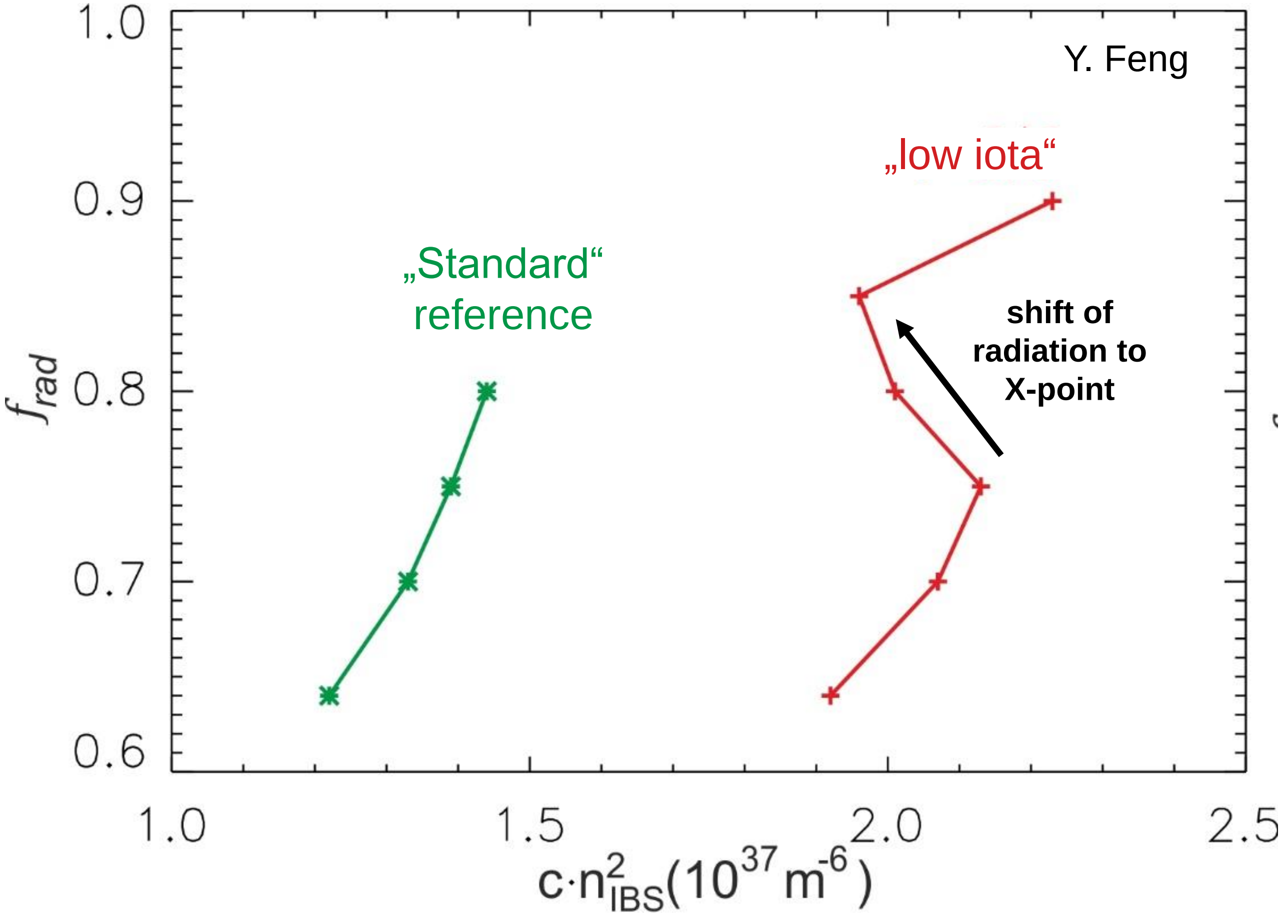
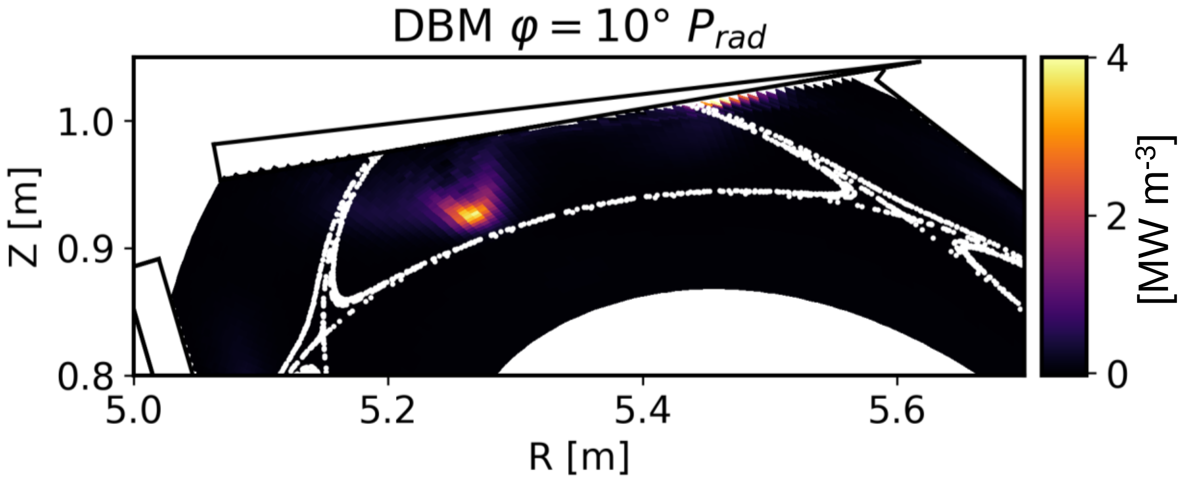
Possible cause of the radiation instability seen in experiment (verification pending)



[Y. Feng et al, *Nucl. Fusion* **64** (2024) 086027]

Is it possible to make detachment in low iota more stable?

- One possible avenue is to increase the field line pitch (increase weight of ∥-transport)



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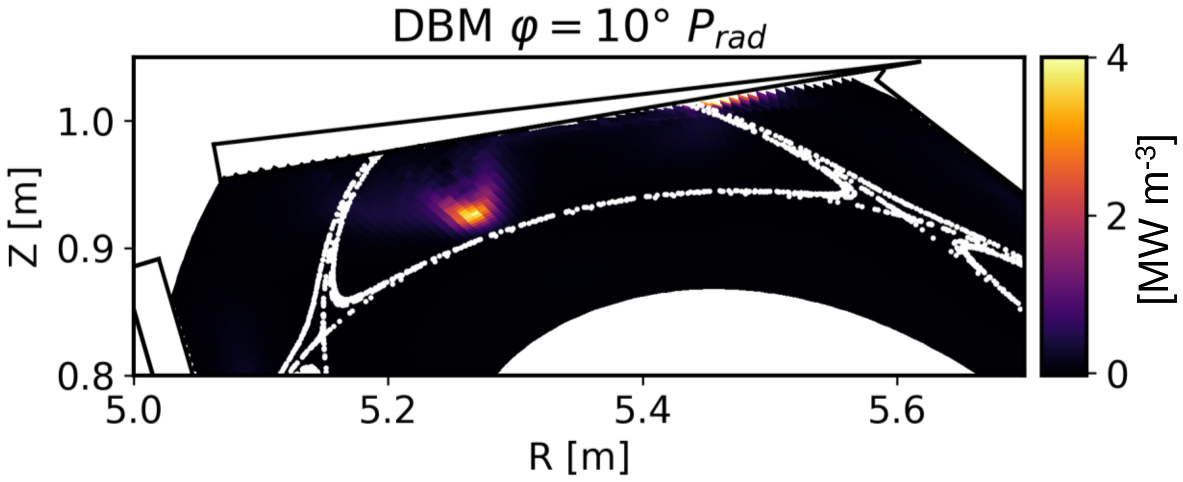

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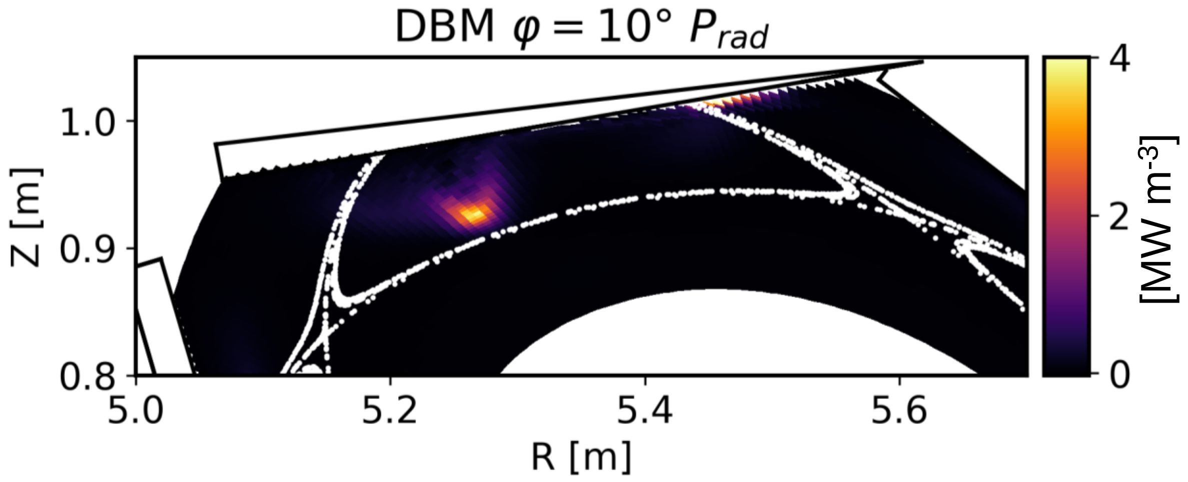

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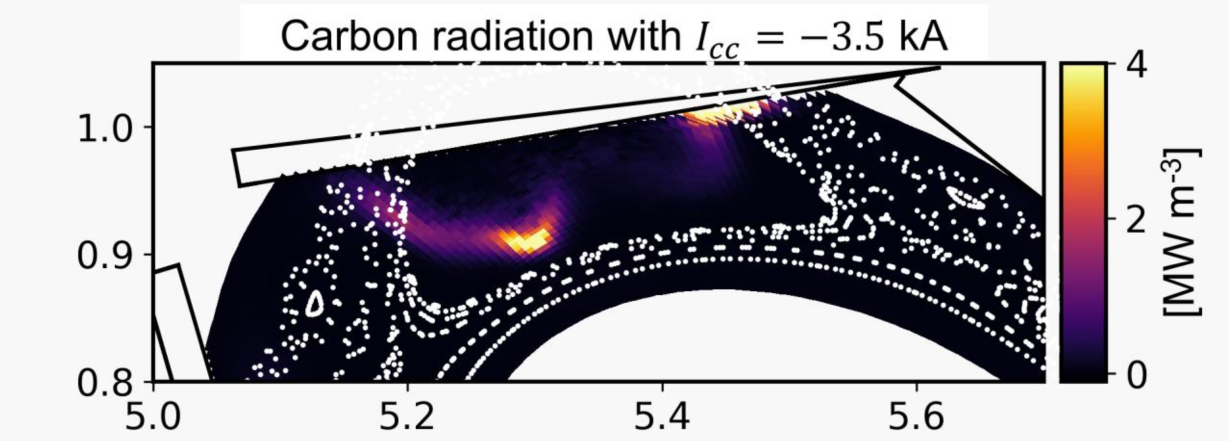

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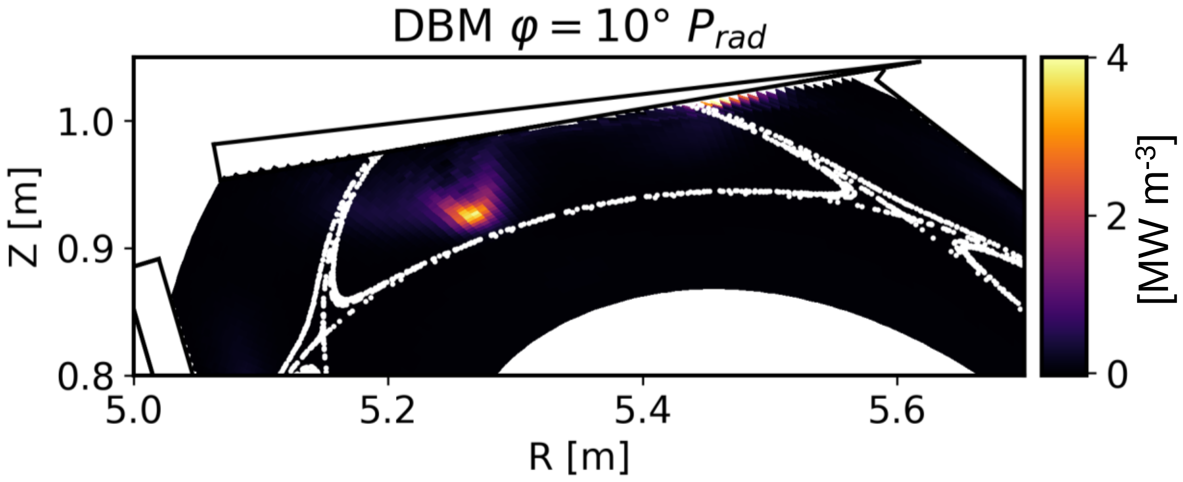

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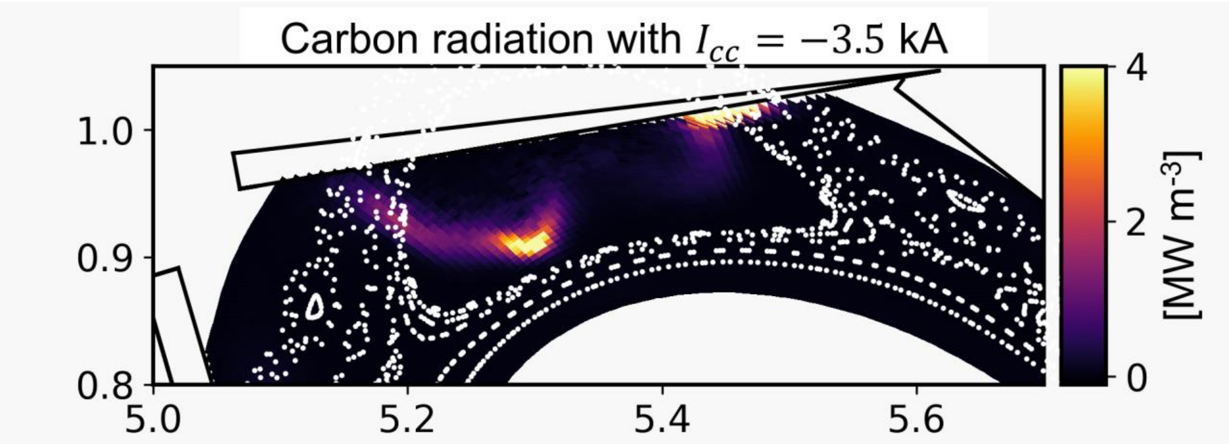

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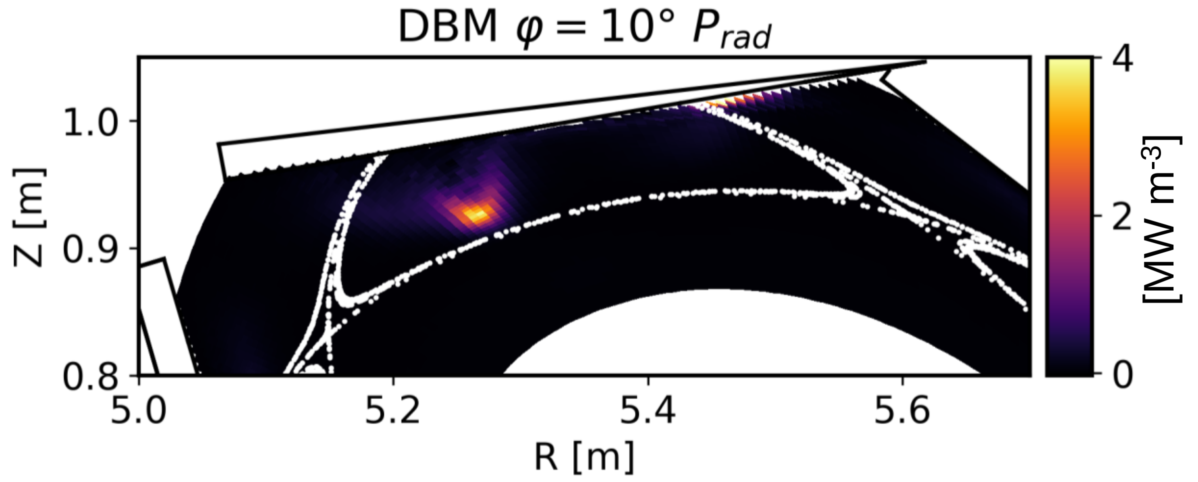
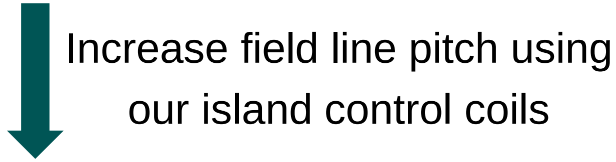
experiments planned for next campaign! (Sept. 2024)





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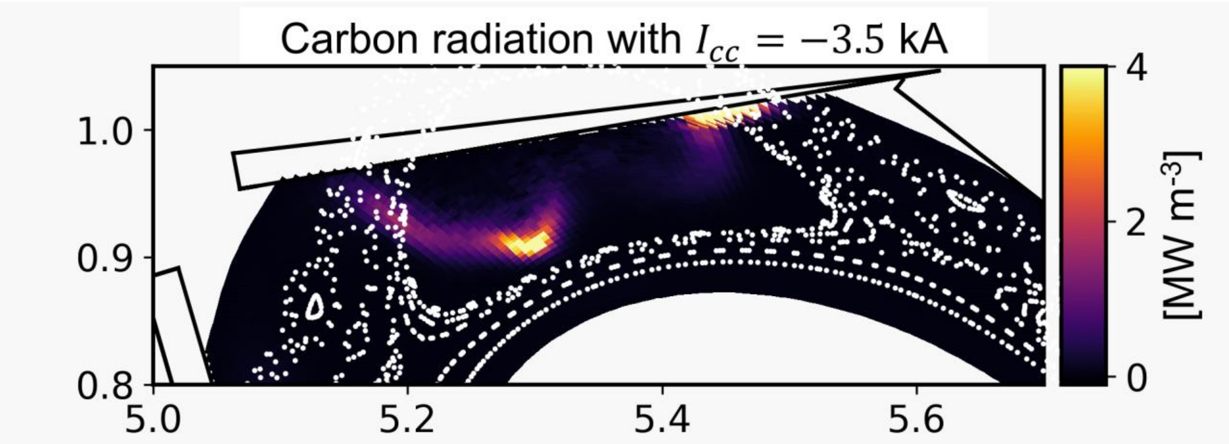

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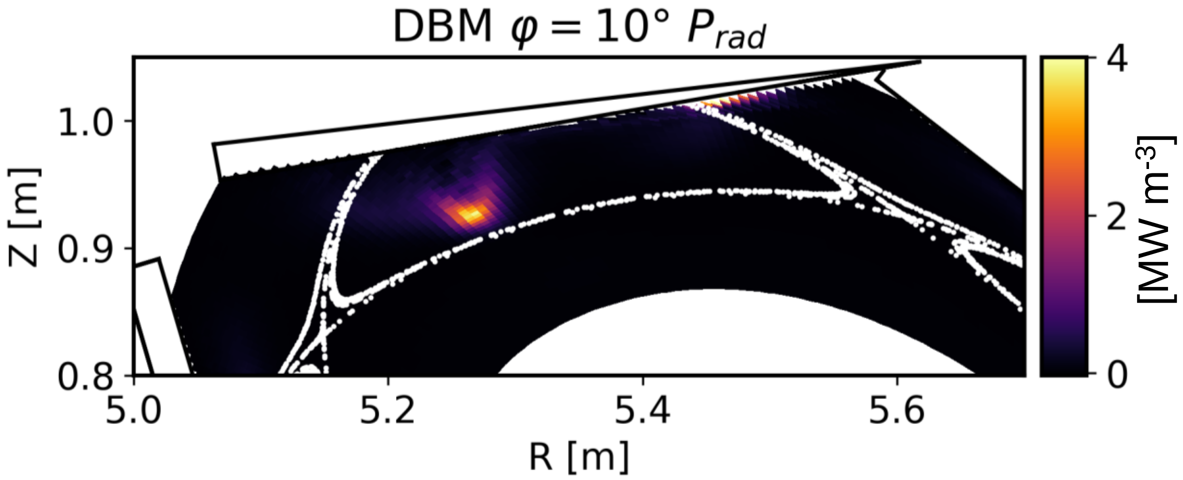

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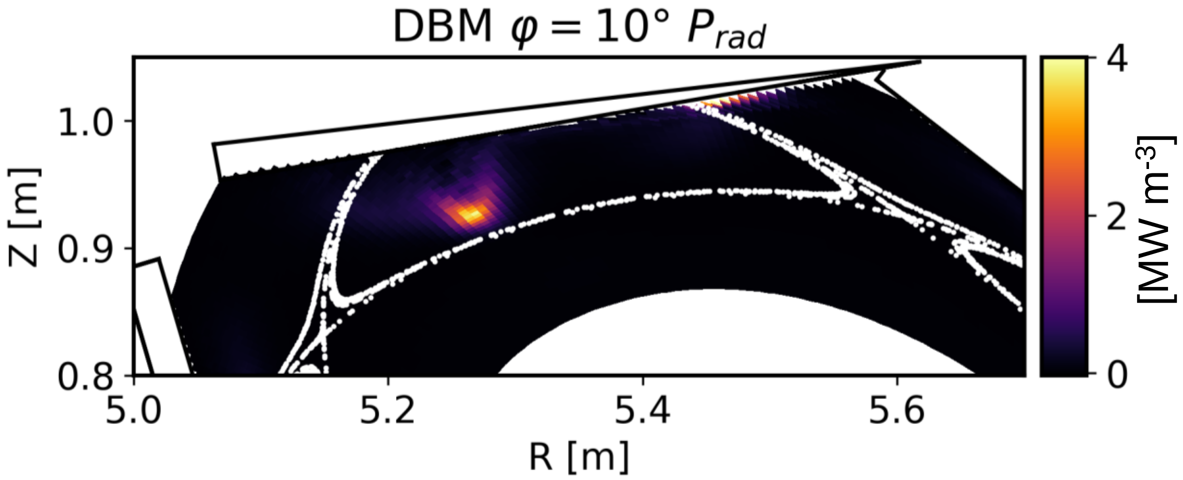

change of main radiator to Neon

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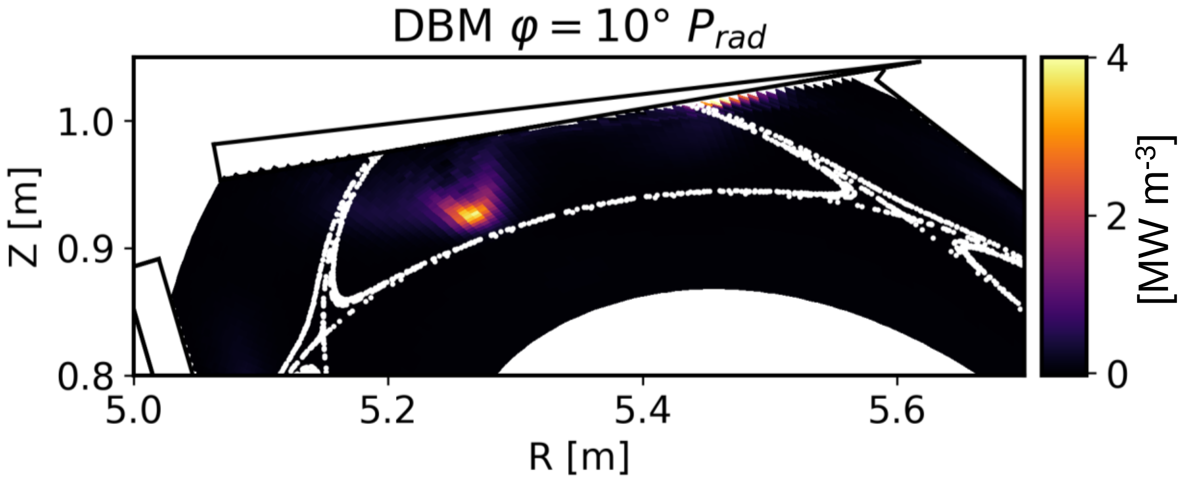

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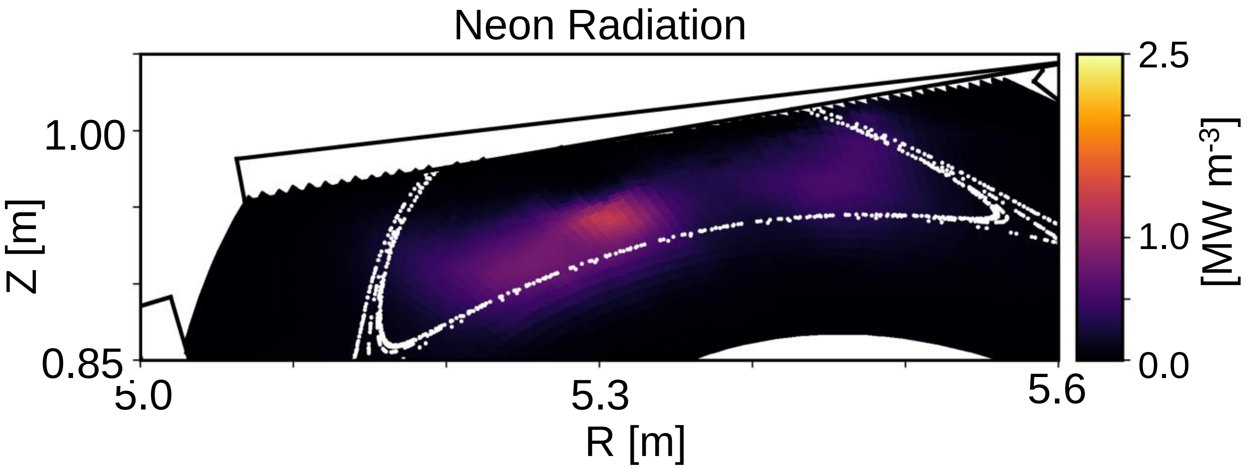

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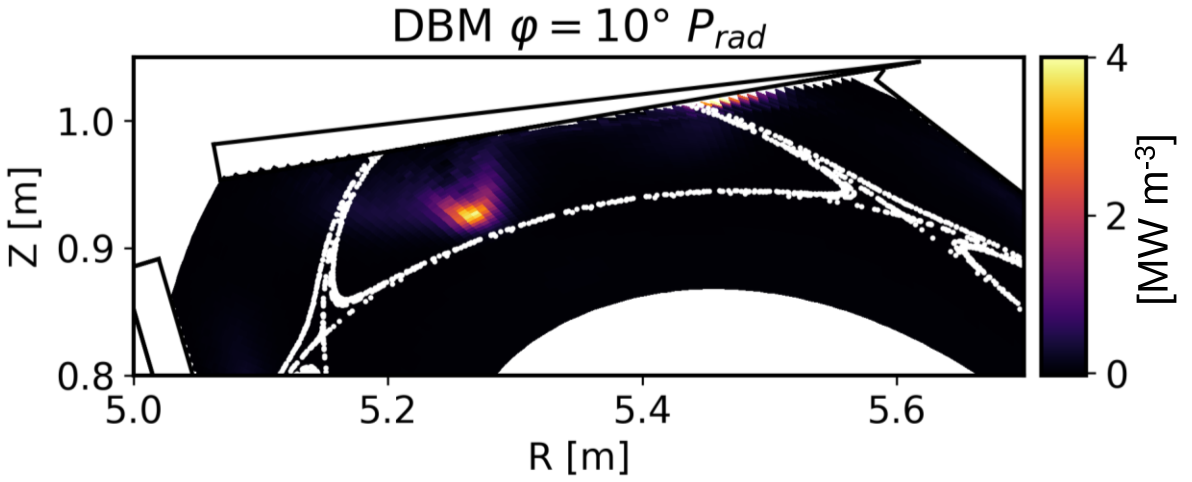

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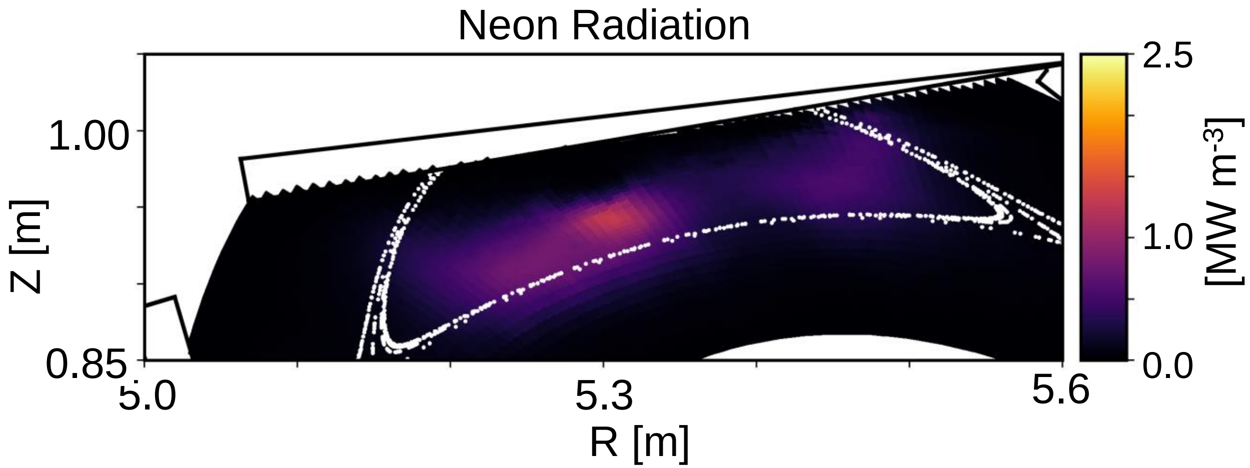

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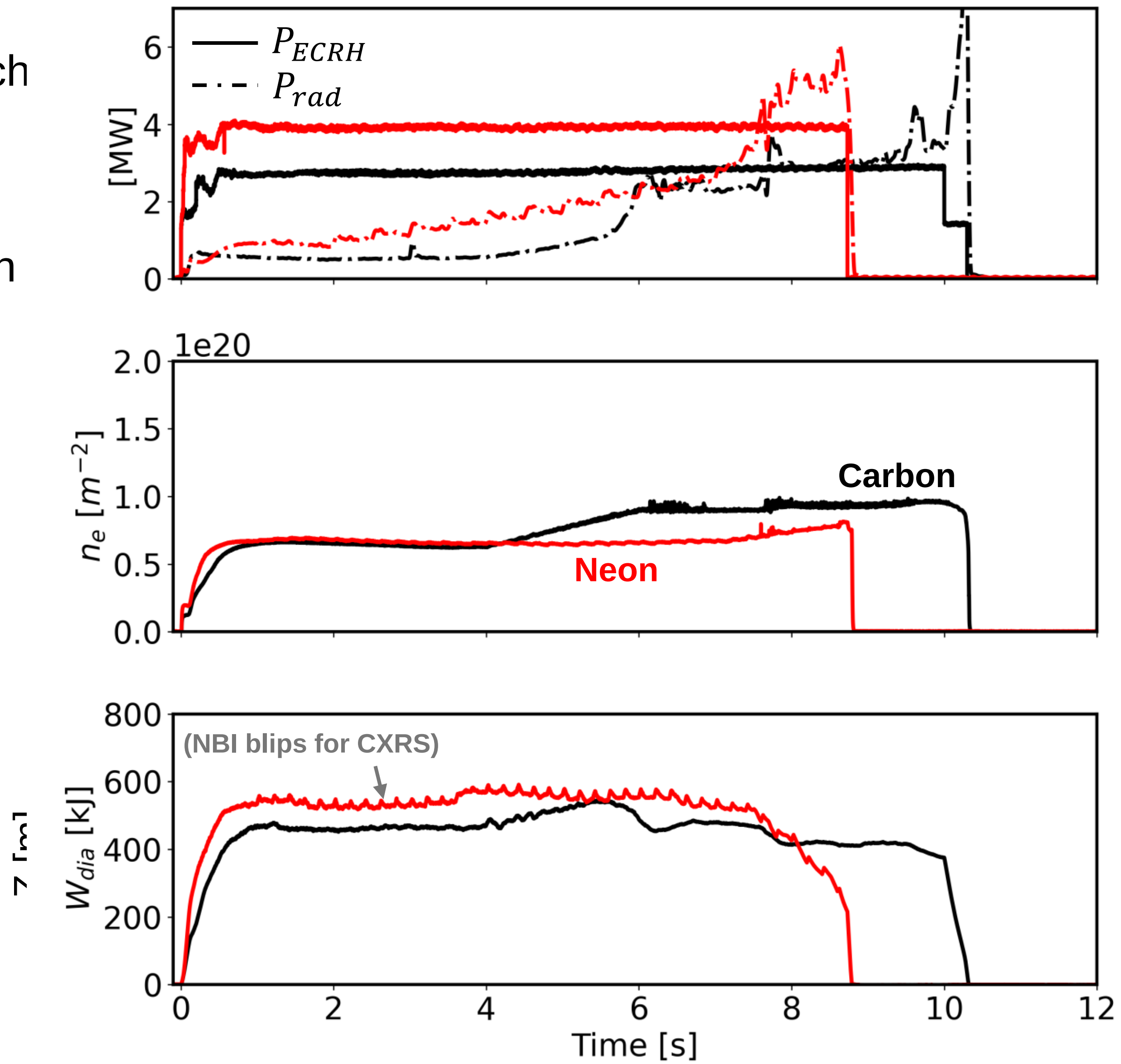

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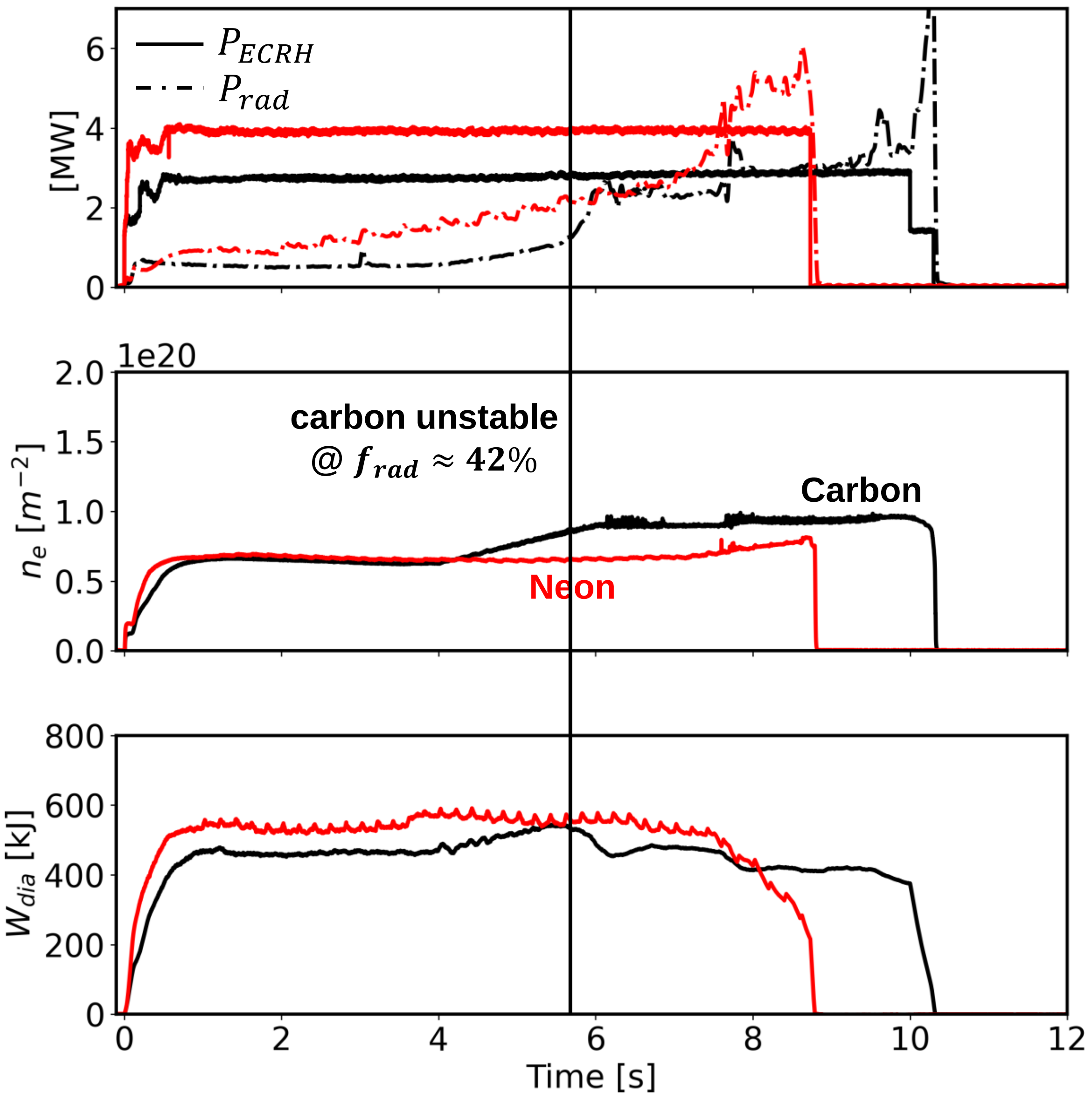

carbon unstable @ $f_{rad} \approx 42\%$

Carbon

Neon

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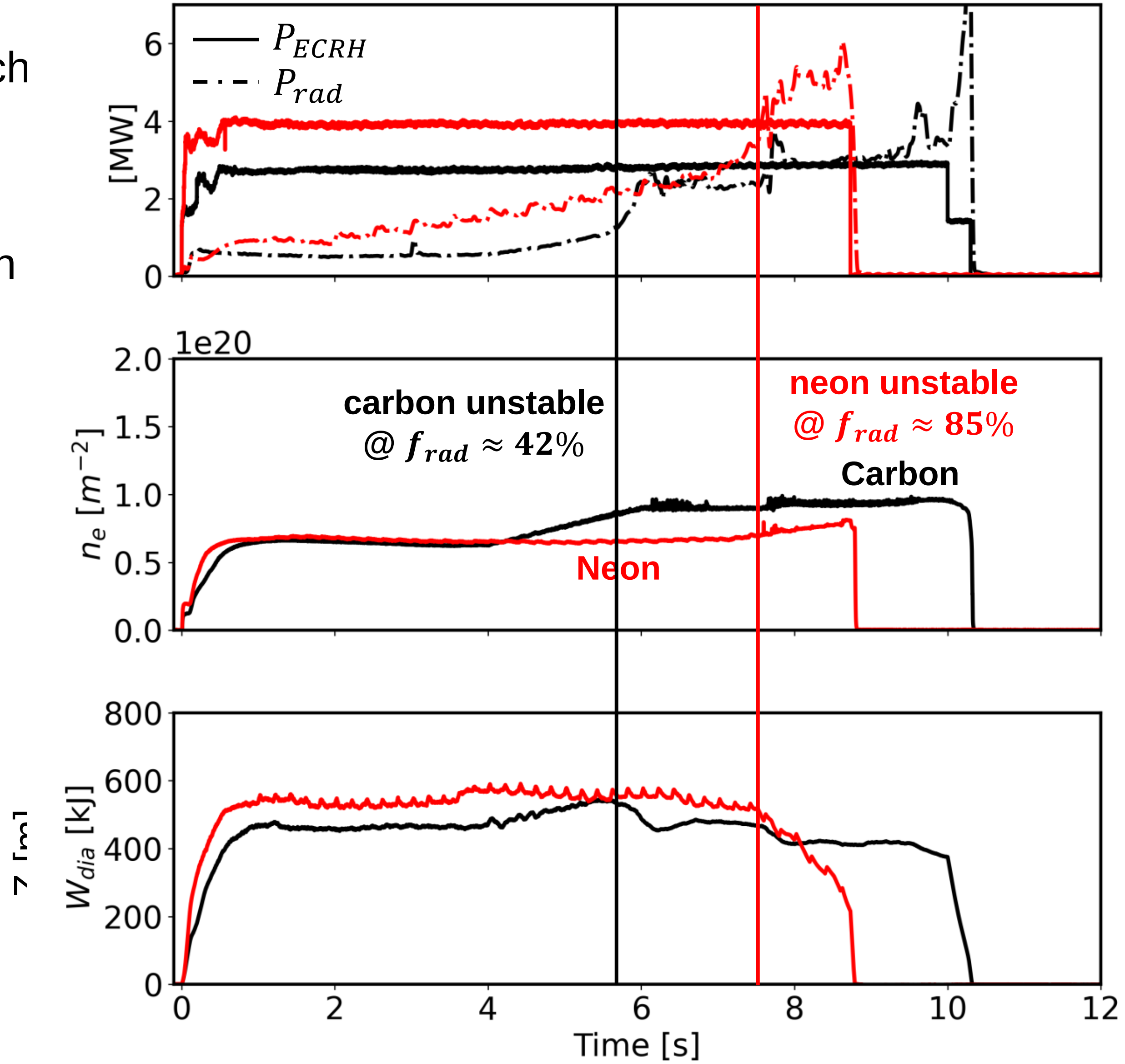


Summary

1. Experimentally, we see that the „low iota“ configuration exhibits unstable detachment, which does not occur in the „standard“ configuration.
2. Tomographic reconstructions of the radiated power distribution show O-point radiation present in „low iota“
3. EMC3-Eirene simulations show similar trends of the radiation pattern as in experiment:
4. EMC3-Eirene results confirm that it is the increased weight of ⊥-transport which results in the radiation pattern shift
5. This this shift in the radiation pattern seems to be associated with radiation bifurcation in simulations

Further experiments planned for OP2.2/2.3 starting this September!

- Destabilization of detachment using island control coils in standard configuration
- Stabilization of detachment using island control coils/neon radiation in low iota configuration

Summary

Thank you for your attention!

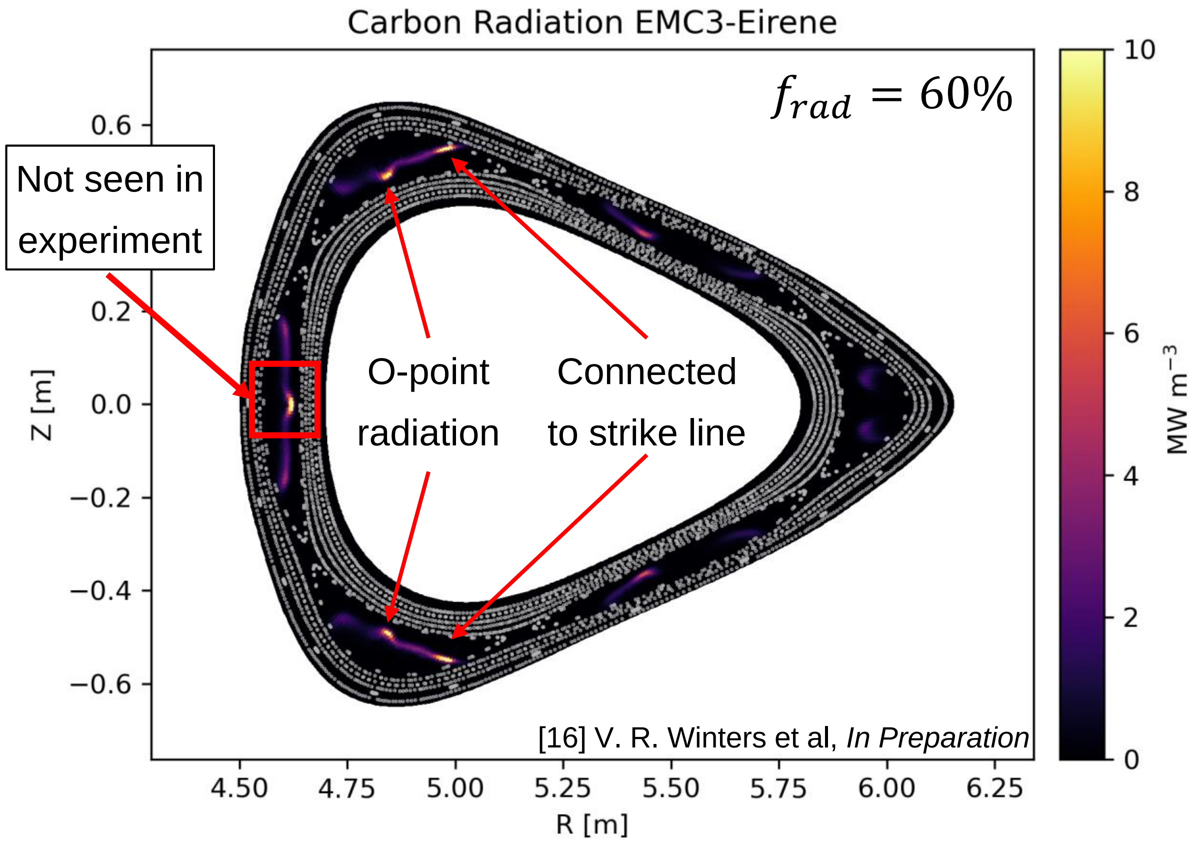
Please check out other W7-X contributions!

D. Carralero	I.135 (next talk)
+ others! ☺	

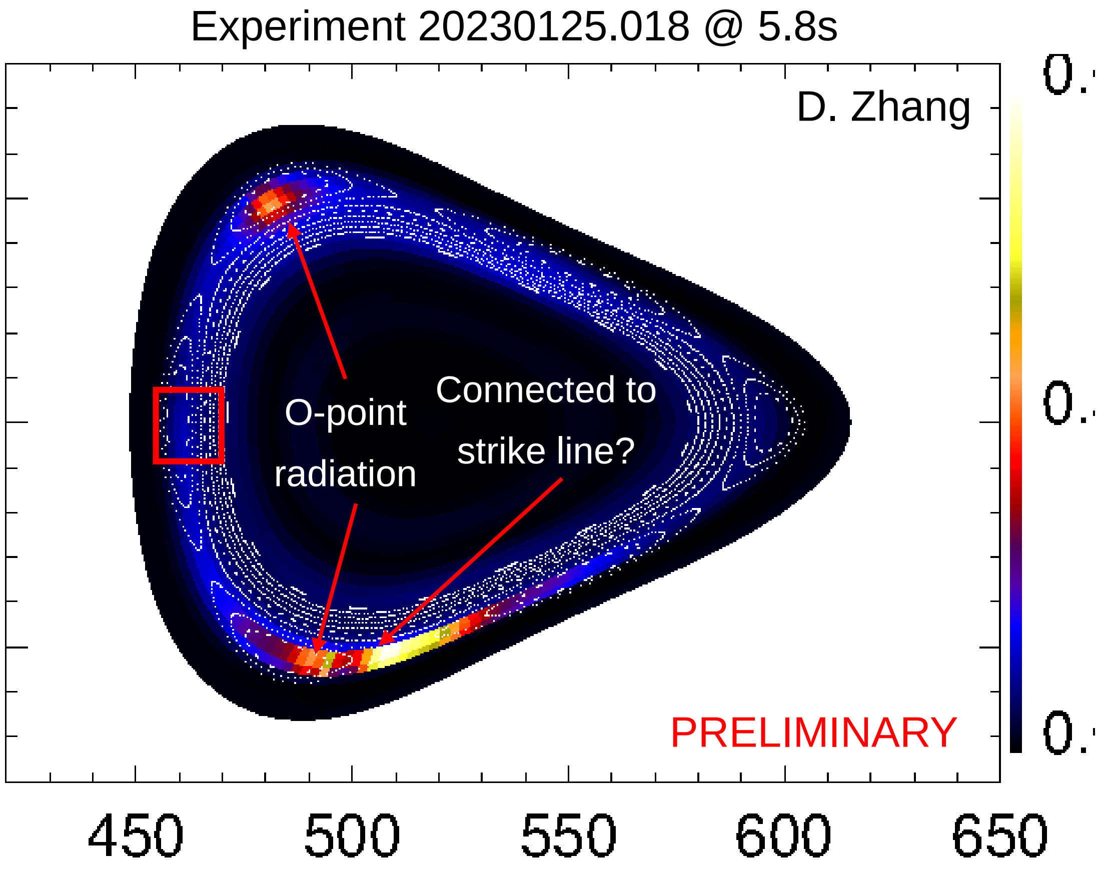
Back-up Slides

Low iota radiation is concentrated at island O-point!

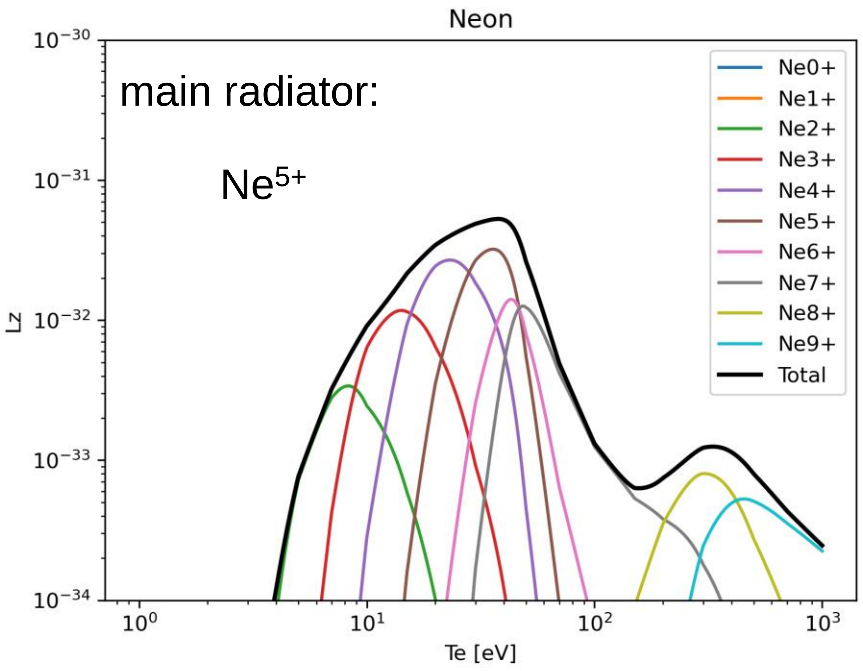
- Detachment in these configurations is unstable

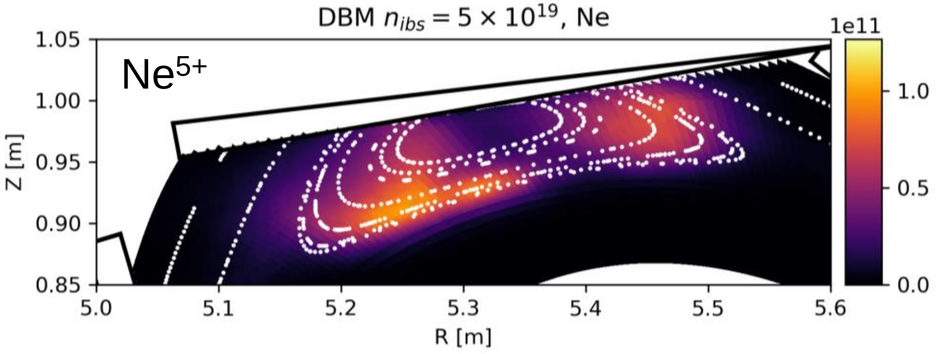


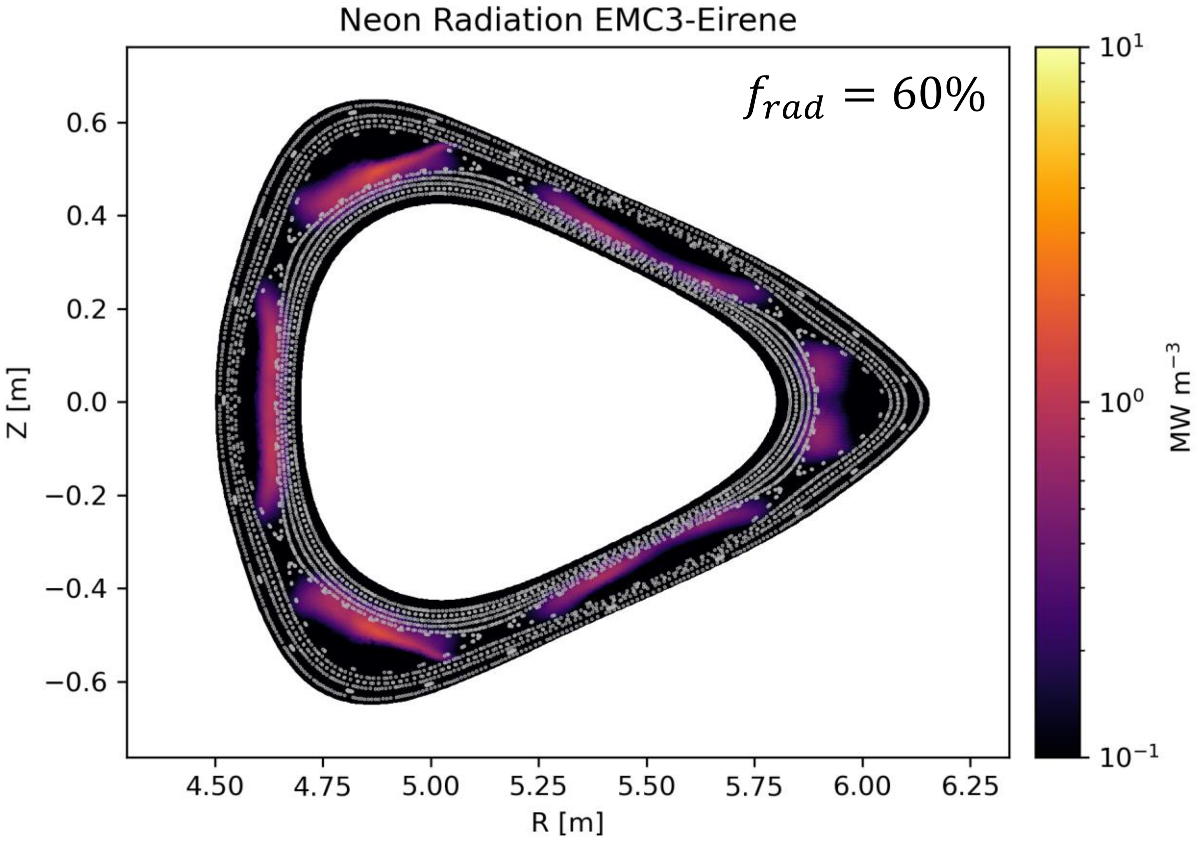
[16] V. R. Winters et al, *In Preparation*



Upstream radiation from Neon means radiation pattern is more distributed







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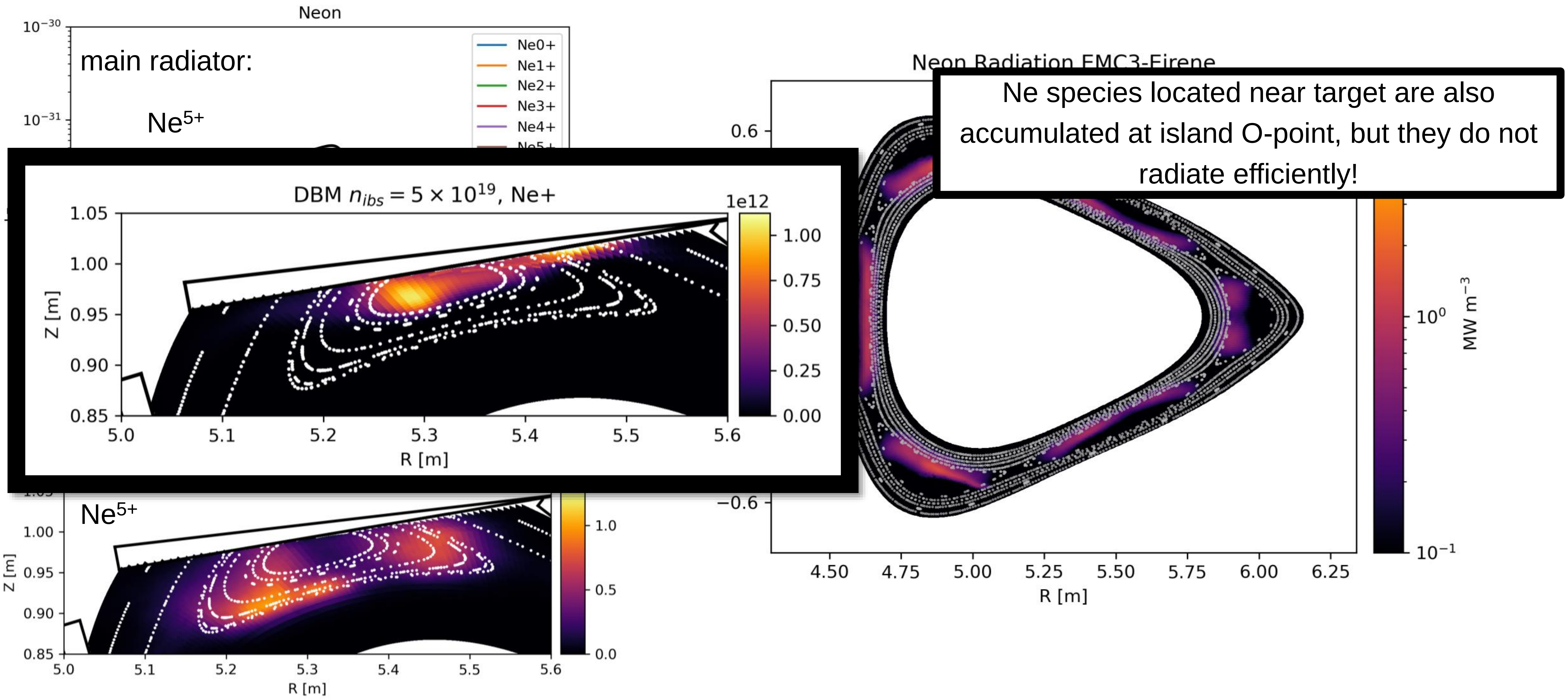

Ne species located near target are also accumulated at island O-point, but they do not radiate efficiently!