MAX-PLANCK-INSTITUT
FÜR PLASMAPHYSIK

Wendelstein 7-X

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

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EUROfusion

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Abstract

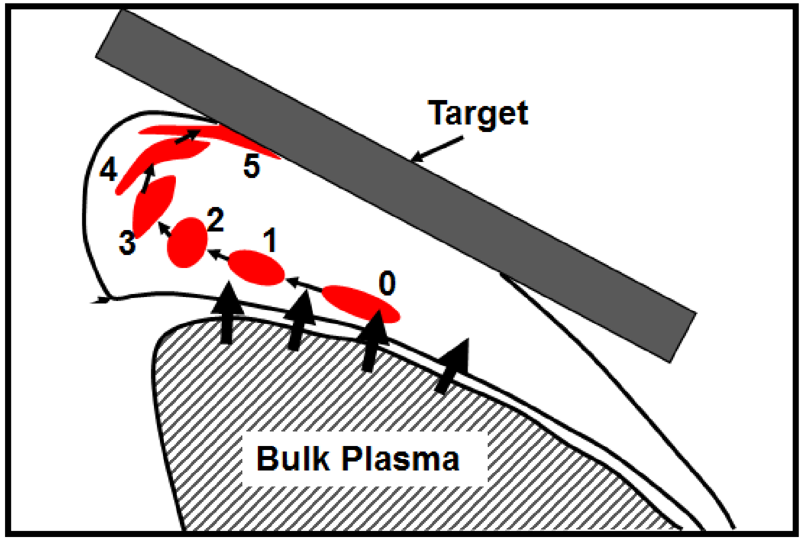
This work characterizes **the detachment behavior and radiation characteristics of the low iota configuration** in the Wendelstein 7-X (W7-X) stellarator. The island scrape-off layer (SOL) of the low iota configuration is comprised of a magnetic island that wraps poloidally around the last closed flux surface (LCFS) 6 times. The island geometry of the low iota configuration is significantly different to that of the standard magnetic field configuration, whose detachment characteristics have already been described in previous work[2, 3, 4]. Experimental results show that **the radiation pattern in the low iota configuration is starkly different to that of the standard magnetic field configuration**, with radiation concentrated at the island SOL O-points, rather than the X-points. Additionally, this O-point localized radiation pattern is associated **with unstable detachment**, with both radiation oscillations in experiments and the lack of a self-consistent plasma solution at high radiated power fraction in EMC3-Eirene simulations. EMC3-Eirene simulations are used to understand the radiation distribution. It was found that the **O-point localized radiation arises first from local impurity and/or ionization sources near the parallel flow stagnation region**, which is located close to the geometrical center of the island (”O-point”). The local cooling in this region leads to plasma condensation in the islands in closest magnetic connection to the divertor target plates. **The heat source to this region of the island, which is thermally isolated from the upstream heat source in terms of parallel transport, must arise via perpendicular heat transport**. This heat source is expected to be large for the low iota configuration due to its very small internal island field line pitch. This work highlights the importance (complementary to previous work, e. g. [5, 6]) of the internal island field line pitch not only on the radiation pattern, but also the detachment performance of the island divertor.

Background: Island geometry plays a critical role in SOL transport

- Ratio of ∥- to ⊥- transport is highly sensitive to the **magnetic field line pitch, Θ, within the island**[1,2]:

$$\Theta = 2a\sqrt{\frac{\iota' b_{rm}}{Rm}} \quad \Rightarrow \quad \frac{q_{\parallel}}{q_{\perp}} = \frac{\kappa_{e,i} T_{e,i}^{5/2} \Theta^2}{\chi_{e,i}\, n}$$

- m is poloidal number of islands, ι' is shear at resonance layer



König et al, *Plasma Phys. Control. Fusion* **44** (2002)

[1] Y. Feng et al, *Plasma Phys. Control. Fusion* **64** (2022)
[2] Y. Feng et al, *Plasma Phys. Control. Fusion* **53** (2011)

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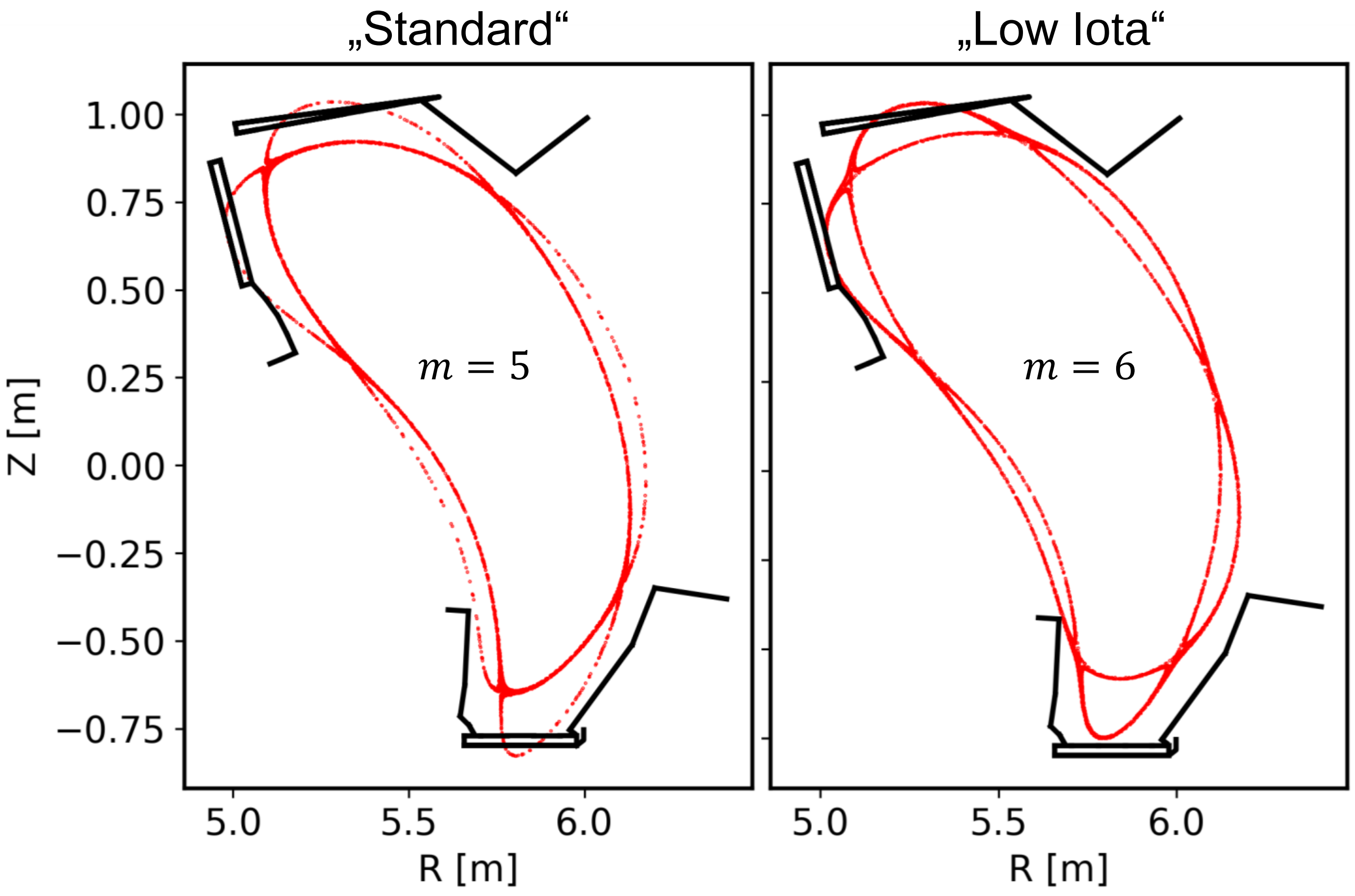
- m is poloidal number of islands, ι' is shear at resonance layer
- We expect the weight of ⊥- transport to be significantly larger for the „low iota“ island SOL
    - Larger m and lower ι'

How does detachment in W7-X behave under these differing geometric conditions?



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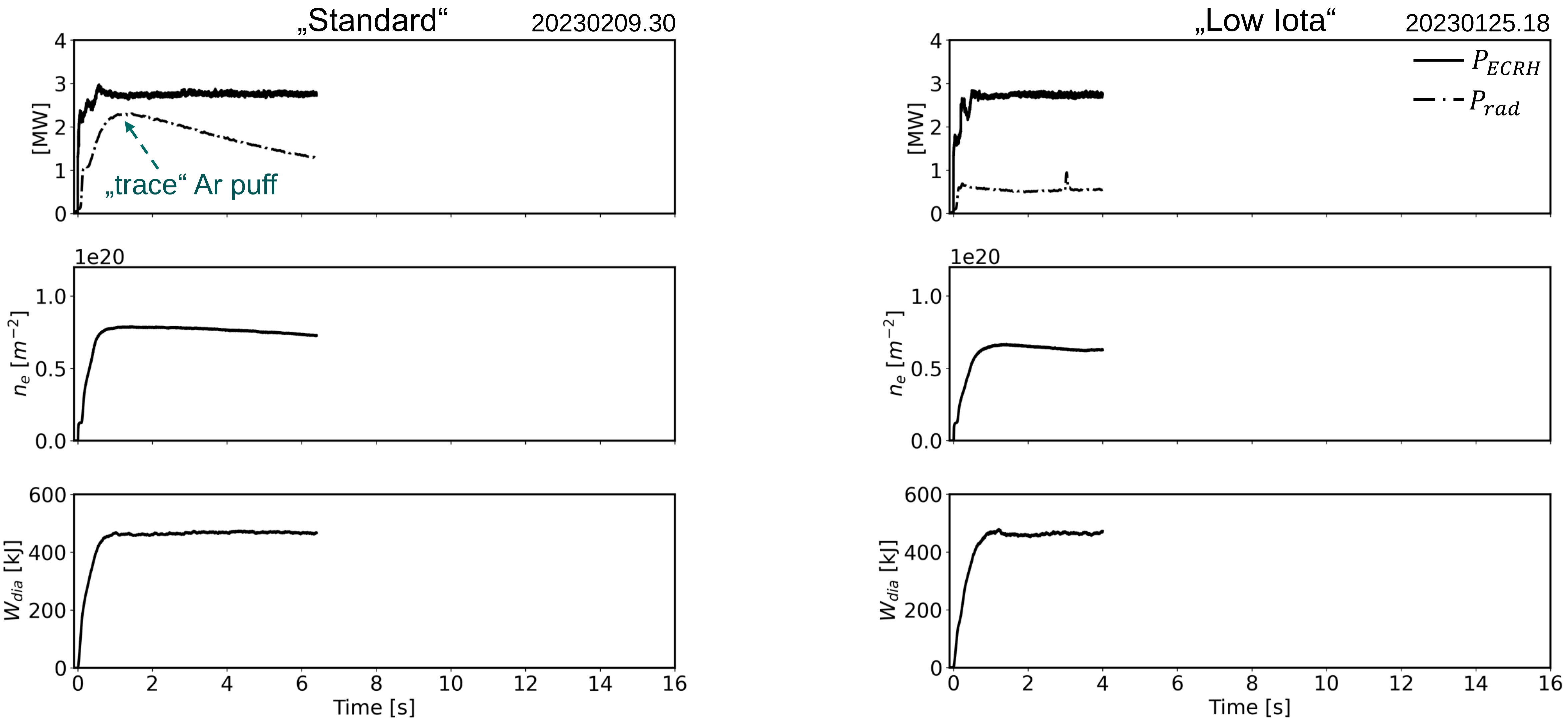
Experimentally, we see fundamentally different detachment behavior between standard and low iota configurations



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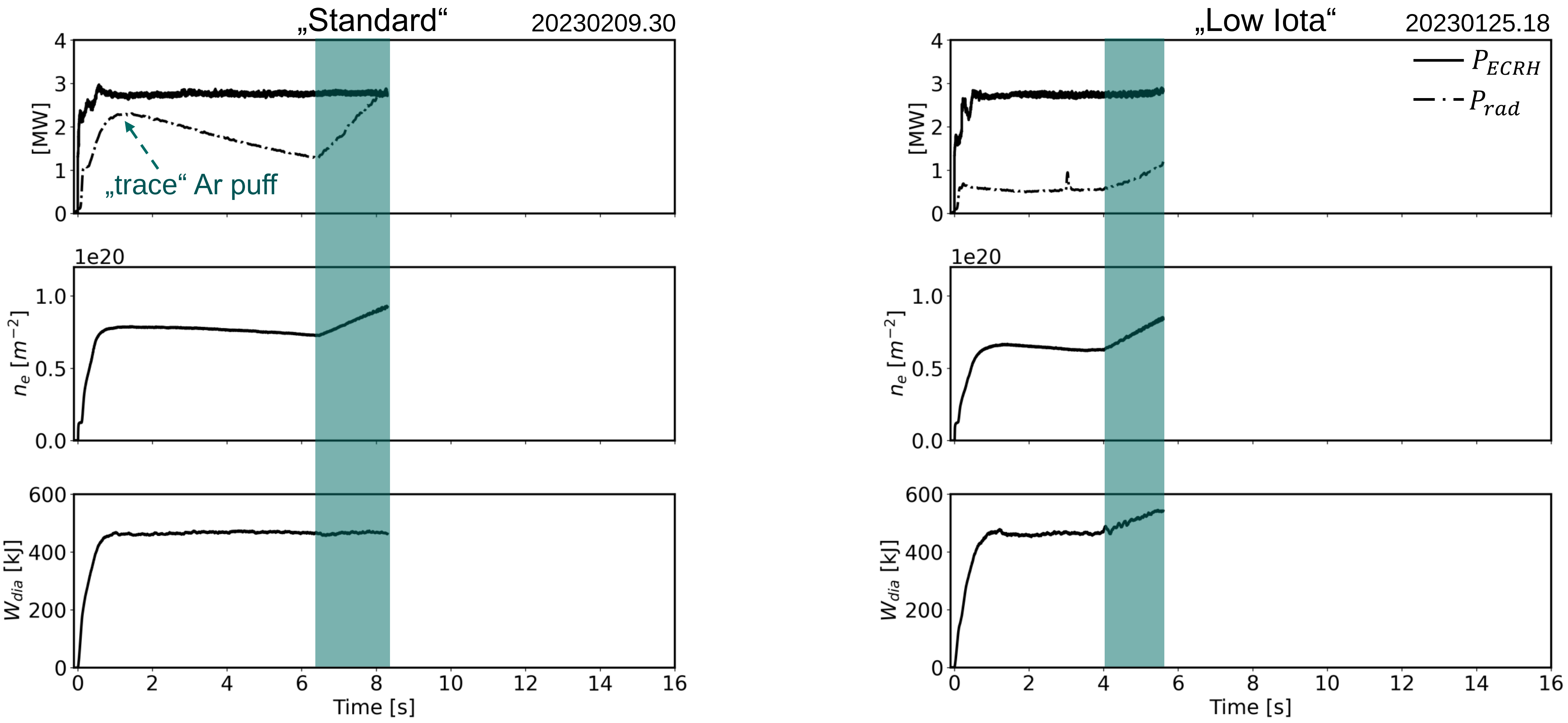

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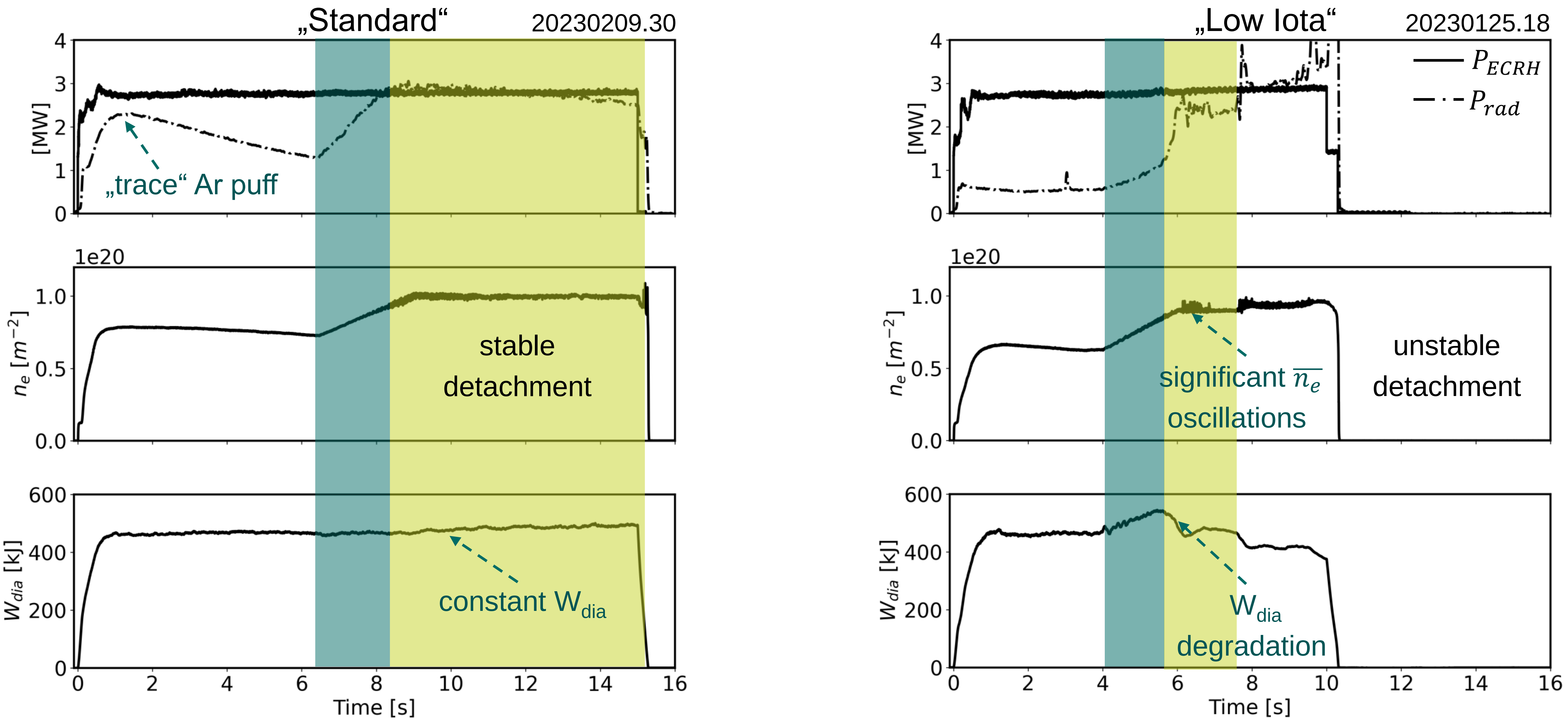
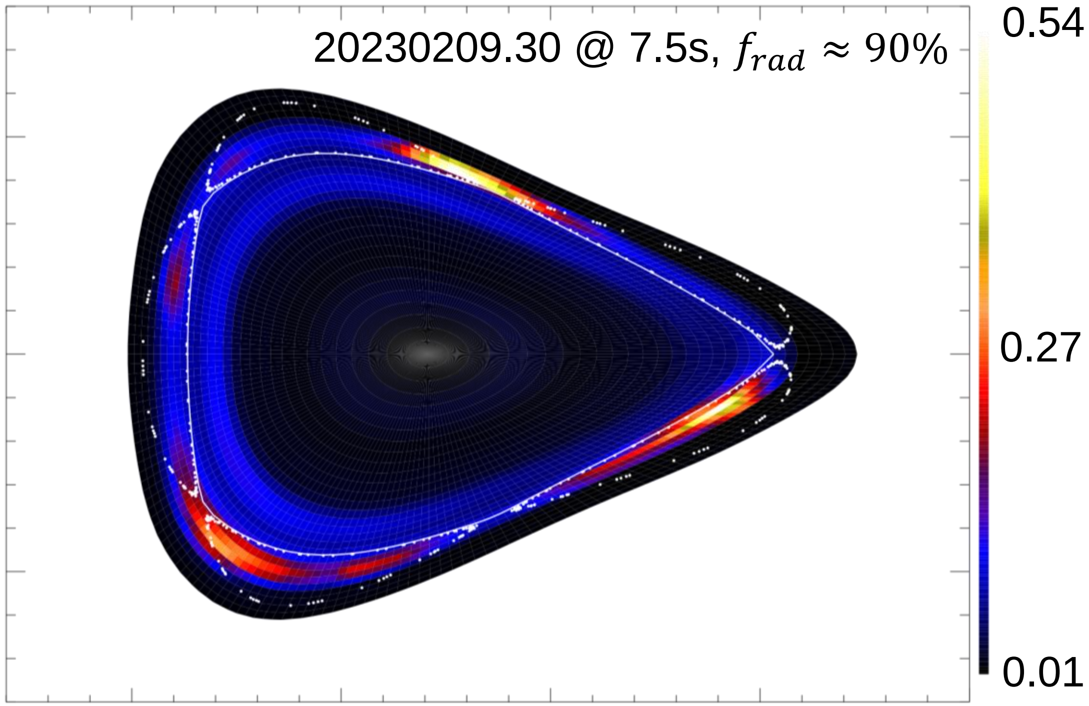


Tomographic reconstructions show differing radiated power distributions between standard and low iota

„Standard“ P_{rad} Distribution



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

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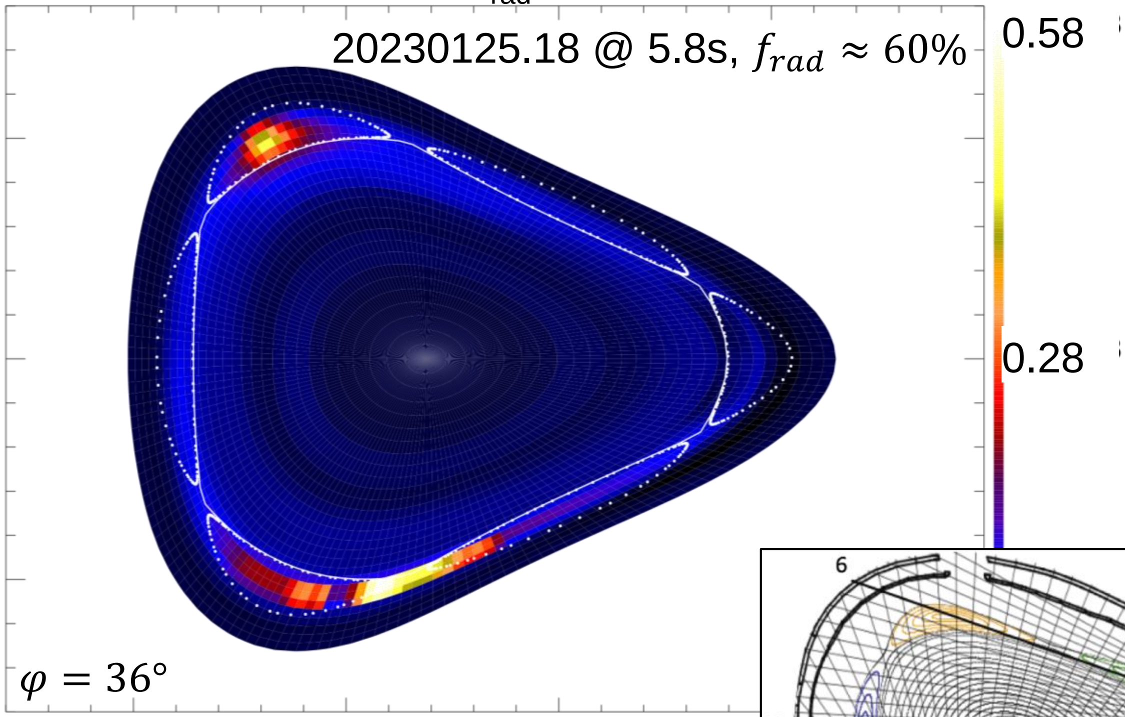

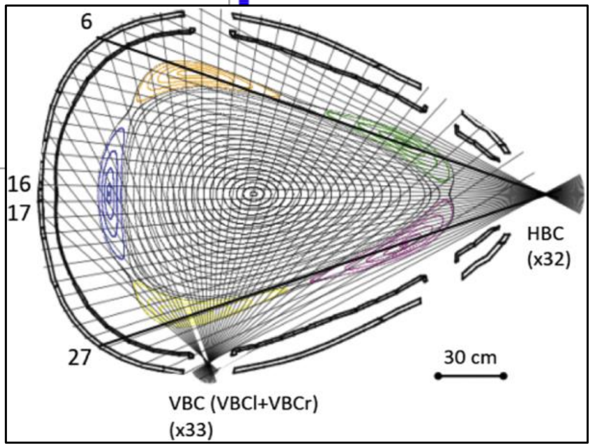

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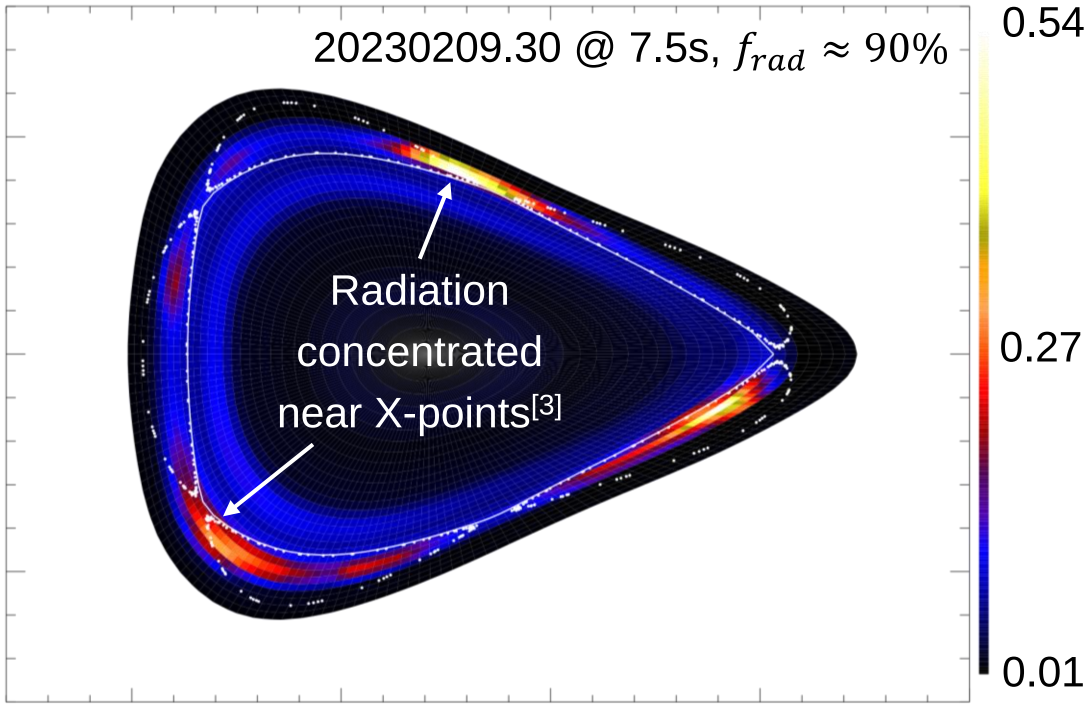

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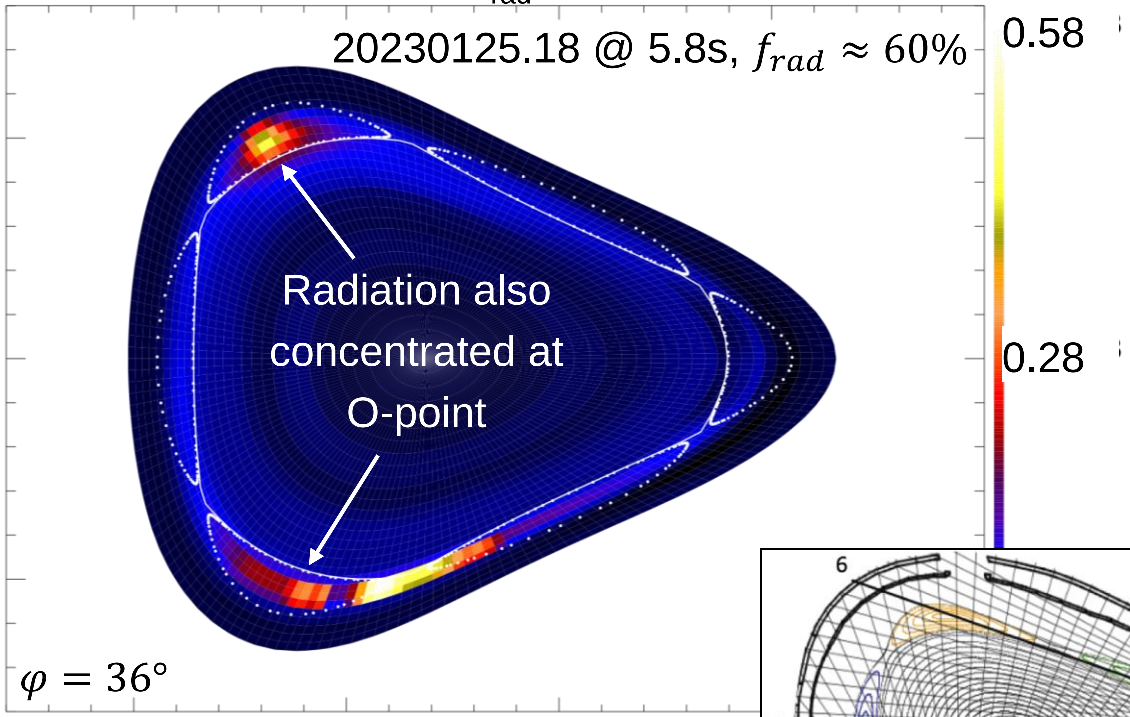
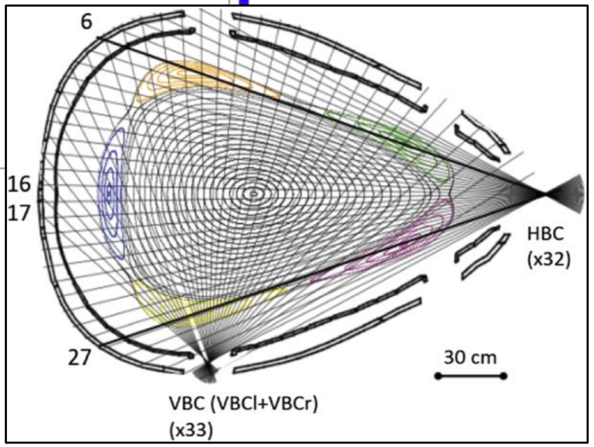
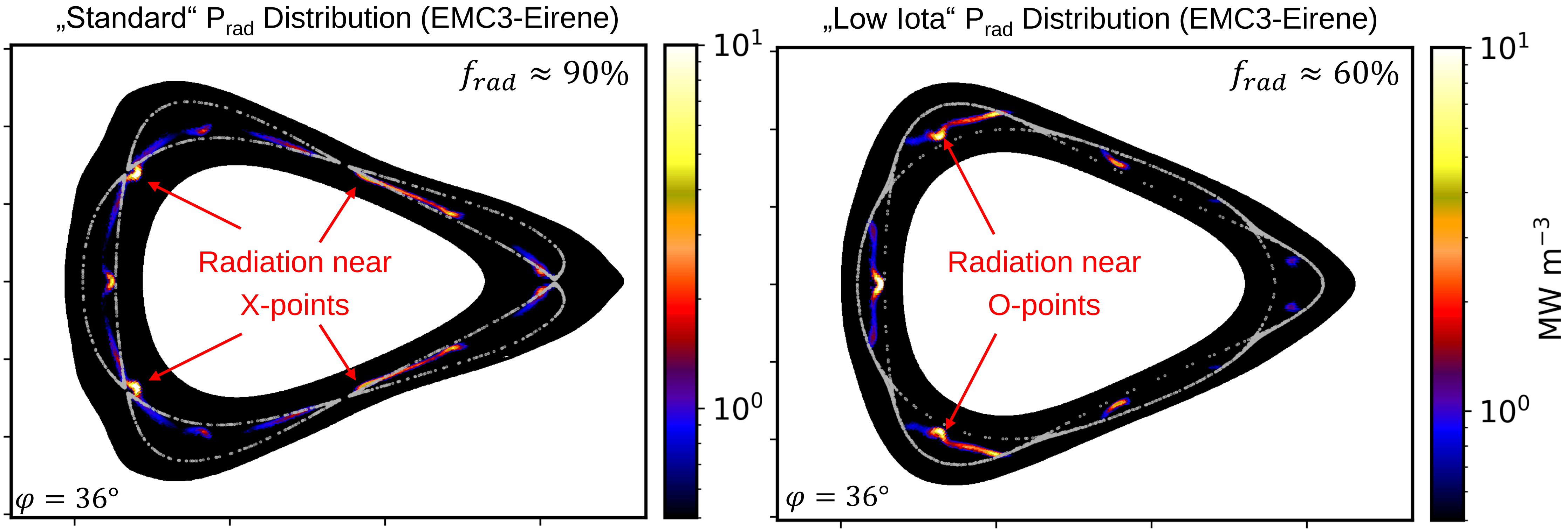




[3] Y. Feng et al, *Nucl. Fusion* **61** (2021)

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



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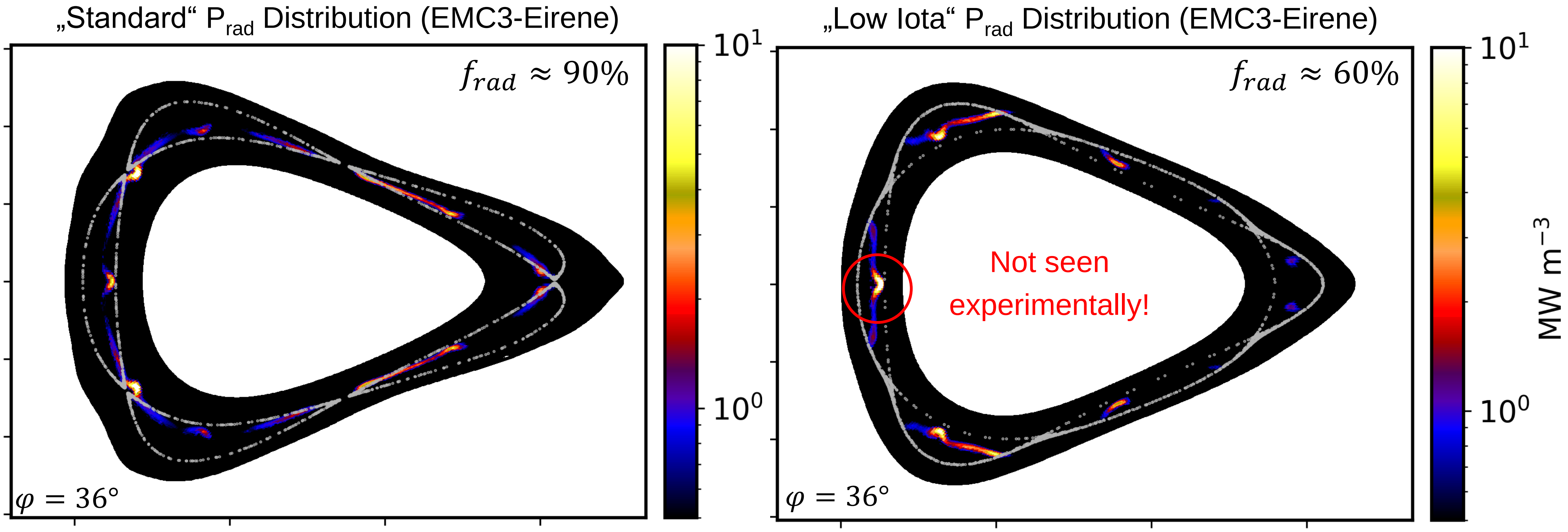

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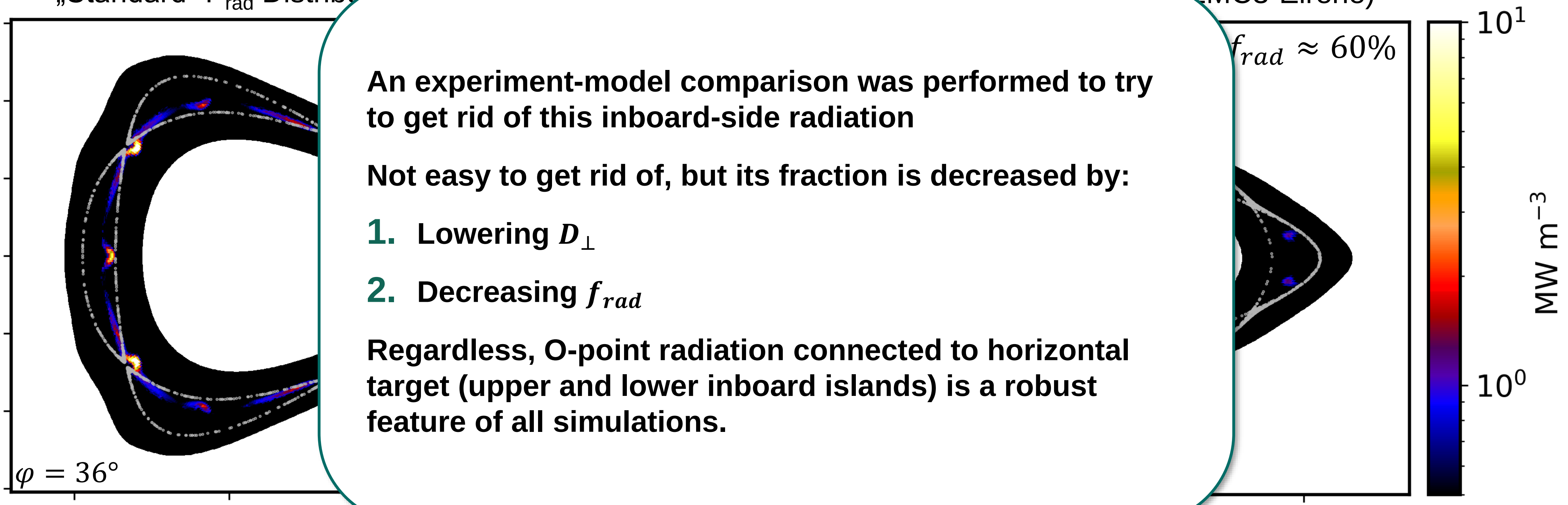

An experiment-model comparison was performed to try to get rid of this inboard-side radiation

Not easy to get rid of, but its fraction is decreased by:

1. **Lowering $D_\perp$**
2. **Decreasing f_{rad}**

Regardless, O-point radiation connected to horizontal target (upper and lower inboard islands) is a robust feature of all simulations.

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

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

- We use the „standard“ configuration as a test bed for understanding the changeover from X- to O-point radiation condensation
- Hypothesis: „low iota“ has a smaller Θ than „standard“ (increased weight $\perp$-transport)
- Two ways of increasing weight of $\perp$-transport:
  1. Increase $\chi_\perp$ in the simulation
  2. Decrease internal island field line pitch: $\Theta = 2a\sqrt{\frac{\iota' b_{rm}}{Rm}}$

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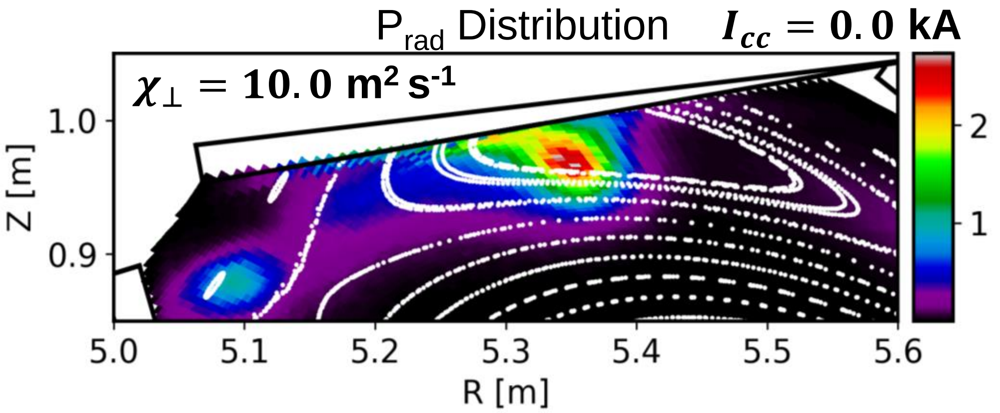
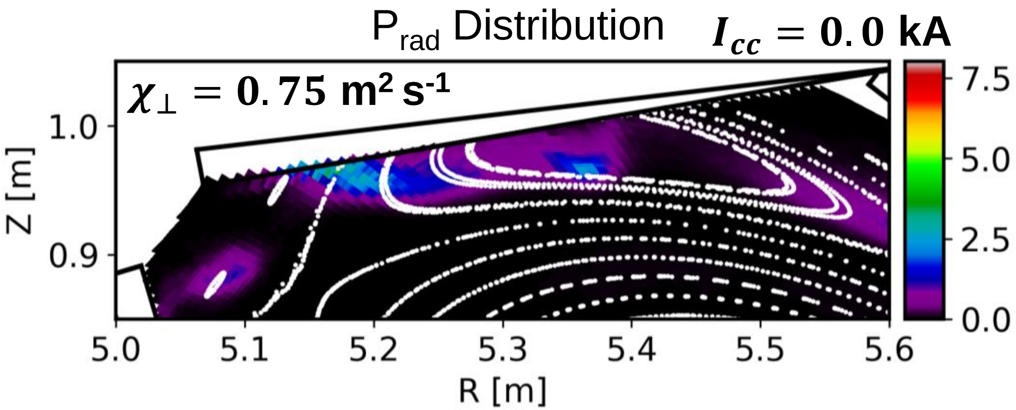


Increasing $\chi_\perp$



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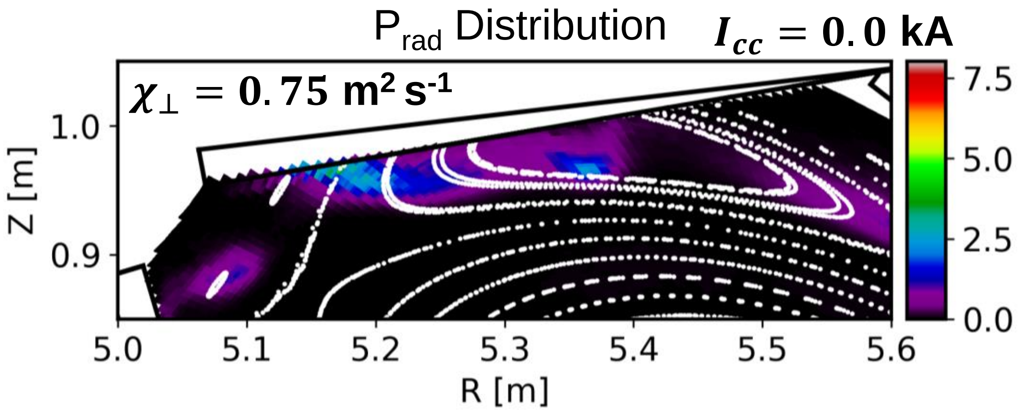
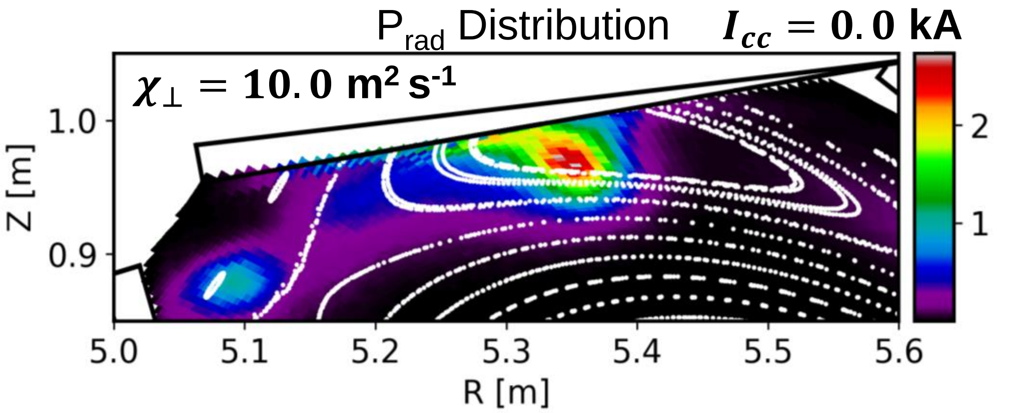
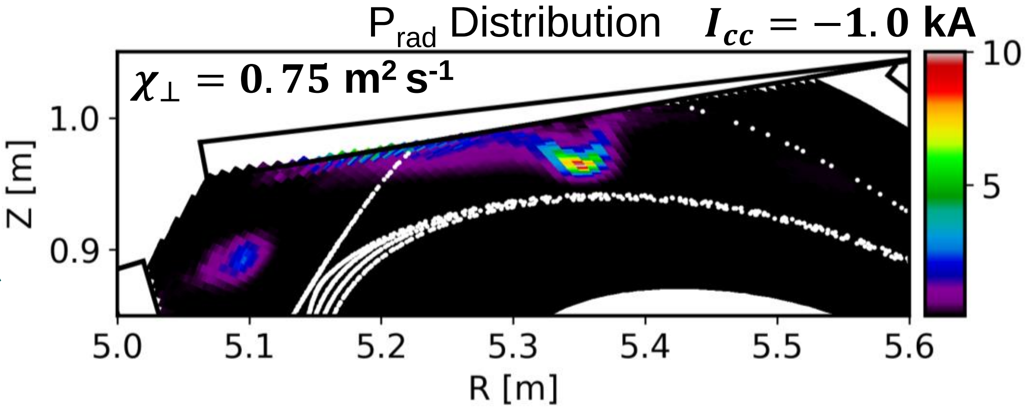


Increasing $\chi_\perp$

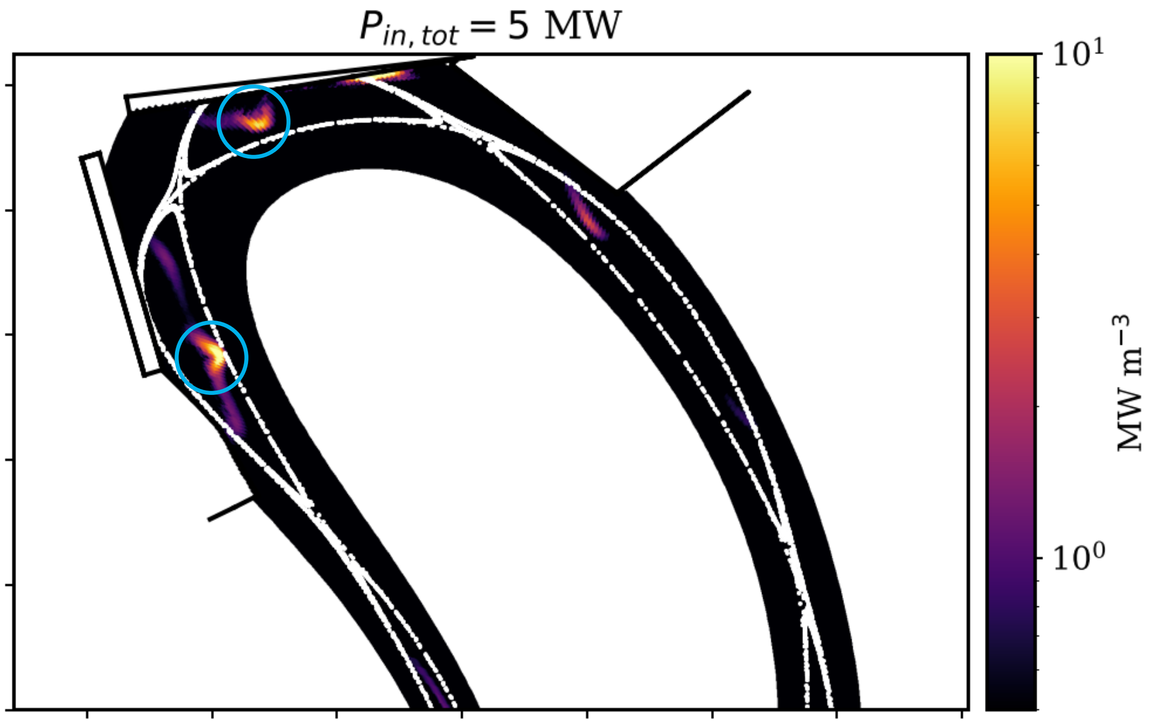


Decreasing b_{rm}



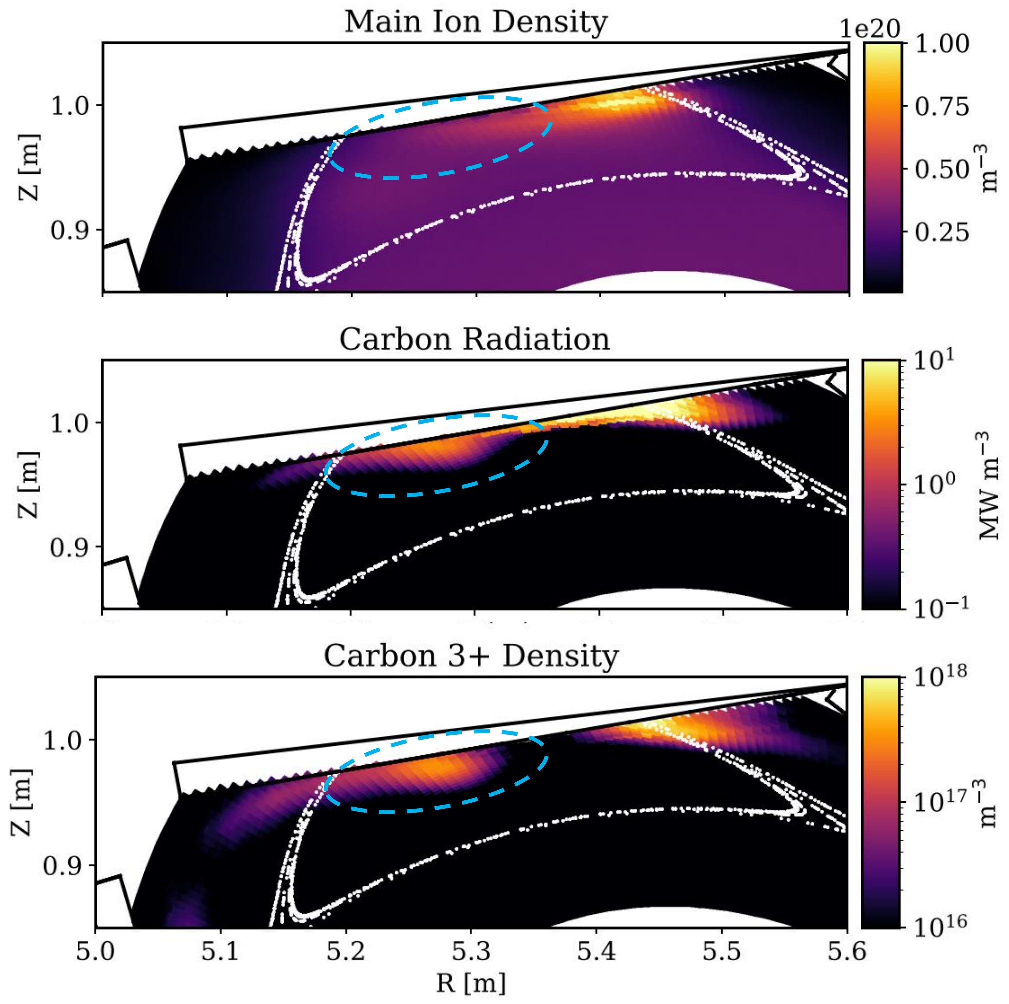
3D effects of radiation distribution: what causes radiation condensation near the O-point?

- No large radiation in all islands surrounding LCFS
- Radiation clearly condensates in islands in *close magnetic proximity to the divertor targets*
- Suggests that local impurity and/or recycling sources play a role in radiation condensation



What is a possible cause of the radiation condensation near the O-point?

- Look at example at *low density* and *low* f_{rad} (where radiation condensation first starts to appear)
- No localized features in the main ion density or ionization source at the radiation peak near the O-point is observed
- BUT: localized peaking of C^{3+} - consistent with impurity accumulation near O-point (parallel flow stagnation region)[4]



At low density, low f_{rad} conditions, carbon impurity sources may play a strong role in the initiation of radiation condensation

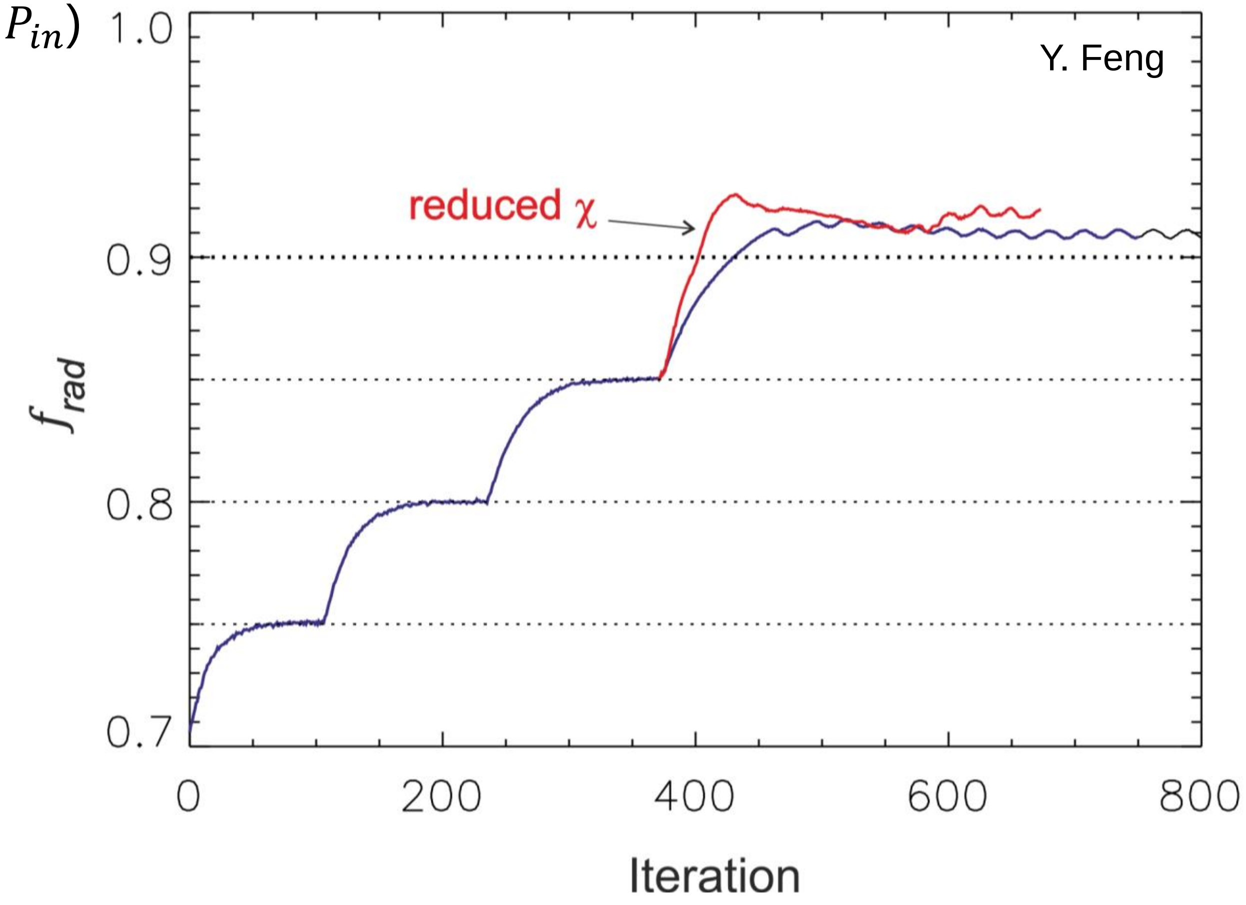
[4] V. R. Winters et al, *Nucl. Fusion* (submitted)

EMC3-Eirene finds no self-consistent plasma solution for low iota at high f_{rad}

- EMC3 self-consistently solves energy, continuity, momentum equations for a fixed point (f_{rad}, $n_{e,s}$, P_{in})
- No self-consistent solution exists in „low iota“ at f_{rad}=90%
  - Always saturates above 90%
  - Plasma solution oscillates
- O-point radiation seems to be associated with experimental/simulation plasma instability

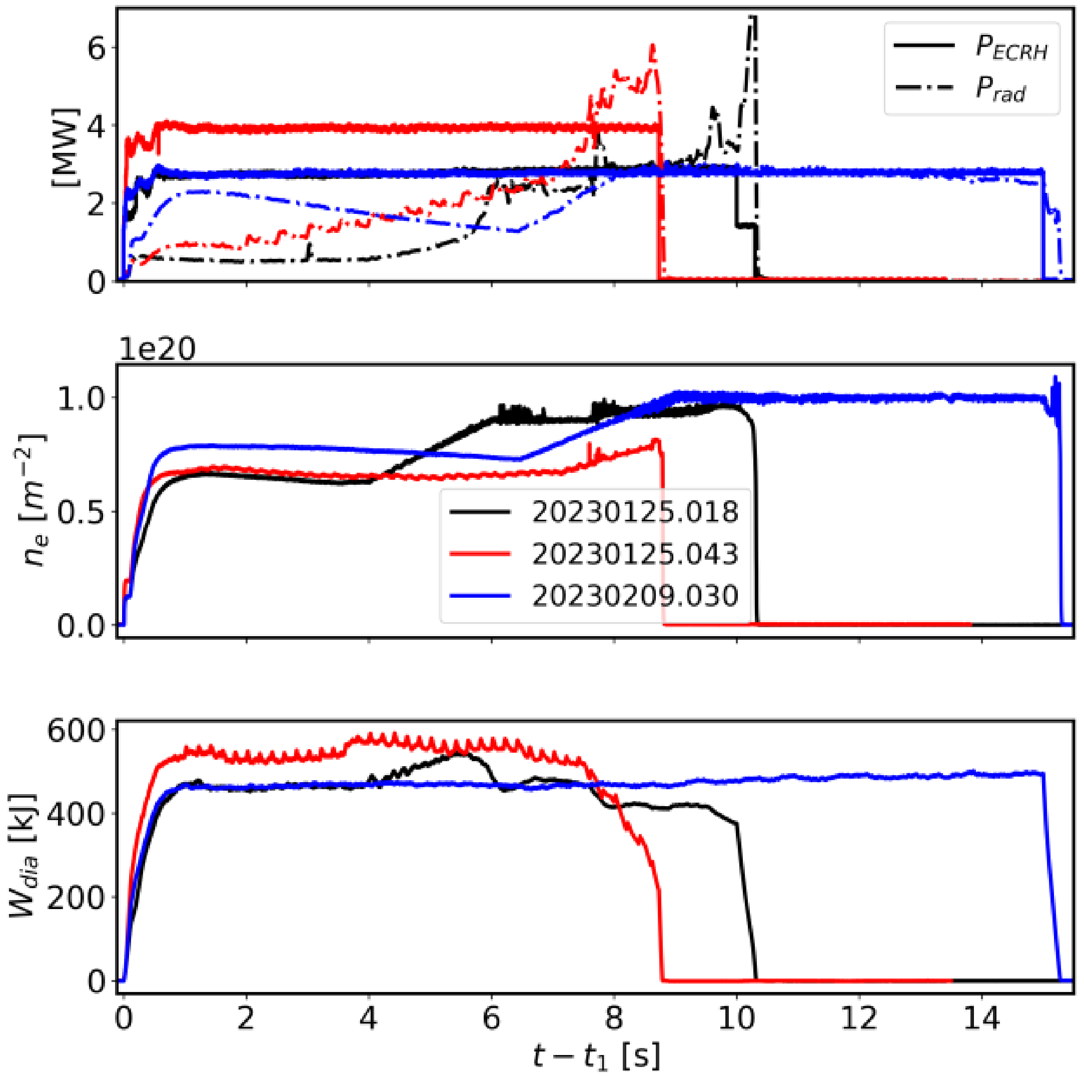
→ **Indication of instability seen in experiment?**

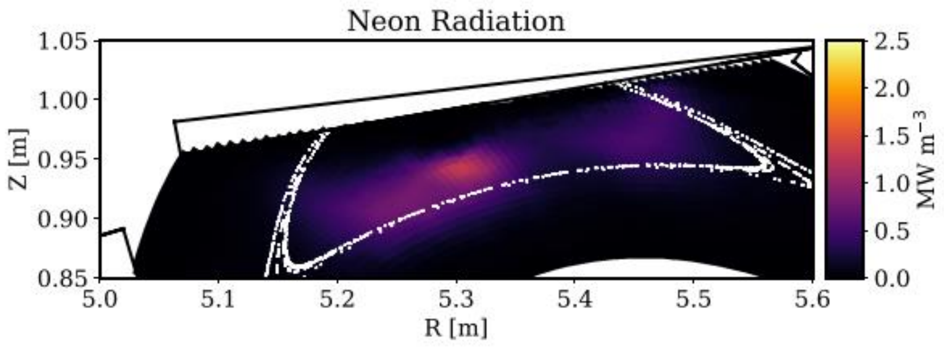
- Exact cause currently under investigation (Y. Feng)



Neon seeding could provide greater controllability of radiated power

- Neon seeding experiments appeared to be more controllable over a larger range of f_{rad}
- Could be related to radiative properties of Neon. O-point condensation not as strong
- Preliminary bolometer tomograms also do not show as strongly localized O-point radiation





Summary

1. Experimentally, we have observed that the „low iota“ configuration exhibits unstable detachment, which does not occur in the „standard“ configuration.
2. Tomographic reconstructions of the radiated power distribution indicate radiation condensation between the X-points („O-Point“ radiation) for „low iota“, which does not occur in „standard“.
3. The qualitative shift of the radiation pattern from X- to O-point dominant is reproduced in EMC3-Eirene simulation
4. EMC3-Eirene results confirm that it is the increased weight of ⊥-transport that results in the radiation pattern shift
5. Radiation condensation only occurs in islands in close magnetic proximity to the divertor targets, indicating that local impurity and/or recycling sources are important in generating this radiation pattern
6. These strong deviations between „standard“ and „low iota“ configuration provide the first strong experimental confirmation of the role of island geometry in detachment in W7-X

Thank you for your attention!