Analysis of the heat flux characteristics in the helical scrape-off layer of Wendelstein 7-X start up scenarios by 3-D modeling

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[4] Los Alamos National Laboratory, PO Box 1663, Los Alamos, NM 87545, USA

58th Annual Meeting of the APS Division of Plasma Physics
October 31-November 4, 2016 • San Jose, CA

Contact: effenberg@wisc.edu

Ackowledgments:
This work was supported in part by the **U.S. Department of Energy (DoE)** under **grant DE-SC0014210** and by **start up funds** of the **Department of Engineering Physics** and of the **College of Nuclear Engineering at the University of Wisconsin - Madison**, USA.
This work has been carried out within the framework of the **EUROfusion Consortium** and has received funding from the **Euratom research and training programme 2014-2018** under **grant agreement No 633053**. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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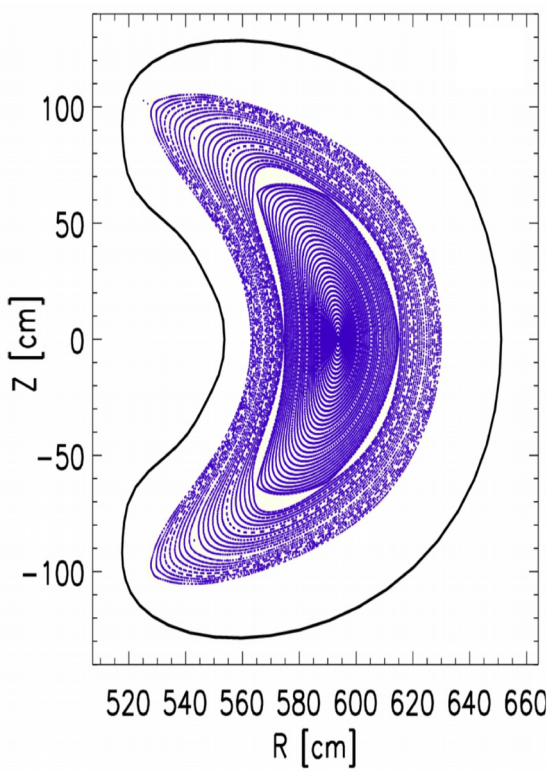
Start-up configuration: closed magnetic flux surfaces, no magnetic islands in the boundary



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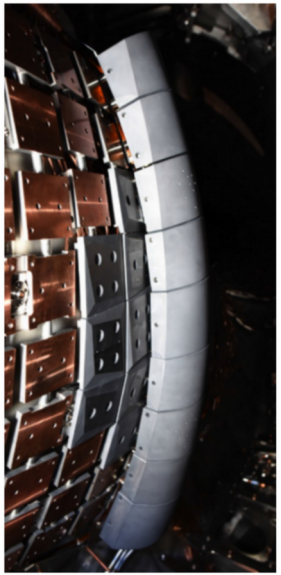

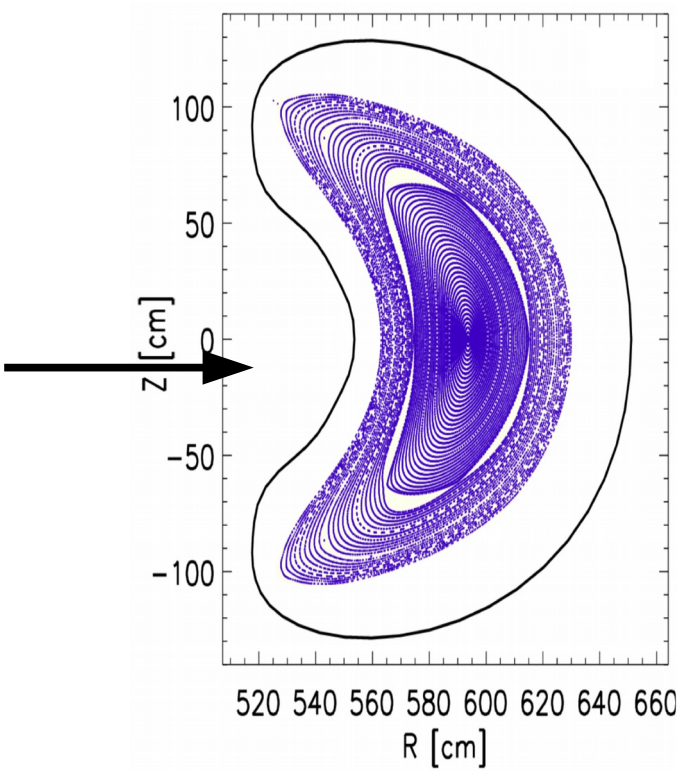

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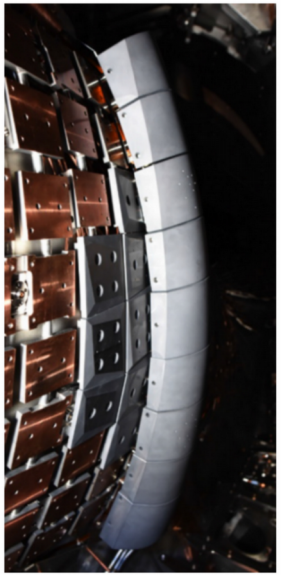

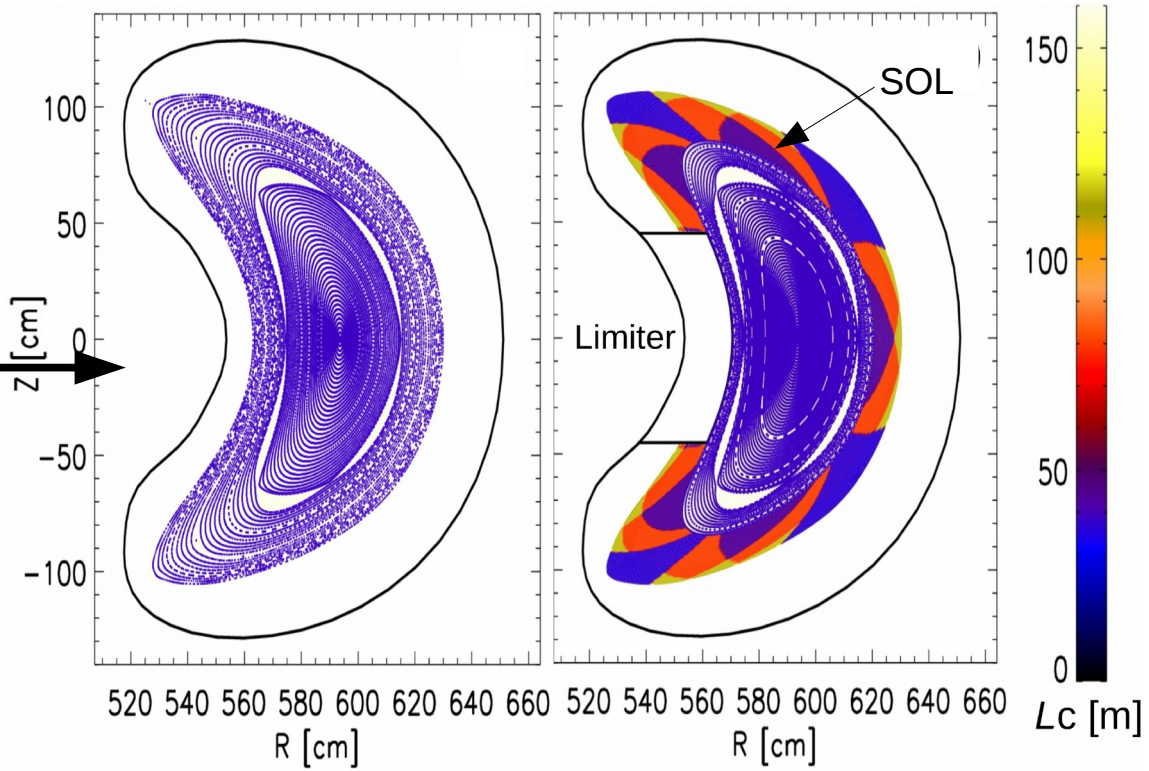

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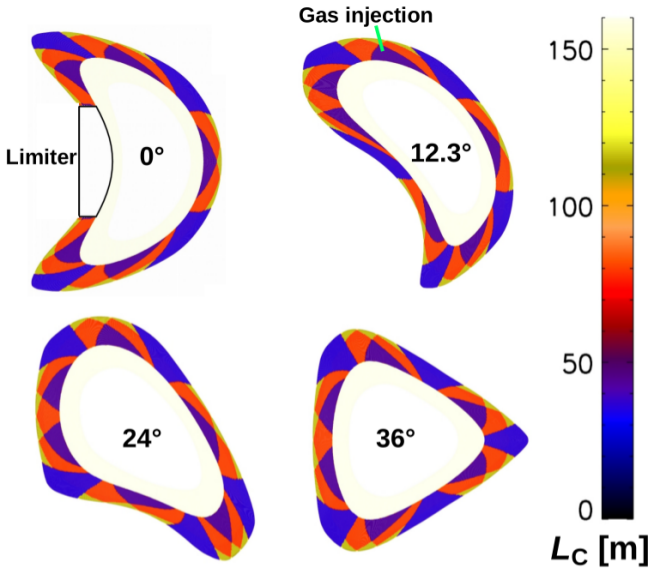
Limiters induce a 3-D helical scrape-off layer (SOL) of helical magnetic flux tubes of 3 different lengths L_C

L_C profiles show poloidal modulation



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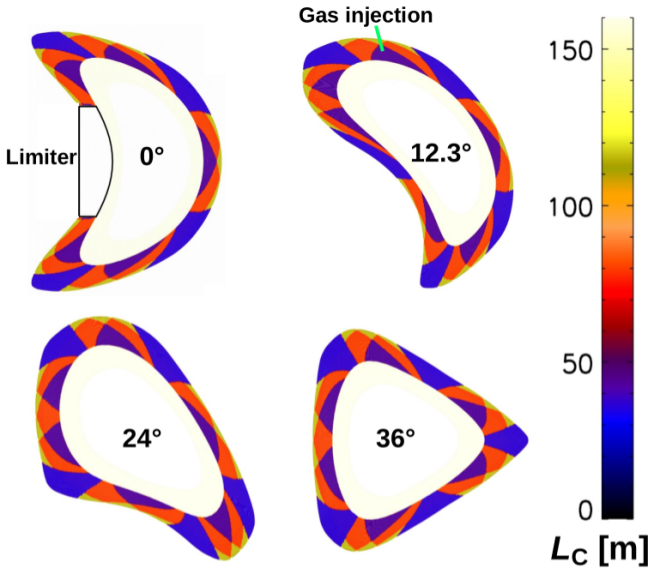
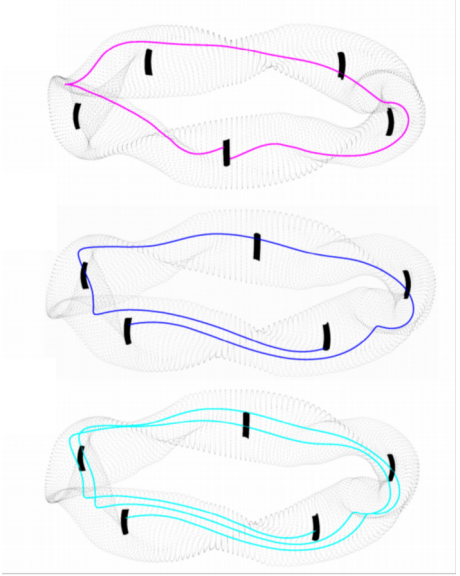


3 types of magnetic flux tubes:



36m

43m

79m

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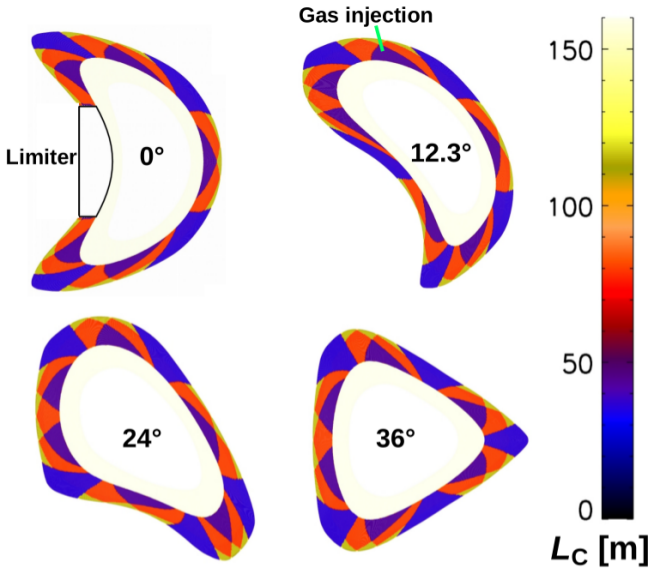

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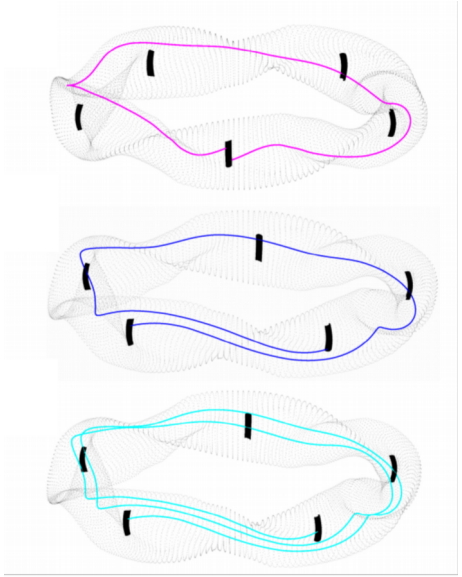

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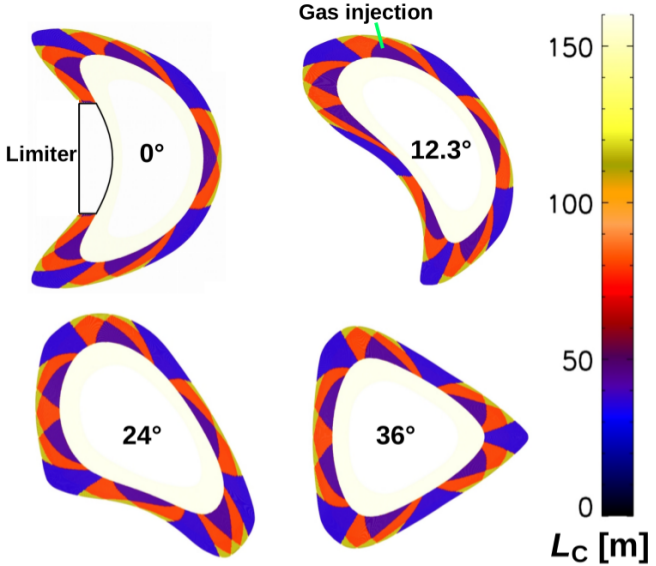

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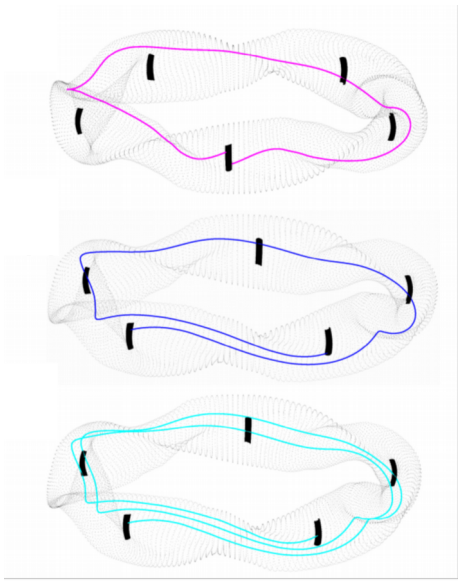
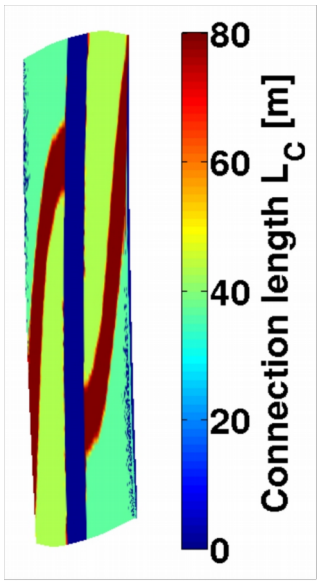


Uneven L_C distribution on limiter surface



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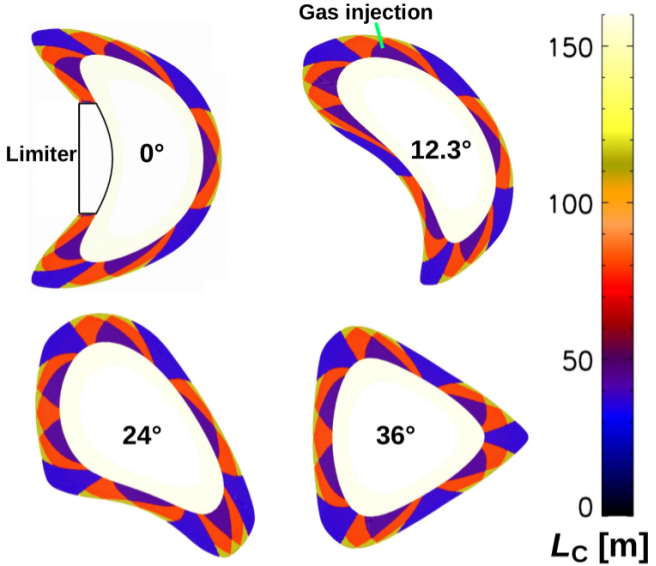

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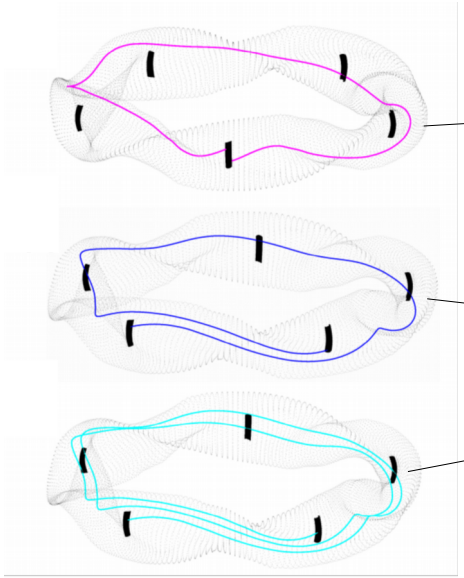

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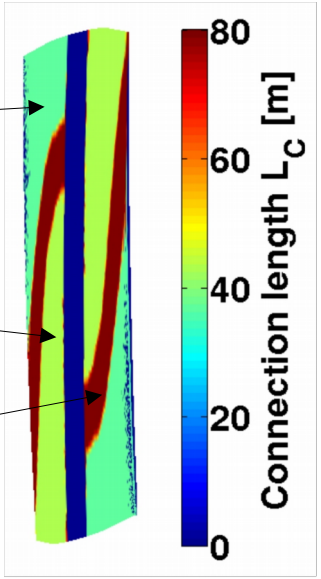

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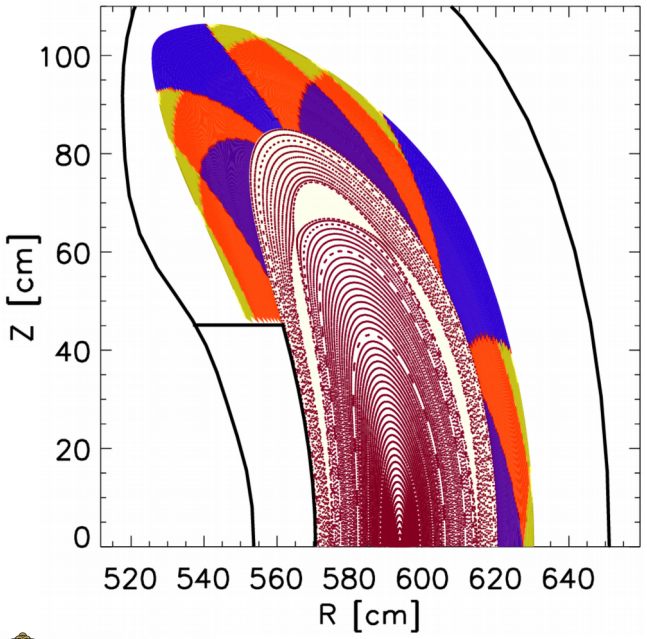
Increase of rotational transform changes SOL magnetic topology and magnetic footprint

optimized (ι_{edge}~0.87)



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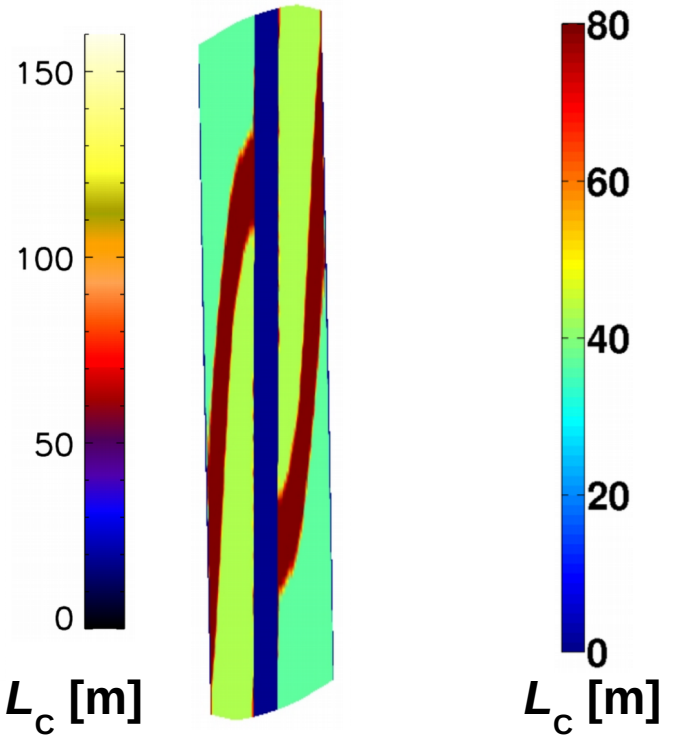

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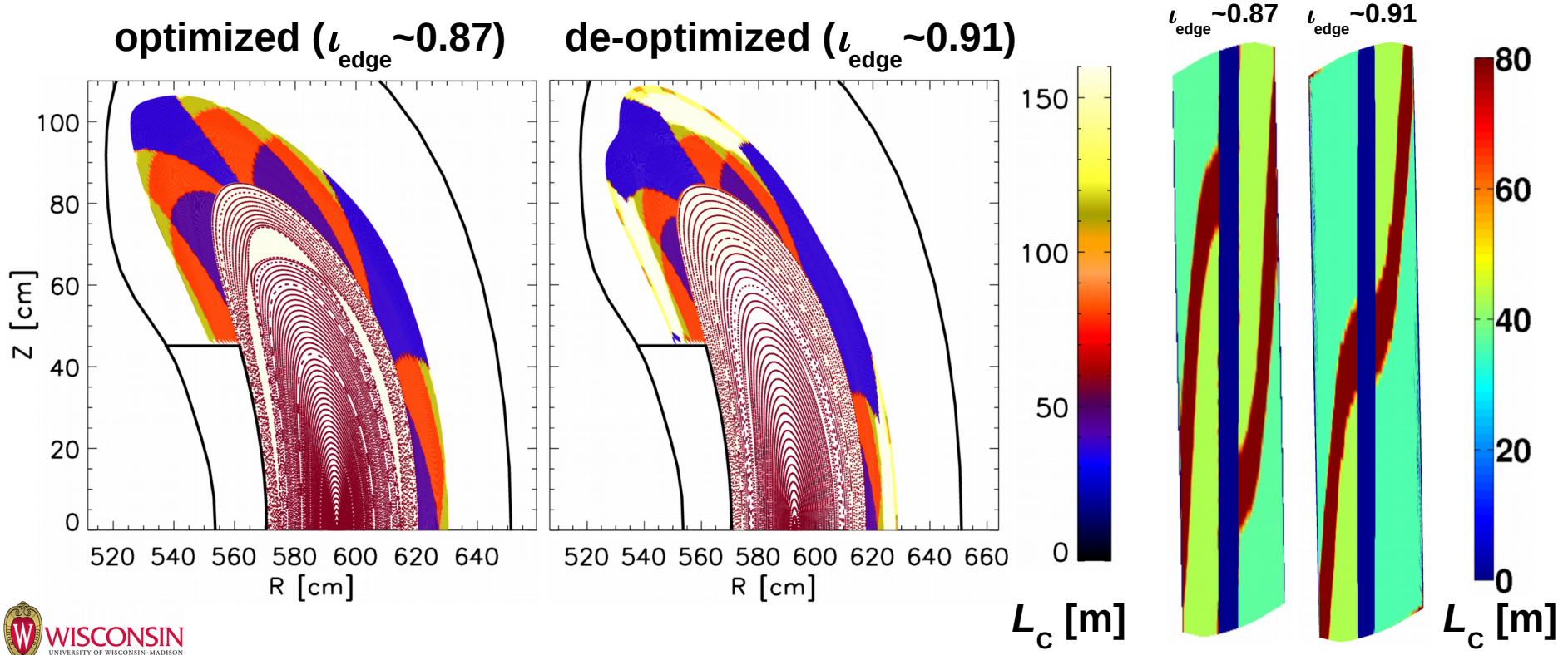
Increase of rotational transform changes SOL magnetic topology and magnetic footprint



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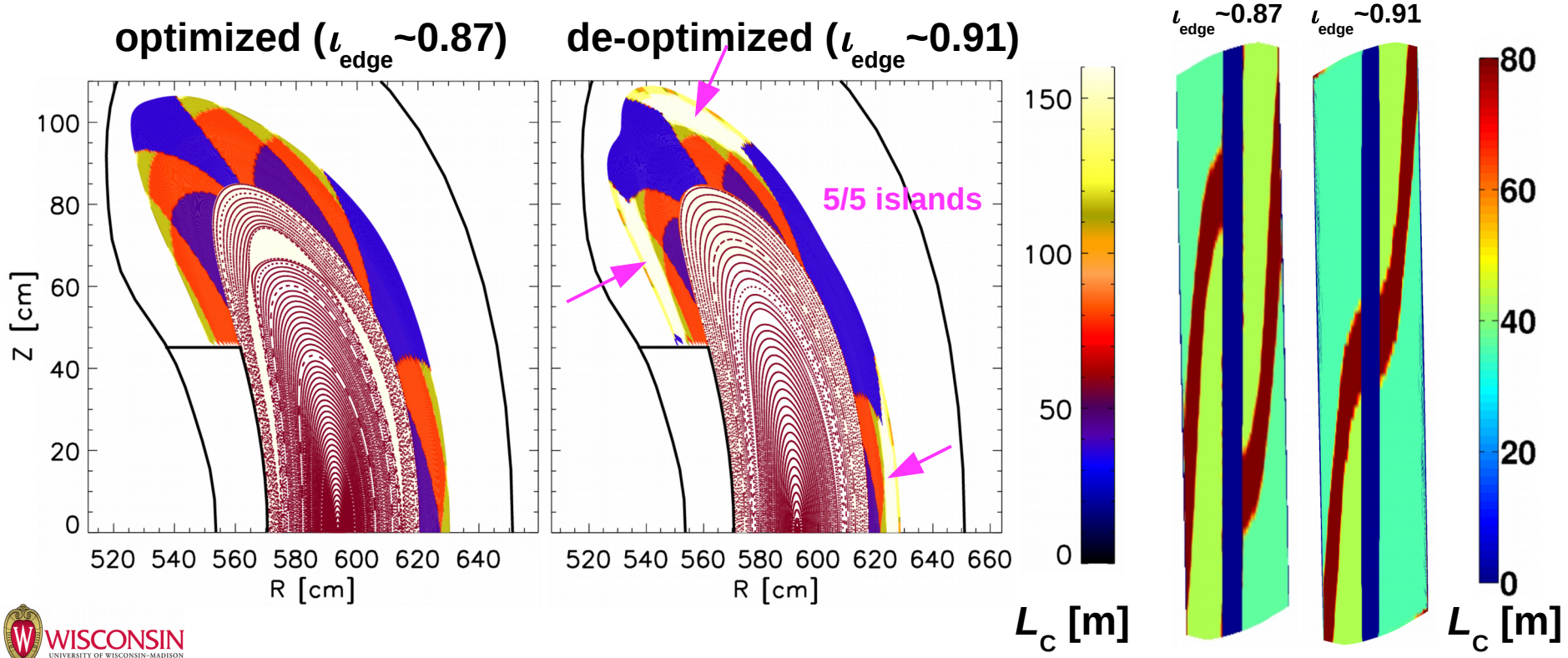

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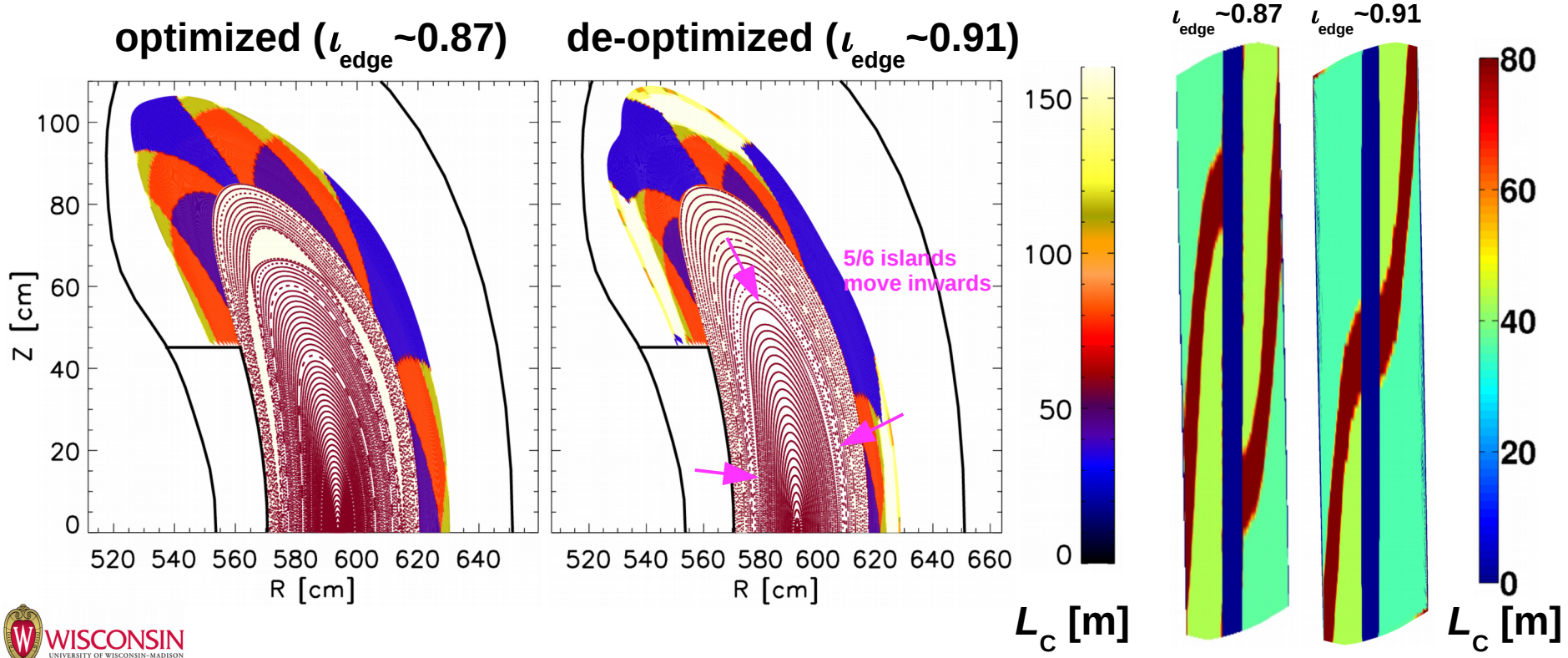

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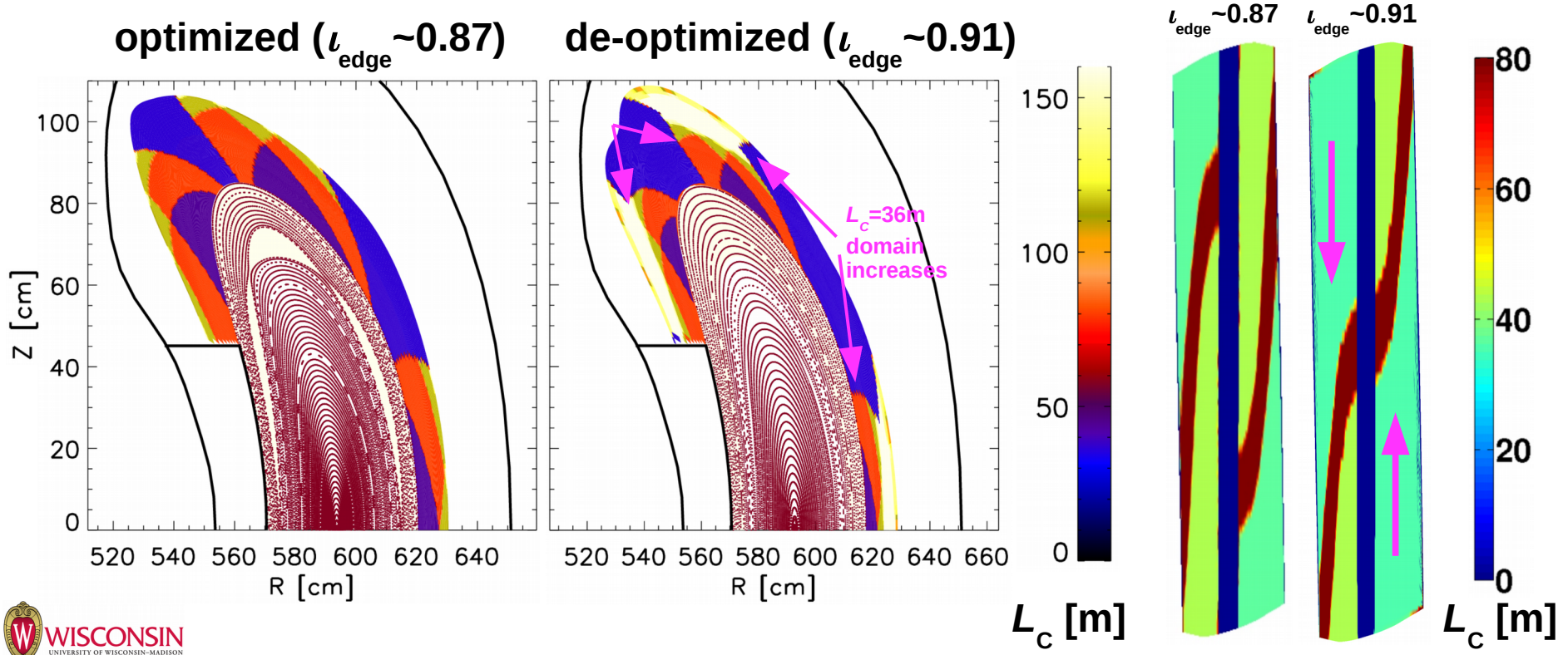

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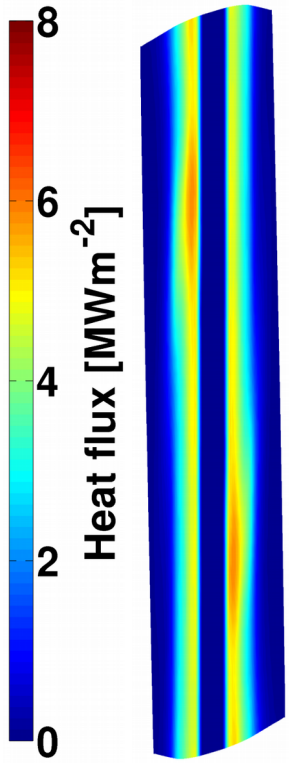
Change of rotational transform: limiter heat load patterns strongly correlated to distribution of L_c



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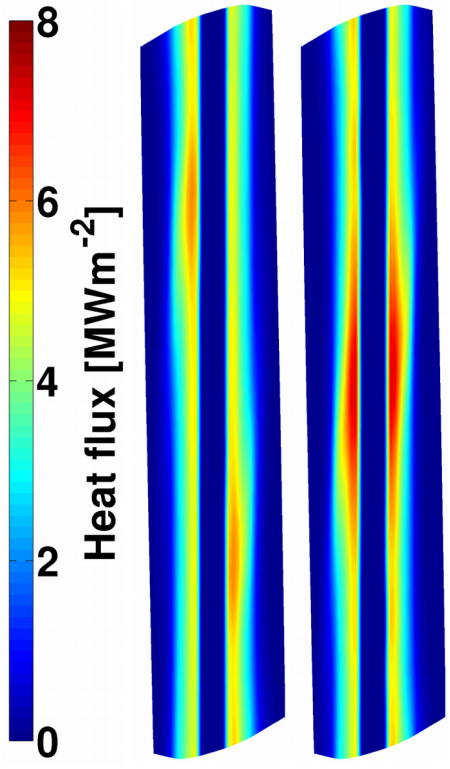

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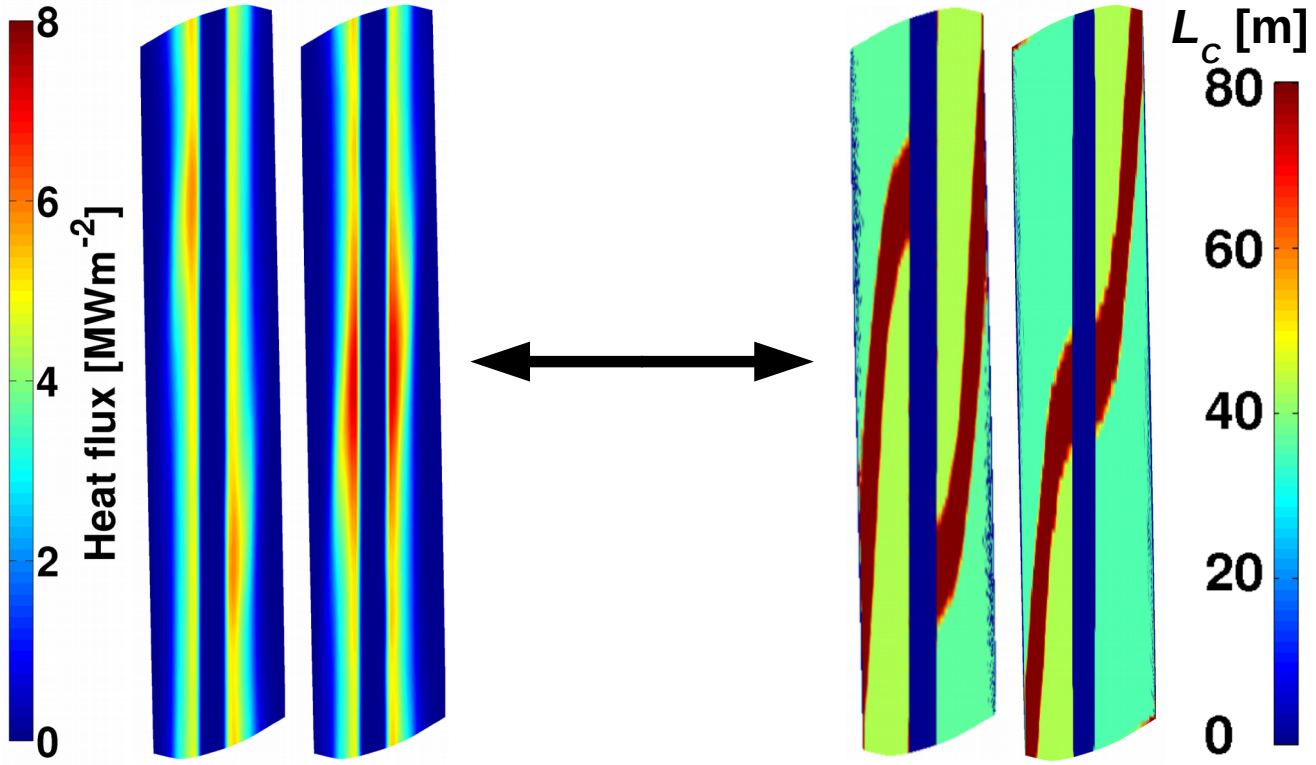

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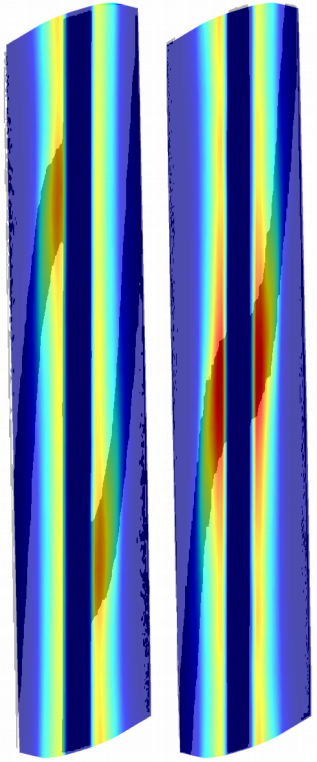
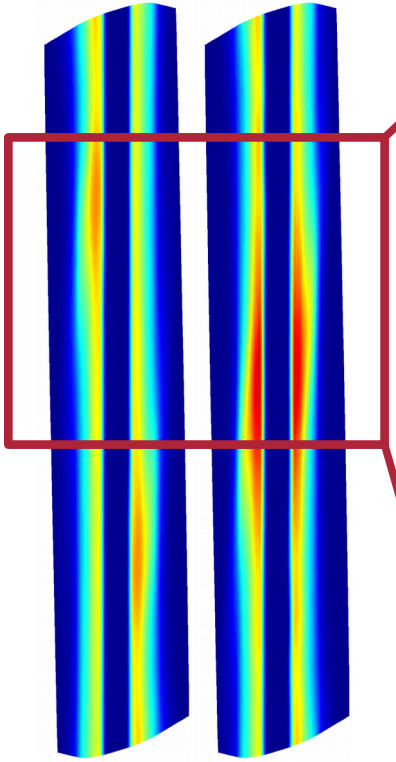


de-optimized
(ι_{edge}~0.91)

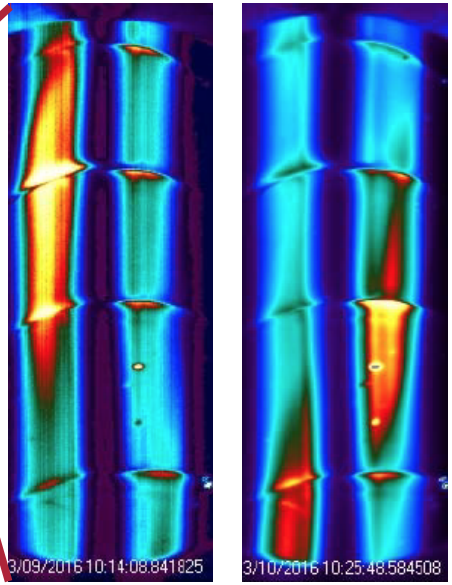
Change of rotational transform: limiter heat load patterns strongly correlated to distribution of L_c

Heat fluxes predicted by EMC3-EIRENE



optimized (ι_{edge}~0.87)

de-optimized (ι_{edge}~0.91)



IR Thermography

→ T_{surf}

F. Effenberg, Y. Feng et al., IAEA, 2016

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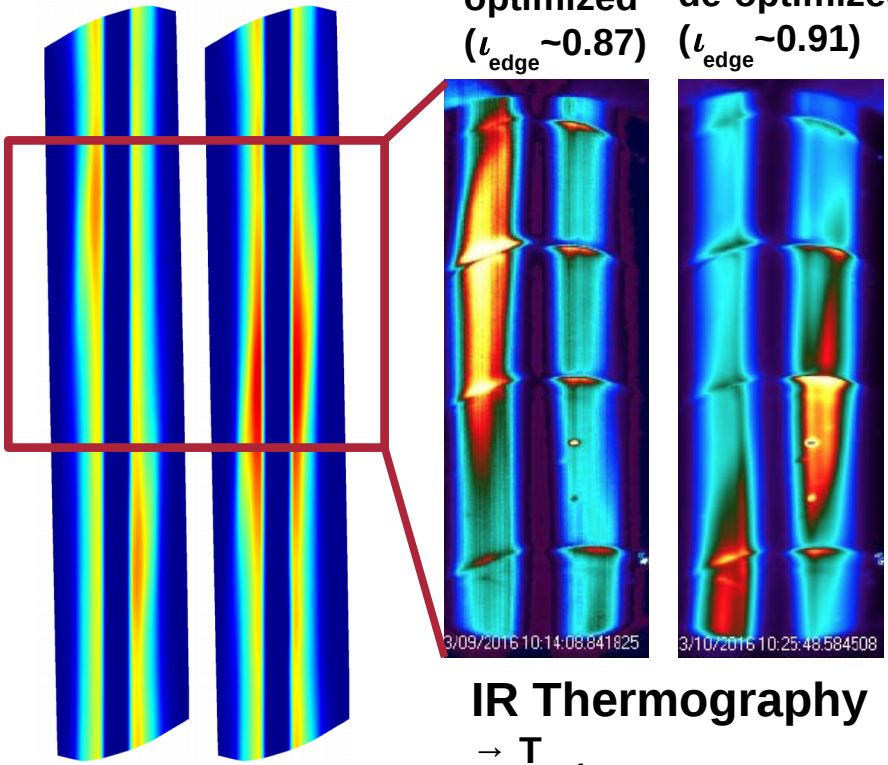

optimized (ι_{edge}~0.87)

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IR Thermography

→ T_{surf}

Good qualitative matching between predictions and measurement

F. Effenberg, Y. Feng et al., IAEA, 2016

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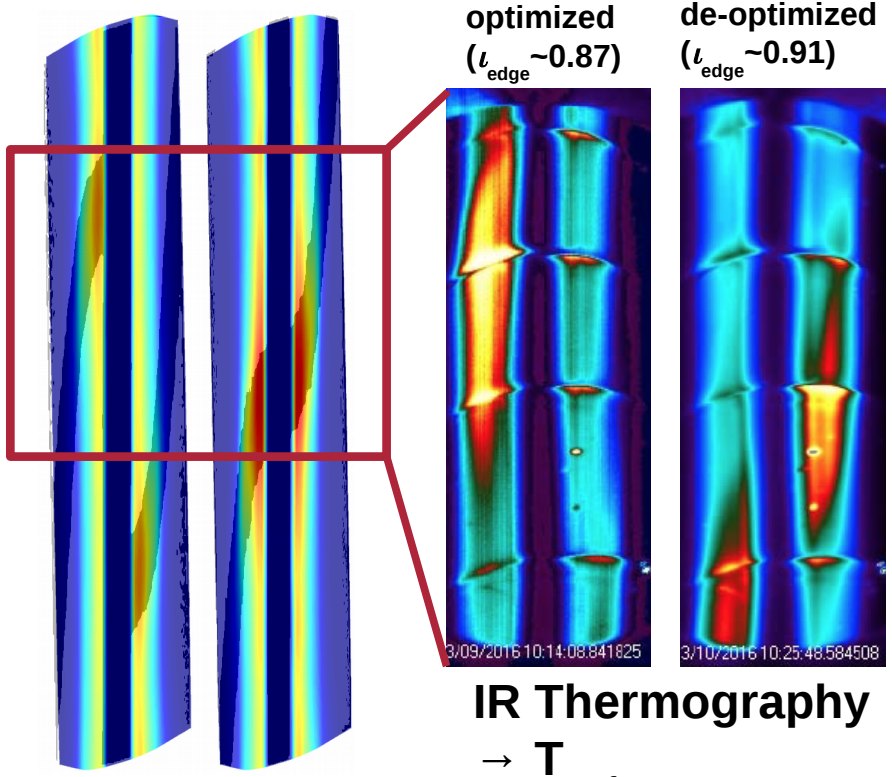


IR Thermography
→ T_{surf}

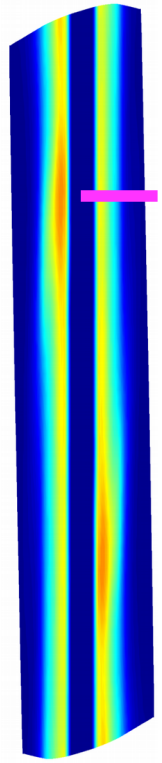
G. Wurden, H. Niemann et al.: CP10.00054 (Mo)

H. Frerichs, F. Effenberg et al.: TP10.00074 (Th)

V. Winters, C. Biedermann et al.: TP10.00073 (Th)

F. Effenberg, Y. Feng et al., IAEA, 2016

Heat fluxes feature different level and decay in near and far SOL and in long and short L_c



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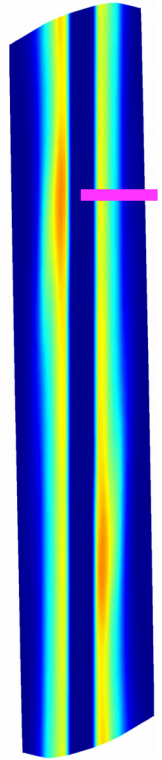
Heat fluxes modeled by EMC3-EIRENE



$q_{||}$

$q_{||Lc=36m}$

$q_{||Lc=43m}$

$q_{||Lc=79m}$

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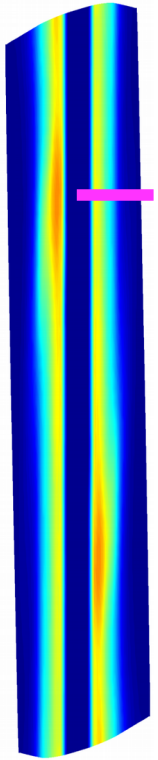
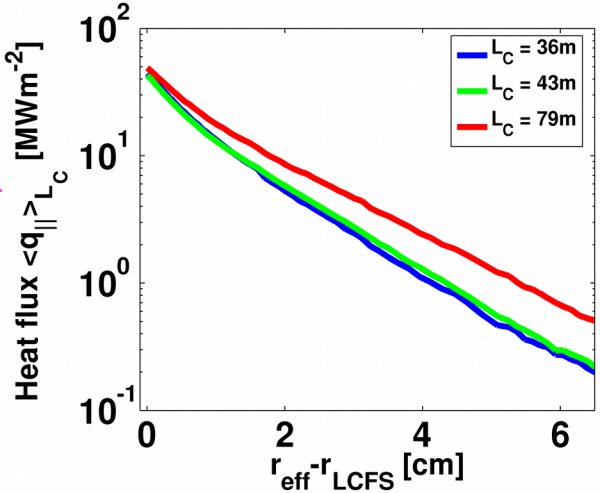
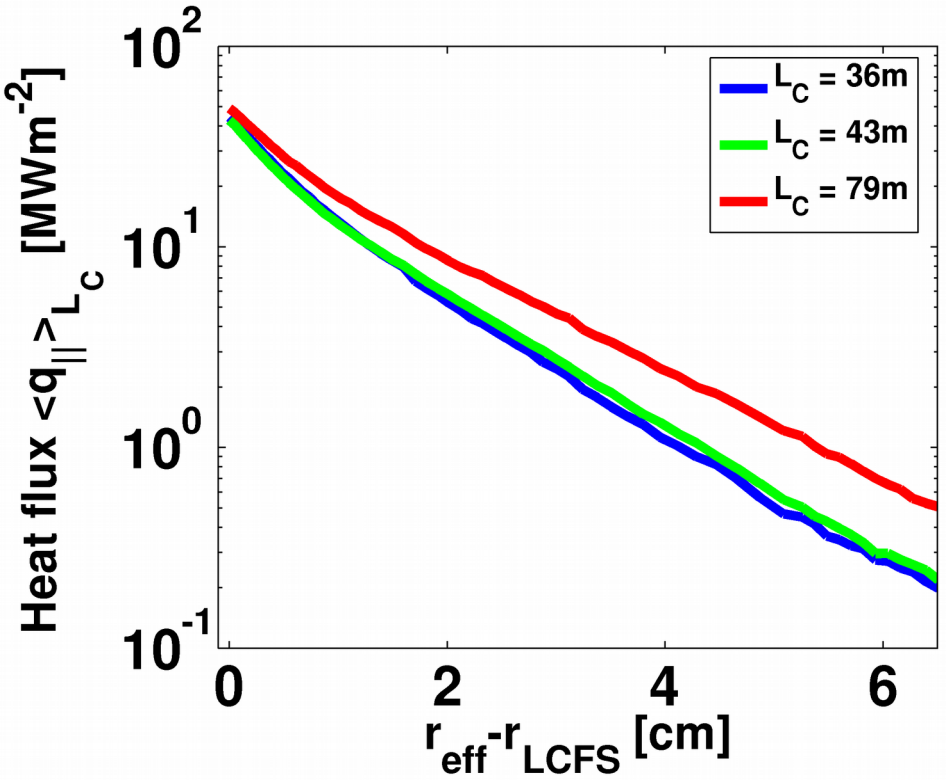




Get radial heat flux profiles (averaged in L_c)

F. Effenberg, Y. Feng et al., IAEA, 2016

Near and far SOL identified in heat flux profile with dependence of heat flux on L_C



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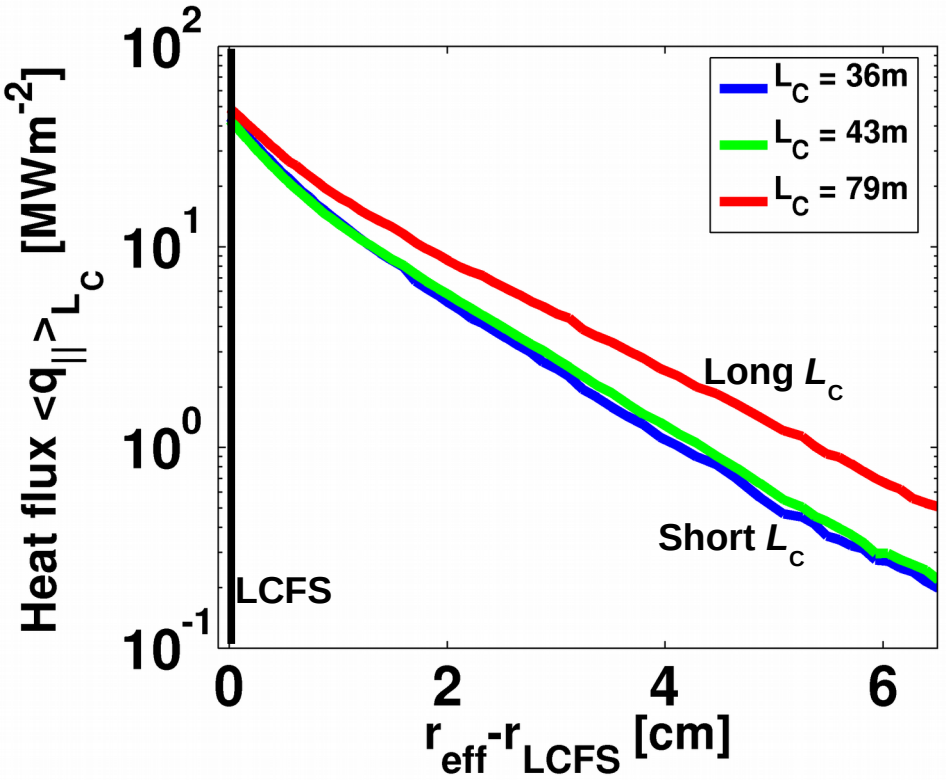

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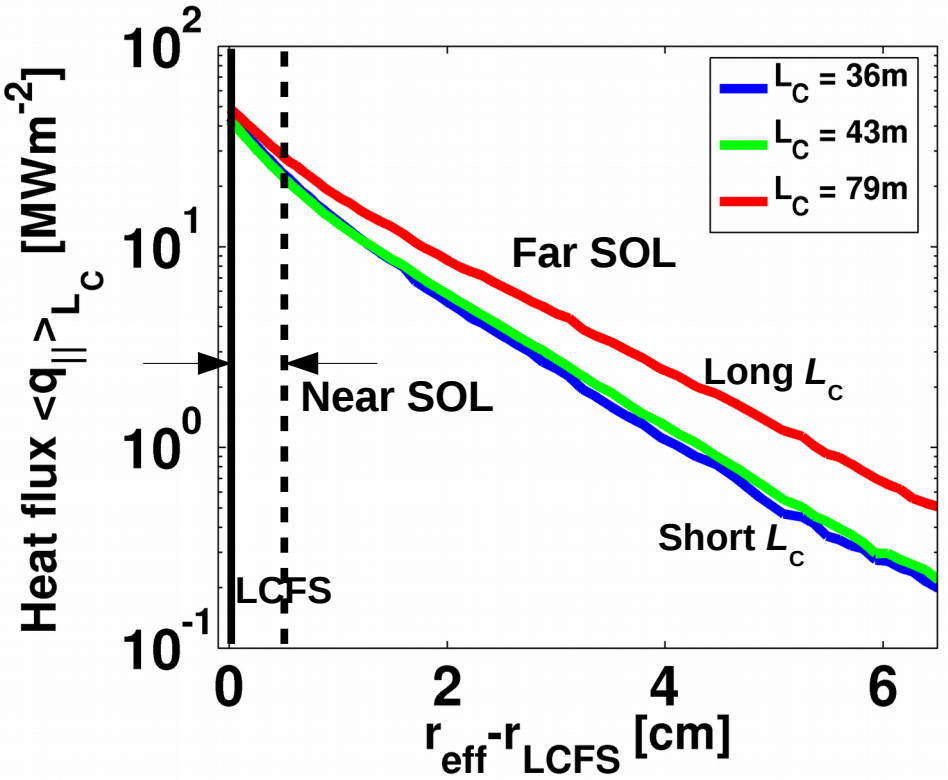

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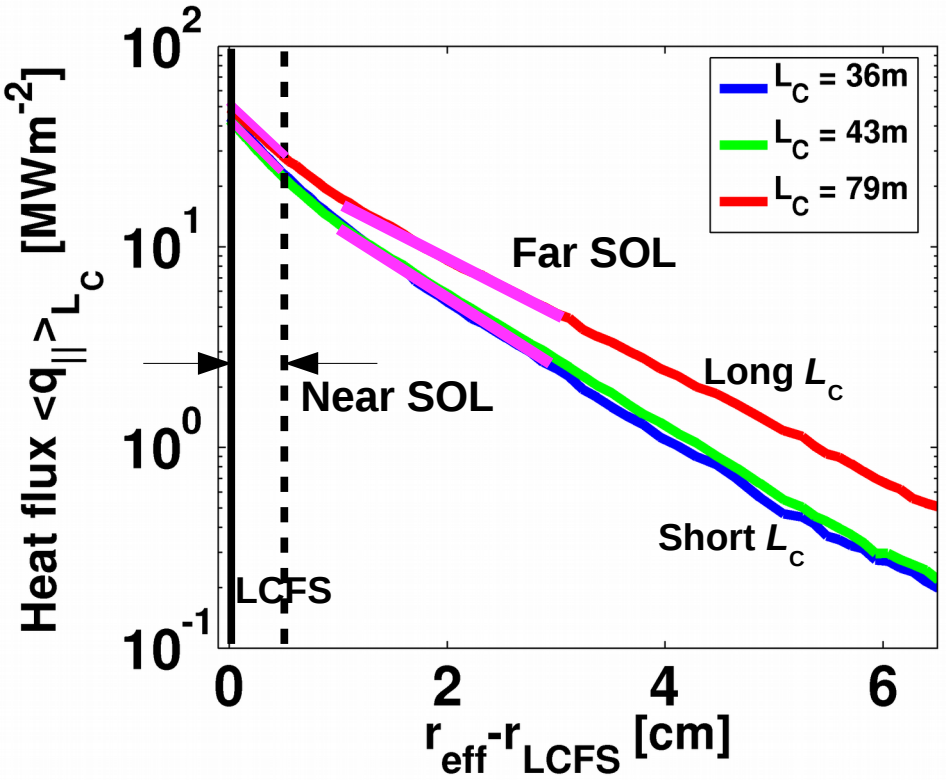

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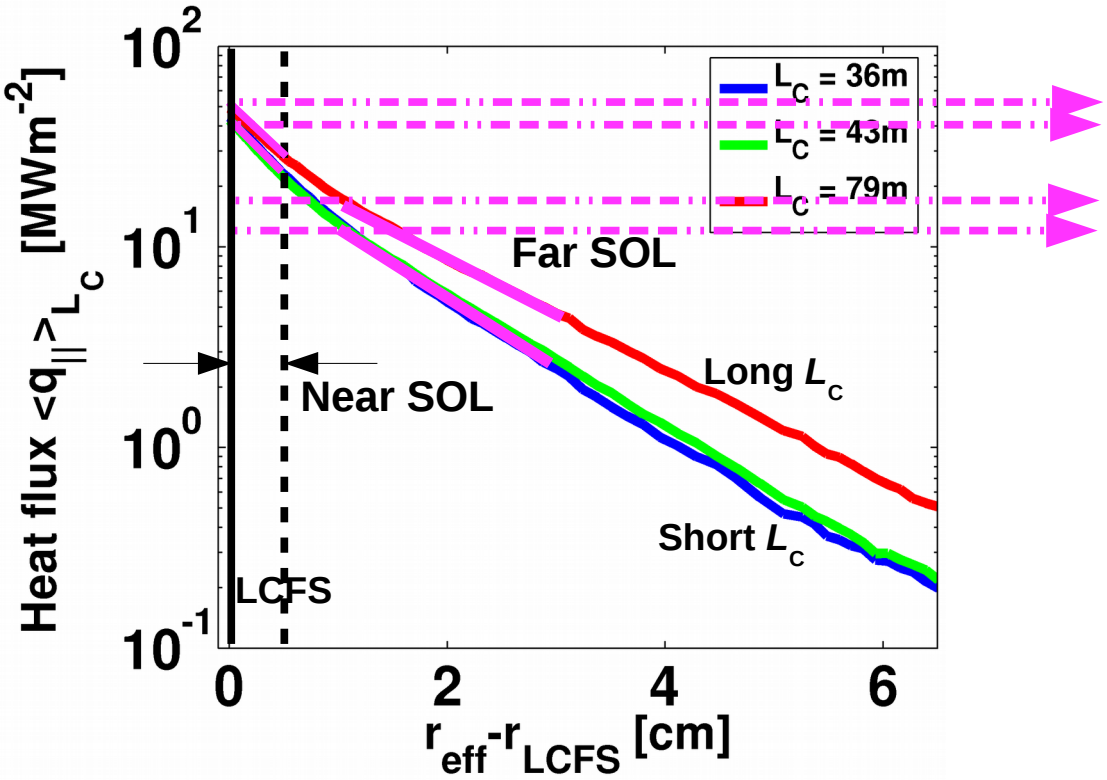

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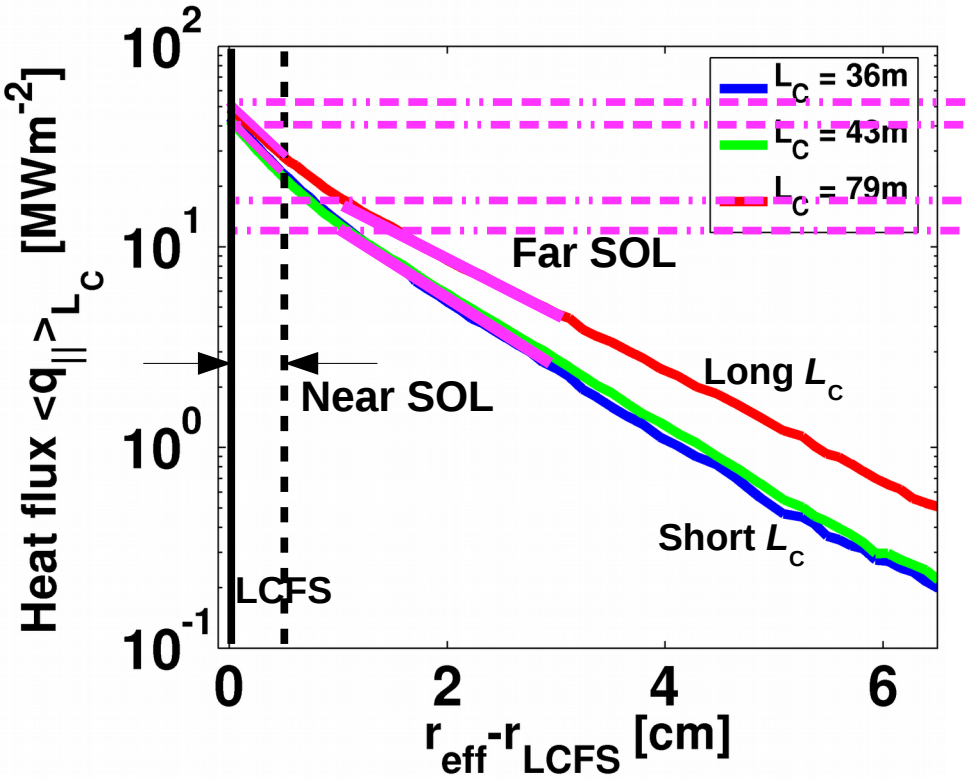
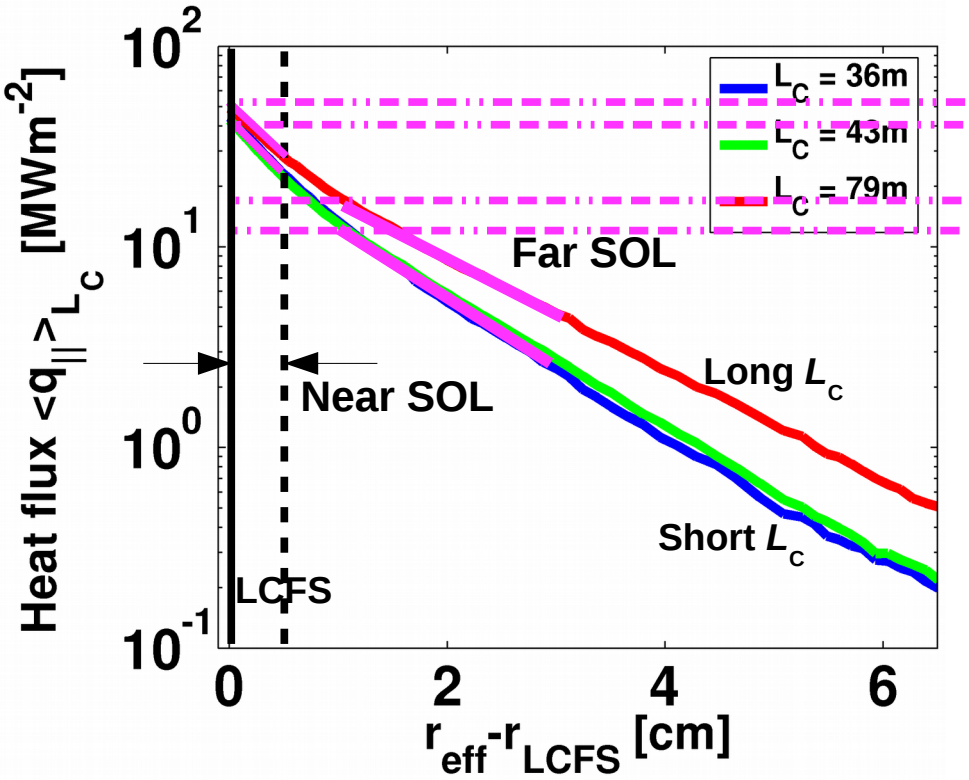


Heat flux characteristics ($\lambda_{q||,near,far}$, $q_{peak,near,far}$) for near and far SOL for long and short L_c

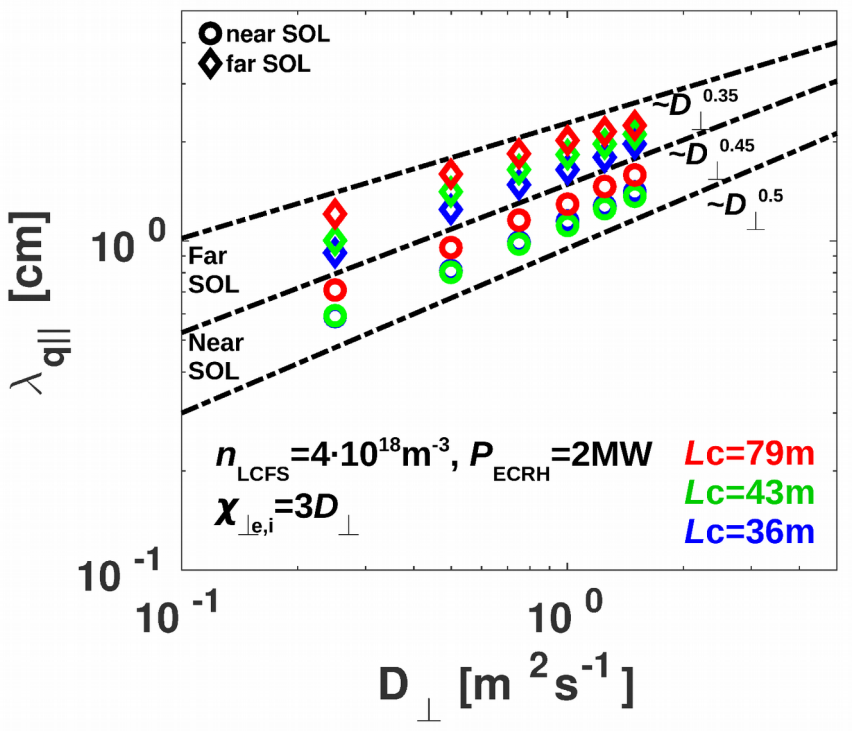
Near and far SOL identified in heat flux profile with dependence of heat flux on L_c



Heat flux characteristics ($\lambda_{q||,near,far}$, $q_{peak,near,far}$) for near and far SOL for long and short L_c

→ How does ⊥ (anomalous) transport affect $q_{||}$?

Near SOL power width and peak power follow mostly simple SOL scaling ~ $D_{\perp}^{\pm 0.5}$



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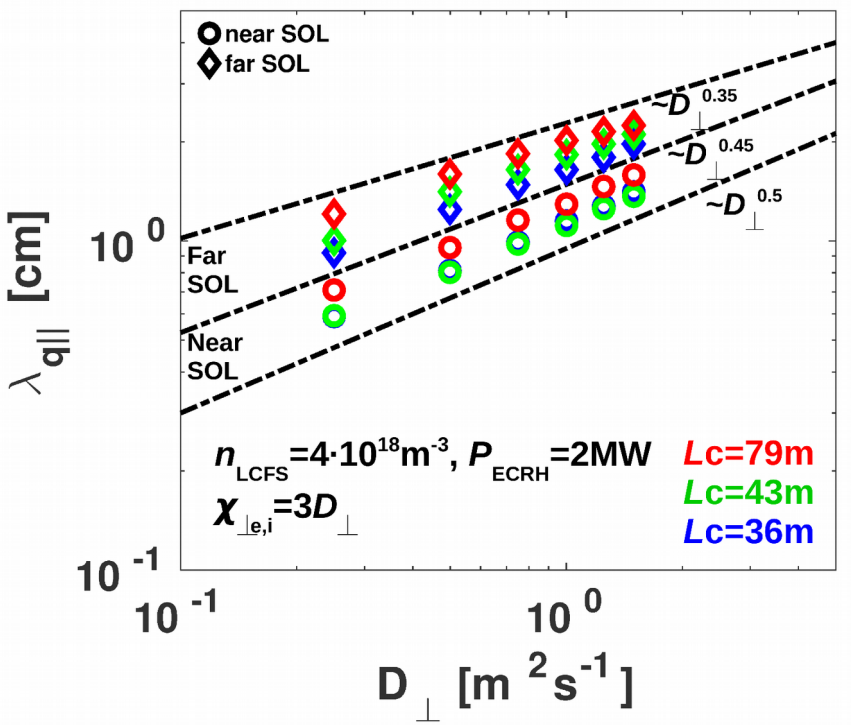
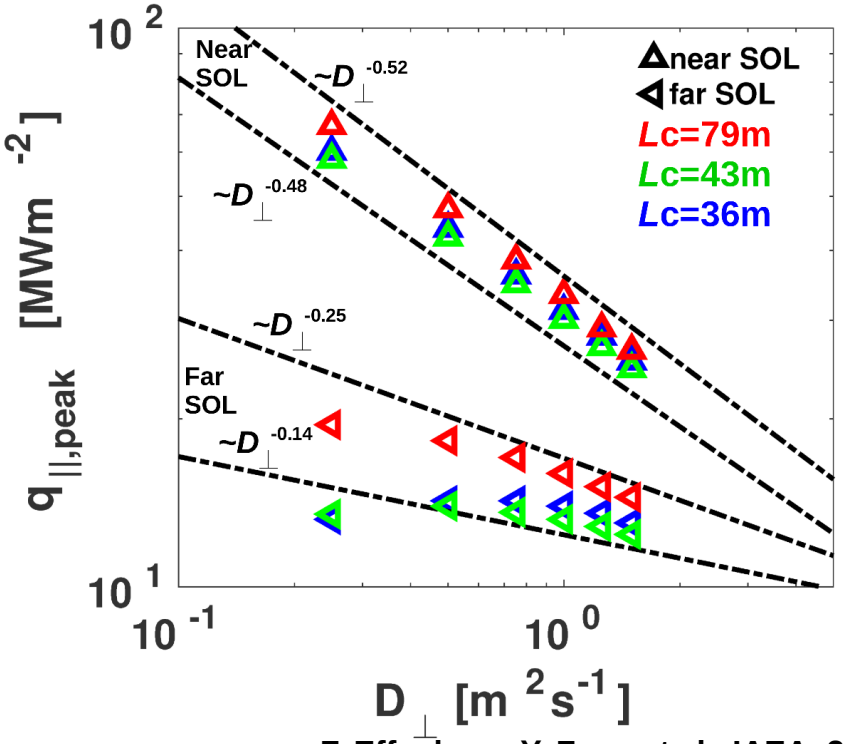
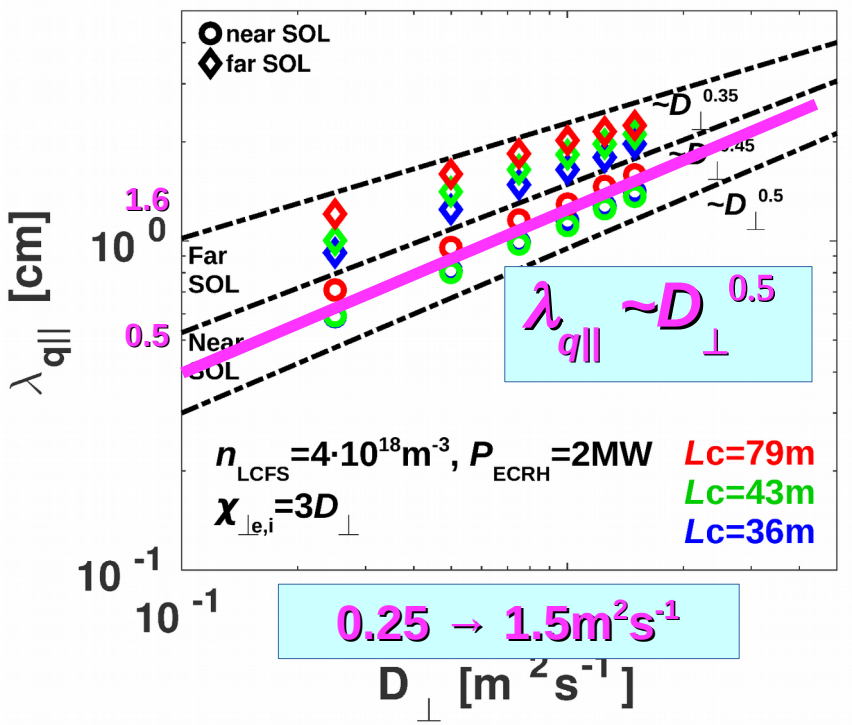
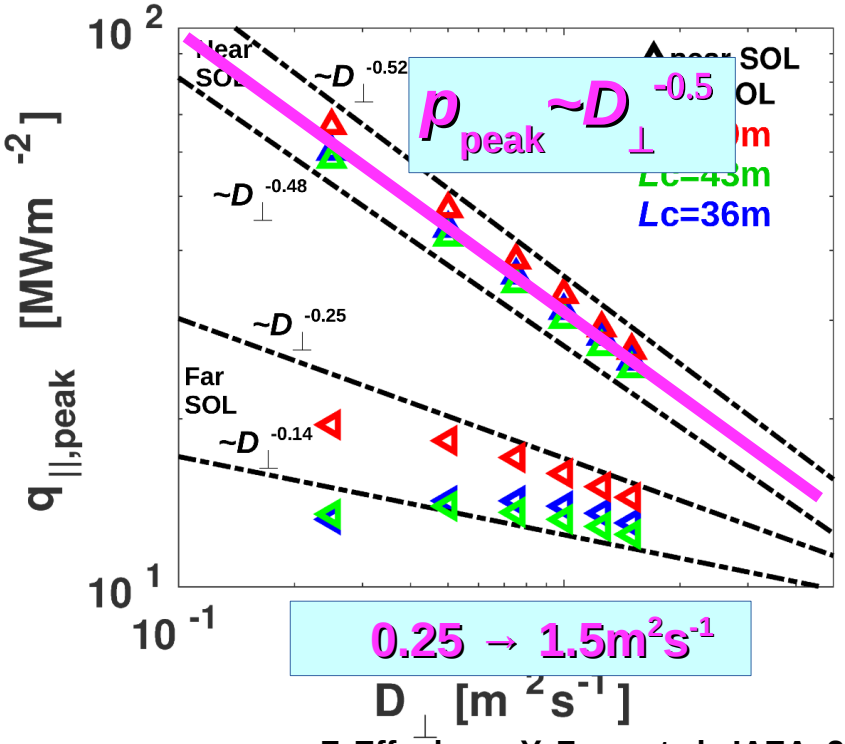




F. Effenberg, Y. Feng et al., IAEA, 2016

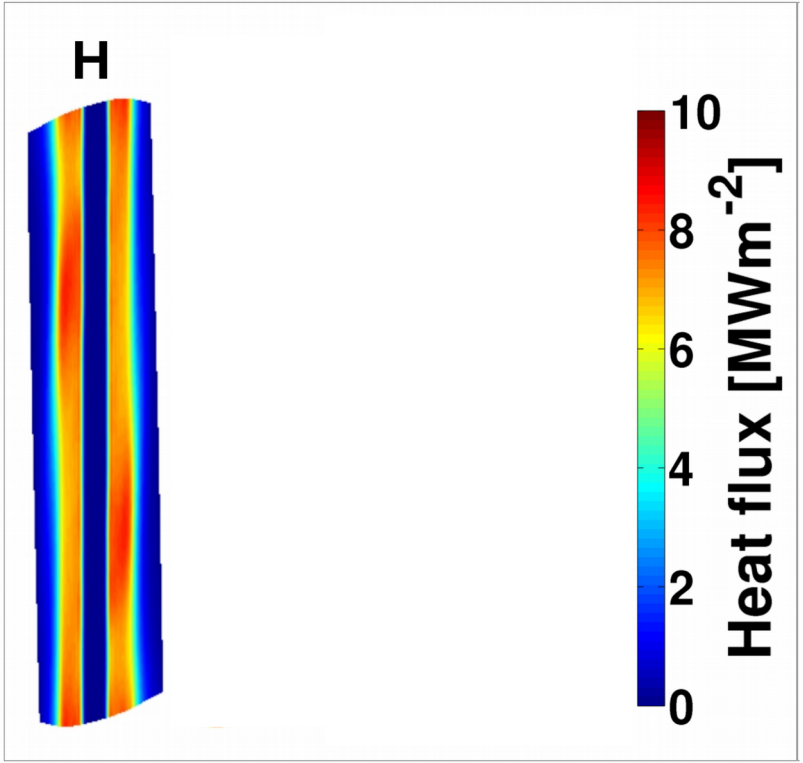
Near SOL power width and peak power follow mostly simple SOL scaling ~ $D_\perp^{\pm 0.5}$



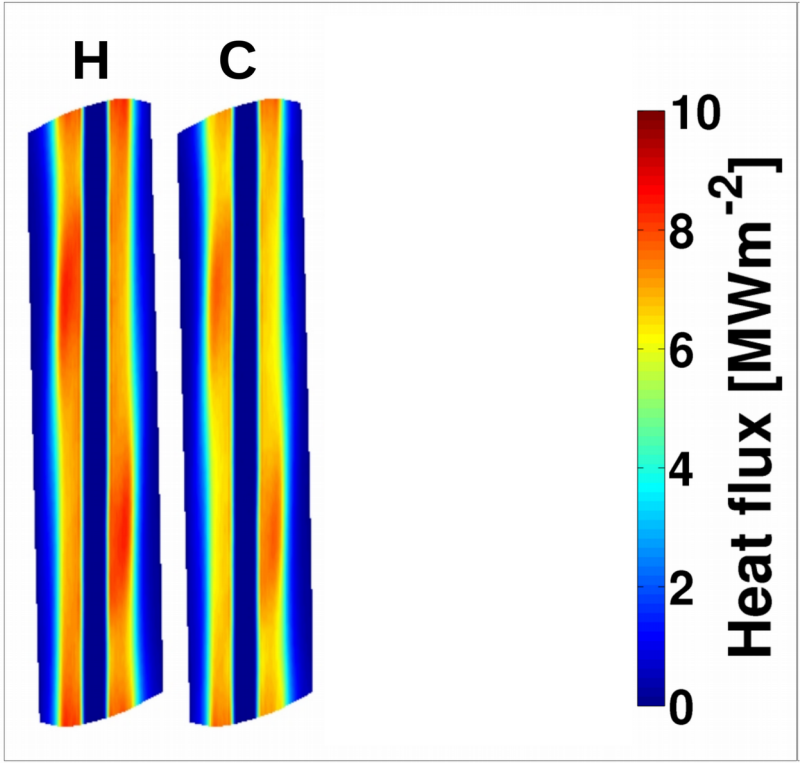


F. Effenberg, Y. Feng et al., IAEA, 2016

Feasibility of heat flux mitigation by radiative edge cooling predicted by 3-D modeling

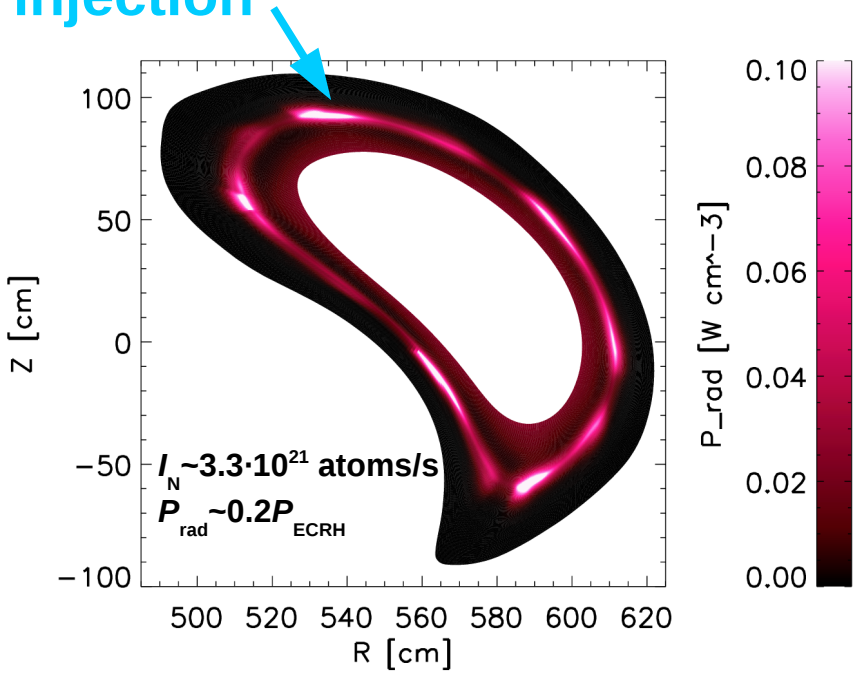


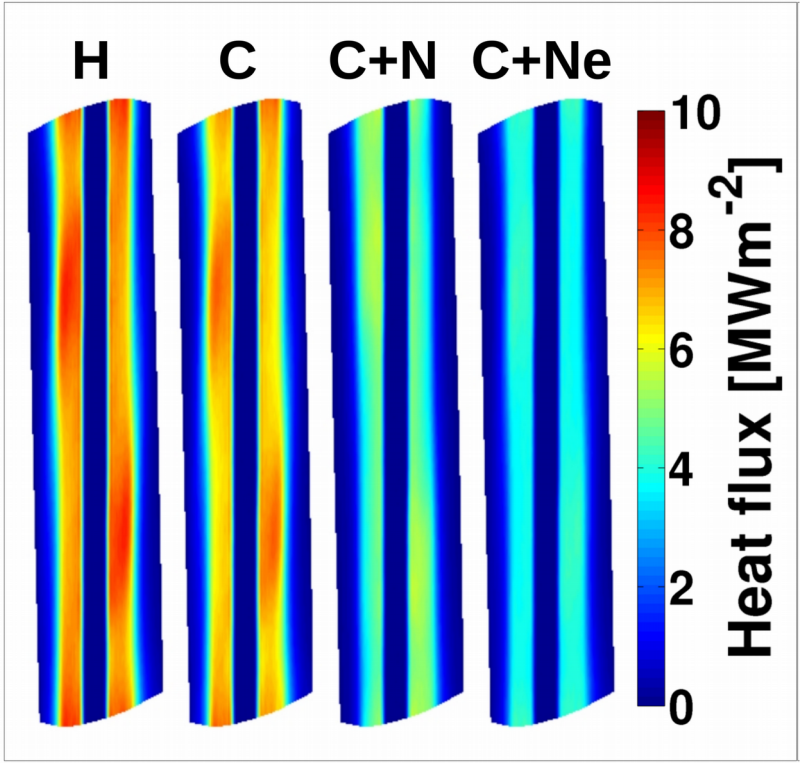
Feasibility of heat flux mitigation by radiative edge cooling predicted by 3-D modeling



Feasibility of heat flux mitigation by radiative edge cooling predicted by 3-D modeling

N injection

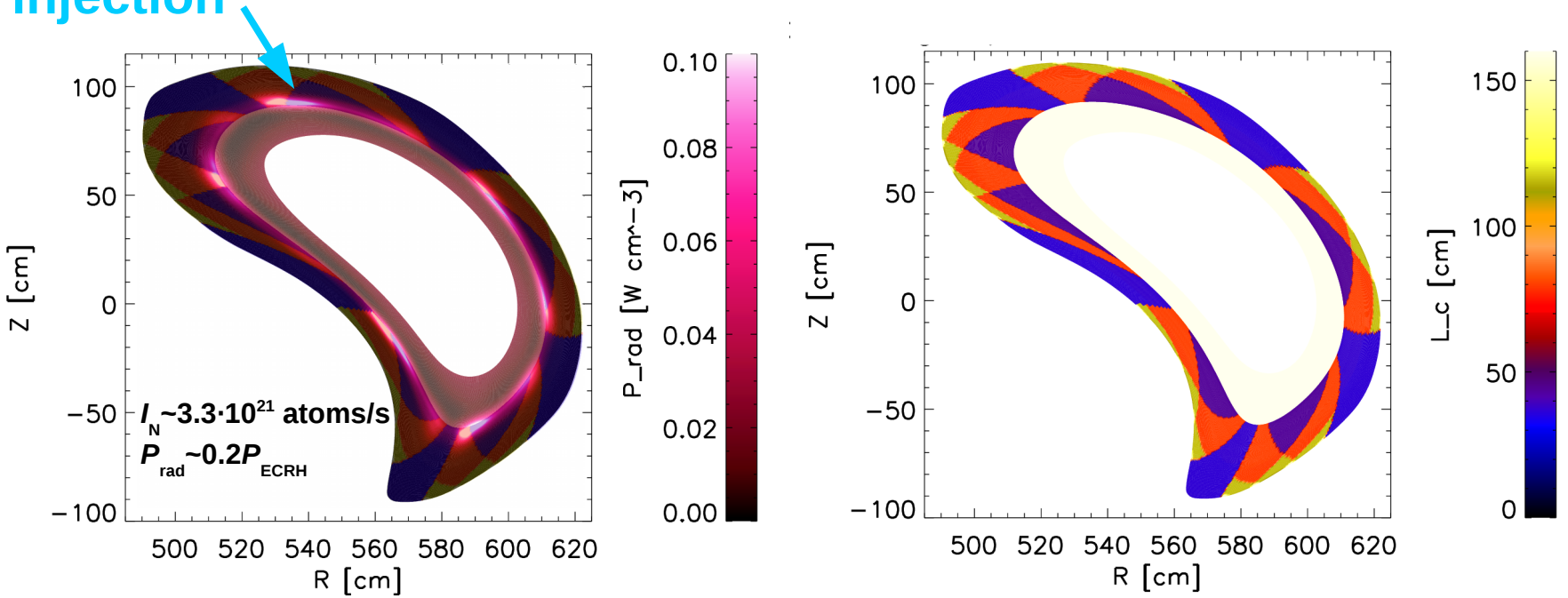




F. Effenberg, Y. Feng et al., Nuclear Fusion, (2016 accepted for publication)

Feasibility of heat flux mitigation by radiative edge cooling predicted by 3-D modeling

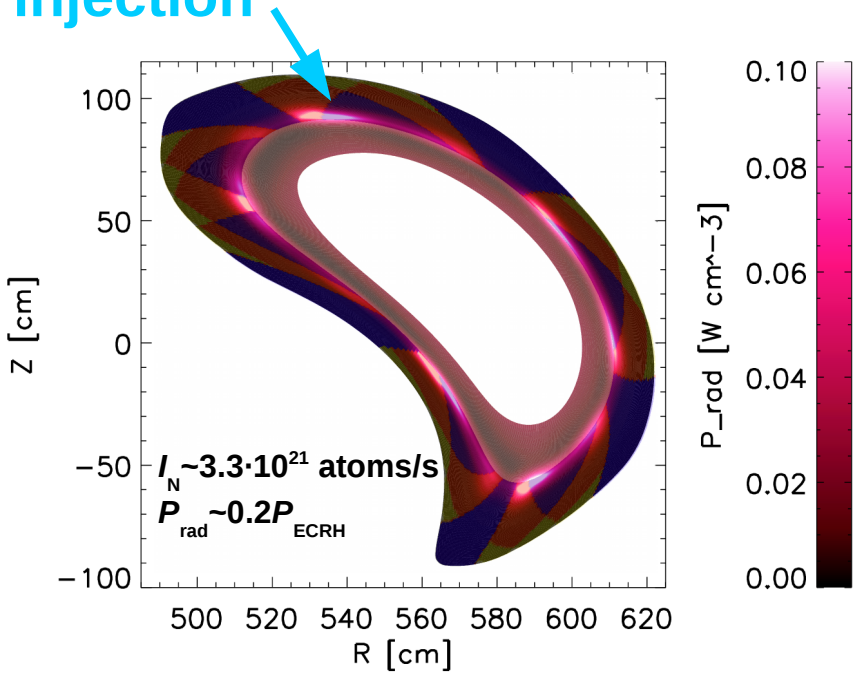
N injection

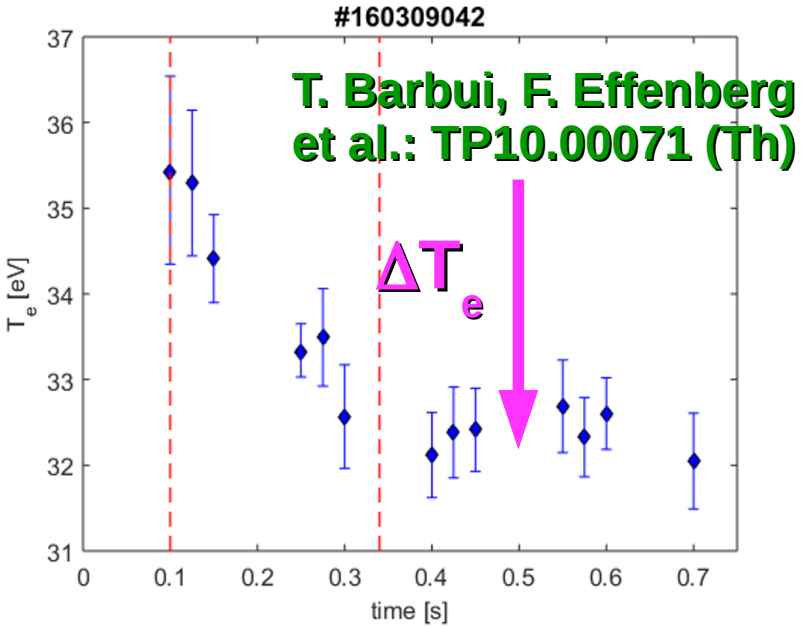


Radiation peaks in longer flux tubes

Feasibility of heat flux mitigation by radiative edge cooling predicted by 3-D modeling

N injection





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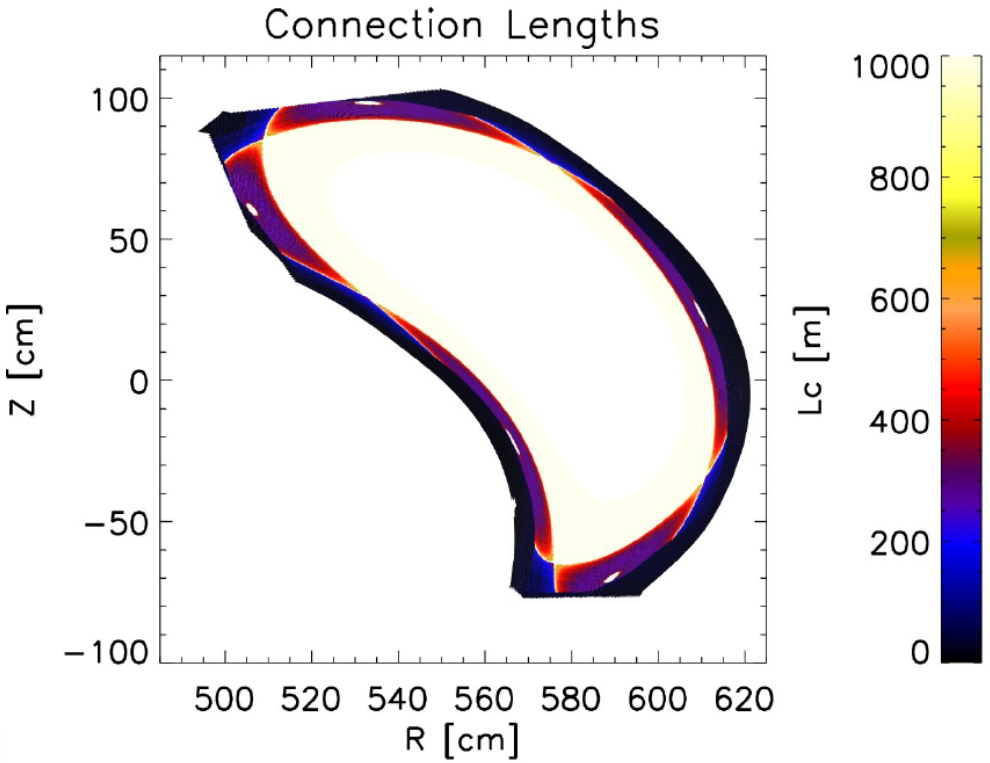
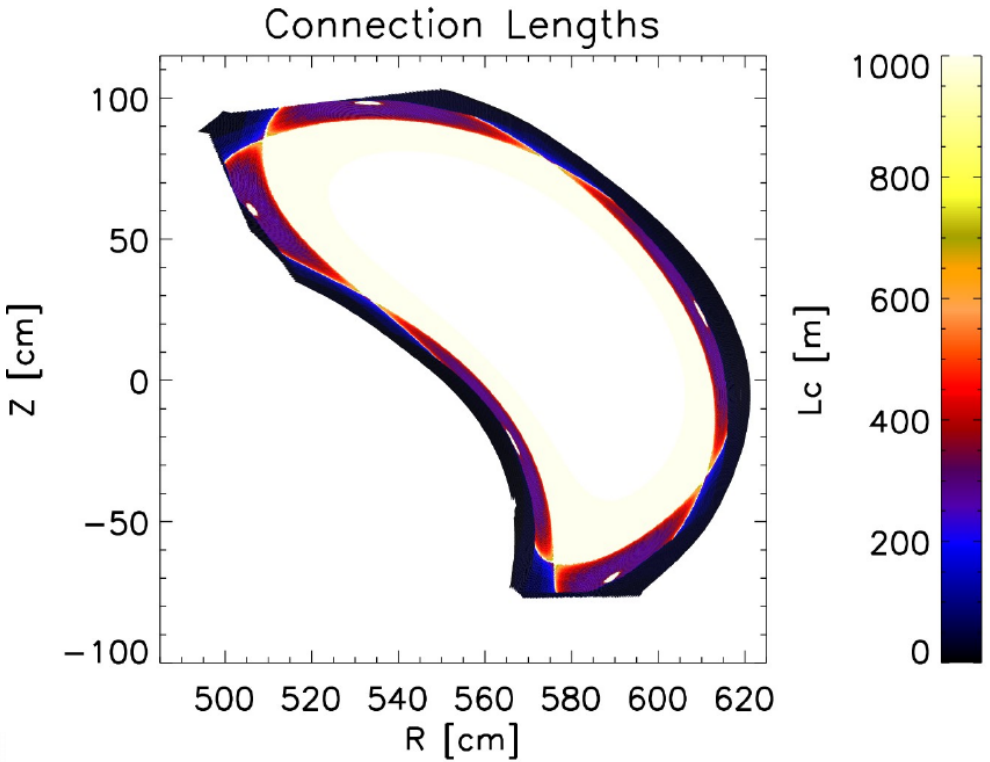
Exploration of heat flux mitigation by impurity seeding for island divertor phase is ongoing

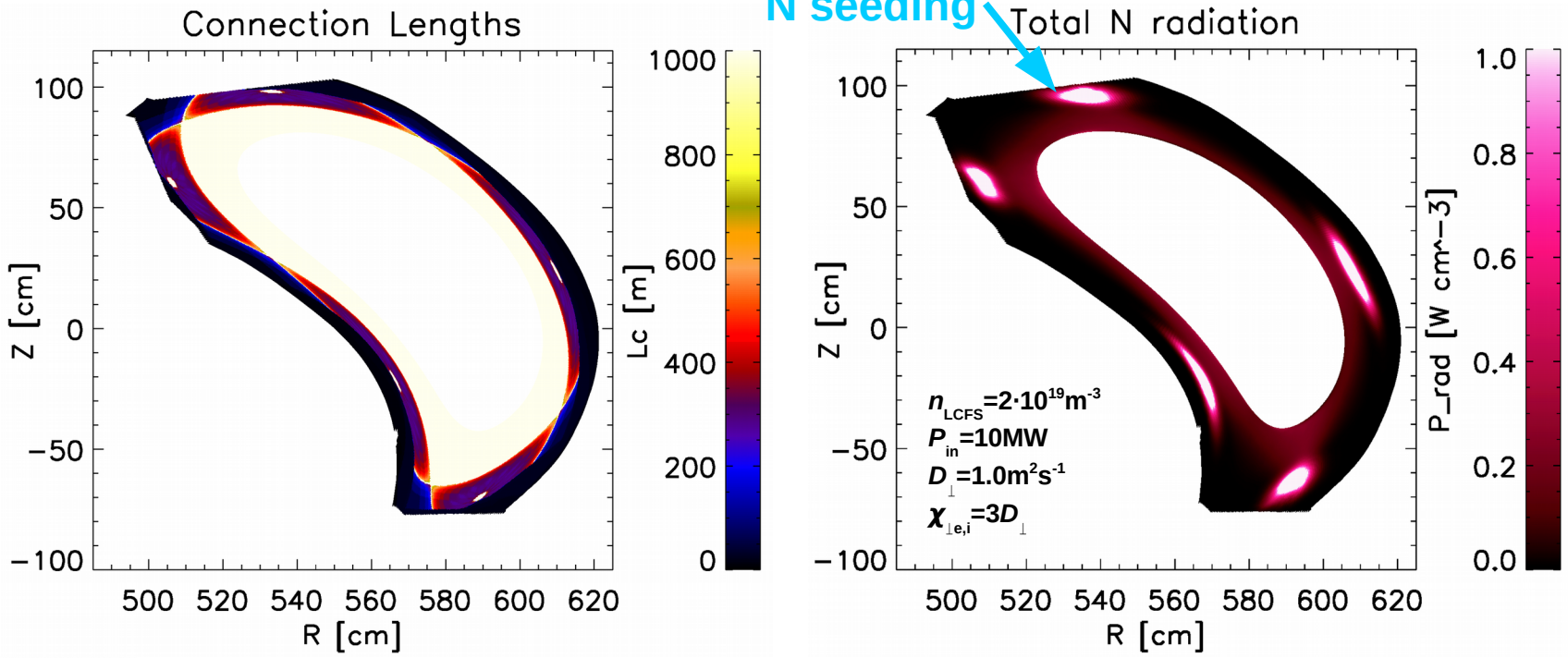


Exploration of heat flux mitigation by impurity seeding for island divertor phase is ongoing



→ L_c increase by a factor ~10

Exploration of heat flux mitigation by impurity seeding for island divertor phase is ongoing



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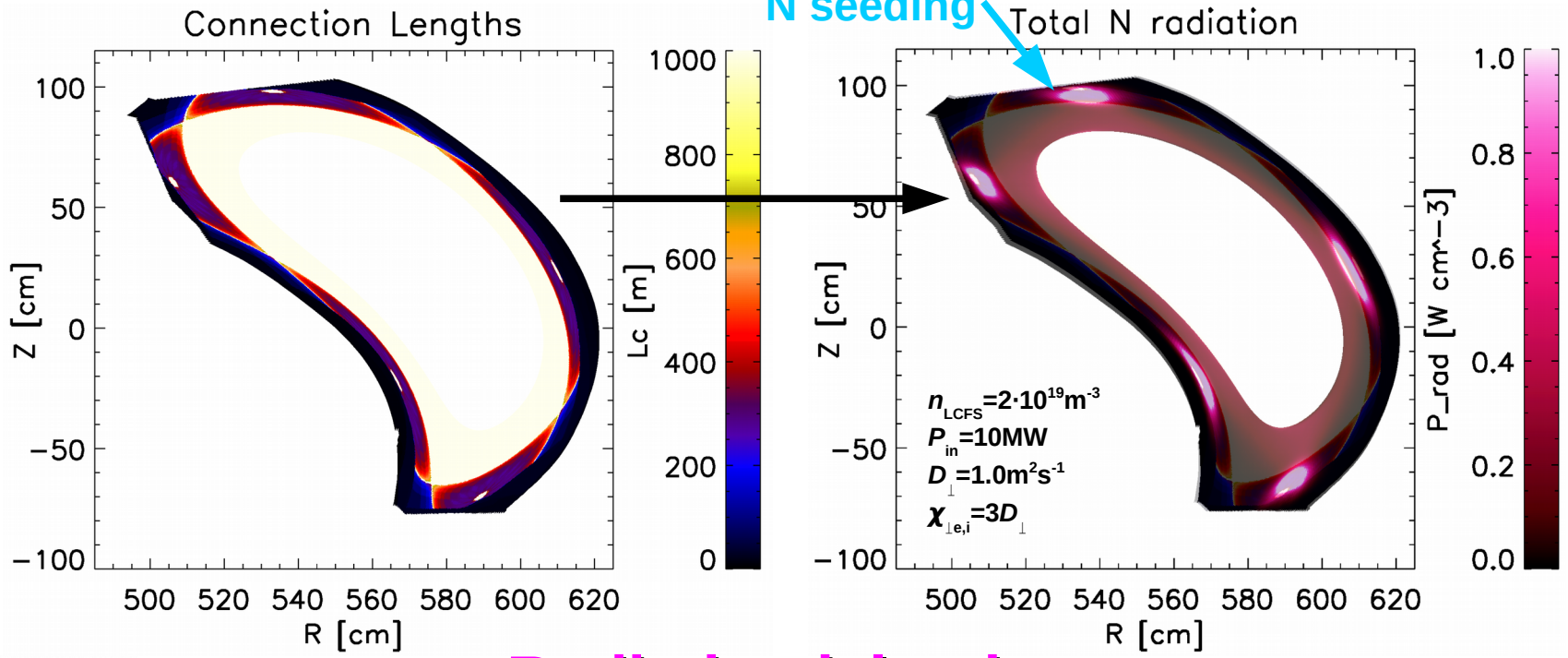

Radiating islands

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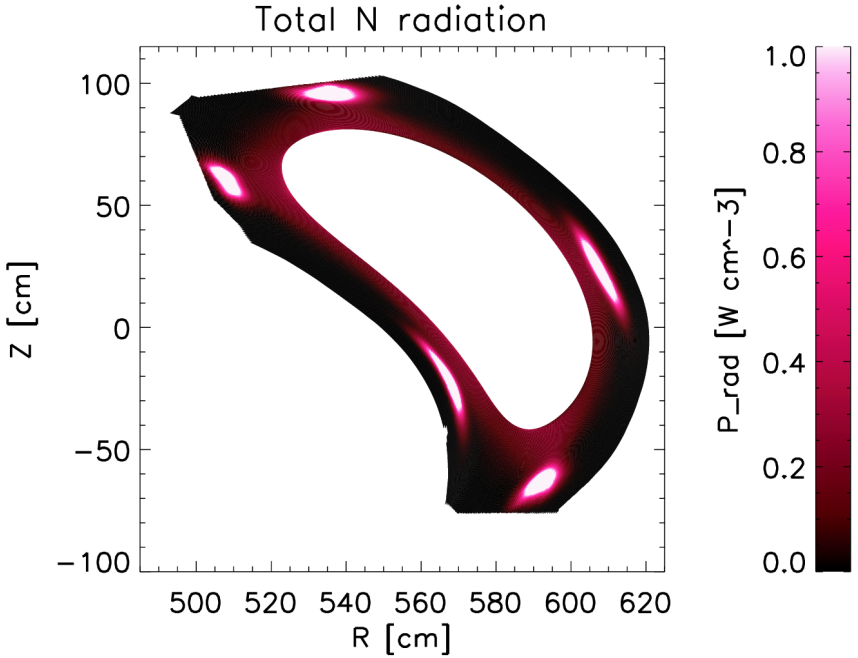
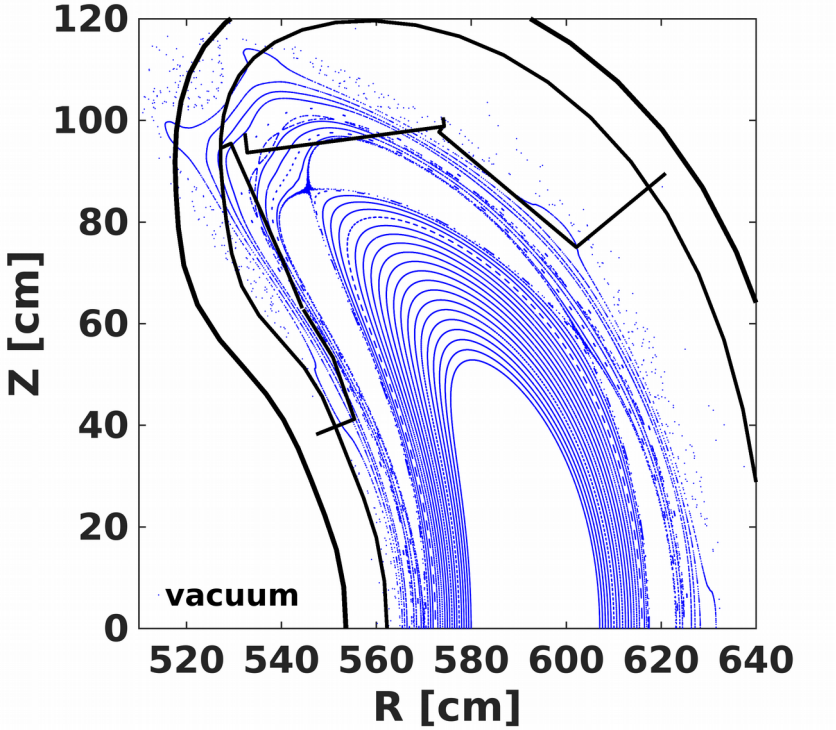
Initial modeling shows accumulation of N injected inside of island divertor domain



Radiating islands potentially beneficial for cooling

High performance operation: how will beta effects affect heat transport and edge cooling? HINT2→ EMC3-EIRENE



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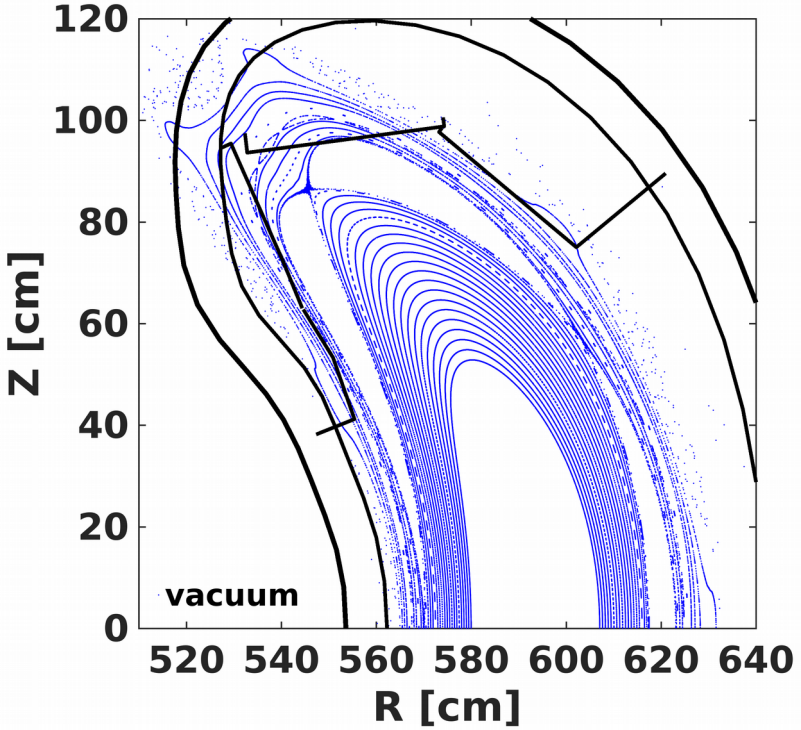
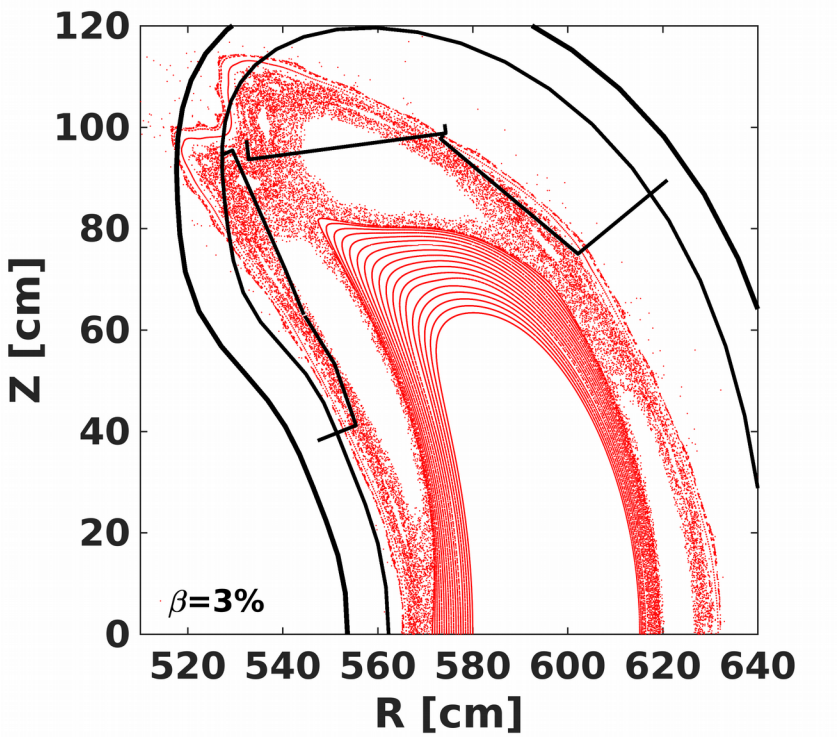
High performance operation: how will beta effects affect heat transport and edge cooling? HINT2→ EMC3-EIRENE





(HINT2 equilibrium: courtesy of Y. Suzuki)

Conclusion

- → Limiter heat fluxes correlated to L_C, confirmed by IR
- → Heat flux characteristics: near and far SOL regime
- → ⊥ transport: q_{peak} and $\lambda_{q||}$ scale for different L_C almost simple SOL like in near SOL
- → Comparison with experimental results is ongoing
- → Radiative edge cooling tested during limiter phase, preparation for Island divertor is in progress

Contributions related to this study

O. Schmitz et al.: TP10.00072 (Th)

T. Sunn Pedersen et al.: AR1.00001 (Mo)

G. Wurden, H. Niemann et al.: CP10.00054 (Mo)

T. Barbui, F. Effenberg et al.: TP10.00071 (Th)

H. Frerichs, F. Effenberg et al.: TP10.00074 (Th)

L. Stephey, F. Effenberg et al.: JI3.00001 (Tu)

V. Winters, C. Biedermann et al.: TP10.00073 (Th)

more results Thursday morning

Ackowledgments (HPC):

This research was performed using the computer resources and assistance of the UW-Madison **Center For High Throughput Computing (CHTC)** and the high performance computing system **”Hydra”** of the **Max-Planck-Society** at **Rechenzentrum Garching (RZG).**

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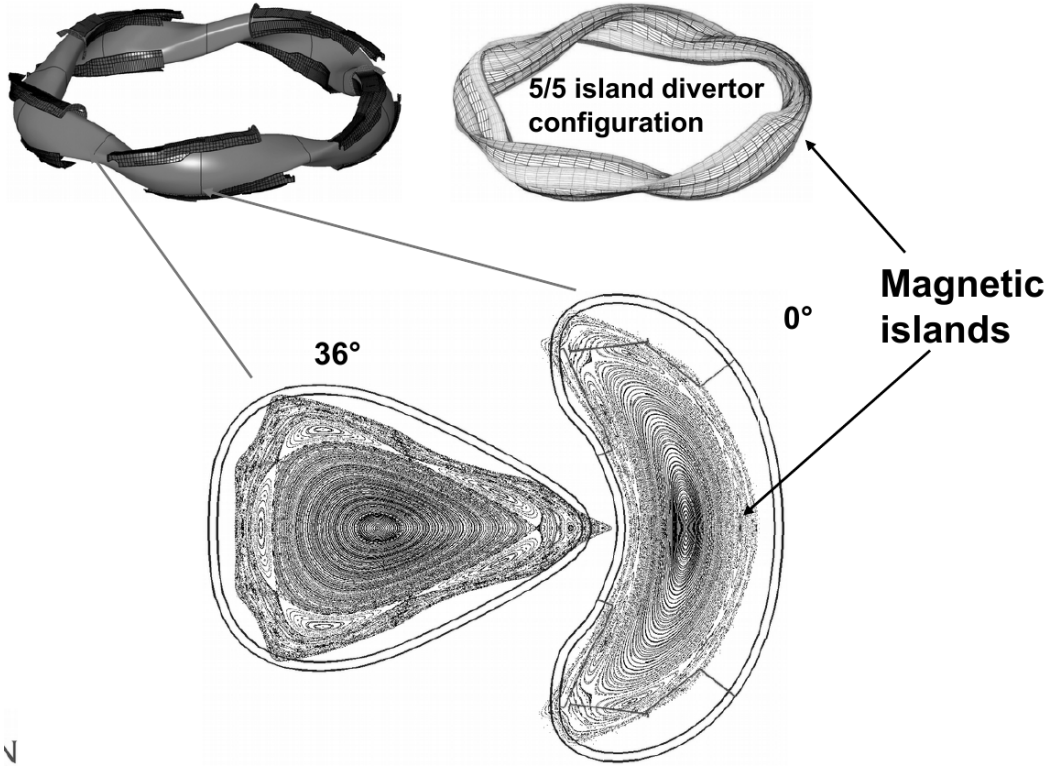
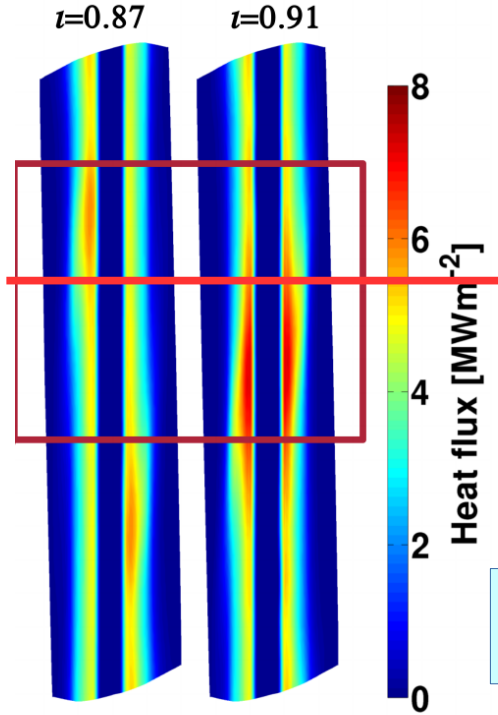
APPENDIX

Island divertor configuration

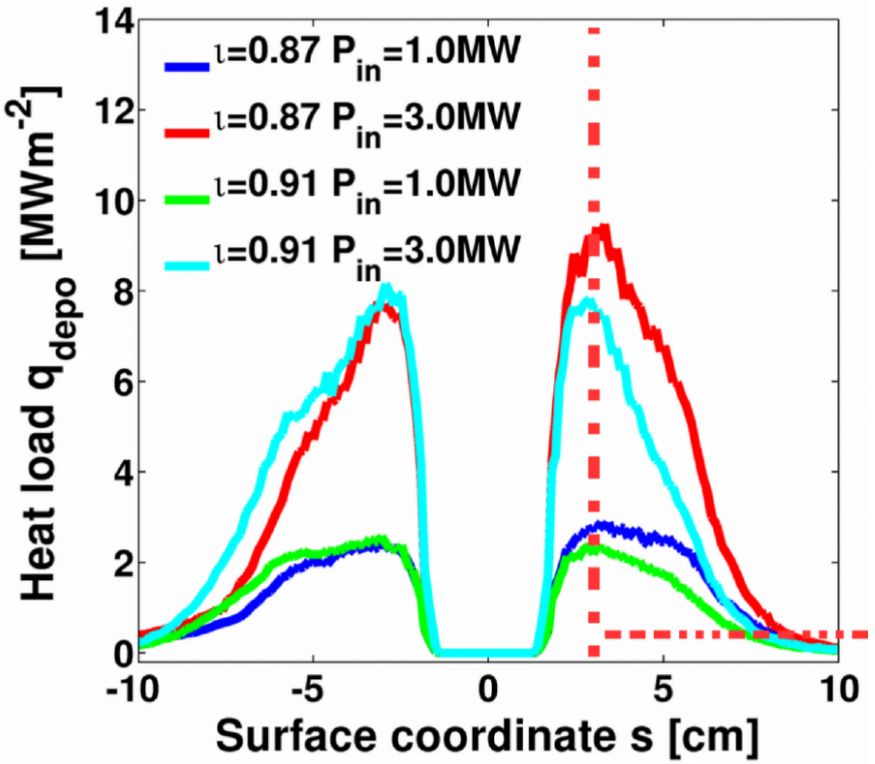


Issue for heat flux analysis: target heat loads strongly modified by target geometry function



EMC3-EIRENE

$q_{depo} \sim q_{||} \sin(\alpha)$



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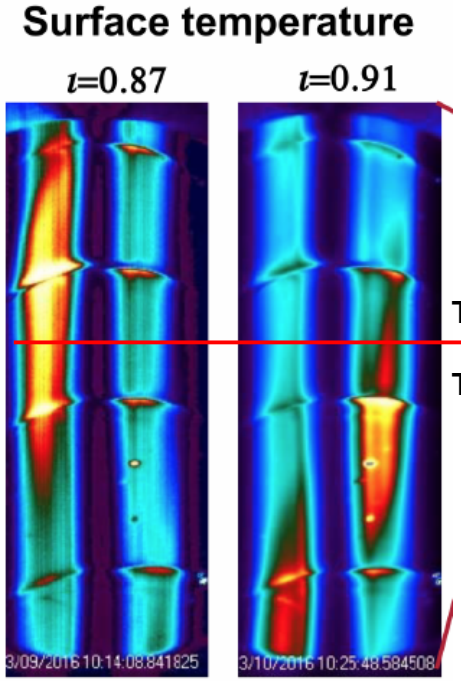
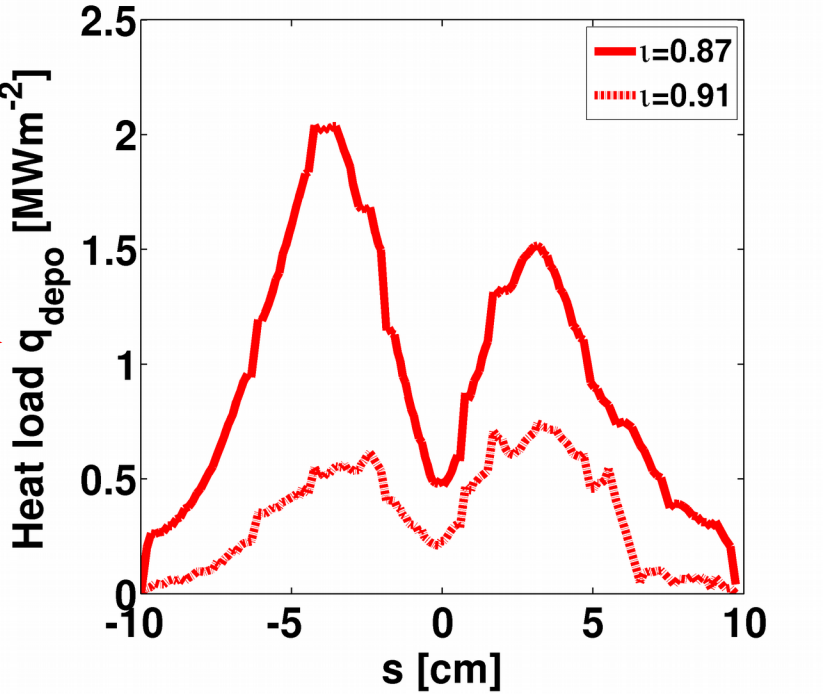
3-D modeling now used to interpret heat fluxes inferred from IR thermography for different iota configurations



IR Thermography

THEODOR Code [2]:

$T_{surf}[C] \rightarrow q_{depo}[Wm^2]$



[2] B. Sieglin, M. Faitsch, A. Hermannn et al., Review of Scientific Instruments, 86, 113502 (2015)

Data courtesy of G.A. Wurden & H. Niemann

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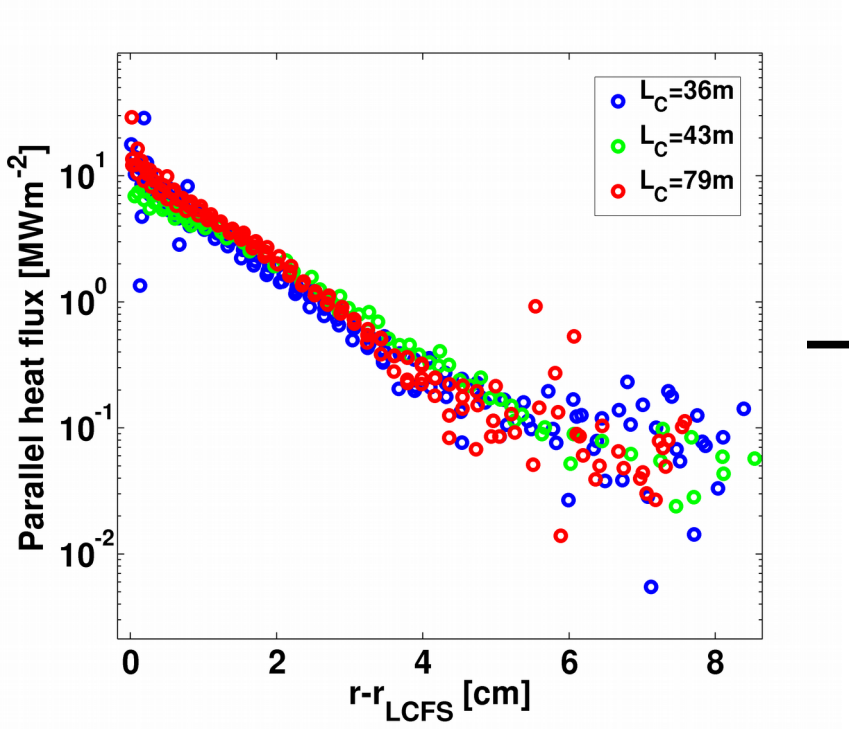
3-D modeling now used to interpret heat fluxes inferred from IR thermography for different iota configurations



→ $\lambda_{q||}$ ~ 1.0-1.4cm

Local measurement!
(→ error fields, transient behavior, impurity mix ….)

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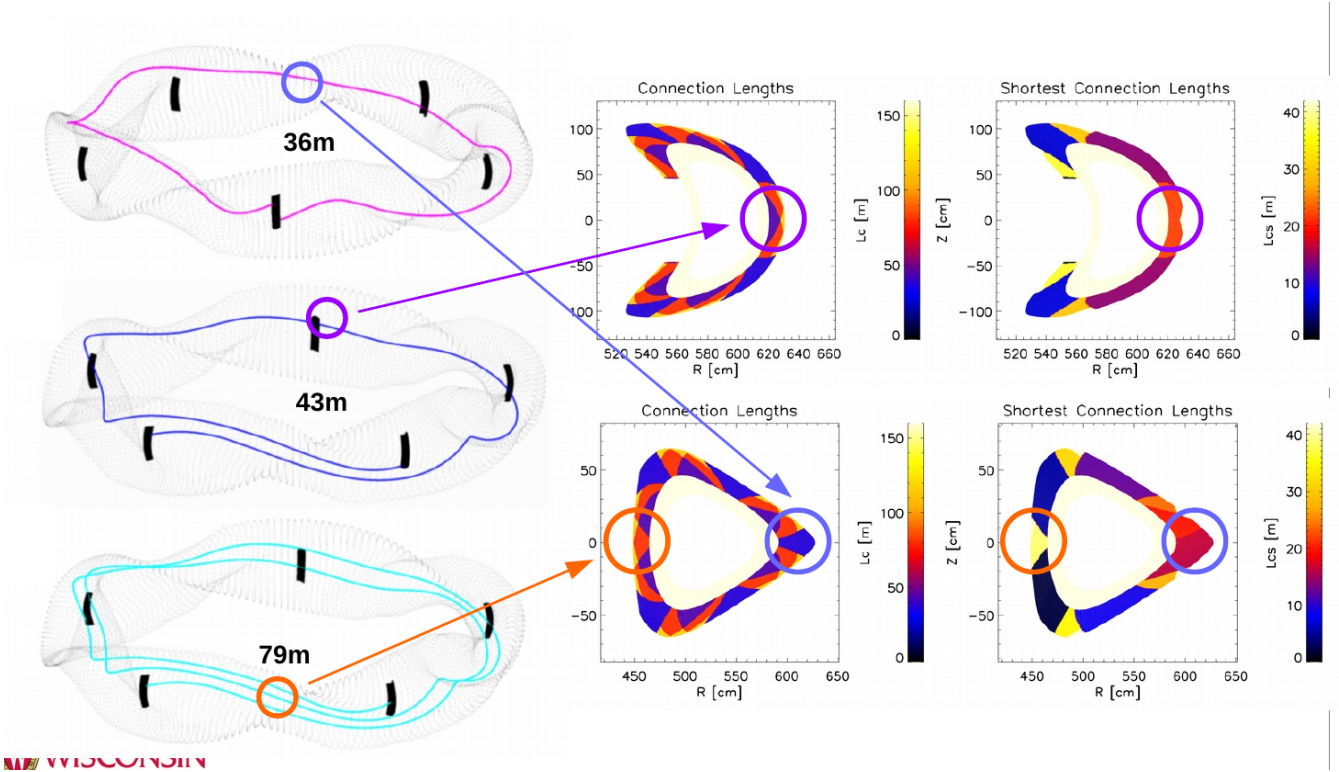
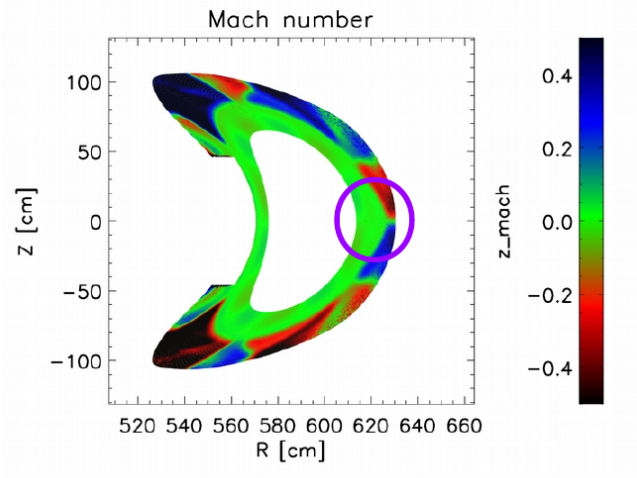
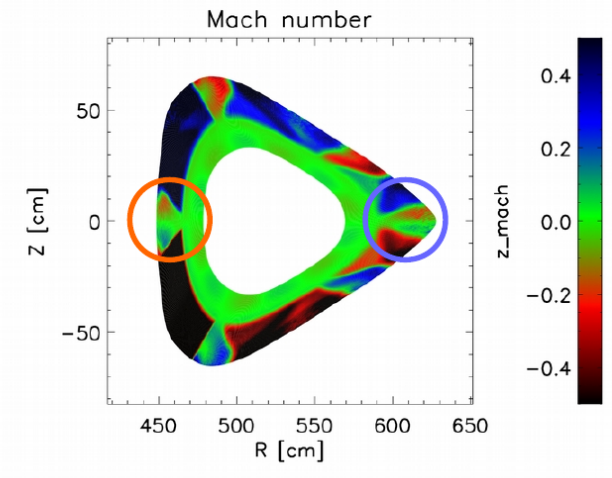
How are upstream positions defined?

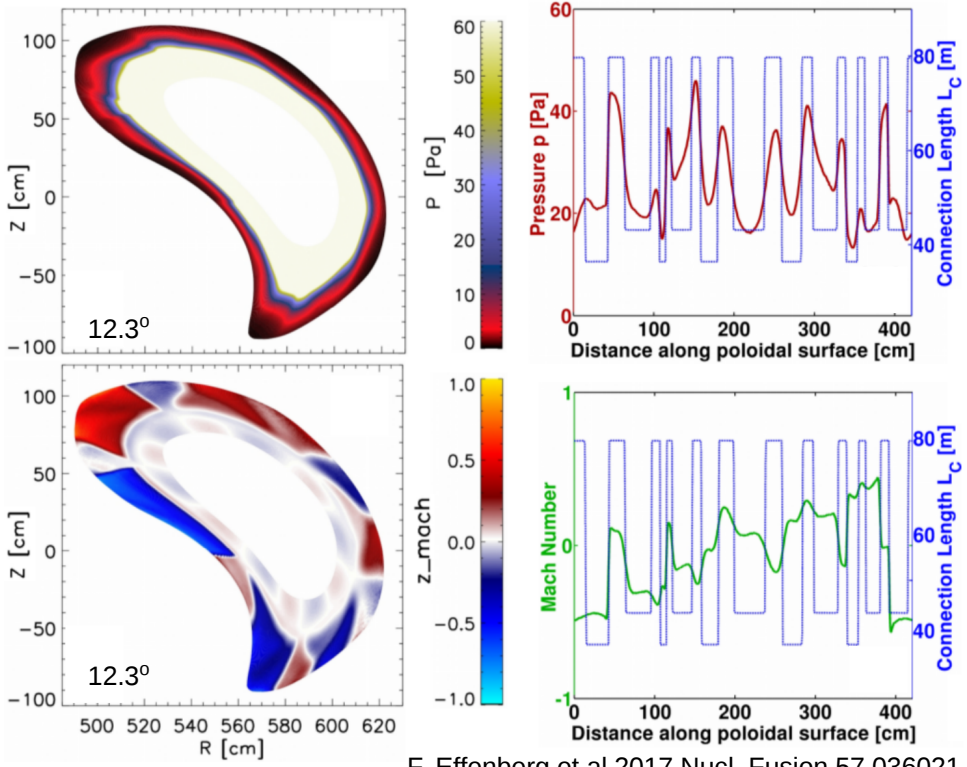


Stagnation points





Plasma pressure is modulated in correlation to L_C and drives counter streaming flows



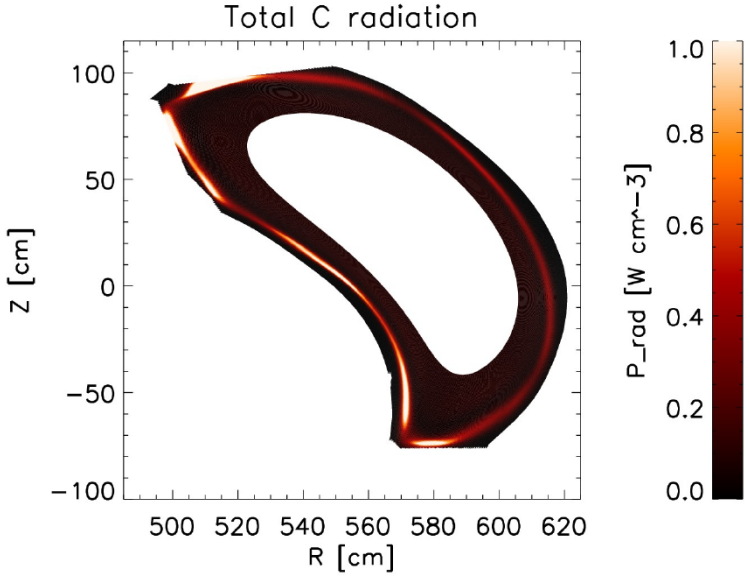
1-D poloidal scan:
$p(\theta_{pol}) \sim L_C(\theta_{pol})$

Flow patterns depend on L_C and shortest distance to target $L_{C,shortest}$

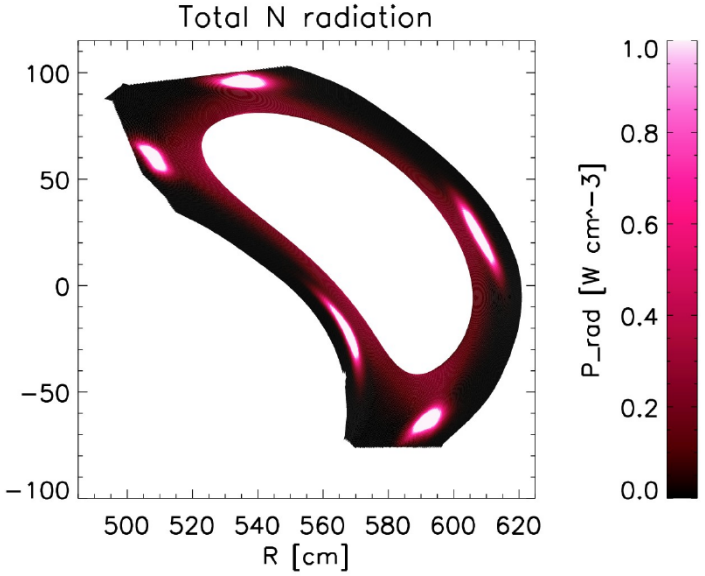
F. Effenberg et al 2017 Nucl. Fusion 57 036021

Initial modeling shows accumulation of N injected inside of island divertor domain

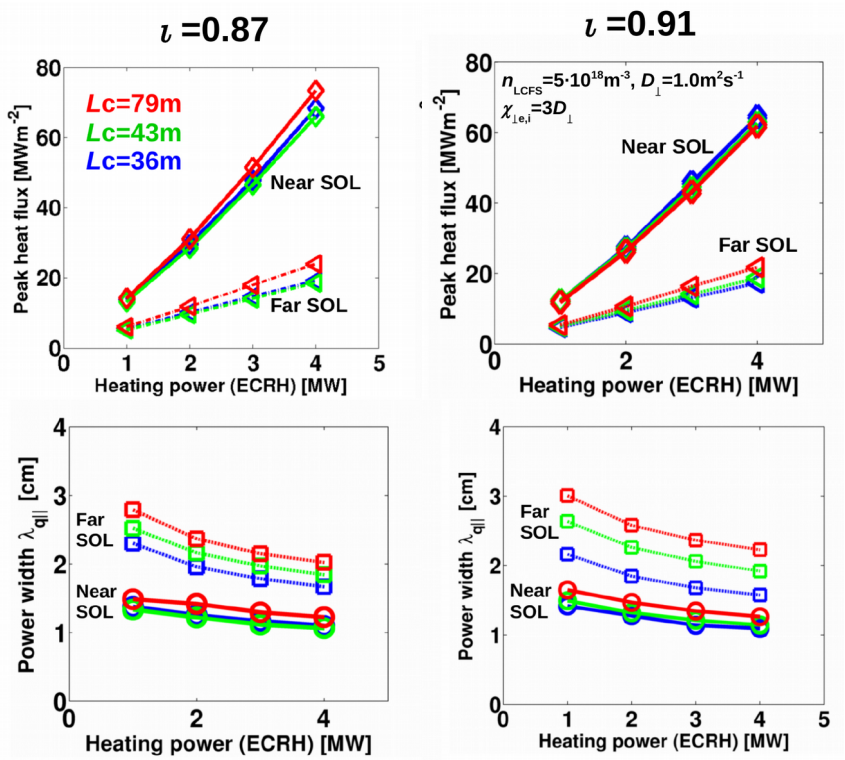
Cooling and detachment based on intrinsic carbon?



Impurity seeding → radiating islands



Strong linear dependence of heat flux level on P_{ECRH}



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The edge transport model

Particle balance

$$\nabla \cdot [n_i u_\parallel \mathbf{e}_\parallel - D_\perp \underline{\mathbf{I}}_\perp \cdot \nabla n_i] = S_p. \tag{A1}$$

Parallel momentum balance

$$\nabla \cdot \mathbf{e}_\parallel [m_i n_i {u_\parallel}^2 - \eta\, \mathbf{e}_\parallel \cdot \nabla u_\parallel] - \nabla \cdot \underline{\mathbf{I}}_\perp \cdot D_\perp \nabla (m_i n_i u_\parallel) = -\mathbf{e}_\parallel \cdot \nabla p + S_m. \tag{A2}$$

Energy balance (electrons and ions)

$$\nabla \cdot \mathbf{e}_\parallel \left[\frac{5}{2} T_e n_i u_\parallel - \kappa_e\, \mathbf{e}_\parallel \cdot \nabla T_e\right] - \nabla \cdot \underline{\mathbf{I}}_\perp \cdot \left[\chi_e n_i \nabla T_e + \frac{5}{2} T_e D_\perp \nabla n_i\right] = -k(T_e - T_i) + S_{ee}, \tag{A3}$$

$$\nabla \cdot \mathbf{e}_\parallel \left[\frac{5}{2} T_i n_i u_\parallel - \kappa_i\, \mathbf{e}_\parallel \cdot \nabla T_i\right] - \nabla \cdot \underline{\mathbf{I}}_\perp \cdot \left[\chi_i n_i \nabla T_i + \frac{5}{2} T_i D_\perp \nabla n_i\right] = +k(T_e - T_i) + S_{ei}. \tag{A4}$$

Equations taken from: H. Frerichs et al., Physics of Plasmas 22, 072508 (2015)