Advances in understanding power exhaust physics with the new, baffled TCV divertor

Christian Theiler

for the TCV team and the EUROfusion MST1 team

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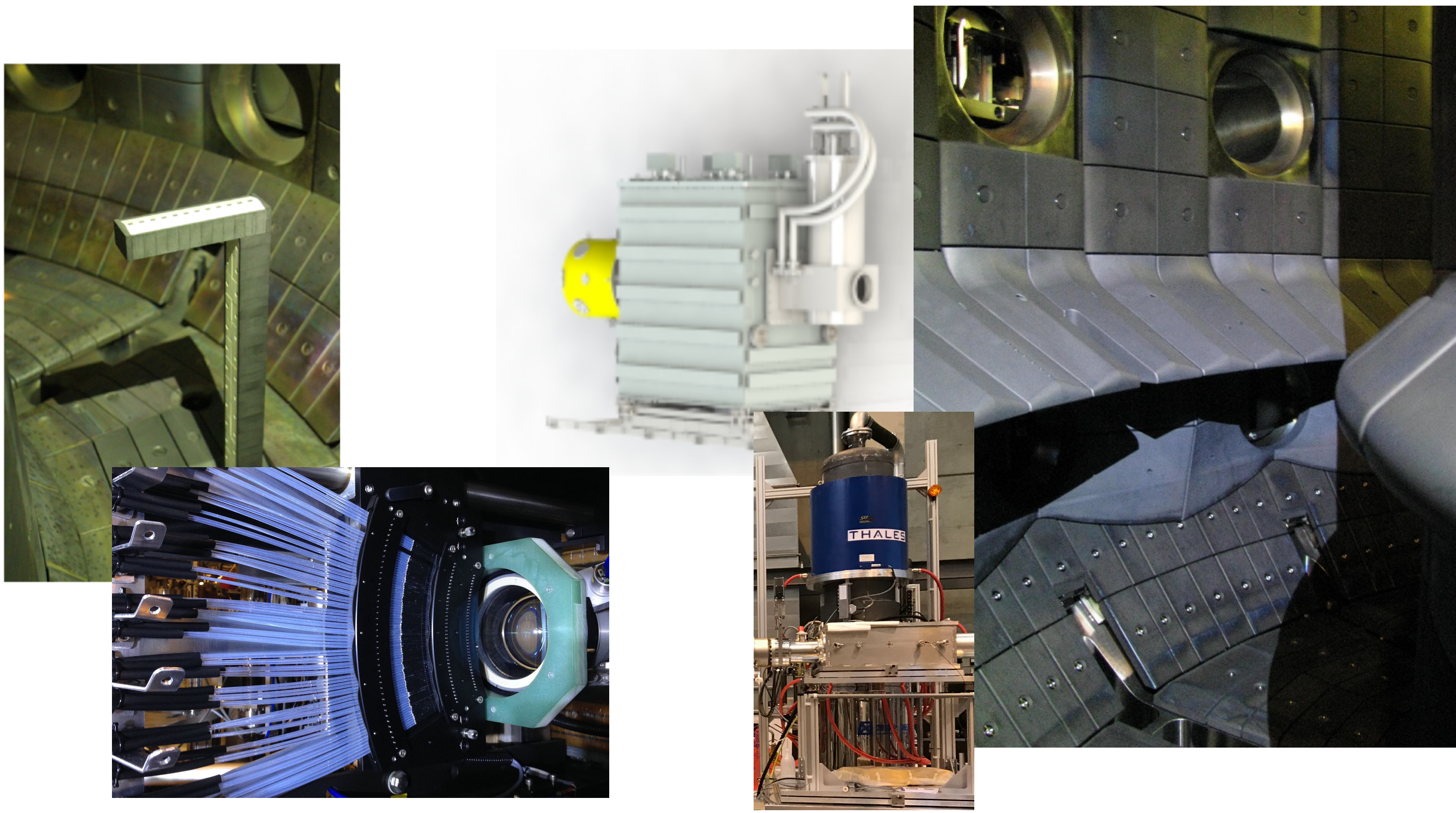
In collaboration with

O. Février[1], H. Reimerdes[1], A. Thornton[2], M. Baquero-Ruiz[1], M. Bernert[3], P. Blanchard[1], D. Brida[3], C. Colandrea[1], H. De Oliveira[1], M. Dunne[3], B. P. Duval[1], A. Fasoli[1], A. Fil[2], L. Frassinetti[4], D. Galassi[1], S. Gorno[1], J. Harrison[2], S. Henderson[2], M. Komm[5], B. Labit[1], B. Linehan[6], B. Lipschultz[7], L. Martinelli[1], N. Offeddu[1], A. Perek[8], H. Raj[1], U. Sheikh[1], G. Sun[1], C. Tsui[9,1], B. Vincent[1], M. Wensing[1], C. Wuethrich[1], the TCV team and the EUROfusion MST1 team

[1]Ecole Polytechnique Fédérale de Lausanne (EPFL), Swiss Plasma Center (SPC), Lausanne, Switzerland
[2]CCFE, Culham Science Centre, Abingdon, United Kingdom
[3]Max Planck Institut für Plasmaphysik, Garching, Germany
[4]Division of Fusion Plasma Physics, KTH Royal Institute of Technology, Stockholm, Sweden
[5]Institute of Plasma Physics of the Czech Academy of Sciences, Prague, Czech Republic
[6]MIT, Plasma Science and Fusion Center, Cambridge, USA
[7]York Plasma Institute, University of York, York, United Kingdom
[8]Dutch Institute for Fundamental Energy Research (DIFFER), Eindhoven, Netherlands
[9]University of California-San Diego, La Jolla, USA

The TCV Plasma EXhaust (PEX) upgrade

Access to more reactor-relevant conditions in TCV, for proof-of-principle studies of alternative divertors and contributions to improved predictive capabilities of exhaust solutions



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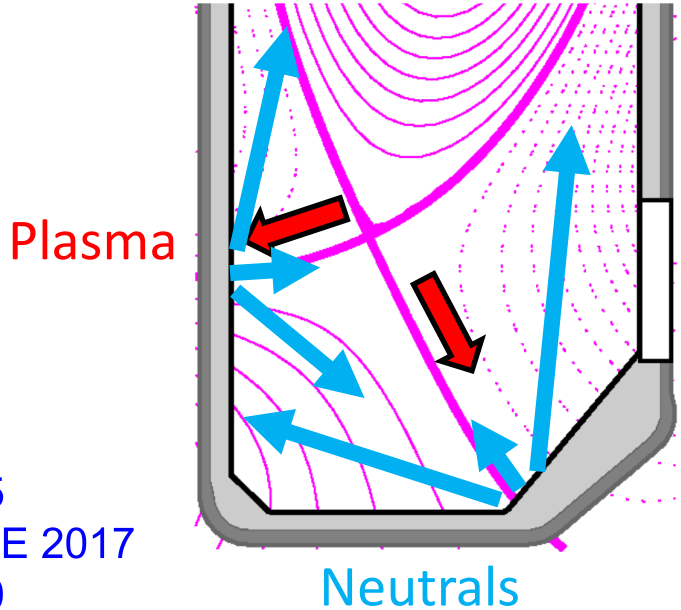
  - Up to 3.5 MW ECRH (X2/X3)
- Removable baffles, optimized with SOLPS-ITER



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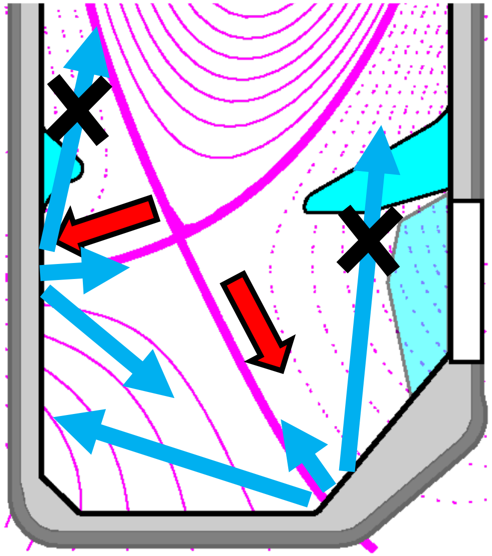

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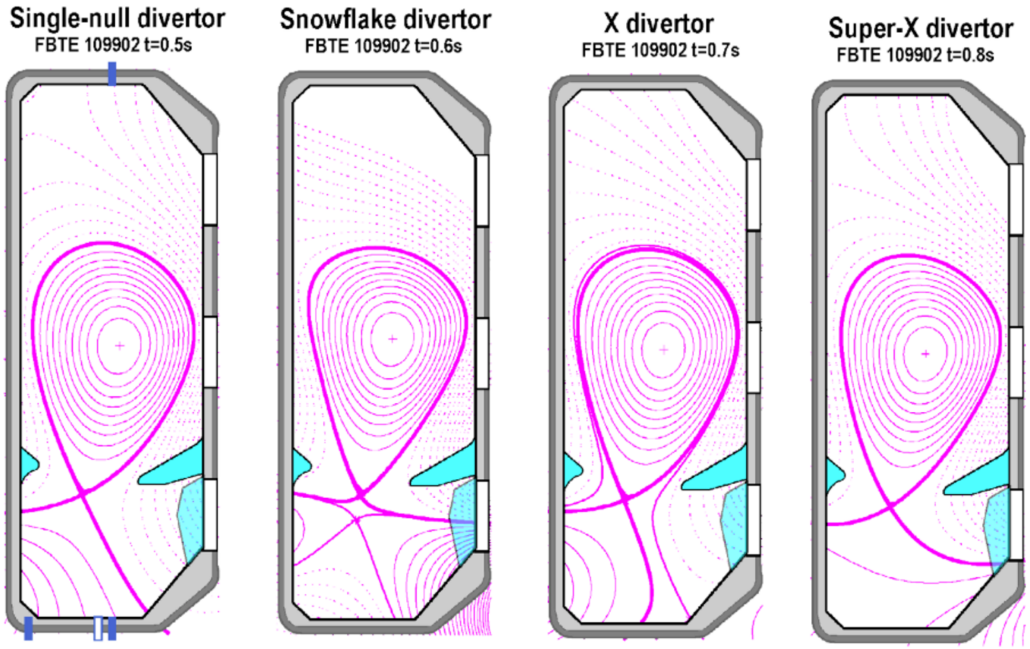
- Compatibility with wide range of alternative geometries



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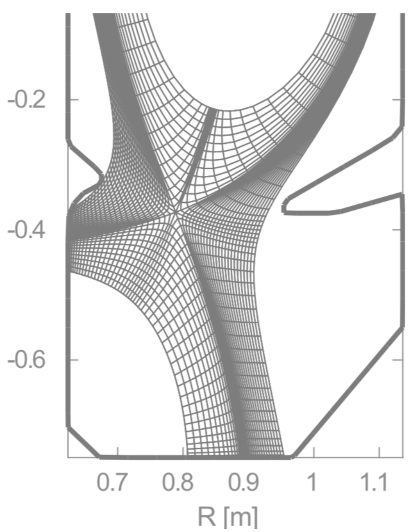
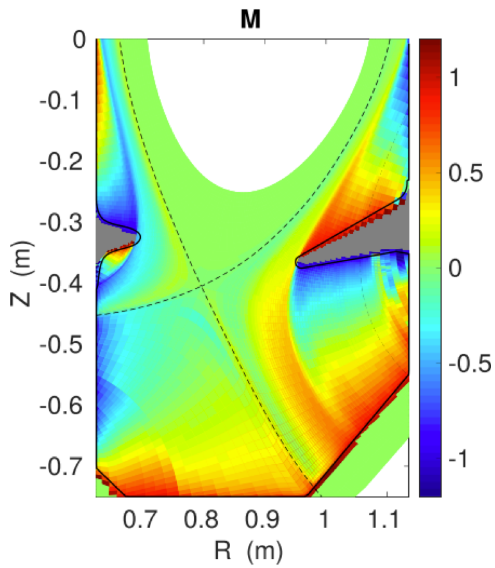
- Substantial increase in edge diagnostics, together with extensive modeling expertise

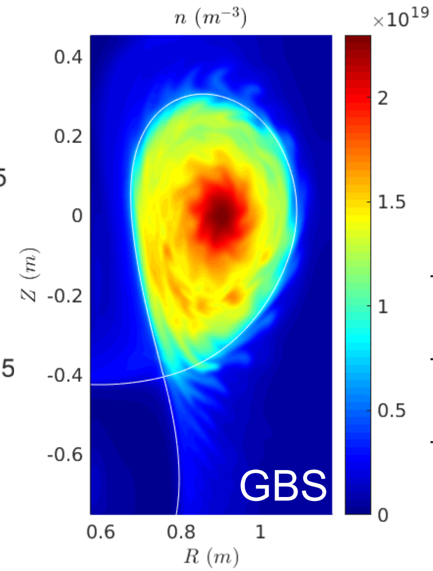
SOLPS-ITER

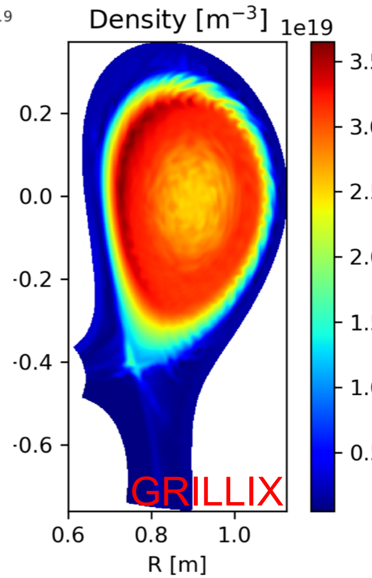


Soledge2D



GBS, GRILLIX, Tokam3X





Outline

- Effect of baffles in L-mode
  - Divertor neutral pressure, optimization
  - Effect of baffles on divertor plasma
- H-mode
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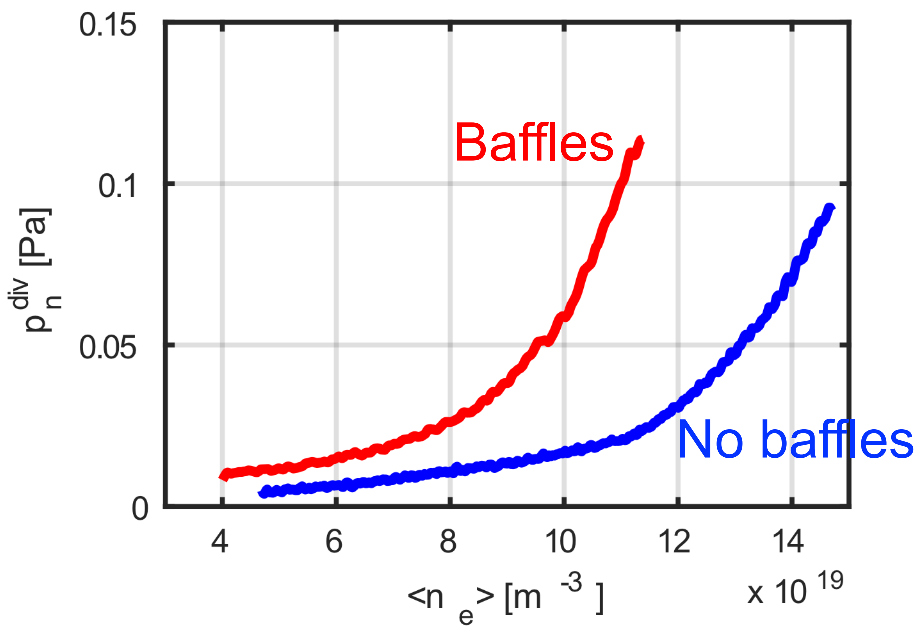
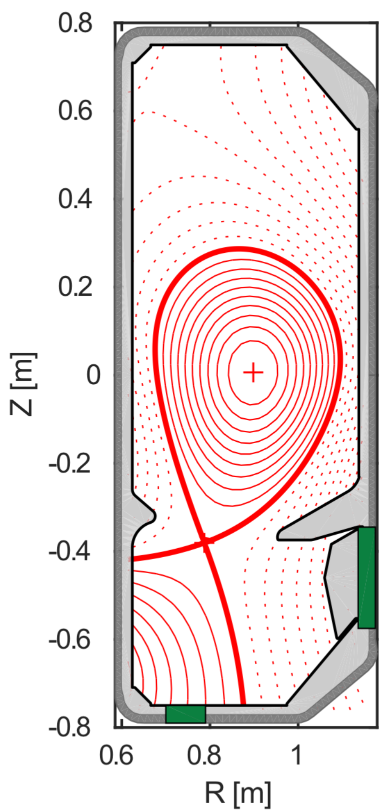
Neutral pressure in divertor increases by up to 5x

- L-mode, core density ramp; Rev. B to avoid H-mode
- Increase of divertor neutral pressure in agreement with predictive SOLPS-ITER simulations





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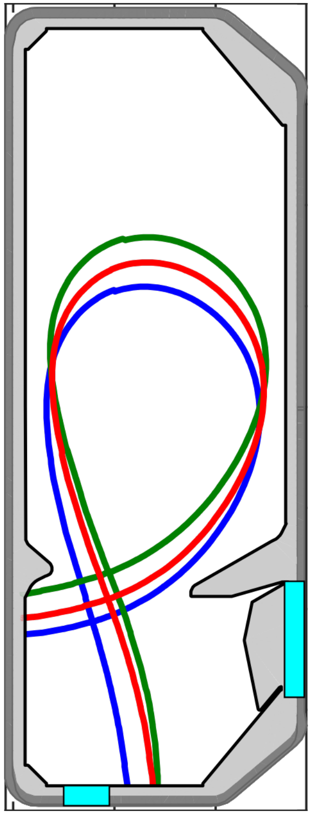
- Increase of divertor neutral pressure in agreement with predictive SOLPS-ITER simulations
- Variation of plasma-baffle distance does not lead to further improvements[2]

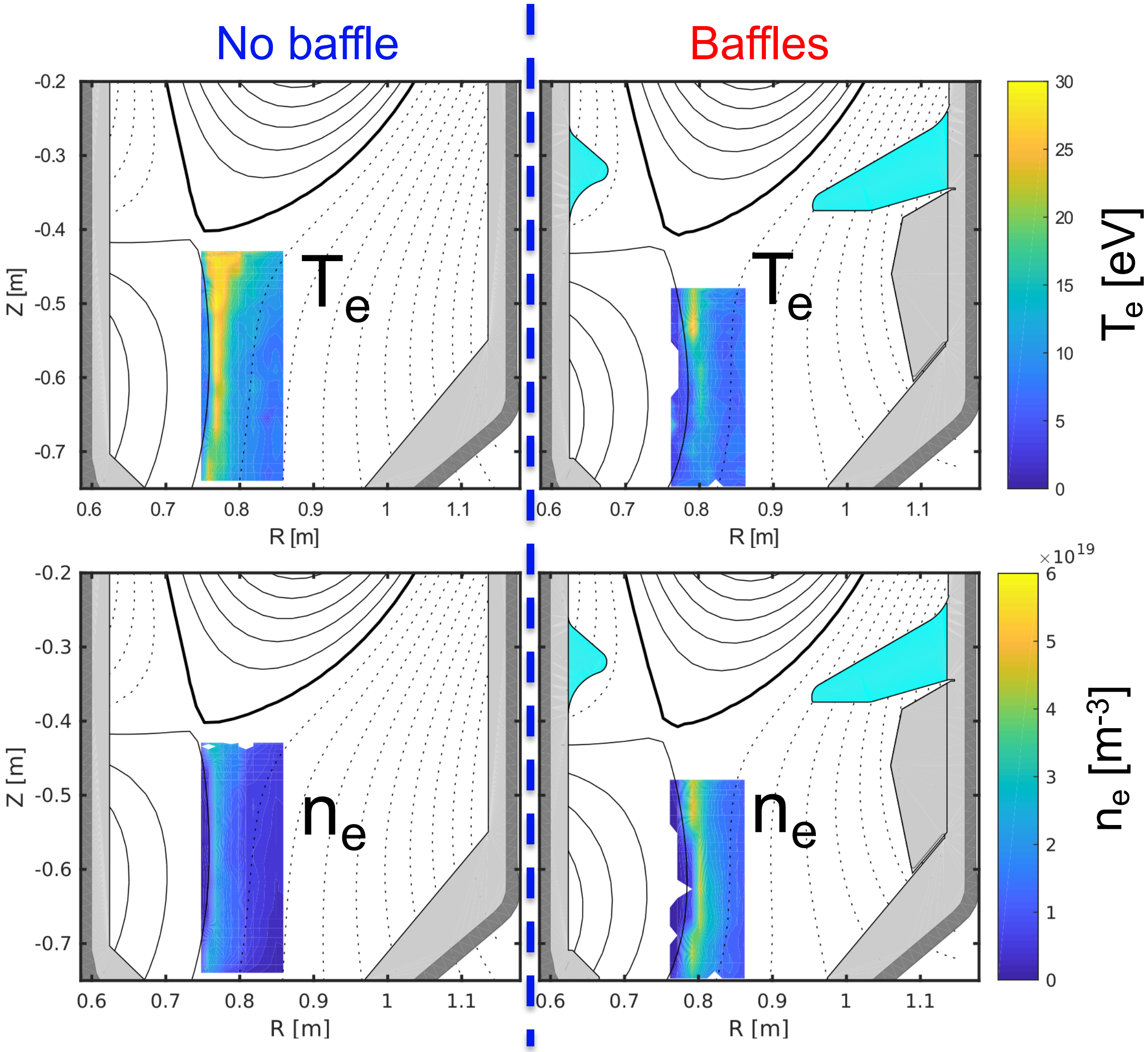


➢ Confirms main design goals of the baffles

[1] Reimerdes *et al.*, NF 2021
[2] Février *et al.*, NME 2021

Presence of baffles cools and densifies divertor plasma…

Reciprocating Divertor Probe array (RDPA)[1]



[1] De Oliveira *et al.*, RSI, in press

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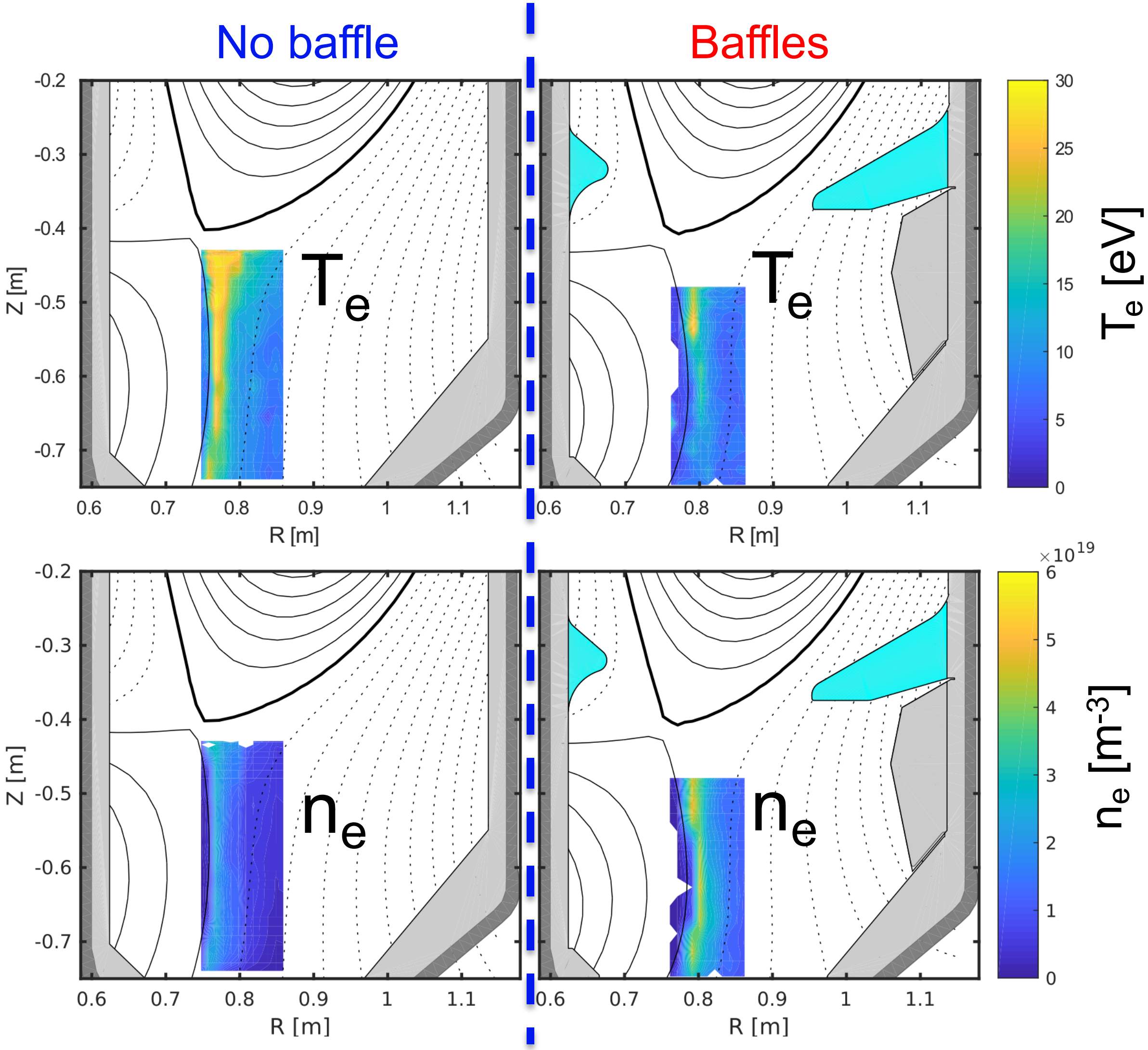

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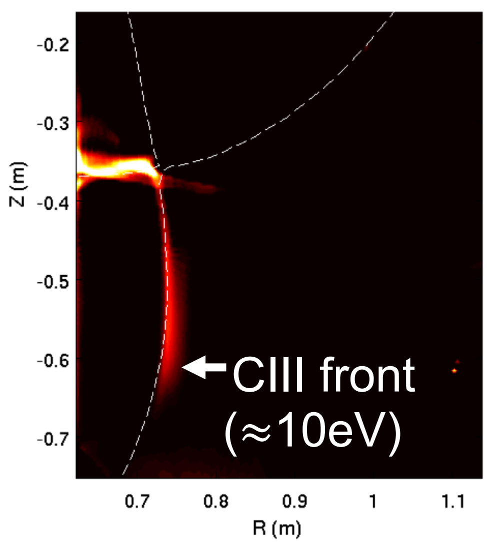
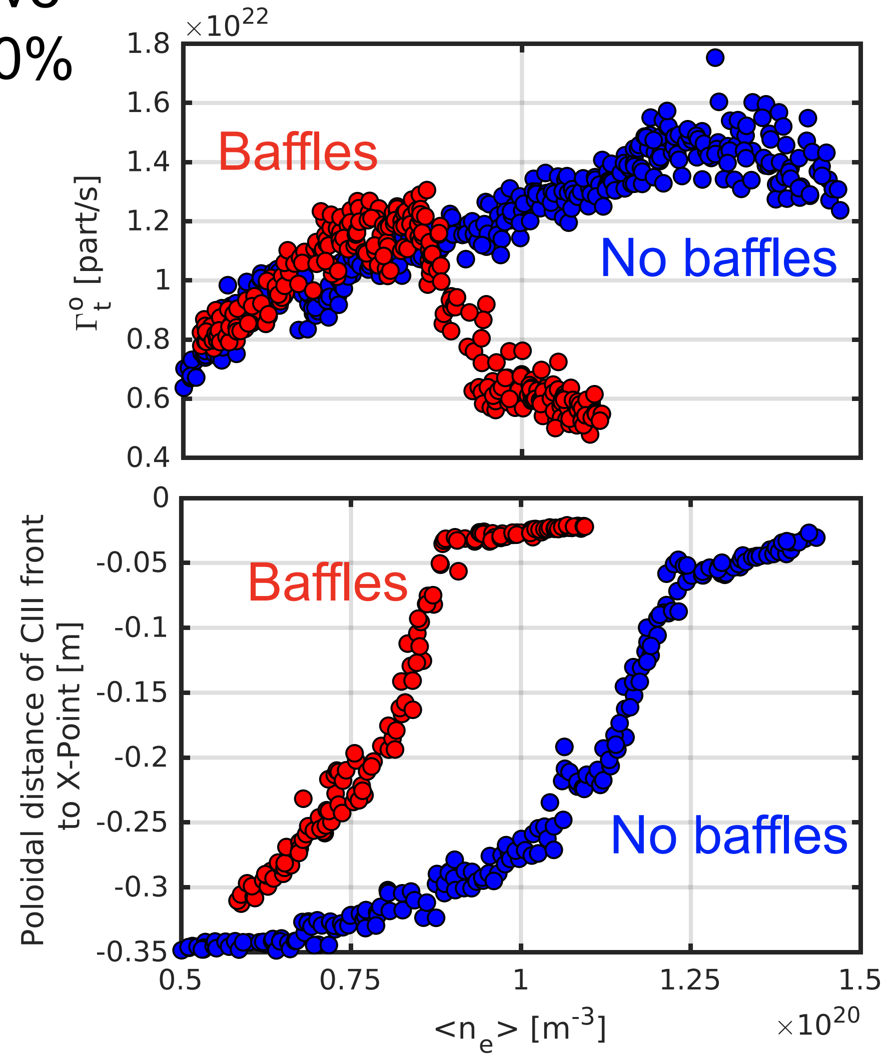
… and reduces detachment threshold

- J_{sat} roll-over and CIII front movement at outer target at ≈20-30% lower core density





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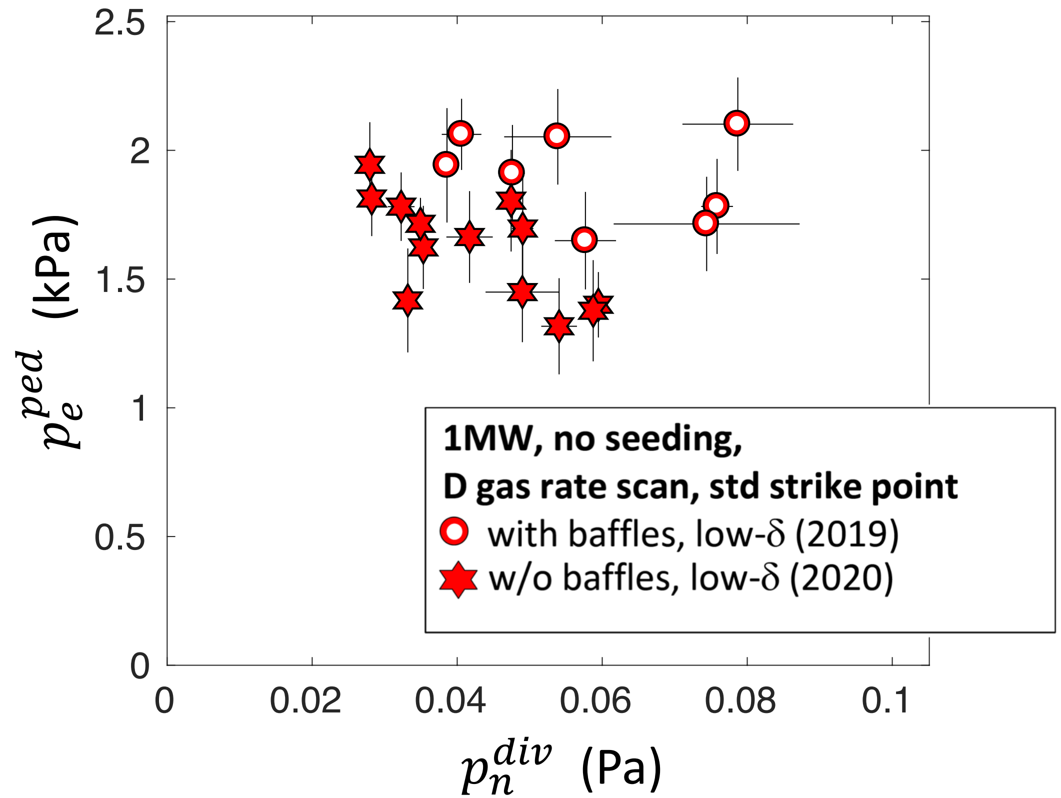
In H-mode and high fuellig, baffles result in higher pedestal top pressure…

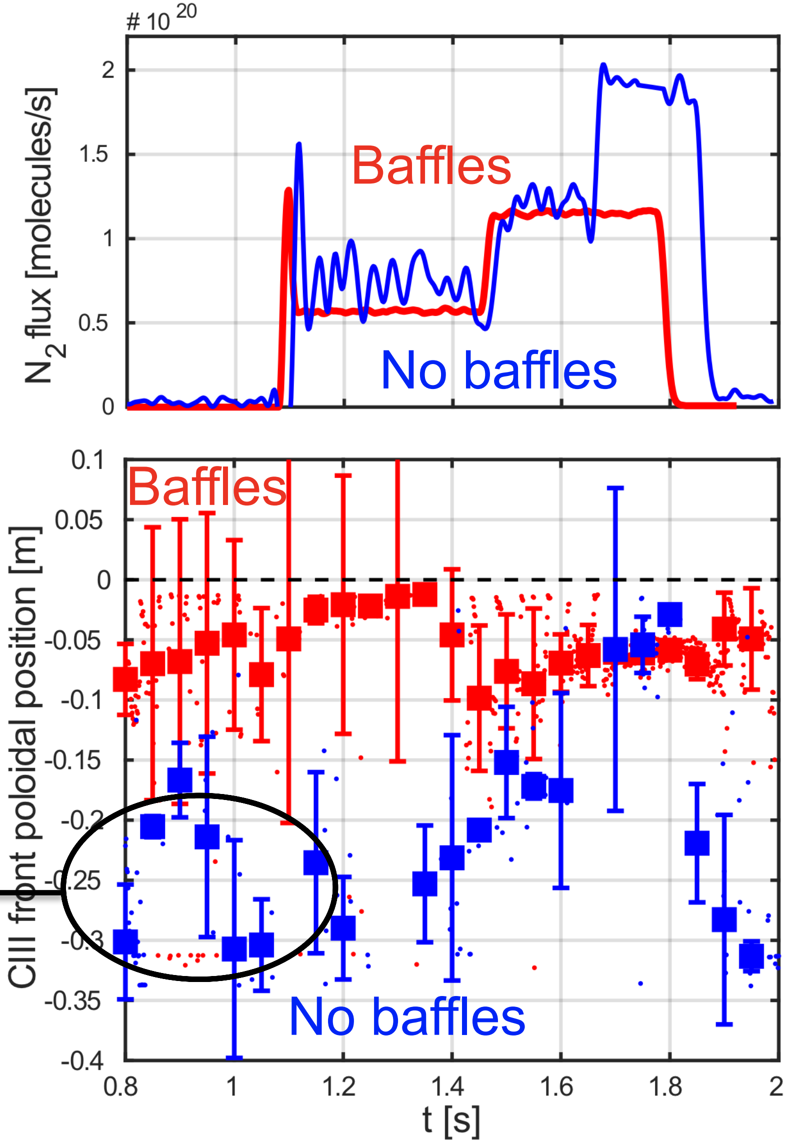
- Type-I ELMy H-mode, 1MW NBI
- P_{ped} improves with baffles at high p_n^{div}



[1] Sheikh *et al.*, NME 2021

… and a colder divertor plasma

Inter-ELM CIII emissivity



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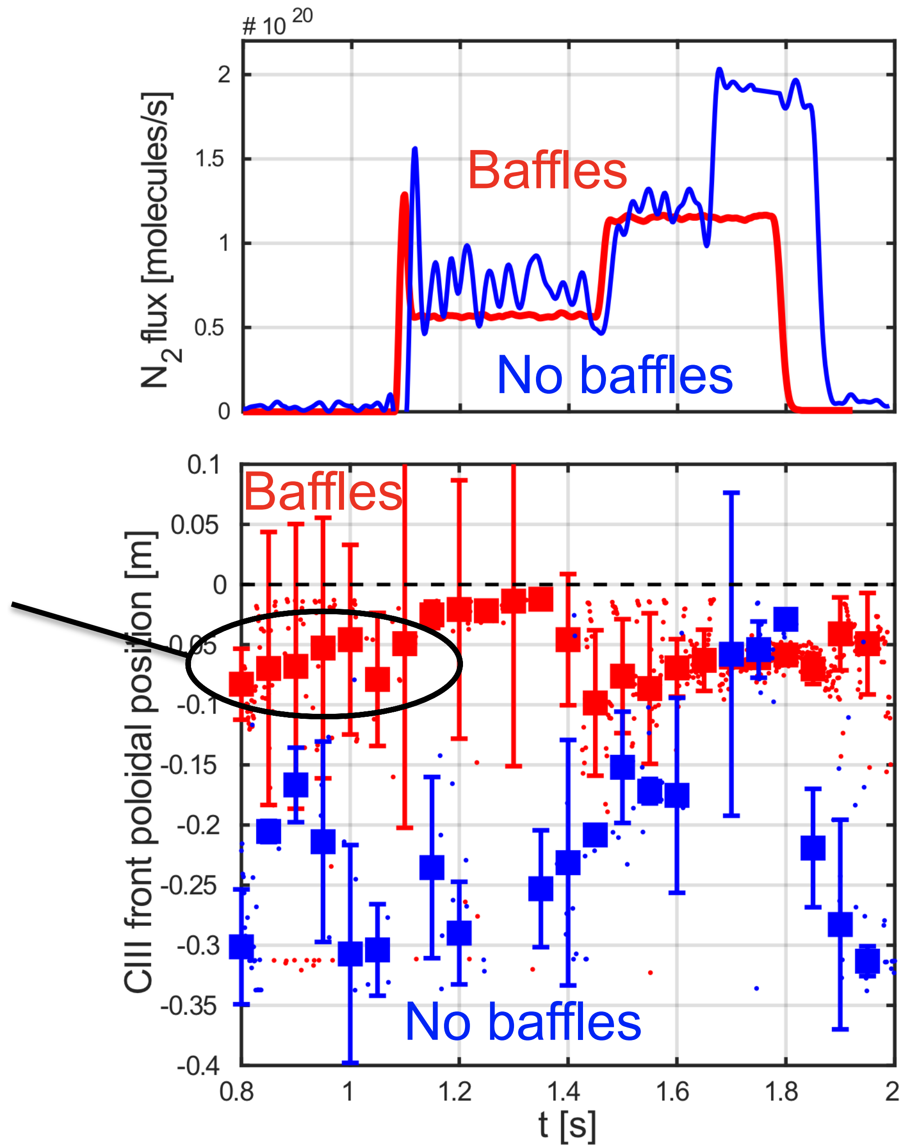

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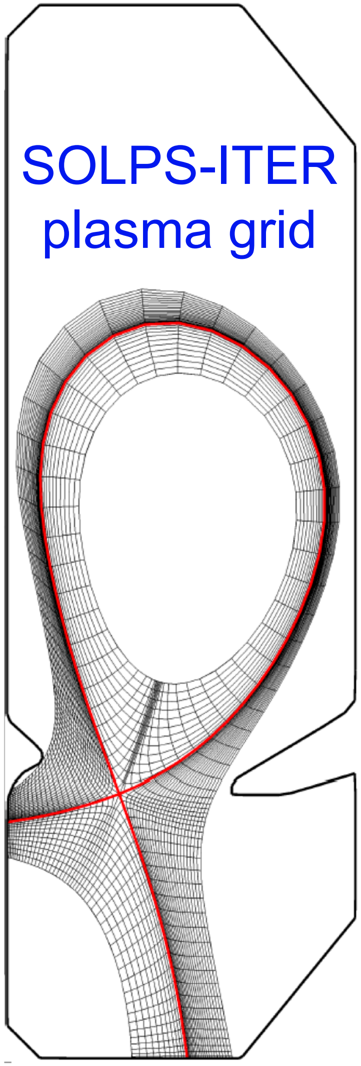
Divertor currents well reproduced with SOLPS-ITER

- SOLPS-ITER simulations **including drifts**
- L-mode density ramps ($f_{Gw} \approx 0.25 - 0.6$), both field directions



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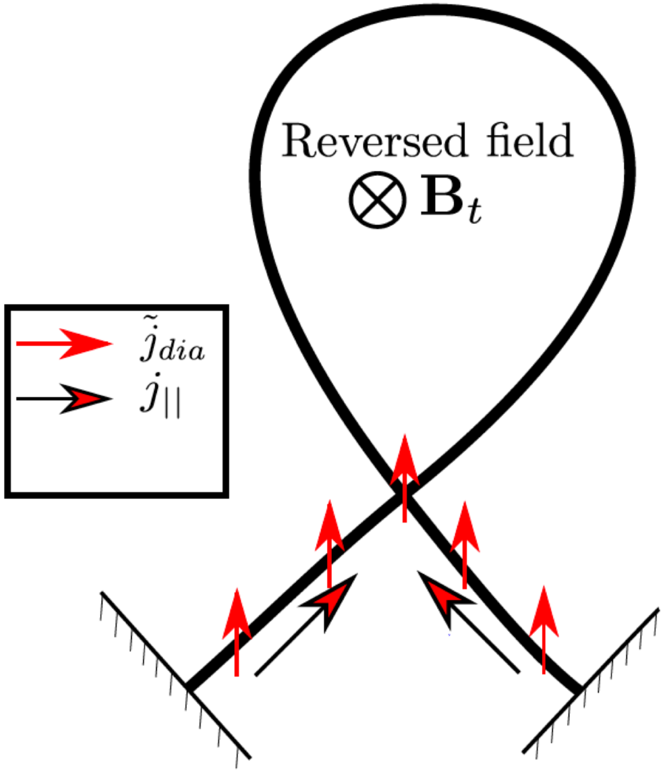
➢ Divertor currents in private flux region are Pfirsch-Schlüter dominated



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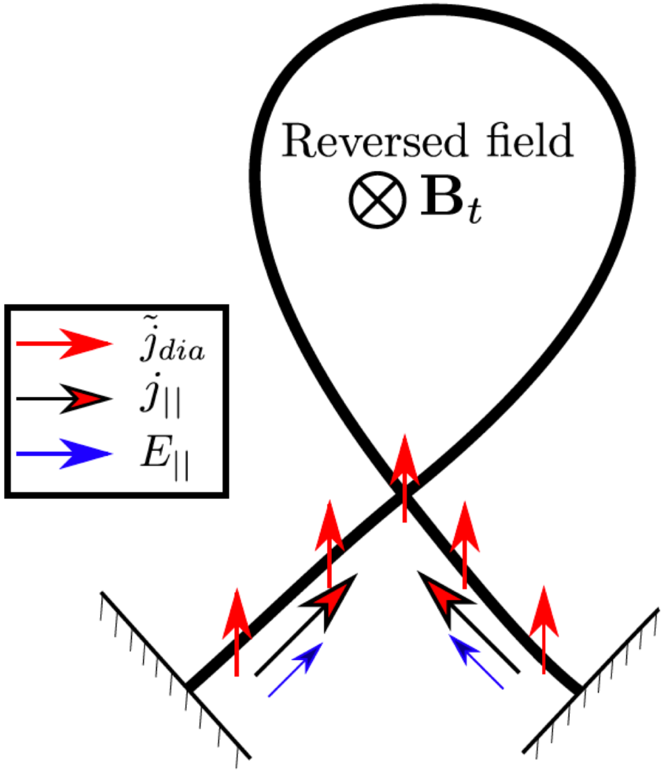
➢ Determine potential structure at low T_e, where

$$E_{\parallel} \approx \eta_{\parallel} j_{\parallel}$$



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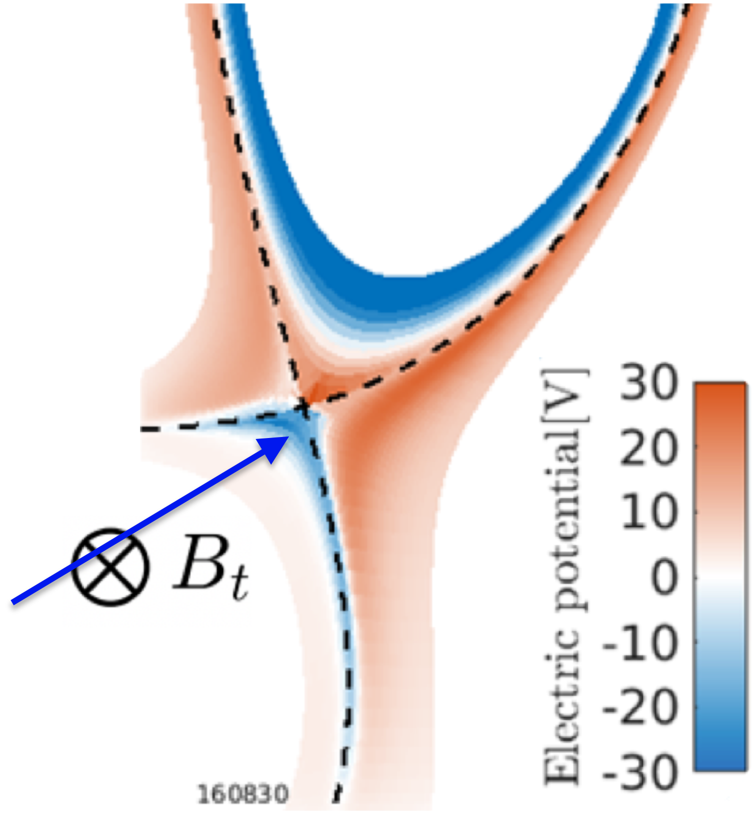
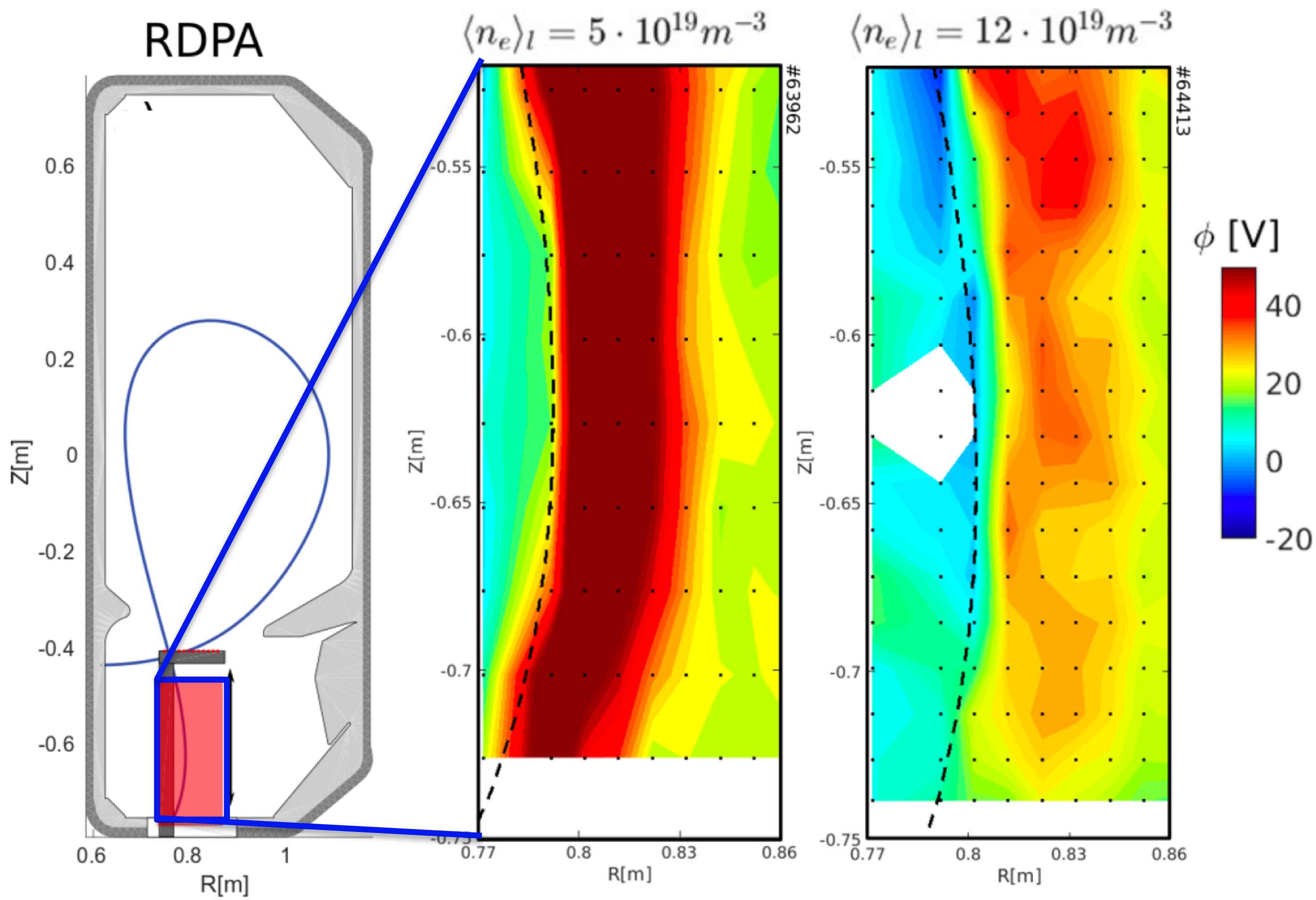
➢ Prediction[2] of neg. potential well in reversed field



[1] Wensing *et al.*, NME 2020
[2] Wensing *et al.*, NF 2020

Confirmation of negative potential well in reversed B_t



➢ Necessary conditions only achieved with baffles

[1] Wensing *et al.*, NME 2020

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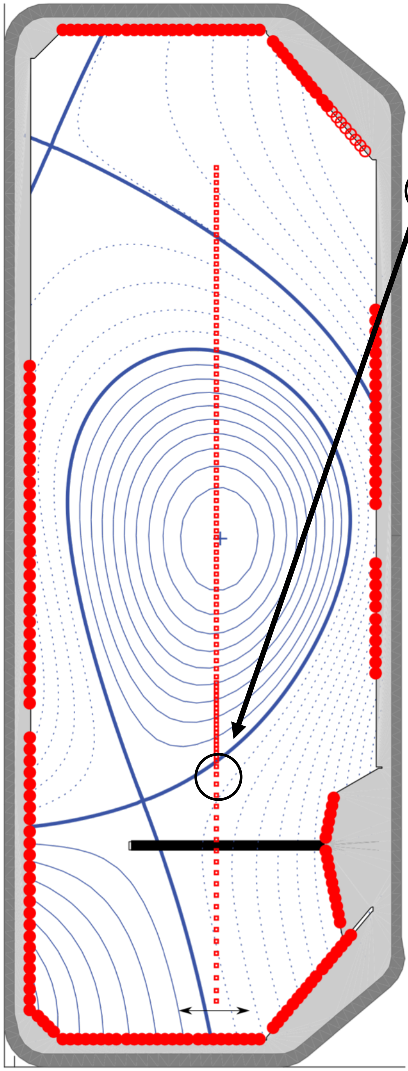
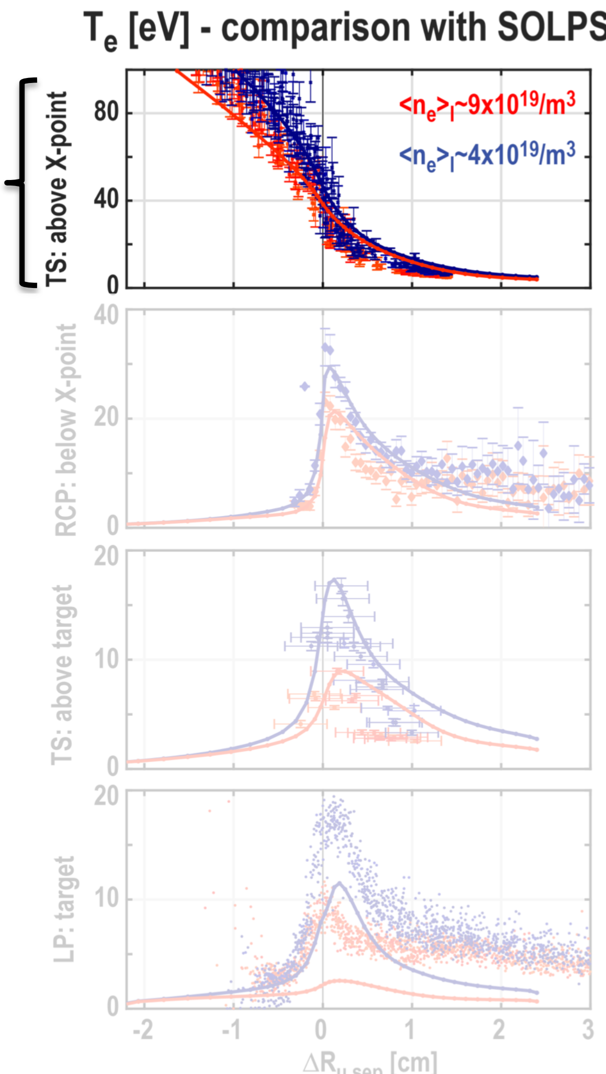
Key open issue: Target quantities mismatch



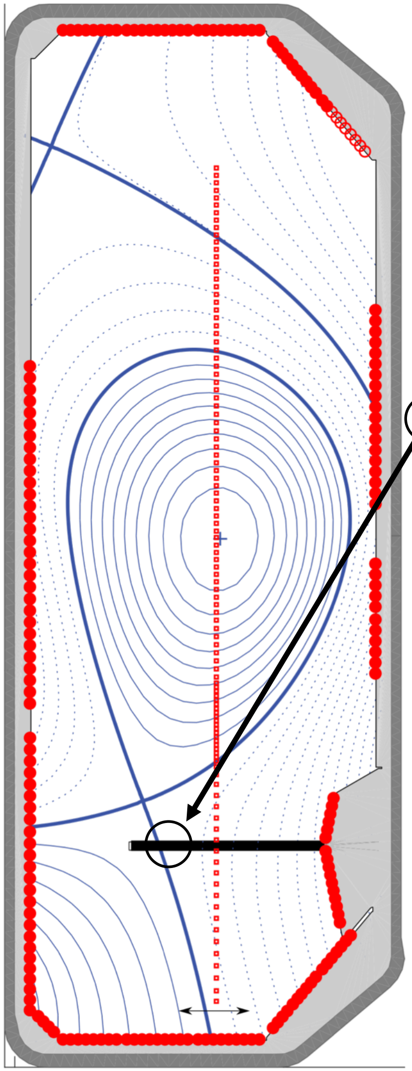


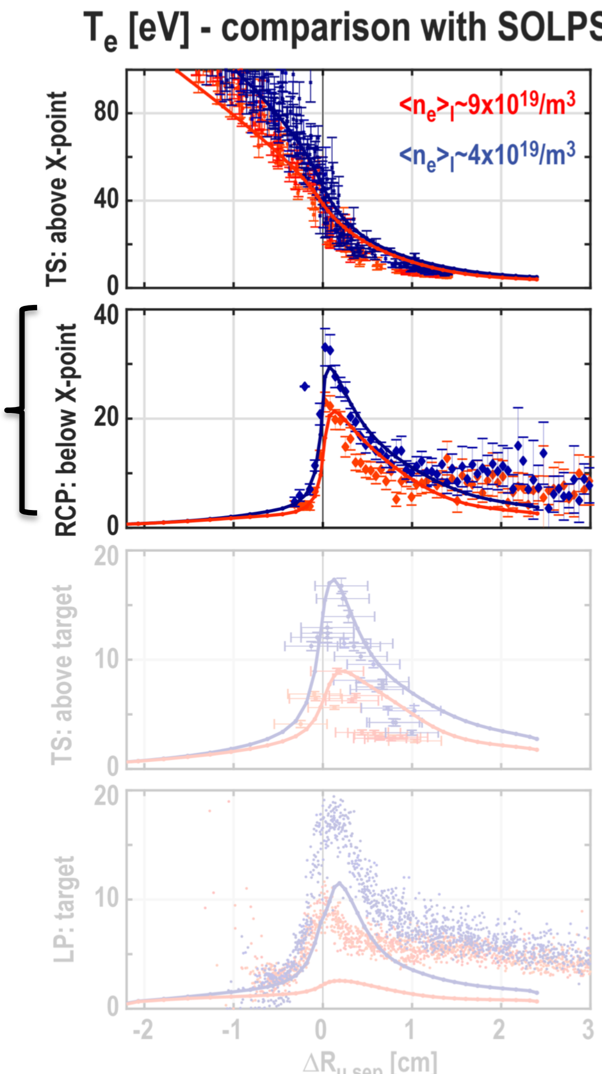
1. Reasonable match
2. Reasonable match
3. SOLPS profiles broader
4. SOLPS under-estimates T_e

[1] Wensing *et al.*, in prep.

Key open issue: Target quantities mismatch

#67378





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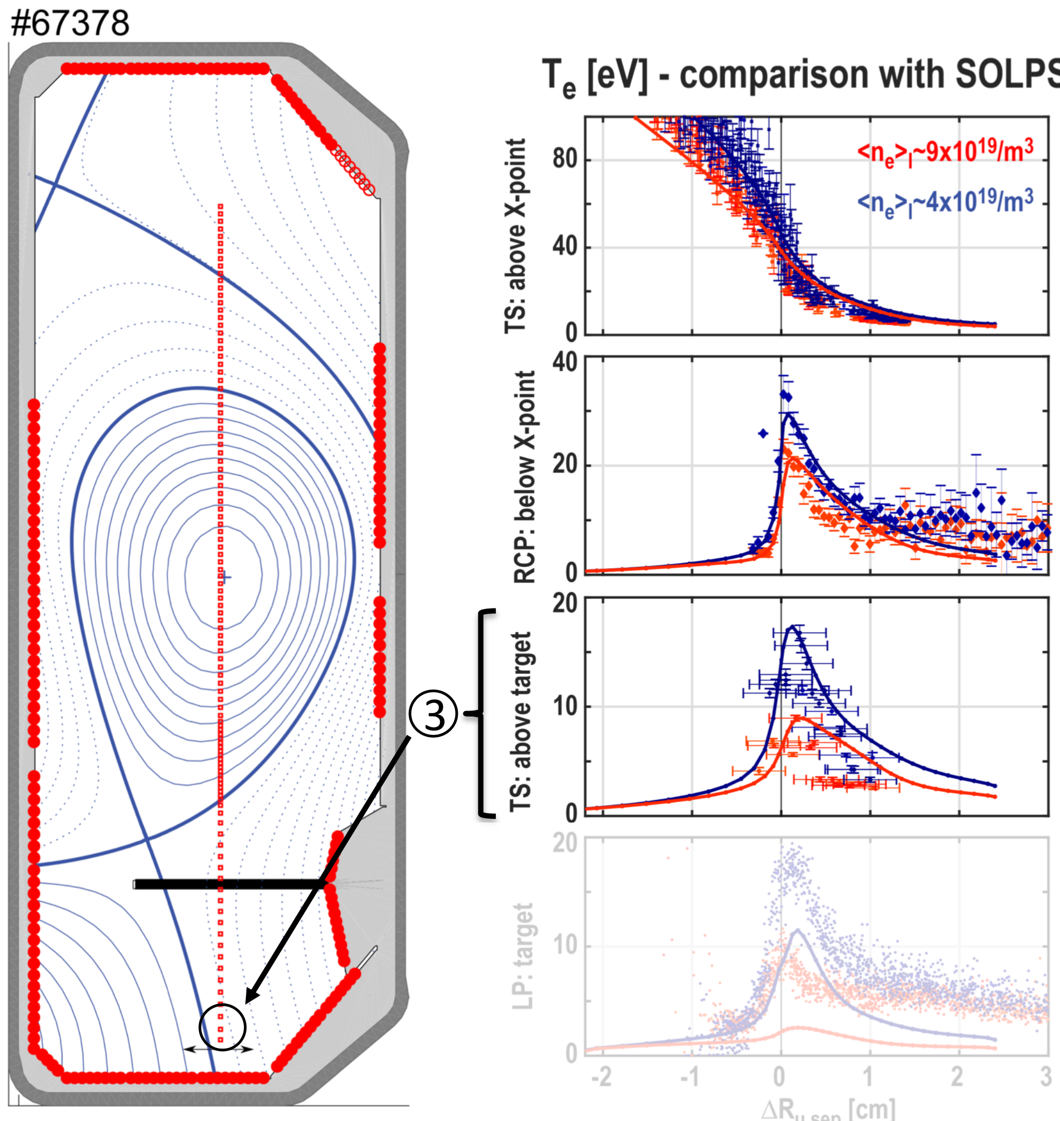

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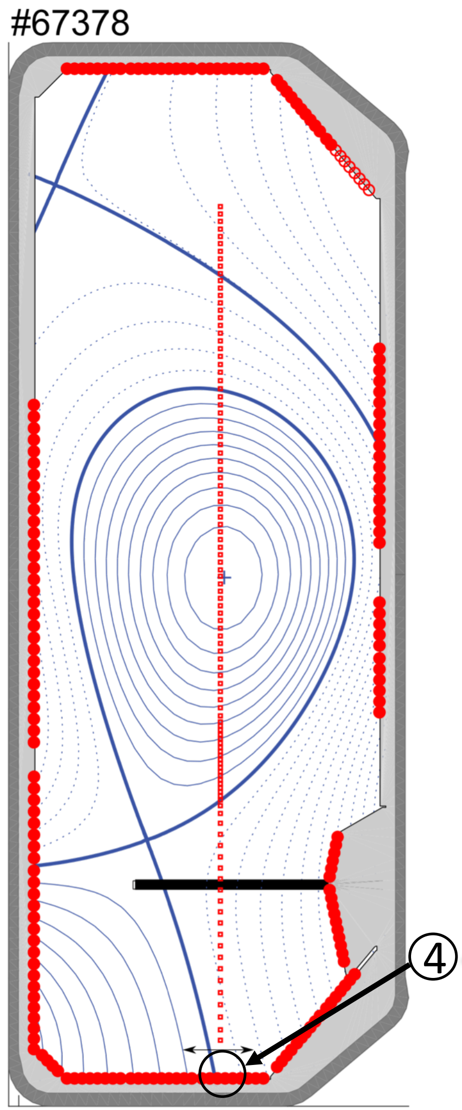

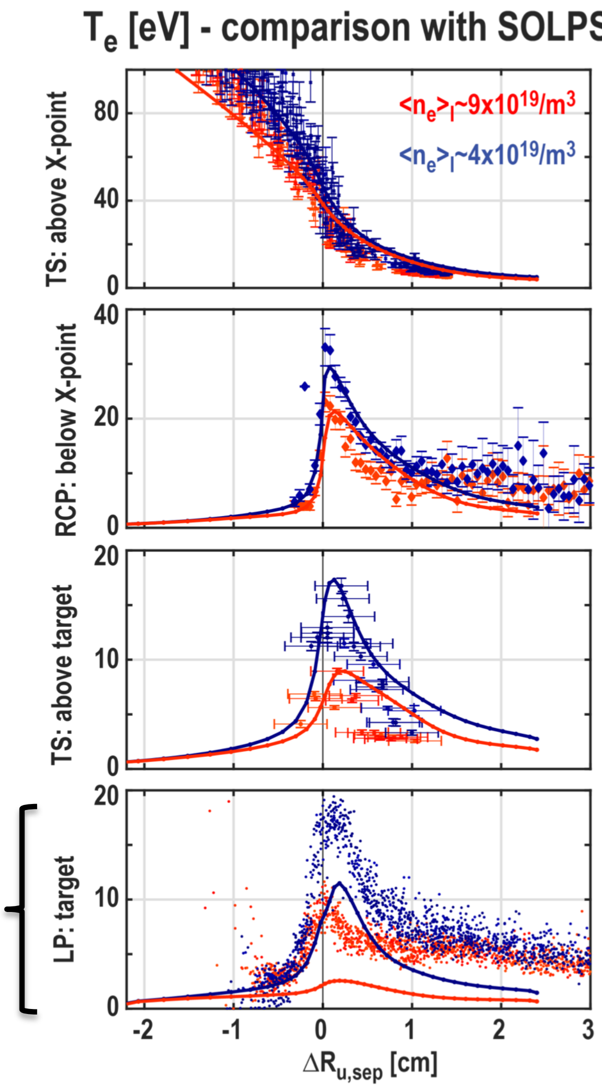

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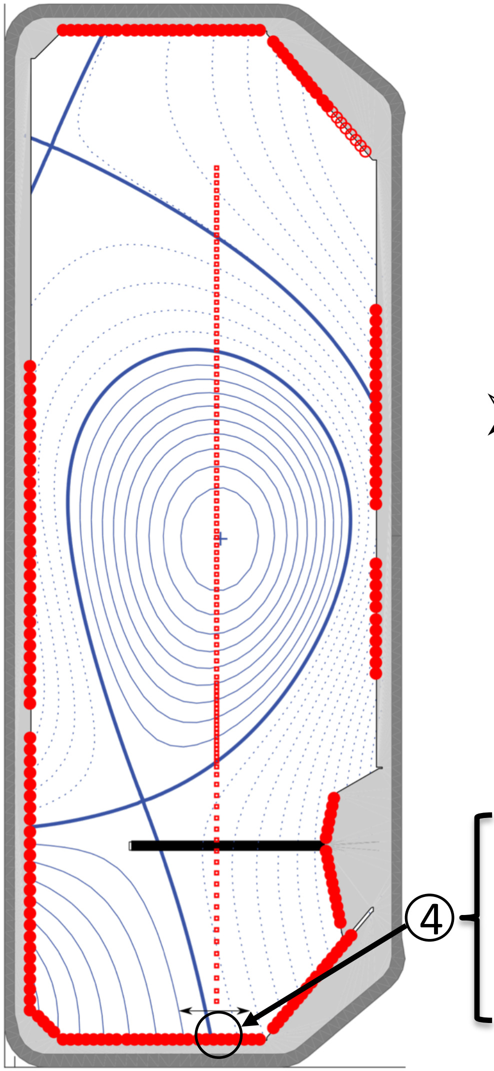
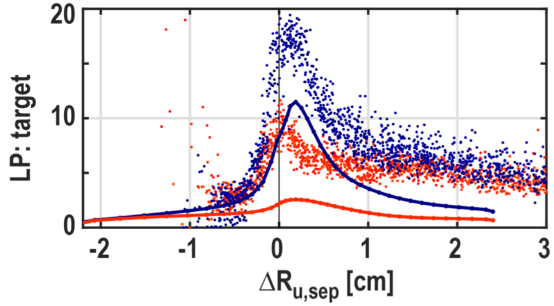


- Remaining disagreement under investigation. Possible route: improved plasma-molecule interaction → Verhaegh, *et al.*, this conference, P4



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Assessment of main Super-X feature

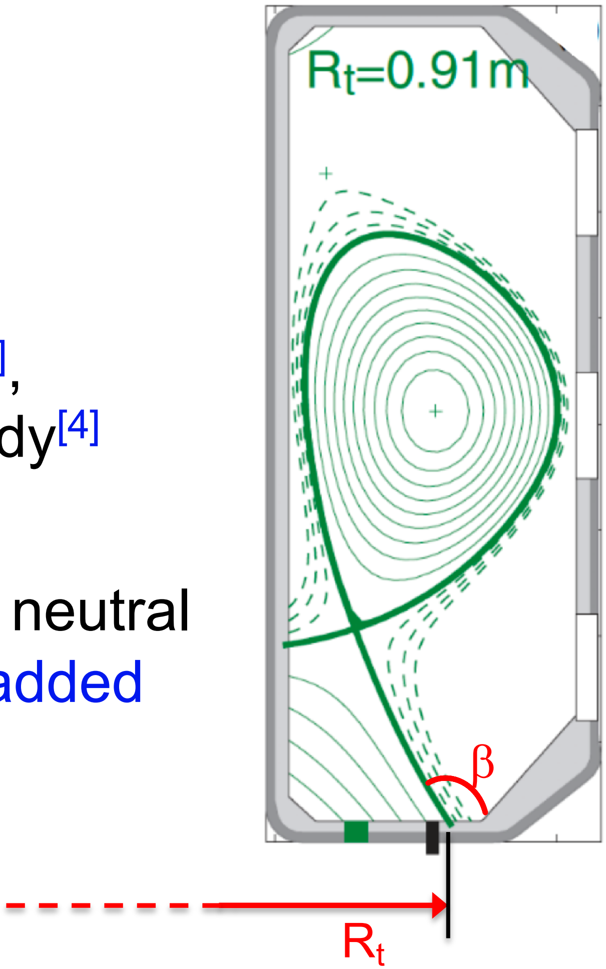
- 2-pt. model[1] and SOLPS[2] predict

$$T_{e,t} \propto 1/R_t^2 \; ; \qquad n_{e,t} \propto R_t^2$$

Detachment threshold $\propto 1/R_t$

- Effect not retrieved previously in TCV[3], consistent with interpretive SOLPS study[4]

- SOLPS predicts recovery of R_t effect if neutral trapping matched – possible if baffles added and angle β kept constant[4]

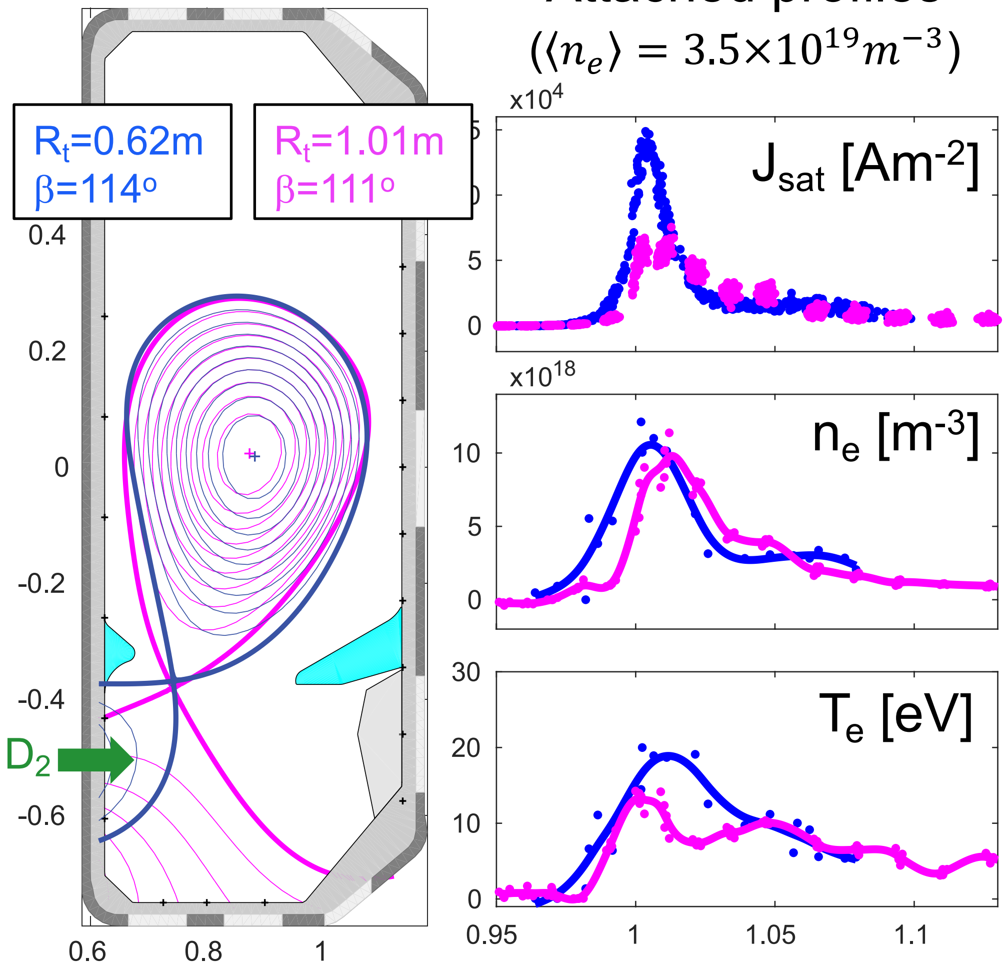


[1] Petrie *et al.*, NF 2013
[2] Moulton *et al.*, PPCF 2017
[3] Theiler *et al.*, NF 2017
[4] Fil *et al.*, PPCF 2020

Target n_e does not increase as $\propto R_t^2$

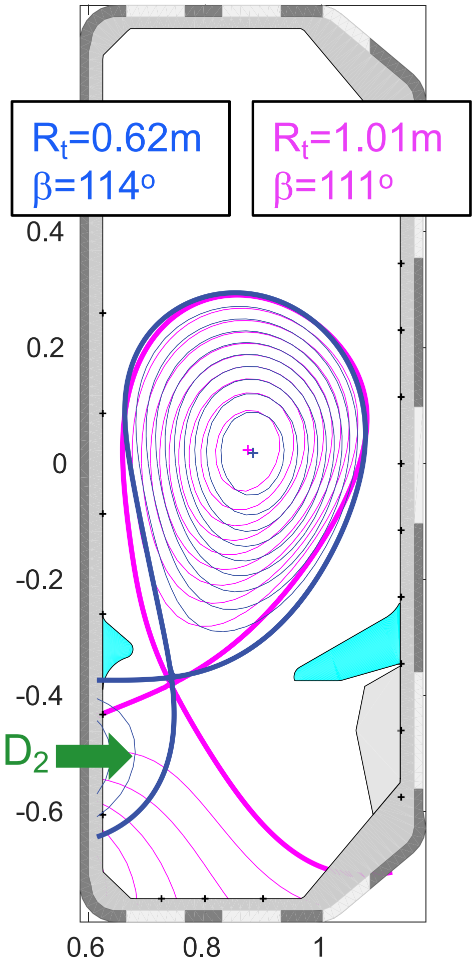
Attached profiles

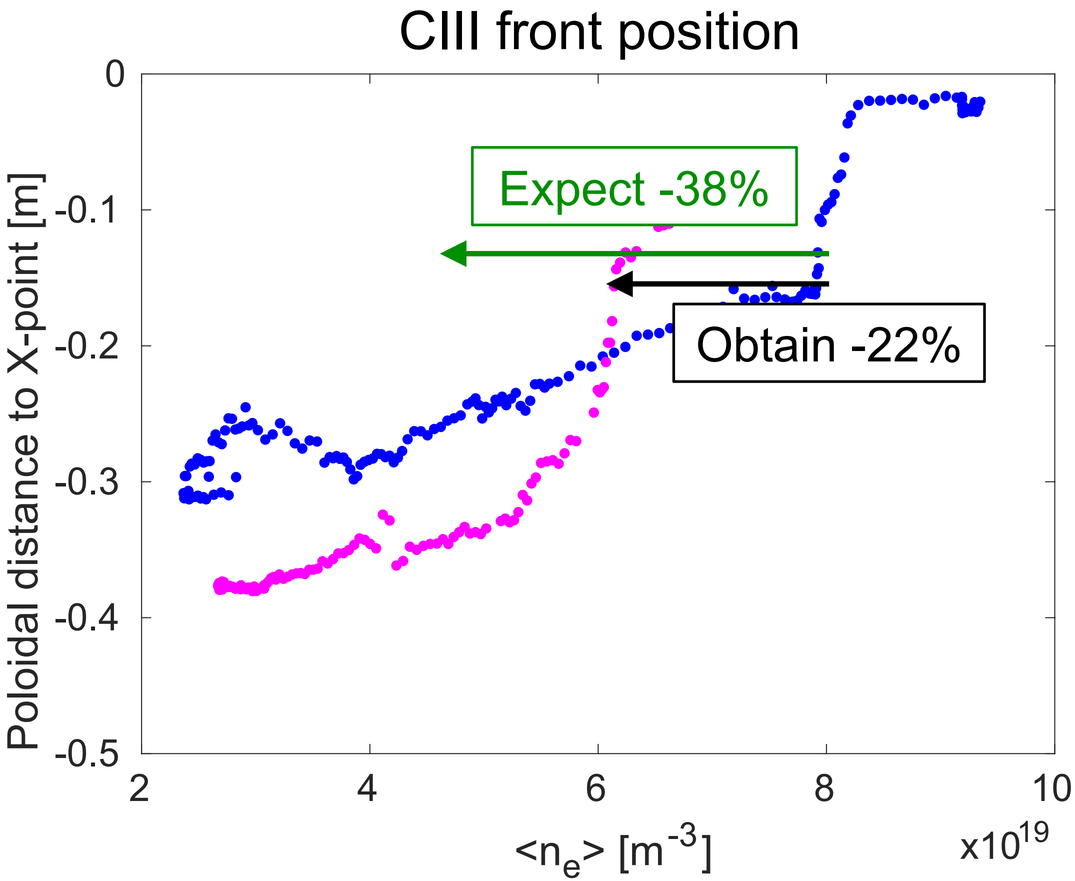
$(\langle n_e \rangle = 3.5\times10^{19} m^{-3})$



- J_{sat} does not increase as $\propto R_t \approx$1.6
- n_e does not increase as $\propto R_t^2 \approx 2.6$
- T_e drops, but more weakly than $R_t^{-2} \approx 0.38$

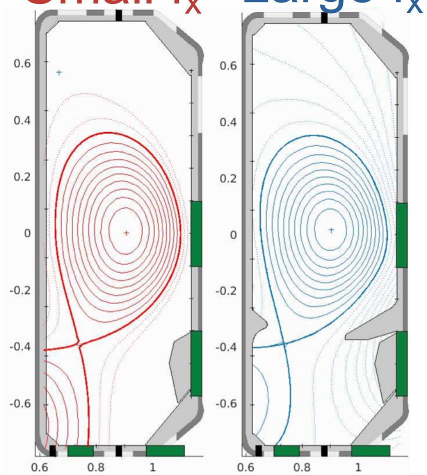
Still, R_t effect on detachment threshold partly recovered





Benefits of baffles and increased pol. flux expansion f_x add up in H-mode

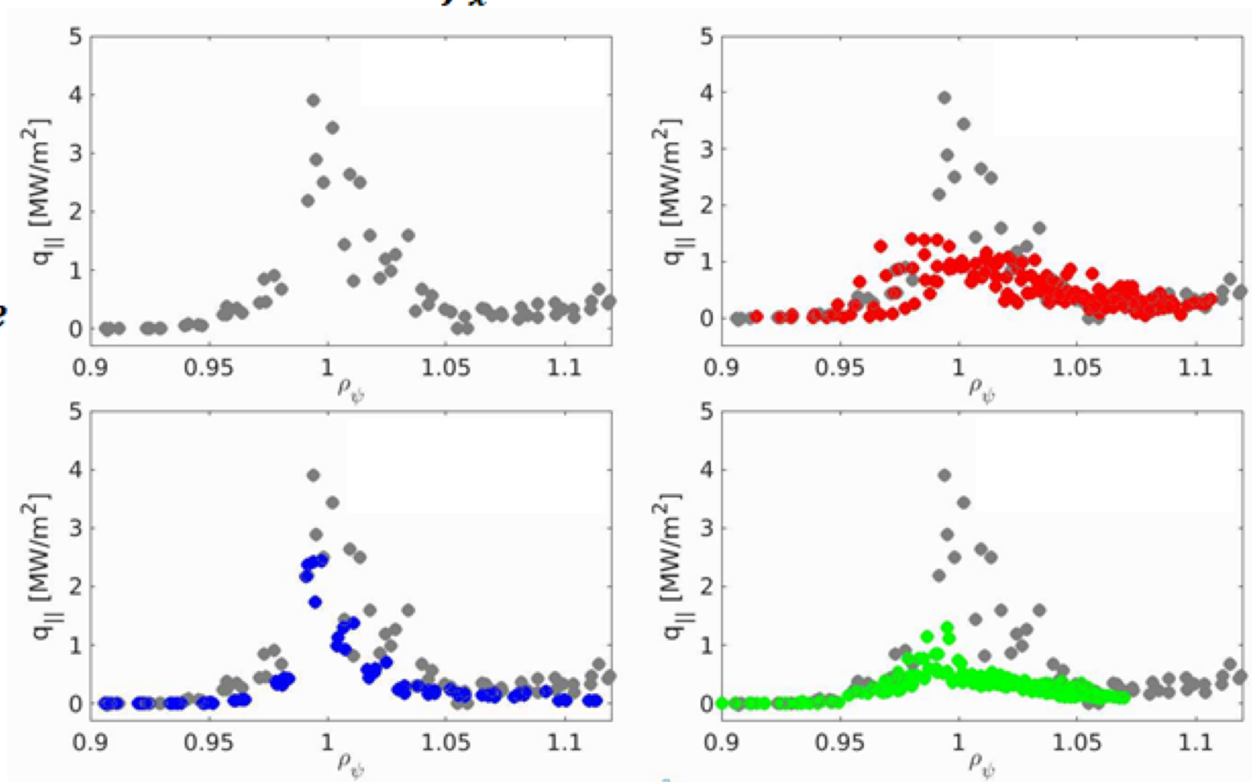
Small f_x Large f_x



Parallel heat flux profile (inter-ELM) at outer target

f_x →

Baffle ↓



H. Raj *et al.*, in prep.

Conclusions

- TCV upgraded to address key open issues of exhaust physics
  - Divertor baffles compatible with a wide range of divertor geometries
  - Enhanced heating power
  - Substantially improved diagnostic coverage of SOL/divertor
- Consistent with modeling (SOLPS-ITER, SOLEDGE2D-EIRENE), baffles allow accessing more reactor-relevant, high divertor neutral pressure regimes
  - ➢ Facilitated access to detachment in both L- and H-mode and enhanced pedestal performance at high fuelling
- SOLPS drift simulations correctly predict key features (nature of parallel currents, potential structure, relative changes with baffles,…). Remaining quantitative differences identified
- Expected benefits of Super-X divertor partly recovered with baffles; Baffles further enhance the benefits of the X-divertor