EUROfusion

Experimental and numerical progress in the assessment of alternative divertor configurations in TCV and extrapolations towards higher power conditions

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4th IAEA TM on Divertor Concepts, Nov. 7-10, 2022, Vienna

EPFL

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.

Prospects of alternative divertor configurations

For risk mitigation, alternative divertors need to be explored in parallel to the conventional one, in today's and in dedicated devices such as DTT[1]

- ➢ Facilitate access to detachment [2,3]
  - Larger divertor volume (connection length), optimized baffling, heat profile broadening, total flux expansion,…
- ➢ Widen detachment window compatible with good core performance[3,4]

[1] EU Fusion Roadmap – 2018
[2] Theiler *et al.*, NF 2017
[3] Umansky *et al.*, NF 2020
[4] Lipschultz *et al.*, NF 2016

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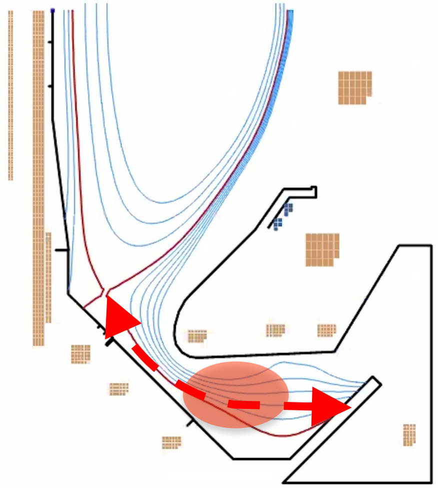
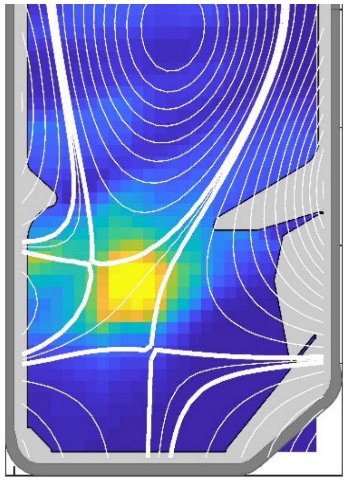
Control radiation zone between X-point and target →long-legged divertors



Optimize X-point radiator properties

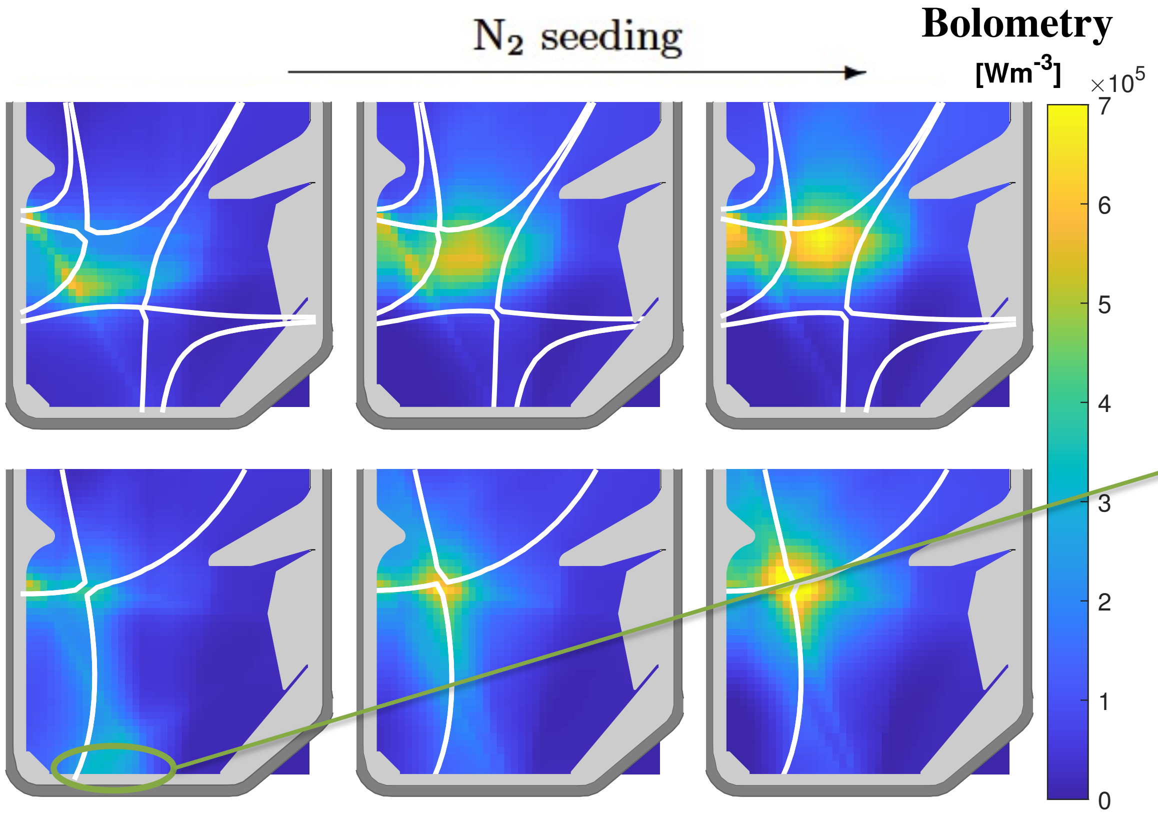


Outline

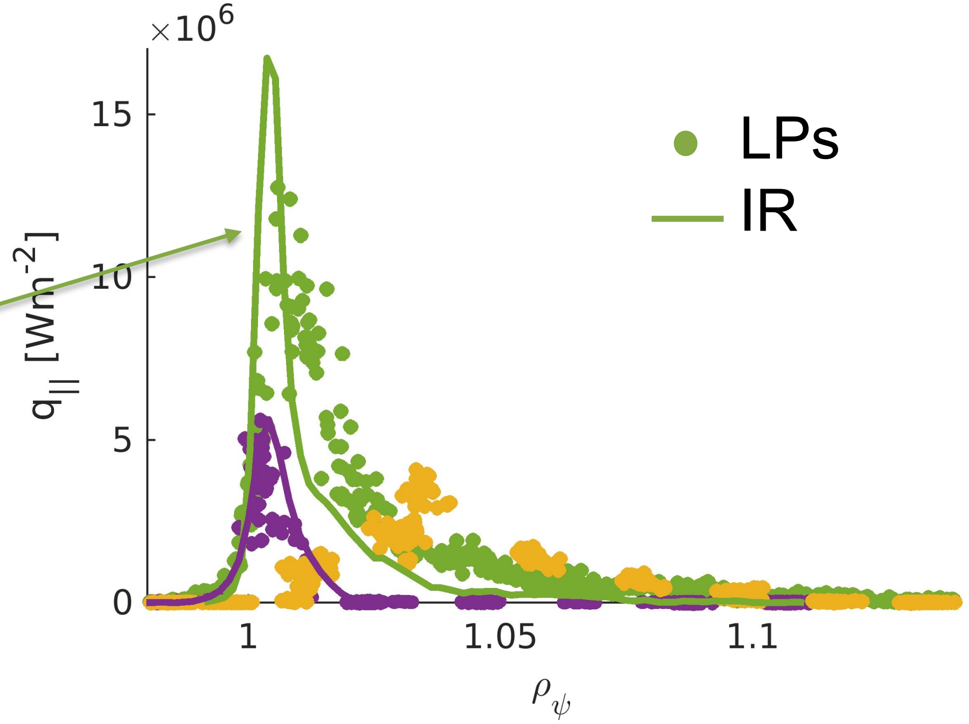
- Recent Snowflake studies on TCV, with focus on divertor-core compatibility
- Progress in the assessment of long-legged divertor options
  - L-mode Super-X
  - H-mode X-Divertor and X-Point Target
- Divertor transport - mean-field vs fluctuation-induced transport
- Conclusions

Manipulation of X-point radiation zone in the baffled Snowflake

L-mode



Significant target heat flux reduction for optimal X-point separation (up to 66%)



[1] Gorno *et al.*, submitted to PPCF
https://arxiv.org/abs/2209.02969

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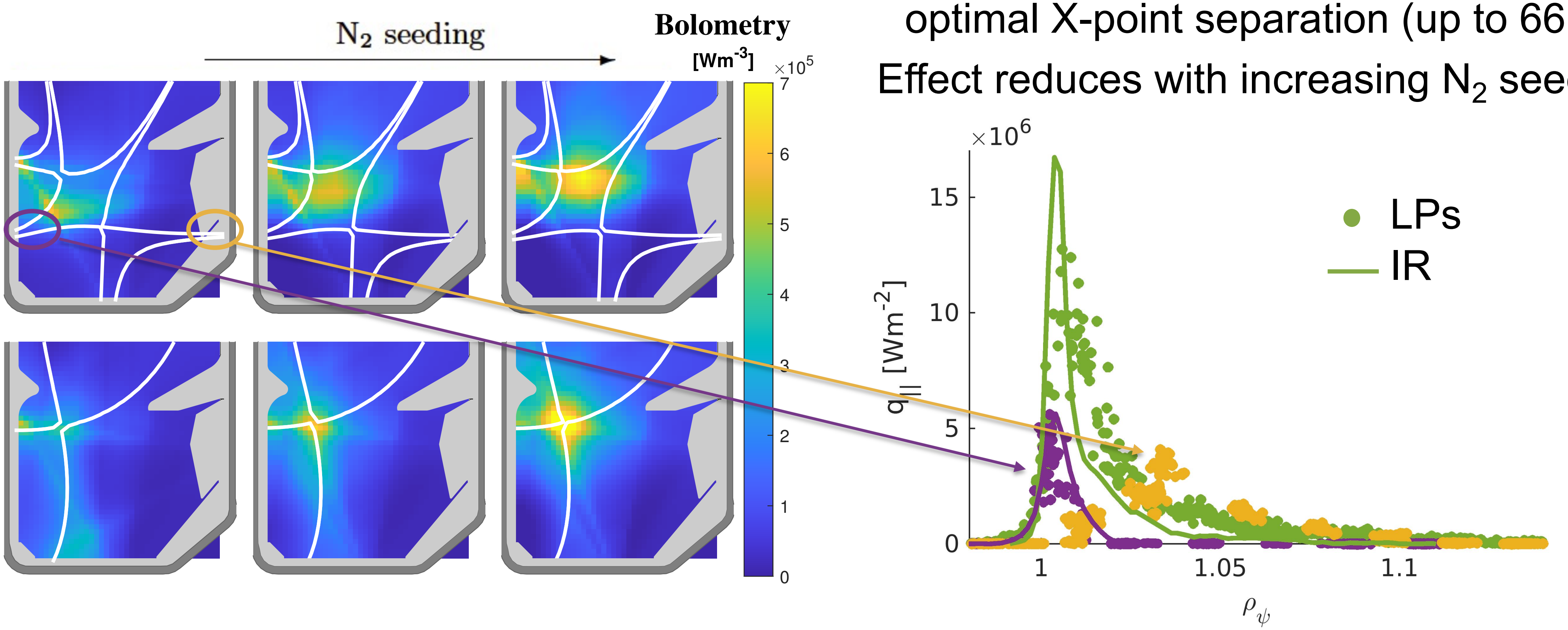
Effect reduces with increasing N_2 seeding



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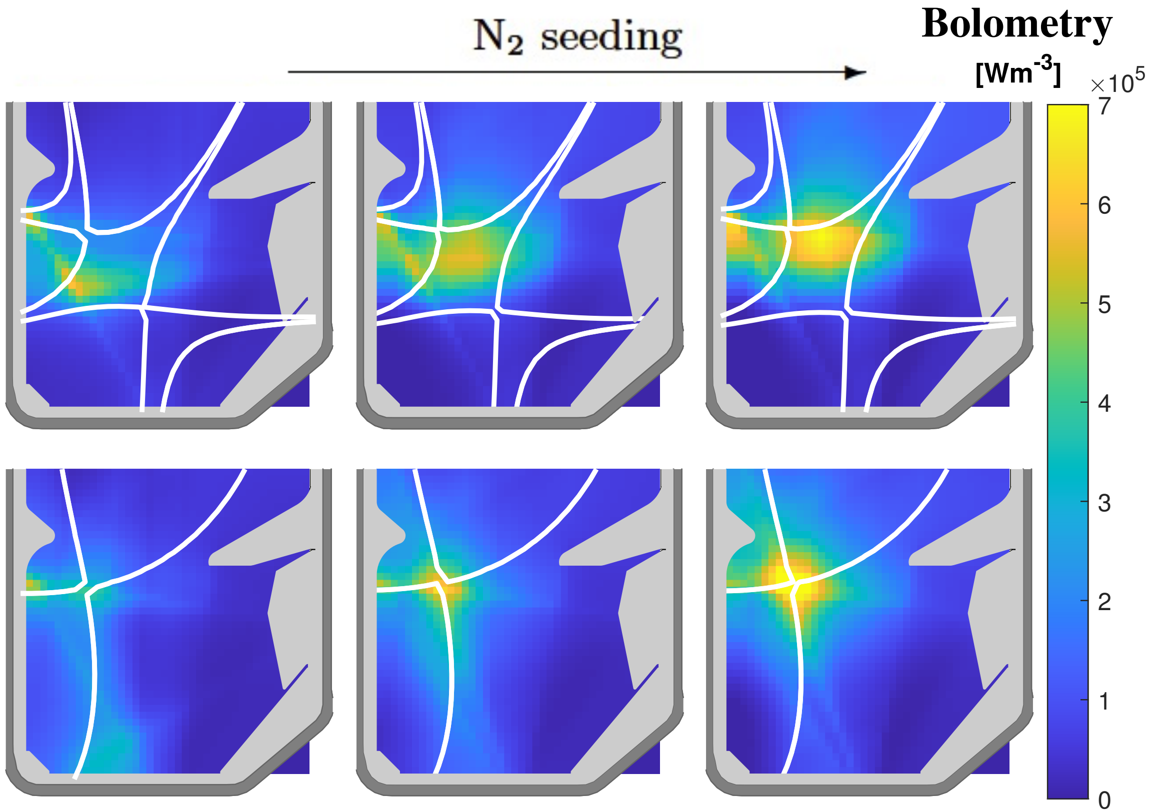
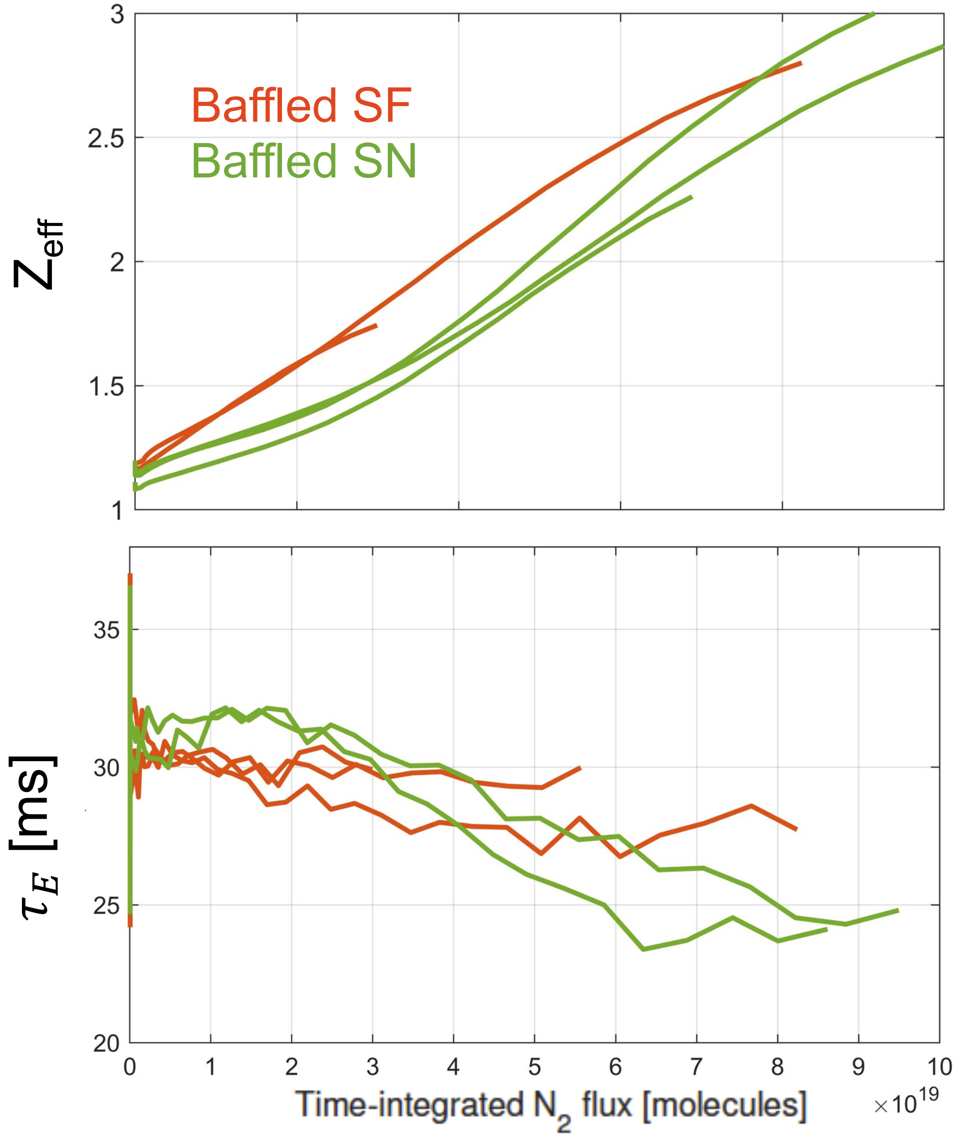
Radiation zone displacement in these Snowflakes shows no apparent benefit for the core plasma

L-mode





[1] Gorno *et al.*, submitted to PPCF

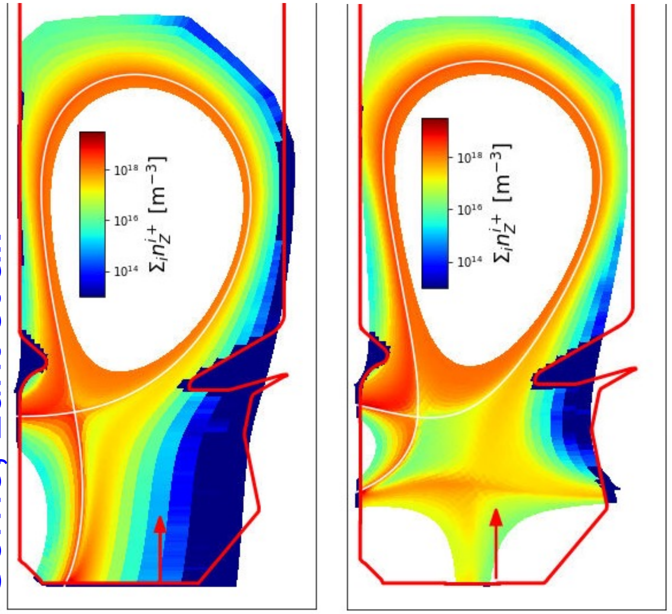
EMC3-EIRENE modelling and extrapolation

- Interpretive modeling with EMC3-EIRENE ongoing, key questions:
  - Can we use same transport coefficients in SF and SN?
  - Is impurity transport modelled accurately? How does impurity compression depend on geometry?
  - What is relation btw. divertor volume and radiation level?
- Extrapolate simulations to higher power conditions

➢ Initial results show similar core impurity levels in SN and SF for given radiation levels, largely consistent with experiment

➢ Enhanced cross-field transport in the SF divertor needed to reproduce target conditions

C density for fixed P_{in}, P_{rad}, n_u



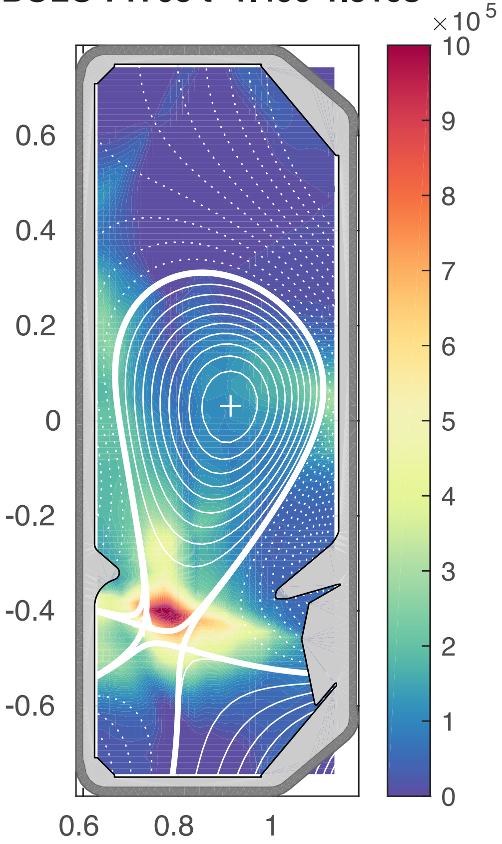
Gorno, Lunt et al.

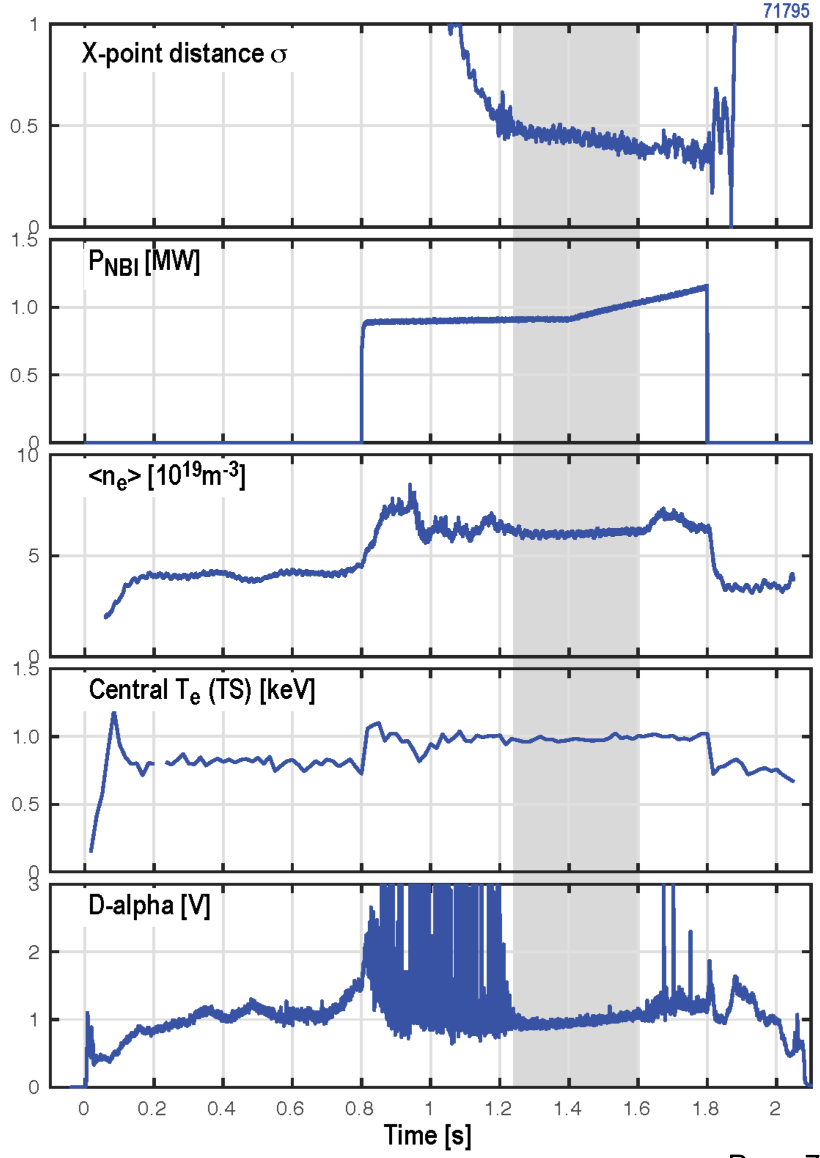
Snowflake facilitates access to ELM-suppressed X-Point Radiator regime

H-mode

- Discharge ELM-free, with radiation zone peaking above X-point

BOLO 71795 t=1.490-1.510s





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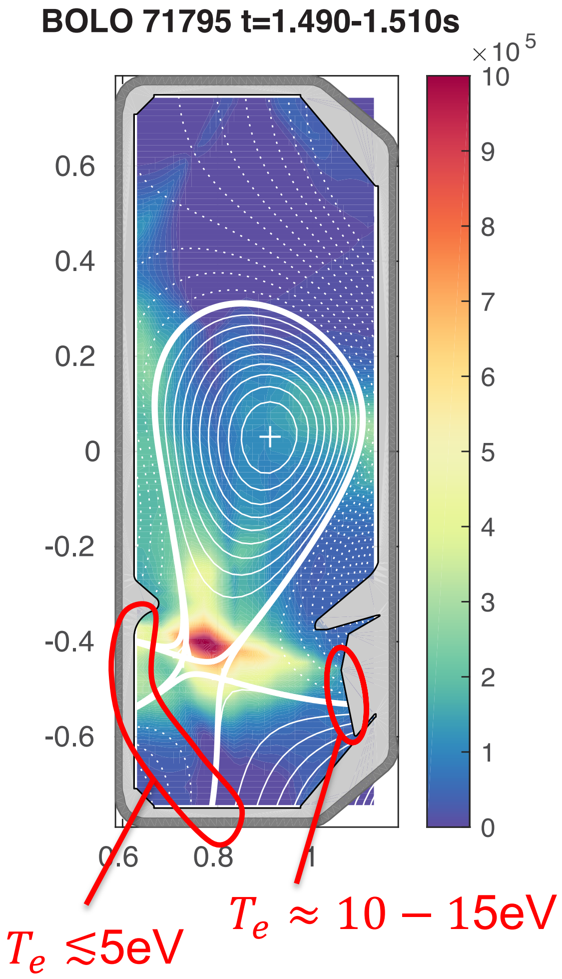
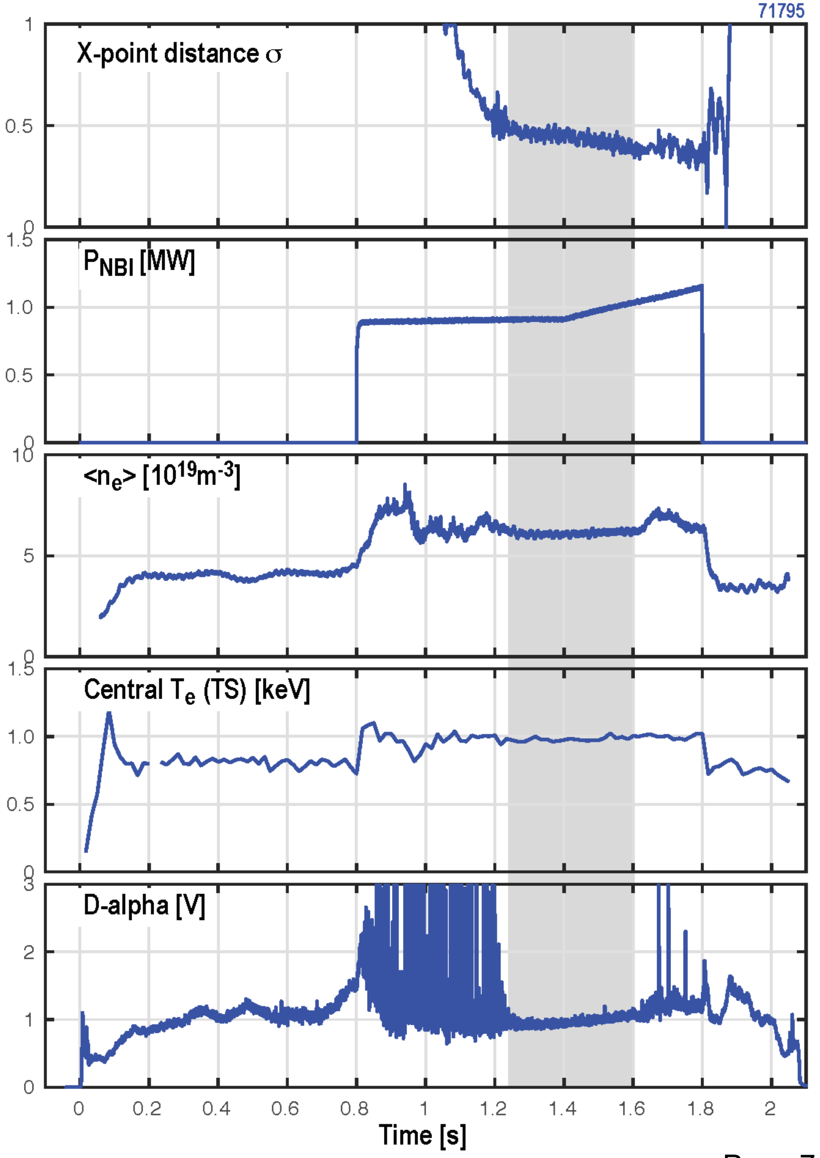
- No seeding, outermost strike-point still attached; Regime also achieved without baffles





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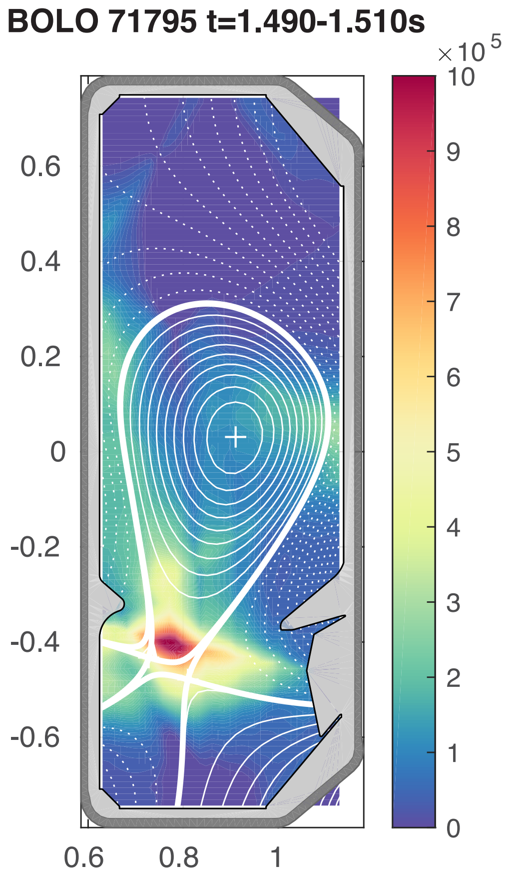
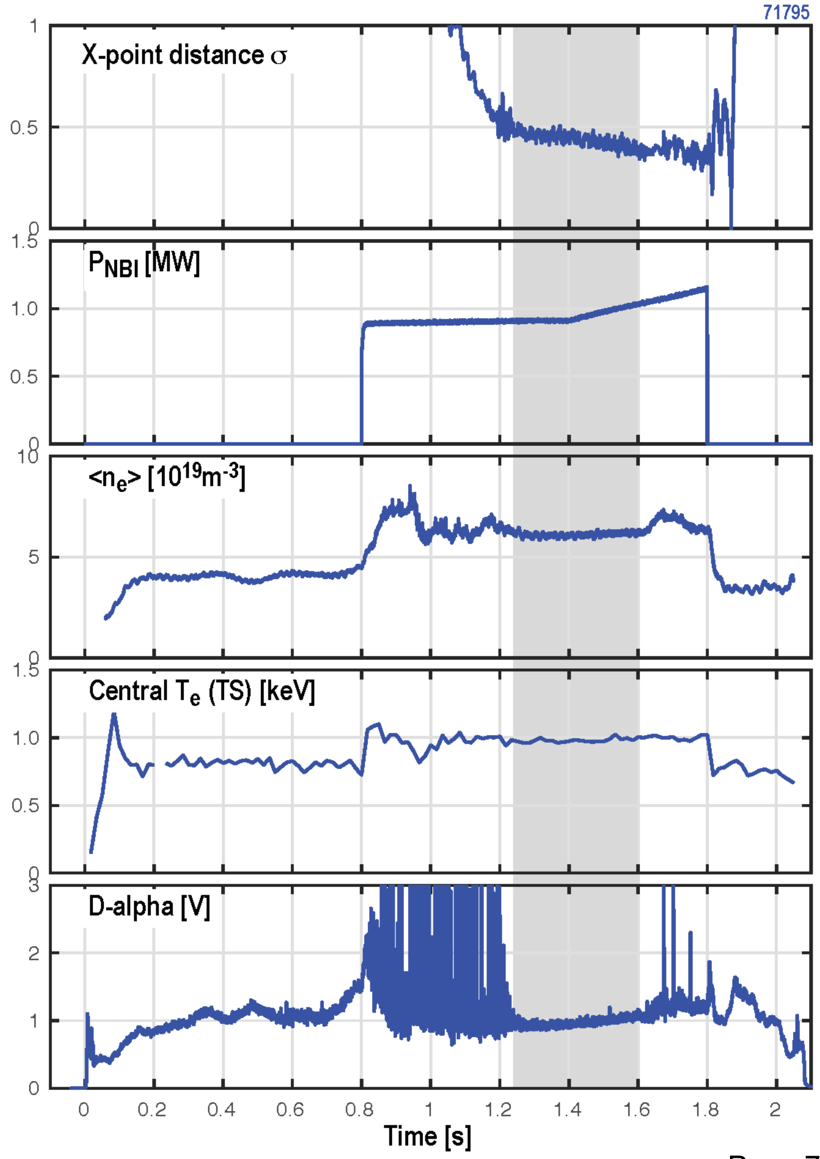
- Regime much easier to access than in LSN (cf. [1]), consistent with large flux expansion near X-point, as expected from [2]





[1] Bernert *et al.*, subm. to NME
[2] Stroth *et al.*, NF 2022

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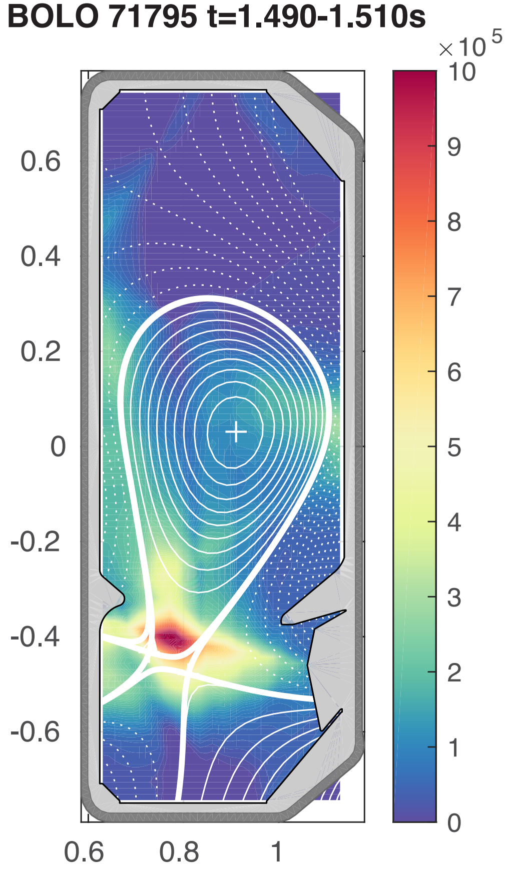
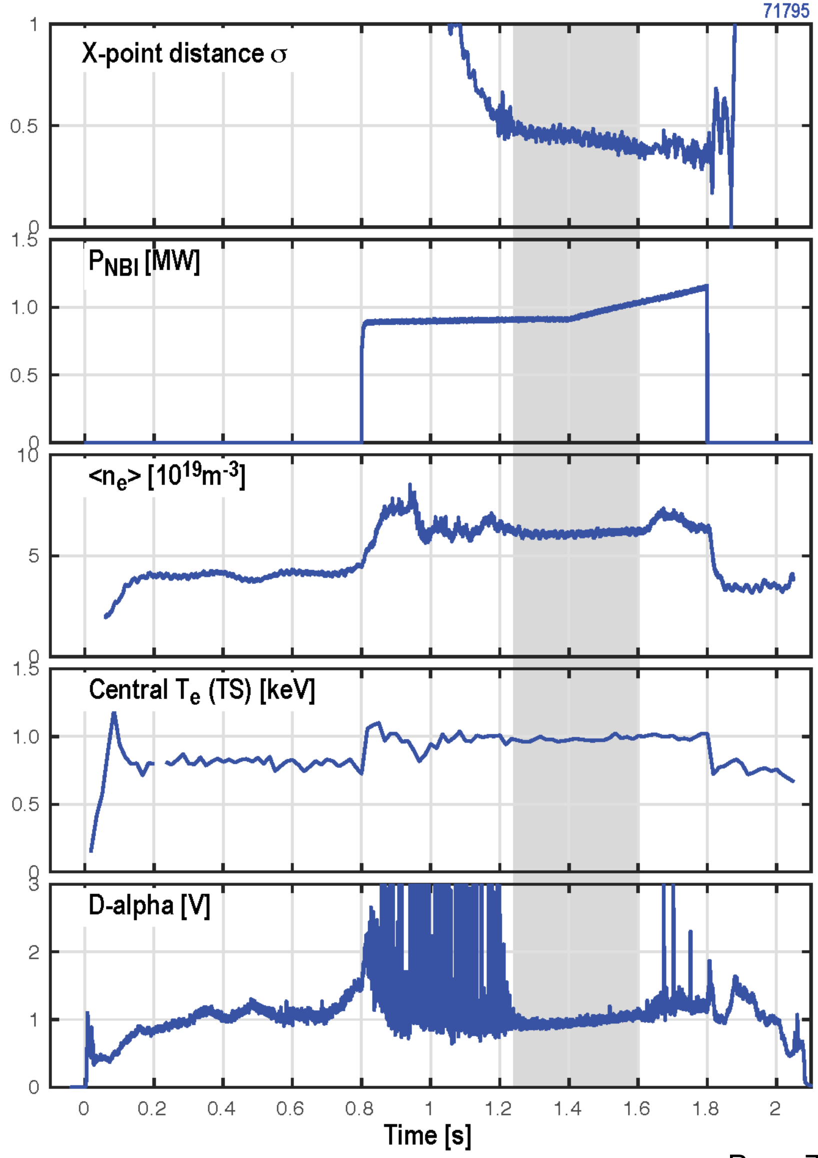
➢ Good target to assess effect of geometry on XPR access and test the model of [2]





[2] Stroth *et al.*, NF 2022

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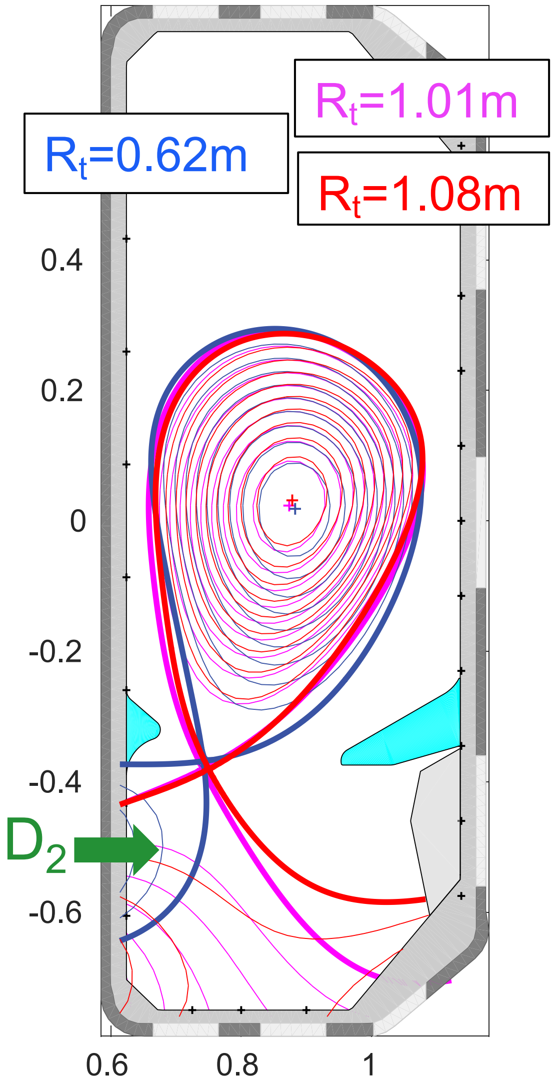
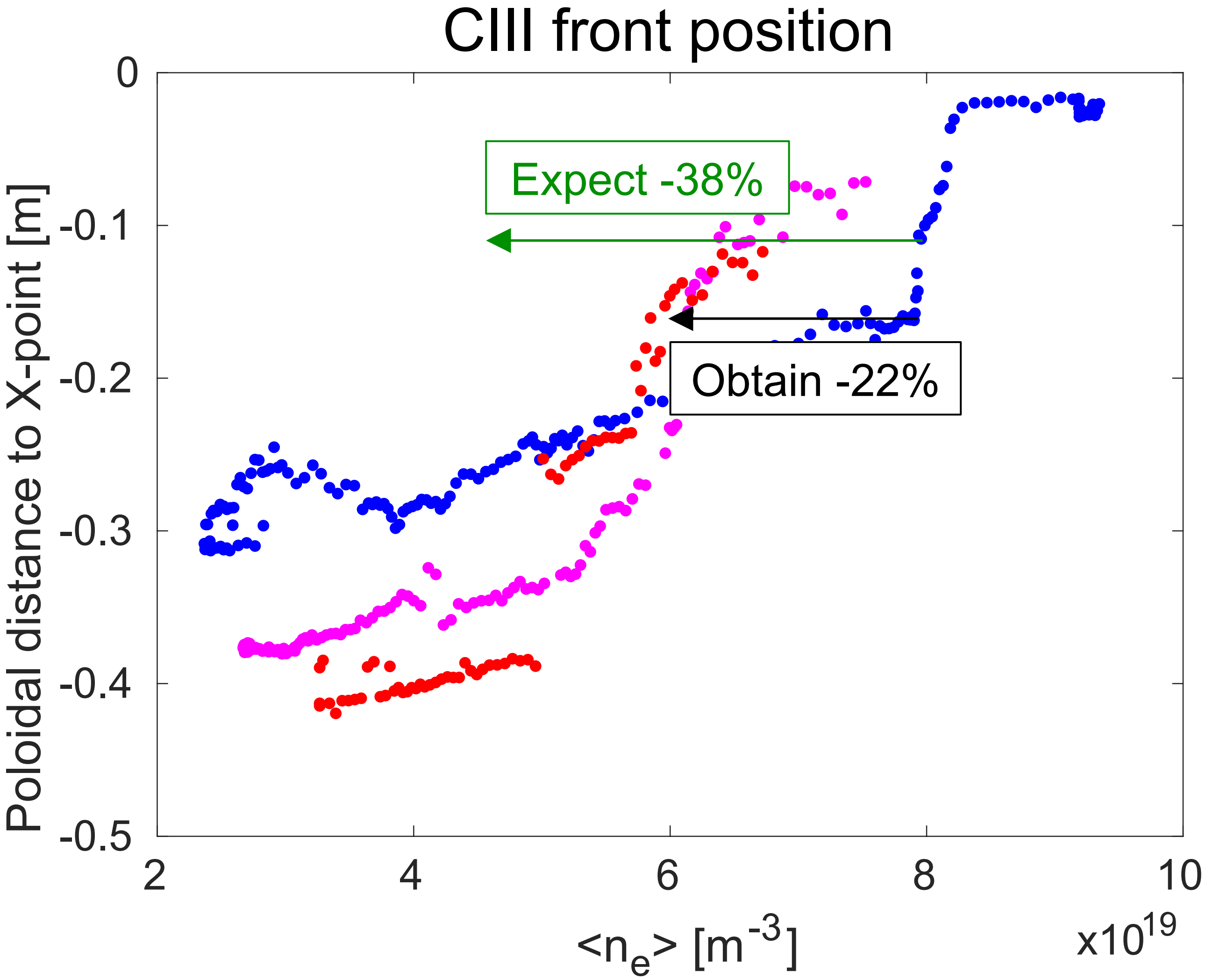
CIII front movement (and LPs) show partially reduced detachment threshold with increasing R_t

L-mode





[1] Theiler *et al.*, Proc. IAEA-FEC 2021
[2] Reimerdes *et al.*, NF 2022

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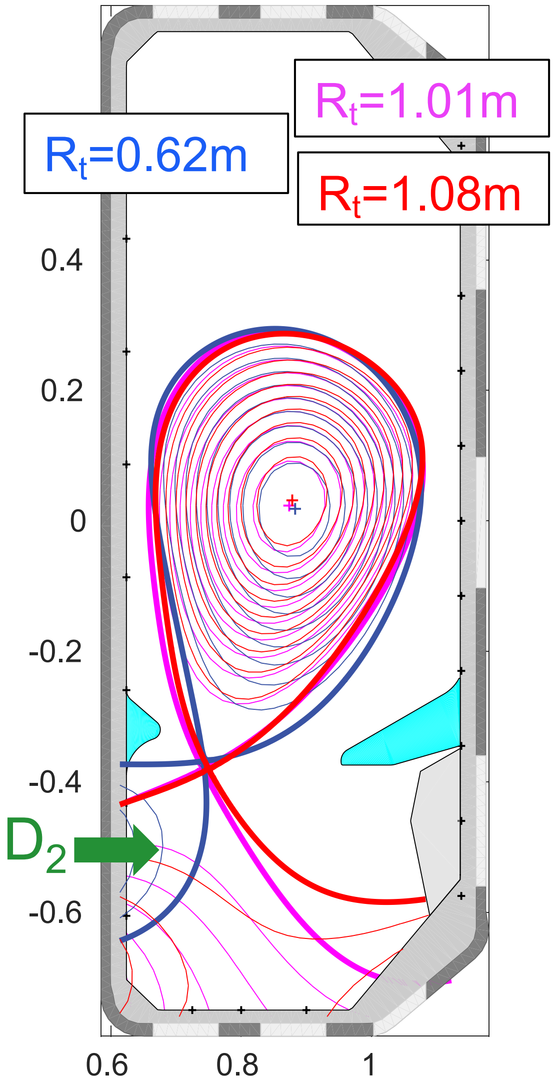

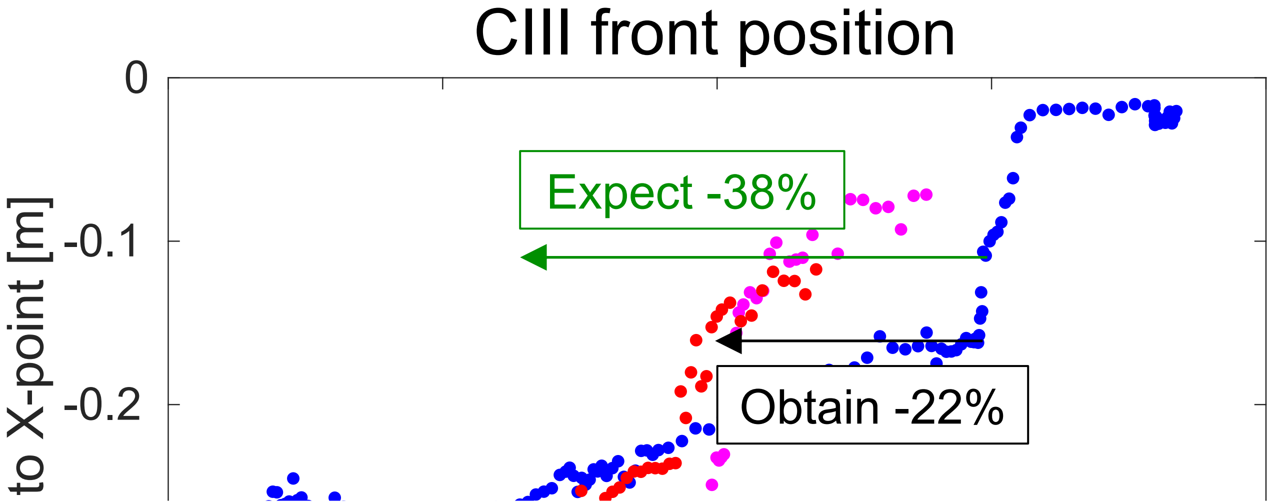

- Target quantities still deviate significantly from 2pt. Model, in particular $n_{e,t} \not\propto R_t^2$

[1] Theiler *et al.*, Proc. IAEA-FEC 2021
[2] Reimerdes *et al.*, NF 2022

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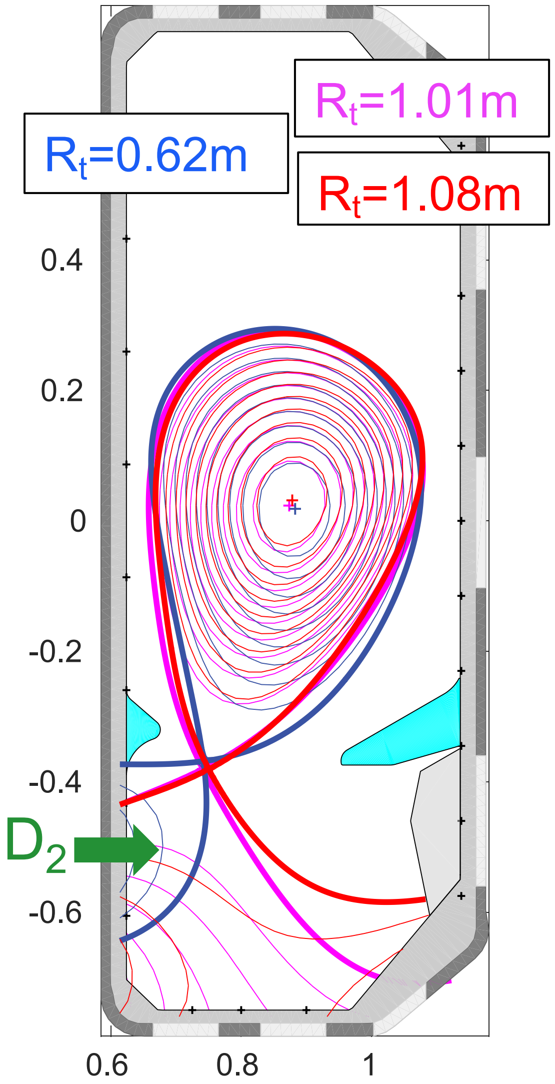
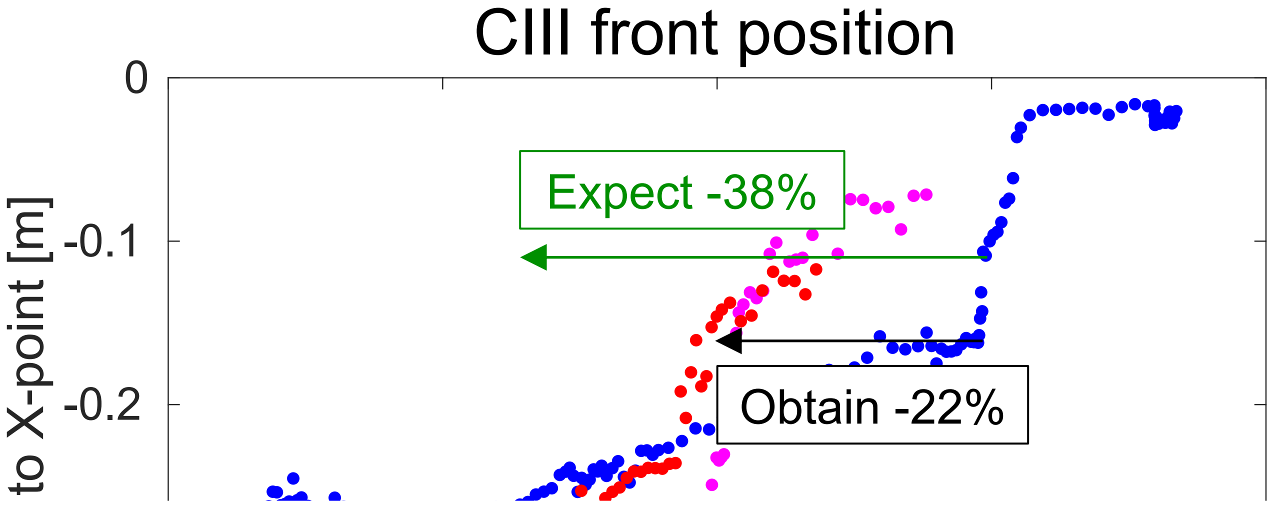


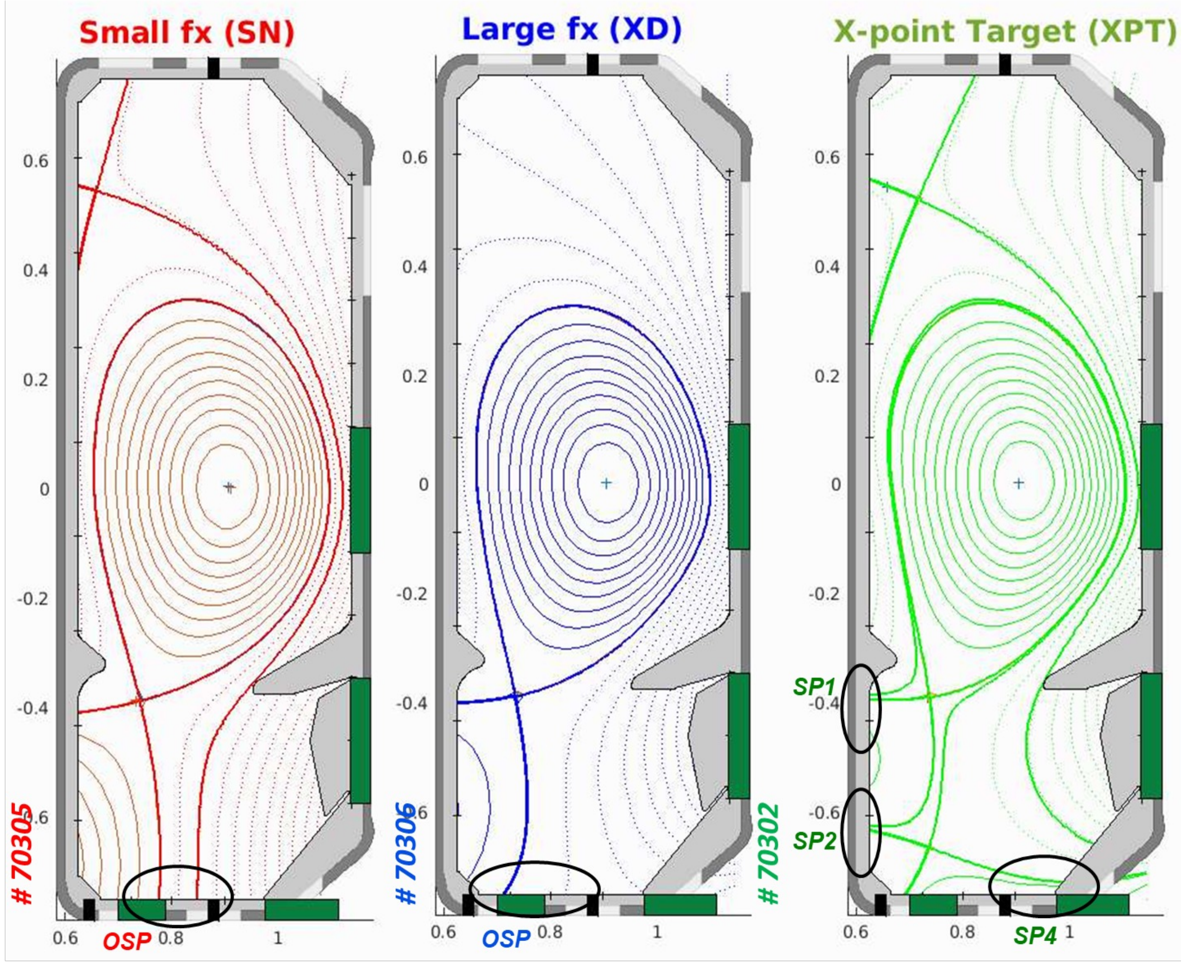


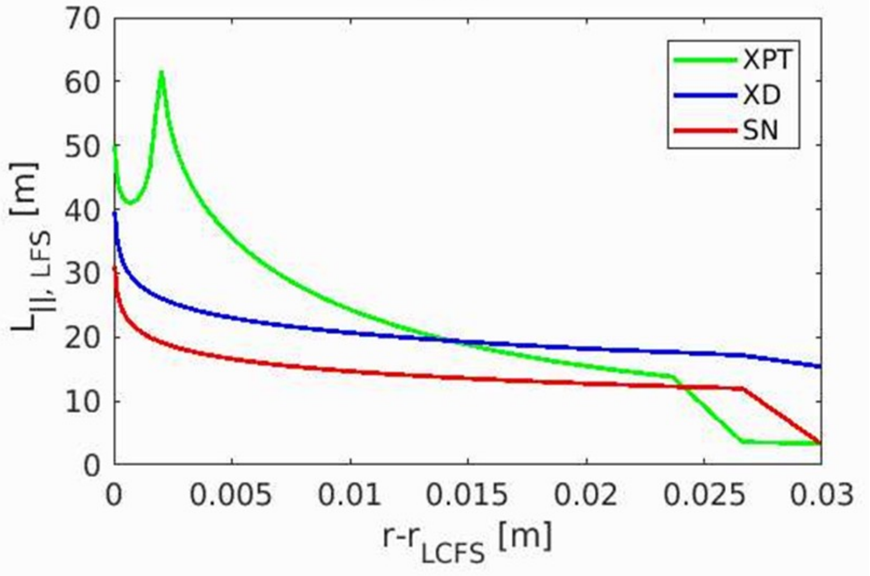
- Full benefits of total flux expansion difficult to achieve experimentally

[1] Theiler *et al.*, Proc. IAEA-FEC 2021
[2] Reimerdes *et al.*, NF 2022

Other long-legged options explored on TCV: X-Divertor and X-Point Target

H-mode

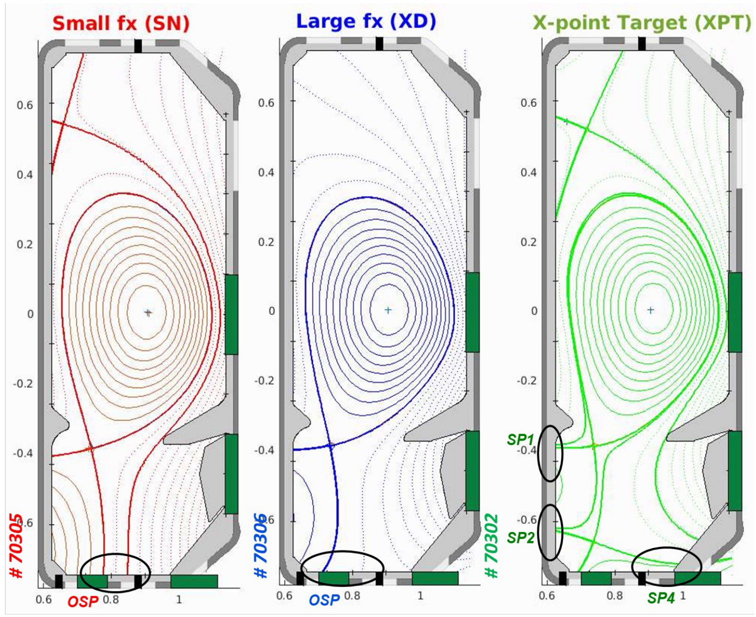


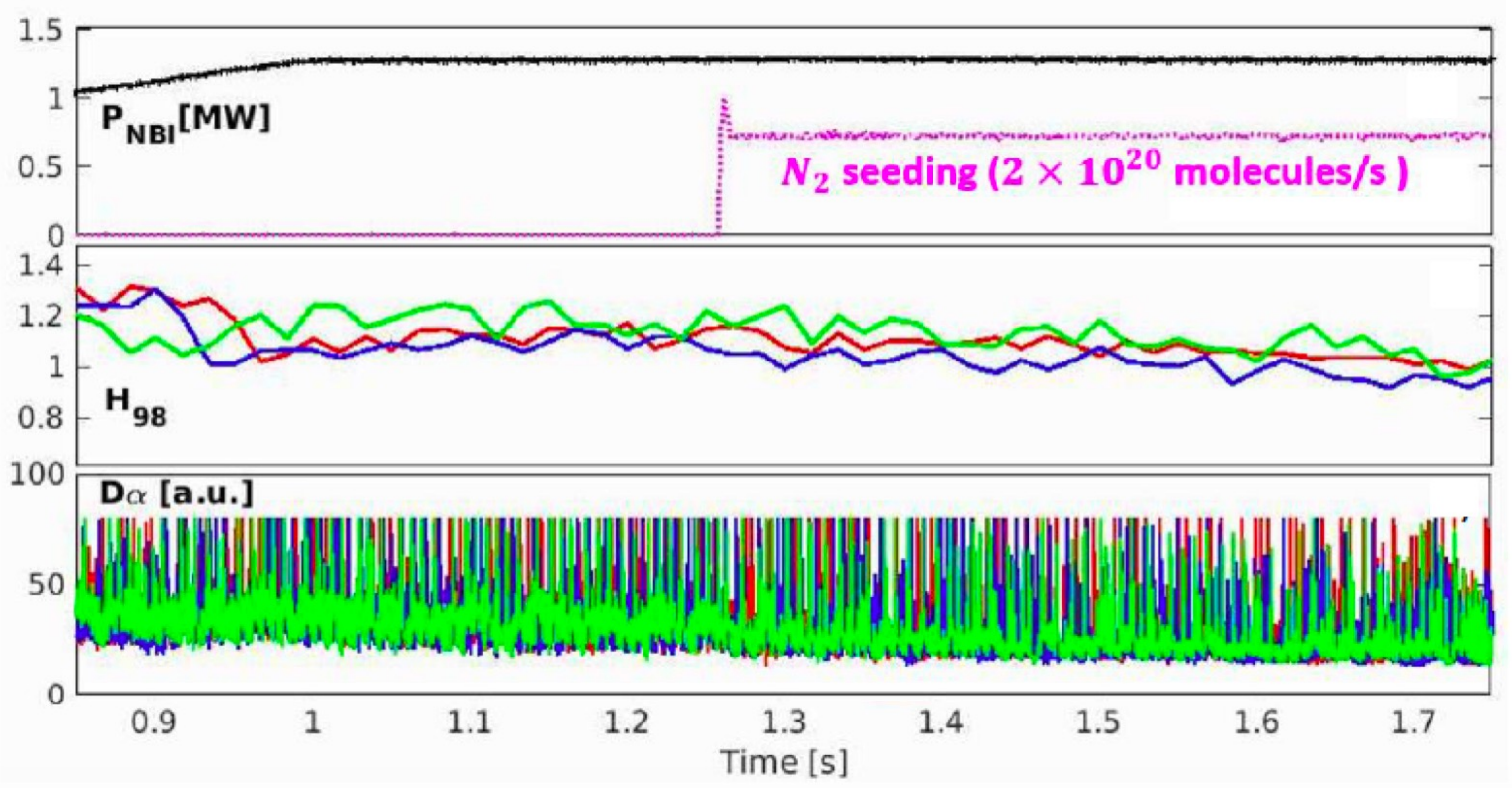


[1] Raj *et al.*, NF 2022

$H_{98} \gtrsim 1$ maintained in seeding phase, similar for all geometries

H-mode



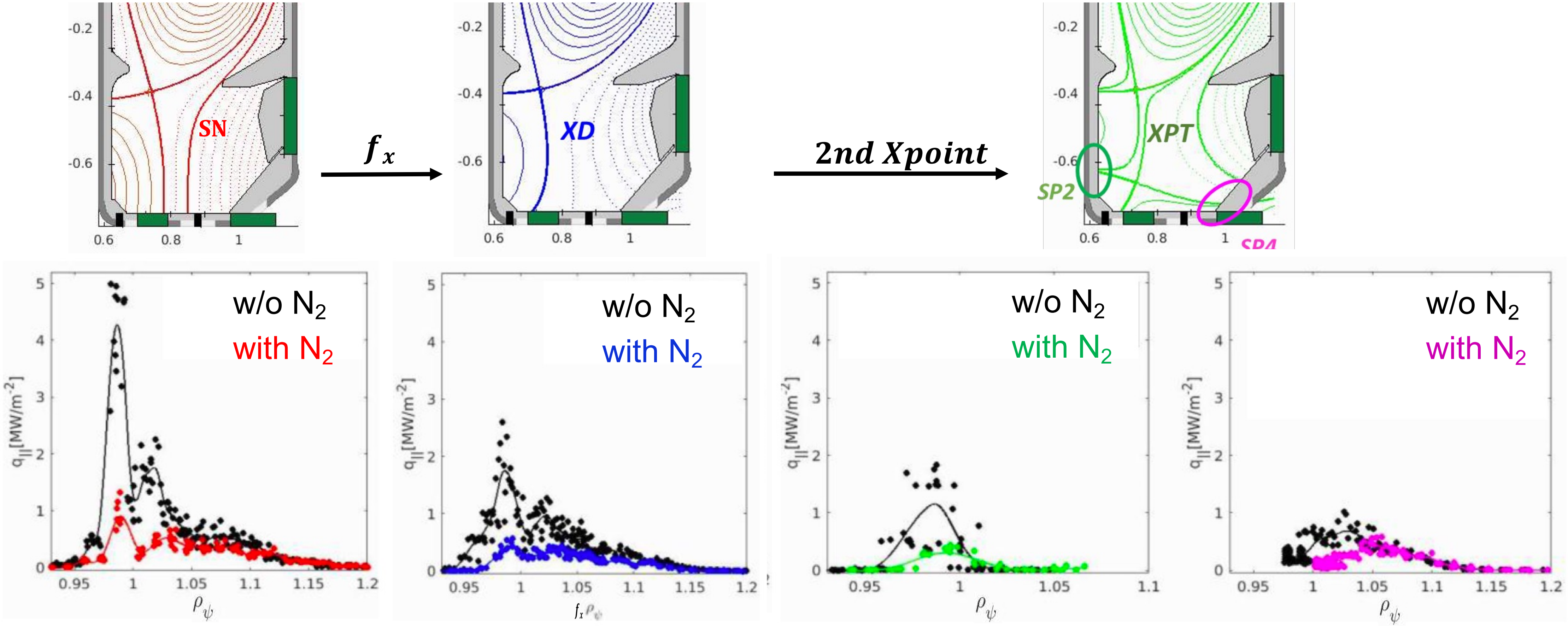


➢ Overall, little effect of divertor geometry on core properties

[1] Raj *et al.*, NF 2022

>50% outer target peak heat flux reduction in alternative geometries

H-mode

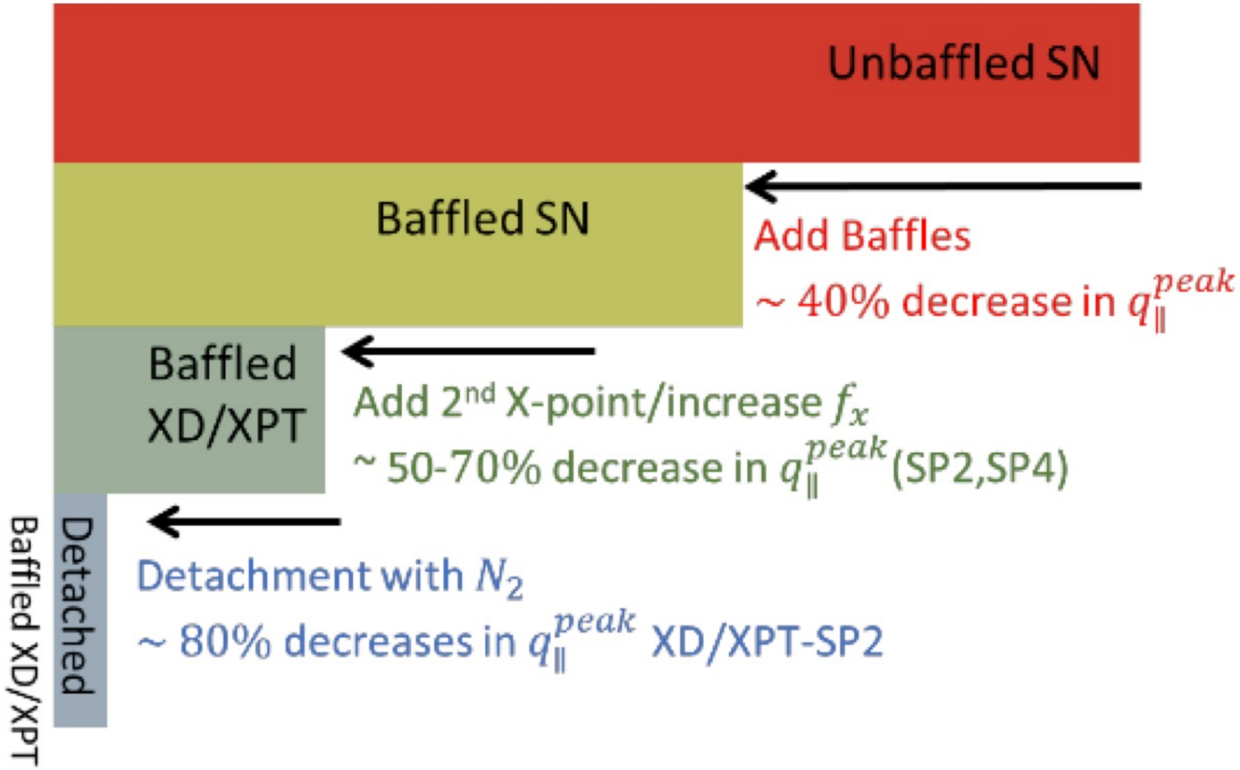


- Similar benefits in small-ELM regimes
- XPT result strongly sensitive to X-point separation

Inter-ELM heat fluxes from LPs

[1] Raj *et al.*, NF 2022

Overall, 95%-98% drop in inter-ELM outer target peak heat flux as a combination of baffles, ADC, and seeding



- Scenarios constitute a good starting point for interpretive modelling, extrapolation towards higher power conditions, and comparisons with DTT and DEMO modelling

[1] Raj *et al.*, NF 2022

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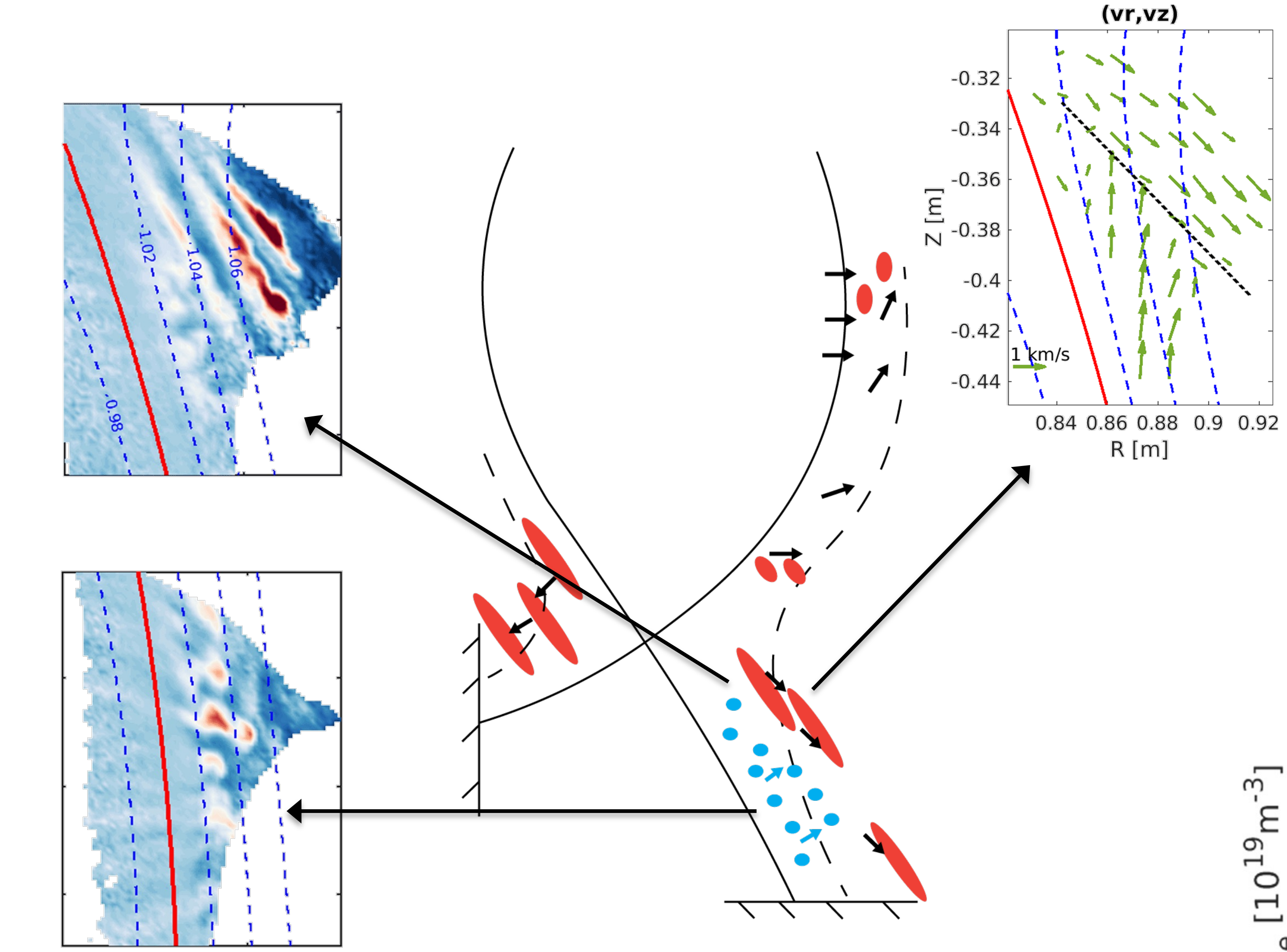
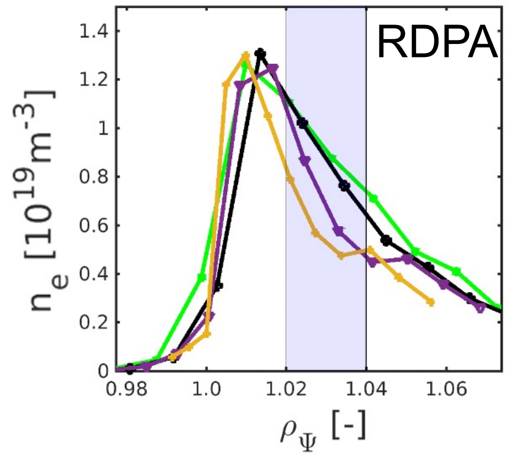
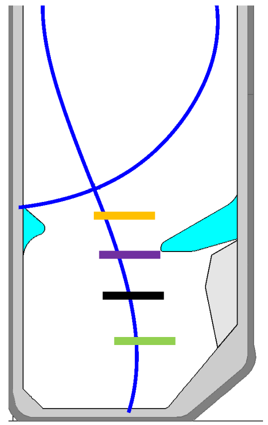
Upstream-connected and divertor-localized blobs in the TCV SOL



- Different blob types have different flow pattern, yet similar v_r (~400m/s)
- Divertor blobs estimated to contribute significantly to profile broadening[1]

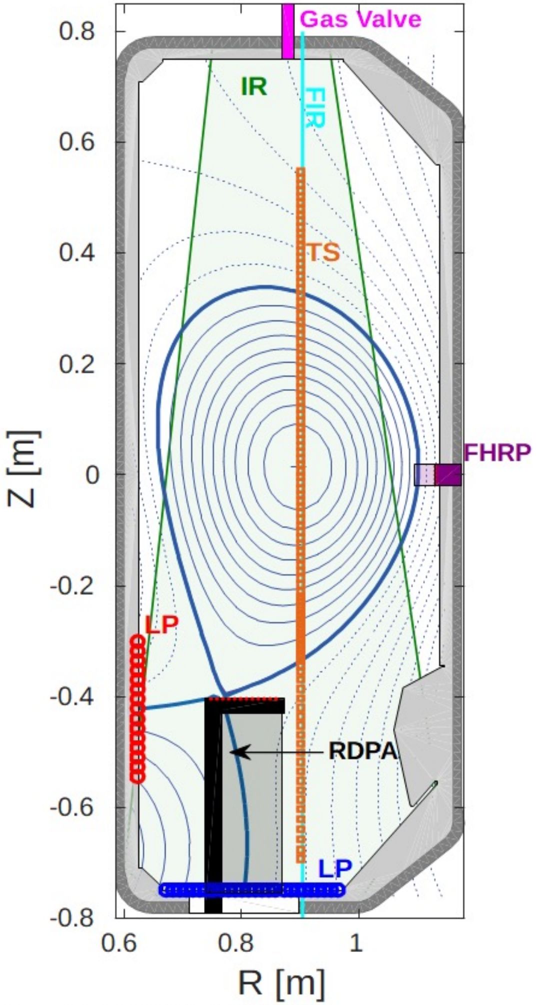
- Consistent with profile broadening measured along leg[1]

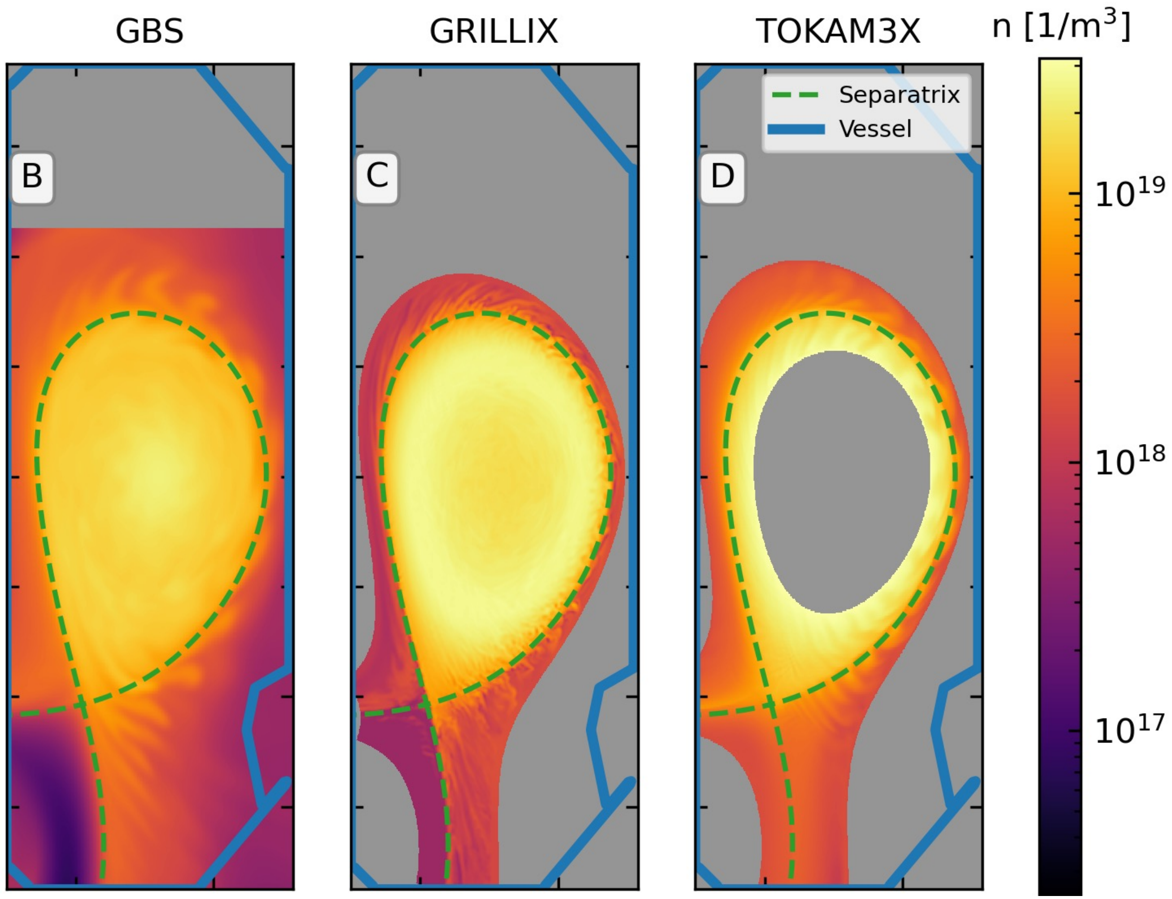




[1] Wüthrich *et al.*, NF 2022

First full-size turbulence simulations of TCV diverted plasmas and validation with experiment





[1] Oliveira and Body *et al.*, NF 2022

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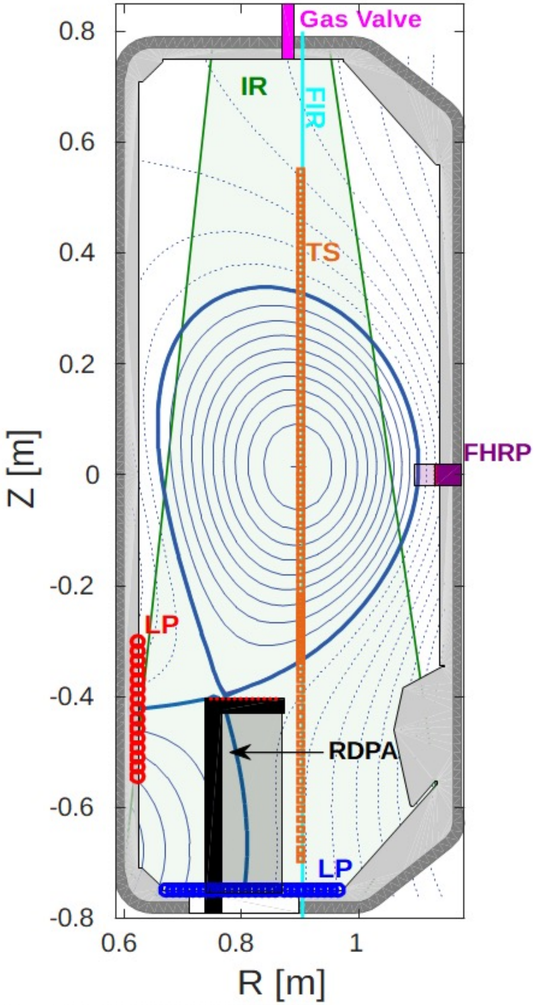
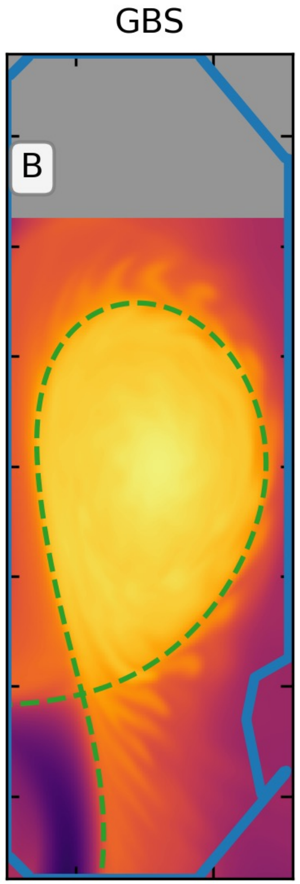
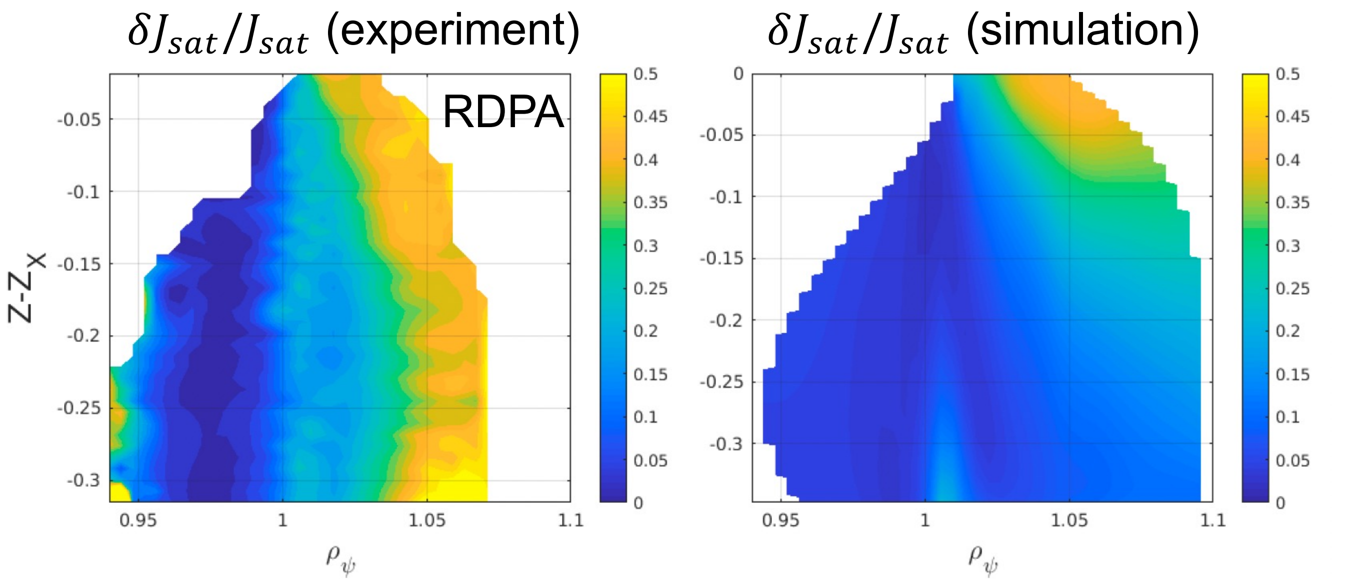




- Generally good quantitative agreement upstream (profiles, fluctuation levels,…)
- Stronger deviations in the divertor and at the targets

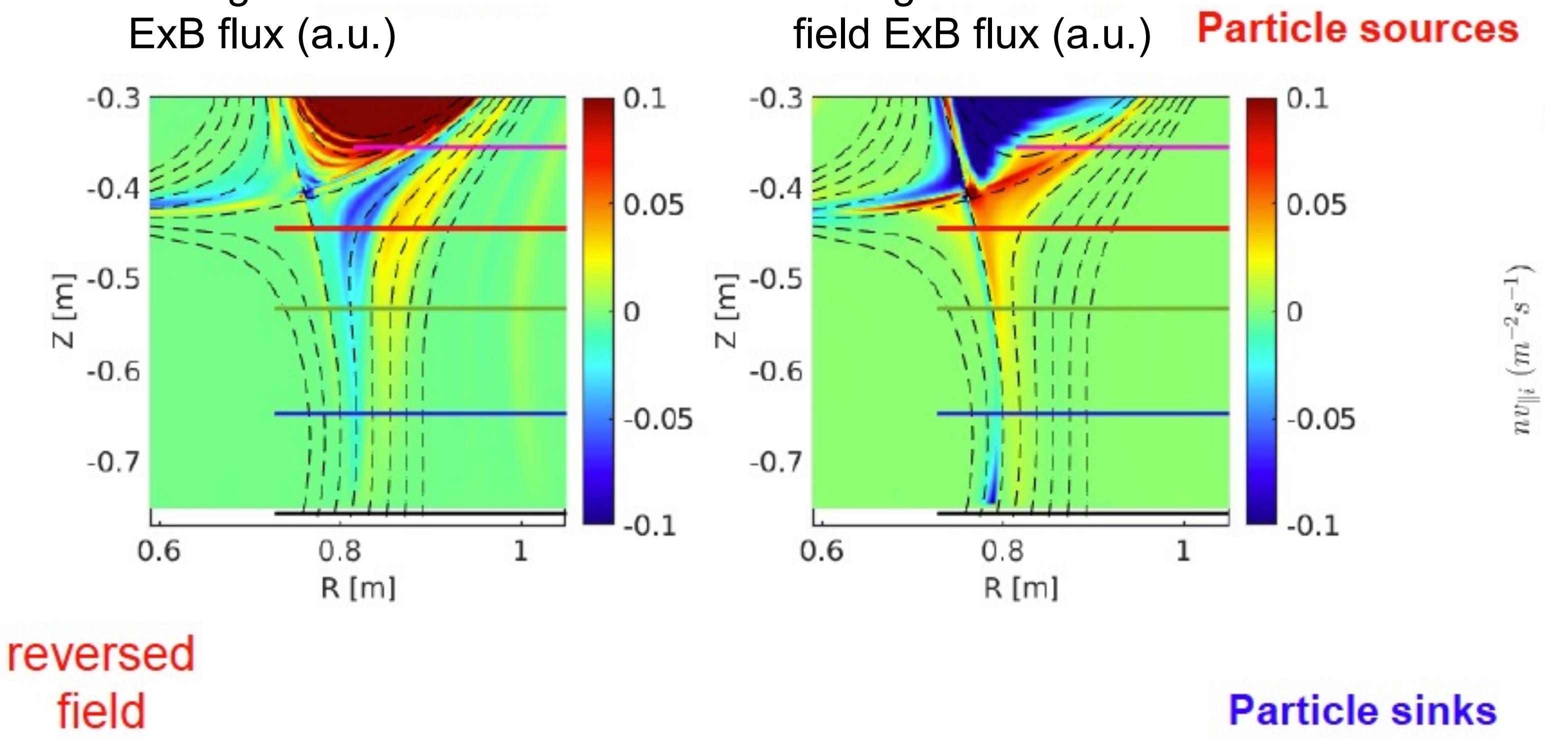


[1] Oliveira and Body *et al.*, NF 2022

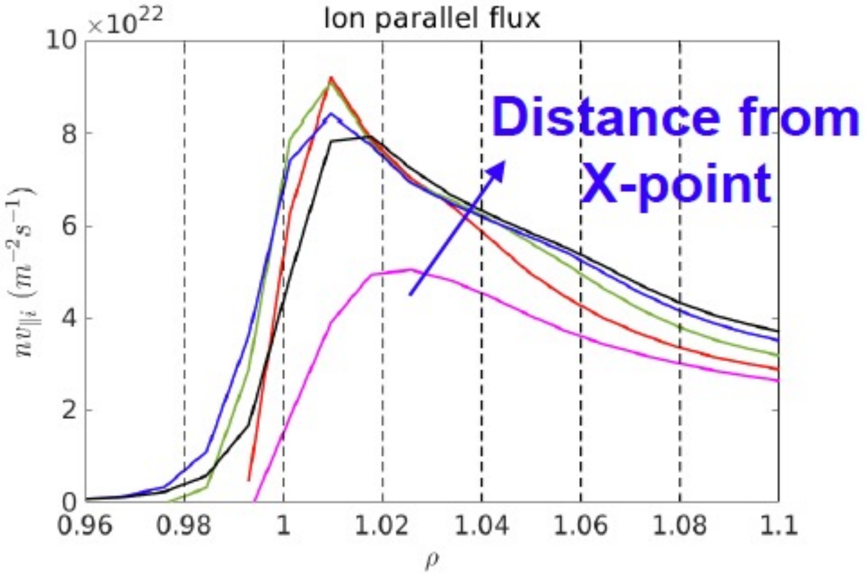
Fluctuation-induced and mean-field ExB fluxes contribute comparably to divertor transport in GBS

Divergence of turbulent ExB flux (a.u.)

Divergence of mean-field ExB flux (a.u.)



➢ Some ion flux broadening along divertor leg



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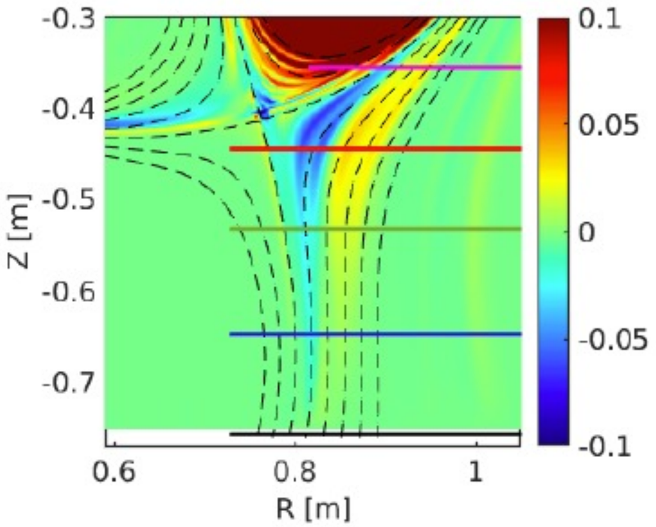
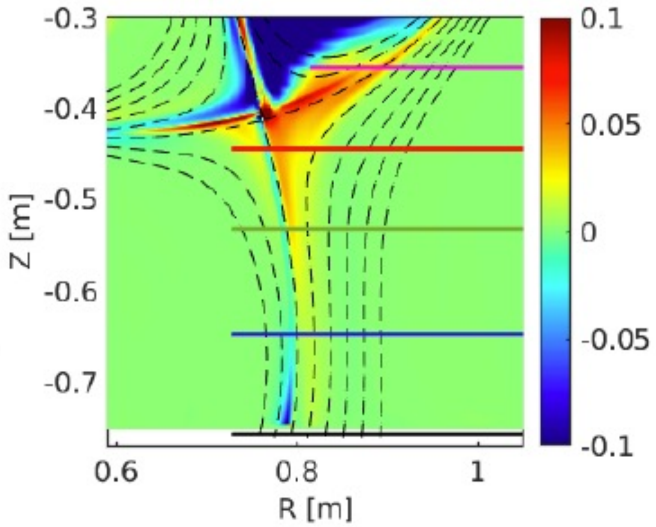
Divergence of mean-field ExB flux (a.u.)

Particle sources

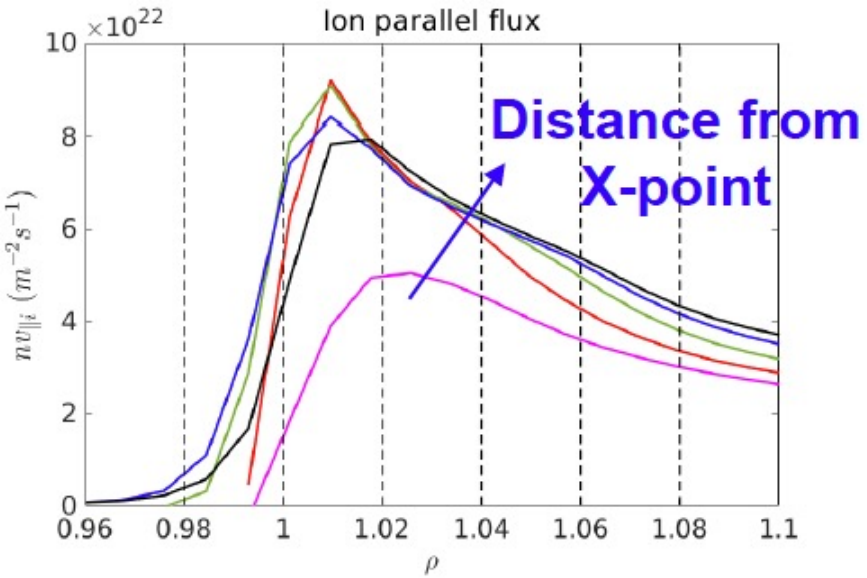




reversed field

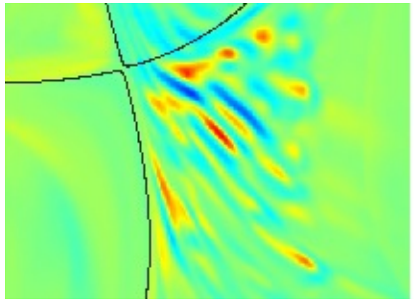
Particle sinks

- ➢ Some ion flux broadening along divertor leg



- ➢ Accurate description of divertor fluctuations important, in particular for assessment of alternative geometries and tight baffling
- ➢ How do fluctuations influence impurity transport from divertor to upstream/core?

$e\delta V_p/\langle k_B T_e\rangle_{t,\varphi}$



EPFL

Conclusions

- Peak parallel heat flux reduced in baffled SF-Minus, but displacement of radiation region outside of core not beneficial for core compared to SN → good starting point for modelling
- SF geometry does substantially facility access to an ELMfree X-Point Radiator regime in H-mode
- Total flux expansion effect so far only partly recovered in TCV
- Partially detached H-mode achieved with good core confinement; significant peak heat flux reductions in alternative geometries while core properties unchanged → Good starting point for interpretive modeling and extrapolation to reactor conditions
- Experimental and numerical findings indicated that fluctuation-induced transport significant in the divertor, comparable to drift effects