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A tightly-baffled, long-legged divertor concept for DEMO and its potential test in TCV

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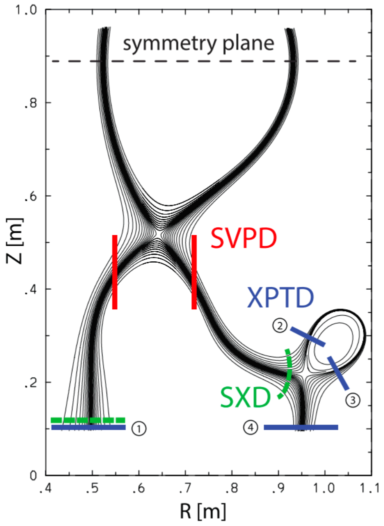
4th Technical Meeting on Divertor Concepts, Nov. 7-11, 2022

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.

A tightly-baffled, long-legged divertor concept for DEMO

- Safe power exhaust compatible with high plasma performance remains a primary challenge for fusion energy
- Alternatives to the single-null configuration adopted in ITER can improve exhaust performance
- Various *Long-Legged configurations* predicted to increase power handling capability by ~5-10x[1]
  - Seek to keep ‘detachment front’ from X-point
- Common characteristic
  - Extended poloidal leg length
  - Compatible with tight baffling



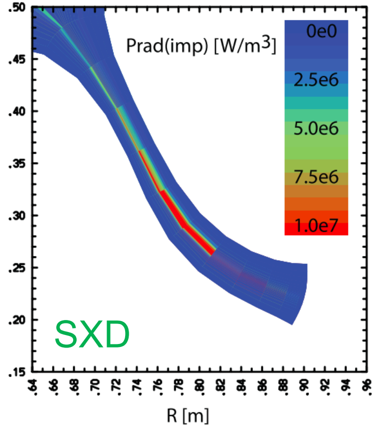


Fig. 1(a) & Fig. 7(g) of [1]

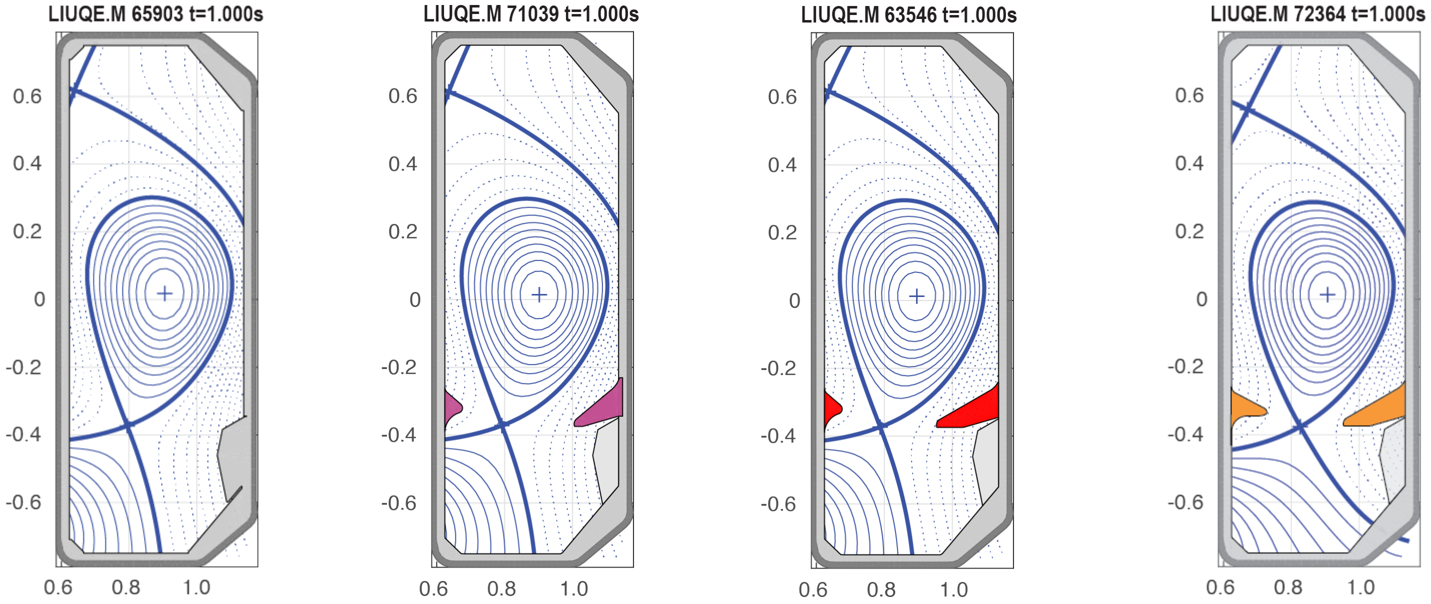
[1] M. Umansky et al., NF **60** (2020) 016004

Outline

- TCV experiments demonstrating improved power exhaust performance with stronger baffling
- Power plant considerations
- Potential test of a power plant relevant tightly-baffled, long-legged divertor in TCV
- Conclusions

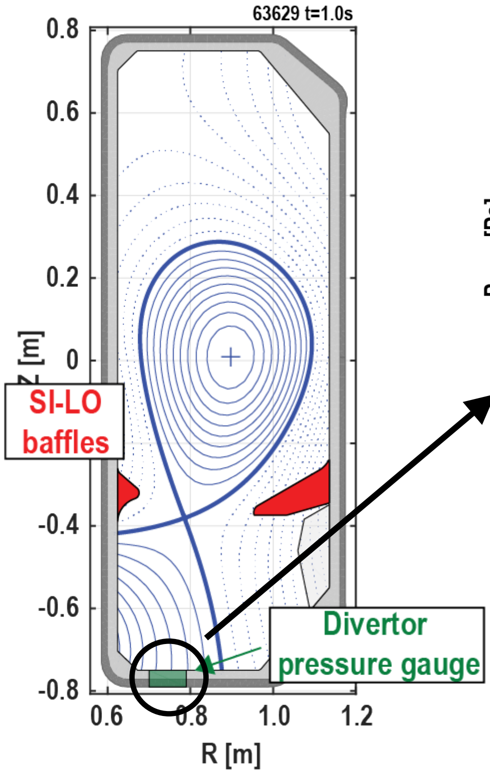
TCV is investigating the effect of baffling

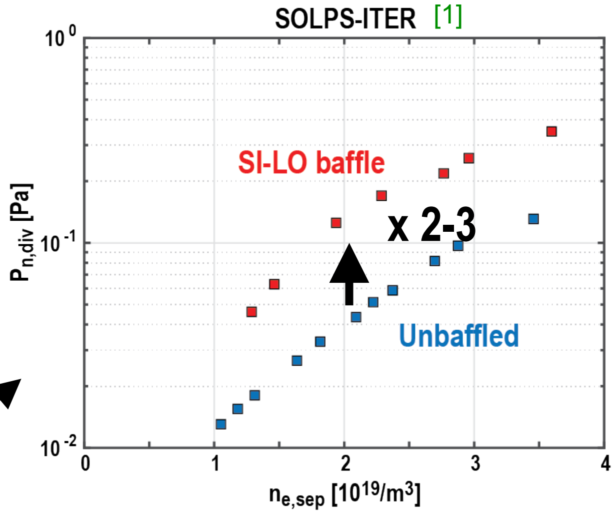
- Upgraded divertor with sets of removable gas baffles allow for a divertor of variable closure[1,2]

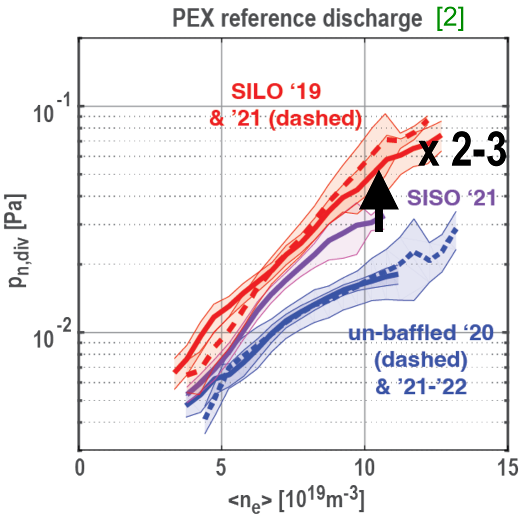


[1] H. Reimerdes, et al., NME **12** (2017) 1106
[2] A. Fasoli, et al., NF **60** (2020) 016019

Baffles increase divertor neutral pressure







Density ramp →

- Experiment confirms magnitude of $p_{\mathrm{n,div}}$ increase
- Absolute magnitude 3-4 x lower than predictions

[1] M. Wensing, et al., PoP **28** (2021) 082508

[2] H. Reimerdes, et al., 25th PSI conference, June 2022

Higher divertor neutral pressure linked to improved exhaust performance

- Empiric scaling of tolerable exhaust power in AUG[1]

$$\frac{P_{\text{sep}}}{R}\left[\frac{\text{MW}}{\text{m}}\right] \leq 0.77\left(p_0 + 18p_{0,N}\right)[\text{Pa}]$$

- Predicted ITER divertor target response[2]

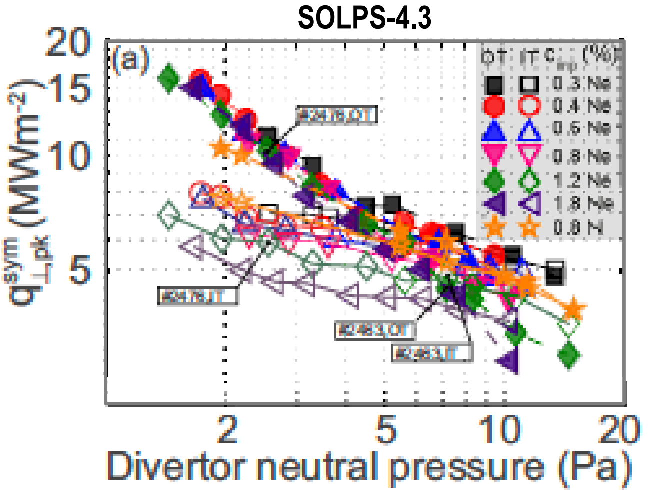


Fig. 5(a) of [2]

- Note that in a fixed geometry it is difficult to disentangle the roles of p_0 and $n_{e,sep}$ for power exhaust

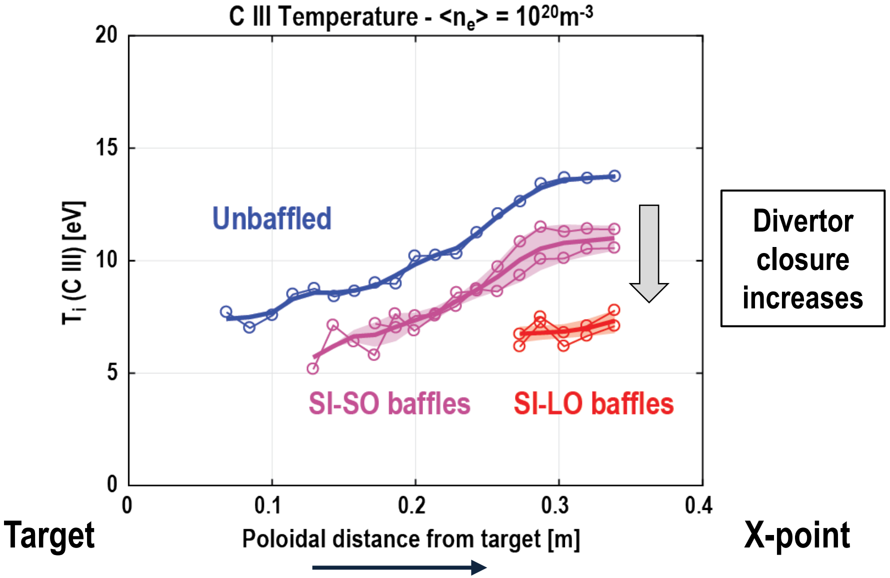
[1] A. Kallenbach, et al., NF **55** (2015) 053026

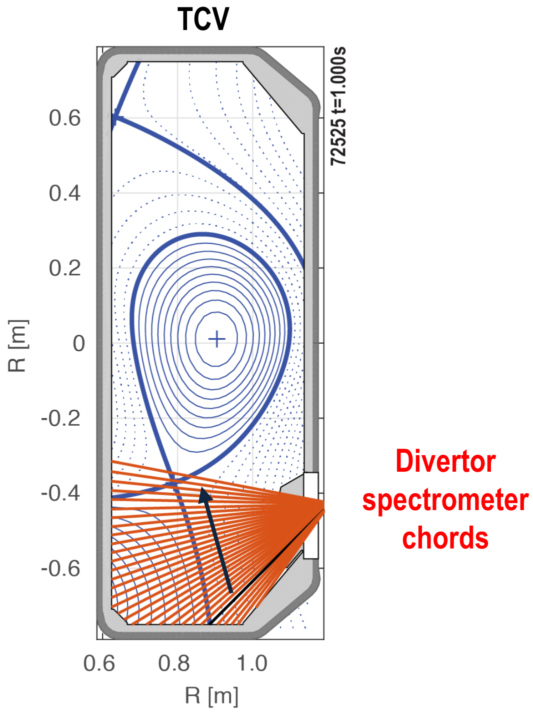
[2] R. Pitts, et al., NME **20** (2019) 100696

TCV divertor baffles decouple effect of divertor neutral pressure and core density

L. Martinelli, et al., 25th PSI conference, June 2022

- Measure ion temperature using Doppler broadening of C-III emission





➢ Higher divertor neutral pressure leads to cooler divertor plasma

Outline

- TCV experiments demonstrating improved power exhaust performance with stronger baffling
- **Power plant considerations**
- Potential test of a power plant relevant tightly-baffled, long-legged divertor in TCV
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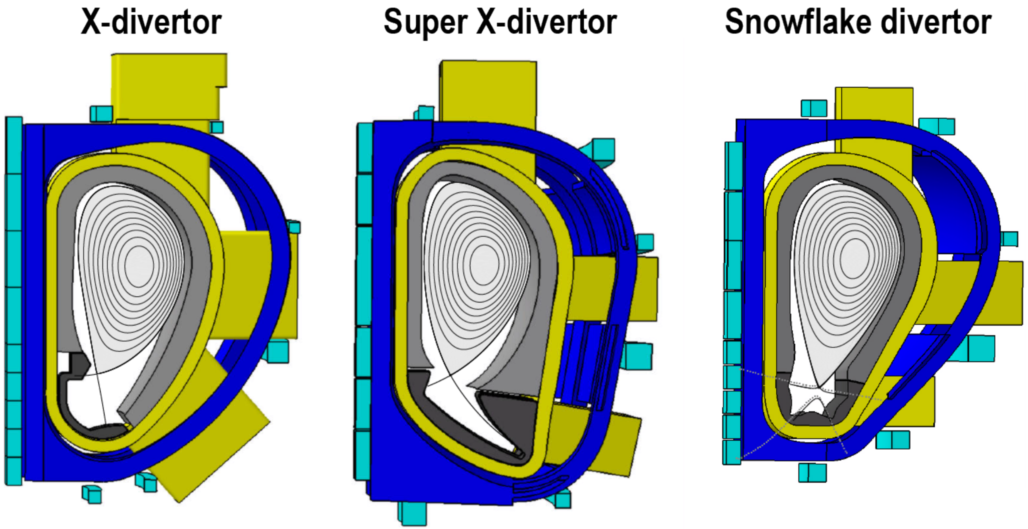
The tightly-baffled, long-legged divertor – a feasible reactor exhaust solution?

- Assessment of DEMO feasibility of a range of alternative divertor concepts raised concerns[1,2]

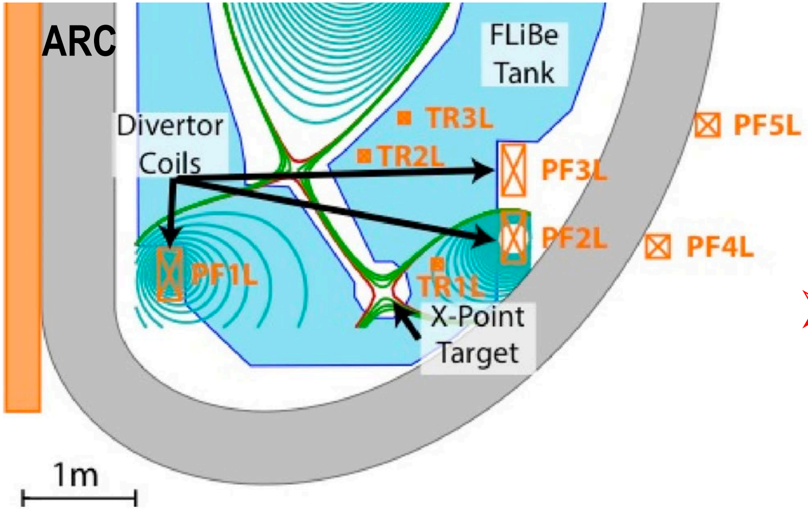


- Larger TF and PF coils increase plant volume & cost
- Larger PF coil currents increase coil stresses
- Increased vertical control challenge → excessive recirculating power
- In-situ winding and neutron shielding of internal coils

[1] H. Reimerdes et al., NF **60** (2020) 066030
[2] F. Militello et al, NME **26** (2021) 100908

The tightly-baffled, long-legged divertor – a feasible reactor exhaust solution?

- Increased poloidal length & tighter baffling can be implemented without major engineering complications[1]
  - Use full depth of the blanket to avoid/limit increase in TF volume

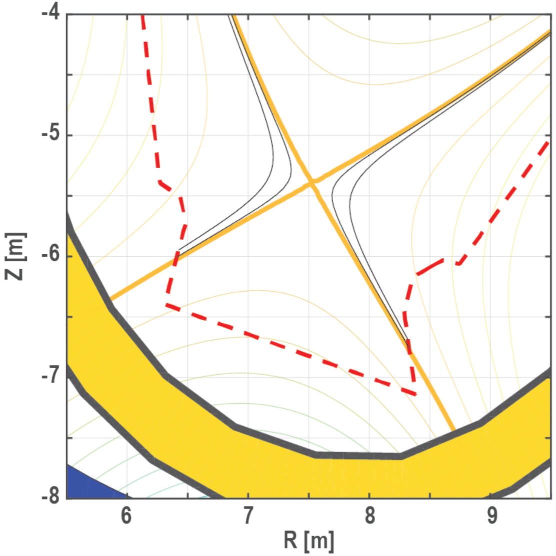


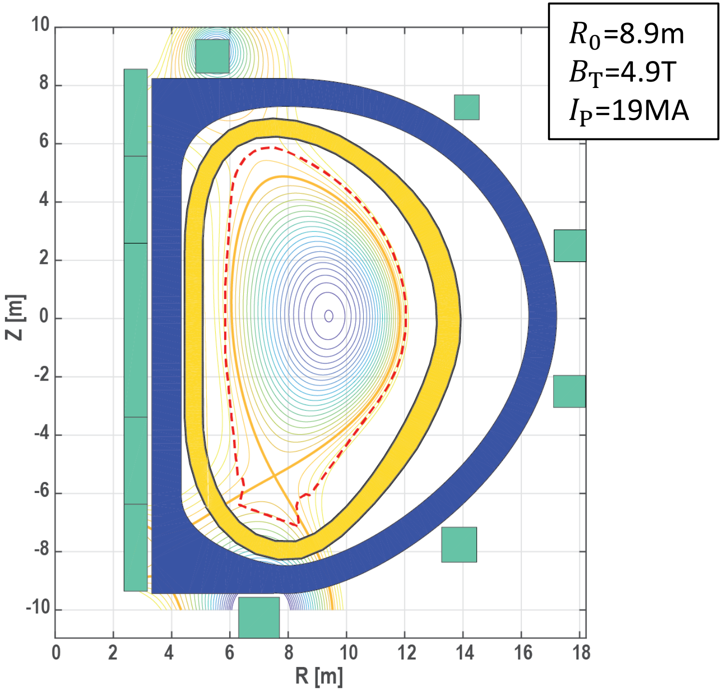
➢ Can we also drop additional X-points, internal coils and larger target radius?

[1] A.Q. Kuang, et al., FED **137** (2018) 221

EU-DEMO SN coil configuration & equilibrium with increased leg-length and stonger baffling

- Coils and magnetic equilibrium of ‘2018’ EU-DEMO configuration[1,2]





[1] H. Reimerdes, et al., NF **60** (2020) 066030
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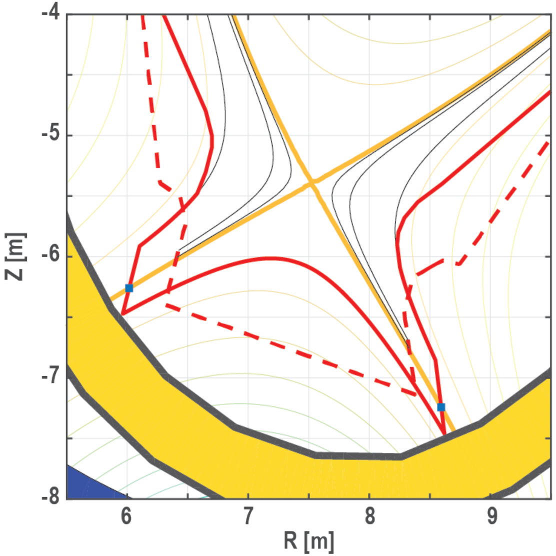
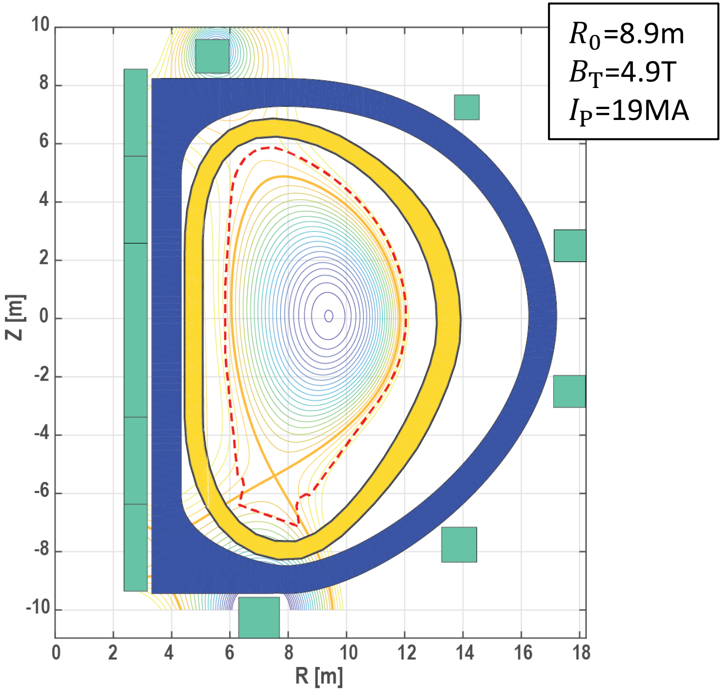
EU-DEMO SN coil configuration & equilibrium with increased leg-length and stonger baffling

- Coils and magnetic equilibrium of ‘2018’ EU-DEMO configuration[1,2]

TBLLD





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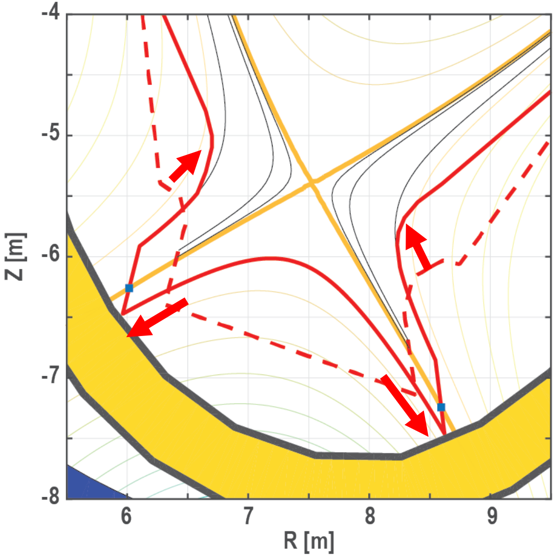
TBLLD



Modifications

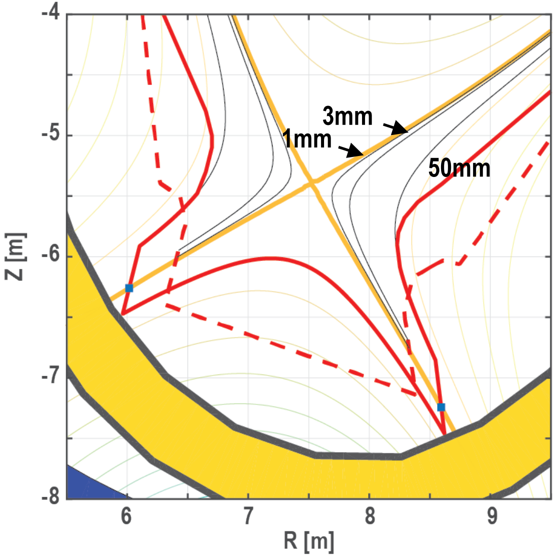
- Extend divertor legs by placing targets closer to the reference vessel
  - + Vessel may have to be modified to allow for larger divertor cassette!
- Extend baffles towards X-point

[1] H. Reimerdes, et al., NF **60** (2020) 066030
[2] F. Militello, et al, NME **26** (2021) 100908

Tightly-baffled, long-legged divertor (TBLLD) in DEMO requires optimisation

- Need to investigate parametric dependencies, e.g. with SOLPS-ITER
  - Compare performance to reference (Ar seeded SN)[1]

TBLLD



Parameters

- Distance of CFR baffle
- Distance of PFR baffle
- Orientation of targets → grazing angle
- Baffle extension towards X-point
- Poloidal length

Features

- Neutral passage between inner and outer target

Physics aspects

- Pumping!

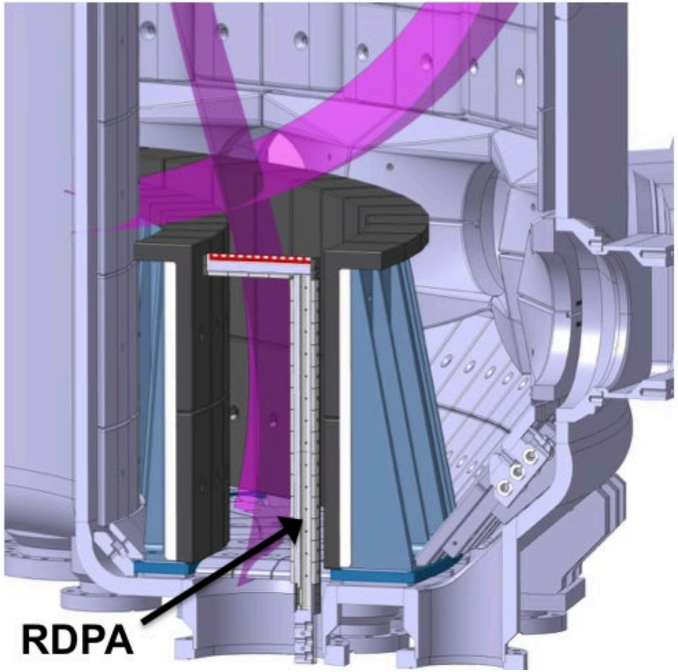
[1] F. Subba, et al., this meeting

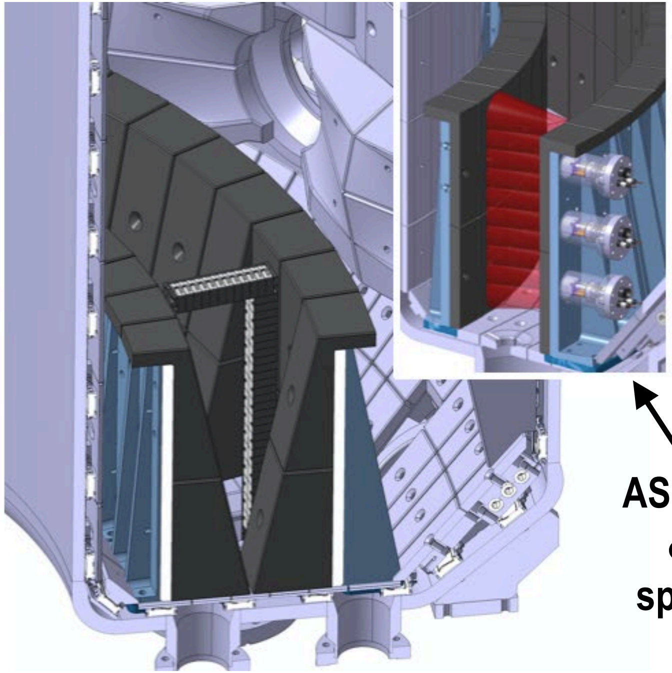
Outline

- TCV experiments demonstrating improved power exhaust performance with stronger baffling
- Power plant considerations
- **Potential test of a power plant relevant tightly-baffled, long-legged divertor in TCV**
- Conclusions

Develop a validated physics basis for tight baffling in a proposed 2nd TCV divertor upgrade

Phase 1: relatively simple, flexible geometry with full diagnostic set



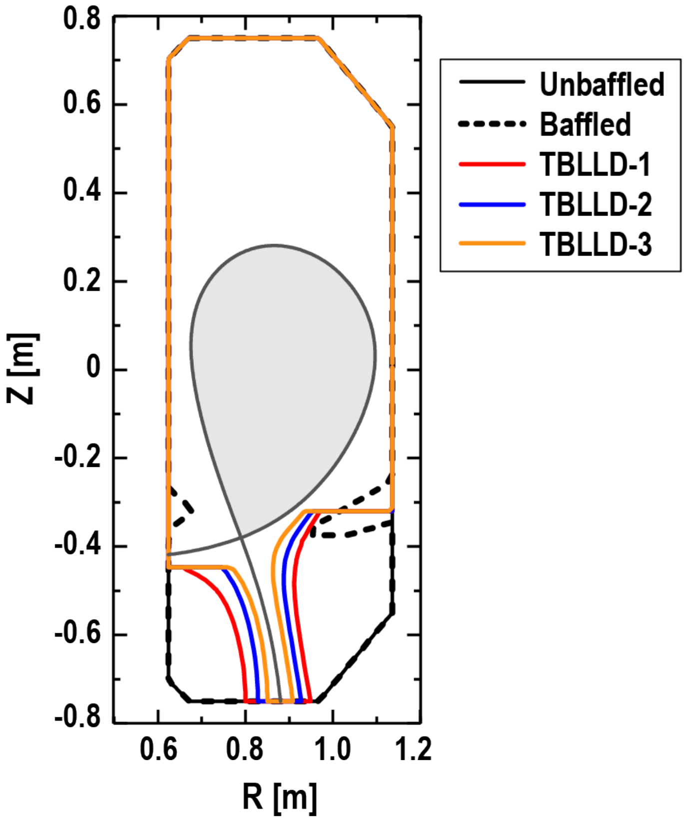


Use SOLPS-ITER to predict performance of a TBLLD in TCV

G. Sun et al., 48th EPS conference, June 2022

- Evaluate tight-baffling of outer divertor with varying wall distance
  - Standard transport coefficients neglecting drifts resulting in generic $\lambda_{q,u} = 3mm$
  - Compare three baffle variants

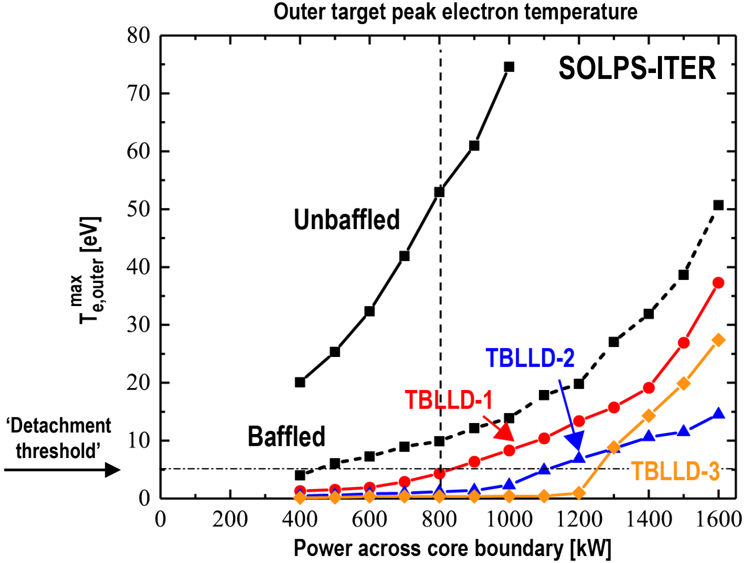
	TBLL1	TBLL2	TBLL3
$dR_{u,\mathrm{baffle}}$	$4.9\ \lambda_q$	$3.3\ \lambda_q$	$1.9\ \lambda_q$

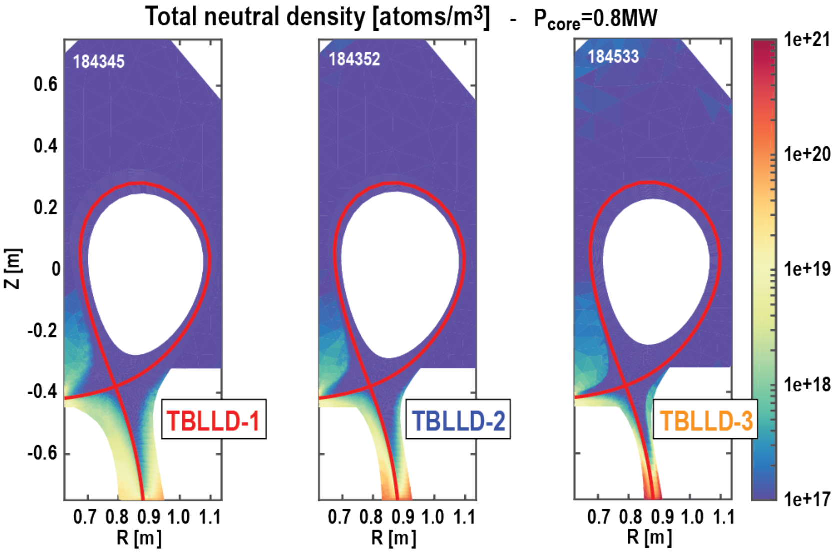


Simulations predict increased exhaust performance with tighter baffling

G. Sun et al., 48th EPS conference, June 2022

- Increase heating power at constant separatrix density





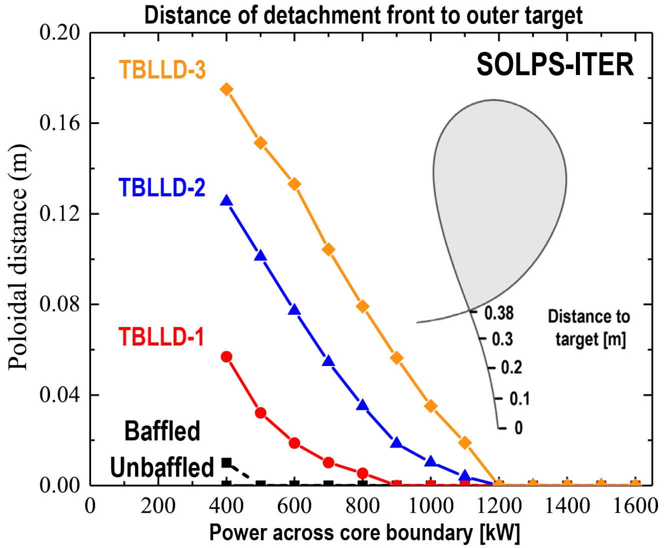
➢ TBLLD remains cooler

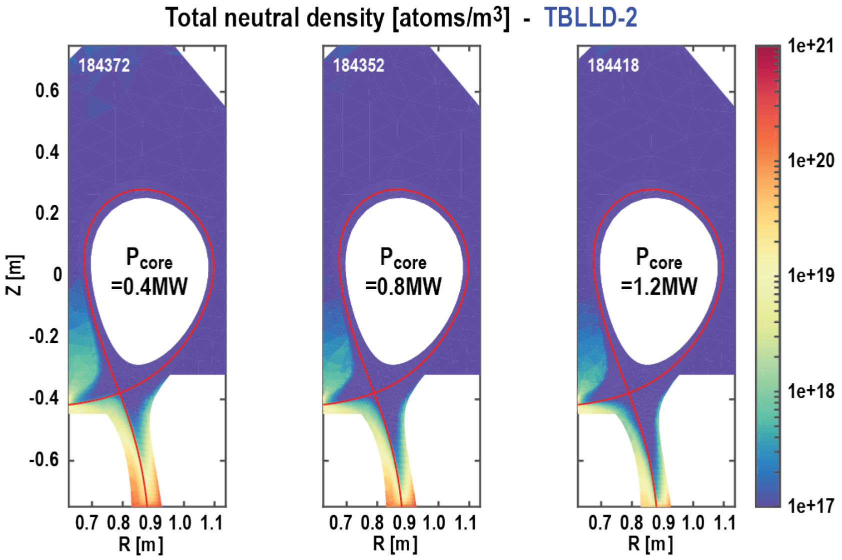
➢ Density of neutral cushion in front of target increases with baffling

Increase in exhaust performance also comes with a larger detachment window

G. Sun et al., 48th EPS conference, June 2022

- Exhaust power variations cause vertical displacement of 5eV "detachment front"





➢ Large detachment window (in power)[1]

[1] M. Umansky et al., NF **60** (2020) 016004

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G. Sun et al., 48th EPS conference, June 2022

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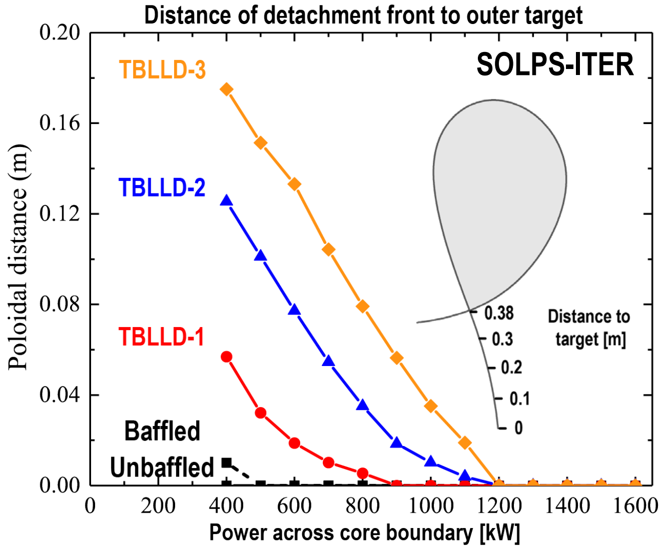
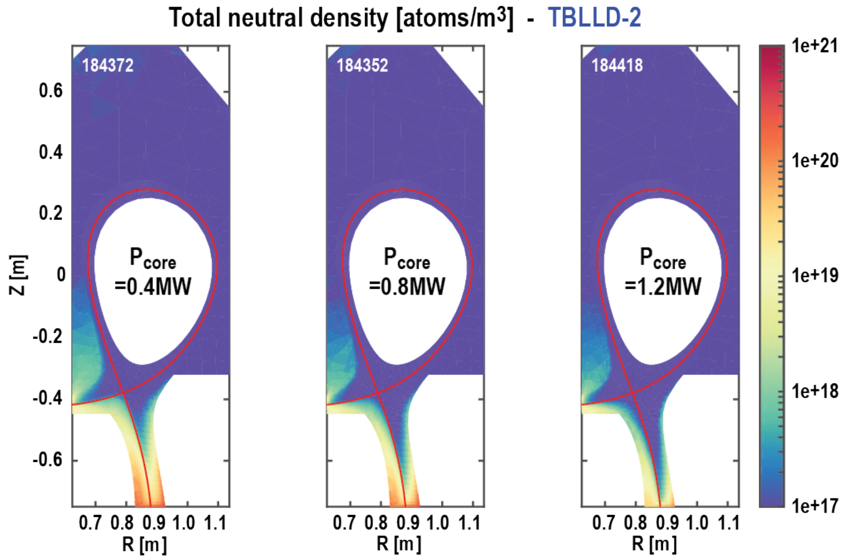




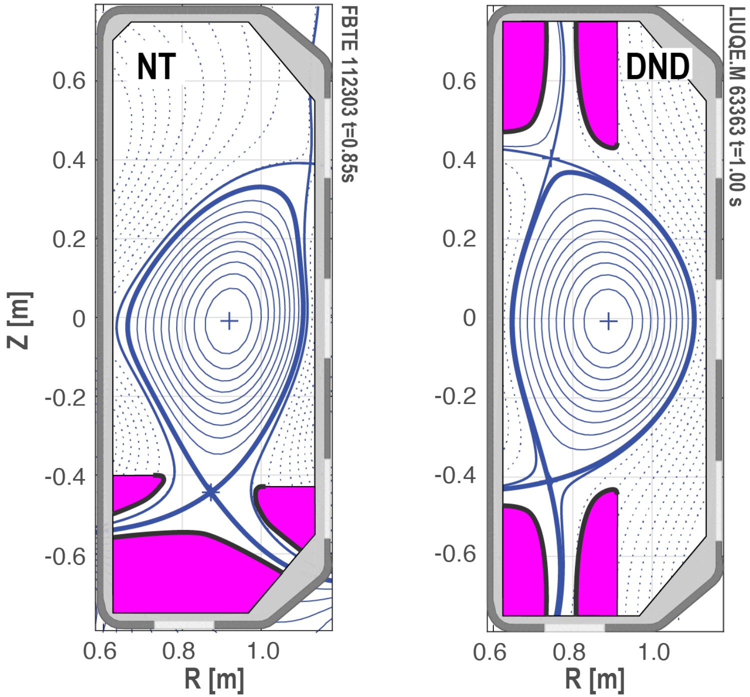
➢ Proposed TCV upgrade could validate boundary models of TBLLD

[1] M. Umansky et al., NF **60** (2020) 016004

Ultimately aim at full integration with an optimised core scenario

Phase 2: Full integration of tightly-baffling of all active divertor legs with optimized core solution

- Considered core solutions
  - Negative triangularity (NT)
  - Up-down symmetric tightly-baffled, long-legged divertor



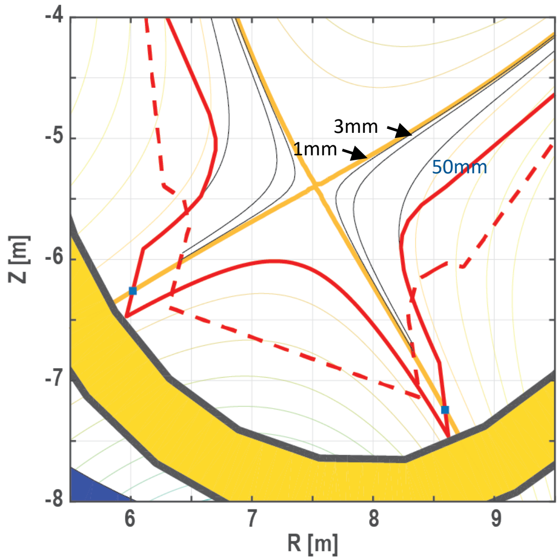
Conclusions

- Tightly-baffled, long-legged divertors (TBLLDs) promise enhanced power exhaust capabilities
  - Neutral pressure in the divertor plays an important role
- Variants without additional null points or large target radius are easier to implement in a power plant design
- TCV research programme addresses physics basis in particular in view of power-plant relevant simplifications
  - SPC has proposed a second, two-phased divertor upgrade to be realised in the 2025-2029 time frame

Additional material

EU-DEMO SN coil configuration & equilibrium with increased leg-length and stonger baffling

- Coils and magnetic equilibrium of '2018' EU DEMO configuration[1]
  - Performance of reference (Ar seeded SN) evaluated using SOLPS-ITER[2,3]



Modifications

- Extend divertor legs by placing targets closer to the reference vessel
  - + Vessel may have to be modified to allow for larger divertor cassette!
- Extend baffles towards X-point

TBLLD

	Inner	Outer
α [Deg.]	3.3	3.1
f_{ext}	4.5	2.4
β [Deg.]	45	22
$L_{pol,div}$ [m]	1.72	2.13

2018 DEMO

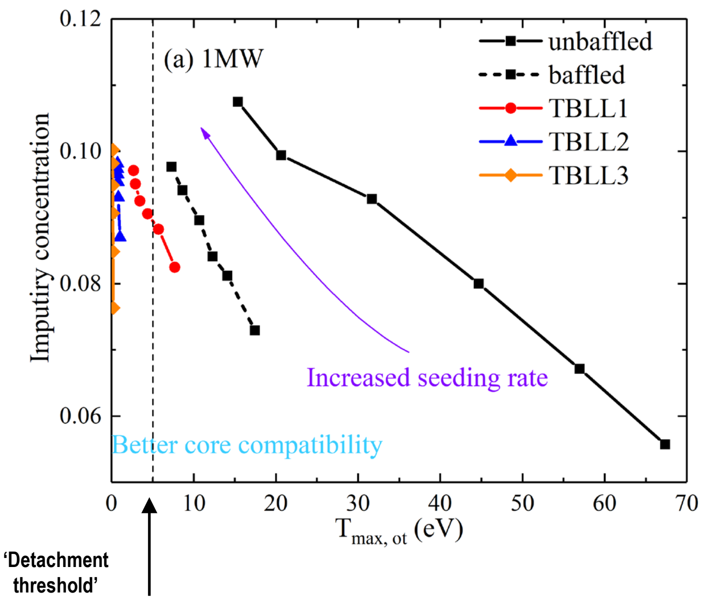
	Inner	Outer
α [Deg.]	2.7	2.4
f_{ext}	5.6	3.4
β [Deg.]	45	22
$L_{pol,div}$ [m]	1.25	1.60

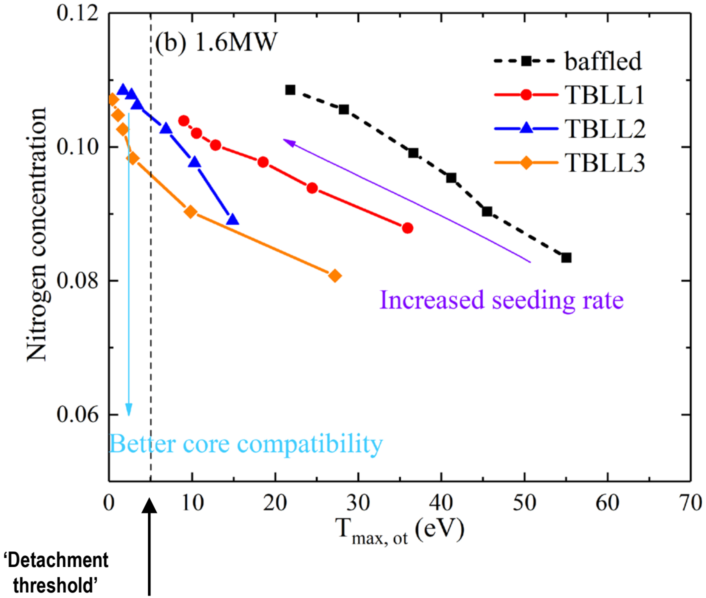
[1] H. Reimerdes, et al., NF **60** (2020) 066030
[2] F. Militello, et al, NME **26** (2021) 100908
[3] F. Subba, et al., this meeting

Simulations predict increased exhaust performance with tighter baffling

G. Sun et al., 48th EPS conference, June 2022

- Seed nitrogen at constant $n_{e,sep}$





➢ Core-compatibility of seeded scenarios improve with tighter baffling