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K Galazka, N Rivals, P Tamain, H Bufferand, G Falchetto, G Ciraolo

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DE LA RECHERCHE À L'INDUSTRIE

Particle transport and heat loads in JT-60SA studied by SOLEDGE-EIRENE code

13 October 2022

K. Gałazka, N. Rivals, P. Tamain, H. Bufferand, G. Falchetto, G. Ciruolo
Acknowledgements: L. Balbinot, P. Innocente

- ▶ Developing and investigating high performance scenarios compatible with plasma facing components on JT-60SA tokamak
- ▶ Focus on scenario #2: Full Current Inductive, Single Null, D operation, C-wall
 - Integrated Research Phase scn#2 transport modeling reported in the past (SONIC¹, COREDIV², SOLEDGE2D³, SOLPS⁴) indicate possible problems with high heat loads
- ▶ *Task*: Assess the heat loads on the first wall and targets in the **Initial Research Phase (limited P_{aux})**
- ▶ *Tool*: SOLEDGE-EIRENE transport code⁵

JT-60SA Research Plan (version v4.0 2018)

Parameter	Unit	scn#2	scn#3
I_p	MA	5.5	5.5
B_T	T	2.25	2.25
R_T / a	m	2.96/1.18	2.96/1.18
κ		1.87	1.87
$H_{98(y,2)}$		1.3	1.3
P_{aux}	MW	41 19/26.5/33	30
$\langle n_e \rangle_{VOL}$	$\times 10^{19} \text{ m}^{-3}$	5.6	9.0
n_e^{sep}	$\times 10^{19} \text{ m}^{-3}$	-2	

No active cooling in the **Initial Research Phase** - power exhaust mitigation is crucial

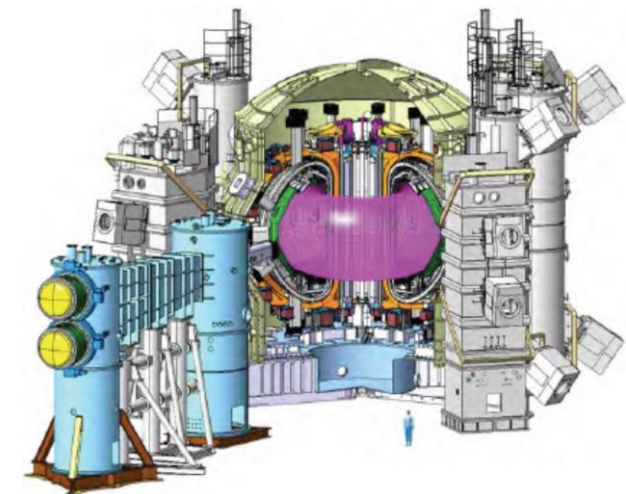
¹ H Kawashima *et al.*, Contrib. Plasma Phys. 56 778 (2016) - W wall

² R. Zagórski *et al.*, Nucl. Fusion 57 066035 (2017);
K Gałazka *et al.*, Plasma Phys. Control. Fusion 59 045011 (2017);
K Gałazka *et al.*, Contrib. Plasma Phys. 58 751–7 (2018)

³ L. Balbinot *et al.*, 3rd IAEA Technical Meeting on Divertor Concepts, (2019)

⁴ G. Rubino *et al.*, Proc. 46th EPS Conf. Plasma Phys. (Milano) P5.1039 (2019) - scn#3

⁵ H. Bufferand *et al.*, Nucl. Fusion 61 116052 (2021)



Assessment of heat loads on the first wall, in particular at targets

- ▶ SOLEDGE simulation domain covers the whole volume of the plasma vessel including the wall and can thus provide information on the heat loads everywhere

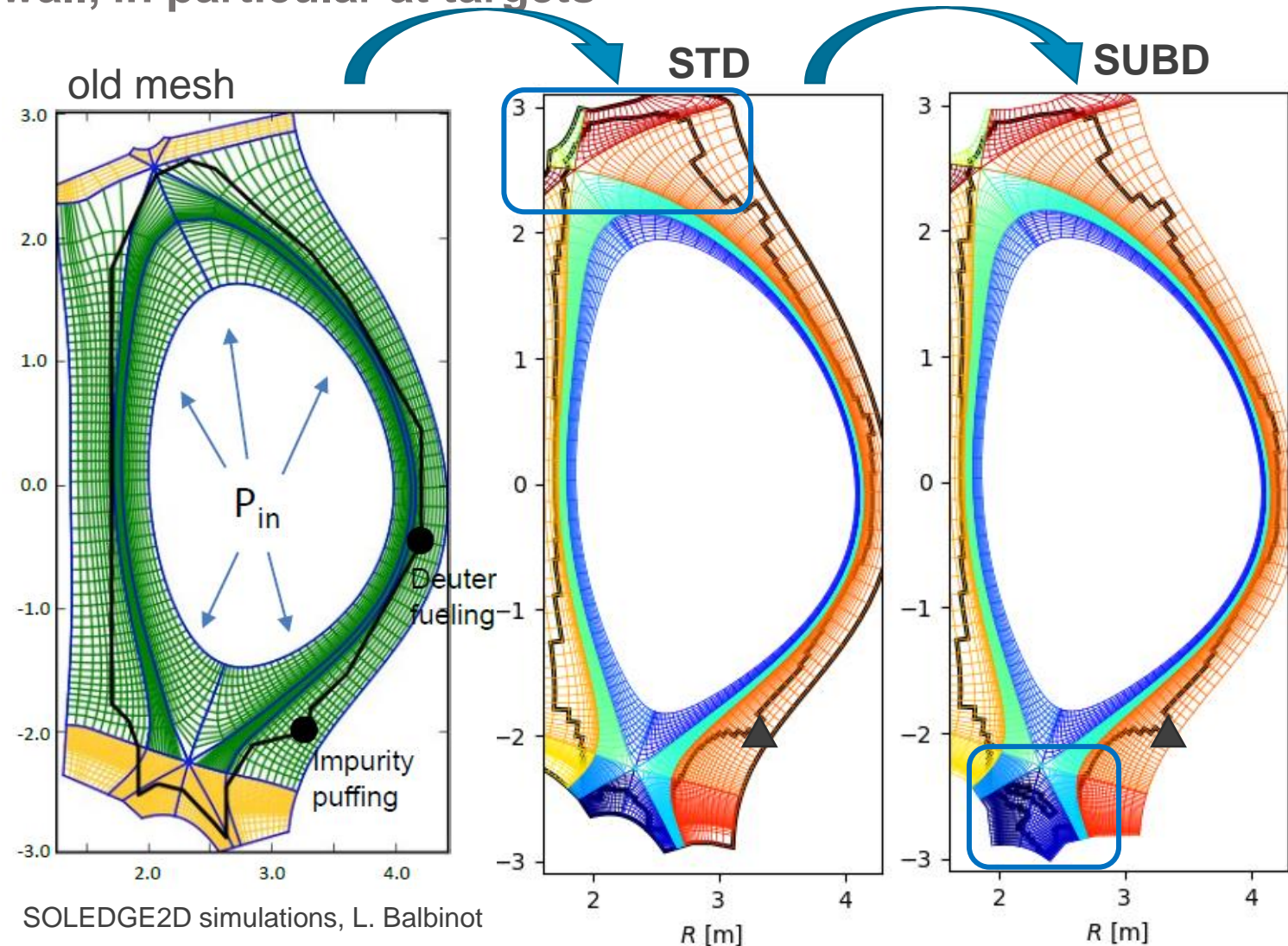
Two configurations modelled:

STD

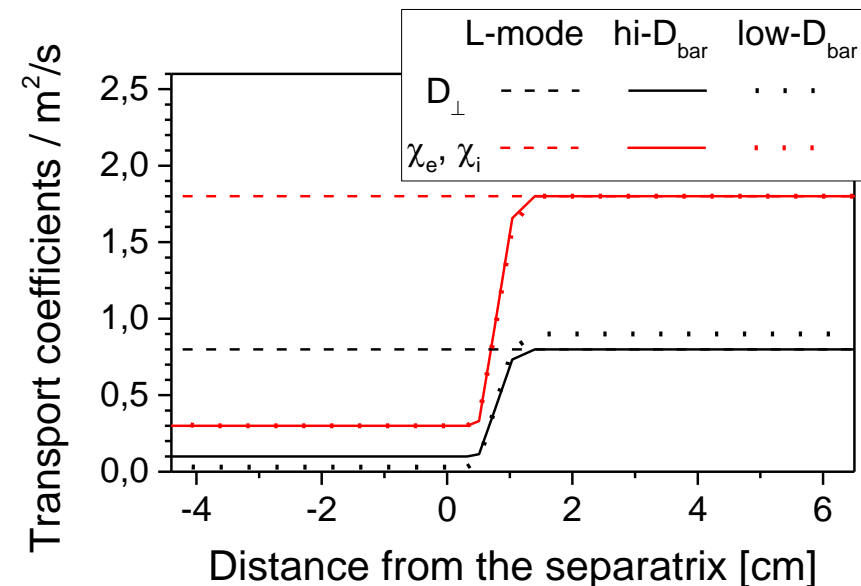
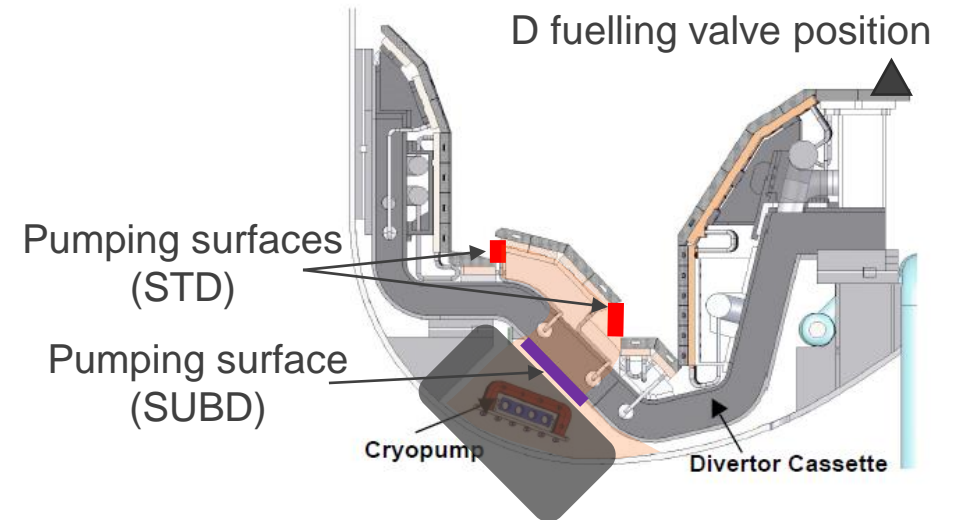
- ▶ Real shape of the vessel (top)
- ▶ 2 pumping surfaces at the entrance of the subdivertor structure

SUBD

- ▶ Real shape of the vessel (top)
- ▶ Model also (part of) the subdivertor structure (1 pumping surface)

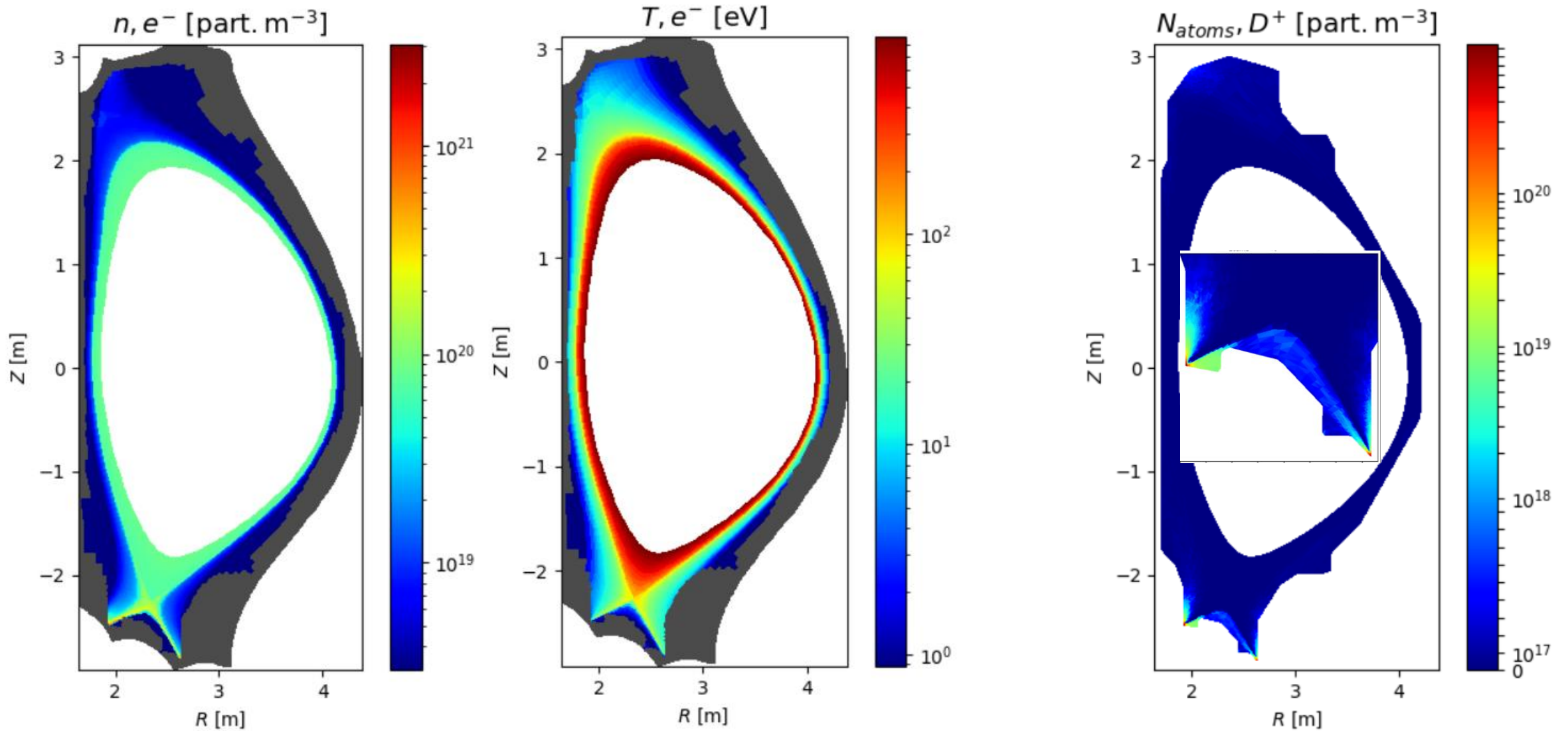


- ▶ two geometries: **STD, SUBD**
- ▶ parameter scan in $P_{aux} = [15, 20, 25, 30]$ MW
- ▶ neutrals: EIRENE⁶ with simplified Kotov model (no elastic collisions on neutrals)
- ▶ **constant** particle sources:
 - D - $\Gamma_{core} = 1 \times 10^{21}$ part./s, $\Gamma_D = 1 \times 10^{21}$ part./s (fuelling)
 - C – (if present) sputtering (Bohdansky formula⁷)
- ▶ sinks:
 - reflective wall for D ($R_D^{wall}=1$),
 - absorbing wall for C ($R_C^{wall}=0.1$),
 - pumps with albedo $R_D^{pump}=0.95$, $R_C^{pump}=0.1$
 - semi-transparent surfaces at the subdivertor entrances for SUBD geometry with $R=0.3$
- ▶ two transport coefficient profiles for different SOL decay lengths:
 - **high $D_{bar}=0.1$ m²/s** in transport barrier
 - **low $D_{bar}=0.03$ m²/s** in transport barrier

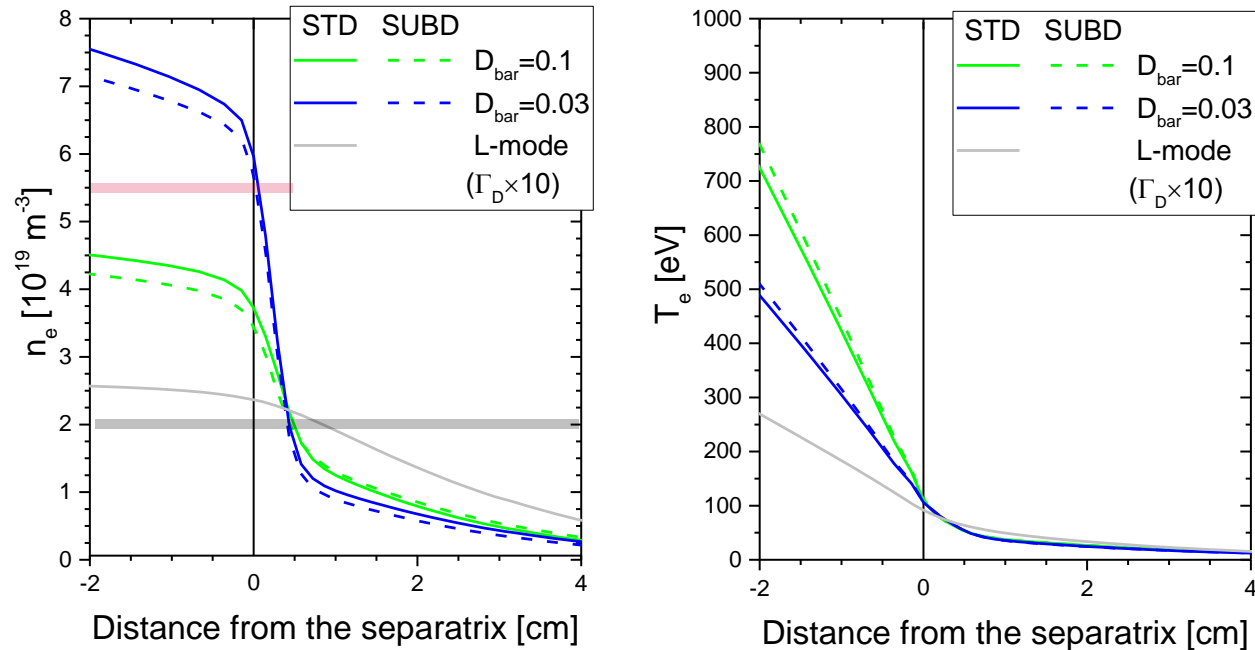


⁶ Forschungszentrum Jülich GmbH 2021 Eirene website (<http://eirene.de>) (accessed 2022-10-01)

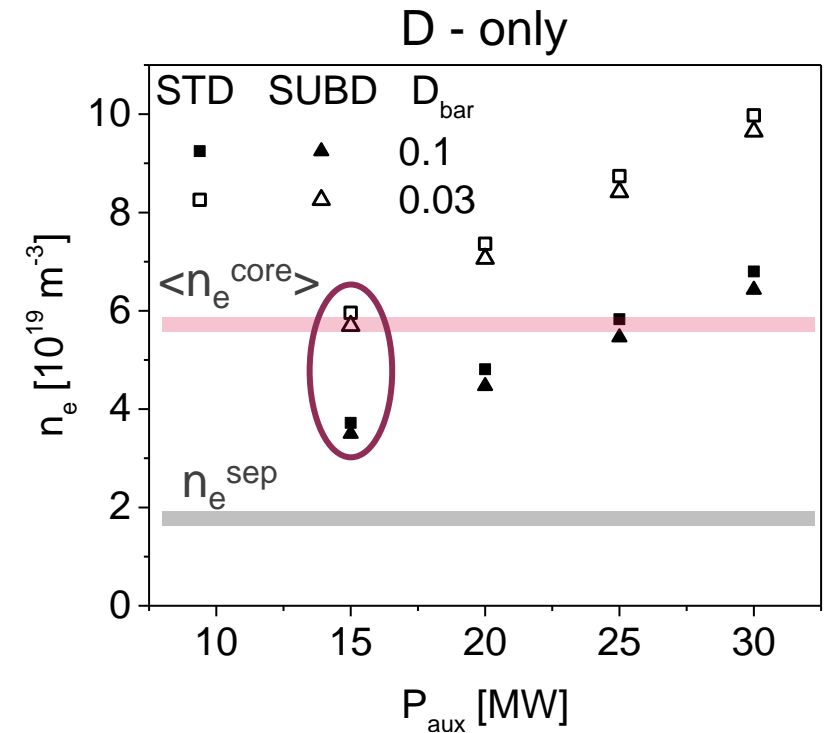
⁷ J. Bohdansky, Nucl. Instr. and Meth. B 2, 587 (1984)



Example: STD case, $P_{aux}=15\text{MW}$, $D_{bar}=0.03\text{ m}^2/\text{s}$

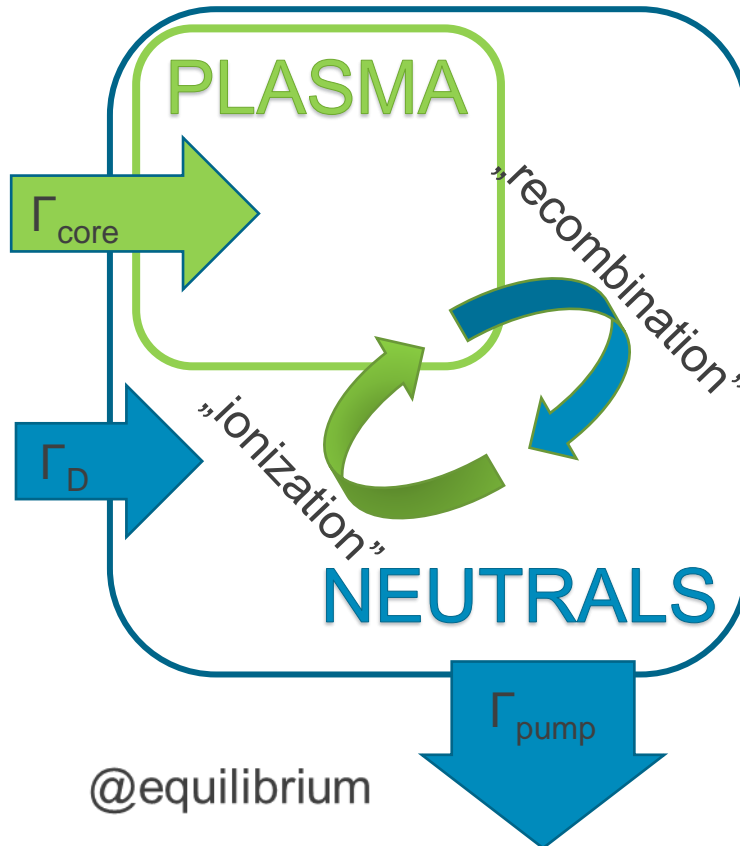
Midplane profiles ($P_{\text{aux}}=15\text{MW}$)

- ▶ High n_e^{sep} already with 15 MW of input power
- ▶ T_e^{sep} in the range of 105-110 eV
- ▶ lower D_{bar} results in higher n_e gradient and higher n_e^{sep} value
- ▶ $\lambda_n = 8$ mm for the $D_{\text{bar}} = 0.1$ m^2/s case and $\lambda_n = 4$ mm for the $D_{\text{bar}} = 0.03$ m^2/s



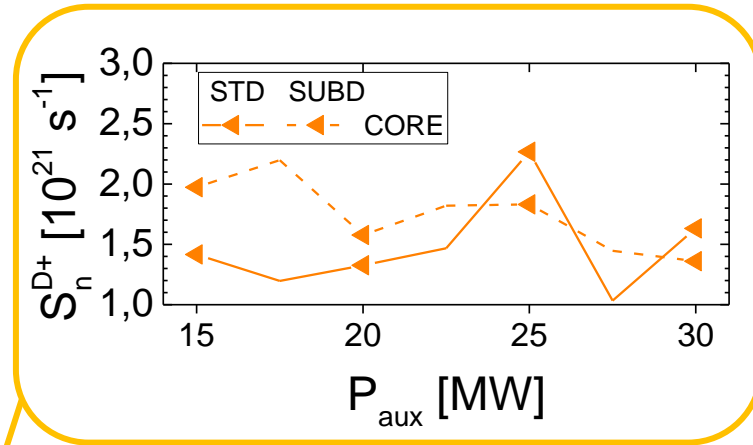
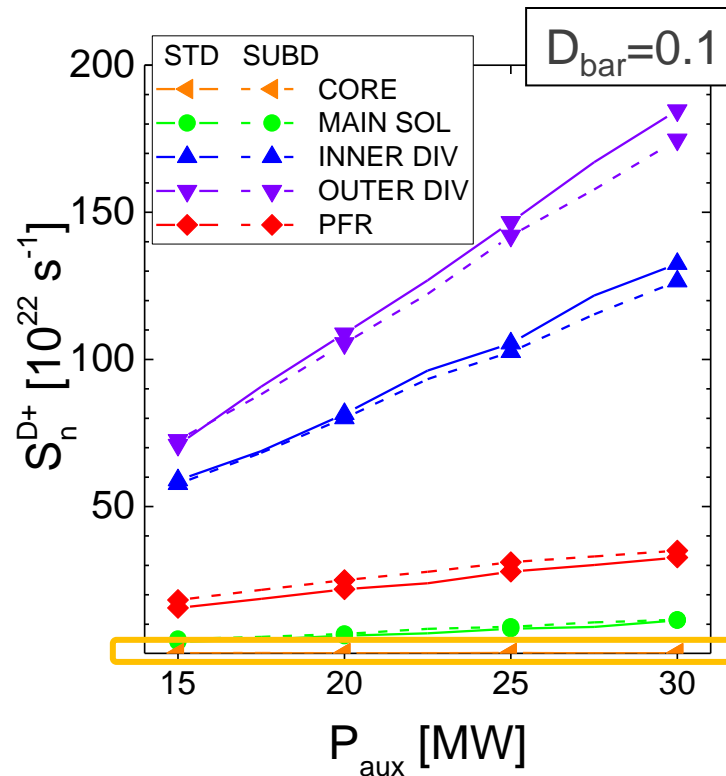
- ▶ n_e^{sep} increases with increasing P_{aux}
- ▶ SUBD geometry shows slightly lower n_e than STD, but the difference is small

Simplified particle balance



$$\Gamma_{core} + \Gamma_D = \Gamma_{pump}$$

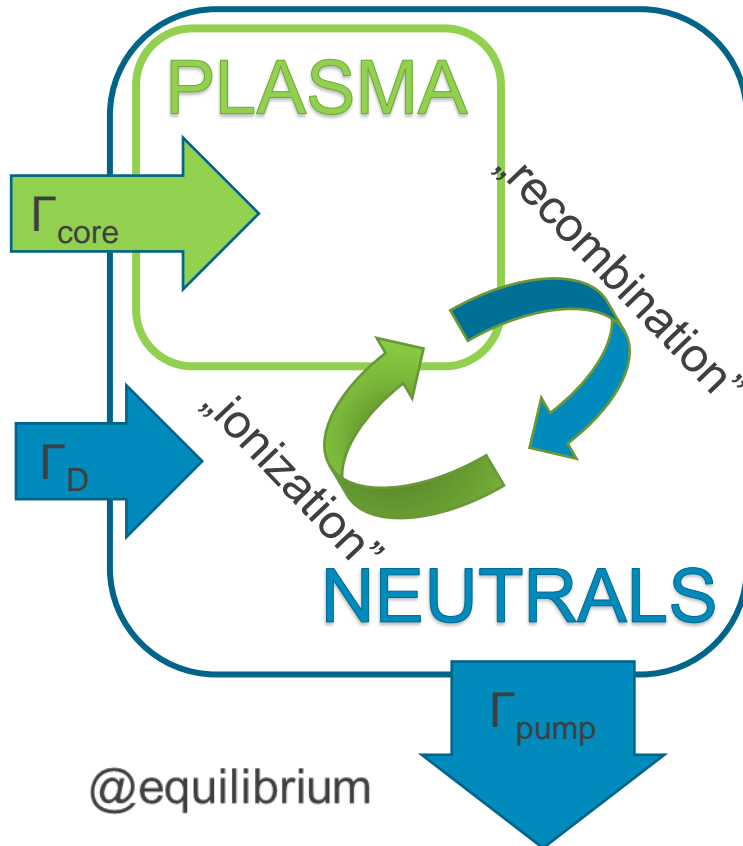
sources = sinks



Note: core plasma source
 $\Gamma_{core} = 1 \times 10^{21}$ part./s

- ▶ particle throughput through the system is constant (IN = OUT)
- ▶ the balance between sources and sinks determines the amount of ionized particles in the plasma
- ▶ core plasma sources (BC + ionization) at least $\sim 100x$ smaller than S_n^{D+} in the divertor
- ▶ ionization is controlled by the amount of energy reaching the ionization zone, which is proportional to P_{aux}

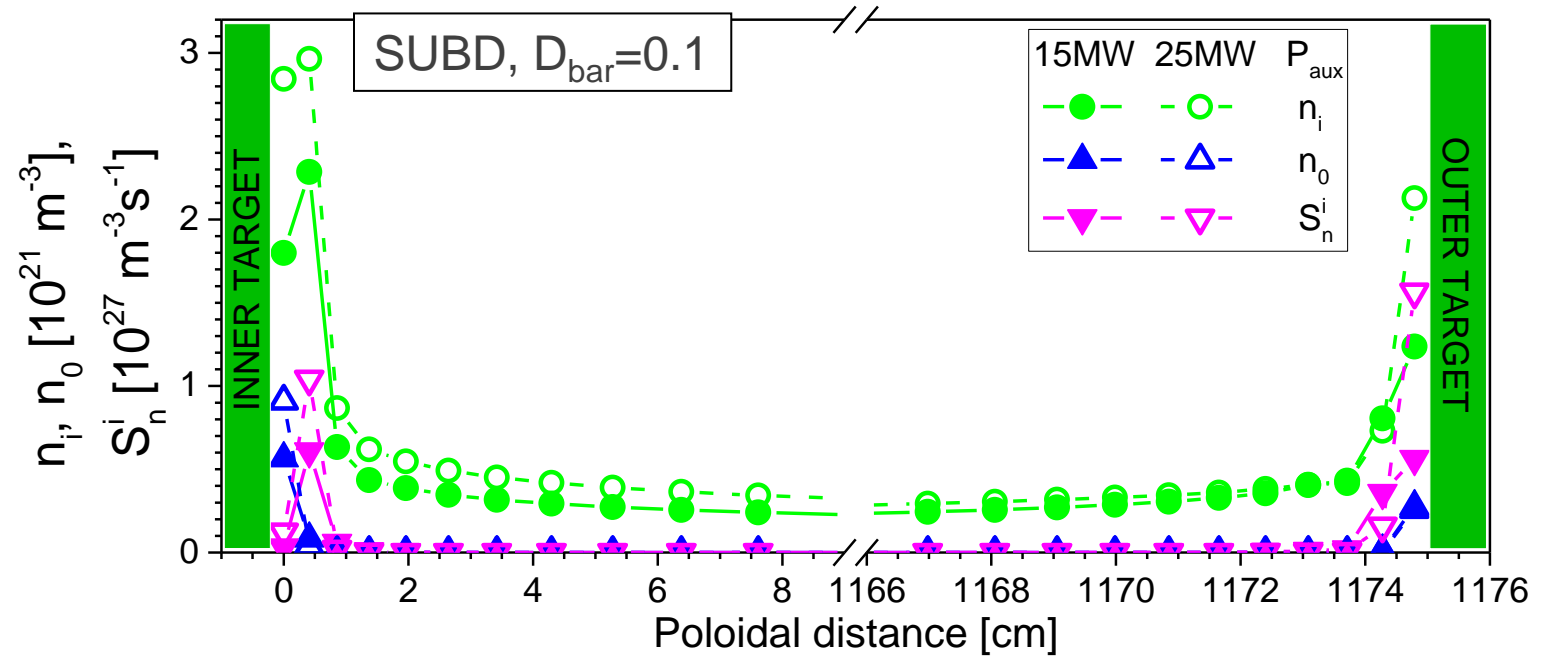
Simplified particle balance



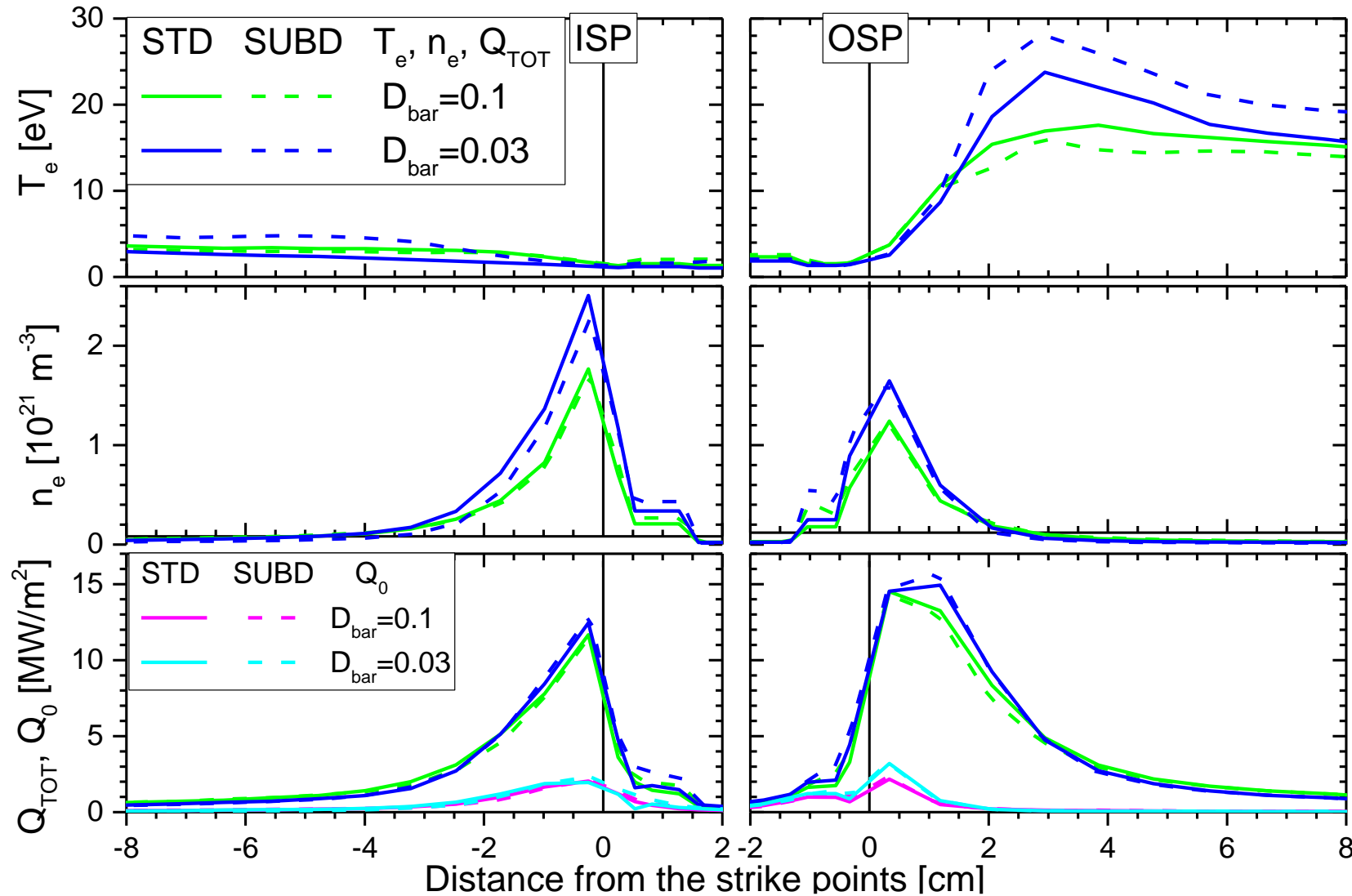
$$\Gamma_{core} + \Gamma_D = \Gamma_{pump}$$

sources = sinks

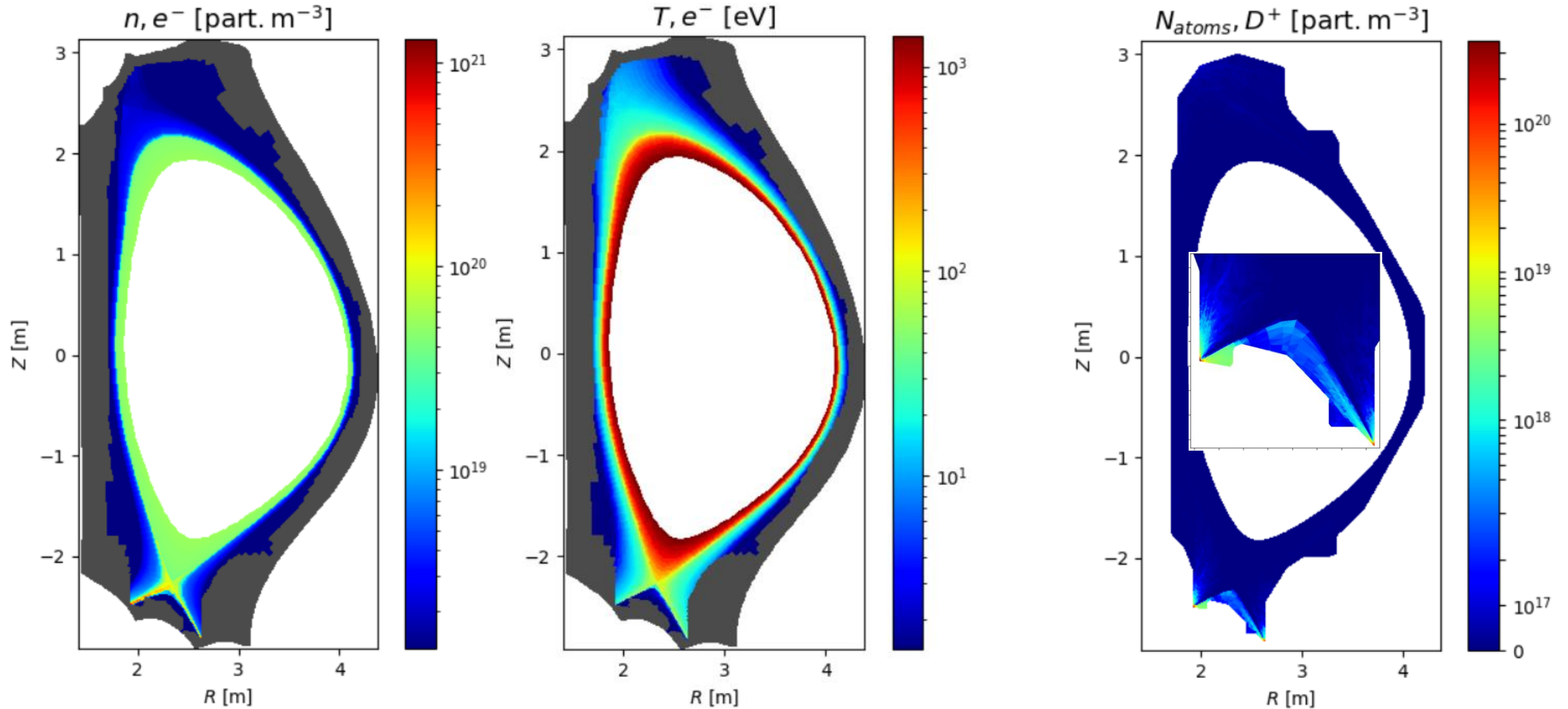
Poloidal plot of ion density, D atoms and ionization source on the first flux tube



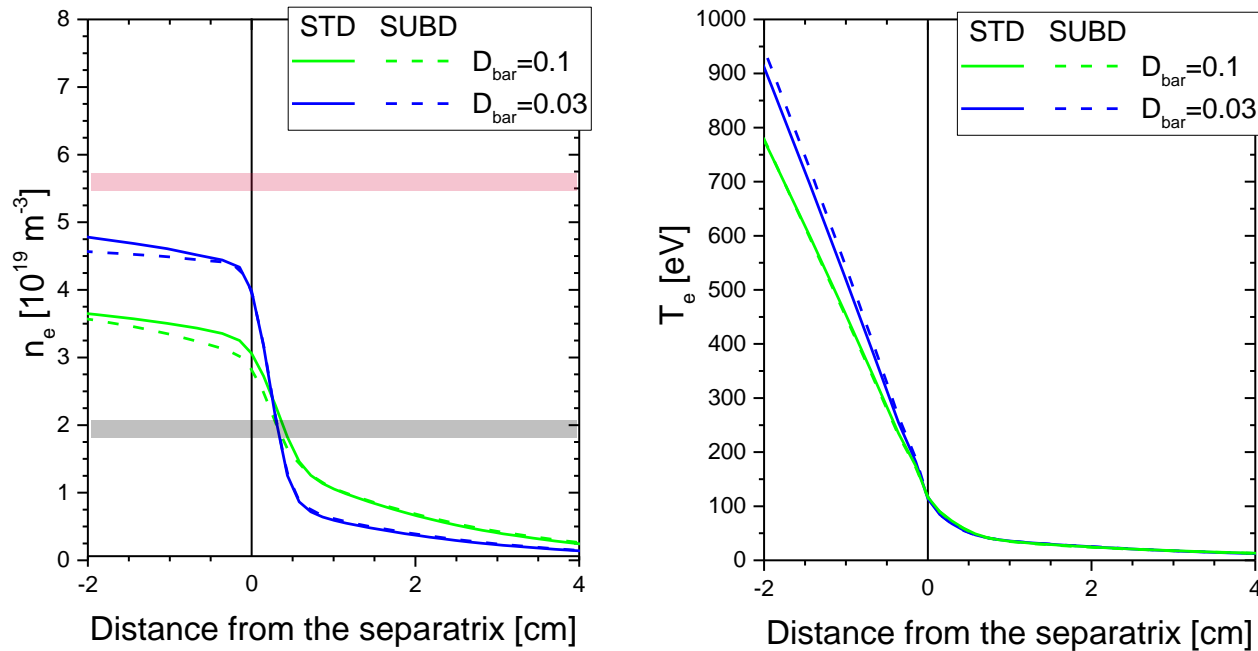
- ▶ higher n_i ($= n_e$) at larger P_{aux} is correlated with higher plasma sources (here ionization source S_n^i)
- ▶ neutrals distribution is affected only at the inner target

$P_{\text{aux}} = 15 \text{ MW}$ 

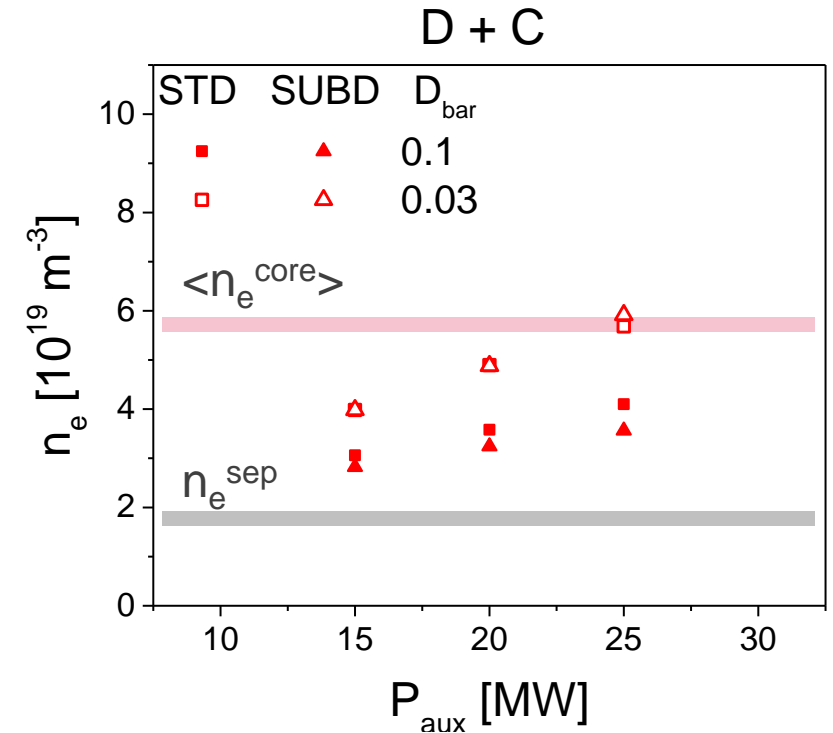
- ▶ lower D_{bar} – higher n_e , lower T_e at the targets
- ▶ Similar heat load profiles
- ▶ differences between STD and SUBD geometries small
- ▶ slightly broader Q_{TOT} profile for lower D_{bar}
- ▶ Heat load above 10 MW/m^2 limit on both targets



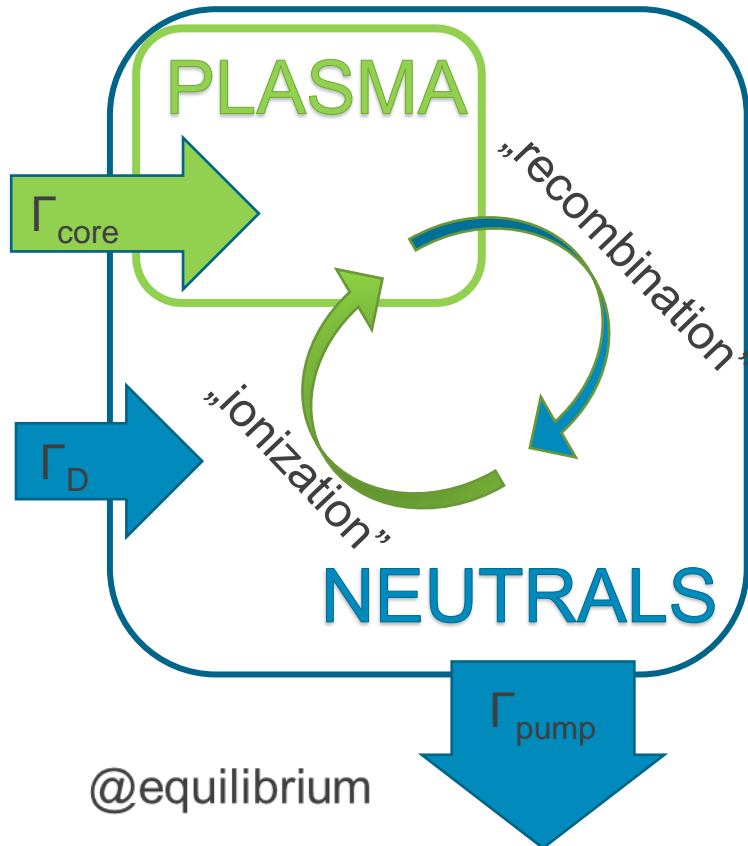
Example: STD case, $P_{aux}=15\text{MW}$, $D_{bar}=0.03\text{ m}^2/\text{s}$

Midplane profiles ($P_{\text{aux}}=15\text{MW}$)

- ▶ n_e^{sep} still high, but approaches the nominal value
- ▶ T_e^{sep} in the range of 113-117 eV

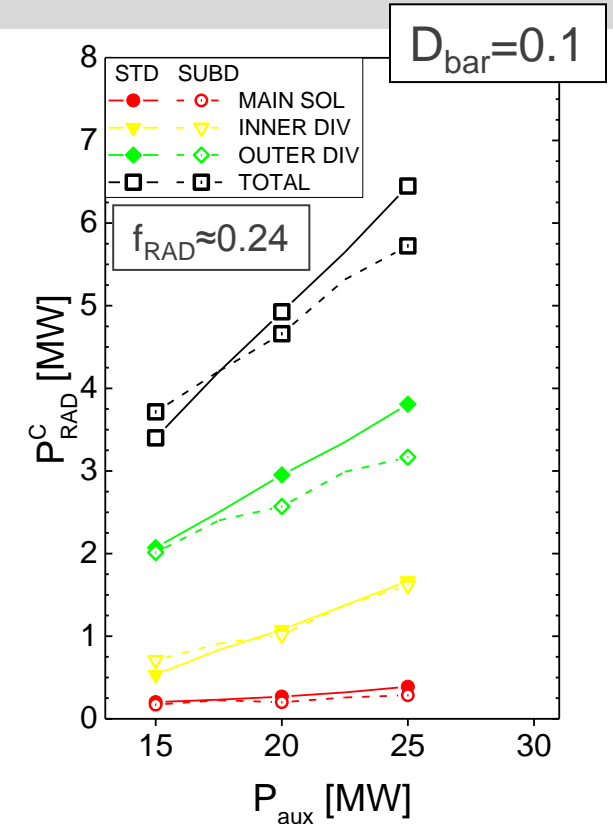
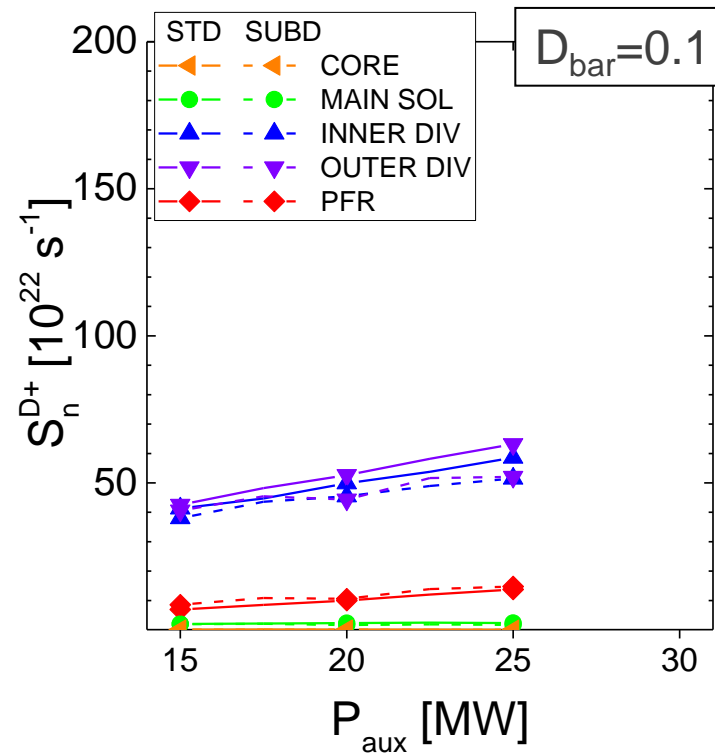


- ▶ n_e^{sep} lower than in the pure D cases
- ▶ $n_e^{\text{sep}}(P_{\text{aux}})$ slope for $D_{\text{bar}}=0.1 \text{ m}^2/\text{s}$ less steep than in the pure-D case
- ▶ SUBD geometry shows slightly lower n_e than STD

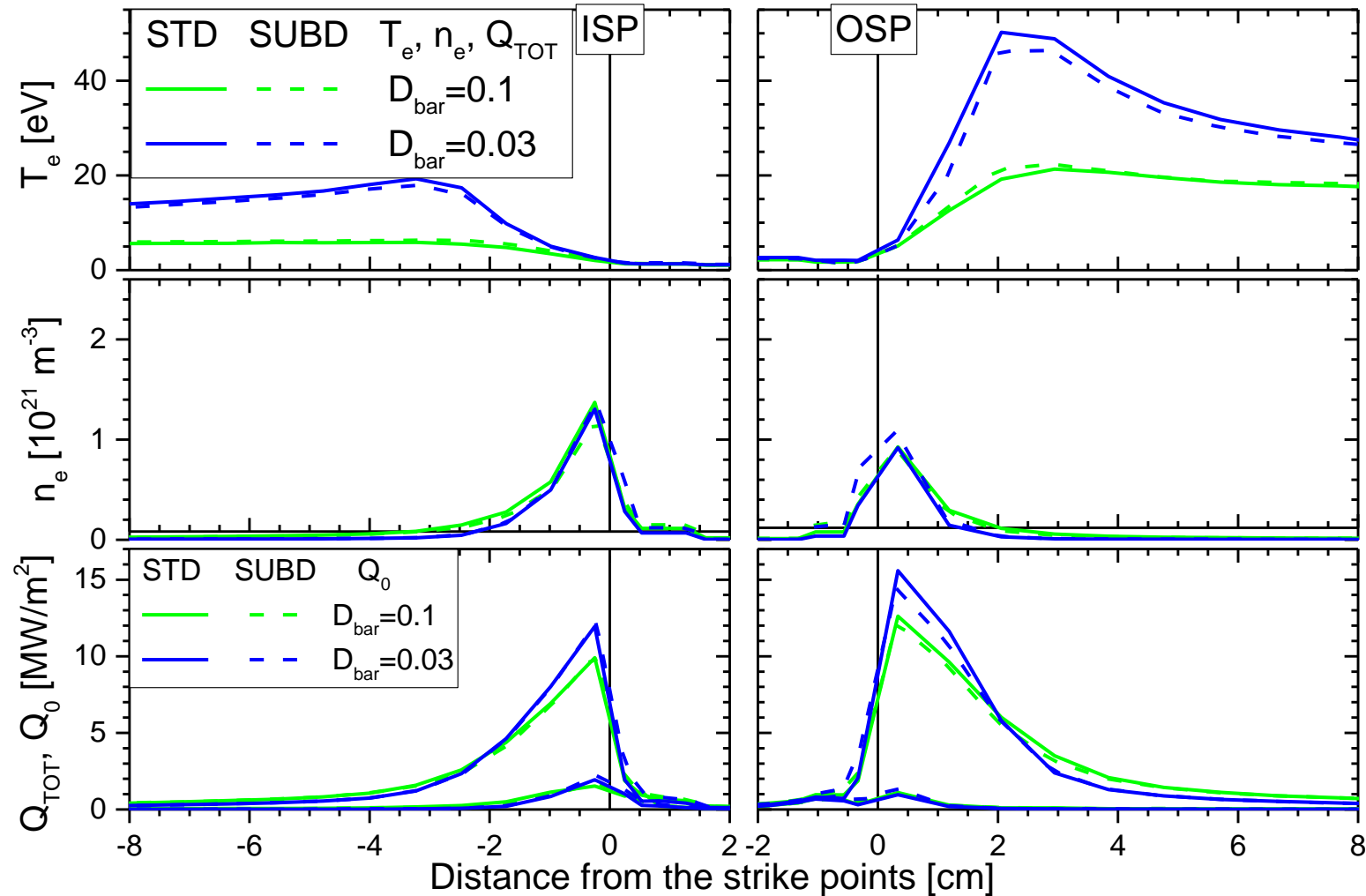


$$\Gamma_{core} + \Gamma_D = \Gamma_{pump}$$

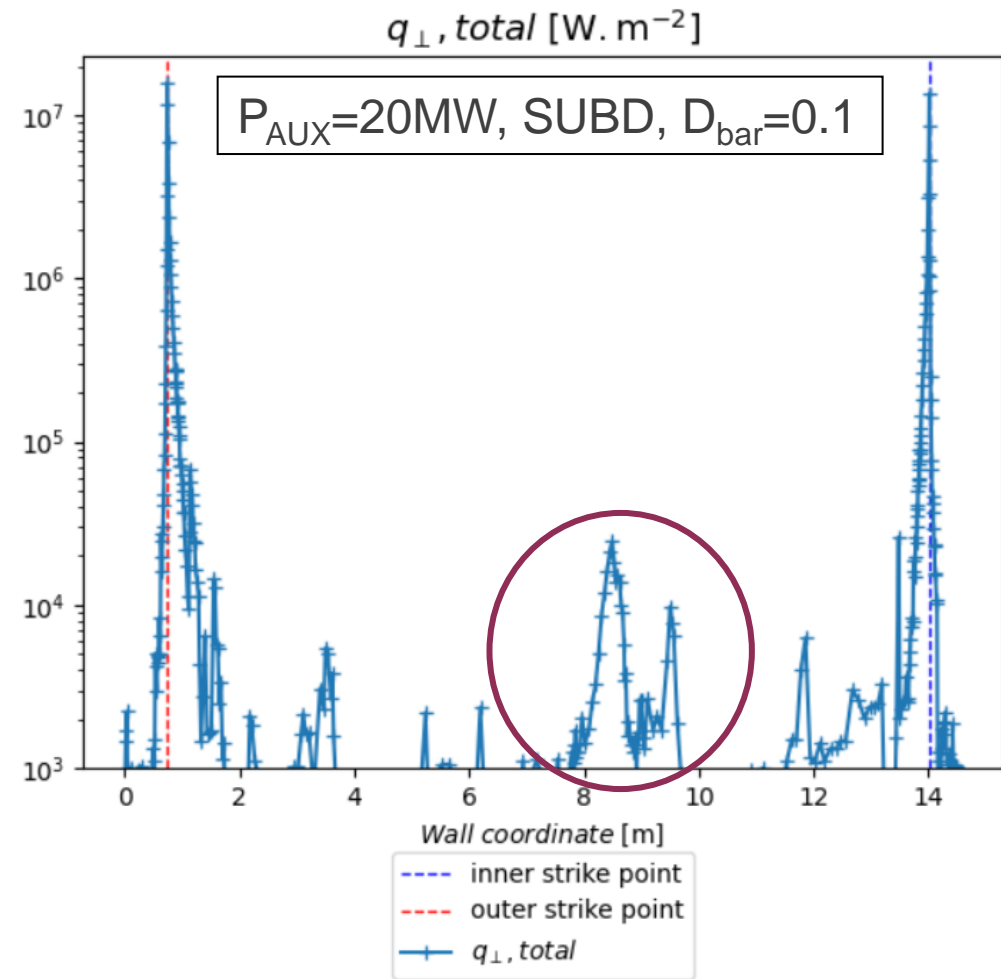
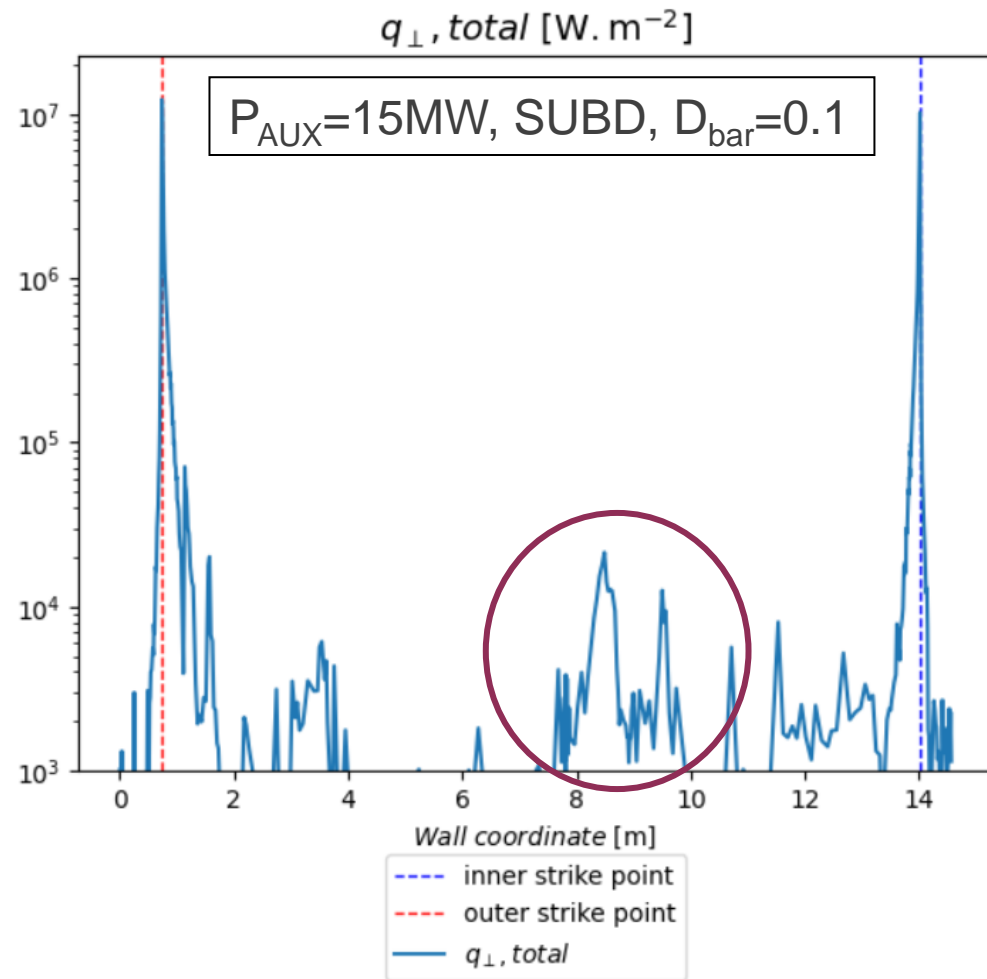
sources = sinks



- ▶ presence of C impurity and its radiation brings the system to a different ionization-recombination balance
- ▶ due to P_{RAD} the power delivered to the ionization zone is lower
- ▶ as a result the plasma sources in the D+C case are weaker
- ▶ the resulting n_e^{sep} is much lower than in the pure-D cases

Target profiles – $P_{\text{aux}} = 15 \text{ MW}$ 

- ▶ lower n_e than in the pure D case
- ▶ much higher T_e than in pure D case
- ▶ significantly lower heat delivered by neutrals
- ▶ larger differences between the different D_{bar} cases
- ▶ still, differences between STD and SUBD geometries small
- ▶ still, heat load exceeds the 10 MW/m^2 material limit



- heat load on the first wall in general does not exceed 10 kW/m^2
- the most exposed areas are targets and their surrounding
- there is an increased heat load at the **top of the chamber, 20 kW/m^2** .

- ▶ JT-60SA Initial Research Phase scenario #2 is investigated via SOL transport modelling with SOLEDGE-EIRENE code including the real vessel geometry :

- 1. geometry (w/w.o. subdivertor – STD/SUBD)**

The influence of presence of subdivertor area is assessed:

when including the subdivertor region (SUBD) slightly lower densities are obtained than in the STD, but the differences are minor in the examined parameter range

- 2. diffusion coefficient in the barrier D_{bar}**

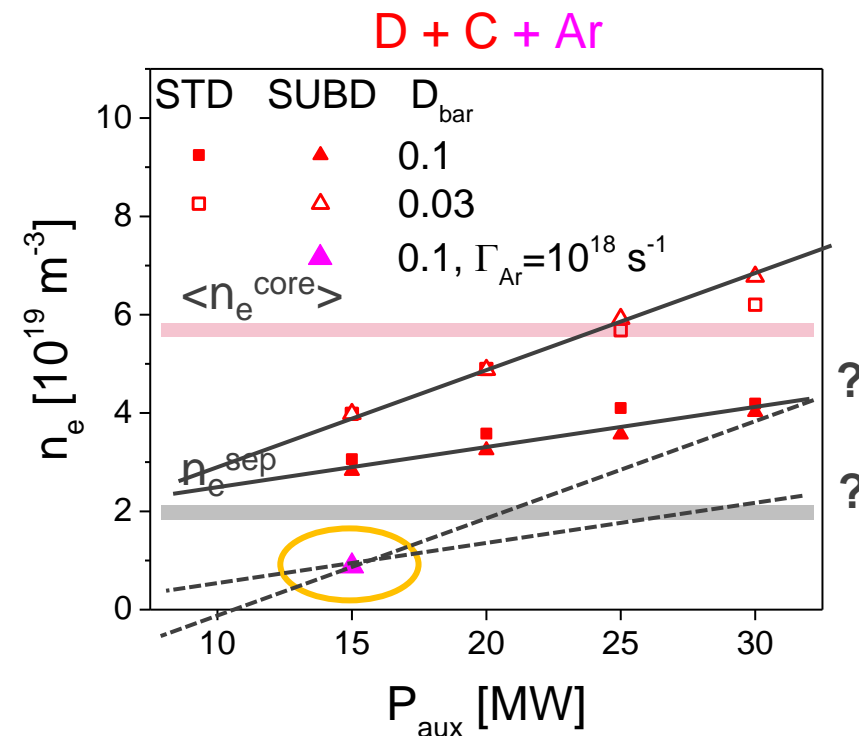
The influence of different perpendicular transport is assessed:

different SOL width ($\lambda_n = 8 \text{ mm} \rightarrow 4 \text{ mm}$): narrower SOL results in sharper profiles, but finally the Q_{TOT} profile difference is minor.

- 3. input power P_{aux}**

With a constant particle throughput a mechanism of density control by P_{aux} through manipulating the plasma ionization source is established. Presence of C leads to lower plasma densities because of radiative energy dissipation.

- ▶ In agreement with previous simulations, in plasmas with C only the conditions at target plates are not sustainable (local heat load exceeds 10 MW/m²) without further seeding strategy. Otherwise heat loads on the chamber wall are acceptable.
- ▶ Including Ar seeding is a plausible solution for the high heat load problem – simulations continue with Ar seeding at rate $\Gamma_{\text{Ar}} = 10^{18} \text{ s}^{-1}$.
- ▶ **preliminary** results allow anticipating that with same sources settings the designed operational regime ($n_e^{\text{sep}} \sim 2 \times 10^{19} \text{ m}^{-3}$) might be achieved with $D_{\text{bar}} = 0.03 \text{ m}^2/\text{s}$, $P_{\text{aux}} > 20 \text{ MW}$





THE END

Integrals

Core

Outer SOL

Inner divertor

PFR

Outer divertor

