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### ► To cite this version:

K Galazka, N Rivals, P Tamain, H Bufferand, G Falchetto, et al.. Particle transport and heat loads in JT-60SA studied by SOLEEDGE-EIRENE code. AAPPS DPP 2022 - 6th Asia-Pacific Conference on Plasma Physics, Oct 2022, Online Conference (Tokyo), Japan. cea-03949501

**HAL Id: cea-03949501**

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Submitted on 20 Jan 2023

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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

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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 (SONIC<sup>1</sup>, COREDIV<sup>2</sup>, SOLEDGE2D<sup>3</sup>, SOLPS<sup>4</sup>) 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 code<sup>5</sup>*

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
$\kappa$		1.87	1.87
$H_{98(y,2)}$		1.3	1.3
$P_{aux}$	MW	<b>41</b> <b>19/26.5/33</b>	30
$\langle n_e \rangle_{VOL}$	$\times 10^{19} \text{ m}^{-3}$	<b>5.6</b>	9.0
$n_e^{sep}$	$\times 10^{19} \text{ m}^{-3}$	<b>-2</b>	

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

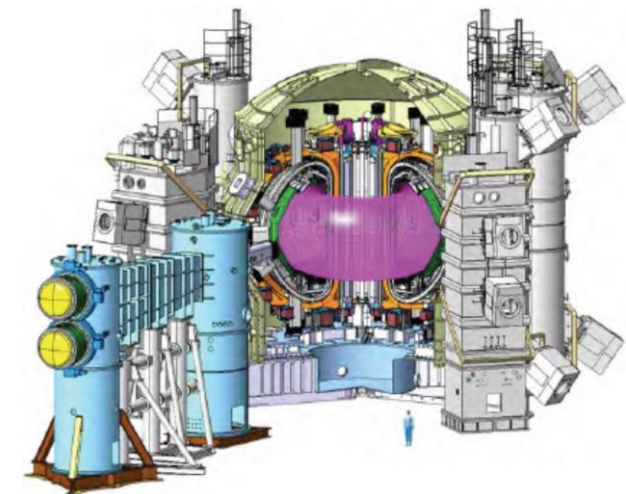
<sup>1</sup> H Kawashima *et al.*, Contrib. Plasma Phys. 56 778 (2016) - W wall

<sup>2</sup> 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)

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

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

<sup>5</sup> 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

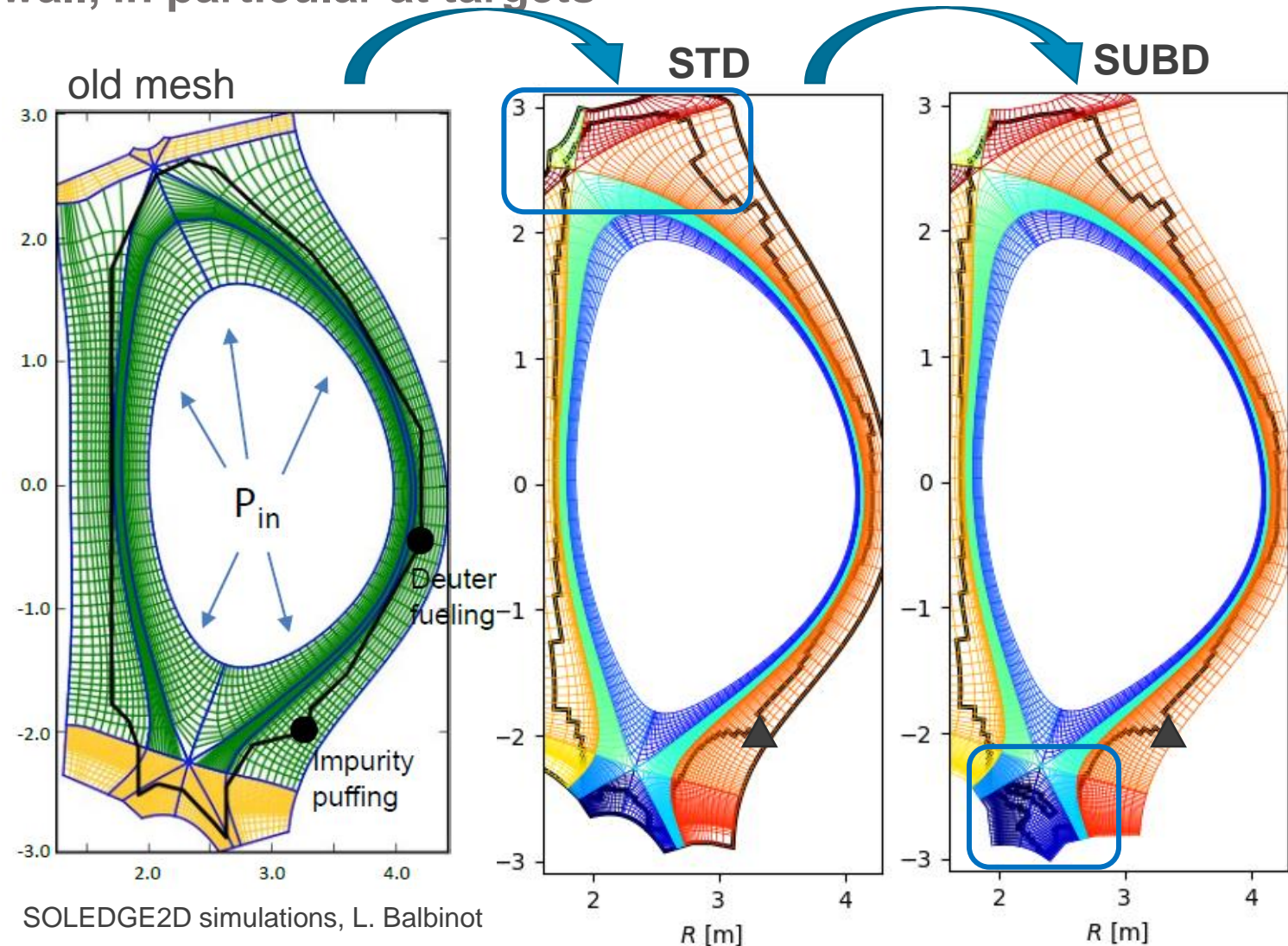
### Two configurations modelled:

#### STD

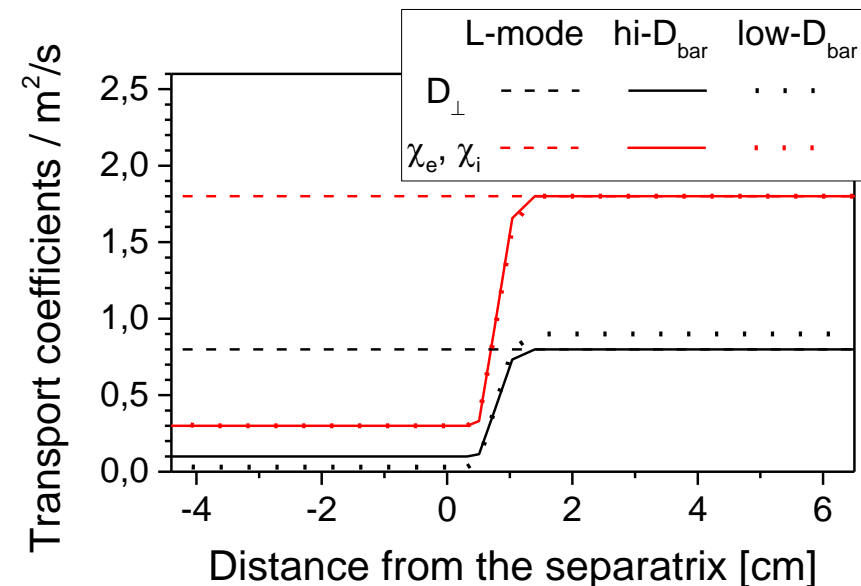
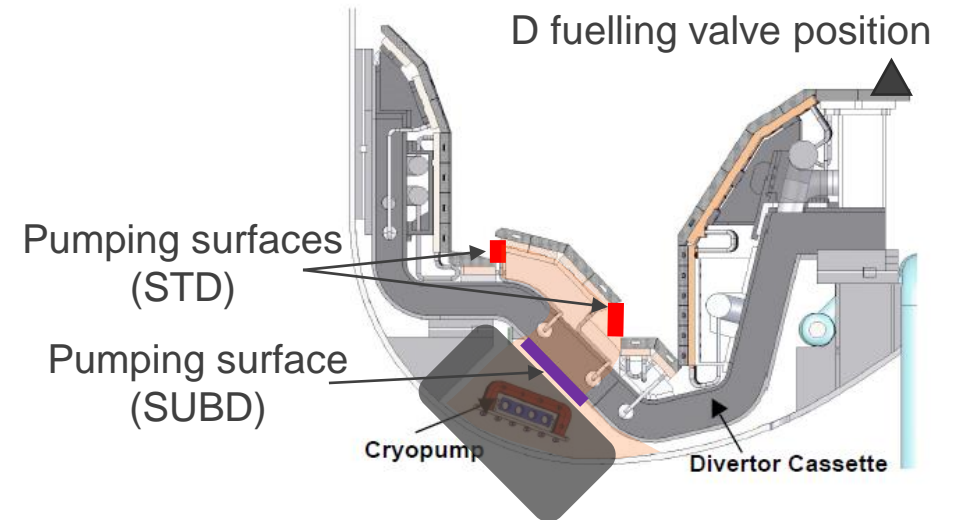
- ▶ Real shape of the vessel (top)
- ▶ 2 pumping surfaces at the entrance of the subdivertor structure

#### SUBD

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



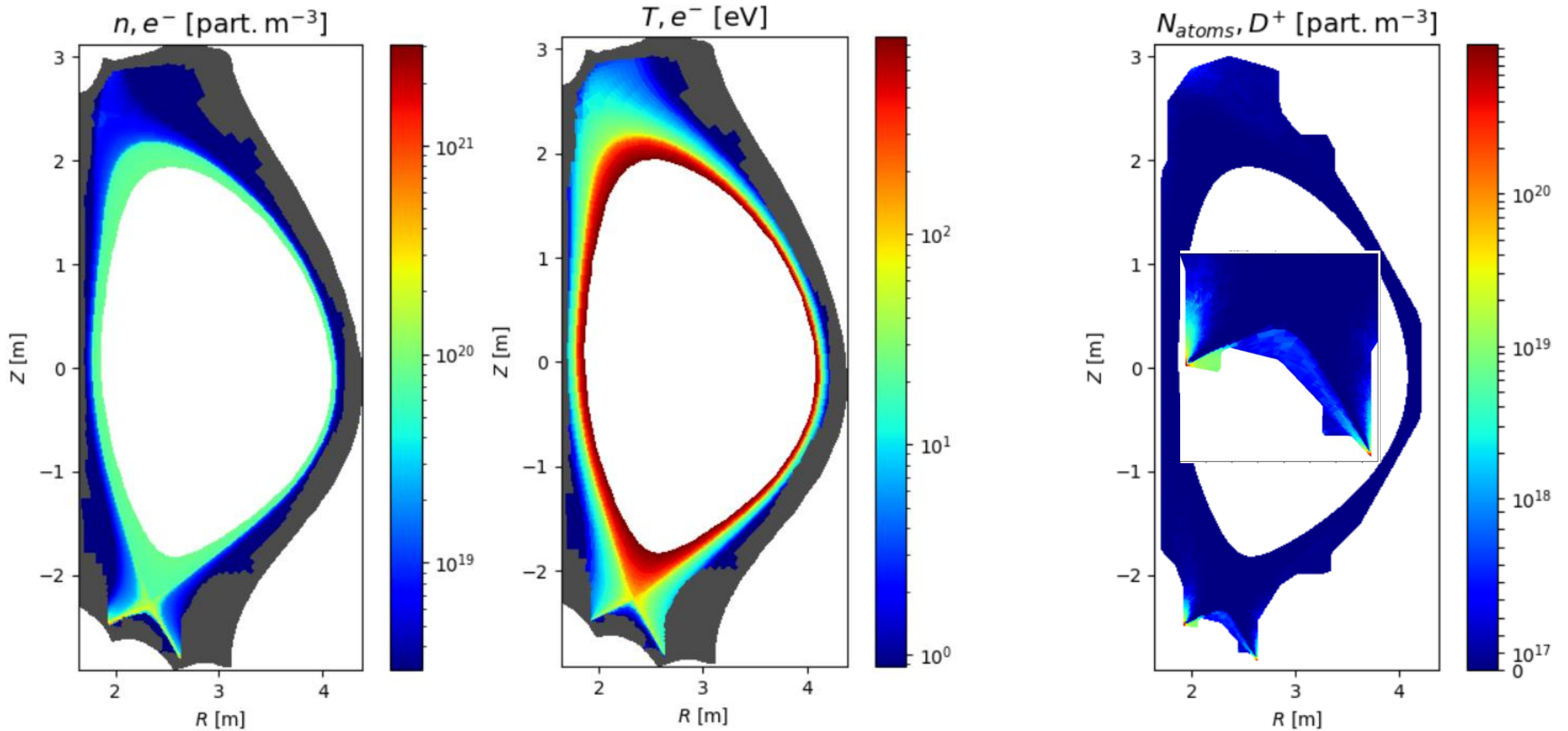
- ▶ two geometries: **STD, SUBD**
- ▶ parameter scan in  $P_{aux} = [15, 20, 25, 30]$  MW
- ▶ neutrals: EIRENE<sup>6</sup> with simplified Kotov model (no elastic collisions on neutrals)
- ▶ **constant** particle sources:
  - D -  $\Gamma_{core} = 1 \times 10^{21}$  part./s,  $\Gamma_D = 1 \times 10^{21}$  part./s (fuelling)
  - C – (if present) sputtering (Bohdansky formula<sup>7</sup>)
- ▶ 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  $D_{bar}=0.1$  m<sup>2</sup>/s** in transport barrier
  - **low  $D_{bar}=0.03$  m<sup>2</sup>/s** in transport barrier



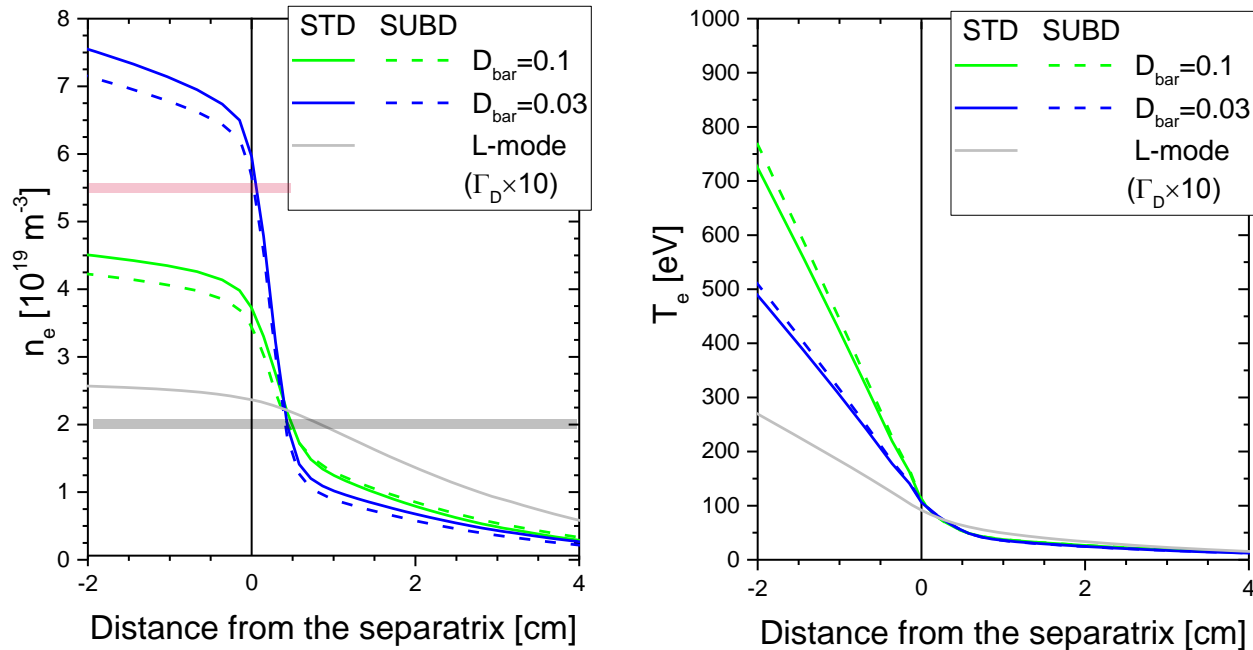
<sup>6</sup> Forschungszentrum Jülich GmbH 2021 Eirene website ( <http://eirene.de>) (accessed 2022-10-01)

<sup>7</sup> J. Bohdansky, Nucl. Instr. and Meth. B 2, 587 (1984)

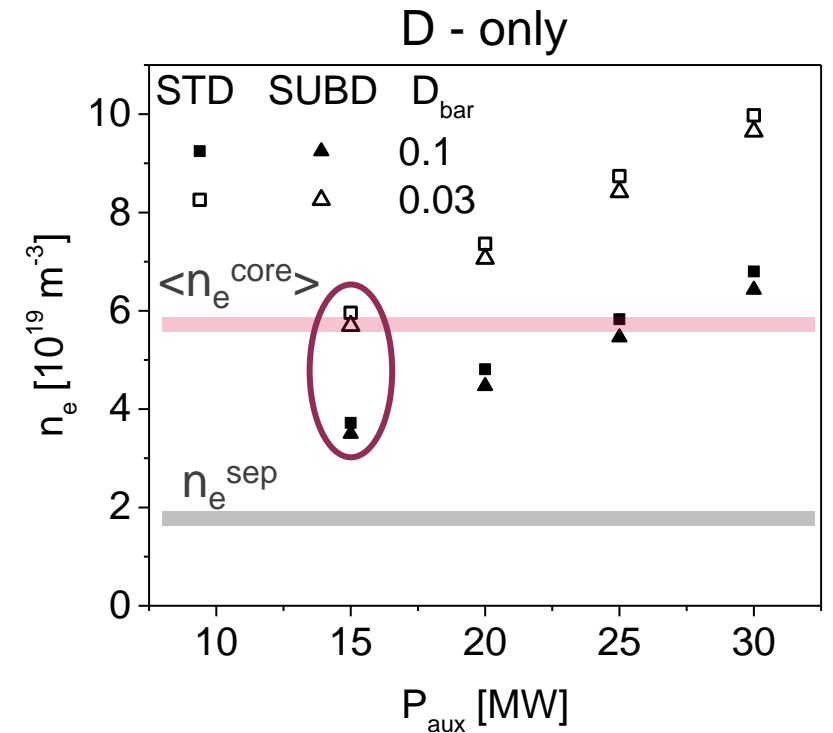




Example: STD case,  $P_{aux}=15\text{MW}$ ,  $D_{bar}=0.03\text{ m}^2/\text{s}$

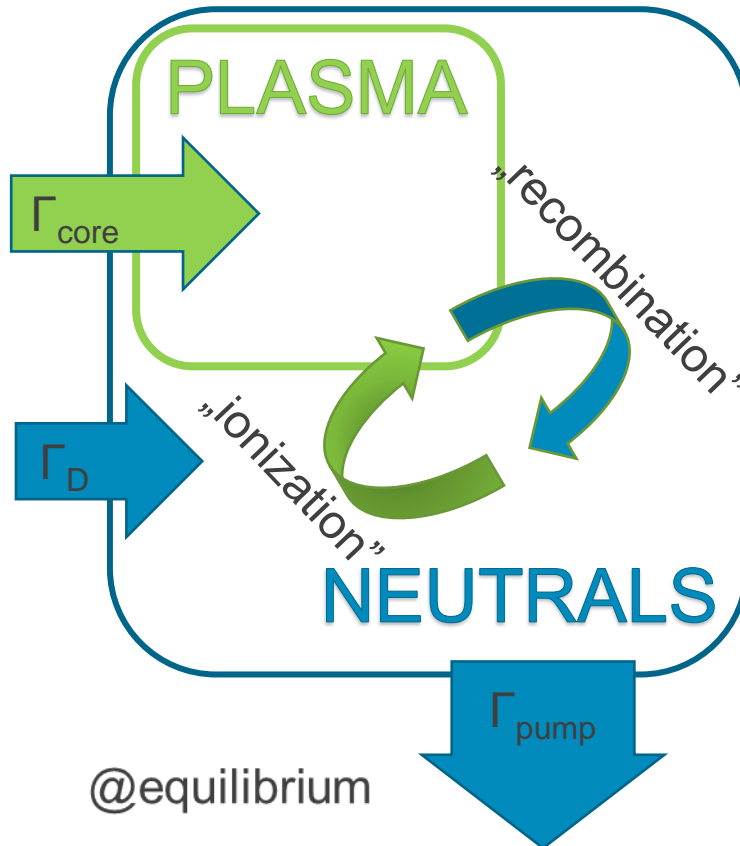
Midplane profiles ( $P_{\text{aux}}=15\text{MW}$ )

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



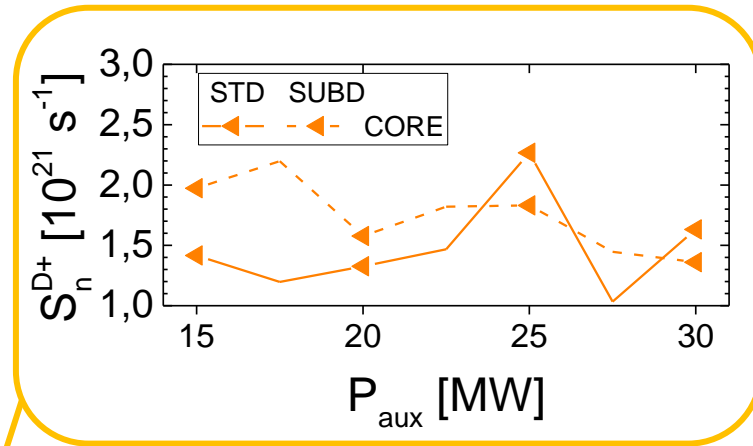
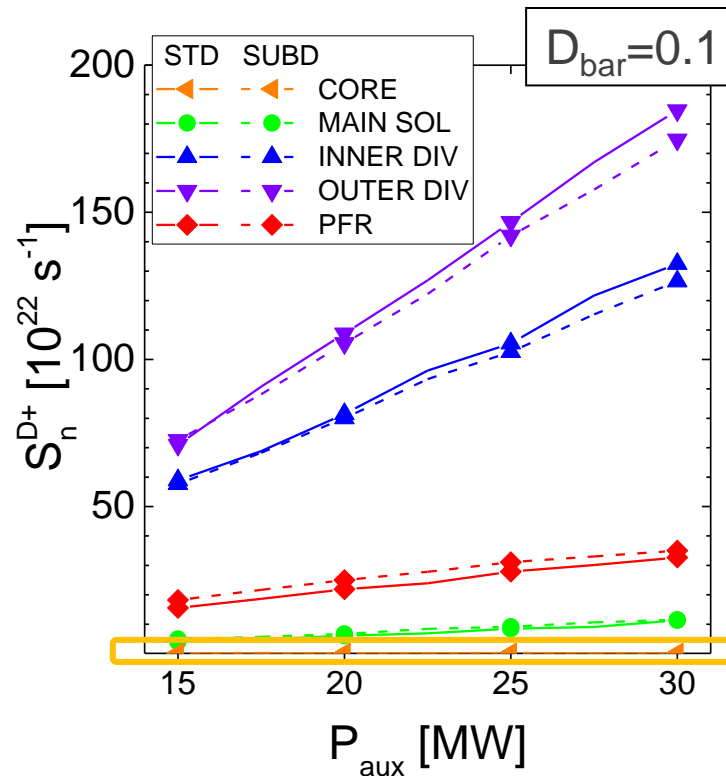
- ▶  $n_e^{\text{sep}}$  increases with increasing  $P_{\text{aux}}$
- ▶ SUBD geometry shows slightly lower  $n_e$  than STD, but the difference is small

## Simplified particle balance



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

*sources = sinks*

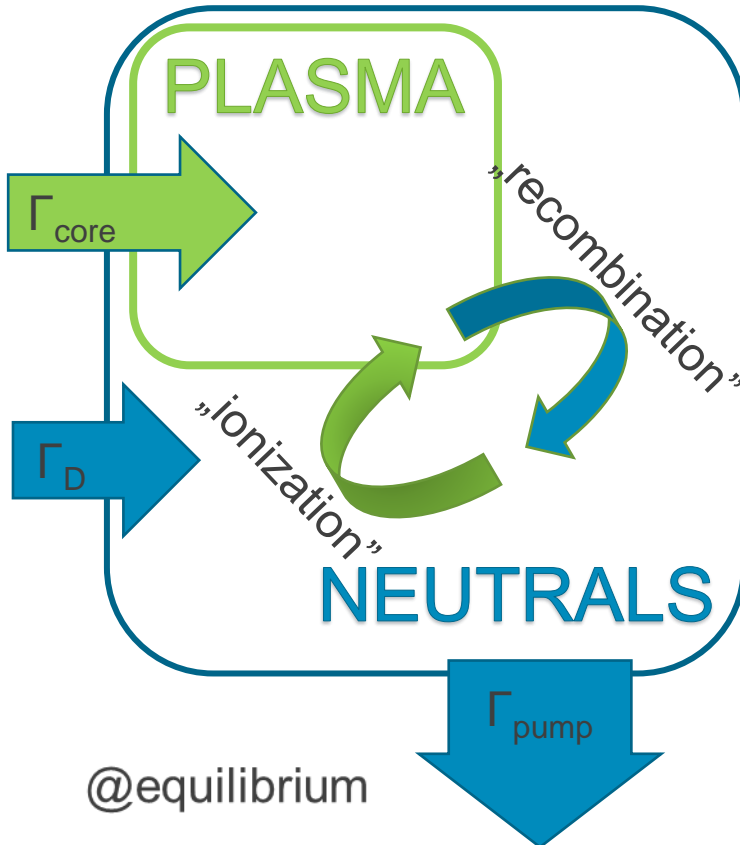


Note: core plasma source  
 $\Gamma_{core} = 1 \times 10^{21}$  part./s

- ▶ 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  $P_{aux}$



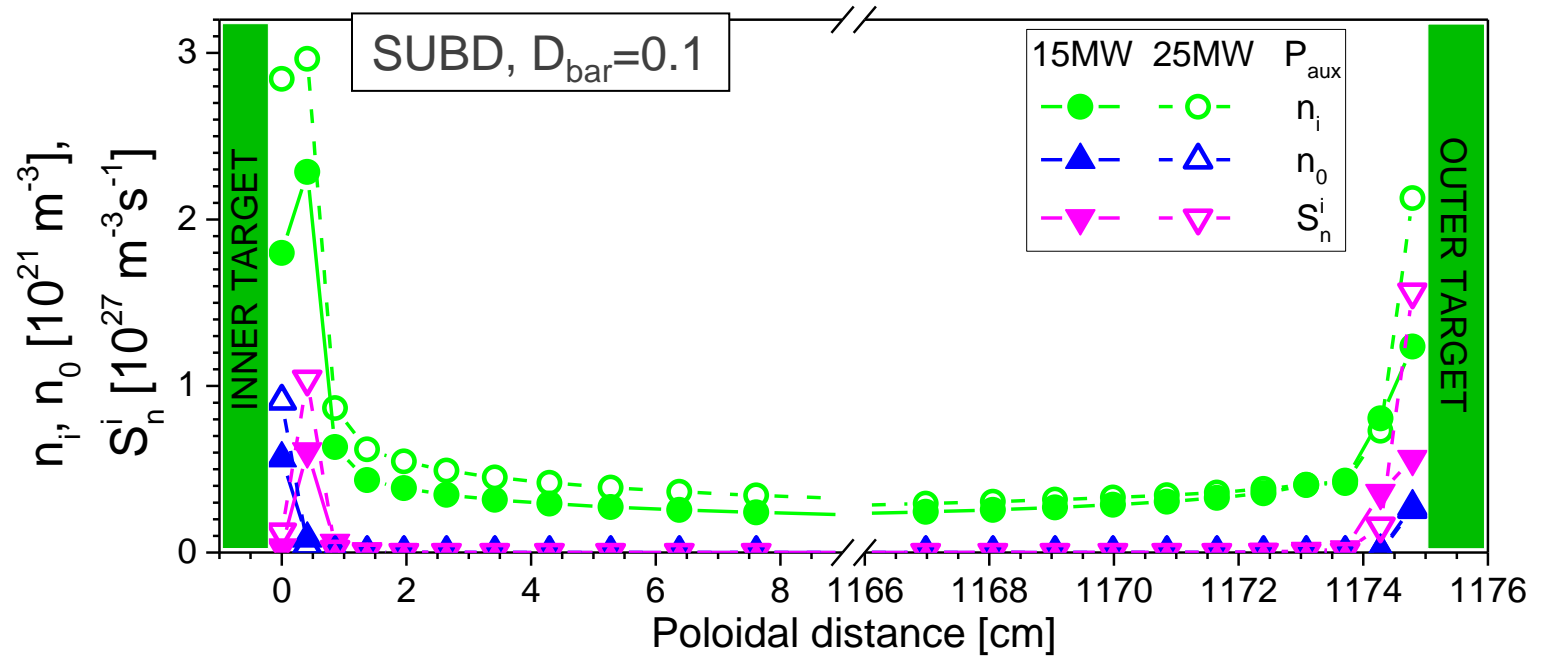
## Simplified particle balance



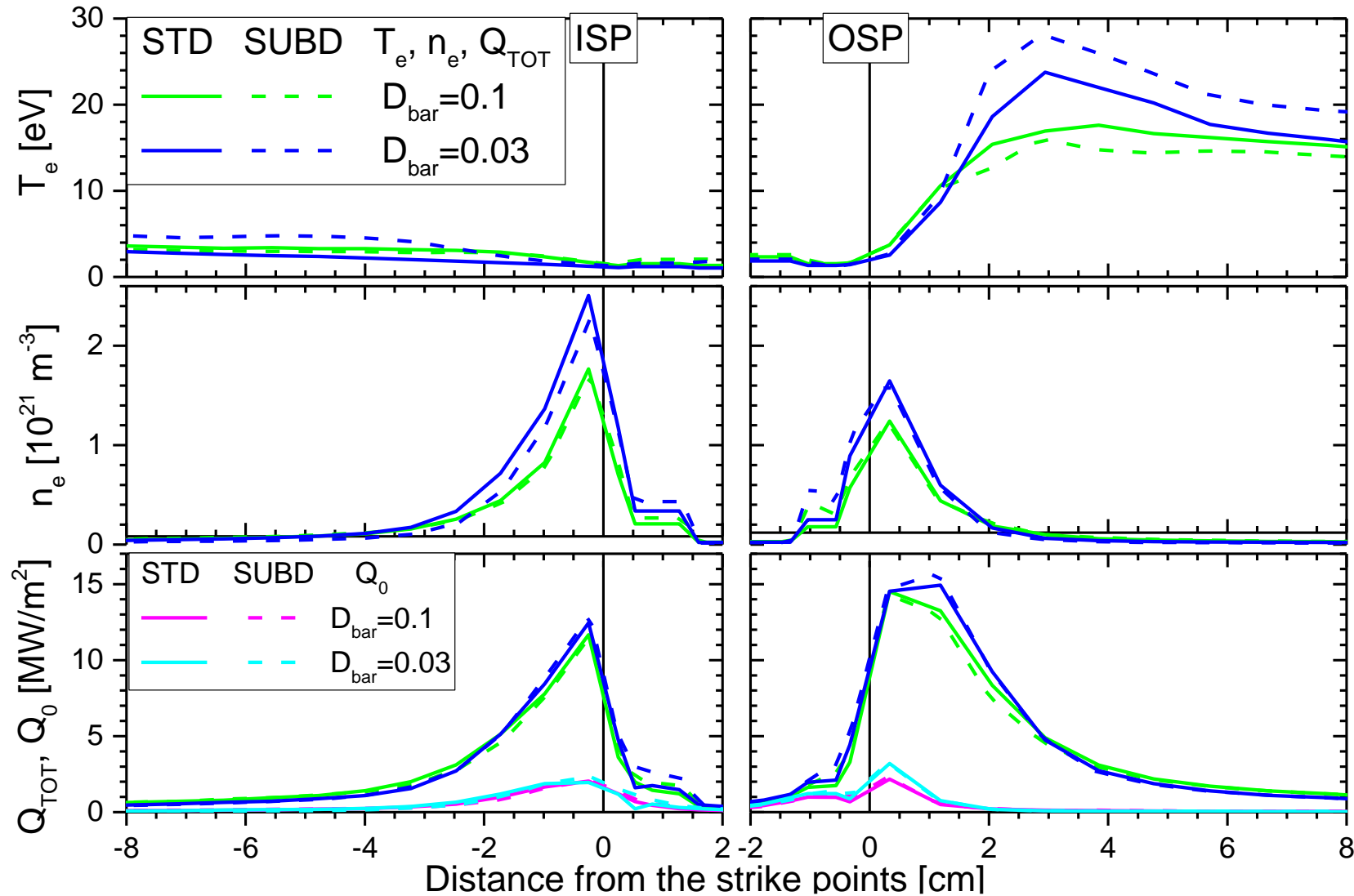
$$\Gamma_{core} + \Gamma_D = \Gamma_{pump}$$

sources = sinks

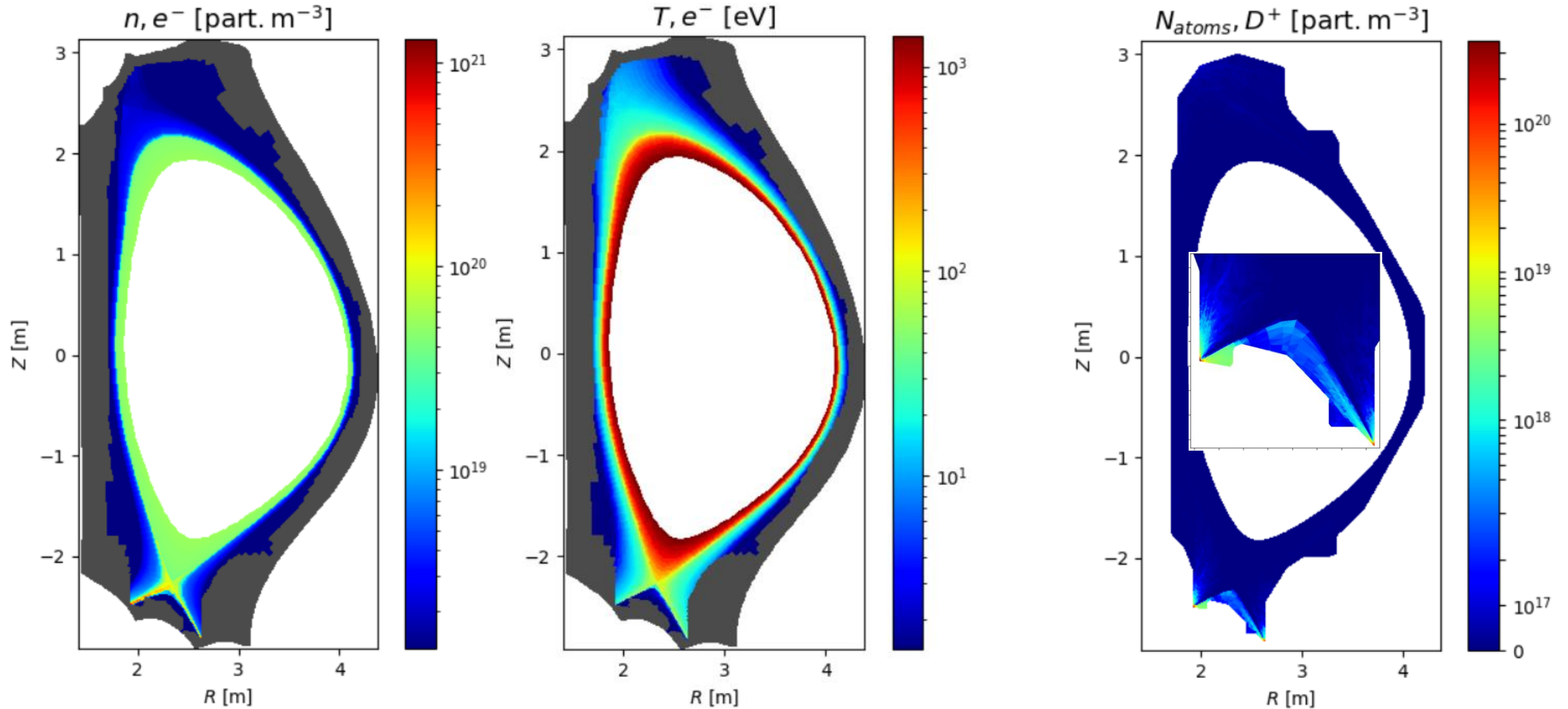
## Poloidal plot of ion density, D atoms and ionization source on the first flux tube



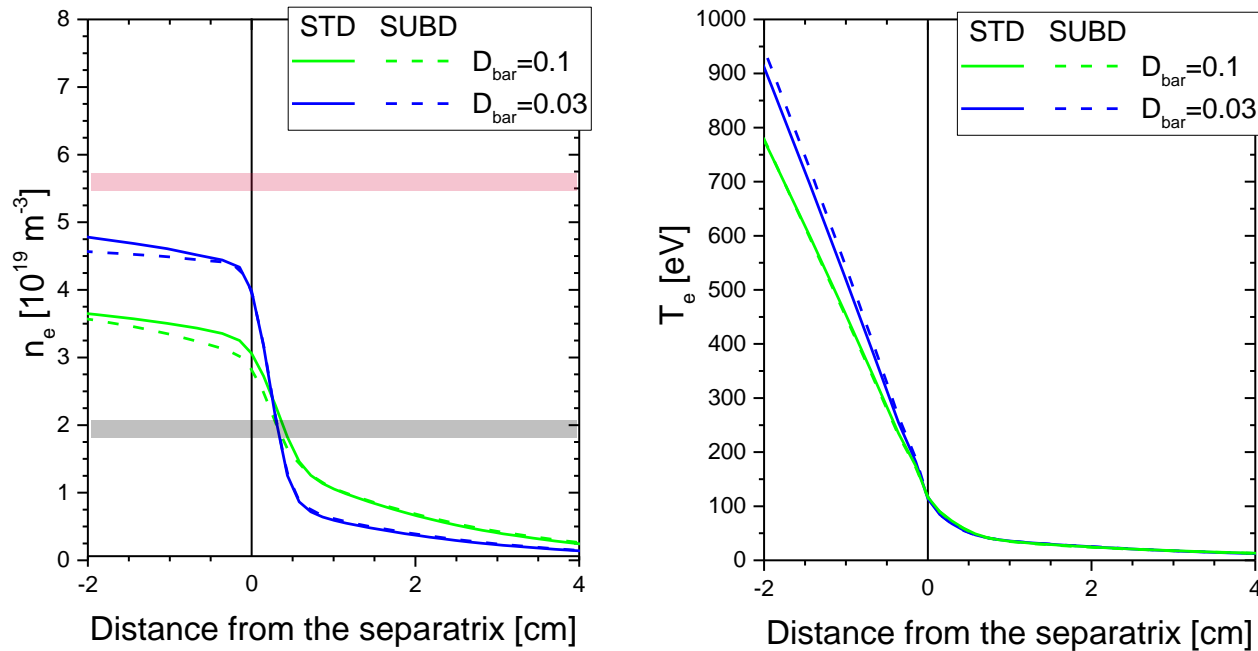
- ▶ higher  $n_i$  ( $= n_e$ ) at larger  $P_{aux}$  is correlated with higher plasma sources (here ionization source  $S_n^i$ )
- ▶ neutrals distribution is affected only at the inner target

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

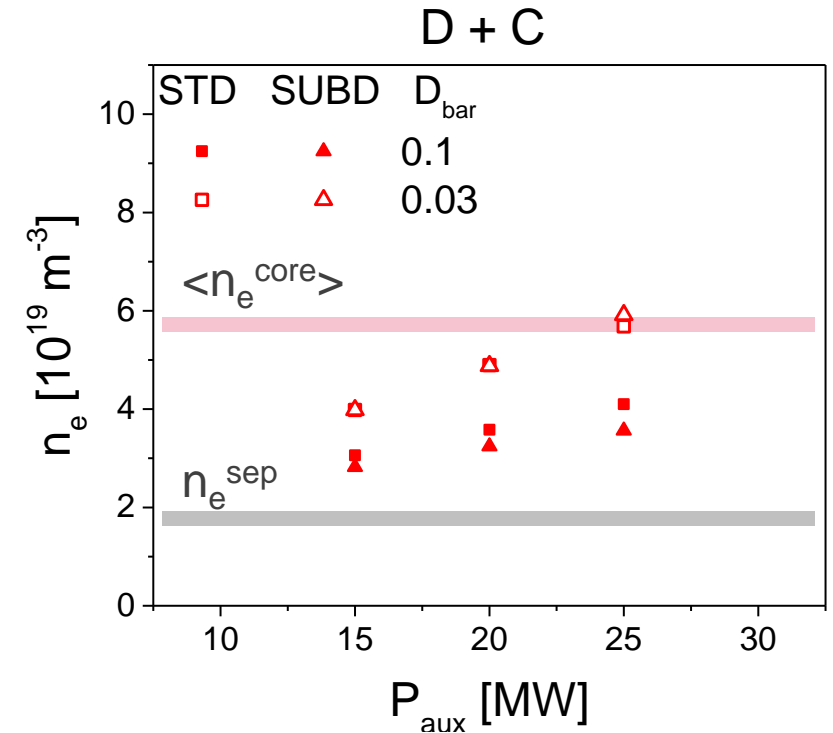
- ▶ lower  $D_{\text{bar}}$  – higher  $n_e$ , lower  $T_e$  at the targets
- ▶ Similar heat load profiles
- ▶ differences between STD and SUBD geometries small
- ▶ slightly broader  $Q_{\text{TOT}}$  profile for lower  $D_{\text{bar}}$
- ▶ Heat load above 10 MW/m<sup>2</sup> limit on both targets



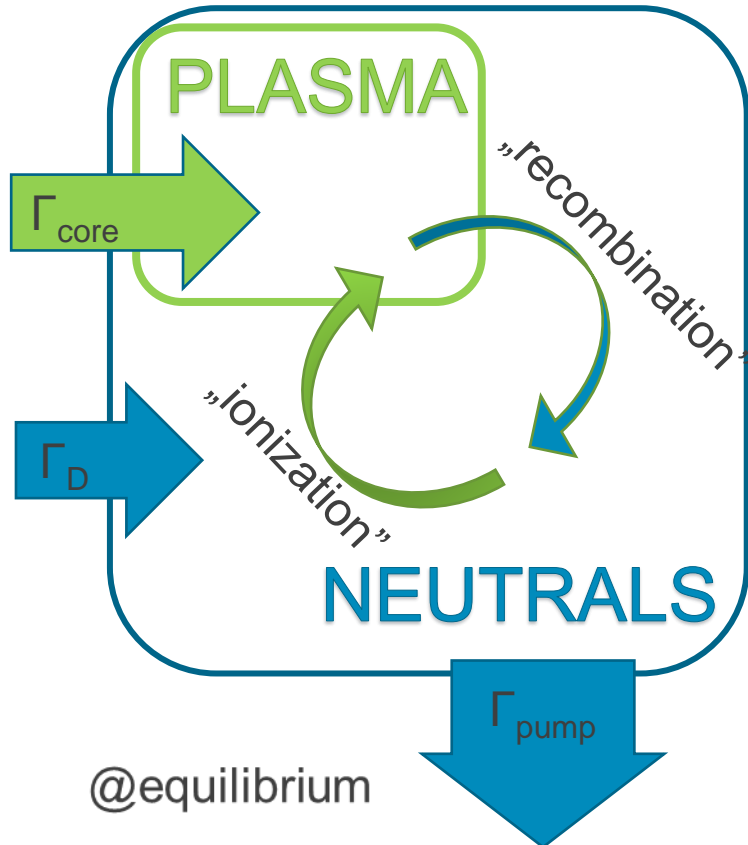
Example: STD case,  $P_{aux}=15\text{MW}$ ,  $D_{bar}=0.03\text{ m}^2/\text{s}$

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

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

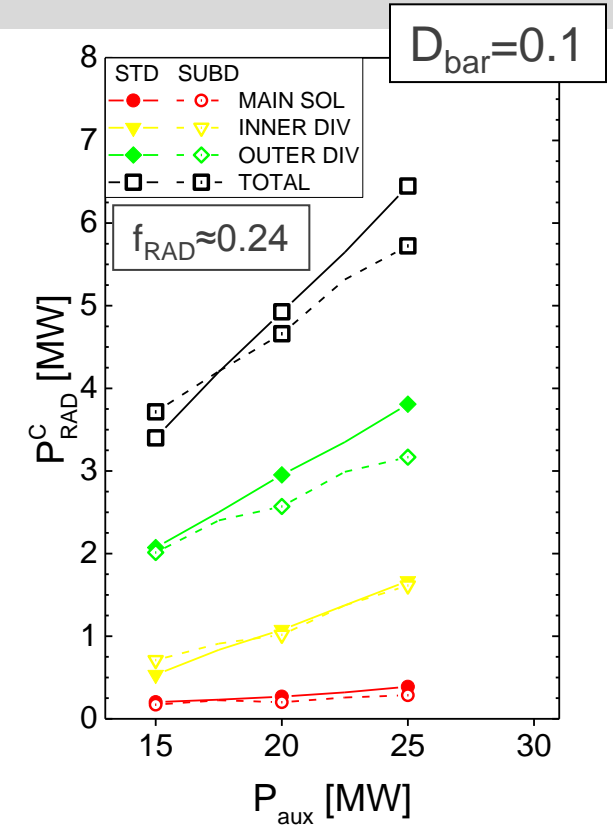
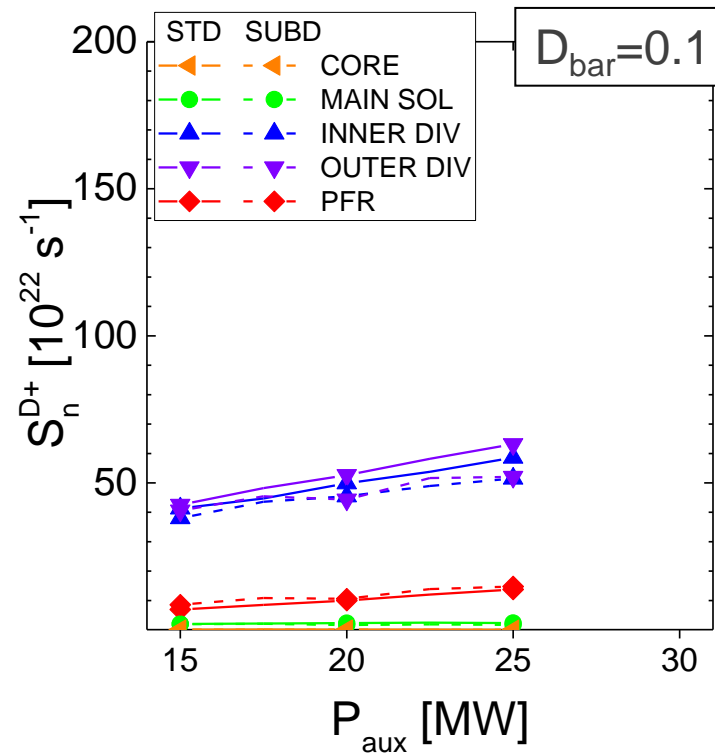


- ▶  $n_e^{\text{sep}}$  lower than in the pure D cases
- ▶  $n_e^{\text{sep}}(P_{\text{aux}})$  slope for  $D_{\text{bar}}=0.1 \text{ m}^2/\text{s}$  less steep than in the pure-D case
- ▶ SUBD geometry shows slightly lower  $n_e$  than STD



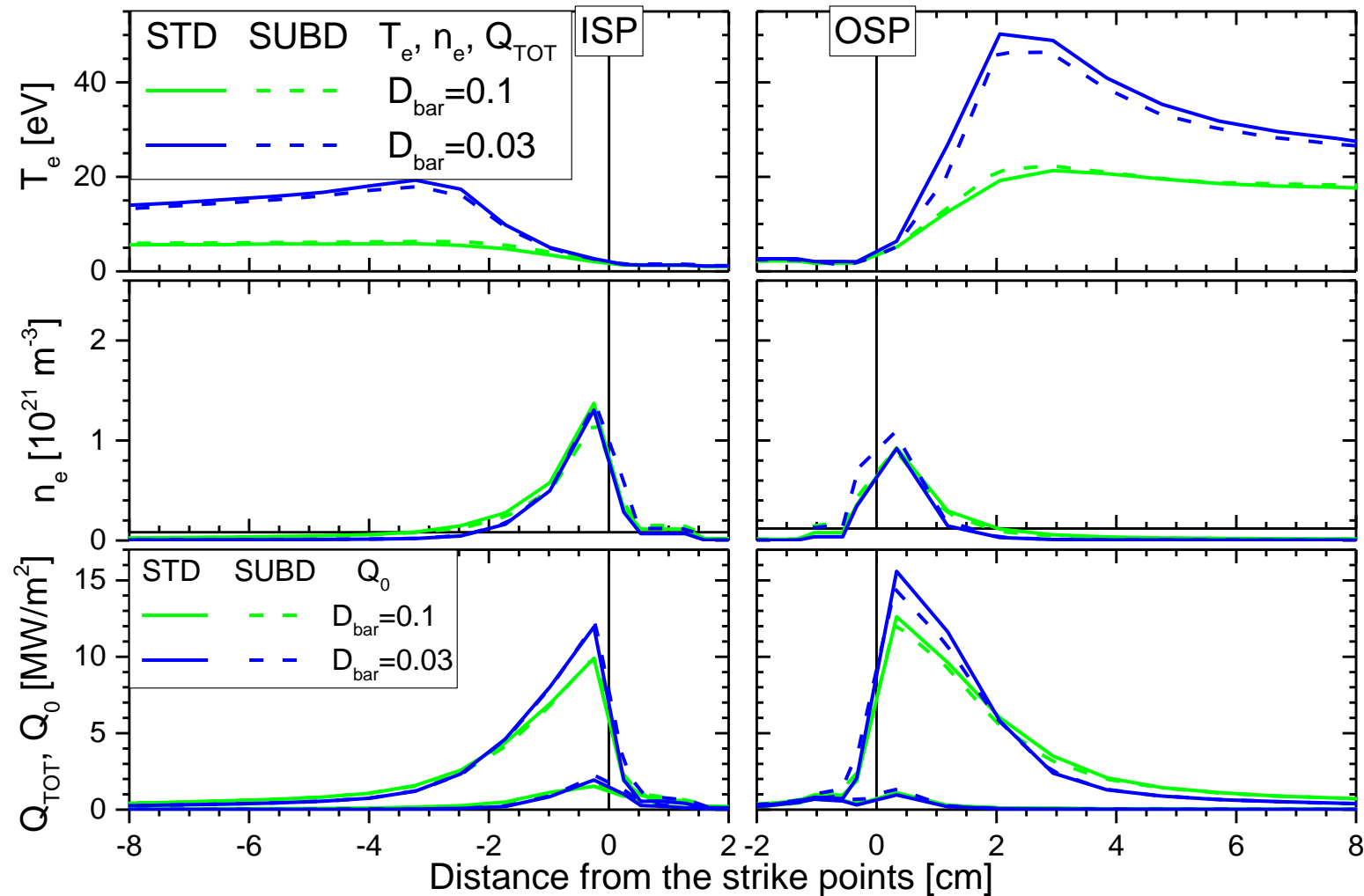
$$\Gamma_{core} + \Gamma_D = \Gamma_{pump}$$

*sources = sinks*

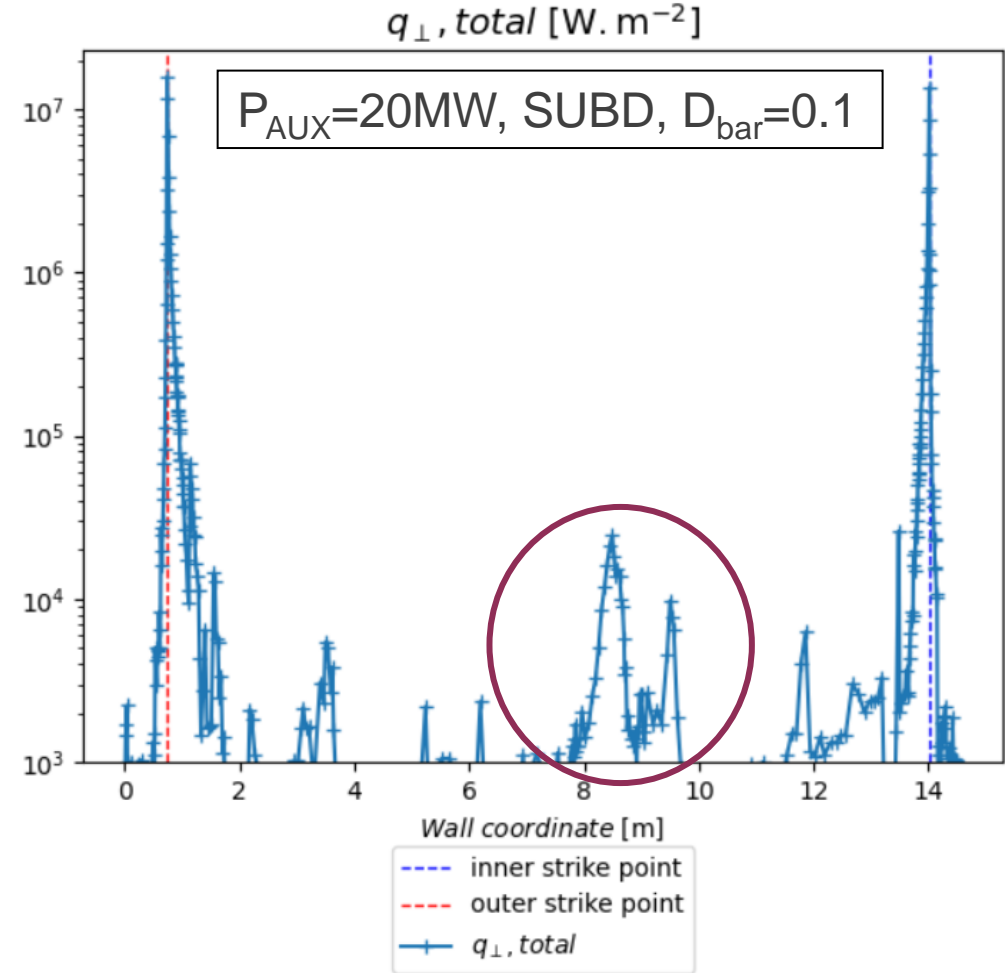
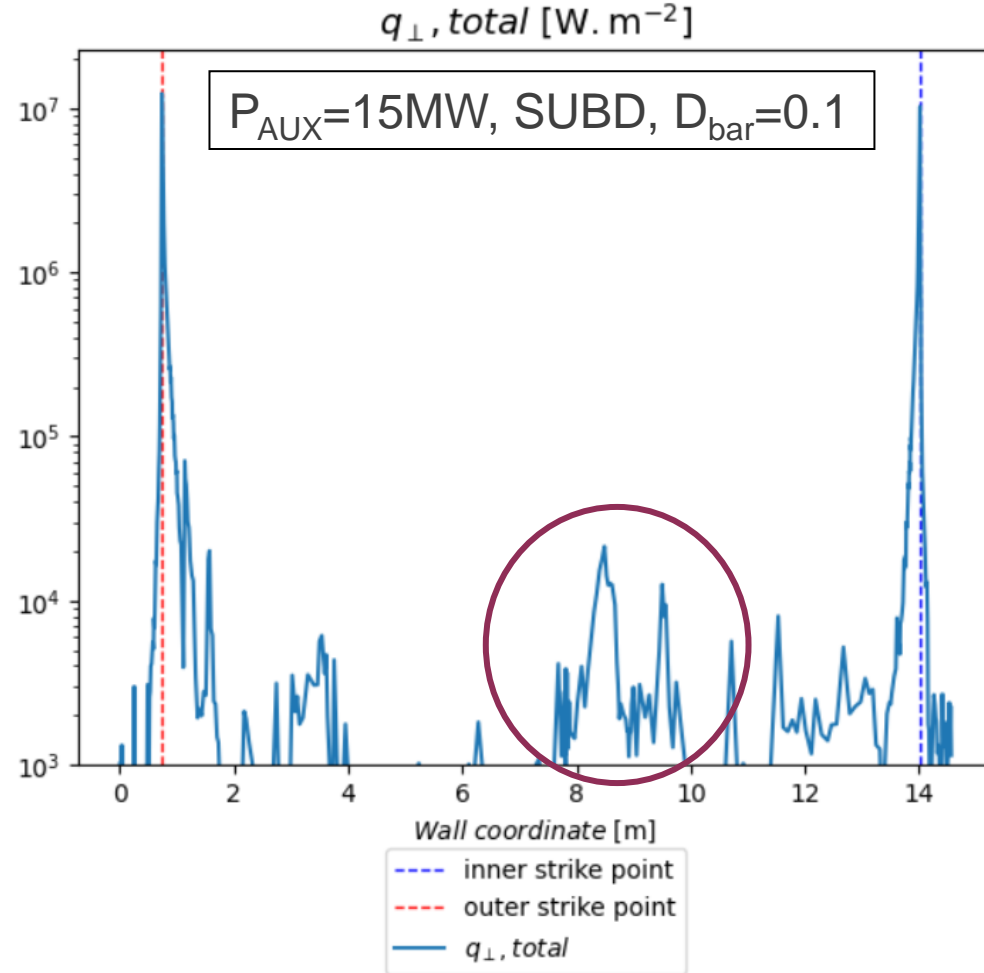


- ▶ presence of C impurity and its radiation brings the system to a different ionization-recombination balance
- ▶ due to  $P_{RAD}$  the power delivered to the ionization zone is lower
- ▶ as a result the plasma sources in the D+C case are weaker
- ▶ the resulting  $n_e^{sep}$  is much lower than in 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  $D_{\text{bar}}$  cases
- ▶ still, differences between STD and SUBD geometries small
- ▶ still, heat load exceeds the  $10 \text{ MW/m}^2$  material limit



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

- ▶ 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  $D_{bar}$**

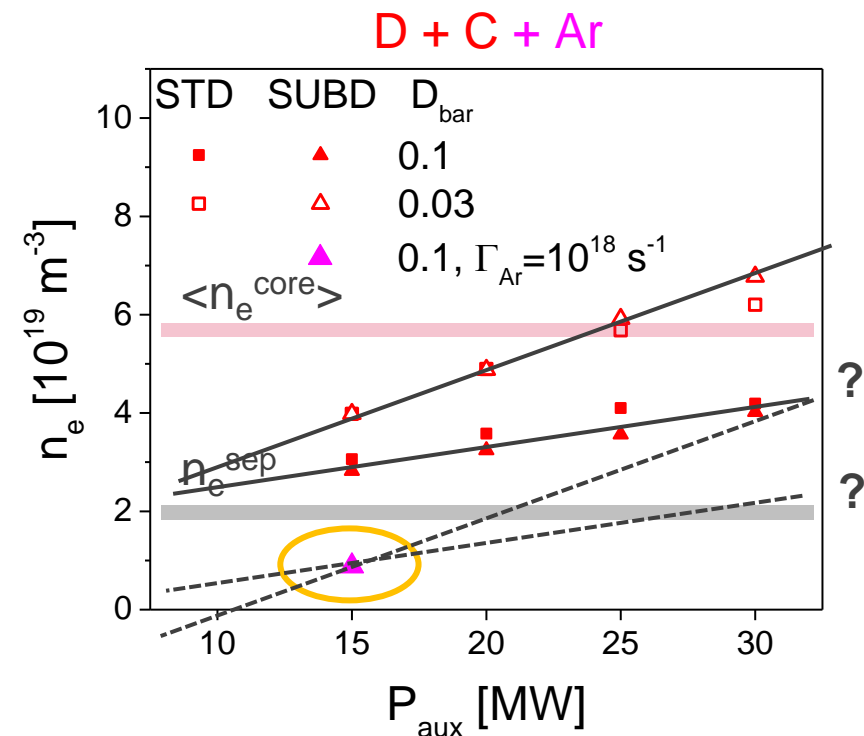
The influence of different perpendicular transport is assessed:

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/m<sup>2</sup>) 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**



