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

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

DE LA RECHERCHE À L'INDUSTRIE

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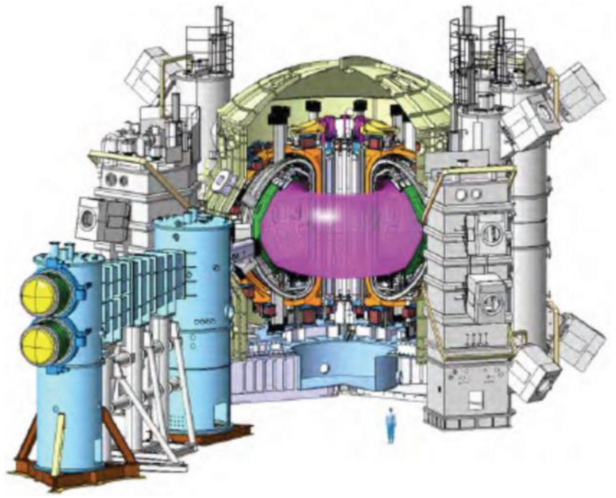
Introduction and context

- **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[1], COREDIV[2], SOLEDGE2D[3], SOLPS[4]) indicate posible 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[5]

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
$\langle n_e \rangle_{VOL}$	$\times 10^{19}$ m^{-3}	**5.6**	9.0
n_e^{sep}	$\times 10^{19}$ 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 Gałązka *et al.*. Plasma Phys. Control. Fusion 59 045011 (2017);
K Gałązka *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

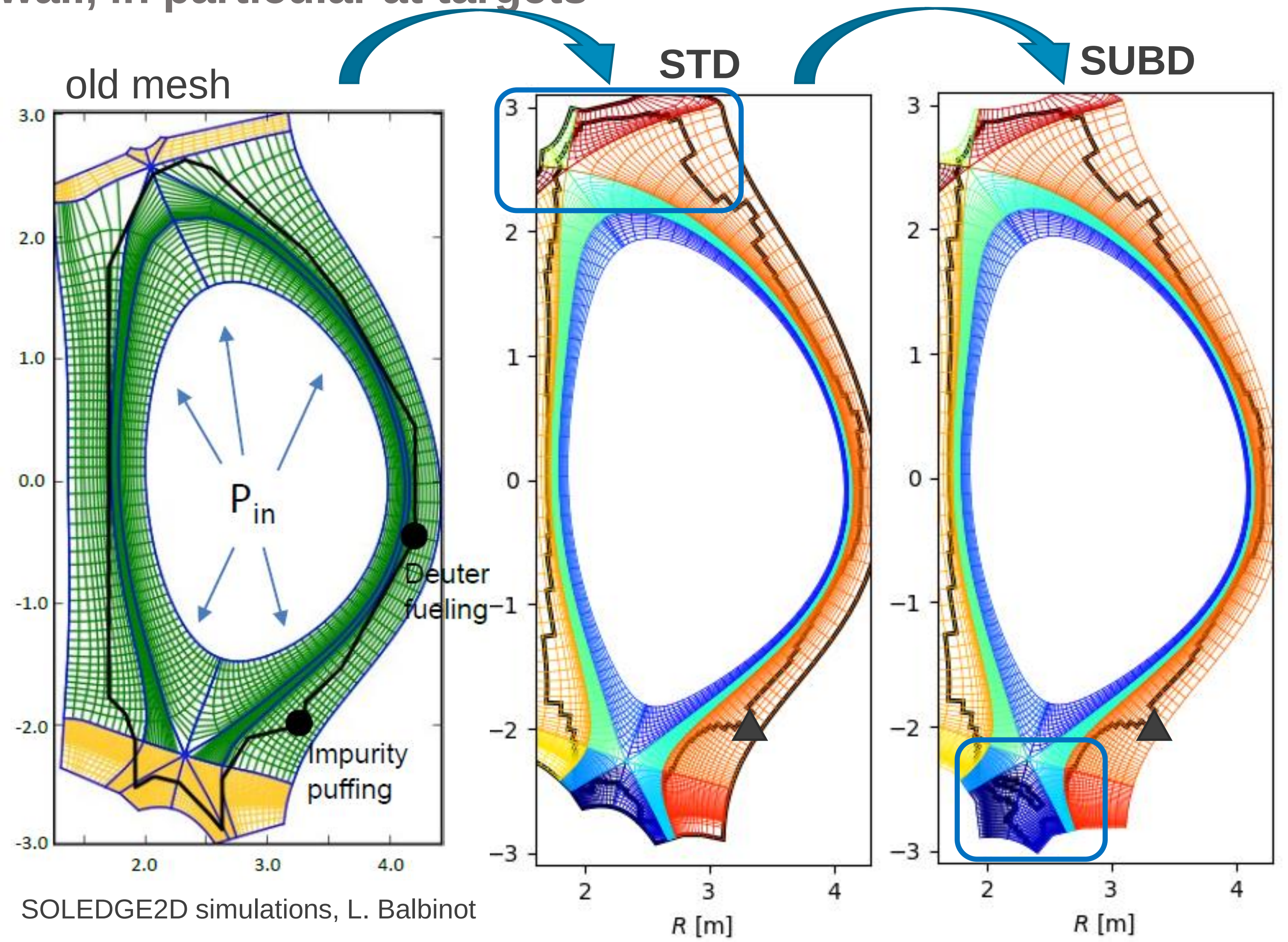
Two configurations modelled:

STD

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

SUBD

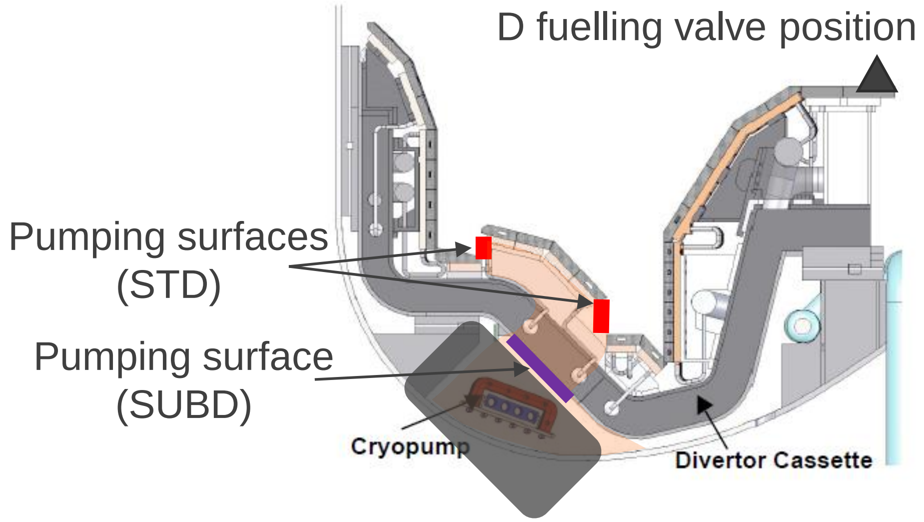
- Real shape of the vessel (top)
- Model also (part of) the subdivertor structure (1 pumping surface)

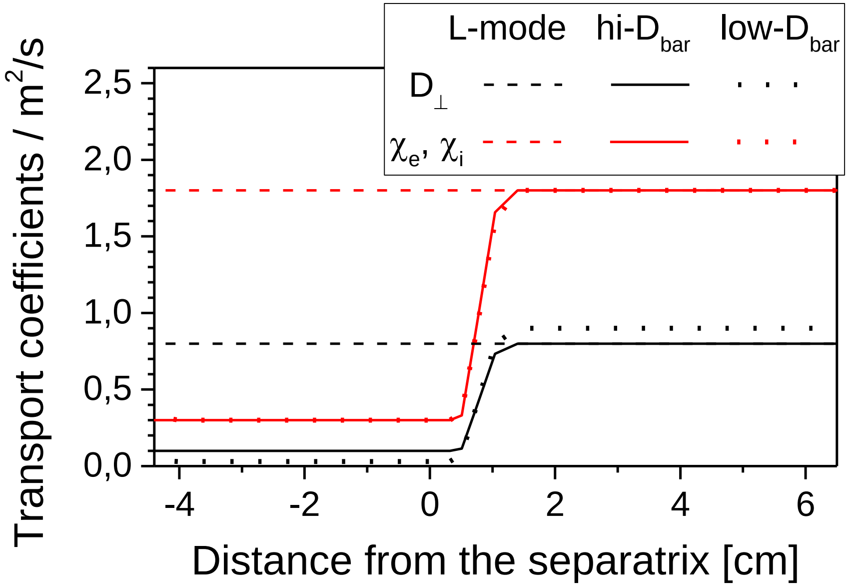


SOLEDGE2D simulations, L. Balbinot

Modelling strategy and simulations setup

- two geometries: **STD, SUBD**
- parameter scan in $\mathbf{P_{aux}}$ **= [15, 20, 25, 30] MW**
- neutrals: EIRENE[6] with simplified Kotov model (no elastic collisions on neutrals)
- **constant** paticle sources:
  D - $\mathbf{\Gamma_{core} = 1\times10^{21}}$ part./s, $\mathbf{\Gamma_D = 1\times10^{21}}$ part./s (fuelling)
  C – (if present) sputtering (Bohdansky formula[7])
- 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 lenghts:
  - **high $\mathbf{D_{bar}}$=0.1 m²/s** in transport barier
  - **low $\mathbf{D_{bar}}$ =0.03 m²/s** in transport barrier

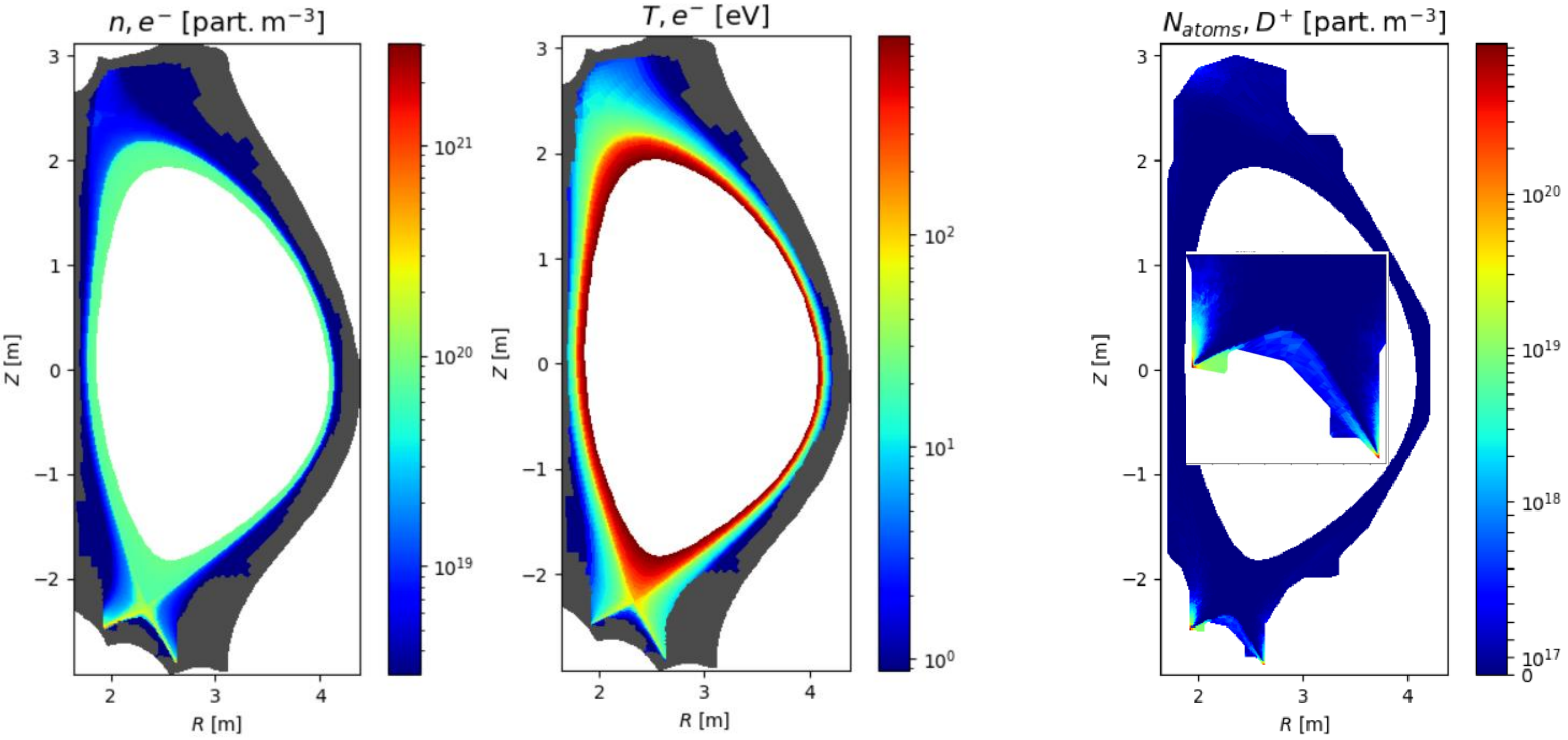




[6] Forschungszentrum Jülich GmbH 2021 Eirene website (http://eirene.de) (accessed 2022-10-01)

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

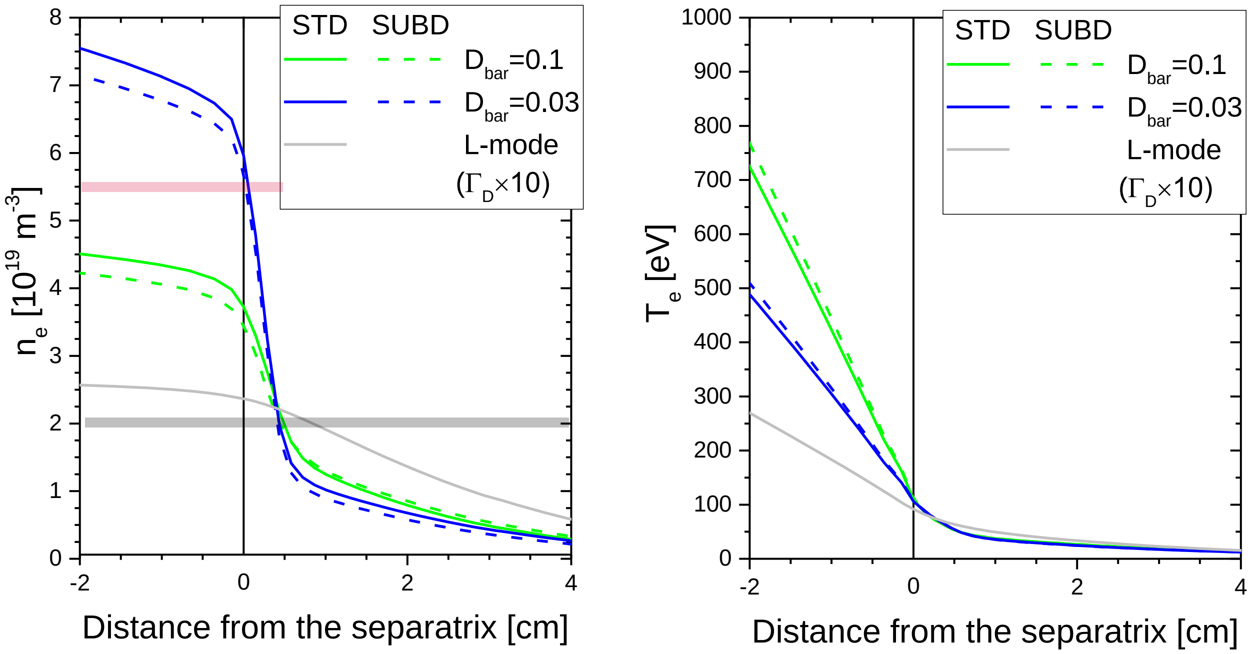
Results of simulations: pure D cases



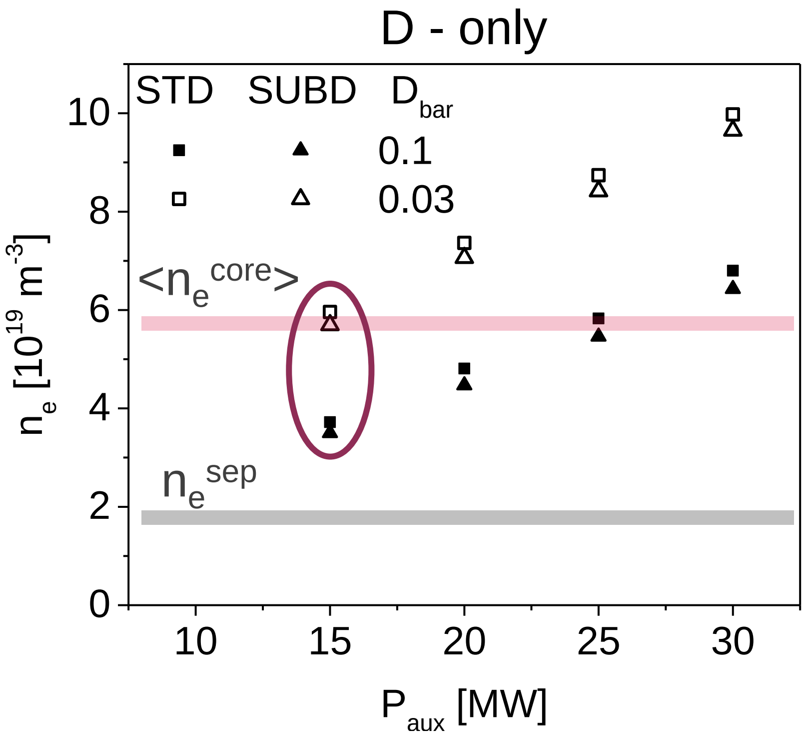
Example: STD case, P_{aux}=15MW, D_{bar}=0.03 m^2/s

Pure D cases – n_e^{sep} operational space

Midplane profiles (P_{aux}=15MW)



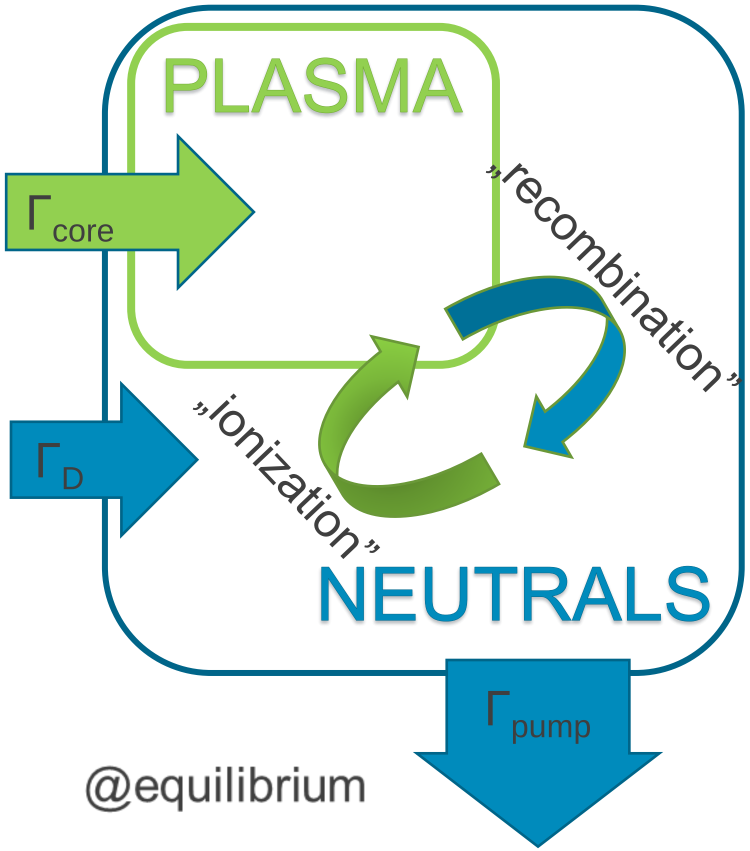
- High n_e^{sep} already with 15 MW of input power
- T_e^{sep} in the range of 105-110 eV
- lower D_{bar} results in higher n_e gradient and higher n_e^{sep} value
- λ_n = 8 mm for the D_{bar} = 0.1 m^2/s case and λ_n = 4 mm for the D_{bar} = 0.03 m^2/s



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

Pure D cases – plasma fuelling mechanism

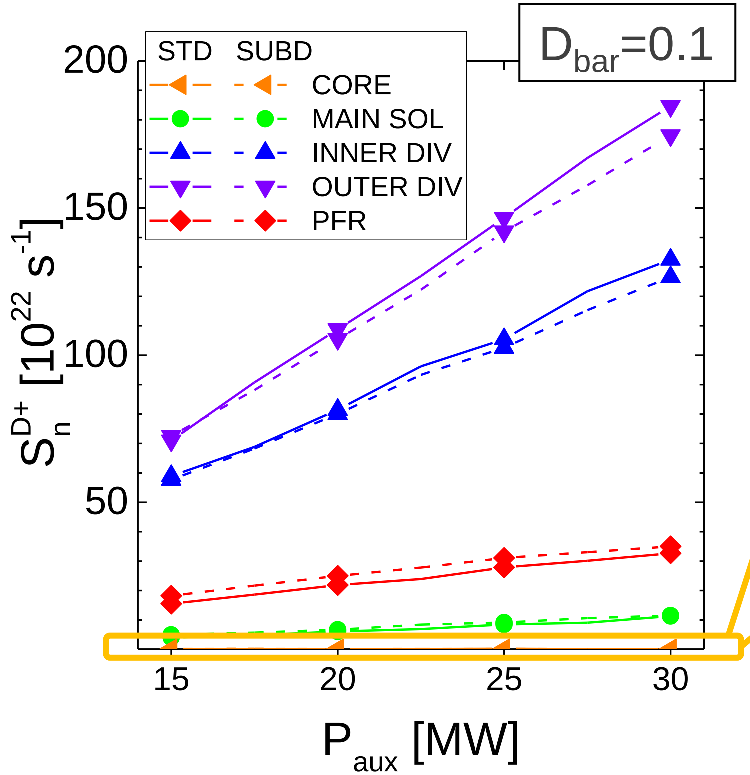
Simplified particle balance

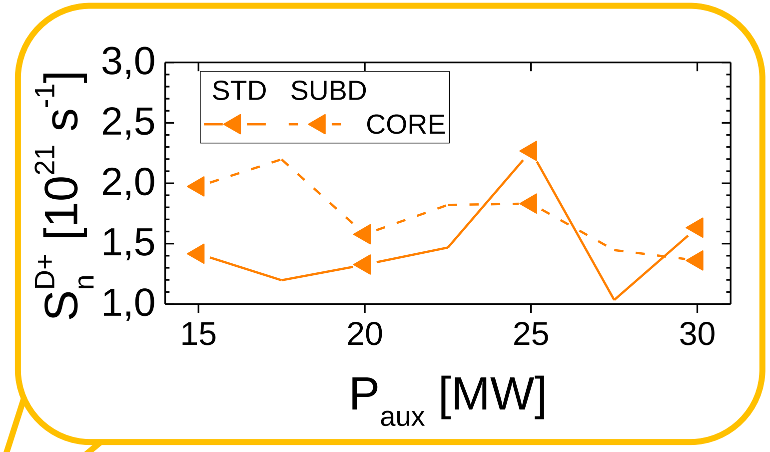


@equilibrium

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

sources = sinks

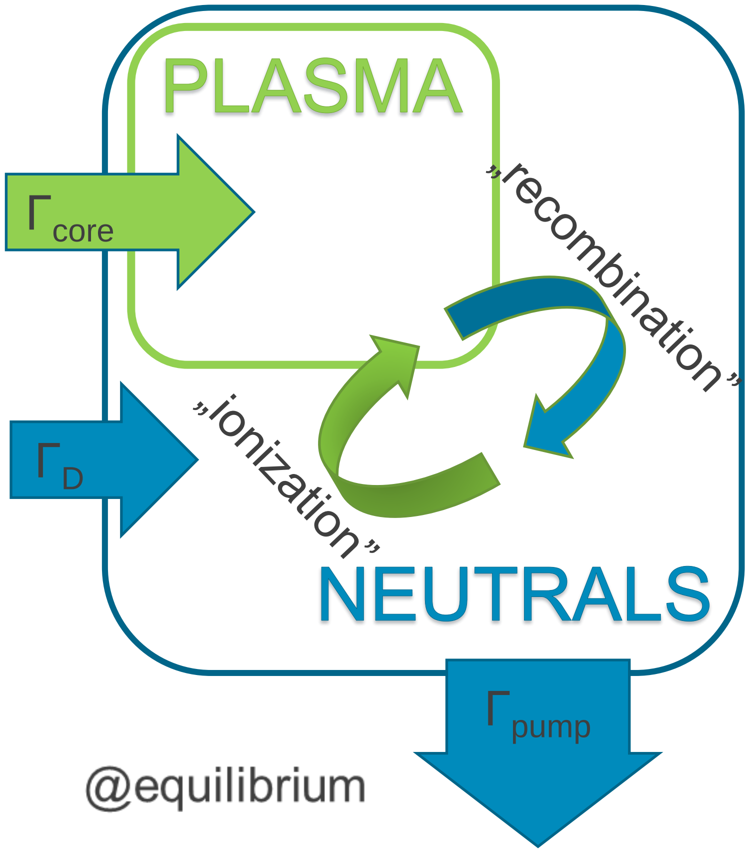




Note: core plasma source
Γ_{core} = 1×10^{21} part./s

- particle trhroughput through the system is constant (IN = OUT)
- the balance between sources and sinks determines the amount of ionized partcles in the plasma
- core plasma sources (BC + ionization) at least ~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

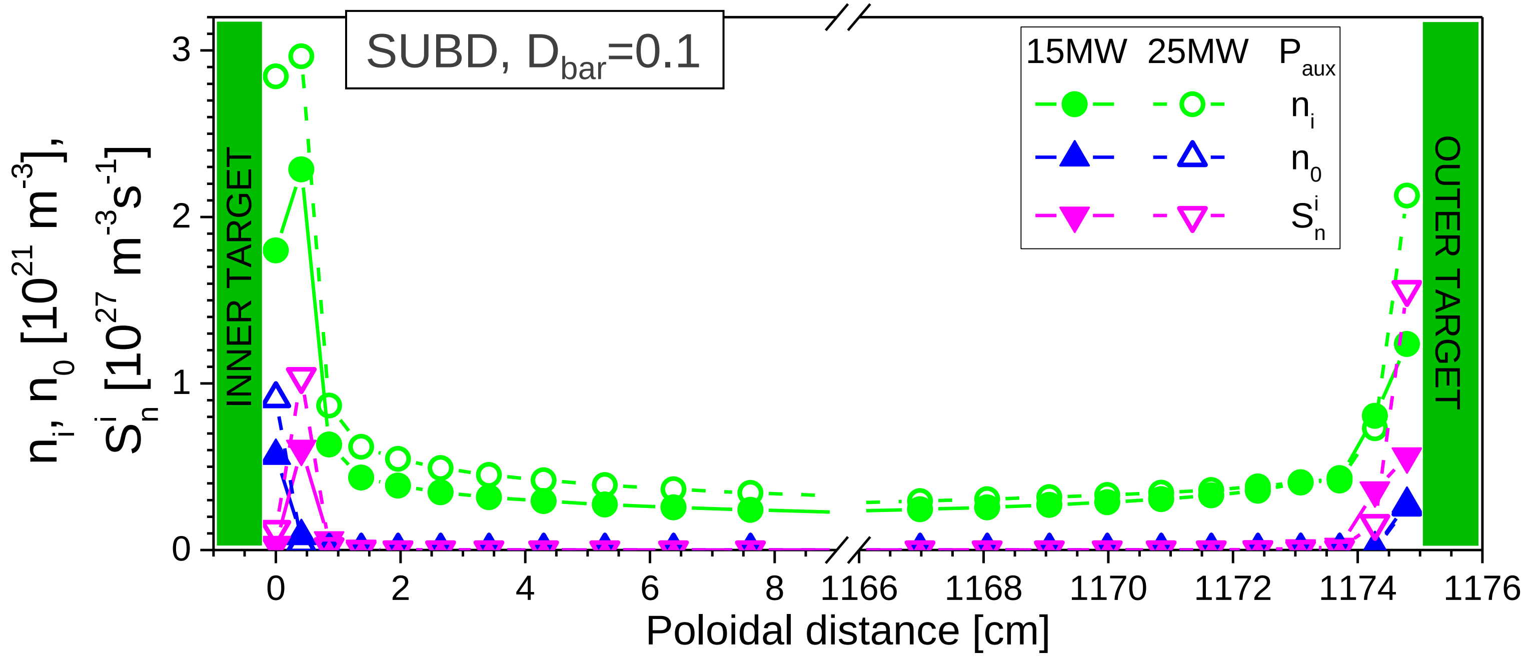


@equilibrium

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

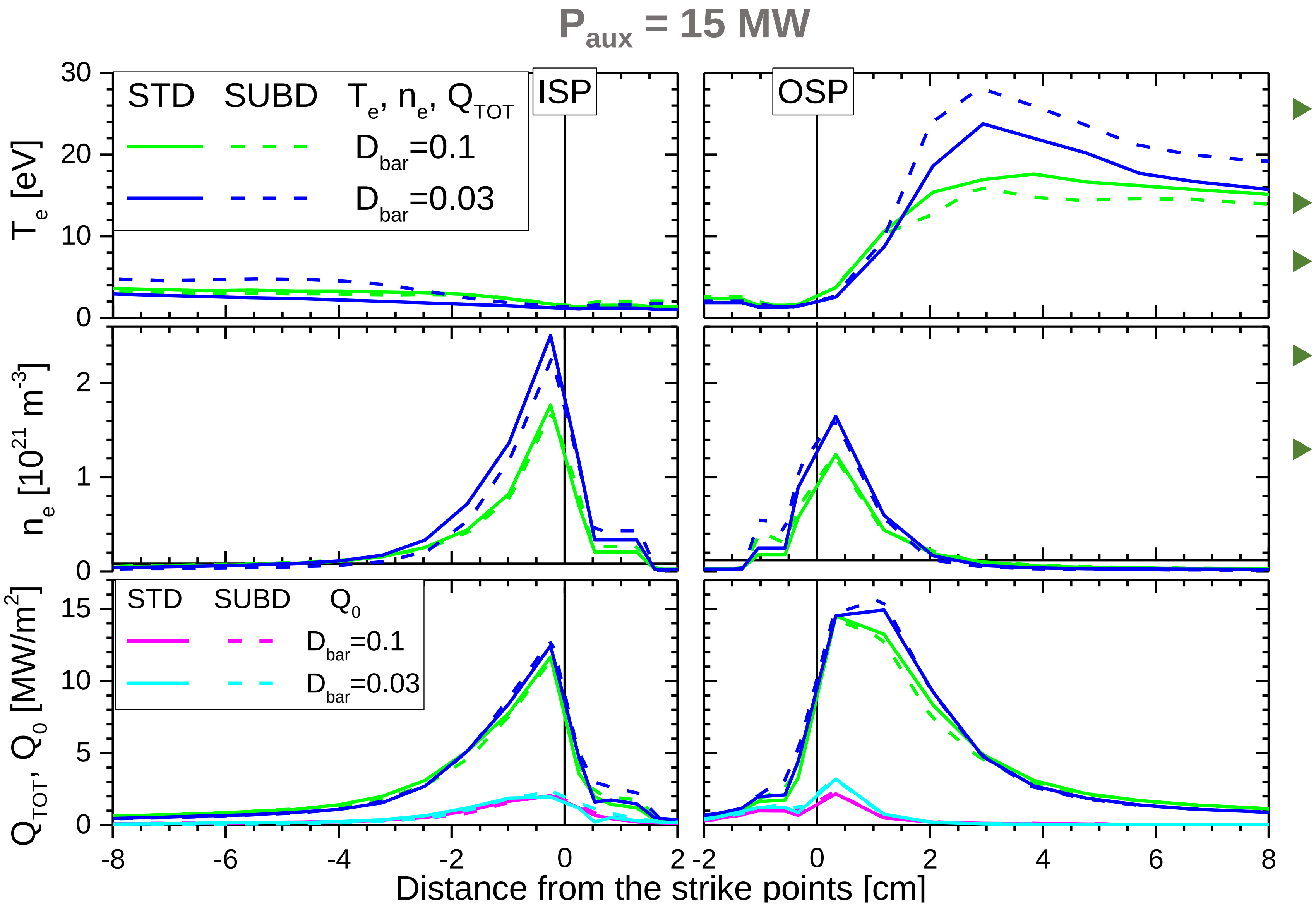
sources = sinks

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



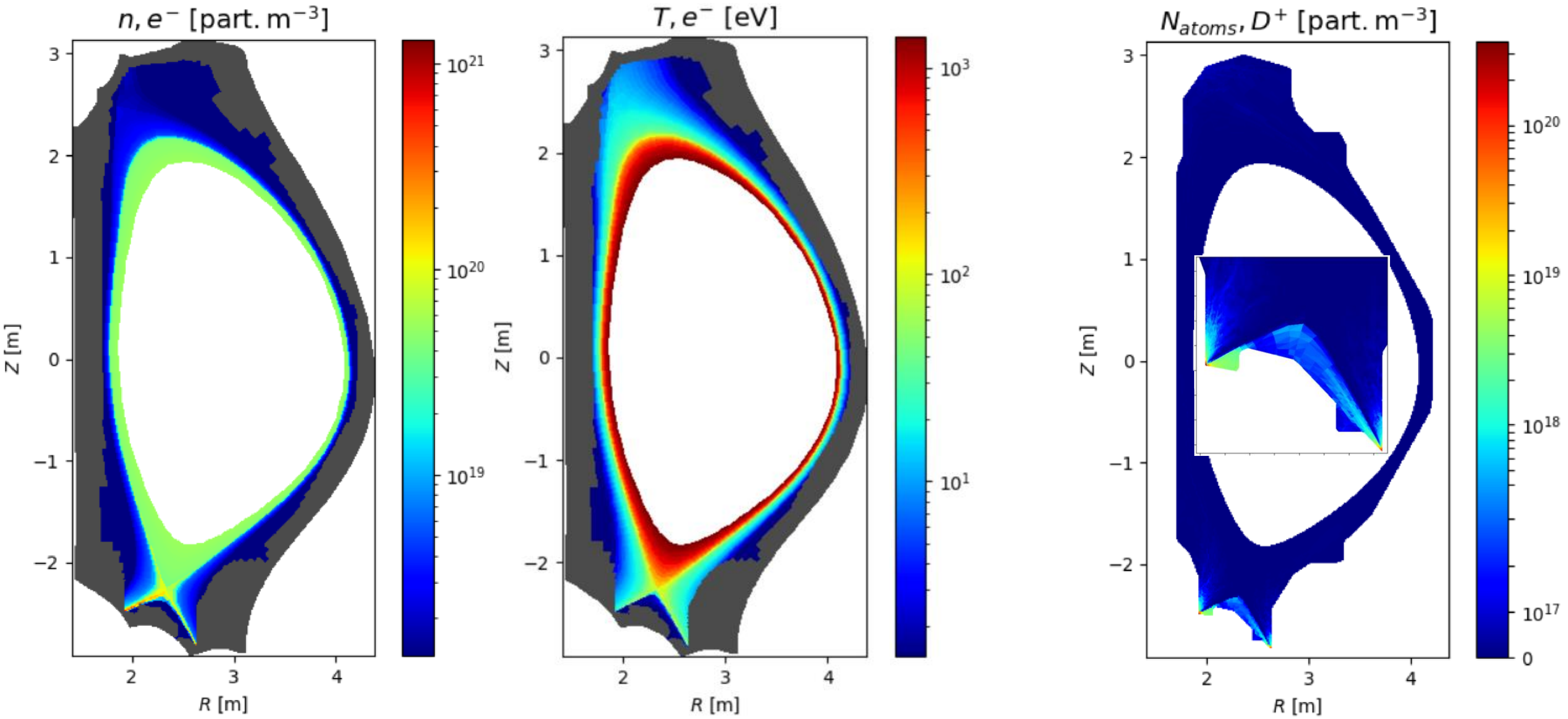
- higher n_i (= n_e) at larger P_{aux} is correlated with higher plasma sources (here ionization source S^i_n)
- neutrals distribution is affected only at the inner target

Pure D cases – profiles at targets



- lower D_{bar} – higer 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

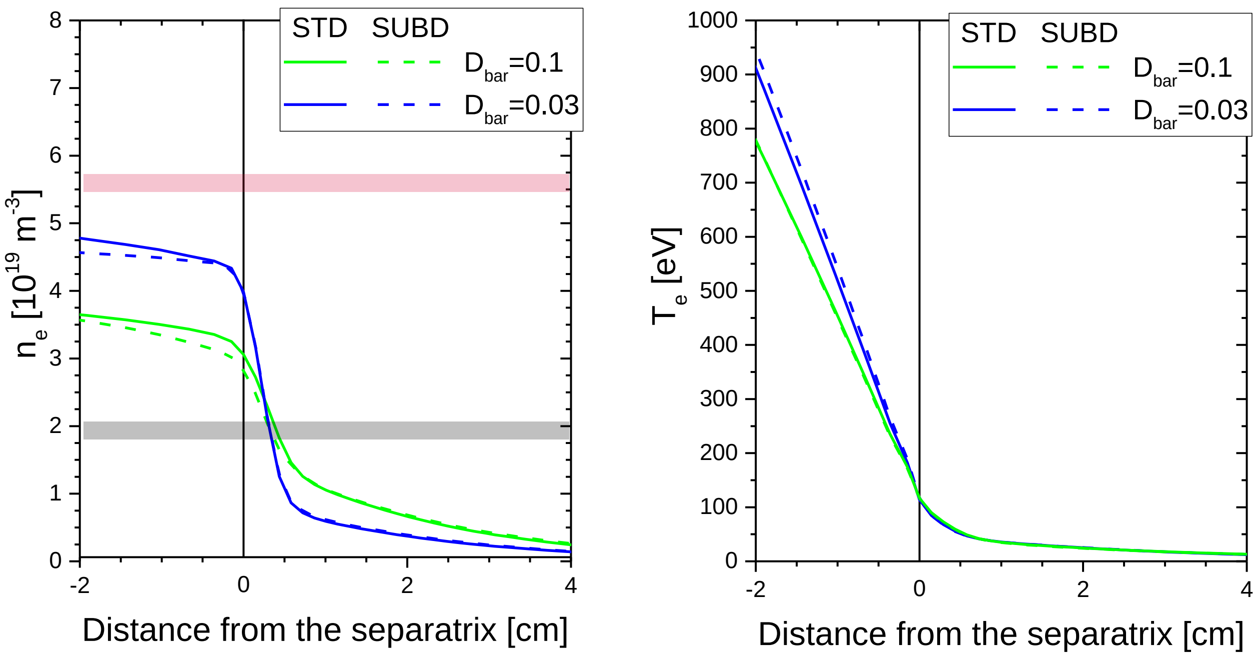
Results of simulations: D+C cases

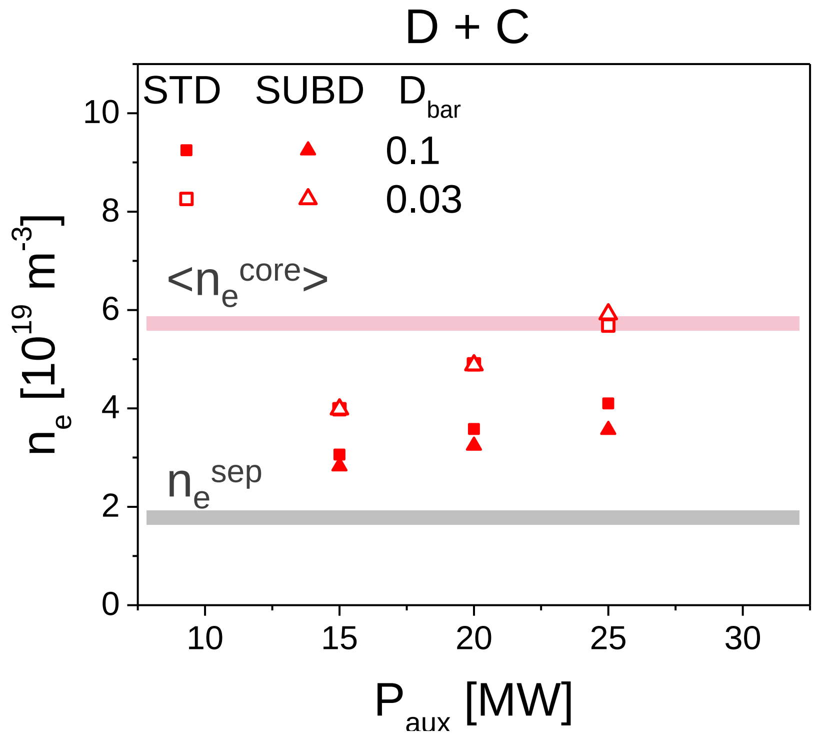


Example: STD case, P_{aux}=15MW, D_{bar}=0.03 m^2/s

D+C cases – impact of C on n_e^{sep} operational space

Midplane profiles (P_{aux}=15MW)

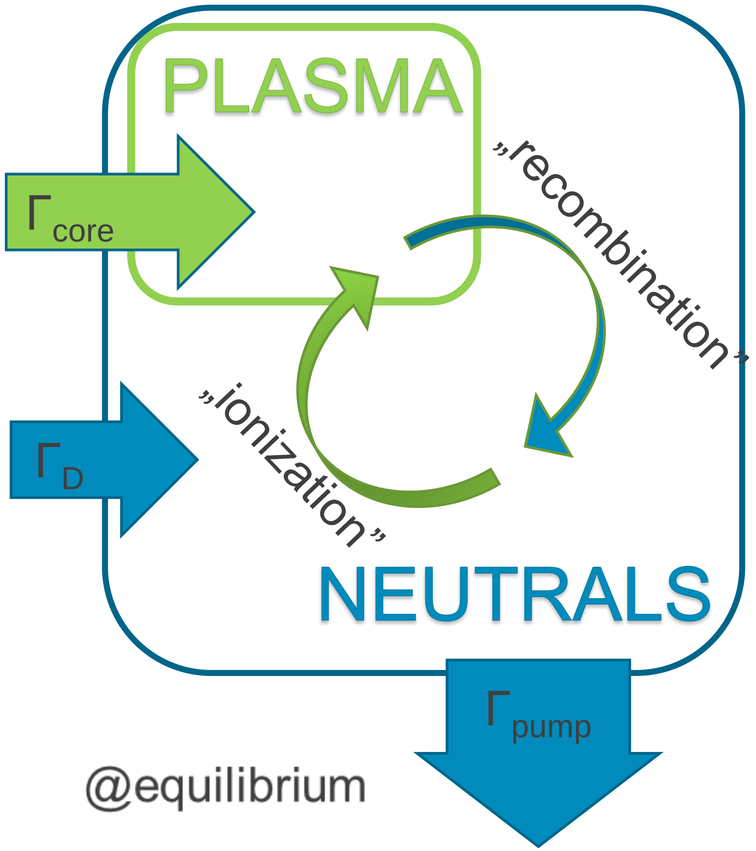




- n_e^{sep} still high, but aproaches the nominal value
- T_e^{sep} in the range of 113-117 eV

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

D+C cases – plasma fuelling mechanism



@equilibrium

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

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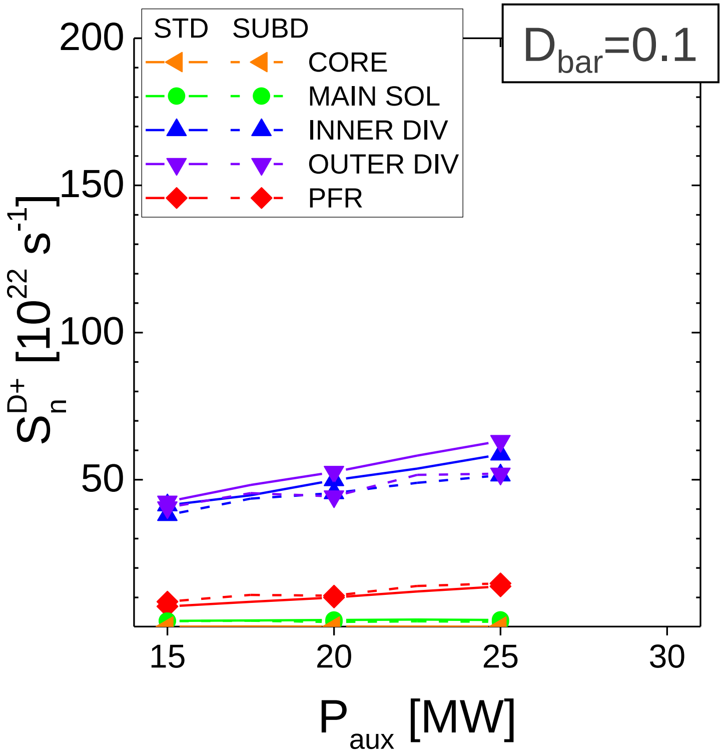
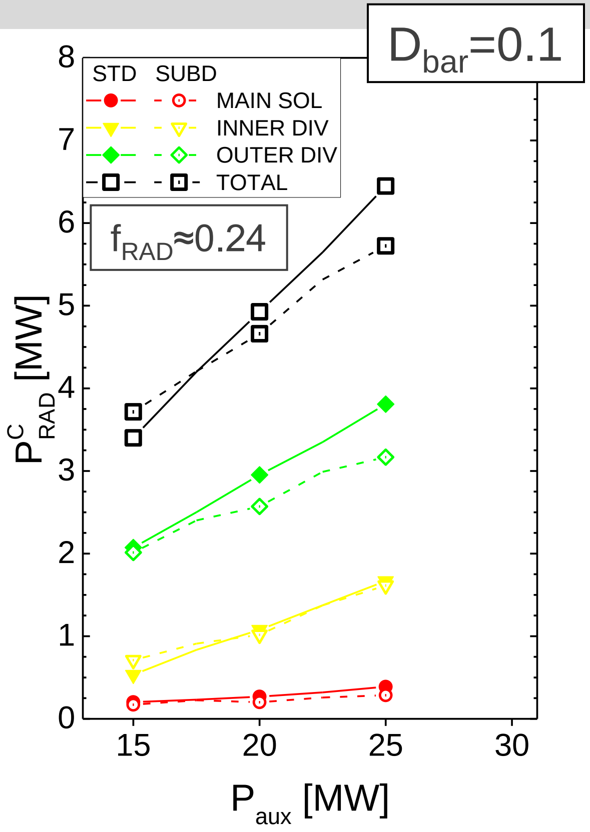
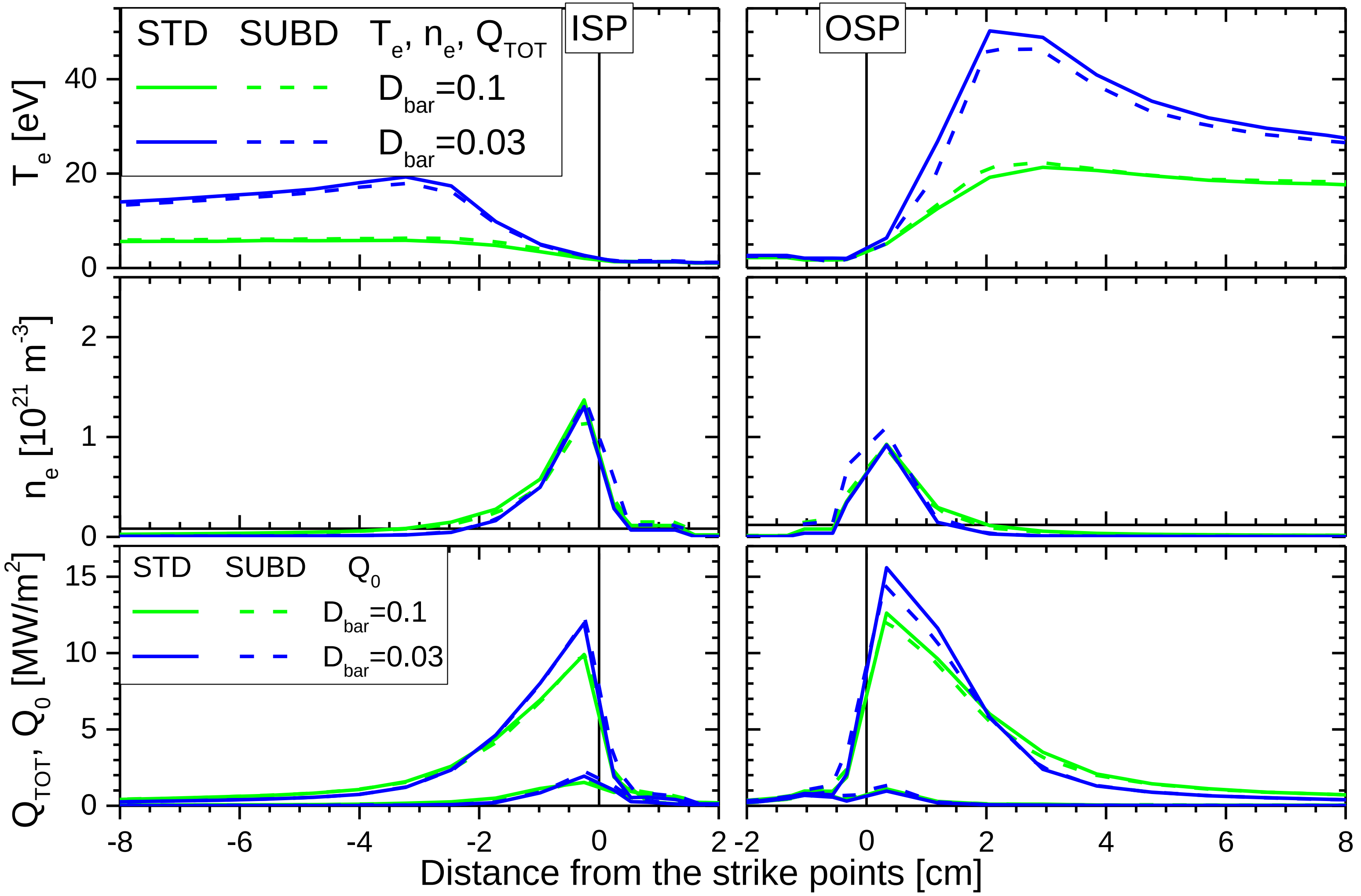




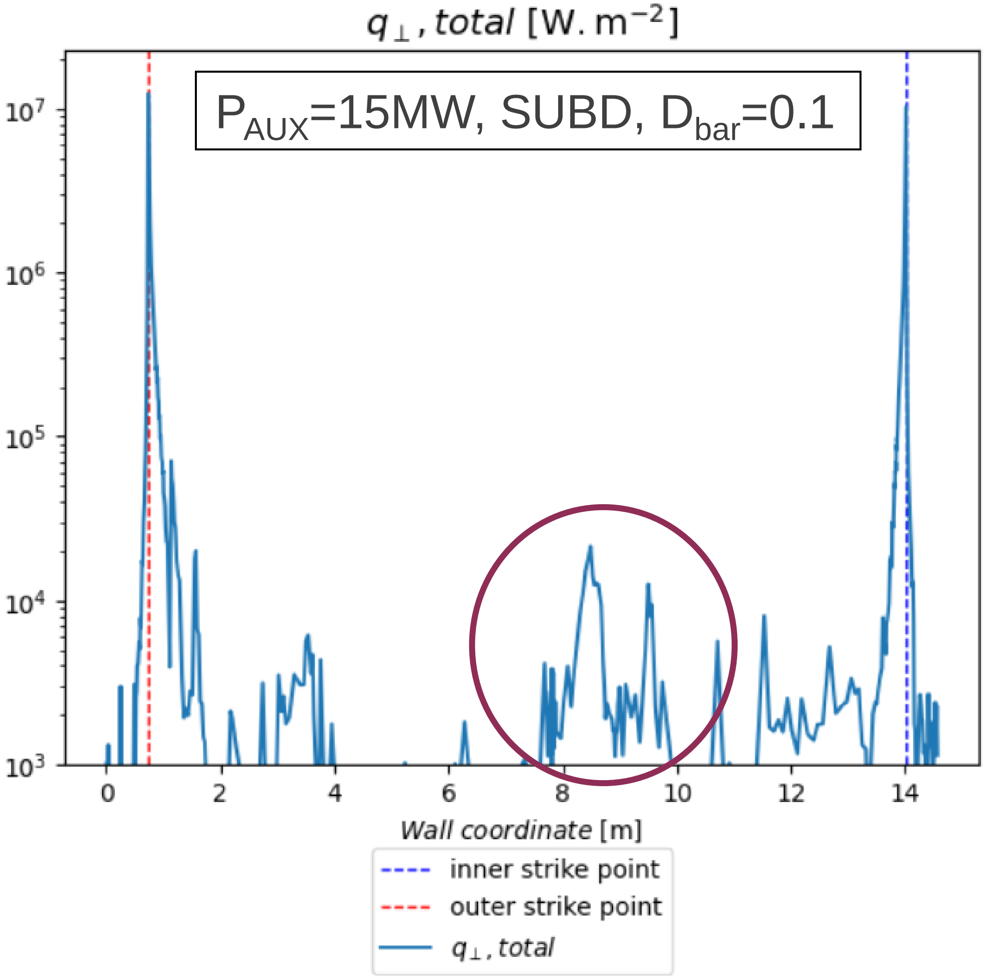
- presence of C impurity and its radiation brings the system to a different ionization-recombination balance
- due to P_{RAD} the power delivered to the ionization zone is lower
- as a result the plasma sources in the D+C case are weaker
- the resulting n_e^{sep} is much lower than in the pure-D cases

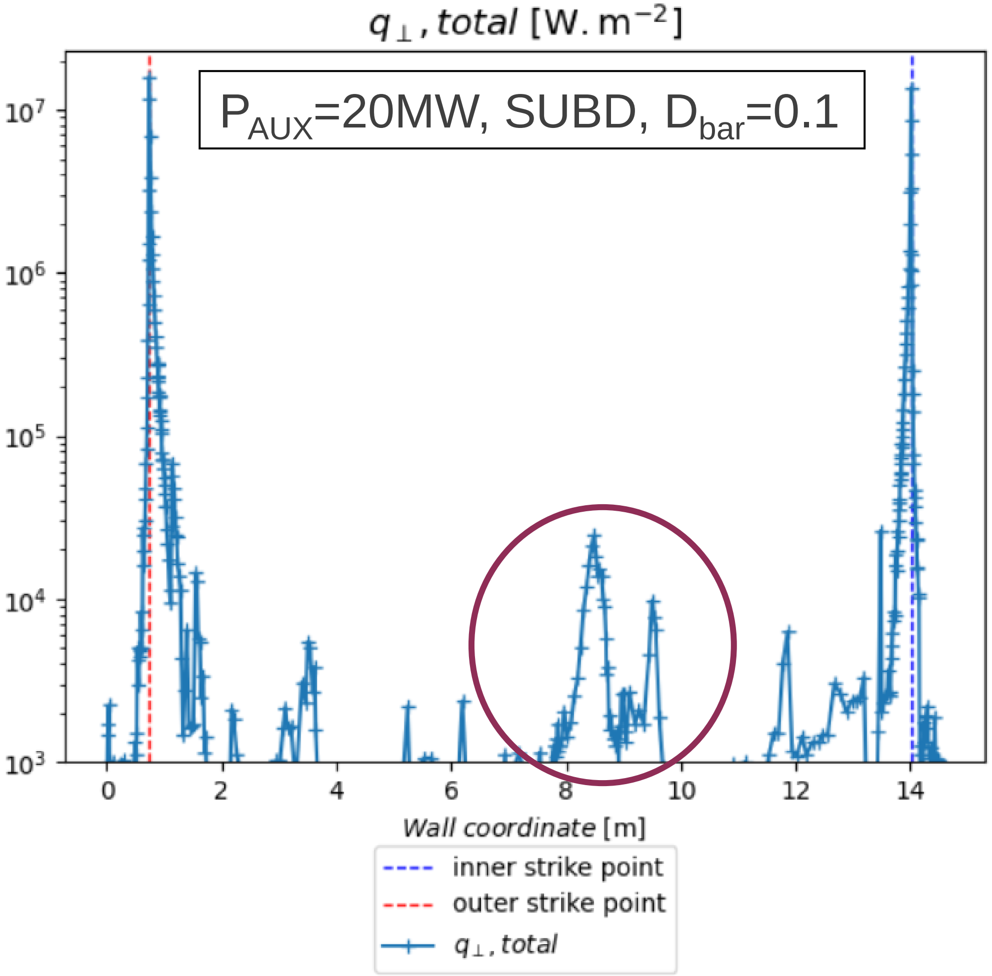
Target profiles – P_{aux} = 15 MW



- 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

D+C cases – heat load on the first wall, D_{bar}=0.1





- 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**.

Conclusions

- 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 infulence of presence of subdivertor area is assesed:
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

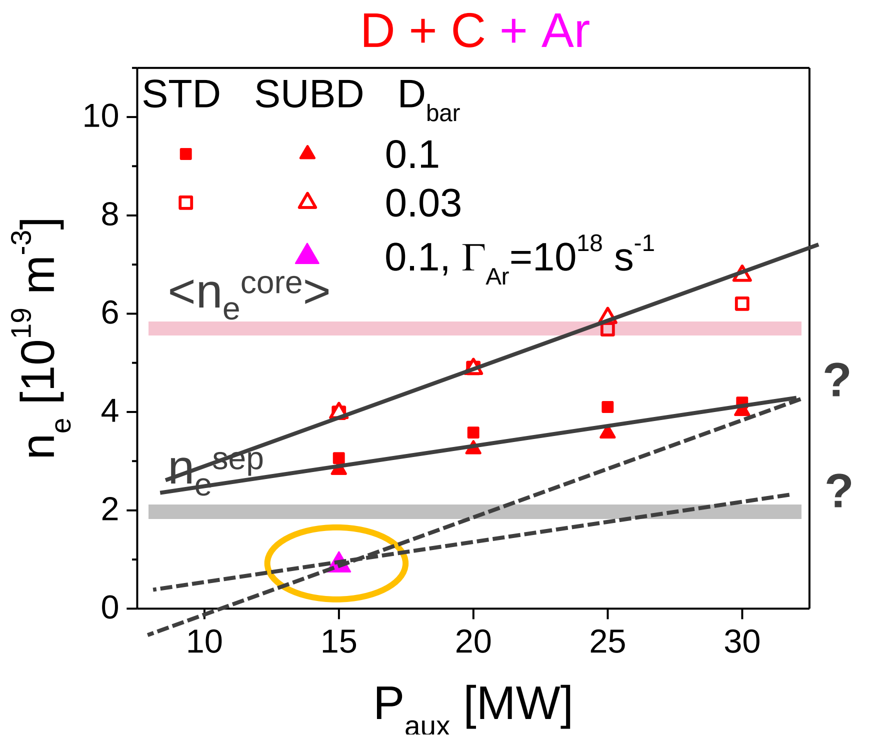
2. **diffusion coefficient in the barier D_{bar}**

The influence of different perpendicular transport is assesed:
different SOL width (λ_n= 8 mm -> 4 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 throuput 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^2) 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 Γ_{Ar} = 10^{18} s^{-1}.
- **preliminary** resluts allow anticipating that with same sources settings the designed operational regime (n_e^{sep} ~ 2×10^{19} m^{-3}) might be achieved with D_{bar}=0.03 m^2/s, P_{aux}>20MW



THE END

Integrals