PSD meeting on the transition to W PFCs in JT-60SA

JT-60SA edge modelling of scenario #2 towards W first wall transition

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Scientific objectives

Evaluate **power exhaust** and impurity concentration of JT-60SA high performance scenario (scenario 2, the most demanding for the divertor) with W first wall

1) Evaluate an operative range for some key plasma parameters for scenario 2

- $n_{e,sep}$
- C_{imp}
- Z_{eff}

That guarantees safe divertor operation

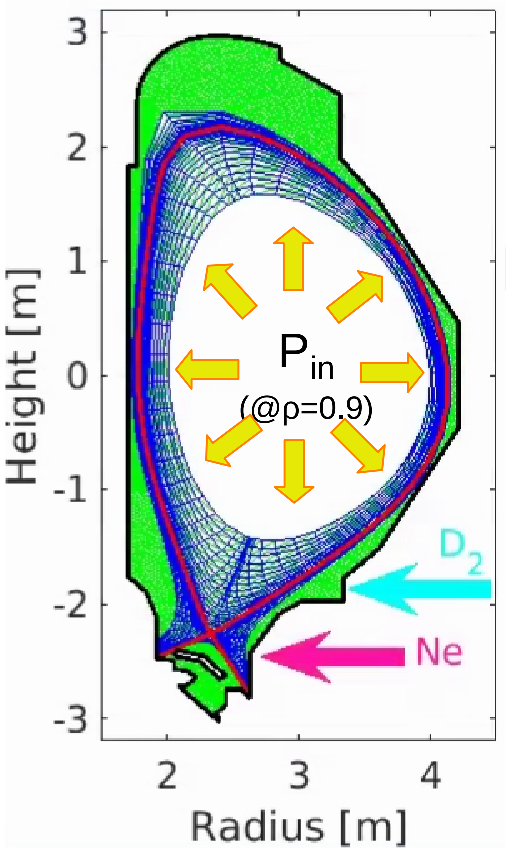
- Power flux peak below 10MW/m2
- Low $T_{e,tar}$ (<5eV in the near SOL) to reduce W sputtering

2) Doing it consistently with core modelling to evaluate the effect on plasma performances

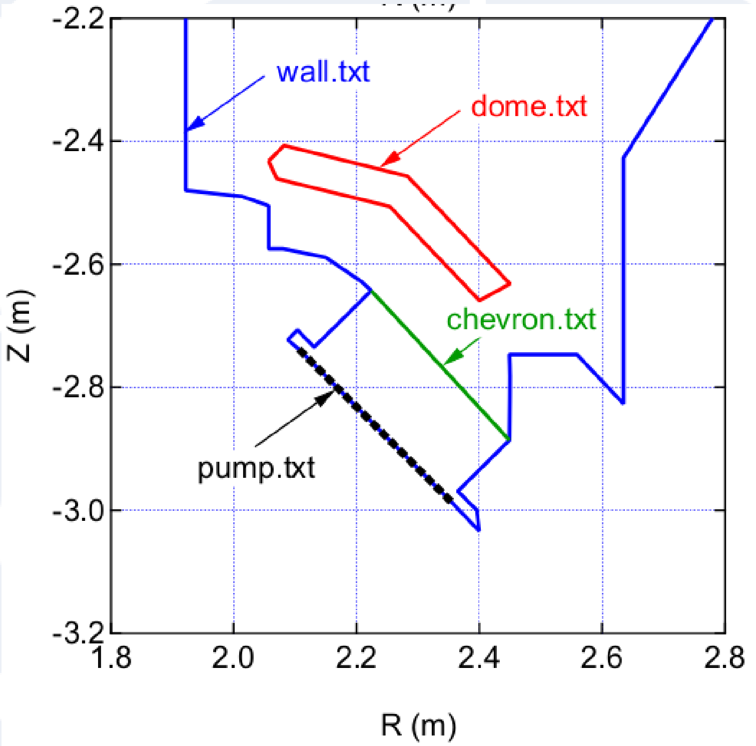
Scenario II parameters and modelling setup

Scenario #2	
R [m]	2.96
a [m]	1.17
I_p [MA]	5.5
B [T]	2.25
P_{aux} [MW]	**41 MW**
P_{in} [MW]	**20MW < P_{in} <30MW**
$\langle n_e \rangle_{sep}$ [m^{-3}]	**$2.0 \times 10^{19} m^{-3}$**
$\langle n_e \rangle_{ped}$ [m^{-3}]	$5.0 \times 10^{19} m^{-3}$
$\langle n_e \rangle_l$ [m^{-3}]	$6.0 \times 10^{19} m^{-3}$
D^+ flux [s^{-1}]	1.8×10^{21} s^{-1}
Transport parameters	Derived from experiments and scalings ($\lambda_q \approx 1.5$ mm)

Drifts not included yet



SOLPS and SOLEDGE mesh



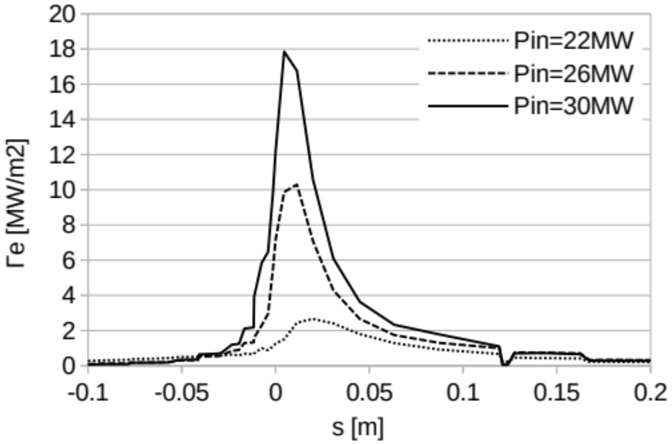
Realistic pumping and sub-divertor modelling

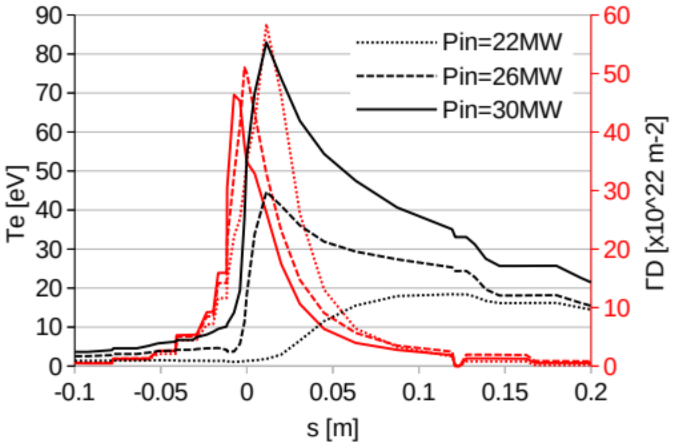
Methodology

Performed an input power scan with:

- Fixed $n_{e,sep}$ → Deuterium puffing feedback

- Feedback on impurity seeding (Ne or Ar) with the objective of achieving a given outer divertor condition
    - Detachment
    - Detachment onset
    - Reducing power flux peak to 10MW/m^2





Compare input parameters (transport parameters, power and particle fluxes, impurity concentration) with core modelling and iterate the process

Main results in Ar seeded case

Input power scan: **P(ρ=0.9) = 20, 22, 26, 30 MW**

Two target densities

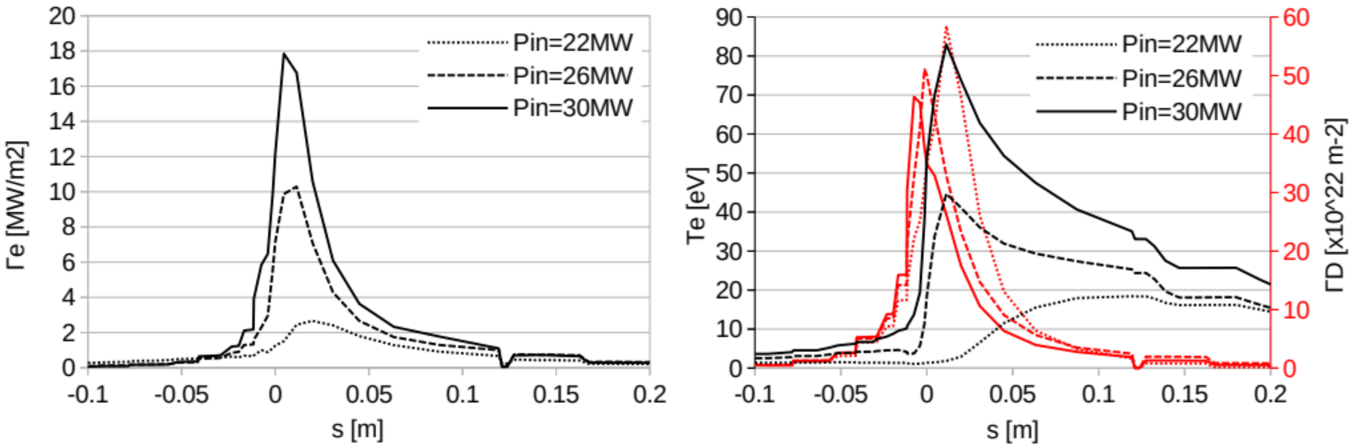
- **$n_{e,sep}$ = 2.0x10^{19}m^{-3}**
- **$n_{e,sep}$ = 3.0x10^{19}m^{-3}** (high value → it has consequences on scenario performances)

Two target condition

- **Roll-over** (Technological/physical constraint on **W sputtering**)
- **power flux** peak compatible with technological constraints **(~10MW/m^2)**

Main results: it is difficult to achieve detachment

- The impurity concentration required to achieve roll-over is higher than that required to reduce power flux peak below 10MW/m^2 (with both densities and both impurities)
- W erosion is a major concern: **detachment threshold is most stringent limit**
- **Power flux peak is not a major concern** (easiest limit to achieve)



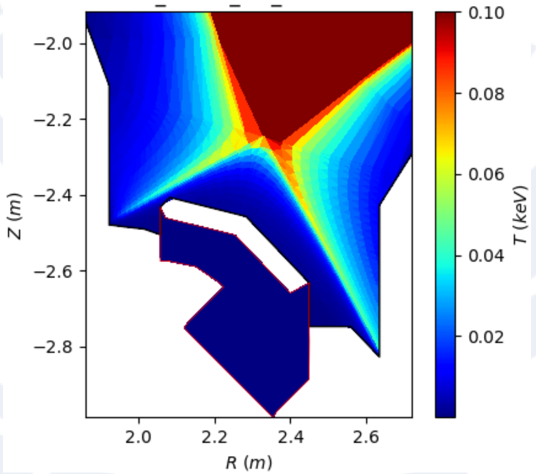
$P_{wall,part}=P_{in}-P_{rad}$ tells us the max. amount of power we can allow particle to deposit to the first wall

$P_{wall,part}$~4-6MW when roll over had to be achieved

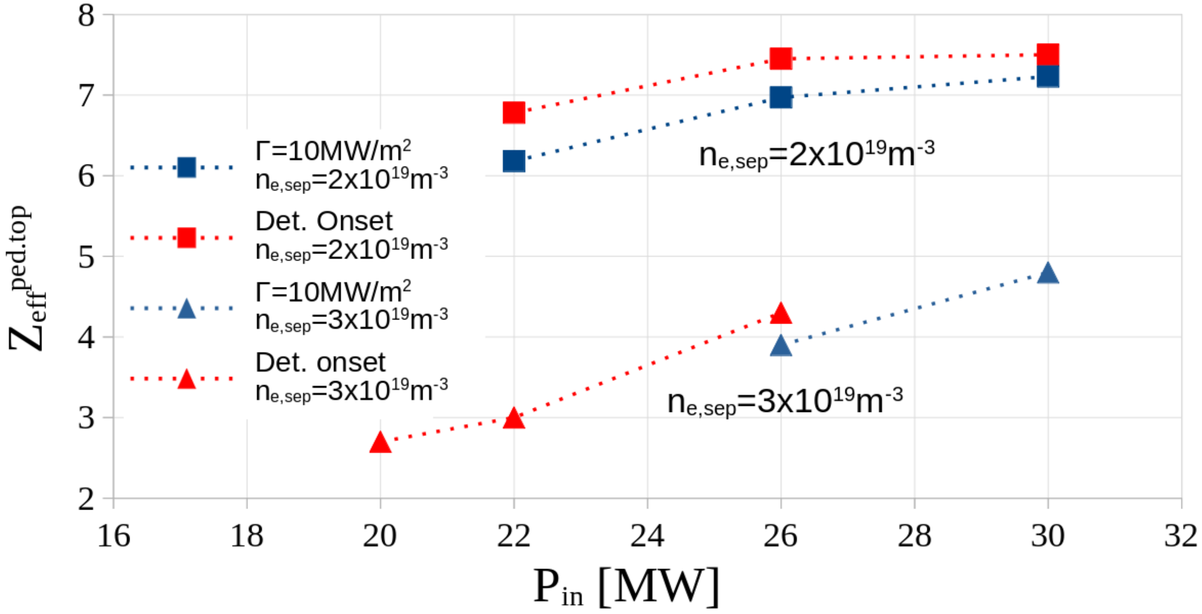
$P_{wall,part}$~8-10MW when the power flux constraint had to be met

High power scenarios will be operated with high radiated power fraction: **$f_{RAD,TOT}$>80%** to meet this requirement

High inner/outer target asymmetry even without drifts



Main results: higher density is required for det. onset

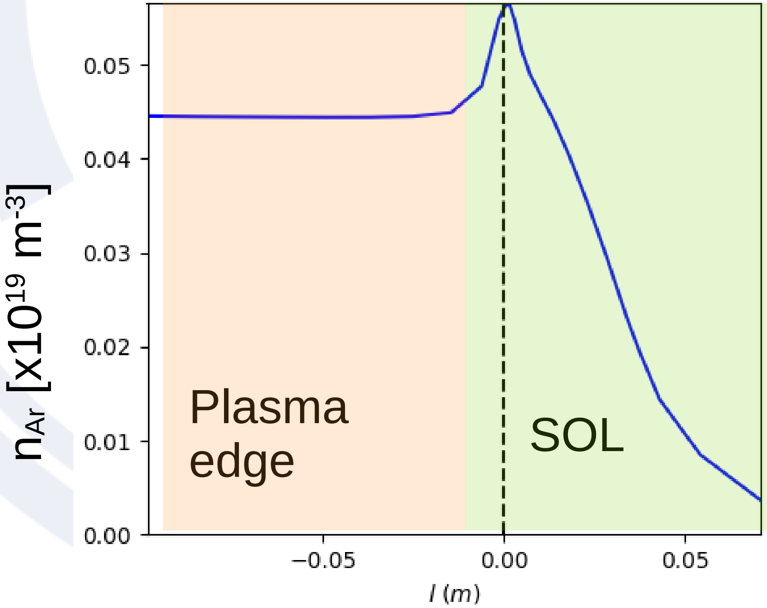


P_{in} = edge code input power = P(rho=0.9)

- The impurity concentration required to operate at low density is not unrealistic
- At higher density, the impurity concentration required is more reasonable
- P_{LH}~15MW so we are well above the threshold in all cases

Modelling limits: we are not considering possible **pinch** effect that would guarantee **impurity screening**; we also can’t estimate core radiation.

- In our simulations $Z_{eff}^{ped,top}$ ~ Z_{eff}^{sep} which is our real requirement to achieve a target detachment treshold
- We need to be able to estimate <Z> and $Z_{eff}^{ped,top}$

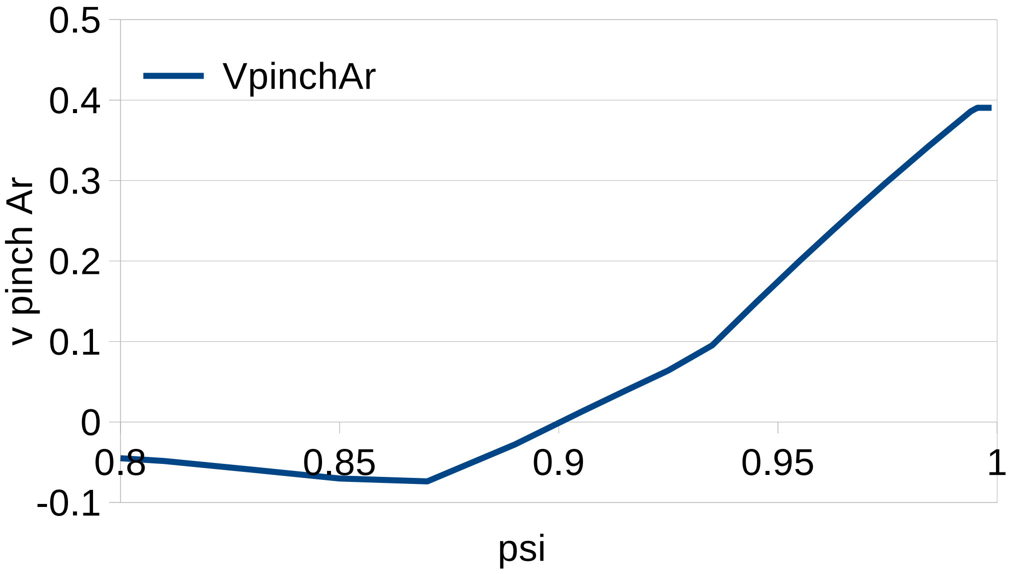


Core modelling results

We provided some inputs to JETTO and COCONUT modellers (S. Gabriellini and R. Cicioni) to find a common solution with matching input/output and profiles

- $n_{e,sep} = 3x10^{19}m^{-3}$
- $T_{e,sep}$=150eV, $T_{i,sep}$=230eV
- <Z_{eff}> (2/3 points scan)
- C_W
- ….

- A strong pinch effect was found between 0.9<rho<1.0
- The intensity of the pinch effect depends on the assumptions made in the pedestal model → started from the most conservative assumption
- More on core modelling from S. Gabriellini and R. Cicioni in dedicated presentations

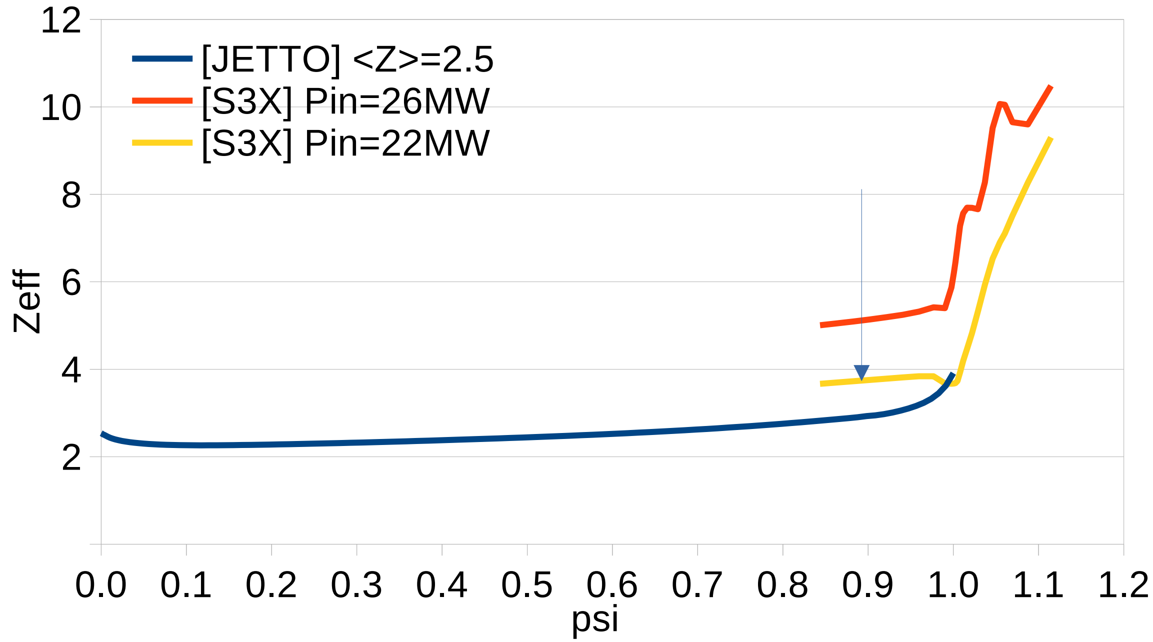


Transport parameters assumed in edge modelling were in good agreement with those derived from core modelling → similar value at the pedestal (within 10% difference)
→ different pedestal width →t.p. changed in SOLEDGE simulations to match JETTO's

SOLEDGE simulations are ongoing

Pinch effect has been included in S3X simulations

- Ar reducing in confined region
- Simulations converging



These are not final results, simulations converging

In new simulations $Z_{eff}^{ped\text{-}top} < Z_{eff}^{sep}$ and we are converging to a common solutions. **Roll-over** conditions are achieved in SOLEDGE by controlling puffing

Power flux not matching yet

Zeff in profile in S3X corresponds to JETTO's with <Z> but with a much lower power flux

- $P(\rho=0.9)$ [JETTO]=35MW
- $P(\rho=0.9)$ [S3X]=22MW

We decided to run JETTO with higher <Z> → cases running

This discrepancy in steady state condition can also be justified with dE/dt in the inter-ELM phase (7/10MW in JET high current high power seeded pulses)

Open conclusions

- **Power exhaust is a <u>critical issue for scenario performances</u>: high radiated fraction and high impurity concentration are required.**
  - High power exhaust removal capabilities are not required, not a critical issue even if working with high grazing angle (°5).
  - **Detachment is a critical issue for scenario performances**. Higher $n_{e,sep}$ ($>2.5\times10^{19} m^{-3}$) is probably required even if performance loss is foreseen, alternatively P_{aux} should be reduced.
  - Assessment of detachment onset conditions should be crucial during OP2-OP3
  - Power flux to the entire first wall were profided to F4E
    - Possible outer divertor re-shape is being considered
- W sputtering and transport should be addressed to assess both core plasma contamination by W and divertor erosion rates (compatible with component lifetime?)
- We are converging to a common integrated solution

Thank you for your attention

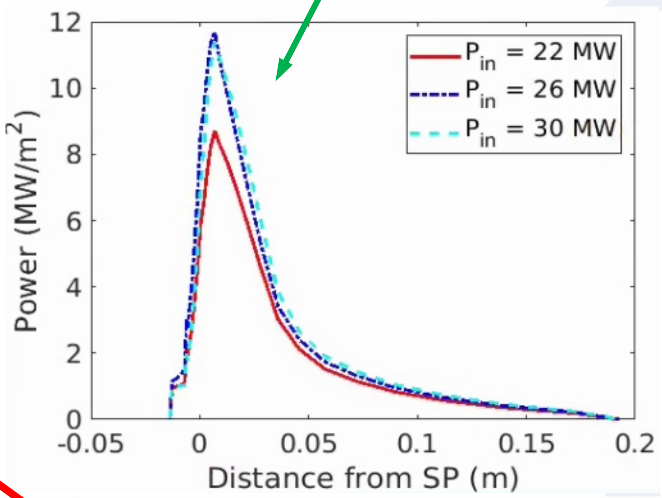
Ne seeding – power flux limit

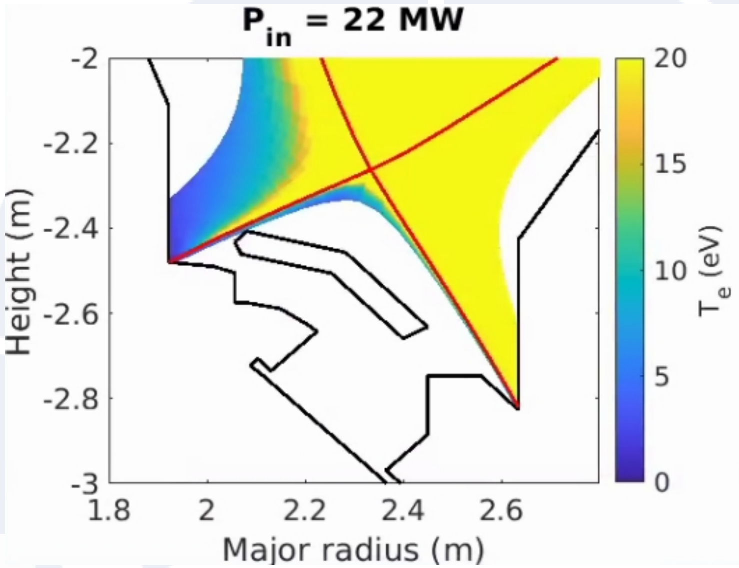
Seeding control: impurity seeding increased until **power flux peak** is below **10MW/m²**

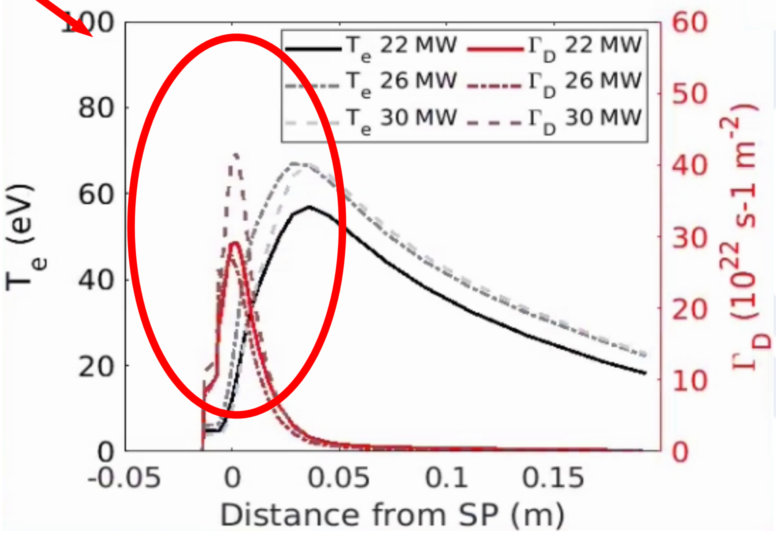
Input power scan was performed

Power flux limit can be reached with $f_{rad,SOLPS}$~50% - $\mathbf{f_{rad,tot}}$**=70/75%**

- $P_{OT} < 10\ MW/m^2$
- $T_{e,OT}$ still too high and plasma attached
- Prescribed $n_{e,sep} \sim 2\times10^{19}\ m^{-3}$ (core initial request) is challenging also in terms of sputtering issue







NOT IDEAL

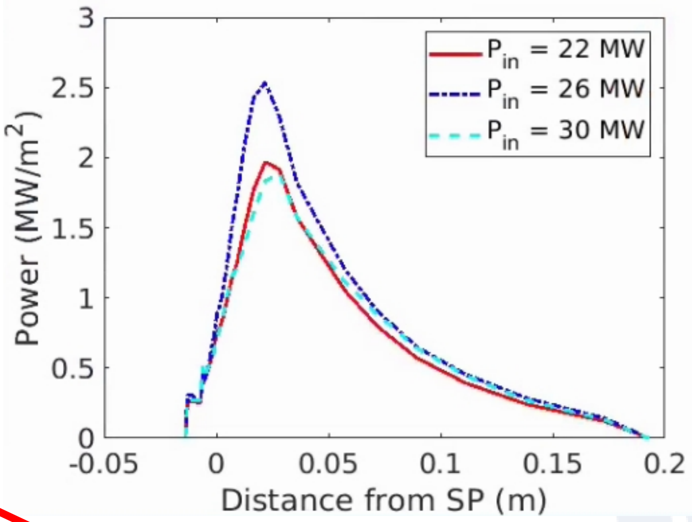
SOLPS-ITER

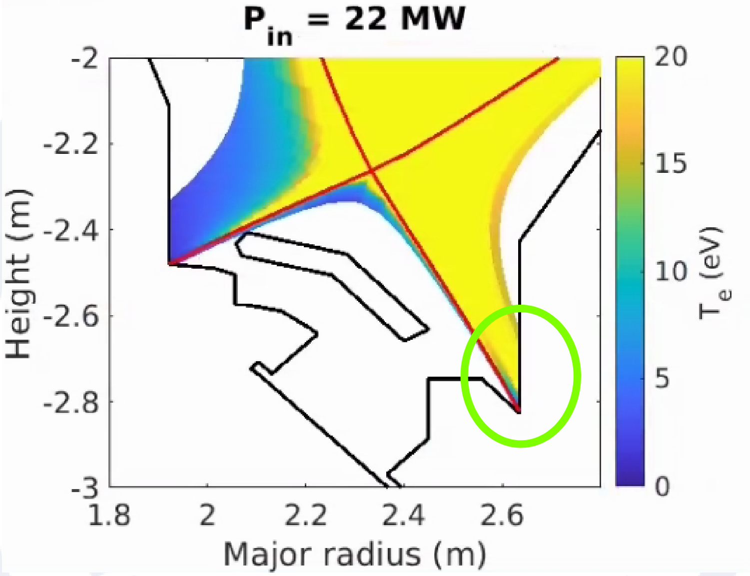
Ne seeding – detachment onset

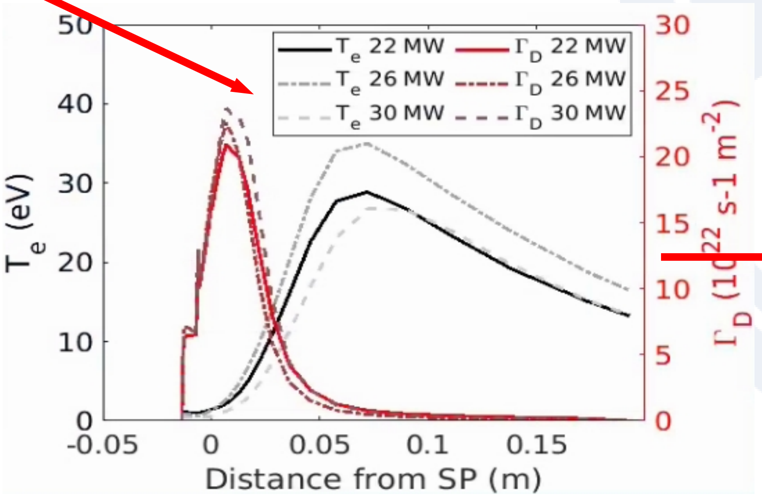
Seeding control: increase impurity to achieve **detachment onset**

Input power scan was performed
Detachment onset achieved with $f_{rad,SOLPS}$>65% **- $f_{rad,tot}$>80%**

- Low P_{OT} and decrease in $\Gamma_{D,max}$
  - ➢ **detachment onset**
- **$T_{e,max,OT}$ moves towards far SOL**
  - ➢ Low Γ_D
- W sputtering and transport is the limiting factor, this issue should be addressed







SAFER
(Actually unsafe)

Compatible with core performances?

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Spare slides

Heat flux decay length scan

- What if λ_q is larger than predicted by scalings?

case	$\chi_{i,sep}$ [m2/s]	$\chi_{e,sep}$ [m2/2]	**λ_q [mm]**
1 (std.)	0.295	0.34	**1.4**
2	0.45	0.50	**2.0**
3	0.59	0.68	**2.3**

(Eich scaling)

Roll-over is obtained with P_{in}=26MW

Fixed $n_{e,sep}$ and plasma purity=66%

- P_{in} = 26MW
- $n_{e,sep} = 3\times10^{19} m^{-3}$
- $n_{D,sep} = 2\times10^{19} m^{-3}$
- $n_{Ar,sep} = 5.6\times10^{17} m^{-3}$

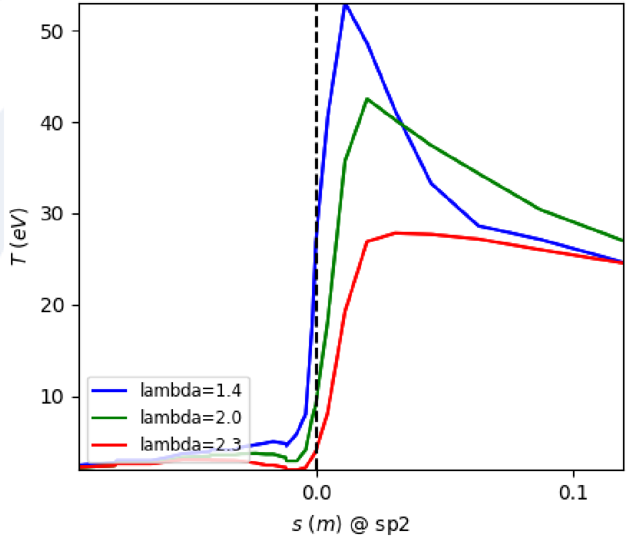
Larger λ_q is beneficial, detachment can be achieved with lower $\mathbf{f_{rad}}$ but still **>70%**

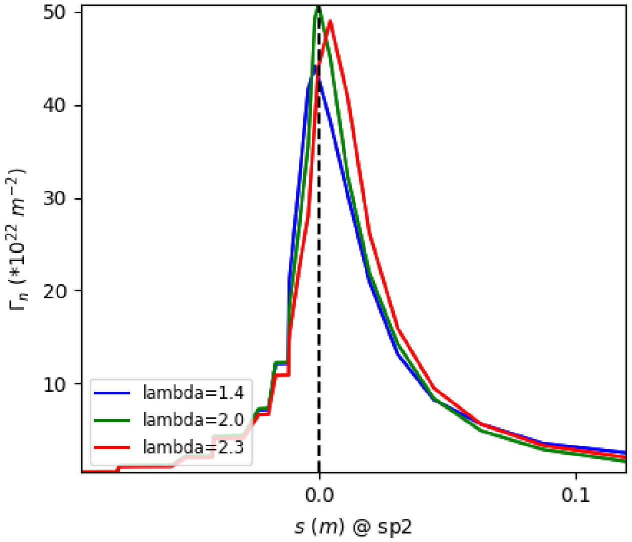
AND

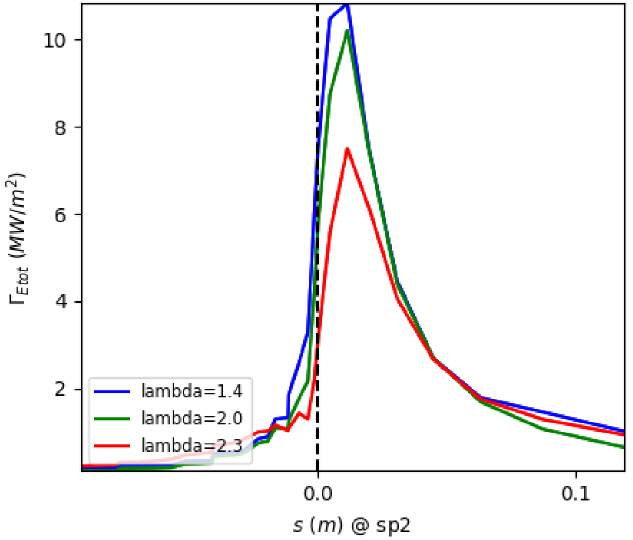
the same behaviour is observed: power flux is not a major issue, *detachment* is

- Sputtering estimations are highly recommended
  - ERO2
  - IMPGYRO
  - ....

SOLEDGE-EIRENE



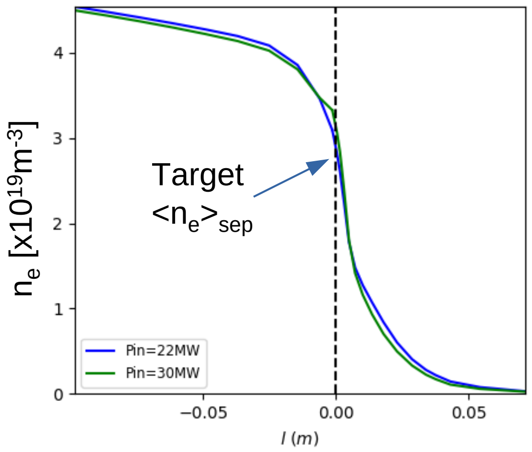




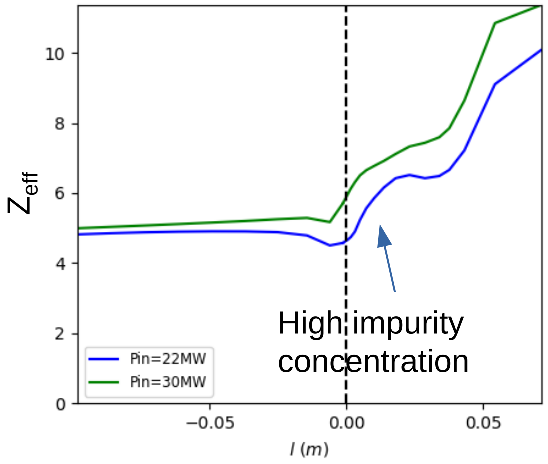
Power exhaust is a critical issue…

… and there may be some consequences on machine performance

Radial outer mid-plane profiles



Target $\langle n_e \rangle_{sep}$



High impurity concentration

- Sustainable divertor conditions were obtained with **higher $\langle n_e \rangle_{sep}$** and with **high impurity concentration**

➢ What is the effect of transport parameters?

Ne seeded case – main results

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MAIN RESULTS

- High power scenarios will be operated with high radiated power fraction: **$f_{RAD,TOT}$>80%**
- Power flux peak is not a major concern (easiest limit to achieve)
- W erosion is a major concern: **detachment threshold is most stringent limit**

$P_{\rho=0.9\ (in.\ bound.)}$	**22 MW**		**26 MW**		**30 MW**	
Tech./phys constr.	Power flux (~10MW/m^2)	Sputtering (det. onset)	Power flux (~10MW/m^2)	Sputtering (det. onset)	Power flux (~10MW/m^2)	Sputtering (det. onset)
$n_{e,sep,OMP}$ (10^{19} m^{-3})	2.0	2.0	2.0	2.0	2.21	2.2
$T_{e,peak,OT}$ (eV)	56.9	28.9	66.9	35.97	66.8	26.6
$P_{peak,OT}$ (MW/m^2)	8.7	1.96	11.7	2.53	11.4	1.88
P_{OT} (MW)	3.8	1.25	4.74	1.51	4.81	1.2
$P_{rad.SOLPS}$ (MW)	12.04	16.5	14.1	17.5	16.25	20.8
$f_{rad,\ TOT}$	76%	**87%**	70%	**79%**	66%	**78%**
$\langle Z_{eff}\rangle_{ped,top}$	6.18	6.78	6.97	7.5	7.23	7.45