EUROfusion

Design of the divertor and power exhaust scenarios development for the Divertor Tokamak Test facility

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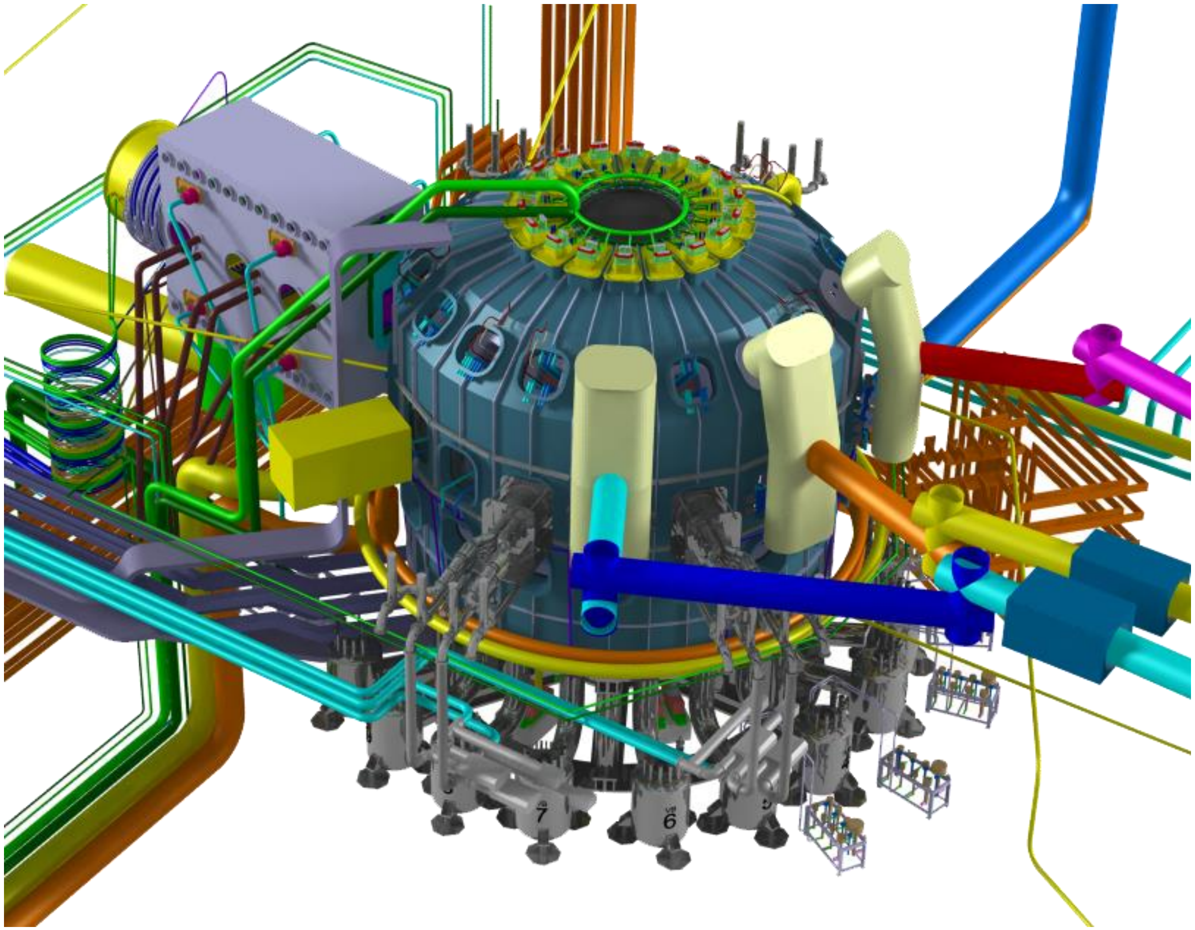
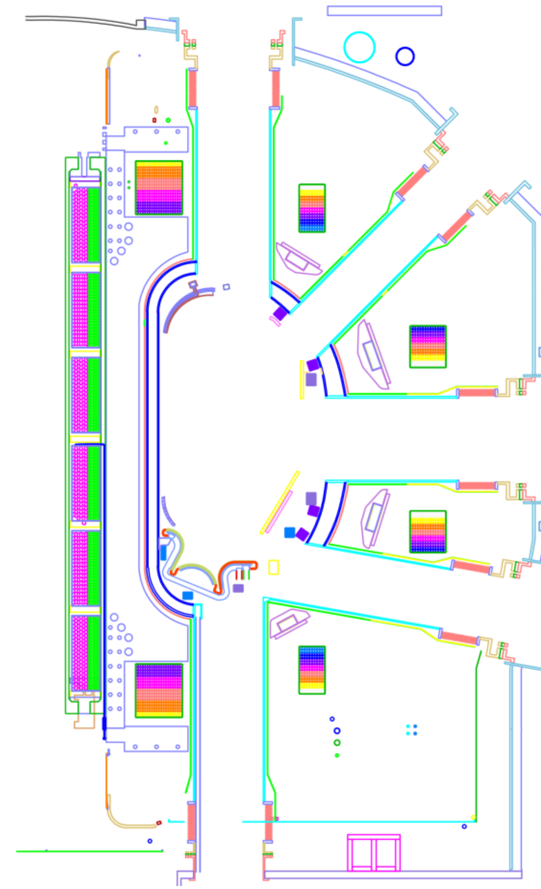
4th Technical Meeting on Divertor Concepts

Divertor test tokamak (DTT) facility





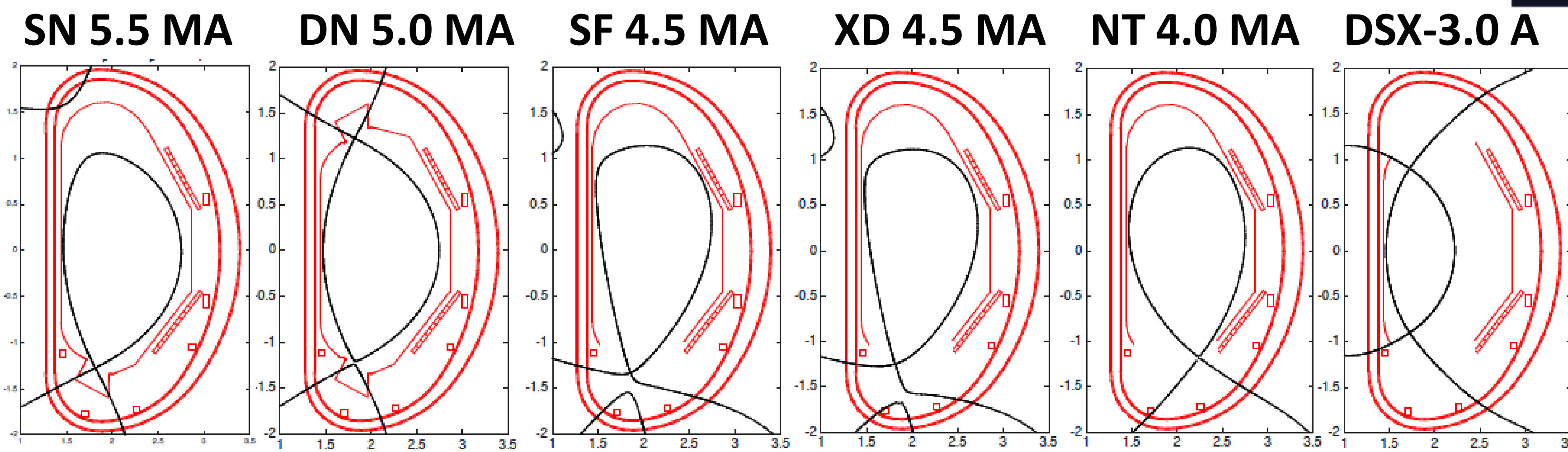
DTT is presently in construction in Italy with the main aim to study power exhaust solutions for DEMO

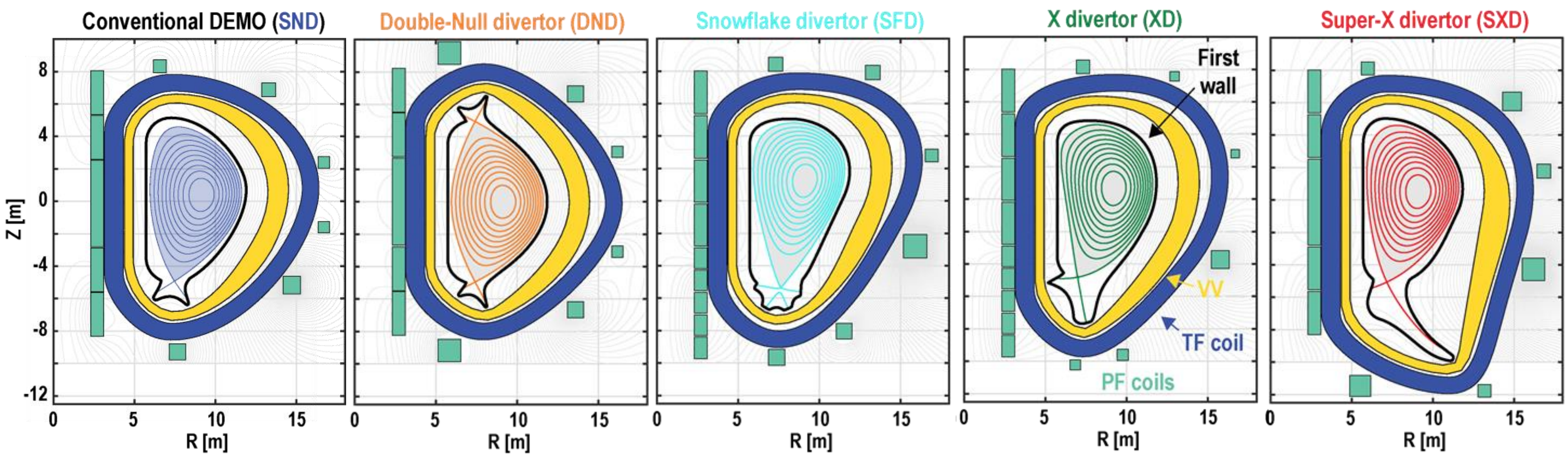
DTT and power exhaust parameters

		AUG	JET	JT60-SA	DTT	ITER	DEMO
	R (m)	1.65	3.0	2.93	2.19	6.2	9
	a(m)	0.5	1.0	1.14	0.69	2.0	2.9
	Ip (MA)	1.6	4	4.6	5.5	15	17.75
	B_T (T)	3.1	3.45	2.28	6	5.3	5.86
	Vp (m^3)	13	80	122	28	853	2218
	<n> (10^{20} m^{-3})	1	1	0.9	1.8	1.0	0.8
	P_{Tot} (MW)	27	40	35	45	150	450
$q \propto P_{SOL}$	P_{SOL} (MW)	22	32	25	35	**120**	**170**
$A_t \propto 1/R$	P_{SOL}/R (MW/m)	13	11	9	**16**	**19.3**	**18.8**
$\lambda_q \propto B^{0.77}$	P_{SOL}B/R (MW*T/m)	40	37	20	**96**	**102**	**110**
	τ_E (s)	*	*	0.48	0.43	8.5	3.4
	<T> (keV)	2	5	3.5	6.2	8.5	12.7
	β (%)	*	*	4.4	2.2	2.2	2.5
	ν*(10^{-2})	*	*	4.1	2.4	2.4	1.4
	ρ*(10^{-3})	*	*	3.2	3.7	1.7	1.5

DTT power exhaust parameters are close to the ones of ITER and DEMO

DTT and DEMO ADCs





DTT magnetic system can realize all foreseen Alternative Divertor Configurations considered for DEMO

But how to design the first divertor to test most of them?

The path towards the DTT divertor shape

1. Requirements, assumption, constraints and fundamental choices for divertor design
2. Development of divertor shape
3. Comparison with reference standard shape
4. Compatibility with pumping
5. Analysis of different effects
6. Shape selection

Requirements and Assumptions

- **Compatible with following magnetic configurations: SN, XD and NT (not a priority)**
- **Compatibility with the PF coil system**, power supply and controllability
- Flexible for experimental exploitation at plasma relevant parameters ➔ **wide range in terms of X-point and strike points positions**
- **Full power operation (P_{ADD}=45 MW)** with about 1/3 of the power dissipated in the core (based on core modeling)
- Density controlled by gas-puffing and pumping **(negligible core particle flux from NBI 10 MW @ 510 keV)**
- Power crossing separatrix higher than minimum requested for H-mode operation in positive triangularity **(no X-point radiation configuration)**

- ❑ **ELMs not considered in modeling** but average ELMs power (5 MW) subtracted from stationary heat flux
- ❑ **Transport in agreement with Eich scaling** with radial profiles as in present devices

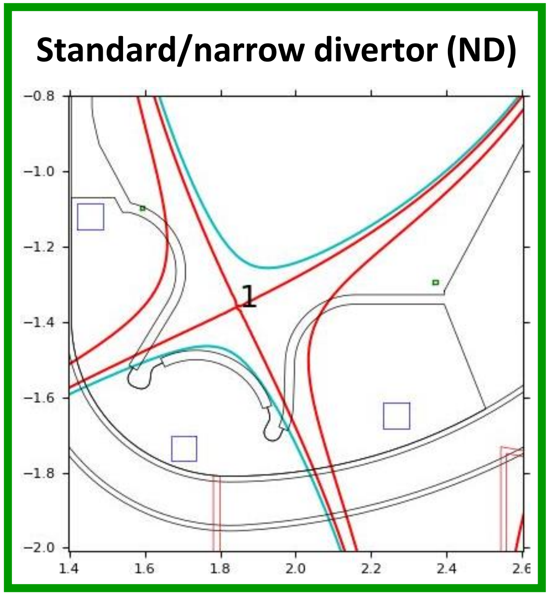
Constraints and fundamental choices

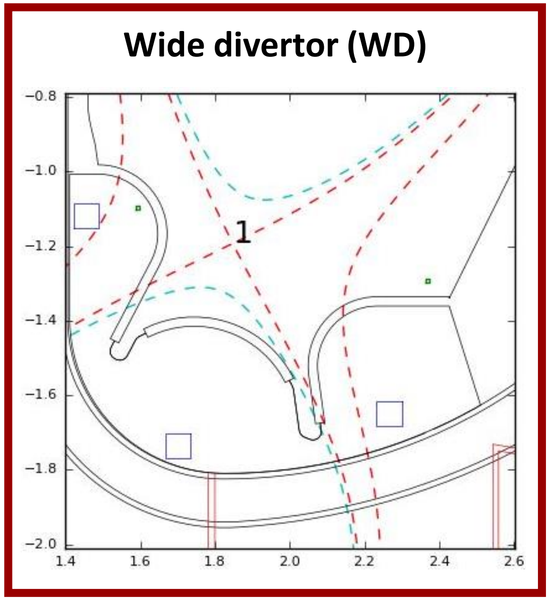
- All PFUs (IVT, OVT and DOME) are in **tungsten actively cooled**
- **Minimum bending radius** (of the plasma facing surface in W) **~ 190 mm** - manufacturing constraint [see G. Dose et al. "An overview of the conceptual design of the plasma-facing components of the DTT divertor" poster]
- **Cooling pipes must be shielded** from parallel plasma heat flux and possible strike points movements

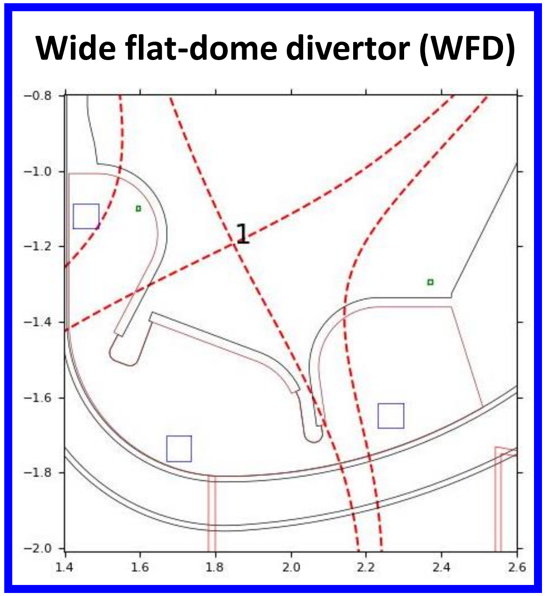
- Inner board and outer board **grazing angle 2°** for reference SN configuration, smaller angle possible for XD configuration
- **Dome can accommodate strike points**
- **Pumping speed 100 m^3/s** and pumping slots between vertical targets and "central dome"

From divertor shape definition to optimization

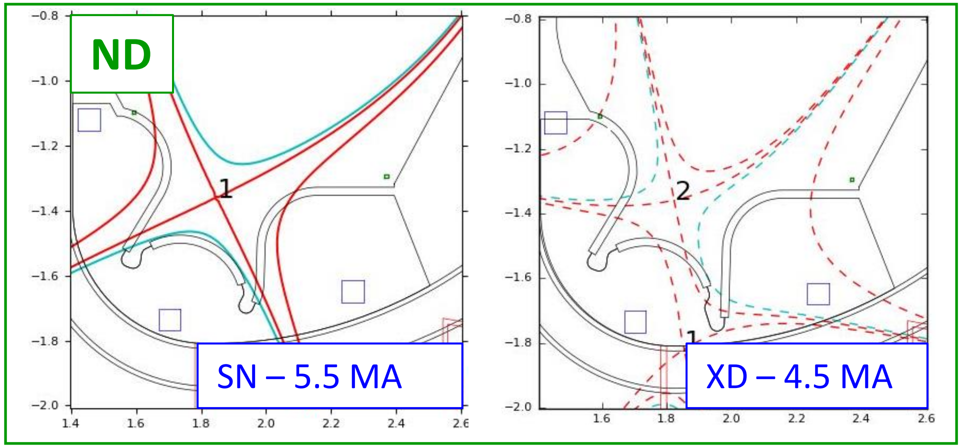
1. Definition of different divertor shapes compatible with constraints and fundamental choices
2. Definition of reference (and additional) magnetic configurations
3. Selection by comparison between shapes and a reference standard shape
4. Divertor shape optimization



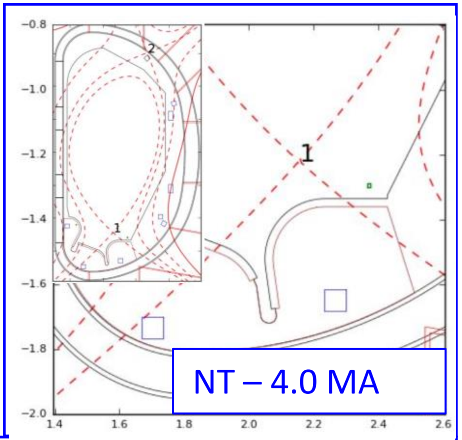




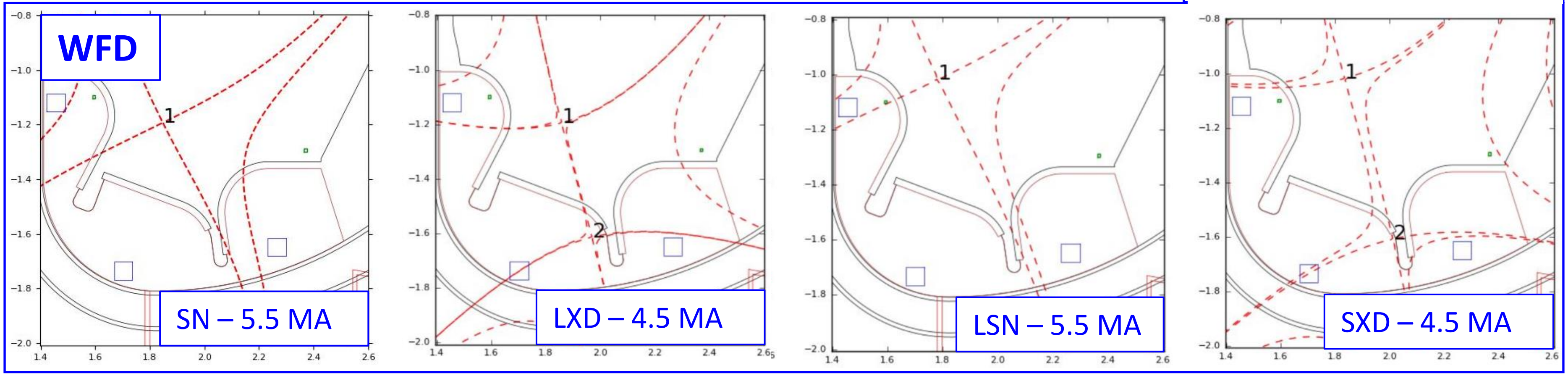
Divertor selection - comparing narrow and wide



A set of magnetic configurations have been produced for all divertor shapes using coils external to the vessel



- **The ND has parameters similar to present DEMO divertor design**
- **The WFD allows configurations with long external legs (LSN & SXD)**
- **The WFD with an appropriate wall allows negative triangularity configurations**



Divertor parameters

SN configuration

Device	L_{IT}/R_x	L_{OT}/R_x	α_{IT}	α_{OT}
DTT (ND)	**0.09-0.15**	**0.15-0.17**	**2.0°**	**1.9°**
DTT (WFD)	**0.07-0.14**	**0.24-0.34**	**1.6°-2.0°**	**2.0°-2.3°**
DEMO	0.15	0.21	1.5°	1.6°
ITER	0.19	0.20	3.2°	2.7°
JT-60SA	0.21	0.29	5.6°	3.5°

- Narrow divertor is similar to **(present)** DEMO divertor in terms of **legs length** and **grazing angle**
- Wide divertor can test a **wide range of leg lengths**
- In general grazing angle is in between ITER and DEMO

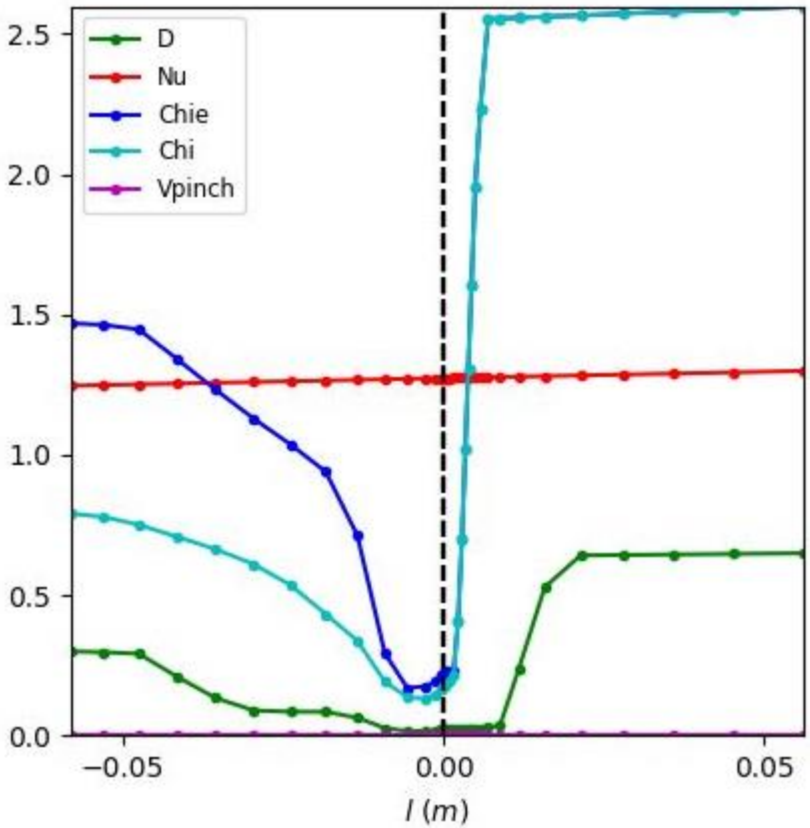
XD configuration

Divertor	L_{IT}/R_x	L_{OT}/R_x	α_{IT}	α_{OT}
DTT (ND)	**0.09-0.11**	**0.11-0.14**	**0.6°**	**0.0-0.2°**
DTT (WFD)	**0.10-0.11**	**0.10-0.25**	**1.1°-1.2°**	**0.3°-0.6°**

Assessment of divertor performance

1. **Edge modeling of a representative set of magnetic configuration:**
   - SN in pure D power scan with P_{SOL}=3.5÷25 MW with five different divertors and different transport parameters and with sub-divertor modeling
   - XD in pure D power scan with P_{SOL}=3.5÷8 MW with five different divertors
   - NT in pure D power scan with P_{SOL}=4÷8 MW with three different divertors
   - SN scan in neon and argon seeding at full power P_{IN}=30 MW with four different divertors and different transport parameters (a few cases), with sub-divertor and variation in transport parameters
   - XD scan in neon seeding at full power P_{IN}=30 MW with four different divertors
   - NT scan in neon seeding at full power P_{IN}=30 MW with two different divertors
2. **Comparison of performance with the narrow divertor**
3. **Gas puffing and top pedestal density estimation – core/edge integration**

Modelling methods and edge code



Transport profiles

1. Transport parameters [*]:
   a) based on **heat flux decay length $\lambda_{q,u}$≈1.5 mm** for the SN in attached condition in agreement with Eich scaling;
   b) Profiles **from JET/C-Mod** experiments modelling;
   c) Two options for divertor region
   d) Equal **for SN, XD and all divertor shapes**
2. Seeding with **neon** and **argon**
3. Fixed **pumping speed S=100 m³/s** ➔ gas-puffing adjusted to achieve target separatrix density
4. **Not considered drifts and neutral-neutral collisions**
5. **SOLEDGE2D-EIRENE** 2D edge fluid/kinetic code
6. Targets:
   - **same separatrix density**
   - **about same radiation (with seeding)**
   - **H-mode condition ➔ P_{SOL}≥18 MW**

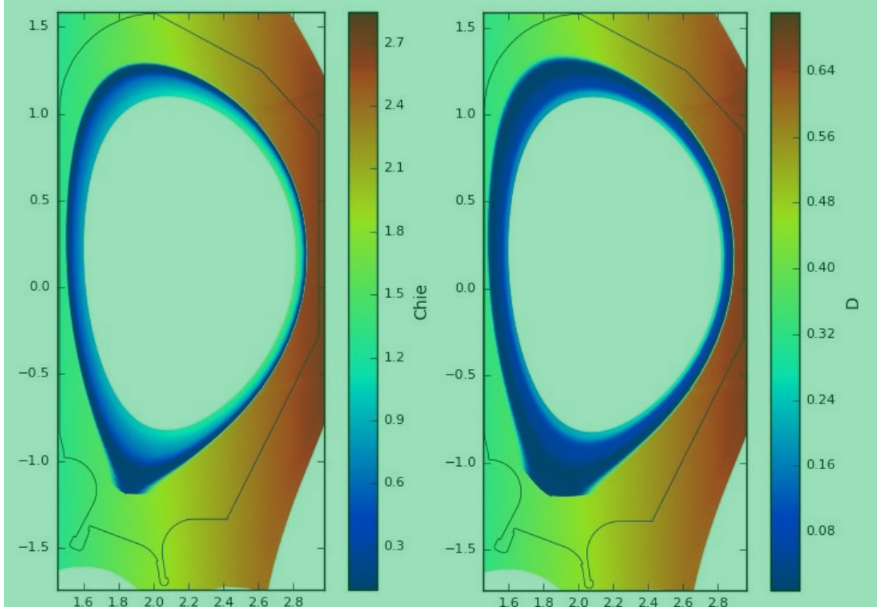
[*] L. Balbinot et al. PSI 2022

2D transport parameters map

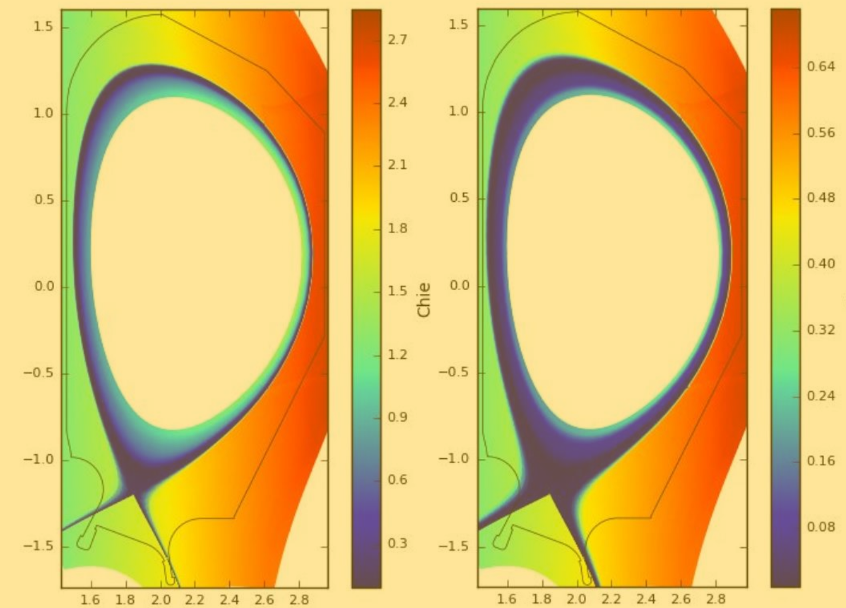
Transport parameters have been normalized to B_t

Two options for the divertor region:

1. Value as in the OMP far SOL (as in the JET/C-Mod modeling)
2. Values like at OMP



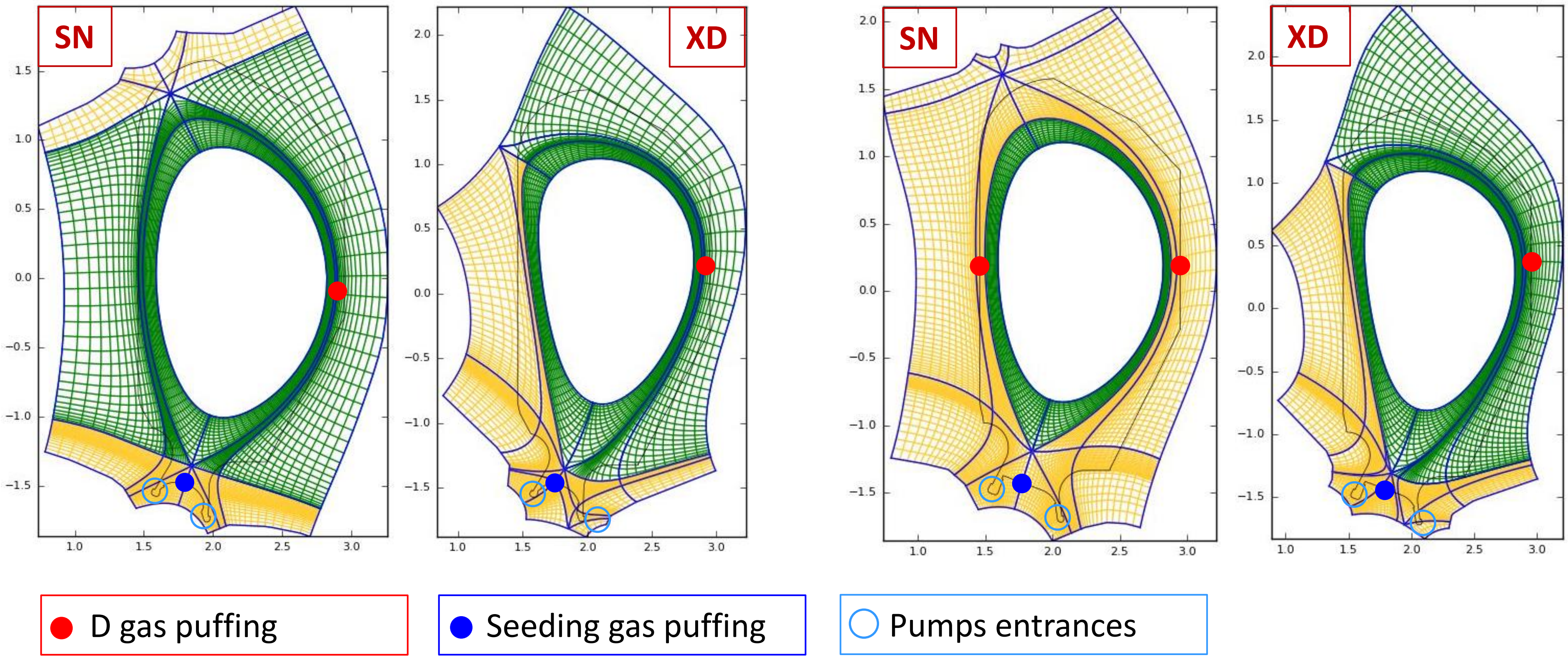
Transport in divertor region as at the OMP far SOL



Transport in divertor region like at OMP

Fluid meshes for base configurations

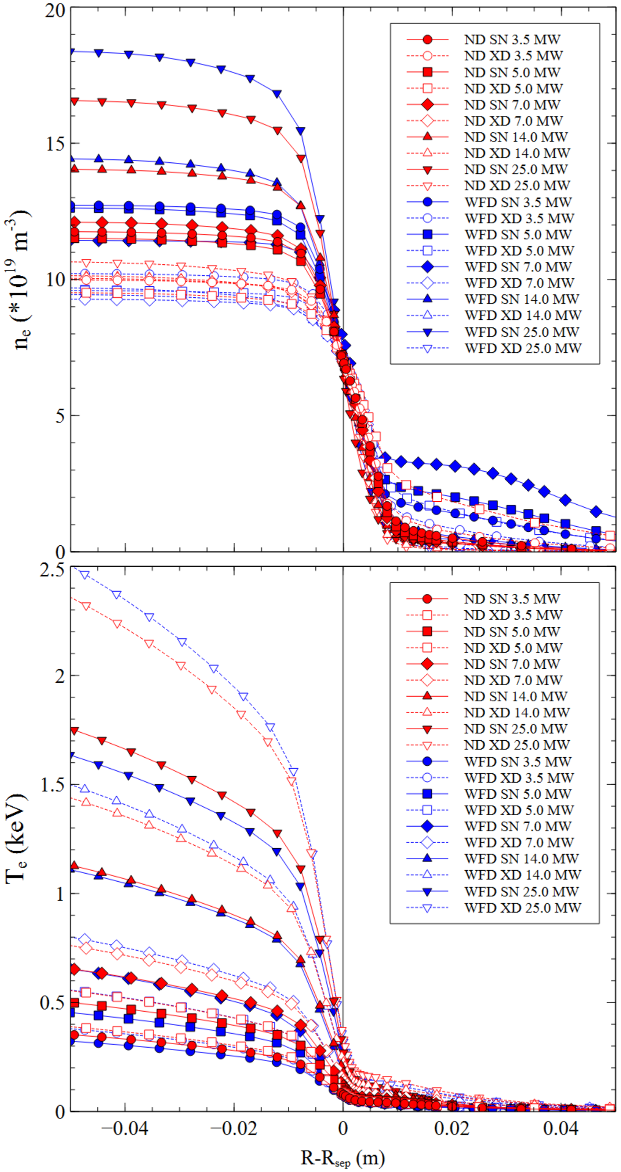
D gas puffing from outer mid plane, few cases also from high field side
Seeding always from top of the dome
Puffing adjusted to achieve separatrix density and detachment/radiation fraction



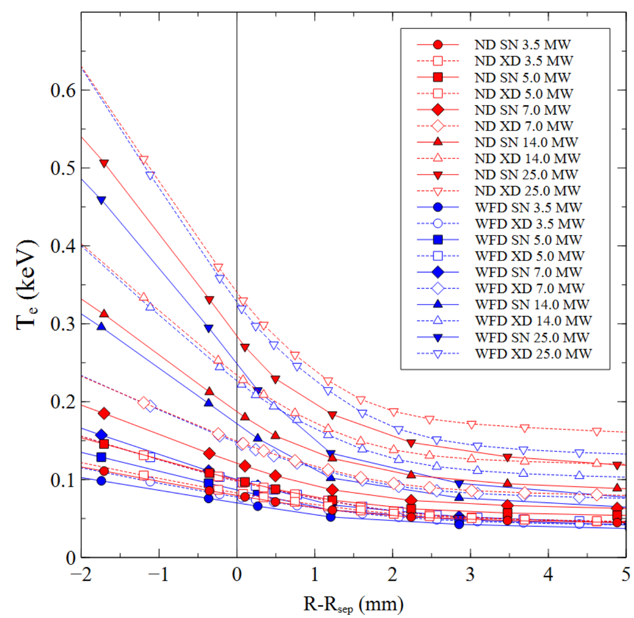
P_{SOL} scan in pure deuterium

- To provide an indication on allowed maximum heat flux for detachment
- To provide a starting point for seeded modeling
- To provide an indication on pumping efficiency

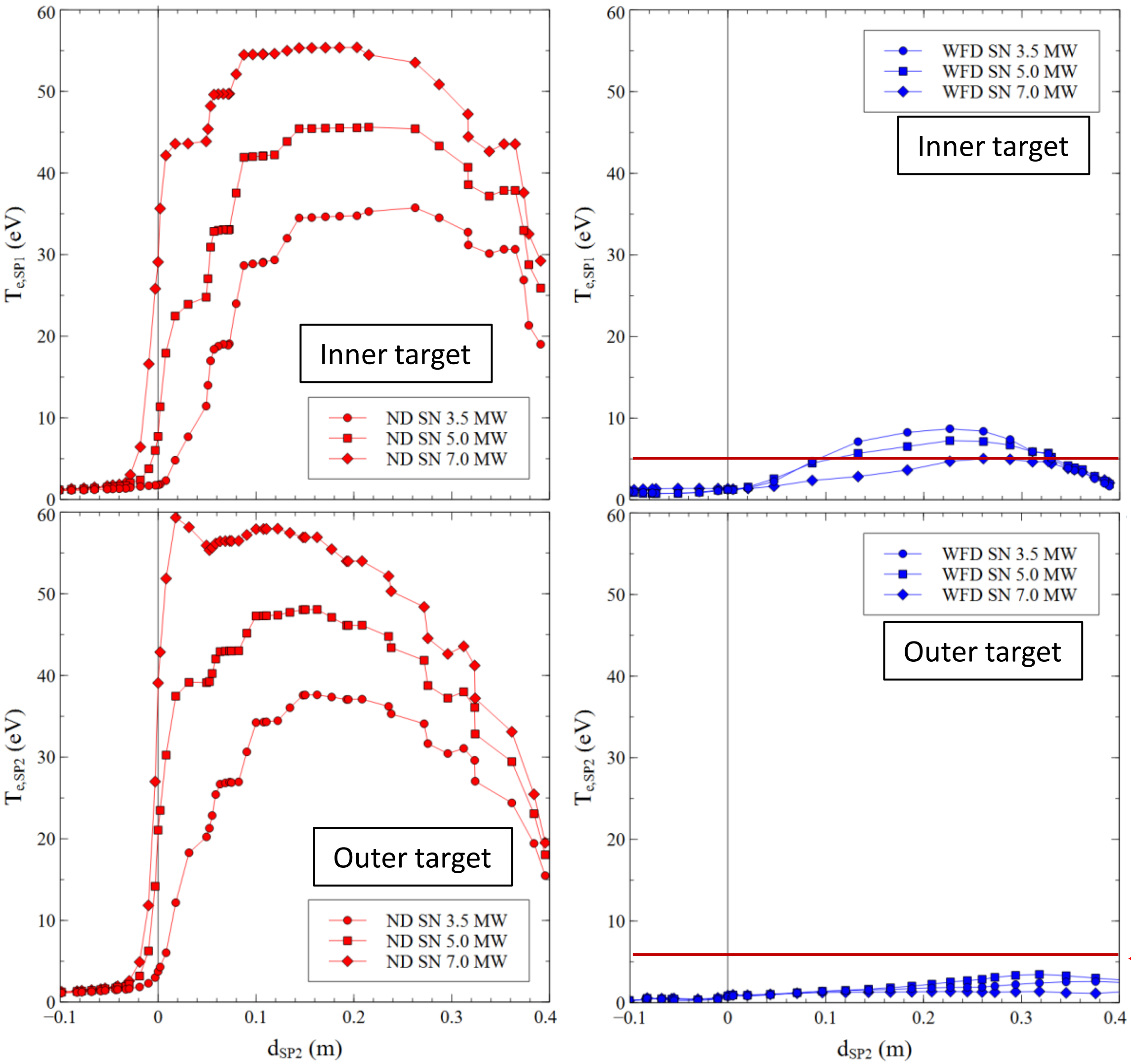
Profiles at outer mid-plane P_{SOL}=3.5-25 MW



- **Same separatrix density**
- Different top pedestal density (higher/lower pumping efficiency ➔ higher/lower gas-puffing)
- Highest top density in SN
- Lowest density in XD (open markers) ➔ low pumping efficiency due to strike points far from pumps slots
- Higher top temperature in XD due to lower density
- Higher separatrix temperature in XD due to longer connection length



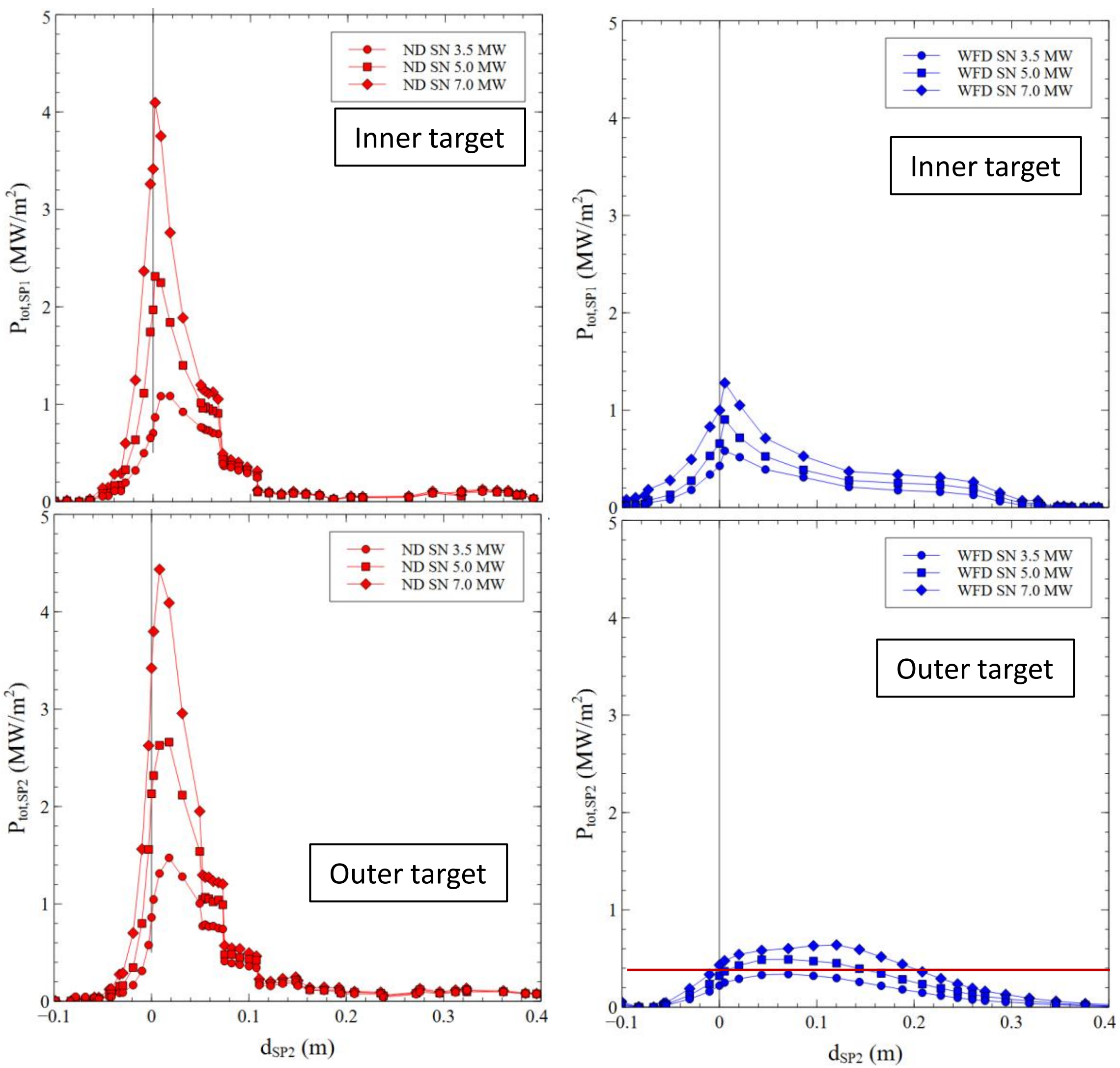
SN: profiles at targets / temperature



In pure D with the wide divertor detachment is obtained below P_{SOL}≈7 MW at $n_{sep}=7\cdot10^{9}$ m^{-3}

Detachment threshold

SN: profiles at targets / heat flux



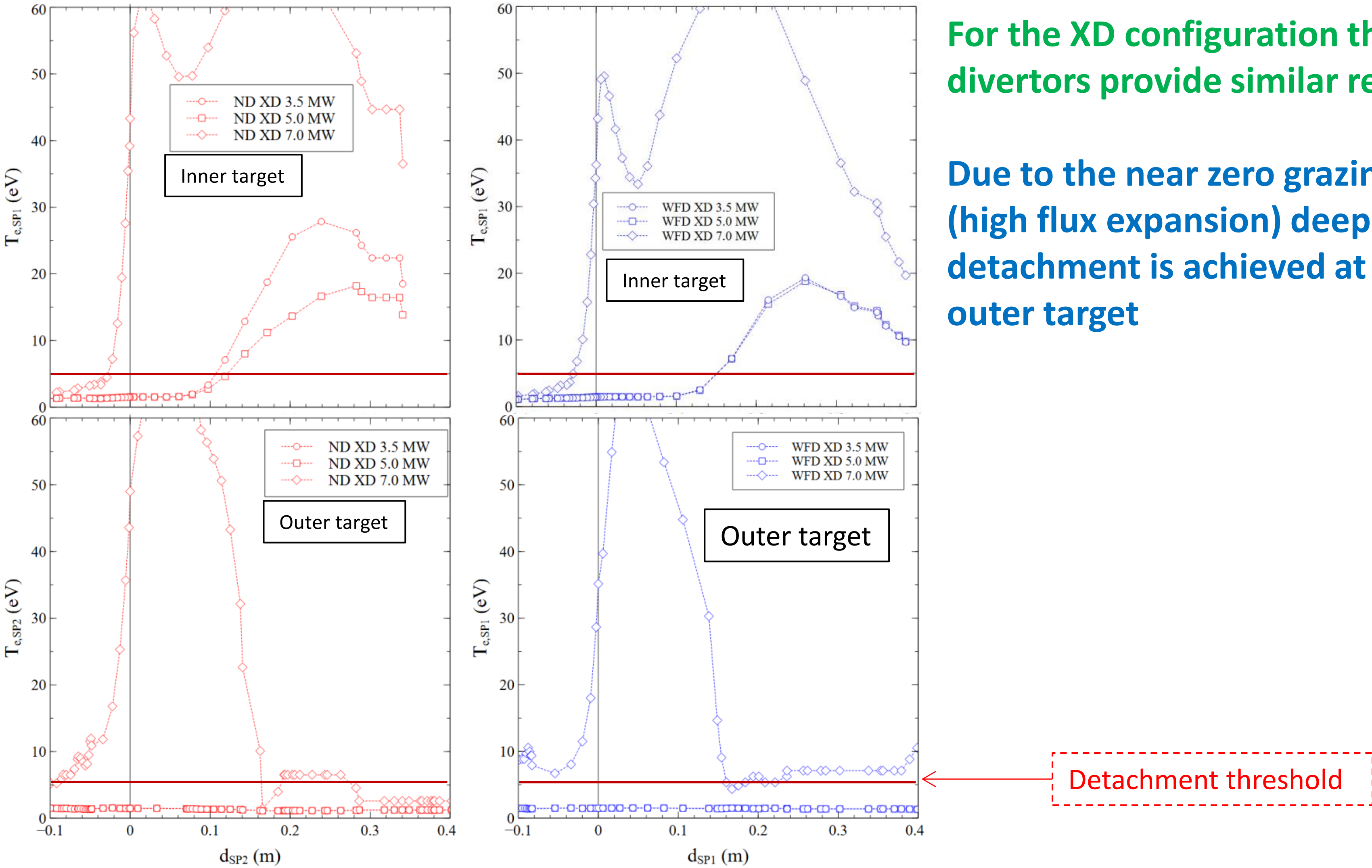
In pure D with the wide divertor detachment is obtained below P_{SOL}≈7 MW at $n_{sep}=7\cdot10^{9}$ m^{-3}

Peak heat flux is well below 10 MW/m^2

Similar conditions at both targets (but drifts not included)

The standard divertor provides worst performance ➔ higher temperatures and peak heat fluxes

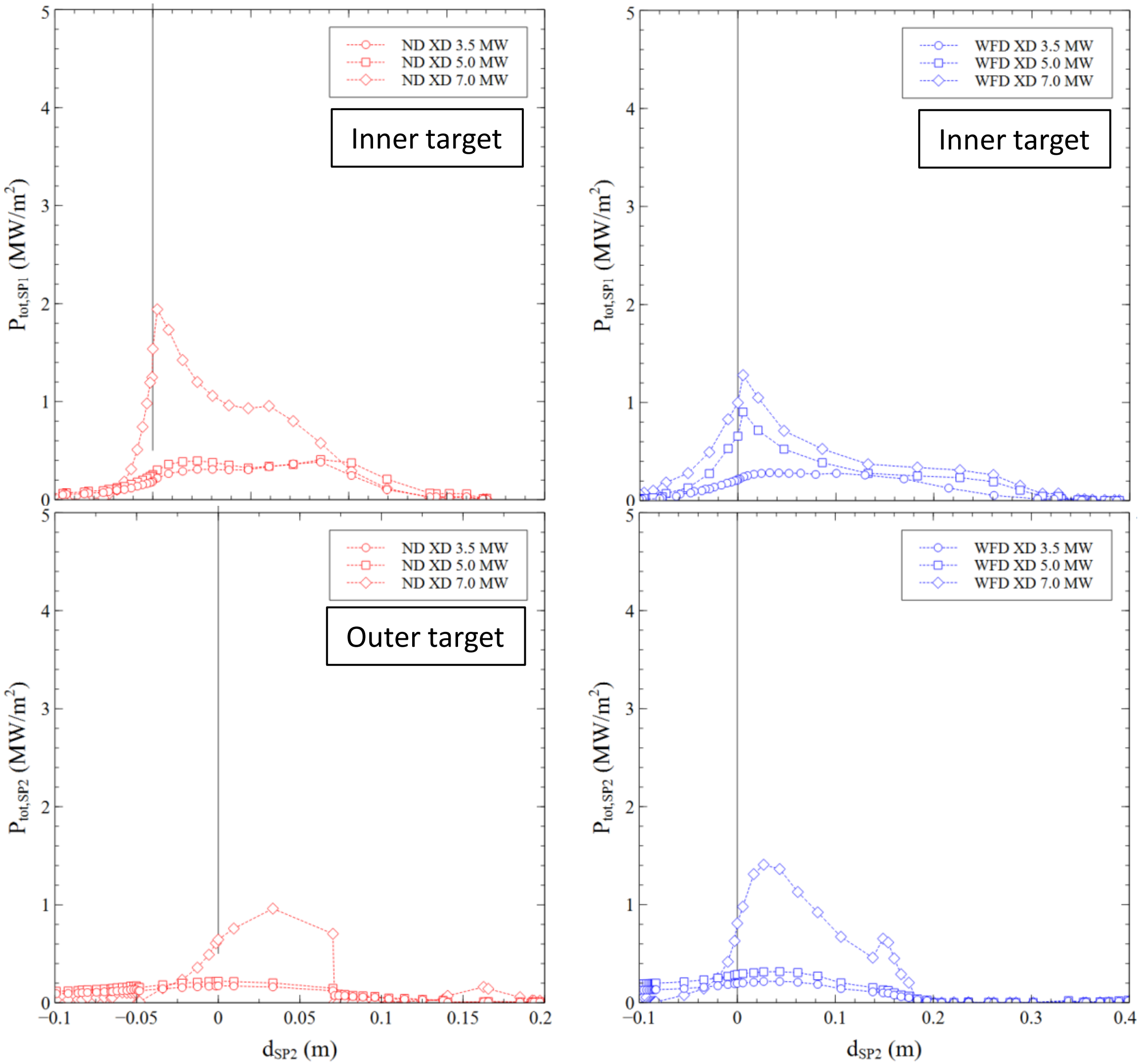
XD: profiles at targets / temperature



For the XD configuration the two divertors provide similar results

Due to the near zero grazing angle (high flux expansion) deep detachment is achieved at the outer target

XD: profiles at targets / heat flux



For the XD configuration the two divertors provide similar results

Due to the near zero grazing angle (high flux expansion) deep detachment is achieved at the outer target

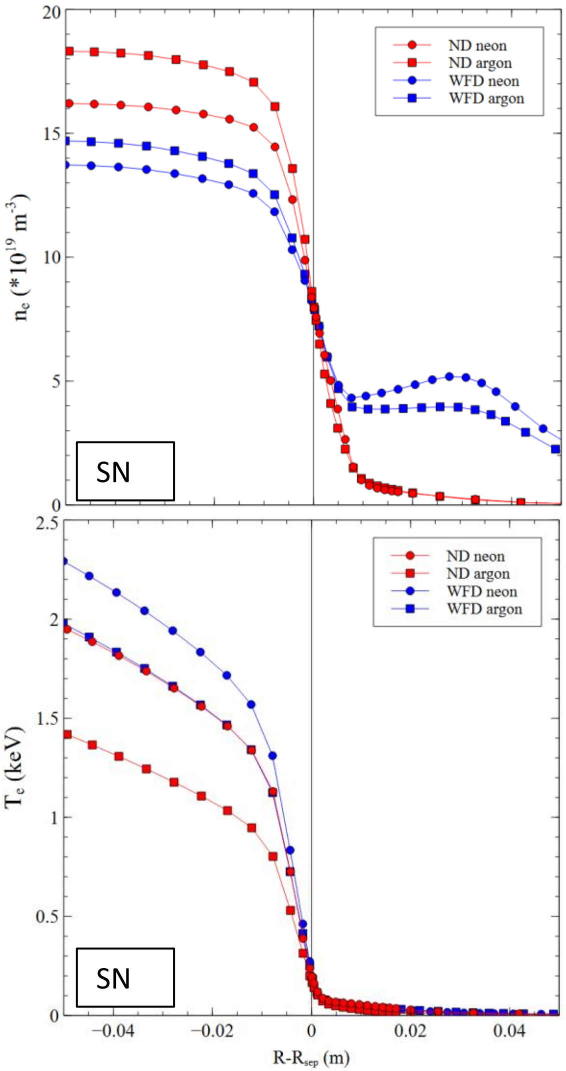
Also peak heat flux is low due to the low grazing angle (also at inner target)

Operation at full power with seeding

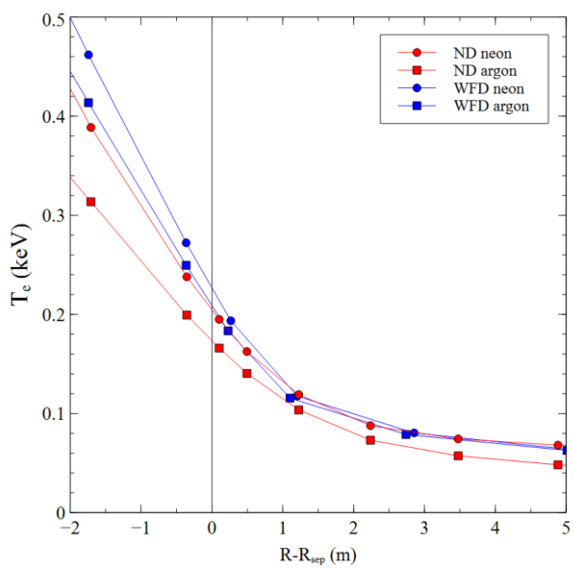
- Evaluated minimum requested contamination to achieve detachment
- Evaluated operative window in impurity content
- Configuration stability against operating condition

Seeding at full power

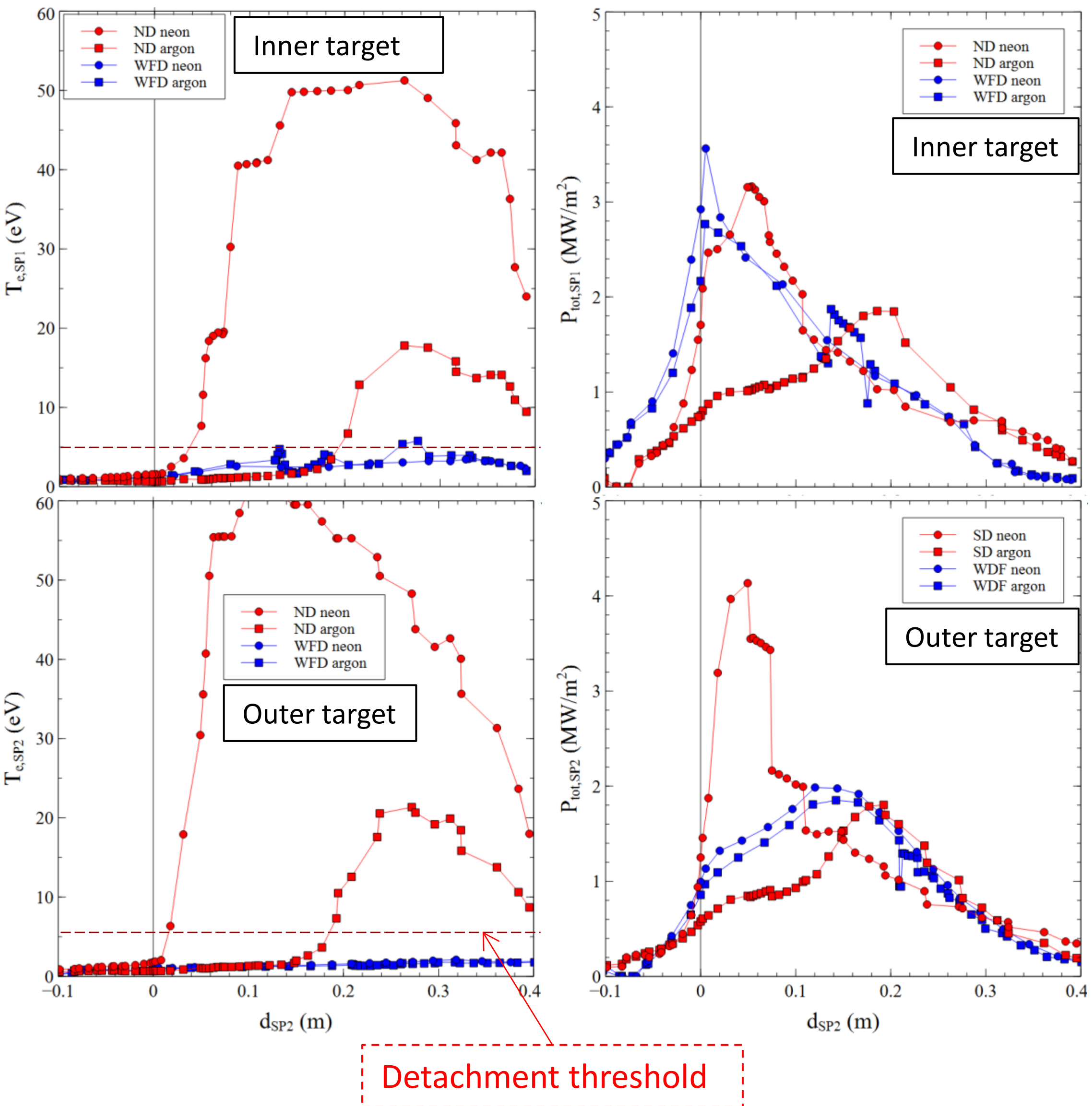
- P_{IB} = 30 MW (10 MW rad. in the inner core, 5 MW ELMs)
- P_{IB} splitted between e and D to achieve similar temperatures
- $n_{sep}=8\cdot10^{19}\ m^{-3}$
- $P_{SOL}=P_{IB}-P_{rad,in}$ **(must be > 18-20 MW to access H-mode)**



- Higher core density with argon
- Higher core temperature with neon
- Higher temperature at separatrix with neon (related to Ne/Ar cooling properties)



SN: profiles at targets



Lower target temperature with **wide divertor** at both targets

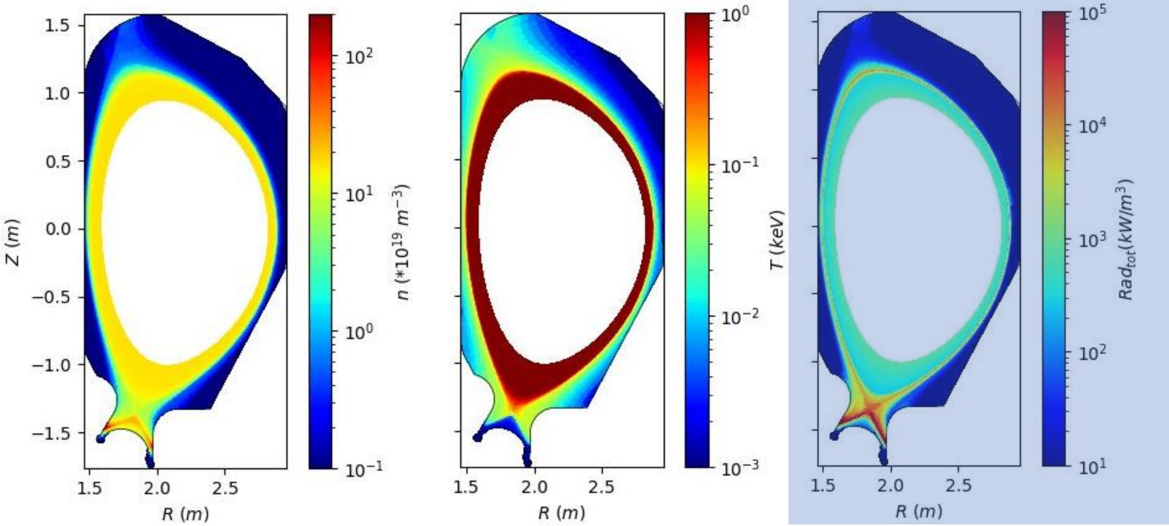
Detached condition on all target achieved only with wide divertor

Detached condition achieved only near strike points with standard divertor

Lower peak heat flux at inner target with standard divertor **(drifts can change this result)**

Standard/narrow divertor - SN

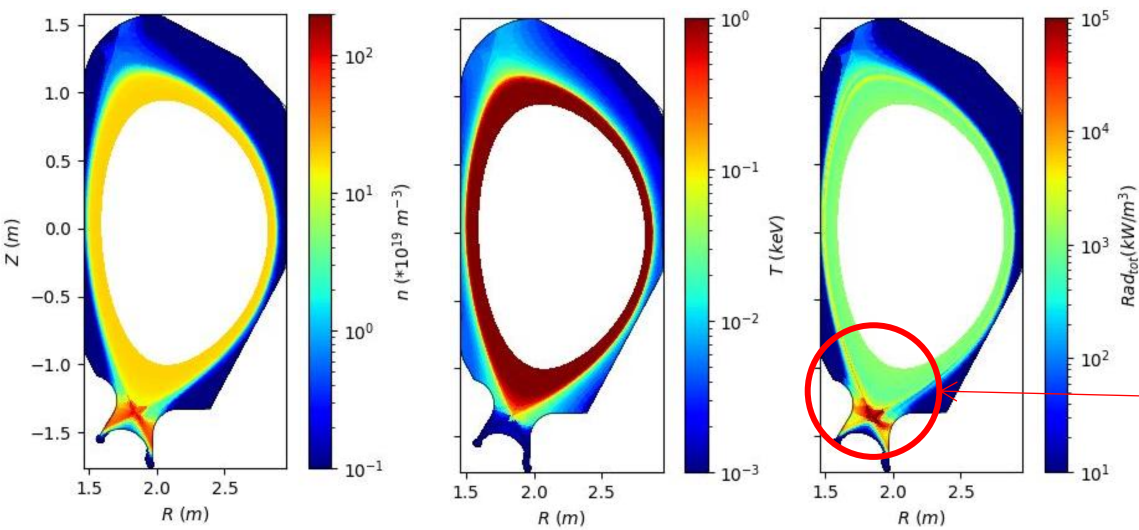
Neon seeding



$\langle Z_{eff} \rangle_{sep}$=4.8
$P_{rad,tot}$=24 MW
P_{SOL}=19 MW
C_{Ne}=4.9%

Radiation is concentrated on divertor legs

Argon seeding



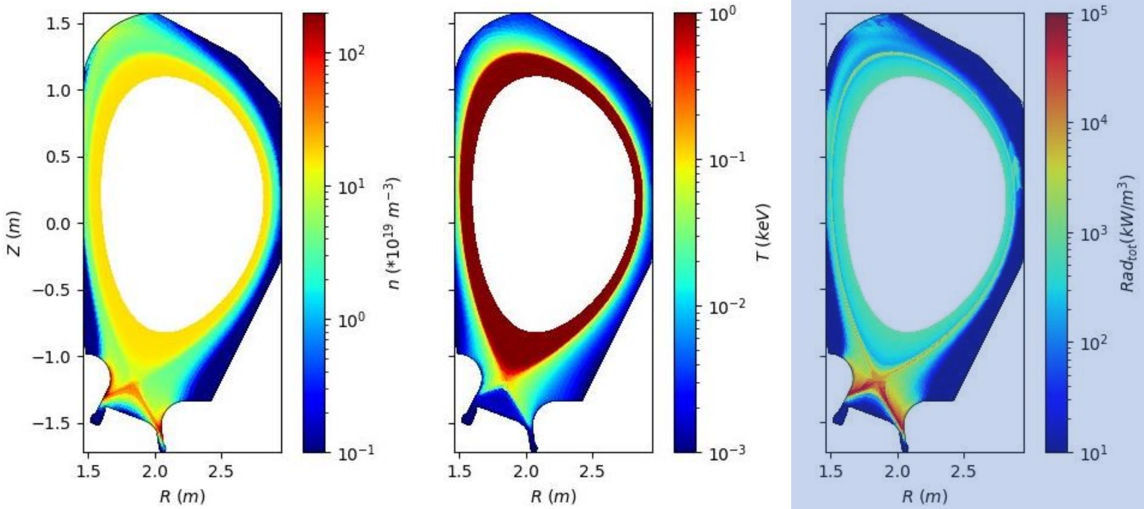
$\langle Z_{eff} \rangle_{sep}$=3.6
$P_{rad,tot}$=27 MW
P_{SOL}=19 MW
C_{Ar}=1.2%

Better result with argon

But more radiation at the x-point

Wide flat divertor - SN

Neon seeding

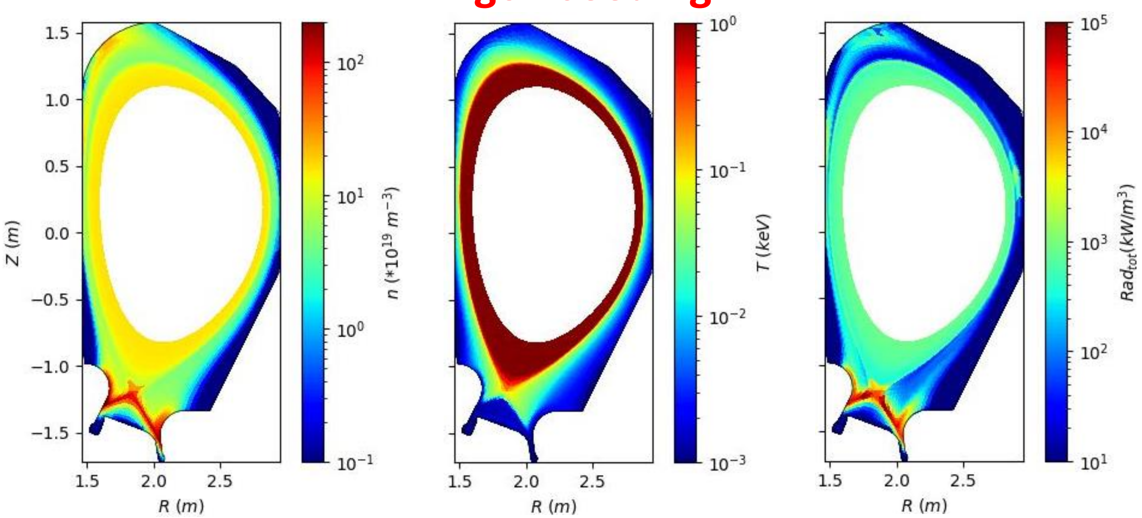


$\langle Z_{eff} \rangle_{sep}$=2.9
$P_{rad,tot}$=22 MW
P_{SOL}=26 MW
C_{Ne}=2.8%

Radiation is concentrated on divertor legs

Longer legs provide larger radiative volume, better performance

Argon seeding

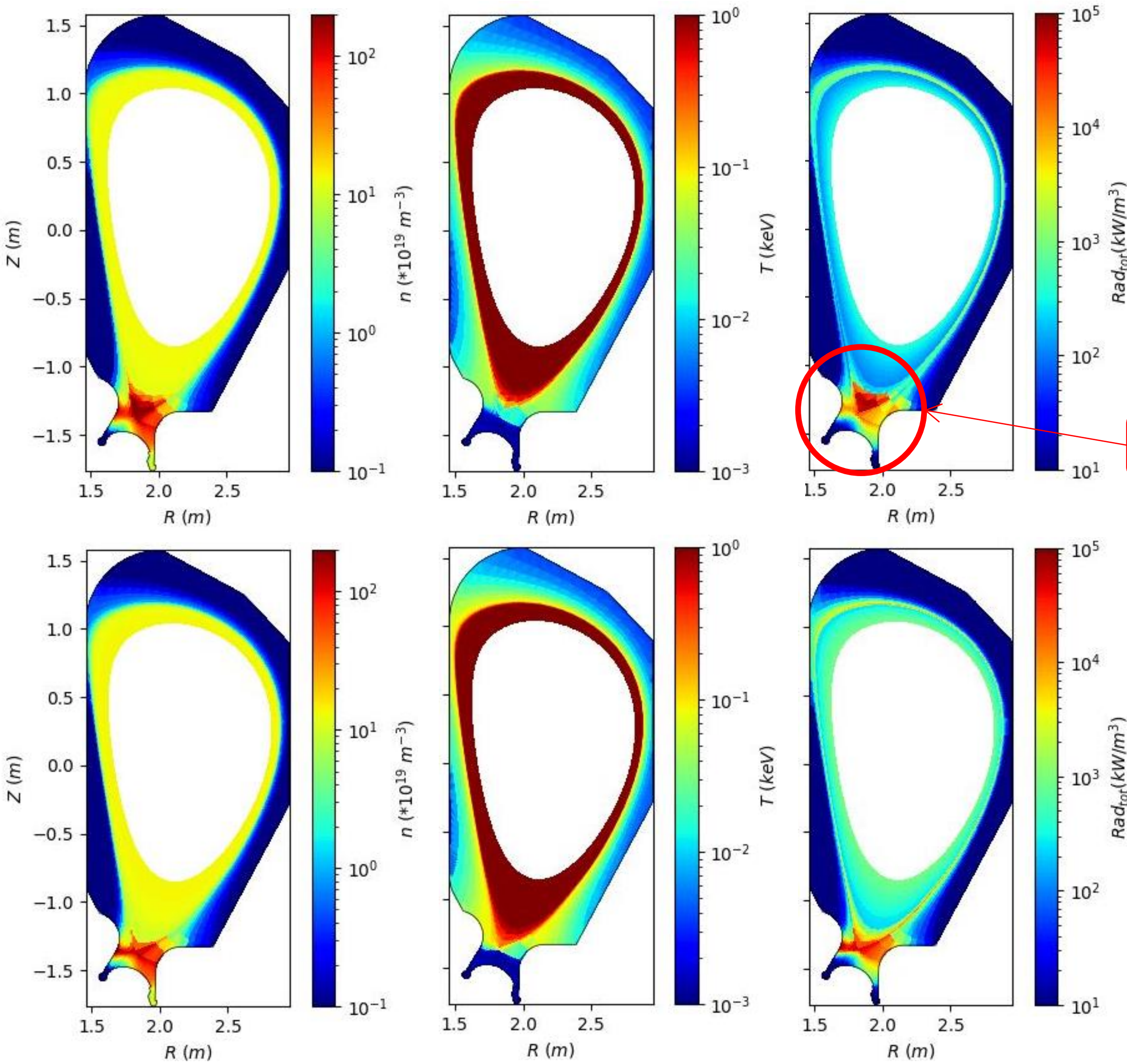


$\langle Z_{eff} \rangle_{sep}$=2.8
$P_{rad,tot}$=23 MW
P_{SOL}=24 MW
C_{Ar}=1.0%

Argon provide better results than neon with similar radiation in the core

Standard/narrow divertor – XD with neon

XD configuration easily falls down to X-point radiator



$\langle Z_{eff}\rangle_{sep}=2.4$
$P_{rad,tot}=28$ MW
$P_{SOL}=8$ MW
$C_{Ne}=3.6\%$

Fast cooling of legs
Radiation localize at the x-point
Most radiation inside separatrix

Seems unable to sustain H-mode

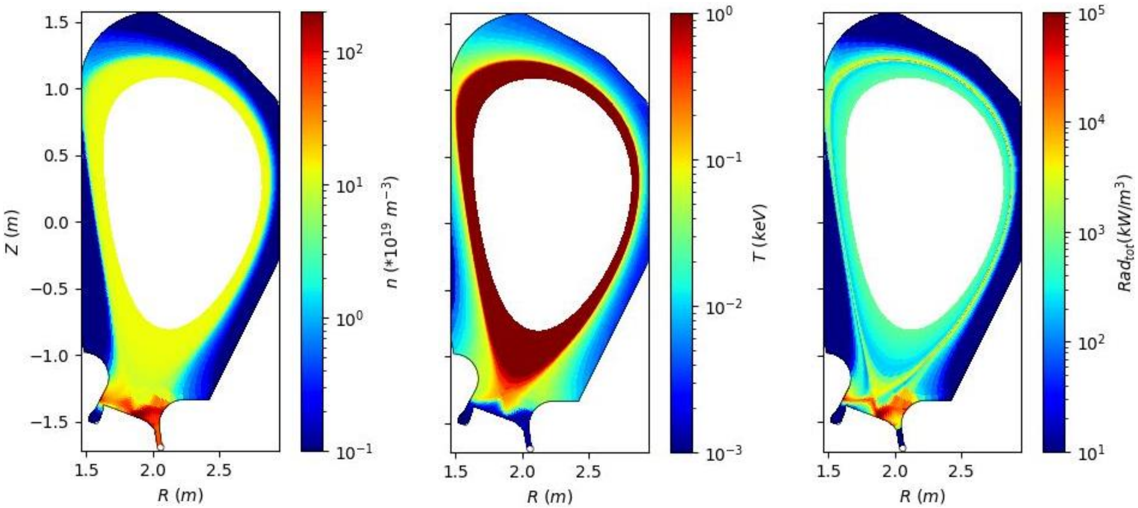
$\langle Z_{eff}\rangle_{sep}=4.5$
$P_{rad,tot}=25$ MW
$P_{SOL}=21$ MW
$C_{Ne}=7.3\%$

H-mode condition can be recovered but at high impurity concentration

Can sustain H-mode

Wide flat divertor - XD (short and long leg)

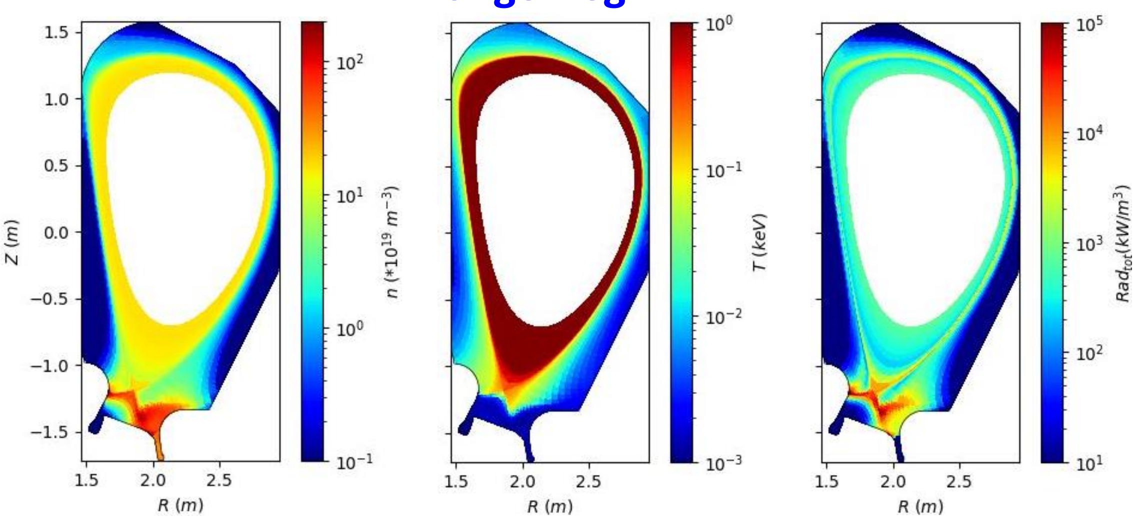
Short leg XD



$\langle Z_{eff} \rangle_{sep}$=3.6
$P_{rad,tot}$=27 MW
P_{SOL}=24 MW
C_{Ne}=4.6%

H-mode operation is possible with a reasonable impurity content

Longer leg LXD

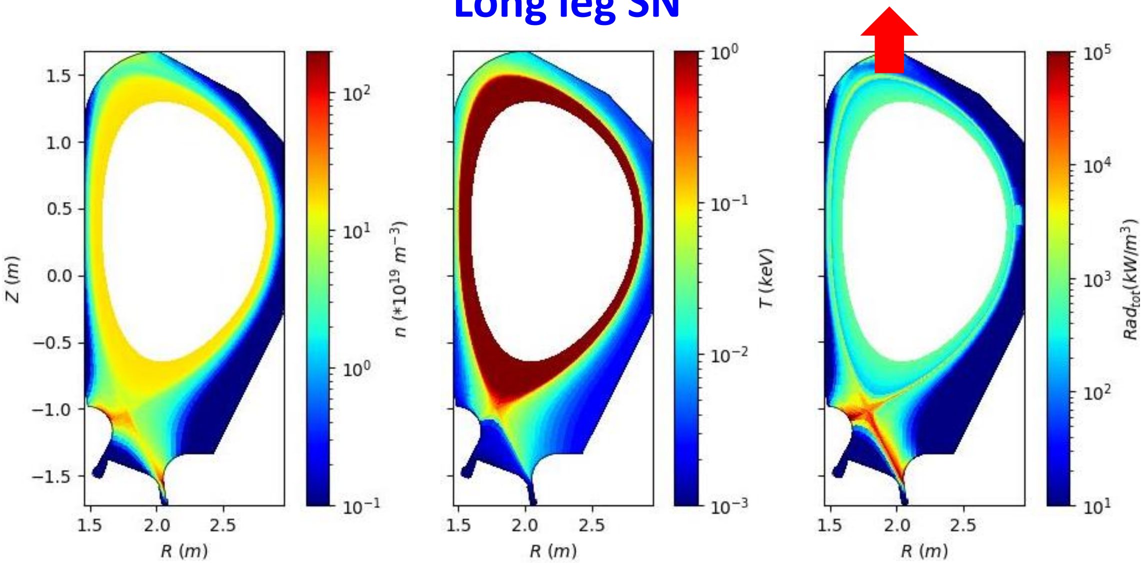


$\langle Z_{eff} \rangle_{sep}$=3.4
$P_{rad,tot}$=25 MW
P_{SOL}=24 MW
C_{Ne}=3.4%

A Longer leg provide better results

Long leg configurations with neon

Long leg SN

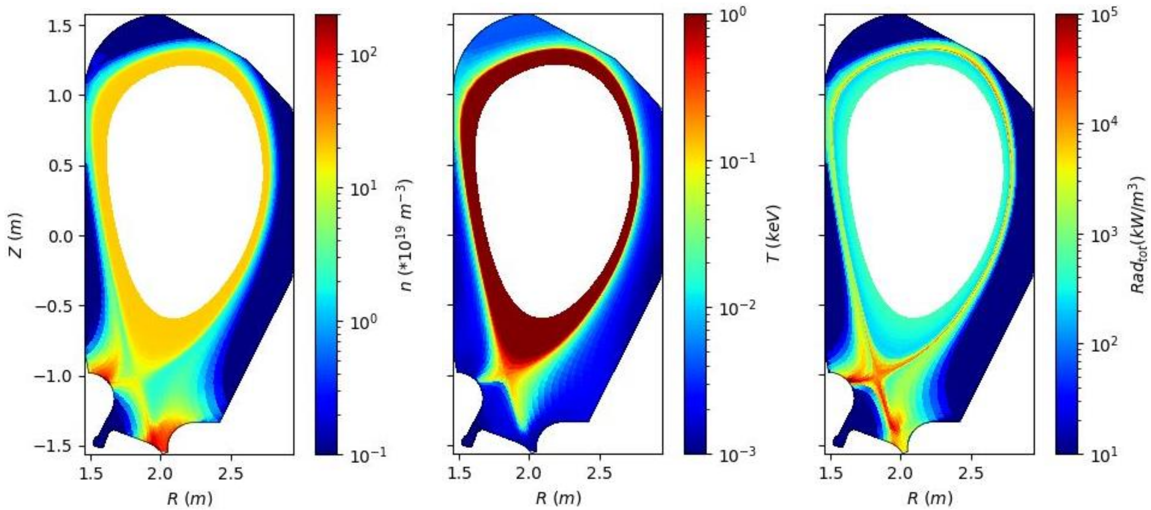


$<Z_{eff}>_{sep}$=3.0
$P_{rad,tot}$=24 MW
P_{SOL}=26 MW
C_{Ne}=2.3%

Long external legs provide a bigger radiative volume reducing request on impurity

But top wall must be moved upward (or equilibrium must be improved)

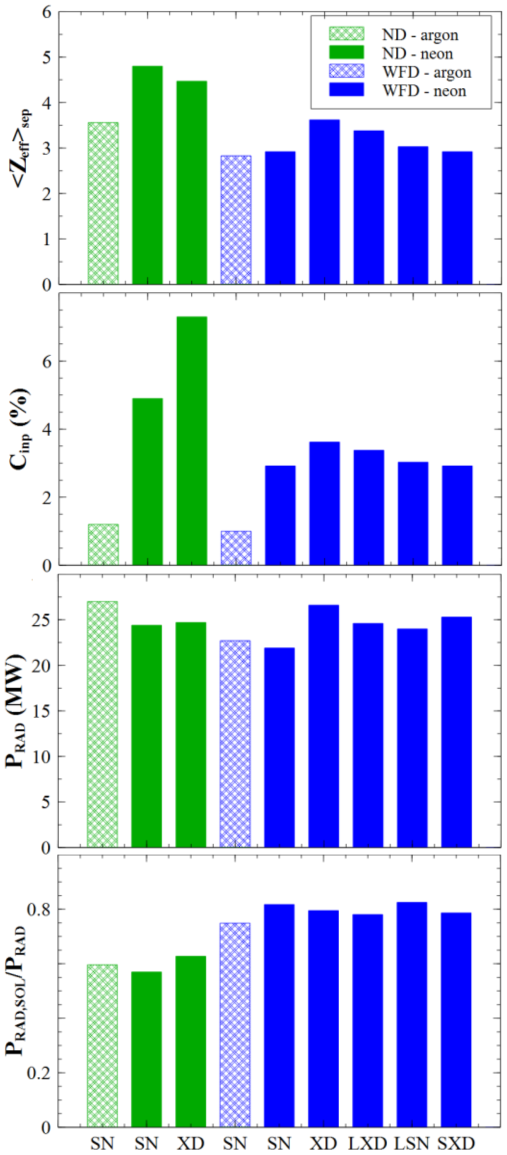
Long leg XD (SXD)



$<Z_{eff}>_{sep}$=2.9
$P_{rad,tot}$=25 MW
P_{SOL}=25 MW
C_{Ne}=1.9%

SXD provides less impurity content in the core thanks to a higher top pedestal density

Summary of seeding results



Full power modeling with P_{IB}=30 MW at fixed separatrix density $n_{sep}=8\cdot10^{9}\ m^{-3}$ with neon (and argon) seeding to achieve detachement

- The **wide flat divertor** performs better than the standard narrow divertor in SN and XD
- Argon performs better than neon in terms of $\langle Z_{eff}\rangle_{sep}$ and impurity concentration (C_{imp}) for both divertors
- In the **wide flat divertor** SXD provides similar result than SN
- The wide flat divertor performs relatively well for all configurations

Conclusions

- A divertor shape able to accept many magnetic divertor configuration has been studied and optimized by the edge code SOLEDGE2D
- The wide divertor can provide reliable operation for SN and XD configurations in pure deuterium at reduced power and with seeding at full power
- The wide divertor provides better exhaust performance than a standard narrow divertor
- With the designed pumping aperture it provides a high pumping capability for the SN configuration, less for the XD one (and NT)
- Results depend on transport parameters, different values for impurities or at different density could affect final conclusions
- Fine tuning on magnetic configurations (strike point position, separatrix distances) can also affect results

Thanks