EUROfusion

T004-D001 - Study of the shaping effect on the monoblock heat load

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WPDIV-IDTT 2023 MID TERM MEETING

CONSORZIO RFX
Ricerca Formazione Innovazione

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UNIVERSITÀ DEGLI STUDI DELLA TUSCIA
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Objectives and methodology

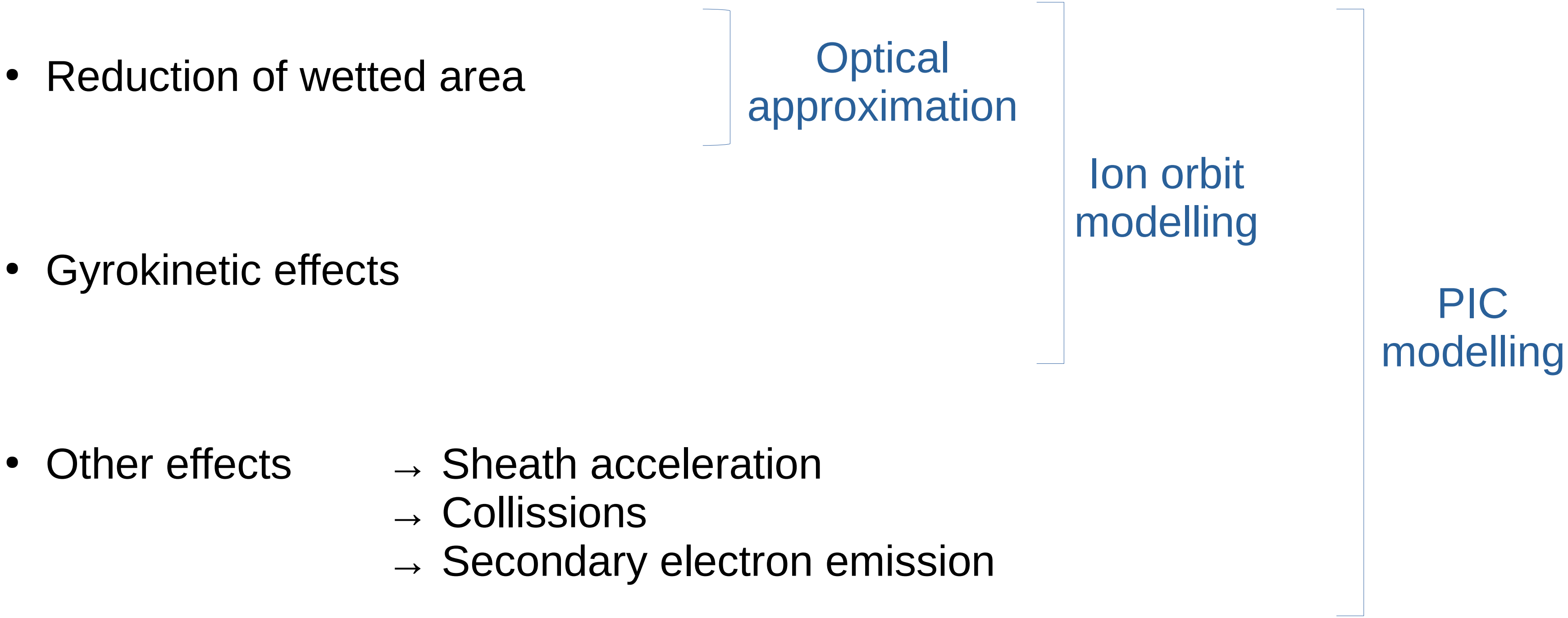
- Evaluate the impact of monoblock shape on power exhaust in DTT
  1) *During steady state conditions or slow transients*
  2) *During fast transients (ELMs)*
- Codes: plasma background: SOLEDGE2D-EIRENE

  plasma-material interaction: ion-orbit code [1]

  PIC code 'DESPICCO' [2]
- Test and propose possible solutions for power exhaust mitigation
- Evaluate the power load to poloidal gaps, toroidal gaps and possible hotspots

[1] J. Gunn et al., Nucl. Fus. (2017)
[2] F. Cichocki et al, Nucl. Fus. (2023)

Plasma interaction with castellated PFC



- Reduction of wetted area
- Gyrokinetic effects
- Other effects → Sheath acceleration
  → Collissions
  → Secondary electron emission

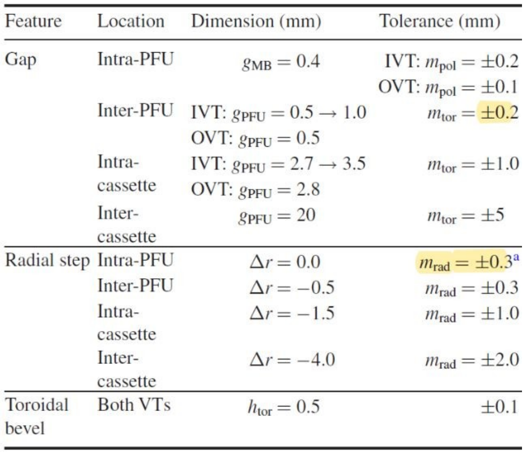
Optical approximation

Ion orbit modelling

PIC modelling

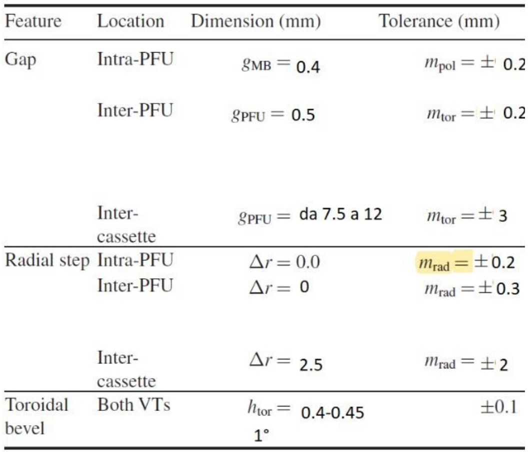
DTT is equiped w/ ITER-like castellated PFC

ITER

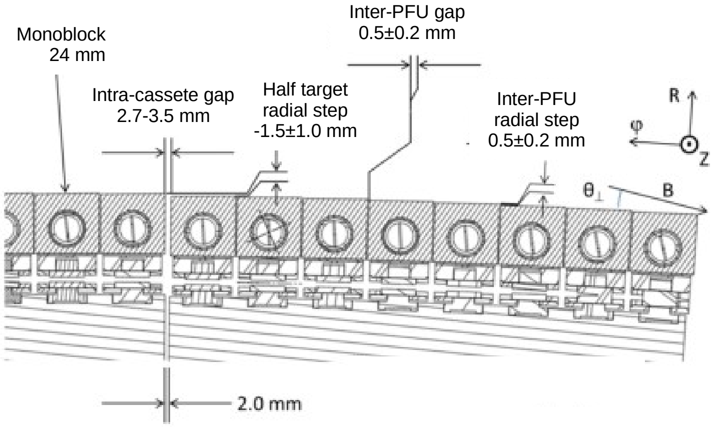


Feature	Location	Dimension (mm)	Tolerance (mm)
Gap	Intra-PFU	$g_{MB} = 0.4$	IVT: $m_{pol} = \pm 0.2$ OVT: $m_{pol} = \pm 0.1$
	Inter-PFU	IVT: $g_{PFU} = 0.5 \rightarrow 1.0$ OVT: $g_{PFU} = 0.5$	$m_{tor} = \pm 0.2$
	Intra-cassette	IVT: $g_{PFU} = 2.7 \rightarrow 3.5$ OVT: $g_{PFU} = 2.8$	$m_{tor} = \pm 1.0$
	Inter-cassette	$g_{PFU} = 20$	$m_{tor} = \pm 5$
Radial step	Intra-PFU	$\Delta r = 0.0$	$m_{rad} = \pm 0.3^{a}$
	Inter-PFU	$\Delta r = -0.5$	$m_{rad} = \pm 0.3$
	Intra-cassette	$\Delta r = -1.5$	$m_{rad} = \pm 1.0$
	Inter-cassette	$\Delta r = -4.0$	$m_{rad} = \pm 2.0$
Toroidal bevel	Both VTs	$h_{tor} = 0.5$	±0.1

DTT

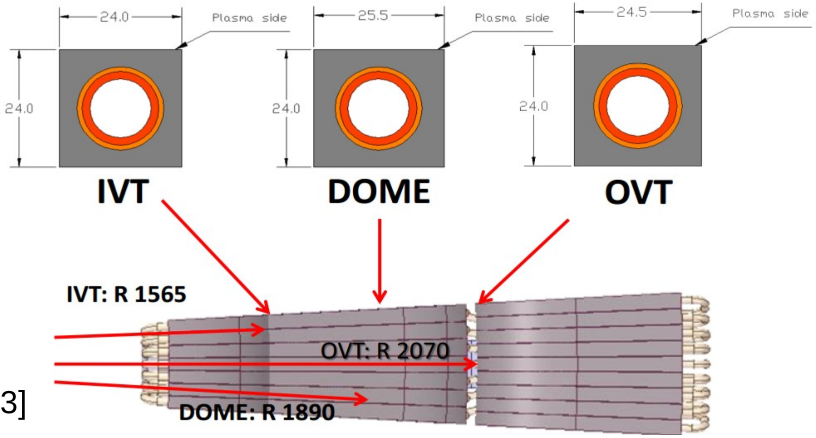


Feature	Location	Dimension (mm)	Tolerance (mm)
Gap	Intra-PFU	$g_{MB} = 0.4$	$m_{pol} = \pm 0.2$
	Inter-PFU	$g_{PFU} = 0.5$	$m_{tor} = \pm 0.2$
	Inter-cassette	$g_{PFU} =$ da 7.5 a 12	$m_{tor} = \pm 3$
Radial step	Intra-PFU	$\Delta r = 0.0$	$m_{rad} = \pm 0.2$
	Inter-PFU	$\Delta r = 0$	$m_{rad} = \pm 0.3$
	Inter-cassette	$\Delta r = 2.5$	$m_{rad} = \pm 2$
Toroidal bevel	Both VTs	$h_{tor} =$ 0.4-0.45 1°	±0.1

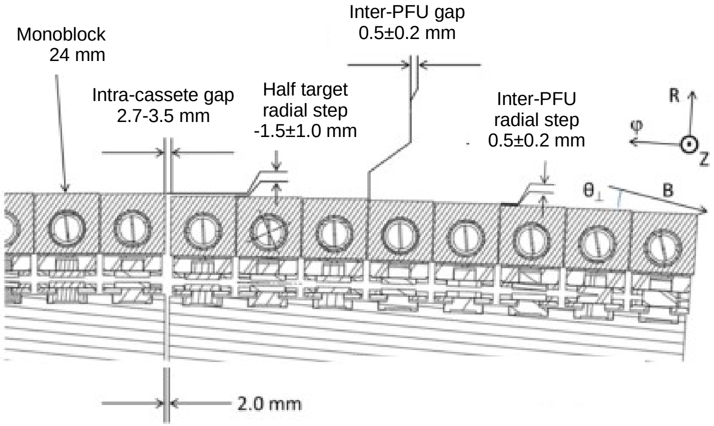


- Monoblock technology analogous to ITER’s with some geometrical differences

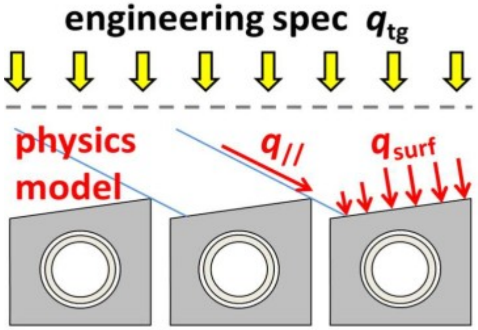
ITER-like castellated target surface



[3]



- Monoblock technology analogous to ITER’s with some geometrical differences
- Toroidal bevel to “optically” protect the leading edges
- The engineering spec q_{tg} obtained assuming toroidally simmetric divertor should be mapped on the 3D shaped PFC



[3] S. Roccella, 32nd SOFT 2022

Poloidal gaps

$$q_{surf} = q_{tg} \frac{\alpha + \theta_{bevel} + \theta_{tilt}}{\alpha}$$

$$\left[\frac{q_{surf}}{q_{tg}}\right]_{opt} = 1.9$$

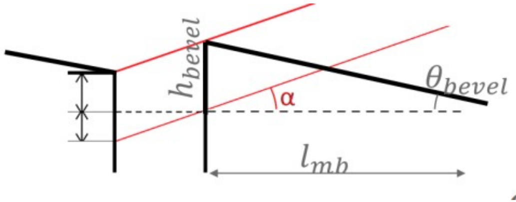
$$\alpha = 2.05° - 1.9°$$ Grazing angle for SN scenario

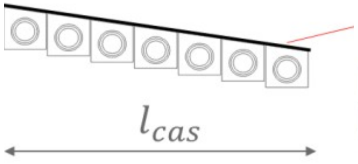
$$\theta_{bevel} = 1°$$

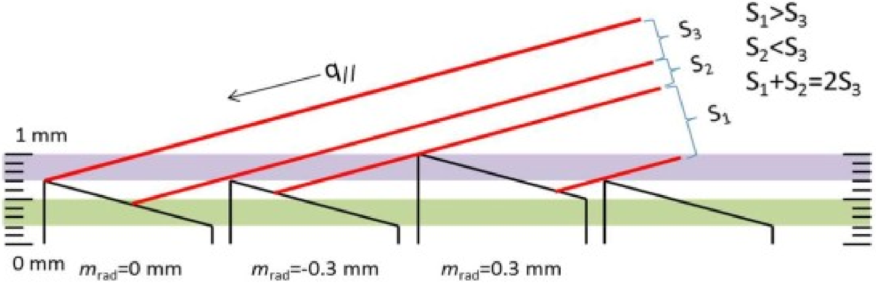
Inner target - outer target

$$\theta_{tilt} = h_{tor} / l_{cas} = 0.85° - 0.65°$$

- The beveling angle and the cassete tilting **completely protects** the leading edges.
- **No relevant gyrokinetic effects**
- Leading edges are not exposed even if **maximum radial displacement** is assumed (m_{rad}=0.2mm)





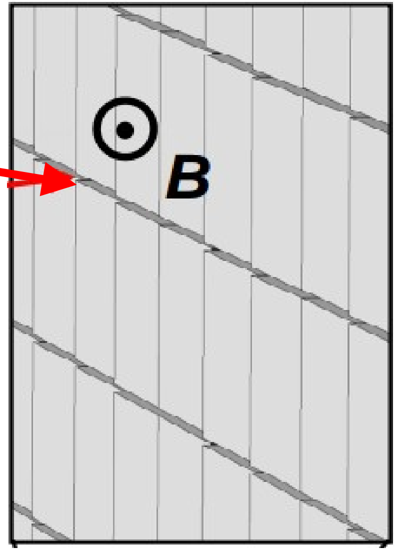


Toroidal gaps

- Poloidal gaps are protected by the toroidal wedge, but toroidal gaps are stil exposed

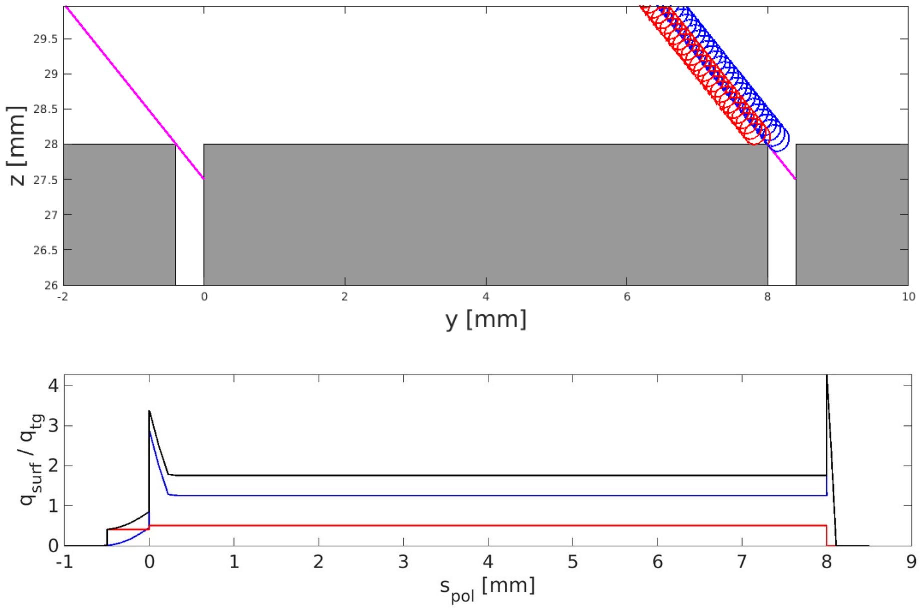
- **No poloidal bevelling** and therefore toroidal gaps are exposed

- Single **poloidal bevelling** could be applied only at the outer divertor



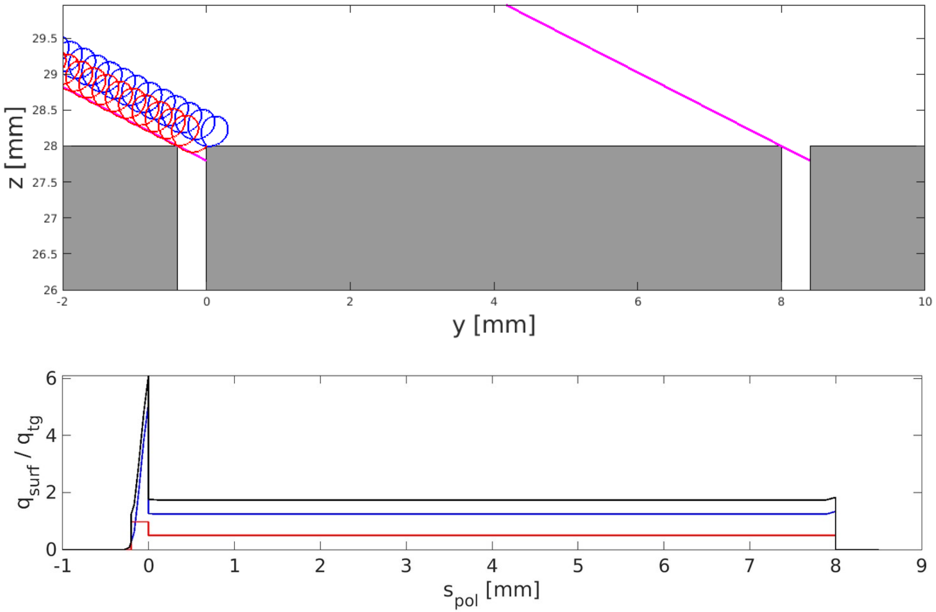
Toroidal gaps

Inner vertical target



Electrons and ions impact on opposite leading edges

Outer vertical target

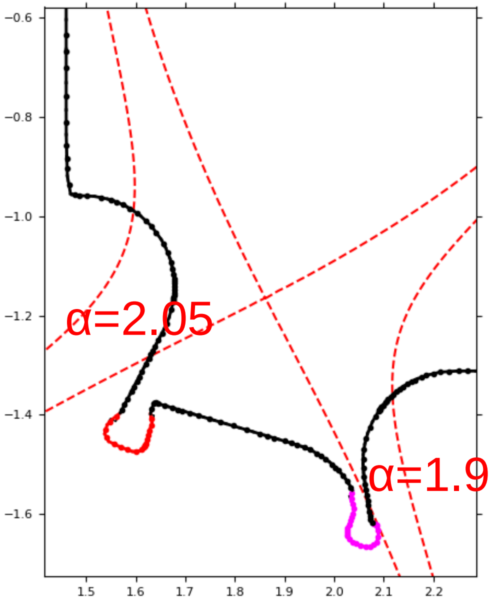


Electrons and ions impact on the same leading edge

Case to be studied

- The analysis is conducted for Sc. A (Day 0) and Sc. E (Day 1)
- Plasma background provided by SOLEDGE2D-EIRENE simulation
  - Detached cases for steady state
  - Attached cases for slow transients

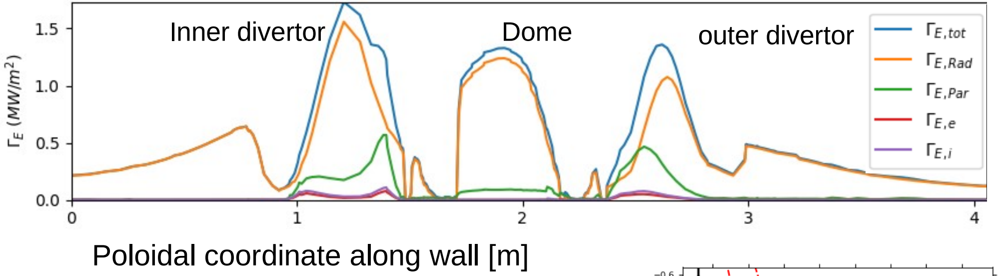
	DTT Sc.E (FP)	DTT Sc.A (Day 0)
Ip [MA]	5.5	2
Bt [T]	5.85	3
ne_ave [m^{-3}]	1.7x10^{20}	6x10^{19}
ne [m^{-3}]	8x10^{19}	3x10^{19}
R [m]	2.19	2.19
a [m]	0.7	0.7
q95	3.0	3.9
qcyl	2.2	3.2
Padd [MW]	45	7
Psol [MW]	25	5
Seeding	Ne	N



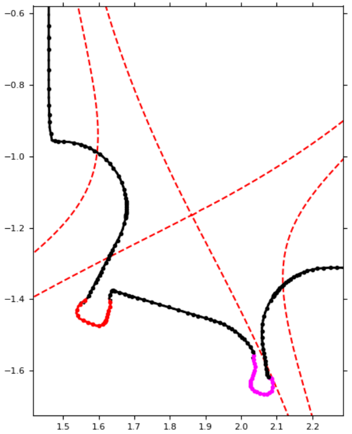
Steady-state conditions

- Power deposition by photons not affected by divertor 2D or 3D shape.

- In detached cases the power flux to the divertor carried by particles is negligible

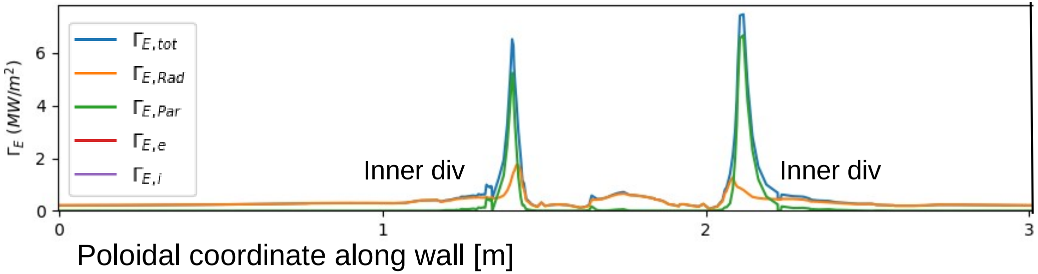


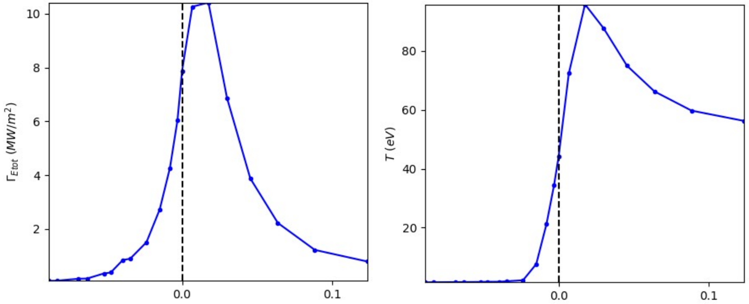
- Two case studies:
  - Temperary loss of detachment (slow transient)
  - Intra-ELM phase



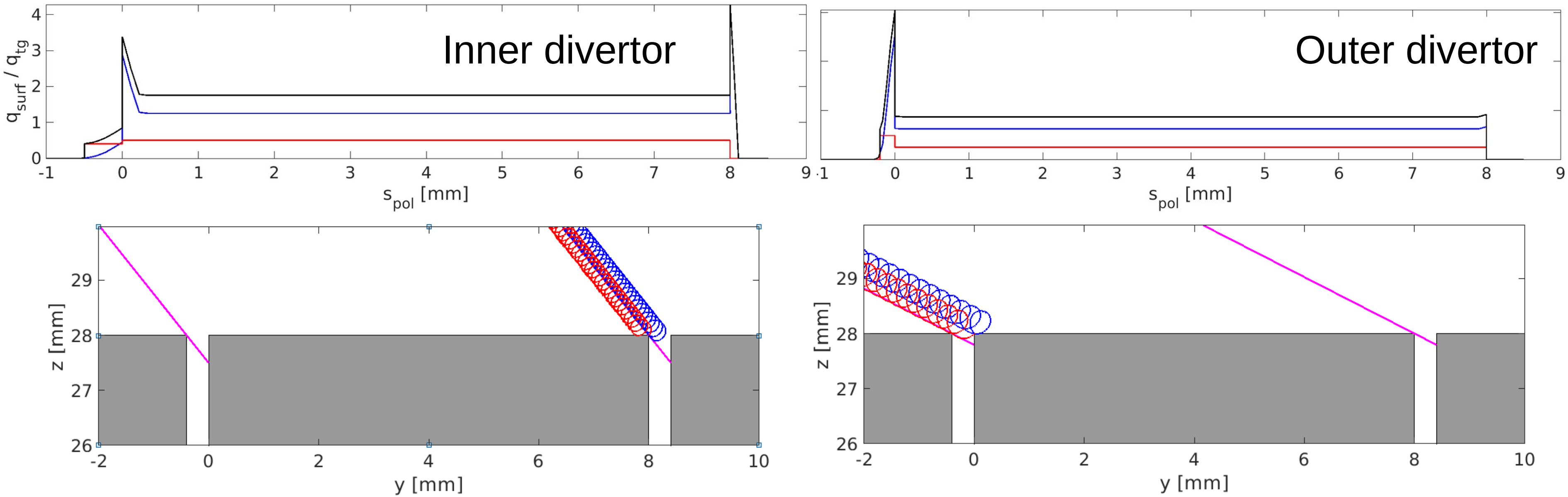
Slow transients: temporary loss of detachment

- DTT simulations show that, in high density cases in steady-state conditions, divertor plasma is either fully detached or attached.
- We used an attached case with f_{rad}=50%





Slow transients: temporary loss of detachment



- The gyrokinetic effect is relevant and toroidal leading edges are exposed to **6 times** higher power flux than the axisymmetric outer divertor and **4** more at the inner divertor
- The effect of **radial misallignement** is also not negligible (up to a factor 6.7 at the outer target)
- **Thermal analysis** may be required to evaluate the maximum exposure time to this kind of plasma

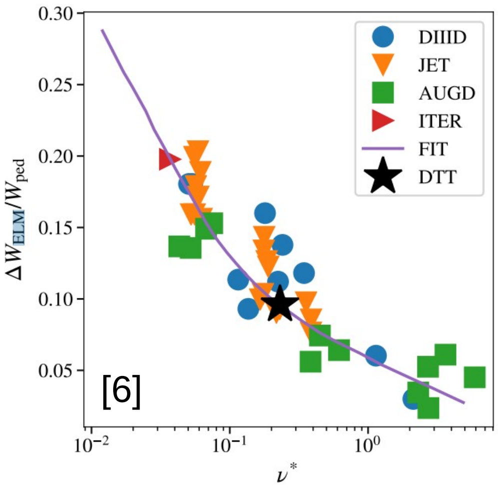
Fast transient modelling

Modelling the worst possible ELM

- Type I ELMs
- Assume T_e and T_i at the PFC equal to pedestal top
- Calculate the peak of the power flux
- Assume that there is no ELM power dissipation in the inter-ELM phase
- Assume that the scaling law applies to the inner target as well
- ✓ A simple 1D thermal model of the PFU can be made for fast transients

Fast transients: ELMs

Which will be the expected tipe-I ELM peak power flux to the SOL?



$\Delta W_{ELM} = (3\langle n_{ped}\rangle \Delta t_{ped,ELM} + 3\langle T_{ped}\rangle \Delta n_{ped,ELM}) V_{ELM}$ [4][5]

$W_{PED} = 3 n_{ped} T_{ped} V_{plasma}$

V_{ELM} = volume of plasma affected by the ELM

$\Delta n/T_{\mathrm{ped,ELM}}$= density and temperature drops caused by ELMs

V_{plasma} = total plasma volume

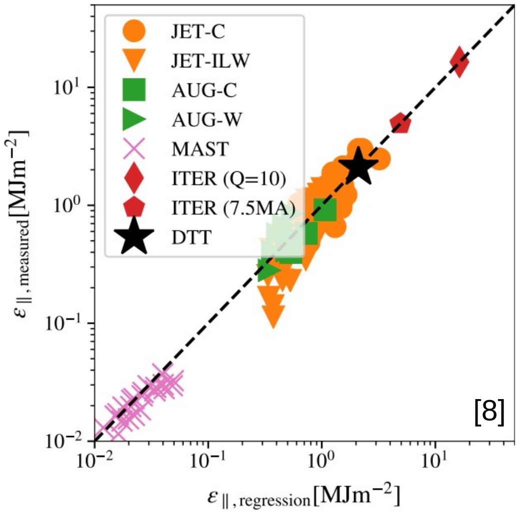
$\nu^*=0.46 q_{95} \mathrm{R[m]/T[keV]}$

$\nu^*_{\mathrm{DTT}}=0.23$ @$\rho_{\mathrm{tor,norm}}=0.94$

$\Delta W_{ELM}/W_{PED}=9.8\%$ $\Delta W_{ELM}=0.34MJ$

[4] A.Loarte et al., *Phys Scri.* (2007)
[5] Igitkhanov et al., IEEE (2014)
[6] I. Casiraghi et al, PPFC (2023)

Type-I ELM power and time in DTT

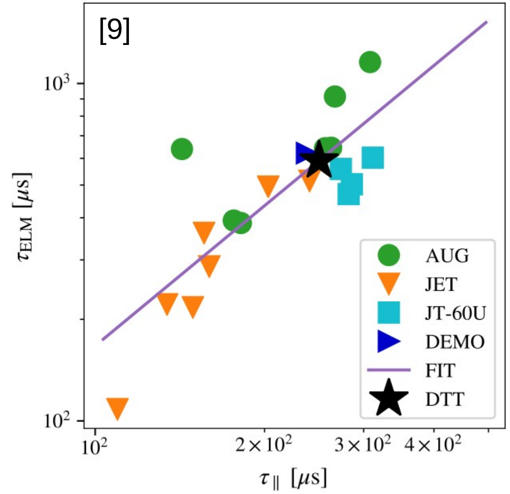


$$\varepsilon_{//}^{peak}=0.28\pm0.14\cdot n_{e,ped}^{0.75\pm0.15} T_{e,ped}^{0.98\pm0.1} \Delta W_{ELM}^{0.52\pm0.16} R_{geo}^{1.0\pm0.4}$$

$$\boldsymbol{\varepsilon_{//}^{peak,DTT}=2.10MJ/m^2}$$

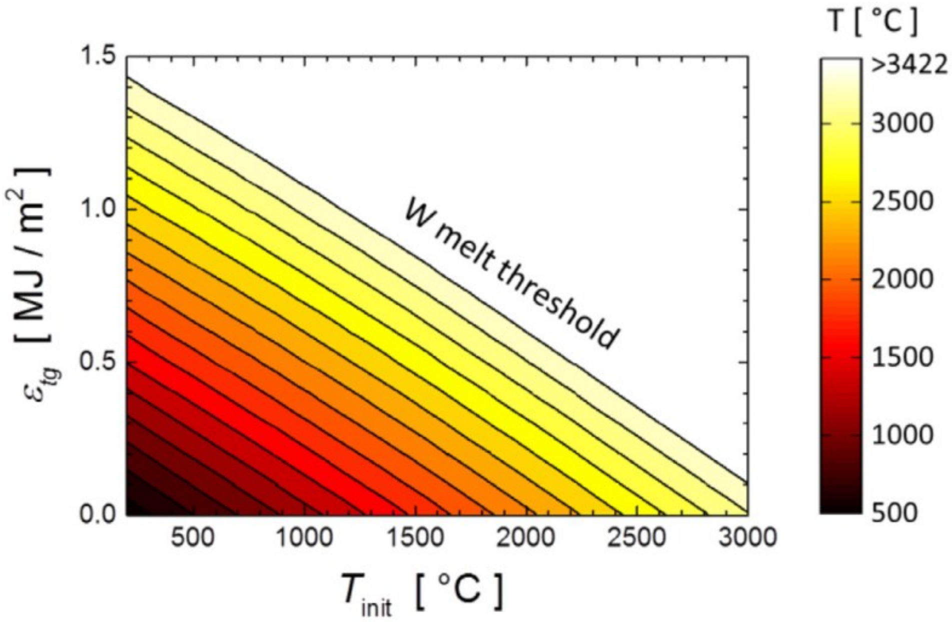
According to the free-streaming-particle model [7]:

- $\tau_{decay}=2\tau_{ELM}$ (from scaling)
- $q_{\parallel,\mathrm{FS}}(t)=\Gamma_{\parallel,\mathrm{FS}}(t)T_e^{\mathrm{ped}}\left[\left(\frac{\tau}{t}\right)^2+1\right]$
- $\Gamma_{\parallel,\mathrm{FS}}(t)=\frac{2\,n_e^{\mathrm{ped}}\,c_s^{\mathrm{ped}}}{L_\parallel/L_{\mathrm{ELM}}}\left(\frac{\tau}{t}\right)^2\exp\left[-\left(\frac{\tau}{t}\right)^2\right]$
- Through ion-orbit simulations we can map $q_{\parallel}$ to q_{surf}



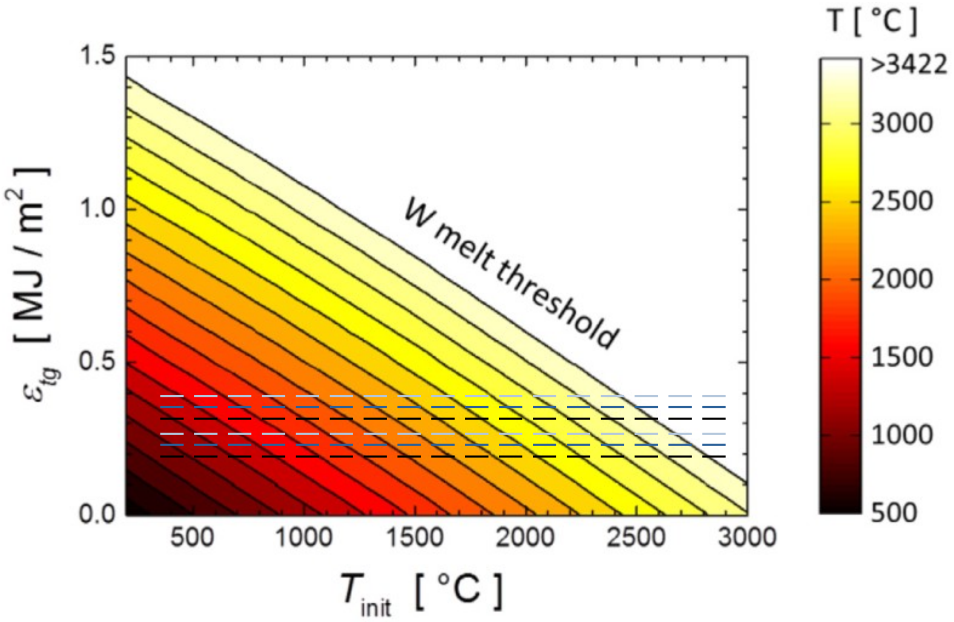
[7] Fundamenski, PPCF (2006)
[8] T.Eich, Nucl Mat and Energy. 2017
[9] T. Eich, J. Nucl. Mat. 2009

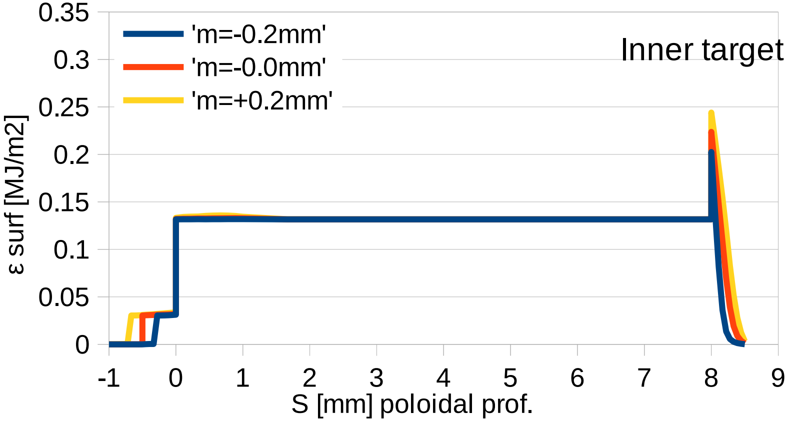
Optical approx. (ELM impact on target temperature)

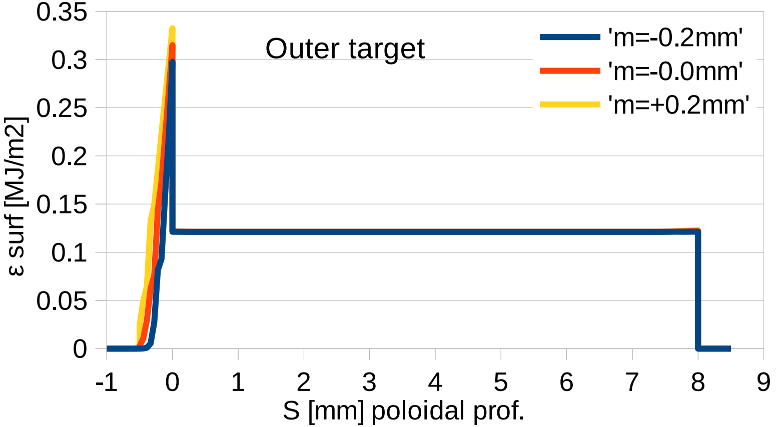


- During an ELM event, the heat flow along the monoblock is negligible
- Use the 1D heat trasmission model to estimate the effect of an ELM event on target temperature
- Use the ion orbit model to estimate $\varepsilon_{surf}^{peak}$ from $\varepsilon_{//}^{peak}$ *scaling*

Optical approx. (ELM impact on target temperature)



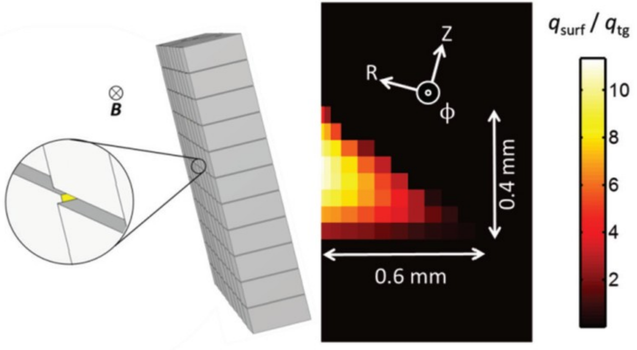




$\varepsilon_{tg}=\varepsilon_{||} \sin(\alpha)=0.7 MJ/m^2$

Activity scheduled for the remaining part of 2023

J. Gunn et al., Nucl. Fus. (2017)



1) Test the full 3D geometry to identify possible hotspots with the current geometry

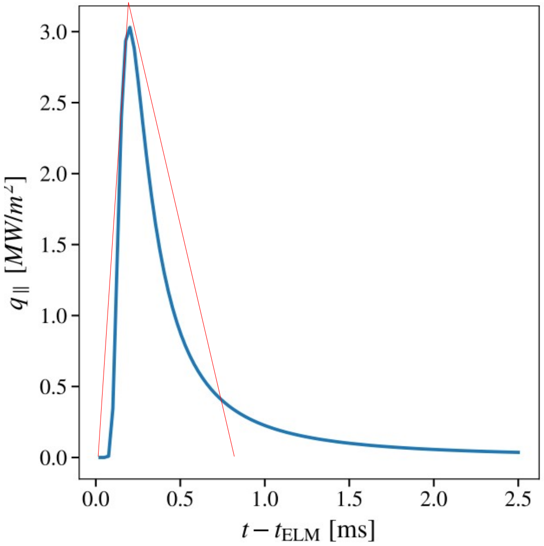
2) Comparison with the newly developed PIC code DESPICCO
3) Test the possible advantage of poloidal beveling at the outer target (thermal analysis needed)
4) Increase the number of case studies including SX configuration which has the outer s.p. on the dome

Conclusions

- The toroidal bevelling effectively protects the poloidal gaps
- ELMs may lead to re-crystallization, possible of bevelling
- Thermal analysis required to evaluate surface temperatures when plasma attaches
- Possible hotspots and the relative power flux have to be identified in the next 3D ion-orbit modelling

Thank you for yout attention

Power flow



$$q_{||,\mathrm{FS}}(t) = \Gamma_{||,\mathrm{FS}}(t) T_e^{\mathrm{ped}} \left[\left(\frac{\tau}{t} \right)^2 + 1 \right]$$

- The power flux to the divertor targets can be calculated according to this time-trace.
- The model or from the simplified triangular signal approximation
- Through ion-orbit simulations we can map $q_{||}$ to q_{surf}

- Estimation on particle flux can be used for sputtering estimation.

$$\Gamma_{||,\mathrm{FS}}(t) = \frac{2\, n_e^{\mathrm{ped}}\, c_s^{\mathrm{ped}}}{L_{||}/L_{\mathrm{ELM}}} \left(\frac{\tau}{t} \right)^2 \exp\left[- \left(\frac{\tau}{t} \right)^2 \right]$$

Power flow

		SN (out. tar.)	SN (dome)	XD (dome)
I_{pl} [MA]	[MA]	5.5	4.5	4.5
$\varepsilon_{//,IT}$	[MJ/m2]	2.1	2.1	2.1
$\varepsilon_{//,OT}$	[MJ/m2]	2.1	2.1	2.1
Grazing IT	[°]	1.9	1.31	0.95
Grazing OT	[°]	1.9	1.7	0.35
$\theta_{bev,IT}$	[°]	1.65	1.65	1.65
$\theta_{bev,OT}$	[°]	1.45	-	-
$\theta_{bev,dome}$	[°]	-	8.6	8.6
$\varepsilon_{surf,IT}$	[MJ/m2]	**0.13±0.05**	0.11±0.04	0.01±0.04
$\varepsilon_{surf,OT}$	[MJ/m2]	0.12±0.05	**0.38±0.15**	**0.33±0.13**

Toroidal gaps

- **Poloidal gaps are protected** by the toroidal wedge, but toroidal gaps are stil exposed
- At the moment, no poloidal bevelling so **toroidal leading edges are exposed**
- Single **poloidal bevelling** could be applied only at the **outer divertor**