Edge Modelling for Ignitor

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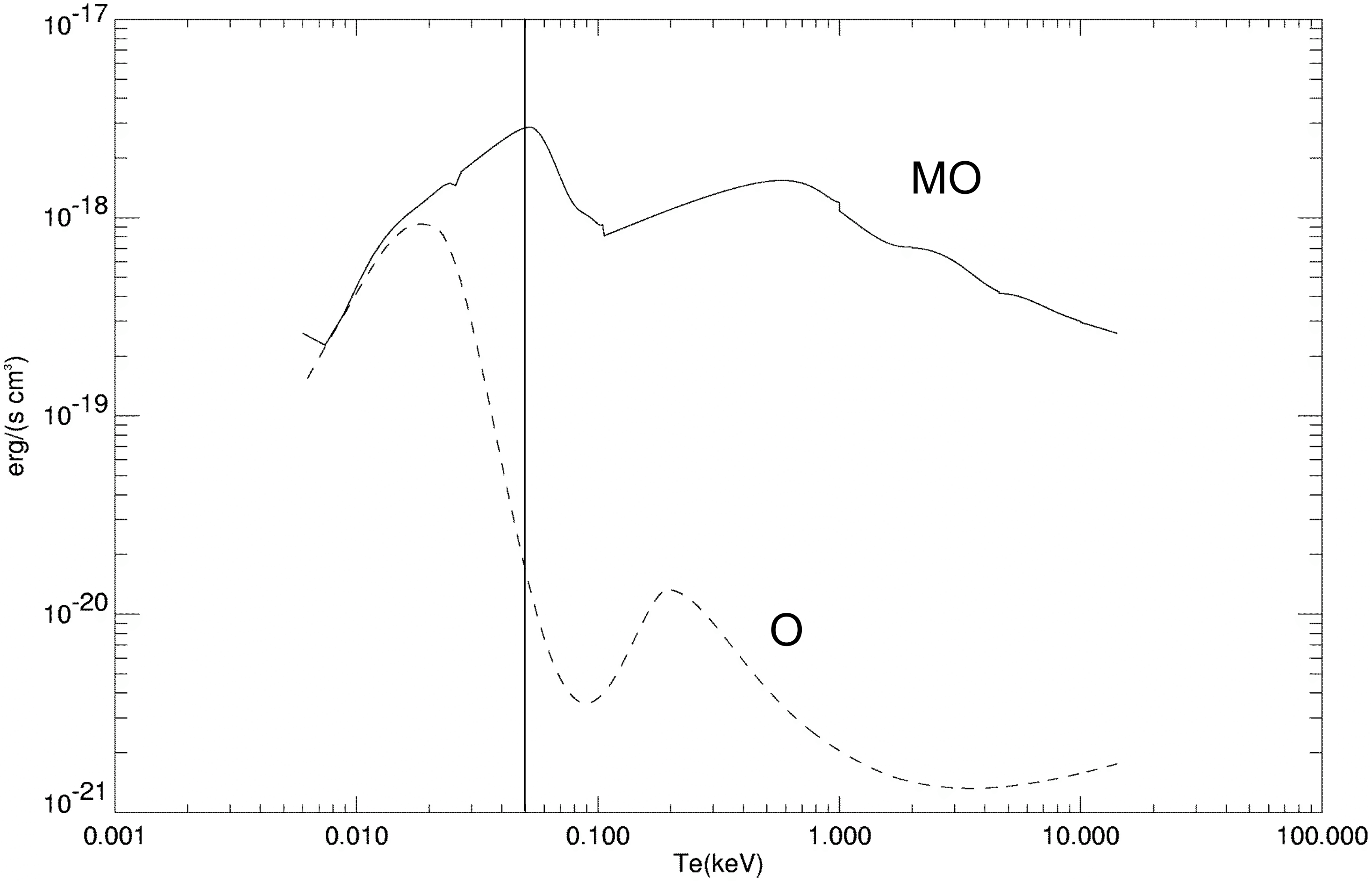
Ignitor Edge Conditions

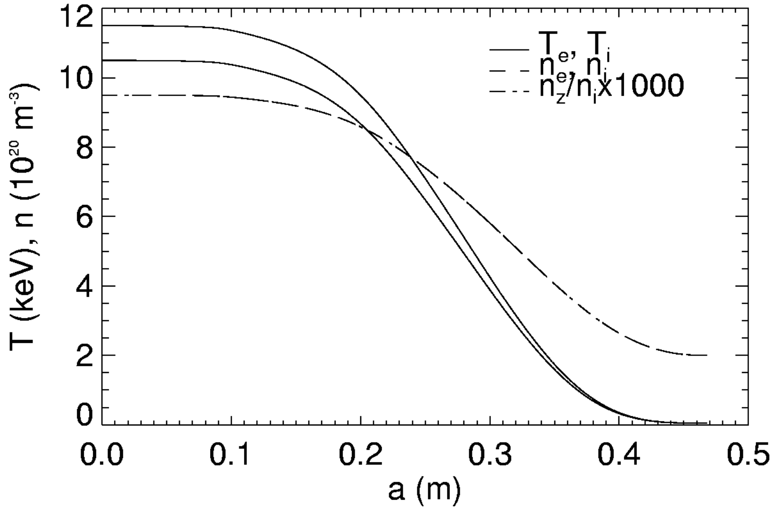
- Ignitor is characterized by the absence of a divertor volume. The plasma chamber is covered by Molybdenum tiles acting as an extended limiter. The first wall follows closely the plasma profile.
- In the reference ignition scenario (no edge transport barriers), the plasma density is high (2-3 x 10^{20}) and the temperature is low (35-60 eV) at the LCFS.
- Under these conditions, a large fraction of the available power can be radiated, and the remaining fraction is assumed to be deposited on the first wall by conduction/convective mechanisms.

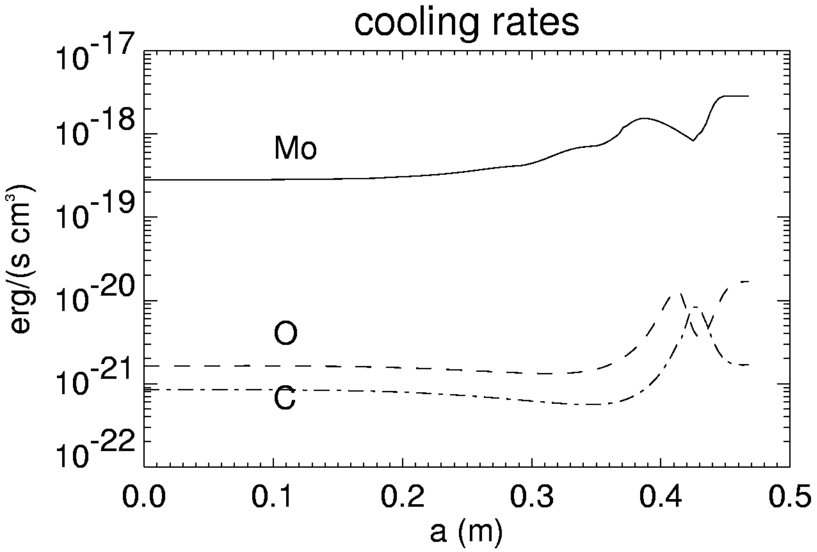
Radiated Power Fraction

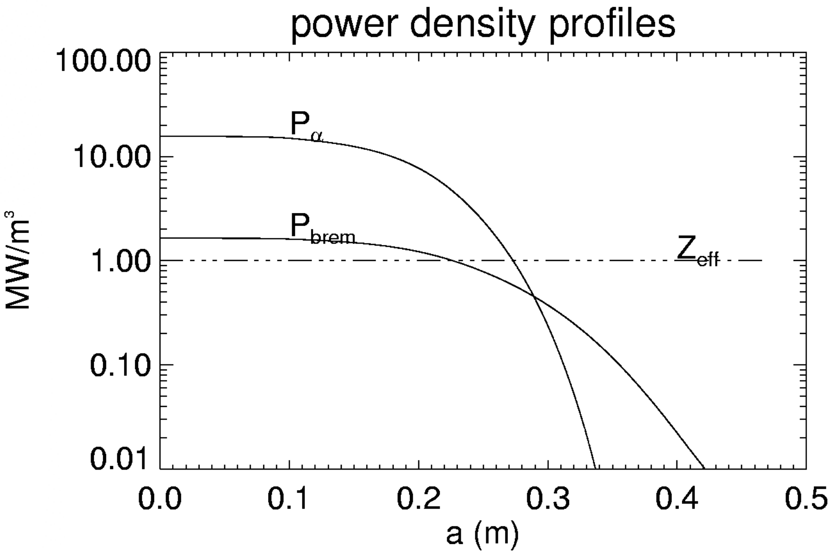
- Simple calculation can be used to justify the adopted fraction of radiated power.
- Standard equilibrium Approximation of closed magnetic surfaces
- Parabolic temperature and density profiles
- Three impurities: O, C (Post), Mo (Fournier et al)
- Assume Z_{eff} profile, impurity composition

Radiation cooling is highest below 50 eV



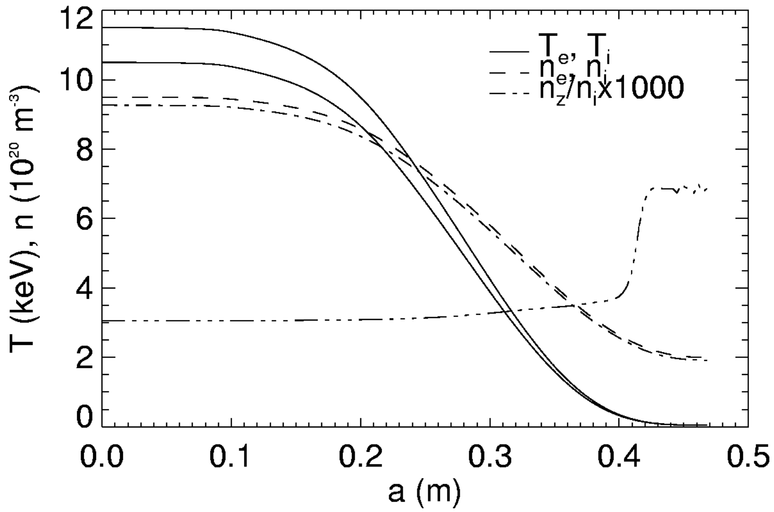


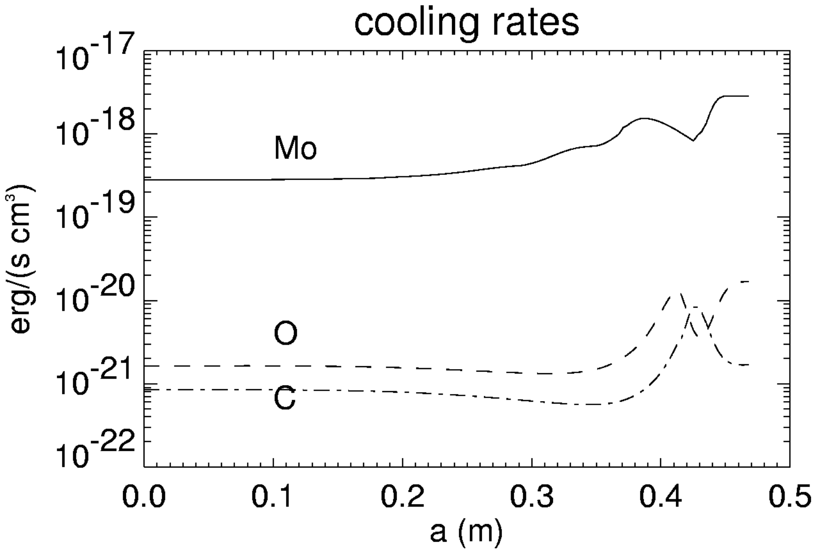


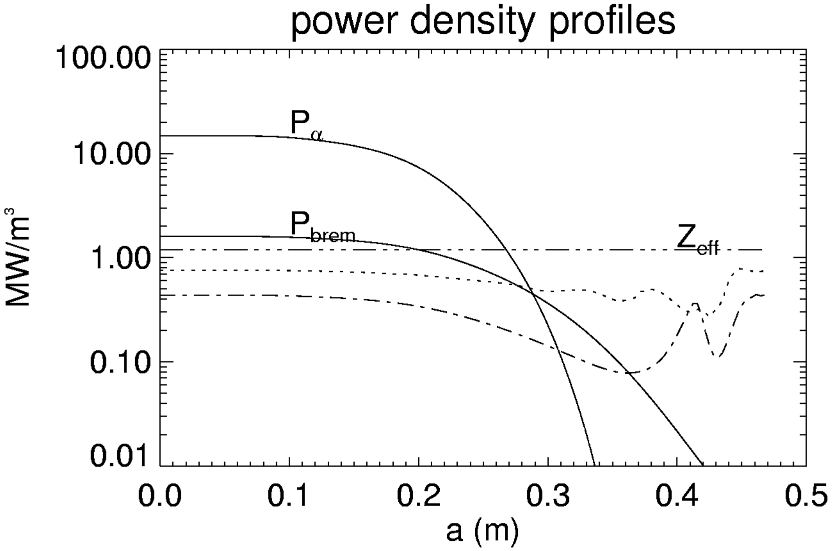


%Mo = 0.000
%C = 0.000
%O = 0.000
P_alpha (MW) = 27.0
P_bremH (MW) = 4.6
Prad_Mo (MW) = 0.0
Prad_C (MW) = 0.0
Prad_O (MW) = 0.0
Radiated Fraction = 0.170
P_rad(a<0.35)/P_rad = 0.971

In a pure plasma, at 10^{21} m^{-3}, 20% of the power is radiated from the core

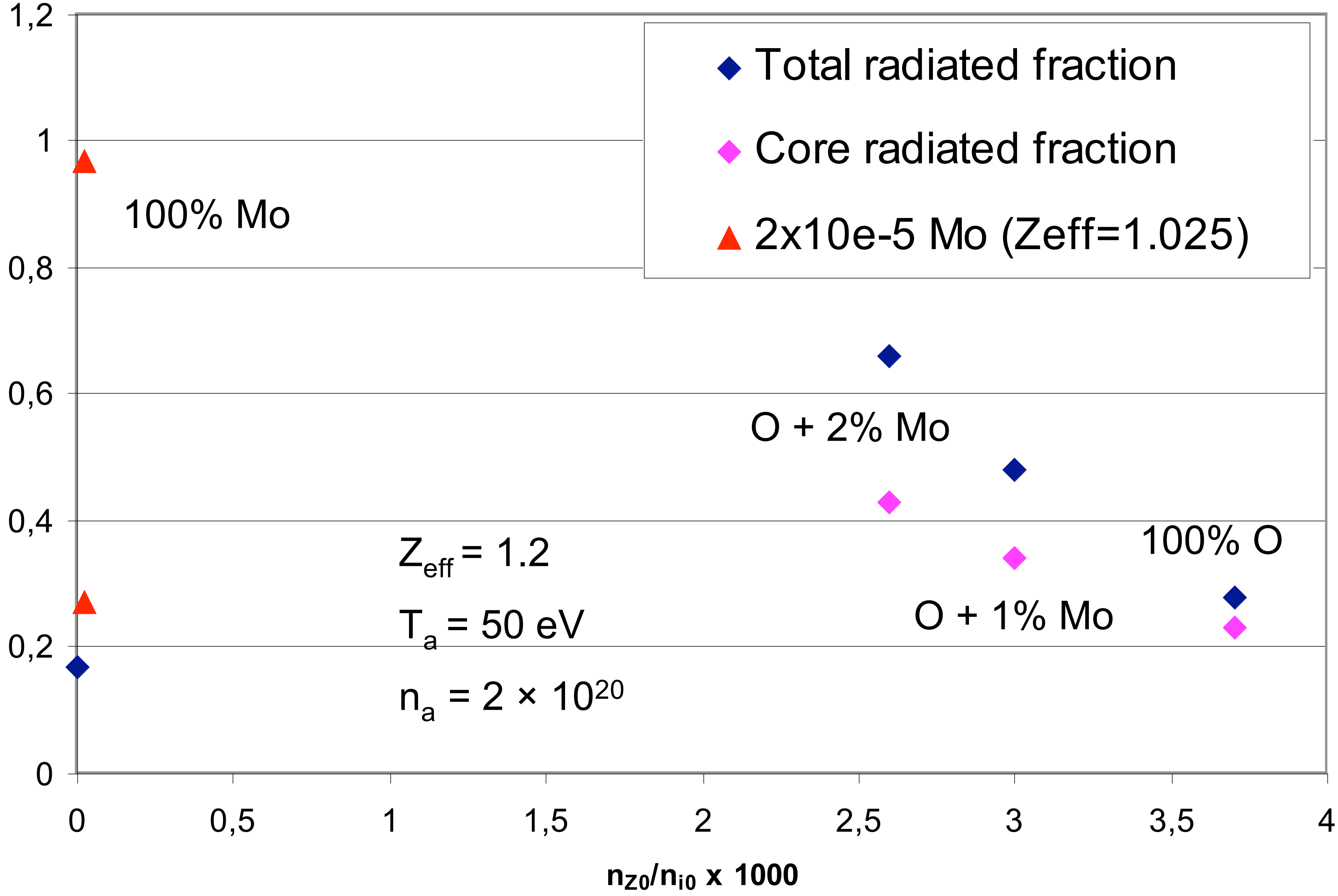



cooling rates

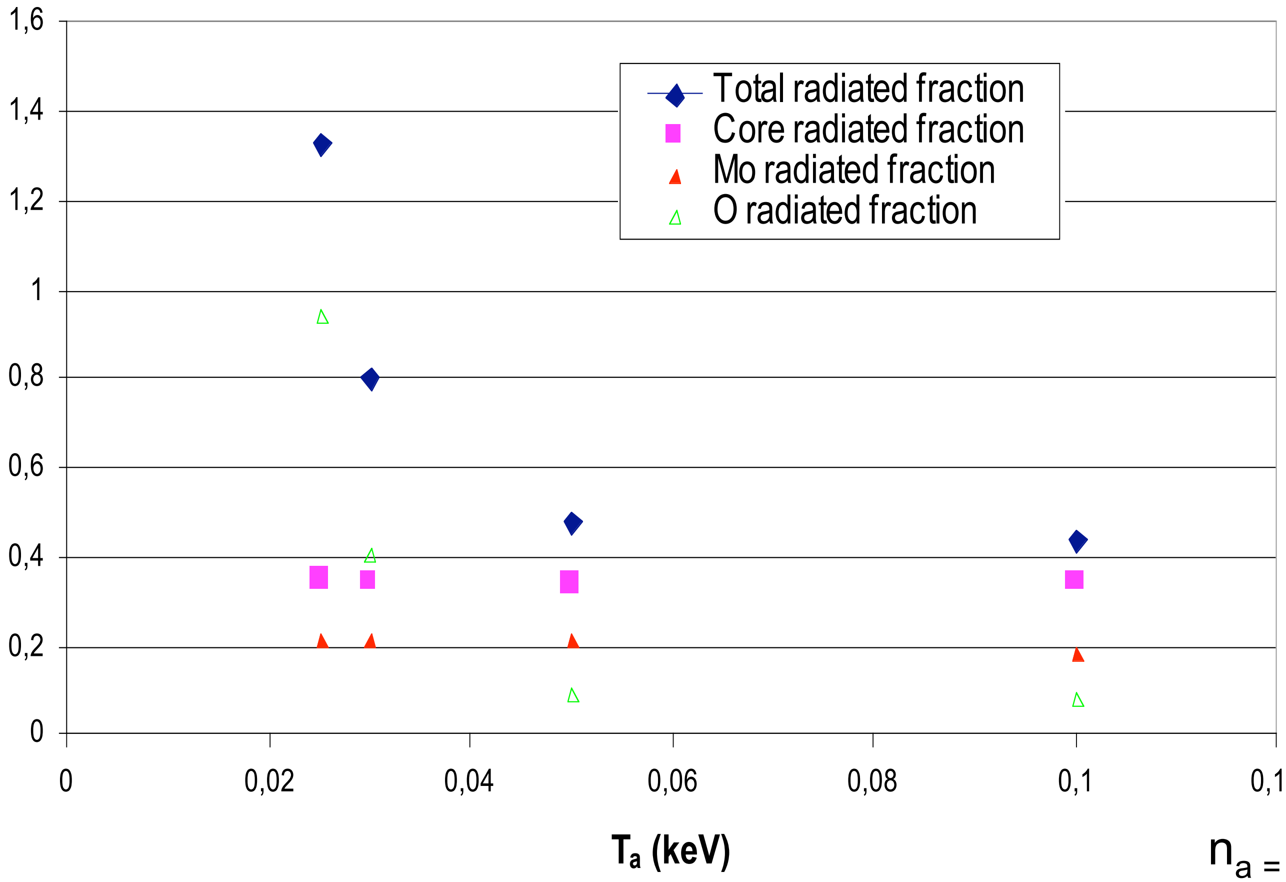

power density profiles

%Mo = 1.000
%C = 0.000
%O = 99.000
P_alpha (MW) = 25.7
P_bremH (MW) = 4.5
Prad_Mo (MW) = 5.6
Prad_C (MW) = 0.0
Prad_O (MW) = 2.4
Radiated Fraction = 0.484
P_rad(a<0.35)/P_rad = 0.708

Light and Heavy impurities



Effect of Edge Temperature



$n_a = 2 \times 10^{20}$

$Z_{eff} = 1.2$

O + 1% Mo

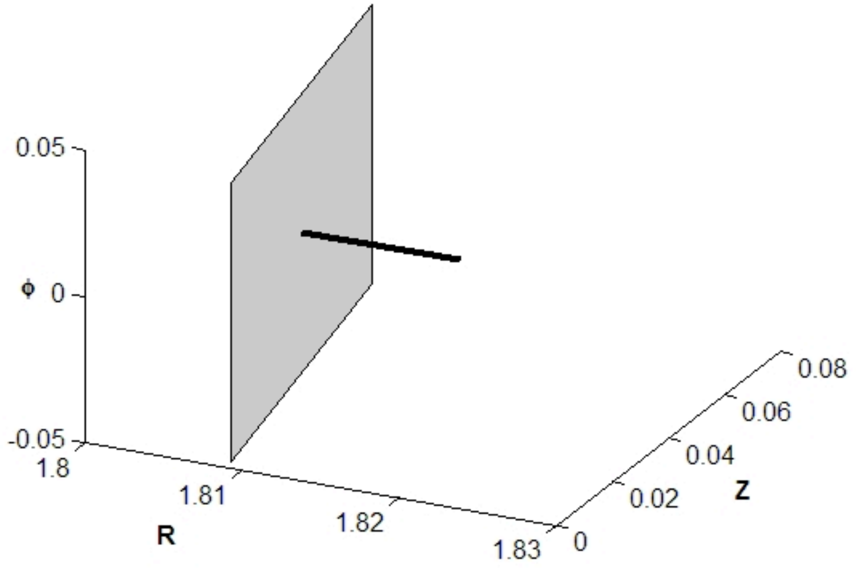
Geometrical model

- The so-called *cosine model* [1] involves some important physical simplifications but accurately accounts for the full (3D) geometry of the plasma column-first wall configuration, particularly when the real magnetic plasma configuration is introduced.
- This model is applied to estimate the power loads onto the first wall in both nominal and displaced configurations.

C. Ferro and R. Zanino, ENEA Report RT/FUS/89/26, Dec. 1989.

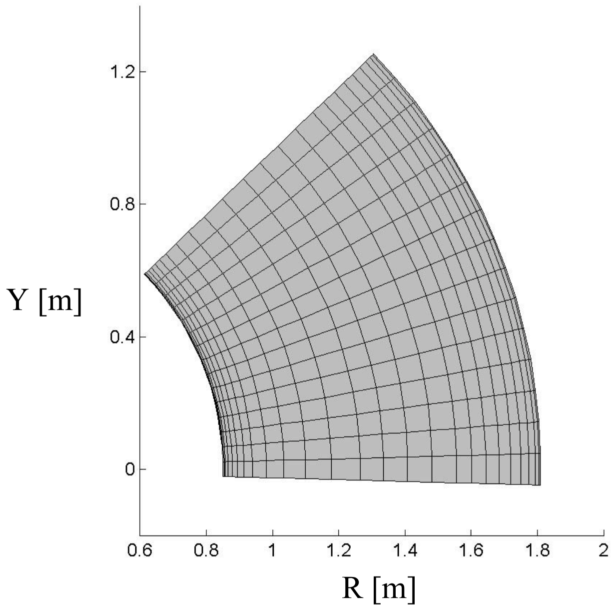
Schematization of the FW

- The FW is built as a set of independent elemental surfaces.
- Each elemental surface can be:
  - Moved independently.
  - Oriented independently.
  - Refined (if necessary).

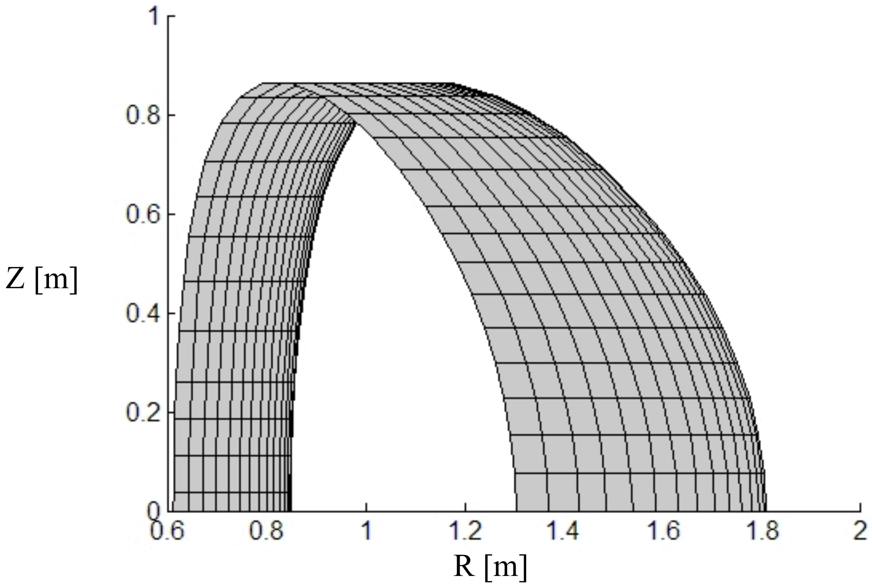


Two views of a portion of FW, obtained by joining many elemental surfaces

Upper view

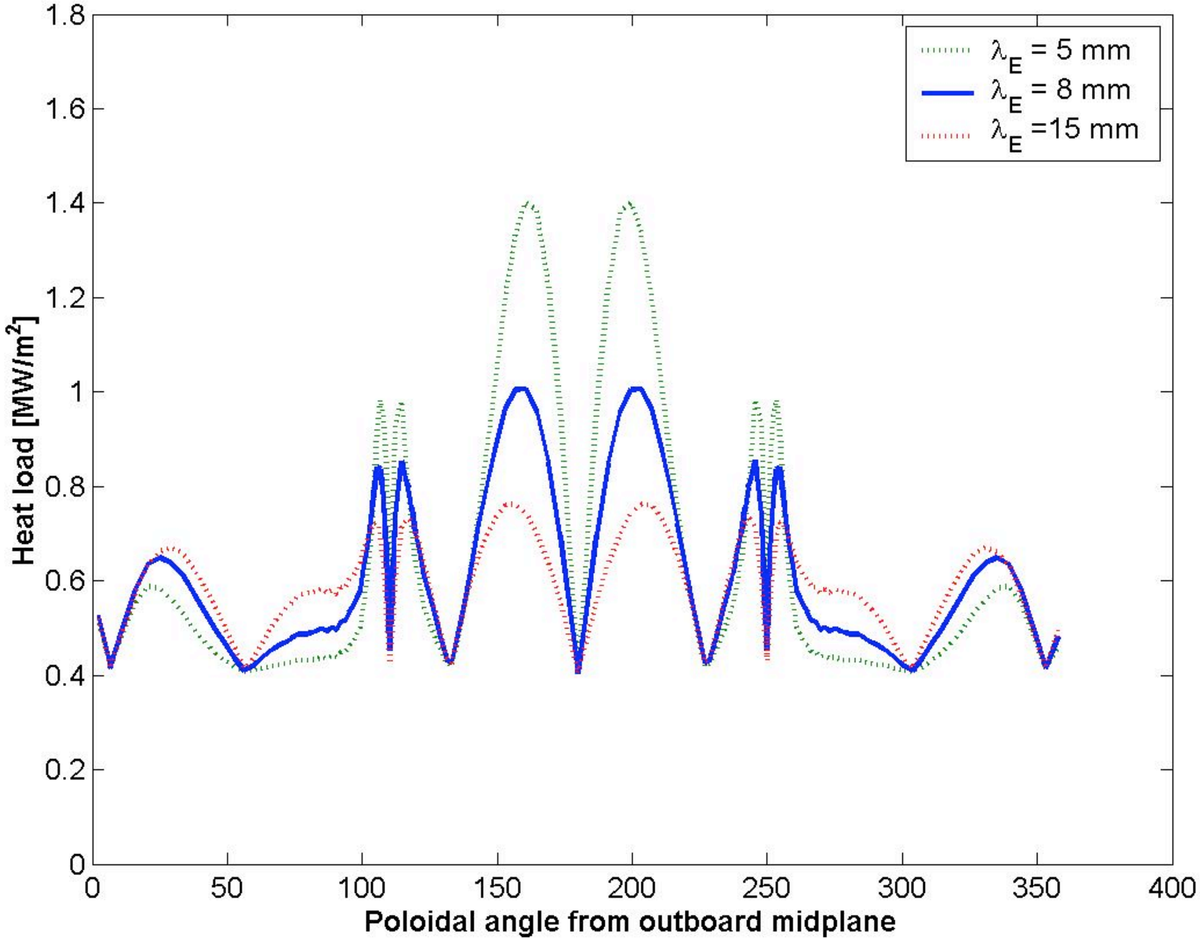


Lateral view

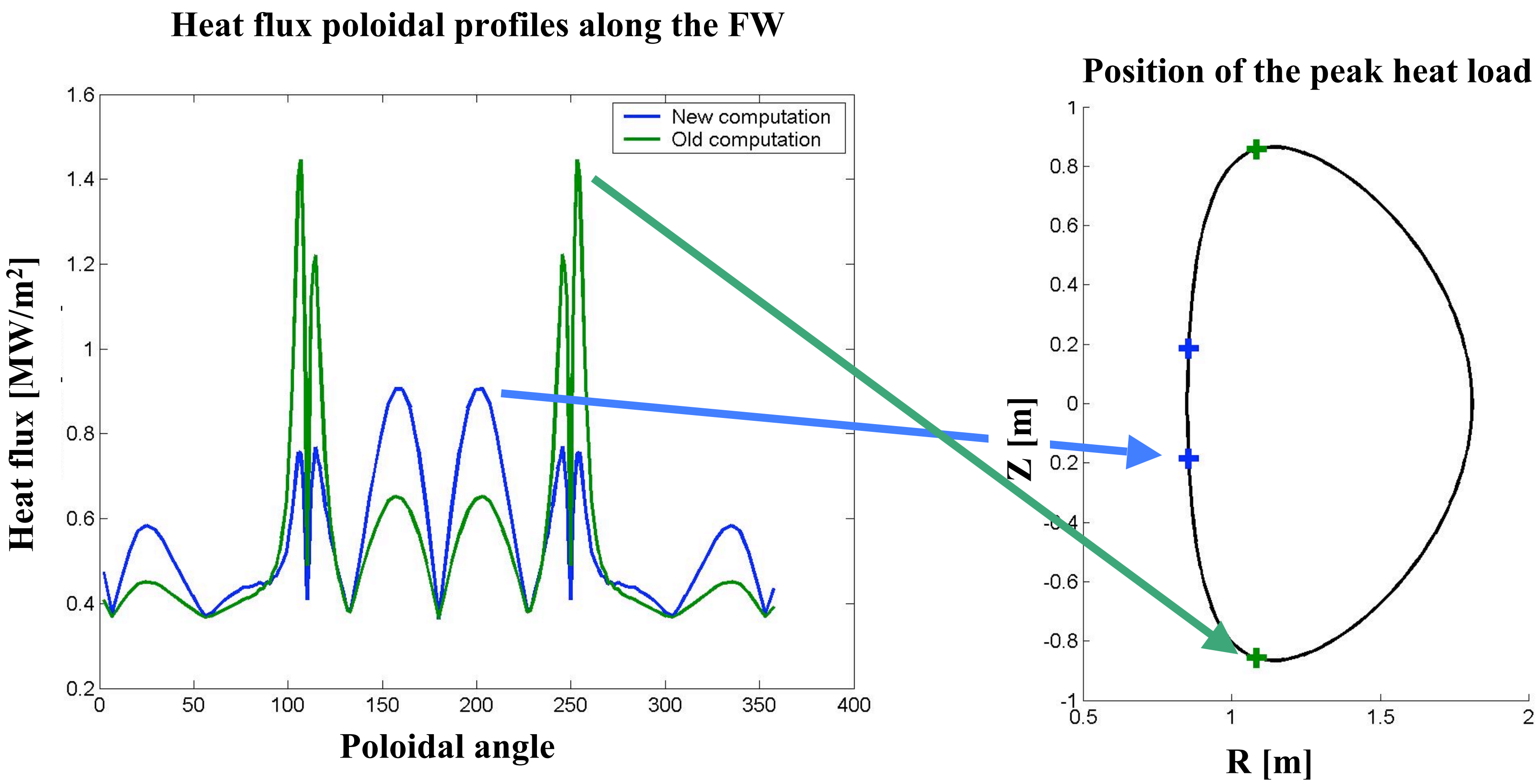


The nominal (axisymmetric) 2D configuration

P_{in} = 20 MW, P_{rad} = 14 MW (= 70%)



A difference is found with respect to previous estimates, for the same input parameters, due to the approximation $B_\theta/B=const.$



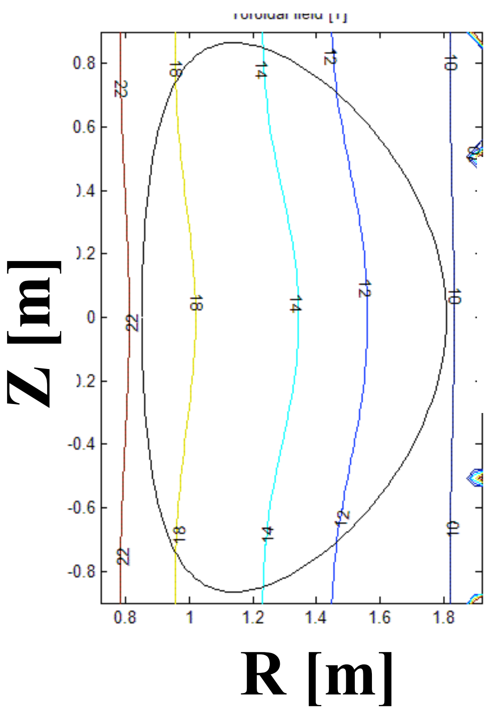
Heat flux poloidal profiles along the FW

Position of the peak heat load

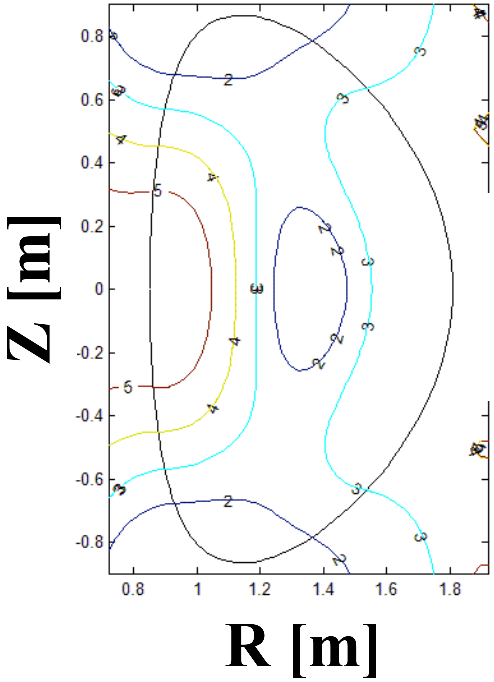
$P_{in} = 18$ MW; $P_{rad} = 12.6$ MW; $\lambda_E = 8$mm

Computed equilibrium

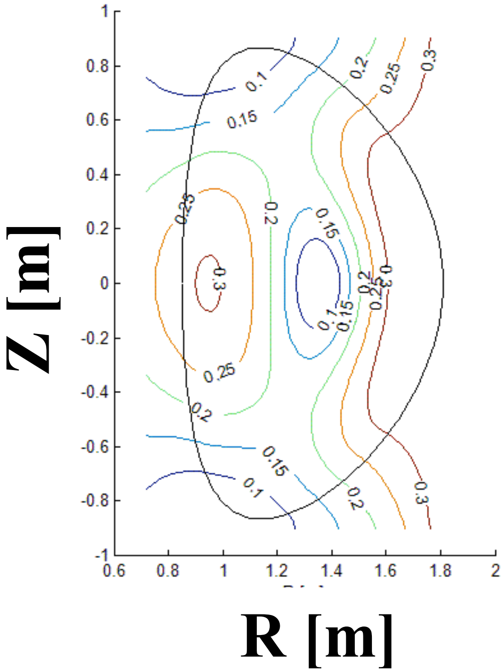
B



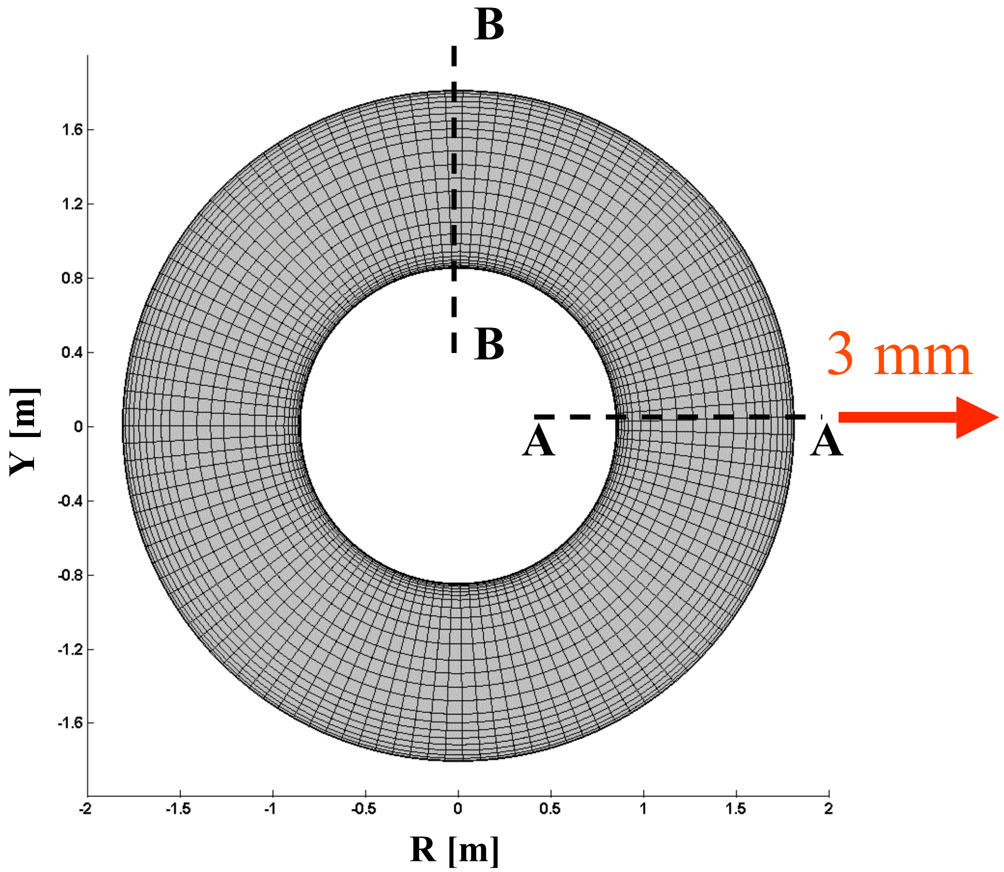
B_{pol}



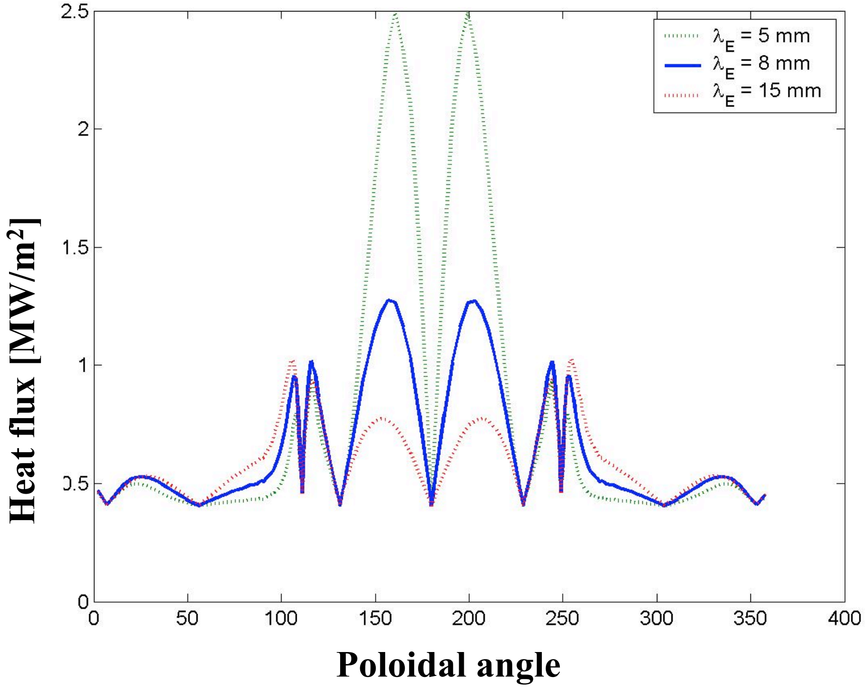
B/B_{pol}

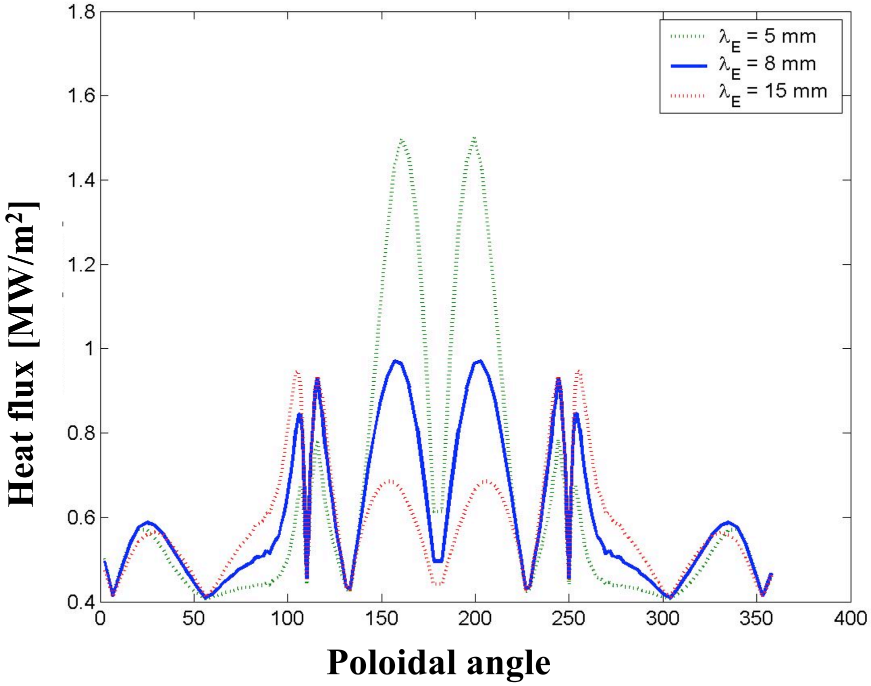


Horizontal displacement of the FW relative to the plasma



Heat load profiles along FW cross sections at 0 and 90 toroidal degrees

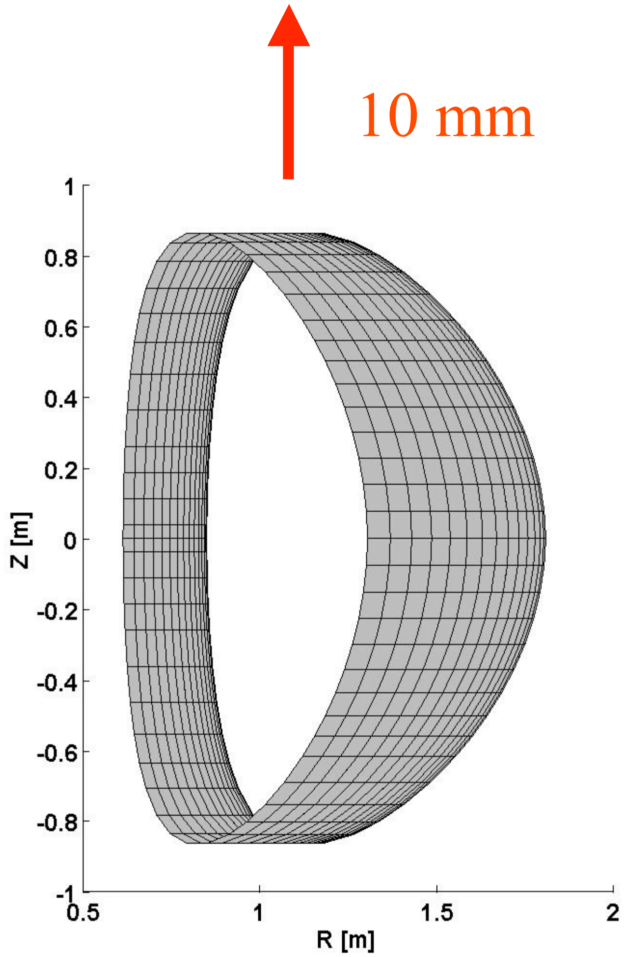

Section A-A


Section B-B

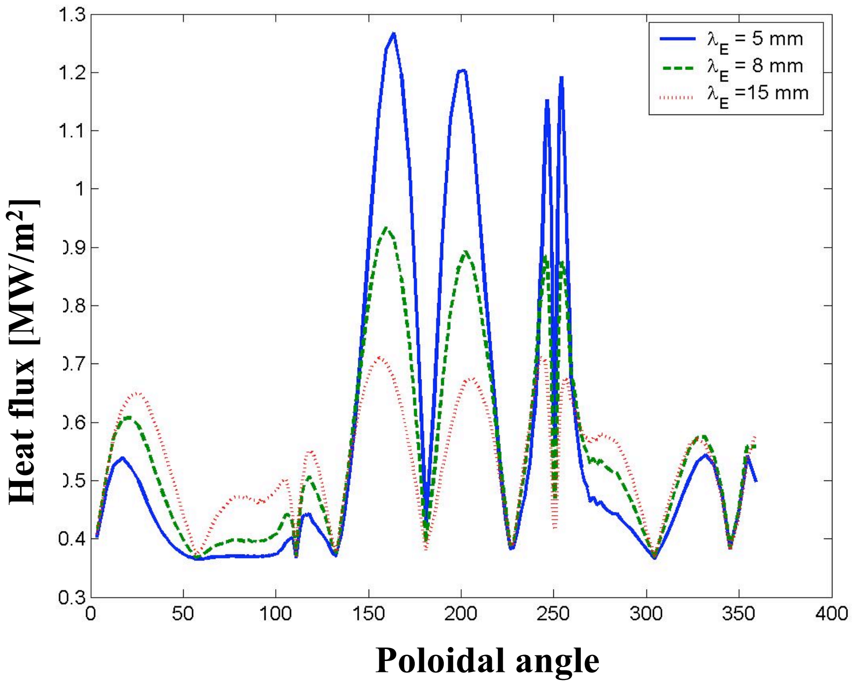
- For the most loaded poloidal section the peak heat flux increases by roughly a factor 2

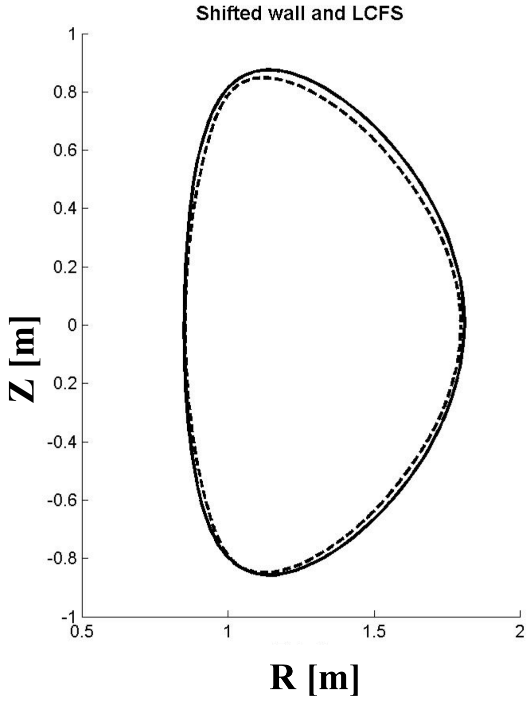
- At different toroidal locations, the peak heat flux can be located at different poloidal positions.

Vertical displacement of the FW relative to the plasma



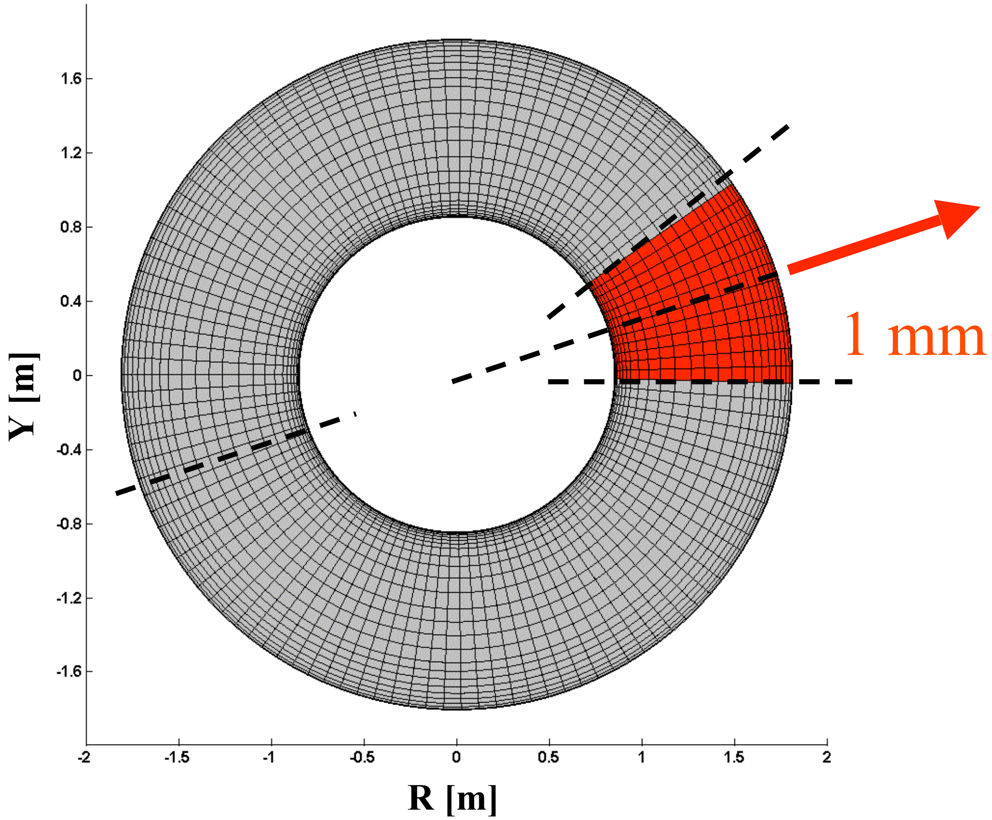
Heat flux profiles for different λ_E along a vertically shifted FW





- No toroidal asymmetry is introduced be a vertical wall displacement.
- However, strong up-down asymmetry is created
- The maximum heat flux does not vary substantially with respect to the nominal configuration.
- However, strong secondary maxima are created at the bottom of the FW.

Horizontal displacement of a single FW sector

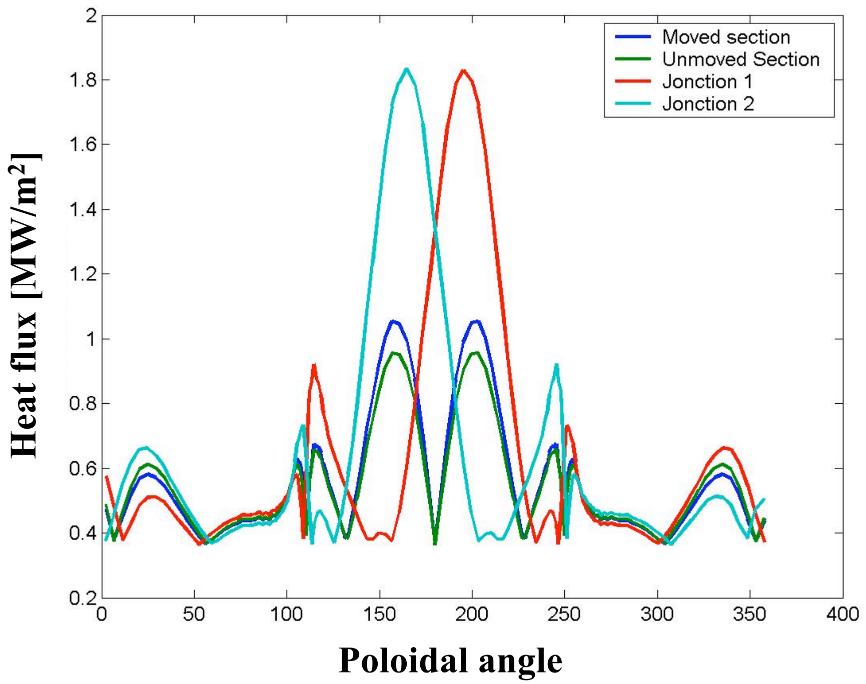


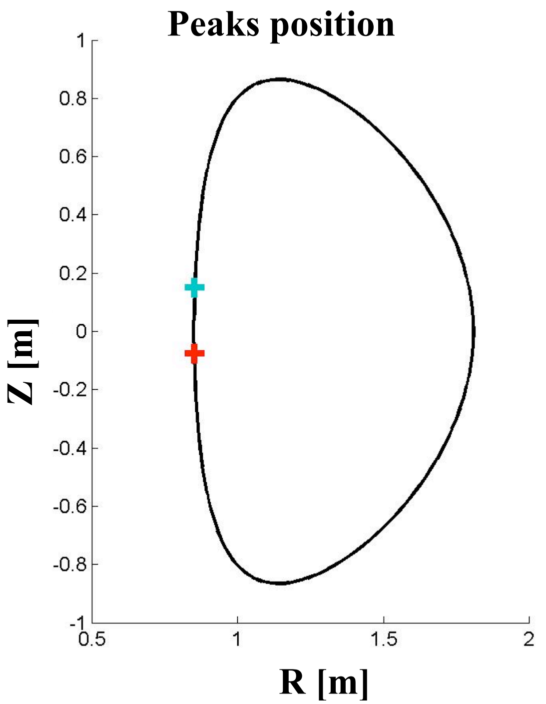
Assumptions used in the analysis

- Each sector of the machine is formed by ½ + 2 + ½ tile carriers (toroidally adjacent).
- Each whole tile carrier comprises 2 poloidal tile rows (toroidally adjacent).
- The ½ tile carrier are shared with the neighbouring sectors.
- Each tile has a toroidal length of about 7 cm (at the inner torus circumference …)
- No sharp leading edges …

Heat flux poloidal profiles for different FW sections, and poloidal location of the peak fluxes

(P_{in} = 18 MW; P_{rad} = 12.6 MW; λ_E = 8mm)





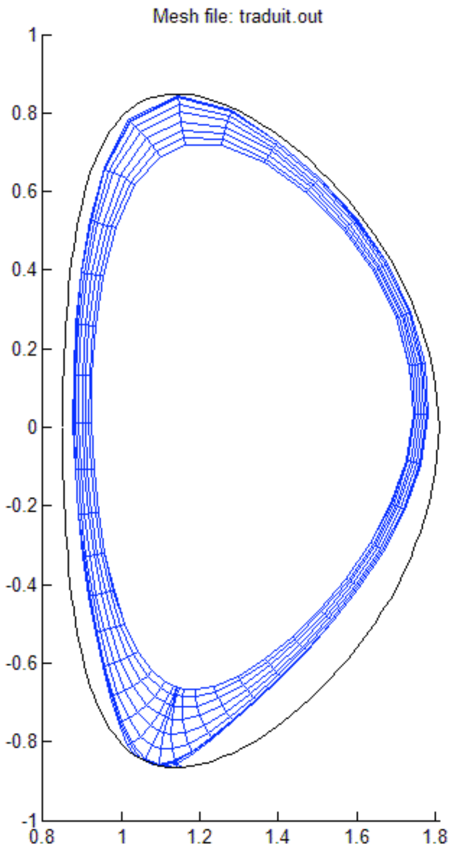
- The maximum heat flux is expected on the junction tiles, due to their finite inclination respect to the toroidal direction
- The maximum is about 2 times the maximum at the nominal configuration.

B2 Modelling of Ignitor

- A more physically comprehensive 2D model of the IGNITOR scrape-off layer was attempted by applying the finite-volume B2 code.
- This code suffers of severe limitations in the case of a limiter geometry, originating from the adoption of a quadrilateral structured grid [2].

[2] F. Subba, and R. Zanino *Modeling Plasma-Wall interactions in IGNITOR*, to appear in *Computer Physics Communications*, **vol 164/1-2***,* December 2004.

“*Ad hoc*” Configurations



- Quasi-symmetric configurations with X-point on the FW and an artificially deformed chamber allow to build a grid, but:
- lead to a very distorted mesh in the X point region.
- The fraction of first-wall actually seen by the code (i.e. intersected by the mesh) is very little. Most of the outer boundary is artificial.

⇒Problems to impose the boundary conditions.

⇒Problems in interpreting the results.

⇒Unrealistic geometrical representation of the wall.

In alternative…

- Approaches based on control-volume finite elements over a triangular grid can guarantee a much larger geometrical flexibility [3]. The application of this class of methods to the IGNITOR case is currently being investigated.

[3] Baliga B.R., *Control-Volume Finite Element Methods for Fluid Flow and Heat Transfer*, Advances in Numerical Heat Transfer, **1**, 97-135, (1996).

Conclusions

- A high radiated fraction can be ensured by the presence of small amounts of intrinsic impurities.
- The effects of the geometrical configuration on the heat load of the IGNITOR FW has been reviewed, removing a hypothesis on the magnetic equilibrium. As a consequence:
  - Peak heat load are reduced.
  - Peak heat load are displaced.
- A few non axisymmetric configurations have been analysed, determining the value and position of the maximum heat flux.
  - With respect to the nominal configuration, the analyzed asymmetries cause an increase of the peak heat flux by up to a factor ~ 2.

A study of the combined effect of various asymmetries is in progress