MAX-PLANCK-INSTITUT
FÜR PLASMAPHYSIK

# Divertor concept development for the W7-X stellarator experiment


Indigo: https://event.ipp-hgw.mpg.de/category/63/

https://datashare.mpcdf.mpg.de/s/EPkFnQ5TXRYoNV8

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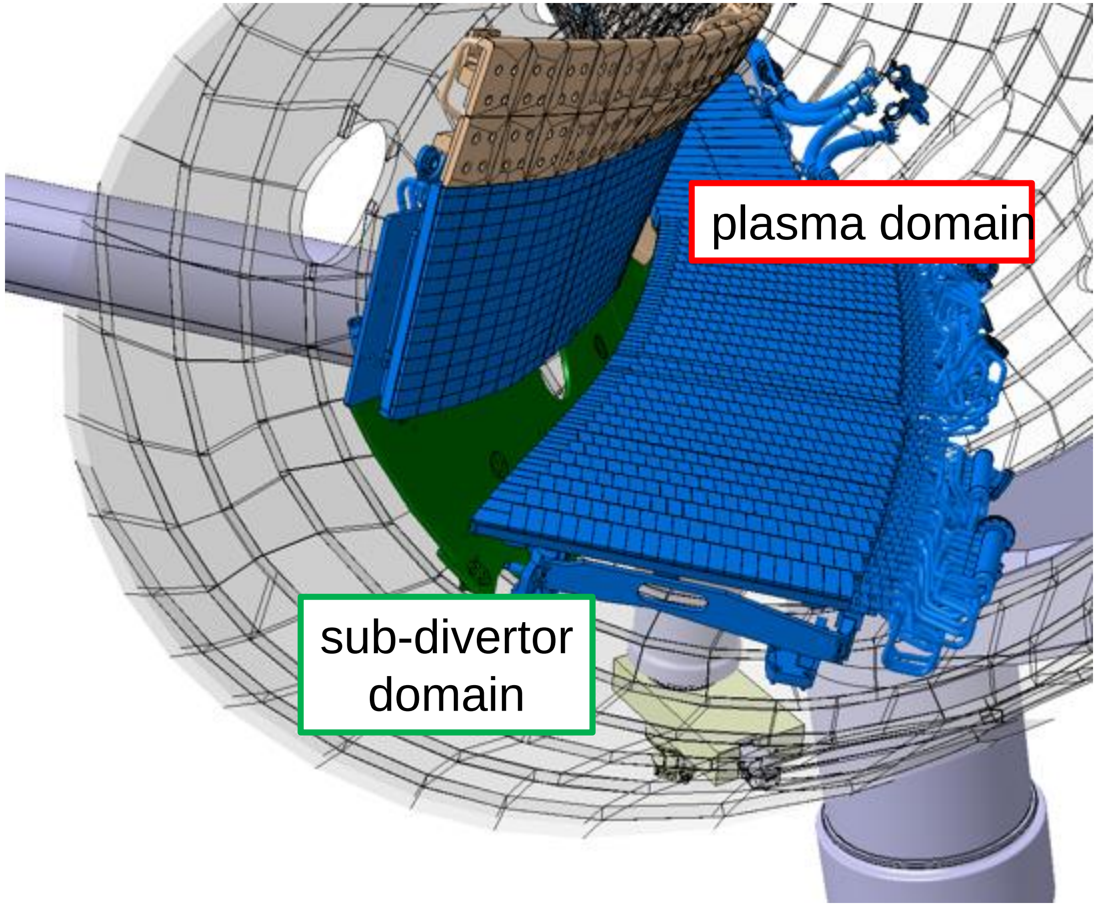
# Geometry modifications

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**Definition of the plasma facing surface (PFS)**

# W7-X Divertor setup OP3 – designs proposed in the past

case I: island divertor for tokamaks/stellarators

case II: open/closed divertors for W7-X

case IIIa,b: divertor for Helias reactor HSR4/18

# Island divertor for tokamaks/stellarators (1977)

Volume 61A, number 6 PHYSICS LETTERS 13 June 1977

## RESONANT HELICAL DIVERTOR

F. KARGER and K. LACKNER
*Max-Planck-Institut für Plasmaphysik, 8046 Garching bei München, FRG*

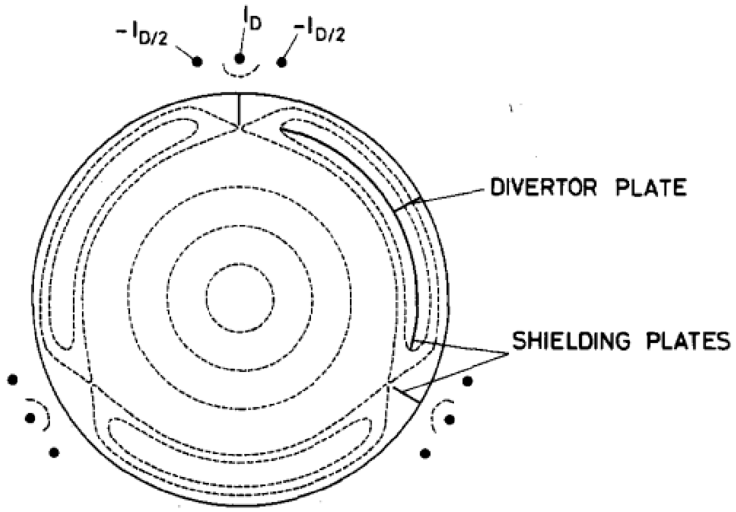



Fig. 5. Cross section of a helical divertor with triplet helical windings outside the vacuum chamber and shielding plates only in the outer section of the torus (resonance at $q = 3$, $I_D/I_p = 0.08$).

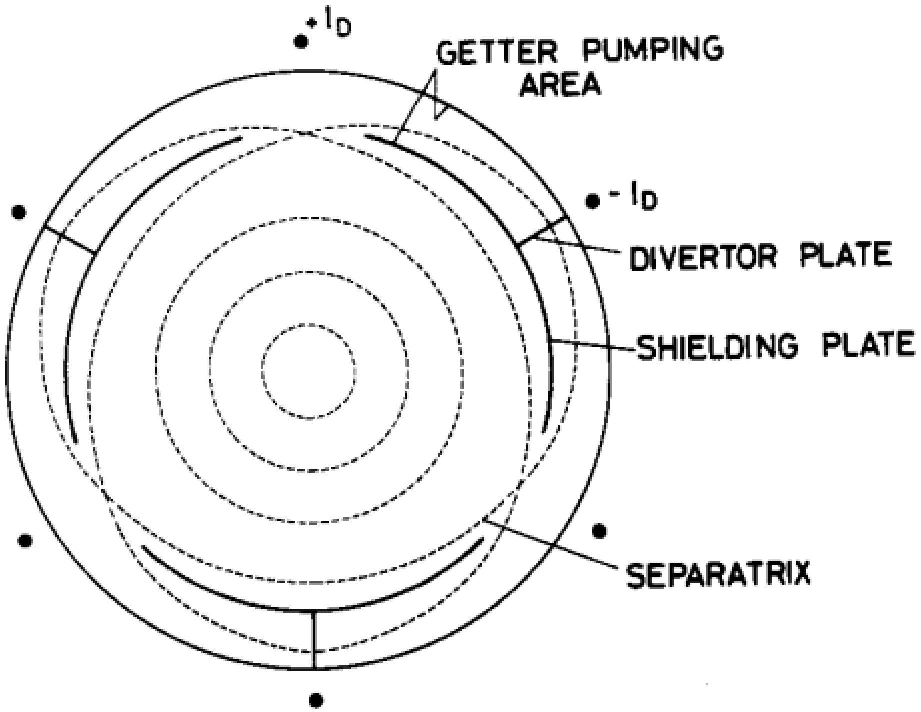



Fig. 1. Schematic picture of the cross-section of a helical divertor with resonance at $q = 3$ ($I_D/I_p = 0.01$).

# open/closed divertors for W7-AS (2000)

Contrib. Plasma Phys. **40** (2000) 3–4, 238–250

**Island Divertors for Helical Devices**

F. SARDEI, Y. FENG, J. KISSLINGER AND W7-AS TEAM

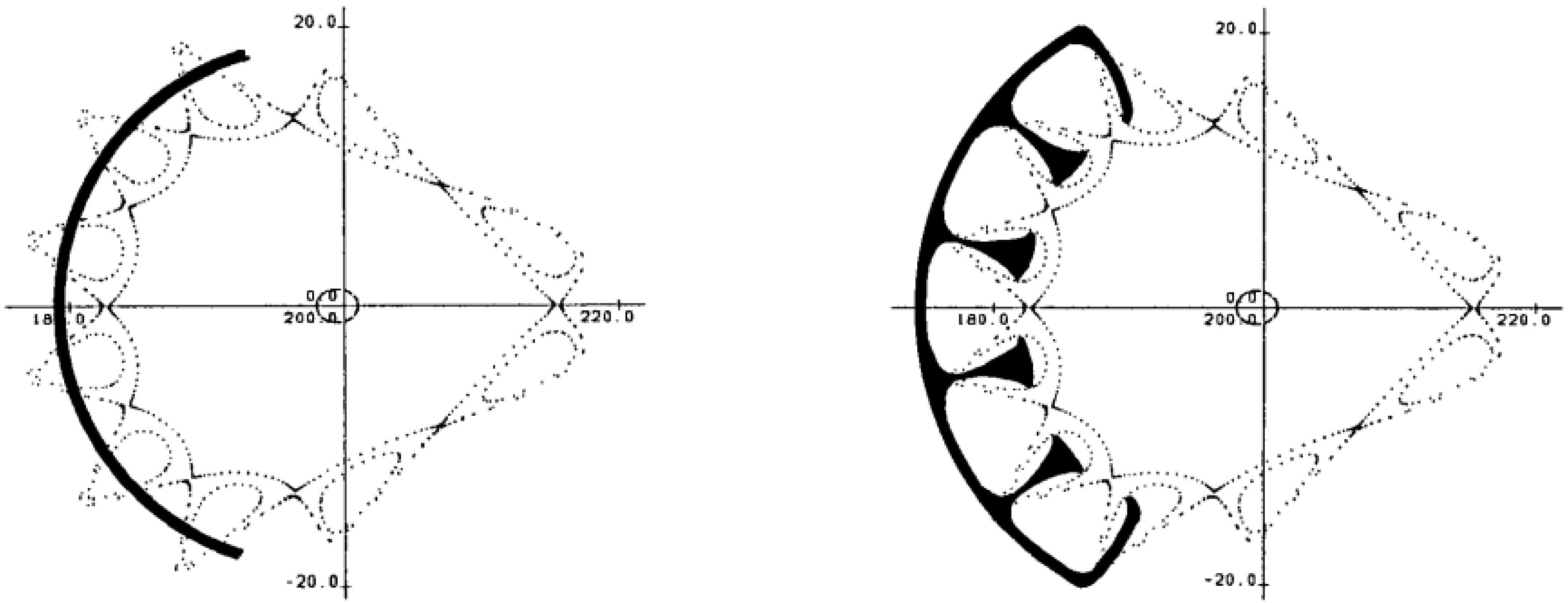



Fig. 1: First proposal of an open (left) and "closed" (right) ID geometry, applied to a W7-AS island configuration.

# Divertor setup OP3 (IIIa) Helias reactor HSR4/18 (2001)

| |
|---|
| power exhaust |
| particle removal |
| impurity control |

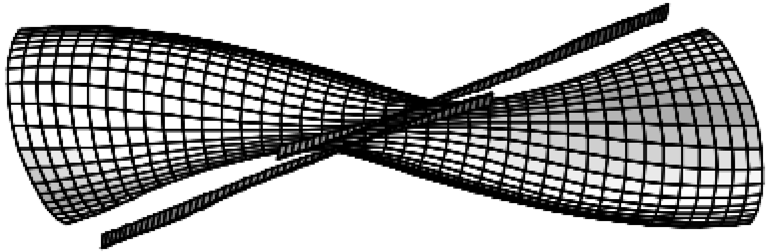


**Figure 6.** One period of the magnetic surface and divertor target plates of HSR4/18, seen from outside. Baffle plates are not shown.

Toroidally, the target and baffle plates extend until the next symmetry plane, as shown in Fig. 6. The heat load on the target plates is a critical issue; preliminary computations indicate a thermal load of more than 10 MW/m$^2$.

large technical effort in W7-X

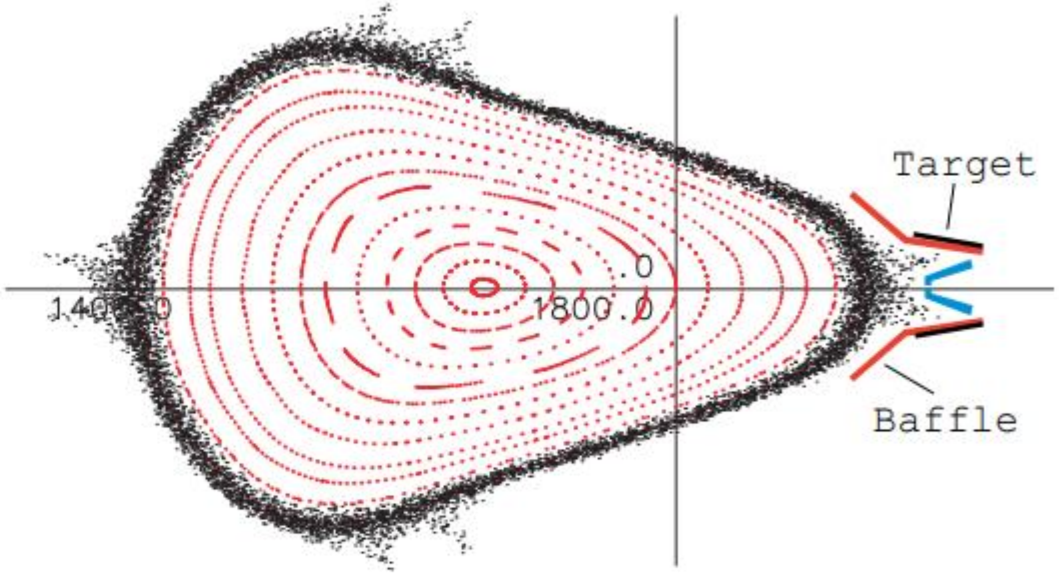
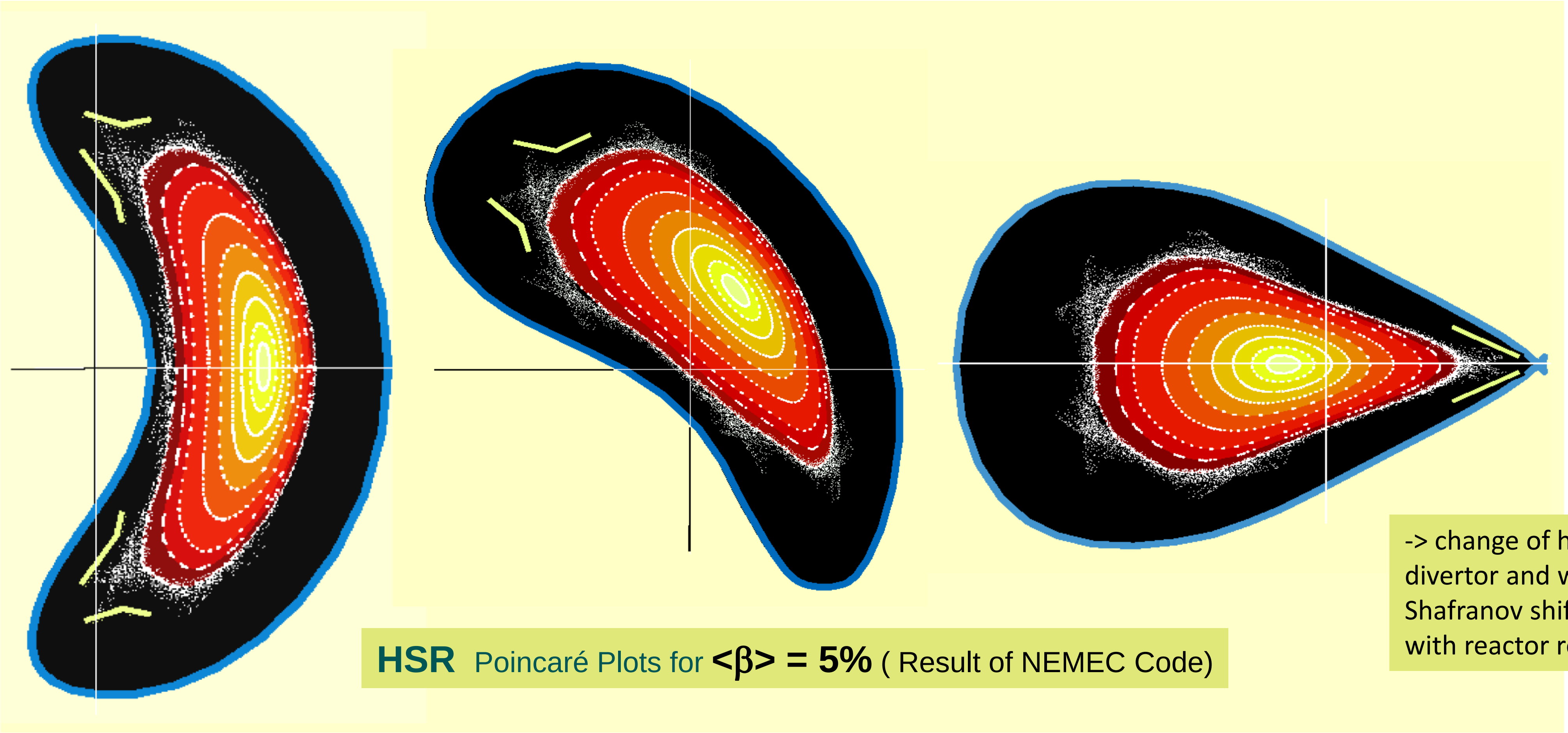



**Figure 5.** Poincaré plot of magnetic surfaces and the scrape-off layer in the symmetry plane $\varphi = 45°$. The stochastic region is created by the intersection points of diffusing particles.

Source: C.D. Beidler et al 2001 Nucl. Fusion 41 1759 [https://iopscience.iop.org/article/10.1088/0029-5515/41/12/303/meta]

# Divertor setup OP3 (IIIb) Helias reactor HSR4/18 (2005)

| power exhaust |
| --- |
| particle removal |
| impurity control |




-> change of heat load on divertor and wall due to Shafranov shift is compatible with reactor requirements

$\varphi = 0°$ $\varphi = 18°$ $\varphi = 36°$

Source: M. Hirsch, IPP Summer University for Plasma Physics, Greifswald, Germany, 25 - 30 Sept. 2005

# W7-X Divertor setup OP3 – design modification ideas

- case A: targets at the x-points
- case B: closure with target surfaces
- case C: closure with baffles, with dome
- case D: one target plate setup
- case E: O-point centered target
- case F: standardized sections (O-point centered)
- case G: O-point centered target plates
- case H: conservative approach
- case I: “open grill” setup with moving panels
- case J: deep slot divertor
- case K: fully detached divertor concept

- start with power exhaust analysis for attached conditions: definition of modified geometries meeting two criteria:
  1. keep maximum heat load below 10 $MW/m^2$ with a heating power of at least 10 MW,
  2. keep the heat load only on the divertor targets (> 95%).
- evaluate modified geometries against particle removal requirements
- identify potential impurity retention drawbacks

# Divertor setup OP3 (A) – targets at the x-points

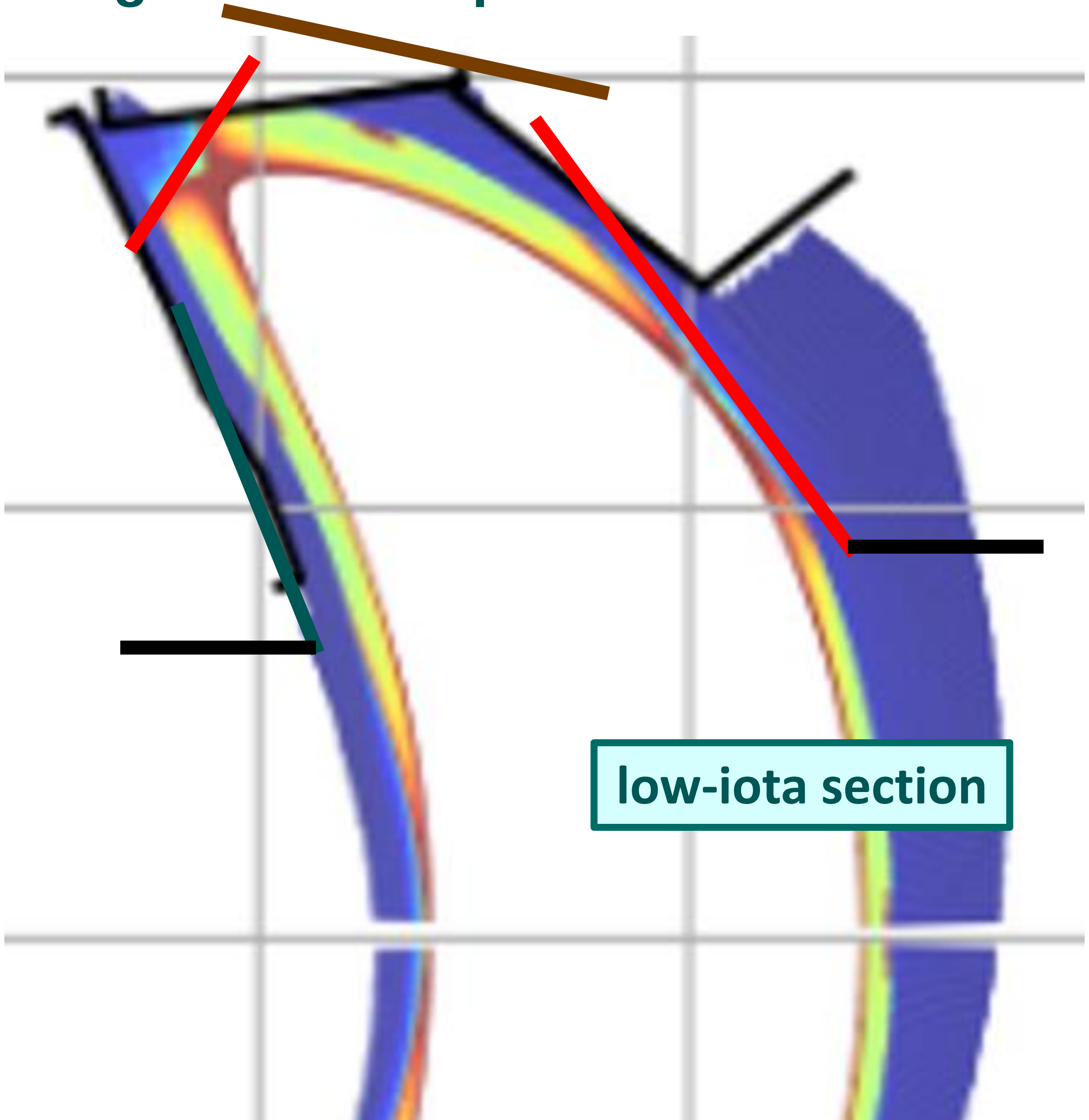
power exhaust
particle removal
impurity control

**reflector plate**
**shielding liner**
**target surface**
**baffle**

+ radiation loads, also with simplified model
- radiating x-lines
- radiating high-energy 3D surface

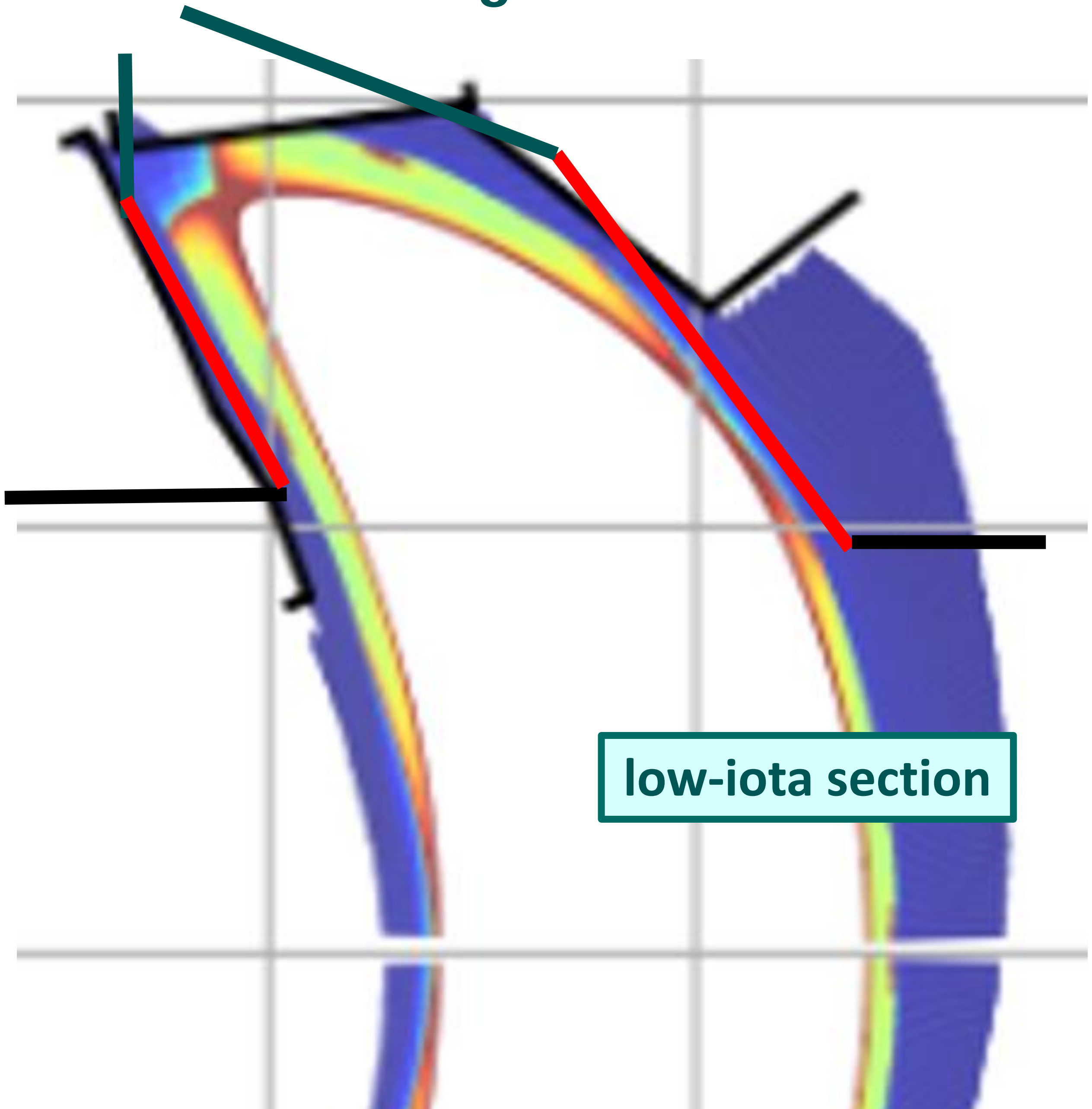
size of pumping gap should be optimized

excessive loads to wall sub-divertor components should be avoided by shielding plates



# Divertor setup OP3 (B) – closure with target surfaces

reflector plate
shielding liner
target surface
baffle



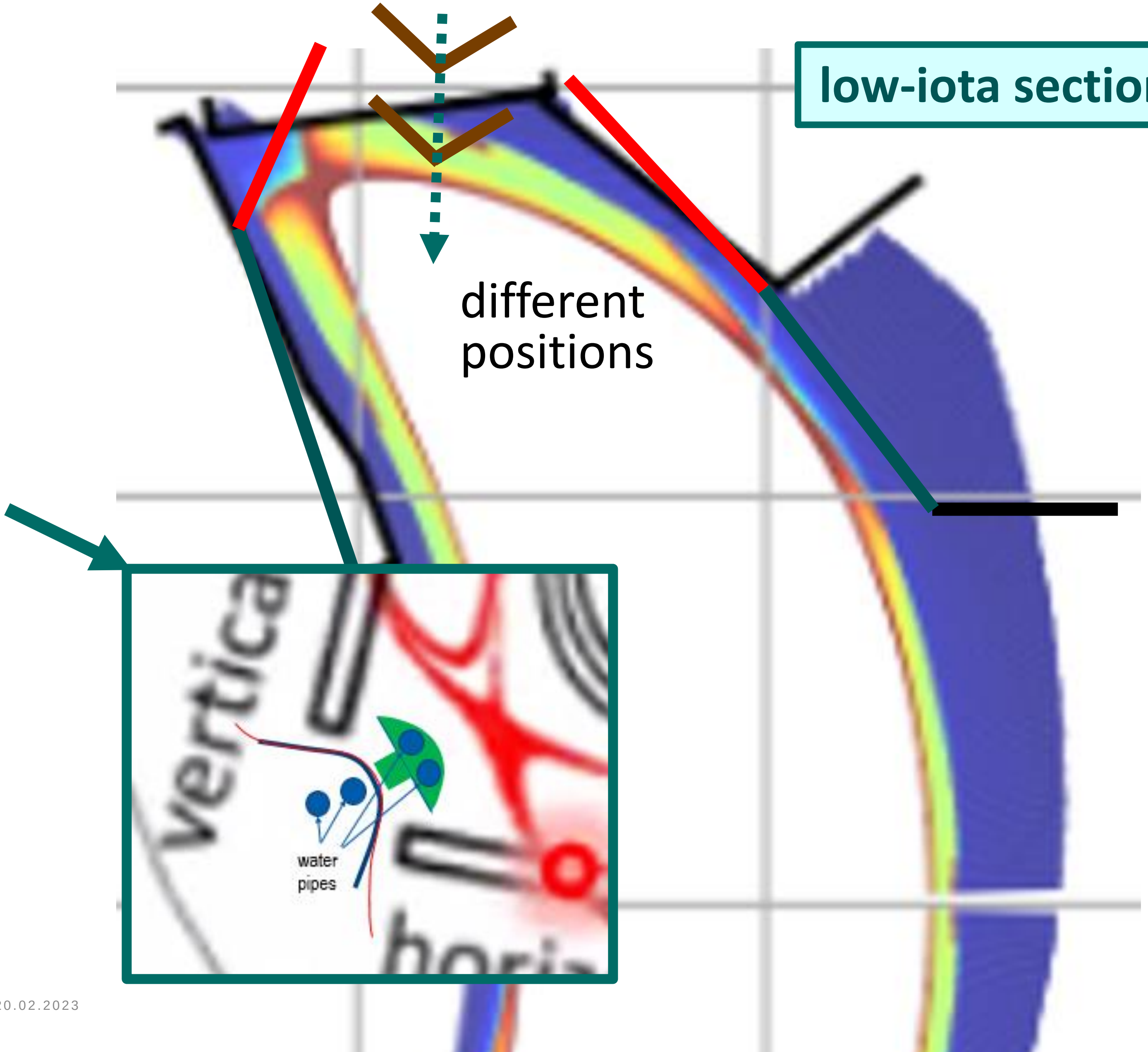

| |
|---|
| power exhaust |
| particle removal |
| impurity control |

# Divertor setup OP3 (C) – closure with baffles, with dome

| |
|---|
| power exhaust |
| particle removal |
| impurity control |

**reflector plate**
**dome**
**target surface**
**baffle**

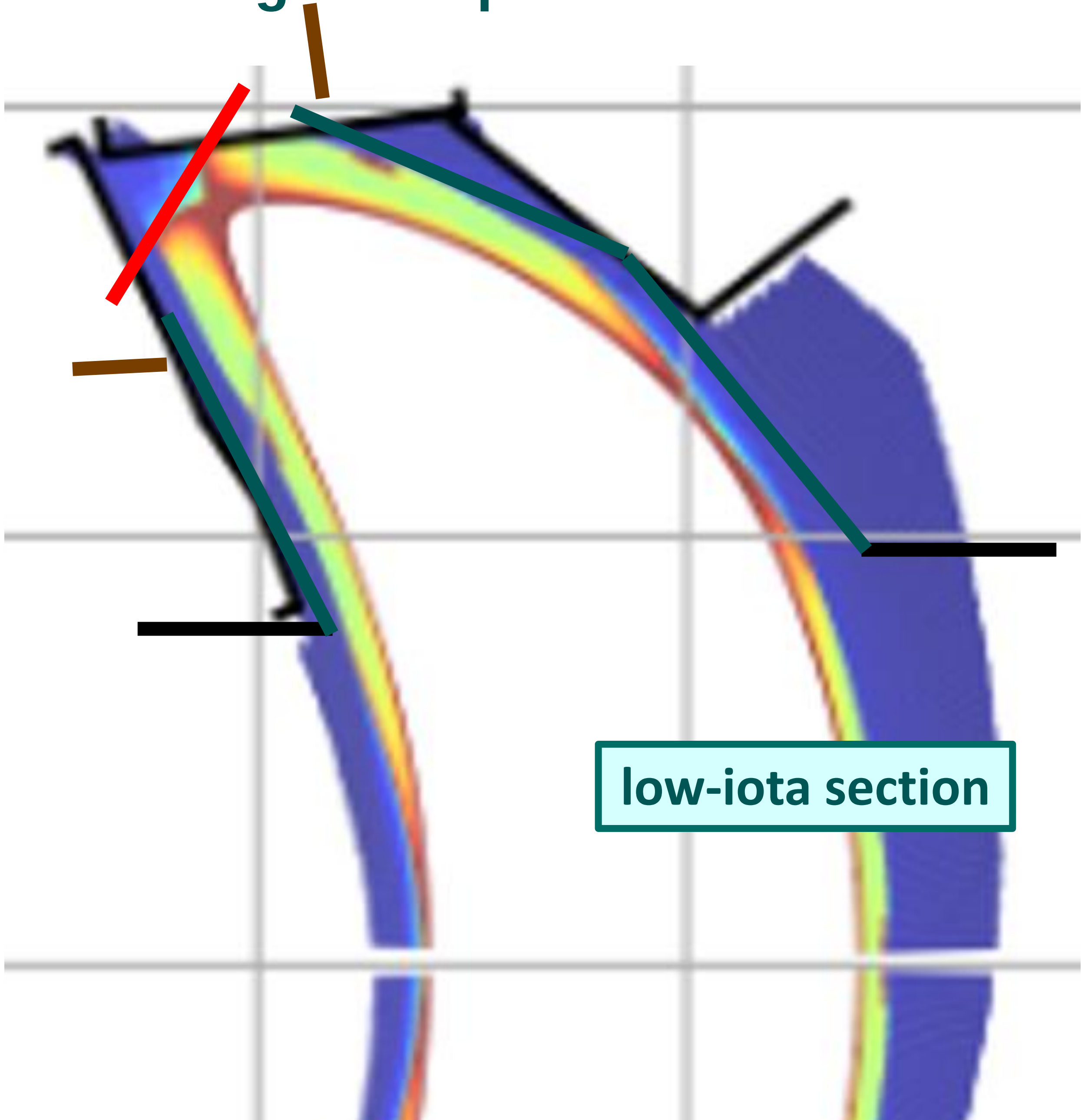
R. König: doom position (inside/behind the gap or outside the gap), gap widths, reflection angles, more sophisticated 3D guiding shapes to TMP & cryo-pumps to improve the ratio of influx versus outflux, vari open pathway to cryo-pump on the PV facing side of the doom



# Divertor setup OP3 (D) – one target setup

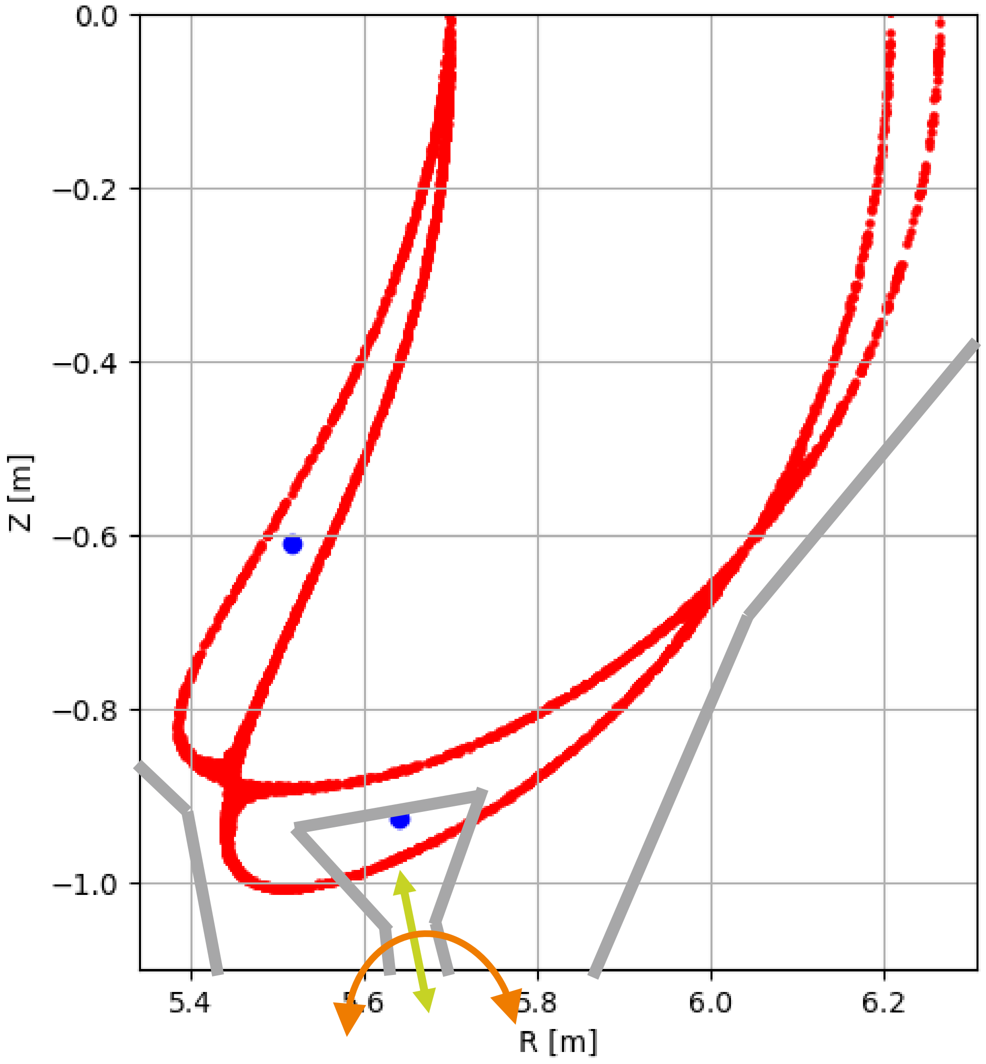
reflector plate
shielding liner
target surface
baffle

| |
|---|
| power exhaust |
| particle removal |
| impurity control |



# Divertor setup OP3 (E) – O-point centered target

- Dimension
- Offset
- Tilt




Source: A. Kharwandikar [https://event.ipp-hgw.mpg.de/event/574/]

| power exhaust |
| --- |
| particle removal |
| impurity control |

# Divertor setup OP3 (F) - standardized sections (O-point centered)

| |
|---|
| power exhaust |
| particle removal |
| impurity control |

- Build up neutral pressure

  **Optimize** $1 - \cos\varphi_{LCFS}$

- Block escaping neutrals

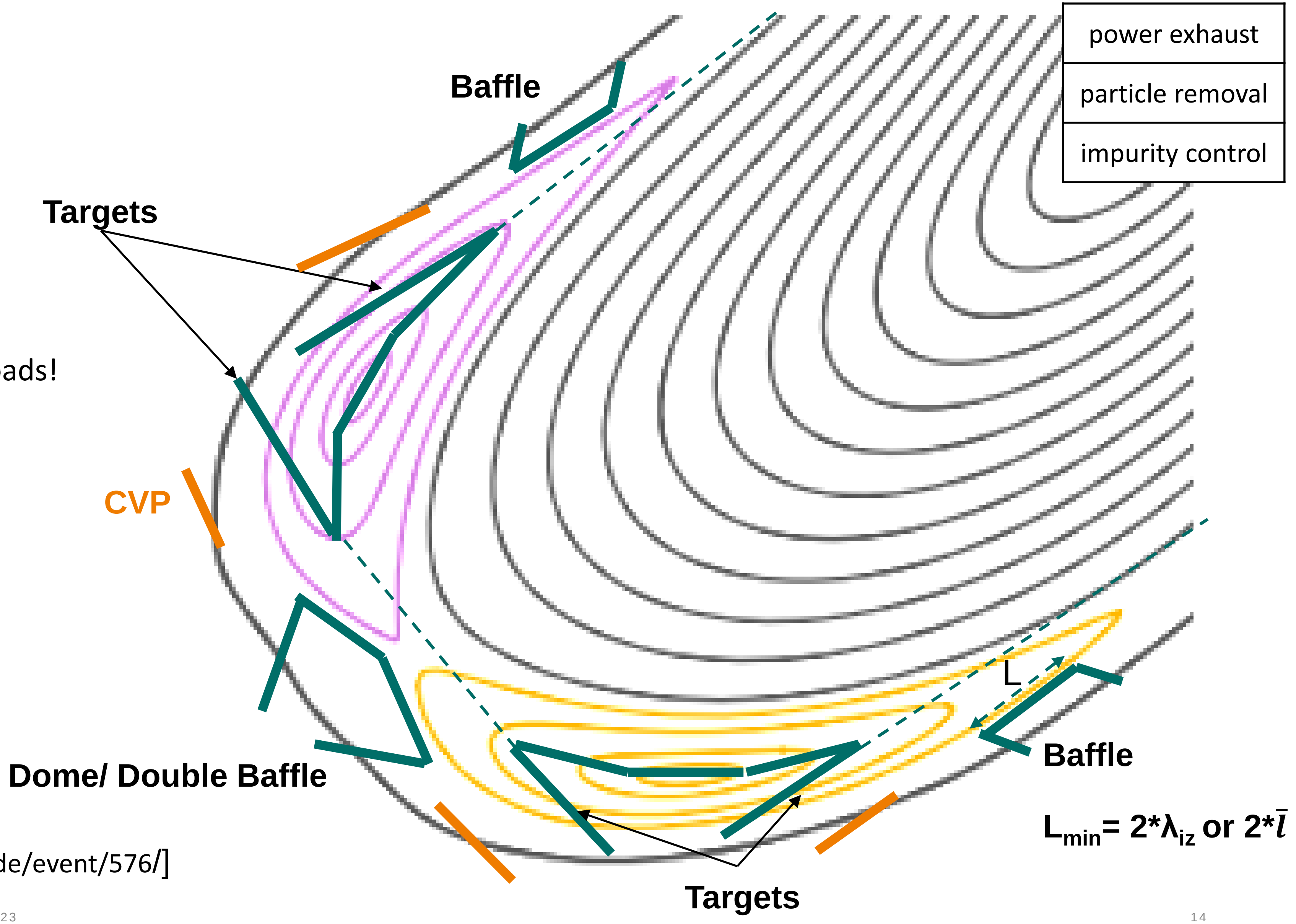
  Hardware (Baffles)  !Thermal loads!

  Re-Ionization

- Direct collection

  **Optimize** $\cos\varphi_{pumpgap}$

  CVP ideally normal to target



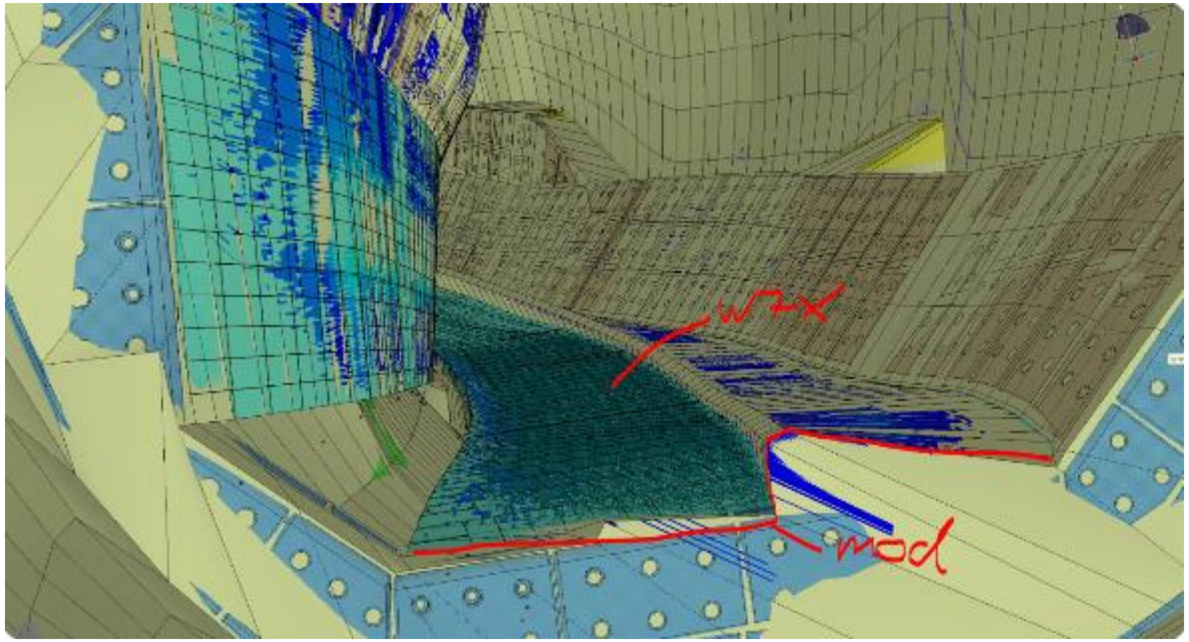

Source: T. Kremeyer [https://event.ipp-hgw.mpg.de/event/576/]

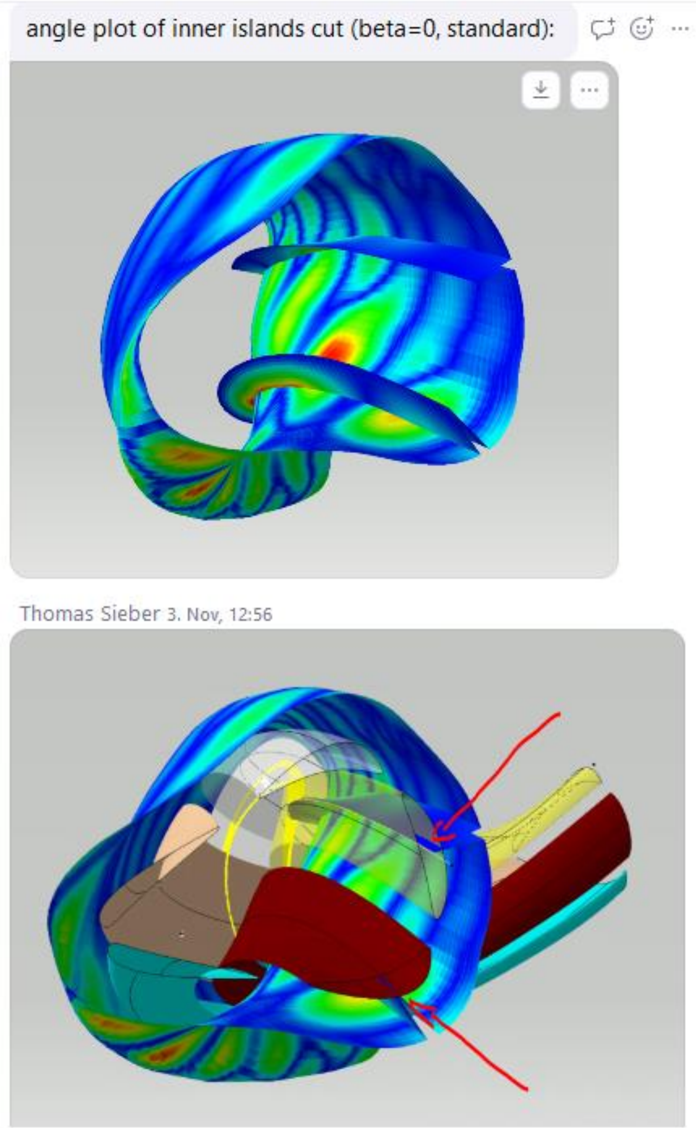
# Divertor setup OP3 (G) - O-point centered target plates

power exhaust

particle removal

impurity control




the outcome power is only 7.0198E+04 (in: 1E+05)

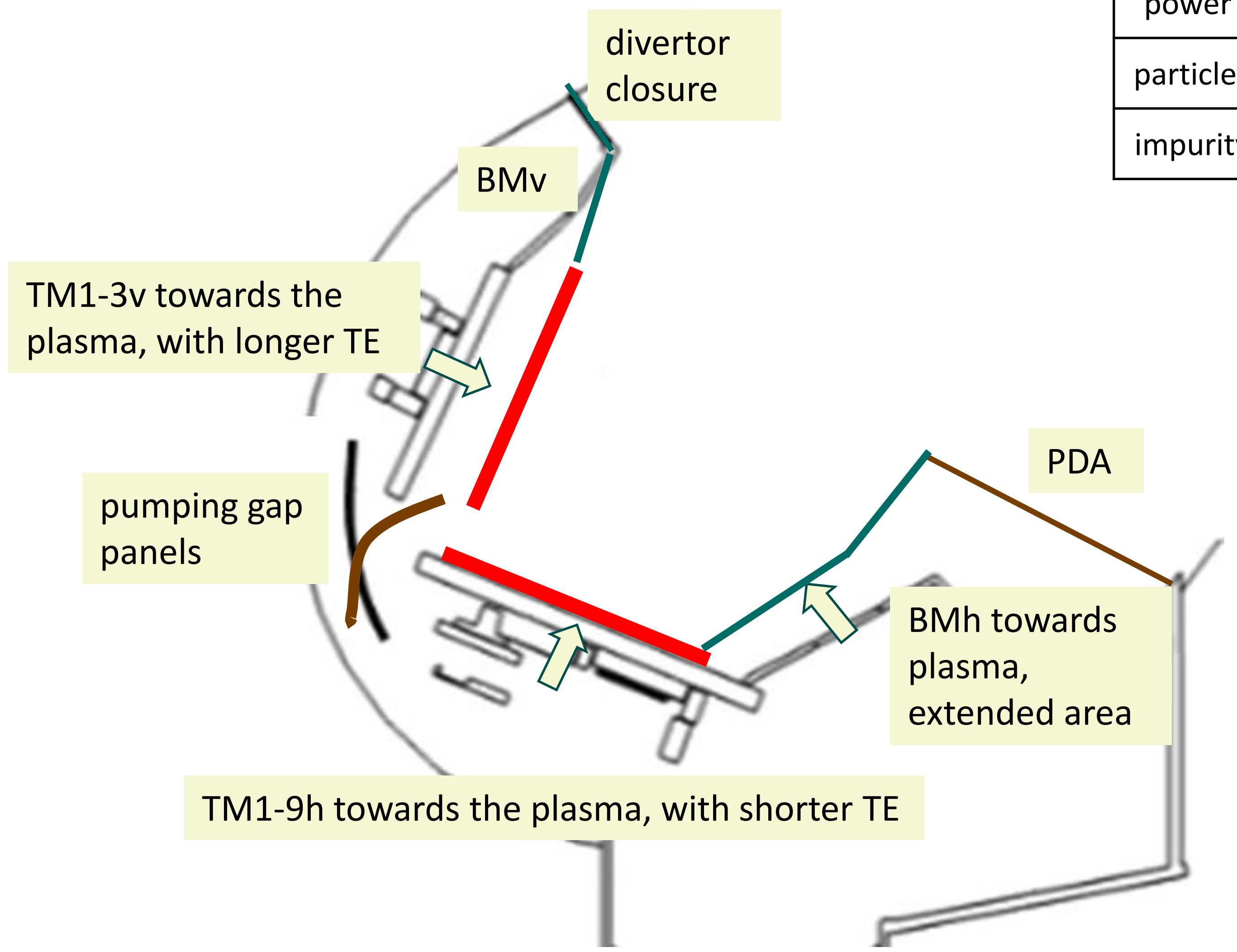
Source: T. Sieber [zoom DivertorMods, 29.9.2023, 3.11.2023 ]

# Divertor setup OP3 (H) – conservative approach (low iota part)

| |
|---|
| power exhaust |
| particle removal |
| impurity control |

**reflector plate**
**shielding liner**
**target surface**
**baffle**

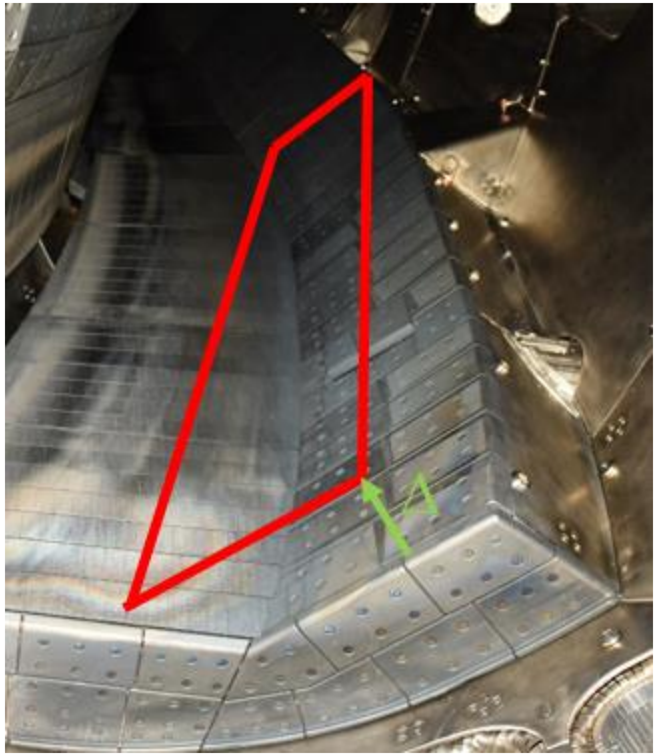
FTM: moving TM1-4v towards the plasma would result in larger core radiation (see in https://event.ipp-hgw.mpg.de/event/570/)

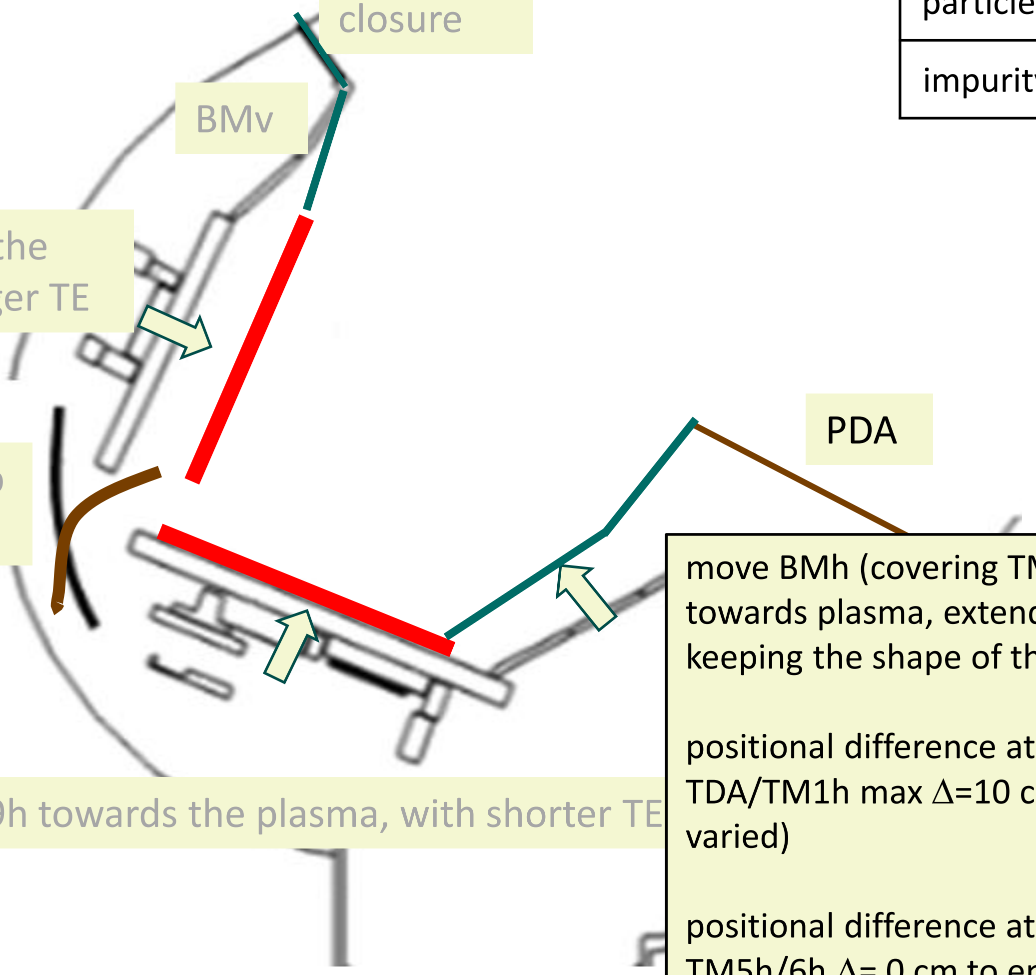


# Divertor setup OP3 (H) – conservative approach (low iota part)

| |
|---|
| power exhaust |
| particle removal |
| impurity control |

**reflector plate**
**shielding liner**
**target surface**
**baffle**






move BMh (covering TM1h-4h) towards plasma, extending PDA, keeping the shape of the BMh

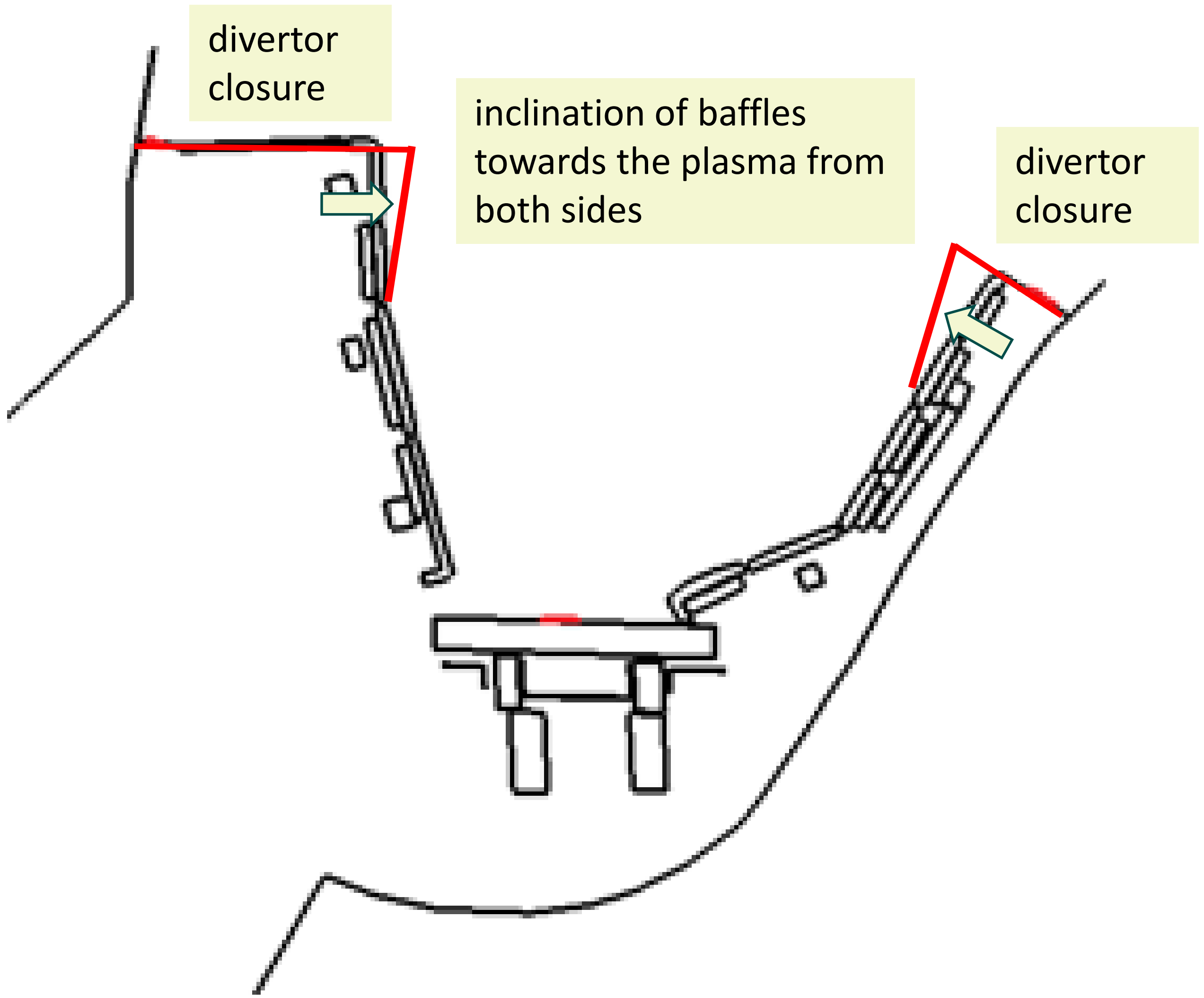
positional difference at TDA/TM1h max $\Delta$=10 cm (to be varied)

positional difference at the TM5h/6h $\Delta$= 0 cm to ensure smooth transition to the unchanged outer baffle areas

# Divertor setup OP3 (H) – conservative approach (high iota part)

| |
|---|
| power exhaust |
| particle removal |
| impurity control |

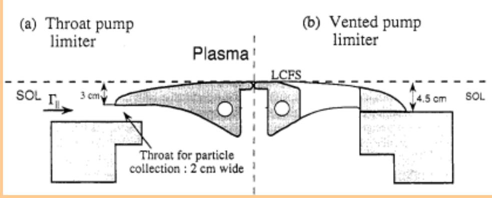
reflector plate
shielding liner
target surface
baffle



# Divertor setup OP3 (I) – “open grill” setup with moving panels

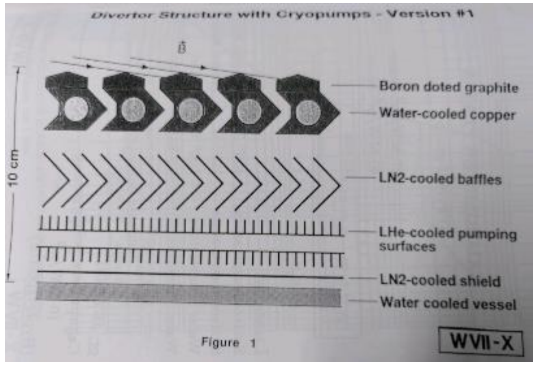
power exhaust
particle removal
impurity control

- EMC3/Eirene studies for „vented“ structures are planned by D. Boeyaert for the ISHW 2024,
- T. Loarer et al 1996 Nucl. Fusion 36 225 Particle exhaust with a vented pump limiter on Tore Supra

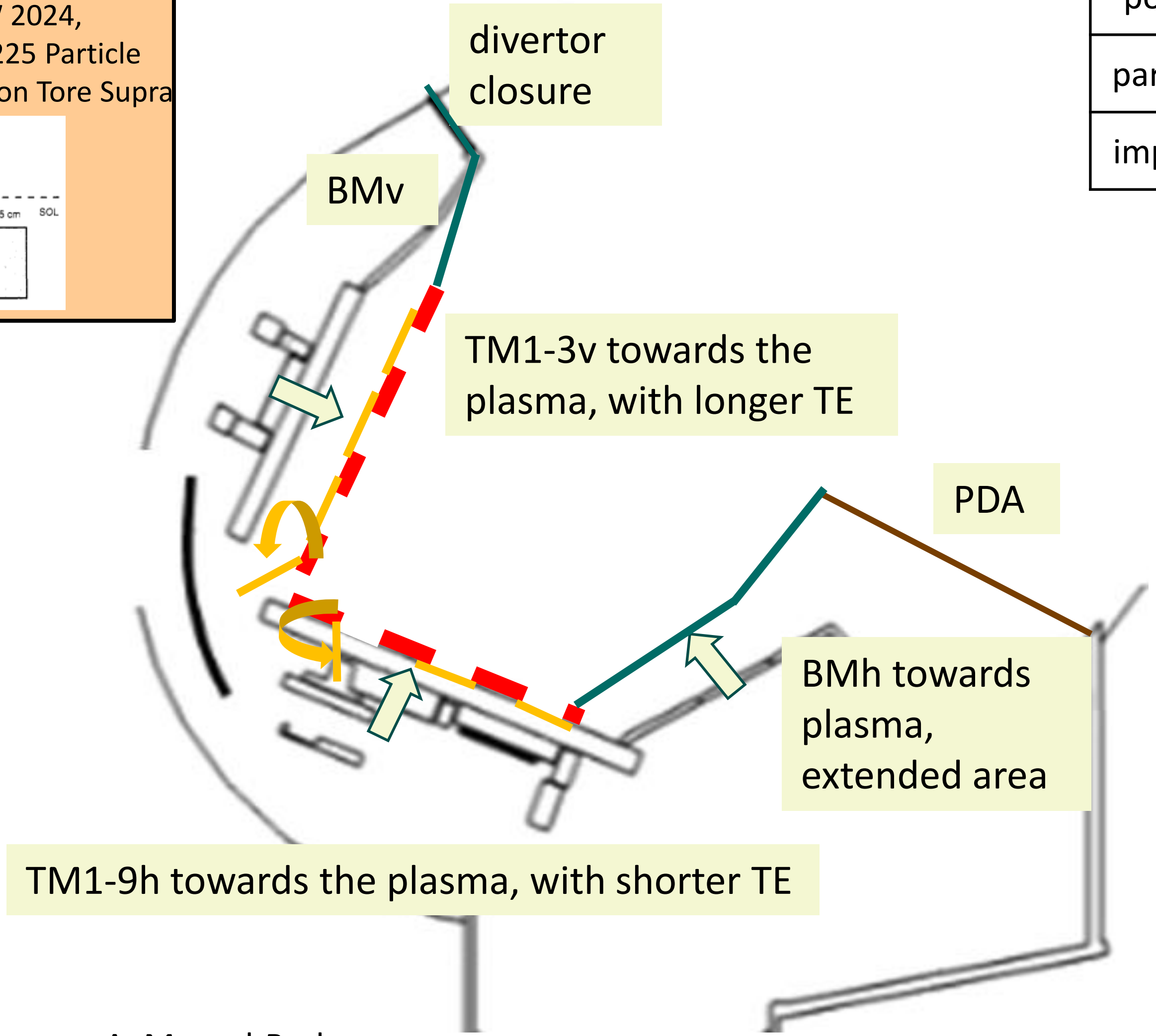



**reflector plate**
**shielding liner**
**target surface**
**baffle**
**actuated pumping gap closure panels**

+ pumping gaps can be close to all strike lines in all magnetic configuration
+ open panels reflect the neutrals towards the pump
+ subdivertor space leakeage can be minimized by having small effective pumping gap
+ can be adapted to current HHF surface geometry
- moving parts

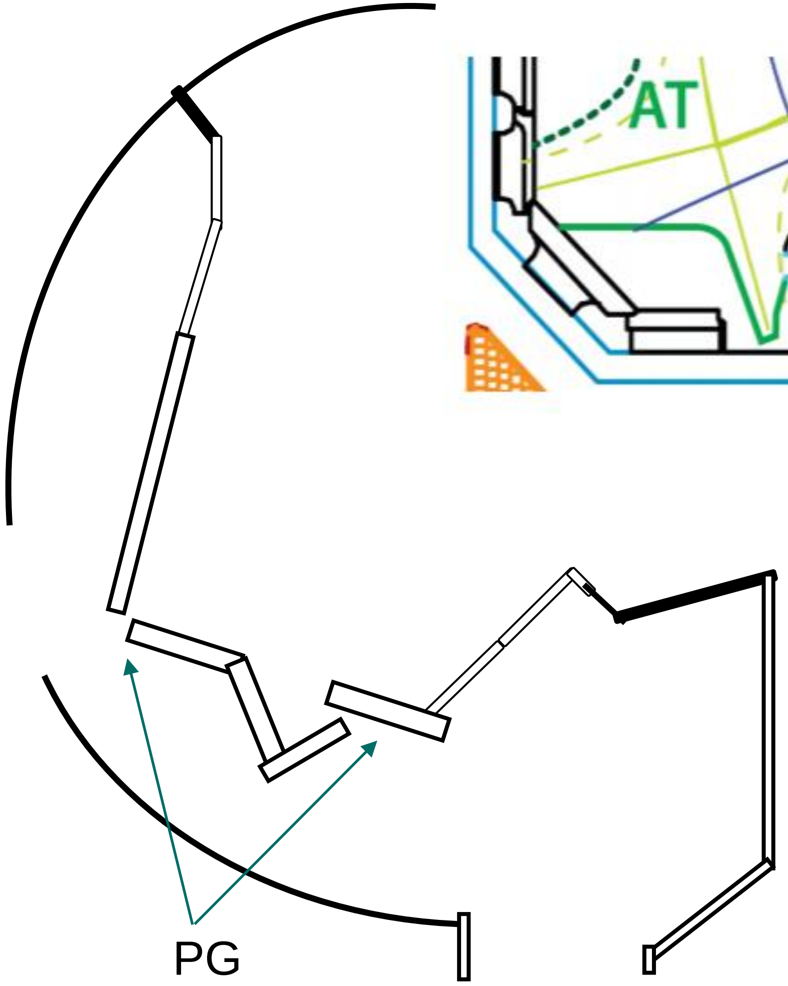


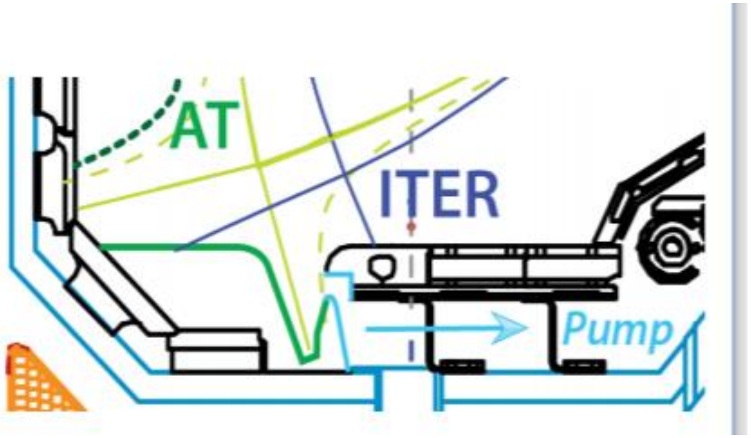

Design proposal W7-X preferential support phase I




Source: A. Menzel-Barbara

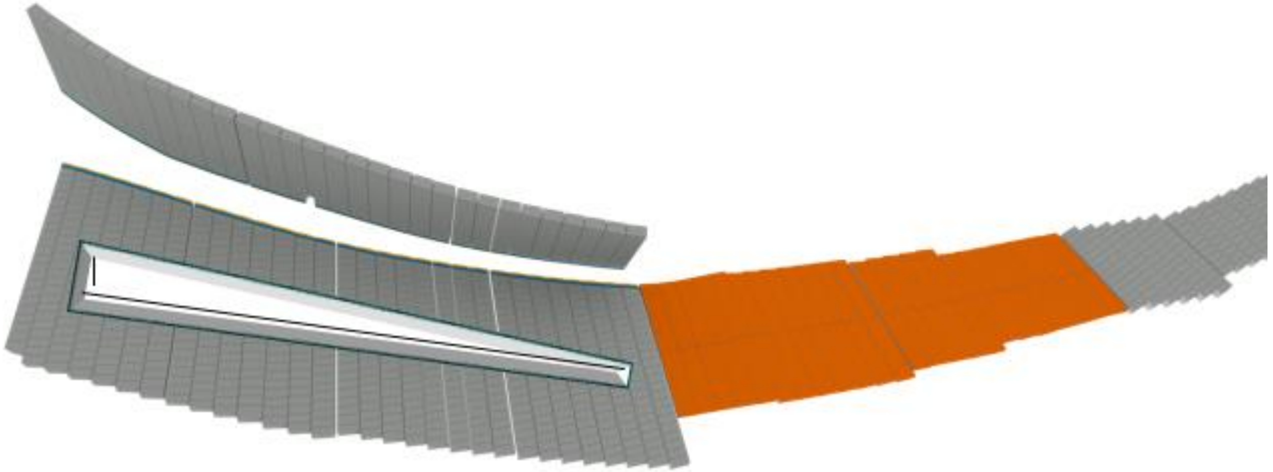
# Divertor setup OP3 (J) – deep slot divertor




- Small Angle Slot (SAS)-like divertor:
  -> place strike-line in lower target
  -> room for recycled neutrals that go below upper target, directly in SDR
  -> avoid edge loads, vary deposition by varying control coil currents
- Same target + Toroidal slits + SAS :
  -> tilted edges to focus heat loads on the edge
  -> translate high pressure at strike-line directly to neutral pressure in divertor

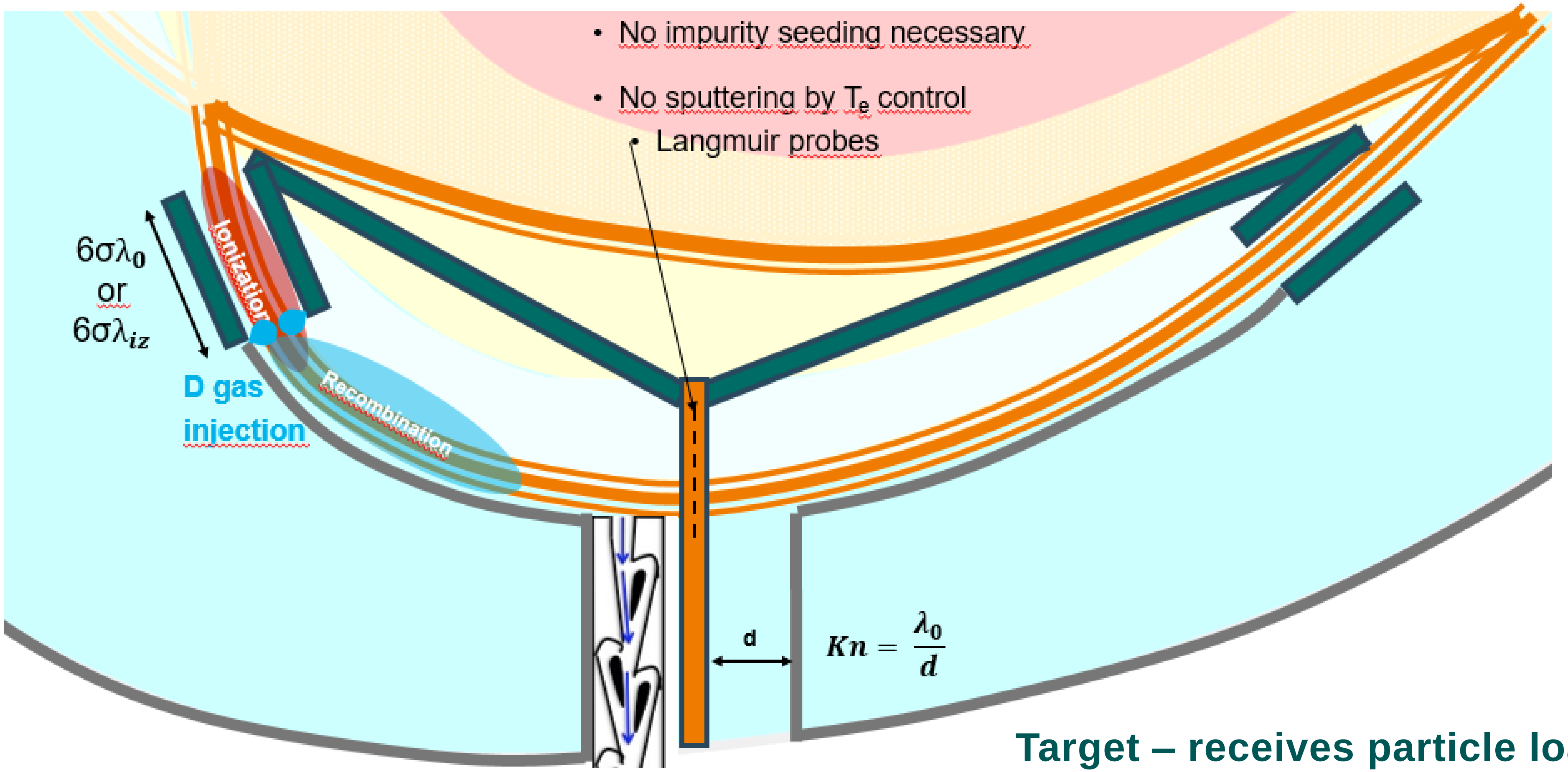
| |
|---|
| power exhaust |
| particle removal |
| impurity control |



Source: A. Kharwandikar [TAC_discussion - Short.pptx, Sept. 2022]

# Divertor setup OP3 (K) – fully detached divertor

| |
|---|
| power exhaust |
| particle removal |
| impurity control |



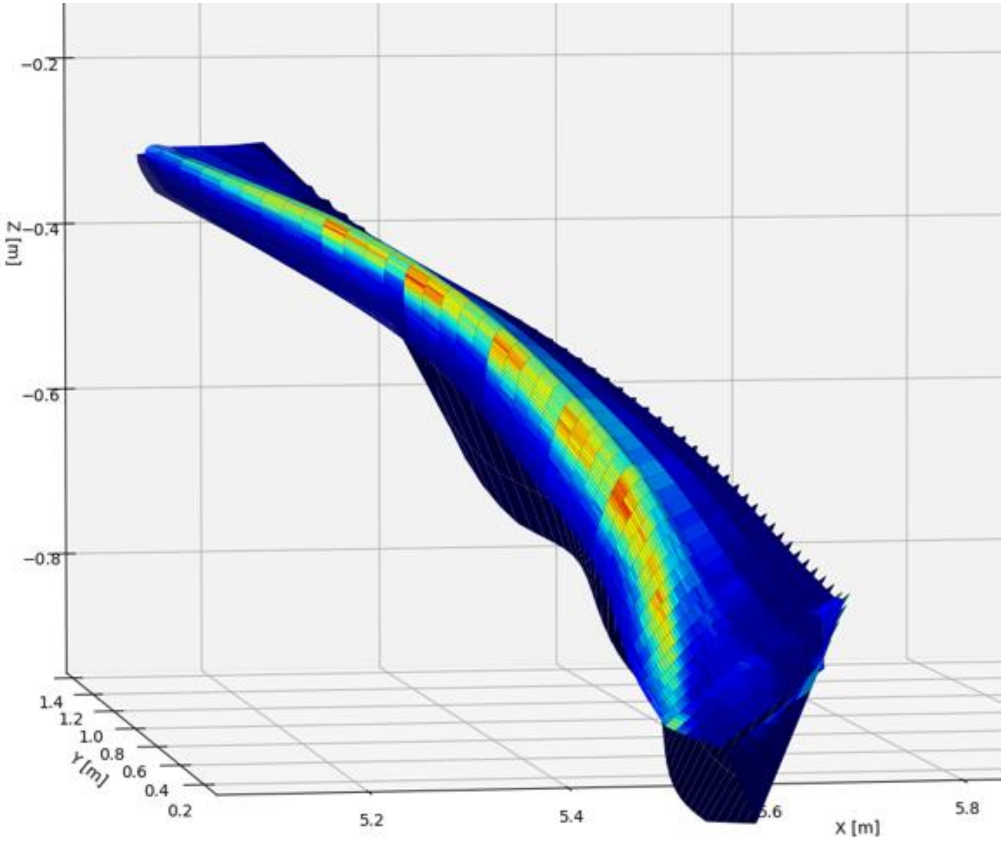

**Target – receives particle loads**

**Baffle – receives radiative loads**

Source: T. Kremeyer [DCD 26.3.2024, 2024-03-26_Fully_detached_divertor_concept_kremeyer.pptx]

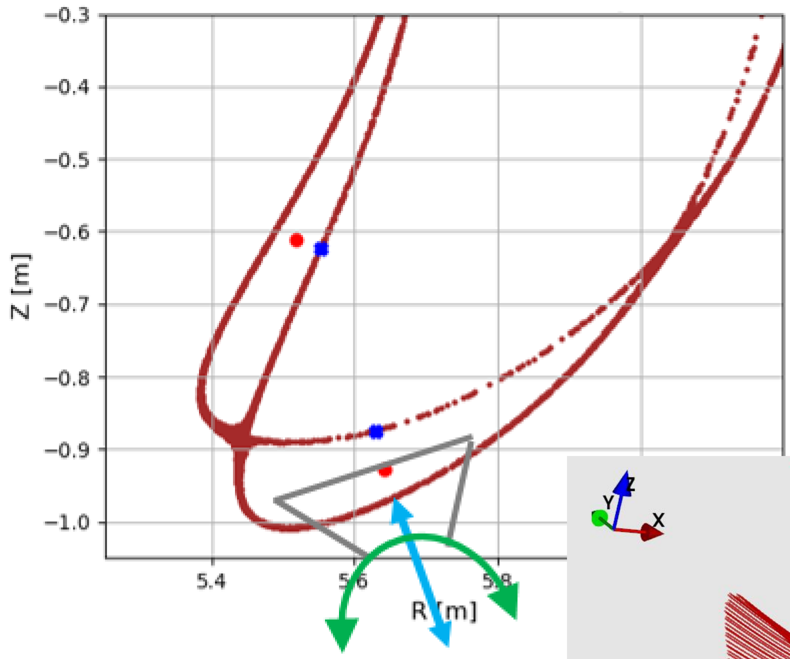
# W7-X DCD: running studies

submerged divertor design tool

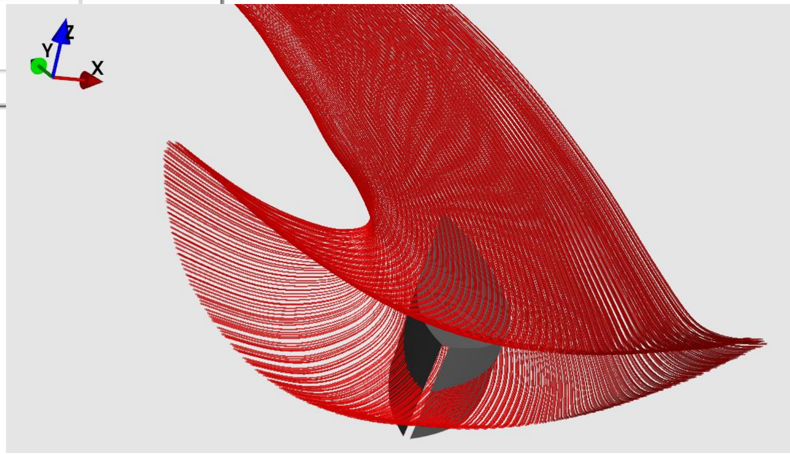



example: standard configuration, target phi=5° to 28°, loads below 10 MW/m$^2$

Source: A. Menzel-Barbara




closed divertor concept: with targets deep in the island




Source: A. Kharwandikar

# Divertor setup OP3 ( )

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