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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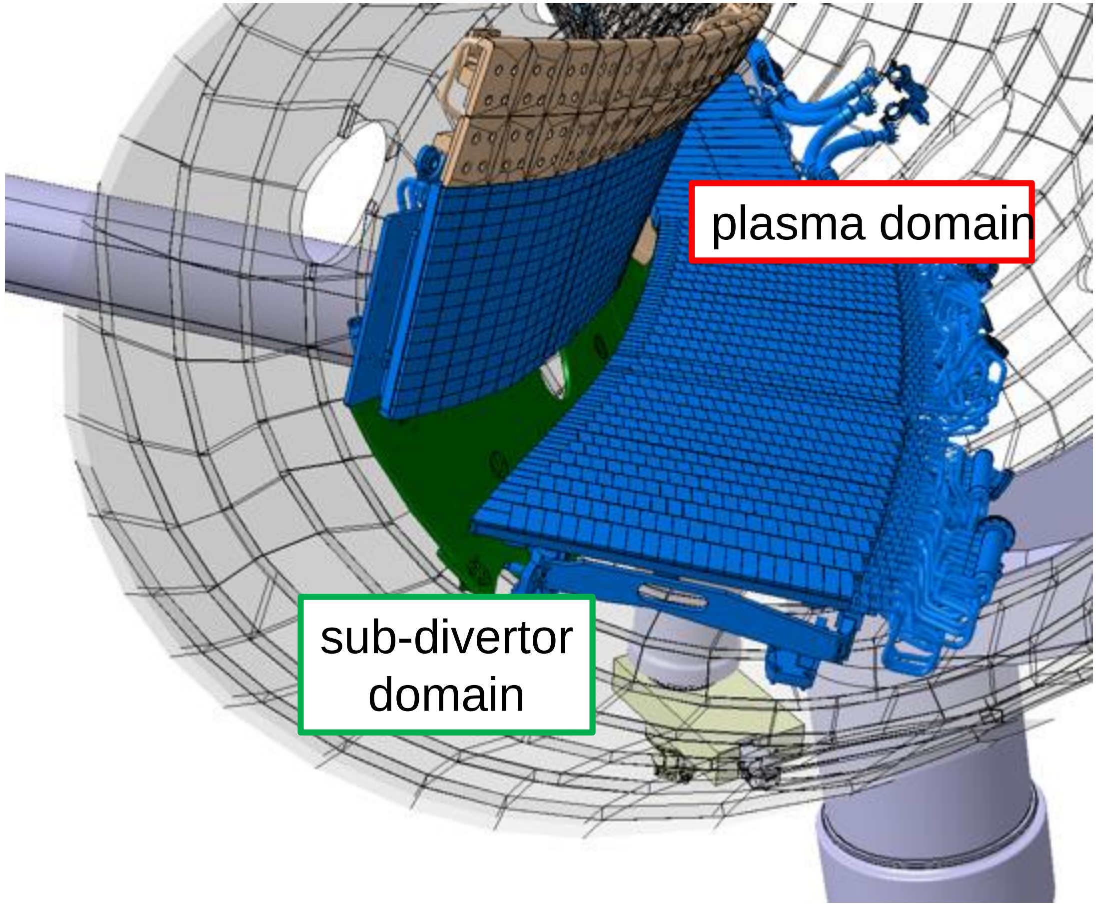
Geometry modifications



1

Definition of the plasma facing surface (PFS)

Priorities for the divertor development

conservative approach

moderate modifications of the current W7-X setup in order to address the issues identified in the experiments

- 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%).
  3. minimize divertor target surface
- evaluate modified geometries against particle removal requirements
  1. ensure high neutral gas pressure
- identify potential impurity retention drawbacks
  1. maximize distance to LCFS
  2. keep ionization front away from LCFS

innovative approach

search for an optimized plasma facing surface that meets carbon-free reactor performance requirements on particle removal and impurity retention while guaranteeing target survival

W7-X Divertor setup OP3 – design modifications

- 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: divertor for Helias reactor HSR4/18
- case K: deep slot divertor
- case L: fully detached divertor concept

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- evaluate modified geometries against particle removal requirements
- identify potential impurity retention drawbacks

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

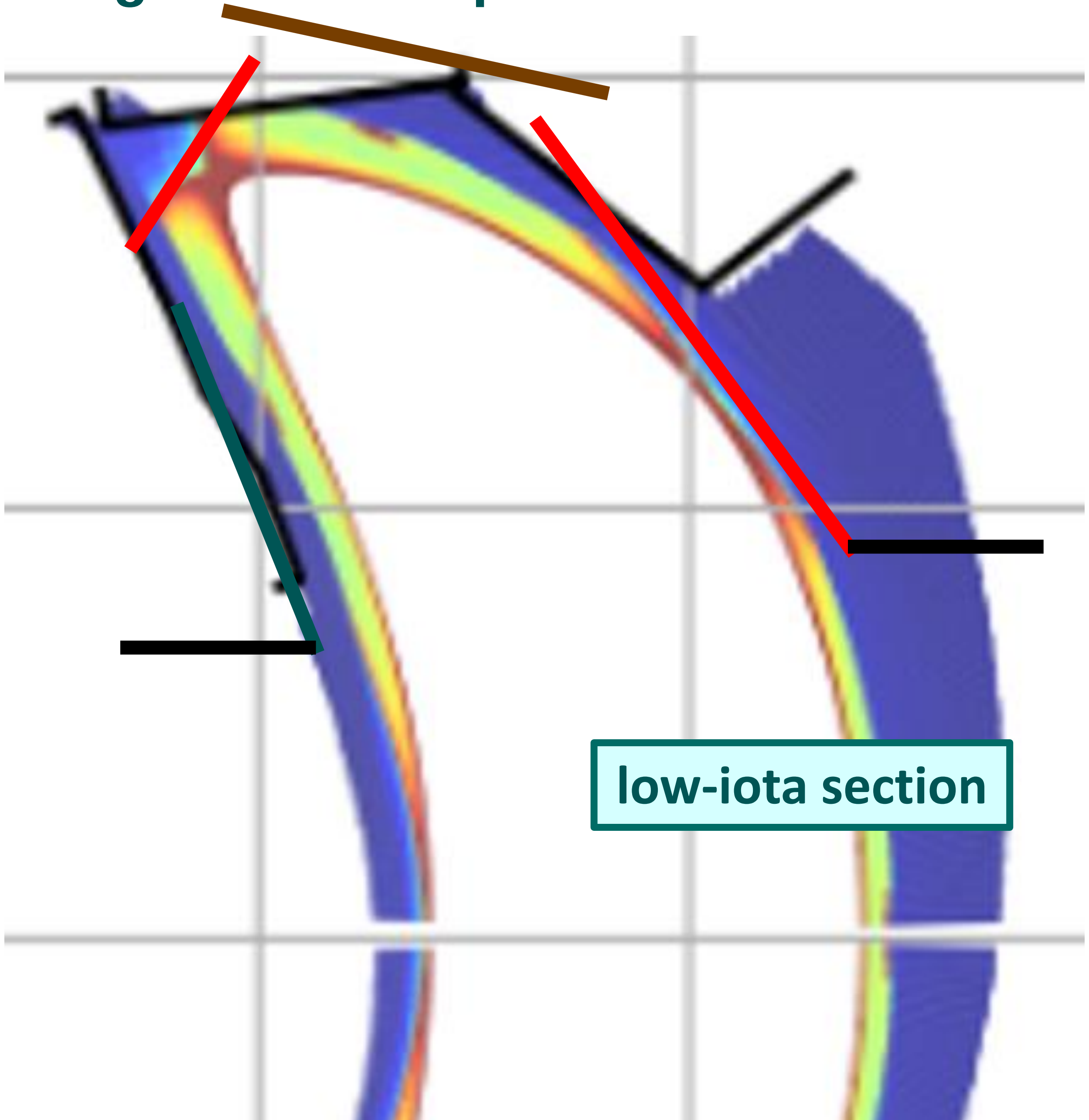
reflector plate
shielding liner
target surface
baffle

+ radiation loads, also with simplified model

- ➢ radiating x-lines
- ➢ radiating high-energy 3D surface

size of pumping gap should be optimized

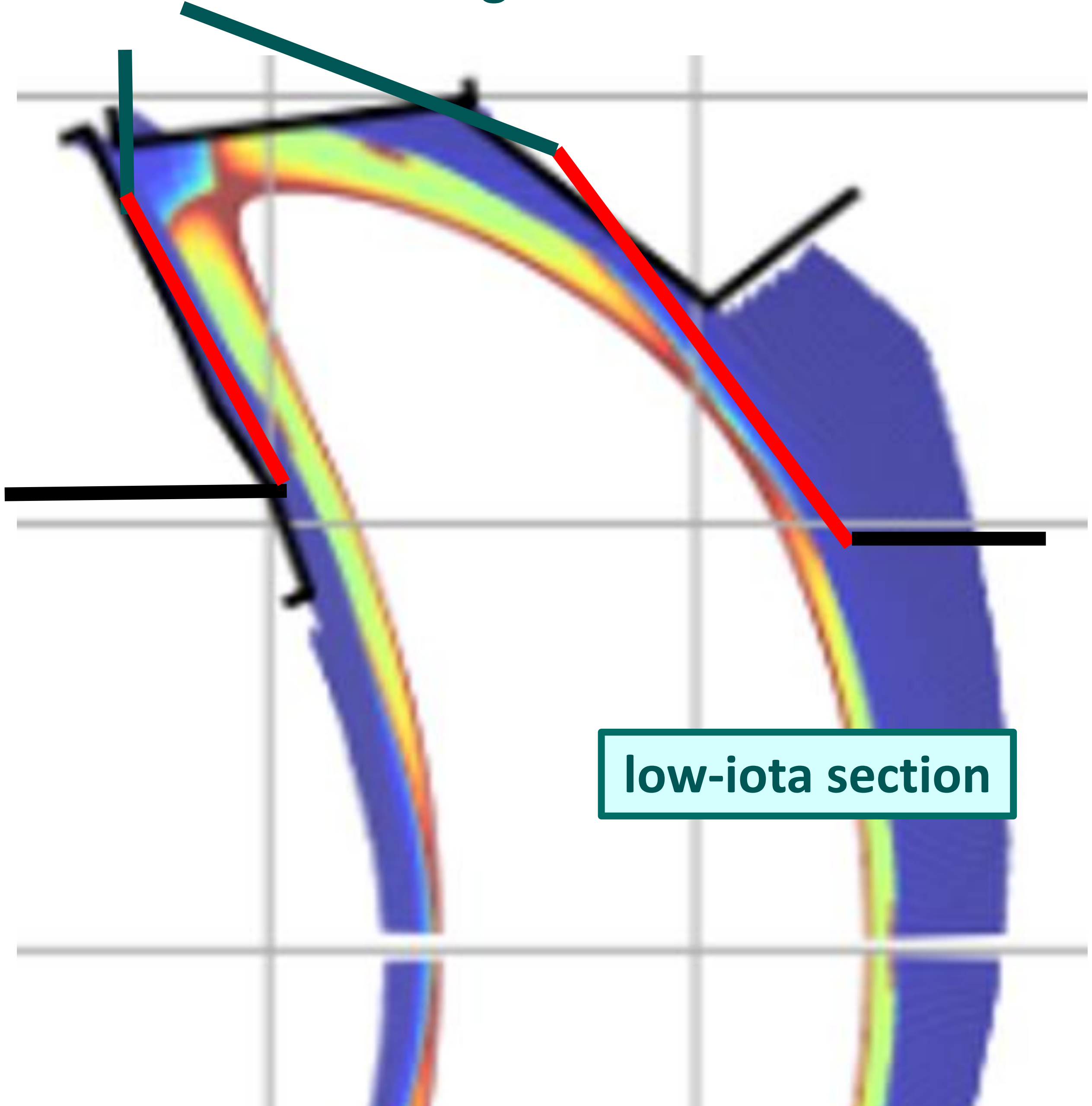
excessive loads to wall sub-divertor components should be avoided by shielding plates



power exhaust
particle removal
impurity control

Divertor setup OP3 (B) – closure with target surfaces

reflector plate
shielding liner
target surface
baffle



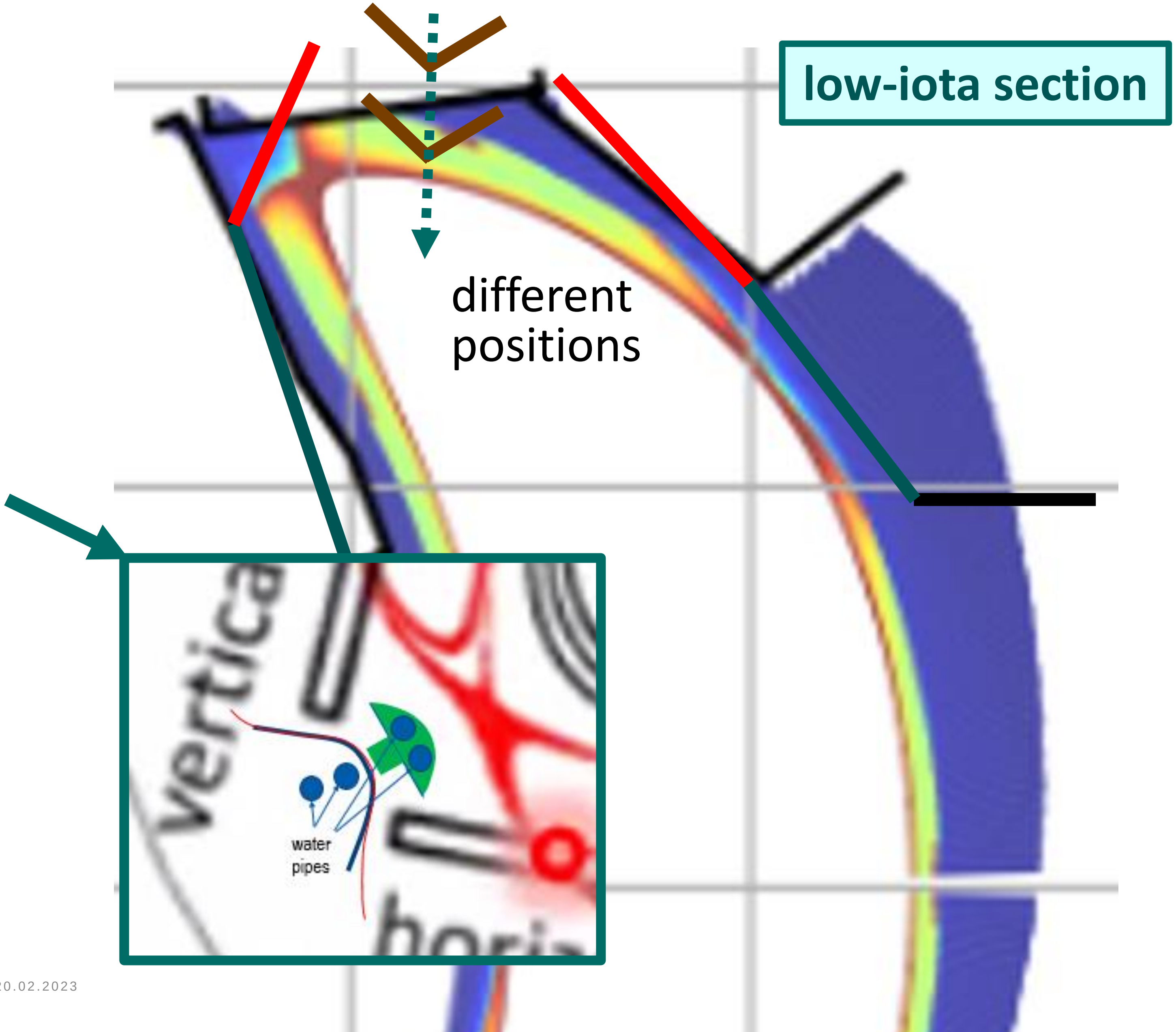
power exhaust
particle removal
impurity control

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



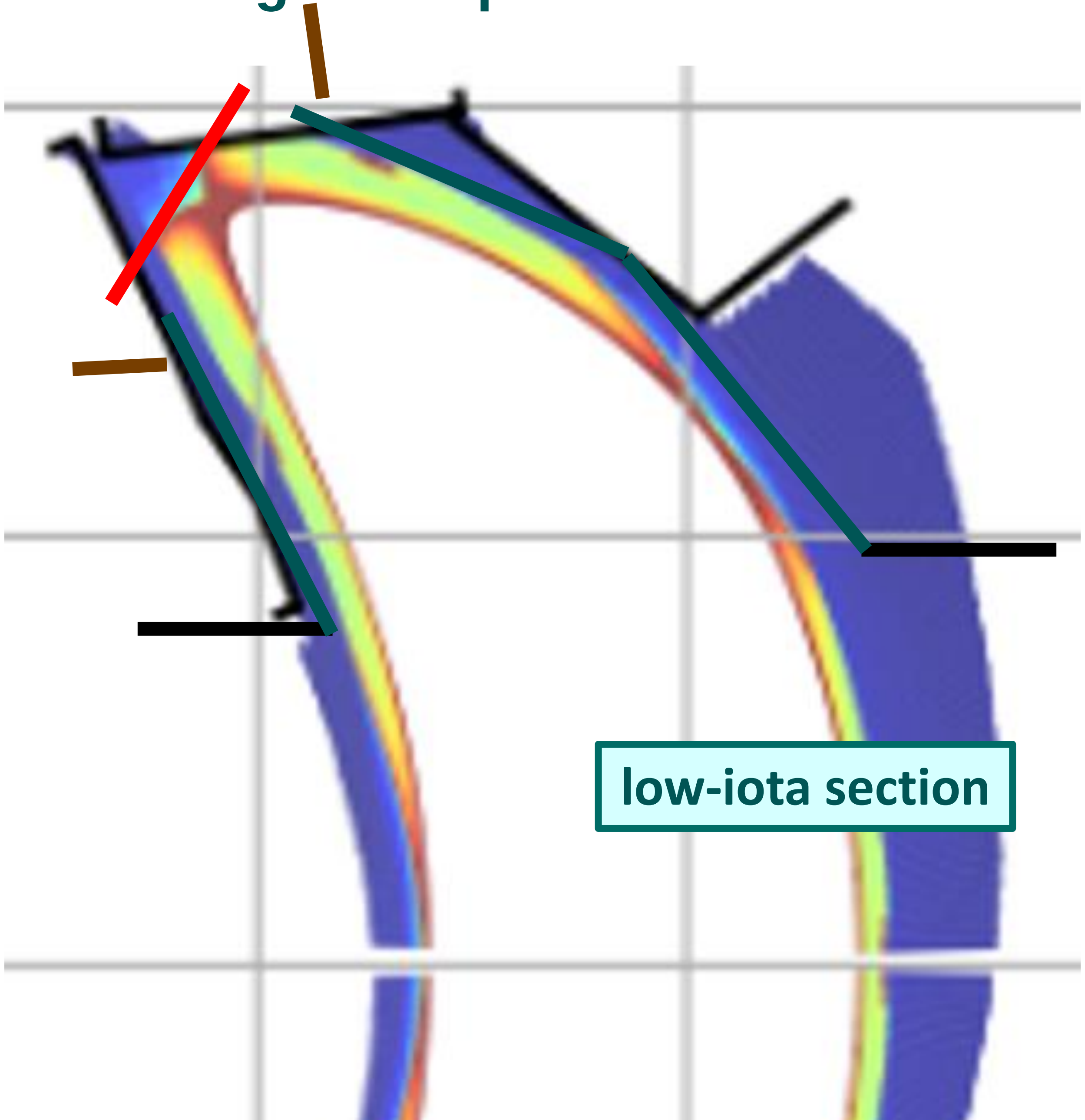
Divertor setup OP3 (D) – one target setup

power exhaust

particle removal

impurity control

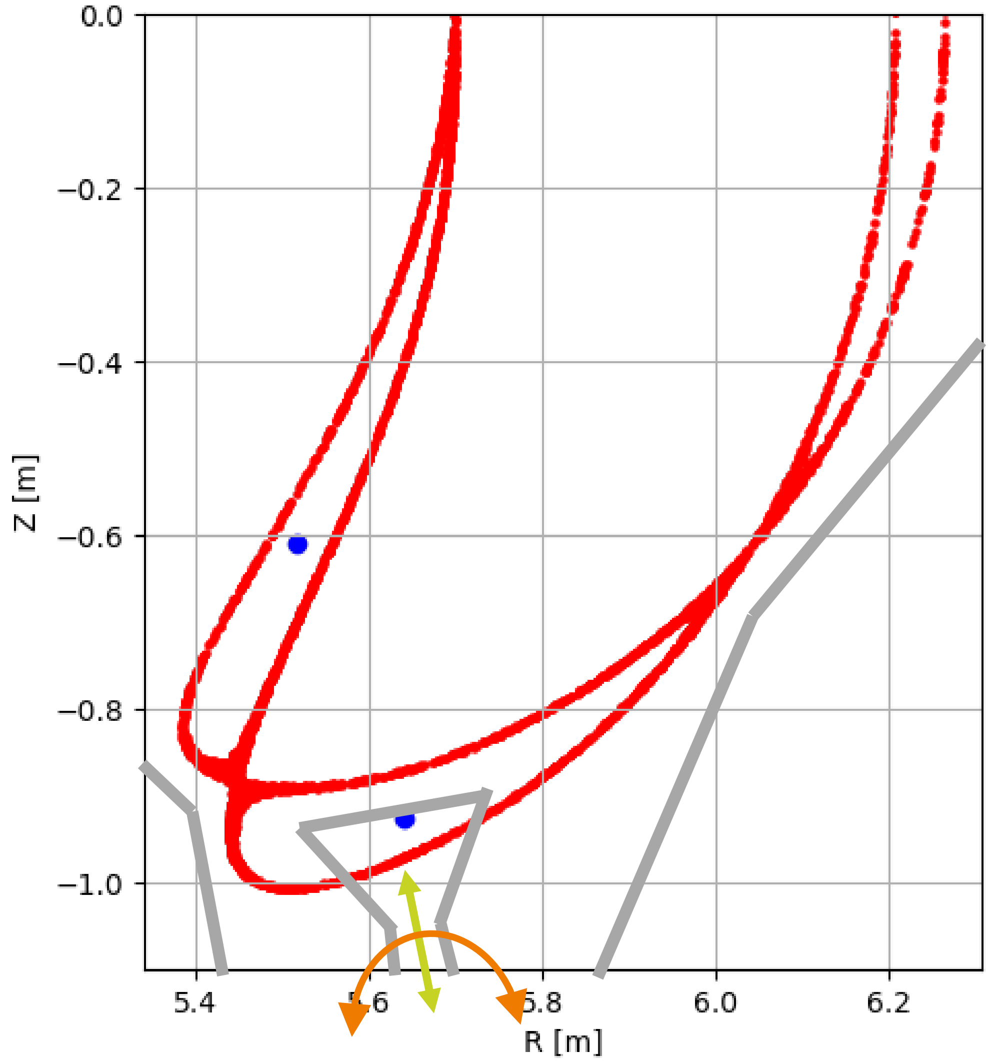
reflector plate
shielding liner
target surface
baffle



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

power exhaust
particle removal
impurity control

- Dimension
- Offset
- Tilt



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

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

- Build up neutral pressure

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

- Block escaping neutrals

  Hardware (Baffles) !Thermal loads!

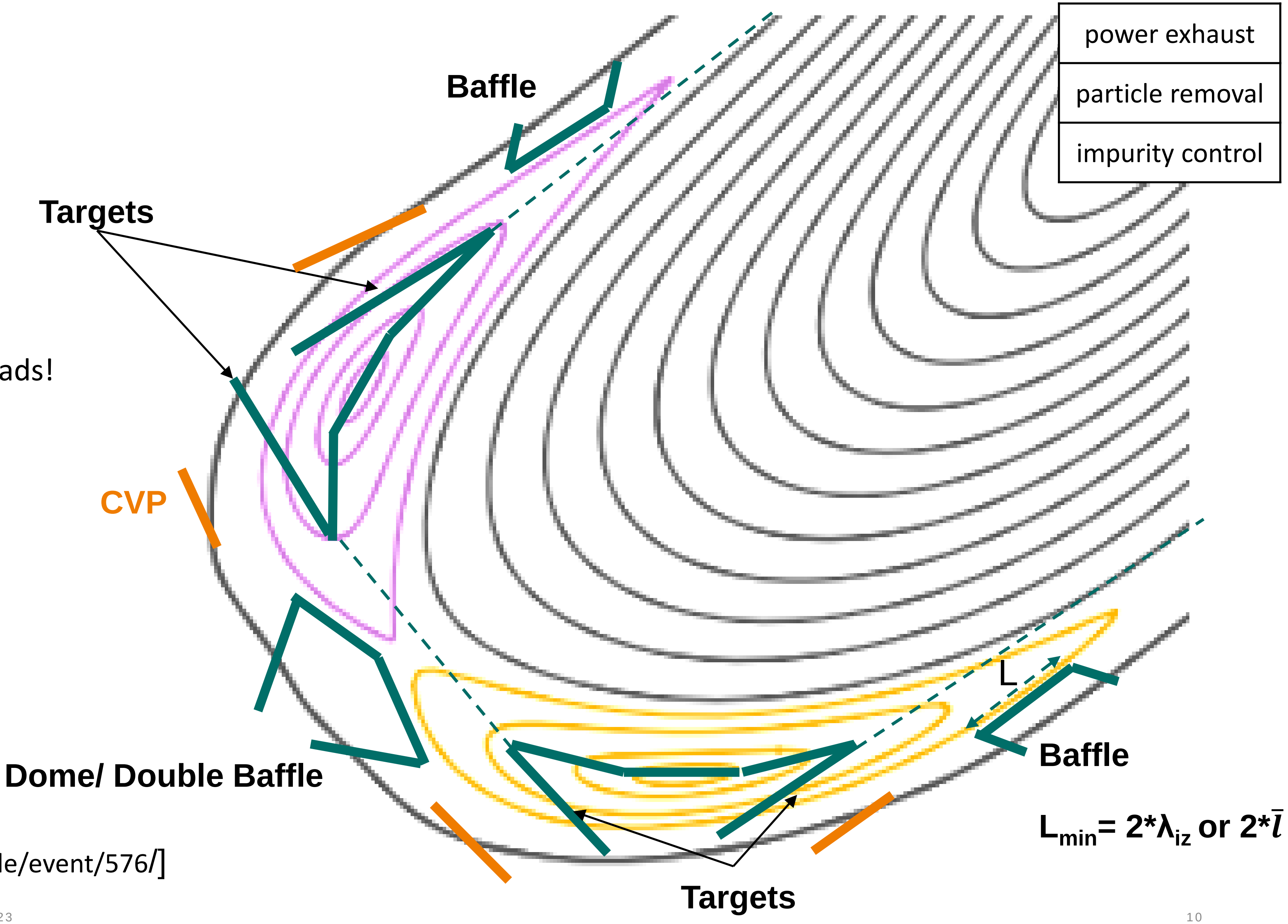
  Re-Ionization

- Direct collection

  Optimize $\cos \varphi_{pumpgap}$

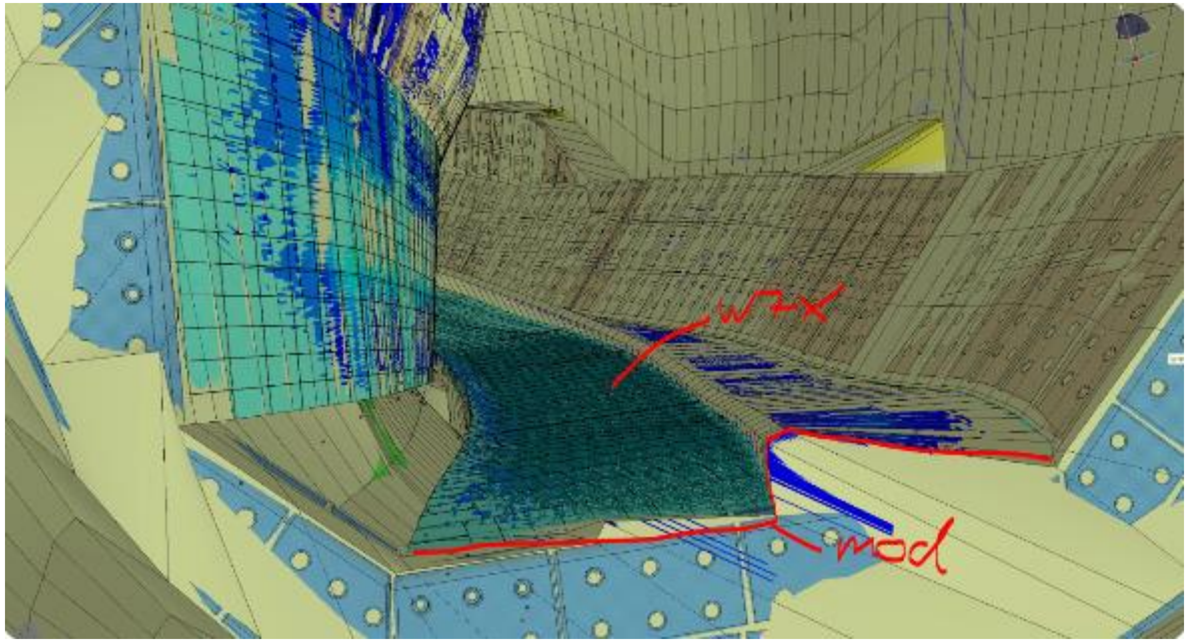
  CVP ideally normal to target

power exhaust
particle removal
impurity control



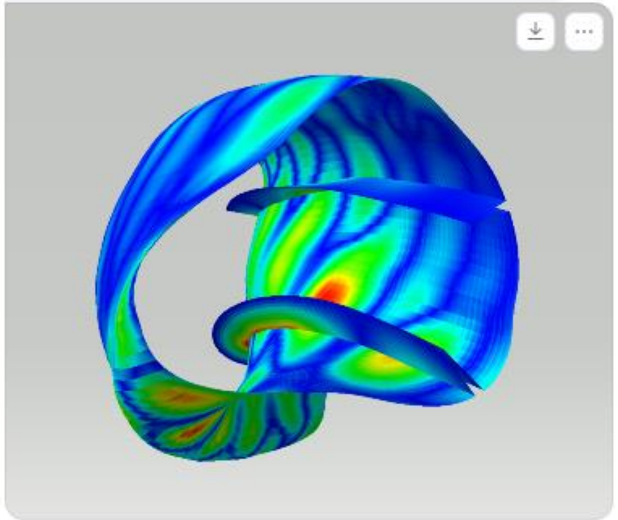
Source: T. Kremeyer [https://event.ipp-hgw.mpg.de/event/576/]

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

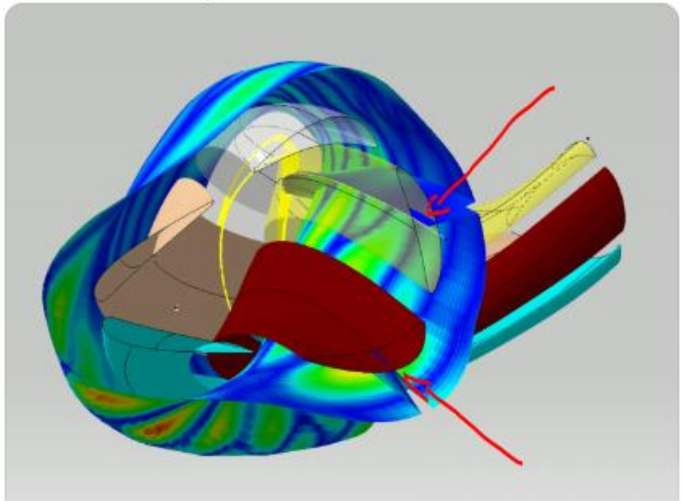


power exhaust
particle removal
impurity control

angle plot of inner islands cut (beta=0, standard):



Thomas Sieber 3. Nov, 12:56



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

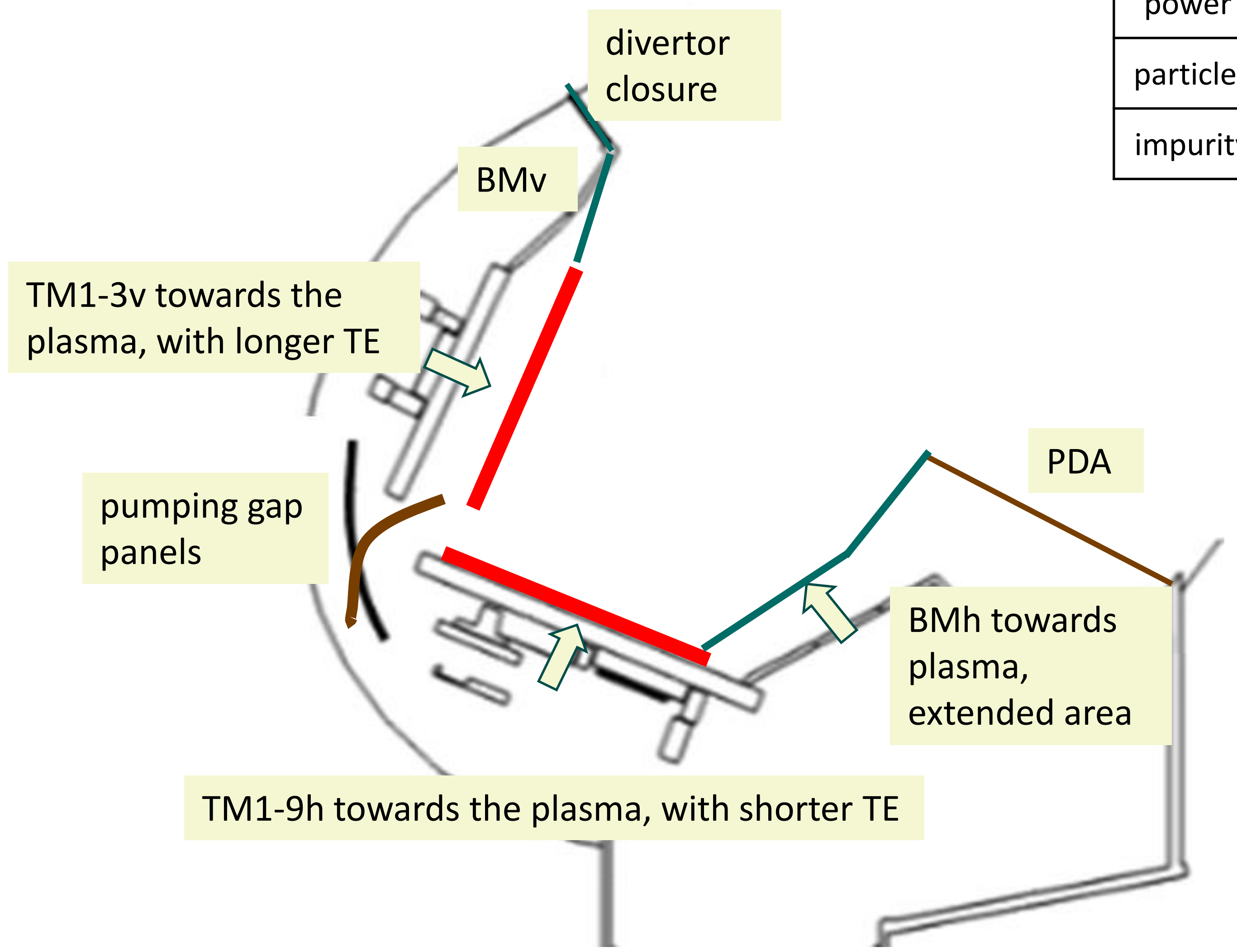
Source: T. Sieber [zoom DivertorMods, 29.9.2023, 3.11.2023]

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/)



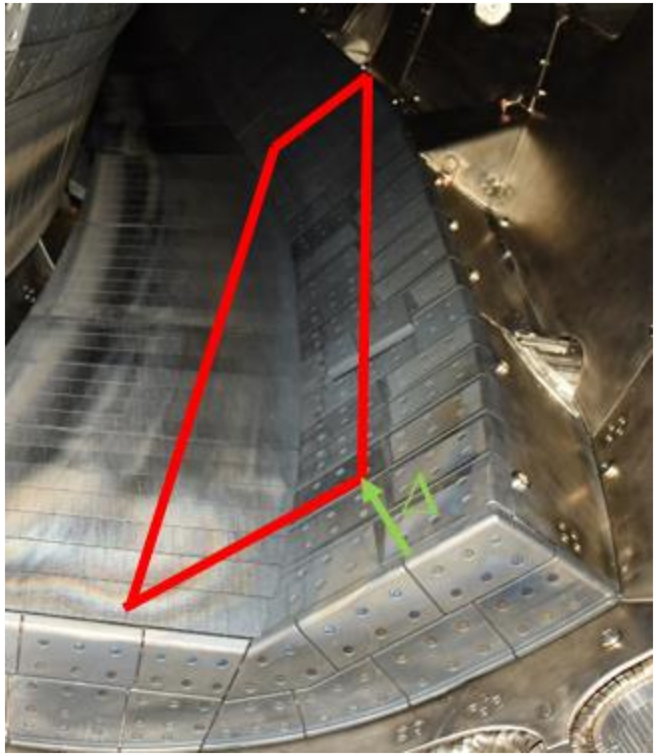
Divertor setup OP3 (H) – conservative approach (low iota part)

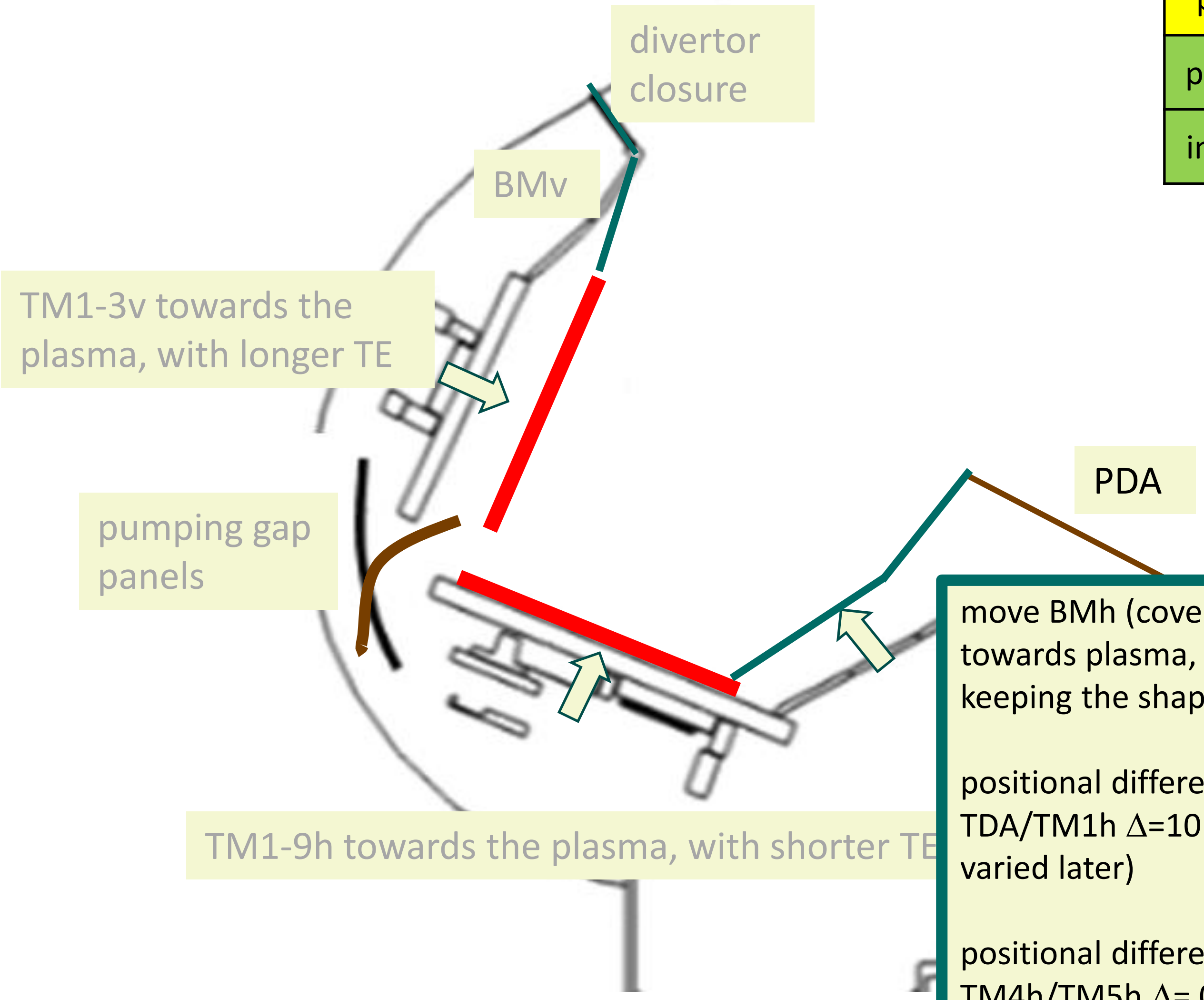
power exhaust

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

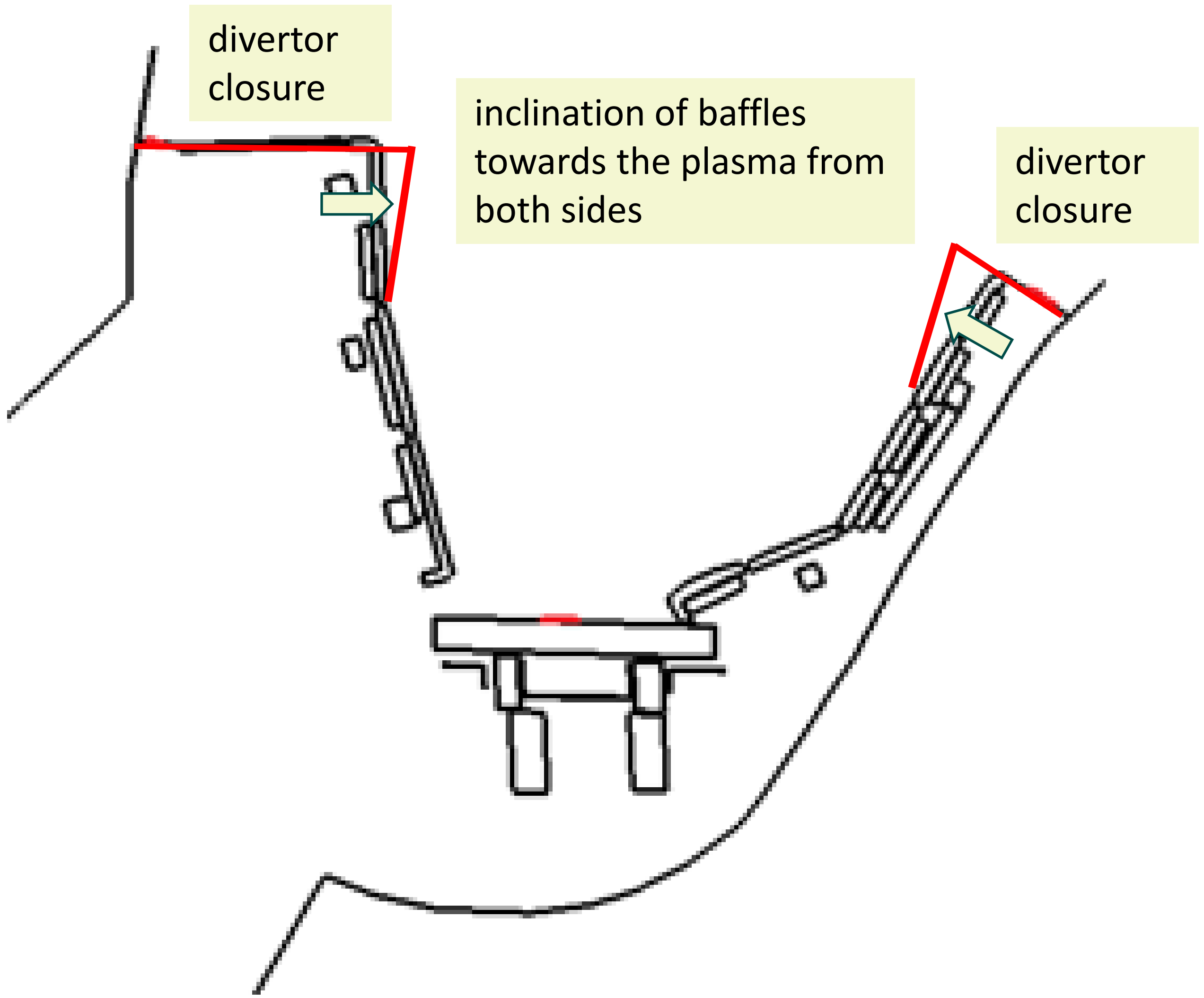
positional difference at TDA/TM1h Δ=10 cm (will be varied later)

positional difference at the TM4h/TM5h Δ= 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

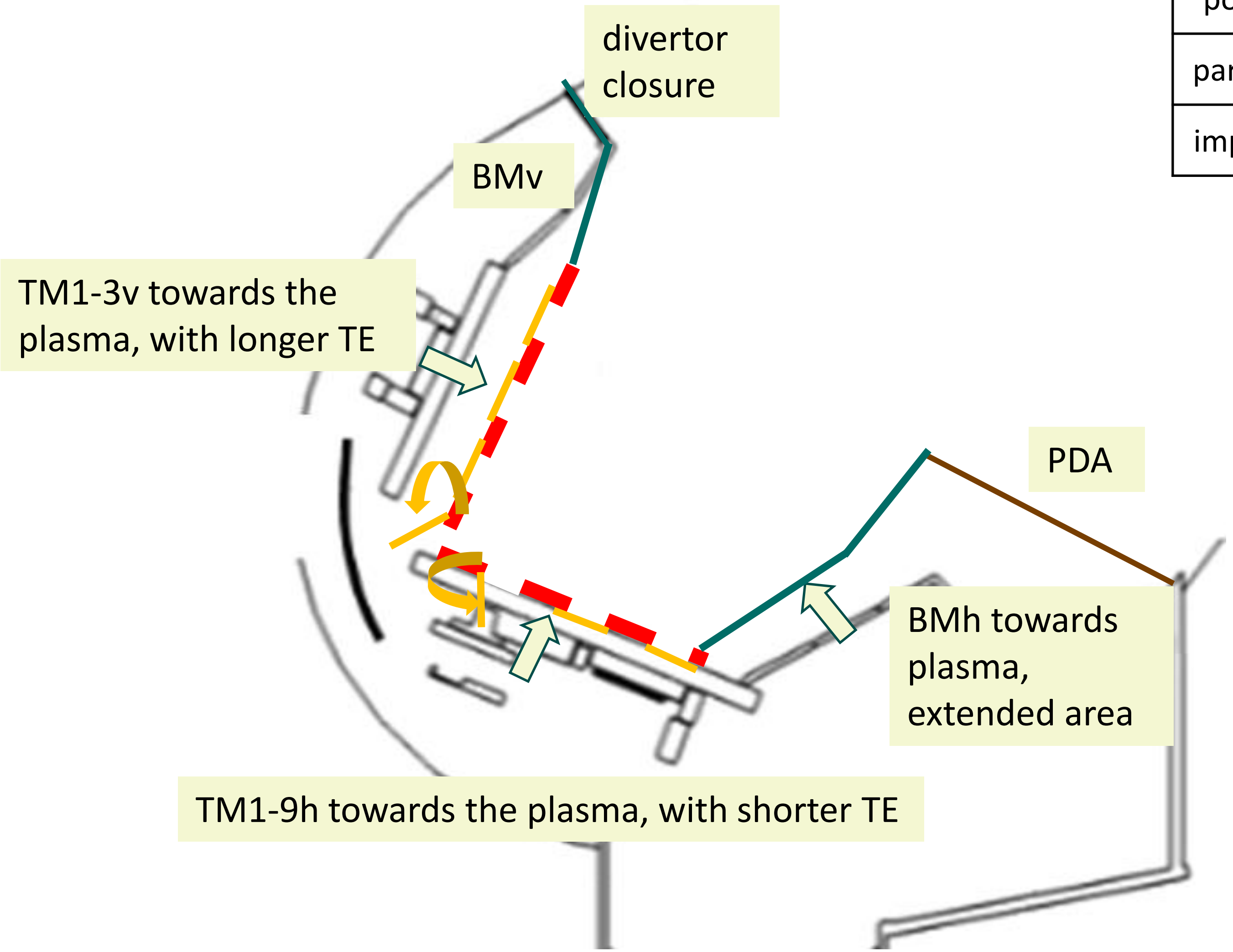


Divertor setup OP3 (I) – “open grill” setup with moving panels

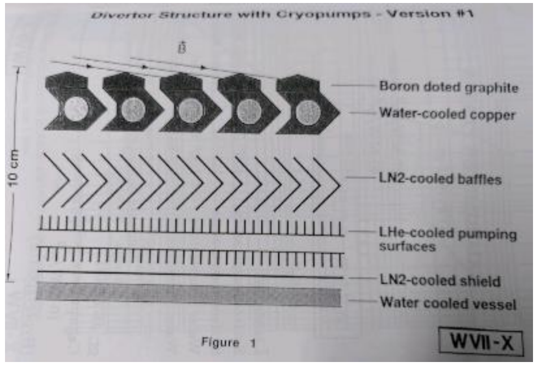
power exhaust
particle removal
impurity control

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



Source: A. Menzel-Barbara



Design proposal W7-X preferential support phase I

Divertor setup OP3 (J) Helias reactor HSR4/18

power exhaust
particle removal
impurity control

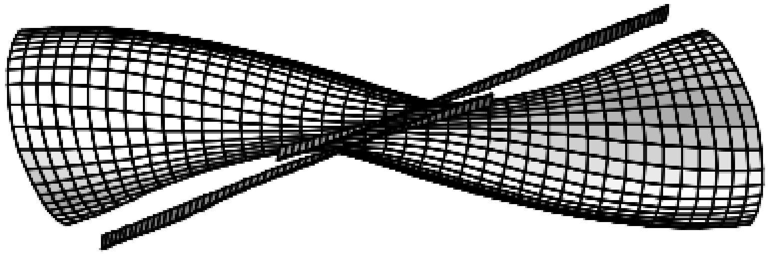


Figure 6. One period of the magnetic surface and divertor target plates of HSR4/18, seen from outside. Baffle plates are not shown.

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

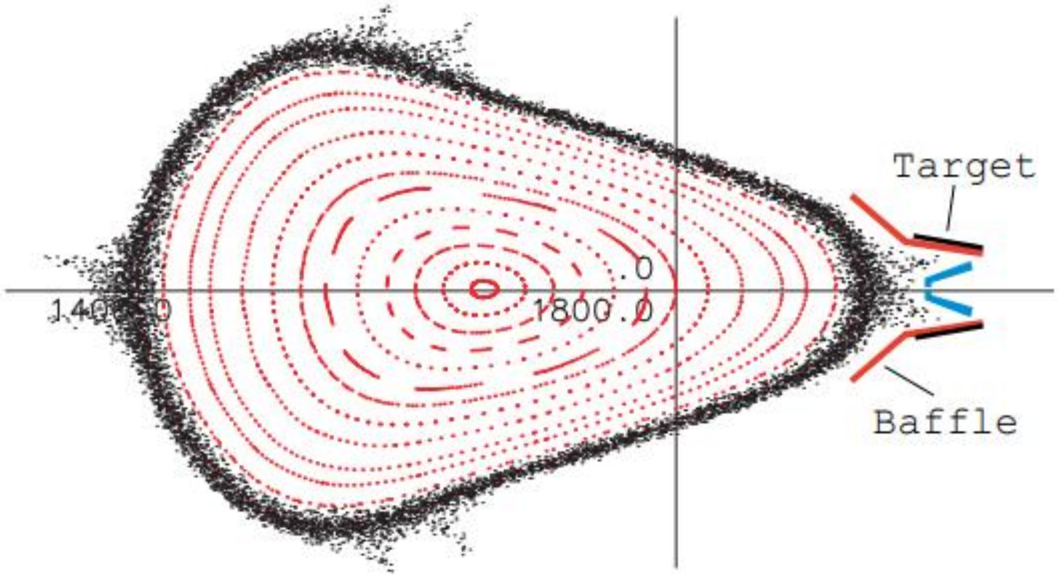
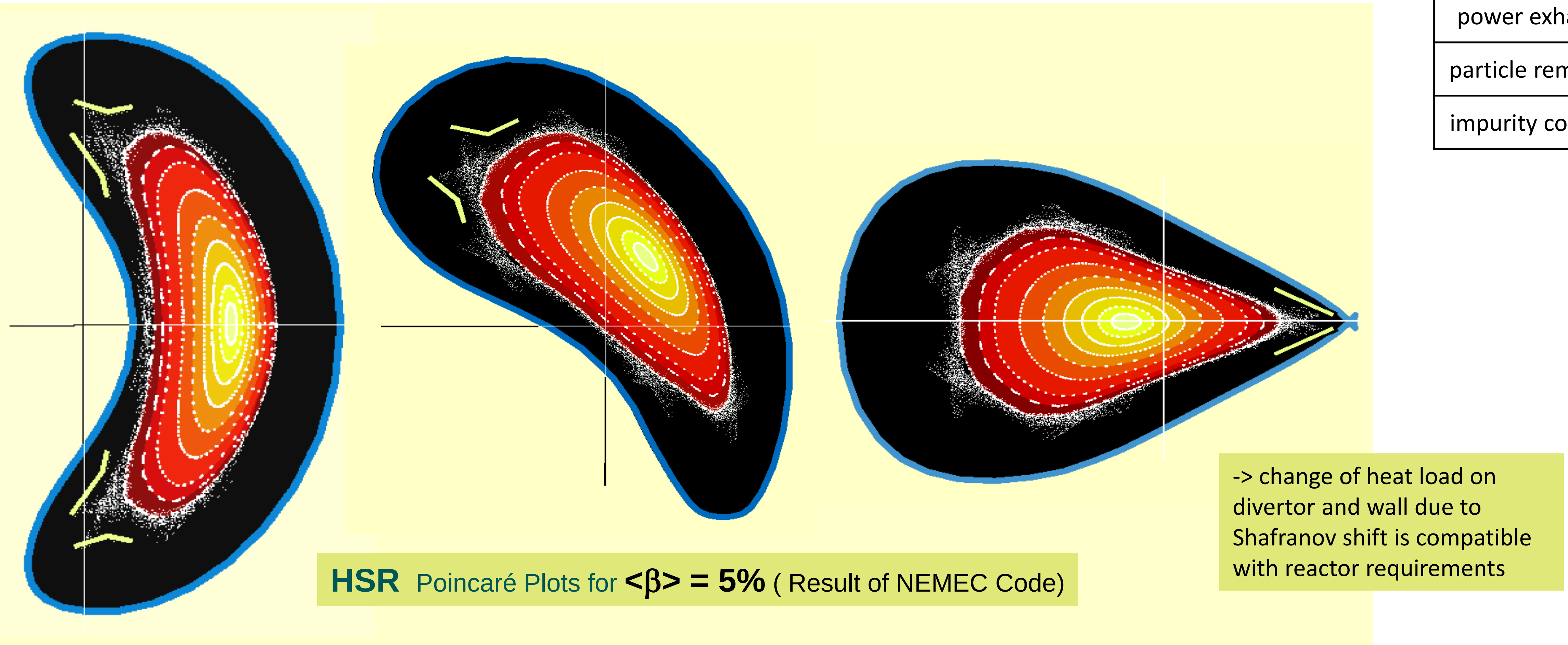


Figure 5. Poincaré plot of magnetic surfaces and the scrape-off layer in the symmetry plane $\varphi = 45°$. The stochastic region is created by the intersection points of diffusing particles.

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 (J) Helias reactor HSR4/18

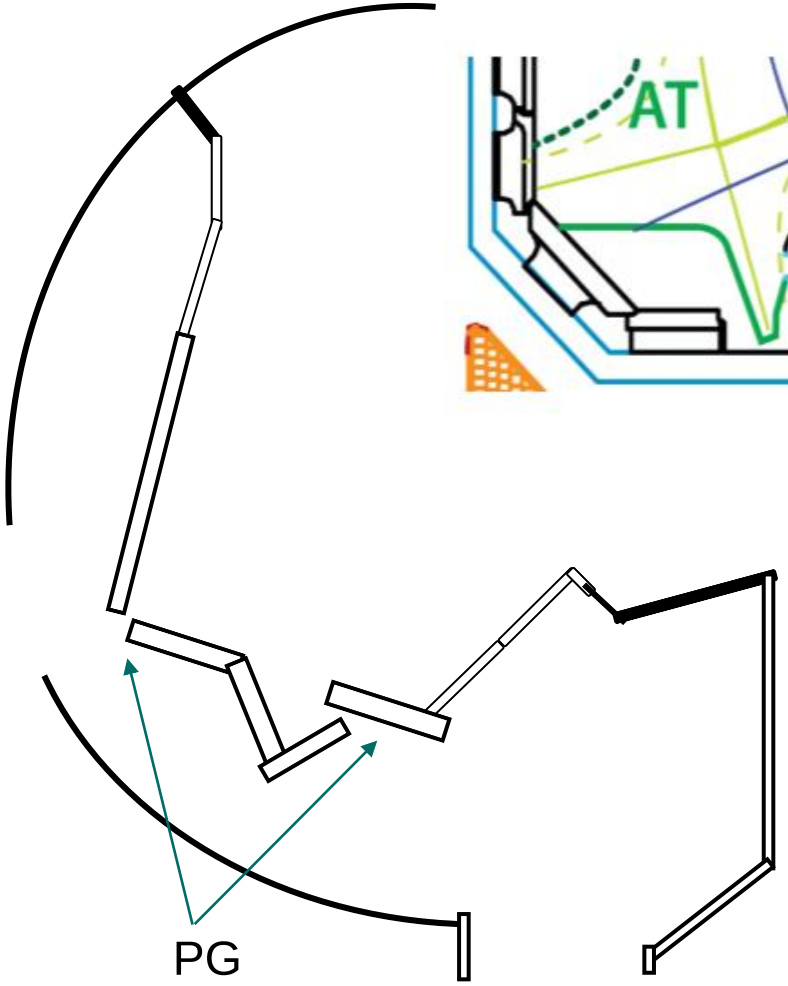
power exhaust
particle removal
impurity control

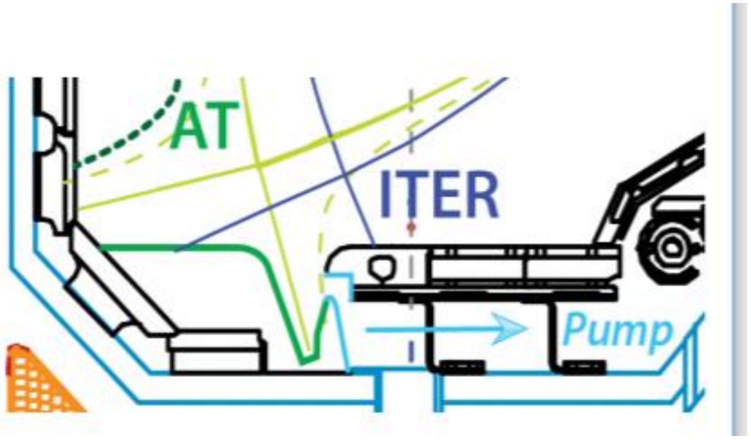


φ = 0° φ = 18° φ = 36°

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

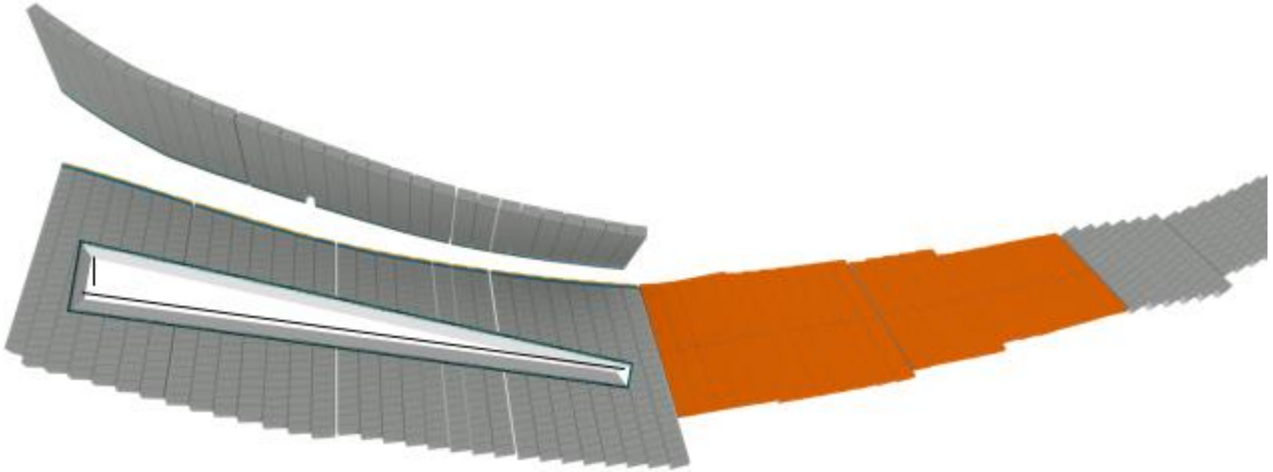
Divertor setup OP3 (K) – deep slot divertor





- 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

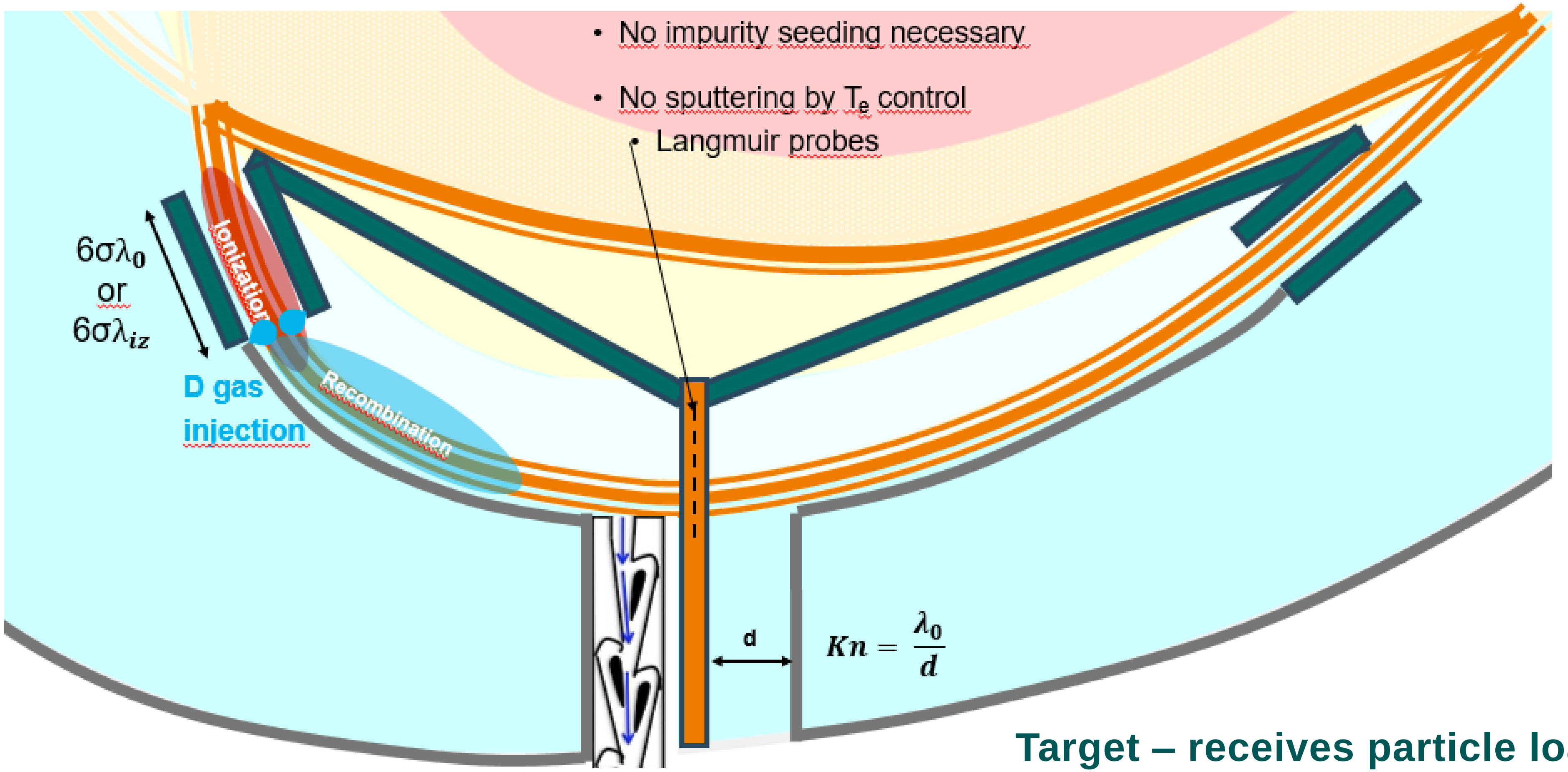
power exhaust
particle removal
impurity control



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

Divertor setup OP3 (L) – 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]

Divertor setup OP3 ( )

Divertor setup OP3 ( )