ERO2.0: W7-X and JET-ILW

J. Romazanov et al.

JÜLICH
Forschungszentrum

Outline

- W7-X:
  - ^{13}C injection simulations.
  - W tiles.
- JET:
  - Global modelling (erosion of beryllium + tungsten; nitrogen seeding).
  - Erosion/deposition of test mirrors.

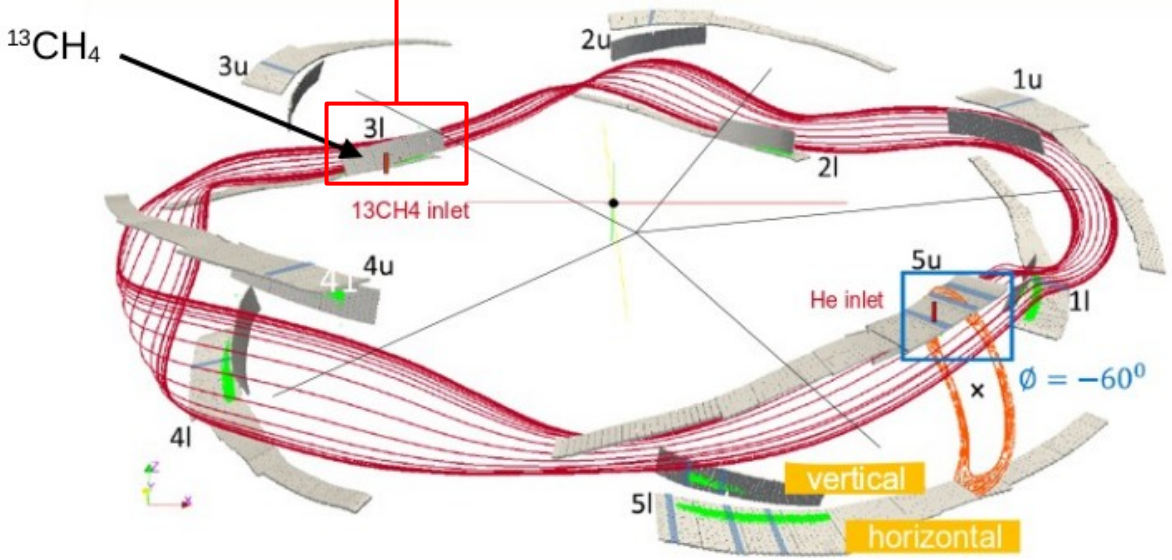
W7-X: ^{13}C injection

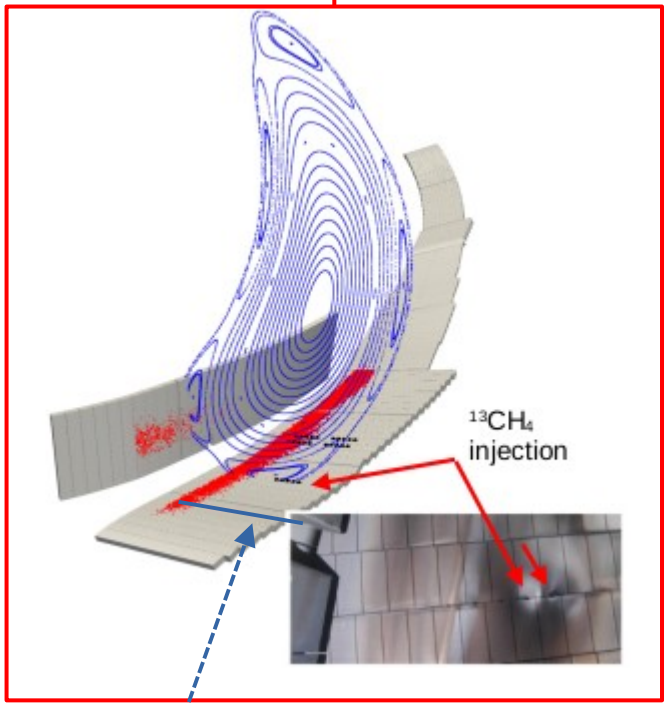
W7-X ^{13}C tracer injection experiment

S. Brezinsek et al., PFMC 2019
S. Brezinsek et al., PFMC 2021
T. Dittmar et al., PSI 2022

Some injection from midplane manipulator → local modelling with ERO, see talk by A. Kirschner.

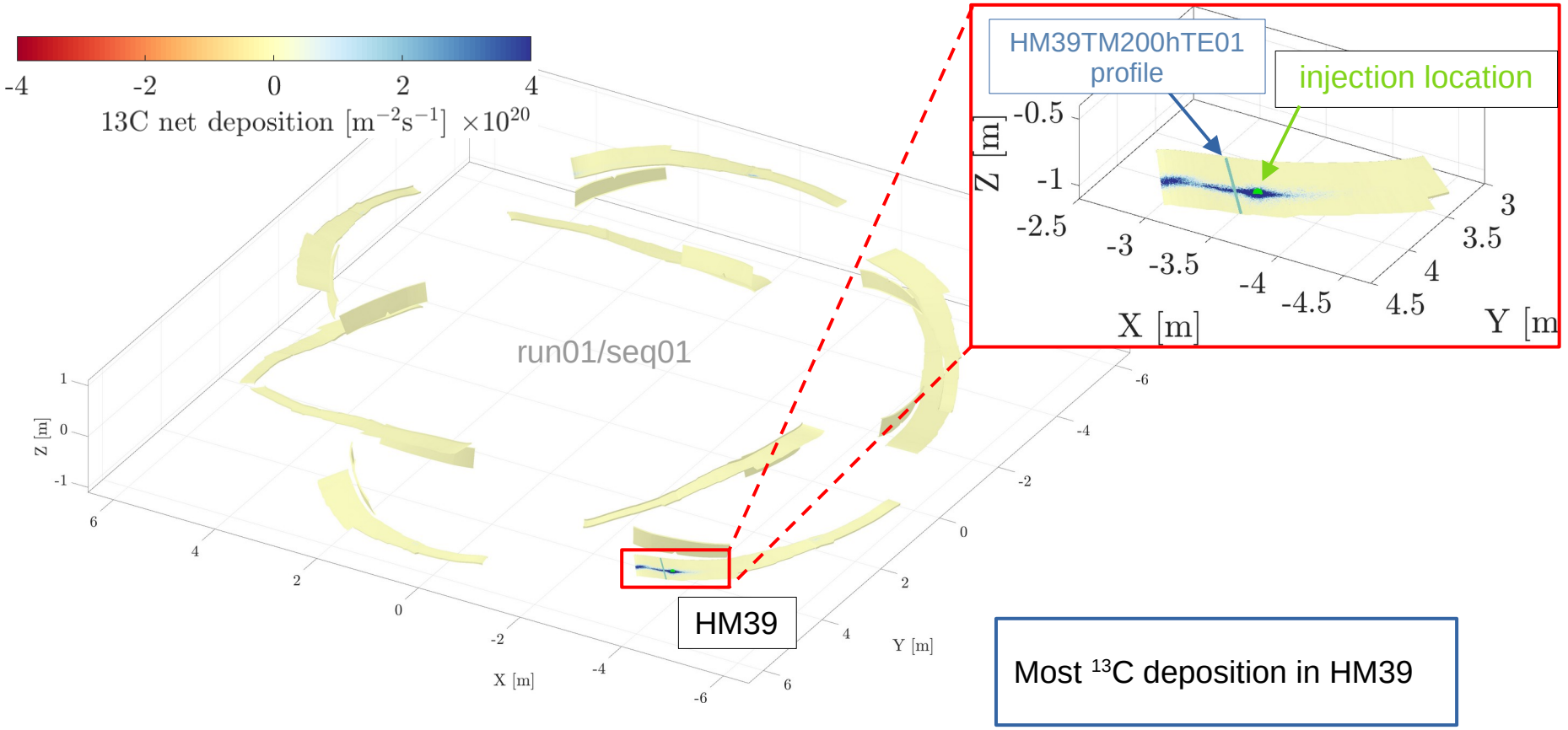
Most injection from divertor nozzles → global modelling with ERO2.0.





Divertor finger "HM39TM200hTE02"

ERO2.0 simulations of ^{13}C injection

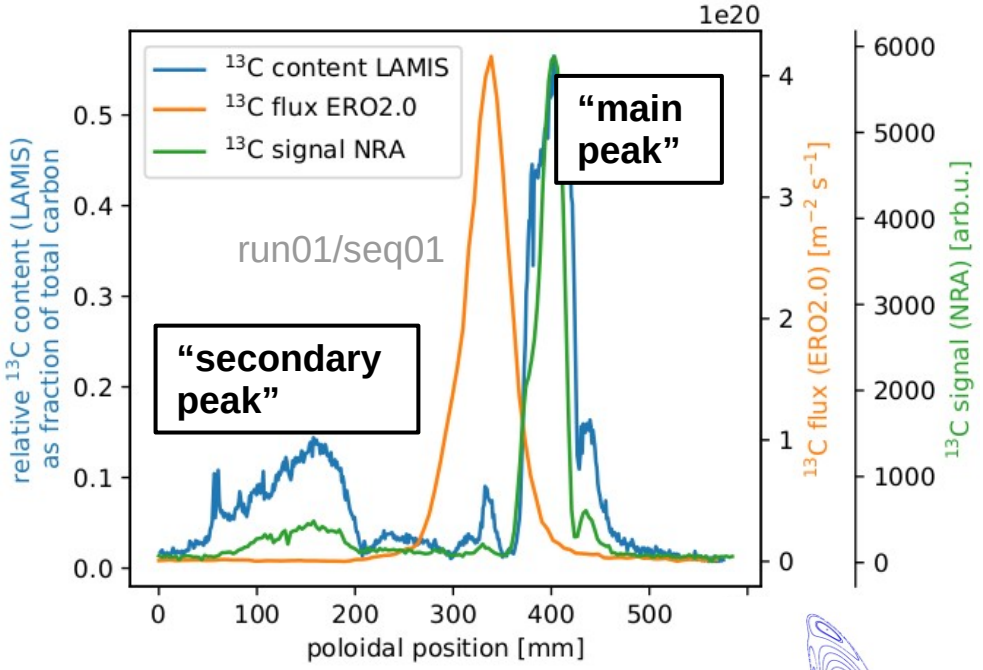


Most ^{13}C deposition in HM39

Analysis of ^{13}C tracer injection

E. Wüst et al., NME 2020

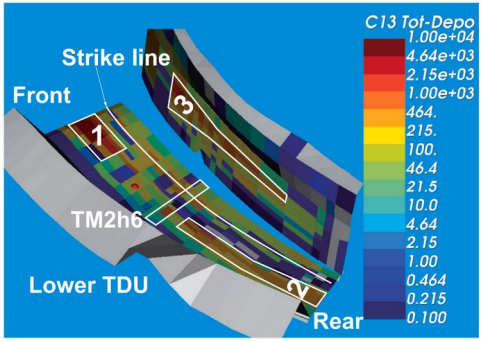
- Analysis of divertor finger HM39TM200hTE01 (16.5 cm away from the injection location):
  - Post-mortem analysis shows **good agreement between NRA and LAMIS**
    - Main deposition peak at 400 mm from Pump Gap (PG) → attributed to ^{13}C **“direct deposition”**
    - Secondary deposition zone at 0-200 mm from the PG → attributed to ^{13}C re-erosion (**“migration”**)
  - ERO2.0 profile:
    - Main deposition peak shifted towards pump gap by ~100 mm
    - No secondary deposition zone at 0-200 mm



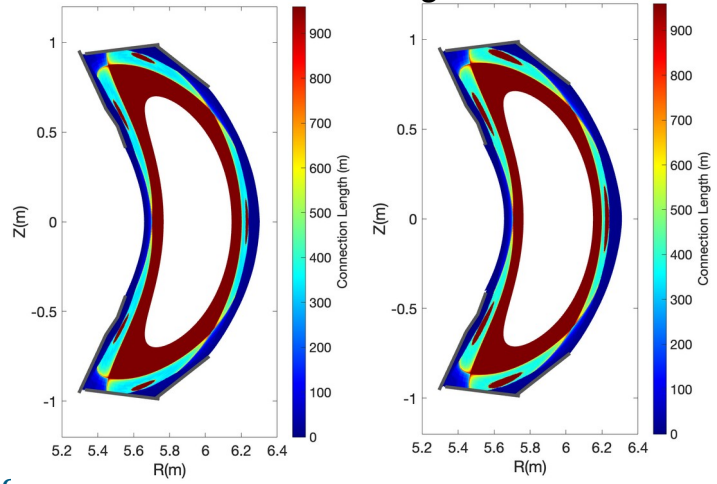
W7-X ^{13}C modelling: next steps

1) Investigate disagreements between simulated and measured ^{13}C profile.
   - Influence of simulation parameters: ExB, ^{13}C re-erosion, injection parameters, cydroharbon sticking, enhanced re-erosion, …
   - Extend the comparison to experimental ^{13}C concentrations (more profiles; 2D maps).
2) Add erosion by charge-exchange neutrals (CXN) in the simulations.
3) Comparison to Walldyn-3D modelling by K. Schmid.
   - Adjust simulation parameters, plasma background, grids, ...
4) Investigate influence of plasma current → new grids were generated by S. Xu.
   - Clarify, who is running EMC3-EIRENE?

^{13}C deposition by WallDYN-3D (K. Schmid et al., NME 2020)



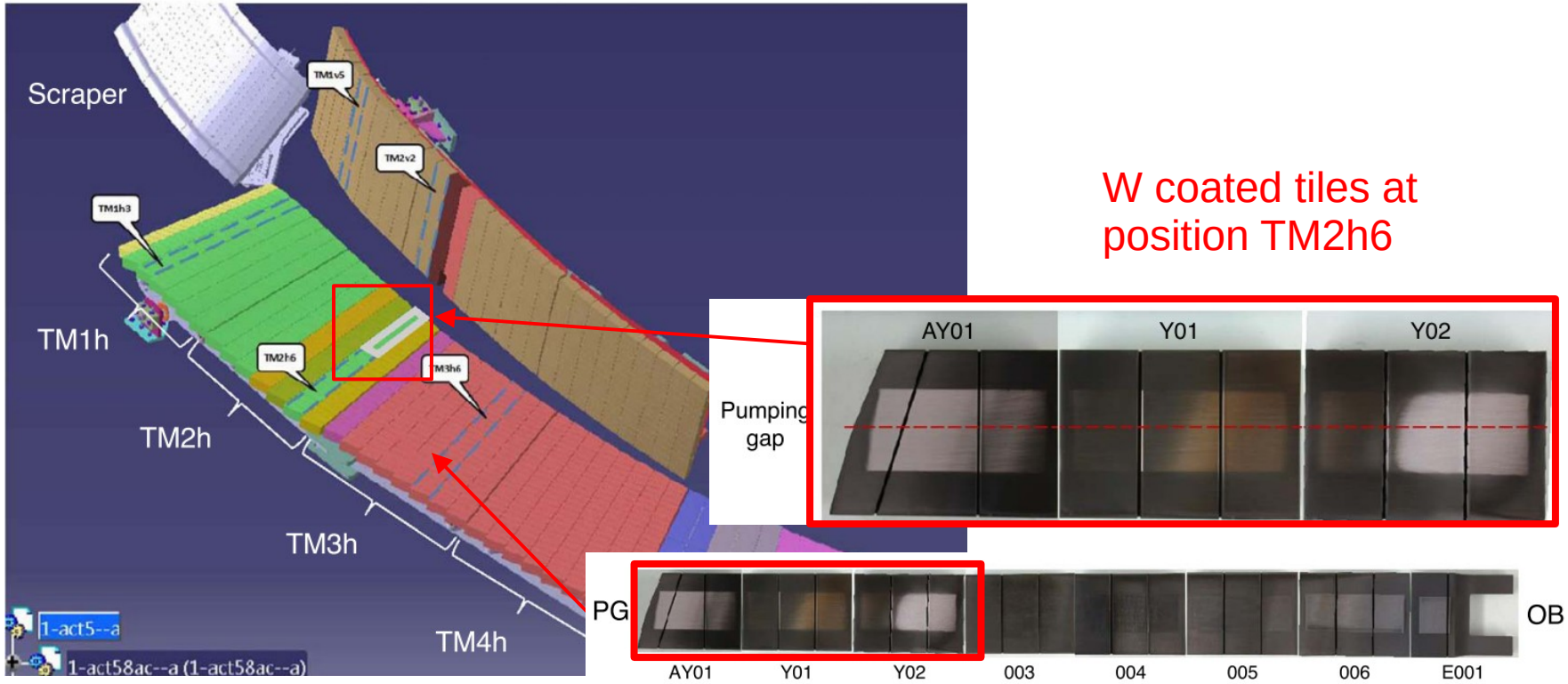
Grids by S. Xu: left: vacuum, right: 3 kA



W7-X: W tiles

W coated tiles location

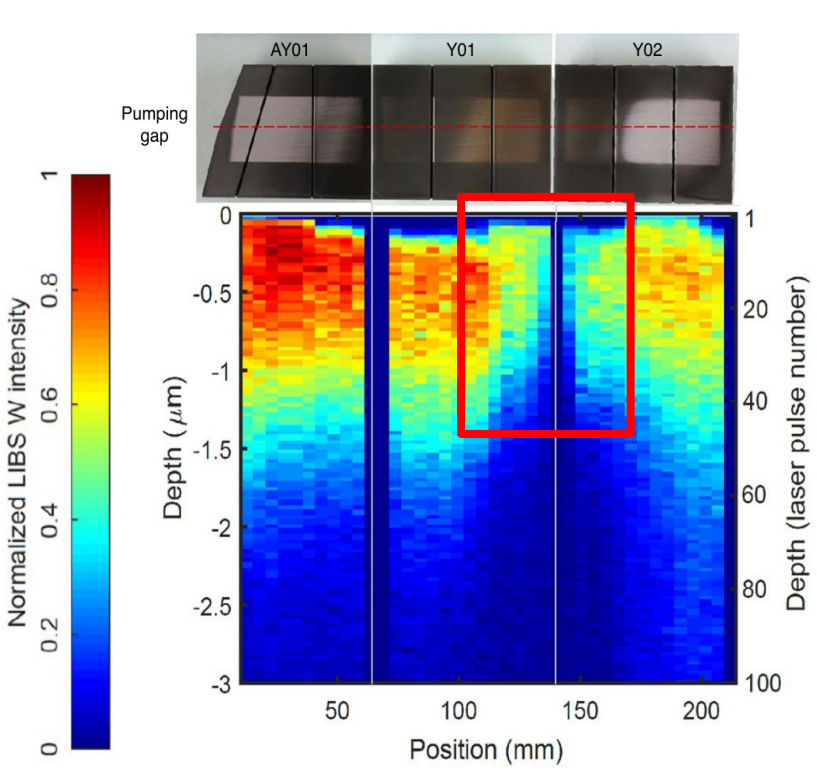
M. Mayer et al., PFMC 2021

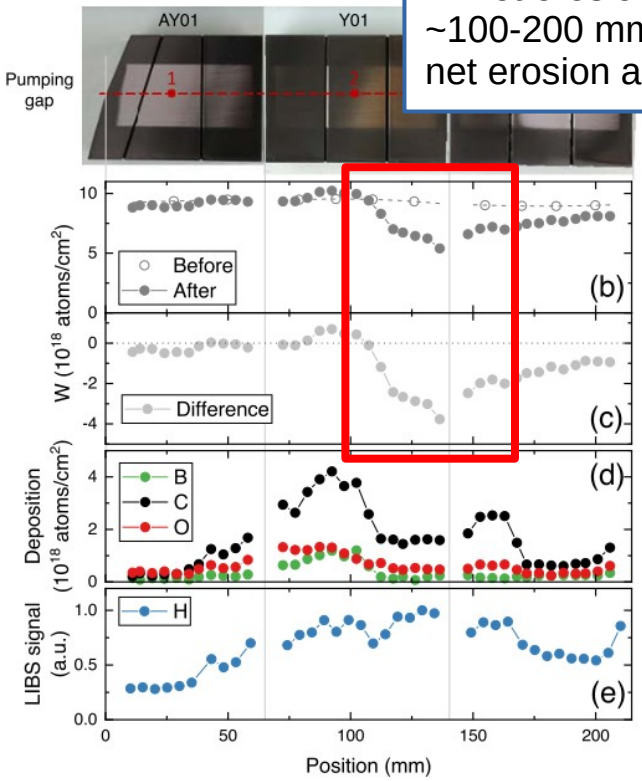


LIBS results

M. Mayer et al., PFMC 2021

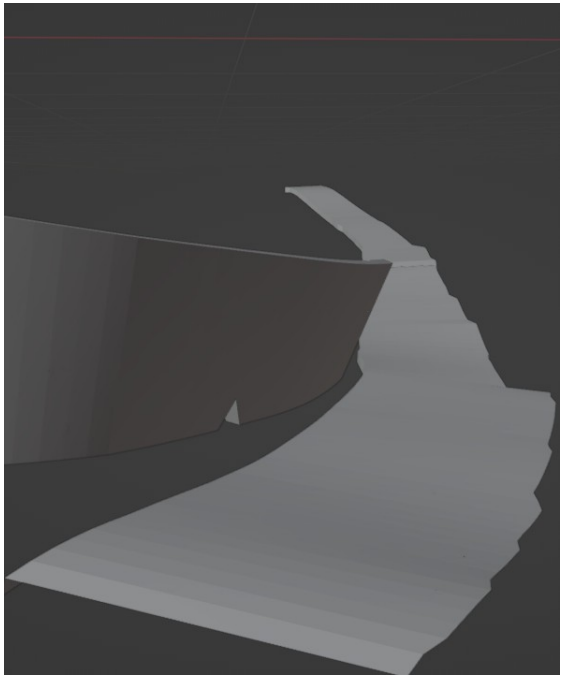
W net erosion in the region ~100-200 mm, with a peak net erosion around ~150 mm.



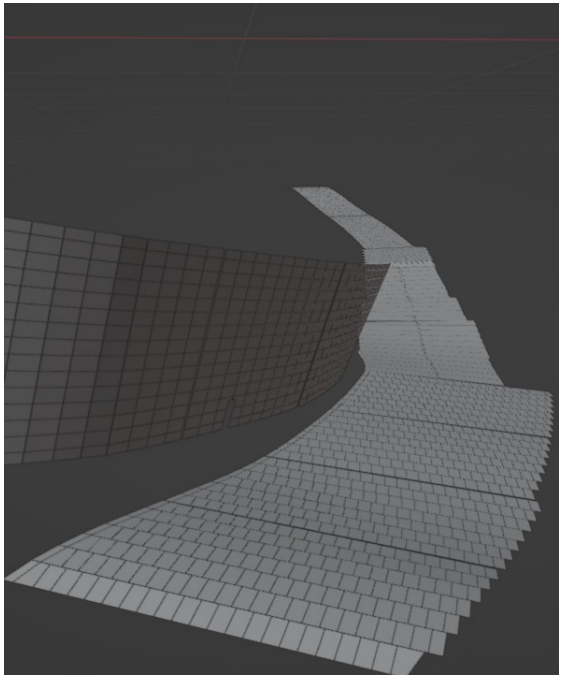


Preparation for modelling: 3D geometry update

old mesh



new mesh



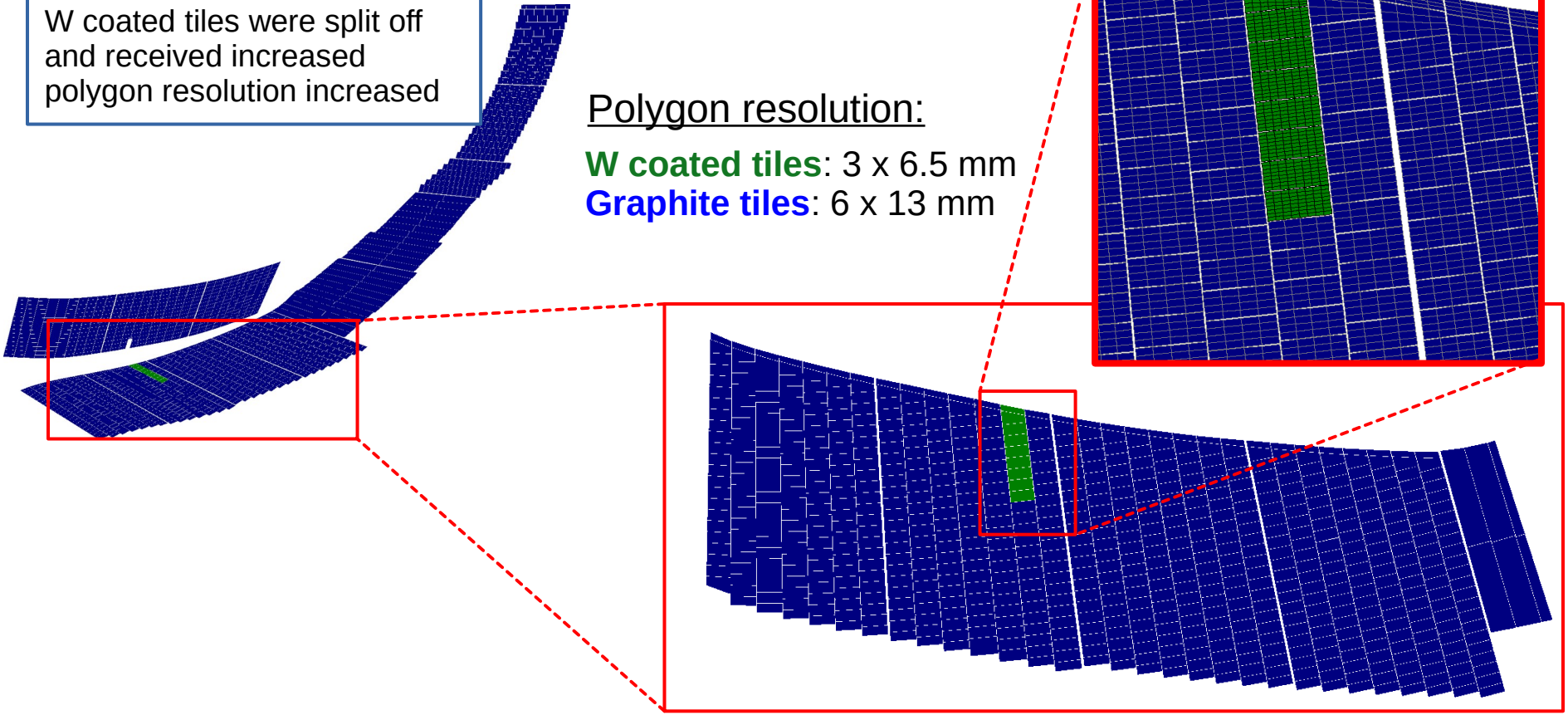
New, detailed meshes available which include the divertor tile structure.

Preparation for modelling: define W coated tiles

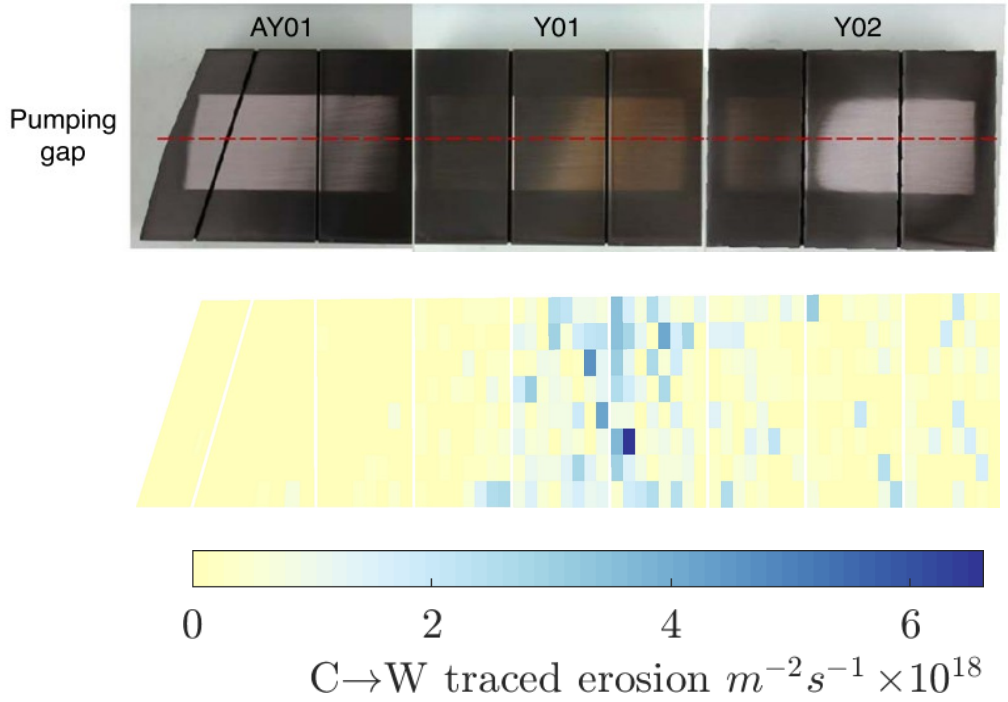
W coated tiles were split off and received increased polygon resolution increased

Polygon resolution:

W coated tiles: 3 x 6.5 mm
Graphite tiles: 6 x 13 mm

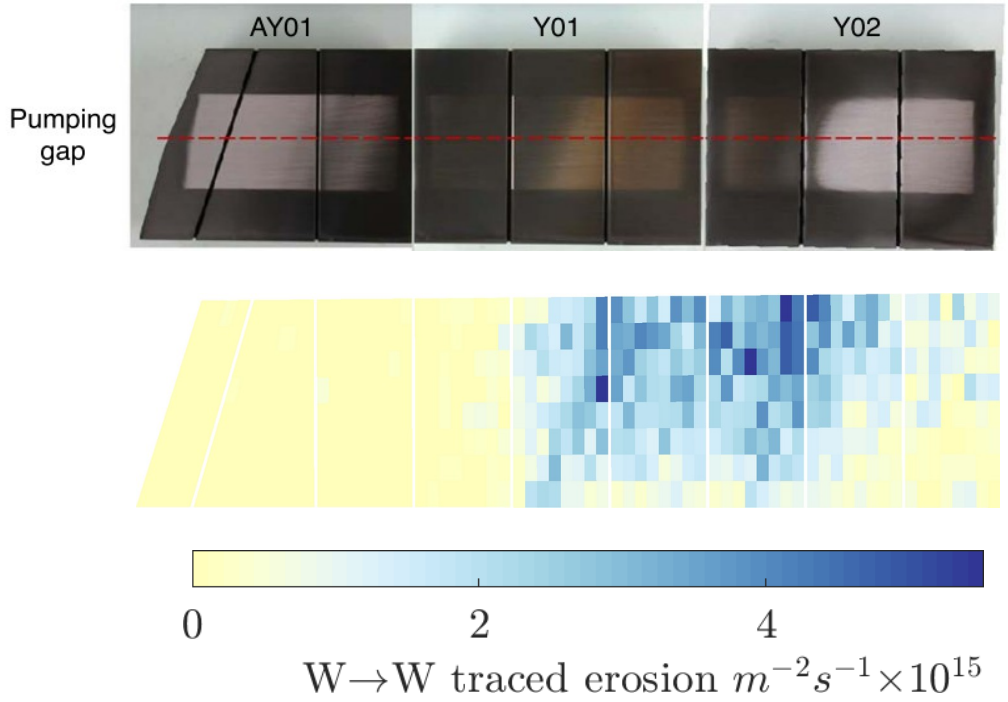


Preliminary results: W sputtering by C



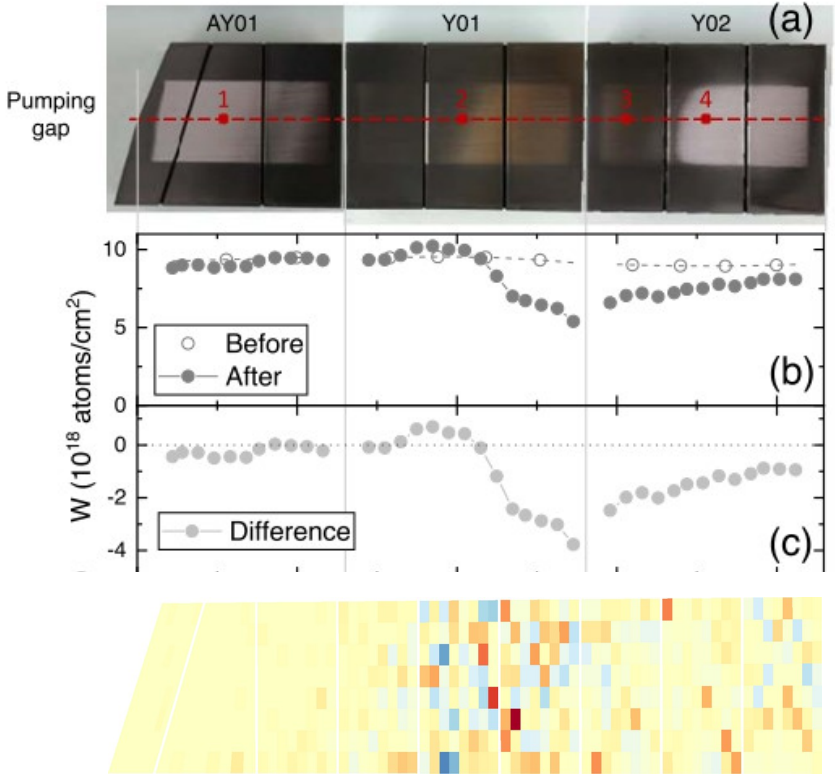
Statistics is pretty low, need to start more C particles.

Preliminary results: W self-sputtering

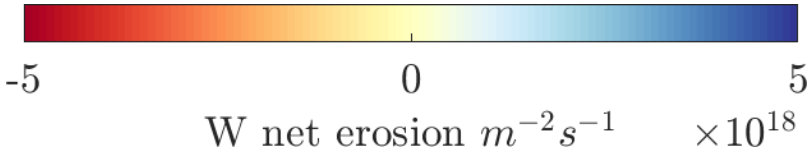


W self-sputtering is ~3 orders of magnitude lower than sputtering by C.

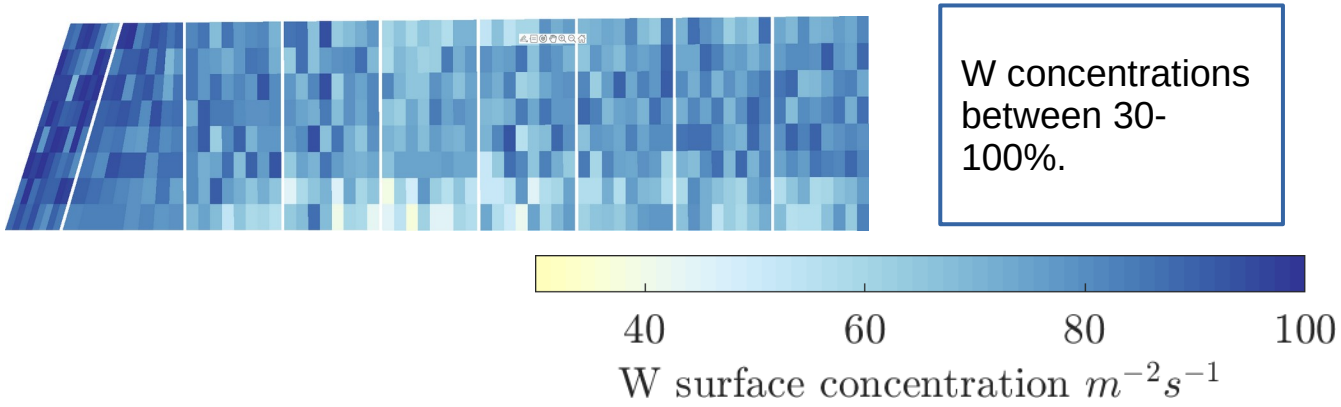
Preliminary results: W net erosion



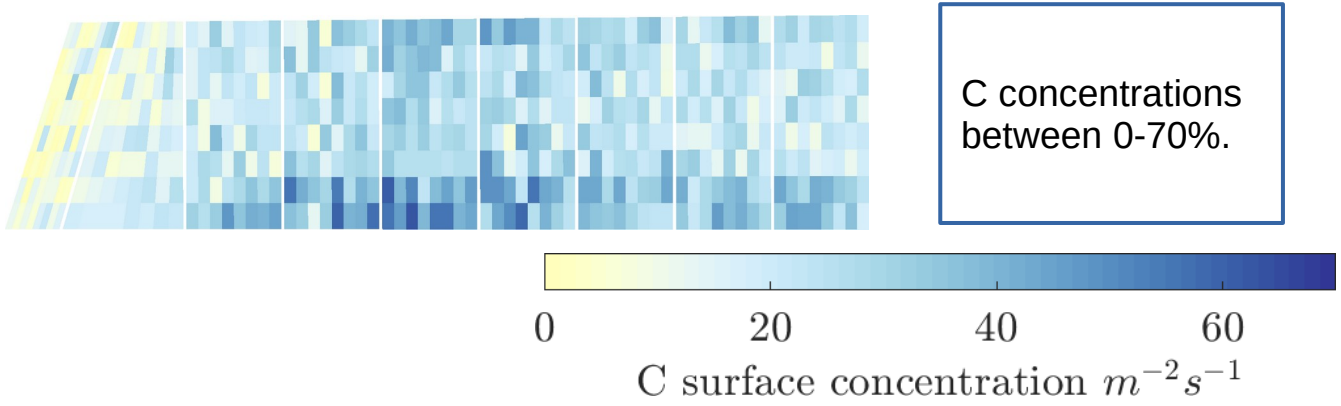
The trend seems to be somehow similar to experiment… but need better statistics.



Preliminary results: W and C concentrations



W concentrations between 30-100%.

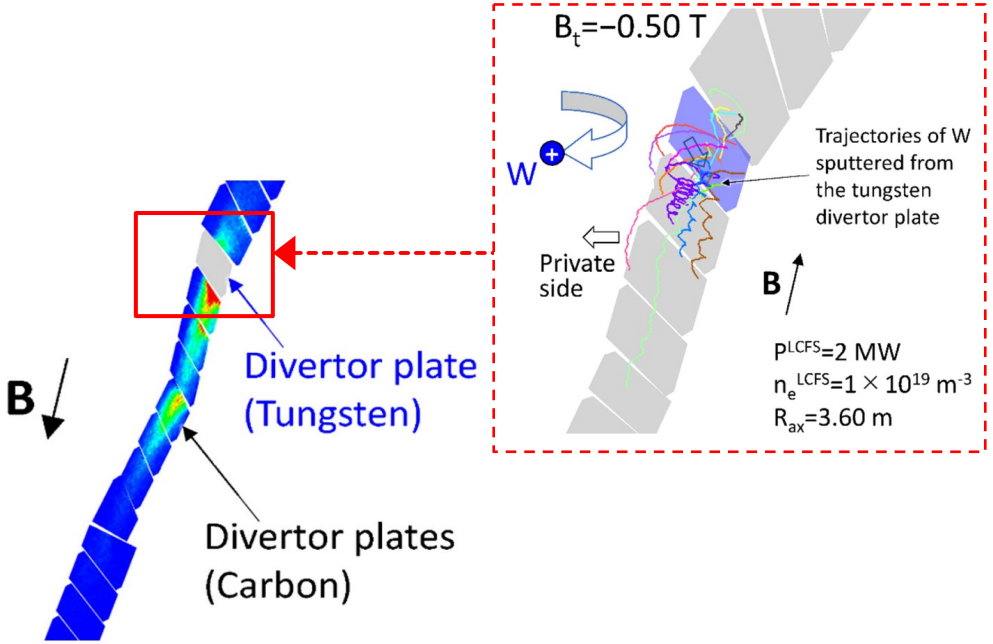


C concentrations between 0-70%.

W7-X W modelling: next steps

1) Refined simulations with better statistics.
2) More detailed comparison with experiment.
3) Co-ordinate efforts with similar modelling of C/W at LHD.
4) Review assumptions affecting W prompt redeposition (ionisation data, energy and angular distributions of sputtered W) → link to similar modelling efforts for WEST, JET, PSI-2.

M. Shoji et al., NME 2022



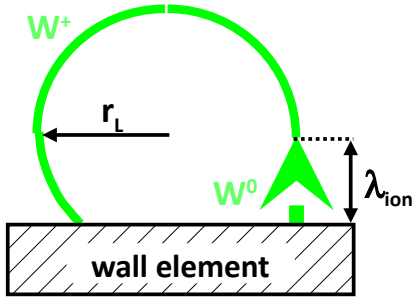
JET: global modelling

JET: W erosion in the divertor

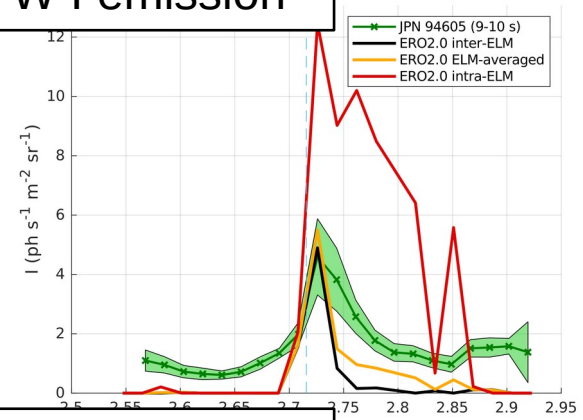
[1] H. Kumpulainen et al., PSI 2022

- ERO2.0 simulations performed with JINTRAC plasma backgrounds for H-mode inter- and intra-ELM phases.[1]
- Large W erosion at strikelines, but also high screening due to prompt redeposition.
- Simulations underestimate W II emission → further studies needed about assumptions affecting W^0/W^+ ratio.
  - Atomic data (incl. metastables), sheath model, sputtering distributions, …
  - Dedicated experiment planned at JET.
- General problem in simulating W global transport with ERO2.0: very high prompt redeposition → low statistics.
  - Advanced sampling methods developed at CEA (S. Di Genova).

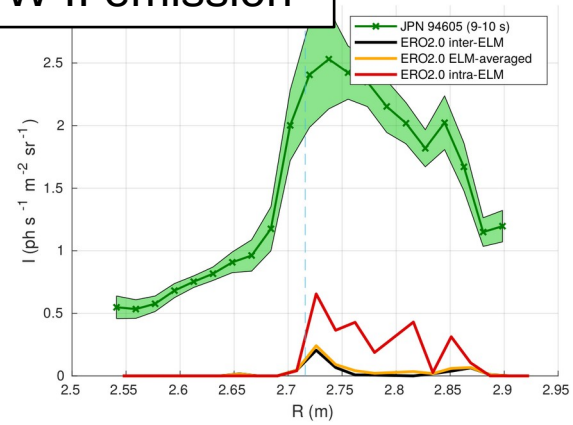
W prompt redeposition:



W I emission



W II emission



Other ongoing or planned efforts for JET (Aalto-FZJ collaboration)

- Beryllium erosion and redeposition (focus on inner divertor):
  - Experimental data in H, D, T available from dedicated Be erosion experiment.
  - EDGE2D-EIRENE plasma backgrounds available for “Be monitoring pulse”.
  - Next steps with ERO2.0:
    - Review Be sputtering yields data base for H, D, T projectiles.
    - Compare to Be line emission; compare Be layer growth in inner divertor with post-mortem data.
- Nitrogen seeding:
  - PhD of R. Mäenpää, EPS 2019, PSI 2020: influence of N_2 molecular physics on the N transport.
  - Next steps: describe ammonia reactions.
- Isotope removal experiment (D. Matveev: PSI 2022, AAPPS-DPP 2022) → modelling of Be co-deposited layers in inner divertor in raised ISP discharge.
- Nickel erosion from recessed Inconel components → B.Sc. thesis of P. Virtanen, 2022 → first comparison available to core spectroscopy.

JET: erosion and deposition of mirrors

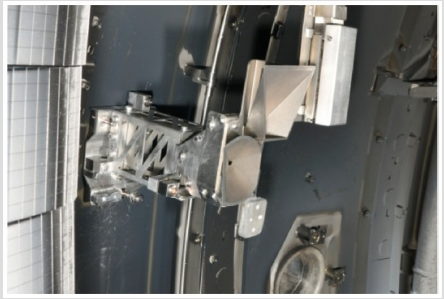
Erosion and deposition of First Mirrors

Experiments at JET

Verification of models (EIRENE+ERO2.0)

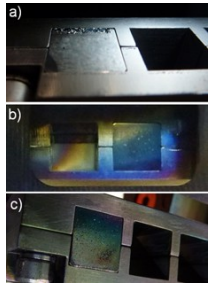
Predictions for ITER First Mirrors

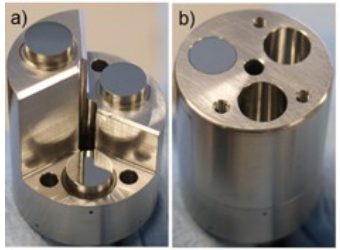
ITER-like Mirror Test Assembly (ILMTA)

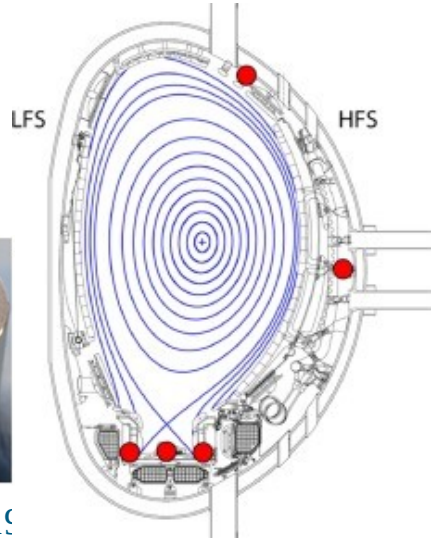


FZJ-ITER contract 2021/22

First Mirror Test (FMT) programme



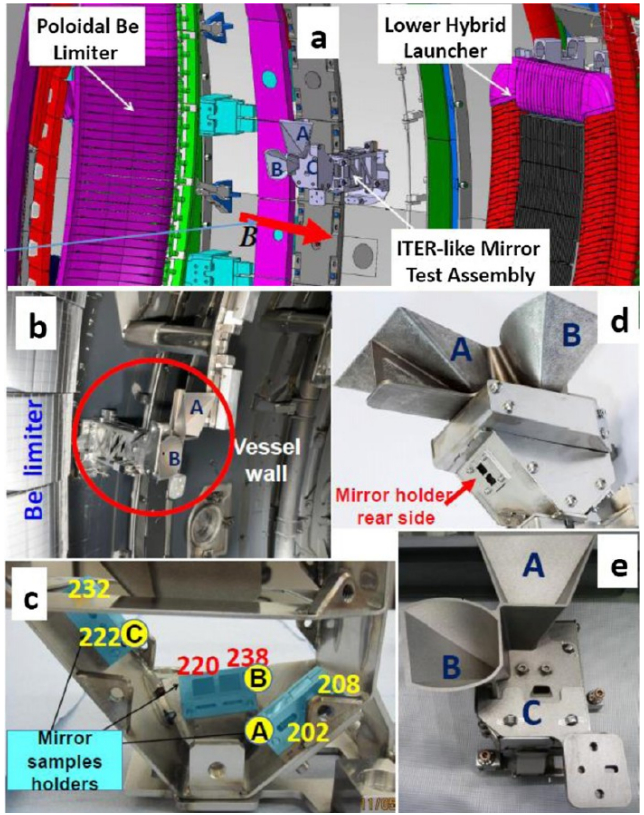




WP PWIE

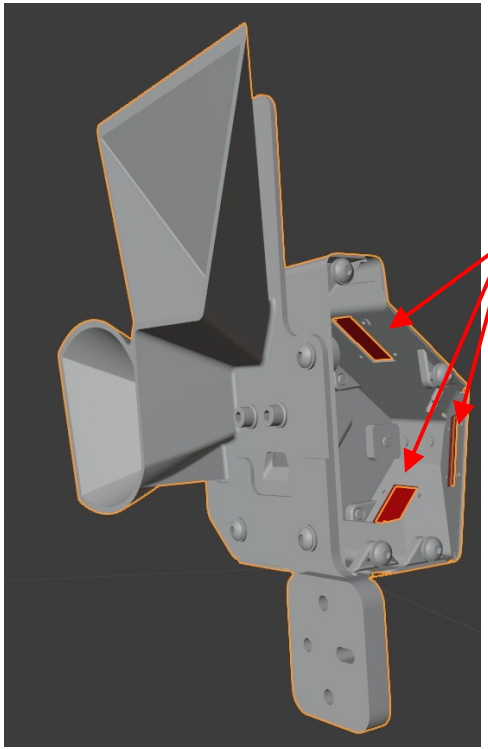
JET ITER-like Mirror Test Assembly (ILMTA)

M. Rubel et al (2021)



exposed in JET ILW-3 campaign (2015-2016), 23.4 h tokamak plasma exposure + 1027 h glow discharge cleaning

3D model cut



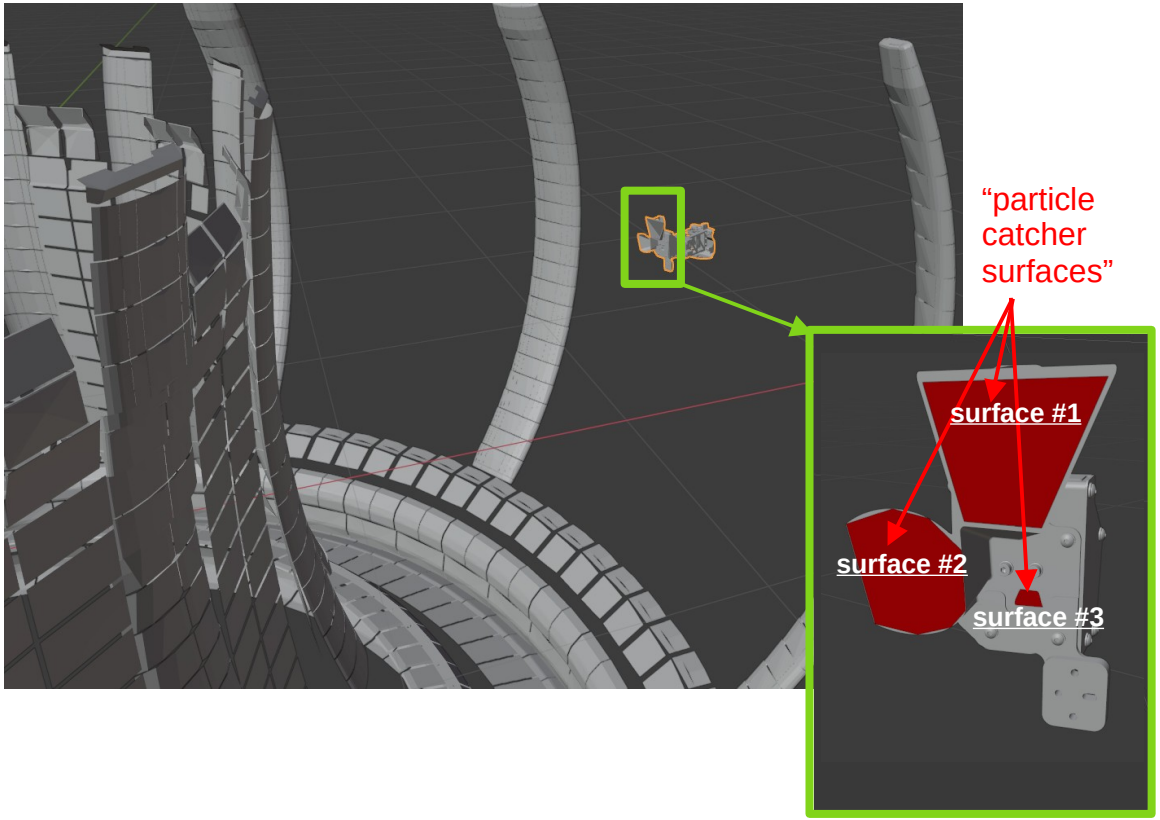
"mirror locations" *

(side was cut away to show the mirrors)

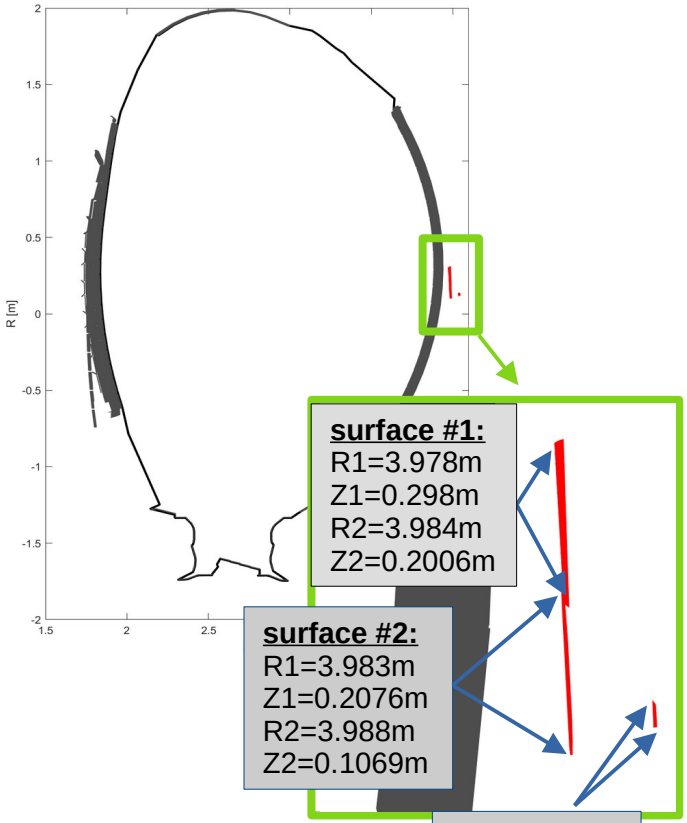
* Actually these are just sample holders, each with two mirror samples on it, but this is not included in the model.

ILMTA location

3D view



2D projection

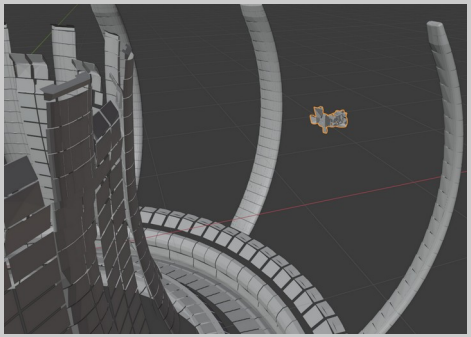


Modelling workflow – multi-stage approach

Two-level approach needed to account for differences in the level of geometric detail and plasma parameters. Also, to have sufficient statistics in local modelling (low fluxes to ILMTA!).

global modelling

EDGE2D-EIRENE or SOLPS solution

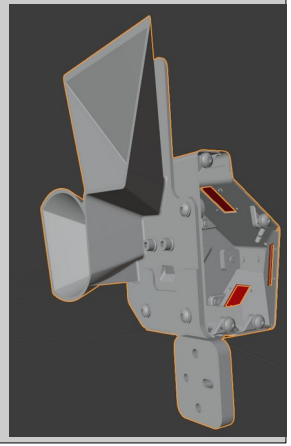


global ERO2.0 simulation → Be

EIRENE post-processing → D CXN

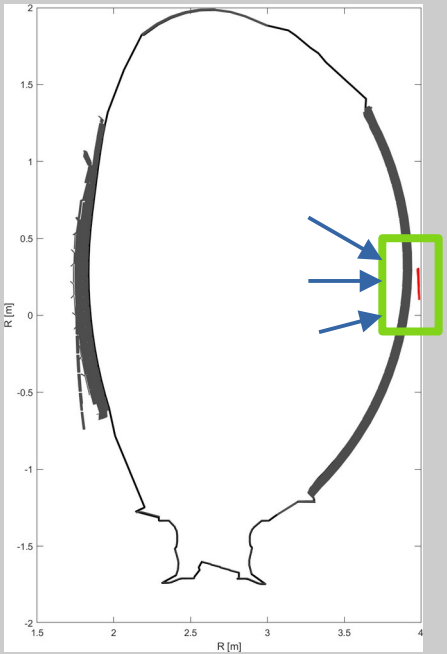
local modelling

local ERO2.0 simulation inside mirror assembly → D, Be, Fe, Ni, Mo



Modelling workflow – multi-stage approach

global modelling

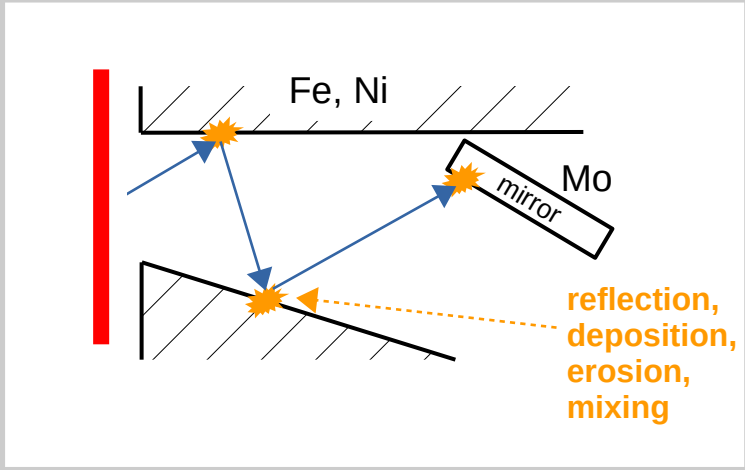


incoming particles distribution function f (flux, energy, angle)

for H, D, Be

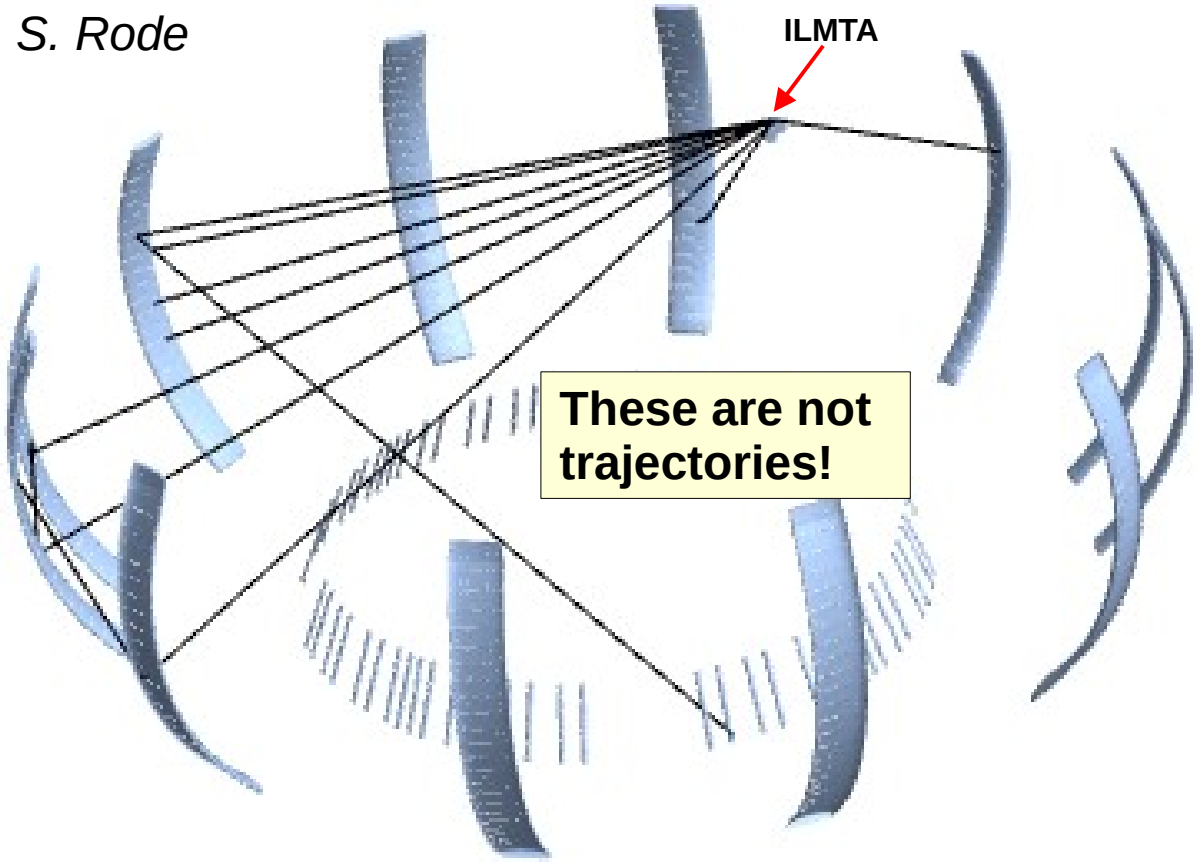
local modelling

re-sample particles at catcher surface with increased statistics and continue tracing inside small volume



Global Be transport to ILMTA (ERO2.0) – first test run

S. Rode



Of 1 Mio Be test particles starting from limiters, only a few reach the ILMTA entrance → statistics problem.

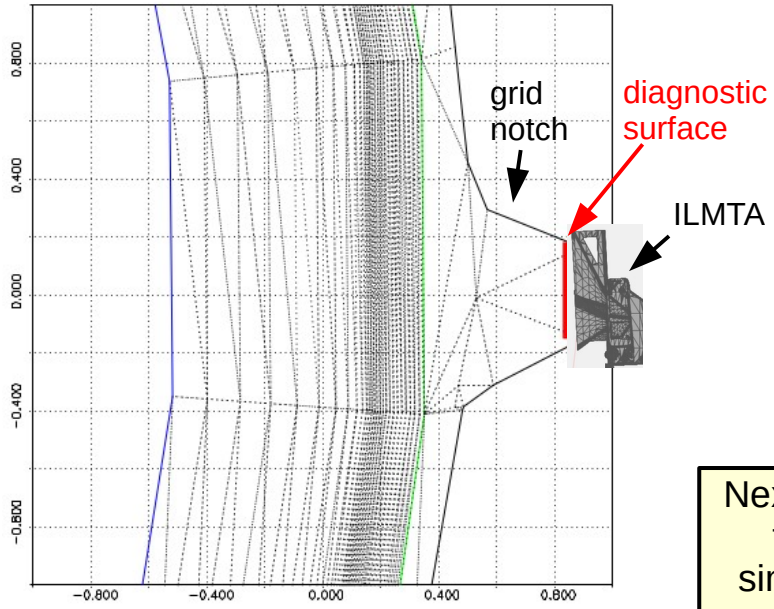
Where do these few particles originate? → Mostly from outer poloidal limiters, only one from inner limiter.

Need to repeat simulation many times to gather better statistics, before proceeding to local run.

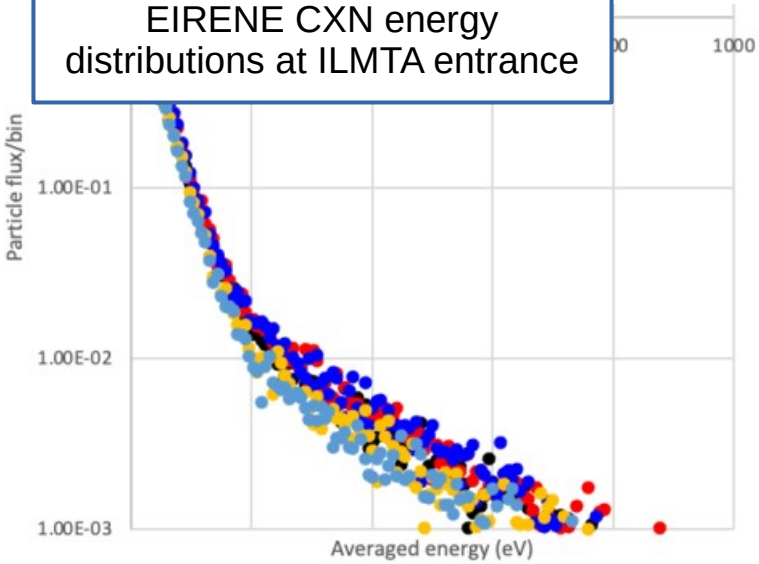
EIRENE-standalone simulations to obtain D CXN fluxes

"Grid notch" with diagnostic surface was introduced in EIRENE to collect CXN distributions at ILMTA entrance

provided by M. Groth



EIRENE CXN energy distributions at ILMTA entrance



Next step: include CXN distribution from EIRENE into ERO2.0 to simulate subsequent erosion and deposition inside ILMTA

Refinement: obtain also CXN angular distribution from EIRENE

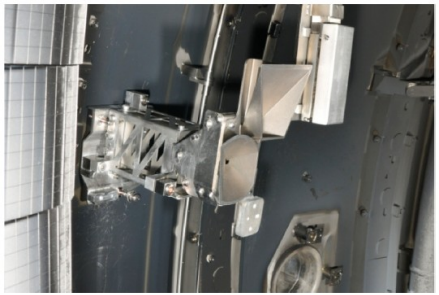
Erosion and deposition of First Mirrors

Experiments at JET

Verification of models (EIRENE+ERO2.0)

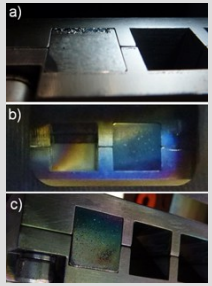
Predictions for ITER First Mirrors

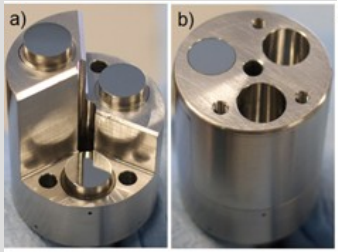
ITER-like Mirror Test Assembly (ILMTA)

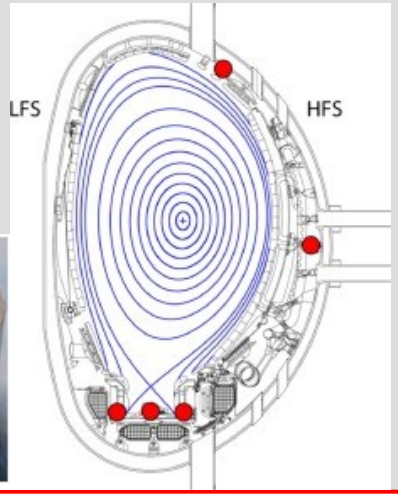


FZJ-ITER contract 2021/22

First Mirror Test (FMT) programme





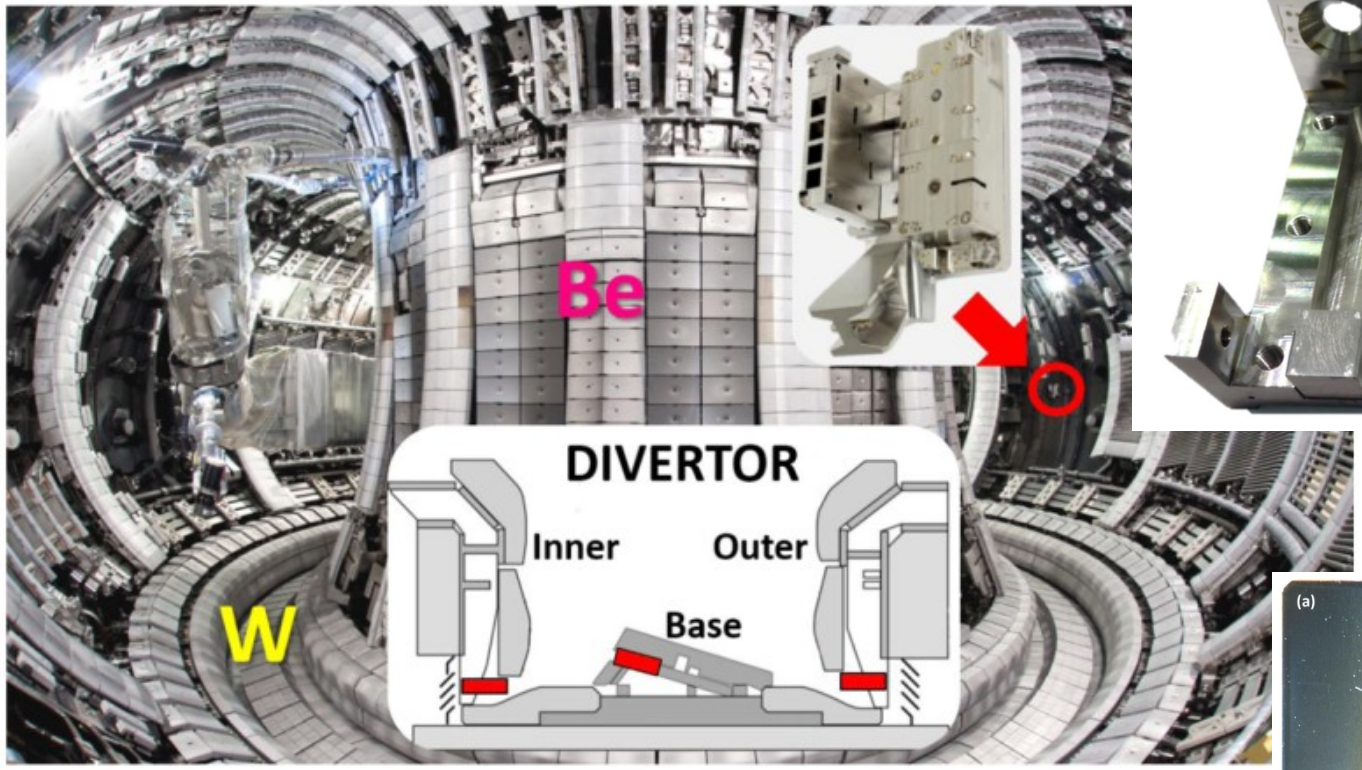


WP PWIE

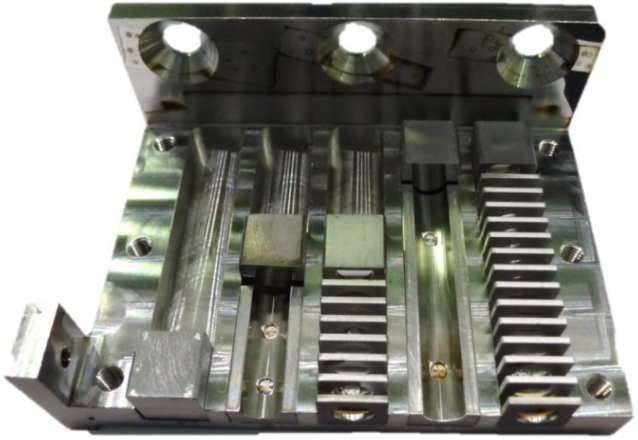
JET First Mirror Test

S. Moon et al (2019)

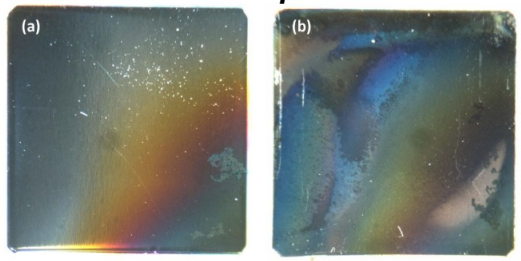
cassettes in main chamber and divertor:



five-way cassette in main chamber:



mirror samples after exposition:



JET First Mirror Test – what is needed?

- Once established, similar modelling workflow as for ILMTA could be applied.
- Locations and geometries (ideally 3D model) of mirror cassettes needed.
- CXN data (fluxes, energy+angle distributions) needed from EIRENE.

Summary on mirror erosion/deposition modelling

- **Modelling for ILMTA:**
  - Ongoing with EDGE2D-EIRENE + standalone EIRENE (Aalto) + ERO2.0 (FZJ).
  - Current status: refinement of global-scale modelling (better Be statistics from ERO2.0, angular D CXN distributions from EIRENE), before going to local-scale modelling.
  - Results can be expected in a few months from now.
- **Modelling of First Mirror Tests:**
  - No work started on this. But can be done more easily after experience with ILMTA.
  - Check if manpower in 2023 is available (EIRENE, ERO2.0).