Development and validation of the MEMOS-U code (link with WP TE – WEST/AUG) (VR)

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Outline

New code basic version is fully functioning

5MF (**M**acroscopic **M**etallic **M**elt **M**otion for **M**agnetic **F**usion)

MEMENTO **ME**tallic **M**elt **E**volution in **N**ext-step **T**okamaks

Heat transfer and fluid blocks are coupled and functioning, current propagation block is being developed now

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- Updated code features of reactor relevance: cooling pipes, complex geometry of PFCs
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- New experiment targeting ITER relevant question: gap bridging
- Plans

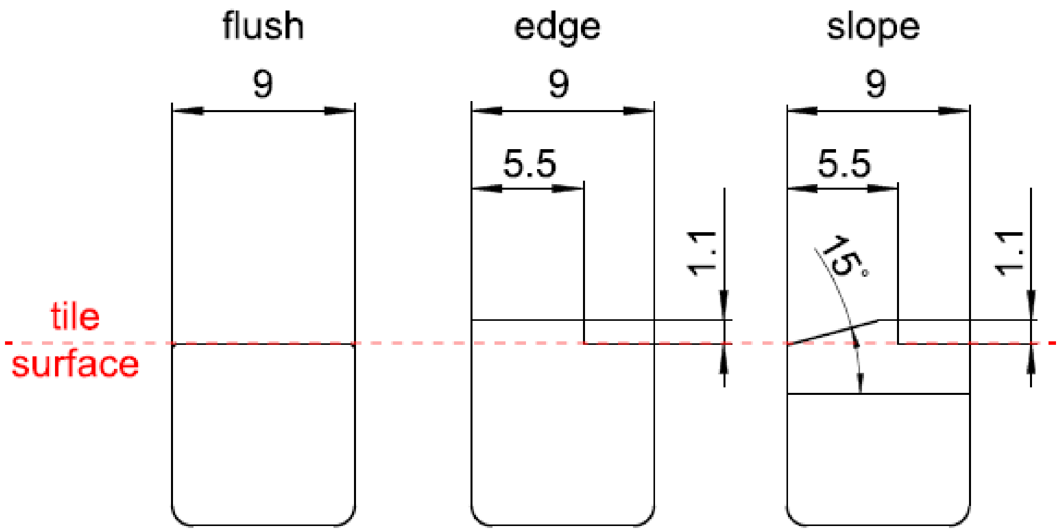
‘Poor’ vs ‘good’ thermionic emitter exposures in AUG

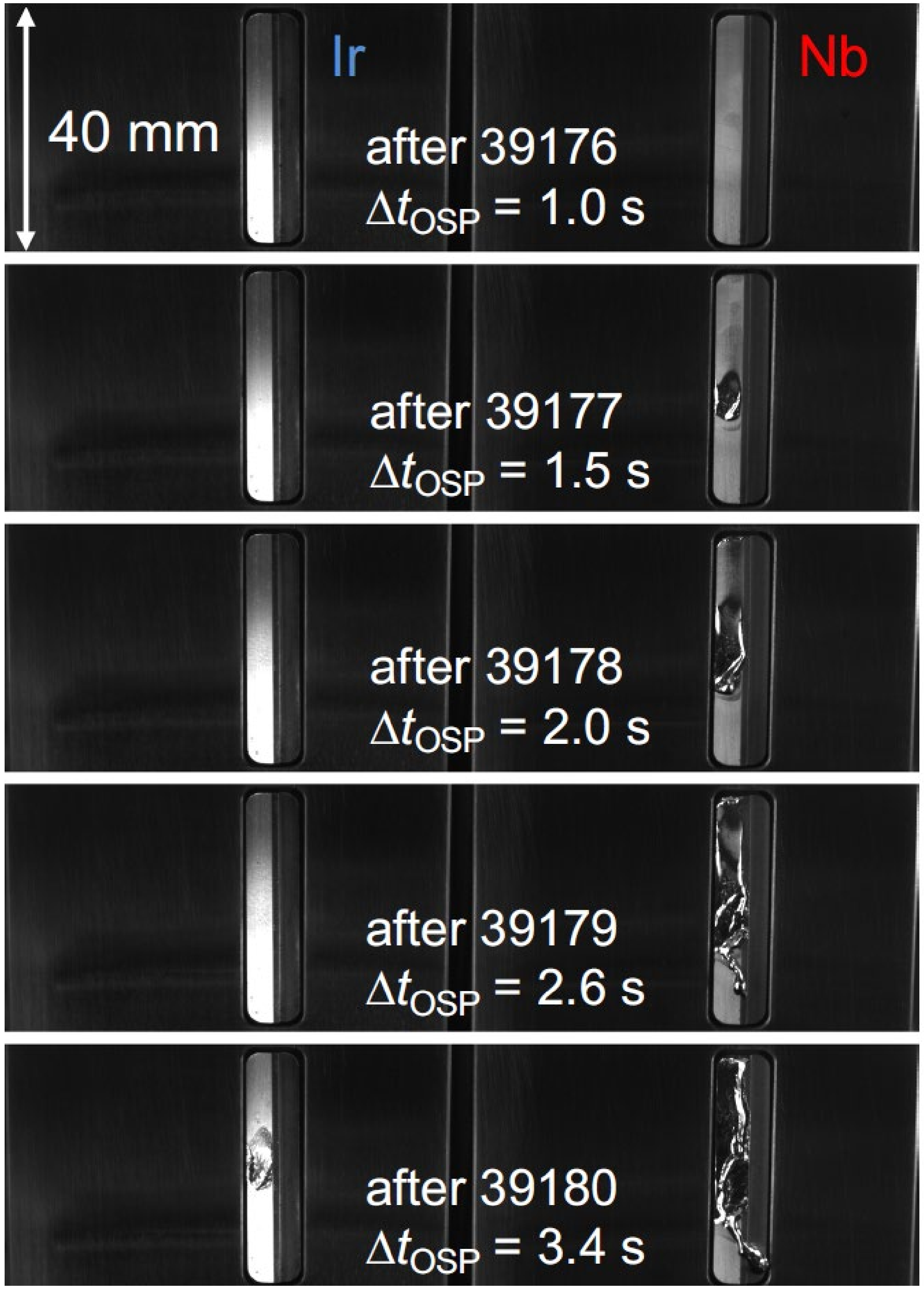
The experiment

Ir and Nb samples were simultaneously exposed to H-mode discharges at the outer divertor target plate using the divertor manipulator II (DIM-II) system

Discharge parameters (# 39175-39180)

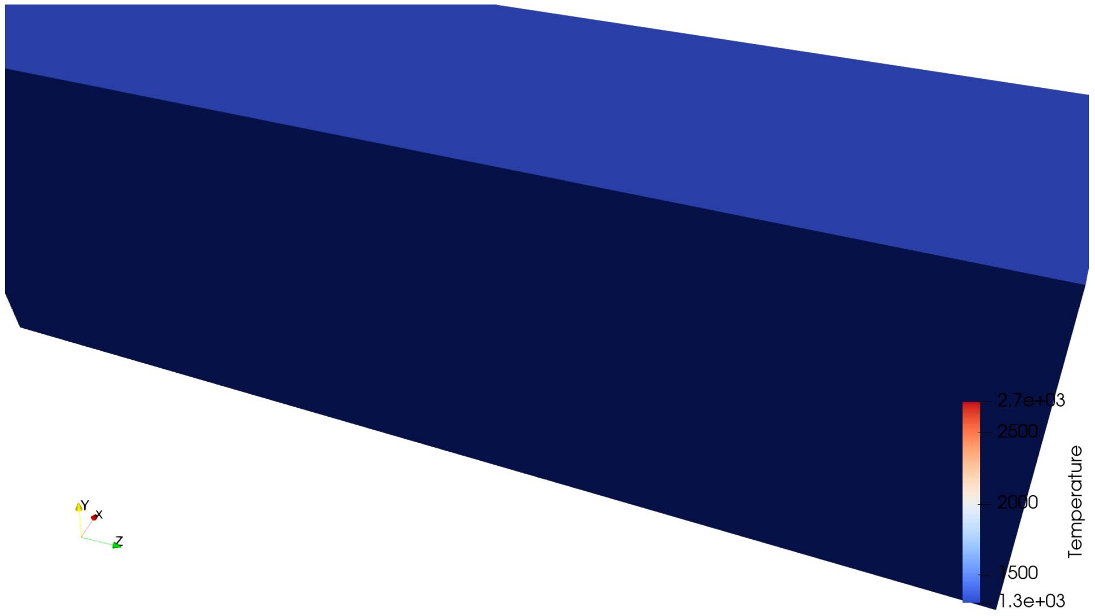
➢ P=2.5 MW (NBI), 4.6 MW (ECRH) ; I_p=1 kA ; B_t= 2.5 T





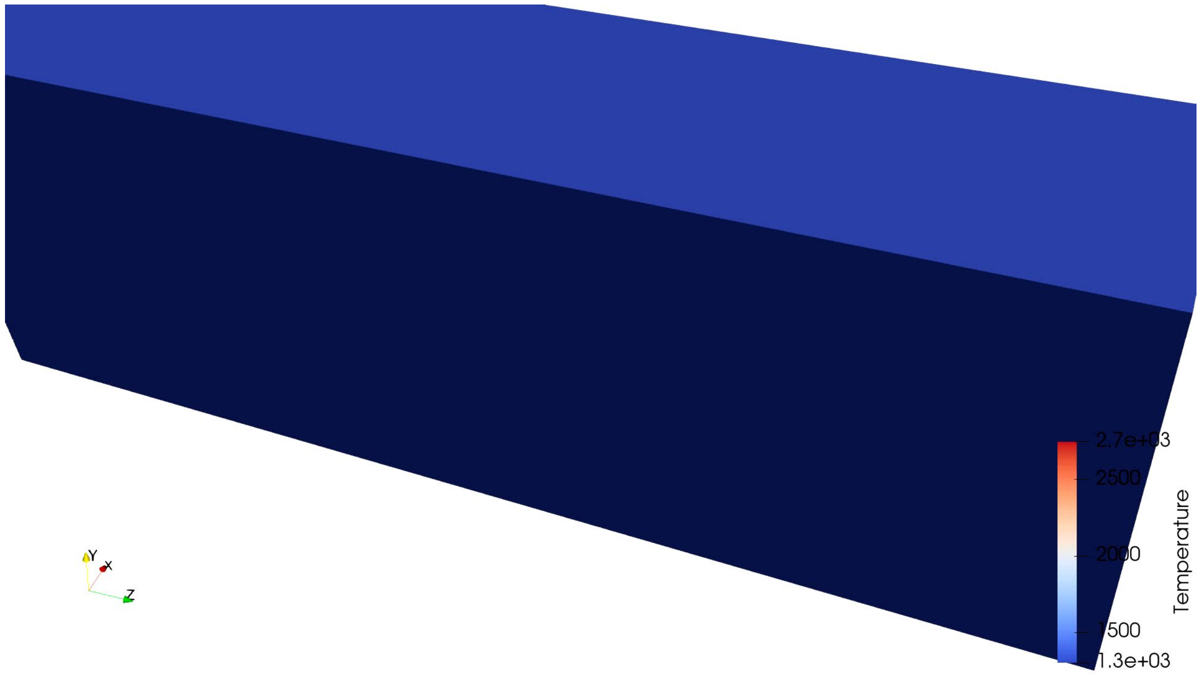
Modelling results: Ir vs Nb

Ir Full exposure 4.5 sec



Transient pools from 2.7 s
Sustained melting from 3.5 s

Up to 2.65 sec **Nb**

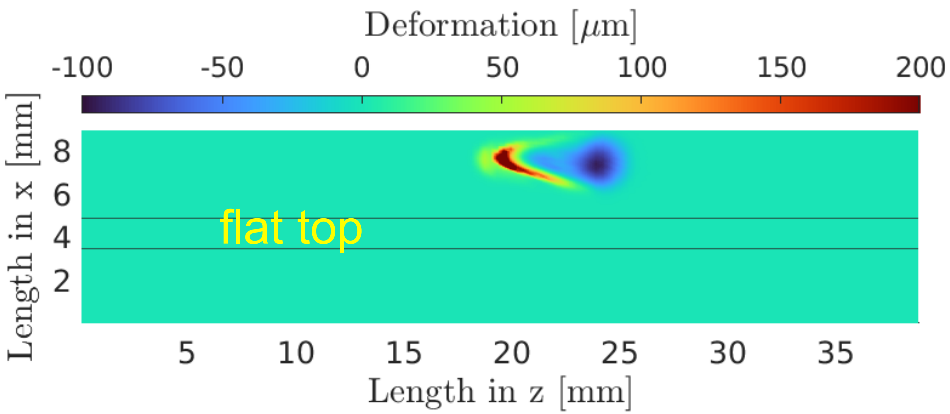


Transient pools from 1.4 s
Sustained melting from 1.8 s

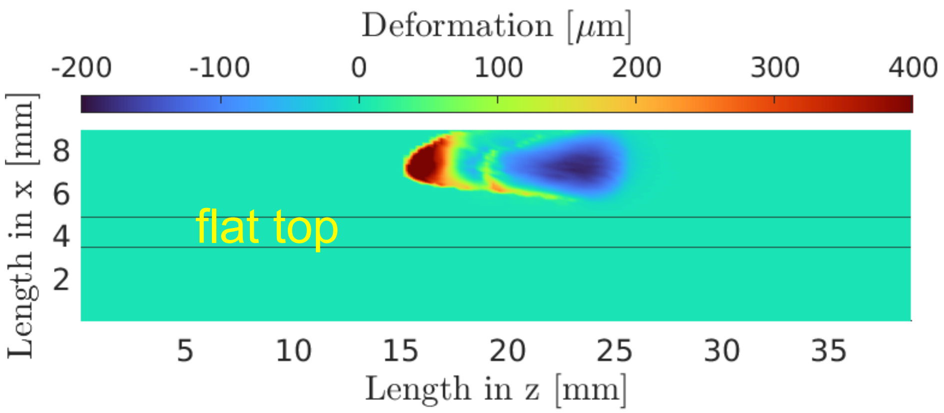
NB: Saturated & truncated temperature bar for clarity of presentation

Modelling results: Ir deformation (2D profiles)

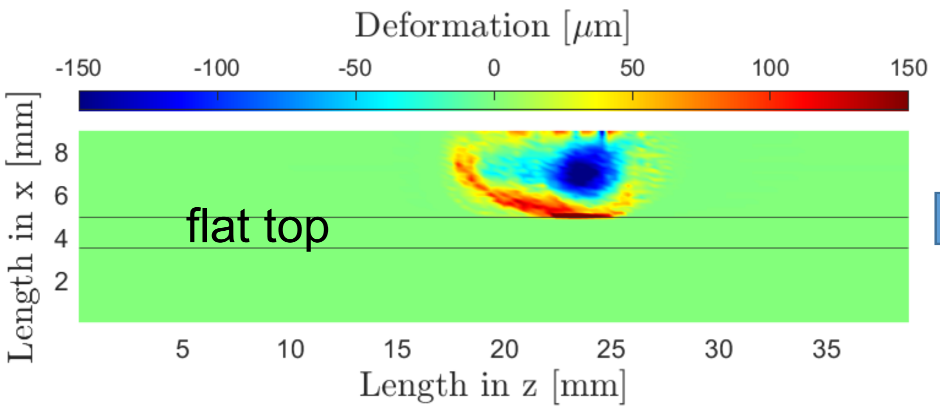
Only JxB



JxB + g

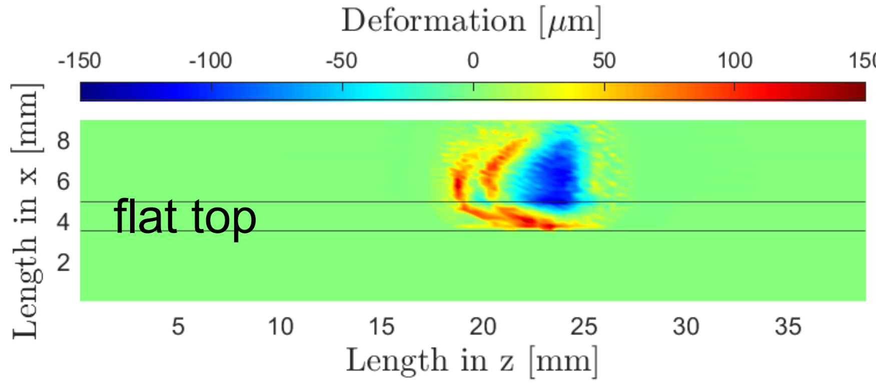


JxB + g+ Marangoni



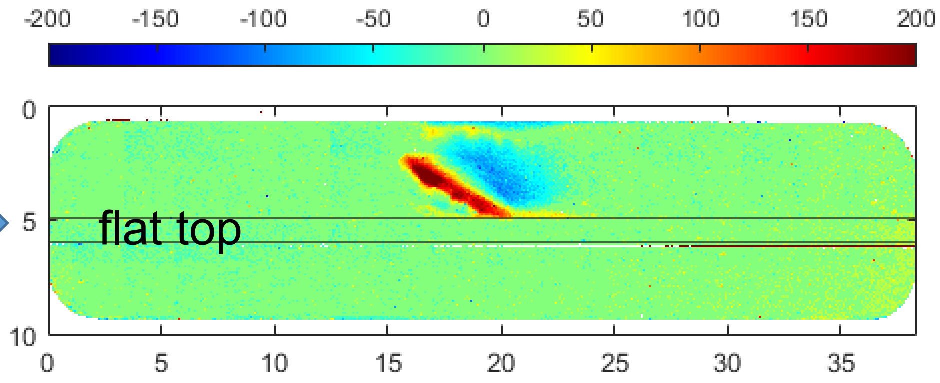
Optical approx. loading

Uniform loading of flat top



Reproducing observations

- Crater depth ~ 150 μm
- Hill height ~150 μm
- Excavated volume ~1 mm^3



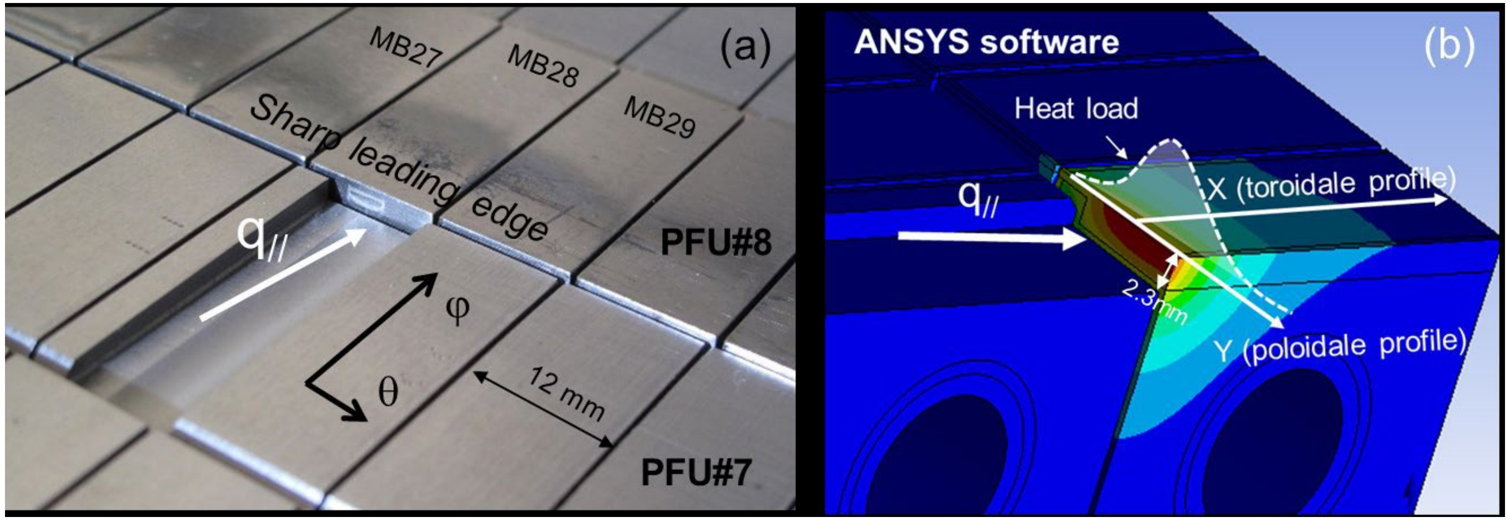
Exper.

ITER-like actively cooled W leading edge melting experiment in WEST

The experiment

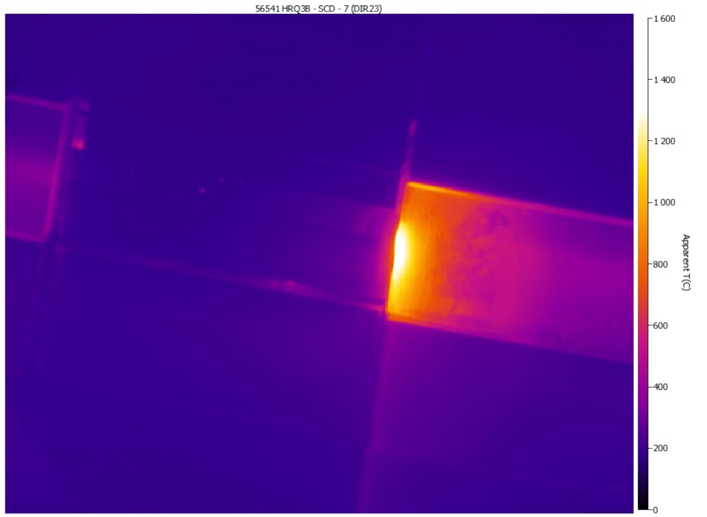
Controlled sustained W-melting on a poloidal sharp leading edge introduced into a W monoblock on one of the actively cooled ITER-like plasma-facing units in the lower divertor.

Y. Corre et al, Phys. Scr. **96** (2021) 124057



Discharge parameters

- P^{inj}=5.5 MW, I_p=500 kA, B=3.7 T
- The X-point height adjusted pulse to pulse to keep the maximum heat flux in the center of the groove
- 3 exposures, 5 sec each



Melting onset

Diagnostics

- High spatial resolution 0.1mm/pixel IR imaging
- Divertor manipulator
- Current measurement

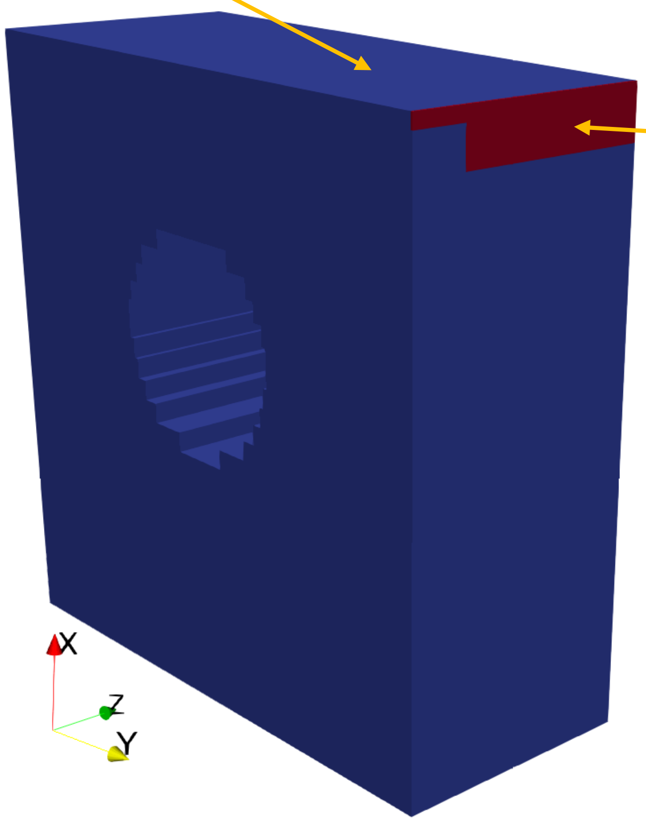
- Deformation of the LE as an indicator of melting
- Detected only in 1 discharge

Melt volume exsibits high sensitivity to small power variations

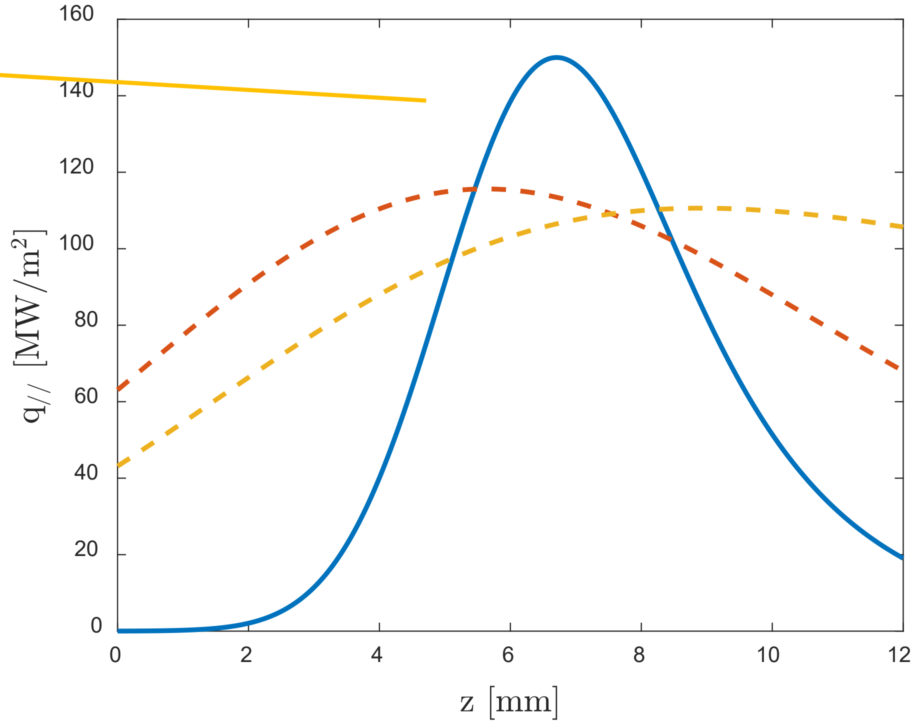
Simulations of WEST LE: loading with experimental heat flux

5 s exposure to the field-line parallel heat flux versus z coordinate (along LE)

flux on the top $1/20\ q_{||}$



$$q_{||}(z) = \frac{q_M}{2} \exp\left[\left(\frac{S}{2\lambda_q}\right)^2 - \frac{z - z_0}{\lambda_q}\right] \mathrm{erfc}\left(\frac{S}{2\lambda_q} - \frac{z - z_0}{S}\right)$$



Simulations here are with $q_M = 382\ \frac{MW}{m^2}, \mathrm{S} = 2\ \mathrm{mm}, \lambda_q = 2\ \mathrm{mm}, \mathrm{z}_0 = 5.5\ \mathrm{mm}$ (blue curve)

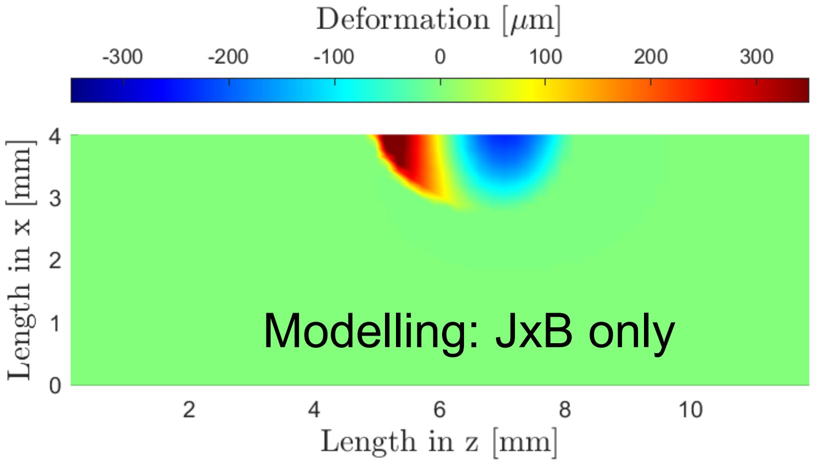
as per experimental input but increased from estimated $q_M = 314\ \frac{MW}{m^2}$ due to surface cooling fluxes

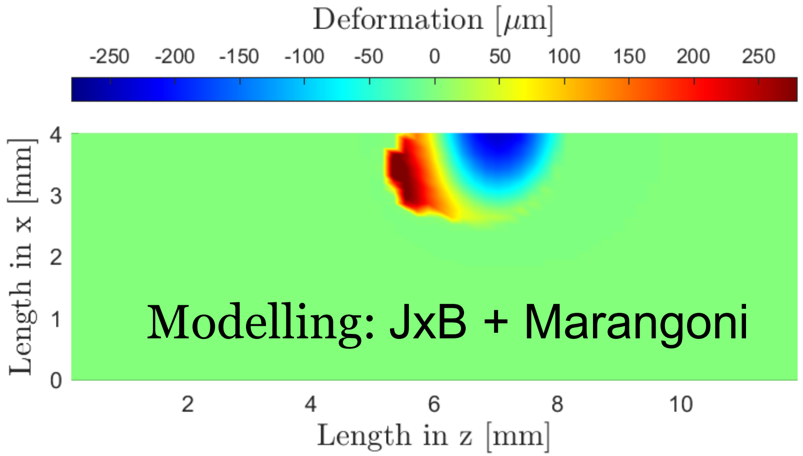
Modelling results

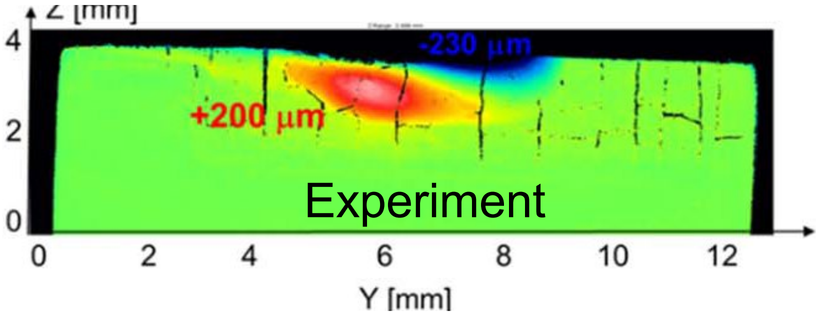
Evolution of deformation over the discharge duration 5 sec

Observed excavated volume ~$0.26\ \mathrm{mm}^3$ and profile are well reproduced in modelling
Also matching timing of the melting onset

Final surface deformation (LE face)







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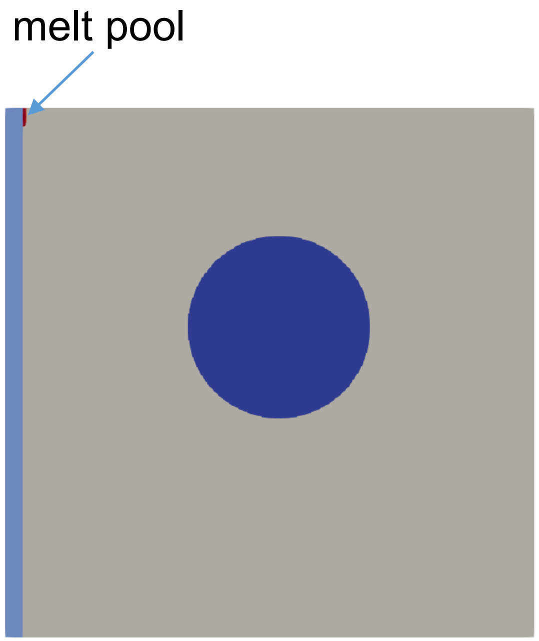
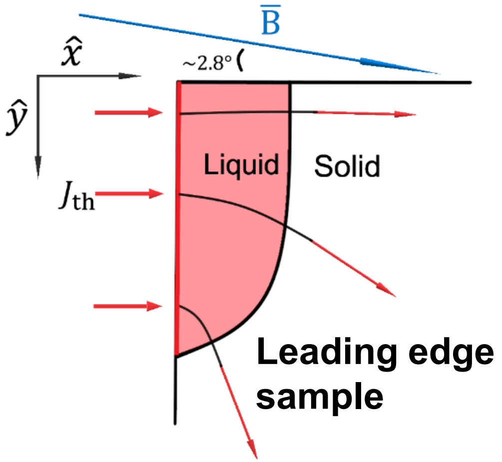
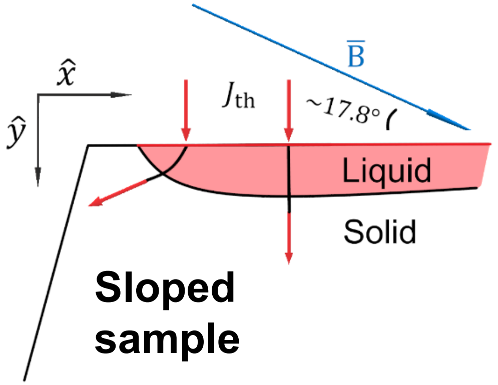
Dynamo component of the bulk current density

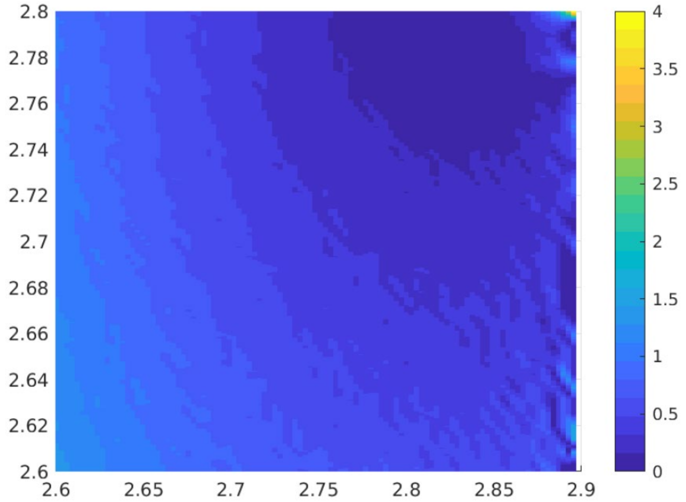






- The bulk current block emerges naturally from TEMHD within the magnetostatic limit – the toroidal B-field is much larger than the B-field generated by the bulk current.
- Neglecting the dynamo term in Ohm's law – questionable for larger v and B in ITER
- Dynamo current contribution to momentum balance results in a friction-like term $\propto -B^2 v$

Relative difference in J_y pipe/no pipe [%]



$$\nabla \cdot \left[\frac{1}{\rho_e[T(\boldsymbol{r})]} \nabla \varphi \right] = 0$$

$$\rho_e \boldsymbol{J} - \boldsymbol{v} \times \boldsymbol{B} = -\nabla \varphi$$

- Tests to confirm insensitivity to specifics of grounding, pipe presence etc
- Assess effect of the dynamo term in the bulk current, Lorentz force and erosion profile

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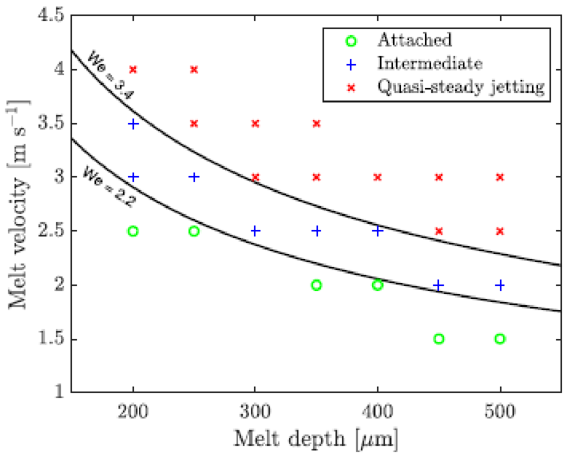
Gap bridging

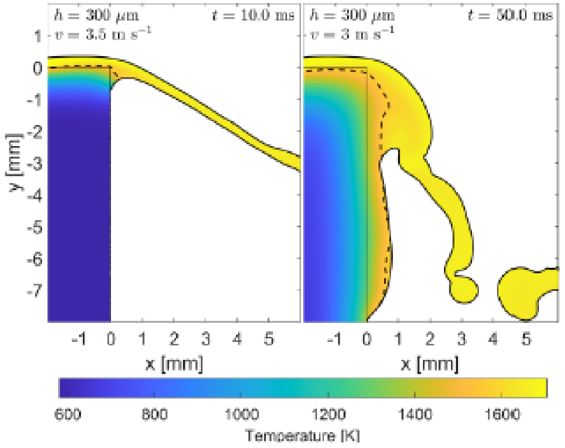
RT-16: W melt flow traversing toroidal gaps and edges

Device: AUG

TFLs: A. Hakola, E. Tsitrone **SCs:** Y. Corre, K. Krieger

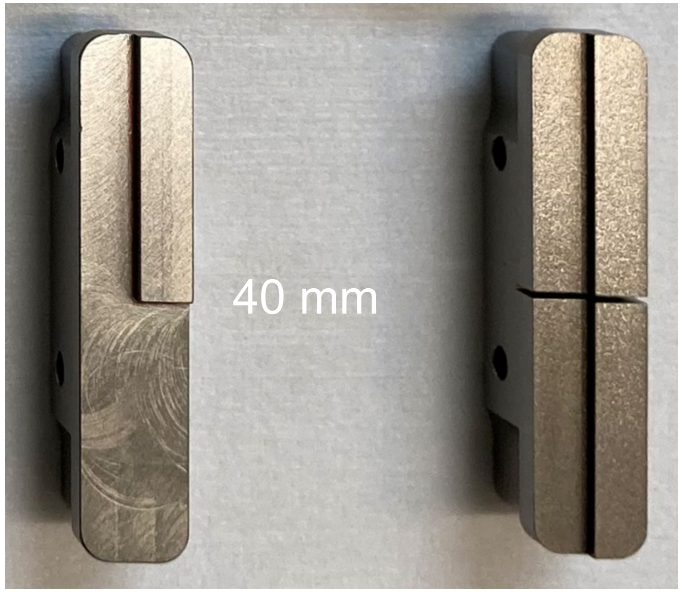


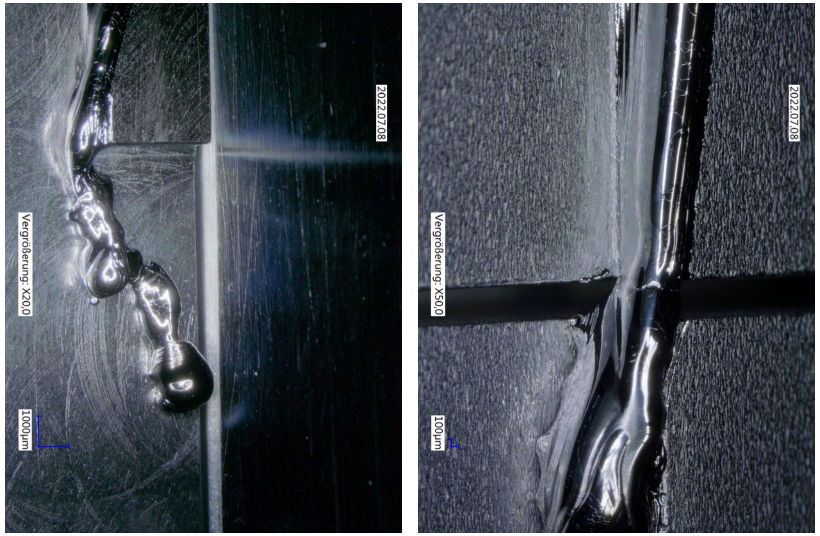
L. Vignitchouk et al PPCF **64** (2022) 044004



S. Ratynskaia et al PPCF **64** (2022) 044004

Modelling goal:
Use 5MF code to model the melt motion continioulsy through the gap





Current status

PSI 2022 invited talk,
S. Ratynskaia *et al*
Experiments and modelling on ASDEX Upgrade and WEST in support of tool development for tokamak reactor armour melting assessments

Nucl Mater Energy special PSI 2022 issue – manuscript same title as above, submitted June 2022

5MF code description
F. Lucco Castello, K. Paschalidis, S. Ratynskaia, P. Tolias, L. Brandt and M. Niazi
To be submitted Oct-Nov 2022

RELATED:

In connection with SPD (to enable the code's reactor relevant boundary conditions)
ITER relevant multi-emissive sheaths at normal magnetic field inclination
P. Tolias, M. Komm, S. Ratynskaia and A. Podolnik, Nuclear Fusion (submitted)

Nuclear Fusion ITPA Special Issue DivSOL Chapter
Sec.9 *PFC damage by excessive heat loads*
first draft completed (11 pages, close to 100 references)

Plans

Physics model validation

Gap bridging: simulations of latest AUG exposures to be performed with the experimental heat flux

Induced current: test role of the dynamo term in melt dynamics / deformation profiles

New experiments: proposal for PWIE experiment on effect of the reduction of the pre-recrystallization thermal conductivity on melting onset and gap wetting by ultra-thin melt layers (WEST exposures) have been selected

Code development

- Implement the current propagation equations in 3D and test the solver
- Enable the full coupling between all three solvers
- Enable the possibility to define in the input files the scenario and relevant physics of the boundary conditions