IPP INSTITUTE OF PLASMA PHYSICS
OF THE CZECH ACADEMY OF SCIENCES

Development of COMPASS-U LMD module and scenario modeling

WPPRD/LMD End-of-Year Meeting, 15th December 2025

R. Dejarnac, J. Horáček, J. Cecrdle, S. Lukes, O. Stukavec and B. Smith (UKAEA)

MINISTRY OF EDUCATION,
YOUTH AND SPORTS

Task Specification (TS)

EUROfusion

Deliverables of the task:

Deliverable	Description
PRD-9.PRC.01-T009 - D001	The deliverable will report on: 1. Thermally enhanced sputtering measurements Li 2. HeatLMD modelling of ELM and core response in COMPASS-U — Modelling part 3. Optimization of CPS mesh attachment 4. Final design of LM-CPS concepts for COMPASS-U 5. Manufacture CPS prototypes 6. Feasability study of COMPASS-U operation with vapour box/cave divertor — Design part [Several concepts still use CPS and likely we still want to test CPS-based designs in COMPASS-U]

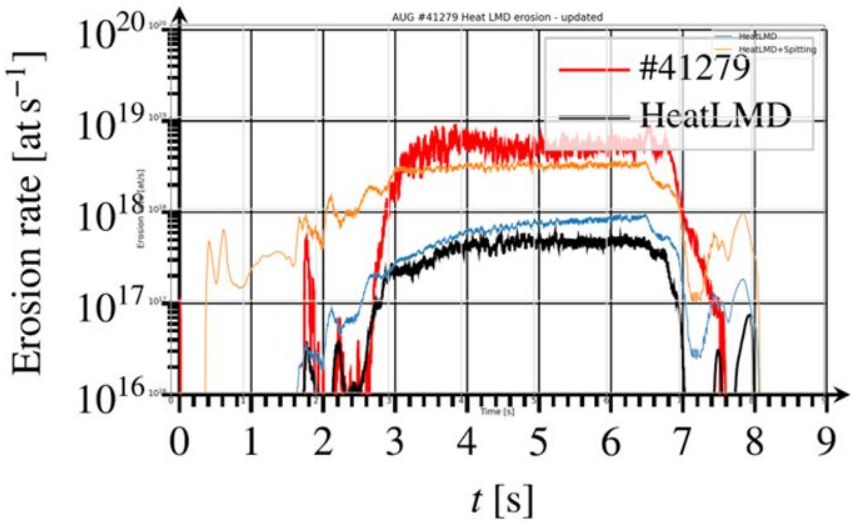
Modeling: HeatLMD

Deliverables:

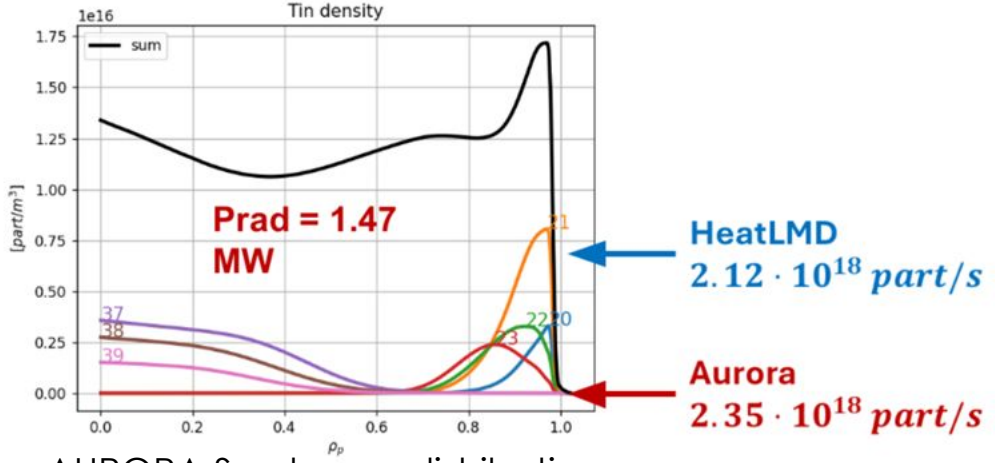
- **Li thermally enhanced sputtering measurements DONE** (data still under analysis)
- **HeatLMD modelling of ELM and core response in COMPASS Upgrade DONE**
- **Publication** J. Horacek et al., *Scaling of HeatLMD-simulated impurity outflux from COMPASS-U liquid metal divertor*, Nucl. Fusion **65** (2025)

Main work:

- **Parallelization** – heat conduction solver (current bottleneck) speed up by >100x at a commercial GPU Par
- **Sn spitting implemented** – simple sputtering yield calculation
- Planned – Coupling with vapor shielding code (Made by PoliTo)
- **Revised AUG modelling**
- Extend to other past works like C-U in the future
- **HeatLMD+AURORA coupling** – match bolometry core radiation within 11% (PoliTo collaboration)
- **Strong Type I ELM resilience and compatibility modelling** – current results show negligible core impurity radiation (work still ongoing)



Comparison of HeatLMD and OES Sn erosion rates



AURORA Sn charge distribution

ERO2.0 code (edge impurity transport)

2024: 1st validation and predictions for Li and Sn (presented at PSI-26, S. Lukes)

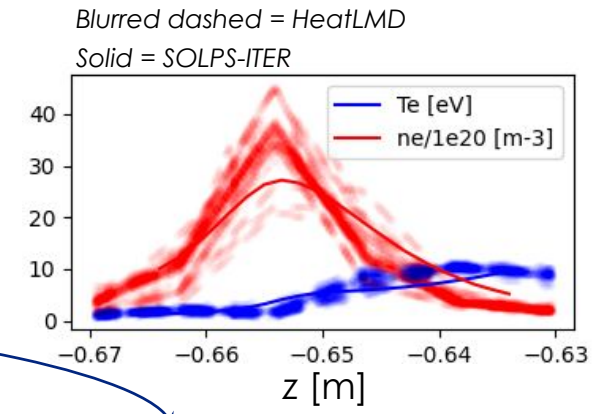
Improvements in 2025 – mid-term meeting:

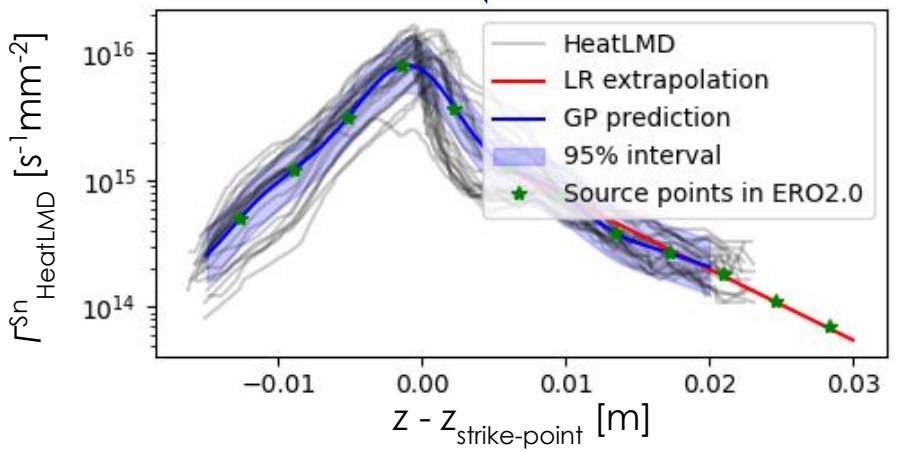
$E_{//}$, $E_{\perp}$ and q_{cond} (thermal force) directly from SOLPS-ITER
2nd simulated scenario #24300
Centrifugal force and new $D_{\perp}$, $v_{\perp}$ (FACIT + METIS)
and many other …

Mid-term meeting – now:

Source profile from HeatLMD
Spatially distributed R_{prompt} (for each source point ★)

Q1-3 2026: Wide-grid SOLPS-ITER inputs and sensitivity study
Q4 2026: ELMs and deposition areas

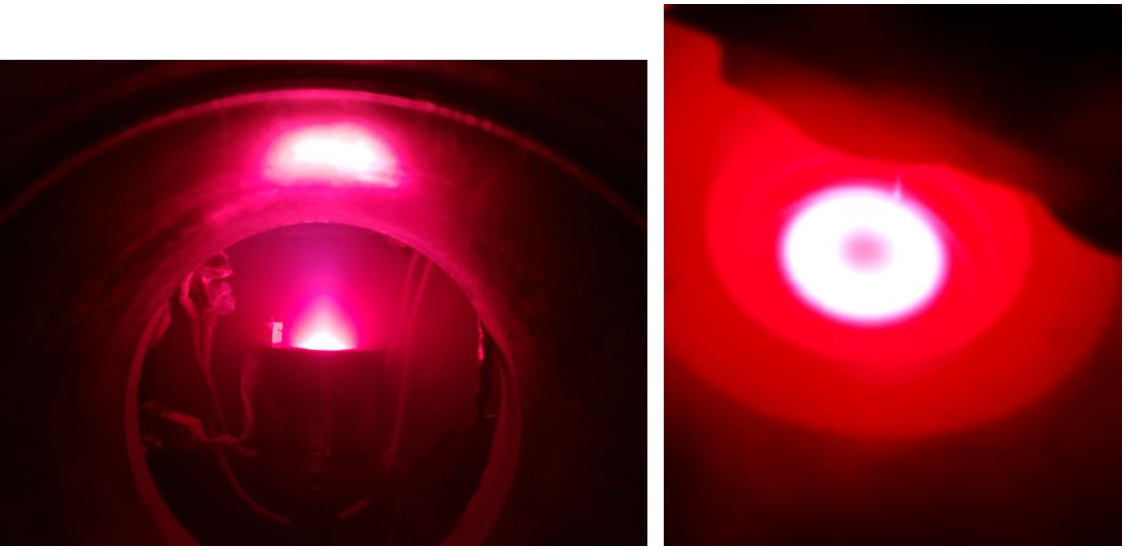




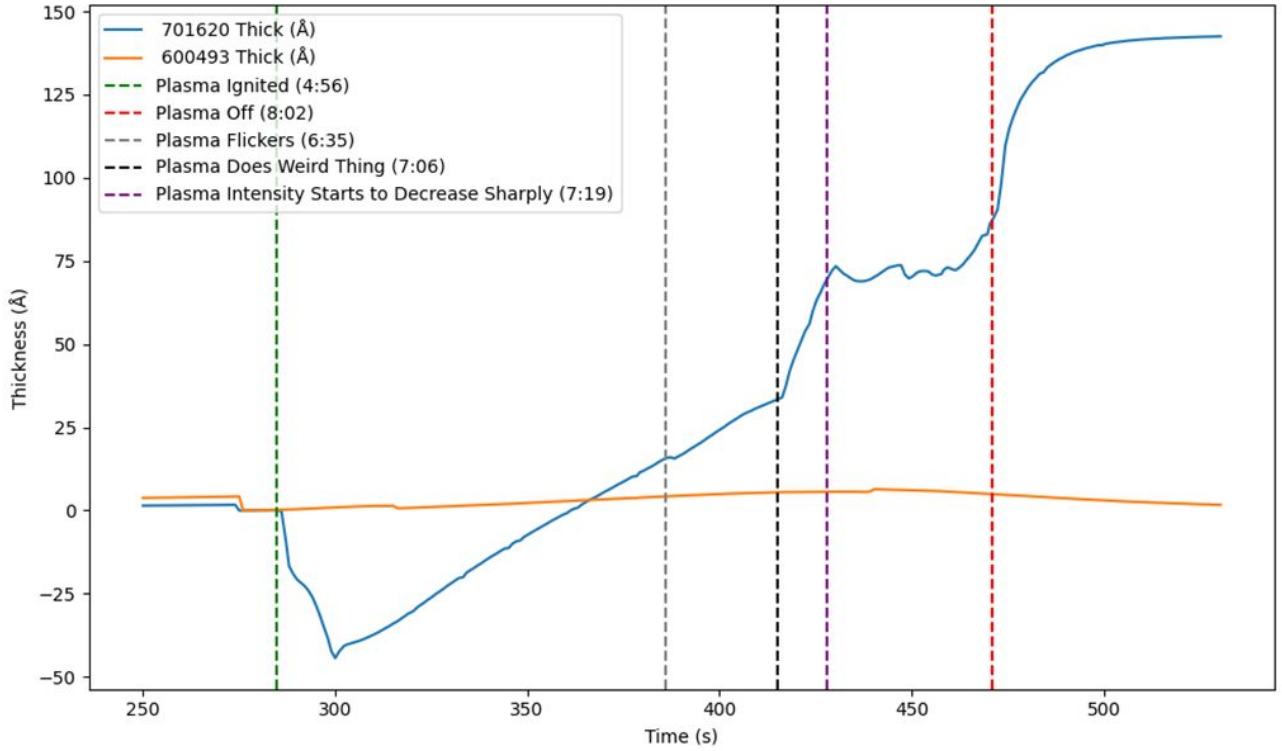
Modeling: Li thermally enhanced sputtering

- A commercial DC magnetron utilized to measure Li erosion across a wide range of parameters **(E_i,T_{surf}) under Ar, H and He bombardment**
- Erosion rate measured by QCM
- **Li TES observed**
- **Data analysis and more runs ongoing**

- Work done at University of Illinois Urbana-Champaign, USA (Jan Cecrdle PhD research stay)



Views of the experimental setup during a discharge



QCM measured layer thickness over time with notable timestamps

Design: tasks summary

Design related tasks

3. Optimisation of CPS mesh attachment

- **Not done**
- To be performed in collaboration w/ENEA (CPS mesh provider + expertise), KoM done (July 2025), Technical specification written, no common time to work on it together

4. Final design of LMD-CPS concepts for COMPASS-U

- **Done**, see details in next slides

5. Manufacturing of CPS prototypes

- No budget for material ⇒ cannot be considered as a deliverable but…
- Collaboration between UKAEA and University of Huddersfield (UK) to provide 3D printed CPS prototypes (see D. Horsley's talk)
- **Done**

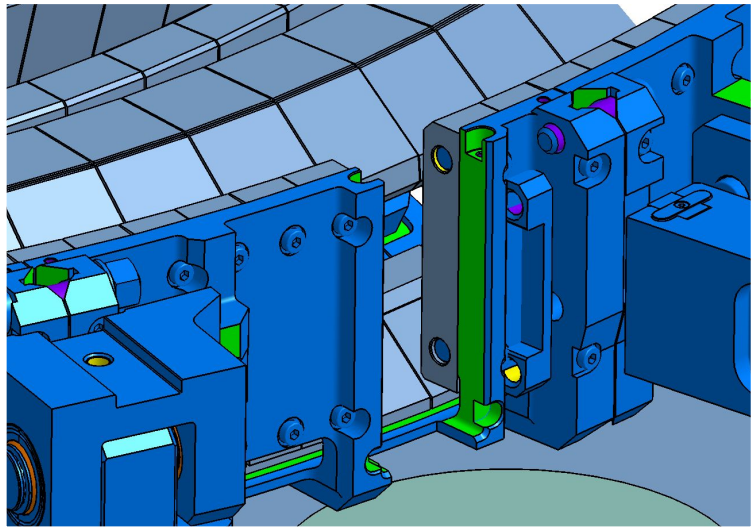
6. Feasibility of vapor box / cave divertor in COMPASS-U

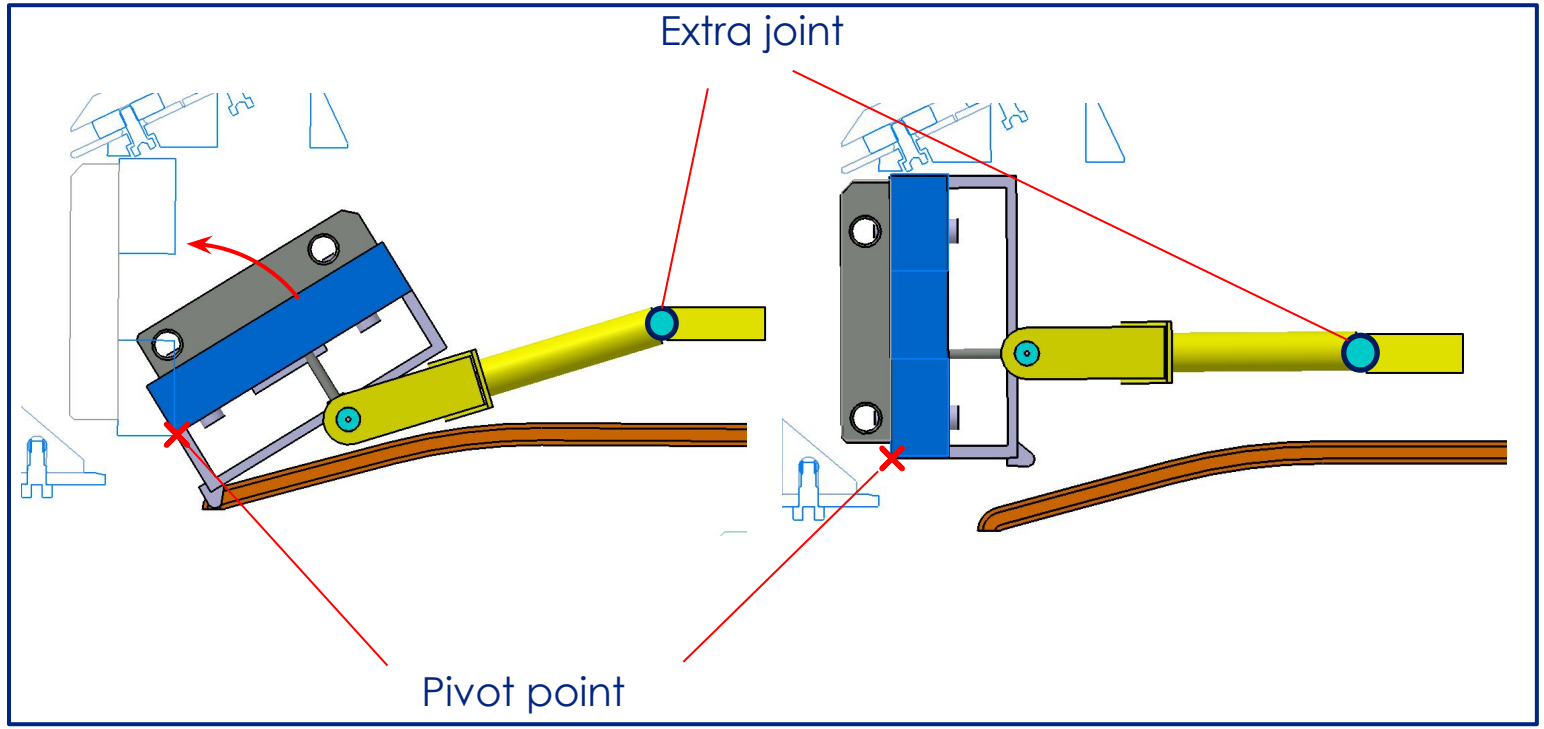
- **Done**, see details in next slides

Design: Divertor Manipulator

4. Final design of LMD-CPS concepts for COMPASS-U (1/3)

- **LMD-CPS modules design strongly depends** on the **divertor manipulator design = in conceptual state,** at present time
- **Different manipulator concepts can have to strong limitations in our CPS_LMD modules** (global volume, attachments, etc.)
- **A concept was chosen** (ASDEX-like divertor manipulator concept) **and design moving forward to preliminary**
- **As a consequence, fixing the BC lead to have now LMD-CPS modules in final design phase** (see next slide)

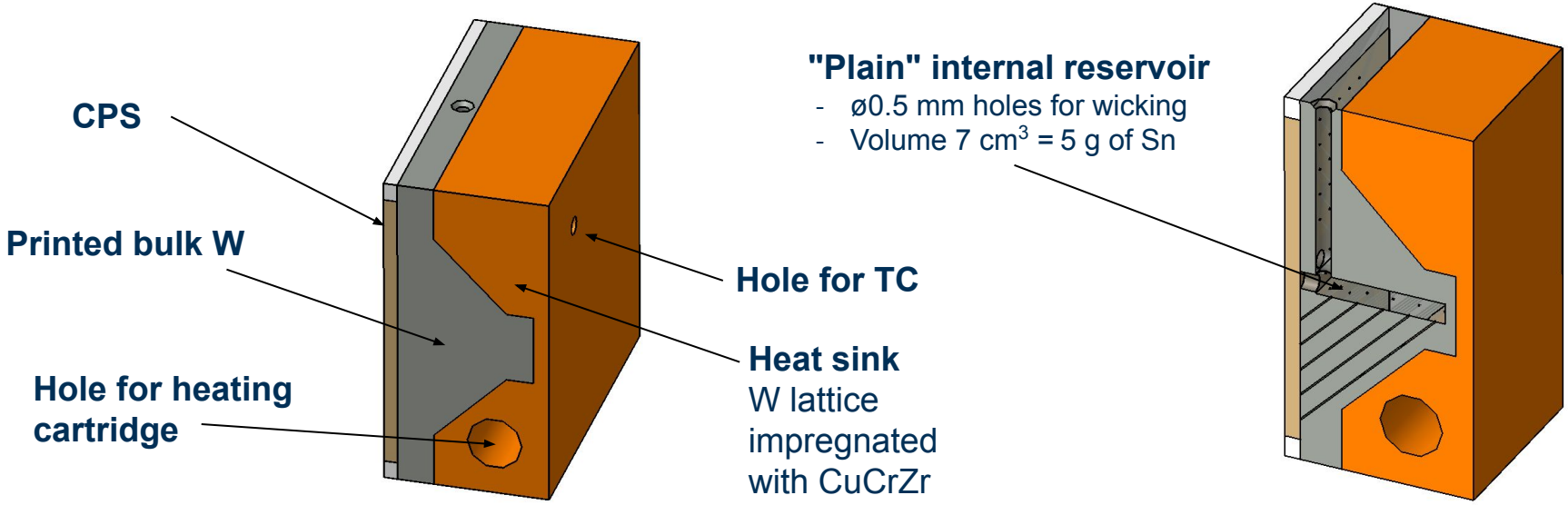




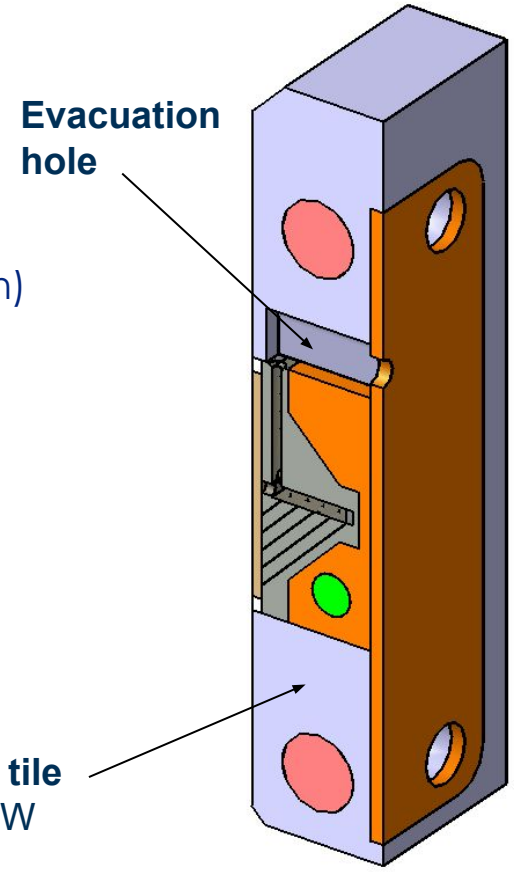
Design: LMD-CPS concepts for COMPASS-U

4. Final design of LMD-CPS concepts for COMPASS-U (2/3) - Task in collaboration with UKAEA

- **The 2024 design was modified** and **integration** of the **3D-printing CPS block changed** (design for the mesh concept unchanged)
- **Focus was put on details** (new orientation of heating cartridge & reservoir, printing venting hole added, etc.)
- **4 prototypes were developed** (see D. Horsley presentation for more details)**:**
  - **1)** plain reservoir, impregnated W lattice (shown below)
  - **2)** tree reservoir, impregnated W lattice
  - **3)** tree reservoir, direct CuCrZr-W printing
  - **4)** fully printed tile
- **Collaboration with University of Huddersfield** (UK) established **by UKAEA** (see D. Horsley's presentation)



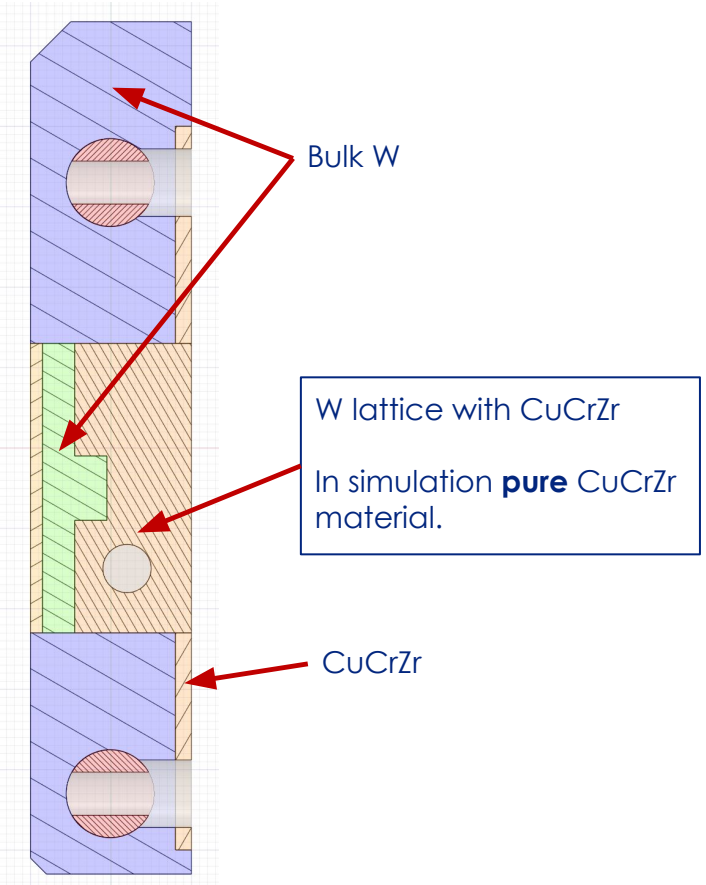
"Plain" internal reservoir
- ø0.5 mm holes for wicking
- Volume 7 cm^3 = 5 g of Sn

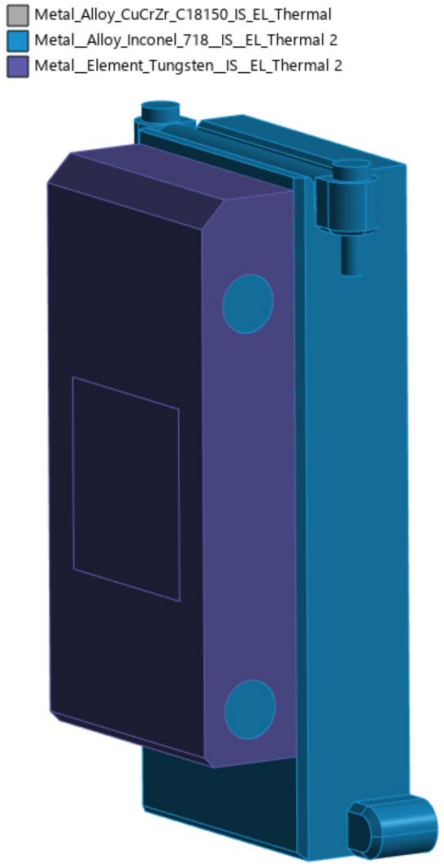


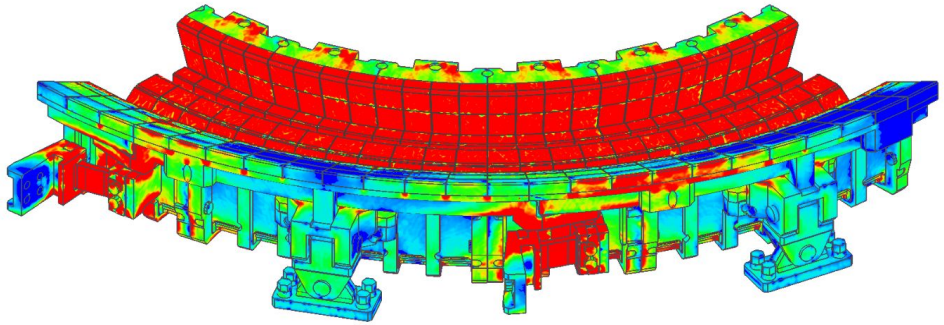
Design: EM loads on LMD-CPS modules

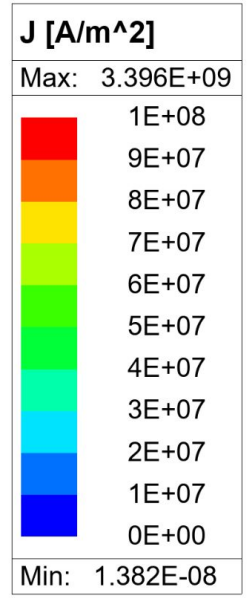
4. Final design of LMD-CPS concepts for COMPASS-U (3/3)

- **New geometry was created** in our **EM model** with **opening for divertor manipulator** in DIV cassette and **special LMD-CPS tiles**
- **EM loads were calculated** for the **most severe disruption scenario** and **structural analysis performed by FEM**





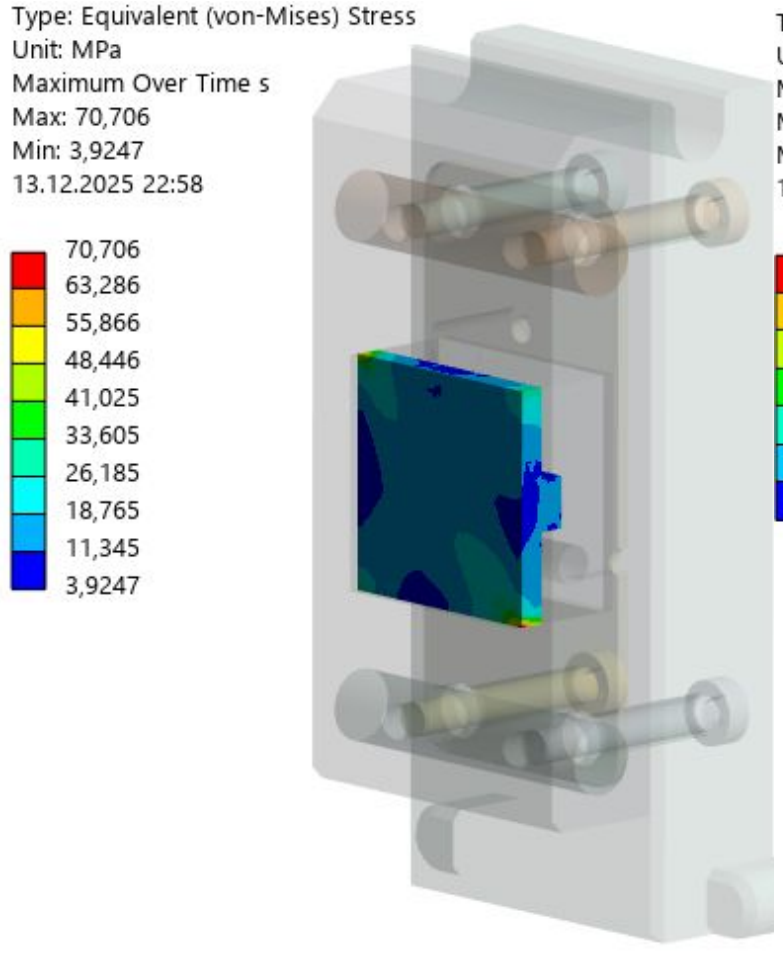


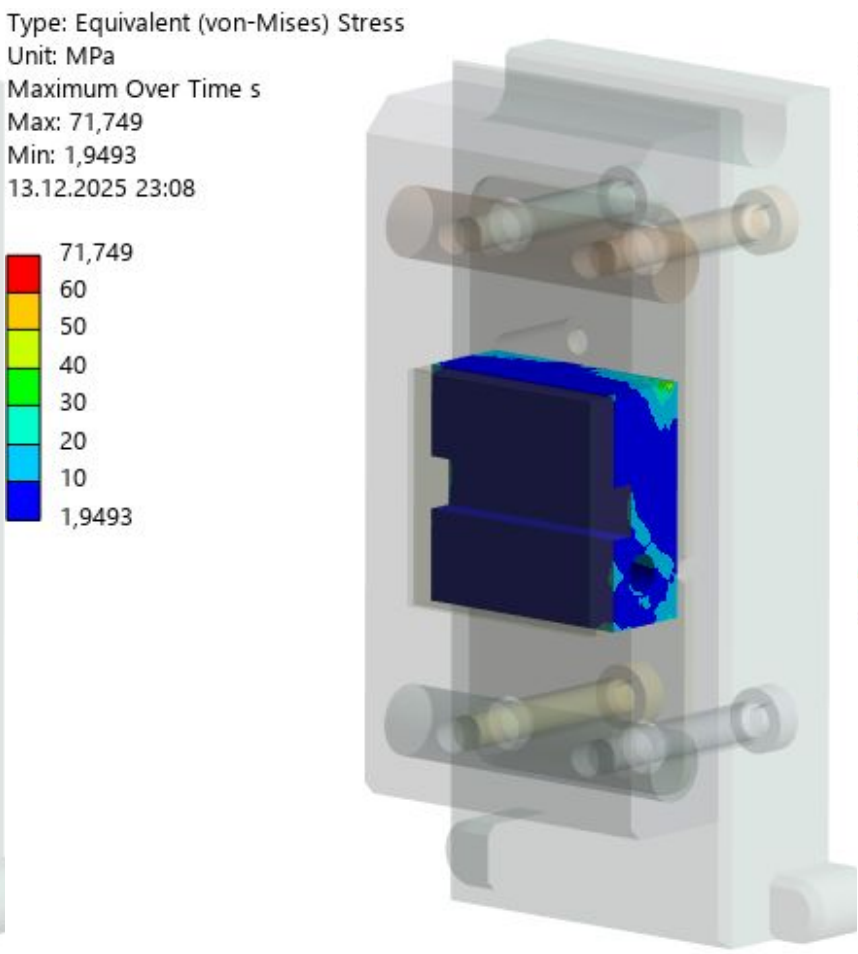


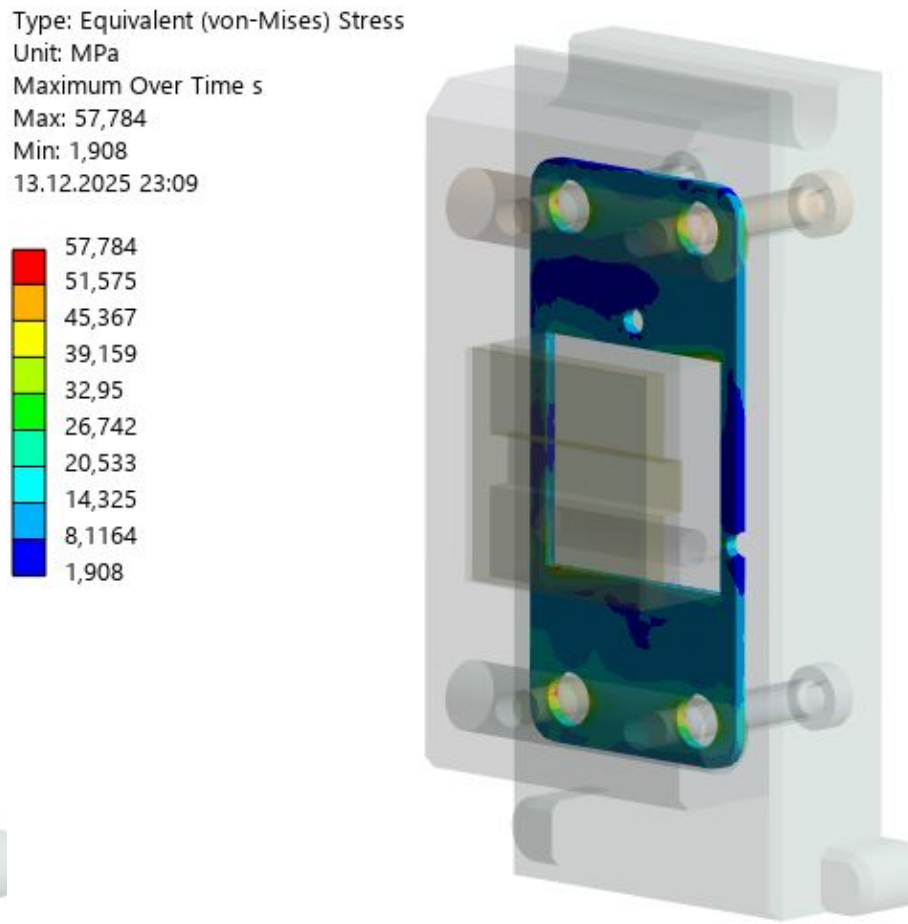
- ➔ Bolts pretension change
- ➔ Contact forces between:
  - CPS bulk W and surrounding tile
  - W lattice and surrounding tile
  - W lattice and CPS bulk W part
- ➔ Stresses

Design: EM loads on LMD-CPS modules

4. Final design of LMD-CPS concepts for COMPASS-U (3/3)







Stress in 3D printed W: < 70 MPa

Stress in W lattice: < 70 MPa

Stress in Cu plate: < 60 MPa

Design: Vapor box / cave divertor for COMPASS-U ?

6. Feasibility study of a vapor box / cave divertor in COMPASS-U

- **General principle & concepts for NSTX-U**

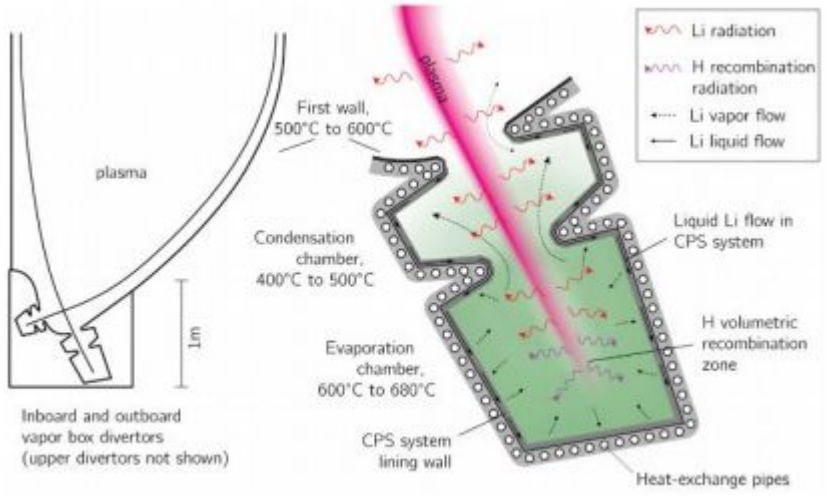


Diagram Credit: Jacob Schwartz

NSTX-U concepts

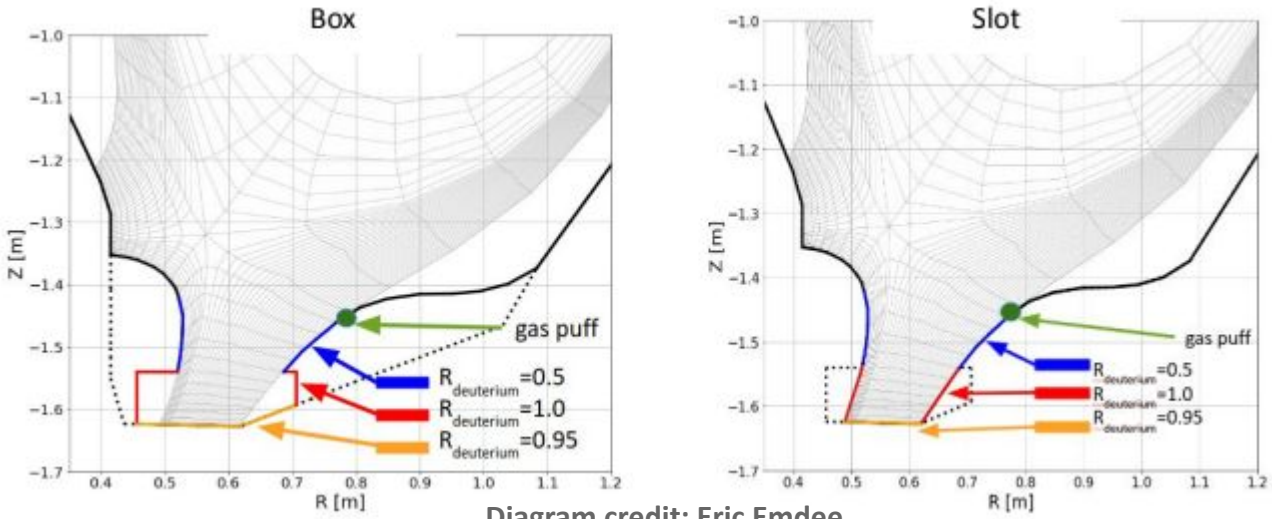


Diagram credit: Eric Emdee

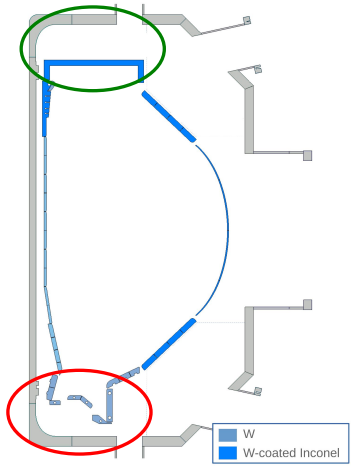
Design: Vapor box / cave divertor for COMPASS-U ?

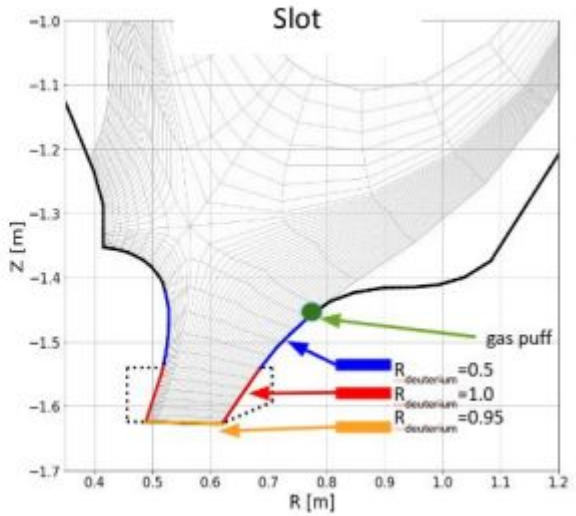
6. Feasibility study of a vapor box / cave divertor in COMPASS-U

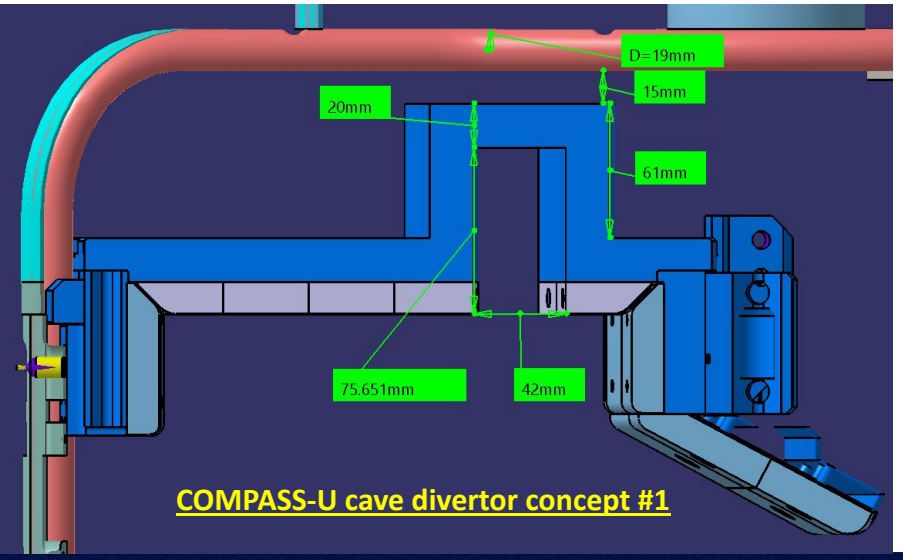
- General principle & concepts for NSTX-U
- In COMPASS-U, **no space available** at the **lower closed divertor**
- **Possible to be implemented** in the **upper open divertor**
  ⇒ gravity pointing towards plasma = issue?
- **Inconel support** could be **modified** (3D printing) **to host a slot/cave**

A: Yes, a vapor box / cave divertor could be feasible in COMPASS-U

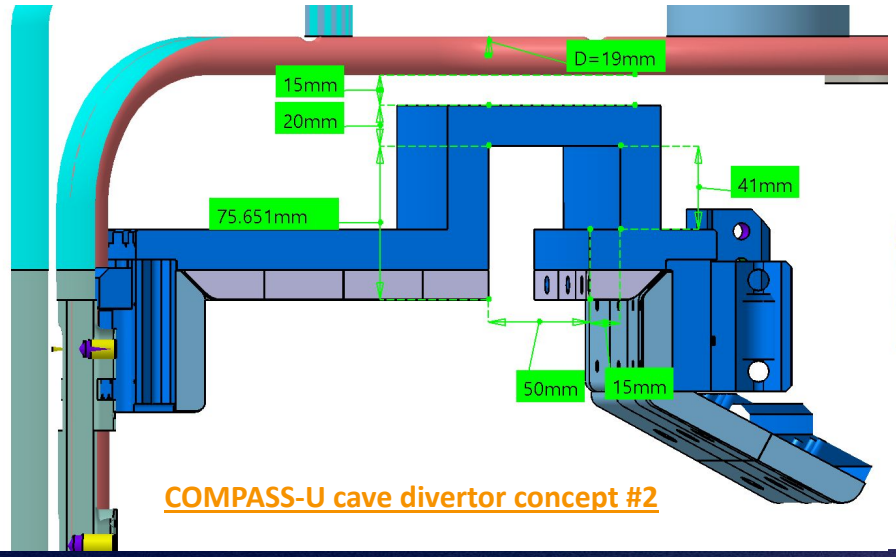
⇒ Big modifications of entire upper DIV support structure needed
⇒ Poloidal extent of the box is important [1,2] ⇒ (SOLPS) simulations needed



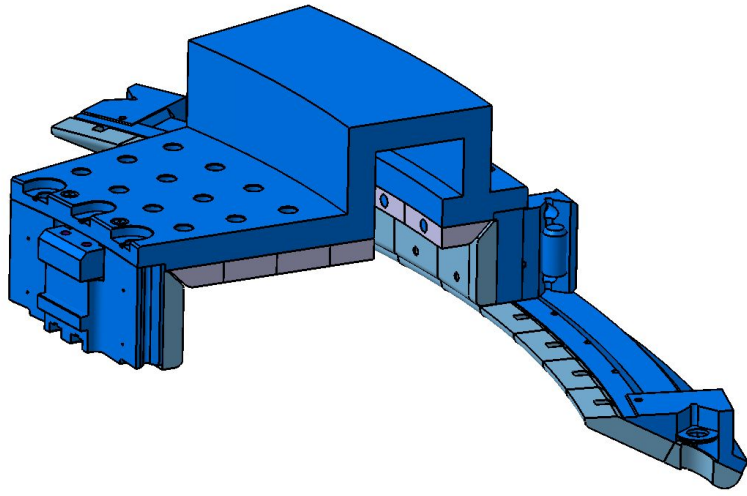




COMPASS-U cave divertor concept #1



COMPASS-U cave divertor concept #2



[1] F. Romano, et al., Fus. Eng. Des. 208 (2024), [2] E. Emdee & R. Goldston, NME 41 (2024)

Planned activities for 2026-2027

Modeling activities

- **HeatLMD (2026), ERO2.0 (2027) model of the cave divertor concept for COMPASS-U**
- **Performing refined models of the SOLPS-ITER wide grid to study COMPASS-U divertor parameters** (in collaboration w/ PoliTo)
  - Plasma profiles will be used as a background for HeatLMD and ERO2.0.
- **Support IPPLM team in CoreDiv modeling of COMPASS-U**
  - Plasma profiles can be used for HeatLMD

Design activities

- **Integration of divertor CPS mock-up design into COMPASS-U divertor manipulator**
- **Coordinate COMPASS-U CPS prototypes manufacturing activities**
- **Prepare specifications for future HHF tests of COMPASS-U CPS module prototypes**