IPP INSTITUTE OF PLASMA PHYSICS OF THE CZECH ACADEMY OF SCIENCES

A Liquid Metal Divertor for COMPASS Upgrade: IPP.CR plans for 2023 and beyond

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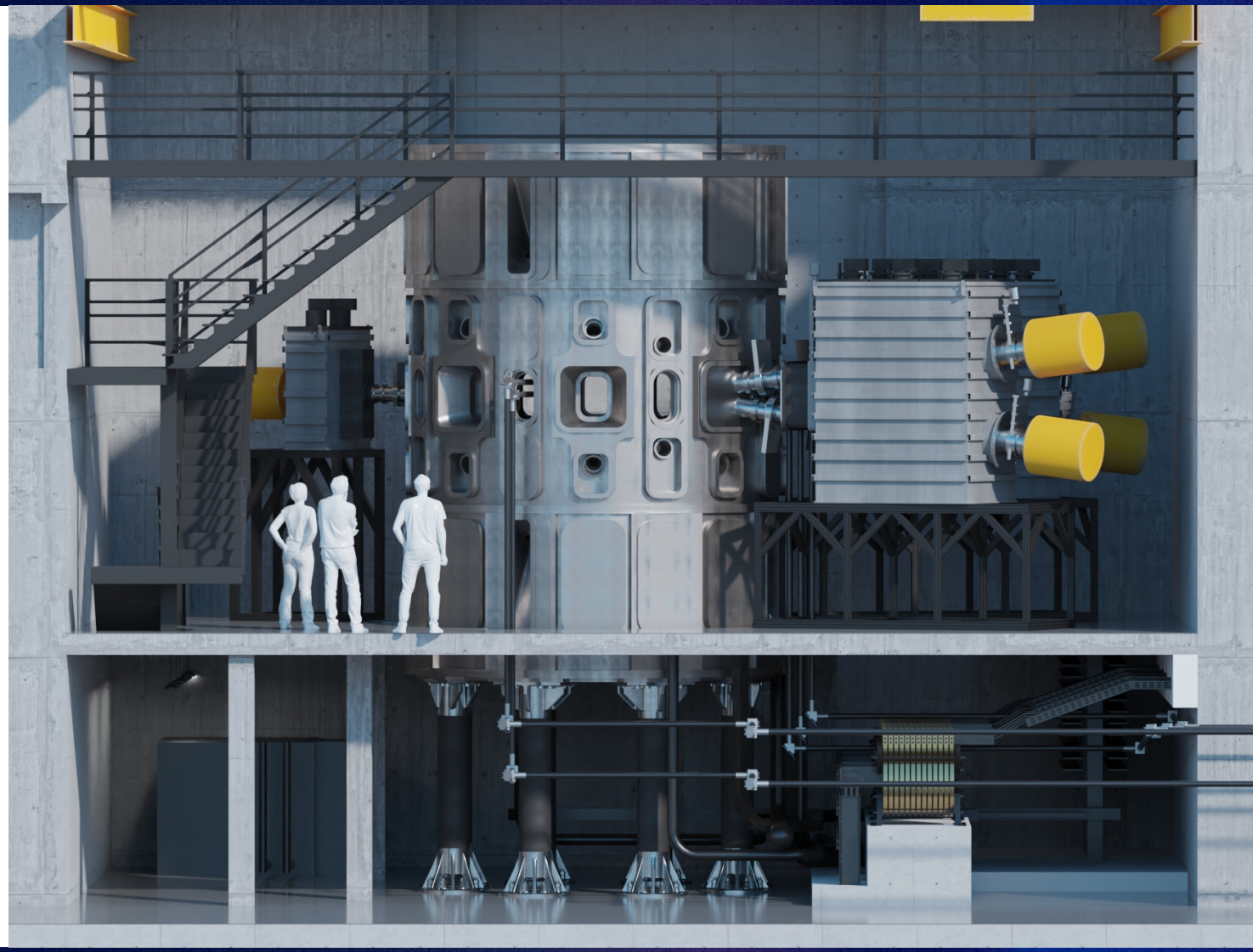
Kick-off meeting WP PRD-LMD, 20.03.2023

MINISTRY OF EDUCATION, YOUTH AND SPORTS

The tokamak COMPASS Upgrade (1/2)

COMPASS-U is a <u>new</u> tokamak under design/construction at IPP Prague

- **High field, high plasma current tokamak**
- **Additional heating = NBI + ECRH**
- **Discharge duration = < 3 seconds**
- **Inertially cooled PFC; copper coils cooled to 80K** (gaseous He)
- **Metallic PFC, bulk-W divertors**
- **Operation with hot walls**
- **Integrate a full-ring LM divertor** in the W DIV
- **First plasma scheduled for 2026**



The tokamak COMPASS Upgrade (2/2)

Main parameters

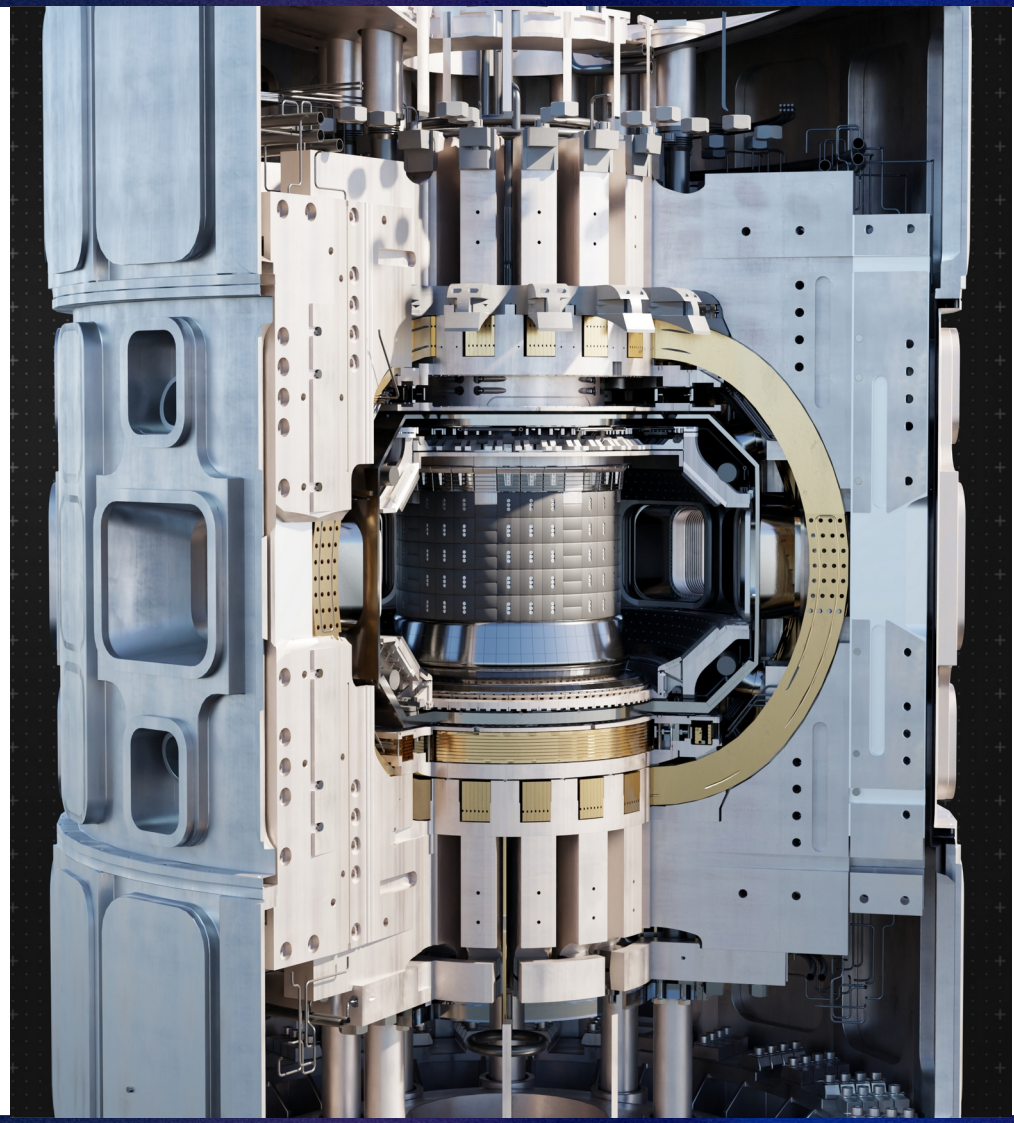
- **Toroidal magnetic field** B_t **= 5 T**
- **Plasma current** I_p **= 2 MA**
- **Major radius** R_g **= 0.9 m**
- Minor radius $a = 0.27$ m
- Aspect ratio $A = 3.3$
- Triangularity $\delta = 0.3\text{-}0.6$
- Elongation $\kappa = 1.8$
- **Two divertors** (open vs. close)
- **Metallic first wall** (tungsten, W-coated Inconel)
- **VV operation temperature at 300°C (up to 500°C)**

Plasma shapes

- lower/upper single null & double null diverted config.
- Snowflake
- Negative triangularity with limited parameters

Plasma heating power

- Phase 1: P_{NBI} **>= 3 MW**, P_{ECRH} **= 1 MW** (P*B/R ~ 25)
- Phase 2: up to $P_{NBI} = 8$ MW, $P_{ECRH} = 10$ MW (P*B/R ~ 100)



COMPASS-U Physics Goals

1) Power exhaust w/ conventional divertor with high PB/R, high neutral density
2) Advanced confinement modes and no-ELM regimes in full recycling regime
3) High power, high performance tokamak plasma operation using a fully integrated liquid metal divertor

Strategy:

- **Predictive modeling & calculations of physical processes at play**
  - Evaporation & vapor shielding for COMPASS-U conditions
  - Erosion & re-deposition
- **Design of a full ring divertor with liquid metal (CPS) as PFC**
  - Selection of the best technology for CPS mesh
  - Design a LMD tile prototype to be tested in HHF devices (& in COMPASS-U on DIV manip.)
  - Design LM loop for continuous fueling of LM during steady-state operation
  - Design full-ring div. = integration of LM loop into LMD tile concept & COMPASS-U VV

IPP.CR Modeling Tools

Modeling of near-target plasma (HeatLMD code)

[J. Horacek & J. Cecrdle]

- 3D+temporal heat conduction
- physical + thermal sputtering & evaporation
- plasma cooling by released metal ionization + excitation
- Monte Carlo prompt re-deposition calculation
- $T_{surface}$ & amount of released metal

Coupling with other codes

- **COREDIV** → metal core concentration
  - with 1x LM-CPS divertor tile [preliminary results]
  - extrapolation for a full-ring divertor [TBP]
    - w/ and w/o inertial cooling
- **SOLPS** → deposition location
  - Detachment in COMPASS-U H-mode scenario simulated
  - Impurities not yet included
- **ERO 2.0** → erosion/re-deposition + cleaning by Ar GDC

Compass modeling:
J. Horacek *et al.* **2020** Nuc. Mat. and Energy 25 100860

COMPASS-U modeling:
J. Horacek *et al.* **2021** *Phys. Scr.* 96

AUG modeling:
J. Cecrdle *et al.* **2023** FusEnDes. (submitted)

IPP.CR Modeling Plans

Work done in 2022

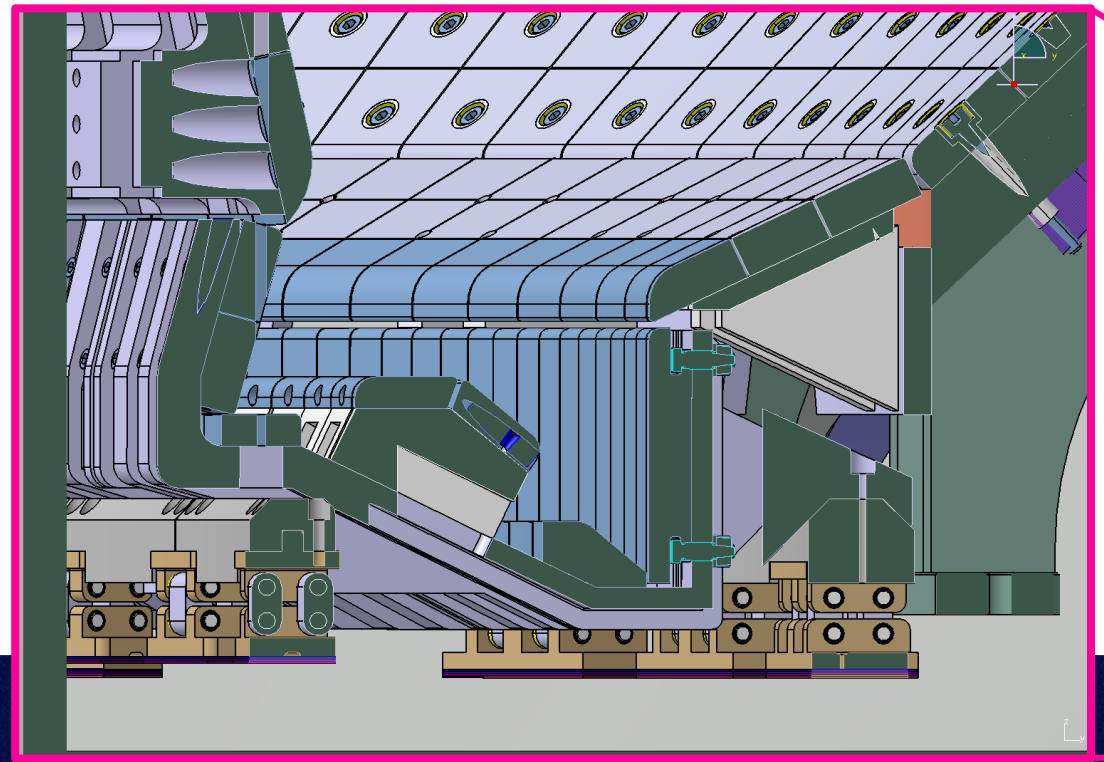
- Transformation of HeatLMD into Python and inclusion of runtime prompt re-deposition calculations
- Predictive and interpretative modeling of the AUG LMD experiment

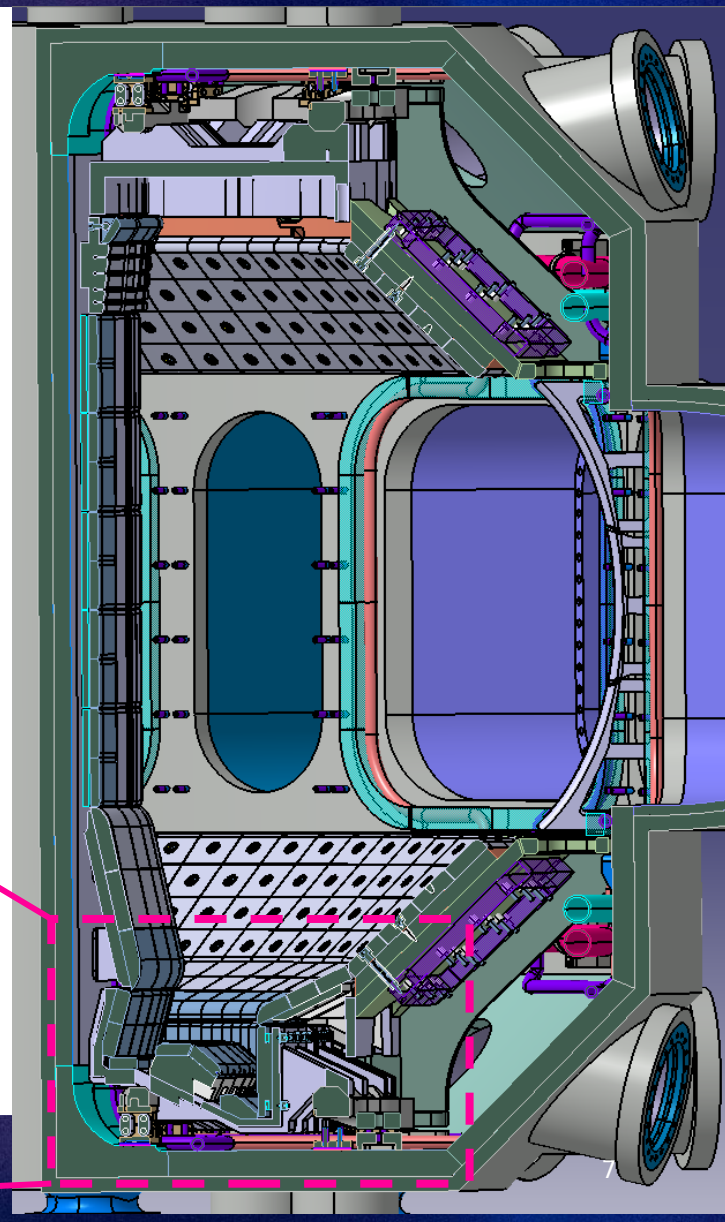
Plans for 2023

- Continuous updating of the HeatLMD code (parallelization)
- Performance study of LM behavior under transient events in HeatLMD
- Coupling of HeatLMD with vapour cooling power model (in collaboration with G. Nallo, Politecnico di Torino)
- Modeling of linear plasma experiments (OLMAT, MAGNUM-PSI)
- Commissioning of ERO 2.0 code (COMPASS -> COMPASS-U -> COMPASS-U + LMD) JÜLICH Forschungszentrum

COMPASS-U Liquid Metal Divertor

Implement a full-ring LMD in the bottom close tungsten DIV* at OVT



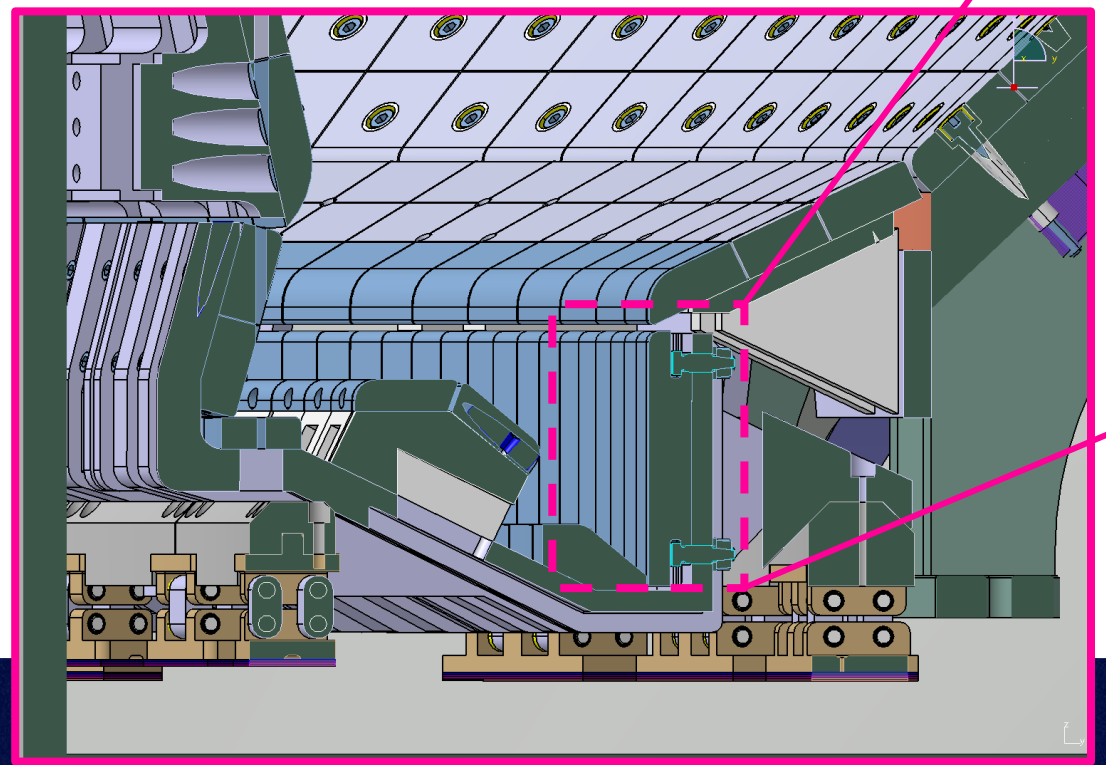


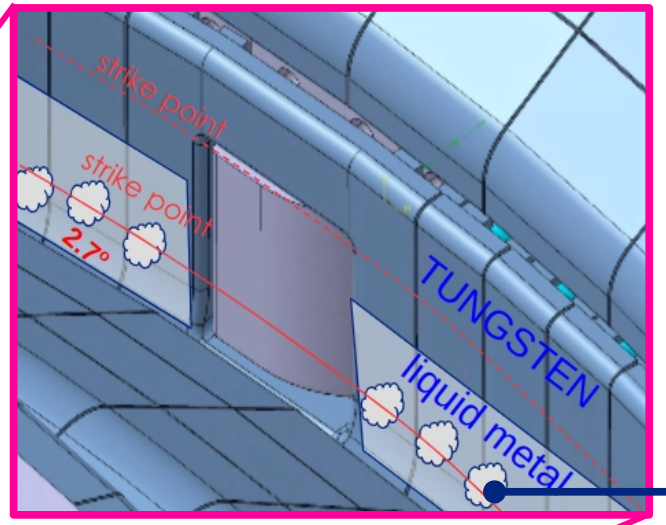
*Divertor still in preliminary design

COMPASS-U Liquid Metal Divertor

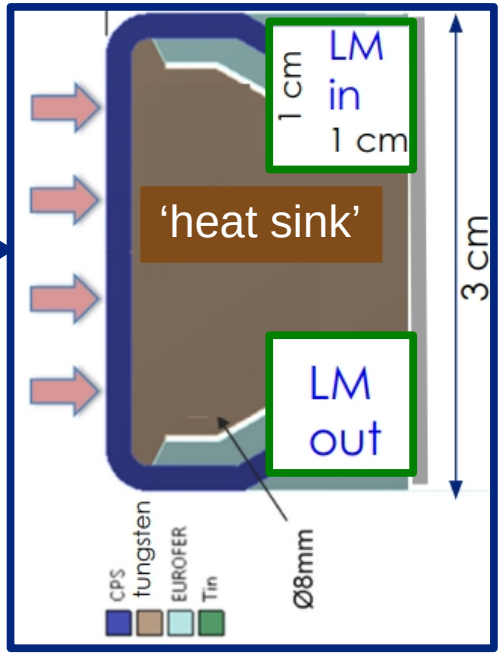
Implement a full-ring LMD in the bottom close tungsten DIV* at OVT

- **OVT tile = bulk-W** w/ area 26x120 mm
- **Implement** a **CPS mesh** in ¼ tile with:
  1) reservoir first; 2) LM loop later
- **DIV manipulator** ~2x OVT tiles





One of the possible solutions inspired by [S. Roccella et al., JoFE, 2020]



Pre-conceptual design is our main task for 2023

*Divertor still in preliminary design

COMPASS-U LMD: Plans 2023-2027

Towards a full-ring LMD for COMPASS-U

2023: Pre-conceptual design of COMPASS-U LM-CPS divertor tile + modeling *(physics)*
[⇒ in collaboration with CCFE]

2024: HHF tests (LiMeS-PSI) of COMPASS-U LM-CPS tile concept + associated modeling
Start design of LM loop for continuous fueling of LM

2025: Final design of COMPASS-U LM-CPS divertor tile
Conceptual Design of LM loop (interface to the LM-CPS tile)

2026: Preparation of 1st exp. on COMPASS-U on DIV manipulator
(manufacturing + commissioning 1x LM-CPS div. tile)
Final Design of LM loop

2027: Power exhaust experiment on COMPASS-U with 1x LM-CPS divertor tile
+ comparison with predictive modeling
Procurement of LM loop and accessories

(under WP PRD-LMD / under IPP Prague domestic program)