

1 INTRODUCTION & OBJECTIVES

WHY MAST-U

Managing power exhaust is one of fusion's greatest engineering challenges. Heat fluxes must be reduced below 5–10 MW m⁻² to the target [1]

MAST-U is uniquely designed to tackle this: strong neutral baffling + extreme divertor shaping (FR up to 2.5) [1]

PROJECT OBJECTIVES

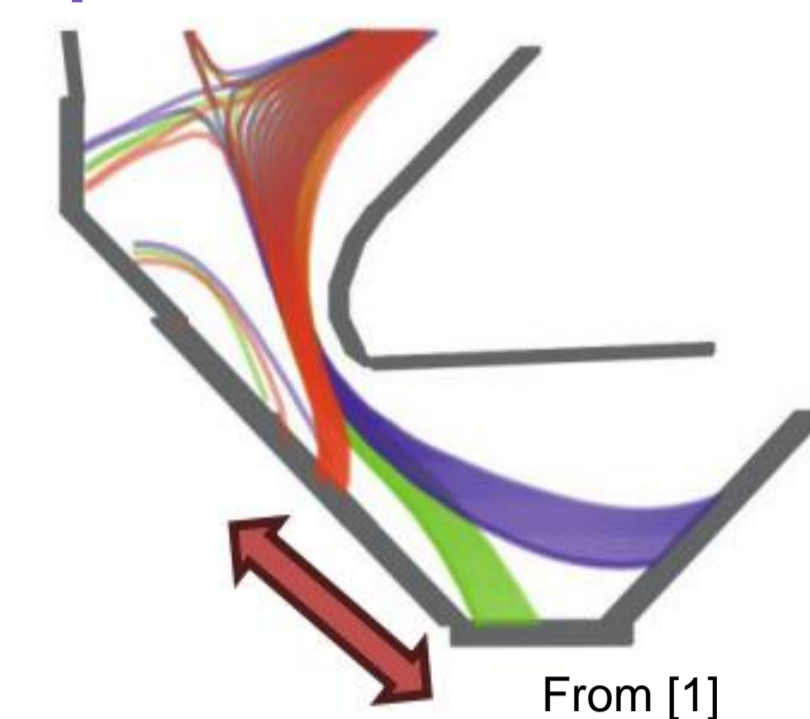
Establish first SOLEDGE3X-EIRENE [2] transport simulations of MAST-U boundary plasma

Benchmark upstream transport profiles against SOLPS-ITER simulations and experimental data [1, 3]

Analyse transport independence from magnetic configuration in CD and SXD

Compare CD, ED and SXD at $f_{GW} = 35\%$ & 45%

Conventional Divertor CD
Elongated Divertor ED
Super-X Divertor SXD



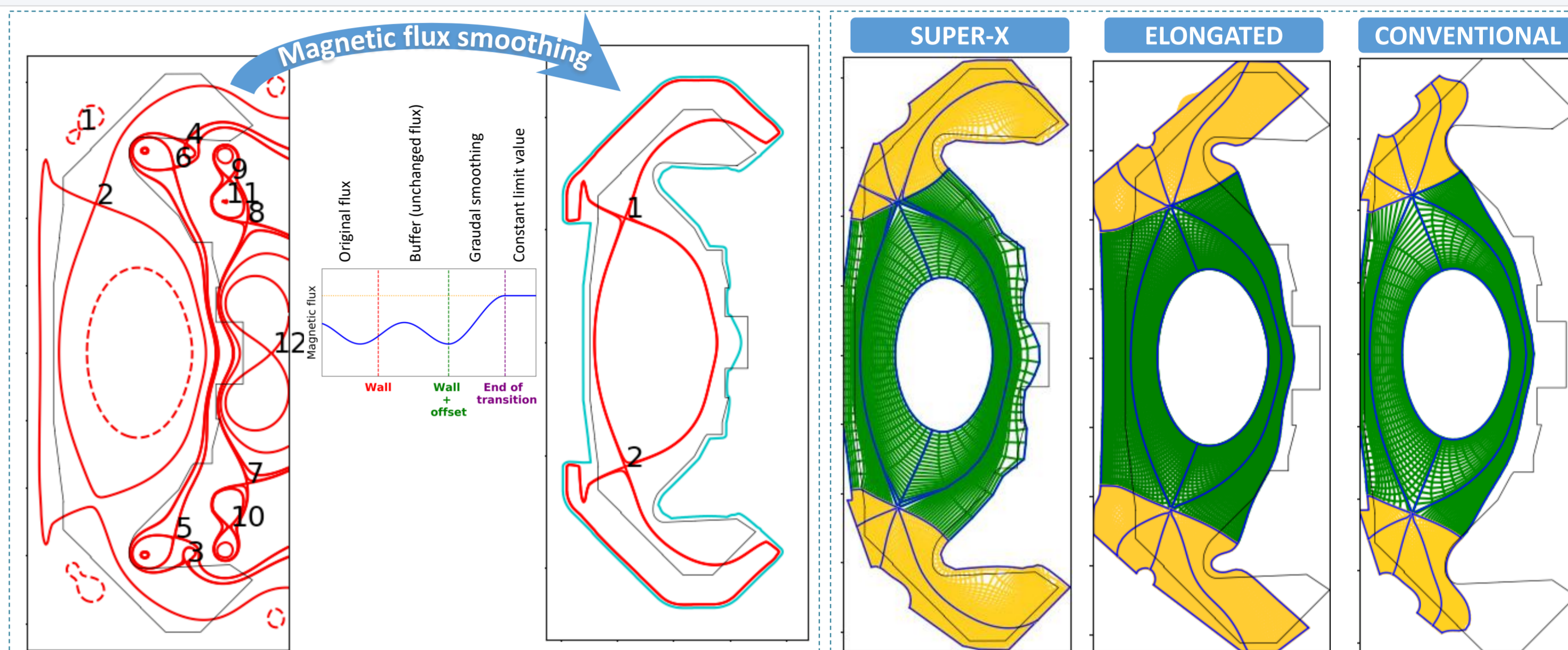
2 EQUILIBRIUM & MESH SETUP

PROBLEMS

- The MAST-U equilibrium features multiple secondary X-points outside the vessel wall
- These constrain the maximum usable flux surface for mesh generation to values that do not enclose the full vessel, making mesh generation impossible

SOLUTIONS

- Gradual smooth of ψ outside the wall boundary → remove X-points outside wall
- Create a continuous field line outside the wall → necessary for generating SOLEDGE mesh
- X-points forced to identical ψ value → Connected Double Null (same as SOLPS-ITER [3])



3 SIMULATION FRAMEWORK

PLASMA CONDITIONS

- Toroidal field: $B_t = 0.55 T$
- Plasma current: $I_p \approx 750 kA$
- NBI heating: $1.5-1.7 MW \rightarrow P_{SOL} \approx 1.2 MW$
- L-mode, unseeded (no impurity seeding)

SIMULATION SETUP

- No drift
- Same transport profiles as SOLPS-ITER [1, 3, 4]
 - $X_e = X_i = 10 m^2/s$ inside separatrix & 4 outside
 - $D_{\perp} = 4 m^2/s$ uniform
- Free parameter: gas puff
- $f_{GW} = 35\%$ & 45% simulated — results shown at $f_{GW} = 35\%$ (qualitatively consistent)

EXPERIMENTAL SETUP

Description	Discharge	R_t (m)	F_X	F_R	L (m)	L_{poi} (m)
Conventional Diveror (CD)	46762	0.79	3.3	1.2	13	0.64
Super-X Diveror (SXD)	46860	1.45	9	2.3	19	1.3

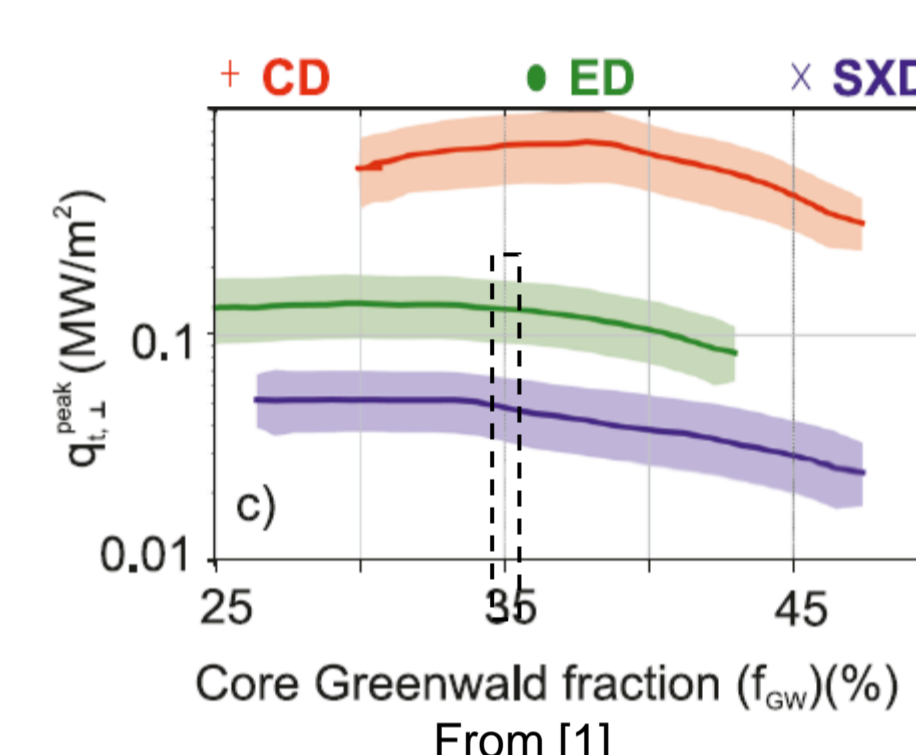
R_t : target radius, F_X : poloidal flux expansion, F_R : total flux expansion, L : connection length from the upstream midplane to the target, L_{poi} : poloidal leg length from the X-point to the target

DIVERTOR PERFORMANCE

From [1]:

At $f_{GW} = 35\%$: estimated perpendicular target heat load $q_{t,\perp}$ (MW/m²):

- CD: $\sim 0.4 \div 0.9$
- SXD: $\sim 0.02 \div 0.06$



4 CONVENTIONAL DIVERTOR - CD

RESULTS

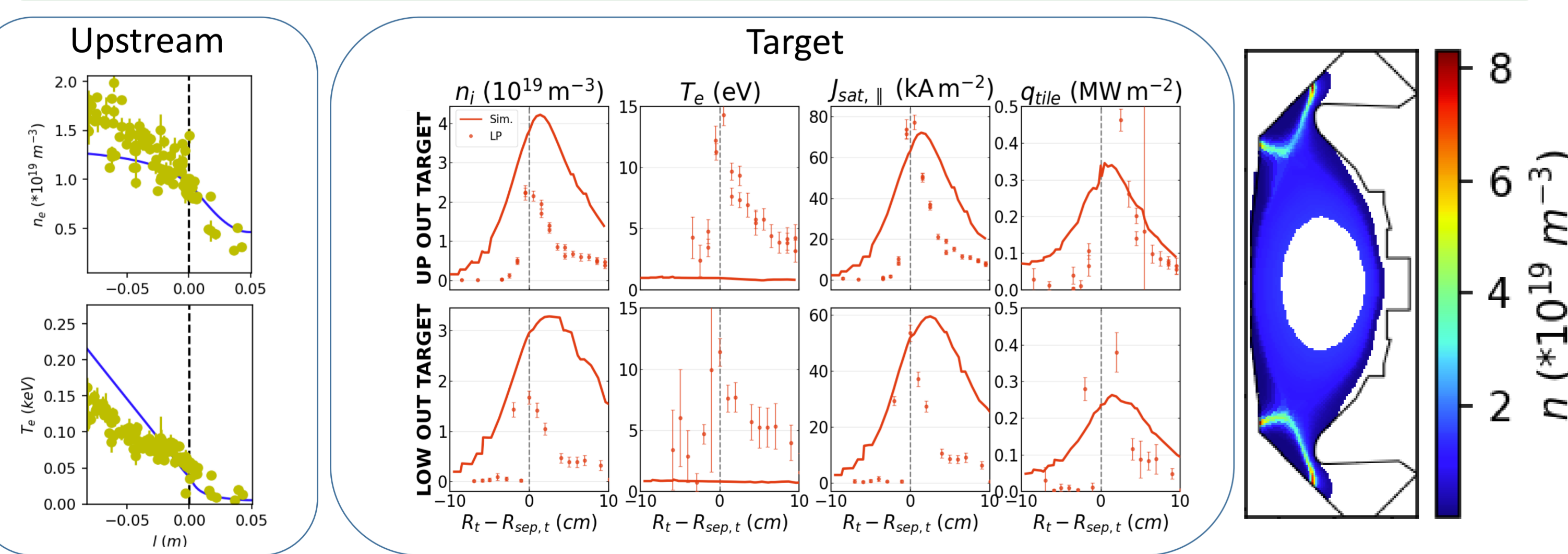
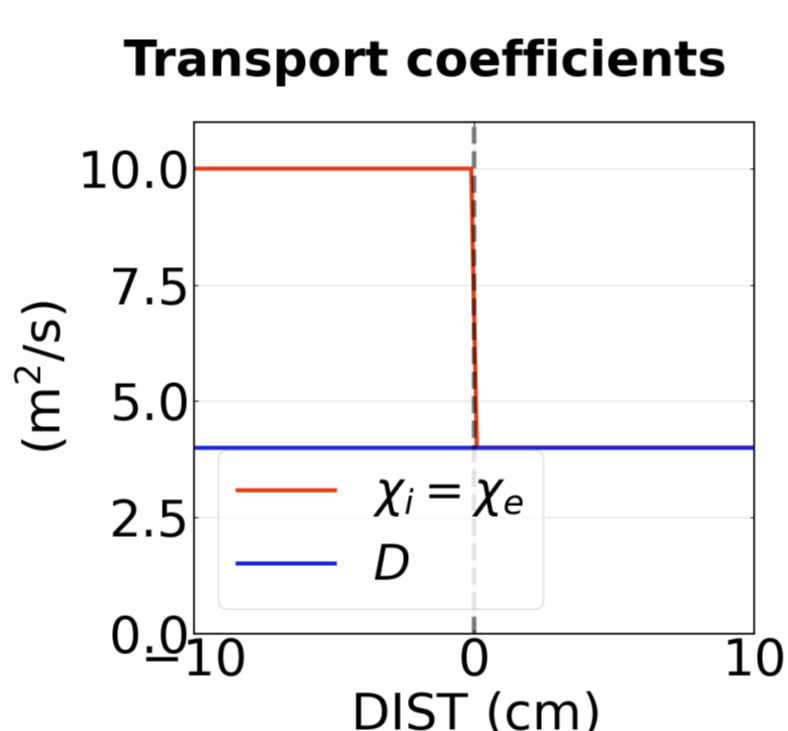
UPSTREAM profiles (n_e and T_e)

- Good agreement between simulation and Thomson Scattering data using same transport coefficient as SOLPS-ITER
- Discrepancies remain inside separatrix

TARGET

- Simulated n_e higher than experimental data → transport profile tuning required
- Simulated T_e very low ($\sim 1 eV$) → detached
- J_{sat} → quite good agreement between experimental data and simulations
- Heat peak $\sim 0.4 MW/m^2$ → similar to experimental data from [1]

SYMMETRIC 2D density maps between upper and lower divertor legs.



5 SUPER-X DIVERTOR - SXD

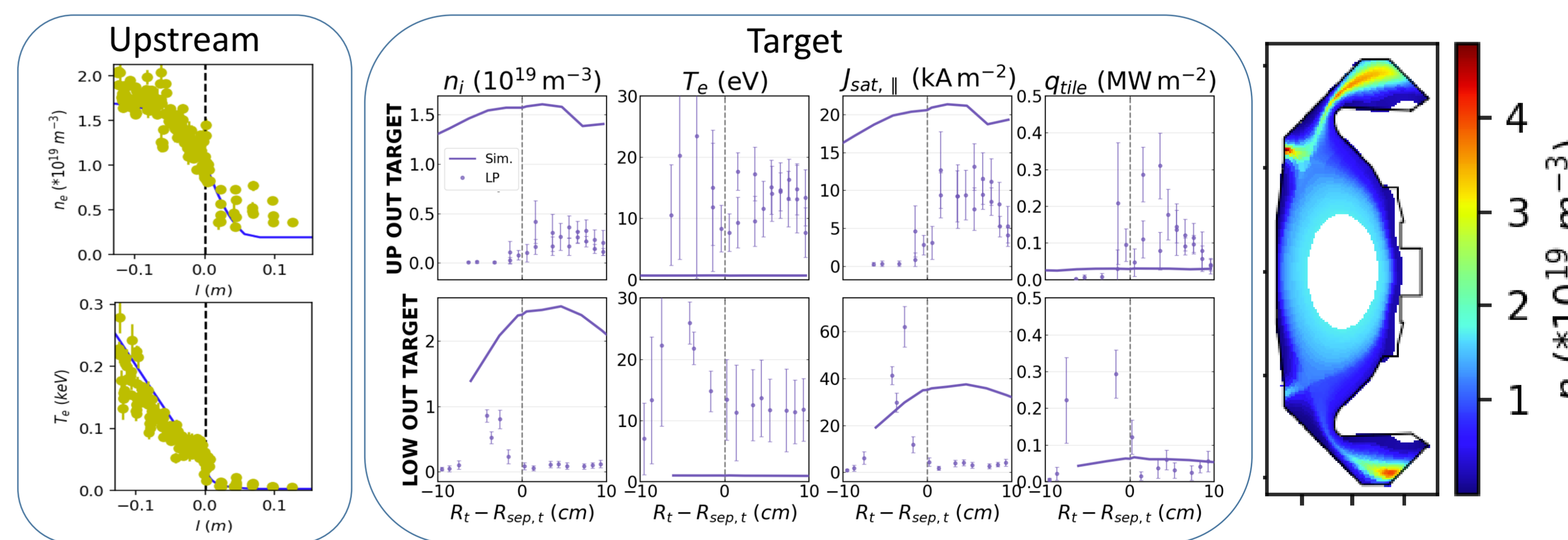
RESULTS

UPSTREAM profiles (n_e and T_e)

- Core-edge matching maintained with same transport coefficient → an improved modeling is necessary to assess detailed magnetic configuration impact on transport

TARGET profiles not yet matched

- Simulated n_e higher → rollover not reached yet
- Simulated T_e very low ($\sim 1 eV$) → detached → Density scan required to determine detachment onset
- Simulated J_{sat} higher than experimental
- Heat peak $\sim 0.06 MW/m^2$ → similar to experimental data from [1]
- Reduced and less peaked profiles than CD → detachment and effect of flux expansion



OPEN ISSUES

ASYMMETRY: 2D maps show up-down asymmetry in divertor region
Causes under investigation: Numerical artifacts, Grid distortions or Physical reasons?

NEXT STEPS

- Transport profile tuning to better match inner SOL midplane and target data
- Density scan to investigate detachment onset and divertor plasma evolution
- SXD mesh optimisation: refine cell density near outer X-points to resolve asymmetry
- Elongated Divertor (ED) simulations to complete the shaping study
- Simulations with Drift

BIBLIOGRAPHY

- [1] K. Verhaegh et al. 2025. Communications Physics. 8. 10.1038/s42005-025-02121-1
- [2] Bufferand H. et al., NME (2019);
- [3] D. Moulton et al 2024. Nucl. Fusion 64 076049.
- [4] E. Havlíčková et al. 2015. Plasma Physics and Controlled Fusion 10.1088/0741-3335/57/11/115001

6 CONCLUSIONS

ACHIEVEMENTS

- Optimized SOLEDGE3X meshes covering the full SOL plasma MAST-U vessel.
- Upstream n_e and T_e reproduced against Thomson Scattering for CD and SXD with same transport coefficient as SOLPS-ITER
- CD baseline shows physically symmetric 2D profiles
- SOL transport reproduced consistently across configurations — independent of divertor geometry, consistent with SOLPS-ITER and experiment