ID: 1299

DIVERTOR DETACHMENT W/ DEUTERIUM GAS INJECTION IN KSTAR H-MODE PLASMAS

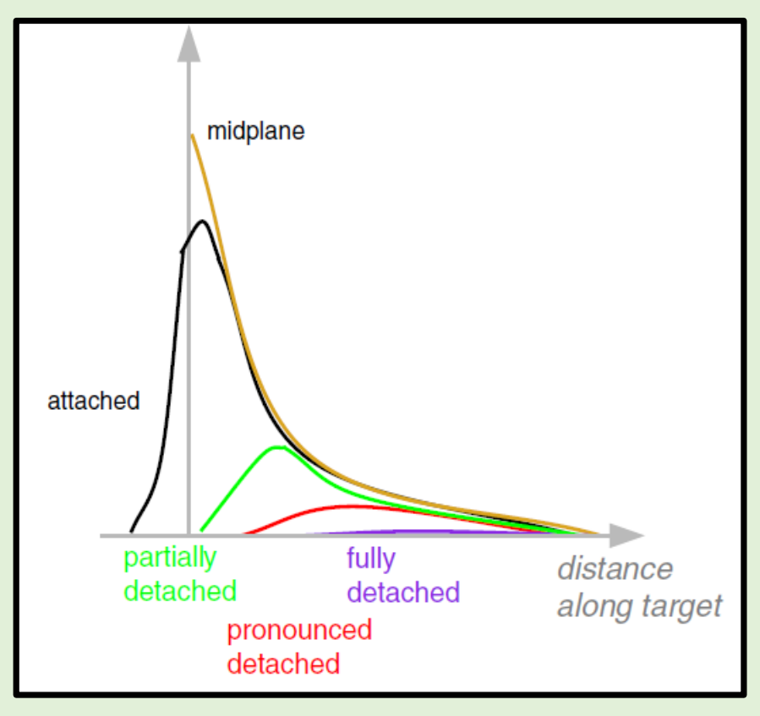
IAEA-CN-268 EX/P2-28, 28th Fusion Energy Conference, 10 – 15 May 2021, France

J. H. Hwang[1,2*], J.-S. Park[3], R. A. Pitts[3], H. H. Lee[4], Y. S. Han[1,2], J. G. Bak[4], J.-W. Juhn[4], J. Jang[4], S. H. Hong[4] and W. Choe[1,2**]

[1]Korea Advanced Institute of Science and Technology (KAIST), Daejeon, Republic of Korea / [2]Impurity and Edge plasma Research Center, KAIST, Daejeon, Republic of Korea /
[3]ITER Organization, St. Paul Lez Durance Cedex, France / [4]Korea Institute of Fusion Energy, Daejeon, Republic of Korea
**Presenter: junghoo.hwang@kaist.ac.kr ; **Corresponding author: wchoe@kaist.ac.kr*

1. Introduction

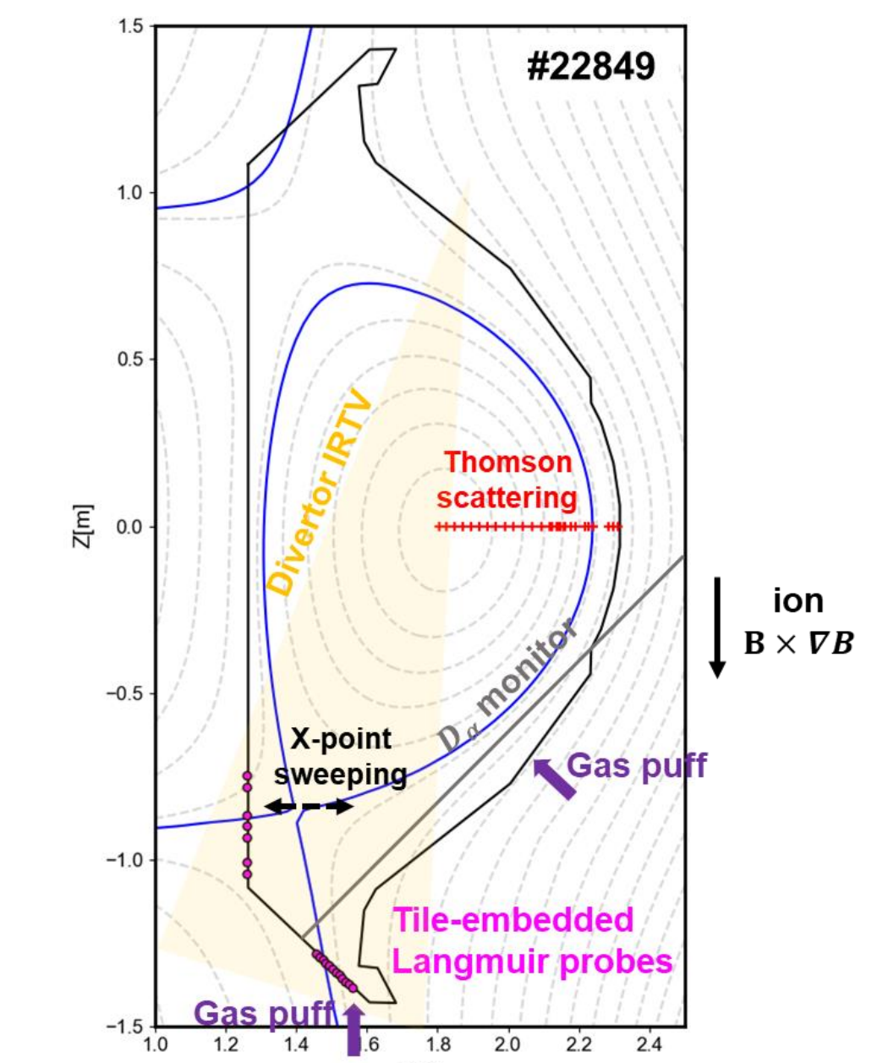
- One of the major challenges for the sustainable operation of future fusion devices including ITER and DEMO: **"Handling the power flux from the hot core to the divertor targets"**
- **Viable solution: "Divertor detachment"**
  - Defined as the momentum loss along a field line
  - Achieved by fuel gas and/or impurity seeding
- **Partial detachment** was successfully achieved with **pure deuterium injection** in KSTAR H-mode plasmas.
- **The experimental results were reproduced reasonably well by SOLPS-ITER simulations.**
- **In this work, quantitative code-experiment comparisons are made to understand/ explain the underlying physics and quantitative predictions.**



Four different detachment states [1]

2. Experimental observations of partial detachment in KSTAR H-mode plasmas with deuterium injection

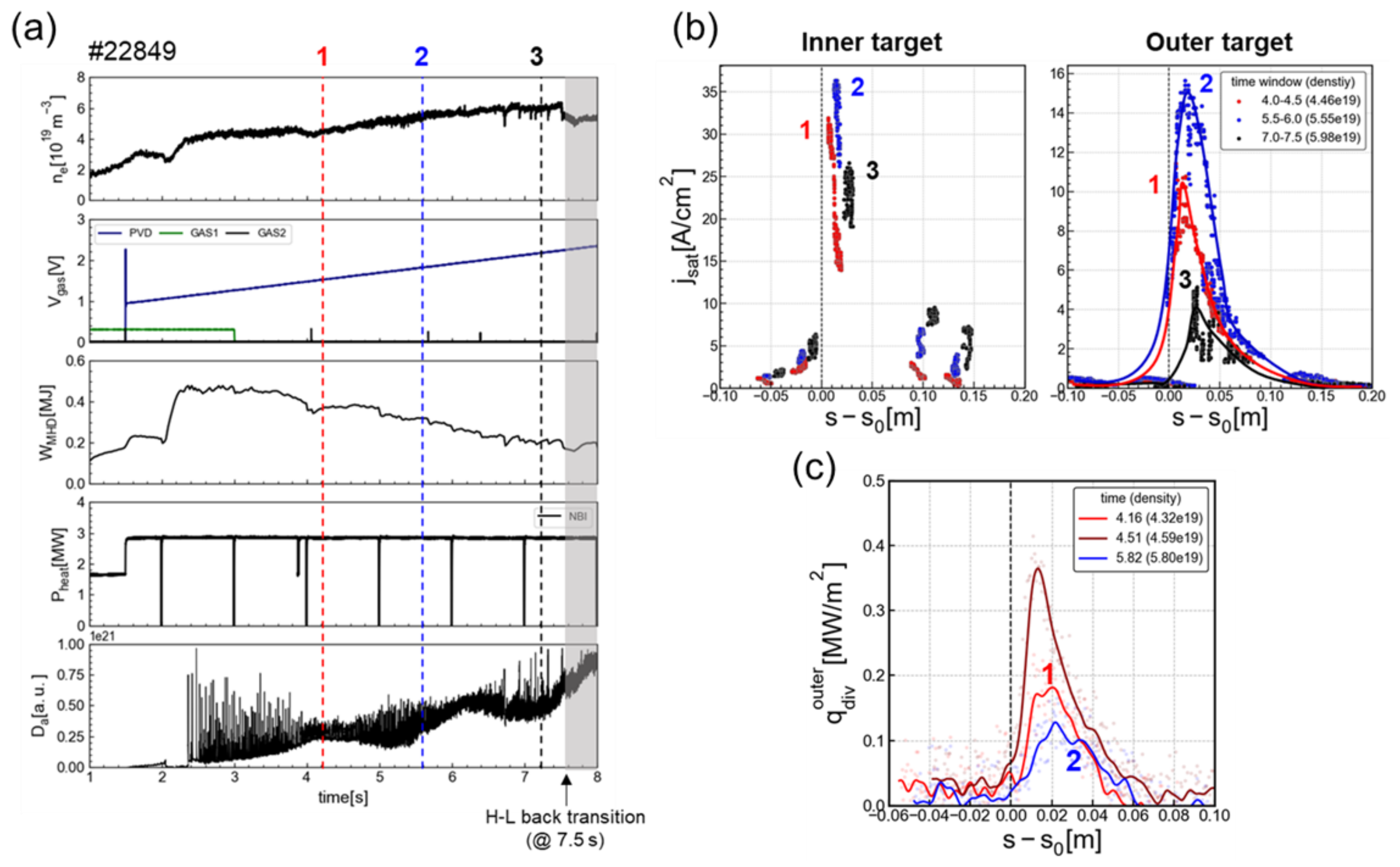
- **D2 fuelling locations**



- P_{heat} = 2.9-3.1 MW, **H-mode discharges**
- I_p = 0.7 MA, B_T = 1.8 T ($q_{95} \approx 4.0$)
- Forward B_T direction (Ion B×∇B-drift pointing down toward the lower divertor)
- Outer strike point on the central divertor with single null
- X-point sweeping with 1.5 cm/s (according to the speed of 4 cm/s for the outer strike point) was applied to get high spatial resolution in ion saturation current profiles from the tile-embedded Langmuir probes.
- **Two different D_2 fuelling locations used**
  1) **Divertor fuelling: partial detachment achieved (!)**
  2) **Main chamber fuelling: no partial detachment**

- **Partial detachment at the outer target with divertor fuelling (#22849)**

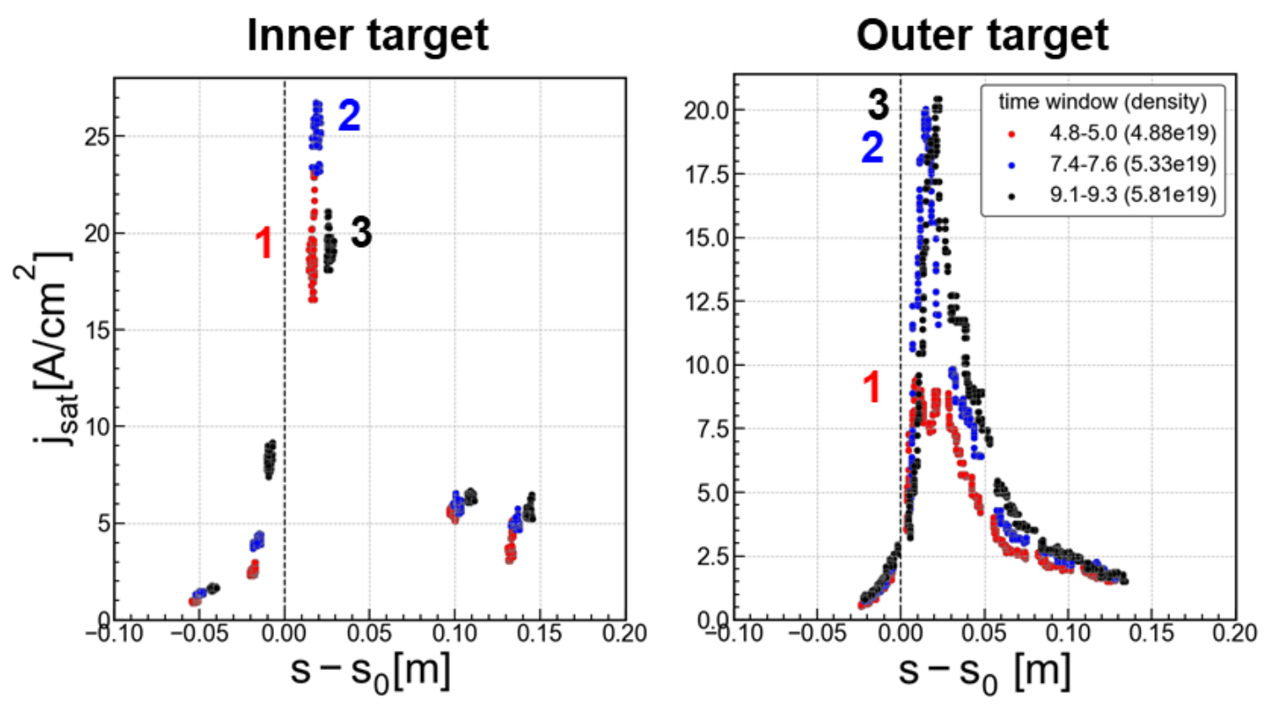
Time windows:
1) Attached state (4.1-4.3 s)
2) Detachment onset (5.7-5.9 s)
3) Partially detached state (7.0-7.2 s)



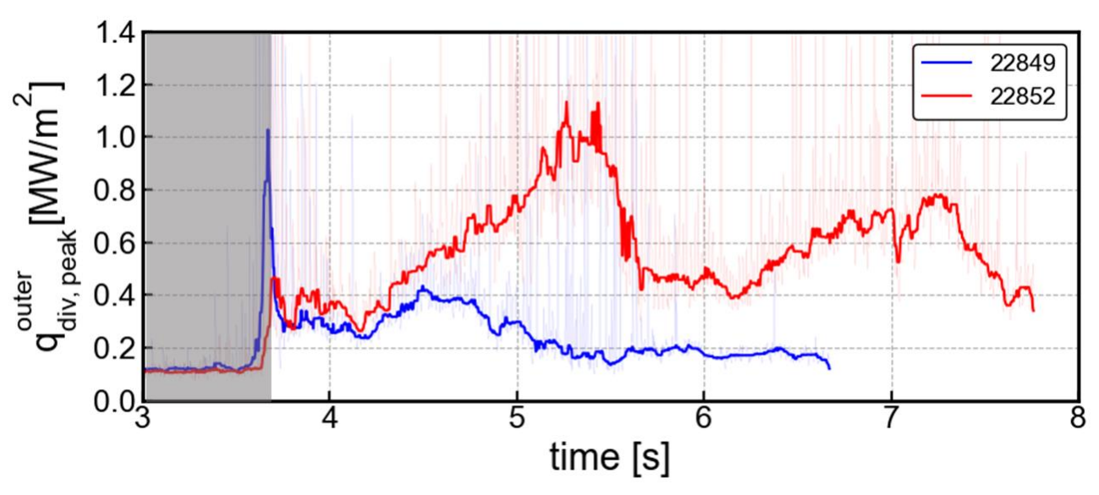
(a) Time evolution of experimental parameters of #22849. The time points used in the j_{sat} profiles are shown as the dashed lines. (b) Inter-ELM j_{sat} profiles at the inner and outer targets measured by the tile-embedded Langmuir probes. (c) Inter-ELM heat flux perpendicular to the outer target measured by the divertor IRTV.

- By ramping the fuelling rate, the line-averaged electron density increased up to $6.0 \times 10^{19} m^{-3}$ (f_{GW} = 0.67).
- **Partial detachment clearly seen at the outer target**
  The peak j_{sat} was reduced by a factor of 3 when comparing the detachment onset and the partially detached state.
- Line-averaged density requirement for detachment onset: **~ 5.5x10^{19} m^{-3}**
- **The outer target heat flux was reduced by a factor of 2.7.**

3. Fuelling location dependency on the outer target detachment (no detachment w/ main chamber fuelling, #22852)



Inter-ELM target j_{sat} profiles for the main chamber fuelling case (#22852) measured by the tile-embedded Langmuir probes

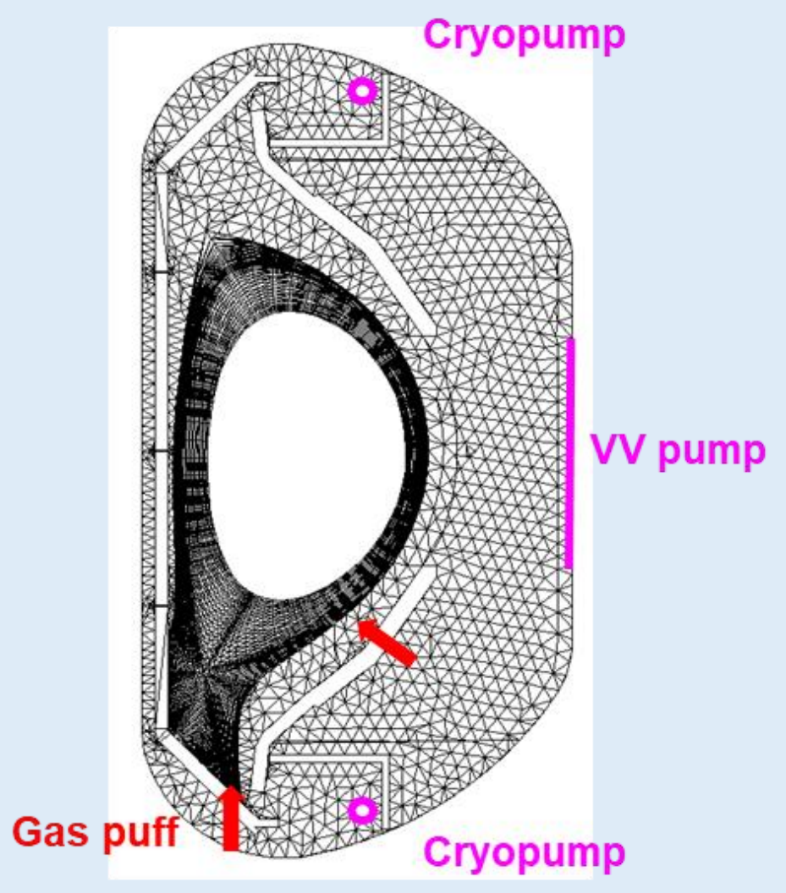


Inter-ELM peak heat flux perpendicular to the outer target for the divertor fuelling case (#22849, blue) and the main chamber fuelling case (#22852, red)

- **The outer target detachment was not achieved w/ main chamber fuelling (#22852) although the maximum line-averaged density was similar to that of #22849.**
  - Outer target peak j_{sat} kept increasing until the end of discharge.
- Reduction factor of inter-ELM outer target peak heat flux is similar for both divertor fuelling (0.4 → 0.15 MW/m^2) and main chamber fuelling (1.0 → 0.35 MW/m^2).
- **However, the peak flux stayed at higher level during the discharge for main chamber fuelling than divertor fuelling.**

4. Setup of SOLPS-ITER simulations

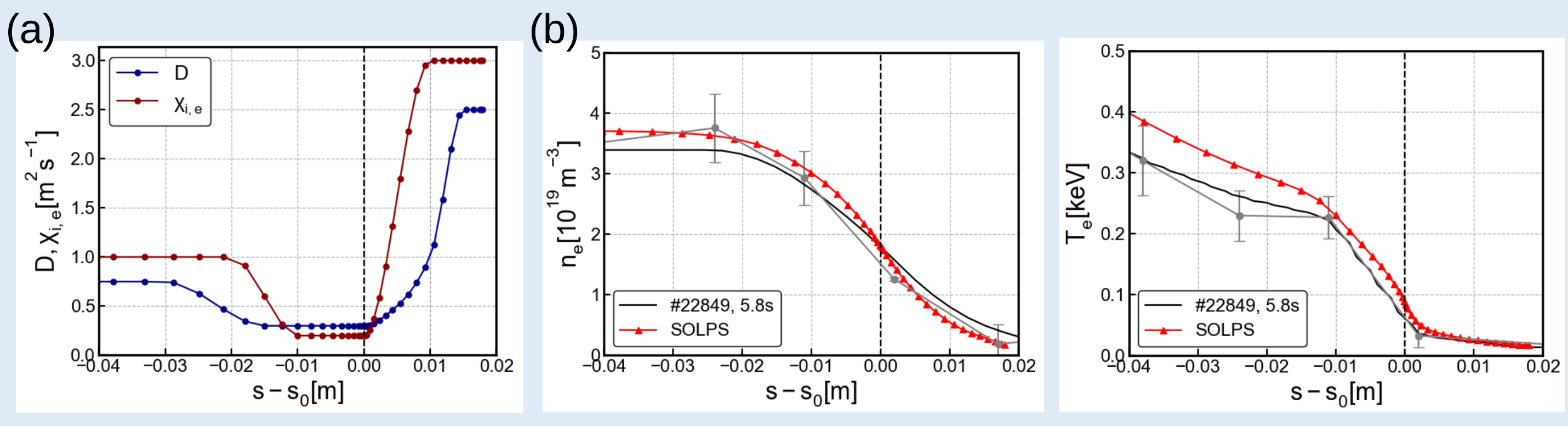
- **SOLPS-ITER code package (version 3.0.7) [2,3] was used.**
  - Main modules:
    1) **B2.5**: 2.5-D (toroidally symmetric) multi-fluid plasma solver
    2) **EIRENE**: kinetic neutral Monte-Carlo tracer
  - Drifts and neutral-neutral collisions are not included.
  - **Two different fuelling locations were used:**
    Divertor fuelling vs. **Main chamber fuelling**



Computational grid based on the magnetic equilibrium

Modelling condition	Setting / Description
Species	D + C
Heating power	2.4 MW across the core boundary
Magnetic equilibrium	Reconstructed from KSTAR #22849, 5.6 s
Density control	Feedback via D_2 gas puff
$n_{e,sep}$	$1.0{\sim}4.0 \times 10^{19}\ m^{-3}$
Physical / Chemical sputtering	TRIM / $\Upsilon_{chem} = 0.04$
Recycling coefficient	1.0 for deuterium
Absorption coefficient of the pumps	0.0029 / 0.0206

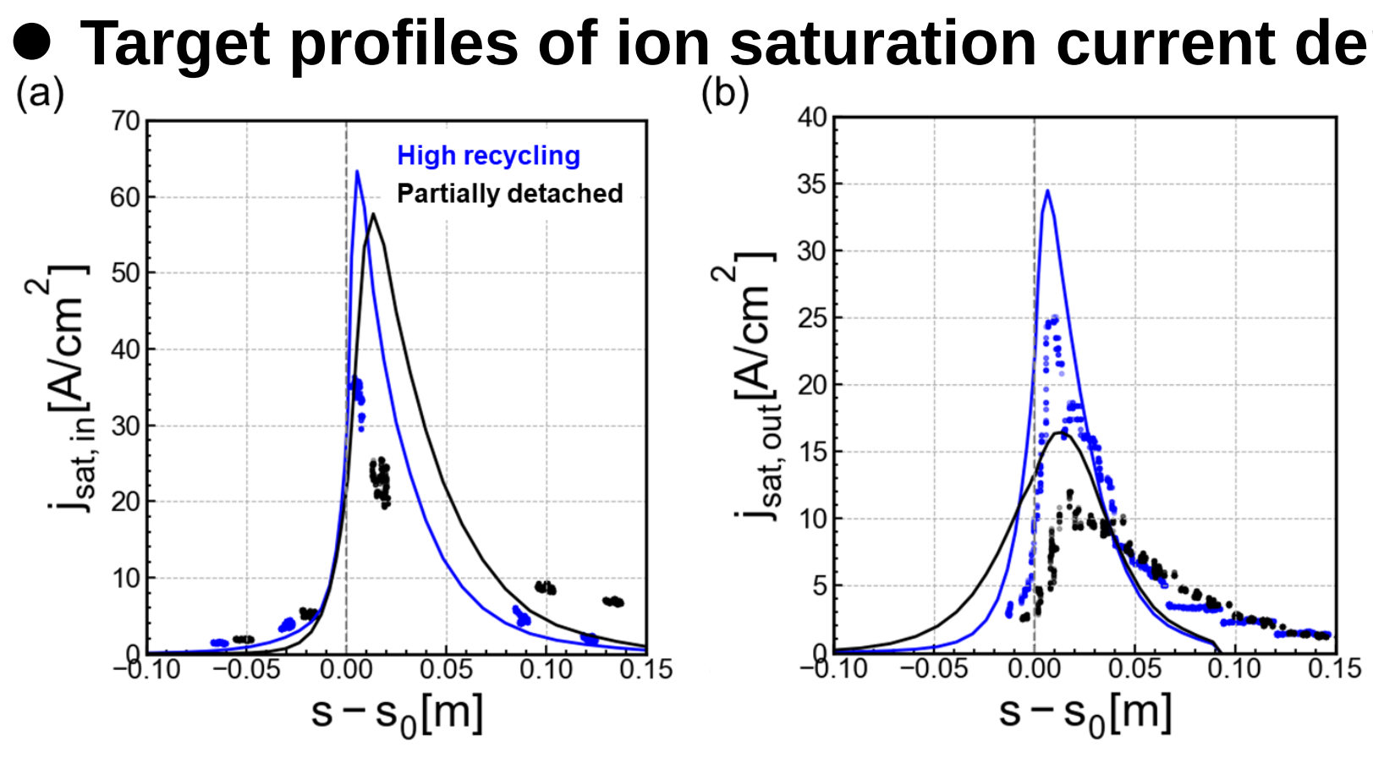
- Perpendicular transport coefficients ($D_\perp, \chi_\perp$) were given in such a way that the simulation reproduces the experimental upstream profiles from the Thomson scattering diagnostic results.



(a) Profiles of the perpendicular transport coefficients used in the simulations (D: particle diffusivity, $\chi_{i,e}$: heat diffusivity of ions and electrons). (b) Upstream n_e, T_e profiles from the experiment and the SOLPS-ITER simulation.

5. Comparison between simulation and experiment

- **Target profiles of ion saturation current density**

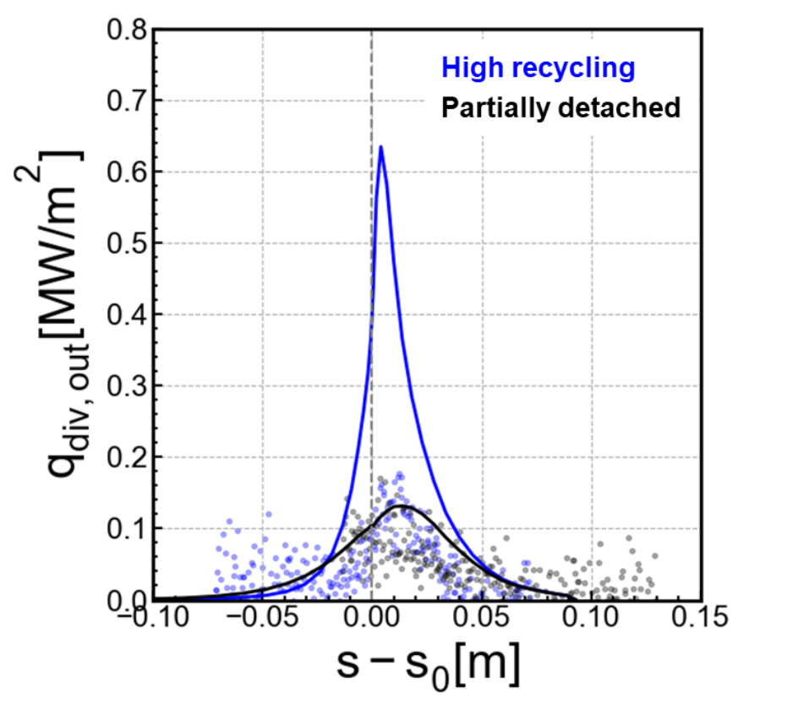


1) High recycling (blue):
   5.7-5.9 s for experiment,
   $n_{e,sep} = 2.0 \times 10^{19} m^{-3}$ for simulation
2) Partially detached (black):
   7.0-7.2 s for experiment,
   $n_{e,sep} = 4.0 \times 10^{19} m^{-3}$ for simulation

Ion saturation current density profiles at (a) the inner target and (b) the outer target. Experimental data: circle, simulation: solid lines

- The reduction factor of the outer target j_{sat} is qualitatively matched between the experiment and the simulation (3.1 vs. 2.1) when comparing the high recycling and the partially detached regime.
- However, the experimental outer target j_{sat} stayed lower level by a factor of 1.4 than the simulation result.

- **Target profiles of heat flux**

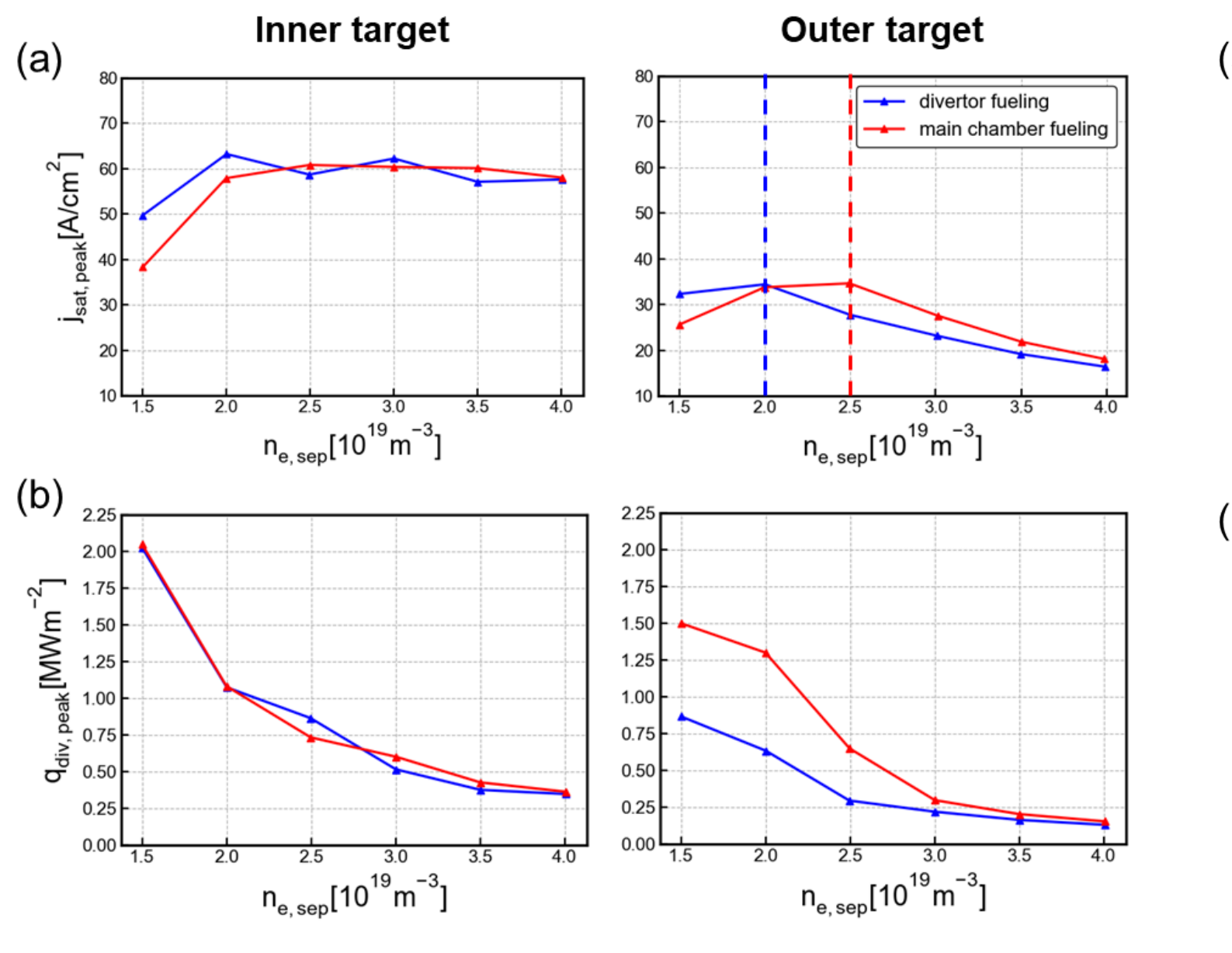


Profile of heat flux density perpendicular to the outer target

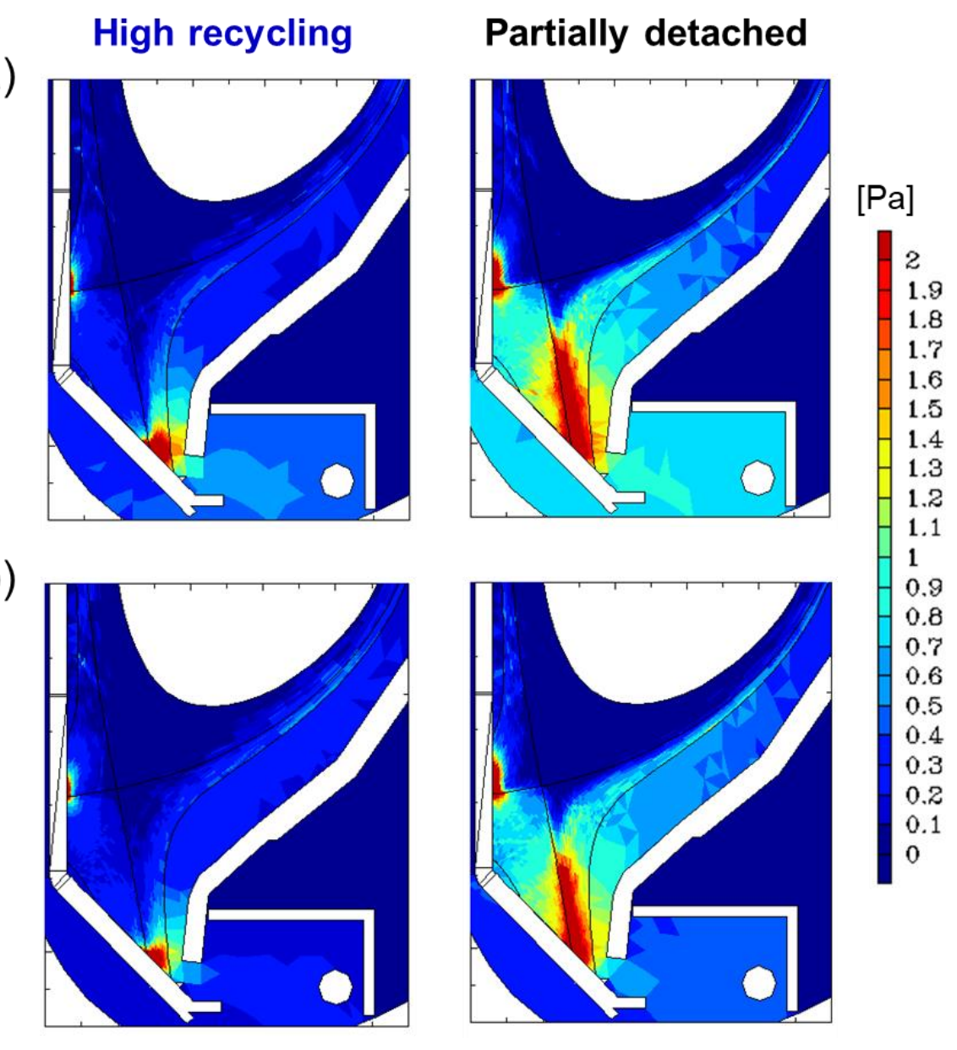
1) High recycling (blue):
   5.7 s for experiment, $n_{e,sep} = 2.0 \times 10^{19} m^{-3}$ for simulation
2) Partially detached (black):
   6.7 s for experiment, $n_{e,sep} = 4.0 \times 10^{19} m^{-3}$ for simulation

- For the partially detached regime, there is a good agreement between the experiment and the simulation.
- However, for the high recycling regime, a factor of 3.6 discrepancy is shown.

- **Fuelling location dependence in the simulation**

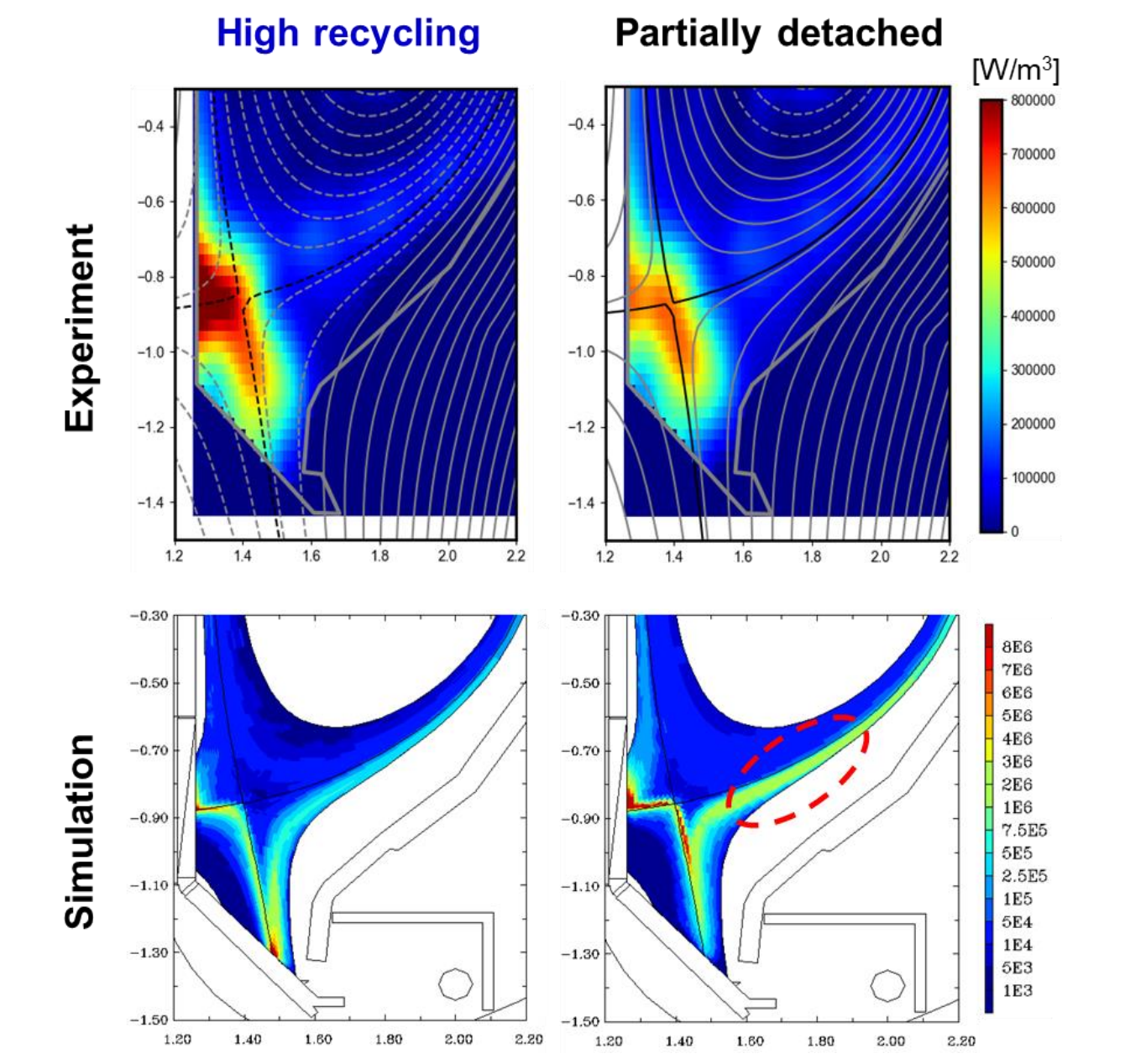


(a) Peak ion saturation current density (j_{sat}) and (b) peak heat flux density (q_{div}) at both targets during the separatrix density ($n_{e,sep}$) scan.



Simulated neutral pressure distributions in the divertor region for (a) the divertor fuelling case and (b) the main chamber fuelling case.

- **Radiated power density distribution**



Radiated power density distribution from the experiment (top) and the modelling (bottom) for two divertor regimes

- For both experiment and simulation, the outer target radiation was reduced and the maximum radiation front at the inner divertor region moved upward toward the X-point.
- Only for the simulation, the maximum radiation was observed in front of the outer target and the intense radiation at the outer SOL was shown.
  - It may be due to the lack of #LoSs and the limited B2.5 grid extent [4].

* Experimental radiation distribution by imaging bolometer [5]

- **The main chamber fuelling case shows later outer target detachment onset at the higher separatrix density ($n_{e,sep}^{onset} = 2.5 \times 10^{19} m^{-3}$) than the divertor fuelling case ($n_{e,sep}^{onset} = 2.0 \times 10^{19} m^{-3}$).**
- Larger peak heat flux for the main chamber fuelling case is also reproduced.
- **The divertor fuelling case has higher neutral pressure in the outer divertor region by the geometrical effect**: the V-shaped divertor geometry and the plenum near the outer divertor.

Conclusions

- **Partial detachment** was successfully achieved with pure **deuterium injection** in KSTAR H-mode discharges.
- The experimental results are reproduced reasonably well by SOLPS-ITER simulations.
- There are still discrepancies between the simulation and the experiment:
  - Higher heat flux density at the outer target for the high recycling regime and the intense radiation at the outer SOL are only shown in the simulation.
- By examining the effects of two different fueling locations (divertor fuelling vs. main chamber fuelling), the divertor fuelling is favorable to get earlier detachment of the outer target.

Future work

- Simulations including drifts and neutral-neutral collisions are planned.

Acknowledgements:
This work was supported by the National R&D program through the National Research foundation of Korea (NRF), funded by the Ministry of Science, ICT (NRF-2019M1A7A1A03087560). The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

References:

[1] Kallenbach, A. et al., Nucl. Fusion 55 (2015) 053026
[2] Wiesen, S. et al., J. Nucl. Mater. 463 (2015) 480
[3] Bonnin, X. et al., Plasma Fusion Res. 11 (2016) 1403102
[4] Wiesen, S. et al., Nucl. Mater. Energy 17 (2018) 174
[5] Jang, J. et al., Curr. App. Phys. 18 (2018) 461