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WP PWIE SP D: Coordination 2025

Plasma background, impurity migration and neutral transport simulations for JET

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Aalto University

Analysis and publication plan for SP D 2025

SP D1 Plasma boundary modelling			
D006	Modelling (e.g. SOLPS-ITER or EDGE2D-EIRENE) of background plasmas to be used as input for migration modelling: JET	Aalto U	3 PM

- JET-ILW scenario simulations for Ni and W erosion → JET-ILW limiter plasmas

In addition: CX under D002, ERO2.0 Ni/W migration under D003

- JET He plasmas

Horiz. and vertical target configuration, 1-5 MW → ERO2.0 for W sputtering, transport

- JET nitrogen transport and ammonia formation

SP D4 Neutral particles modelling			
D002	Atomic and molecular fluxes spatially resolved to the wall surfaces (including divertor) in JET. Explore pressure range, sub-divertor geometry and conclusions for effective pumping speed in JET	Aalto U	2 PM

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Explore pressure range, sub-divertor geometry → effective pumping speed

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→ Pyry Virtanen M.Sc. thesis 2025 → PSI 2026

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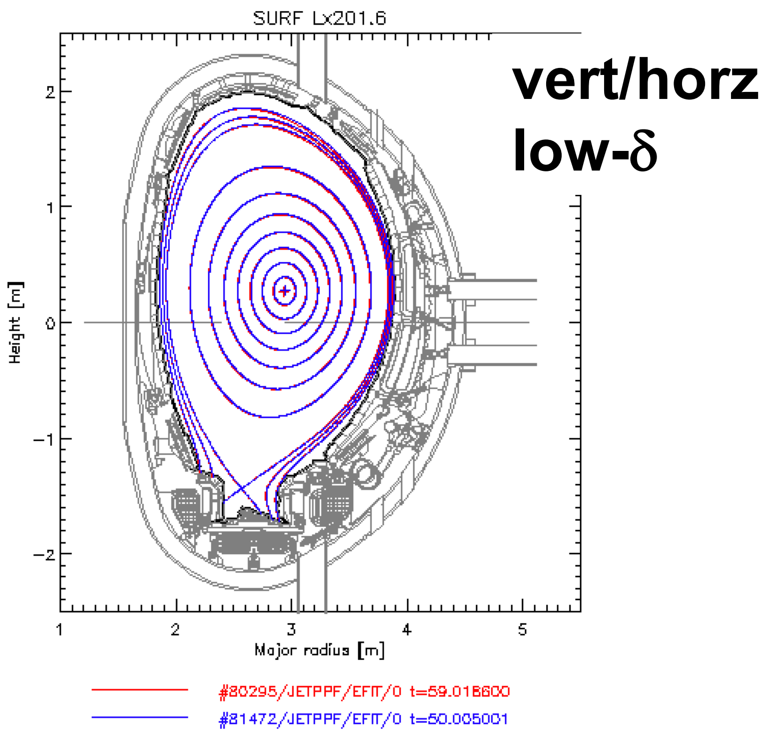
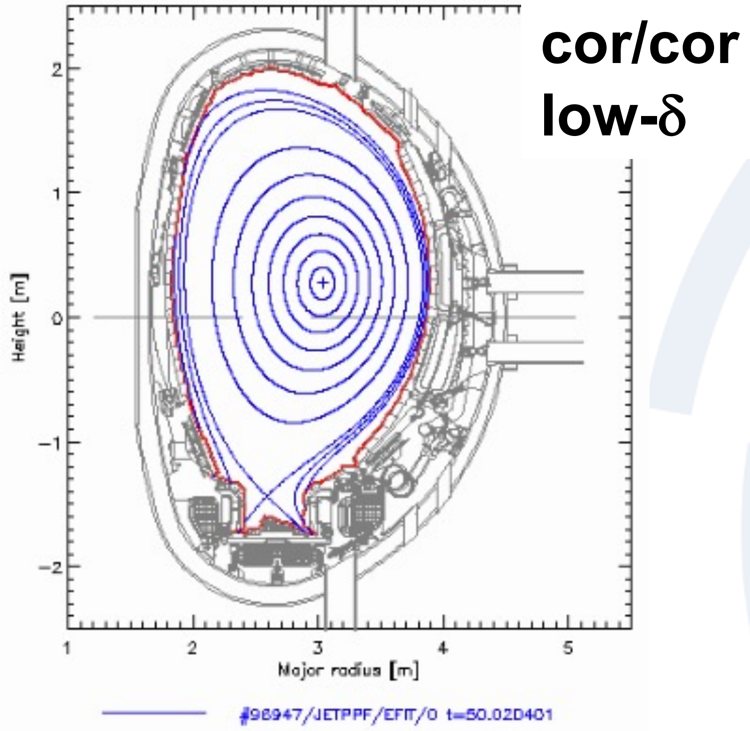
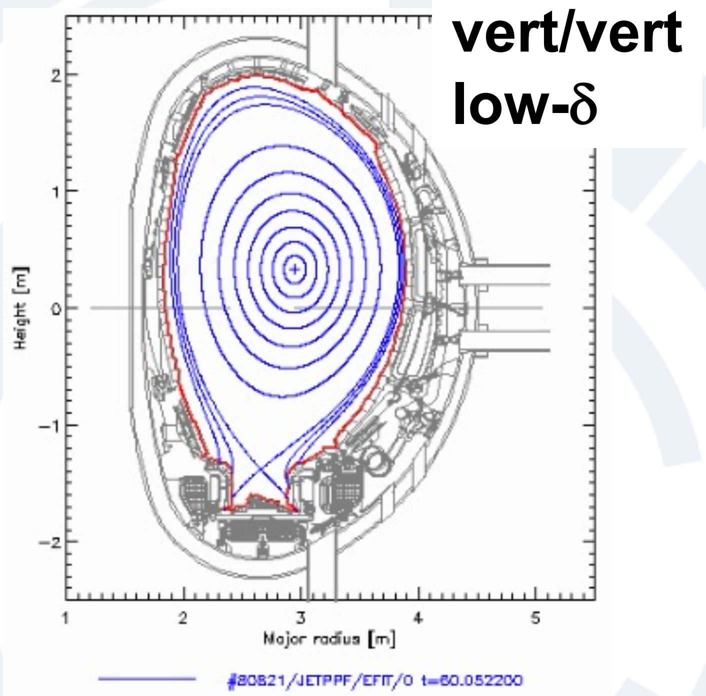
Ni and W erosion and deposition were predicted for representative plasma configs. and scenarios in the JET-ILW campaigns 2011-2015







- Deuterium plasmas, EDGE2D-EIRENE density scan at low (2 MW) and moderate (up to 15 MW) heating power

- Deuterium plasmas, JINTRAC (including EIRENE) density scan at low (2 MW) and high (up to 25 MW) heating power
- Inter and intra-ELM time slices for subset of density/power scans

- Deuterium plasmas, EDGE2D-EIRENE density scan at low (2 MW) and moderate (up to 10 MW) heating power

Pyry Virtanen et al., PSI 2024 → NME 2025

Campaign-representative plasma scenarios were analysed for their approximate durations in the JET-ILW campaigns 2011-2015

Configuration	LFS-midplane density (1e19 m^{-3})	P_{in} (MW)	Total time (s)
V5	0.85	2.2	30125
	1.8	2.2	12965
	2.0	4.8	1880
	4.0	4.8	1668
	3.6	6.6	2397
	3.4	10	3716
	3.4	15	723
CC	0.85	2.2	34112
	1.5	6	3877
	2.5	14	2426
	1.6	24	454
VC	0.85	2.2	28096
	1.8	6	3263
VV	0.85	2.2	9971
	4.0	14	1764

Pyry Virtanen et al., PSI 2024 → NME 2025

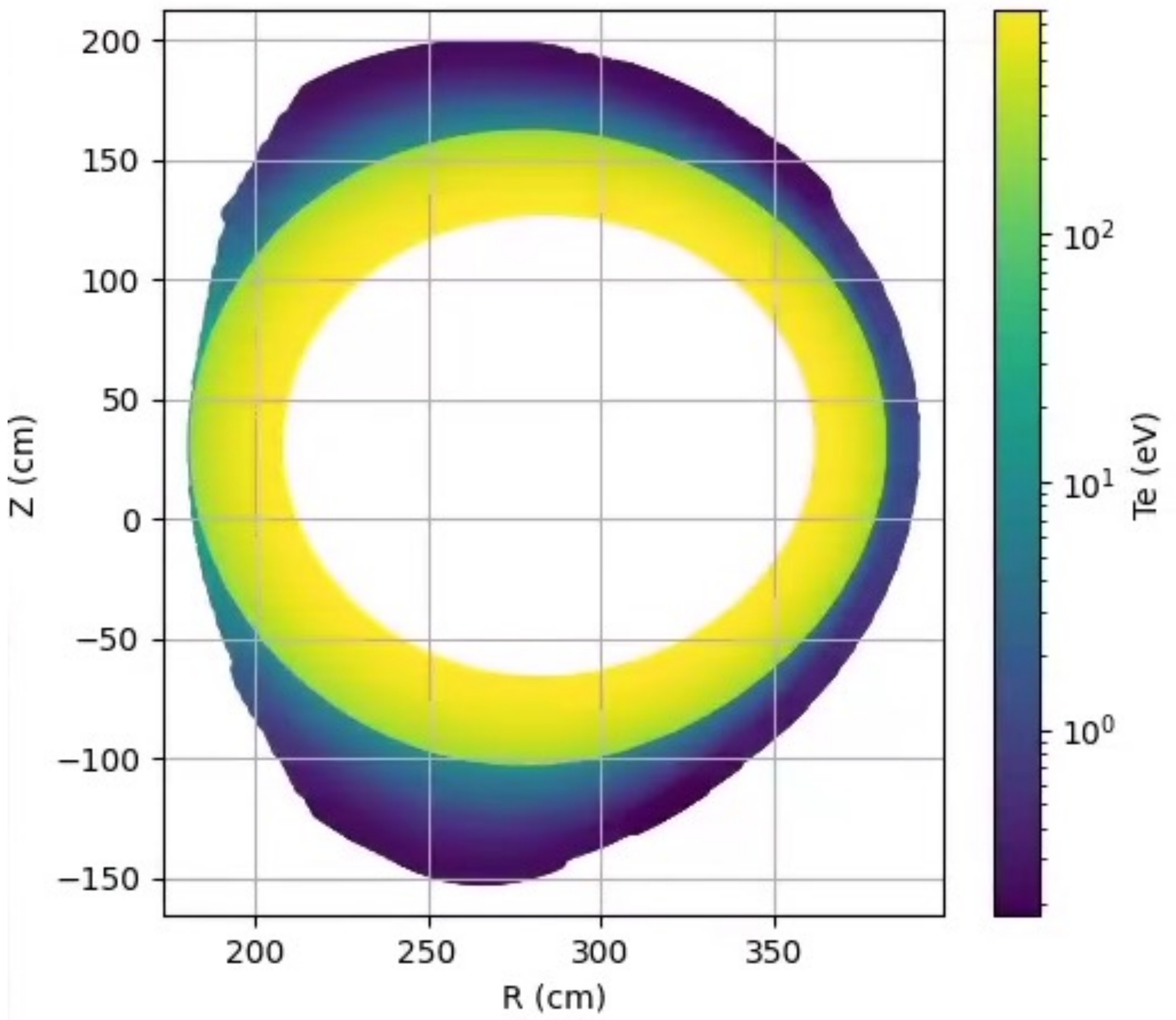
- Existing EDGE2D-EIRENE and core-edge coupled JINTRAC cases were expanded in density and auxiliary power
- **Limiter configurations, albeit at low heating power, account for approximately 30% (68409 s) of the total plasma time:**
  HFS / LFS limited = 22707 / 45702 s

⇒ 2024: develop dedicated limiter configurations for SOLPS-ITER based on two representative limiter configs. from 2011 (c.f., G. Arnoux et al., NF 2013, C. Silva et al., NF 2014)

2024: JET limiter plasmas were simulated using a 2-PM/OSM (including internal grid generation) ⇒ CARRE grid for SOLPS-ITER (EIRENE CX fluxes)

LiPBaLM prediction for T_e

Pyry Virtanen



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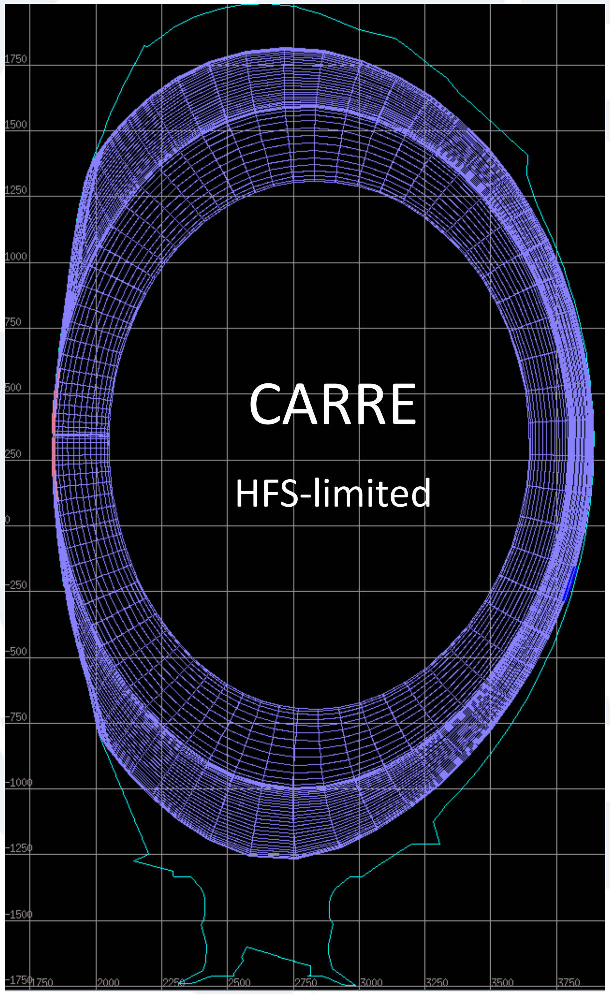
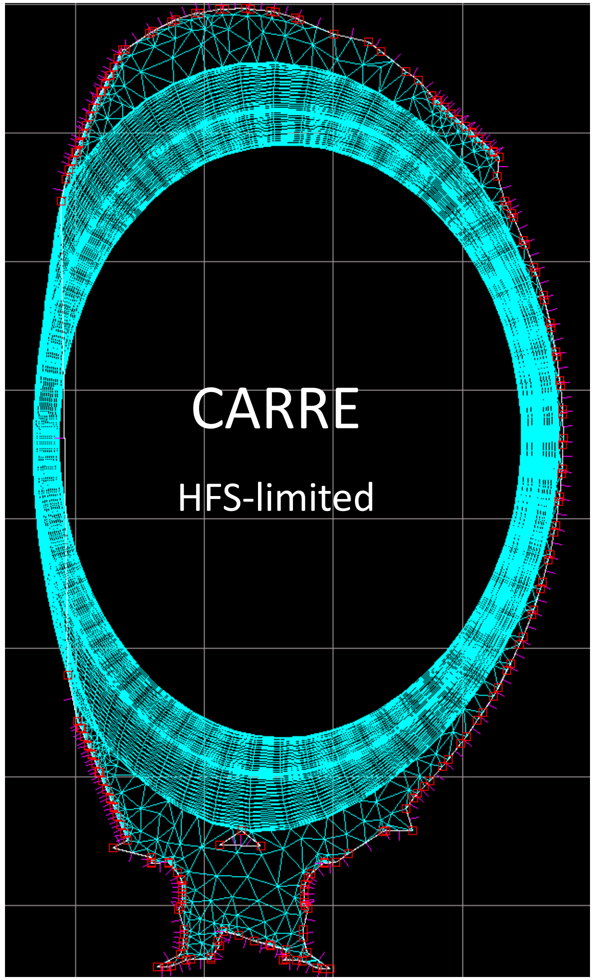
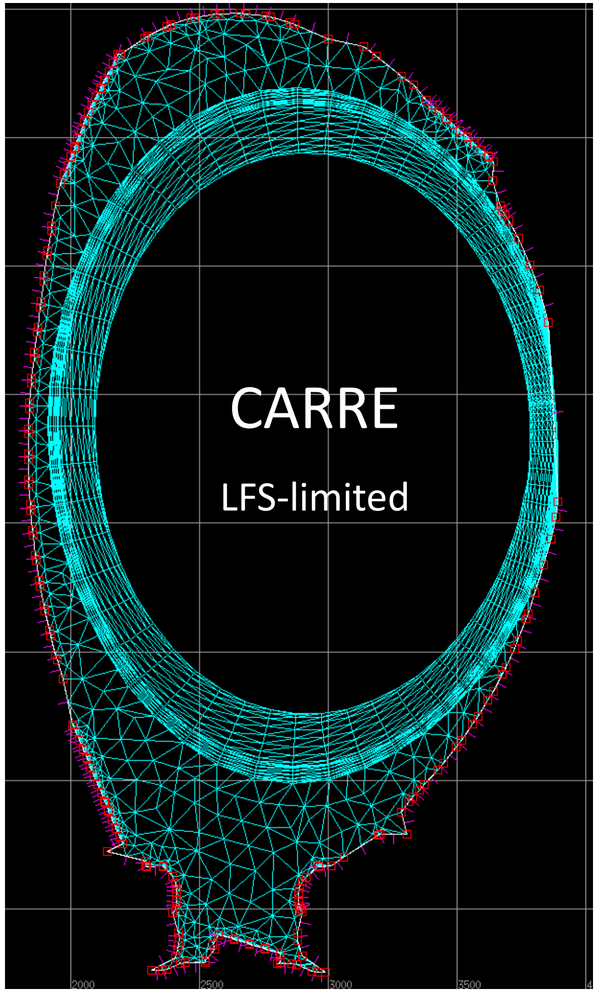


2025: perform SOLPS-ITER density and power scans in HFS and LFS limited configuration ⇒ extract CX fluxes for ERO2.0 Ni, W erosion and migration

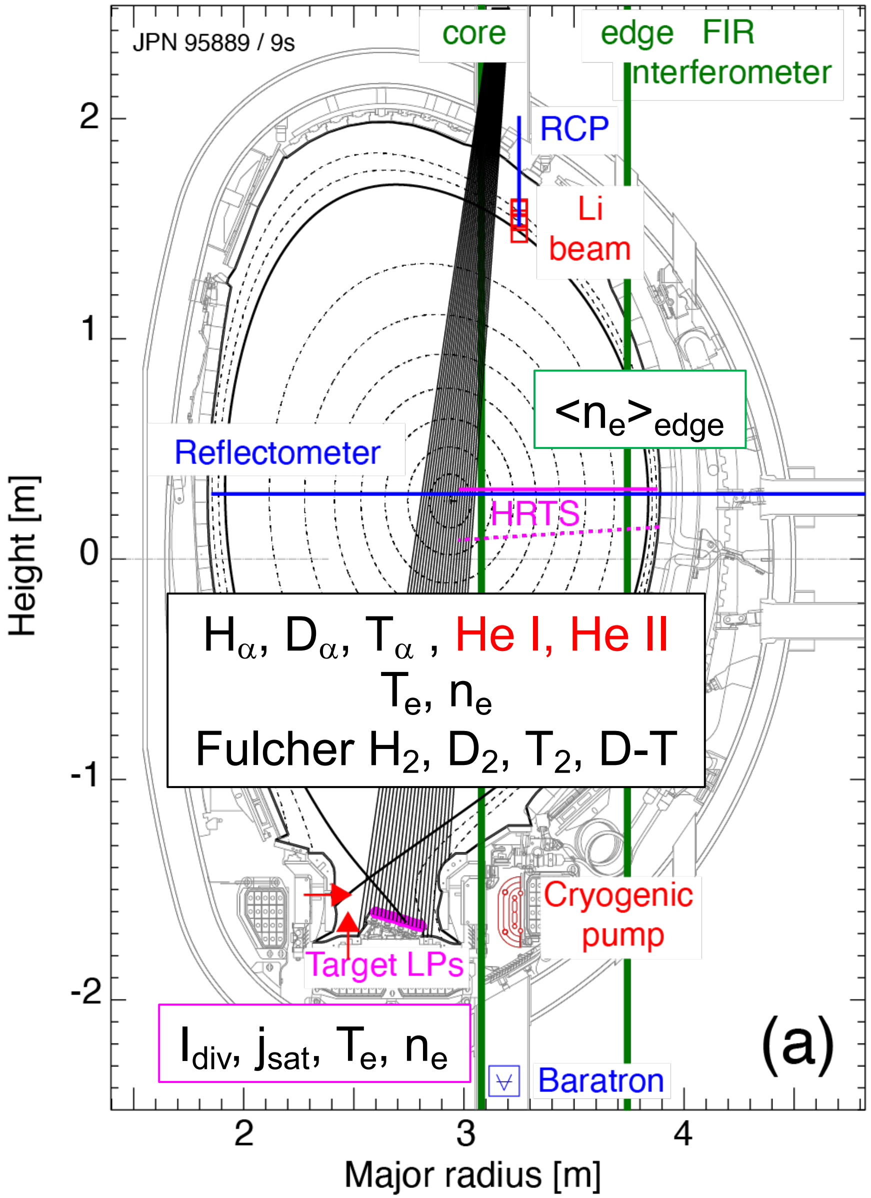
Pyry Virtanen





- First proof-of-principle SOLPS-ITER runs achieved for HFS-limited case → setup and predicted plasma parameters being cross-checked with David Coster and Xavier Bonnin
- Using ERO2.0, CX atomic flux contributions from limiter configurations to campaign-integrated Ni, W and Be migration topic of Pyry Virtanen's M.Sc. thesis in 2025 → PSI 2026

Set of He L-mode plasmas was performed in JET-ILW in C43 (Oct 2022) to elucidate atomic and molecular physics for detachment (RT-He-04)



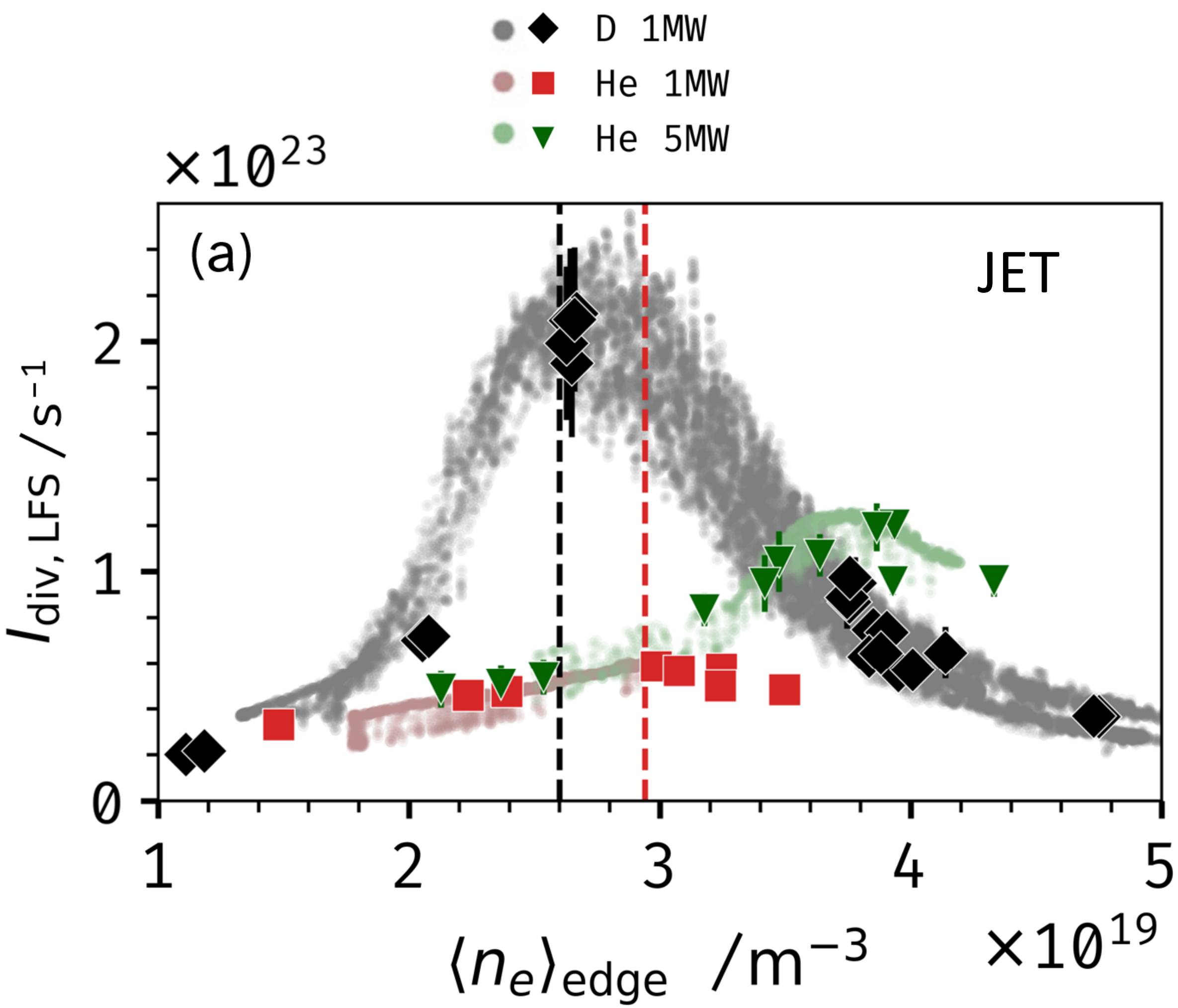
- Single I_P / B_T pair: 2.5 MA / 2.5 T
- V5/C and VT configuration, optimized for diagnostics and edge modelling
- Ohmic and NBI (He) heating up to 5 MW; D 1.0 MW
- **He: Ar-frosted cryo panel** for improved density control
- D and He injection through divertor G/TIMs: fuelling ramps and steps

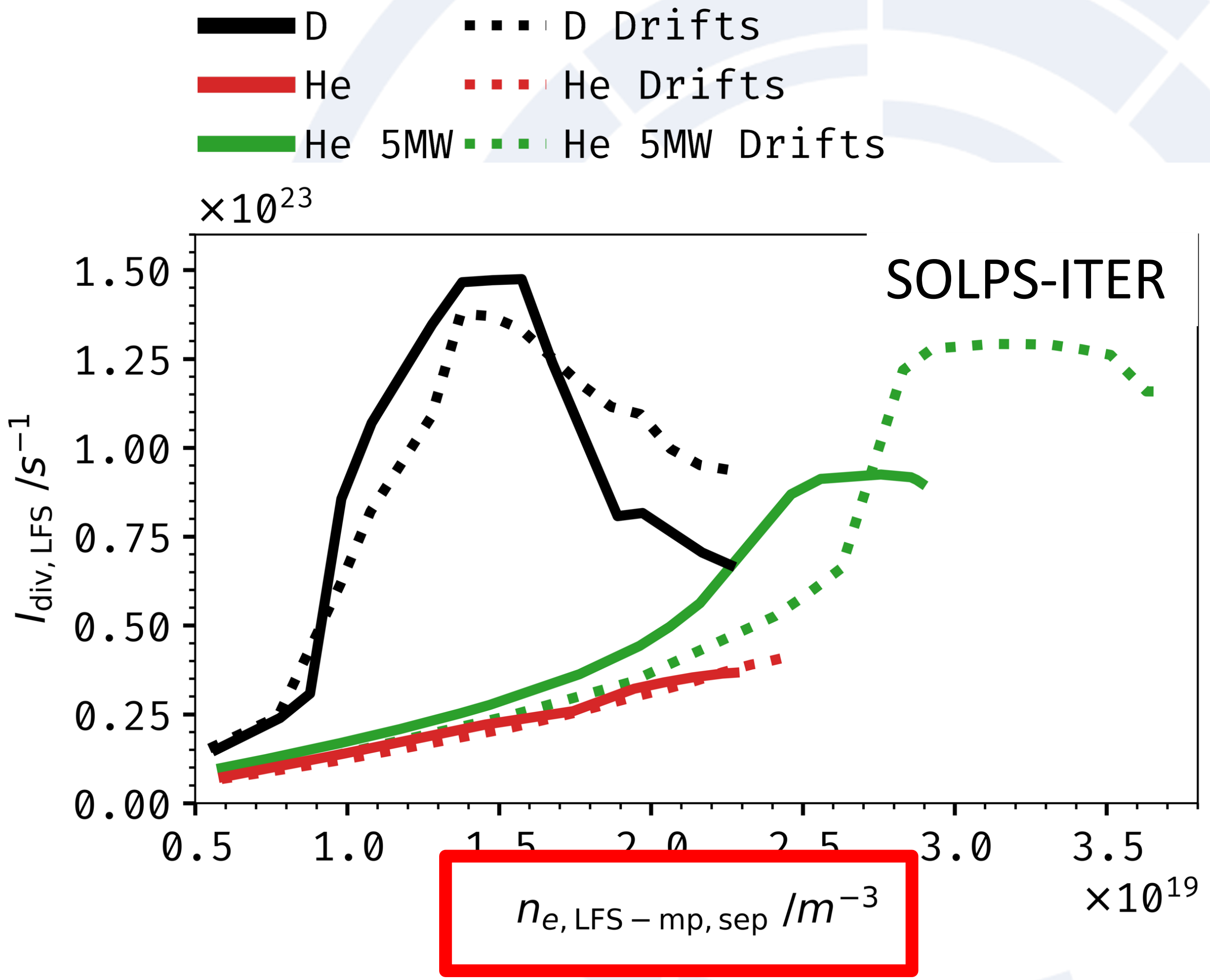
⇒Initial measurement analyses presented at PFMC 2023 and PET 2023 by David Rees → interpretation using SOLPS-ITER prepared for PSI 2026

- C.f., additional configurations, machine setup and plasma conditions under RT-He-03 (limiter config., Be monitoring pulse at 2.0 MA / 2.0 T, V5/B for W fuzz) and RT-He-17 (RISP and corner configurations)

SOLPS-ITER simulations of He vs D plasmas qualitatively consistent with measurements (70% lower $I_{div,LFS}$ in He) due to 1.5-3x higher eff. ionisation cost

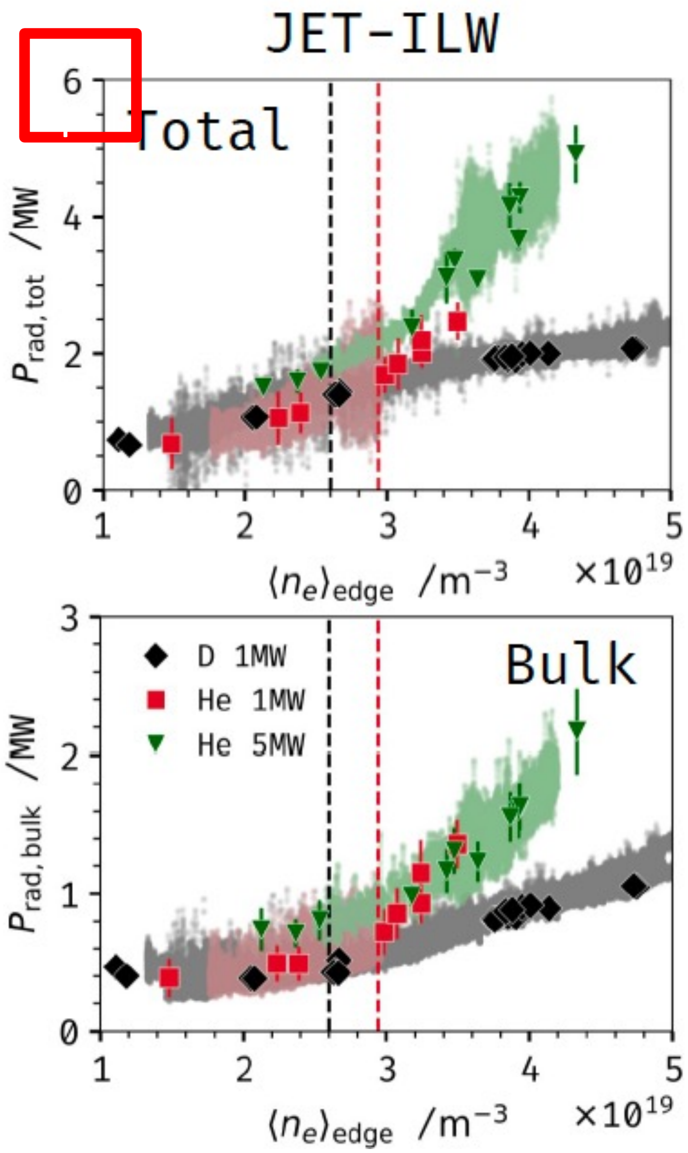
David Rees → PSI 2026

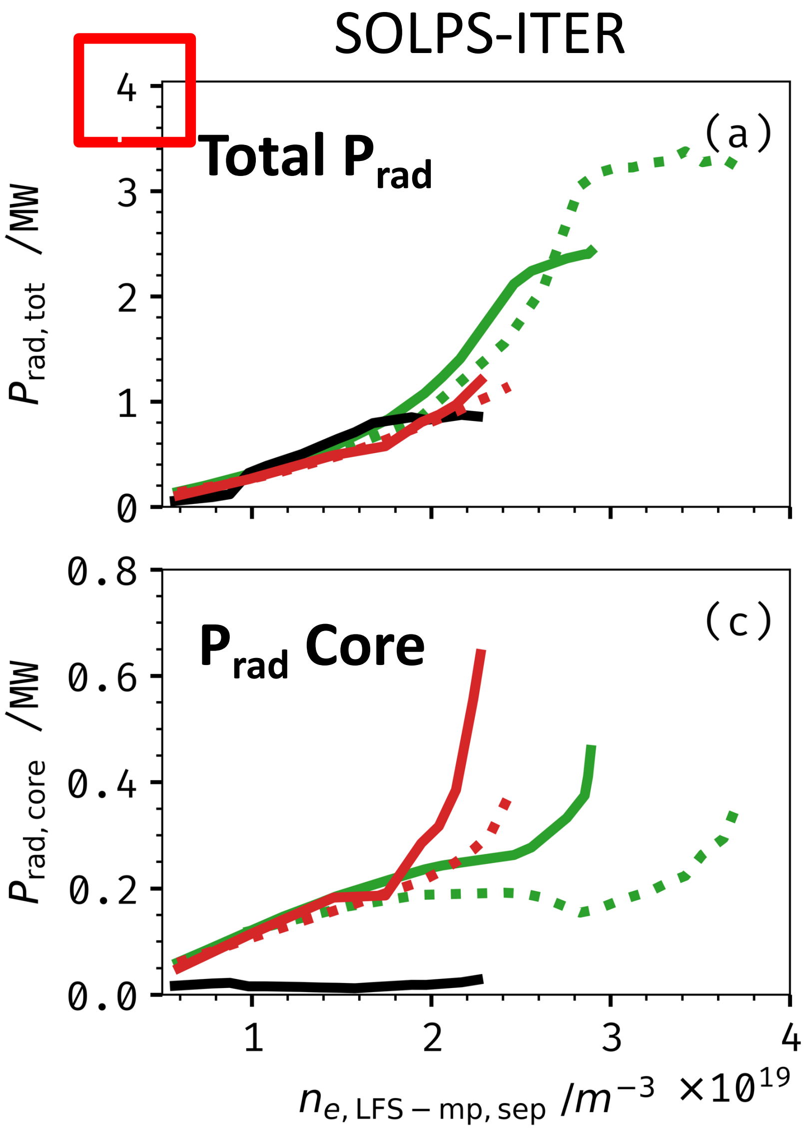




(Global) power balance: qualitatively, higher core radiation (He^{2+}) leads to stronger reduction in P_{SOL} in He than in D plasmas

David Rees → PSI 2026



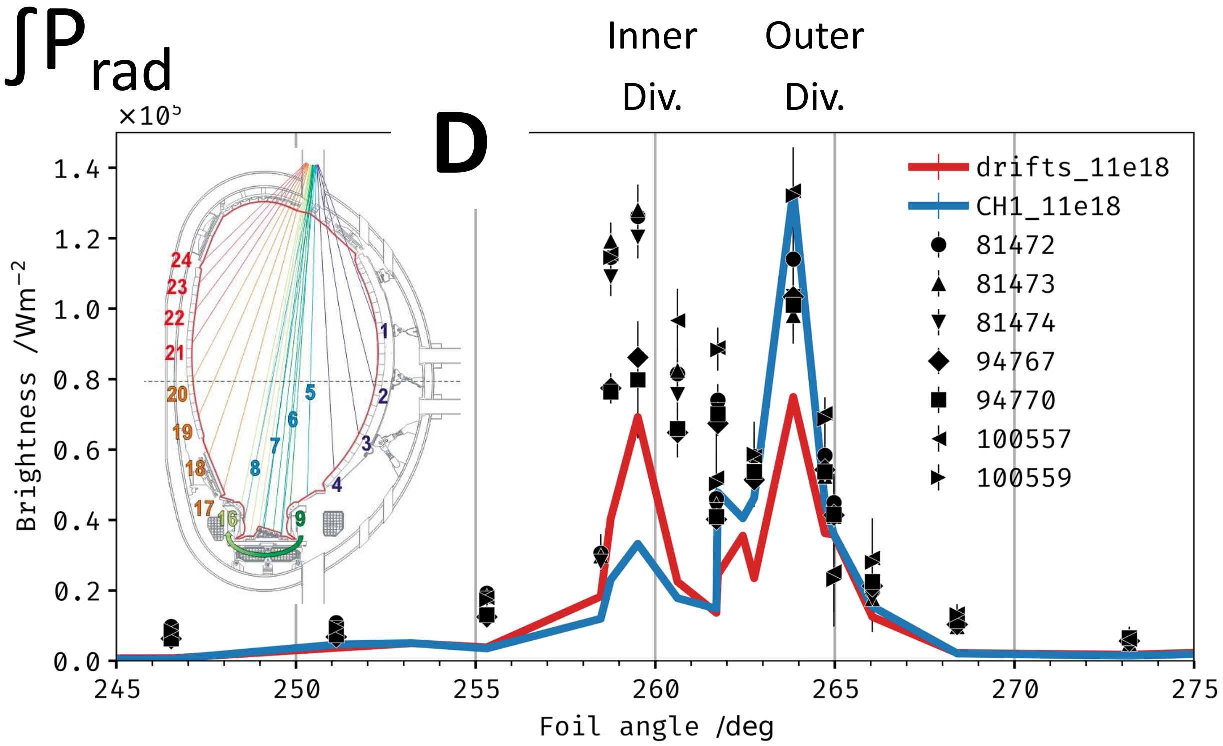


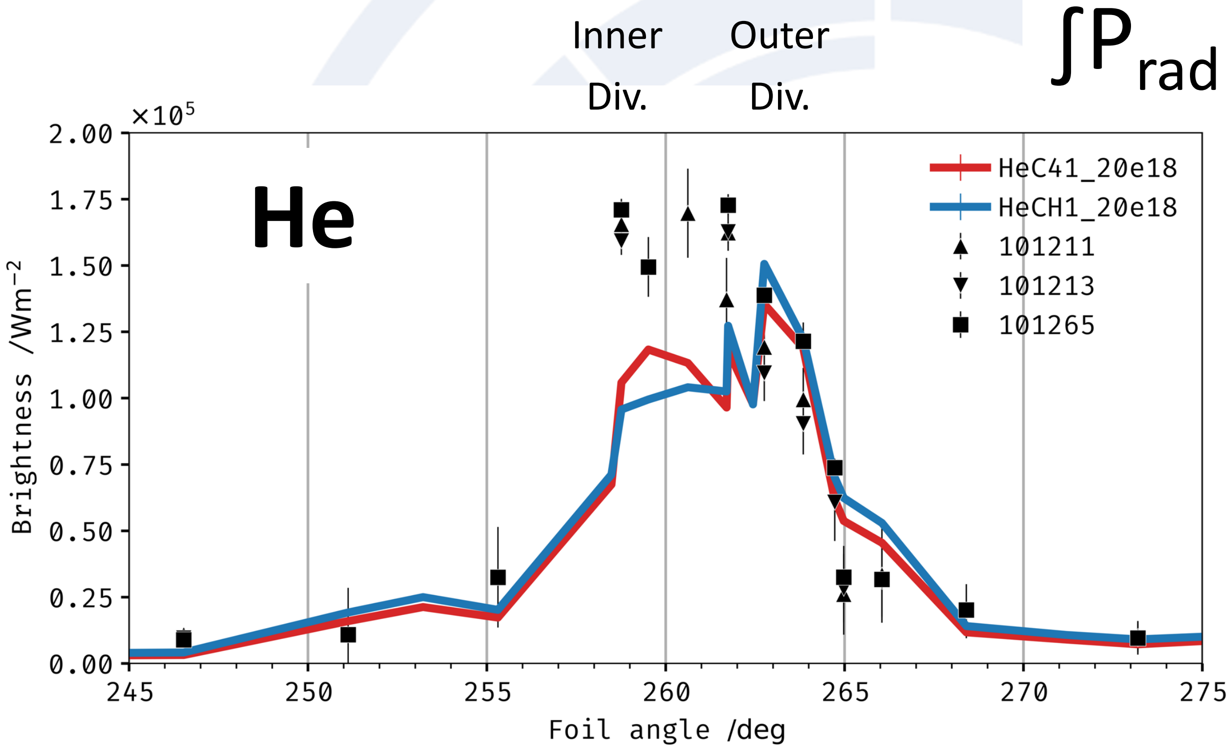
- 2x lower radiative power predicted by SOLPS-ITER, for both D and He (general edge modelling issue)
- Inclusion of cross-field drifts and currents pushes radiative collapse of solution to higher separatrix densities in He plasmas
- C.f., in experiments, He plasmas have lower density limits (wrt. line-averaged edge densities)

Predicted line-integrated power lower than measured not artifact of tomographic reconstruction, isolate issue to inner divertor / X-point region

David Rees → PSI 2026

At onset of detachment, P_{NBI} = 1 MW





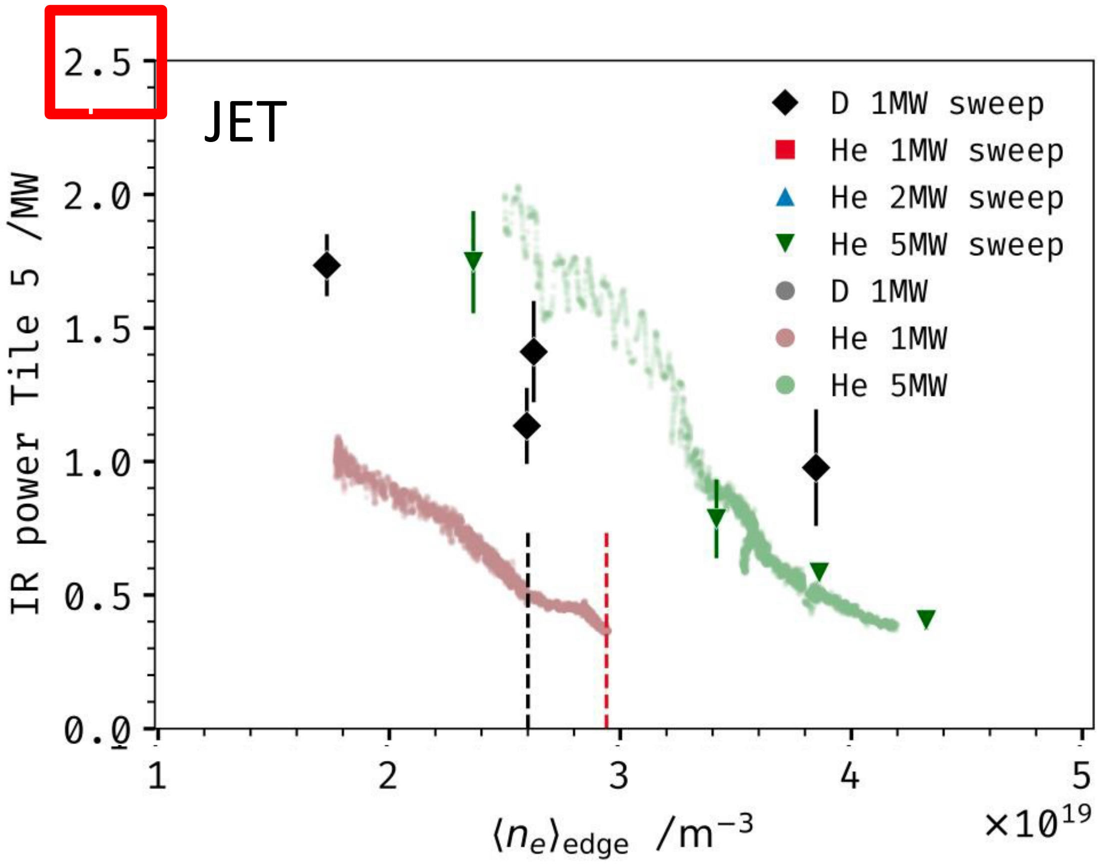
- For deuterium, drifts increase $\int P_{rad}$ across inner divertor, but reduce $\int P_{rad}$ across outer divertor

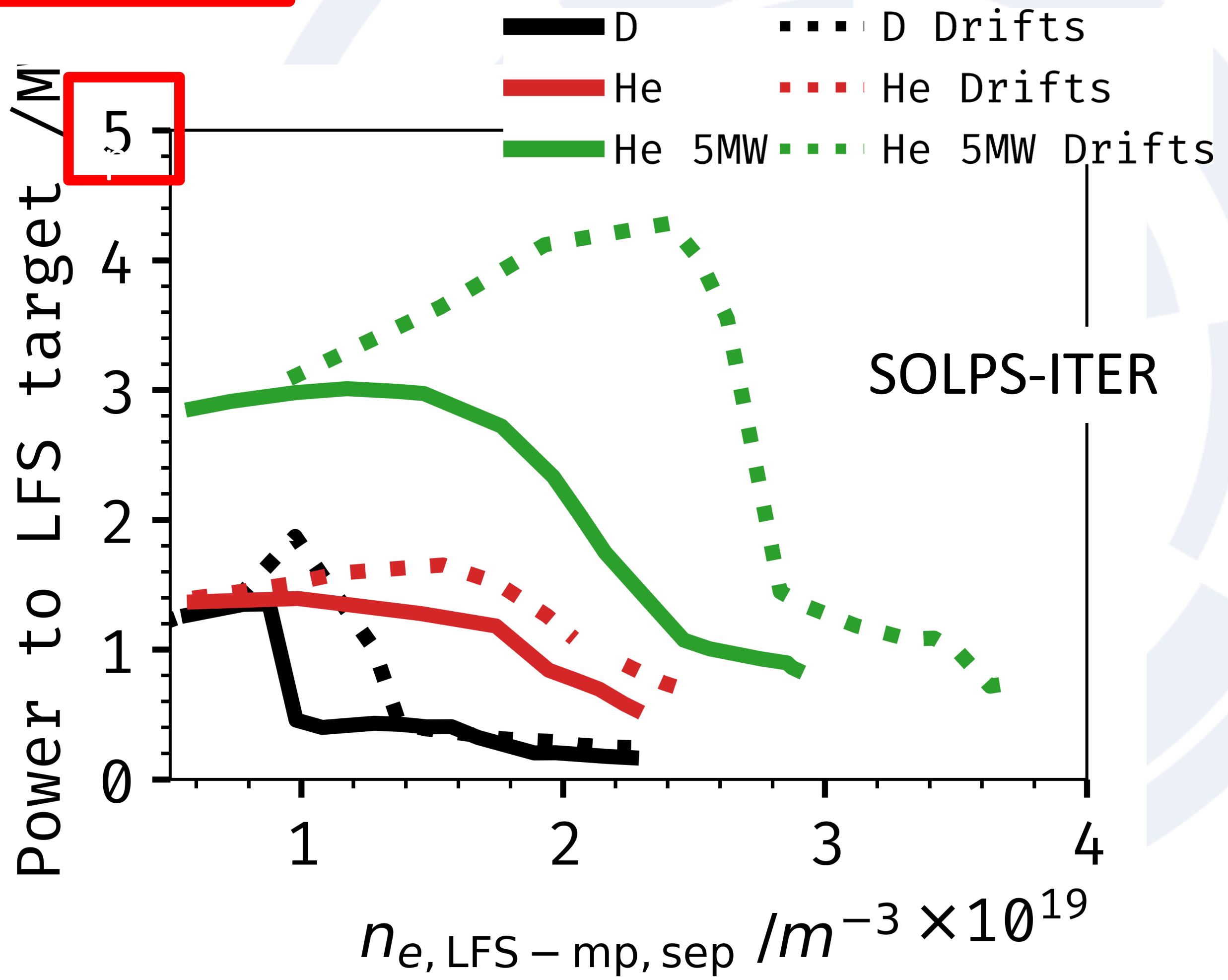
⇒**Next analysis step: compare (KS3, KT3) He I and He II emission**

Predicted power to LFS divertor plate consistent with IRTV measurements for 1MW D and He plasmas, factor of 2 higher for 5 MW

David Rees → PSI 2026

Work in progress

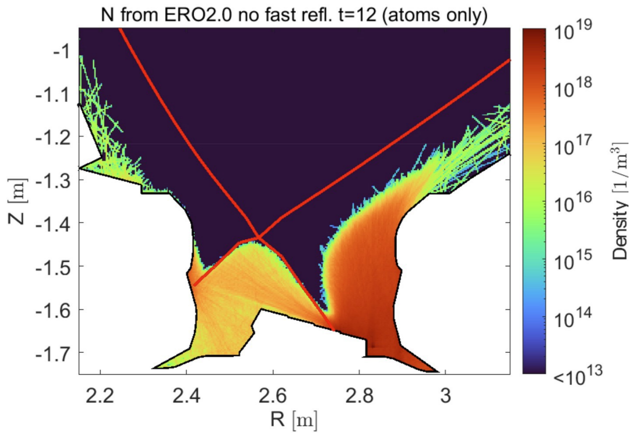




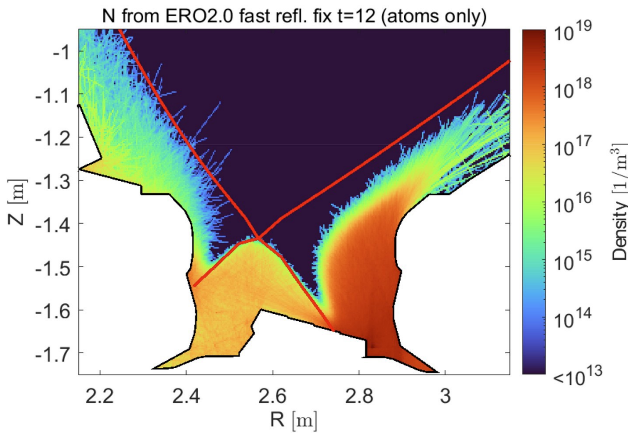
Inclusion of fast-reflected N ions in ERO2.0 increases N penetration ⇒ assessment of N reflections via MD sims. for pure-W vs NW surfaces

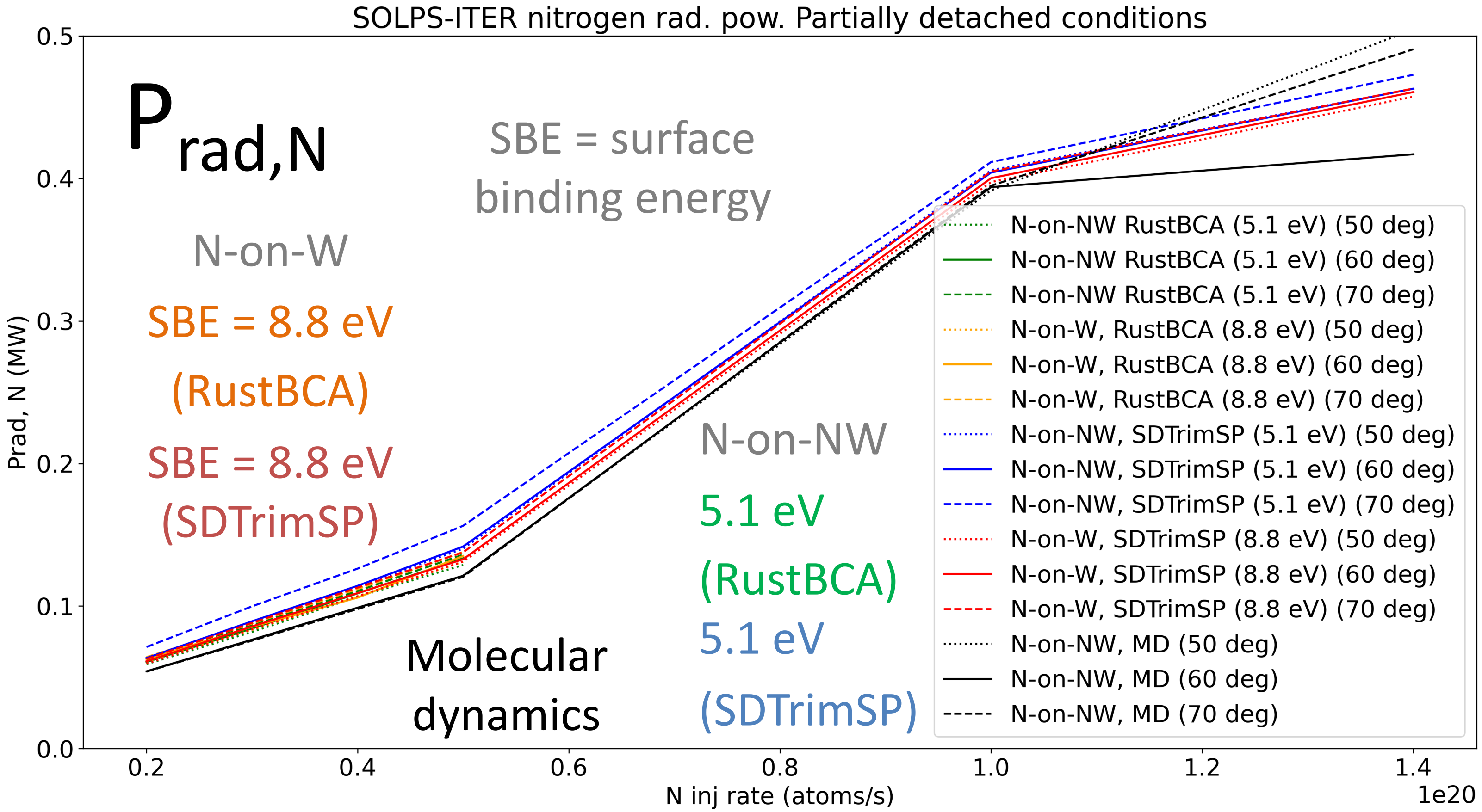
Roni Mäenpää et al., PSI 2024 → NME 2025

Thermal recycling



Ther. recycl. + fast reflections

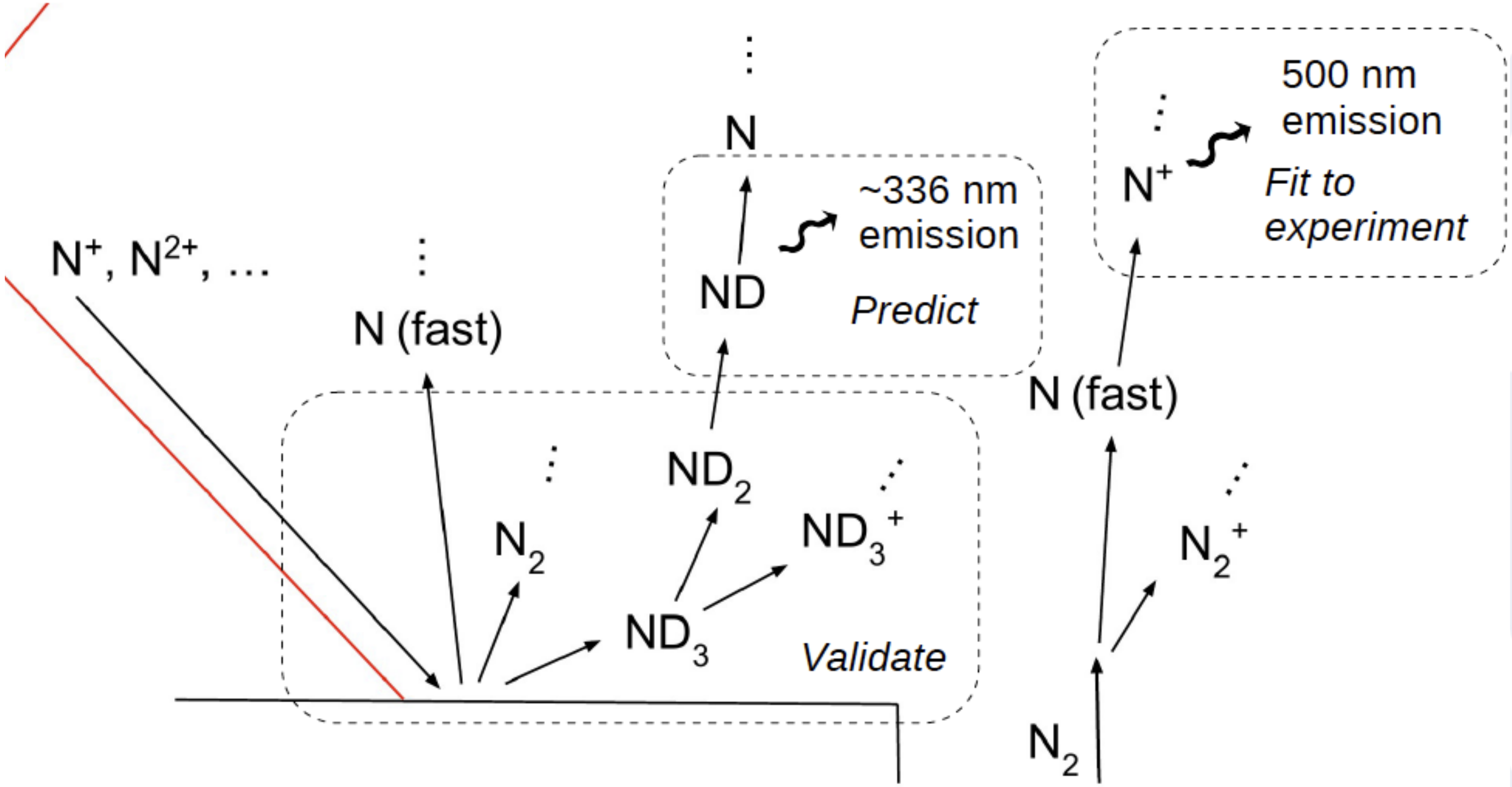


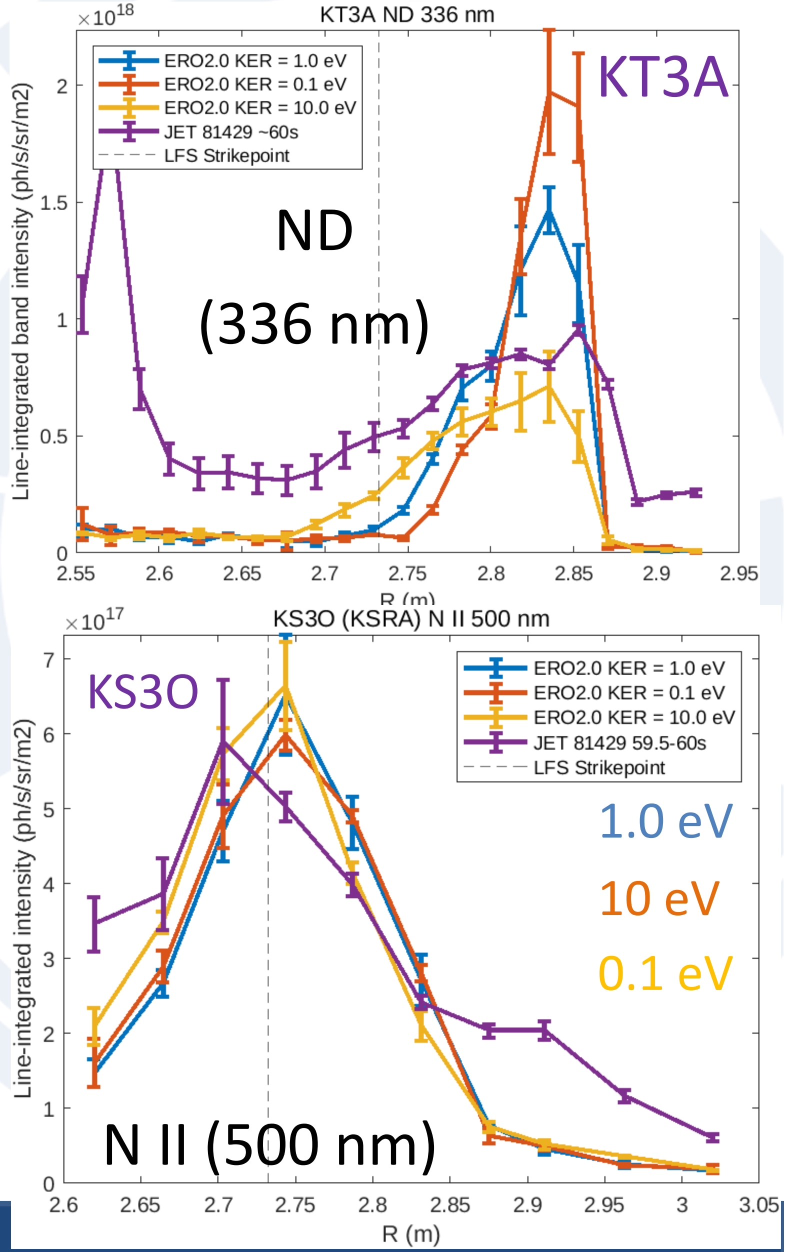


- N-on-WN with SBE = 5.1 eV, best estimate for surf. composition and binding energy
- N-on-W with SBE = 8.8 eV, a lower estimate for reflection coefficients
- 3 incidence angles have been tested (50, 60 and 70 degrees wrt the surface normal)
- **$P_{rad,N}$ insensitive to (reasonable) choice of SBE, BCA vs. MD, impact angle**

Initial ERO2.0 simulations of ammonia formation in JET-ILW: ND emission 50% above (KER = 1 eV) or 25% below (KER = 10 eV) measurement

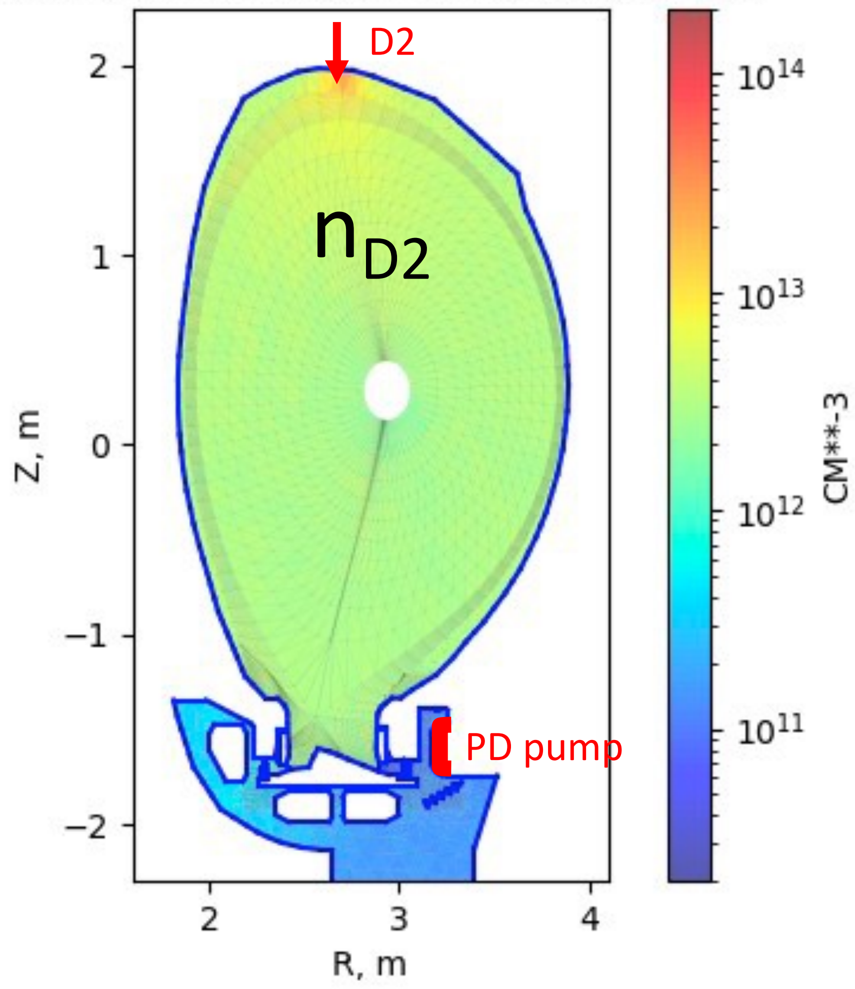
Roni Mäenpää et al., PFMC 2025 → submitted to NME





- Agreement of measured and predicted ND emission achieved by fitting the N II 500 nm peak line emission ⇒ **50% conversion rate of N radicals to ND_3**
- Calibration of KT3 and fitting of measurement data significant challenge, yet uncertainties in the kinetic energy release values much more significant

Time-dependent EIRENE simulations of gas-into-(empty) vessel calibrations in JET ⇒ vacuum conductance and pumping speed for H_2, D_2 and T_2

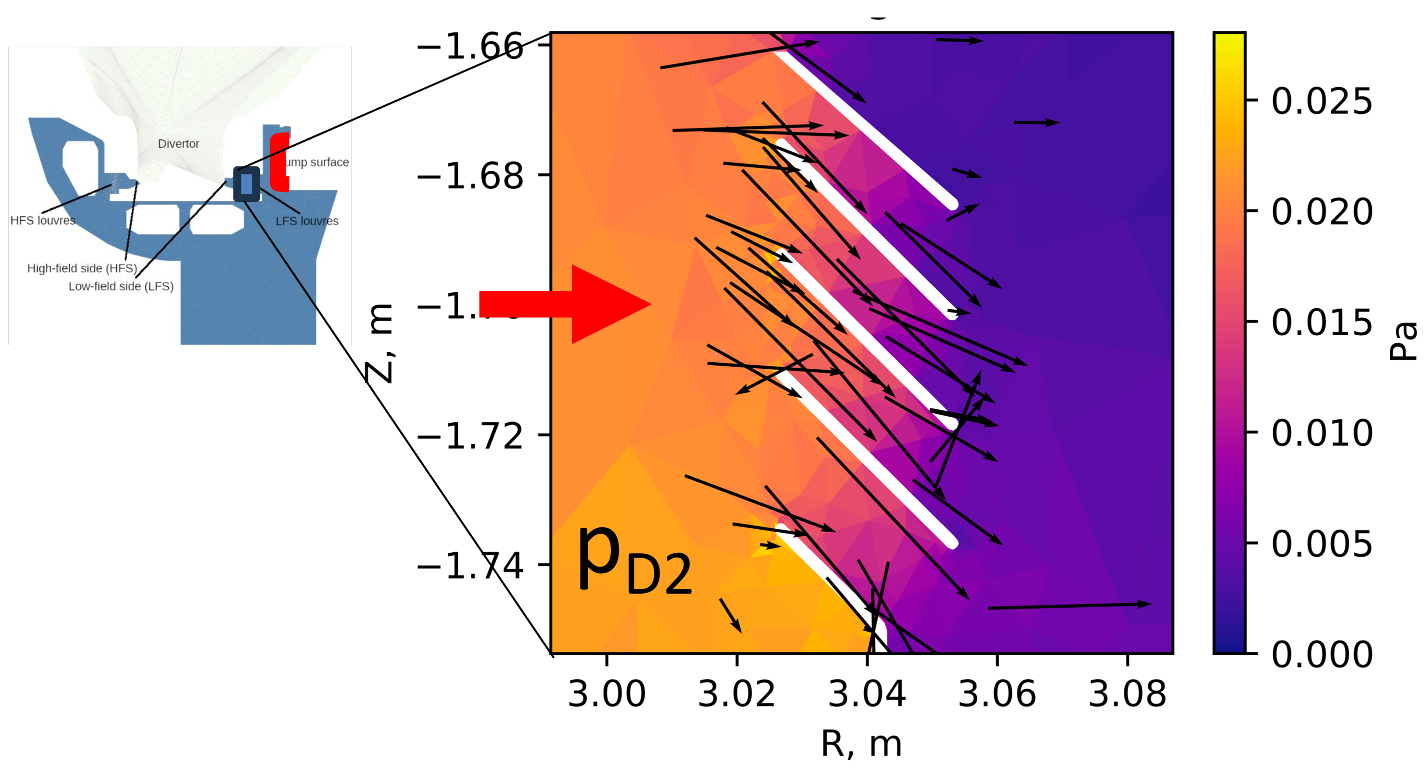


- I. Jepu (UKAEA): dedicated gas-into-vessel calibs. for H_2, D_2 and T_2 with divertor cryo sc-He/LN_2 temp, torus isolation valves for divertor turbo-molecular pumps open/close, NBI torus isolation ("rotary") valves open/close in autumn 2023
- Time-dependent EIRENE on full-device grid, including sub-divertor structures (louvres), actual injection locations, pump locations and speeds, valves open/closed

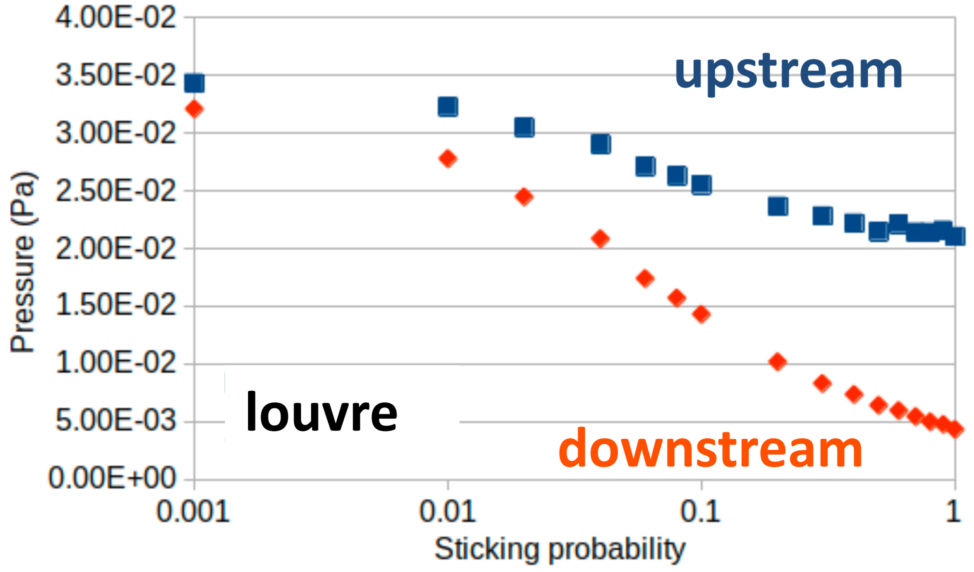
⇒ Simulate pressure rise and pump-out ⇒ compare predicted to measured $p_{sub\text{-}div}$ to validate SOLPS-ITER assumptions ⇒ **simplify sub-divertor geometry** (c.f., A. Scarabosio, A. Zito for AUG)

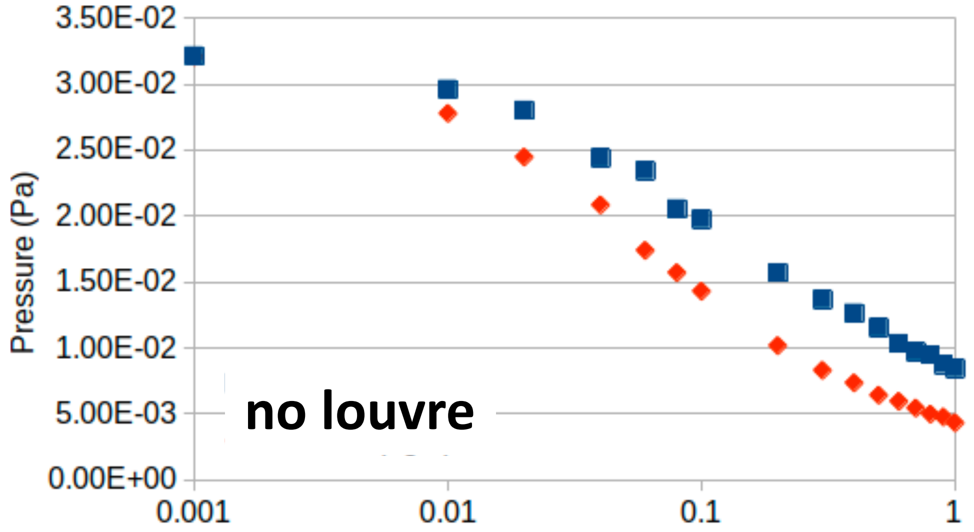
Aaron Vesa → EPS 2025, M.Sc. thesis 2025

Sub-divertor louvres inhibit gas flow to pump / ability to control plasma density by factor of two



Aaron Vesa, Timo Kiviniemi



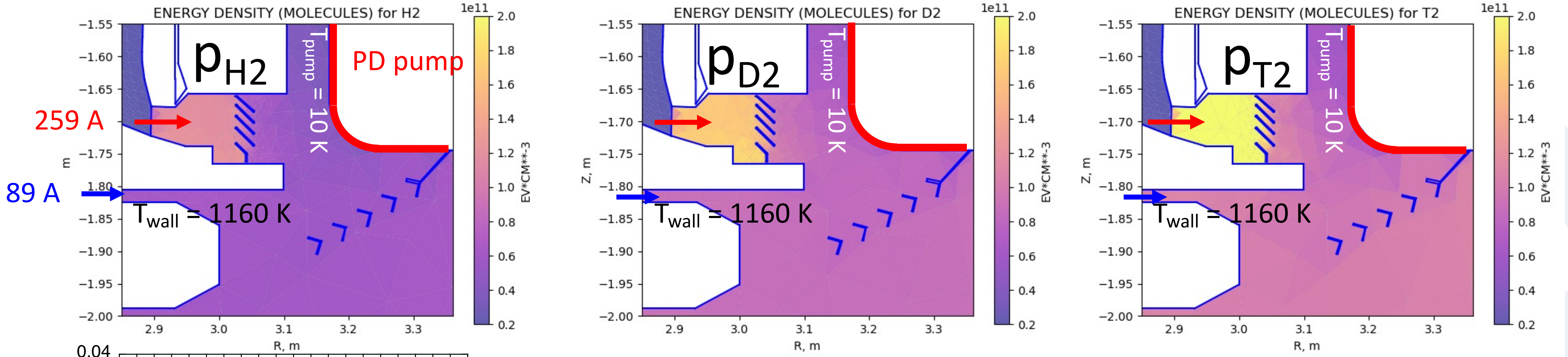


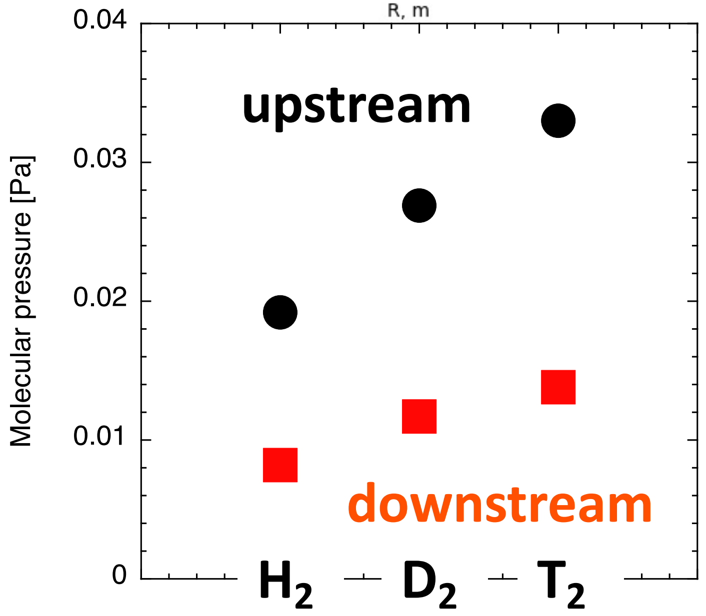
- Standalone EIRENE simulations of gas dynamics in JET sub-divertor (sealed-off at sub-div.) → impose gas influx at divertor/sub-divertor partition based on previous

Ability to pump

Raising isotope mass from H2 to D2 and T2 reduces thermal velocity, thus molecular pressure by factor square root of mass upstream of louvres

Aaron Vesa, Timo Kiviniemi





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JET and AUG neutral dynamics using EIRENE, isotope effect

Explore pressure range, sub-divertor geometry → effective pumping speed

→ Aaron Vesa, M.Sc. thesis 2025 → EPS 2025

Points for discussion

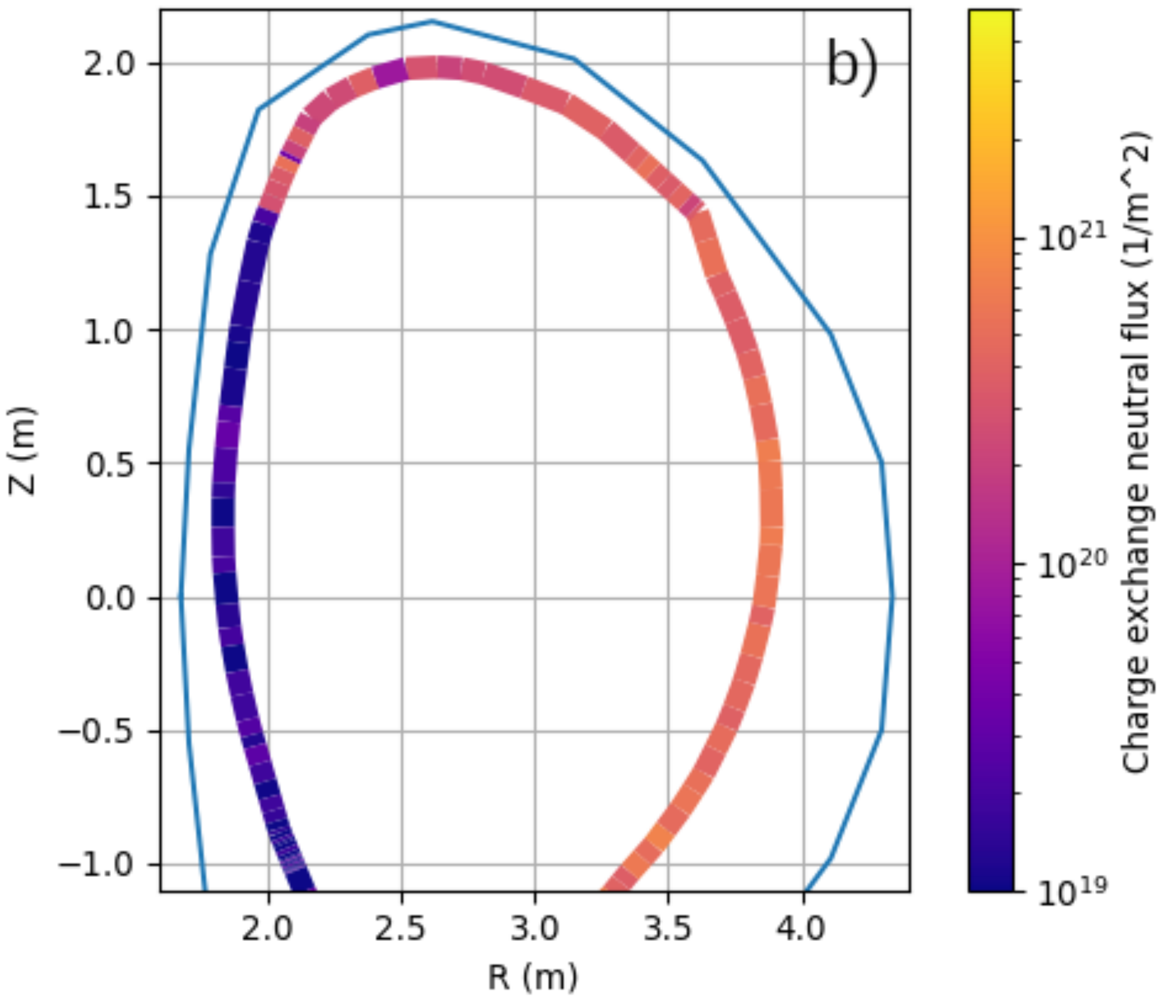
- Further characterisation of JET H-mode scenarios for W erosion and migration:
  - H, D, T, DT isotope effect
  - (Characterisation, impact of) scrape-off layer flows
  - Re-erosion and re-deposition of W
  - Impact of ELMs
- JET He plasma → erosion studies
- Conversion of D_2 Fulcher band emission to D_2 influxes for dedicated GIM 14 injection experiment using SOLPS-ITER/EDGE2D-EIRENE and EIRENE (JET experiment B18-17)
- …

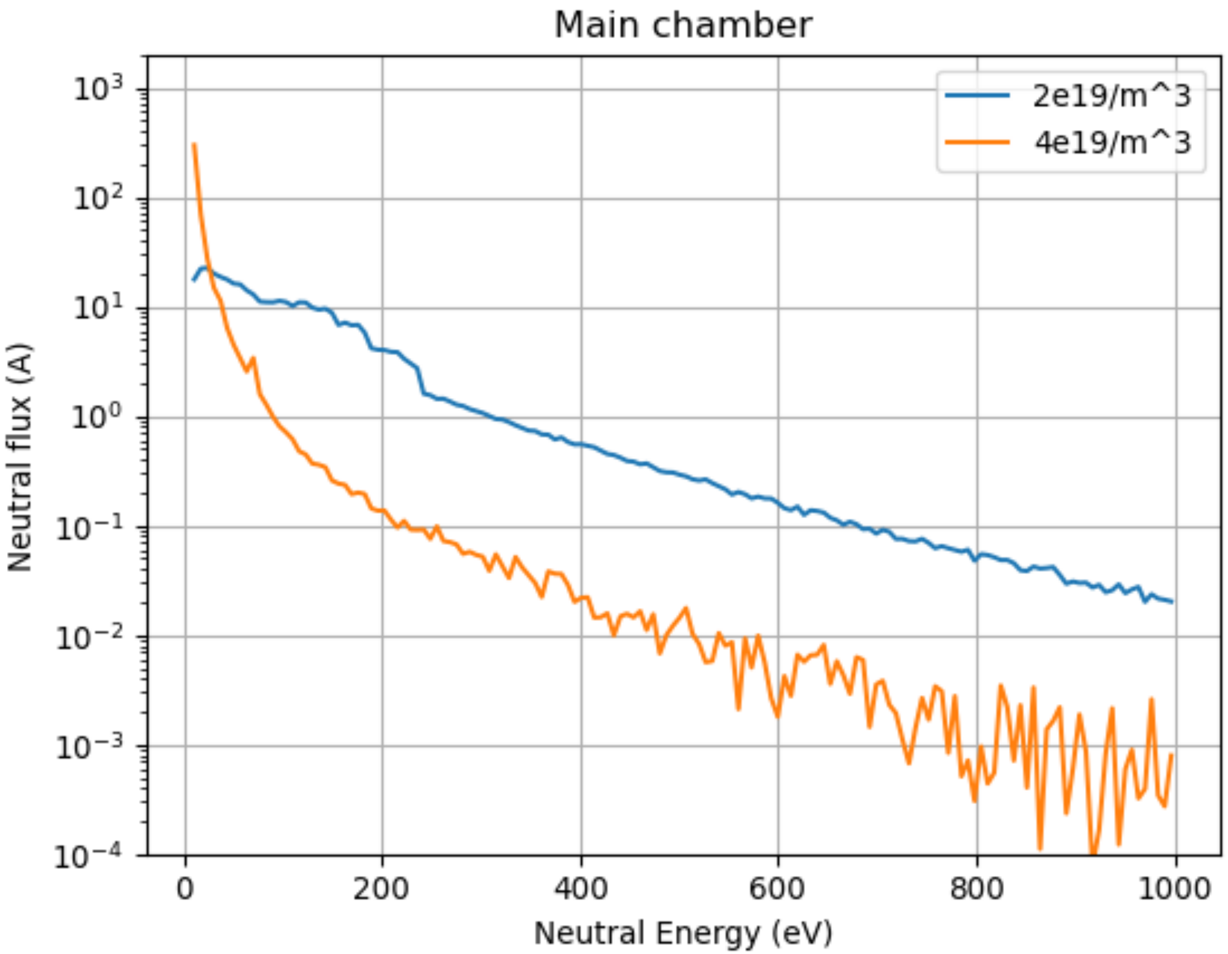
Backup slides

Energy-resolved CX fluxes to the wall predicted by EIRENE: raising the core plasma density by 2x, EIRENE predicts up to 50x lower high-energy CX atoms

EIRENE predicted CX total atomic flux to vacuum vessel wall

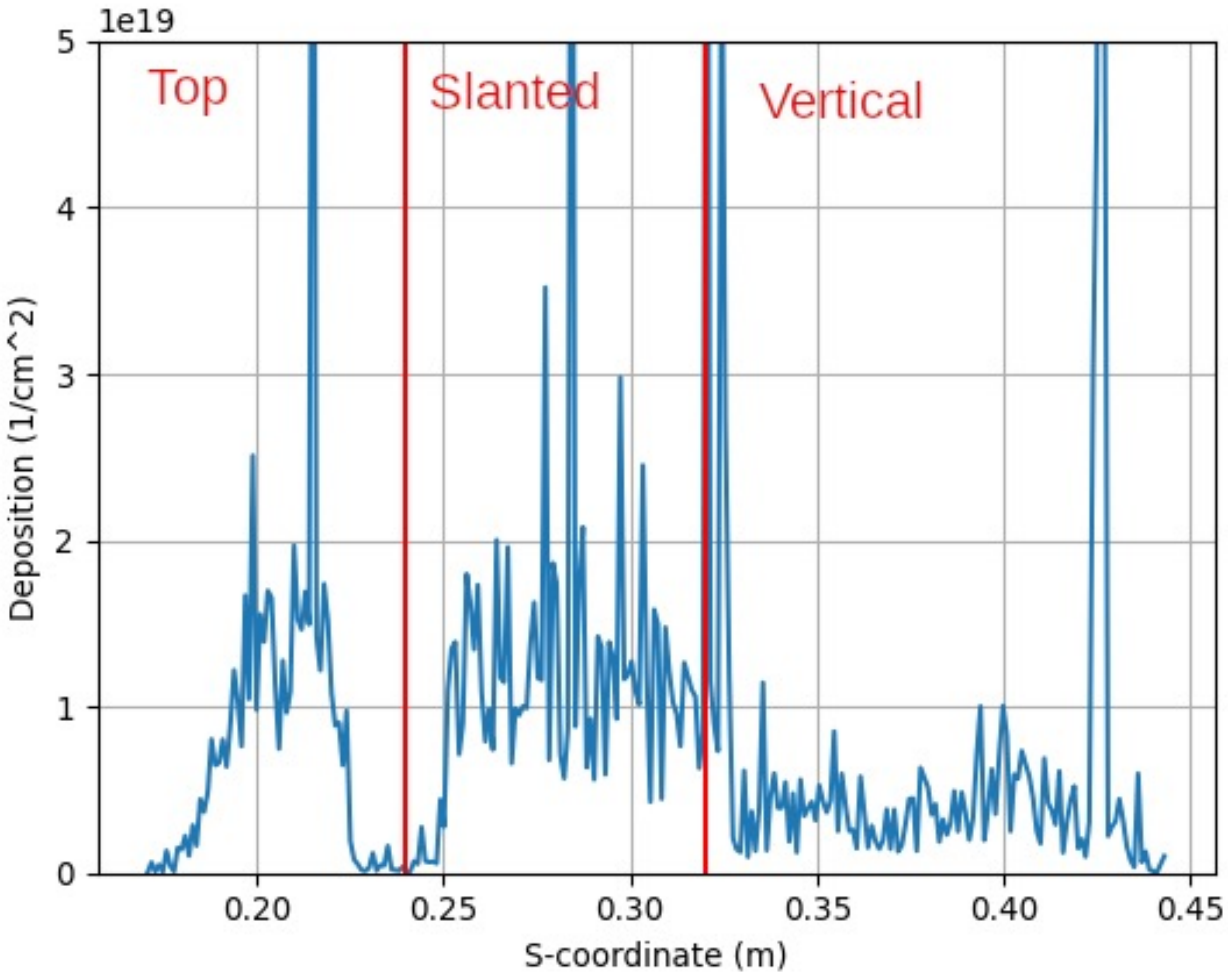
Pyry Virtanen et al., PSI 2024 → NME 2025





ERO2.0 predicted gross deposition of Ni onto tile 1 is of the order of 1019/cm2, of the same order of magnitude as measured post-mortem

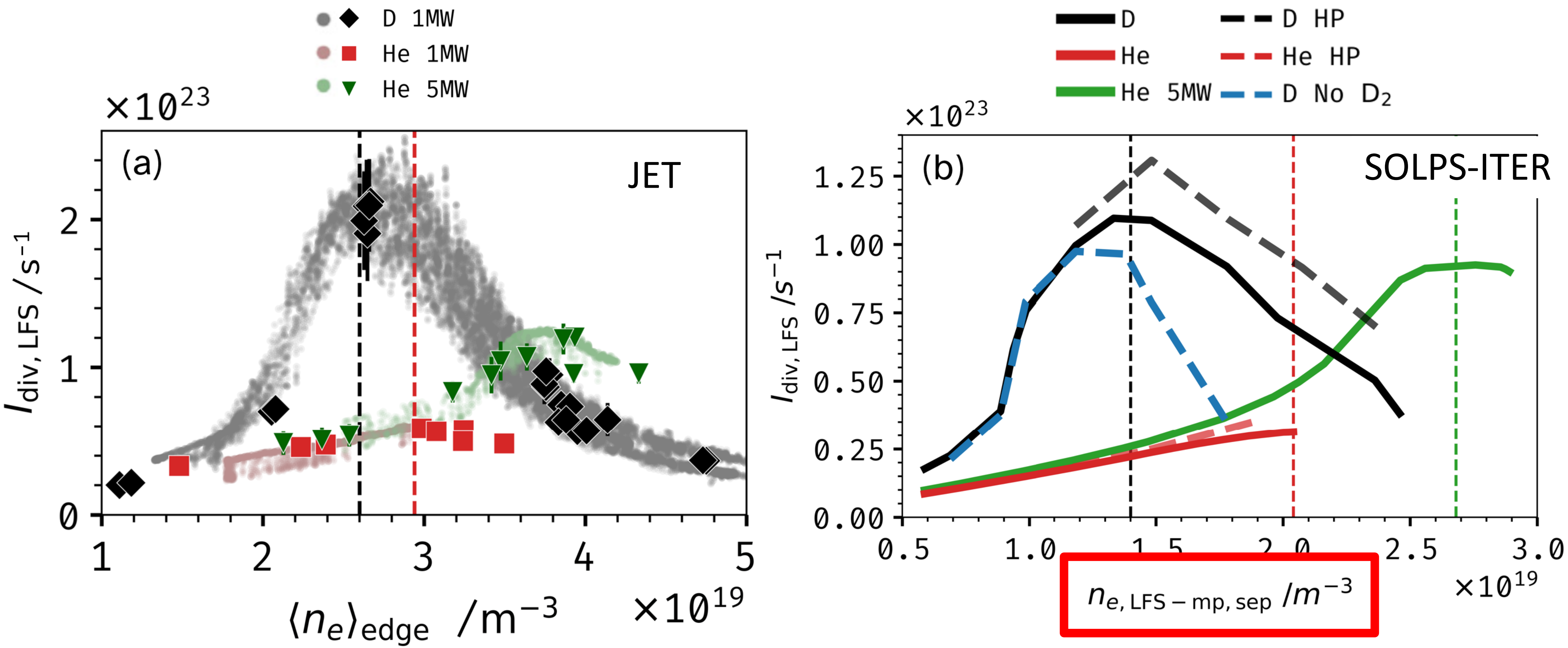
Pyry Virtanen et al., PSI 2024 → NME 2025



- EDGE2D-EIRENE to background plasmas (including flow) and CX atomic fluxes
- ERO2.0 to predict nickel erosion, transport and deposition in the JET-ITER-like-wall through years 2011-2016
- Primary erosion location on the vacuum vessel wall is predicted to be on the LFS near the midplane
- Nickel is transported onto the HFS divertor top ⇒ single deposition (no re-erosion yet assumed)

SOLPS-ITER simulations of He vs D plasmas qualitatively consistent with measurements (70% lower $I_{div,LFS}$ in He) due to 1.5-3x higher eff. ionisation cost

David Rees → PSI 2026



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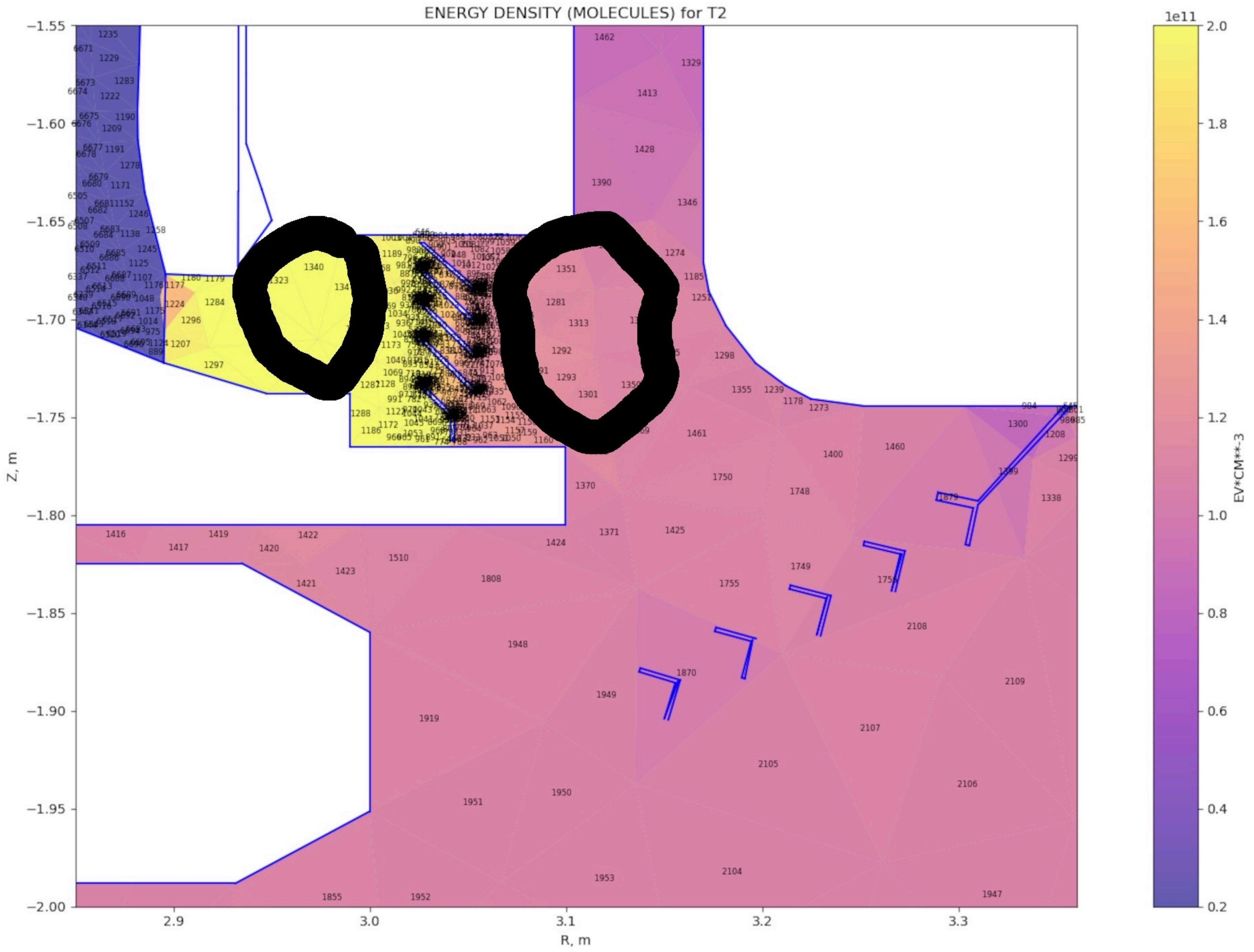
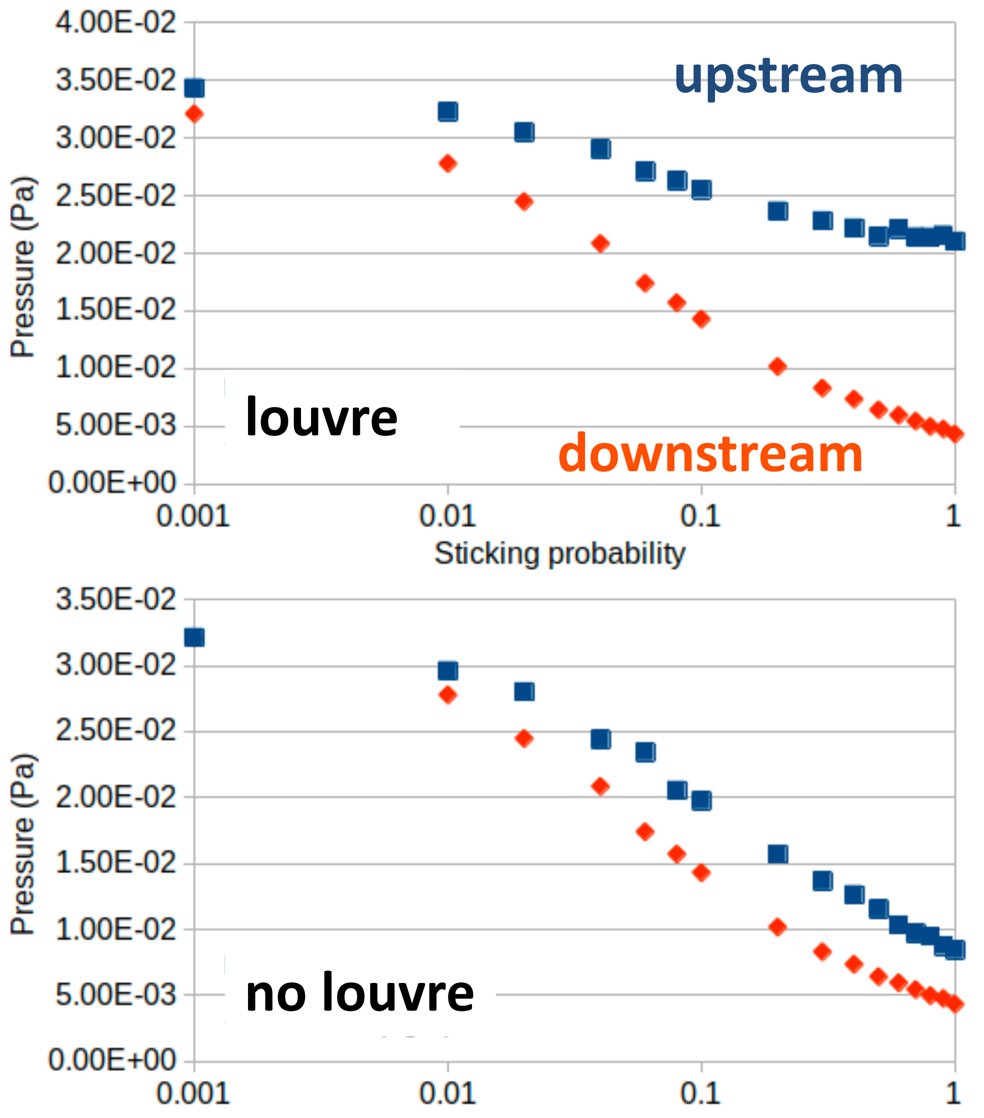
Aaron Vesa, Timo Kiviniemi





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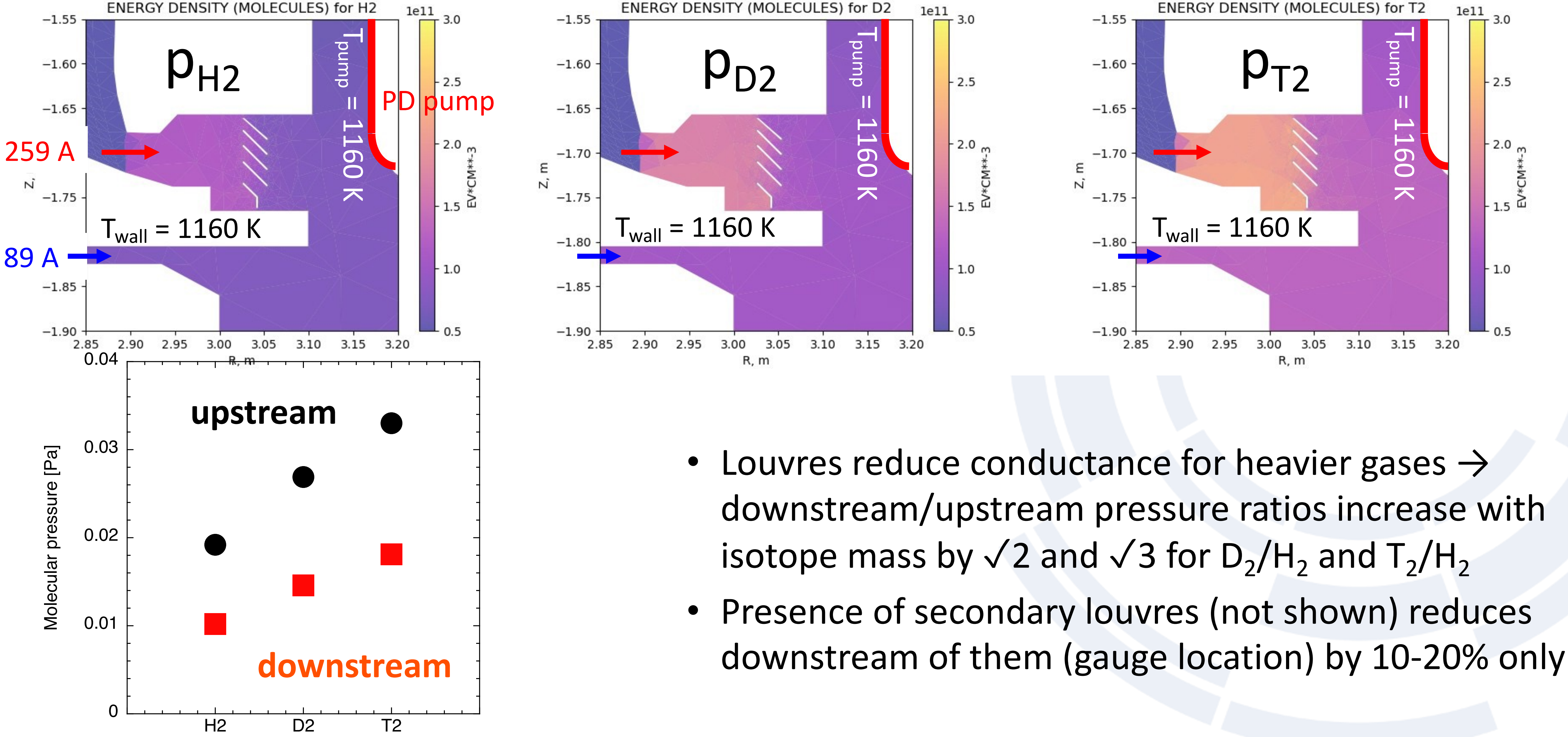

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- Presence of secondary louvres (not shown) reduces downstream of them (gauge location) by 10-20% only

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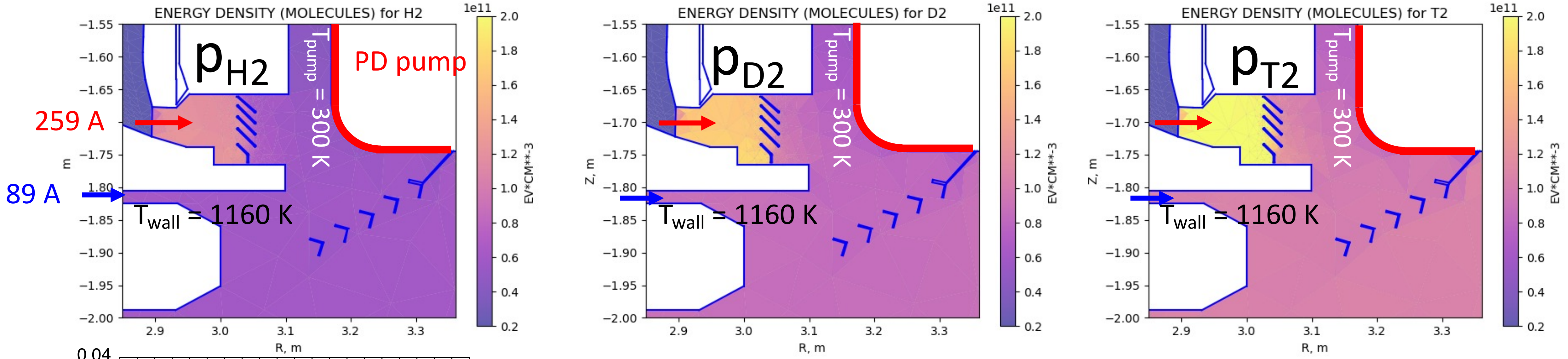

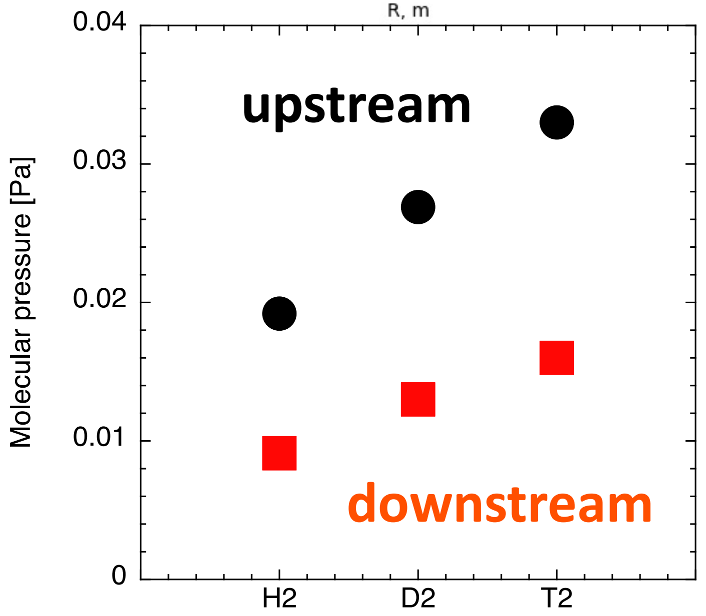

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