EUROfusion

Validation of SOLPS-ITER and EDGE2D-EIRENE simulations for H, D, and T JET ITER-like wall low-confinement mode plasmas

N. Horsten, M. Groth, V.-P. Rikala, B. Lomanowski, A.G. Meigs, S. Aleiferis, X. Bonnin, G. Corrigan, W. Dekeyser, R. Futtersack, D. Harting, D. Reiter, V. Solokha, B. Thomas, S. Van den Kerkhof, N. Vervloesem, and JET Contributors

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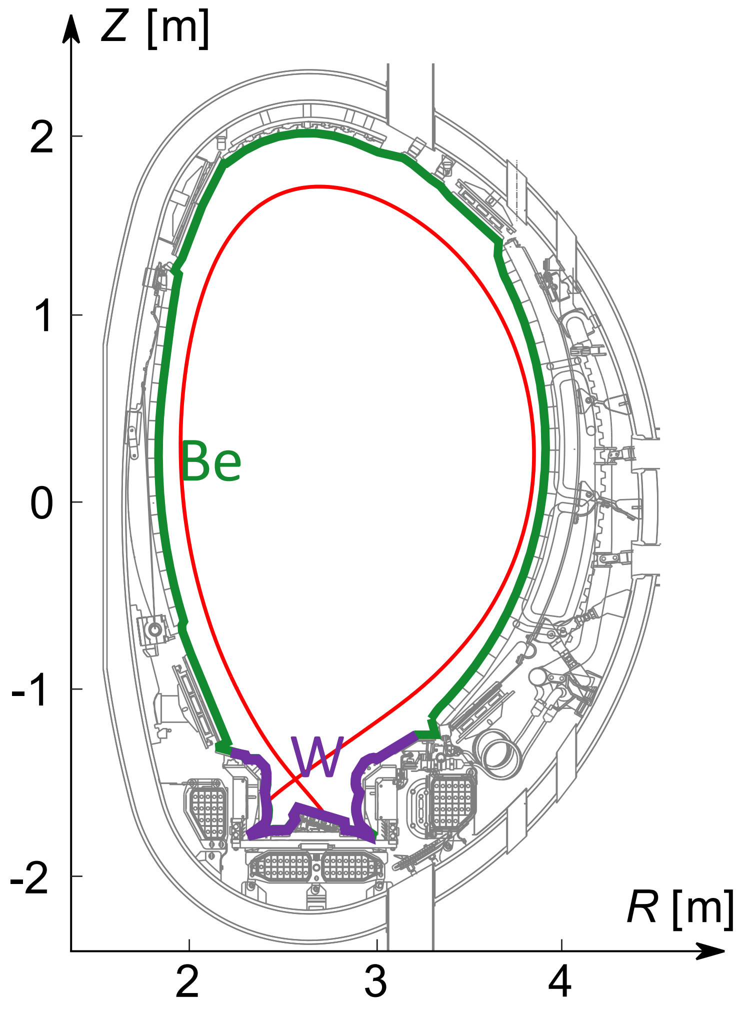
Characterization of LFS divertor conditions for JET-ILW L-mode plasmas with different isotopes



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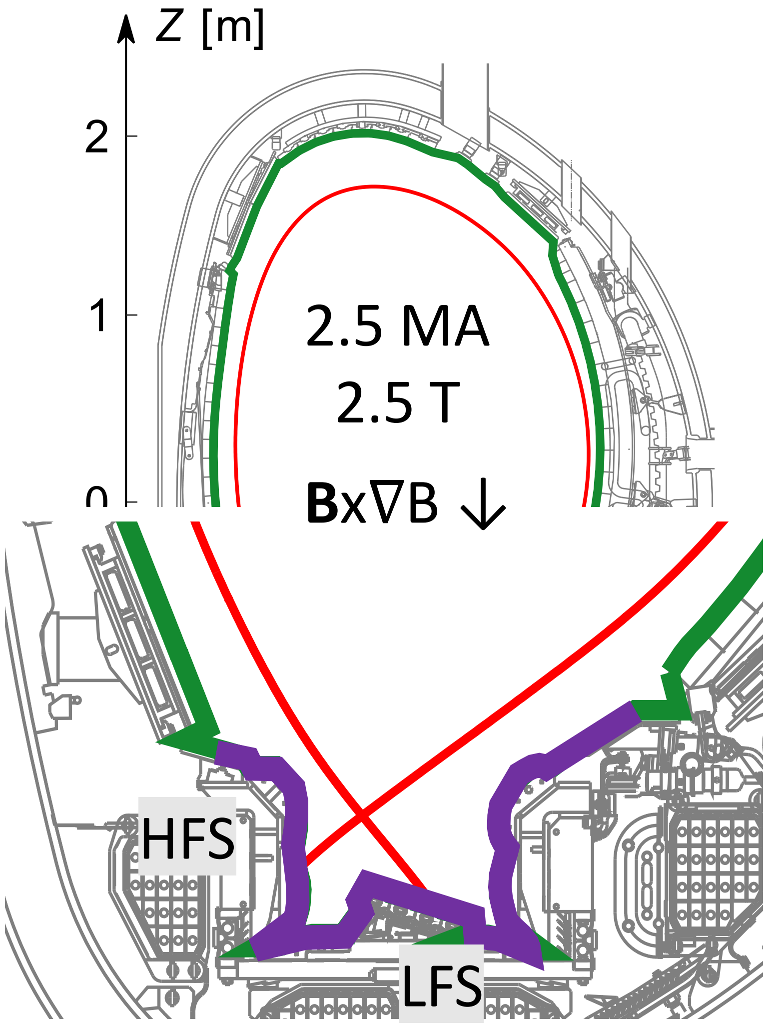

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  [M. Groth et al., NF **53** (2013)]

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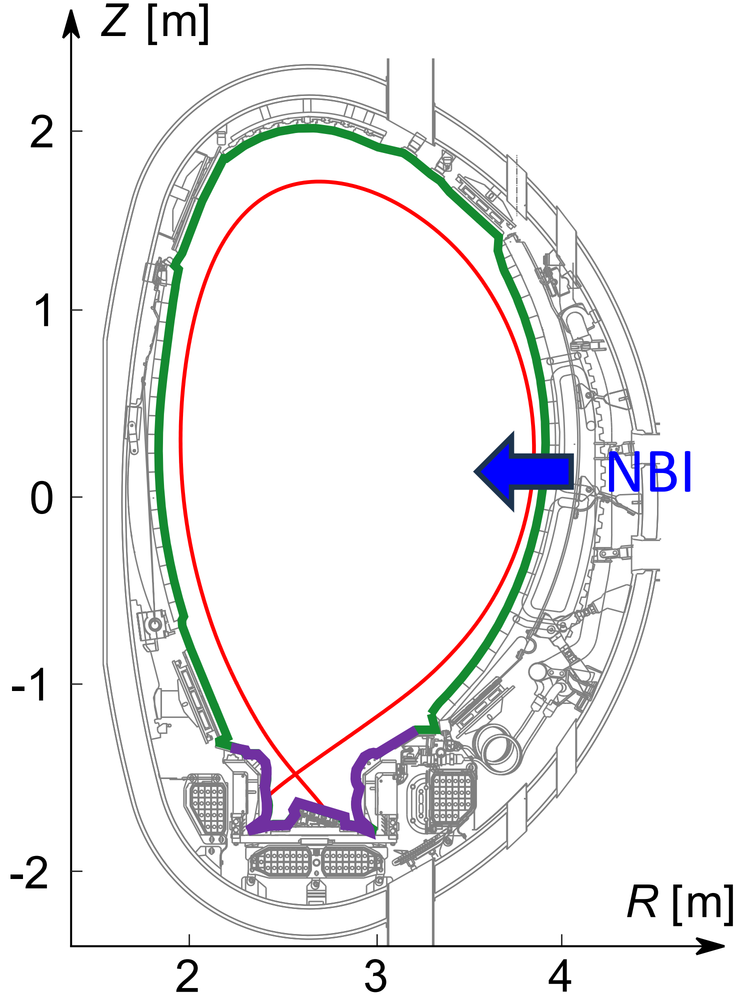

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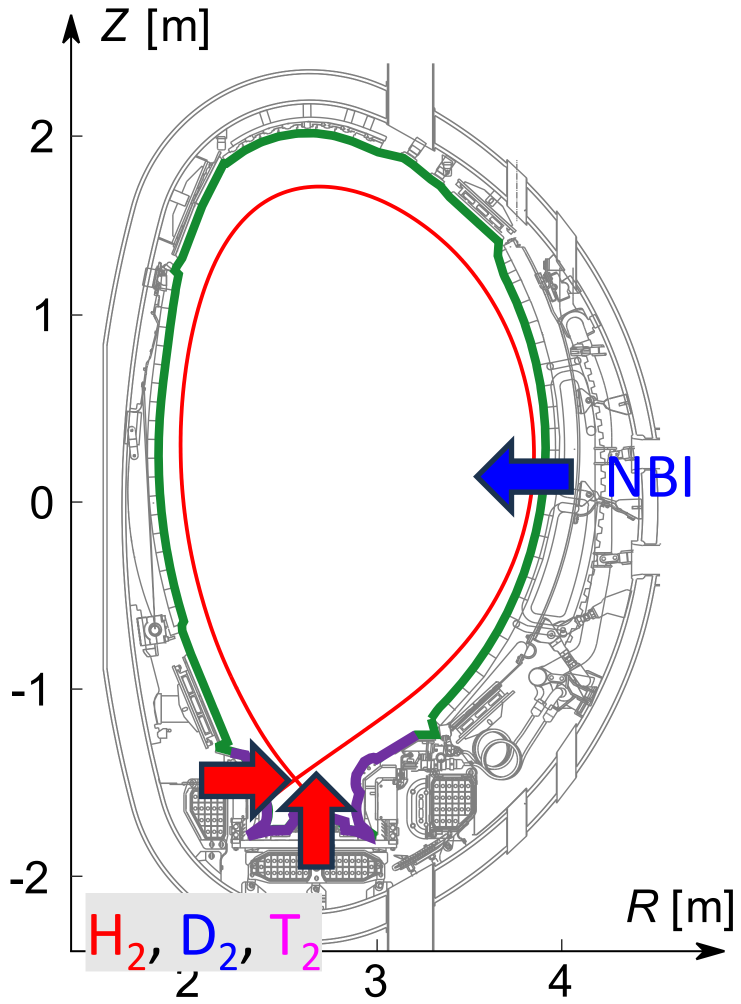

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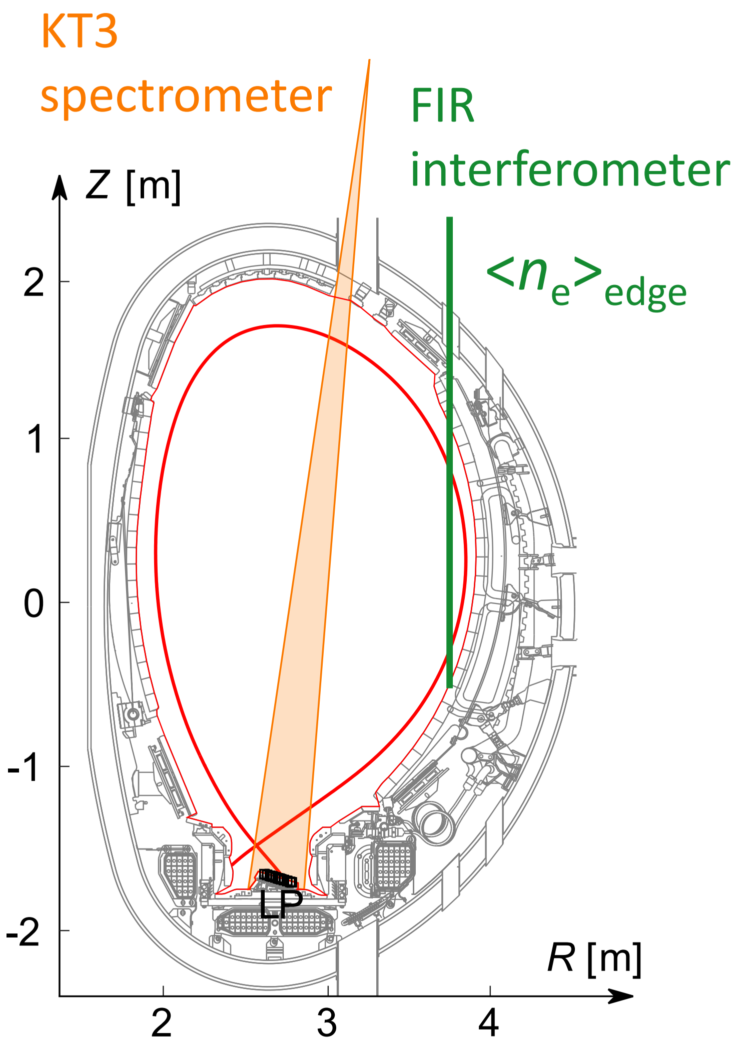

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- **Experimental validation of simulation results**
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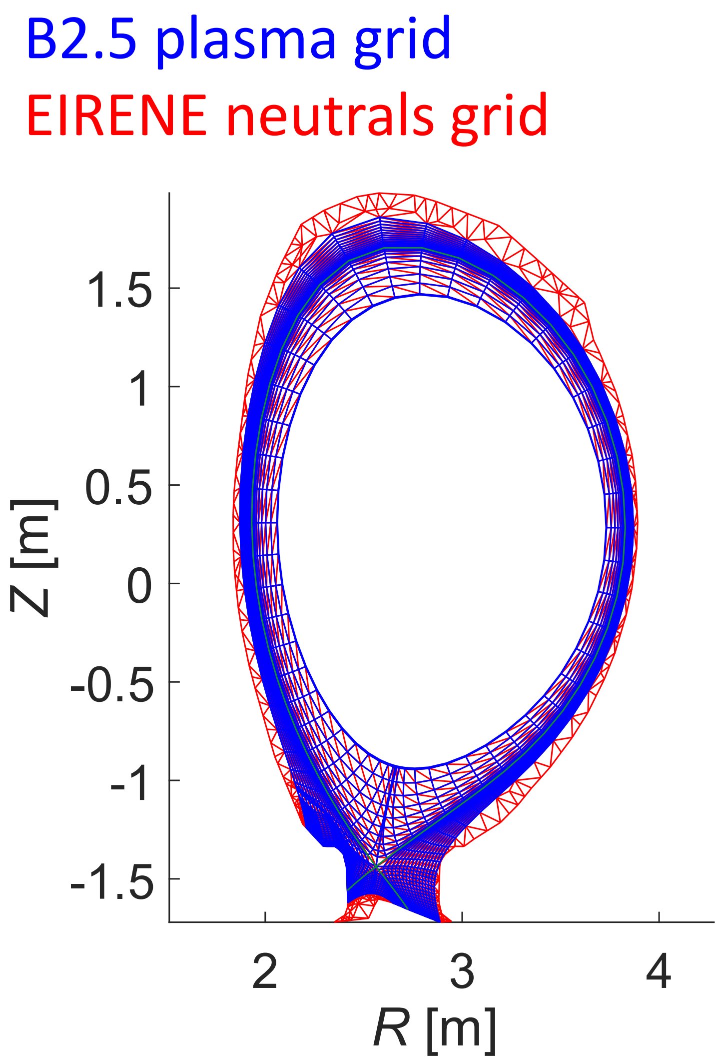

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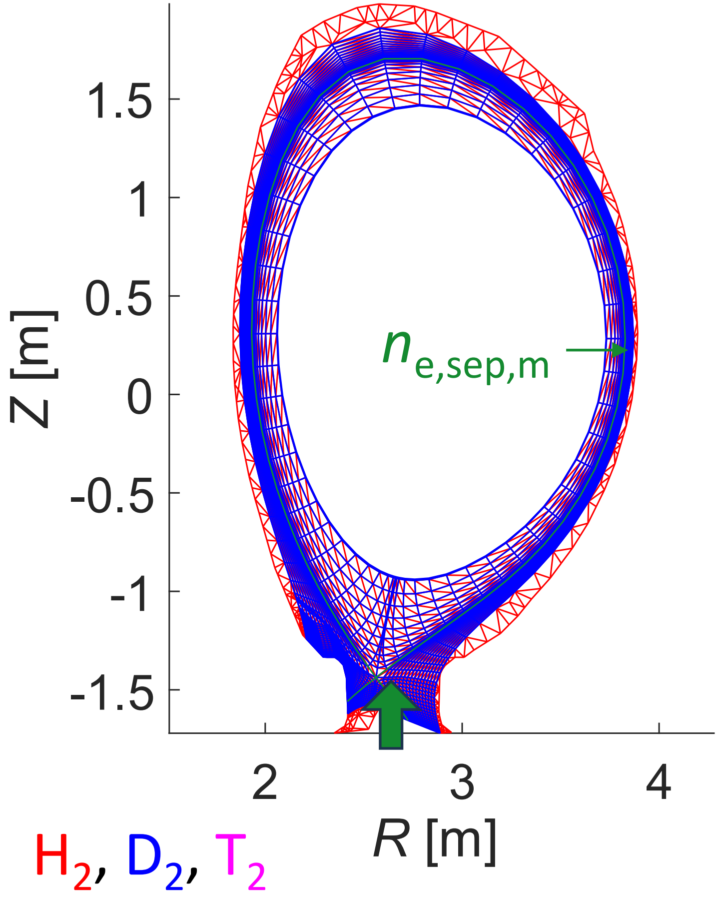

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  Initial assumption: $\langle n_e \rangle_{edge} = 2 \times n_{e,sep,m}$
  [M. Groth et al., JNM **438** (2013)]
  ➔ $\langle n_e \rangle_{edge} - n_{e,sep,m}$ relationship to be re-assessed

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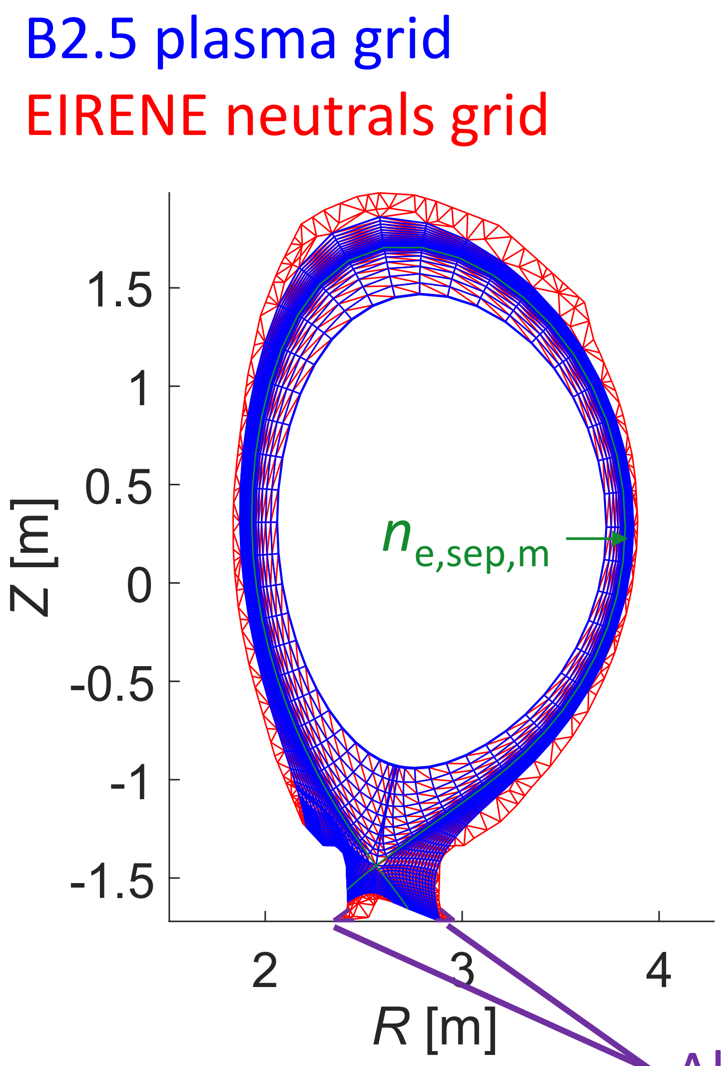

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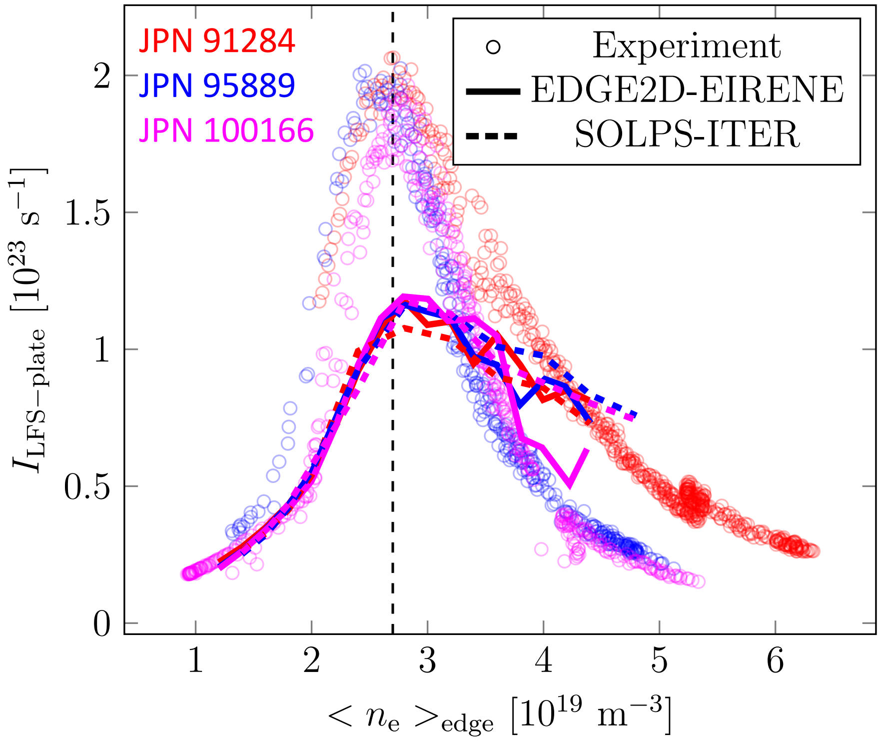
Simulations also predict an isotope-independent onset of detachment

H D T



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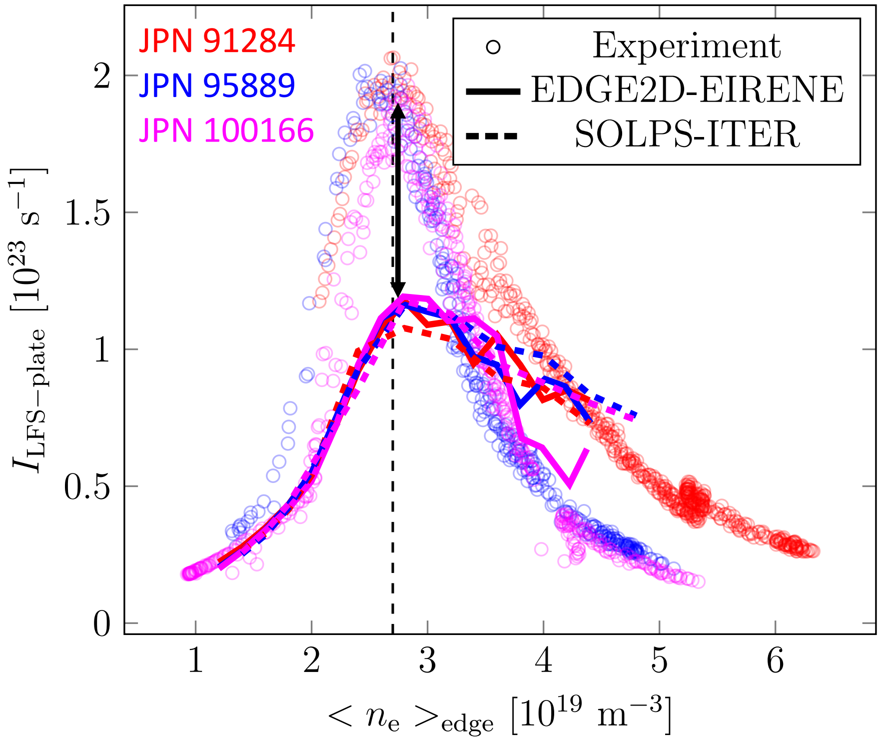

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1. Peak $I_{\text{LFS-plate}}$ lower in simulations

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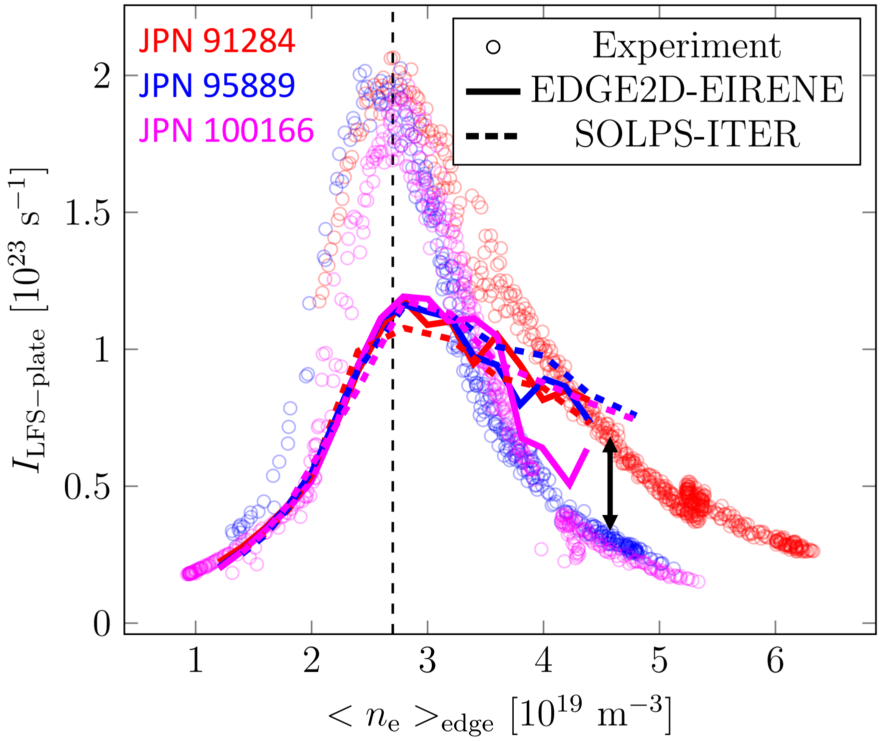

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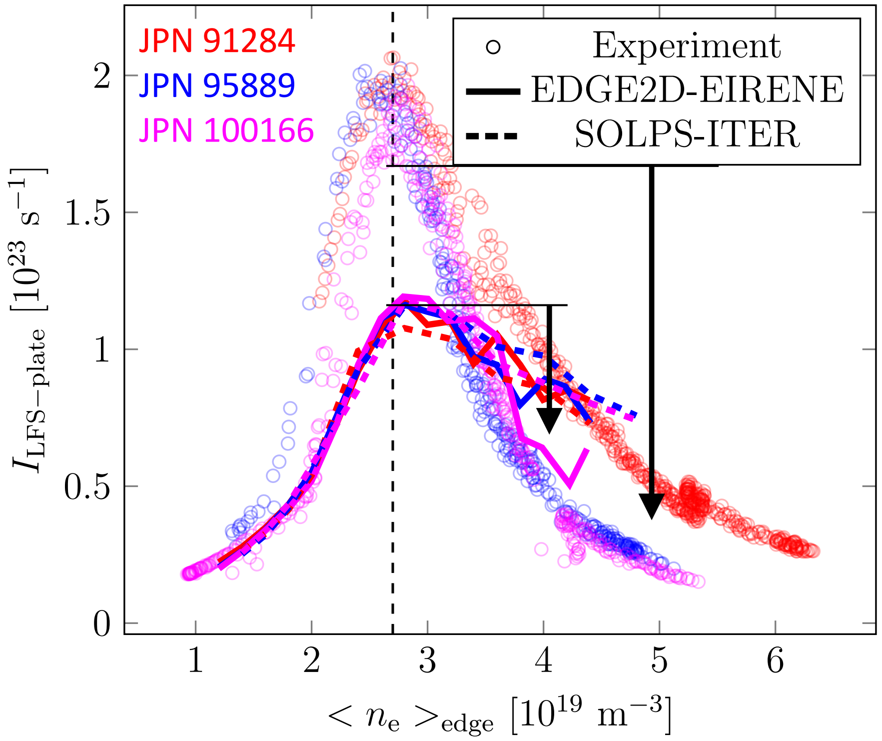

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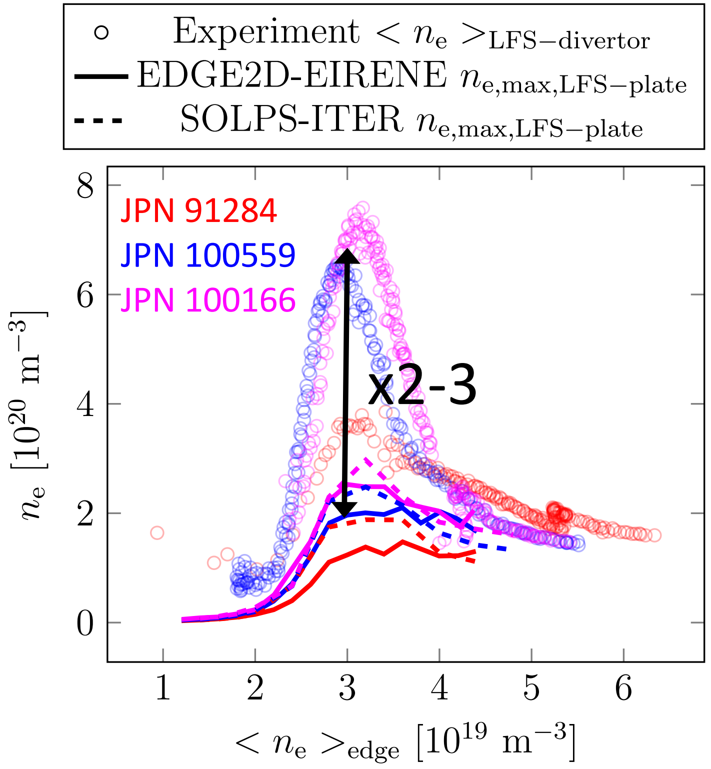
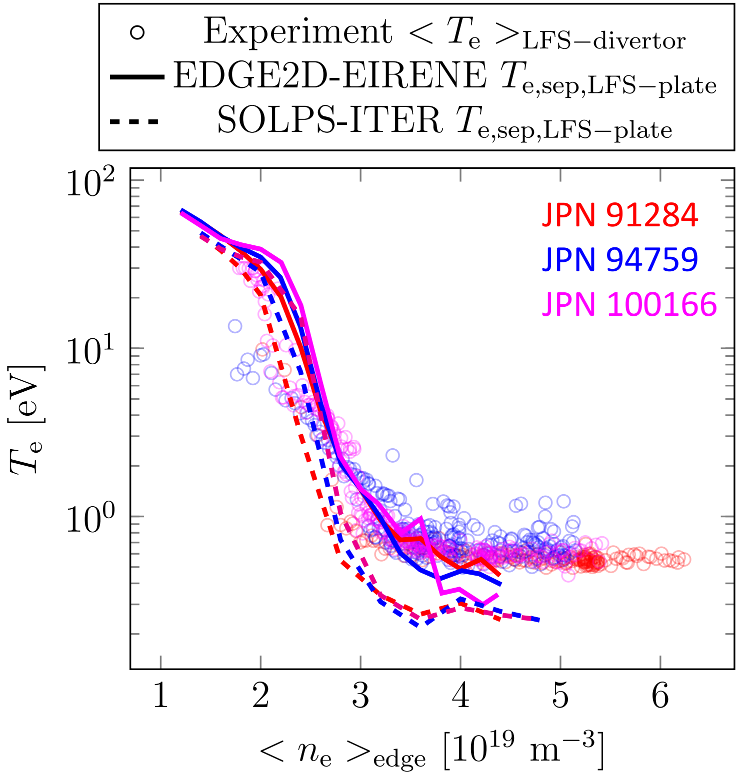
Several simulation-experiment discrepancies:

1. Peak $I_{LFS\text{-}plate}$ lower in simulations
2. No clear difference between isotopes in simulations
3. Steeper drop of $I_{LFS\text{-}plate}$ for detachment in experiments

Peak density at LFS plate in simulations is already a factor 2-3 lower than the line-averaged measured density

H D T





Max $n_e \sim \sqrt{m}$ in both experiment and simulation

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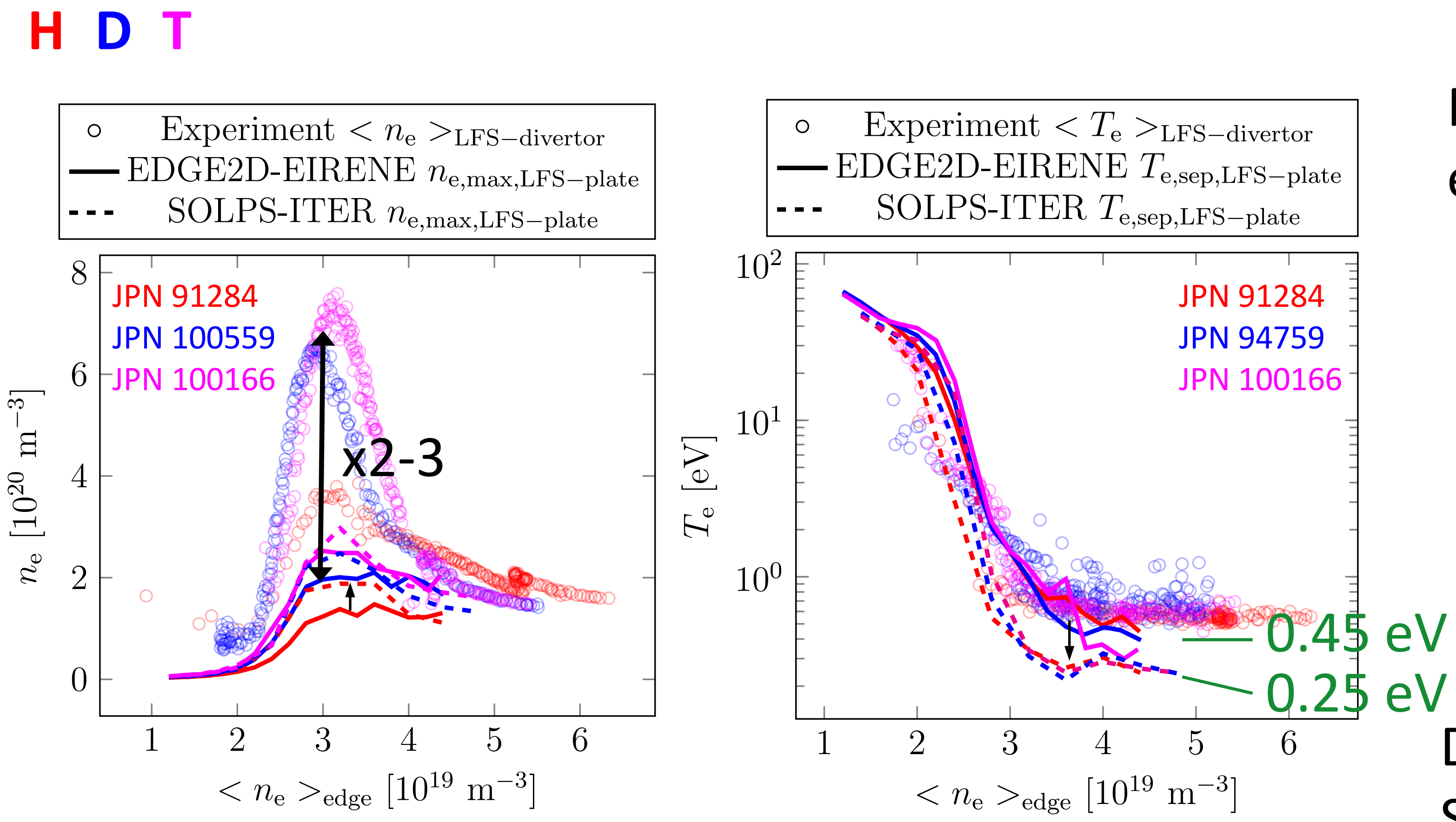

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Differences in sheath b.c.'s in SOLPS-ITER and EDGE2D-EIRENE

n_e (SOLPS) > n_e (E2D)

T_e (SOLPS) < T_e (E2D)

The line-averaged synthetic diagnostics further worsen the simulation-experiment discrepancies for n_e

Spectro. inferred n_e and T_e from simulation with PESDT-Cherab

[B. Lomanowski et al., NME **20** (2019); M. Carr, EPS (2017)]

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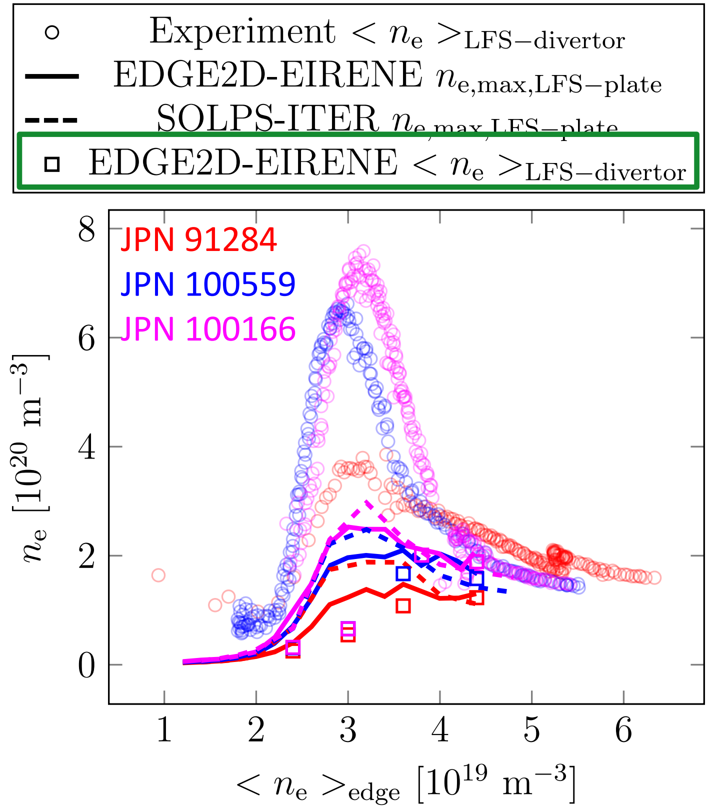

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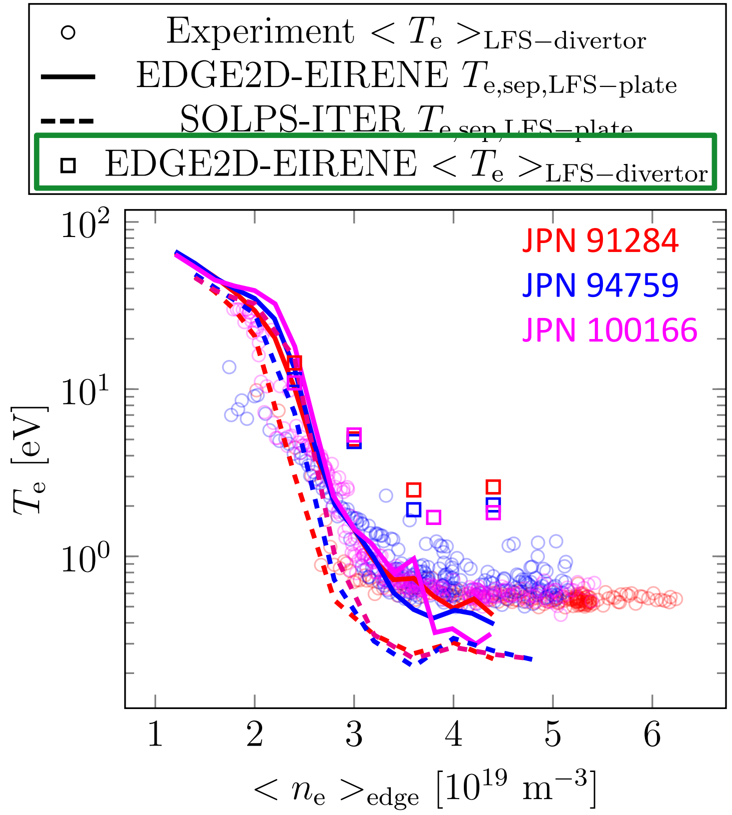

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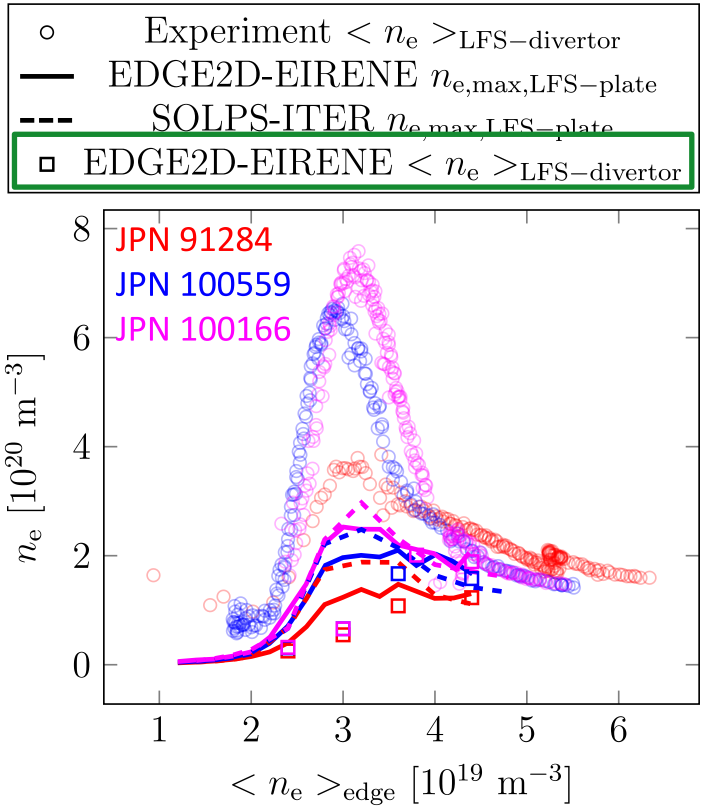

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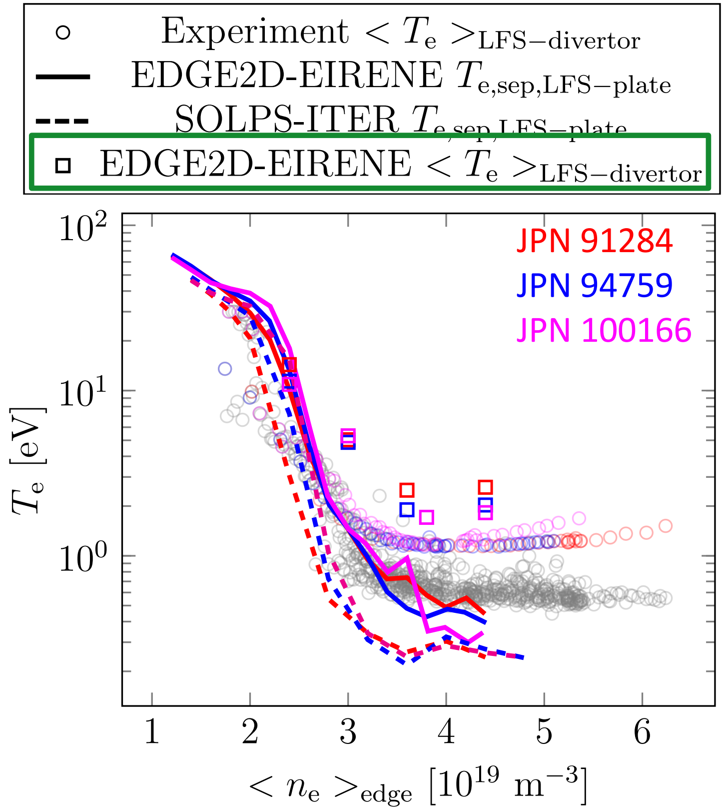

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T_e derived from differentiation of continuum emission between two wavelengths: increased T_e for 360-393 nm (incl. recombination edge)
[B. Lomanowski et al., PPCF **62** (2020)]

Differences in sheath b.c.'s in SOLPS-ITER and EDGE2D-EIRENE

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Still 25% underestimate of $I_{\text{LFS-plate,max}}$ in simulations with increased input power

Particle balance: $\Gamma_{\mathrm{w}} \approx S_{\mathrm{ion}} - S_{\mathrm{rec}}$

Energy balance: $Q_{\mathrm{w}} \approx \gamma T_{\mathrm{w}} \Gamma_{\mathrm{w}}$

$$\approx Q_{\mathrm{SOL}} - E_{\mathrm{ion}}^{\mathrm{eff}} S_{\mathrm{ion}} - Q_{\mathrm{imp}}$$

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Combining eqs.

[S. Krasheninnikov et al., PoP **23** (2016)]

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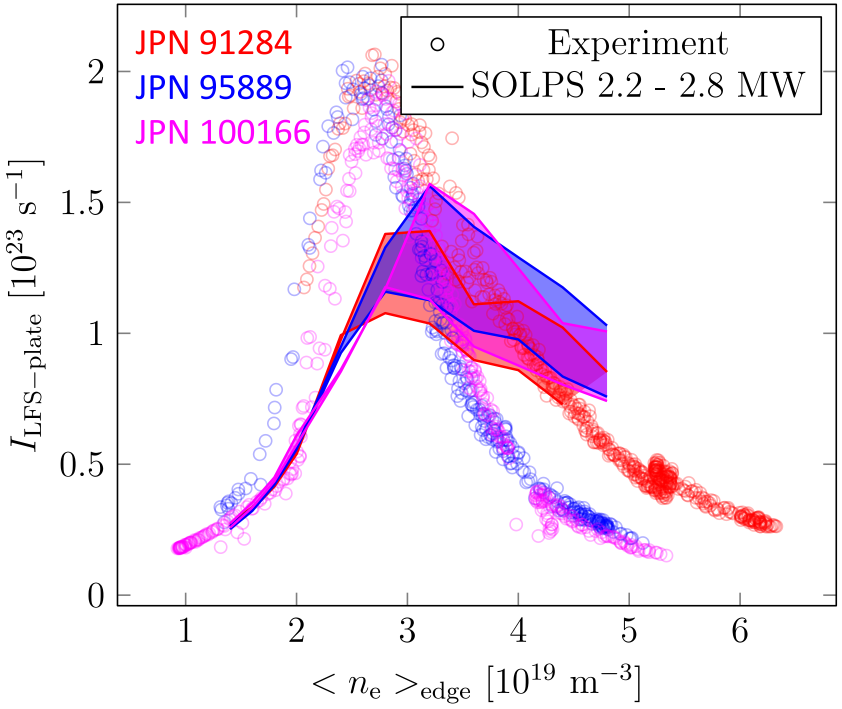

- Uncertainties on power due to increasing Q_Ohm and $Q_\mathrm{rad,core}$ for increasing $<n_e>_\mathrm{edge}$
- $T_\mathrm{e,sep,m}$: ≈60 eV → ≈70 eV at original onset of detachment when increasing power to 2.8 MW
- $<n_e>_\mathrm{edge} \approx 2 \times n_\mathrm{e,sep,m}$ needs revision to obtain correct pressure [R. Wilcox et al., PSI (2022)]
- Large sensitivity of simulation results w.r.t. $n_\mathrm{e,sep,m}$, $T_\mathrm{e,sep,m}$, and $T_\mathrm{i,sep,m}$

Peak $I_{\text{LFS-plate}}$ increases with 65% when using fully Lyman-opaque ionization rate coefficients

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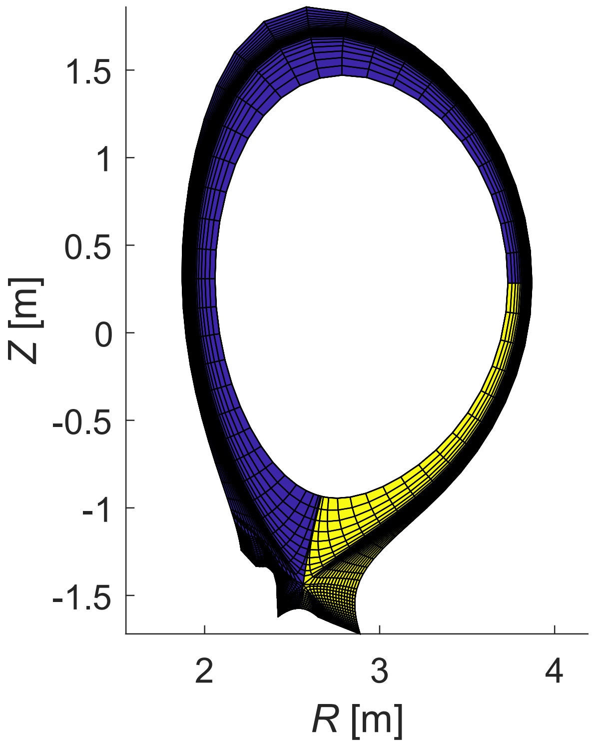
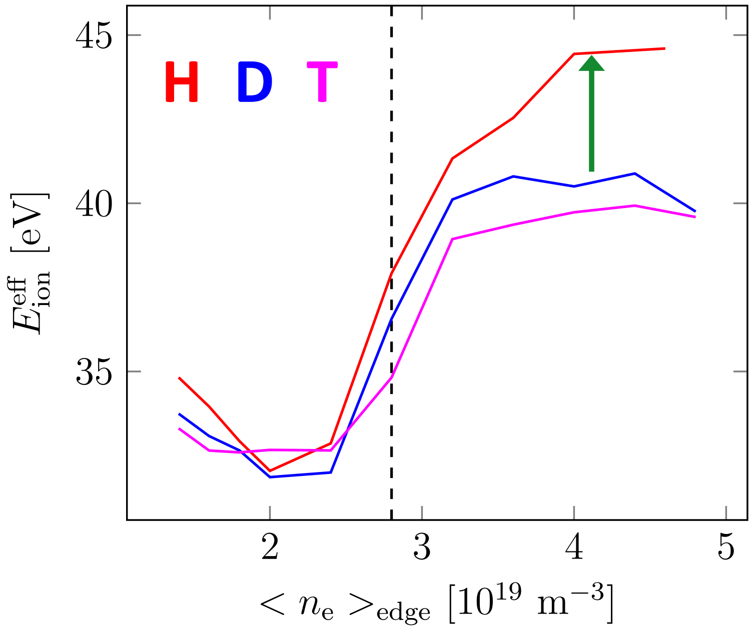


Increased power loss due to molecular processes for H



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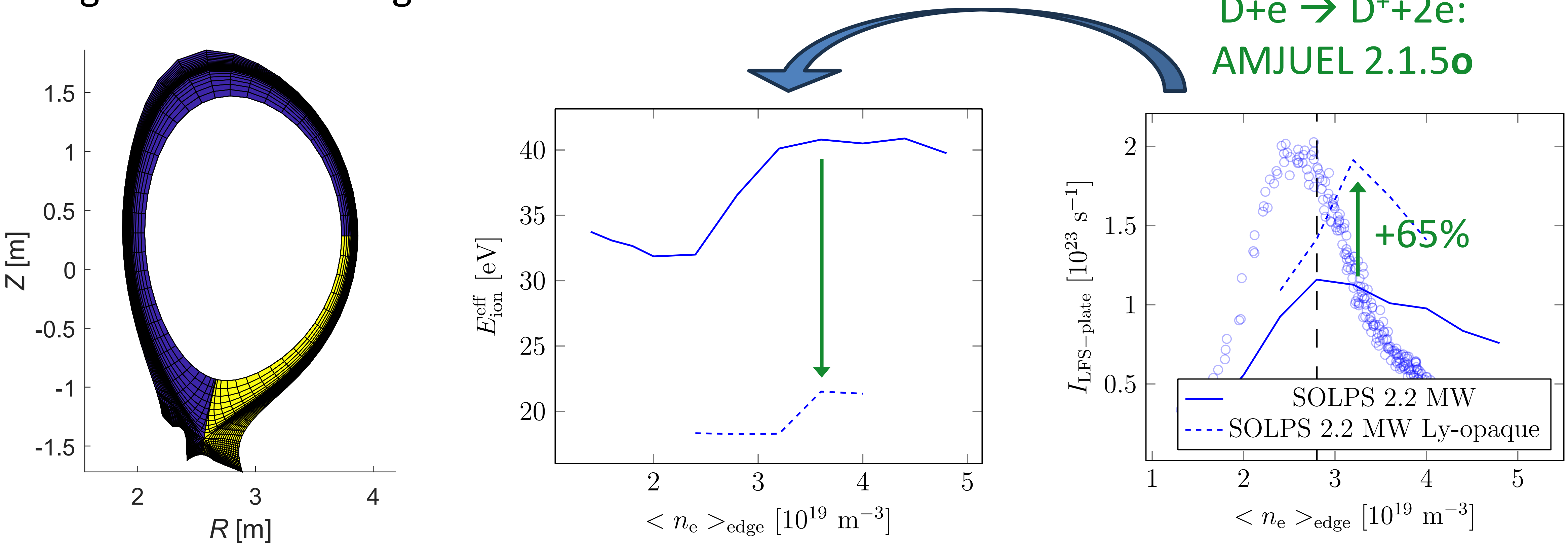
D+e → D$^+$+2e: AMJUEL 2.1.5**o**



Experiments and simulations indicate more than 60% Lyman reabsorption for JET-ILW high-recycling plasmas

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- Experimental evidence for JET-ILW [B. Lomanowski et al., PPCF **62** (2020); J. Karhunen et al., submitted to NME]

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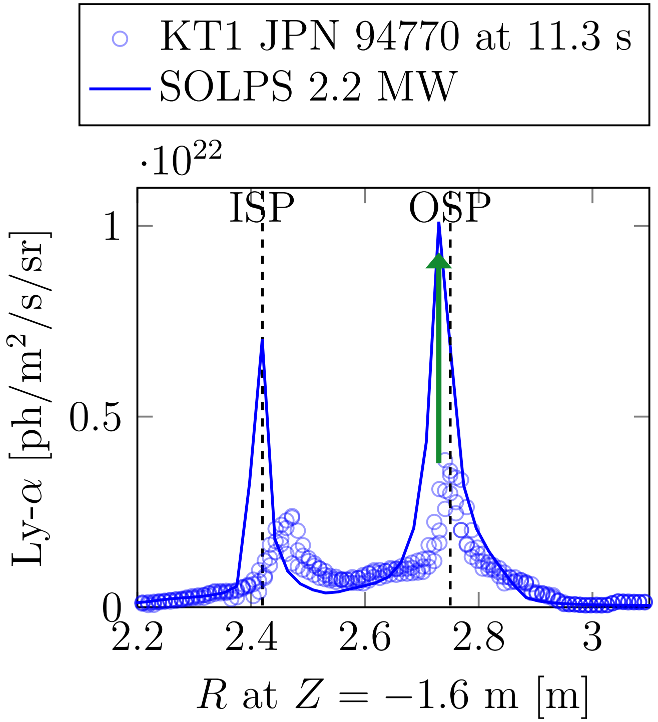

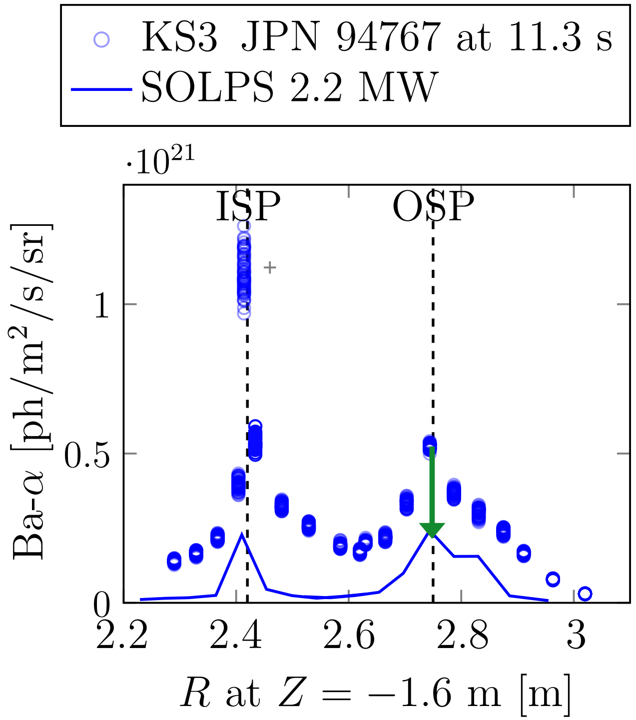

At onset of detachment, simulations overestimate Ly-α and underestimate Ba-α [N. Horsten et al., NME **33** (2022)]

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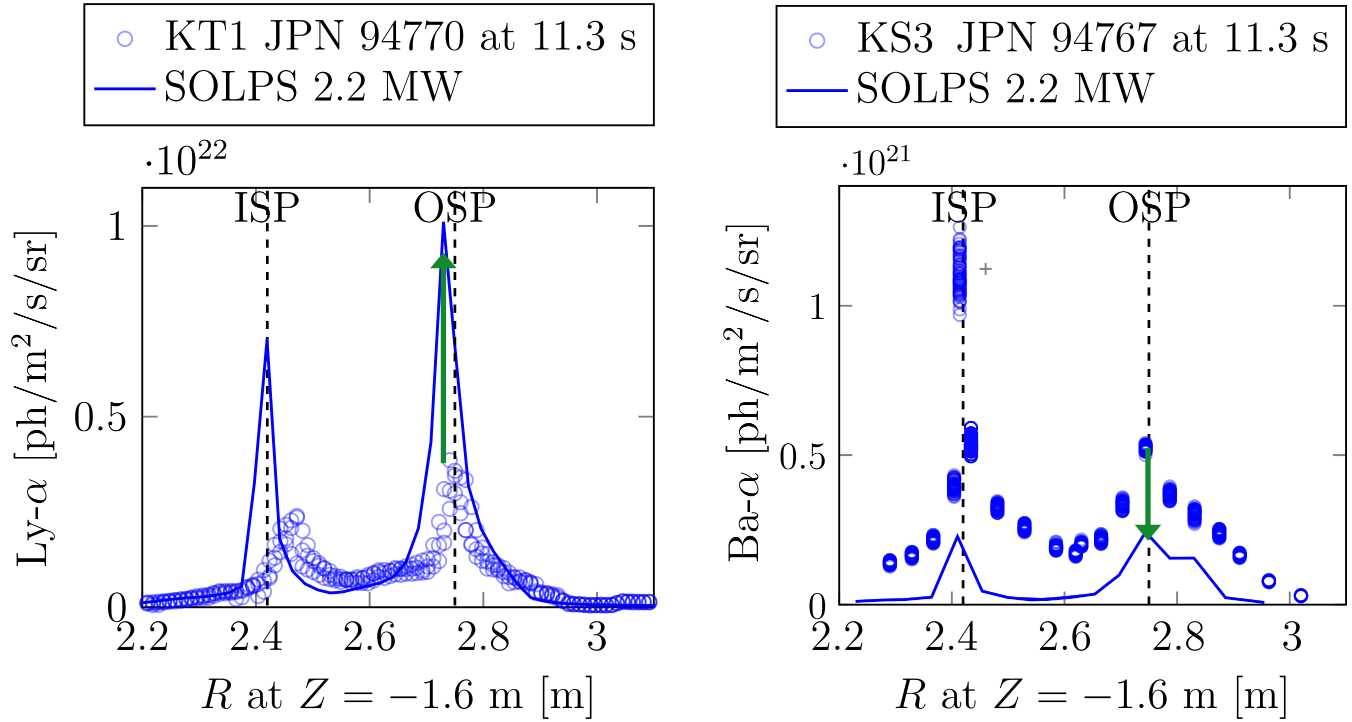

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Need for coupled plasma-neutral-**photon** simulations!
[R. Chandra et al., NME **41** (2024)]

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Net recombination source is similar for H, D, and T

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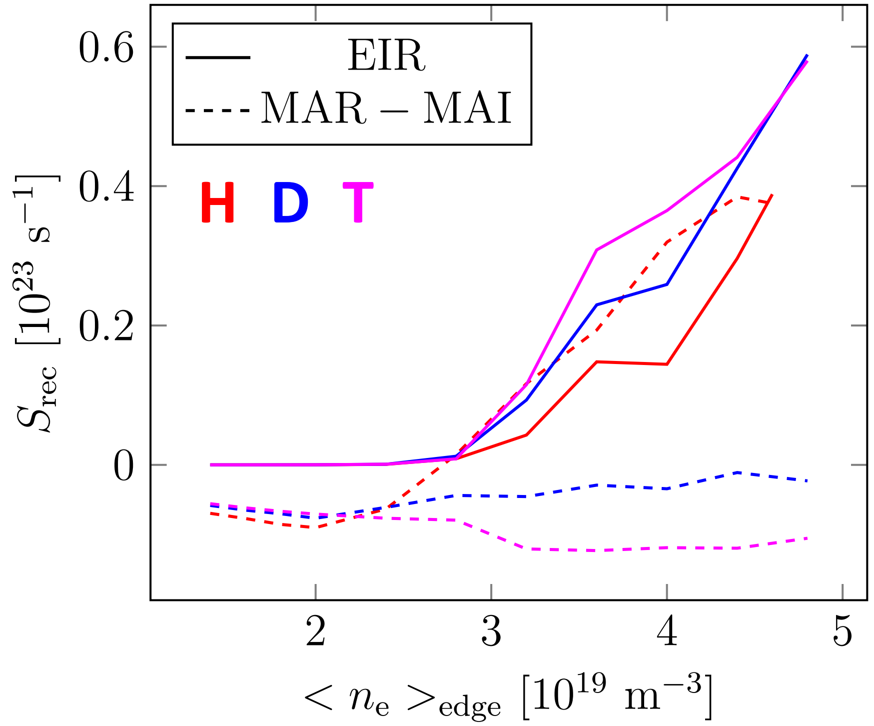
SOLPS-ITER, 2.2 MW



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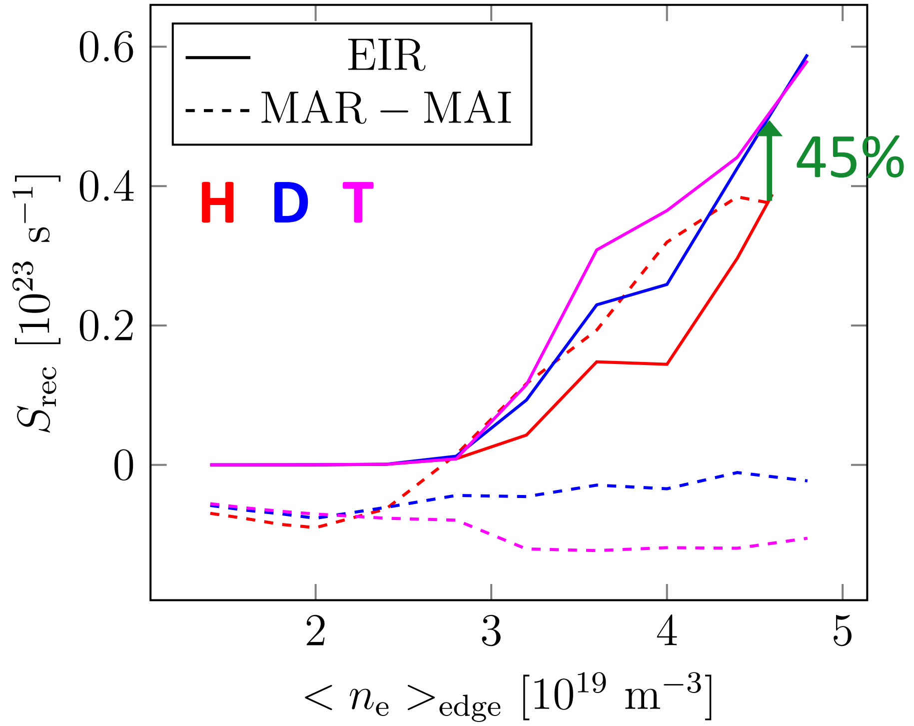
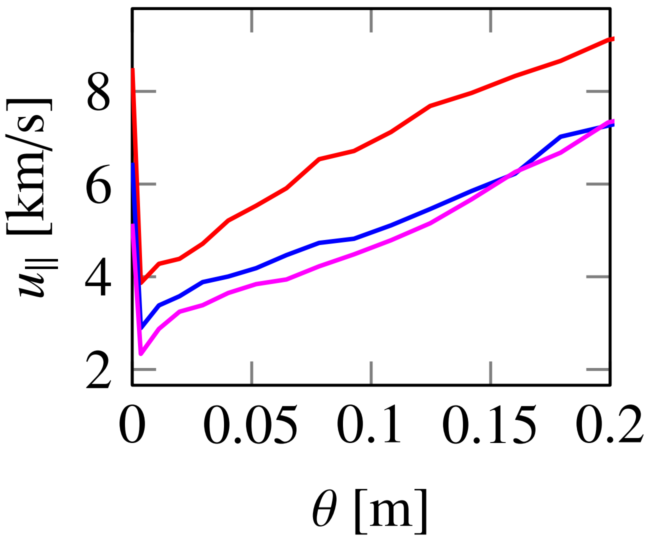


- 45% increase in electron-ion recombination (EIR) for D/T plasmas compared to H plasmas

Velocity ~ $1/\sqrt{m}$ ➔ more time to recombine for heavier species



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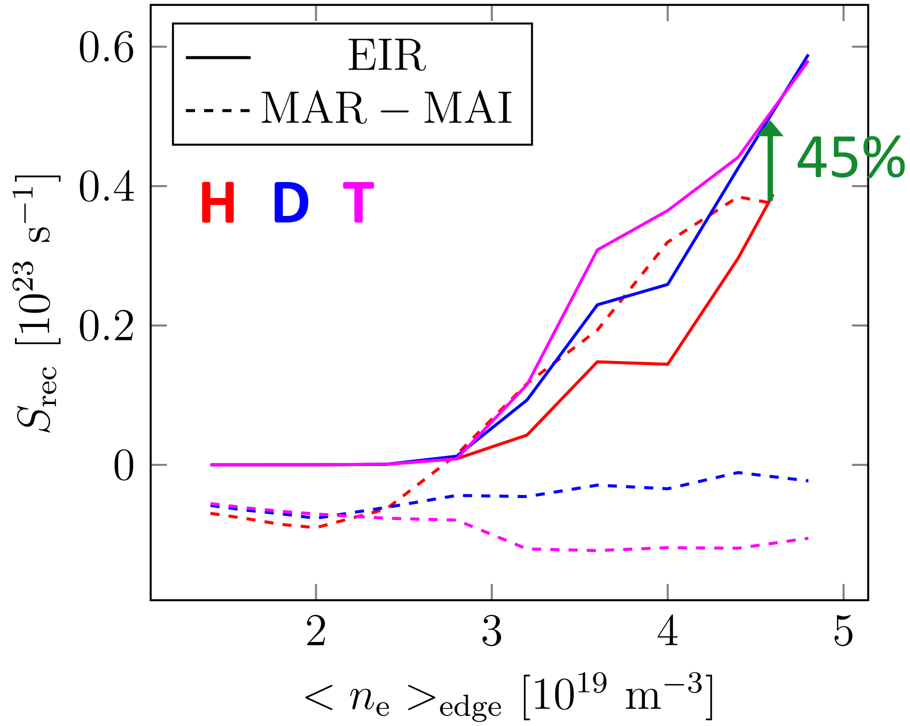

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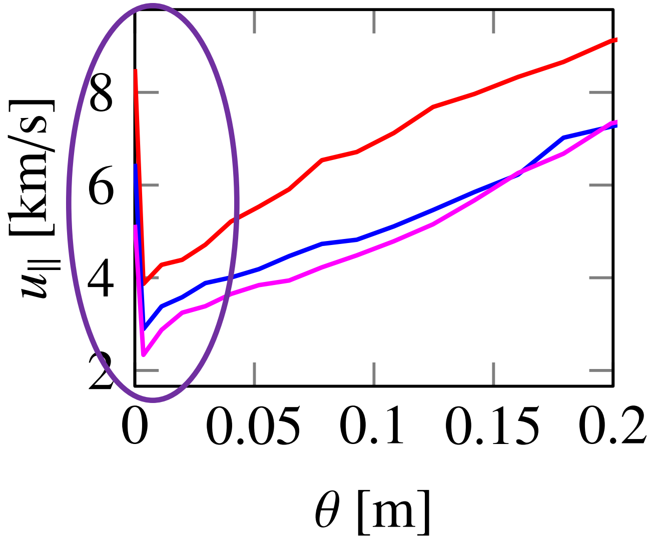

Revision of sheath b.c.'s needed
[D. Tskhakaya, D. Moulton]

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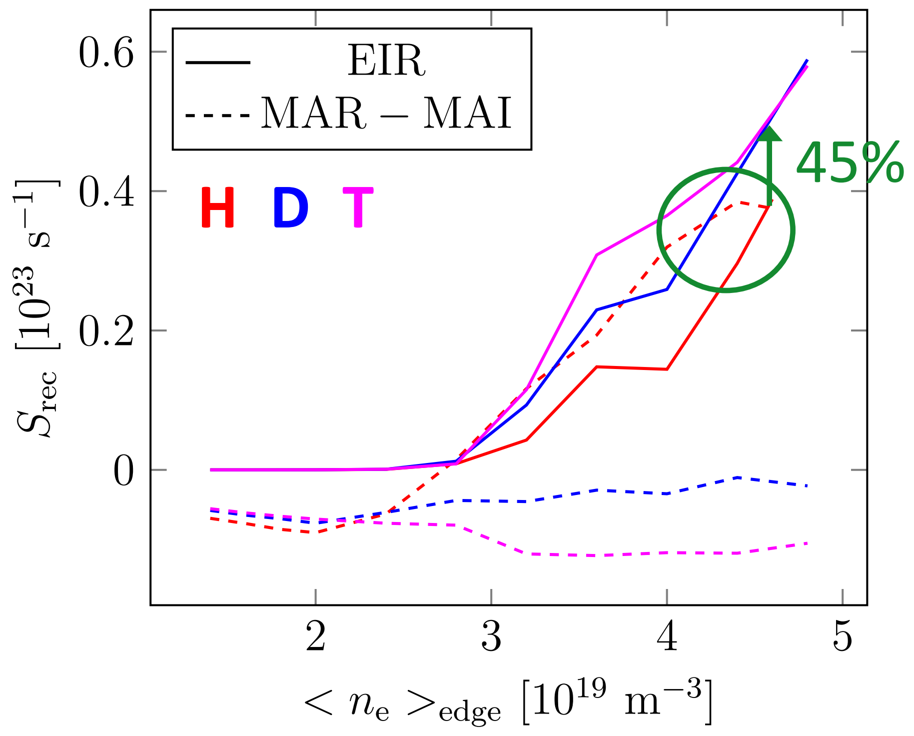
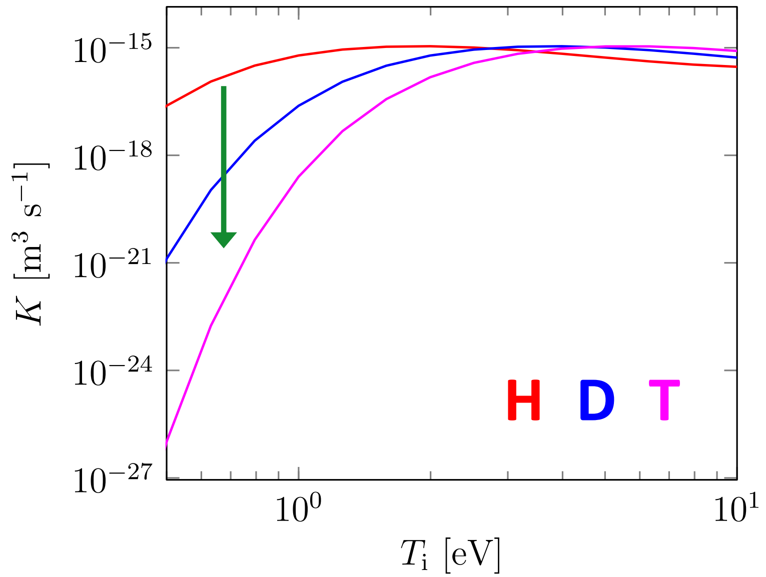


- 45% increase in electron-ion recombination (EIR) for D/T plasmas compared to H plasmas
- Only net **H** production from molecular processes (MAR – MAI) for H plasmas

Rate coefficient $\mathbf{H_2} + \mathbf{H^+} \rightarrow \mathbf{H_2^+} + \mathbf{H}$



Revision for D and T necessary?
[K. Verhaegh et al., NF **63** (2023)]

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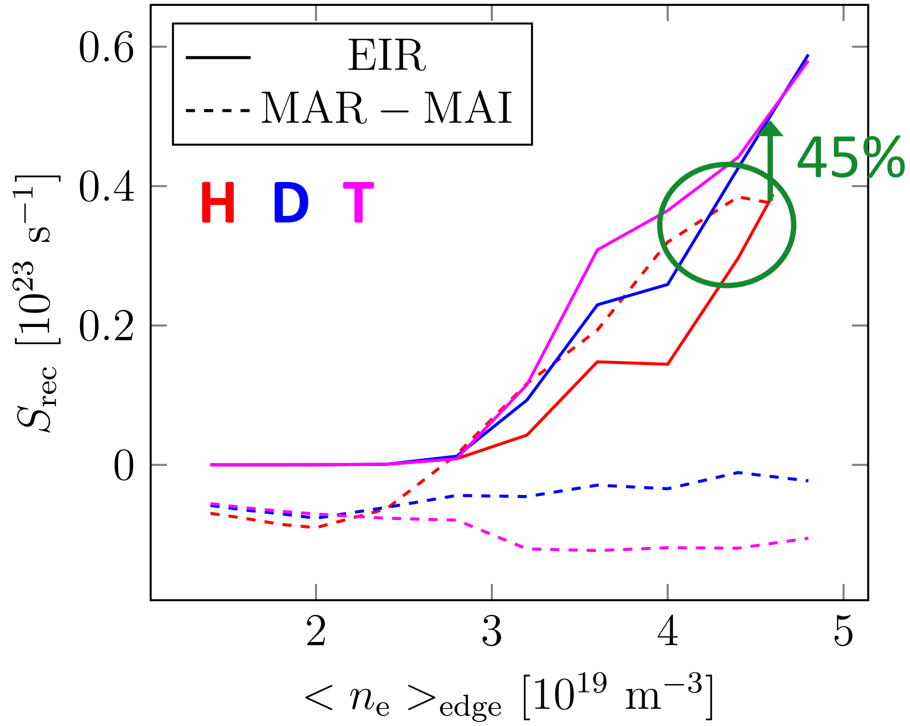

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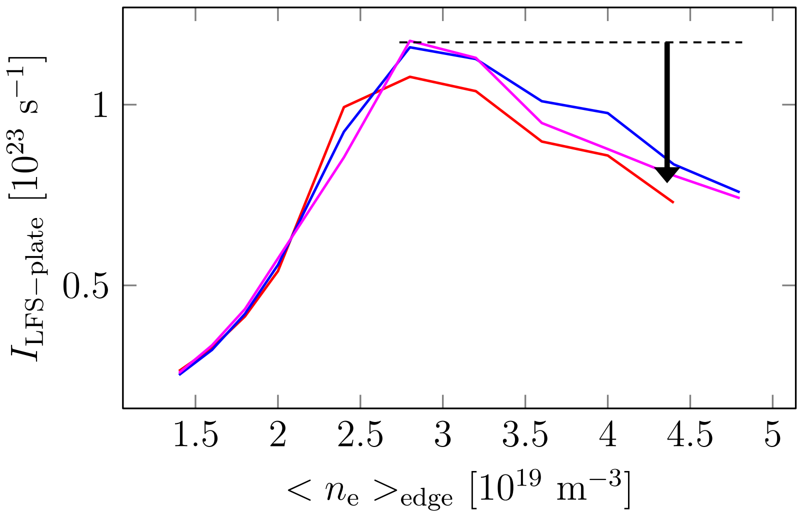
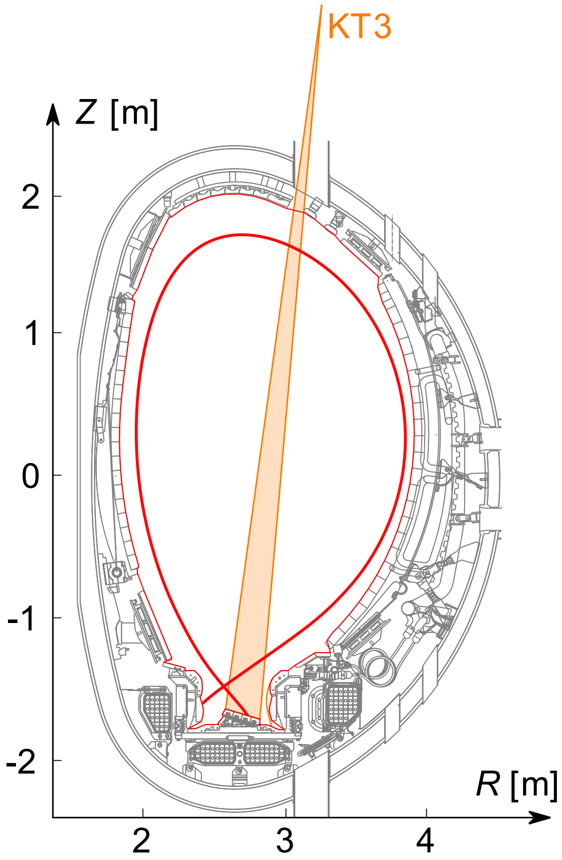
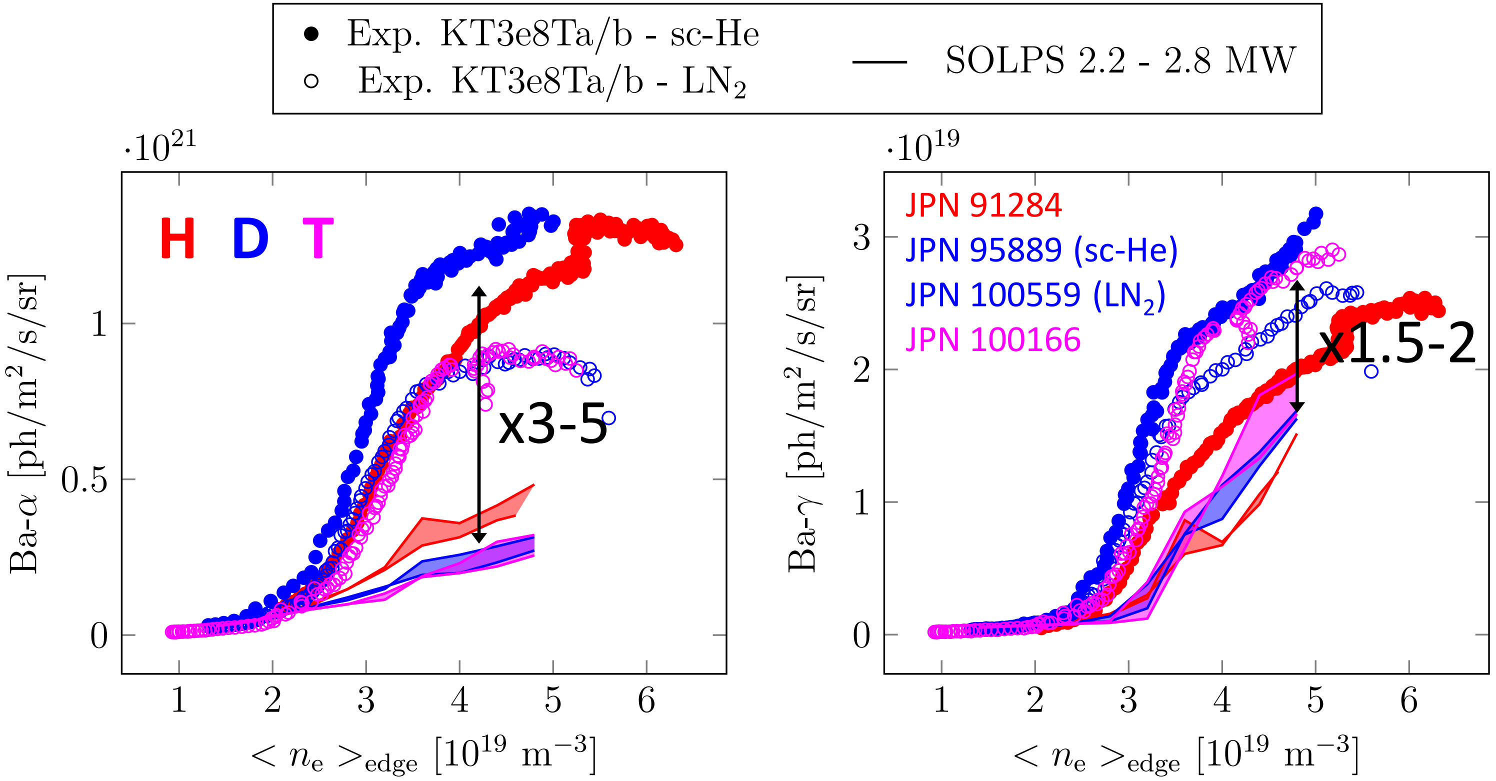
➔ Combined effect gives similar $I_{\mathrm{LFS\text{-}plate}}$



Simulations underestimate Ba-α and Ba-γ emission with factor 3-5 and 1.5-2, respectively

Ba emission
averaged over tile 5





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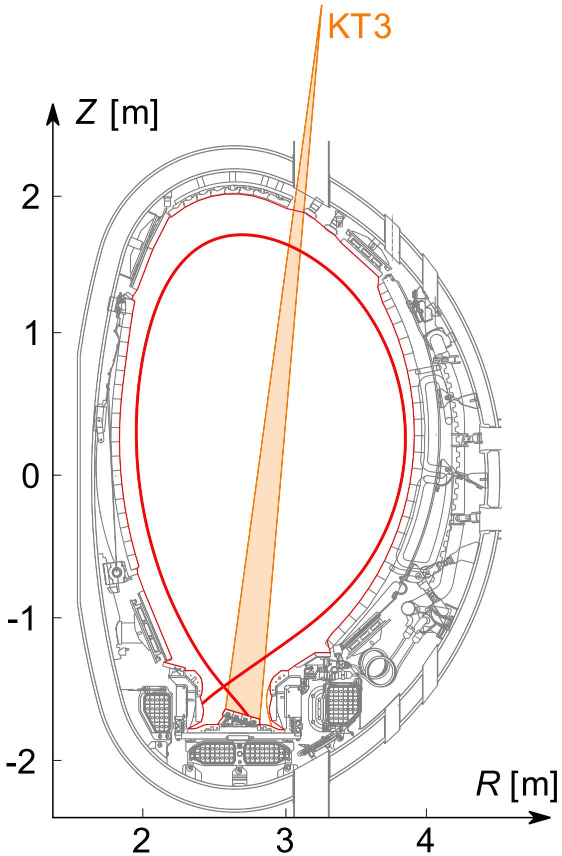
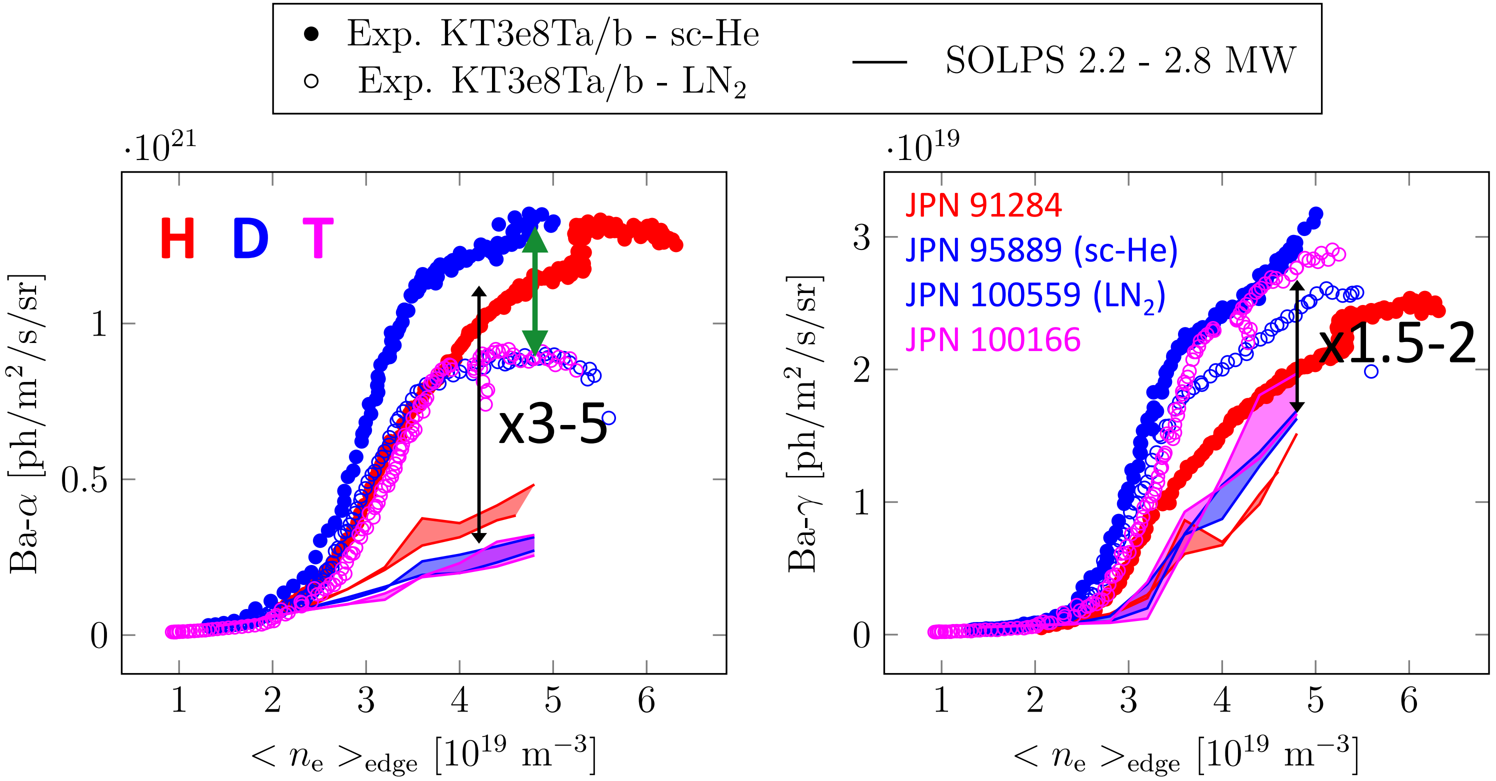
Simulations underestimate Ba-α and Ba-γ emission with factor 3-5 and 1.5-2, respectively

Ba emission
averaged over tile 5





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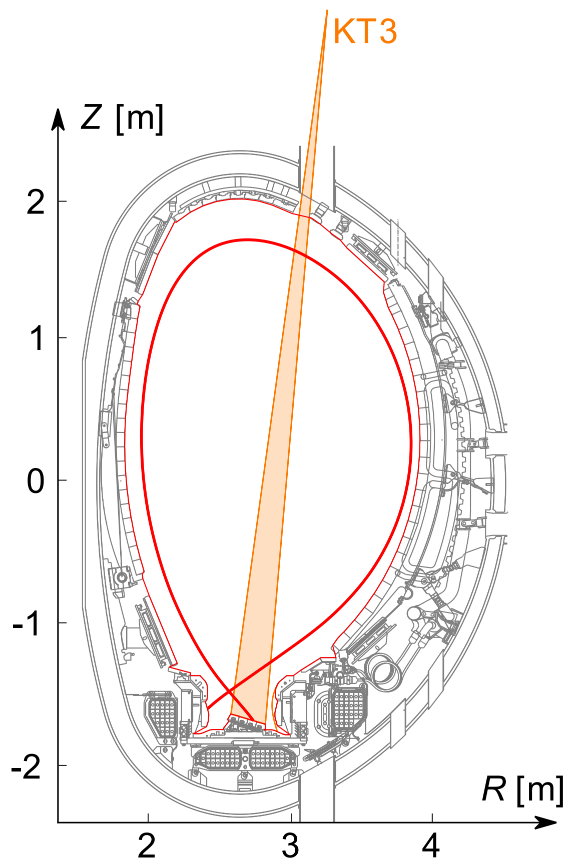

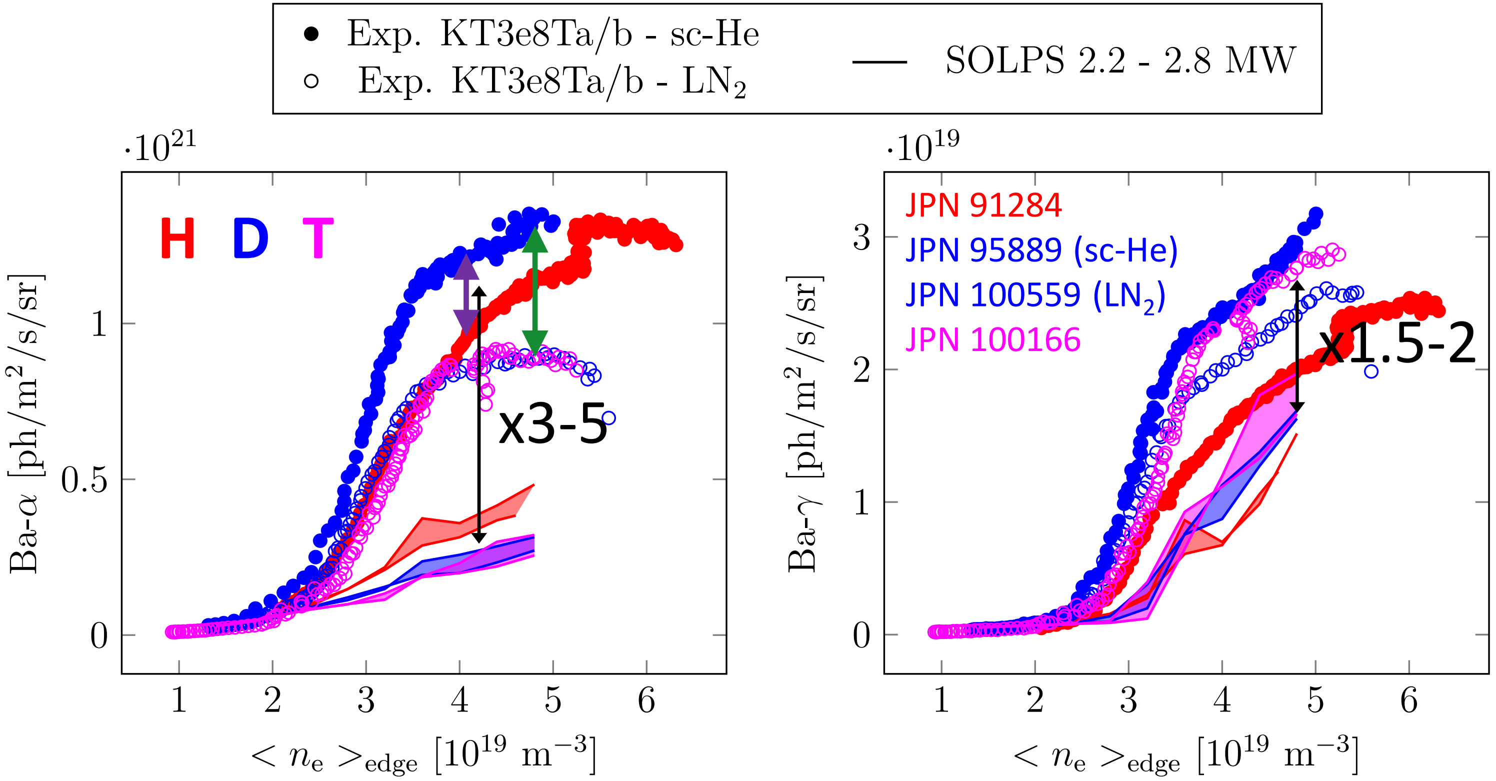

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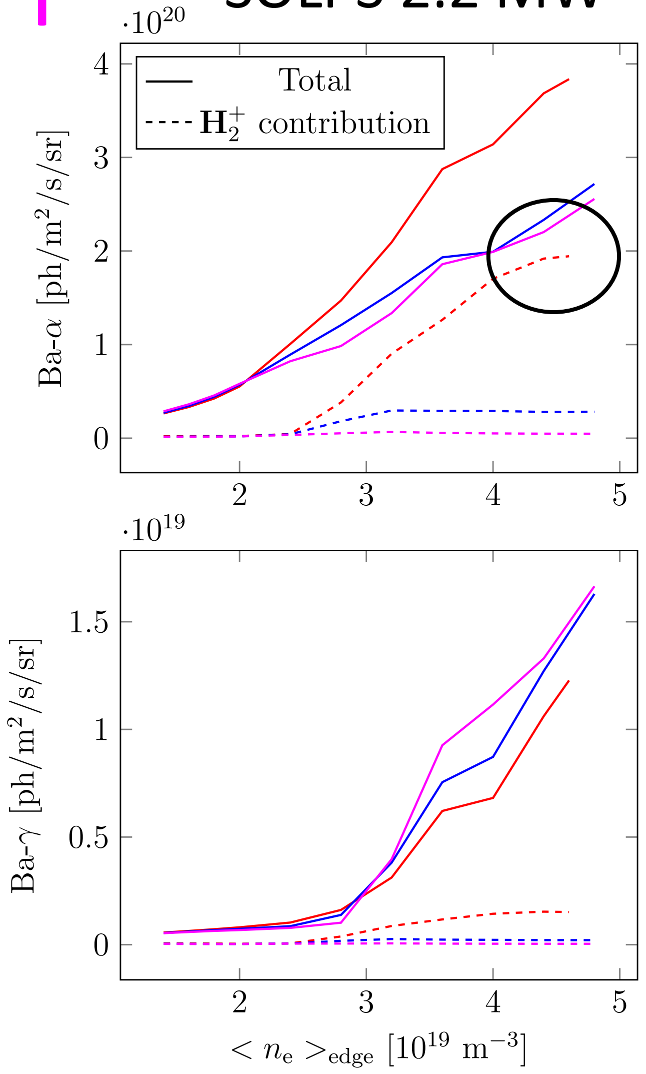
[A. Meigs et al., submitted to NME]

Ba-α lower for H than D/T in experiment ↔ opposite in simulation

H_2^+ is predicted to contribute to 50% of total Ba-α emission from H

H D T

SOLPS 2.2 MW



- Consistent with observation of importance of MAR for H in simulations
  ➔ underestimate of MAR for D/T?
  [K. Verhaegh et al., submitted to NME;
  J. Karhunen et al., NME **34** (2023)]

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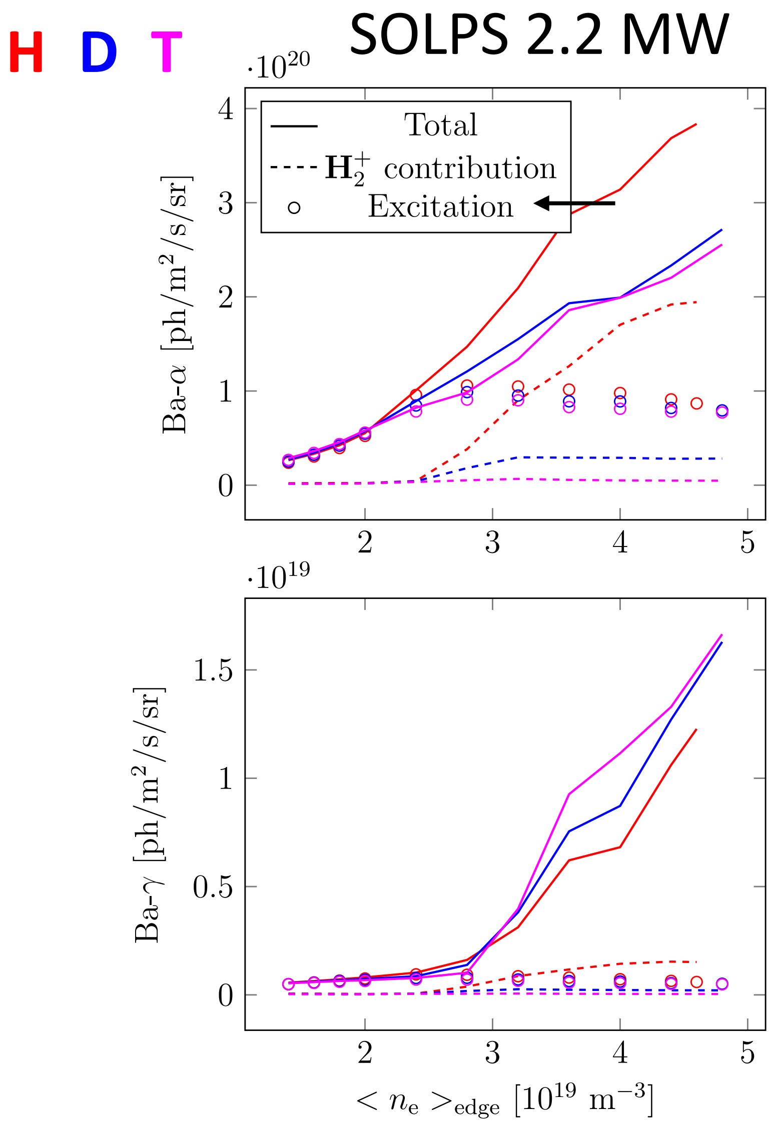

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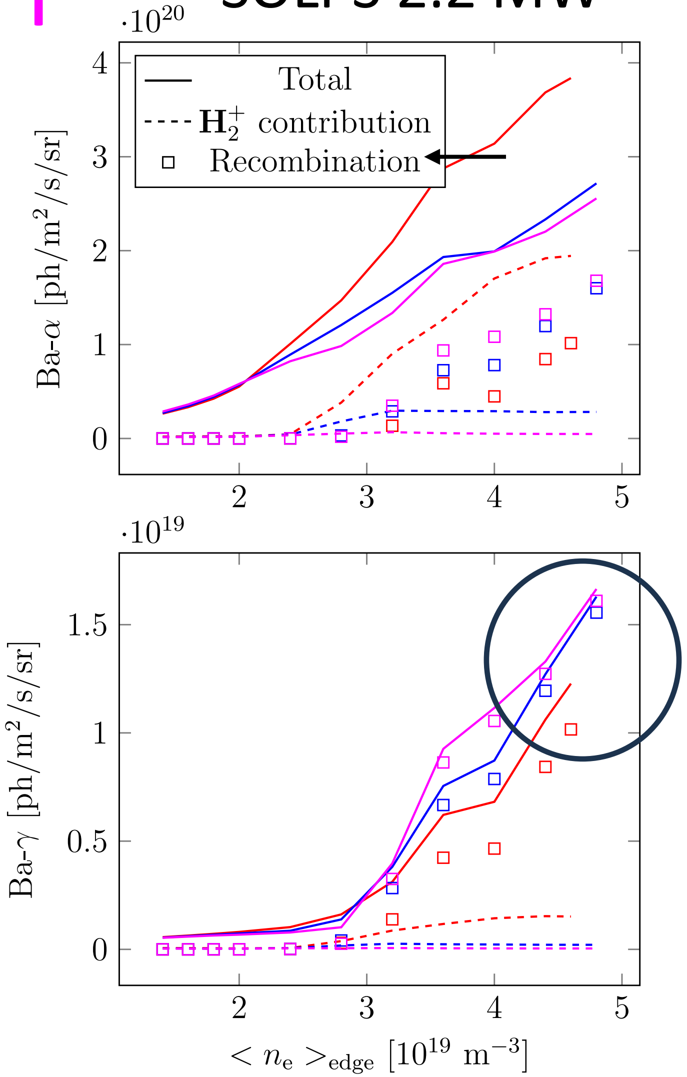

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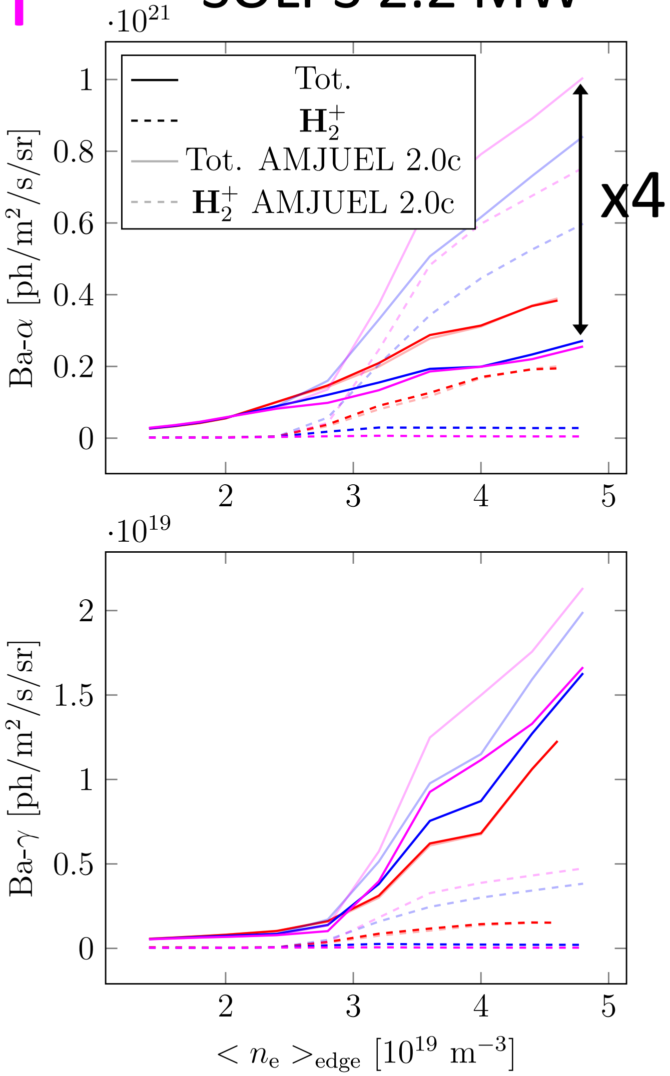

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  J. Karhunen et al., NME **34** (2023)]

- Atom excitation similar for all isotopes

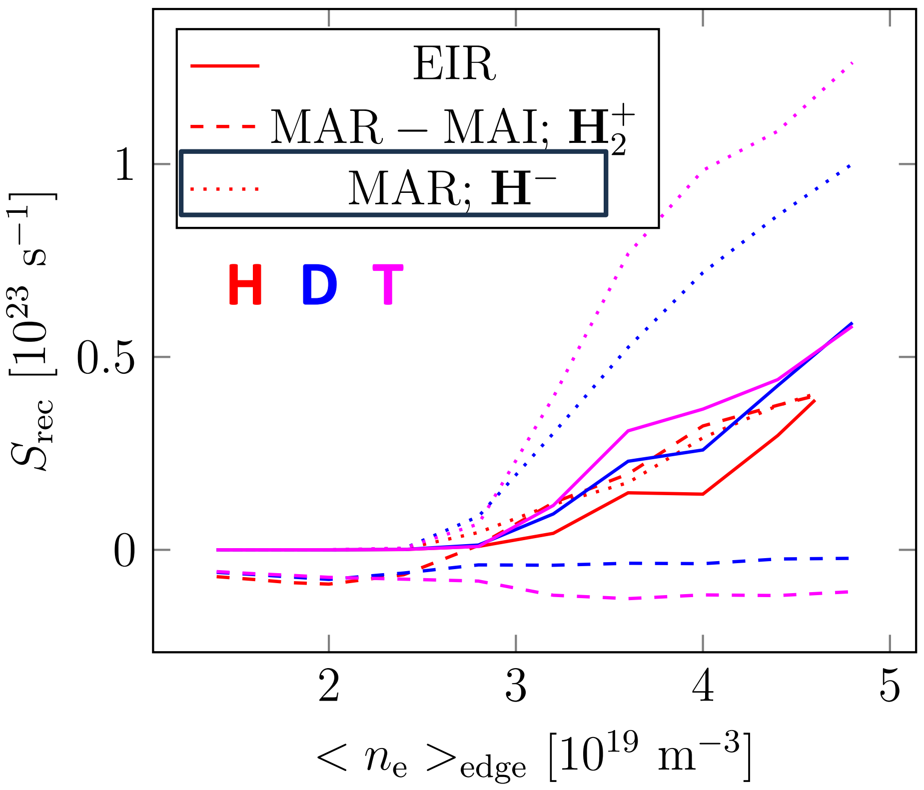
- Ba-γ is excellent indicator for EIR [V.-P. Rikala et al., submitted to NME; A. Meigs et al., submitted to NME]

- Factor 4 overestimate of Ba-α when using AMJUEL H.12 3.0c to calculate $\mathbf{H_2^+}$ density from $\mathbf{H_2}$ density for D/T ➔ E.g., *emissmol* in SOLPS-ITER is wrong

Recombination chain via H⁻ is important for H and needs to be re-assessed for D and T

$$\mathbf{H}_2 + \mathrm{e} \rightarrow \mathbf{H}^- + \mathbf{H}$$

$$\mathbf{H}^- + \mathbf{H}^+ \rightarrow 2\mathbf{H}$$



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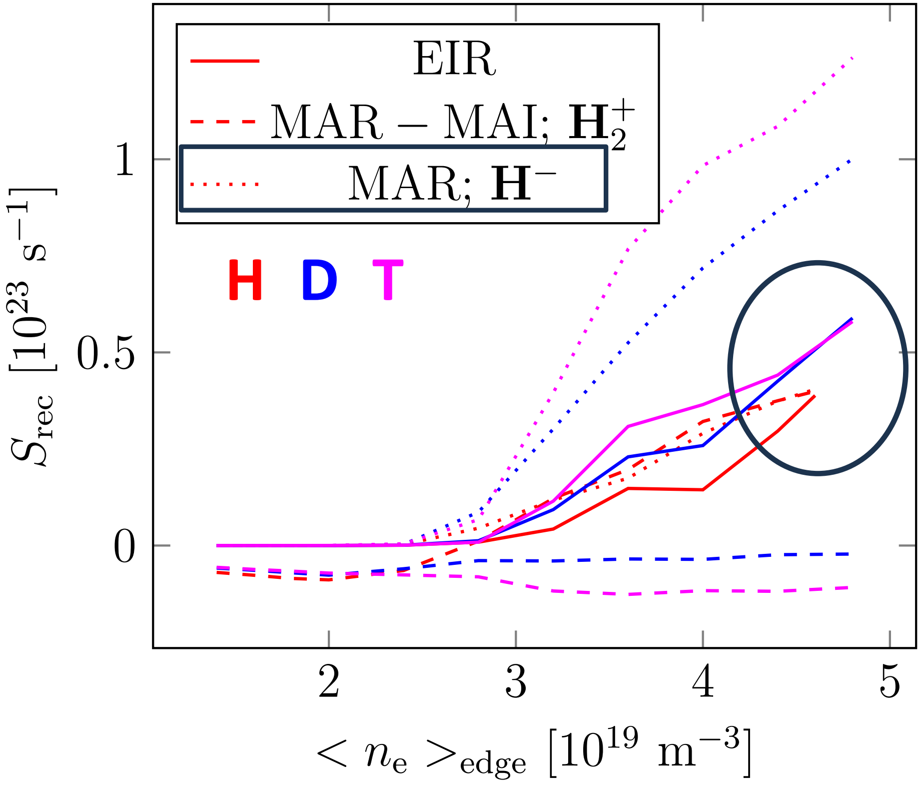

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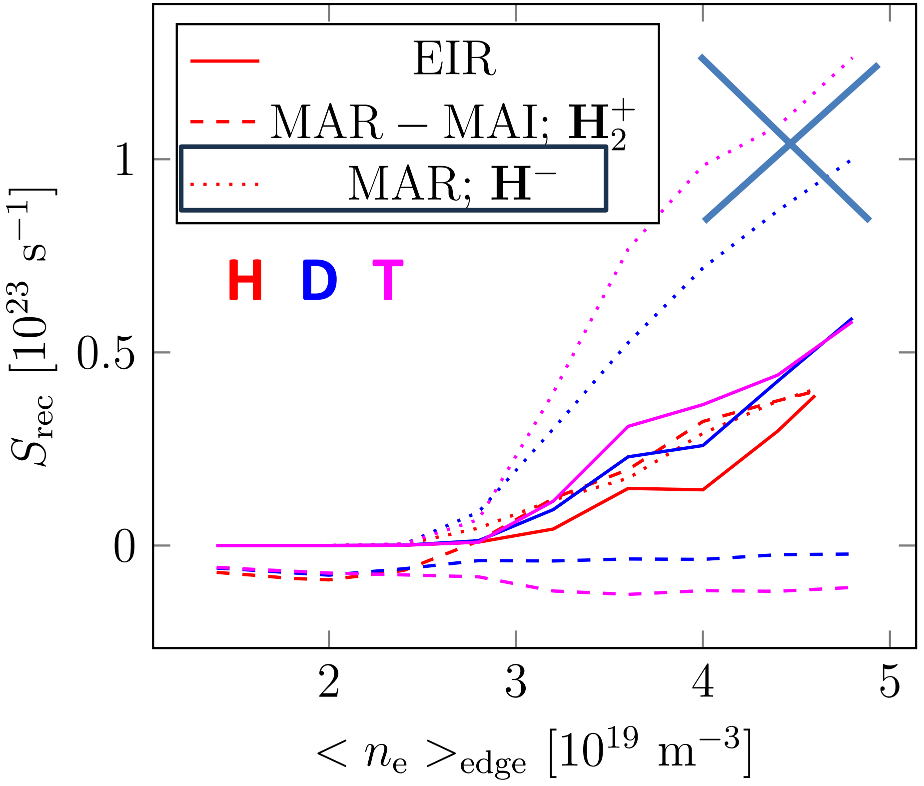

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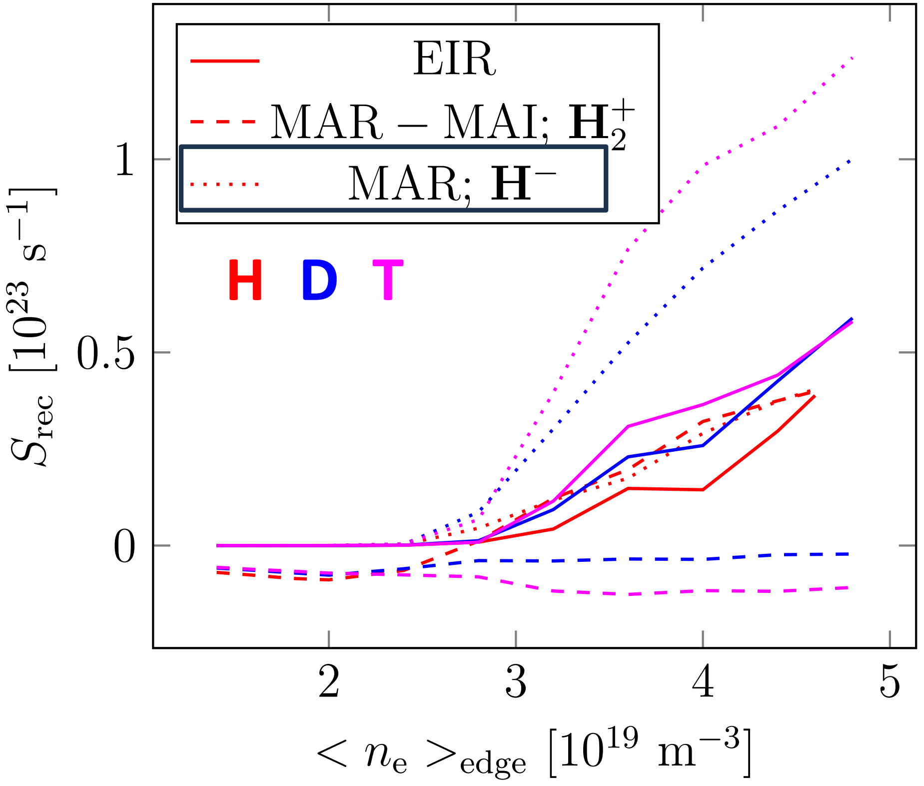

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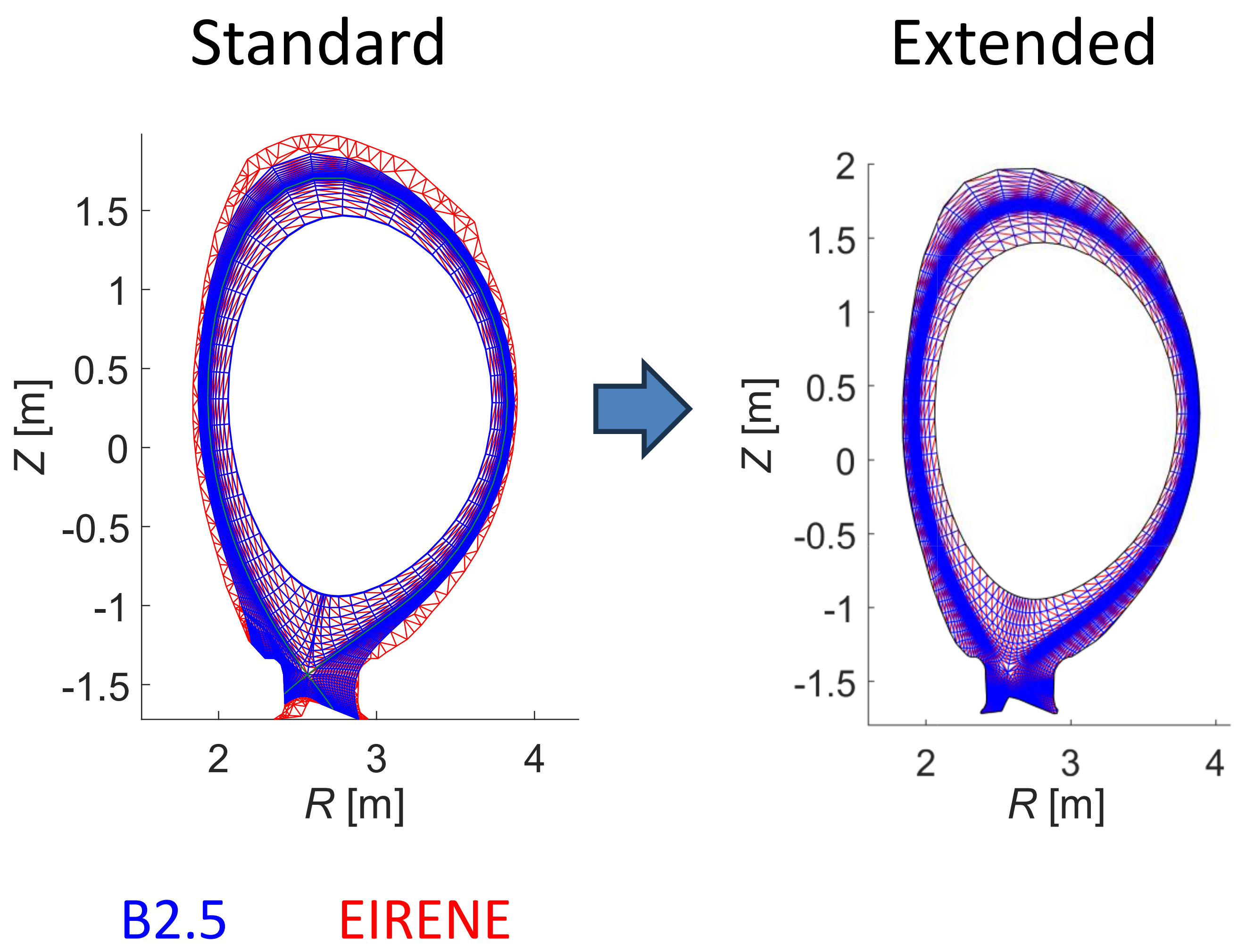
Collisional-radiative model (CRM) to properly assess the isotope effect!

Overview

- Introduction
- Experimental validation of simulation results
- **Impact of plasma grid extension to main chamber wall**
- Conclusions & outlook

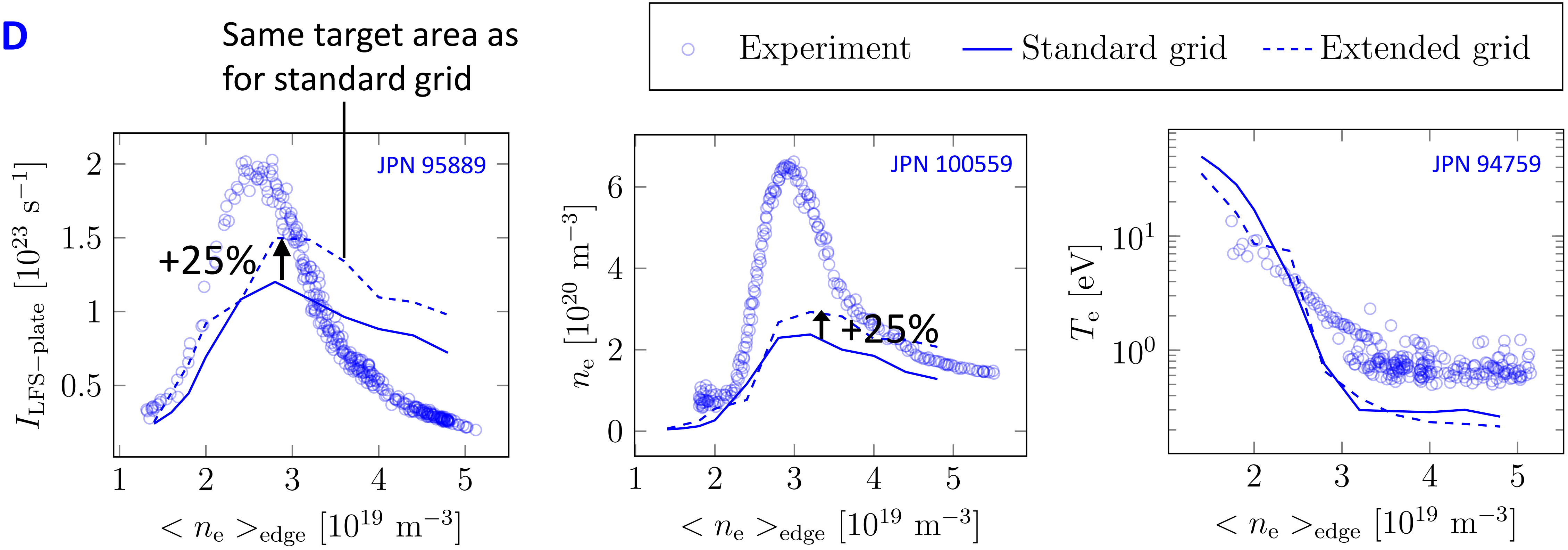
New unstructured SOLPS-ITER version allows plasma grid extension to the vessel wall



- Grid smoothing with GOAT [N. Vervloesem et al., CPP (2024)]
- Drifts & currents turned off

Extending the grid increases the peak $I_{LFS\text{-}plate}$ and n_e by 25%

D



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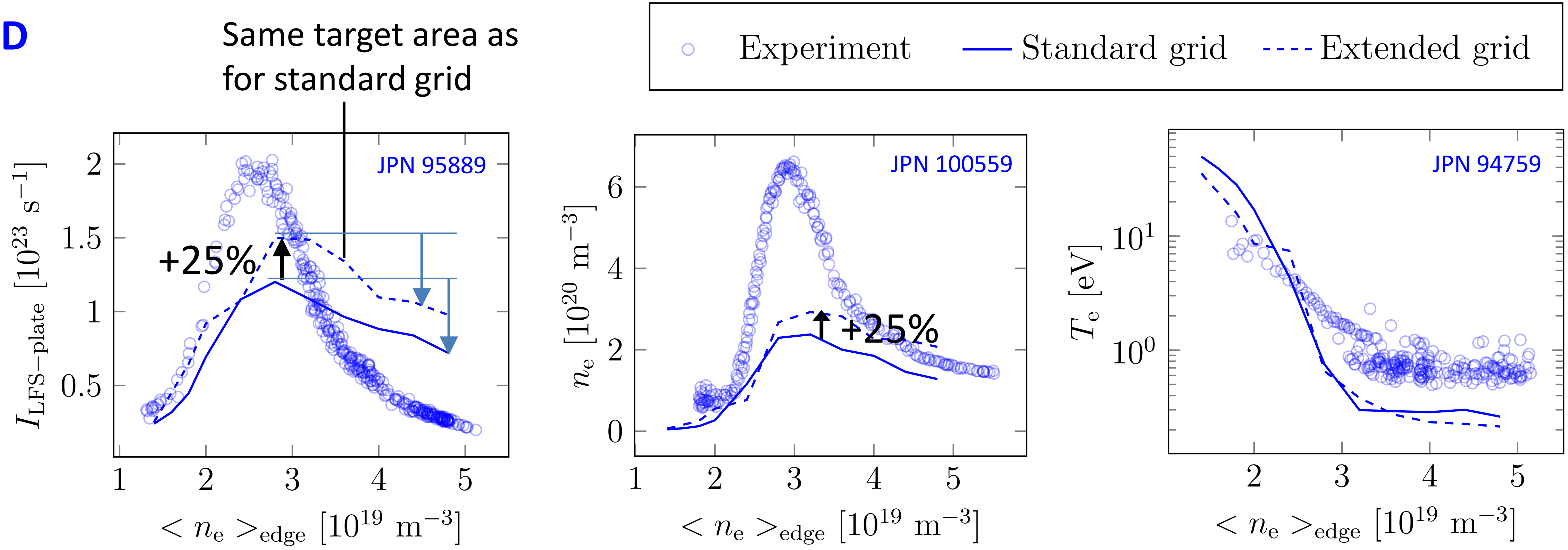
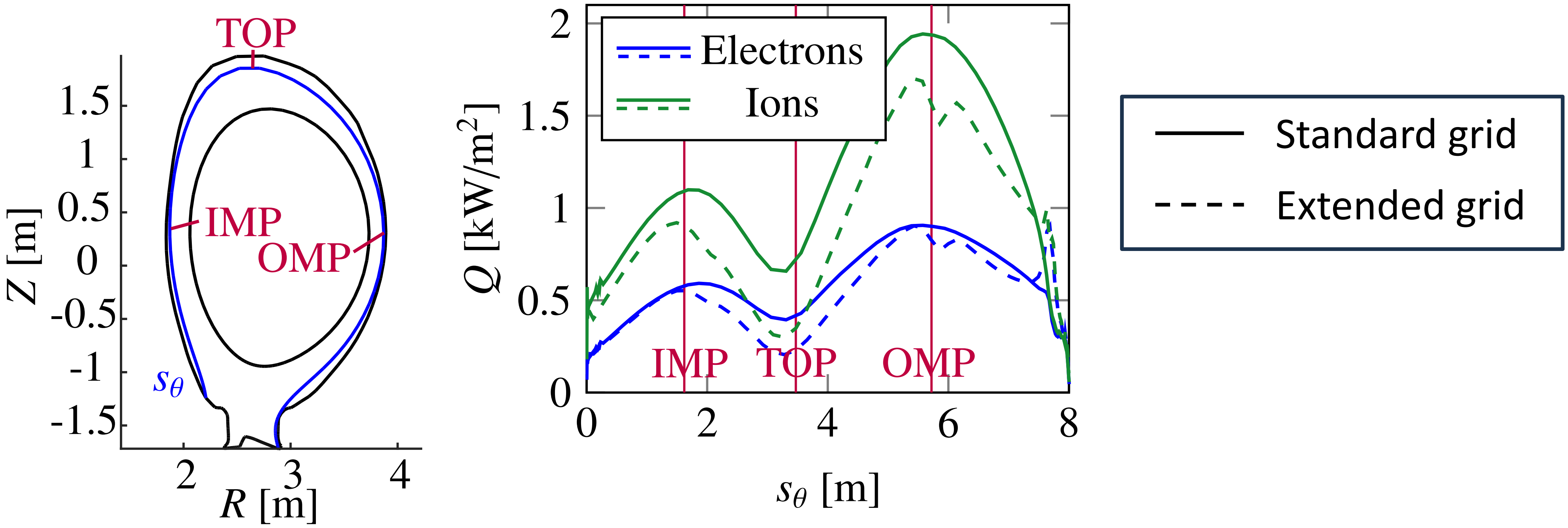


No significant difference for the decrease of $I_{LFS\text{-}plate}$ with increasing $\langle n_e \rangle_{edge}$ in detached conditions between standard and extended grids

Extending the grid reduces the plasma power to the main chamber wall by 20%

Power crossing the standard grid boundary



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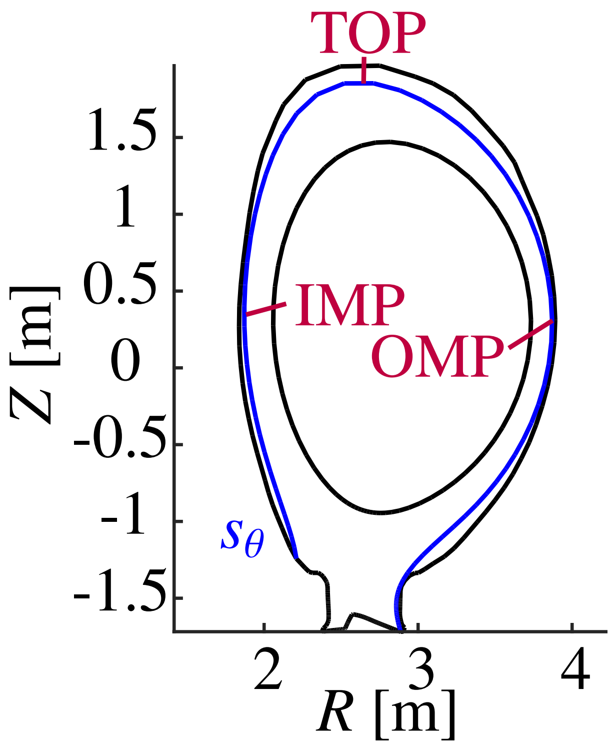

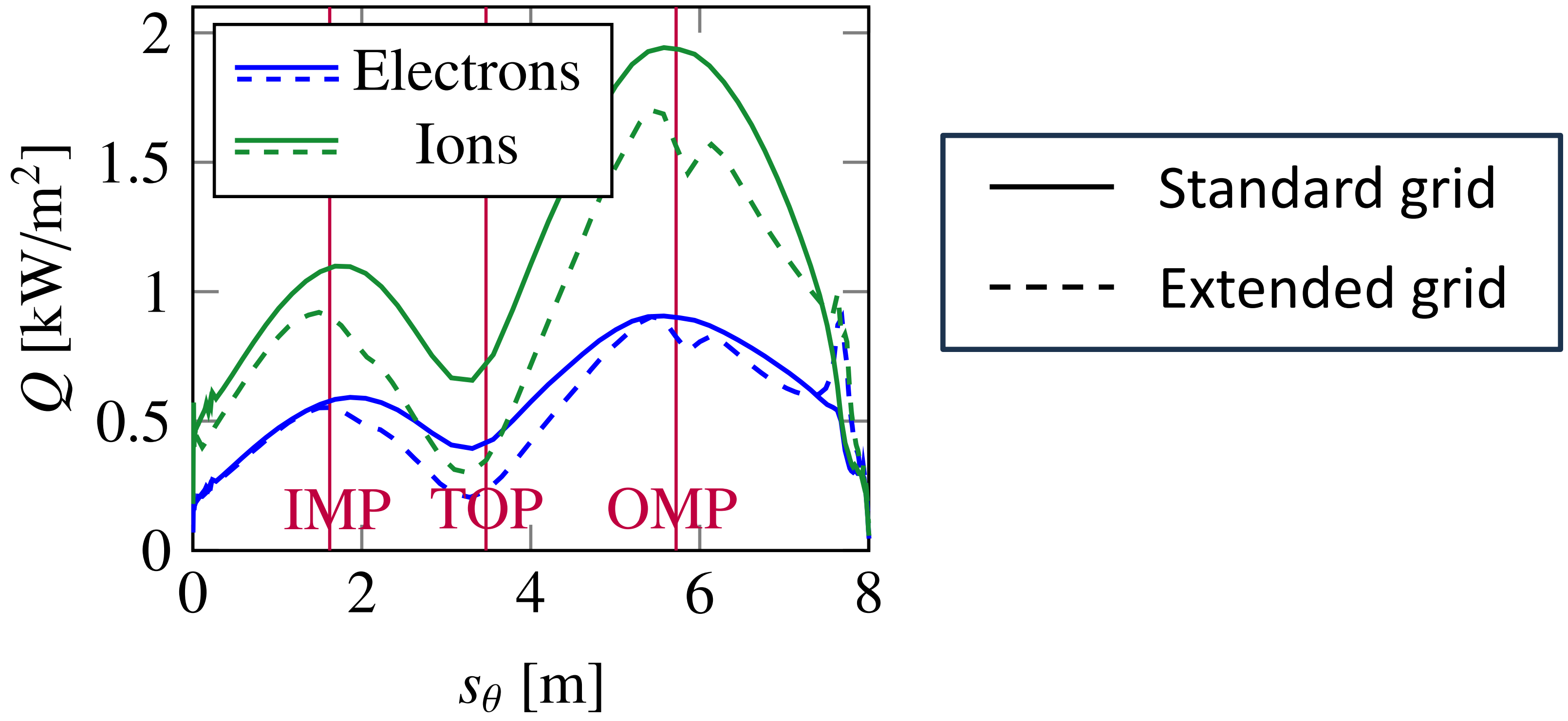

More power available for ionization ➔ $\Gamma_{\mathrm{w}} \approx \frac{Q_{\mathrm{SOL}}}{E_{\mathrm{ion}}^{\mathrm{eff}} + \gamma T_{\mathrm{w}}} - S_{\mathrm{rec}}$

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Conclusions & outlook

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Similar onset of detachment for H, D & T

Stronger detachment for D & T than H due to increased electron-ion recombination

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Lower density and LFS target peak fluxes than experiment
➔ Indication of Ly-opacity

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Conclusions & outlook

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Outlook

Need for increased-fidelity reference simulations:

➔ Extended grid + CRM + photons

Simulations

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Possible TSVV 5 activities

- Coupled plasma-neutral-photon simulations for these JET L-mode plasmas (R. Chandra)

- Revival of H2-colrad in EIRENE (initiated by D. Reiter & P. Börner)
  ➔ application to JET L-mode plasmas

- Transport of vibrationally excited molecules with H2VIBR
  - Done when launching as $\nu = 3$ ➔ no significant impact
  - Launching as $\nu = 4$ ➔ significant impact expected due to resonance
  - Understanding observed instabilities reported by F. Reimold and J. Bryant