EUROfusion

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

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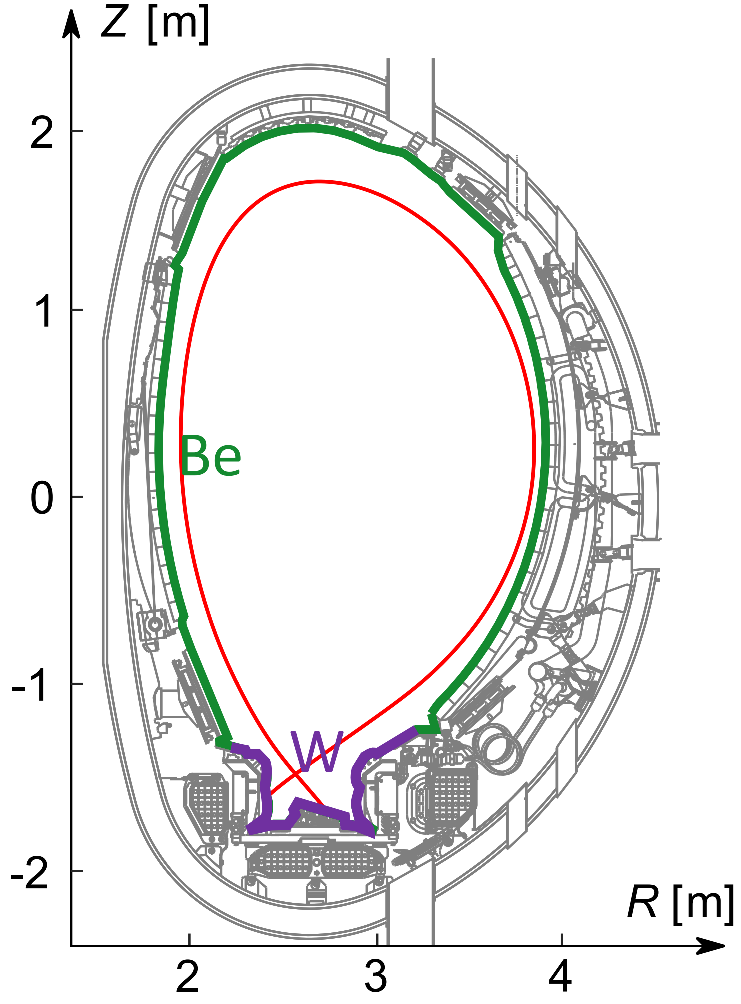
Characterization of LFS divertor conditions for JET-ILW L-mode plasmas with different isotopes



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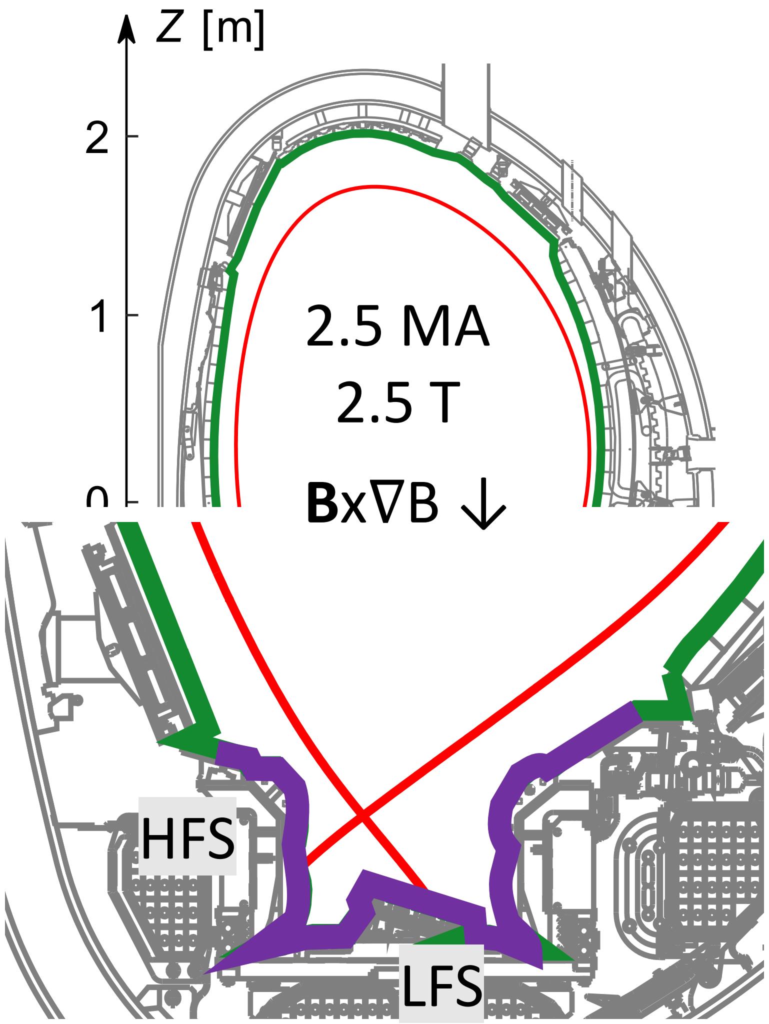

- JET-ILW ➔ removed impact of carbon radiation on detachment
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  [M. Groth et al., NF **53** (2013)]

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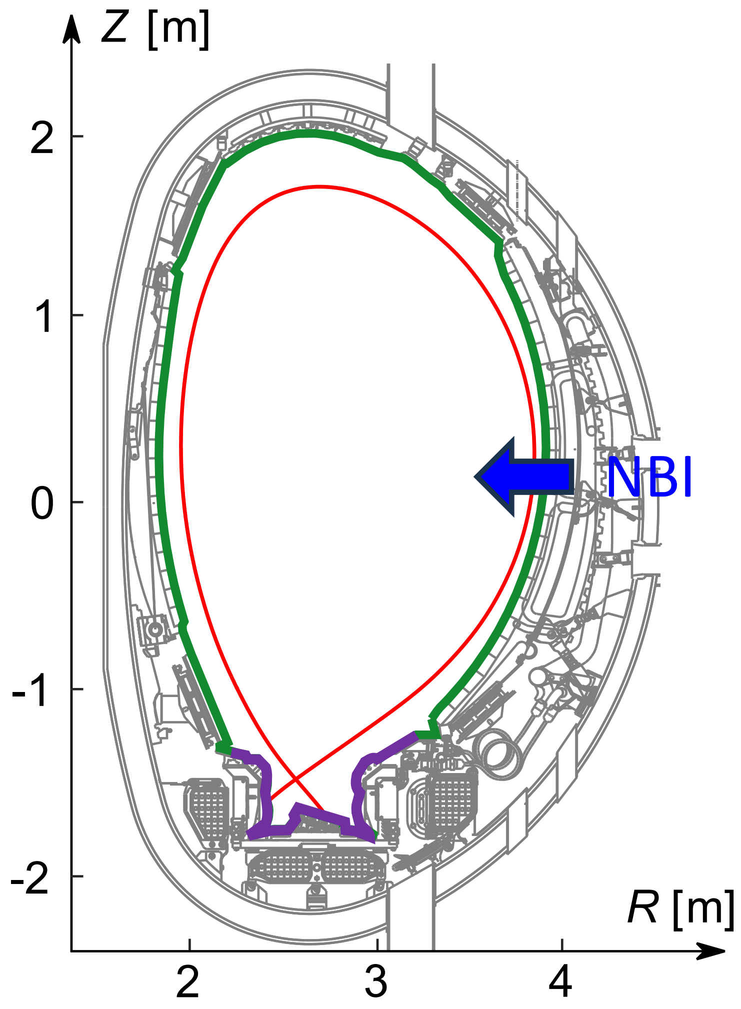

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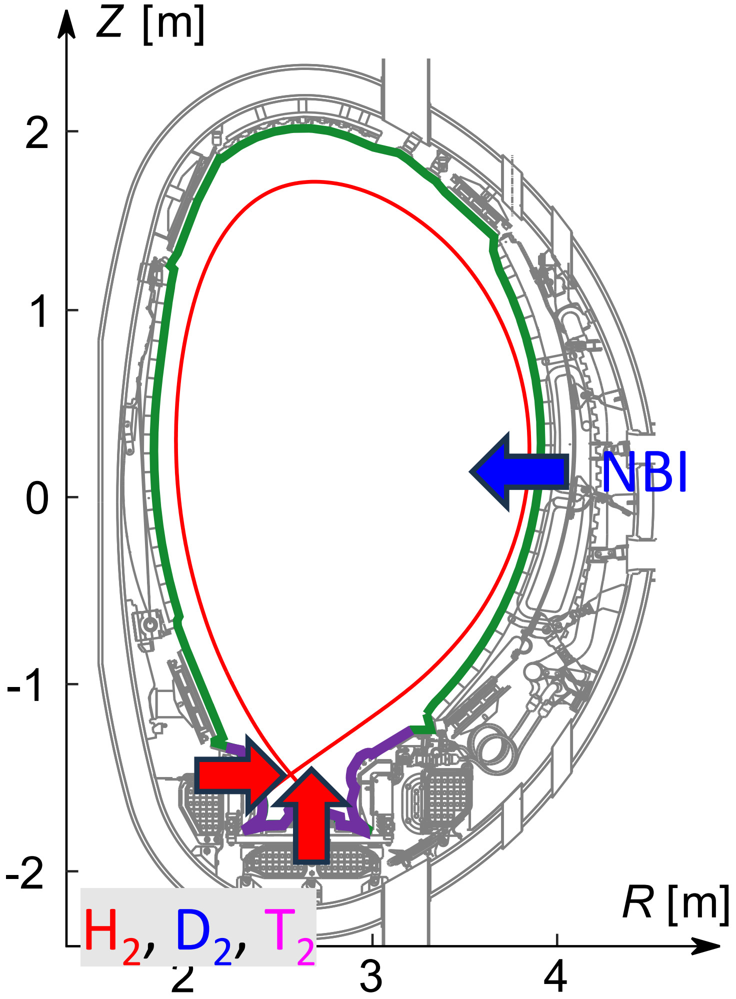

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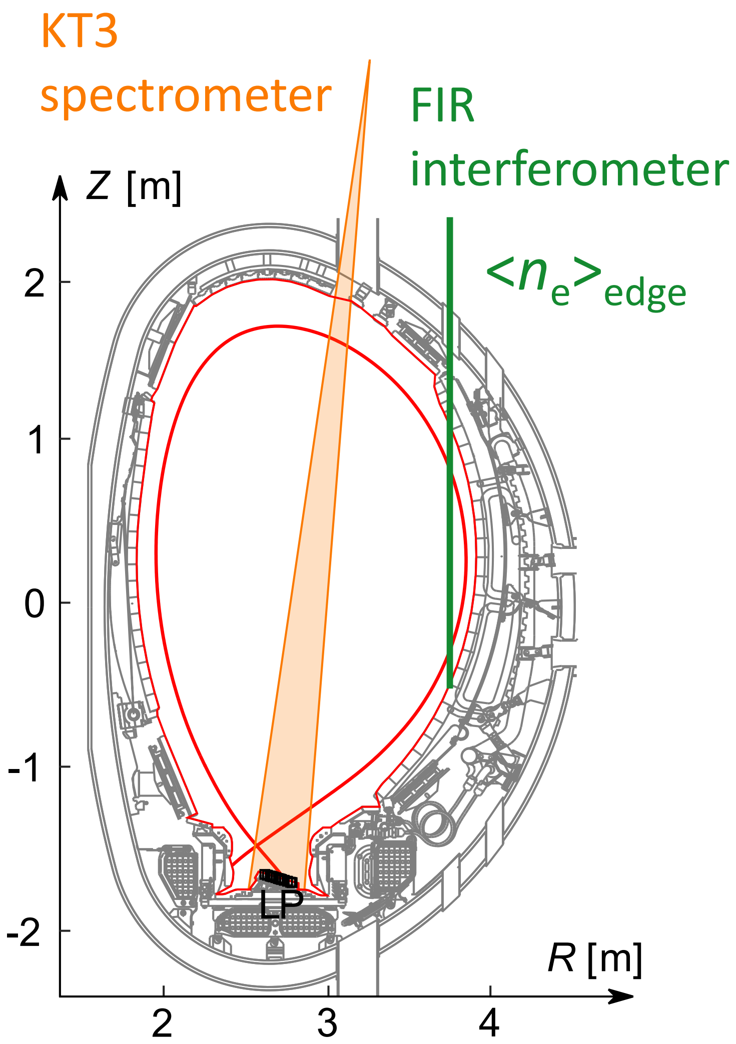

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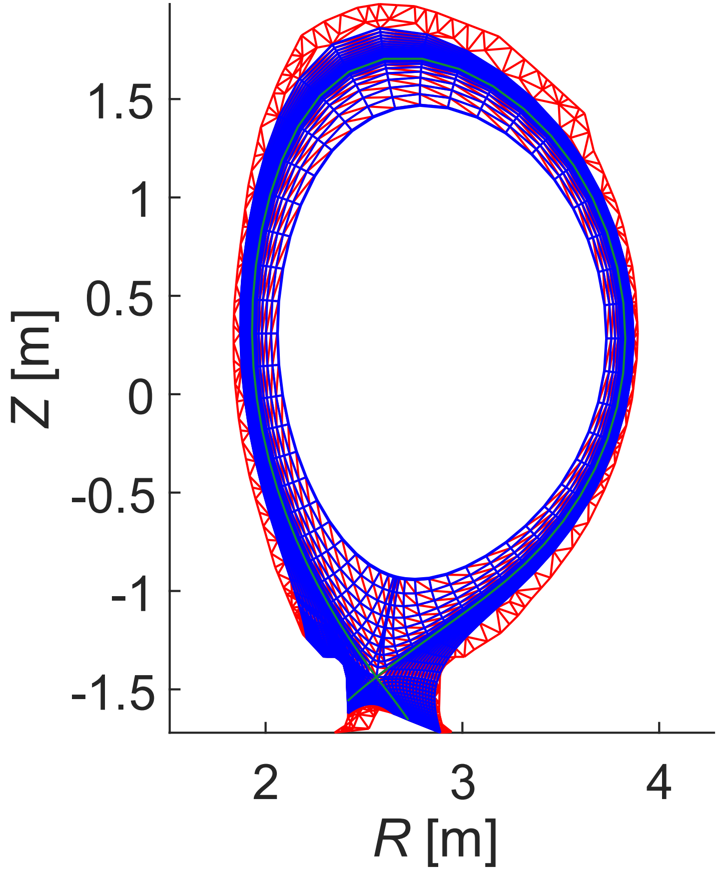
Overview

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

Validation with EDGE2D-EIRENE and SOLPS-ITER

B2.5 plasma grid
EIRENE neutrals grid



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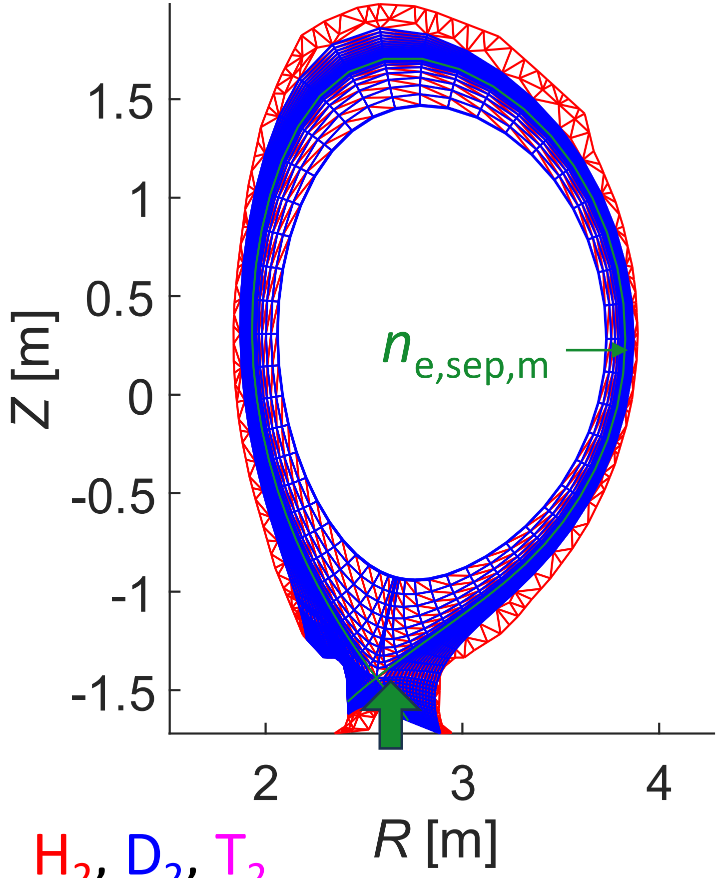

H_2, D_2, T_2

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  Initial assumption: $\langle n_e \rangle_{edge} = 2 \times n_{e,sep,m}$

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  ➔ $\langle n_e \rangle_{edge} - n_{e,sep,m}$ relationship to be re-assessed

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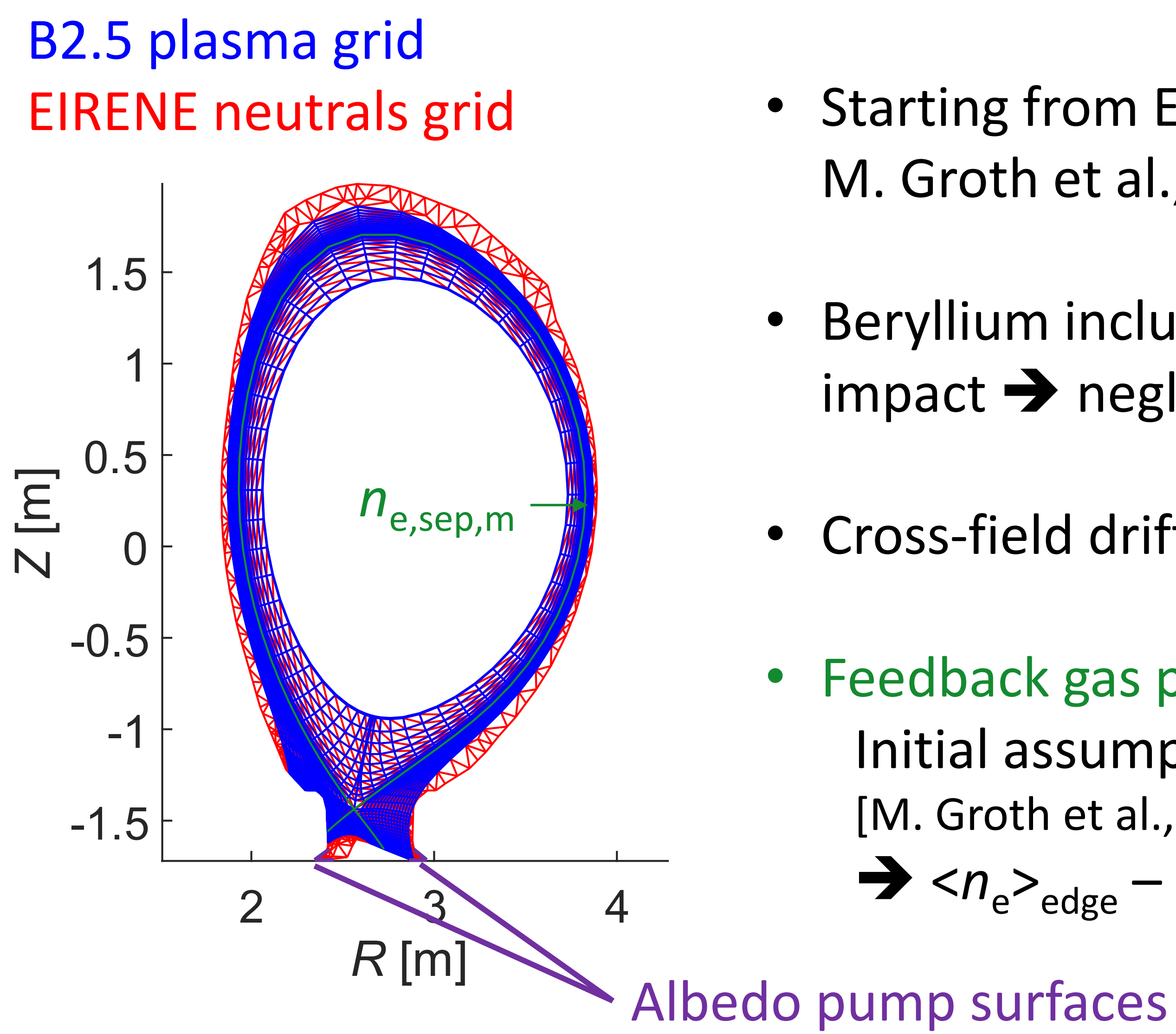

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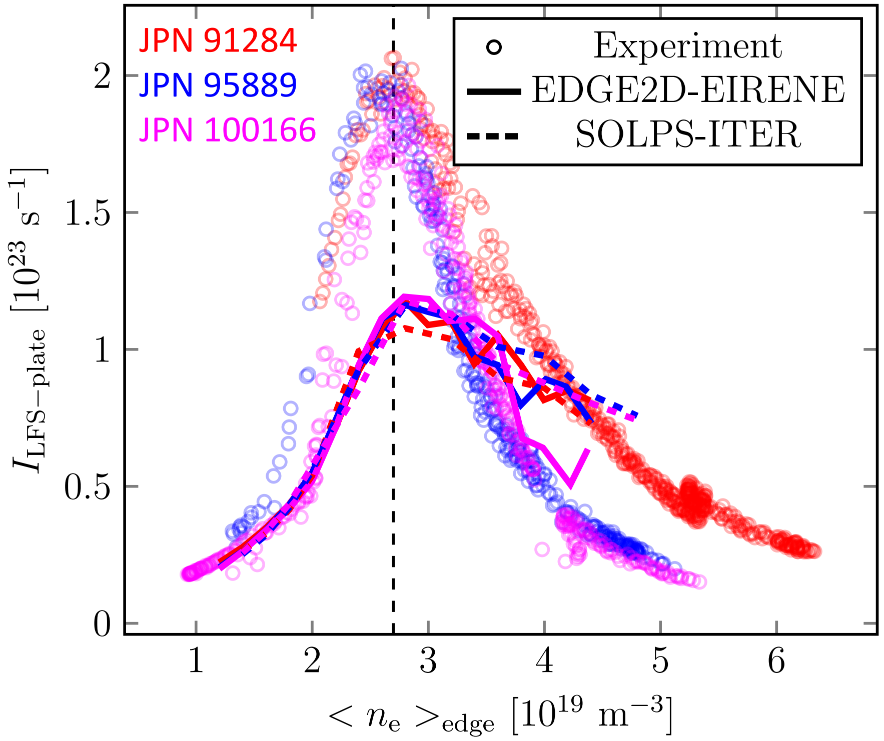
Simulations also predict an isotope-independent onset of detachment

H D T



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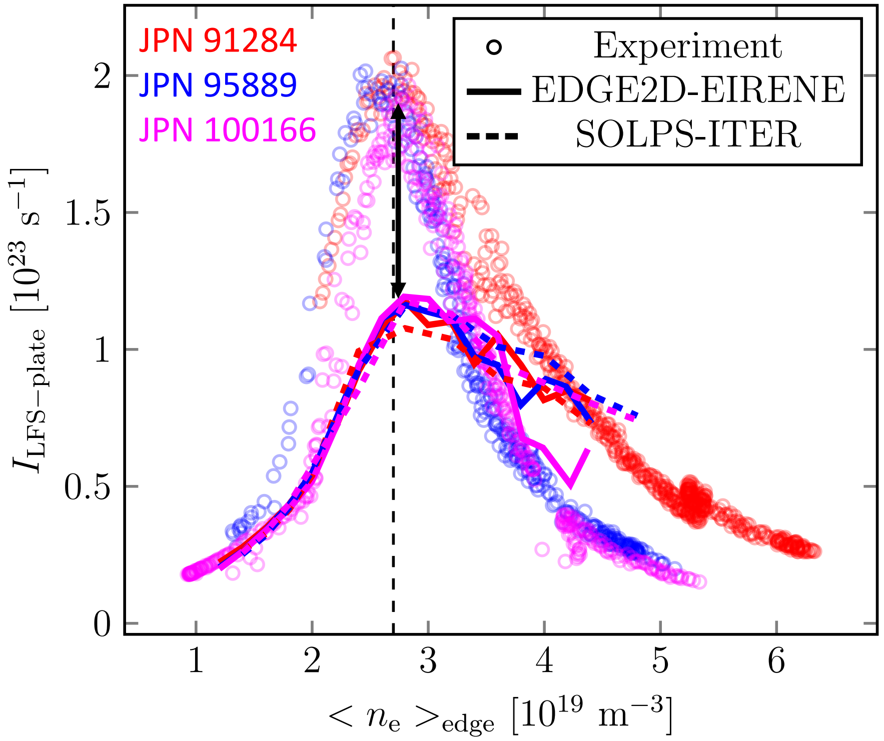

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1. Peak $I_{\text{LFS-plate}}$ lower in simulations

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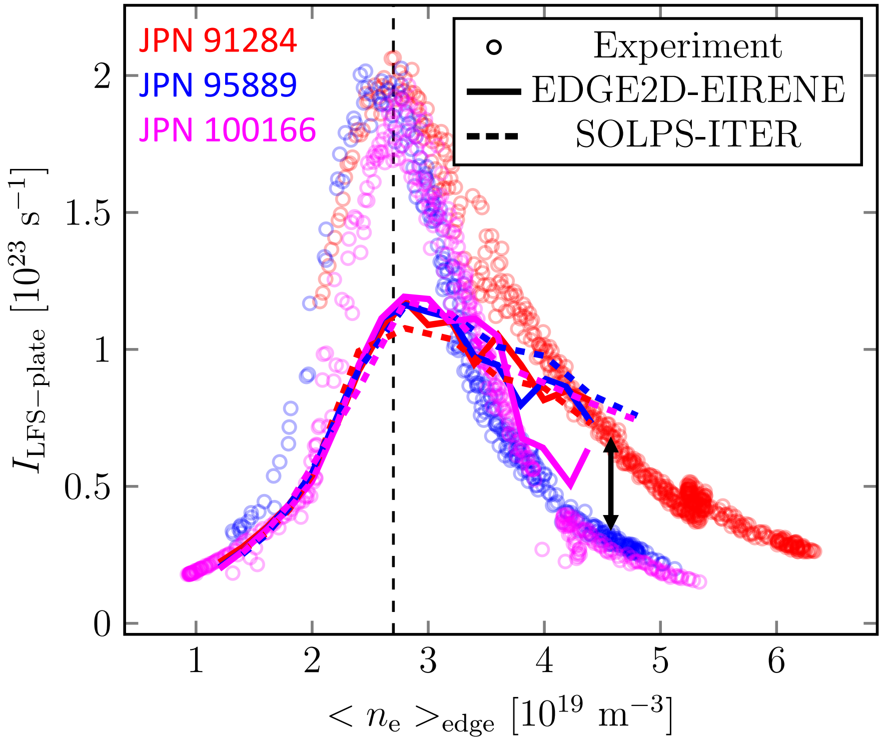

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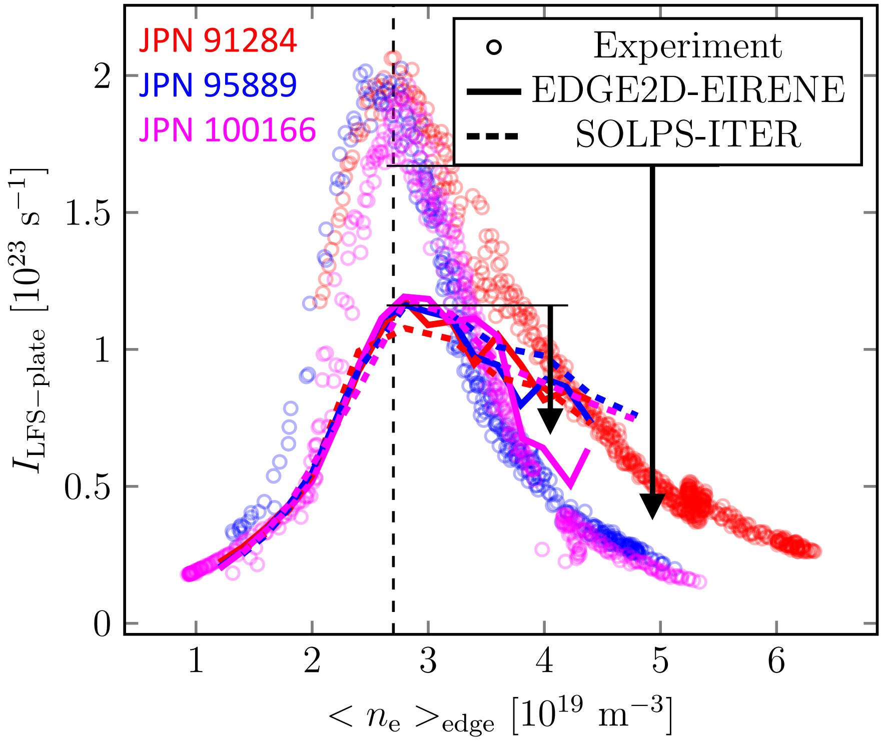


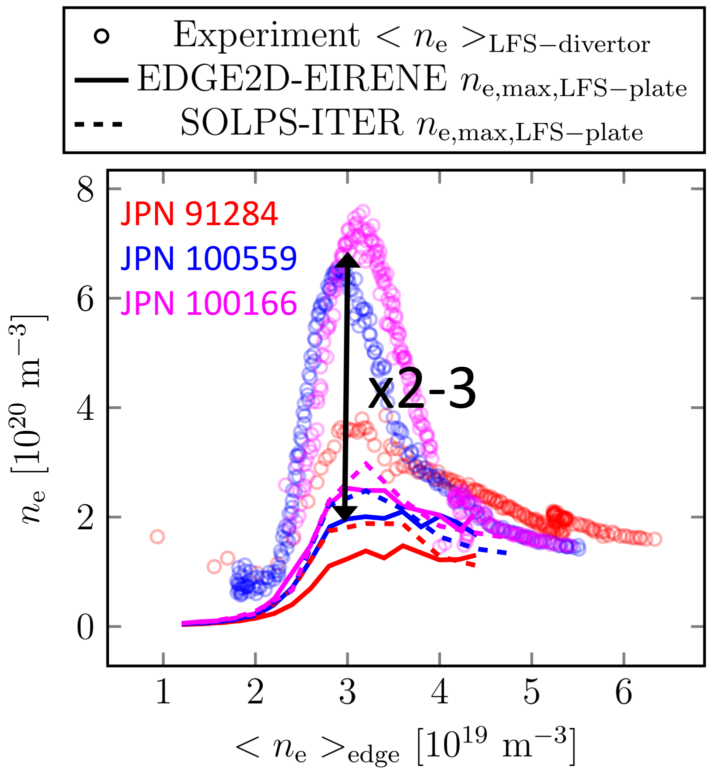
No significant differences between EDGE2D-EIRENE and SOLPS-ITER

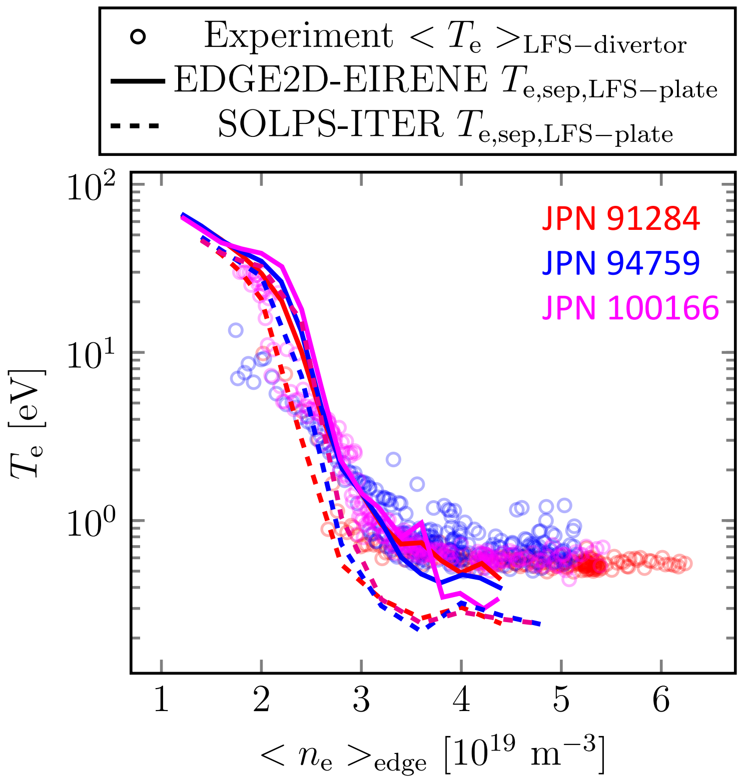
Several simulation-experiment discrepancies:

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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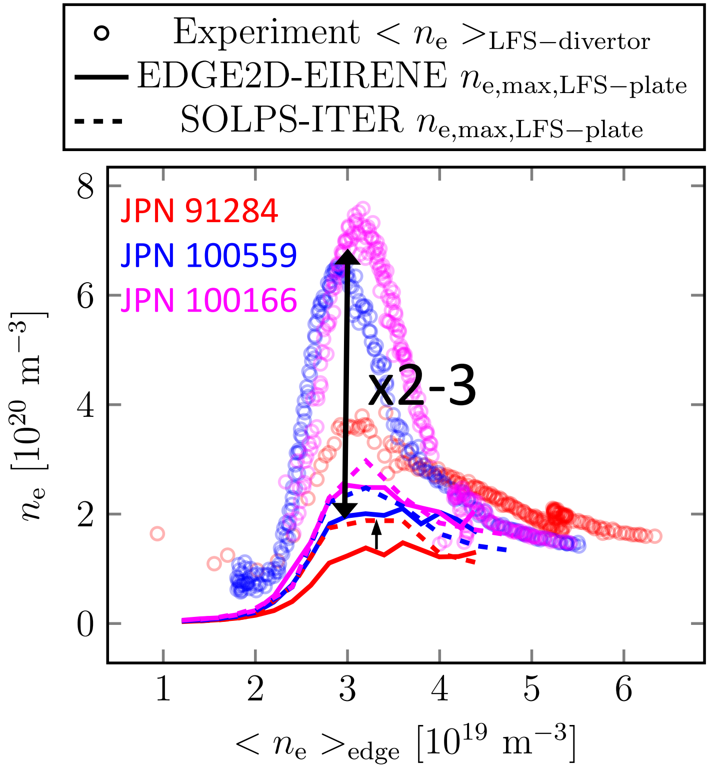
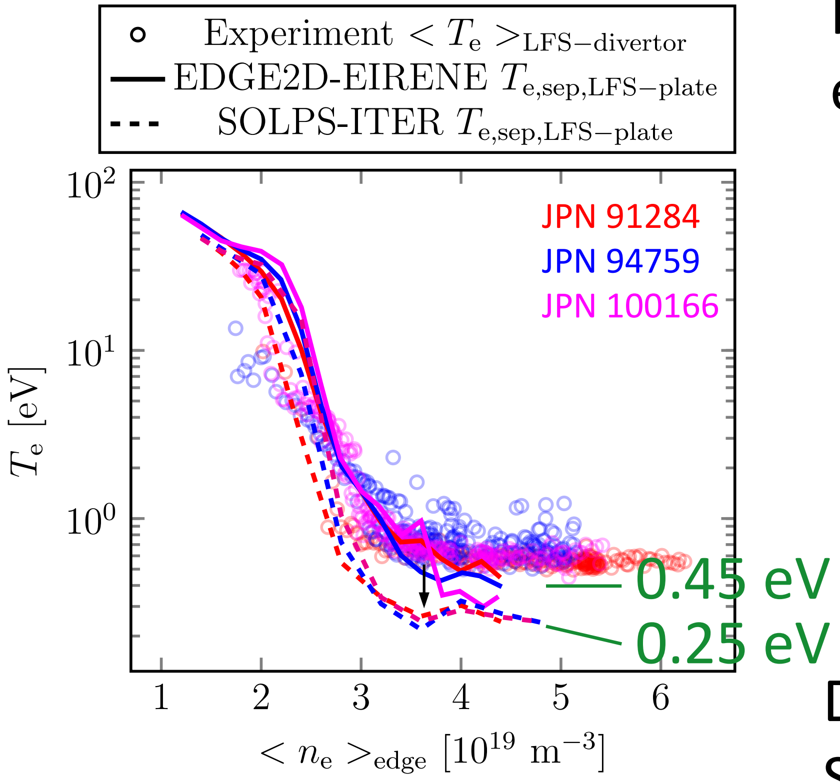


n_e (SOLPS) > n_e (E2D)



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

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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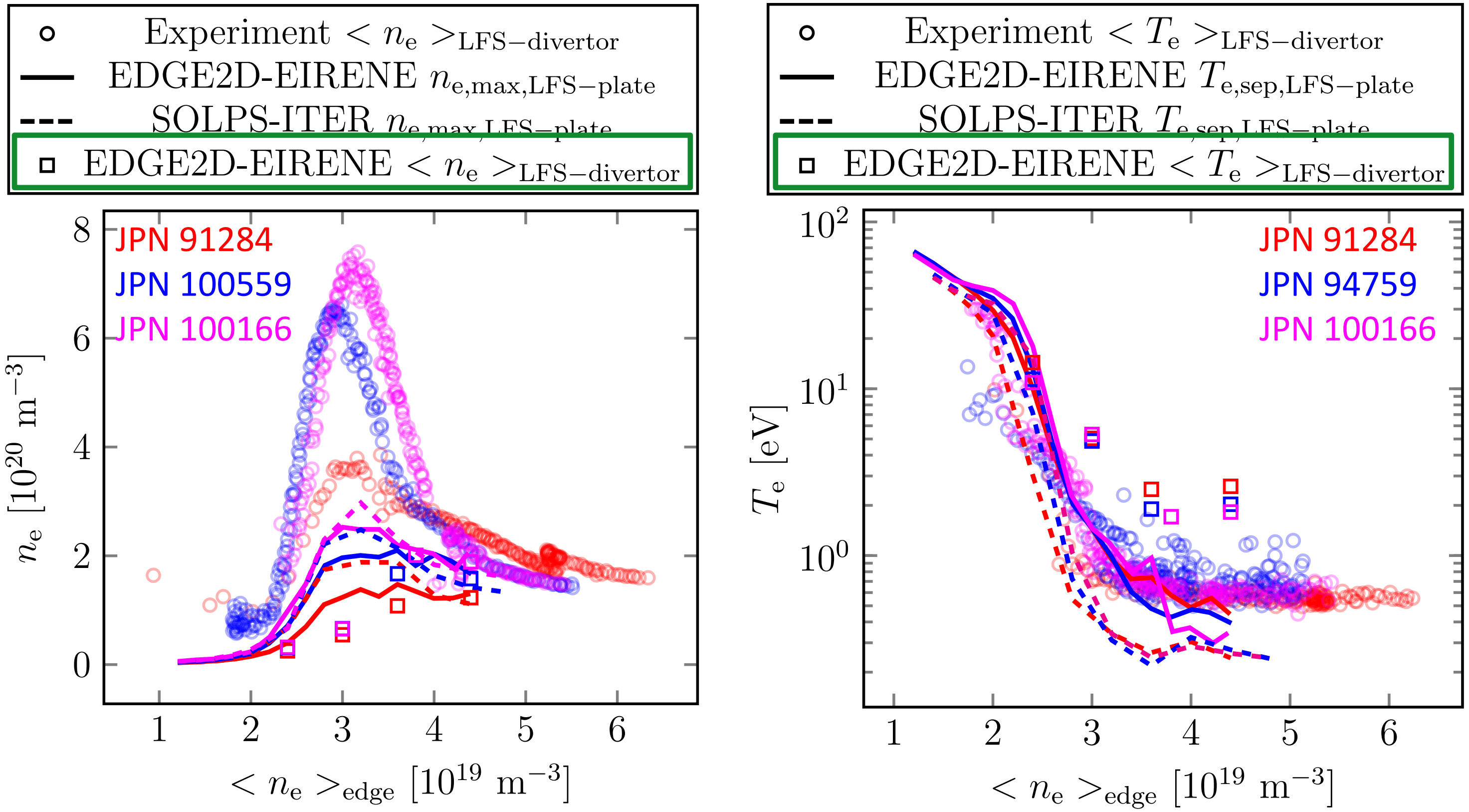

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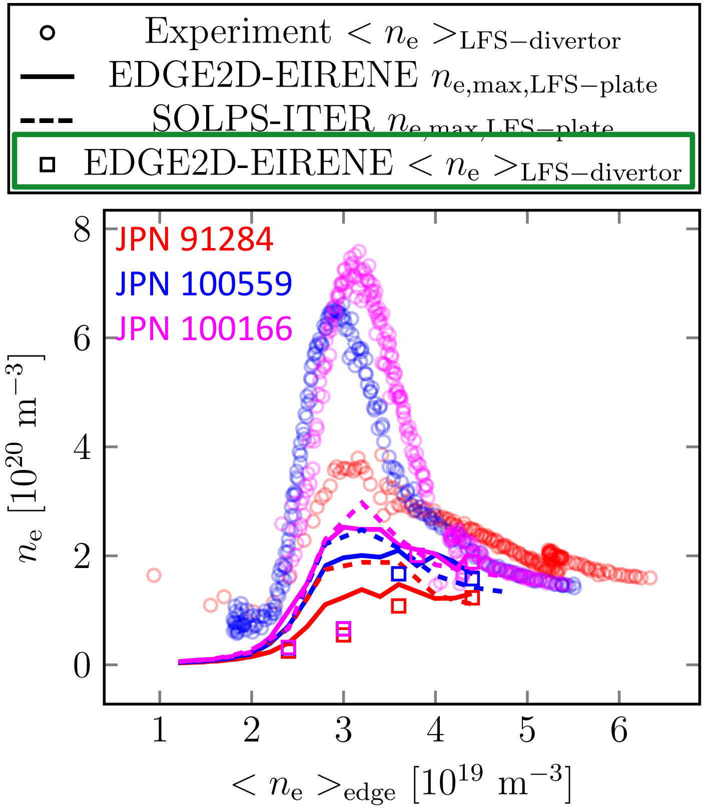

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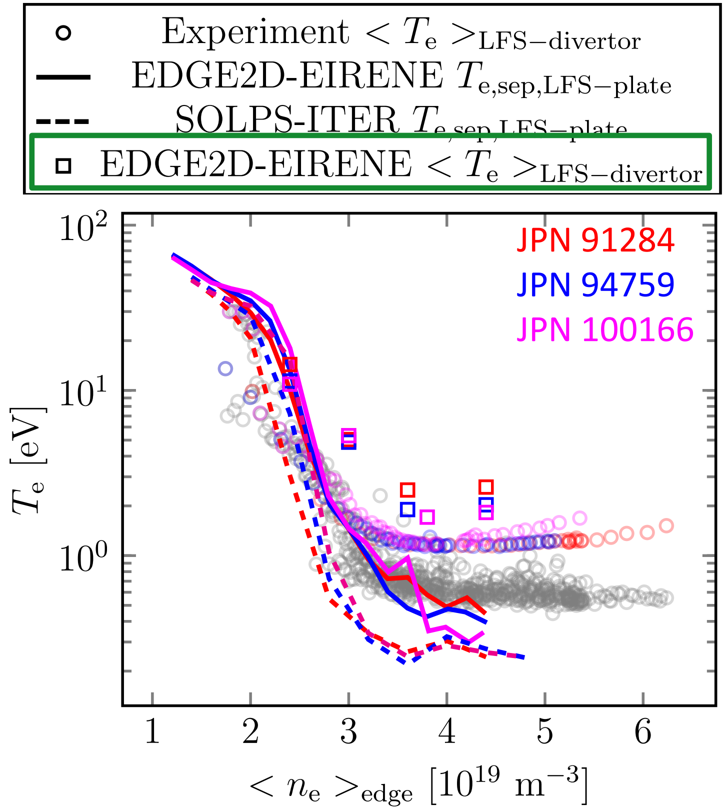

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T_e derived from differentiation of continuum emission between two wavelengths: increased T_e for 360-393 nm (incl. recombination edge)

[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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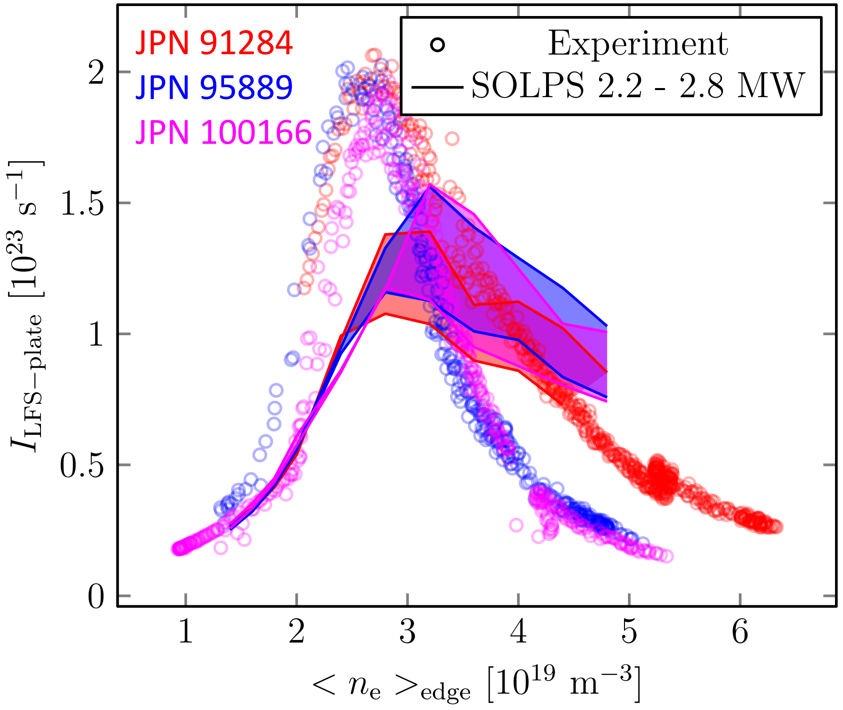

- Uncertainties on power due to increasing Q_Ohm and $Q_\text{rad,core}$ for increasing $<n_e>_\text{edge}$
- $T_\text{e,sep,m}$: ≈60 eV → ≈70 eV at original onset of detachment when increasing power to 2.8 MW
- $<n_e>_\text{edge} \approx 2\times n_\text{e,sep,m}$ needs revision to obtain correct pressure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

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

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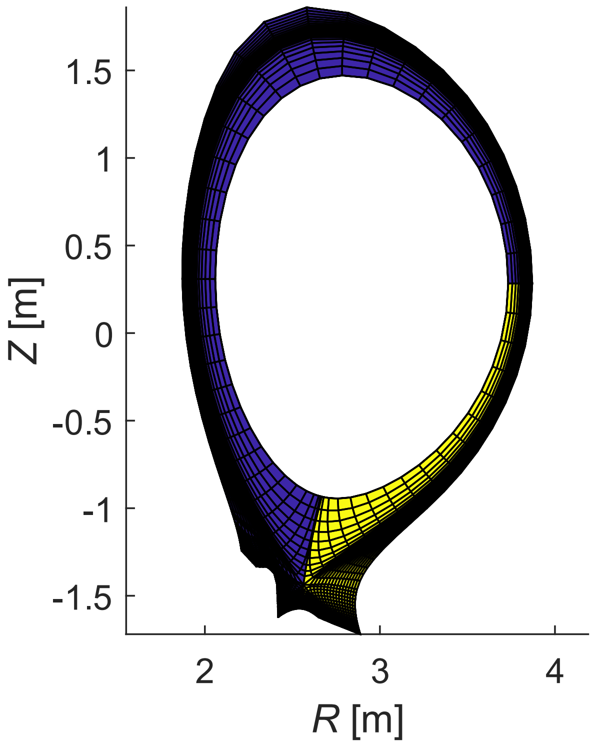
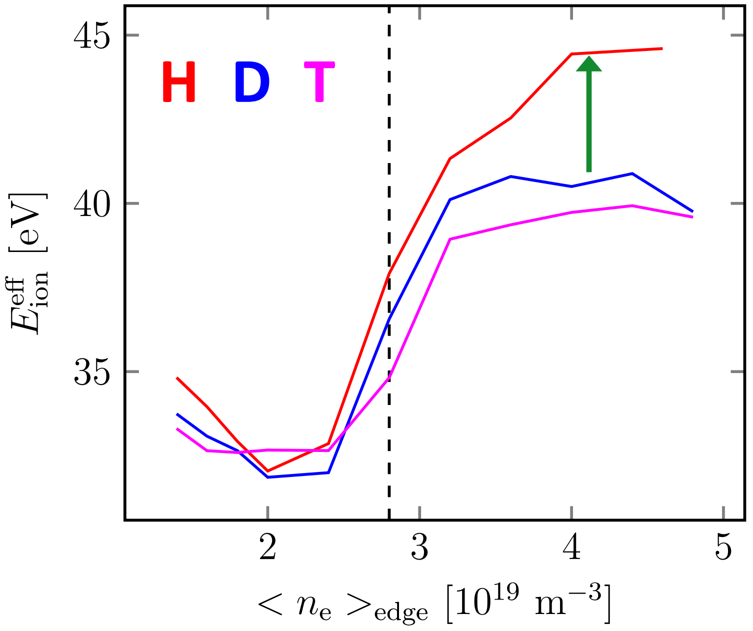
Integrated over LFS region



Increased power loss due to molecular processes for H



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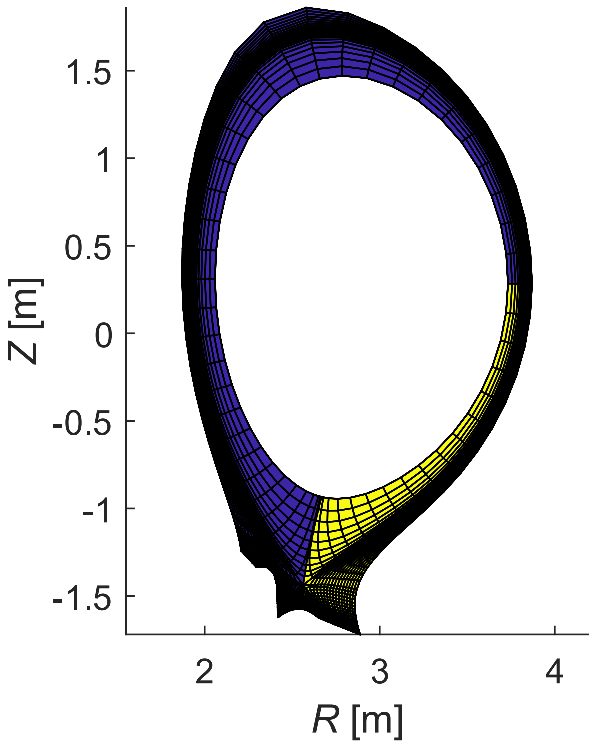
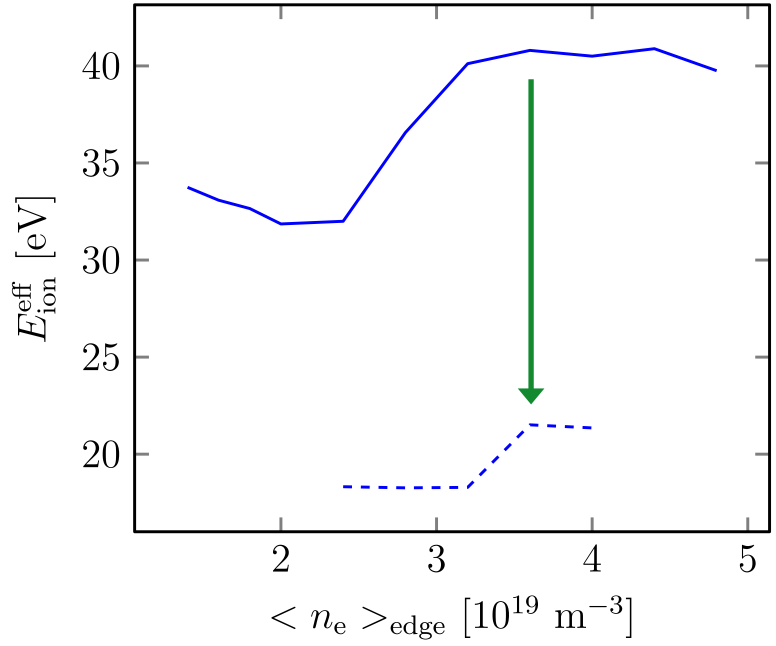
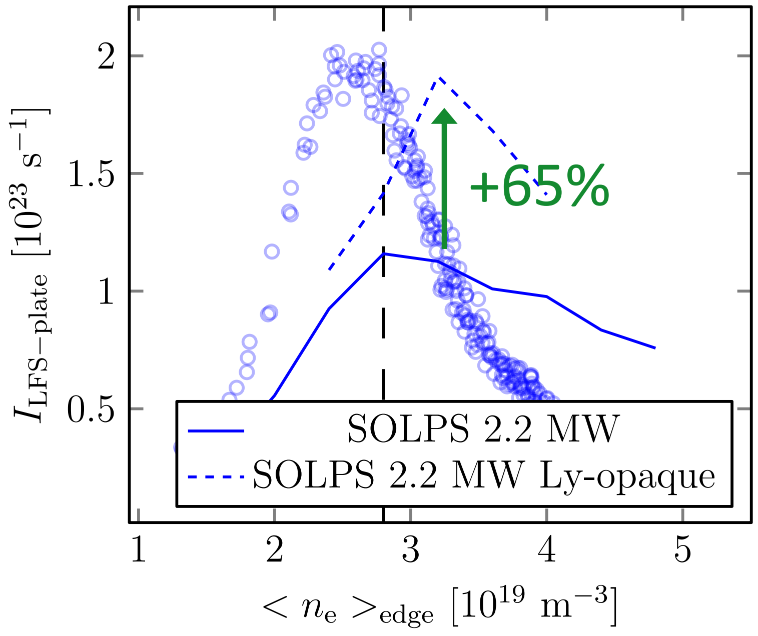




D+e → D^{+}+2e:
AMJUEL 2.1.5**o**



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

- General overview [A. Pshenov et al., NME **34** (2023)]
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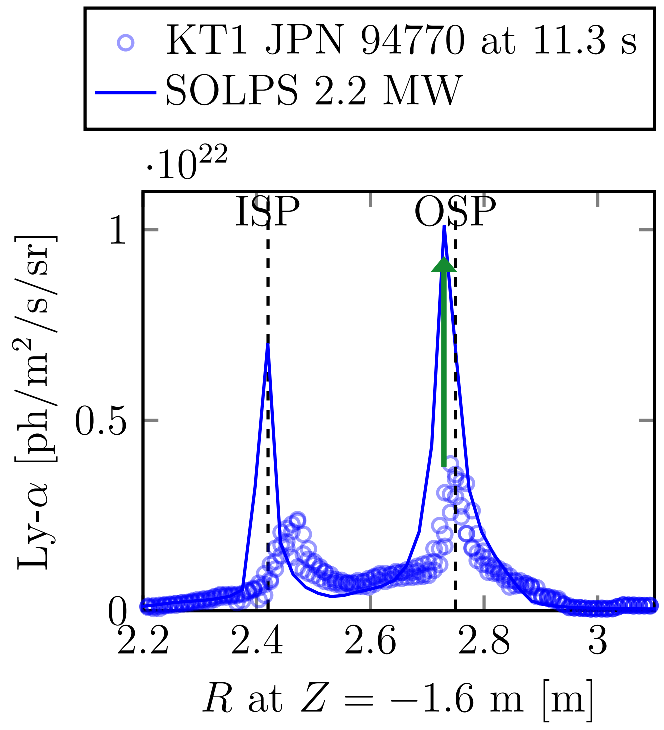

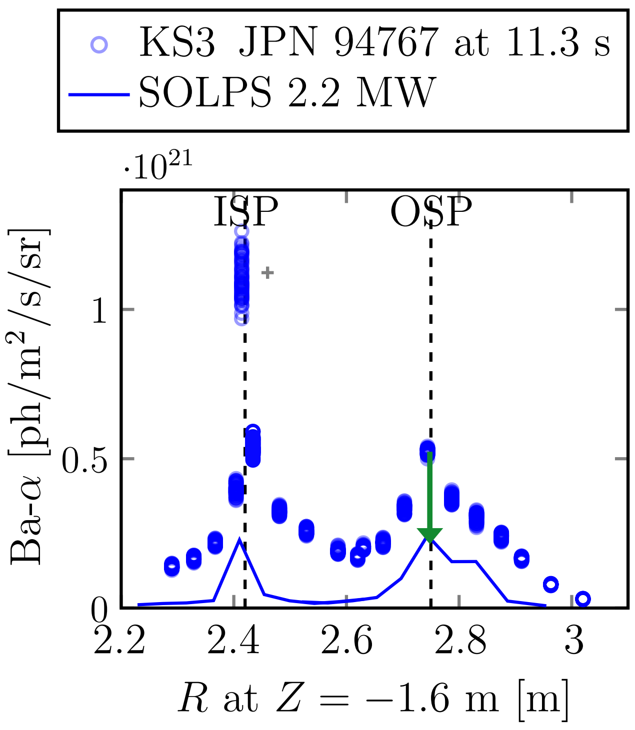

At onset of detachment, simulations overestimate Ly-α and underestimate Ba-α [N. Horsten et al., NME **33** (2022)]

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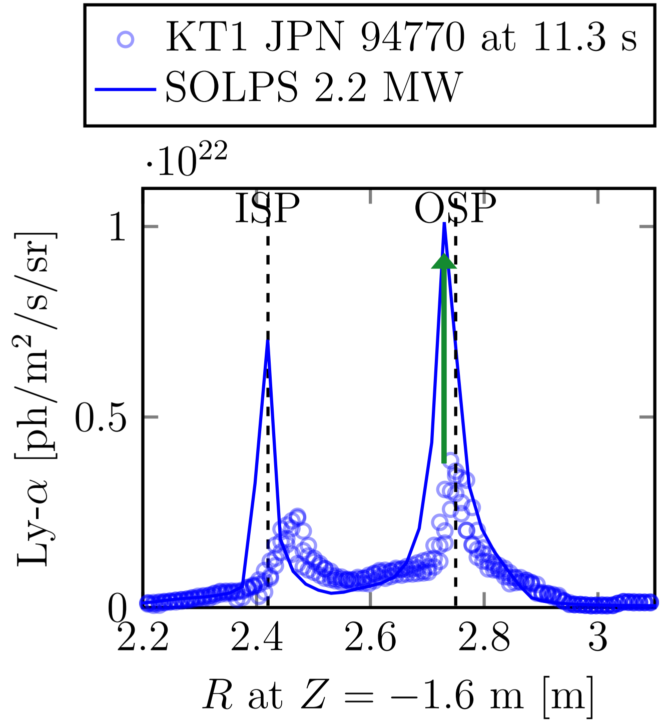

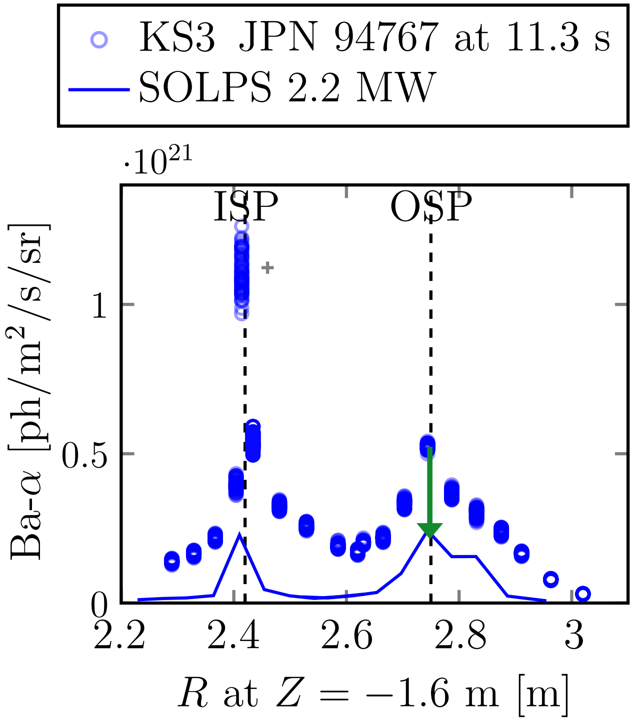

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Need for coupled plasma-neutral-**photon** simulations!
[R. Chandra et al., NME **41** (2024)]

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

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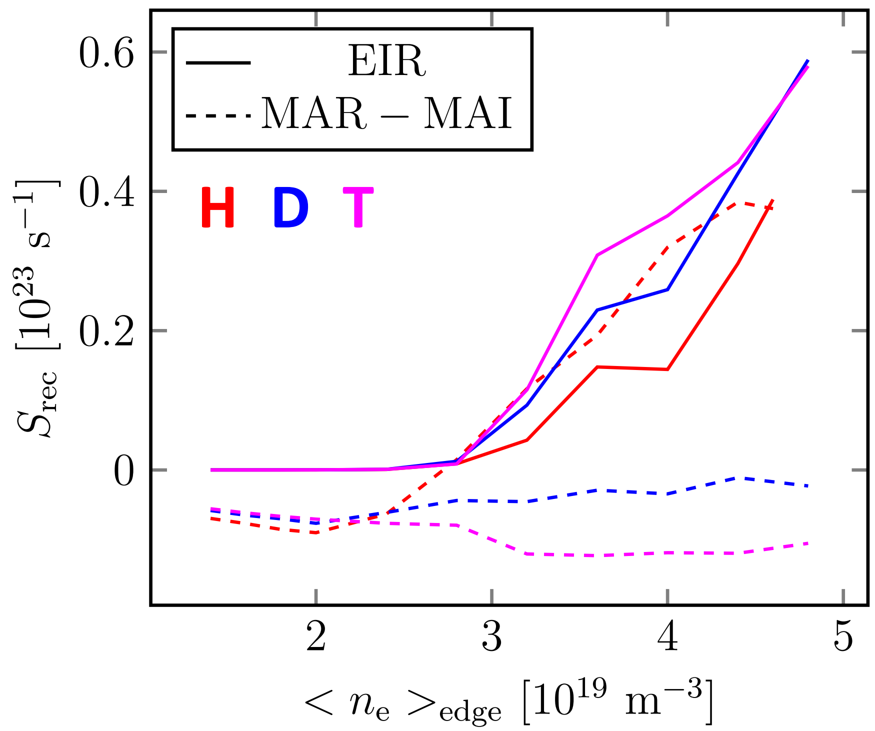
SOLPS-ITER, 2.2 MW



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

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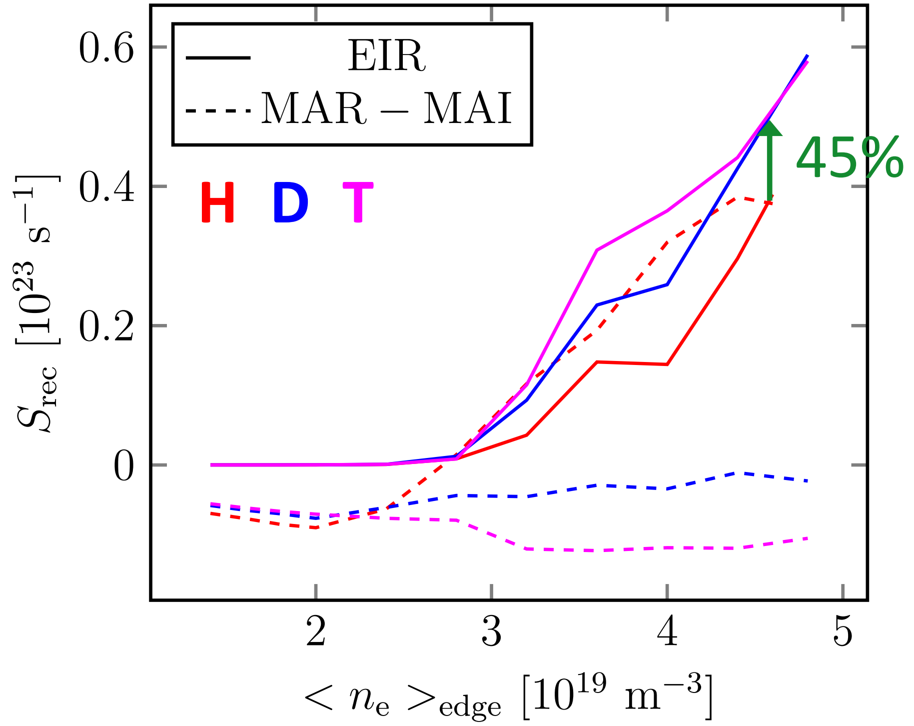
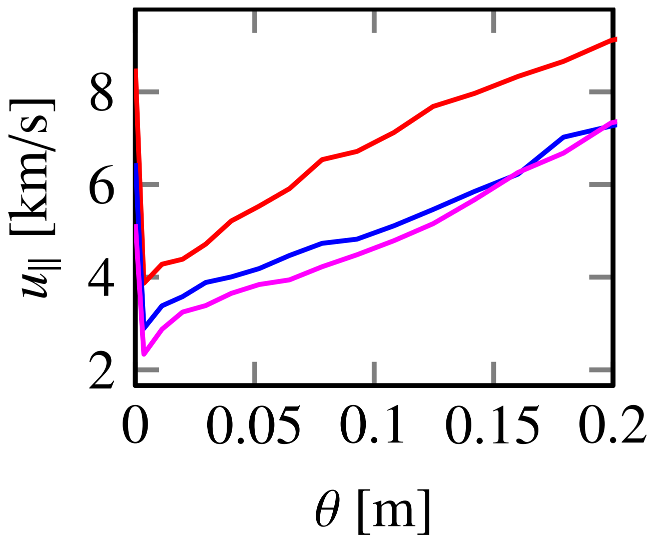


Velocity $\sim 1/\sqrt{m}$ ➔ more time to recombine for heavier species



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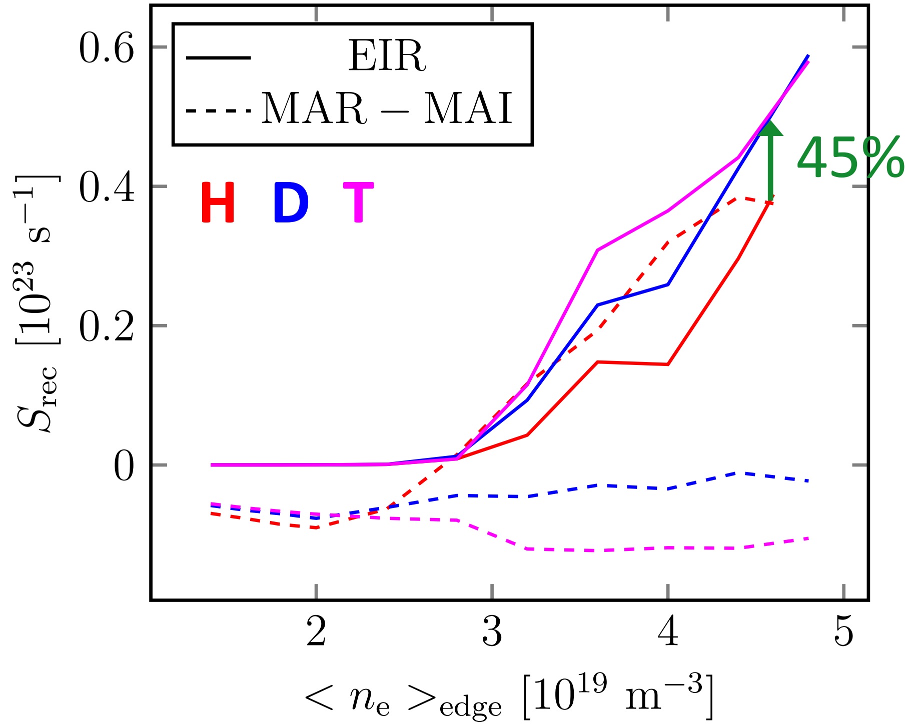

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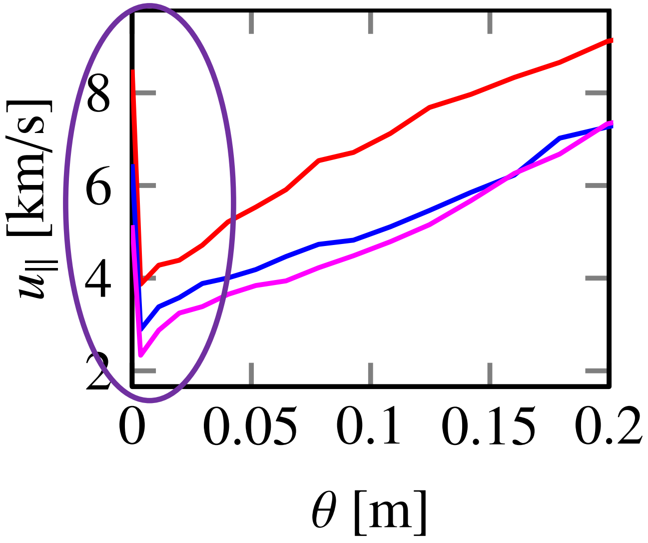

Revision of sheath b.c.'s needed [D. Tskhakaya, D. Moulton]

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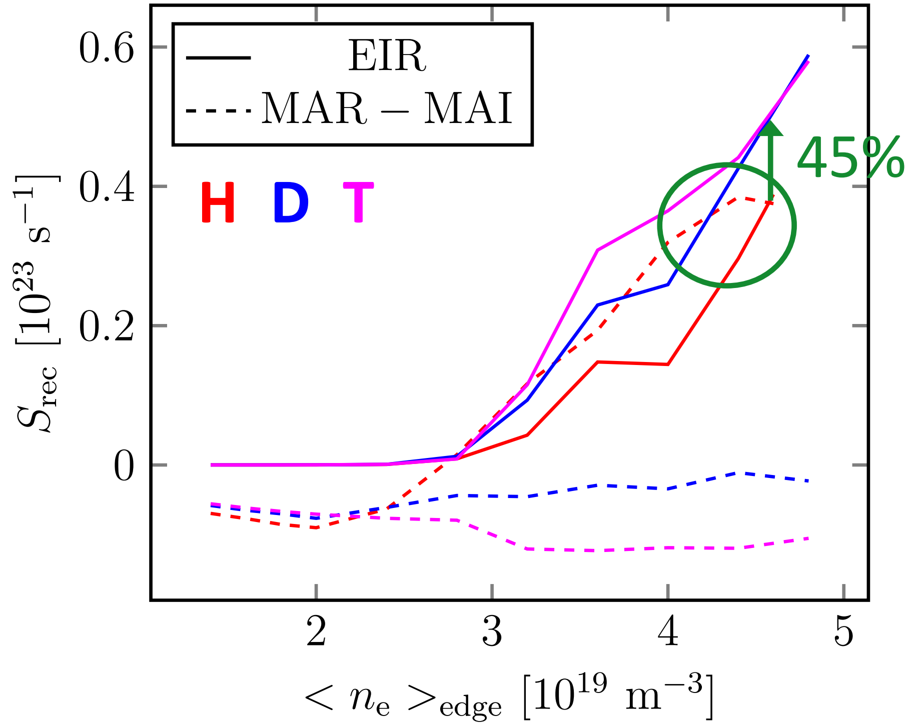

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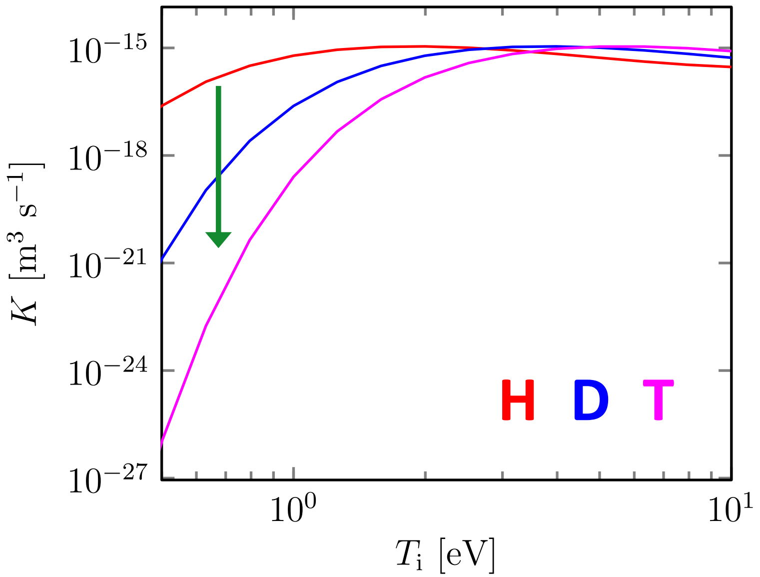
- Only net **H** production from molecular processes (MAR – MAI) for H plasmas

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



Revision for D and T necessary?

[K. Verhaegh et al., NF **63** (2023)]

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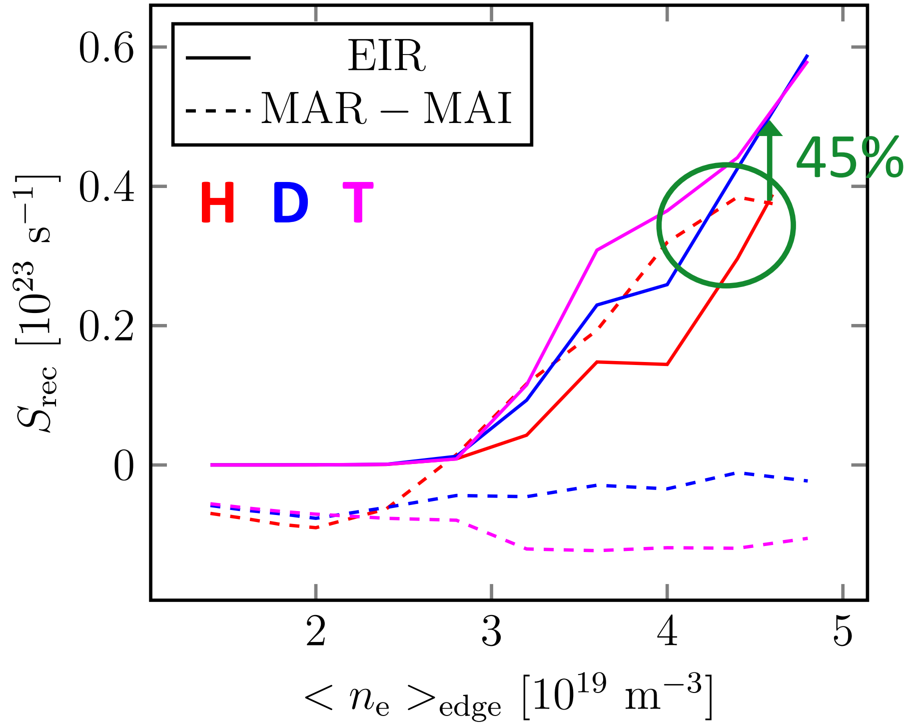
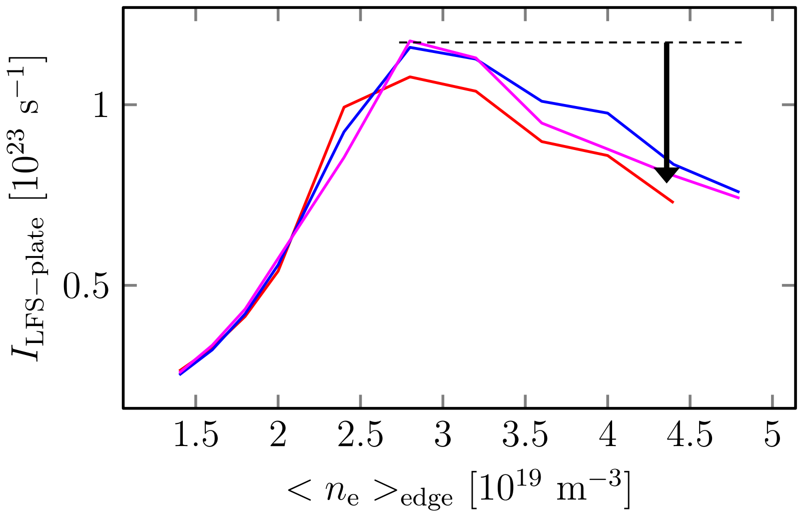


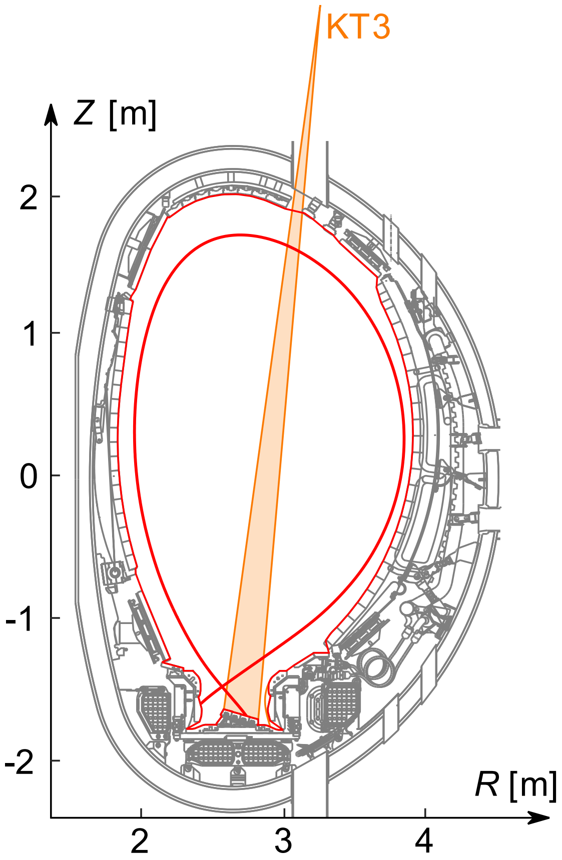
- 45% increase in electron-ion recombination (EIR) for D/T plasmas compared to H plasmas
- Only net **H** production from molecular processes (MAR – MAI) for H plasmas

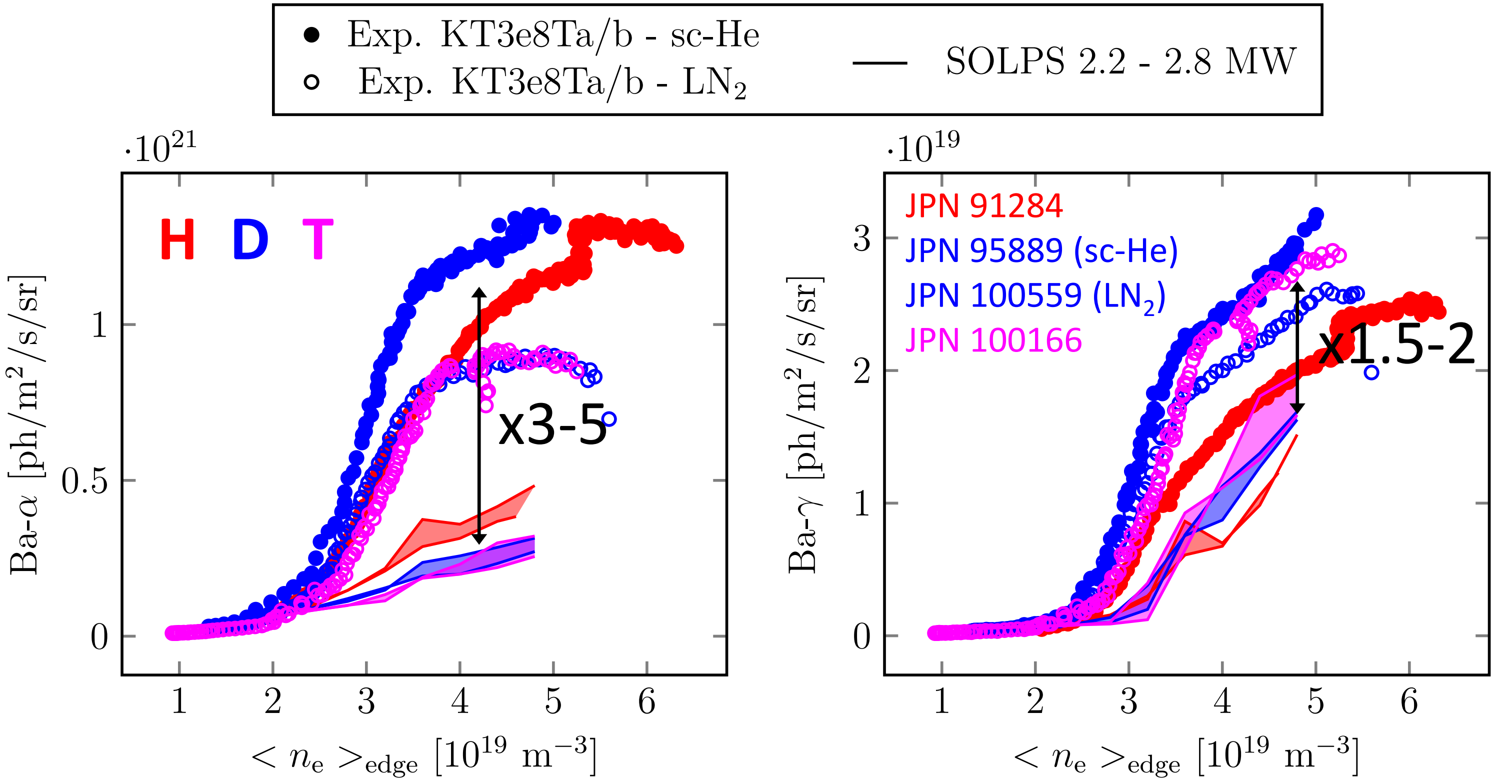
➔ Combined effect gives similar $I_{\text{LFS-plate}}$



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

Ba emission
averaged over tile 5





*No contributions of reflected light in simulations (~30-40%)

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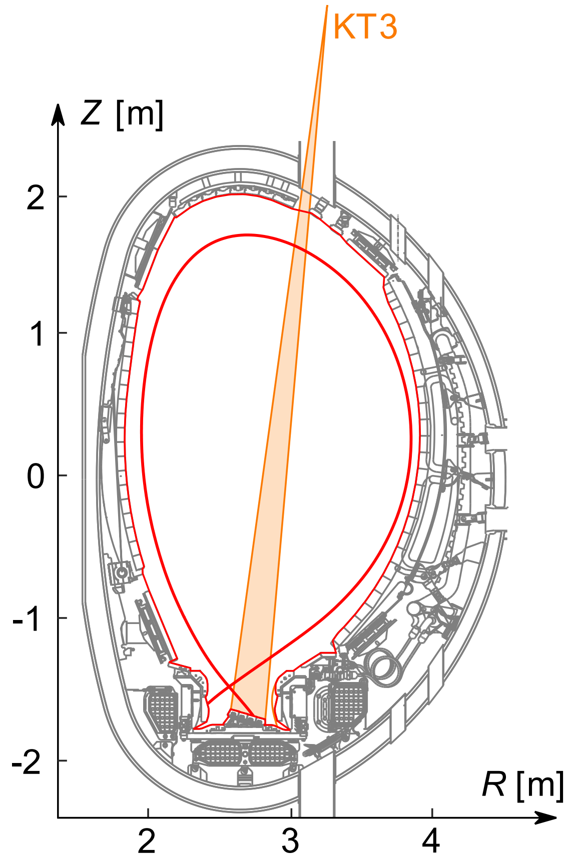

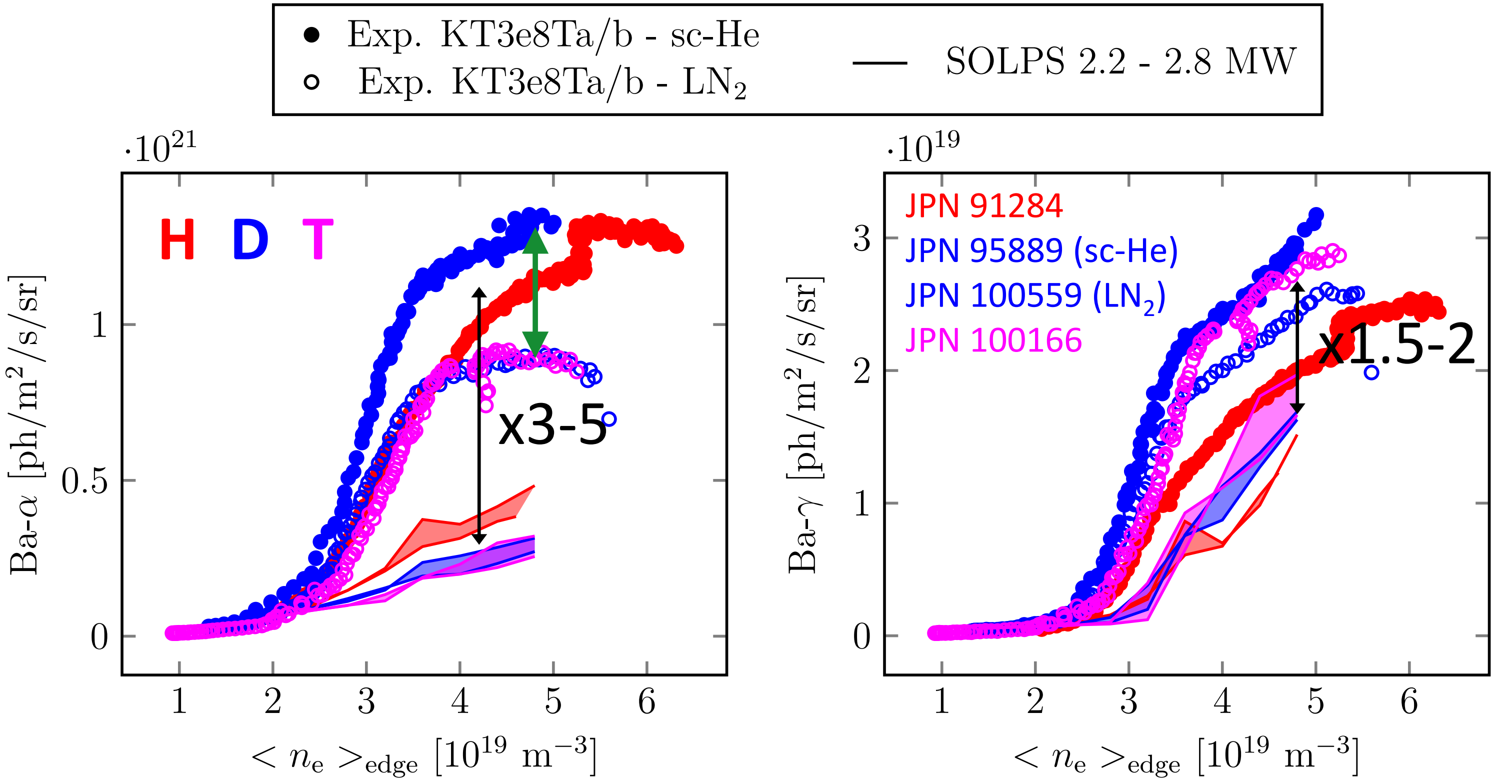

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Significant effect of pump in experiment

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

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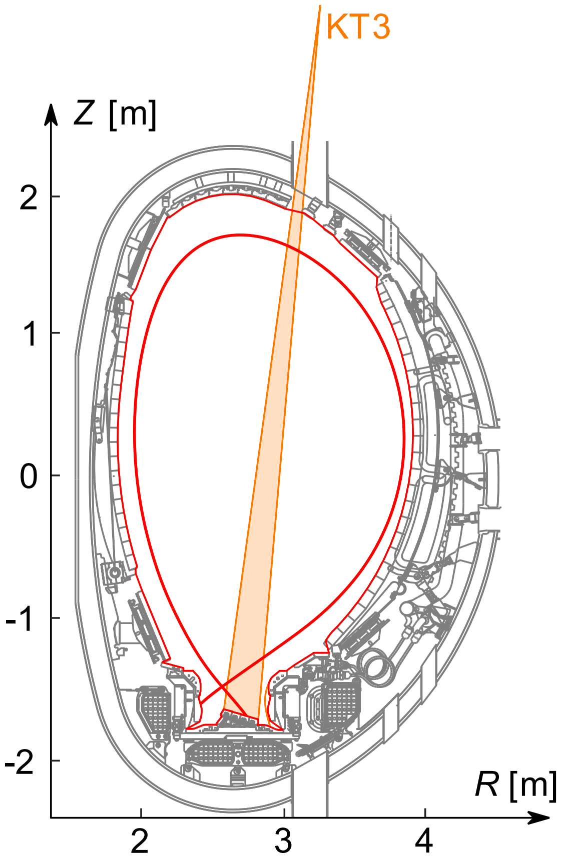

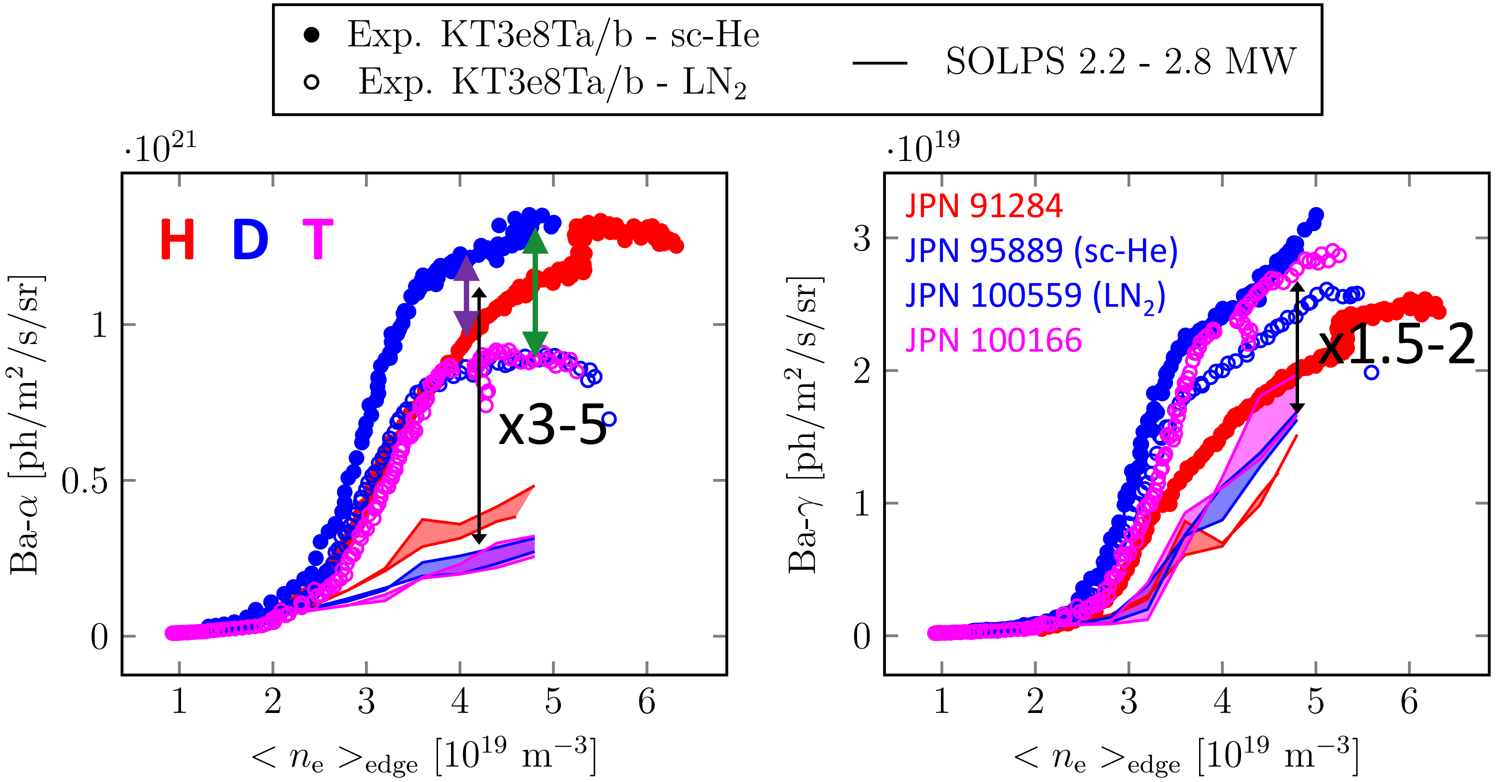

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Significant effect of pump in experiment
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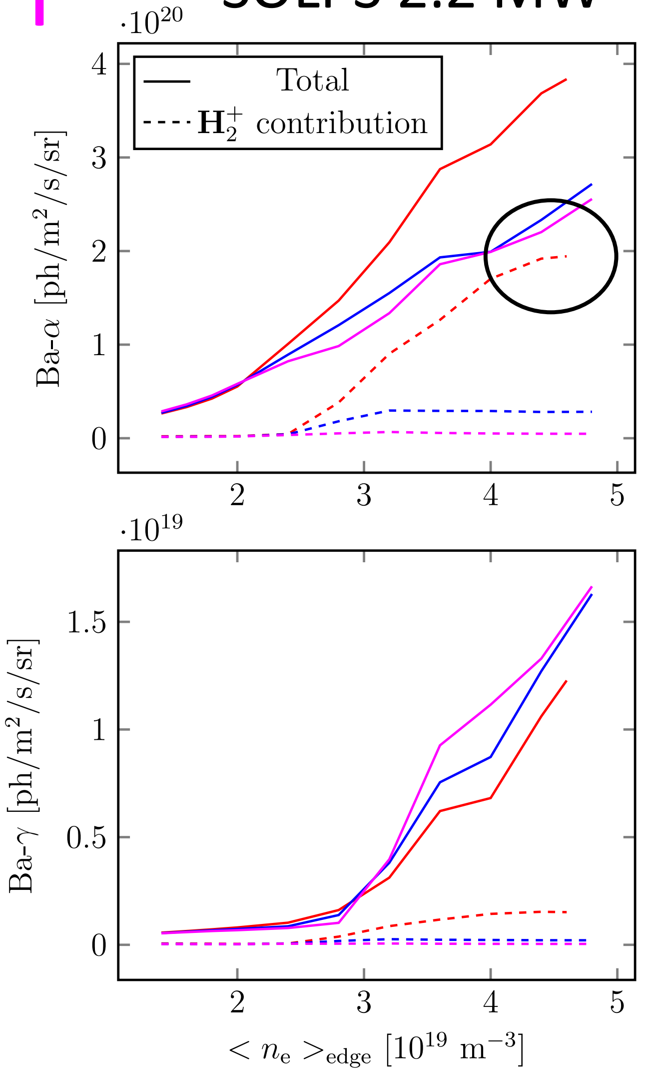
Ba-α lower for H than D/T in experiment ↔ opposite in simulation

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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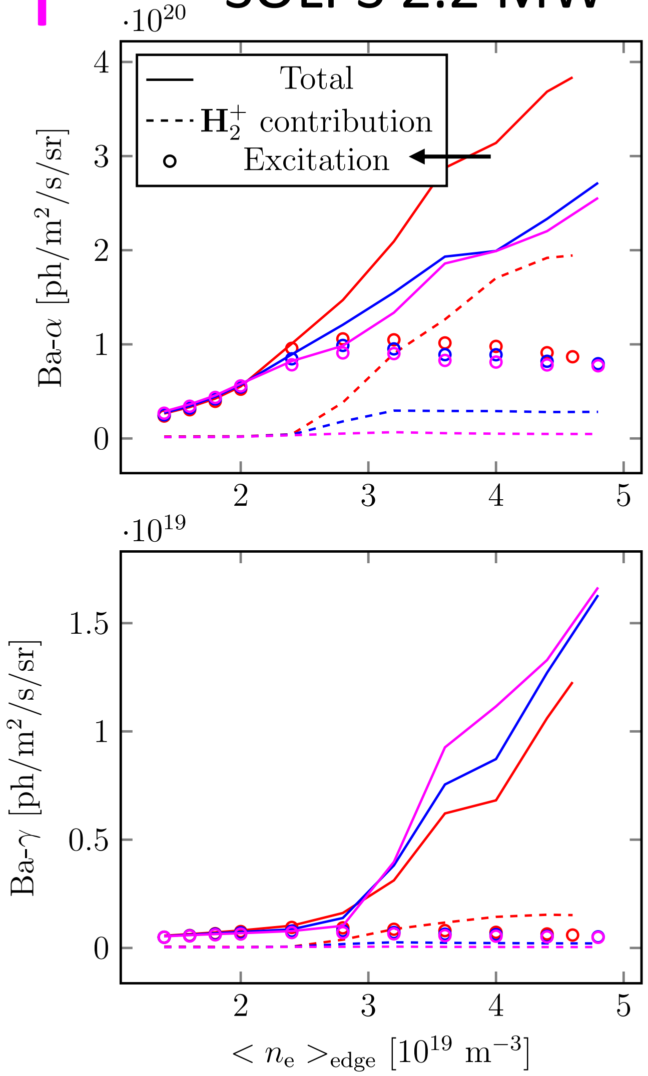

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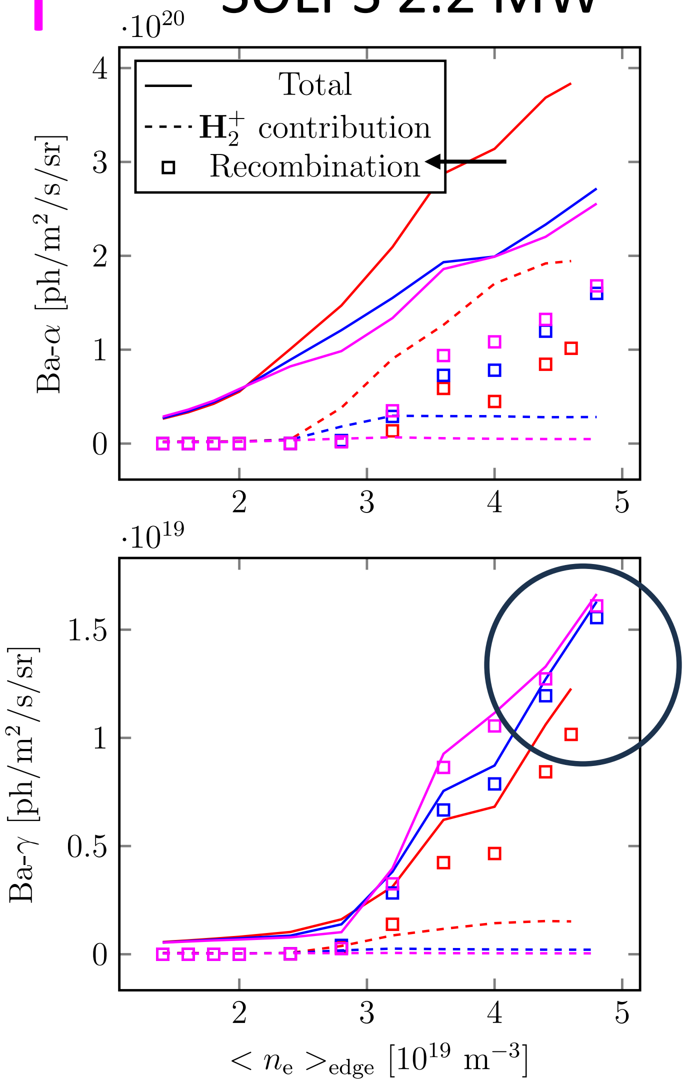

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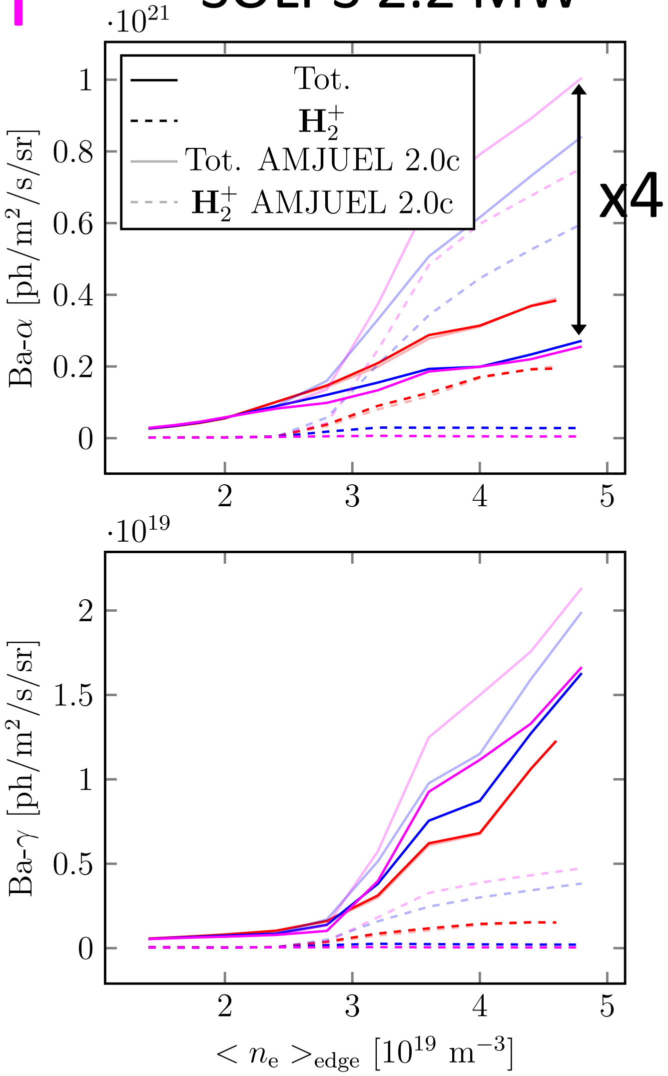

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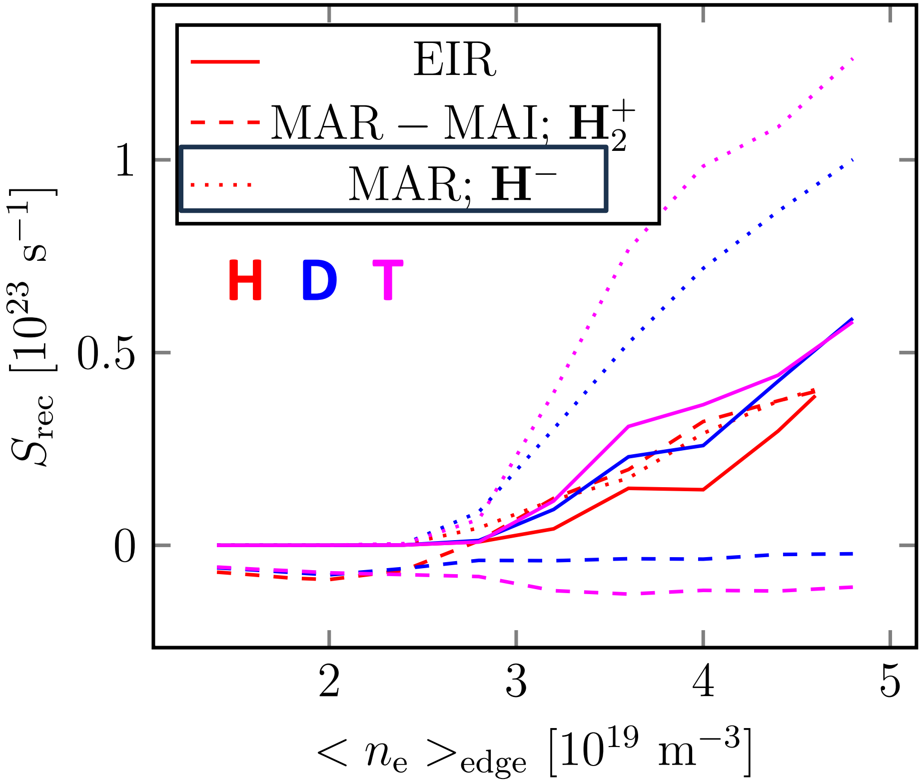
- Atom excitation similar for all isotopes

- 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., *emolrad* 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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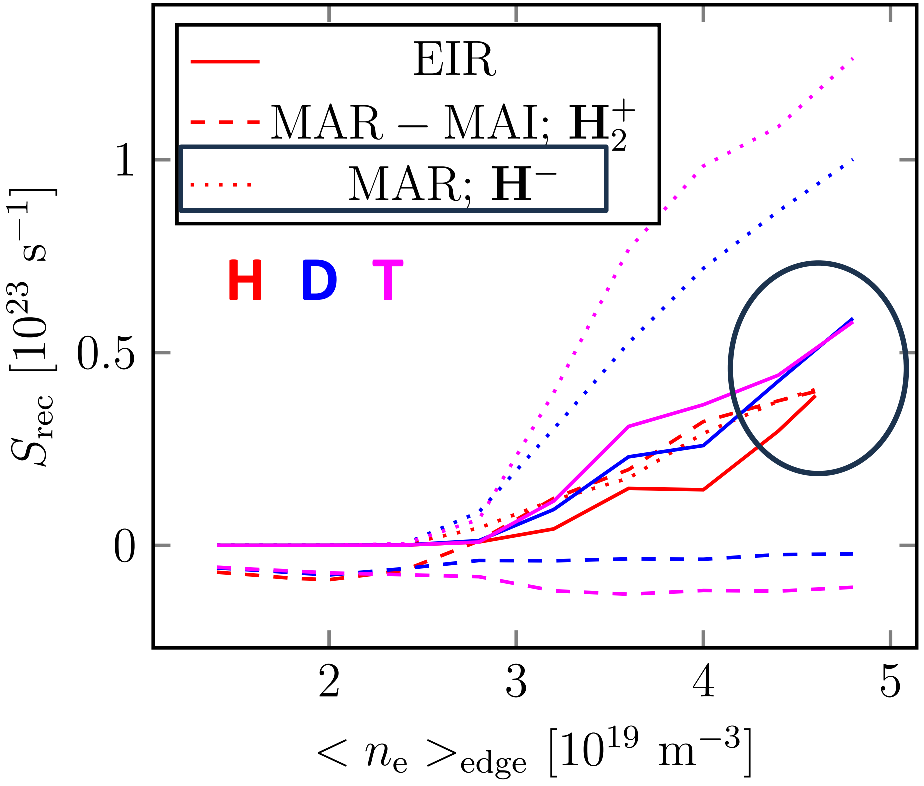

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$$H_2 + e \rightarrow H^- + H$$
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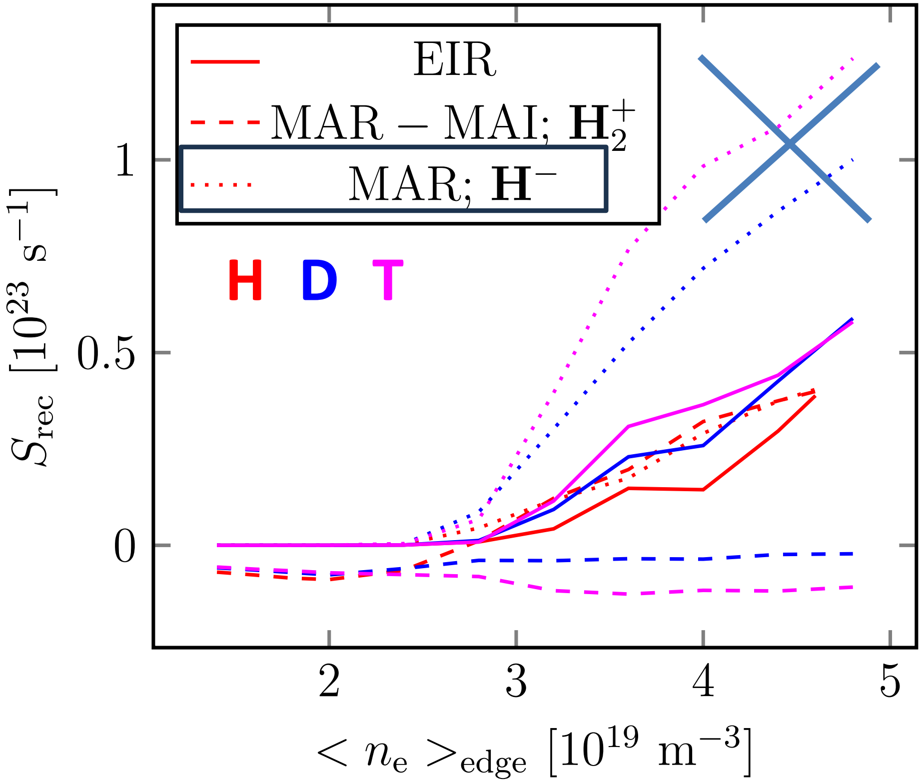

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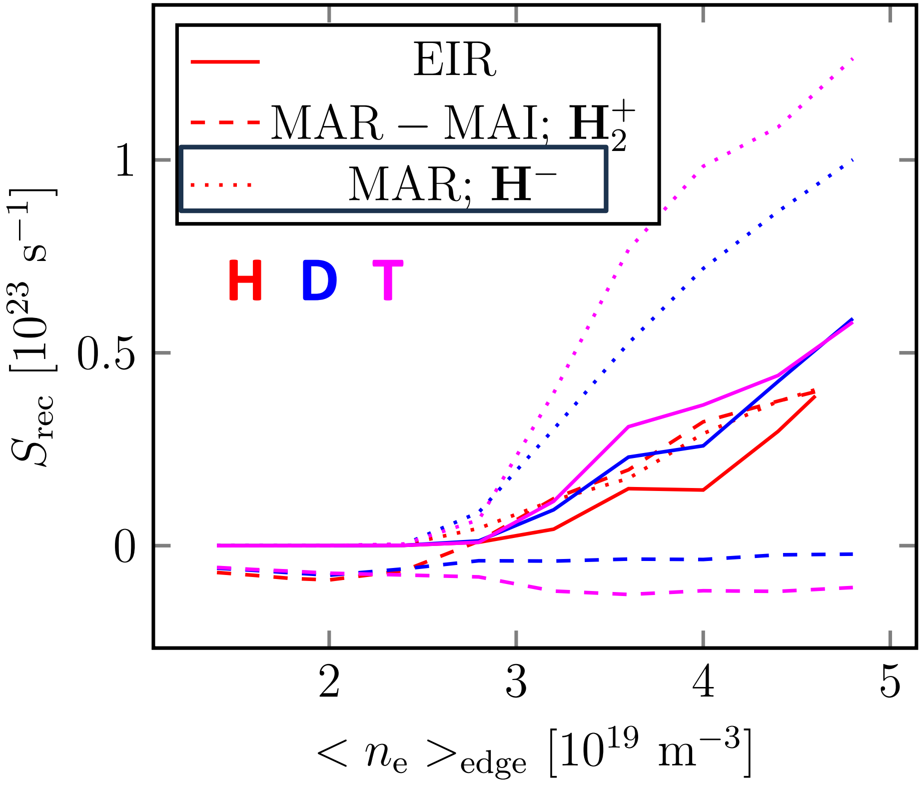

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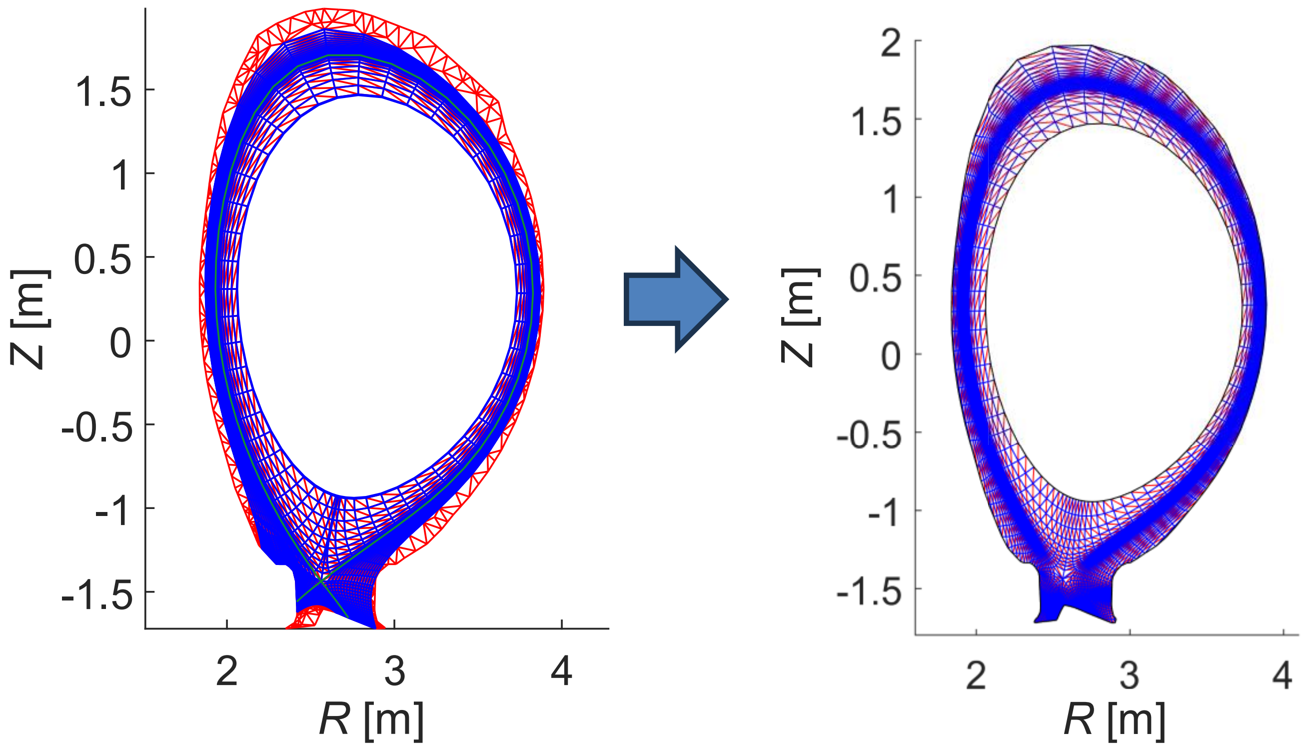
Collisional-radiative model (CRM) to properly assess the isotope effect!

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

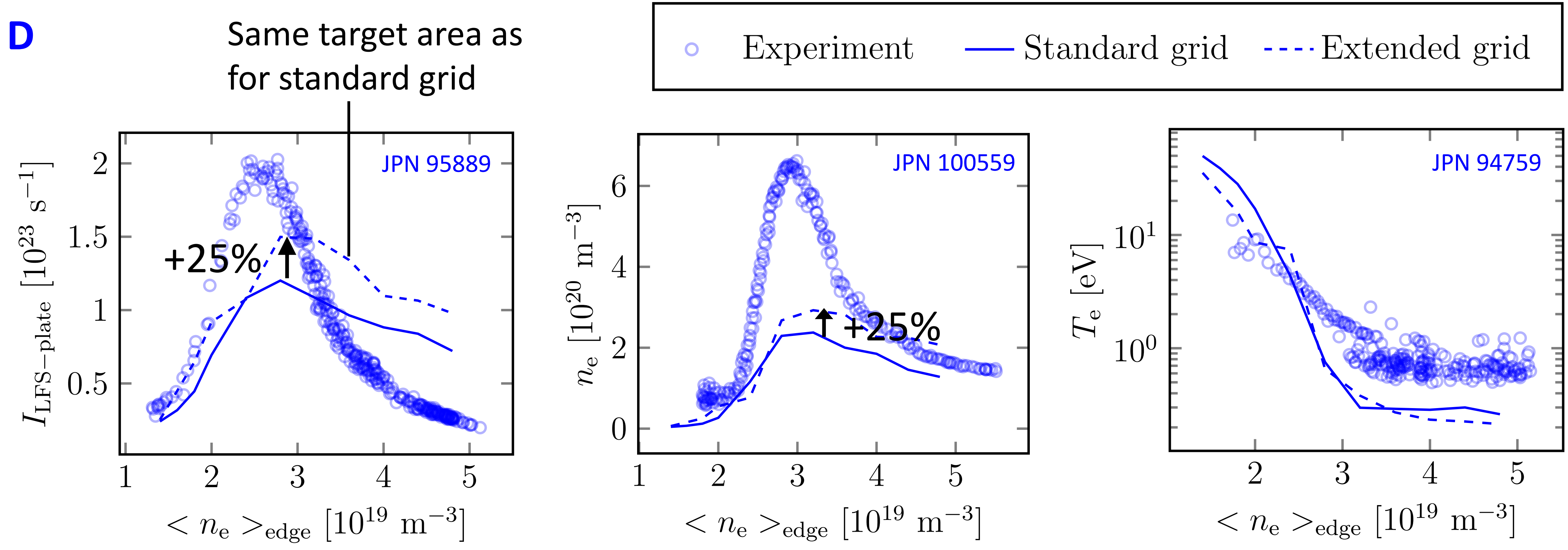
Standard Extended



B2.5 EIRENE

- 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%



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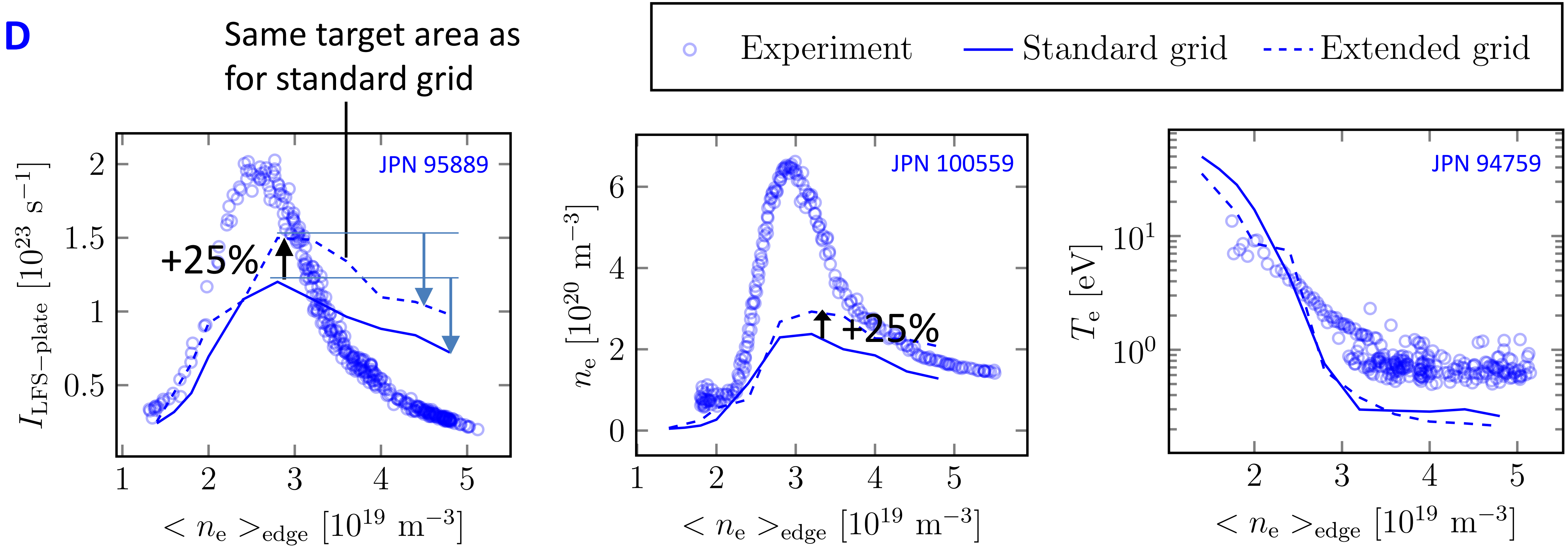
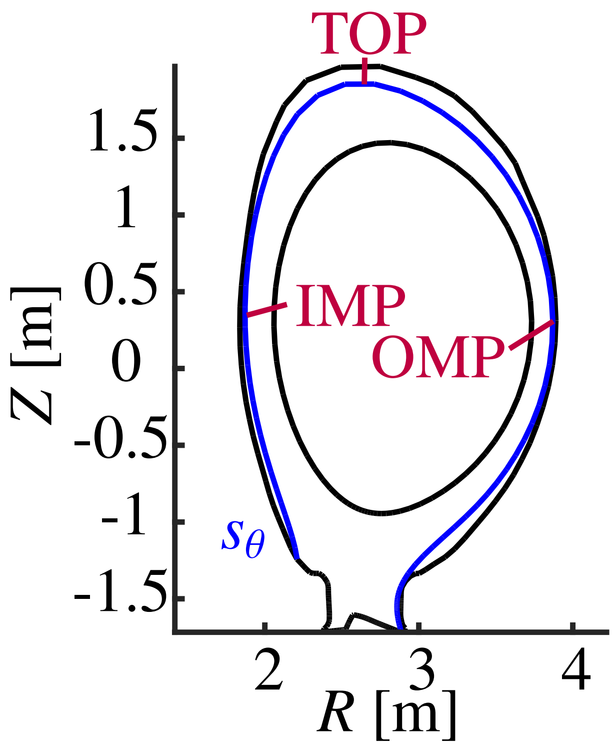
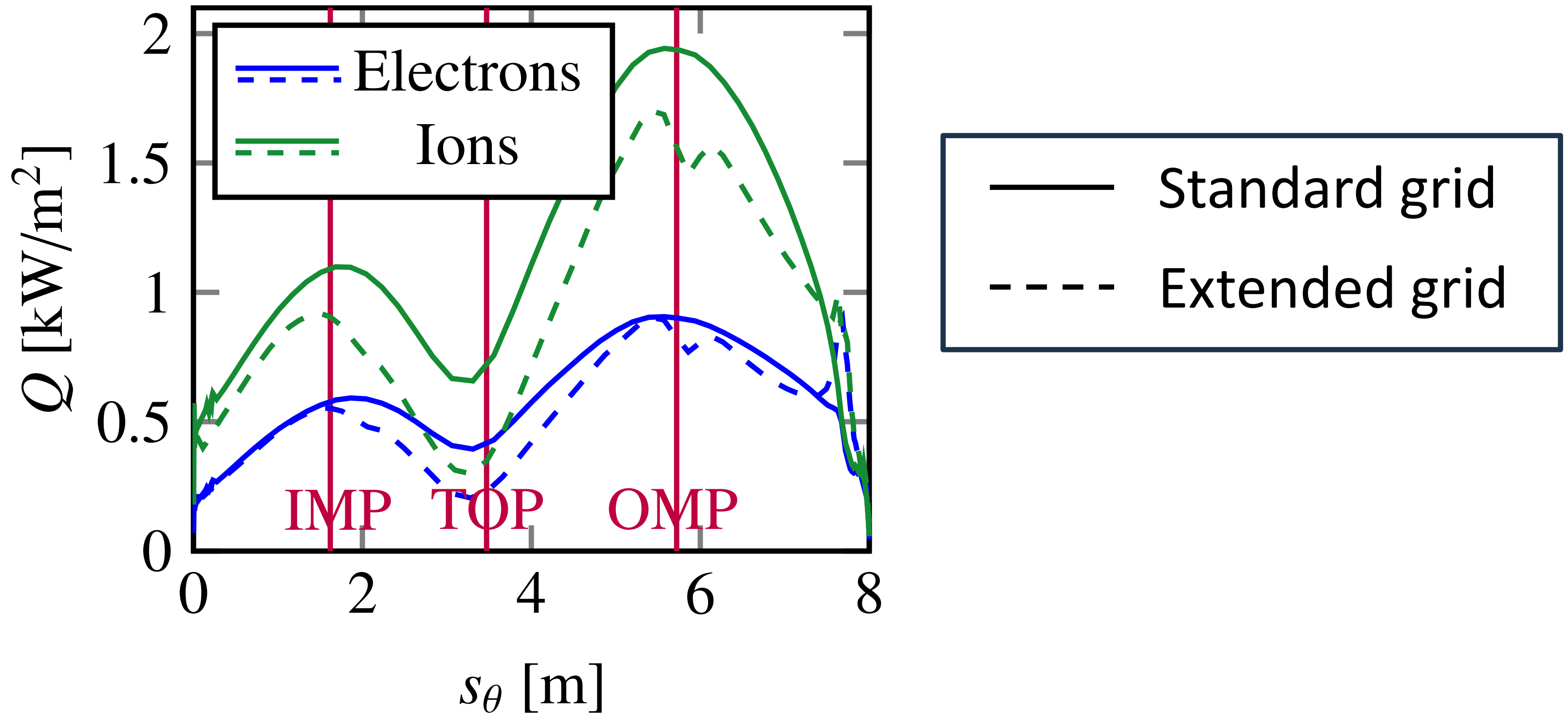


No significant difference for the decrease of $I_{LFS\text{-}plate}$ with increasing $\langle n_e \rangle_{edge}$ in detached conditions between standard and extended grids

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

Power crossing the standard grid boundary





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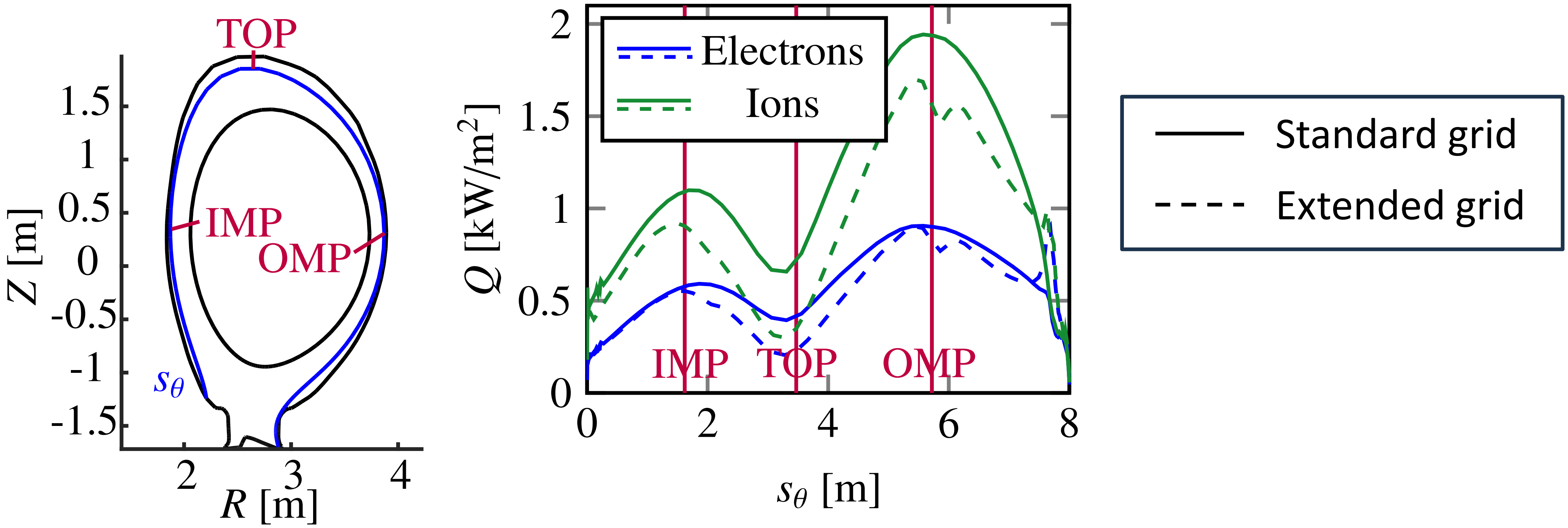

More power available for ionization ➔ $\Gamma_w \approx \frac{Q_{SOL}}{E_{ion}^{eff} + \gamma T_w} - S_{rec}$

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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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➔ Underestimate of MAR for D/T?

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

Increased ionization & recombination for extended grids

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