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The impact of main ion species on divertor plasma detachment in tokamaks

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Aim is to improve understanding of SOL physics and detachment through comparison of Deuterium (D) and Helium (He) plasmas.

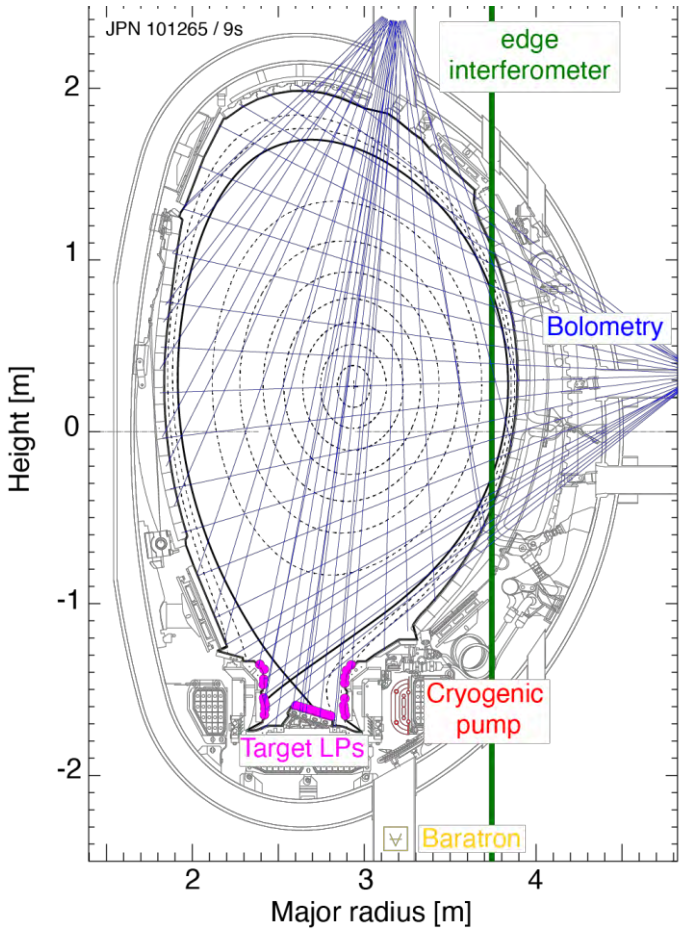
- JET ITER-like wall (JET-ILW) experiments with Deuterium and Helium as the main ion species
- SOLPS-ITER density scans matched to the D and He experiments

- Detachment moves the ionisation front away from the targets, temperatures are reduced to T_e<<3 eV, and the upstream plasma pressure is maintained.
  - Favourable for future reactors to reduce heat flux to the divertor

- He has a higher mass, two charge states, a longer mean-free-path of ionisation and higher ionisation cost

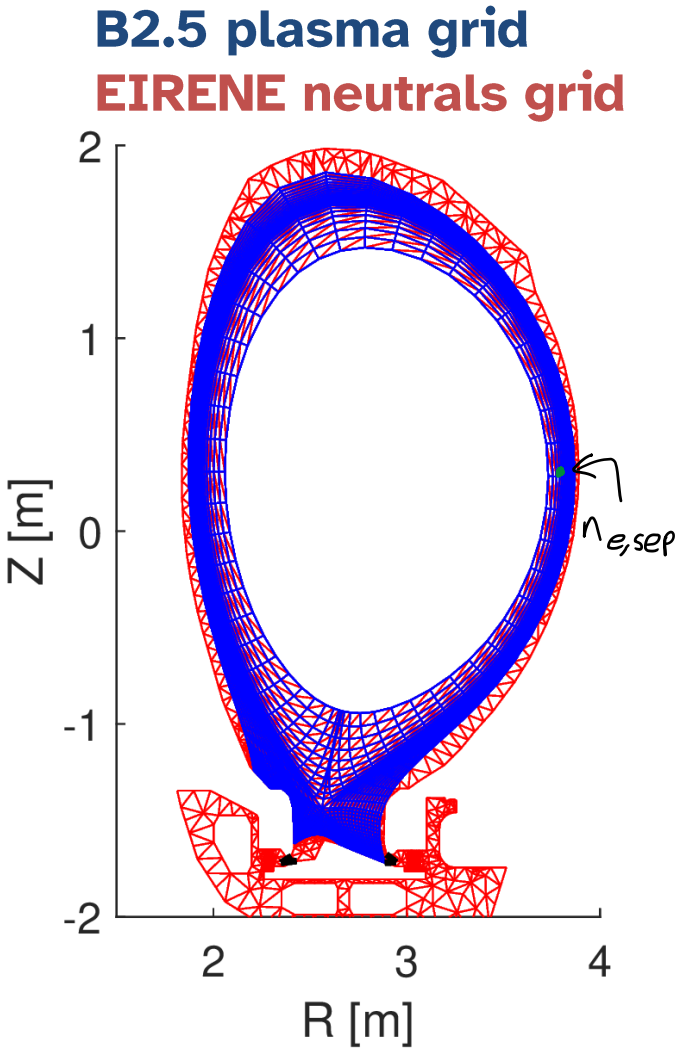
- Pure He plasmas offer a way to validates codes and SOL physics understanding

Fuelling ramps and steps with pure D and He L-mode plasmas were performed in JET-ILW



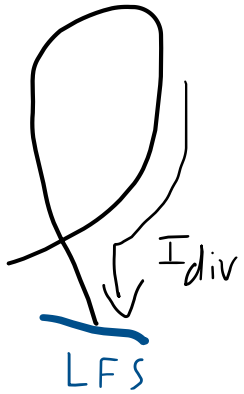
- LFS strike-point on horizontal tile
  - Optimised for diagnostics and edge modelling [M. Groth et al., NF (2013)]
  - $B_T = 2.5$ T, $I_P = 2.4$ MA, **B**x∇B into divertor (Typical for JET)
- 1 MW of neutral beam injection (NBI) heating
  - Also 5 MW NBI in He
  - NBI with same species as main ion
  - Higher L-H transition power threshold in He [E.R Solano et al., NF (2022)]
- Ar-frosting of cryo panel in He plasmas
- Sweeps of strike points for improved target profiles
- Edge line-averaged electron density, $\langle n_e \rangle_{edge}$, as proxy for SOL upstream density
- JET-ILW has W divertor and Be walls

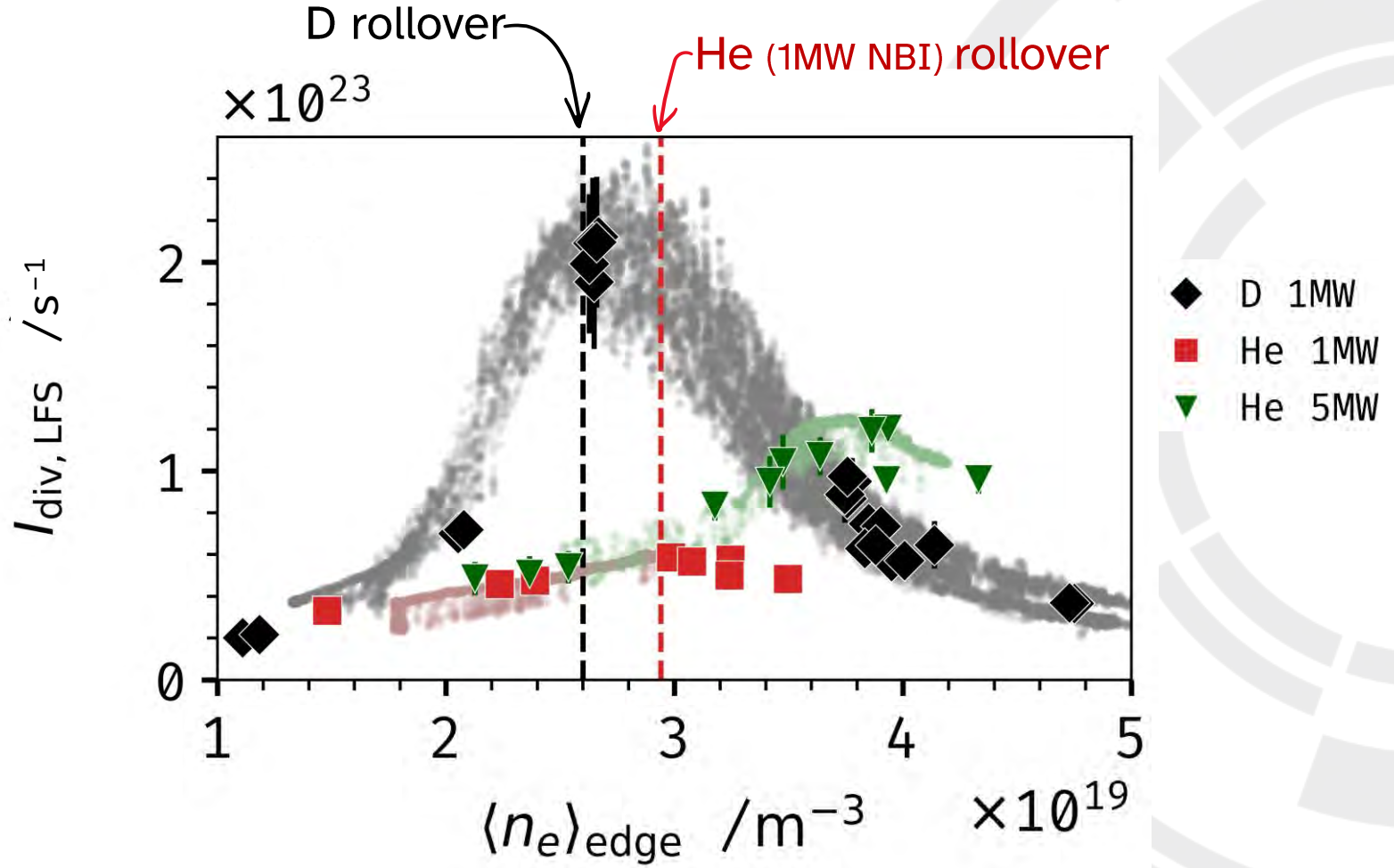
SOLPS-ITER density scan matching the JET-ILW experiments



- Original D case from [N. Horsten, et al. NME (2022)]
- Structured grid, with sub-divertor block
- Core boundary power 2.5 MW for He and 2.2 MW for D
  - And 5.5 MW for He 5 MW NBI case
- In He cases, 1% D at core boundary
  - No other impurities
- Spatially dependent transport coefficients
  - See M. Groth, et al. NF (2013)
  - Coefficients not altered for He cases

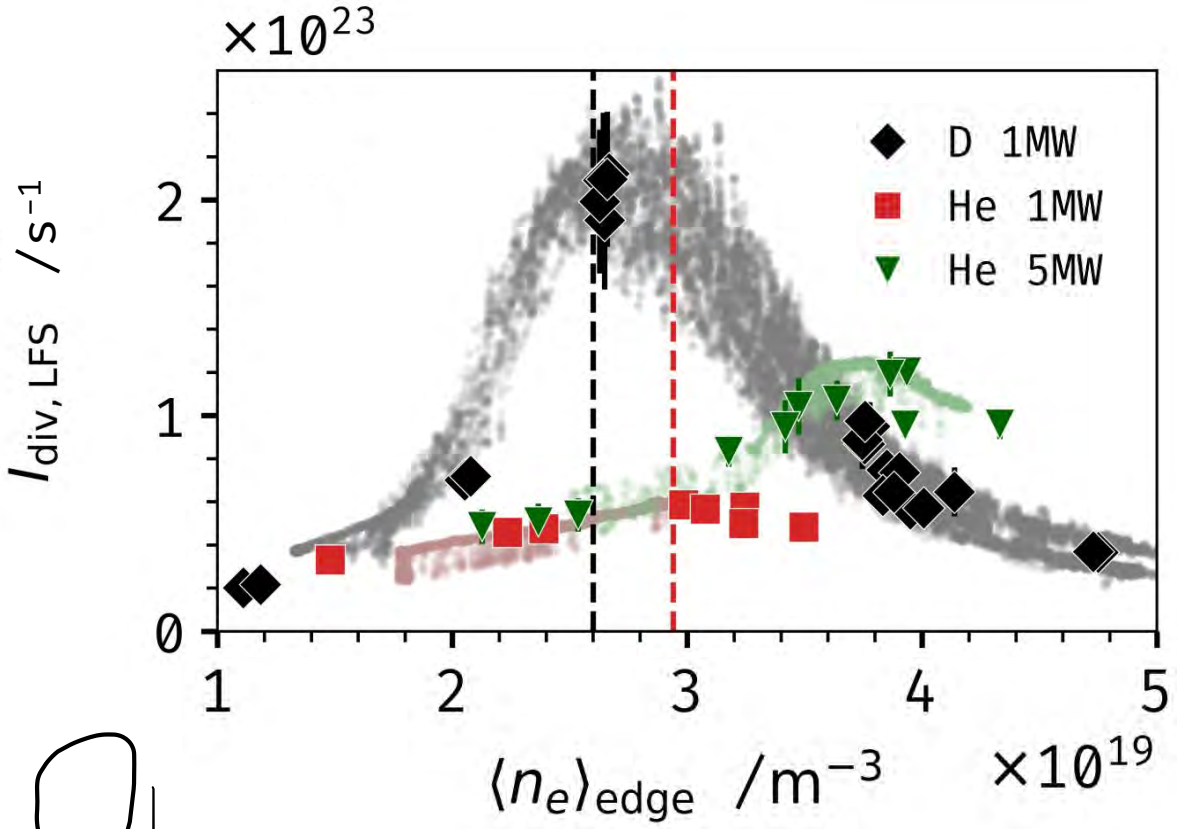
I_{div} rollover occurred at 10% higher $\langle n_e \rangle_{edge}$ in He than D on LFS. LFS current was 4 times lower in He than D. Increasing He NBI power from 1MW to 5MW increased rollover $\langle n_e \rangle_{edge}$ by 25%

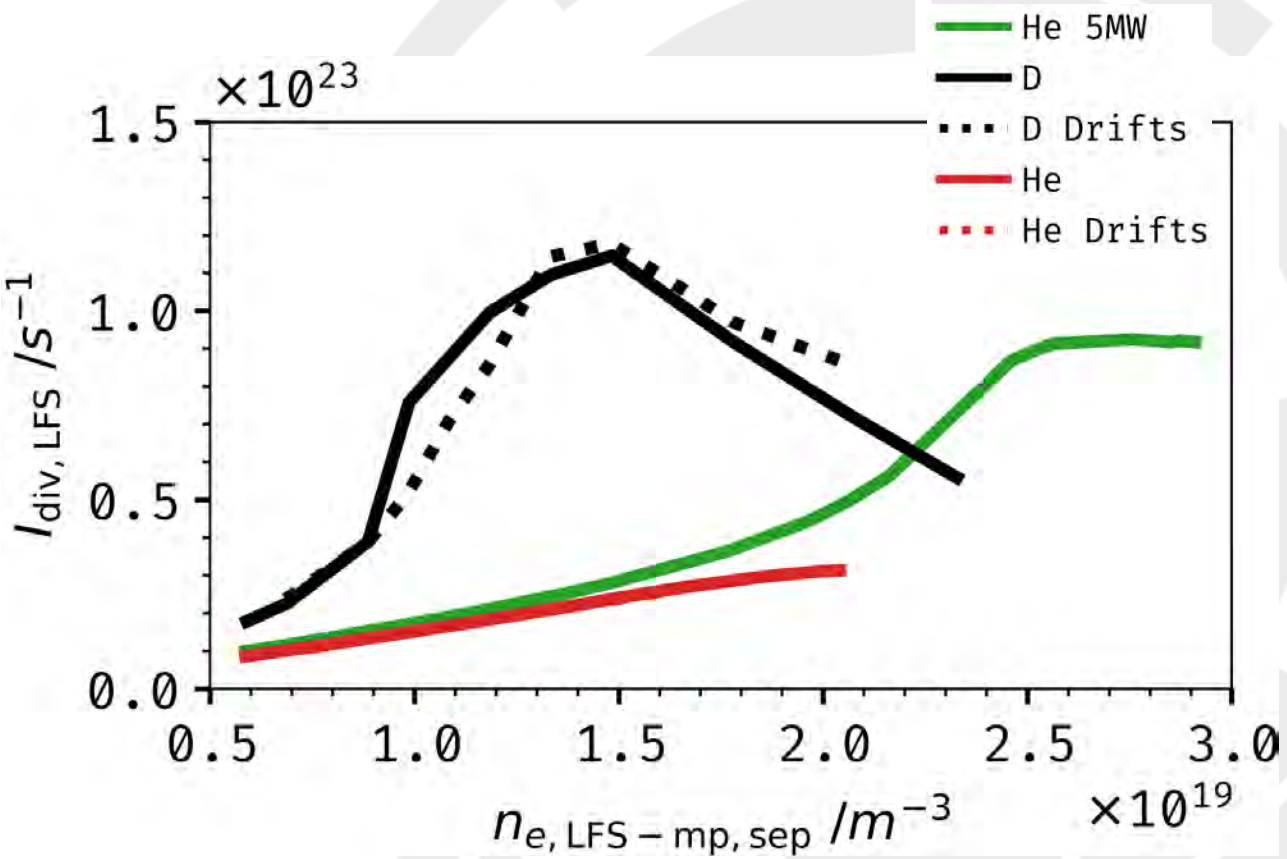




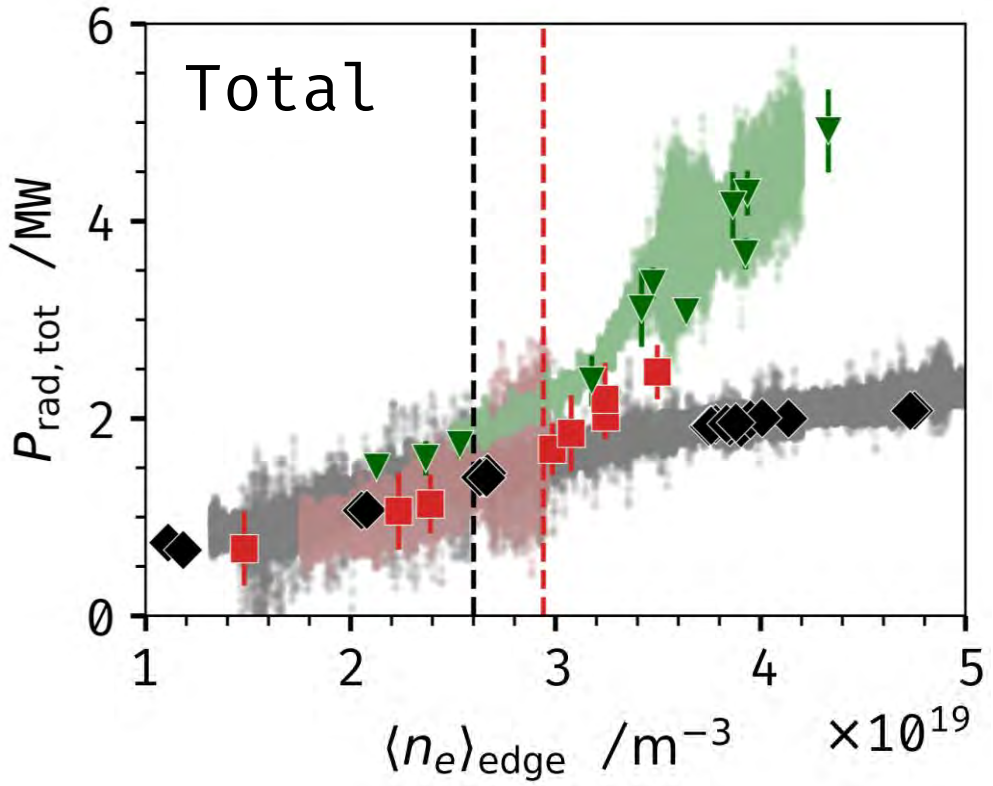
Plot modified from [Rees, D. et al NME (2024)]

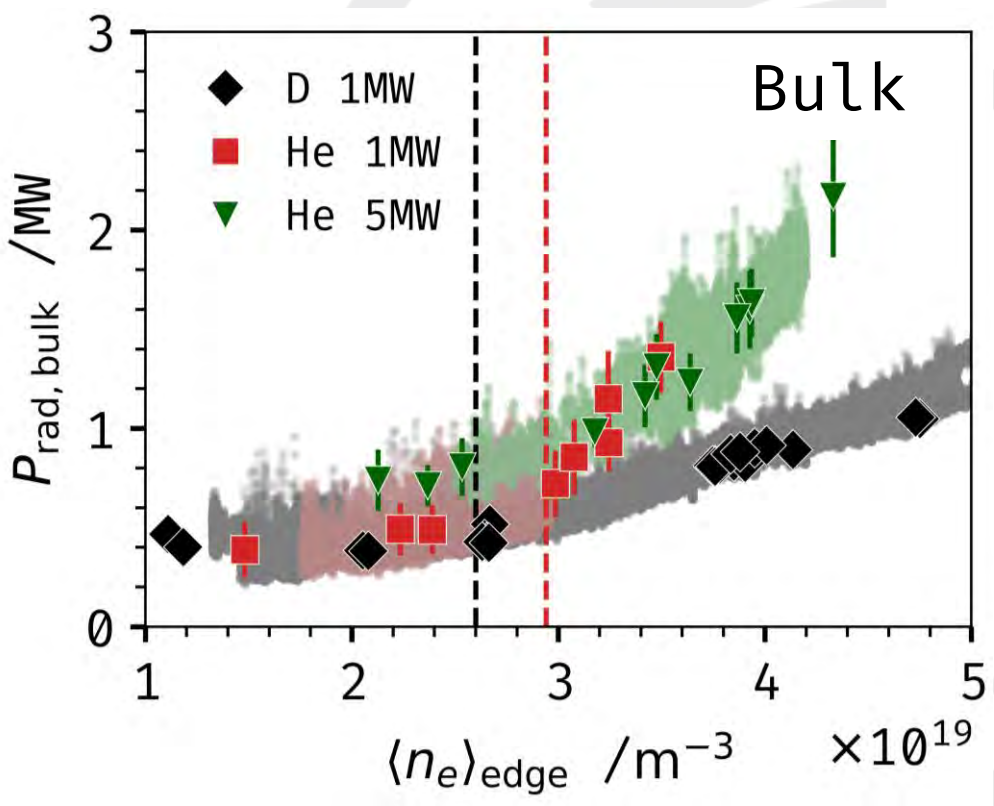
SOLPS-ITER underpredicts peak I_{div} by a half in both species for 1MW of NBI but does correctly predict the 4x difference. He onset of detachment is at 45% higher $n_{e,sep}$. Scaling of $n_{e,sep}$ to $\langle n_e \rangle_{edge}$ is to be determined.



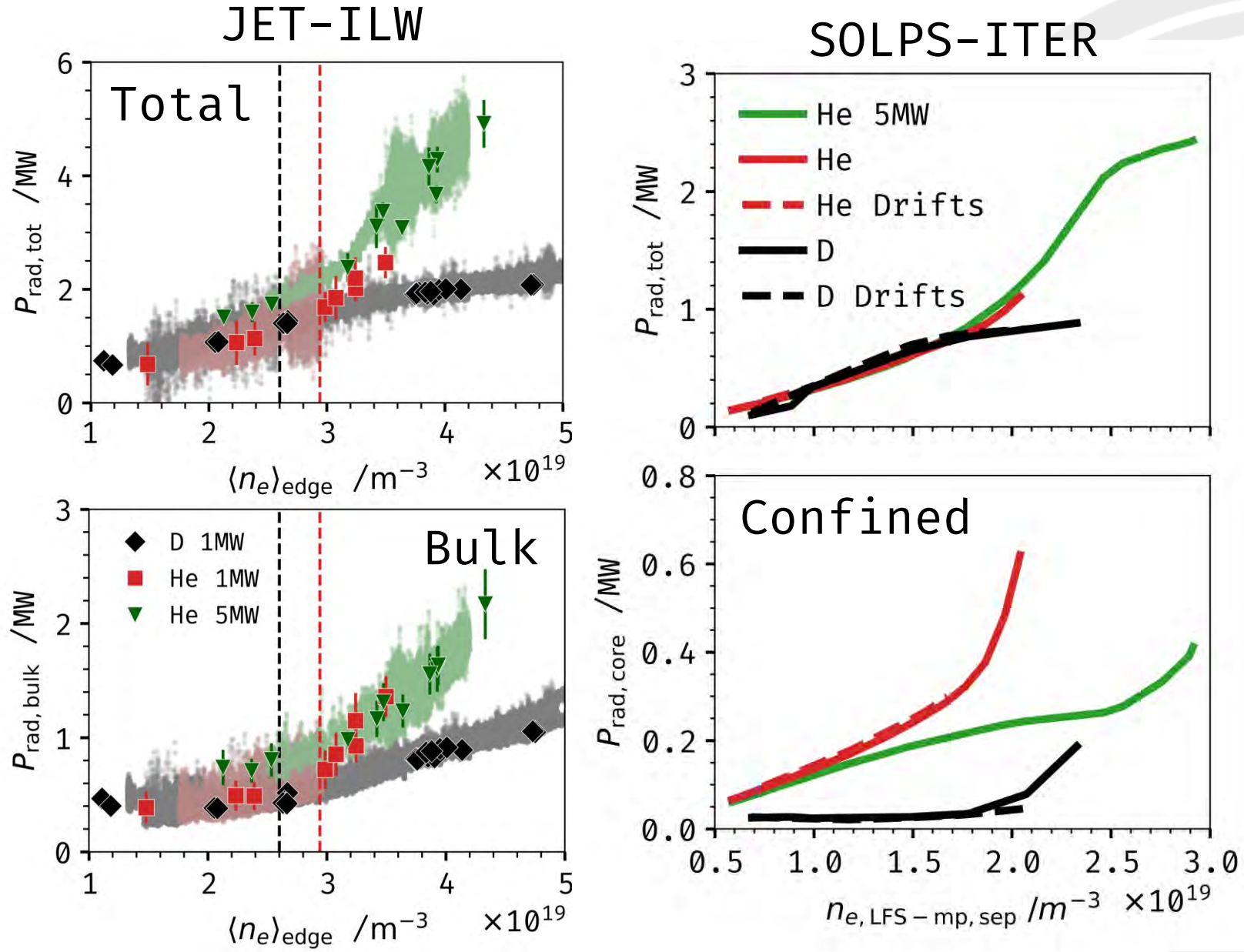


Total and bulk radiated power is the same species before He 1MW rollover. He total and bulk power increase after rollover, which is not seen in D.

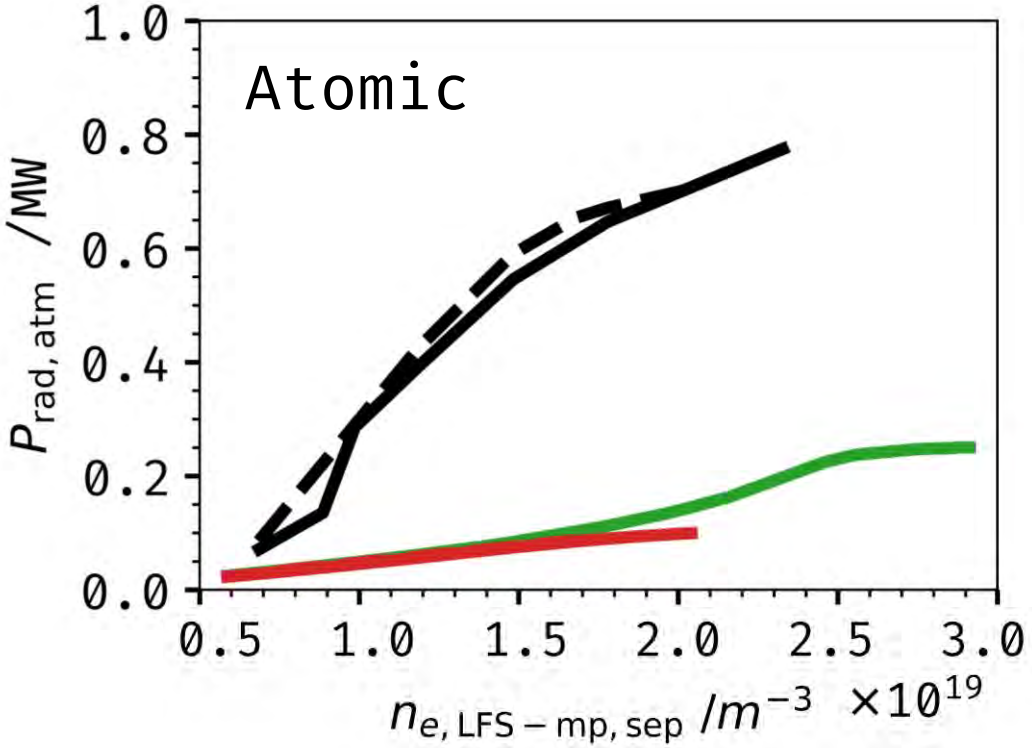


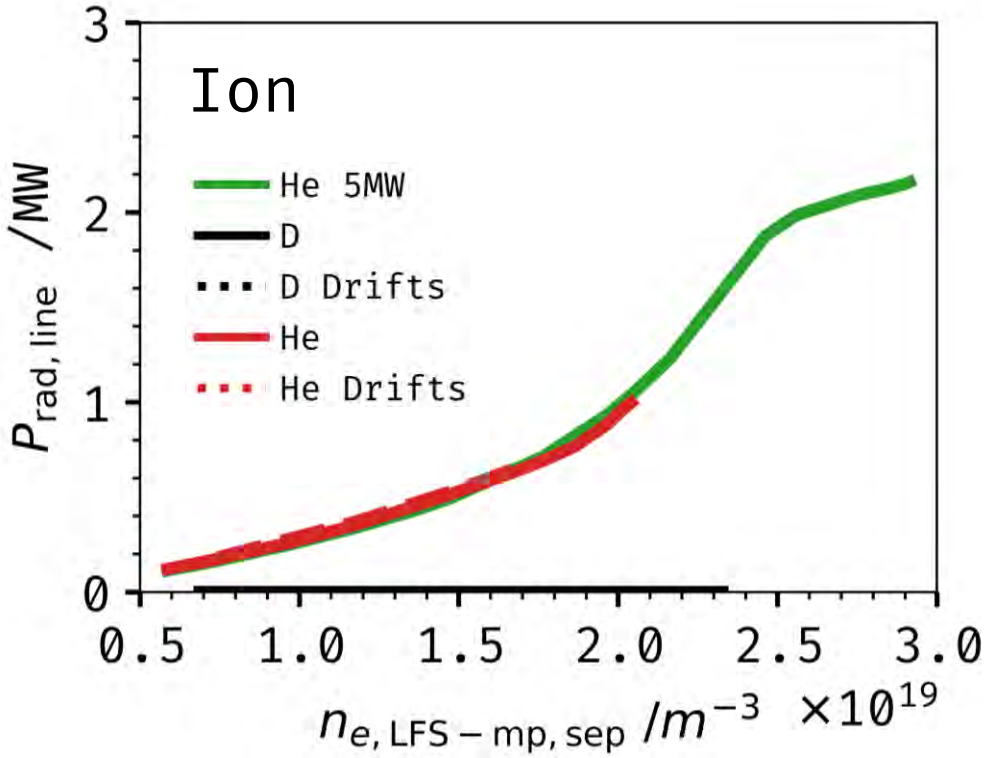


Predicted radiated power is half that of bolometry.



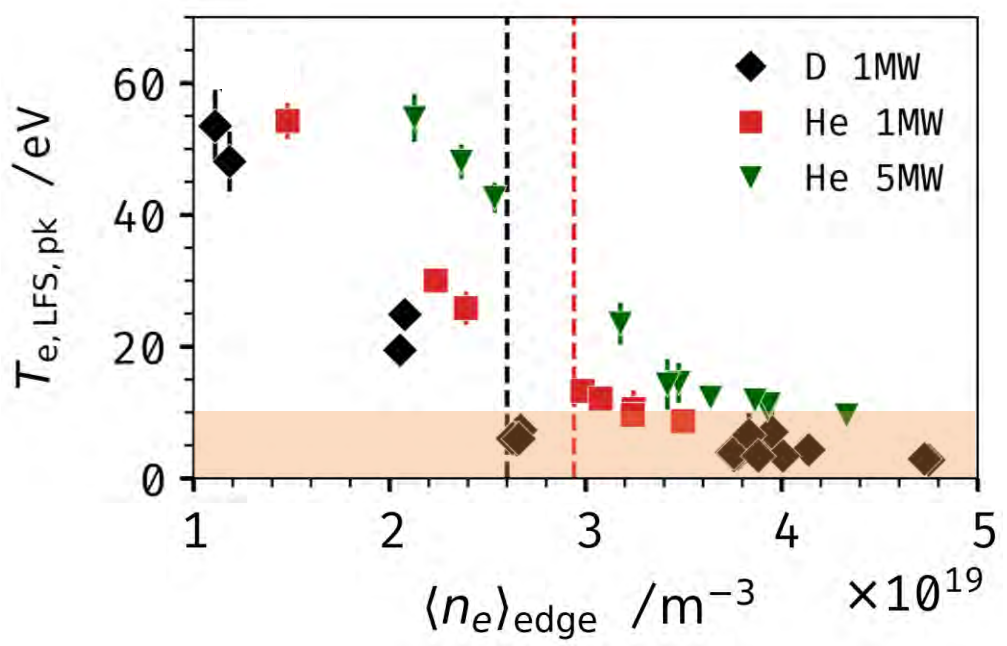
Although total radiated power is similar between the two species, D radiation is primarily from atomic emission (70-90% of $P_{rad,tot}$) and He from line emission (80-90%)



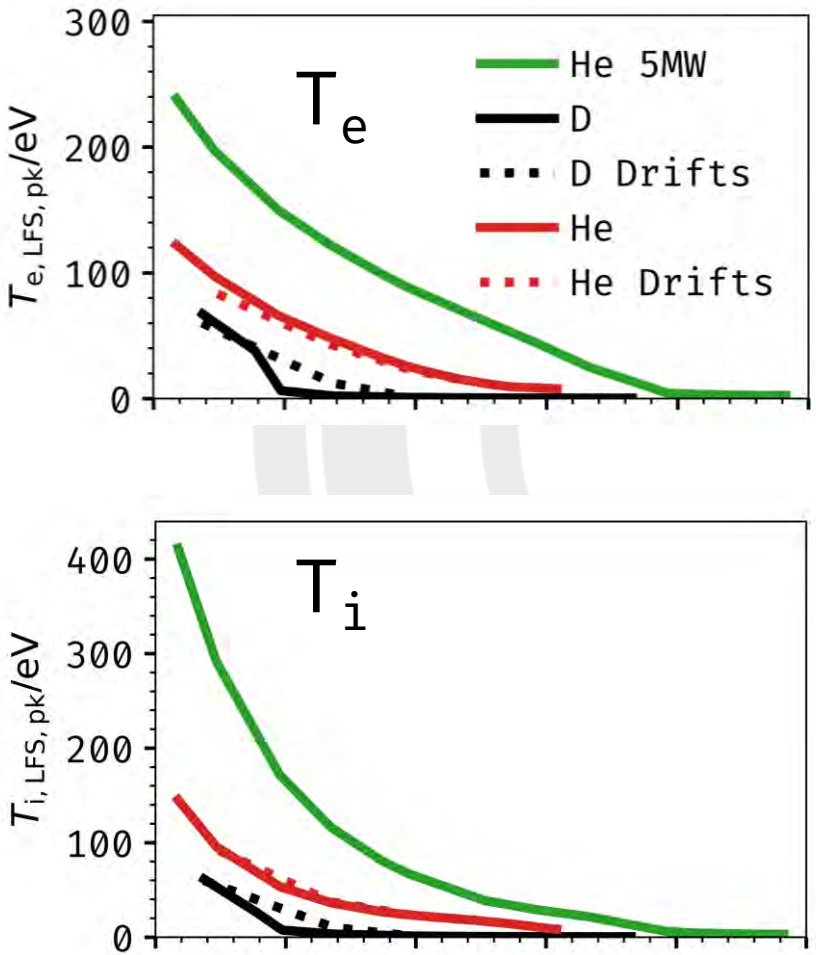


T_e is higher in **He** and does not reach the <1eV seen in D simulations. In both experiment and simulation, the temperature falls with density before reaching I_{div} rollover.

JET-ILW LFS



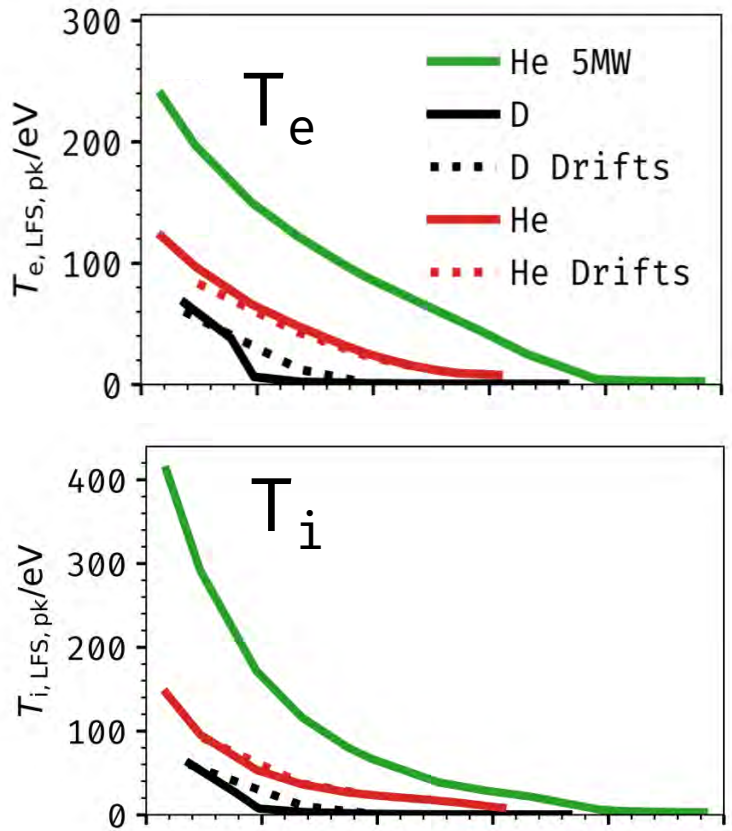
SOLPS LFS

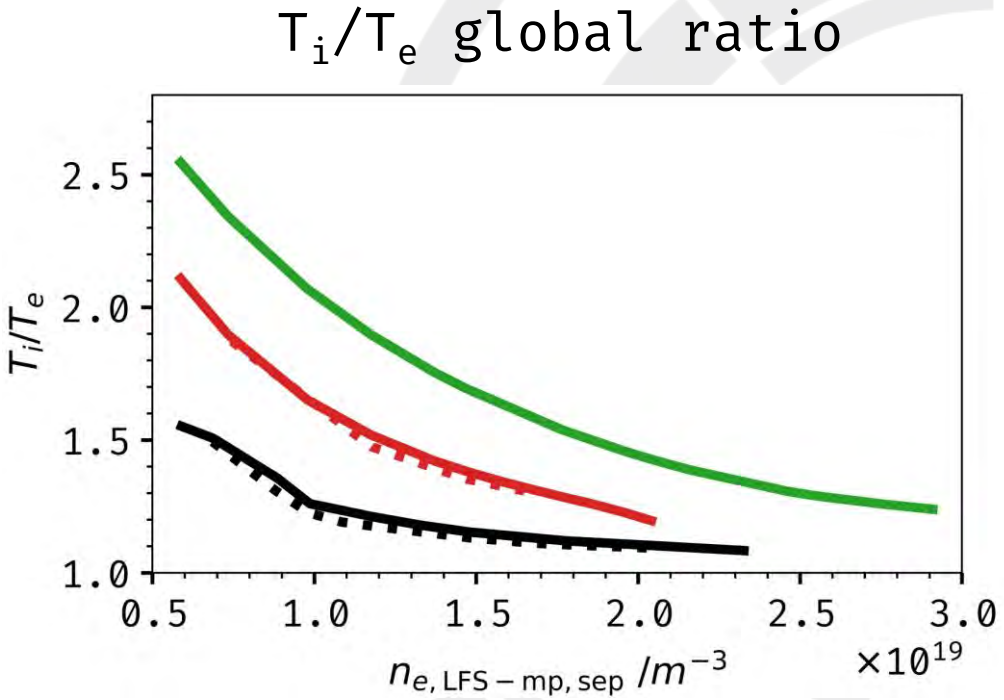


Langmuir probes overestimate T_e in detached conditions.

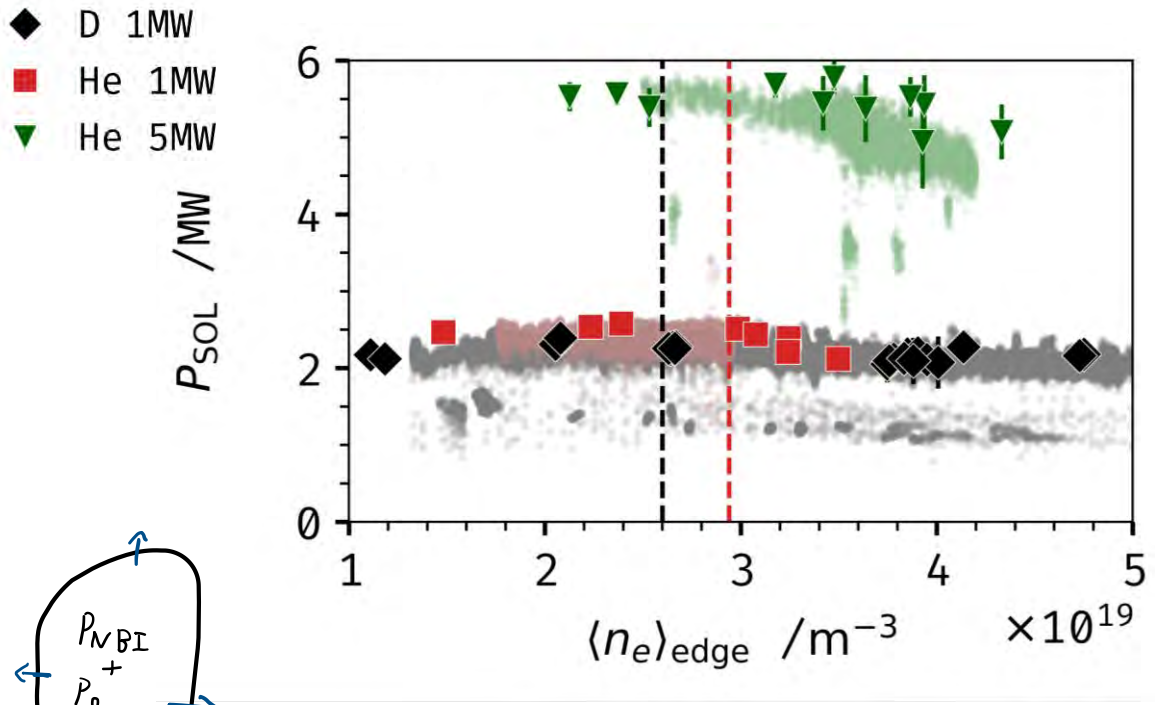
Spectroscopy shows Te <1 eV for $\langle n_e \rangle_{edge} > 3 \times 10^{19} m^{-3}$ in the D plasmas [J. Karhunen et al. NME 2023]

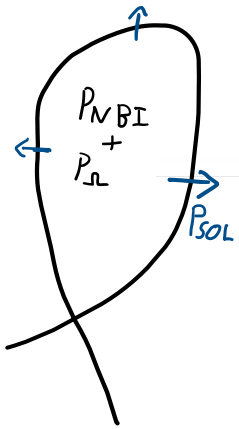
Ions are hotter relative to electrons in He and the difference increase with heating power.

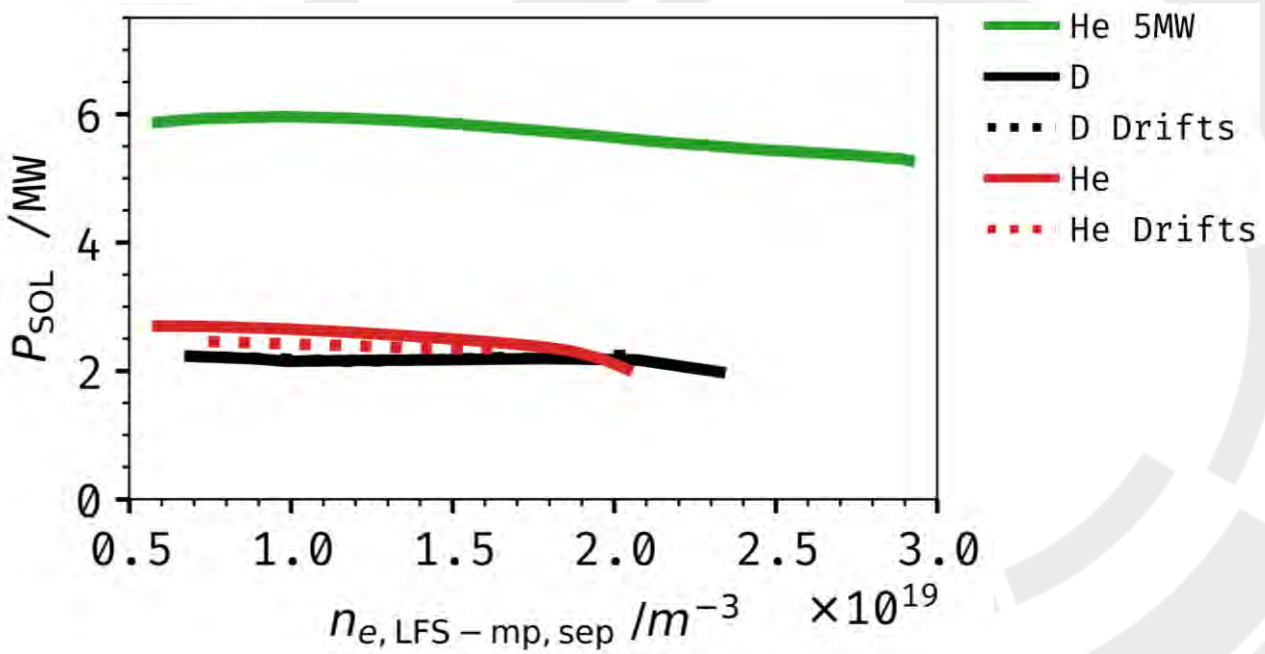




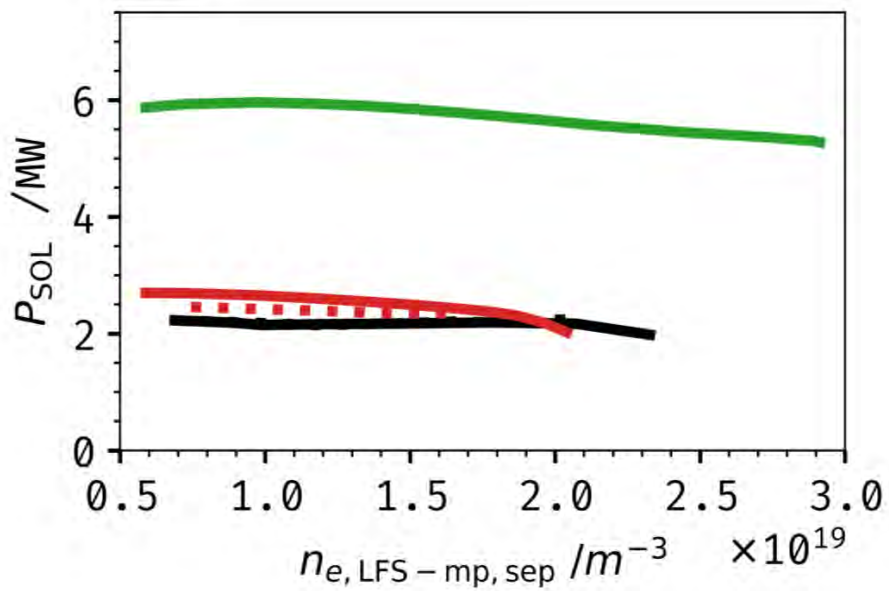
P_{SOL} is ~10% higher He due to 30% higher P_{Ω} compared with D. P_{SOL} decreases in He after rollover but is steady with edge density in D.

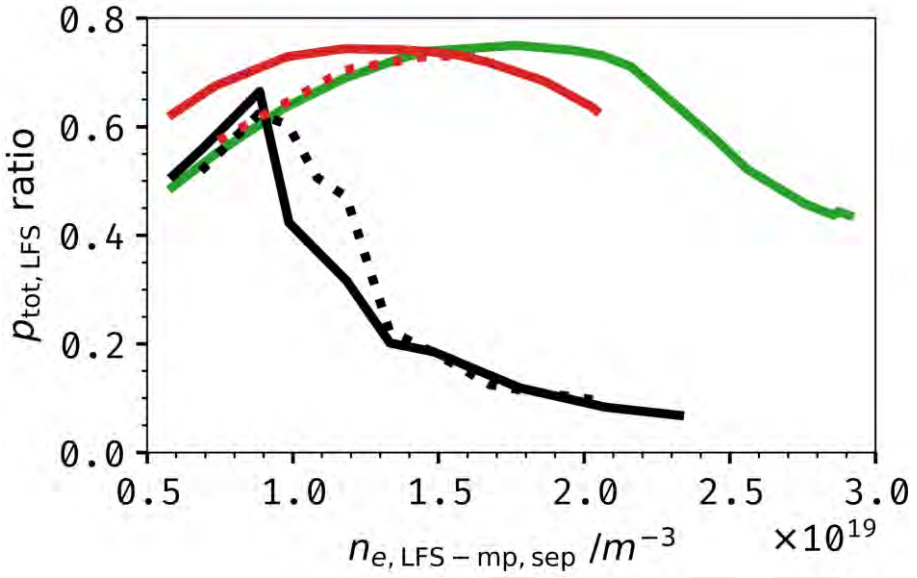


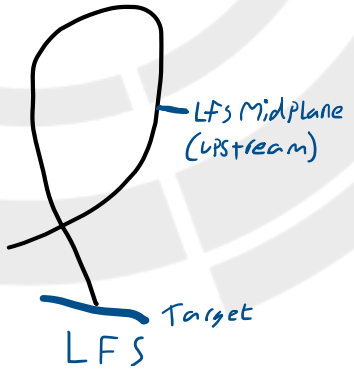




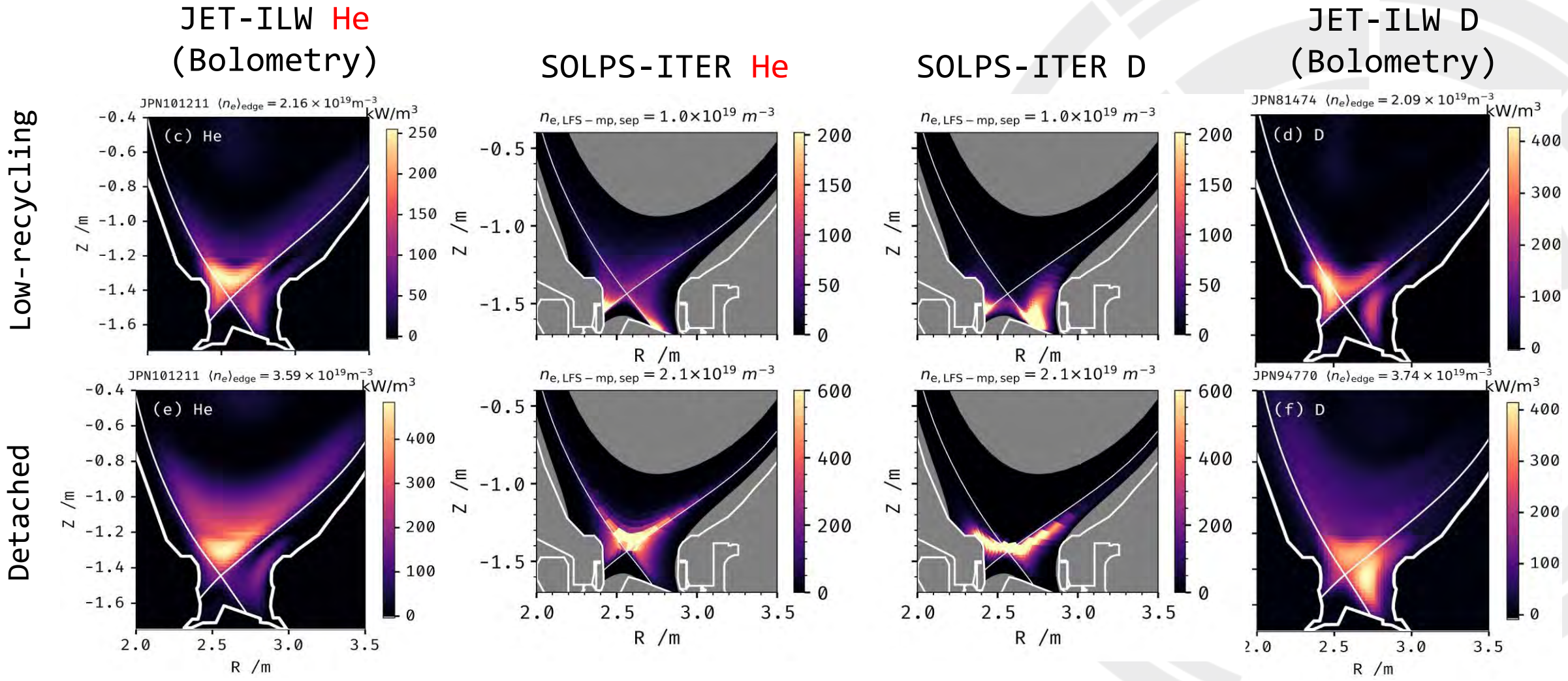
SOLPS-ITER shows the expected pressure ratio drop for D and only minor pressure loss in He. Suggesting that the divertor is power starved in He.







Both experiment and simulation show radiation above the X-point within the confined region for He at high densities.



SOLPS-ITER plots colour range has been clipped for readability

Conclusion

- Recycled He^0 can reach the confined region in He plasmas increasing $P_{tot,core}$ which decreases P_{SOL} and subsequently I_{div}
- Current to the LFS target is four times lower in He than D in experiment and SOLPS-ITER simulations
- Total radiated power is the same in both species before detachment, but from primarily neutral sources in D and line emission in He
- Simulations show He doesn't lose plasma pressure at higher densities to the extent of D