Impact of carbon and tungsten as divertor target materials on the SOL conditions in JET

Mathias Groth et al.

24th IAEA Fusion Energy Conference, 8-13 October, San Diego, USA

Acknowledgement

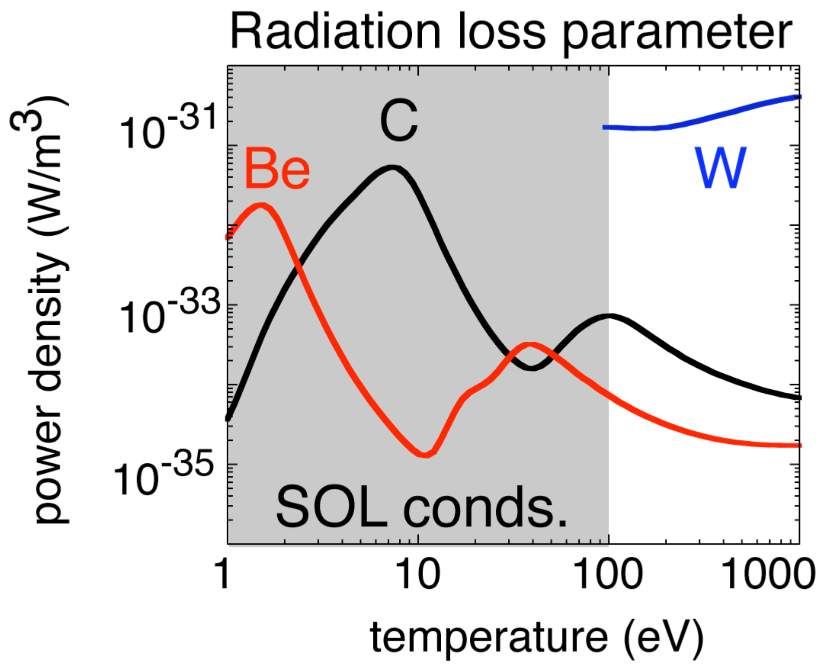
M Groth[1], S Brezinsek[2], P Belo[3], M N A Beurskens[4], M Brix[4], M Clever[2], J W Coenen[2], G. Corrigan[4], T Eich[5], M J Flanagan[5], D Harting[2], C Giroud[4], C Guillemaut[6], A Huber[2], S Jachmich[7], M Lehnen[2], C Lowry[8], C F Maggi[5], S Marsen[9], A G Meigs[4], R A Pitts[10], G. Sergienko[2], B Sieglin[5], C Silva[3], A Sirinelli[4], M F Stamp[4], G J van Rooij[11], S Wiesen[2] and JET EFDA contributors*

JET-EFDA, Culham Science Centre, Abingdon, OX14 3DB, UK

[1]Aalto University, Association EURATOM-Tekes, Espoo, Finland.
[2]Institute for Energy and Climate Research, Association EURATOM-FZJ Jülich, Germany.
[3]Institute of Plasmas and Nuclear Fusion, Association EURATOM-IST, Lisbon, Portugal
[4]Culham Centre of Fusion Energy, EURATOM association Culham Science Centre, Abingdon, UK
[5]Max-Planck-Institute for Plasma Physics, EURATOM association, Garching, Germany.
[6]Association Euratom CEA, CEA/DSM/IRFM, Cadarache, France.
[7]Association "EURATOM Belgium State", Laboratory for Plasma Physics, Brussels, Belgium.
[8]EFDA Close Support Unit, Culham Science Centre, Abingdon, UK.
[9]Max-Planck-Institute for Plasma Physics, EURATOM association, Greifswald, Germany.
[10]ITER Organisation, 13115 Saint-Paul-Lez-Durance, France.
[11]FOM Institute DIFFER, Association EURATOM-FOM, Nieuwegein, The Netherlands.

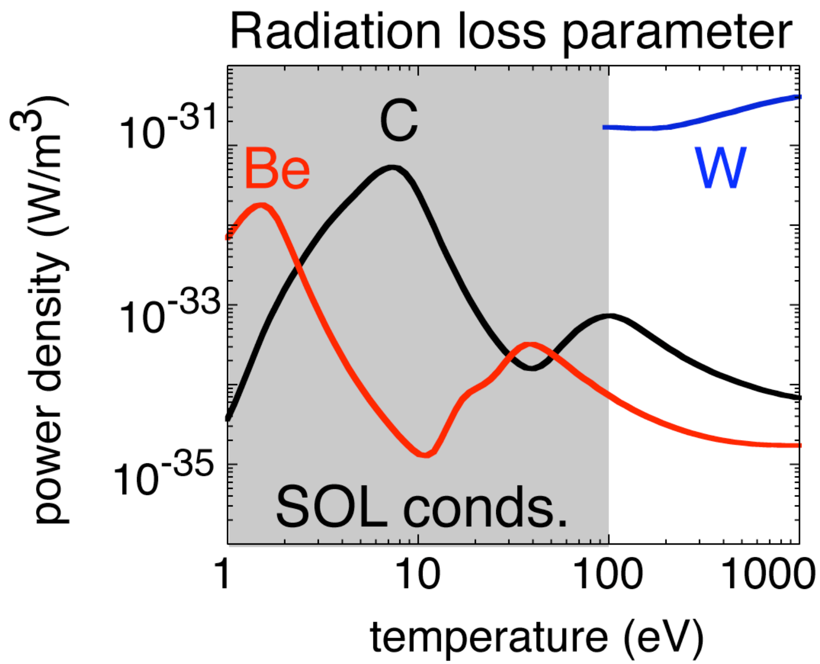
** See the Appendix of F. Romanelli et al., 24th IAEA Fusion Energy Conference 2012, San Diego, USA*

How does scrape-off layer plasma change when going from C to Be/W in JET?



- Transition of JET-C to JET-ILW (Be/W) in one single shutdown ⇒ anticipate decrease of radiated power in SOL ⇒ increase in conducted power to plates + higher divertor plasma temperatures

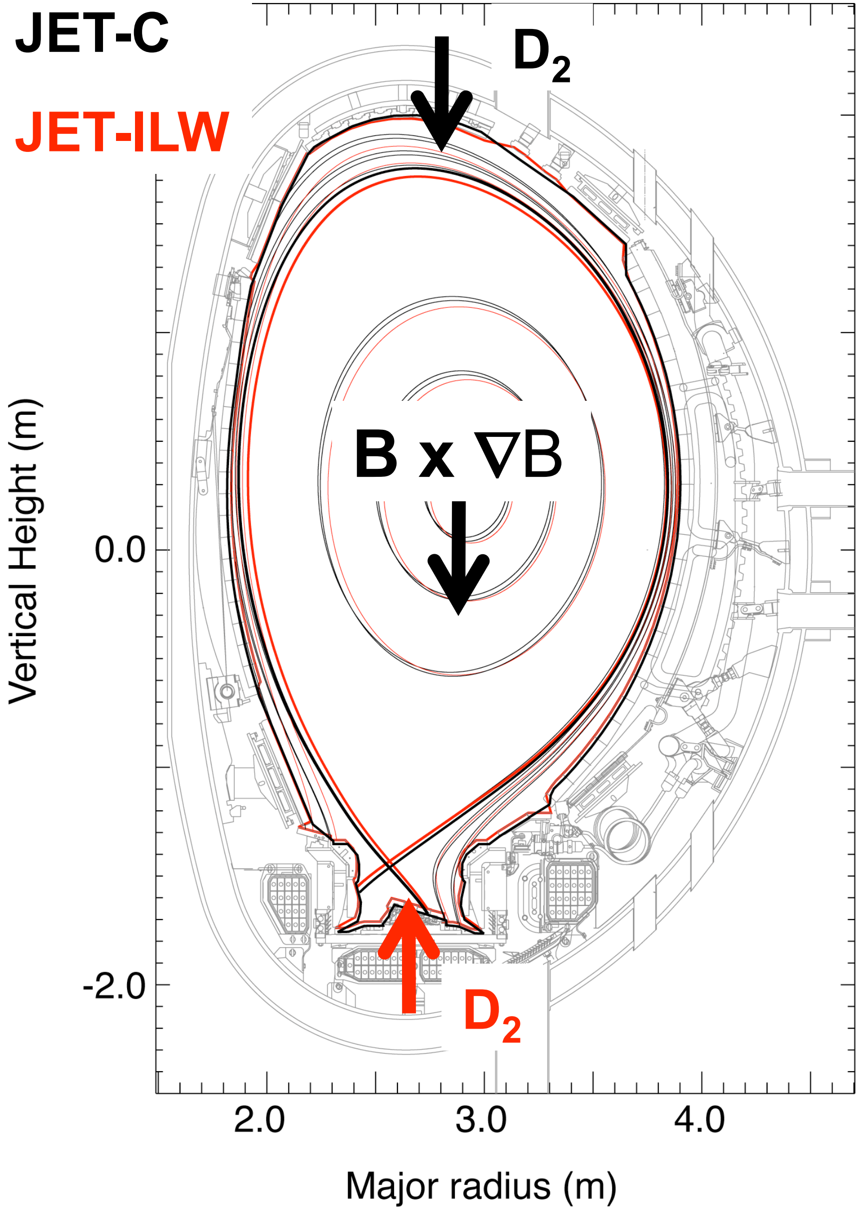
How does scrape-off layer plasma change when going from C to Be/W in JET?



- Transition of JET-C to JET-ILW (Be/W) in one single shutdown ⇒ anticipate decrease of radiated power in SOL ⇒ increase in conducted power to plates + higher divertor plasma temperatures

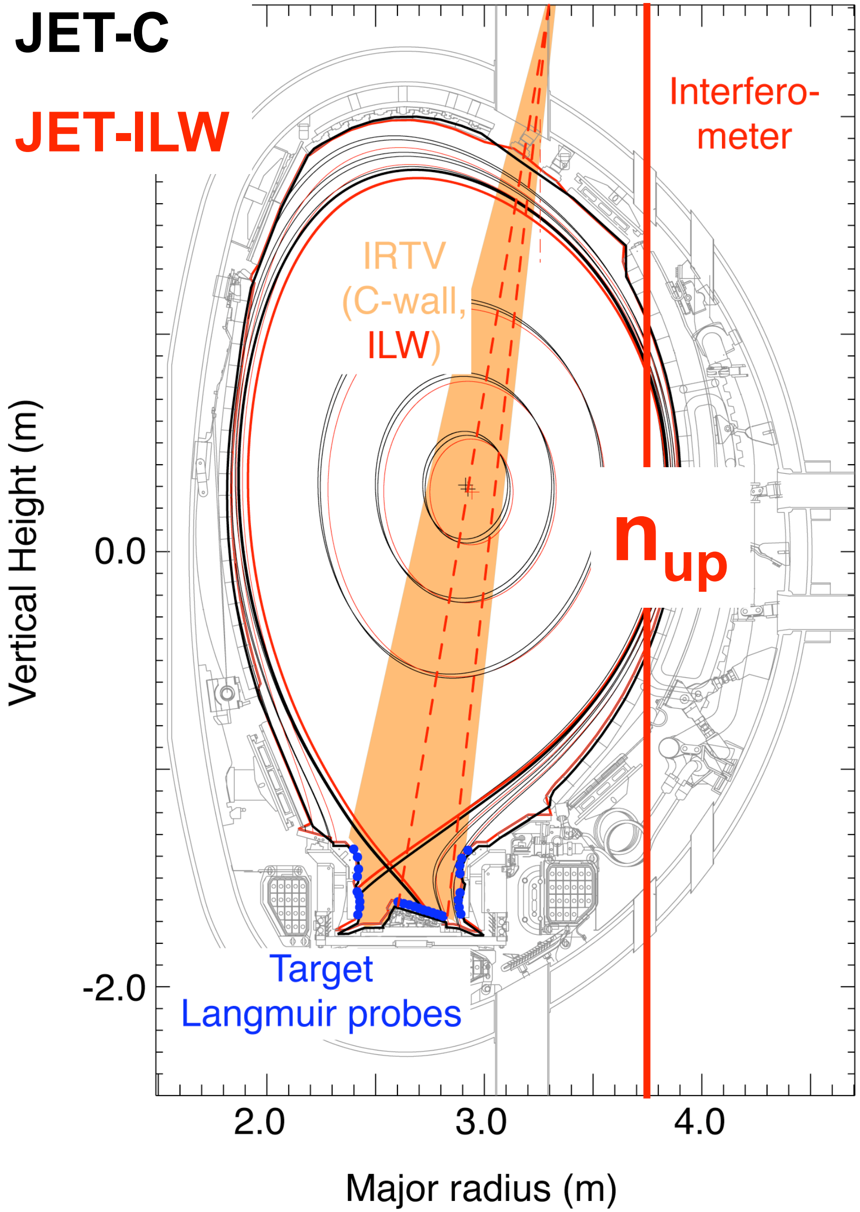
- Comparison of **measured** powers, currents, and temperatures in attached and detached **L-mode plasmas** in **JET-C and JET-ILW** ⇒ **onset of detachment and density limit at 30% higher n_{up} in JET-ILW**
- Rollover of ion currents to LFS plate (~ momentum detachment) successfully observed with fluid edge code EDGE2D/EIRENE

The SOL conditions were characterised in neutral beam-heated L-mode plasmas



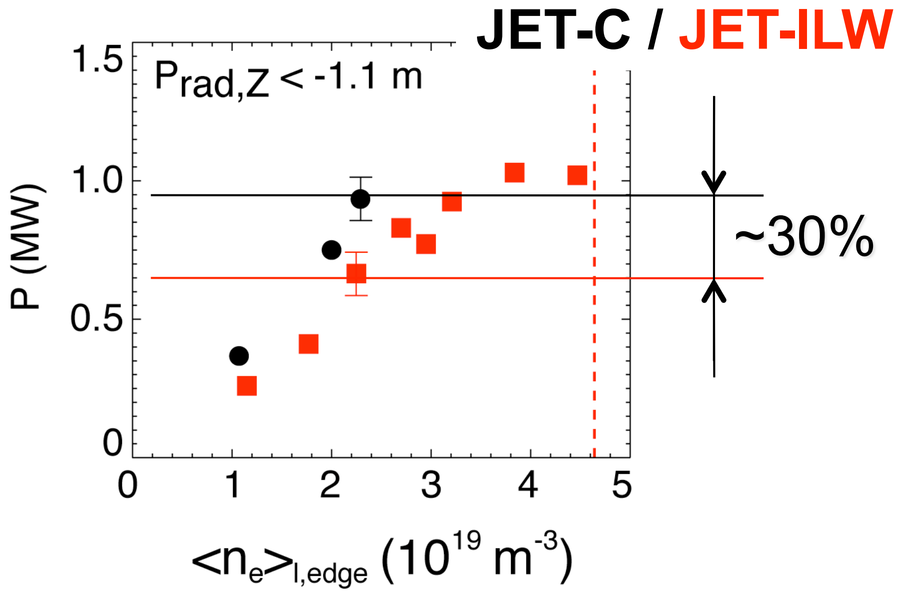
- Configuration optimised for diagnosis of LFS strike zone
- Varied core/SOL density by D_2 fuelling ⇒ **low and high recycling** divertor conditions in JET-C and JET-ILW
  - Fully detached conditions in JET-ILW

The SOL parameters were measured with a comprehensive suite of diagnostics



- 2D profiles of total radiation → $P_{rad,SOL}$ and $P_{rad,div}$
- Target power and particles fluxes → P_{div} and I_{div}
- Principal scaling parameter upstream density, n_{up}
  - Spatially resolved profiles of n_e and T_e upstream → $n_{e,sep}$

In going from JET-C to JET-ILW, the radiation in the divertor decreased by 30%

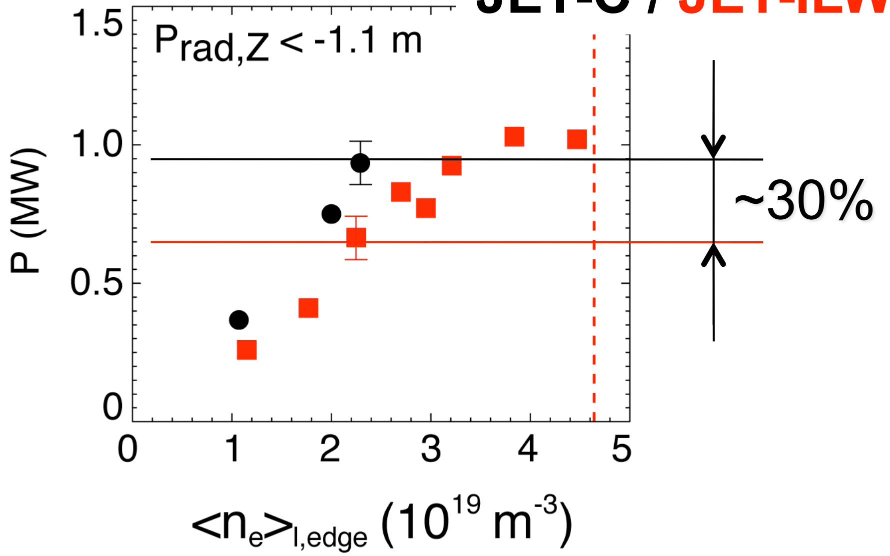


- Decrease qualitatively consistent with reduction of C radiation in the SOL by order of magnitude*
  - Cleaner plasmas: Z_{eff} decreased from 1.4 to 1.1

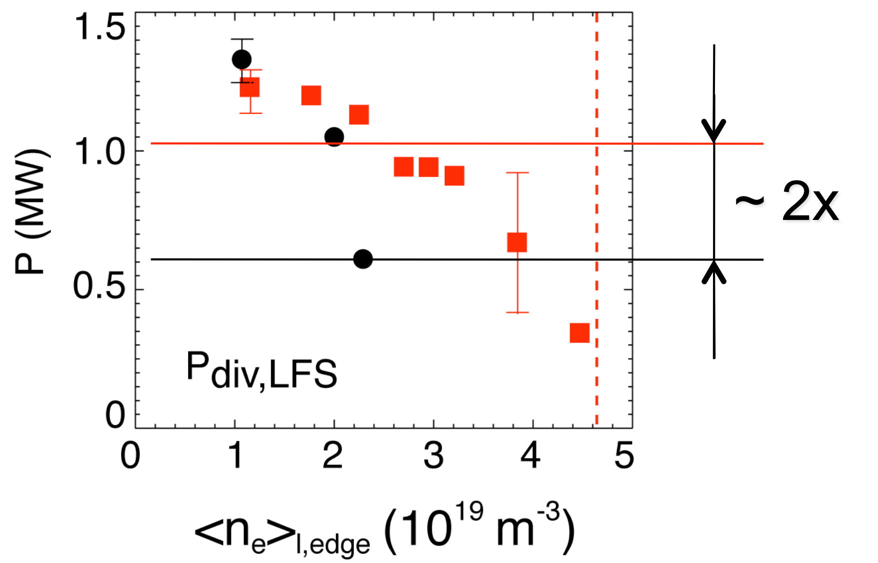
*Brezinsek et al., PSI2012
Coenen et al., EX/P5-04

In going from JET-C to JET-ILW, power to LFS plate increased by 2x

JET-C / JET-ILW

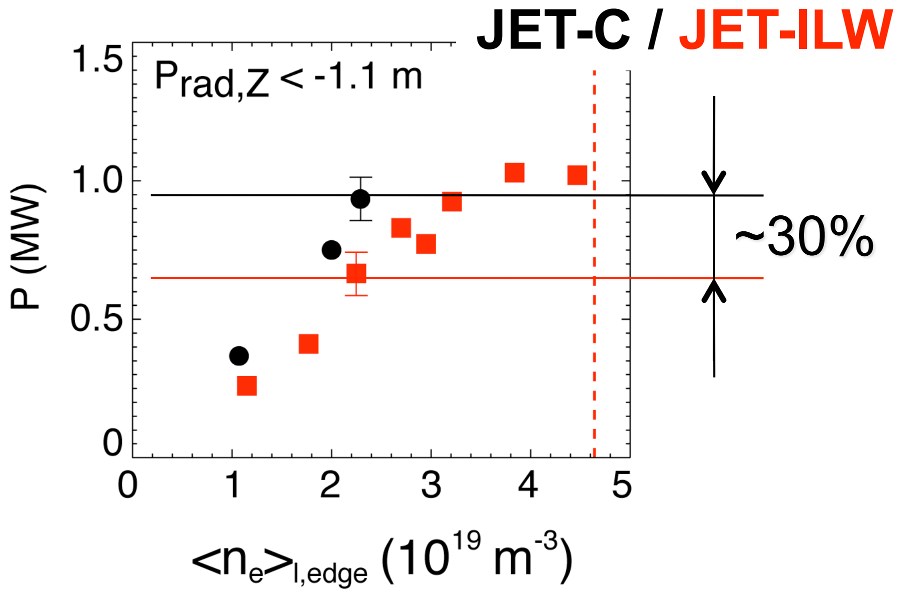


- Decrease qualitatively consistent with reduction of C radiation in the SOL by order of magnitude*
  - Cleaner plasmas: Z_{eff} decreased from 1.4 to 1.1

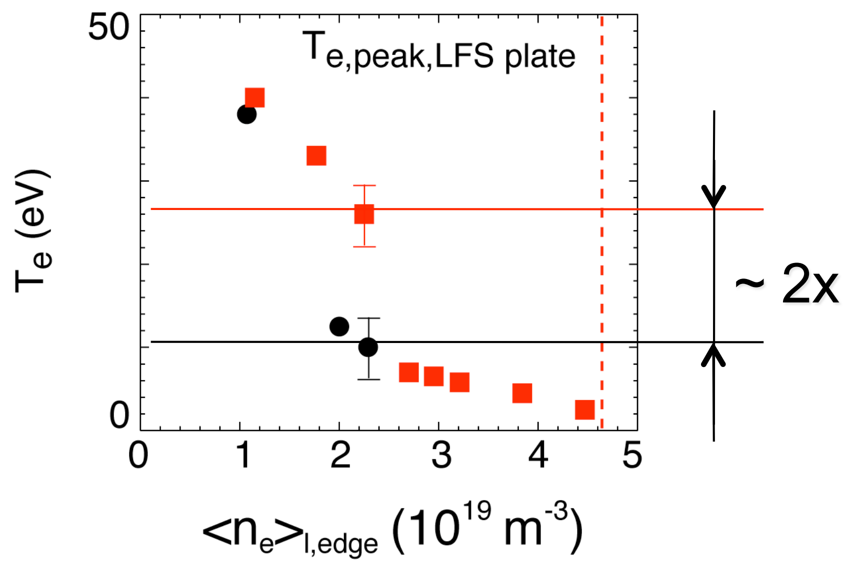


- Increase of $P_{div,LFS}$ by ~2x in high-recycling conditions
  - Similar $P_{div,LFS}$ in low-recycling conditions

In going from JET-C to JET-ILW, peak T_e at LFS plate increased by 2x

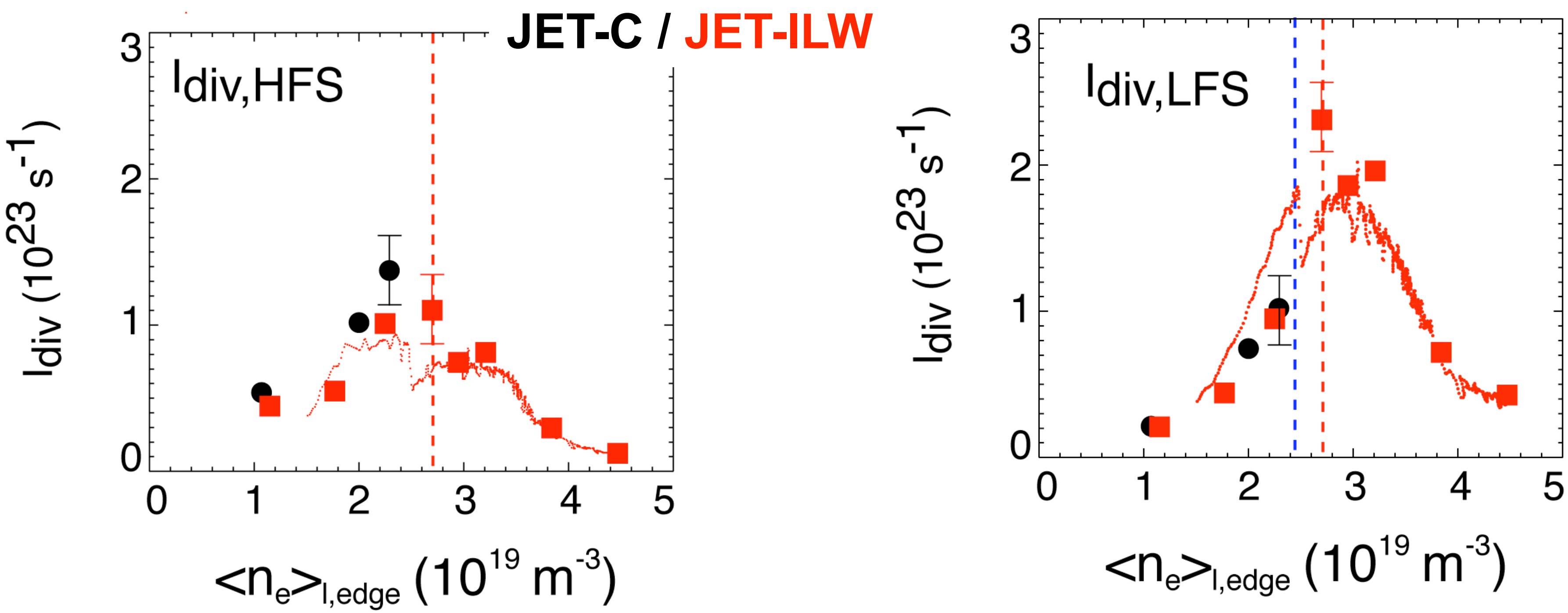


- Decrease qualitatively consistent with reduction of C radiation in the SOL by order of magnitude*
  - Cleaner plasmas: Z_{eff} decreased from 1.4 to 1.1



- Increase of $P_{div,LFS}$ by ~2x in high-recycling conditions
  - Similar $P_{div,LFS}$ in low-recycling conditions
- Increase of T_e at LFS plate by ~2x in high-recycling conditions

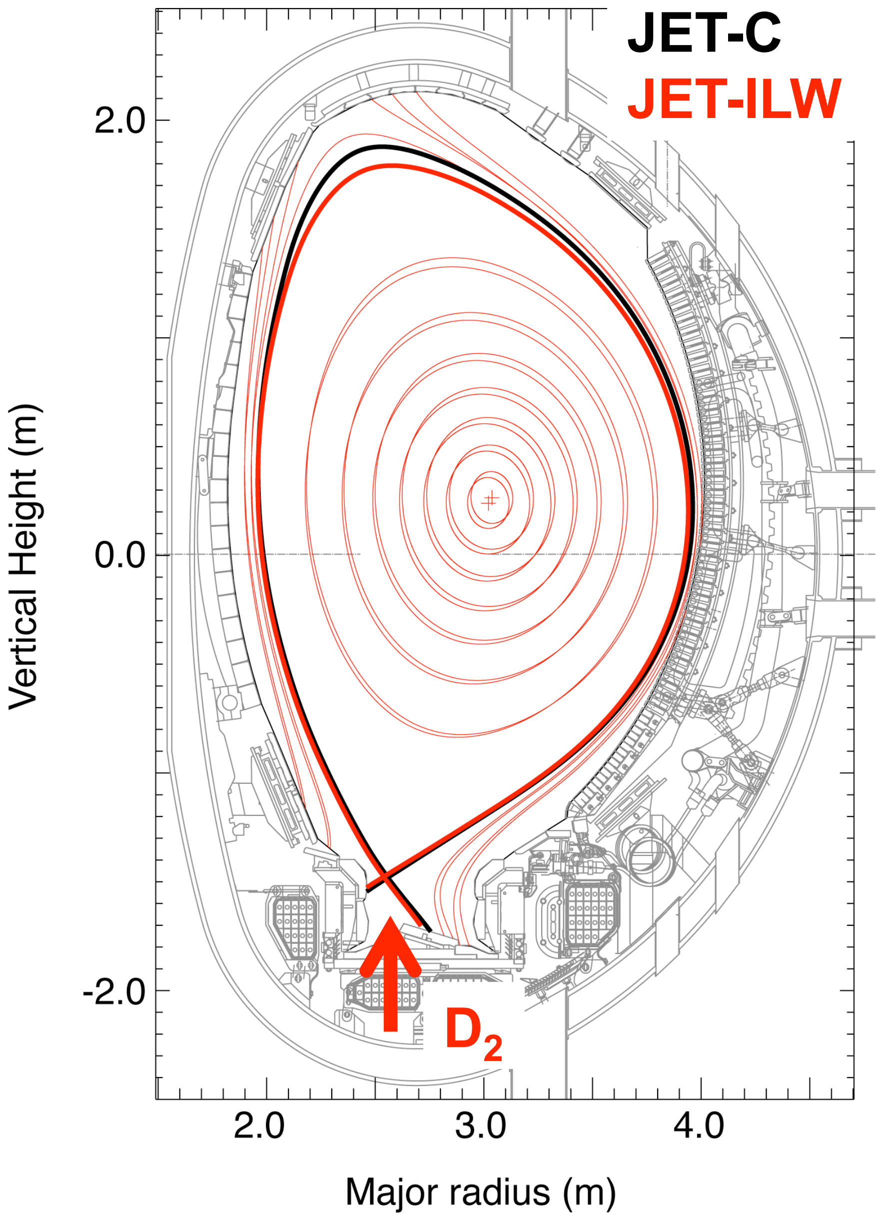
In attached conditions, I_{div} to the plates are similar within 50% in JET-C and JET-ILW



- Rollover of I_{div} at the HFS and LFS plates occurred at the same n_{up}
- Drop in $T_{e,peak,LFS}$ occurred at distinctly (20%) lower n_{up} than $I_{div,LFS}$

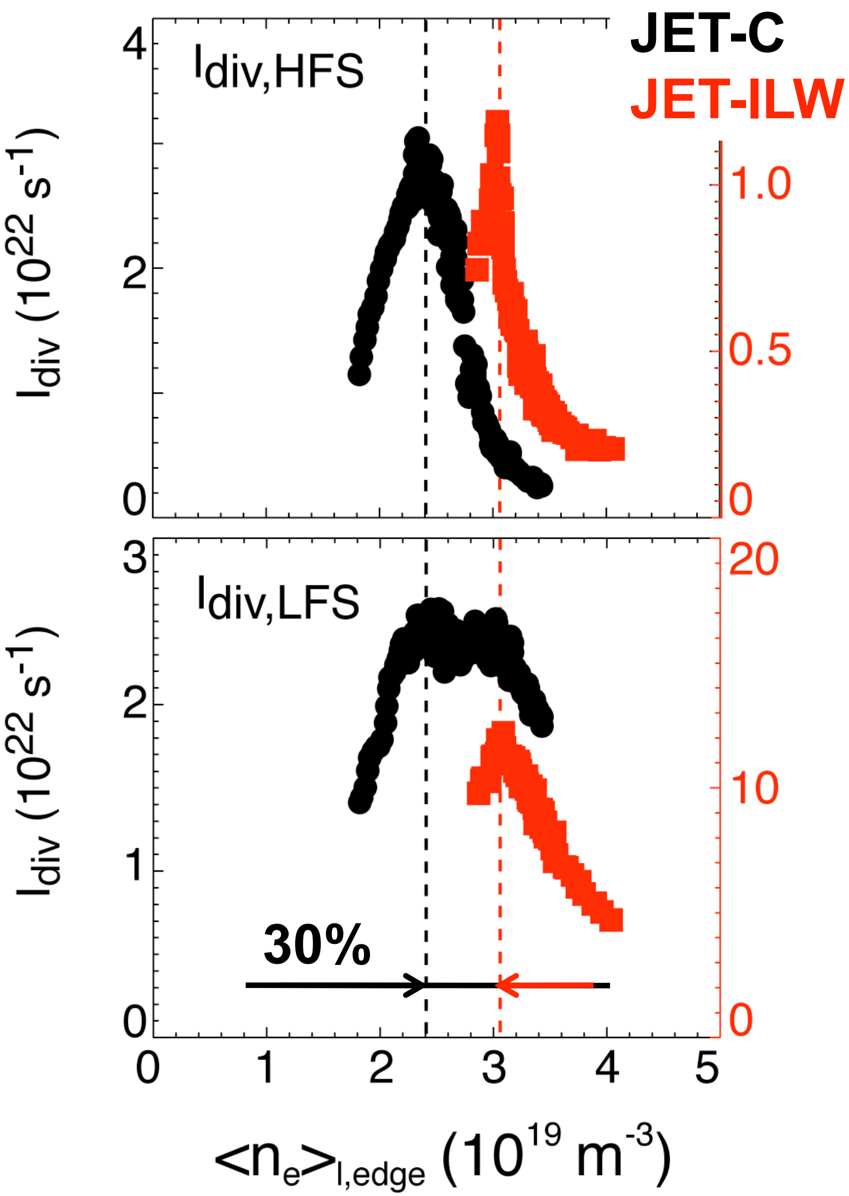
⇒ Significant operational space beyond rollover ⇒ stable and well-controllable detachment for n_{up} up to 1.5 x $n_{up,rollover}$

Detached SOL regimes were investigated in almost the same divertor plasma configuration



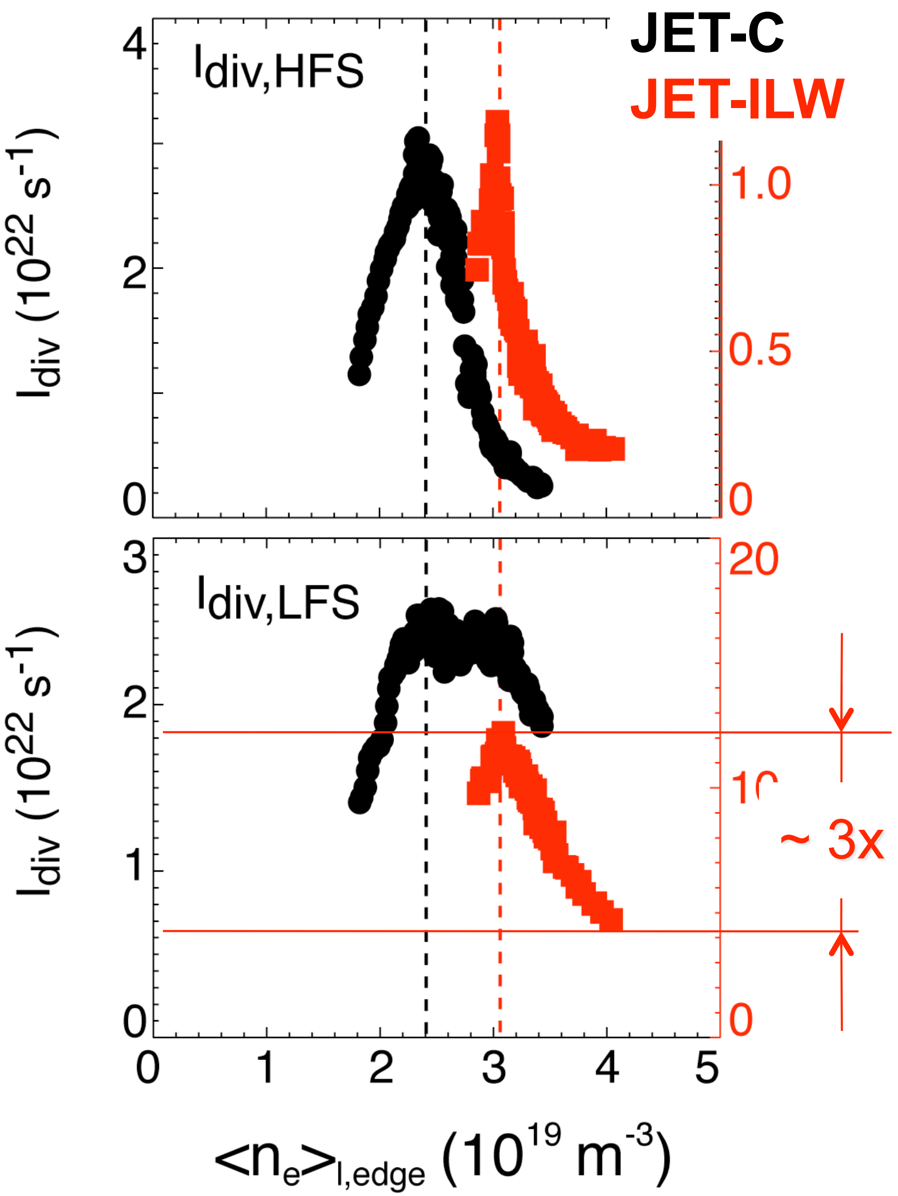
- High-triangularity configuration: lower magnetic clearance to top of vessel
- Continuous fuelling ramp to density limit starting slightly below rollover of I_{div}

Rollover of I_{div} occurred at 30% higher n_{up} in JET-IWL than in JET-C



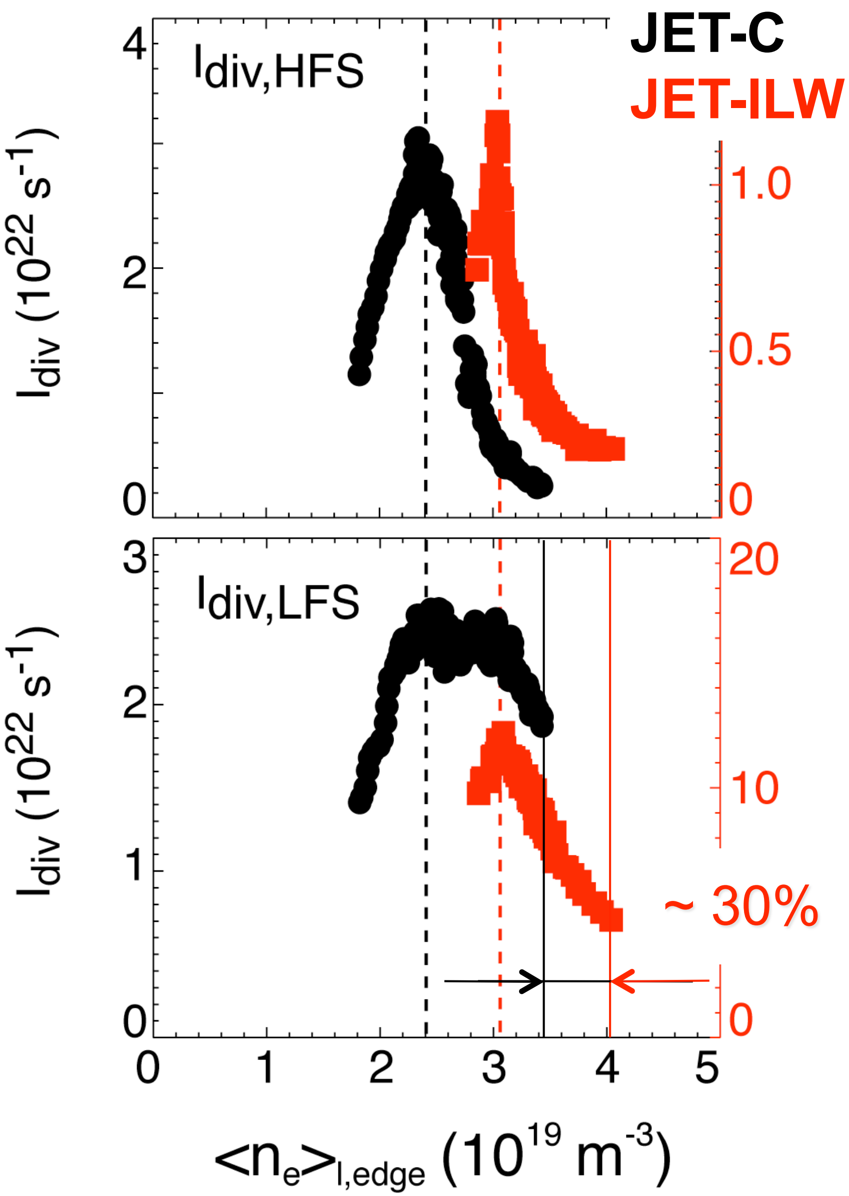
- Rollover occurred for same n_{up} at HFS and LFS plate
  - Radiative power fraction ~40% at I_{div} rollover in both materials configurations

Significantly stronger reduction of I_{div} at the LFS plate in the JET-ILW than in JET-C



- Rollover occurred for same n_{up} at HFS and LFS plate
  - Radiative power fraction ~40% at I_{div} rollover in both materials configurations
- In JET-C, flat $I_{div,LFS}$ for $n_{up} > n_{up,rollover}$ $\Rightarrow$ 25% reduction at density limit only

Operation in more stable detached conditions in the JET-ILW than in JET-C

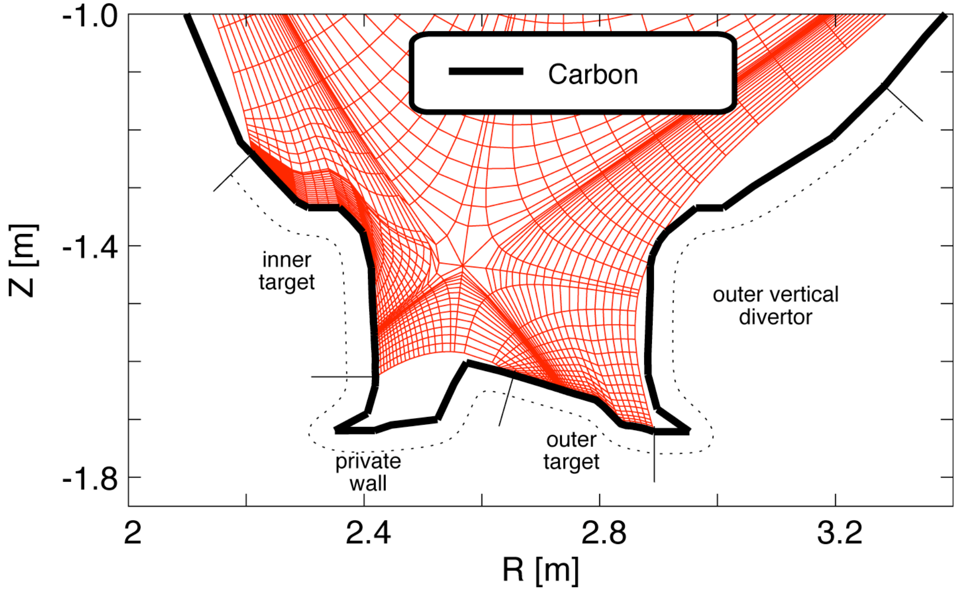


- Rollover occurred for same n_{up} at HFS and LFS plate
  - Radiative power fraction ~40% at I_{div} rollover in both materials configurations
- In JET-C, flat $I_{div,LFS}$ for n_{up} > $n_{up,rollover}$ ⇒ 25% reduction at density limit only
- Density limit 30% higher in JET-ILW than in JET-C*

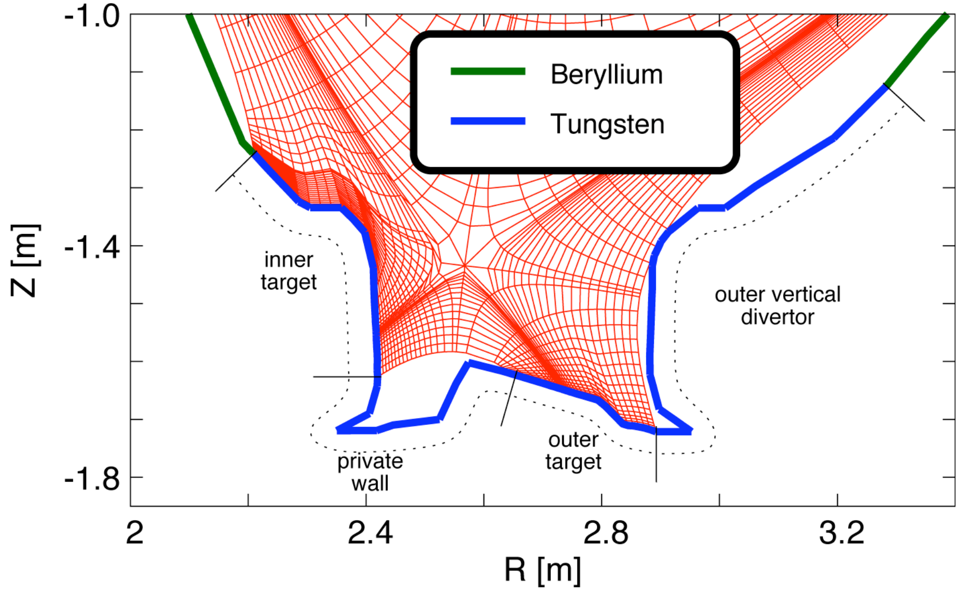
*Huber et al., PSI2012

Are predictions from edge fluid codes consistent with the experimental data?

JET-C divertor



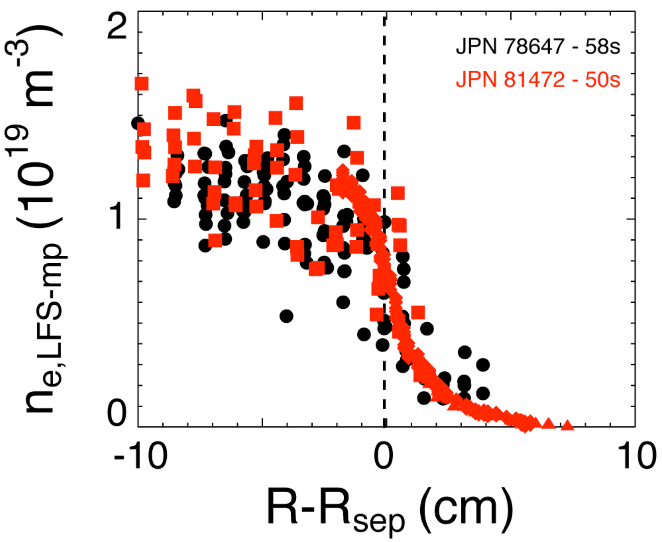
JET-ILW divertor



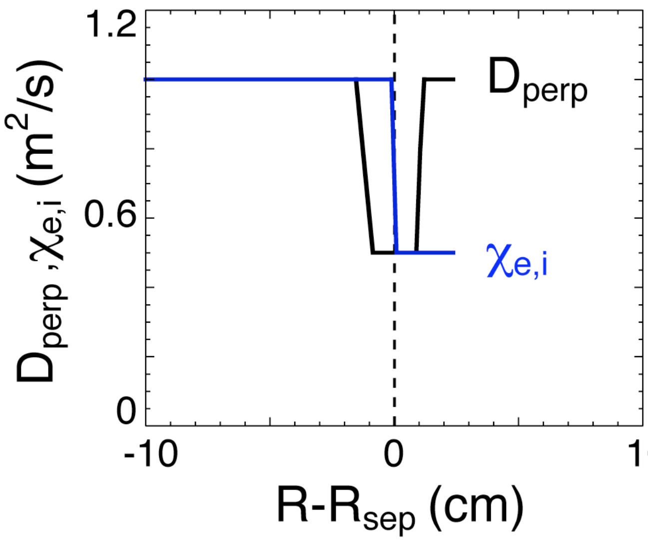
- EDGE2D/EIRENE = coupled fluid plasma/Monte-Carlo neutral code, including deuterium molecules and their radicals
- Adapted actual C and Be/W walls ⇒ physical sputtering (Eckstein yields) and chemical sputtering (C only, Roth 2004 yields)

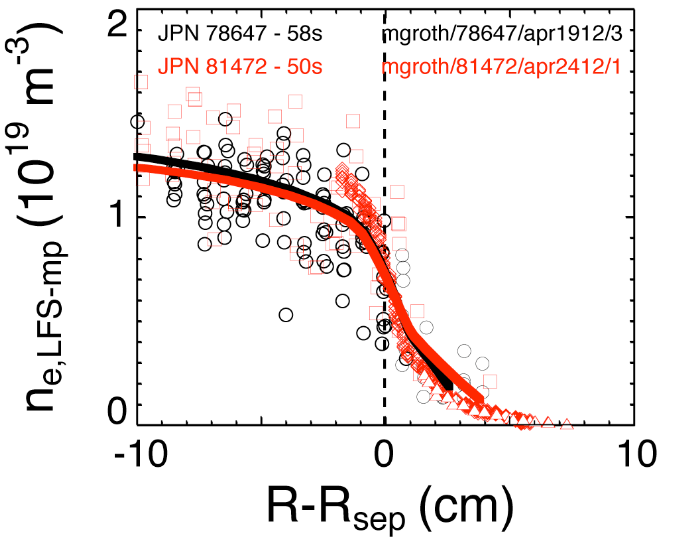
⇒ Output: D + impurity radiation, target fluxes and plasma conditions

Performed fuelling scan utilising measured upstream conditions for n_e and T_e

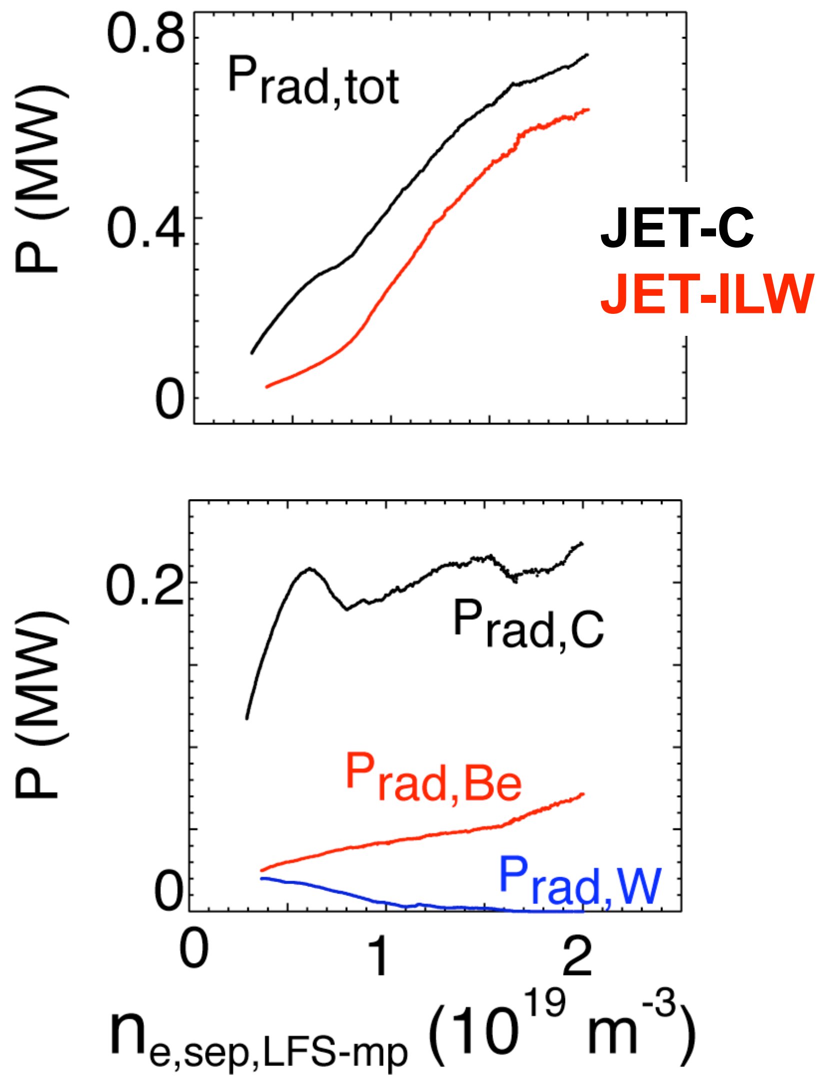


- Identical profiles of n_e (and T_e) were obtained in JET-C and JET-ILW
- Assumed diffusive model w/ transport barrier in $D_\perp$, step for $\chi_{e,i}$
- Omit cross-field drifts ⇒ focus comparison on LFS plate



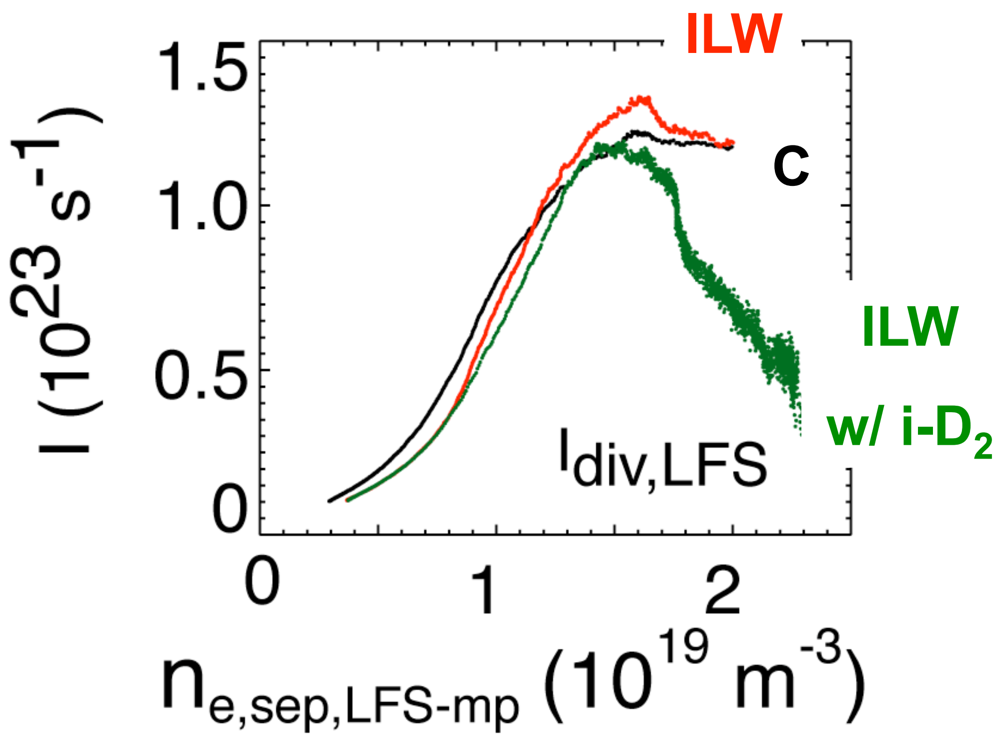


In going from JET-C to JET-ILW, a 50% reduction in $P_{rad,SOL}$ is predicted (c.f. exp: 30%)



- Reduction of $P_{rad,SOL}$ due to lower radiation from Be:
  - $P_{rad,Be}$ ~ 1/4 x $P_{rad,C}$
  - Similar $P_{rad,SOL}$ from deuterium
- $P_{rad,W}$ negligible for high-recycling / detached conditions

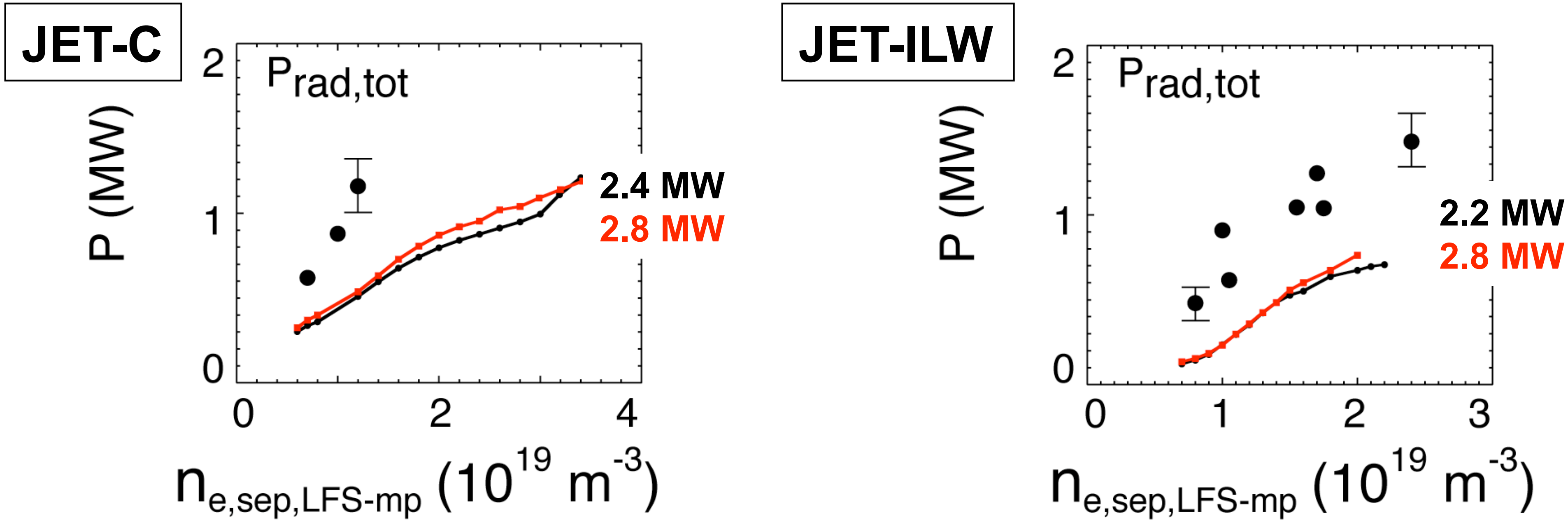
Extension of neutral model in EIRENE produced rollover and reduction of I_{div} at the LFS plate



- Extended EIRENE includes collisions between ions and D_2 molecules / radicals, and T_e and n_e dependent radiative rates*
- Density limit shifted to ~20% higher n_{up}
- Rollover is predicted to occur at the same n_{up} for both JET-C and JET-ILW (c.f. exps: at ~30% n_{up} higher in JET-ILW)

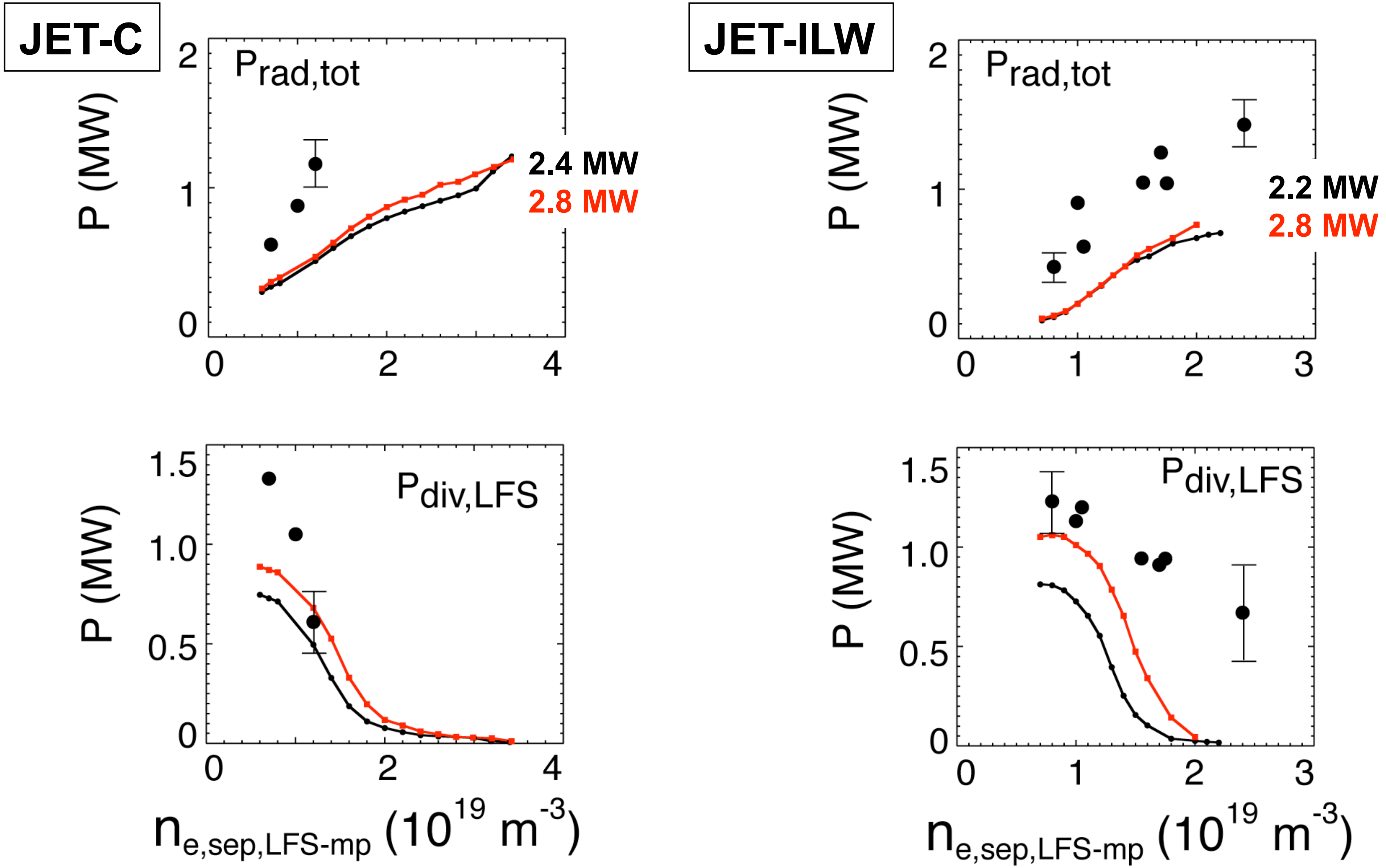
*Kotov et al., PPCF 2008
Guillemaut et al., PSI 2012

Simulations underestimate radiated power in the SOL by factors of 2-3

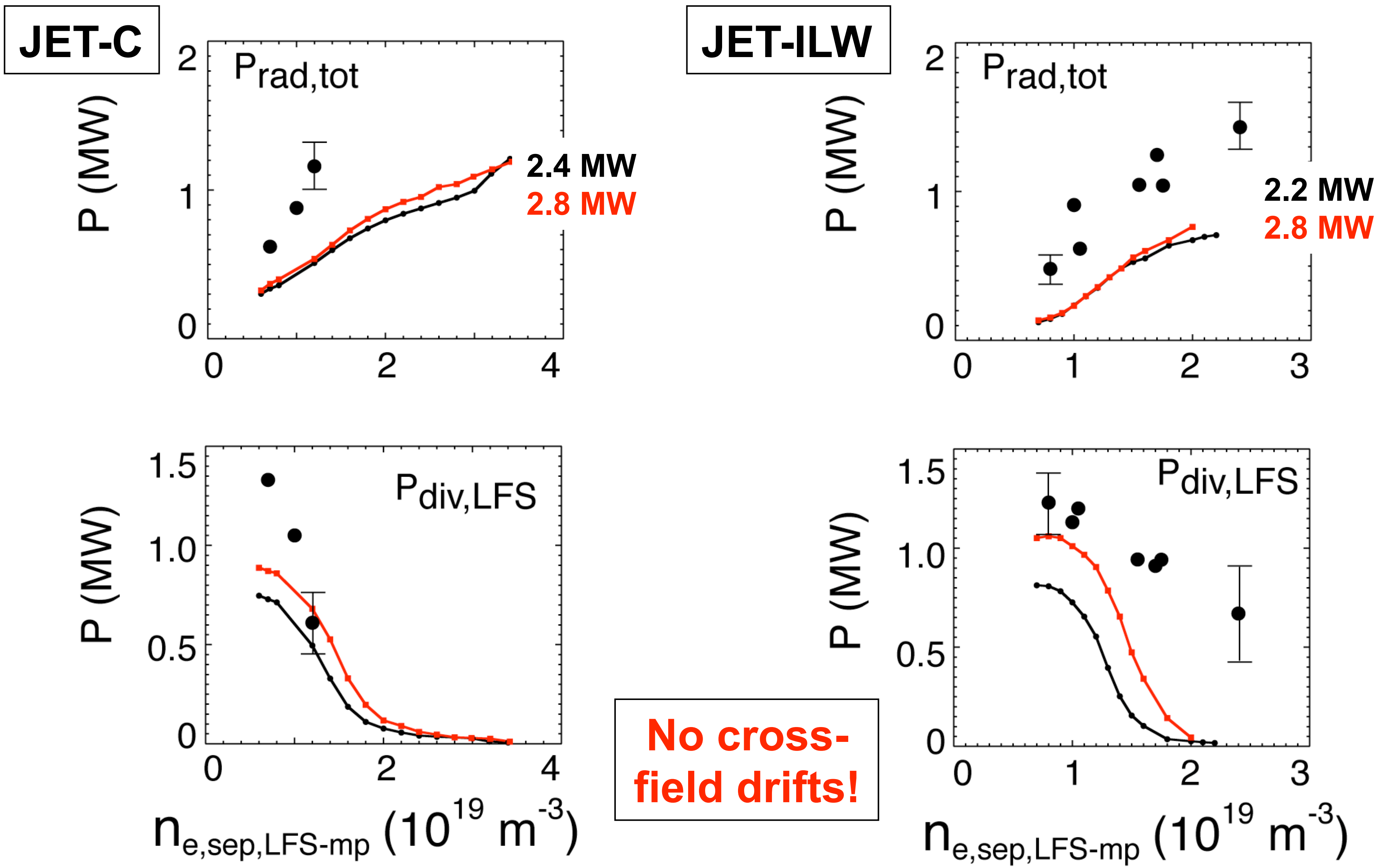


- $P_{core \rightarrow ped}$ dependence is too weak to explain discrepancies in P_{rad}

Simulations are within 50% of the measured P_{div} to LFS plate in attached conditions

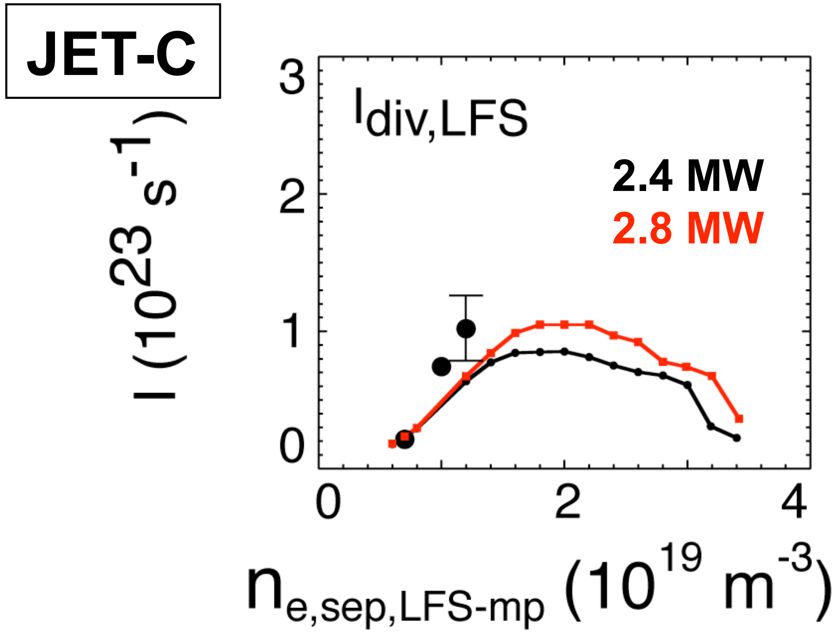


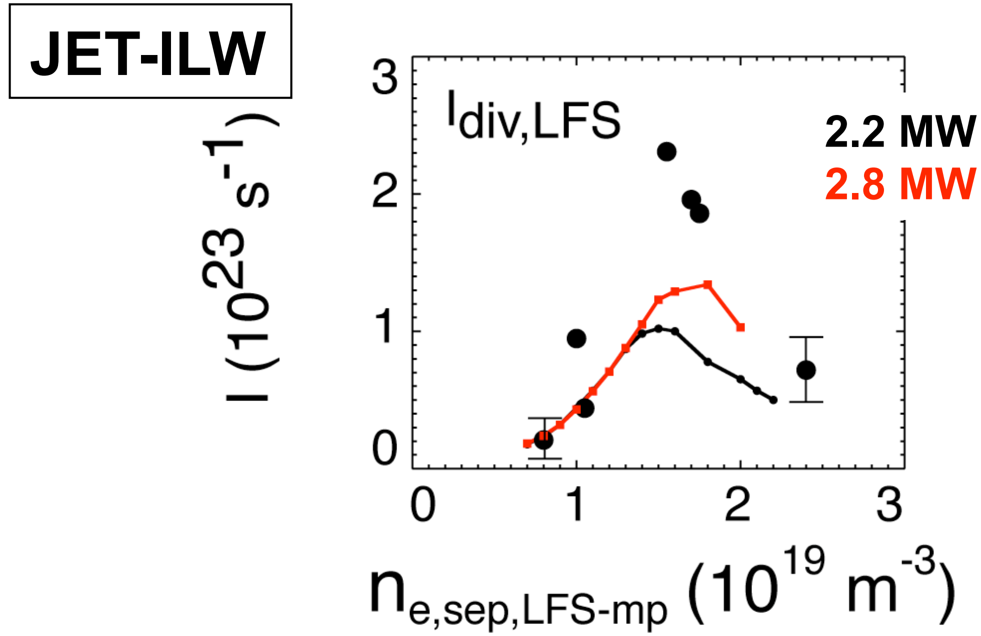
Simulations are within 50% of the measured P_{div} to LFS plate in attached conditions



No cross-field drifts!

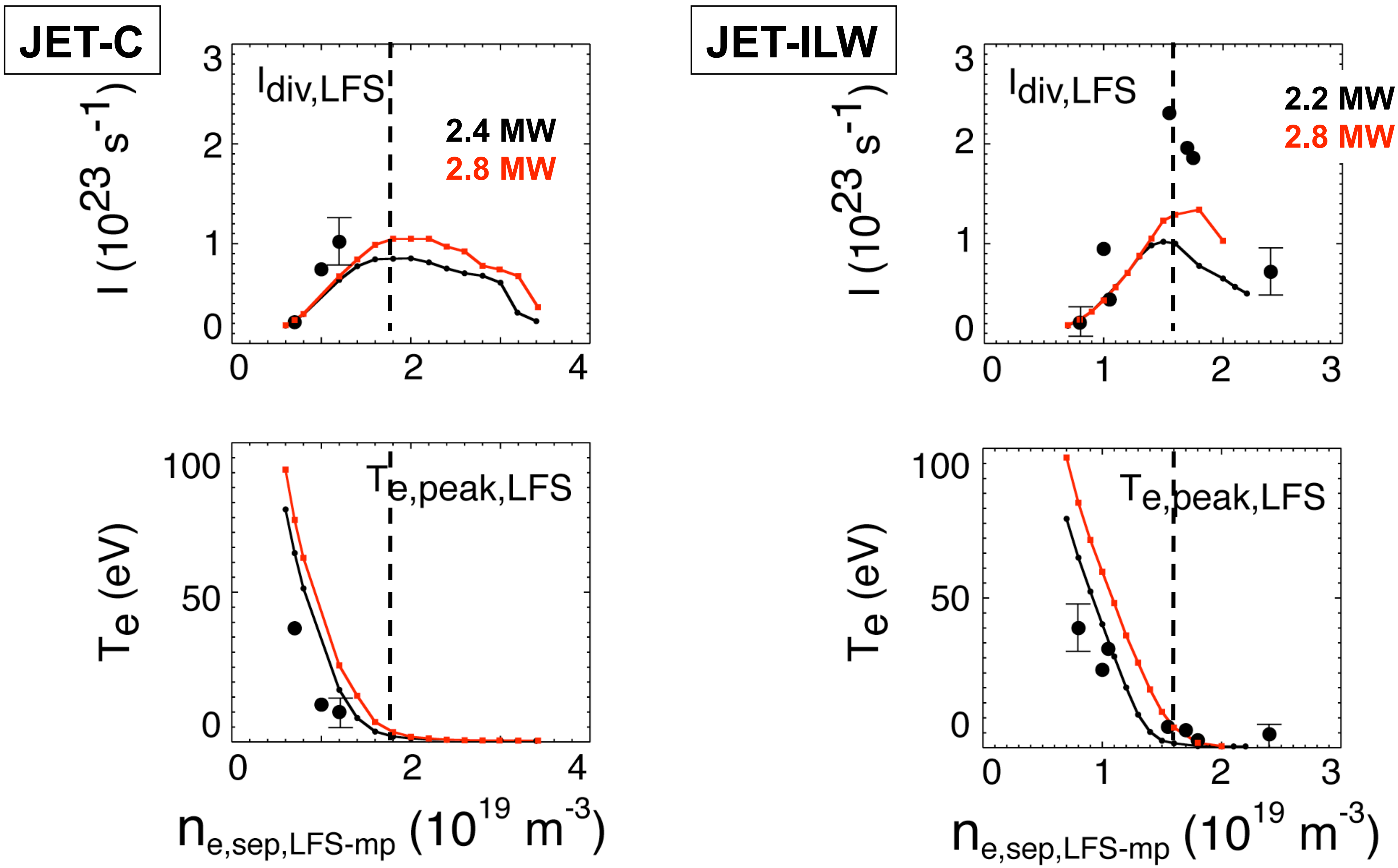
Simulations predict rollover of I_{div} at the LFS plate matching measurements within factor of 2



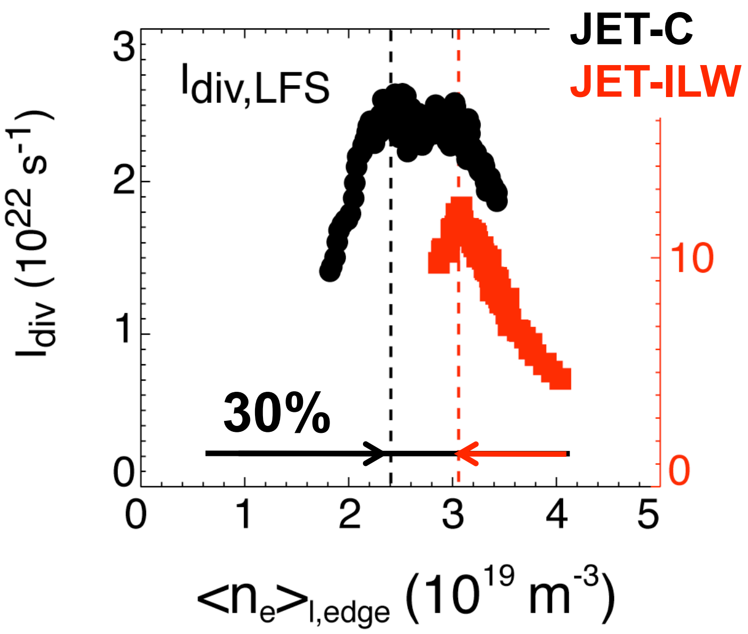


- Predicted rollover more shallow for JET-C than for JET-ILW, as observed experimentally
- Rollover of $I_{div,LFS}$ only obtained when including collisions of plasma ions with deuterium molecules / radicals + n_e and T_e dependent collisional radiative model (Guillemaut et al., PSI 2012)

Simulations predict T_e at the separatrix on LFS plate to drop to 2 eV before rollover of I_{div}

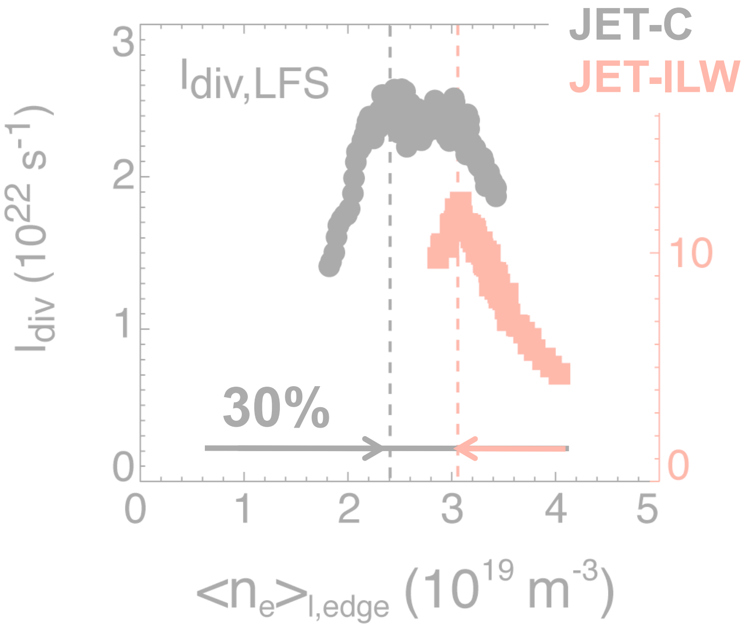


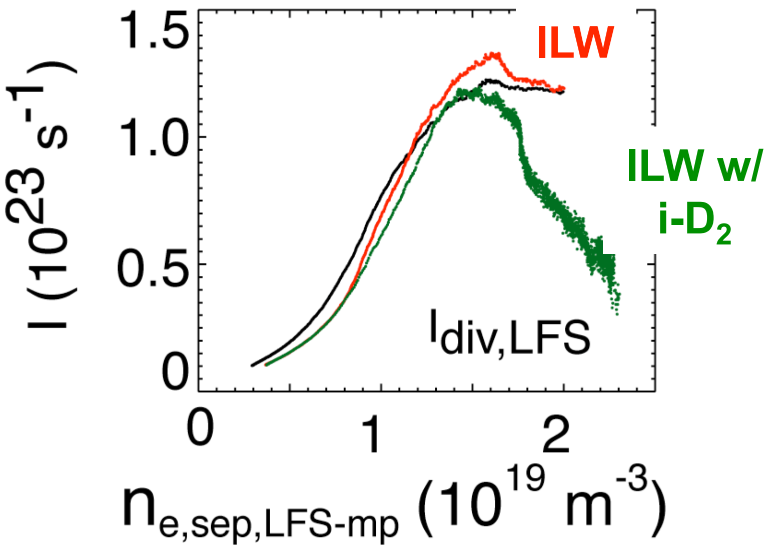
Conclusions



- In high-recycling and detached **L-mode plasmas**, $P_{rad,SOL}$ is 30% lower in JET-ILW than in JET-C ⇒ increase in P_{div}
- Onset of detachment and density limit occurs at 30% higher n_{up} in JET-ILW ⇒ wide detachment window: $n_{DL} \approx 1.5 \times n_{rollover}$
- Detachment of HFS and LFS legs at same n_{up}

Conclusions





- In high-recycling and detached **L-mode plasmas**, $P_{rad,SOL}$ is 30% lower in JET-ILW than in JET-C ⇒ increase in P_{div}
- Onset of detachment and density limit occurs at 30% higher n_{up} in JET-ILW ⇒ wide detachment window: $n_{DL} \approx 1.5 \times n_{rollover}$
- Detachment of HFS and LFS legs at same n_{up}
- Rollover of I_{div} to LFS plate achieved in EDGE2D/EIRENE simulations when extending neutral model

⇒ Physics likely to play a role in simulating H-mode plasmas ⇒ assessment for ITER divertor plasmas ongoing

Please visit the following poster relating to this topic!

- J. Coenen et al., "*Long-term Evolution of the Impurity Composition and Impurity Events with the ITER-like Wall at JET*", **EX/P5-04**

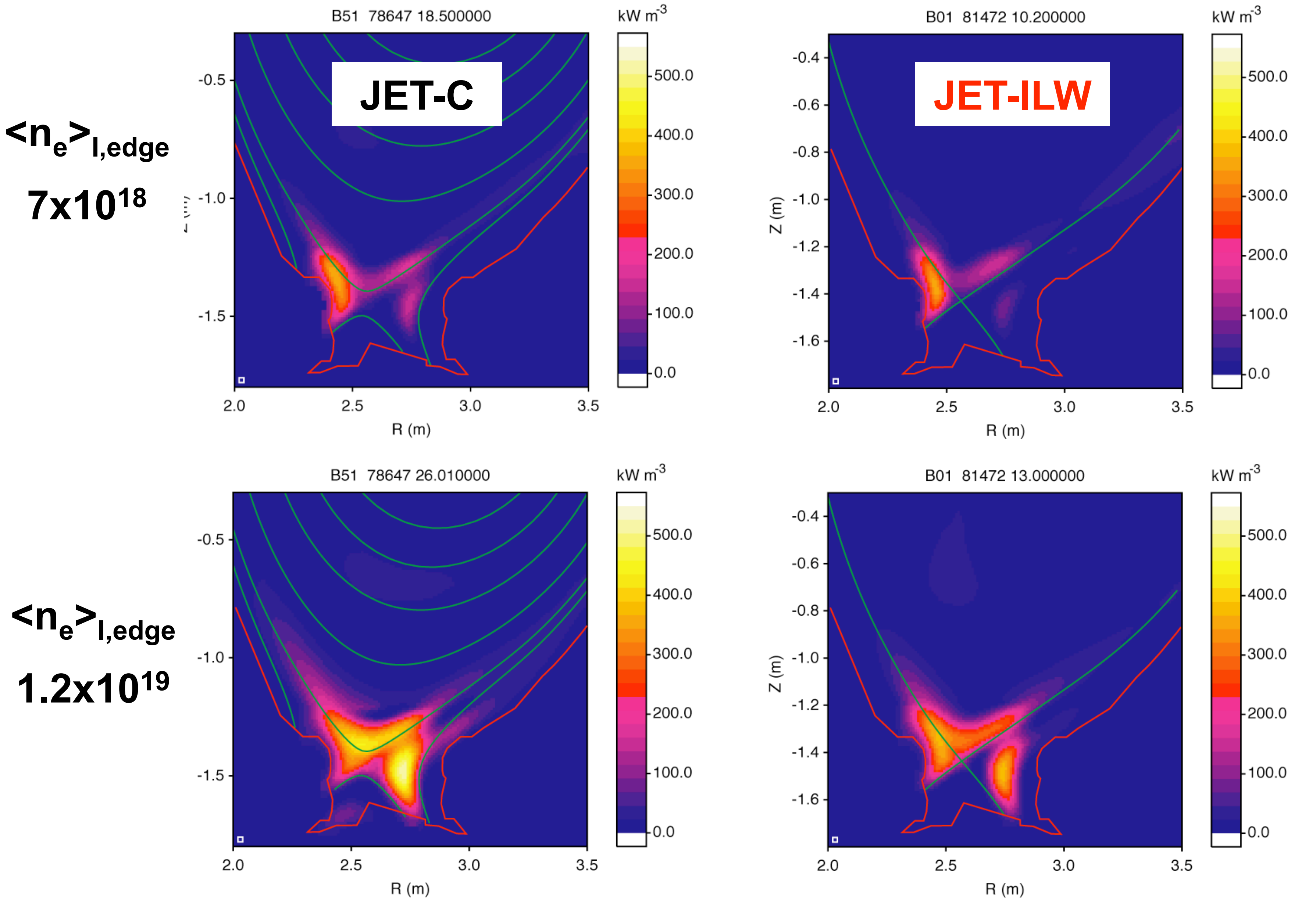
- G. van Rooij et al., "*Characterization of Tungsten Sputtering in the JET divertor*", **EX/P5-05**

- C. Giroud et al., "*Nitrogen seeding for heat load control in JET ELMy H-mode plasmas and its compatibility with ILW materials*", **EX/P5-30**

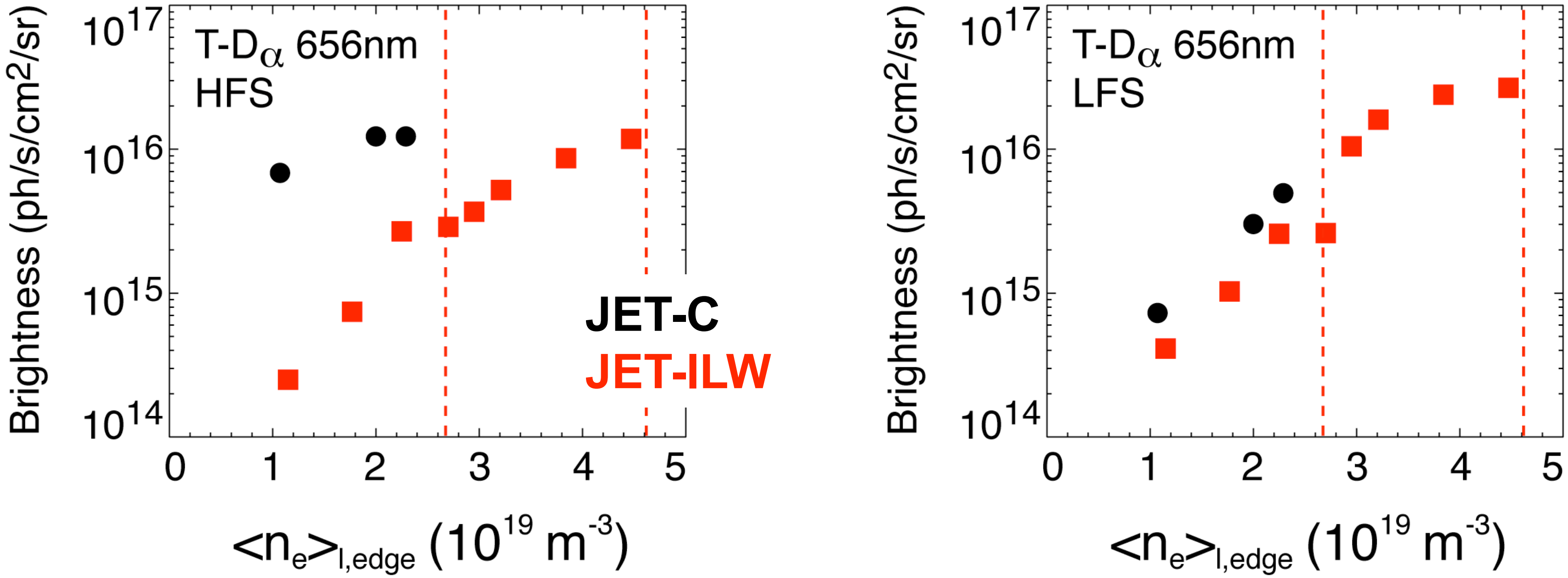
- E. Joffrin et al., "*Scenario development at JET with the new ITER-like wall*", **EX/4-3**

Backup slides

Discernable difference in radiation pattern in high-recycling conditions

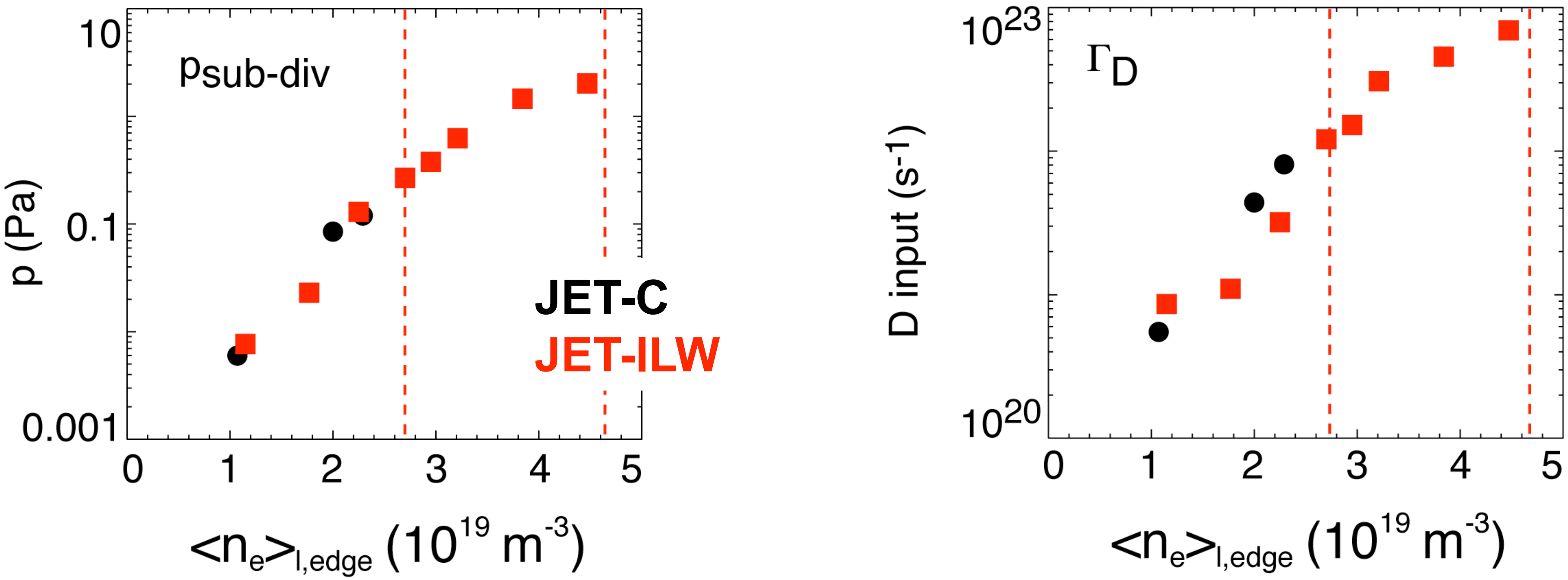


Almost identical D_α emission was measured across LFS plate, consistent with $I_{div,LFS}$



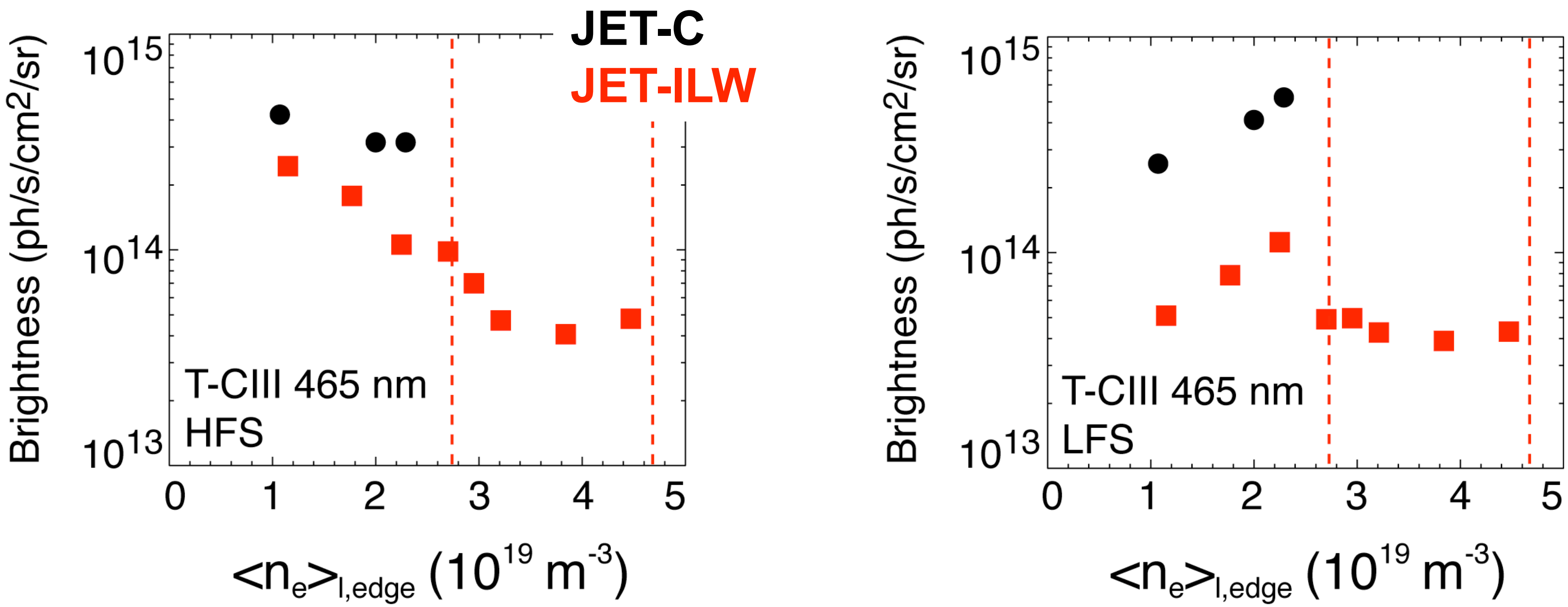
- Significantly higher D_α emission in HFS divertor in JET-C, indicative of lower T_e in HFS divertor

Identical subdivertor pressures were measured in JET-C and JET-ILW



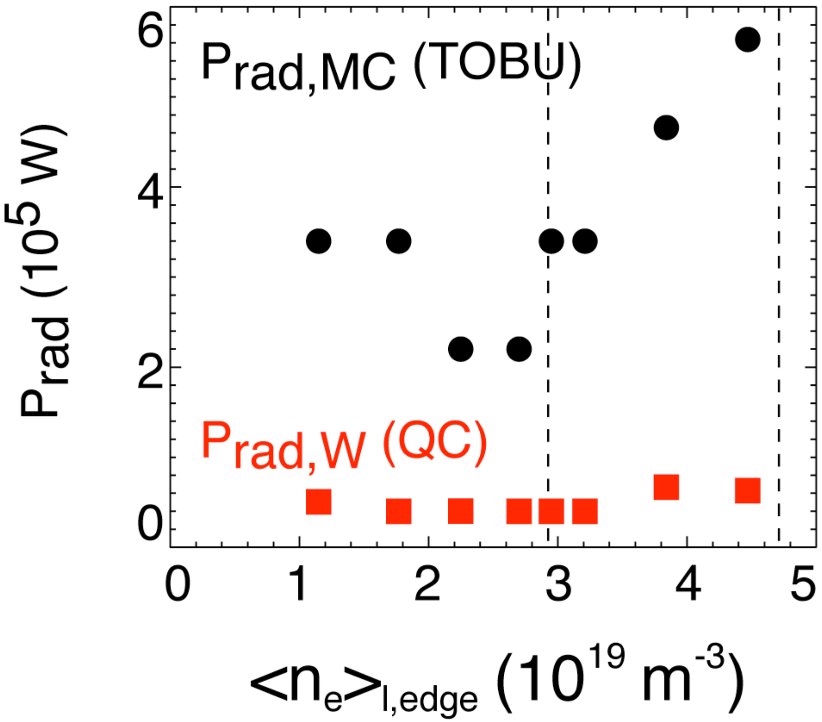
- Identical subdivertor pressures despite elevated height of LFS plate in JET-ILW ⇒ consistent with $I_{div,LFS}$ and $D_{\alpha,LFS}$
- In THESE plasmas, D_2 input was about 2-3 times lower in JET-ILW to achieve same line-averaged edge density

Order-of-magnitude reduction in CIII emission across LFS divertor in JET-ILW



- Reduction in CIII emission (photomultiplier) across LFS divertor leg is consistent with CII measurements using divertor spectrometer (Brezinsek et al., PSI 2012)
- Factor of 2 - 3 reduction of CIII across HFS divertor leg only

Tungsten plays an insignificant role in these L-mode plasmas



- c_W dropped from $5x10^{-6}$ in low-recycling conditions to below $1x10^{-6}$ when detached
- Contribution of W radiation to total radiation in the main chamber is max. 20%

Inclusion of extended neutral physics in EIRENE leads to n_e rollover in high-δ L-mode plasmas

Guillemaut et al., PSI2012

JET-ILW