EUROfusion

L-H TRANSITION STUDIES AT JET: TRITIUM, HELIUM AND DEUTERIUM

Emilia R. Solano and JET L-H transition team*

JET

Laboratorio Nacional de Fusión

Ciemat

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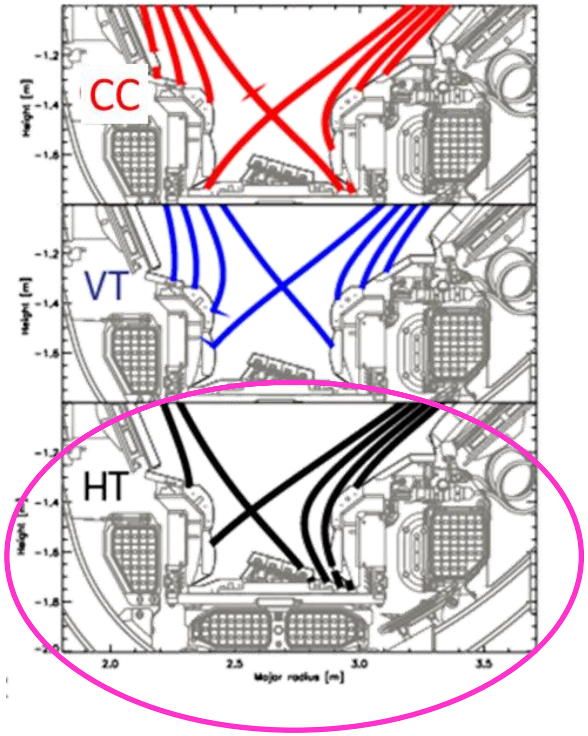
L-H transition studies in JET

- **RF-heated Tritium** plasmas: L-H power threshold, preliminary!
- **Helium** plasmas, comparison with Hydrogen, **Deuterium**:
  - L-H power threshold, $n_{e,min}$
  - ELMs in Helium
  - Transition modelling
- **Deuterium** plasmas:
  - Doppler reflectometry
  - Ion heat flux: modelling and $n_{e,min}$
  - Scaling laws for L-H power threshold



Horizontal **T**arget: HT

$$P_{loss} = P_{Ohm} + P_{Aux} - dW/dt$$
$$P_{sep} = P_{loss} - P_{rad,bulk}$$

L-H transition studies in JET

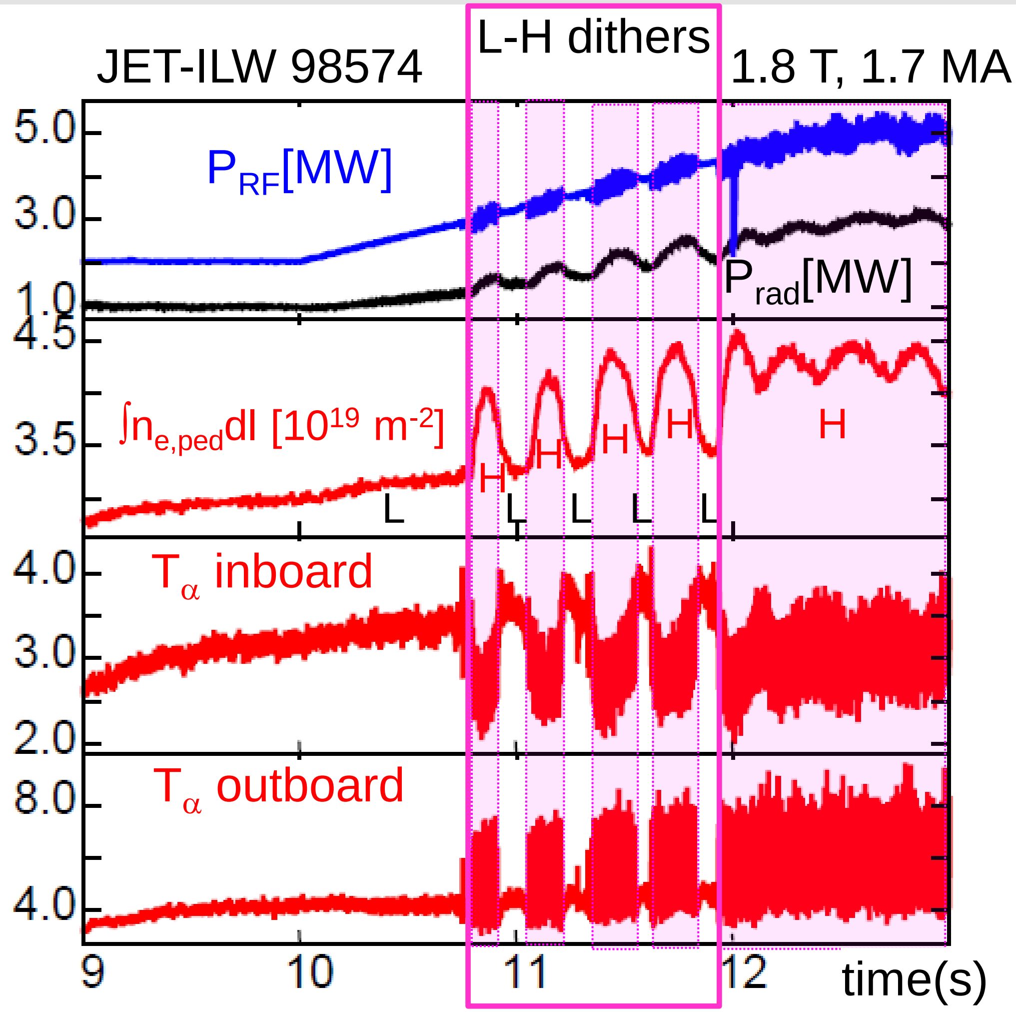
- **RF-heated Tritium** plasmas: L-H power threshold, preliminary!

  From JET-C P_{LH} studies: expect P_{LH}(**T**)= 2/3 P_{LH}(**D**) [1]

[1] E Righi et al 1999 Nucl. Fusion 39 309

RF-heated Tritium in JET-ILW: dithering transitions

L-H transition experiments in **Tritium** with RF heating: difficult to enter good H-mode with ICRH



Clear **L-H dithers** observed:

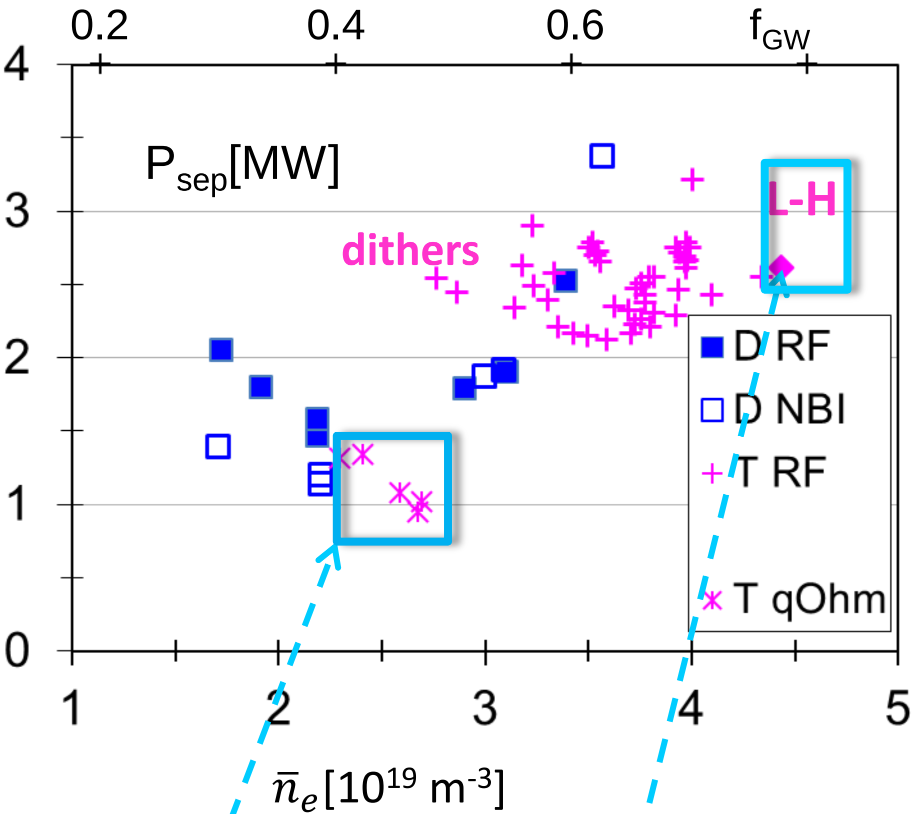
- L-H transition, clear rise of $\bar{n}_e$
- Increase in P_{rad}
- H-L transitions

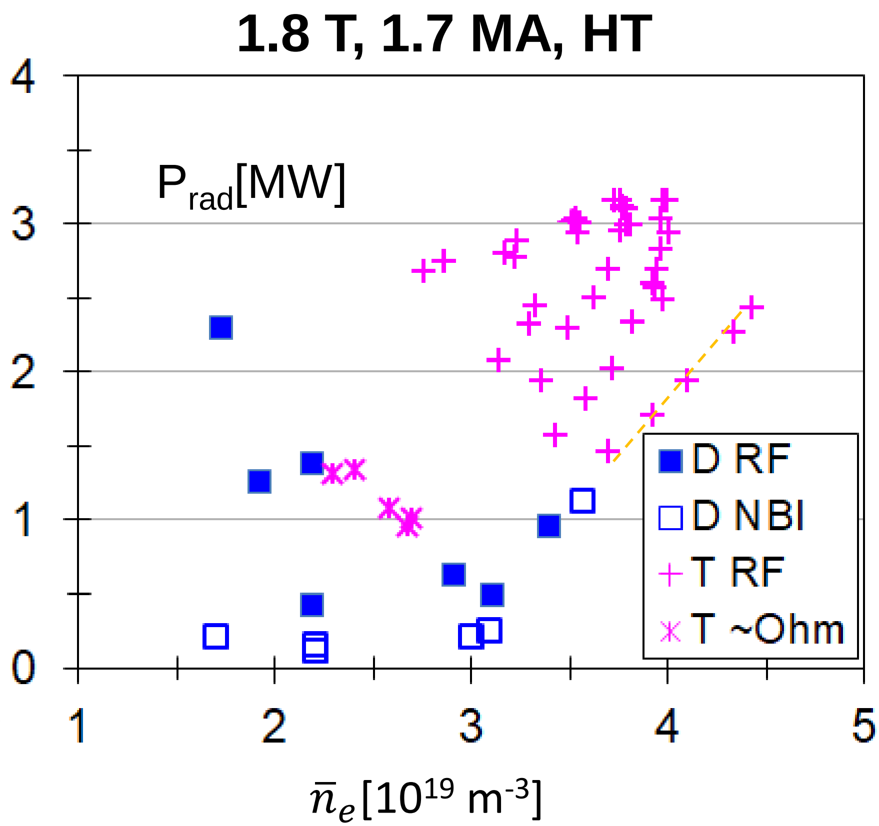
Eventually, at 0.77 n_{GW}, weak H-mode: $T_{e,ped}$ ~100-150 eV

H-minority RF heating
n_T/n_{HDT}>94%, n_H/n_{HDT}<6%

G. Birkenmeier, to be submitted to NF.

L-H power threshold: Deuterium/Tritium comparison





- P_{sep} (**T**)<P_{sep}(**D**) at high density, f_{GW}=0.77
- Dithers: power sufficient for L-H transition in **Deuterium** fails to produce steady H-mode in **Tritium**
- Ohmic and quasi-ohmic **transient** H-modes

- Radiation higher in RF heated **Tritium**: increased W influx
- $P_{rad,bulk}$ already subtracted from P_{sep}: *not the whole story?*

G. Birkenmeier, to be submitted to NF.

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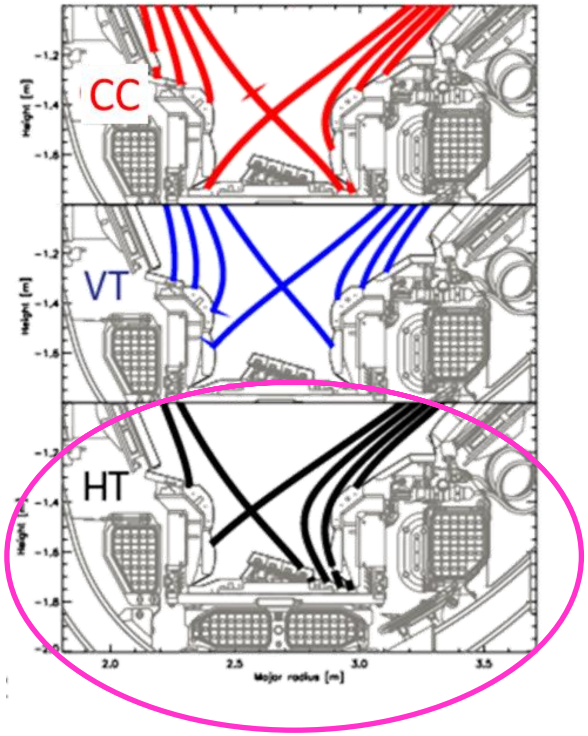
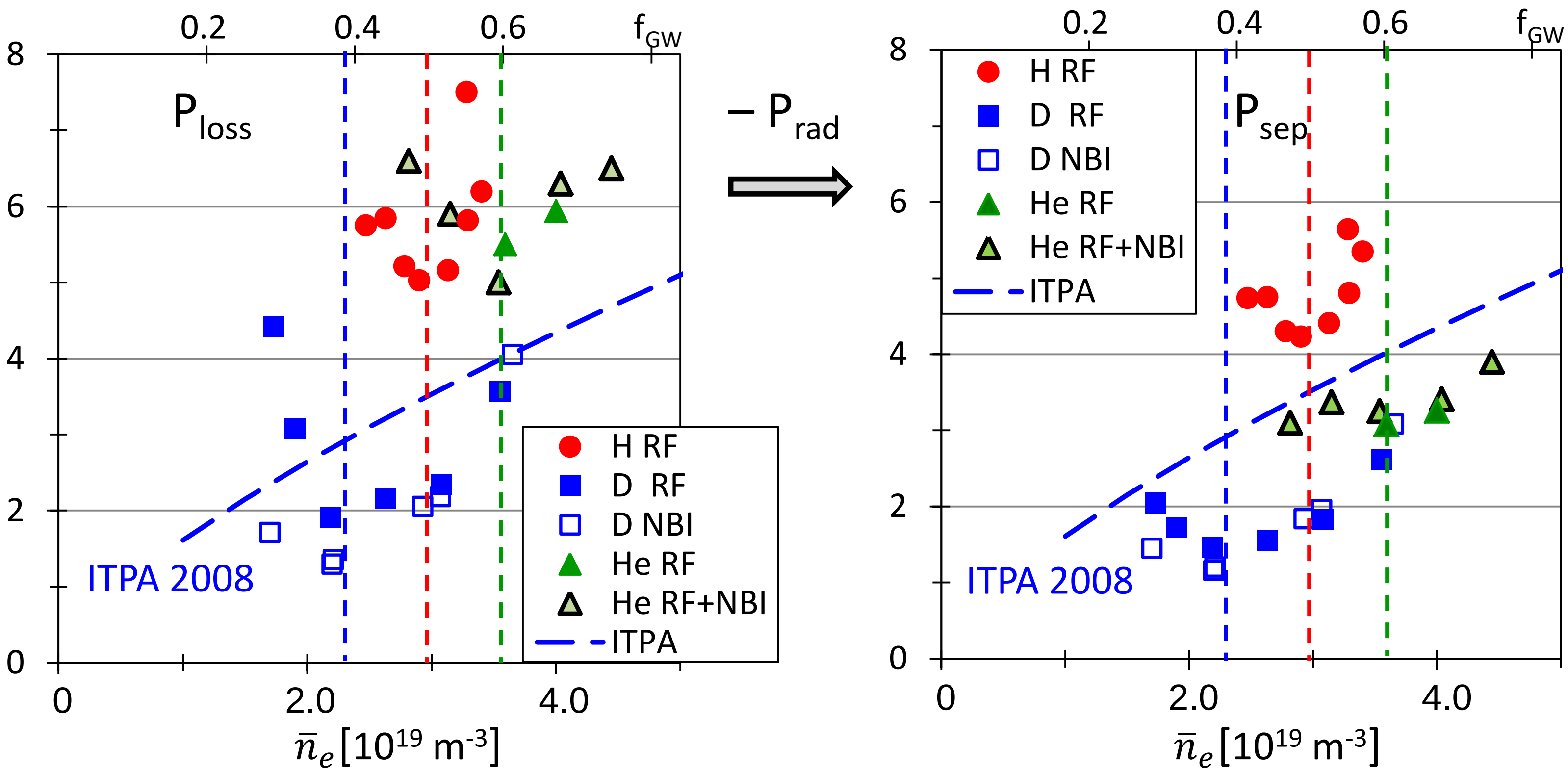


Horizontal Target: HT

$P_{L\text{-}H}$ in Hydrogen, Deuterium, Helium: 1.8 T, 1.7 MA HT

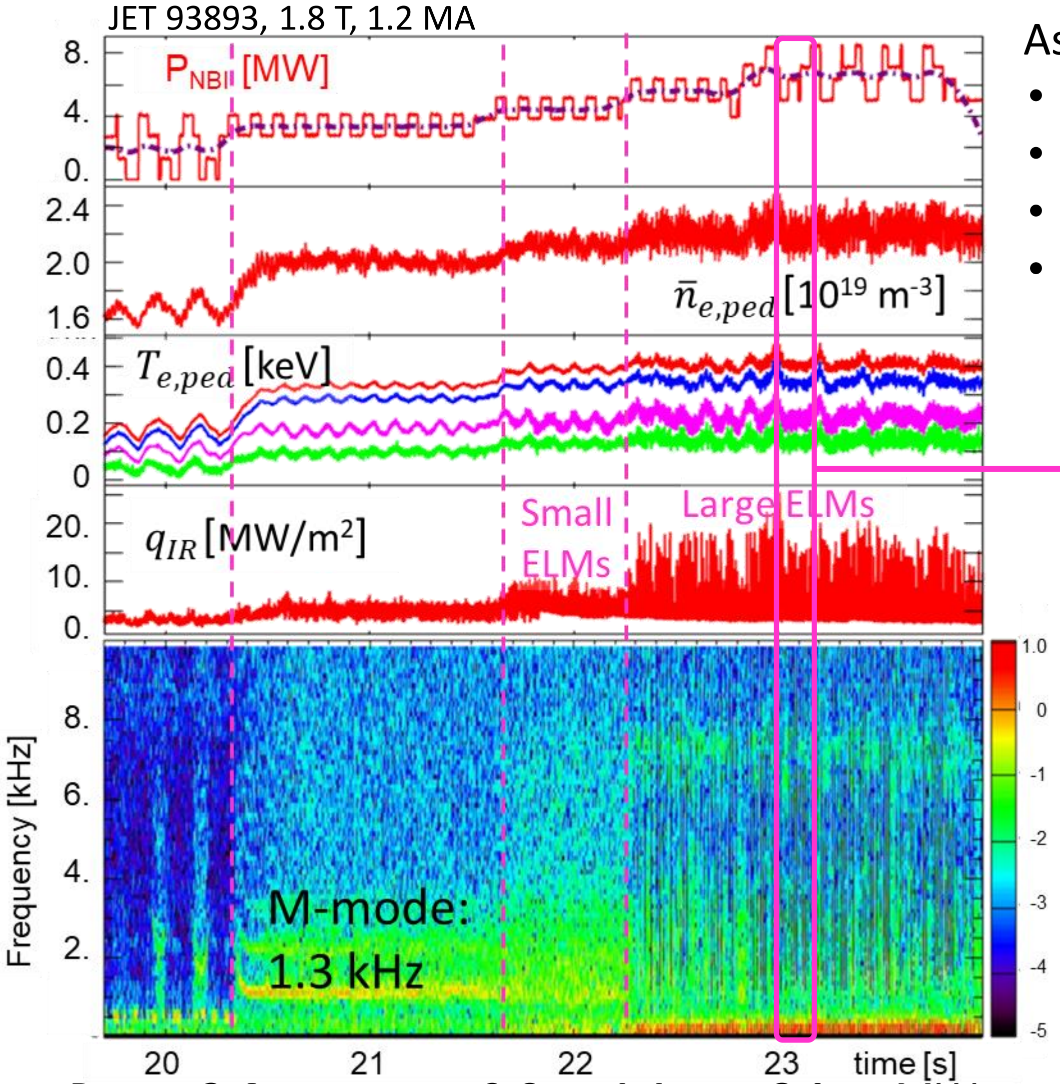


$\bar{n}_{e,min}$(D) = 0.4 f_{GW}
$\bar{n}_{e,min}$(H) = 0.5 f_{GW}
$\bar{n}_{e,min}$(He) = 0.6 f_{GW}

- Clear shift in $\bar{n}_{e,min}$ towards higher densities for **H** and **^{4}He**
- Above $\bar{n}_{e,min}$(He): P_{LH}(He)~P_{LH}(D) (not 40% higher) [2]
- Although P_{rad}(He)>P_{rad}(H or D), $\bar{n}_{e,min}$ shift not due to P_{rad}
- Increase in $\bar{n}_{e,min}$(He) compensated by decrease in P_{LH}: unchanged ITER estimate, provided P_{rad}(He) is not very high in ITER

[2] D McDonald et al, PPCF 46 519 (2004)

Helium Type I ELMs, 1.8 T, 1.2 MA HT



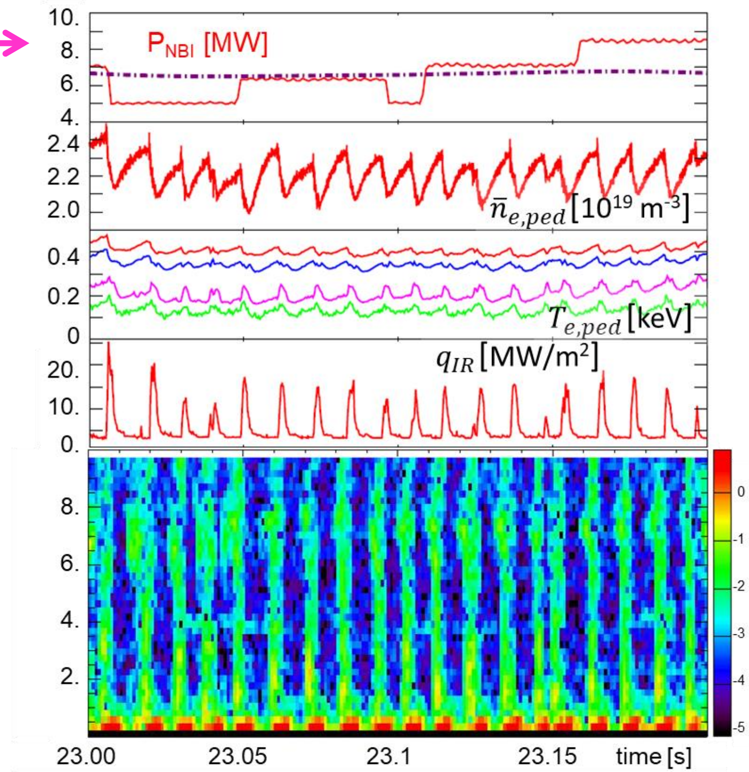
P_{loss} = **2.4** 3.8 4.4 **6.1** MW
P_{sep} = **2.2** 3.3 4.0 **5.5** MW

ER Solano et al, NF 57, 022021 (2017)

As average NBI power increases:

- 3.3 MW: M-mode, 1.3 kHz
- 4.4 MW: small ELMs (type III?), M-mode
- 5.6 MW: 100 Hz isolated + small ELMs
- 6.5 MW: 100 Hz isolated ELMs, **Type I**

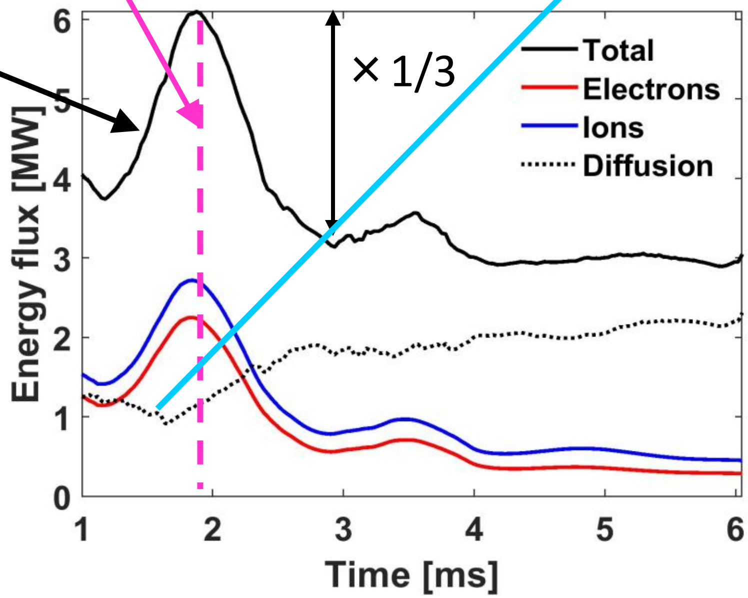
P_{sep}(type I)/P_{sep}(L-H)~2.5



Helium: HESEL modelling of L-H transition

Electrostatic 4-field drift fluid model, slab
Connects confined edge region and SOL
Flux driven - interchange turbulence
Increase in ∇T_i induces L-H transition

Collisional transport $\propto Z^2$



Helium: transition at similar total power to **Deuterium**, but at ~ 2× ∇T_i, $n_i = n_e/2$
Collisional diffusion ~0.5× turbulent transport before L-H, unlike H, D, T
Significant drop in interchange transport at L-H, below collisional diffusion

L-H transition studies in JET

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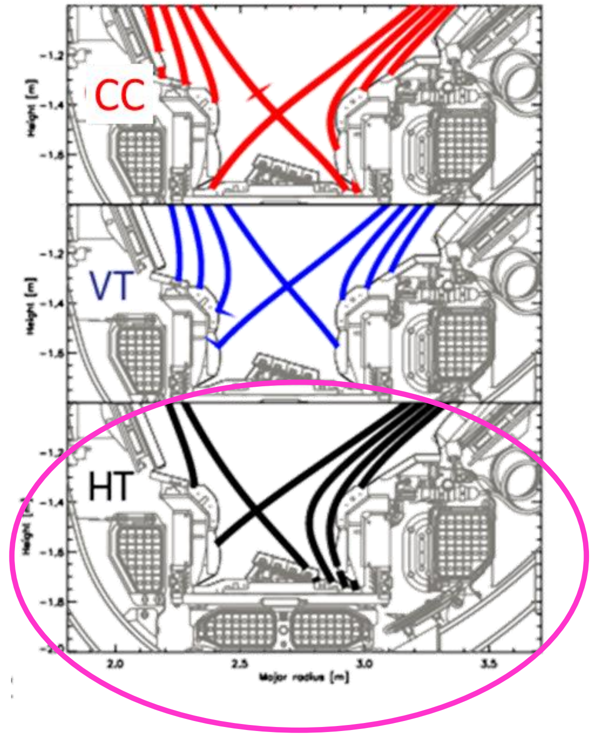
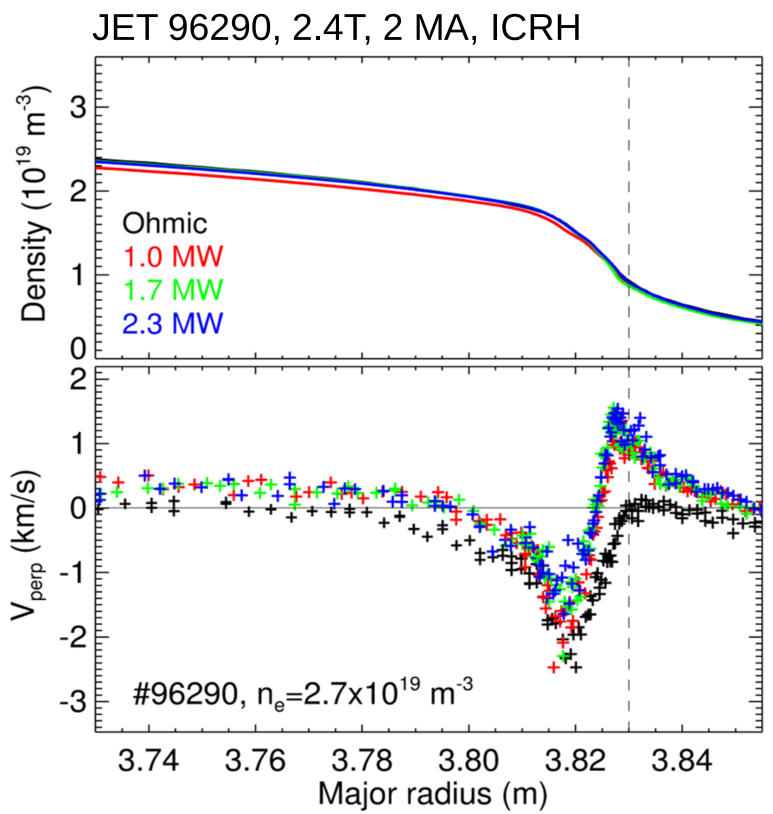


Horizontal Target: HT

Deuterium: Doppler reflectometry $v_\perp \sim E_r$ measurements



Evolution of $v_\perp \sim E_r/B$ measured with Doppler reflectometry along especially slow RF power steps (200 kW every 0.5 s)

Ohmic: low $v_\perp$ at separatrix/SOL, deep well

During power ramp:

- high $v_\perp$ at separatrix/SOL when ICRH on
- reduction in depth of $v_\perp$ well with ICRH
- similar $v_{\perp\ maximum}$ shear during power ramp
- L-H: 200 ms after last $v_\perp$ profile, 2.5 MW

It doesn't appear likely that E_r shear controls the transition.

C. Silva, to be submitted to NF.

Deuterium: Edge ion heat flux Q_i

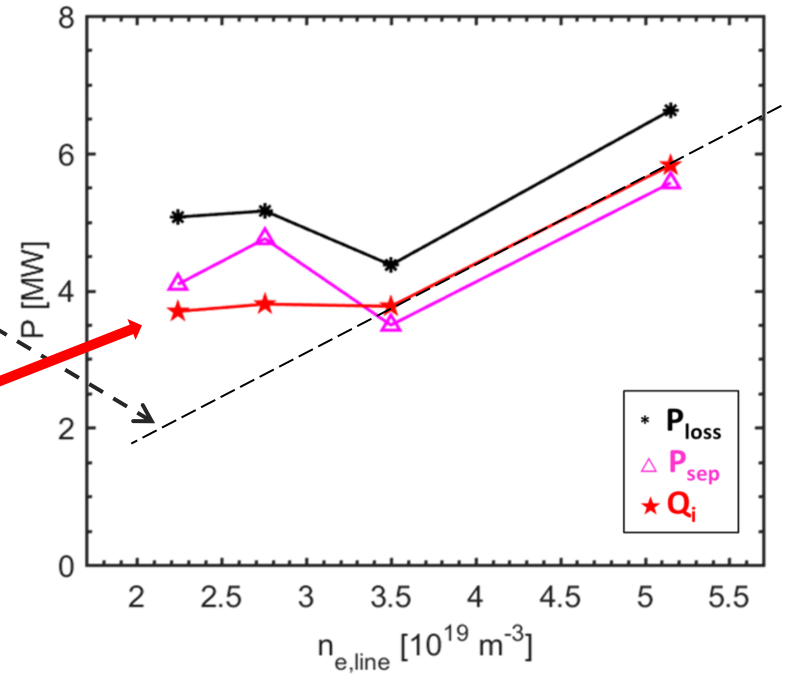
B_{tor} = 3 T, I_p = 2.5 MA, NBI, n_e scan, measured T_i, T_e, n_e, P_{rad} profiles, JINTRAC+ASCOT[1]

Linear Q_i trend below $\bar{n}_{e,min}$ reported for e-heated plasmas in C-mod and AUG[1]

$$P_{sep} = P_{loss} - P_{rad} = \underbrace{(P_{aux,i} + P_{ei} - dW_i/dt)}_{\text{Edge ion heat flux, } Q_i} + \underbrace{(P_{aux,e} - P_{ei} + P_{ohm} - dW_e/dt)}_{Q_e} - P_{rad}$$

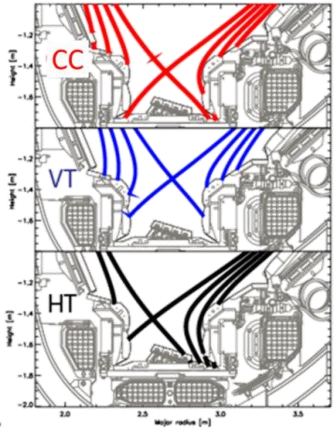
Results from JET power balance analysis[2]

- strong ion heating from NBI and P_{ei}
- dominant ion heat transport, confirmed by QuaLiKiz gyrokinetic simulations
- Core $T_e > T_i$, edge $T_e \approx T_i$
- Non-linear Q_i vs n_e, like P_{loss} and P_{sep}
- Non-linear Q_i similar to AUG NBI[3]
- In this case $\bar{n}_{e,min}$ is not determined by P_{ei}



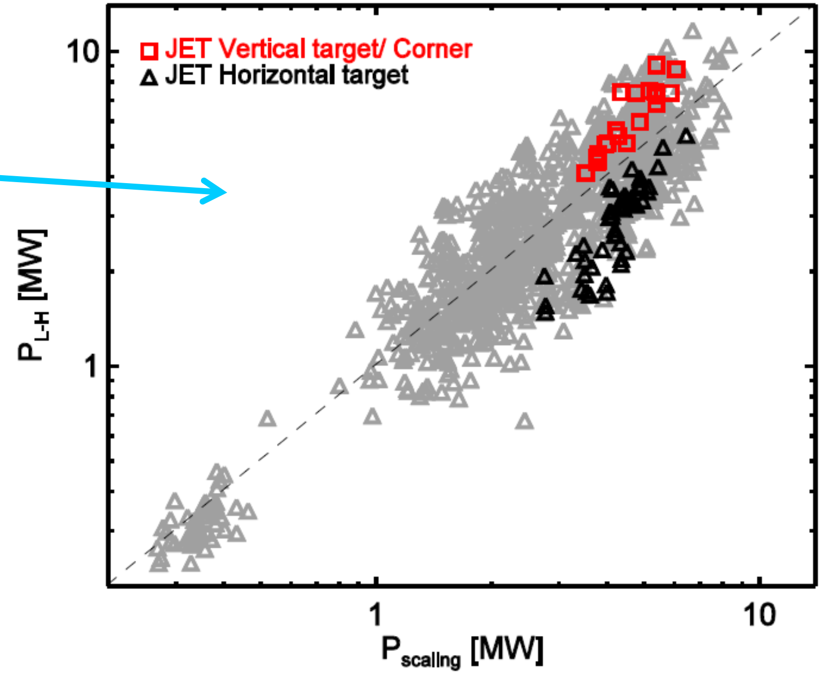
[1]*P. Vincenzi et al., submitted to NF*
[2]*M. Schmidtmayr et al, 2018 Nucl. Fusion 58 056003*
[3]*F Ryter et al, 2014 Nucl. Fusion 54 083003*

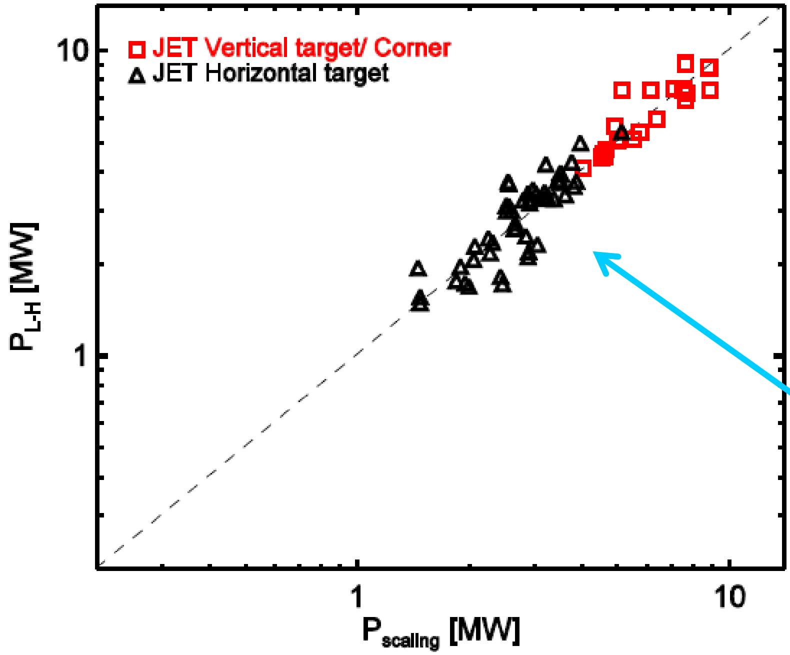
Deuterium: P_{LH} Scaling Laws. ITPA TC-26



JET-ILW vs 2008 ITPA scaling: $P_{LH}=(0.049\pm0.006)\ n_{e20}^{0.72\pm0.03}\ B_T^{0.83\pm0.03}\ S^{0.94\pm0.02}$

- JET-ILW added 106 data points
- New data points don't fit old scaling law
- Introduce shape parameter **D**, new fit to JET-ILW data only





E. Delabie et al, ITPA meeting Sept. 2017

$P_{L-H}=$ **D** $(0.046\pm0.009)\ n_{e20}^{1.31\pm0.09}\ B_T^{0.85\pm0.13}\ S^{1}$

RMSE= 16%

with **D**=1.0 for HT and **D**=2.06 ±0.07 for VT/CC

Stronger n_e trend, especially for HT

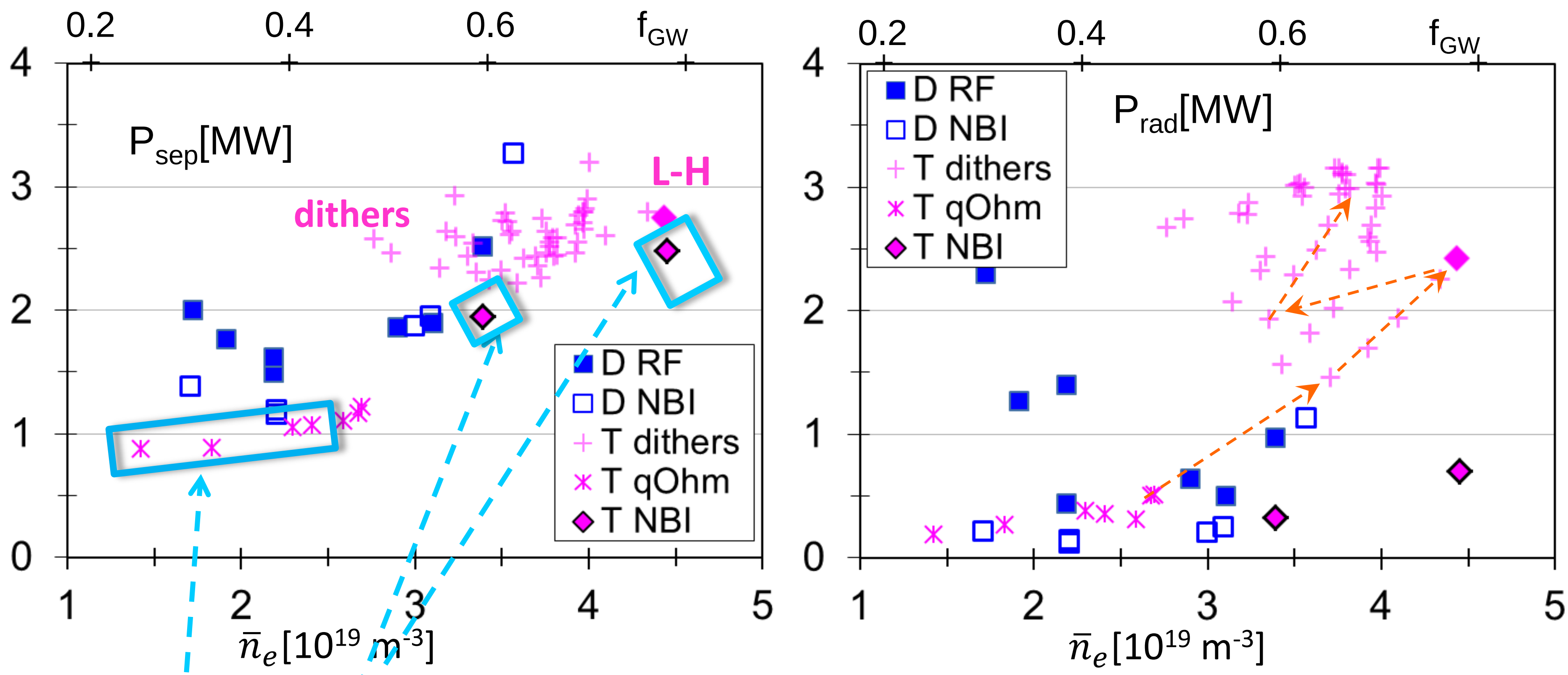
Summary of L-H transition studies in JET

- **RF heated Tritium** plasmas: dithers indicated that $P_{L\text{-}H}(T) > P_{L\text{-}H}(D)$ (preliminary results)
- **Helium** plasmas, comparison with Hydrogen, **Deuterium**:
  - Shifts in $n_{e,min}$: $\bar{n}_{e,min}(D) = 0.4\ f_{GW}$, $\bar{n}_{e,min}(H) = 0.5\ f_{GW}$, $\bar{n}_{e,min}(He) = 0.6\ f_{GW}$
  - Above $n_{e,min}$: $P_{LH}(He) = P_{LH}(D)$
  - Transition modelling: Z^2 collisional diffusion
  - Observed high frequency Type I ELMs in Helium
- **Deuterium** plasmas:
  - Doppler reflectometry: E_r shear doesn't evolve along power ramp
  - Ion heat flux is not a linear function of density below $n_{e,min}$
  - Scaling laws for L-H power threshold in JET-ILW

- **Outlook:** further L-H transition studies in **Tritium** and **DT** planned in 2021

1.8 T, 1.7 MA, HT

L-H power threshold: Deuterium/Tritium comparison



- RF and NBI: P_{sep} (**T**)<P_{sep}(**D**)
- **More** Ohmic H-modes in **Tritium**
- RF dithers at medium n_e? ⟹
- In **Tritium**: P_{rad}(**NBI**)<< P_{rad}(**RF**)

  W content increases with RF and time
- Not enough RF power available to compensate increase in P_{rad}(time,n_e)

G. Birkenmeier, to be submitted to NF.