MAX-PLANCK-INSTITUT
FÜR PLASMAPHYSIK

ASDEX Upgrade

Experimental assessment of the role of the main ion species composition on the access into H-mode

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EUROfusion

Motivation

Fusion power plant:

- DT operation, He as fusion product
- Influence of main ion composition on access into and sustainment of H-mode?

Present-day devices:

- In pure H P_{LH} is 2x higher than in pure D [1,2]
- In pure He: 1 – 1.4 x P_{LH} (D) [3]
- In D+H: non-linear dependence of P_{LH} on relative hydrogen content [4,5]
- Impact of He admixture in H unclear [4,5,6]

AUG

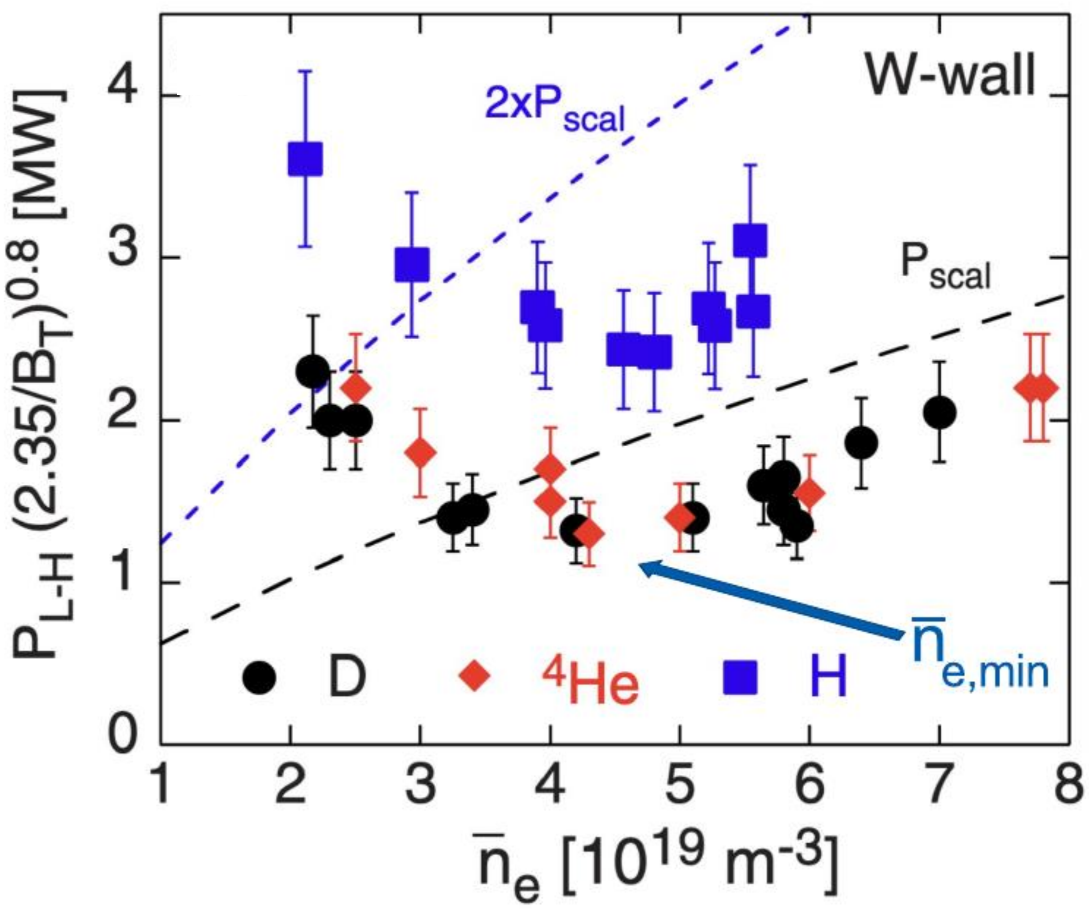


Figure from [2]

[1] E. Righi NF 1999 [2] F. Ryter NF 2013 [3] ITER report 2018 [4] J. Hillesheim IAEA FEC 2018
[5] U. Plank NF 2020 [6] L. Schmitz NF 2022

L-H Transition: Underlying Physics Mechanism

Global:

- Multi-machine scaling P_{scal} for D plasmas [1]

$$P_{scal} = 0.049\, n_e^{0.72} B_t^{0.8} S^{0.94}$$

Local:

- Edge turbulence suppression by ExB shear flow leads to L-H transition [2]

$$E_r = \frac{\nabla(p_i)}{eZ_i n_i} + (\boldsymbol{v}_\mathrm{i} \times \boldsymbol{B})_{\boldsymbol{r}}$$

- Critical edge ion heat ($Q_{i,edge}$) flux at L-H transition [3]
  → connects global P_{LH} with local edge E_r

→ Characterization of global and local edge quantities at the L-H transition in H+D and H+He plasmas at AUG

AUG

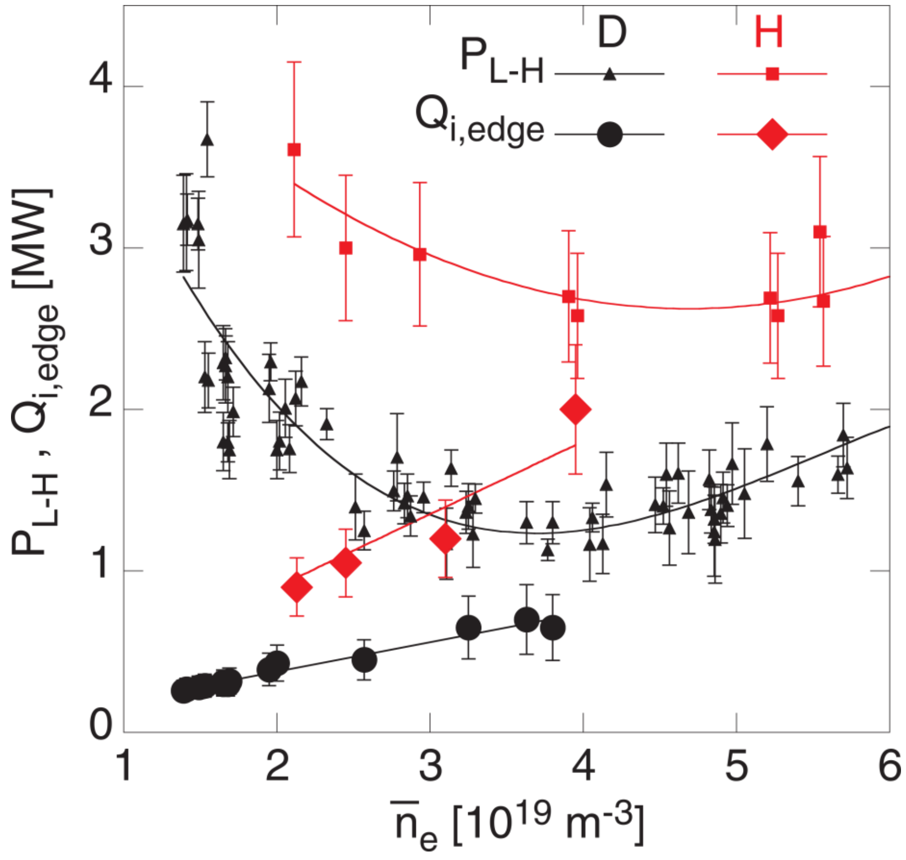


Figure from [4]

[1] Y Martin J. Phys. Conf. 2008 [2] H. Biglari PoP 1990 [3] F. Ryter NF 2014 [4] F. Ryter PPCF 2016

Overview

- Experiment design
- L-H transition in H-D plasmas [1]:
  - Power threshold and edge ion heat flux
  - Radial electric field and ion heat diffusivity
  - H-L back transition
- L-H transition in H-He plasmas [2]:
  - Power threshold and edge ion heat flux
- Summary & conclusions

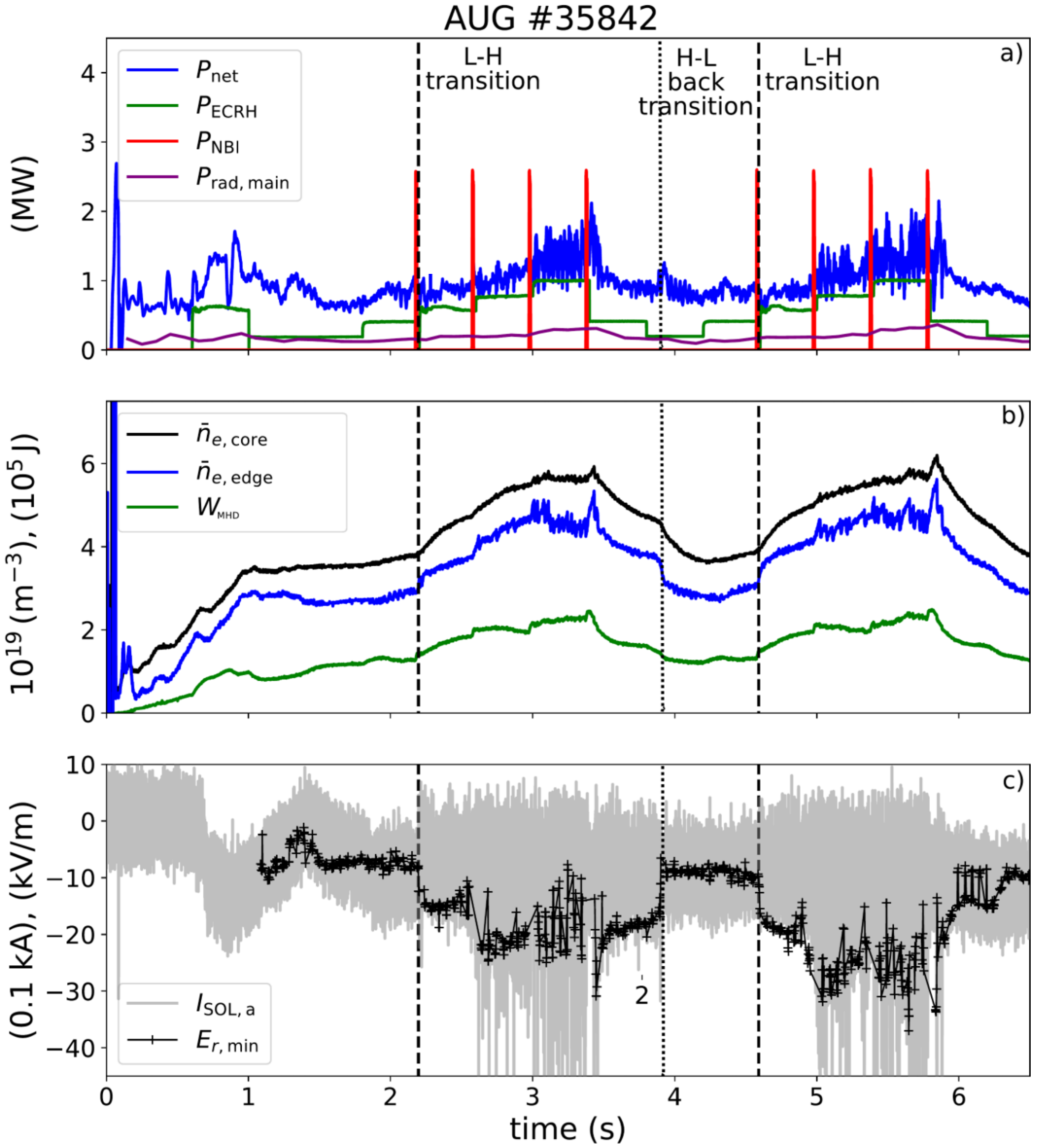
[1] U. Plank PPCF 2023 [2] U. Plank NF 2020

Experiment Design

- LSN with I_p=0.8MA, B_t =-2.5T in fav. drift
- L-H transitions with ECRH or NBI
- Target density: 4x10^{19} m^{-3} (density minimum)
- Feed forward D/H/He gas puffs
- P_{LH} := P_{net} at L-H transition

$P_{net}=P_{aux}-P_{aux,loss}-dW/dt$

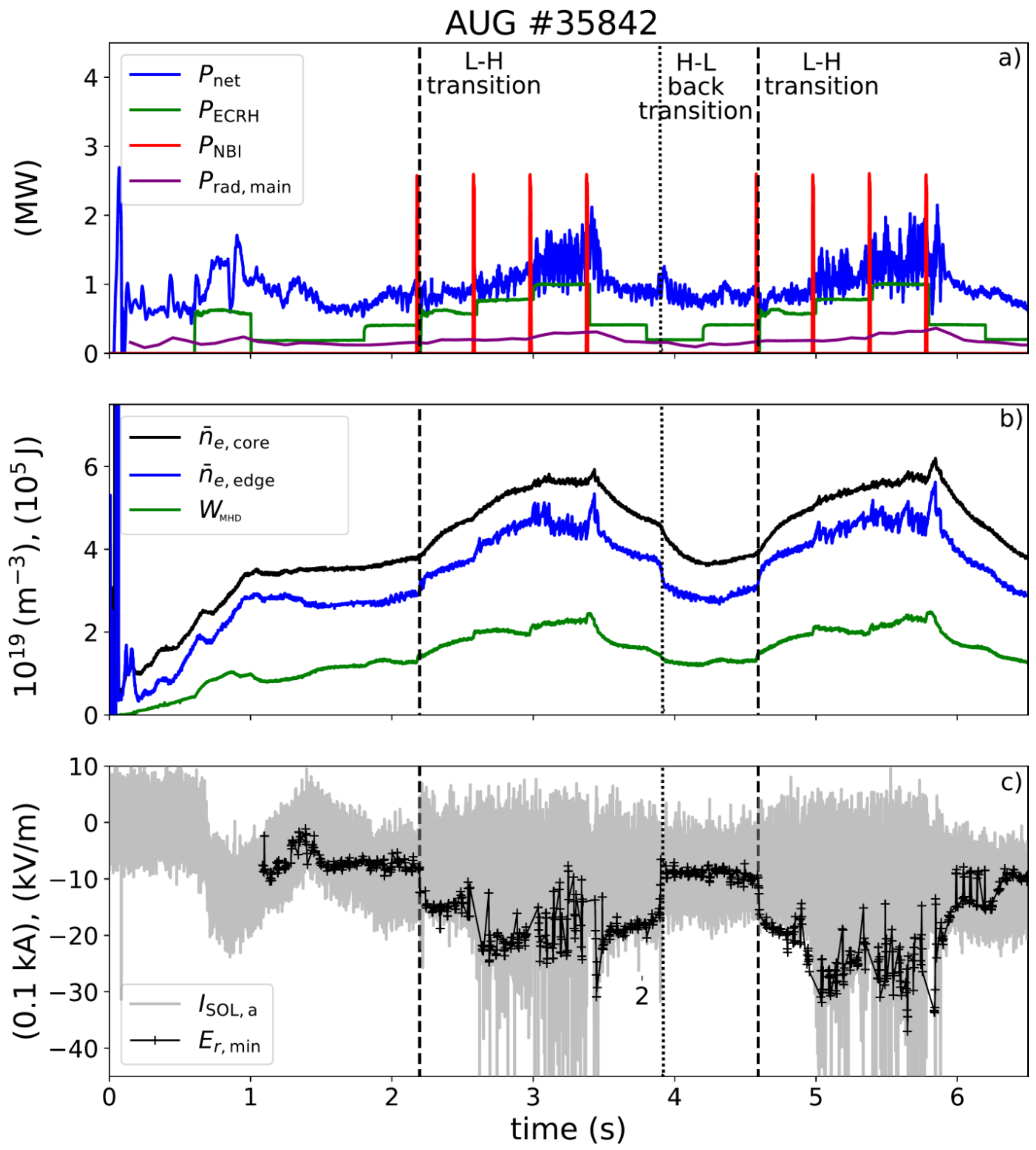
- Main chamber radiation losses measured by bolometry [1] are small



[1] P. David NF 2021

Diagnostics and Analysis Methods

- Relative hydrogen with NPA [1], He content via CXRS [2]
- Edge E_r via Doppler reflectometry (DR) [3, 4] and He II spectroscopy (HES) [5]
- IDA for T_i, $T_{e,}$ n_e [6, 7]
- Power balance (Q_i, Q_e) with ASTRA and RABBIT/Torbeam [8, 9,10]

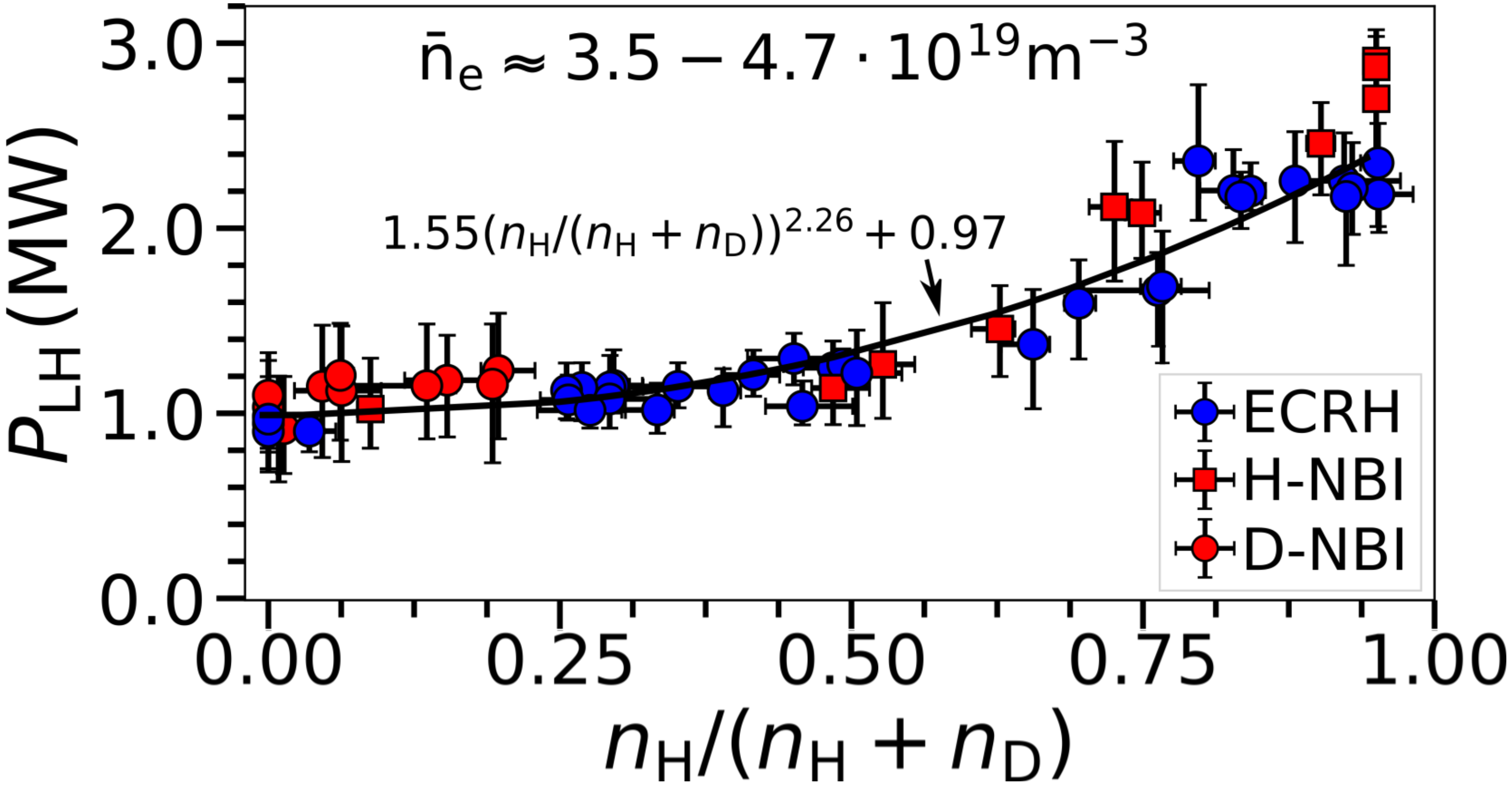


[1] Bartiromo RSI 1987 [2] A. Kapppatou PPCF 2018 [3] G.D. Conway PPCF 2004 [4] T. Happel PoP 2015 [5] U. Plank PhD in prep. for RSI 2023 [6] E. Viezzer RSI 2012 [7] R. Fischer Fus. Sci. Techn. 2010 [8] G.V. Pereverzev IPP-Report 5/98 [9] M. Weiland NF 2018 [10] E. Poli Comp. Phys. Comm. 2000

Non-linear Dependence of P_{LH} & $Q_{i,edge}$ on Relative Hydrogen Content

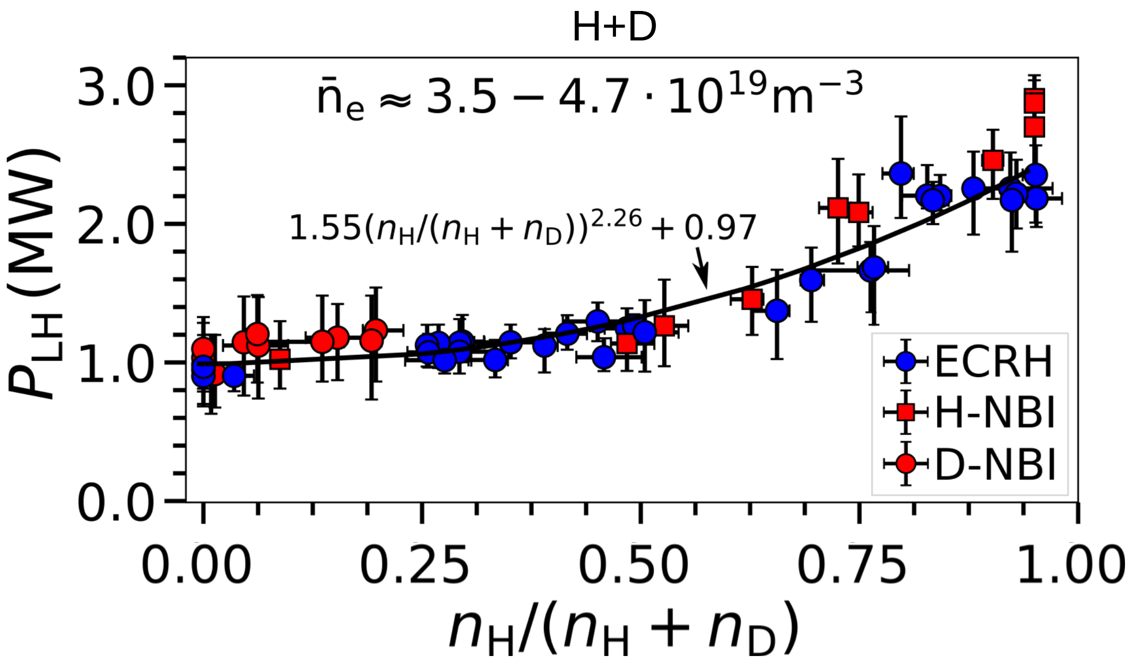
- P_{LH} starts to increase from D to H level at $n_H/(n_H+n_D) \sim 0.6$

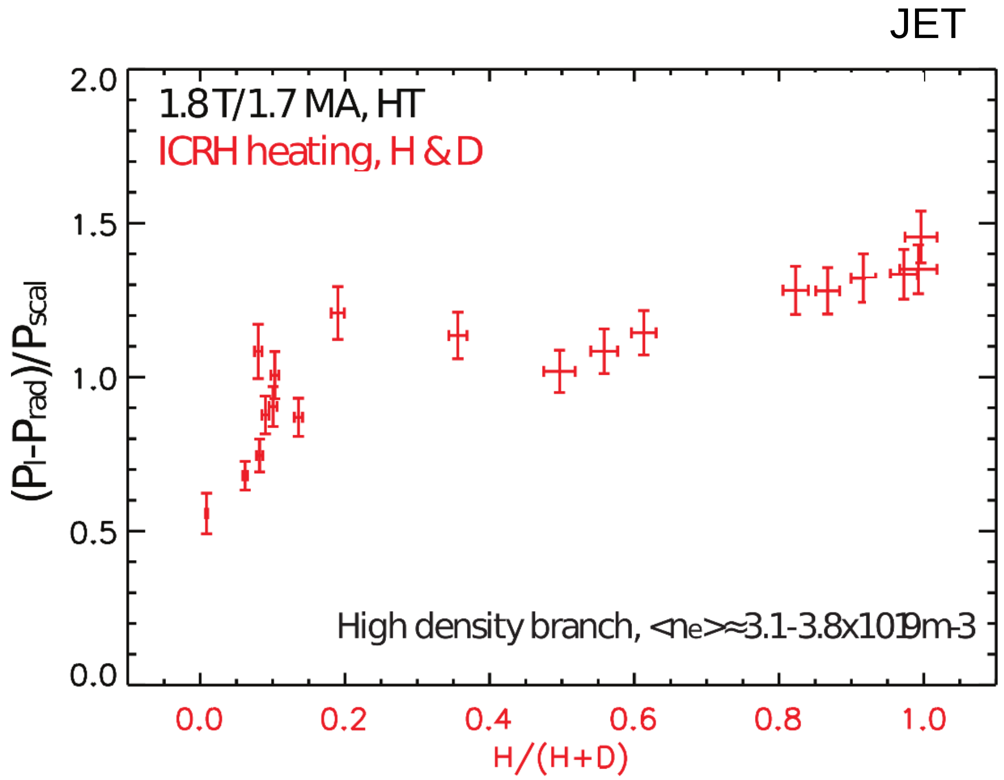
H+D



Non-linear Dependence of P_{LH} & $Q_{i,edge}$ on Relative Hydrogen Content

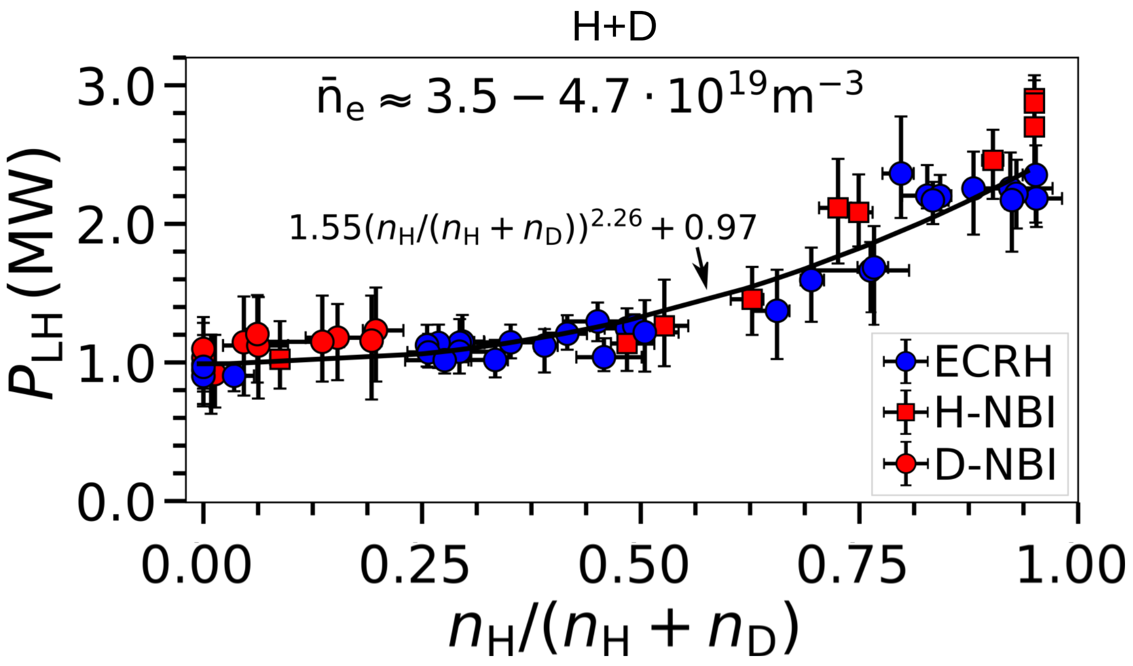
- P_{LH} starts to increase from D to H level at $n_H/(n_H+n_D)$ ~ 0.6
- Different to JET results

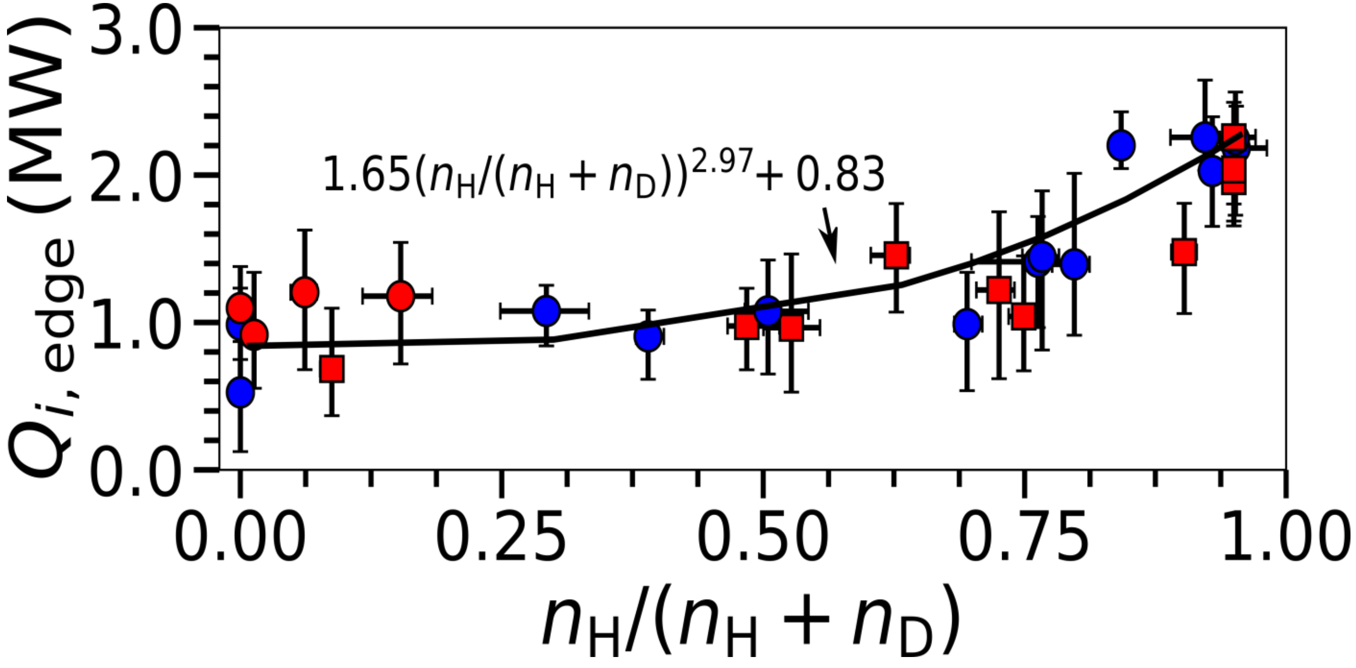




Non-linear Dependence of P_{LH} & $Q_{i,edge}$ on Relative Hydrogen Content

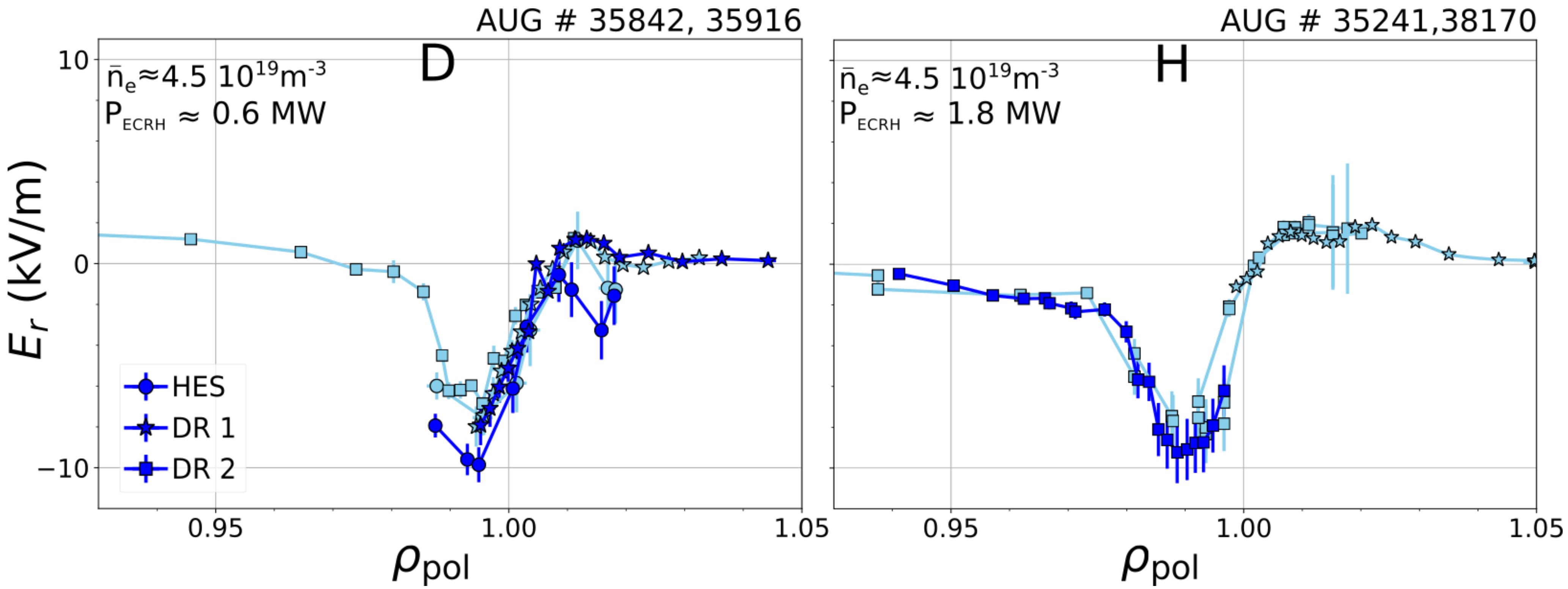
- P_{LH} starts to increase from D to H level at $n_H/(n_H+n_D) \sim 0.6$
- $Q_{i,edge}$ follows this trend





E_r gradients at L-H transition Similar in Pure D and H Plasmas

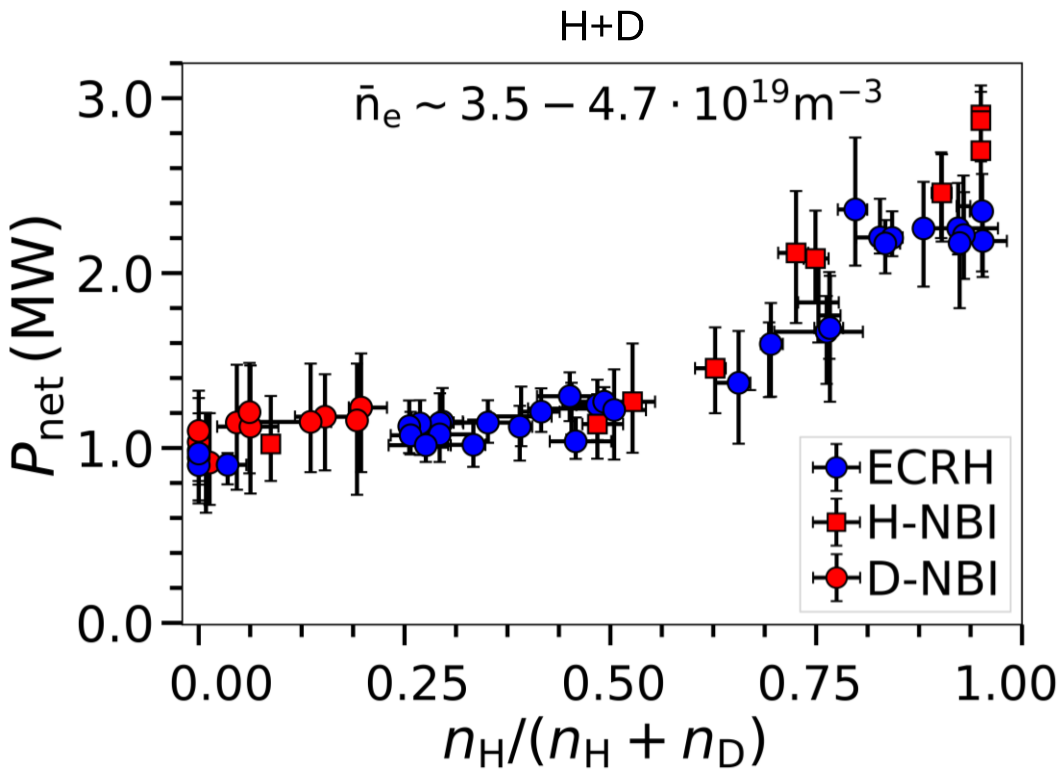
- $E_{r,min}$ and E_r gradients the same in D and H (in line with [1])
- $E_{r,min}$ can be used as proxy for its gradients in these L-mode conditions [2,3]
- Diamagnetic term ($\nabla_r p_i / e n_i$) is a good proxy for the edge E_r in these L-mode conditions [2,3]

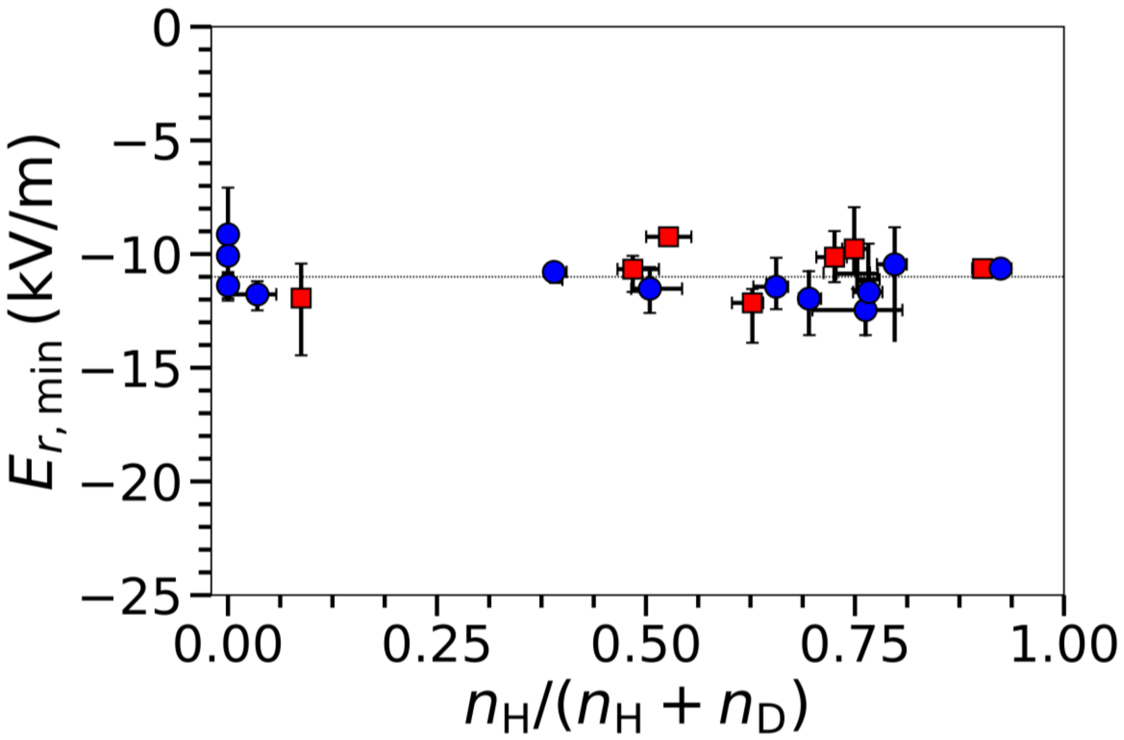


[1] M. Cavedon NF 2020 [2] U. Plank PoP 2023 [3] U. Plank PPCF 2023

$E_{r,min}$ Constant at the L-H Transition

- $E_{r,min}$ ~ -11 kV/m (in line with [1]) → same E_r gradients for different $n_H/(n_H+n_D)$





[1] M. Cavedon NF 2020

Ion Heat Transport Increases with Relative Hydrogen Content

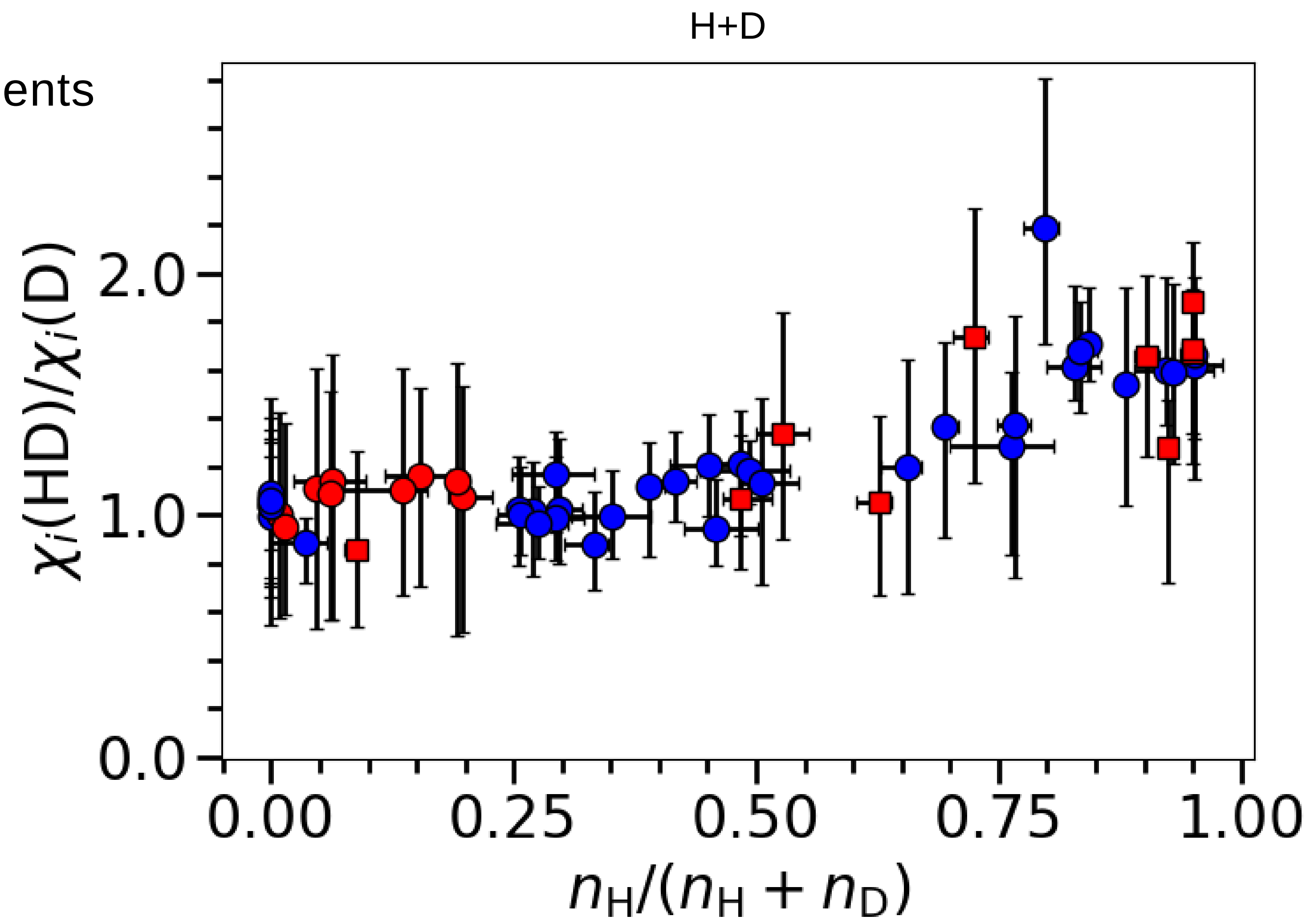
- Increasing $Q_{i,edge}$ + const. E_r gradients (including const. $\nabla_r T_i$) at same n_e

$$Q_i = -\chi_i n_i \nabla T_i$$

→ χ_i must increase non-linearly with increasing $n_H/(n_H+n_D)$

- In line with theoretical [1,2] and experimental work from other machines [3-5]

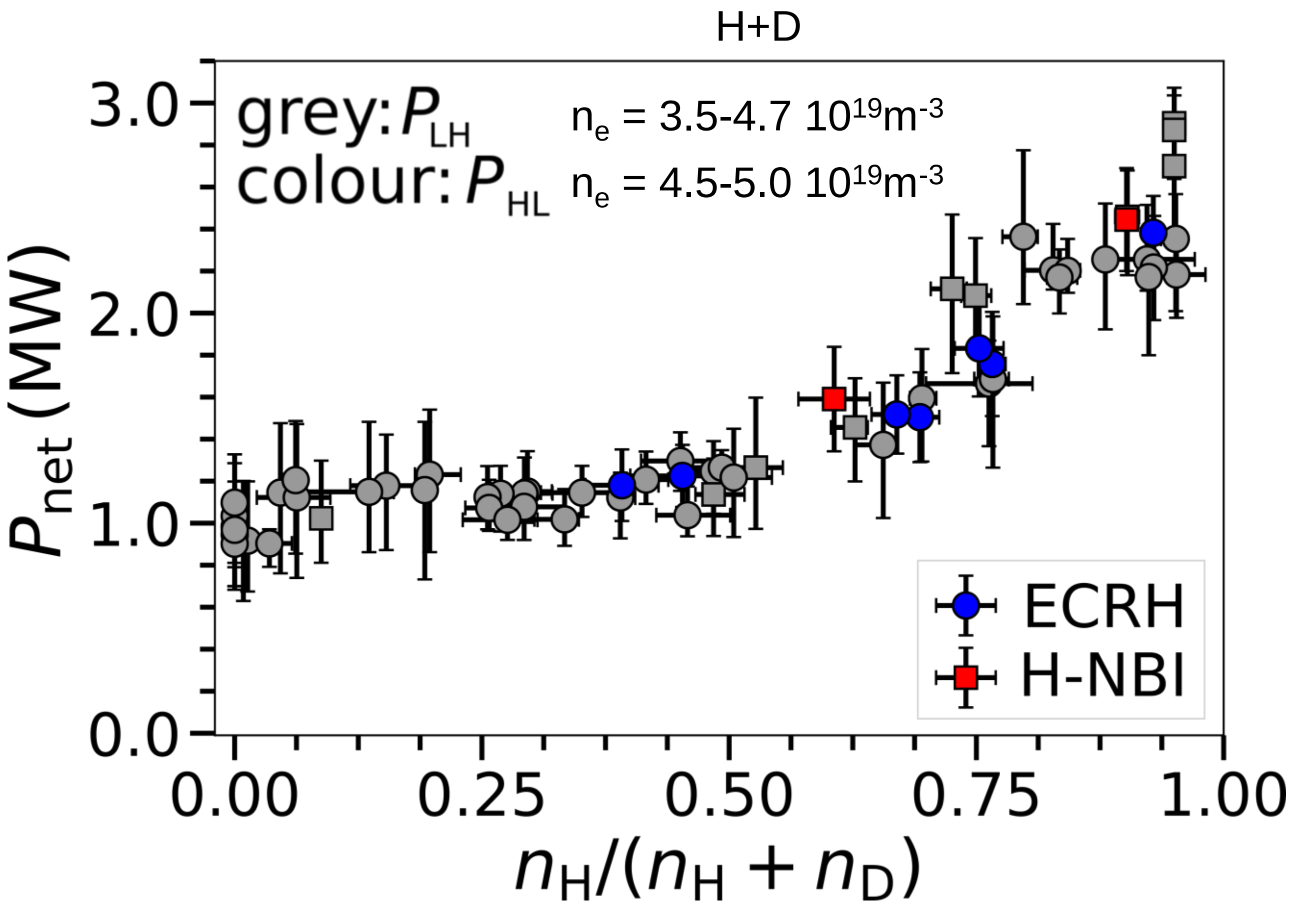
→ Possible explanation for increased P_{LH}



[1] N. Bonanomi PoP 2021 [2] E. Belli PRL 2020 [3] P. Schneider PPCF 2021 [4] C. Maggi NF 2019 [5] G. Birkenmeier PPCF 2023

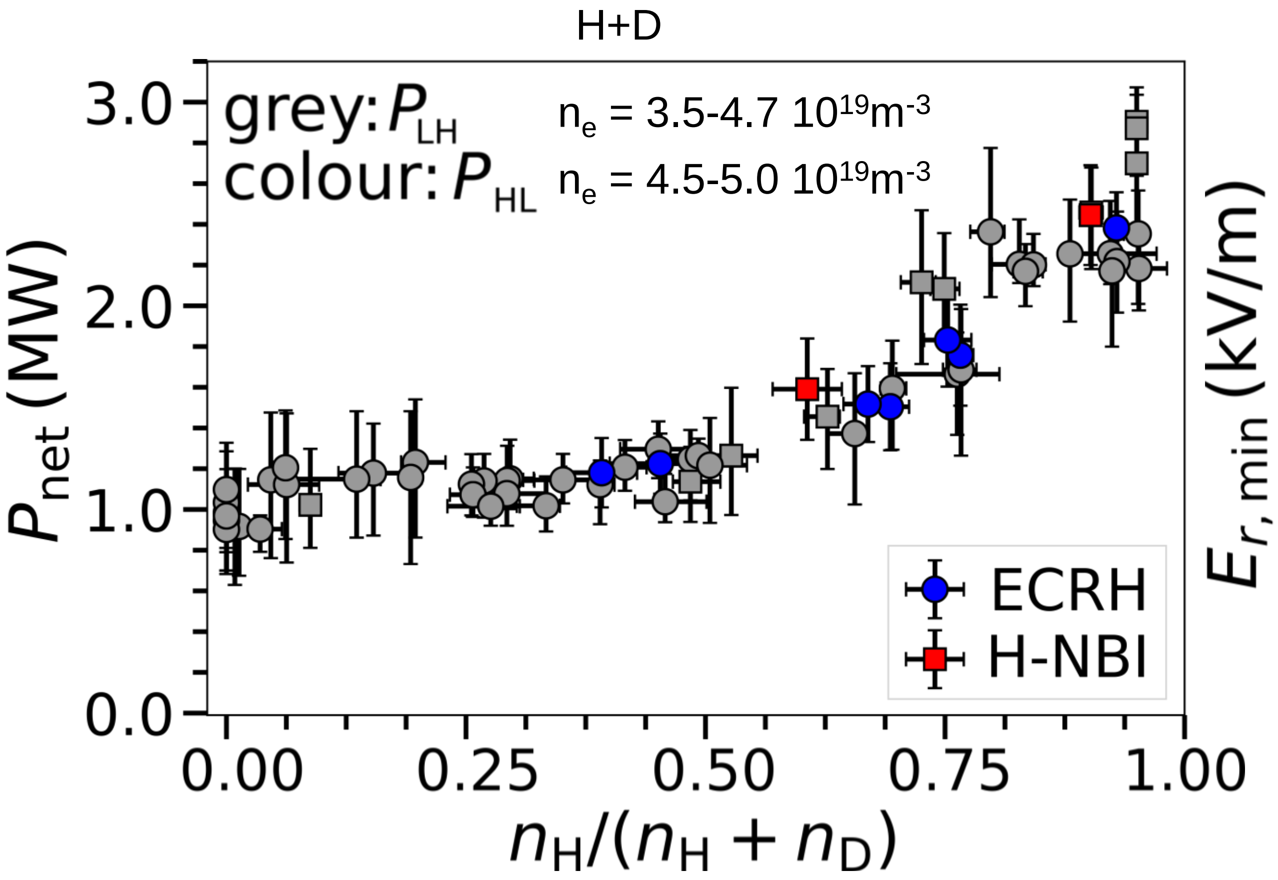
Same Non-linear Dependence of H-L Back Transition on Relative Hydrogen Content as L-H Transition

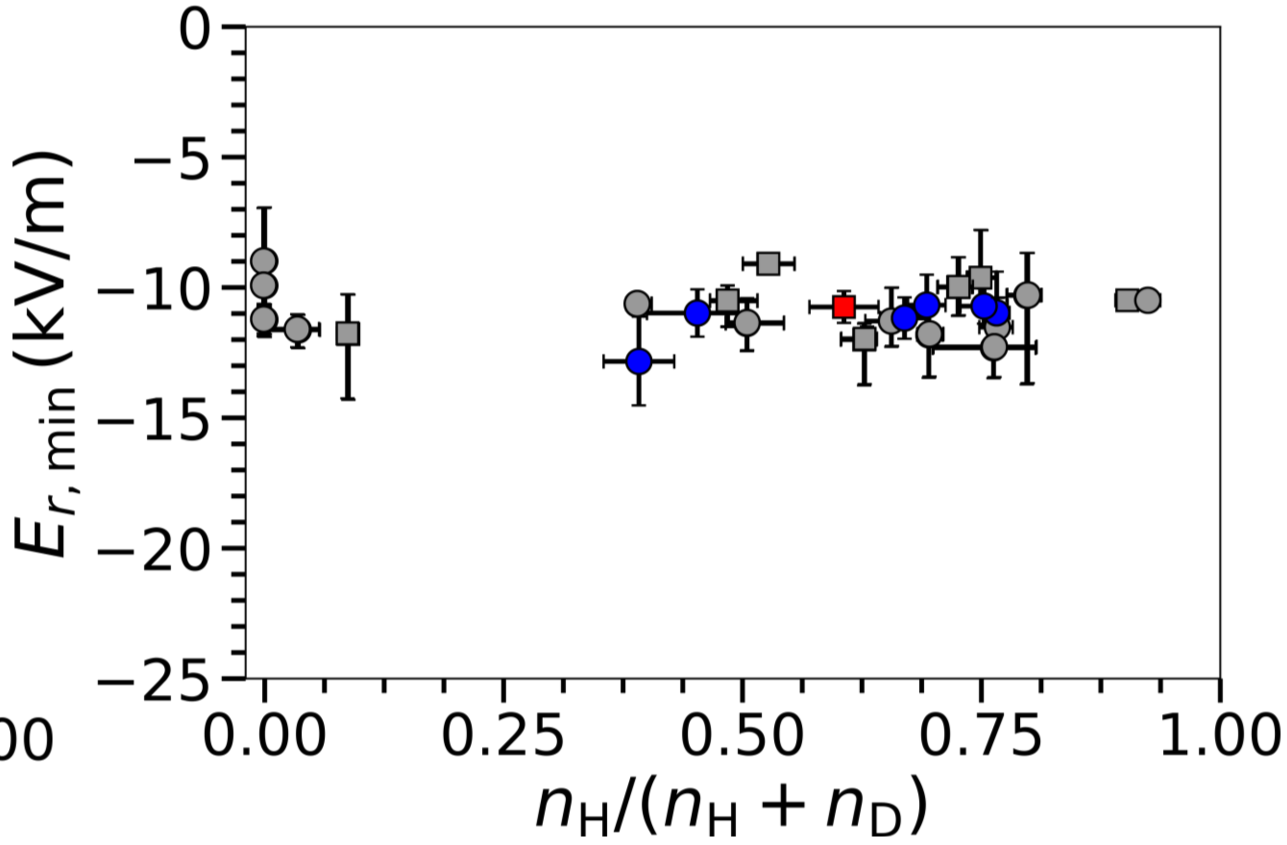
- Small hysteresis of P_{LH} and P_{HL} if higher plasma density at H-L is taken into account



$E_{r,min}$ the Same at L-H and H-L Back Transition

- No hysteresis in $E_{r,min}$



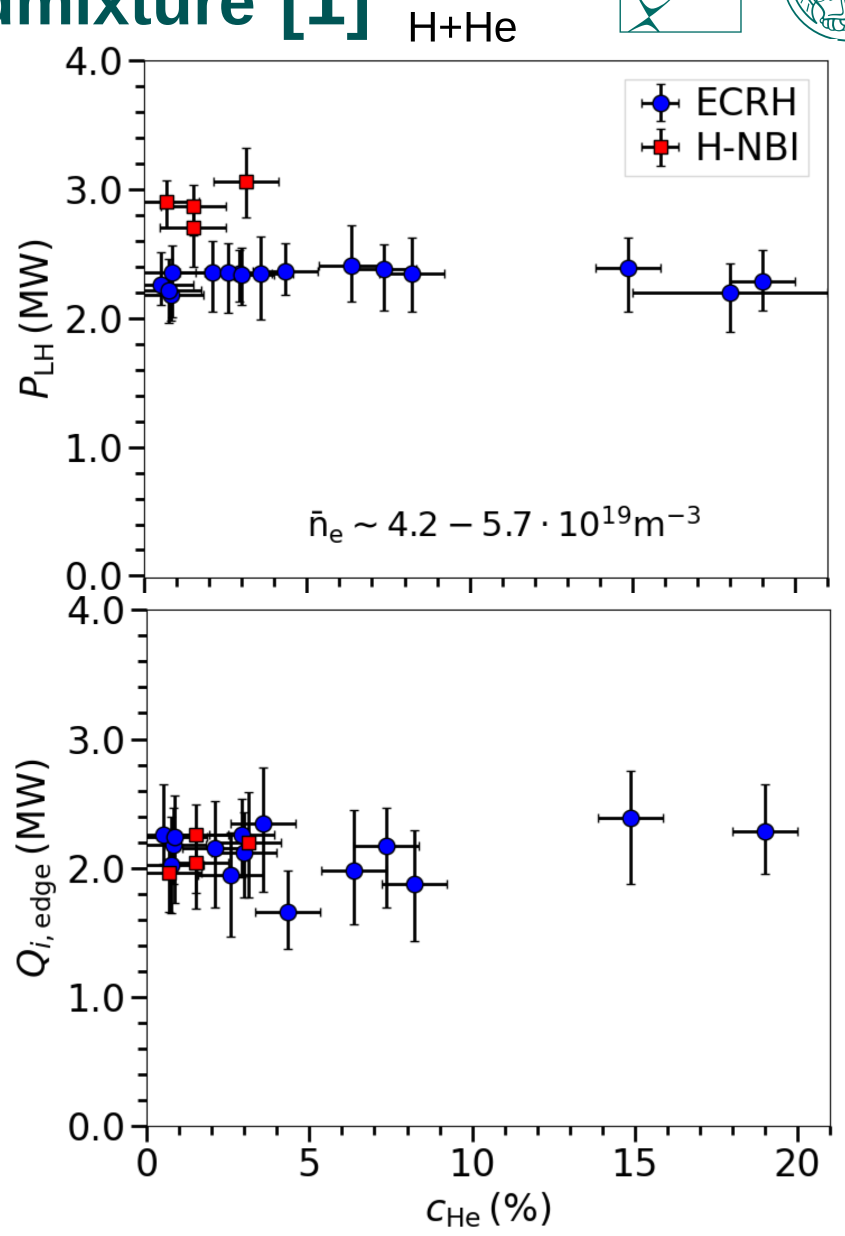


No Reduction of P_{LH} in H with up to 20% He Admixture [1]

- At high H level:
  - No reduction of P_{LH} by He doping
  - Influence of heating method on P_{LH} , but not on $Q_{i,edge}$

  → Same critical $Q_{i,edge}$ has to be established to enter H-mode

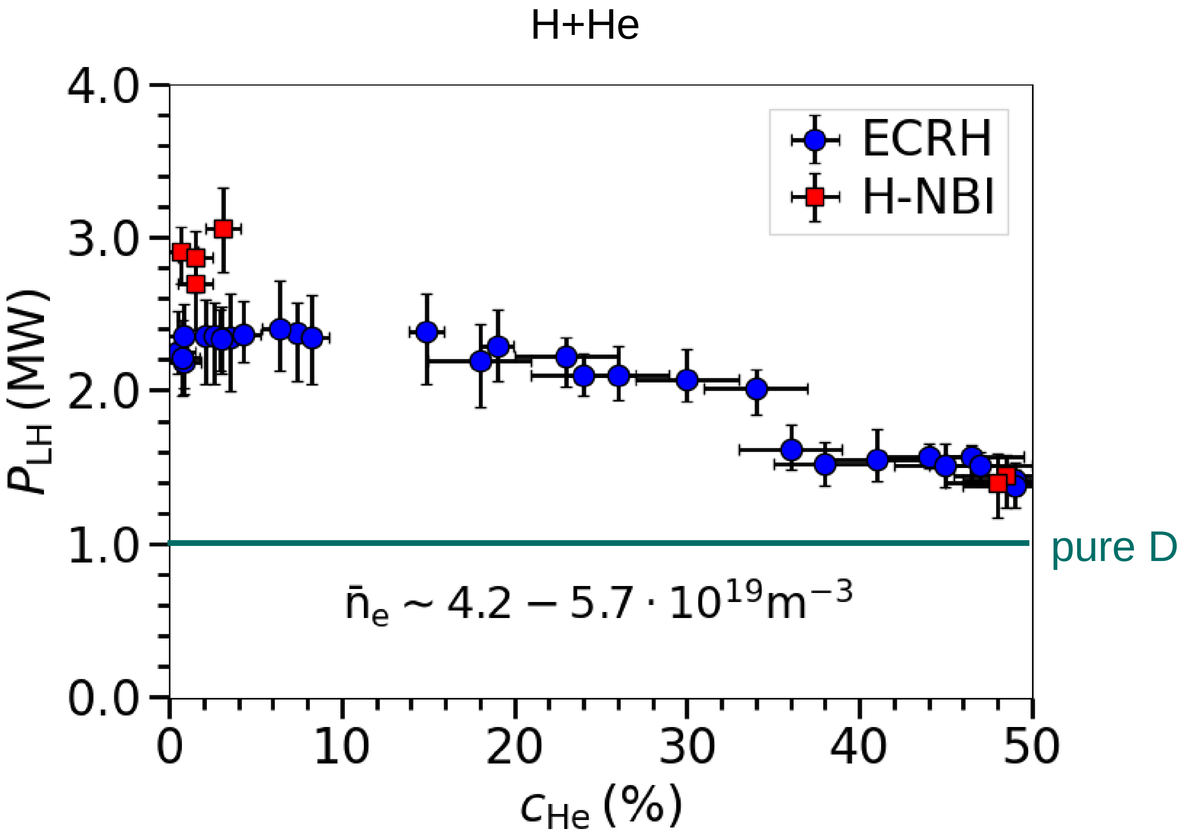
- For P_{LH}: same trends at DIII-D [2], but not at JET [3]



[1] U. Plank NF 2020 [2] L. Schmitz NF 2022 [3] J. Hillesheim IAEA FEC 2018

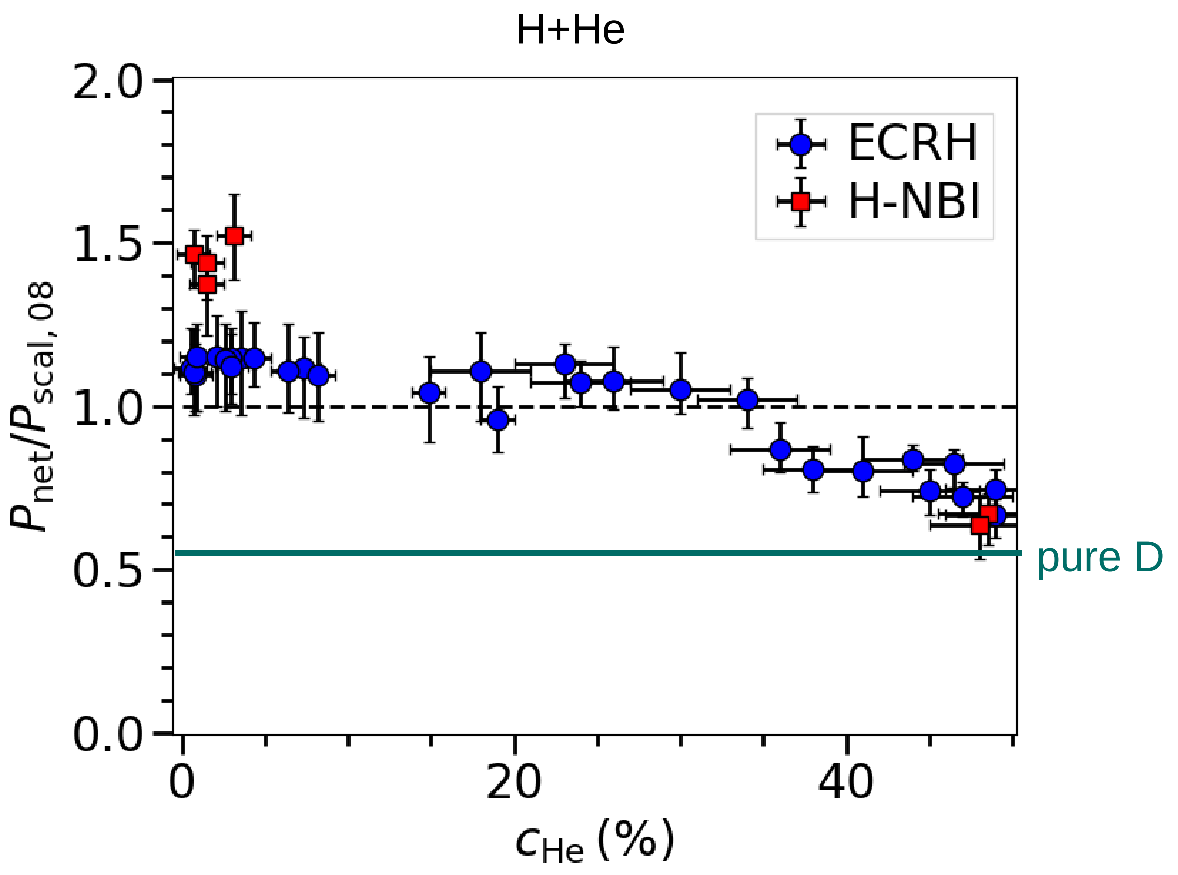
Reduction of P_{LH} only when He is Dominant Ion Species

- When P_{LH} is low, heating method has no influence



Reduction of P_{LH} only when He is Dominant Ion Species

- When P_{LH} is low, heating method has no influence
- No change if density variation (via P_{scal} [1]) is taken into account
- As known, P_{scal} overestimates experimental P_{LH} close to density minimum & in W-wall machines



[1] Y Martin J. Phys. Conf. 2008

Summary and Conclusions

D+H

- **Non-linear dependence of P_{LH} and $Q_{i,edge}$ on relative hydrogen fraction**
- **P_{LH}, which yields the required E_r gradients, increases since ion heat diffusivity increases with H fraction in L-mode**
- **Similar E_r gradients found at L-H and H-L back transition → no hysteresis in edge quantities**

H+He:

- **P_{LH} decreases from H to He (~D) level once He is dominant ion species**
- **Importance of $Q_{i,edge}$ for L-H transition confirmed**