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# Operating near the L-H power threshold in WEST full tungsten environment

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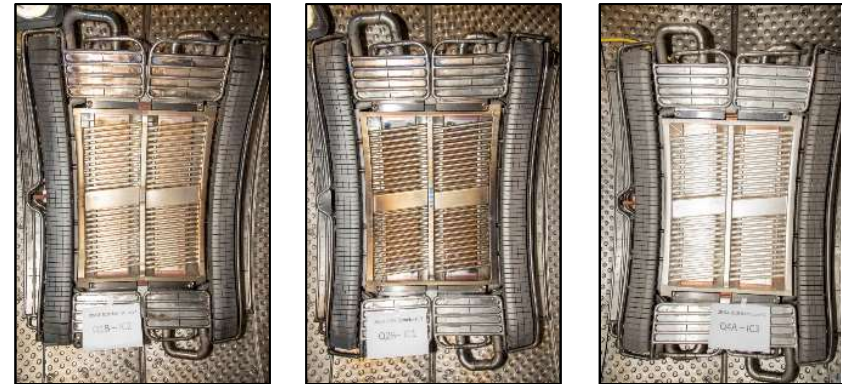
\*<http://west.cea.fr/WESTteam>

**47th European Physical Society Virtual Conference  
21-25 June 2021**

*Bourdelle, NF15*

*Bucalossi, 28th IAEA*

W-coated guard limiters  
3 ICRH antennas (9 MW)

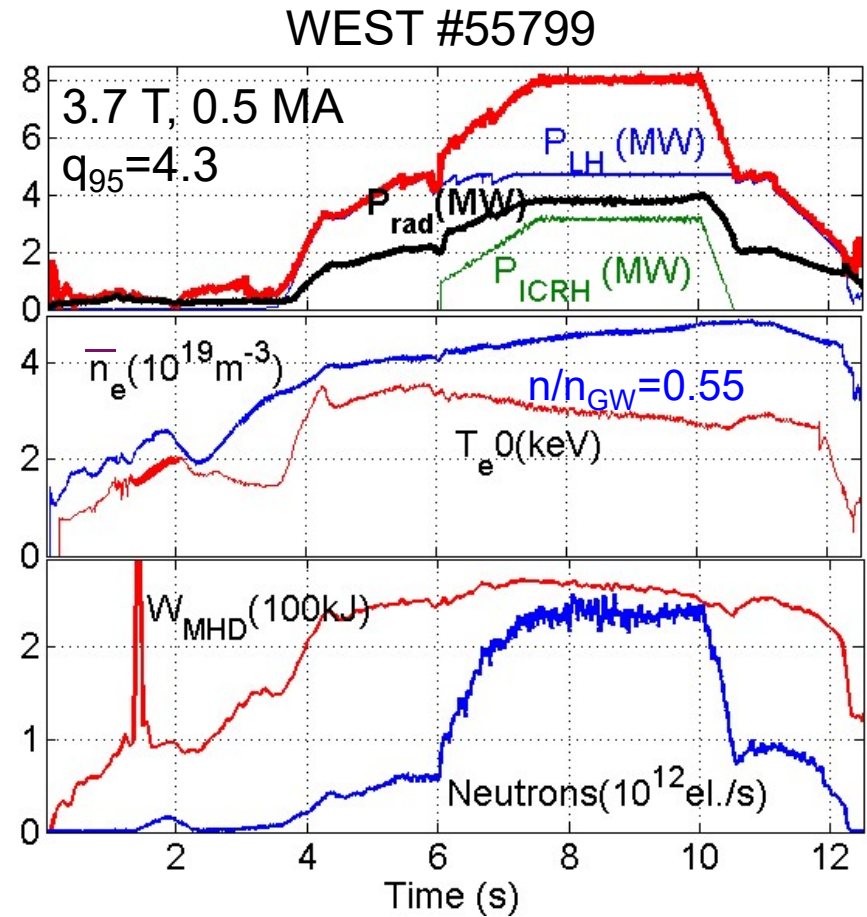
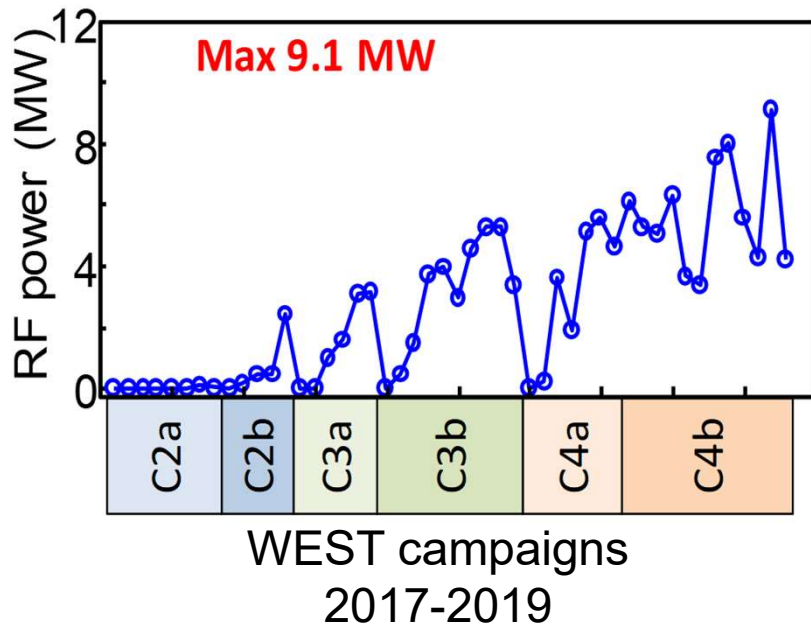


W-coated guard limiters  
2 LHCD antennas up (7 MW)

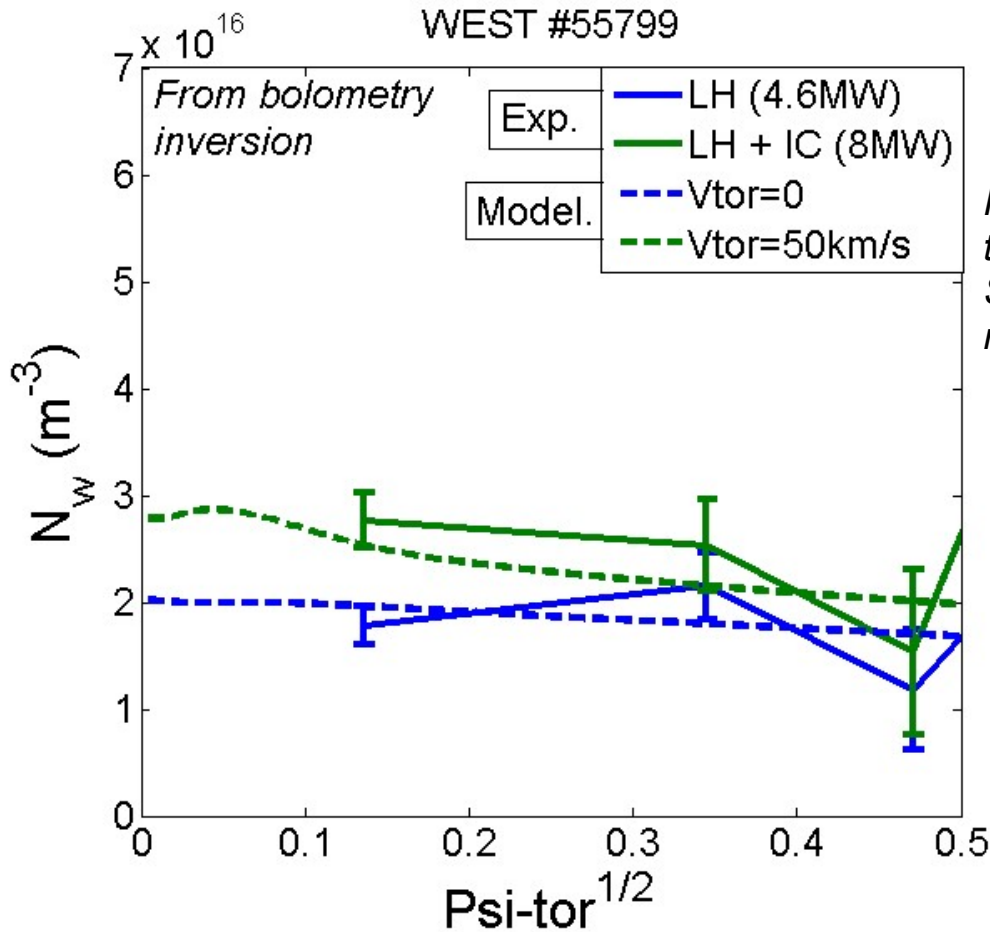


- Low/no toroidal torque
  - No central particle source
  - Low/no Ware effect ( $V_{loop} \sim 0$ )
  - Dominant electron heating
- Issues with tungsten accumulation are minimized
- W sources from 5 RF antennas : an issue?

- **Plasma radiation and tungsten contamination / sources**
- Confinement of high RF power discharges



- ❑ Steady radiated power
- ❑ Coherent with low core W peaking due to subdominant neoclassical transport in low torque plasmas

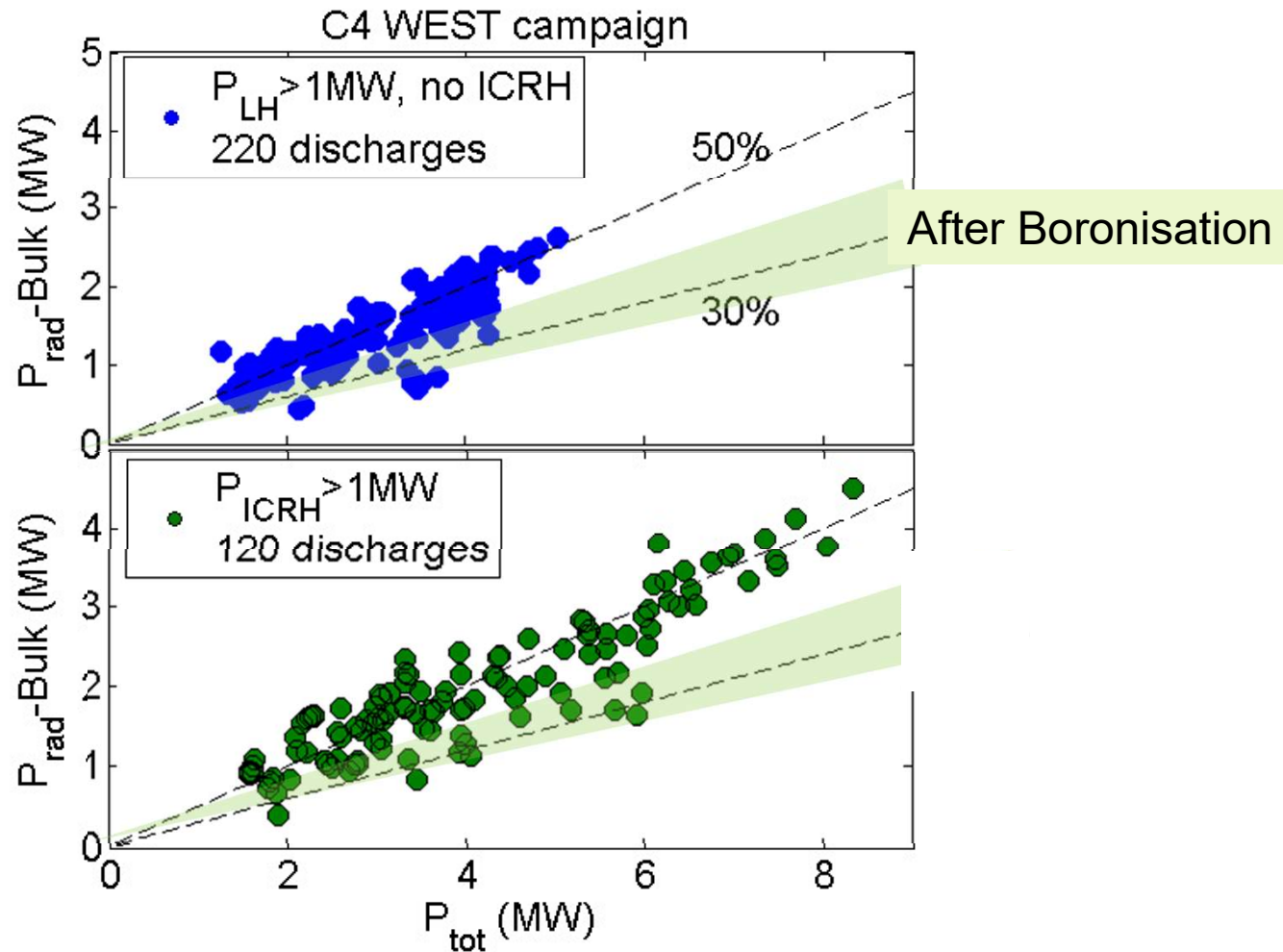


Yang X. et al., NF 2020  
 Maget P. et al., PPCF 2020

NC + turbulent (QUALIKIZ)  
 transport  
 Screening by minority H ions  
 not included

☐ Coherent with low core W peaking due to subdominant neoclassical transport in low torque plasmas

See O. Chellai (P4.1013)  
 T. Barbui (P3.1013).



- $P_{\text{rad-Bulk}}/P_{\text{tot}}$  insensitive to power ( $P_{\text{RF}} > 1\text{MW}$ ) and density ( $3-6 \times 10^{19} \text{m}^{-3}$ )
- $P_{\text{rad-Bulk}}/P_{\text{tot}} \sim 30\%$  after boronisation but lasts  $< 10$  discharges

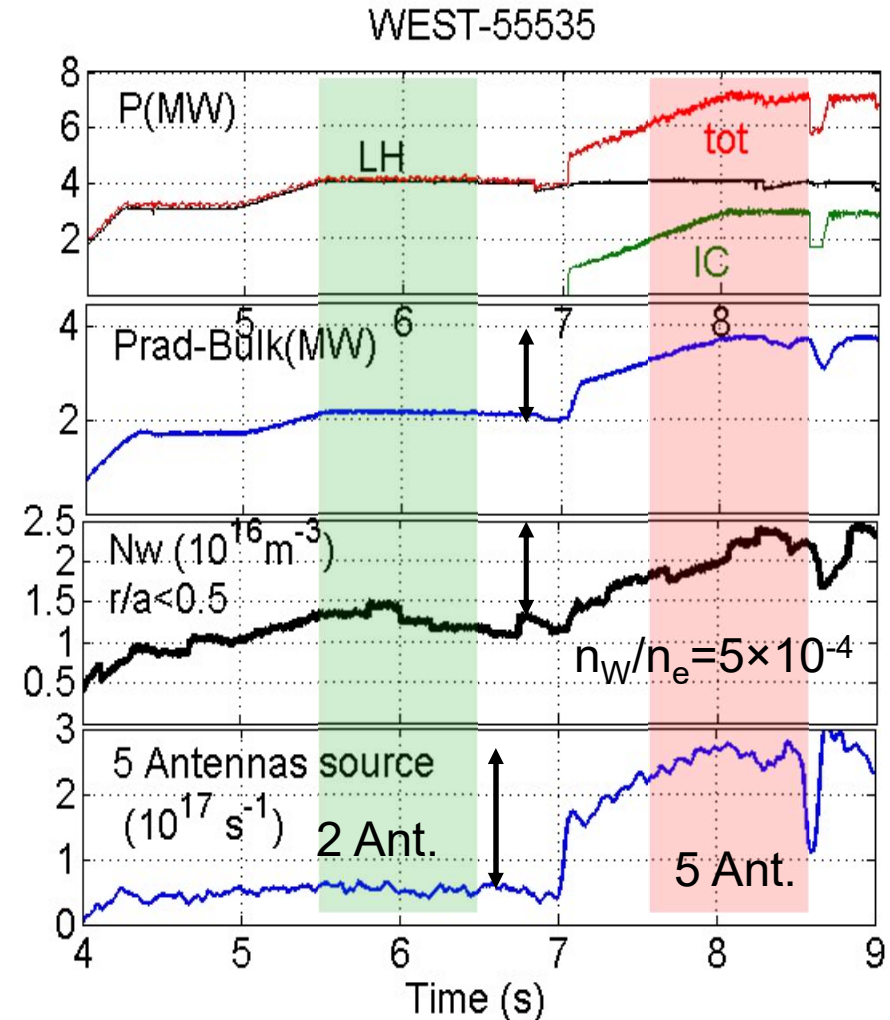
4MW (LH) → 7MW (LH+IC)

Prad-Bulk &  $n_W$  ( $\rho < 0.5$ ) : **X2**  
Frad 51 => 53%

Antenna limiters WI visible spectroscopy source\* : **X5**

\*Accounting for prompt redeposition<sup>1</sup>

<sup>1</sup> Chankin, PPCF14



- ❑ Other W sources contribute to W contamination of the plasma: lower and upper divertor, baffle.

See C.Klepper I4.106



## Diapositive 7

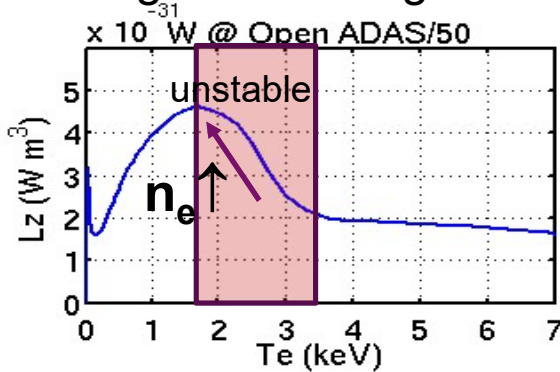
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**BC17**

je rajouterai les sources div. Car c'est intéressant de voir qu'elles ne montent pas avec IC

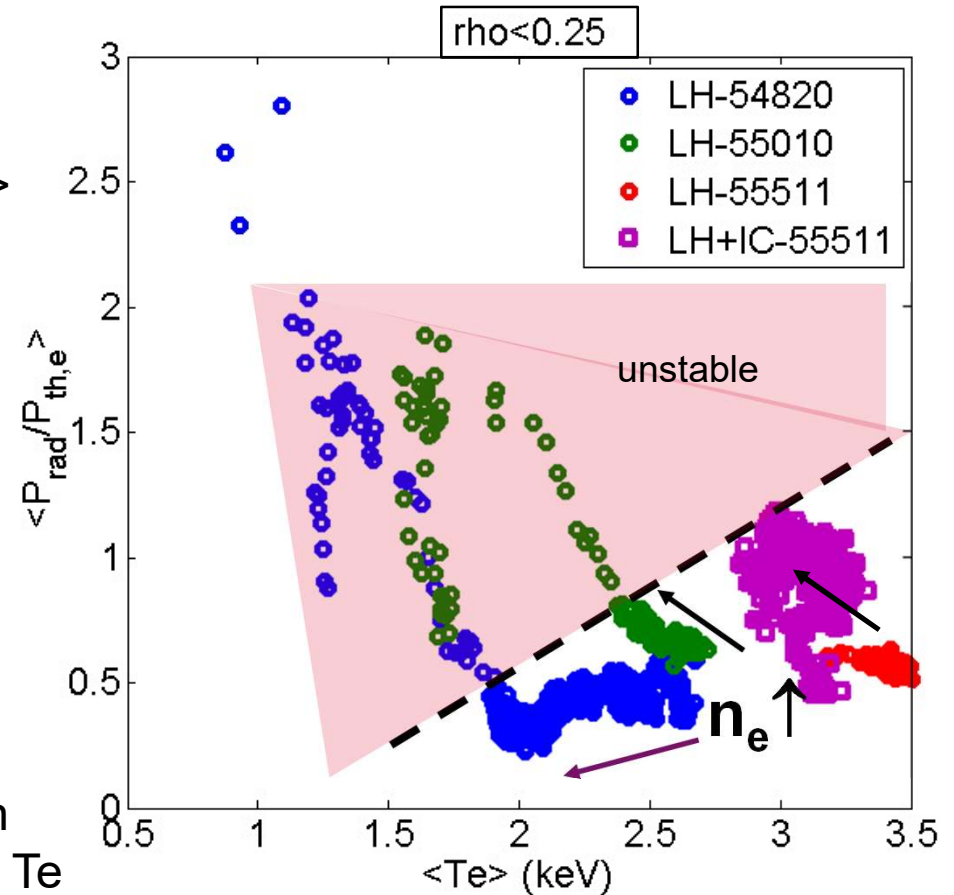
BOURDELLE Clarisse 165101; 11/06/2021

## Tungsten Cooling factor



$$P_{th,e} = \frac{\langle n_e T_e \rangle}{\tau_E}$$

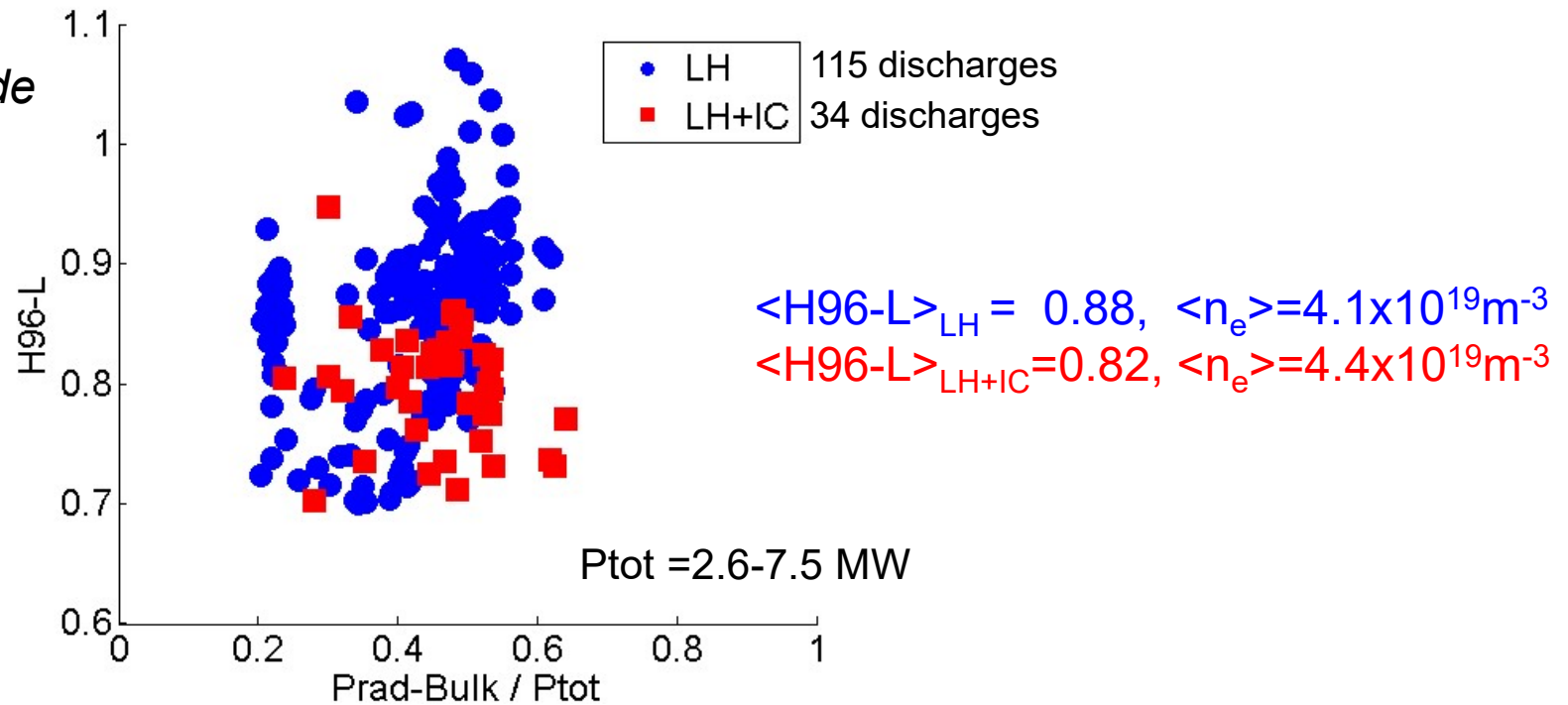
- ❑  $P_{rad}/P_{th,e} > \text{threshold}$ 
  - Radiation instability is triggered
- ❑ Threshold increases with  $T_e$
- ❑ Threshold vanishes for  $T_e > 3\text{keV}$  when cooling factor is low and insensitive to  $T_e$



- The density control is essential when crossing the unstable W radiation zone.
- More detailed understanding is on-going with RAPTOR code .

- Plasma radiation and tungsten contamination / sources
- **Confinement of high RF power discharges**

ITER L-mode  
scaling



□ Energy confinement is uncorrelated to Prad-Bulk/Ptot

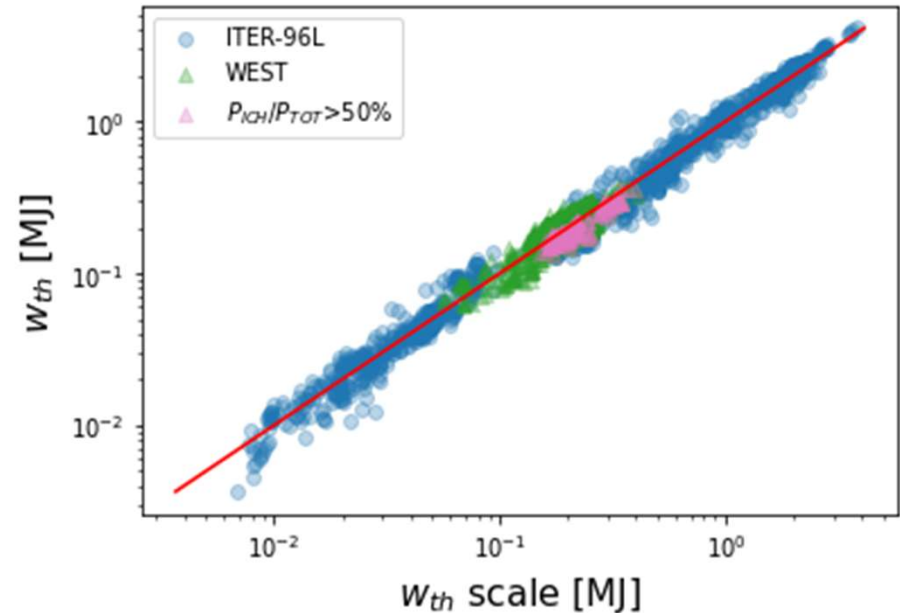
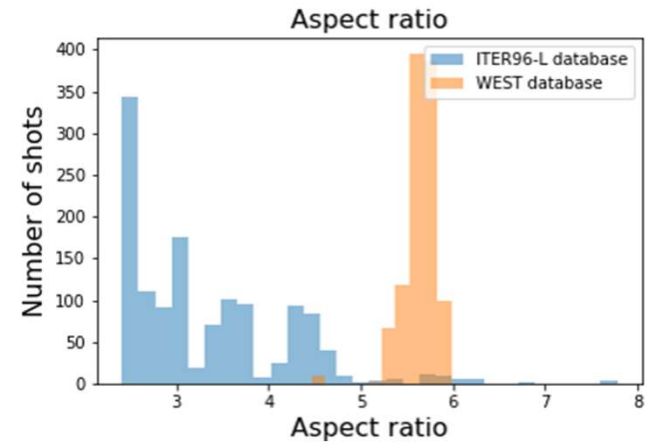
WEST database (1087 entries)

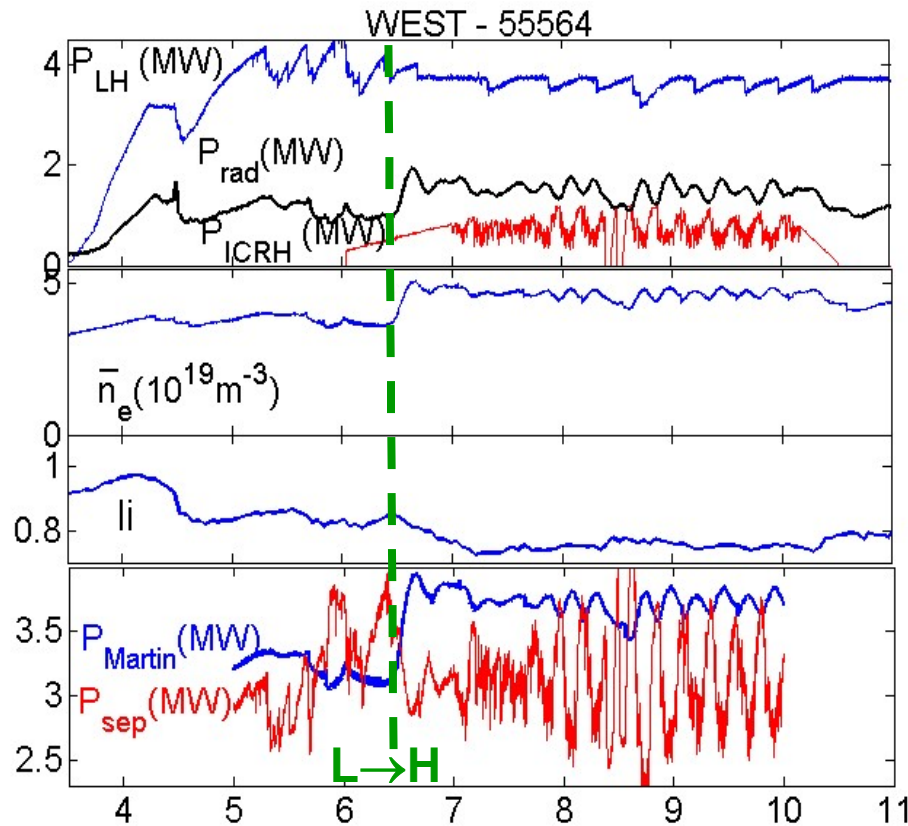
A=5-6

$I_p=0.2-0.8\text{MA}$ ,  $P_{\text{AUX}}=0.5-9\text{MW}$ ,  $n_e=1-9 \cdot 10^{19}\text{m}^{-3}$

$$\Omega_i \tau = \rho_*^{x_{\rho_*}} \beta^{x_{\beta}} \nu_*^{x_{\nu_*}} q^{x_q} M^{x_M} \varepsilon^{x_{\varepsilon}} B^{x_B} k^{x_k}$$

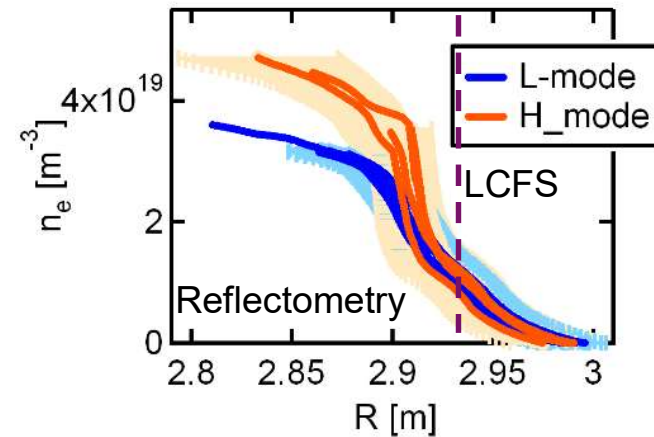
Variable	ITER96-L	ITER96+WEST	Exponent x
q	-3.74	-3.88	
$B_T$	0	0	
k	3.22	3.26	
$R/a = 1/\varepsilon$	<b>0.04</b>	<b>0</b>	
$M_{\text{eff}}$	0.67	0.67	
$\rho_*$	-1.85	-1.91	
$\nu_*$	0.19	0.18	
$\beta$	-1.41	-1.45	
Entries	1313	2400	
WEST entries	-	1087	
RMSE	15.8%	16.3%	



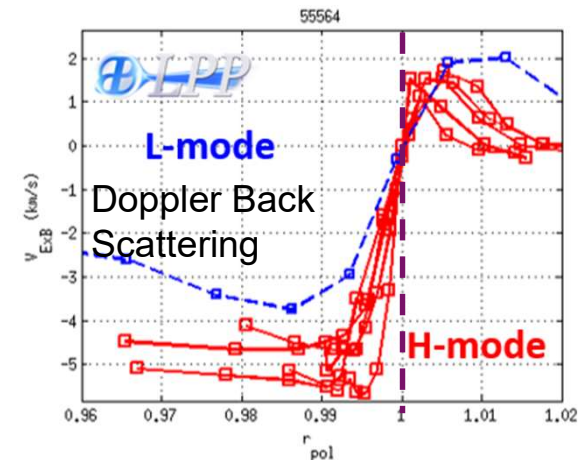


- Prad-Bulk: + 50%
- Plasma density: +30%
- Li: 0.85  $\Rightarrow$  0.75
  - Higher bootstrap current at the edge

L.Vermare et al., P4, 1078  
submitted to NF

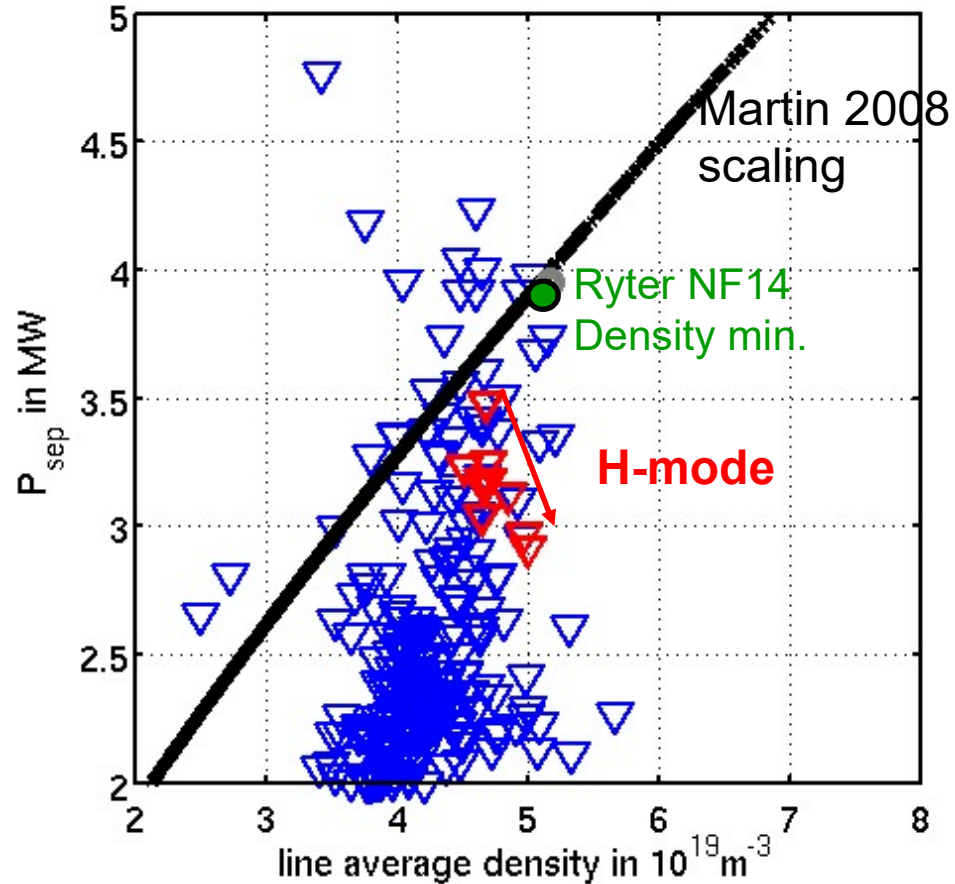


□ Steeper density profile



□ Deeper  $v_{ExB}$  well

L mode, LSN,  $I_p=0.5$  MA,  $B_T=3.7$  T



- Possibly on low density branch
  - More margin at higher density

# SUMMARY



- High RF up to 8MW/3s without W accumulation
- High Prad-Bulk/Ptot ~50% ( $P_{RF} > 1\text{MW}$ ) independent of RF scheme (LH or IC) and density
- Good confinement (ITER H96-L>0.9), confirm the weak aspect ratio dependence of the L mode scaling law, uncorrelated to Prad/Ptot
- H-mode accessed, deep well of Er measured but weak increment in energy content ( $P_{sep} \sim P_{threshold}$ )
- *High LHCD efficiency crucial for long pulse operation*
  - *K.Krol (P2, 1072) G.Wallace (P4, 1047)*
- Full ITER-grade actively cooled lower divertor from 2021
  - towards plasma duration of 1000s
- ECRH 3MW/CW by 2023