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

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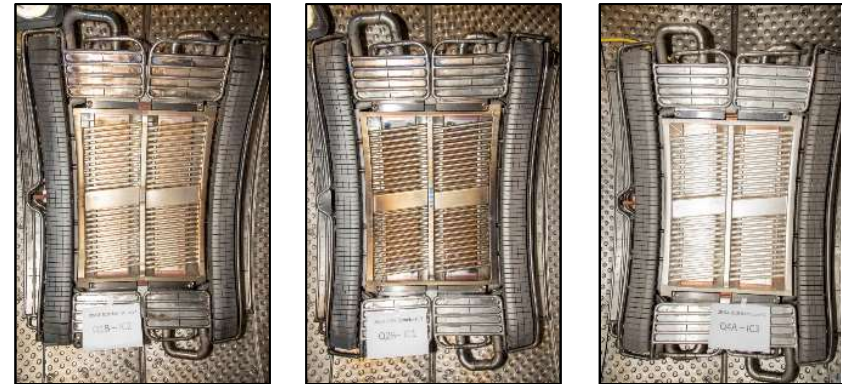
*<http://west.cea.fr/WESTteam>

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

Bourdelle, NF15

Bucalossi, 28th IAEA

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

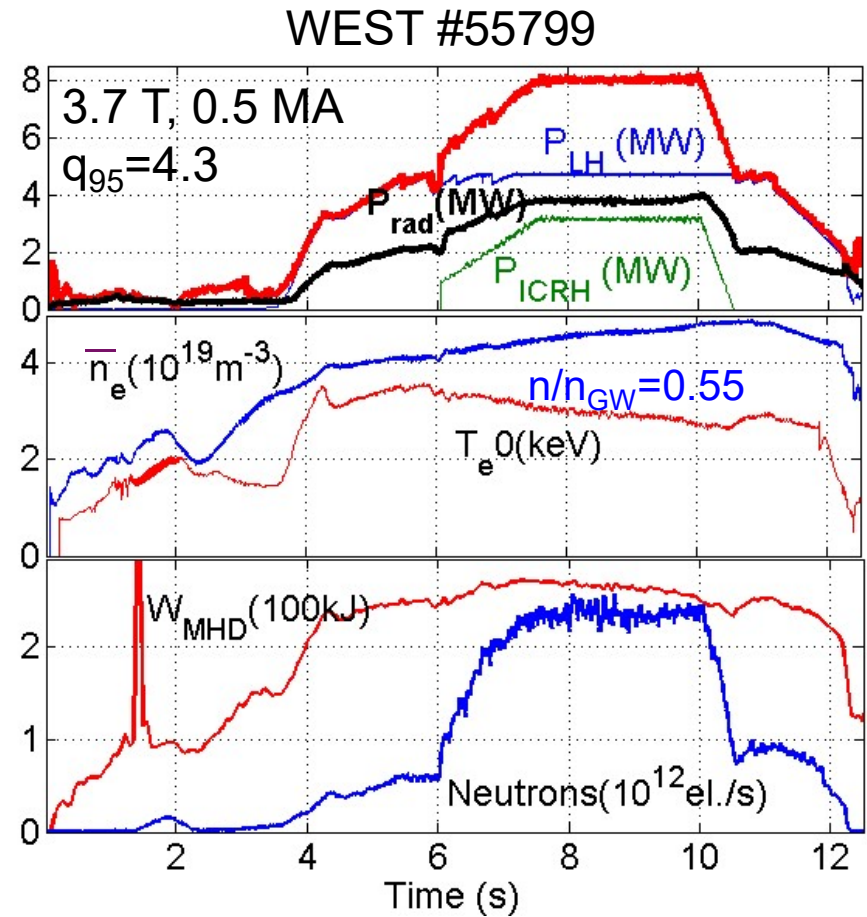
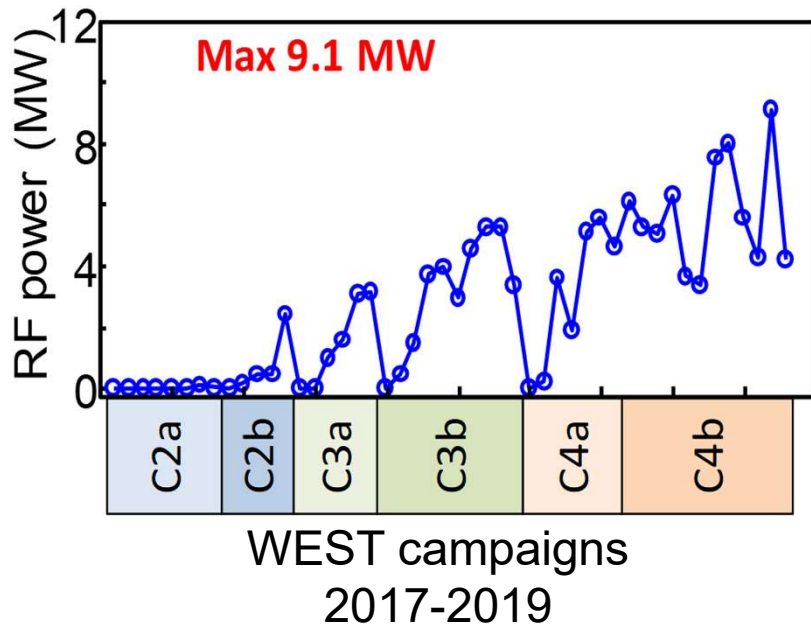


W-coated guard limiters
2 LHCD antennas up (7 MW)



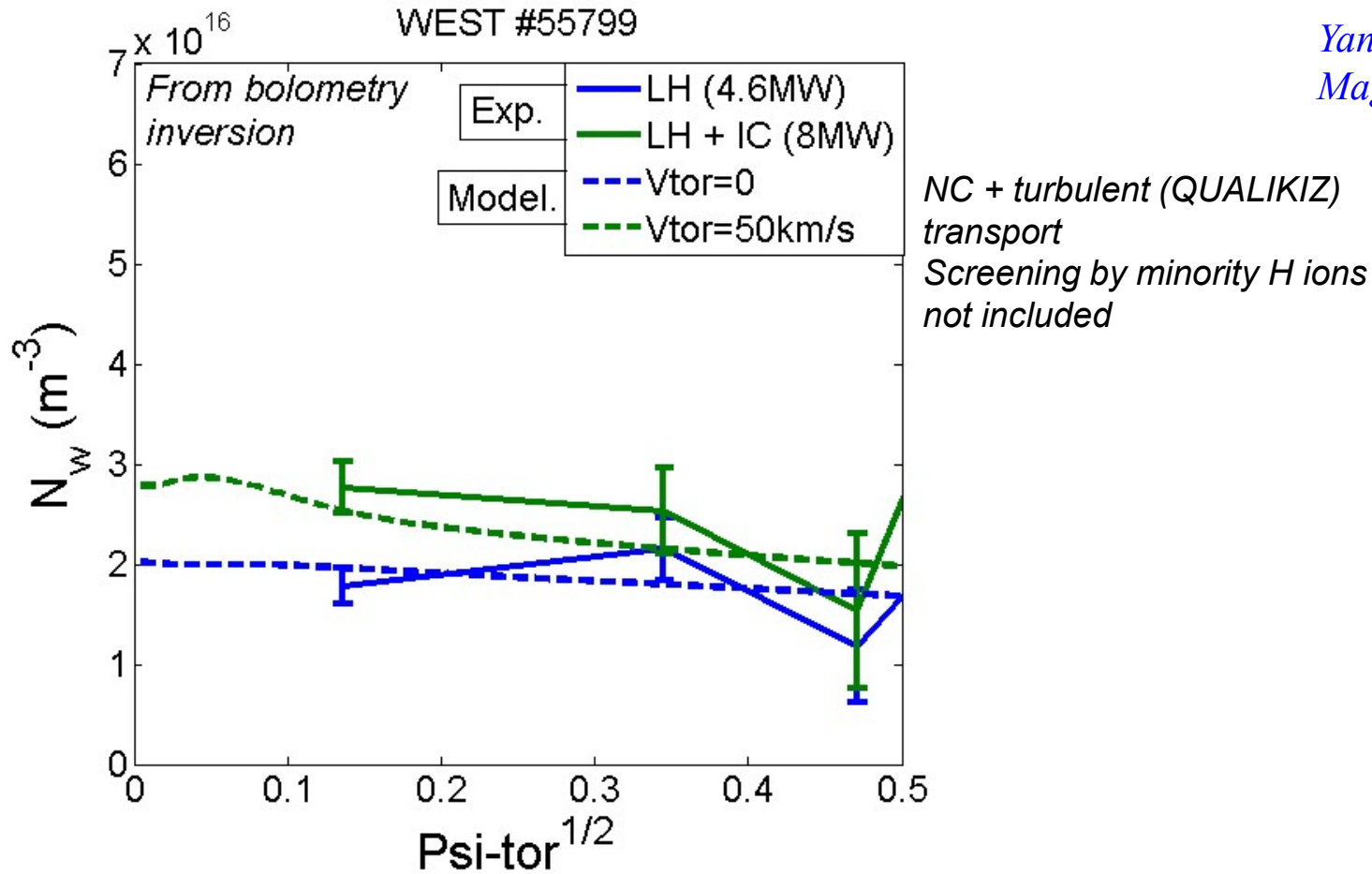
- Low/no toroidal torque
 - No central particle source
 - Low/no Ware effect ($V_{loop} \sim 0$)
 - Dominant electron heating
- Issues with tungsten accumulation are minimized
- W sources from 5 RF antennas : an issue?

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



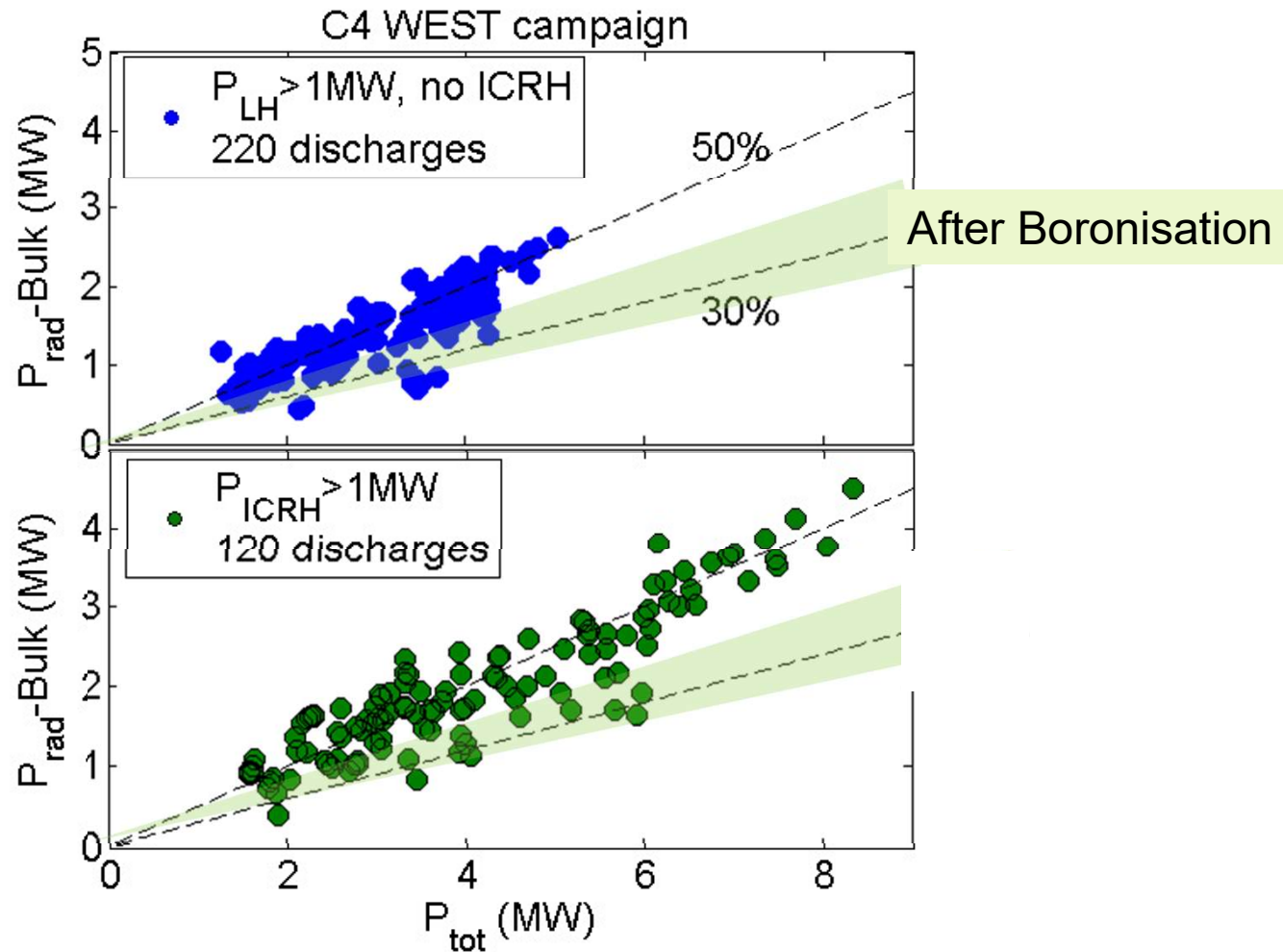
- ❑ Steady radiated power
- ❑ Coherent with low core W peaking due to subdominant neoclassical transport in low torque plasmas

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



☐ 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

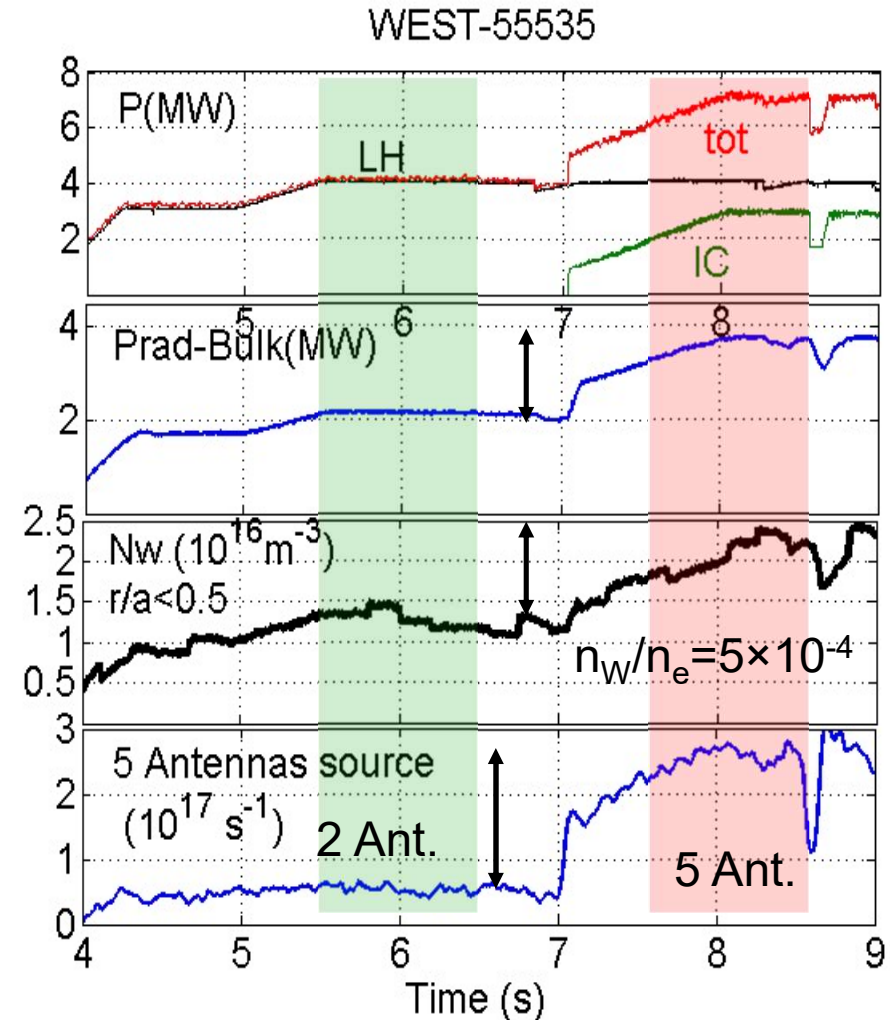
4MW (LH) → 7MW (LH+IC)

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

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

*Accounting for prompt redeposition¹

¹ Chankin, PPCF14



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

See C.Klepper I4.106

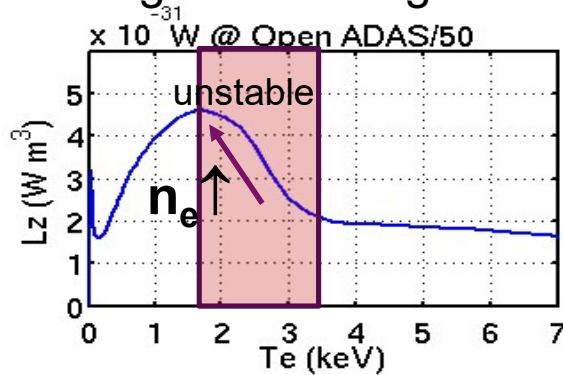
Diapositive 7

BC17

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

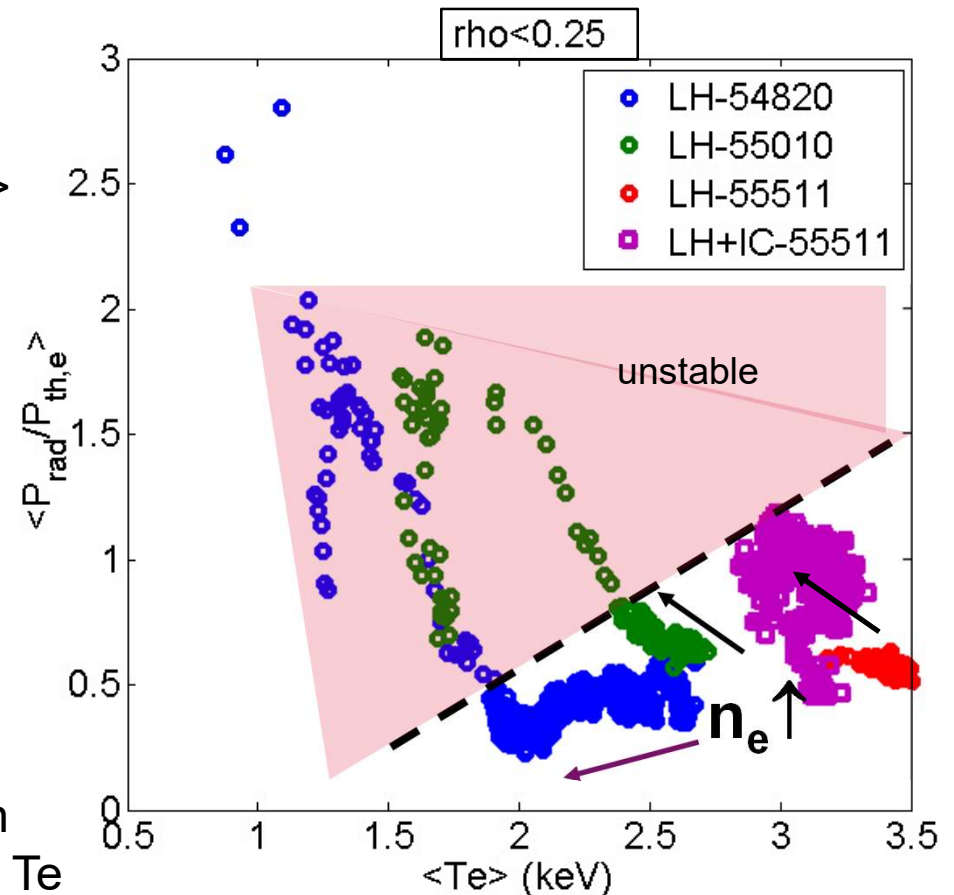
BOURDELLE Clarisse 165101; 11/06/2021

Tungsten Cooling factor



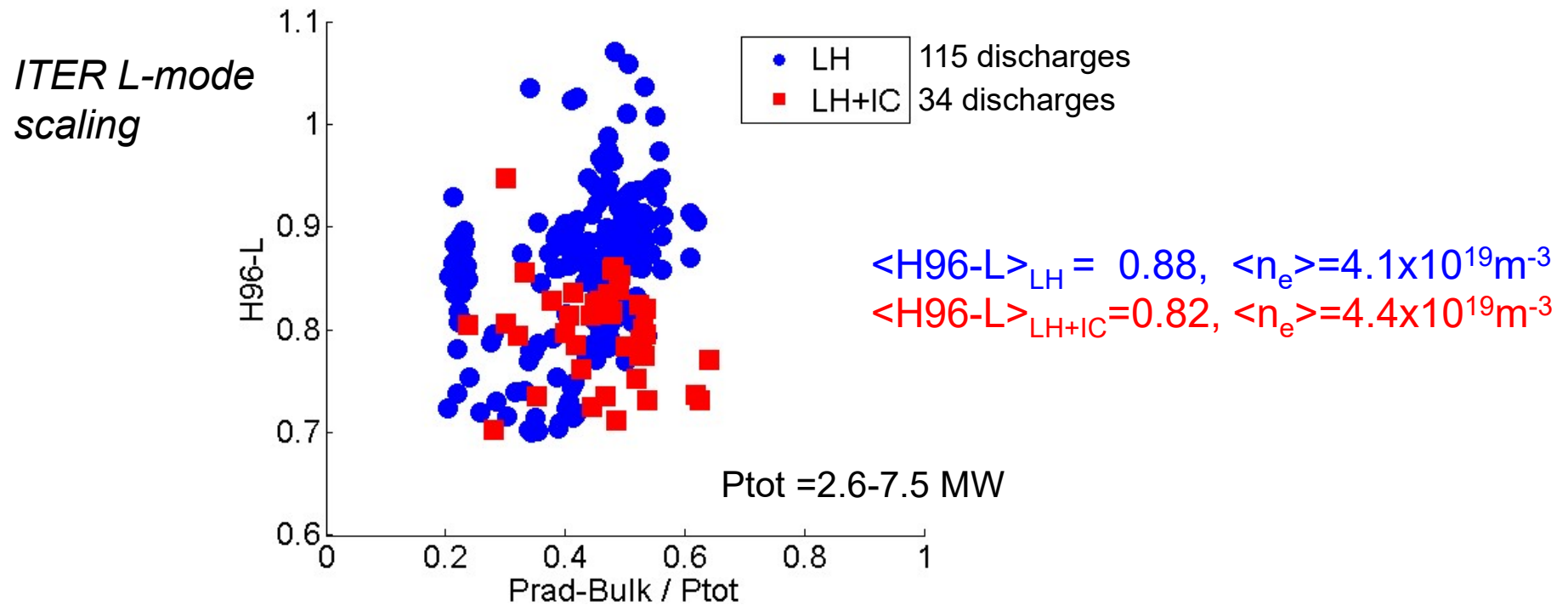
$$P_{th,e} = \frac{\langle n_e T_e \rangle}{\tau_E}$$

- $P_{rad}/P_{th,e} > \text{threshold}$
 - 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**



□ Energy confinement is uncorrelated to Prad-Bulk/Ptot

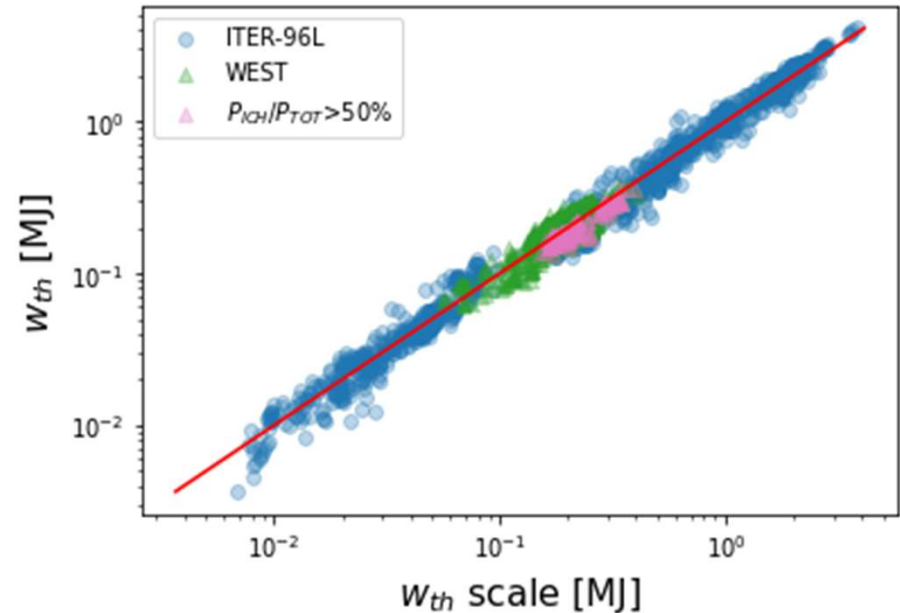
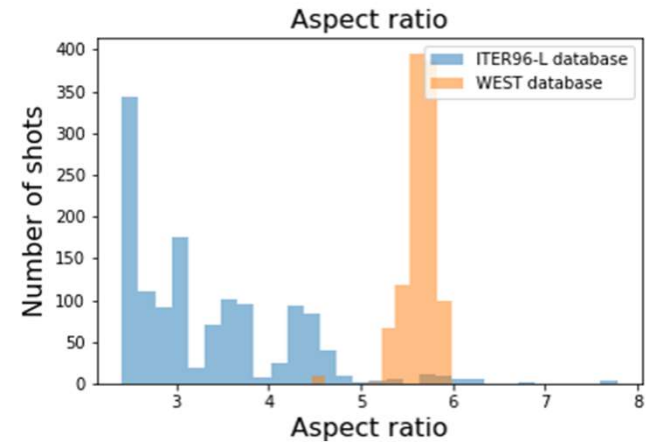
WEST database (1087 entries)

A=5-6

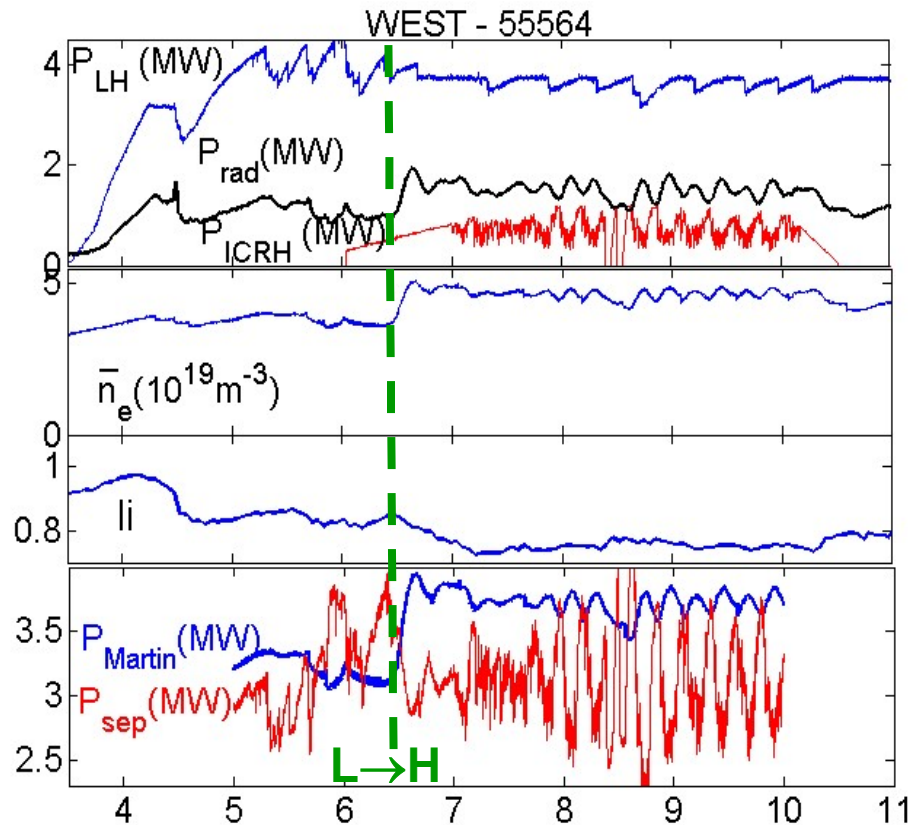
$I_p=0.2-0.8\text{MA}$, $P_{\text{AUX}}=0.5-9\text{MW}$, $n_e=1-9 \cdot 10^{19}\text{m}^{-3}$

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

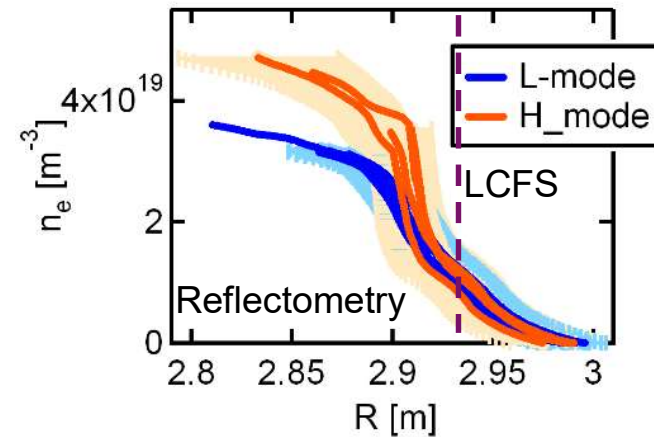
Variable	ITER96-L	ITER96+WEST	Exponent x
q	-3.74	-3.88	
B_T	0	0	
k	3.22	3.26	
$R/a = 1/\varepsilon$	0.04	0	
M_{eff}	0.67	0.67	
ρ_*	-1.85	-1.91	
ν_*	0.19	0.18	
β	-1.41	-1.45	
Entries	1313	2400	
WEST entries	-	1087	
RMSE	15.8%	16.3%	



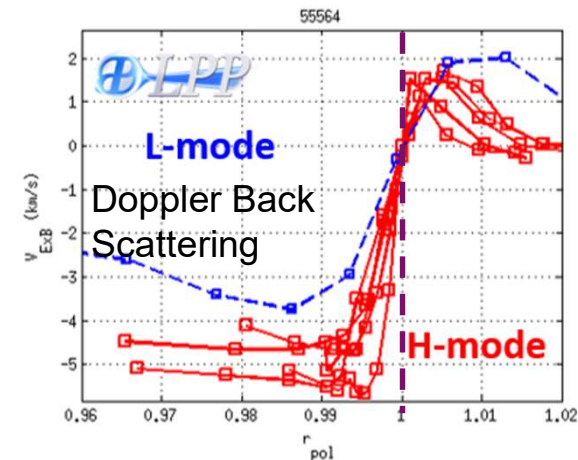
L.Vermare et al., P4, 1078
submitted to NF



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

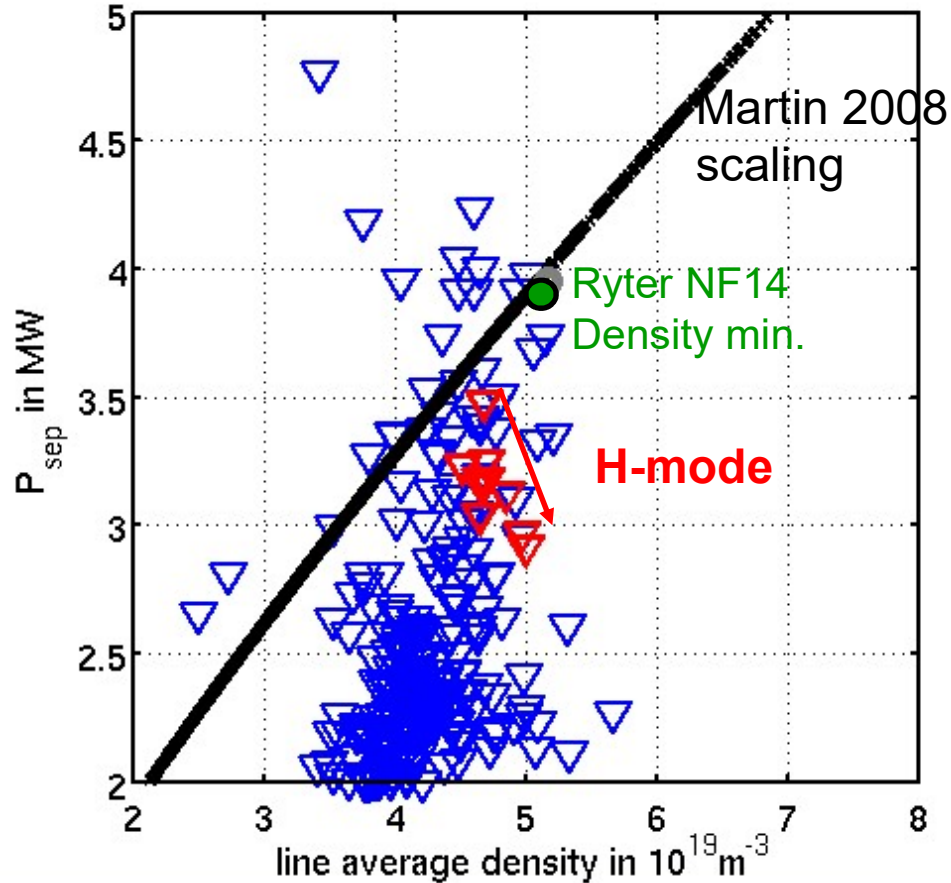


□ Steeper density profile



□ 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