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Clarisse Bourdelle, Jorge Morales, Jean François Artaud, T. Radenac, Jérôme Bucalossi, Frédéric Clairet, Guido Ciraolo, Rémi Dumont, Nicolas Fedorczak, Christophe Gil, et al.

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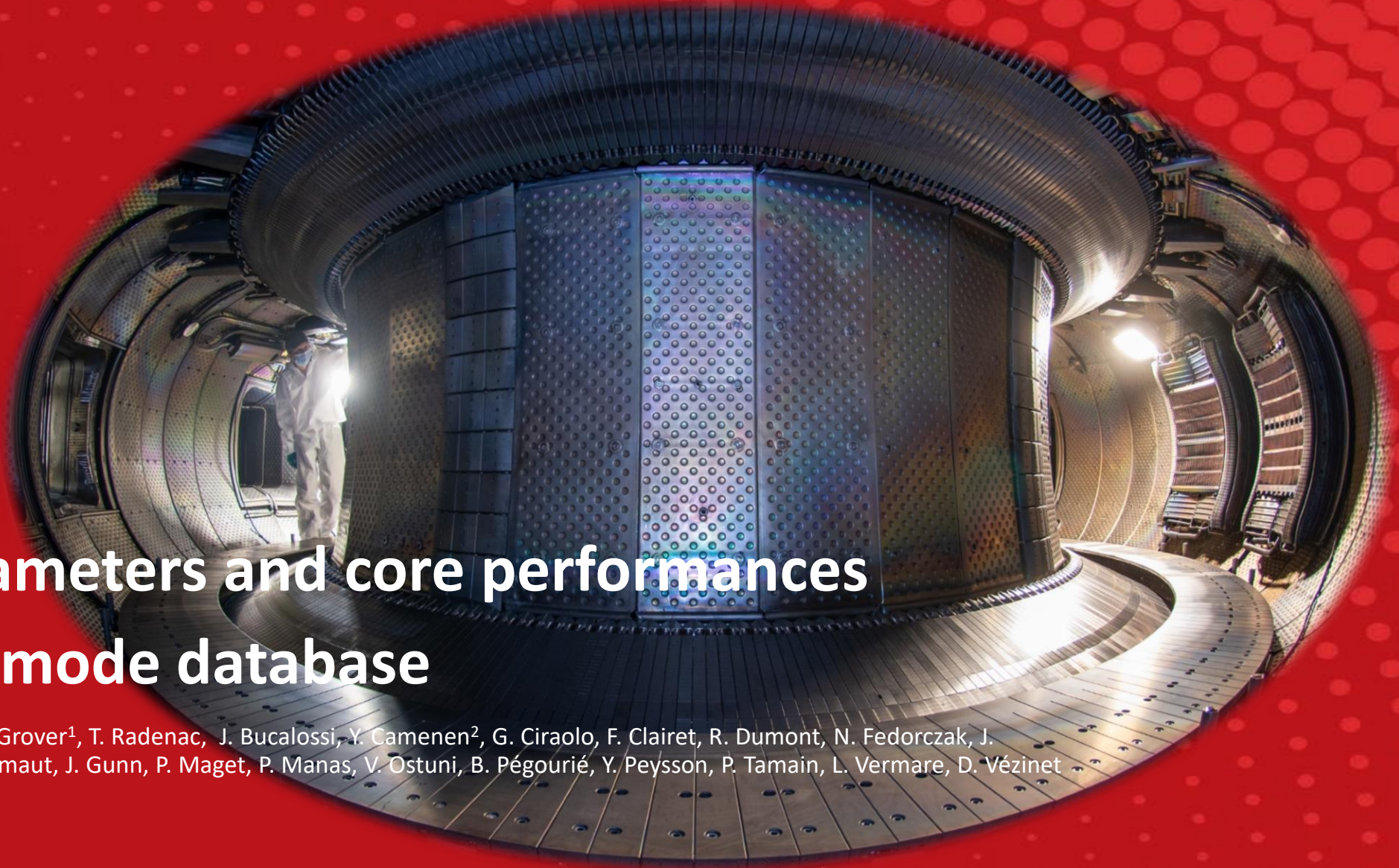
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The logo for IRFM (Institut de Recherches pour la Fusion Magnétique) features the letters 'IRFM' in a stylized font with a green and yellow circular graphic element.The logo for WEST (WEST-Upgrade Tokamak Experiment) features the word 'WEST' in a stylized font with a green and yellow circular graphic element.The logo for CEA (Commissariat à l'énergie atomique et aux énergies alternatives) features the word 'cea' in a stylized font with a green horizontal line underneath.

# Separatrix parameters and core performances across WEST L-mode database

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APS, Spokane, Oct. 2022

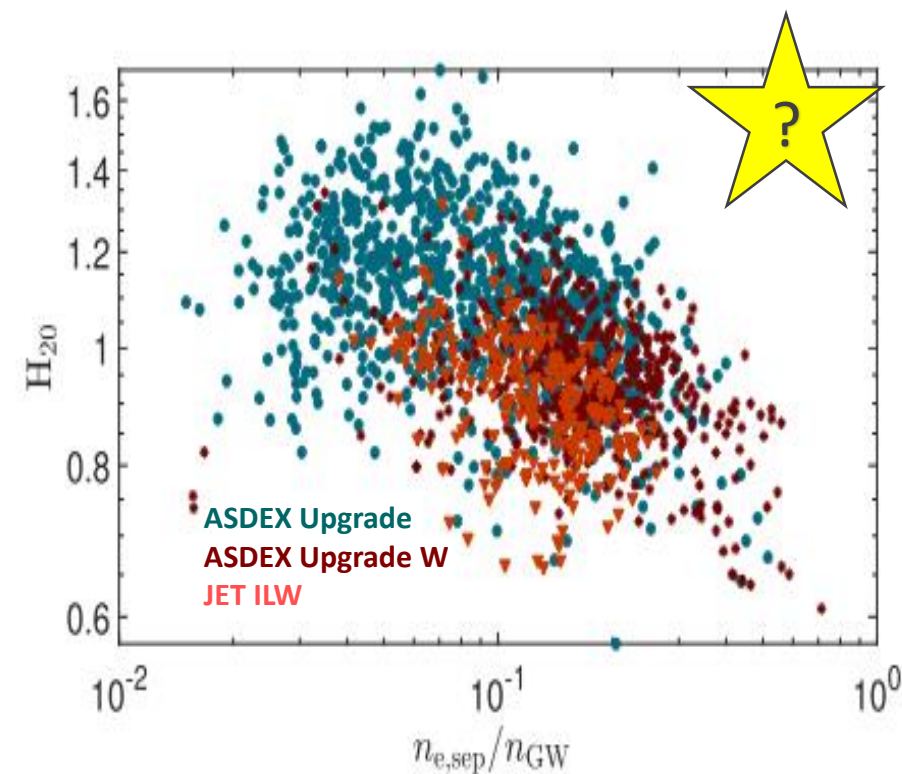
- ▶ Since early tokamak operation, wall conditioning key impact on core performances

TFTR (limited) supershots [Strachan NF1994]. Lower recycling = better core performances.

$$\tau_E = 73 H_{\alpha}^{-0.24} \left( \frac{\beta_{\parallel}}{\beta_{\perp}} \right)^{0.85} n_e(0)^{0.60} B^{0.35} C_{NB}^{0.19}$$

Seen in Lithium conditioning in CDXU-LTX, (diverted) NSTX, EAST etc.

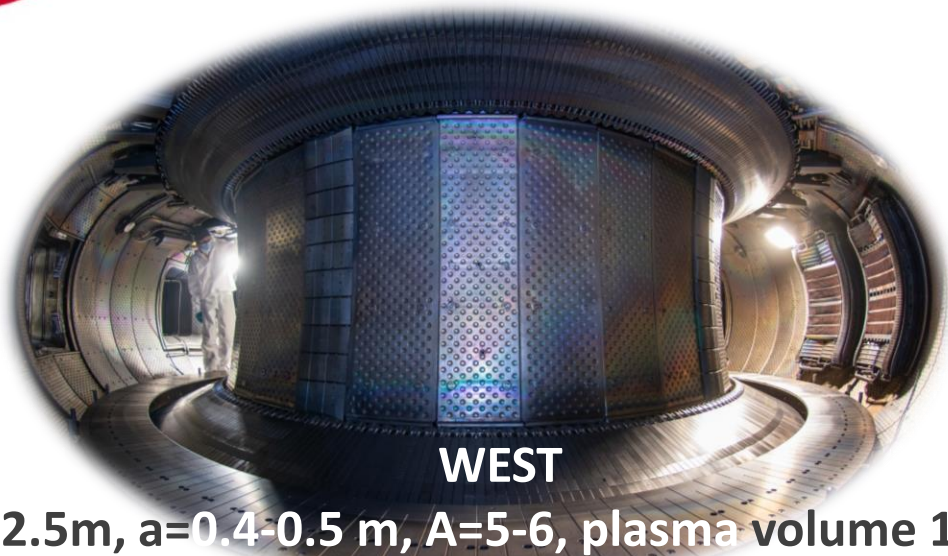
- Recently impact of  $n_{sep}$  (or  $T_{target}$ ) on H factors reported [G. Verdoolaege, NF 2021, Lomanowski NF 2022]
- In ITER or DEMO W environment need  $T_{target} < \sim eV$  to avoid W sputtering (and reduce heat load), hence large recycling, - depending on opacity- possibly large  $n_{sep}$ : this is not where the best performances of today/past tokamaks are reported



[G. Verdoolaege, NF 2021]



- ▶ systematic database analysis to avoid bias towards best performances
- ▶ WEST C4 and C5 campaigns exhaustive database of time averaged quantities over plateaus (>0.3s stable  $I_p$  and  $P_{tot}$ ) 1249 Deuterium pulses [Morales @3:36PM 100C]
- ▶ Filtered  $P_{tot} > 2\text{MW}$  (no ohmic pulses),  $I_p = 0.5\text{ MA}$ , Lower Single Null, gas puff (no pellet): 800 plateaus



WEST

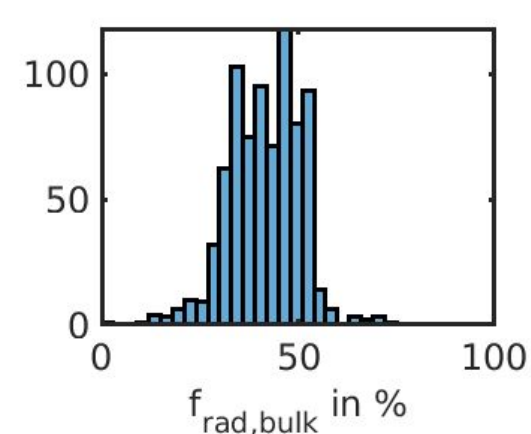
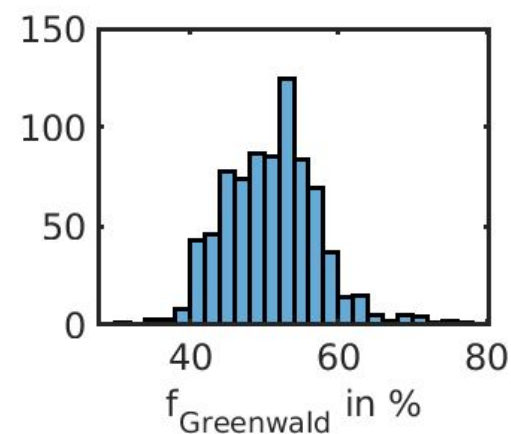
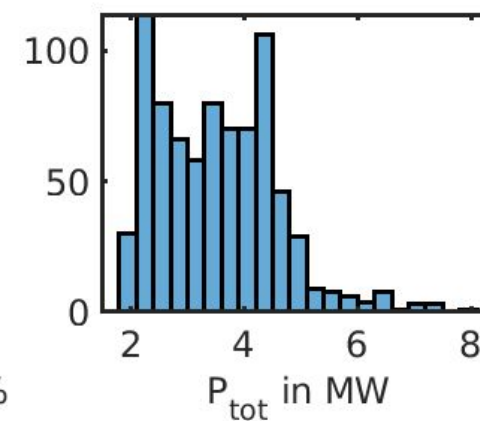
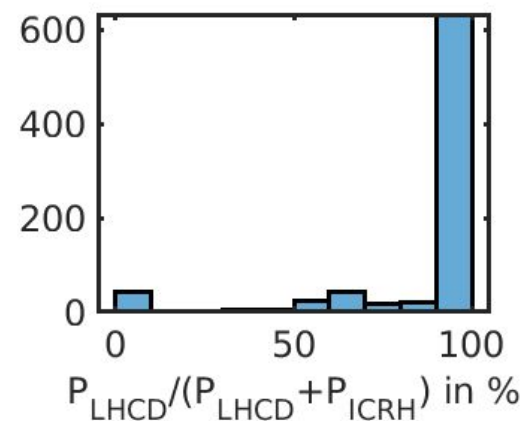
$R=2.5\text{m}$ ,  $a=0.4\text{-}0.5\text{ m}$ ,  $A=5\text{-}6$ , plasma volume  $15\text{ m}^3$

3.7 T, W environment  $f_{rad,bulk} \sim 42\%$

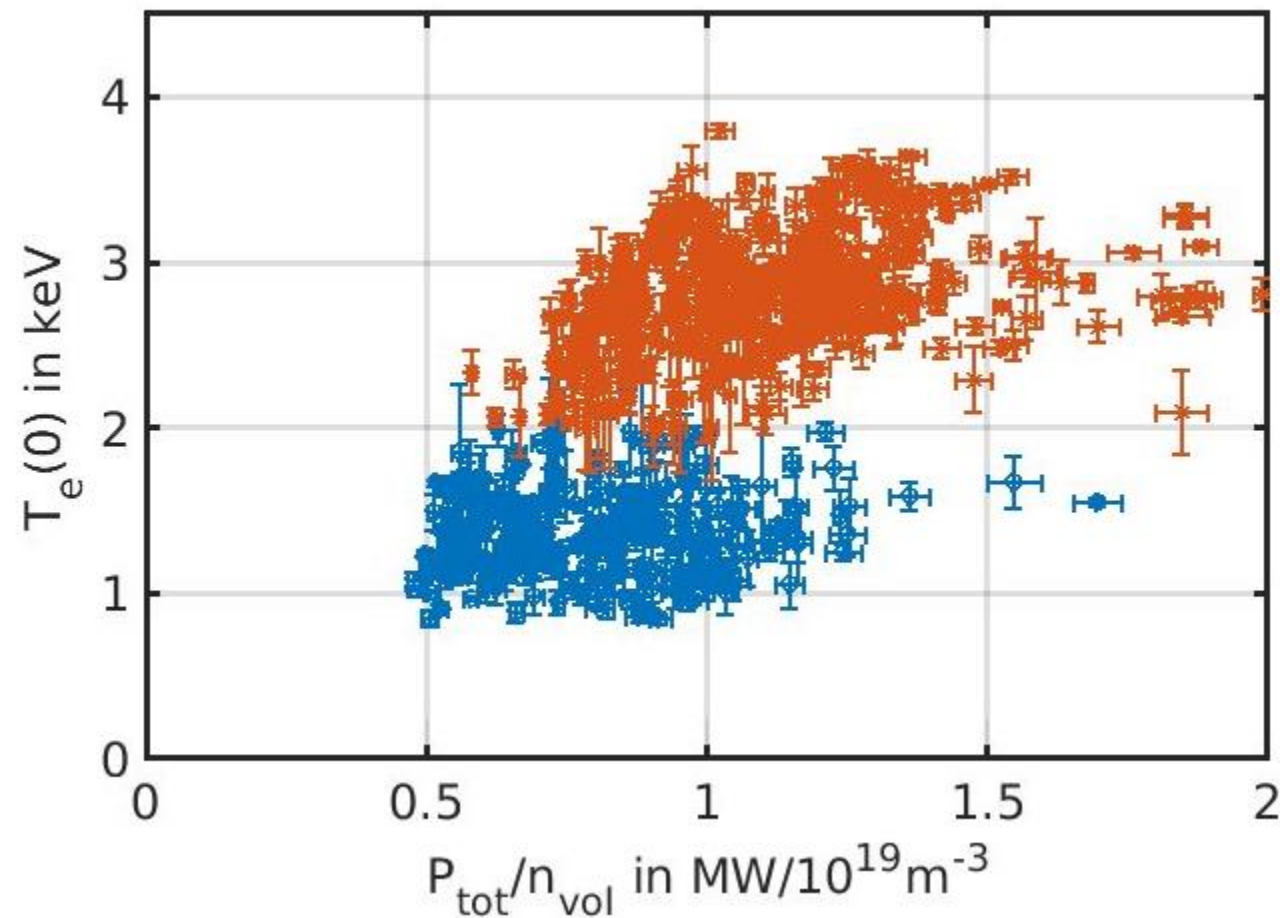
Dominant electron heating (LHCD/ICRH)

No NBI, hence intrinsic density peaking

**L mode high recycling plasmas**



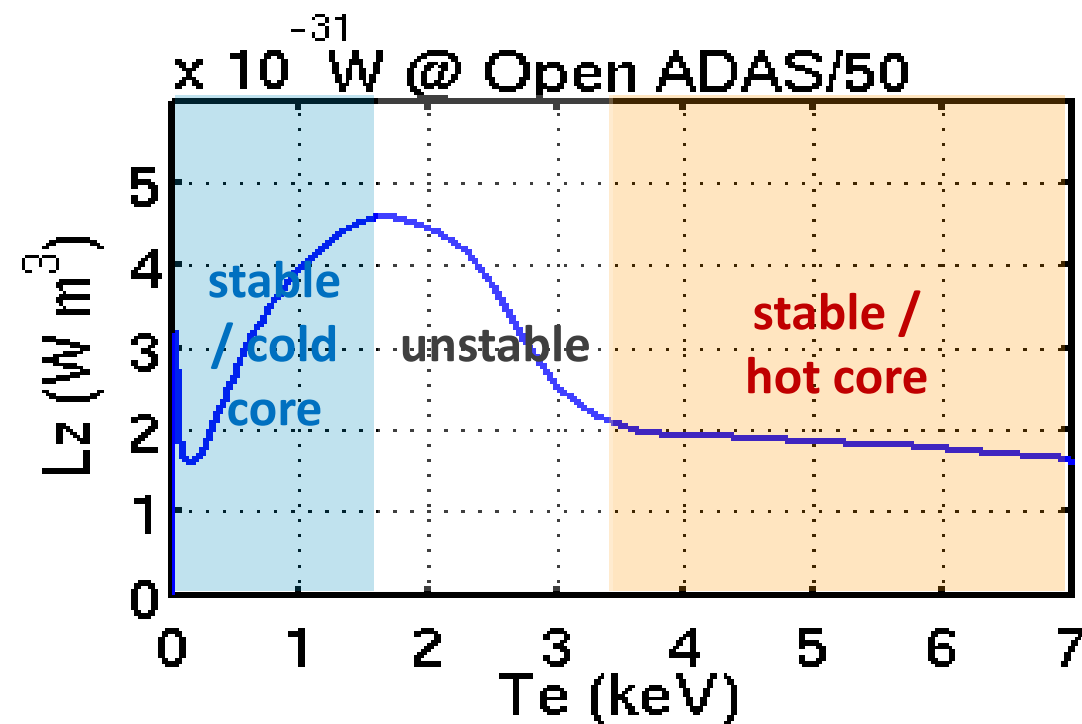
- ▶ **Coexistence of a cold branch with a hot one in WEST W environment**
- ▶  **$n_{\text{sep}}$ ,  $\bar{n}$ , density peaking and energy confinement time**
- ▶ **Collisionality at separatrix and energy confinement time**
- ▶ **Recycled neutrals and energy confinement time**
- ▶ **Conclusions and perspectives**



Same core  $n_W$  peaking and  $P_{rad}/P_{tot}$  on both branches

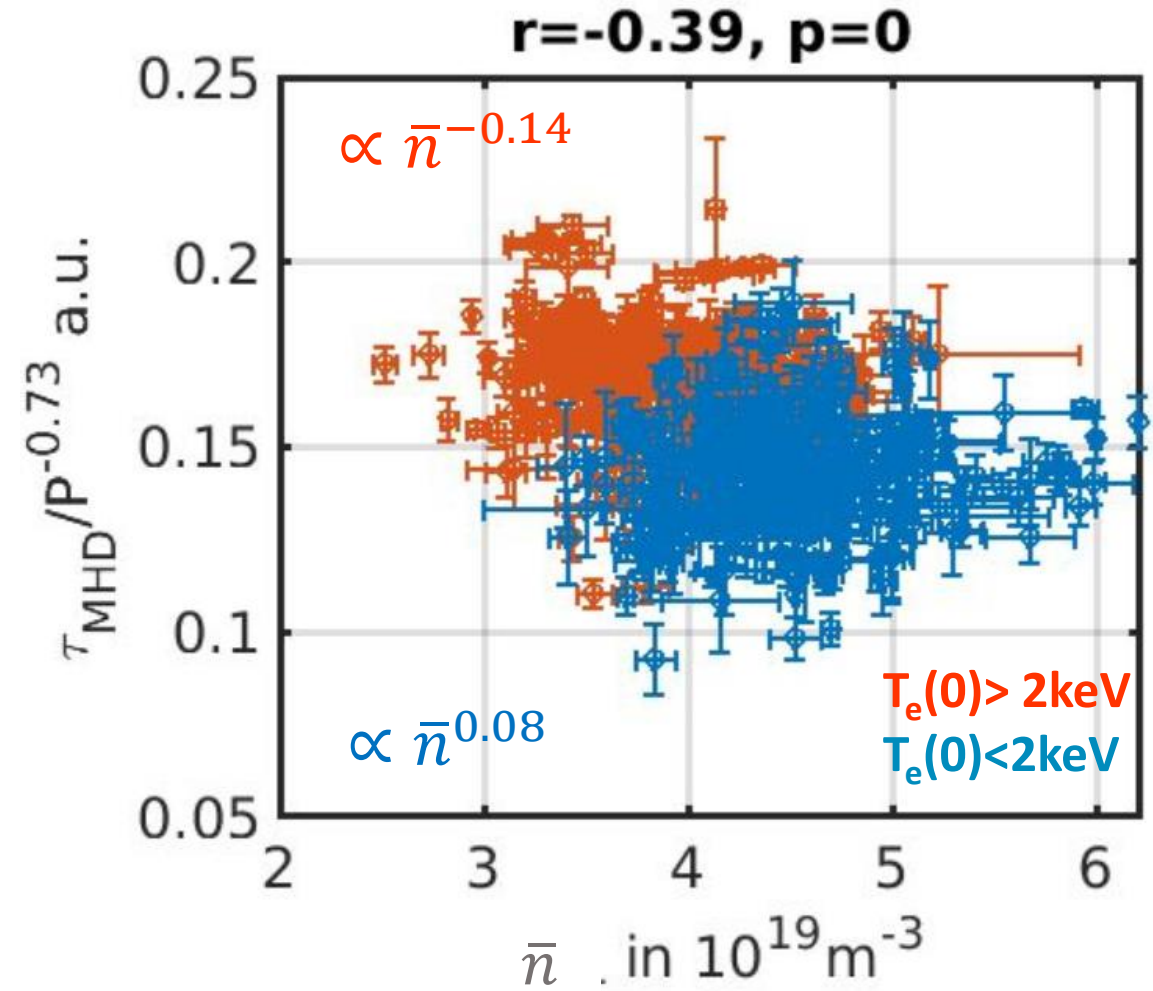
on hot branch: larger li, larger  $W_{MHD}$

- Hot branch  $T_e(0) > 2$  keV and increases with higher  $P_{tot}/n$
- Cold branch:  $T_e(0) < 2$  keV no impact of larger  $P_{tot}/n$

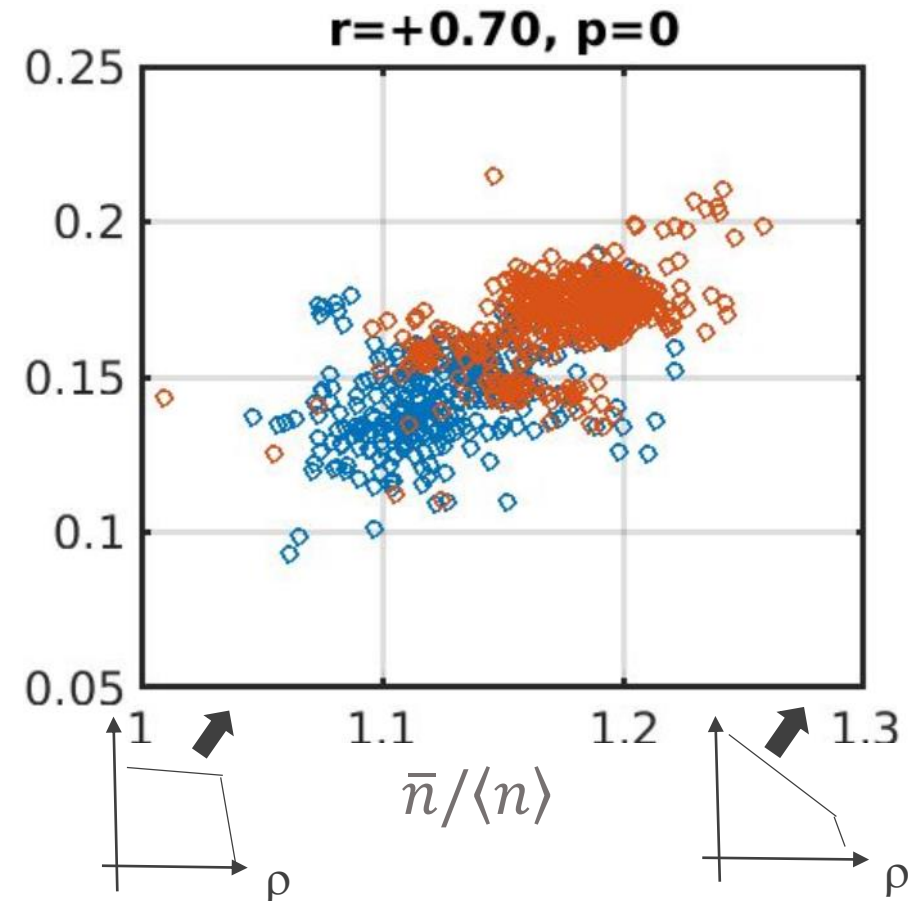
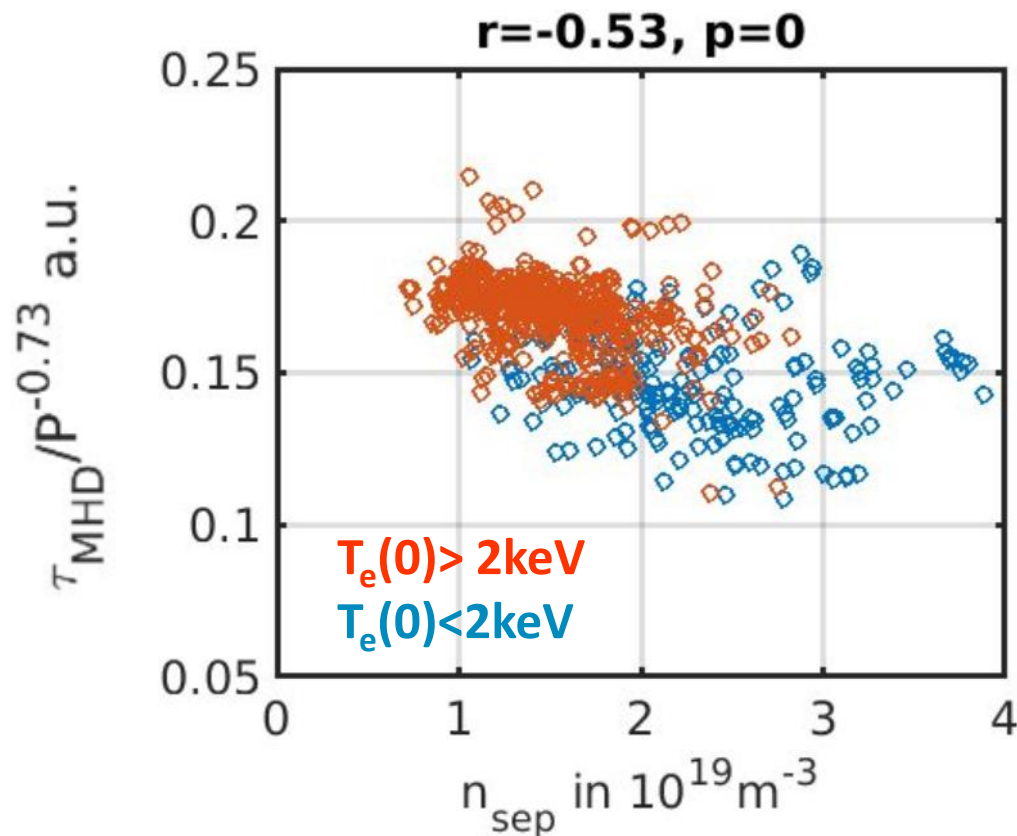


All data at 3.7T and 0.5 MA

- Power degradation on WEST database [Goniche NF 2022]:  $P^{-0.73}$  as ITER L96 scaling
- Weak correlation  $\tau_{MHD}/P^{-0.73}$  with line average density  $\bar{n}$  (interf.) unlike  $L_{96} \propto \bar{n}^{0.40}$  closer to ITPA2020  $\propto \bar{n}^{0.147 \pm 0.097}$
- next plots confined plasma perf. characterized by  $\tau_{MHD}/P^{-0.73}$  in a.u.



- ▶ Energy confinement degradation with higher  $n_{\text{sep}}$  (reflectometry) as H mode in AUG/JET [Verdoolage NF2021]
- ▶ higher correlation btw larger  $\tau_{\text{MHD}}/P^{-0.73}$  and larger density peaking (interferometry)



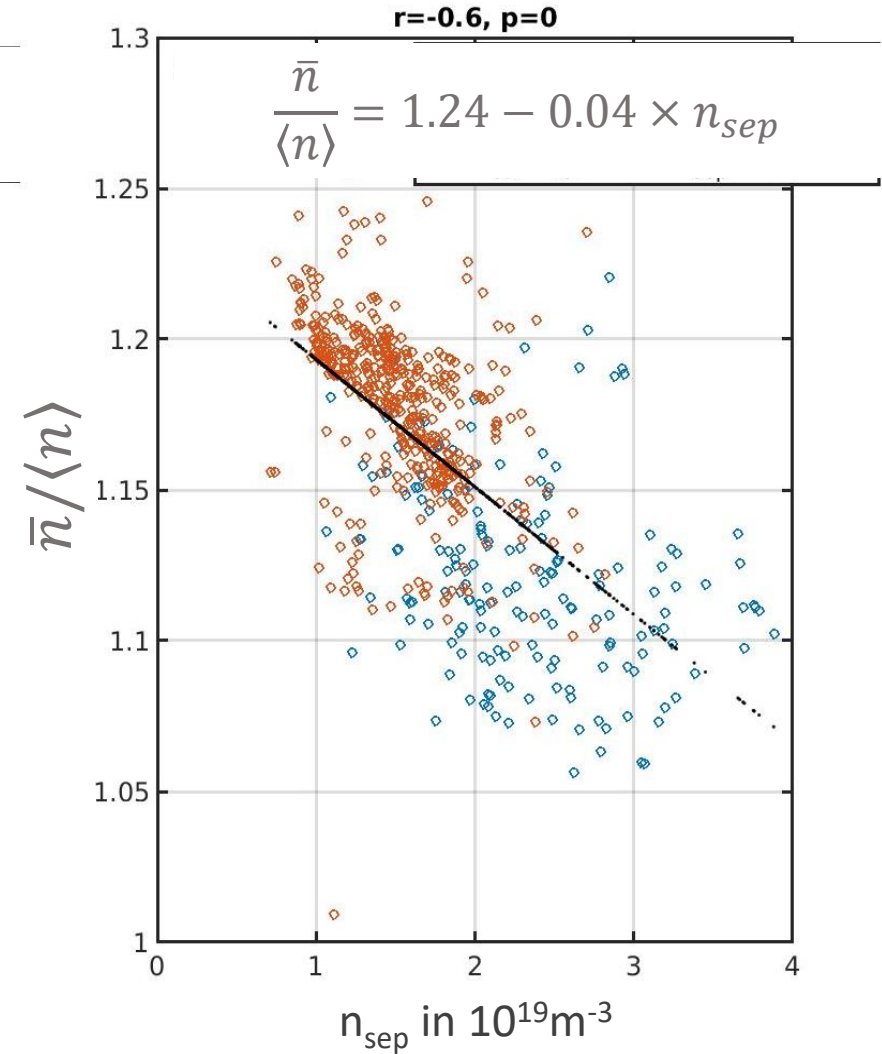
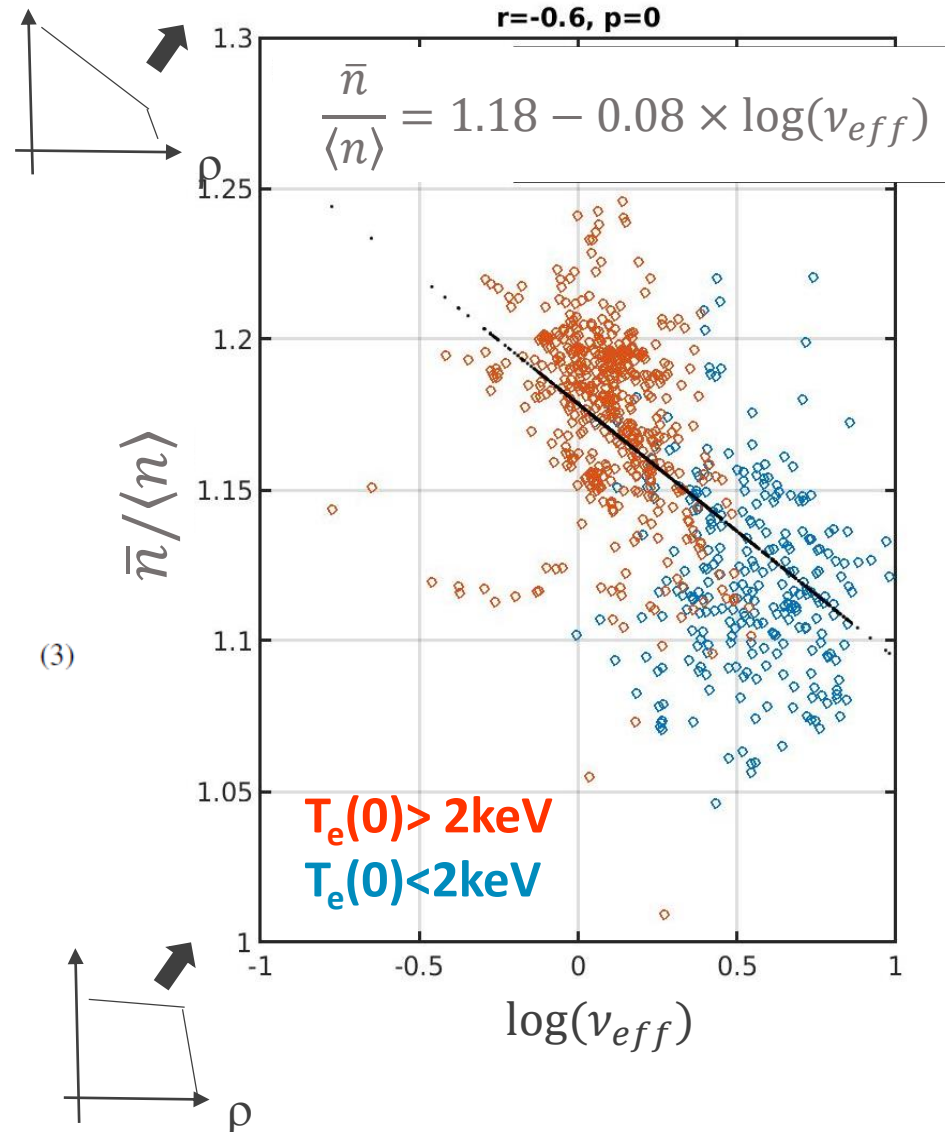


►  $\bar{n}/\langle n \rangle$  is larger for lower  $n_{sep}$

► AND recover  $\bar{n}/\langle n \rangle$  scaling with vol. averaged  $\nu_{eff}$  as found on AUG and JET H mode database [Angioni NF2007]

$$pk_{sclv} = 1.347 \pm 0.014 - (0.117 \pm 0.005) \log(\nu_{eff}) + (1.331 \pm 0.117) \Gamma_{NBI}^* - (4.030 \pm 0.810) \beta, \quad (3)$$

► Extrapolation towards ITER density peaking likely differ if using correlation with  $\nu_{eff}$  or with  $n_{sep}$

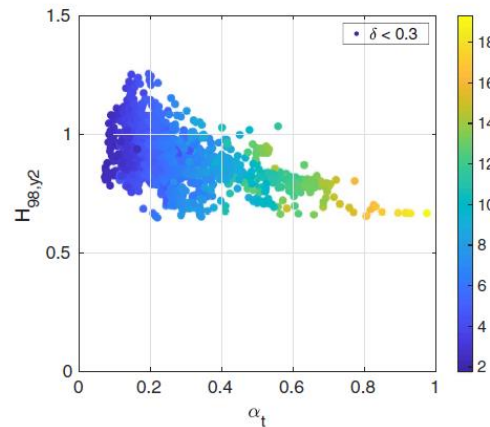


- ▶ Resistive interchange turbulence drive in separatrix

figure of merit :  $\alpha_t = 3.13 \cdot 10^{-18} R_{geo} q_{cyl}^2 \frac{n_{sep}}{T_{sep}^2} Z_{eff}$

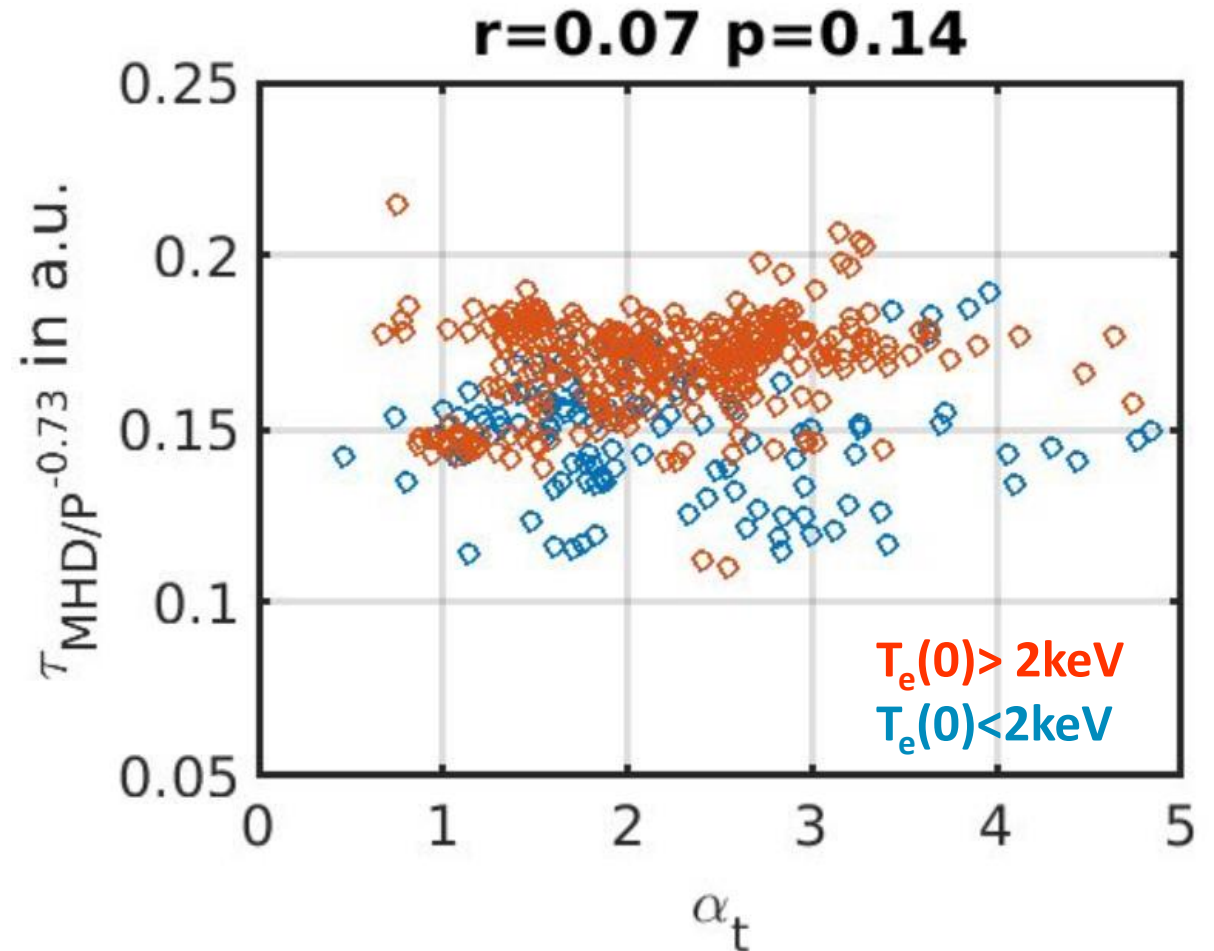
[Scott PoP2005] similar to  $\alpha_d$  of [Rogers PRL98]

- ▶ In AUG H mode database, lower H factor for higher  $\alpha_t$  [Eich NF2020]

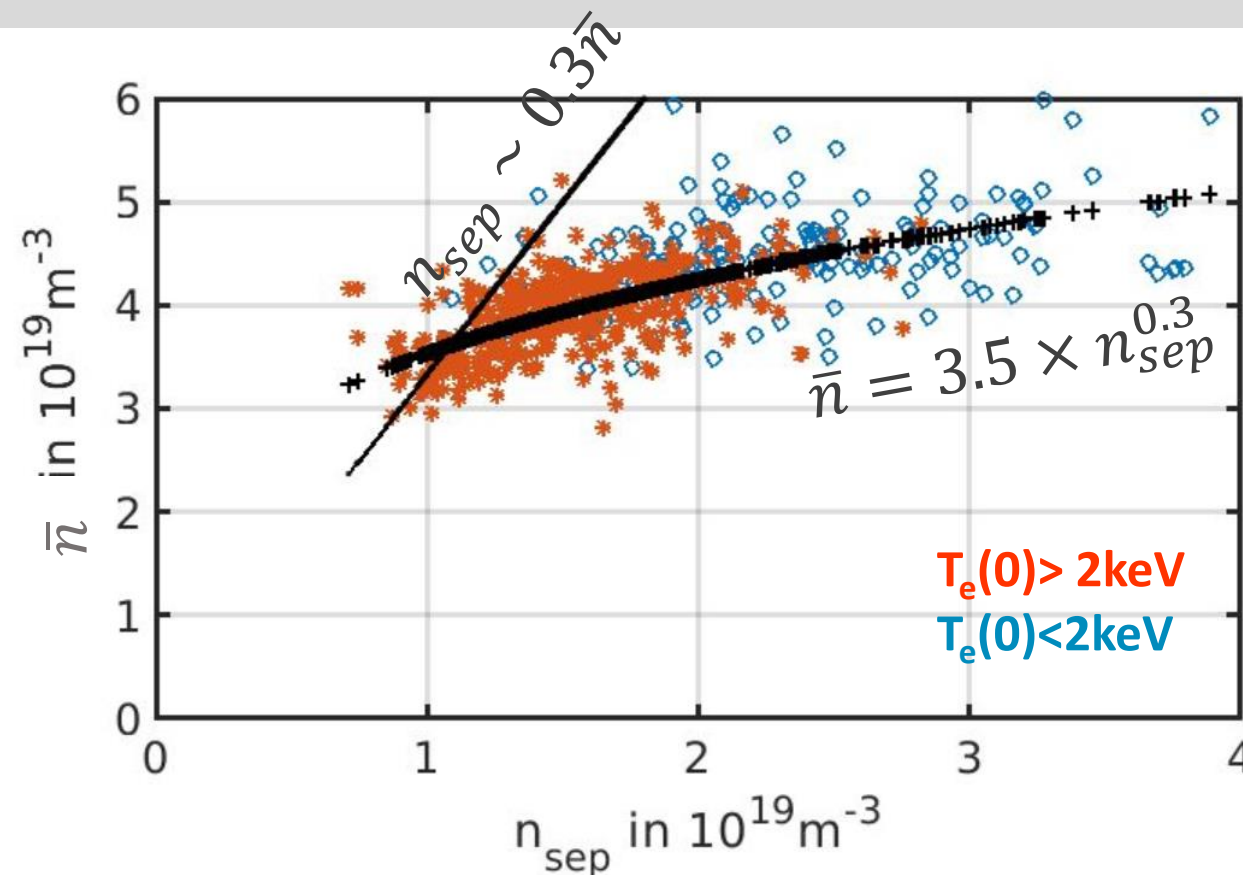
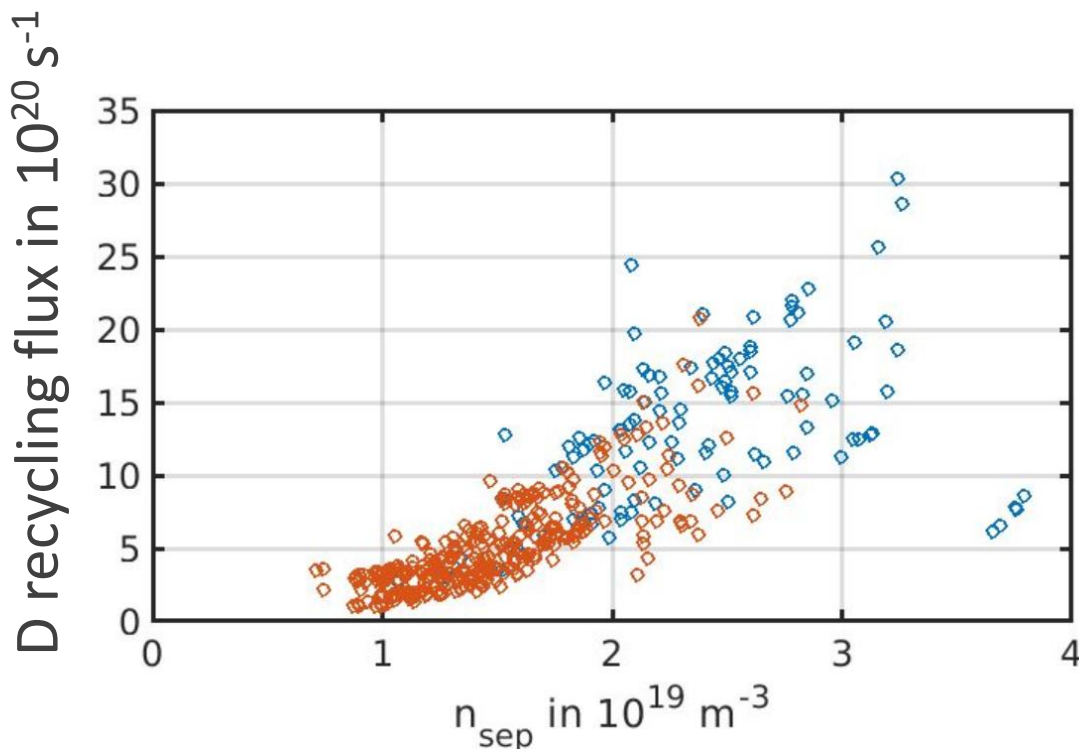


- ▶ Here:  $n_{sep}$  from reflectometry,  $T_{sep}$  from reversed 2 point model using Langmuir Probes in divertor target

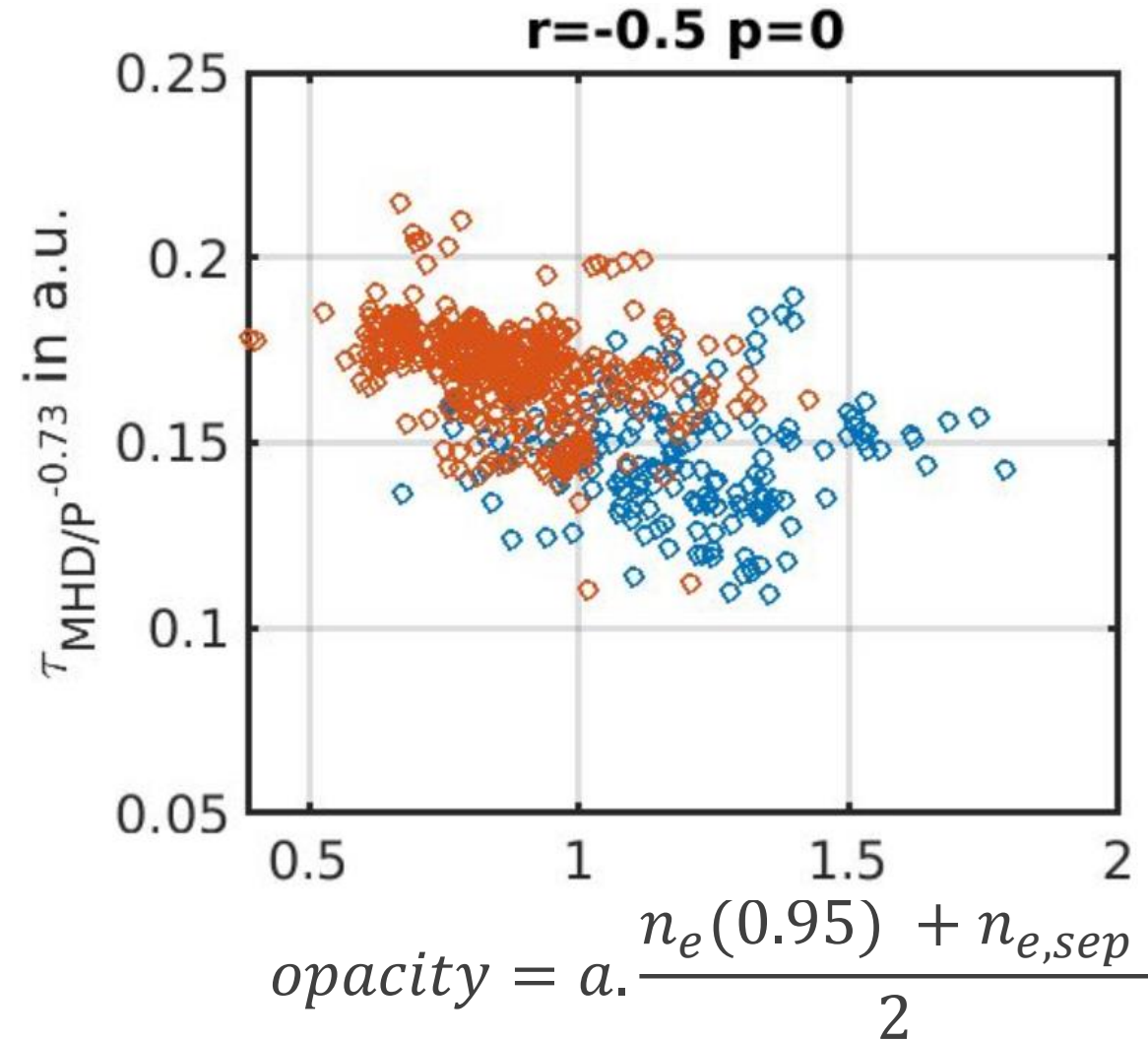
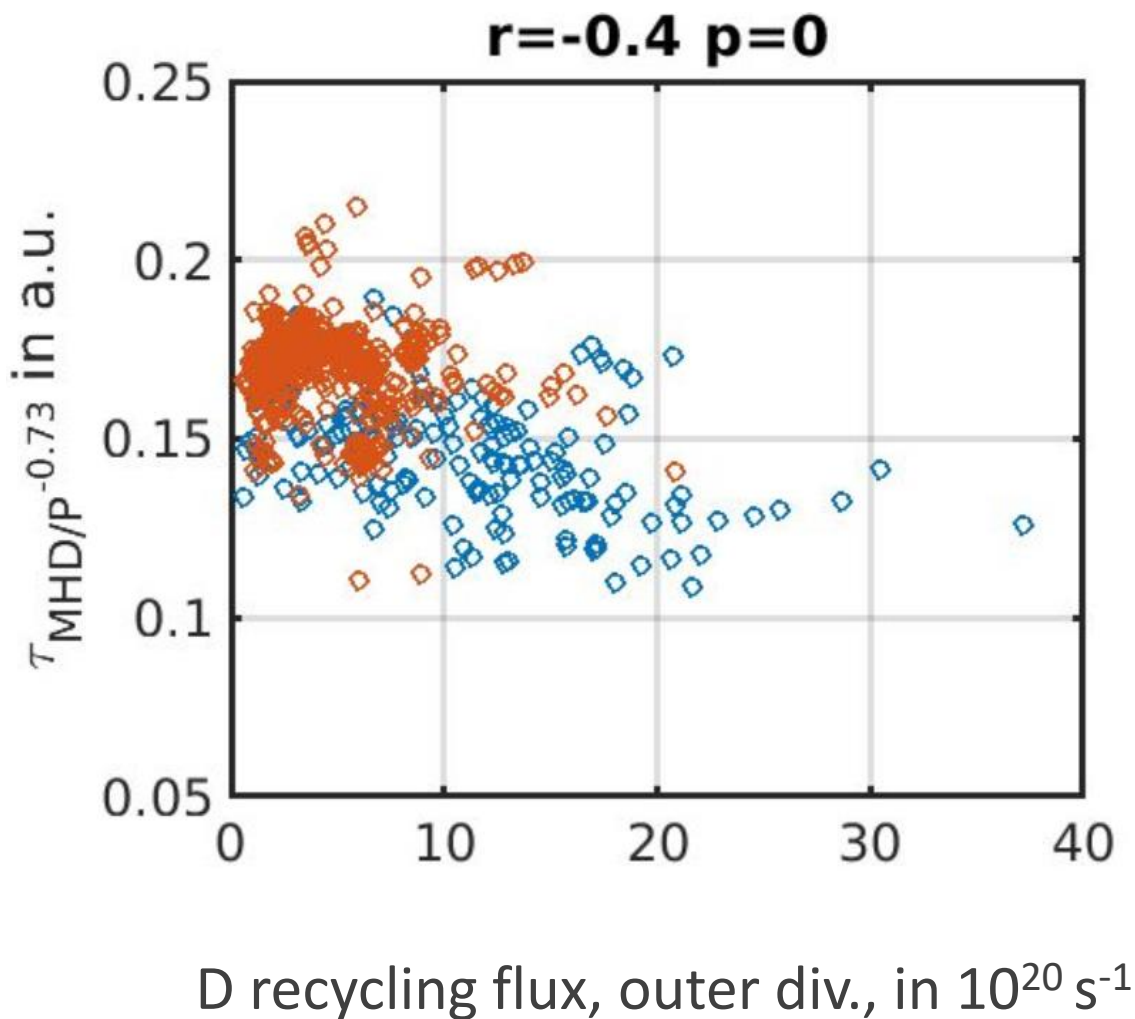
- ▶ No correlation between confinement quality and  $\alpha_t$  reported in our L mode database



- High recycling regime. **no control of  $n_{sep}$**  through feedback controlled interferometry central line integrated density,  $\bar{n}$



- On contrary  $n_{sep}$  **correlates strongly with D recycling flux** (visible spectro, 4341 Å corrected for S/XB) at divertor target (inner and outer)



In WEST L mode high recycling database, **higher core performances correlate** with:

- Lower:  $n_{sep}$ , opacity, D recycling flux at divertor, volume average collisionality
- Higher:  $\bar{n}/\langle n \rangle$ ,  $\frac{-\nabla n}{n}$  at separatrix (reflec.),  $T_e(0)$ , internal inductance

[Bourdelle sub. to NF]

- I. **Extend** such analysis to **multi machines databases** (using IMAS data format standard), **to H mode database, to different divertor closures (with metric for closure)** to challenge universality of trends
- II. **Causality chain? integration of neutral models with L-mode edge validated turbulent transport** TGLF-sat2 [Angioni NF22] in the High Fidelity Pulse Simulator [more @ my poster Tomorrow]
- III. **Extrapolation** towards future machines ITER, DEMO,... where smaller ratio of the ionization/CX length to machine size & weaker pumping w.r. vessel. Also **guide the divertor/wall material choice also with respect to core performances**. Liquid metals, an optimized choice? Reinforce R&D on liquid metal loops?



Thank you for your attention

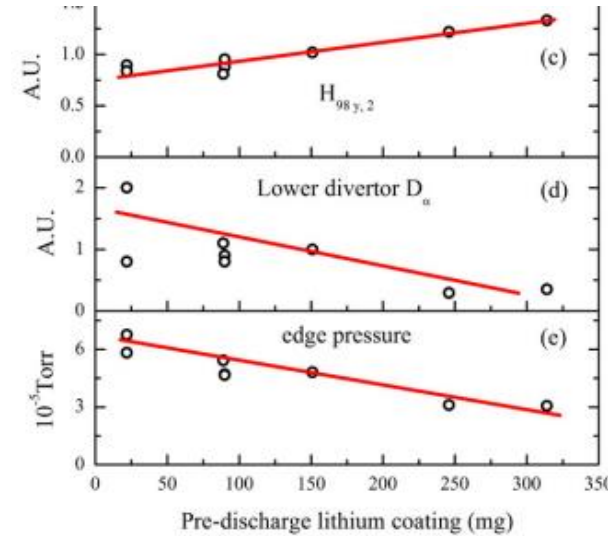


**Some experimental observations:**

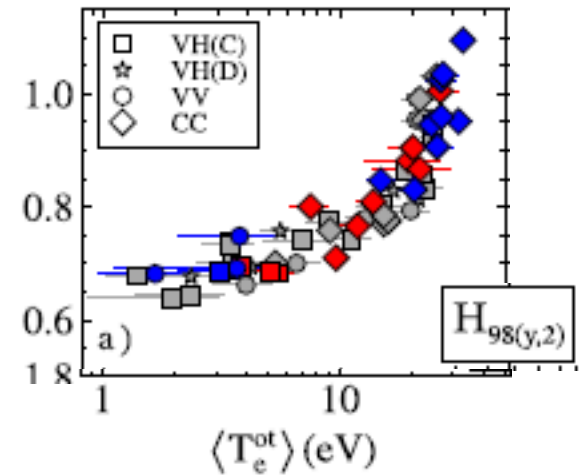
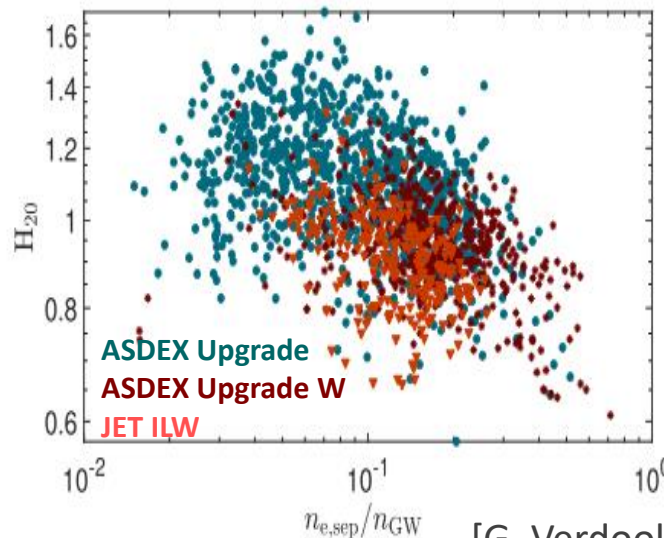
- ▶ Neutral recycled from wall, divertor and/or limiters impacting the performances.
- ▶ Better performances if lithiumisation/boronization/siliconisation (NSTX, EAST, TEXTOR etc)
- ▶ Higher H factor correlates with lower  $n_{sep}$  and also higher  $T_{target}$

**Pointing towards an impact of neutral recycling source on core performances**

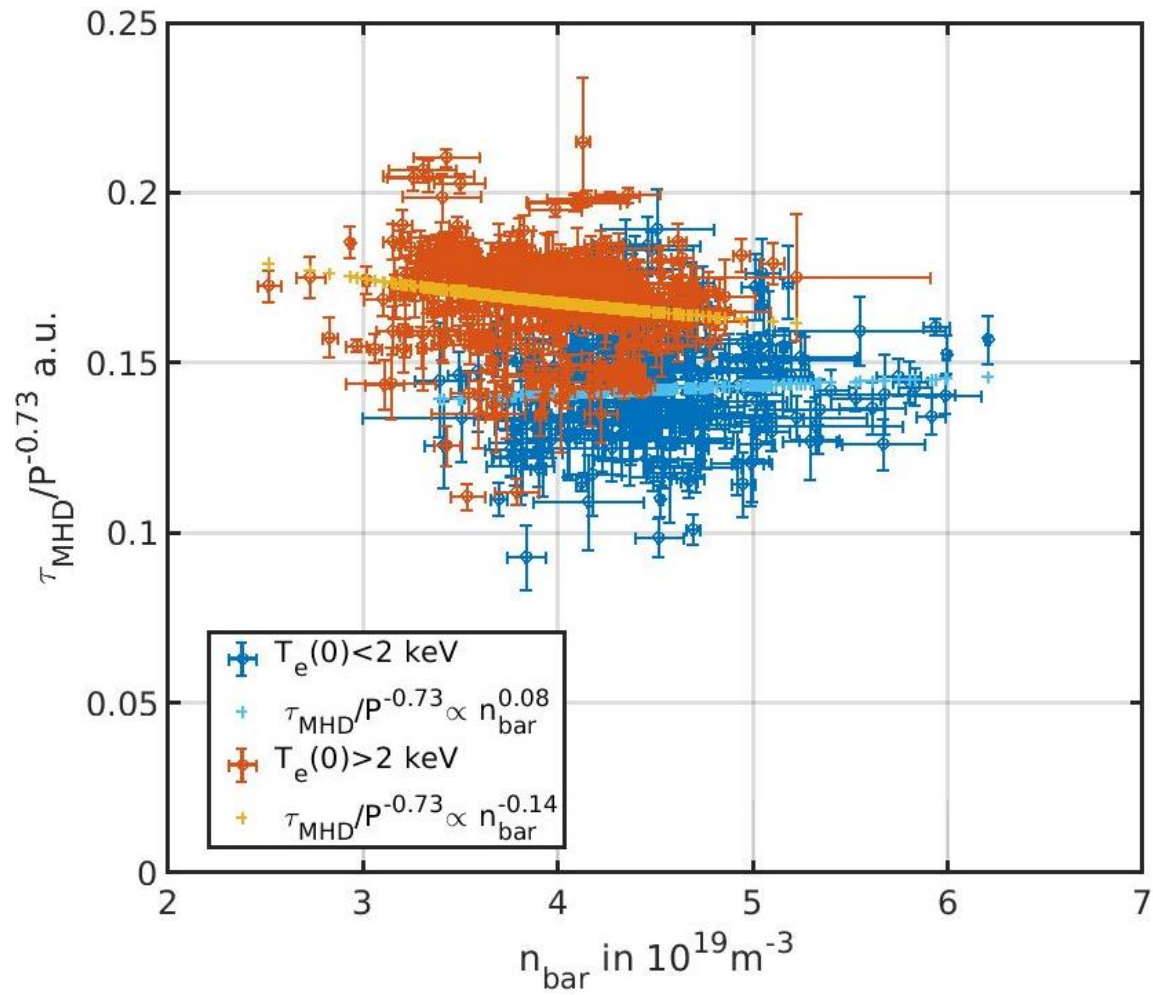
$$\tau_E = 73 H_\alpha^{-0.24} \left( \frac{\beta_{||}}{\beta_{\perp}} \right)^{0.85} n_e(0)^{0.60} B^{0.35} C_{NB}^{0.19} \quad [\text{Strachan PoP1994}] \text{ TFTR C limiter}$$



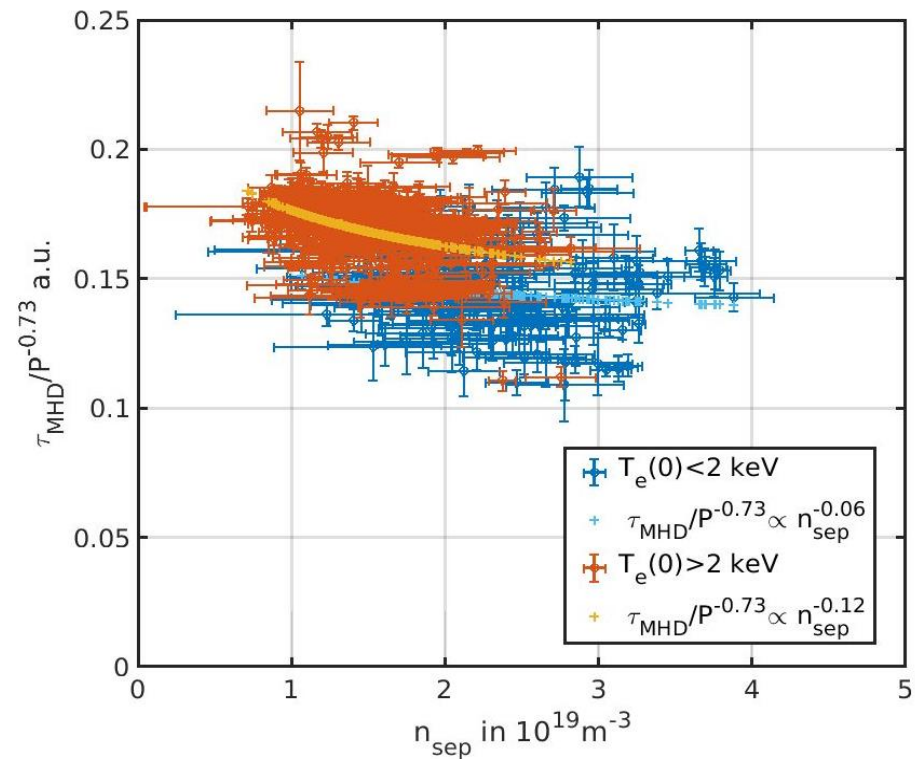
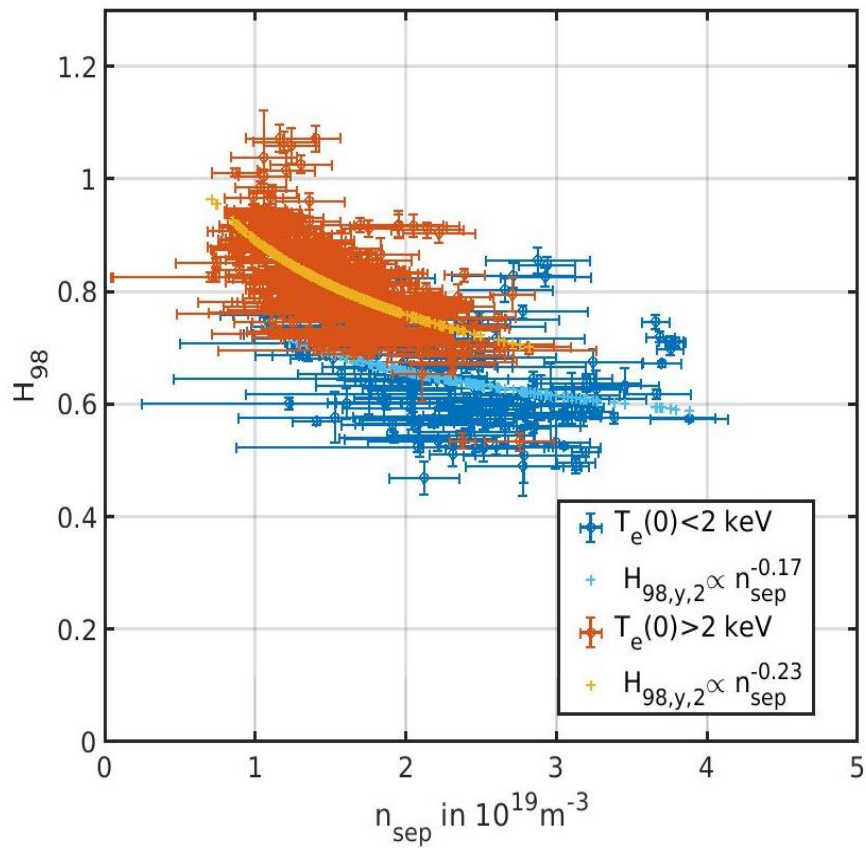
[Cao PPCF2012] NSTX Li coating



[B. Lomanowski, NF 2022], JET ILW







parallel heat flux conservation to infer from the measured target  $T_t$  and parallel heat flux,  $q_{\parallel,t}$  by Langmuir Probes, the upstream temperature,  $T_u$

2 equations (inner and outer targets), 2 unknowns  $T_u$  and  $L_{\parallel,out}$  :

$$T_{e,u}^{7/2} = T_{e,t,in}^{7/2} + \frac{7}{2} \frac{1}{\kappa_{\parallel 0}} (L_{\parallel} - L_{\parallel,out}) (q_{\parallel,e,ufcondfin})$$

$$T_{e,u}^{7/2} = T_{e,t,out}^{7/2} + \frac{7}{2} \frac{1}{\kappa_{\parallel 0}} L_{\parallel,out} (q_{\parallel,e,ufcondfout})$$

With:

$$q_{\parallel,e,ufcondfin} = q_{\parallel,e,t,in} / (1 - f_{cooling,in}) \text{ and } q_{\parallel,e,ufcondfout} = q_{\parallel,e,t,out} / (1 - f_{cooling,out})$$

$$q_{\parallel,e,t} = \gamma T_t j_{sat}^+ / e \text{ the electron heat flux on target measured by the probes, } \gamma \approx 5.3.$$

$$A = \frac{7}{2} \frac{1}{\kappa_{\parallel 0}}, \kappa_{\parallel 0} \approx 2000 / Z_{eff}$$

$$L_{\parallel} = 2\pi R_{geo} q_{cyl}$$

Assuming:

$$T_i = T_e$$

$$(1 - f_{cooling}) \approx 1$$

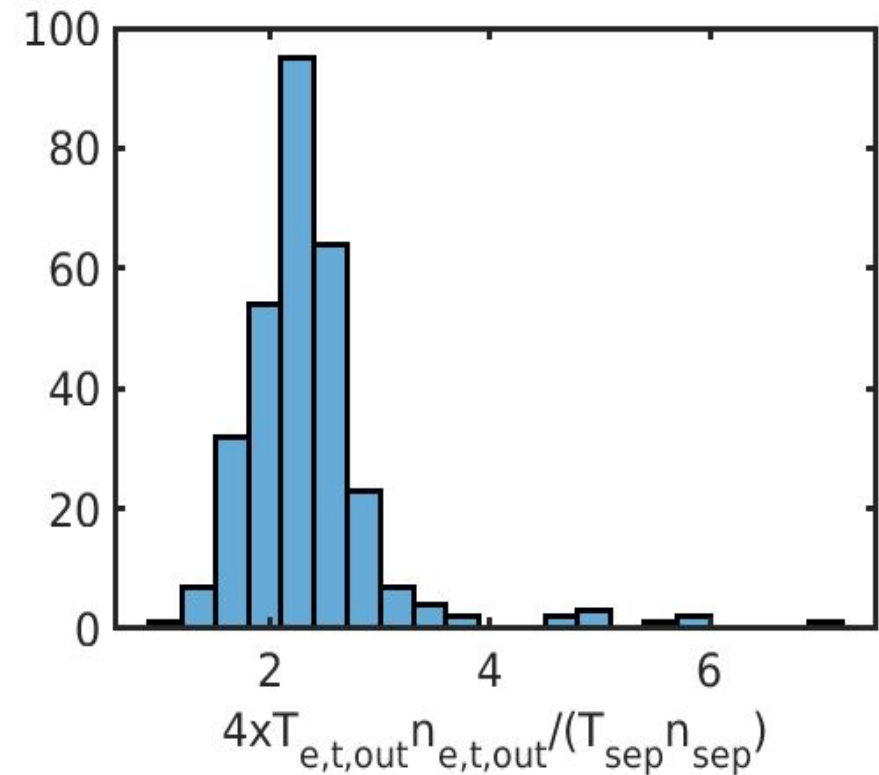
$T_{\text{sep}} = T_u$  in **momentum conservation equation** :

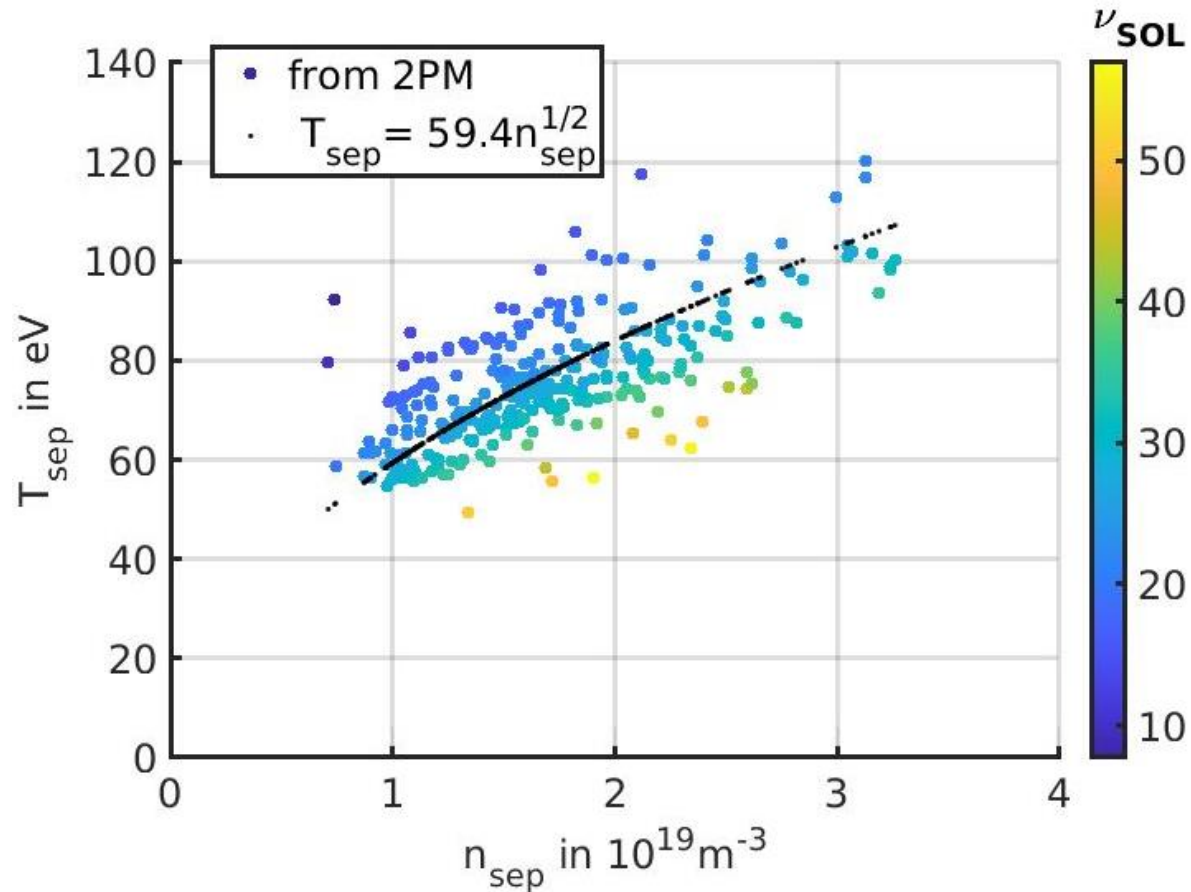
$$n_{e,u} T_{e,u} \left( 1 + \frac{T_{i,u}}{T_{e,u}} \right) f_{\text{mom}} = 4 n_{e,t} T_{e,t}$$

assuming no dilution of the main ions and  
 $T_i = T_e$  on the target plates.

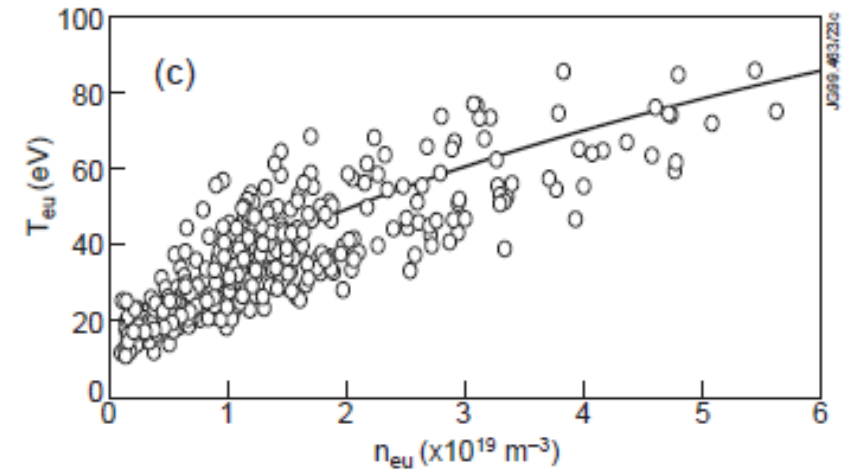
$n_{e,t}$  from Langmuir probes measurements

If  $T_{e,u}$  is meaningful,  $\frac{4 n_{e,t} T_{e,t}}{n_{e,u} T_{e,u}} = \left( 1 + \right.$





As reported in JET and Cmod  
High recycling L and H modes



**Figure 2.** (a)  $T_{\text{eu}}$  versus  $n_{\text{eu}}$  for separatrix values: OSM results for the JET Mark II divertor, H mode. A sin-

Erents NF2000

