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Close Support Unit - Garching

Scaling Studies of ELMy H-modes global and pedestal confinement at high triangularity in JET

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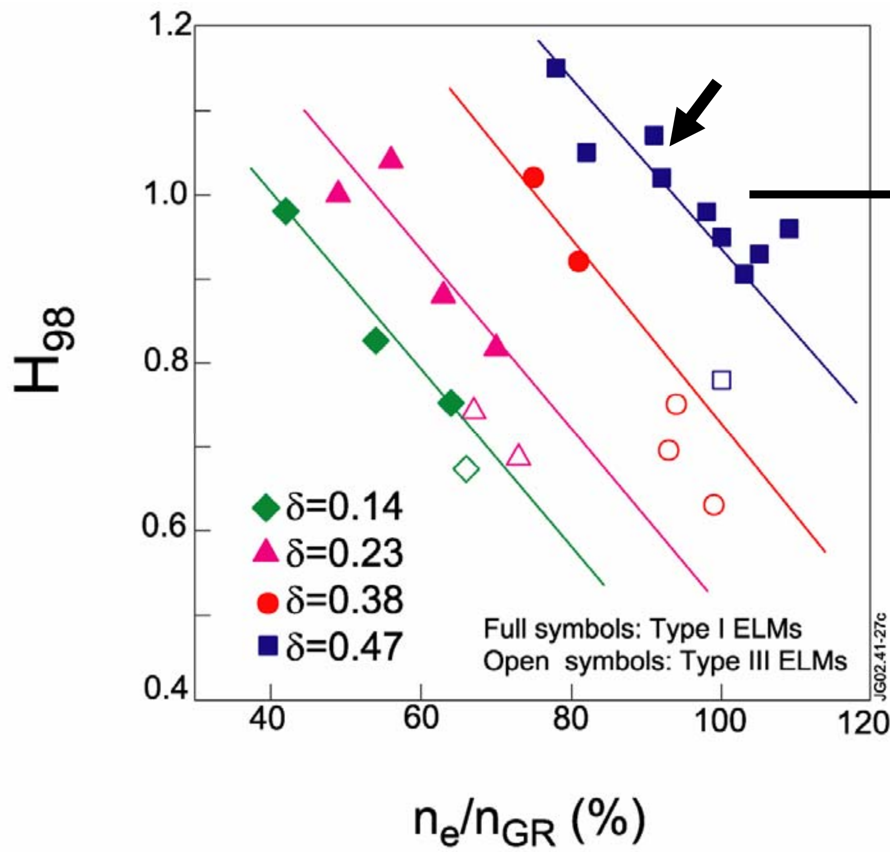
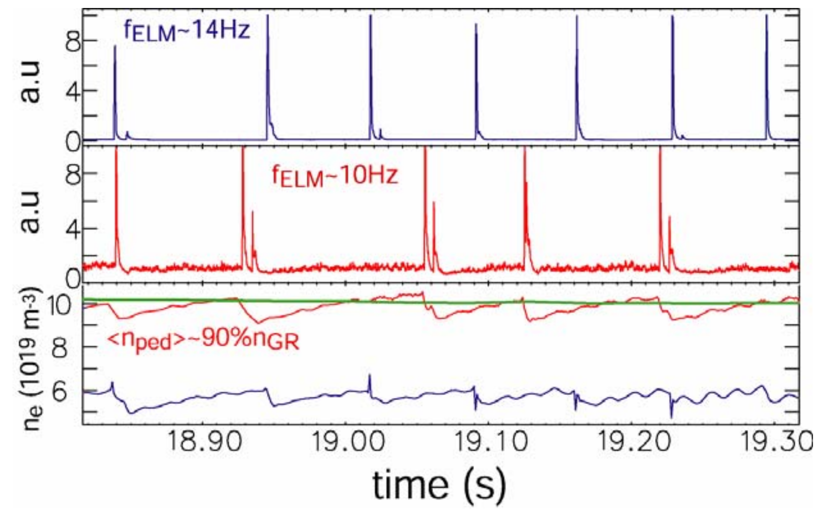
EFDA EUROPEAN FUSION DEVELOPMENT AGREEMENT

JET

Background





Higher δ ⇒ higher H factor is obtained for a given density

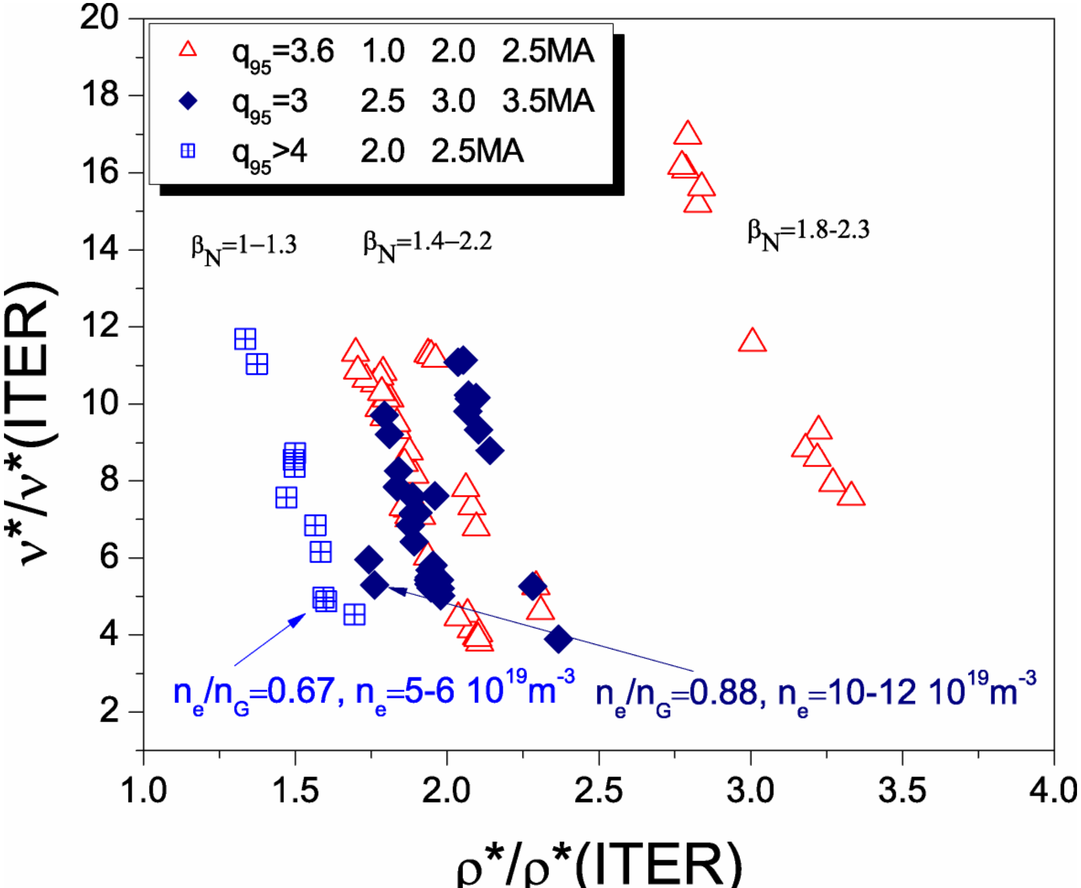
JET⇒ δ ≅0.47 ⇒ H_{98} =1, n_e/n_G=0.85 at q_{95}=3

Mixed Type I/II ELMs ⇒ reduced power lost by ELMs (50 ↓ 20%)

enhanced inter ELM transport J Stober EXP P1-4

Aim and description of the experiments

- Extend operation at high δ (δ >0.4) to wider range of parameters (in particular to lower ρ*)
- Explore the operational space of mixed type I/II ELMs



$\delta \cong 0.42$, I_p 1 to 3.5MA,

q_{95} from 3 to 5

For $n_e/n_G \geq 0.8$ closest match to ITER ρ* and ν* at 3.5MA/3.2T:

ρ*≅1.7ρ*ITER, ν*≅5.3ν*ITER at

$n_e \cong 11 \times 10^{19}\ m^{-3}$,

$P_{NB} \cong 22MW$ ($P_{IN} \propto I_p B_t$)

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Synopsis

1- Mixed Type I/II ELMs: pedestal pressure and global confinement

2- Relation between pedestal and global confinement

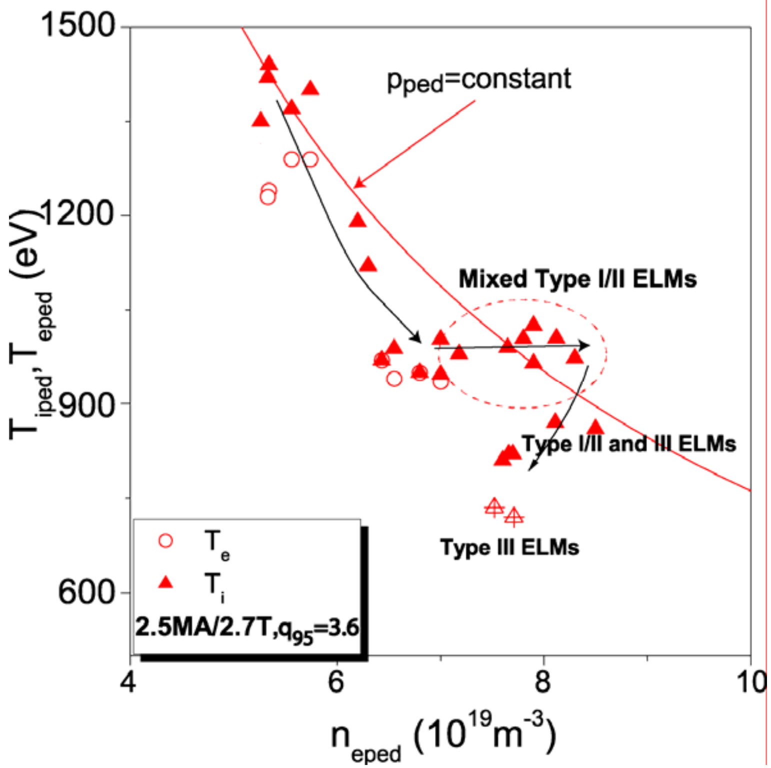
3- I_p scan at q_{95}=3 up to 3.5MA

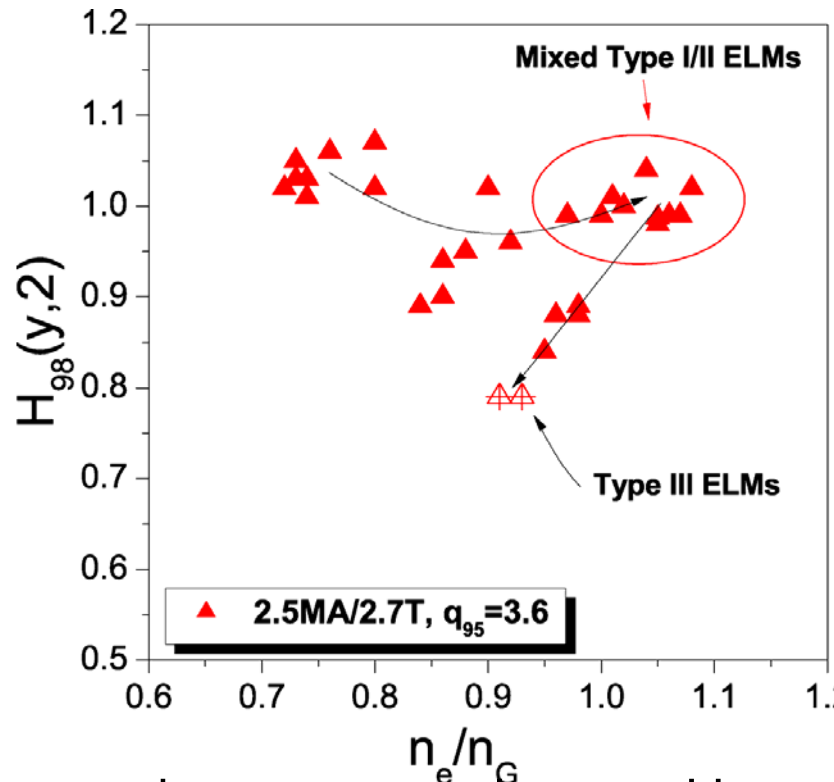
4- Effect of q_{95} on pedestal and global confinement

5- ELM size

6- Summary

Mixed Type I/II ELMs:pedestal pressure and confinement





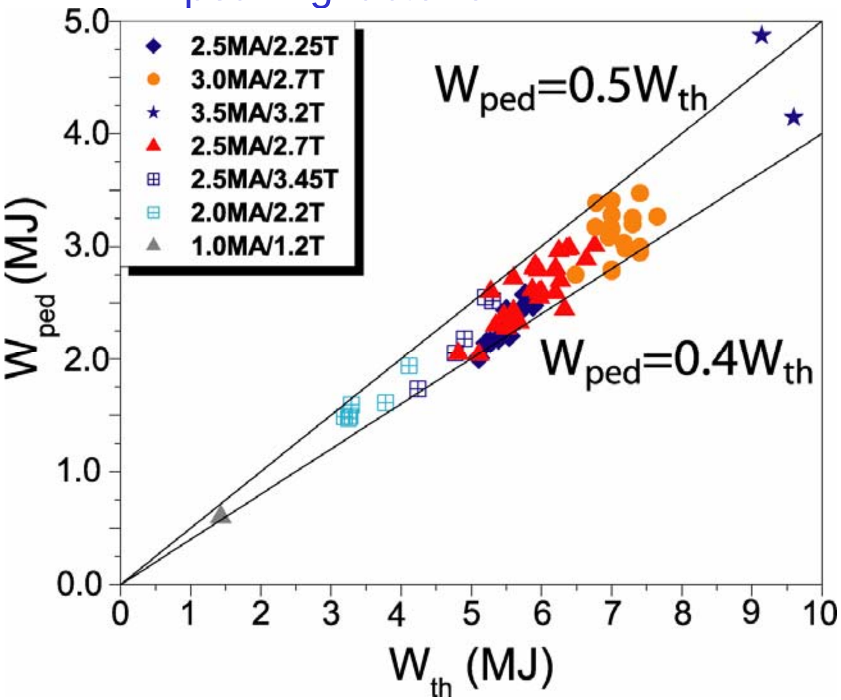
Type I ELMs ⇒ p_{ped} decreases with increasing n_{ped} up to the transition to Type III ELMs

Mixed Type I/II ELMs⇒ p_{ped} increases: n_e increases at constant T_{iped} ⇒ good global confinement at high density observed

Type I/II ELMs in the whole range of I_p and q_{95} explored with one exception ⇒ later

Relation between pedestal and global confinement

Similar core profiles, with density peaking factor of ≅1.2

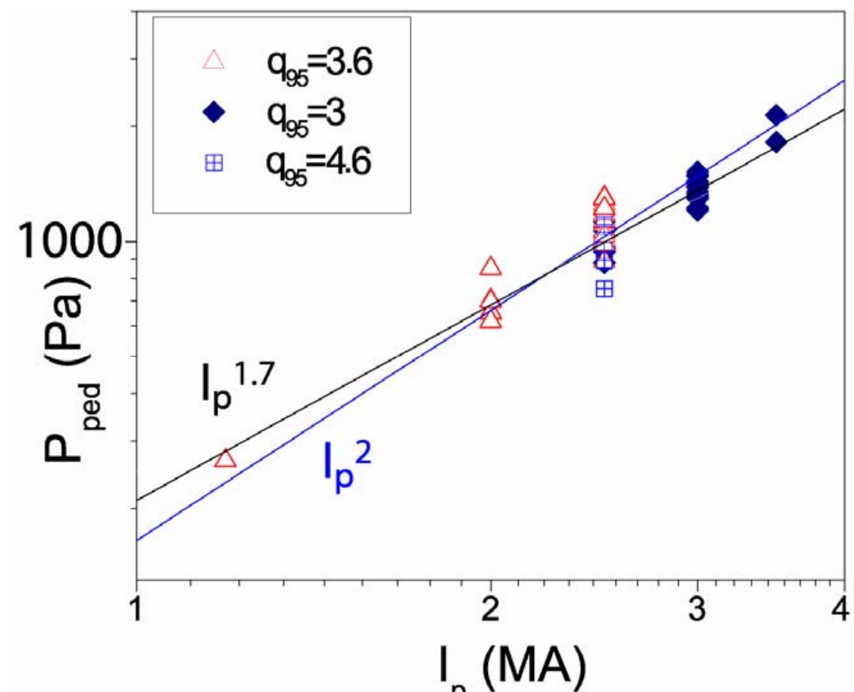


Pedestal / thermal stored energy W_{ped}/W_{th}:

- **independent of I_p, q_{95} and density**
- **good confinement with Type I/II ELMs due to high p_{ped}.**
- Trend with β_N: < W_{ped}/W_{th}> ≅ 0.48 at β_N=1.4, <W_{ped}/W_{th}> ≅ 0.42 at β_N=2.0.

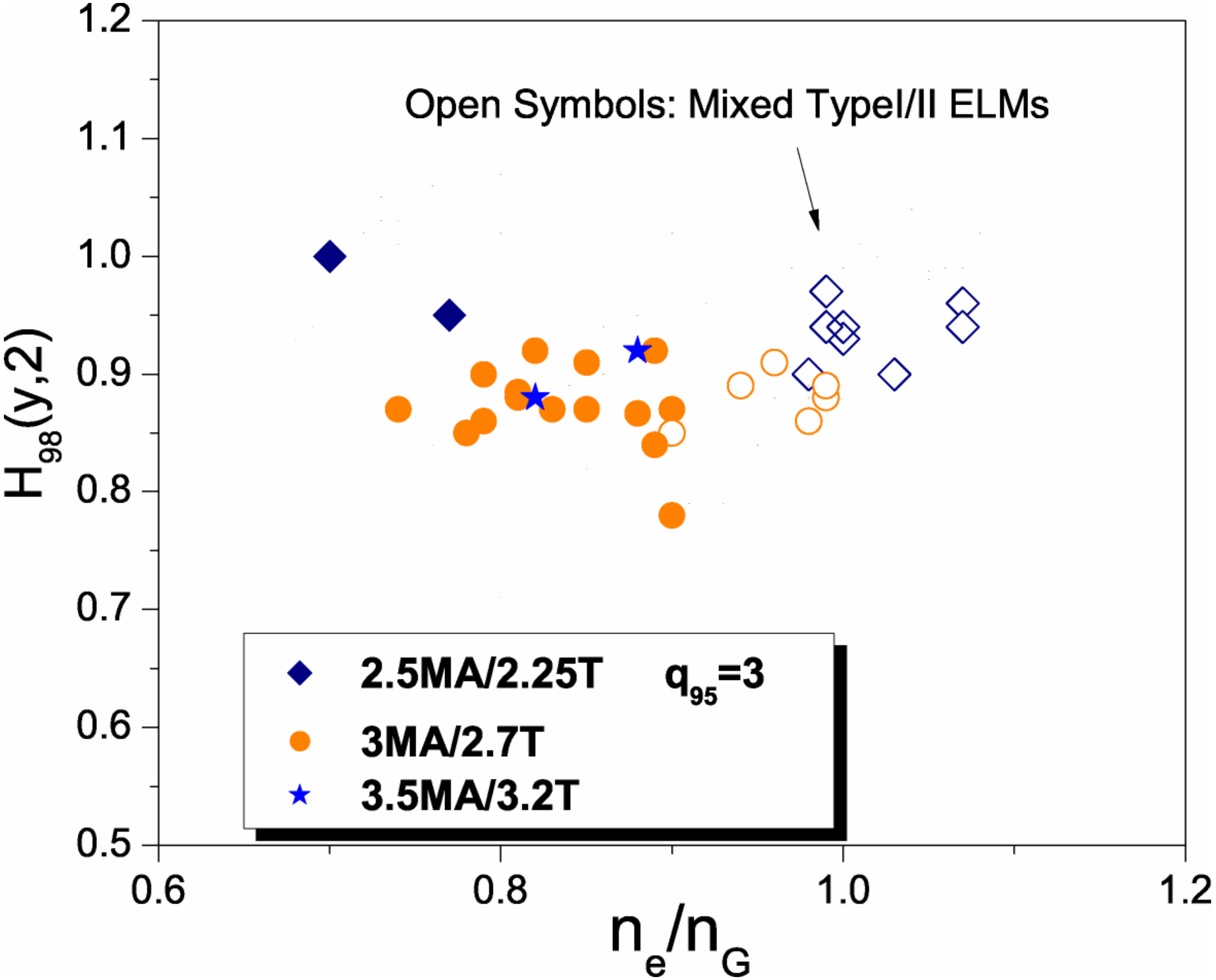
Pedestal pressure p_{ped} (and W_{th}) increases as $I_p^{1.7-2}$ as predicted by ideal ballooning stability for constant Δ_{ped}

(global result- n_e and loss power correlated with I_p)



q_{95}=3 - I_p scan: global confinement

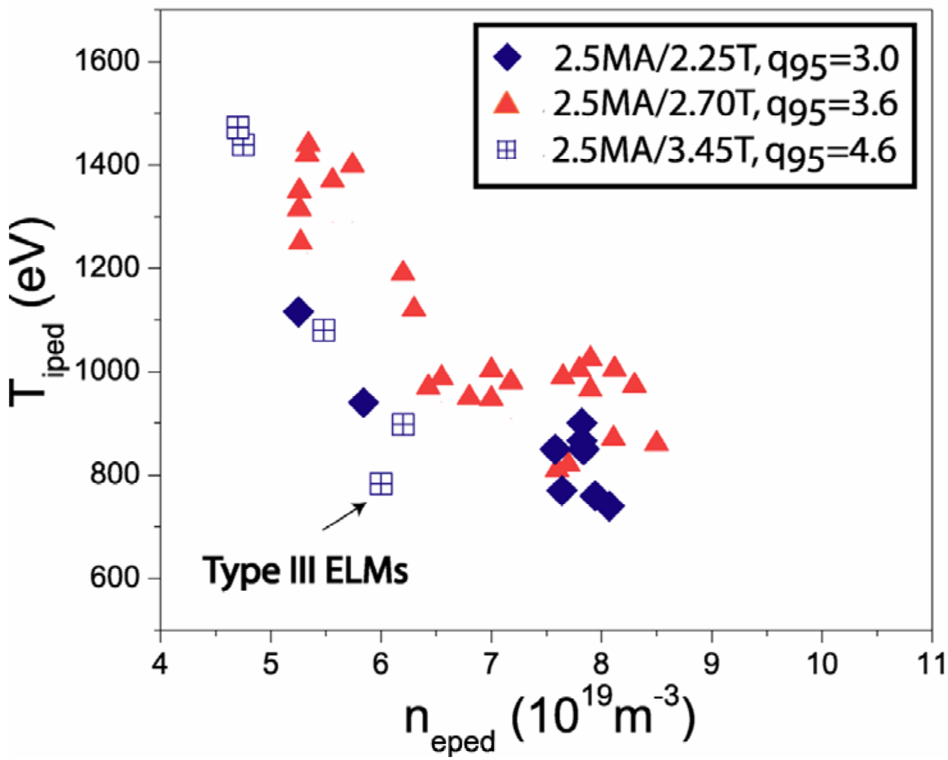
Variation of $H_{98}(y,2)$ with I_p is ≤ 5% ⇒ data well described by the scaling

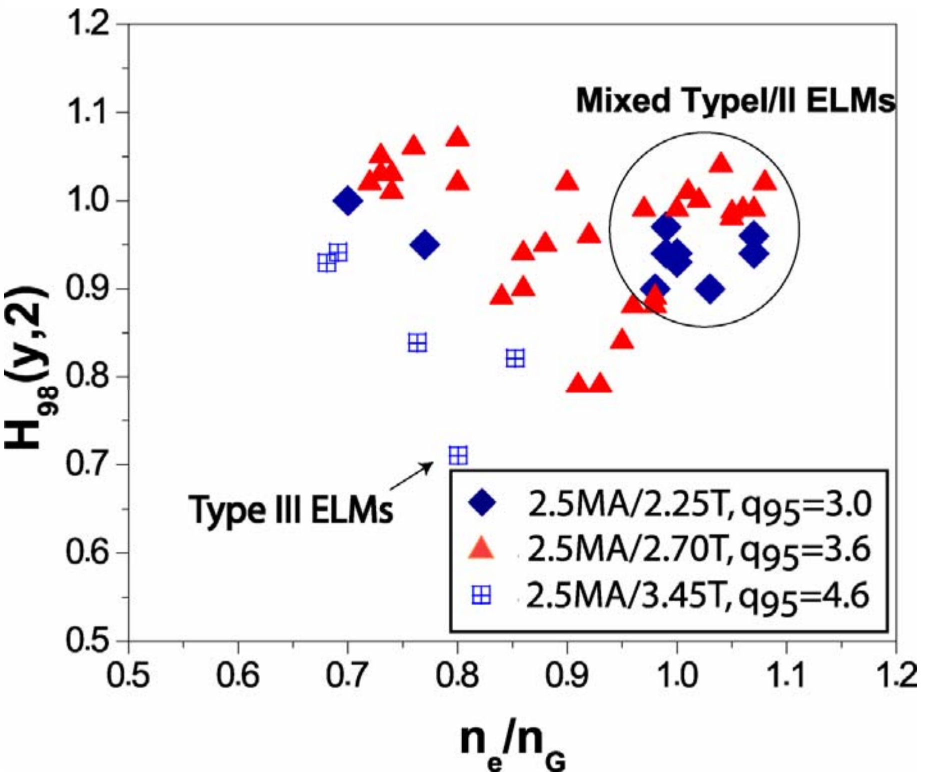


- n_e/n_G ≅0.75-0.8 ⇒ 3MA H-modes affected by (4,3) NTM ⇒ up to 10% reduction in H [1].
- At 2.5MA $\langle\beta_N\rangle$ =1.95, while $\langle\beta_N\rangle$ =1.75 at 3MA and 3.5 MA
- Lower normalised density at 3MA ⇒ higher density not explored

[1] R Buttery EX/7-1

Effect of q_{95} on pedestal and global confinement





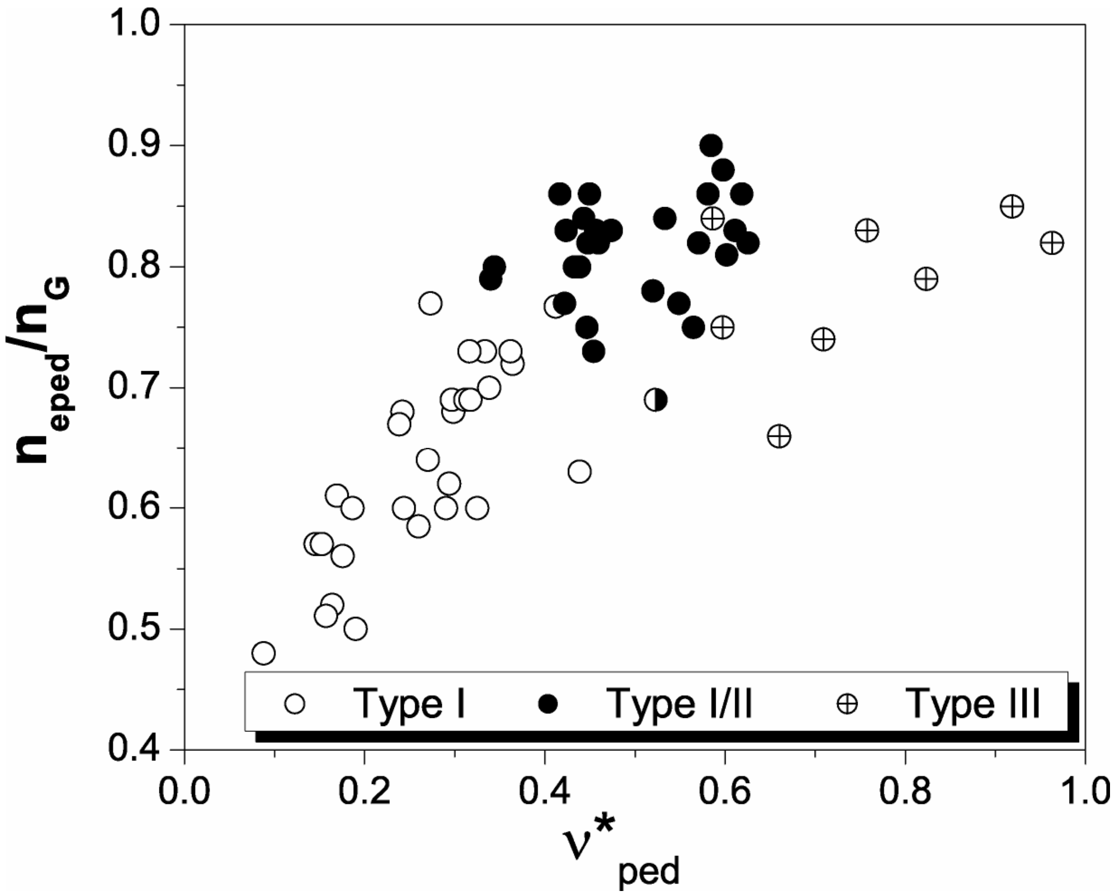
At q_{95}=3.6 p_{ped} higher than at q_{95}=3.0 (same I_p) $\Rightarrow$ higher T_{ped} for the same n_{ped}

$H_{98}\cong$10% higher at the higher q_{95}

At q_{95}=4.6 $\Rightarrow$ transition to Type III ELMs at lower density.

No or marginal access to mixed Type I/II ELMs. n_e/n_G=0.85 with H_{98}=0.82

Access to Mixed Type I/II ELMs



Mixed Type I/II ELMs $\Rightarrow$ good confinement at high density

Type I/II ELMs at high density$\Rightarrow$$n_e/n_G$ or ν^*?$\Rightarrow$ answer requires higher P_{IN} and I_p to better decouple dependencies ($\nu^* \propto q_{95}/I_p^{\alpha}$, α=0.4 - 1)

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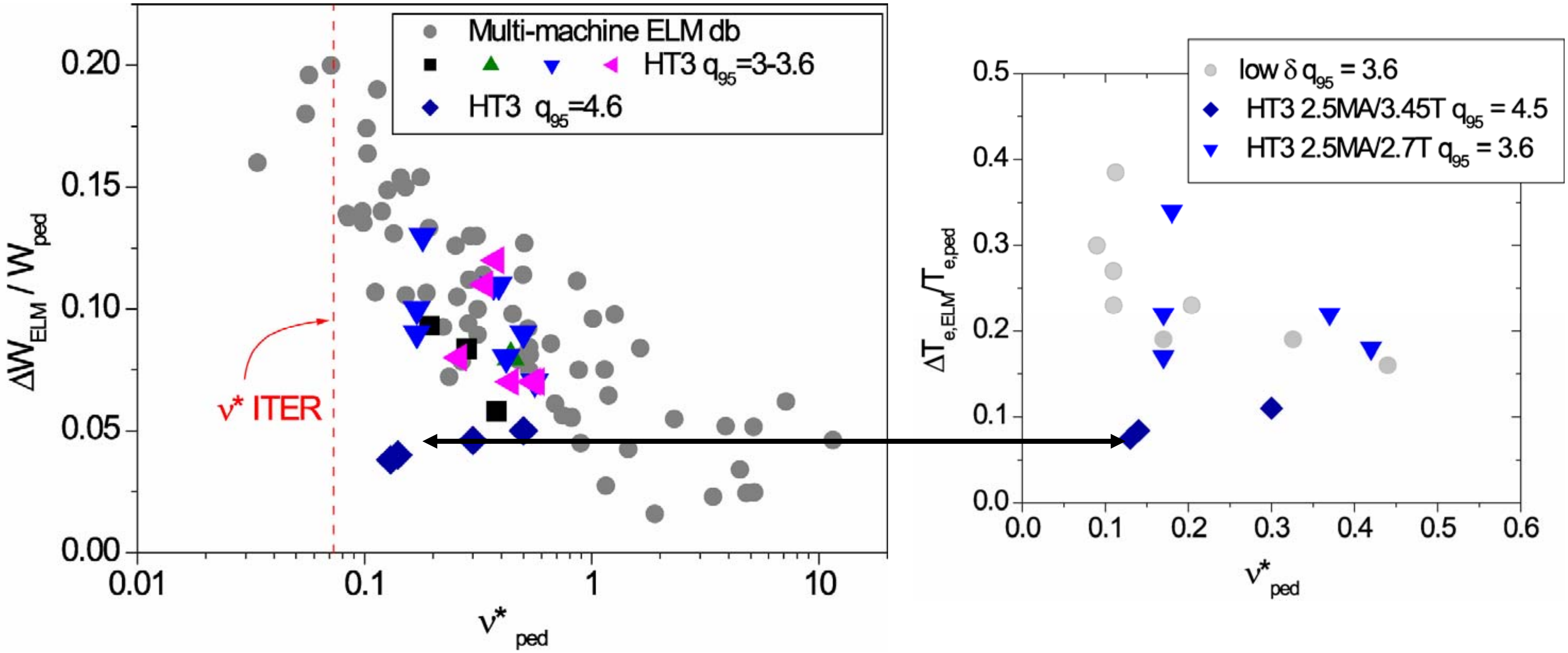
ELM size

A Loarte, Physics of Plasma 11, 2004



Type I ELMs in mixed Type I/II regime⇒ $\Delta W_{ELM}/W_{ped}$=0.07⇒$\Delta W_{ELM}{}^{ITER}$≅8.5MJ
$\Delta W_{ELM}{}^{Div}$ < 5 MJ

If ν^* determines $\Delta W_{ELM}/W_{ped}$ ⇒ ELMs not acceptable

At q_{95}=4.6 ⇒ first evidence of breaking $\Delta W_{ELM}/W_{ped} \propto \nu^*$ link

Small $\Delta W_{ELM}/W_{ped}$ at low ν^* + convective ELMs

Summary: Confinement at high triangularity and density

In extended range of parameters (I_p ρ^* q_{95})$\Rightarrow$

⊕ **Mixed Type I/II ELMs at high density (or ν^*) $\Rightarrow$**

- **only regime with no p_{ped} degradation with density (~ constant p_{ped} up to n_e/n_G=1)**

⊕ **p_{ped} determines global confinement $\Rightarrow$**

- **W_{ped}/W_{th}~ constant and independent of n_e, I_p, q_{95}**
- **p_{ped} increases with I_p**

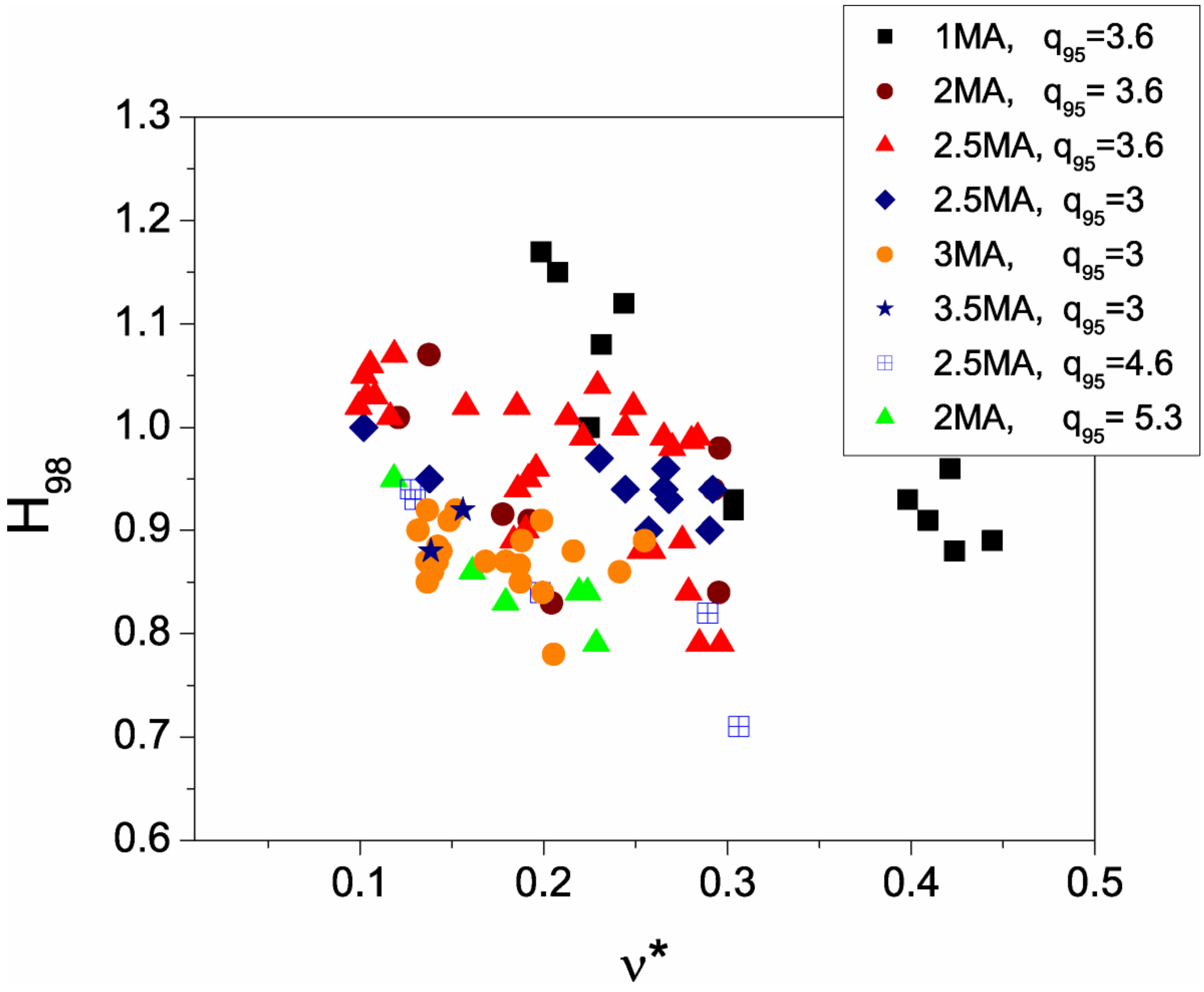
Summary: Confinement at high triangularity and density

⊕ q_{95} dependence of ⇒

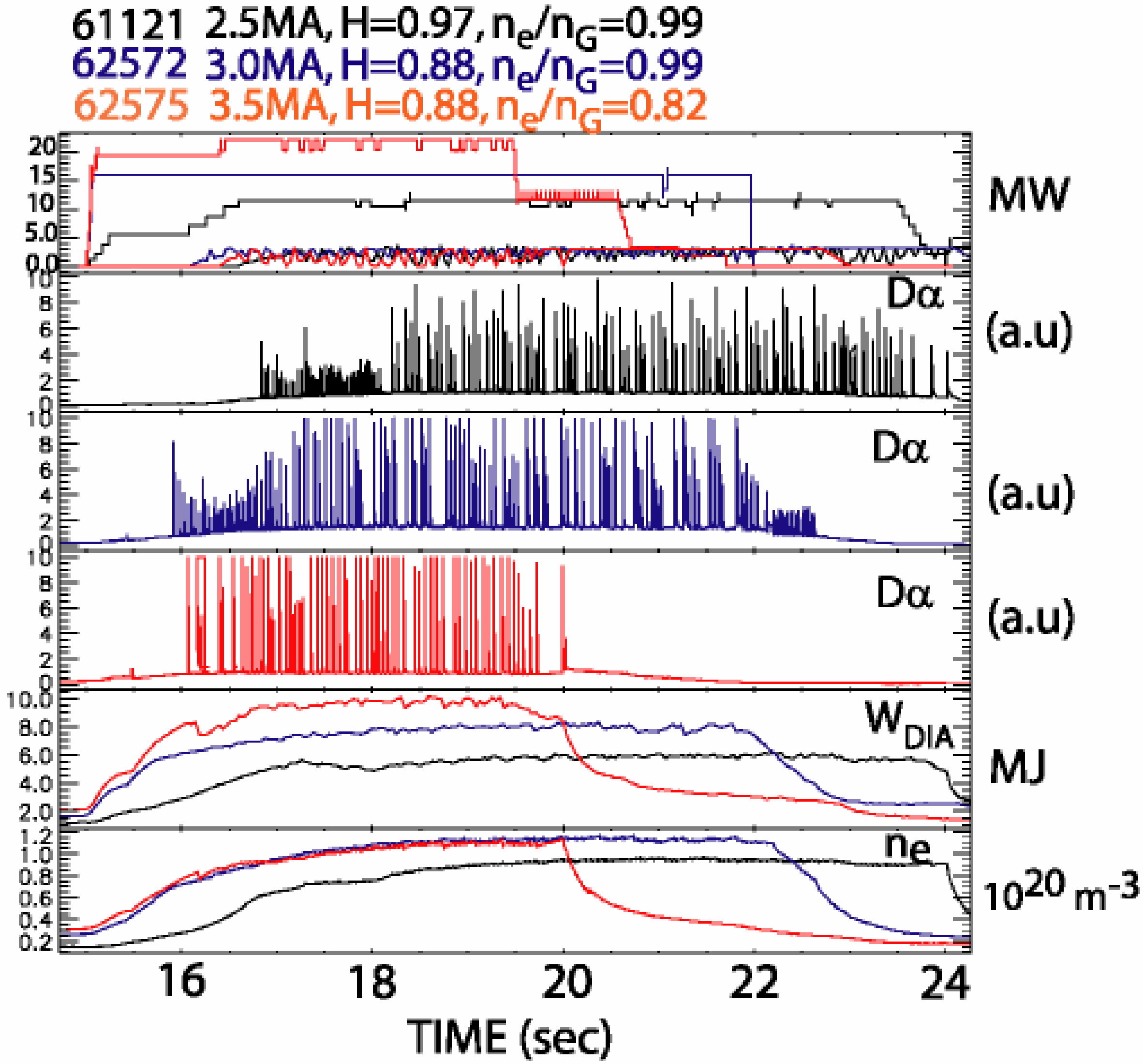
- Confinement at high δ ⇒ optimum confinement at q_{95}=3.6
- Access to the Mixed Type I/II regime⇒marginal at q_{95}>4
- ELM size⇒convective ELMs at q_{95}>4 break the link between ELM size and collisionality

⊕ Improving of energy confinement and ELM size scaling to ITER requires high δ + high density + lower collisionality

H vs collisionality



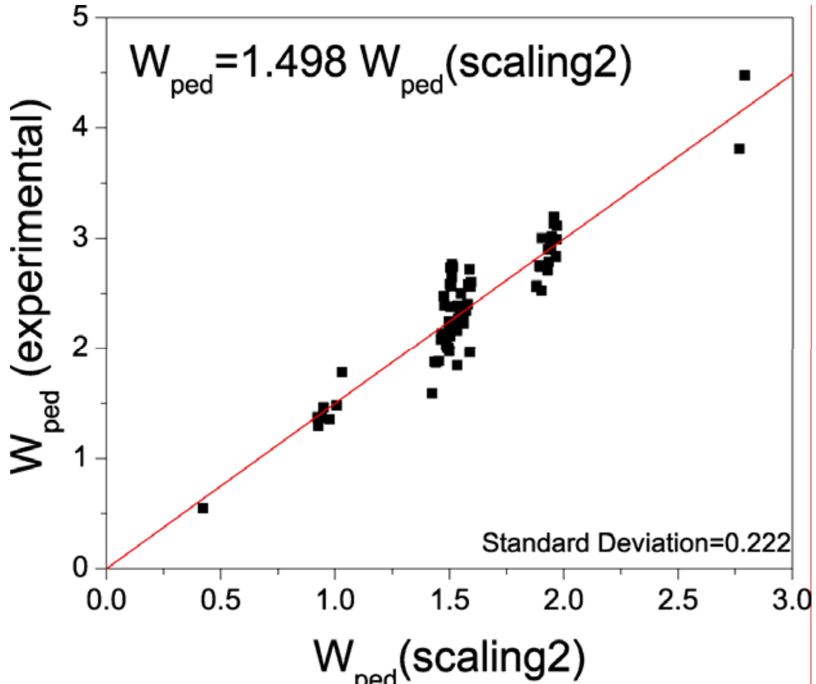
I_p scan at q_{95}=3

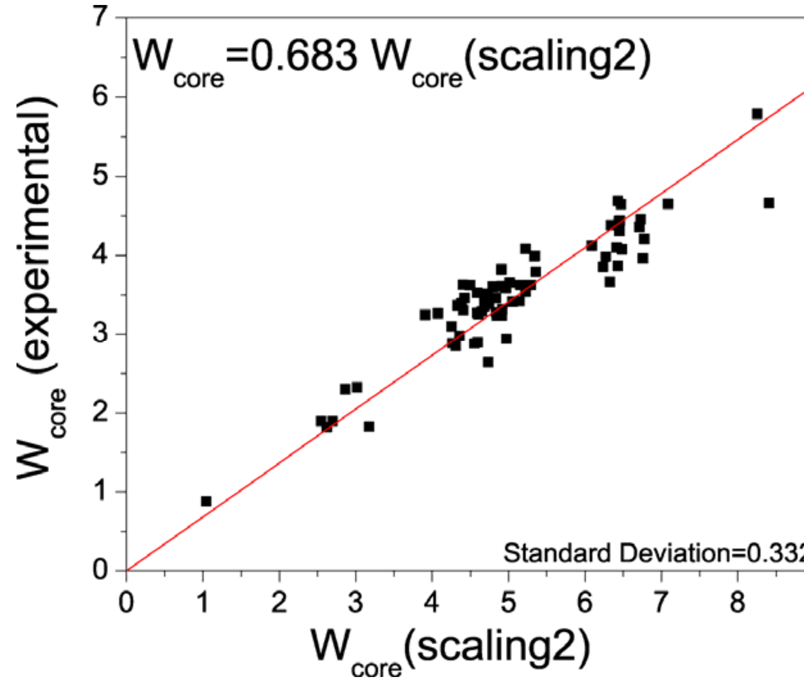


Comparison with "two-term" scaling

$W_{ped}(2)=RI^2\beta_{ped}=RI^2 6.43\,10^{-4}\rho^{*0.3}m^{0.2}F_q^{2.18}\varepsilon^{-2.67}k_\alpha^{2.27}$

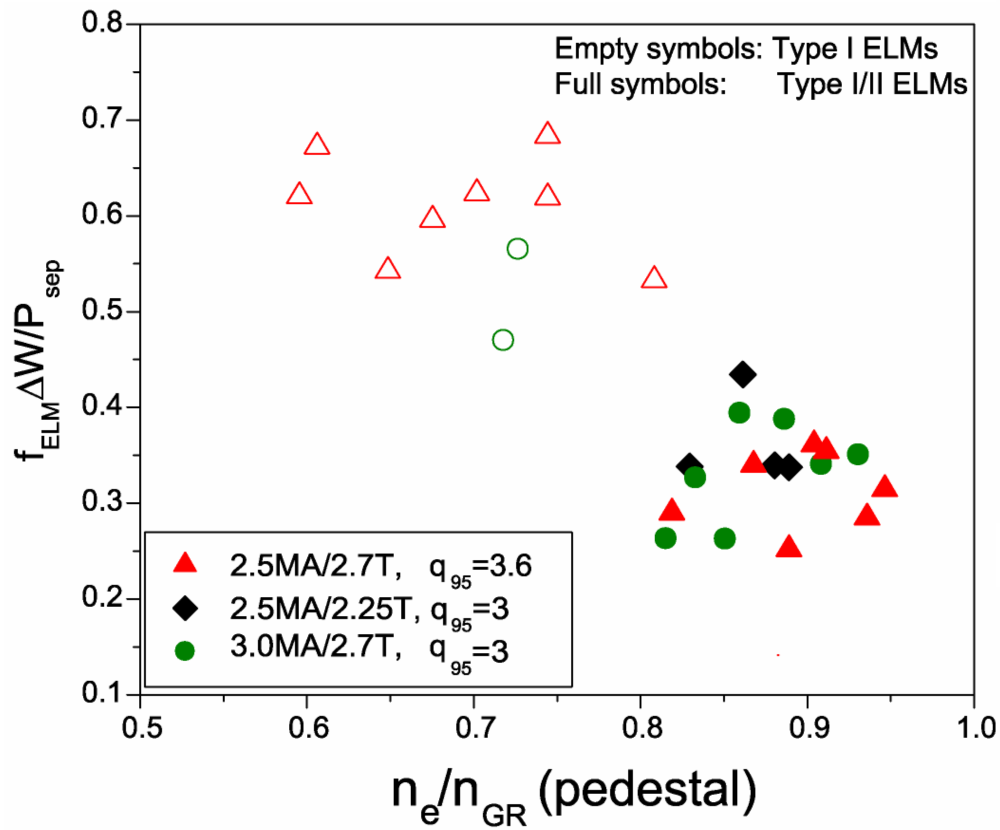
$W_{core}(2)=0.151I^{0.68}R^{2.32}P^{0.42}n^{0.59}B^{0.13}k^{-0.34}\varepsilon^{1.96}m^{0.34}$

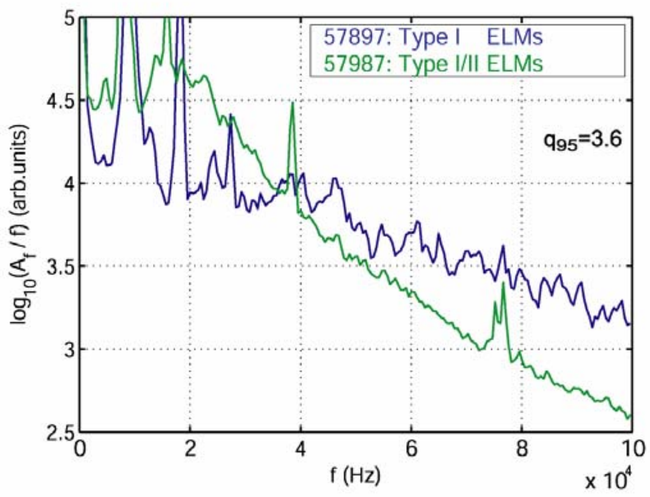


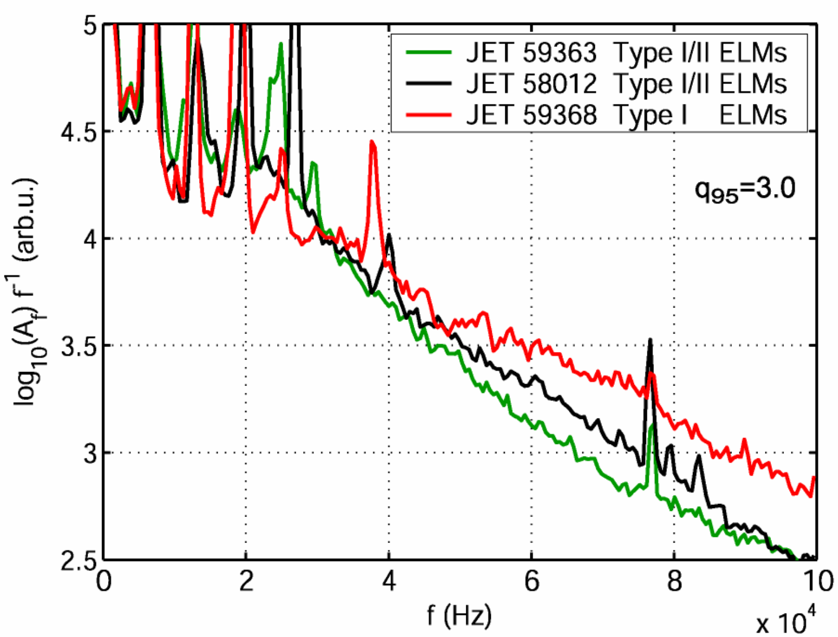


The two models behind the scaling are assuming two different energy loss mechanisms from the pedestal: the first scaling (1), assumes the transport in the steep edge gradient region to be dominated by thermal conduction, while the second (2) assumes ELM losses to be dominant and the pedestal pressure gradient to be determined by MHD limit (ballooning or peeling modes). The fitting of W_{core} gives similar standard deviation for both scaling. The vertical spread of the pedestal data is due to the density dependence of the pedestal pressure which is not accounted for in either scaling.

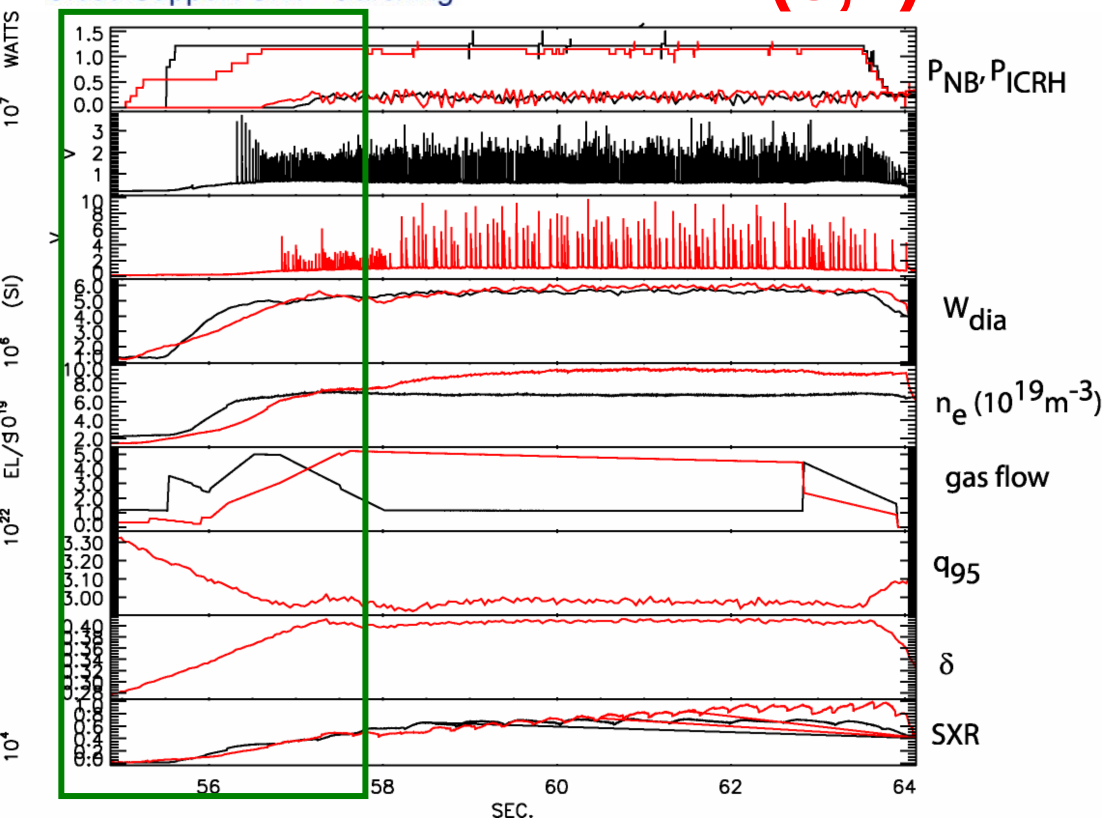
Type I/II ELMs

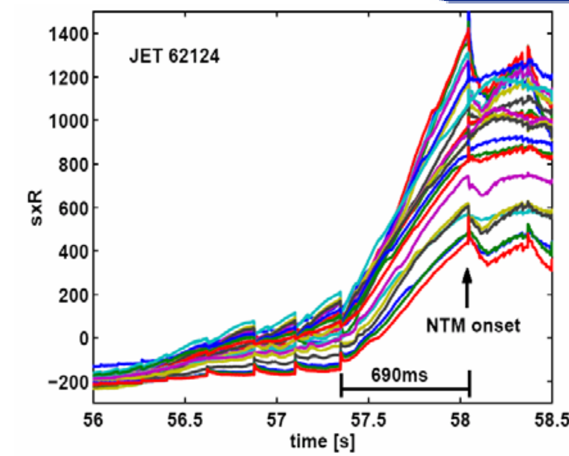


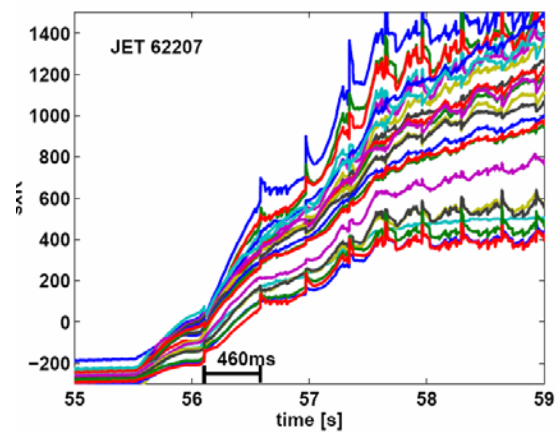




(3,2) NTMs







(3,2) NTM ⇒ triggered by a sawtooth crash in the initial phase of the additionally heated plasma near L-H transition⇒ density, input power and magnetic configuration are ramping up to their final value

NTM avoidance scenario ⇒ lower density phase with high power/ q_{95} and with lower δ ⇒ the final values of q_{95} and δ are reached only at high density.

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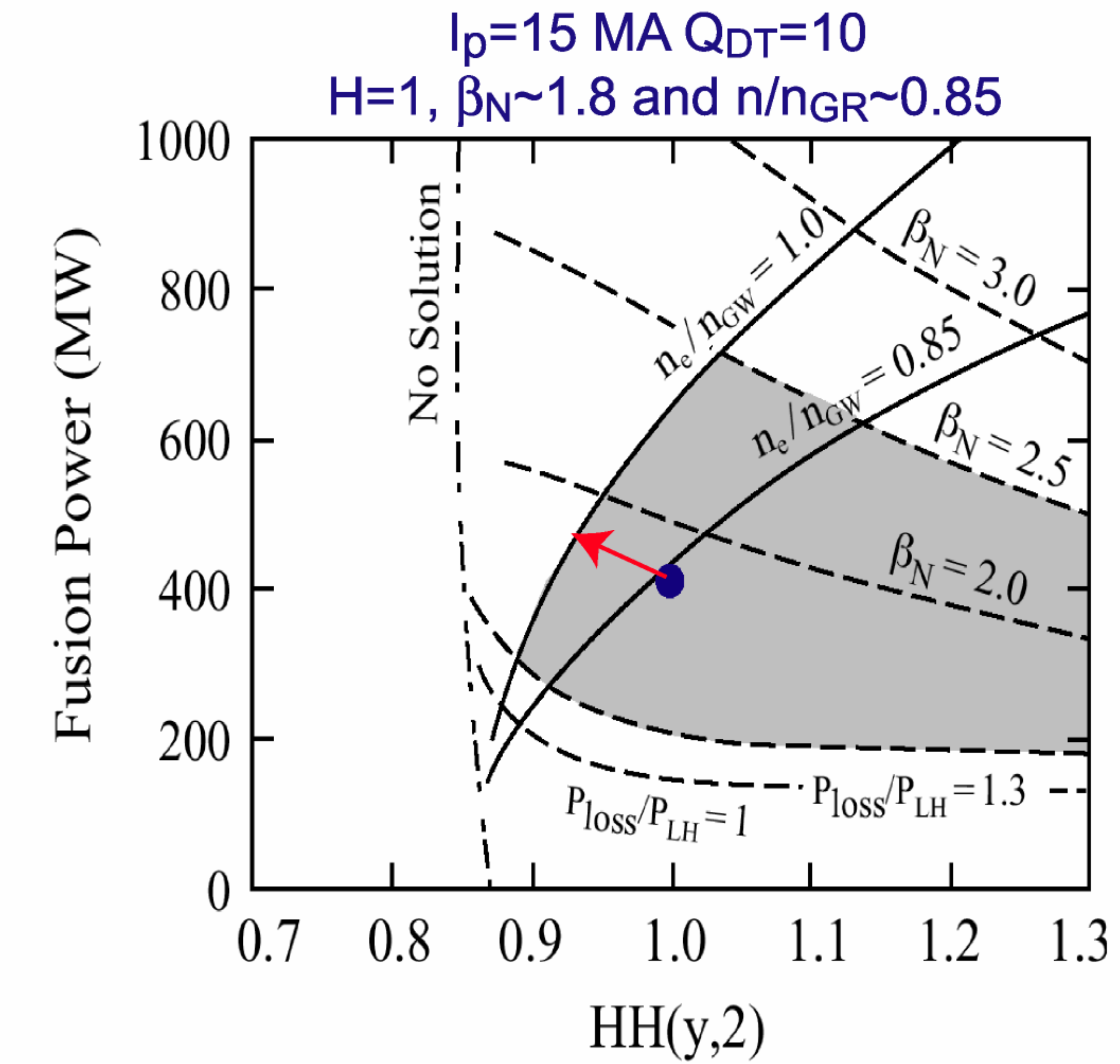
Ip=15 MA QDT=10
H=1, βN~1.8 and n/nGR~0.85
Fusion Power (MW)
1000
800
600
400
200
0
0.7
0.8
0.9
1.0
1.1
1.2
1.3
HH(y,2)
No Solution
ne/nGW = 1.0
ne/nGW = 0.85
βN = 3.0
βN = 2.5
βN = 2.0
Ploss/PLH = 1
Ploss/PLH = 1.3