Studies of the Pedestal Structure in JET with the ITER-like Wall

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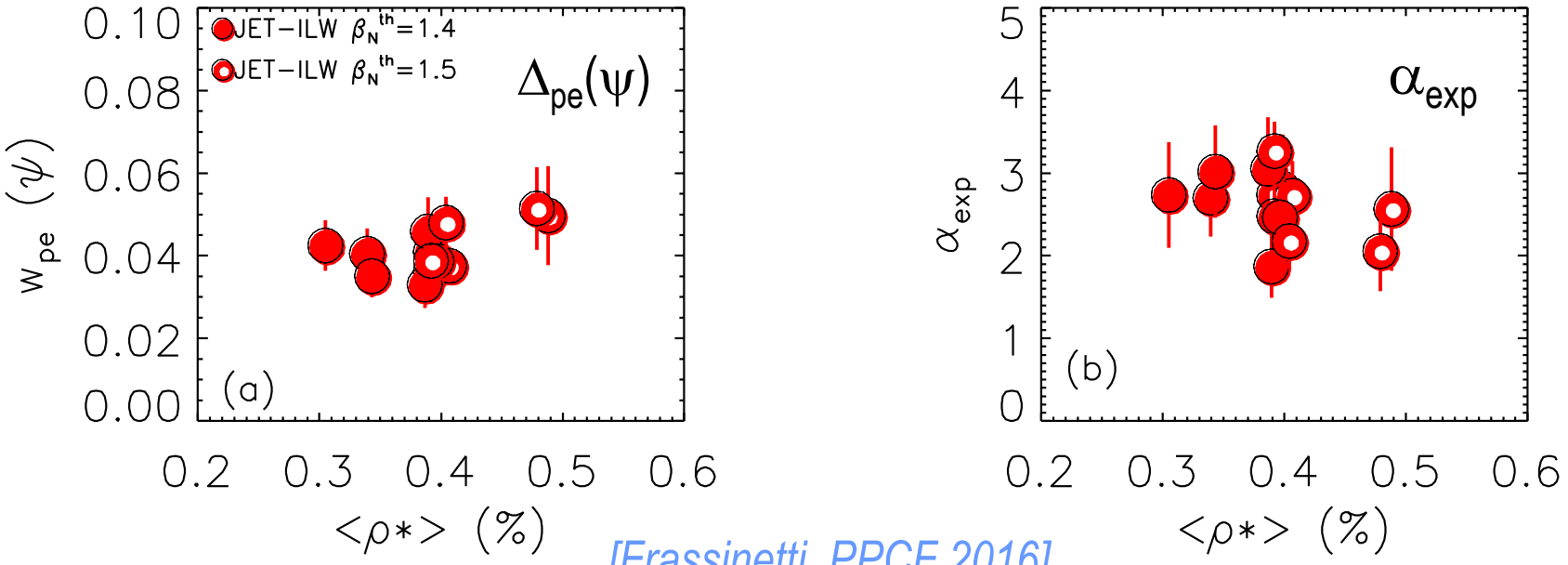
Outline

- Pedestal width scaling
- Pedestal evolution during the ELM cycle
- First results on isotope effects

Width & gradient independent of ρ*

Dimensionless ρ* scan



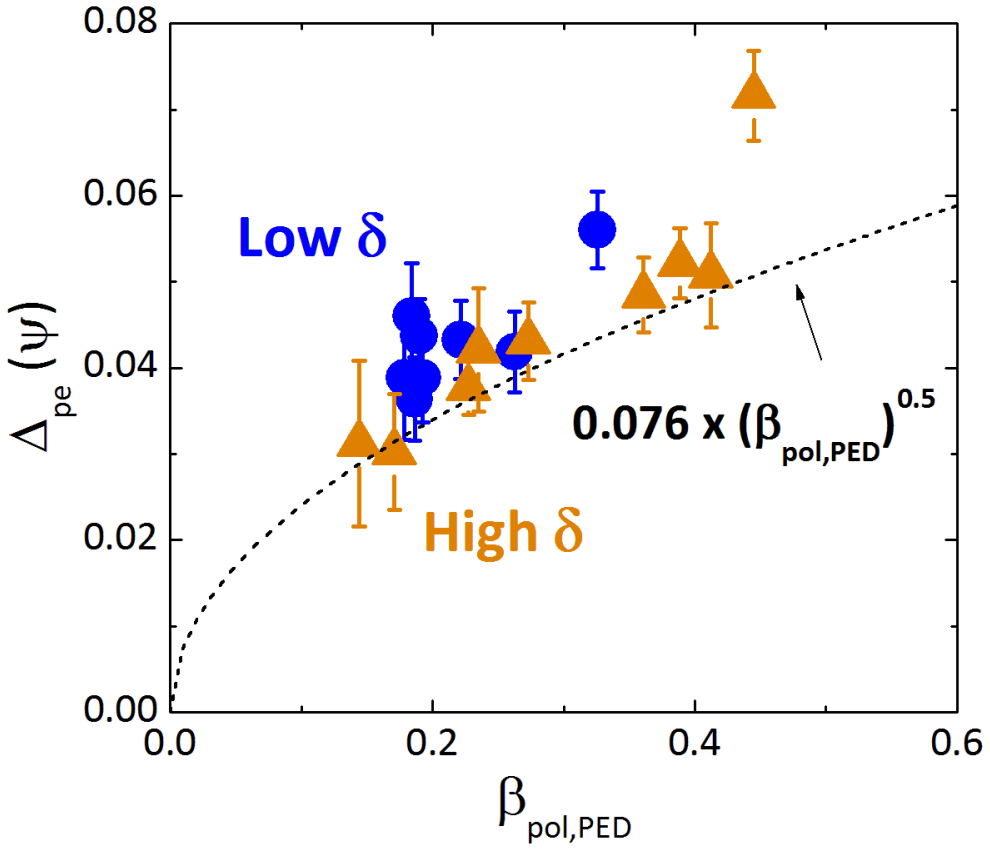
[Frassinetti, PPCF 2016]

- No sizeable dependence of $\Delta_{pe}(\psi)$ and α_{exp} on ρ*
- Consistent with JET-C/DIII-D and JT-60U

[Beurskens, PoP 2011] *[Urano, NF 2008]*

Pedestal width broadens with beta poloidal

- $\Delta_{pe}(\psi)$ broadens consistently with $\sqrt{\beta}_{pol,PED}$ dependence at low D_2 gas injection rates

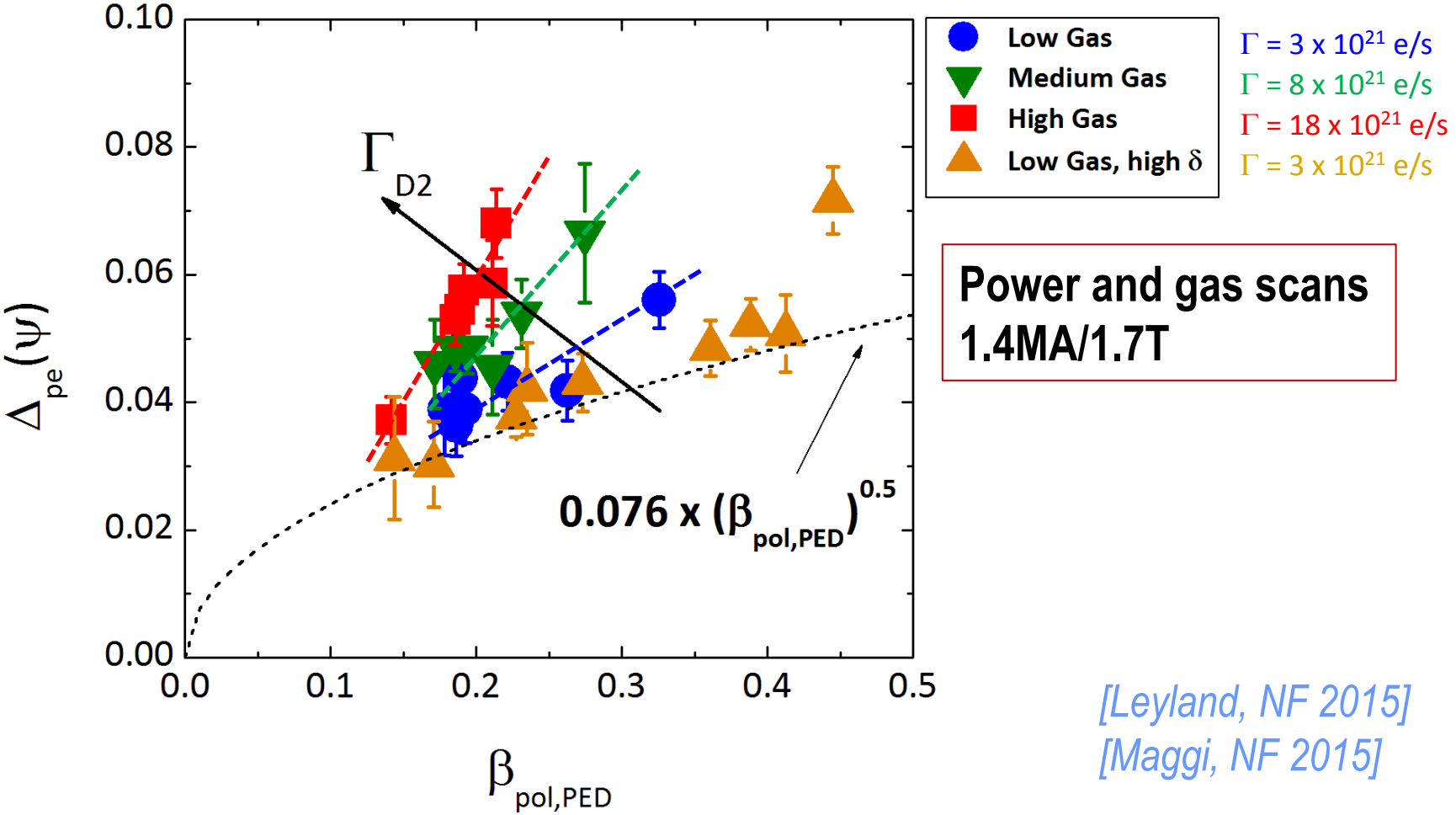


Power scans at low and high δ
1.4MA/1.7T
Low D_2 gas rate ~ 3 x 10^{21} e/s

[Maggi, NF 2015]

Pedestal width broadens with gas rate

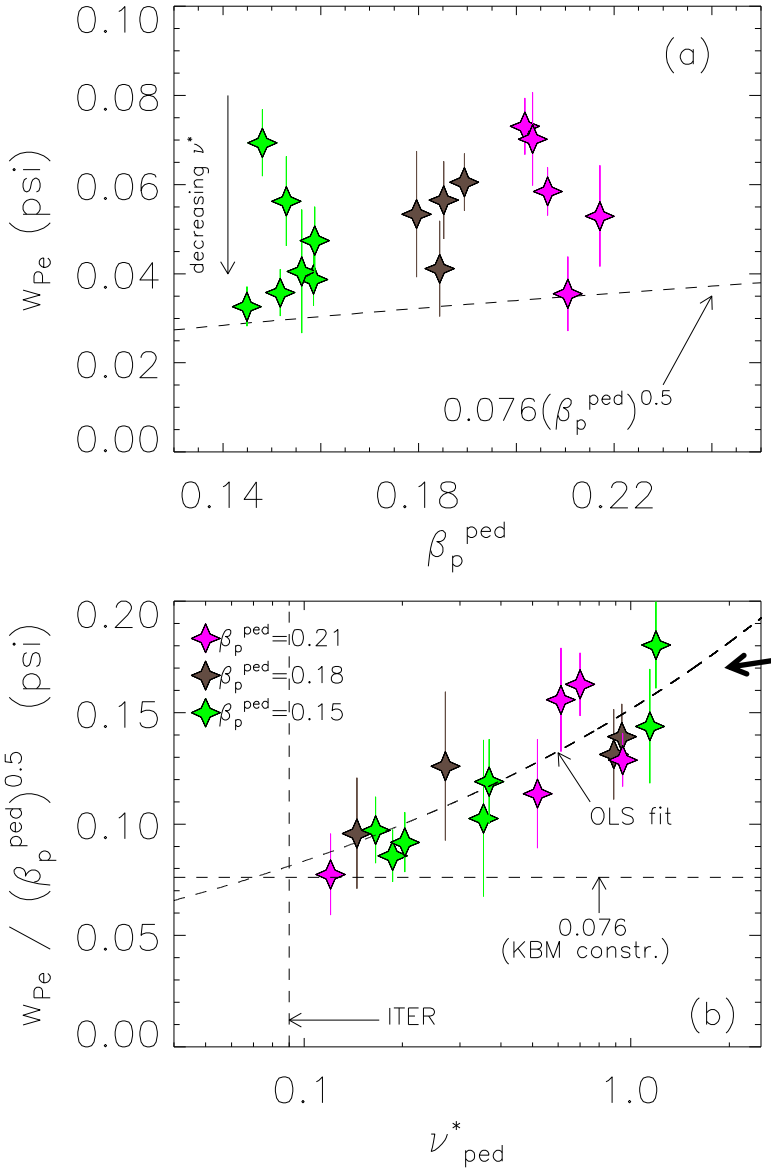
- $\Delta_{pe}(\psi)$ broadens with increasing D_2 gas rate at constant $\beta_{pol,PED}$



Power and gas scans
1.4MA/1.7T

[Leyland, NF 2015]
[Maggi, NF 2015]

$\Delta_{pe}(\psi)$ broadens with ν^* at constant $\beta_{pol,PED}$

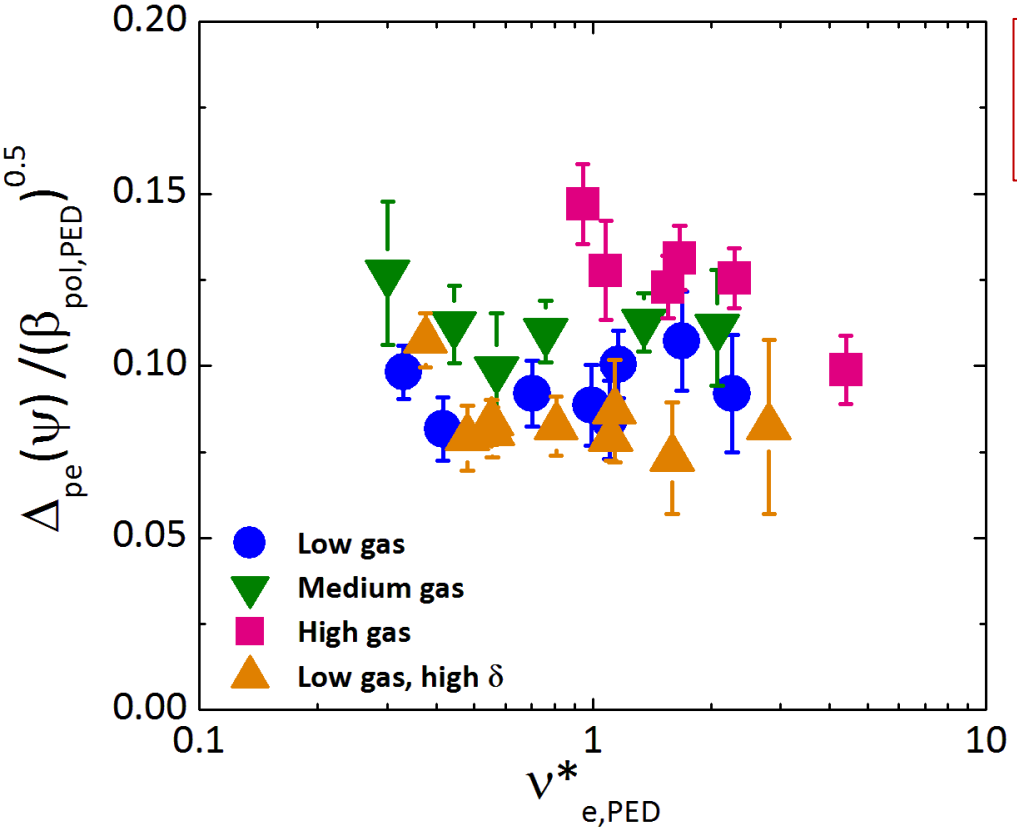


Dimensionless ν^* scan at low δ

[Frassinetti, NF 2016]

$$\Delta_{pe}(\psi) \sim (\beta_{pol,PED})^{0.5} (\nu^*_{PED})^{0.26}$$

Normalized Δ_{pe} broadens at constant ν^*



Power and gas scans
1.4MA/1.7T

$\Gamma = 3 \times 10^{21}$ e/s
$\Gamma = 8 \times 10^{21}$ e/s
$\Gamma = 18 \times 10^{21}$ e/s
$\Gamma = 3 \times 10^{21}$ e/s

- $\Delta_{pe}(\psi)/\sqrt{\beta_{pol,PED}}$ broadens with increasing D_2 gas rate at constant ν^*_{PED} → possible role of atomic physics

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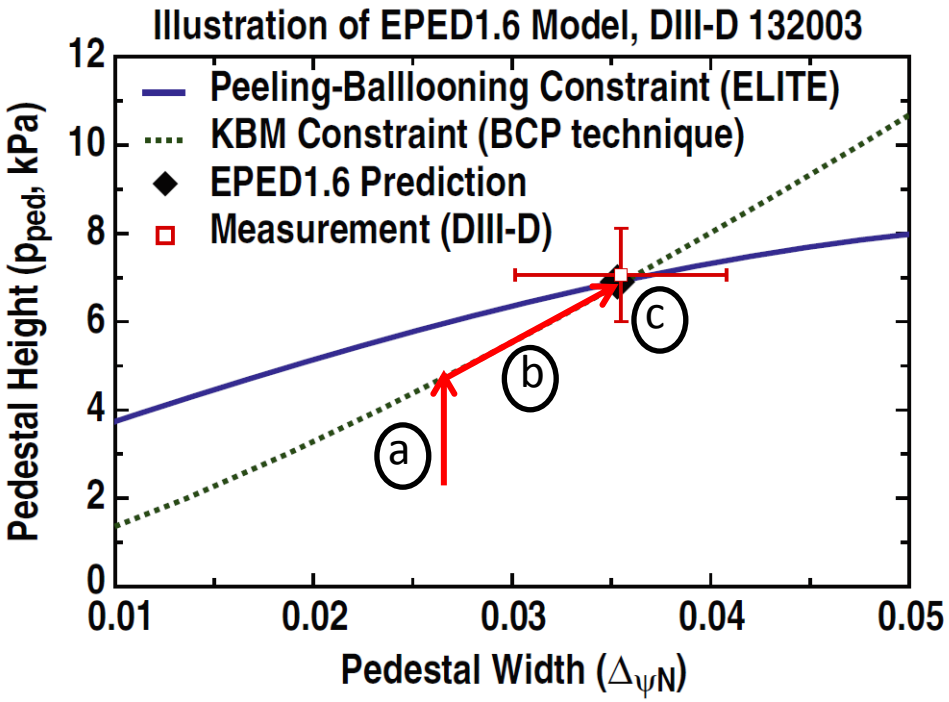
- Pedestal width scaling
- **Pedestal evolution during the ELM cycle**
- First results on isotope effects

EPED model assumption

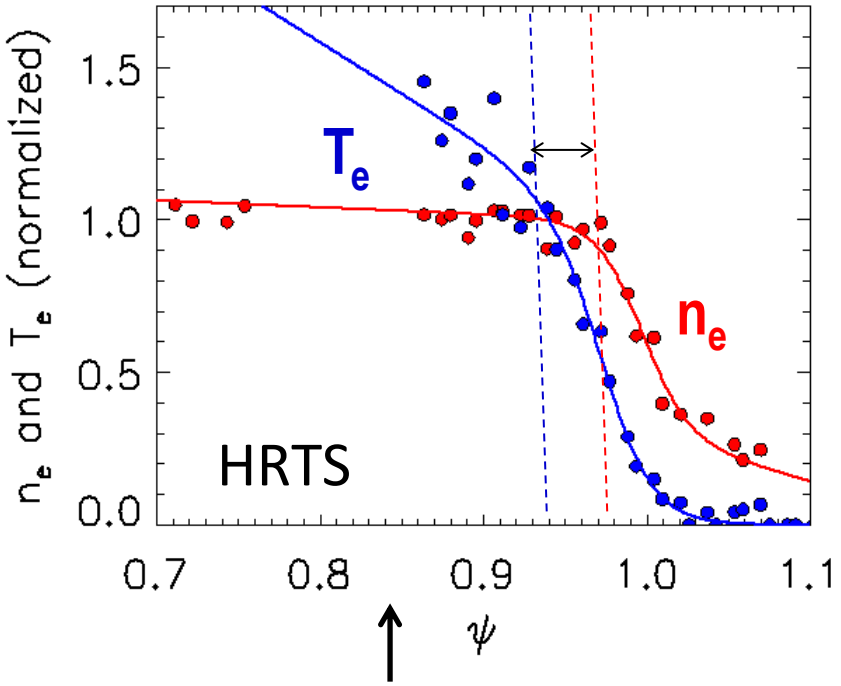
- **P-B constraint**
- **KBM constraint**

[Snyder, NF 2011]

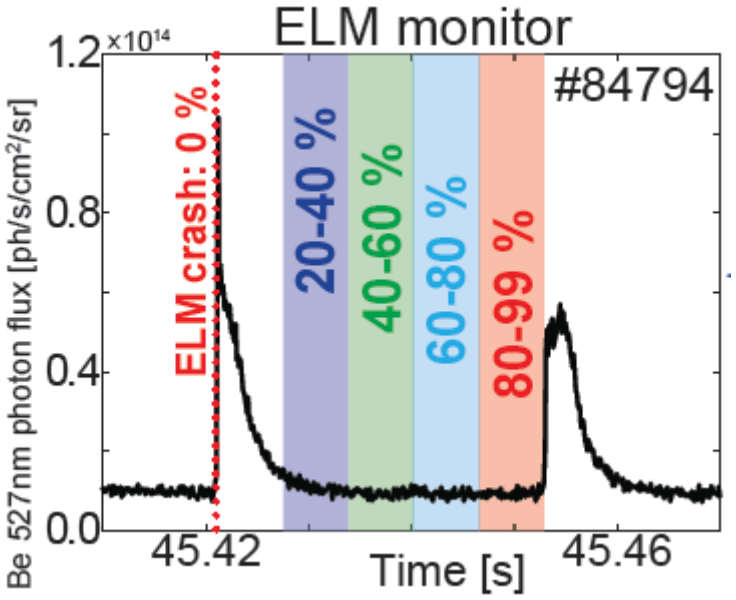


- **Pedestal pressure gradient grows unconstrained** **(a)**
- **KBM boundary is reached (proxy: $\Delta_p \sim \sqrt{\beta_{pol,PED}}$)**
- **p_{PED} can only increase further via widening of Δ_p at fixed ∇p** **(b)**
- **P-B boundary is reached → type I ELM is triggered** **(c)**

Profile analysis during the ELM cycle



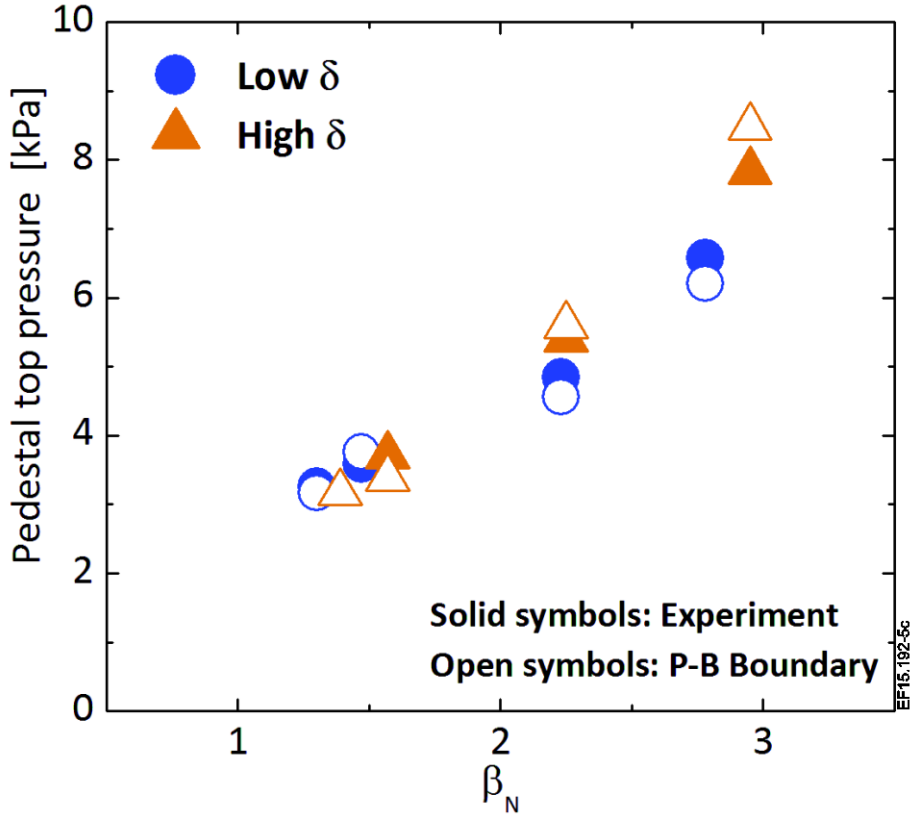
$T_{e,PED}$ and $n_{e,PED}$ typically *not* at same radial location



- **$p_{e,PED}$ and Δp_e from *mtanh* fit to experimental HRTS pressure data**

Low gas injection: P-B constraint satisfied

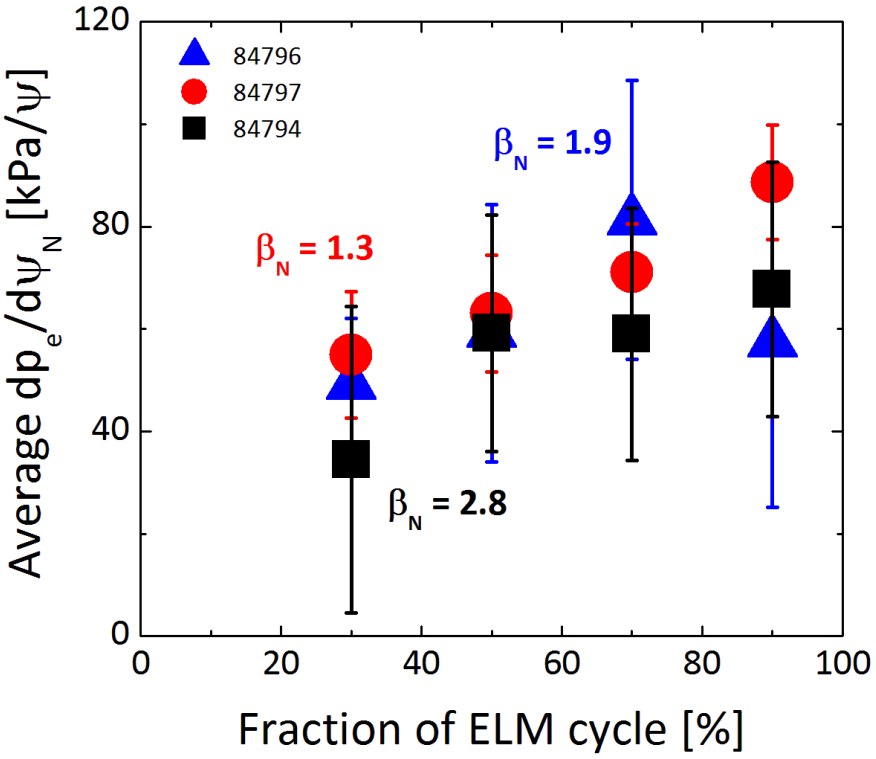
The pre-ELM edge stability (Helena/ELITE) is consistent with the ELMs being triggered by P-B modes, both at low and high β_N

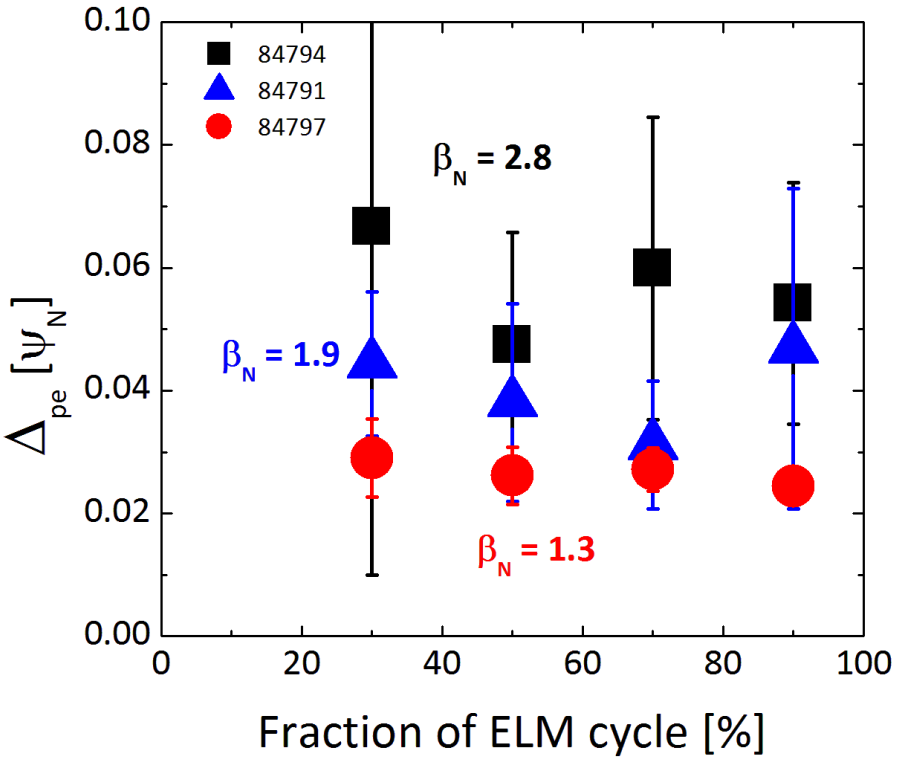


Power scans at low and high δ
1.4MA/1.7T
Low D_2 gas rate ~ 3 x 10^{21} e/s

[Challis, NF 2015]
[Maggi, NF 2015]
[Saarelma, PoP 2015]

$p_{e,PED}$ evolution at low gas injection





- Low β_N: $p_{e,PED}$ increases due to steepening of ∇p_e at ~ constant width

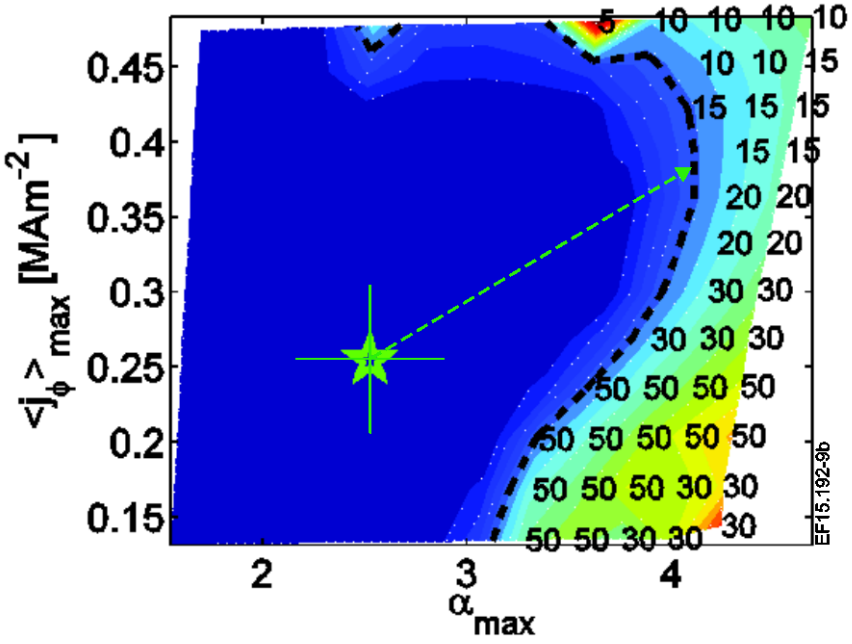
→ **not consistent with KBM constraint → not consistent with EPED**

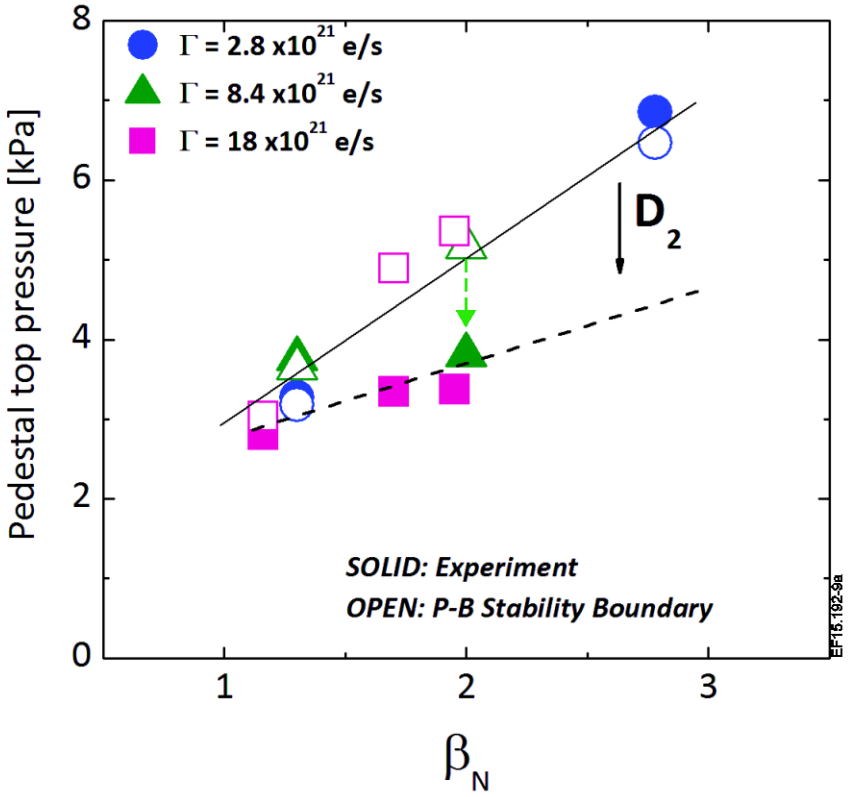
- High β_N: ∇p_e increases, then saturates & Δ_{pe} narrows then widens

→ **consistent with KBM constraint → consistent with EPED**

Power scans at high D_2 gas injection

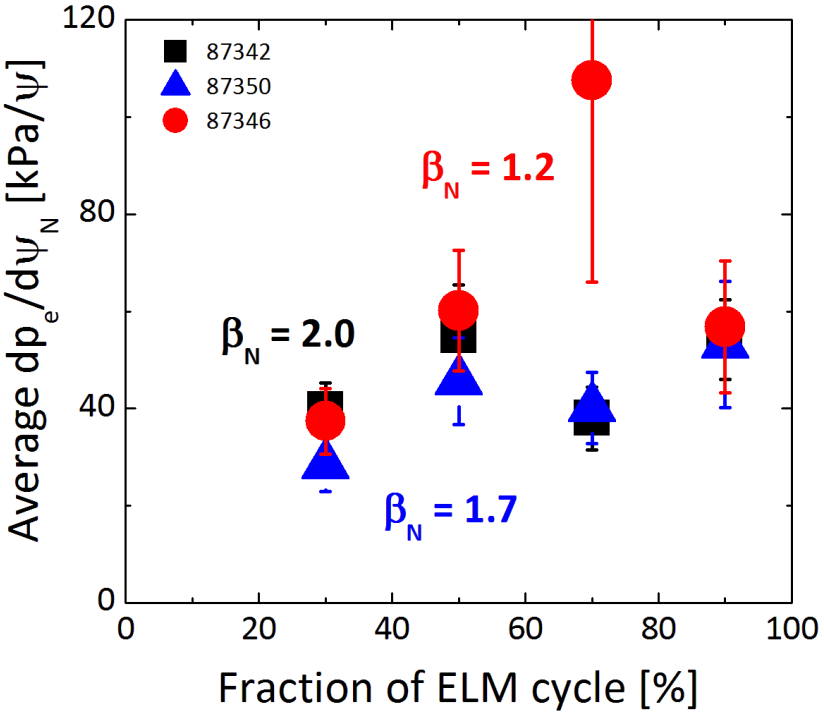
- **P-B constraint satisfied at low β_N**
- **P-B constraint not satisfied at higher β_N: missing physics for the ELM trigger?**

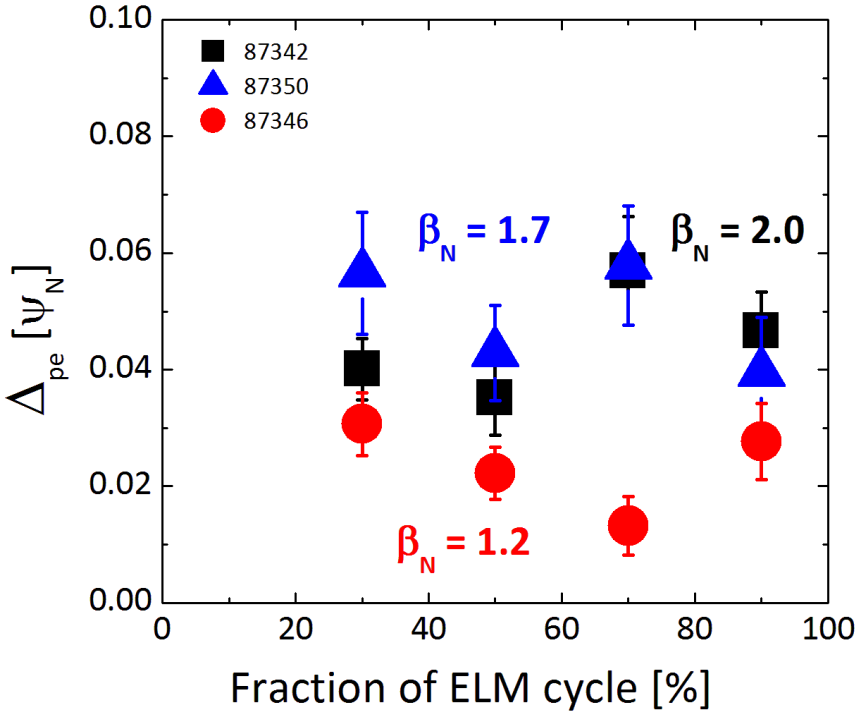




[Maggi, NF 2015]

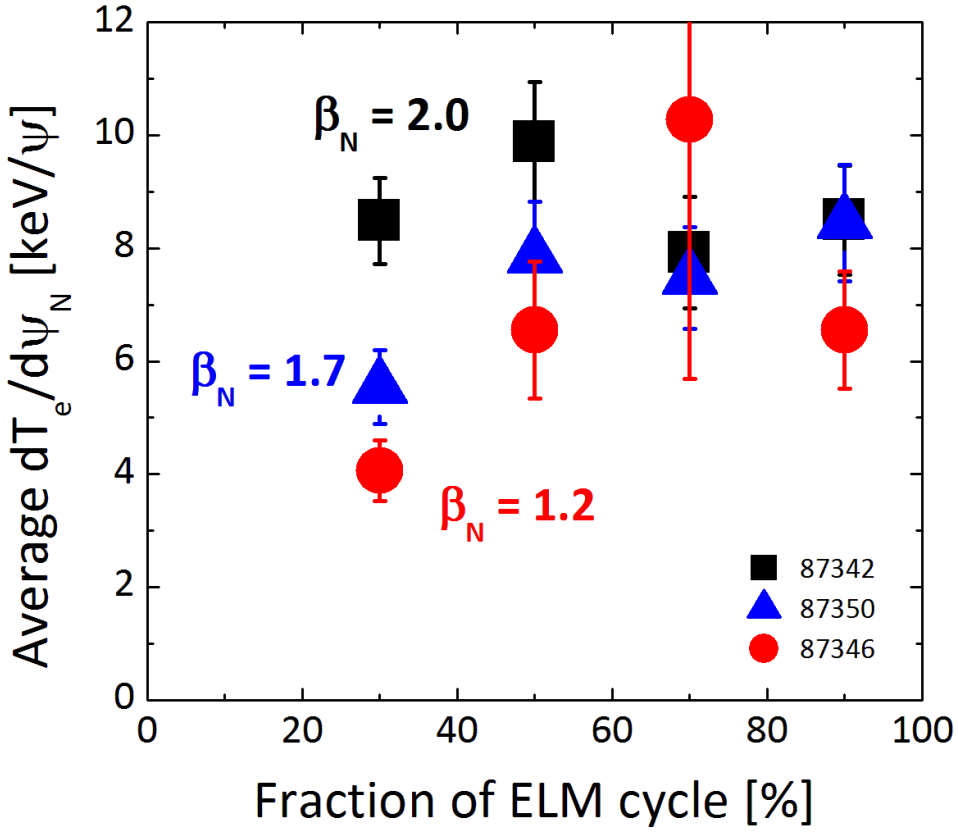
$p_{e,PED}$ evolution at high gas injection





- Low β_N: width narrows & gradient steepens, then Δ_p broadens & ∇_p reduces → **qualitatively consistent with KBM constraint + P-B constraint satisfied → consistent with EPED**
- High β_N: Δ_{pe} ~ constant and ∇_{pe} first increases, then ~ saturates → **qualitatively consistent with KBM constraint + P-B constraint not satisfied → not consistent with EPED**

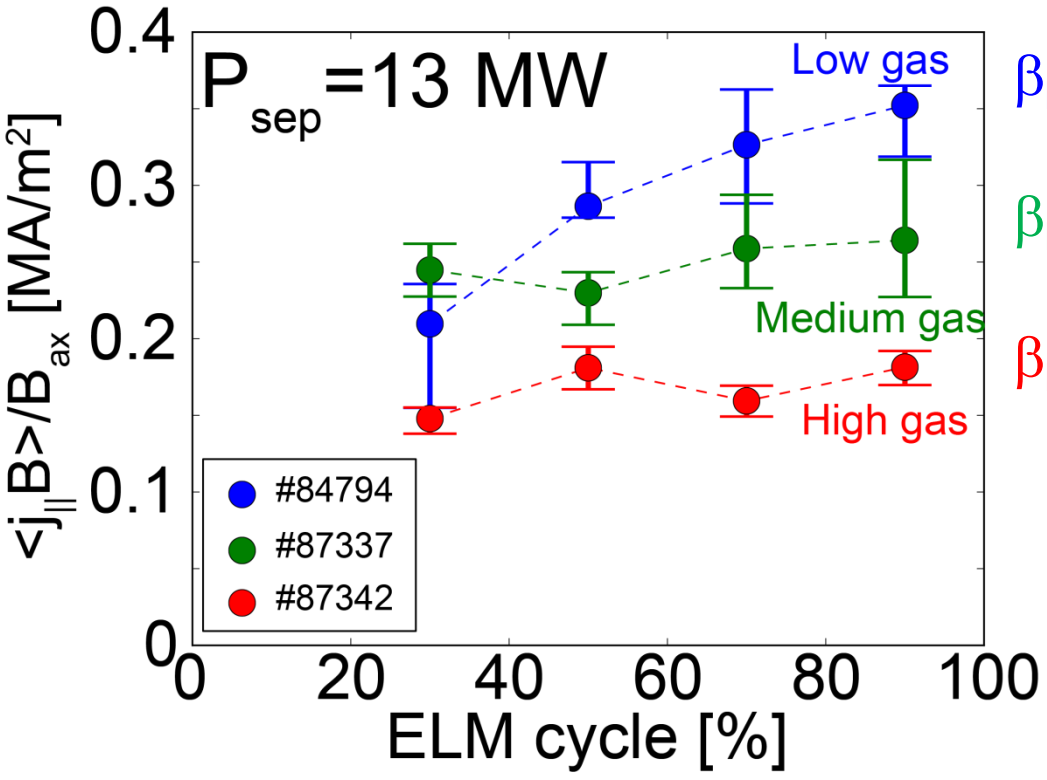
Temperature gradient saturates at high gas rate



- ∇_{Te} **initially increases, then clamps half way of ELM cycle**
- → suggestive of instabilities limiting growth of $T_{e,ped}$: MTMs?

See e.g exploratory GK study by [Hatch, NF 2016]

Increasing neutral gas (ν^*) reduces j_{BS}



[Horvath, EPS 2016]

- **Avoiding saturation of ∇T_e during the ELM cycle is crucial to maximizing pedestal performance**

Outline

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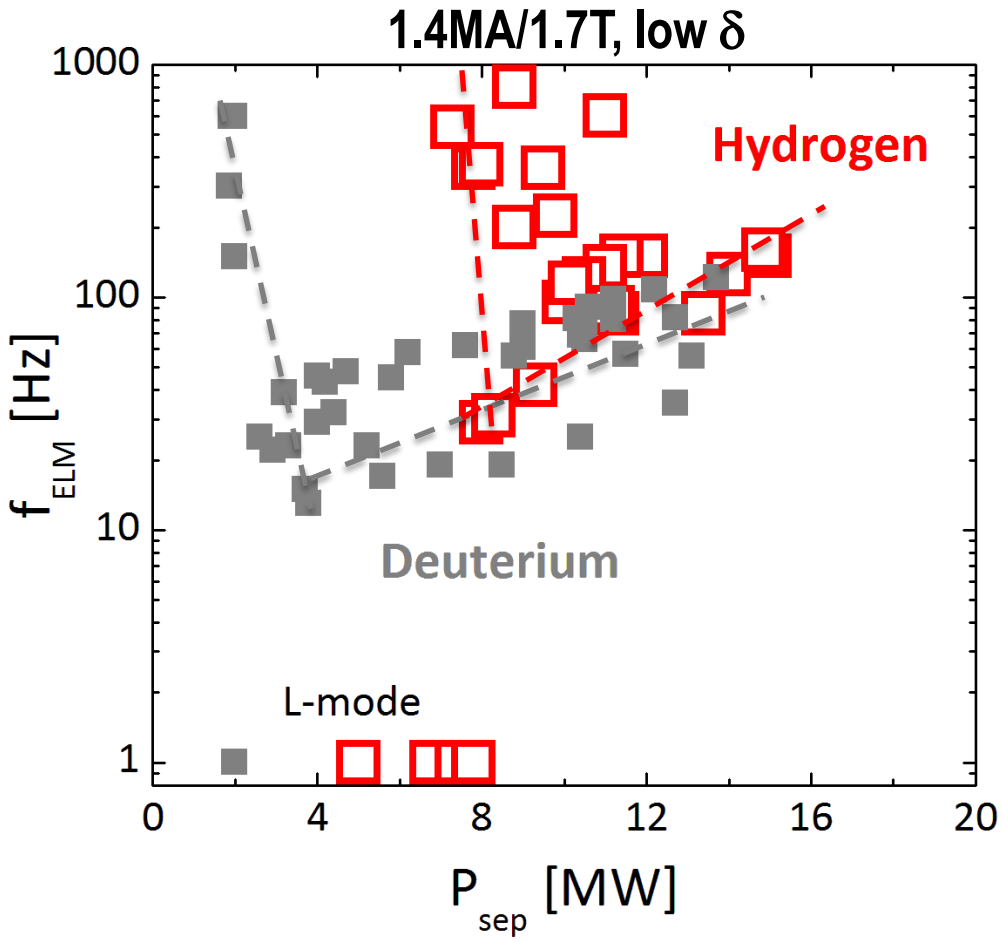
- Pedestal evolution during the ELM cycle
- **First results on isotope effects**

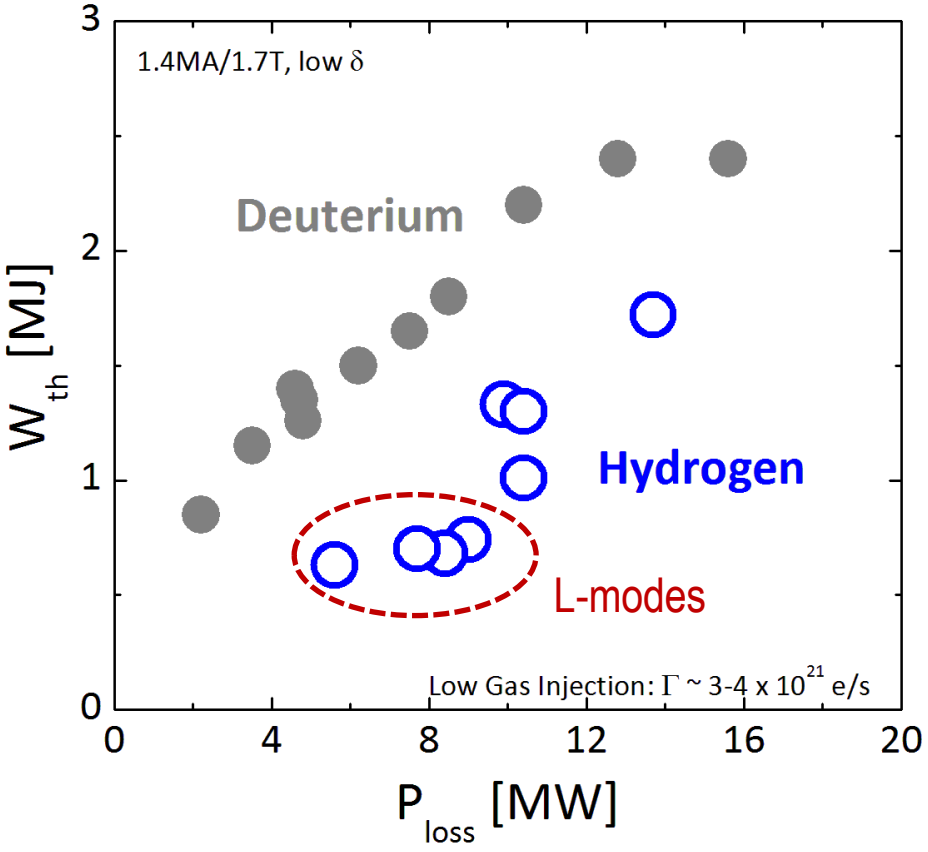
Isotope effect of type I / type III ELM threshold



Power and gas scans

- **Power threshold for type I ELMs ~ doubles from D to H**

Isotope effect of energy confinement

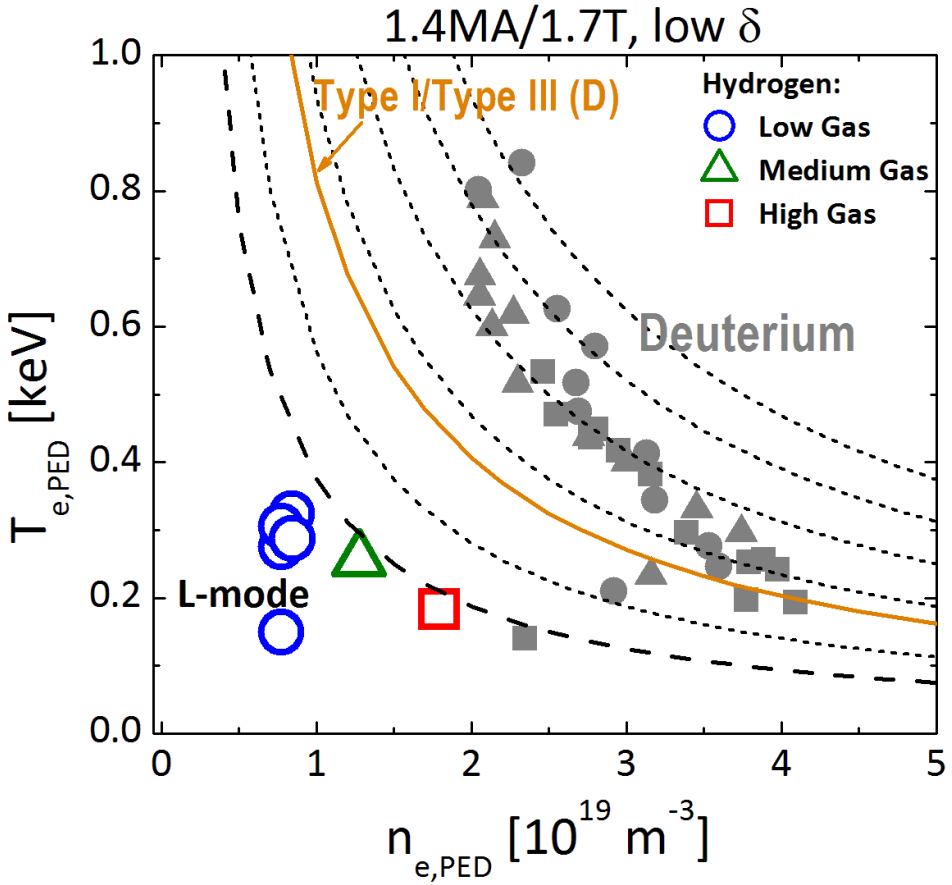


Power scans at same gas injection rate

Preliminary, assuming $T_i = T_e$

- **Lower energy confinement in H than in D**

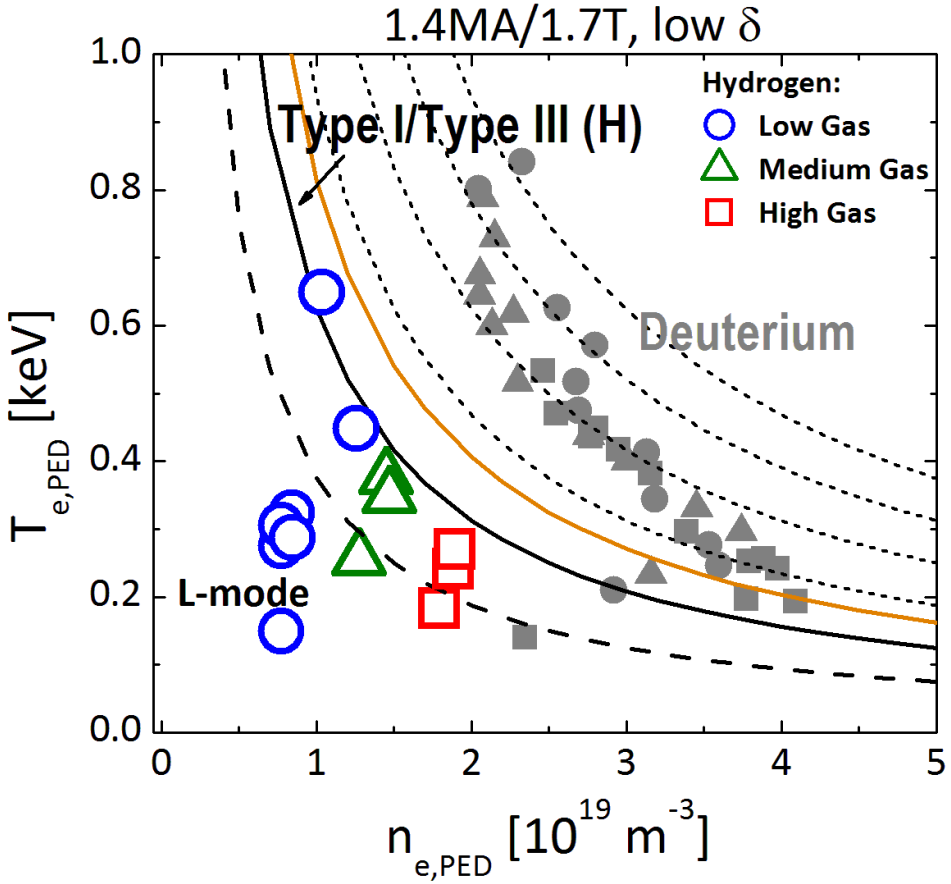
Edge T_e - n_e diagram



Γ = 3-4 x 10^{21} e/s
Γ = 8 x 10^{21} e/s
Γ = 16 x 10^{21} e/s

- Weak fuelling efficiency in D type I ELMy H-modes
- $p_{e,PED}$ decreases in D as gas rate ↑ and power ↓

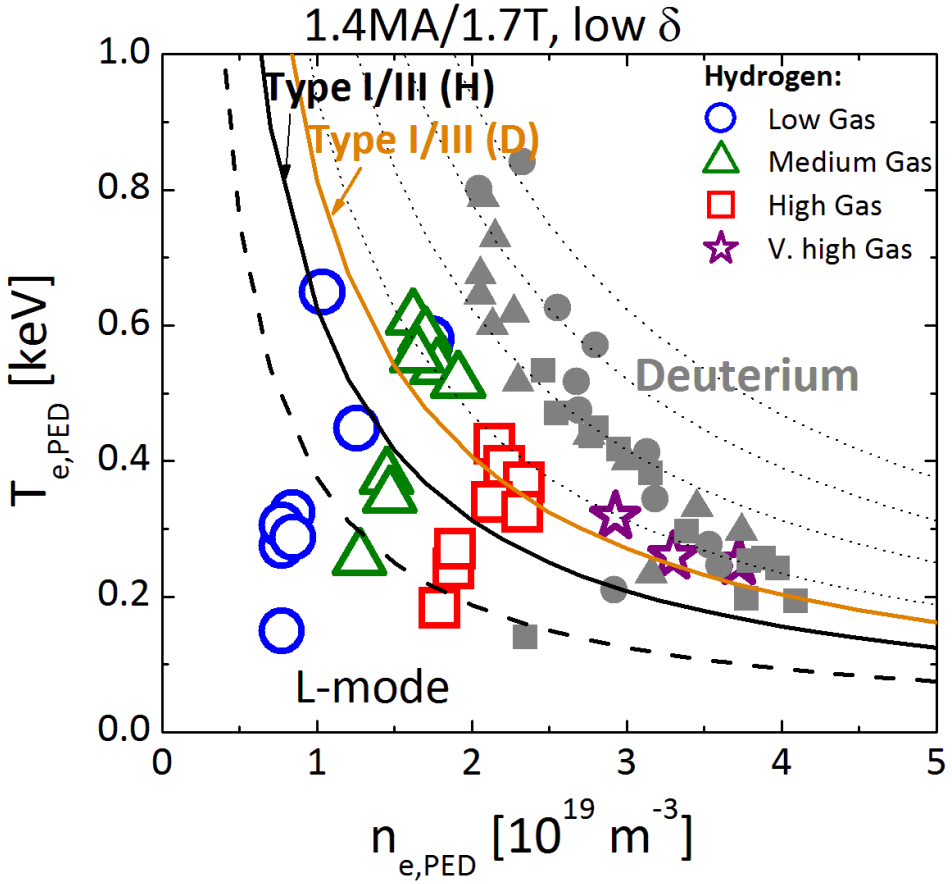
Hydrogen type III ELMy pedestals



Γ = 3-4 x 10^{21} e/s
Γ = 8 x 10^{21} e/s
Γ = 16 x 10^{21} e/s

- **Lower density in H than in D**

H vs D type I ELMy pedestals



Γ = 3-4 x 10^{21} e/s
Γ = 8 x 10^{21} e/s
Γ = 18 x 10^{21} e/s
Γ = 3.5 → 7.5 x 10^{22} e/s

- **Lower density and stronger fuelling efficiency in H than in D**
- **Hydrogen type I ELMy pedestals evolve at similar $p_{e,PED}$**

Conclusions

- Pedestal width is independent of ρ^*, widens with $\sqrt{\beta}_{pol,PED}$ at low gas injection and with ν^*/gas rate at constant $\beta_{pol,PED}$
- Inter-ELM pedestal evolution depends on discharge conditions & not always consistent with EPED paradigm
- Avoiding saturation of ∇Te as pedestal re-builds between ELMs is crucial for maximizing pedestal performance
- Edge GK analyses and experimental identification of nature of pedestal turbulence in JET-ILW are needed
- Strong isotope effect in energy and particle confinement