EFDA JET

EX/3-3: Pedestal Confinement and Stability in JET-ILW ELMy H-modes

CF Maggi

Max Planck Institut für Plasmaphysik, Garching, Germany

25th IAEA FEC Conference, St Petersburg, Russian Federation, 2014

Acknowledgements

S. Saarelma[1], M. Beurskens[1], C. Challis[1], I. Chapman[1], E. de la Luna[2], J. Flanagan[1], L. Frassinetti[3], C. Giroud[1], J. Hobirk[4], E. Joffrin[5], M. Leyland[6], P. Lomas[1], C. Lowry[7], G. Maddison[1], J. Mailloux[1], I. Nunes[8], F. Rimini[1], J. Simpson[1], A.C.C. Sips[7], H. Urano[9] and JET Contributors*

JET-EFDA, Culham Science Centre, Abingdon, OX14 3DB, UK

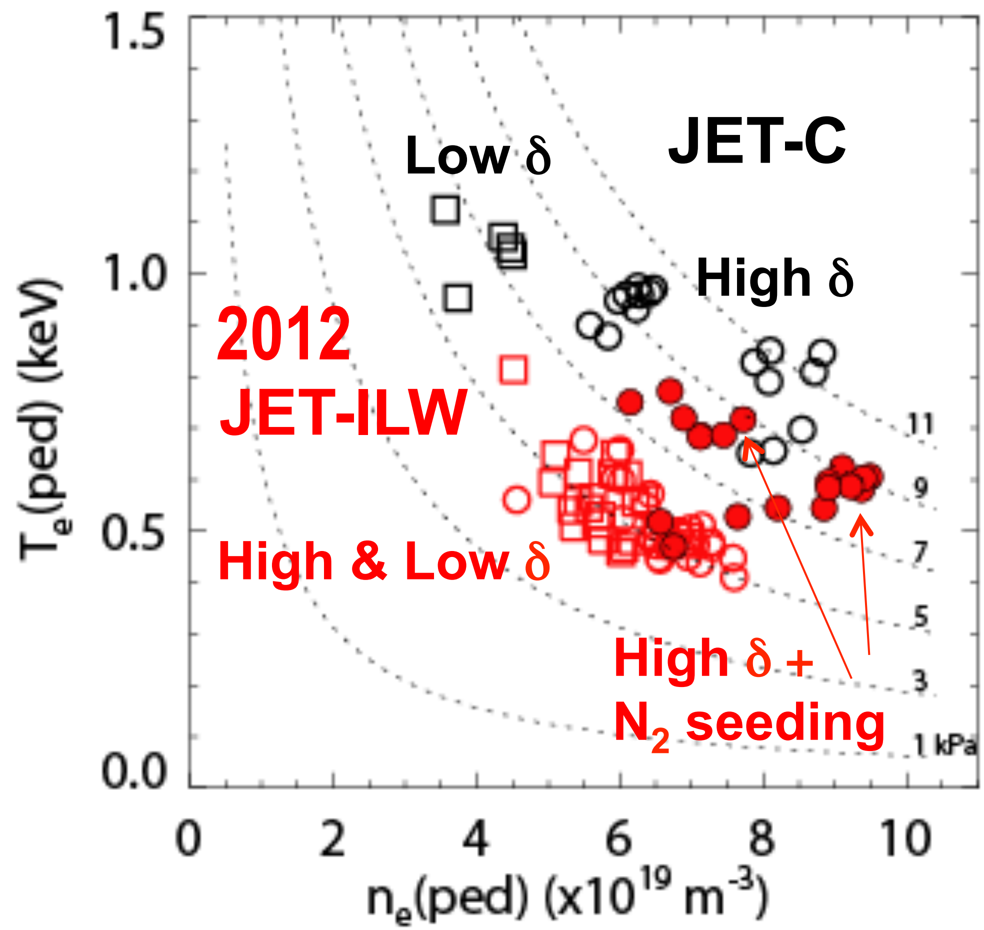
[1]CCFE, Culham Science Centre, Abingdon OX14 3DB, UK
[2]Asociacion CIEMAT, Madrid, Spain
[3]Association VR, Fusion Plasma Physics, KTH, SE-10044 Stockholm, Sweden
[4]Max Planck Institut für Plasmaphysik, Boltzmannstr. 2, 85748 Garching, Germany
[5]CEA, IRFM, F-13108 Saint-Paul-lez-Durance, France
[6]York Plasma Institute, Department of Physics, University of York, York YO10 5DD, UK
[7]European Commission, B1049 Brussels, Belgium
[8]Associação IST, Instituto Superior Técnico, Av Rovisco Pais, 1049-001 Lisbon, Portugal
[9]Japan Atomic Energy Agency, 801-1 Muko-yama, Naka, Ibaraki 311-0193, Japan

**See the Appendix of F. Romanelli et al., Proc. 25th IAEA FEC 2014, St Petersburg, Russian Federation*

Confinement reduction in pedestal

In JET-ILW, H-mode operation needs to be compatible with W control

- Lower $T_{e,PED}$ in initial phase of JET-ILW at all densities
- → Confinement loss is dominantly in pedestal
- N_2 seeding in high δ H-modes allows recovery of $T_{e,PED}$ to values approaching JET-C



[Beurskens, PPCF 2013]
[Giroud, Nucl. Fusion 2013]

(2.4-2.6 MA / 2.3-2.7 T, P_{NBI} = 12-16 MW), β_N ~ 1.2

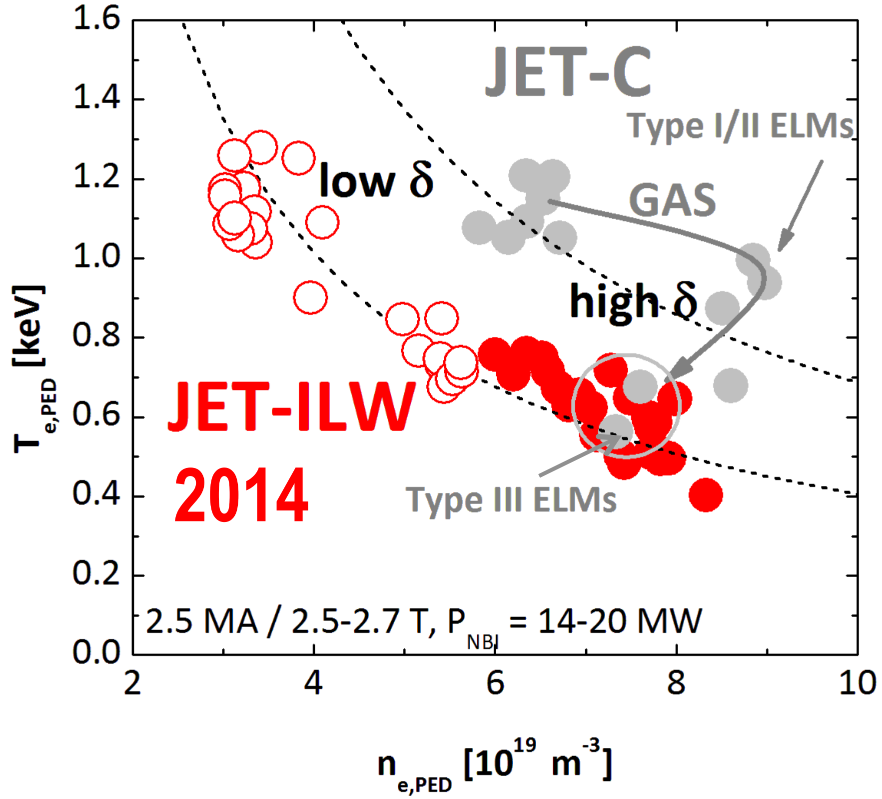
Similar p_{PED} at low and high δ in JET-ILW at low β_N (~ 1.2)

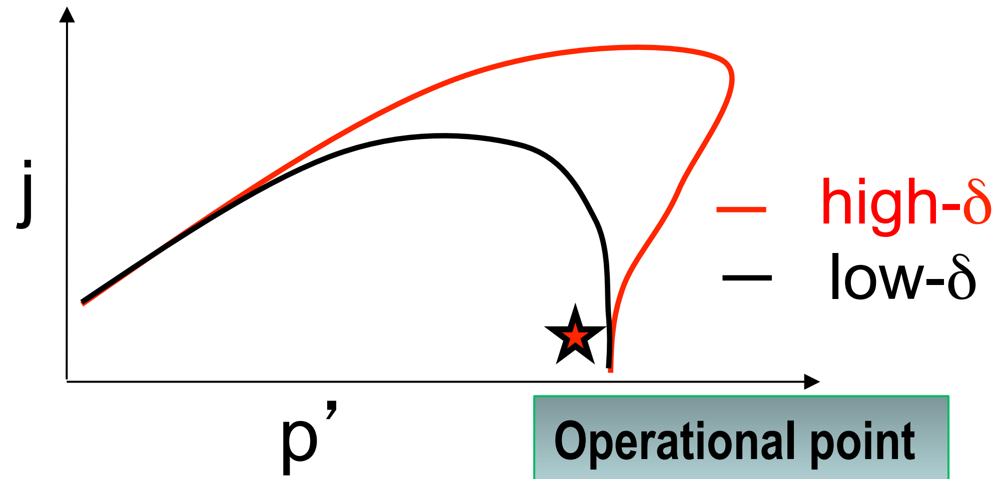
Outline

Experiments in 2013-2014 with the JET-ILW have investigated the pedestal confinement and stability with respect to:

- Triangularity
- Beta
- Neutrals (D and low-Z impurities)

Triangularity





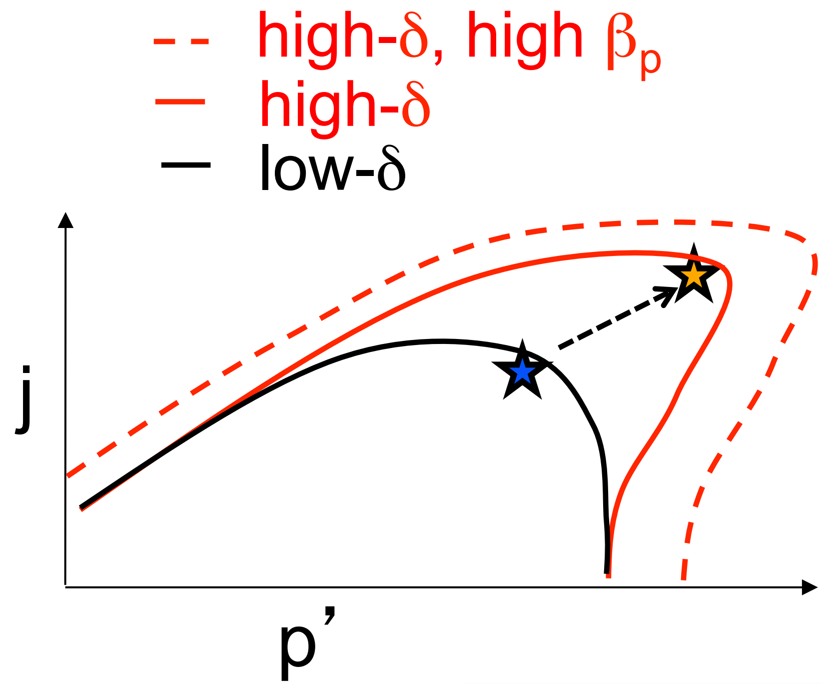
Operational point at low $T_{e,PED}$

de la Luna, EX/P5-29

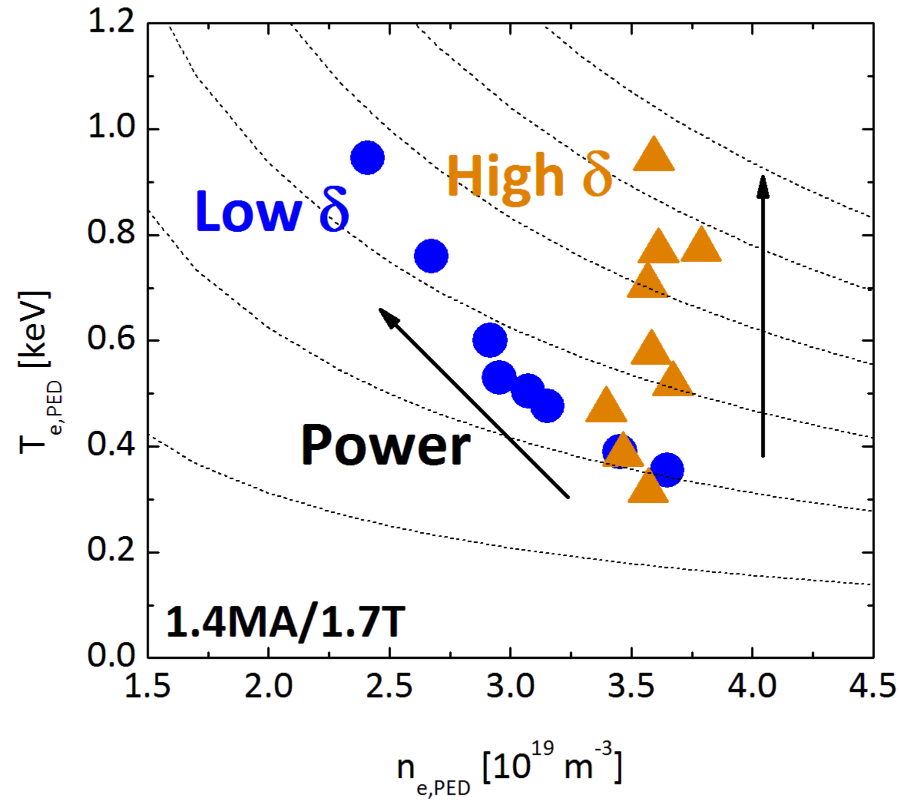
- Lower $T_{e,PED}$ → Higher ν^*_{PED} → lower bootstrap current
- → plasma shaping barely affects the achievable pedestal height
- Similar p_{PED} at low and high δ

Triangularity alone does not recover pedestal height

Pedestal pressure and beta



Low D_2 gas injection

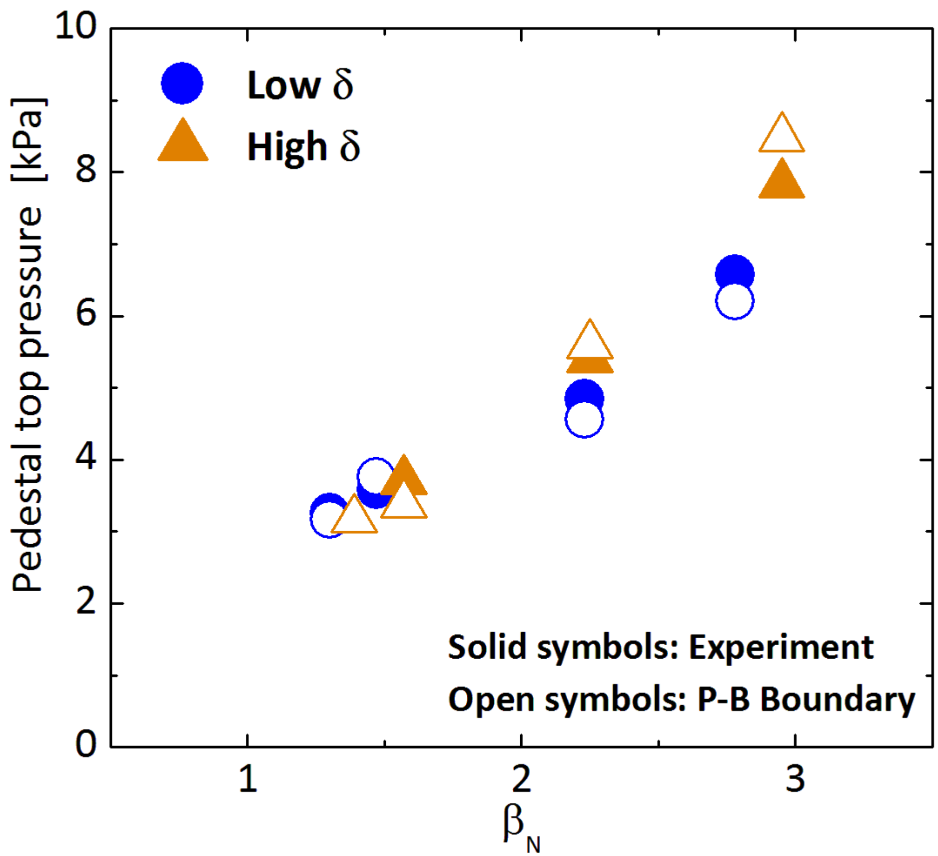


- Increasing power/beta increases p_{PED} <u>both at low and high δ</u>
- At low beta similar pedestal pressures
- At high δ, stronger increase in p_{PED} with power at constant density

Challis, EX/9-3

Pedestal stability consistent with P-B

- Increasing core pressure stabilises ballooning modes due to Shafranov shift, which raises P-B boundary



- Pedestals limited by intermediate-*n* P-B instabilities before type I ELM crash, both at low and high δ

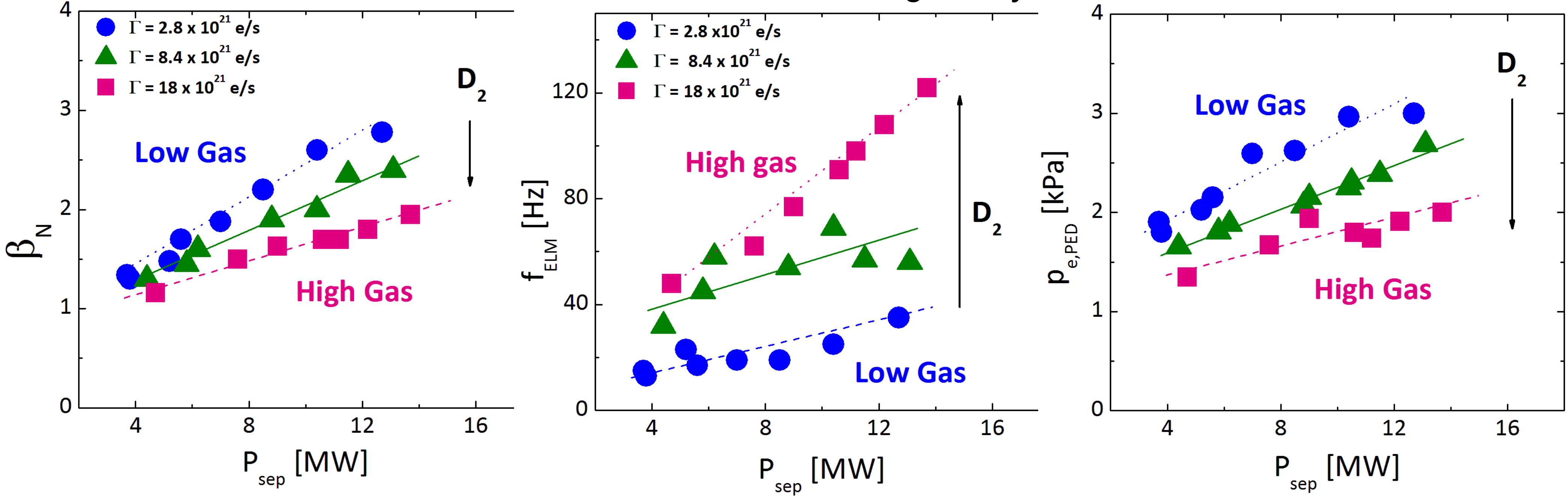
Low D_2 gas injection

Challis, EX/9-3

Power scans at higher gas rates

- Higher D_2 gas rate, typical of JET-ILW steady H-modes

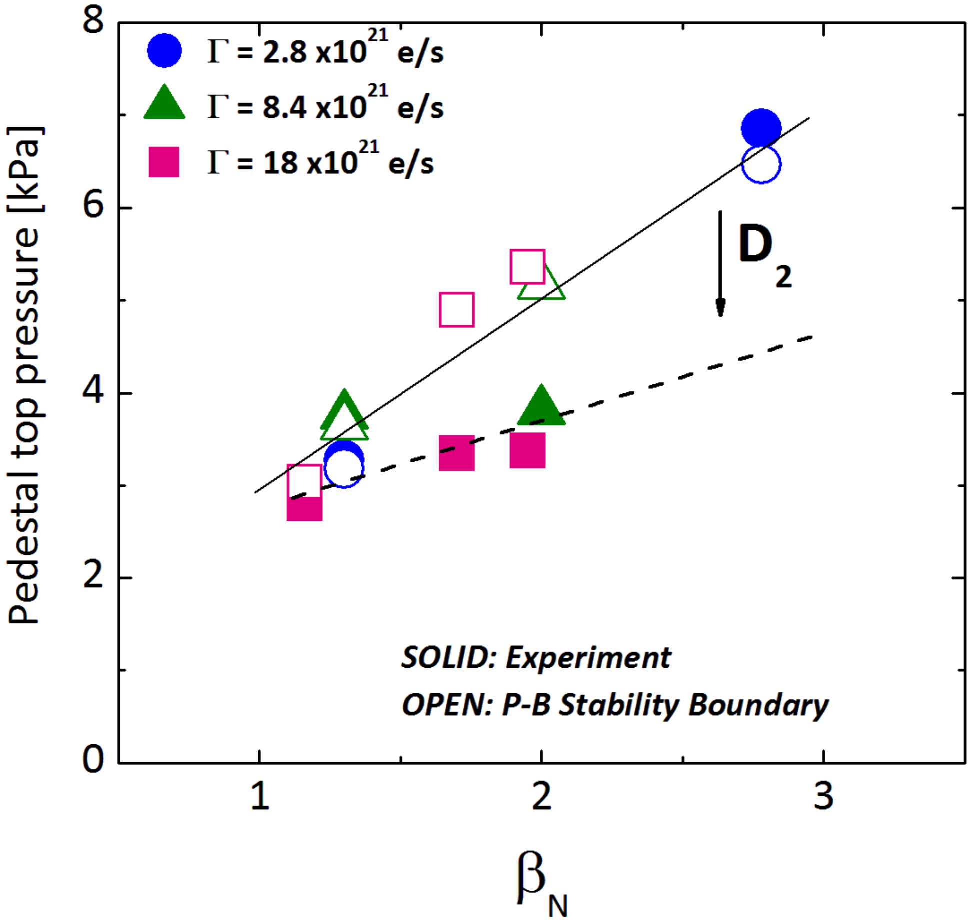
1.4MA /1.7T, Low triangularity



(*P_{sep} = P_{heat} – $P_{rad,bulk}$*)

- Lower β_N at higher D_2 gas rate
- Type I ELMs
- Lower p_{PED} at larger gas rate

Peeling-Ballooning stability



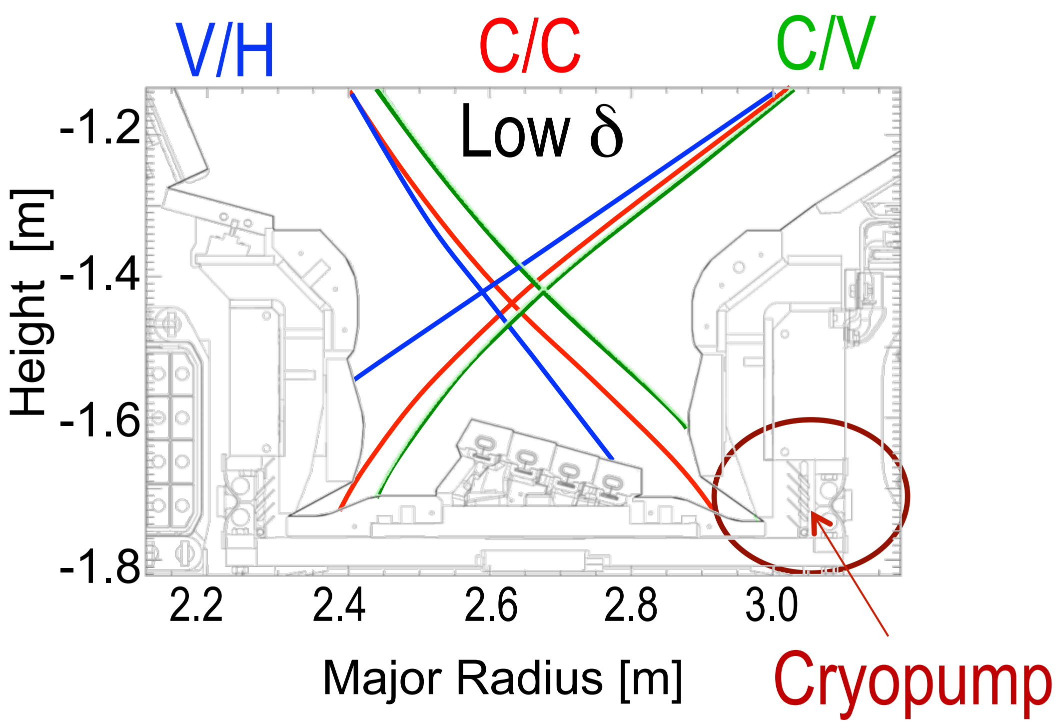
- At low gas rates, pedestals are at P-B boundary
- At high gas rates, pedestals are stable to P-B modes at higher beta
- All type I ELMy H-modes

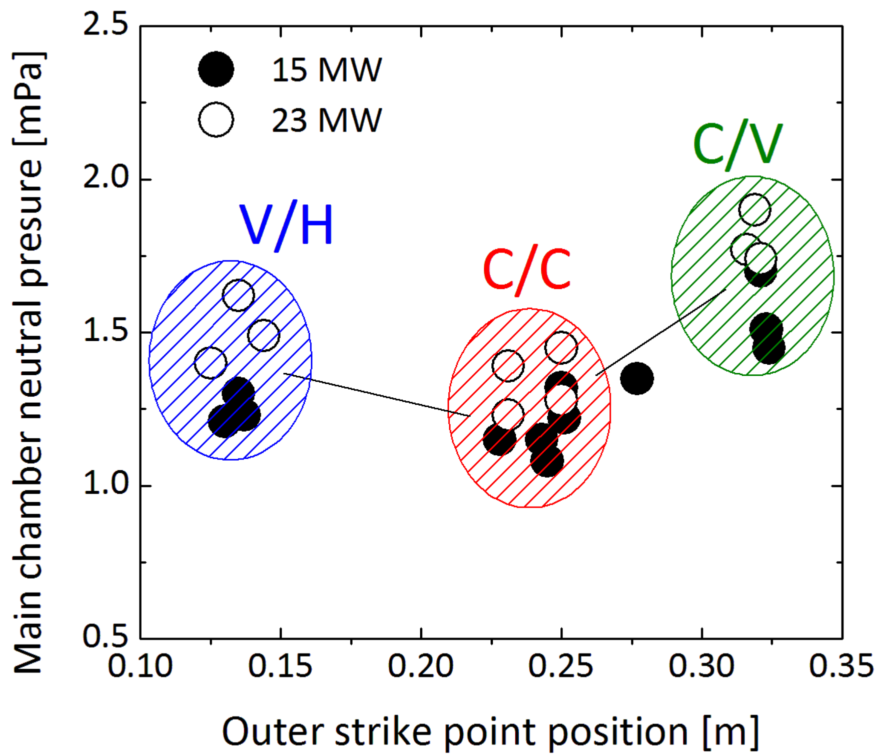
Weaker increase of pedestal pressure with power at high D_2 gas rates is not consistent with peeling-ballooning model

Varying the plasma neutral content

Neutral D content increases when

- D_2 injection rate is increased ← W control tool
- Divertor configuration is varied from C/C or V/H → C/V (pumping efficiency + neutrals recirculation to main chamber)



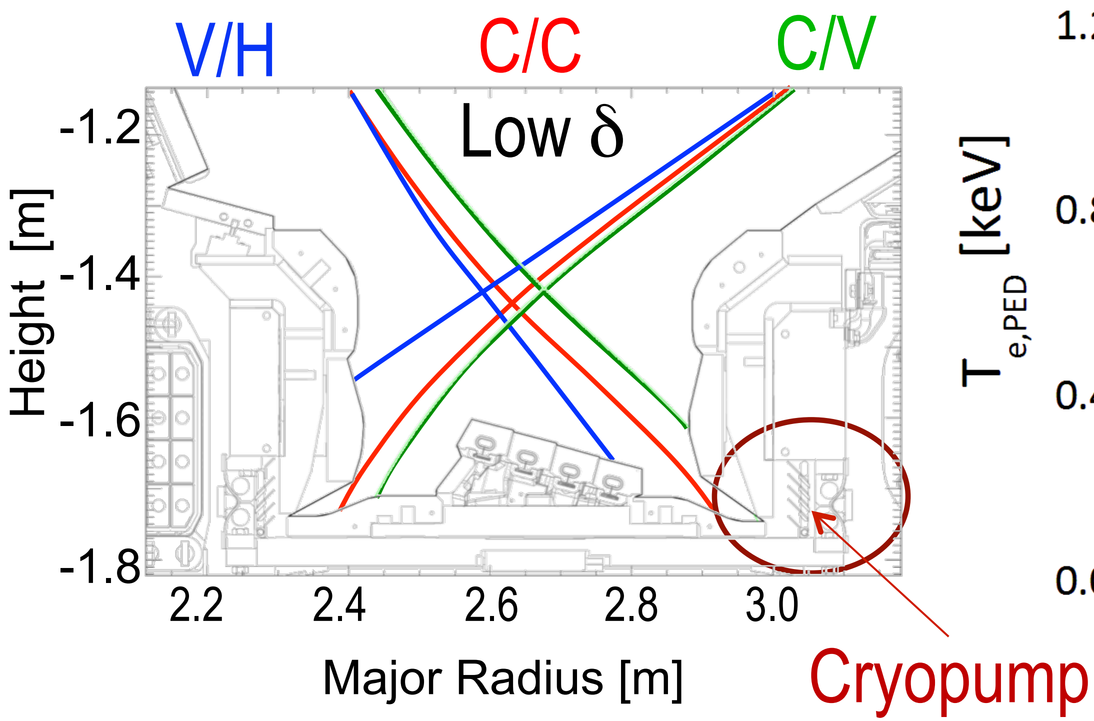


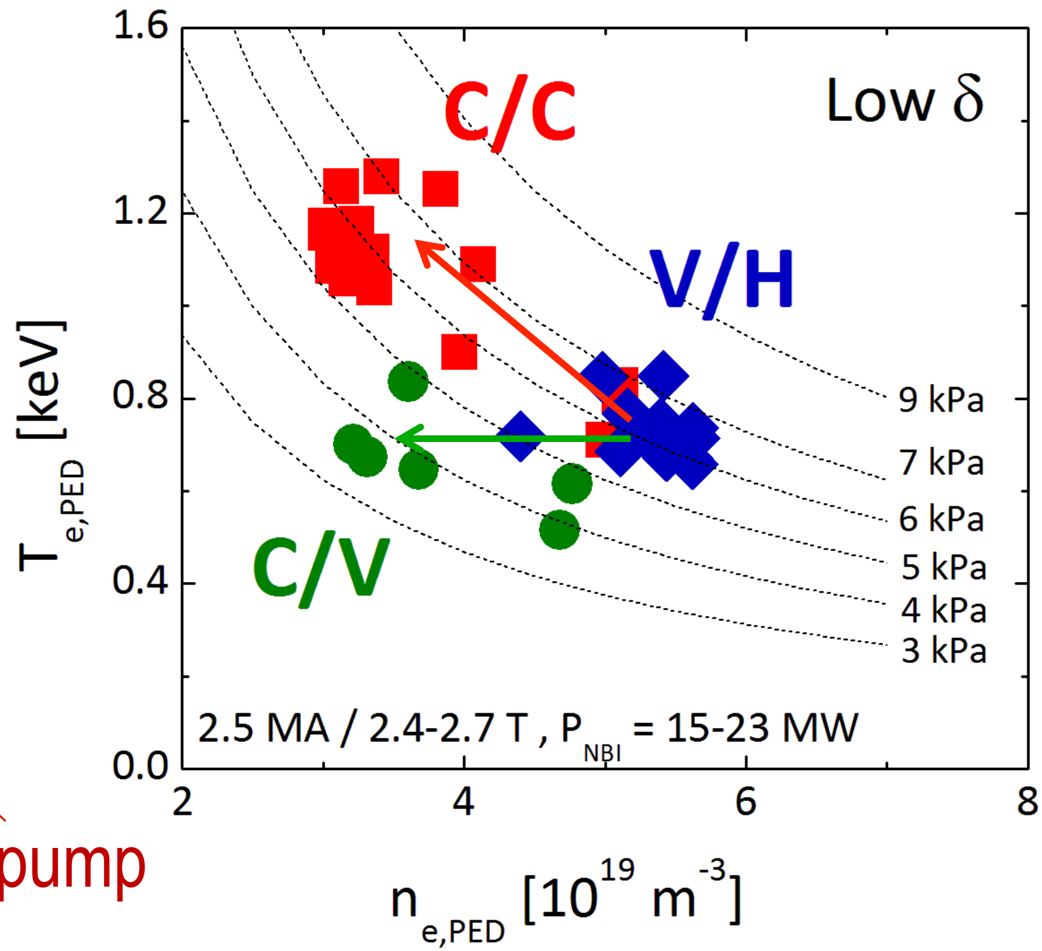
[Tamain, PSI 2014], [Frassinetti, EPS 2014]

Joffrin, EX/P5-40

Pedestal pressure and neutrals

- C/C: good pumping + lower neutral content → $n_{e,PED}$ ↓, $T_{e\&i,PED}$ ↑
- C/V: good pumping + higher neutral content → $n_{e,PED}$ ↓, low $T_{e\&i,PED}$

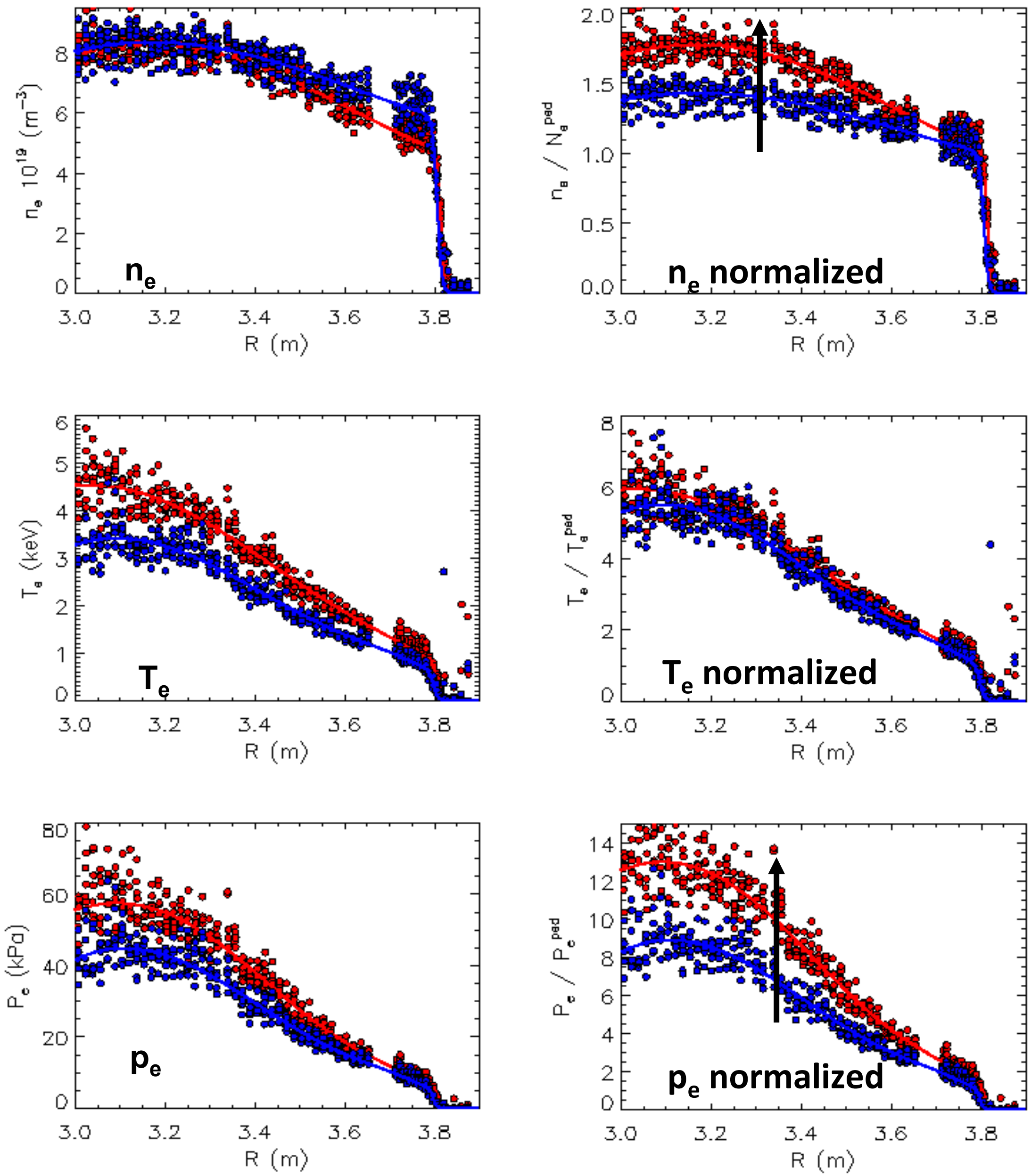




de la Luna, EX/P5-29

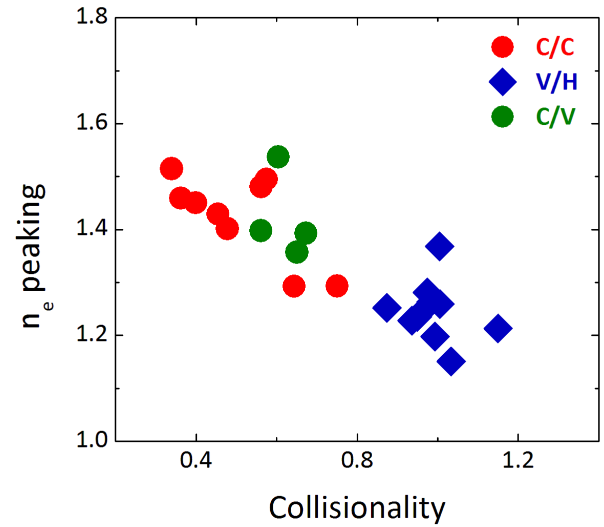
Joffrin, EX/P5-40

In C/C, H_{98} ~ 1 and β_N ~ 1.8 at 2.5MA



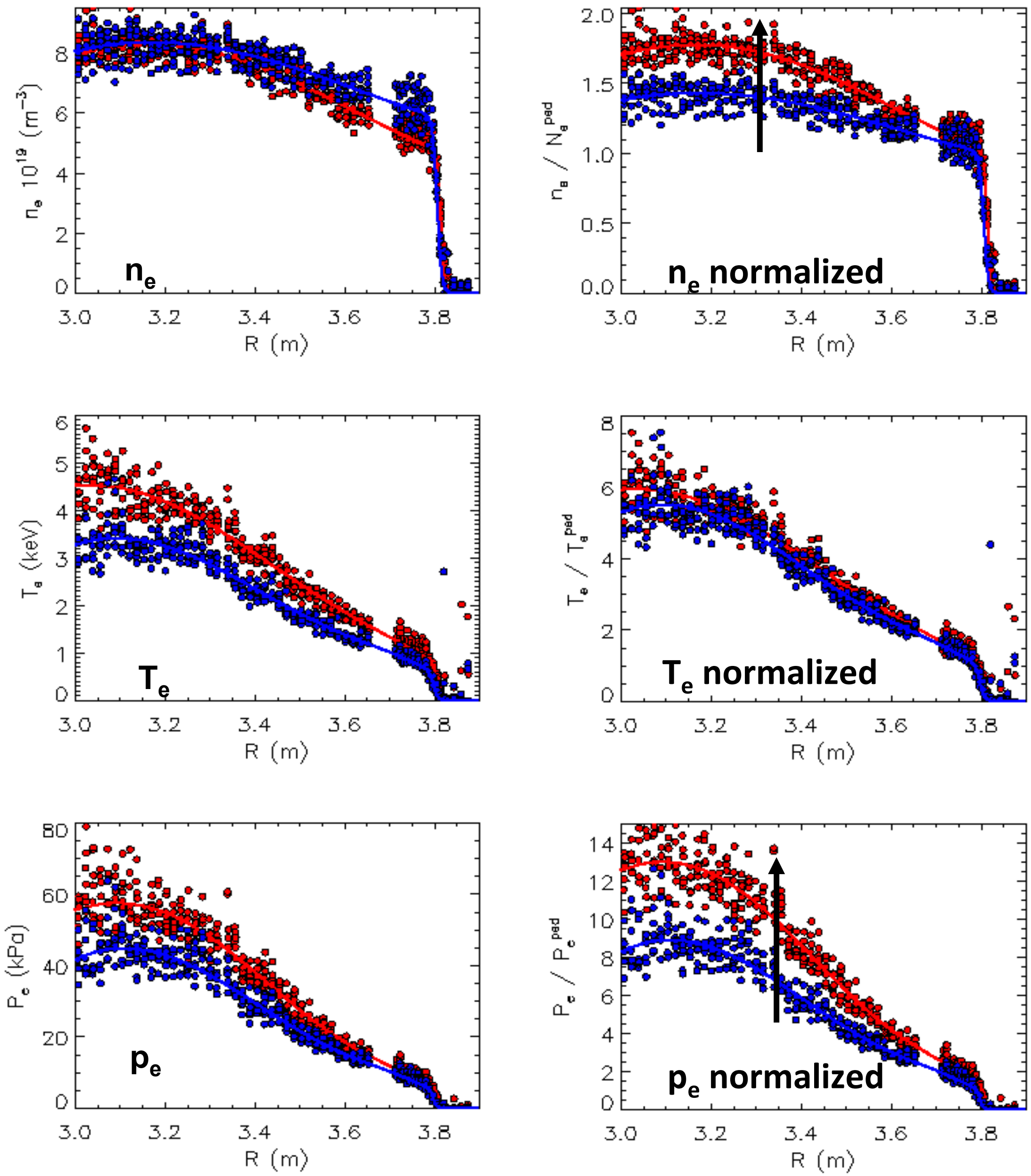
V/H → C/C

Increase of W_{th} at similar p_{PED} but lower collisionality



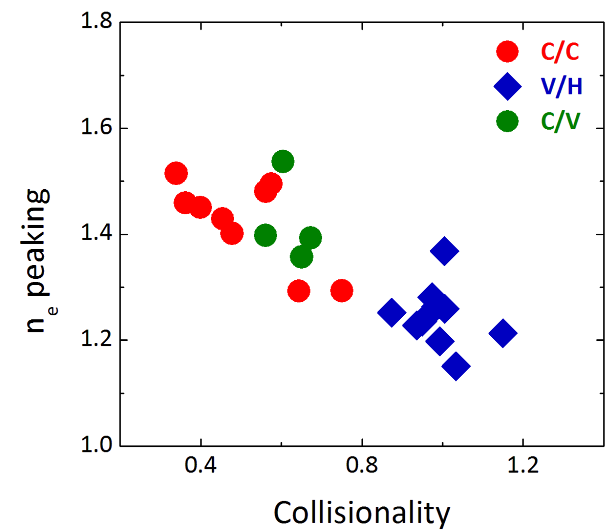
[Frassinetti, EPS 2014]

In C/C, H_{98} ~ 1 and β_N ~ 1.8 at 2.5MA



V/H → C/C

Increase of W_{th} at similar p_{PED} but lower collisionality

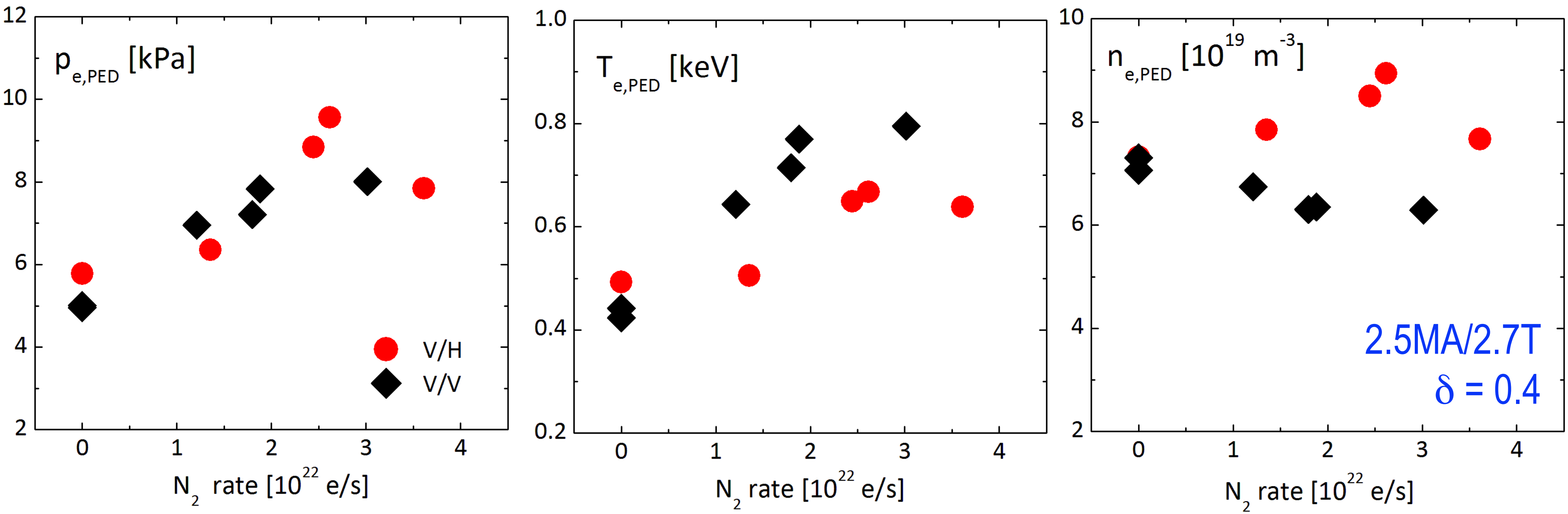


V/H → C/V

Low pedestal and core pressure

[Frassinetti, EPS 2014]

At high δ N_2 seeding increases $T_{e,PED}$

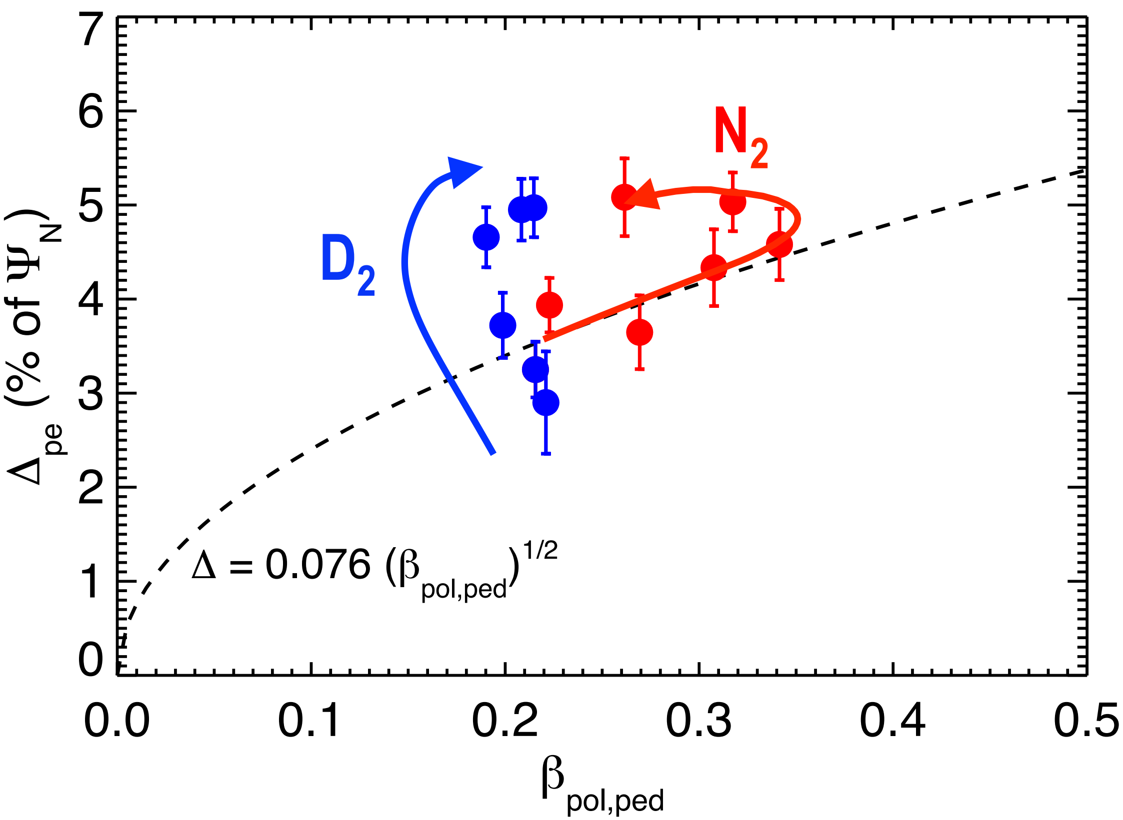


- Increase of $T_{e,ped}$ is independent of divertor configuration
- Effect on density depends on divertor configuration
- Increase of $T_{e,PED}$ with N_2 is weaker at low δ
- The underlying physics process is not yet understood

Giroud, EX/P5-25

Pedestal structure with D_2 and N_2

2.5MA/2.7T, High Triangularity, V/H Configuration



- With increasing D_2 rate, pressure gradient decreases and width increases at constant β_{pol}
- With increasing N_2, temperature pedestal widens and peak density gradient increases

- At high gas rates, challenge for KBM based EPED model

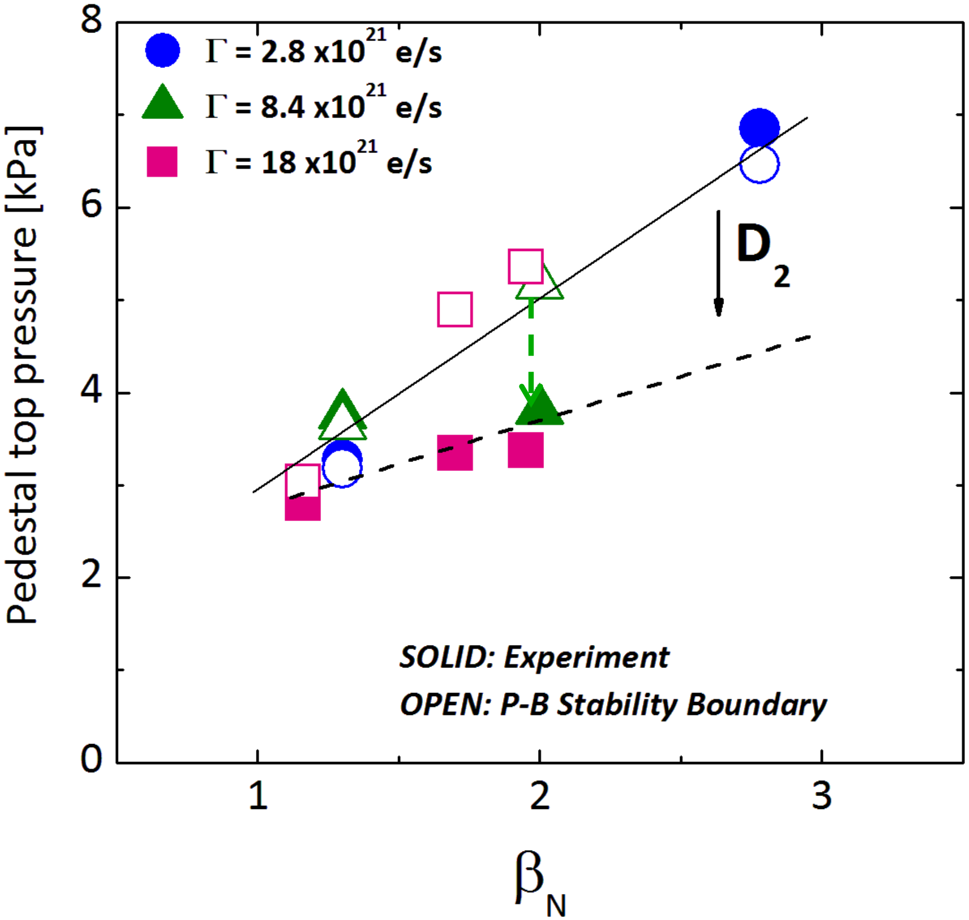
[Leyland, Nucl. Fusion, accepted]

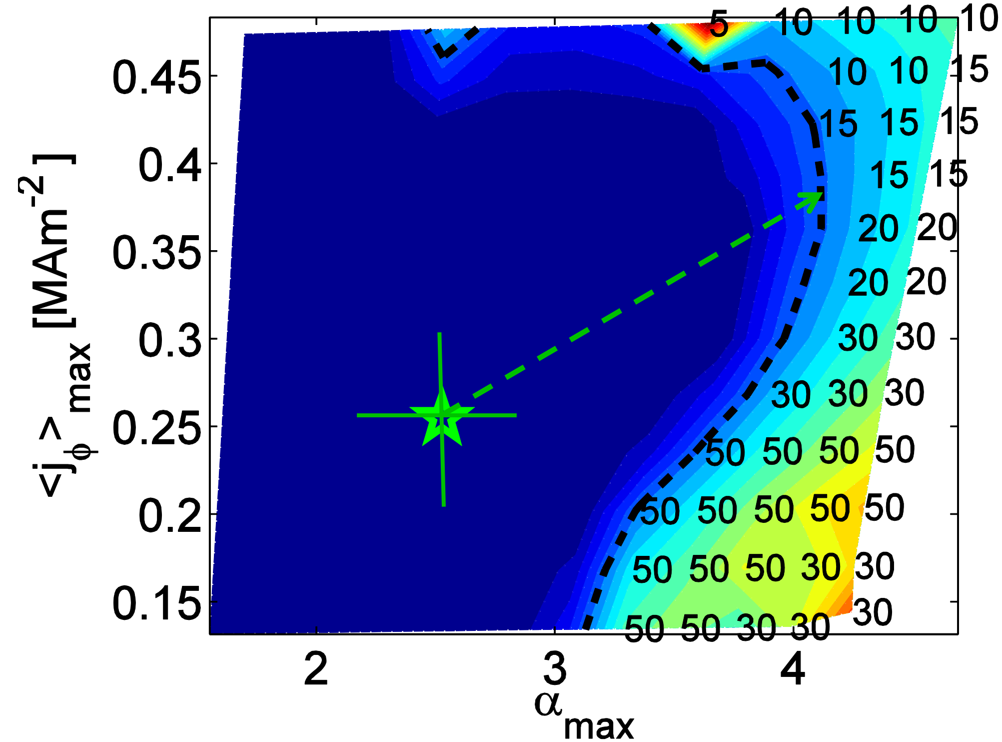
Conclusions

- The changeover from JET-C to JET-ILW has forced us to re-optimize pedestal confinement and stability
- What we understand within the P-B framework and EPED model:
  - Stabilizing effects of beta and plasma shaping at low D_2 gas rates
- What we still need to understand in order to advance our predictive capability of the pedestal height:
  - Physics process through which D neutrals degrade $T_{e,PED}$ (inter-ELM transport?...)
  - Physics process through which N_2 impurities increase $T_{e,PED}$

Back-up slides

P-B stability analysis

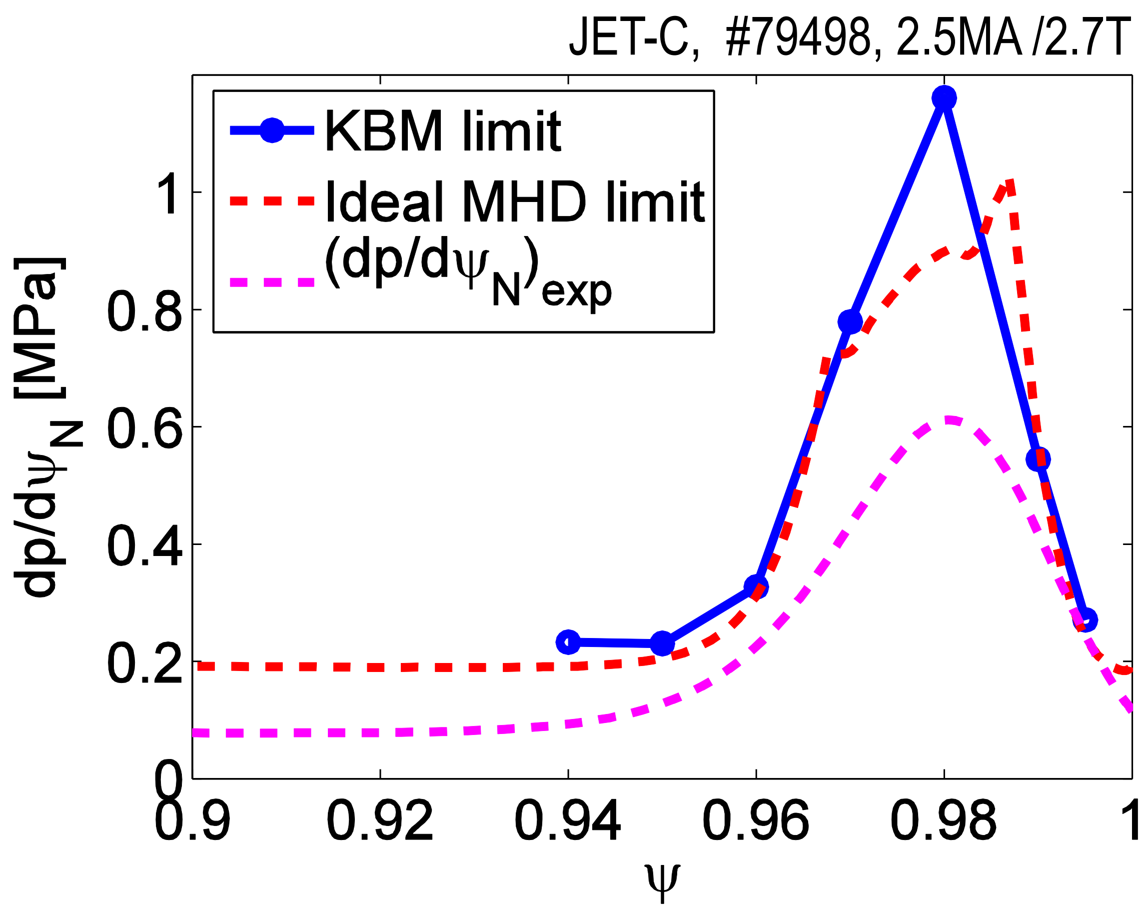




Distance of operational point to P-B boundary is length of arrow, calculated at fixed pedestal width and increasing $T_{e,PED}$

Gyrokinetic analysis of the pedestal

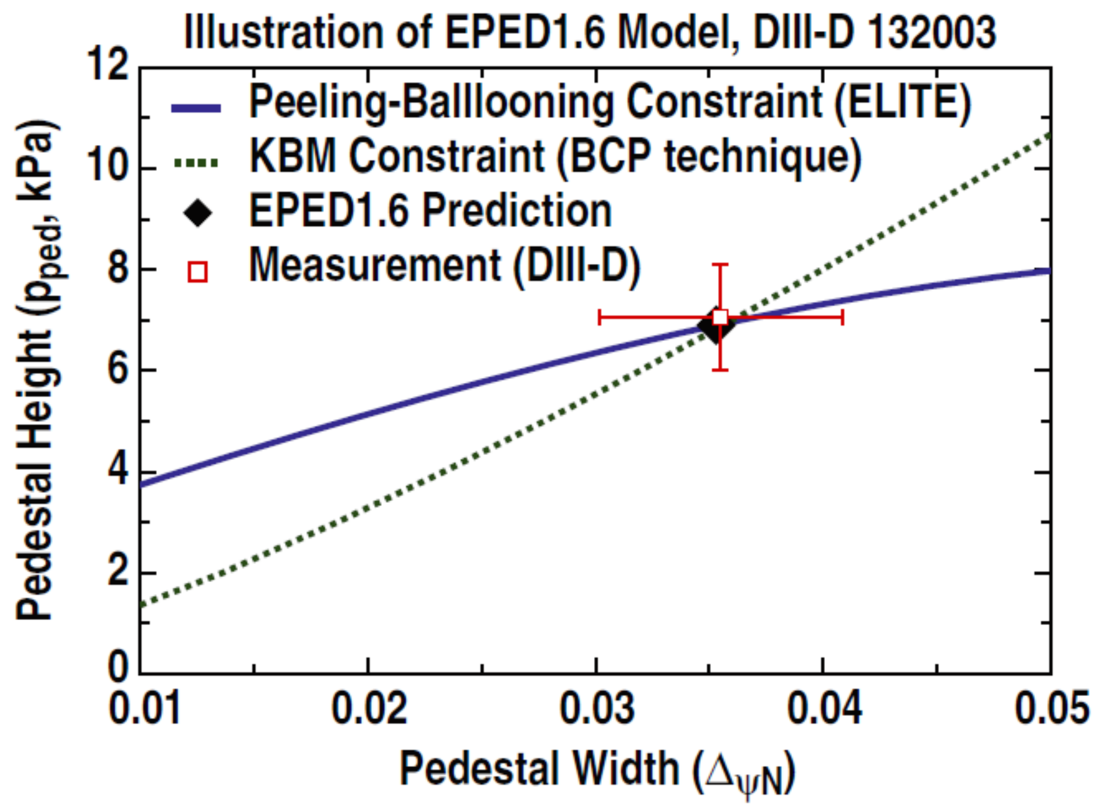
Local flux tube simulation (GS2) indicates that JET pedestal is stable to KBMs due to high bootstrap current



[Saarelma, Nucl. Fusion 2013]

Pedestal prediction

- EPED predicts fully developed pedestal before an ELM at crossing of KBM and P-B stability limits
- EPED has predicted the pedestal height in several devices within ± 20%



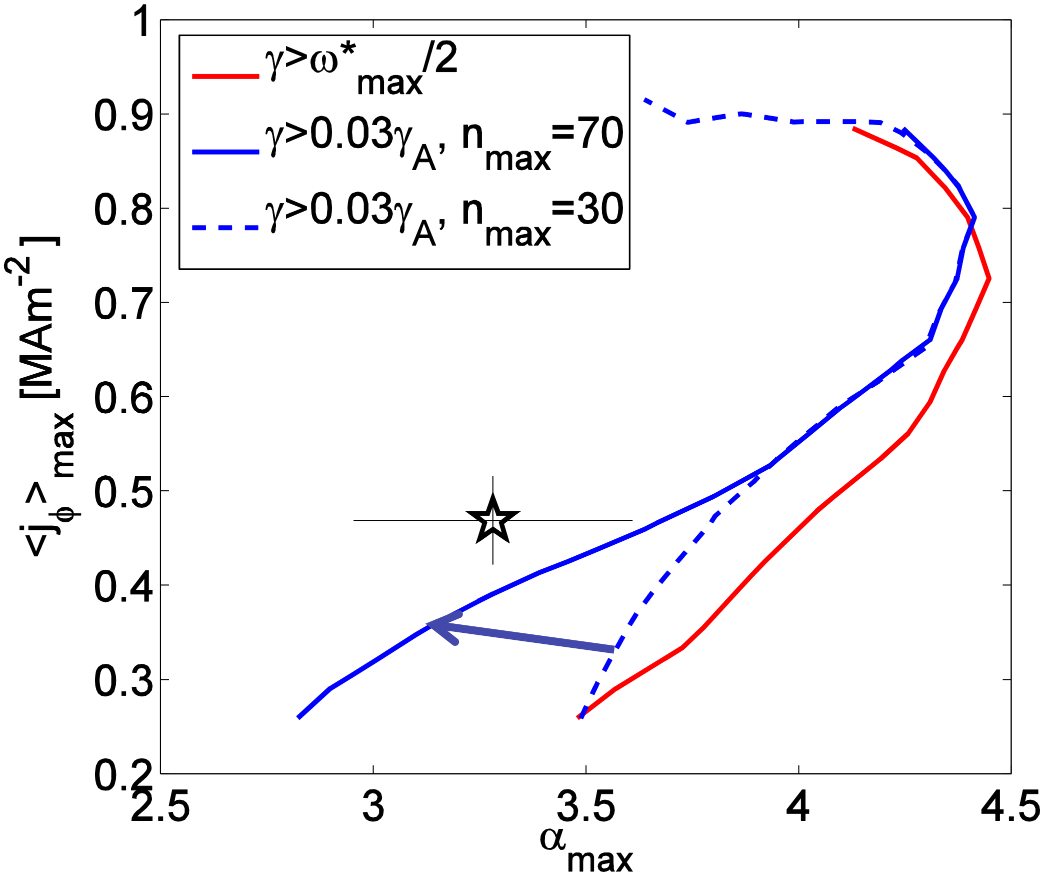
[Snyder et al., NF 2009]

[Snyder et al., NF 2011]

Stability boundary in P-B analysis

High-n ballooning:

- Inclusion of higher toroidal mode numbers reduces the critical pressure gradient at which ballooning modes become unstable, changing the stability boundary



Diamagnetic stabilization:

- BOUT++ simulations indicate that $\gamma > \omega^*_{max}/2$ at low *n* and $\gamma > C * \omega_A$ at high *n* is more appropriate