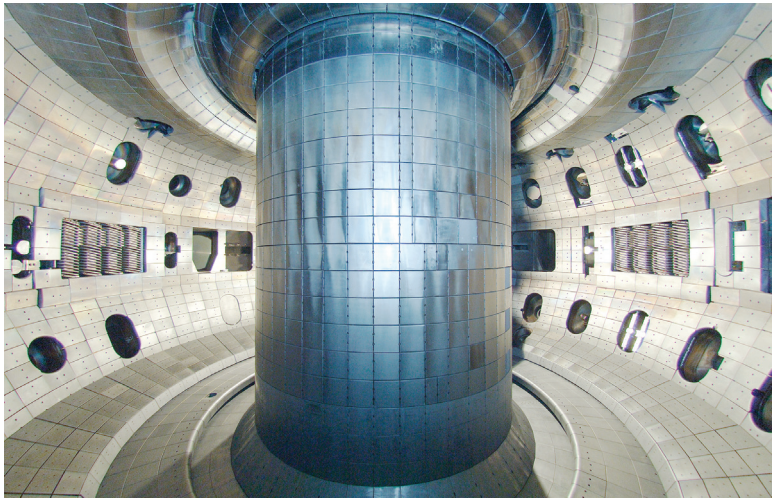
Rapporteured Orals: EXC/2-4Ra and EXC/2-4Rb

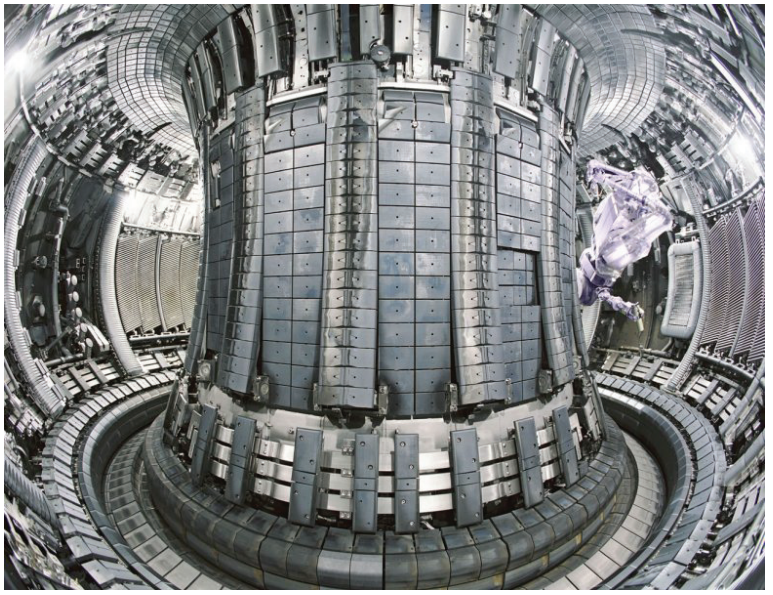
L-H Transition Studies on DIII-D to Determine H-mode Access for Operational Scenarios in ITER (EXC/2-4Ra)

by
P. Gohil, et al.



JET Helium-4 ELMy H-mode Studies (EXC/2-4Rb)

by
D.C. McDonald, et al.



Presented at
Twenty-Third IAEA Fusion Energy Conference
Daejeon, Republic of Korea

October 11-16, 2010

DIII-D NATIONAL FUSION FACILITY

CCFE CULHAM CENTRE FOR FUSION ENERGY

EFDA JET

Author Lists

EXC/2-4Ra: P. Gohil, et al.

P. Gohil, T.E. Evans, M.E. Fenstermacher, J.R. Ferron, D.C. McDonald, T.H. Osborne, J.M. Park, O. Schmitz, J.T. Scoville and E.A. Unterberg

EXC/2-4Rb: D.C. McDonald, et al.

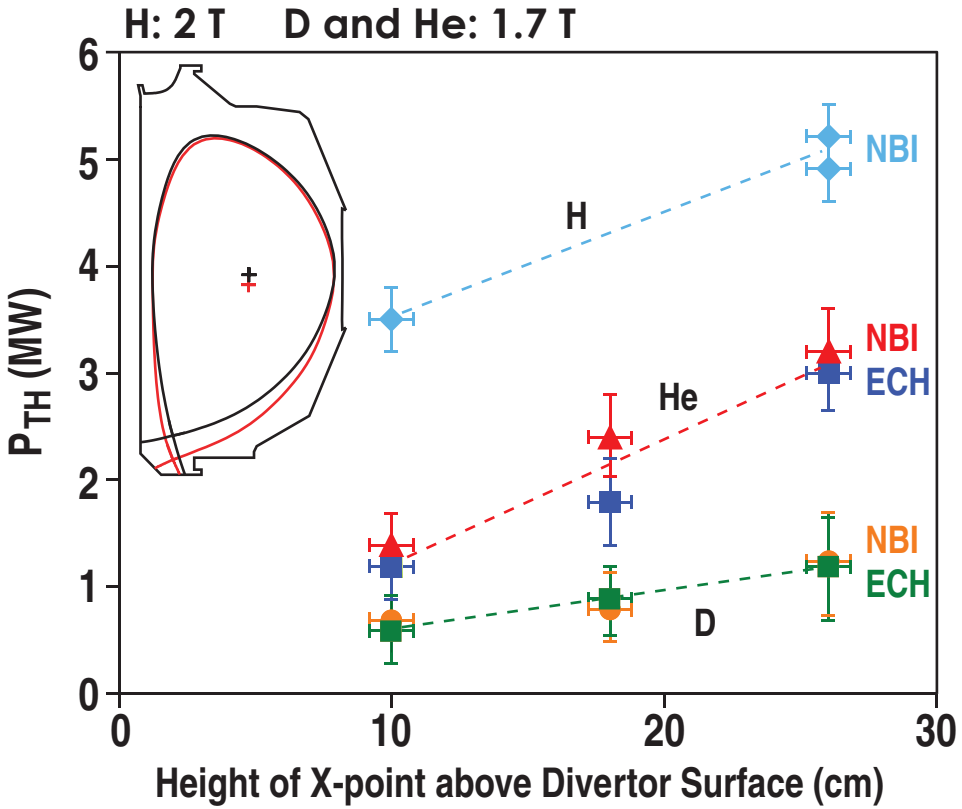
D.C. McDonald, G. Calabro, M. Beurskens, I. Day, E. de la Luna, S. Devaux, T. Eich, N. Fedorczak, O. Ford, W. Fundamenski, C. Giroud, P. Gohil, M. Lennholm, J. Lonnroth, P.J. Lomas, G.P. Maddison, C.F. Maggi, I. Nunes, G. Saibene, R. Sartori, W. Studholme, E. Surrey, I. Voitsekhovitch, K-D. Zastrow, and JET-EFDA contributors

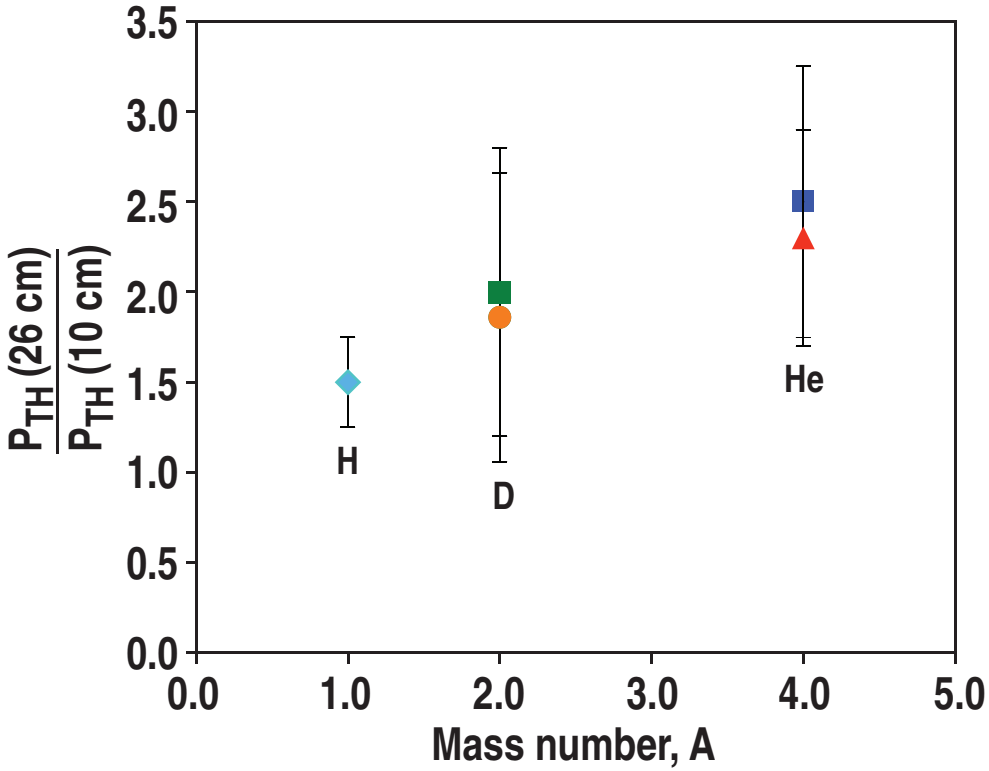
Background/Motivation

- **Can H-mode be achieved in the first (non-nuclear) phase of ITER operations with He (and/or H) plasmas ?**
  - Need H-mode to test ELM mitigation techniques and hardware in ITER environment
- **DIII-D experiments performed with balanced NBI (i.e. ~zero torque) and ECH in H, D and He plasmas (all reference to He imply ^{4}He)**
- **JET experiments performed with NBI and ICRH in D and He plasmas**
- **Examine physical trends not included in H-mode power threshold (P_{TH}) scaling**
- **Determine methods to reduce the H-mode power threshold and extrapolate to ITER**
- **Quality of H-mode performance dependent on input power above threshold power**
  - Affects pedestal behavior, ELM characteristics, etc

The X-point Height has a Strong Effect on the H-mode Power Threshold for H, D and He

- Effect previously observed on DIII-D and other devices
- First systematic study of effect for H, D and He

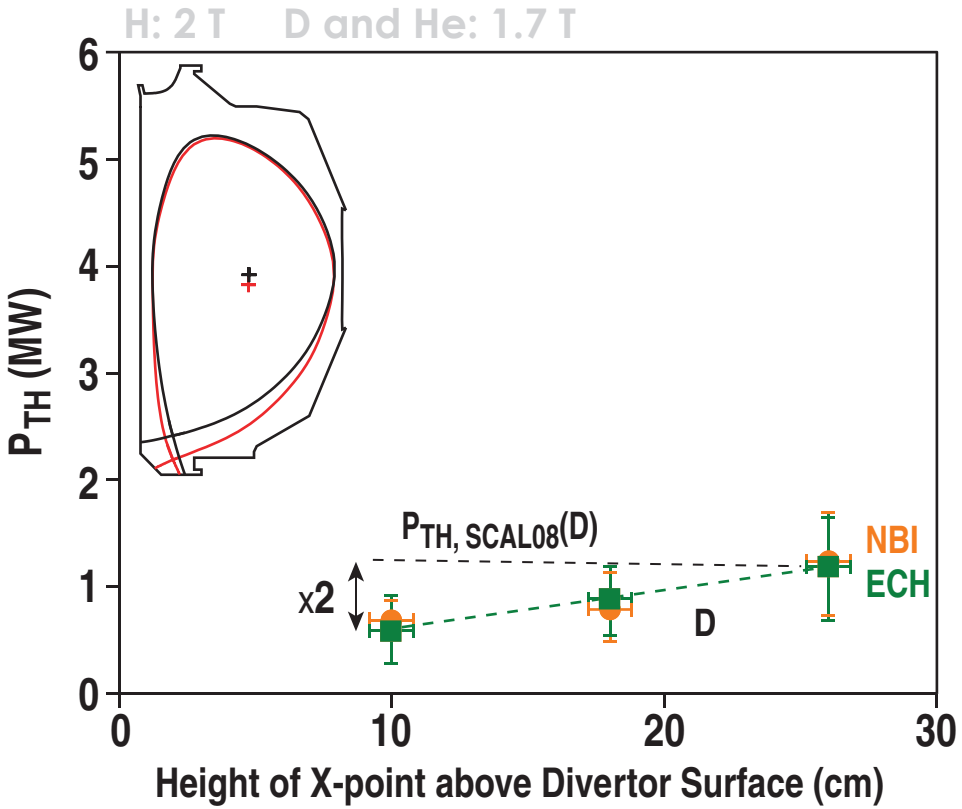




- Edge E_r shear and edge magnetic shear profiles show no significant change for low and high X-point locations
- Preliminary analysis indicates edge neutrals may be affecting the power threshold

The X-point Height has a Strong Effect on the H-mode Power Threshold for H, D and He

- Effect previously observed on DIII-D and other devices
- First systematic study of effect for H, D and He



- **H-mode power threshold scaling for D plasmas**
  - $P_{TH, SCAL08}$ (D) = 0.049 $n_e^{0.72}$ $B_T^{0.80}$ $S^{0.94}$ (units: 10^{20} m^{-3}, T, m^2)
- **X-point dependence is not included in the power threshold scalings**
  - Results in factor of 2 difference between P_{TH} at low X-point and the scaling prediction

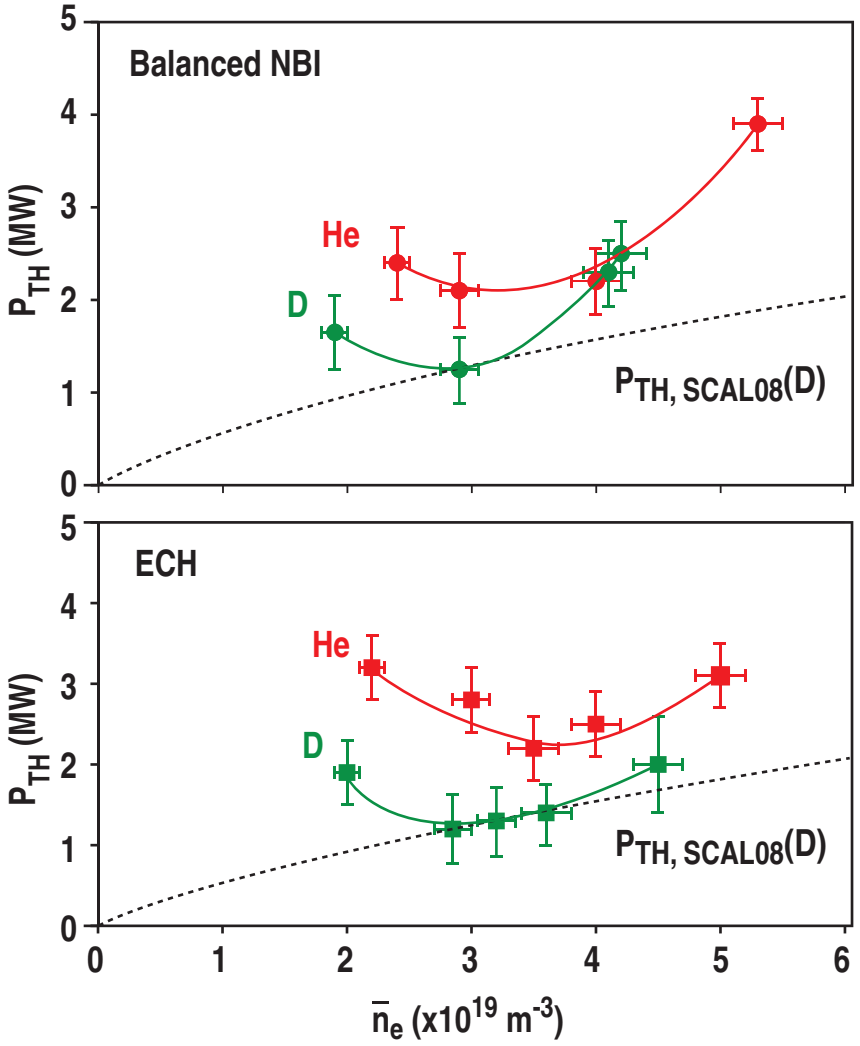
- Edge E_r shear and edge magnetic shear profiles show no significant change for low and high X-point locations
- Preliminary analysis indicates edge neutrals may be affecting the power threshold

Difference in the H-mode Power Threshold Between He and D Plasmas Decreases at Higher Densities

- **He and D plasmas (I_p = 1.0 MA, B_T = 1.65 T)**
  - Balanced NBI (i.e. zero torque) at same ion species as plasma species (D - NBI → D; He - NBI → He)
  - ECH
  - High X-point location

- **At low densities (<3x10^{19} m^{-3}) P_{TH} (He) ~1.5-2 P_{TH} (D)**

- **At high densities (>3x10^{19} m^{-3}) P_{TH} (He) ~1-1.5 P_{TH} (D)**



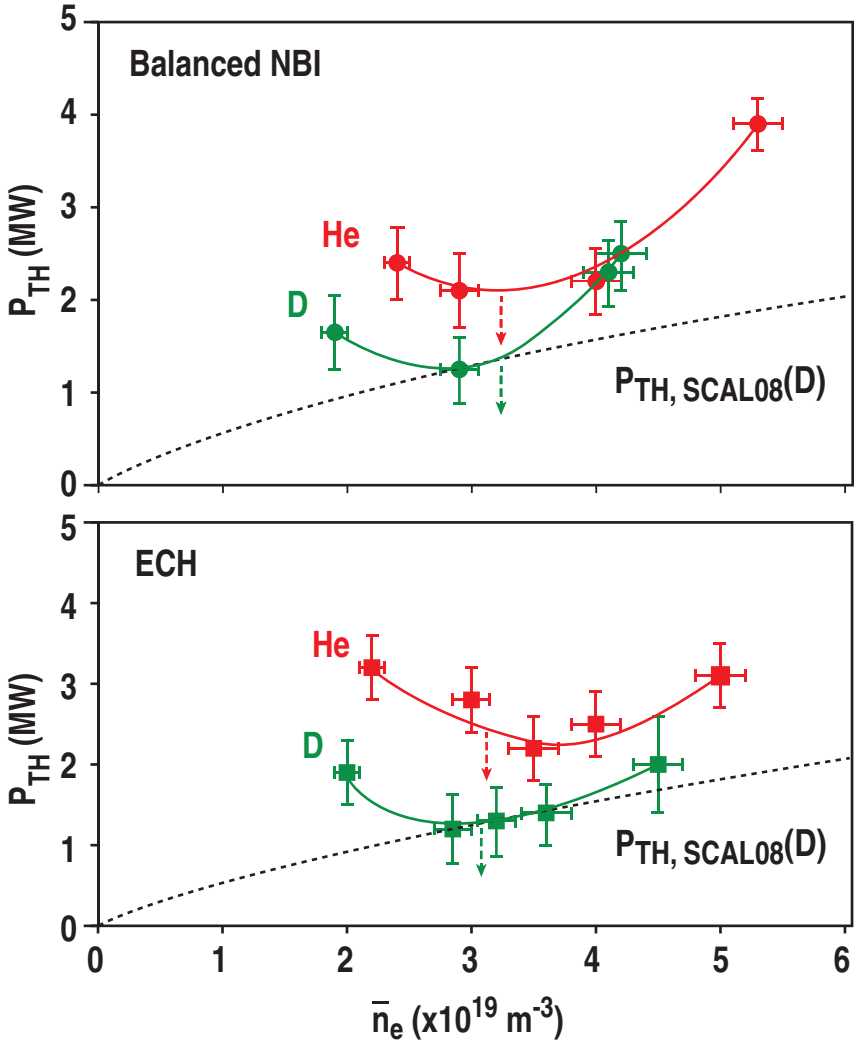
Difference in the H-mode Power Threshold Between He and D Plasmas Decreases at Higher Densities

- He and D plasmas (I_p = 1.0 MA, B_T = 1.65 T)
  - Balanced NBI (i.e. zero torque) at same ion species as plasma species (D - NBI → D; He - NBI → He)
  - ECH
  - High X-point location

- At low densities (<3x10^{19} m^{-3}) P_{TH} (He) ~1.5-2 P_{TH} (D)

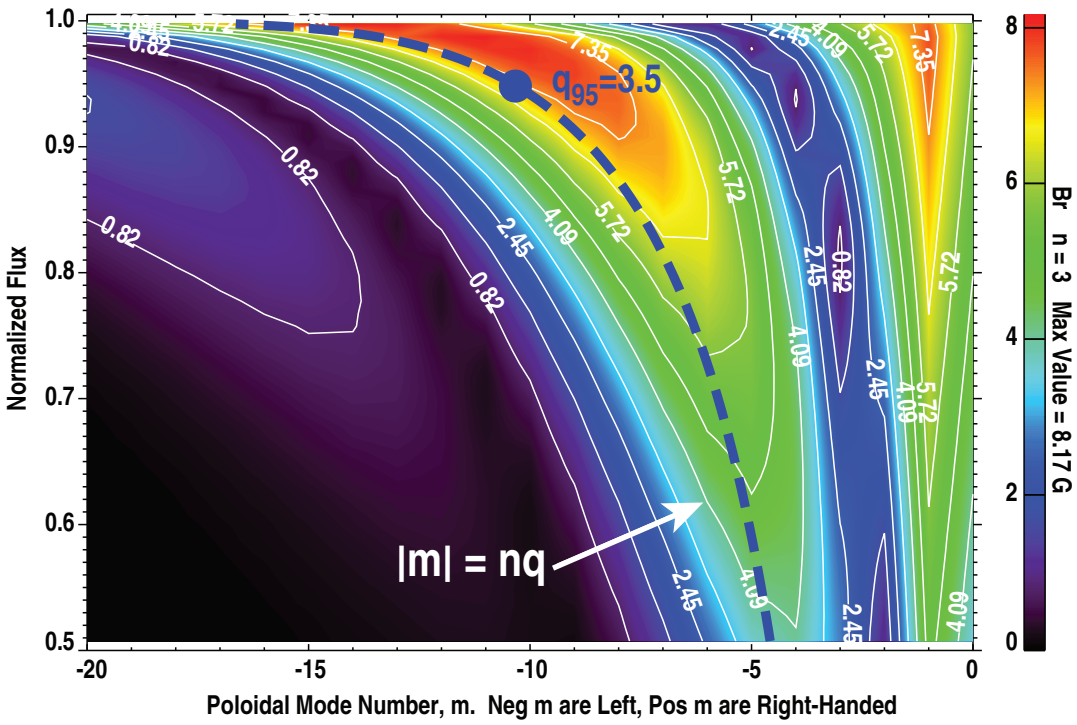
- At high densities (>3x10^{19} m^{-3}) P_{TH} (He) ~1-1.5 P_{TH} (D)

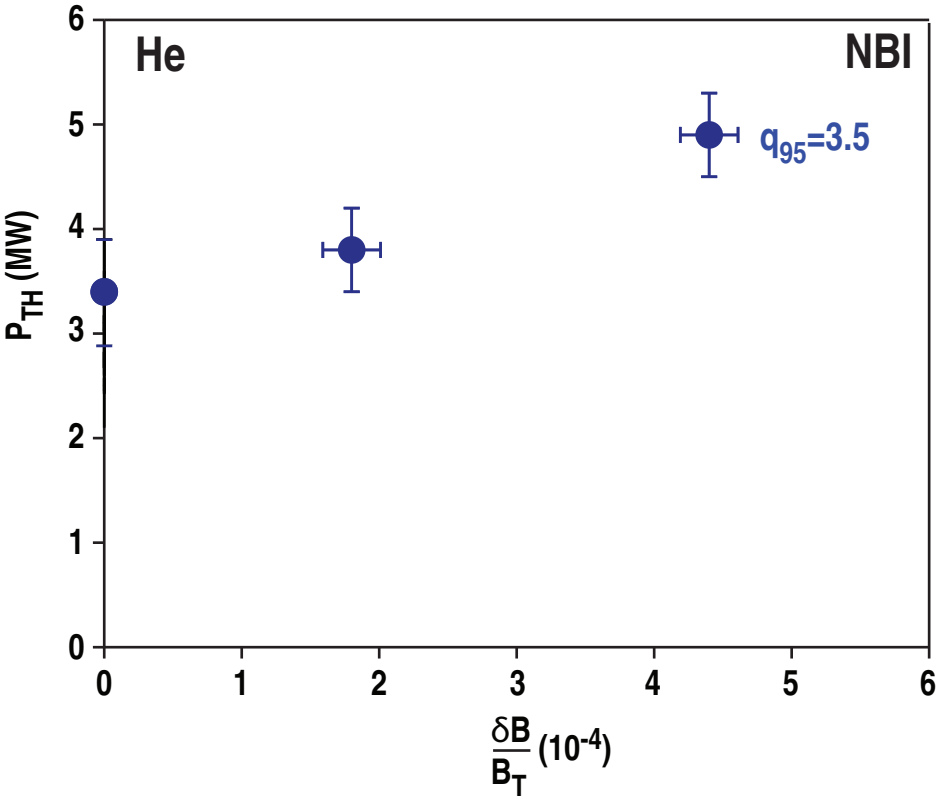
- **Lowering the X-point will move all curves significantly downwards with respect to the scaling**



Application of Strong Resonant n=3 RMP Fields Increase P_{TH} in Helium Plasmas

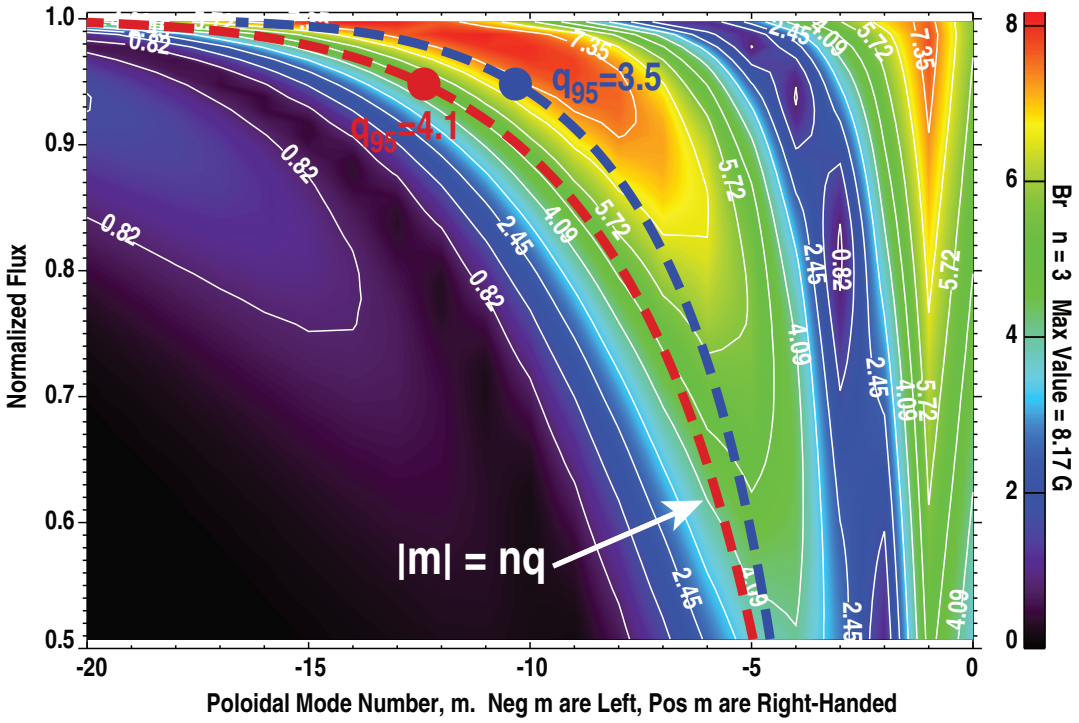
- n=3 resonant magnetic perturbations (RMPs) applied by in vessel coils (I-coils)

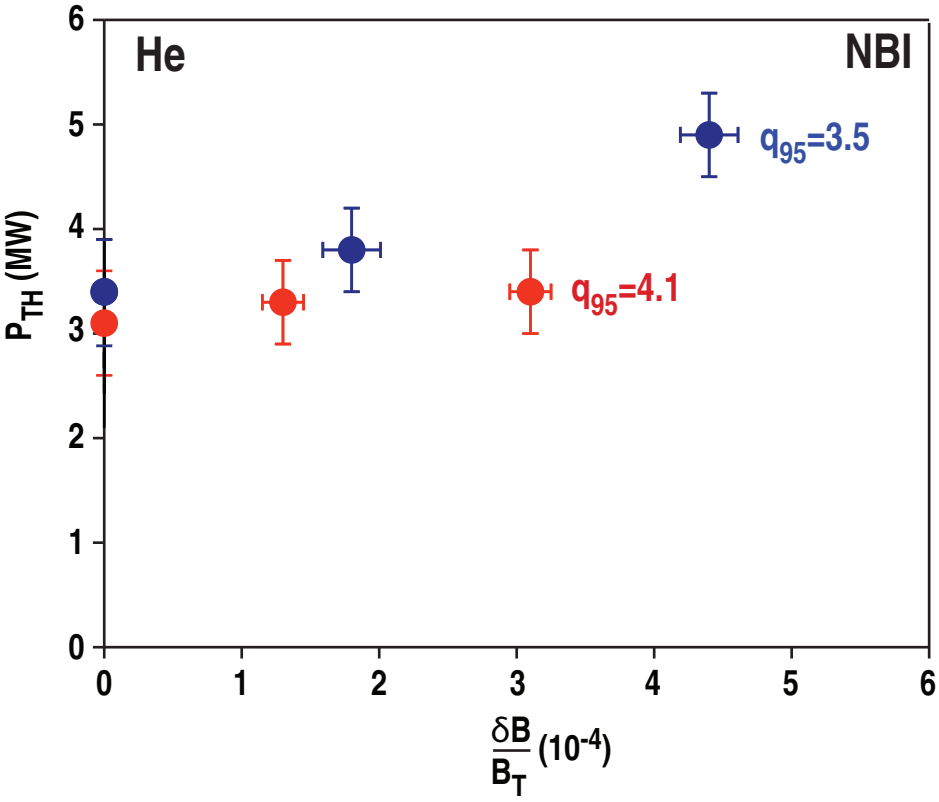




Application of Strong Resonant n=3 RMP Fields Increase P_{TH} in Helium Plasmas

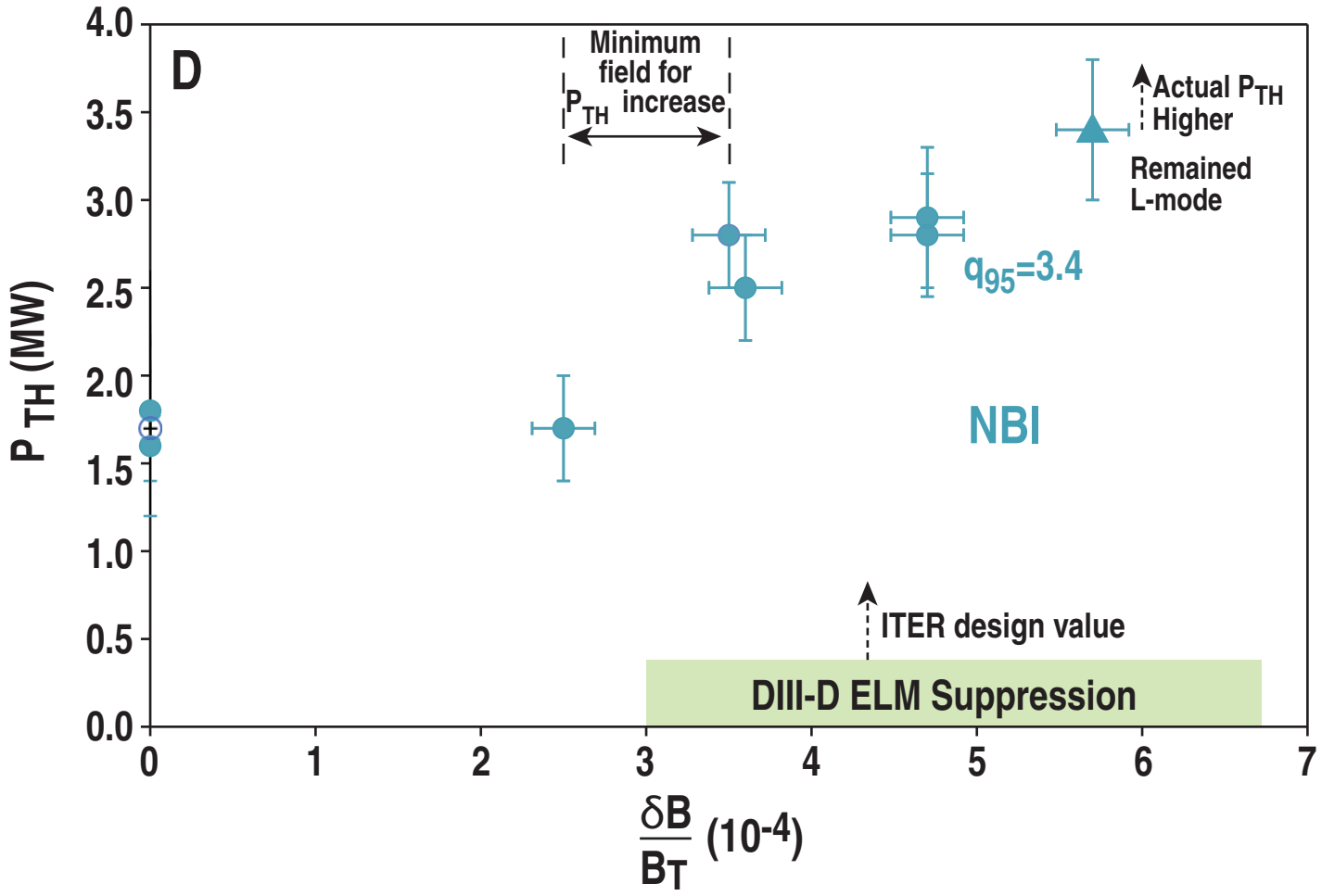
- n=3 resonant magnetic perturbations (RMPs) applied by in vessel coils (I-coils)
- Stronger resonant components lead to higher P_{TH}
- Similar effect observed with ECH





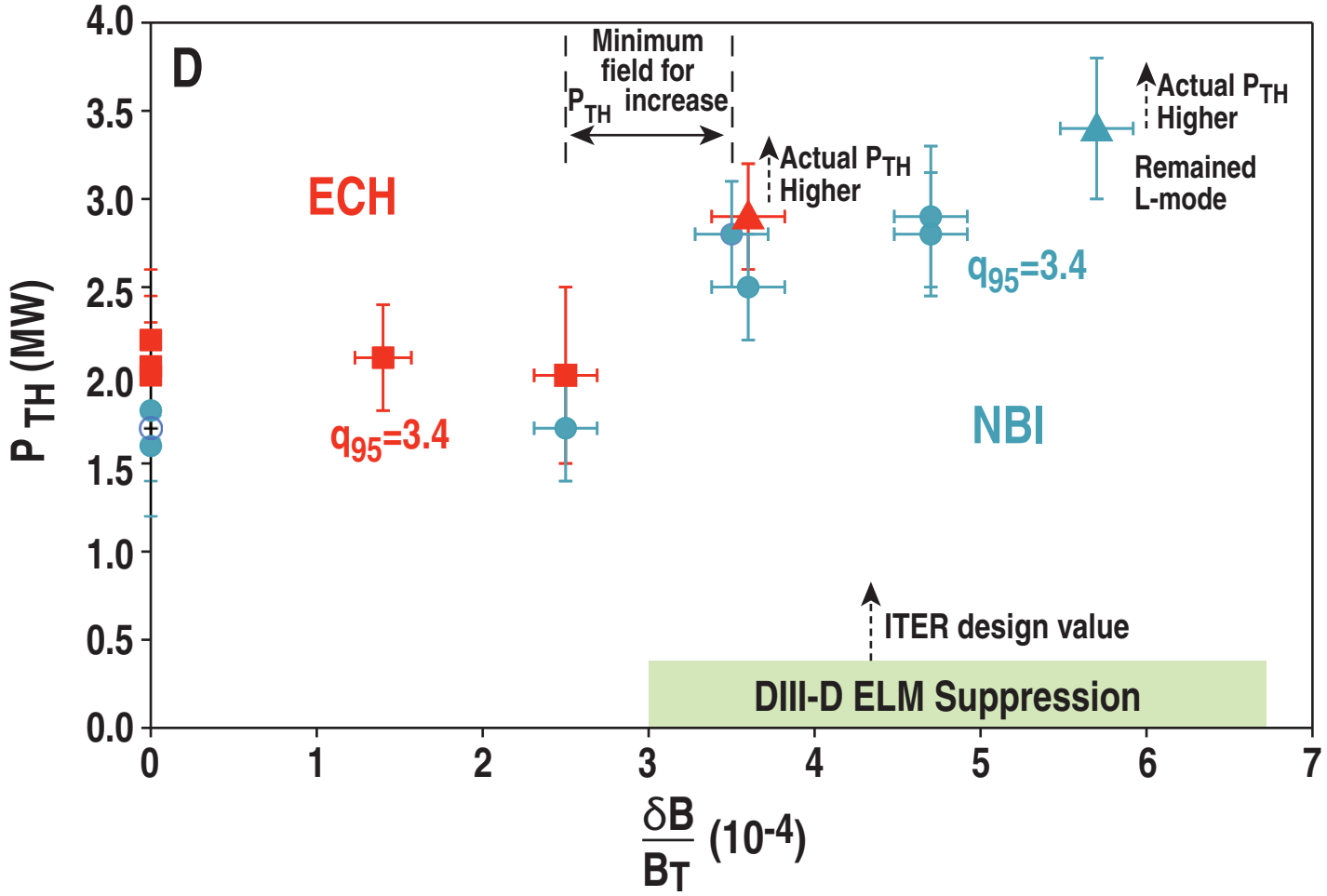
For D Plasmas, there is a Minimum Required RMP Field Before P_{TH} Increases

- Effect on P_{TH} observed for $\delta B/B_T$ > ~ $3x10^{-4}$

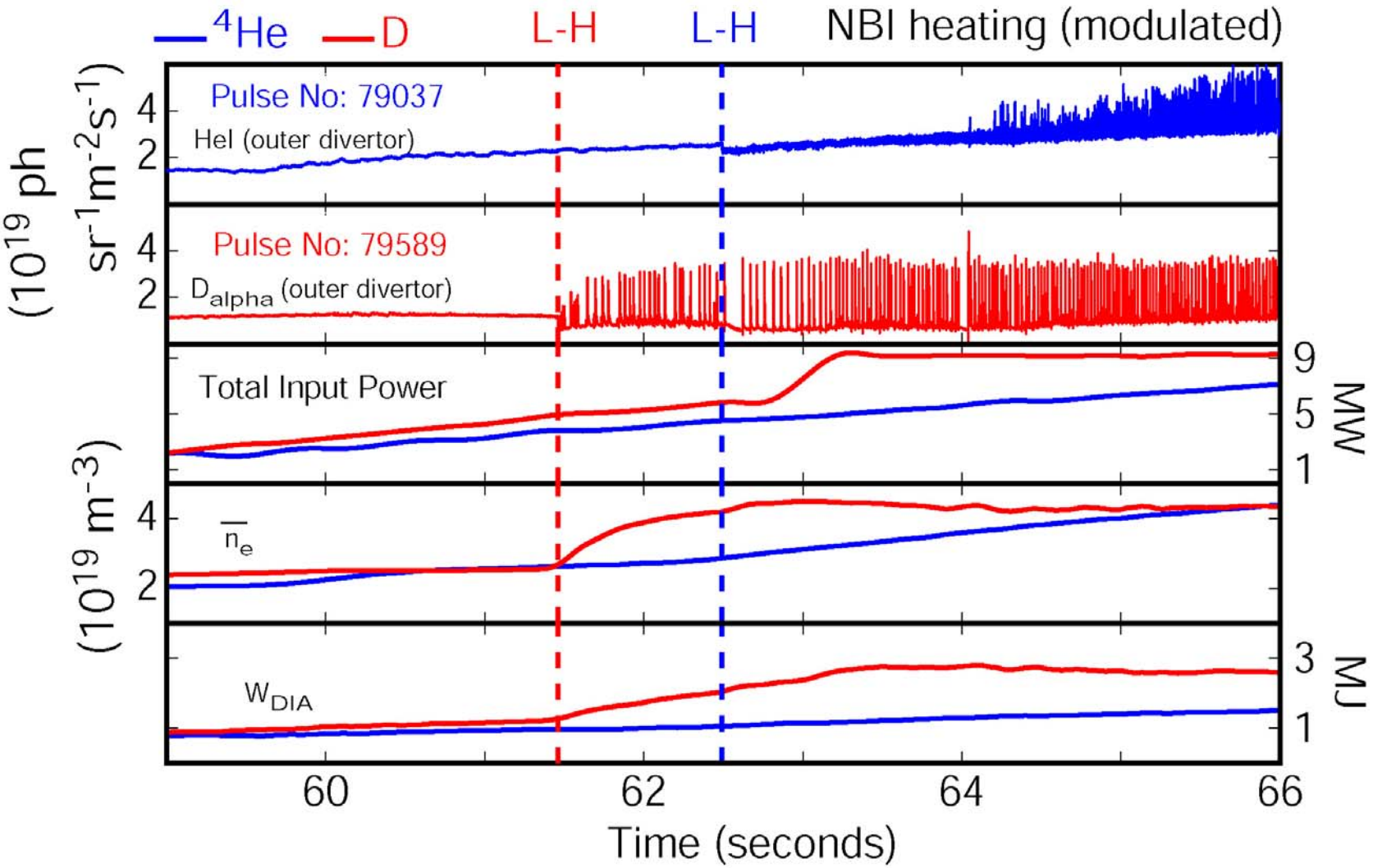


For D Plasmas, there is a Minimum Required RMP Field Before P_{TH} Increases

- Effect on P_{TH} observed for $\delta B/B_T$ > ~ $3x10^{-4}$
- Determined for both ECH and balanced D-NBI (plasma shape different to He plasma study)

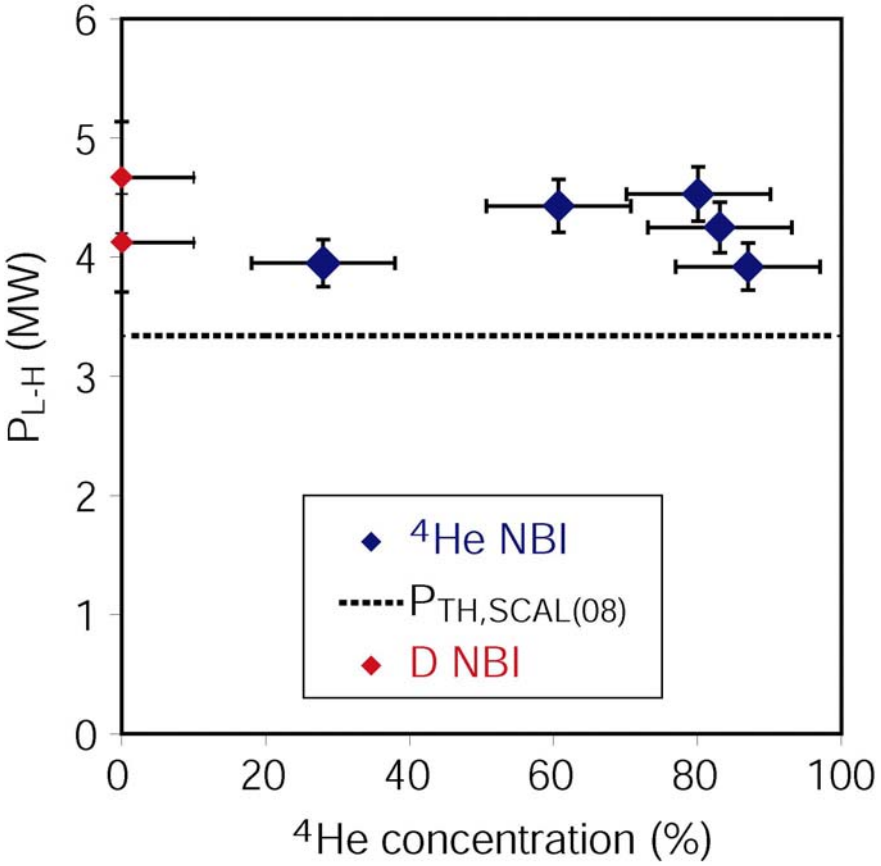


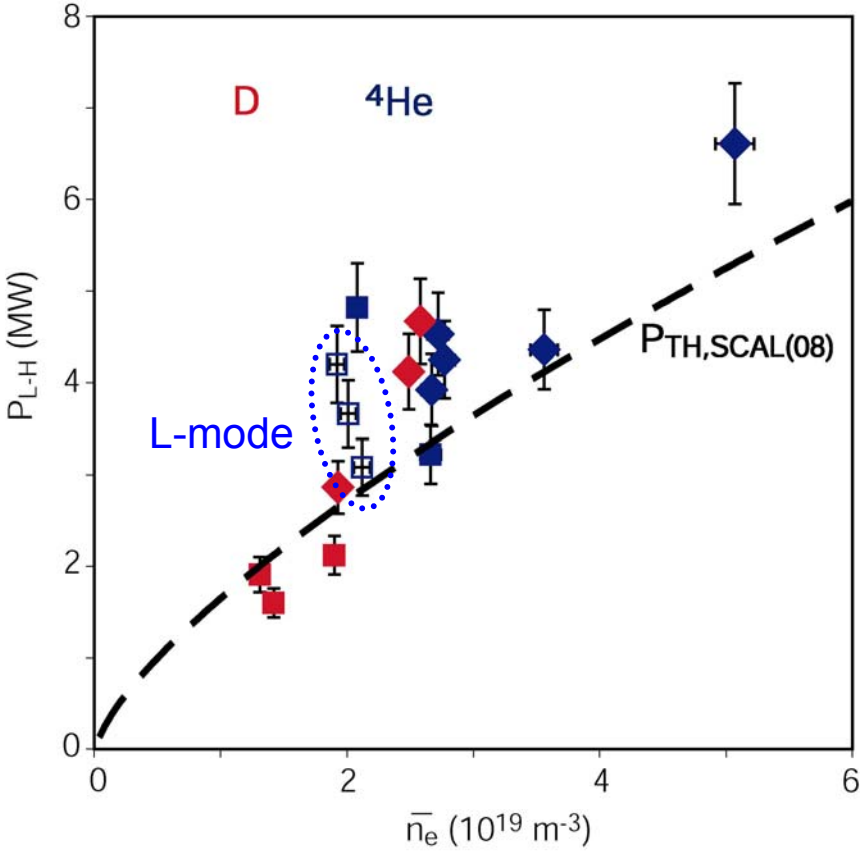
2009 JET ^{4}He campaign



- **In JET, L-H transitions followed by high f_{ELM} phase identified as Type III, which is then followed by a transition to Type I ELMs**

L-H threshold



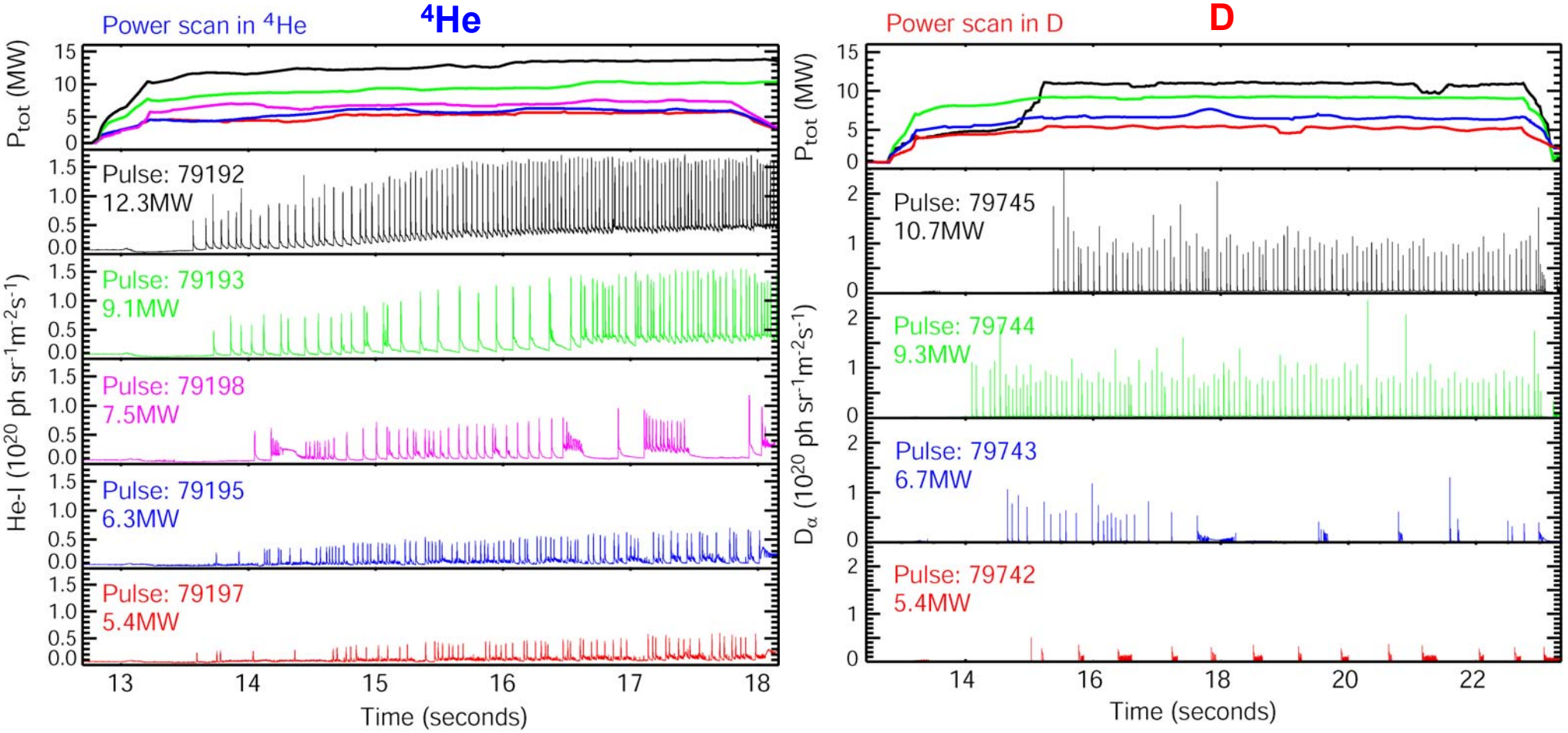


- **L-H power threshold is not observed to change with ^{4}He concentration:**

  $P_{L-H}/P_{TH,SCAL(08)} \approx 1.4$

- **^{4}He L-H power threshold is significantly higher than in D at lower densities**

Similar power threshold for Type I ELMs in D and ^{4}He



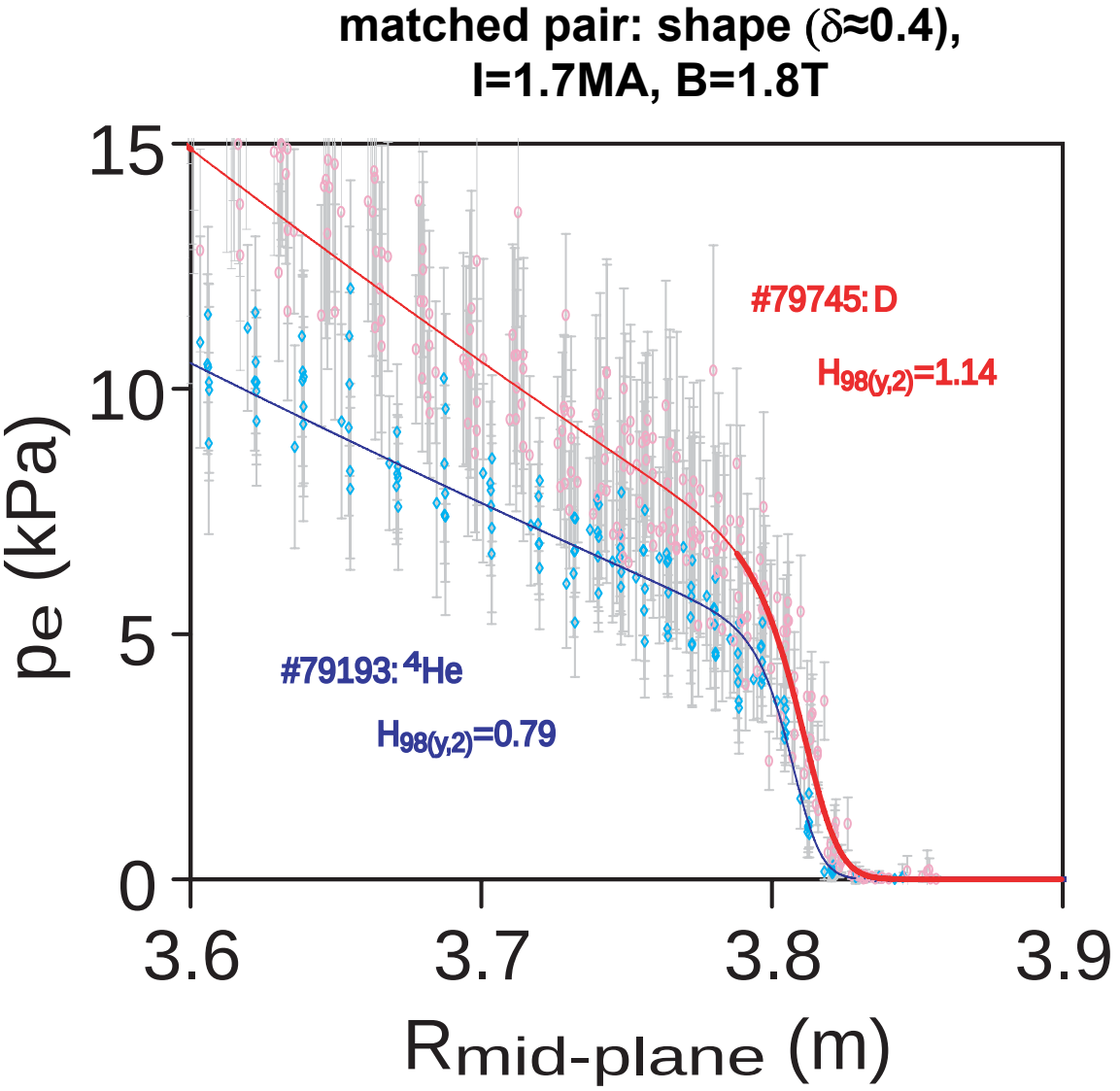
$P_{Type\ I}$ (^{4}He) = 7.5-9.3 MW

$P_{Type\ I}/P_{TH,SCAL(08)}$(^{4}He) = 1.4-1.6

$P_{Type\ I}$ (D) = 6.7-9.3 MW

$P_{Type\ I}/P_{TH,SCAL(08)}$(D) = 1.2-1.8

Low τ_E in ^{4}He associated with low p_{ped}



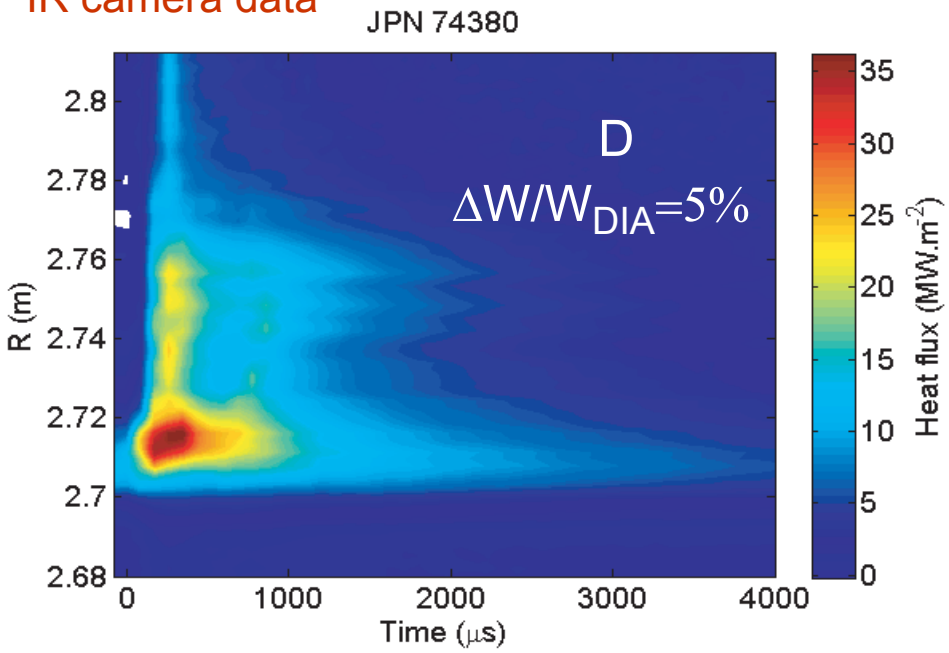
- **In matched ^{4}He/D pair**
  - $W_{th}(^4He)/W_{th}(D)$=0.6-0.8
  - $p_{e,ped}(^4He)/p_{e,ped}(D)$=0.6-0.8

- **Not purely an isotope effect as ^{4}He discharges had high n_{neut} and some ^{4}He discharges had high P_{rad}/P_{loss}<30%.**

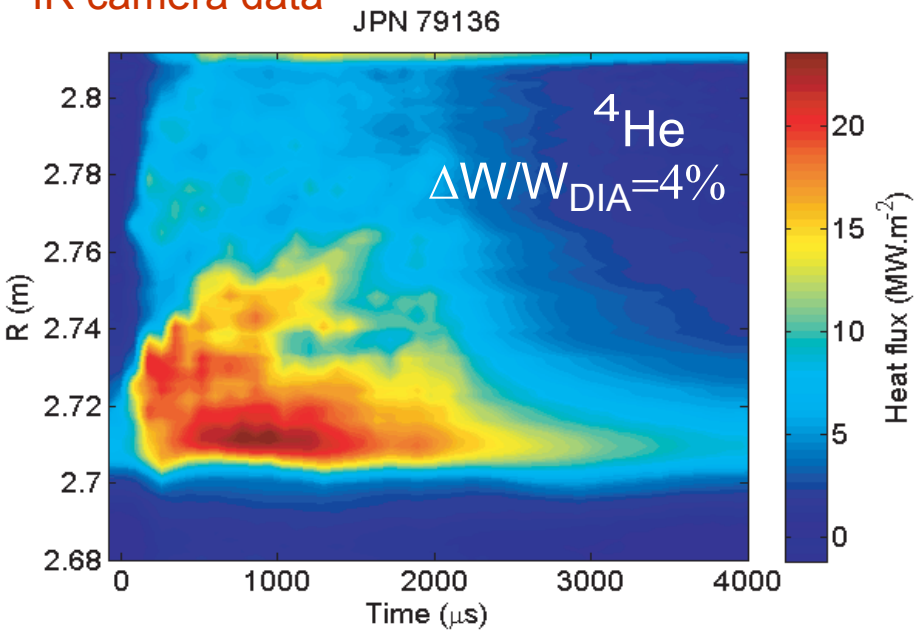
$\Rightarrow$ improved $\tau_E(^4He)/\tau_E(D)$ possible

Type I ELM divertor heat loads

IR camera data



IR camera data



- **ELM heat loads:** ^{4}He and D have similar widths, but with ^{4}He ELMs having much longer arrival times – **see W Fundamenski, EXD/P3-11,Wed am**
- **RMPs did not mitigate ^{4}He ELMs.** Believed to be related to the high n_{neut} in ^{4}He rather than an isotope effect – **see E de la Luna oral, EXC/8-4, Fri**

ITER predictions

$P_{L-H}/P_{TH,SCAL(08)}(^4He) = 1\text{-}1.4$

$P_{I-III}/P_{TH,SCAL(08)}(^4He) = 1.4\text{-}1.6$

$P_{L-H}/P_{TH,SCAL(08)}(H) = 2$

$P_{I-III}/P_{TH,SCAL(08)}(H) = 3?$

$H_{98(y,2)}\ (^4He)=0.6\text{-}0.8$

ITER Half-field (7.5MA/2.65T) baseline

	$<n_e>$ (10^{20} m^{-3})	f_{Gr}	Threshold power			
			^{4}He plasma		H plasma	
			(MW)	95% interval (MW)	(MW)	95% interval (MW)
L-H	0.25	0.42	18-25	12-40	37	20-66
L-H	0.5	0.85	30-42	20-65	60	33-108
Type I	0.5	0.85	42-48	23-86	90?	

- Existing physics base predicts hydrogen Type I ELMy H-mode operation is outside of maximum design power levels (73MW)
- ^{4}He Type I ELMy H-mode operation is within design power levels

Summary

- Strong dependence of P_{TH} on the X-point height at the divertor for H, D and He plasmas (not included in P_{TH} scaling)
- The difference between the H-mode threshold power (P_{TH}) for He and D plasmas decreases at higher densities
- Resonant magnetic perturbations (n=3) increase P_{TH} in He and D plasmas
- Scan from D to He in JET showed no change in L-H power threshold, but density dependence of L-H power threshold in He was different from that in D
- Type I ELM threshold was found to be similar for D and He at approximately 1.5 times the ITPA 2008 L-H threshold scaling for D
- ITPA 2008 scaling predicts type I ELMy H-mode operation is unlikely in H, but likely in He
- Essential to include certain effects (e.g. X-point) and determine underlying physics of all known effects for reliable predictions by H-mode power threshold scalings

DIII-D NATIONAL FUSION FACILITY

CCFE CULHAM CENTRE FOR FUSION ENERGY

EFDA JET