

L-H Transition Studies on DIII-D to Determine H-mode Access for Operational Scenarios in ITER

by

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for

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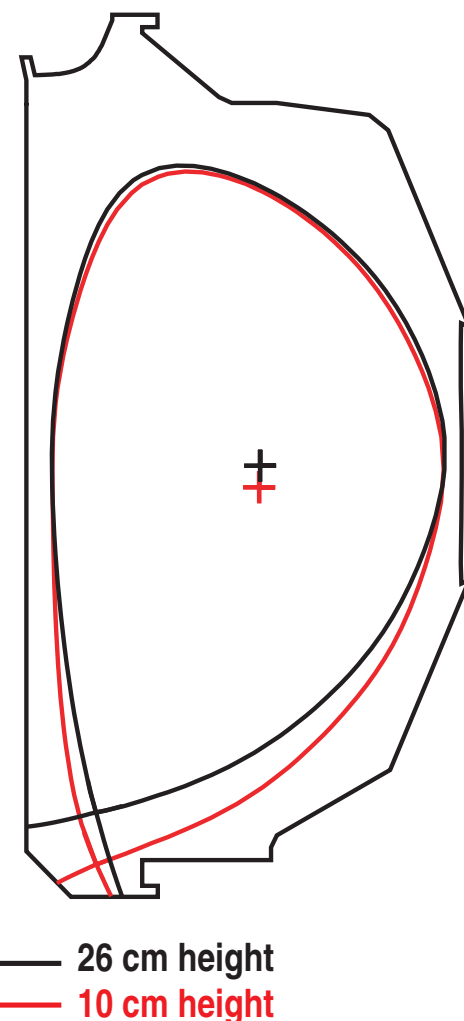
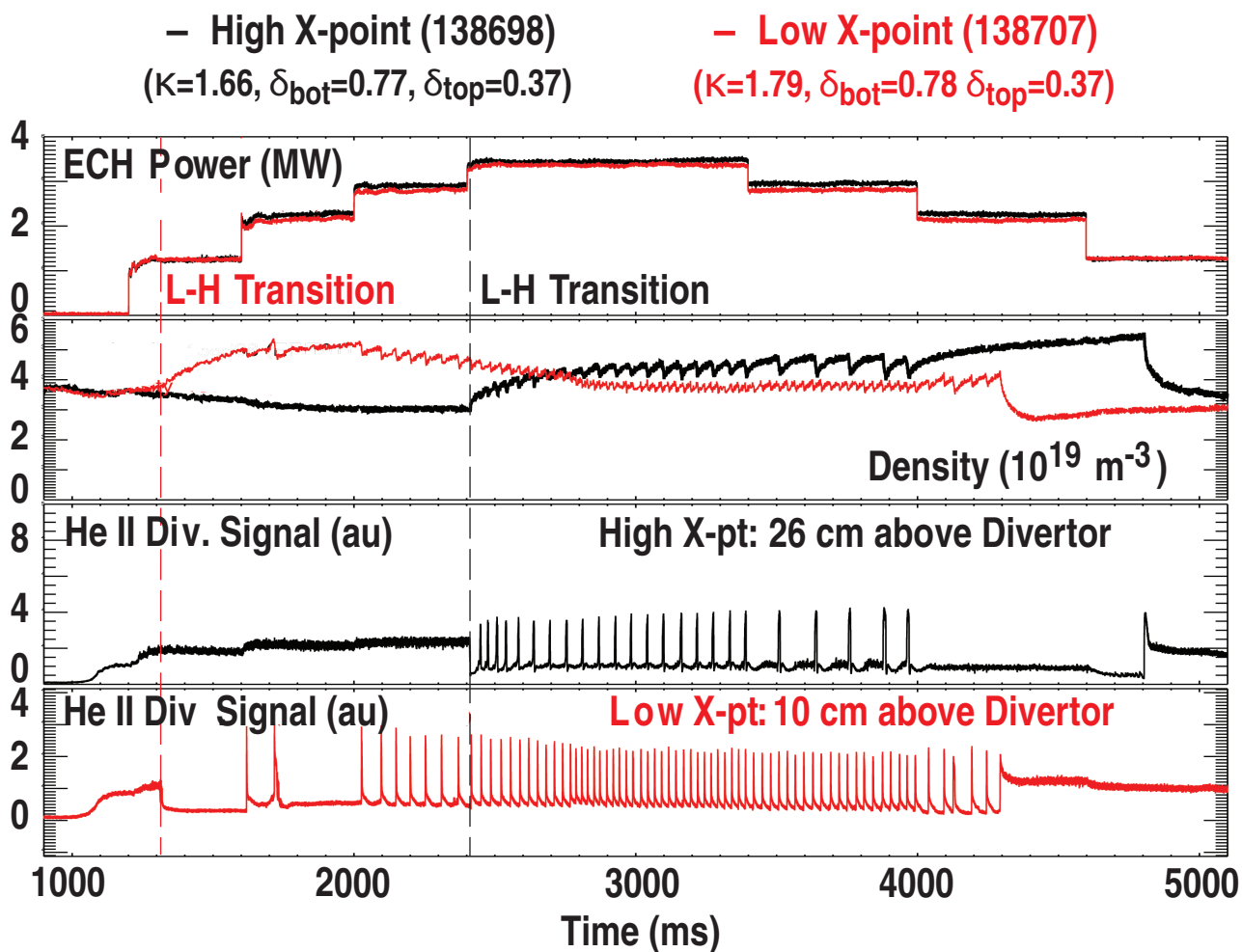


Background/Motivation

- **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**
- **Reduce the large scatter in H-mode power threshold database and large range in scaling predictions**
 - Examine physical trends not included in P_{TH} scaling
- **Determine methods to reduce the H-mode power threshold and extrapolate to ITER**
- **Knowledge beyond the L-H transition is important; quality of H-mode performance dependent on input power above threshold power**
 - Affects pedestal behavior, ELM characteristics, etc.

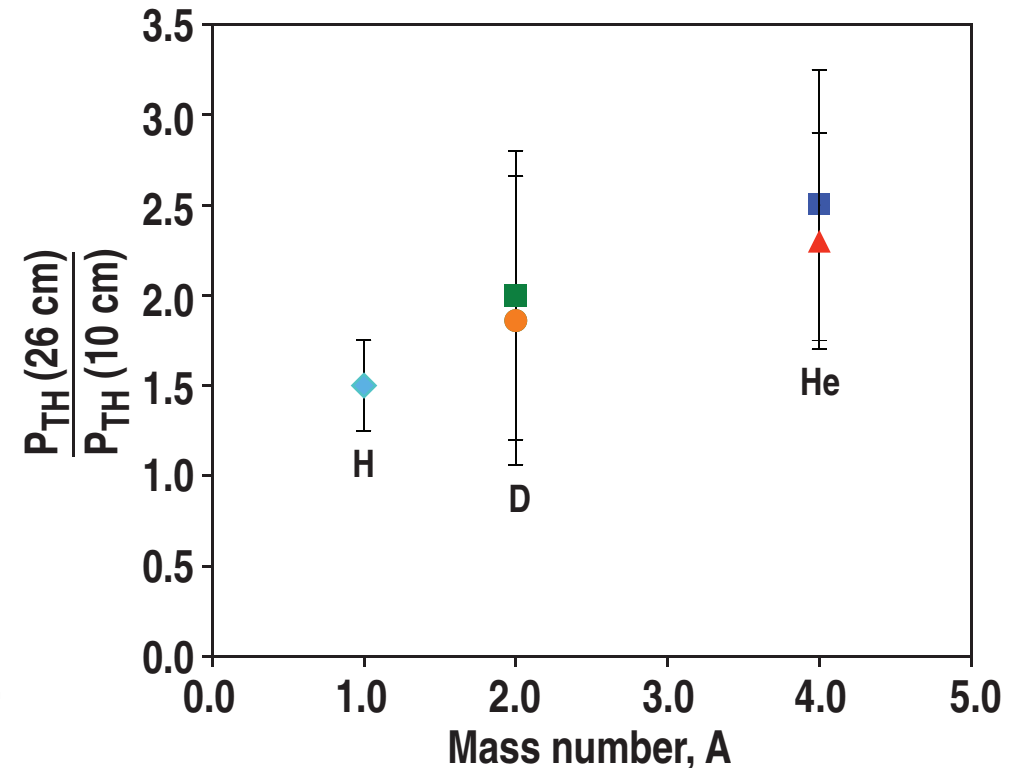
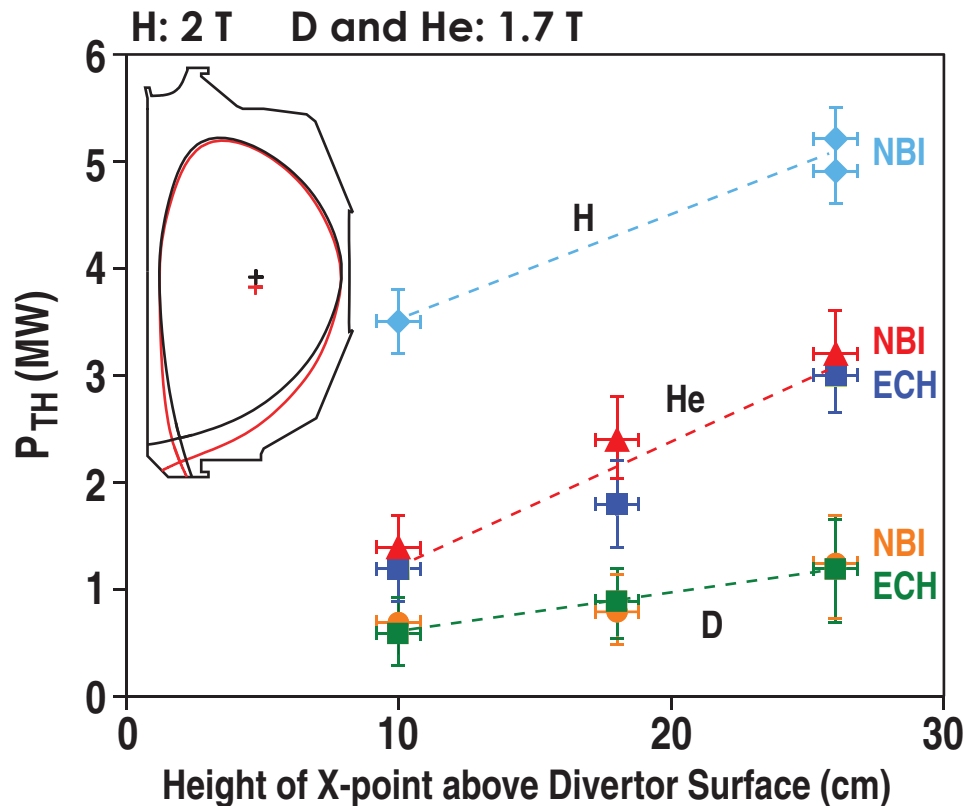
The Plasma Geometry in Vicinity of Divertor has a Strong Effect on P_{TH}

- ECH into He plasmas



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

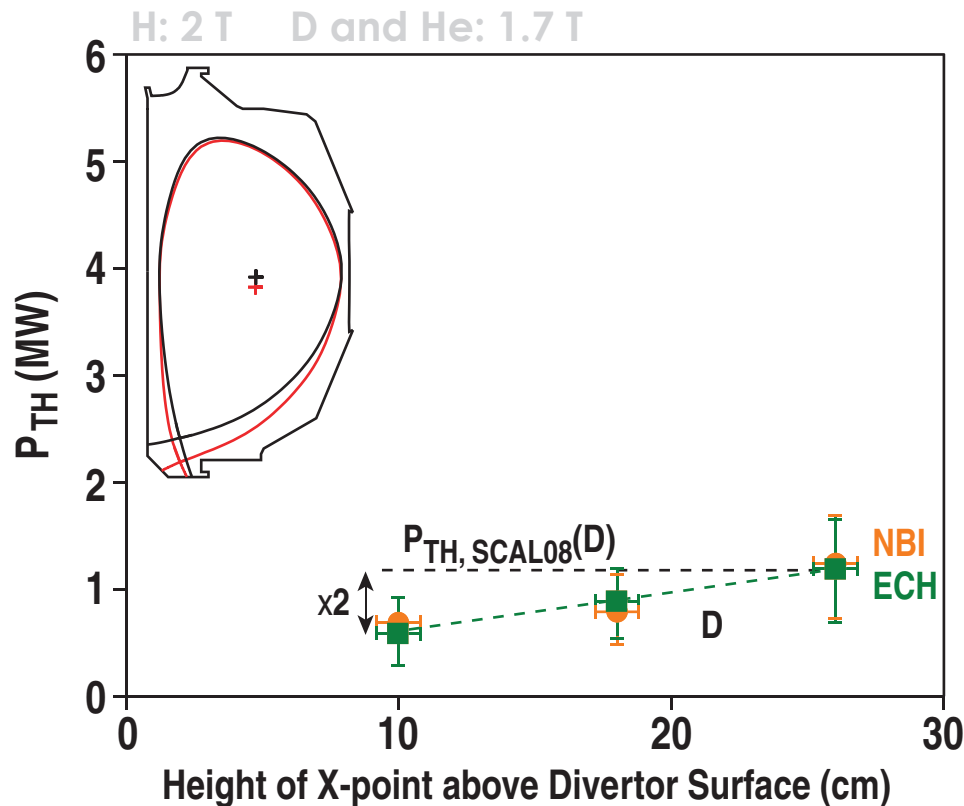
- Effect previously observed on DIII-D and other devices
- First systematic study of effect for H, D and He
- $P_{TH} = P_{OH} + P_{AUX} - \dot{W} - P_{rad}$



- Preliminary analysis indicates edge neutrals may be affecting the power threshold

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- **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

- Preliminary analysis indicates edge neutrals may be affecting the power threshold

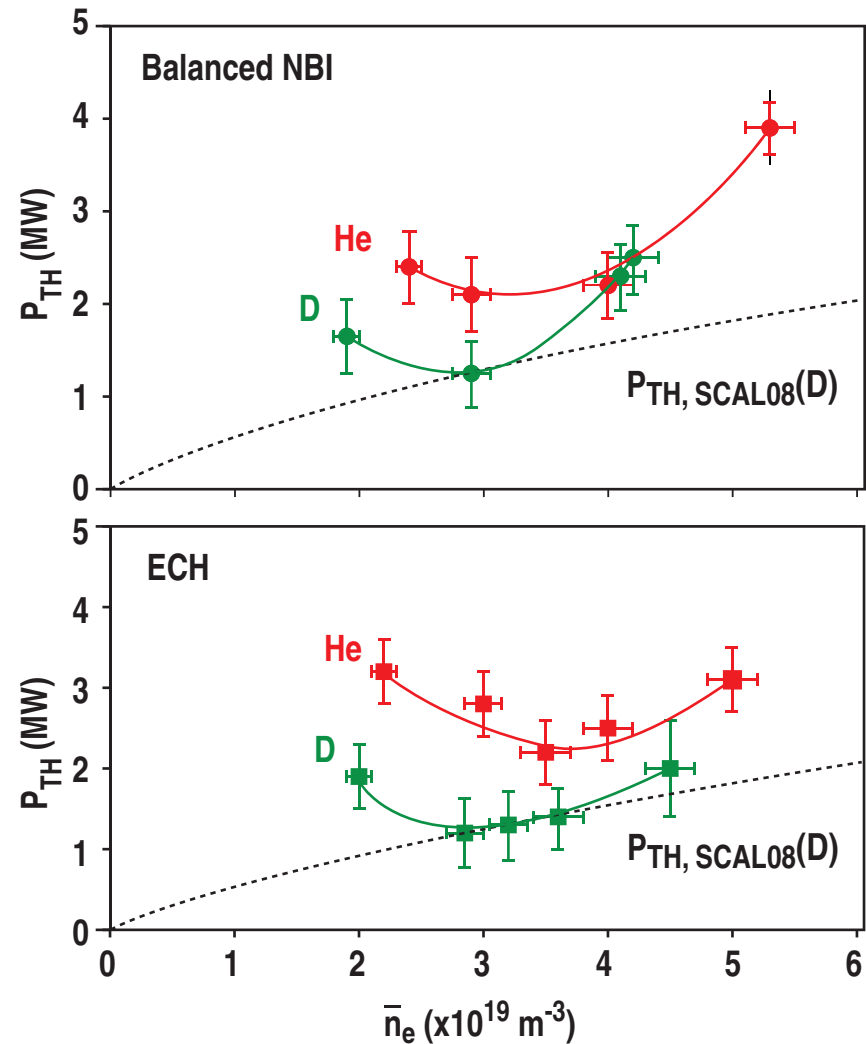
Difference in the H-mode Power Threshold Between He and D Plasmas Decreases at Higher Densities

- **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 \rightarrow D; He - NBI \rightarrow He)
- ECH
- High X-point location

- **At low densities ($<3 \times 10^{19}$ m $^{-3}$)**
 P_{TH} (He) ~ 1.5 - $2 P_{TH}$ (D)

- **At high densities ($>3 \times 10^{19}$ m $^{-3}$)**
 P_{TH} (He) ~ 1 - $1.5 P_{TH}$ (D)



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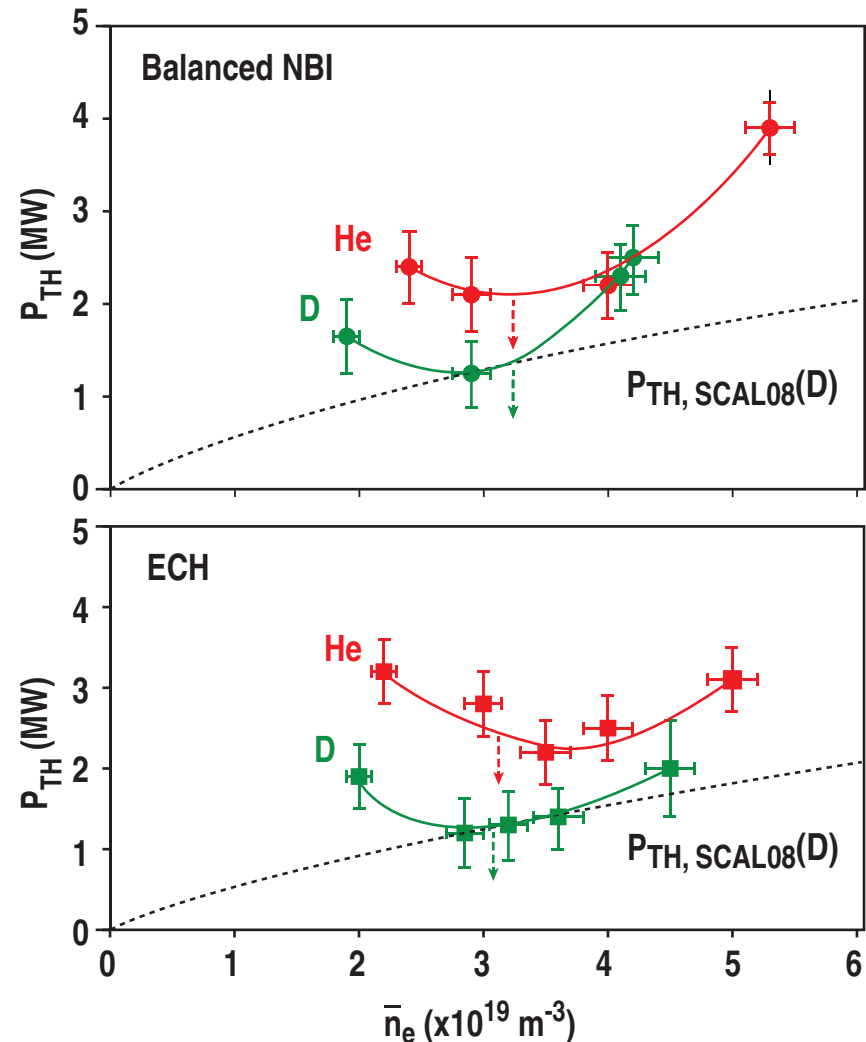
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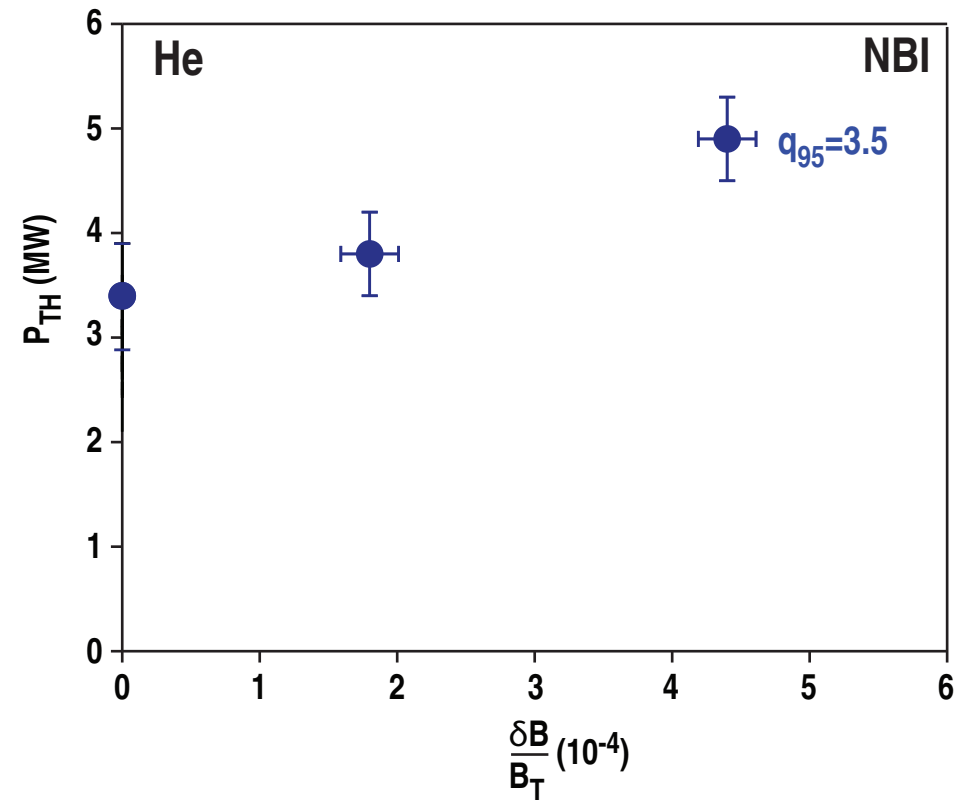
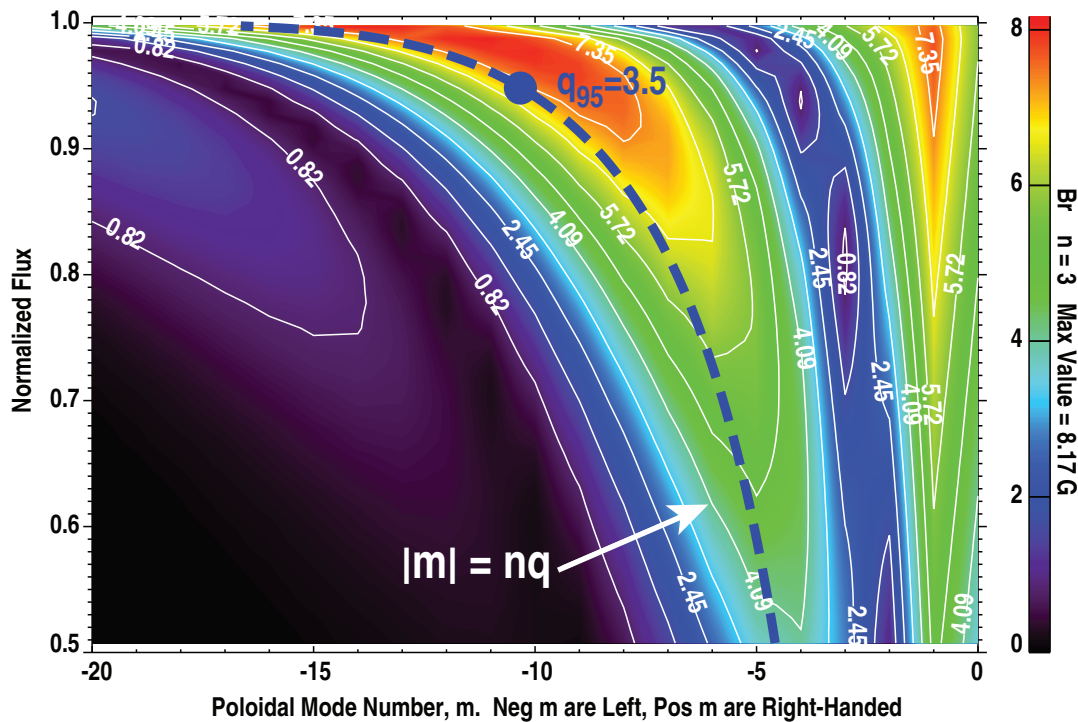
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- Lowering the X-point will move all curves significantly downwards with respect to the scaling



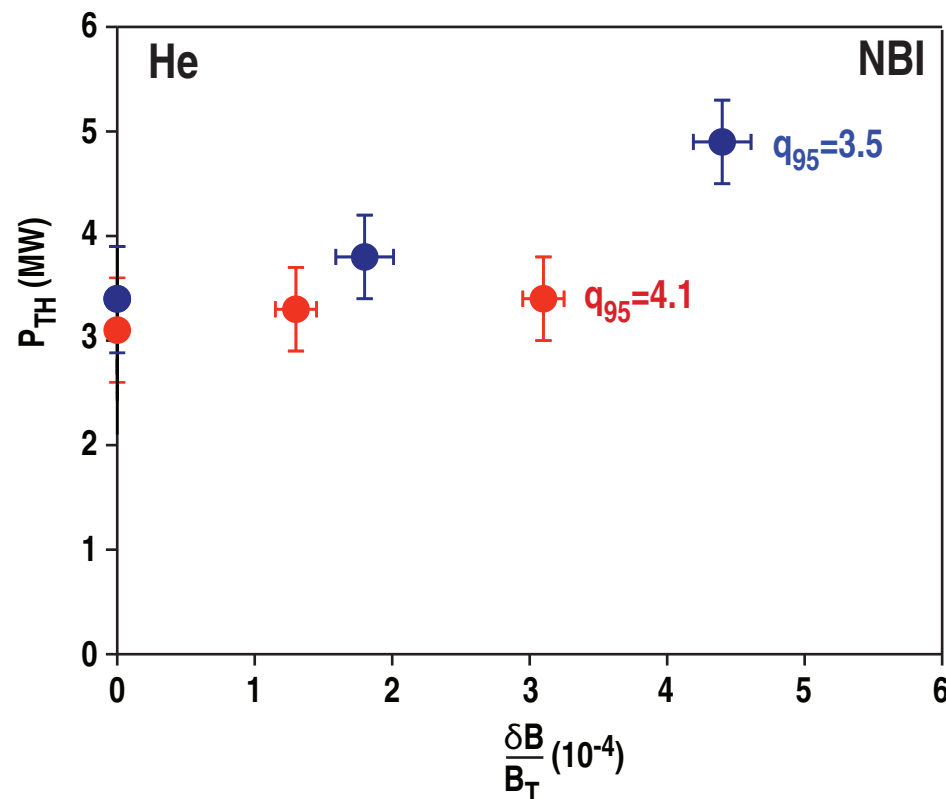
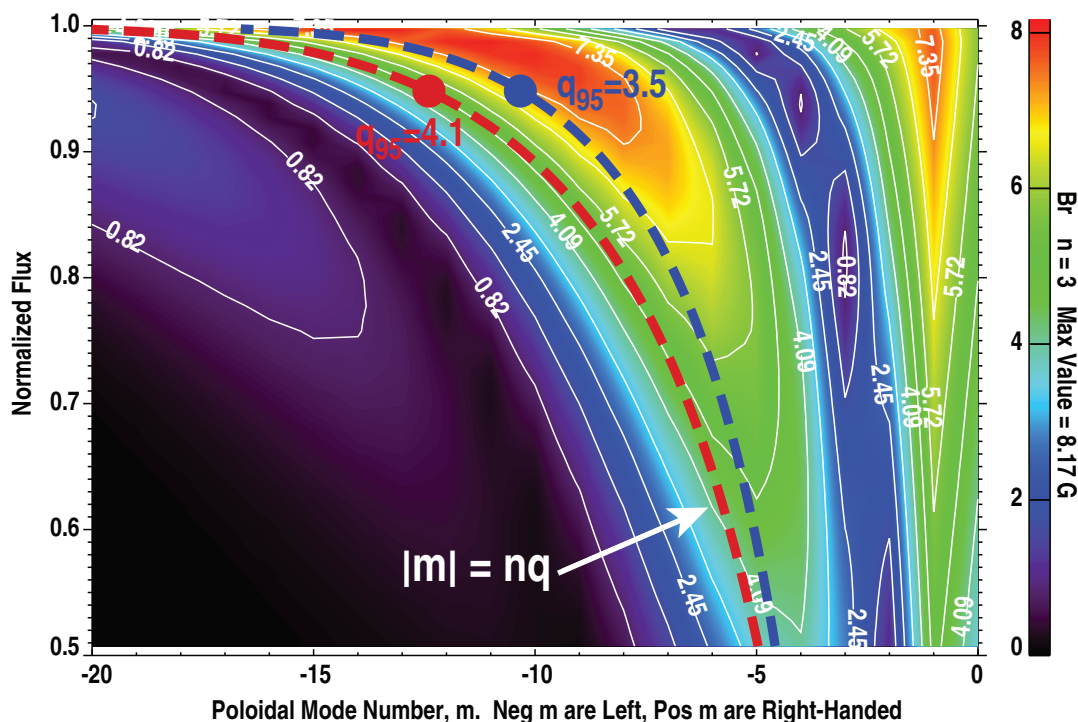
Application of Strong n=3 RMP Fields Increase P_{TH} in Helium Plasmas

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



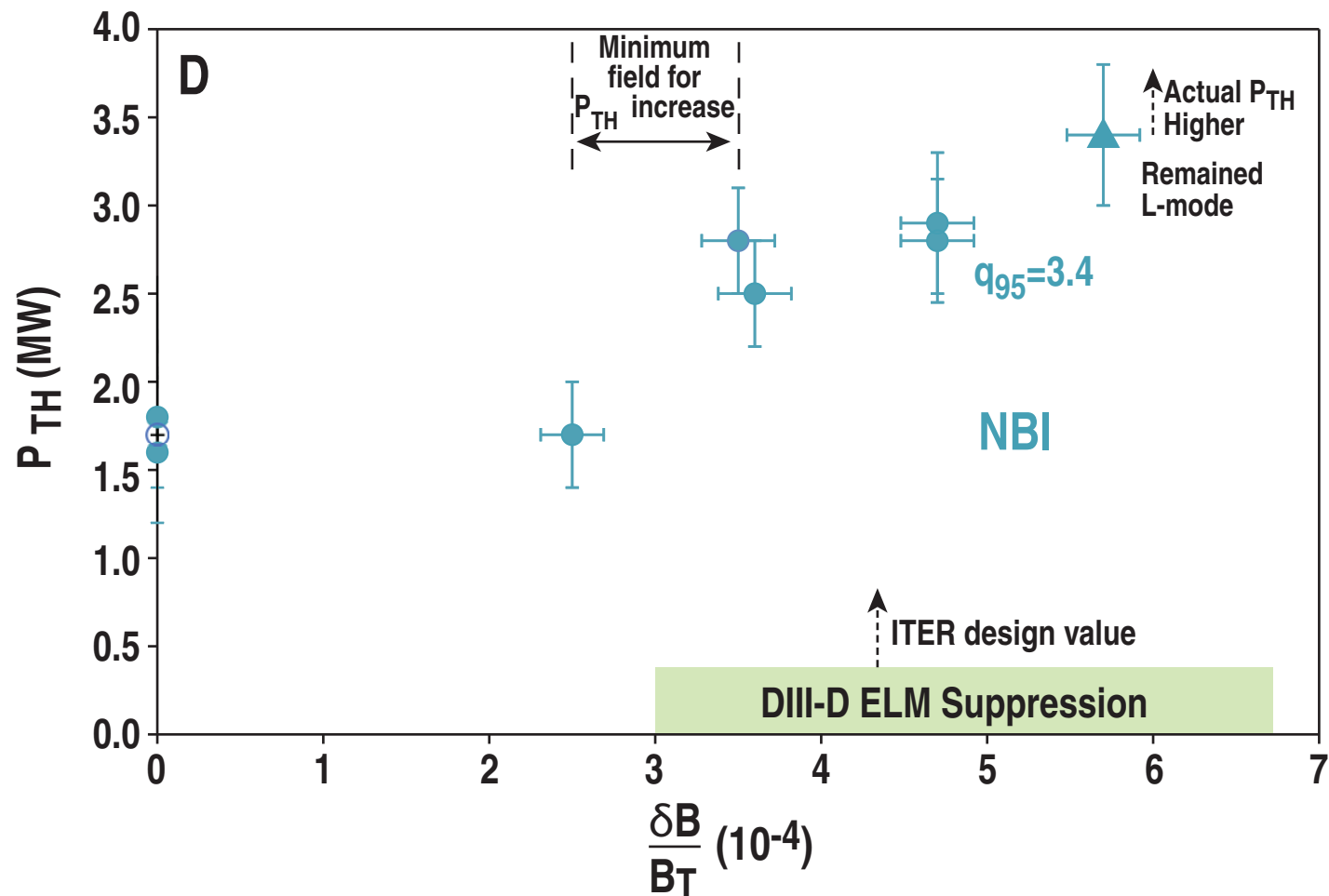
Application of Strong $n=3$ RMP Fields Increase P_{TH} in Helium Plasmas

- $n=3$ resonant magnetic perturbations (RMPs) applied by in vessel coils (I-coils)
- Strongly pitch aligned perturbing fields lead to higher P_{TH}
- Similar effect observed with ECH



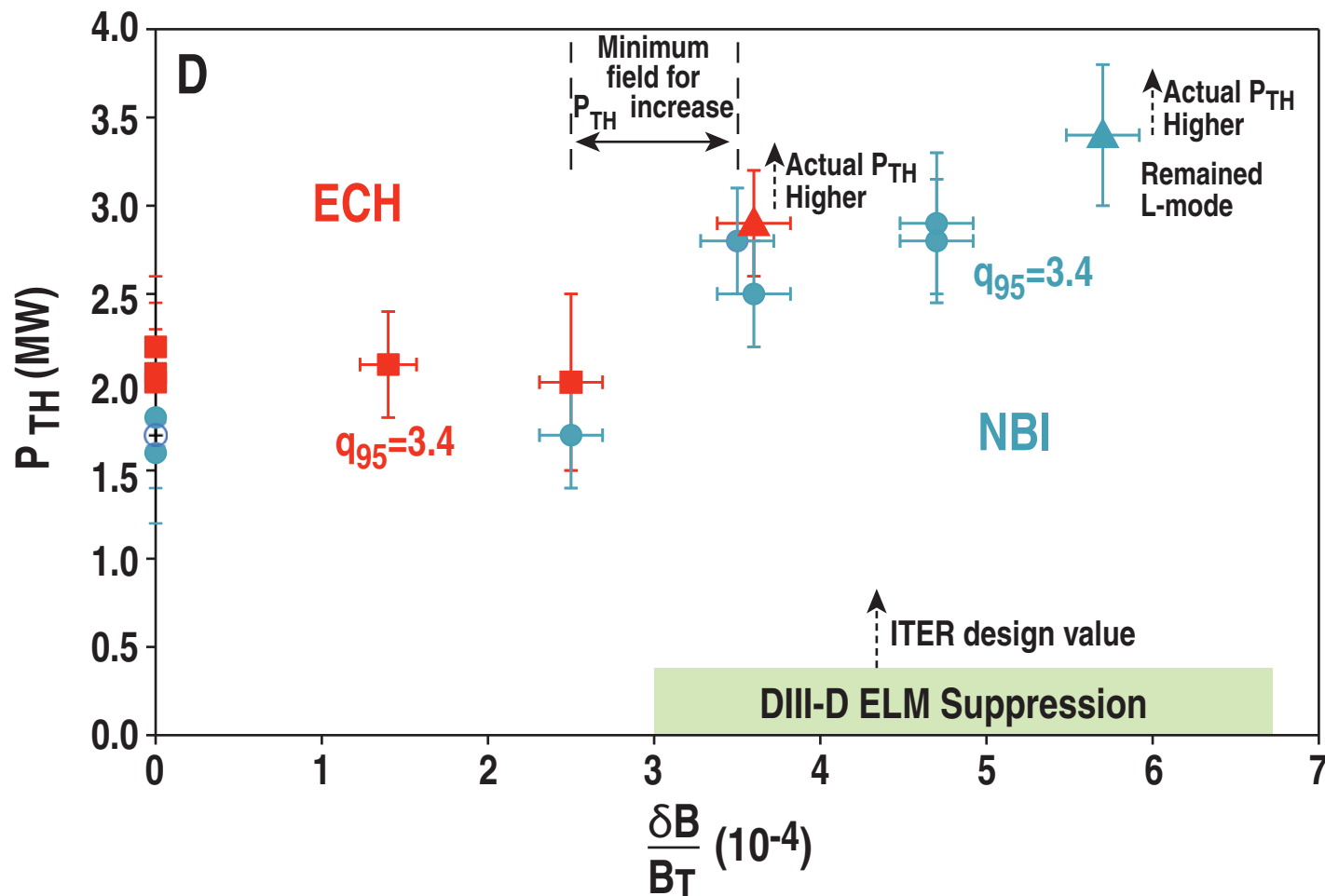
For D Plasmas, there is a Minimum Required RMP Field Before P_{TH} Increases

- Effect on P_{TH} observed for $\delta B/B_T > \sim 3 \times 10^{-4}$



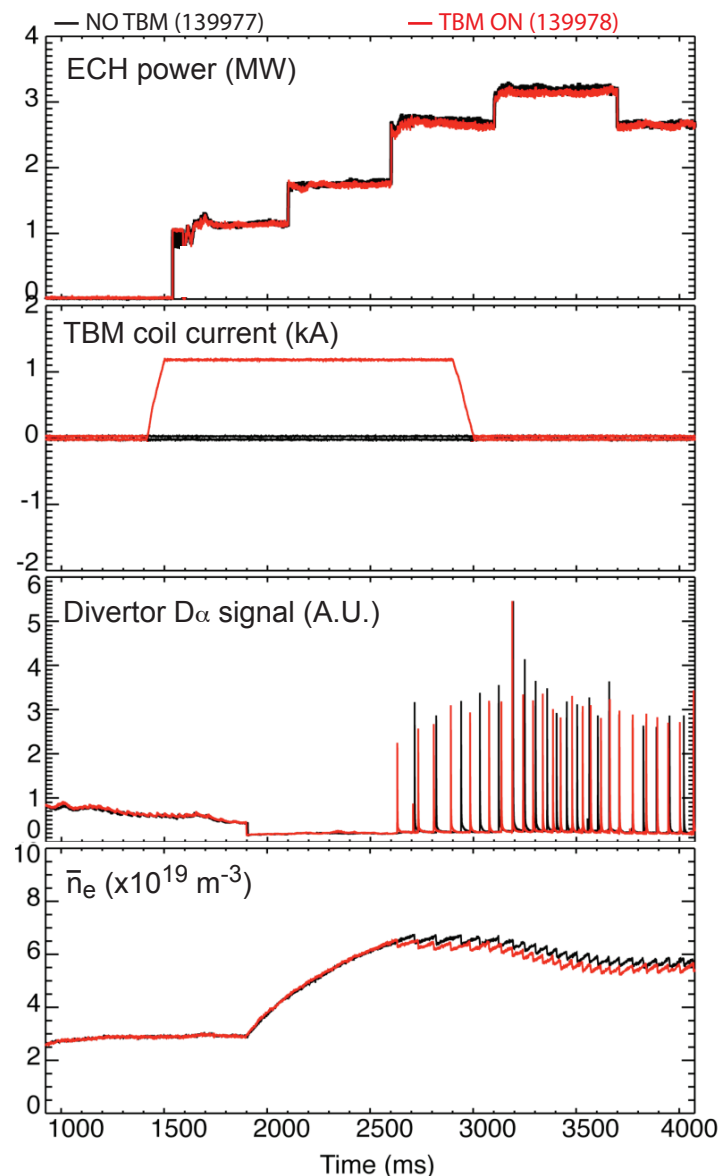
For D Plasmas, there is a Minimum Required RMP Field Before P_{TH} Increases

- Effect on P_{TH} observed for $\delta B/B_T > \sim 3 \times 10^{-4}$
- Determined for both ECH and balanced D-NBI (plasma shape different to He plasma study)



The H-mode Power Threshold is Unaffected by the TBM

- **Test Blanket Module (TBM) magnetic ripple replicated using mock up coils on DIII-D**
 - Results are for TF + TBM local ripple ~3.1% (expected TF + TBM local ripple in ITER ~1.3%)
- **Determined for ECH, balanced D-NBI and co D-NBI in D plasmas**



Summary

- **Strong dependence of the H-mode power threshold (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 P_{TH} for He and D plasmas decreases at higher densities**
- **Resonant magnetic perturbations ($n=3$) increase P_{TH} in He and D**
 - Threshold in RMP field for effect on P_{TH} in D
 - May require appropriate timing of RMP coil activation after L-H transition
- **Need to include certain dependences (e.g. X-point) and determine underlying physics of all known effects for reliable predictions by H-mode power threshold scalings**