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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DIII-D
NATIONAL FUSION FACILITY

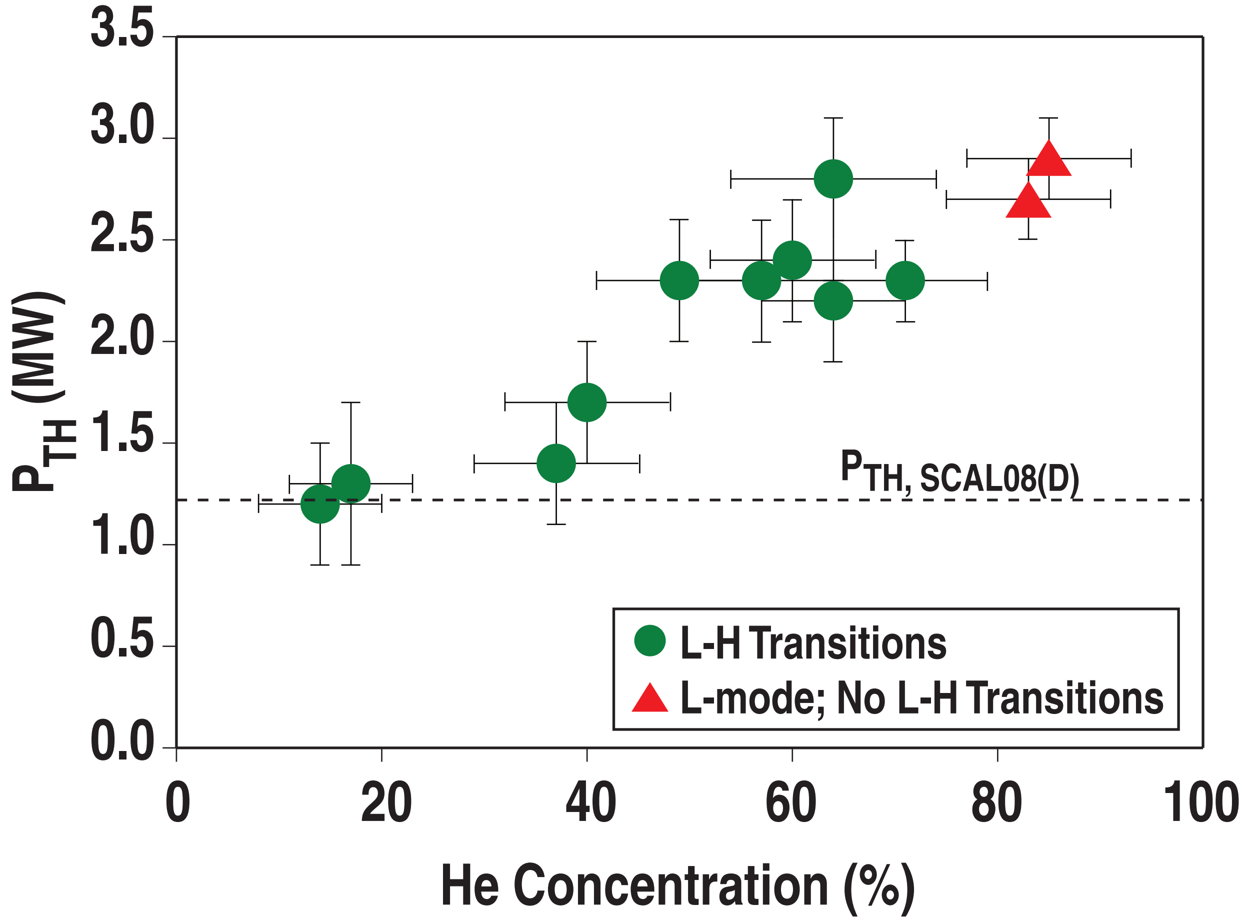
GENERAL ATOMICS
266-10/PG/jy

Background/Motivation

- **Can H-mode be achieved in the first (non-nuclear) phase of ITER operations with He (and/or H) plasmas ?**
- **Need to access H-mode in non-nuclear phase of ITER operations**
  - Assess machine hardware and systems in higher performance H-mode plasmas e.g. heat loads, fueling, heating, etc.
  - Test ELM mitigation techniques and hardware in ITER environment
- **Reduce the large scatter in H-mode power threshold database and large error in scaling predictions**
  - Examine physical trends not included in P_{TH} scaling
  - Obtain physics basis for the scaling laws
- **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.

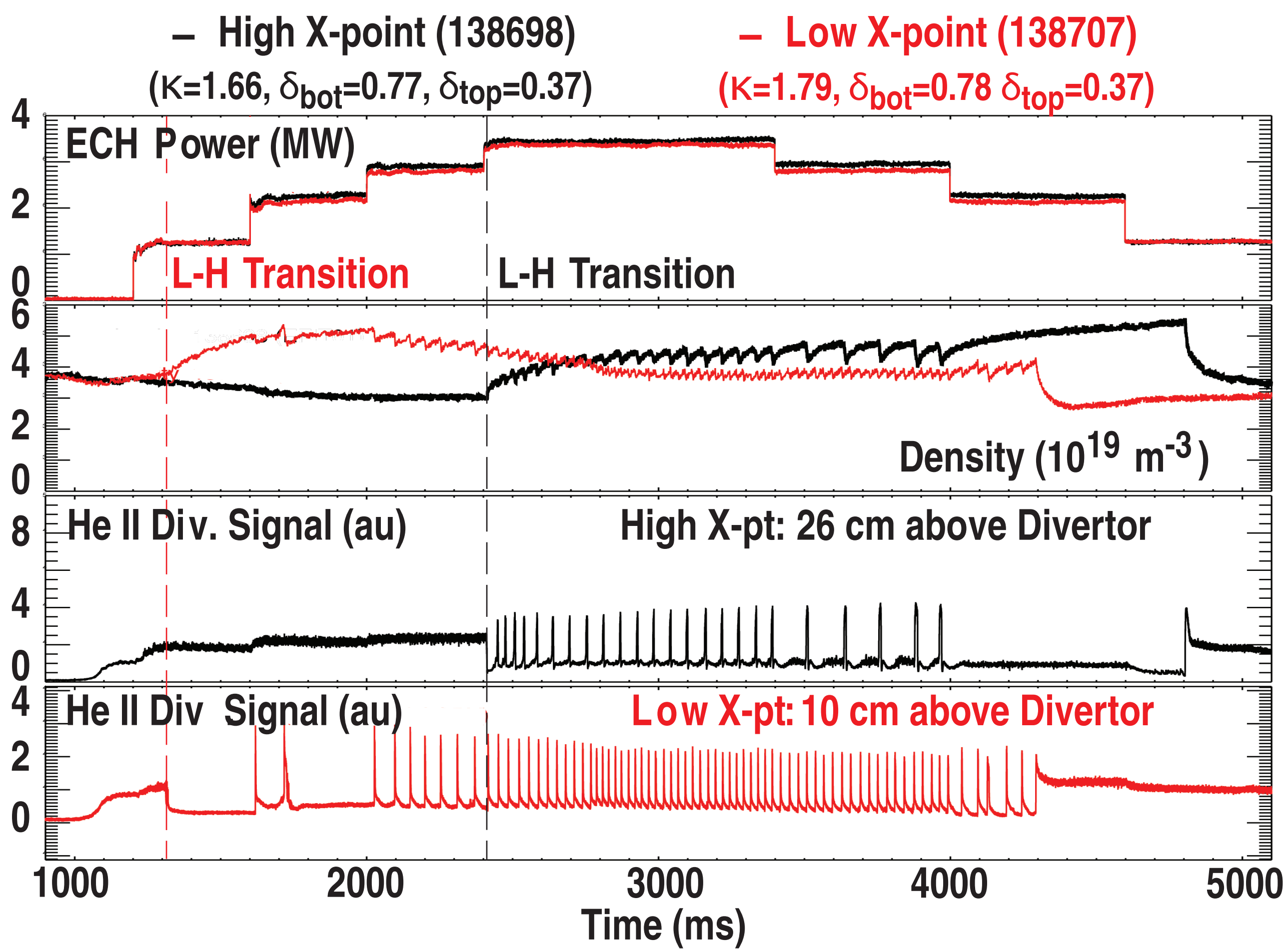
H-mode Power Threhold Increases Smoothly from Near Pure D Plasmas to Near Pure He Plasmas

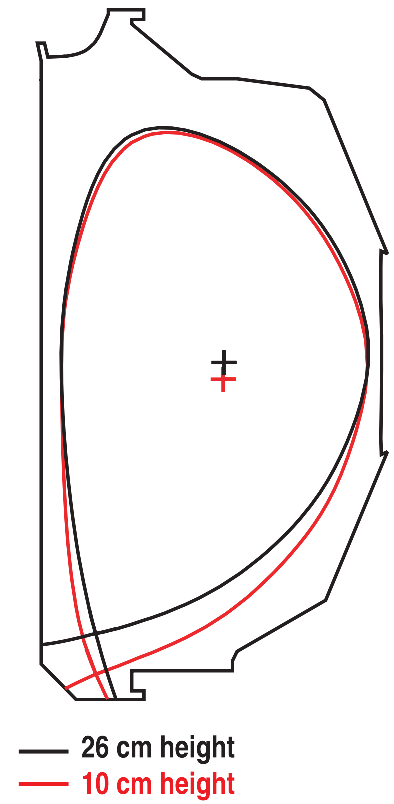
- **No sudden change in P_{TH} observed**
  - He concentrations exceeding 40% exhibit discernible increase in P_{TH}
- **D plasmas: I_p = 1.0 MA, B_T = 1.65 T, n_e = 2.8-3.0x10^{19} m^{-3} with ECH**



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

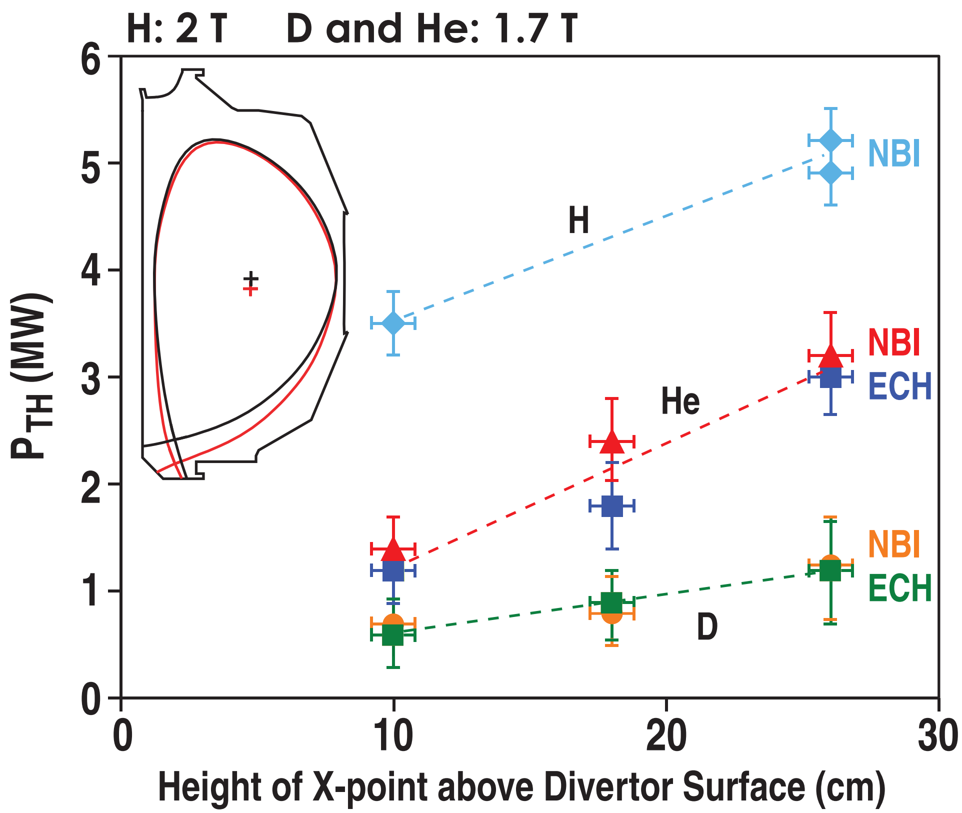
- Decreasing the height of the X-point above the divertor surface significantly decreases P_{TH} (> factor of 2)
- ECH into He plasmas

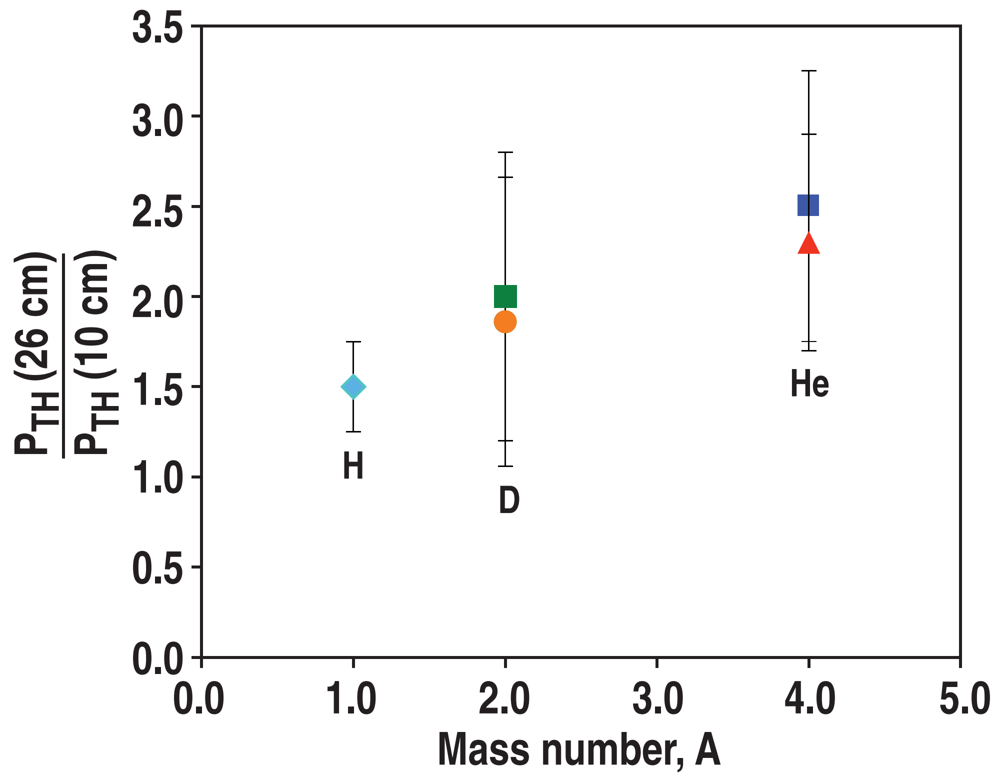




The X-point height has a Strong Effect on the H-mode Power Threshold for H, D and He

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





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

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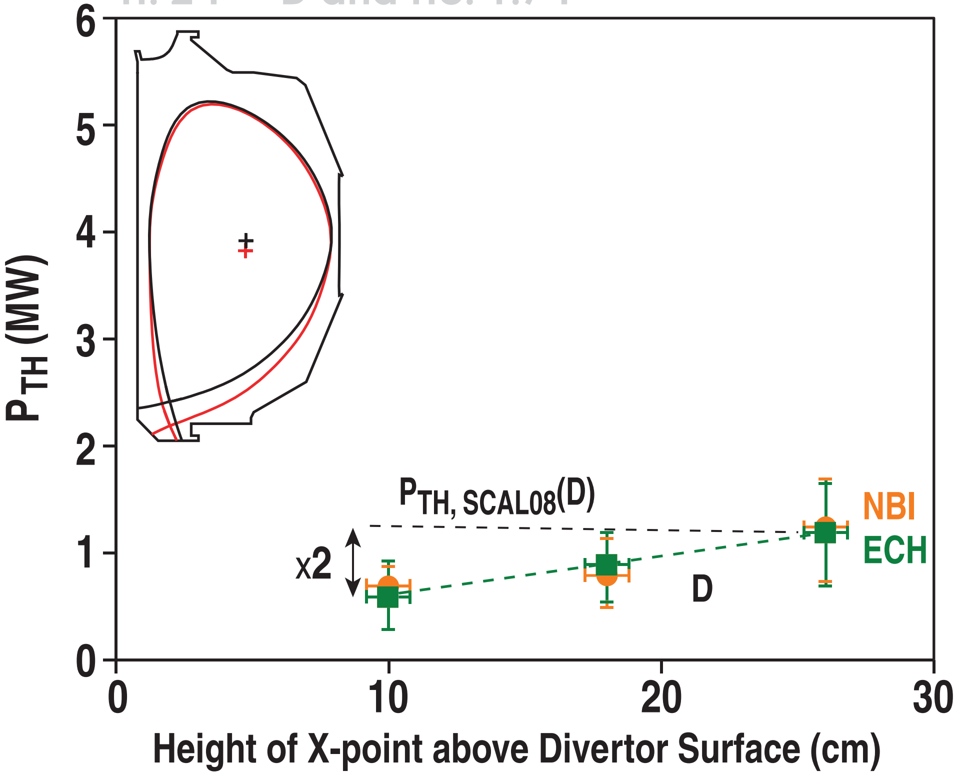
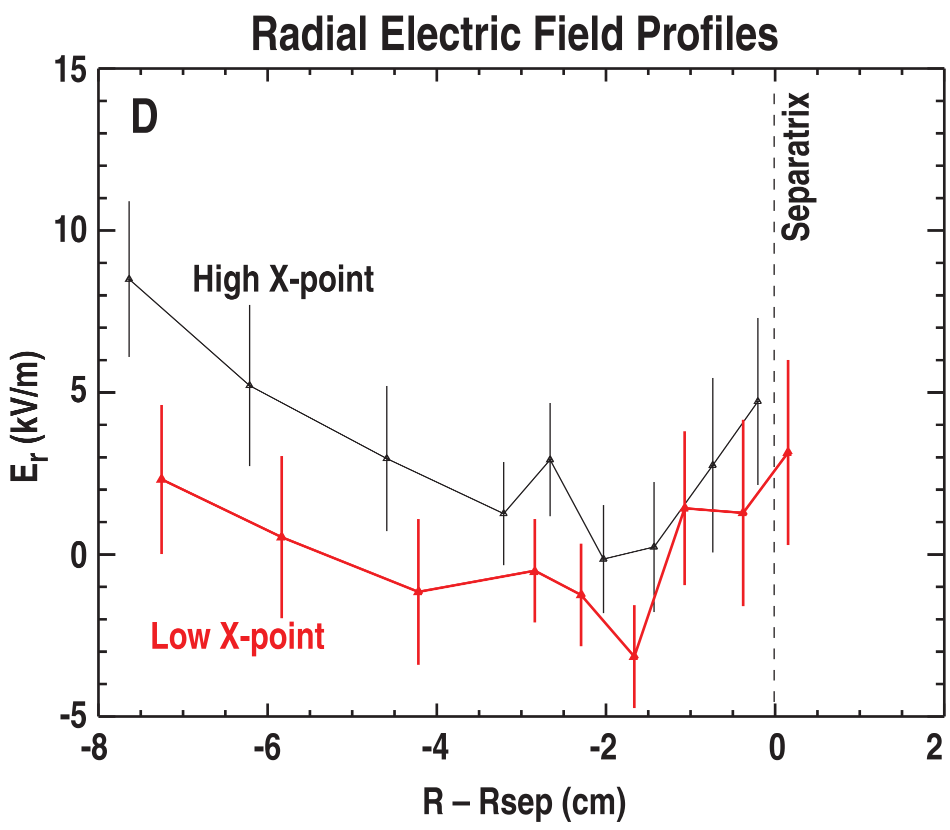
H: 2 T   D and He: 1.7 T

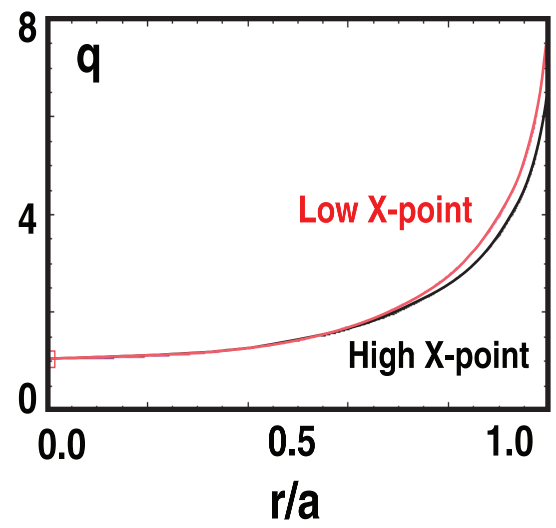


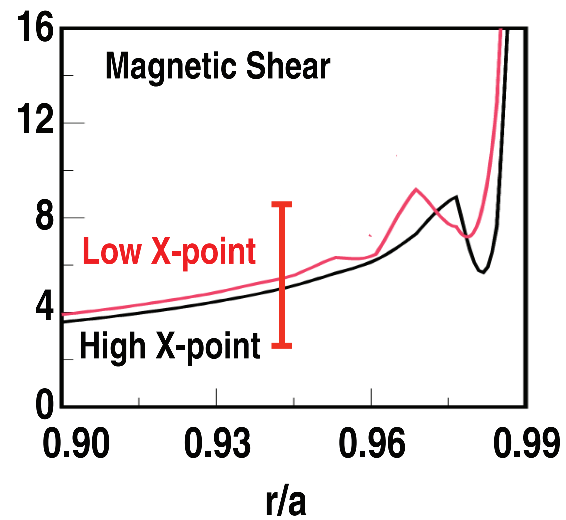
- **H-mode power threshold scaling for D plasmas**
  - $P_{TH, SCAL08}$ (D) = $0.049\, n_e^{0.72}\, B_T^{0.80}\, S^{0.94}$ (units: 10^{20} m^{-3}, T, m^2)
- **X-point dependence is not included in the power threshold scalings**
  - Results in factor of 2 difference between P_{TH} at low X-point and the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

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

Edge E_r Shear and Edge Magnetic Shear Show No Significant Change with X-point Height







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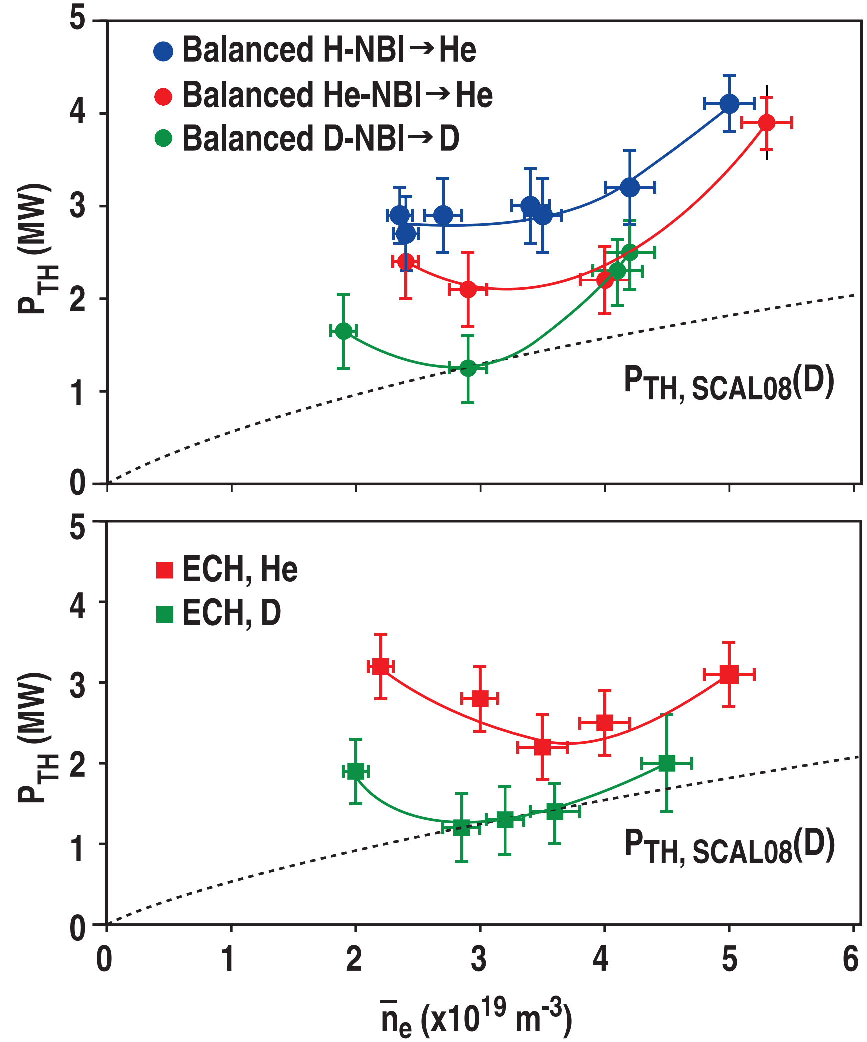
Difference in the H-mode Power Threshold Between He and D Plasmas Decreases at Higher Densities

- **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)**



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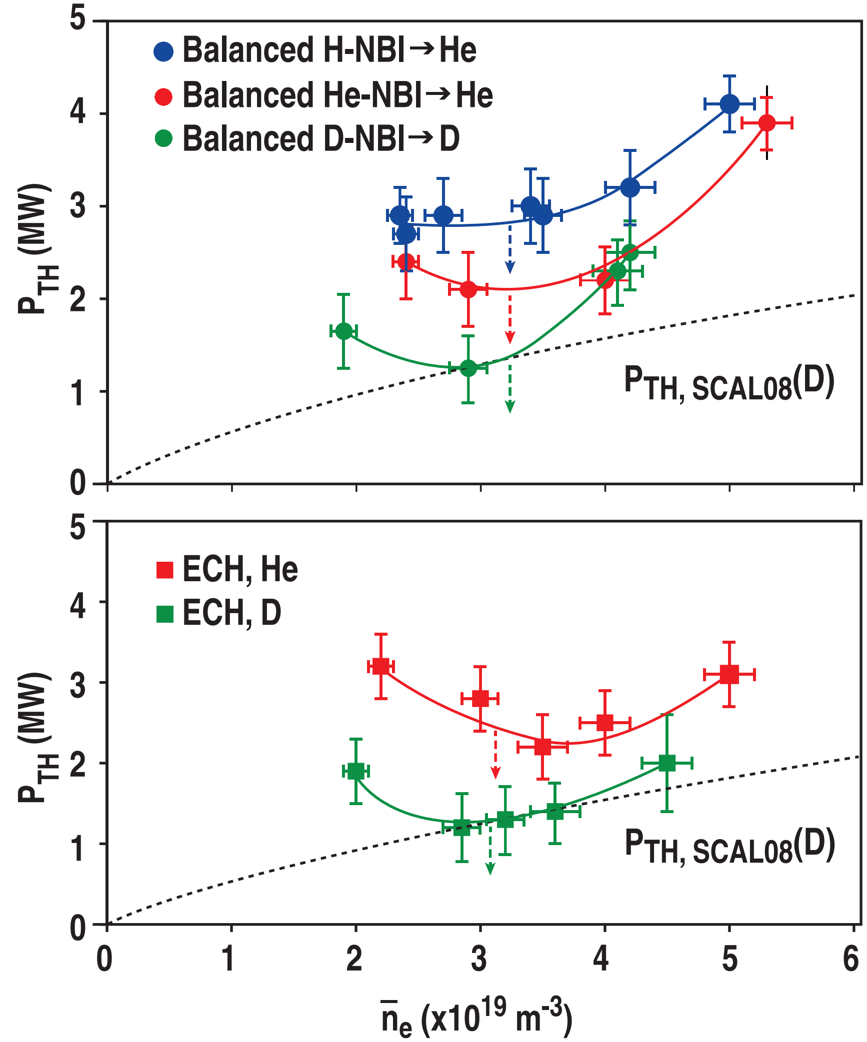
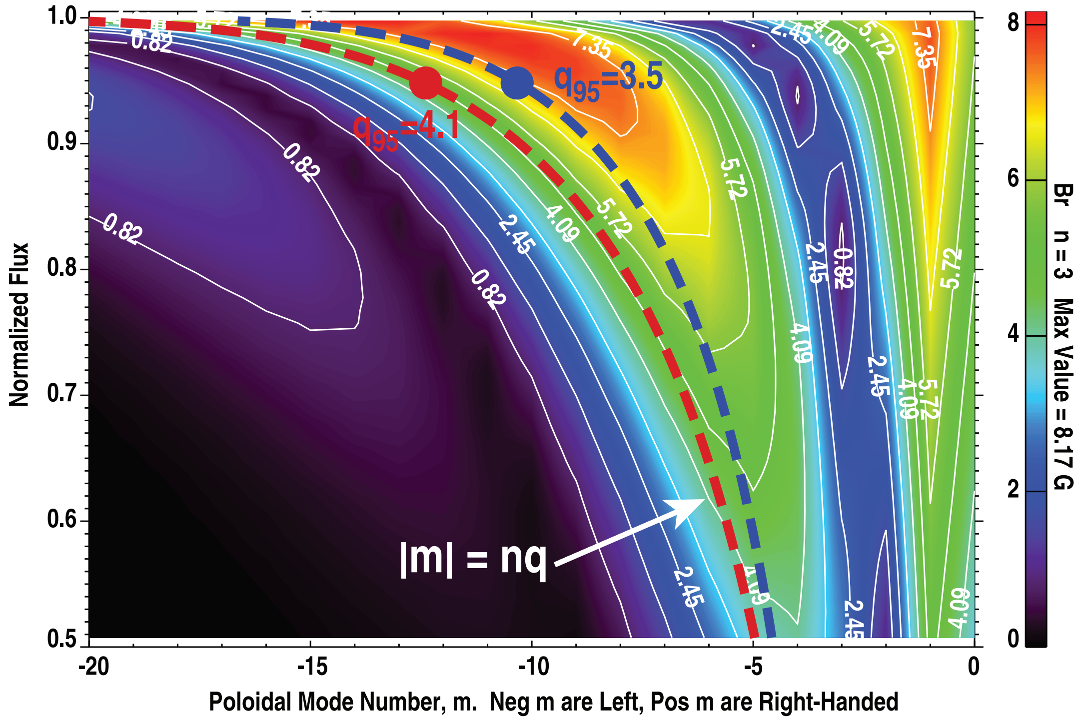
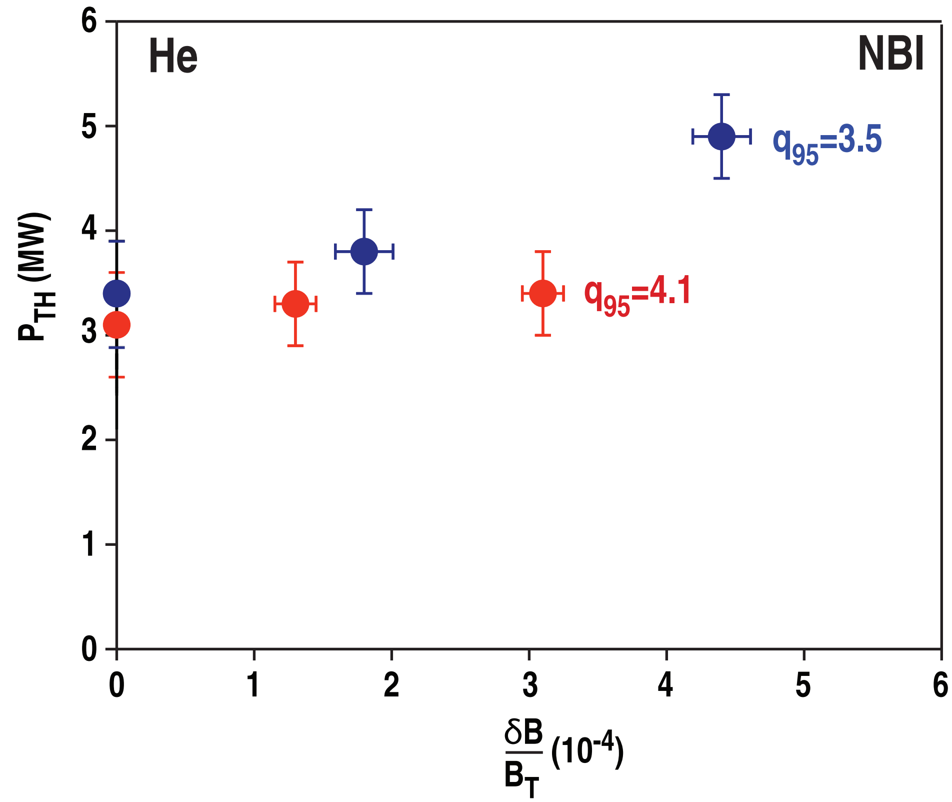
- At low densities (<3x10^{19} m^{-3}) P_{TH} (He) ~1.5-2 P_{TH} (D)
- At high densities (>3x10^{19} m^{-3}) P_{TH} (He) ~1-1.5 P_{TH} (D)
- **Lowering the X-point will move all curves significantly downwards with respect to the scaling**



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)
- Stronger resonant components lead to higher P_{TH}
- Similar effect observed with ECH





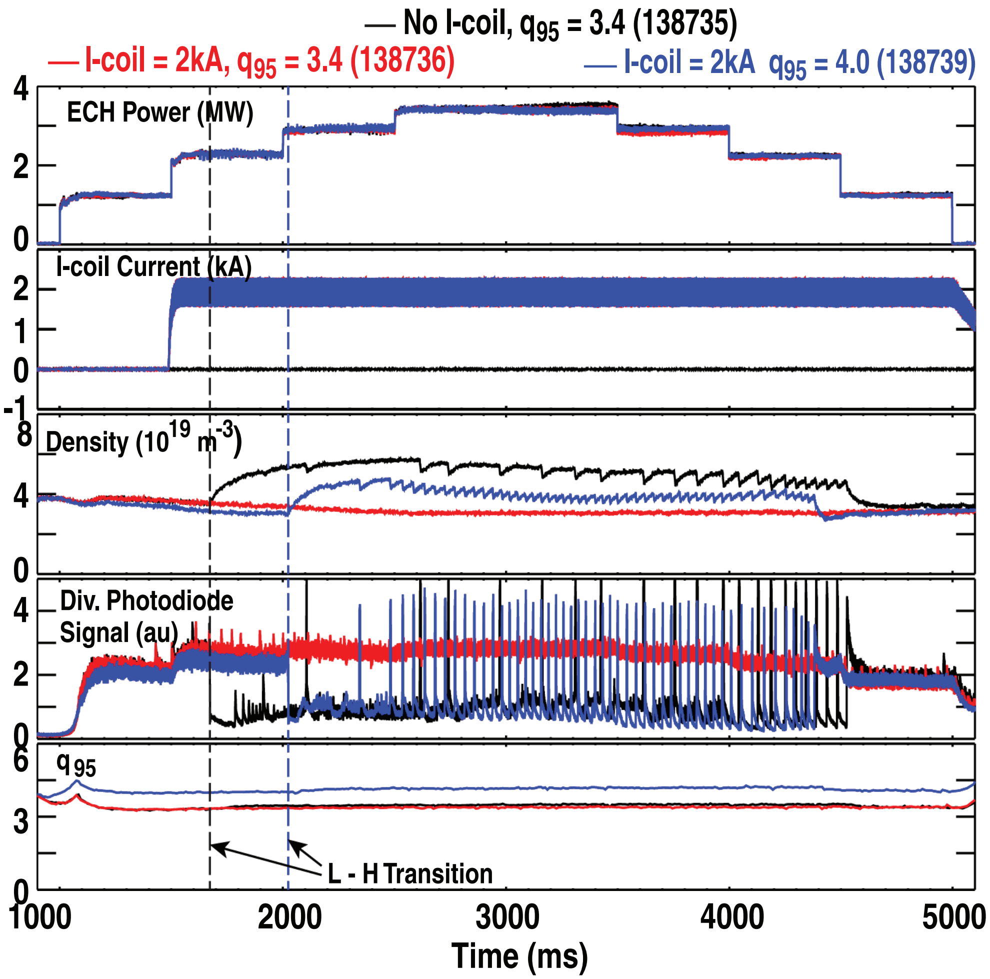
Resonant Magnetic Perturbations Increase the H-mode Power Threshold (Helium Plasmas)

- **n=3 resonant magnetic perturbations (RMPs) applied by in-vessel coils (I-coils) to be resonant at specific values of q_{95} (=3.4)**

- **3 He plasma discharges with**
  - No I-coil at q_{95} = 3.4
  - I-coil current = 2 kA at q_{95} = 3.4
  - I-coil current = 2 kA at q_{95} = 4.0

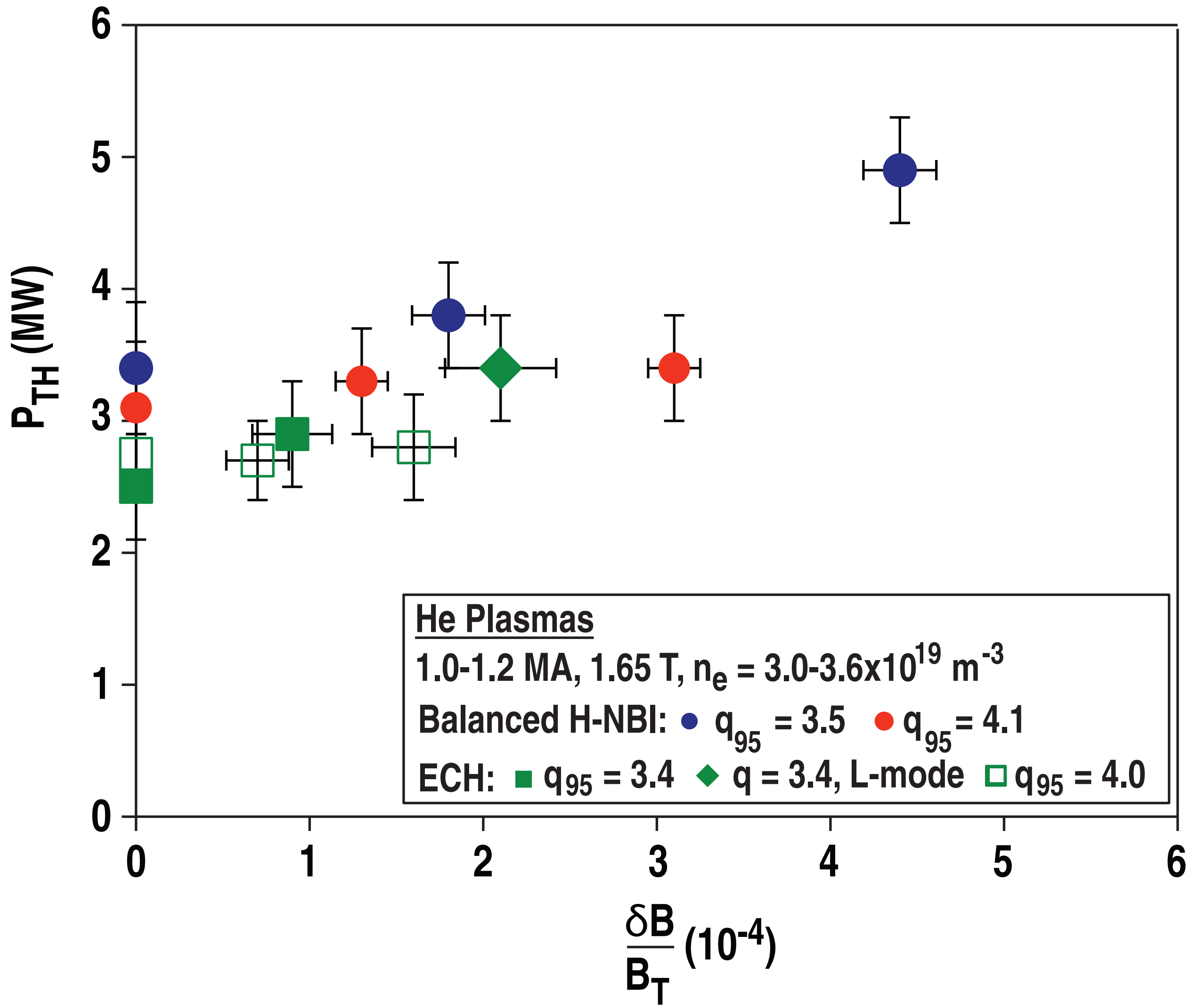
- **Application of I-coil current = 2 kA**
  - Resonant field at q_{95} = 3.4 remained in L-mode at up to P_{ECH} = 3.5 MW
  - H-mode achieved again with non-resonant RMP fields (q_{95} = 4.0)

- **Careful timing of I-coil activation required after L-H transition, but before first type I ELM**



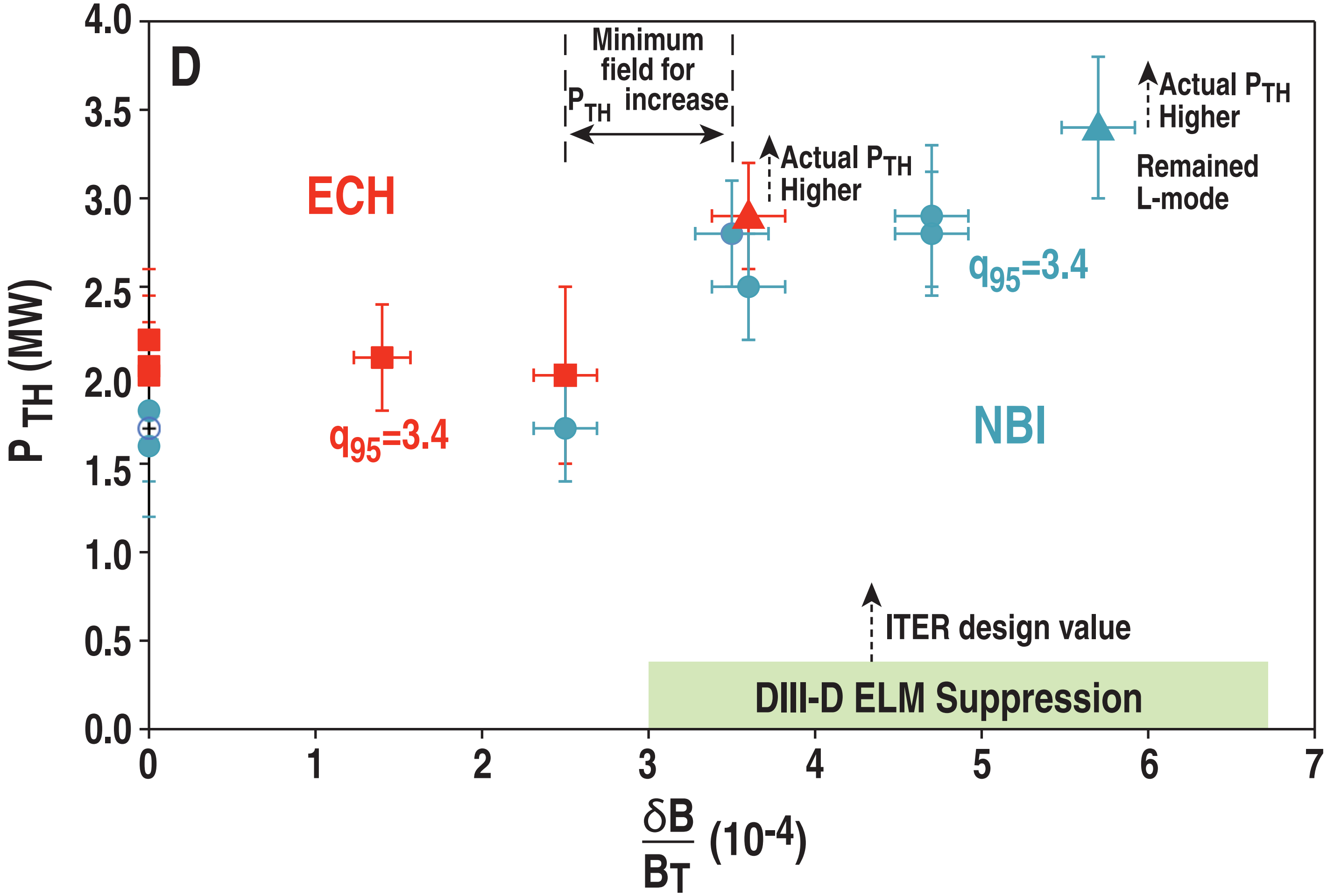
Application of Strong Resonant n=3 RMP Fields Increase P_{TH} for Both ECH and Balanced H-NBI Heating (Helium Plasmas)

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



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

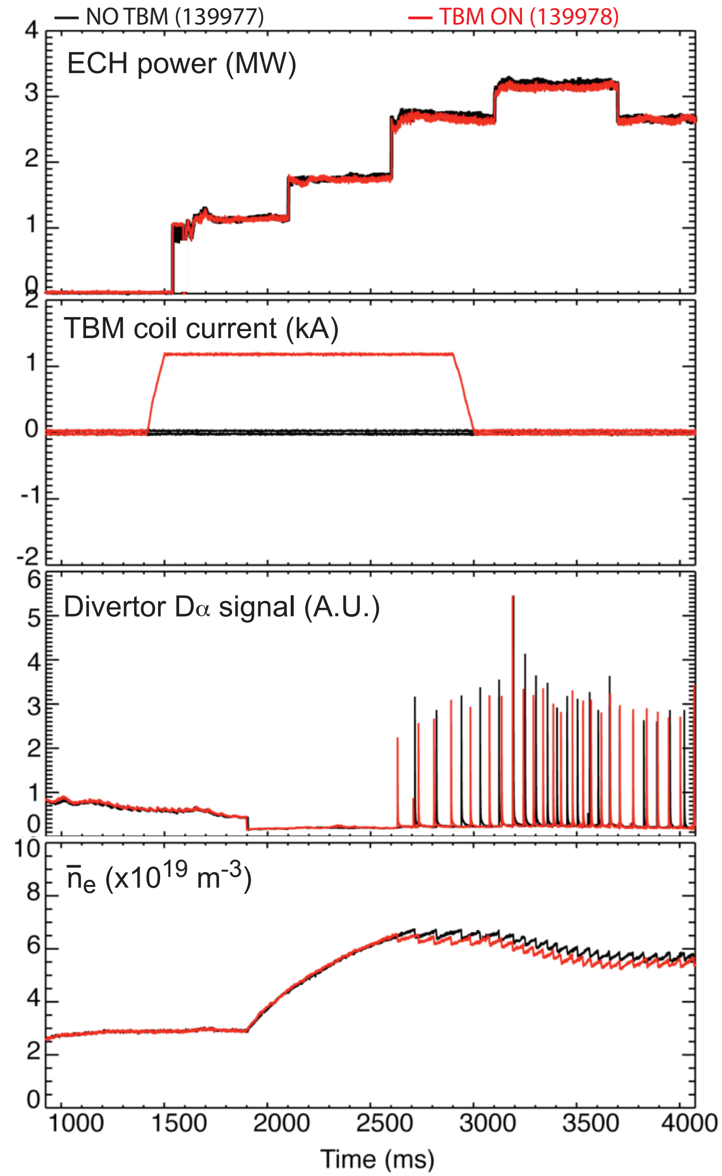
- Effect on P_{TH} observed for $\delta B/B_T > \sim 3x10^{-4}$
- Determined for both ECH and balanced D-NBI (plasma shape different to He plasma study)



The H-mode Power Threshold is Unaffected by the TBM

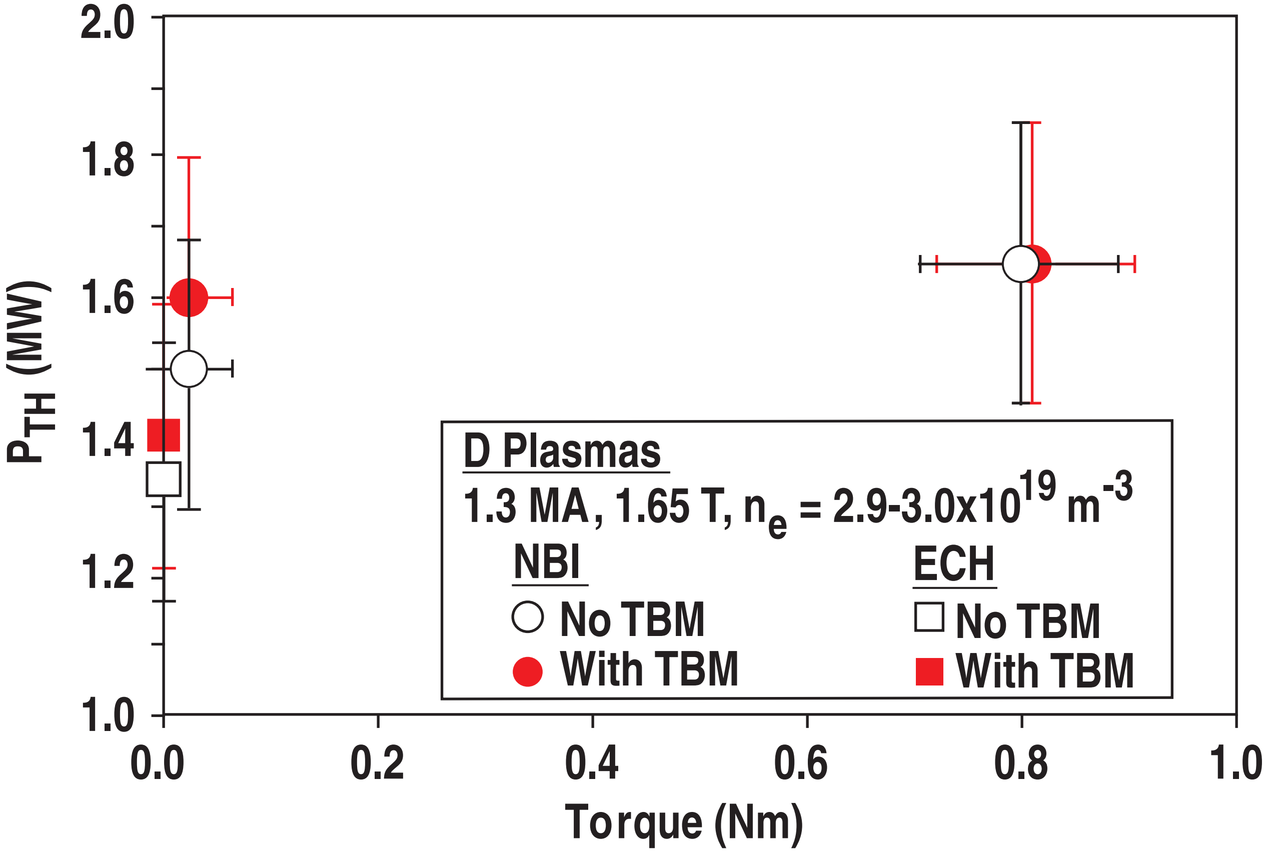
- **Test Blanket Module (TBM) magnetic ripple replicated using mock up coils on DIII-D**
  – Results are for TF + TBM local ripple ~3.1% (expected TF + TBM local ripple in ITER ~1.3%)

- **Determined for ECH, balanced D-NBI and co D-NBI in D plasmas**



The TBM has no Significant Effect on the H-mode Power Threshold

- **TBM magnetic ripple replicated using mock up coils on DIII-D**
  - Results are for TF + TBM local ripple ~3% (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 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**
  - Threshold in RMP field for effect on P_{TH} in D
  - Requires appropriate timing of RMP coil activation after L-H transition
- **Local magnetic ripple from test blanket module mockup coils have no significant effect on P_{TH} in D plasmas**
  - TBMs not expected to significantly affect P_{TH} in ITER
- **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**