H-mode Power Threshold, Pedestal and ELM Characteristics and Transport in Hydrogen Plasmas in DIII–D

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Motivation

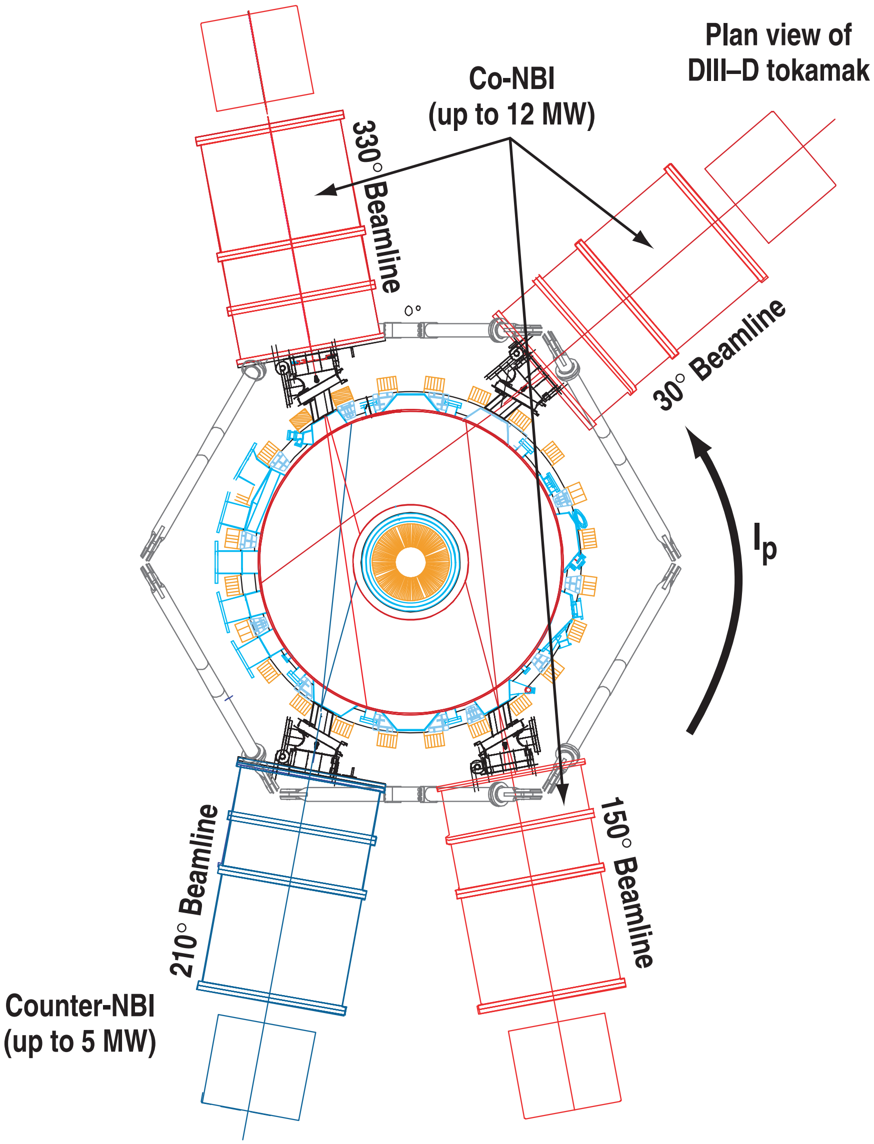
Operations

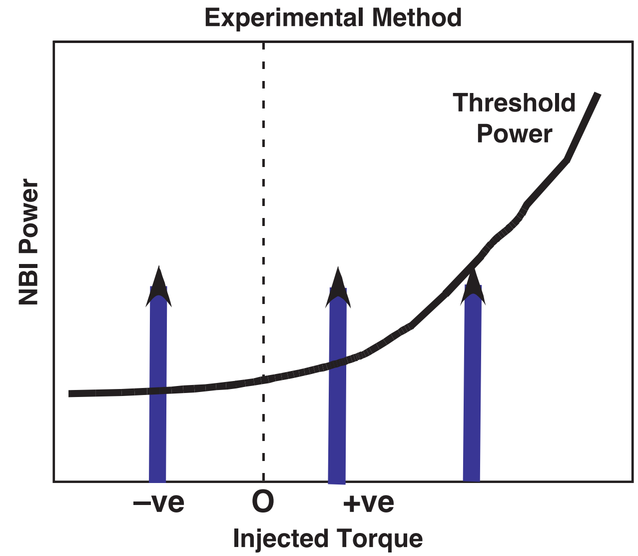
- **First (non-activated) operational phase in ITER is planned to be with hydrogen and/or helium plasmas**
  - Important phase for developing control hardware and techniques (e.g. for ELMs NTMs, etc)
  - Determine the interaction with plasma facing components (e.g. divertor heat loads and erosion, etc)
  - Dependent on obtaining H-mode plasmas

Physics

- **Dependence of the pedestal width on β_θ^{ped} or $\rho_{i\theta}$**
  - Mass dependence can resolve this issue

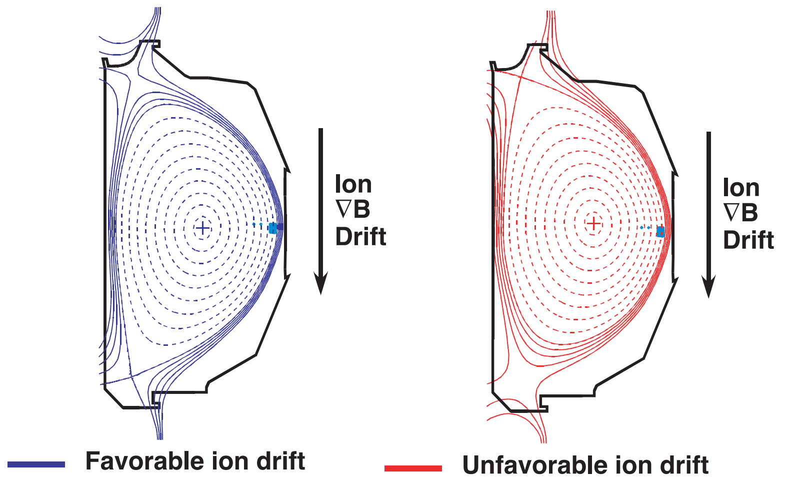
The Injected Torque was Controlled by Careful Selection of the DIII–D Neutral Beams



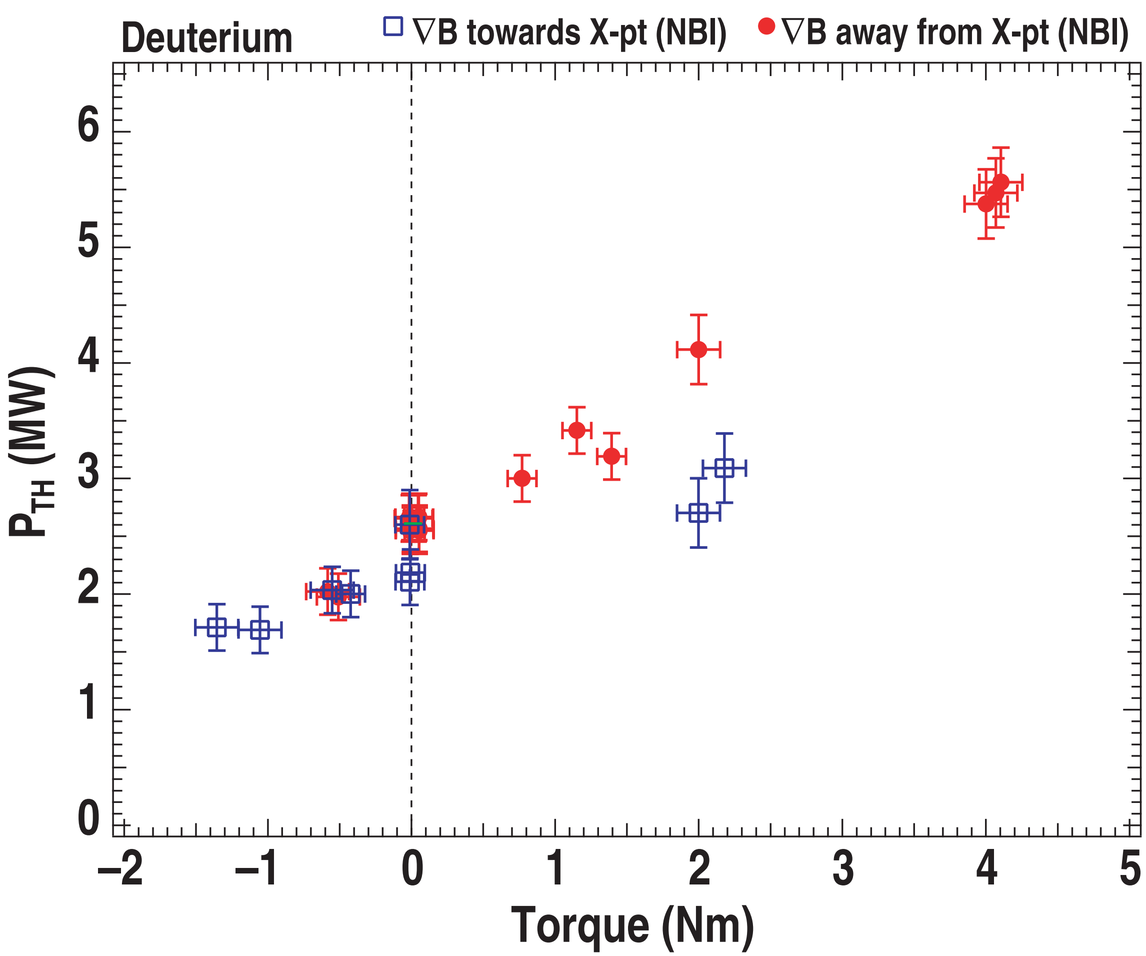


- **Experiments performed with**
  - NBI (H°) → H+ plasmas
  - NBI (D°) → D+ plasmas
- **Capability for performing simultaneous co-current and counter-current NBI**
  - Provides independent control of torque and power

For D Plasmas with D-NBI, the H-Mode Power Threshold Varies Strongly with the Applied Beam Torque

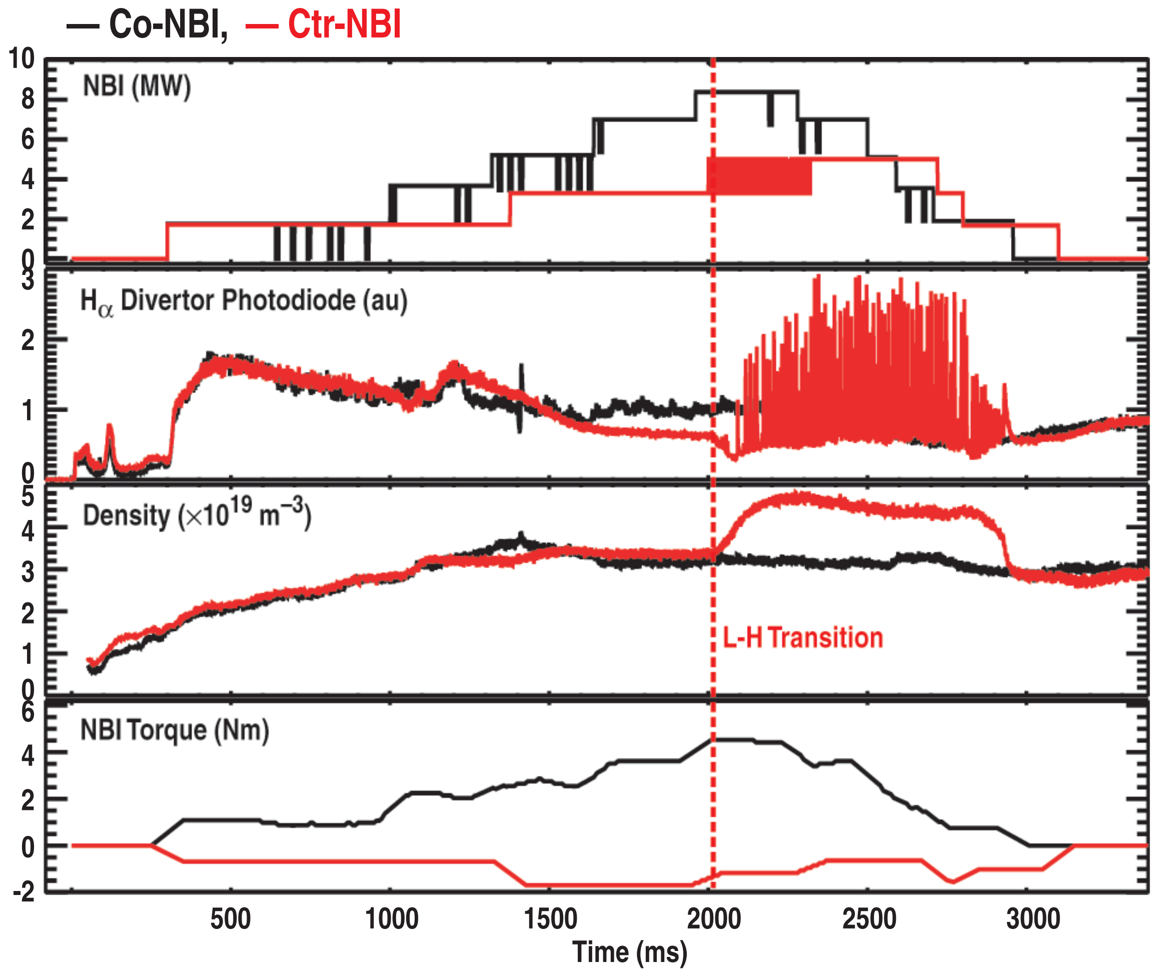


- Factor of ~3 increase in P_{TH} for discharges with unfavorable ion drift
- Factor of ~2 increase in P_{TH} with favorable ion drift



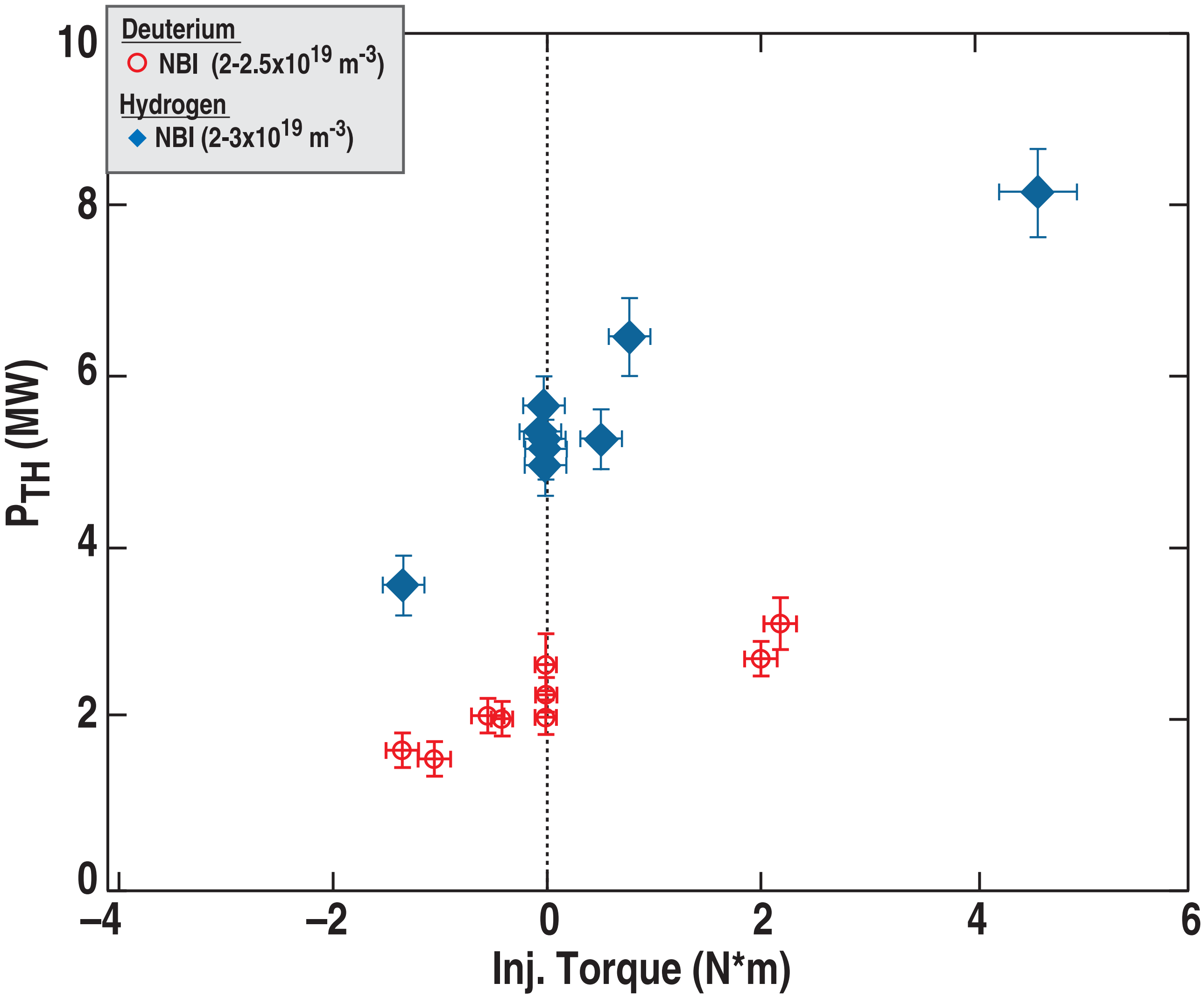
Hydrogen Plasmas: The H-mode Power Threshold with Counter-NBI is at Least a Factor of 2 Lower Than with All co-NBI

- **NBI(H^o) → H^+ plasmas**
- **With co-NBI: stays in L-mode at medium target density (3×10^{19} m^{-3})**
- **Hydrogen purity (H/H&D) was above 90% in L-mode**



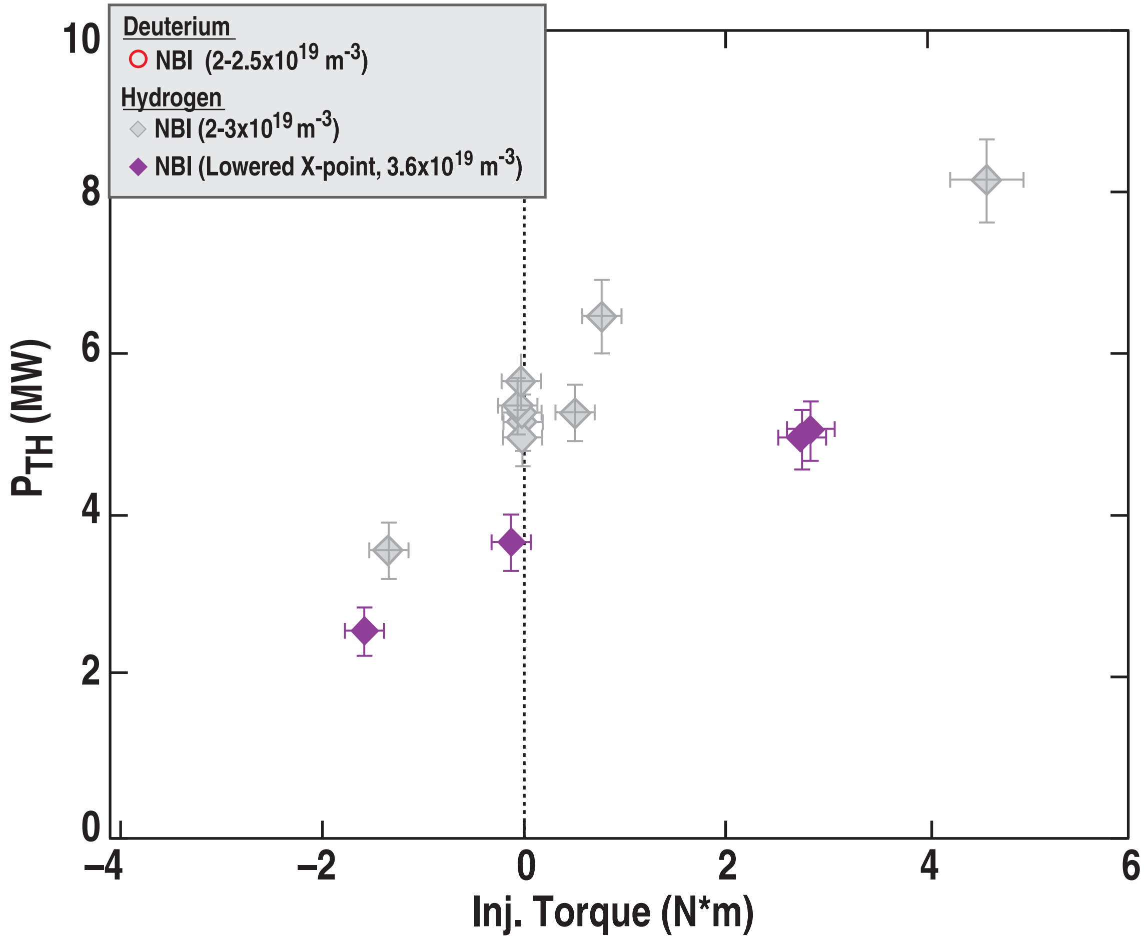
The H-mode Threshold Power Increases With Injected Torque in Hydrogen Plasmas (Similar to Deuterium Plasmas)

- **Hydrogen threshold power is twice that for deuterium at zero torque**

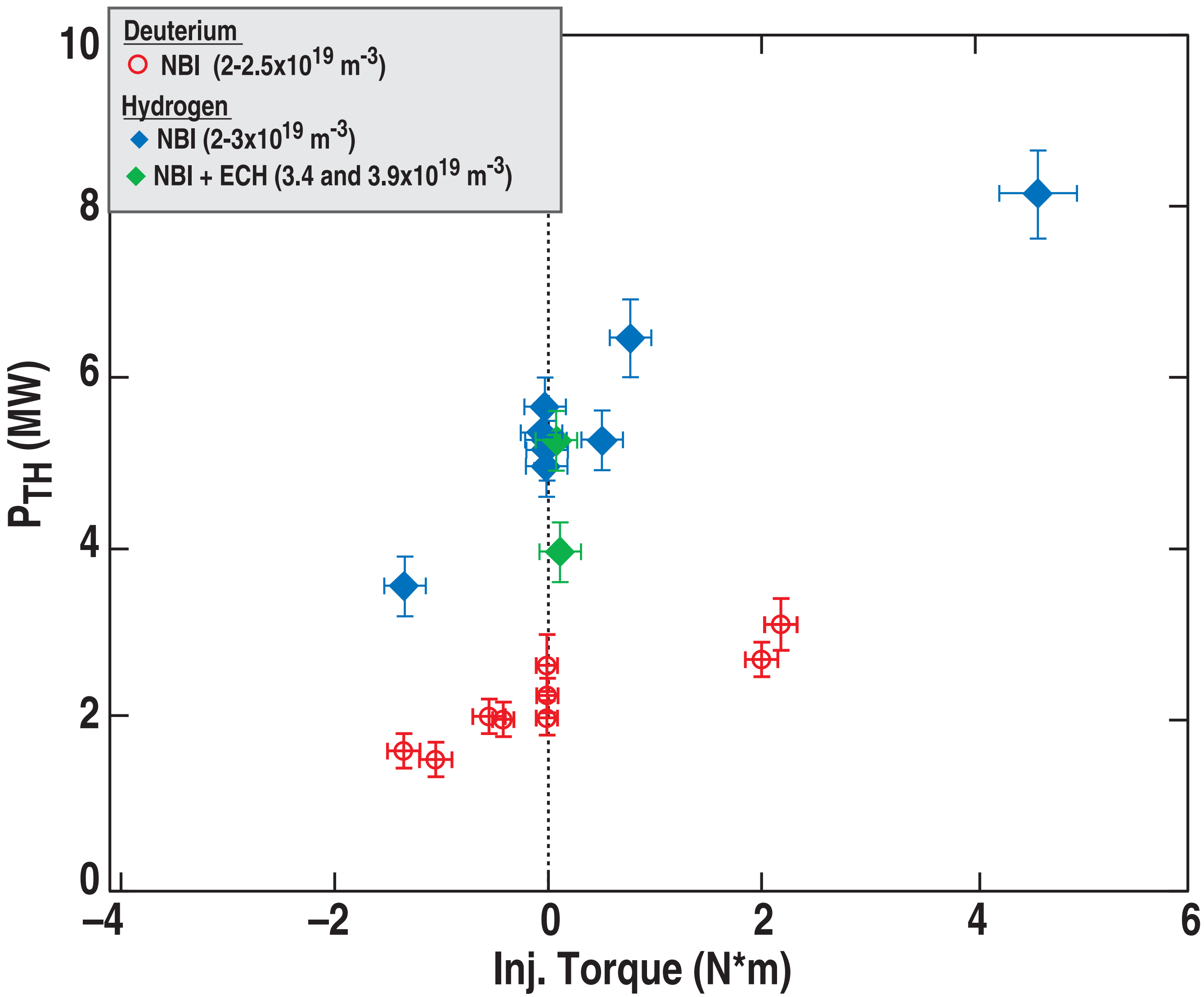


The H-mode Power Threshold is Dependent on the Location of the Plasma X-point From the Divertor Surface

- **Threshold power lowered by 20%–40% by reducing height of X-point above lower divertor from 26 to 10 cm**
- **Trend of increasing threshold power with increasing torque still present**

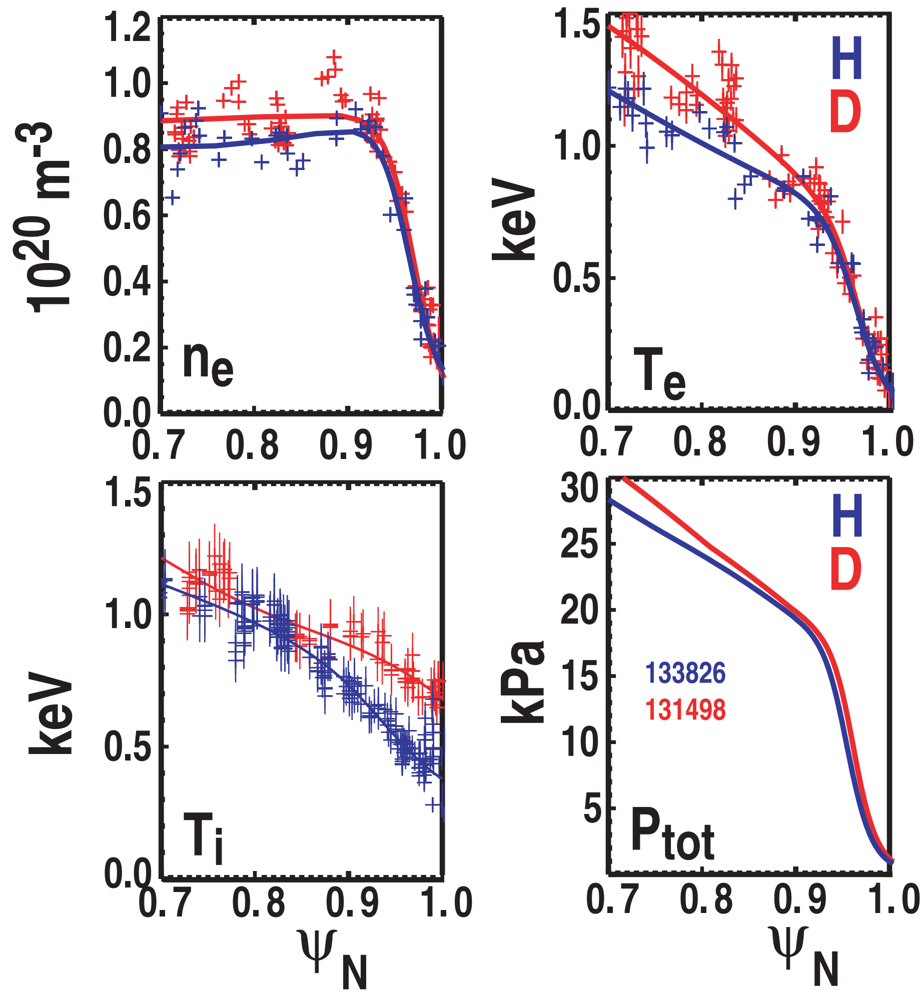


Application of ECH Lowers the Required Threshold Power Slightly (~15%) Compared to the NBI Discharges



Pedestal Width Studies With H and D Plasmas Allows Determination of Width Dependence on β_θ^{ped} or $\rho_{i\theta}$

- **Comparing the pedestal widths in D and H plasmas provides an opportunity to break the degeneracy**
  - $\rho_{i\theta}$ scales with ion mass as $\sqrt{M_i}$
  - β_θ^{ped} has no explicit mass dependence
- $\sqrt{\beta_\theta^{ped}}$ **scaling:** $\Delta_p^H/\Delta_p^D = 1$
- $\rho_{i\theta}$ **scaling:** $\Delta_p^H/\Delta_p^D = 0.7$
- **Actual** $\Delta_p^H/\Delta_p^D = 1.15$
  - Consistent with $\sqrt{\beta_\theta^{ped}}$ scaling



Conclusions

- **The net power required to access the H-mode increases with applied torque**
  - For both hydrogen and deuterium
  - Hydrogen threshold power is twice that for deuterium at zero torque
  - Trend with torque is favorable for ITER where low input torque is expected
  - The threshold power is sensitive to the plasma geometry; specifically, to the X-point height above divertor surface
- **Present power threshold scaling studies do not include torque, plasma rotation or plasma geometry effects**
  - may explain the large range/error in prediction for present and future fusion devices
- **The pedestal width is consistent with a $\sqrt{\beta_\theta^{ped}}$ scaling**