Exploring an Alternate Approach to Q=10 in ITER

by
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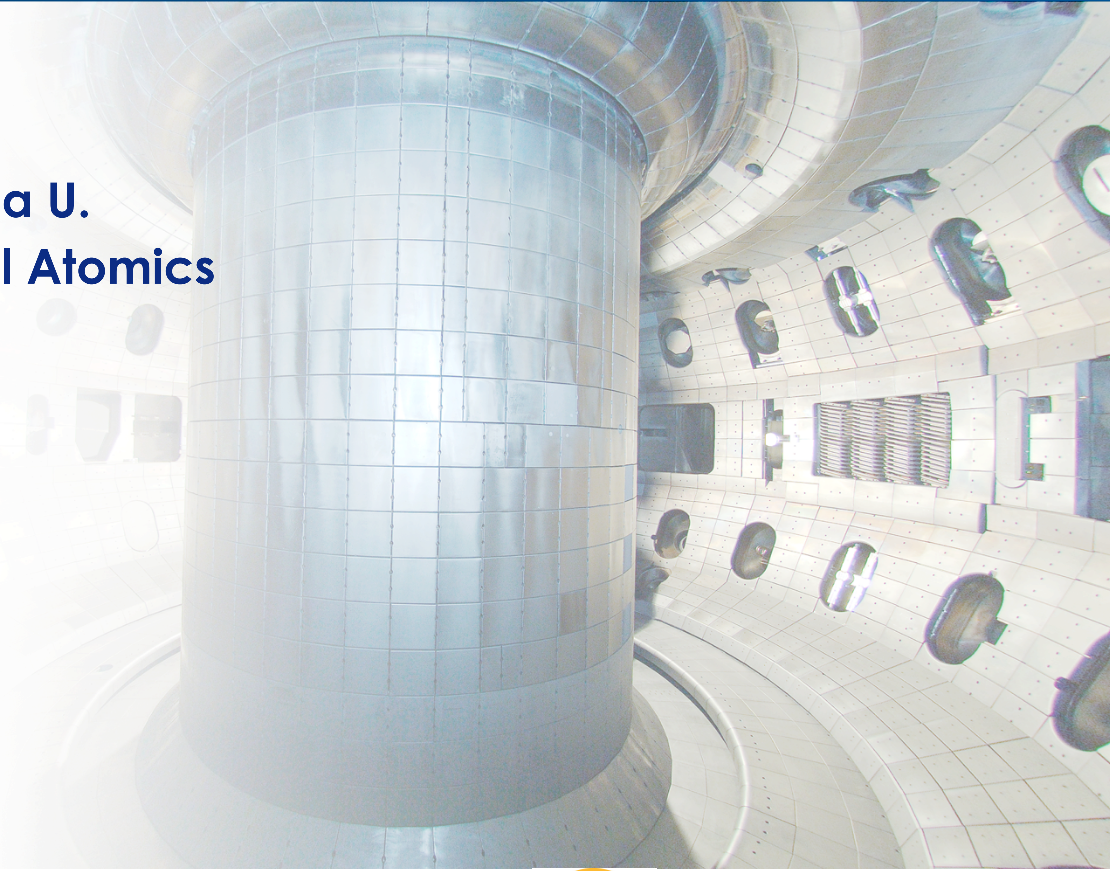

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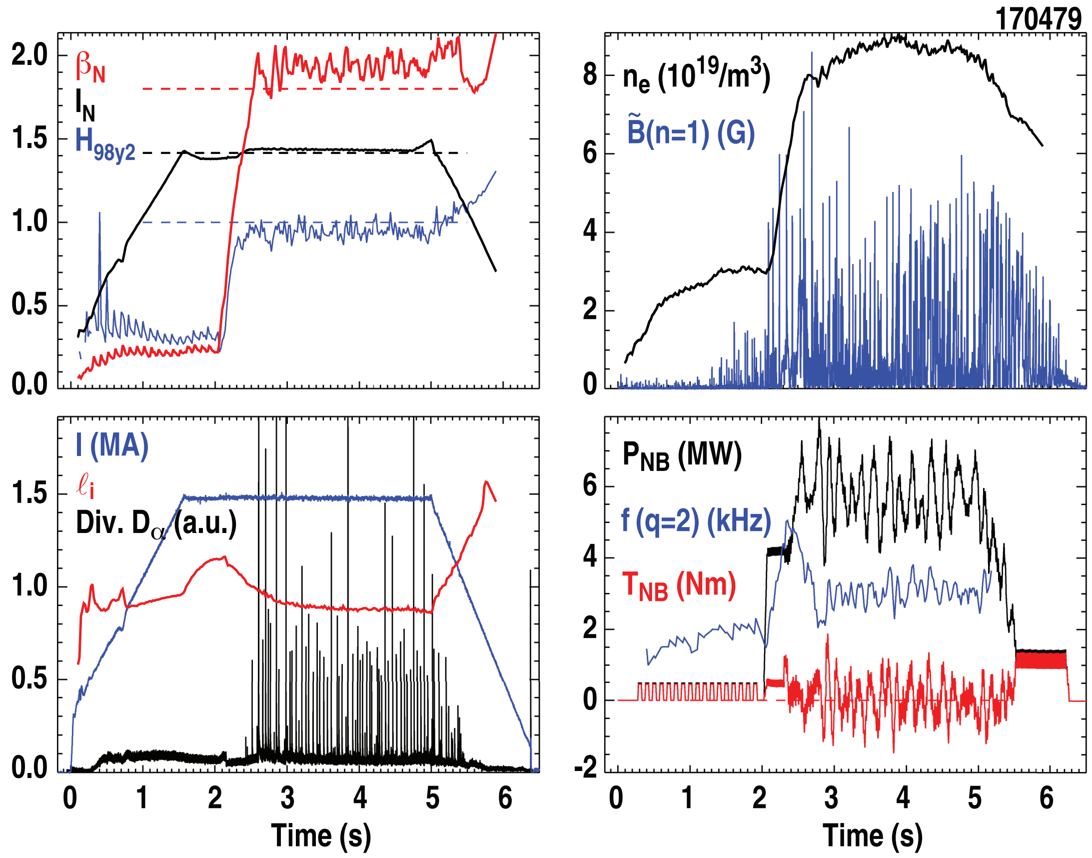
Stable Zero Torque ITER Baseline Scenario Achieved

ITER relevant parameters:

- β_N~1.9-2.1
- I/aB~1.4
- Cross-section shape (incl. aspect ratio)
- Zero input torque

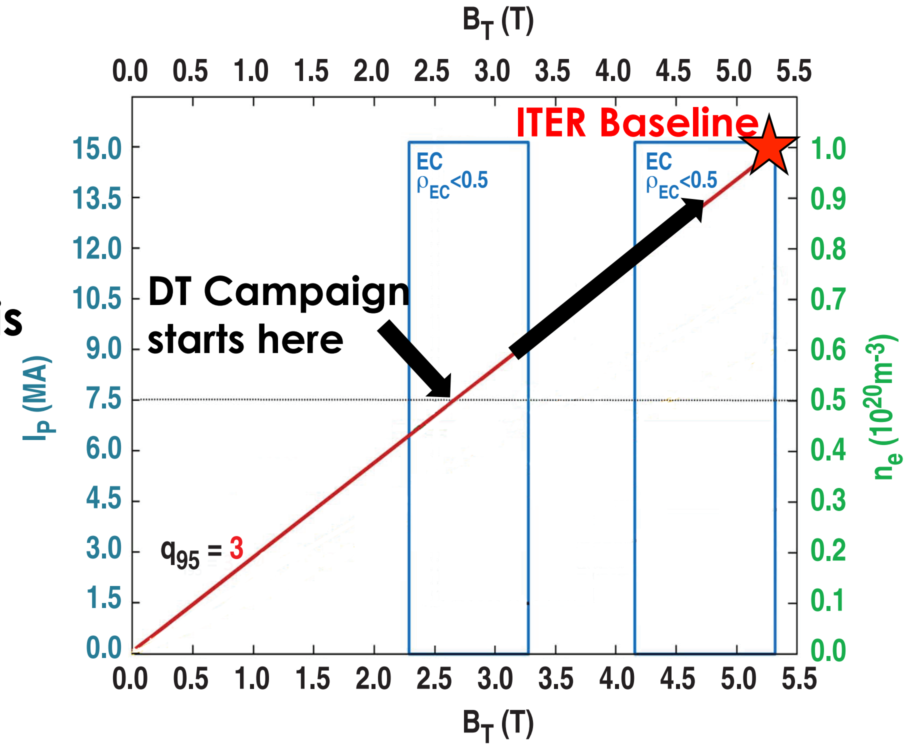


T.C. Luce/IAEA FEC/26 Oct 2018

How Will ITER Approach Q=10?

- **ITER Research Plan takes a constant q_{95} route**
  - Addresses q_{95}=3 issues at lower current (lower disruption impact)

- **q_{95}=3 may not be needed, but max(B) is**



Adapted from S.H. Kim, et al., Nuclear Fusion 57, 086021 (2017)

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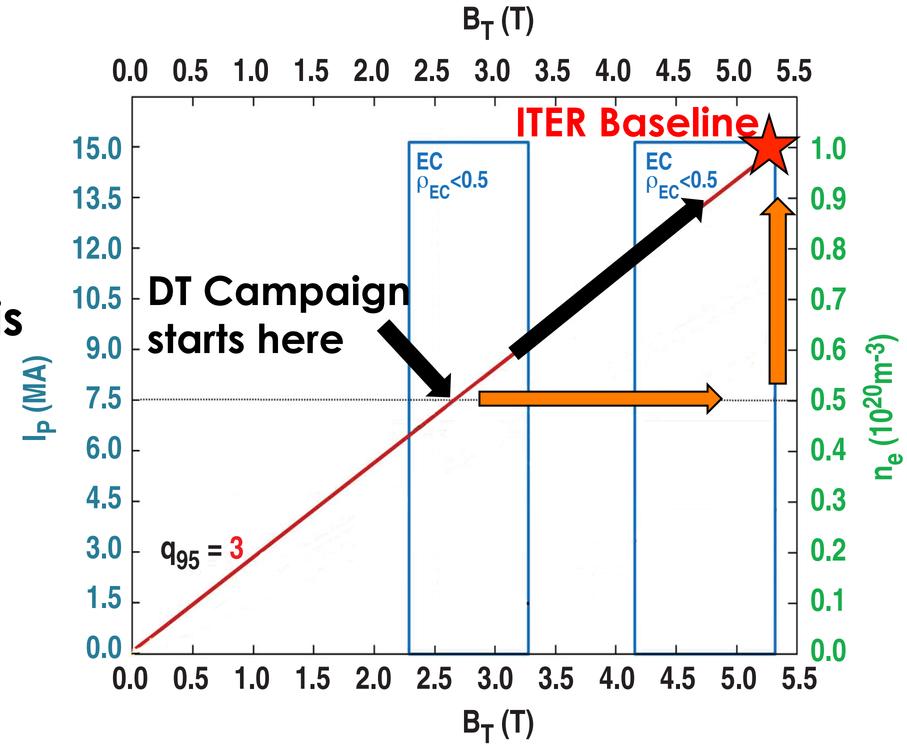
- **Alternate route starts at high q_{95} and max(B)**
  - Potential to reach Q=10 goal at lower current (lower disruption risk)
  - Overlap with advanced scenario development



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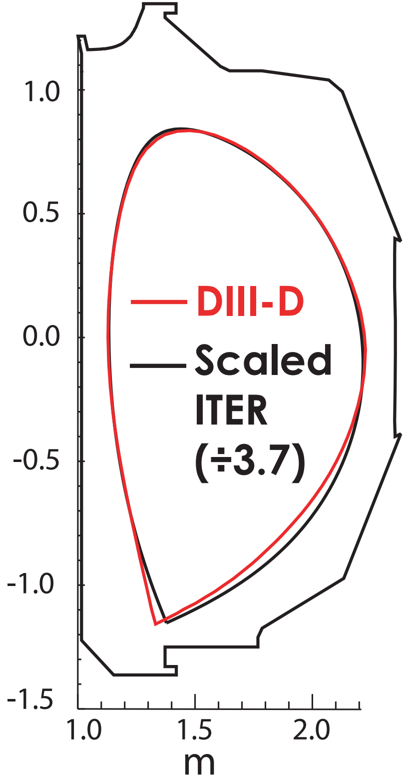
Experimental Design Mimics Proposed Alternate Path for ITER

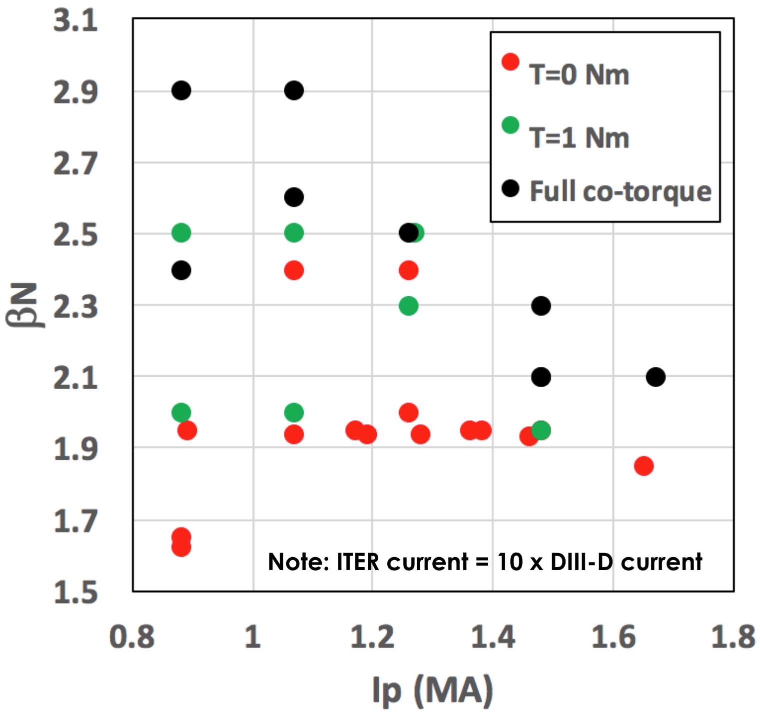
- **Plasma shape designed to match the ITER shape (incl. aspect ratio) while maintaining pumping**
- **Fixed magnetic field B, varying current I**
- **Co-NBI, low torque, and zero torque performance are compared in order to compare with the existing ITER physics basis (largely co-NBI)**



Overview of the Parameter Space Explored

- **Maximum stable stationary β_T is found at each current**
- **Note that these are not indicative of the potential of the advanced inductive regime — the plasmas enter H mode from a sawtoothing ohmic plasma**
- **Focus was on the new regime (T=0 Nm) in part because it requires no argument about the applicability to ITER of the input torque value**

Graph includes stable and unstable plasmas



Metrics for Evaluation of the Performance

- **Fusion power in DT plasmas of interest in ITER will have:**

  $P_{fus} \propto \langle p^2 \rangle \propto \beta_T^2(\%)$ at fixed B
  $\Rightarrow$ use β_T as a proxy for fusion power because it makes pressure scaling dimensionless

  – In ITER, P_{fus} = 500 MW at B=5.3 T requires β_T=2.55%

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- **At low gain:**

  $Q_{fus} \propto \langle nT \rangle \tau \Rightarrow$ use $\beta_T \tau$ as a proxy for gain (not dimensionless)

  - Can also use $G \equiv \beta_N H_{89} / q_{95}^2$ as a proxy for gain, but the accuracy of a confinement scaling is assumed
  - ITER Q=10 requires G=0.38-0.42 (depends on precise value assumed for q_{95} at 15 MA)

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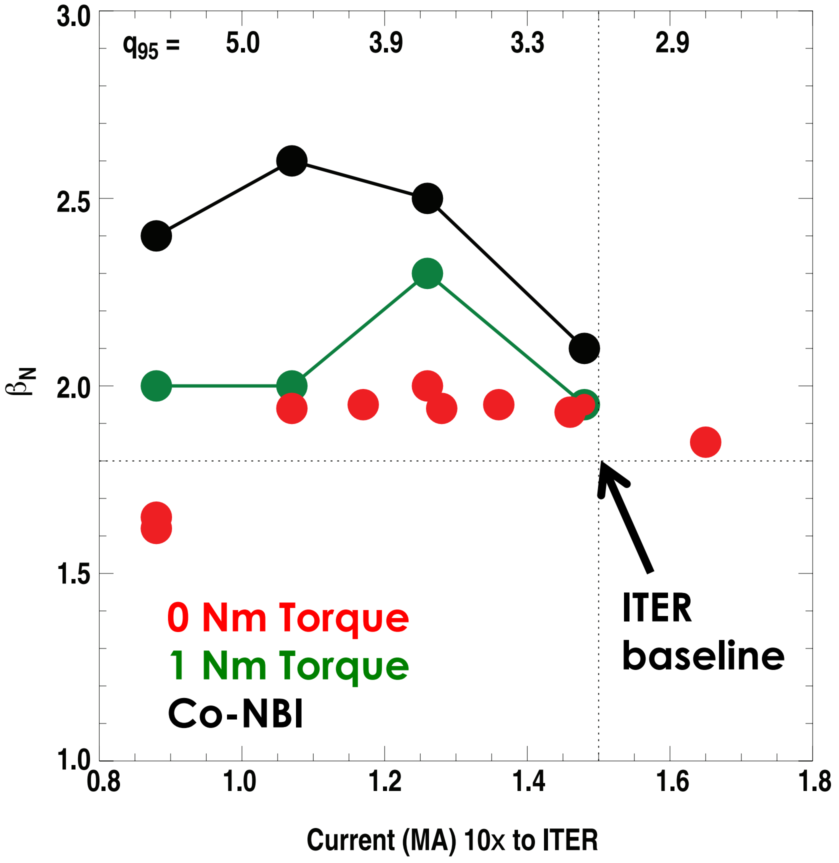
- **Will also show the standard stability and confinement metrics (β_N, H_{98y2})**

Achievable Normalized Pressure is Not Constant Across the Current Scan

- **For co-NBI, the stable β_N drops with increasing current (q_{95}<4)**
- **Achievable β_N is lower at lower torque**
- **Not strictly a pressure limit**
  - In all cases, the limit to stable operation is an n=1 tearing mode



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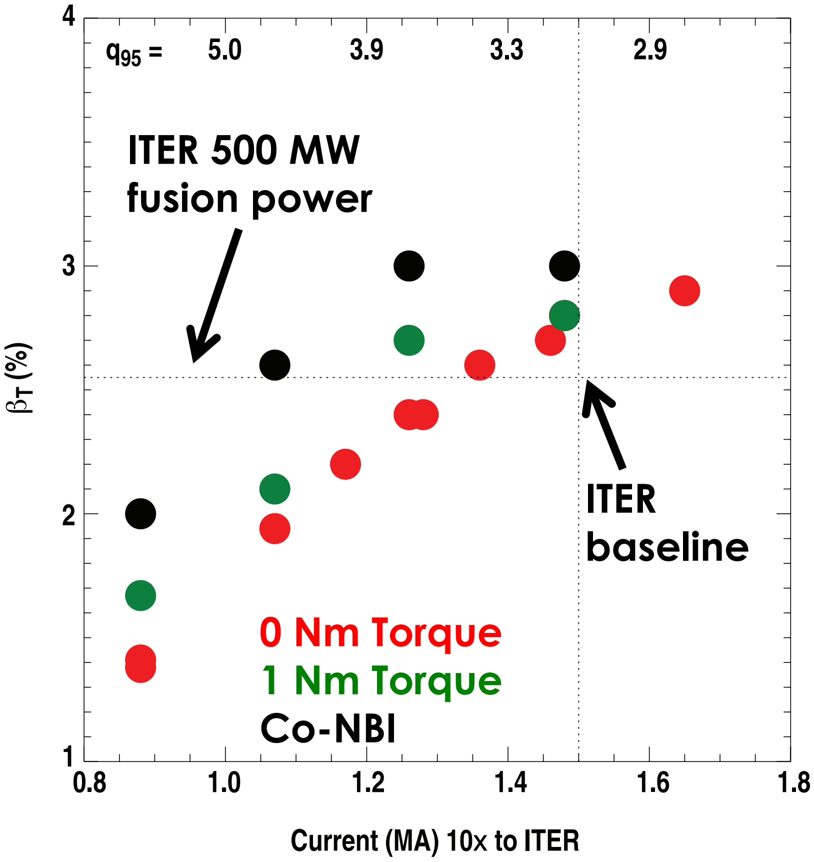
Performance to Reach 500 MW of Fusion Power in ITER Achieved at All Torque Levels

- With co-NBI, the goal is reached by 11 MA equivalent
- With 0 Nm torque, 13.5 MA may be sufficient
- For co-NBI, the achieved β does not increase above 12.5 MA



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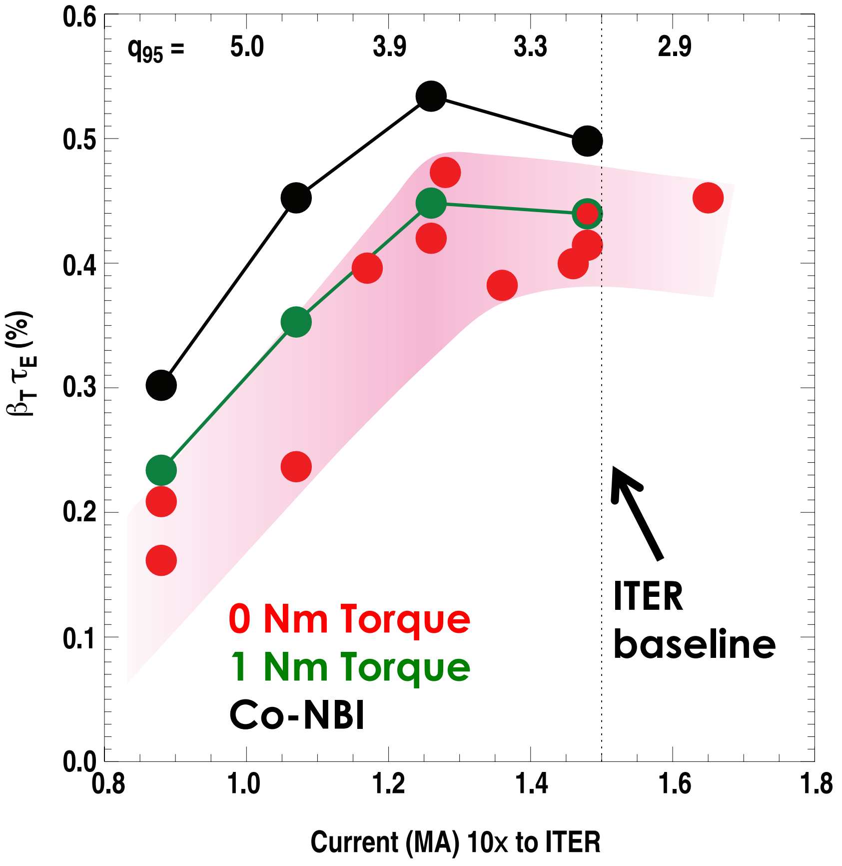
Gain Metric (βτ) Does Not Improve Above 13 MA Equivalent Current

- **Curves at all torque levels have similar shapes**
  - Effect is not likely due to ExB shear
- **Increase in gain seems to saturate around 13 MA**
  - Corresponds to q_{95}≈3.7
  - Previously seen on DIII-D, but not explained [Schissel, et al., NF 32, 107 (1992)]



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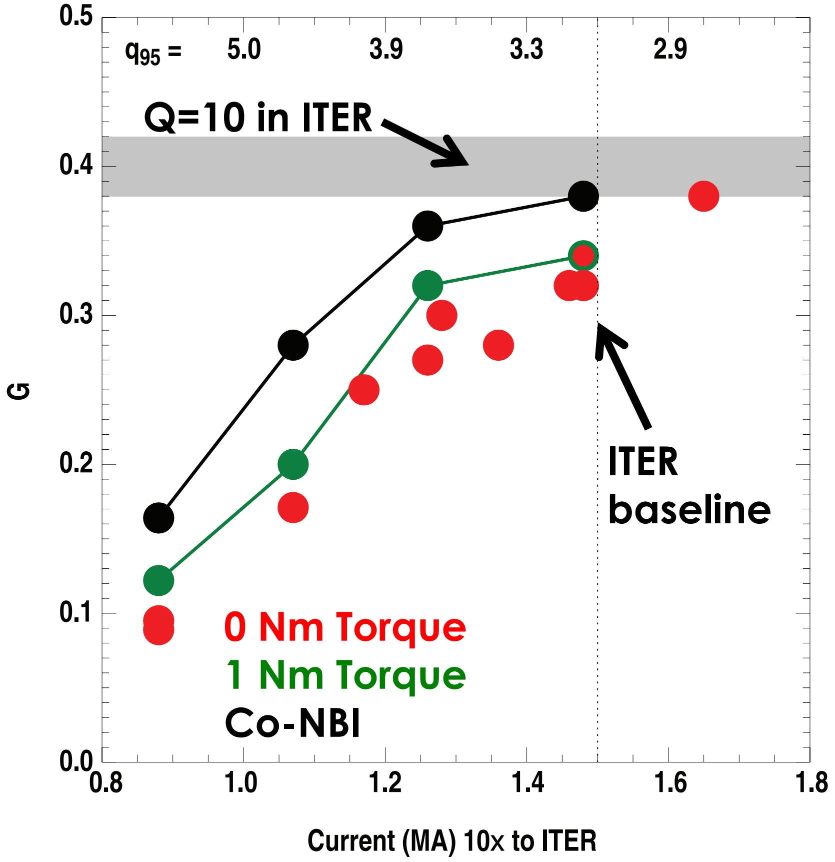
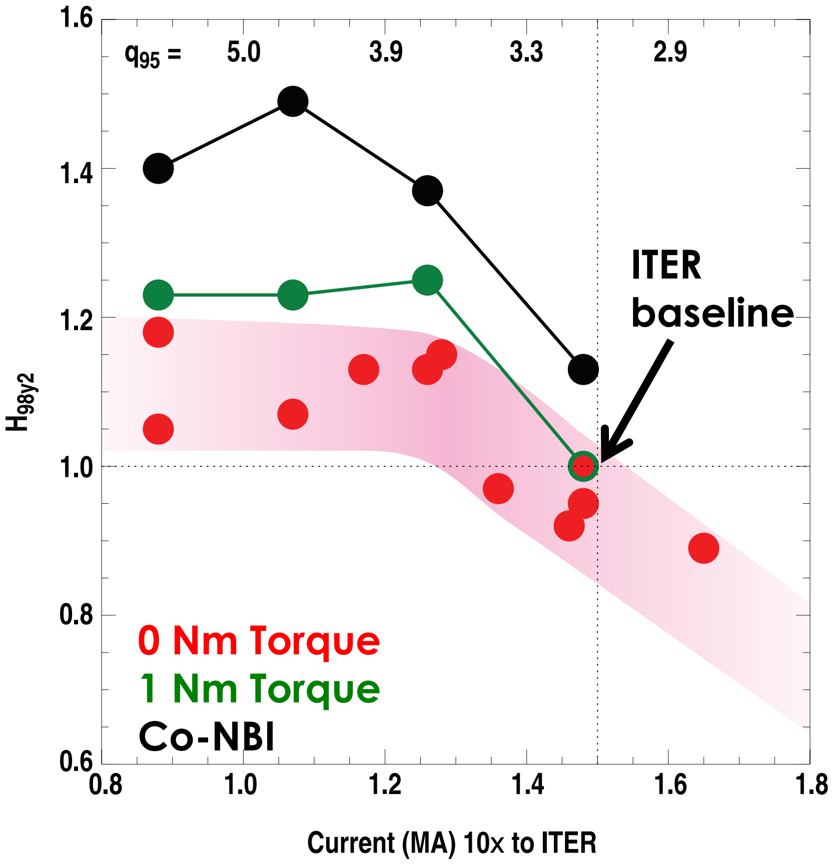
Alternate Gain Metric Increases with Current

- $G \equiv \beta_N H_{89}/q_{95}^2$ shows some saturation, but not as strongly as $\beta\tau$
- Q=10 requires G=0.38-0.42
- Zero torque appears to fall short of Q=10 at 15 MA equivalent
  - Need actual projections from profiles



Confinement Quality Drops with Increasing Current

- **Above 13 MA (q_{95} ≈ 3.8), H_{98y2} drops**
  - However, drop is down to ~1
- **Primarily due to loss of linear current scaling**



Origin of Drop in Confinement Not Clear

Comparing 15 MA and 13 MA equivalent current, the following causes for the confinement change should be considered:

- **All dimensionless parameters (ρ^*, β, ν^*, q) change**
  - Most important are ρ^* and q
  - Reduction of q at 15 MA should give lower transport in the outer part of the plasma, not higher

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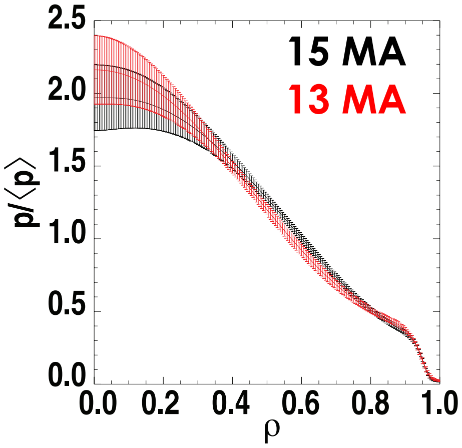

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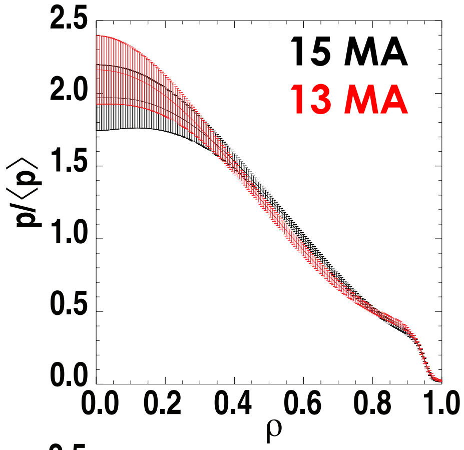
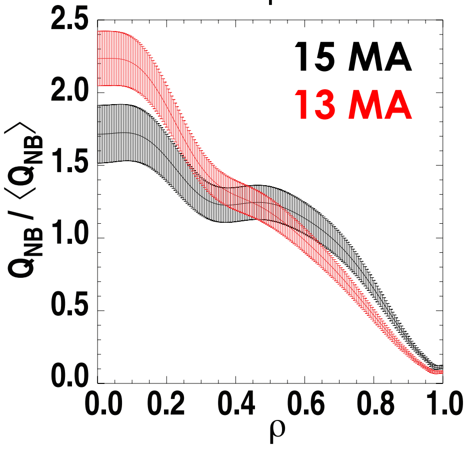
- **NB deposition profile broadens**
  - 'Effective' minor radius is smaller at 15 MA
  - ➜ Should not affect ITER, which has strong central heating





Summary and Conclusions

- Stable operation with β sufficient for 500 MW fusion power in ITER obtained below 15 MA equivalent at all torque values
- Fusion gain metric βτ did not increase with current beyond 13 MA equivalent at all torque values and is reduced with lower torque input
- Stable operation at zero applied torque achieved down to q_{95}=2.8

Conclusion:

- Expected benefits to fusion energy performance of increasing current may not be realized, but further study is needed
- This would not be seen on the path to Q=10 in the ITER Research Plan

Look ahead: Will need to assess changes in stability and confinement when ELM mitigation measures are added