Performance of Discharges with High Elongation and β in NSTX and Near-Term Paths Toward Steady State.

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The steady state spherical torus may be useful for studying high-power plasma-wall interactions, for nuclear component testing, or as the core of a fusion reactor. In all cases, strong shaping and high β are required in order to increase the bootstrap current fraction; high neutral-beam current drive efficiency is further assumed in the non-reactor scenarios. Scenario development research in NSTX has addressed the needs of these devices, by developing high-κ and β scenarios i) with the highest β_P and non-inductive fraction, ii) with the longest possible pulse for equilibrated profiles, and iii) high-β_T at large normalized current.

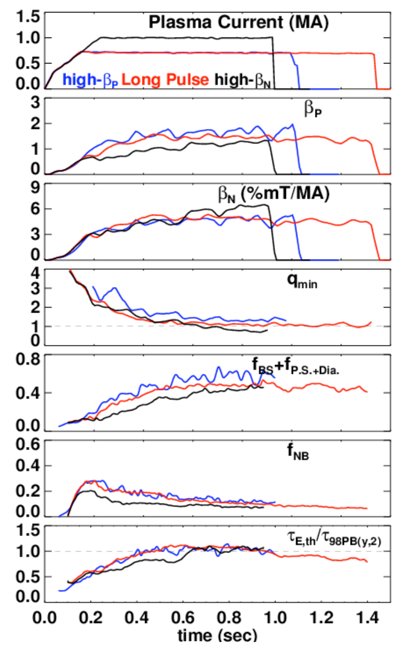

Fig1: Time evolution of high-β discharges with κ~2.6.

Waveforms for a representative discharge in each case are shown in Fig.1, for discharges with κ≈2.6 and δ≈0.8. The discharges range from β_P~1 at high current and low q*, to 1.8 at low current. β_N>4.5, exceeding the no-wall stability boundary, has been achieved for long periods. This high β was facilitated by the use of resistive wall mode (RWM) control, dynamic n=1 error field correction, and static n=3 error field correction [1]. The two scenarios at lower current have achieved steady-state values of q_{min}>1, which is highly desirable for the avoidance of core MHD, while the higher-current case has q_{min}<1 before disruption. The high-β_P scenarios have NSTX record low flat-top averaged surface-voltages of 130mV. The pressure driven currents are largest in that high-β_P scenario, and ≥40% by discharge end in all scenarios; they increase through the discharge as the density increases. This density increase also results in a decrease in the neutral beam current fraction, which is typically ≤15% at the end of the discharges (through it can approach 30% in the low-density early phase). In all cases, the confinement is comparable to or better than that

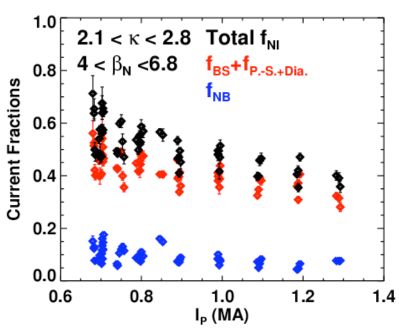

Fig 2. Non-inductive current fractions as a function of plasma current for many high-performance discharges.

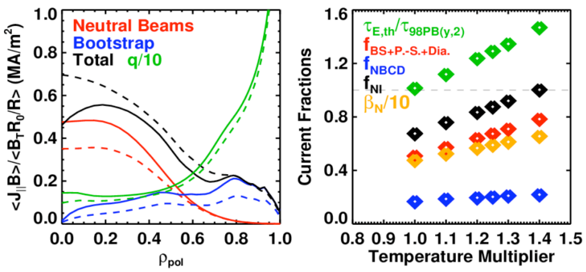

Fig. 3 left) Experimental profiles (dashed) and fully non-inductive profiles (solid) with scaled temperatures, and right) non-inductive fractions, required confinement, and normalized β, as a function of the temperature multiplier.

predicted by the standard H-mode scaling. All of these configurations utilized lithium evaporation to improve confinement [2].

The high-β_P configuration at higher toroidal field (0.48 T) reliably sustained β_N~5 without disruption, using the available 6 MW of input power. The high-β_T case tended, even with the use of RWM control, to develop RWMs when the input power was too high (β_N/l_i ~11). Reducing the power, however, lead to a more rapid approach to q_0=1, typically resulting in the onset of rotating core n=1 modes with a large reduction in confinement. These results emphasize the need to control β near, but below, the ideal stability limit in order to maintain elevated q_{min} through increases in the bootstrap fraction and the slowing of resistive diffusion.

The current profile constituents as a function of plasma current are shown in Fig. 2. The total non-inductive fraction approaches 70% for the best 700 kA cases, but falls off approximately linearly with current. Poor confinement of the heating ions prevents accessing increased f_{NI} at reduced I_P in NBI heated plasmas. Predictive simulations have been done with the TRANSP code, based on as the 700 kA discharges 133964 (blue in Fig, 1), in order to determine alternative near-term routes to higher non-inductive fraction. The high κ & δ experimental plasma boundary was used with Z_{eff}=3, and the input thermal profiles scaled; the base configuration had f_{BS}= 45% and f_{NBCD}=17%. A 25% reduction in density, consistent with that predicted by lithium pumping with the Liquid Lithium Divertor (LLD) [3], coupled to an 18% rise increase in temperatures ($\tau_E \propto n_e^{0.4}$), resulted in f_{NBCD} increasing to 27%, but the bootstrap fraction decreasing to 38%. If, however, the electron temperature changed inversely to the density, then the bootstrap current was mostly unchanged (f_{BS}= 44%) while the neutral beam current increased (to f_{NB}=30%); the total non-inductive fraction was then ~83%. A simple route to fully non-inductive operation is shown in fig. 3, where the electron & ion temperatures were both scanned with the density fixed. Increasing the temperatures by 40% is sufficient to achieve essentially non-inductive operation, via increases in both the bootstrap and beam driven current; the final plasma has $\beta_N \approx 6.5$, and H_{98}=1.5 (for 6 MW injected beam power). Decreasing Z_{eff} to 2 leads to a 25% increase in the temperatures for fully non-inductive operation. Achieving this increase in temperature at similar density may be possible through use of the LLD, if confinement continues to increase beyond the ~20% improvement observed with solid lithium coatings [2]. These simulations indicate that the thermal transport response to the liquid lithium surface pumping is of critical importance in determining the impact of LLD on integrated performance. Alternatively, fast wave electron heating may provide the needed temperature increase.

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[2] M. Bell, et al,, Plasma Phys. Control Fusion **51**, 124054 (2009)
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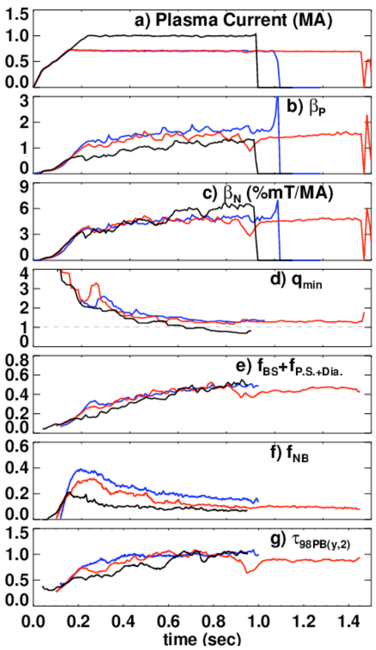

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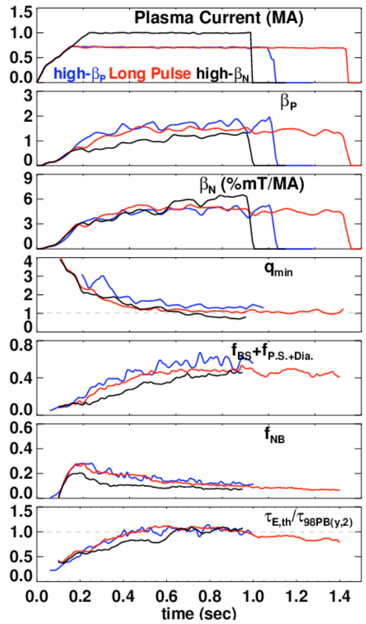

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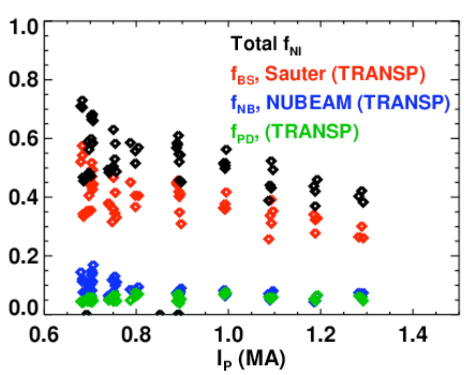
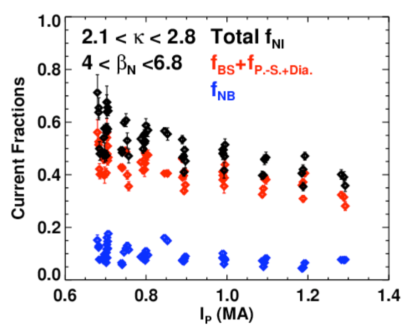


Fig 2. Non-inductive current fractions as a function of plasma current for a series discharges with κ>2.3 and β_N>4



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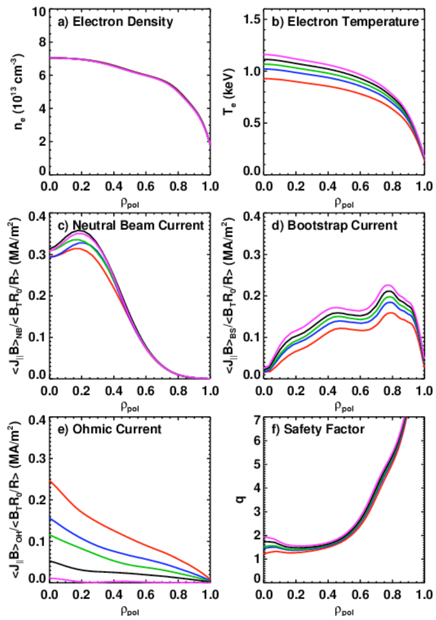
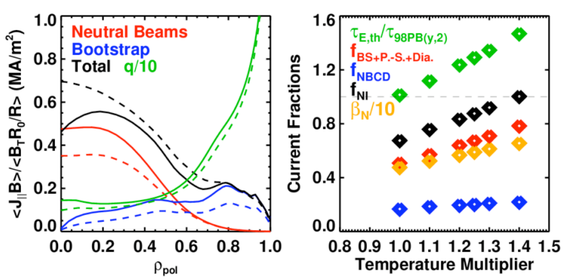


Fig. 3: Scaling temperature profiles to reach non-inductive operations.



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