PF1A upgrade physics review

Presented by D. A. Gates

With input from J.E. Menard and C.E. Kessel

10/27/04

Outline

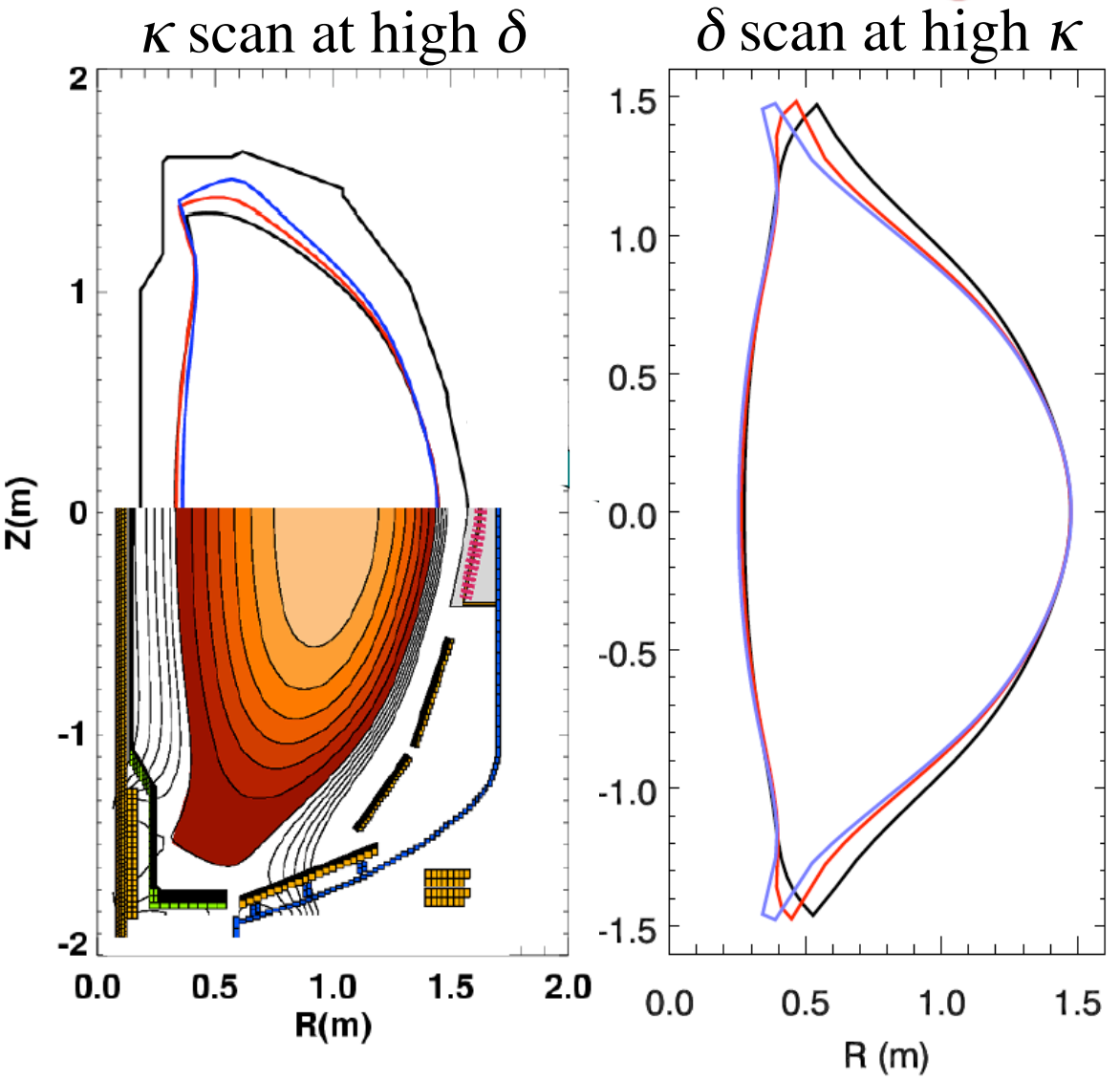
- History - how did we get here?
  - What were the limitations of the old PF1A?
- Physics optimization for target equilibrium
- Do we give anything up with the change?
  - and if so, what?
  - Survey of equilibria available with the new coils
- Summary

PF1A upgrade product of 5 yr. plan process

- Goal was to find an MHD stable 100% non-inductively sustained scenario w/ f_{bs} ~ 70% at 40% β_t
- Unable to find scenarios/equilibria that satisfied requirements with original coil set (Kessel/Menard)
- Expectation was a requirement of simultaneous high κ and δ

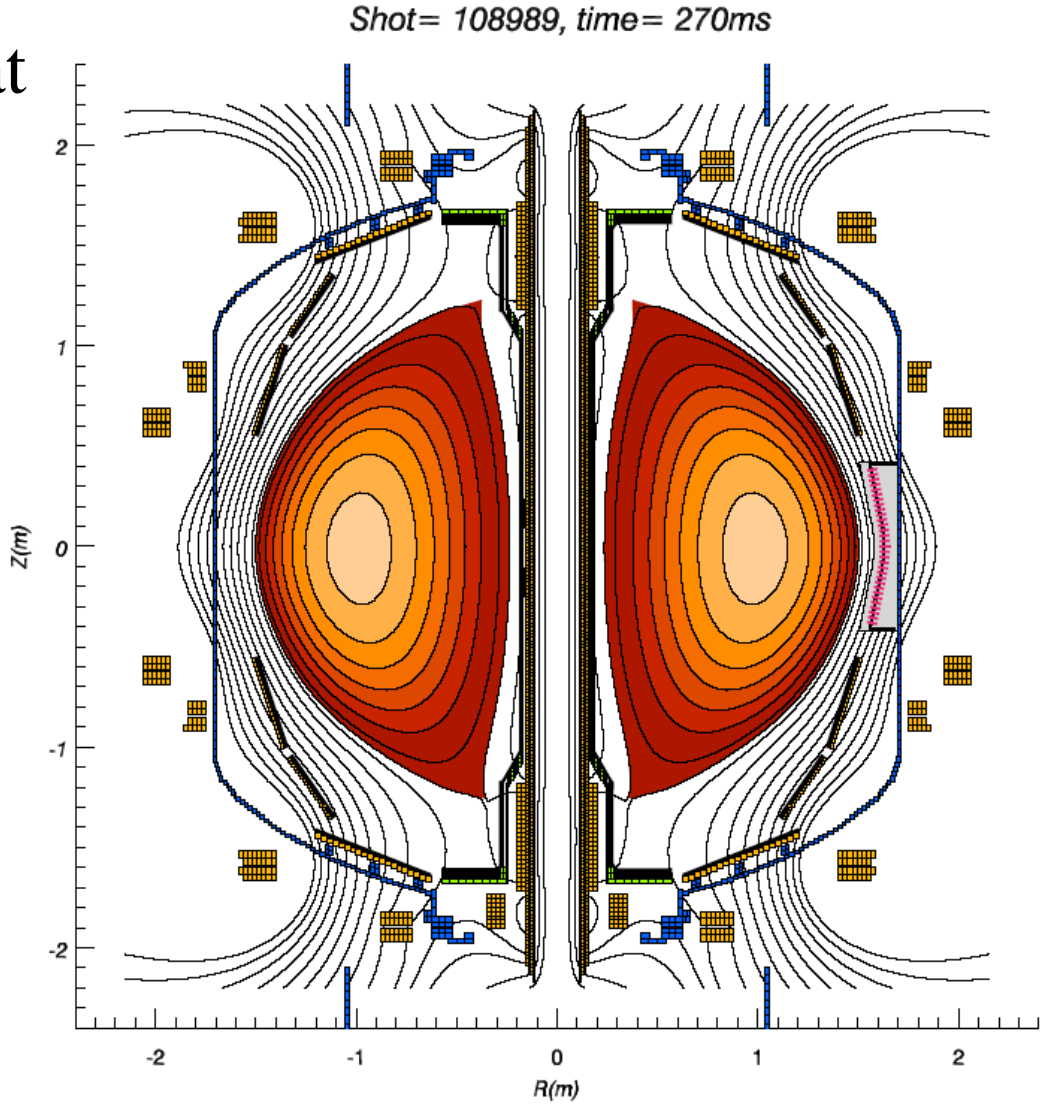
High κ, δ not compatible with old PF1A

- For $\kappa \sim 2.4$, as δ is increased, outer squareness decreases
- For $\delta \sim 0.8$, as κ is increased, second x-point forms
- Not conducive to MHD stability
  - Also not easily realized equilibria
- Problem is solenoid like shape of PF1A
  - Lots of field on the ends of the coil, little on the sides



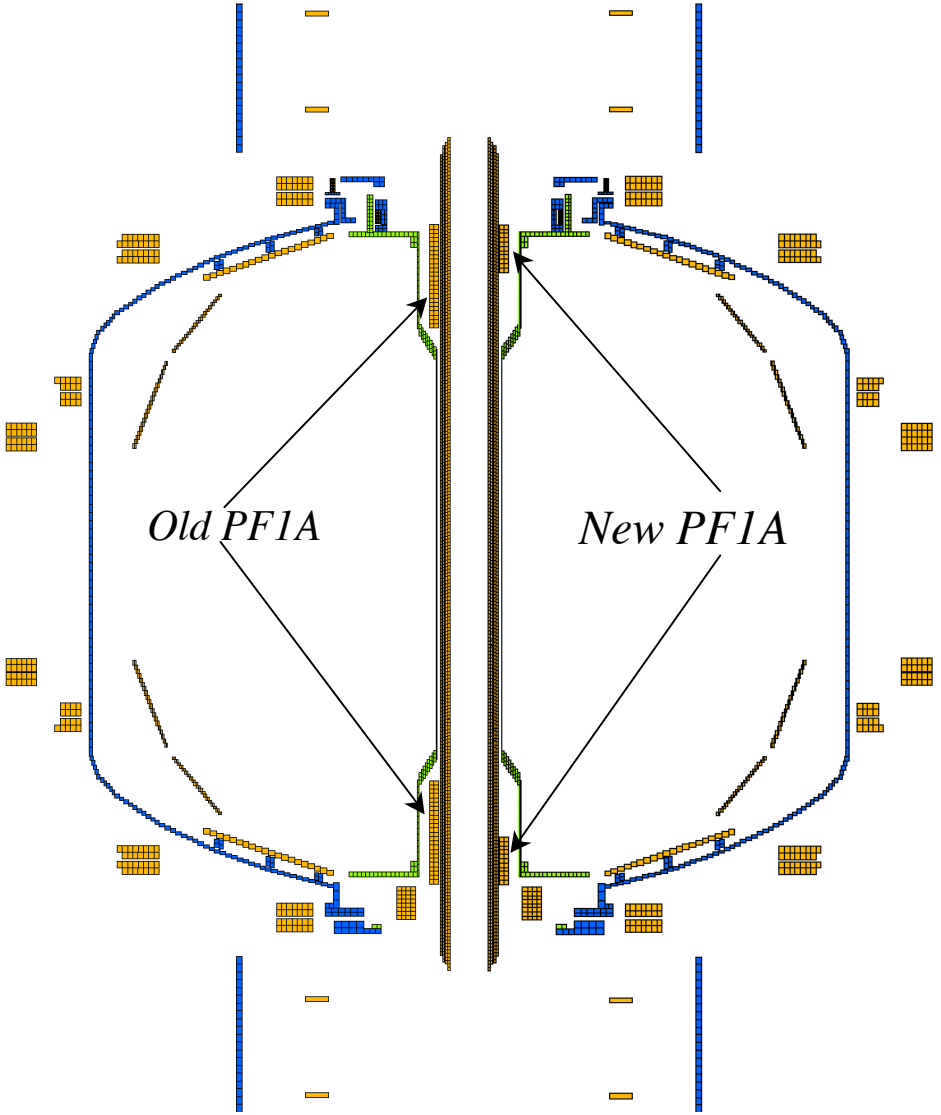
Proposal to modify PF1A

- Based on observation that PF1A capable of making high δ at lower κ when plasma height is near the bottom of the PF1A coil
- Original proposal was to make 2 coils to maintain low κ high δ capability
  - No room for leads
  - proposed shifting present coil away from midplane

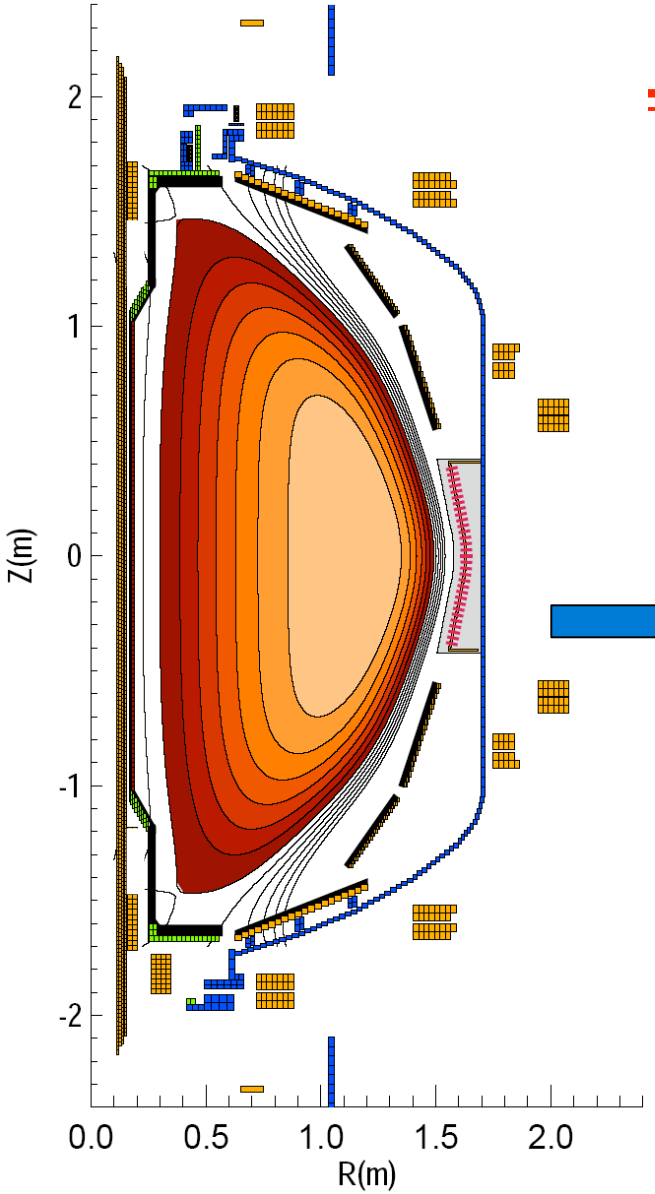


Final coil design

- Single ~half-height coil design located near the upper half of the original PF1A
- > Half as many turns (20 vs. 48) but more current (24kA vs 15kA) gives 2/3 amp-turn rating
  - Does not appear to limit operation (more later)



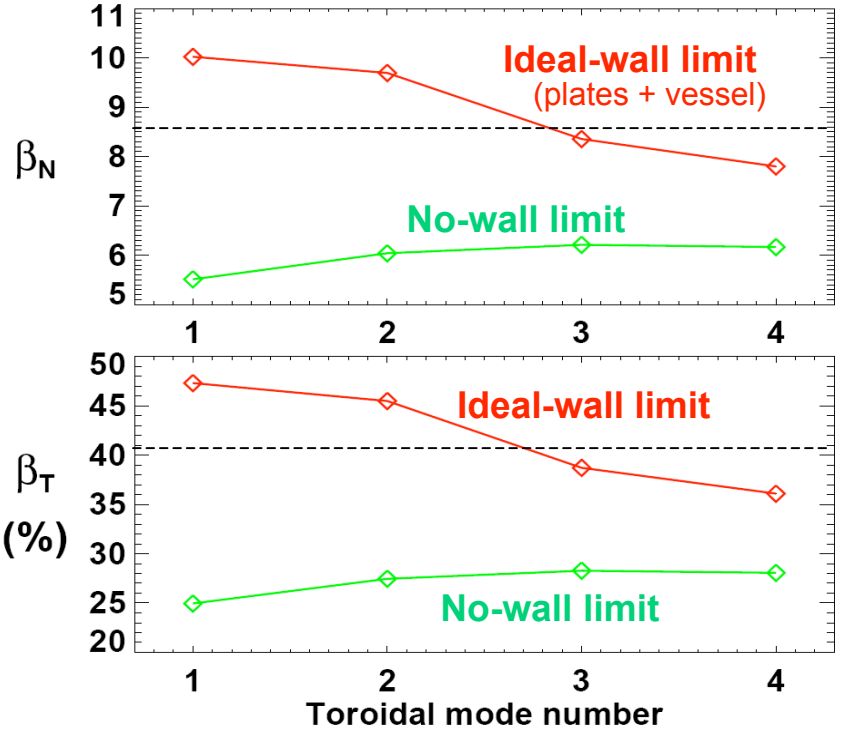
PF1A upgrade required for β_T=40%, f_{NI} = 100%



J. Menard

- **Need $\beta_N > 8$ at $\kappa > 2.4$ for f_{BS}=50-70%**
  - Assumes χ profiles like 109070
  - Remaining CD from NBI and EBW
- **High-δ wall-stabilizes n=1-3 @ high-κ**
  - **β limits drop 10-20% without high-δ**

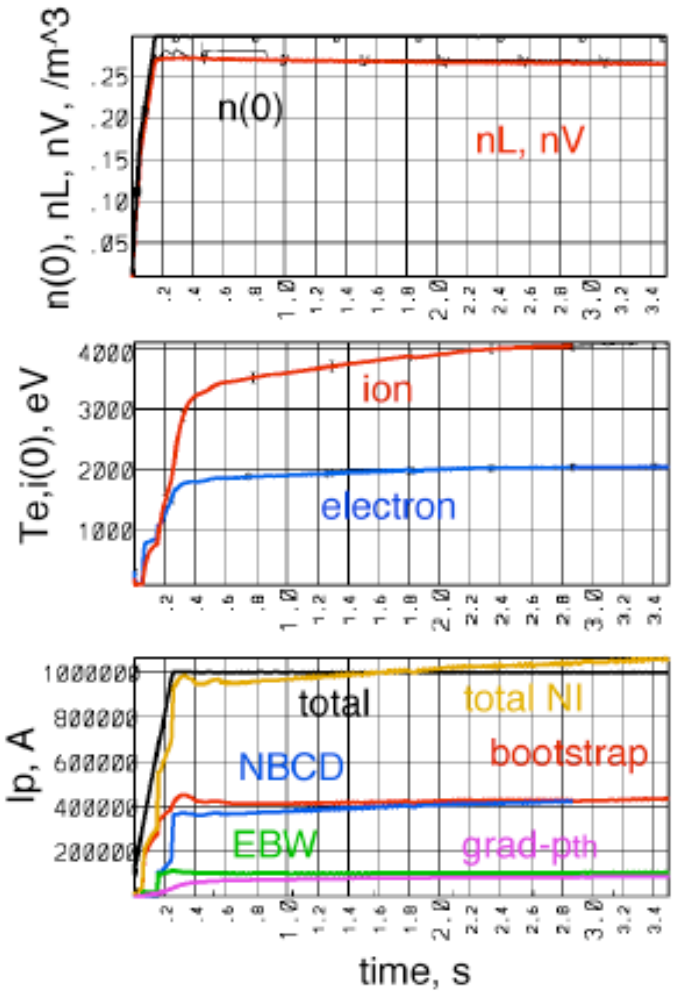
Stability limits for high-κ + high-δ

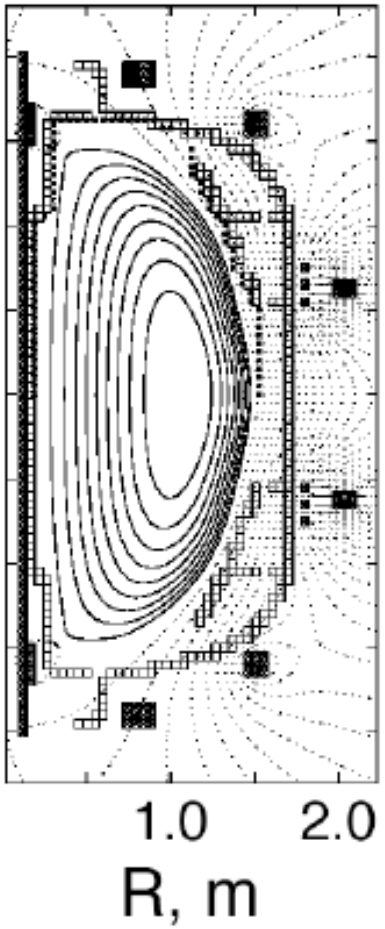


Steady State Scenario

- TSC used to demonstrate full time dependent non-inductively sustained scenario, consistent with transport and MHD stability and available external current drive (assuming EBW available)

Time histories of the plasma density, temperature current for the fully non-inductive high β scenario with TSC

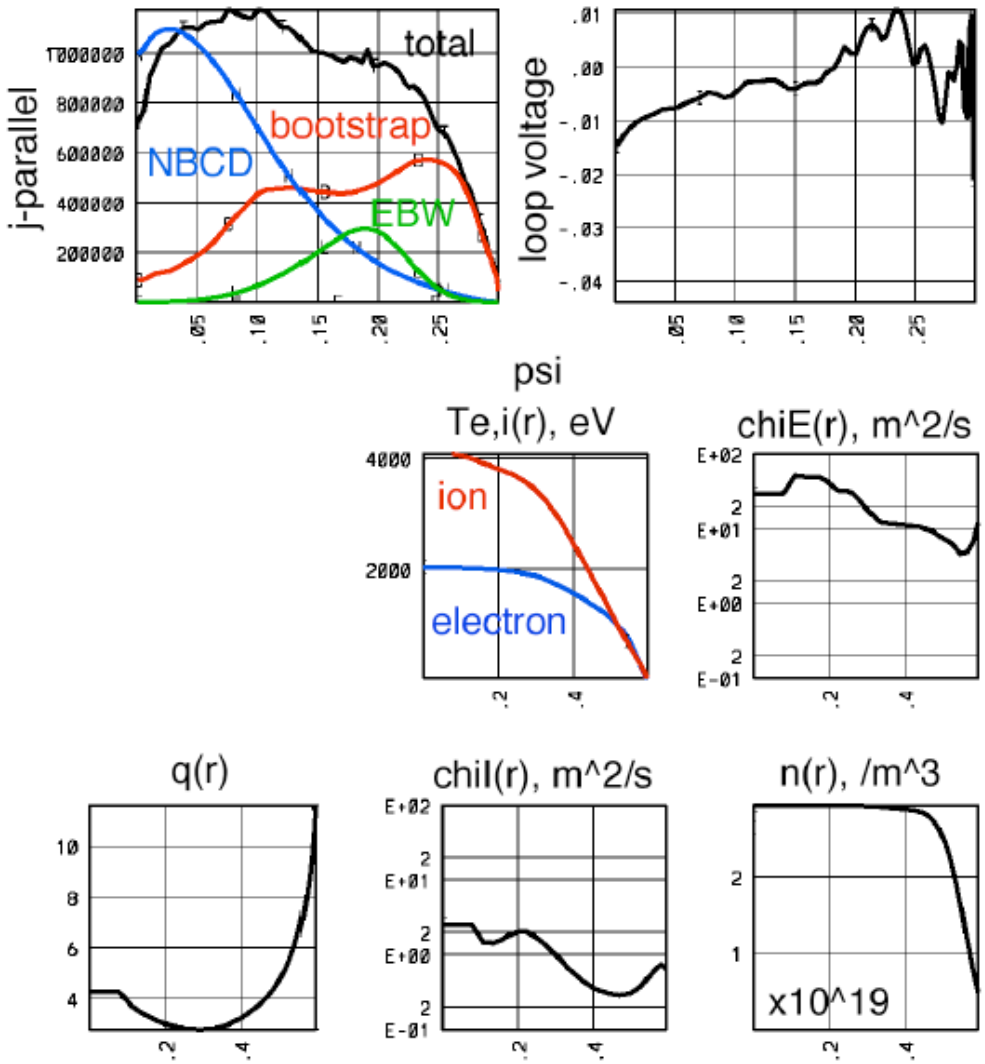




C. Kessel 5 yr. plan

Profiles indicate future challenges

- Profiles of parallel current, loop voltage, temperatures, density, safety factor and thermal diffusivities for fully non-inductive high β scenario with TSC
- Requires shape control for high β
- Also requires density control for non-inductive current

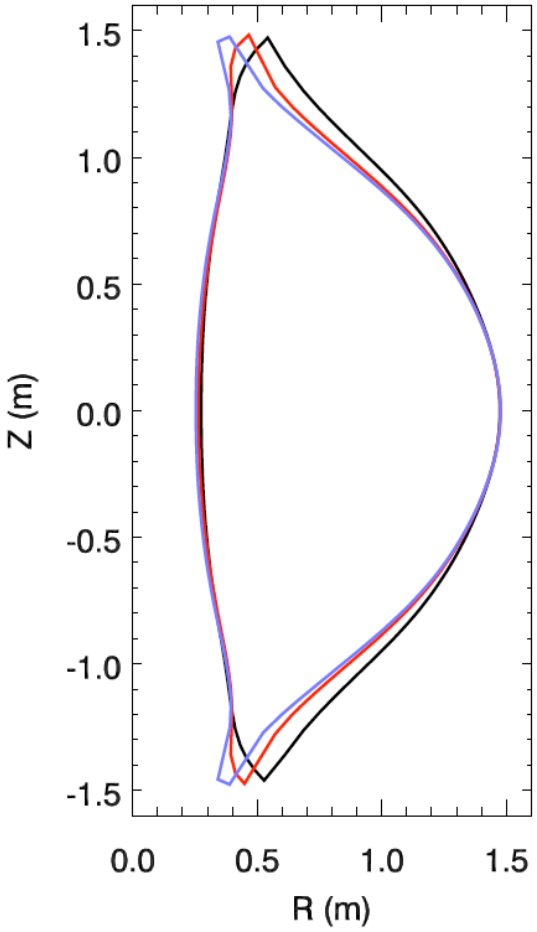


C. Kessel 5 yr. plan

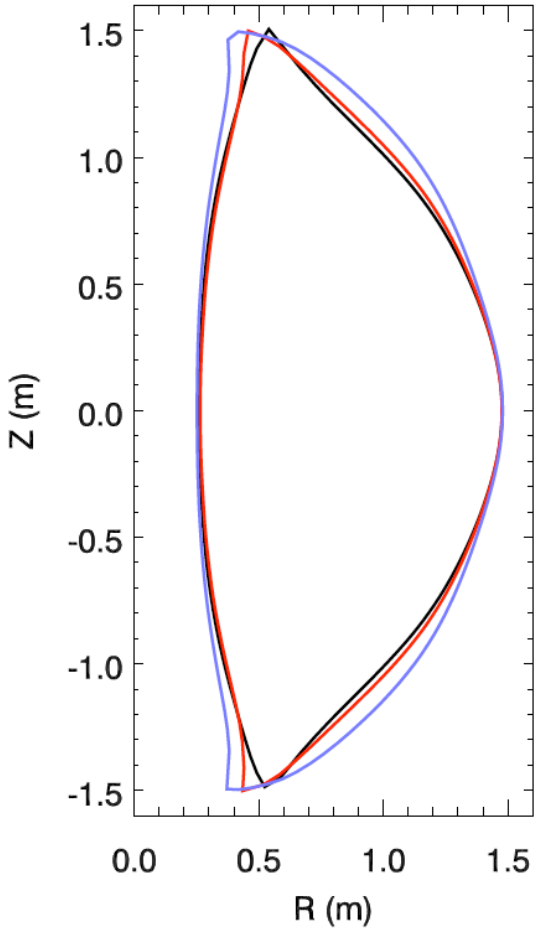
What does PF1A change imply for shape flexibility?

- δ scan gives much better shapes at high κ
- Squareness increases with increasing δ unlike with previous PF1A coil

δ scan - Old PF1A



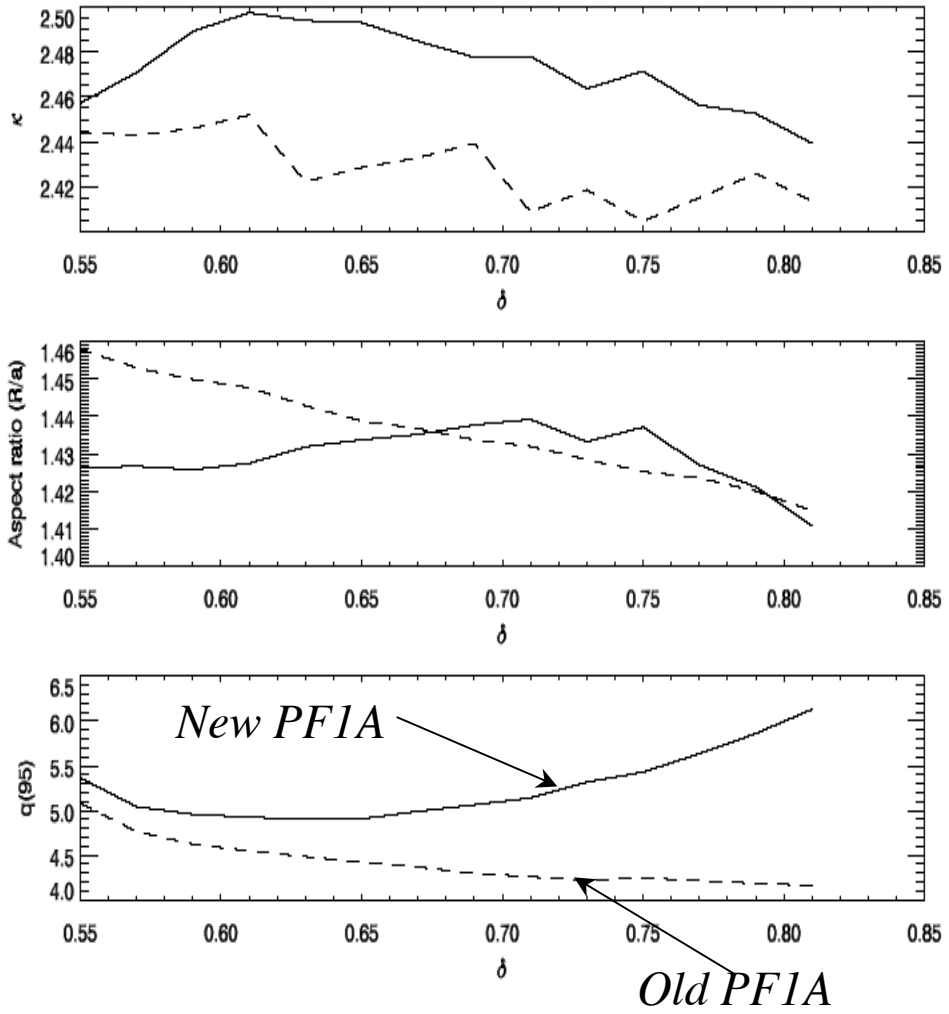
δ scan - New PF1A



PF1A upgrade memo - D. Gates

Equilibrium behavior

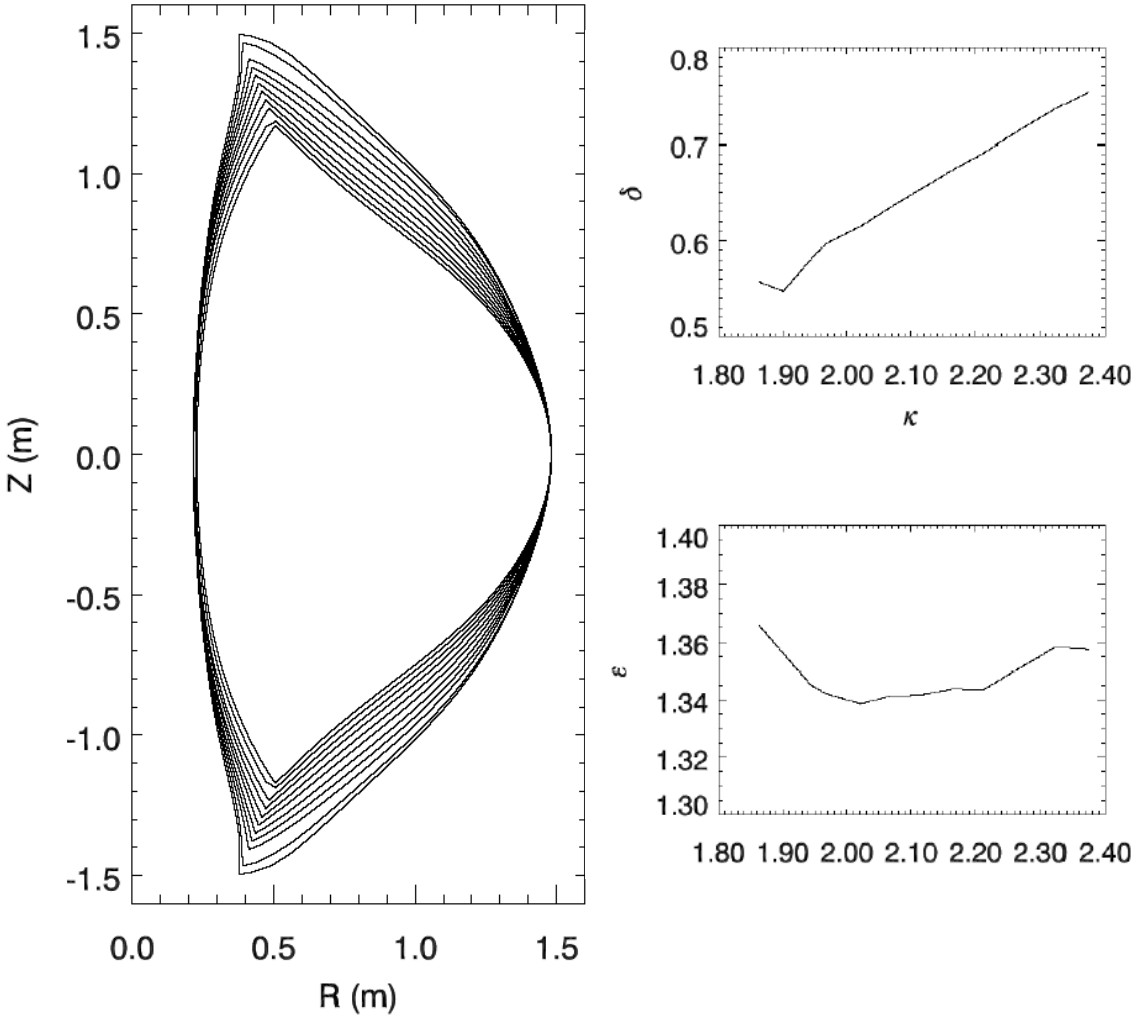
- As δ is scanned, *q(95)* increases by 50% with new PF1A relative to the old PF1A scan
  - Increased MHD stability
- Plasma parameters for scan
  - $I_p = 1.0MA$
  - $B_t = 3kGauss$
  - $\beta_N = 6.0$



Low κ, high δ inaccessible with new PF1A

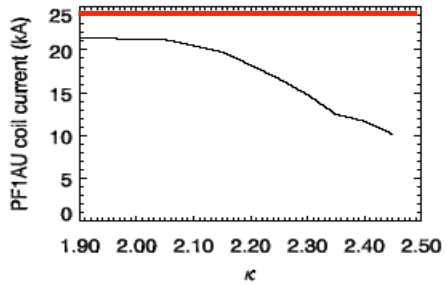
- Direct consequence of upgrade
- Could be repaired if deemed necessary by addition of second coil (lower half of old PF1A)
- PF1A current does not limit shape - hits PF2 limit first

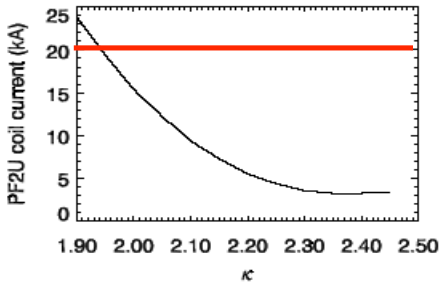
κ scan at fixed A

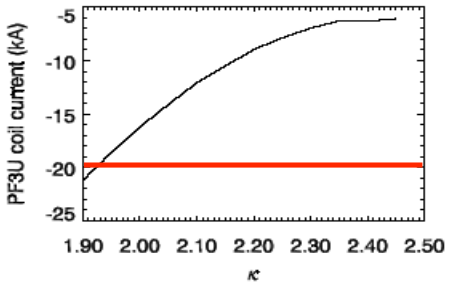


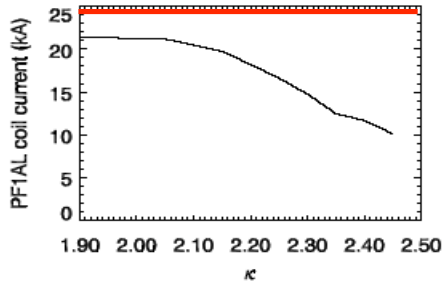
Coil currents from κ scan

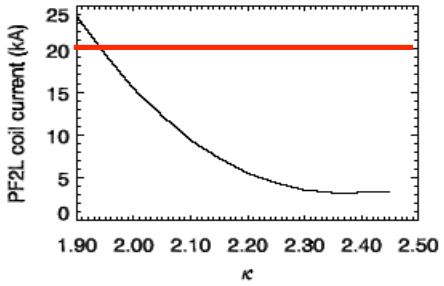
- PF2 is limiting coil (for this scan)

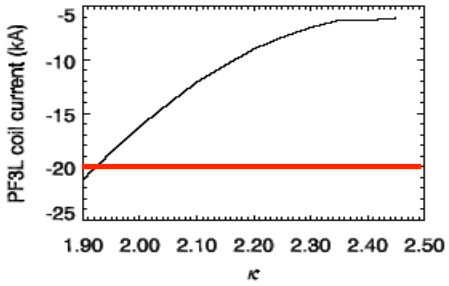


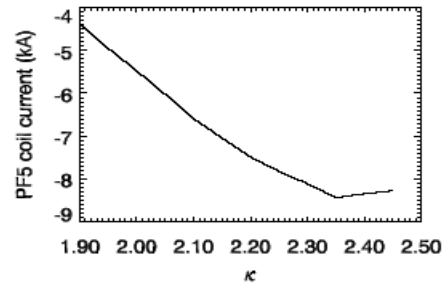








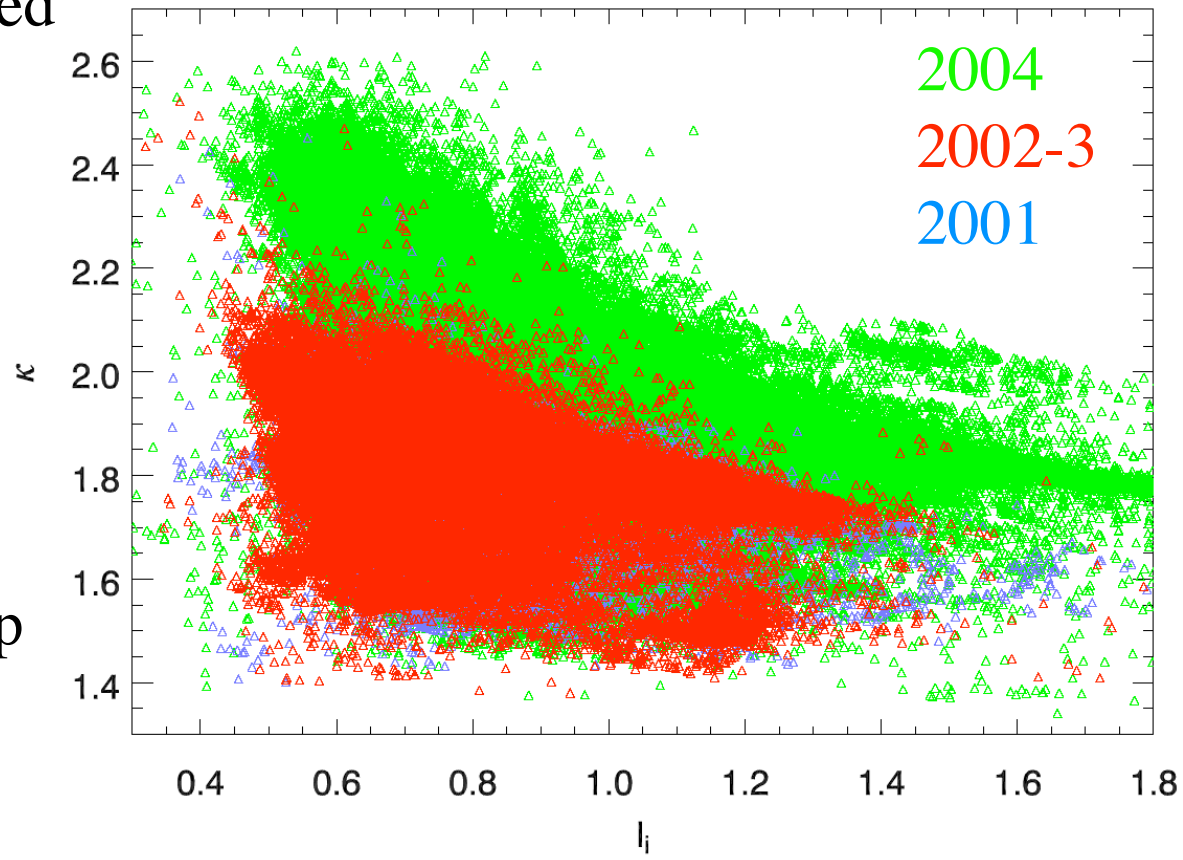




Why now?

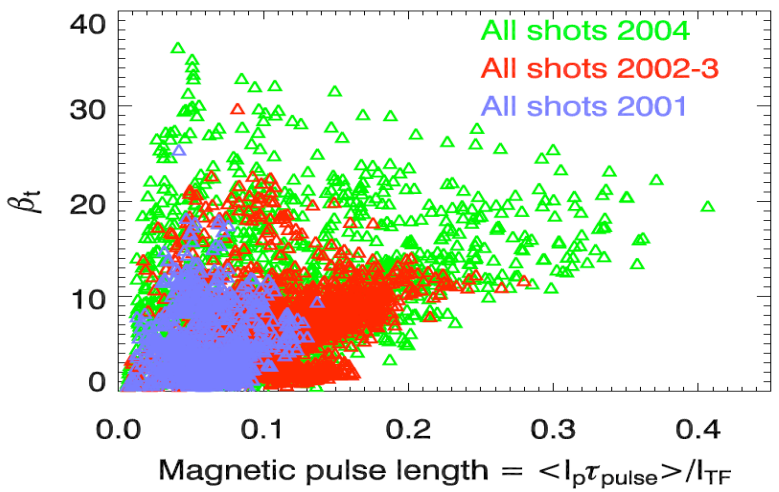
- Reduction in control system latency increased achievable κ
  - No further technical barrier to shape control for 5 year plan target equilibrium
- Center stack was removed early for additional TF repair
- Modification moved up to take advantage of opportunity

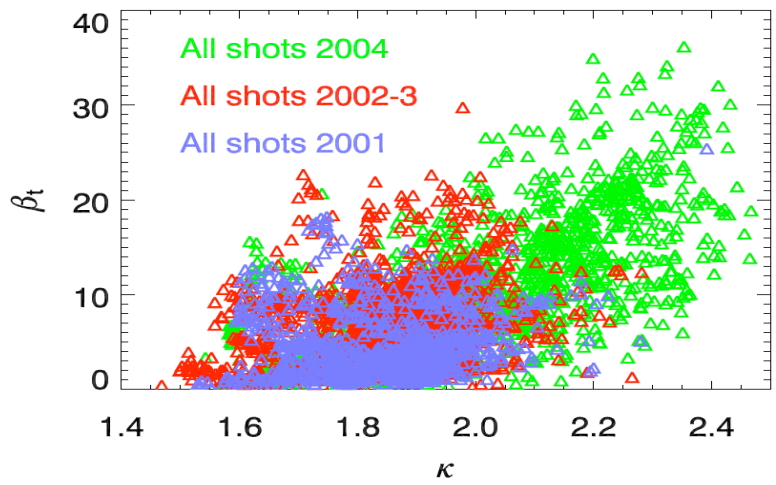
Vertical stability diagram showing improved operating space for NSTX in 2004

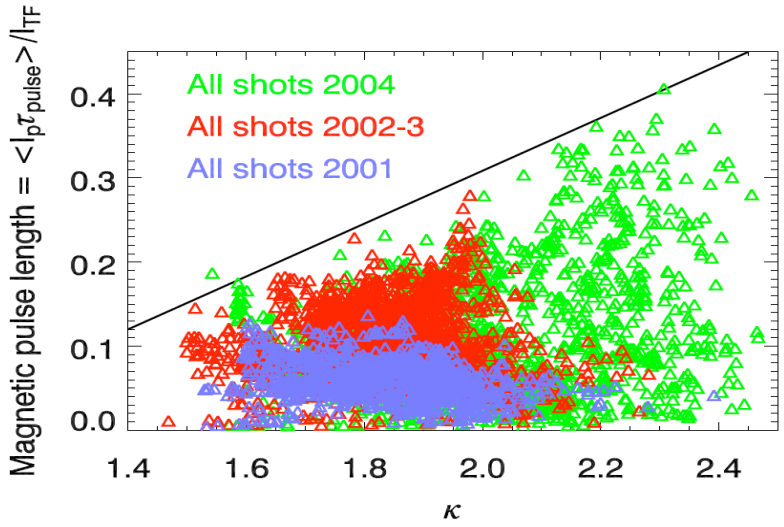


Benefits of increased κ confirmed

- Simultaneous doubling of β_t (pulse averaged) and 50 % increase in normalized pulse length
- Increase correlates strongly with high κ







Summary

- PF1A upgrade enables predicted 100% non-inductive operation with $f_{bs} \sim 70\%$ and $\beta_t \sim 40\%$
  - Indicates n=1 with wall stability for $\beta_N > 9$
  - No wall limit $\beta_N \sim 6$
  - (Also requires EBW and density control)
- Plasma vertical position control improvements have removed the major technical barrier to achieving this goal
- Reduction in operating space is tolerable
  - Give up low κ, high δ regime