NSTX-U

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Profiles Variations in NSTX-U and their Potential Impact on Equilibrium and Stability

Magnetoboss

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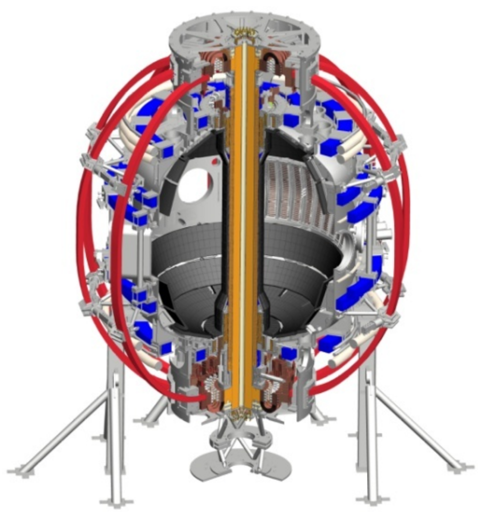

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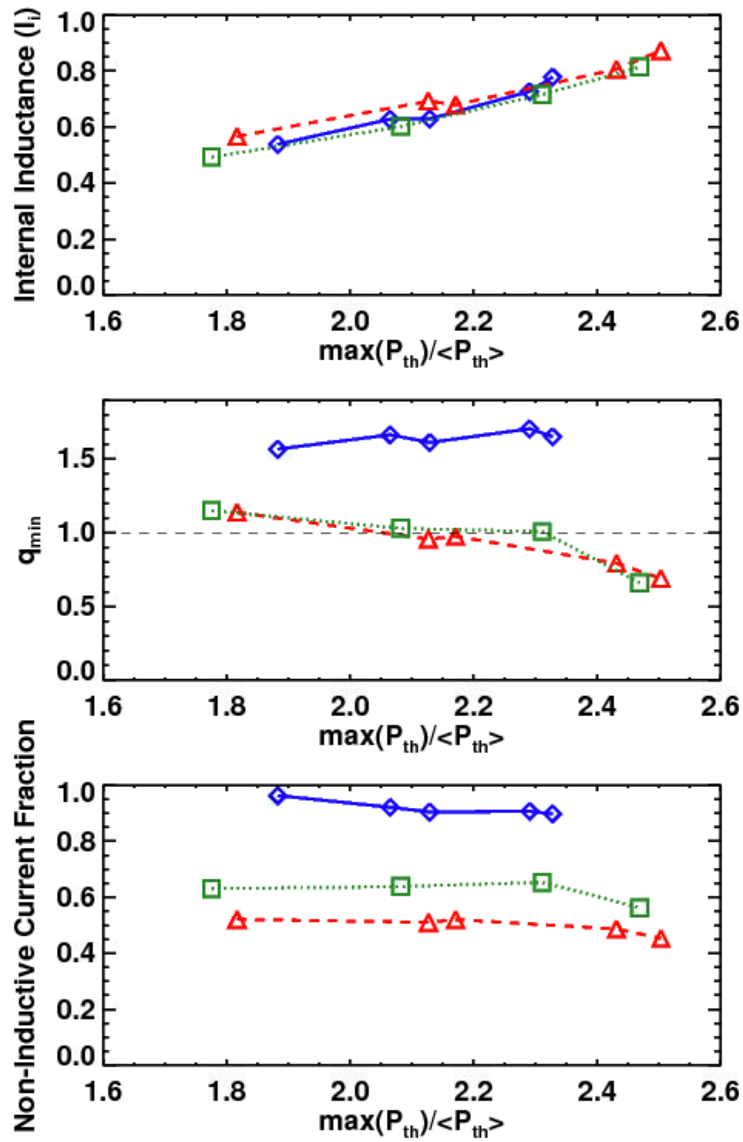
What was done…

- ISOLVER-TRANSP
  - Scale existing electron density profiles, use Z_{eff}=2 to derive ion density profiles.
  - Use Chang-Hinton model for ion transport, scale electron temperature to give a desired H_{98} or H_{ST}.
  - NUBEAM for the beam heating, torque, and current drive.
  - ISOLVER to compute self-consistent internal equilibrium
  - Run simulations long enough that the simulations reach steady state, and only use the steady state part of the solution.
- Stand-alone ISOLVER
  - Used input pressure and current (ff') profiles from various NSTX shots.
    - Range of shots taken to give a wide range in l_i.
  - Auto-generate thousands of equilibria with different shapes to look for trends in the PF requirements.

For Relaxed Scenarios, the Thermal Pressure Peaking Strongly Impacts the Equilibrium Parameters

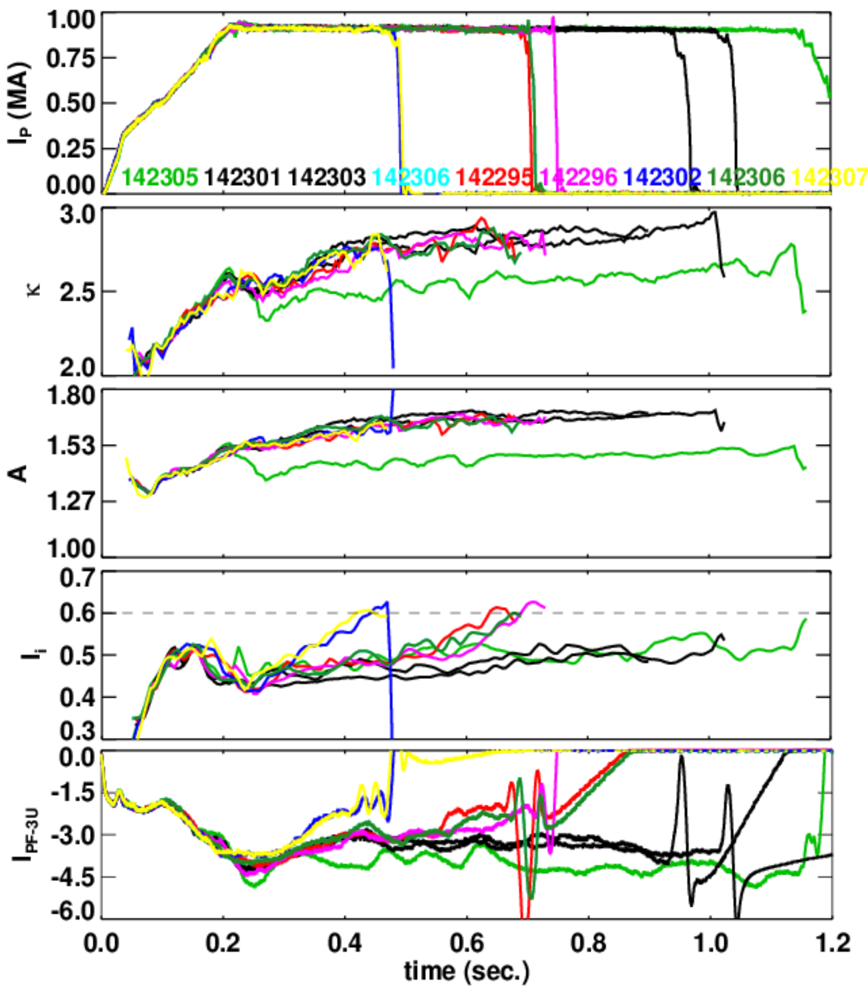
1.0 MA, 1.0 T, P_{inj}=12.6 MW, near non-inductive
1.6 MA, 1.0 T, P_{inj}=10.2 MW, partial inductive
1.2 MA, 0.55 T, P_{inj}=12.4 MW, high β_T
All: f_{GW}=0.7, $H_{98y,2}$=1

- Concerns: n=0 stability and control (VDE, boundary) and n=1 (core kink/tearing)
- Regardless of the target, too much thermal pressure peaking will drive l_i too high.
  - And values above 2.3 will probably be unacceptable for n=0 (next slide)
  - (note, l_i reaches approximate steady state faster than q_{min}).
- When pushing to higher I_N (or lower q_{95}), broader thermal profiles will allow the final q_{min} to equilibrate above 1.

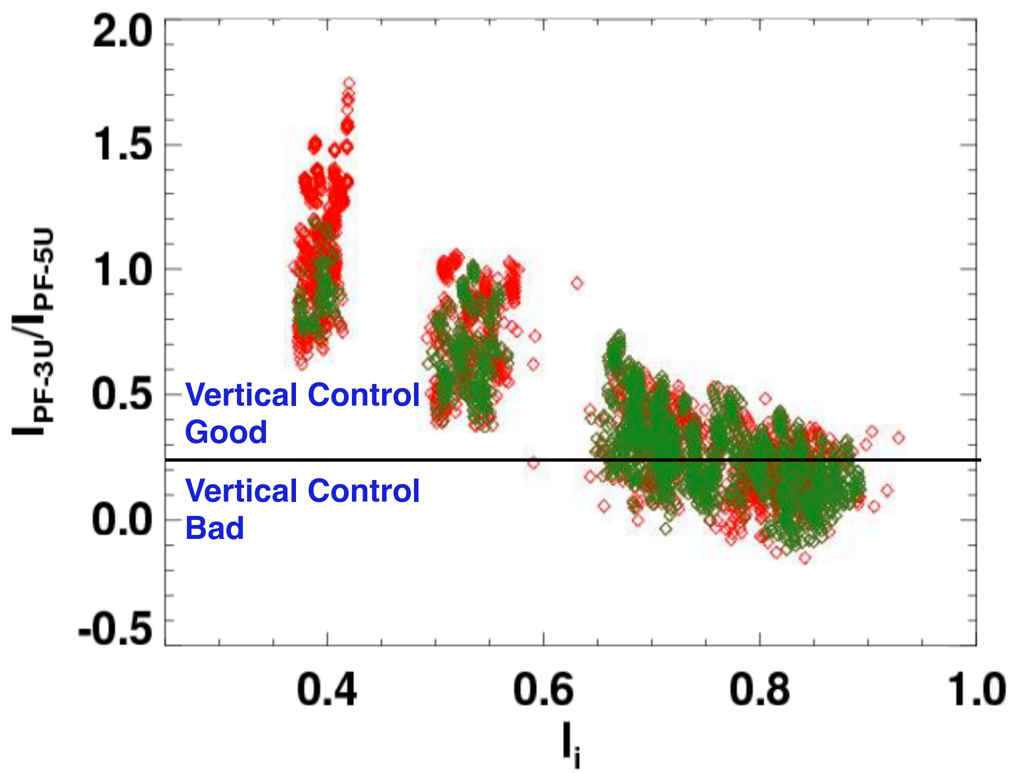


Vertical Stability May Provide Limitations on Global Stability With Narrower Profiles

Empirically, $I_{PF-3U}/I_{PF-5}<0.25$ Leads to a VDE.
(These had ~9 kA of PF-5 Before the VDE)



- Use stand-alone ISOLVER simulation of NSTX-U
- Scan many values of δ, κ, dr-sep, for each of a large number of profile shapes.
- Plot the PF-3 to PF-5 ratio for all the cases

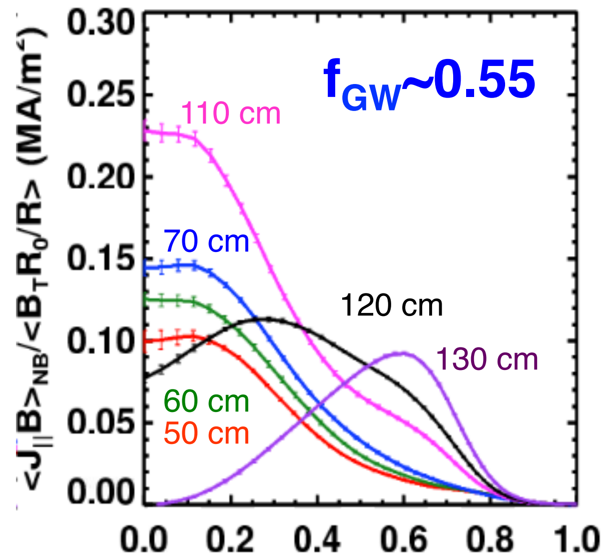


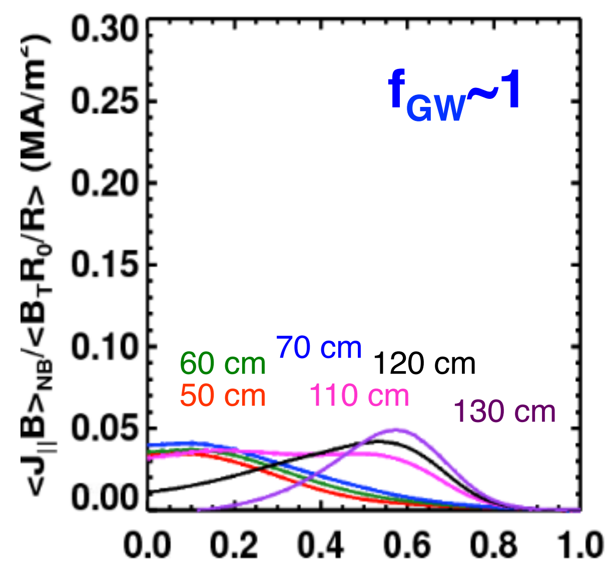
Rules For NBCD…

- Call the sources by the tangency radius
  - 50 cm: old source C
  - 60 cm: old source B
  - 70 cm: old source A
  - New beams at 110 cm, 120 cm, 130 cm

- Highest core NBCD efficiency:
  - 110 cm, 120 cm
- Highest mid-radius NBCD efficiency:
  - 130 cm
- Lowest total NBCD efficiency: 50 cm
  - Then 60 cm, then 70 cm

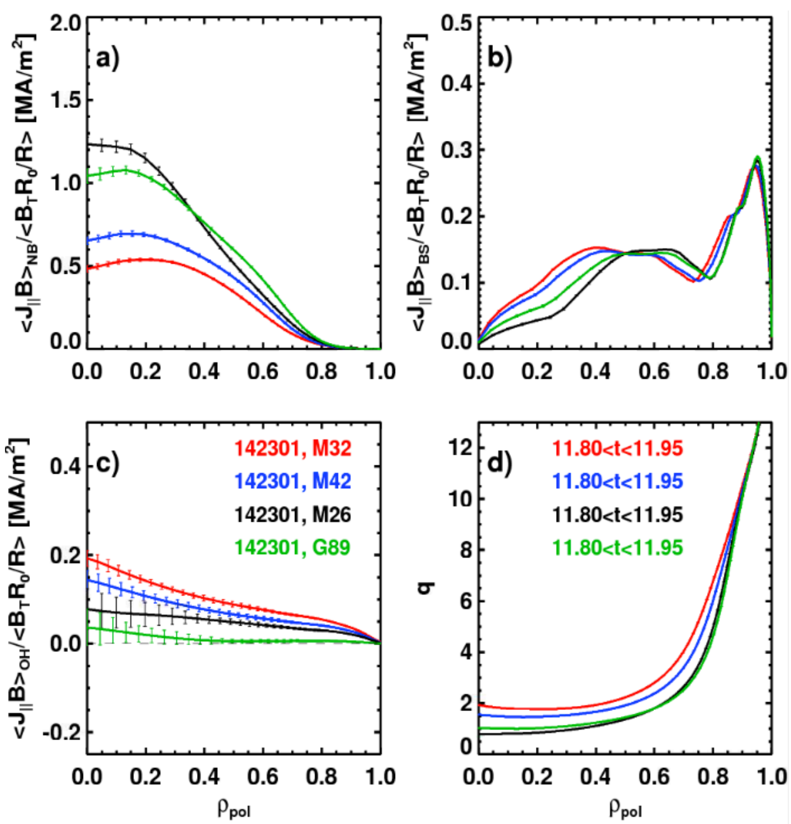
- Want to maximize NBCD?
  - Use 110 cm, 120 cm, 130 cm
  - But will be dominant in the core.
- Want to minimize NBCD?
  - use 50 cm, 60 cm
- Want to raise q_{min} with 4 sources?
  - use 50, 60, 70, 130
- Want to lower q_{min} with 4 sources?
  - use 60, 70, 110, 120





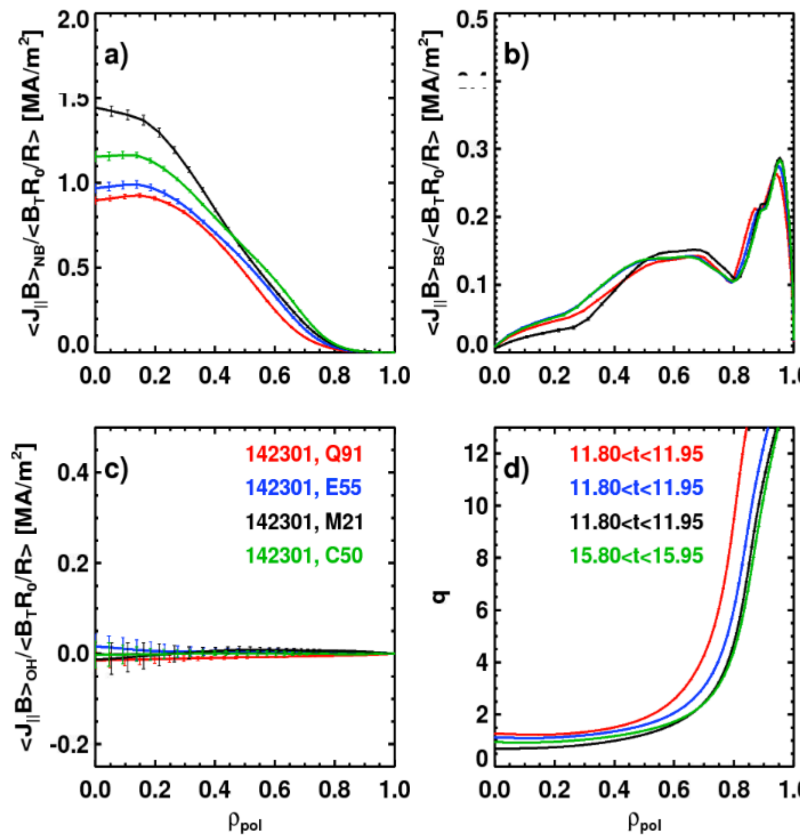
At B_T=0.75 T, Significant Variation in the Current Profile May be Possible: f_{GW}=0.7

4 Source Combinations at Fixed Current
I_P=800kA, f_{GW}=0.74



All: E_{inj}=90 kV, P_{inj}=8.4 MW, B_T=0.75 T, I_p=800 kA, f_{GW}=0.72, $H_{98y,2}$=1
R_{tan}=[50,60, 70, 130] cm, q_{min}=1.77, f_{NI}=0.85, l_i=0.49
R_{tan}=[50,60, 120,130] cm, q_{min}=1.46, f_{NI}=0.89, l_i=0.53
R_{tan}=[60,70, 110,120] cm, q_{min}=0.79, f_{NI}=0.93, l_i=0.55
R_{tan}=[70,110,120,130] cm, q_{min}=1.00, f_{NI}=0.99, l_i=0.58

*4 Source Combinations at **100% NI Fraction***

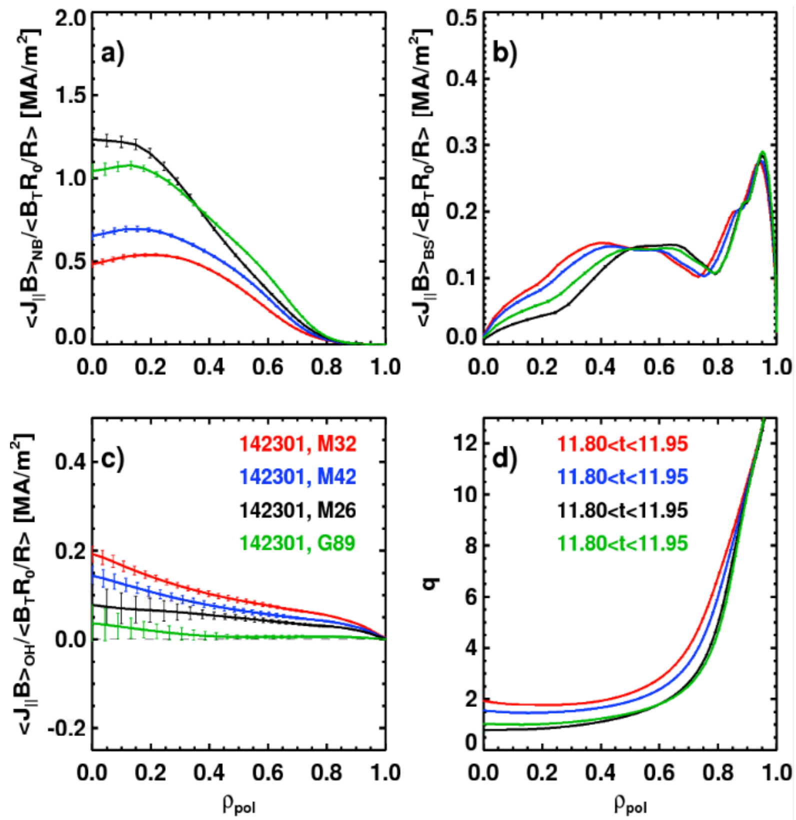


All: E_{inj}=90 kV, P_{inj}=8.4 MW, B_T=0.75 T, $H_{98y,2}$=1, f_{GW}=0.7, f_{NI}=100%
R_{tan}=[50,60, 70, 130] cm, I_P=650 kA, q_{min}=1.22, l_i=0.43
R_{tan}=[50,60, 120,130] cm, I_P=725 kA, q_{min}=1.10, l_i=0.52
R_{tan}=[60,70, 110,120] cm, I_P=765 kA, q_{min}=0.68, l_i=0.55
R_{tan}=[70,110,120,130] cm, I_P=775 kA, q_{min}=0.93, l_i=0.59

At B_T=0.75 T, Significant Variation in the Current Profile May be Possible: Varying f_{GW}

4 Source Combinations at Fixed Current

I_P=800kA, f_{GW}=0.74



All: E_{inj}=90 kV, P_{inj}=8.4 MW, B_T=0.75 T, I_p=800 kA, f_{GW}=0.72, $H_{98y,2}$=1

R_{tan}=[50,60, 70, 130] cm, q_{min}=1.77, f_{NI}=0.85, l_i=0.49

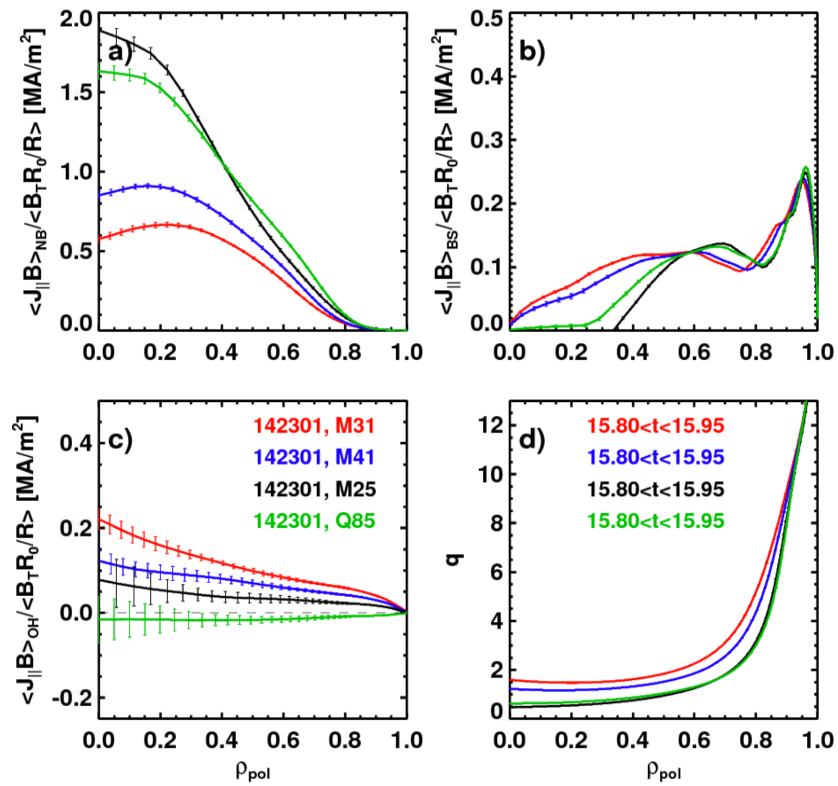
R_{tan}=[50,60, 120,130] cm, q_{min}=1.46, f_{NI}=0.89, l_i=0.53

R_{tan}=[60,70, 110,120] cm, q_{min}=0.79, f_{NI}=0.93, l_i=0.55

R_{tan}=[70,110,120,130] cm, q_{min}=1.00, f_{NI}=0.99, l_i=0.58

4 Source Combinations at Fixed Current

I_P=800kA, f_{GW}=0.6



All: E_{inj}=90 kV, P_{inj}=8.4 MW, B_T=0.75 T, I_p=800 kA, f_{GW}=0.57, $H_{98y,2}$=1

R_{tan}=[50,60, 70, 130] cm, q_{min}=1.48, f_{NI}=0.85, l_i=0.60

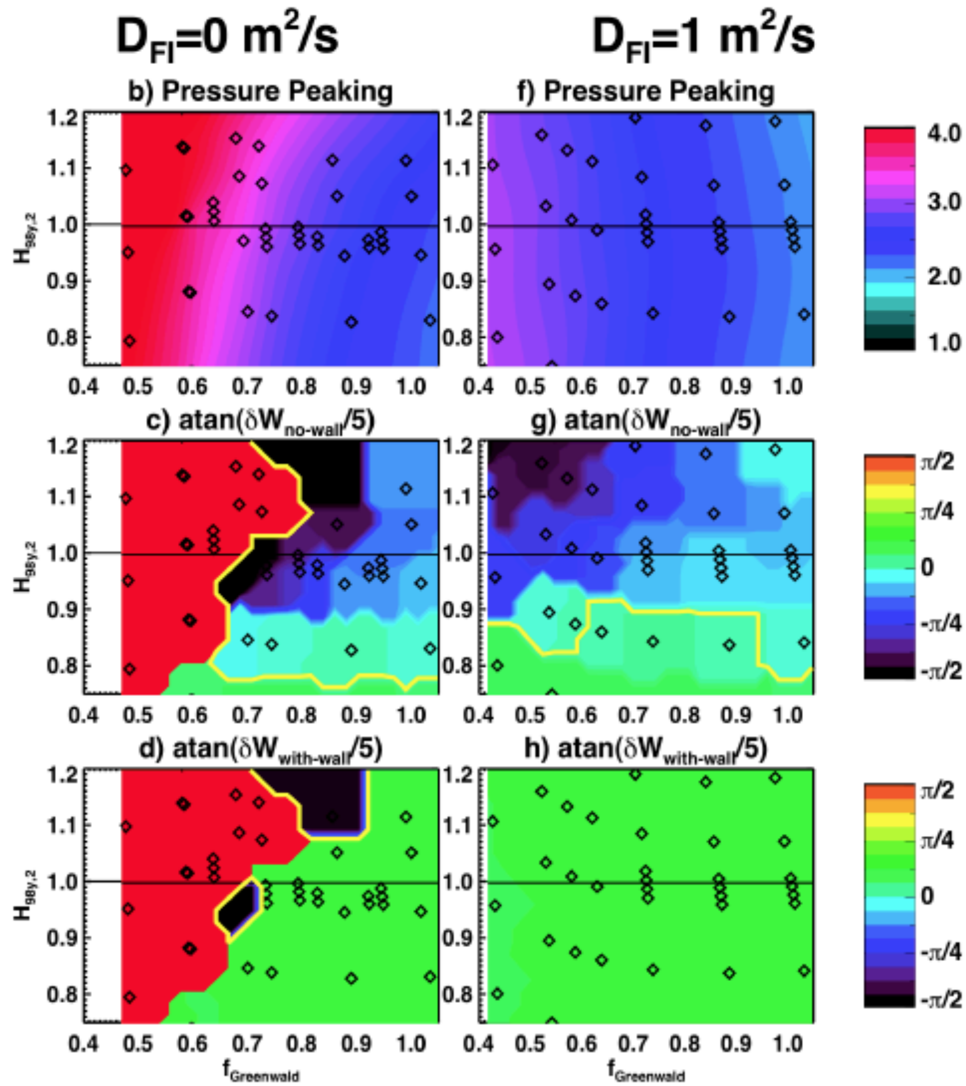
R_{tan}=[50,60, 120,130] cm, q_{min}=1.16, f_{NI}=0.89, l_i=0.65

R_{tan}=[60,70, 110,120] cm, q_{min}=0.47, f_{NI}=0.94, l_i=0.72

R_{tan}=[70,110,120,130] cm, q_{min}=0.63, f_{NI}=1.02, l_i=0.75

A Small Amount of Fast Ion Diffusion Might Be Good!

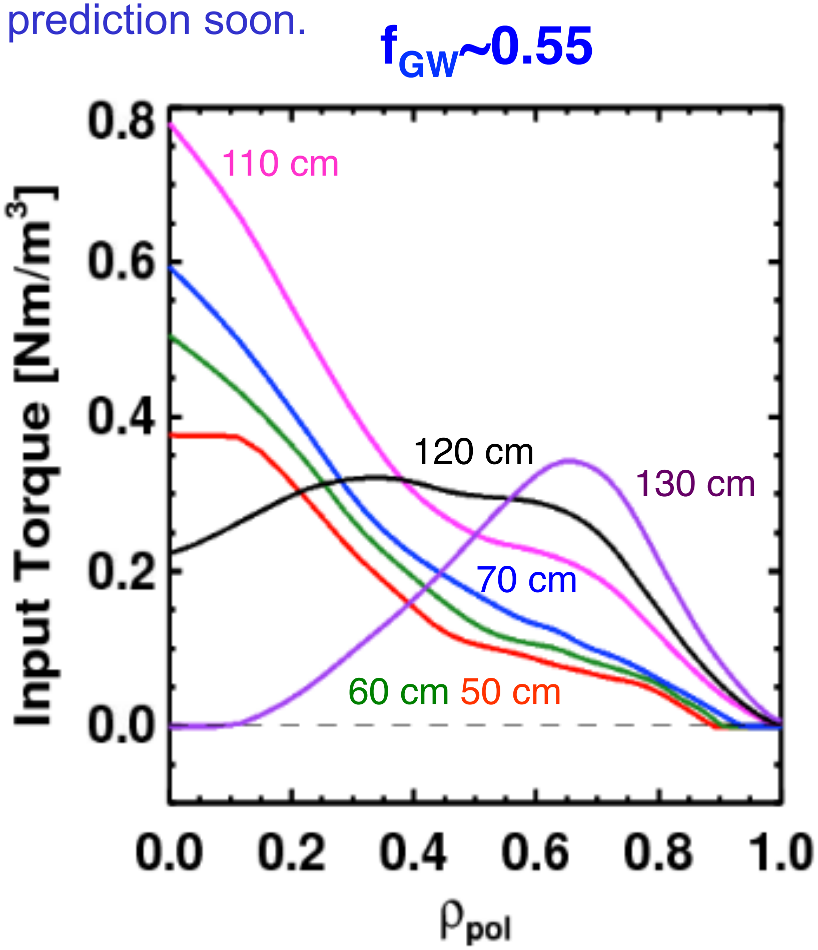
- Consider the nearly 100% non-inductive scenario at 1.0 MA, 1.0T, and P_{inj}=12.6 MW
  - H_{98}=1.06 yields f_{NI}~1
- Consider D_{FI}=0 &1 m^2/s.
- Small fast ion diffusion results in:
  - Reduced pressure peaking, and increased q_{min}, at lower density.
  - Improved external mode stability.
  - Elimination of internal modes due to low-q.
- When combined with a conducting wall, the space is stable to all n=1 modes.
  - See MS talk for RWM stability calculations

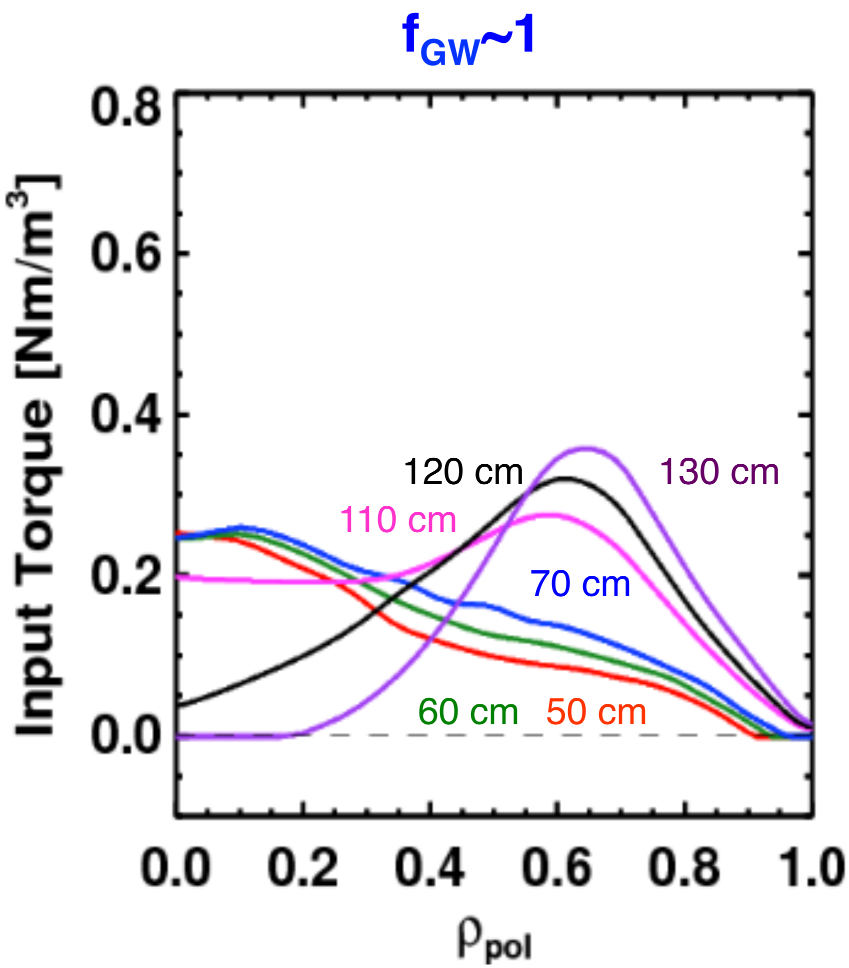


Red: Internal Modes Unstable
Green: stable
Blue/Black: External modes unstable

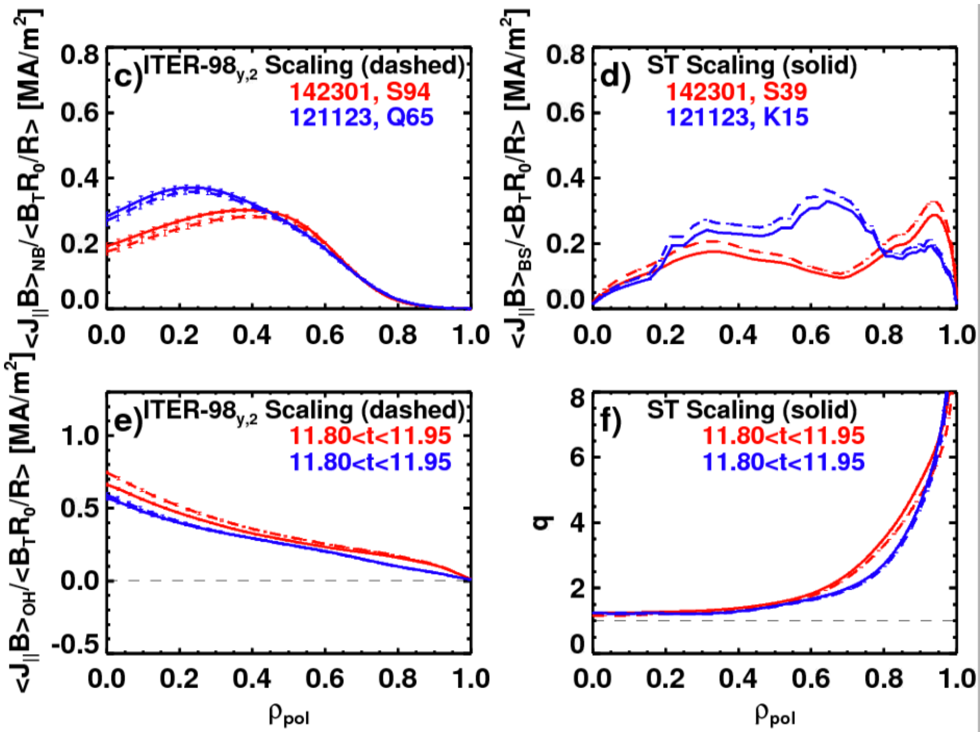
It MAY be Possible to Generate Large Changes in the Rotation Profiles

- Details of torque profile depend on the density.
- No predictions yet, because so validated momentum transport model.
  - But note that I Goumiri has a very simple control-oriented model that could be used for prediction soon.





Optimized Equilibrium For Maintaining High β_T
(At B_T=0.55 T, How Can the Plasma Current Be Maximized with q_{min}>1?)



Target Equilibria:
B_T=0.55 T, I_P=900-1100 kA
κ=2.9-2.9
β_N=5.2-5.9, β_T=18-22%
q_{min}=1.2, $t_{flat-top}$>>τ_{CR}
Can only work for broad thermal profiles

Broad Profs., (I_P [kA],β_T [%],I_l)=(1100,22,0.54) for $H_{98y,2}$=1, (1000,19,0.56) for H_{ST}=1

Peaked Profs., (I_P [kA],β_T [%],I_l)=(950 ,19,0.79) for $H_{98y,2}$=1, (900 ,18,0.81) for H_{ST}=1

Key Experimental Questions

- Can we use variations in the beams to control q_{min}?
- How does the transport change with q_{min}?
  - Does transport get worse as q_{min} increases at fixed q_{95}?
- Can we use the available current drive actuators to maintain profiles consistent with vertical and n=1 stability?
- Can we systematically change the rotation shear at the mid-radius/edge (not pedestal) to assess changes in confinement?
- Can we optimize the NBCD, profiles, and plasma shape to maximize β_N at low-q_{95}?
  - Same as asking what is the highest β_T that we can operate at for longer than a few τ_{CR}?

Backup

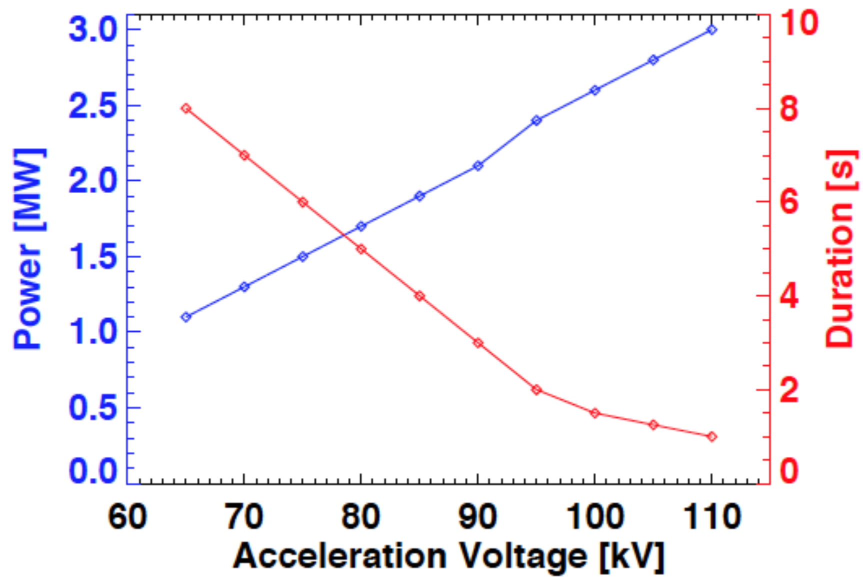
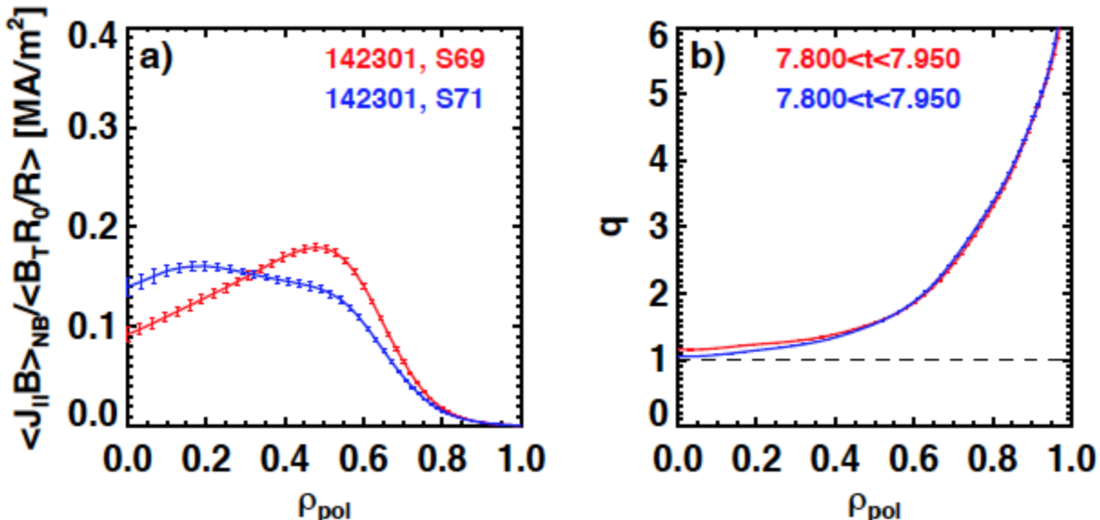


Fig. 2: Power and allowable pulse duration for the NSTX neutral beam sources, as a function of the acceleration voltage.



All: I_P=1.2 MA, B_T=0.55 T, 20 cm outer gap, $H_{98y,2}$=1, f_{GW}=0.88

R_{tan}=[50,60,120,130] cm, D_{FI} = 0 m^2/sec, XKFAC = 1, q_{min}=1.14

R_{tan}=[50,60,70, 130] cm, D_{FI} = 0 m^2/sec, XKFAC = 1, q_{min}=1.05

Fig. 26: Test of two difference neutral beam source combinations for maintaining elevated q_{min} in the high-β_T scenario optimization