# Evidence for Closed Flux in CHI Plasmas

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# Introduction

Limited and diverted OH plasmas have a poloidal field ($B_p$) structure showing "obvious" closed flux.

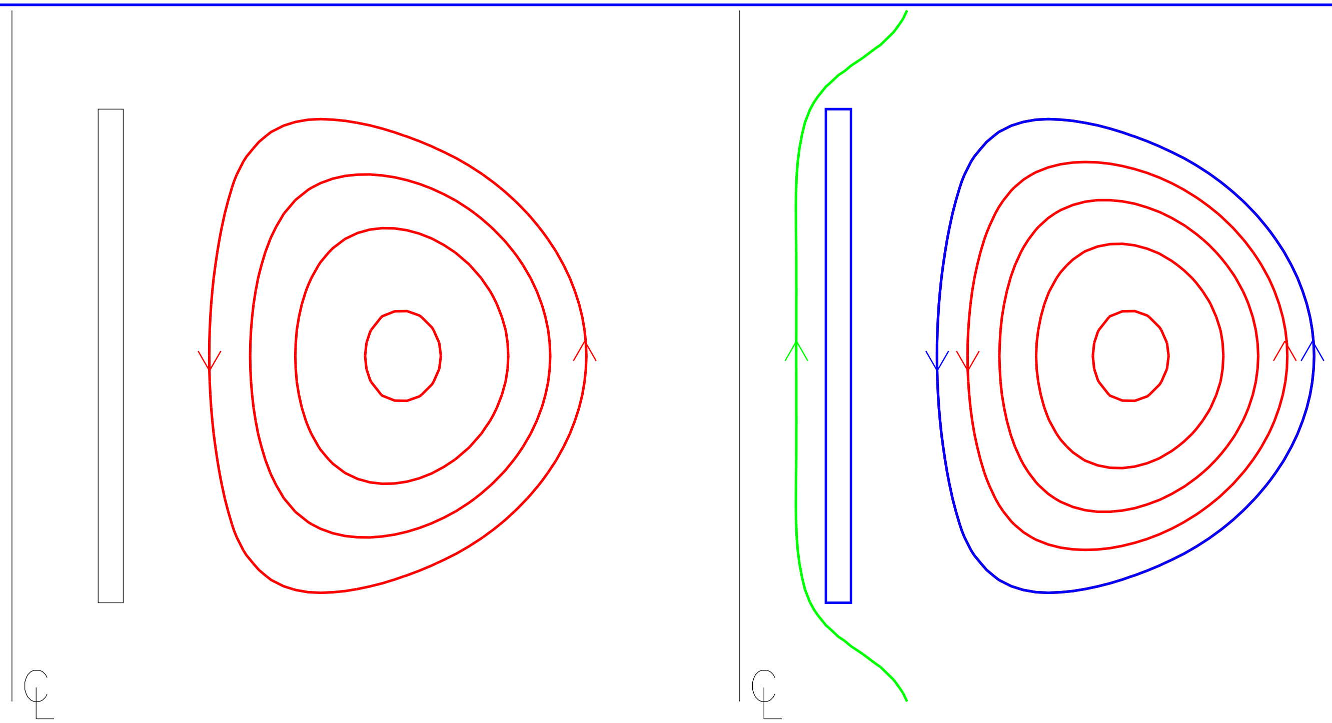
It is difficult to "prove" the existence of closed flux in CHI plasmas. CHI expands the injector flux ($\psi_{\text{inj}}$), exhibiting a $B_p$ structure similar to a diverted plasma. However, the hoop force of closed flux would be expected to modify the $B_p$ structure.

Additional evidence is needed to evaluate closed flux in CHI.

# Outline

- Discussion of closed flux in CHI plasmas
- Evidence in the HIT and HIT–II Experiments
- Evidence in the NSTX Experiment
- Future plans
- Summary

# Ohmic Current Drive Maintains Helicity by Injecting Poloidal Flux Linking Toroidal Flux

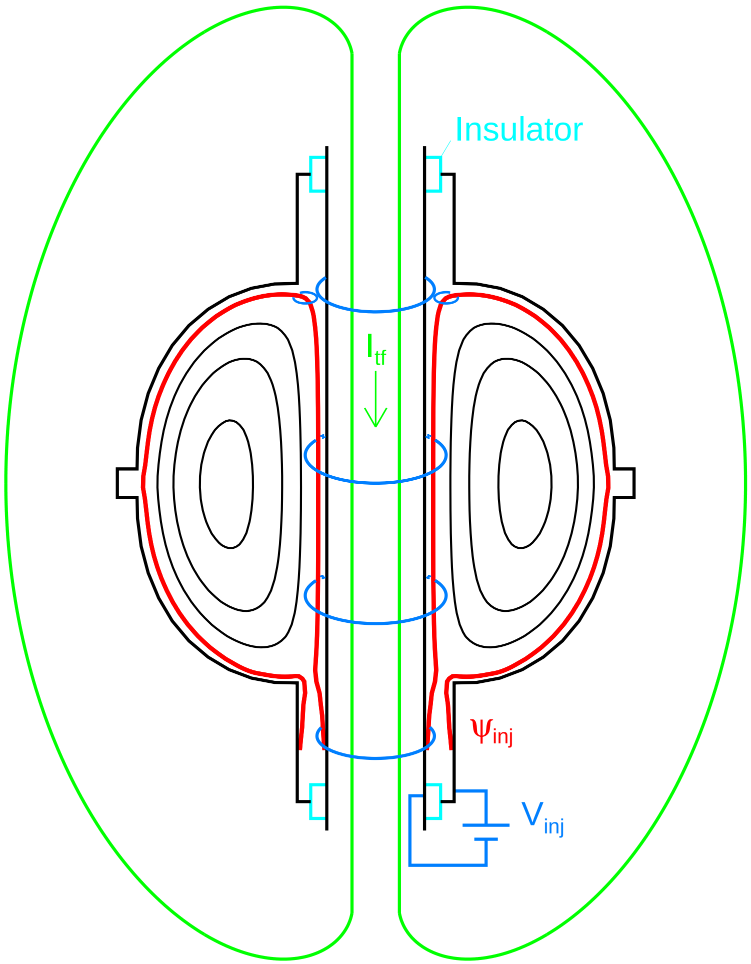


$V_{\text{loop}}$ injects $\dot{\psi}_p$ completely linking $\Phi_T$

$\Rightarrow \dot{K}_{\text{inj}} = 2 V_{\text{loop}} \Phi_T$

Edge-driven current relaxes to flatten current profile

# CHI Injects Toroidal Flux Linking Poloidal Flux



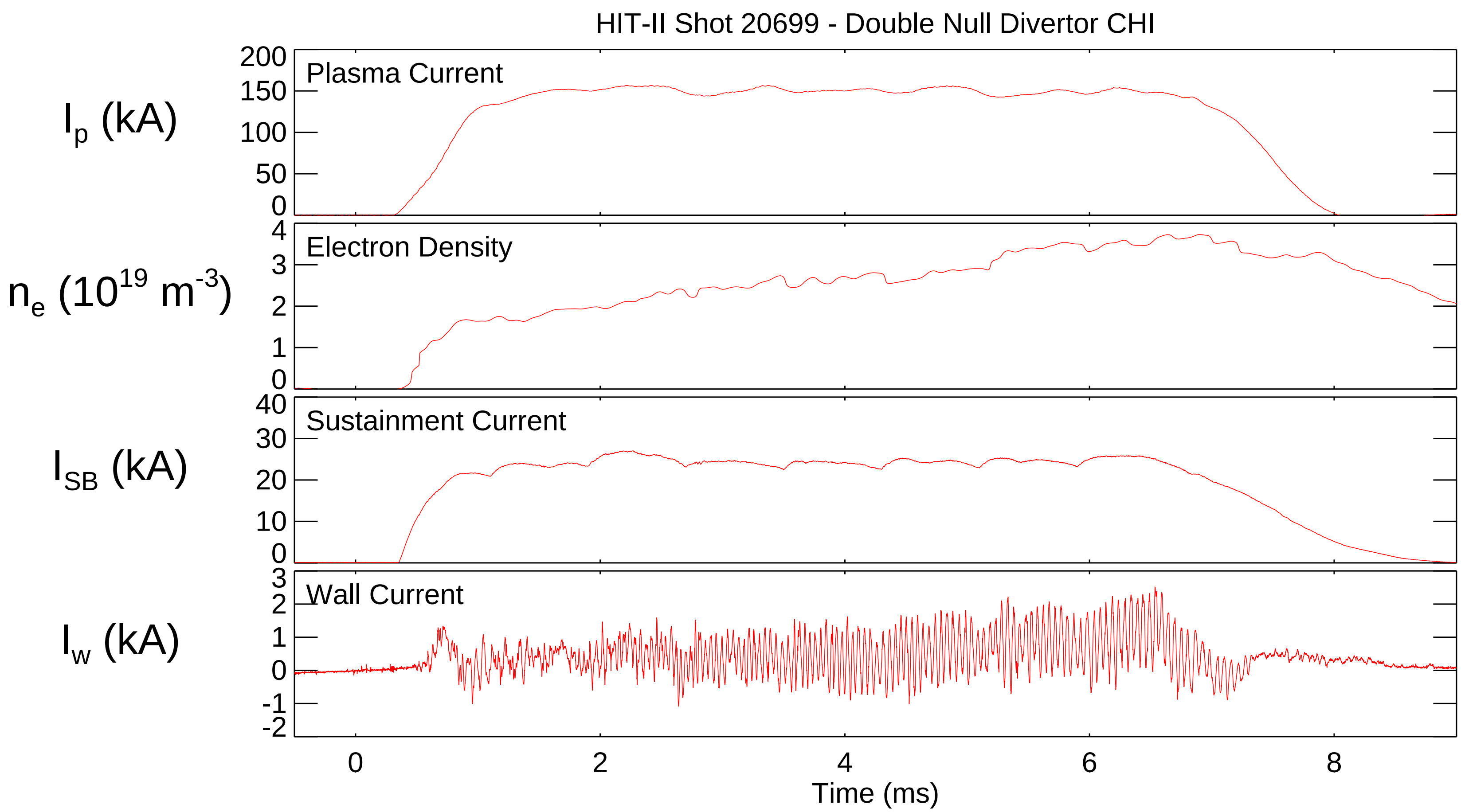

$V_{inj}$ injects $\dot{\Phi}_{inj}$

completely linking $\psi_{inj}$

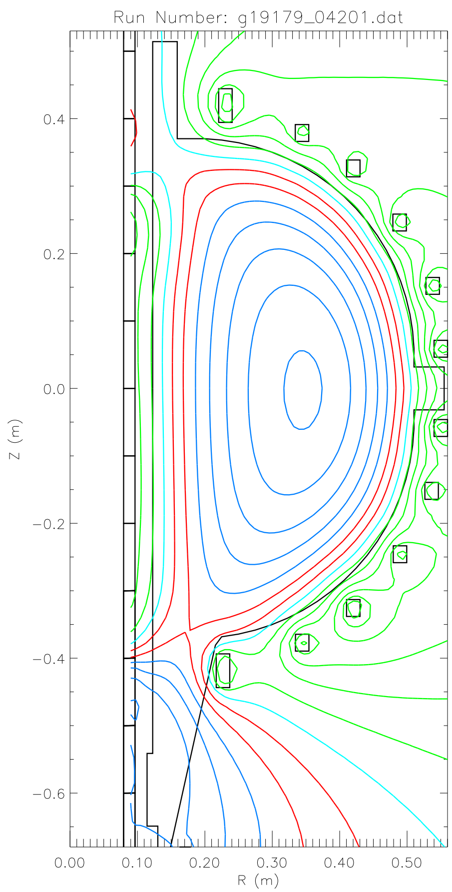
$\Rightarrow \dot{K}_{inj} = 2V_{inj}\psi_{inj}$

Edge-driven current relaxes
to flatten current profile

# HIT–II Double Null Divertor CHI has Low $I_w$

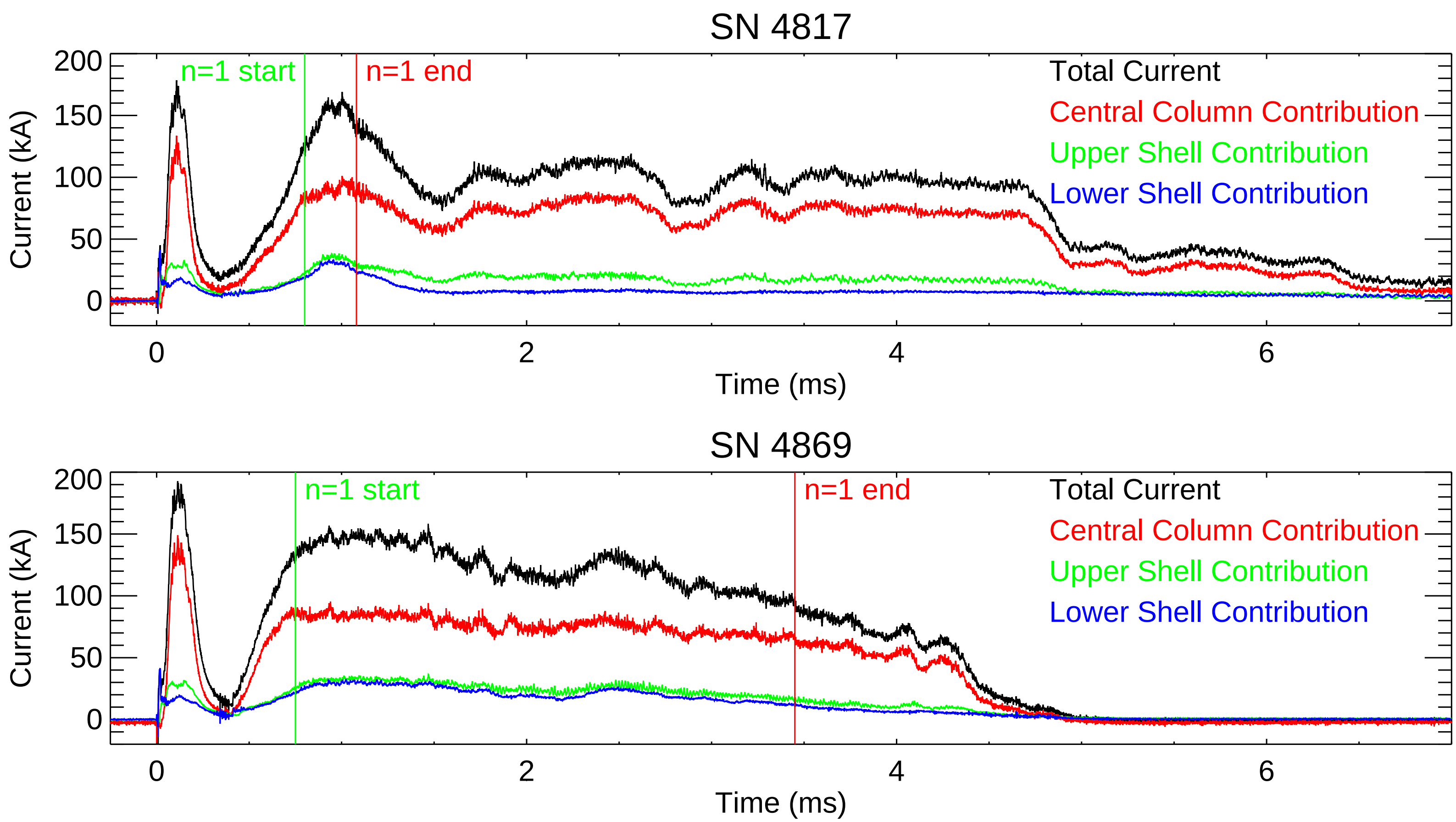


# HIT–II DND CHI Yields Best Results




- Injector current flows completely around closed flux with low $I_w$
- Operates at low densities
- Continuous $n$=1 activity
- EFIT converges with low $\chi^2$ (modified for open flux current, fitting to $I_{\text{inj}}$, and different $FF'(\psi)$ across X-point)

# Outer Shell $B_p$ is Up/Down Symmetric During $n$=1



# Evidence for Closed Flux in HIT/HIT–II

After $n$=1 mode begins:

- Up / down symmetry in $B_p$
- Higher ratio of outer to inner $B_p$
- Spectroscopy shows increasing temperature
- $T_e \sim 100$ eV (single point Thomson in HIT)
- EFIT converges

# Characteristics of the $n$=1 Rotating Distortion in HIT and HIT–II

- Onset coincident with drop in wall current and edge density. Always seen with high current ($I_p >$ 100 kA)

- Observed by surface probes only on outer shell. Has the same pitch as the edge magnetic field lines.

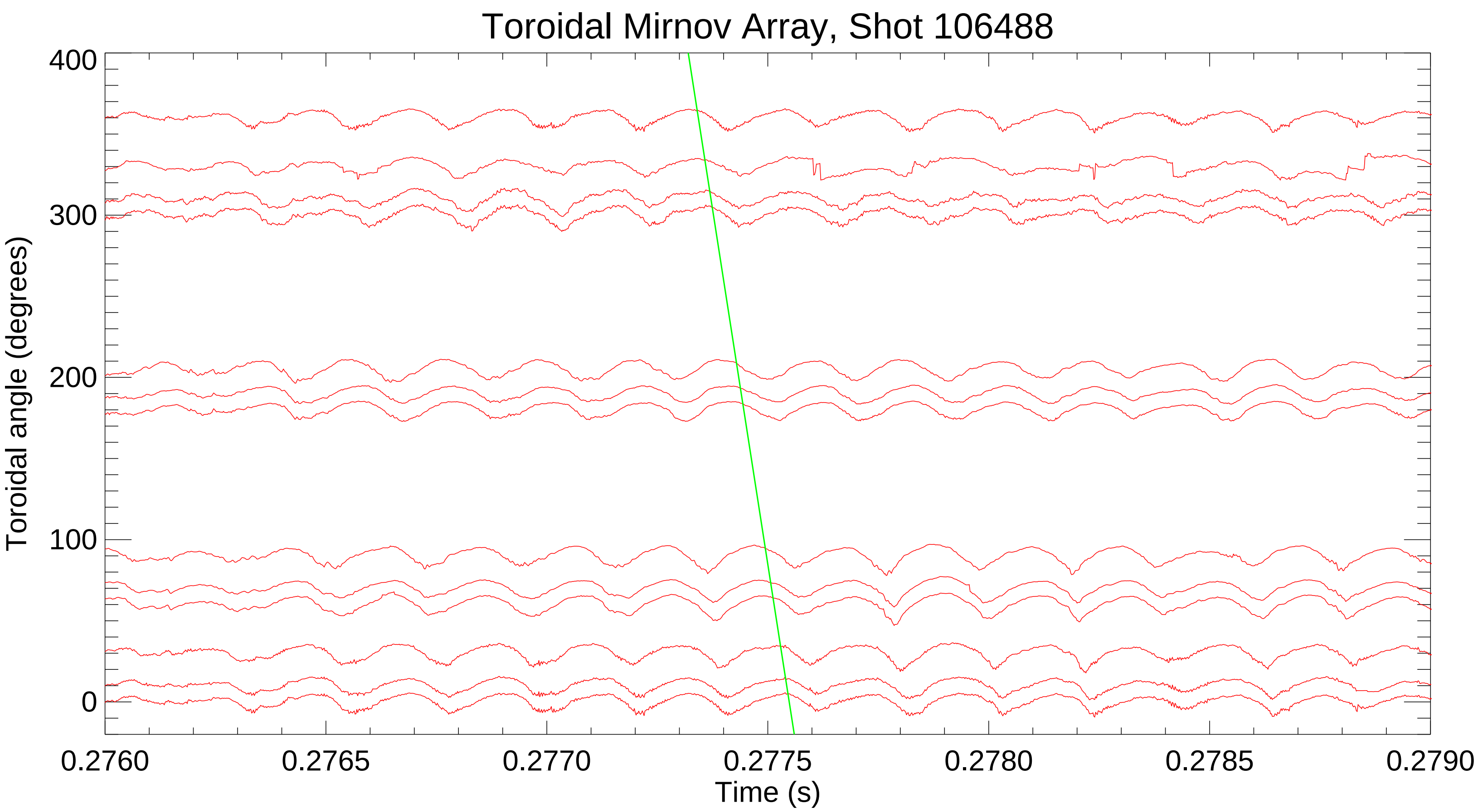
- Rotates in the direction of $\mathbf{E} \times \mathbf{B}$, with frequency 40 – 70 kHz (HIT), 10 – 60 kHz (HIT–II)

- Predicted by ideal MHD for a hollow current profile with a rational $q$ in a vacuum layer

# Major Differences of HIT–II and NSTX

- HIT and HIT–II
  - Robust insulators (accessibility to explore operating regimes)
  - Plasma near conducting wall (limits $n$=1 amplitude)
- NSTX
  - Insulators limit operational regimes
  - Much more complete diagnostic suite, larger volume (injector more isolated, larger $S$), longer pulse length, and higher current capability

# NSTX Shows Continuous $n$=1 Toroidal Oscillations



# Characteristics of the $n$=1 Rotating Distortion in NSTX

- Appears for $I_p \sim$ 200–250 kA, robust for $I_p >$ 300 kA
- Observed near outer midplane
- Rotates in the direction of $\mathbf{E} \times \mathbf{B}$
- Rotation frequency 5 - 12 kHz
- Need more magnetic measurements to determine poloidal structure and more analysis to determine up/down symmetry

# Additional Evidence in NSTX

- Spectroscopy shows increasing temperature

- MPTS up to 50 eV (plasma may not be far past midplane)

- Reconstructions with MFIT (no force balance) and EFIT (no fitting to $I_{\text{inj}}$) show some closed flux

  $\Rightarrow$ Need EFIT with $I_{\text{inj}}$ fitting for NSTX

# NSTX Future Plans

- Feedback control of plasma equilibrium, increase $I_p$
- More analysis and measurements of surface/edge probes
- Double-null divertor flux boundary conditions
- At the absorber: improve insulator and add field nulling coils
- EFIT with $I_{\mathrm{inj}}$ fitting

# Summary

- "Proving" closed flux in CHI plasmas is not straightforward

- High-performance CHI discharges in NSTX, HIT, and HIT–II observe $n$=1 toroidally rotating oscillations

- HIT and HIT–II high-performance CHI plasmas show reduction of wall current, up/down symmetry, higher temperature, and convergence of EFIT

- Results from NSTX are encouraging, (similar to HIT/HIT–II) but more CHI data (shots) and futher analysis are needed