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NSTX

Overview of Transient CHI Plasma Start-up in NSTX and HIT-II

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Outline

- Implementation of Coaxial Helicity Injection (CHI) in HIT-II and NSTX
  - Similarities and differences
- Requirements for Transient CHI
- What was achieved on HIT-II
- Results from NSTX and Future plans
- Summary and Conclusions

Solenoid-free Plasma Startup is Essential for the ST Concept

NSTX

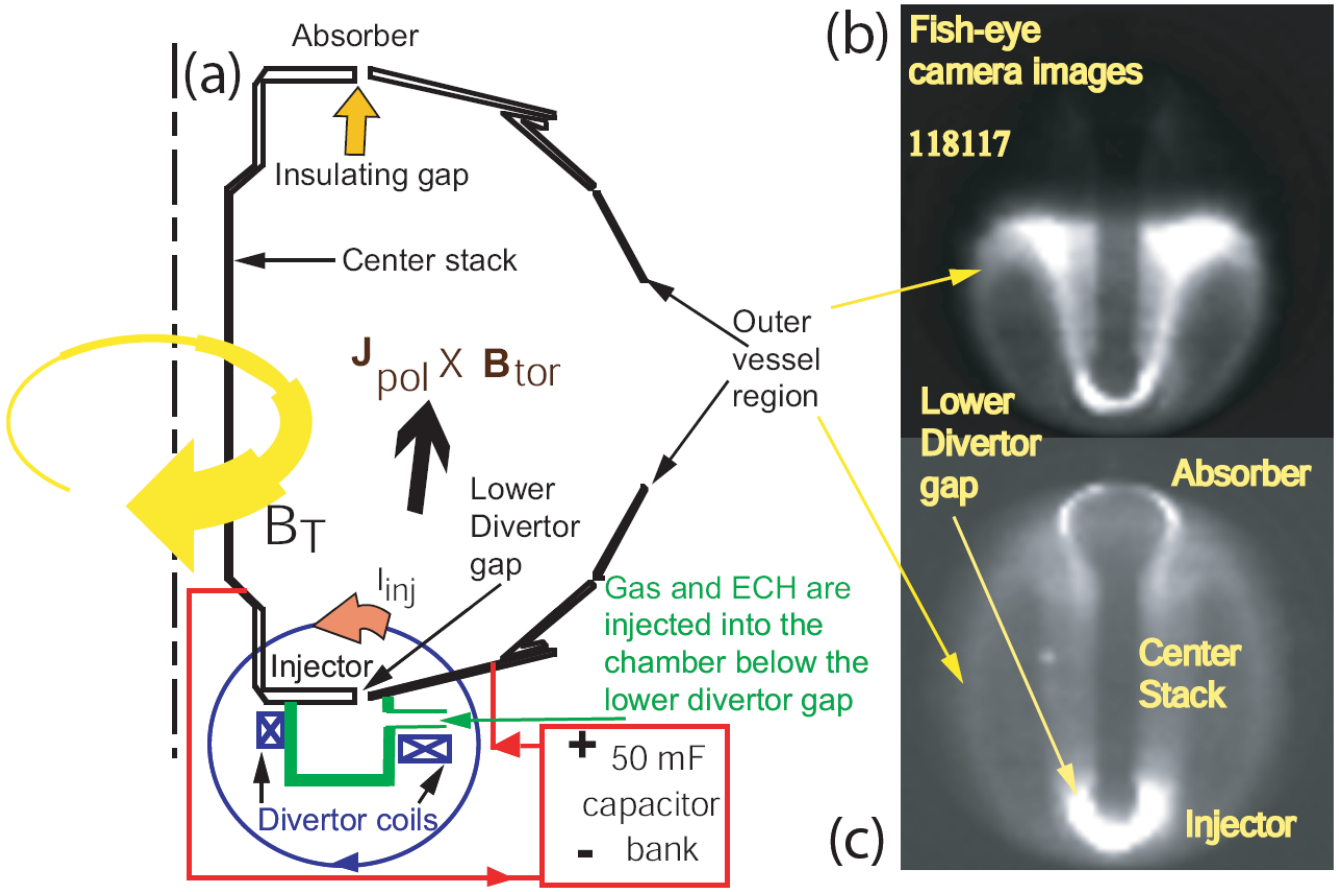
- Elimination of the central solenoid simplifies the engineering design of tokamaks (Re: ARIES AT & RS)
- CHI is capable of both plasma start-up and edge current in a pre-established diverted discharge
  - Edge current profile for high beta discharges
- Applicable to reactors with Super Conducting PF coils
  - As shown on HIT-II (no time changing coil currents)

Requirements for optimizing Transient CHI

- Bubble burst current* $\propto \psi_{inj}^2 / \psi_{toroidal}$
- Volt-seconds to replace the toroidal flux
- Energy for peak toroidal current $\frac{1}{2}CV^2 = \frac{1}{2}LI^2$
- Energy for ionization of injected gas and heating to 20eV (~50eV/D)
  - For 2 Torr.L injected, need ~2kJ

* T.R. Jarboe,"Formation and steady-state sustainment of a tokamak by coaxial helicity injection," *Fusion Technology* **15**, 7 (1989).

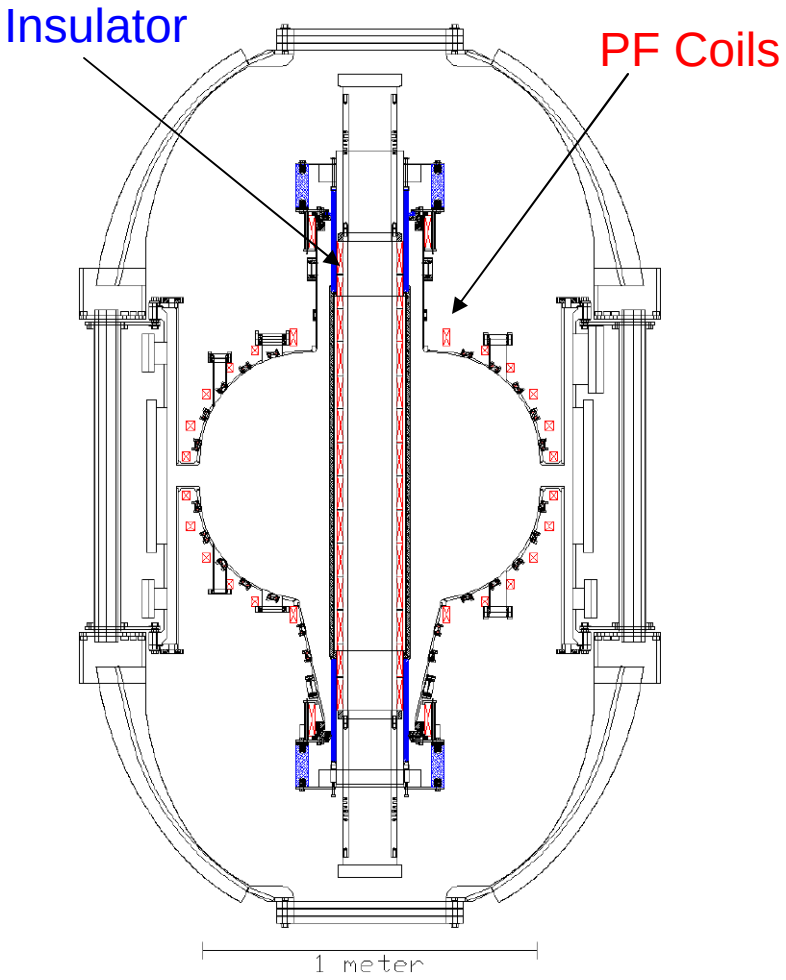
Implementation of CHI in NSTX



Non-axisymmetric relaxation activity *(driven CHI)* or axisymmetric reconnection *(transient CHI)* at the injector needed for formation of closed flux surfaces

*Simpler insulator design possible
- Insulate Divertor plates

Remarkable Transient CHI achievements in HIT-II



R/a: 0.3/0.2 m
Te > 250 eV (OH or CHI + OH)
24 feedback controlled PF coils
- Improved absorber arc control

*Closed flux generation (100kA) [160 kA in NSTX]

*Closed flux coupling to induction

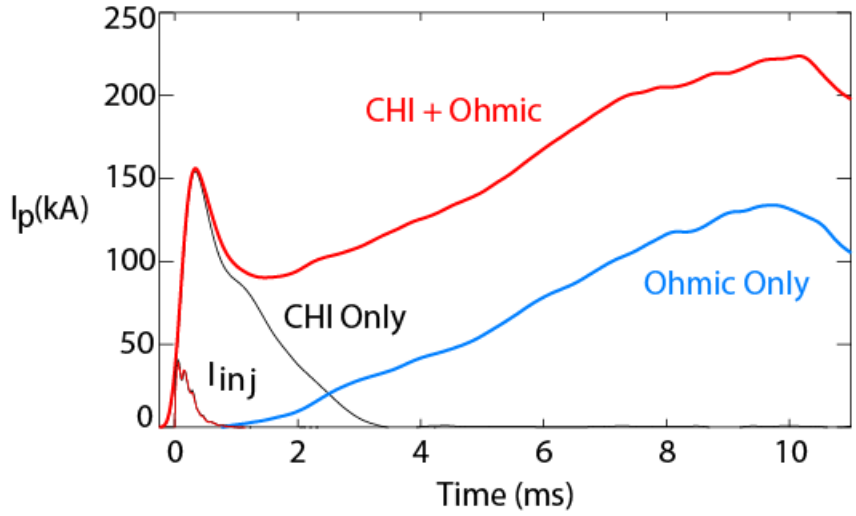
Closed flux quality similar to that inductively produced

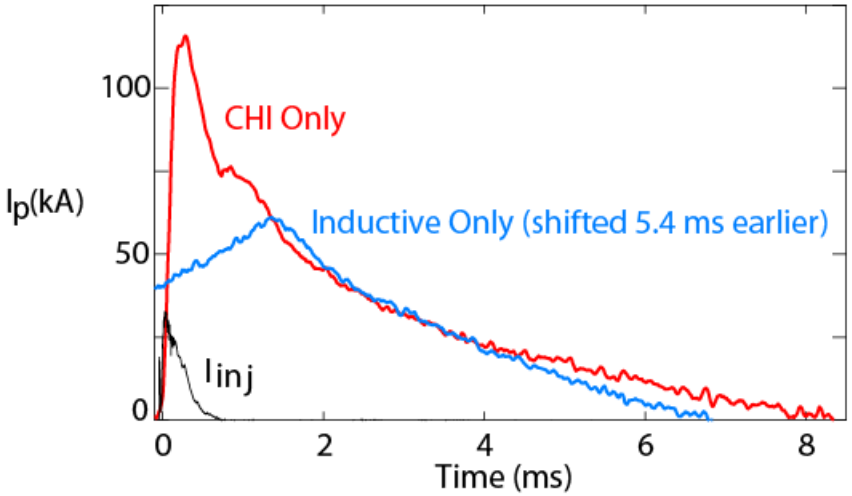
Solenoid flux savings when coupled to induction
- Under Zero CS pre-charge
- Under Full CS pre-charge
- When CS is being pre-charged

Closed flux formation when strong error fields introduced (similar to that used for outer PF start-up)

*Also achieved by NSTX

Closed Flux Generation and Coupling to OH in HIT-II





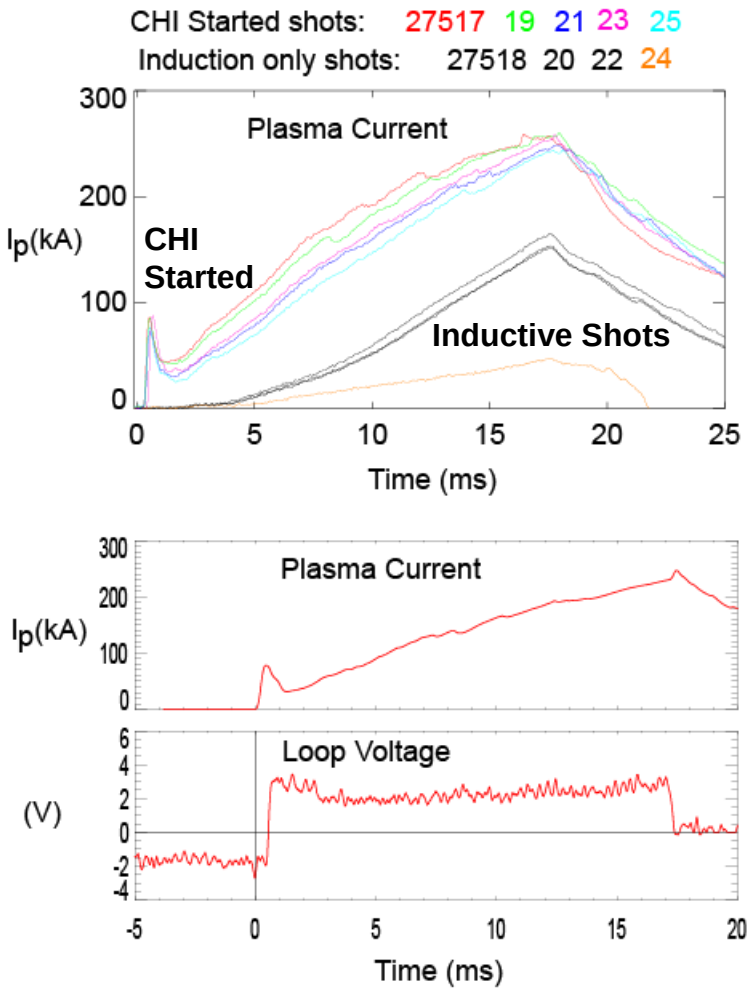
Nearly all CHI produced closed flux current couples to OH

- Both discharges have same Loop Voltage programming

CHI produces current comparable in quality to that produced inductively

- Both have similar current decay rates

CHI startup compatible with pre-charged CS in HIT-II



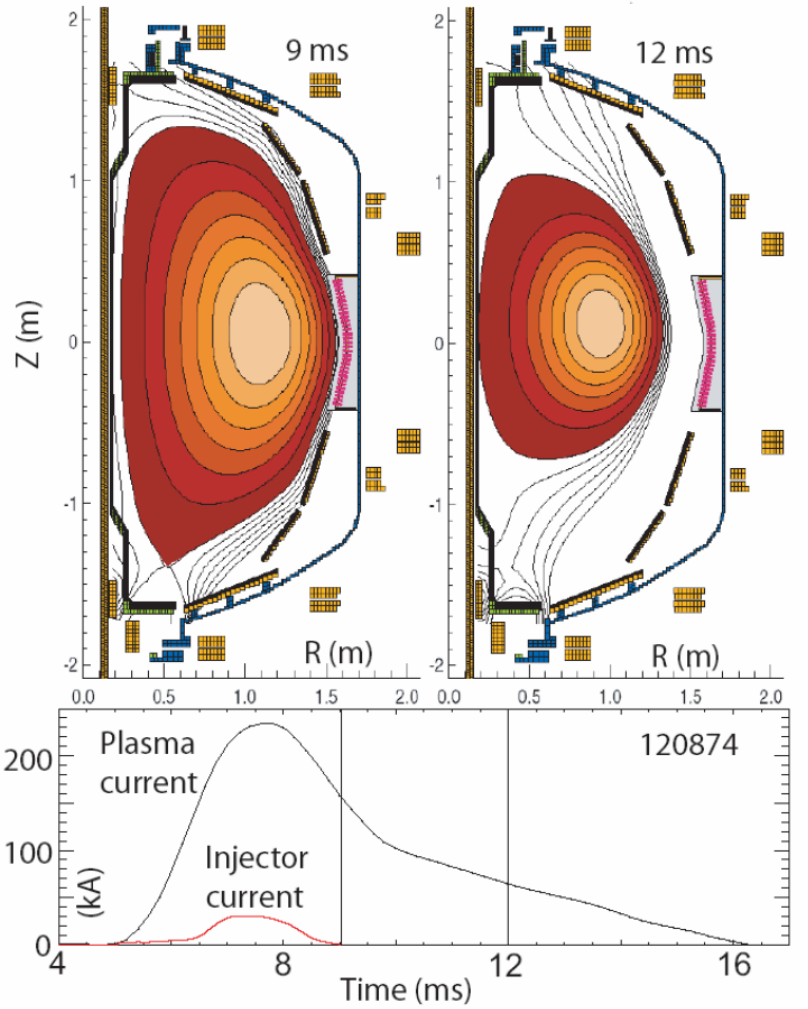
CHI started discharges much more reproducible under changing wall conditions

-Note that OH only shots (27518, 20, 22, 24) degrade rapidly

CHI can also be stared when the CS Is in the process of being pre-charged

-Note that -2V is being applied during startup phase

Record 160 kA of Non-inductively Generated Closed Flux Current in NSTX



During Absorber Arc-free discharges, very high current multiplication ratios of 70 observed in NSTX
- compared to 6 in HIT-II

- Scaling favorable to larger machines

LRDFIT (J. Menard)

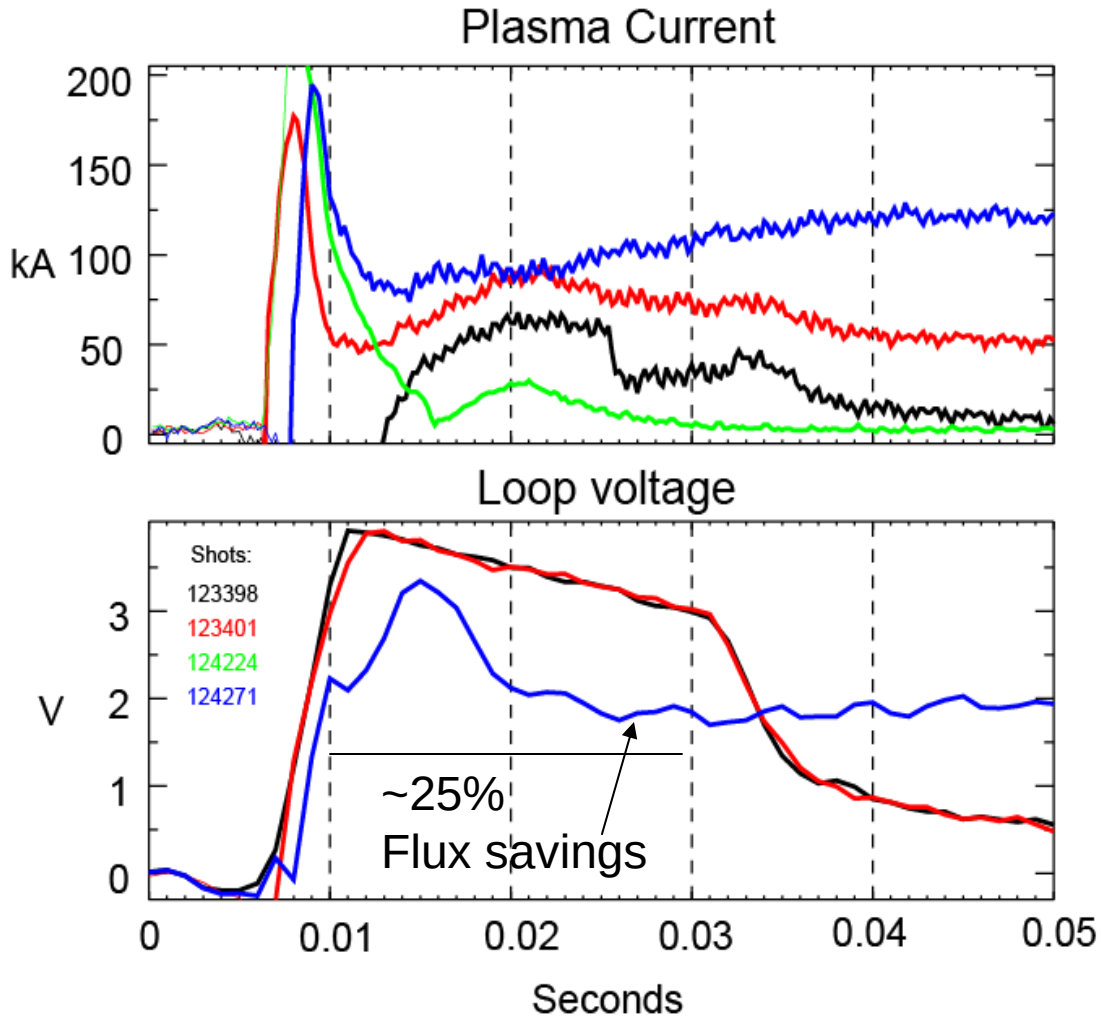
CHI plasmas successfully couple to transformer induction in NSTX for first time

CHI only

Induction only

CHI + induction

CHI + induction: I_P = 120kA
(Boronization & improved PF programming)



- FUTURE optimization:
  - Improved divertor conditions
  - Use 350kW ECH
  - Reduce absorber arcs
  - Use CHI flux savings to extend long-pulse discharges
    - Use pre-charged solenoid from standard OH I_P ramp

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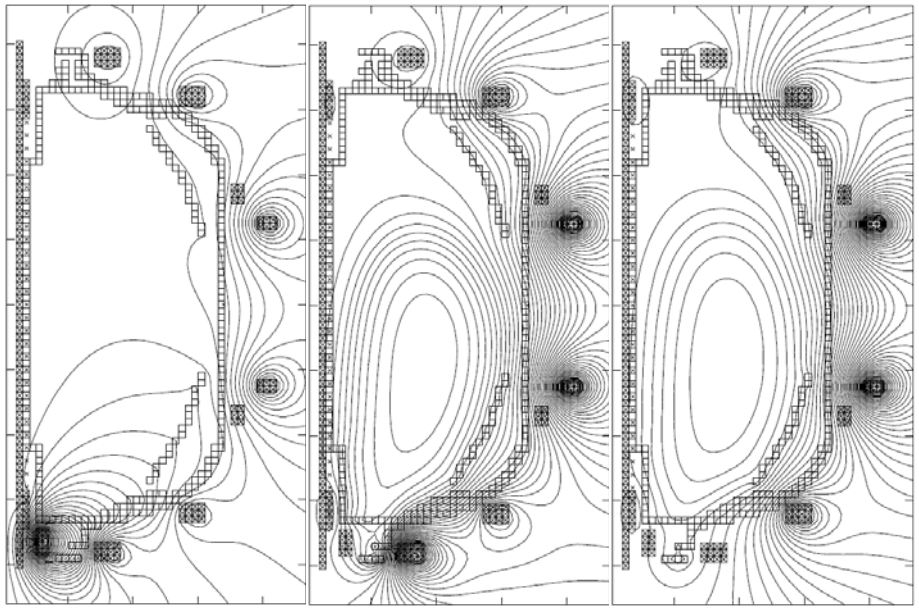
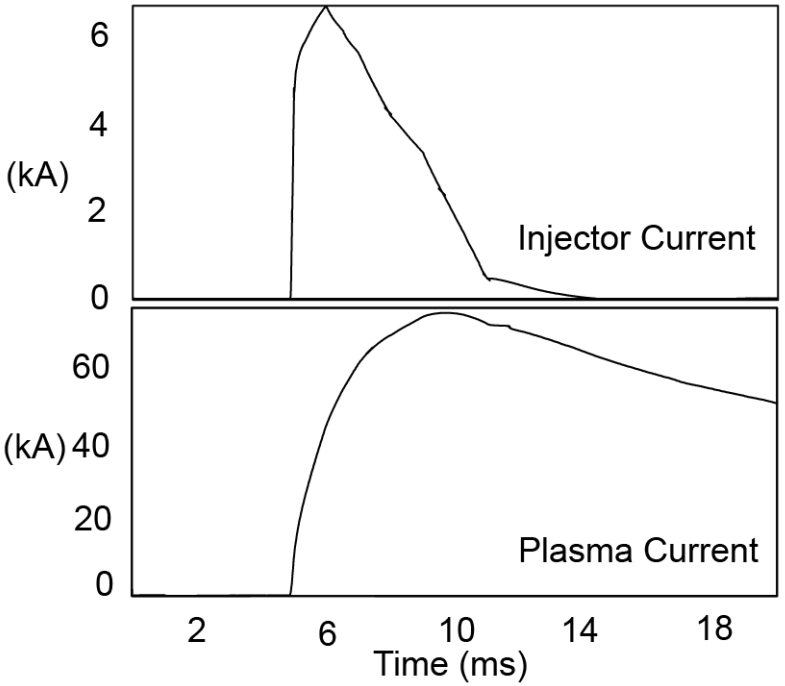
Preliminary TSC Simulations of Transient CHI in NSTX

Poloidal Flux



4.2 ms 11.6 ms 16 ms

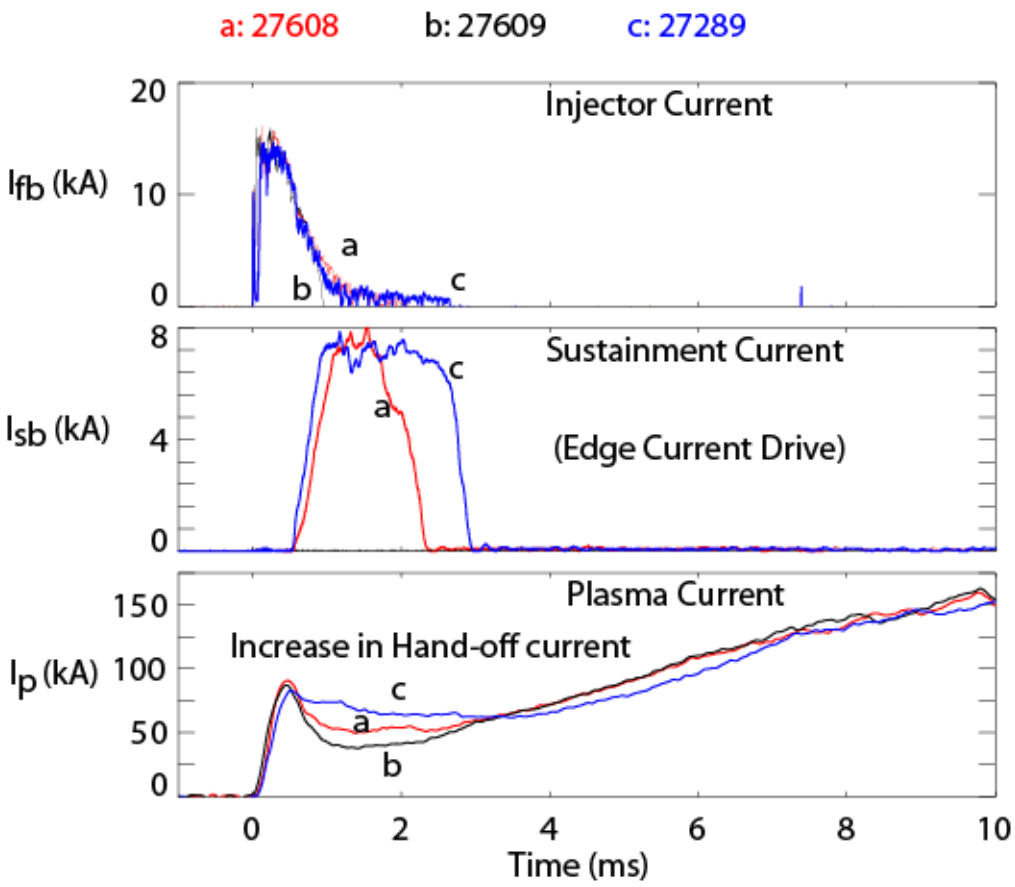


After reproducing 60kA discharge, the 160kA discharge will be simulated for benchmarking TSC – Then CHI capability in NSTX could be predicted

TSC Code: developed by SC Jardin (PPPL)

Plans for CHI optimization on NSTX

- Couple CHI to OH for flux savings
  - Improve divertor conditions
  - Increase Te (350kW ECH)
  - Absorber stray field reduction (absorber arc reduction)
- Use pre-charged CS
  - Use compensating vacuum field pattern using LRDFIT
- Test Edge current drive
- Longer term goal is to test Relaxation current drive



Staged capacitor bank (2008) would allow hand-off current to be boosted during coupling to OH (as in HIT-II)

Results From NSTX and HIT-II Indicate Favorable Scaling of CHI to Larger STs

NSTX

- Record non-inductive startup currents in a tokamak (160kA in NSTX) verifies high current capability of CHI for plasma startup applications
  - –Scales well to larger devices (~70 x CM in NSTX vs. 6 in HIT-II)

- HIT-II has demonstrated CS flux savings
  - –CHI plasma of quality similar to inductive plasmas
    - First such demonstration for electrode generated plasmas
  - –Closed flux generation for scenarios with strong error fields
  - –Edge current drive appears possible
  - –Method compatible with super conducting PF coils

- Extension to ~300kA should be possible
  - –TSC is being used to explore CHI capability in NSTX and later in NHTX
  - –ECH + HHFW (HHFW demonstrated heating 250kA plasmas to 1keV)
  - –Couple to NBI and RF CD