Recent results from Transient CHI start-up in HIT-II*

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Acknowledgements

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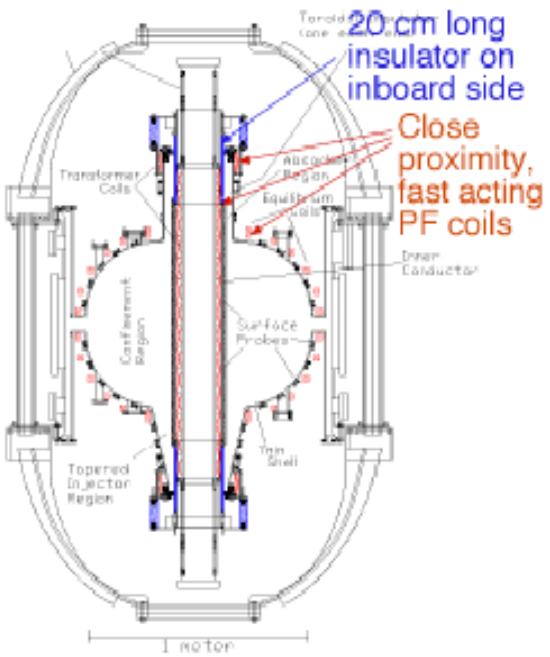
Outline of talk

- Brief summary of previous work (August 2002)
- Recent results from HIT-II (March 2003)
- Implications for NSTX-CHI
- Summary and Conclusions

Non inductive current initiation needed for STs

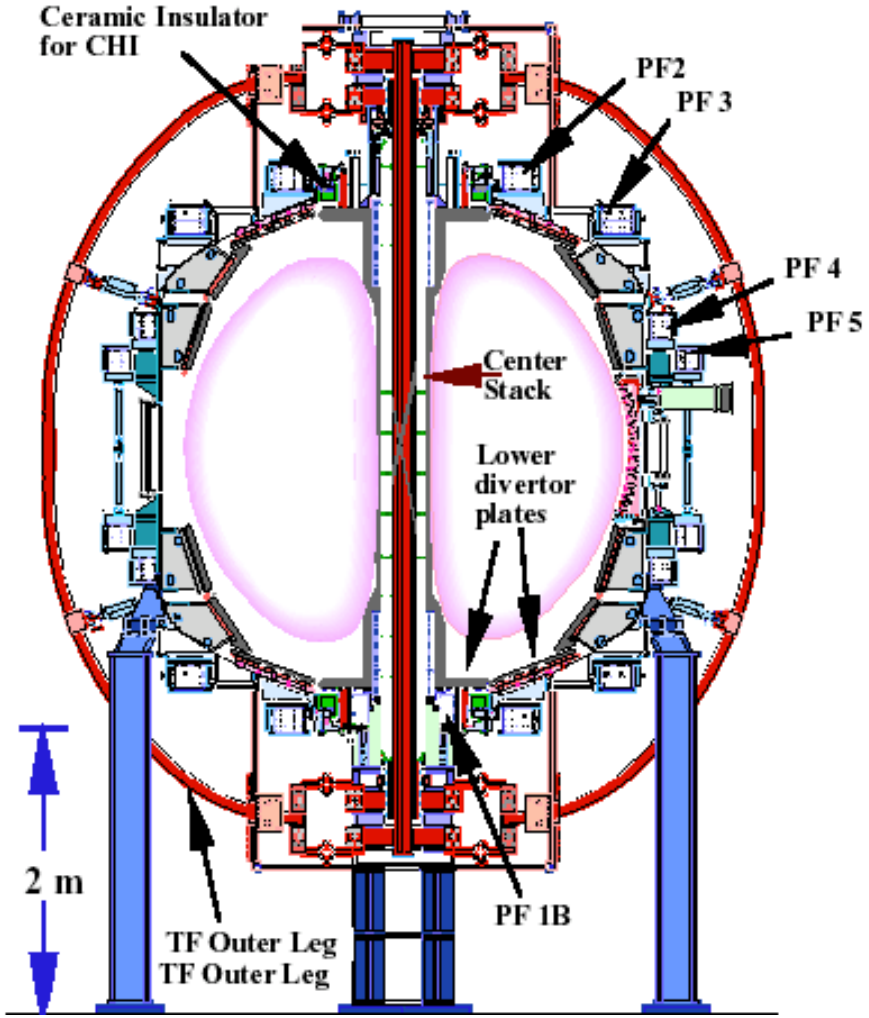
- The ST is a magnetic confinement concept that has the advantages of high beta and a projected high fraction of bootstrap current drive.
- The favorable properties of the ST arise from its very small aspect ratio, which leaves very restricted space for a central solenoid to induce the toroidal current.
- An ST reactor with a solenoid will require extensive neutron shielding for the solenoid. This may increase the aspect ratio to undesirable values.
- Central solenoid-free plasma start-up and sustainment is essential for the viability of the ST concept

HIT-II has a thin metal wall and a close fitting fast PF coil system

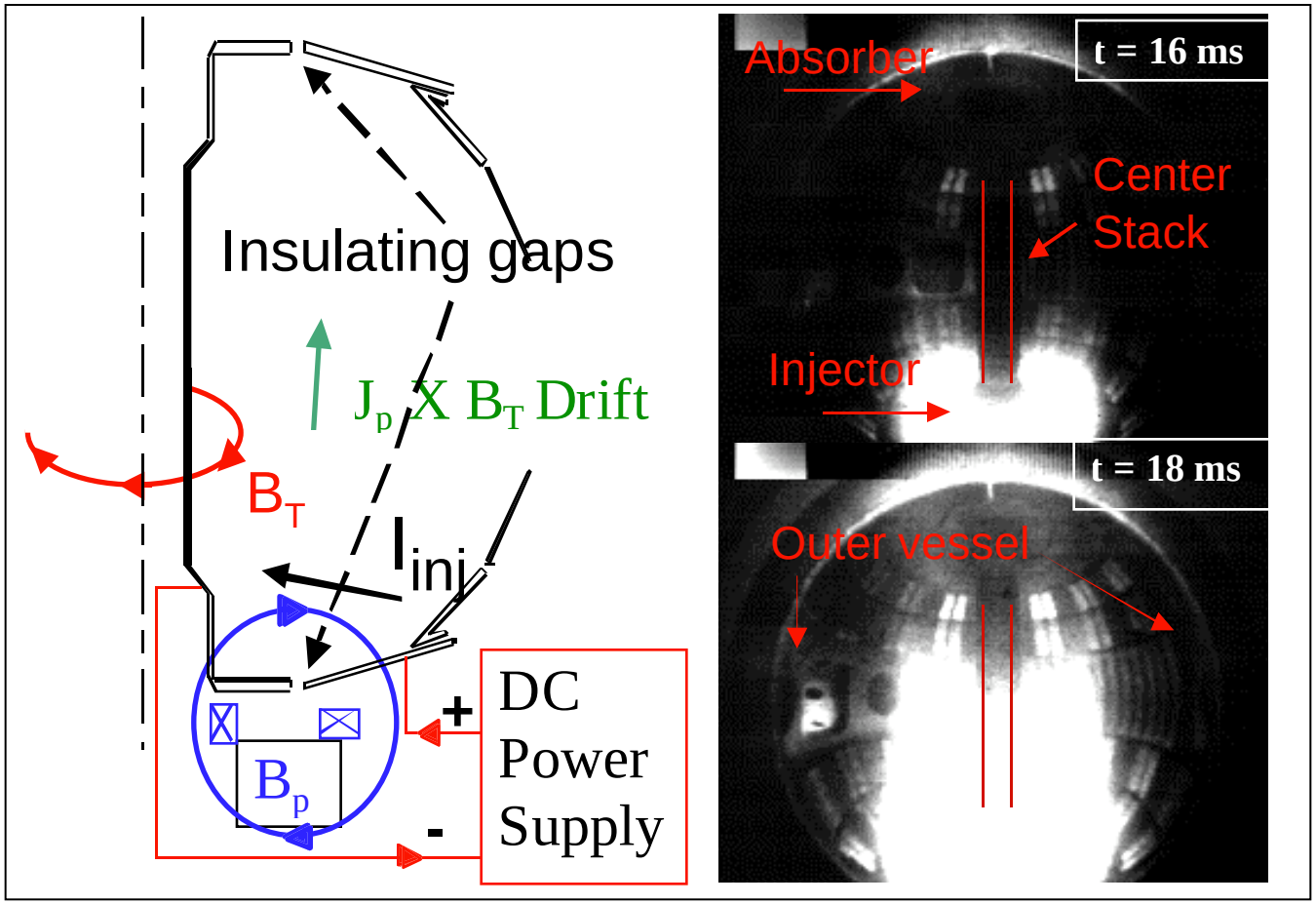


x 30 volume →

NSTX pulse length much longer (x 20)



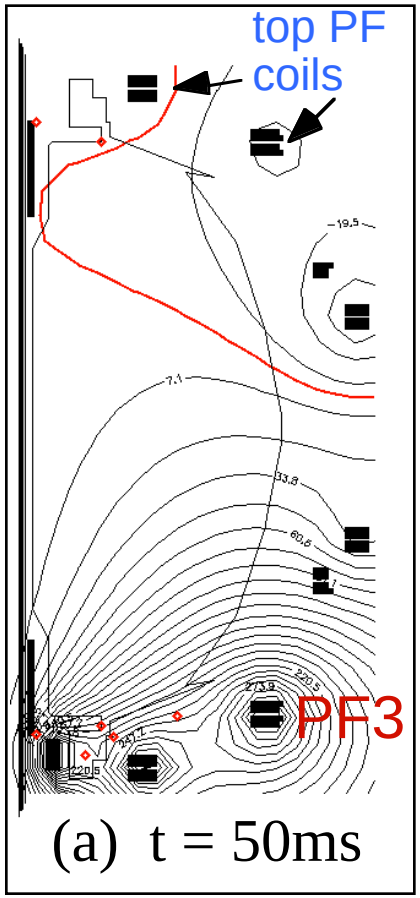
CHI injects toroidal flux linking poloidal flux ($\dot{K}_{inj} = 2V_{inj}\psi_{inj}$)

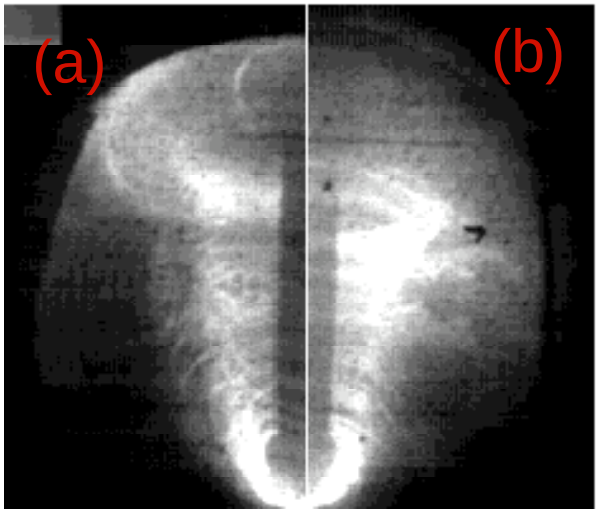


Expect reconnection processes to redistribute edge current to the interior, forming closed surfaces

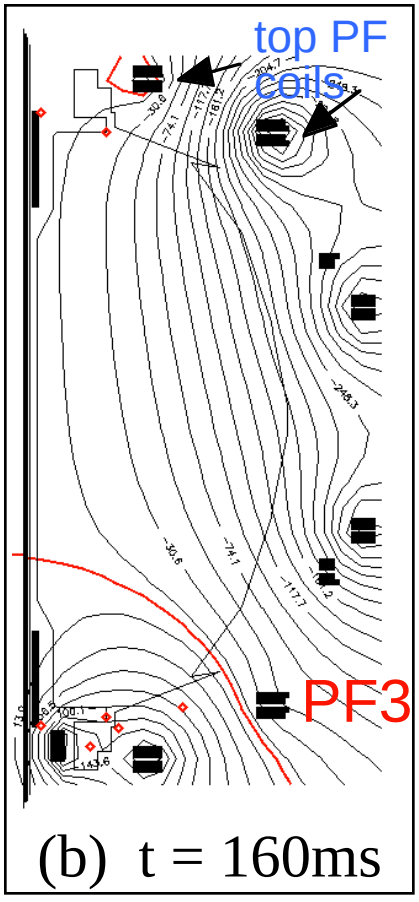
Previous method on NSTX used discharge programming to produce discharges with boundary conditions favorable for inducing flux closure

High current configuration ⟶ Preferred configuration



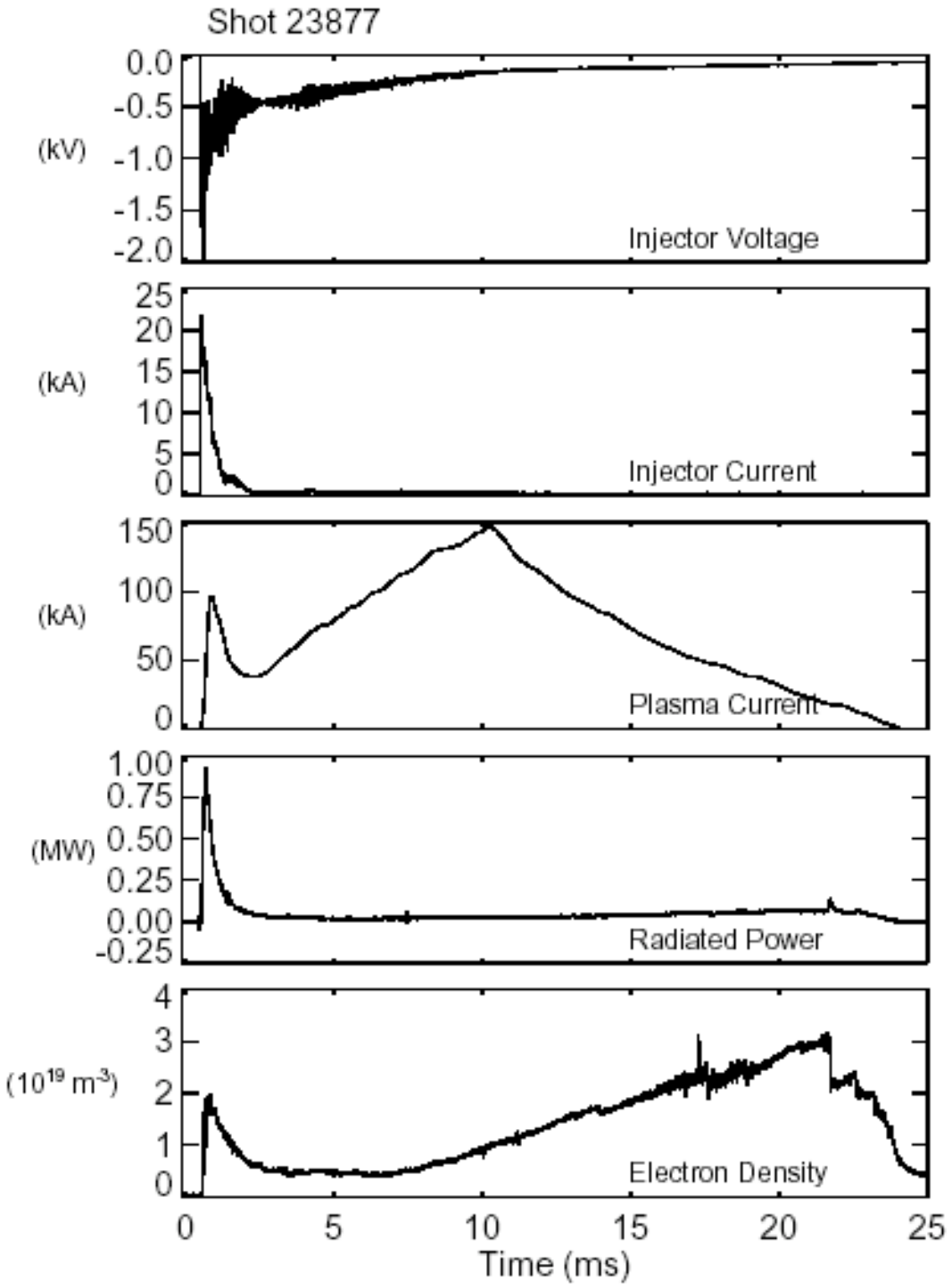


- Reverse current in PF3
- Increase current in top PF coils
- Increase vertical field



Demonstration of CHI assisted plasma start-up on the HIT-II spherical torus (August 2002)

HIT-II

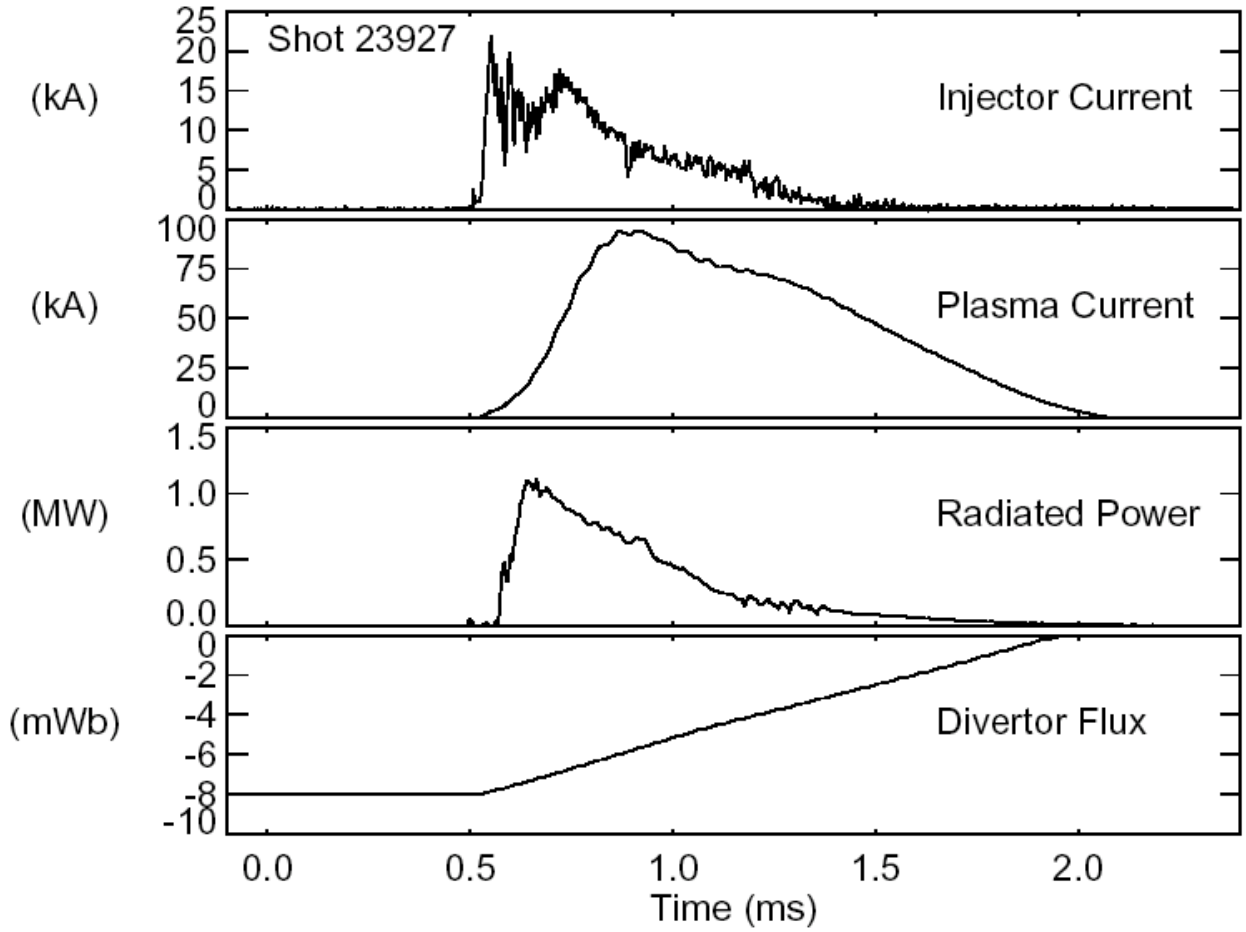


Raman, NSTX Phys Meet. 4/21/03

R. Raman, T.R. Jarboe, B.A. Nelson et al.,
Phys Rev. Lett., **90**, 075005-1 Feb **23** (2003)

First unambiguous demonstration of the production of closed field line configuration in an ST discharge initiated by CHI

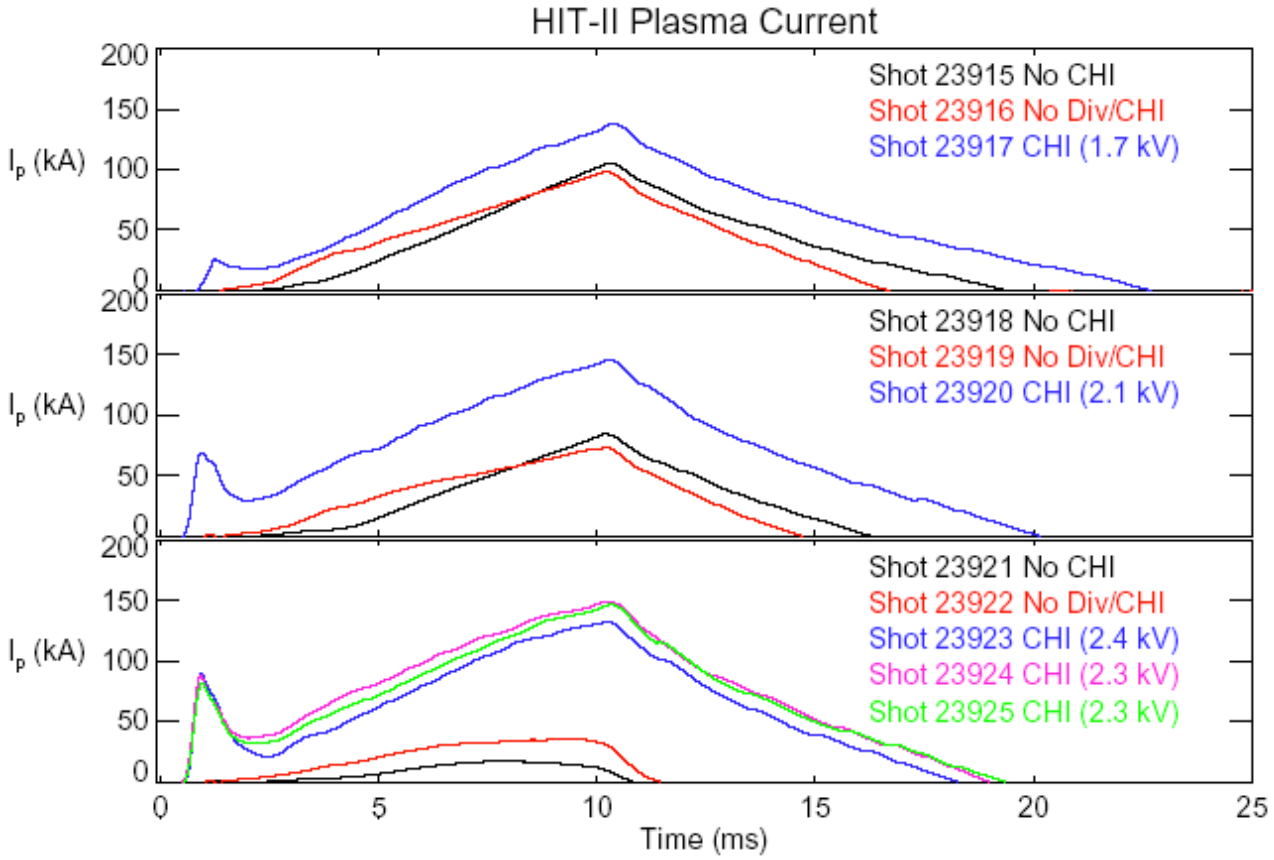
HIT-II



CHI only discharge: After the injector current is reduced to zero, substantial plasma current still remains. This can only result from the presence of a closed field line plasma configuration. This closed field line plasma configuration is used as the target for the inductive ramp.

Discharges with CHI start-up are robust, maintain shot-to-shot reproducibility and result in substantial volt-seconds savings

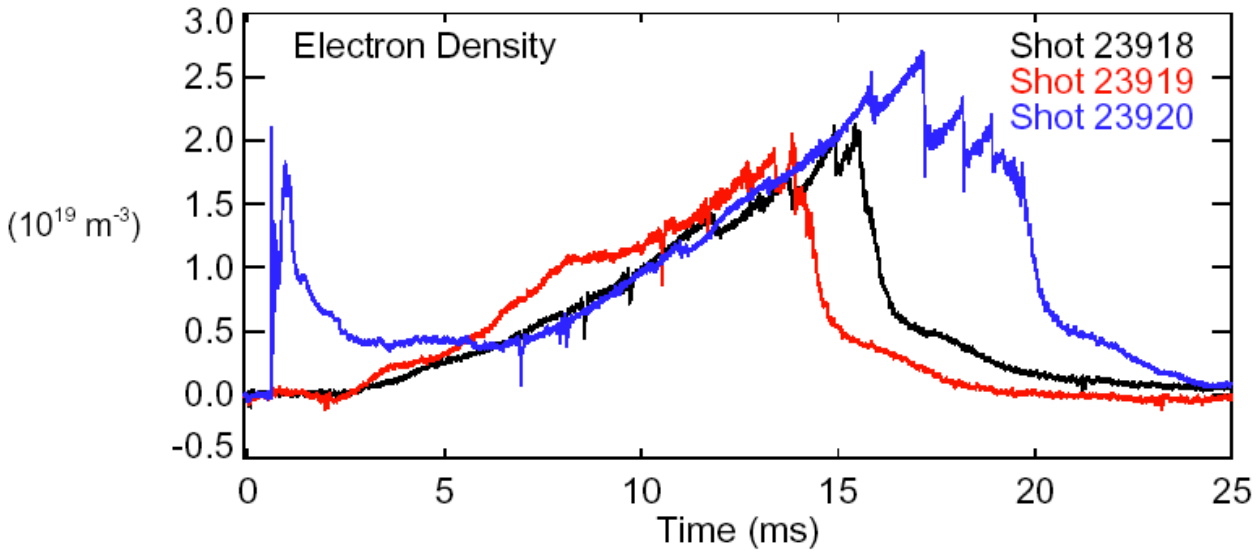
HIT-II



Sequence of traces showing plasma current. Shots 23915, 23918 and 23921 correspond to discharges that have the same magnetic flux condition as in 23877, but with zero CHI voltage. Shots 23916, 23919 and 23922 contain only the magnetic flux conditions needed for inductive operation, and do not contain the CHI injector flux component; the applied CHI voltage is zero. All other cases correspond to the case of discharges with CHI startup, and have the same magnetic flux configuration as shot 23917. For all discharges a constant inductive voltage of 4 V is applied for 2 ms, followed by 3.2 V for the next 6.8 ms.

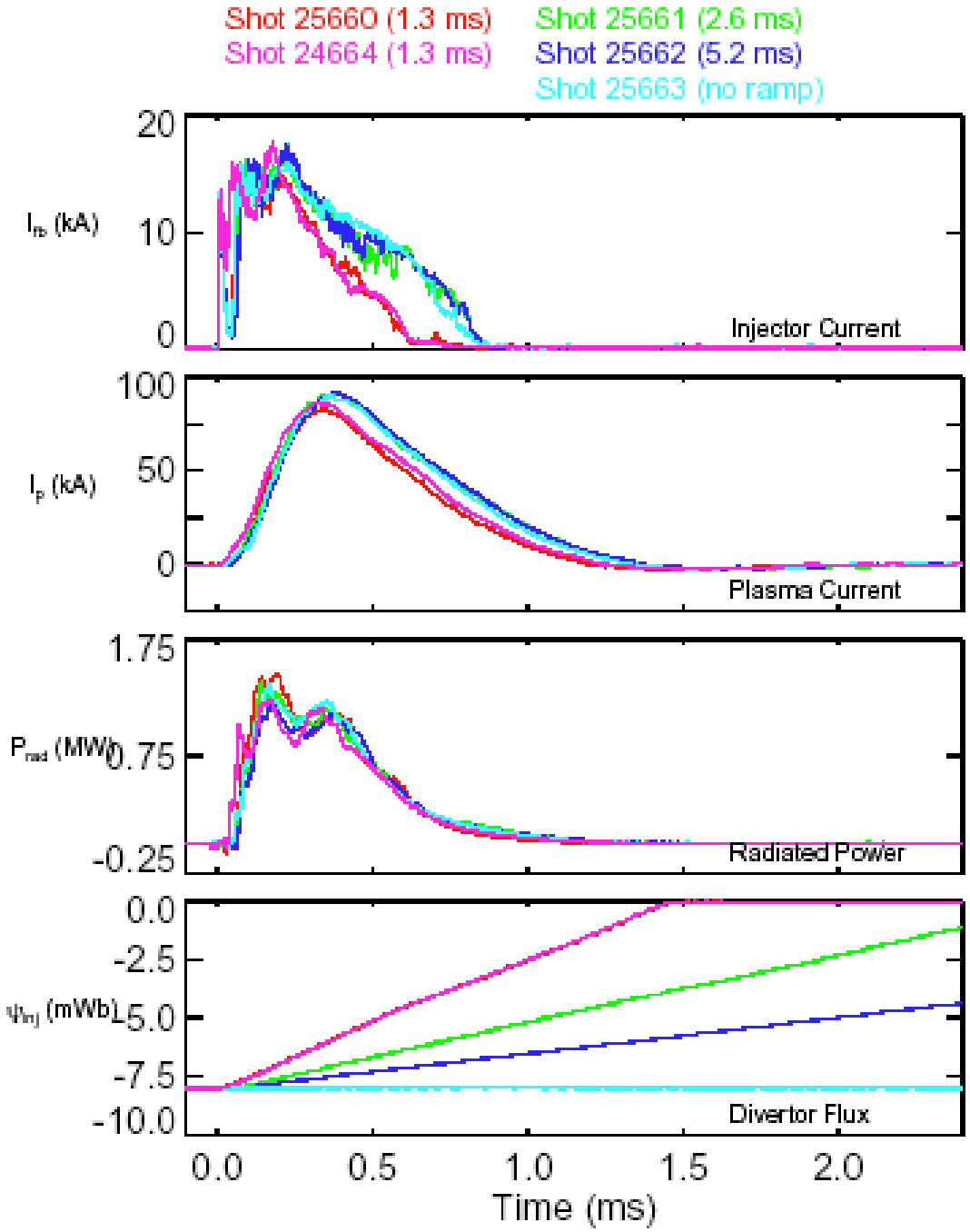
Central chord averaged density evolution during transition shows it to be similar to that for inductive only discharges

HIT-II



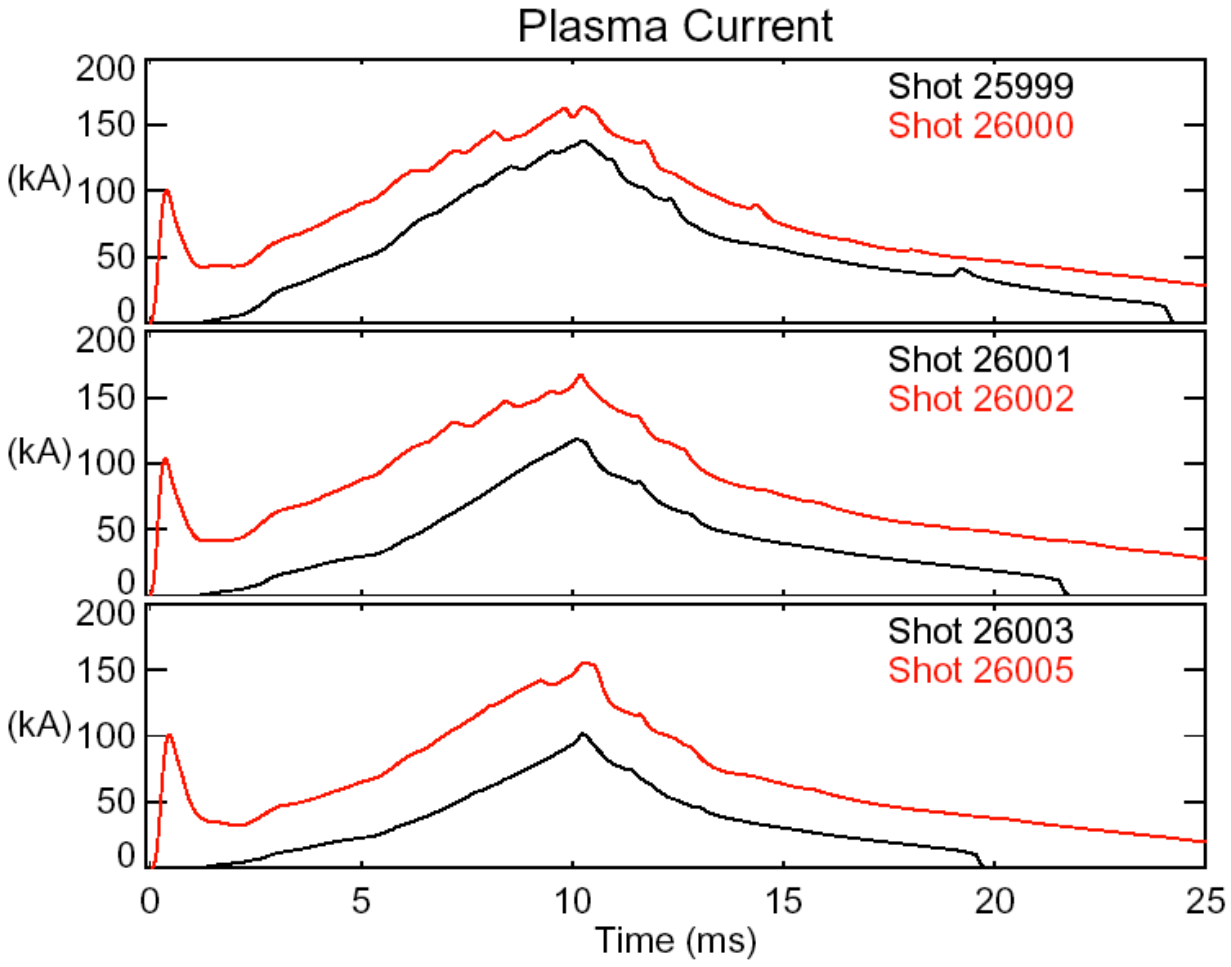
Persistence of toroidal current observed without divertor coil ramp-down (March 2003)

HIT-II



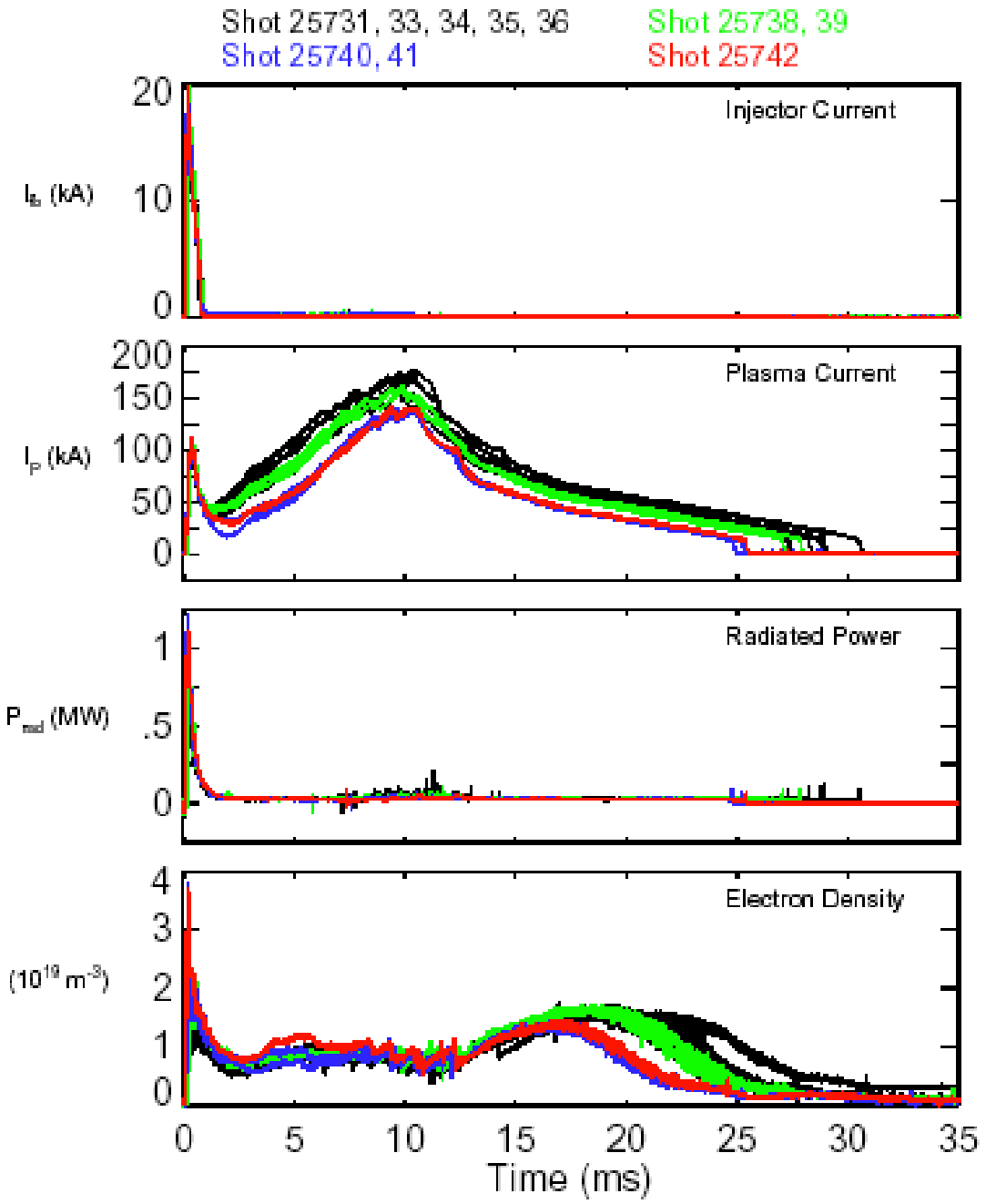
CHI started discharges without divertor coil ramp-down also outperform inductive only discharges and are similar to discharges produced using divertor coil ramp-down

HIT-II



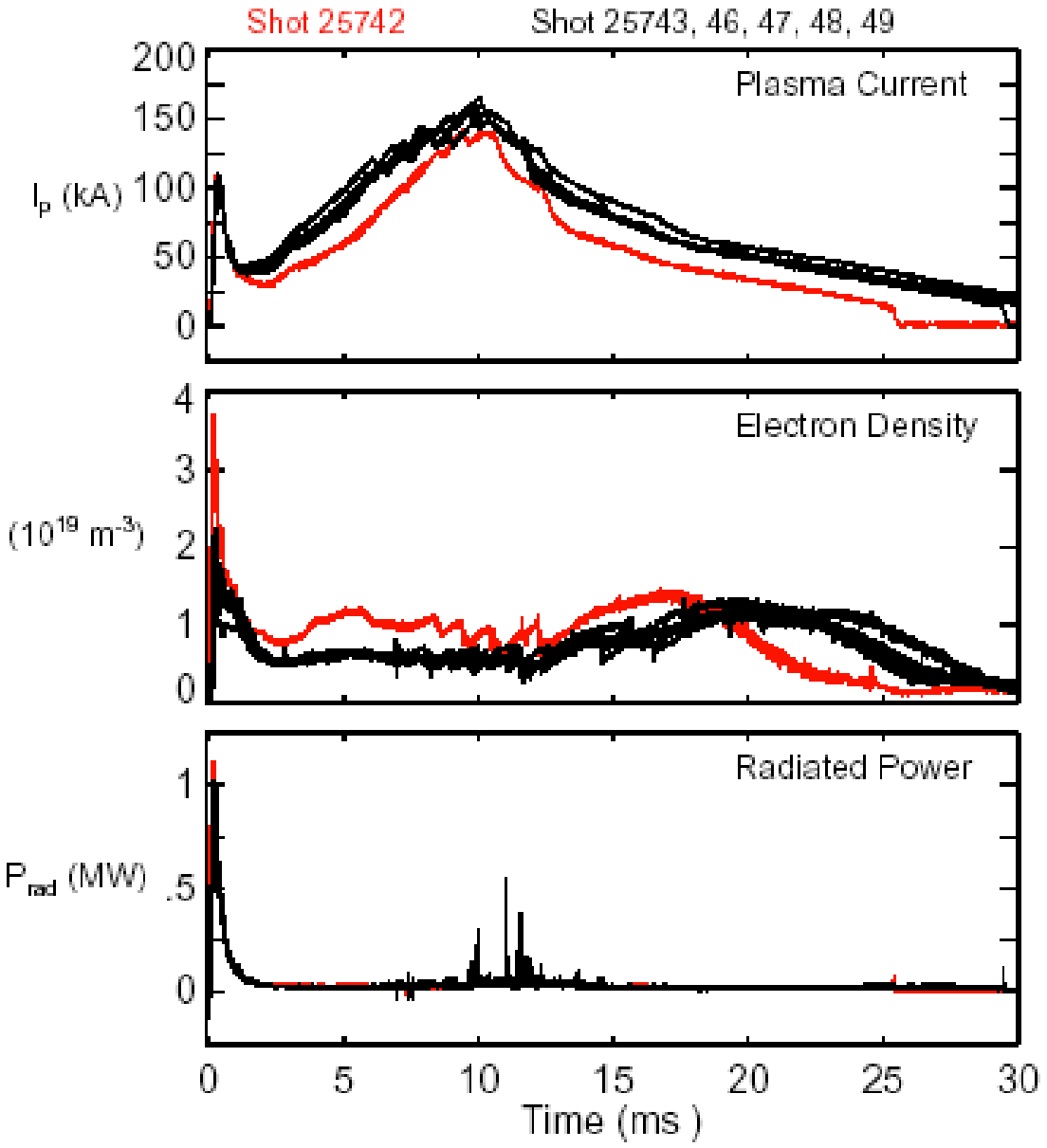
Coupling to induction reduces at higher CHI plasma densities, which results due to reduced wall pumping during later shots

HIT-II



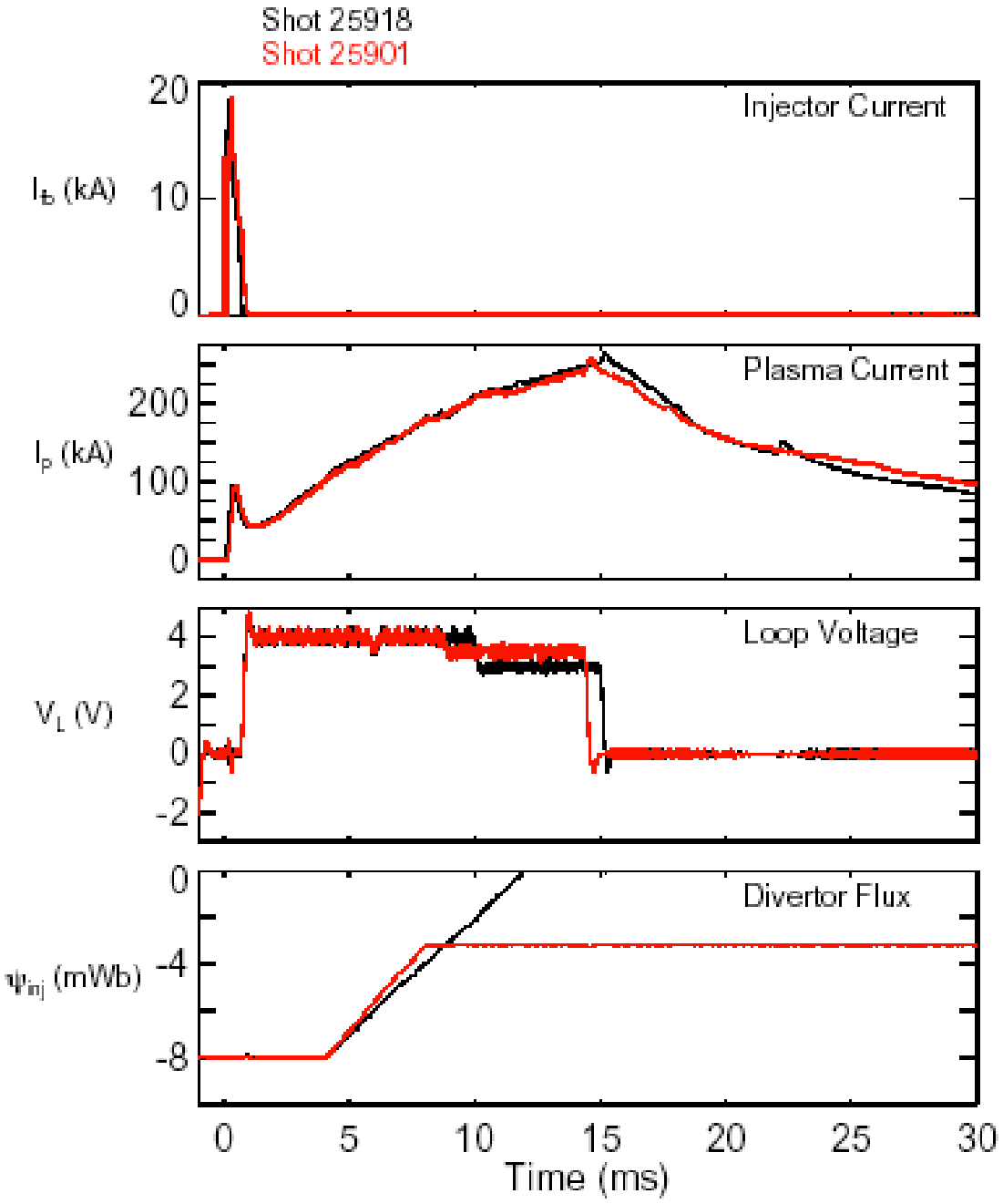
Under gas loaded wall conditions, good coupling to induction can be regained if gas injection for CHI formation is reduced

HIT-II



Highest ever plasma current (265kA) obtained using CHI start-up. Discharges can be now *initiated* and maintained *in a diverted configuration*

HIT-II



Methods developed on HIT-II are fully adaptable to NSTX

Previous method (technically difficult)	New method (simple method)
Long CHI pulse (~300ms)	Short pulse (< 50ms), much simpler power system requirements for future NSST
Relies on good feedback controlled operation during a steady-state CHI pulse (Equilibrium feedback control for CHI not yet tested on NSTX)	Transient discharge considerably simplifies feedback control requirements 1. CHI pre-programmed phase 2. OH pre-programmed phase, CHI off 3. OH feedback control phase
Absorber and external hardware should be arc-free during 300 ms pulses	Probability of absorber and external arcs decreases as the CHI pulse length decreases
Relies on pressure profile characterization and possible auxiliary heating of CHI plasmas	Details of pressure profile not too important, auxiliary heating may not be needed

Other small NSTX hardware modifications (gas injection, speeding up CHI coils, absorber PF coil activation for absorber field control) will be implemented if needed.

Implications for NSTX-CHI

- Methods to improve pre-ionization will save considerable experimental time

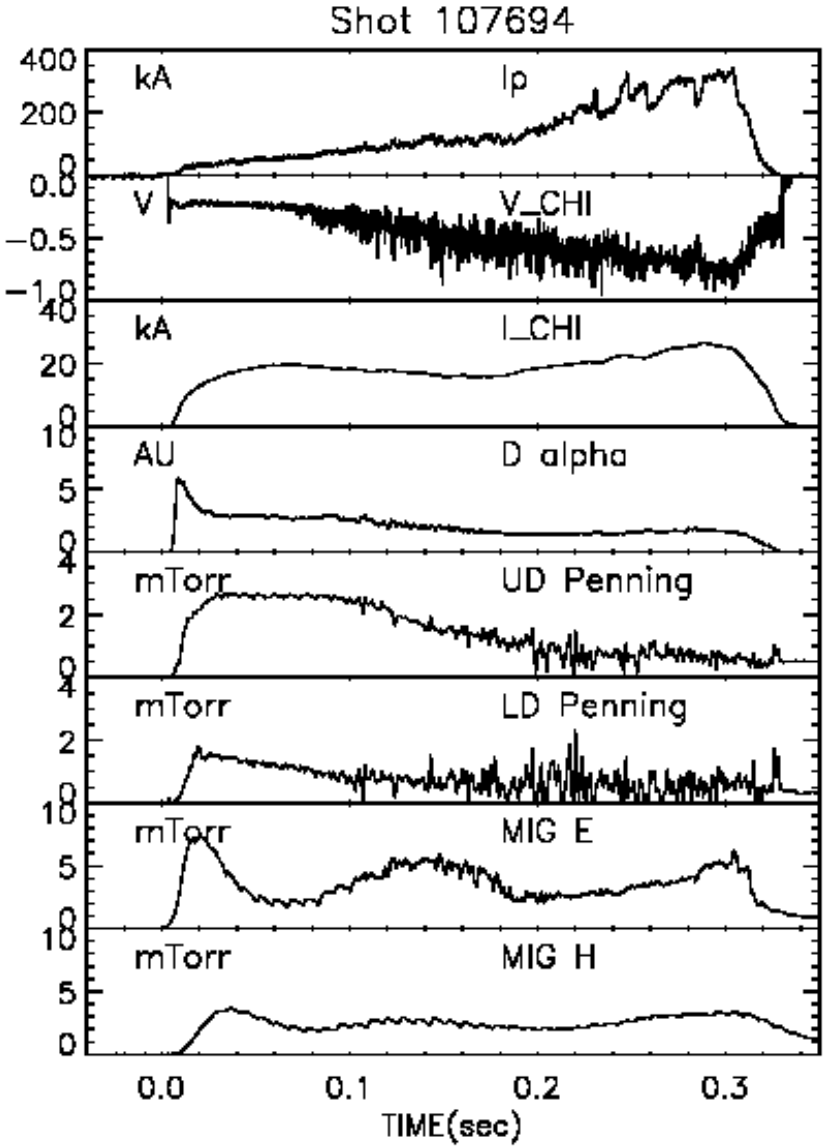
  - Plasma gun installation being investigated
  - Small impurity doping is another possibility
  - Investigate the possibility of 2kV application for a few ms
  - Redirecting the ECH power towards the divertor region may help

A careful experimental study of pre-ionization conditions in NSTX is needed before proceeding with coupling studies. Neutral pressure measurements on NSTX show that once a CHI discharge has been initiated, it can be maintained without large additional gas injection

- Modifications to CHI power supply circuit may be important

Divertor and mid-plane neutral pressure measurements

- Pressure in the upper divertor region saturates within the first 30ms.
- It stays saturated until 100ms.
- After 100ms, the upper divertor pressure decreases (**E X B** drift is still into this region).
- Accompanied by an increase in the vessel pressure at the mid-plane.
- After 250ms, the upper divertor pressure is similar in magnitude to that in the lower divertor.



Raman, NSTX Phys Meet. 4/21/03

R. Raman, H. Kugel et. al., Rev. Sci. Inst. **74**, 1900 (2003)

Summary and Conclusions

- CHI start-up works very well on HIT-II
  - Improves the quality of inductive discharges
- Flux closure can be achieved without relying on divertor coil ramp-down
  - This considerably simplifies application of CHI on reactor scale devices, including NSTX, as one need not be concerned with flux soak through thick walls
- At increased CHI plasma density, coupling to induction decreases
  - This implies that pre-ionization techniques are important and methods should be identified that allows initiation of CHI discharges at lower density
- Flux closure results from proper injector voltage programming and boundary conditions
  - Voltage programming requires an appropriately sized capacitor or proper voltage programming of a DC power supply
  - Critical boundary conditions are non-transient

The method and requirements to initiate and transfer a CHI discharge to induction in an ST is now relatively well understood