Demonstration of Plasma Startup by Coaxial Helicity Injection

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Non inductive current initiation needed for a Spherical Torus (ST)

HIT-II

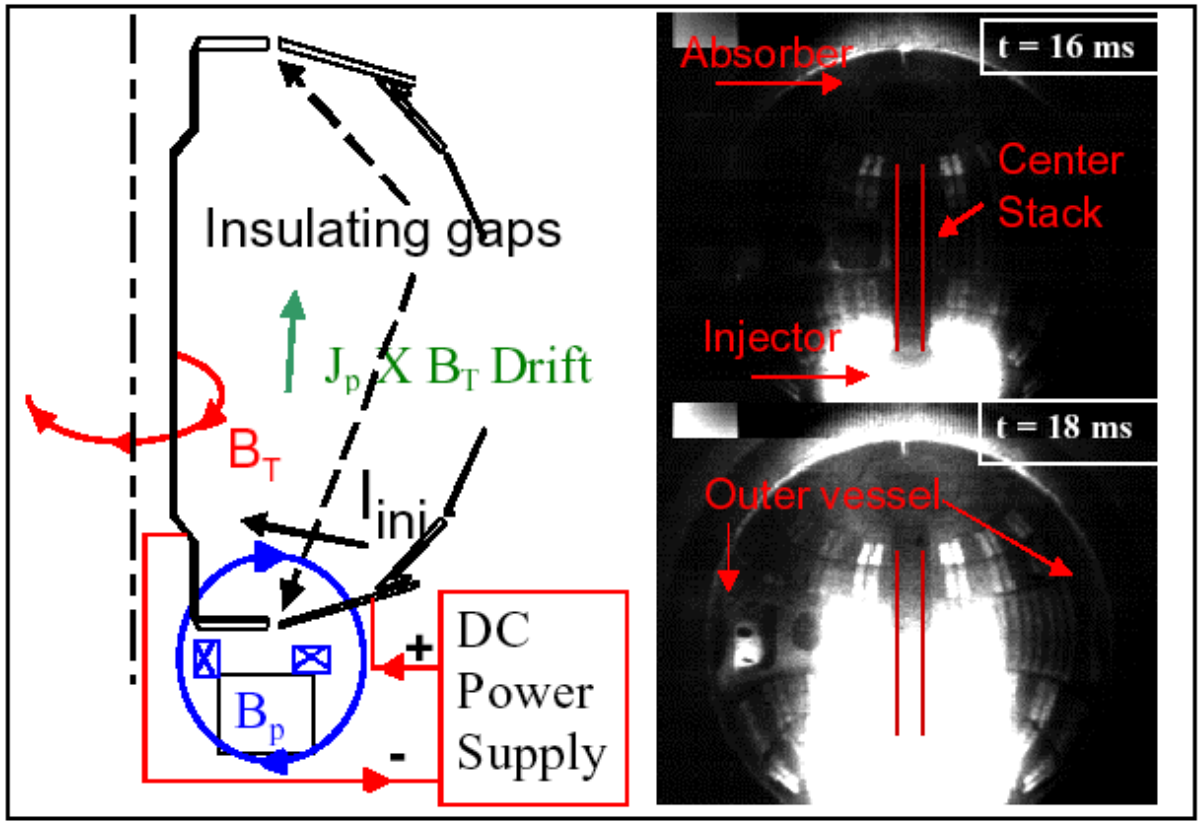
- The ST is a magnetic confinement concept that has the advantages of high beta and a projected high fraction of bootstrap current drive.

- 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.

- Demonstration of plasma start-up without using the central solenoid is an essential milestone for the ST program.

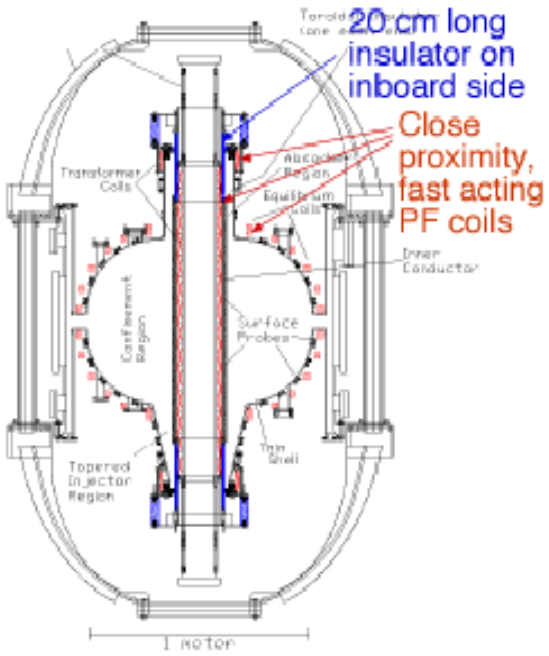
Simple description of CHI start-up



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

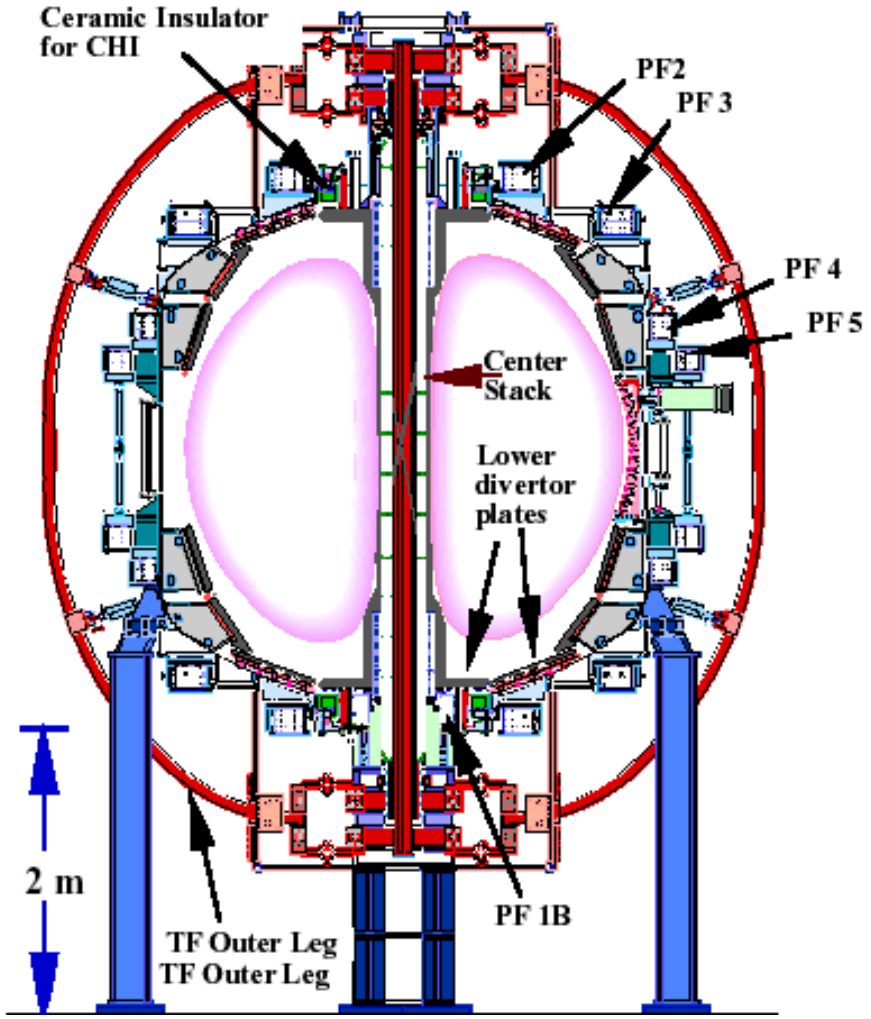
Figure (M. Ono, PPPL), Fast Camera (R. Maqueda, LANL)

CHI Start-up methods developed on HIT-II are tested on NSTX



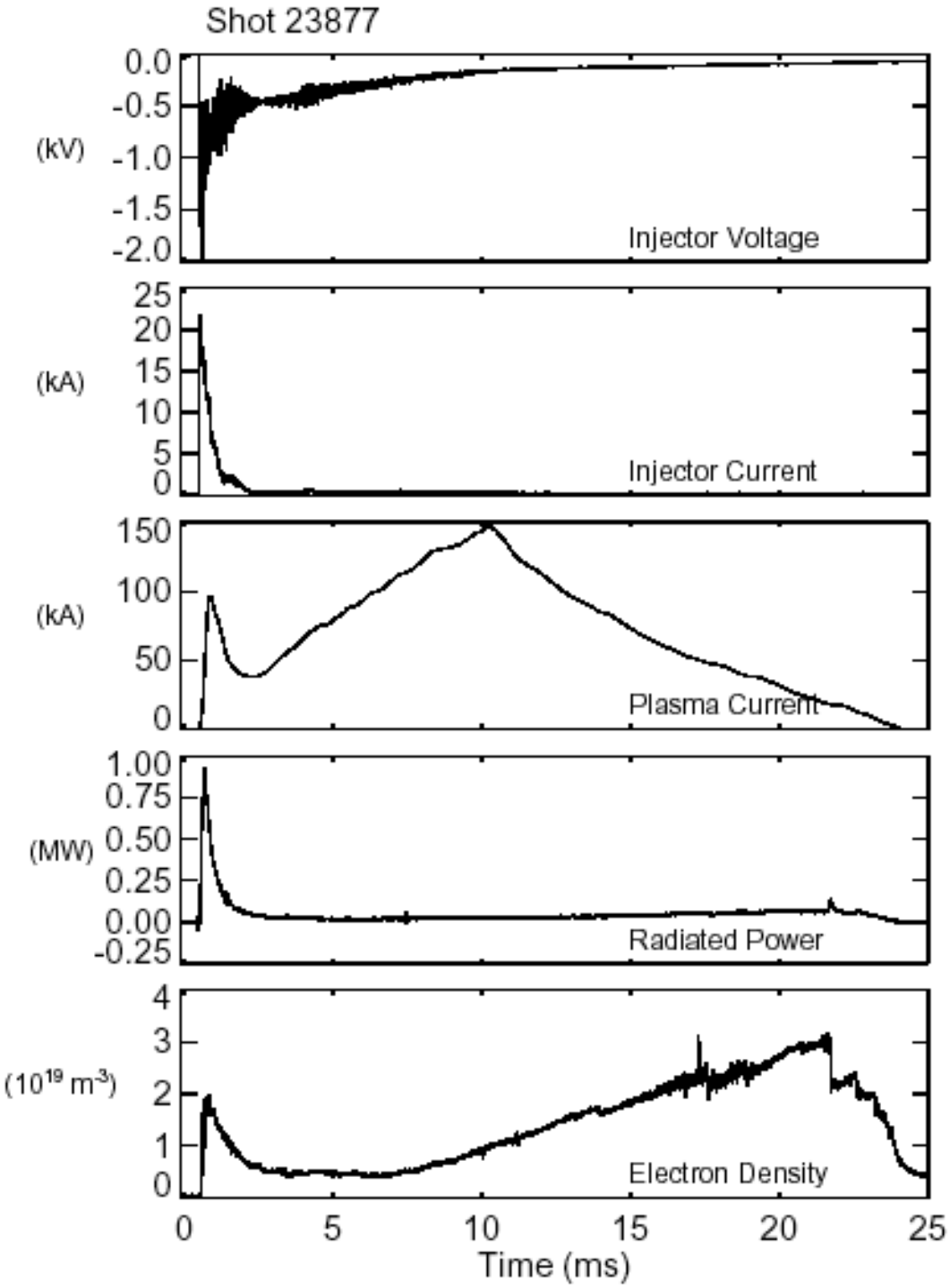
x 30 volume →

NSTX pulse length much longer (x 20)



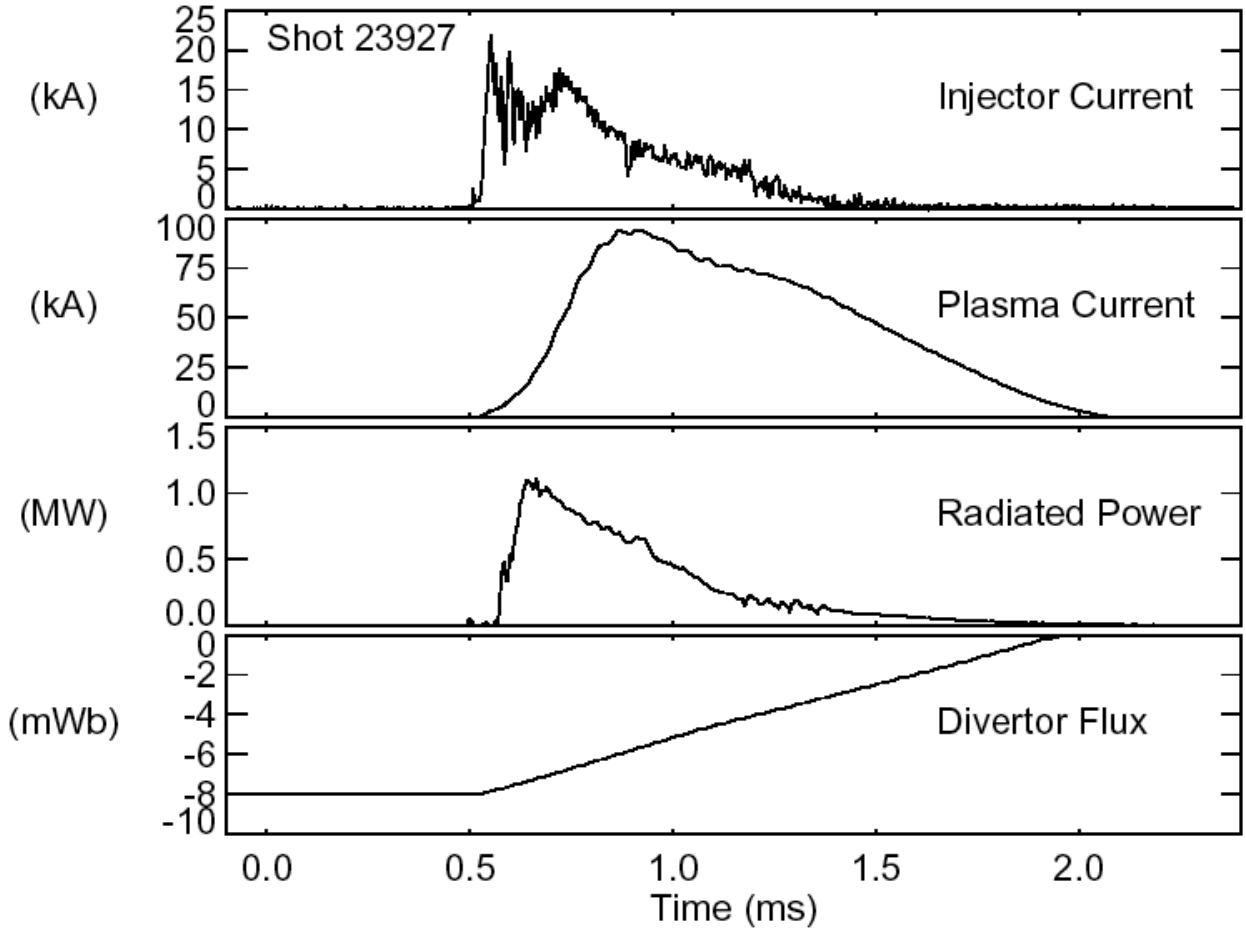
Demonstration of CHI assisted plasma start-up on the HIT-II spherical torus

HIT-II



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

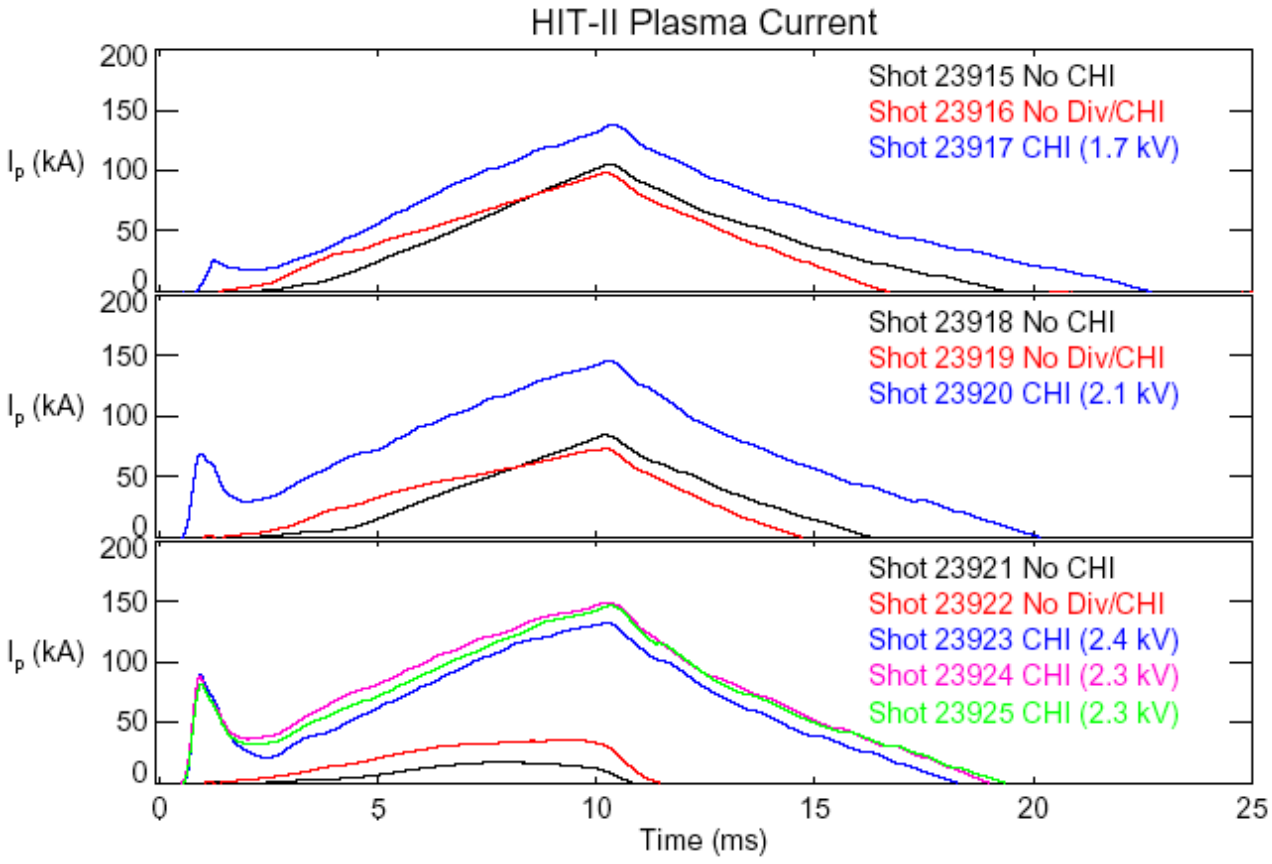
HIT-II



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 assist are robust, maintain shot-to-shot reproducibility and result in substantial volt-seconds savings

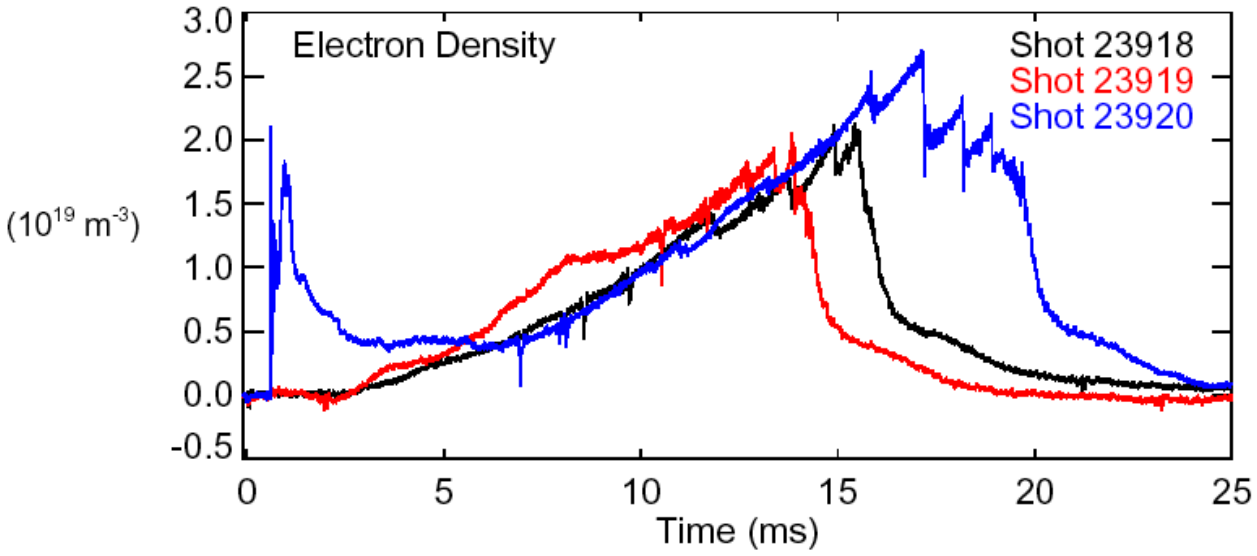
HIT-II



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 23915. 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.

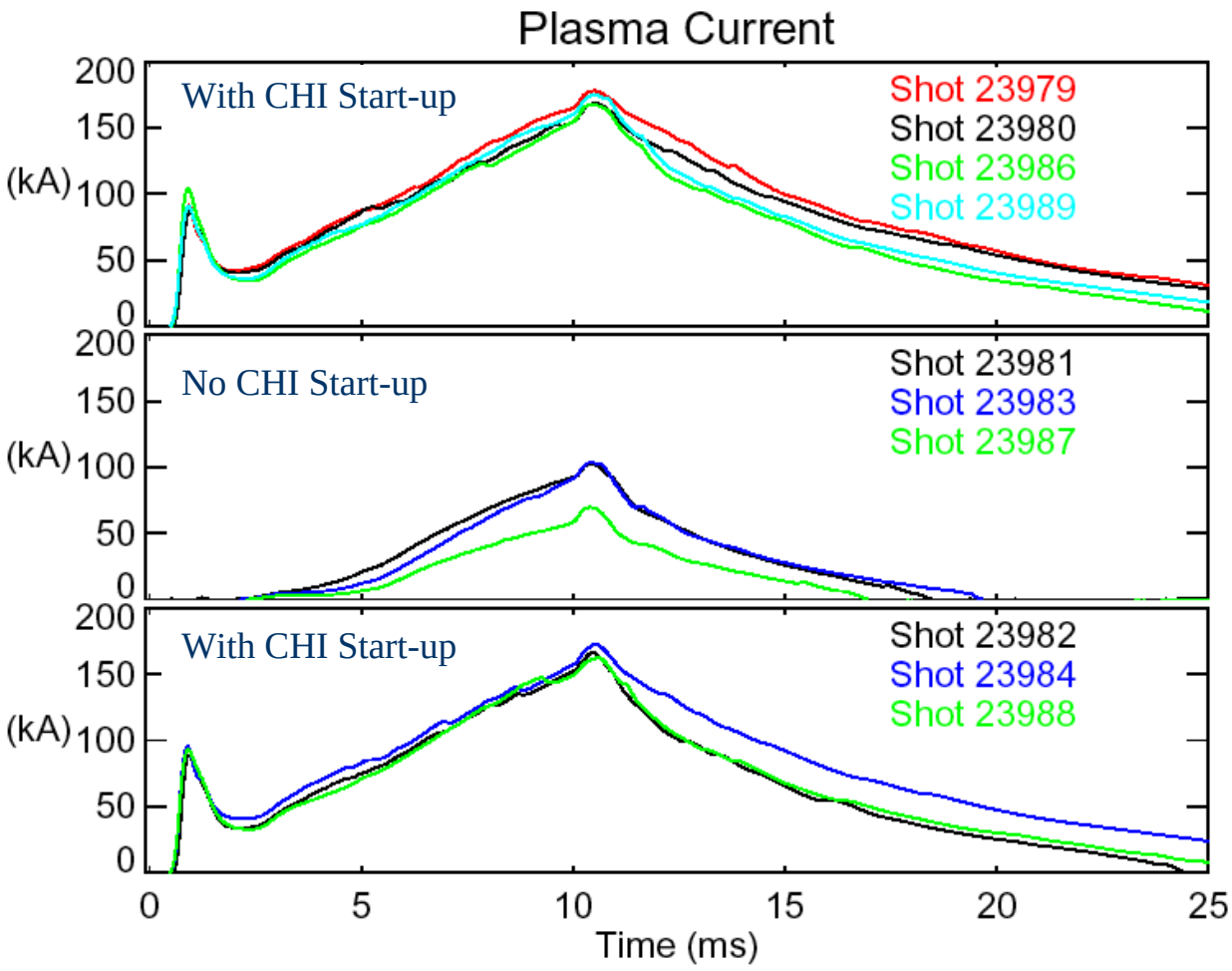
Central chord averaged density evolution during transition shows it to be similar to for inductive only discharges

HIT-II



Demonstration of volt-seconds savings with CHI start-up assist on the HIT-II experiment

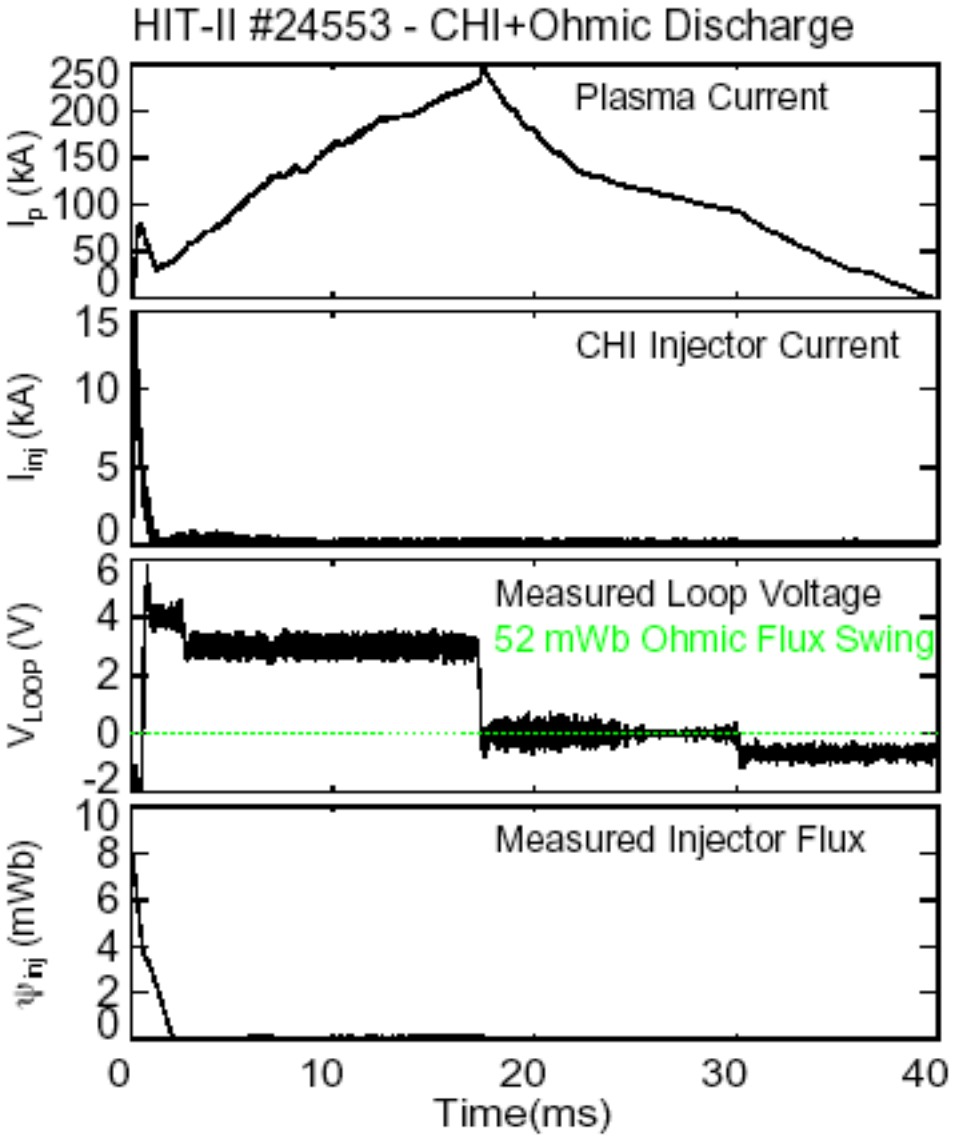
HIT-II



Comparison of discharges with the same magnetic flux configuration and with vertical field along the outer wall, and operated with and without the application of CHI voltage startup. In shots 23981, 23983 and 23987, no CHI voltage was applied. For shot 23988 the applied CHI voltage of 2.5 kV was above the threshold voltage of 2.4 kV used for the rest of the shots with CHI startup. The inductive voltage history is the same as that for the shot sequence in Figure.

Highest ever current of 248kA produced using CHI start-up

HIT-II



CHI start-up in discharges where the central solenoid is *in the process of being pre-charged* have resulted in record current of 248kA. Even though the transformer induces a negative voltage during the charging phase, it does not adversely affect the CHI start-up process. This result is of particular importance to a burning plasma ST reactor.

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.

Summary

HIT-II

- CHI start-up works very well on HIT-II.
- CHI start-up on HIT-II is a very robust plasma start-up method. (for plasma start-up in a steady-state ST reactor volt-seconds savings is not necessary)
- CHI start-up results in volt-seconds savings, and consistently outperforms inductive-only operation.
- CHI start-up can be initiated as the central solenoid is being pre-charged. (therefore it is also applicable to a transient burning plasma ST device)
- Steps needed to implement CHI start-up are now understood, methods developed on HIT-II will be implemented on NSTX.
- These are significant performance enhancing results. These results show that a physics solution exists to ST plasma start-up using CHI.

Acknowledgements: We would like to acknowledge Dr. Masa Ono of PPPL for suggesting that a demonstration of CHI start-up while the transformer is being pre-charged would be more convincing of the use of CHI in a burning plasma ST. We are grateful to Dr. Vlad Soukhanovskii and Dr. Robert Kaita of PPPL for providing us on short term loan a visible spectroscopy system.