NSTX Supported by U.S. DEPARTMENT OF ENERGY | Office of Science

Demonstration of Plasma Start-up in NSTX Using Transient CHI

College W&M
Colorado Sch Mines
Columbia U
Comp-X
General Atomics
INL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
Old Dominion U
ORNL
PPPL
PSI
Princeton U
Purdue U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Maryland
U Rochester
U Washington
U Wisconsin

D. Mueller, M. Bell, M. Ono, J. Menard, S.C. Jardin (PPPL)
R. Raman , T.R. Jarboe, B.A. Nelson (Univ. of Washington)
and the NSTX Research Team

This work is supported by US DOE contract numbers FG03-96ER5436, DE-FG02-99ER54519 and DE-AC02-09CH11466

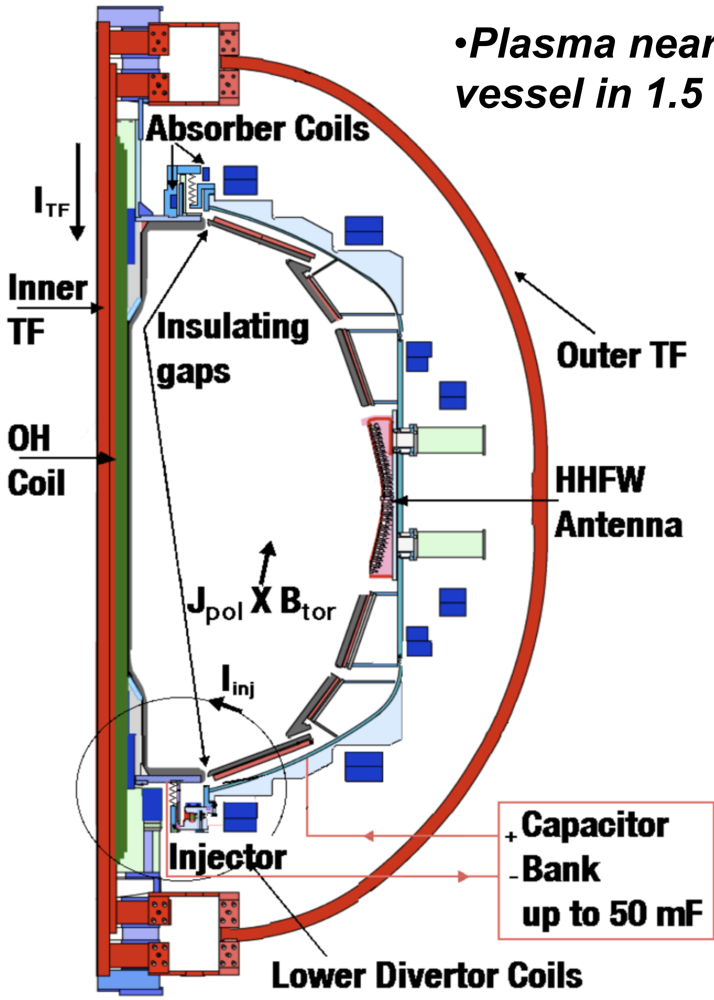
2010 NSTX Results Review
December 1, 2010

Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
KBSI
KAIST
POSTECH
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep
U Quebec

NSTX has now Demonstrated the Savings of Inductive Flux Equivalent to 300kA Current

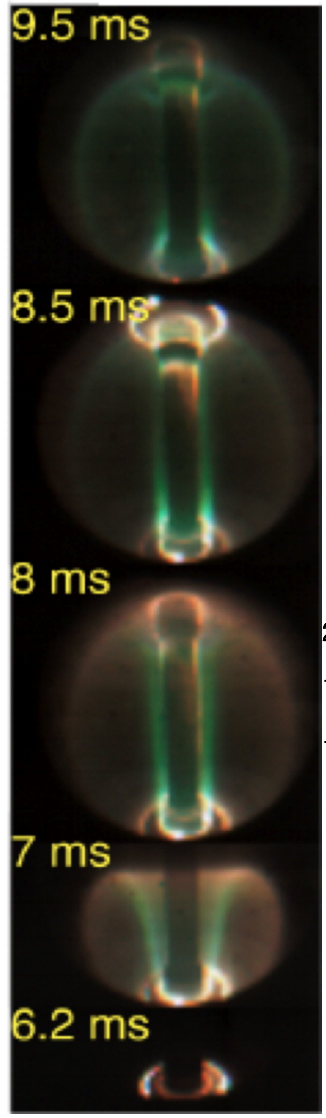
- Reduction of Low-Z impurities, and amelioration of absorber arcs was essential for good results
- Utilized 35 mF of 50 mF available from the variable injector capacitor
- Transient Coaxial Helicity Injection plasma startup method developed on HIT-II at U-Washington
  - For plasma start-up, CHI is *now* unique to NSTX
- Enables lower aspect ratio configurations
  - Simplifies tokamak design

NSTX is designed to permit coaxial helicity injection

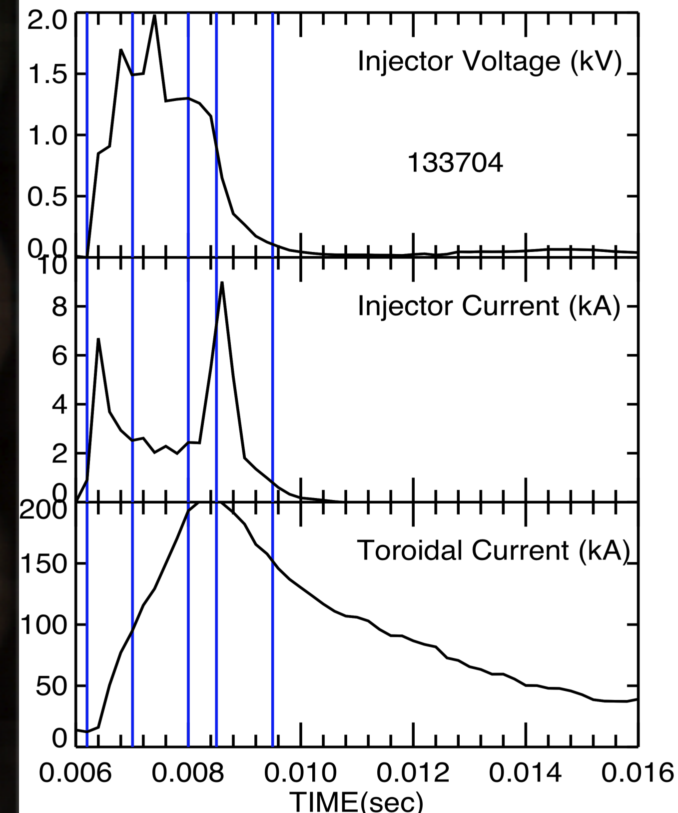


•Plasma nearly fills vessel in 1.5 ms

•The limited space for the center column in an ST necessitates alternative start-up and current drive.



•Axisymmetric reconnection leads to formation of closed flux surfaces

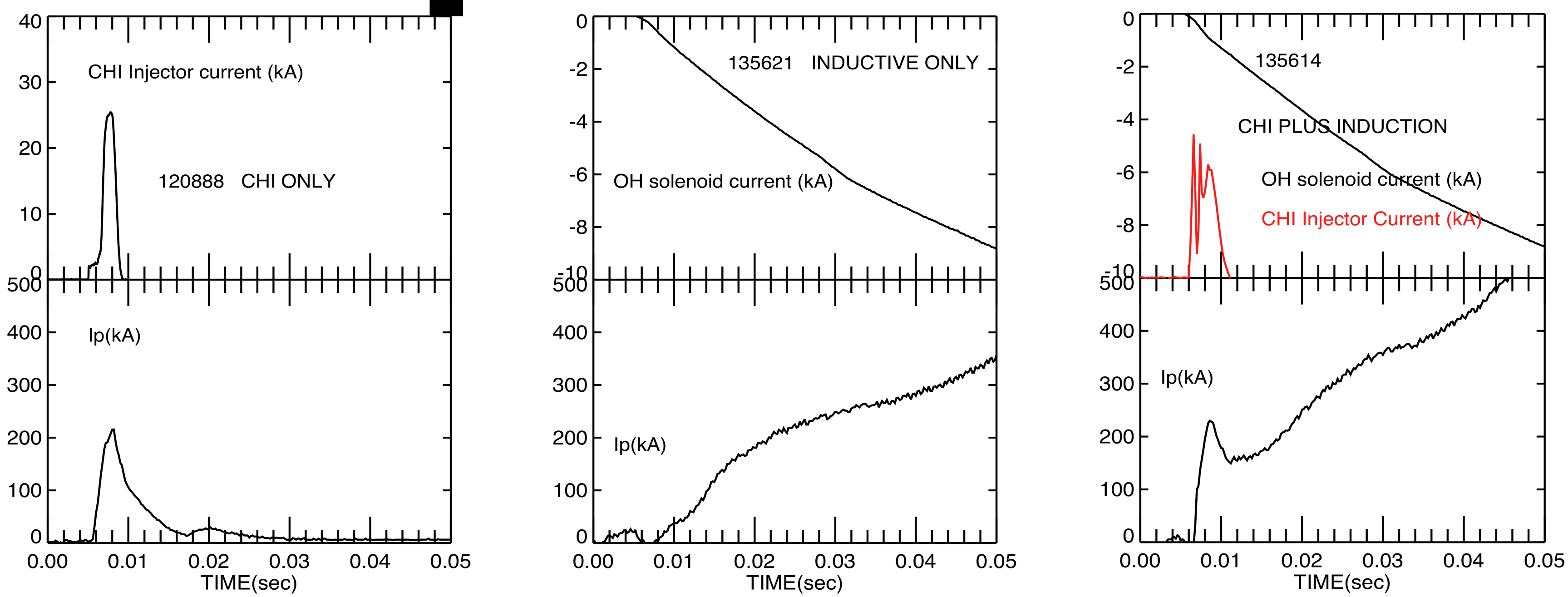


•Starts as helical discharge following the magnetic field

•J_{pol} X B_{tor} is up into vessel

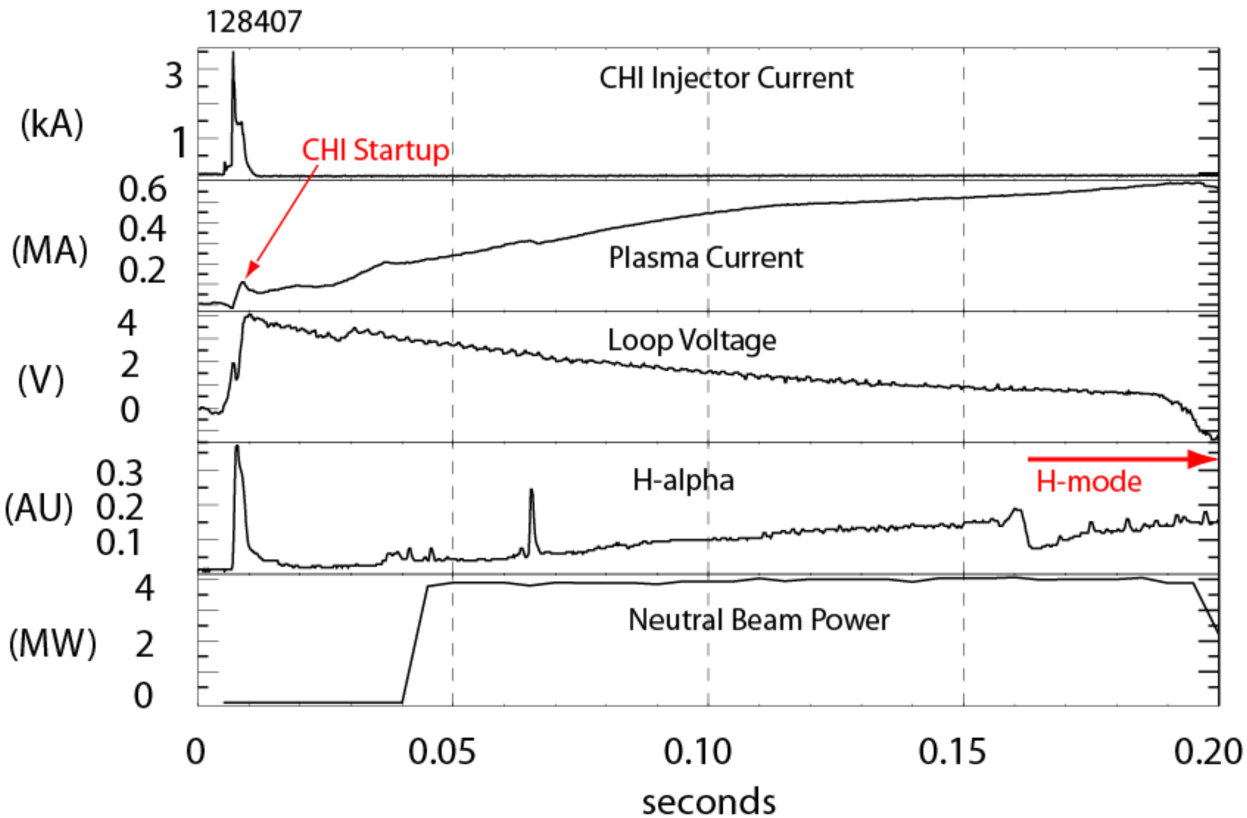
Add inductive drive to CHI formed plasma

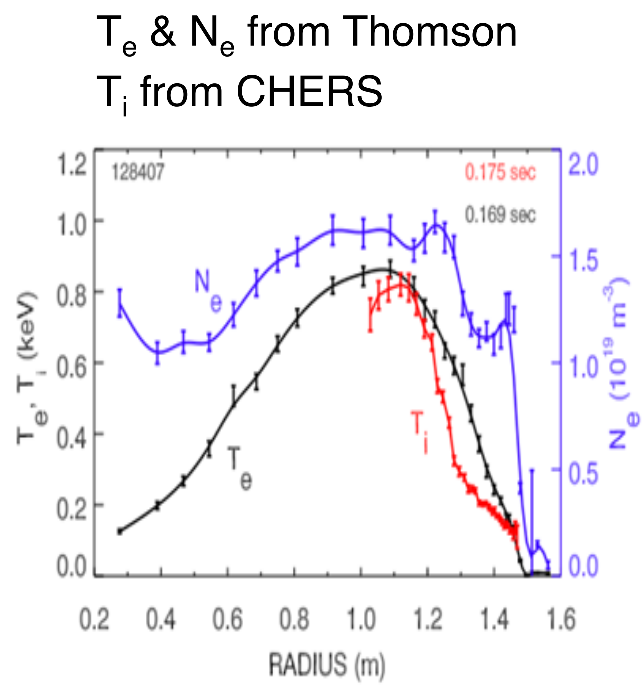
CHI START-UP + INDUCTIVE RAMP → HIGHER CURRENT



- The goal is to use CHI to establish a discharge that can be ramped up by other means
- It is necessary to limit oxygen and carbon impurities to permit inductive ramp-up
- The divertor plates at the top and bottom of the machine can be sources of carbon and oxygen.
- Avoiding unwanted arcs at the top of the machine can limit impurities from that area
- Conditioning, Li-coating and use of metal electrodes can limit the influx of carbon and oxygen from the lower divertor

CHI Started Discharge Couples to Induction and Transitions to an H-mode Demonstrating Compatibility with High-performance Plasma Operation

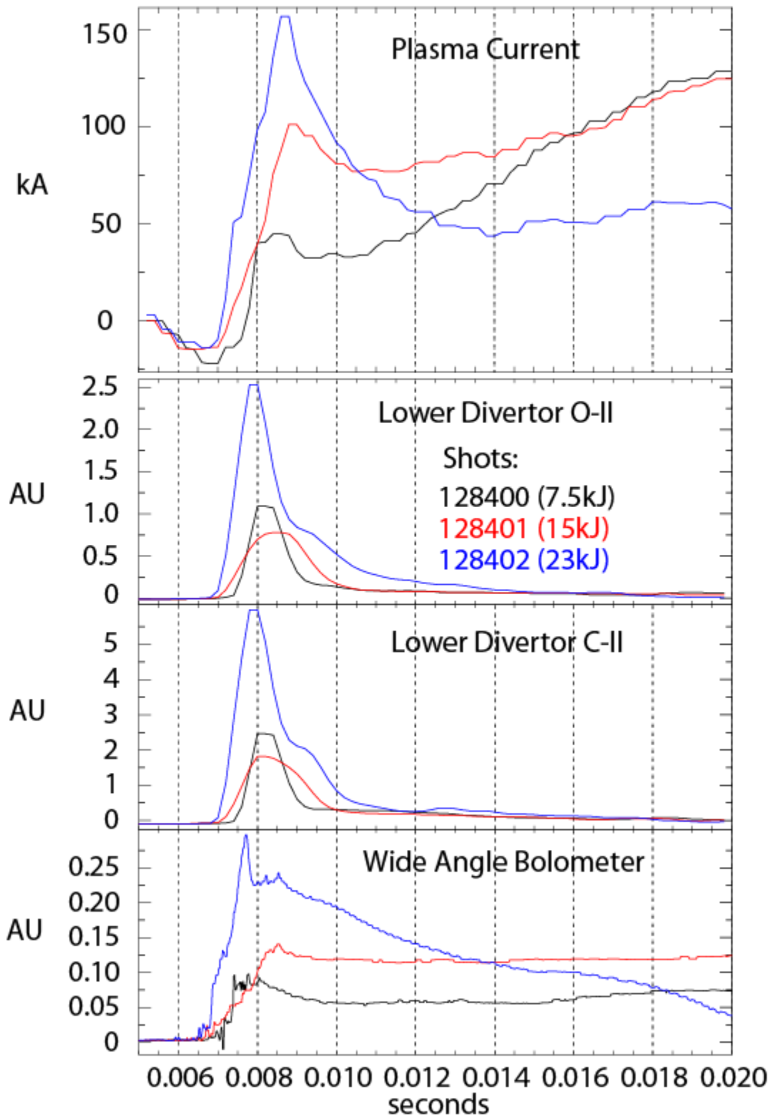




- Discharge is under full plasma equilibrium position control
  - Loop voltage is preprogrammed

CHERS : **R. Bell**
Thomson: **B. LeBlanc**

Low-Z Impurity Radiation Needs to be Reduced for Inductive Coupling



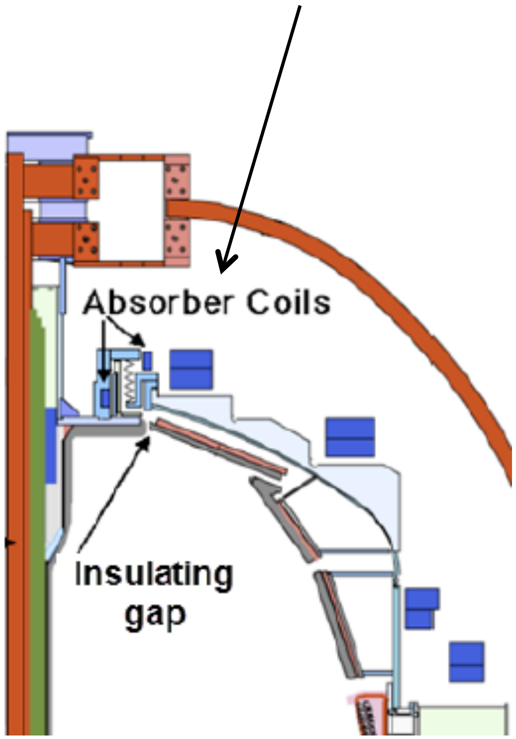
- Low-Z impurity radiation increases with more capacitors

- Possible improvements
  - Metal divertor plates should reduce low-Z impurities
    - High Te in spheromaks (500eV) obtained with metal electrodes
  - Discharge clean divertor with high current DC power supply
  - Use auxiliary heating during the first 20ms

Filter scopes: **V. Soukhanovskii**

Flux Savings on NSTX Now Realized After Low-Z Impurity Reduction

Absorber coils provide buffer field



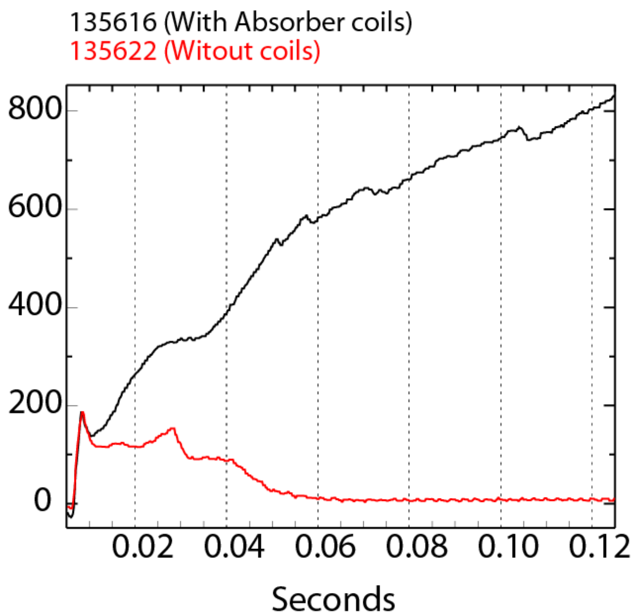
Long-pulse (400ms) CHI discharges with high injector flux to avoid “bubble-burst”
- ablate low-Z impurities from lower divertor

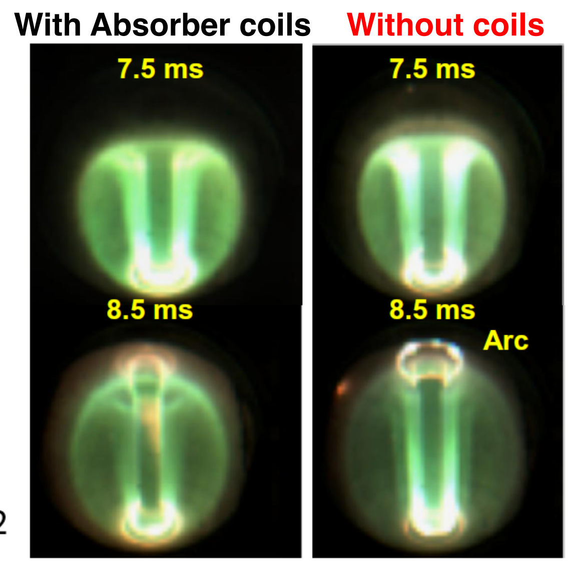
Deuterium glow discharge cleaning employed to chemically sputter and reduce oxygen levels

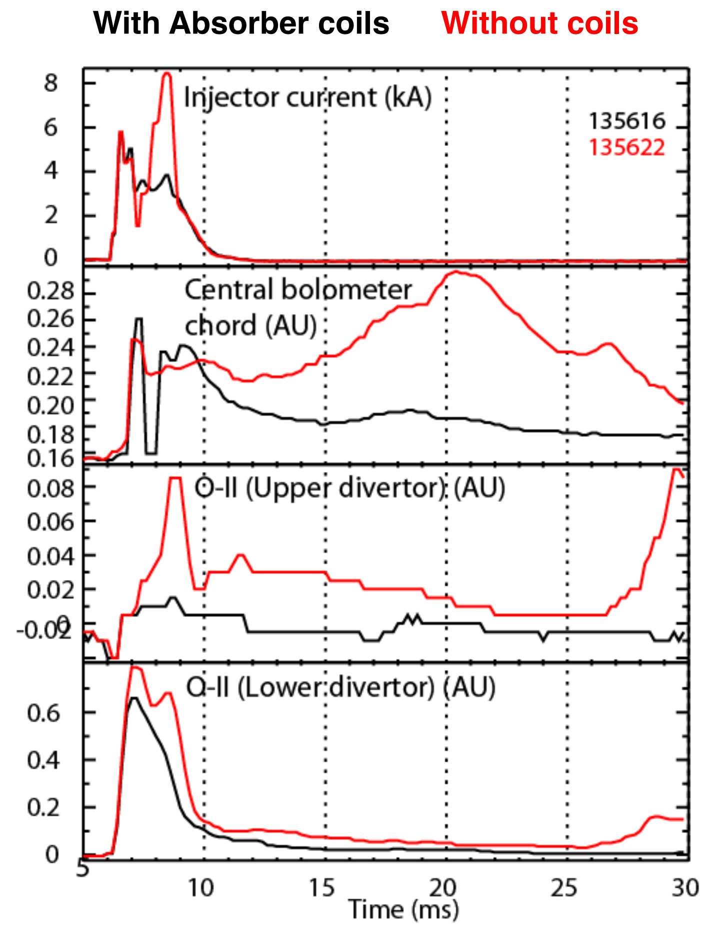
Lithium evaporation on lower divertor plates improved discharge performance

A buffer field was provided using new PF coils located in the upper divertor region
- reduced interaction of CHI discharge with un-conditioned upper divertor plates

Absorber Coils Suppressed Arcs in Upper Divertor and Reduced Influx of Oxygen Impurities



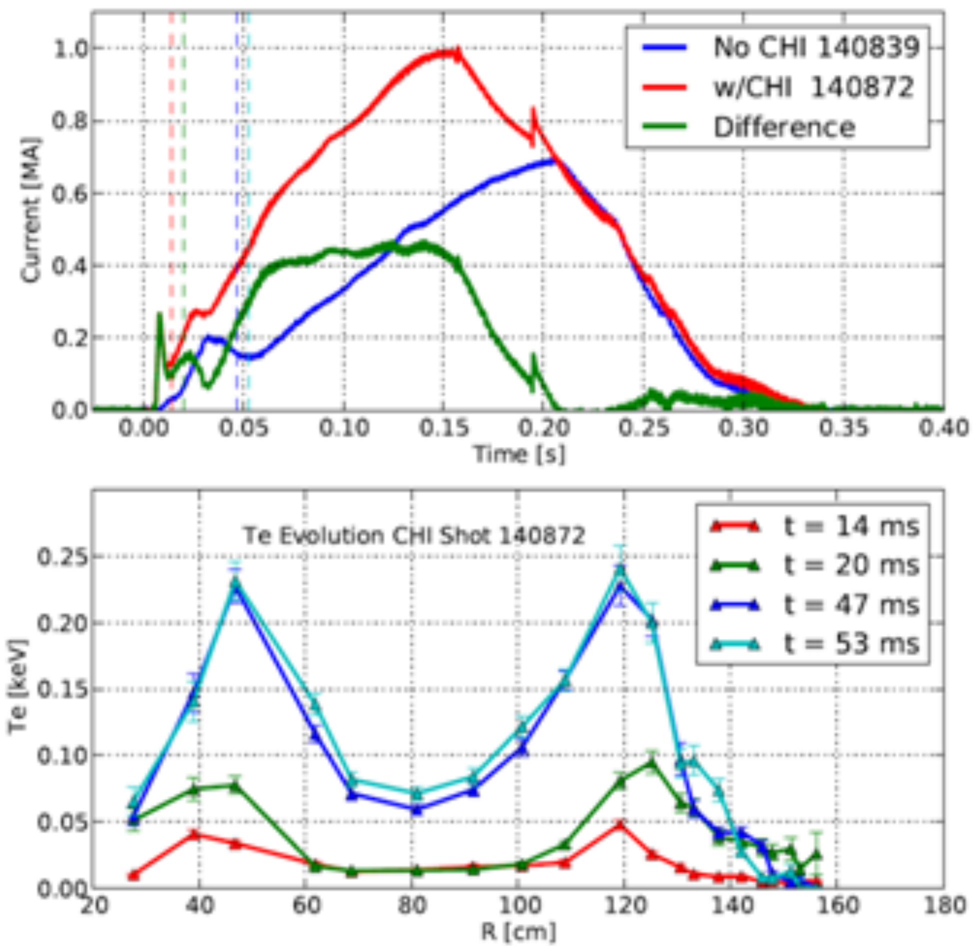




- **Divertor cleaning and lithium used to produce reference discharge**
- **Buffer field from PF absorber coils prevented contact of plasma with upper divertor**

R. Raman, D. Mueller, B.A. Nelson, T.R. Jarboe, et al., PRL 104, (2010) 095003

Using Only 27kJ of Capacitor Bank Energy CHI Started a 300kA Discharge that Coupled to Induction

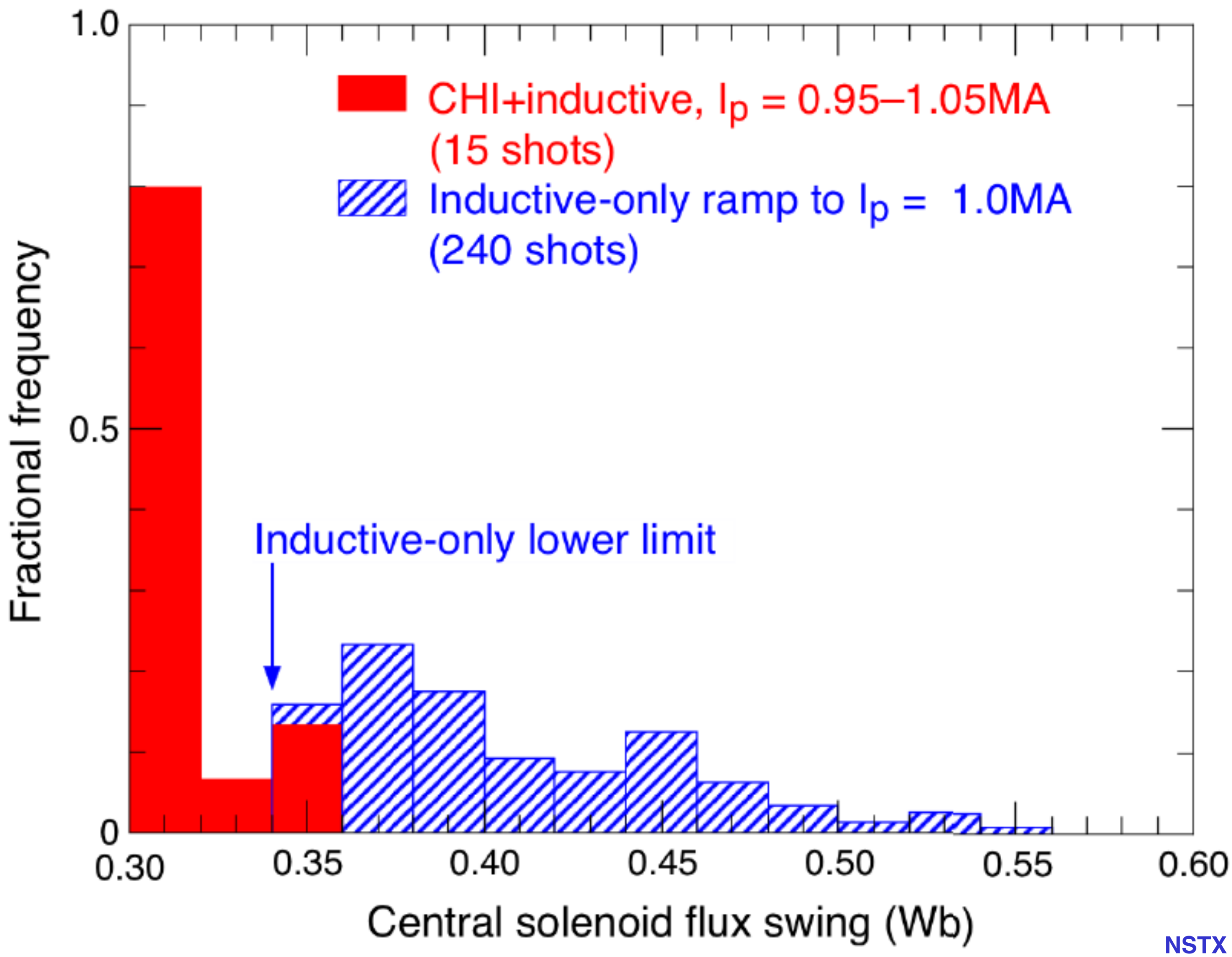


- Ramped up to 1MA after startup, using 0.3Wb change in solenoid flux
- Hollow electron temperature profile maintained during current ramp
  - Important beneficial aspect of using CHI startup

- Discharges with early high T_e ramp-up to higher current

CHI Started Discharges Require Less Inductive Flux than Discharges in NSTX Data Base

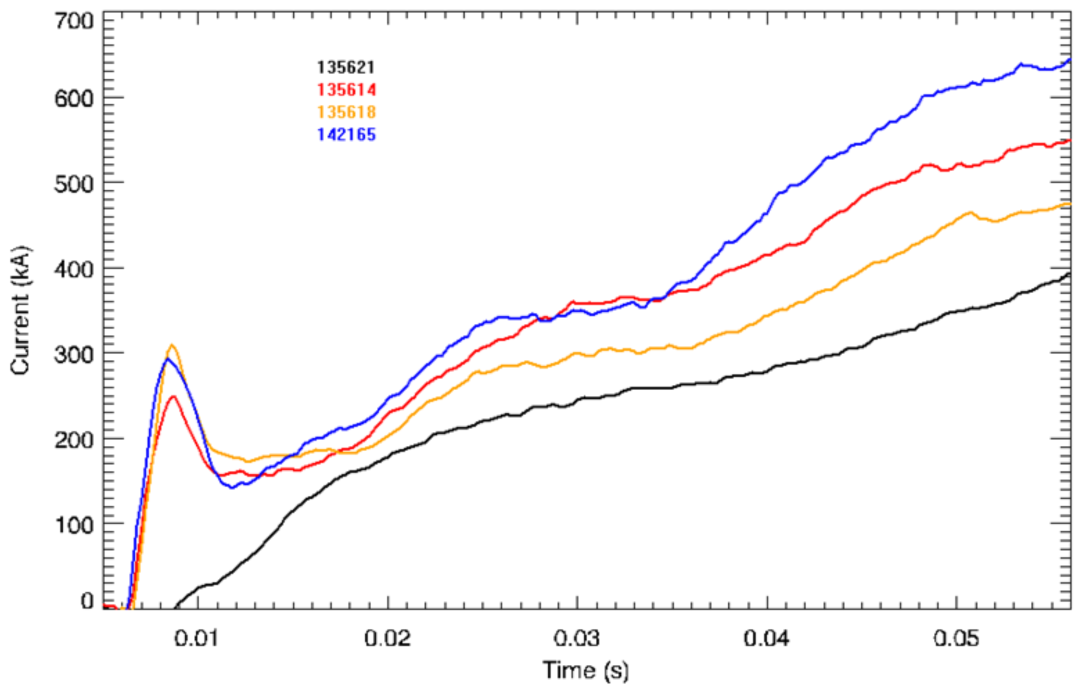
Comparison of CHI Startup to H-modes using more than 1 NBI source



Most recent CHI-started discharges require less flux than shown here

NSTX Data Base Analysis: **M. Bell**

2010 Discharge Reaches 650kA, 50ms after start of CHI (100kA higher than during 2009)



•2010,
•27 kJ

•2009,
•20 kJ

•2009,
•27 kJ

- 2009 discharges with 4-capacitors reaches 480kA
  - Induction-only discharge reaches only 400kA

- 2010 discharges with 4-capacitors reaches 650kA
  - 250kA higher than induction-only discharge

Poloidal flux is larger in CHI initiated discharges

2010 results

- ***An increase in I_p of 200 to 300 kA is observed in the CHI initiated discharge shown in red compared to the inductive discharge in blue.***

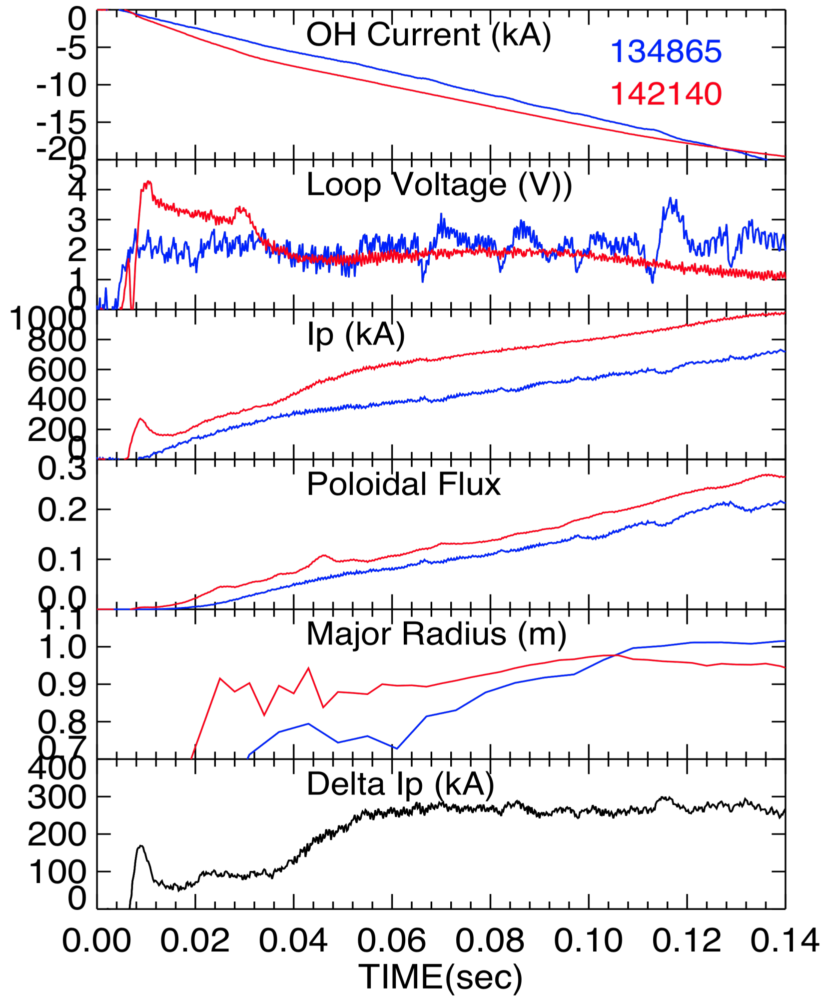
- ***The CHI initiated discharge shown in red used 30 mF of capacitance at 1.465 kV.***

- ***The discharge in blue is an inductively driven discharge that is among those on NSTX that reached 1 MA with the lowest ohmic flux.***

- ***The poloidal flux is $I_p \cdot R_p \cdot l_i \cdot \mu_0/2$.***

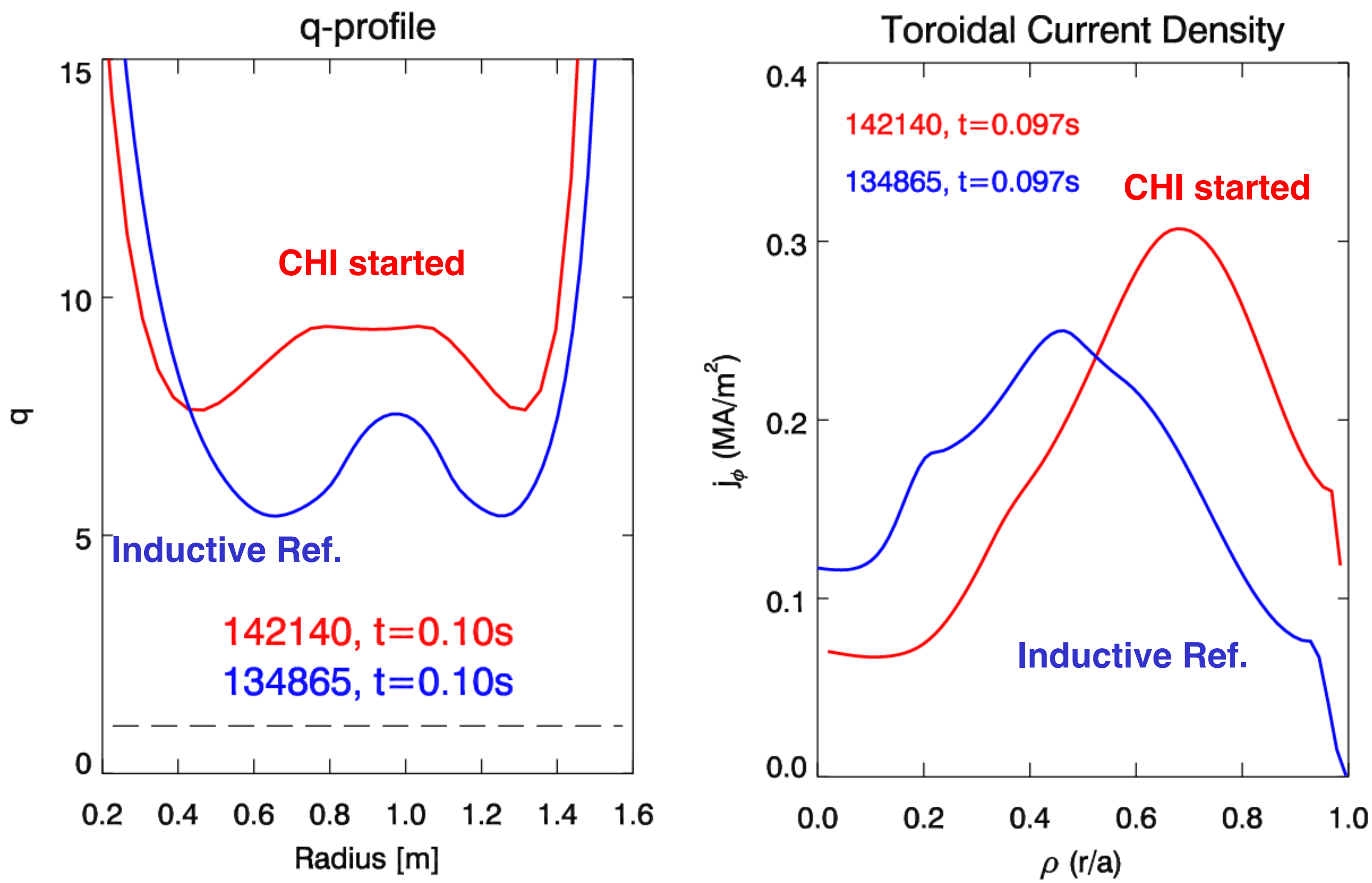
- ***The internal inductance (l_i) and plasma major radius (R_p) are from EFIT analysis.***

- ***Both shots had the benefit of neutral beam injection.***



CHI Start-up Discharges Show Plasma Current Driven at Large Radius

2010 results

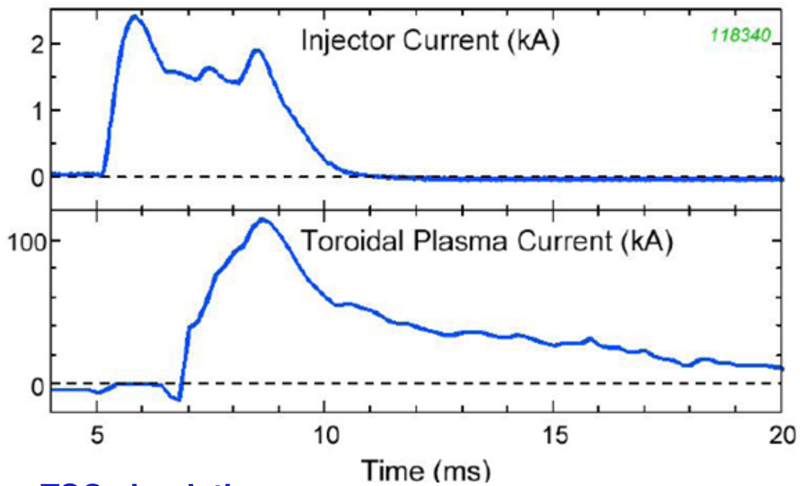


These are the type of plasmas needed for advanced scenario operations

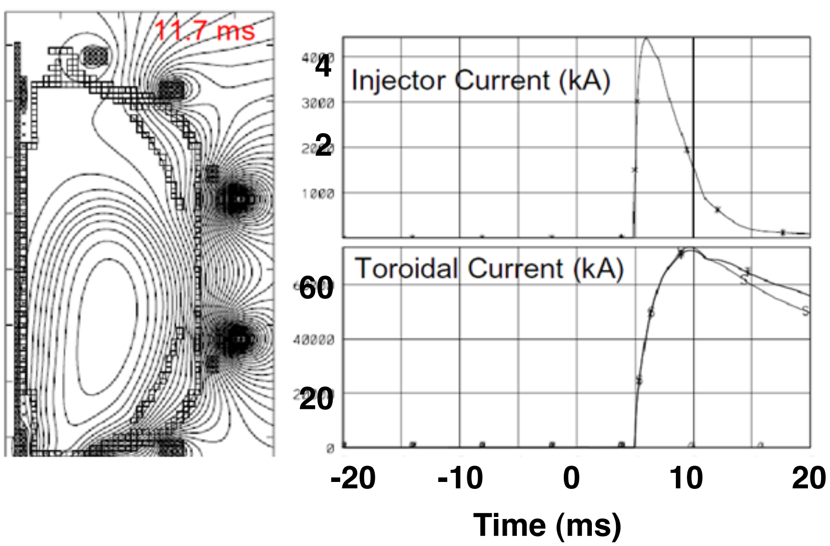
MSE & LRDFIT: H. Yuh, J. Menard, S. Gerhardt

TSC Simulations are being Used to Understand CHI-Scaling with Machine Size

NSTX Experimental result

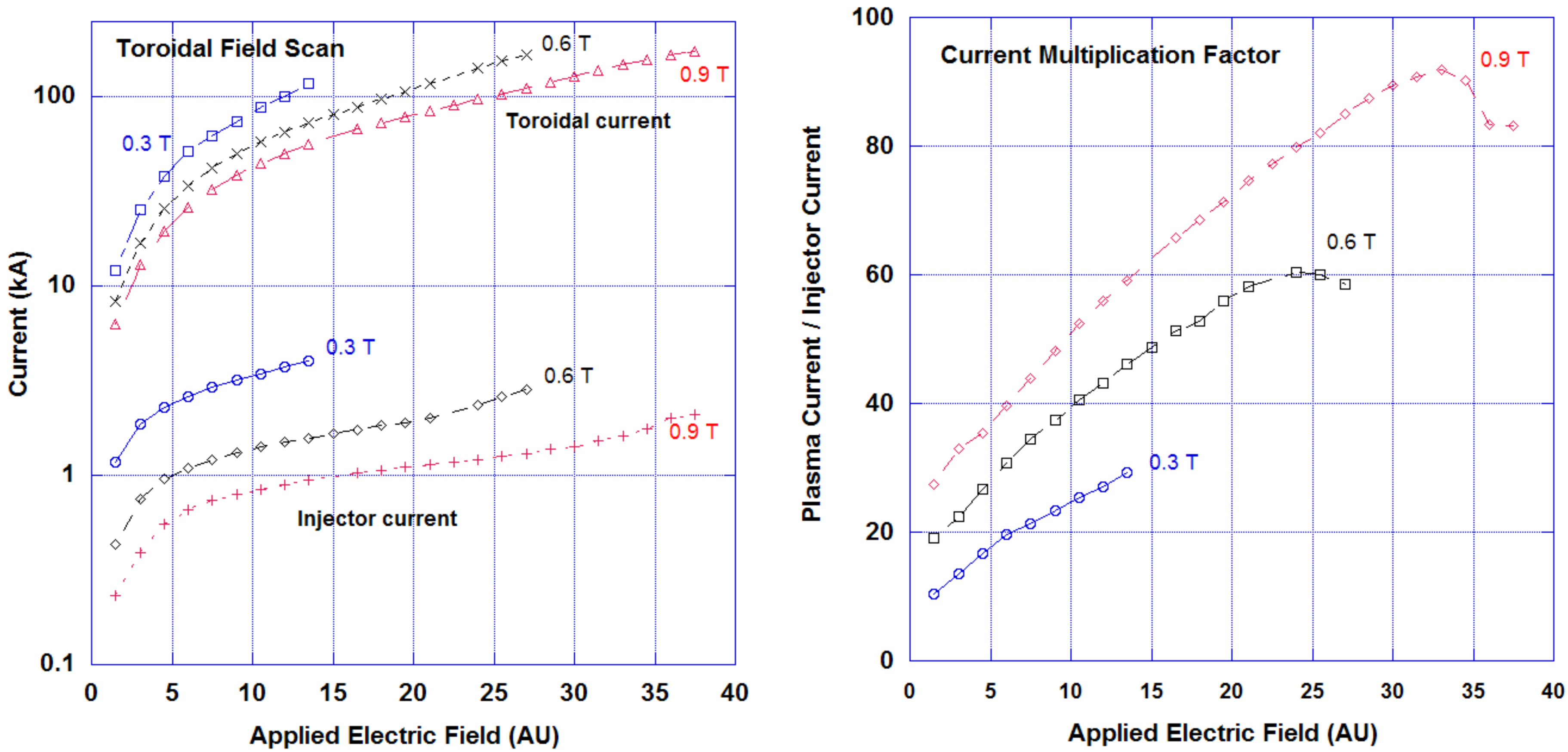


TSC simulation



- **Time-dependent, free-boundary, predictive equilibrium and transport**
- **Solves MHD/Maxwell's equations coupled to transport and Ohm's law**
- **Requires as input:**
  - **- Device hardware geometry**
  - **- Coil electrical characteristics**
  - **- Assumptions concerning discharge characteristics**
- **Models evolutions of free-boundary axisymmetric toroidal plasma on the resistive and energy confinement time scales.**
- **NSTX vacuum vessel modeled as a metallic structure with poloidal breaks**
  - **- An electric potential is applied across the break to generate the desired injector current**

TSC Simulations Show Increasing Current Multiplication as TF is Increased (NSTX geometry)



- Observed current multiplication factors similar to observations in NSTX
  - Higher toroidal field important as it reduces injector current requirement

NSTX has Made Considerable Progress Towards Developing a Viable Solenoid-Free Plasma Startup Method

- 0.3MA current generation in NSTX validates capability of CHI for high current generation in a ST
- Successful coupling of CHI started discharges to inductive ramp-up & transition to an H-mode demonstrates compatibility with high-performance plasma operation
- CHI start-up has produced the type of plasmas required for non-inductive ramp-up and sustainment (low internal inductance, low density)
- Favorable scaling with increasing machine size observed experimentally and in TSC simulations

Next steps

- **Assess capability of auxiliary heating to increase T_e (RF and NBI)**
- **Increase the bank energy to increase the start-up current magnitude**
  - **Assess initial current requirements for direct coupling to NBI**
  - **Increase current magnitude in absorber coils**
  - **Full Lithium coverage of the lower divertor plates**
  - **Assess benefits of metal divertor plates**