NSTX

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Solenoid Free Plasma Startup Progress and Plans

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for the NSTX Research Team

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PPPL B318
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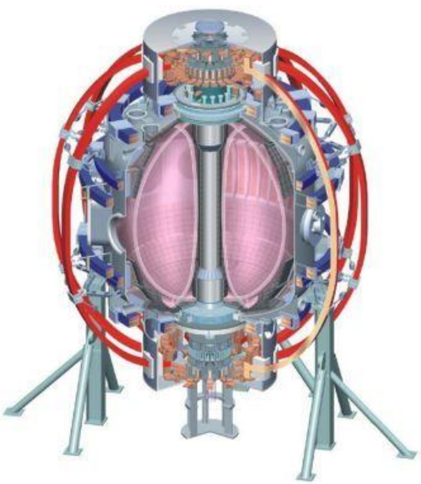
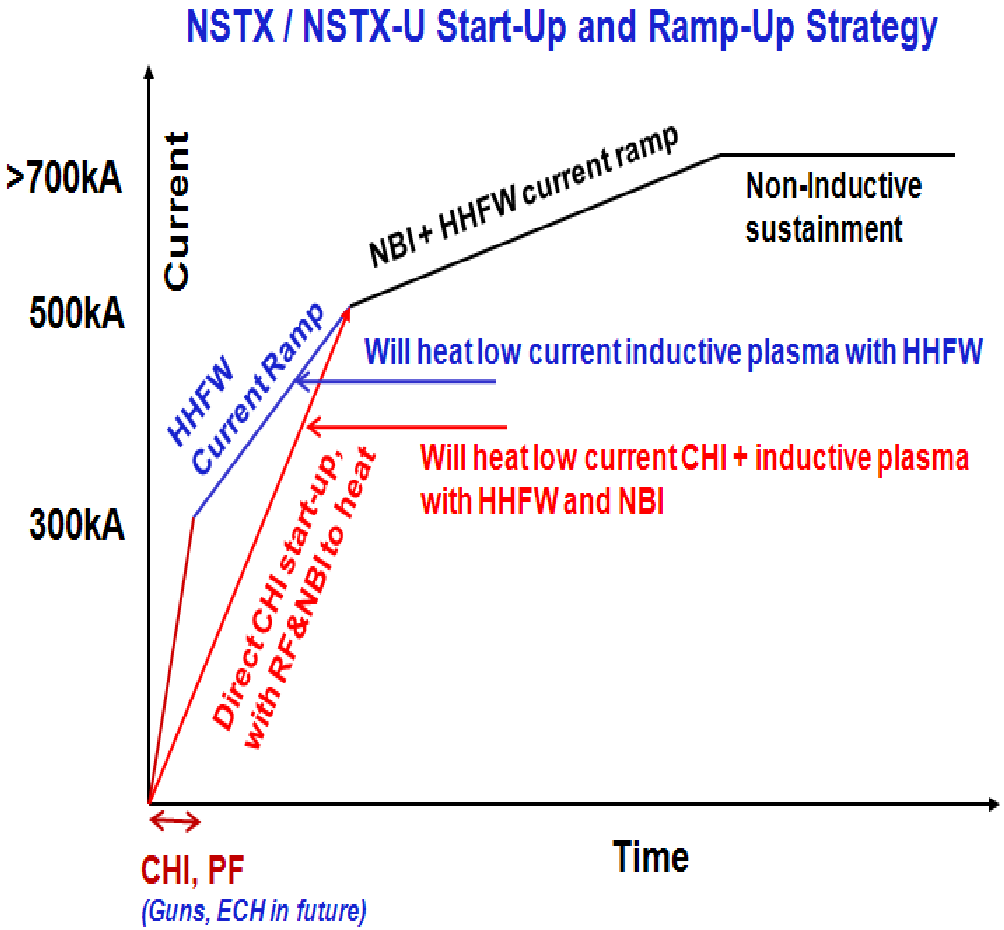


Motivation for Solenoid-free Plasma Startup

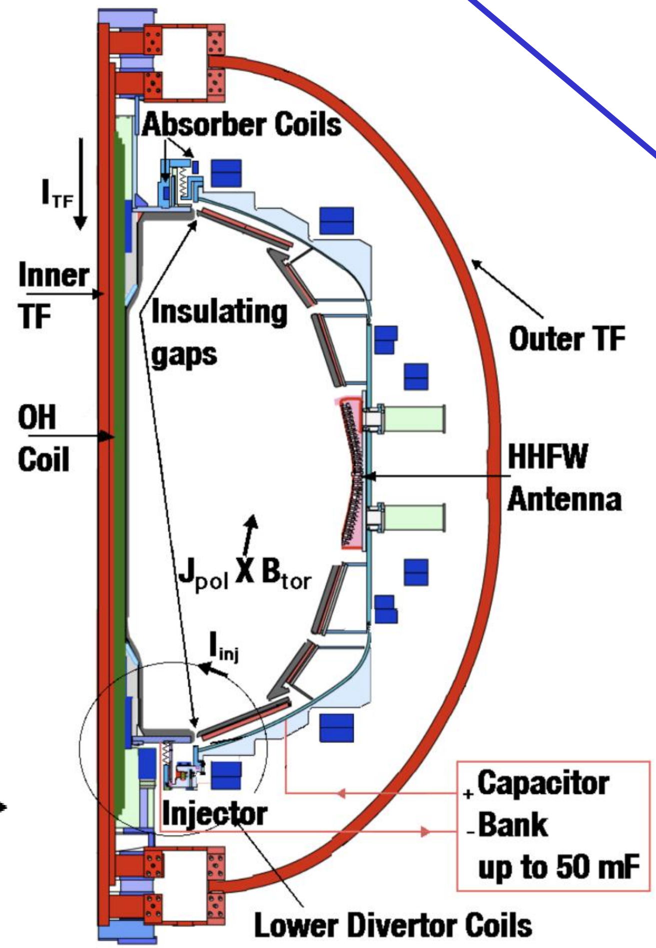
- Non-inductive plasma start-up, ramp-up and sustainment is an important goal of the NSTX / NSTX-U program
- Solenoid-free current initiation would improve the prospects of the ST as a CTF and fusion reactor (and possibly tokamak)
- NSTX is exploring Coaxial Helicity Injection (CHI) and Outer PF start-up for plasma current initiation
  - Collaboration with DIII-D on outer PF start-up with ECH*
  - UW PEGASUS is exploring plasma gun start-up

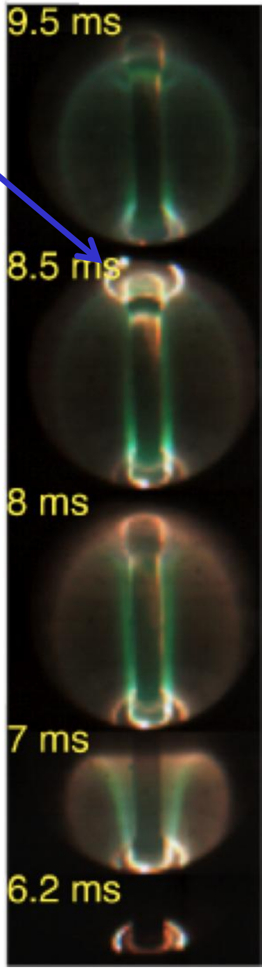
*** D. Mueller collaborating with DIII-D on outer PF start-up (Torkil Jensen Award) [PAC 27-32]**

CHI Generates Closed Flux Equilibrium by Driving Current on Poloidal Flux that Connects Inner Divertor Plates



Absorber Arc

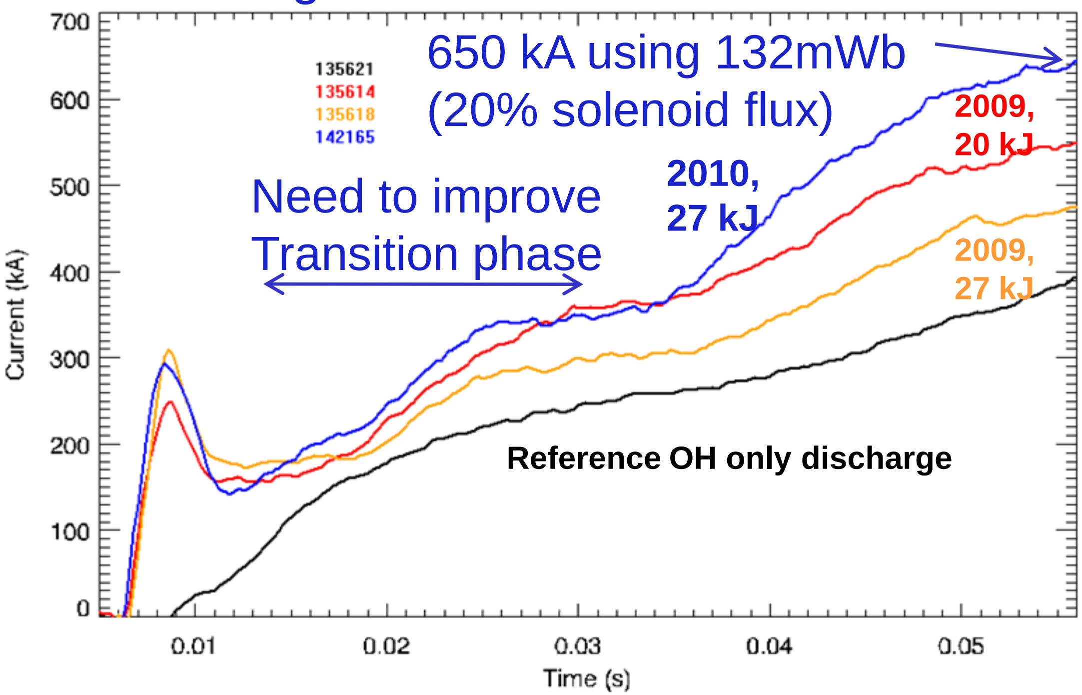


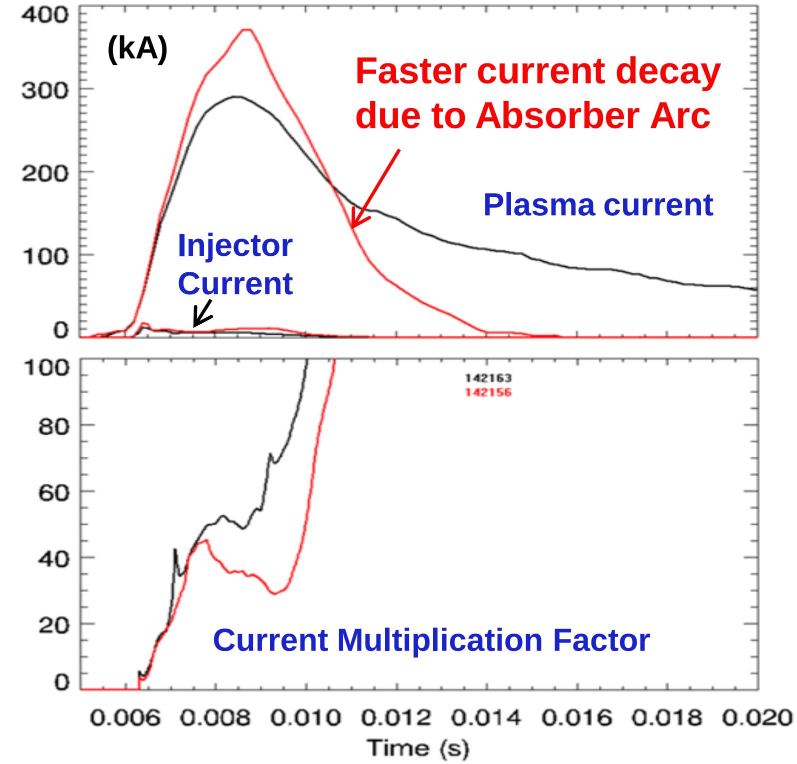


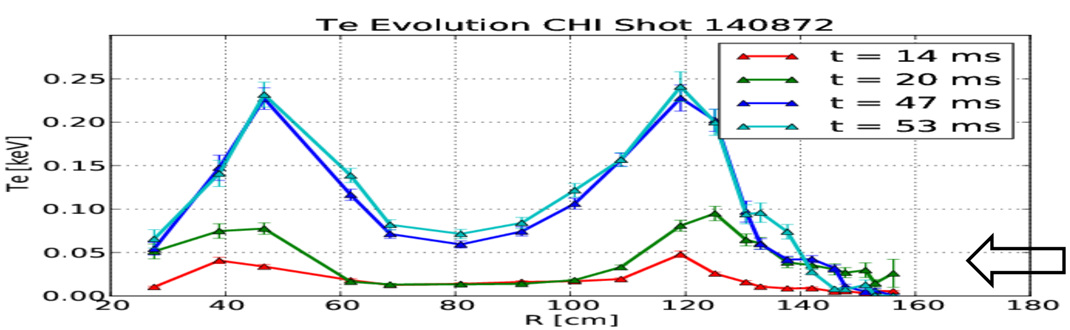
Direct CHI ramp-up to 500kA projected to be possible at 1T in NSTX-U

FY2010 CHI Experiments Achieved Further Reduction in OH Solenoid Flux Required to Achieve High Plasma Current

20% solenoid flux is adequate to ramp CHI target to 80% of nominal current







- Will increase current in absorber coils to improve arc-free start-up current magnitude

- Hollow Te profile retained during ramp-up

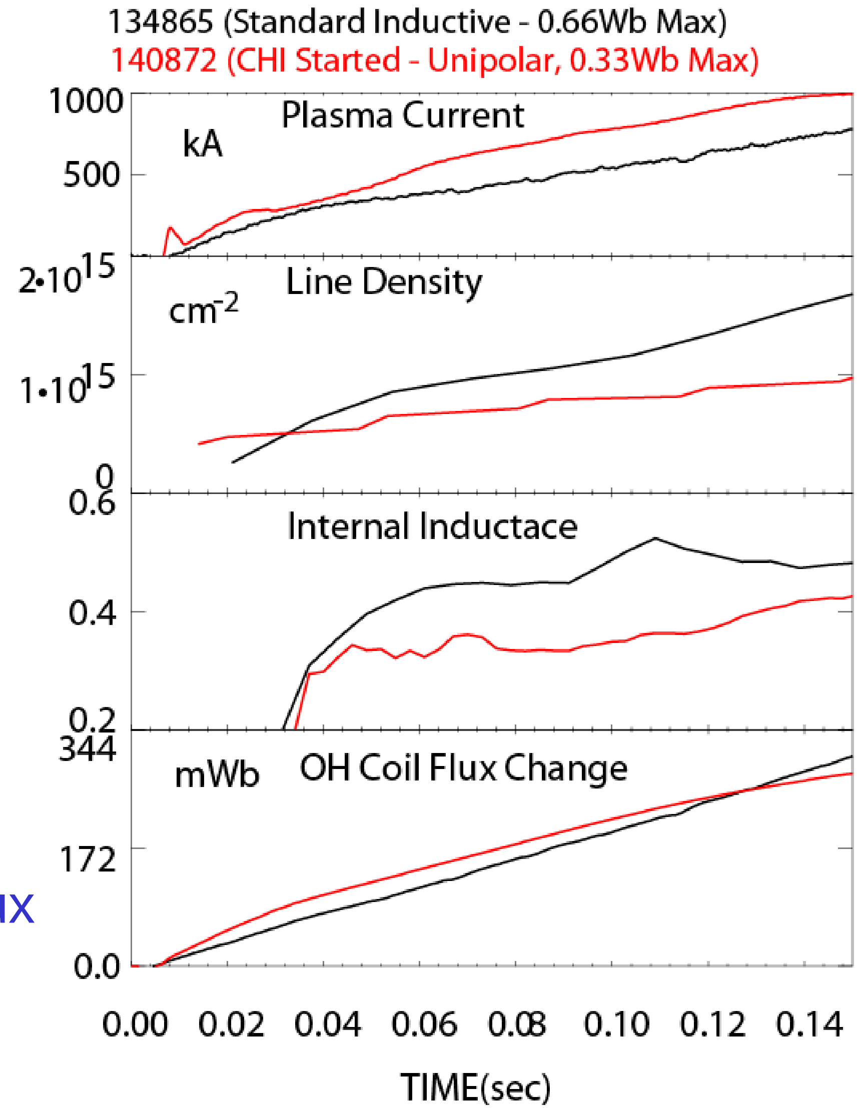
CHI Start-up Discharges have Low Internal Inductance and Electron Density Starting from Early in the Current Ramp

[Li was used - PAC27-31]

- Standard L-Mode discharge ramps to 1MA requiring 50% more inductive flux than a CHI initiated discharge

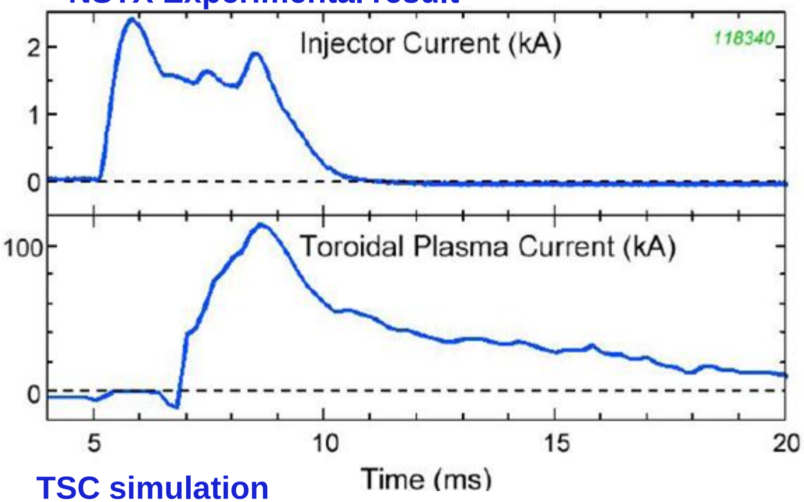
- Reference Inductive discharge (total OH flux 660mWb)
  - Uses 400mWb to get to 1MA
  - Best H-Mode Inductive discharge requires 340mWb to get to 1MA

- CHI started discharge (total OH flux 330mWb)
  - Uses 260mWb to get to 1MA
  - High NI fraction discharges have a flux consumption of ~100mWb/s
  - Higher current startup will further reduce flux usage

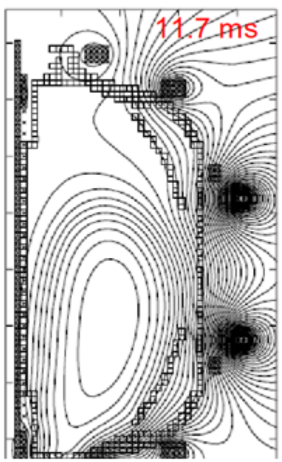


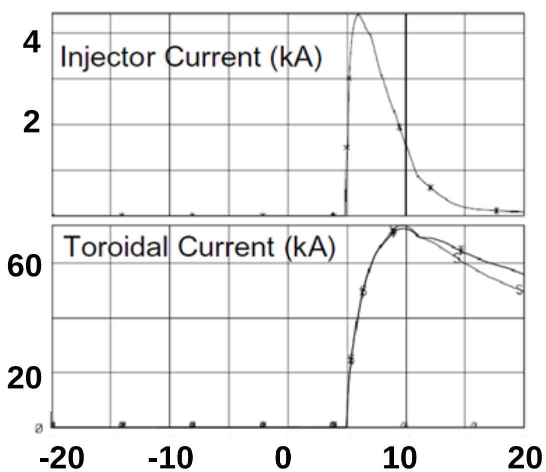
TSC Simulations Show Increasing Current Multiplication as TF is Increased (NSTX geometry) [PAC27-32]

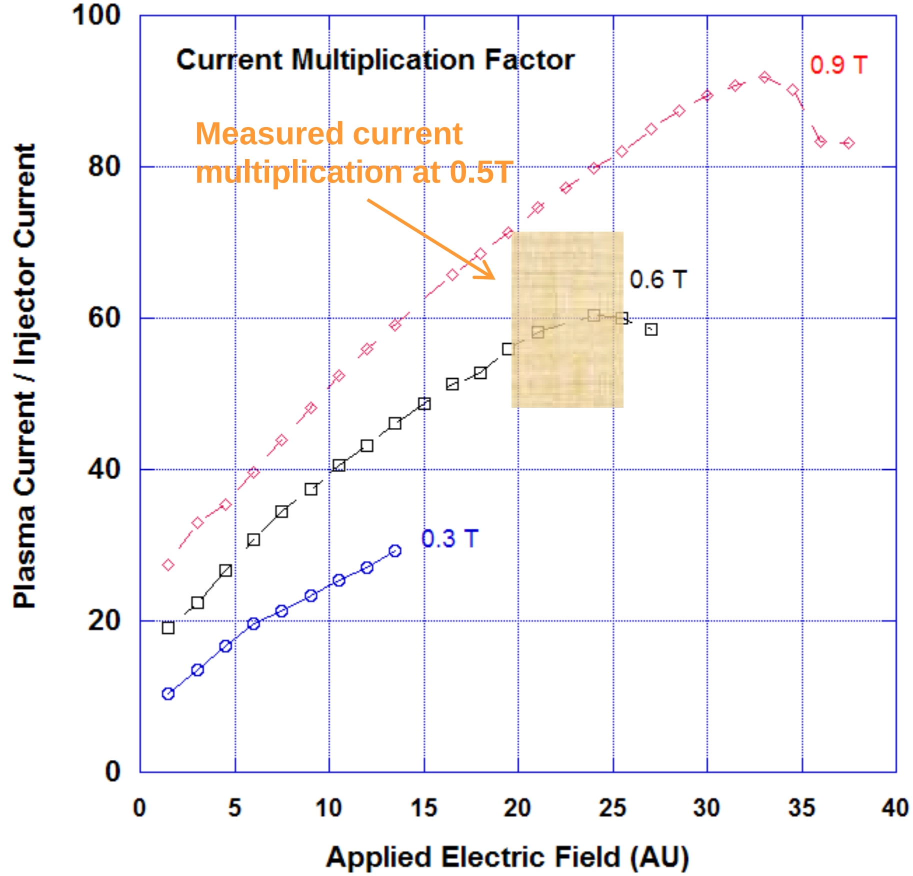
NSTX Experimental result



TSC simulation





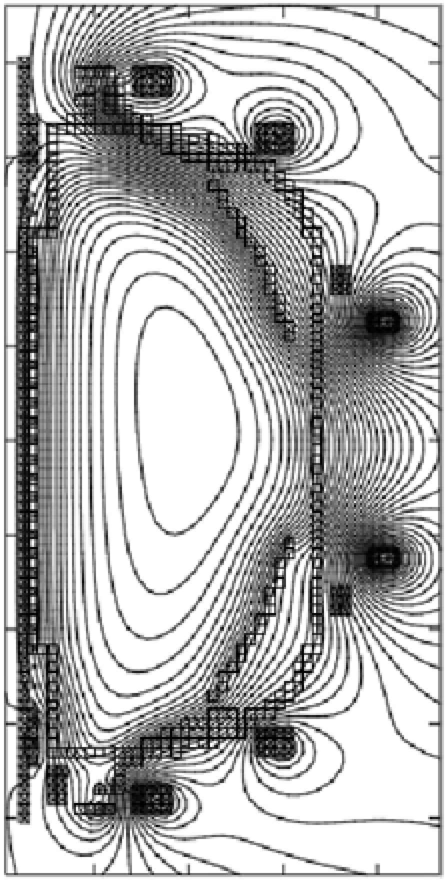


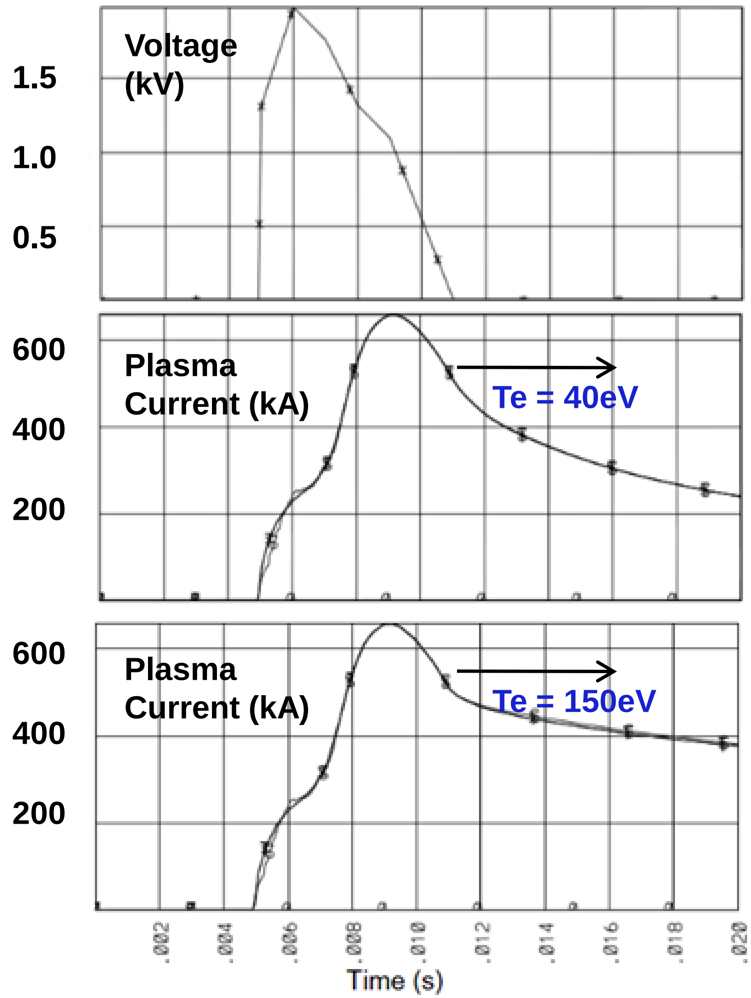
Now starting to use NIMROD code (in collaboration with Bick Hooper, LLNL)

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

TSC Simulations Show 600kA CHI Start-up Capability in NSTX as TF is Increased to 1T

Poloidal Flux





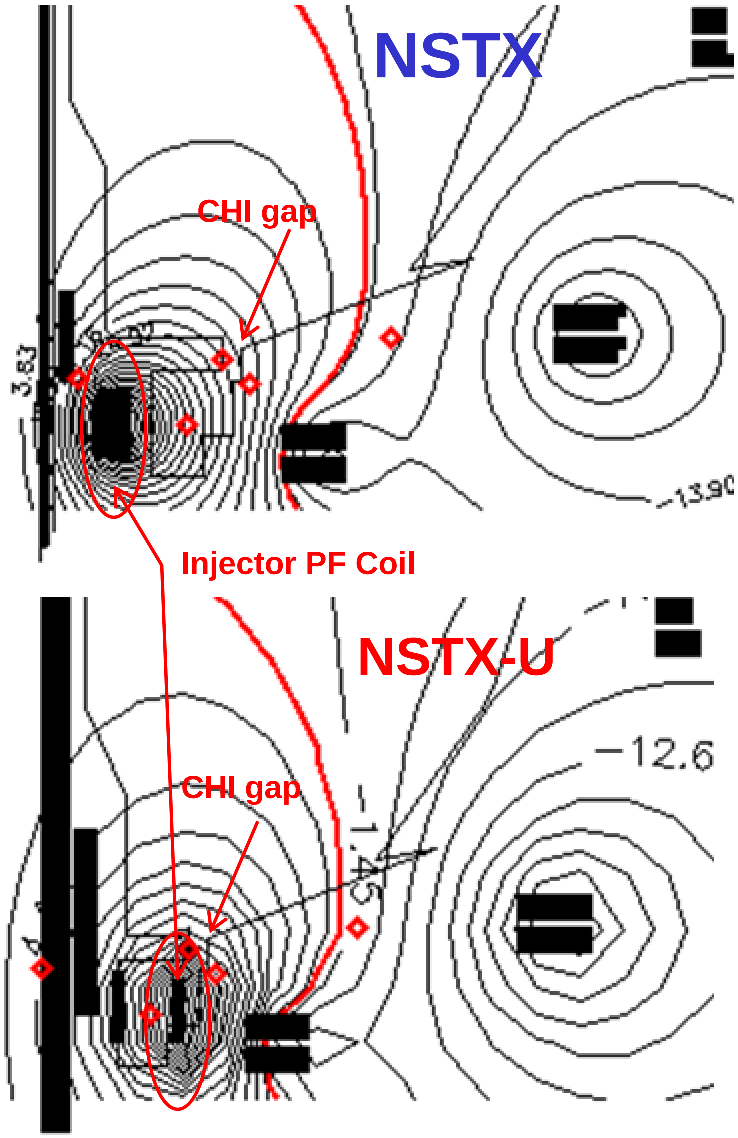
Projected closed flux plasma current for NSTX-U is >450 kA [$I_p = I_{inj}(\psi_{Tor}/\psi_{Pol})$]*

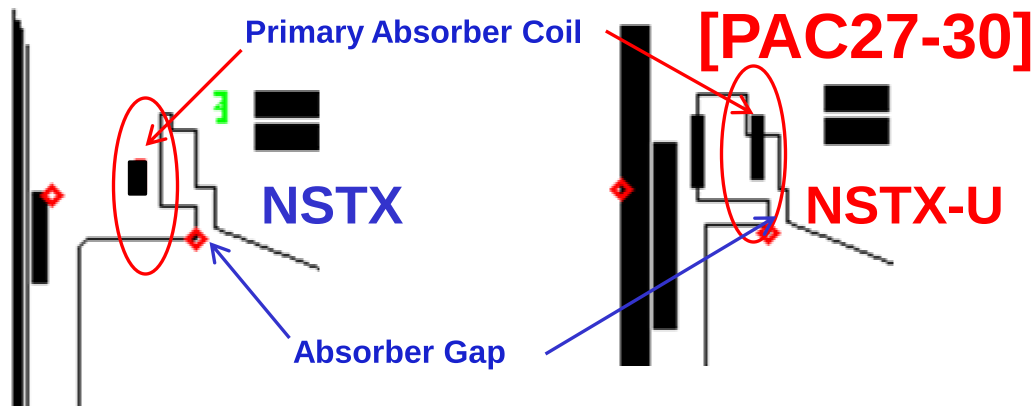
- Based on 11 kA injector current
- Current multiplication of 55 (achieved in NSTX)
- Applied voltage ~2x that at 0.5T, further optimization may reduce voltage requirement

Consistent with present experimental observations in NSTX that attain >300kA at 0.5T

* T.R. Jarboe, FT (1998)

NSTX-U PF Coils are Better Positioned and have Higher Current Slew-Rates for Improved Flux Programming and Absorber Arc Control





- Injector coil in NSTX-U positioned closer to CHI Injector gap
  - Closer to HIT-II configuration
  - More efficient use of coil current
  - Flux slew rate >5x NSTX
- Absorber coil in NSTX-U positioned closer to Absorber gap
  - More efficient use of coil current
  - 318 kA.Turn capability vs. 100 kA.Turn in NSTX
  - Current slew rate is 40 kA.Turns/ms vs. 5 kA.Turns/ms in NSTX

FY11 Plans for Solenoid Free Plasma Startup

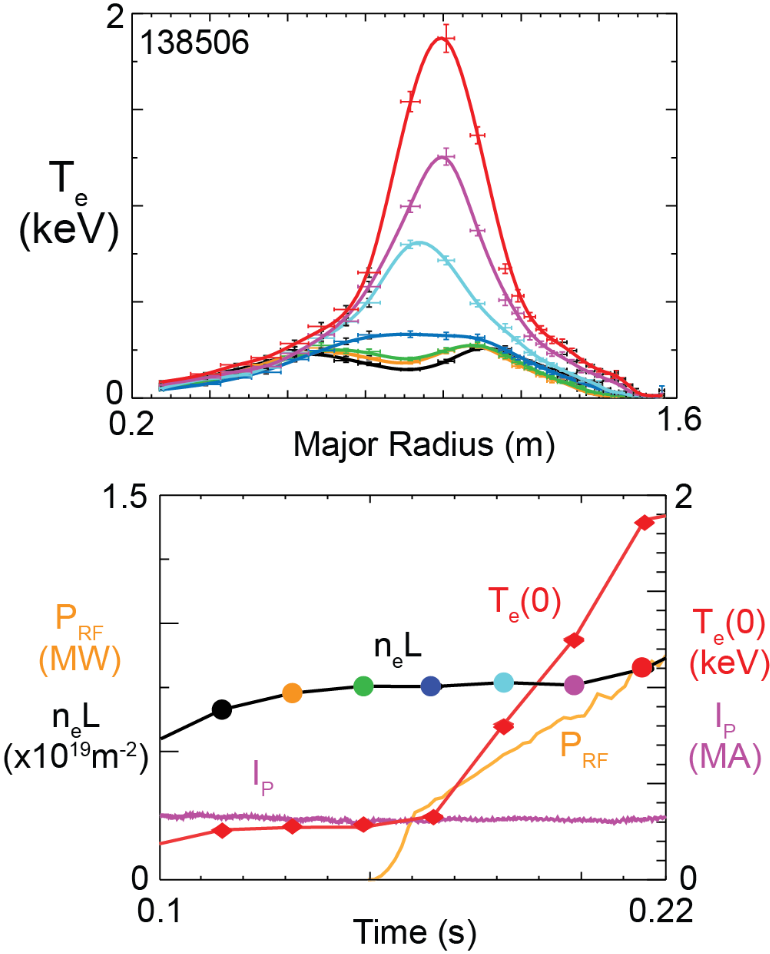
- Increase the initial CHI start-up current using more capacitors
  - Increase the current in the Absorber coils
  - CHI cap bank firing optimization potentially advantageous a possibility
- Assess improvements to CHI started discharge electron temperature
  - Use early NBI and HHFW
- Increase the magnitude of CHI started current that couples to induction by further reducing low-Z impurities
  - Use full lithium coverage (dual LITERS unavailable for CHI experiments in 2010)
  - First test of the use of a molybdenum cathode (if available)
  - Explore lithium dropper interactions/synergy with CHI
- Start CHI discharges with a partially pre-charged central solenoid
  - To develop low density discharges for ASC TSG (Priority II)

FY12 Plans for Solenoid Free Plasma Startup

- Use methods developed during FY2011 to support the FY12-2 Milestone
  - Assess the capability of HHFW and NBI to heat a high-current CHI target, assess the confinement of CHI started discharges
  - Obtain adequate data set on coupling of HHFW and NBI to a 300-500kA plasma target for use in TRANSP simulations in support of NSTX-U

- Establish the maximum magnitude of current initiated by CHI
  - Scaling with B_T and Injector flux input for TSC and NSTX-U

300kA Inductive plasma



500kW HHFW increases Te(0) to 1keV in ~30ms

FY13 Analysis Plan in Preparation for NSTX-U Start-up

- Use TSC to simulate FY2011/12 results on CHI start-up and coupling to induction & adapt it to the NSTX-U configuration
  - Develop start-up scenarios for the initial start-up phase of NSTX-U
  - Use TRANSP/TSC to model CHI start-up to allow direct coupling to NBI current drive
  - Confirm and extend the TSC results to full MHD using NIMROD
- Use TSC and NIMROD capability to do a next-step ST design that includes CHI capability
  - Collaborate with PPPL/Culham engineering/physics groups
- Design and upgrade the CHI capacitor bank for improved voltage programming capability
  - Design and upgrade voltage snubbing systems
  - Design and upgrade CHI related diagnostics (voltage monitors, current monitors, fast neutral pressure gauges for operation at 1T)

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

- CHI startup enables achievement of record-low flux consumption to get to 1MA in NSTX
- Successful coupling of CHI started discharges to inductive ramp-up & transition to an H-mode (2008) demonstrates compatibility with high-performance plasma operation
- CHI start-up has produced low internal inductance, low density plasmas beneficial to non-inductive ramp-up and sustainment
- Favorable scaling of current multiplication with TF predicted with TSC (consistent with experimental observations)

Next steps

• Working to couple auxiliary heating and CD to CHI-initiated plasmas in prep for NSTX Upgrade and next-steps

• 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

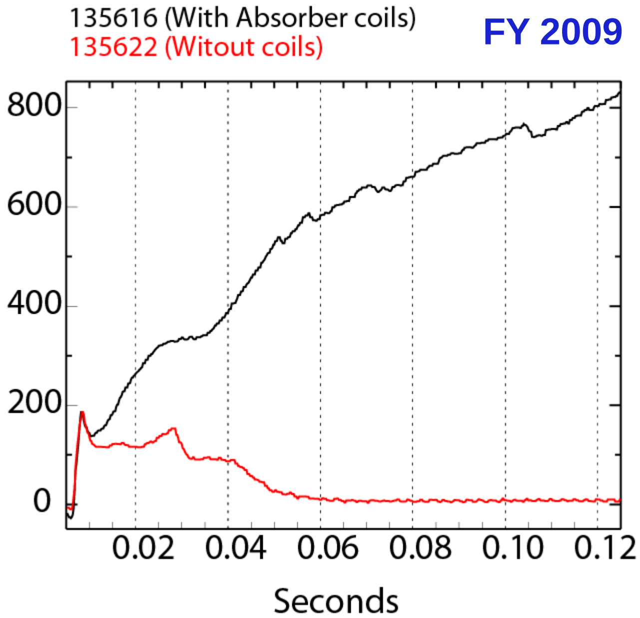
- Full lithium coverage of the lower divertor plates

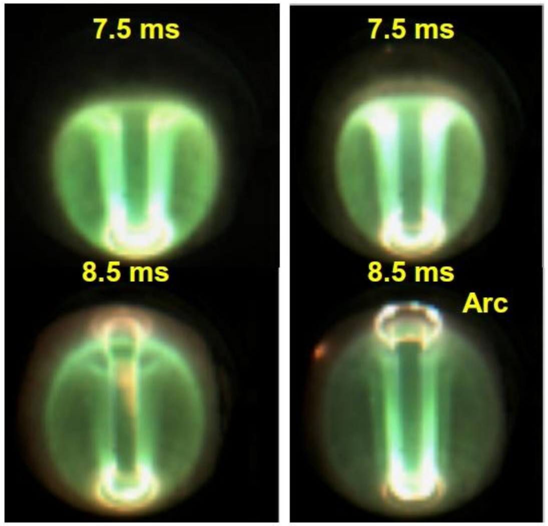
- Assess benefits of metal cathode

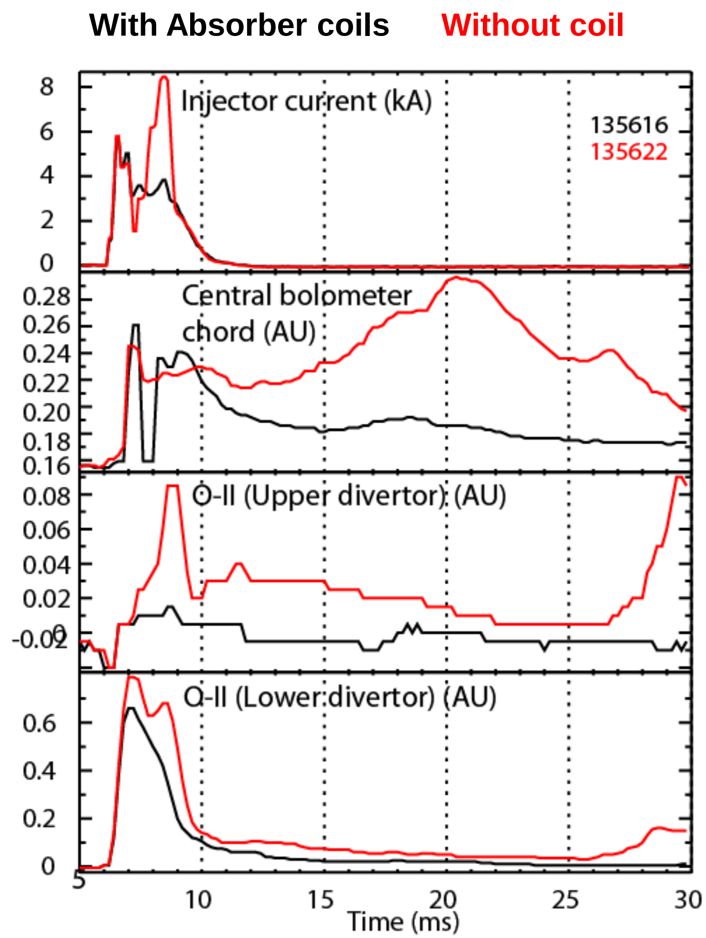
Back-up Slides

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

FY 2009







- 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