Transient CHI Start-up in NSTX-U

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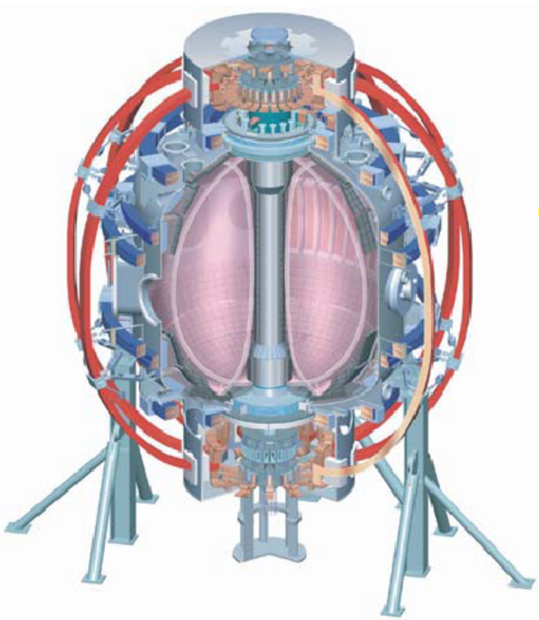
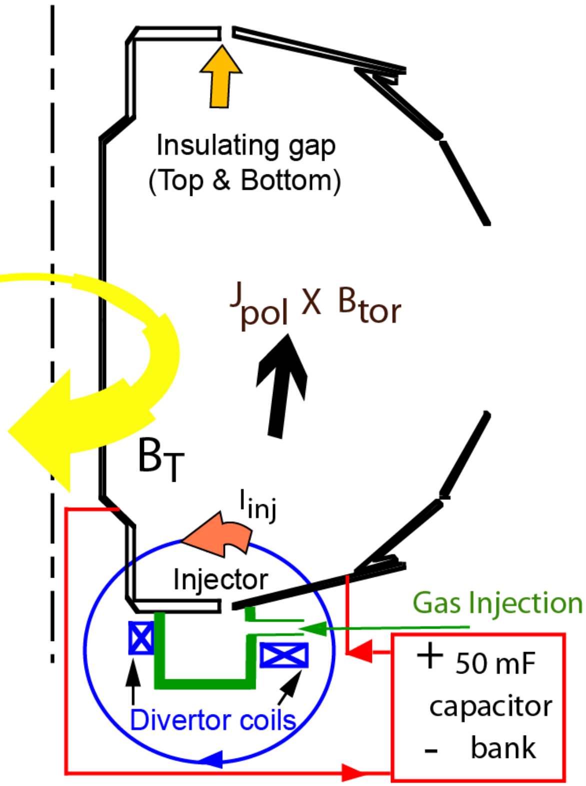
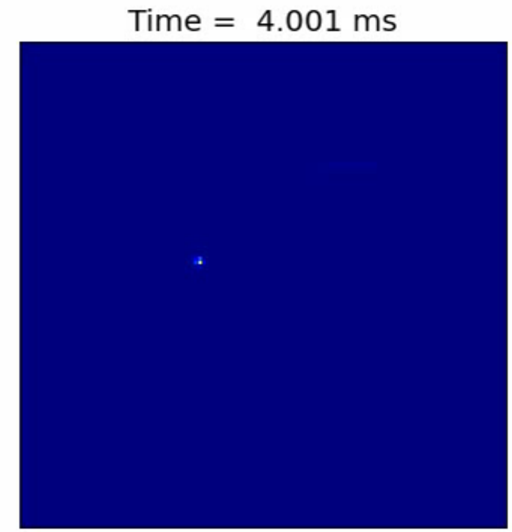
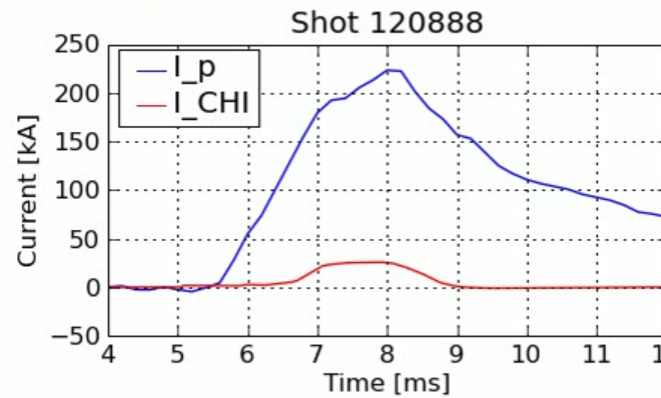
NSTX-U Research Forum
PPPL, Princeton, NJ, February 24-27, 2015

Transient CHI: Axisymmetric Reconnection Leads to Formation of Closed Flux Surfaces









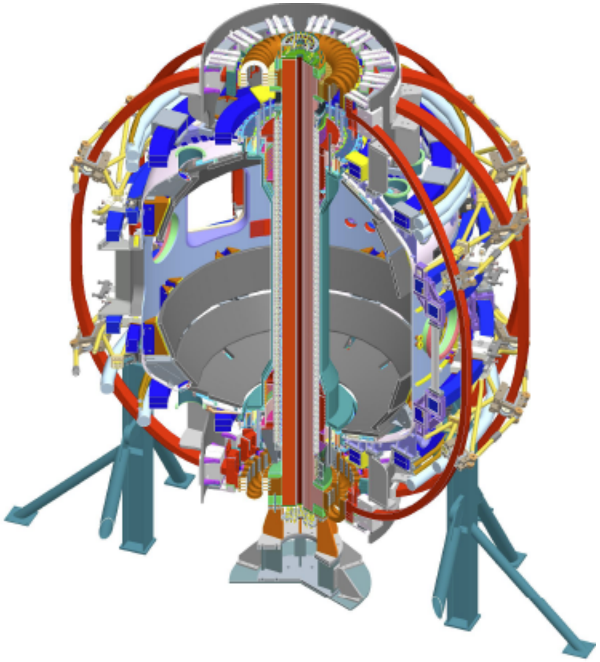
- Parameters to consider
  - Current multiplication factor
  - Effect of toroidal field
  - Magnitude of generated plasma current
  - New desirable features?

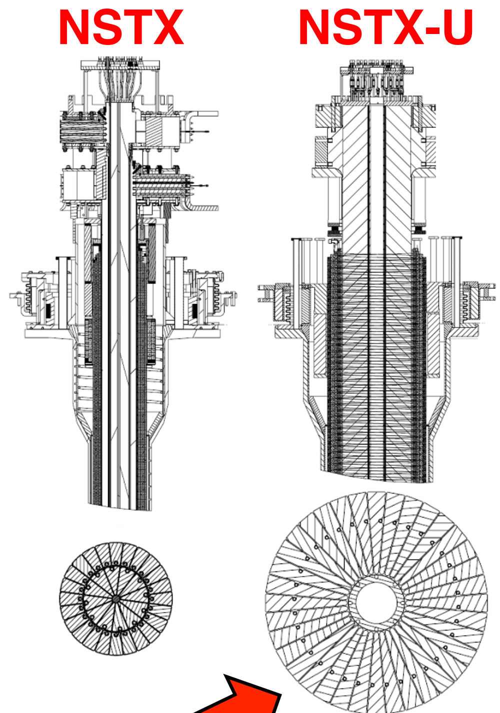
Fast camera: F. Scotti, L. Roquemore, R. Maqueda

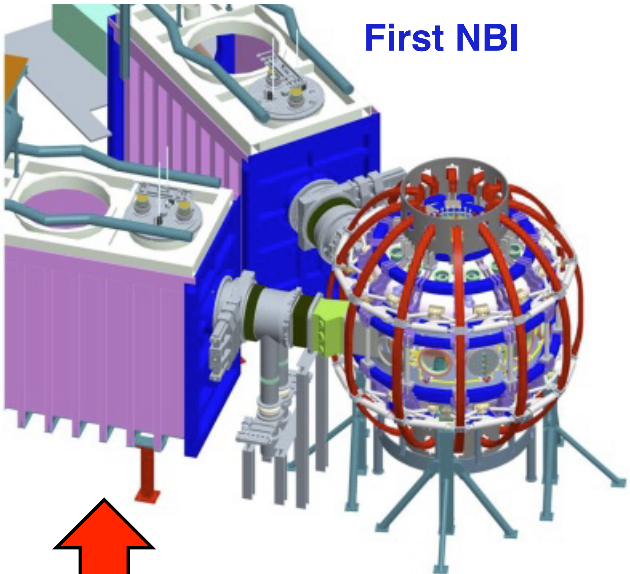
CHI for an ST: T.R. Jarboe, Fusion Technology, 15 (1989) 7

Transient CHI: R. Raman, T.R. Jarboe, B.A. Nelson, et al., PRL 90, (2003) 075005-1

NSTX-U Research will Advance the ST as a Candidate for a Fusion Nuclear Science Facility (FNSF)







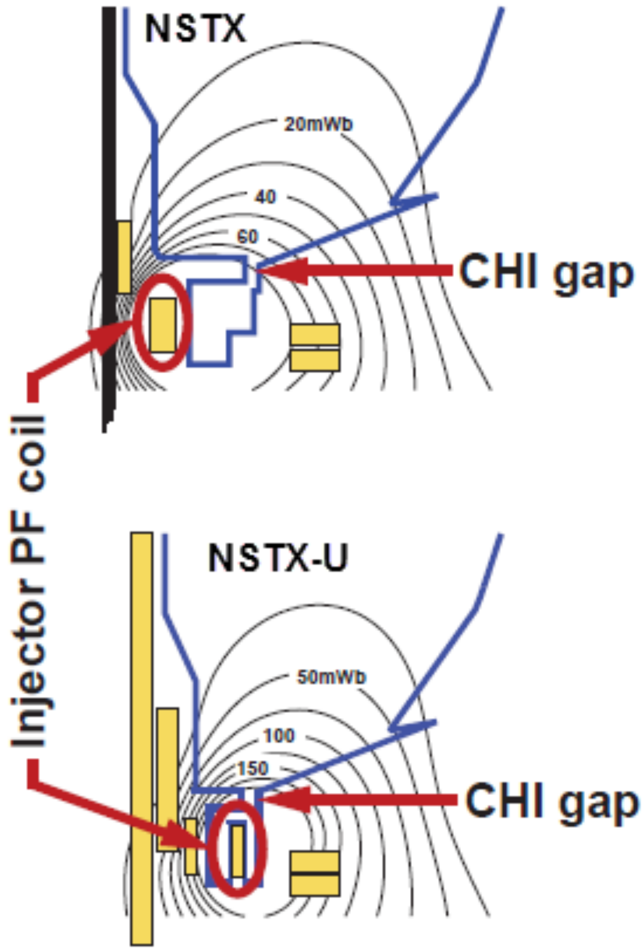
New large center stack in NSTX-U enables

- B_T: Increases from 0.55 to 1 T
- Plasma current: 1 to 2 MA
- Discharge pulse duration: 1s to 5 s

Second tangential Neutral Beam in NSTX-U enables development of

- Non-inductive current ramp-up and 100% NI sustained operation

CHI start-up to ~0.4MA is projected for NSTX-U, and projects to ~20% start-up current in next-step STs



Parameters	NSTX	NSTX-U	ST-FNSF	ST Pilot Plant
Major radius [m]	0.86	0.93	1.2	2.2
Minor radius [m]	0.66	0.62	0.80	1.29
B_T [T]	0.55	1.0	2.2	2.4
Toroidal flux [Wb]	2.5	3.9	15.8	45.7
Sustained I_p [MA]	1	2	10	18
Injector flux (Wb)	0.047	0.1	0.66	2.18
Projected Start-up current (MA)	0.2	0.4	2.0	3.6

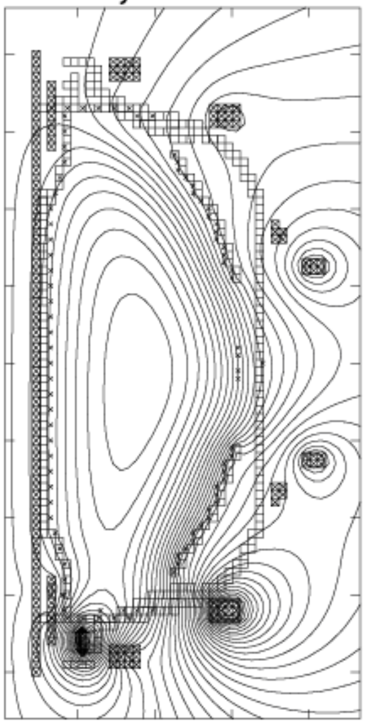
Injector flux in NSTX-U is ~ 2.5 times higher than in NSTX → supports increased CHI current

Transient CHI Scaling:

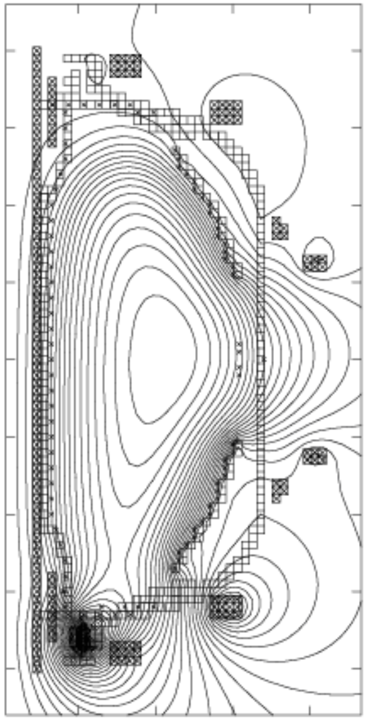
Generated Toroidal Current is proportional to Injector Flux

CHI Produced Toroidal Current Increases with Increasing Levels of Current in the CHI Injector Coil (NSTX-U)

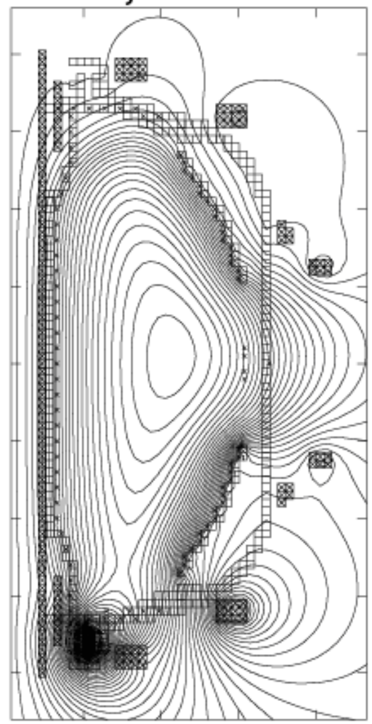
Poloidal Flux at 15 ms
2 kA in Injector Coil



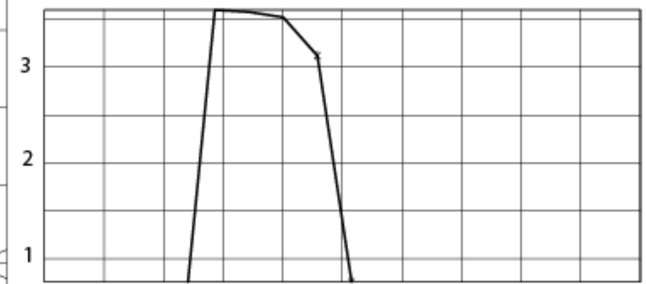
4 kA in injector Coil



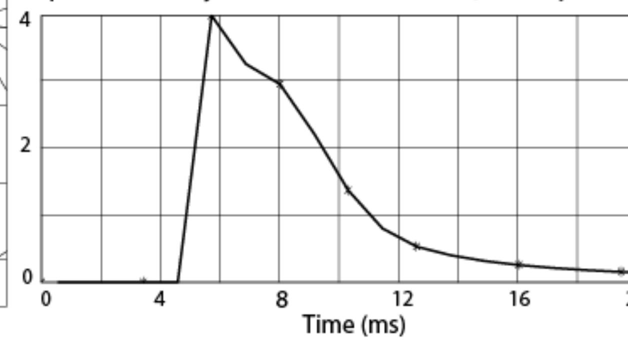
8 kA in Injector Coil



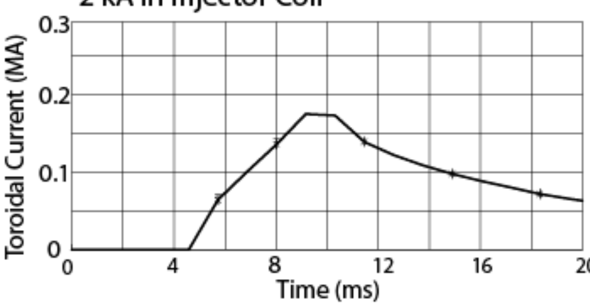
Representative Injector Volatge Waveform (Arbitrary Units)



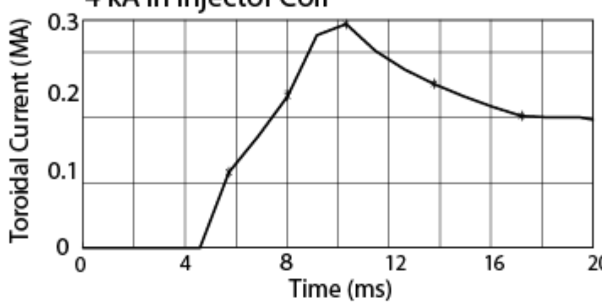
Representative Injector Current Waveform (Arbitrary Units)



2 kA in Injector Coil



4 kA in injector Coil



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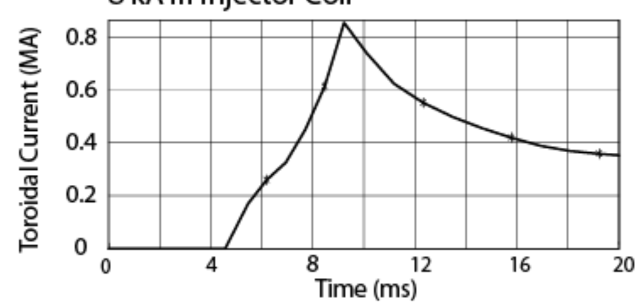
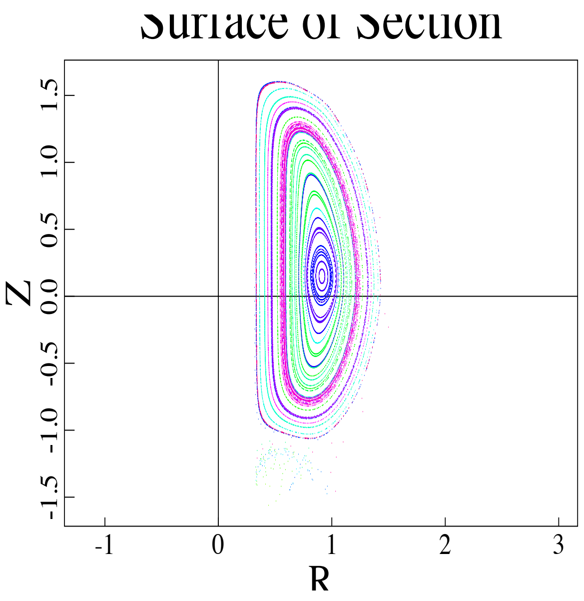
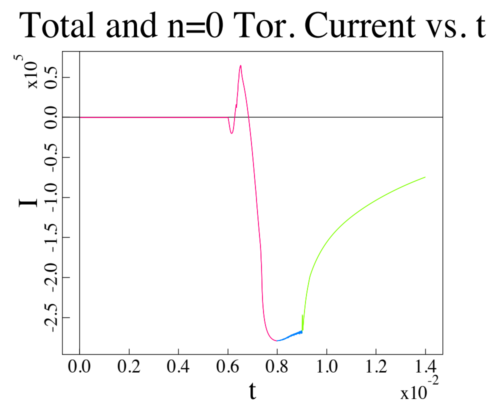


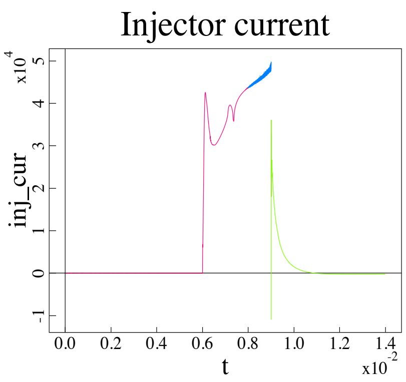
Raman, et al., IEEE Transactions on Plasma Science, Vol 42, No. 8 2154 (2014)

Full flux closure is obtained in MHD simulations of NSTX-U



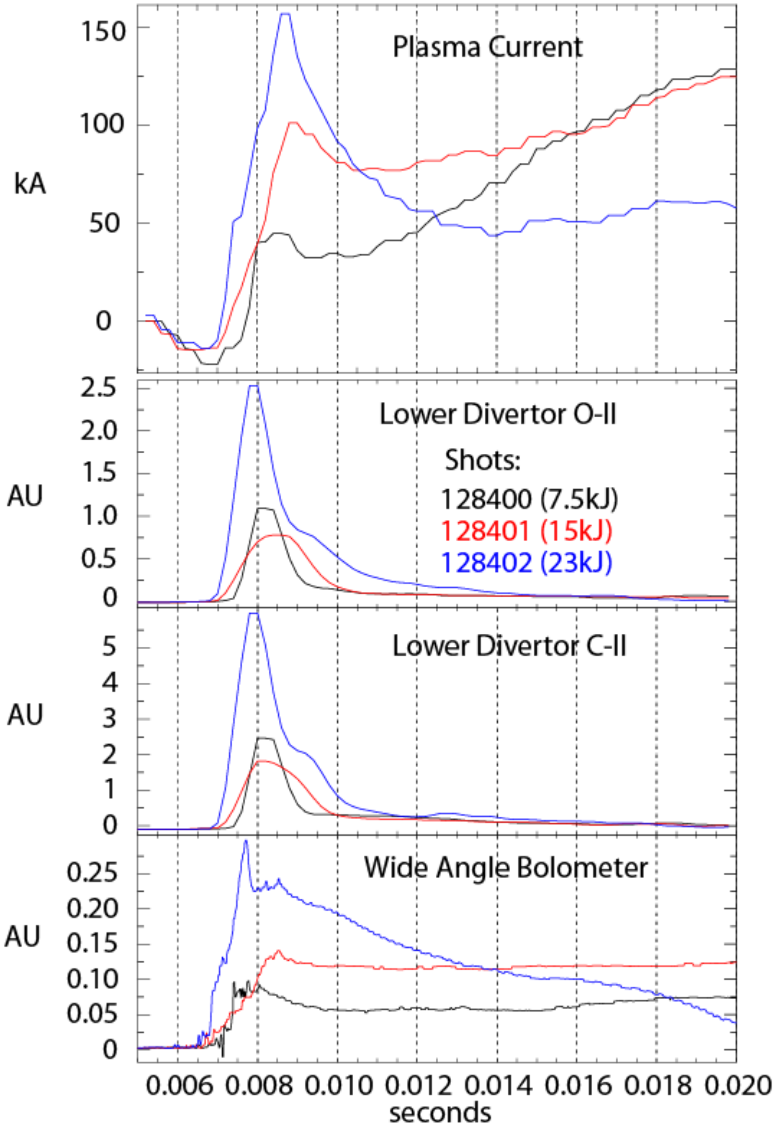
- Resistive MHD NIMROD simulations are performed in NSTX-U geometry at Te ~ 15eV.
- Some features of reconnection process is similar to NSTX, i. e. closed flux surfaces expand in the NSTX global domain through a local Sweet-Parker type reconnection with an elongated current sheet in the injector region [F. Ebrahimi et al. PoP 2013, 2014]
- The fraction of closed flux current in NSTX-U is much higher (almost 100%) than what obtained in the simulations of NSTX.





NIMROD simulations (Ebrahimi)

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

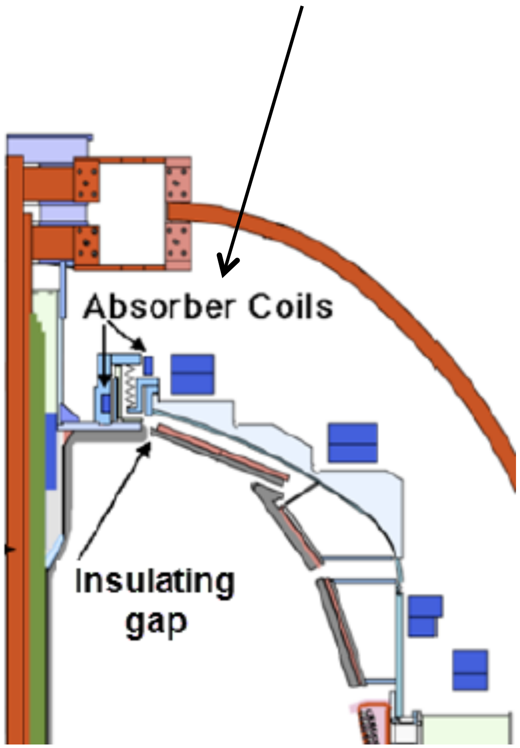


- Low-Z impurity radiation increases with more capacitors
- Possible improvements
  - Metal divertor plates should reduce low-Z impurities
    - High Te in spheromaks (500eV) obtained with metal electrodes
  - Discharge clean divertor with high current DC power supply
  - Use auxiliary heating during 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

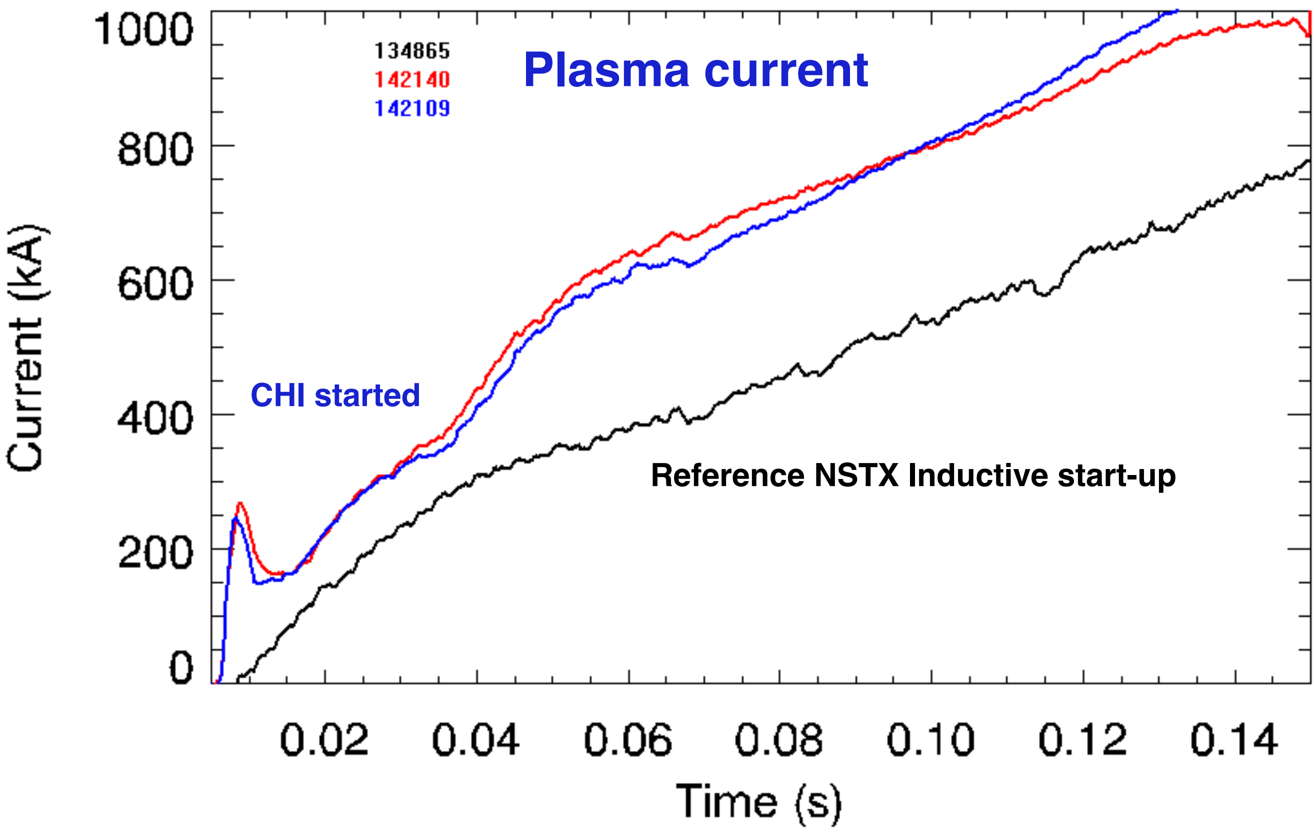
Deuterium glow discharge cleaning employed to chemically sputter and reduce oxygen levels

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

Standard L-mode NSTX Discharge Ramps to 1MA Requiring 50% More Inductive Flux than a CHI Started Discharge



2010 results
Post IAEA

- **Reference Inductive discharge**
  - **Uses 396mWb to get to 1MA**
- **CHI started discharge**
  - **Uses 258 mWb to get to 1MA (138 mWb less flux to get to 1MA)**

Experimental Plan for Establishing Transient CHI discharges on NSTX-U

- Start with BT ~ 0.5T, and PF1CL = 4kA
- CHI gas injection at = -13ms, at 2400Torr Plenum pressure
- Apply 1.5 to 2kV using the CHI cap bank configured for 10 mF to initiate the discharge.
- Adjust PF1C, so that discharge fills a good portion of the vessel
- Now, add currents in PF1AL and PF2L to shape the injector flux to make the footprint narrow. Add a small buffer field using PF1AU. Adjust the CHI voltage, gas injection amount, and if necessary the current in PF1CL to grow the plasma half way into the vessel without creating any absorber arcs.
- Add currents in PF5 and PF3L and PF3U to keep the plasma away from the walls. Start with currents waveforms that were used in NSTX.

Experimental Plan for Establishing Transient CHI discharges on NSTX-U

- After the discharge is able to reliably extend half-way into the vessel, increase the capacitor bank size in steps, to allow the discharge the fully fill the vessel.
- Increase the buffer filed magnitude in PF1CU, PF2U and PF1AU to keep the expanding plasma for contacting the upper divertor region.
- If necessary use the crowbar system in the capacitor bank to rapidly reduce the injector current
- Assess the level of current persistence obtained.
- Now readjust the time history of currents in PF1CL, PF2L and PF1AL to assess they impact of closed flux current generation.
- Once a reliable start-up scenario has been obtained, gradually increase the magnitude of the injector flux to increase the closed flux current magnitude.

Systems Required

- Li evaporator to fully coat the lower divertor tiles
- Li coating of the upper divertor (if available)
- Capacitor Bank
- Upgraded MOV capability
- ECH for pre-ionization
- Both CHI gas injections systems
- Multiple view fast cameras (Fish eye view & lower divertor view with optical filters)
- Thomson, and diagnostics used for CHI on NSTX

Run Time and Goals

- Based on NSTX experience, and noting that the CHI hardware configuration on NSTX-U has important differences compared to NSTX, estimate 4 run days.
- Progress will be made with any amount of run time, but CHI configuration on NSTX-U has important differences compared to NSTX
  - Also, time between shots will increase from 10 minutes to 20 minutes, effectively reducing to every day shot count by half compared to that in NSTX
- Goal is to establish 200kA in FY15 & 400kA in FY16.
- 200 kA target is adequate to proceed with inductive current ramp-up experiments, & test HHFW heating
- Also, provides good target for reconnection studies, and other experiments that need CHI capability