NSTX

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Absorber arc mitigation during CHI on NSTX

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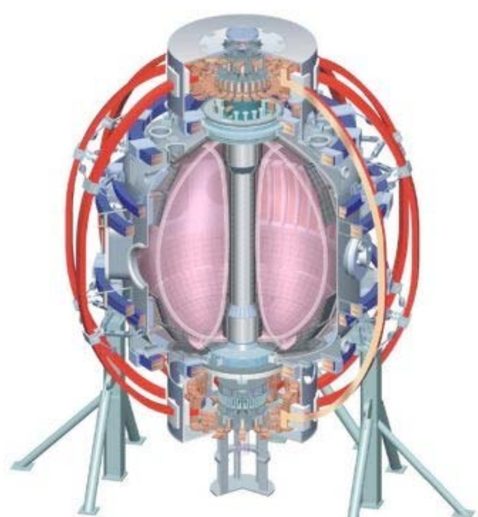

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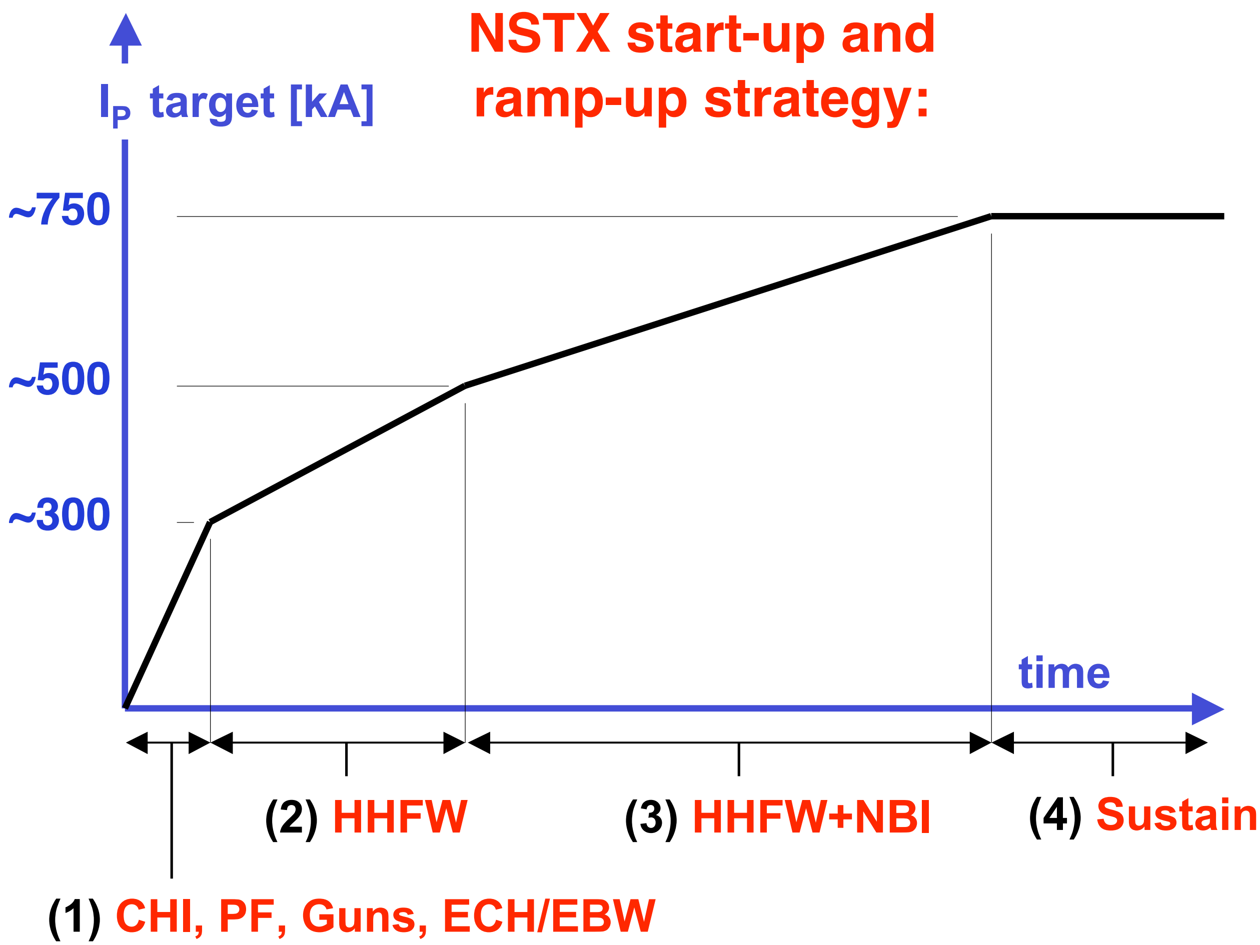
Three Phases for Non-inductive Start-up and Ramp-up in NSTX



Start-up/ramp-up requirements:

(1→2) I_P, T_e must be high enough for HHFW to be absorbed

(2) High P_{RF}, τ_E must be achieved for I_P overdrive with BS and HHFW current drive

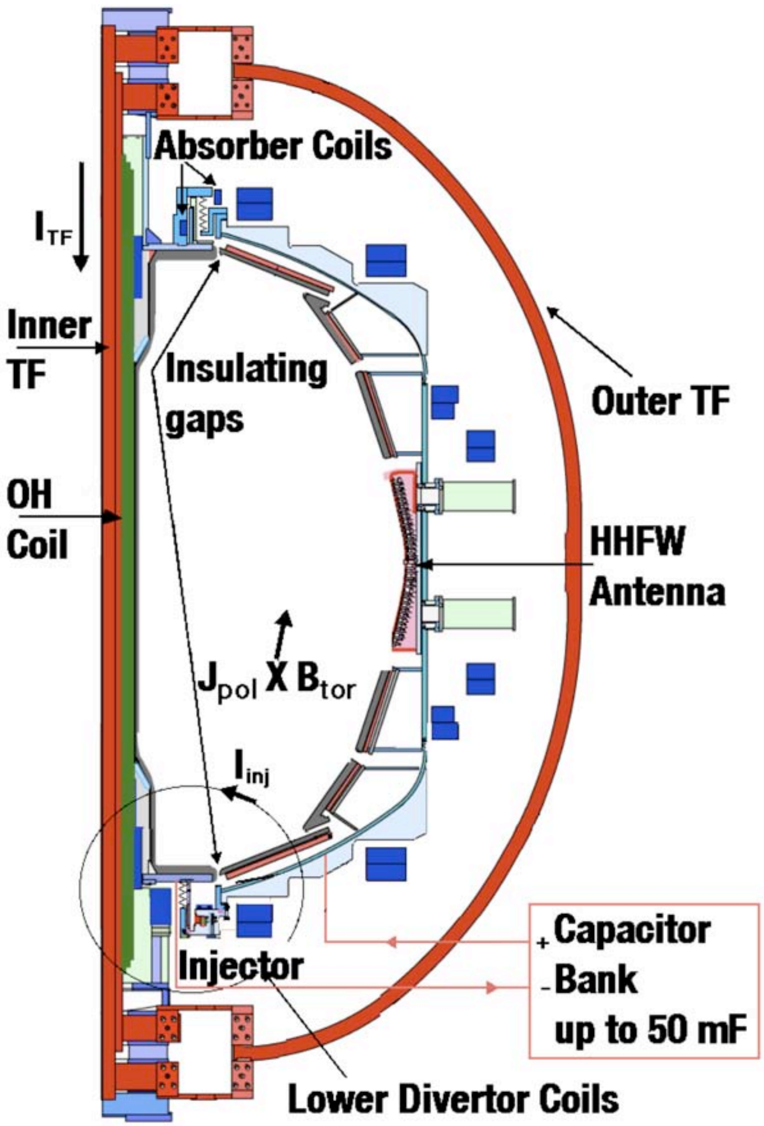
(2→3) High I_P needed to absorb NBI, high P_{HEAT}, τ_E, β_P needed for current overdrive

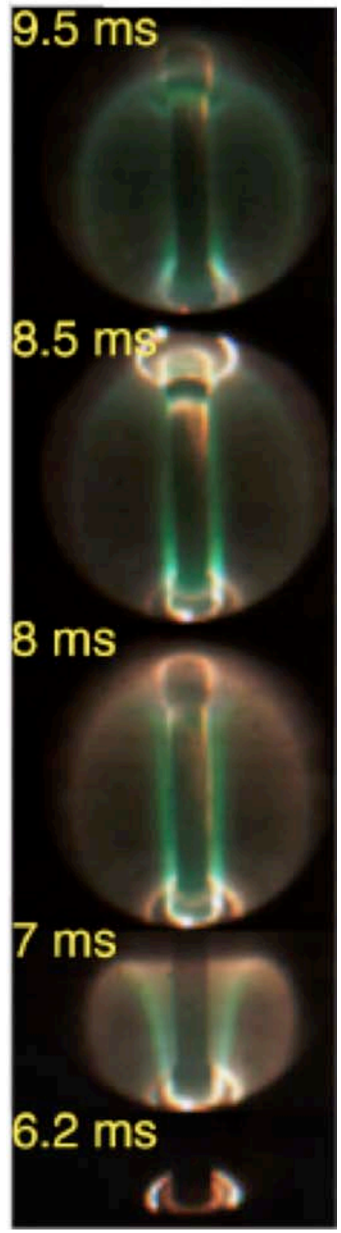
(3→4) Ramp-up plasma must be consistent with sustained high-f_{NI} scenario

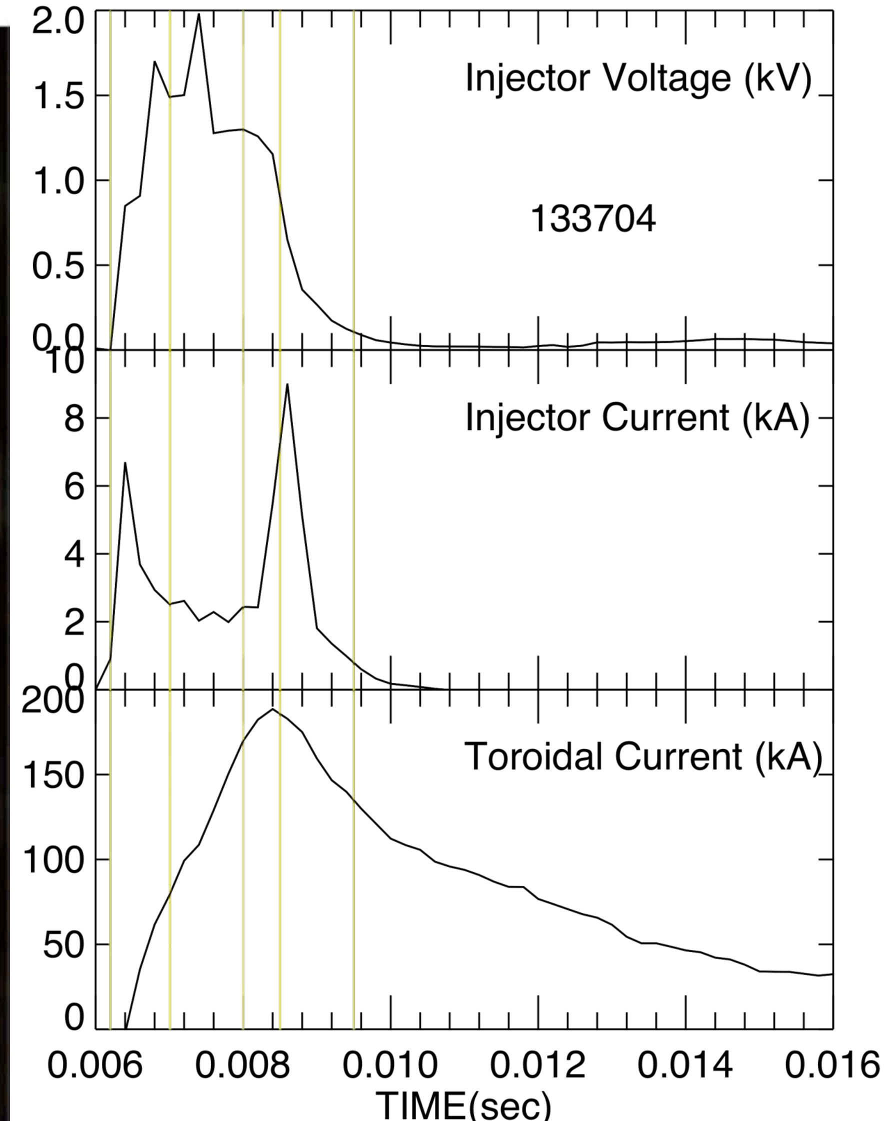
Use OH as needed to simulate I_P ramp-up

Focus on transition form CHI start-up to ohmic ramp-up

Transient CHI: Axisymmetric reconnection leads to formation of closed flux surfaces







- ***Peak T_e ~ 20 eV***

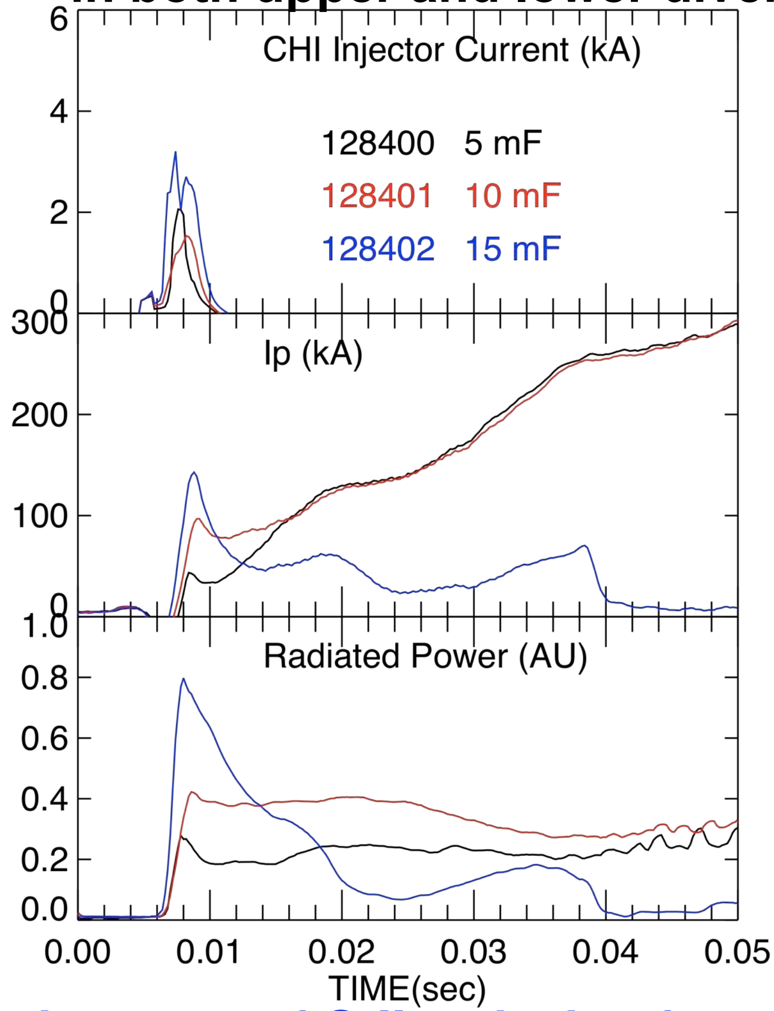
Three successive CHI discharges using an ohmic ramp exhibit increased radiated power with increased energy

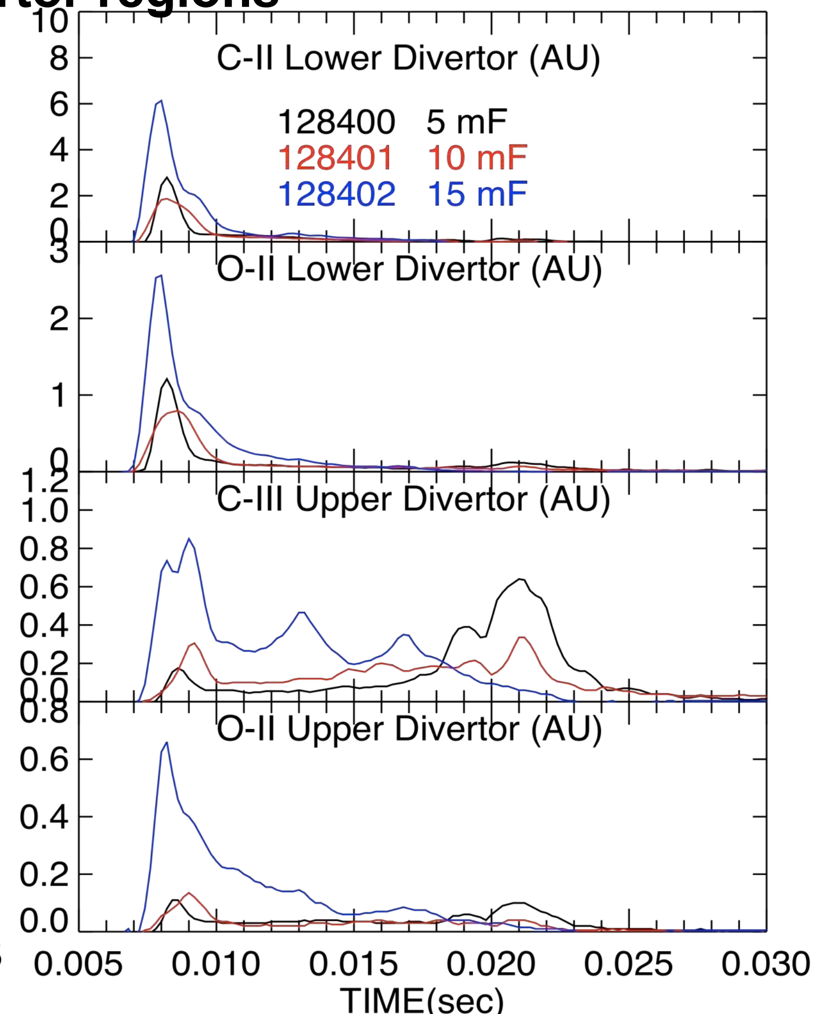
Low-Z impurity radiation increases with increased injection energy in both upper and lower divertor regions

128400
5mF (7.6kJ)
Peak T_e(8,12 ms) ~10eV

128401
10mF (15.3kJ)
Peak T_e(8,12 ms) ~20eV

129402
15mF (22.8kJ)
Peak T_e(8,12 ms) <10eV



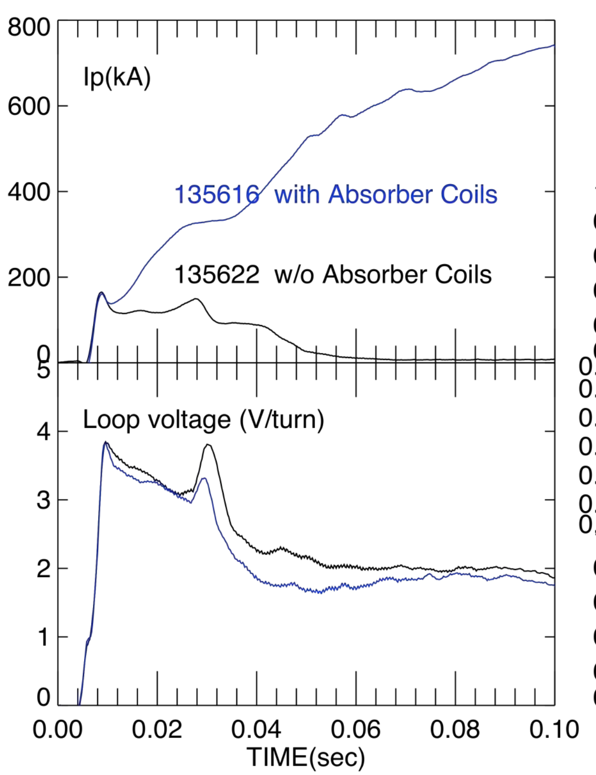


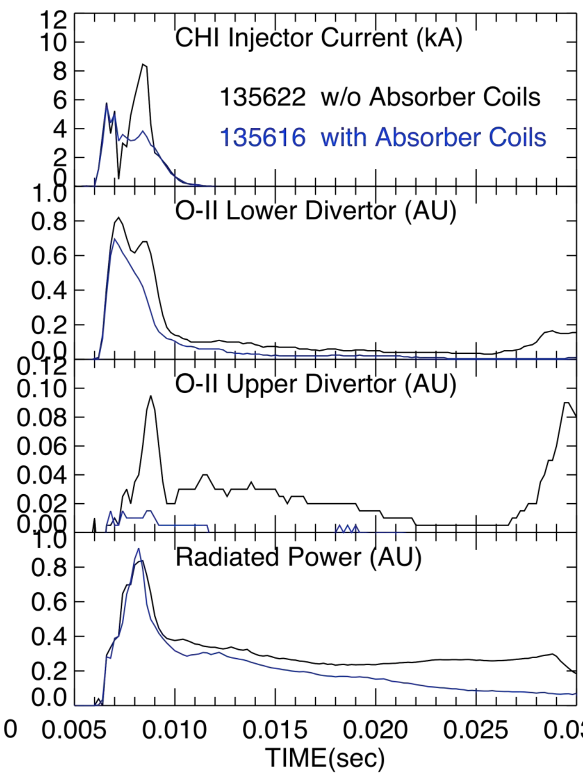
- **Note Dramatic increase of O-II emission from the upper divertor region**
- **Absorber arcs are major cause of this emission and lead to low T_e**

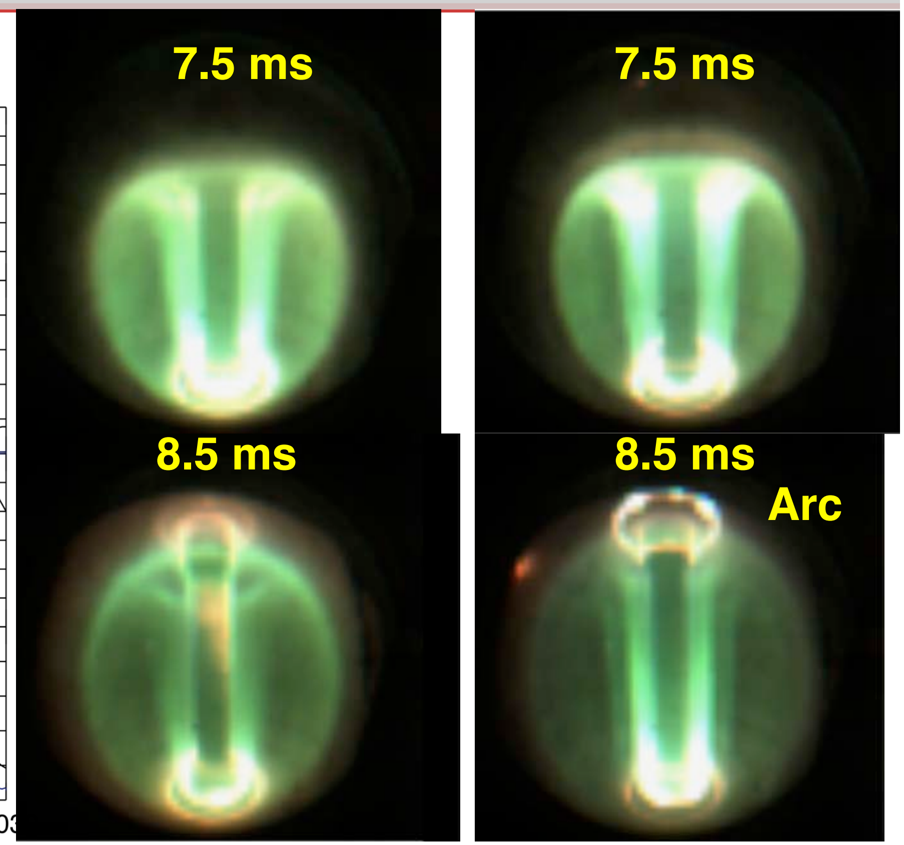
Strategies to reduce oxygen or mitigate absorber arcs

- Coat surfaces with Lithium to reduce Oxygen
  - Best results with LITER, little experience with Li powder
- Condition divertor surfaces with rectifiers with 400 ms, 5 kA CHI discharges
  - Best results followed a day of this conditioning
- Increase impedance of absorber (upper) gap
  - Use absorber coils to reduce poloidal field at absorber
  - Did not achieve better result, dynamic response is too slow
- Use absorber coils to provide buffer flux to prevent plasma from reaching absorber during CHI
  - Clearly reduced incidence of absorber arcs

Radial field from absorber coils prevents plasma from reaching absorber gap during CHI



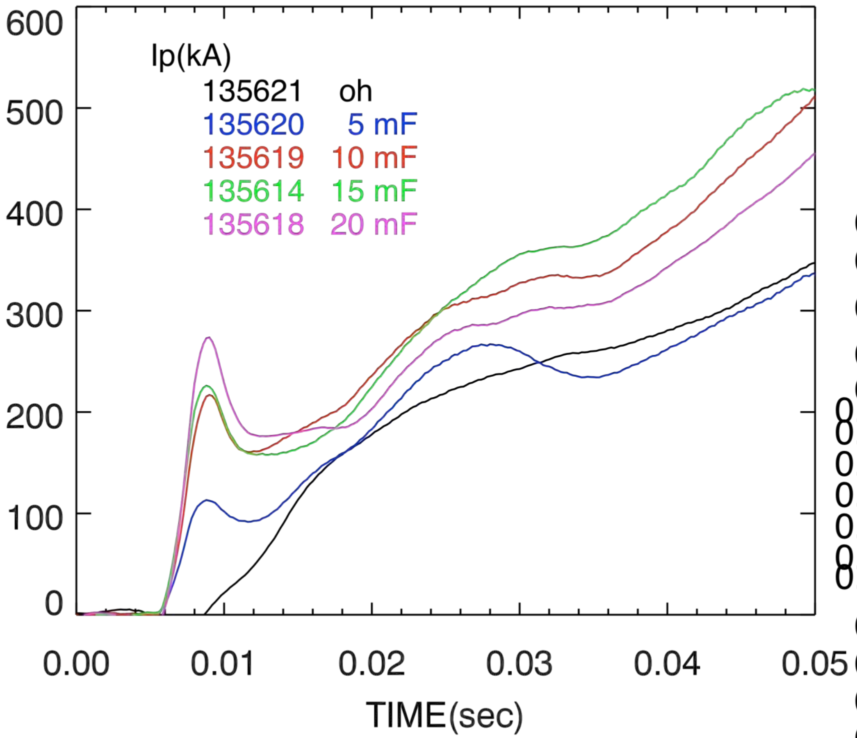


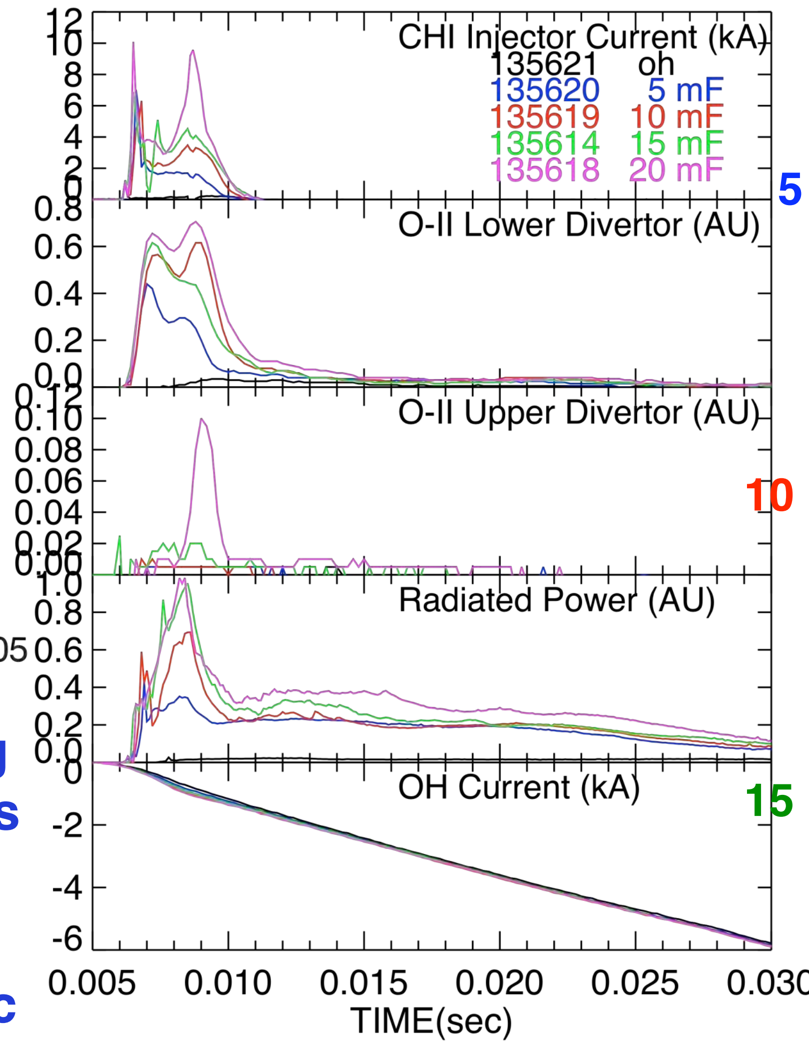


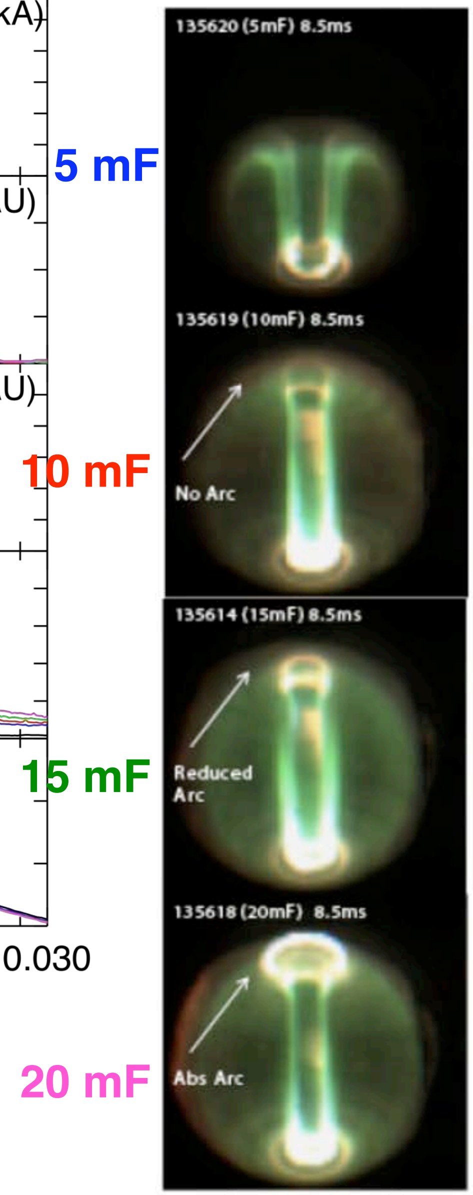
With Absorber Coils **Without**

- Two CHI initiated discharges, one shown in blue with the absorber coils energized, the other in black has no current in the absorber coils
- The absorber clearly limit the vertical growth of the CHI plasma and prevent absorber arc
- Only the discharge without the arc couples to inductive ramp-up

CHI increases I_p with increasing CHI energy until arc occurs



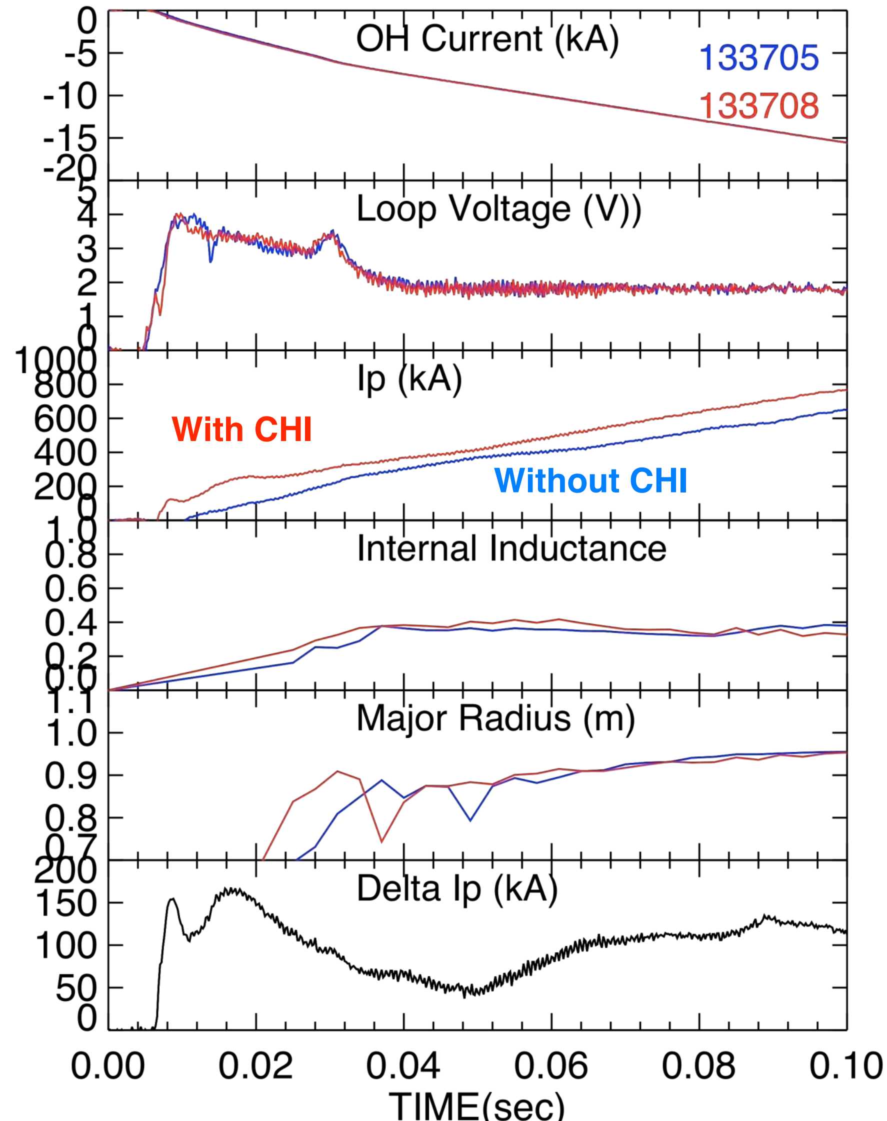




- **Before conditioning and using absorber coils, CHI discharges using > 5 mF at 1.7 kV had absorber arcs**
- **I_p ~ 200 kA greater than ohmic only**
- **First successful coupling of OH with use of 20 mF (out of 50)**

Comparison of well-controlled shots demonstrates a flux savings with CHI initiation

- I_p is 110 kA greater in the CHI initiated discharge
- The discharge in blue is a purely inductive discharge
  - Both had low levels of O_{II} emission
  - The discharges had identical solenoid (OH) current programming
- The internal inductance, plasma radius and plasma shape (not shown) from EFIT analysis are essentially identical
- The density of the CHI initiated discharge was about 25% greater than the inductive only discharge



- *The CHI initiated discharge shown in red used 10 mF of capacitance at 1.65 kV*

Demonstrated progress in avoiding arcs during CHI, further improvements could raise CHI start-up current to near 0.5 MA

- **CHI discharges with low levels of low Z impurity radiation can be coupled to inductive ramp-up**
  - 400 ms duration CHI discharges condition lower divertor plates
  - Lithium evaporative coating (LITER) reduces low Z impurities
  - Buffer flux prevents plasma from reaching the absorber gap and causing an absorber arc
- **CHI start-up plasmas with current of up to 300 kA have been ramped inductively to produce a plasma current increase of 110 to 200 kA compared to inductive only**
  - Using about 1/3 of the available CHI capacitance

BACKUP SLIDES

CHI Scaling

- From helicity and energy conservation, for a Taylor minimum energy state $\lambda_{inj} \geq \lambda_{tok}$

  -$\lambda_{inj} = \mu_0 I_{inj}/\psi_{inj}$; ψ_{inj} = poloidal injector flux

  -$\lambda_{tok} = \mu_0 I_p/\psi_{tok}$: ψ_{tok} = toroidal flux in vessel

- $I_p \leq I_{inj}(\psi_{tok} / \psi_{inj})$
- For similar B_T NSTX has 10 times ψ_{tok} of HIT-II
- Bubble burst condition:

  $I_{inj} = 2\, \psi_{inj}^2/(\mu_0^2 d^2 I_{TF})$

  -For HIT-II, ψ_{inj} = 8mWb, d = 8 cm is flux footprint width

  -For NSTX, ψ_{inj} = 10mWb, d = 16 cm is flux footprint width

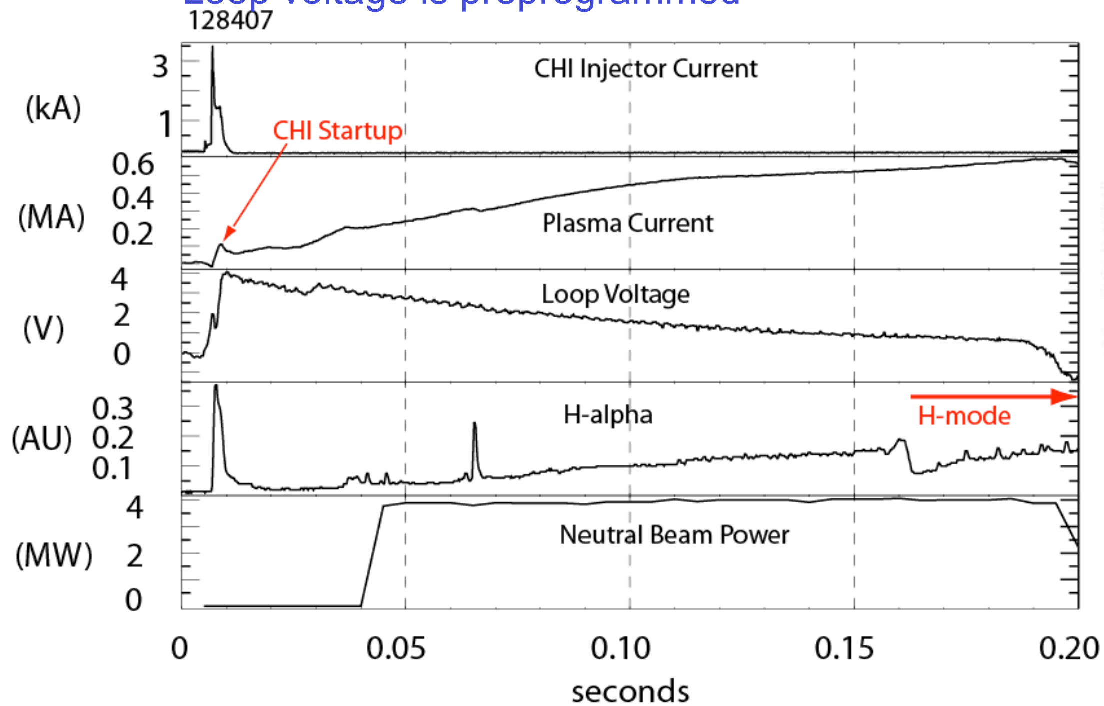
  -$I_{inj} \geq 15$ kA for HIT-II, $I_{inj} \geq 2$ kA for NSTX

- Sufficient energy to produce CHI discharge $W_{cap} > W_{plasma}$; $½ CV^2 > ½ L_p I_p^2$
  - L_p plasma inductance ~ 0.5 μH, and C= 50 mF limits I_p to ~ 500 kA for present NSTX system
- NSTX has achieved $I_p > 60\, I_{inj}$; HIT-II has achieved I_{inj} ~ 50 kA

  ⇨ I_p over 2.5 MA is possible for CTF if I_{inj} ~ 50 kA

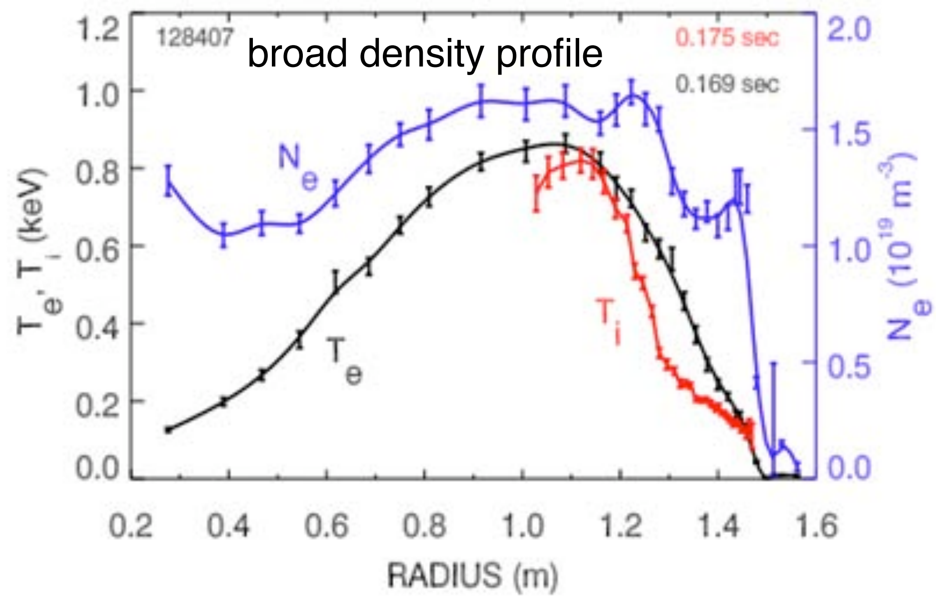
CHI started discharge couples to induction and transitions to an H-mode demonstrates compatibility with high-performance plasma operation

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



Te & Ne from Thomson

Ti from CHERS



Central Te reaches 800eV

Central Ti > 700eV

•*PAC-23*

- Projected plasma current for CTF > 2.5 MA $[I_p = I_{inj}(\psi_{Tor}/\psi_{Pol})]^*$
  - Based on 50 kA injected current (Injector current densities achieved on HIT-II)
  - Current multiplication of 50 (achieved in NSTX)
  - In HIT-II nearly all CHI produced closed flux current is retained in the subsequent inductive ramp

CHERS: R. Bell, Thomson: B. LeBlanc

***T.R. Jarboe, Fusion Technology, 15 (1989) 7**