NSTX

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Demonstration of Coupling CHI Started Discharges to Induction in NSTX

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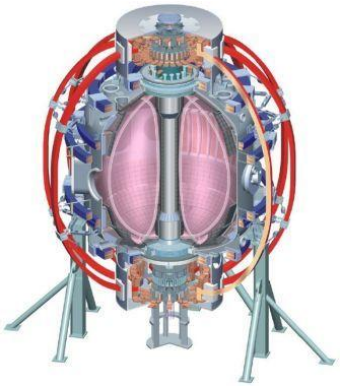
[4]Lawrence Livermore National Laboratory

and the NSTX Research Team



50th Annual Meeting of the DPP
Nov 17-21, 2008
Dallas, TX

Presentation: CO3.00013

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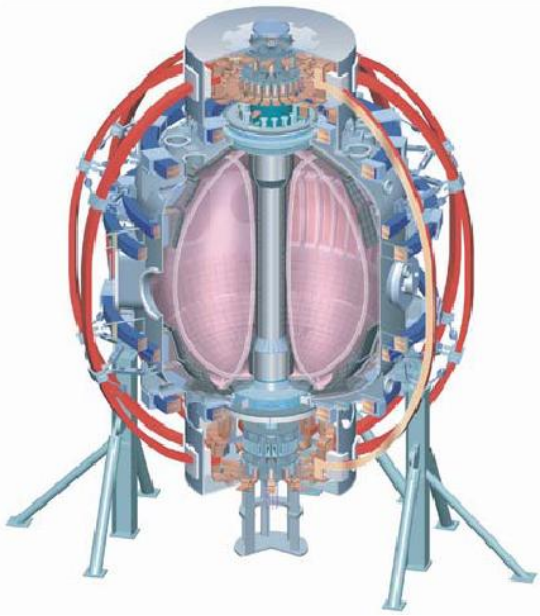
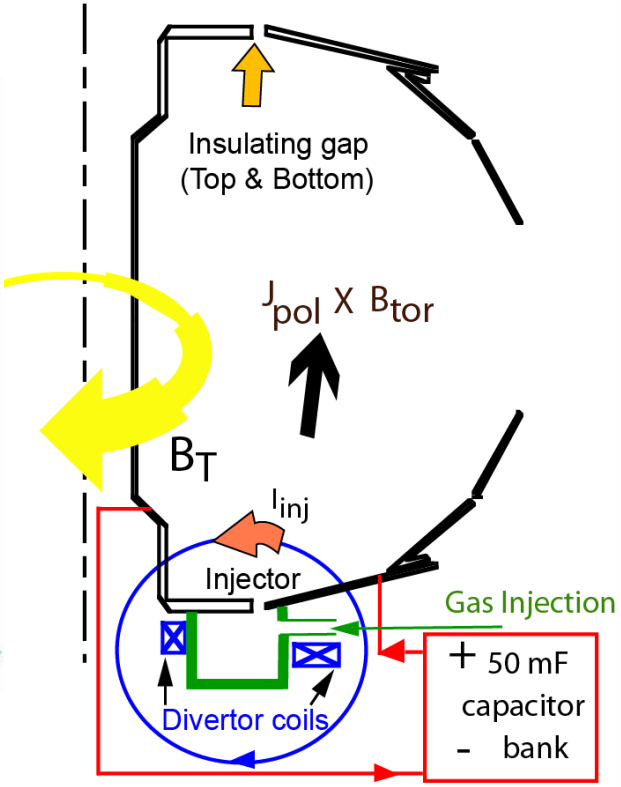
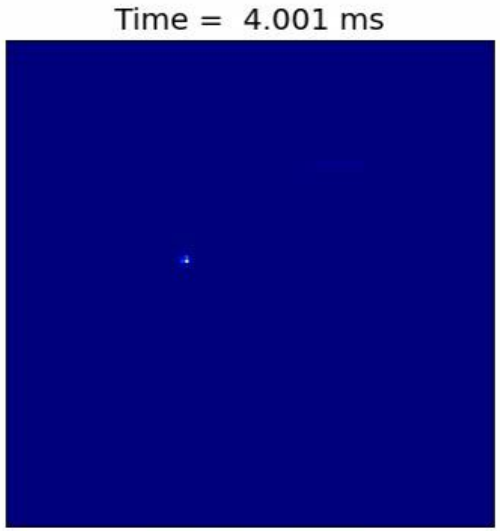
Solenoid-Free Current Initiation would Improve the Prospects of the ST as a CTF and Fusion Reactor

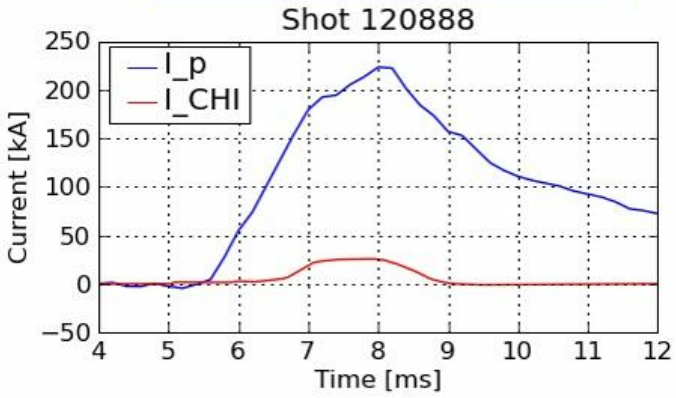
- Could also aid Tokamak designs
  - Access lower aspect ratio configurations & reduce cost
- Of the three large tokamaks in the US, only NSTX is engaged in solenoid-fee plasma startup research
- Transient Coaxial Helicity Injection plasma startup method developed on HIT-II at U-Washington
- NSTX has now demonstrated 160kA non-inductively generated closed flux current in a ST or Tokamak
- NSTX has now demonstrated coupling to induction leading to H-mode

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







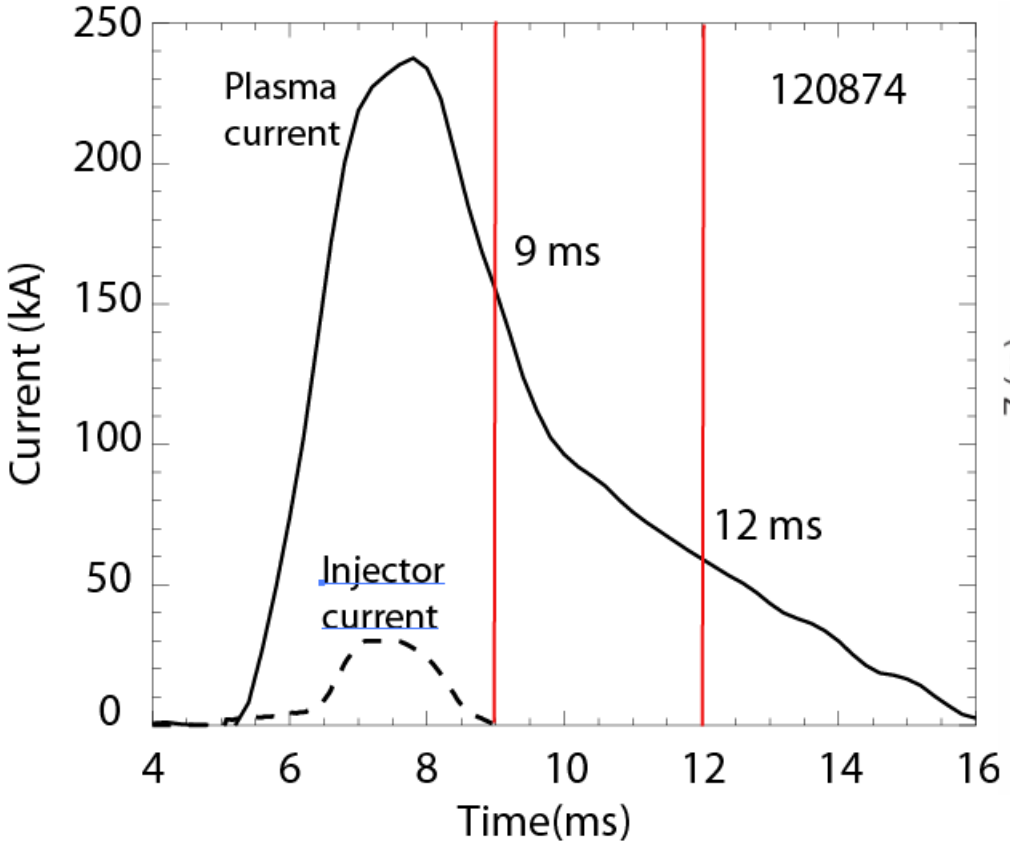


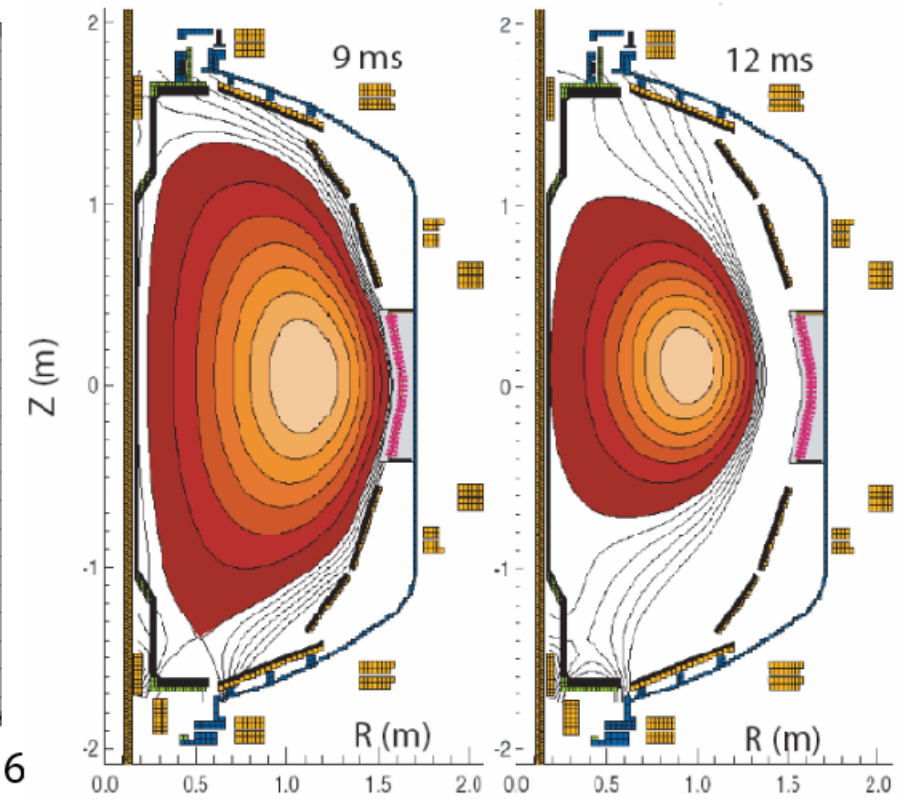
- Demonstration of closed flux current generation
  - Aided by gas and EC-Pre-ionization injection from below divertor plate region
- Demonstration of coupling to induction (2008)
  - Aided by staged capacitor bank capability

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

Very high current multiplication (~70) aided by higher Toroidal Flux

$I_p = I_{inj}(\psi_{Tor}/\psi_{Pol})$





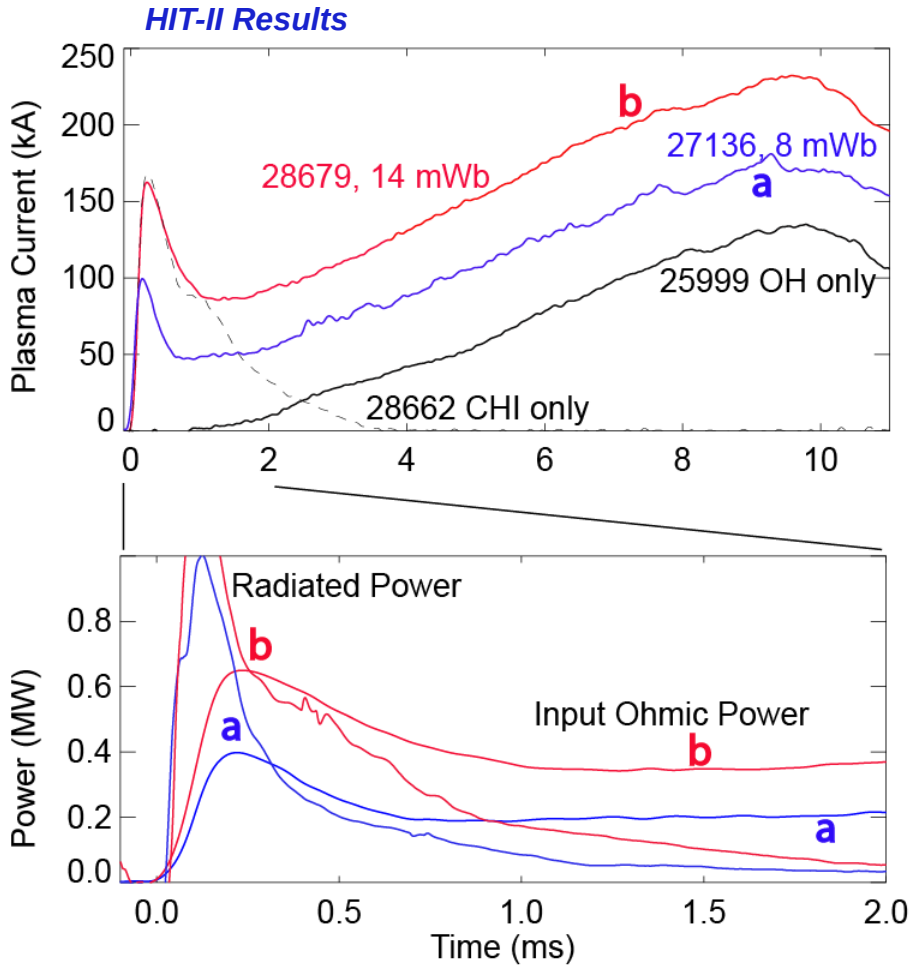
Record 160kA non-inductively generated closed flux current in ST or Tokamak produced in NSTX

Used LRDFIT reconstructions

LRDFIT (J. Menard)

R. Raman, B.A. Nelson, M.G. Bell et al., PRL 97, 175002 (2006)

Inductively Coupled Current Ramps-up After Input Power Exceeds Radiated Power

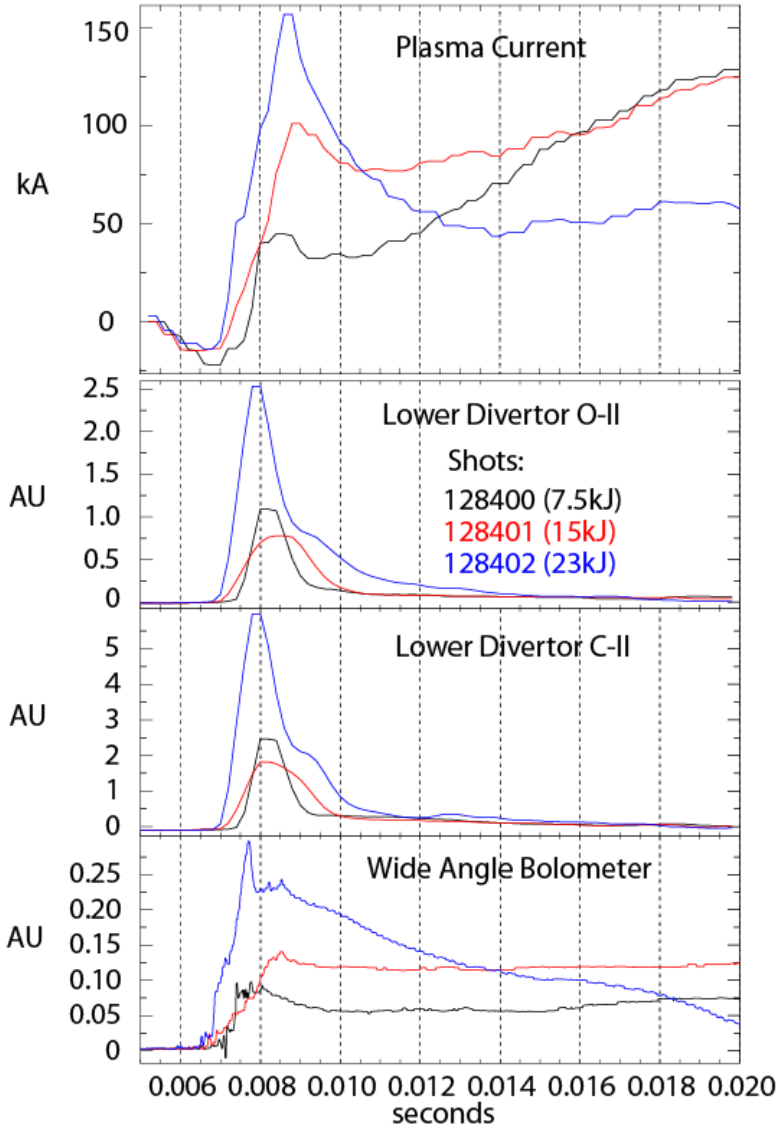


- Identical loop voltage programming for all cases
- Coupling current increases as injector flux is increased
- Radiated power can be decreased by using W or Mo target plates
  - Start-up plasma (inductive or CHI) is cold (few 10s of eV)
    - Reduce Low-z line radiation
  - Auxiliary heating would ease requirements on current ramp-up system

R. Raman, T.R. Jarboe, R.G. O'Neill, et al., NF 45 (2005) L15-L19

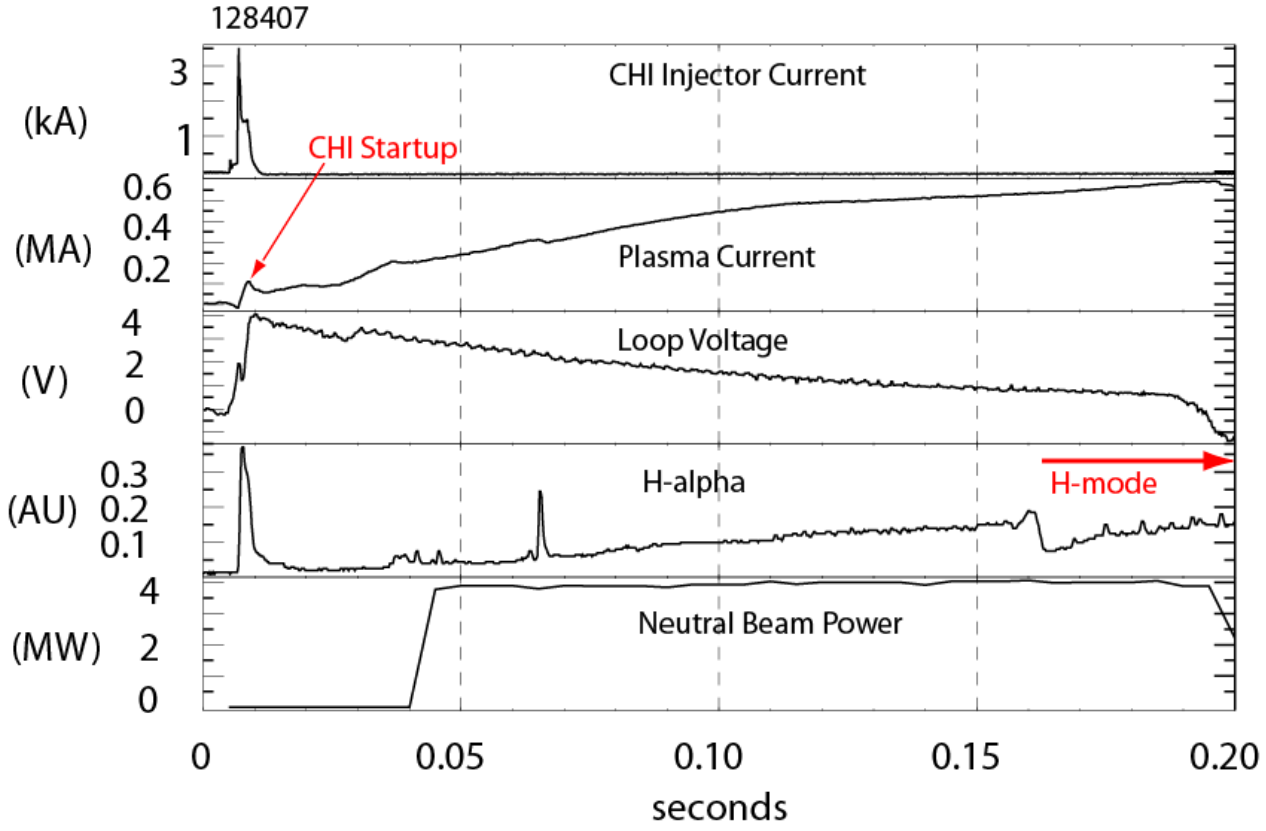
R. Raman, T.R. Jarboe, W.T. Hamp, et al., PoP 14 (2007) 022504

Low-z Impurity Radiation Should be Reduced for Inductive Coupling



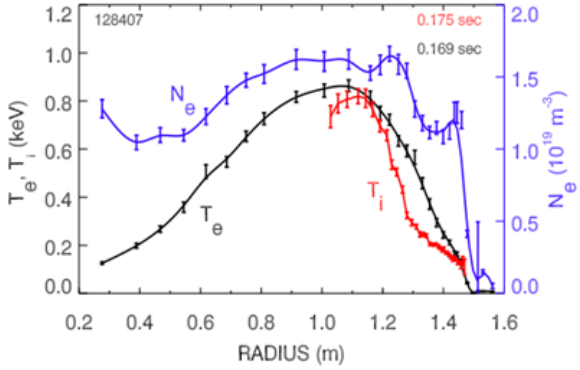
- Low-z impurity radiation increases with more capacitors
- Future improvements
  - Test CHI in NSTX with partial metal outer divertor plates as part of liquid Li divertor upgrades
    - High Te in spheromaks (500eV) obtained with metal electrodes
  - Discharge clean divertor with high current DC power supply
  - Use 350kW ECH during FY11

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



Te & Ne from Thomson

Ti from CHERS



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

- Projected plasma current for CTF >2.5 MA

  $[I_p = I_{inj}(\psi_{Tor}/\psi_{Pol})]$*
  - Based on 50 kA injector current (250kA equivalent achieved on HIT-II)
  - Current multiplication of 50 (70 achieved in NSTX)

CHERS: R. Bell

Thomson: B. LeBlanc

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

NSTX has Demonstrated a Viable Solenoid-Free Plasma Startup Method for the ST

- Demonstration of the process in a vessel volume thirty times larger than HIT-II on a size scale more comparable to a reactor
- Remarkable multiplication factor of 70 between the injected current and the achieved toroidal current, compared to six in previous experiments
- Results were obtained on a machine designed with mainly conventional components and systems
- Favorable scaling with increasing machine size

1) 160 kA closed flux current generation in NSTX validates capability of CHI for high current generation in ST
2) Successful coupling of CHI started discharges to inductive ramp-up & transition to an H-mode demonstrates compatibility with high-performance plasma operation

Simultaneous Requirements for Transient CHI

- Bubble burst current*: $I_{inj} = 2\psi_{inj}^2 / (\mu_o^2 d^2 I_{TF})$

  ψ_{inj} = injector flux

  d = flux foot print width

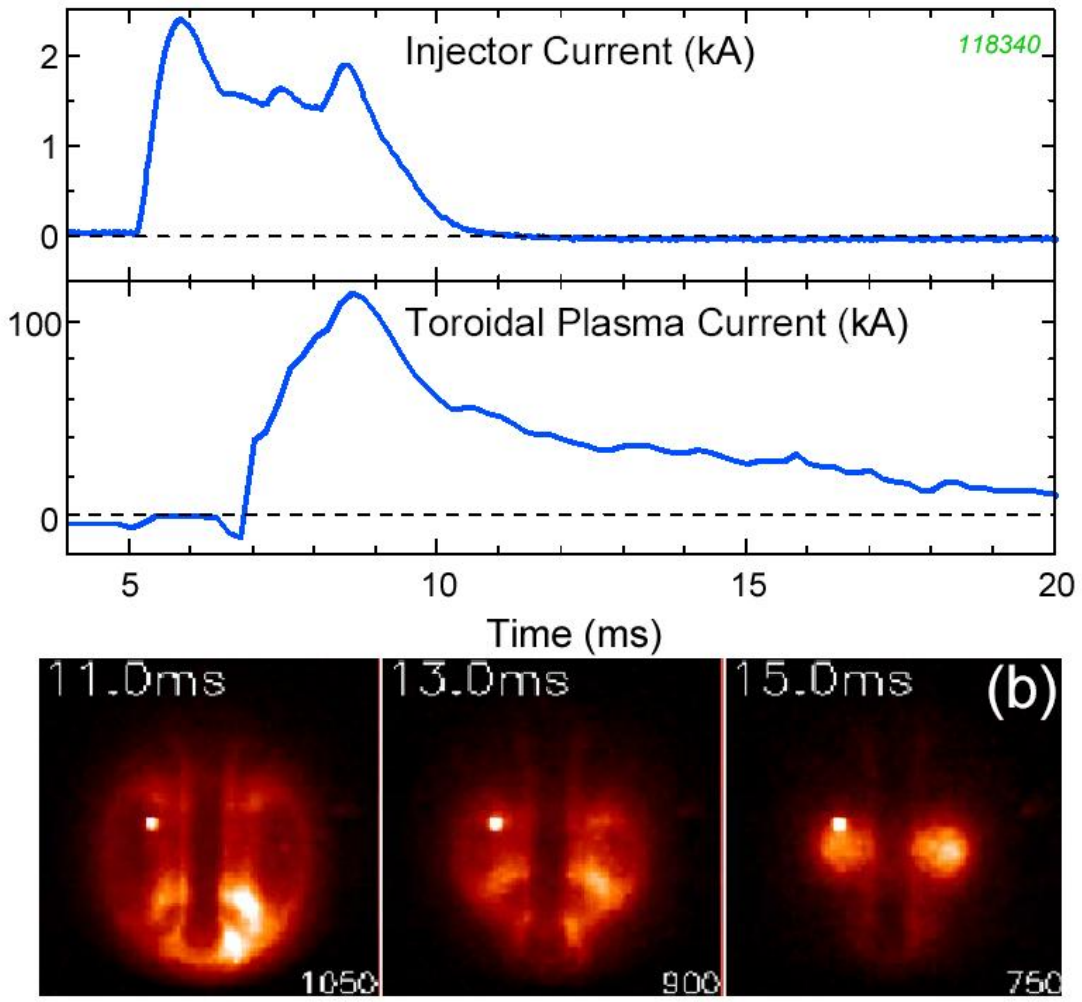
  I_{TF} = current in TF coil

- Time needed to displace toroidal flux
  - For typical voltage at the injector after breakdown ~500V need ~1 ms to displace 600 mWb

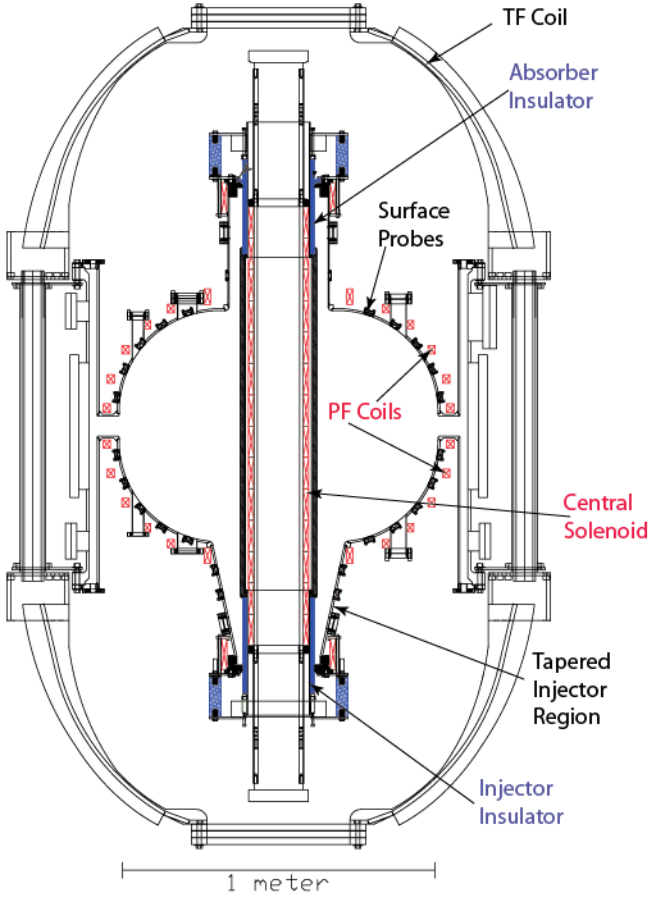
- Energy for peak toroidal current: $\frac{1}{2} CV^2 > \frac{1}{2} LI^2$

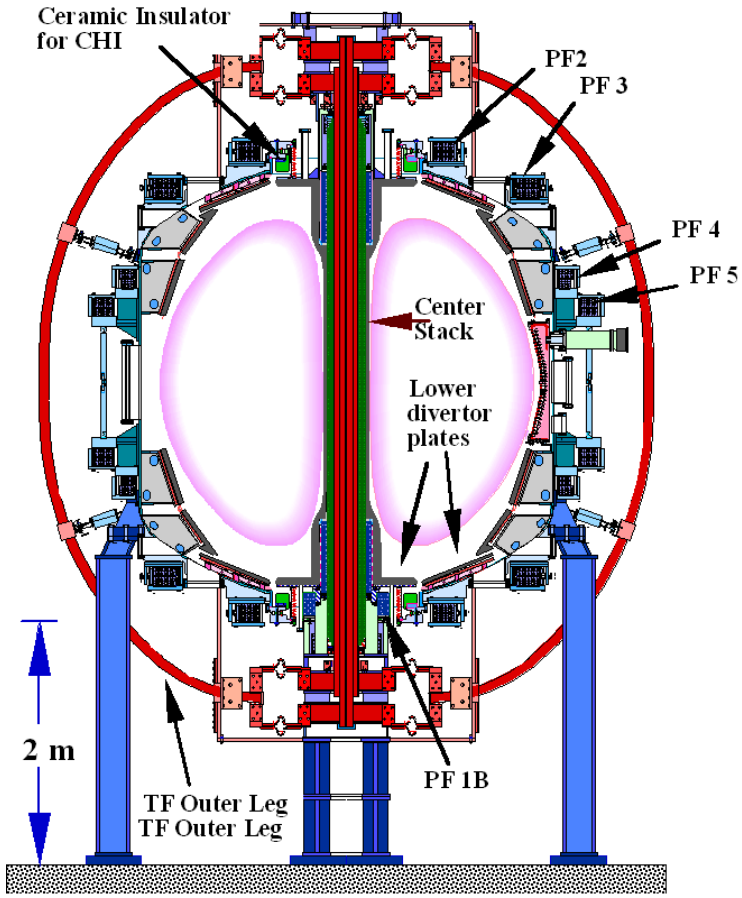
- Exceed Energy for ionization and heating to 20eV (~50eV/D)
  - For 2 Torr.L injected, need ~2kJ

Discharges Without Absorber Arc Have High Current Multiplication Ratios (I_p/I_{inj} ~ 70)



NSTX Plasma is ~30 x Plasma Volume of HIT-II





Concept exploration device HIT-II

- Built for developing CHI
- Many Close fitting fast acting PF coils
- 4 kV CHI capacitor bank

Proof-of-Principle NSTX device

- Built with conventional tokamak components
- Few PF coils
- 1.7 kV CHI capacitor bank