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NSTX PLASMA START-UP USING TRANSIENT CHI

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Presented at the ANS-TOFE
Albuquerque, NM, Nov. 23-26, 2006

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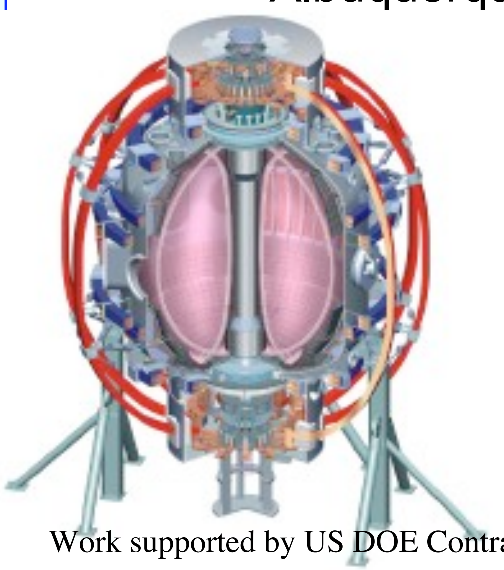

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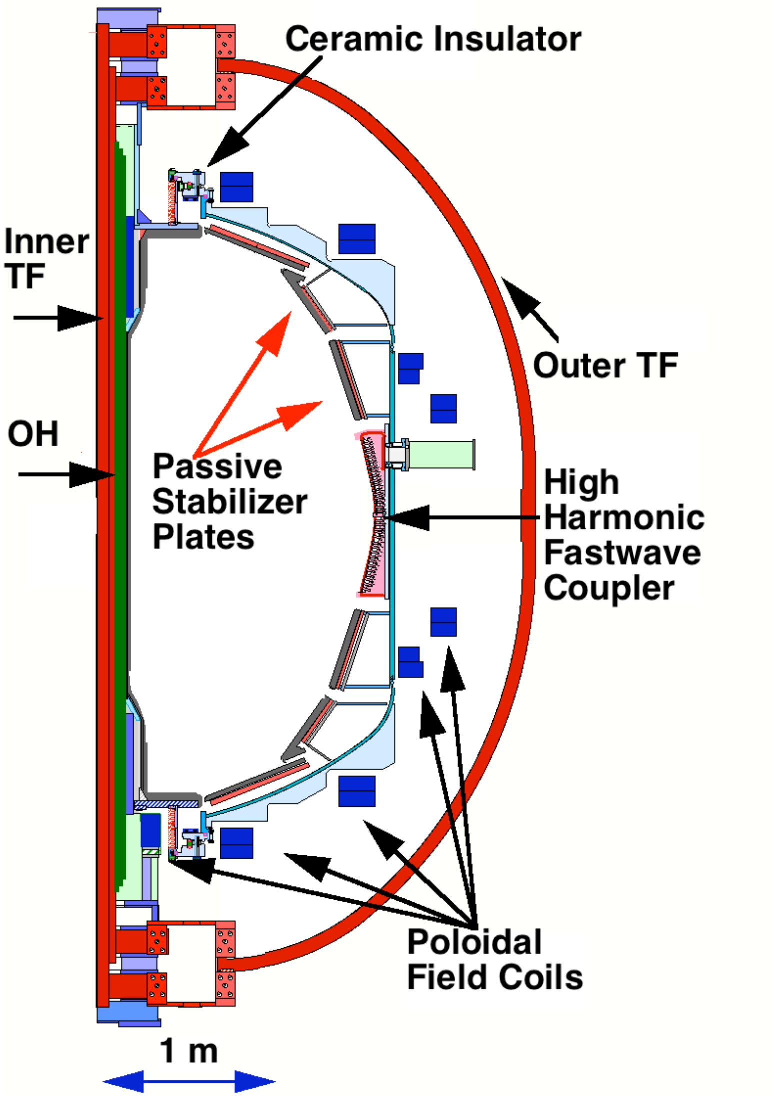
Work supported by US DOE Contract Nos. DE-AC02-76CH03073 and DE-FG03-96ER54361.

Outline

- Non-solenoid current drive is required for spherical torus concept
- Description of Transient Coaxial Helicity Injection
- Present results
- Scaling of transient CHI

NSTX is designed to explore low aspect-ratio toroidal confinement

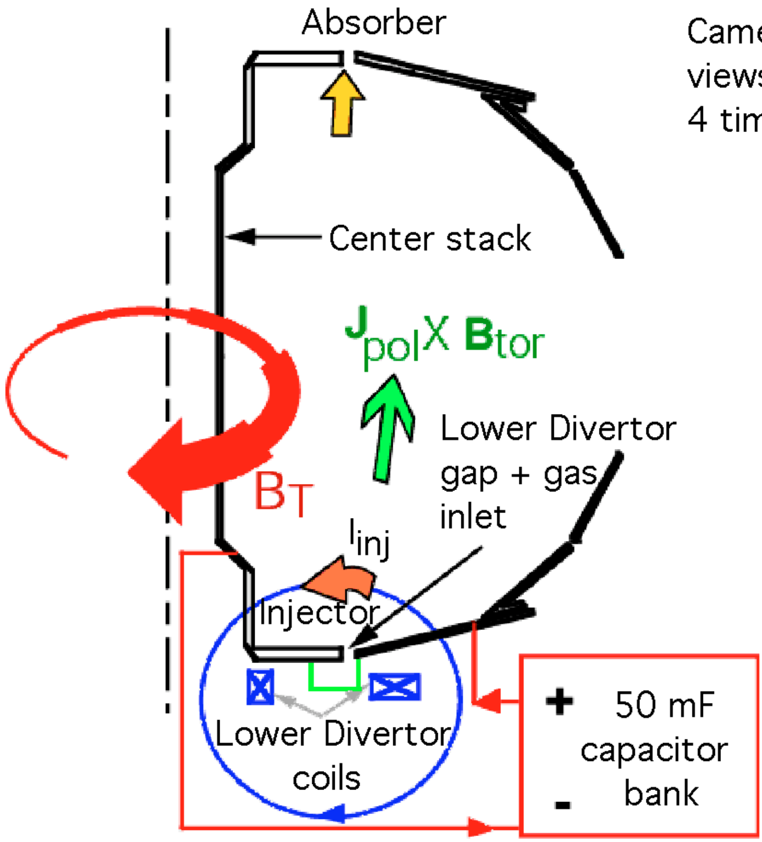


arameters

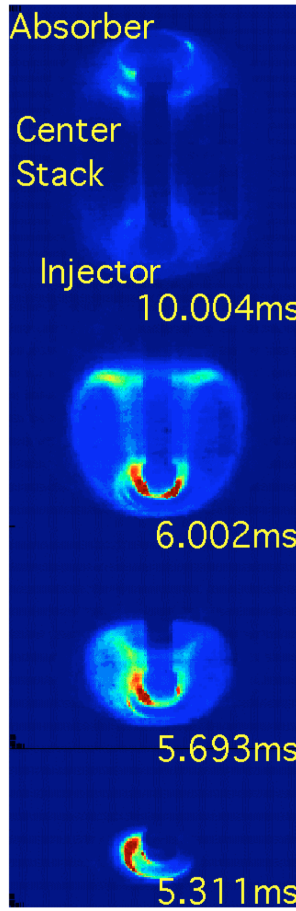
ajor Radius	}⇒A ≥ 1.27
nor Radius	
ongation	2.5
iangularity	0.8
asma Current	1.5 MA
roidal Field	≤0.6T
eating and Current Drive	
nduction	0.6Vs
IBI (100keV)	7 MW
IHFW (30MHz)	6 MW
ulse Length	1 s

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

Machine components for transient CHI in NSTX



Fisheye Camera views at 4 times



After Injector current is reduced to zero

Plasma nearly fills vessel in 1 ms

Plasma expands

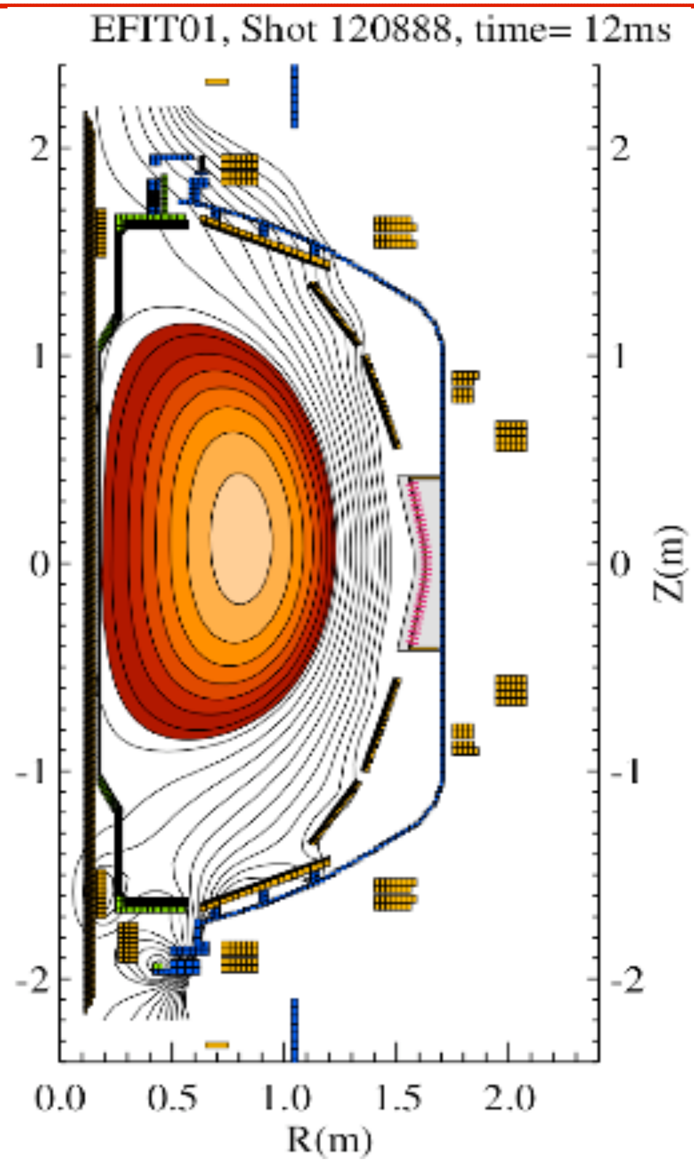
Fast camera image early during discharge

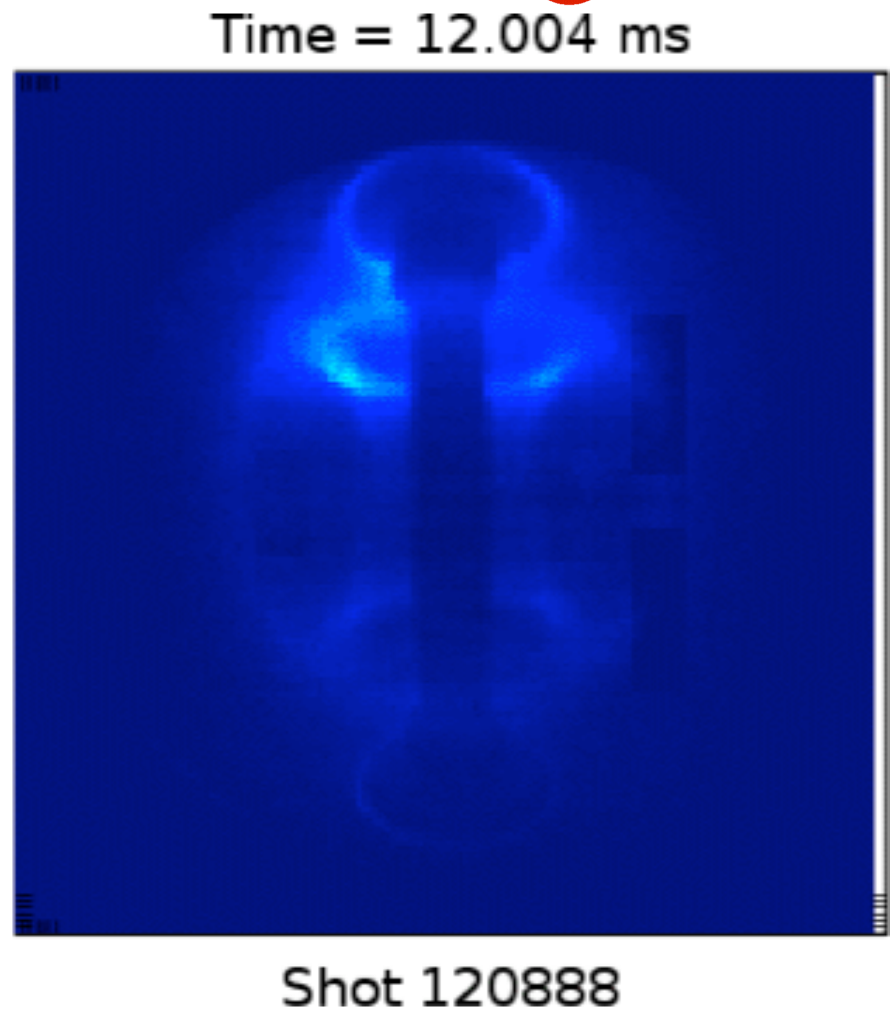
- Starts as helical discharge following B
- J_{pol} X B_{tor} is up into vessel

Fast Camera movie of the entire discharge

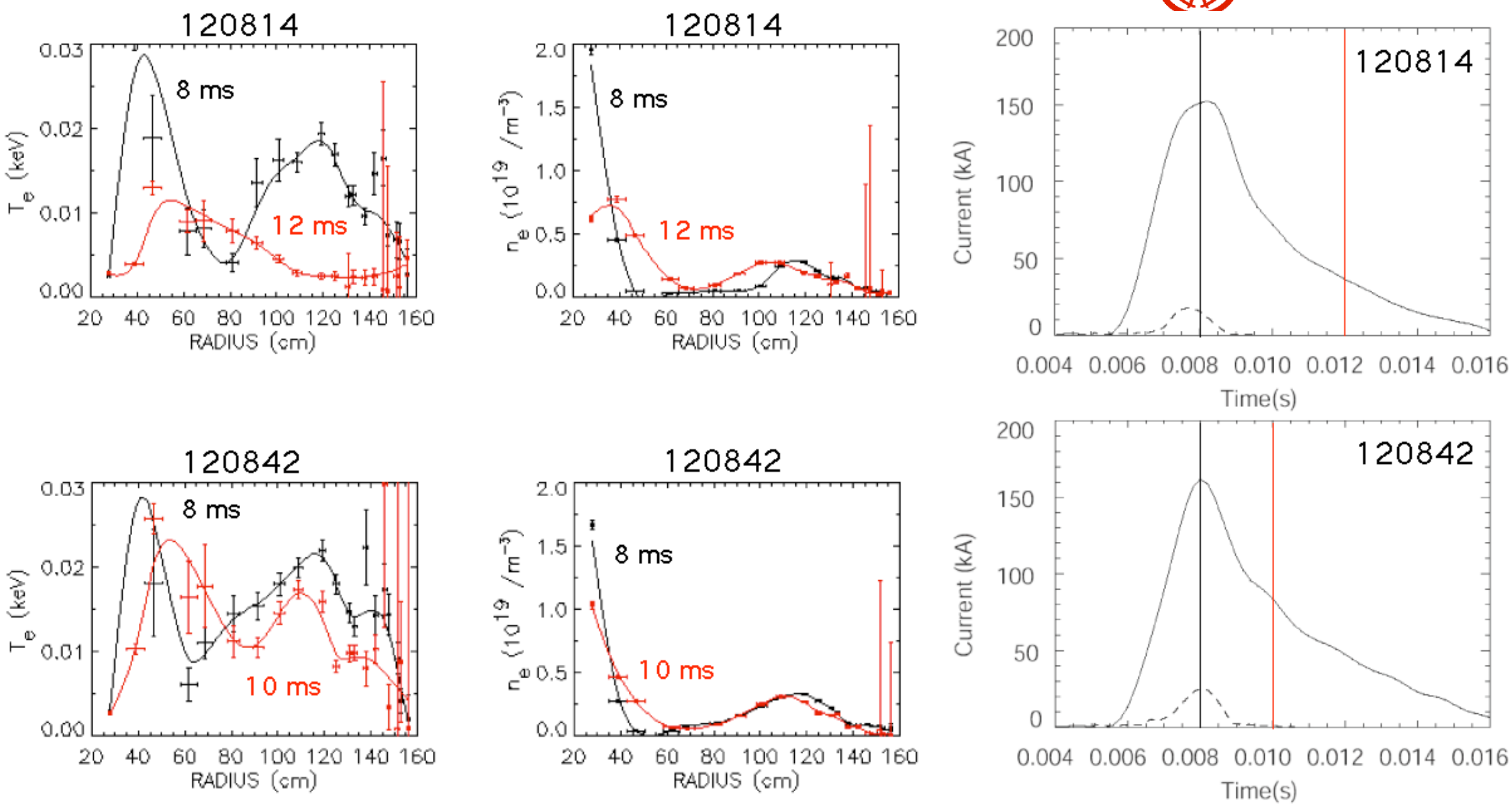
QuickTime™ and a
decompressor
are needed to see this picture.

Equilibrium analysis confirms plasma position





Electron Temperature from Thompson scattering begins hollow and fills in with time



Electron temperature 20 eV,

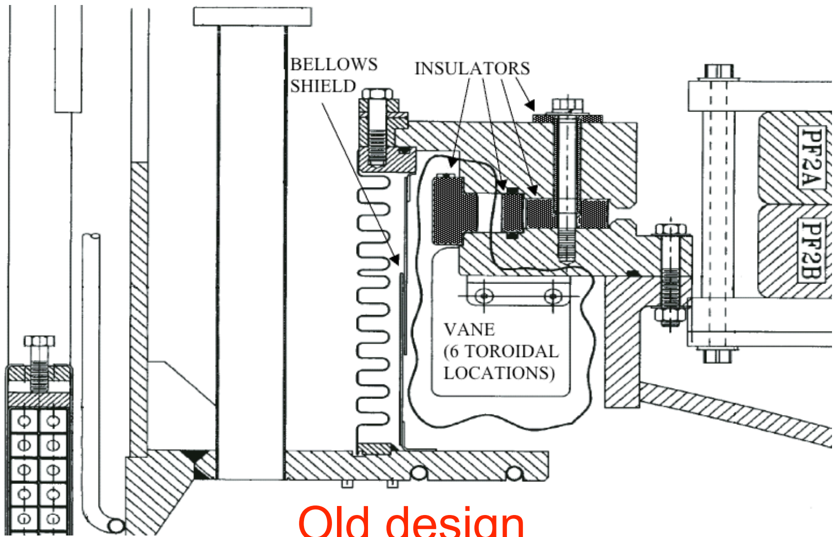
Average electron density few X $10^{18}/m^3$

Plasma position agrees with magnetic analysis

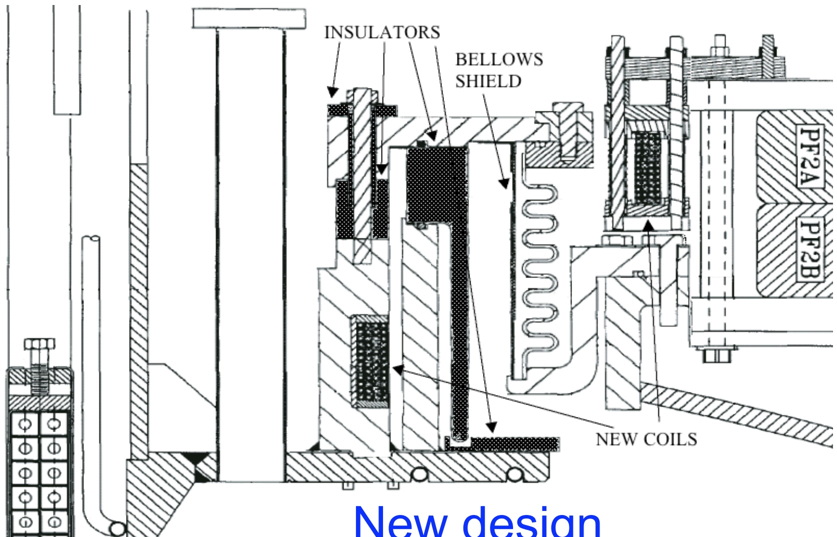
Hardware modifications were required to facilitate CHI studies

- HIT-II was designed to study CHI, NSTX is a normal ST that was modified
- Insulator design
- Capacitor bank to supply CHI voltage
- Gas injection from below divertor gap
- Snubber circuit and Metal oxide varistors (MOV) to limit voltage spikes

Insulator design prevents internal arcs that can terminate the discharge



Old design



New design

Discharge terminating arcs ~2/3 of the time Arcs occur, but do not terminate discharge

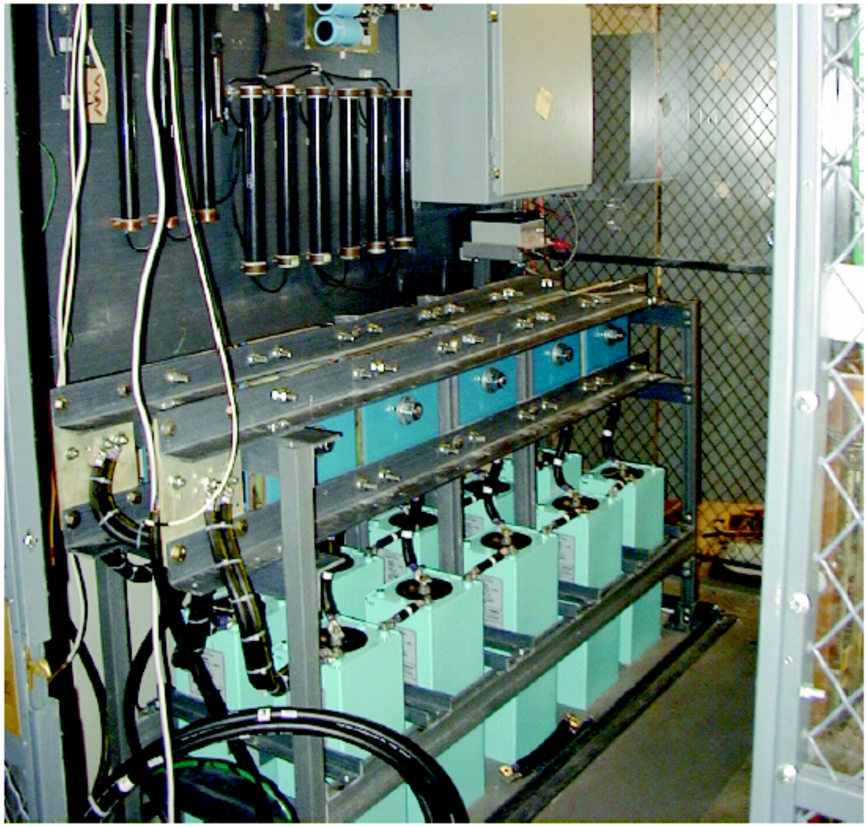
- New design
  - Bigger insulator
  - Insulator on high field side of gap
  - No short, simple connection path between inner and outer vessel

Capacitor bank supplies injector voltage and current

•50mF, 2.0 kV capacitor bank
15 to 45mF , up to 1.75 kV used in experiments

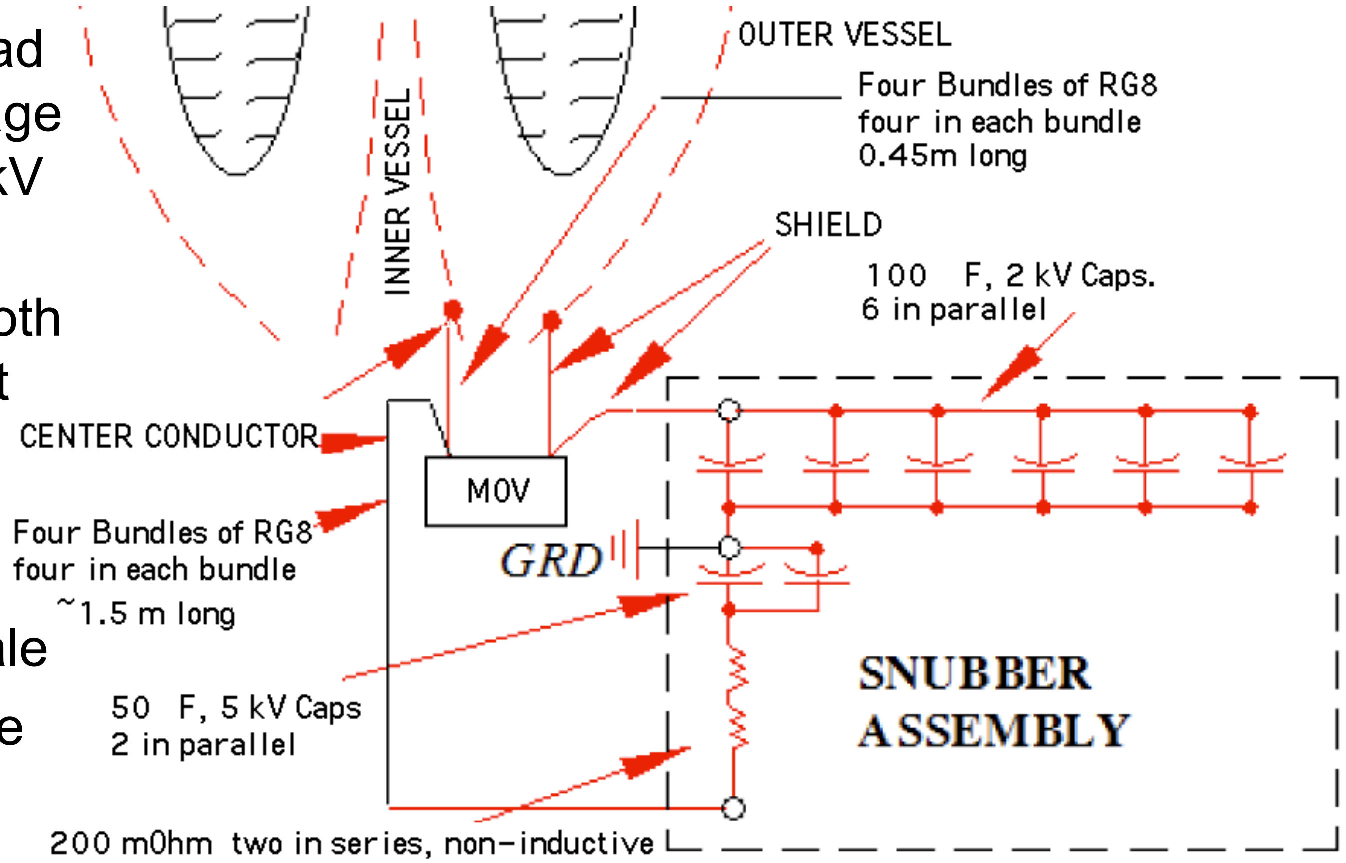
•Fast crowbar system to interrupt injector current

•Gas feed into injector region requires only as much gas as is used for a normal ohmic start-up



External arcs prevented by metal oxide varistors (MOV s) and snubber circuit

- Transient plasma load produced large voltage spikes (>3kV with 1kV supply)
- Analysis indicates both AC and DC transient suppression is required
- Capacitive snubber circuit for μs timescale
- MOVs for longer time scales

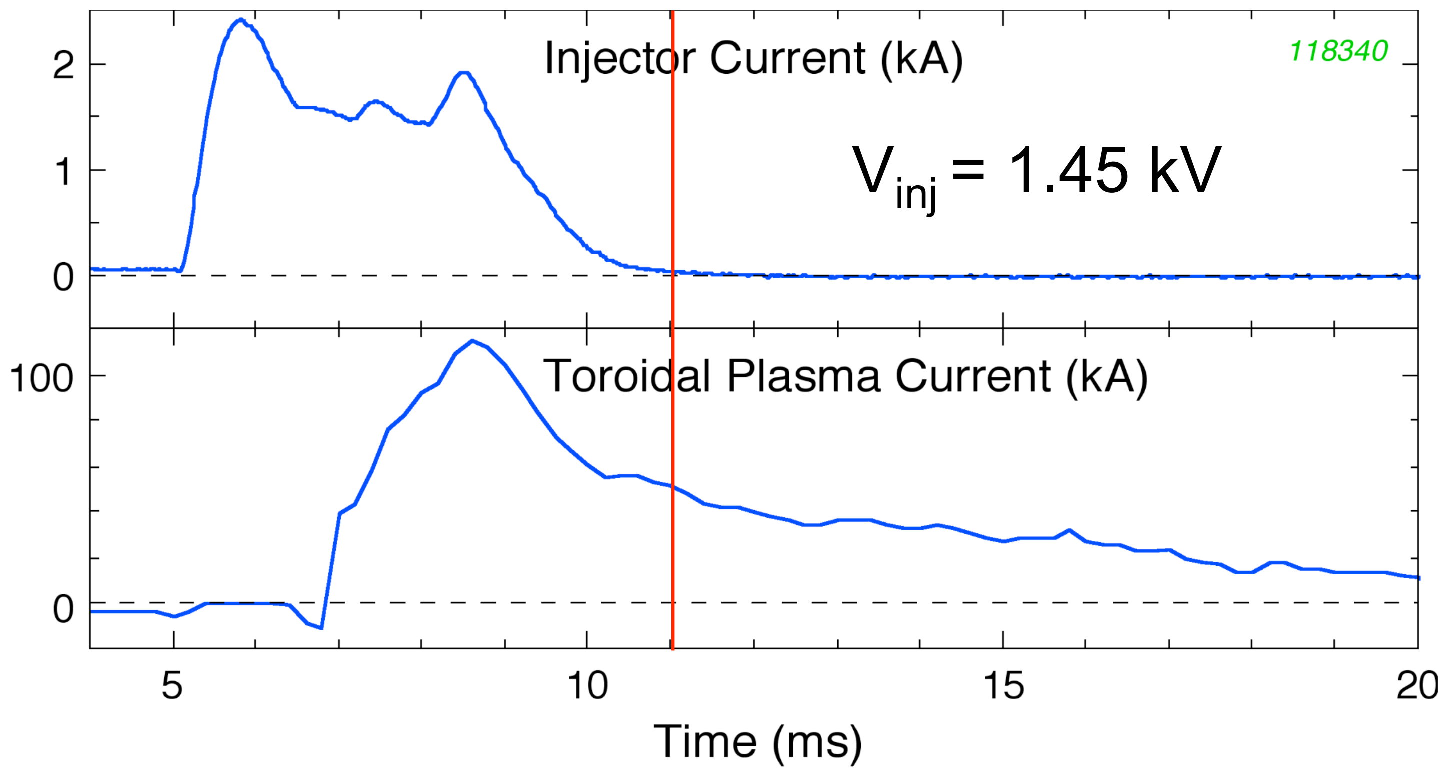


•Effective to limit spikes to 2.2 kV on inner, 0.5 kV on outer at 1.75 kV

CHI scaling implies I_p/I_{inj} in NSTX 10 X that in HIT-II

- 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 flux across injector
  - $\lambda_{tok} = \mu_0 I_p/\psi_{tok}$: ψ_{tok} = toroidal flux in vessel
- $Ip \leq I_{inj}(\psi_{tok} / \psi_{inj})$
- For similar B_T NSTX has 10 X ψ_{tok} of HIT-II
  - Expect 10 X bigger I_p/I_{inj} ratio in NSTX
- 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

NSTX results in 2005 show clear evidence of current on closed field lines and high current multiplication



NSTX - $I_p > 60\ I_{inj}$

(HIT-II - $I_p > 6\ I_{inj}$)

Allowable injector currents are determined by maximum voltage

- Assuming constant resistivity,
  - $I_{inj} \propto V_{inj} (\psi_{inj} / \psi_{tok})$
  - But $I_p \propto I_{inj} (\psi_{tokj} / \psi_{inj})$

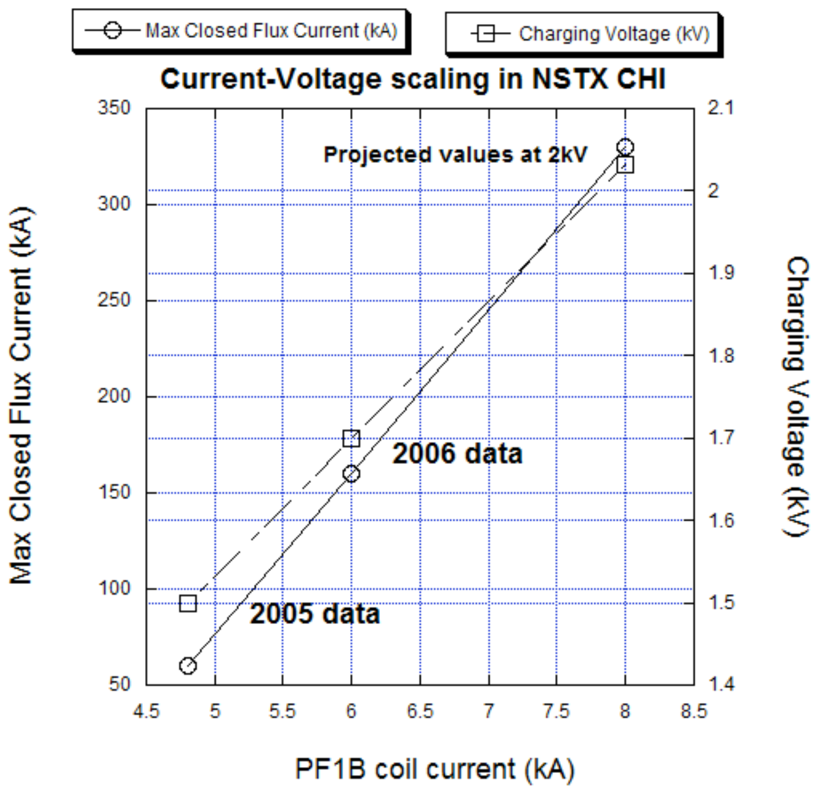
- If discharge conditions are optimized expect $I_p \propto V_{inj}$
  - In 2005 V_{inj} = 1.5 kV, I_p = 60 kA
  - In 2006 V_{inj} = 1.7 kV, I_p = 160 kA

- Proper choice of poloidal flux, toroidal field, and gas fill pressure matters.

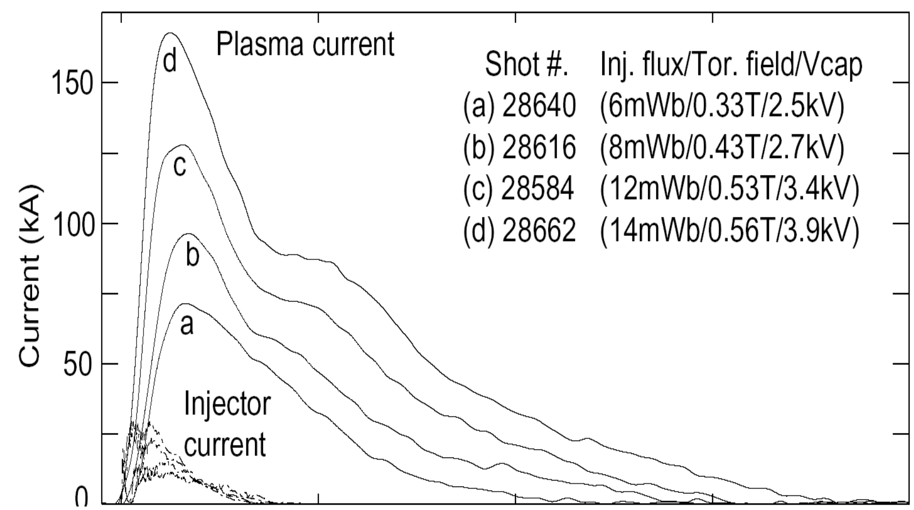
- Simple scaling of I_p with V_{inj} may limit I_p under optimized conditions, but need further experimental time to determine if that limit has been reached.

Full 2kV capability in NSTX would increase I_p to about 300kA

Best results from NSTX 2005 and 2006

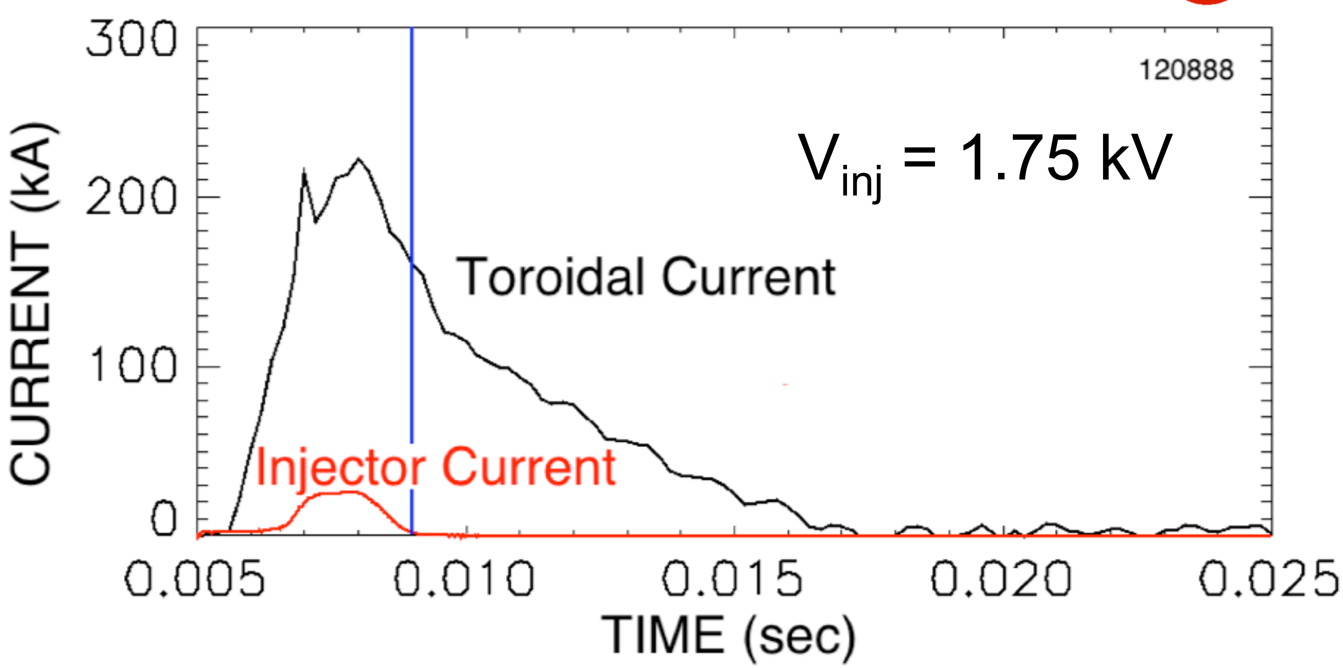


HIT-II data: R. Raman, T.R. Jarboe et al., Nuclear Fusion, **45**, L15-L19 (2005)



Voltage, flux optimization allowed HIT-II to increase closed flux current as capacitor charging voltage was increased

World record non-inductive start-up 160 kA plasma current



- I_p = 160 kA on closed flux surfaces with I_{inj} = 0
- JT60U achieved 80 kA and PLT achieved 100 kA with RF start-up
- Note an absorber arc raised the apparent injector current from a few to nearly 30 kA

CHI has initiated discharges with up to 160 kA of plasma current

- Multiplication factor I_p/I_{inj} is ~10 times greater in NSTX than in HIT-II as expected.
- Plasmas with substantial plasma current have been produced with CHI.
- Will increase V_{inj} to full 2 kV for future experiments.
- Handoff to inductive drive will be explored during the next campaign.
- Need to raise T_e to ~ 200 eV for HWFW current drive.