Supported by

Initial results from transient CHI startup in NSTX

R. Raman, T.R. Jarboe, B.A. Nelson

University, of Washington, Seattle, WA, USA

M.G. Bell, D. Mueller et al.,

Princeton Plasma Physics Laboratory

NSTX Results Review

17 – 28 September 2004

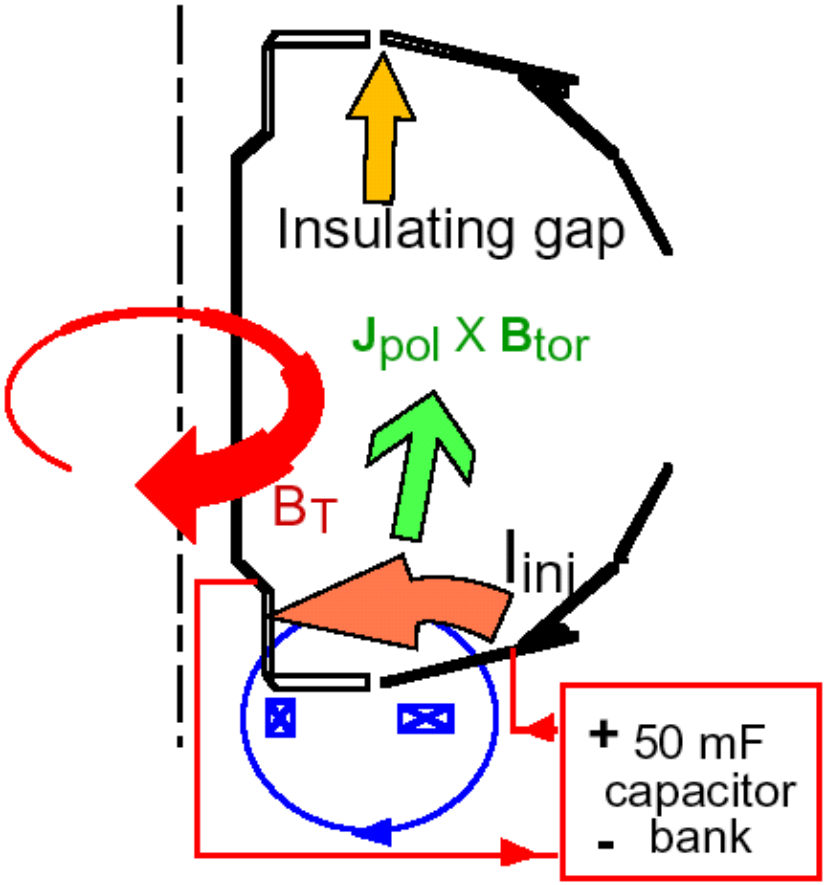
PPPL, Princeton, NJ

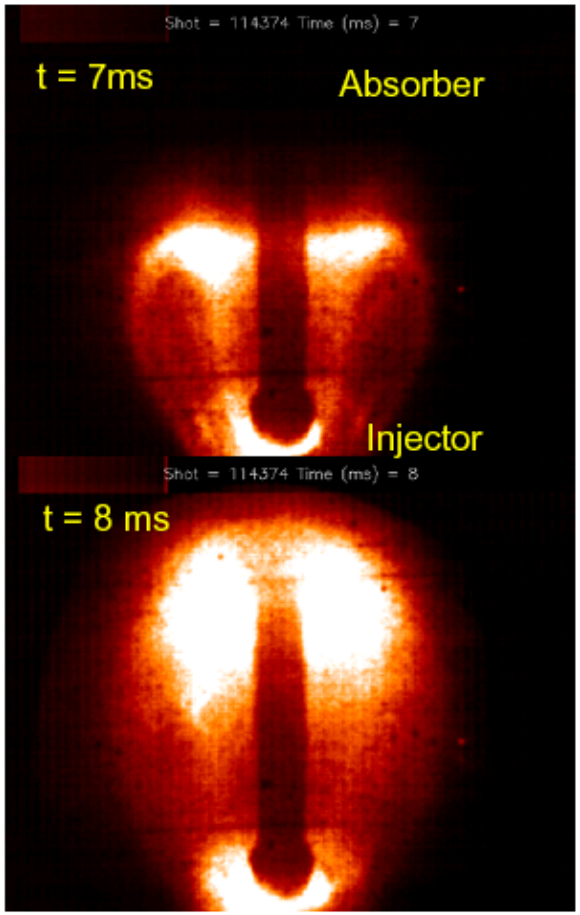
Research supported by U.S. DOE contract numbers. DE-FG03-96ER54361, DE-FG03-99ER54519

Outline

- Implementation of transient CHI
- Power supply requirements
- The Transient CHI discharge
- Yr-2004 Transient CHI discharge from HIT-II
- Summary and Conclusions

Implementation of Transient CHI





Expect axisymmetric reconnection at the injector to result in formation of closed flux surfaces

Fast camera: C. Bush (ORNL)

DC power supply versus capacitor bank for Transient CHI

- Previously, tried transient CHI with brief 1kV pulses applied by standard CHI rectifier supply
  - Observed jitter in supply output at low current
    - breakdown was unreliable
  - After breakdown, inductance in CHI circuit limited rate of current rise below optimum level
    - inductance required to limit fault current
- Analysis indicated that a small capacitor bank would be a better matched supply for transient CHI

Capacitor bank requirements for Transient CHI

Bubble burst current that is equal I_{inj}

- $I_{inj} \propto \Psi^2_{inj}/\Psi_{toroidal}$ (easily met)

Volt-seconds to replace the toroidal flux

- For $\Psi_{toroidal}$ 600 mWb, at ~500V need ~1.2ms just for current rampup - *OK, but will improve at higher voltage*

Energy for peak toroidal current ($LI^2/2$, L=1μH)

- Maximum possible Ip (at 17.5 kJ) ~ 190 kA (achieved ~ 140 kA)
- *Need to increase Ecap*

Energy for ionization of all injected gas and heating to 20eV (~50eV/D)

- At lowest gas pressure 16.8 Torr.L injected, need ~21kJ just to ionize and heat – *Need to reduce total injected gas*

Equilibrium and pre-ionization requirements

The equilibrium coil currents provide the following:

- An equilibrium for the target closed current when the open field line current is back to zero
- The initial injector flux with a narrow enough footprint and high enough value so that λ_{inj} is higher than the target λ_{ST}.

$$\lambda_{inj} = \mu_o I_{inj} / \Psi_{inj} \quad \lambda_{ST} = \mu_o I_p / \Psi_{toroidal}$$

Gas puff provides the following:

- Just enough gas for breakdown (need $j/n > 10^{-14}$Am, Greenwald)
- Highest density at the injector

ECH provides the following:

- Pre-ionization for rapid and repeatable breakdown
- Initial plasma in the injector gap

Capacitor bank for Transient CHI commissioned

- Maximum rating:
  50 mF (10 caps), 2 kV
- Operated reliably at up to 1kV (7 caps, 17.5 kJ)
- Produced reliable breakdown at ~ 1/ 3rd the previous gas pressure
  - Constant voltage application allowed more precise synchonization with gas injection
  - HHFW used for Pi assist

Injector flux and gas pressure scanned at Vcap ~ 1kV

- PF1B coil current (measure of Ψ_{inj}) varied from 3.3 to 9.4kA

At high injector flux:

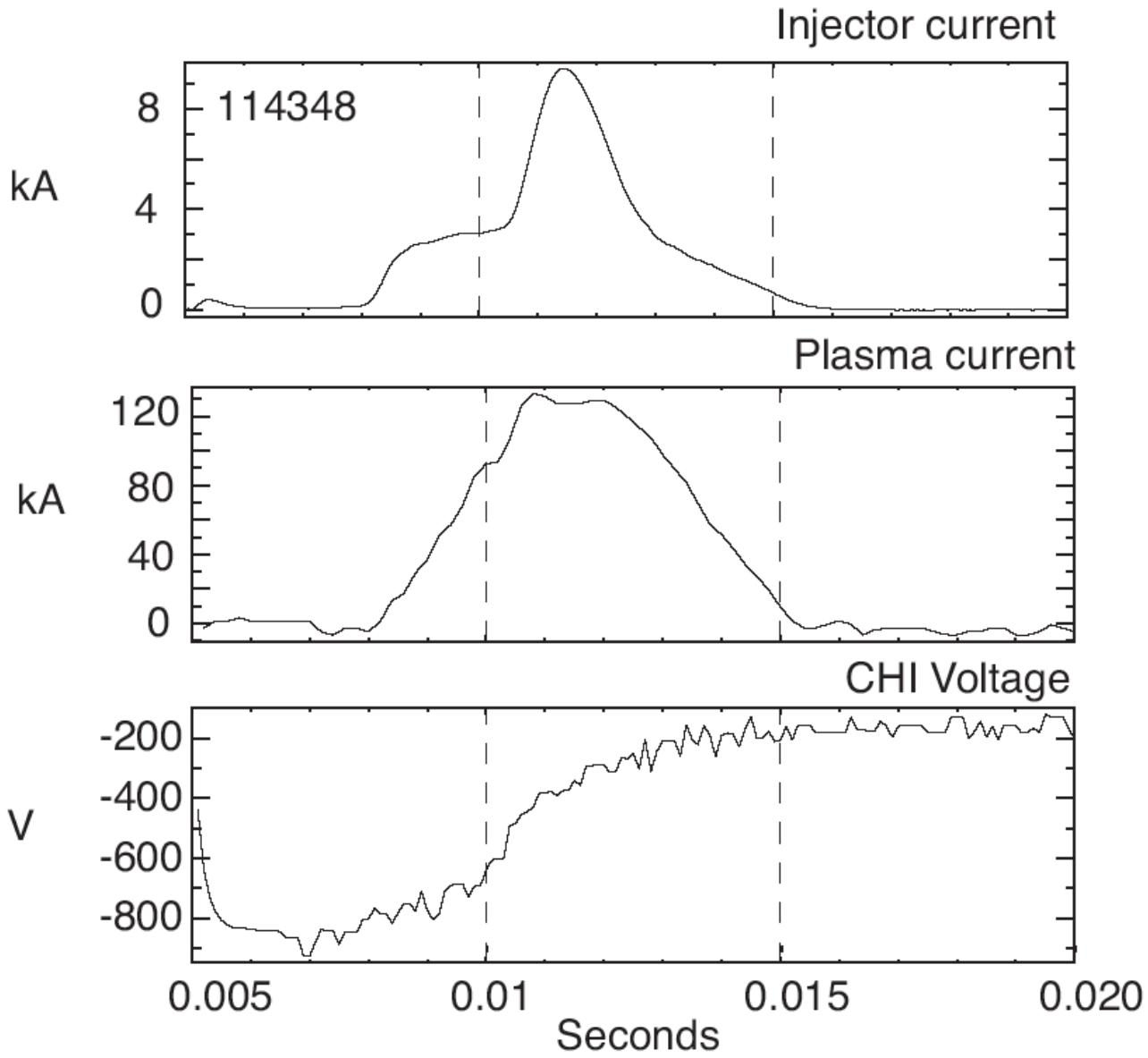
- No bubble burst at I_PF1B of 9.4kA (even at I_{inj} ~ 20kA)
- High gas pressures needed for I_PF1B ≥ 6.5kA (1 x 10^{-3} Torr)
- Low current multiplication in high injector flux discharges

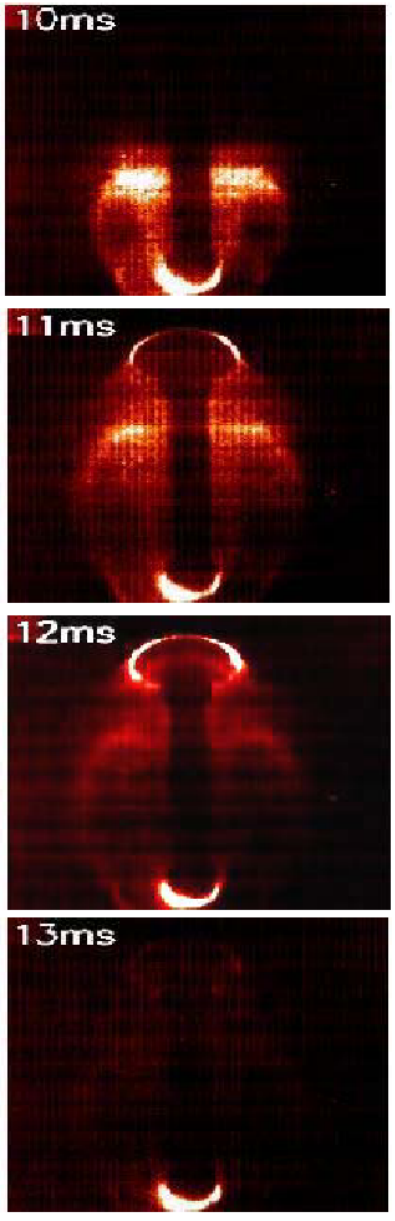
At low injector flux:

- For I_PF1B < 4kA, current multiplication up to 40 (I_{inj} ~ 4kA)
- Allowed operation at lowest fill pressures (2 x 10^{-4} Torr)

- Operated in 1, 2 capacitor configuration to study breakdown
- Operated in 4 and 7 capacitor configuration to increase energy

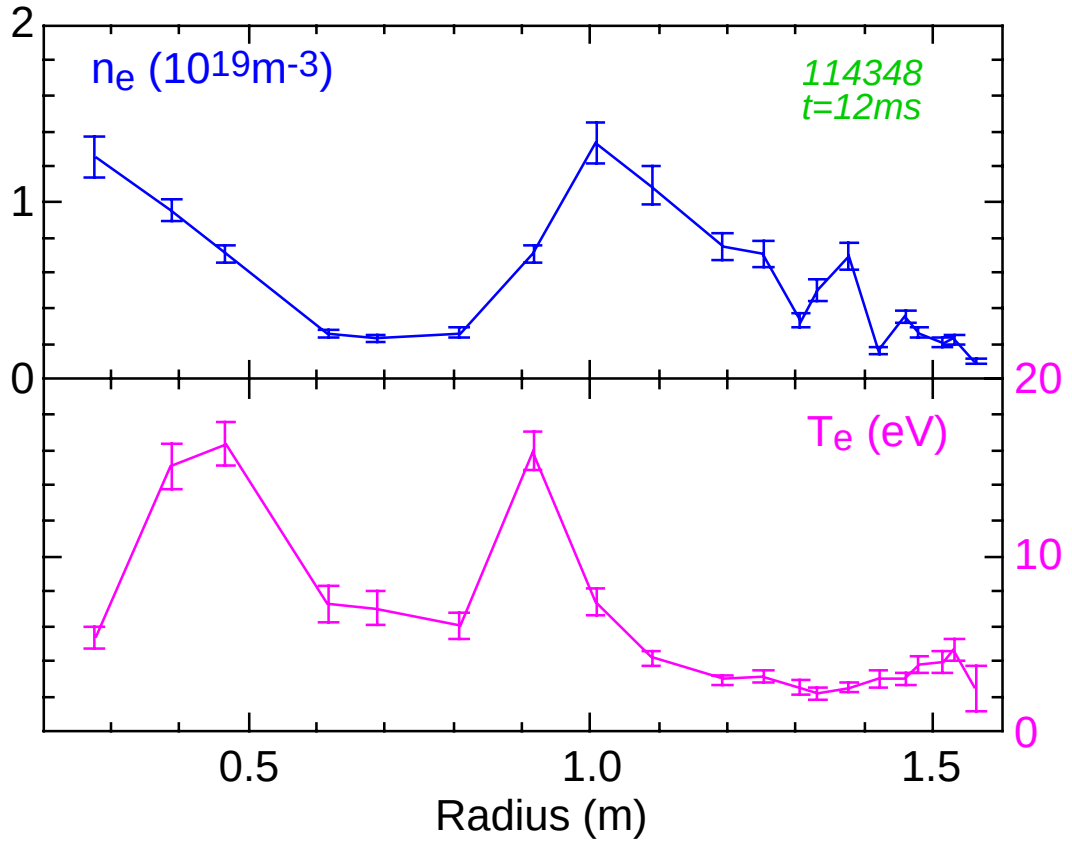
Initial transient CHI discharge in NSTX





Current persistence not yet observed

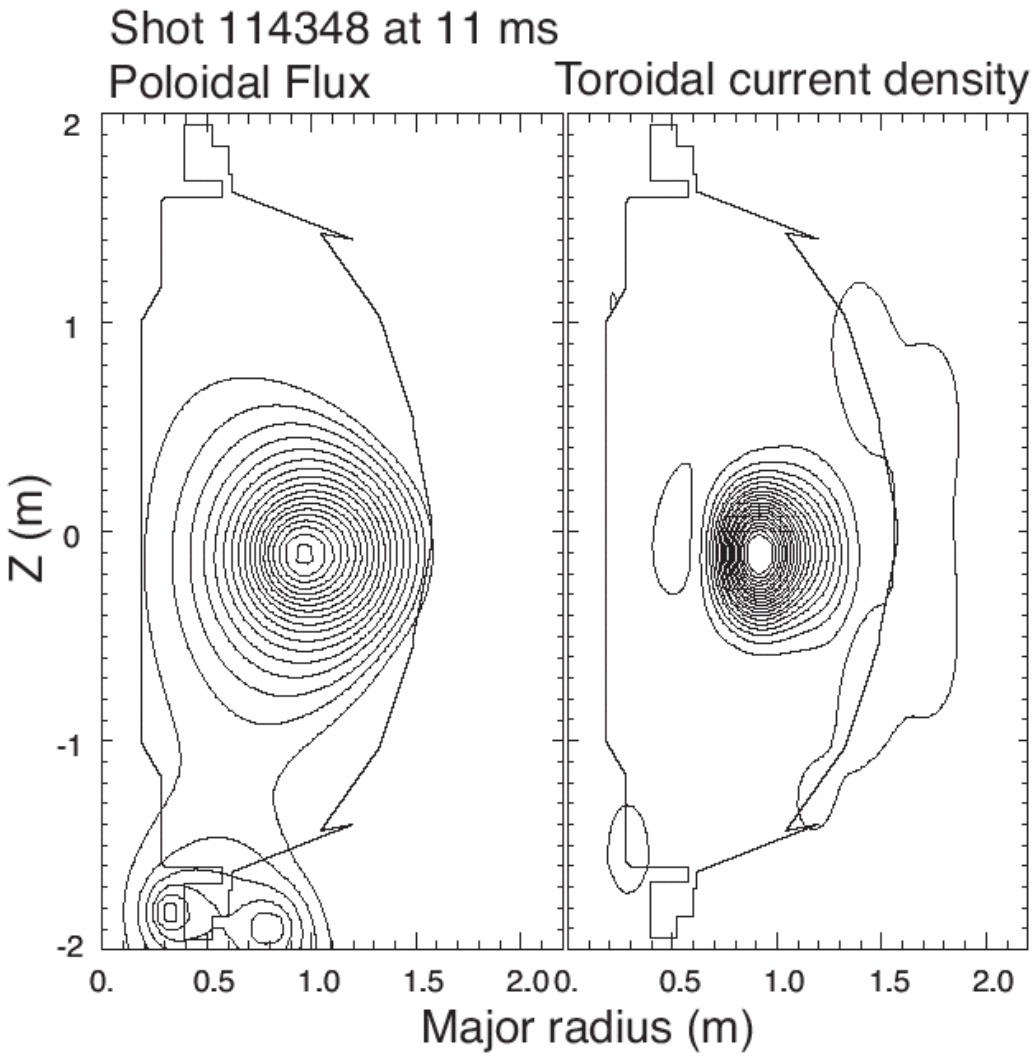
Te ~ 16eV measured in lowest neutral pressure discharge

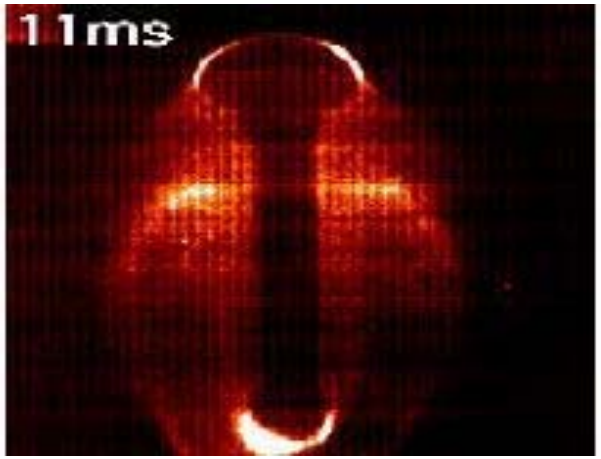


- Te increases with reduction in fill pressure
- Breakdown constraints prevented operation at the more optimal low pressures.

Thomson: B. Leblanc (PPPL)

EFIT reconstruction consistent with fast camera image

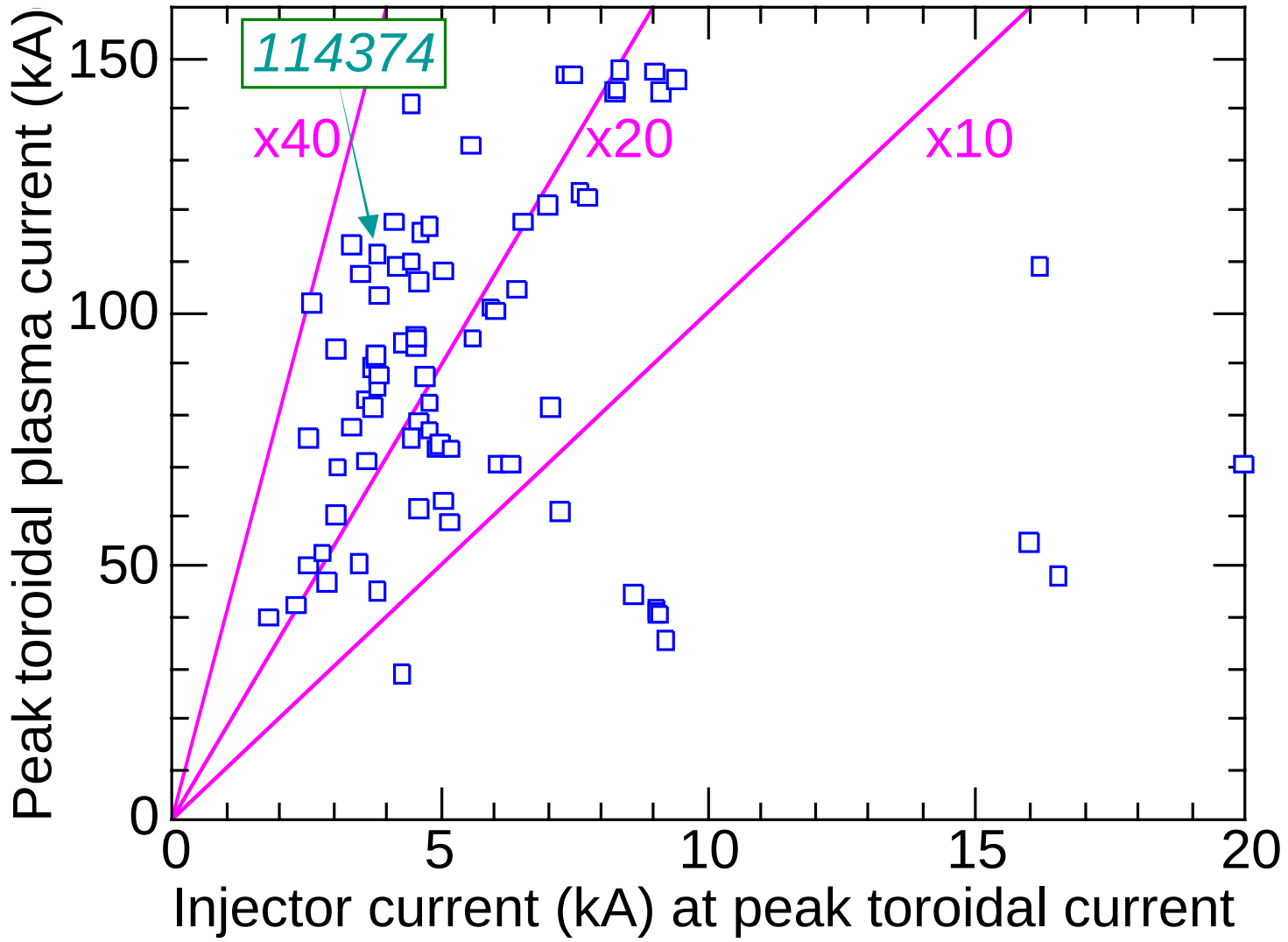




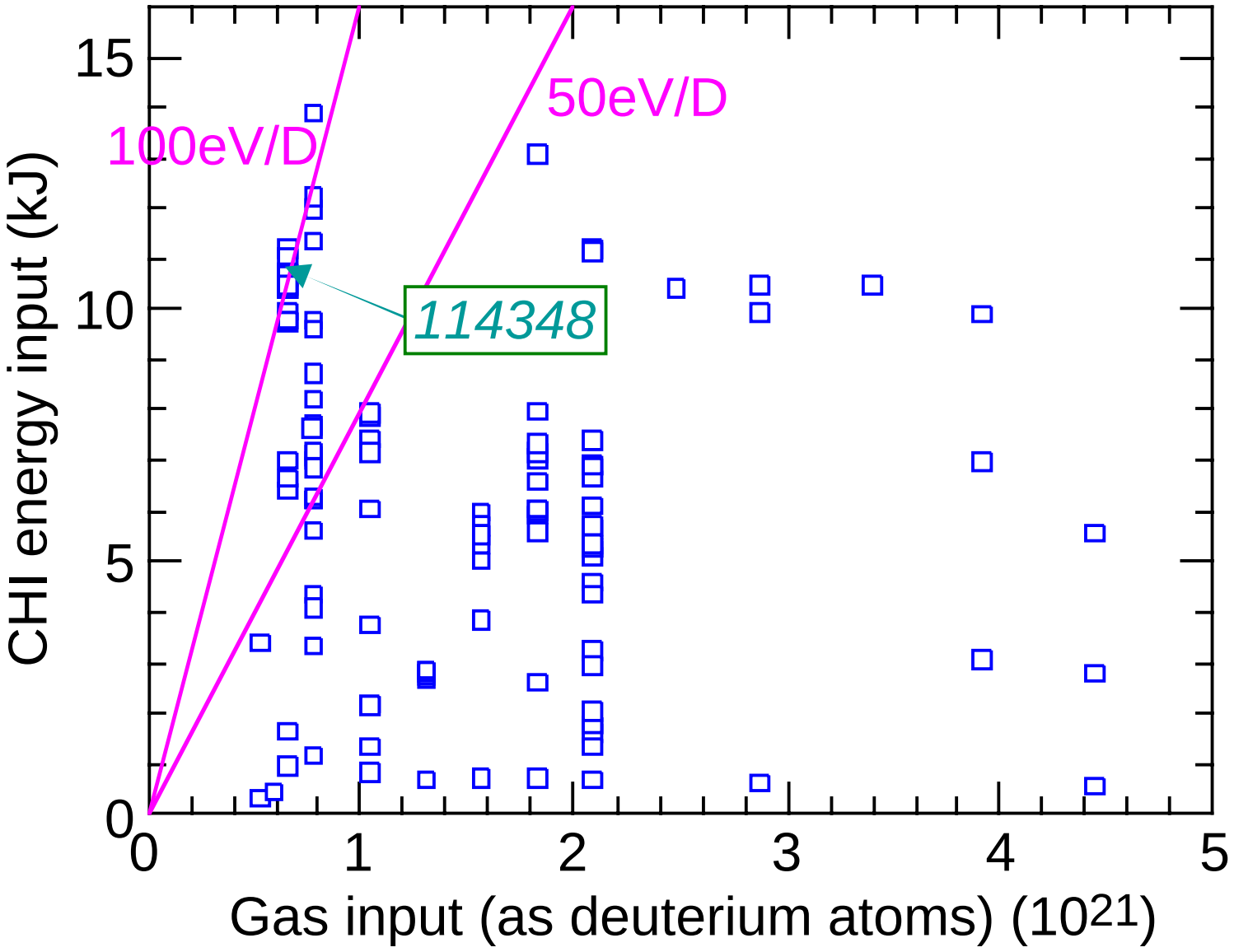
Require internal measurements (Re: MSE) to confirm closed flux

Fast camera: C. Bush (ORNL)
EFIT: M. Schaffer (GA)

Highest current multiplication obtained in discharges with the lower injector current (these also have lower Ψ_{inj})

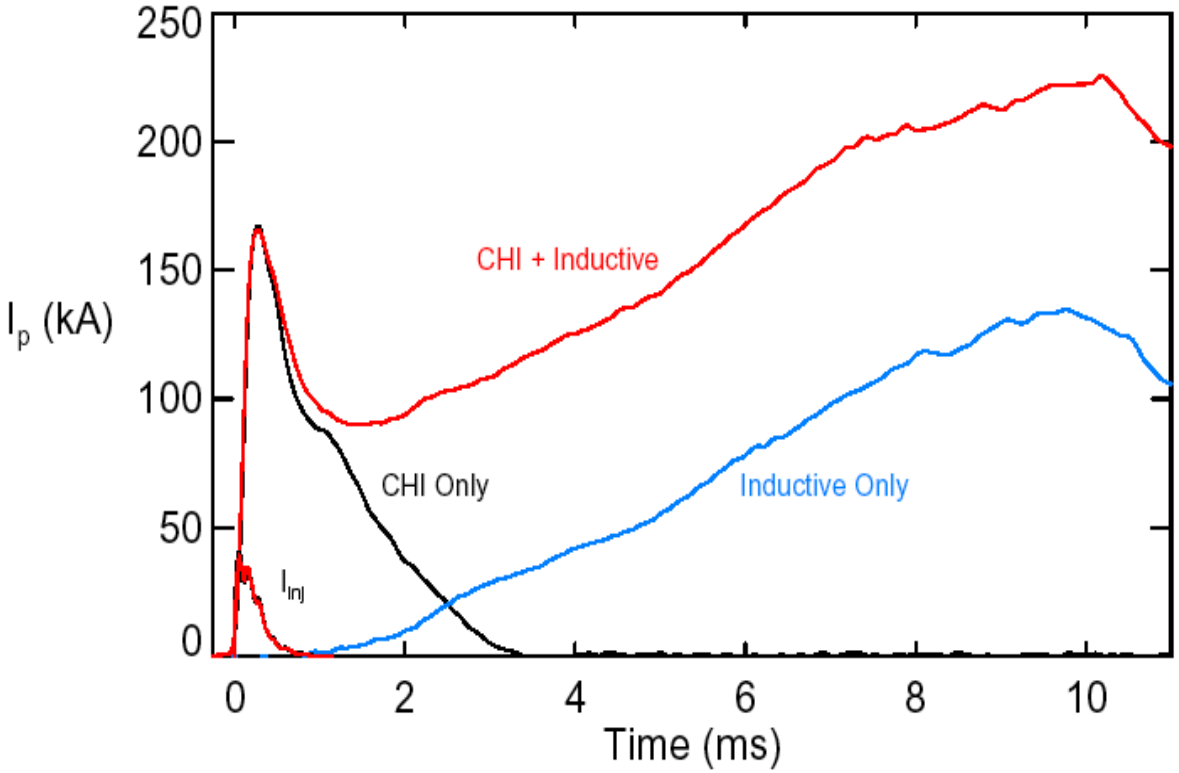


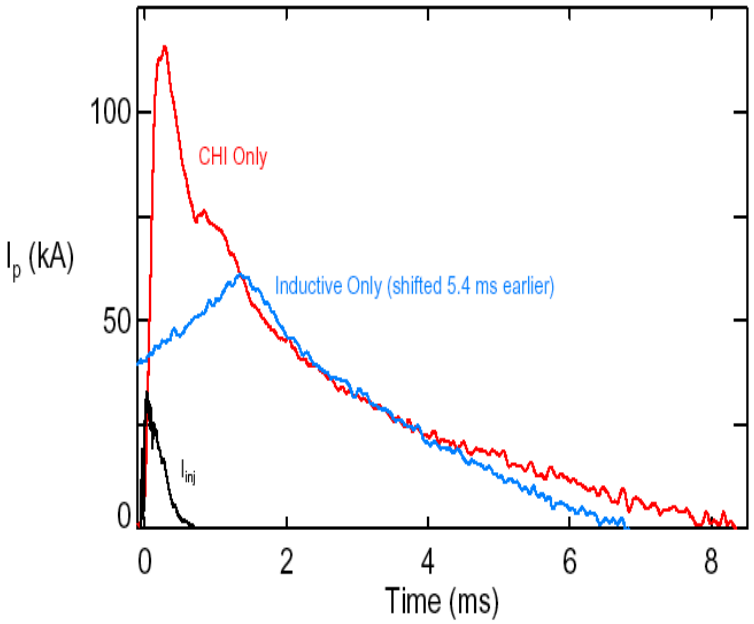
Capacitor bank energy was barely adequate to ionize only those discharges with the lowest gas input



A CHI startup plasma has sufficient quality to be ramped up by induction. The startup discharge was produced with CHI followed by relaxation on HIT-II.

HIT-II





Both discharges (CHI + induction and induction-only) have identical loop voltage programming

The CHI discharge has the same current decay time as the inductively produced discharge

Conclusions

- The physics capability of CHI clearly demonstrated on HIT-II
- The capacitor bank system has worked reliably
- Transient CHI results on NSTX are consistent with our understanding and point to the need for certain technical improvements in NSTX
  - Reduced gas injection, while increasing gas pressure in the injector
    (inject gas below divertor plates)
  - Pre-ionize the injected gas and provide conditions similar to that from the SSI injectors on HIT-II
    (redirect one of the ECH wave guides into the lower divertor region)
  - Increase cap bank energy while maintaining short current pulse
    (increase cap bank voltage - up to 2kV possible)