NSTX EXPERIMENTAL PROPOSAL

Title: Transient CHI Startup **OP-XP 406**

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1. Overview of planned experiment

We will apply the "Transient CHI" scheme developed in HIT-II to demonstrate persistent current following a pulse of coaxial helicity injection (CHI) in NSTX. When this technique is established, we will apply induction to ramp the current up.

2. Theoretical/ empirical justification

Toroidal currents up to 0.4MA have been produced by CHI in NSTX (see *e.g.* T. Jarboe, *et al.*, IAEA 2002). However, since diagnostics for the internal distribution of plasma current are not yet available, it has not yet been possible to conclude that any of that current was flowing on closed flux surfaces. Analyses of the equilibrium with several codes, including MFIT, EFIT and ESC, have indicated the possibility of closed flux consistent with external magnetic data and encouraging signs have been seen in the magnetic fluctuation measurements and in the soft x-ray emission profile, but these are not definitive.

A scheme has recently been developed in HIT-II (U. Washington), which proves the production of closed flux by demonstrating the persistence of significant toroidal plasma current after the CHI injector current has been rapidly reduced to zero. Induction from the central solenoid is applied to this resistively decaying toroidal equilibrium to ramp the current up to high levels and to sustain it. Using this technique, record plasma currents were obtained in HIT-II.

Suitable conditions for producing "forced reconnection" can be produced in NSTX.

3. Experimental run plan

The demonstration of persistent current will start with waveforms for shot 102539, which through CHI, achieved a high toroidal current (almost 0.2MA) very quickly (in about 5ms) before an absorber arc terminated the main CHI discharge. This discharge was run in 2000 in the "narrow footprint" configuration, which should be conducive to reconnection but has previously been prone to absorber arcs in NSTX. In 2001, CHI experiments concentrated on the "wide footprint" configuration, which was found to be more resistant to absorber arcs. In 2003, several discharges, similar to 102539, in the 100kA level were produced but the discharge current waveform could not be controlled as needed for forced reconnection because of power supply hardware limitations. A CHI specific capacitor bank power supply is presently under development and will be used for the experiments described in this XP. During the 2003 run, the considerably improved NSTX absorber was resistant to absorber arcs under transient CHI conditions.

3.1 Persistence of toroidal current

The initial part of this experiment (up to part c) will establish conditions for breakdown and injector current generation up to the 10kA level. Set up the NSTX clock cycle for a 10 minute cycle time.

Impose the following conditions:

Extend TF flat-top pulse to 1000 ms.

No currents in the central solenoid system.

Restrict diagnostics to plasma current measurement, all CHI system measurements, edge pressure gauges, fast camera, main vessel bolometer, filterscopes, fire-tip, magnetic flux loops, mirnov signals, loop voltage, essential HHFW signals and SPRED.

a) Start with the waveform for 102539 (109635 from Fy 03) and extend TF pulse to 1000 ms. Note that the waveforms for the transient CHI runs conducted in 2003 are the same as for 102539 but with the added condition that the PF2L, 3L and 1B coil currents are ramped down. This ramp-down is no longer required, which simplifies the procedure used in 2003.

   Program PF3U to be–2.4kA, and if necessary increase at the rate of –2.4kA/100kA of Ip as the plasma current increases. Program PF2U to be +1.2kA/100kA initially and if necessary, increase at the rate of +1.2kA/100kA of Ip. Initially program PF5 to be about –0.3kA/100kA of I_p

   Keep the NBI valves open and use the NBI cryo pumps for additional pumping.

   To maintain same wall conditions use 5min HeGDC between shots. If breakdown is not achieved, then skip HeGDC for the subsequent shot.

   Inject gas from the LDGIS at 100 Torr, triggered at –15ms. Use EC-Pi from –5 to + 15ms. Use HHFW for Pi, based on experience gained from XMP-30. Apply HHFW from –5 to +20ms.

b) If good breakdown conditions are achieved at 950V or less, reduce the gas pressure and repeat at higher voltages. At t = 0, discharge the CHI capacitors (in the 2 capacitor configuration) at 700 Volts and increase voltage in 100 Volt steps to establish the voltage requirements needed to initiate a discharge at the lowest gas pressure and to establish the maximum injector current and toroidal current that can be obtained at this condition. Reduce or increase LDGIS pressure to produce discharges at the lowest possible gas pressure.

c) If breakdown is not achieved, repeat with two plenums filled to 200 Torr.

   If breakdown is not achieved, repeat with one plenum filled to 400 Torr.

   If breakdown is not achieved, repeat with four plenums filled to 200 Torr.

   If breakdown is not achieved, repeat with two plenums filled to 400 Torr.

   If breakdown is not achieved, repeat with one plenum filled to 800 Torr.

d) After conditions for reliable discharge initiation and absorber-arc-free-operation are established, increase the CHI injector current up to 17kA, or make further increases to IP, as follows.

Use the full complement of magnetics, which will be needed for between shots MFIT and EFIT.

In the four to six-capacitor configuration increase the voltage up to the 1kV level, while avoiding absorber arcs.

Then increase the size of the capacitor in steps of two to maximize the amount of current persistence after the injector current has been ramped to zero.

As the plasma current increases, and if absorber arcs occur, then pre-program PF2U and 3U to higher currents as described in step (a).

At higher plasma currents, increase the current in PF5 to maintain radial position control, at the rate of –0.3kA/100kA of Ip.

If the plasma equilibrium appears to be off the midplane, adjust the relative currents in the PF3 coils to force the plasma onto the midplane.

e) Assess the persistence of toroidal current after the injector current has reached zero.

f) Increase the applied CHI voltage to get to as high a toroidal current as possible at the end of the CHI without producing an absorber arc.

g) Using the optimized condition in step (f), repeat at 90% and 110% of the injector flux used in step (f) to maximize the closed flux current. Based on the results of step (g), if necessary, make additional small changes to the magnitude of the injector flux to maximize the closed field line current.

h) Use Thomson scattering to diagnose the plasma temperature and density profiles, as well as diagnose using other diagnostics (interferometer, spectral lines, ion Doppler for plasma rotation, bolometer). Make the Thomson measurements at the time of the peak plasma current and at 3-5ms later.

i) Make these diagnostic measurements again after a 20 ms pulse of auxiliary heating, including 60keV NBI, is applied from +5 to +25ms.

<u>3.2 Hand-off to inductive operation using the central solenoid</u>

a) Starting from the time of peak toroidal current and starting from zero current in the central solenoid, apply induction from the central solenoid. Use 6, 4 and 2 volts or lower to determine the loop voltage at which the CHI produced toroidal current does not drop to zero.

Ramp the central solenoid from 0 to -10kA (+10kA for PCS programming to provide

-10kA in physics convention)

2V: t_1 to t_1+62ms, t_1 = time at which OH ramp is initiated

4V: t_1 to t_1+41ms

6V: t_1 to t_1+21ms

b) Apply the optimum initial loop voltage for the time needed to ramp the plasma current by about 50 to 100% of the minimum of the plasma current during hand-off or by 100kA, whichever is higher. If not already implemented in step 3.1(d), then during this period begin pre-programmed current ramps in PF5 and PF3 to provide radial and vertical equilibrium, using the prescription in step 3.1(a and d).

   a. Note that as the inductive ramp takes over, at an appropriate time the PF1B coil current should to be reduced to zero and the upper and lower PF2 and PF3 coils should become balanced to maintain vertical equilibrium control.

   b. The most appropriate time to reduce the current in PF1B and to adjust the current in PF2 may be when the inductive ramp is initiated. Simultaneously the currents in the upper and lower PF3 coils should be adjusted to balance them, as shown in the attached figure.

c) If the CHI produced current does not couple to induction, apply auxiliary heating as follows.

   a. Apply a 40 ms pulse of HHFW phased for plasma heating as developed in XMP-30

   b. If the edge neutral conditions permit, apply ≥20 ms pulse of NBI at 60 keV from all three sources.

d) At the end of the initial pre-programmed inductive ramp, continue with further pre-programmed ramp, if necessary at a different loop voltage, until the current in the CS reaches the maximum of +24kA. Use EFIT reconstructions to adjust the currents in PF3 and PF2 coils.

3.3 Assessment of Inductive Flux Saving

a) After reliable, reproducible discharges are obtained, repeat 5 shots in a row using CHI start-up assist. If magnetic analysis shows that the plasma is reasonably well controlled during the startup phase, open shutters of spectroscopic diagnostics, soft-x-ray arrays and MPTS and document plasma characteristics. If necessary, use feedback controlled current ramp after an initial phase of pre-programmed current ramp. Based on the observed current evolution, the value for the current setting at which feedback controlled operation commences may need to be revised in the plasma control system software.

b) Develop an inductive startup discharge which reaches the same current flattop and configuration in the same time as the CHI-assisted discharges in a). This will require changing the OH to bipolar operation, reprogramming the initial PF waveforms and switching to the standard LFS gas injector.

c) Run 5 shots in a row with inductive-only start-up to measure the poloidal flux consumption under identical current ramp-up conditions. Determine differences in density profile, current profile and temperature profile evolution.

4. Required machine, NBI, RF, CHI and diagnostic capabilities

All the standard magnetic diagnostics used for equilibrium analysis are needed. If reproducible shots with persistent current can be obtained, we will attempt to diagnose them with a variety of diagnostics, including MPTS, the USXR arrays, the GEM x-ray camera, and spectroscopy.

Configuration

4.1 Configure for CHI operation. If necessary, reduce the voltage on OH from the nominal 6kV. Change PF1B setting to provide 10kA capability (from the present 5kV).

4.2 Configure PF1B for 2kV operation to drive current in the anti-clockwise direction as seen from above (normal for CHI). Configure PF2L for 2kV operation.

4.3 Setup EC-PI for maximum power operation from t = -5 to +15ms.

4.4 Increase the gain on the Mirnov coils by connecting the appropriate cables and changing the attenuation factor. For the flux savings portion of the experiment which begins in step 3.3, return the Mirnov coil gains to their standard values normally used for inductive discharges.

LDGIS system checks

4.5 Ensure LDGIS is in the “Puff” mode and tested the day before the experiments.

4.6 Ensure LDGIS gas pressure interlocks (PE107, PE104) are functional.

4.7 Set LDGIS Helium line pressure to 100Psig.

4.8 Ensure 1800 Torr D2 regulator gas pressure in LDGIS system.

4.9 Ensure LDGIS interlocks are in the “green” state prior to conducting any “hi-pot” tests.

4.10 Ensure that NSTX machine high-pots are not conducted with the CHI capacitors connected to NSTX, as the capacitors have a rating of only 2kV.

4.11 Ensure that NSTX machine high-pots are not conducted with the new CHI snubber connected to the machine as this capacitor has a rating of only 2kV.

Pre-operational checklist

4.12 Ensure MIG and Penning gauges are selected for operation.

4.13 Remove CHI jumpers.

4.14 Check TF interlock is set to 10kA.

4.15 Check for the appearance of ionization light on the fast camera during the EC-PI pulse to ensure correct triggering.

5. Planned analysis

The magnetic analysis codes MFIT, EFIT and ESC will be used to analyze the plasma equilibrium. It is hoped to be able to use data from the MPTS and other kinetic diagnostics to supplement the magnetic data for the assessment of flux closure. 6.

6. Planned publication of results

These results will be published at meetings and in journal articles.

PHYSICS OPERATIONS REQUEST

Title**: Transient CHI Startup** **OP-XP-406**

Machine conditions (specify ranges as appropriate)

I_{TF} (kA): **35 – 40** Flattop start/stop (s): **-0.05 / 0.45**

I_P (MA): **0.5** Flattop start/stop (s): **n/a**

Configuration: **CHI transitioning to CS limited**

Outer gap (m): **NA**, Inner gap (m): **NA**

Elongation κ: **NA**, Triangularity δ: **NA**

Z position (m): **0**

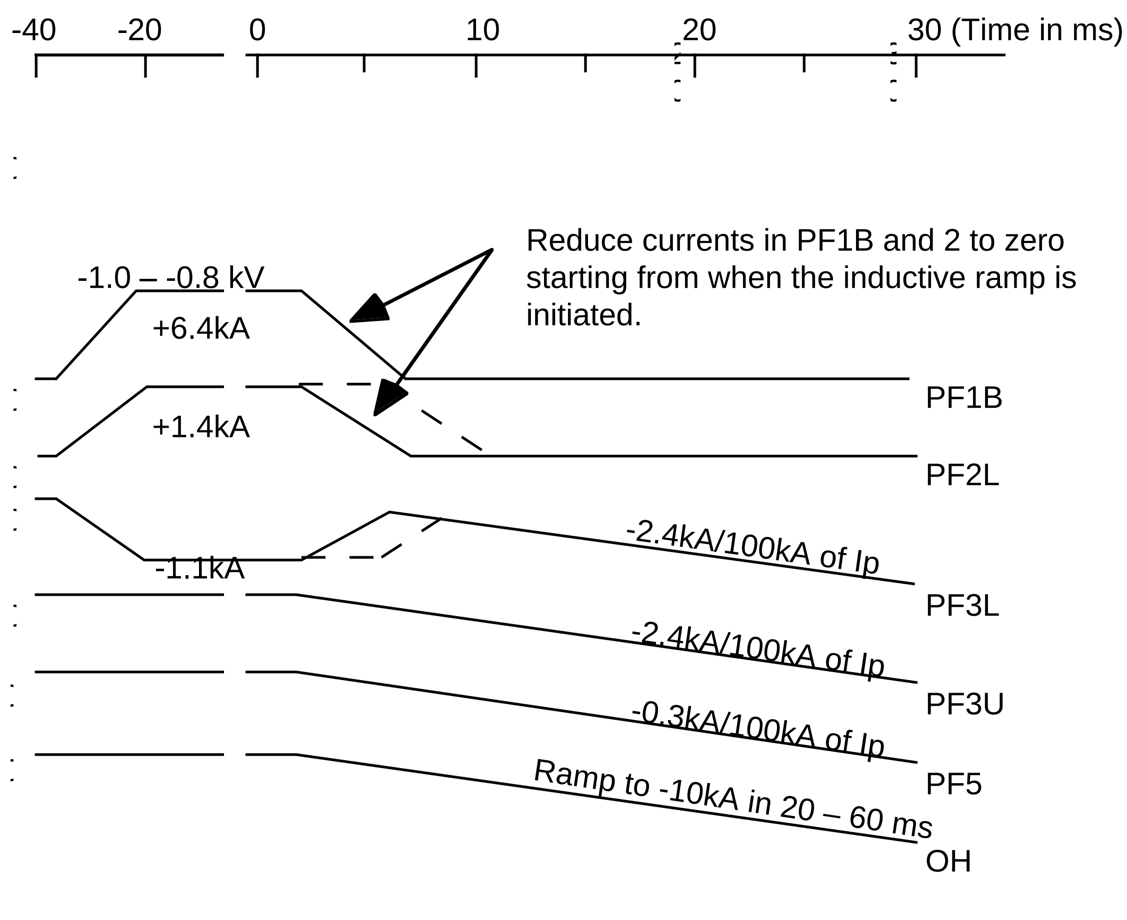
Gas Species: **D**, Injector: **LDGIS + LFS midplane**

NBI – **Off**

ICRF – **Off**

CHI: **On**

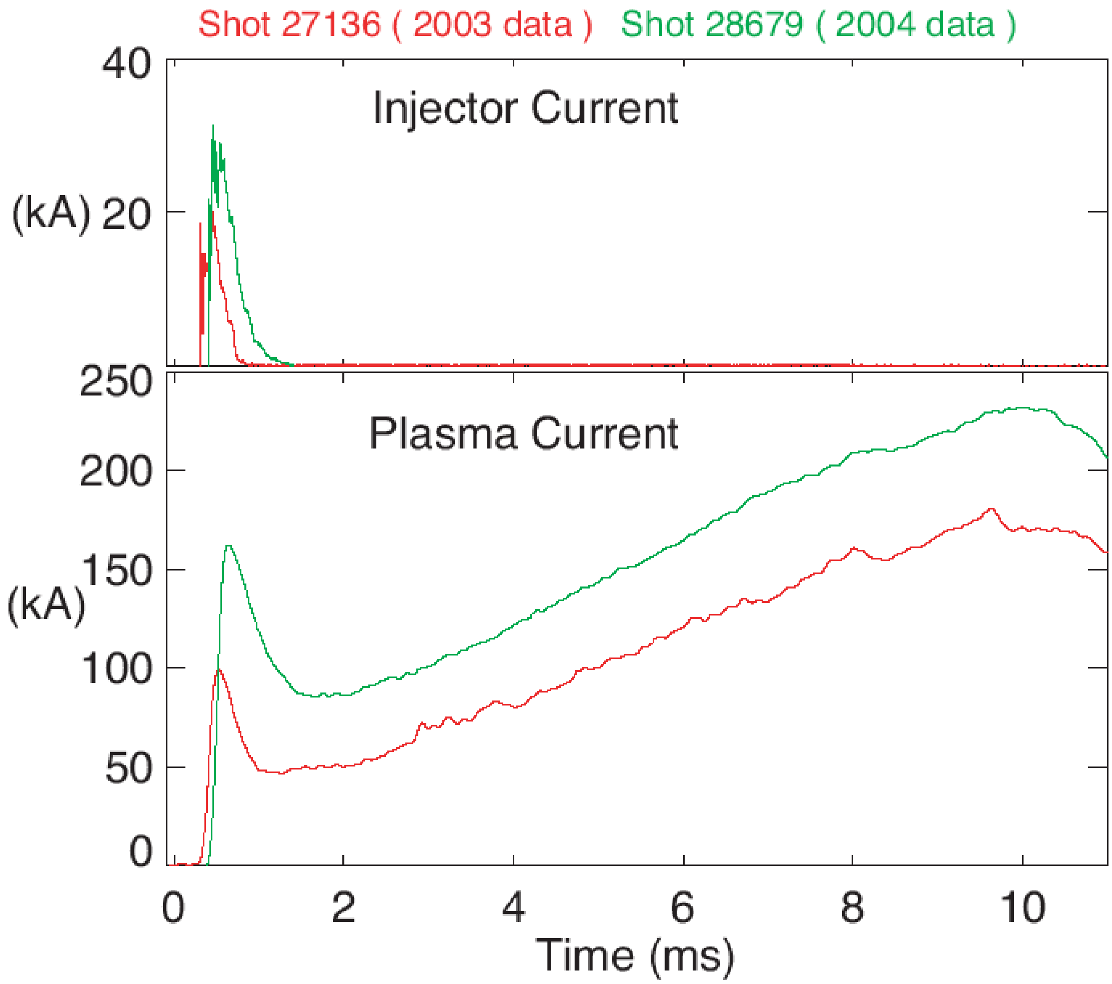
Shot numbers for setup: **102539, 109635 and neighboring shots.** Timing shown below

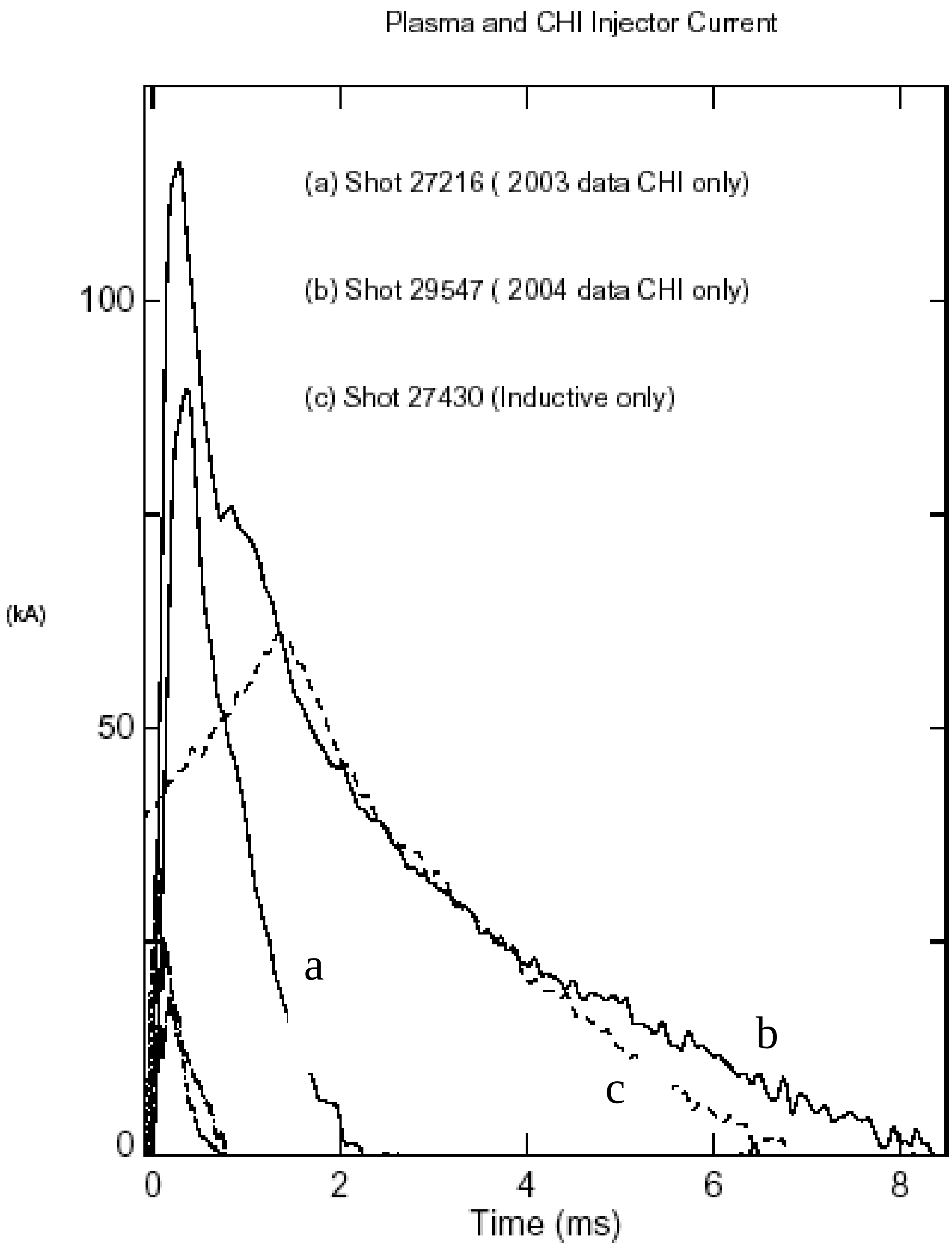


DIAGNOSTIC CHECKLIST

Title**: Transient CHI Startup** **OP-XP-406**

Diagnostic	**Need**	**Desire**	**Instructions**
Bolometer – tangential array	yes		* Use when reproducible conditions achieved
Bolometer array - divertor		yes	
CHERS			
Diamagnetism	yes		
Divertor fast camera		yes	
EBW radiometer			
Edge pressure gauges	yes		
Edge rotation spectroscopy		yes	*
Fast lost ion probes			
Filterscopes		yes	
FIReTIP		yes	*
Gas puff imaging			
H_a camera - 1D		yes	*
Infrared cameras		yes	
Interferometer - 1 mm			
Langmuir probe array			
Magnetics - Flux loops	yes		
Magnetics - Locked modes			
Magnetics - pickup coils	yes		
Magnetics - Rogowski coils	yes		
Magnetics - RWM sensors			
Mirnov coils – high frequency	yes		
MSE			
Neutral particle analyzer			
Neutron measurements			
Plasma TV	yes		
Reciprocating probe			
Reflectometer – core			
Reflectometer - SOL			
SPRED		yes	
Thomson scattering		yes	*
Ultrasoft X-ray arrays		yes	*
Visible bremsstrahlung det.		yes	*
Visible spectrometer (VIPS)		yes	*
X-ray crystal spectrometer - H			
X-ray crystal spectrometer - V			
X-ray GEM camera		yes	*
X-ray pinhole camera		yes	*


Shot 27136 (2003 data)
Shot 28679 (2004 data)
Injector Current
(kA)
40
20
250
Plasma Current
200
150
(kA)
100
50
0
0
2
4
6
8
10
Time (ms)


Plasma and CHI Injector Current
(a) Shot 27216 (2003 data CHI only)
(b) Shot 29547 (2004 data CHI only)
(c) Shot 27430 (Inductive only)
(kA)
100
50
0
0
2
4
6
8
Time (ms)
a
b
c