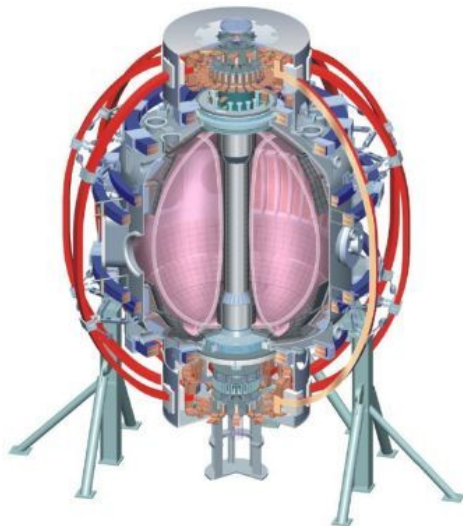


ASC XP-954

Early error-field correction in long-pulse plasmas

J. Menard, S. Gerhardt, D. Gates

PPPL
July 28, 2009



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U Quebec

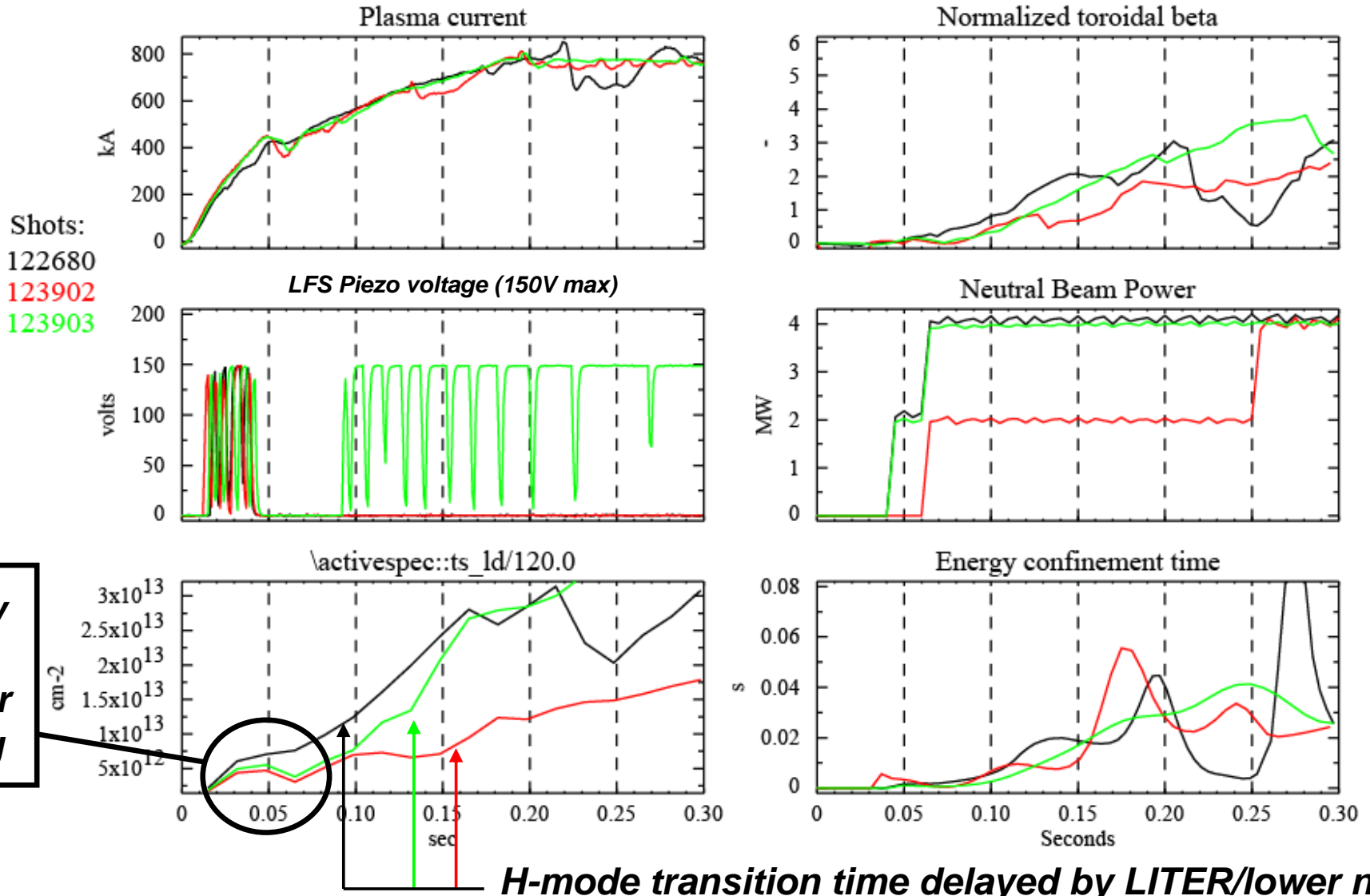
Motivation for “Early error-field correction in long-pulse plasmas”

- Insufficient fueling during LiTER generally results in “unstable” plasma early in discharge
 - Commonly attributed to “locked-modes”
 - Likely seeded by intrinsic error fields
 - But there are other effects of LiTER:
 - Confinement improvement from Li \rightarrow hit beta limit at fixed P_{NBI}
 - Delayed H-mode mode, likely due to reduced density
 - Most (but not all!) EFC XPs rightly focused on sustaining high beta
 - Strong fueling during high-evap LiTER defeats purpose of Li
 - May not even be possible during (effective) LLD operation
- Reduced early EF could reduce mode locking, lower P_{LH}
 - Now “know” $n=3$ EF is from PF5 \rightarrow early correction easy to test
 - $n=1$ EF caused by $\text{OH} \times \text{TF}$, and have correction algorithm in PCS
 - Try to get NBI-CD data at lower n_e for FY09 milestone/ITPA
 - Possibility of new operational regimes

Insufficient fueling during LiTER consistently leads to delayed (or no) early H-mode, and can cause early disruption

Old XP701 data...
(there are certainly better and more recent examples)

Black → reference discharge w/o LITER from 2007
 Red → with LITER (different beam programming unfortunately)
 Green → Strong LFS fueling needed in I_p ramp to match reference



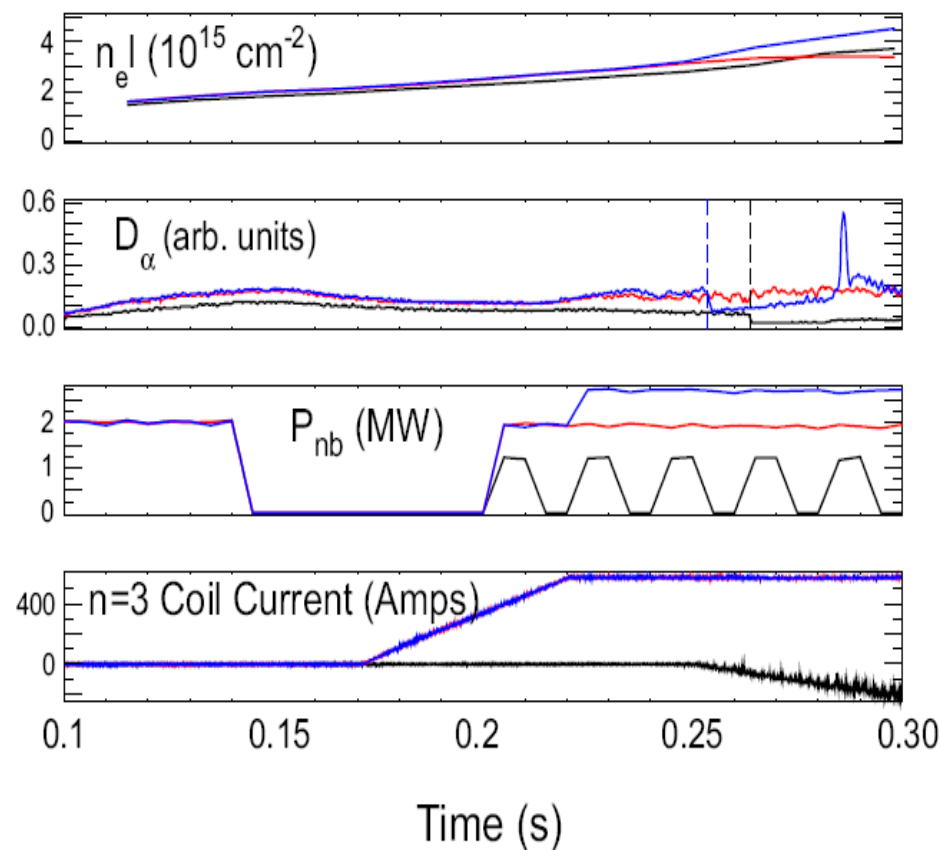
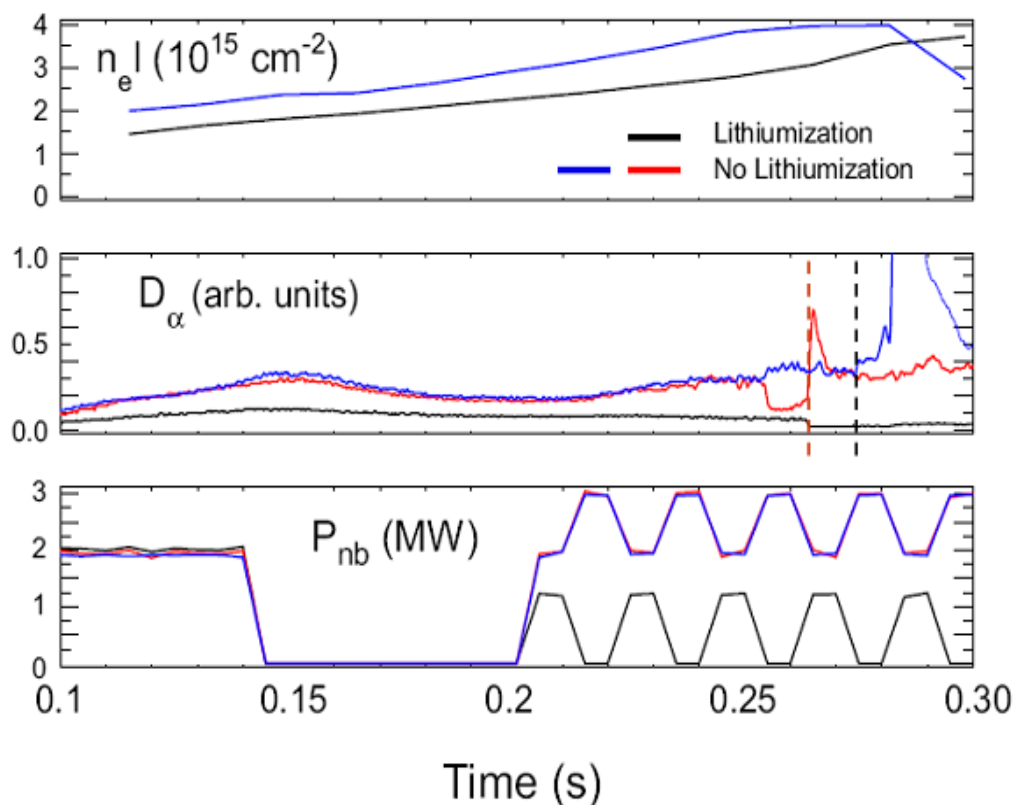
Early density reduced by factor of 2 for same fueling

H-mode transition time delayed by LITER/lower n_e

Kaye XPs show Li evaporation lowers the L-H threshold power, and higher EF raises L-H threshold power

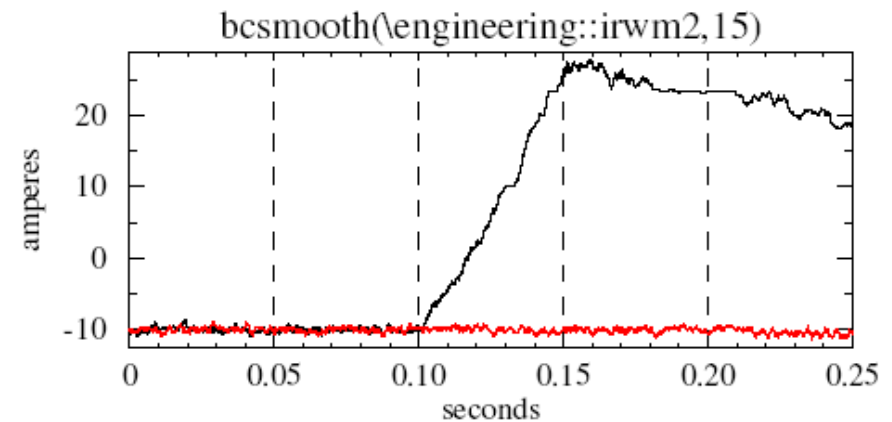
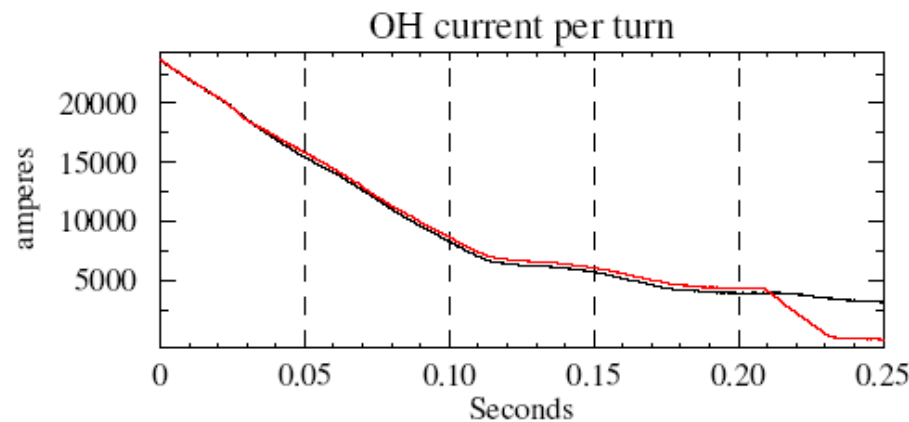
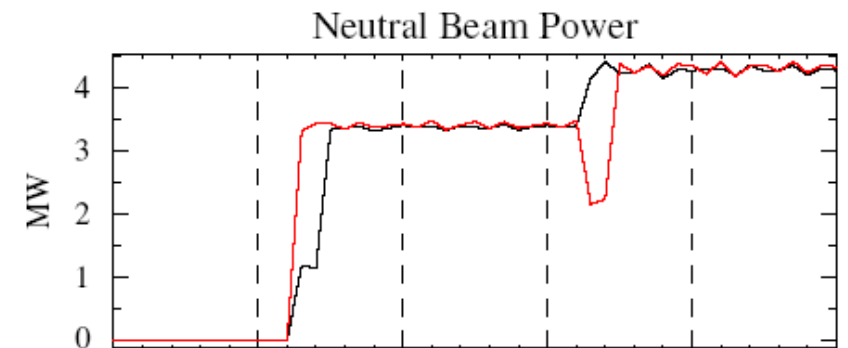
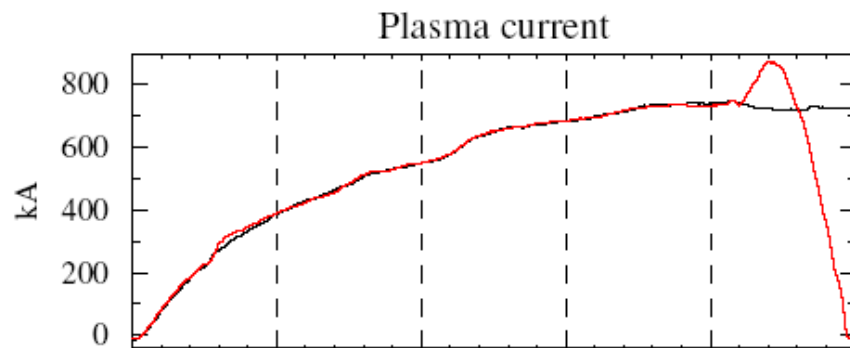
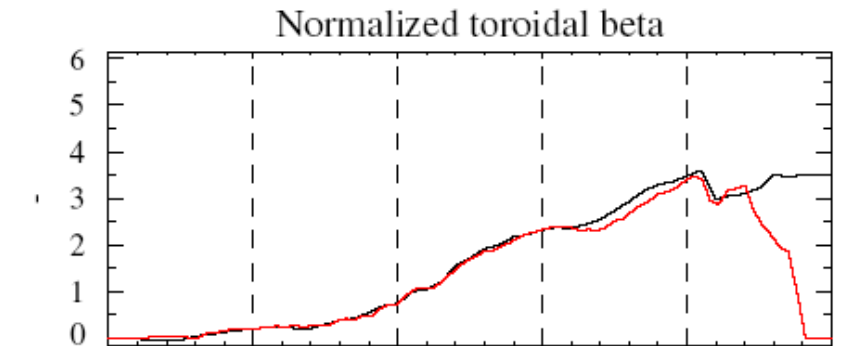
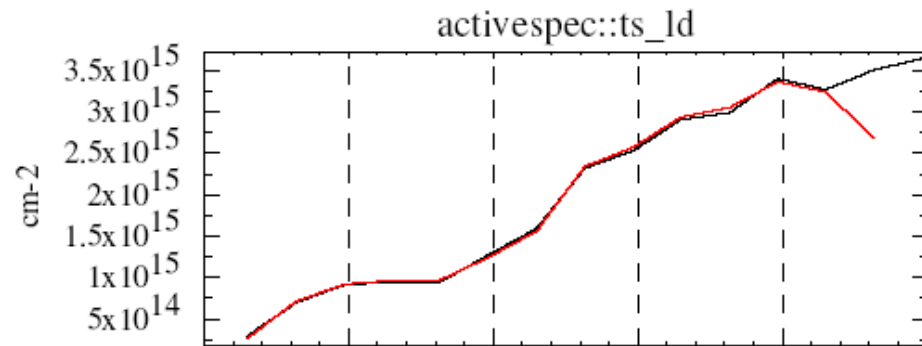
$P_{LH} \sim 2.5$ MW NBI w/o Li evap
 < 0.6 MW NBI w/ Li evap

- P_{L-H} increases from $P_{NBI} \sim 0.6$ MW to 2.5 MW for 2-4 \times higher $n=3$ (including intrinsic $n=3$ EF)



XP614 showed applying early n=1 EFC can make early phase less disruptive

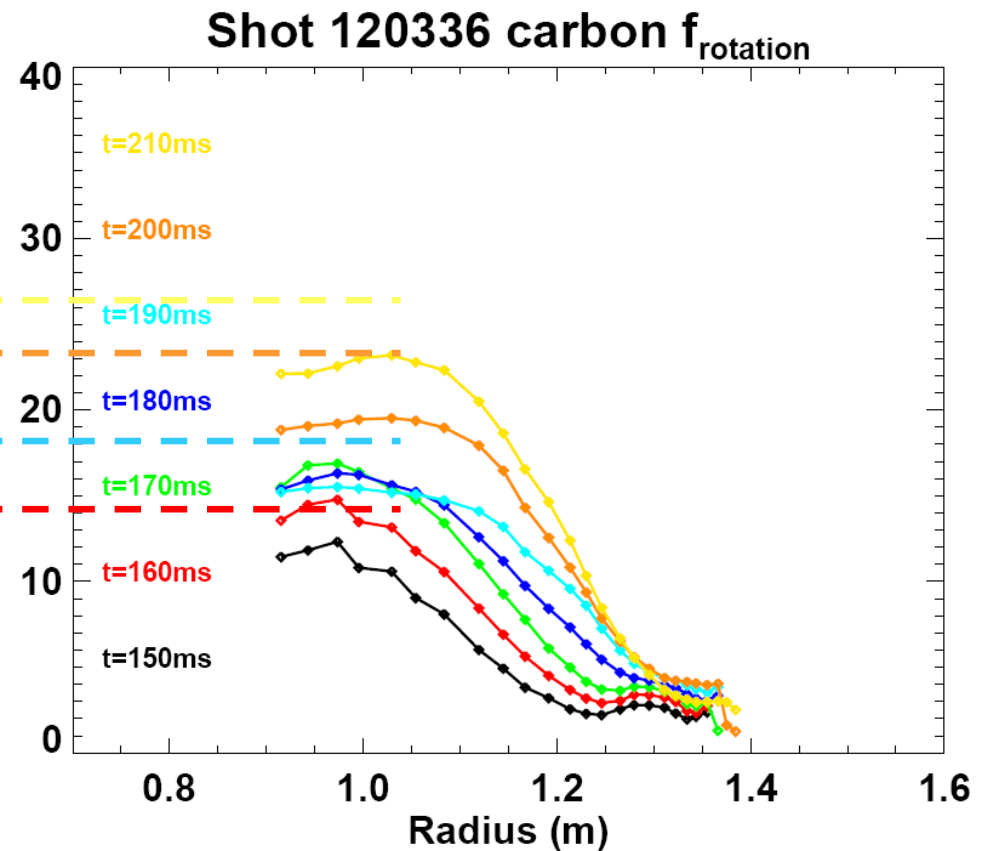
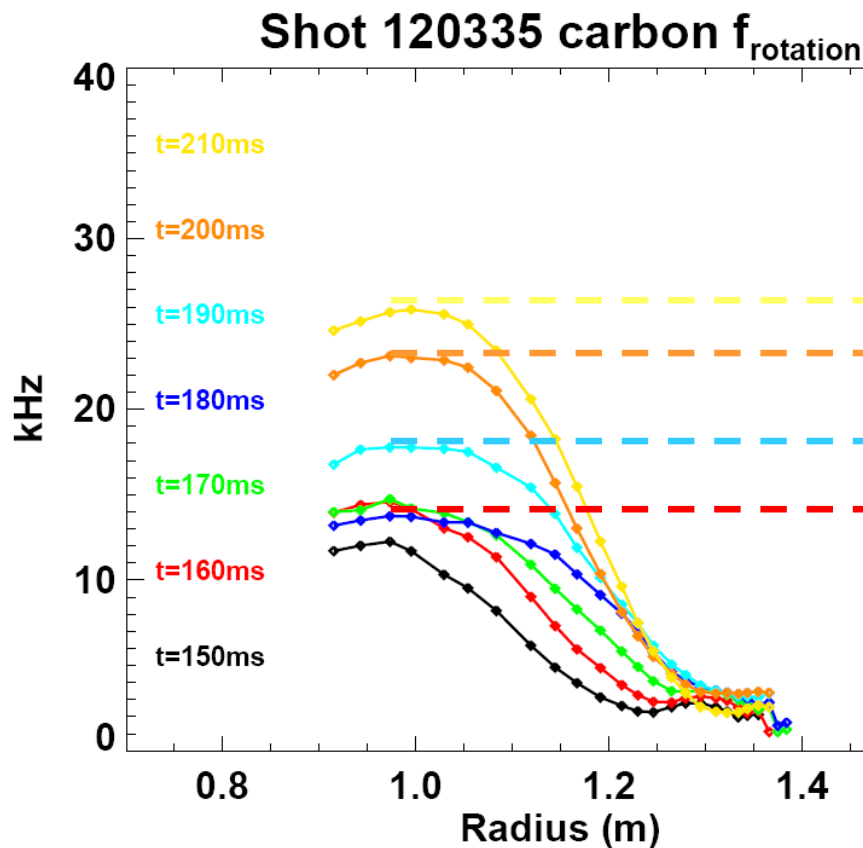
Shots:
120335
120336



XP614 demonstrated applying early n=1 EFC (based on OHxTF intrinsic EF) can increase early plasma rotation

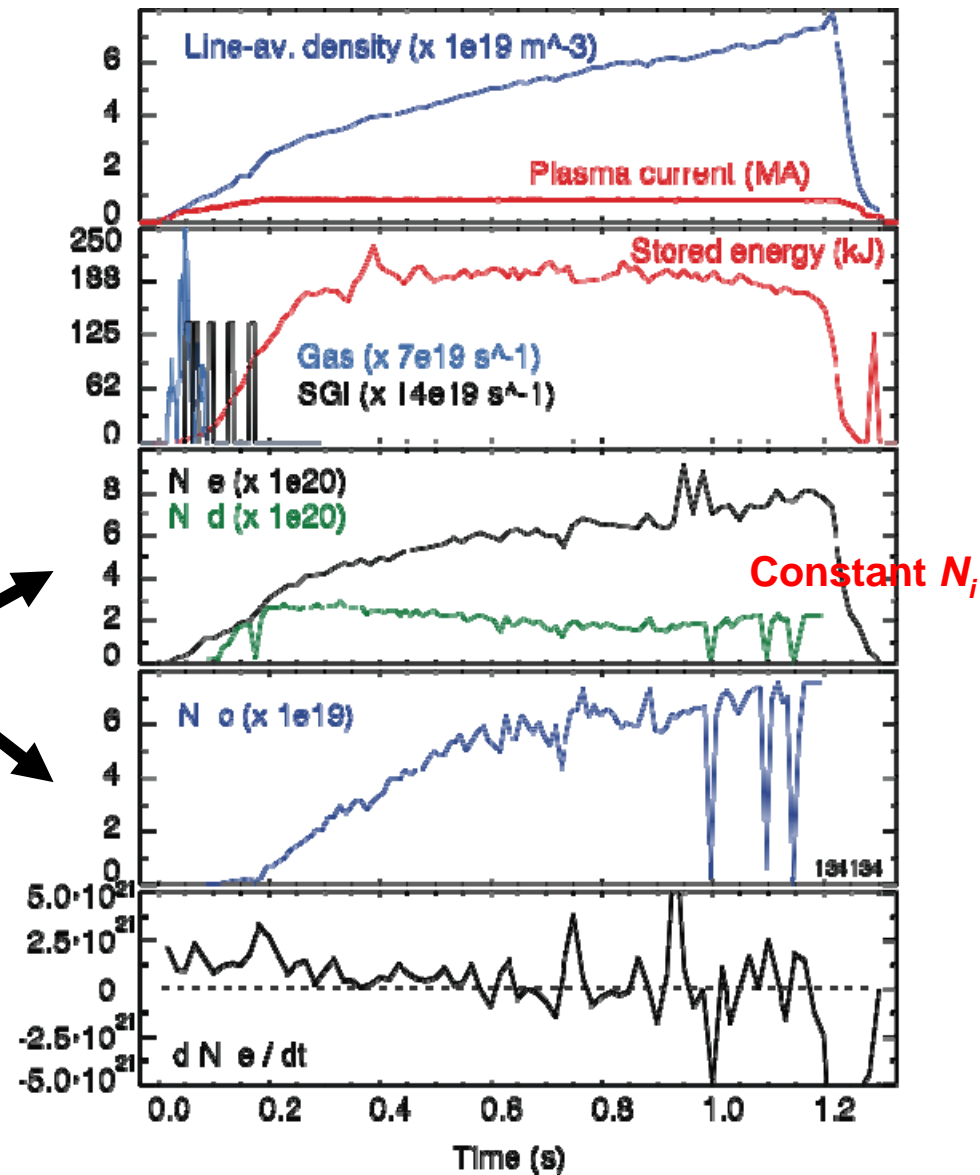
Predictive OHxTF EFC on by t=150ms

EFC off



SGI+LFS can improve early n_e control in long-pulse plasmas (XP-912 Soukhanovskii et al.)

- SGI-only fueling scenario with ion density control
 - N_i constant, while N_e is rising due to carbon; LITER at 9 mg/min
- SGI could provide early density control, which is useful in this experiment



Run Plan

1. Reproduce a long-pulse and late-MHD-free discharge at 750-800kA **(3 shots)**
 1. Start with evaporation rate = 10mg/min (or value from best recent shot)
 1. Use LITER shutter to fix evaporation duration at 10min with 12min shot cycle
 2. Use 129125 or best XP836/948 discharge with 1.2-1.4s period without low-n MHD
 3. Use 16cm outer gaps to reduce impurity density and Z_{eff}
 2. Increase evaporation rate to 20mg/min (if necessary)
 1. Increase fueling as needed to achieve similar early density and long pulse duration
2. Reduce high-field side gas in 200 Torr steps to trigger early MHD event/mode locking
 1. Reduce early NBI power if beta-limit is reached, but maintain early H-mode
 2. Start n=3 EF correction at t=20ms with gain = 200A/10kA (IRWM/IPF5) **(3 shots)**
 1. Assess locking behavior and rotation modification from n=3 EFC
 3. With n=3 EFC off, turn on n=1 OHxTF EFC from XP 614 (120335) **(6 shots)**
 1. Ramp-down OHxTF EFC by t=400ms
 2. Scan timing of OHxTF correction ramp-up in steps of 20ms (moving earlier)
 3. Assess locking behavior and rotation modification from n=3 EFC
 4. Combine early n=3 and n=1 EFC, and assess mode-locking and rotation **(4 shots)**

2nd HALF DAY

1. Further reduce early fueling to find threshold of mode locking/MHD **(4 shots)**
2. Working at an early density near and above locking threshold:
 1. Attempt to produce an MHD-stable discharge with reduced late density replacing the LFS/HFS fueling with SGI-based fueling from XP-912 shot 134134 **(3 shots)**
 2. Increase LITER evaporation rate to 30mg/min, adjust SGI fueling for stability **(5 shots)**
3. Increase I_p to 0.9MA and 1MA to assess n_e evolution at higher current **(4 shots)**

**Princeton Plasma Physics Laboratory
NSTX Experimental Proposal**

Early error-field correction in long-pulse plasmas

OP-XP-954

Revision: **0**

Effective Date: **July 30, 2009**
(Approval date unless otherwise stipulated)

Expiration Date: **July 30, 2011**
(2 yrs. unless otherwise stipulated)

PROPOSAL APPROVALS

Responsible Author: Jon Menard

Date July 30, 2009

ATI – ET Group Leader: David Gates

Date July 30, 2009

RLM - Run Coordinator: Roger Raman

Date July 30, 2009

Responsible Division: Experimental Research Operations

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

TITLE: Early error-field correction in long-pulse plasmas
AUTHORS: J. Menard, S. Gerhardt, D. Gates

No. **OP-XP-954**
DATE: **07/30/2009**

1. Overview of planned experiment

The combination of active suppression of $n=1$ RFA, $n=3$ pre-programmed error field correction (EFC), and LITER have produced record plasma pulse-durations in NSTX. High elongation + EFC + LITER have produced record poloidal beta and record low flux-consumption in NSTX. This experiment will attempt to systematically lower the plasma density while avoiding disruptive MHD activity by optimizing early error-field correction to reduce mode locking. Reduced density could increase the NBI CD efficiency, and if T_e increases at reduced density, density reduction could increase the conductivity and further increase NBI-CD and reduce OH flux consumption. This experiment will focus on discharges with little or no late MHD activity to simplify NBICD analysis, and with sufficient flat-top that the inductive and non-inductive profiles become equilibrated.

2. Theoretical/ empirical justification

Reduced density is predicted to increase beam current drive efficiency, and higher T_e at reduced density could further increase NBI-CD efficiency and conductivity – all resulting in increased pulse duration and higher non-inductive fraction plasmas. Higher non-inductive fraction is important for improved operation of NSTX and NSTX-Upgrade and is essential to future ST devices such as NHTX and ST-CTF. Variations in plasma density should modify the beam current drive fraction at fixed heating power, thereby providing data for the ITPA IOS group for validating beam current drive models. Finally, this experiment is important for the anticipated operation of the liquid lithium divertor (LLD) which could result in reduced early density and locked-modes if the LLD acts as an effective pump.

3. Experimental run plan

FIRST ½ RUN DAY

- A. Reproduce a long-pulse and late-MHD-free discharge at 750-800kA (3 shots)
 - 1. Start with evaporation rate = 10mg/min
 - i. Use LITER shutter to fix evaporation duration at 10min with 12min shot cycle
 - ii. Use 129125 or best XP836/948 discharge with 1.2-1.4s period without low-n MHD
 - iii. Use 16cm outer gaps to reduce impurity density and Zeff
 - 2. Increase evaporation rate to 20mg/min
 - i. Increase fueling as needed to achieve similar early density and long pulse duration
- B. Reduce high-field side gas in 200 Torr steps to trigger early MHD event/mode locking
 - 1. Reduce early NBI power if beta-limit is reached, but maintain early H-mode
 - 2. Start $n=3$ EF correction at $t=20$ ms with gain = 200A/10kA (I_{RWM}/I_{PF5}) (3 shots)
 - i. Assess locking behavior and rotation modification from $n=3$ EFC
 - 3. With $n=3$ EFC off, turn on $n=1$ OHxTF EFC from XP 614 (120335) (6 shots)
 - i. Ramp-down OHxTF EFC by $t=400$ ms
 - ii. Scan timing of OHxTF correction ramp-up in steps of 20ms (moving earlier)
 - iii. Assess locking behavior and rotation modification from $n=3$ EFC
 - 4. Combine early $n=3$ and $n=1$ EFC, and assess mode-locking and rotation (4 shots)

SECOND ½ RUN DAY

- C. Further reduce early fueling to find threshold where until mode locking/MHD occurs (4 shots)
- D. Working at an early density near and above locking threshold:
 - 1. Attempt to produce an MHD-stable discharge with reduced late density by replacing the LFS/HFS fueling with SGI-based fueling from XP-912 shot 134134 (3 shots)
 - 2. Increase LITER evaporation rate to 30mg/min, adjust SGI fueling for stability (5 shots)
- E. Time permitting, increase I_p to 0.9MA and 1MA to assess n_e evolution at higher current (4 shots)

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

The usual diagnostic capabilities are required, NBI voltage on A, B, C = 90, 90, 80kV.

5. Planned analysis

EFIT/LRDFIT, TRANSP, MPTS, CHERS, and RWM/EF sensor analysis will be performed.

6. Planned publication of results

Results will be published in conference proceedings and/or journal such as Nuclear Fusion or Physics of Plasmas within one year of experiment.

PHYSICS OPERATIONS REQUEST

TITLE: Early error-field correction in long-pulse plasmas
 AUTHORS: **J. Menard, S. Gerhardt, D. Gates**

No. **OP-XP-954**
 DATE: **07/30/2009**

Machine conditions (specify ranges as appropriate)

I_{TF} (kA): up to **63kA** Flattop start/stop (s): **0.0, ~2s**

I_p (MA): **0.75 or 0.8MA** Flattop start/stop (s): **0.2, ~2s**

Configuration: **DN / LSN**

Outer gap (m): **15cm** Inner gap (m): **2-8cm**

Elongation κ : **2.4-2.7** Upper/lower triangularity δ : **0.75 / 0.5**

Z position (m): **0cm**

Gas Species: **D** Injector(s): **CS midplane, outer midplane, SGI**

NBI Species: **D** Sources: **A, B, C** Voltage (kV): **90, 90, 80kV** Duration (s): **2s**

ICRF Power (MW): **0** Phasing: **0** Duration (s): **0**

CHI: **Off** Bank capacitance (mF):

LITER: **On – 10-30 mg/min**

Either: List previous shot numbers for setup: 129125 or more recent discharge

Or: Sketch the desired time profiles, including inner and outer gaps, κ , δ , heating, fuelling, etc. as appropriate. Accurately label the sketch with times and values.

DIAGNOSTIC CHECKLIST

TITLE: Early error-field correction in long-pulse plasmas

No. **OP-XP-954**

AUTHORS: **J. Menard, S. Gerhardt, D. Gates**

DATE: **07/30/2009**

Note special diagnostic requirements in Sec. 4

Note special diagnostic requirements in Sec. 4

Diagnostic	Need	Want
Bolometer – tangential array		
Bolometer – divertor		
CHERS – toroidal	X	
CHERS – poloidal	X	
Divertor fast camera		
Dust detector		
EBW radiometers		
Edge deposition monitors		
Edge neutral density diag.		
Edge pressure gauges		
Edge rotation diagnostic		
Fast ion D_alpha - FIDA		
Fast lost ion probes - IFLIP		
Fast lost ion probes - SFLIP		
Filterscopes		
FIReTIP		
Gas puff imaging		
H α camera - 1D		
High-k scattering		
Infrared cameras		
Interferometer - 1 mm		
Langmuir probes – divertor		
Langmuir probes – BEaP		
Langmuir probes – RF ant.		
Magnetics – Diamagnetism	X	
Magnetics – Flux loops	X	
Magnetics – Locked modes	X	
Magnetics – Pickup coils	X	
Magnetics – Rogowski coils	X	
Magnetics – Halo currents		
Magnetics – RWM sensors	X	
Mirnov coils – high f.	X	
Mirnov coils – poloidal array	X	
Mirnov coils – toroidal array	X	
Mirnov coils – 3-axis proto.		

Diagnostic	Need	Want
MSE	X	
NPA – ExB scanning		
NPA – solid state		
Neutron measurements	X	
Plasma TV		
Reciprocating probe		
Reflectometer – 65GHz		
Reflectometer – correlation		
Reflectometer – FM/CW		
Reflectometer – fixed f		
Reflectometer – SOL		
RF edge probes		
Spectrometer – SPRED		
Spectrometer – VIPS		
SWIFT – 2D flow		
Thomson scattering	X	
Ultrasoft X-ray arrays	X	
Ultrasoft X-rays – bicolor		
Ultrasoft X-rays – TG spectr.		
Visible bremsstrahlung det.		
X-ray crystal spectrom. – H		
X-ray crystal spectrom. – V		
X-ray fast pinhole camera		
X-ray spectrometer – XEUS		