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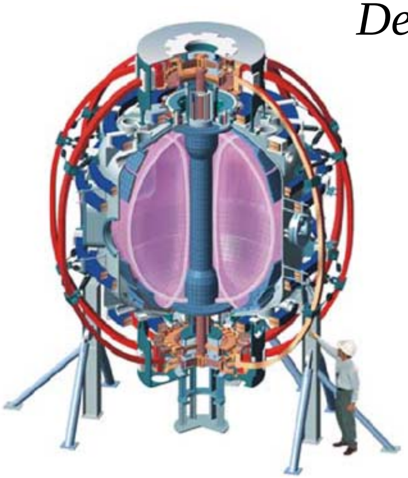
XP1023: Optimized RWM control for high $\langle\beta_N\rangle_{pulse}$ at low collisionality and l_i

S.A. Sabbagh, J.M. Bialek, S.P. Gerhardt, R.E. Bell, J.W. Berkery, B. LeBlanc, J.E. Menard, et al.

Department of Applied Physics and Applied Mathematics, Columbia University, New York, NY, USA

Princeton Plasma Physics Laboratory



NSTX Macrostability TSG Meeting
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Princeton Plasma Physics Laboratory

XP1023: Optimized RWM feedback control for high $\langle\beta_N\rangle_{pulse}$ at low collisionality and l_i

- **Motivation**
  - Next-step ST devices (including the planned upgrade of NSTX) aim to operate at plasma collisionality and l_i, below usual NSTX levels
  - 2009 XP948 showed significantly higher RWM activity, lower β_N limit, in reduced l_i plasmas (l_i ~ 0.45 and below)
- **Goals / Approach**
  - Improve reliability of RWM stabilization at low l_i, understand impact of reduced plasma collisionality using new LLD capability
    - Assess upper/lower RWM B_p, B_r sensors, with NEW AC compensation in feedback
    - B_r sensor feedback provides RFA correction, B_p provide RWM stabilization
    - Address differences in experimental vs. single mode vs. multi-mode RWM model expectation of best spatial phase offset of lower / upper Bp sensors
    - Examine stabilization of unfavorable ω_ϕ profiles for RWM stability
    - Provide superior control system settings for general NSTX XPs
- **Addresses**
  - NSTX Research Milestone R(10-1), ReNeW Thrust 16.3, 16.4
  - ITPA joint experiment MDC-2, MDC-17; 2010 IAEA FEC submission

Steady-State STs Targeted to Operate High B_N/l_i

Common Features of Present & Future STs

- High-κ and strong shaping.
- β_N values at or above the no-wall limit.
- Bootstrap fractions ≥50%.
- Confinement ≥ H-mode scaling.
- Comprehensive shape, profile and stability control.

Configuration Specific Features

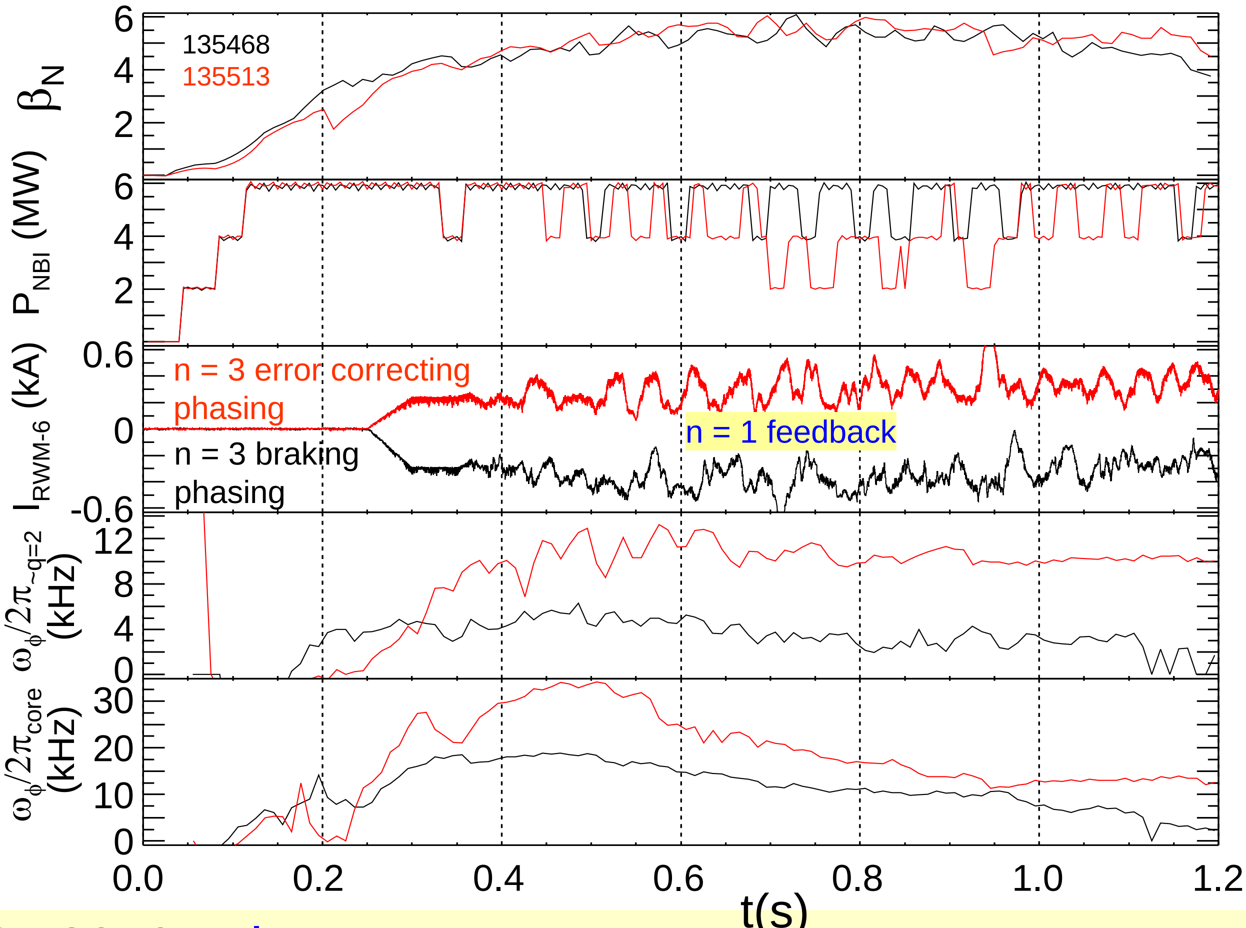
- Range of normalized currents.
- Wide range of NBCD fractions.
- Wide range of normalized densities.

[1]: Peng, et al, PPCF 2005, Phase #3, 2 MW/m[2] NWL
[2]: ARIES-ST

	NSTX	NSTX-U	NHTX	ST-CTF[1]	ST-Demo[2]
κ	2.6	2.7	3	3.1	3.5
β_N	5.7	5.7	5	4-6	7.5
$l_i(1)$	0.55	0.65	0.6	0.35	0.25
I_N	2.5	2.1	3	4.5	6.7
f_{GW}	0.8	0.7	0.45	0.28	0.8
f_{BS}	0.54	0.7	0.7	0.5	0.96
f_{NBCD}	15	30	0.3	0.5	0
H_{98}	1.	1.2	1.3	1.5	1.3

S.P. Gerhardt (NSTX PAC-27)

β_N feedback combined with n = 1 RWM control to reduce β_N fluctuations at varied plasma rotation levels



Addresses PAC25-17-(1)

- Prelude to ω_ϕ control
  - Reduced ω_ϕ by n = 3 braking does not defeat FB control
  - Increased P_{NBI} needed at lower ω_ϕ
- Steady β_N established over long pulse
  - independent of ω_ϕ over a large range

- 2010+ plans
  - XP to investigate lower plasma rotation, l_i, collisionality

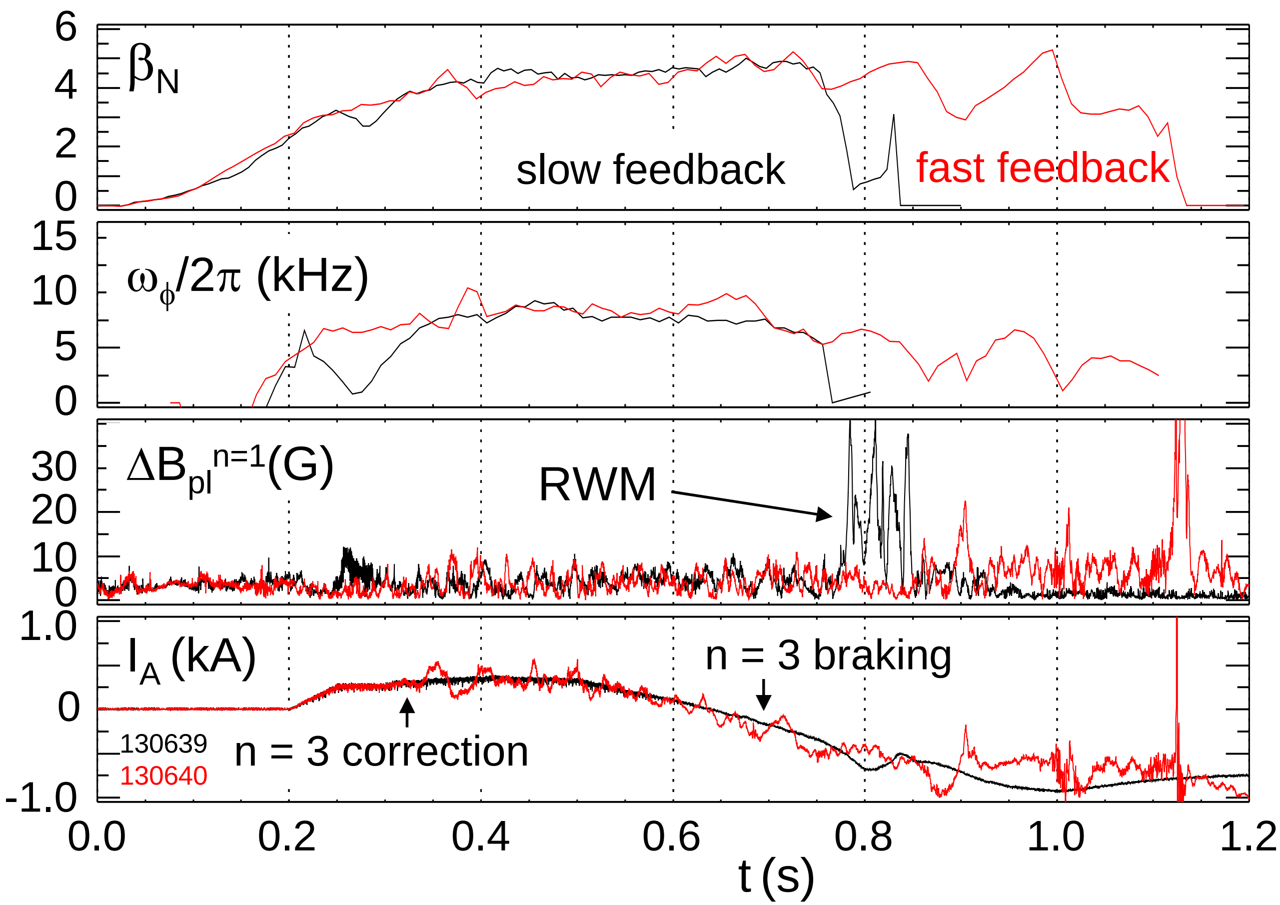
S.A. Sabbagh, S. Gerhardt, D. Mastrovito, D. Gates

NSTX

XP934: Sabbagh (Columbia U.)

High β_N difficult to access at low plasma rotation when RWM feedback response sufficiently slowed

Addresses PAC25-17-(1); ITPA MDC-2

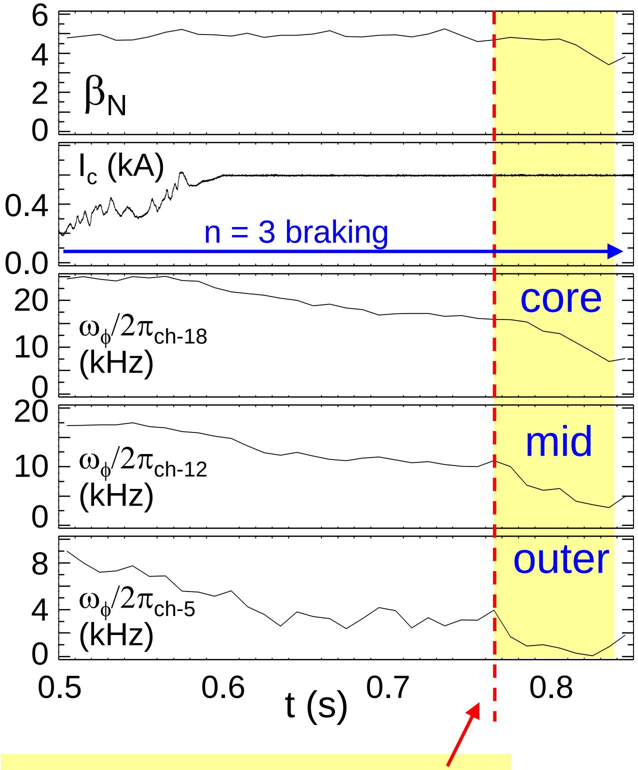


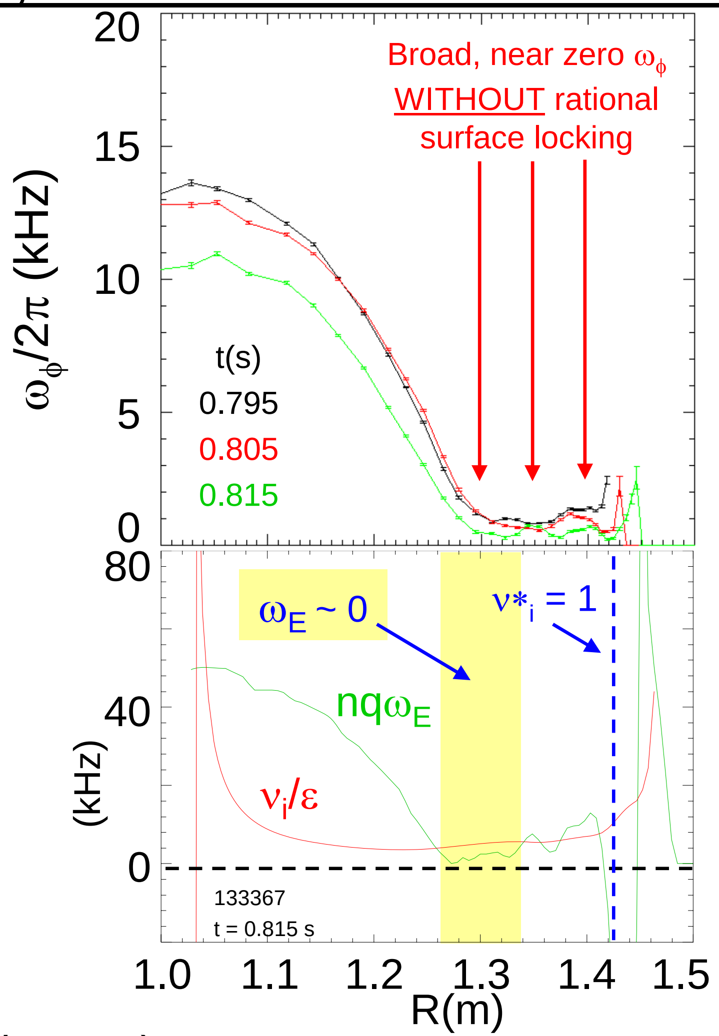
S.A. Sabbagh, et al, NF **50** (2010) 025020

- Low ω_ϕ access study for ITER
  - used n = 3 braking
- n = 1 feedback response speed significant
  - "fast" feedback allows high β_N at low V_ϕ
  - "slow" n = 1 "error field correction" (75ms smoothing of control current) suffers RWM
- Large β_N excursions at low ω_ϕ
  - Related to excursions in ω_ϕ as well (see next slide)
  - Motivated work to reduce β_N variation

NSTX

Rotation control needs to model certain complexities of NTV rotation damping physics, such as behavior at low ω_E

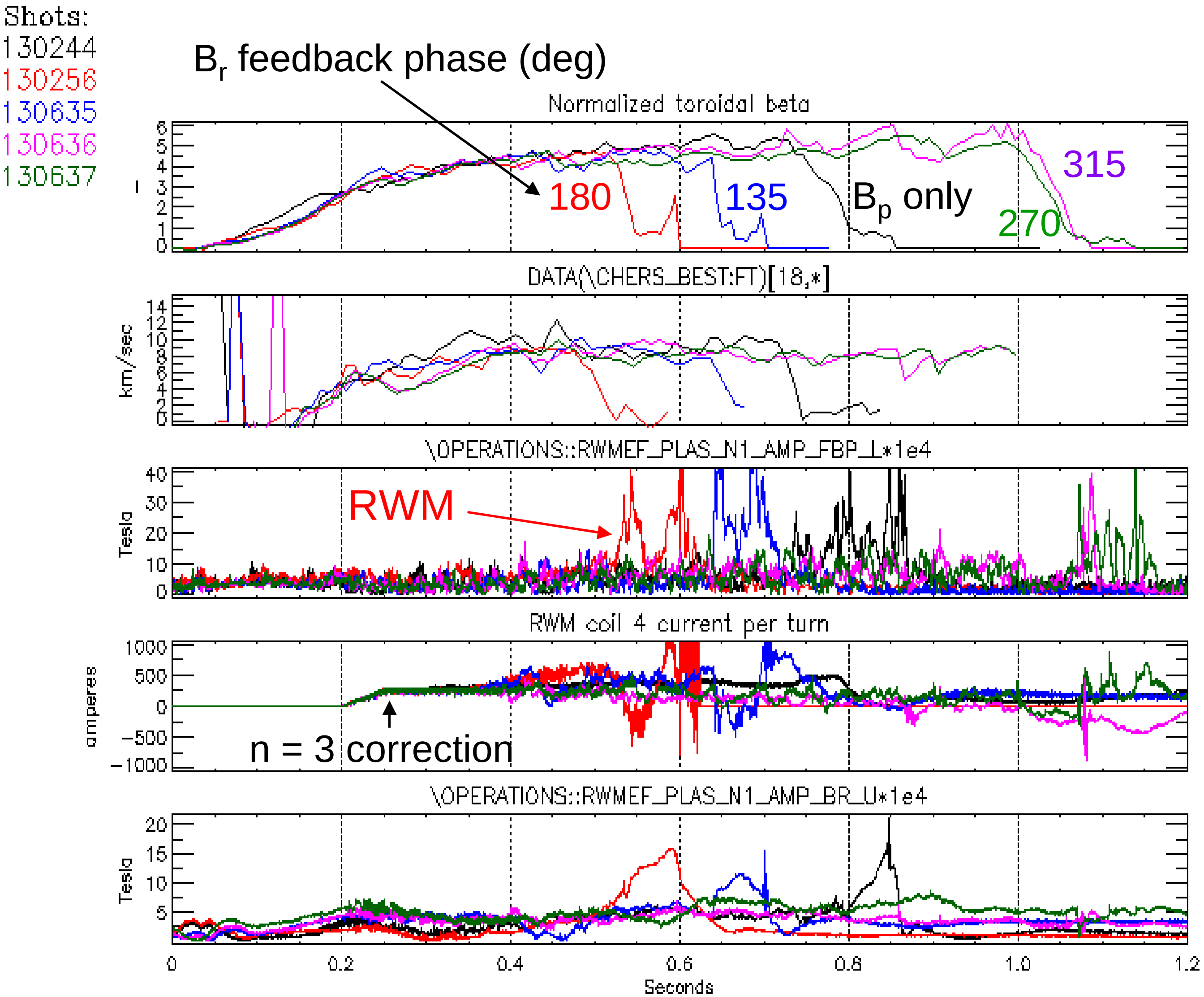




XP933: Sabbagh (Columbia U.)

- Faster braking with
  - Constant β_N, applied n = 3 field
  - No mode activity
- Torque not $\propto 1/\omega_\phi$ (non-resonant)
  - NTV in "1/ν regime" ($|nq\omega_E| < \nu_i/\varepsilon$ and $\nu^*_i < 1$)
  - Stronger braking expected when $\omega_E \sim 0$ (superbanana plateau) (K.C. Shaing et al., PPFC **51** (2009)) – analysis continues

Favorable feedback settings found for B_p + B_r sensors



- B_r feedback phase scan
  - B_r gain, phase varied to find best settings
- New XP
  - Use ~XP948 low l_i target
  - Low ν by LLD
  - Find new favorable RWM FB settings at low l_i, low ν
  - Demonstrate stable long pulse, vary ω_ϕ
  - Request 1 run day

XP802: S.A. Sabbagh

Significant leverage from XPs and (non-invasive) piggyback time will make XP1023 run efficient

- LLD Survey XP
  - Some (perhaps all?) target development will be run in the LLD survey XP
- XP1060 "RFA Suppression With Different Sensors and Time Scales in NSTX" (Gerhardt, et al.)
  - Shot plan of present XP1023 complements XP1060
    - aimed at plasmas with $\beta_N > \beta_N^{no\text{-}wall}$, to attain low l_i with long pulse
    - aimed at optimizing fast feedback
- Piggyback time
  - Evaluation of new compensations on B_p and B_r RWM sensors can be evaluated in piggyback during XPs not using "standard" n = 1 feedback system
    - Additionally – could run on 2nd control computer during another XP that is using n= 1 RWM feedback

XP1023: Optimized RWM feedback control for high $<\beta_N>_{pulse}$ at low collisionality and l_i – shot plan

Task	Number of Shots
0) Piggyback / pre-analysis	
A) Determine best upper/lower RWM sensor spatial offset from experiment (with new compensations), compare to single, multi-mode VALEN expectations; (choose settings for following runs)	-
1) Generate low li and low collisionality targets	
(use low li, ν target from LLD survey XP; optionally fall back on low li, long pulse target from 2009	
A) Establish target plasma (2 or 3 NBI sources)	2
B) Generate unstable RWM (by low l_i, and/or reduce plasma rotation / alter profile by n = 3 braking)	4
C) Vary l_i and/ or collisionality, and/or edge pressure gradient	4
2) Assess optimal settings for n = 1 feedback	
A) feedback phase scan, B_p sensors with new AC compensation; +best setting w/ AC comp. off	6
B) feedback phase scan, B_r sensors, new OHxTF, AC compensation; +best setting w/ AC comp. off	6
C) Introduce β_N feedback to run steady, high $<\beta_N>_{pulse}$	2
3) Generate high $<\beta_N>_{pulse}$ at low ω_E	
A) Generate lowest possible rotation at high β_N with n = 1 feedback on	2
B) Introduce β_N feedback to (A) to run steady, high $<\beta_N>_{pulse}$	2
C) RF Approach: Apply best FB settings above to RF target with $\beta_N > \beta_N^{no-wall}$ (PAC recommendation) (target established in other XPs (e.g. XP1012: LeBlanc RF H-mode XP, etc.)	6

Total: 28; 6

XP1023: Optimized RWM feedback control for high $<\beta_N>_{pulse}$ at low collisionality and l_i – Diagnostics, etc.

- Required diagnostics / capabilities
  - RWM feedback algorithm “miu” available in the PCS
  - RWM coils in standard n = 1,3 configuration
  - CHERS toroidal rotation measurement
  - Thomson scattering
  - MSE
  - Standard magnetics / diamagnetic loop
- Desired diagnostics
  - USXR and ME-SXR
  - FIDA
  - FIReTip
  - Fast camera