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

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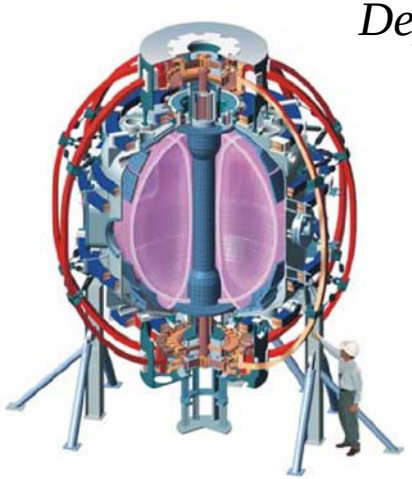

NSTX Team Review

April 12th, 2010

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XP1023: Optimized RWM feedback control for high $<\beta_N>_{pulse}$ 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 to provide RFA correction, B_p to provide RWM control
    - Provide superior control system settings for general NSTX XPs
    - Examine stabilization of unfavorable ω_ϕ profiles for RWM stability at low l_i
    - Address differences in experimental vs. single mode vs. multi-mode RWM model expectation of best spatial phase offset of lower / upper Bp sensors
- 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

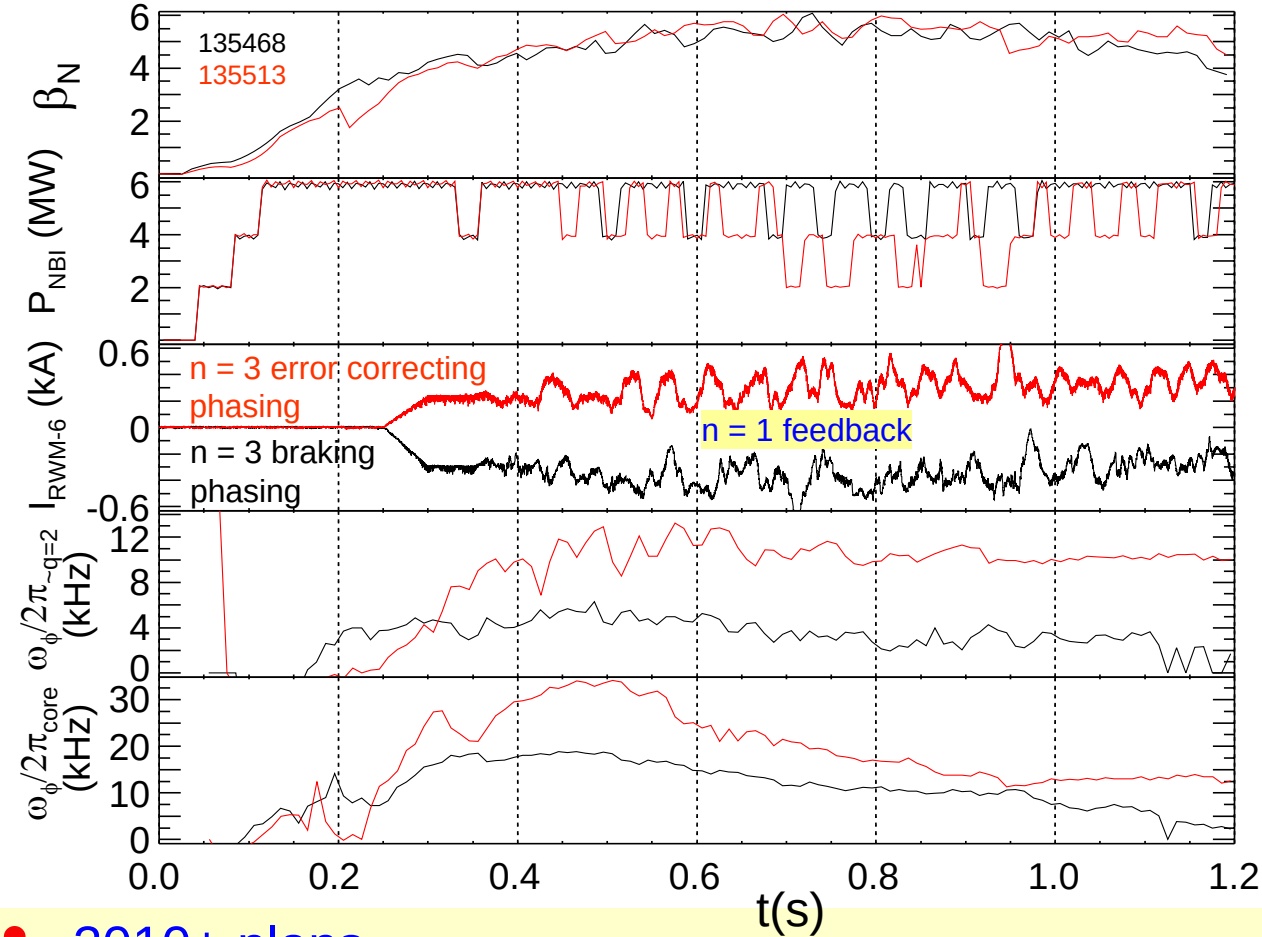
- *Range of normalized currents.*
- *Wide range of NBCD fractions.*
- *Wide range of normalized densities.*

[1]: Peng, et al, PPCF 2005, Phase #3, 2 MW/m² 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



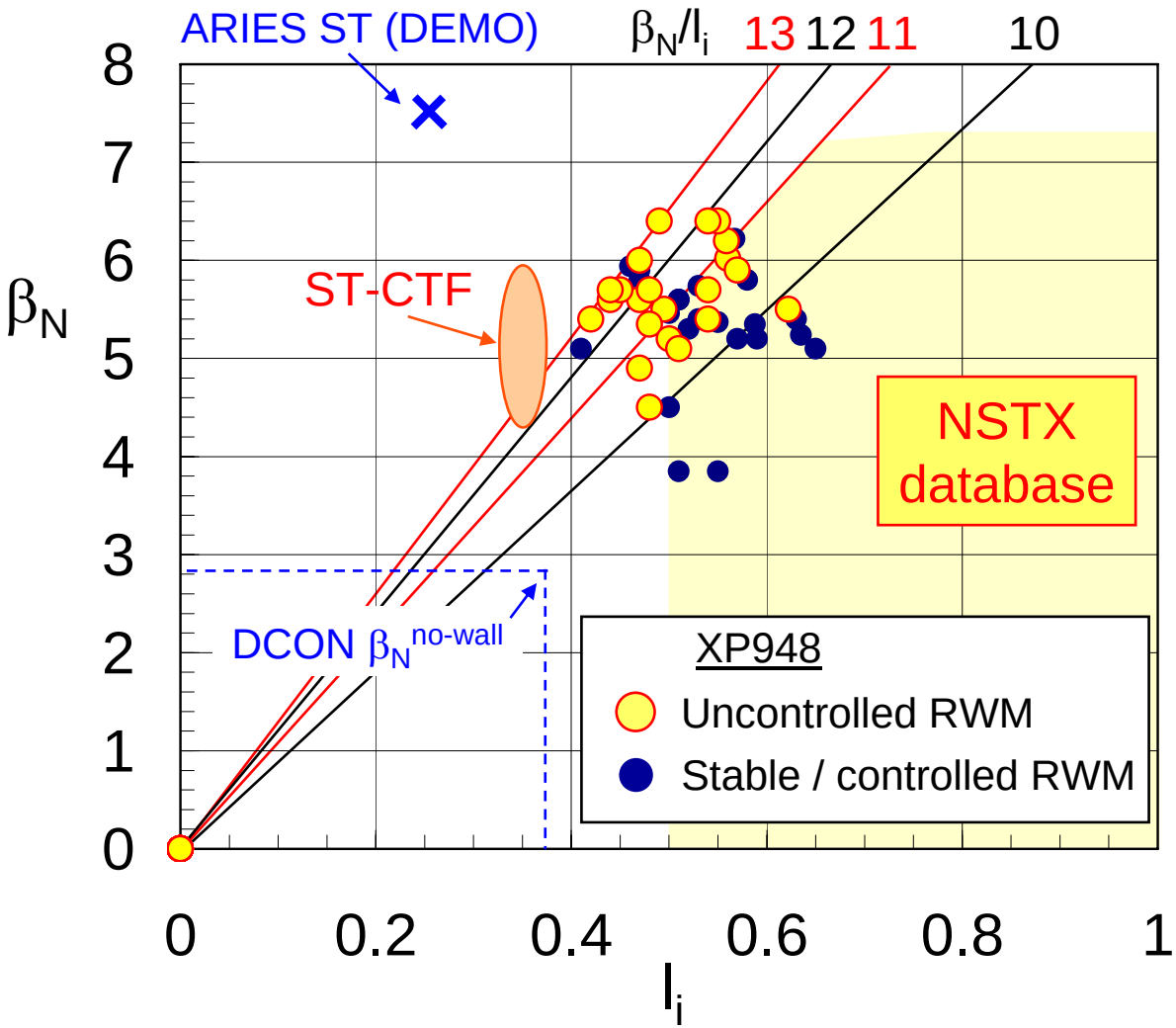
- Prelude to ω_ϕ control
  - Reduced ω_ϕ by n = 3 braking does not defeat FB control
  - Increased P_{NBI} needed at lower ω_ϕ
- Steady β_N established over long pulse
  - independent of ω_ϕ over a large range

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

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

XP934: Sabbagh (Columbia U.)

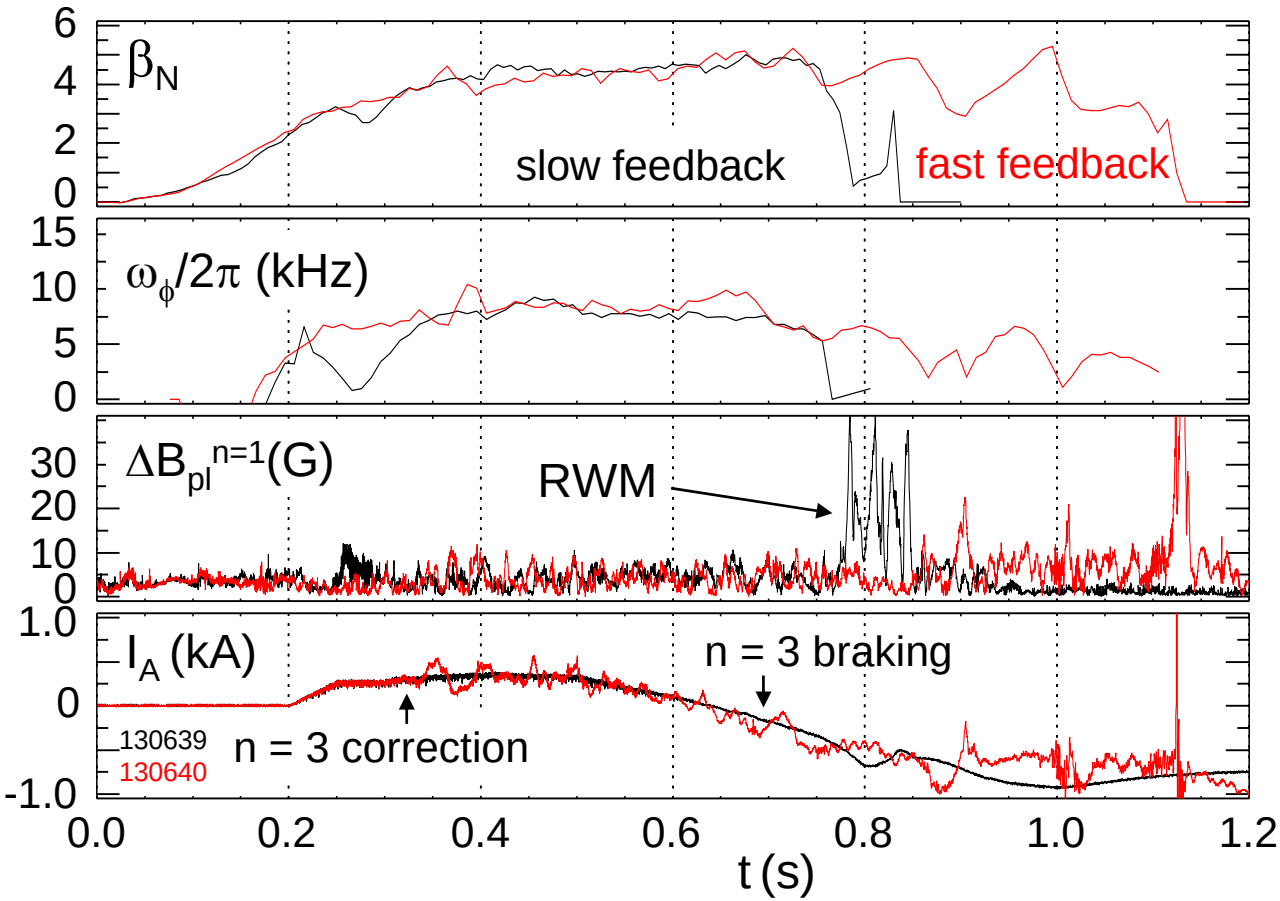
NSTX XP948 operated very low l_i, with high probability of RWM – can these plasmas be better controlled?



- Advancement in β_N/l_i toward targets
  - 2006 value: 11
  - XP948 (2009): 13
  - ST-CTF: 16
- Uncontrolled growing RWM occurred in about 50% of shots
  - ST-CTF target must be sustained indefinitely
- What value of l_i is the current-driven kink limit (unstable any β)?
  - DCON n = 1 no-wall limit for 135111 low: $\beta_N = 2.8$ ($l_i = 0.38$)

XP948: S.P. Gerhardt

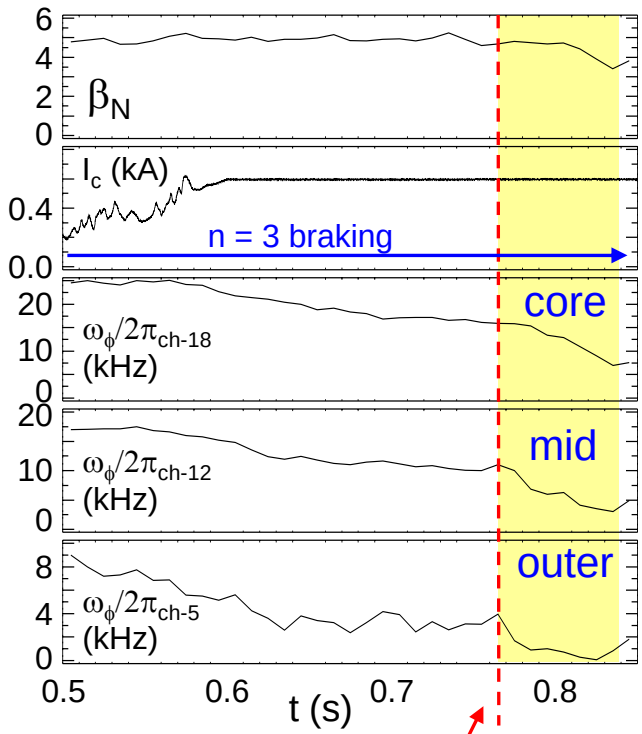
High β_N difficult to access at low plasma rotation when RWM feedback response sufficiently slowed

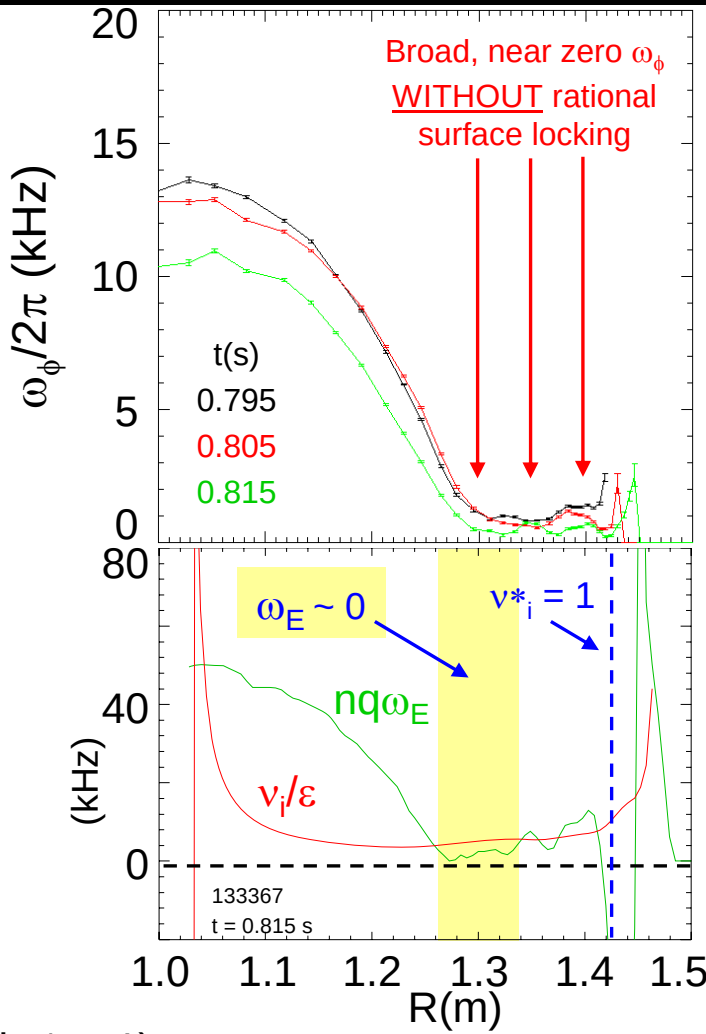


S.A. Sabbagh, et al, NF **50** (2010) 025020

- 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

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

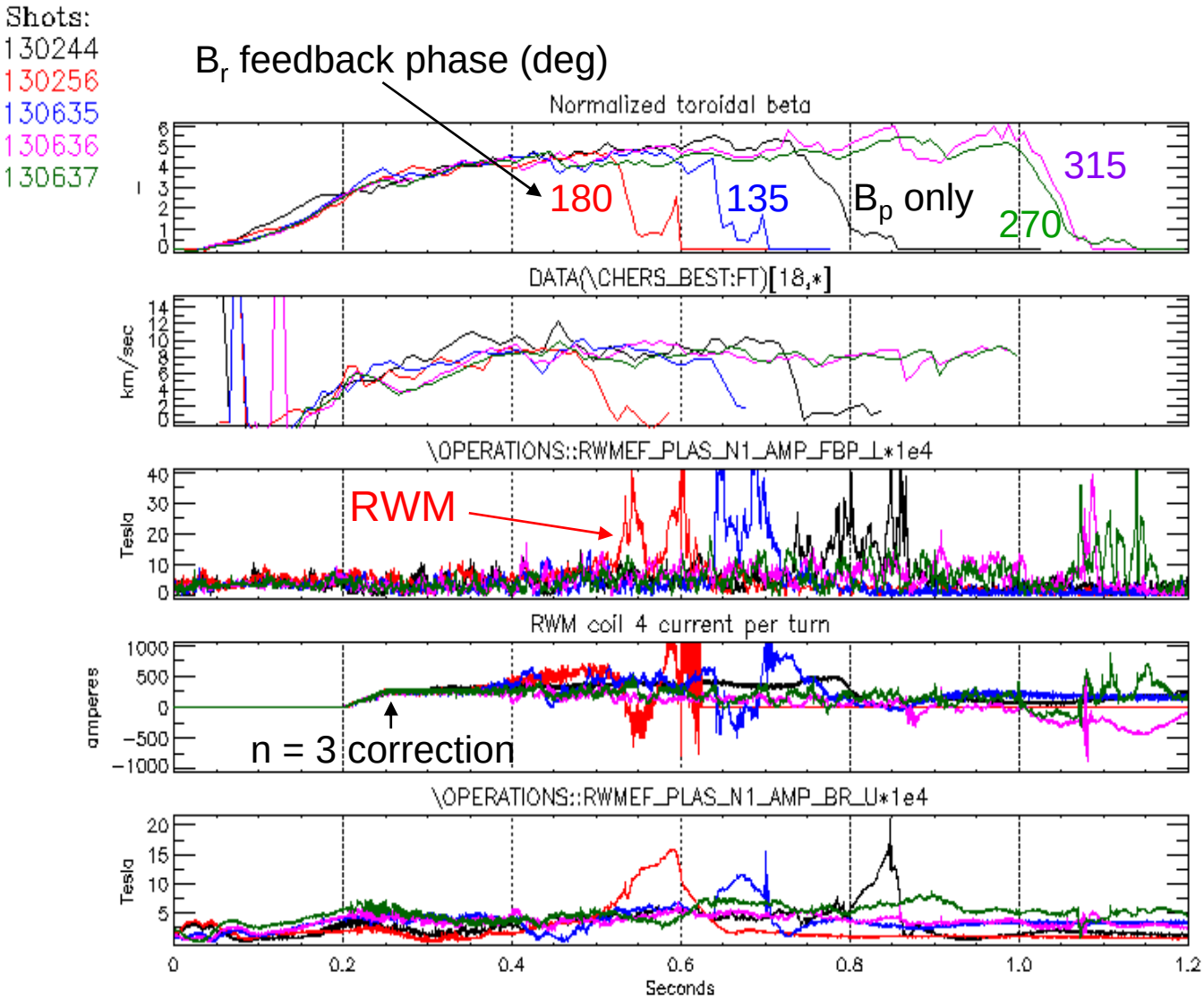




XP933: Sabbagh

- 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))

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 piggyback time will make XP1023 run efficient

Change of plans!

- LLD Survey XP

  No survey XP yet – target development in this XP

  - Some (perhaps all?) target development will be run in the LLD survey XP

- XP1019 "β_N FB" and XP1060 "RFA Suppression With Different Sensors/Time Scales in NSTX" (Gerhardt, et al.)
  - Shot plan of present XP1023 complements XP1060
    - aimed at plasmas with $\beta_N > \beta_N^{\text{no-wall}}$, to attain low l_i with long pulse
    - aimed at optimizing fast FB

  XP1023 will run early; support XP1020

- 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 will run early: B_r sensors ready?

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 (estimate ~ ½ day under revised schedule, no ν scan w/LLD)	
(use low li, ν target from LLD survey XP, optionally fall back on low l_i, long pulse target from 2009 (shot 135111)	
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 (focus on l_i under revised schedule)	4
2) Assess optimal settings for n = 1 feedback; add other tools for control/stabilization	
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 $<\beta_N>_{pulse}$; use n = 3 braking if at unstable ω_ϕ for RWM	4
3) Generate high $<\beta_N>_{pulse}$ at low ω_E	
A) Generate lowest possible ω_ϕ at high β_N with n = 1 FB on; also with AC field and no FB for Xp1020	4
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 $\beta_N > \beta_N^{no\text{-}wall}$ (PAC recommendation) (target established in other XPs (e.g. XP1012: LeBlanc RF H-mode XP, etc.)	8
Total: 32;	8

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
  - FIDA
  - FIReTip
  - Fast camera