Supported by Office of Fusion Energy Sciences Office of Science

Active Resistive Wall Mode Feedback with Expanded Sensors in NSTX

College W&M
Colorado Sch Mines
Columbia U
Comp-X
General Atomics
INEL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
Old Dominion U
ORNL
PPPL
PSI
Princeton U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Maryland
U Rochester
U Washington
U Wisconsin

S.A. Sabbagh[1], J.M. Bialek[1], R.E. Bell[2], D.A. Gates[2], B. LeBlanc[2], J.E. Menard[2], A.C. Sontag[1], A.H. Boozer[1], A.H. Glasser[3], F. Levinton[4], K. Tritz[5], H. Yu[4]

[1]Department of Applied Physics, Columbia University, New York, NY, USA
[2]Plasma Physics Laboratory, Princeton University, Princeton, NJ, USA
[3]Los Alamos National Laboratory, Los Alamos, NM, USA
[4]Nova Photonics, Inc., Princeton, NJ, USA
[5]Johns Hopkins University, Baltimore, MD, USA

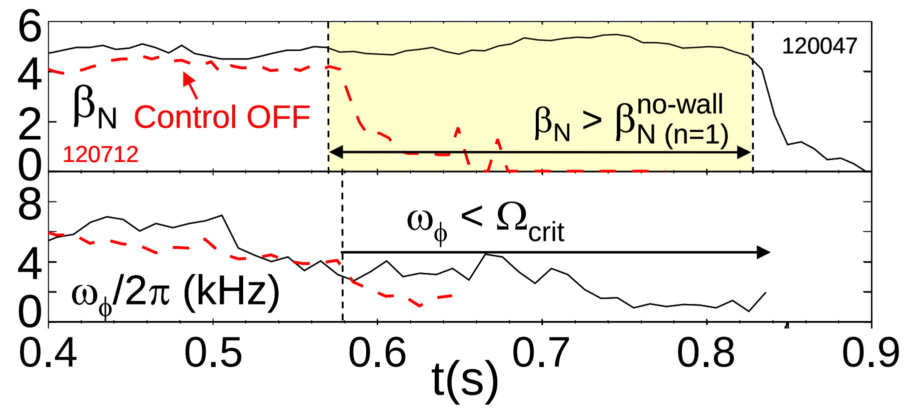
49th Annual Meeting of the Division of Plasma Physics
American Physical Society
November 12, 2007
Orlando, FL

Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
KBSI
KAIST
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep
U Quebec

Increase reliability and understanding of RWM active control

- **Motivation**
  - RWM growth leads to beta collapse, disruption
  - High reliability control needed for future burning plasma devices (at low or high plasma rotation, ω_ϕ)
- **Outline**
  - Analysis of RWM control system performance
  - RWM control experiments using expanded magnetic sensor combinations
  - Variations for improved control

Active n = *1* RWM control in NSTX (2006)

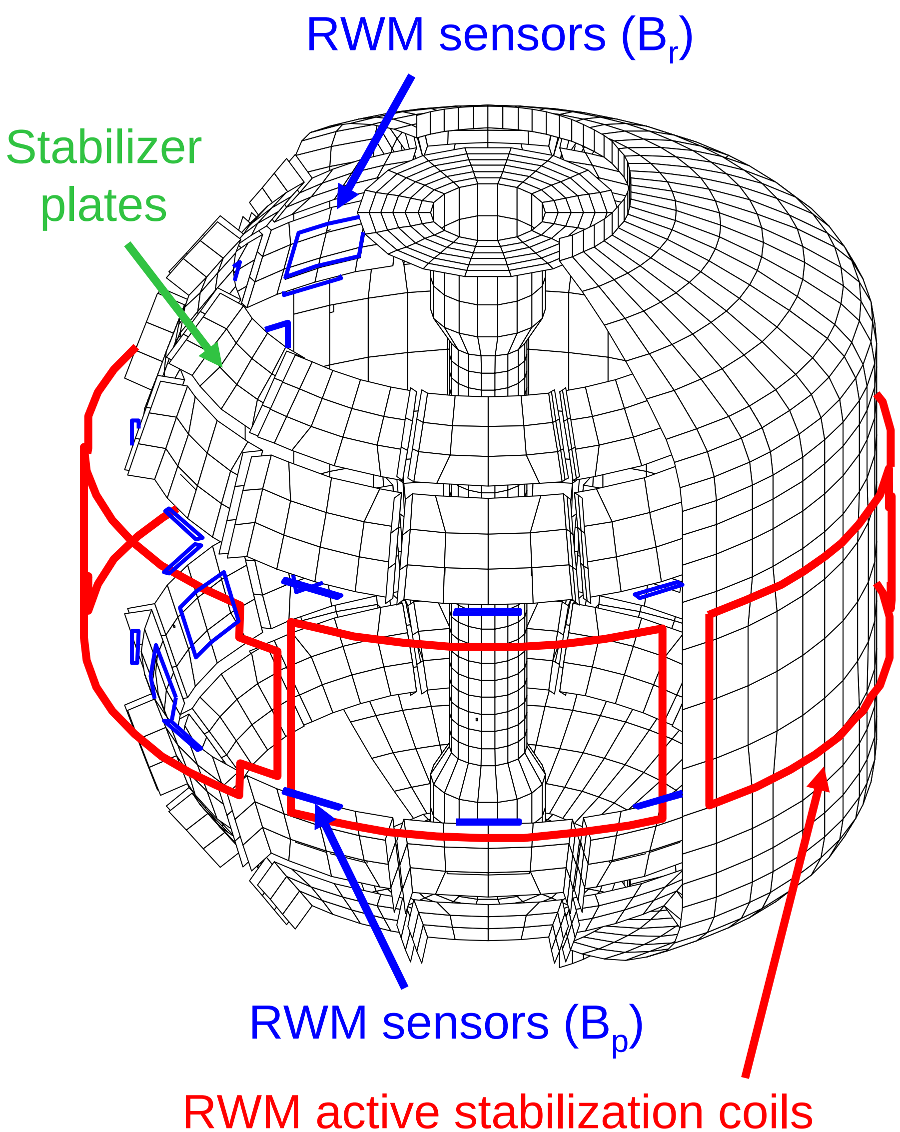


- Upper B_p sensors for feedback
- Non-resonant magnetic braking
- n = 2 RWM amplitude rises, remains stable while n = 1 stabilized
- Plasma $\beta_N > 5.5$ reached

S.A. Sabbagh, et al., PRL **97**, 045004 (2006).

RWM control system uses expanded sensor set

- Stabilizer plates for kink mode stabilization
- External midplane control coils closely coupled to vacuum vessel
- Varied sensor combinations used for feedback
  - 24 upper/lower B_p: (B_{pu}, B_{pl})
  - 24 upper/lower B_r: (B_{ru}, B_{rl})
- Midplane n = 1 B_r sensors
  - Outboard of control coil
  - Not used for feedback to date

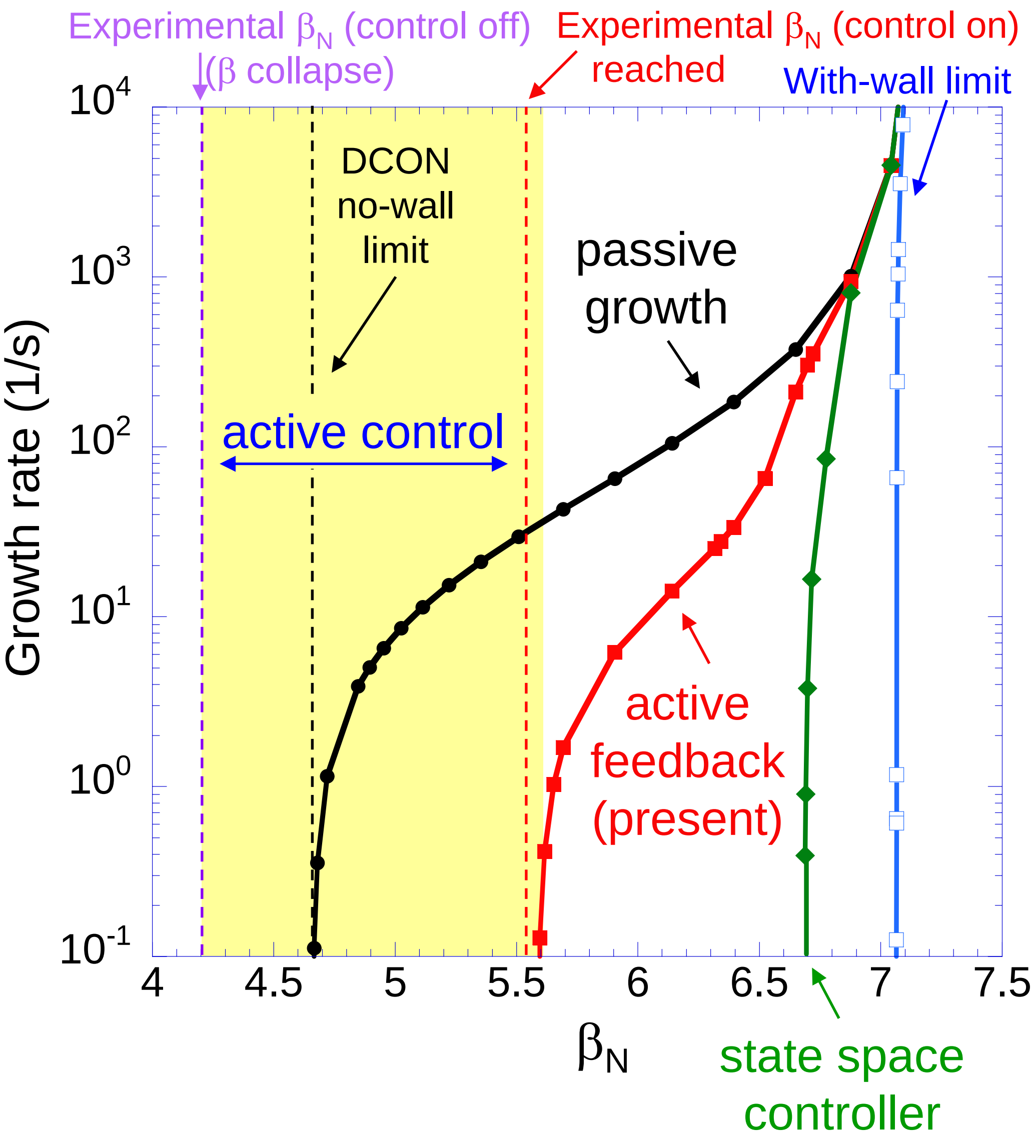


VALEN code reproduces B_{pu} sensor feedback performance

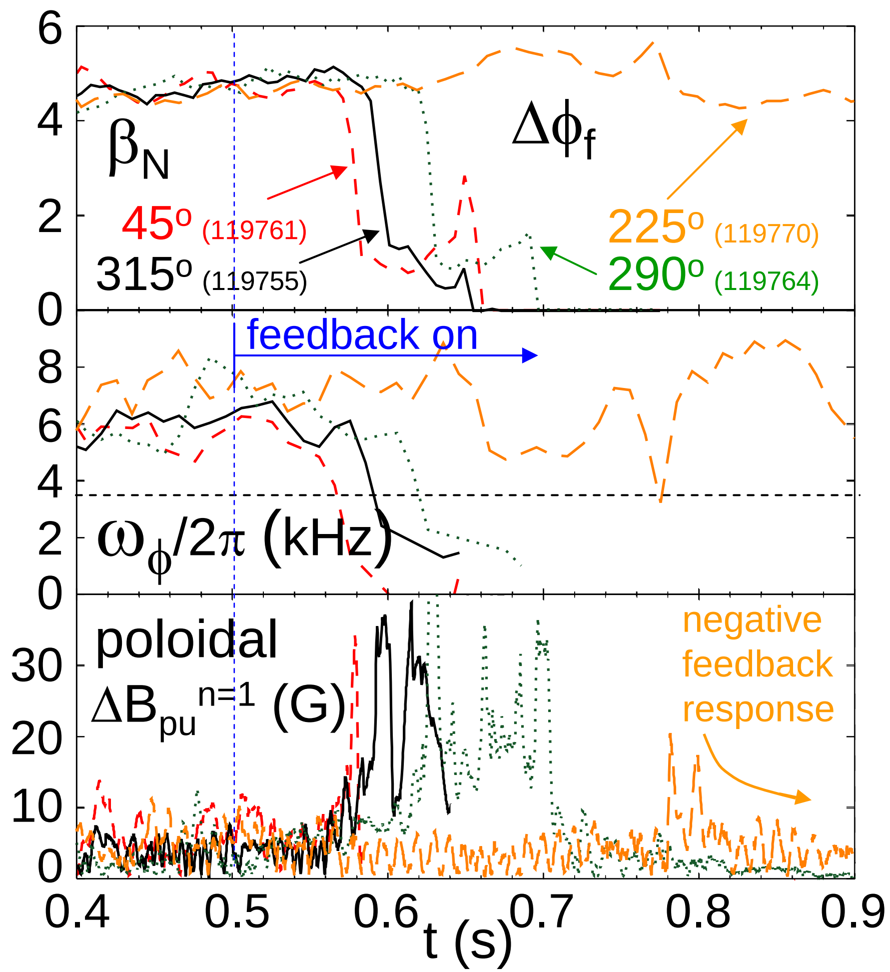
- New model simulates experiment
  - Upper B_p sensors located as on device
  - Compensation of control field from sensors
  - Experimental equilibrium reconstruction (including MSE data)
  - Proportional gain

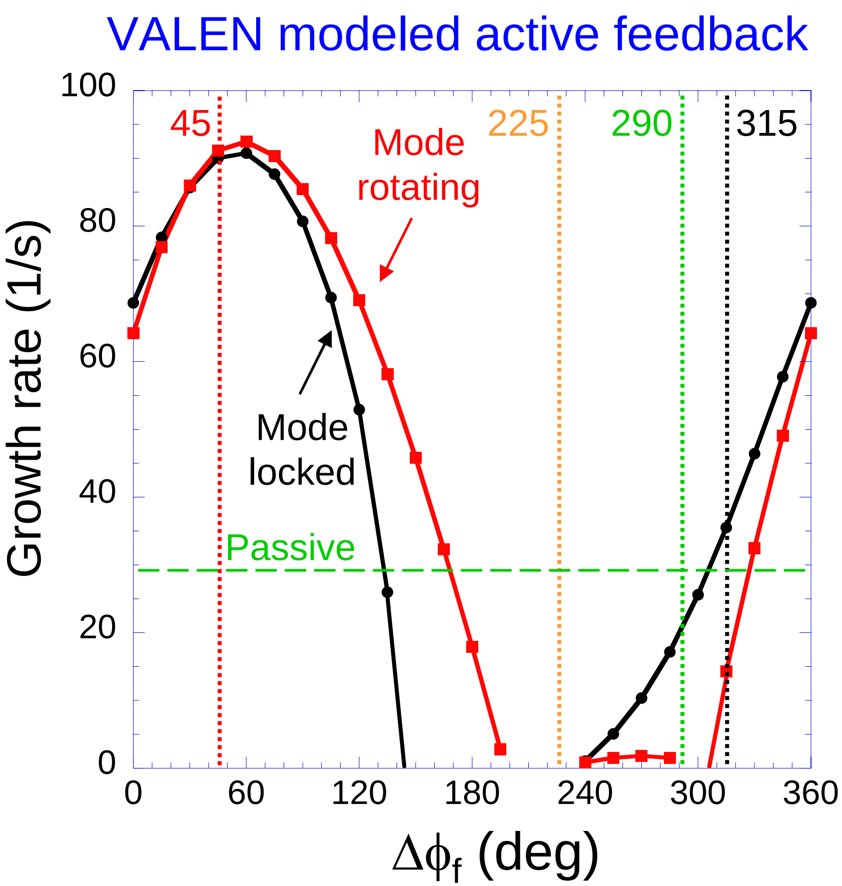
- Advanced feedback control may significantly improve future performance
  - Optimized state-space controller with B_{pu} sensors may stabilize $\beta_N/\beta_N^{wall} < 95\%$

Katsuro-Hopkins NP8.00125



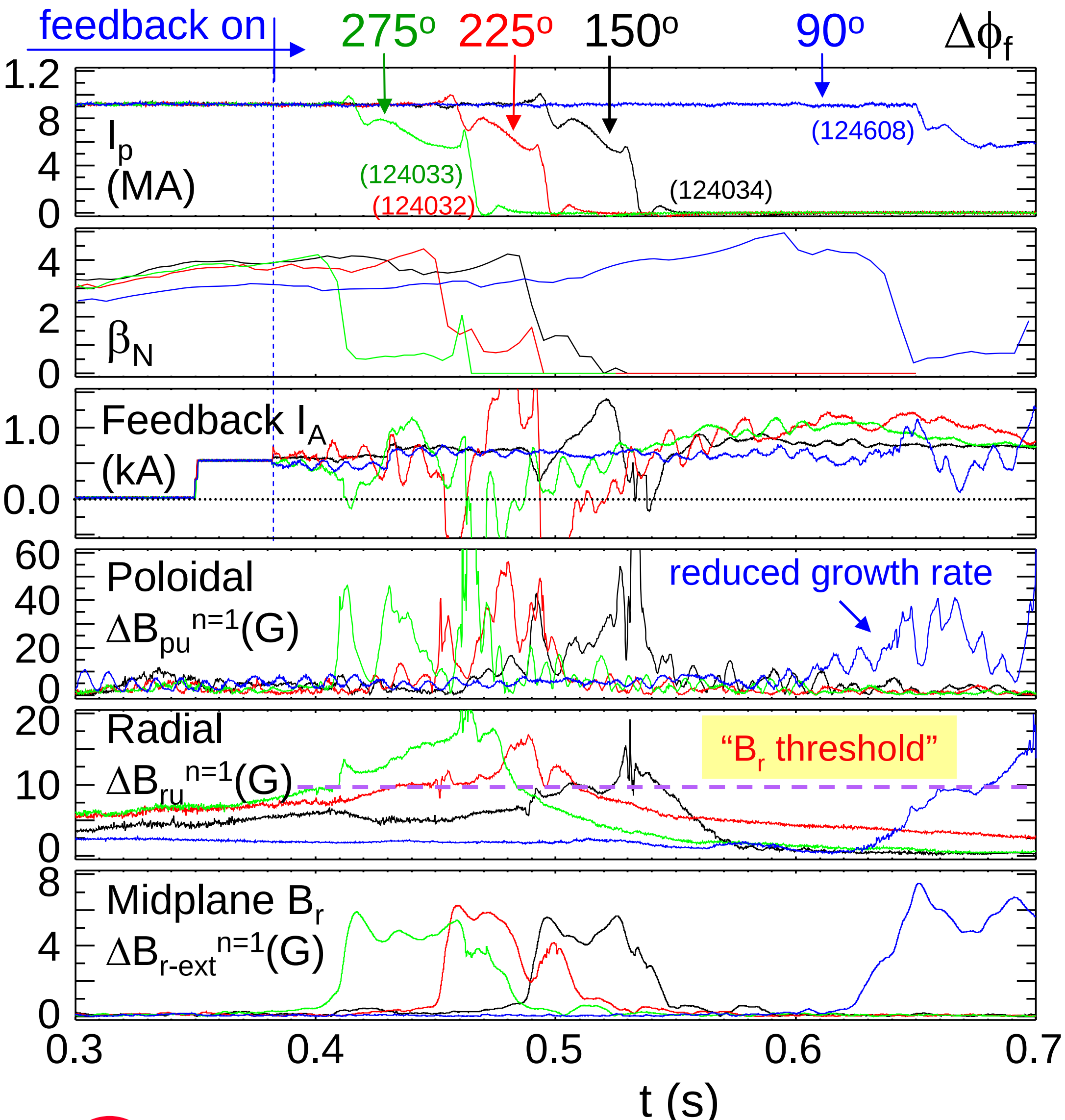
Varying relative phase shows positive/negative feedback





- Feedback control current has relative phase $\Delta\phi_f$ to measured ΔB_{pu}
  - Internal plasma mode seen at $\Delta\phi_f$ = 225°, damped feedback system response
- Phase scan shows superior settings for negative feedback
  - Agreement between theoretical and experimental feedback behavior

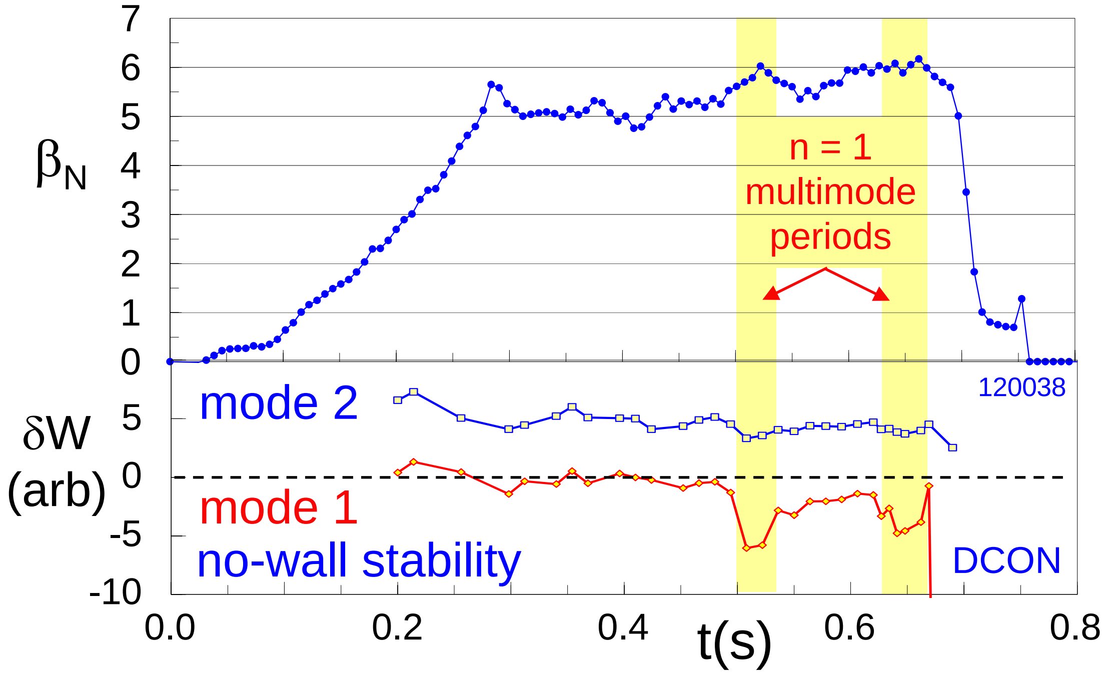
Combination of upper/lower B_p sensors used to improve control

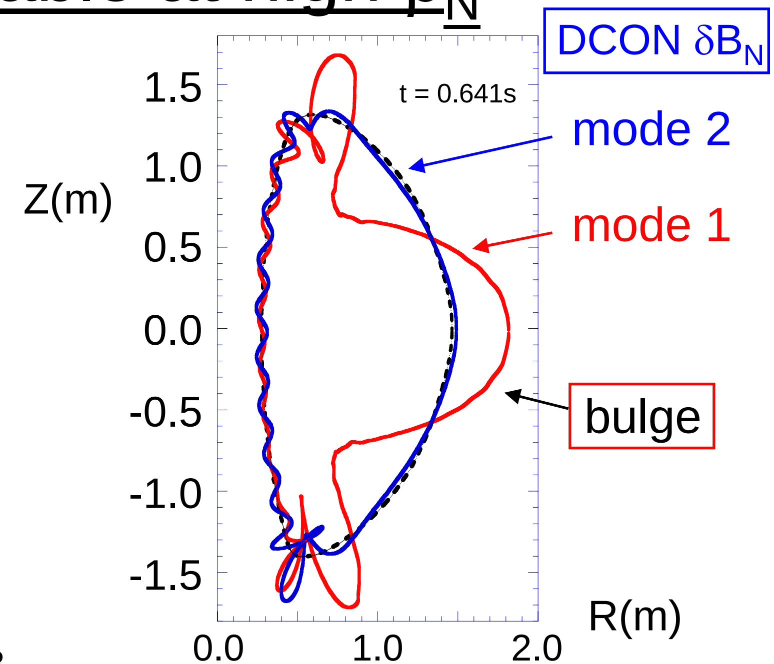


- Feedback phase scan using B_{pu} and B_{pl}
  - Best phase shown 90°, not optimal configuration
    - Reduction in $\Delta B_{pu}^{n=1}$ growth rate
  - Spatial phase offset between upper/lower B_p sensor flux can improve feedback
- Control using B_{pu} and B_{pl} also reduces ΔB_r
  - Correlation of β_N collapse and $\Delta B_{ru}^{n=1}$ amplitude
  - Attempted feedback on ΔB_r - RWM control not reliable
    - Reduced ΔB_r successfully
    - Fast n = 1, 2 RWM onset ($\gamma\tau_w \sim 1$) occurs

NSTX

Multimode theory applicable at high β_N



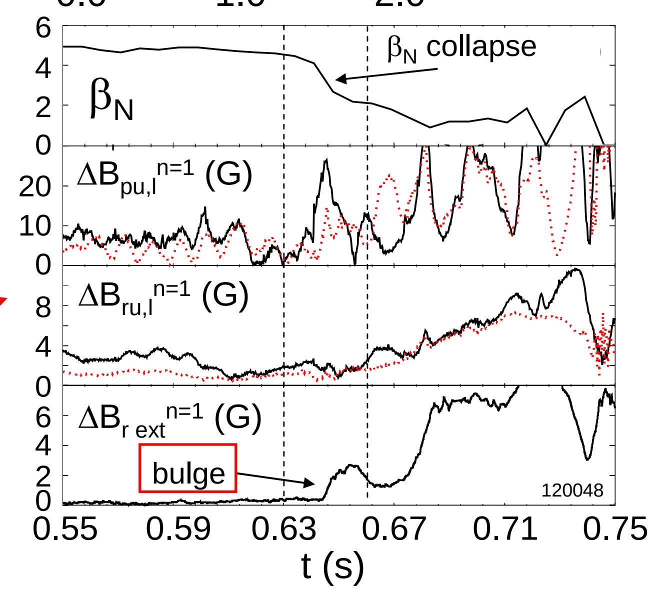


- Boozer multimode criterion for n = 1 met at high β_N (PoP 10 (2003) 1458.)
  - $|\delta W|$ smallest for 2nd n = 1 eigenfunction
- Multiple n > 1 RWM also observed in NSTX

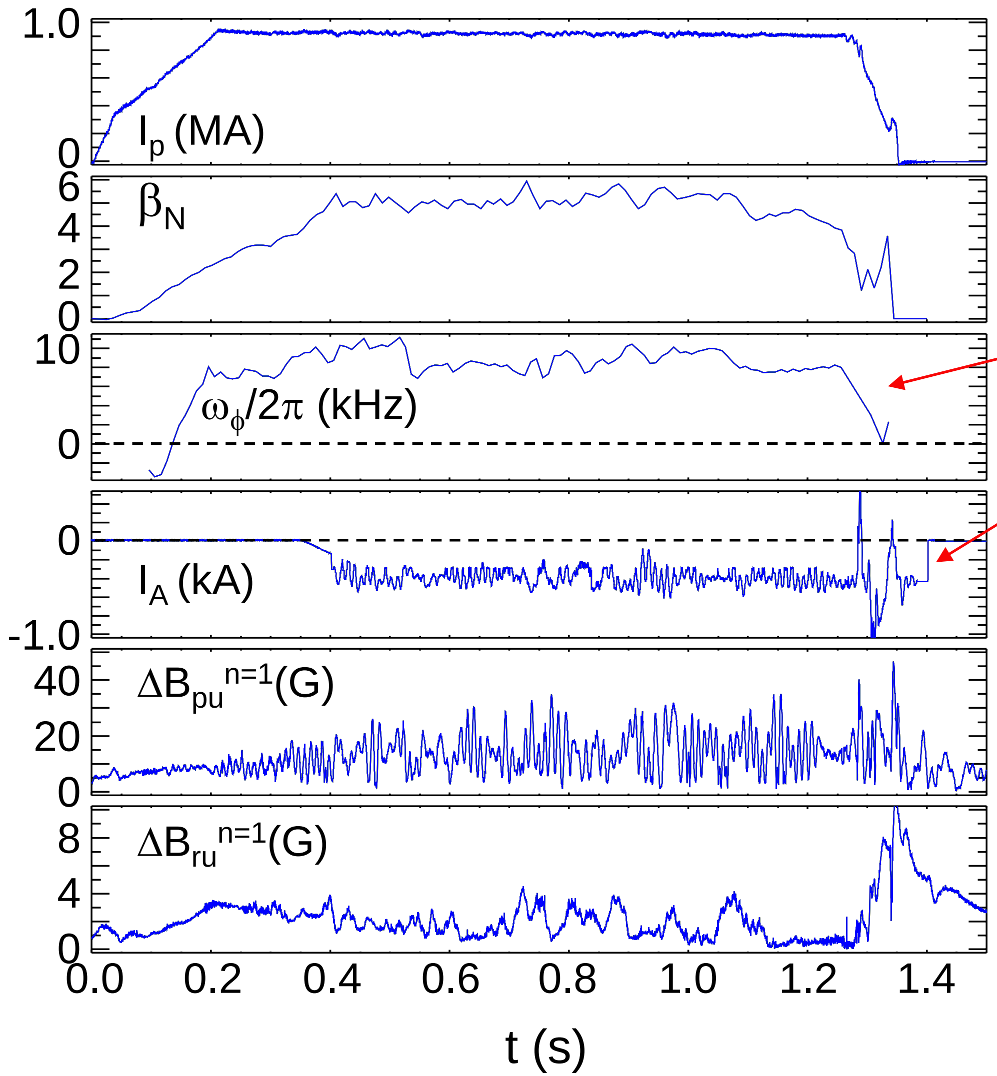
(Sabbagh, et al., Nucl. Fusion **46** (2006) 635.)

- Multiple n = 1 modes may explain observations
  - Upper/lower sensor phases do not always match single mode
  - Poloidal deformation of mode during feedback (mode "non-rigidity")

S.A. Sabbagh, et al., PRL **97** (2006) 045004.



Feedback control modifications used successfully at moderate ω_ϕ



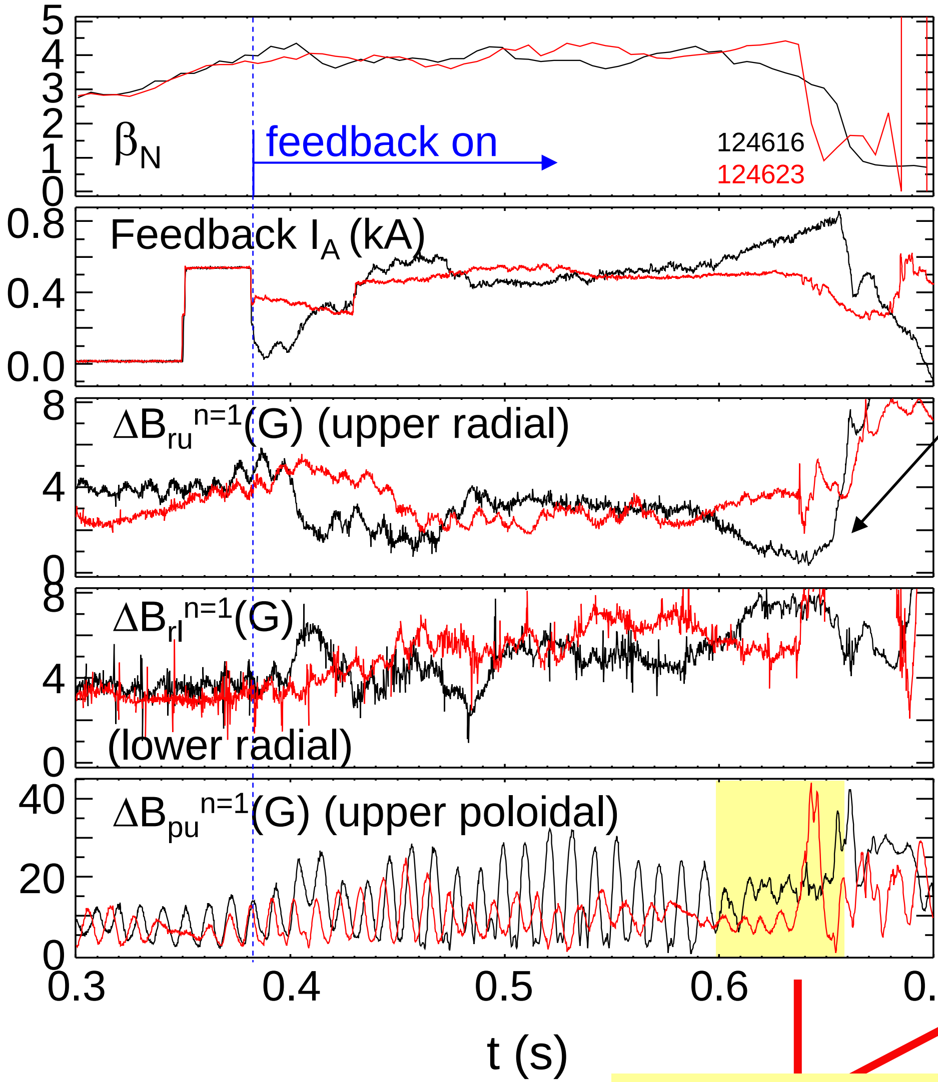
- **NSTX record pulse length at I_p = 0.9 MA**
  - Feedback used combined upper/lower B_p sensors with spatial phase offset
  - Moderate plasma rotation keeps ΔB_r in check
  - n = 3 DC field phased to best maintain ω_ϕ

- **Next steps toward further control reliability**
  - Feedback on upper and lower arrays of both B_r and B_p sensors
  - Determine optimal sensor spatial phase offsets
  - Test reliability at further reduced plasma rotation

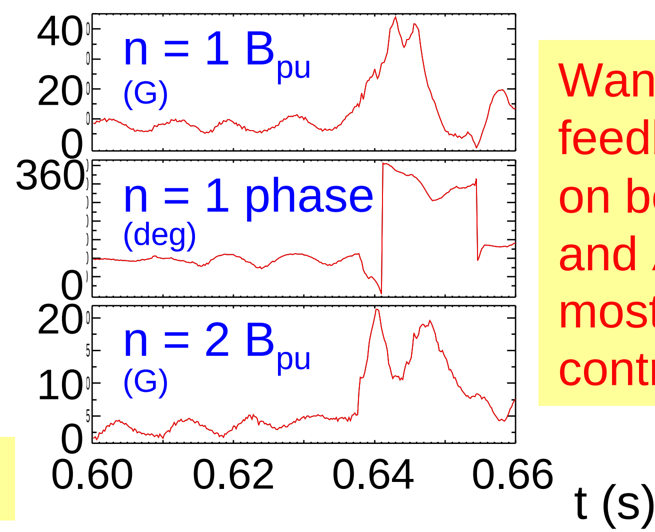
J.E. Menard UI1.001

Extra Slides

Feedback on B_r sensors alone insufficient for control



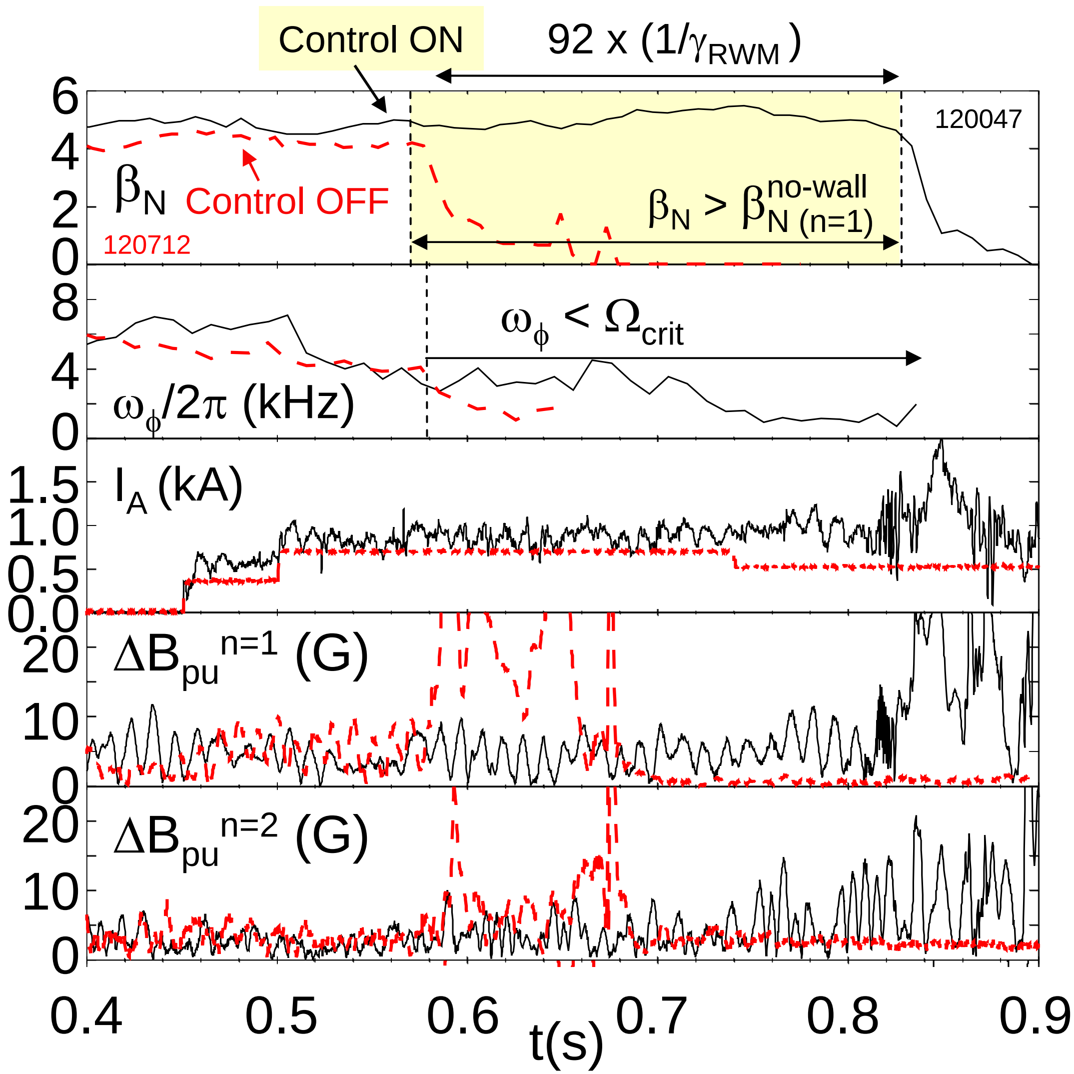
- Feedback on ΔB_{ru} alone
  - Clear initial drop in ΔB_{ru}
  - Continued drop in ΔB_r and *increase* in ΔB_{rl} (also ΔB_{pu})
  - leads to β_N collapse
- Feedback on ΔB_{ru} and ΔB_{rl}
  - Controlled, steady ΔB_{ru}, ΔB_{rl}
  - rapid RWM growth, rotation: β_N collapse



Want feedback on both ΔB_r and ΔB_p for most reliable control

unstable RWM

RWM actively controlled using upper B_p sensors



- Plasma rotation ω_ϕ reduced by non-resonant $n = 3$ magnetic braking
  - Large ω_ϕ range produced
- Stabilized period has
  - Long duration > $90/\gamma_{RWM}$
  - Exceeds DCON $\beta_N^{no\text{-}wall}$ for $n = 1$ and $n = 2$
  - $n = 2$ RWM amplitude increases, mode remains stable while $n = 1$ stabilized
  - $n = 2$ internal plasma mode seen in some cases
  - Plasma $\beta_N > 5.5$ reached