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Resistive Wall Mode Active Stabilization (XP615) and Plasma Rotation Damping Physics

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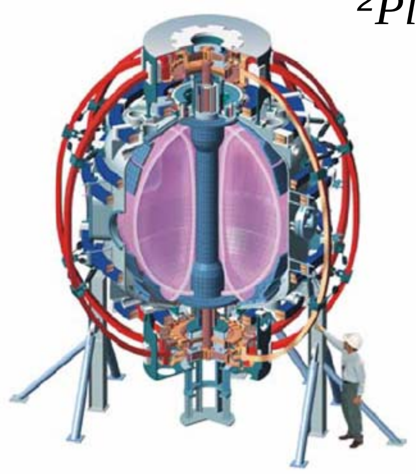


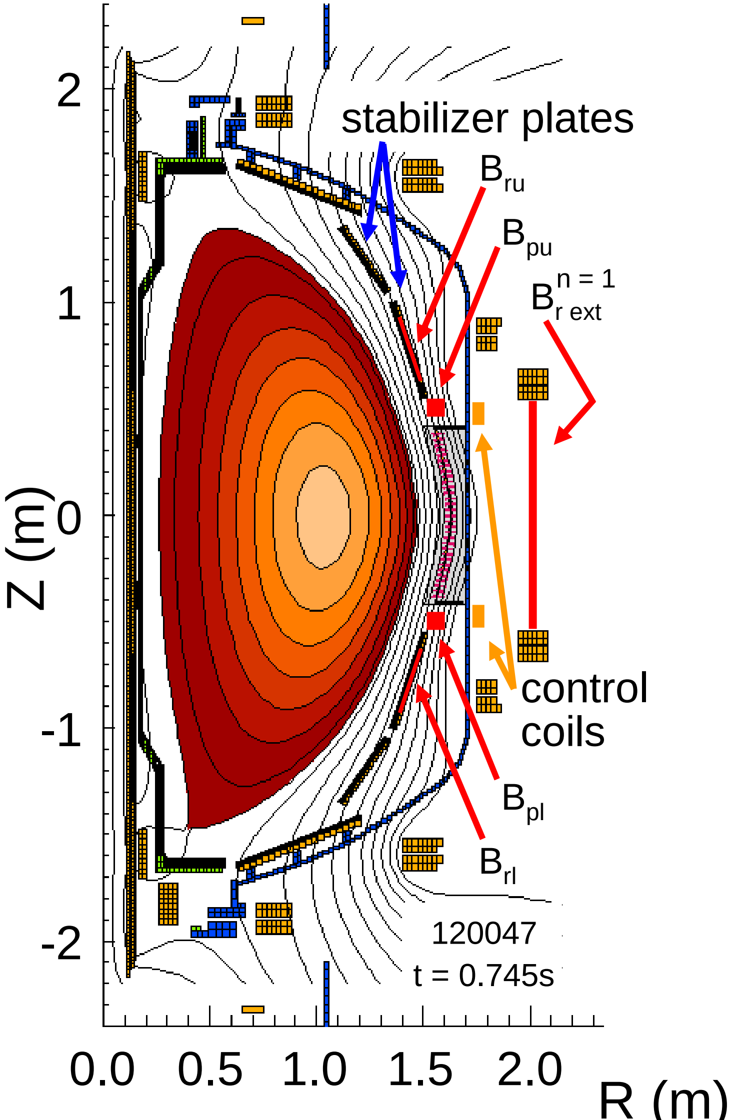
NSTX Results Review
July 26th, 2006
Princeton Plasma Physics Laboratory

RWM active stabilization is a key milestone in RWM stabilization physics research in NSTX

- RWM active stabilization
  - First demonstration in high β, low aspect ratio tokamak plasmas with low plasma rotation (Sabbagh, et al., to appear in PRL, 7/28/06 (est.))
  - Physics relevant to future tokamaks (ITER, KSTAR)

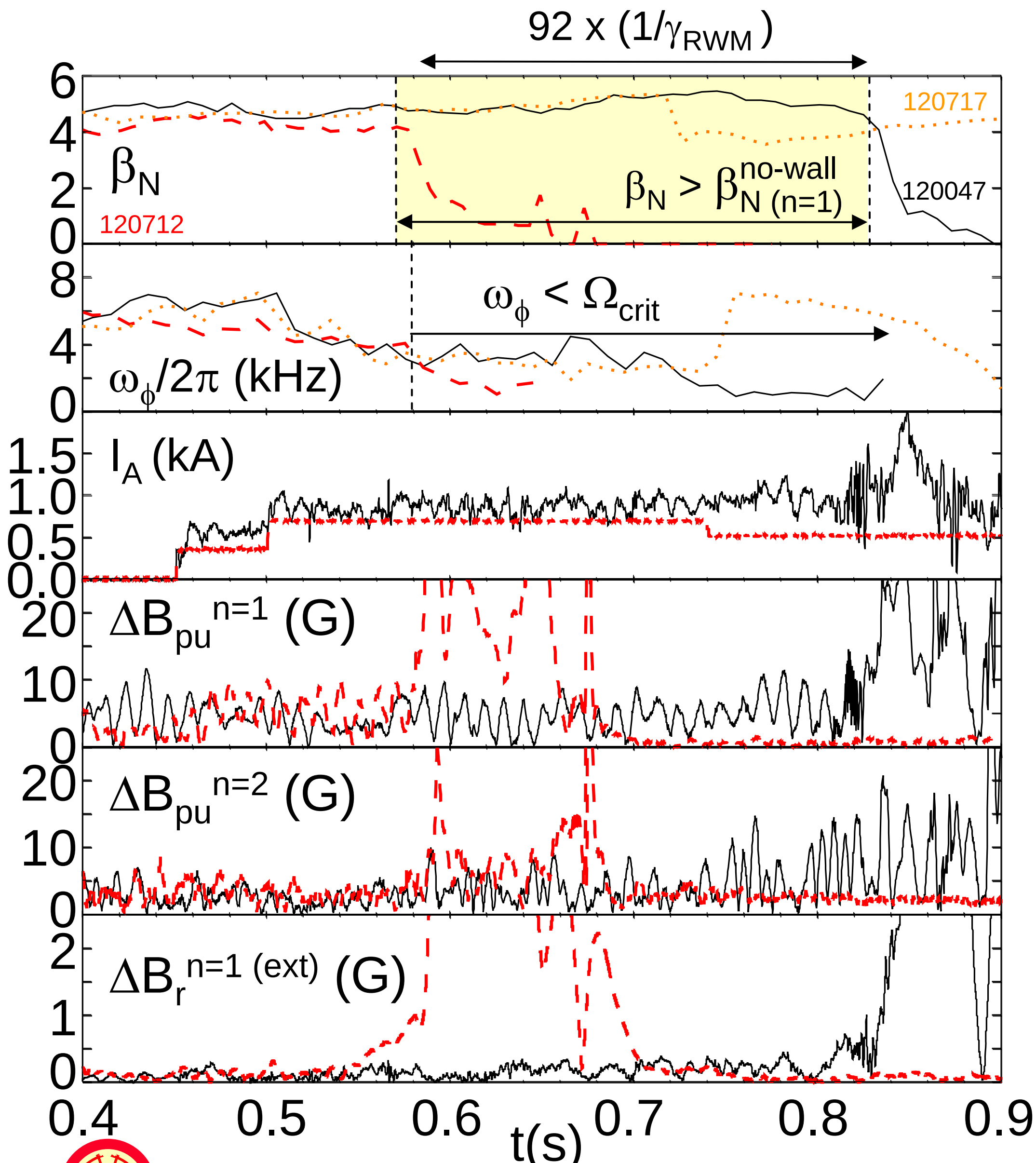
- RWM passive stabilization
  - Several years of research in NSTX (several publications)
  - Although a decade of general research, no definitive conclusion regarding RWM stabilization physics
    - Plasma energy dissipation, torque balance central to RWM dynamics
    - XP619 (next talk) will examine energy dissipation
    - Torque balance examined in NSTX over past year (covered in this talk)

RWM Active Feedback System Installed on NSTX



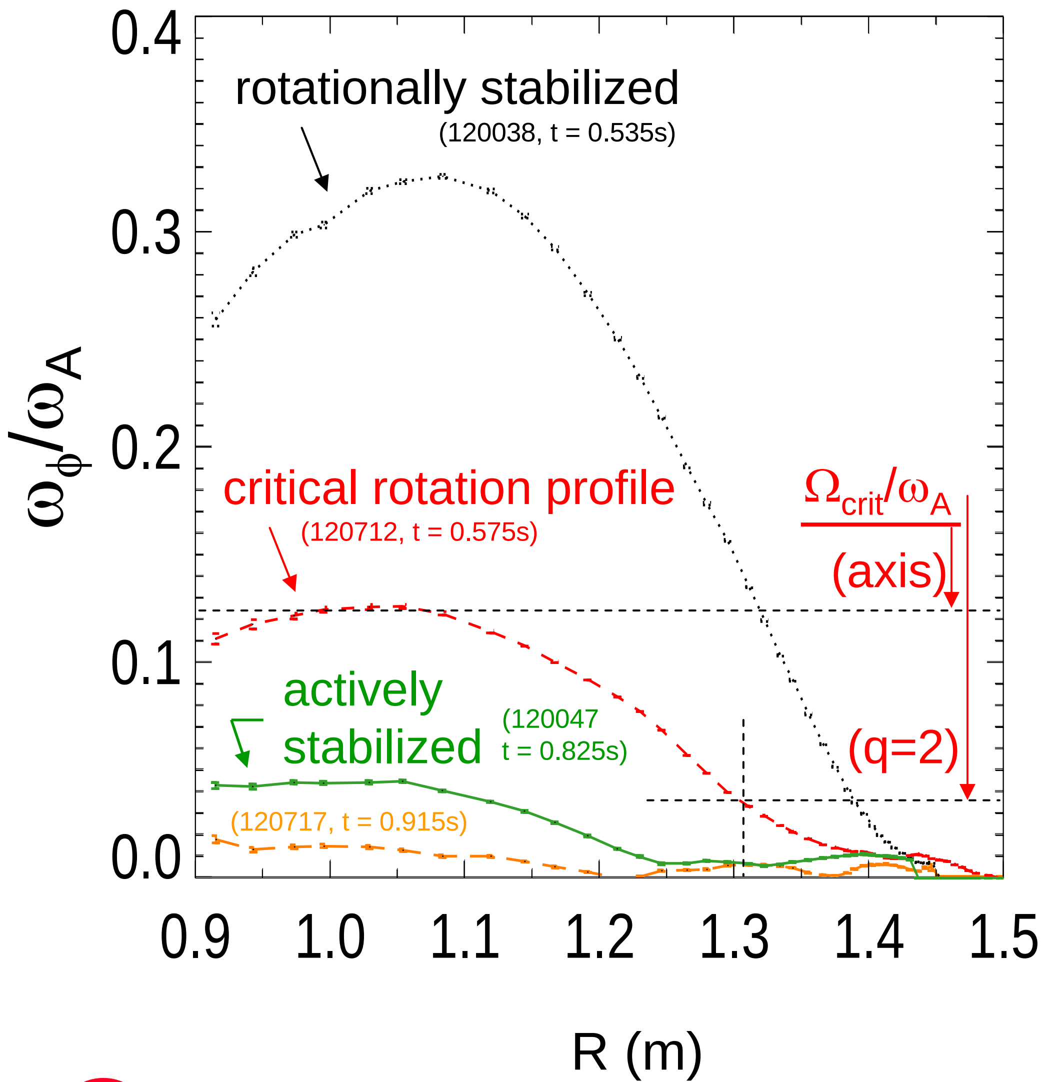
- Stabilizer plates for passive stabilization at sufficient plasma rotation
- External midplane control coil closely coupled to vacuum vessel
  - Similar to ITER port plug designs
- Behavior of n > 1 RWM can be studied
  - Unstable n = 1 – 3 RWMs already observed in NSTX (Sabbagh, et al., NF **46** (2006) 635.)

RWM stabilized at ITER-relevant rotation for ~ $90/\gamma_{RWM}$



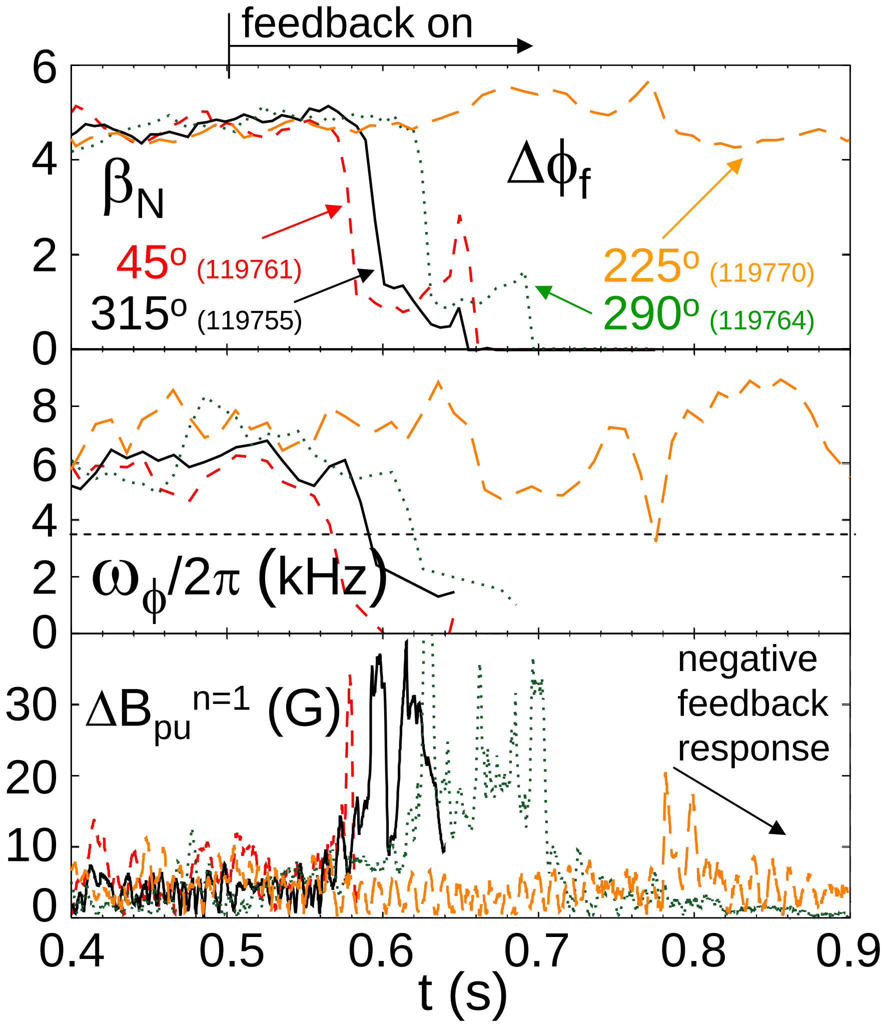
- DCON computed time evolution of $\beta_N^{no-wall\ (n=1)}$
  - Exceeds DCON $\beta_N^{no-wall\ (n=2)}$ as well
  - n = 2 RWM amplitude increases but mode remains stable during n = 1 stabilization
  - n = 2 internal plasma mode seen in some cases
    - Consistent with DCON
- Plasma rotation ω_ϕ reduced by non-resonant *n* = 3 magnetic braking
  - Due to neoclassical toroidal viscosity
  - Rotation less than ½ of ITER predicted $\omega_\phi/\Omega_{crit}$ (Liu, et al., NF **45** (2005) 1131.)

Rotation reduced far below RWM critical rotation profile



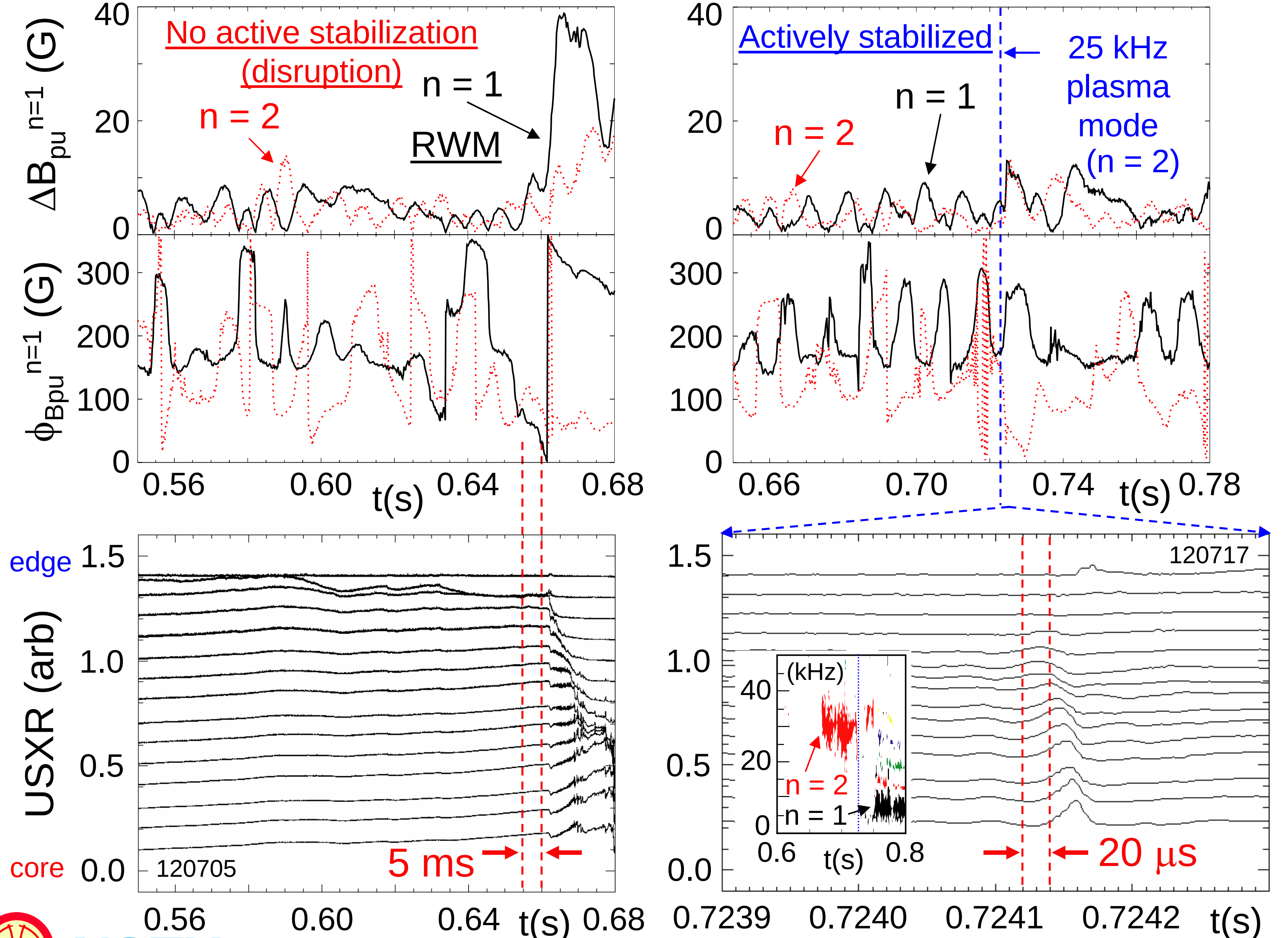
- Rotation typically fast and sufficient for RWM passive stabilization
  - Reached $\omega_\phi/\omega_A = 0.48|_{axis}$
- Generally, rotation profile responsible for RWM passive stabilization, not just single radial location
- Non-resonant n = 3 magnetic braking used to slow entire profile
  - The $\omega_A/\Omega_{crit} = 0.2|_{q\,=\,2}$
  - The $\omega_A/\Omega_{crit} = 0.3|_{axis}$
  - Below ITER Advanced Scenario 4 by at least a factor of 2.

Varying relative phase shows positive/negative feedback

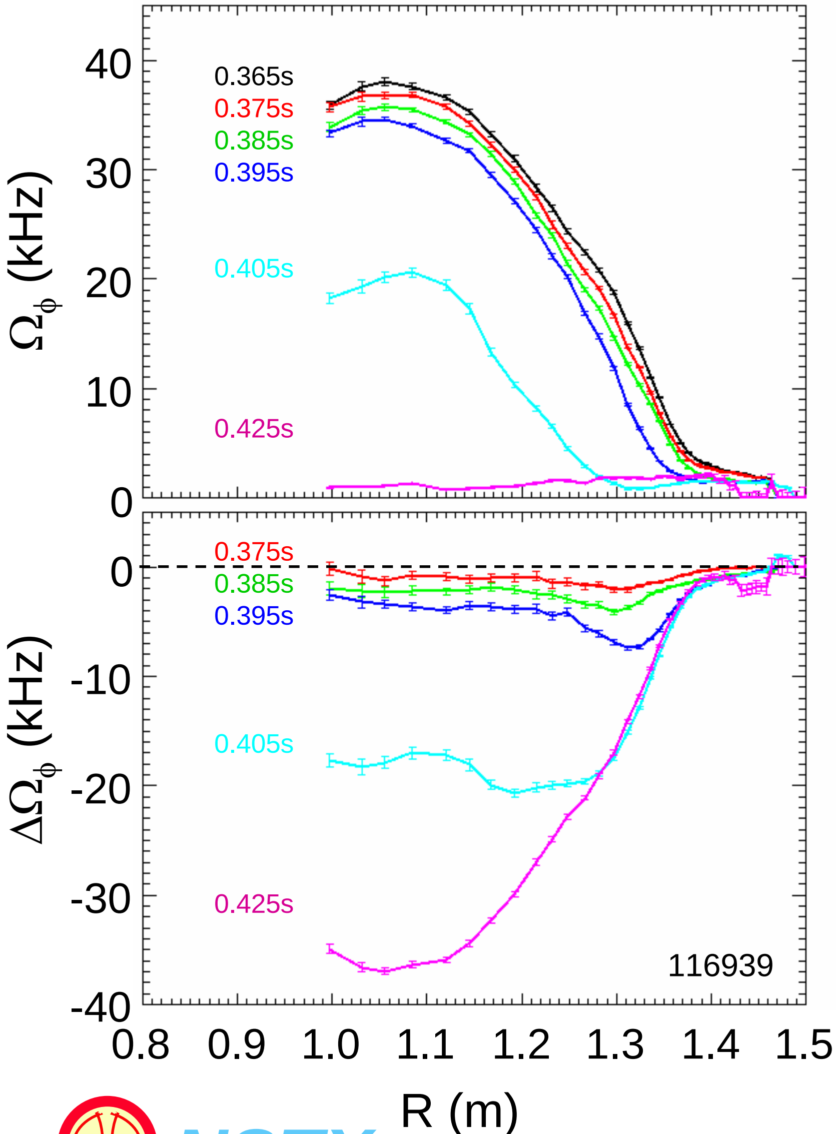


- Active feedback on n = 1 RWM amplitude, phase
  - Control current relative phase, $\Delta\phi_f$
- Phase scan shows superior settings for negative feedback
  - Pulse length increases
  - Internal plasma mode seen at $\Delta\phi_f$ = 225, damped feedback system response
- Gain scan also performed
  - Sufficiently high gain showed feedback loop instability

Clear differences between RWM and internal plasma mode



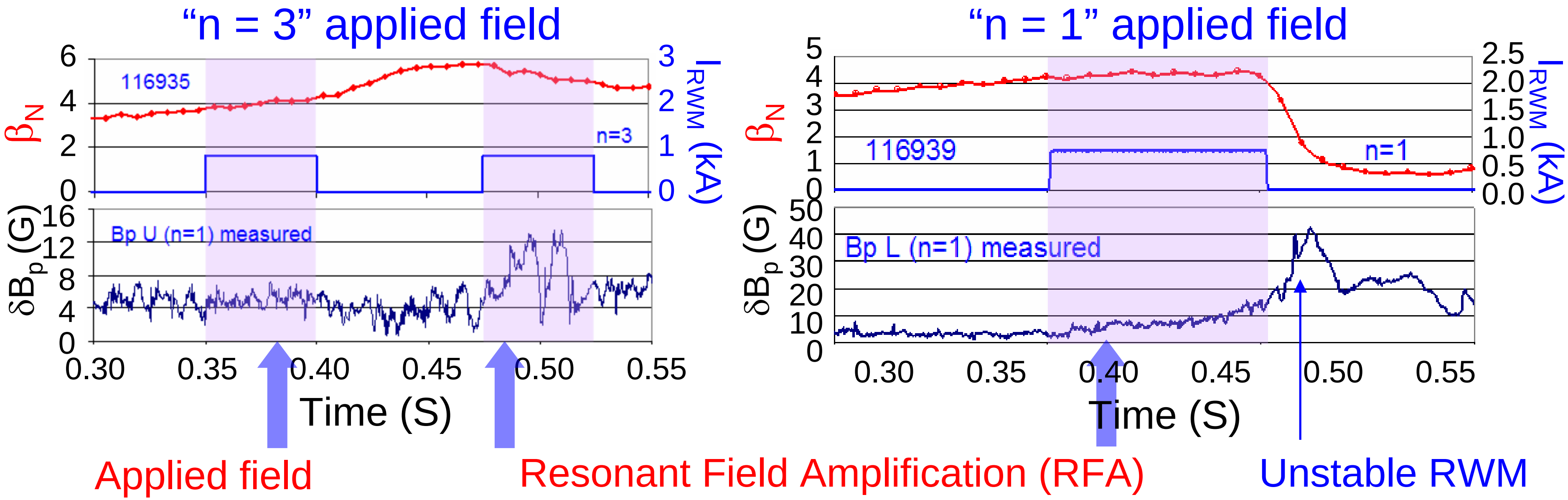
Neoclassical toroidal viscosity (NTV) theory tested as non-resonant rotation damping mechanism



- Measured rotation damping modeled is non-resonant, global in character
  - Unlike local damping due to islands
  - Outward momentum diffusion across rational surface not observed
- Torque balance compares measured $d(I\omega_\phi)/dt$ to sum of torques on plasma
  - Magnitude of NBI torque verified by TRANSP code
- Full Shaing NTV model compared to XP for first time
  - Valid for all collisionality regimes, no scaling factors – O(1) agreement
  - Past, simplified comparisons showed theory orders of magnitude too small

See W. Zhu, S.A. Sabbagh, R.E. Bell, et al., PRL **96** (2006) 225002 for equations, detail

Braking field applied at various β_N to test NTV theory



1 Applied field

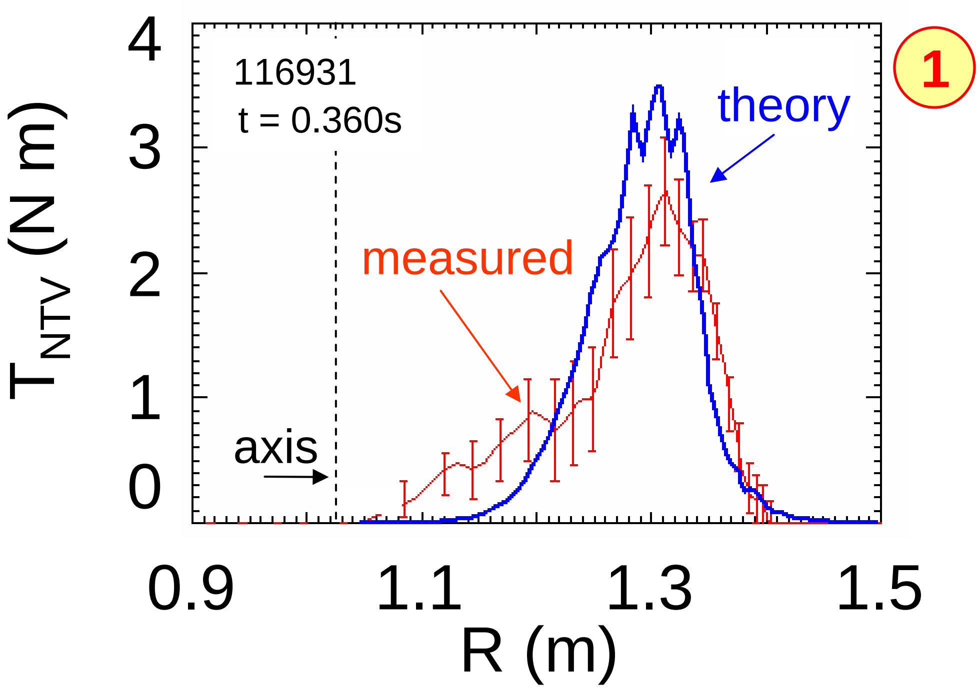
- Plasma β_N at or below no-wall limit

2 RFA, early RWM growth

- Plasma β_N above no-wall limit
- Applied field is amplified by stable RWM

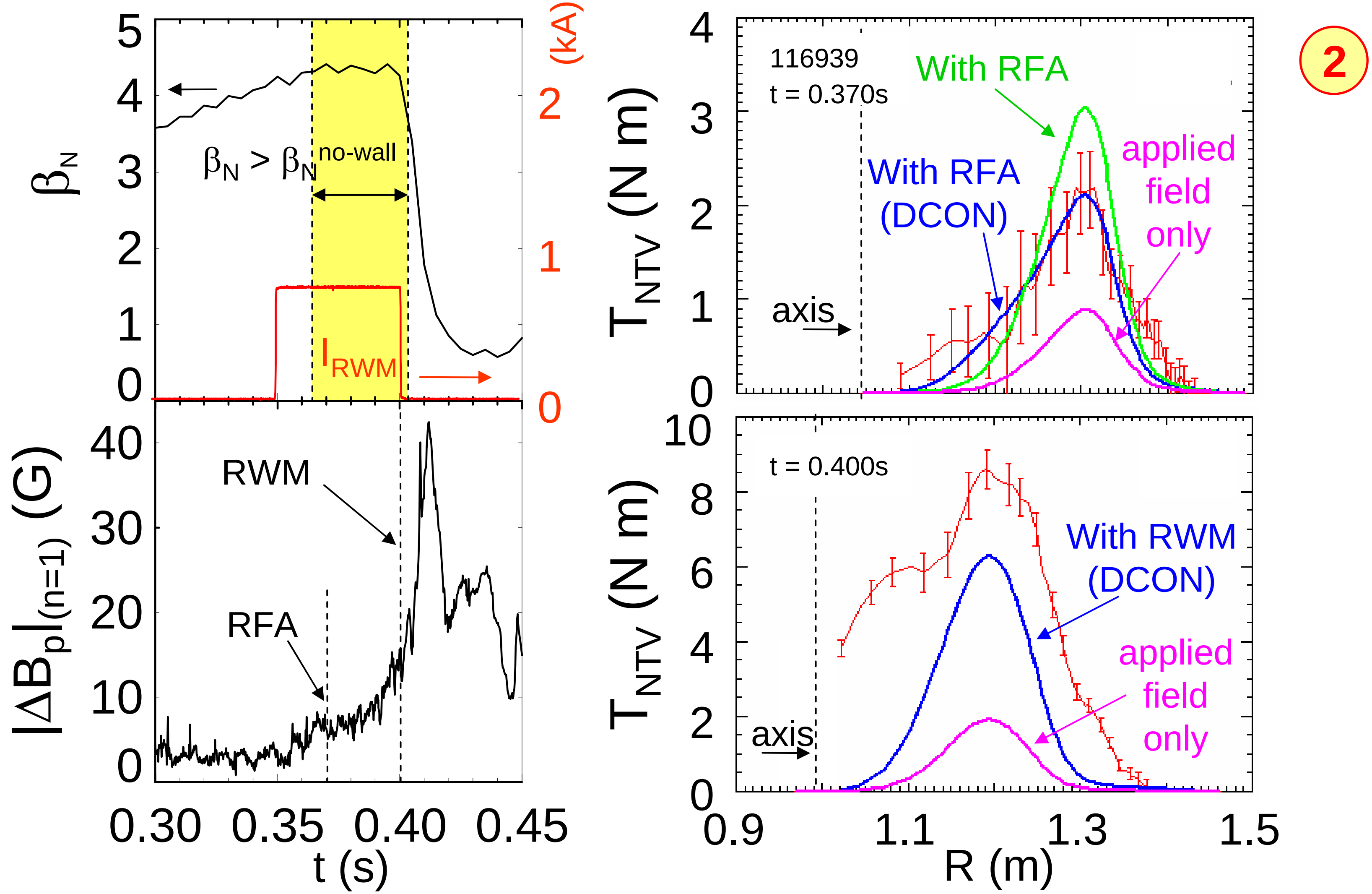
Observed rotation damping follows NTV theory

"n = 3" applied field



- Trapped particle effects are required for quantitative agreement
- Detailed model of applied damping fields required for quantitative agreement
  - 3-D Biot-Savart computation
- Numerically computed using broad spectral decomposition of 3-D non-axisymmetric field
  - $(0 < n < 15)$
  - $(-15 < m < 15)$

NTV theory follows measurement during RFA, RWM



- Pressure-driven RFA, RWM increases non-axisymmetric field at high β_N
  - NTV based on applied field mode spectrum, or DCON computed mode spectrum

Major goals in RWM research were reached in 2006

- First demonstration of RWM active stabilization in high β, low A tokamak plasmas with ω_ϕ significantly less than Ω_{crit}
  - In the predicted range of ITER
  - Positive and negative RWM feedback demonstrated by varying feedback gain and relative phase
- Stability of n = 2 RWM demonstrated during n = 1 RWM stabilization
  - n = 1,2 plasma mode sometimes observed; fast β collapse, recovery
- Plasma rotation damping by non-axisymmetric applied field, RFA, or RWM follows NTV theory
  - First full NTV calculation, yielded quantitative agreement to XP
  - Key component of RWM stability physics and dynamics; general momentum transport relevance

More details in publications mentioned; analysis continues!