NSTX

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Columbia U. Group 2011-12 Macrostability XPs

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NSTX FY2011-12 Research Forum

March 16th, 2011

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Columbia U. Group 2011-12 Macrostability TSG XPs (Short Summary)

- ❑ General Comments
  - ❑ XPs address NSTX milestones and ITPA MHD joint experiments, MHD Working Groups
  - ❑ XPs slated for 2011 could bridge into 2012, especially if not completed
  - ❑ XPs slated for 2012 indicated as guidance, could run earlier if machine capabilities support them

- ❑ Macrostability TSG (2011)
  - ❑ RWM stabilization dependence on energetic particle profile (Berkery) 1.0 days
  - ❑ RWM stabilization/control, NTV V_ϕ alteration of higher A ST targets (Sabbagh) 1.5 days
  - ❑ RWM state space active control physics (independent coil control)(Sabbagh) 1.0 days
  - ❑ RWM state space active control at low plasma rotation (Y-S Park) 1.0 days
  - ❑ NTV steady-state rotation at reduced torque (HHFW) – XP 1062 (Sabbagh) 0.5 days

- ❑ Macrostability TSG (2012)
  - ❑ RWM control physics with partial control coil coverage (JT-60SA) (Y-S Park) 0.5 days
  - ❑ RWM stabilization physics at reduced collisionality (Berkery) 1.0 days
  - ❑ Neoclassical toroidal viscosity at reduced ν (independent coil control) (Sabbagh) 1.0 days

V1.2

Columbia U. Group 2011-12 Macrostability XPs (Detailed Summary)

- Macrostability TSG (2011)
  - RWM stabilization dependence on energetic particle profile (Berkery) 1.0 days
    - Joint NSTX/DIII-D experiment, ITPA MDC-2
  - RWM stabilization/control, NTV V_ϕ alteration of higher A ST targets (Sabbagh) 1.5 days
    - R(11-2), IR(12-1), MDC-2, MDC-17, WG7, PID control (examine snowflake configuration as well)
    - Use A scan at fixed κ (from SPG XP) to carefully examine NTV variation + gap scan for RWM
  - RWM state space active control physics (independent coil control) (Sabbagh) 1.0 days
    - R(11-2), R(11-3), MDC-17, WG7, n = 1&2, vary gains/targets: (i) fiducial, (ii) low li, (iii) higher A, (iv) snowflake
  - RWM state space active control at low plasma rotation (Y-S Park) 1.0 days
    - R(11-2), MDC-2, MDC-17, ITPA WG7
  - NTV steady-state V_ϕ at reduced torque with HHFW – XP 1062 (Sabbagh) 0.5 days
    - IR(12-1), ITPA MDC-12, key data to complete XP1062

- Macrostability TSG (2012)
  - RWM control physics with partial control coil coverage (JT-60SA) (Y-S Park) 1.0 days
    - MDC-2, MDC-17, WG7, mode non-rigidity, support for JT-60SA, connection to ITER
  - RWM stabilization physics at reduced collisionality (Berkery) 1.0 days
    - R(12-3), ITPA MDC-2, test RWM stability theory for NSTX-U, ITER
  - Neoclassical toroidal viscosity at reduced ν (independent coil control) (Sabbagh) 1.0 days
    - R(12-3), IR(12-1), ITPA MDC-12 , test NTV theory for NSTX-U, ITER, other tokamaks
    - Include scans to investigate island-induced NTV (XP743 – approved, but never run)

V1.2

XP: RWM stabilization, control, and NTV rotation alteration of higher A ST targets

- Motivation
  - Next-step ST devices (and the planned upgrade of NSTX) aim to operate at higher aspect ratio (A) than usual NSTX values
  - Evaluate changes in RWM stabilization physics, RWM control, and NTV V_ϕ alteration to directly address R(11-2), IR(12-1) milestone tasks
- Goals / Approach
  - Utilize higher A plasmas developed by ASC TSG to study key n > 0 stability physics, control, and non-resonant NTV alteration
    - RWM stabilization physics: effect of A changes, plasma/plate gap, EP profile on marginally stable β_N, ω_ϕ profile
    - RWM control physics: Influence of proximity to plates, influence of snowflake divertor
    - Neoclassical toroidal viscosity: dedicated A scan to address explicit R(11-2) milestone task
- Addresses
  - NSTX Research Milestones R(11-2), IR(12-1)
  - ITPA joint experiment MDC-2, MDC-17, MHD WG7

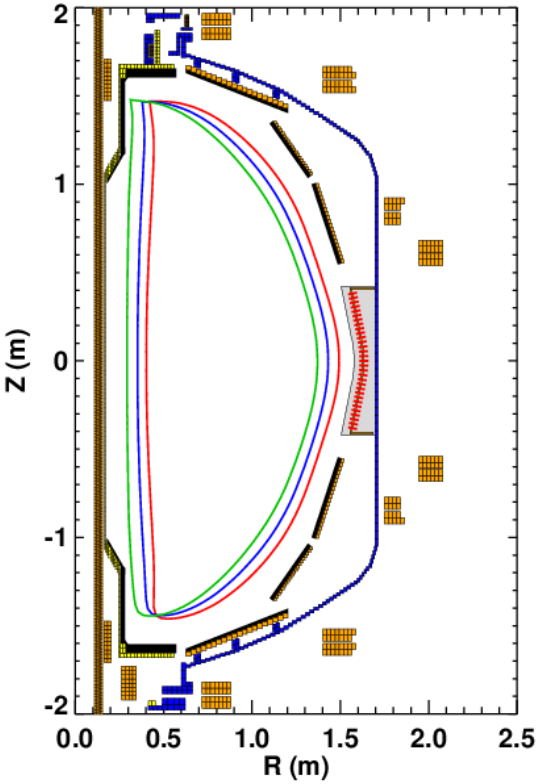
Investigate RWM stability physics, control, NTV at higher A most efficiently by starting from ASC target development

- Further target development
  - Where possible, run target attributes closest to next step STs and determine affect on stability (e.g. high κ, low l_i, snowflake divertor)
  - Generate “future ST” target comparison plasma
    - with most consistent parameters for “next-step” STs (stability challenge)
- RWM stabilization physics
  - Scan of A at fixed κ yields
    - Variation of plasma/plate distance
    - Variation of EP profile, ω_ϕ profile
  - Determine influence on RWM marginal boundary vs. ω_ϕ
  - Compare to A scan with fixed outer gap
  - Compare to “future ST” target plasma
- RWM control
  - Determine control alteration for A scan at fixed κ by examining change in RWM controllability, RWM marginal boundary vs. ω_ϕ
  - Compare control of “future ST” target with/without snowflake div.
- NTV plasma rotation alteration
  - Use both n = 2, n = 3 applied field if possible (broader NTV profile)
  - Run A scan with fixed outer gap, compare to A scan fixed κ
    - Make maximum A variation possible! (largest gaps possible)
- XP needs
  - Request: 1.5 run days

ASC TSG 2011 XP to develop higher A targets (S.P. Gerhardt)

Aspect ratio scan

($1.53 < A < 1.74$, $\kappa \sim 2.7$)

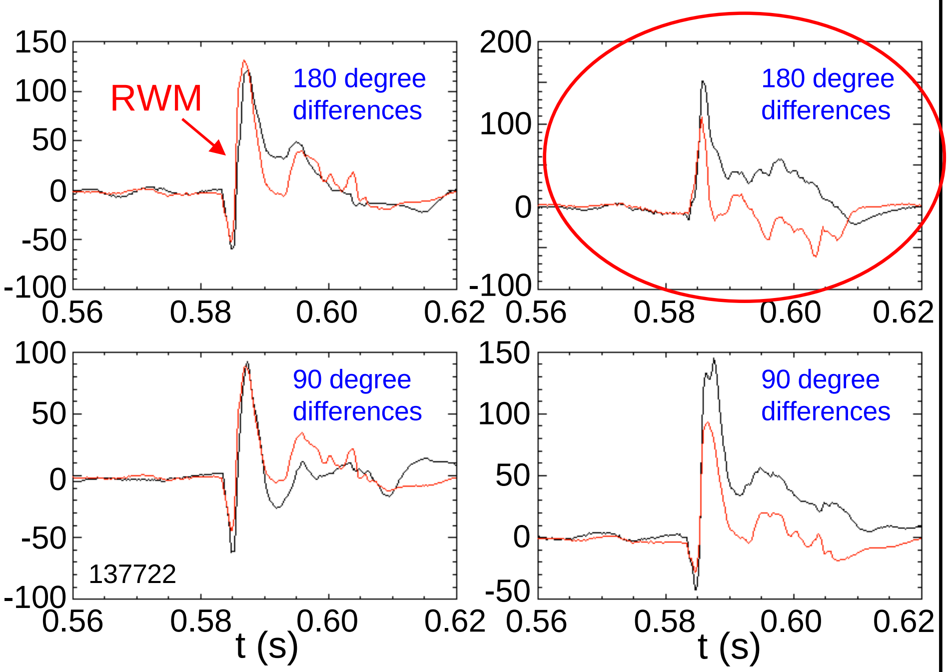


XP: RWM state space active control physics

- Motivation
  - RWM state space controller (RWMSC) allowing influence of conducting structures, plasma mode shape / response expected to improve control performance, allows greater shielding of control coils needed in future devices
  - Improve capability of present NSTX RWMSC by using new 2nd SPA
- Goals / Approach
  - Determine control physics advantages of including influence of wall, choice of input eigenfunction set, inclusion of n > 1 eigenfunctions
  - Examine control aspects of several high performance target plasmas
  - Determine effect of control with 6 independent RWM coils
  - Determine influence of reducing effect of conducting structure
  - Examine influence of adding n = 1 RWM PID control using B_r sensors
- Addresses
  - NSTX Research Milestones R(11-2), R(11-3)
  - ITPA joint experiment MDC-2, MDC-17, MHD WG7

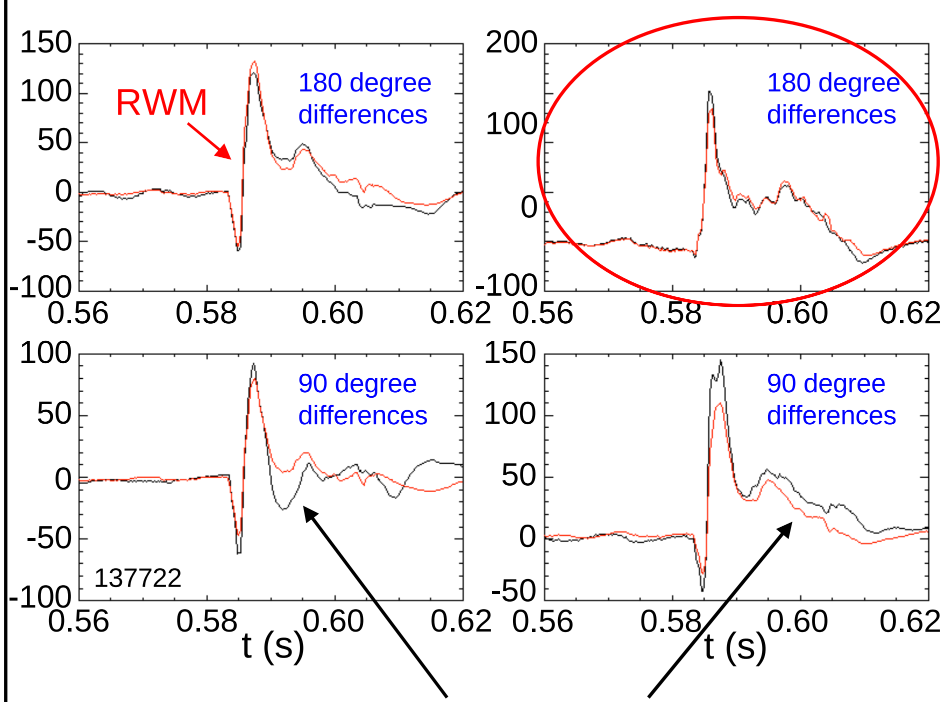
Increased number of states in RWM state space controller improves match to sensors over entire mode evolution

RWM Upper B_p Sensor Differences (G) – 2 States



- Reasonable match to all B_p sensors during RWM onset, large differences later in evolution

RWM Upper B_p Sensor Differences (G) – 7 States



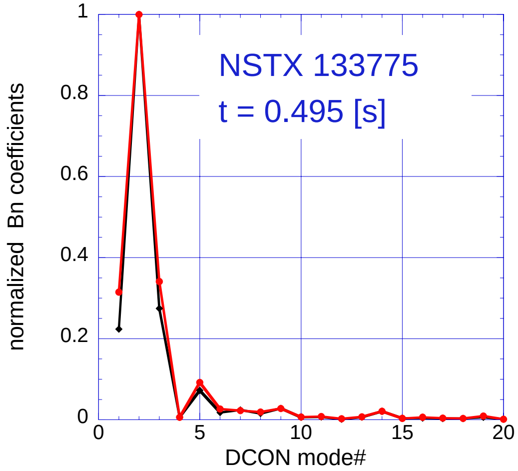
- Some 90 degree differences not as well matched
  - Indicates potential need for an n = 2 eigenfunction state
  - Plan for n = 2 control in 2011

Black: experiment Red: offline RWM state space controller

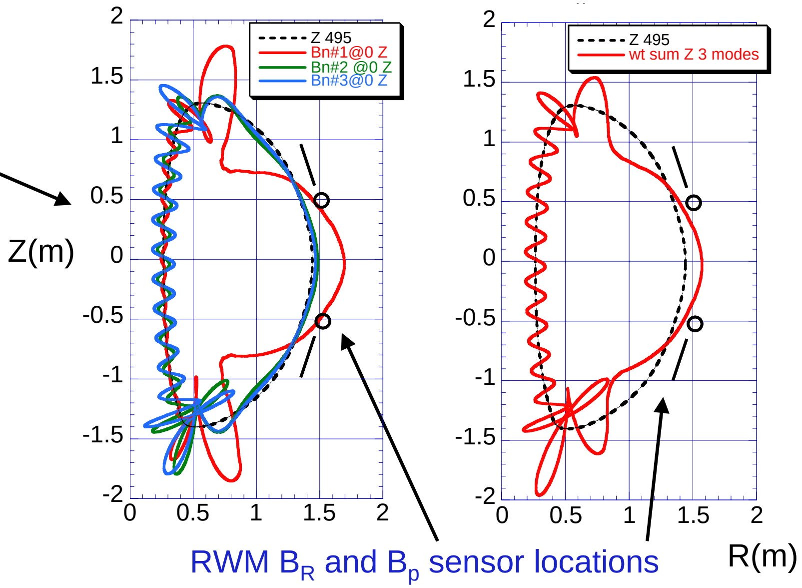
Upgrades of new RWM state space controller will leverage new 2nd SPA power supply to study physics effects

- 2nd SPA power supply allows independent control of the 6 RWM coils
- New RWM state space controller physics studies
  - Addition of n > 1 eigenfunction will then yield n = 1, 2 feedback, and higher n based on observer match to wall states
  - Test controller on various high performance targets
    - (i) fiducial, (ii) low li, (iii) higher A, (iv) snowflake divertor
    - Eigenfunction variations: e.g. does snowflake divertor configuration reduce divertor mode?
  - Compare controller with influence of wall vs. without influence of wall
- XP needs
  - Request: 1 run day
  - n > 1 control requires 2nd SPA, but other studies (e.g. add n = 2) do not require it

n = 1 multi-mode RWM spectrum (mmVALEN)



n = 1 ideal eigenfunctions for fiducial plasma



NTV steady-state offset velocity at reduced torque with HHFW (XP1062)

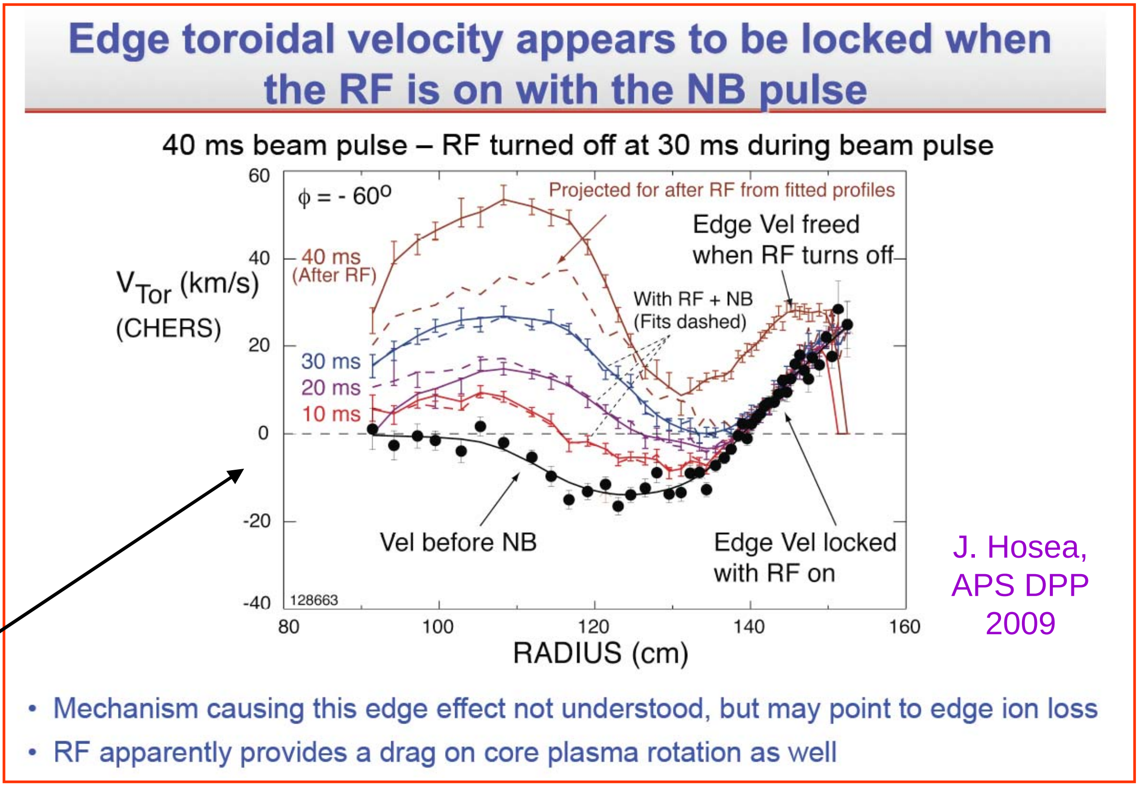
- Motivation
  - Measure and understand neoclassical toroidal viscosity (NTV) steady-state offset velocity physics to gain confidence in extrapolation of the effect to future devices
    - Background: NSTX low ω_ϕ NTV experiments with co-NBI + non-resonant magnetic braking do not show NTV steady-state offset velocity to be in the counter-I_p direction (e.g., shown in DIII-D (Garofalo, PRL 2008), claimed consistent with theory)

- Goals
  - Complete XP1062, partially run in 2010 (excluded HHFW portion of shot list)
  - Determine NTV offset rotation in plasmas with no NBI torque (HHFW heated)
    - Use demonstrated technique to measure ω_ϕ in RF plasmas
    - Use n = 3 applied field, compare to results with n = 2 applied field (if available)
  - (optional) Determine if low ω_ϕ (low ω_E superbanana plateau (SBP) regime) can be reproduced during the NBI portion of these discharges with non-resonant braking
    - Can attempt to measure NTV steady state offset velocity this way as well when varying non-resonant applied field magnitude

- Addresses
  - NSTX Milestone IR(12-1), key data to complete XP1062
  - ITPA MDC-12

Zero input torque ω_ϕ profile diagnosed in 2009 RF XPs

- Determine NTV offset rotation – RF approach
  - Generate ω_ϕ with RF at highest T_i, W_{tot} possible, diagnose similar to Hosea/Podesta 2009
  - Repeat for different *initial* values of n = 3 (or 2) field, determine if pre-NBI ω_ϕ changes
  - Note that if NTV offset is indeed only in counter-I_p direction, the ω_ϕ profile will change (it's presently counter in core, co at the edge
- Attempt to maintain near-zero ω_ϕ during NBI phase
  - New way to enter/sustain low ω_E SBP regime



Edge toroidal velocity appears to be locked when the RF is on with the NB pulse

40 ms beam pulse – RF turned off at 30 ms during beam pulse

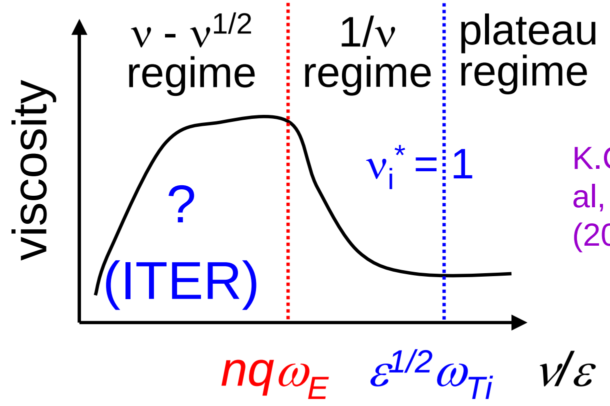
J. Hosea, APS DPP 2009

- Mechanism causing this edge effect not understood, but may point to edge ion loss
- RF apparently provides a drag on core plasma rotation as well

- Since SBP regime yields maximum NTV
  - Entering it by lowering ω_ϕ yielded an observed increase in NTV without mode locking (2009-10)
  - Conversely, attempt to measure decrease in NTV as SBP regime is exited
- <u>Request</u>: 0.5 run days

XP: Neoclassical toroidal viscosity at reduced collisionality

- ❑ Motivation
  - ❑ Experimentally, the dependence of neoclassical toroidal viscosity (NTV) on collisionality is not well known
  - ❑ Understanding important for NSTX V_ϕ control, NSTX-U, and future devices
- ❑ Goals / Approach
  - ❑ Examine the dependence of NTV on ion collisionality
    - expected to increase with decreasing ν_i from present experiments)
    - leverage low ν_i target development by the ASC TSG for milestone R(12-3)
  - ❑ Determine if superbanana plateau increase of NTV depends on ν_i
  - ❑ Operate with pre-programmed n = 2, 3 applied fields for V_ϕ control testing
- ❑ Addresses
  - ❑ NSTX Milestones R(12-3), IR(12-1)
  - ❑ ITPA joint experiment MDC-2, MDC-17, MHD WG7



K.C. Shaing, et al, PPCF **51** (2009) 035004

Simplified expression of NTV force ("$1/\nu$ regime")

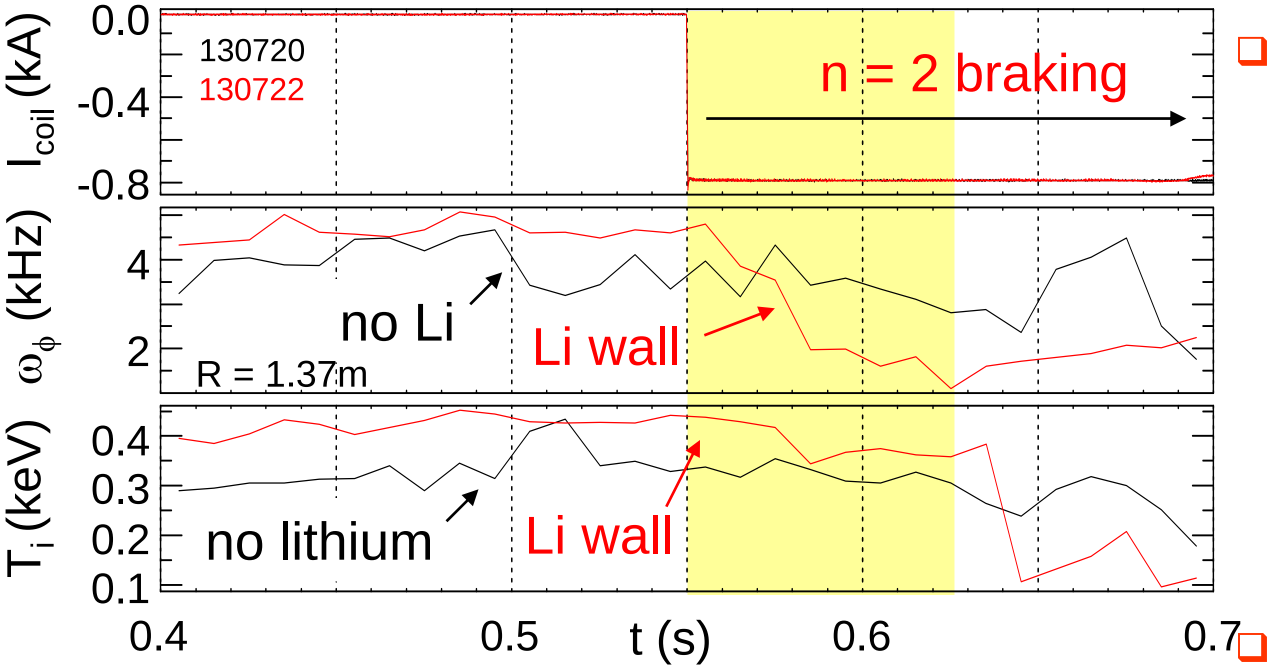
$$\left\langle \hat{e}_t \bullet \vec{\nabla} \bullet \overleftrightarrow{\Pi} \right\rangle_{(1/\nu)} = B_t R \left\langle \frac{1}{B_t} \right\rangle \left\langle \frac{1}{R^2} \right\rangle \frac{\lambda_{1i} p_i}{\pi^{3/2} \nu_i} \varepsilon^{3/2} (\omega_\phi - \omega_{NC}) I_\lambda$$

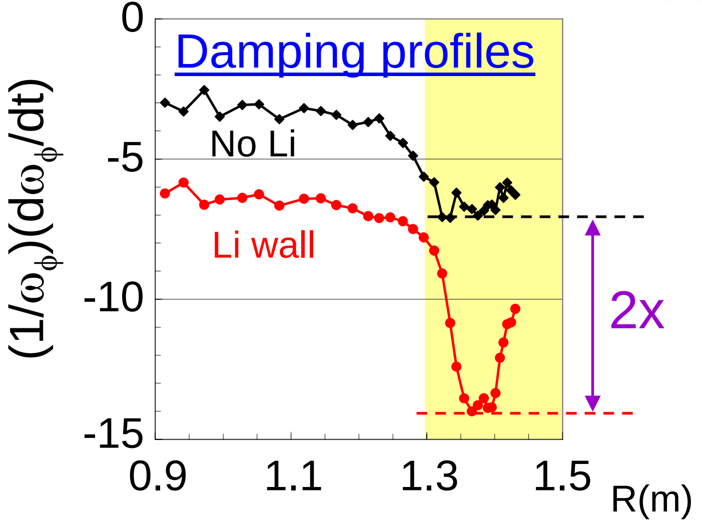
$T_i^{5/2}$

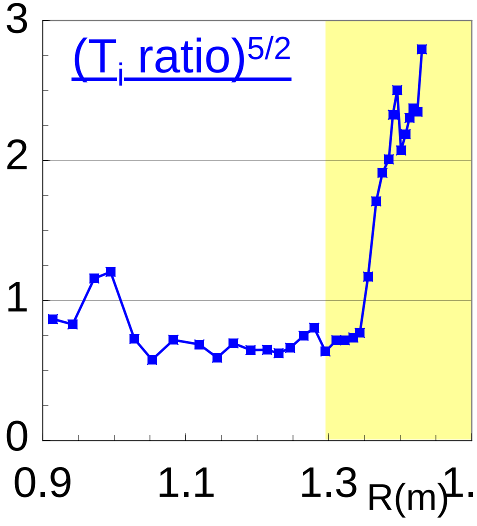
Steady-state velocity

Inverse aspect ratio

Stronger non-resonant NTV braking at increased T_i







- Expect stronger NTV torque at higher T_i $(-d\omega_\phi/dt \sim T_i^{5/2}\,\omega_\phi)$
  - At braking onset, T_i ratio$^{5/2}$ = $(0.45/0.34)^{5/2} \sim 2$
  - Consistent with measured $d\omega_\phi/dt$
    S.A. Sabbagh, et al, NF **50** (2010) 025020
- Present XP
  - Operate with larger change in ν_i
  - Attempt to reach quasi-steady-state ω_ϕ for each ν_i
  - Use braking field envisioned for V_ϕ FB
- Request: 1 run day

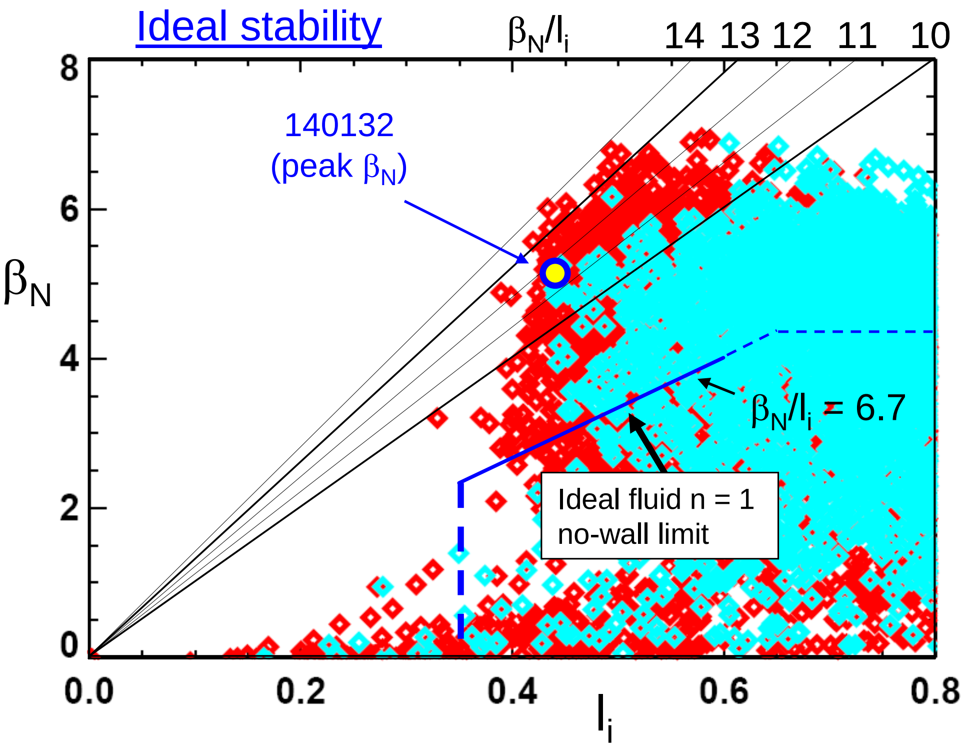
XP: RWM state space active control at reduced plasma rotation

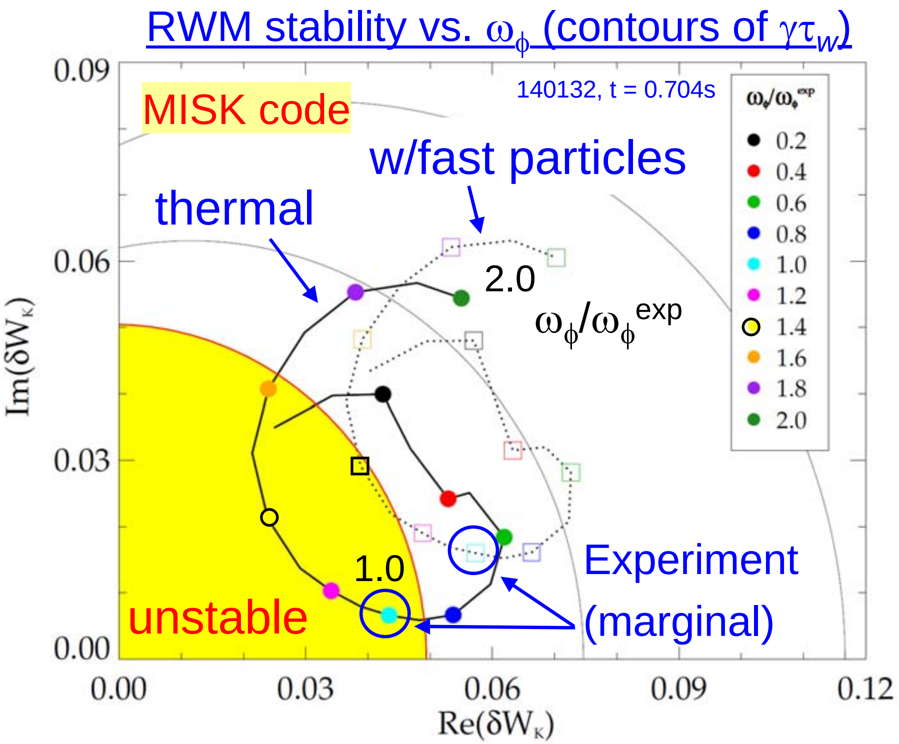
- Motivation
  - Present theory shows ITER advanced scenario plasmas are RWM unstable just above the n = 1 no wall limit, and alpha particle stabilization is weak; Amount of kinetic resonance stabilization in future ST is uncertain

- Goals / Approach
  - Demonstrate RWM control over a greater range of plasma rotation using RWM state space control (incl. low ω_ϕ, intermediate ω_ϕ at marginal stability)
  - Determine control physics differences of varying input eigenfunction set (including allowance of n > 1 eigenfunctions) at various ω_ϕ
  - Vary key controller parameters to examine influence on stability
  - Test compatibility with applied fields for NTV rotation damping
    - Ensure controller doesn't reduce n = 3 braking field significantly
  - Examine influence of adding n = 1 RWM PID control using B_r sensors

- Addresses
  - NSTX Research Milestones R(11-2)
  - ITPA joint experiment MDC-2, MDC-17, MHD WG7

Kinetic stability calculations show reduced stability in low l_i target plasma as ω_ϕ is reduced; also at low ω_ϕ


Ideal stability


RWM stability vs. ω_ϕ (contours of $\gamma\tau_w$)

- Can RWM unstable regions be controlled?
  - Ideal stability analysis shows high margin over no-wall limit
    - RWM stabilization by kinetic effects large
  - MISK: RWM marginal stability at various ω_ϕ
    - Demonstrate control in these regions!
- Find controller parameters important for stabilization
  - Includes n > 1 control, variation of eigenfunctions used in controller, etc.
- Request: 1 run day

XP: RWM control physics with partial control coil coverage

Motivation

- Effect of partial coil coverage (e.g. JT-60SA)*, and impact of internal coil loss (e.g. ITER) may lead to “mode non-rigidity” during RWM feedback – the effect on mode control needs to be understood
- Provides key physics input for NSTX NCC design**

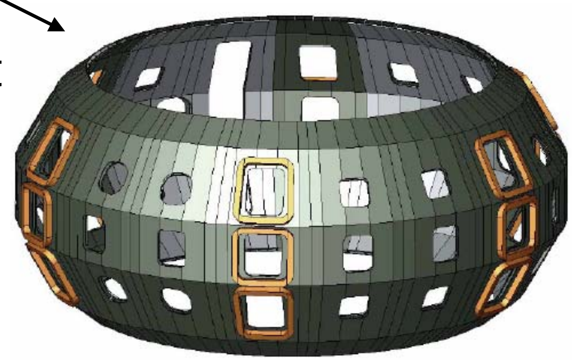
Goals / Approach

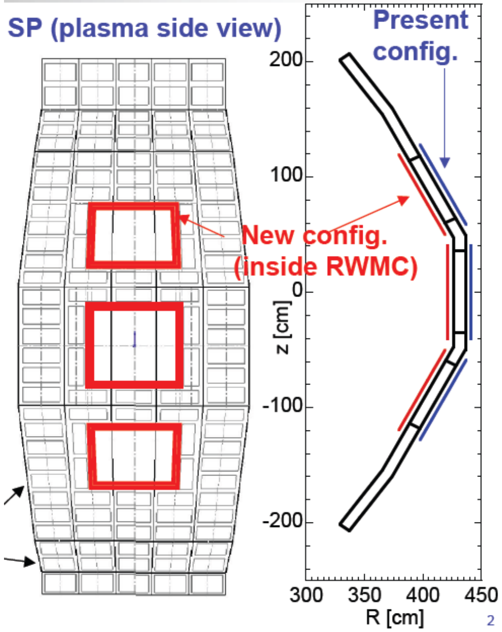
- RWM control in NSTX will be attempted with partial coverage of the RWM coils to test the physics of RWM mode rigidity
- Leverage new independent control of the RWM coils
- Determine the change in the computed multi-mode RWM spectrum and compare to experiment
- Compare attempted control with both the RWM PID controller, and RWM state space controller

Addresses

- ITPA joint experiment MDC-2, MDC-17, MHD WG7
- *Collaborative RWM stabilization research with JAEA (for JT-60SA); **physics input for NSTX NCC design

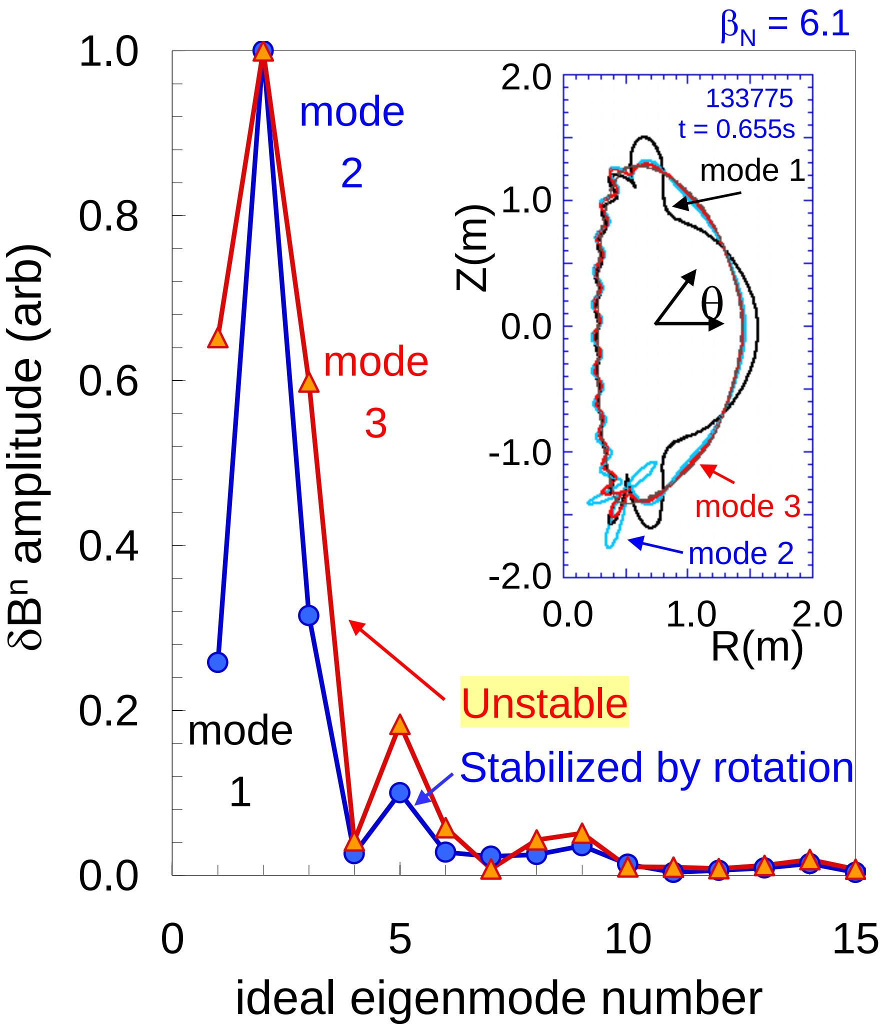
JT-60SA passive plates and RWM control coils





Multi-mode RWM computation shows 2nd eigenmode component has dominant amplitude at high β_N in NSTX stabilizing structure

NSTX δB_n RWM multi-mode spectrum



mmVALEN code

- ❑ XP Approach, physics investigated
  - ❑ Deactivate (i) one RWM coil, (ii) two neighboring RWM coils, (iii) every other RWM coil
  - ❑ Determine computed RWM multi-mode spectrum change for each condition
    - Include n > 1 spectrum
    - Compare to measured n = 1,2,3 δB
  - ❑ Compare effect on RWM PID and state space control
    - PID should be more subject to failure by n > 1 mode content, error in tracking toroidal phase
    - State space controller with n > 1 eigenfunctions and wall effects may provide greater control
    - Attempt to “correct” control failures by adjusting controller inputs
    - Re-try failed control at reduced β_N to determine if/when control is regained
- ❑ Request: 1 run day