MHD Stability of High β NSTX Plasmas

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NSTX Has Observed Several β-Limiting Instabilities

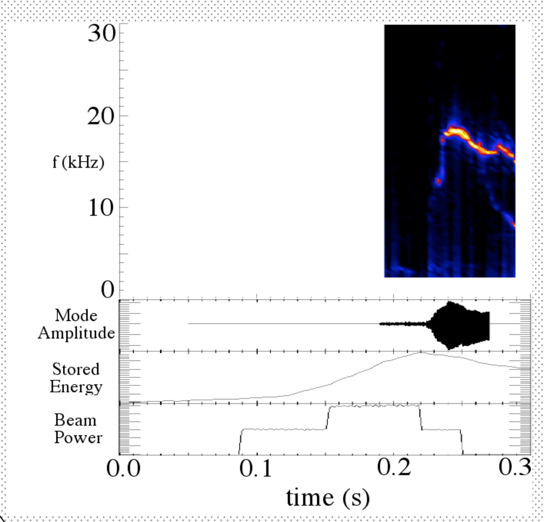
NTM

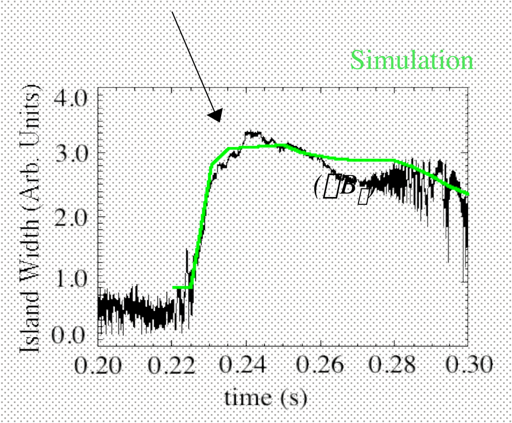
•Slowly growing MHD mode observed
–drive appears to be neoclassical - mode decays when β_p drops

•Obeys modified Rutherford equation*
–compare solution to measured field perturbation

$$\frac{\tau_0}{1.22\tau_{nc}}\frac{dw}{dt} = \Delta' + a_1\varepsilon^{1/2}\beta_\theta\frac{L_q}{L_p}\left(\frac{w}{w^2+w_c^2}\right) - a_2\frac{\rho_{\theta i}^2\beta_\theta g(\varepsilon)}{w^3}\left(\frac{L_q}{L_p}\right)^2$$

Beam Turn-Off Experiment





Avoid by operating at elevated q

*Synakowski E.J.,et al. Nucl. Fusion **43** (2003) 1653

Pressure Driven Internal Kink

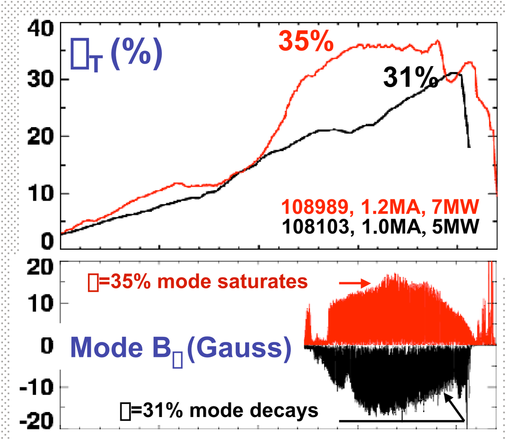
•High fast ion pressure and large region with q~1 leads to calculated ideal 1/1 instability

•Observed 1/1 can cause:
– β saturation
–rotation damping
–plasma disruption

• β saturates or rises in highest β shots
•1/1 can saturate or decay

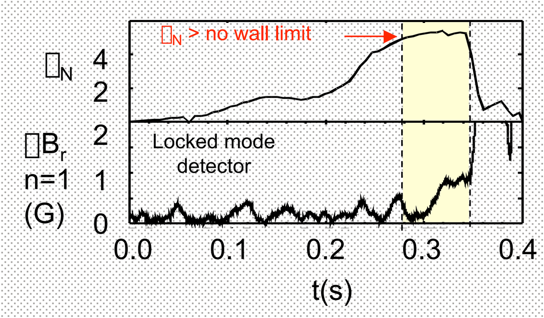
•Flow shear stabilization consistent with observed results
–M3D simulations show possible saturation mechanism

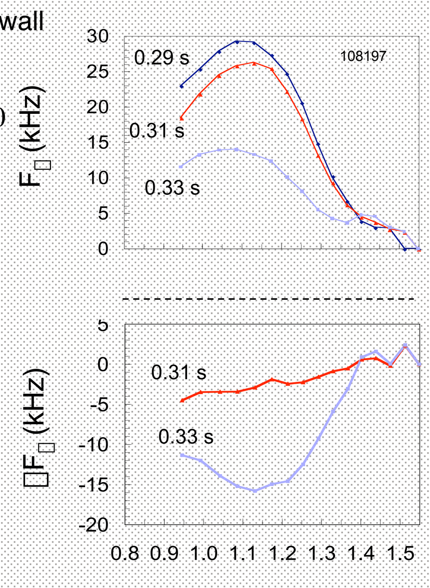
•Work on these modes ongoing
–Menard J.E., et al., Nucl. Fusion, **43** (2003) 330



RWM

•RWM indications when $\beta_N > \beta_{N\ no\text{-}wall}$
–n=1 locked mode
–global rotation collapse
–Sabbagh S.A., et al., Nucl. Fusion **44** (2004) 560





•RWM stability being acitvely researched
–roles of rotation, dissipation, toroidicity, etc need clarification
–understanding needed for passive and active stabilization of RWM

RWM Stability Dependant On Toroidal Rotation and Dissipation

Toroidal Inertial Enhancement Leads to Rotational Stabilization Criterion

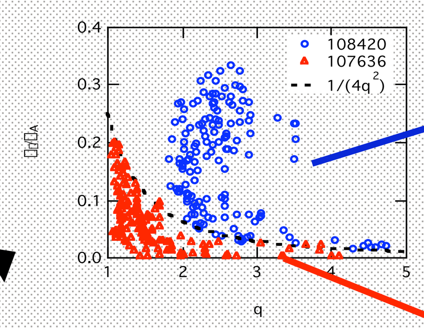
•RWM stability requires rotation and dissipation
–dissipation mechanism uncertain
–coupling to sound or Alfven continua are possibilities

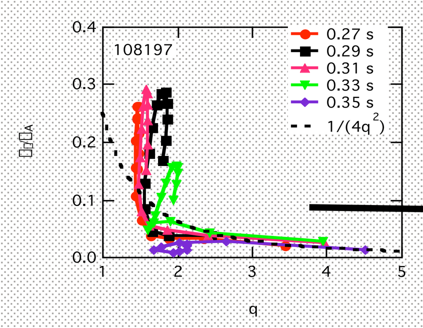
•Critical rotation for inertial enhancement
–from Bondeson A., Chu M.S., Phys. Plasmas **3** (1996) 3013
–change in mode structure for sufficient rotation

$$\Omega_{rot} > \frac{\omega_A}{4q^2}$$

–assumes cylindrical geometry

•3 states observed in NSTX:
–profile entirely stable – 108420
–profile entirely unstable – 107636
–profile partially stable – 108197

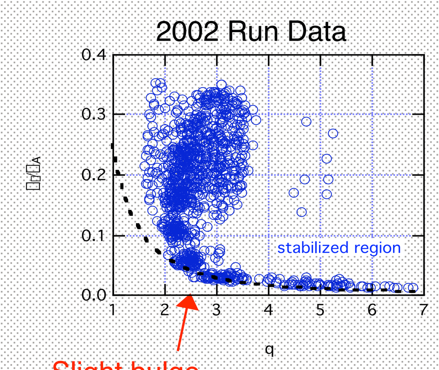


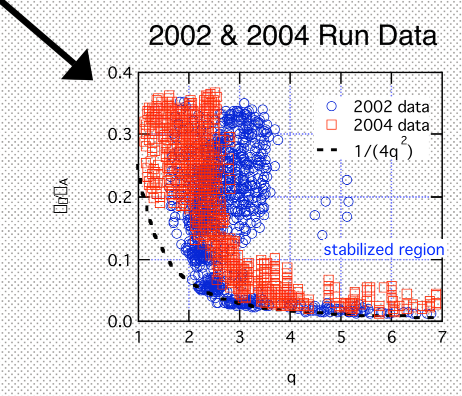


•Entire profile stable:
–all shots examined survive for > 10τ_{wall} in wall-stabilized regime
–over 1500 shot*radius*time points
–bulge due to points near edge
–*uncertainity in V_{Alfven} near edge*
–perhaps 1/(6q²) more appropriate?
–*better q constraint needed*
–2004 long pulse data show similar trend

•Entire profile unstable:
–reaches no-wall limit 3 times
–experiences immediate β collapse when $\beta_N = \beta_{N\ no\text{-}wall}$
–ideal stability restored after collapses

•Partially stabilized profile:
–several shots examined in this regime
–all experience β collapse after ~ 3τ_{wall}





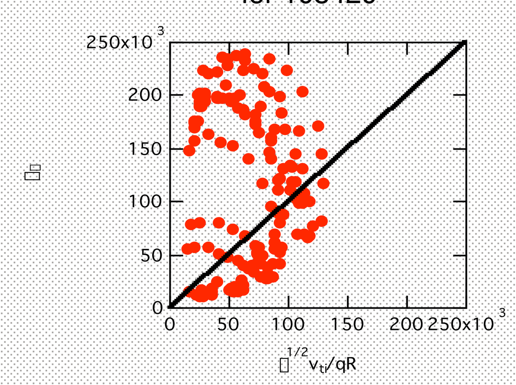
Dissipation Dependant on Toroidal Rotation

•Dissipation due to ion Landau damping
–requires sufficent rotation for resonance

$$\Omega_{rot} > \frac{\varepsilon^{1/2}v_{ti}}{qR}$$

•Should be operative in part of plasma
–numerical calculations required to determine magnitude for stability

Rotation vs Damping Parameter for 108420



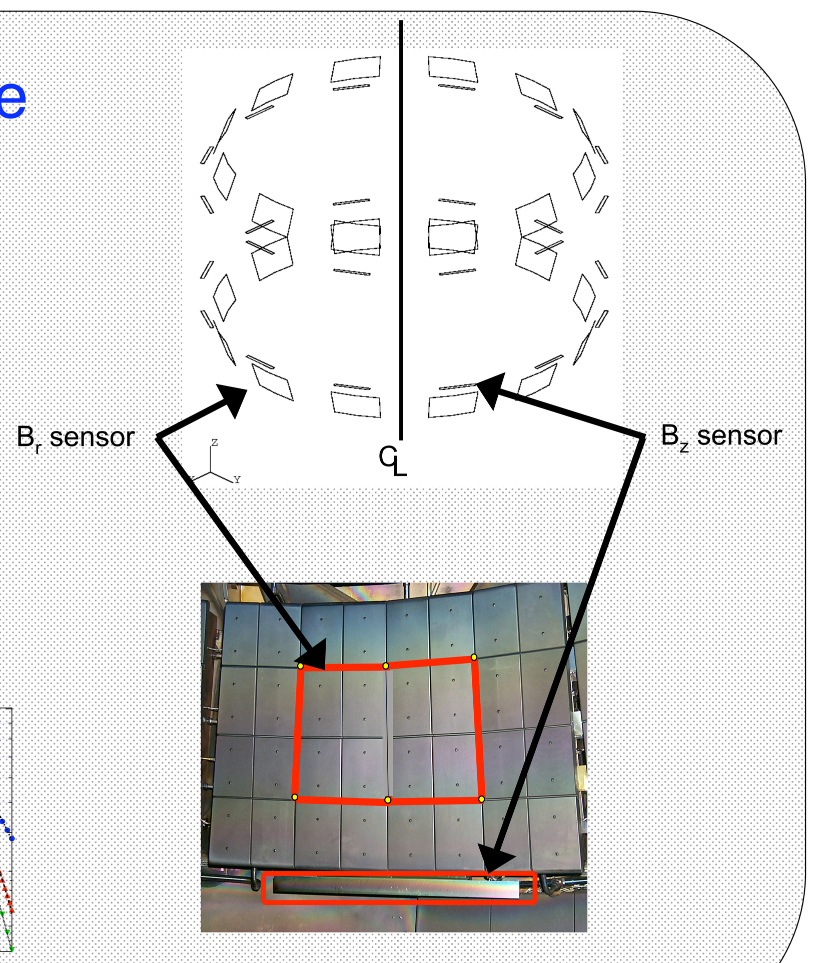
Internal Sensors and External Control Coil Installed in NSTX Allow for Mode Detection/Control

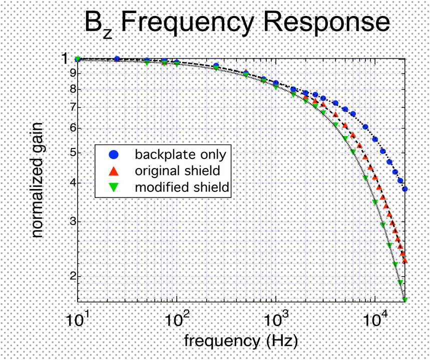
Sensor Hardware

• δB_p and δB_r arrays installed above and below midplane on passive plates
–12 sensors in each array - toroidally symmetric
–instrumented for n=1,2,3 mode detection
–coil pair sums and differences recorded
–2 x 180° pairs, 4 x 90° pairs

•Frequency response with shielding adequate for slowly rotating/locked mode detection
–rotation of RWM ~1/τ_{wall} < 200 Hz (away from with-wall limit)

•Background compensation necessary
–pickup due to:
slight misalignments
non-balanced coil pairs
eddy current asymmetries
•measured coil currents/loop voltages used for compensation





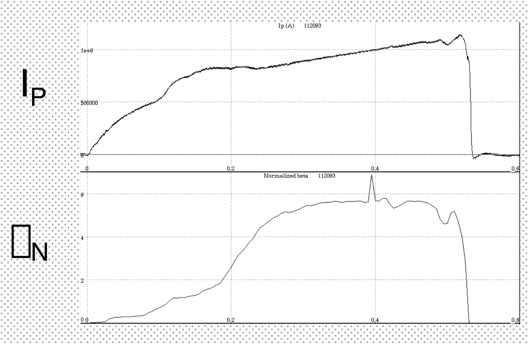
Possible Indications of RWM Observed in 2004 Run Campaign

•Most high β_N shots appear RWM stable
–other instabilities also a factor
–high rotation appears to be stabilizing

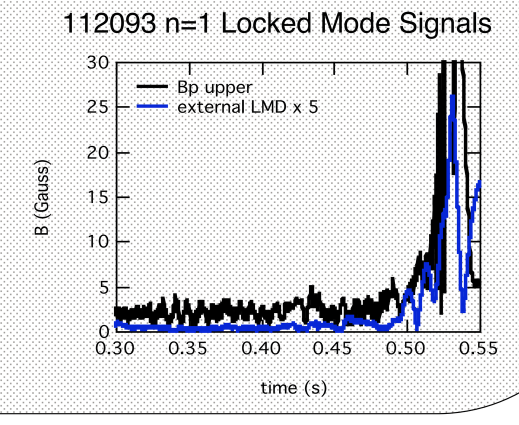
•Shot 112093 is possible RWM candidate

•Growth in n=1 before collapse
–difficult to resolve from noise in internal detectors
–n=1 starting to grow at ~0.47s?
–SXR data confirms toroidal asymmetry

•Vertical instability at ~0.49s
–n=1 'bounce' observed on both internal and external sensors
–pure n=0 mode should be removed by SVD mode detection
–global n=1 triggering n=0 displacement?



112093 n=1 Locked Mode Signals



Internal Sensors Show Improvement Over External Array

•VALEN model of sensors predicts ~ 4x greater signal than external array

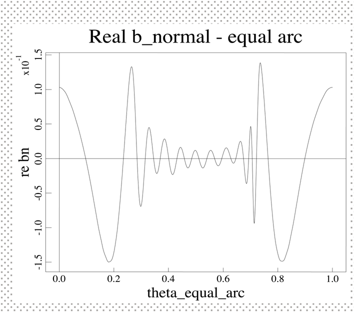
•DCON used to determine mode structure
–shot 108420 mode structure

•Internal sensors observe rotating n = 1 when rotation drops below ~ 10kHz
–consistent with measured sensor frequency response

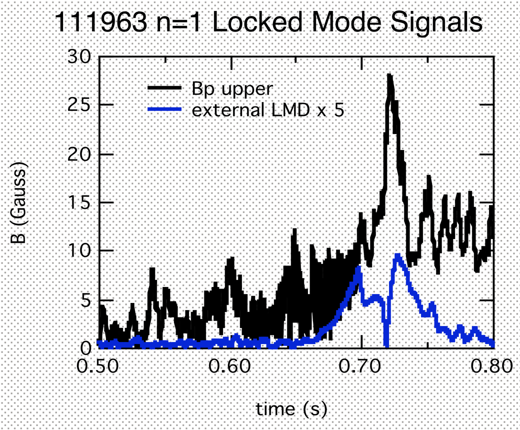
•Signal Strength Consistent with VALEN calculations

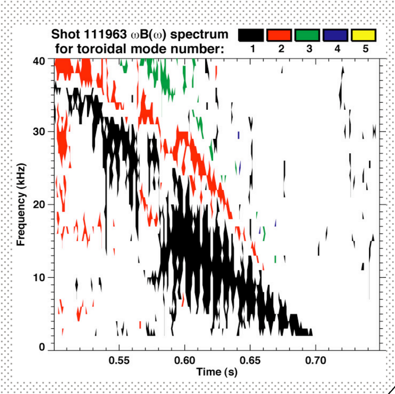
•Mode lock much more clear on internal array

•Noise on internal array due to imperfect compensation



111963 n=1 Locked Mode Signals





Active Feedback Coil Currently Under Construction

•1st coil pair to be commissioned by July 6

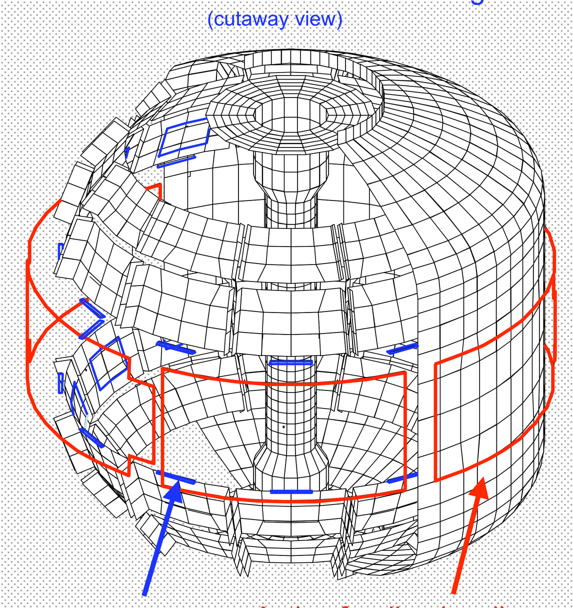
•Will initially provide n=1 field for magnetic braking/ MHD spectroscopy

•Capable of stabilizing up to C_β = 0.68

$$C_\beta \equiv \frac{\beta_N - \beta_{N\_no-wall}}{\beta_{N\_ideal-wall} - \beta_{N\_no-wall}}$$

•fast switching power amplifier (SPA) on order
–control system response will limit feedback capabilities
–slow (3-4 ms latency) TFTR coil supply to provide power on day 1

VALEN model – external coil design
(cutaway view)



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