NSTX 2011-2012 Experimental Proposals: RWM Passive Stabilization Physics

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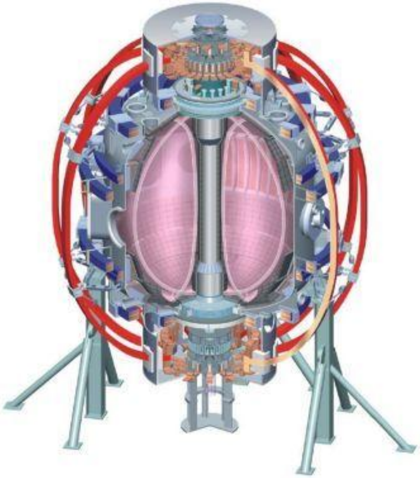

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Two RWM Passive Stabilization Physics XP Proposals

1. RWM Stabilization Dependence on Energetic Particle Distribution
2. RWM Stabilization Physics at Reduced Collisionality

RWM Stabilization Dependence on Energetic Particle Distribution

- Motivation

[J.W. Berkery *et al.*, Phys. Plasmas **17**, 082504 (2010)]

  - EPs are known to play an important role in RMW kinetic stability.
  - NSTX-U will have an off-axis neutral beam, so it is important to assess the profile and pitch angle dependence on stability.
  - Comparison to DIII-D through 2011 joint experiment.
- Goals
  - The physics of resistive wall mode (RWM) stability on the kinetic effects of energetic particles (EPs) will be investigated by changing the EP distribution function, principally from using off-axis neutral beam injection in downward or horizontally shifted plasmas.
- Addresses:
  - ITPA: MDC-2: Joint experiments on resistive wall mode physics.

Including anisotropy requires rewriting code for general *f* and including new terms

Isotropic Maxwellian:

$$\delta W_K = \sum_j \sum_{l=-\infty}^{\infty} \sqrt{\pi} \int\int\int n_j T_j \left[|\langle H/\hat{\varepsilon}\rangle|^2 \frac{n\left(\omega_{*N}^j + \left(\hat{\varepsilon} - \frac{3}{2}\right)\omega_{*T}^j + \omega_E\right) - \omega}{n\langle\omega_D^j\rangle + l\omega_b^j - i\nu_{\mathrm{eff}}^j + n\omega_E - \omega} \right] \frac{\hat{\tau}}{B_0} \hat{\varepsilon}^{\frac{5}{2}} e^{-\hat{\varepsilon}} d\hat{\varepsilon} d\Lambda d\mathbf{\Psi}$$

General:

$$\delta W_K = \sum_j \sum_{l=-\infty}^{\infty} 2\sqrt{2}\pi^2 \int\int\int \left[|\langle H/\hat{\varepsilon}\rangle|^2 \frac{(\omega - n\omega_E)\frac{\partial f_j}{\partial \varepsilon} - \frac{n}{Z_j e}\frac{\partial f_j}{\partial \Psi}}{n\langle\omega_D^j\rangle + l\omega_b^j - i\nu_{\mathrm{eff}}^j + n\omega_E - \omega} \right] \frac{\hat{\tau}}{m_j^{\frac{3}{2}} B} |\chi| \hat{\varepsilon}^{\frac{5}{2}} d\hat{\varepsilon} d\chi d\mathbf{\Psi},$$

Changed pitch angle variable from: $\Lambda = \mu B_0/\varepsilon$ to: $\chi = v_\parallel/v$

A new δW term arises from this term of the perturbed distribution function:

$$\tilde{f}_j = -\boldsymbol{\xi}_\perp \cdot \boldsymbol{\nabla} f_j + Z_j e \frac{\partial f_j}{\partial \varepsilon}\left(\tilde{\boldsymbol{\Phi}} + \boldsymbol{\xi}_\perp \cdot \boldsymbol{\nabla}\Phi_0\right)$$
$$+ i m_j \left(\omega \frac{\partial f_j}{\partial \varepsilon} - n \frac{\partial f_j}{\partial P_\phi}\right)(\mathbf{v} \cdot \boldsymbol{\xi}_\perp - \tilde{s}_j) - \frac{m_j}{B}\boxed{\frac{\partial f_j}{\partial \mu}}\left(-i\omega \boldsymbol{\xi}_\perp \cdot \mathbf{v}_\perp + \left(\frac{\mu}{m_j}\frac{\mathbf{B}}{B} + \frac{v_\parallel \mathbf{v}_\perp}{B}\right) \cdot \tilde{\mathbf{B}}\right)$$

Also requires corrections to fluid terms with an anisotropic parameter:

$$\sigma = 1 + \frac{\mu_0 \left(p_\perp - p_\parallel\right)}{B^2}$$

and effect on equilibrium itself, etc…

[T. Antonsen and Y. Lee, Phys. Fluids **25**, 132 (1982)]

RWM Stabilization Dependence on Energetic Particle Distribution

- Approach
  - Establish target downward or horizontally shifted plasmas with off-axis neutral beam injection.
    - In 2010 XP1030 (D. Battaglia) produced plasmas that were shifted off axis by $\Delta z = -25$ cm. He only used 2MW of beam power, however.
  - Add n=1, 30 Hz., 1kA peak to peak traveling wave for active MHD spectroscopy.
  - Use n=2 and n=3 non-resonant magnetic braking to decrease plasma rotation, find marginal point or peak in RFA.
  - Change plasma conditions, such as height and beam power. Repeat for comparison to theory at multiple conditions.
    - Can also use previous technique to change the EP content by changing the plasma current and field (which changes the thermal plasma as well).

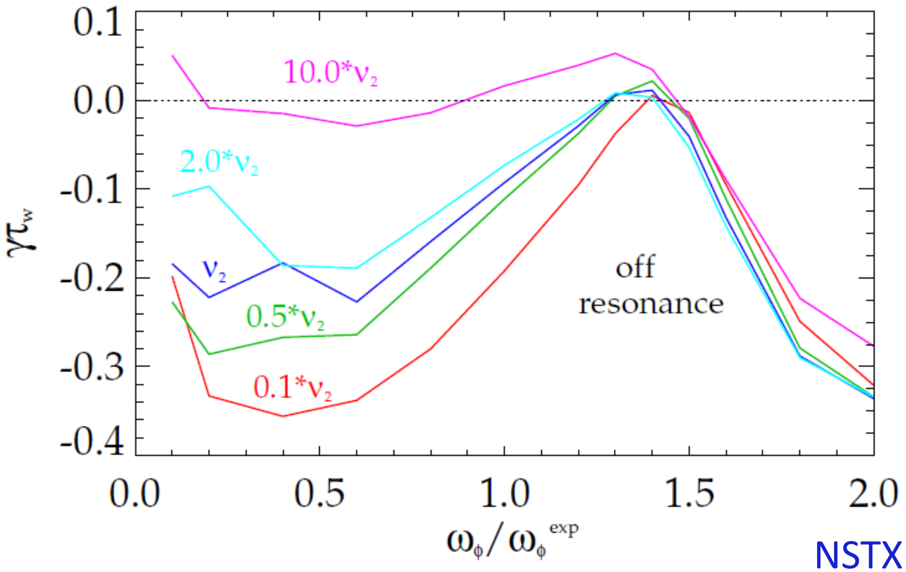
RWM Stabilization Physics at Reduced Collisionality

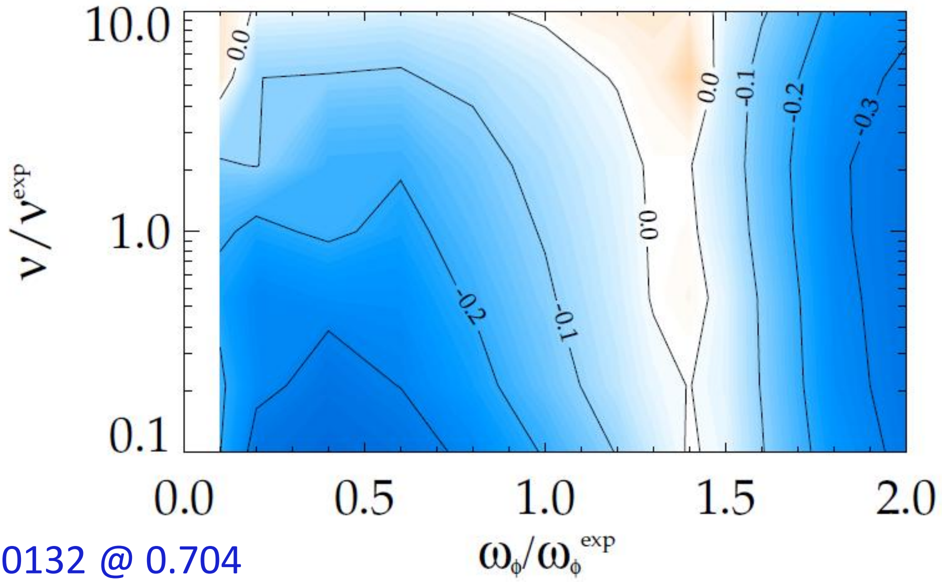
- Motivation
  - In future devices with lower ν, plasmas in resonance will gain stability, but the stability gradient with rotation will increase.

[J.W. Berkery *et al.*, Phys. Rev. Lett. **106** 075004 (2011)]

- Goals
  - Resistive wall mode stability with respect to plasma rotation will be experimentally determined in low ν, NSTX-U relevant plasmas, and compared to expectation from kinetic stabilization theory.
- Addresses:
  - NSTX Milestone R(12-3): Assess access to reduced density and collisionality in high-performance scenarios.
  - IR(12-1): Investigate magnetic braking physics and develop toroidal rotation control at low collisionality (incremental).
  - ITPA: MDC-2: Joint experiments on resistive wall mode physics.

In contrast to previous theory, reduced ν_{eff} is stabilizing for on-resonance plasmas, increasing stability gradient





NSTX 140132 @ 0.704

Reducing collisions has two competing effects:

- reduces collisional dissipation that is important when plasma rotational resonances are not present
- reduces damping of resonant kinetic stabilizing effects, allowing them to be more powerful

[J.W. Berkery *et al.*, Phys. Rev. Lett. **106** 075004 (2011)]

In future devices with lower collisionality:

- plasmas in rotational resonance will be even more stable; off-resonance almost no effect
- plasma stability *gradient* with rotation will increase
- it will be especially important to avoid unfavorable rotation through rotation or active mode control

RWM Stabilization Physics at Reduced Collisionality

- Approach
  - Establish target low collisionality plasmas.
    - This XP will leverage the successful development of a reliably operating low collisionality target, which will be pursued as part of the R(12-3) milestone.
  - Add n=1, 30 Hz., 1kA peak to peak traveling wave for active MHD spectroscopy.
  - Use n=3 non-resonant magnetic braking to decrease ω_ϕ.
  - Go to both higher and lower collisionality. Repeat for comparison to theory at multiple conditions.
  - Lower density plasmas are expected to be subject to more EPMs. It is possible that we could find EPM-triggered RWMs in this XP.
  - Techniques to diagnose the eigenfunction, with edge ME-SXR, reflectometer, or BES, as in Menard's proposal, can also be tried.

RWM Passive Stabilization Physics - Diagnostics

- Required diagnostics / capabilities
  - n=2 braking capability highly desired (in addition to usual n=3)
  - RWM sensors
  - CHERS toroidal rotation measurement
  - Thomson scattering
  - USXR
  - MSE
  - Toroidal Mirnov array / spectrogram with toroidal mode number analysis
  - FIDA
- Desired diagnostics
  - Advanced USXR diagnostics
  - Reflectometer
  - BES
  - Fast camera
  - CHERS poloidal rotation measurement