Measuring Kinetic Contributions to Resistive Wall Mode Stability Using Active MHD Spectroscopy

by
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In collaboration with
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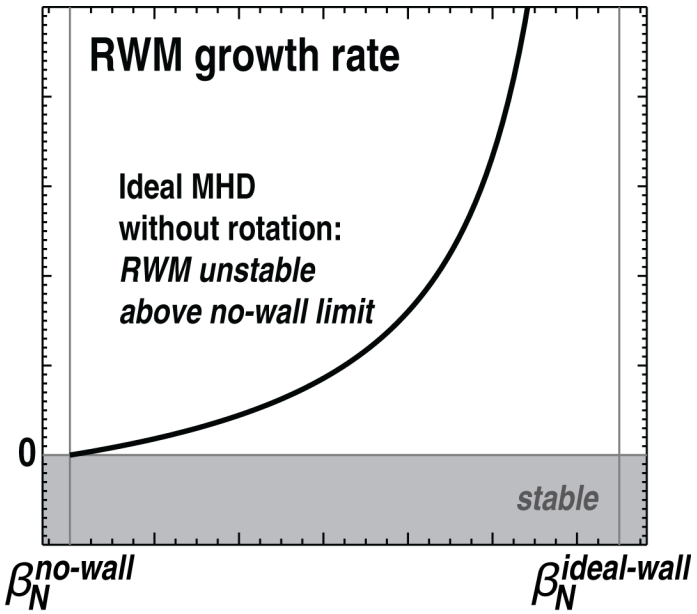
Off-axis NBI Used to Probe Kinetic Contributions to RWM Stability

- **Motivation: need to validate theories of RWM stability for ITER, beyond**
  - Resistive wall modes arise from the interaction between an external kink mode and wall eddy currents. RWMs can be ***global, beta-limiting instabilities***
  - Recent experiments on several devices have shown complex dependence of stability on plasma rotation, ***lack of a critical rotation threshold***
  - ***Kinetic stabilization theory*** needed to explain recent results: MISK, HAGIS, MARS-K codes
- **Off-axis NBI used to probe kinetic damping of RWM stability in DIII-D experiment**
- **Rotation dependence of RWM stability extended, consistent with theoretical expectations**
- **Off-axis NBI leads to *increased* RWM stability**

Kinetic Wave-particle Damping Leads to Enhanced RWM Stability Above No-wall Limit

- **Ideal MHD energy principle modified to include kinetic damping physics**
  [Hu and Betti, Phys. Rev. Lett, (2004)]

$$\gamma\tau_w = -\frac{\delta W_{nw}}{\delta W_{iw}}$$



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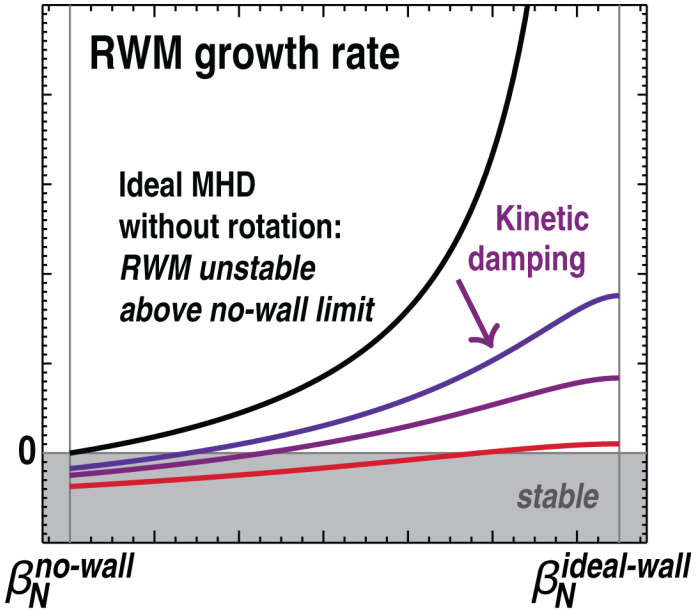
$$\delta W_K = \frac{1}{2}\int \vec{\xi}_\perp \cdot \vec{\nabla} \cdot \tilde{P}_K d\vec{v}$$



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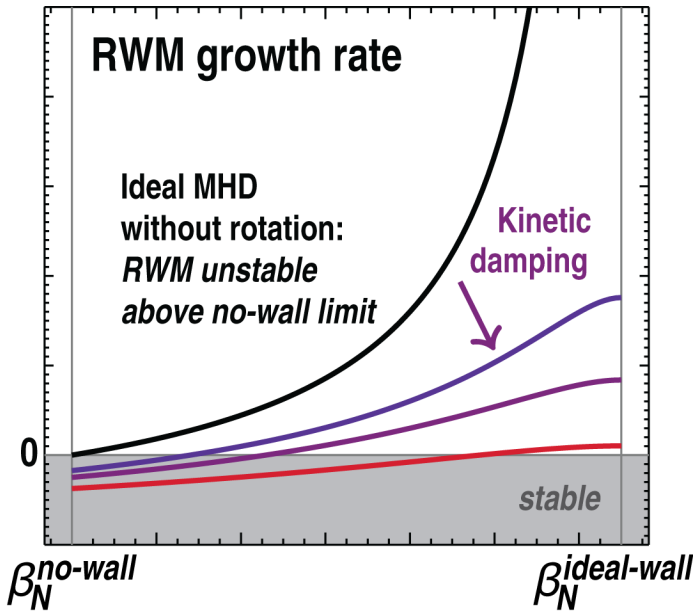
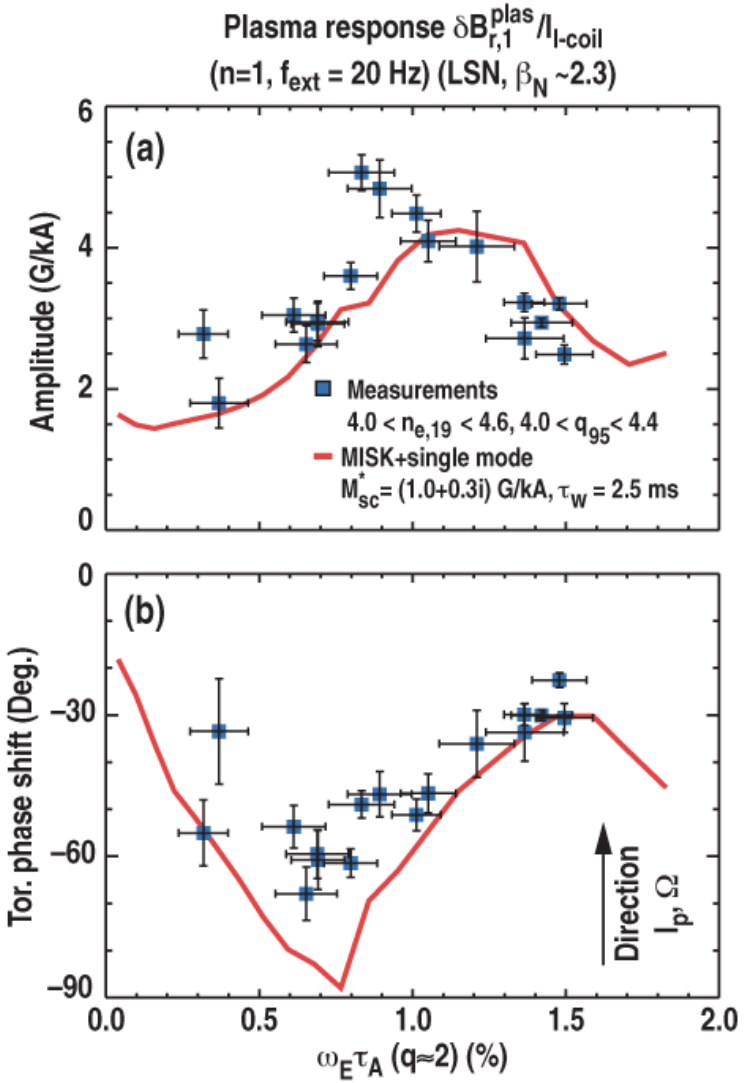


- **Kinetic energy principle δW_K allows for energy exchange between RWM and kinetic particle populations**
  - Resonances between motion of ***trapped particles*** and ***plasma rotation***
  - ***Non-resonant*** effects that depend on alignment of distribution function gradients and the RWM eigenfunction

Kinetic RWM Stability Effects Investigated in Stable Plasmas Above the No-wall Limit

- Measurements of ***plasma response*** to slowly rotating *n* = 1 perturbations used to compare theory and experiment
- ***Rotation scan*** revealed evidence of ***trapped particle resonances*** in DIII-D; complemented NSTX work on the RWM stability threshold



[Berkery, *et al.*, *Phys. Rev. Lett.* (2010)]

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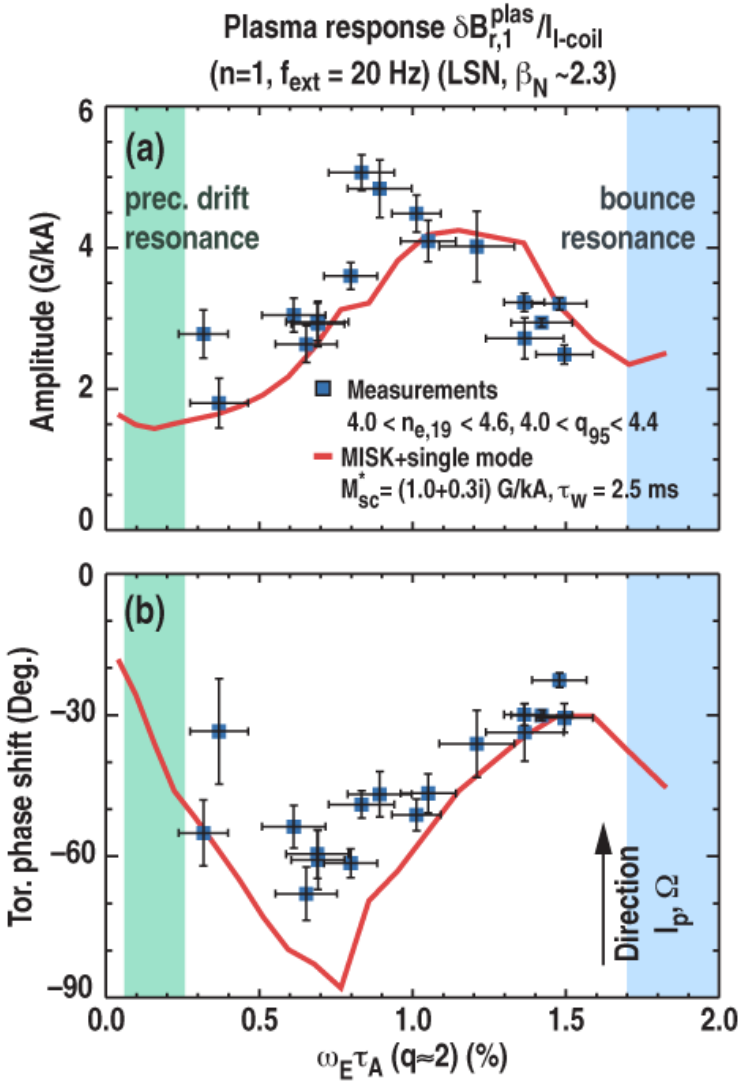

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Kinetic RWM Stability Effects Investigated in Stable Plasmas Above the No-wall Limit

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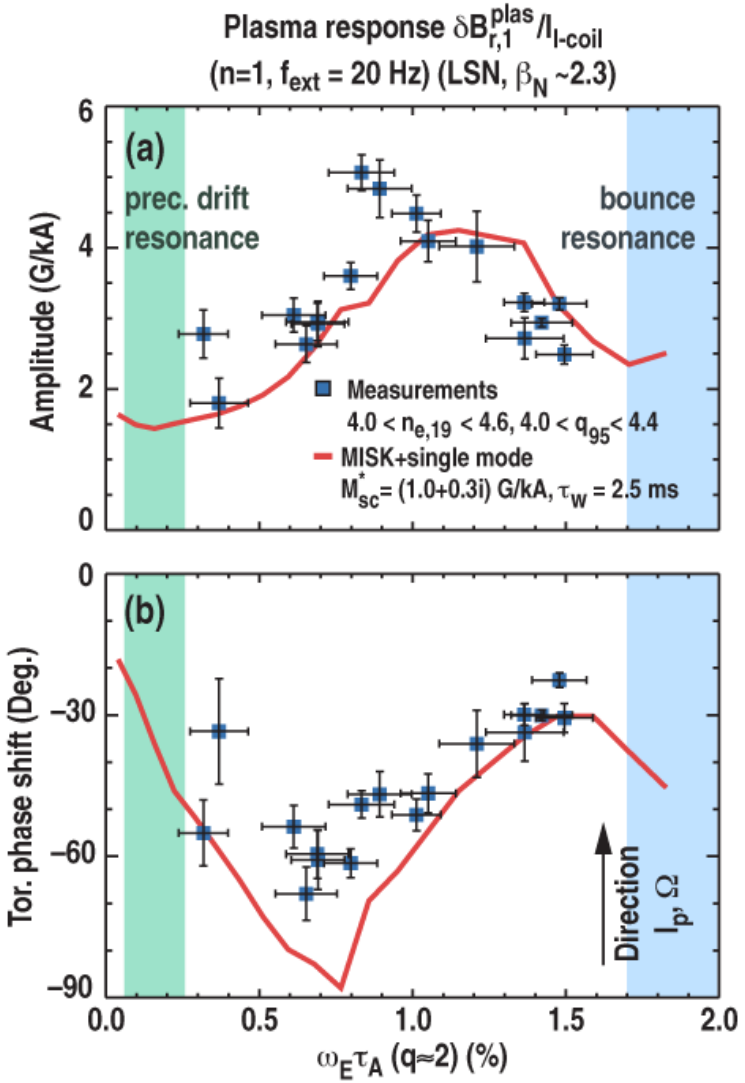
- Ratio of β_{fast} / $\beta_{thermal}$ investigated in MAST using ***density scans***
- Recent DIII-D experiment: use ***off-axis NBI*** to impact ***trapped ion fraction***

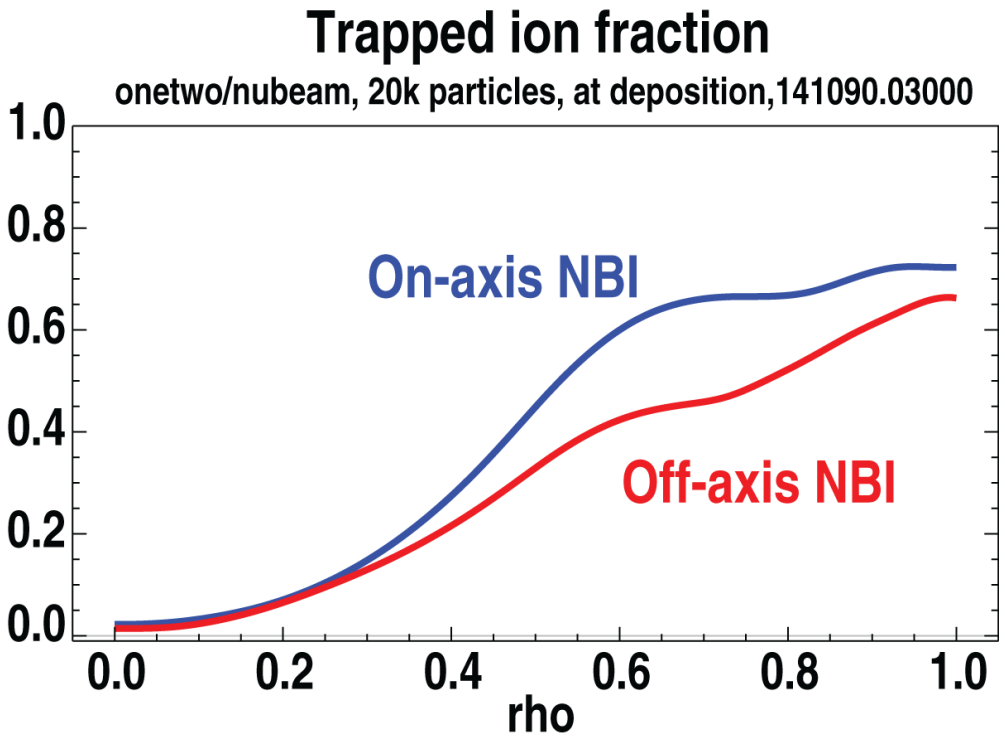


[Reimerdes, *et al.*, Phys. Rev. Lett. (2011)]

[Berkery, *et al.*, *Phys. Rev. Lett.* (2010)]

[Chapman, *et al.*, *Plasma Phys. Control Fusion*, (2011)]

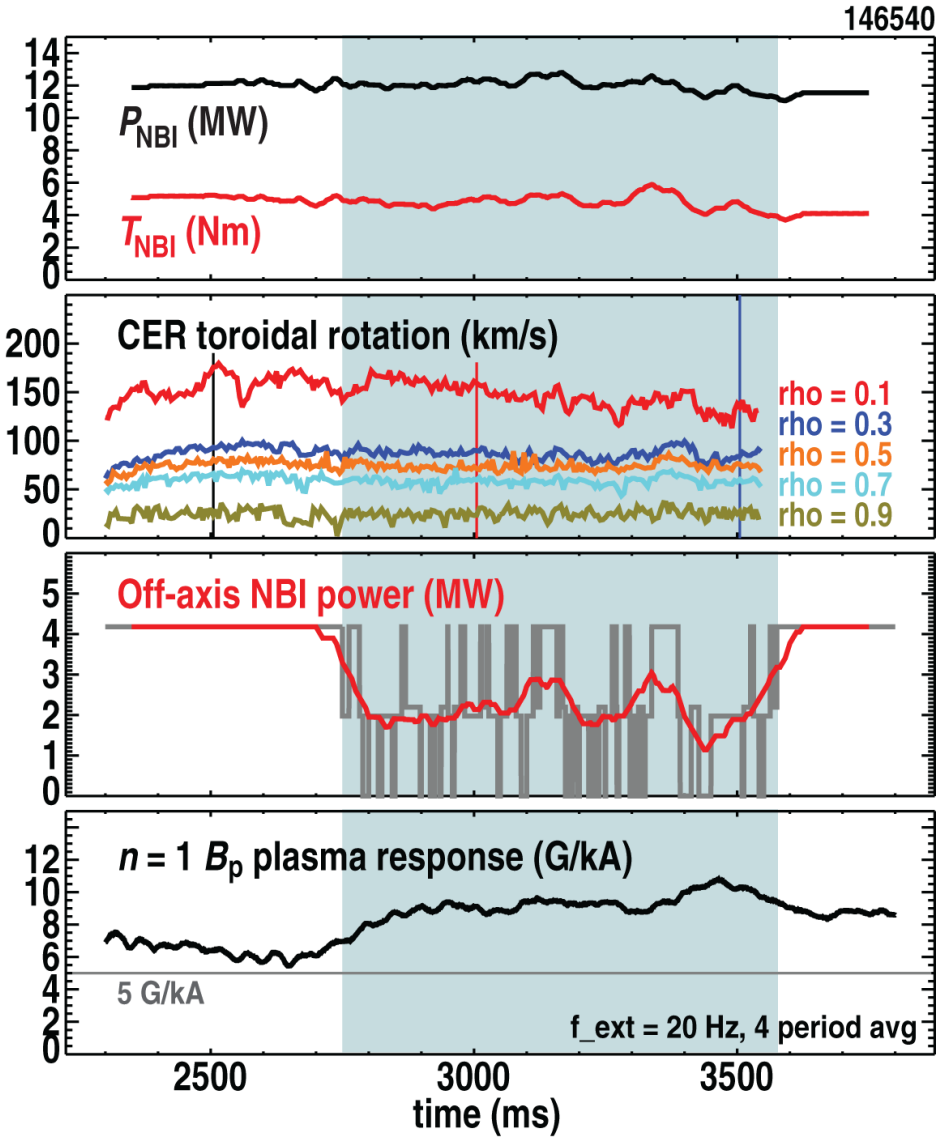
Off-axis NBI Expected to Decrease RWM Stability



- **Transport modeling: reduced trapped ion fraction with off-axis NBI**, due to more favorable alignment of injection angle with field line pitch
- **Reduced RWM stability expected with off-axis NBI**; stabilizing effect of passing particles expected to be localized near resonant surfaces, small

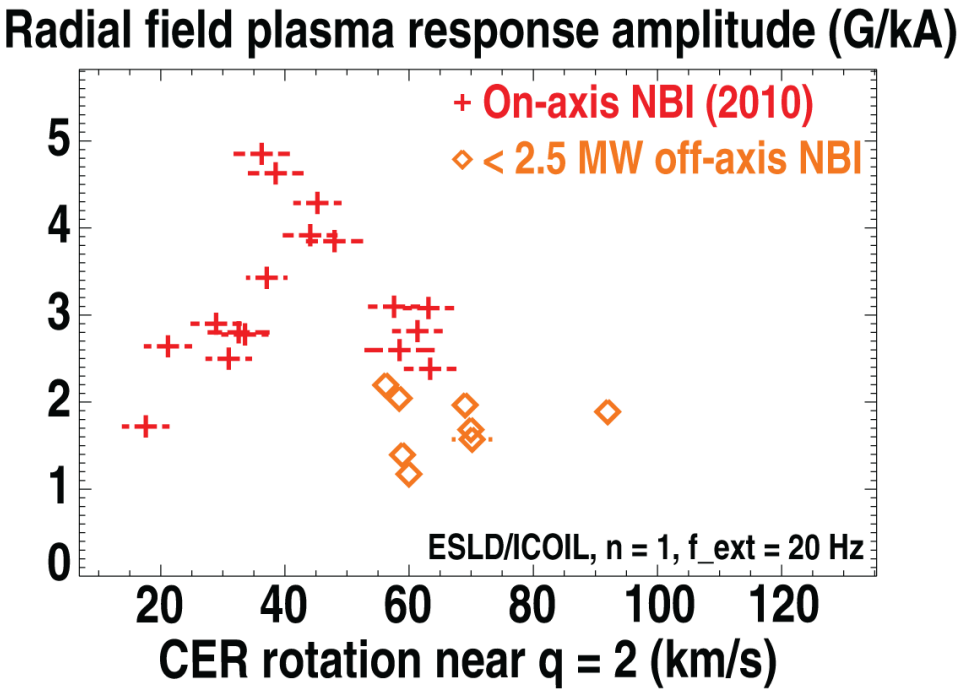
Off-axis NBI Leads to *Increased* RWM Stability

- **Off-axis NBI power modulated at constant β_N, ℓ_i, density**
  - Minor variations in rotation profile
- **Plasma response *increases* with *decreased* off-axis power**
  - Opposite of expectation from considerations of trapped ion fraction
- **Preliminary results from HAGIS code**
  - Increased stabilizing contribution from passing particles with off-axis NBI, consistent with observations.
  - Finite ion orbit width effects could be important, as with internal kink mode



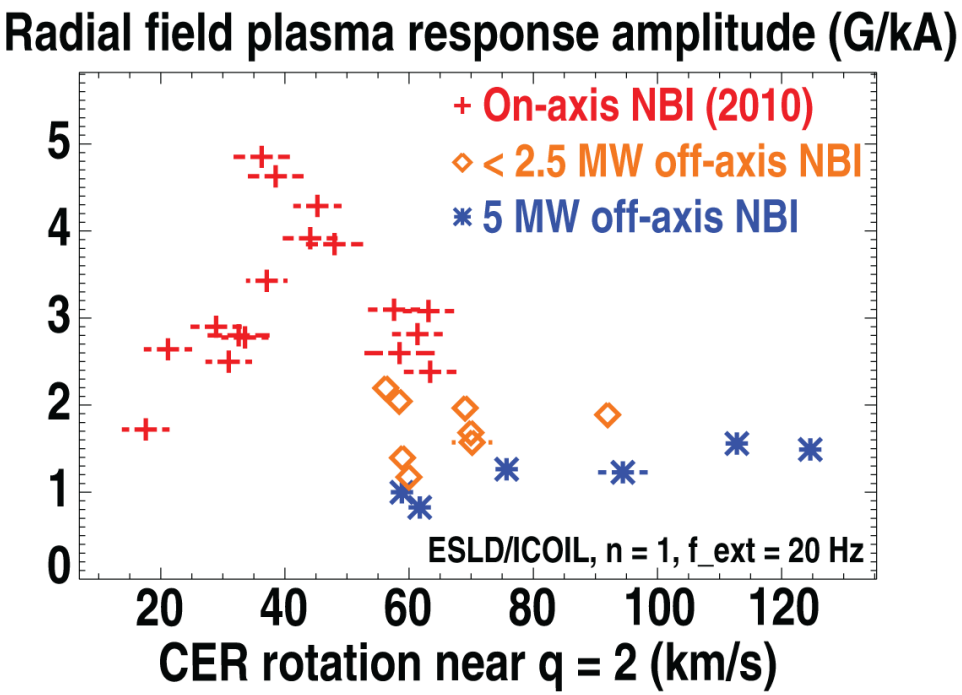
Stabilizing Effect of Off-axis NBI Observed Over a Range of Rotation

- Existing 2010 dataset extended to higher rotation



Stabilizing Effect of Off-axis NBI Observed Over a Range of Rotation

- Existing 2010 dataset extended to higher rotation
- See ~50% *reduction* in plasma response amplitude with 5 MW off-axis NBI, at intermediate rotation



- Continued damping at increased rotation qualitatively consistent with theoretical expectations
- Resonances with additional bounce frequency harmonics encountered as rotation increases

Off-axis NBI Leads to Increased RWM Stability

- **Off-axis NBI used to probe kinetic contributions to RWM stability in DIII-D experiment**
- **Rotation dependence of RWM stability extended**, consistent with theoretical expectations
- **Off-axis NBI leads to *increased* RWM stability**, contrary to qualitative expectations based on the trapped fraction
- **New data obtained for comparison with predictive RWM stability models.** Preliminary calculations indicate finite ion orbit width effects may be important