NSTX

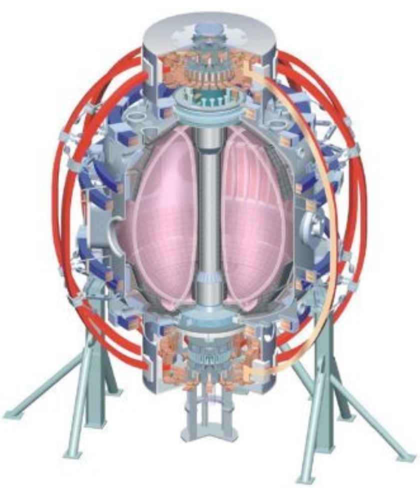
Supported by U.S. DEPARTMENT OF ENERGY | Office of Science

XP-930: Use of RFA Measurements To Establish MHD Stability Boundaries

S.P.Gerhardt, L. Delgado-Aparicio, D.A. Gates, J.E. Menard, J. K. Park, H. Reimerdes, S. Sabbagh

NSTX Team Review

College W&M
Colorado Sch Mines
Columbia U
CompX
General Atomics
INEL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
Old Dominion U
ORNL
PPPL
PSI
Princeton U
Purdue U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Illinois
U Maryland
U Rochester
U Washington
U Wisconsin



Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
KBSI
KAIST
POSTECH
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep
U Quebec

XP-930 Goal: Test RFA as an Indicator of Proximity to β limits.

- When an an n=1 field is applied to a high-β plasma, the plasma responds by amplifying that error field.
  - Error field is amplified by the stable resistive wall mode.
  - The RWM can be current or pressure driven.
- The error field amplification is larger when modes are close to unstable.
- Ideal stability depends on many parameters:
  - Pressure Limits: Decreasing triangularity and internal inductance are bad for stability.
  - Current Limits: $q^* <\sim 2-2.3$ is unstable.
- We want to measure RFA in the vicinity of these limits.
  - Can we measure increased error field amplification as the plasma is driven closer to instability?
- Technique:
  - Create a plasma near to, but not exceeding, a stability limit.
  - Apply an n=1 traveling wave, monitor the amplitude and phase of the plasma response.

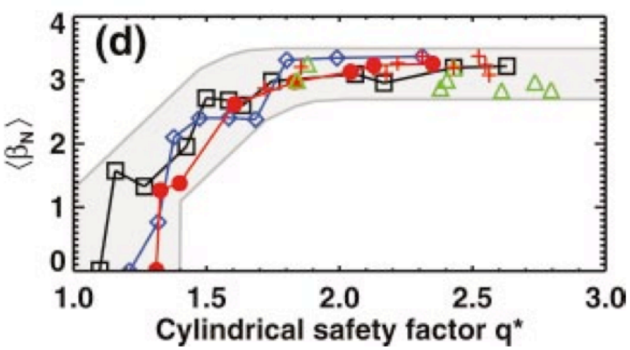
XP Contributes to FY-09 & FY-10 Milestones

- For FY-09, probing the stable resistive wall mode over a wide range of parameter space.
  - XP-931: Kinetic measurements of the stable resistive wall mode.
  - XP-930: Determination of relationship between stable and unstable mode, using magnetic and kinetic measurements.
  - XP-931: Test of stable mode amplitude as a function of plasma parameters.
- For FY-10, contributes to disruptvitiy characterization and disruption avoidance milestone.
  - Likely need real-time stability estimates.
  - Highly-converged equilibria + stability code seems to be a long-way off.
  - Use realtime RFA measurement to asses proximity to stability boundary.
  - This XP focuses on the physics basis to this approach.

κ =2.5
κ =2.0
κ =1.6

Examples of Stability Boundaries to Be Probed

Menard, et al., Phys Plasmas 11, 639



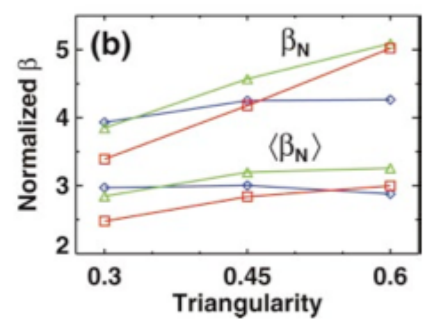


FIG. 2. (Color) (a) Marginally stable $\beta_T(\%)$ and (b) normalized beta values as a function of triangularity and elongation at 50% self-driven current fraction for aspect ratio $A=1.6$.

We Have Experience From 2005 & 2007 Probing the Stable RWM With MHD Spectroscopy

- Thorough study of RFA vs. traveling wave frequency in XP-501
  - Confirms that a single mode model can explain the observed dynamics.

$$\tau_W \frac{dB_s}{dt} - \gamma_0 \tau_w B_a = M_{sc}^* I_C$$

$$\gamma_0 = \gamma_{RWM} + i\omega_{RWM}$$

$$B_s^{ext} = \frac{M_{sc} I_C}{1 + i\omega_{ext}\tau_w}$$

$$A_{RFA,s} = \frac{B_s - B_s^{ext}}{B_s^{ext}} = c_s \frac{1 + \gamma_0 \tau_w}{i\omega_{ext}\tau_w - \gamma_0 \tau_w}$$

- Free parameters: c_s, γ_{RWM}, ω_{RWM}, τ_w
- Use amplitude and phase to fit these parameters.

Sontag, et al, Nuclear Fusion **47**, 1005 (2007)

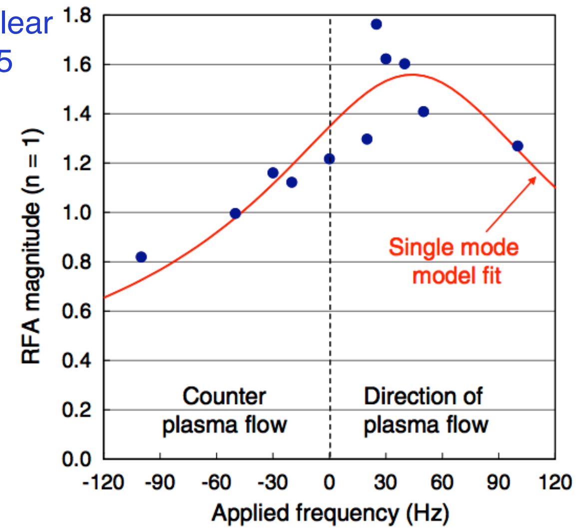


Figure 2. RFA magnitude of stable $n = 1$ RWM versus applied $n = 1$ non-axisymmetric field frequency.

- However, there is more to do:
  - No MSE data for those shots…stability analysis is difficult.
  - Only a single equilibrium: can we use the same coupling coefficient (c_s) and wall times (τ_w) for different equilibria?
- Use this technique to understand RFA dynamics vs. aforementioned plasma parameters.

Test RFA as a Function of β_N, l_i, δ, q* (I)

- Step #0 Before XP runs: Develop low-δ, high-κ discharge.
  - Call this *Shape #1*
- Step #1: Demonstrate more conclusively RFA vs. β_N trends in a single discharge. *(6 shots)*
  - Create a discharge at high δ, with κ and outer gap matched to Dis. #1, with both β_N ramp-up and ramp-down.
  - Call this *Shape #2*.
  - Apply n=1 traveling waves and measure RFA vs β_N
- Step #2: Test RFA vs Triangularity *(10 shots)*
  - Apply Traveling Waves to *Shape #1*
- Step #3: Test RFA vs l_i *(6 shots)*
  - Take Shape #2, delay H-mode to start of I_P flat-to
  - Apply traveling waves.
- Step #4: Test RFA vs q* *(6 shots)*
  - Take Shape #2
  - Keep B_T=0.45, but increase I_P to 1.3 MA (q*~2.3)
  - Apply Traveling waves.

In all RFA cases test traveling waves at 30 & 50 Hz, Co & Counter, in order to constrain single-mode model.

A Key To Success Is Reproducible Low-Delta Target

- Plan to develop this target in preparation for NTM XPs.
- Use ISOLVER to anticipate what result will be:
  - Profiles from efit 02 for a recent fiducial (133025).
  - Fix a set of PF1A and PF2 currents, in kA/MA, to scan δ at fixed (2.25).
  - Difficult to make intermediate δ shape at high κ...strike-points tends to enter the CHI gap (very bad.)
  - Compare only highest and lowest δ cases at first, fill in intermediate points if time permits.