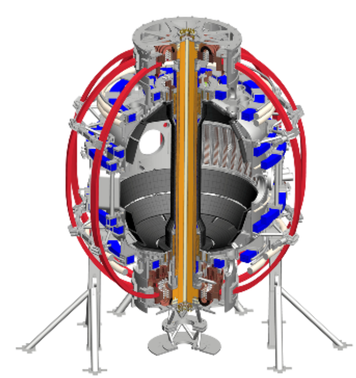
Resonant error field threshold with non-resonant braking (XP1543)

Jong-Kyu Park,
J. E. Menard, C. E. Myer, M. Lanctot, Z. R. Wang, R. La Haye et al.

XP MS Group Review
PPPL - April 28, 2016



Goal is to test n=1 EF scaling with rotation and non-resonant field, and also change in non-linear phase by non-resonant field

- Test n=1 error field threshold scaling with significantly different rotation, using each n=2, n=3, and n=2+3 magnetic braking
  - Error field threshold relies on engineering scaling, which works in "typically" produced Ohmic plasmas

    R. La Haye APS (2012), R. Buttery ITPA (2012)
  - Physics implies the scaling can break down if rotation changes
  - Contribute to ITPA MDC-19 "Error Field Control at Low Rotation
  - Contribute to ITER error field correction for inductive scenario

- Isolate rotation (cross-field viscosity) effect from direct non-resonant field effect (mode coupling + NTV) A. Cole PRL (2007)
  - Produce the same rotation level using each n=2, n=3, and n=2+3

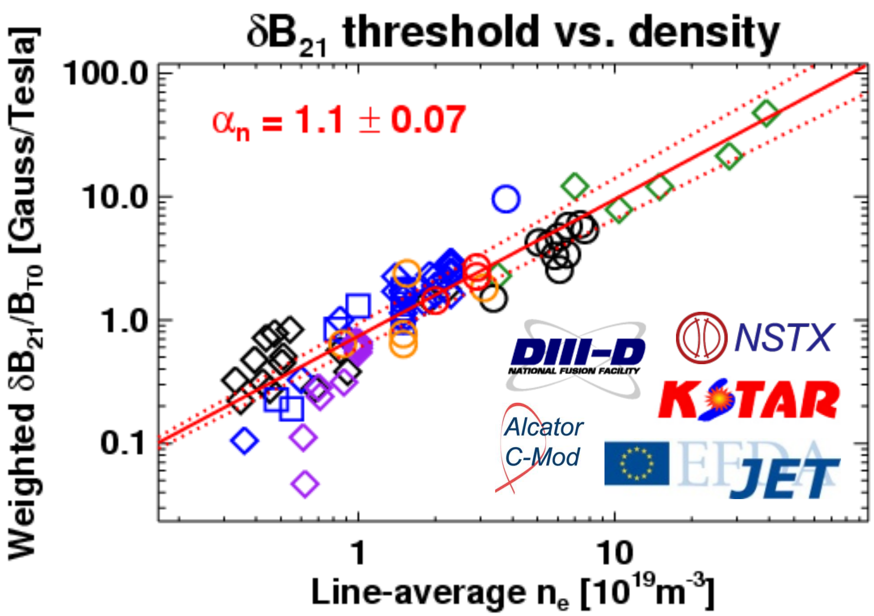
- Test if n=2 or 3 can change non-linear phase in locking
  - KSTAR showed mitigation of n=1 locking-driven disruption by n=2

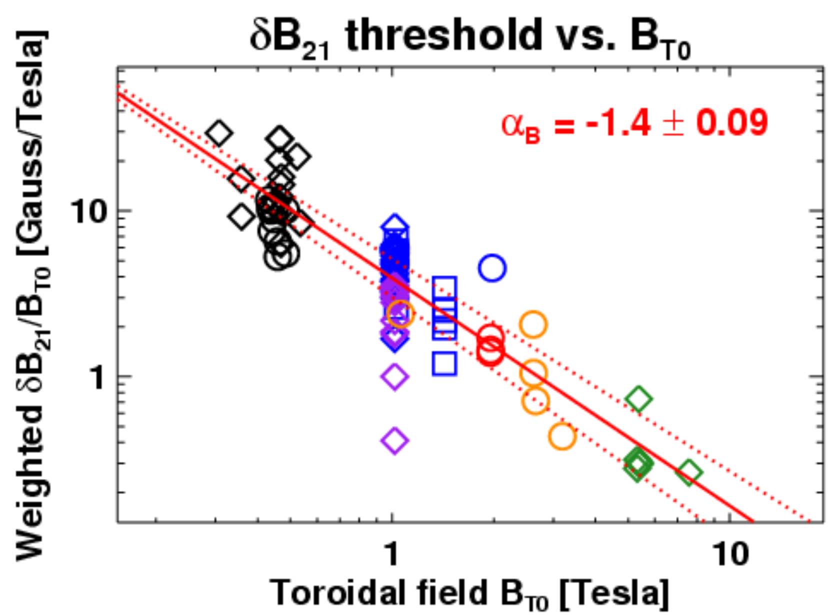
Locked mode scaling for Ohmic plasmas has been established with engineering parameters

- Error field threshold (by locked modes) scaling across devices

$$\frac{\delta B_{21}}{B_{T0}} \cong 0.96 \times 10^{-4} \left(n_e[10^{19} m^{-3}]\right)^{1.1\pm0.07} \left(B_{T0}[T]\right)^{-1.4\pm0.09} \left(R[m]\right)^{-0.60\pm0.16}$$

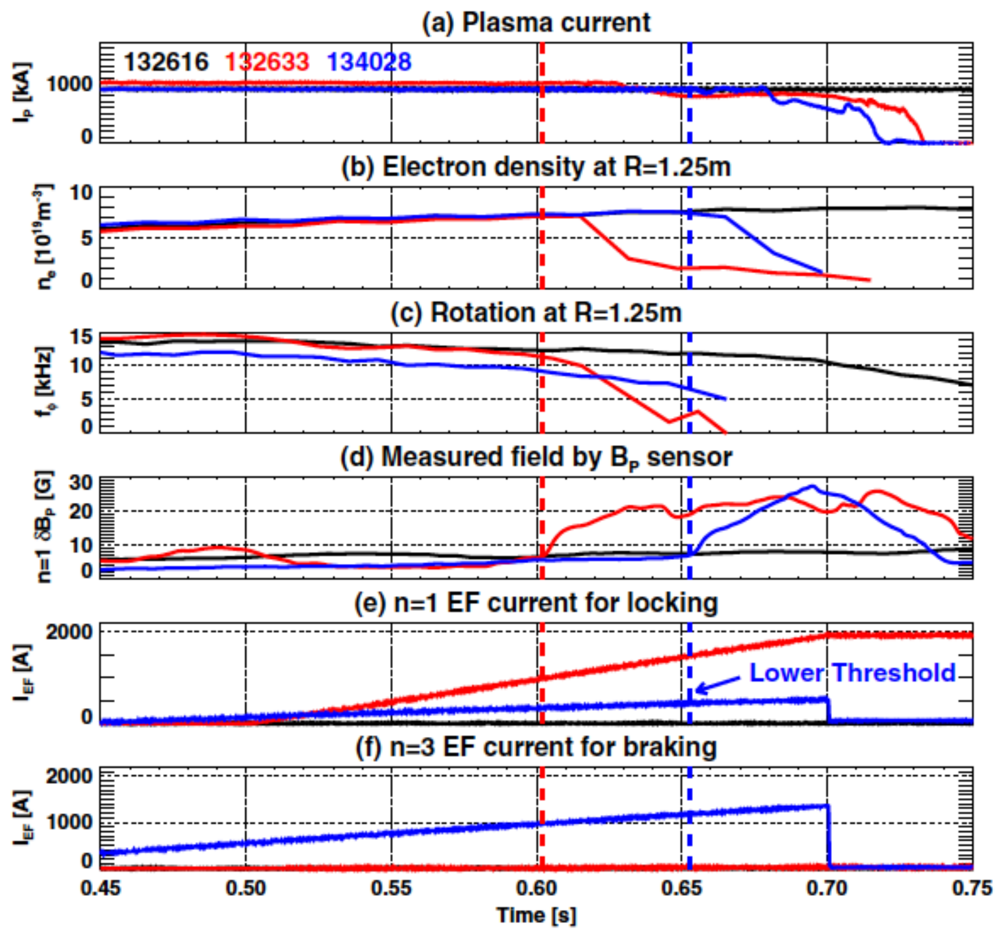
◇ Low-β NSTX ◇ Low-β DIII-D ◇ Low-β CMOD □ Low-β DIII-D with Right-handed config.
○ High-β NSTX ○ High-β DIII-D ◇ TBM DIII-D ○ Low-β JET ○ Low-β KSTAR





Threshold change by rotation is well known, but not systematically with non-resonant fields

- Non-resonant field can change locking onset by rotation (secondary cross-field viscosity) or directly by geometric distortion or NTV



J.-K. Park, J. E. Menard et al., NF (2015)

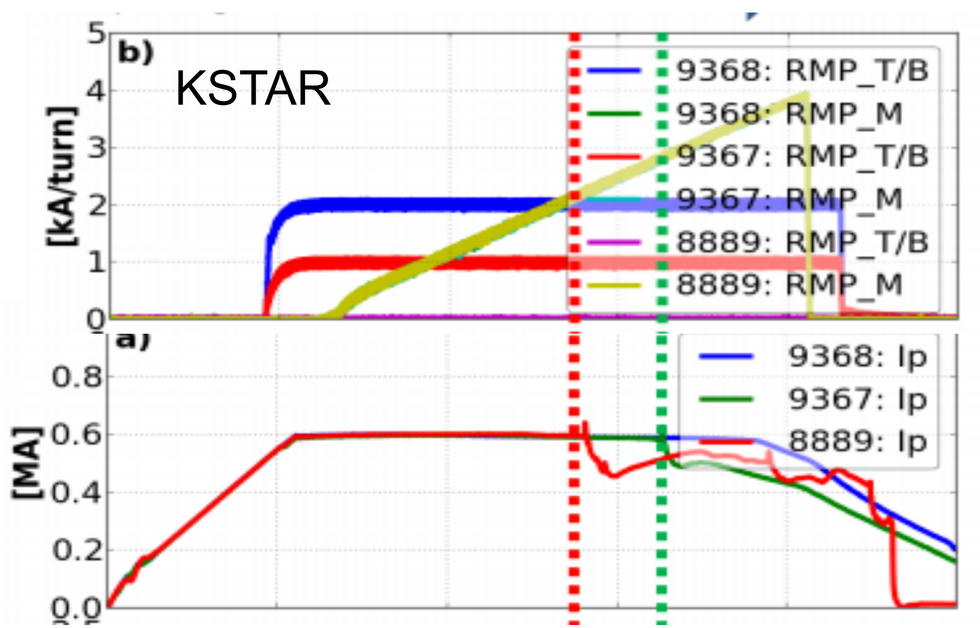
- NSTX including high β shots, and also 4 shots where n=3 was used to reduce rotation, produced dimensionless threshold scaling:

$$\frac{\delta B_{21}}{B_{T0}} \cong 0.24\times10^{-4} n_e^{\;0.60} B_{T0}^{\;0.45} R^{1.74} s^{0.76} \left(\frac{\omega_\phi}{\omega_D}\right)^{1.46}$$

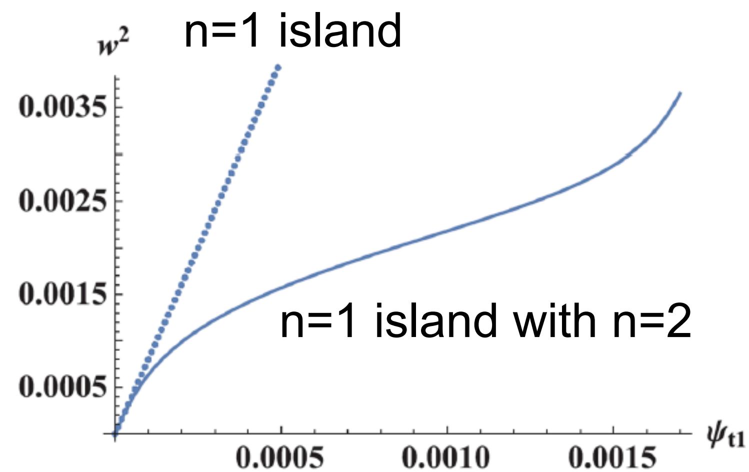
- Important to develop database for ITER, and to understand critical parameters for locking

KSTAR shows delay of n=1 locked mode disruption by n=2, explained by island shrink

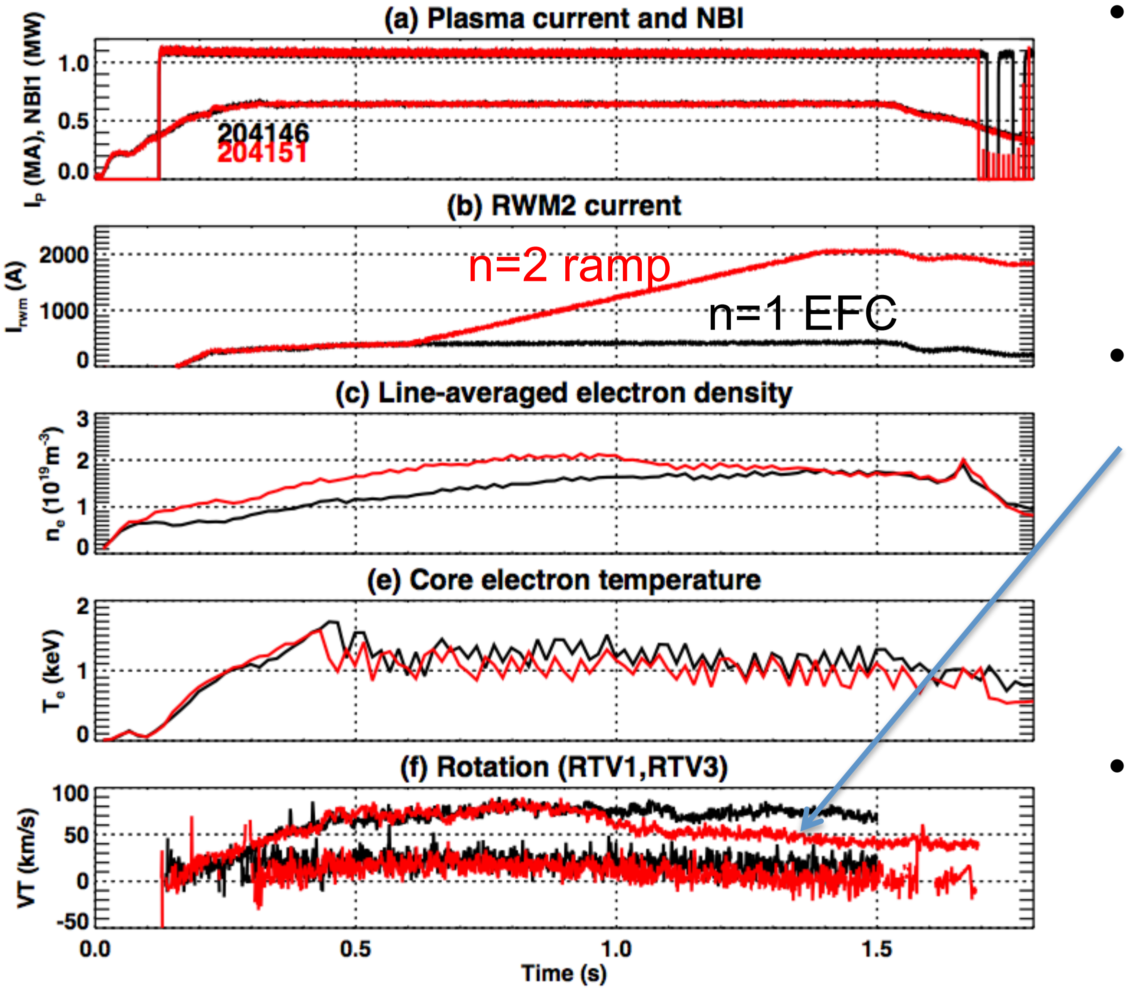
- KSTAR n=1 (midplane) ramp-up experiments, on the top of n=2 (top and bottom coils) fields showed
  - Error field threshold reduction, as expected
  - However, driven disruption can be delayed and strongly mitigated by n=2, which can be possibly explained by geometric island shrink



J. Kim, Y. In, A. Aydemir, J.-K. Park, Submitted (2015)

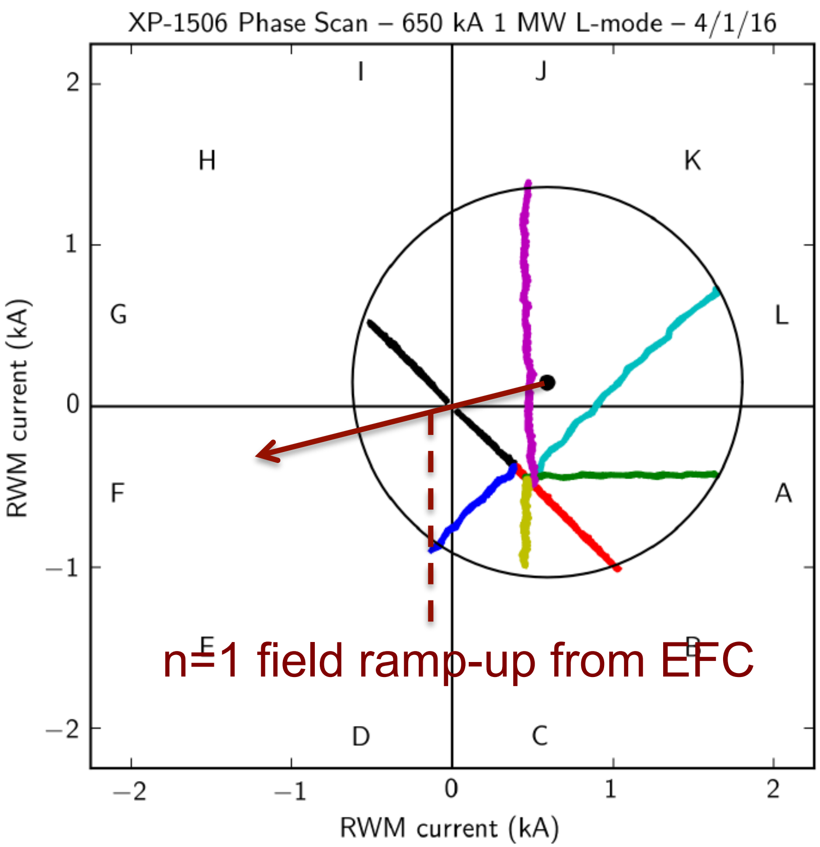


1MW L-mode is a good reference in NSTX-U and n=2 1-2kA can be used to change rotation



- Reference target is likely the recently developed 700kA L-mode discharge, with 1.1MW source 1B NBI and EFC
- n=2 applications showed that rotation can be substantially modified (measured by RTV), as β_N~1.5 and T_e~1keV is high enough to induce NTV
- 1-2kA or even more n=2 (or n=3) currents might be necessary on the top of n=1

Current waveform with n=1+2+3



- Start with PF5-proportional EFC
- Apply n=1 with $\varphi_{n=1}$=195° to cause locking with minimum $I_{n=1,lock}$
  - Expected to be ~602A based on XP1506
- Apply n=2 with $\varphi_{n=2}$=75° to distribute currents and have maximum $I_{n=2}$
  - Can afford $I_{n=2}$=3kA with 1.5*$I_{n=1,lock}$
- Apply n=3 with $\varphi_{n=3}$=180° to distribute currents and have maximum $I_{n=3}$
  - Can afford $I_{n=2}$=2kA with 1.5*$I_{n=1,lock}$
  - Can afford $I_{n=3}$=1.8kA with $I_{n=2}$=1.5kA with 1.5*$I_{n=1,lock}$
-
- Current waveform formula:

$$I_{rwm} = (0.088A*I_{PF5} - I_{n=1})*\cos(\varphi-15°) + I_{n=2}*\cos(2\varphi-75°) + I_{n=3}*\cos(3\varphi-180°)$$

Shot plan (12~15 shots, 0.5 day)

1. (L-mode ref. #204146 or Ohmic) reference target + PF5-proprotional EFC (0.088 $_{rwm}A/_{PF}A$, $\varphi_{n=1}$=15)
2. EFC + n=1 locking (0.7s-1.2s, 2.4kA/s ramp-up, $\varphi_{n=1}$=195)
3. EFC + n=2 pulses (1kA 0.5s-0.8s, 2kA 1.1s-1.4s, $\varphi_{n=2}$=90)

   : Here $I_{n=2}$=1kA, but can be changed based on RTV
4. EFC + $I_{n=2}$ long pulse + $I_{n=1}$ ramp-up (and steady after $I_{n=1}$=1.2kA)
5. EFC + 2×$I_{n=2}$ long pulse + $I_{n=1}$ ramp-up

6. EFC + n=3 ramp up to check $I_{n=3}$ level to match V by $I_{n=2}$ and 2×$I_{n=2}$
7. EFC + n=3 pulses to double check ($I_{n=3,1}$ 0.5s-0.8s, $I_{n=3,2}$ 1.1s-1.4s)
8. EFC + $I_{n=3,1}$ long pulse + $I_{n=1}$ ramp-up
9. EFC + $I_{n=3,2}$ long pulse + $I_{n=1}$ ramp-up
10. EFC + $I_{n=2}$ + $I_{n=3,1}$ long pulse + $I_{n=1}$ ramp-up (Assume linearity for V change)

- 10 shots without failure and doable for 0.5 day
- Time permitting, Try 2,4,5 step for Ohimc target

Diagnostics and other issues

- This XP heavily relies on RTV measurements
  - 1kHz sampling rate might be adjusted to 100Hz for better S/N
- CHERS and MSE are strongly desired but uncertain in present reference
- All magnetics are required to probe the onset and evolution of locked islands

- Prerequisite XP is XP1506, and can be better done after n=2 and n=3 error fields are checked
- Results will be generally useful, but not easily combined with Ohmic error field scaling nor comparable with KSTAR – Good to perform Ohmic cases if time permitting
- Rotation changes by n=2 and n=3 will be useful for XP1512 and other NTV and momentum studies, and vise versa