

Quiescent H-Mode Plasmas with Rotation Driven By Static Nonaxisymmetric Fields

Andrea M. Garofalo (GA)

With:

K.H. Burrell, G.L. Jackson, T.H. Osborne (GA)

M.J. Lanctot, H. Reimerdes (Columbia U.)

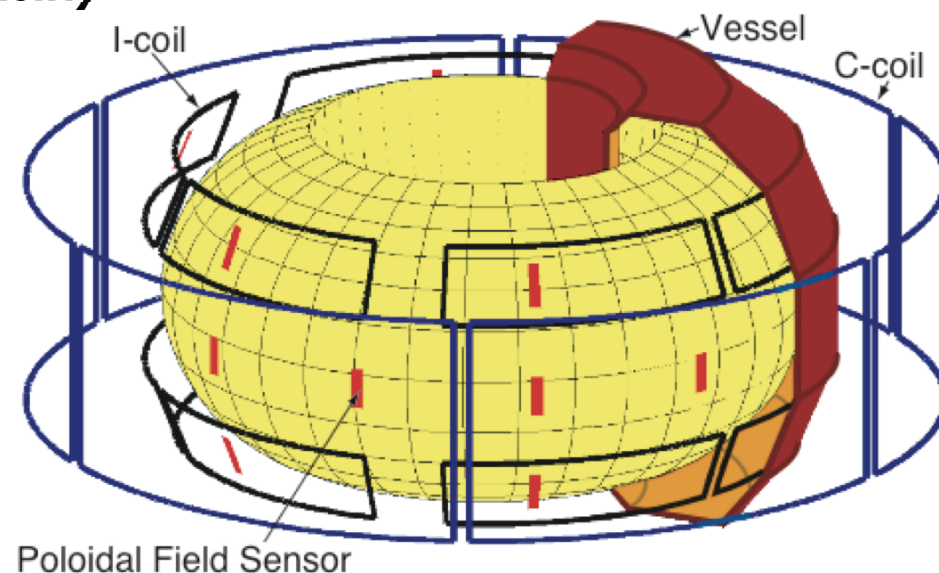
W.M. Solomon (PPPL)

L. Schmitz (UCLA)

A.J. Cole, G.R. McKee (U. of Wisconsin)

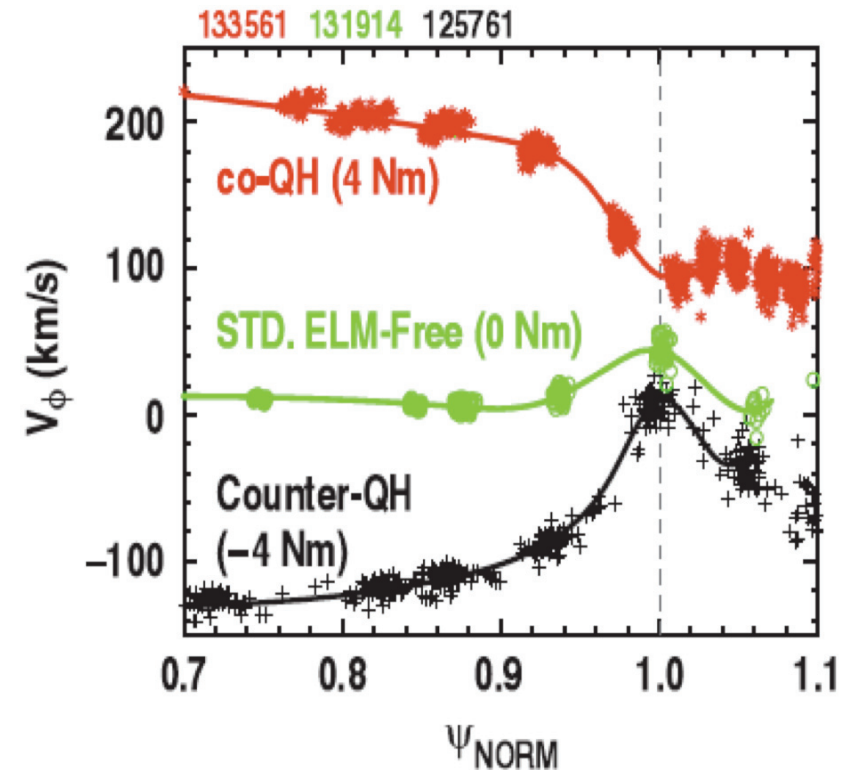
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To Open a Path Toward ELM-free H-mode in Self-heated Burning Plasma Regime, with Little or No NBI Torque

- **QH-mode is the ideal H-mode**
 - H-mode pedestal without ELMs
 - Edge harmonic oscillation (EHO) replaces role of ELMs for edge particle transport
- **QH-mode is more easily accessed in counter-rotation, but previously required rapid rotation rate**

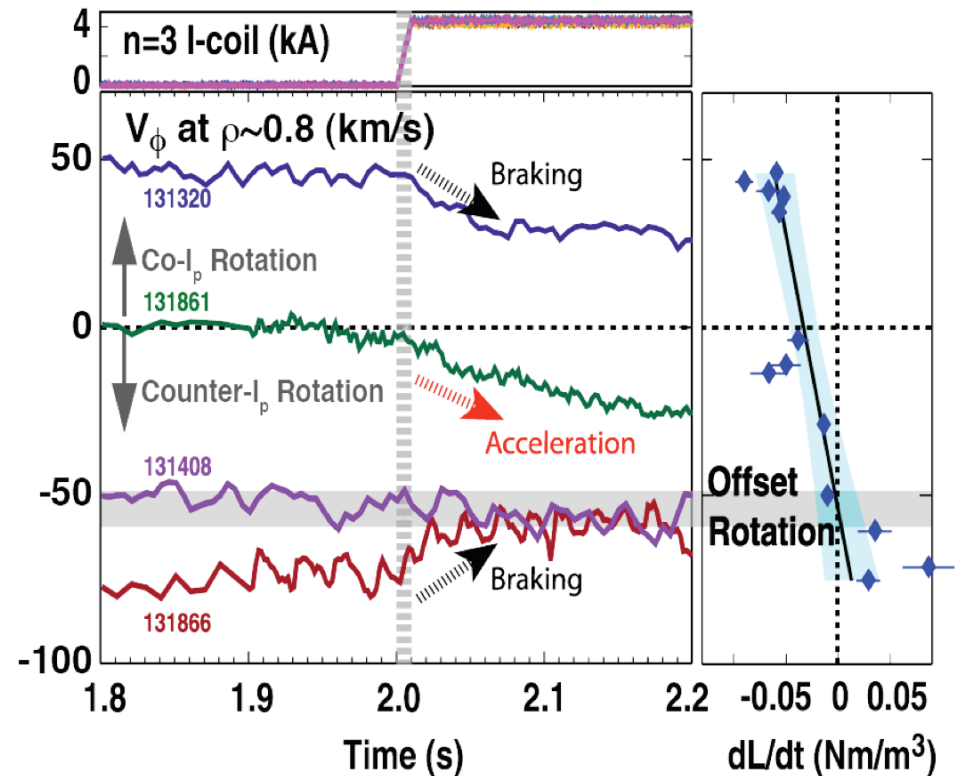


Minimum pedestal velocity shear necessary for QH-mode

Burrell et al., PRL (2009)

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- **Can we use NRMF torque to provide the necessary counter-rotation with net NBI torque=0 or slightly co- I_p ?**



$$T_{NRMF} \propto (V_\phi - V_\phi^{0,NC})$$

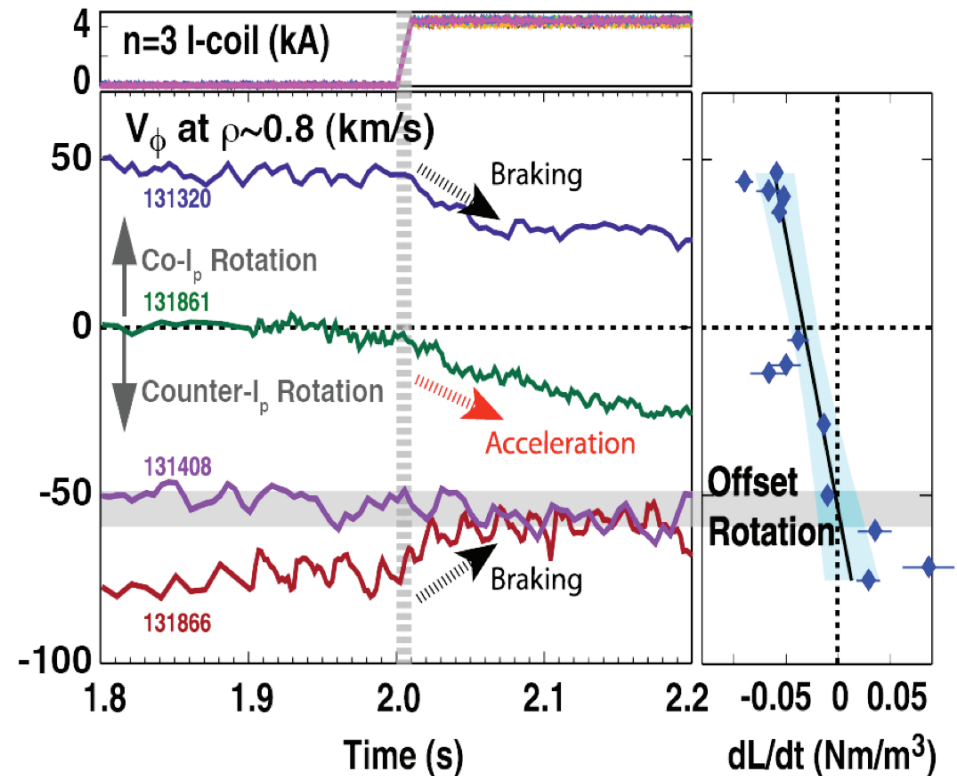
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DEMO

ITER

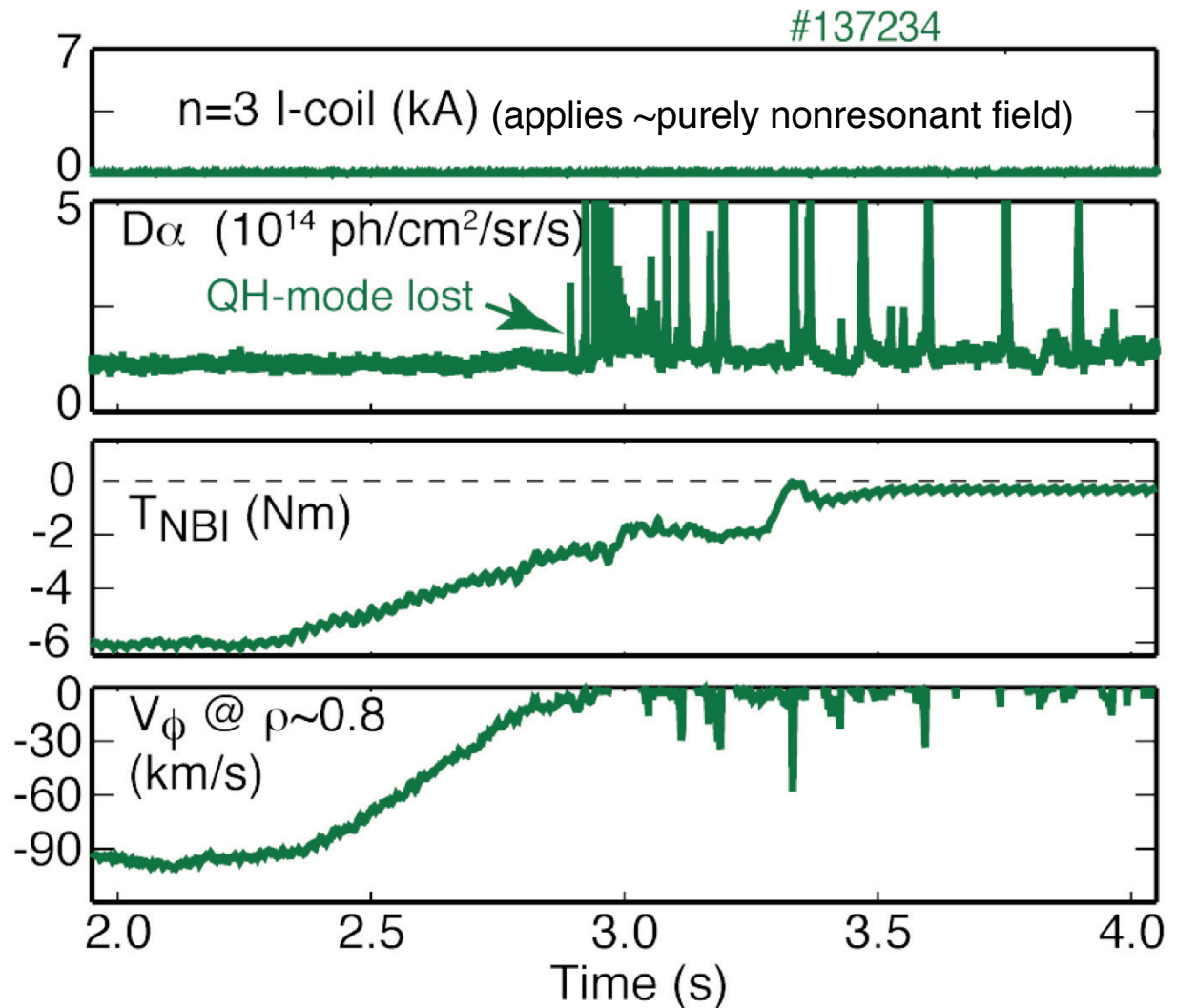


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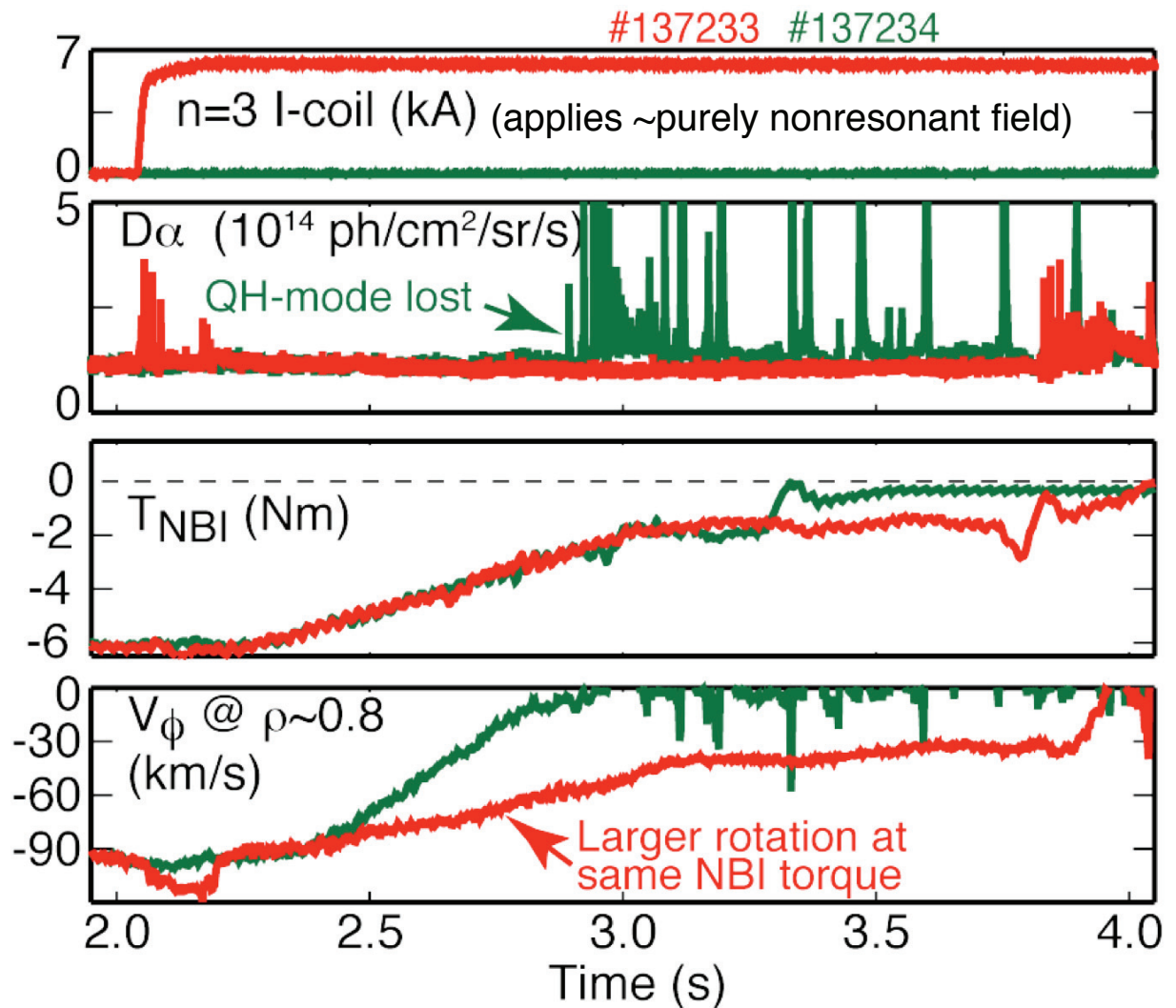
QH-mode Maintained with Low NBI Torque and $n=3$ NRMF in DIII-D

- Torque ramps used to investigate minimum rotation requirements
- Without the $n=3$ NRMF, rotation drops to zero, QH-mode is lost



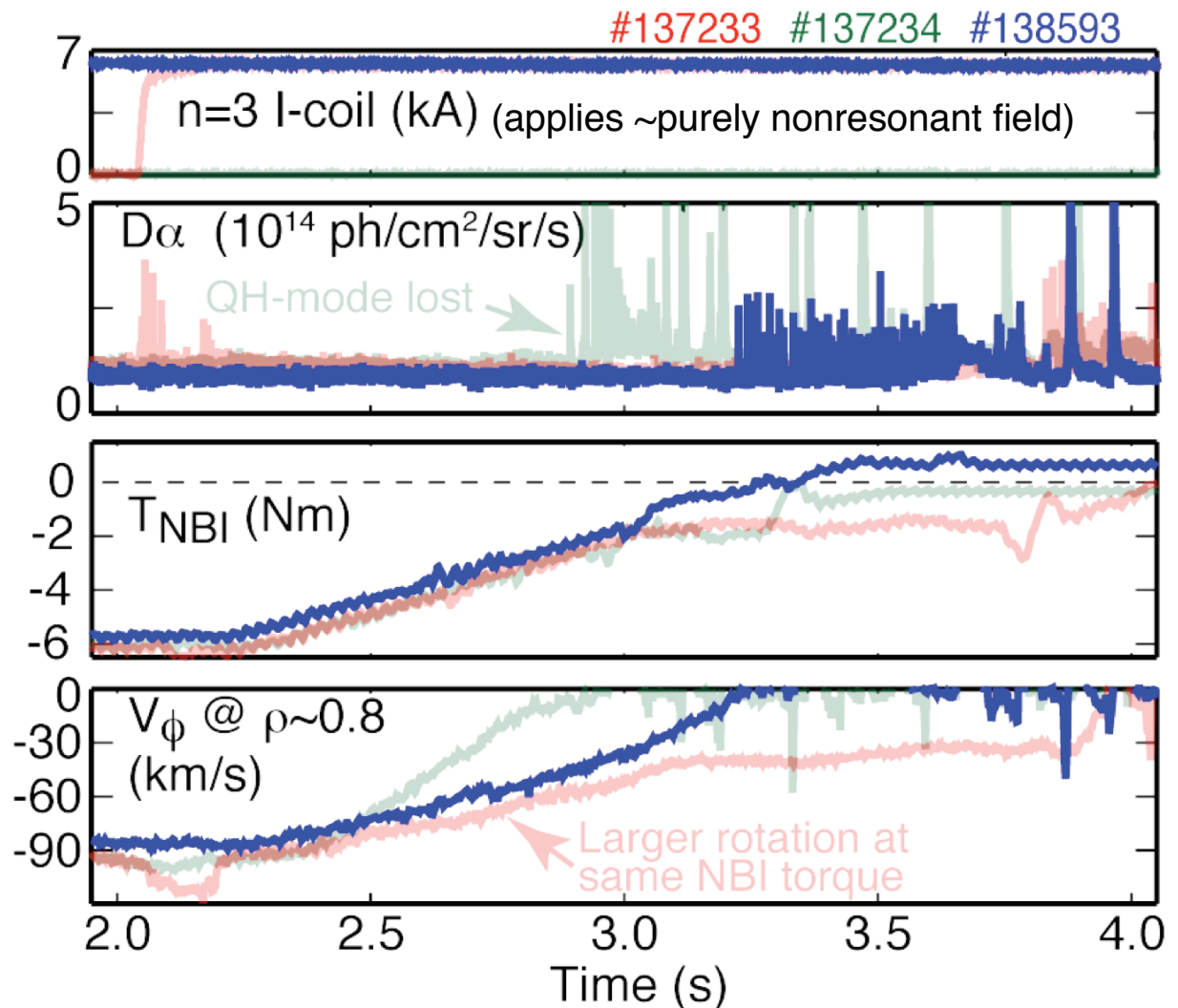
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 - Maintains larger counter-rotation for the same NBI torque



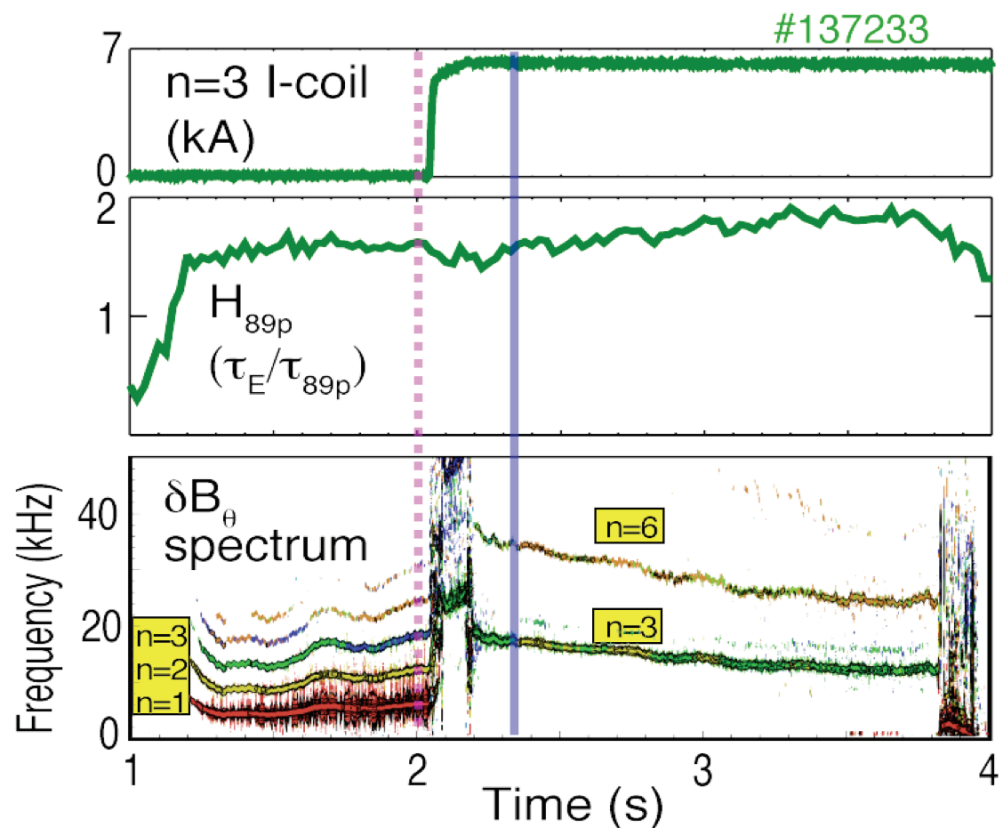
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- With the n=3 NRMF, QH-mode lost at $T_{\text{NBI}} \sim 0$



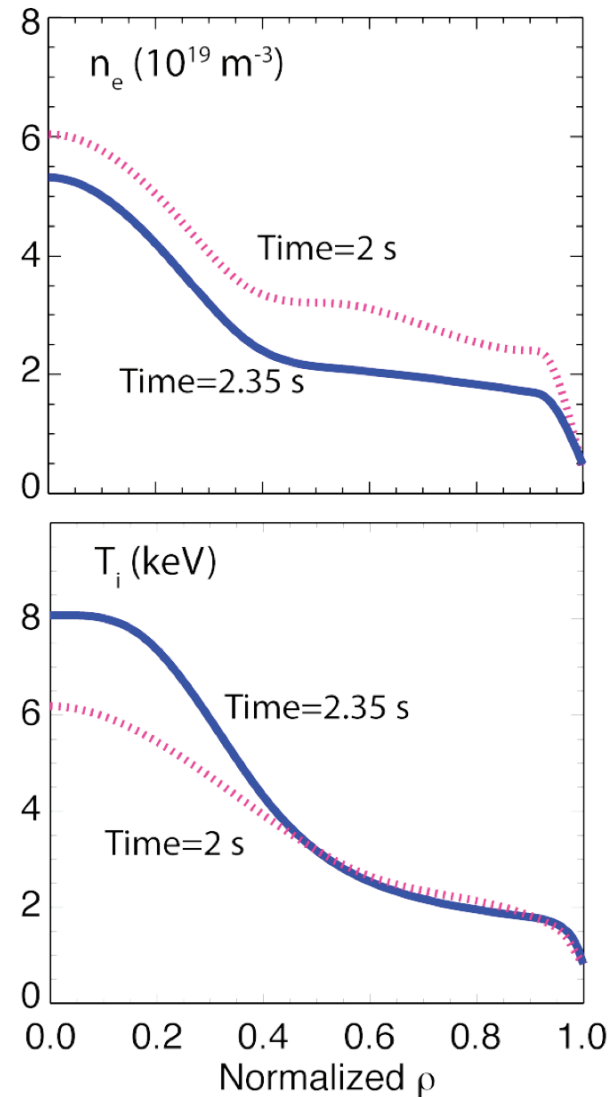
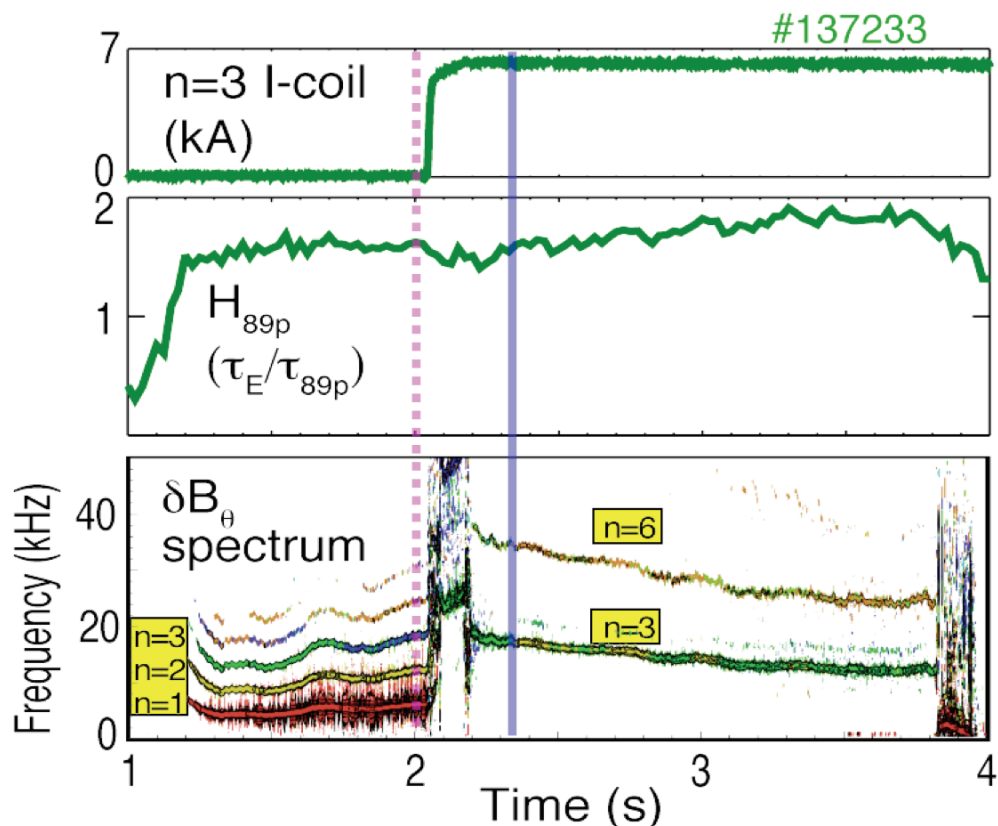
No Adverse Impact of NRMF on Global Energy Confinement Is Observed

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- Density is reduced, core ion temperature is increased, electron temperature \sim unchanged

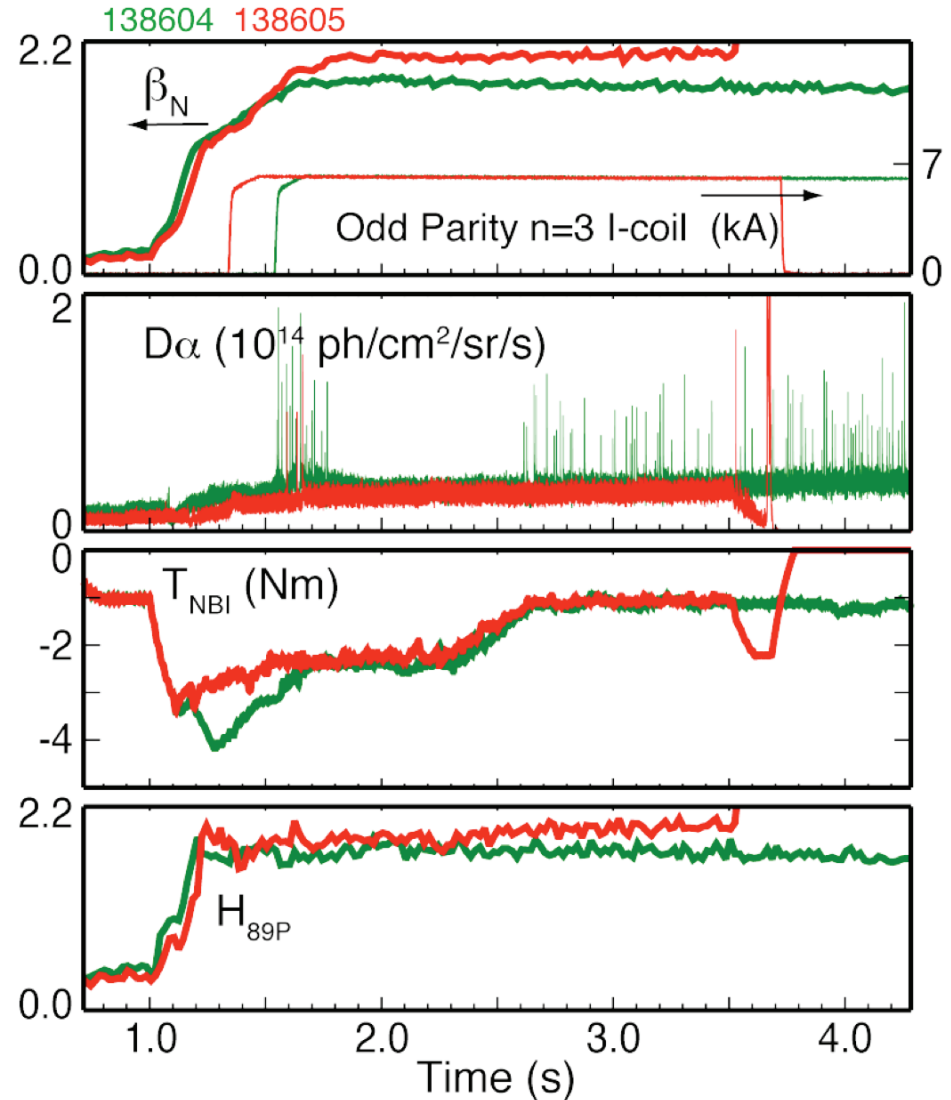


Energy Confinement Increases with β_N

- Energy confinement increases at higher beta and lower torque
- Measured turbulence (δn from DBS, $0.8 \leq \rho \leq 0.95$) is reduced at higher beta and lower rotation, consistent with improved confinement
- NBI torque (magnitude) required to maintain QH-mode is lower at higher beta

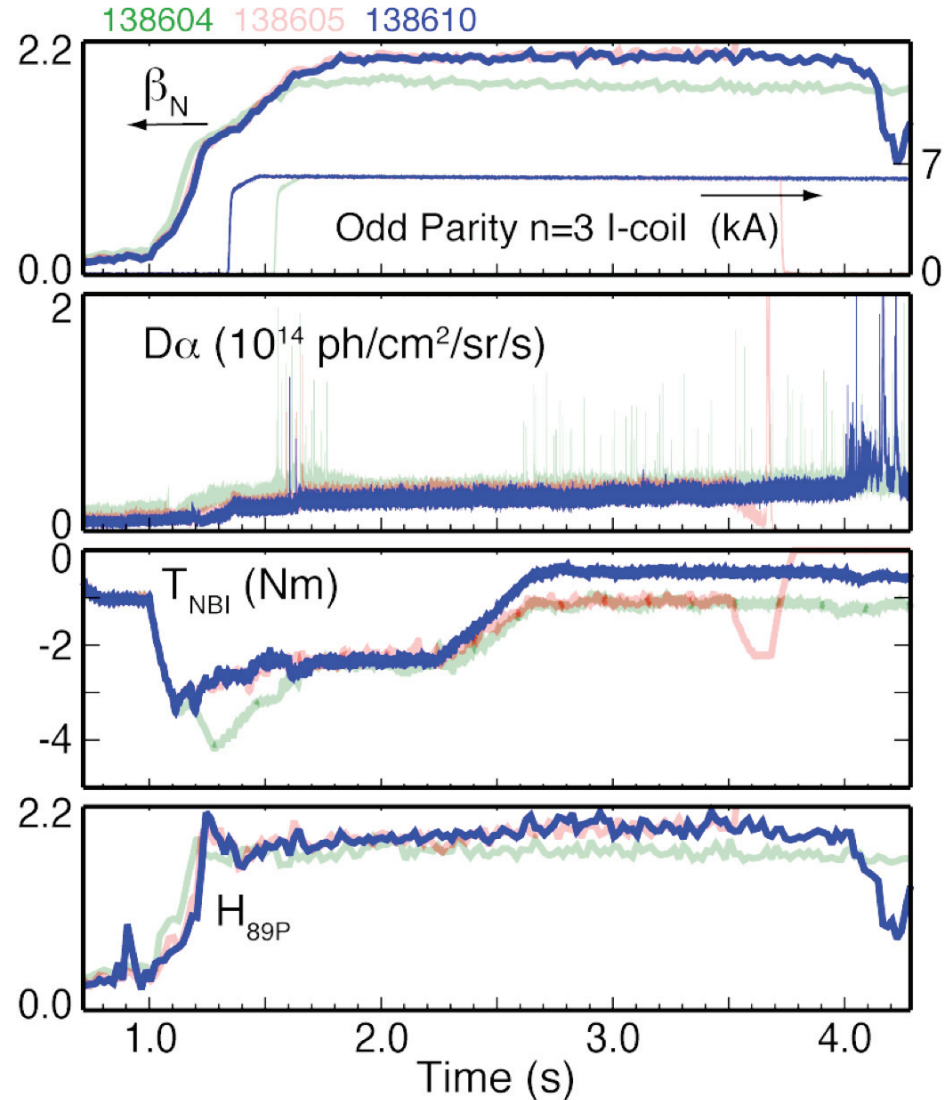
For details:

L. Schmitz, TP8.00014, Thursday AM



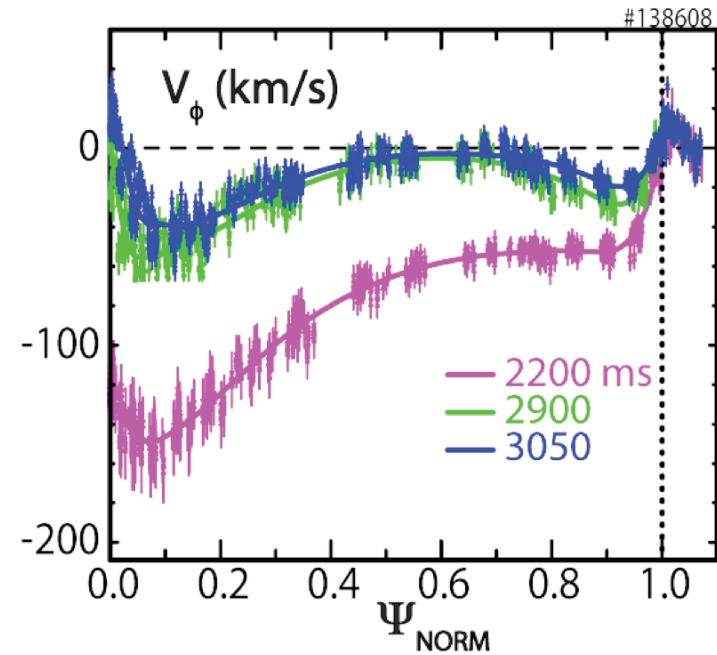
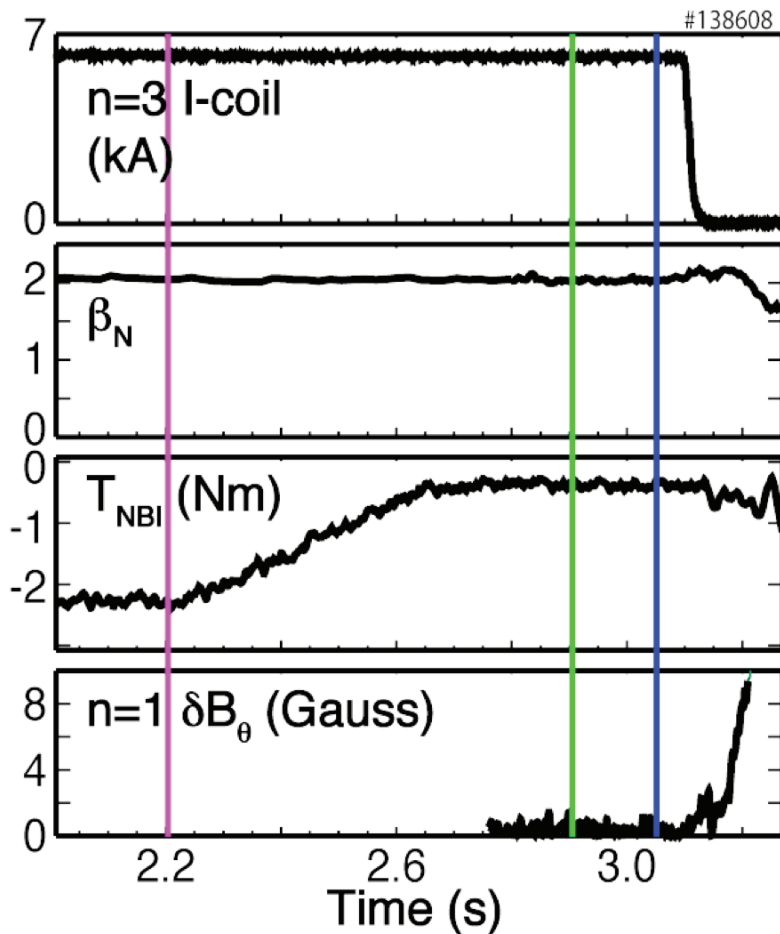
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- NBI torque (magnitude) required to maintain QH-mode is lower at higher beta
 - Minimum $T_{\text{NBI}} \sim -0.5$ Nm



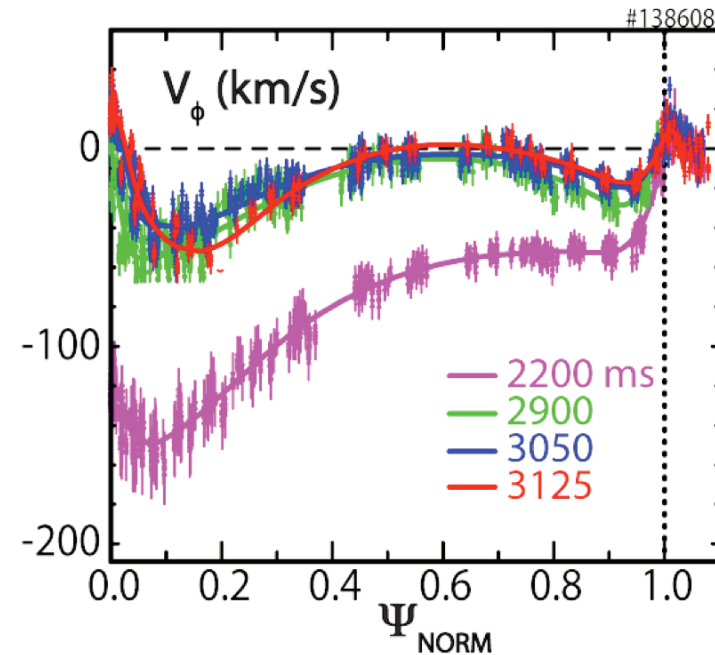
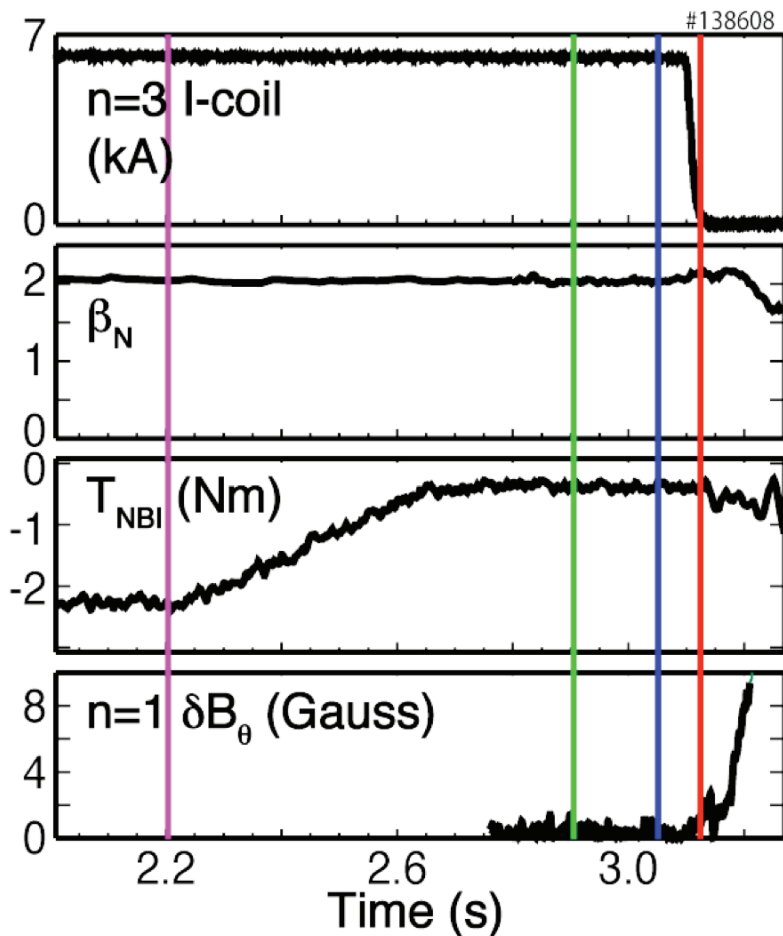
NRMF Improves Resilience to Locked Modes

- Removing the $n=3$ NRMF leads to locked mode



NRMF Improves Resilience to Locked Modes

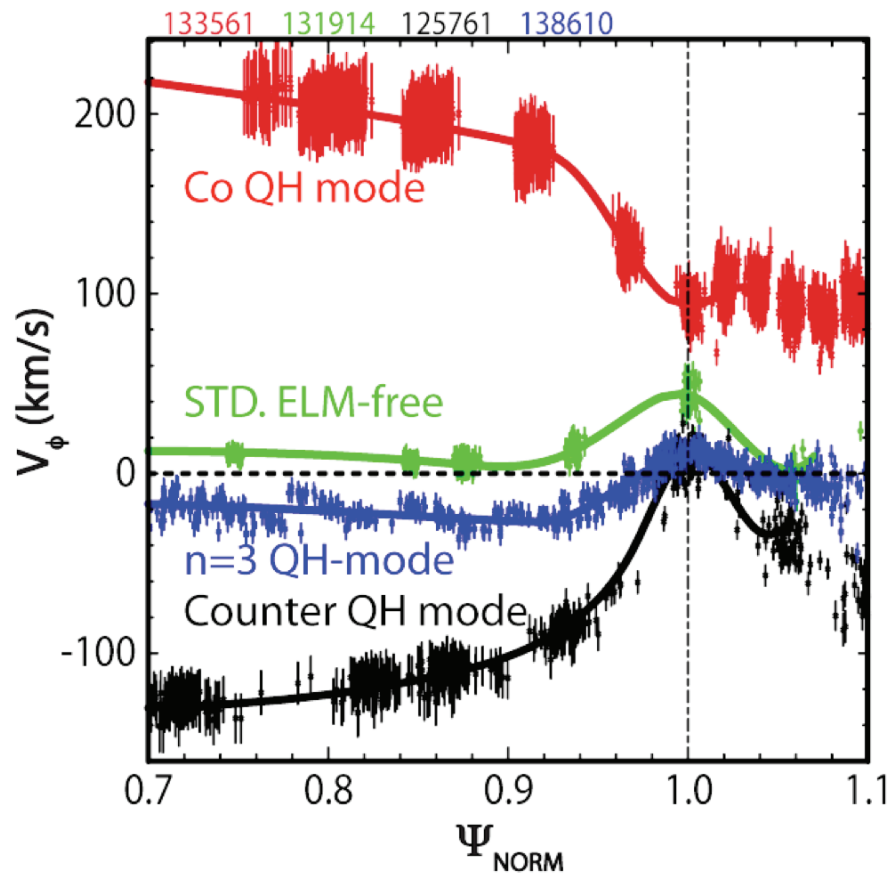
- Removing the n=3 NRMF leads to locked mode with little or no change in the rotation



- May be case of “NTM suppression by large externally applied helical modes”
 - Enhanced χ_\perp weakens helically perturbed bootstrap destabilization
- Q. Yu, S. Gunter, and K. Lackner, PRL (2000)
R.J. La Haye, et al., Phys. Plasmas (2002)

Rotation Shear Requirement for QH-mode Operation May Be Different Than Previously Thought

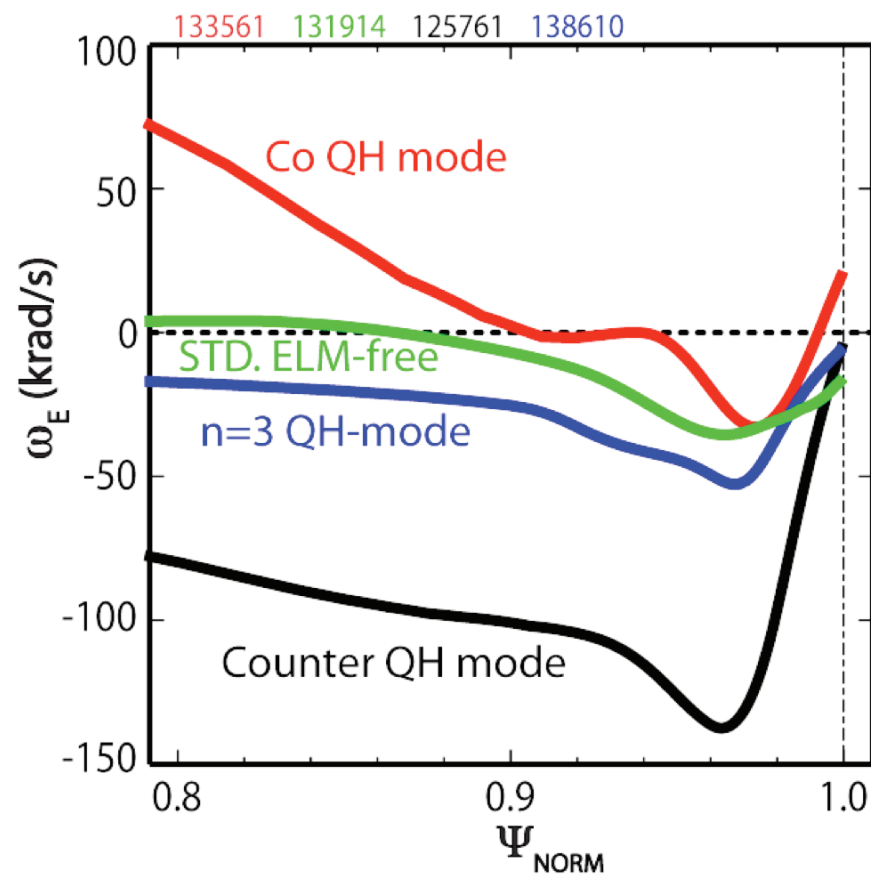
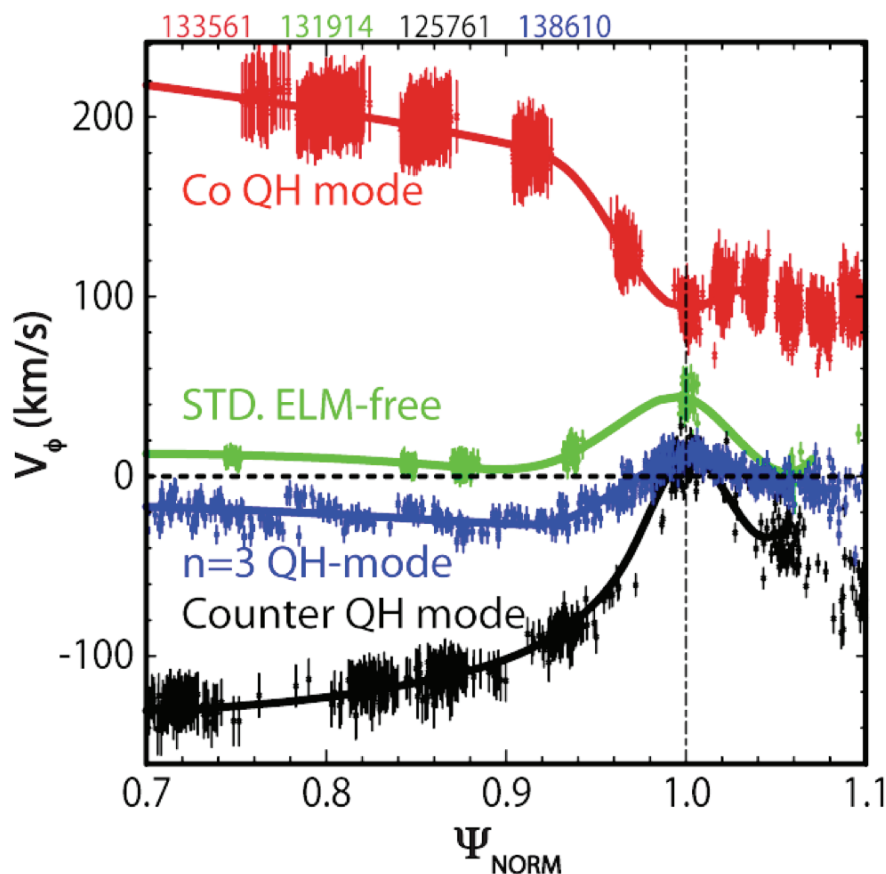
- Large shear in edge velocity of impurity ions (C) not required to sustain QH-mode with NRMF



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- Shear in edge ω_E rotation similarly high in QH-mode discharges; smaller in STD. ELM-free H-mode



Counter-Ip Torque Driven by NRMFs Used to Expand QH-mode Operating Space

- **NRMF torque allows sustained operation with a quiescent H-mode (QH-mode) edge and near-zero profiles of both toroidal rotation and neutral beam injected torque**
- **No adverse impact of the NRMF on the energy confinement is observed**
- **Resilience to locked modes is improved**
- **Test of theory: Large edge rotation shear requirement for QH-mode violated in C impurity ion rotation of n=3 QH-mode plasmas**
 - Requirement may be related to ω_E rotation