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Physics and Control of Toroidal Rotation Damping in NSTX

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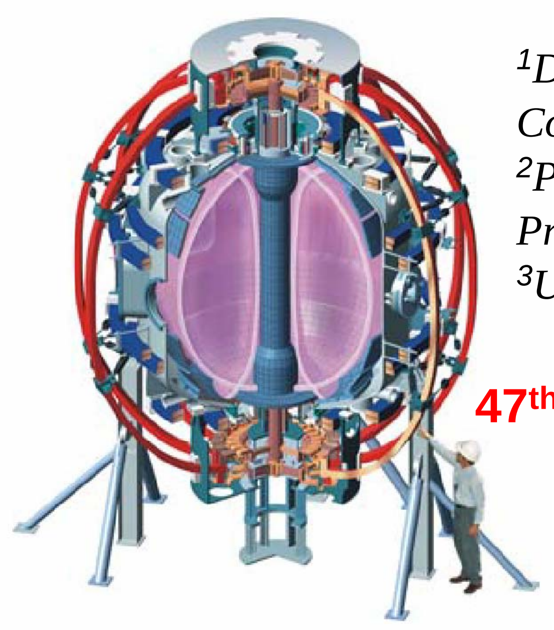

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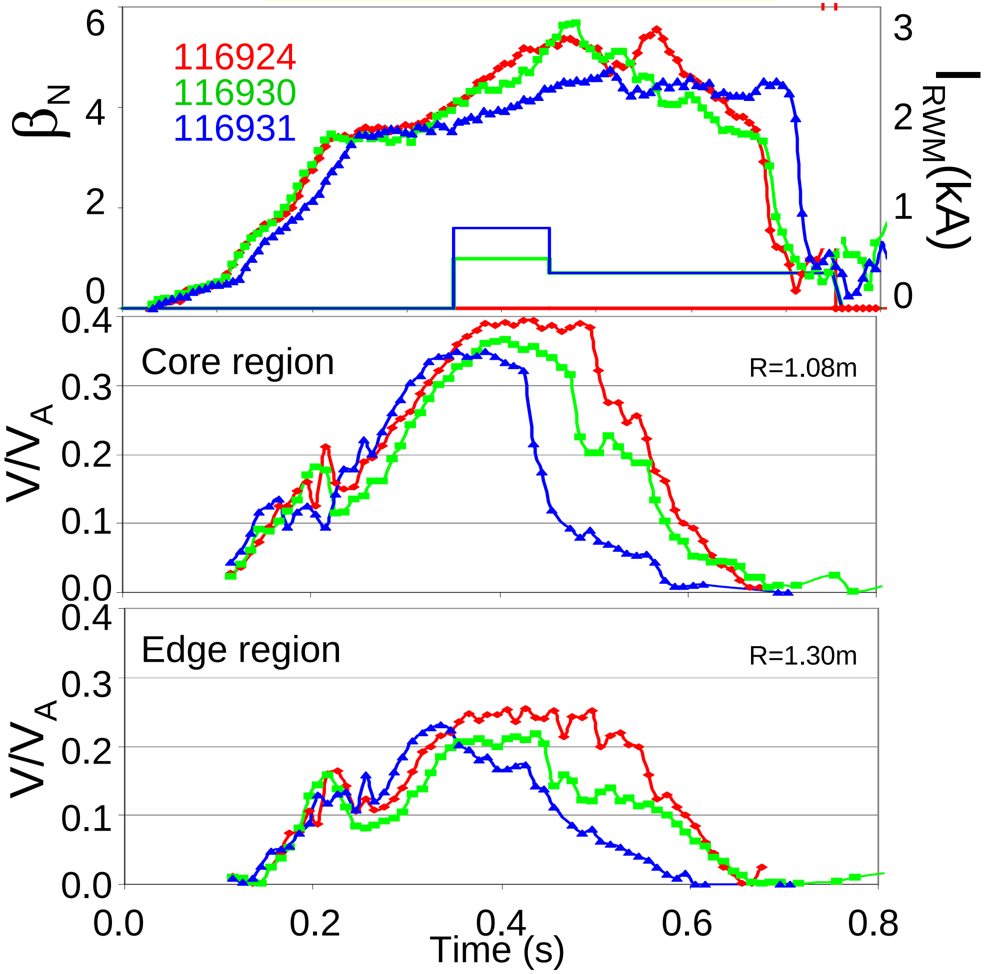
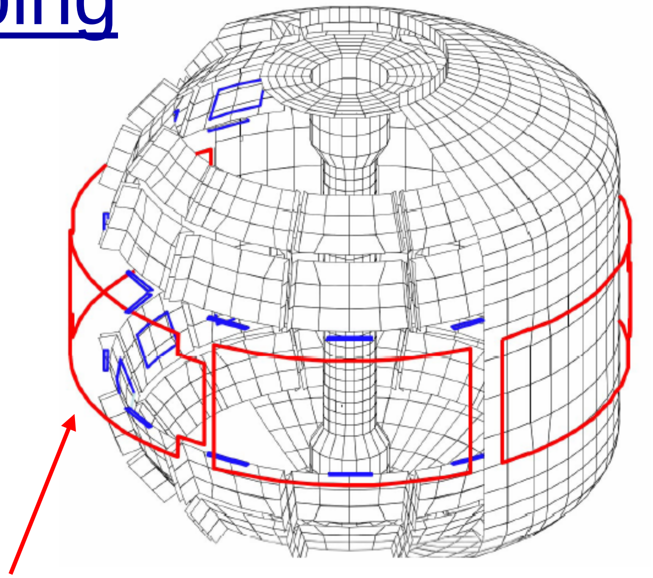
Non-axisymmetric fields used to study plasma rotation damping

n=3 DC field pulse

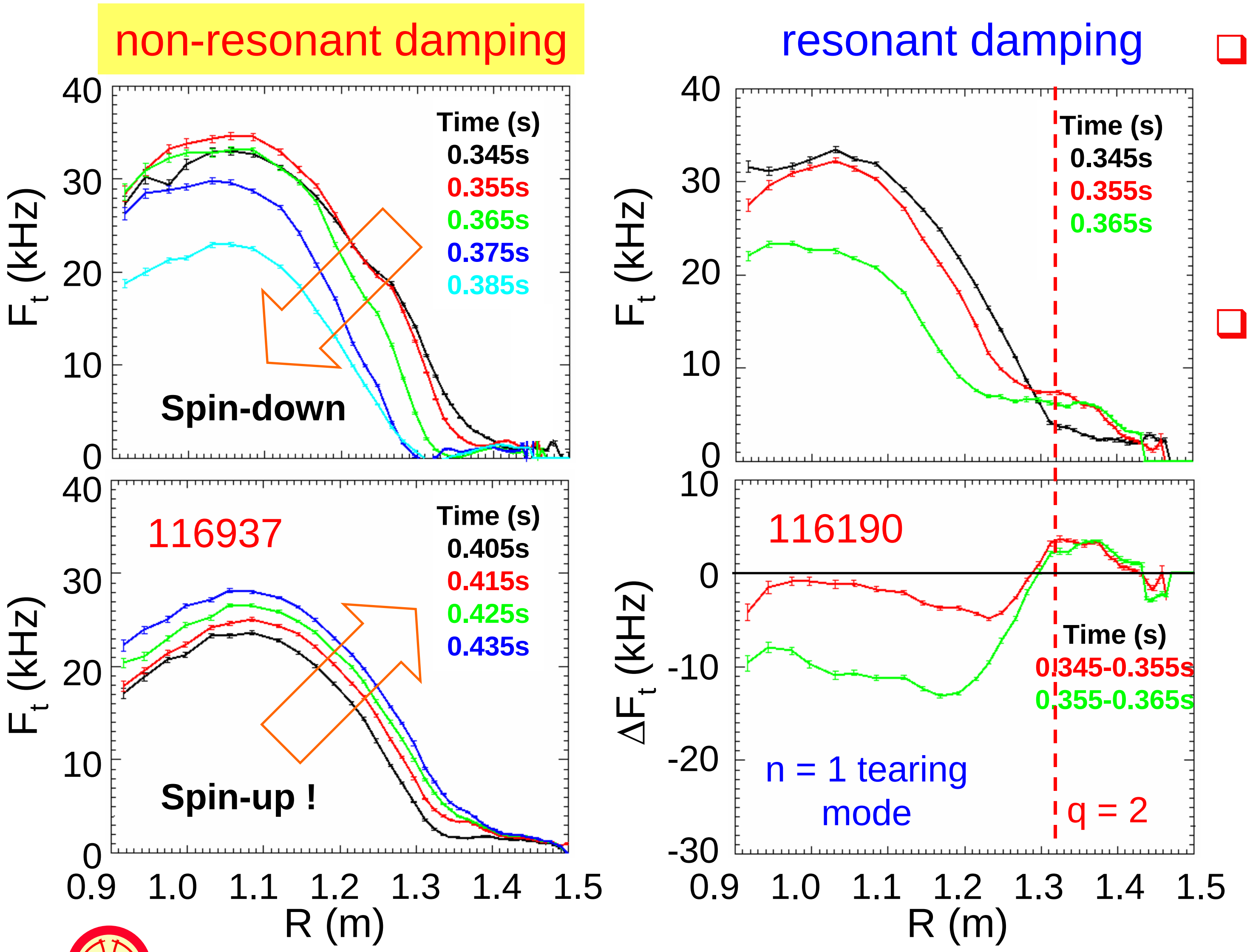




6 ex-vessel non-axisymmetric field coils

- Produce low rotation (ITER relevant) target plasmas
  - Good control by current timing / magnitude
- Study physics of plasma rotation damping due to applied field / RWM
  - n=1 and n=3 fields used

Attention placed on studying non-resonant rotation damping physics



- ❑ Non-resonant
  - ❑ Global profile control by pulsing the applied field
- ❑ Resonant
  - ❑ Local JxB torque can explain damping by tearing modes
  - ❑ Outward momentum transfer across rational surface
  - ❑ Leads to rigid rotor core

Neoclassical toroidal viscosity (NTV) theory tested as non-resonant damping mechanism

Torque balance: $$-\rho R^2 \left(\frac{\partial \Omega_\phi}{\partial t}\right) = T_{\vec{J}\times\vec{B}} + T_{\mathrm{NTV}}$$

computed

measured

(Set = 0 here - tearing modes avoided.)

$$T_{NTV} = \mathrm{K} \cdot \left[R \frac{\pi^{1/2} p_i}{v_{t_i}} \Omega \varepsilon^2 \frac{1}{B_t^2} q \sum_{n,m\neq 0} \frac{\mu_{ps1} n^2 \left(b_r^{nm}\right)^2}{C_\nu + \mu_{ps1} \left|m - nq\right|} + T_{NTV}^{m=0} \right]$$

factor

$T_i^{1/2}$

profiles

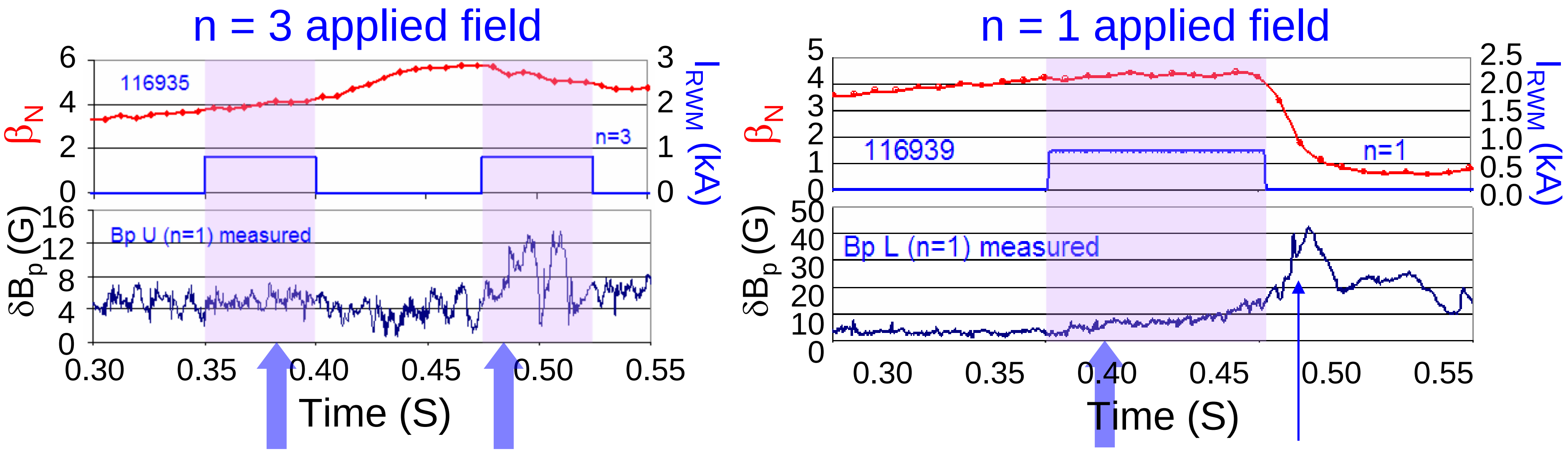
collisionality

$$\mu_{ps1} = 1.365 \qquad C_\nu = \frac{2\sqrt{\pi}}{3} \frac{2\nu_{\mathrm{ii}}}{v_t / Rq}$$

Damping caused by kinked field

K.C. Shaing, Phys. Fluids 29 (1986) 521.; E. Lazzaro Phys. Plasmas 9 (2002) 3906.

NTV theory applied to different periods in discharge


n = 3 applied field

n = 1 applied field

Applied field

Resonant Field Amplification (RFA)

Unstable RWM

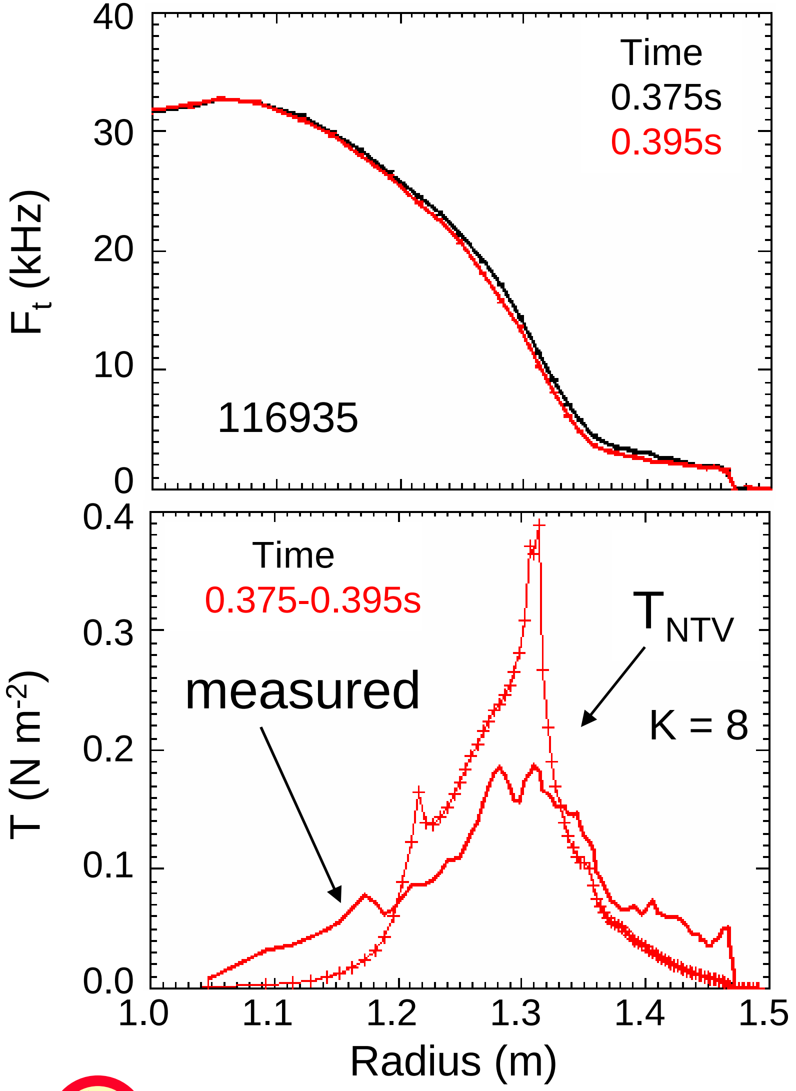
① Applied field

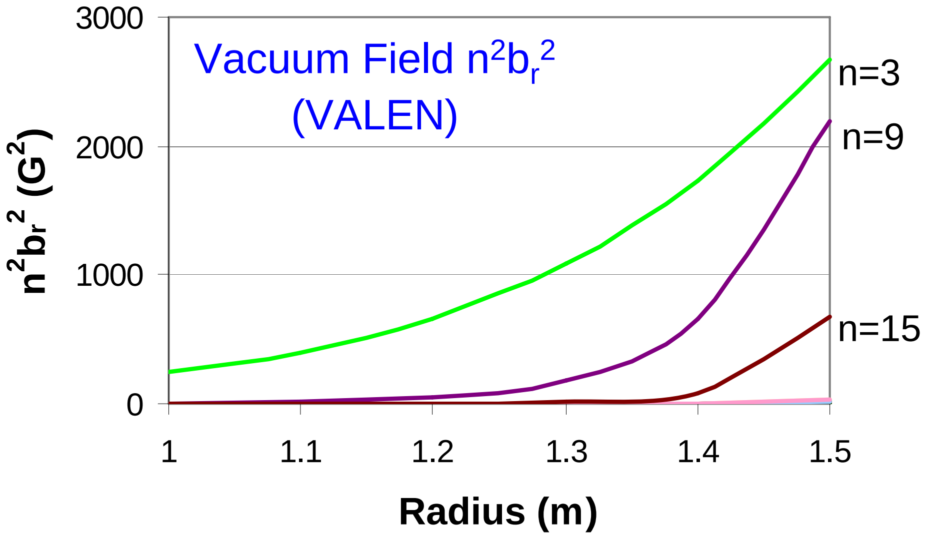
- Plasma β_N at or below no-wall limit

② RFA

- Plasma β_N above no-wall limit
- Applied field is amplified by stable RWM

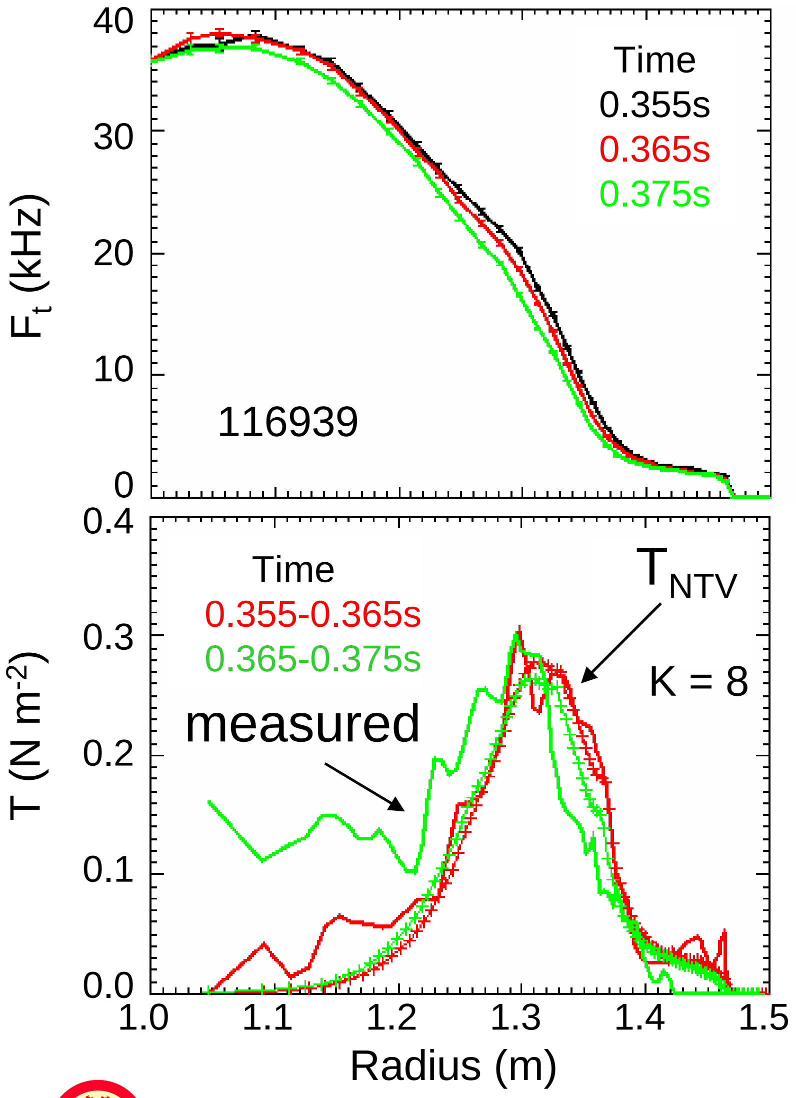
Applied field alone yields moderate, global rotation damping

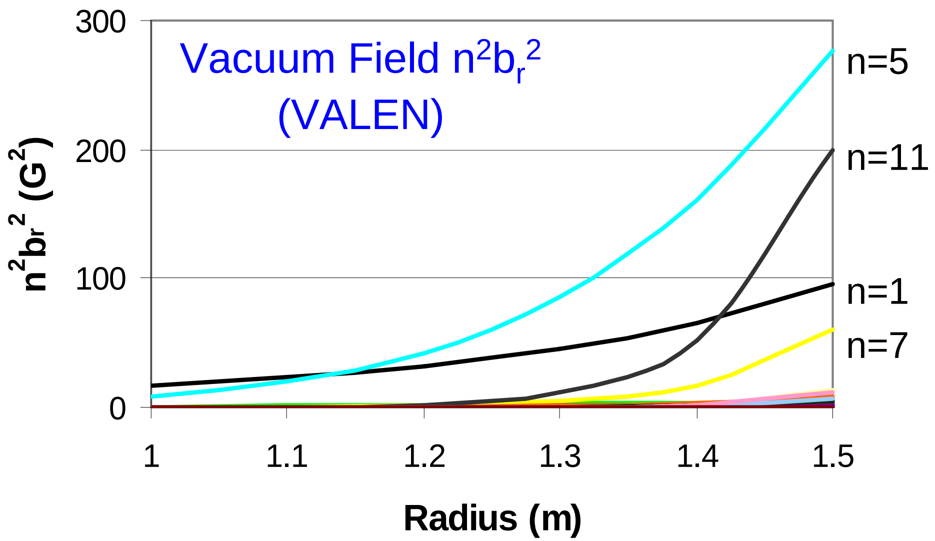




- ❑ n = 3 DC field (800A)
- ❑ Damping reduced at large R due to reduction in T_i
- ❑ n=1-15 field components included
- ❑ Resonant denominator in NTV theory might be overemphasized
  - ❑ Function of collisionality

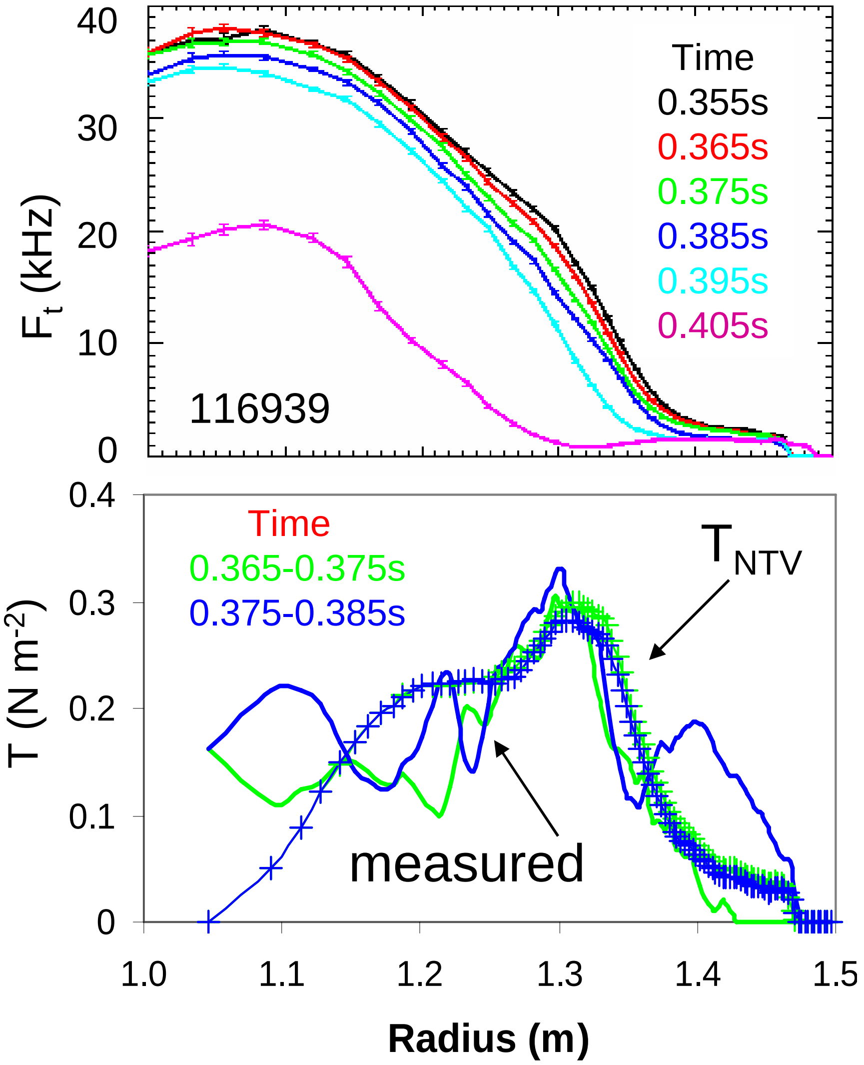
RFA enhances, broadens rotation damping



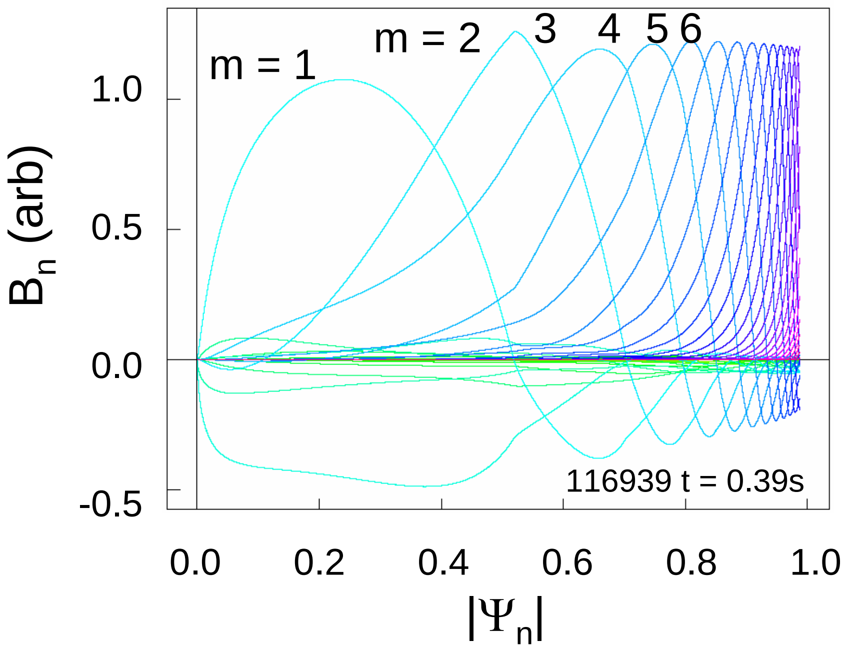


- n = 1 DC field (800A)
- n=5 torque larger than n=1 torque (n^2b^2 scaling)
- n=1-15 components included
- Broadening damping profile

RWM eigenfuction can explain broader damping



RWM mode decomposition



- DCON n = 1 (m = -12 to 26) RWM calculated eigenfunction
  - No-wall boundary condition
  - Need to evaluate with-wall boundary condition; inclusion of measured n = 2 component

Control of plasma rotation profile allows study of rotation damping physics

- Applied n=1,3 DC and AC fields used to alter plasma rotation profile in a controlled fashion
- Plasma rotation recovers if applied field reduced before RWM critical rotation profile reached (Sontag RP1.00021 Thurs.)
- Rotation damping profile from applied n = 1,3 fields and RFA follows neoclassical toroidal viscosity (NTV) theory
- NTV theory tested, including *n* scaling, reduced damping at low T_i, global/non-resonant mechanism
  - Continued work to resolve magnitude (multiplicative factor, K)
  - Presently, K = 8; low collisionality regime effects may reduce this to 2 – 3 (*priv. comm.* K.C. Shaing)