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Wall Stabilized Operation in High Beta NSTX Plasmas

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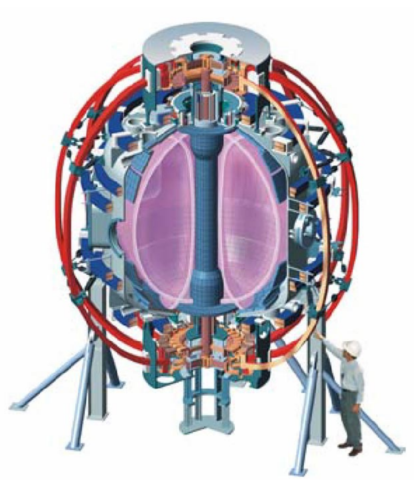

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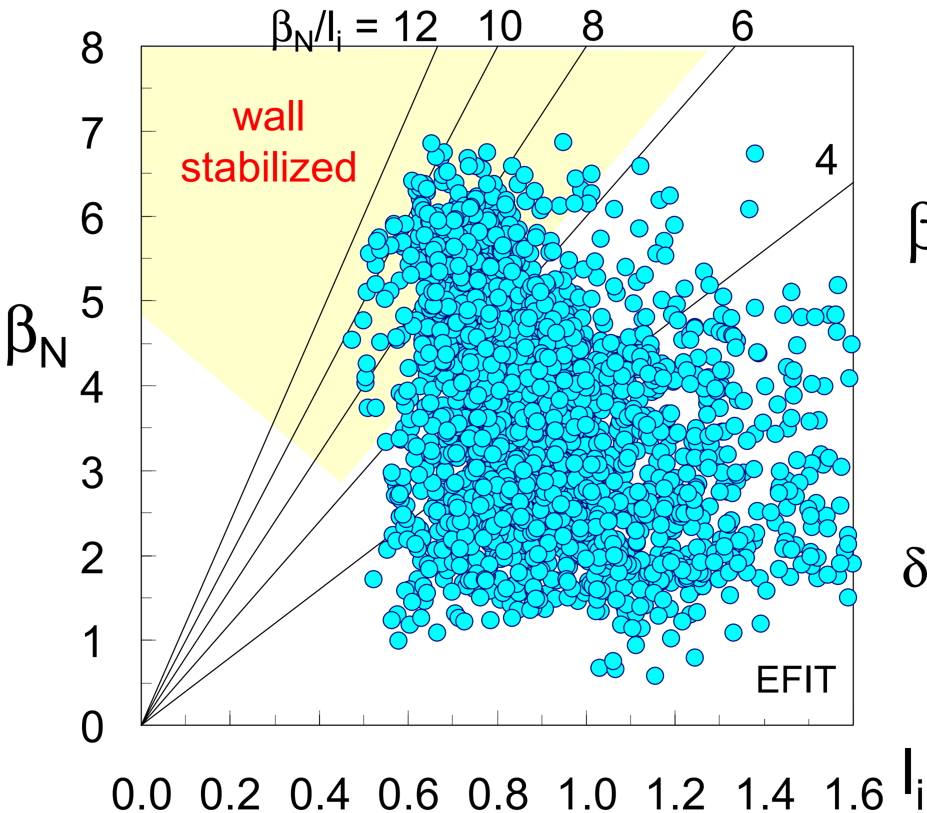
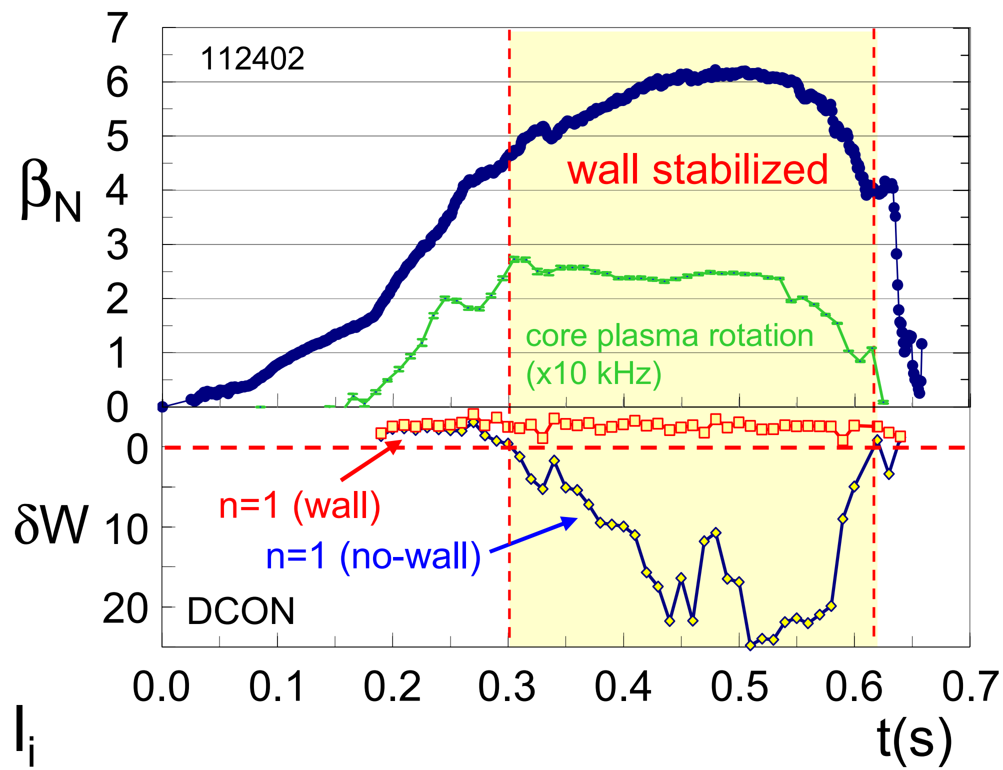
NSTX

Wall stabilization physics understanding is key to sustained plasma operation at maximum β

- High β_t = 39%, β_N = 6.8 reached



- Operation with $\beta_N/\beta_N^{no\text{-}wall}$ > 1.3 at highest β_N for pulse >> τ_{wall}



- Global MHD modes can lead to rotation damping, β collapse
- Physics of sustained stabilization is applicable to ITER

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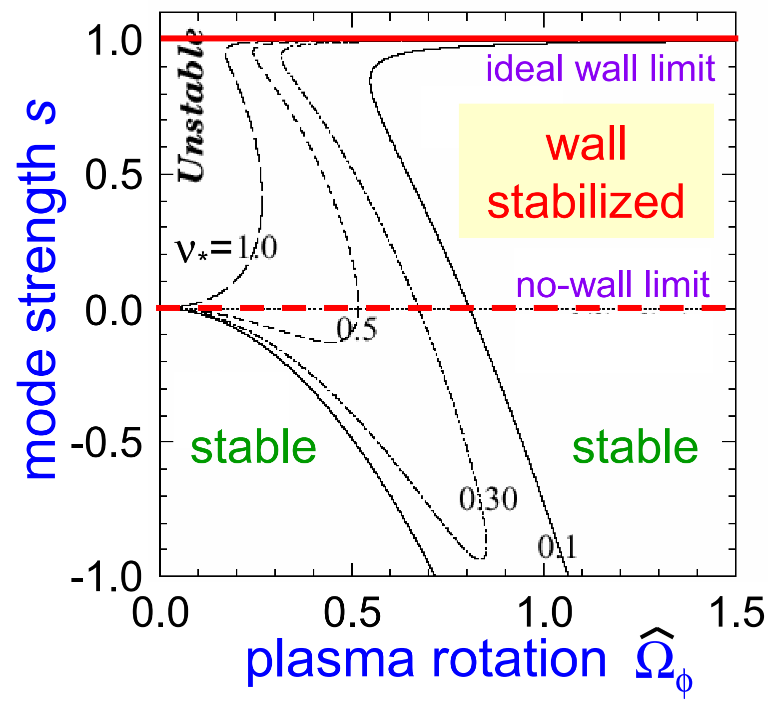
Theory provides framework for wall stabilization study

- This talk: Resistive Wall Mode physics
  - RWM toroidal mode spectrum
  - Critical rotation frequency, Ω_{crit}
  - Toroidal rotation damping
  - Resonant field amplification (RFA)

- Theory
  - Ideal MHD stability – DCON (Glasser)
  - Drift kinetic theory (Bondeson – Chu)
  - RWM dynamics (Fitzpatrick – Aydemir)

Fitzpatrick-Aydemir (F-A) stability curves

Phys. Plasmas **9** (2002) 3459



$$\left[\left(\hat{\gamma}-i\hat{\Omega}_\phi\right)^2+\nu_*\left(\hat{\gamma}-i\hat{\Omega}_\phi\right)+(1-s)(1-md)\right]\left(S_*\hat{\gamma}+(1+md)\right)=\left(1-(md)^2\right)$$

plasma inertia — dissipation — mode strength — wall response — wall/edge coupling

$S_* \sim 1/\tau_{wall}$

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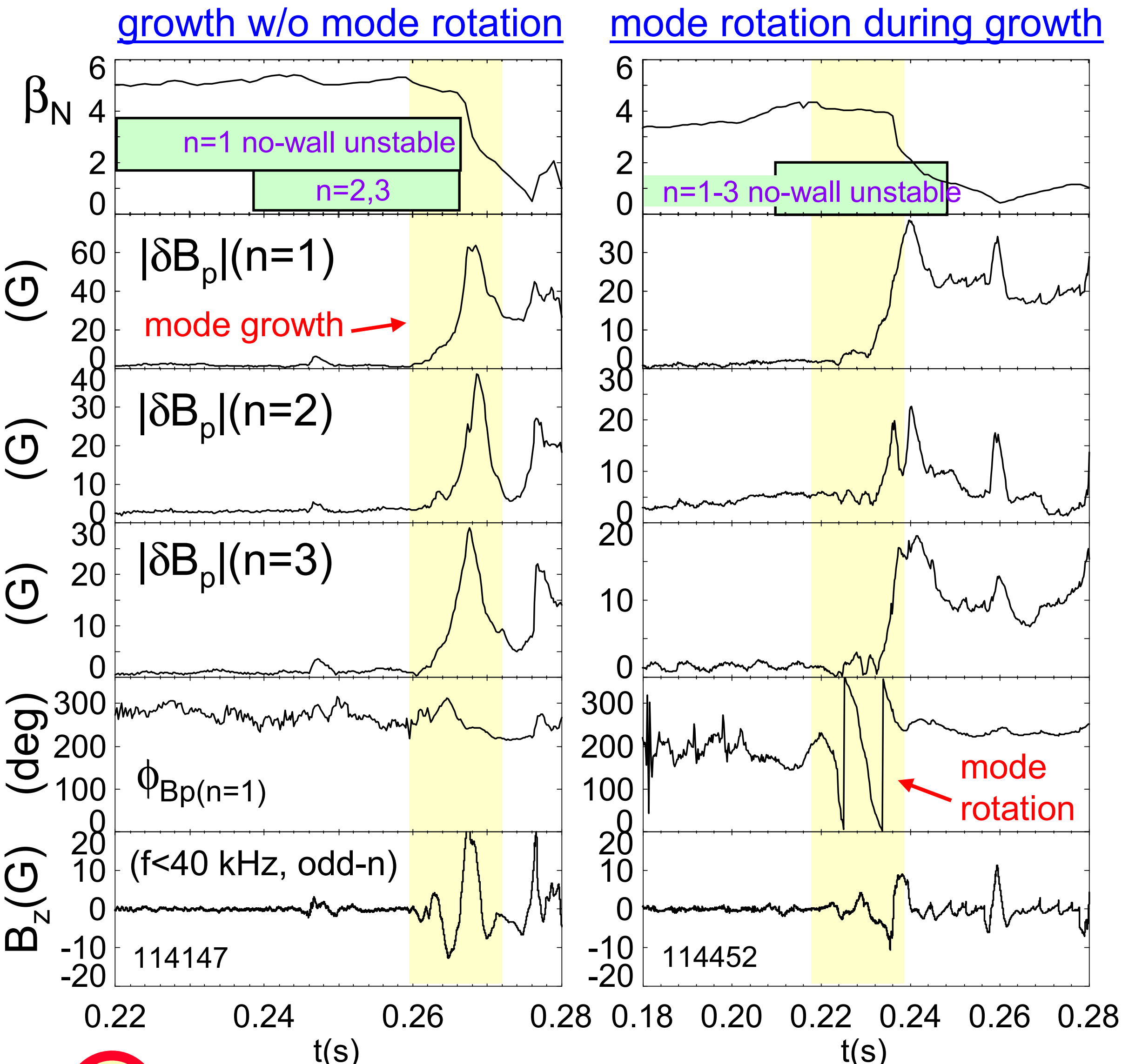
Unstable RWM dynamics follow theory



- Unstable n=1-3 RWM observed
  - ideal no-wall unstable at high β_N
  - n > 1 theoretically less stable at low A
- F-A theory / experiment show
  - mode rotation can occur during growth
  - growth rate, rotation frequency ~ $1/\tau_{wall}$
    - << edge Ω_ϕ > 1 kHz
  - RWM phase velocity follows plasma flow
  - n=1 phase velocity not constant due to error field
- Low frequency tearing modes absent

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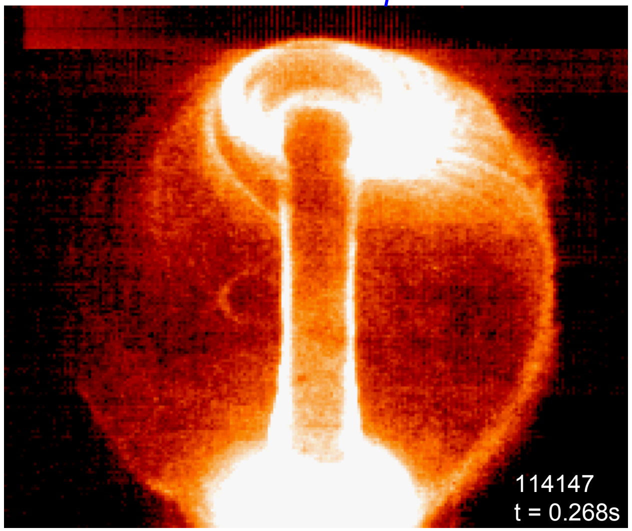
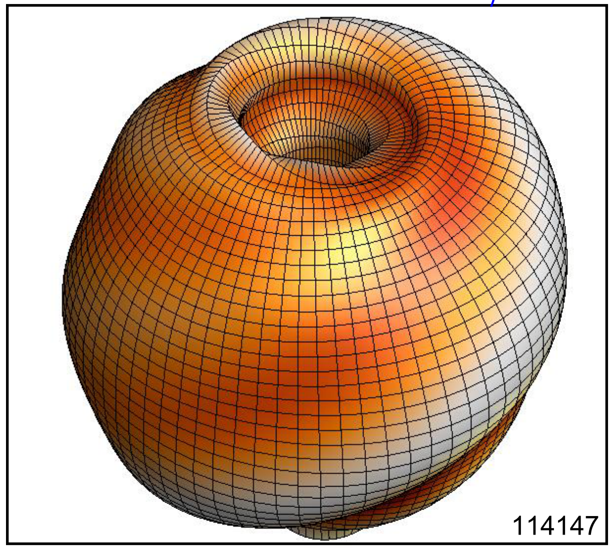
Camera shows scale/asymmetry of theoretical RWM

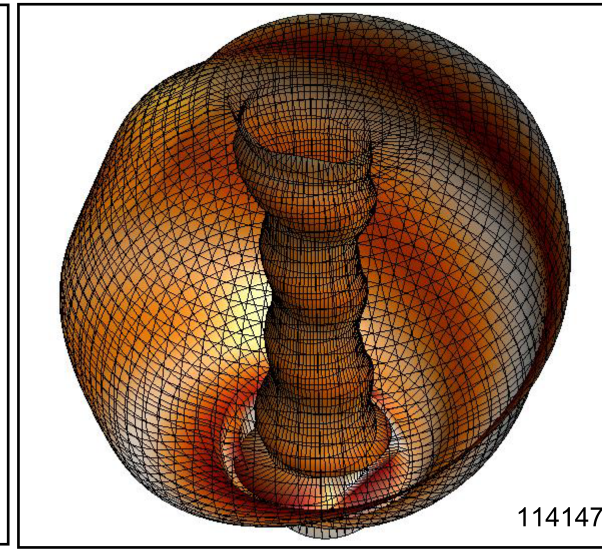
RWM with ΔB_p = 92 G



Theoretical ΔB_ψ (x10) with n=1-3 (DCON)

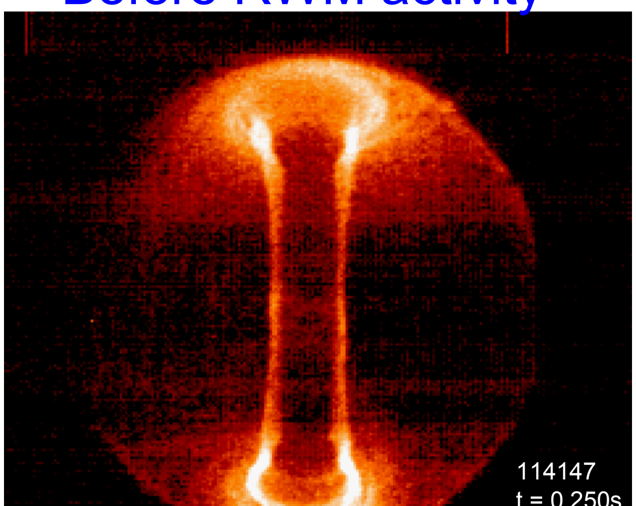


(exterior view)



(interior view)

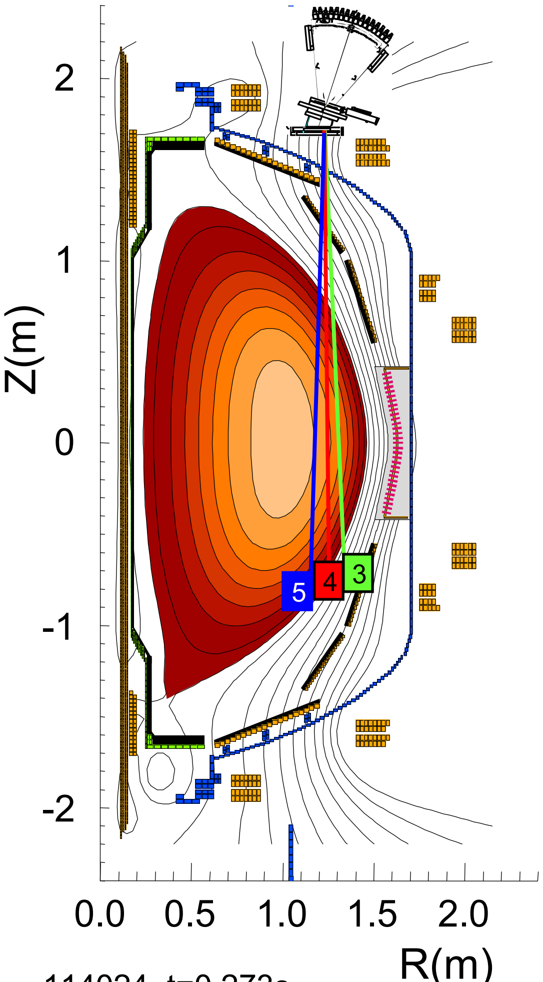
Before RWM activity



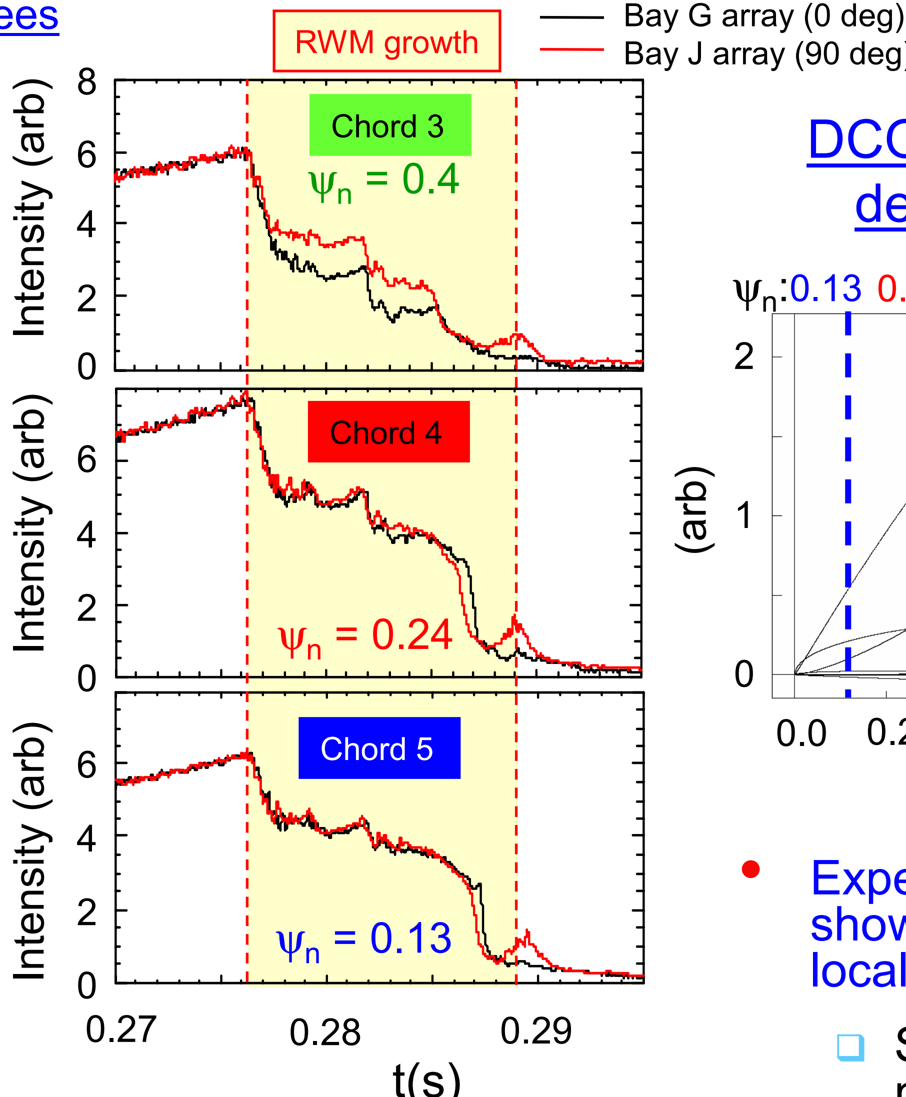
- Visible light emission is toroidally asymmetric during RWM
- DCON theory computation displays mode
  - uses experimental equilibrium reconstruction
  - includes n = 1 – 3 mode spectrum
  - uses relative amplitude / phase of n spectrum measured by RWM sensors

Soft X-ray emission shows toroidal asymmetry during RWM

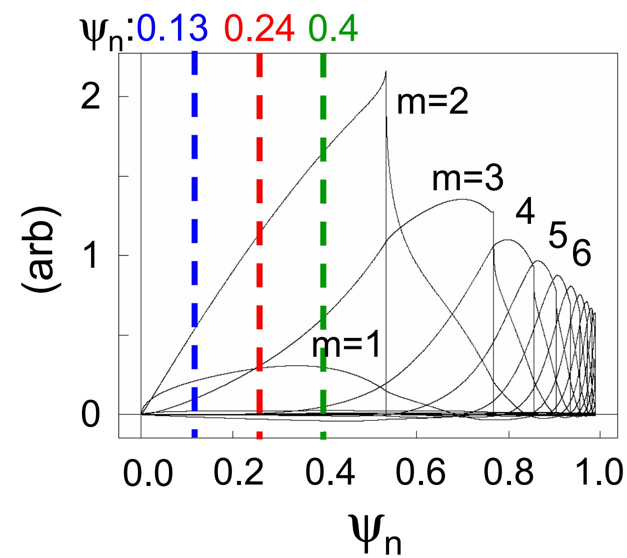
USXR separated by 90 degrees



114024, t=0.273s
β_N = 5



DCON *n* = 1 mode decomposition



- Experiment / theory show RWM not edge localized
  - Supported by measured ΔT_e

Experimental Ω_{crit} follows Bondeson-Chu theory

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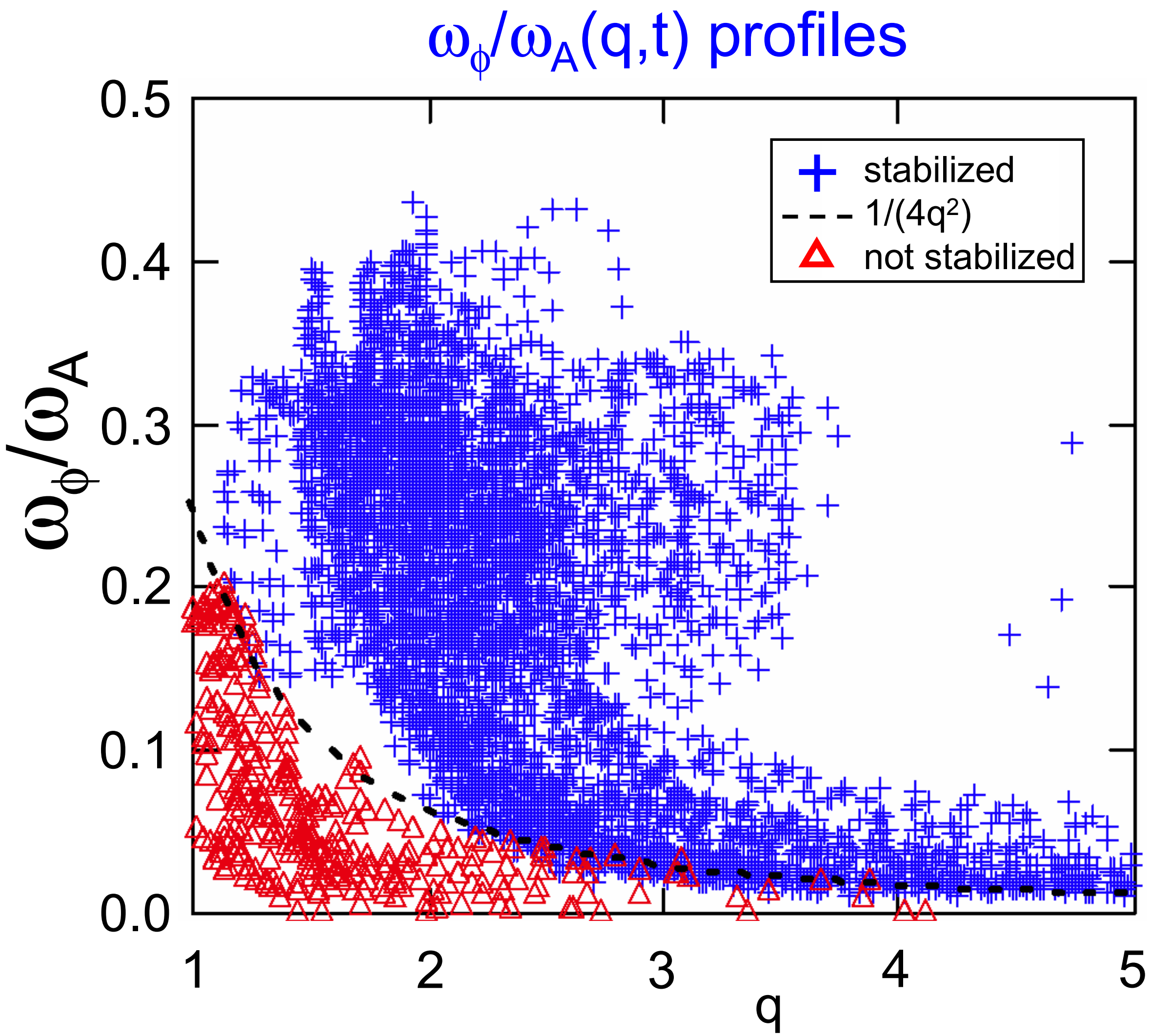

- **Experimental Ω_{crit}**
  - stabilized profiles: $\beta > \beta_N^{no\text{-}wall}$ (DCON)
  - profiles not stabilized cannot maintain $\beta > \beta_N^{no\text{-}wall}$
  - regions separated by $\omega_\phi/\omega_A = 1/(4q^2)$
- **Drift Kinetic Theory**
  - Trapped particle effects significantly weaken stabilizing ion Landau damping
  - Toroidal inertia enhancement more important
    - Alfven wave dissipation yields $\Omega_{crit} = \omega_A/(4q^2)$

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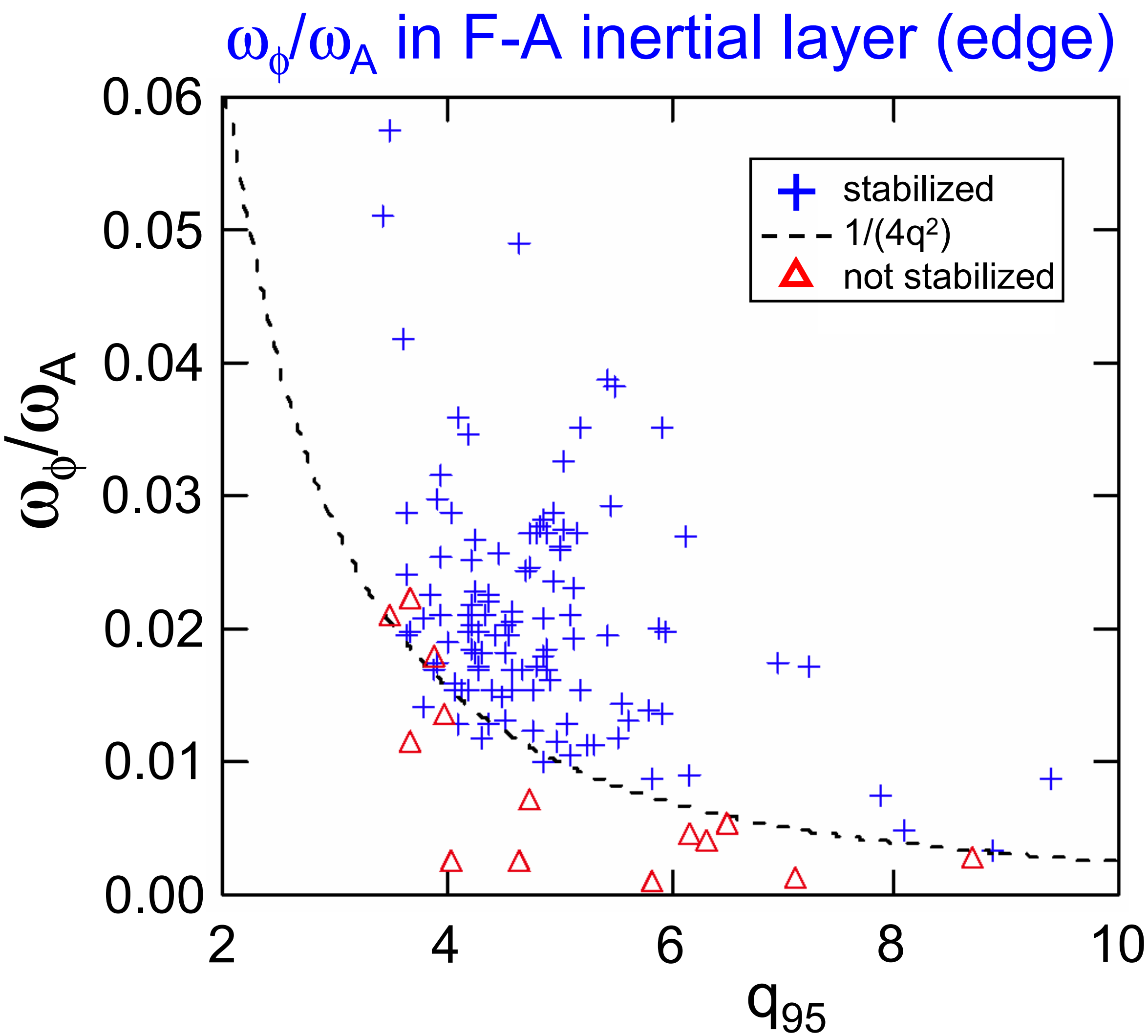
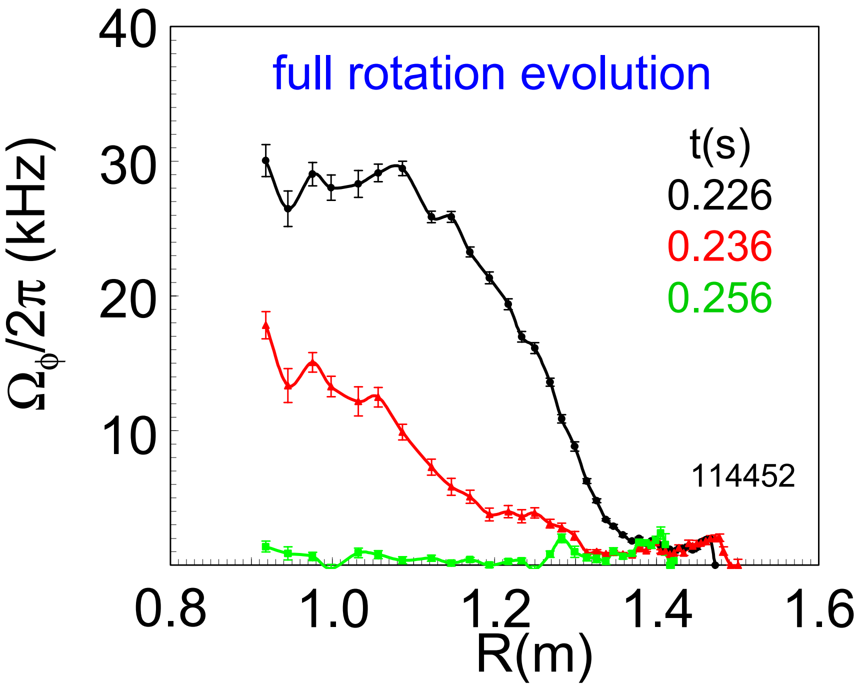
Ω_{crit} follows F-A theory with neoclassical viscosity



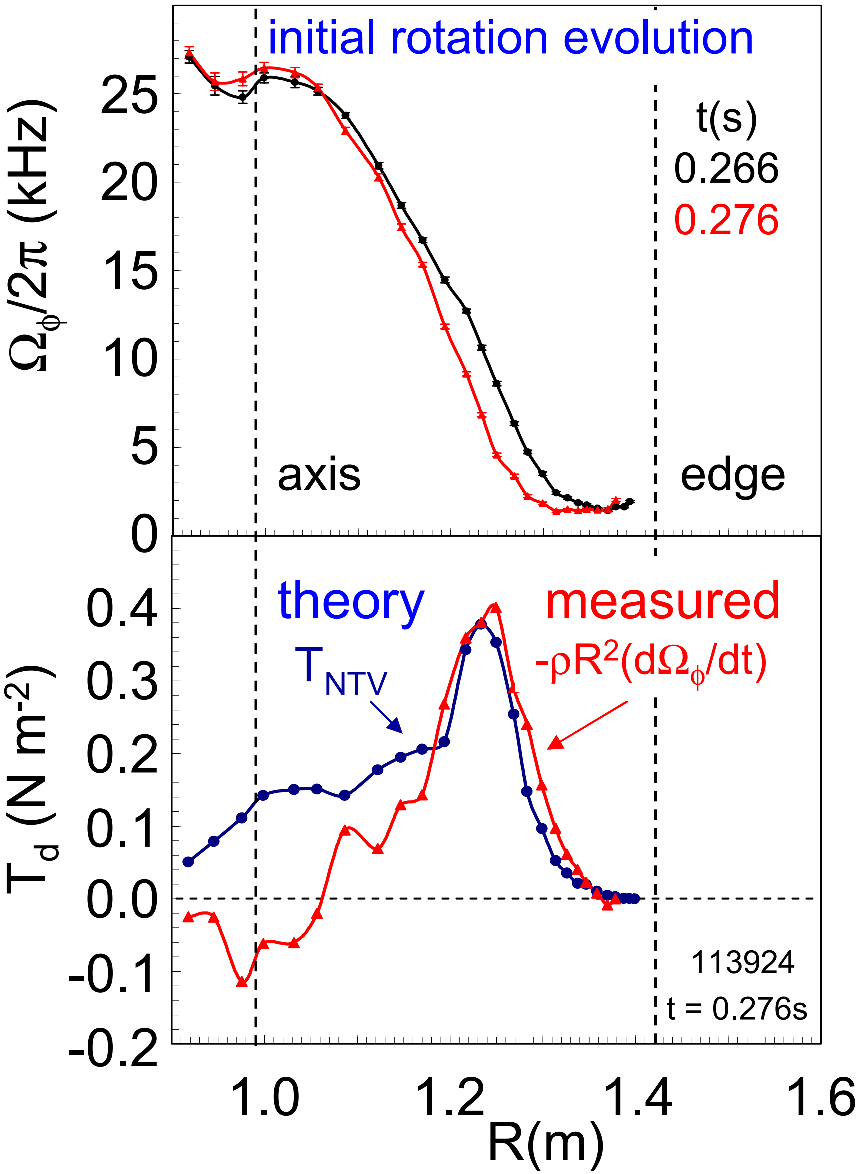
- Experimental Ω_{crit}
  - stabilized points: $\beta > \beta_N^{no\text{-}wall}$ (DCON)
  - points not stabilized cannot maintain $\beta > \beta_N^{no\text{-}wall}$
  - regions separated by $\omega_\phi/\omega_A = 1/(4q^2)$
- F-A Theory
  - Standard F-A theory has $\Omega_{crit} \sim 1/q$
  - neoclassical viscosity includes toroidal inertia enhancement (K. Shaing, PoP 2004)
    - yields $\Omega_{crit} \sim 1/q^2$

Plasma rotation damping described by NTV theory

- Neoclassical toroidal viscosity (NTV) ~ $\delta B^{2} * T_i^{0.5}$
- Rapid, global damping observed during RWM
  - Edge rotation ~ 2kHz maintained
  - Low frequency tearing modes absent



- Evolution detail differs for other modes
  - no momentum transfer across rational surfaces
  - no rigid rotor plasma core (internal 1/1 mode)



see EX/P2-26 Menard

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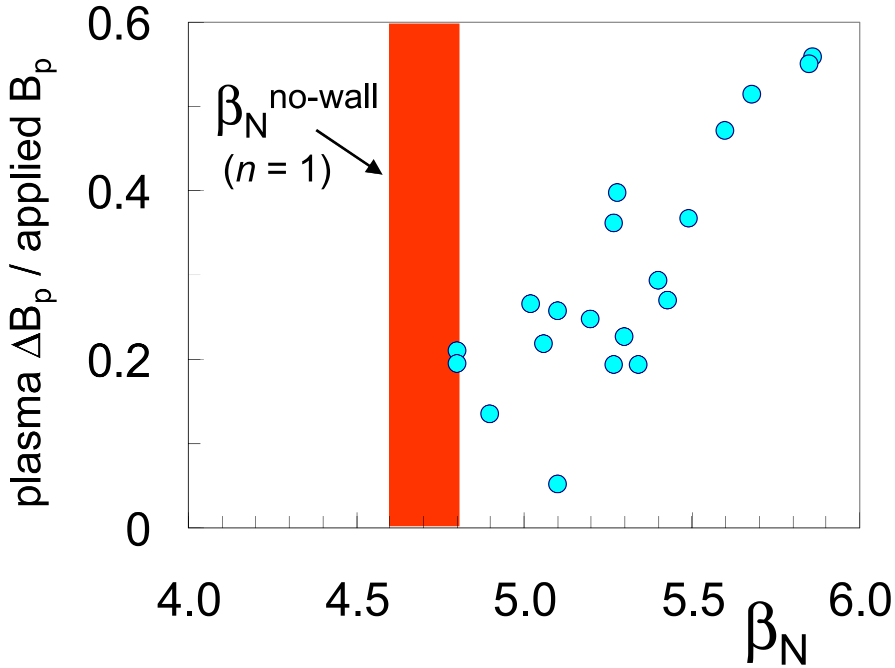
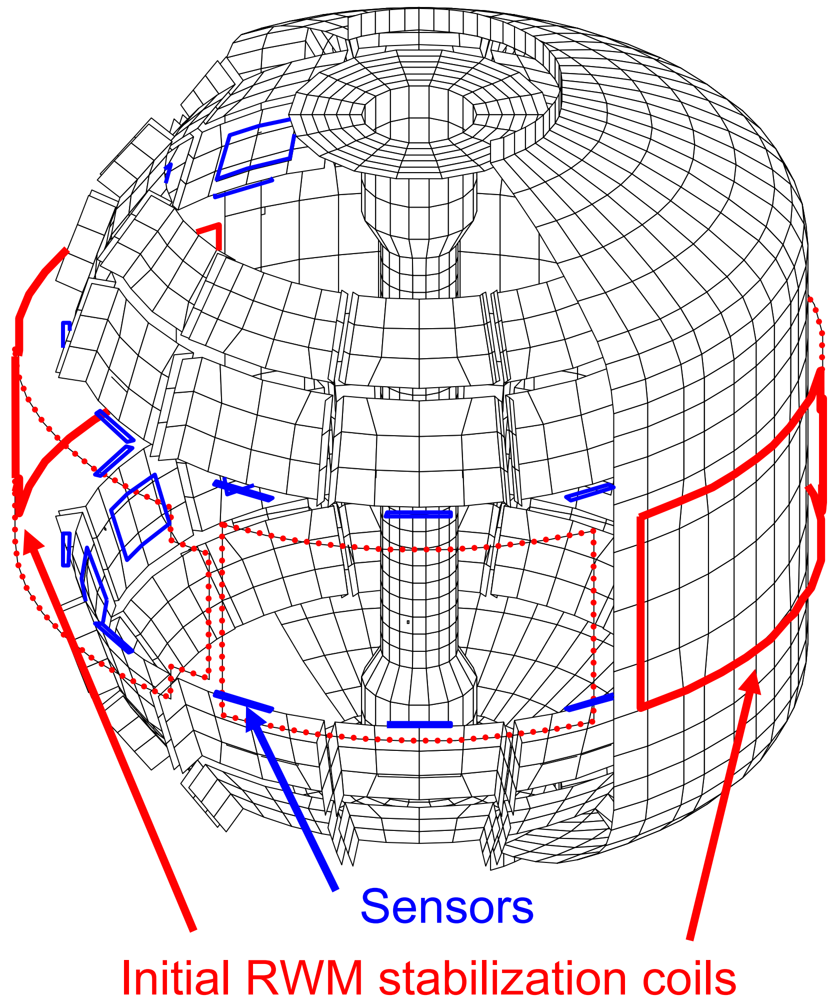
Resonant Field Amplification increases at high β_N





- Plasma response to applied field from initial RWM stabilization coil pair
  - AC and pulsed n = 1 field
- RFA increase consistent with DIII-D
- Stable RWM damping rate of $300s^{-1}$ measured

Completed coils will be used to suppress RFA, stabilize RWM, sustain high β

Wall stabilization research at low aspect ratio illuminates key physics for general high β operation

- Plasma β_t = 39%, β_N = 6.8, β_N/l_i = 11 reached; $\beta_N/\beta_N^{no\text{-}wall}$ > 1.3
- Unstable *n* = 1-3 RWMs measured (n > 1 prominent at low A)
- Critical rotation frequency ~ ω_A/q^2 strongly influenced by toroidal inertia enhancement (prominent at low A)
- Rapid, global plasma rotation damping mechanism associated with neoclassical toroidal viscosity
- Resonant field amplification of stable RWM increases with increasing β_N (similar to higher A)
- Evidence for AC error field resonance observed (see poster)
- Effect of rotation on equilibrium reconstruction evaluated (see poster)

Completed RWM active stabilization coil to be used for research in 2005