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Wall Stabilization Physics and Rotating Equilibrium Reconstruction

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for the

NSTX Research Team

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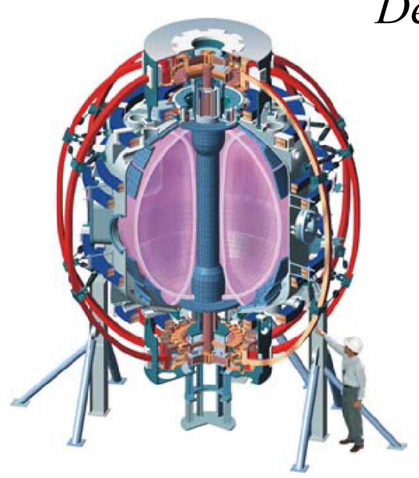

16th NSTX Program Advisory Committee Meeting

September 9 - 10, 2004

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NSTX

Wall stabilization physics understanding enhanced by use of upgraded capabilities

- Motivation
  - Resistive wall mode (RWM) leads to rotation damping, β collapse
    - Original NSTX RWM observed and published in 2001
  - Use new diagnostic and control capabilities to examine physics detail

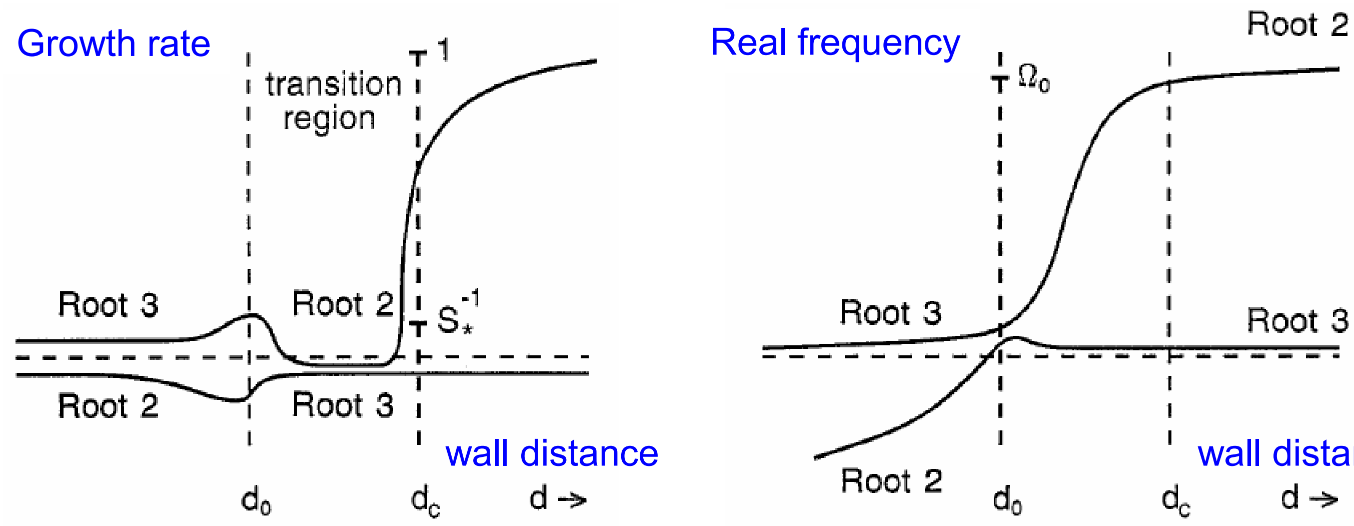
- Outline
  - Experiments examine unstable, resonant, and stable high β_N regimes
  - Significant mode detail observed with new/upgraded diagnostics
  - Enhanced experimental capability with initial RWM coil
  - Equilibrium reconstruction with rotation (Ω_ϕ/ω_A up to 0.48)
  - Theory comparison to experiment reveals new insight

…conducting wall stabilization research is flourishing!

Theory provides framework for wall stabilization study

Fitzpatrick – Aydemir (F-A) RWM dispersion relation

Nucl. Fus. 36 (1996) 11



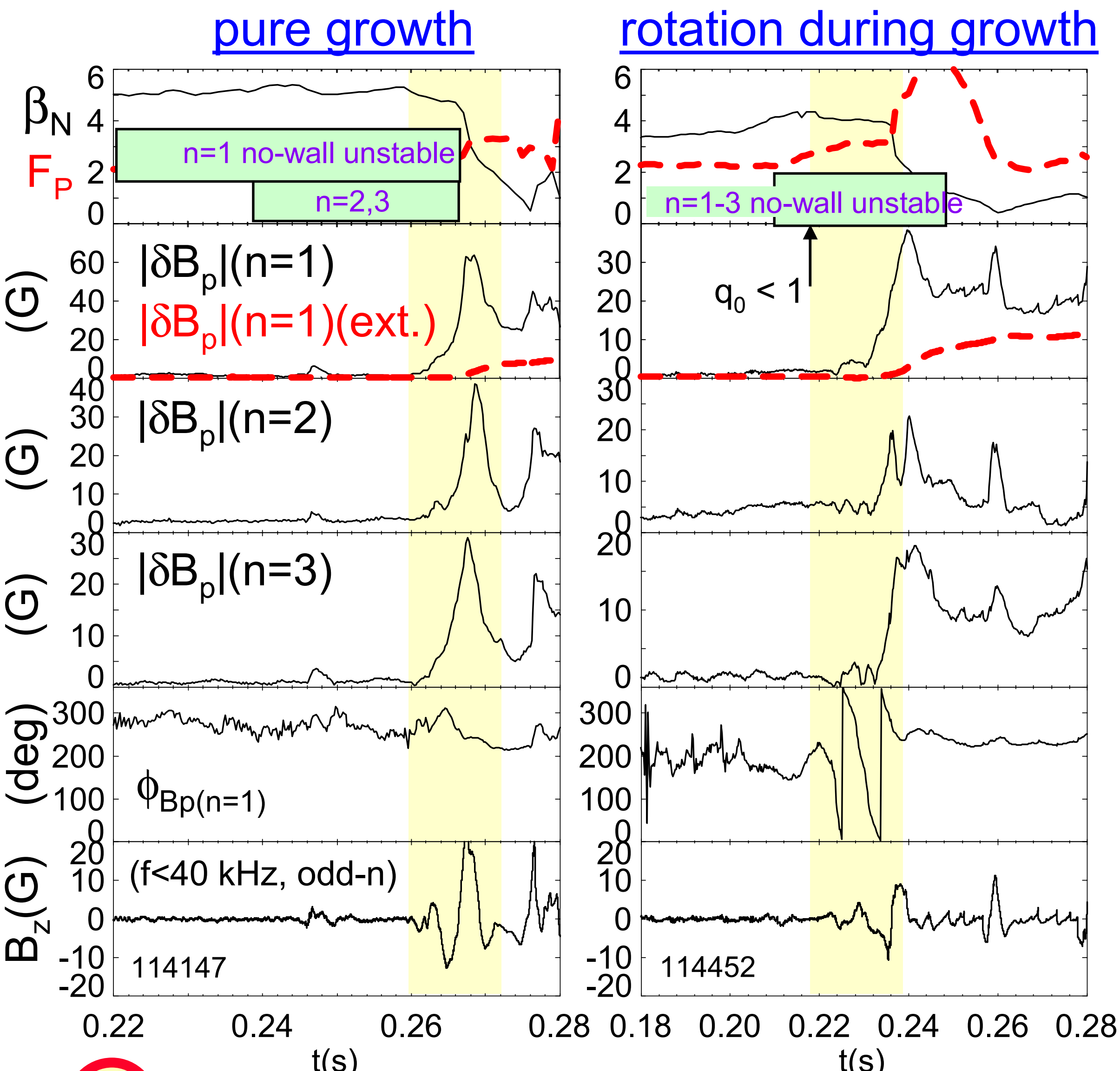
plasma rotation — $s \sim \beta_N$ — $S_* \sim 1/\tau_{wall}$ — poloidal mode number

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

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

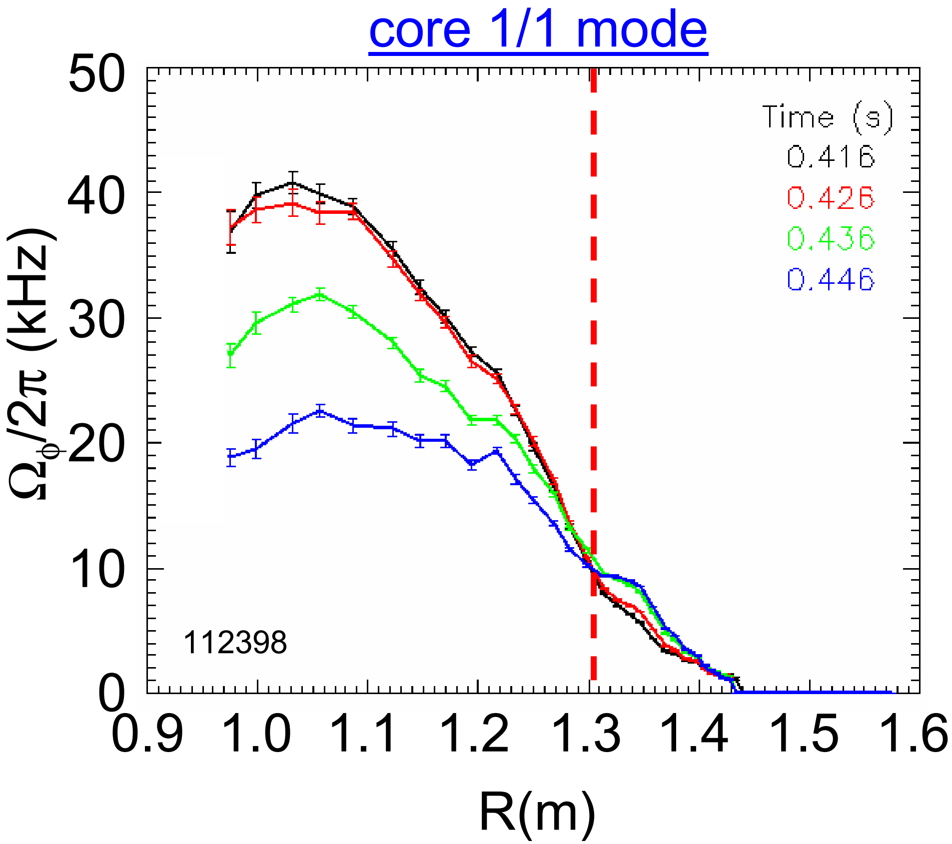
- RWM / external kink “branches” are eigenmodes of the system
- Examine stable/unstable operating regimes and resonances

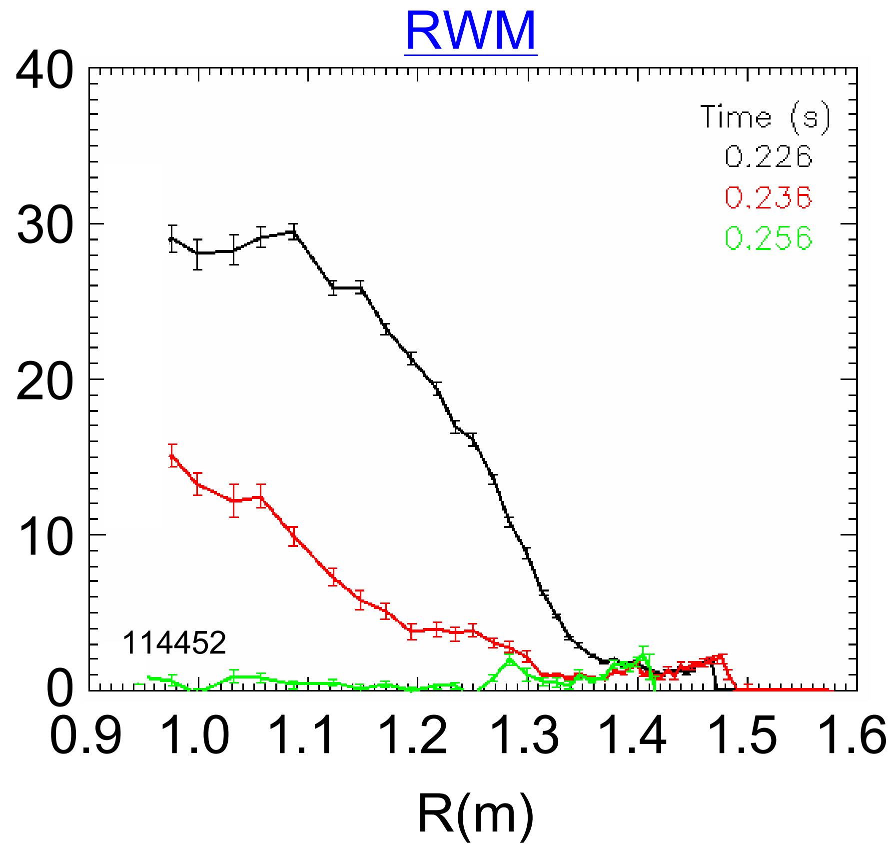
Unstable RWM dynamics follow theory



- F-A theory / XP show
  - mode unlock/ rotation can occur during mode growth
  - "RWM branch" phase velocity in direction of plasma flow
  - growth rate, rotation frequency ~ $1/\tau_{wall}$
- n=1-3 unstable modes observed on new sensors
  - modes are ideal no-wall unstable (DCON) at high β_N
- Low frequency tearing modes absent

RWM rotation damping differs from other modes

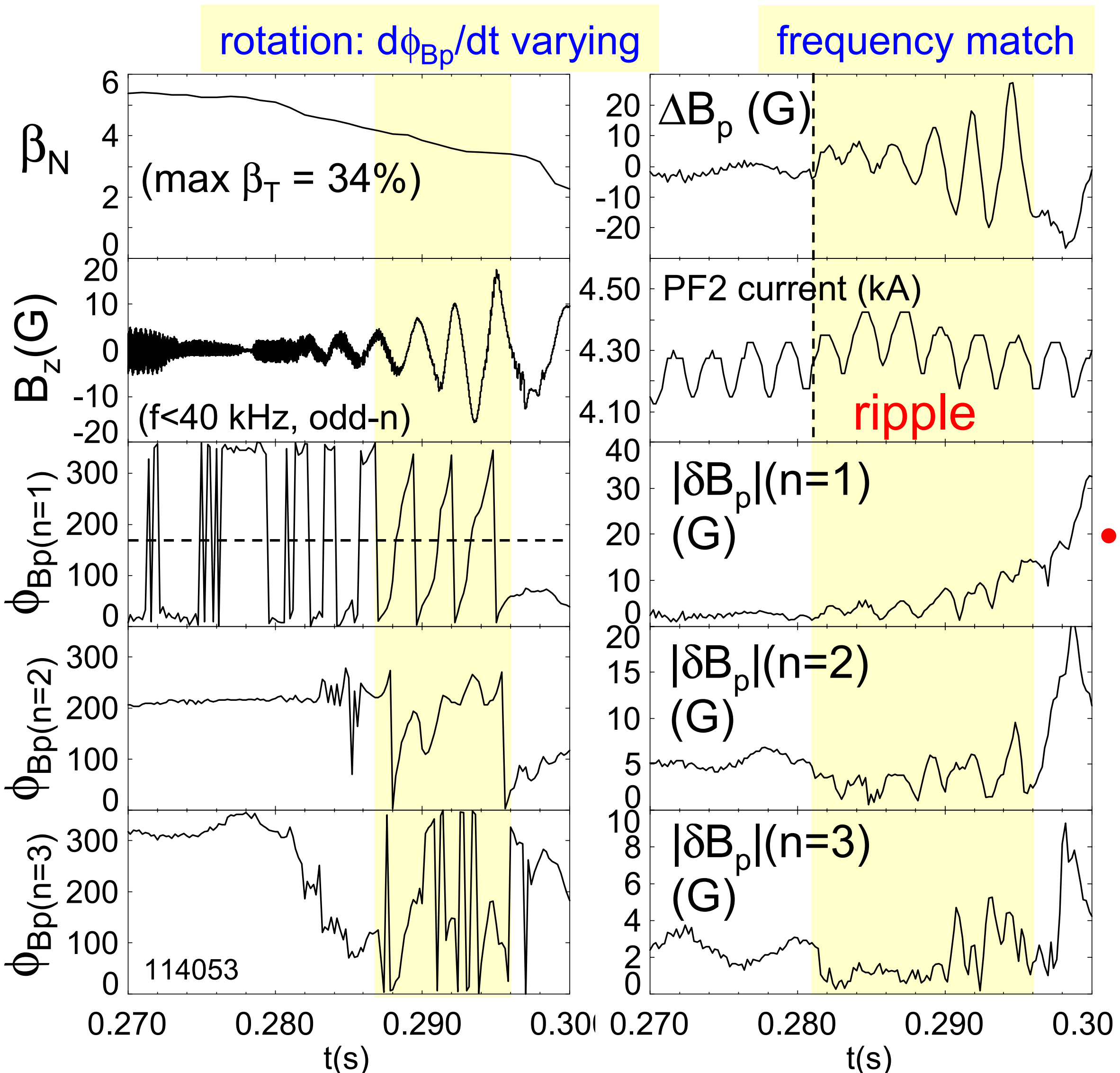




- Core rotation damping when 1/1 mode onsets
  - leads to "rigid rotor" plasma core
- Clear momentum transfer across rational surface near R = 1.3m

- Global rotation damping by RWM
  - 1/1 tearing mode is absent
- Edge rotation does not halt
  - consistent with neoclassical toroidal viscosity ~ $\delta B^2 * Ti^{0.5}$
  - testing ideal δB as perturbation

Resonance with AC error field possibly identified



Modified resonance

$$\left(S_* \nu_* / (1 + md) + 1\right)\hat{\omega}_f^2 + \left(s(1 - md) + \Omega_\phi^2\right) = 0$$

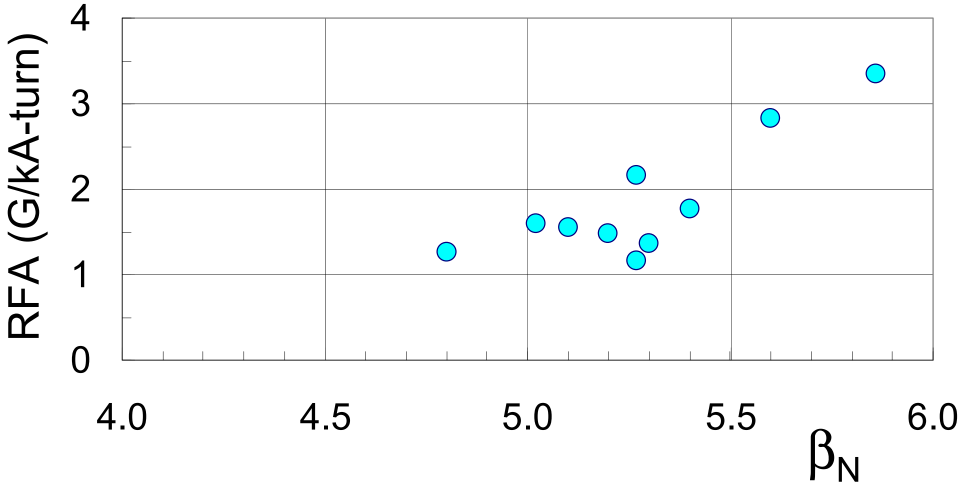
"static error field" response

New resonance

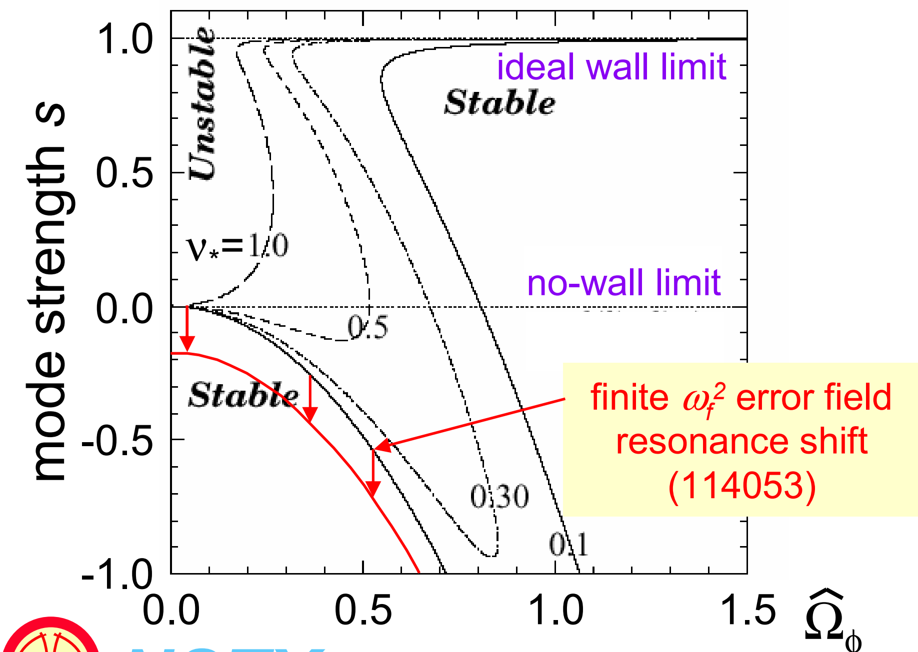
$$\hat{\omega}_f^2 = \nu_* (1 + md) / 2S_*$$

- Theory / XP show
  - Time-dependent error field yields new resonance
    - may be responsible for mode trigger
  - Mode rotates *counter* to plasma rotation – F-A theory shows as "kink branch"
    - n=1 phase velocity not constant due to error field
  - Rough calculation of $\omega_f/2\pi$ ~ 350 Hz; agrees with PF coil ripple
  - Initial results – quantitative comparison continues

Resonant field amplification increases at high β_N



Fitzpatrick-Aydemir stability curves



- Plasma response to applied field from initial RWM coil pair
  - Conducted pulsed field and initial MHD spectroscopy XPs
    - DIII-D RFA: 0-3.4 G/kA-turn
- Increase in RFA with increasing β_N consistent with DIII-D
  - thought to be *inconsistent* with F-A RWM theory (A. Garofalo, PoP 2003)
- AC error field ~ cos($\omega_f t$)
  - significantly shifts the error field resonance *away* from stability boundary
  - finite ω_f^2 resonances might fill amplification "gap" between modified error field resonance and stability limit
  - consequently, must be careful to include the effect of active error field resonances in RFA calculations

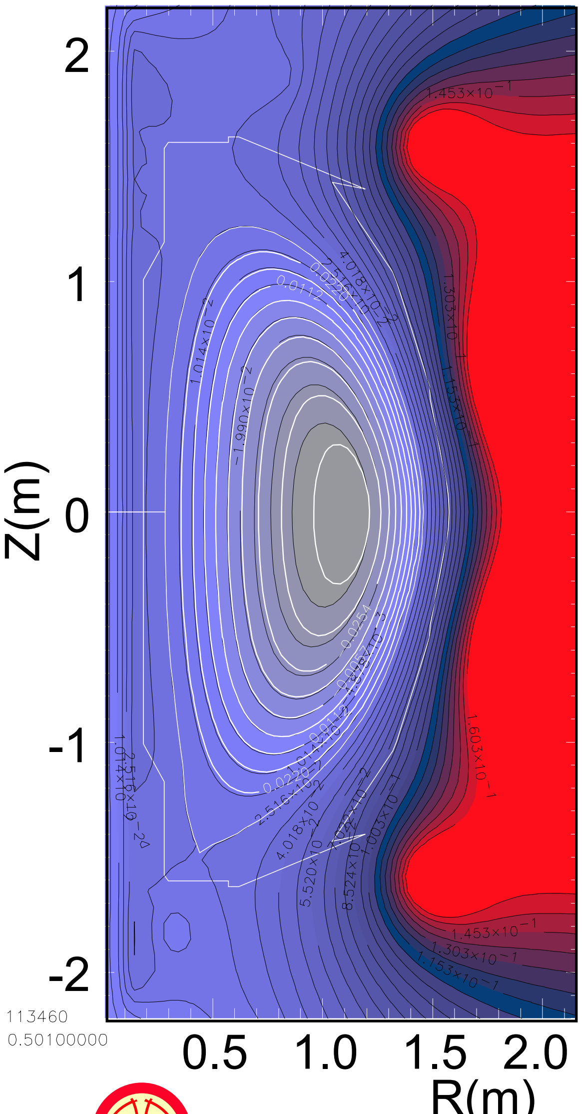
Between-shots equilibrium reconstruction with rotation introduced in 2004 (EFIT)*

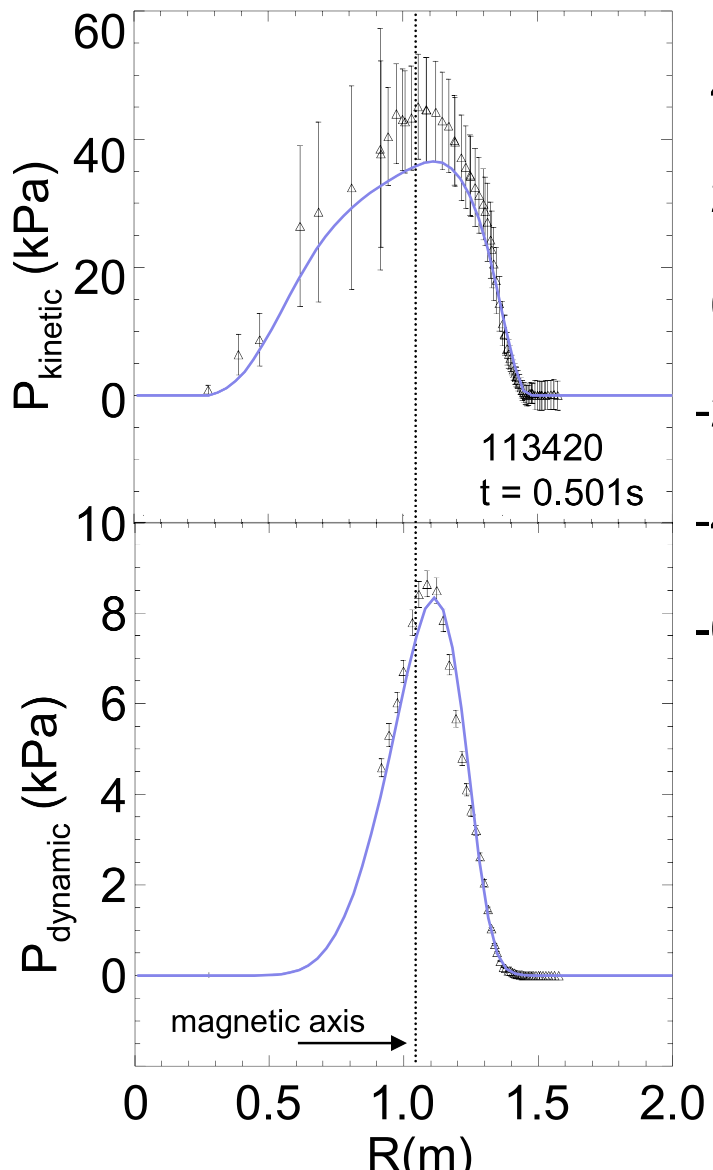
- Data
  - 51 radial channel, Δt =10ms CHERS data generated between-shots
    - Dynamic (rotational) pressure $P_d(\psi,R)|_{z=0}$
    - P_i available – reduces error bars on "partial kinetic" $P(\psi,R)|_{z=0}$
  - Significant upgrade of divertor magnetics set / vessel voltage monitors
    - Reduces uncertainty in X-point position and plate currents
  - Over 350 total measurements are used per time point
    - Allows fit with 21 free basis function parameters and *no* artificial constraints
    - One or two artificial constraints may be necessary to reduce noise
  - Over 11,000 shot*times run – further testing still needed for 100% reliability
- Physics constraints
  - Flux iso-surface constraint
    - Use $T_e = T_e(\psi(R)|_{z=0})$ *directly* from Thomson scattering data - rapid analysis
      - required to insure self-consistent solution with toroidal rotation
    - Better flux surface / q profile determination
    - Other data (e.g. soft X-ray emission) can be used as constraint

**in collaboration with Lang Lao (GA), Z. Cheng (IPPCAS)*

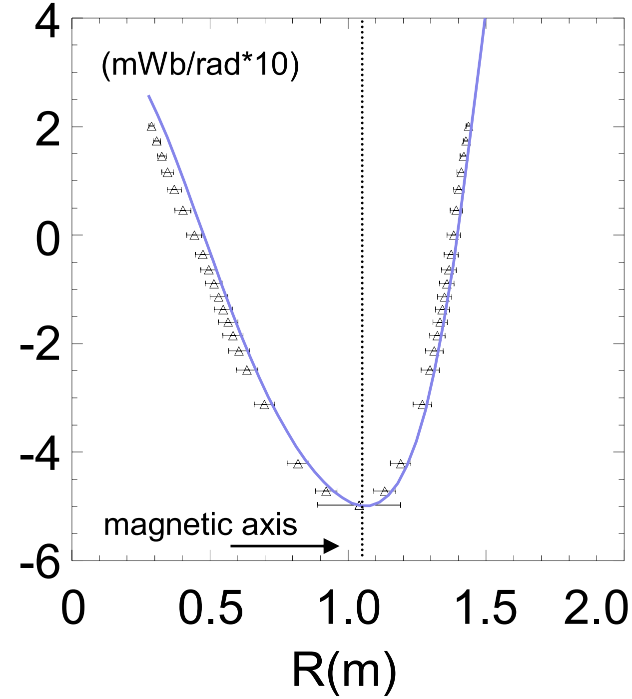
Significant separation of magnetic axis and peak pressure

Poloidal flux and pressure





ψ isosurface constraint



- V_ϕ broadens P profile
  - simple estimate for P_{fast}
  - completing testing of diagnostic consistency
- $(R_{pmax} - R_{axis})/a$ = 11%

NSTX

Significant progress in high β_N wall stabilization research

- Unstable, resonant, and rotationally stabilized plasmas have been created and global modes diagnosed
- Greater insight on RWM physics critically aided by diagnostic upgrades
  - new internal magnetic sensors
  - higher time and spatial resolution CHERS for T_i, Ω_ϕ (rotation damping)
  - two-toroidal position USXR data taken during RWM experiments
- Initial RWM coil pair already used for first RFA experiments
- Between-shots equilibrium reconstruction with rotation capability now available
- NSTX on schedule to perform active stabilization XPs in 2005
  - Full RWM coil installation almost completed now
  - RWM coil power supply to be ready for start of run

Key goal – run first NSTX active feedback stabilization experiments in 2005!