Beta-limiting Instabilities and Global Mode Stabilization in NSTX

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NSTX

NSTX beta limits have been established and research on mode stabilization has begun

- Research Plan
  - Establish experimental beta limit
  - Identify and research behavior of instabilities that set beta limit
  - Stabilize equilibrium directly or stabilize modes after onset

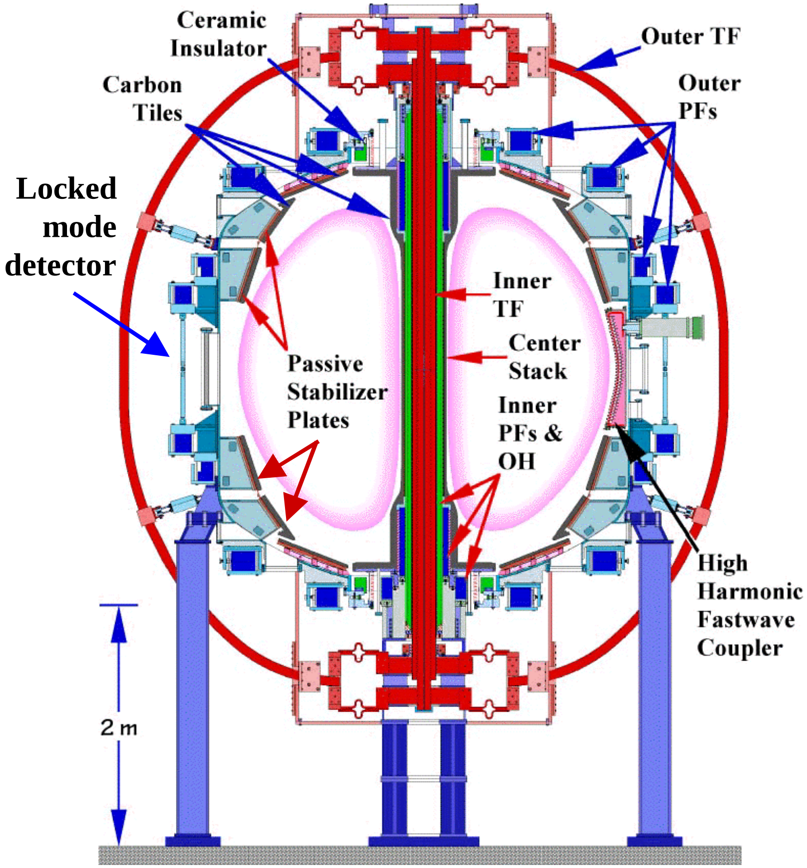
- Outline
  - Identified instabilities that limit beta
  - Current and pressure profile dependence of stability limit
  - Conducting wall stabilization in ST geometry
  - Wall coupling experiments - resistive wall modes

Several key instabilities observed and are being studied

Instability	Beta limiting?
Ideal low-*n* kink/ballooning	yes
Resistive wall modes	yes
Neoclassical tearing modes	yes
Current-driven kinks	at reduced q
Locked modes	can be
Sawteeth	can trigger NTM
Compressional Alfven eigenmodes	no

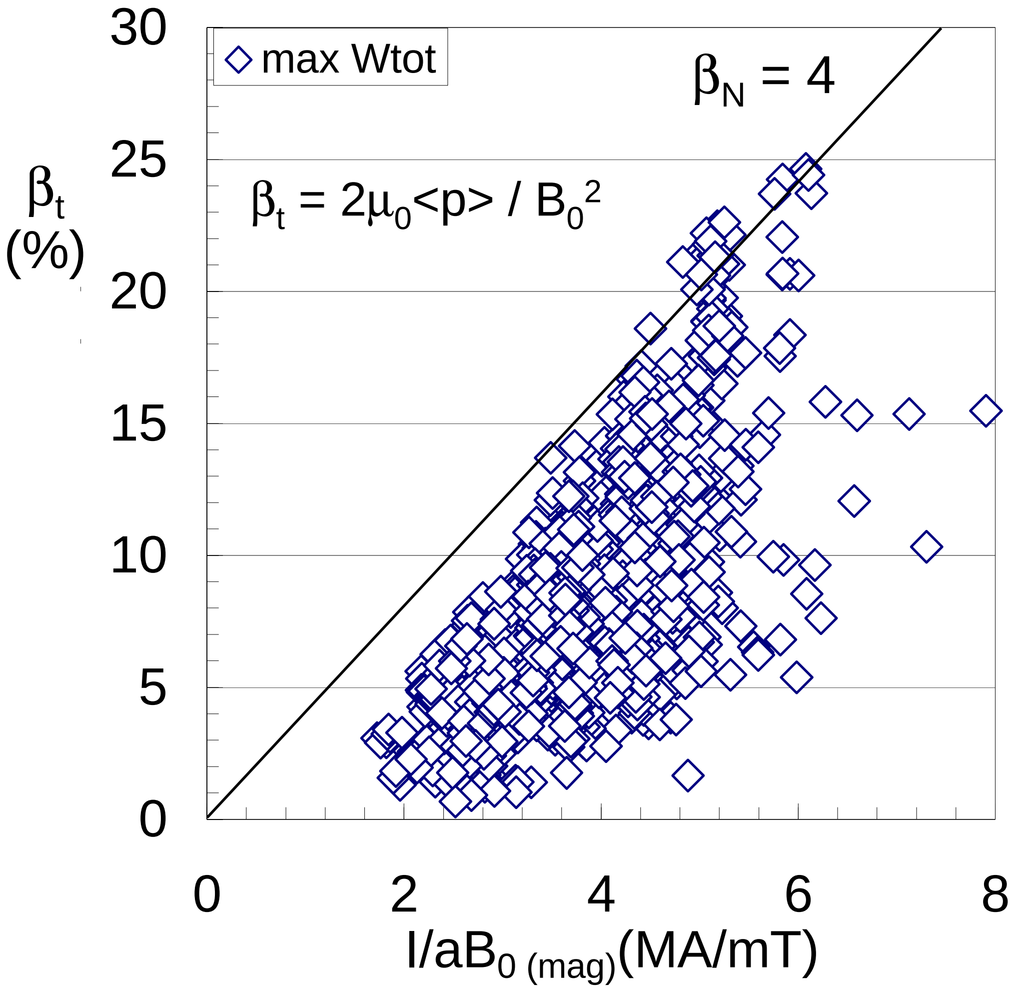
} This talk

Plasmas reached ideal no-wall β_t limit (β_t = 25%)



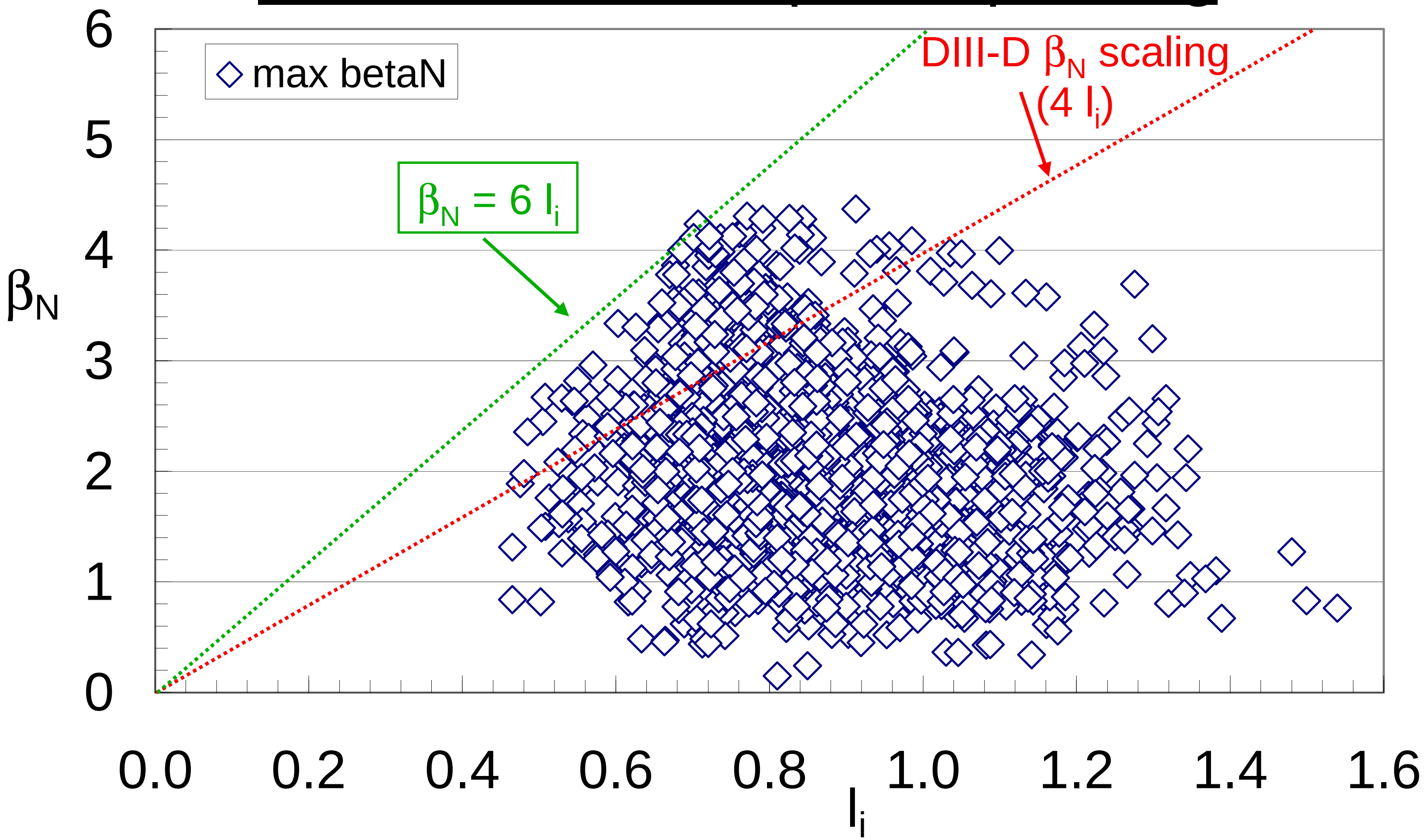
Machine Parameters

I_p < 1.4 MA
B_t < 0.45 T
R = 0.86 m
A = 1.27
κ < 2.5, δ ~ 0.7



EFIT (L. Lao)

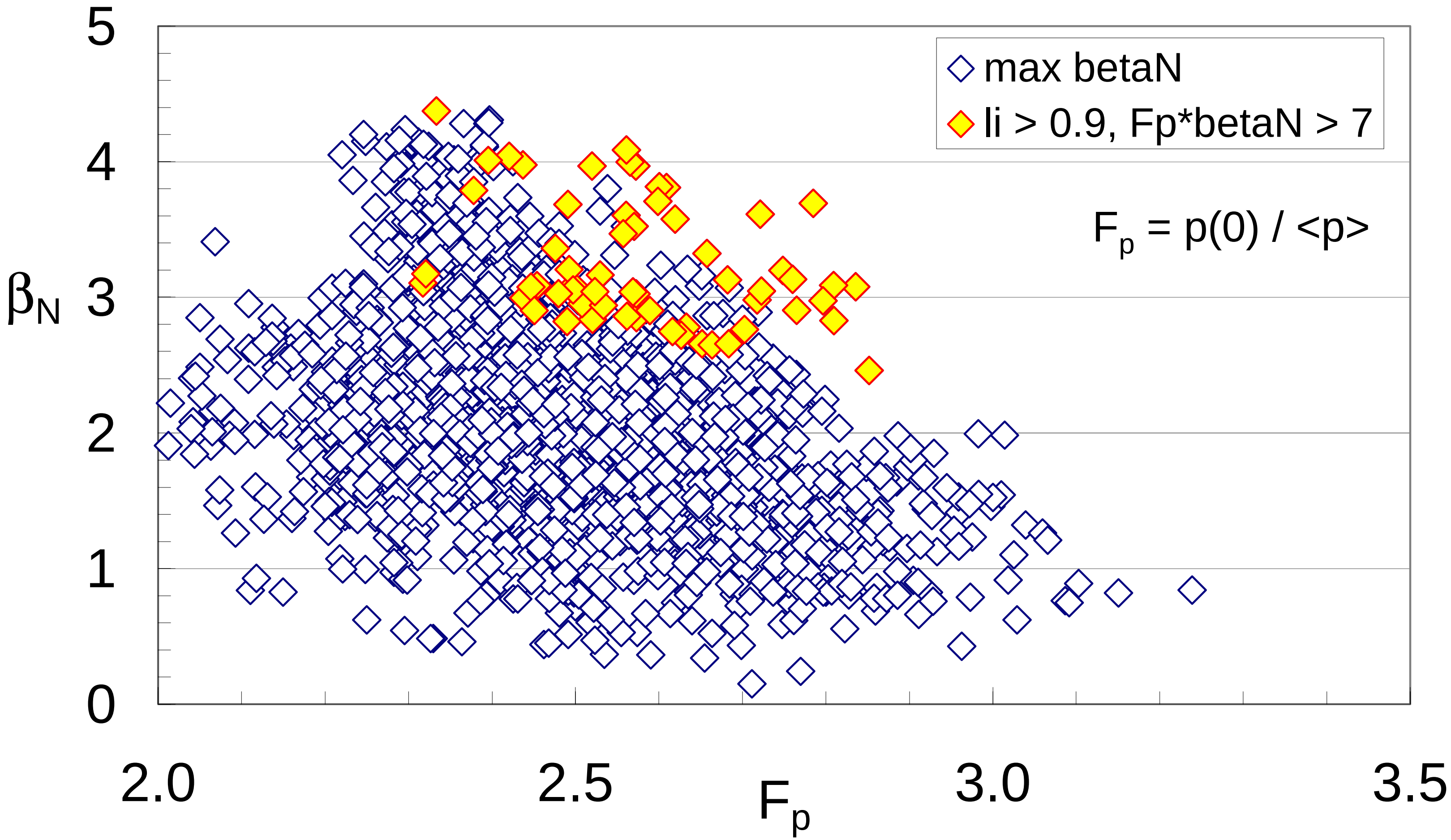
Maximum β_N increases, then saturates with increased current profile peaking



- fast beta collapses observed at all values of l_i
- beta saturation coincident with NTM activity at $\beta_p > 0.4$ at high I_p

NSTX

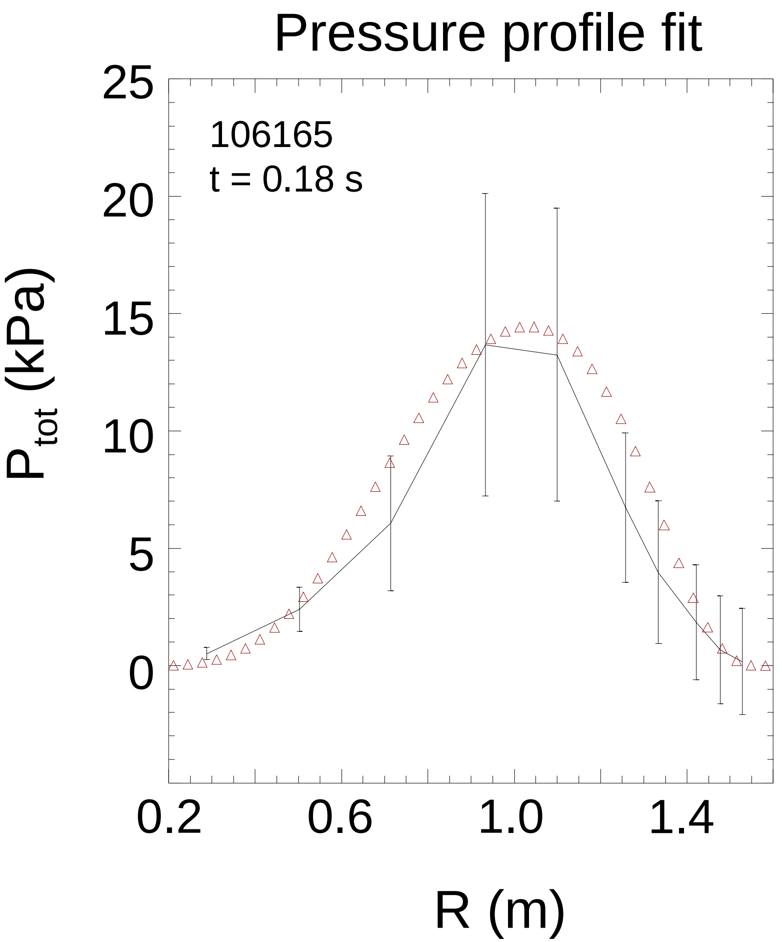
Maximum β_N reduced by increased pressure peaking



- High β_N at high F_p created with current profile shaping (I_p ramps)
- Pressure peaking from "magnetics-only" equilibrium reconstructions

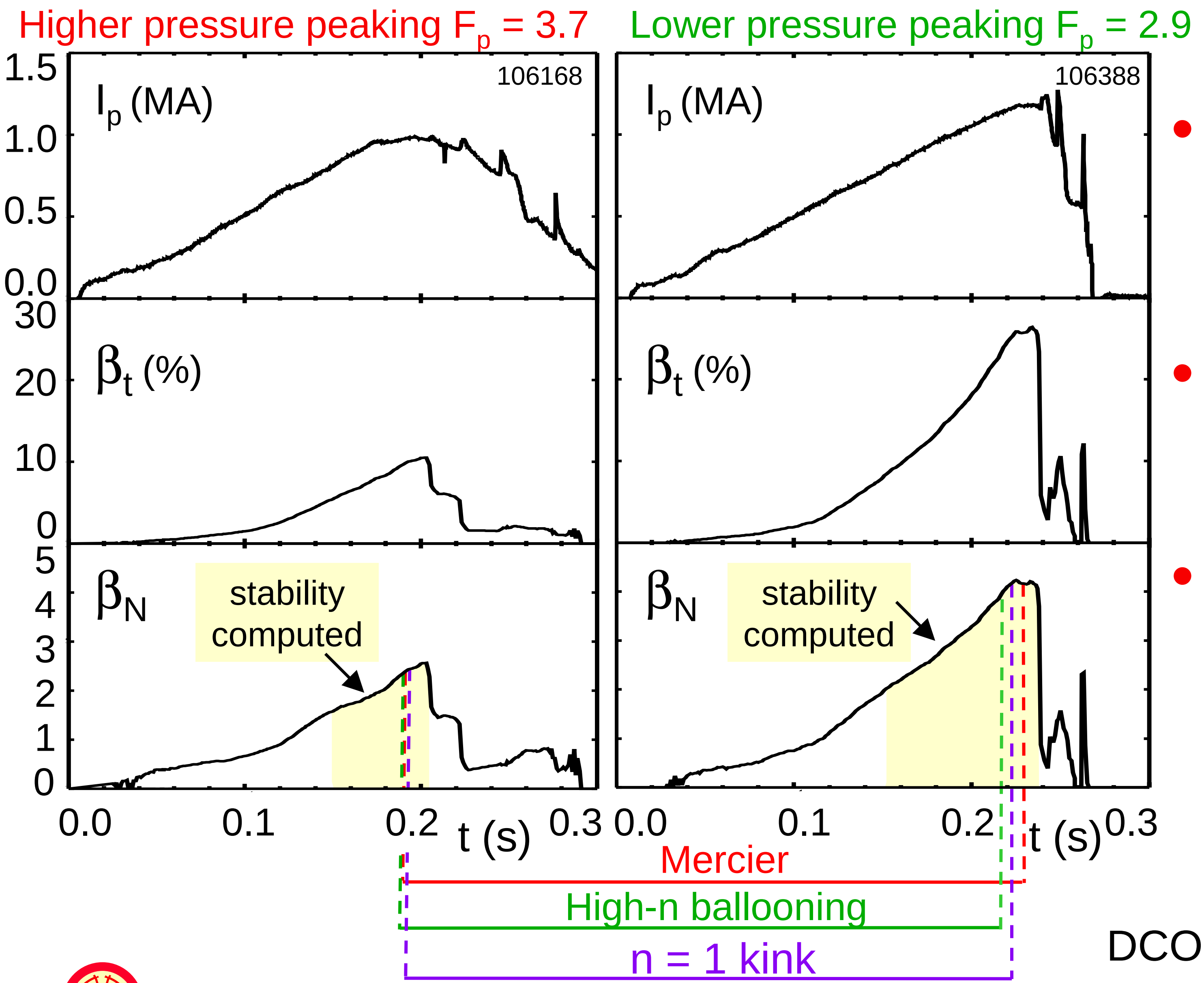
Partial kinetic equilibrium reconstruction improves stability analysis

- Pressure profile fit guided by electron pressure shape
  - Increase in pressure peaking factor by ~ 50% compared to magnetics-only fit
- Pressure magnitude (stored energy) determined by fit to diamagnetic loop
  - Stored energy increases by ~ 8 – 10%
- Constraint controlling q(0) needed without internal magnetics data
  - Analogous to procedure successfully used for magnetics-only reconstructions
  - Matches sawtooth onset, inversion radius, island position (i.e. D. Gates: GO1.009 Tuesday)



NSTX

Computed n=1 ideal instability agrees with experiment

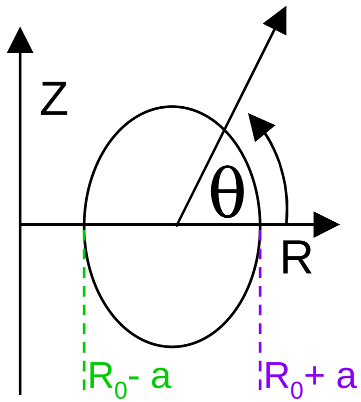


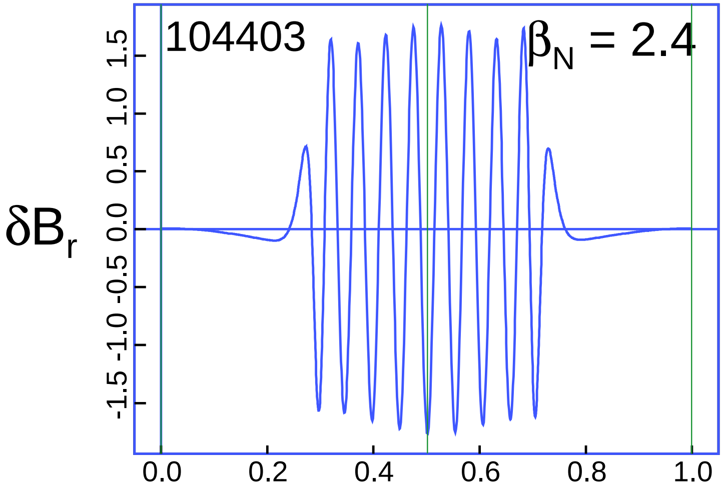
- Increased pressure peaking reduces maximum β_N
- Beta collapses after n = 1 mode destabilized
- F_p determined by partial kinetic EFIT reconstruction

DCON (A. Glasser)

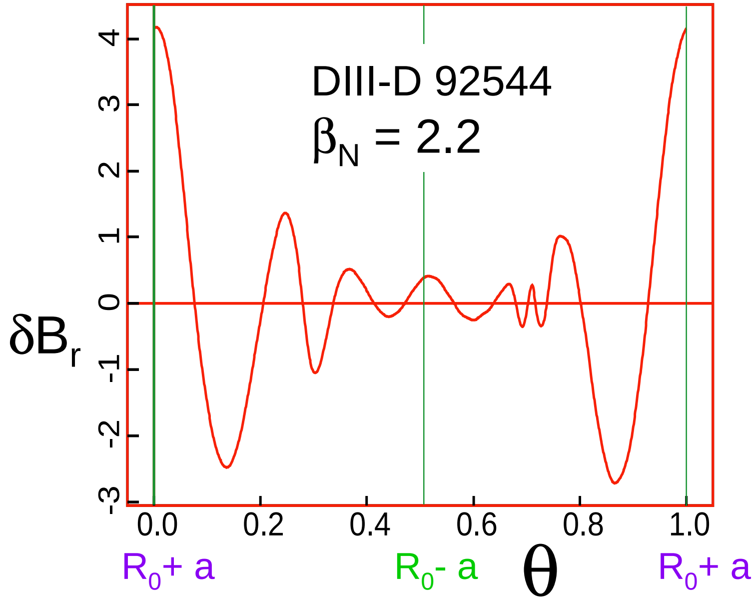
Edge δB_r significantly different in ST magnetic field geometry relative to advanced tokamak

- δB_r n = 1 at edge: NSTX at β_N ~ 2.4
  - Minimum amplitude on outboard side
  - short poloidal wavelength on inboard side
  - Weak wall coupling

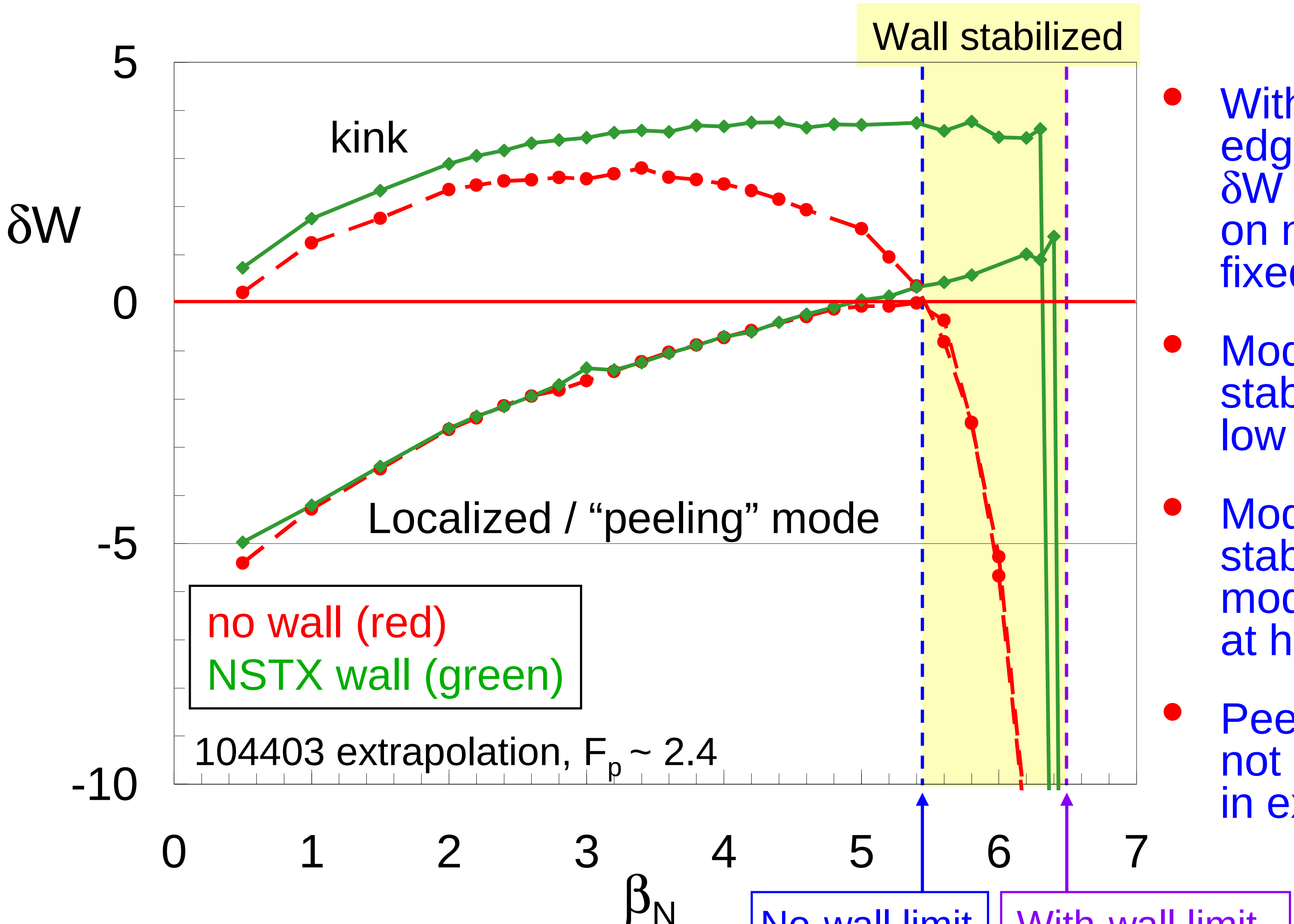




- δB_r n = 1 at edge: DIII-D at β_N ~ 2.2
  - Maximum amplitude on outboard side
  - relatively long poloidal wavelength
  - Strong wall coupling

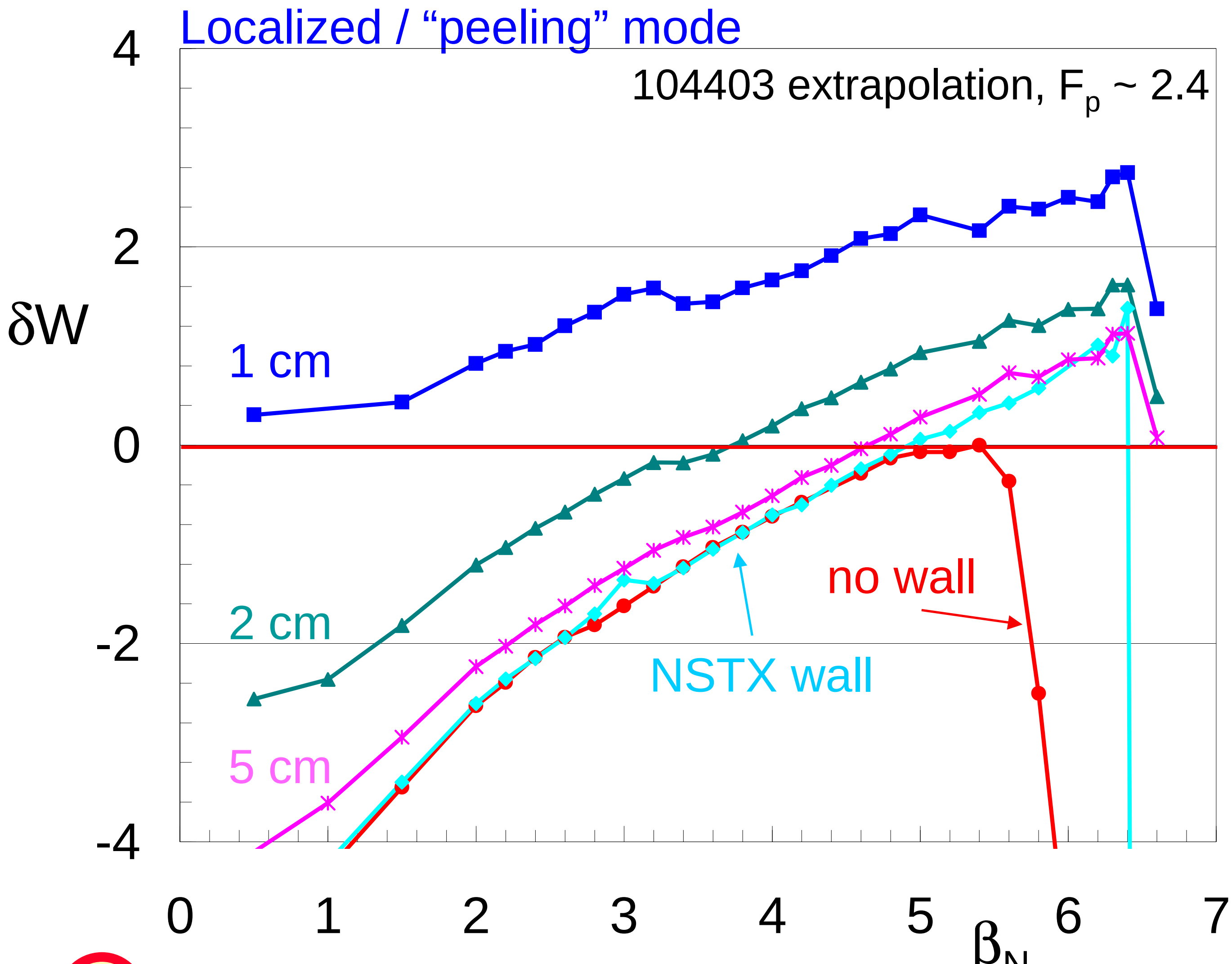


Wall stabilization more effective at high β_N



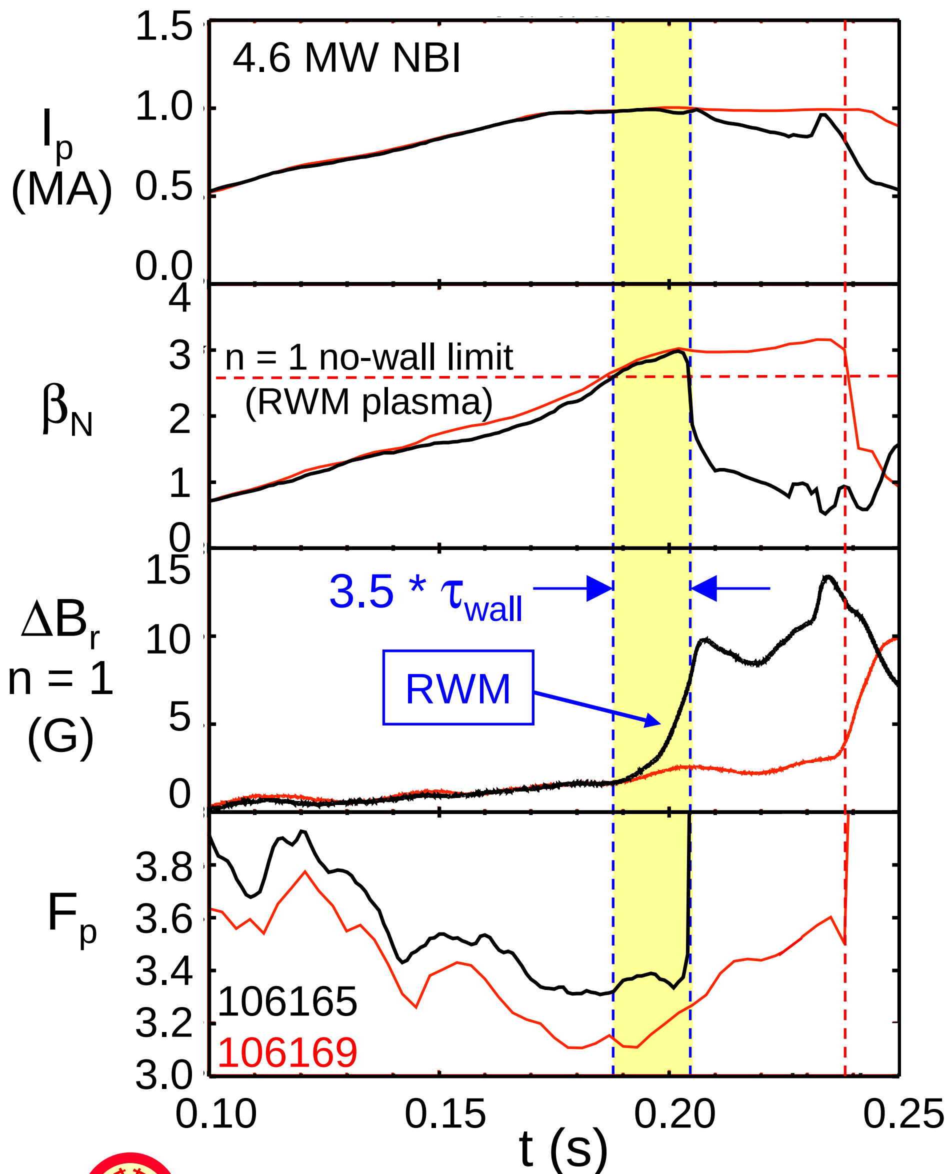
- With finite edge current, δW depends on $n{*}q_{edge}$ at fixed β_N
- Mode not wall stabilized at low β_N
- Mode is wall stabilized as mode balloons at high β_N
- Peeling mode not disruptive in experiment

Conformal wall with 2 cm gap cannot stabilize mode at low β_N



- Short poloidal wavelength on inboard side not coupled effectively to wall
- Inner wall stabilization is ineffective
- At high β_N, long poloidal wavelength on outboard side couples well, and is therefore stabilized

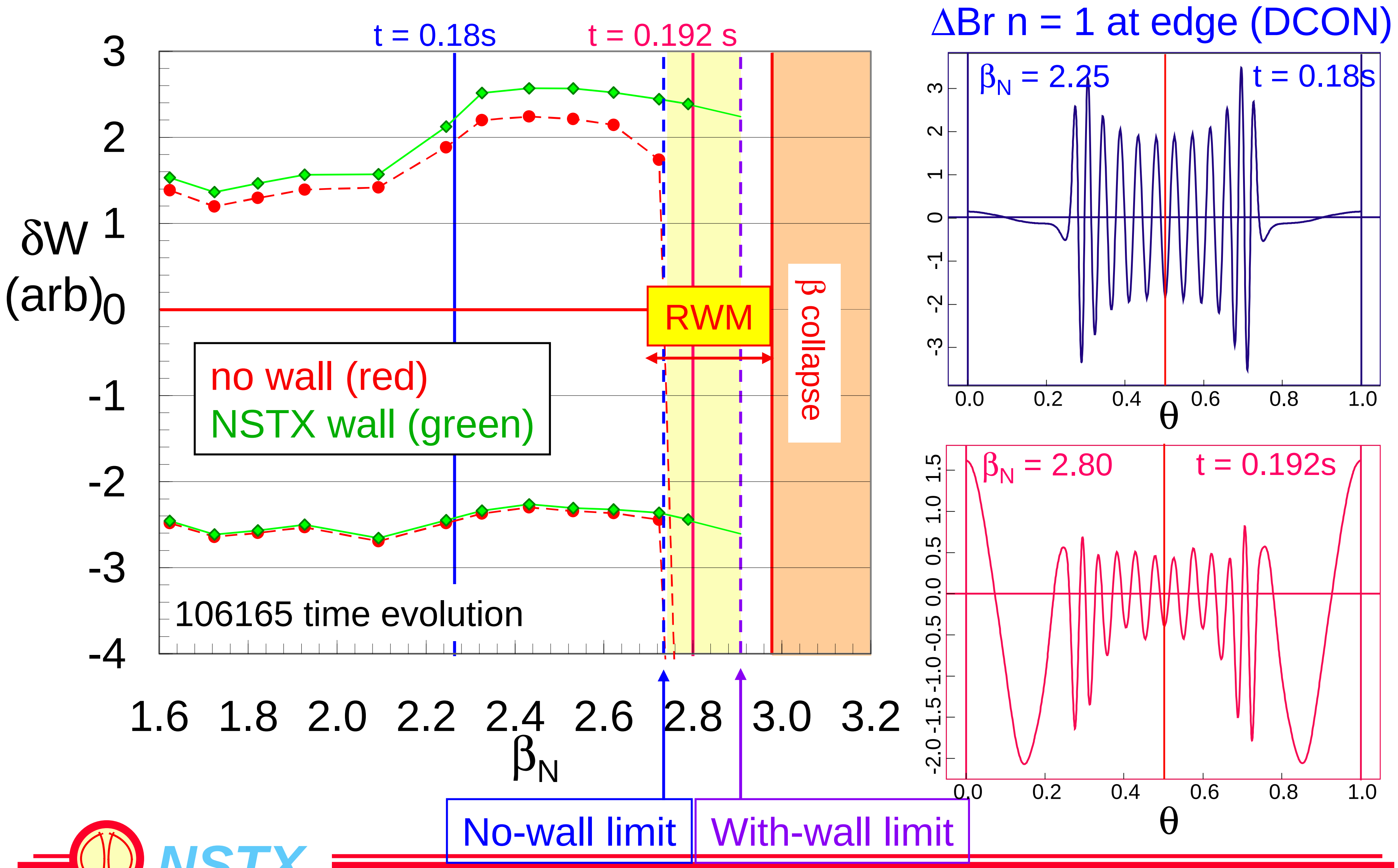
Resistive wall mode observed on locked mode detector



- Observed when ideal no-wall limit violated
  - Not observed with low NBI power
- Observed in locked mode signal
  - when mode computed to be coupled to wall
  - after toroidal rotation decrease
- Growth rate ~ 1 / τ_{wall}
- Grows while plasma is rotating and β_N increasing
- Unique rapid rotation decrease across plasma core
- No clear precursor in Mirnov signals
- USXR shows kink perturbation

NSTX

RWM observed when computed eigenfunction couples to wall



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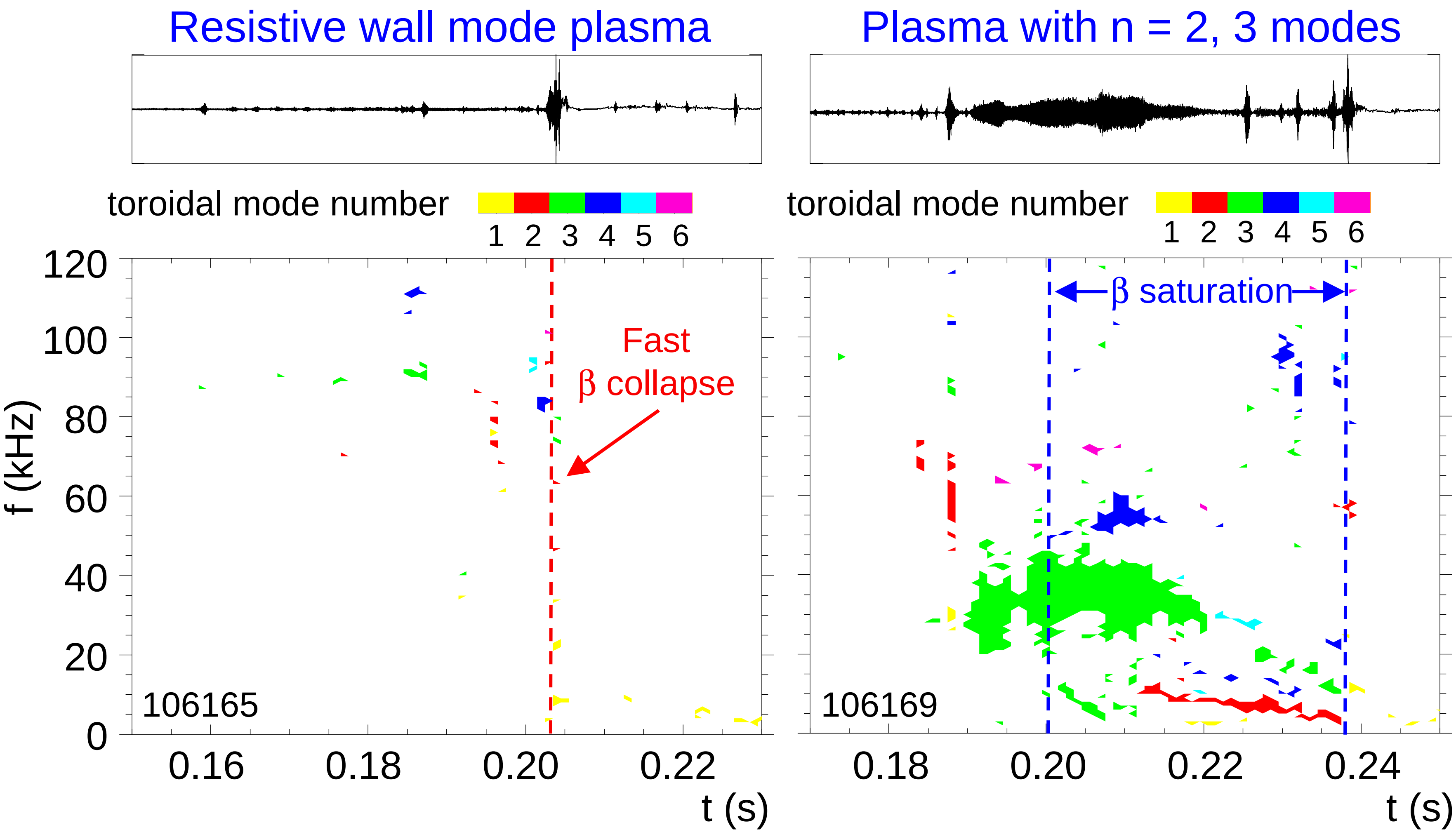
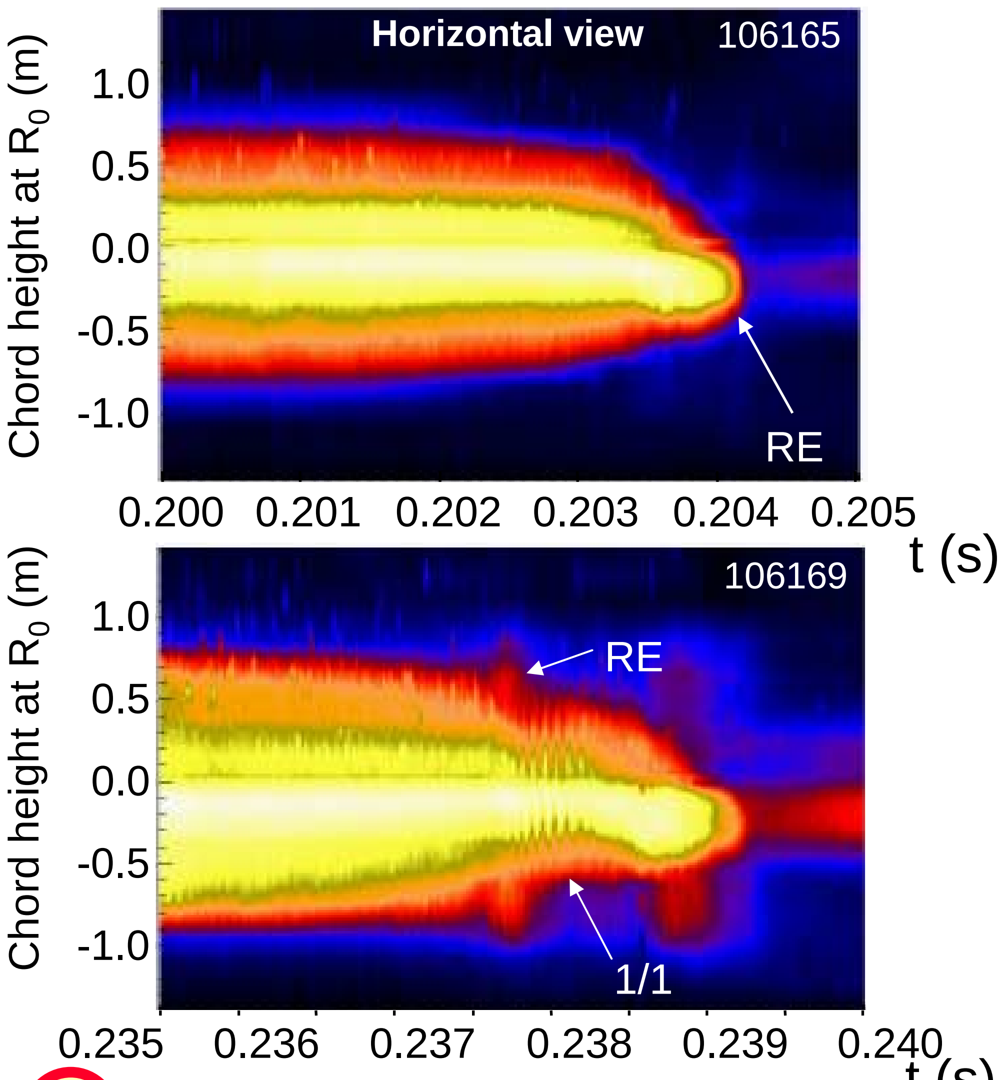
No strong Mirnov signal precursors in RWM plasma



- Plasmas with rotating modes lead to beta saturation and have lower pressure peaking factor

Soft X-ray emission shows mode structure resembling a global kink in RWM plasma



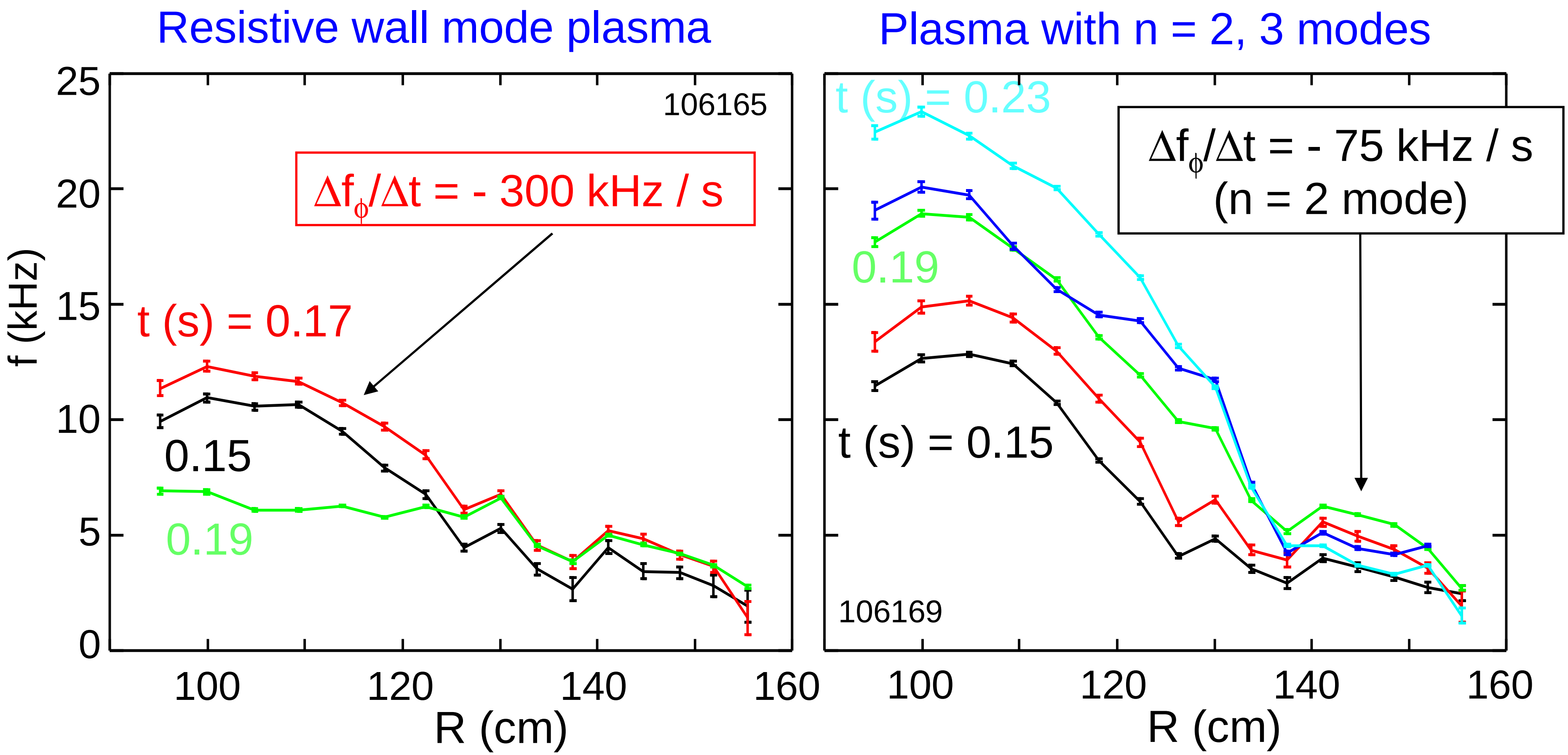
Fast collapse with RWM

- No core or edge islands and no 1/1 mode before reconnection event (RE)
- More likely a kink mode onset
- Fluctuations consistent with outboard helical deformation before RE

Plasma with n = 2, 3 modes

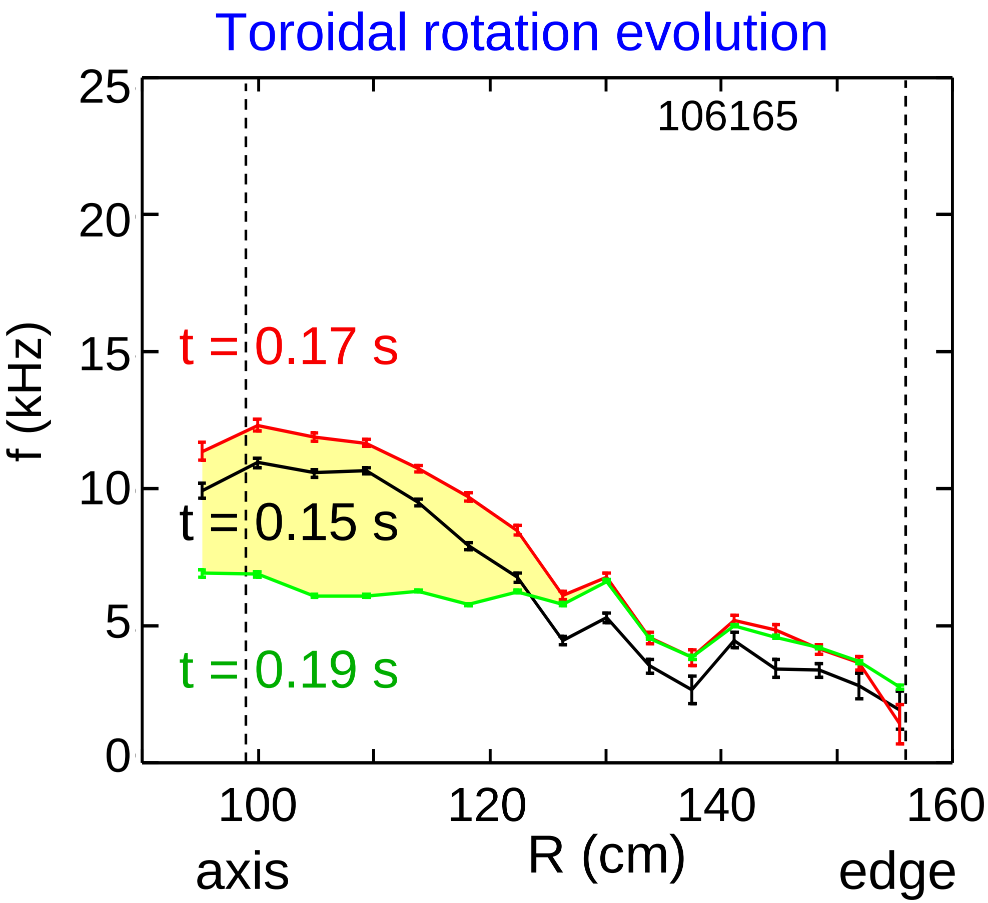
- Reconnection event leads to 1/1 mode
- Less likely a kink mode onset

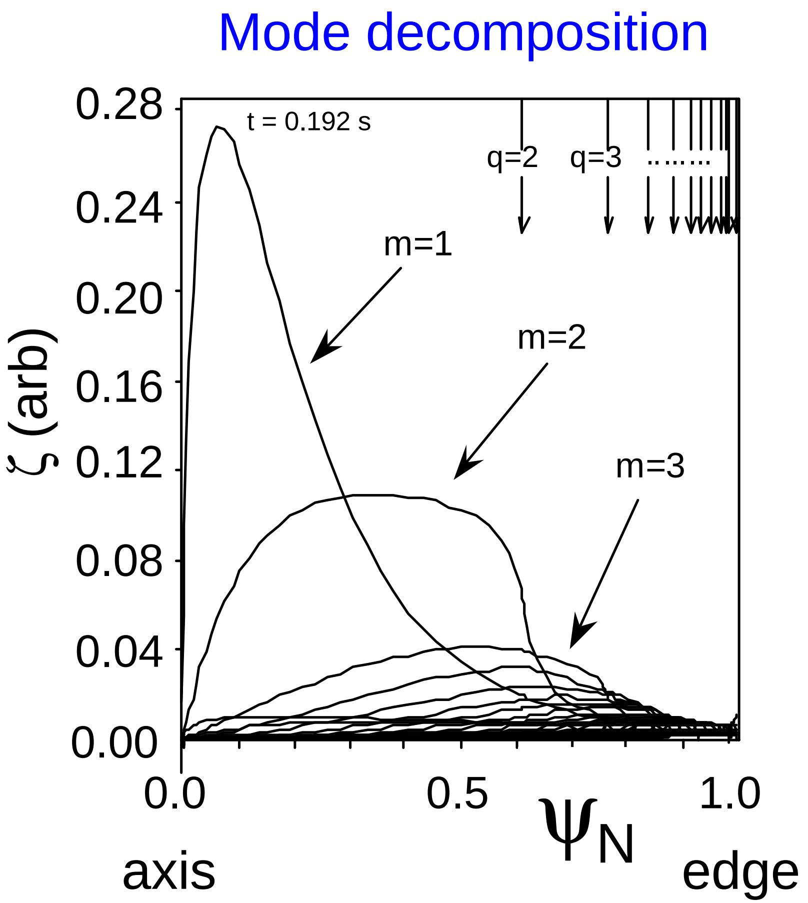
RWM plasma shows rapid toroidal rotation damping across core



- Rapid rotation damping occurs in spite of maximum NBI momentum input
- Initial rotation damping may be due to RWM drag or marginally stable mode drag against the recently discovered error field

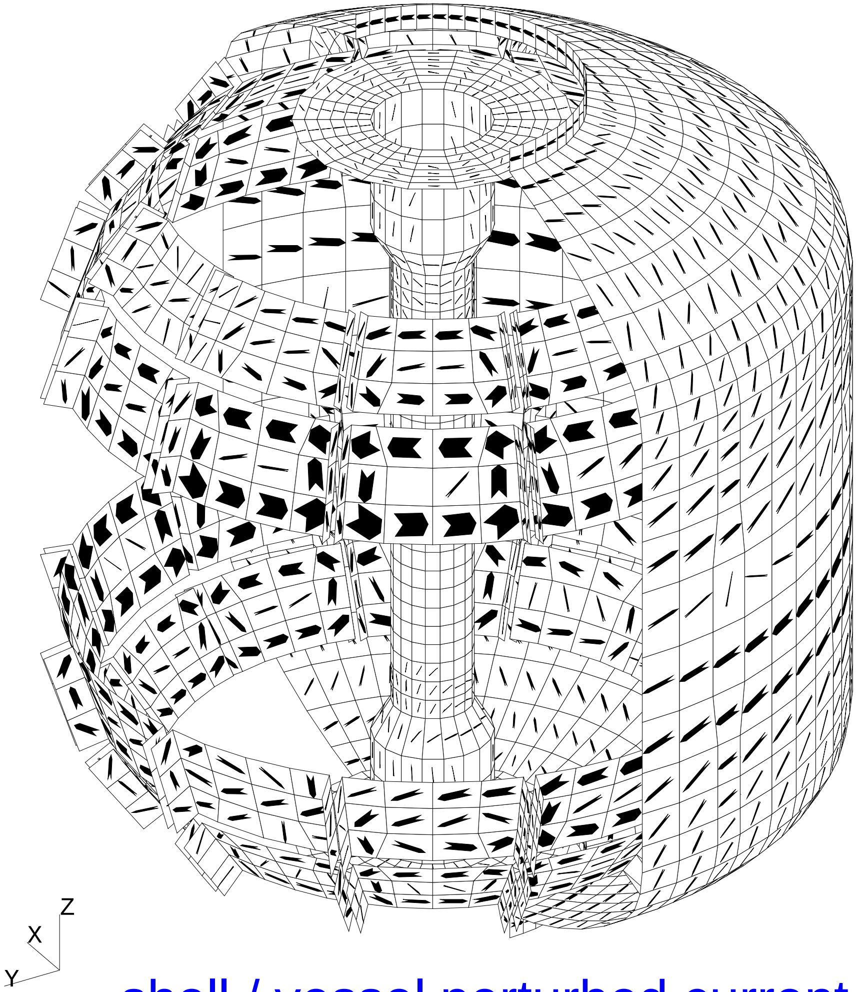
Toroidal rotation damping strongest where mode amplitude is largest in RWM





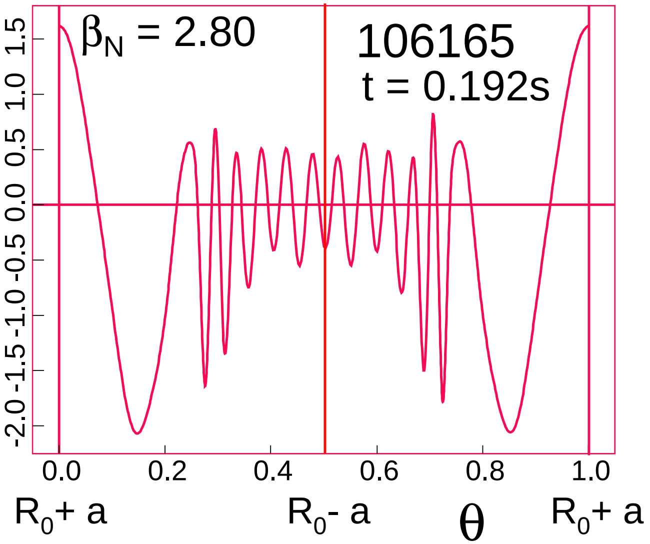
GATO

Growth time of RWM agrees with computed growth time for n=1 mode



shell / vessel perturbed current

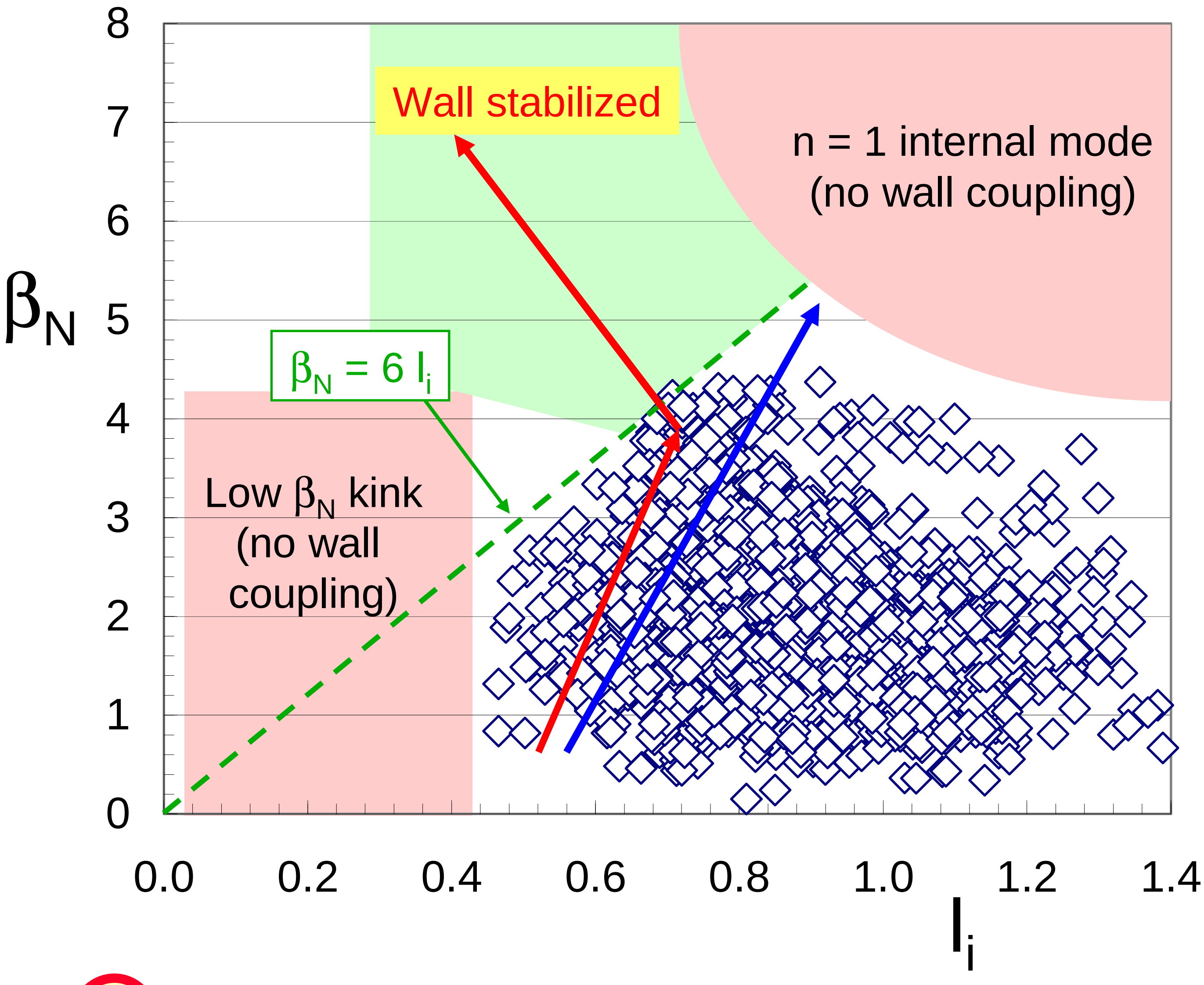
ΔBr n = 1 at edge (DCON)



- Computed mode growth time of 4.6 ms agrees with experimental value of 5 ms
- Shell / vessel perturbed currents dominant in primary passive plates

VALEN (J. Bialek)

Analysis suggests specific route to high β_N



Low l_i

- Operate at low $F_p < 3$
- Increase l_i as β_N increases until pressure drive couples plasma to plates
- Bootstrap current will reduce l_i with mode stabilized by wall

High l_i

- Operate at high l_i and reduced F_p without wall stabilization (lower β_N)

Research on stability limits and wall stabilization at low A has begun

- Plasmas have reached ideal no-wall β_t limit (β_t = 25%)
- Experimentally, normalized beta limit:
  - Increases, then saturates with increasing current profile peaking
  - Decreases with increasing pressure profile peaking
- Ideal low-n stability of kinetic equilibrium reconstructions agrees with experimental β_N threshold for beta collapses
- Theory predicts generally weak coupling to conducting structure at β_N and F_p presently reached in experiment
  - Inner wall stabilization not effective at low A and high q_{edge}
- Resistive wall mode identified when ideal no-wall limit exceeded and plasma coupling to wall is adequate

APS DPP 2001 presentations covering observed instabilities in NSTX

Instability	APS 2001 Presentation
• Ideal low-*n* kink/ballooning	poster of this talk, Monday afternoon Menard, et al., GO1.008 Tuesday
• Resistive wall modes	poster of this talk, Monday afternoon
• Neoclassical tearing modes	Gates, et al., GO1.009 Tuesday
• Sawteeth	Zhu, et al., QP1.018 Thursday
• Current-driven kinks	Manickam, et al., QP1.017 Thursday
• CAE	Fredrickson, et al., LI1.003 Wednesday

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