NSTX MHD Experimental Task Group

CY 2001 Results Overview

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for the NSTX MHD ET Group

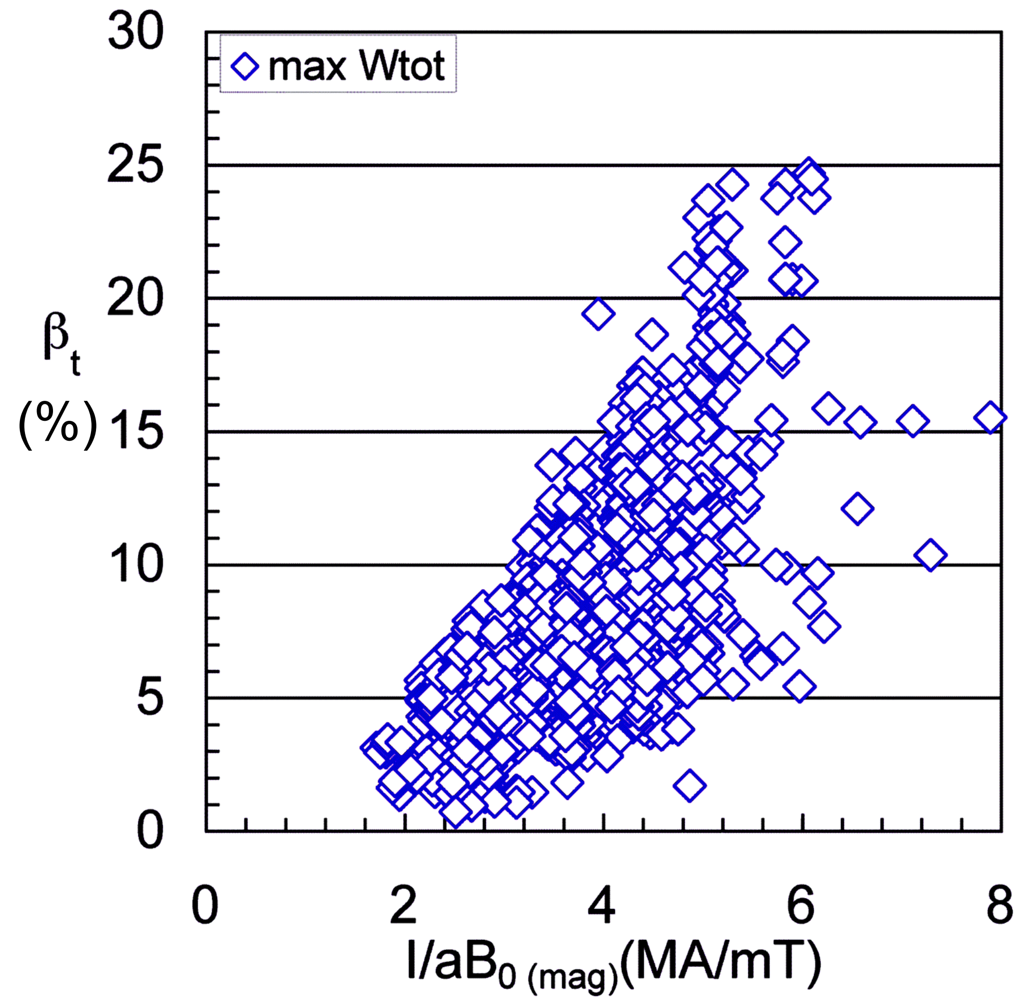
NSTX CY2001 Results Review – 9/19/01

Princeton Plasma Physics Laboratory

CY 2001 run has resulted in an MHD ST database with both depth and breadth

- CY 2001 experiments have addressed all major instabilities
  - More than 2000 plasma shots run (total)
  - Most XPs have publication quality data
  - Even distribution of XP topics and leaders
  - Diagnostic coverage not fully mature, but should be adequate
- CY 2001 meetings provide an opportunity to establish NSTX as an ST plasma stability research facility
  - APS DPP Meeting: Oct 29th – Nov 2nd
  - Mode Stabilization Workshop: Nov 5th – Nov 7th

NSTX Stability: Toroidal Beta vs. $I/(aB_0)$



Several key instabilities have been observed and are being studied

Instability	Beta limiting?
Ideal low-*n* kink/ballooning	yes
Neoclassical tearing modes	yes
Current-driven kinks	at reduced q
Sawteeth	for large r(q = 1)
Resistive wall modes	under investigation
Compressional Alfven eigenmodes	under investigation
Reconnection events	can be delayed

Status of NSTX MHD Task Group XPs

Experimental Proposal	(run days completed) Leader
XP17 Influence of J profile on MHD stability at low A	(C) S. Sabbagh
XP22 Survey of modes in Alfven/ICE frequency range	(C) E. Fredrickson
XP16 Investigation of Troyon Scaling in NSTX	(3) J. Menard
XP23 NBI Heating with small q=1 radius in NSTX	(2) M. Bell
XP24 Observation of NTMs in NSTX	(3.5) D. Gates
XP28 Study of current driven kink modes in NSTX	(1) J. Manickam
XP32 Compressional Alfven eigenmodes	(2) E. Fredrickson
XP38 Dependence of beta limit on triangularity	(1) D. Gates
XP20 Characterization of resistive wall modes at low A	(FR) S. Sabbagh

(FR): Pending formal review (##): In progress (C): Completed

NSTX CY2001 Results Review – MHD Session

Beta limits / resistive wall modes	Sabbagh
Tearing mode research	Gates
Access to wall stabilized high beta	Paoletti
Locked modes and error fields	Menard
Current driven kink research	Manickam
CAE mode studies	Fredrickson
Development of small sawtooth scenarios	Bell

NSTX Beta Limit and Initial Wall Stabilization Experiments

S. A. Sabbagh, R. Bell, M. Bell, J. Bialek, E. Fredrickson, A. Glasser,

B. LeBlanc, J. Menard, F. Paoletti, and the NSTX Team

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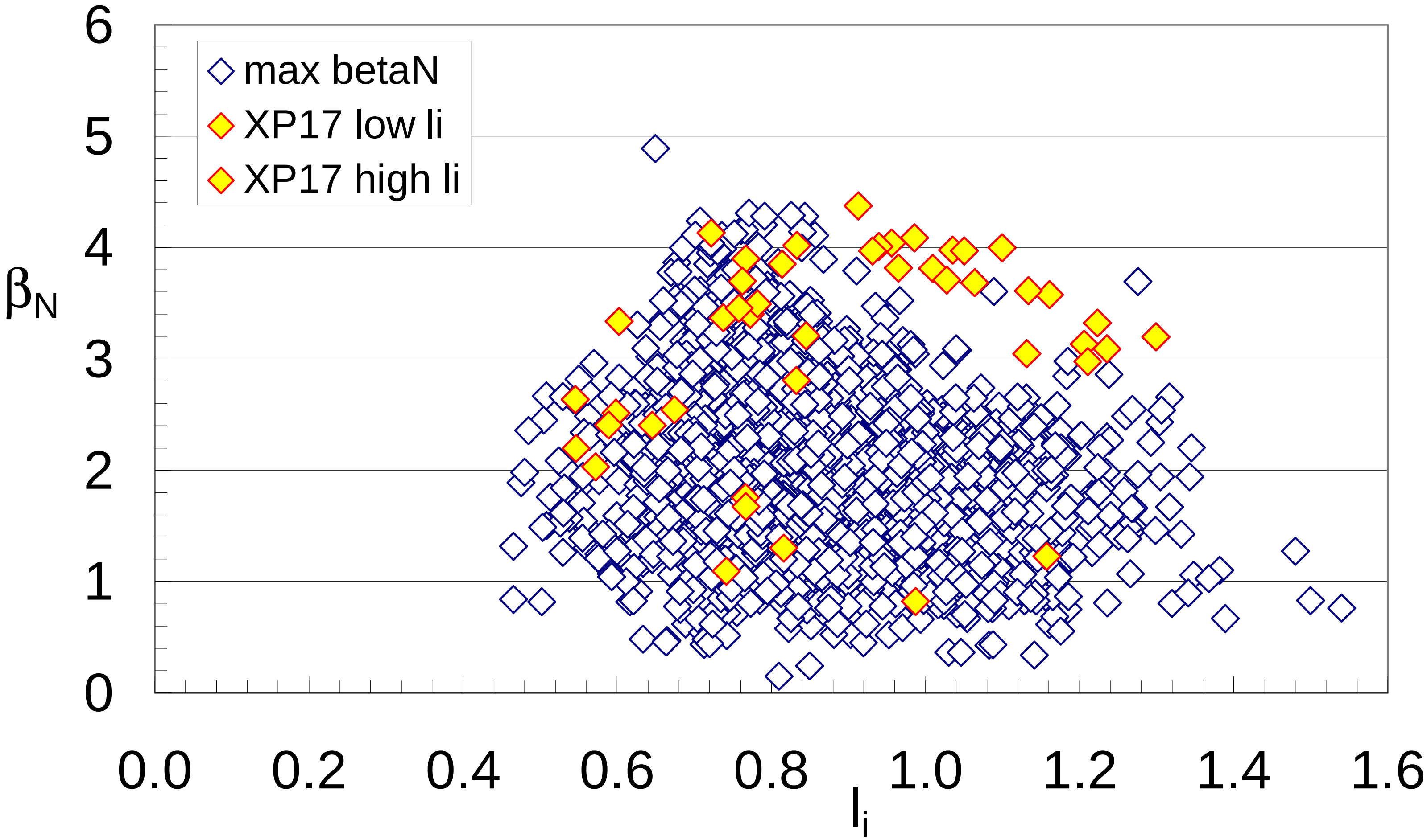
NSTX beta limits have been established and research on wall stabilization has begun

- XP17 Goals
  - Determine beta limit dependence on profiles at low A
  - Examine plasma / wall coupling for future mode stabilization

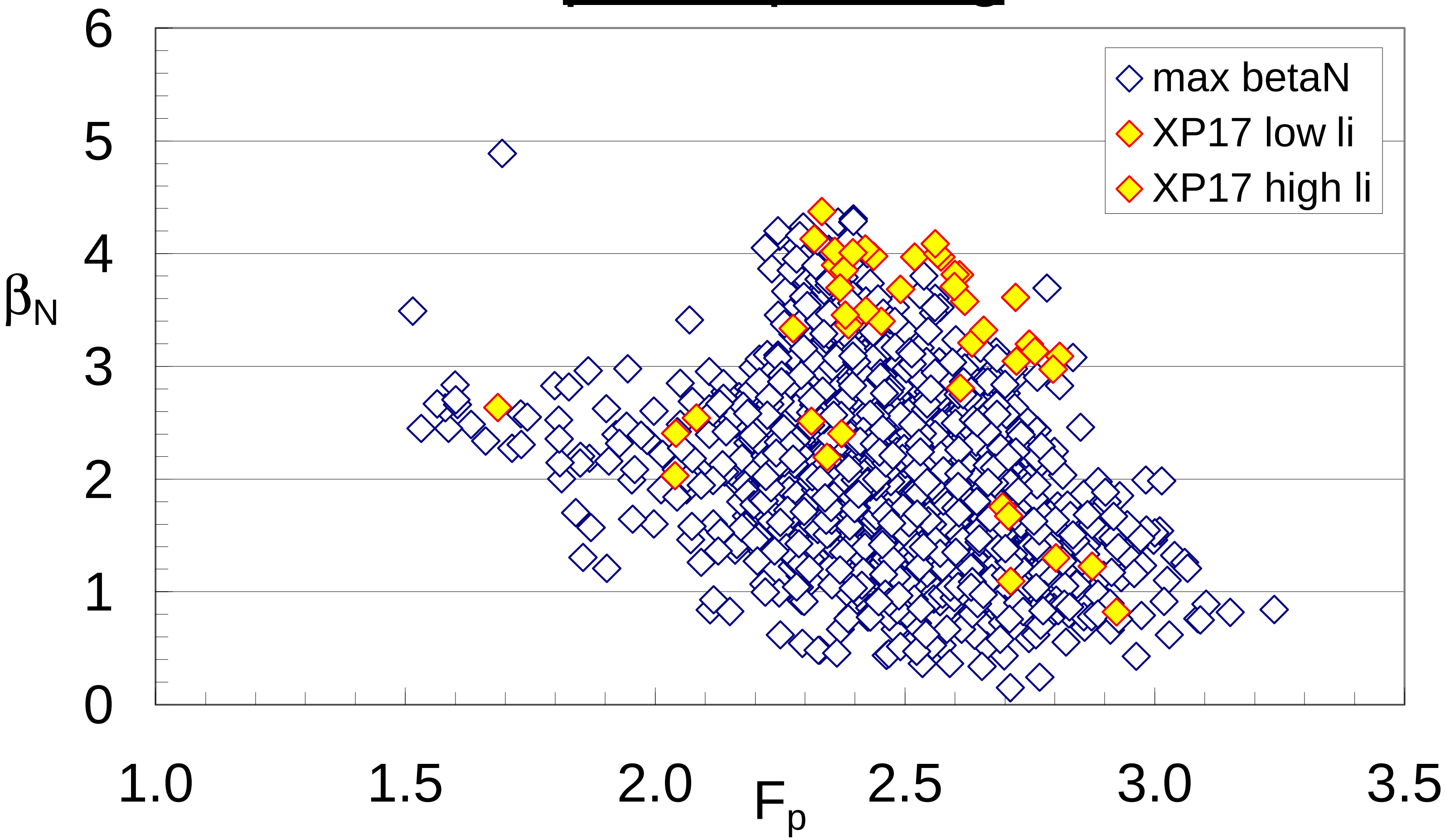
- Outline
  - Current and pressure profile dependence of beta limit
  - Equilibrium reconstruction refinement
  - Ideal stability limit calculation / comparison to experiment
  - Effect of wall coupling - resistive wall modes

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 tearing activity at higher β_N, $\beta_p \sim 0.45$

Maximum β_N reduced by increased pressure profile peaking

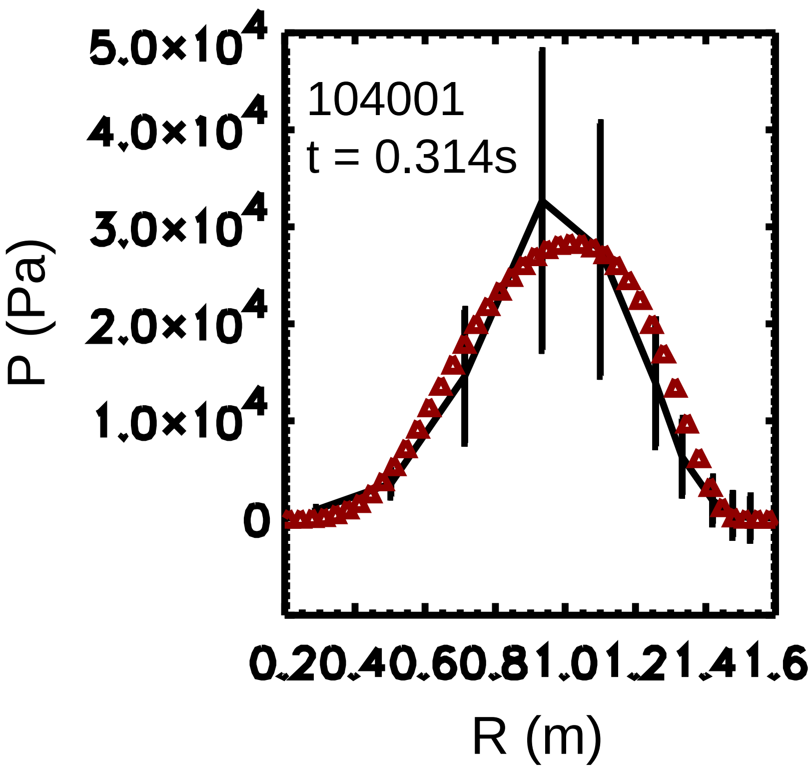


- Database of “magnetics-only” equilibrium reconstructions
- Stability analysis of “kinetic” equilibrium reconstructions just underway

Recently refined equilibrium reconstruction allows more faithful stability analysis

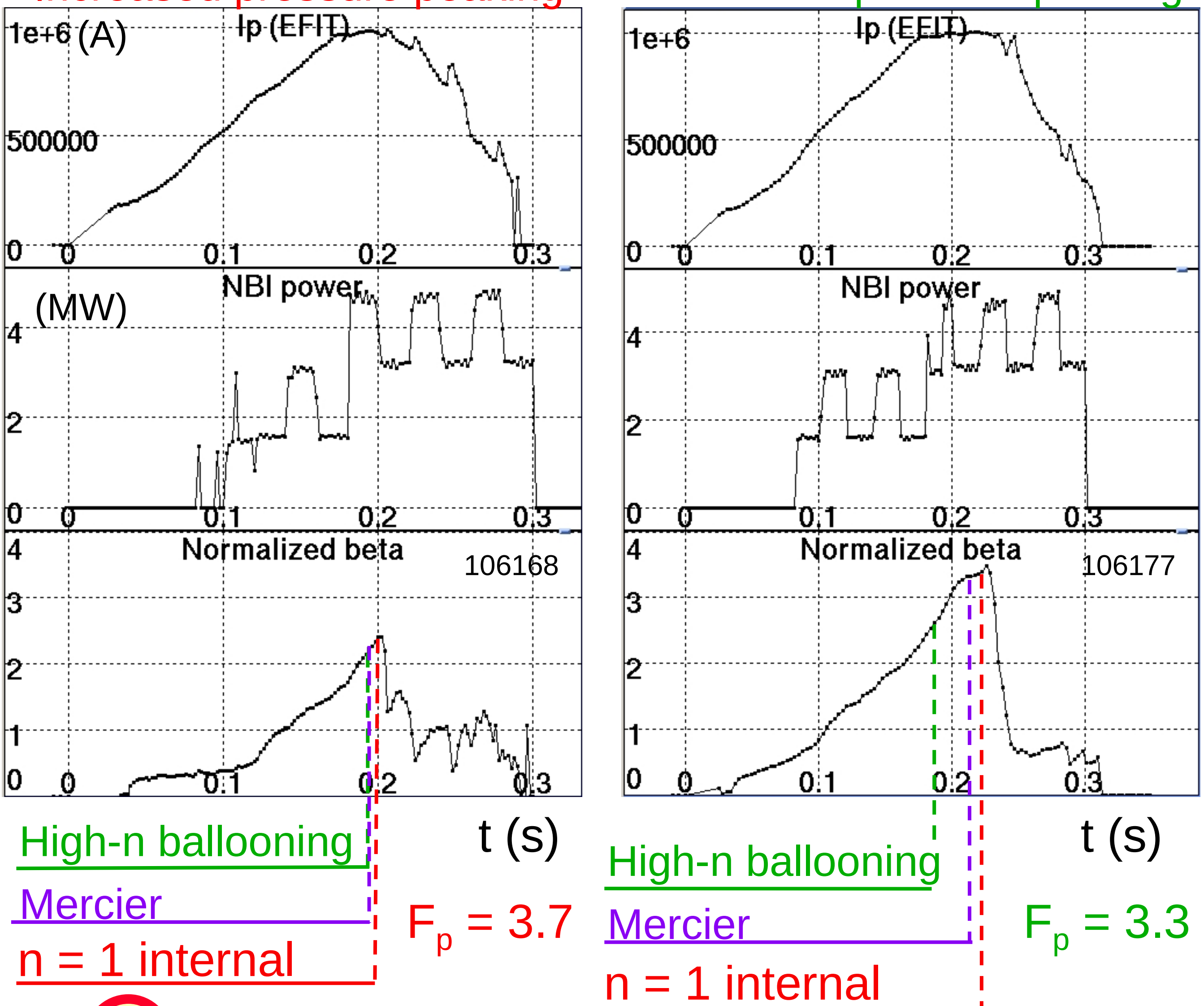
- Pressure profile fit guided by electron pressure shape
  - 5 free parameters to describe p profile, as opposed to 1 in magnetics-only fit
  - Yields time evolving pressure peaking factor
- Pressure magnitude (stored energy) determined by fit to diamagnetic loop
- q(0) “calibrated” to match sawtooth characteristics
  - Analogous to procedure used for magnetics-only fits
- First results available in NSTX database
- full database run pending availability of diamagnetic loop signals for all shots

Pressure profile fit



Computed stability in good agreement with experiment

Increased pressure peaking | Decreased pressure peaking



- Increased pressure peaking results in decreased β_N
- Beta collapse after n = 1 internal mode unstable
- Both plasmas unstable to current driven kink during the rise in β_N

DCON (A. Glasser)

XP17 run to search for Resistive Wall Mode in ST

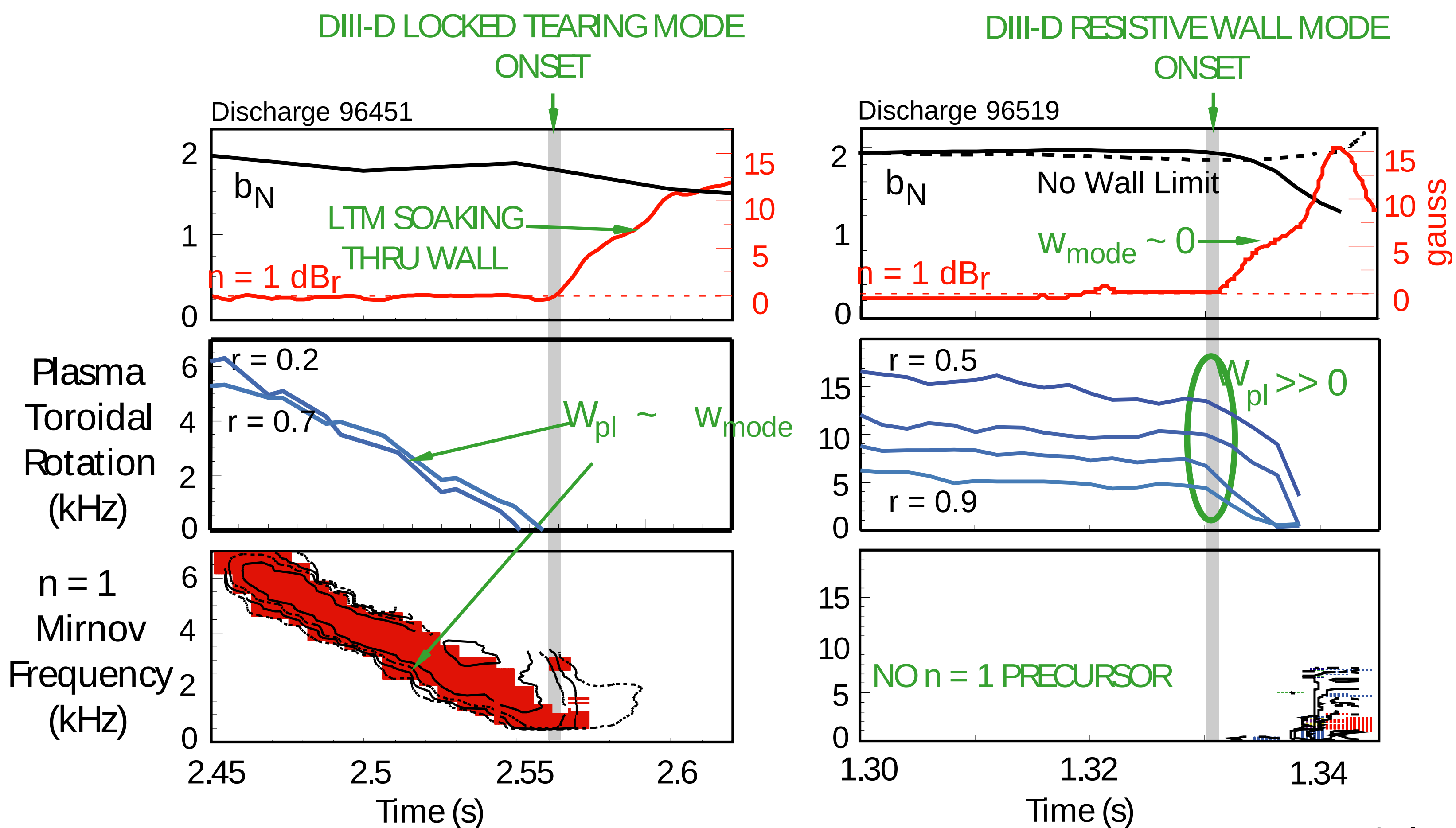
- Goals
  - Operate at or above the ideal no-wall beta limit
  - Measure plasma rotation evolution leading up to the instability
  - Determine variation of mode stability as a function of outer gap
  - Determine critical rotation frequency for onset of RWM

- Techniques
  - Operate in regime where RWM is expected (l_i ~ 0.6, β_N > 3)
  - Operate in a regime clear of sawtooth and low *n* islands
  - Once resistive wall mode is established, vary outer gap
  - Utilize several diagnostics and MHD analysis
    - no single diagnostic can identify the mode as a RWM

Plasma / wall gap scan yields evidence for RWM

Resistive Wall Mode Characteristic	**Observed in XP**
• Observed when ideal MHD unstable (no wall)	YES
• Mode observed in locked mode signal	YES
• Mode growth rate ~ 1 / τ_{wall}	~ YES
• Less stable as outer gap decreases	YES
• Slowed rotation leading to fast beta collapse	YES
• Mode growth during plasma rotation	YES
• Critical rotation frequency for mode growth	~ YES
• No clear island-like precursor in Mirnov signal	YES
• USXR shows kink-like perturbation	YES

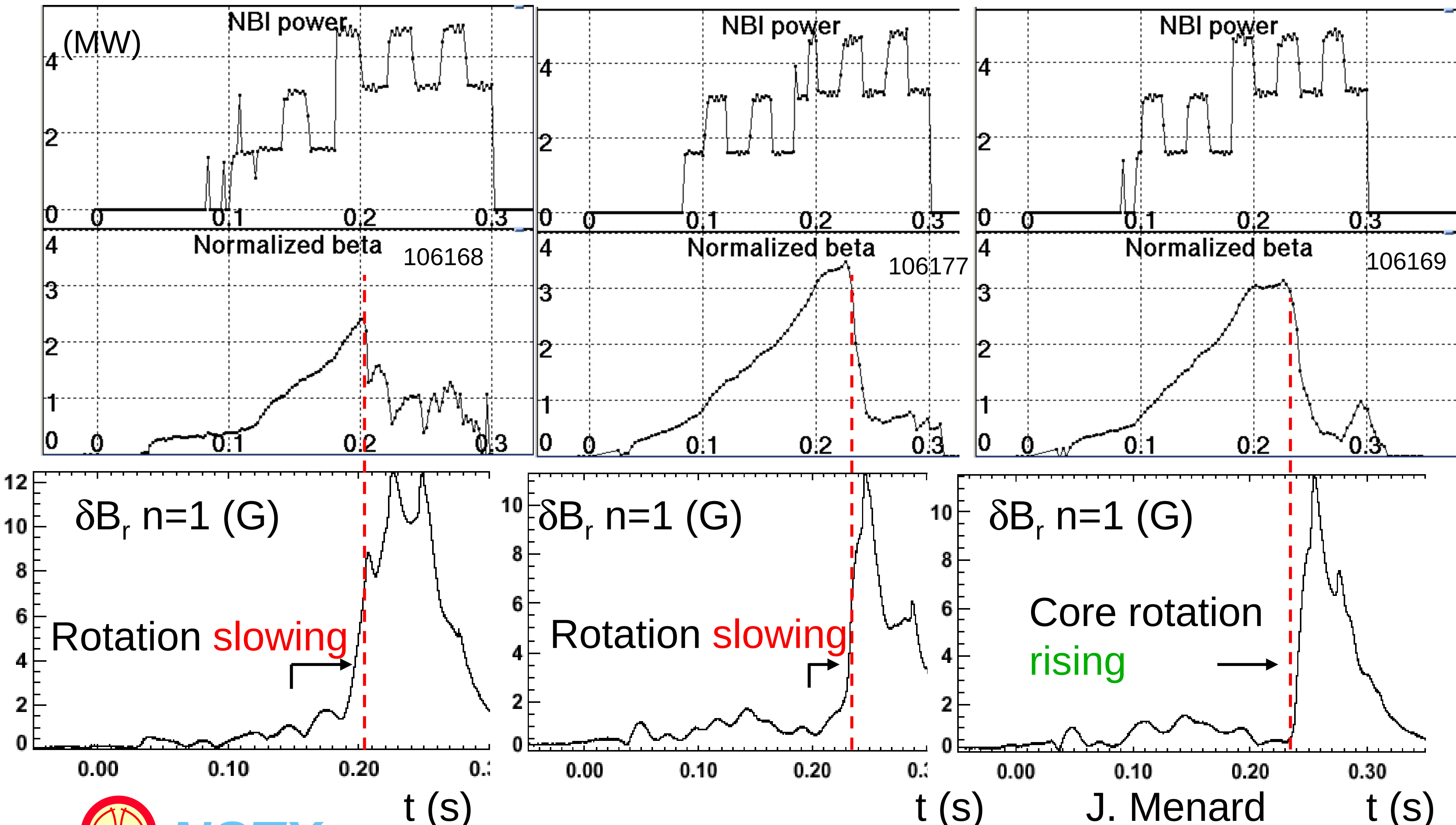
In DIII-D: Nearly stationary RWM grows in presence of plasma rotation, unlike locked tearing mode



A. Garofalo

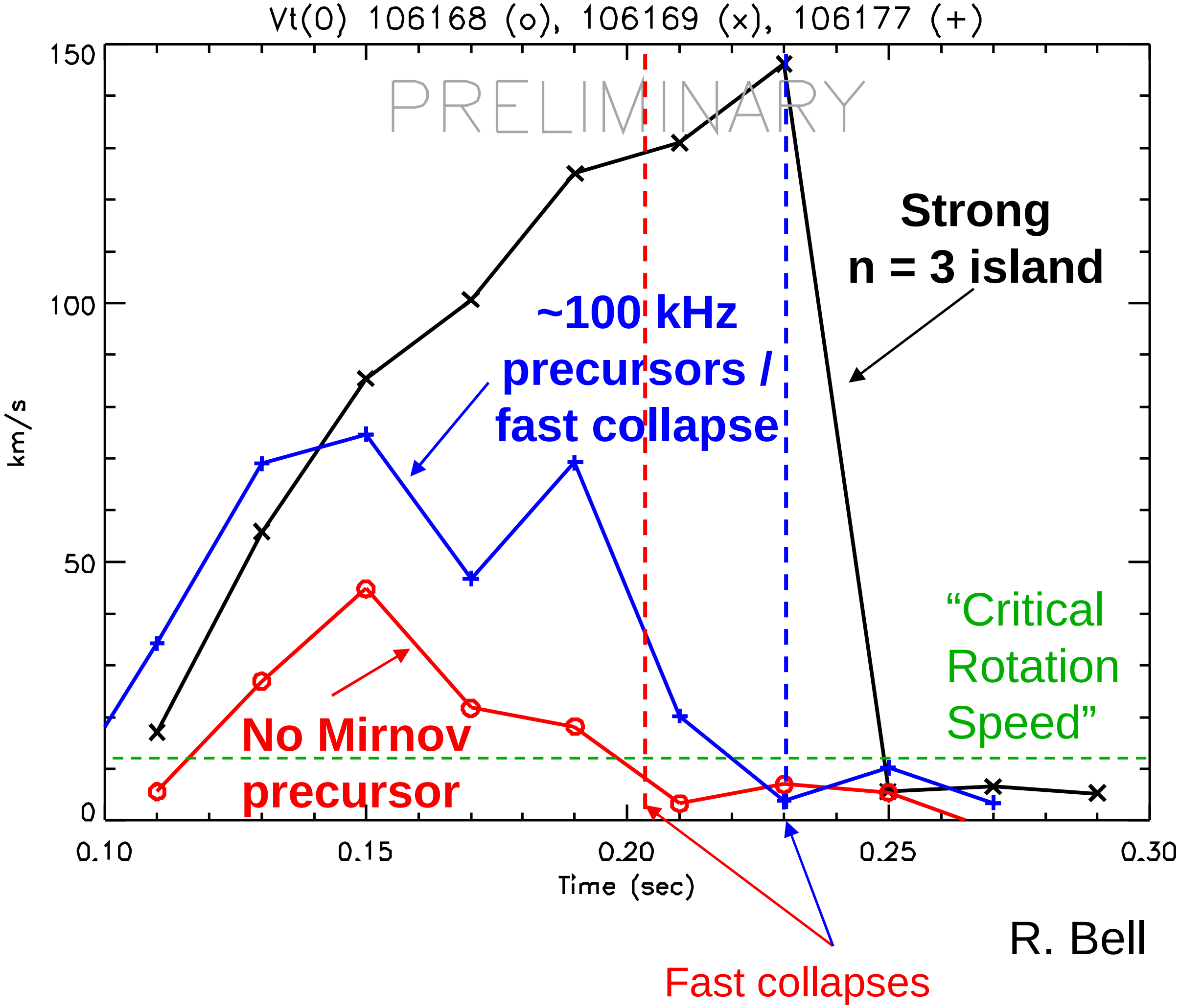
Locked mode observed before fast β collapse when toroidal rotation slows

Fast beta collapse (small gap) | Fast collapse (larger gap) | Tearing mode activity



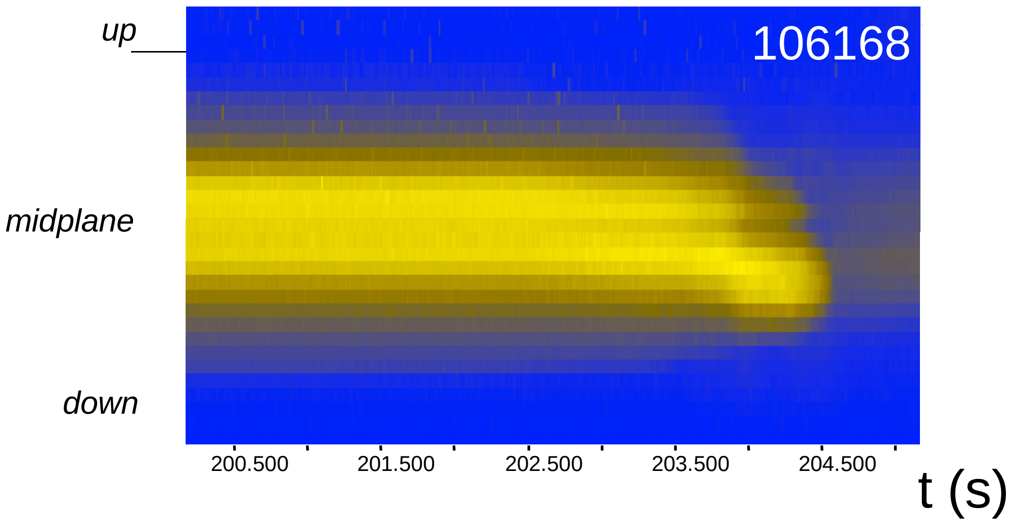
Early fast beta collapses occur in plasmas with reduced toroidal rotation

- "Critical" rotation frequency < 2 kHz at the plasma core
- Rotation decrease occurs across the entire plasma (preliminary CHERS analysis)
- CHERS rotation profile analysis is needed

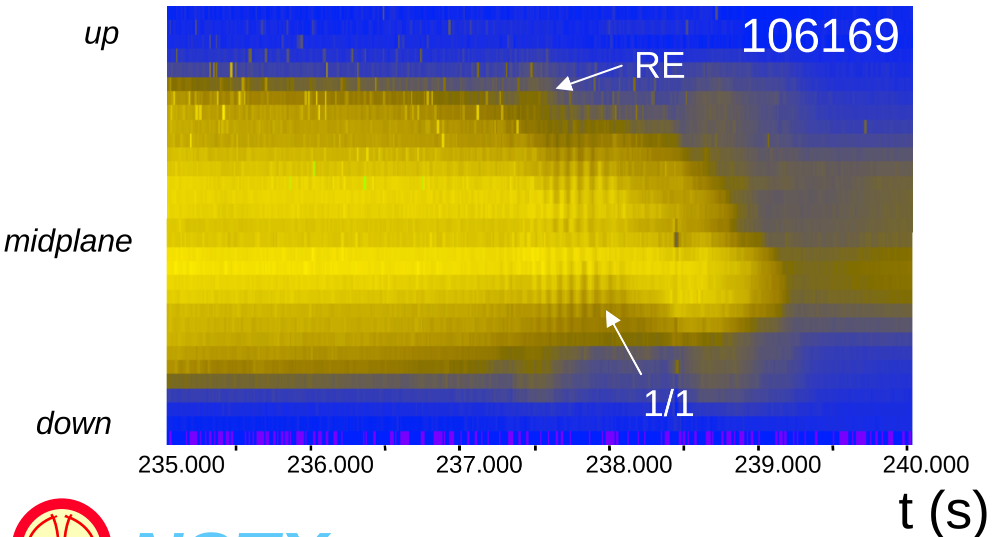


R. Bell

USXR data shows a mode structure resembling a global kink in RWM candidate shots



- Fast collapse with RWM
- No core islands and no 1/1 mode before reconnection event (RE)
  - More likely a kink mode onset

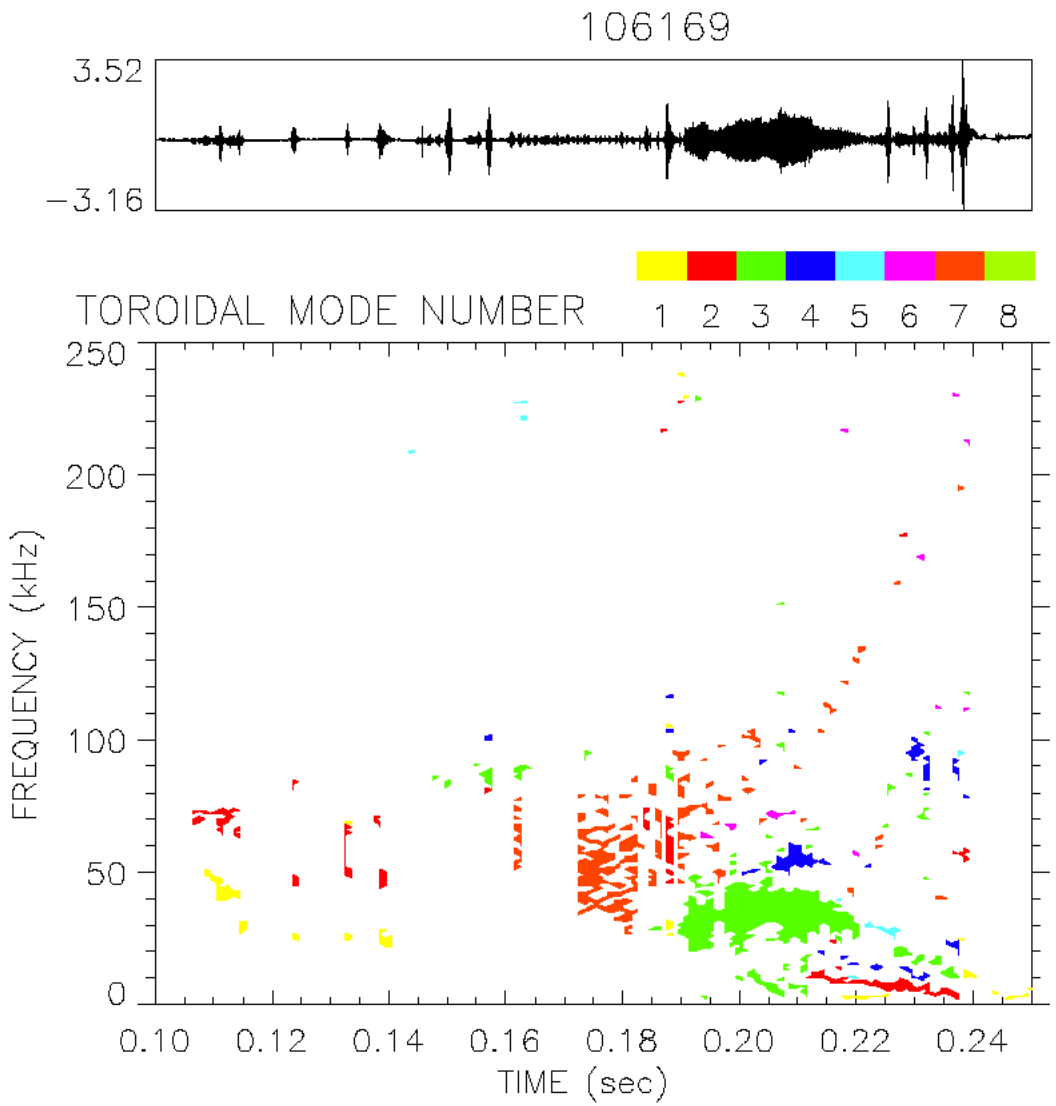


- Plasma with island activity
  - Reconnection event leads to 1/1 mode (kink ?) at 237 ms
  - Less likely a kink mode onset

D. Stutman

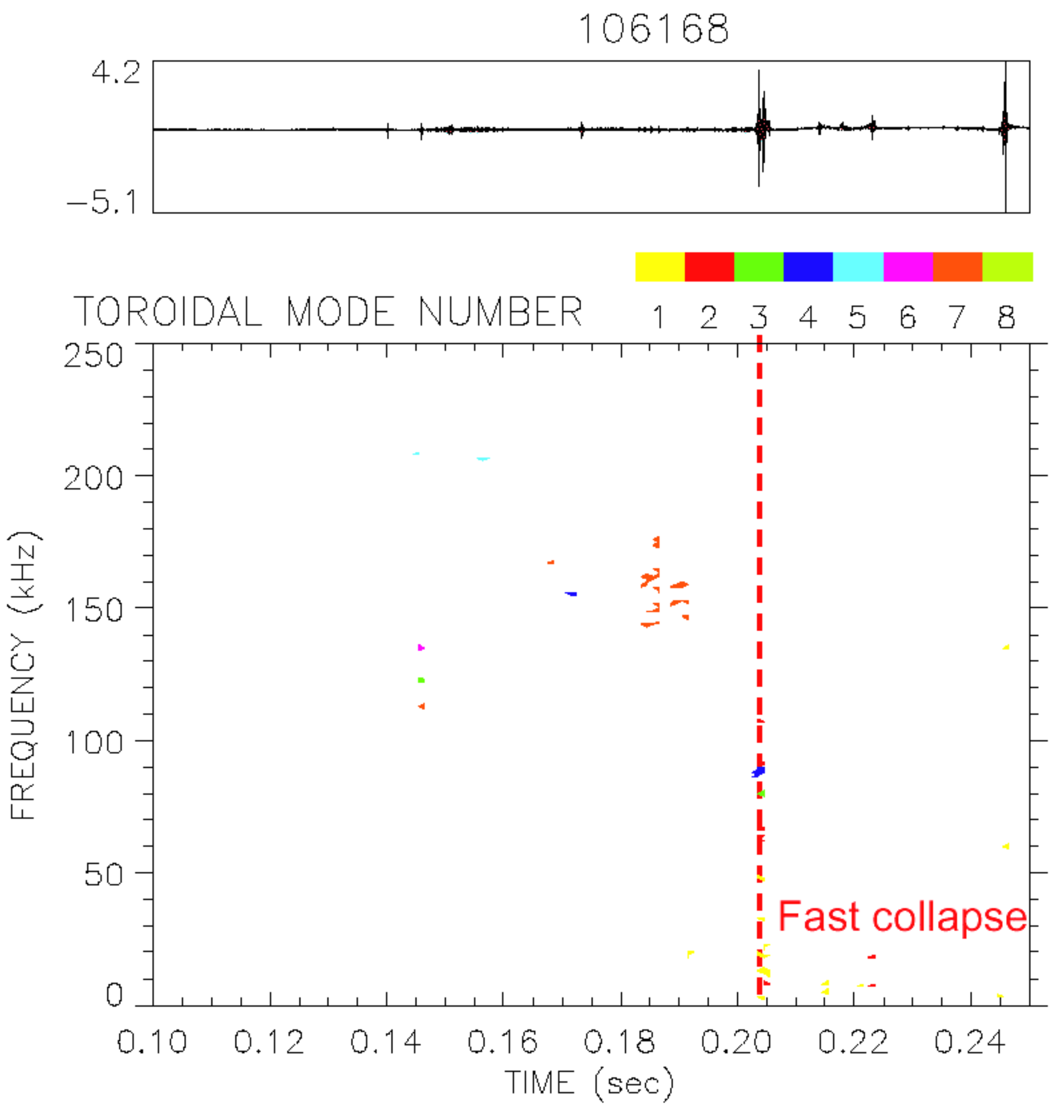
Plasmas with strong islands lead to beta saturation

- Slow beta reduction occurs over several 10's of milliseconds
- Core plasma rotation (CHERS) continues to increase until discharge termination
- In similar plasmas, slow reduction in frequency of n = 2, 1 indicates slowing of island rotation



No Mirnov precursors in candidate RWM shots

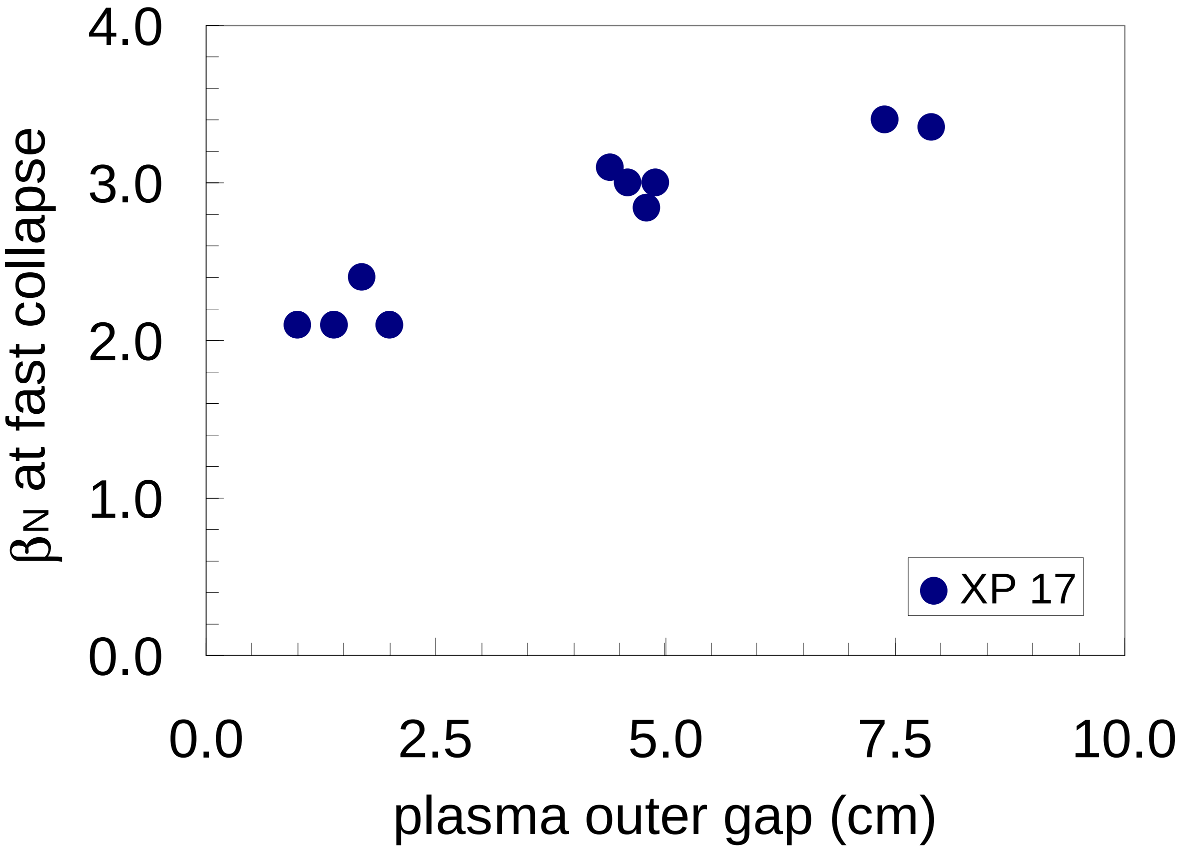
- Small, fast "bursts of MHD observed when plasma boundary / conducting wall gap drops to ~ < 3 cm
- Electron pressure peaking larger than in plasmas with islands
  - Local pressure gradient could be drive mechanism



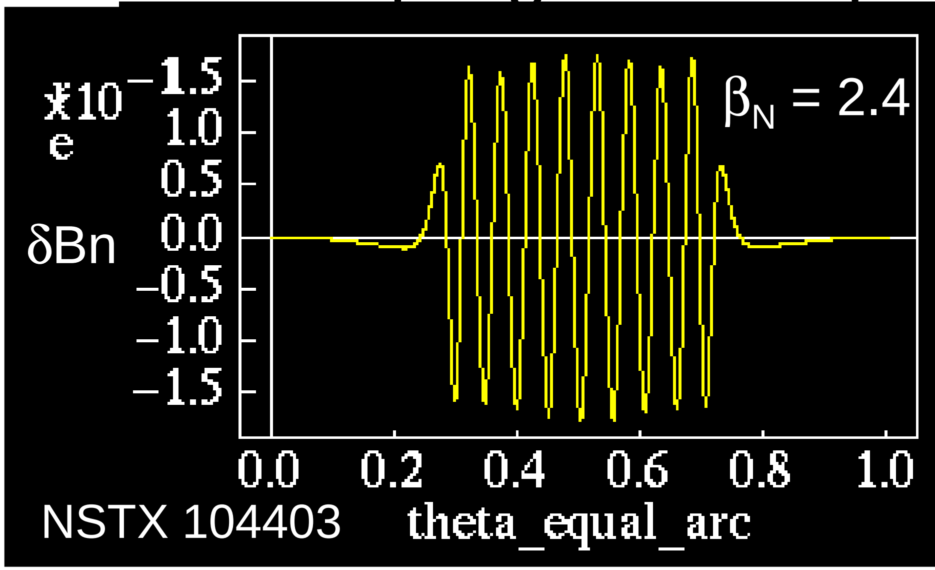
Achieved β_N decreases with decreasing outer gap

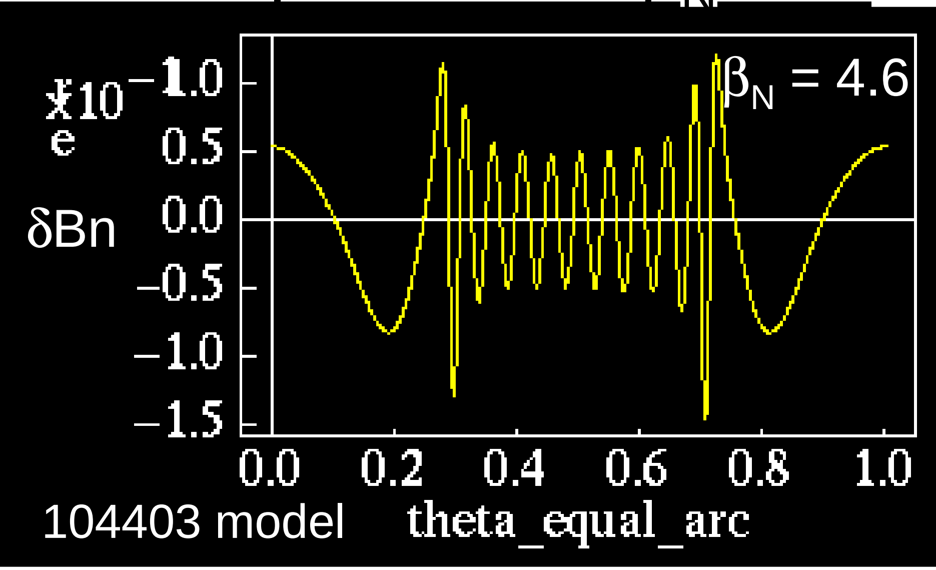
- Consistent with theory, RWM stability is decreased as plasma-wall gap is decreased

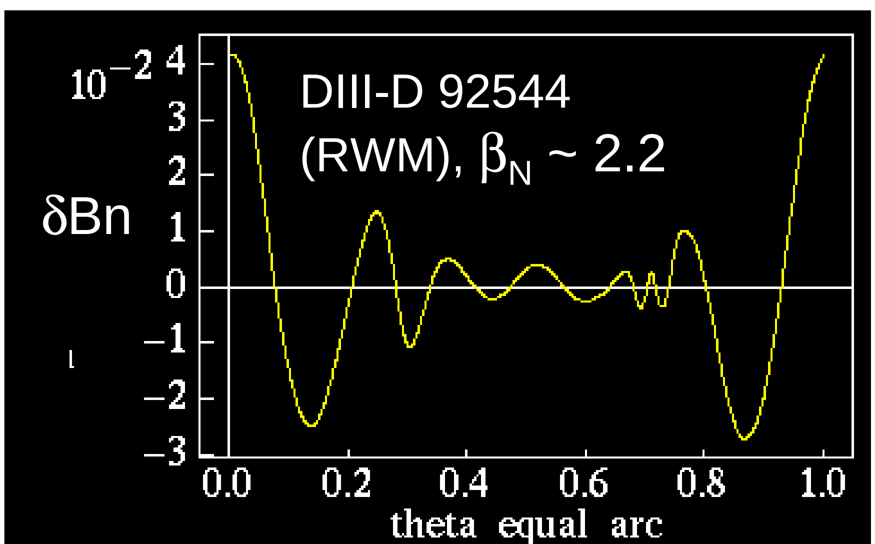
- In contrast, ideal mode becomes less stable as gap increases



In theory, low aspect ratio, high q_a should make mode wall coupling weak at present experimental β_N limit







- NSTX at β_N ~ 2.4
  - Max. amplitude on inboard side
  - long poloidal wavelength on outboard side, short on inboard
  - VALEN code shows weak coupling
- DIII-D at β_N ~ 2.2
  - Max. amplitude on outboard side
  - relatively low poloidal mode #
  - VALEN code shows strong coupling

Hypothesis for low aspect ratio RWM evolution differs from usual tokamak picture

- Wall mode causing slowing of toroidal rotation occurs during period ideal *current* driven kink instability
- Pressure driven mode causing fast beta collapse is only weakly coupled to the conducting plates at $\beta_N \sim 3$
  - Greater coupling, and therefore enhanced wall stabilization theoretically occurs at ***higher*** β_N
- Fast collapse observed when toroidal rotation becomes sufficiently small – but is this coincidence?
  - RWM and pressure driven internal mode could be decoupled
  - Data exists to test this, however need CHERS analysis for more shots to reach a conclusion
- Feedback stabilization system design hinges on this hypothesis
  - If true, feedback stabilization in an ST will require higher β_N and more precise profile control than in a tokamak at higher A and lower q_a

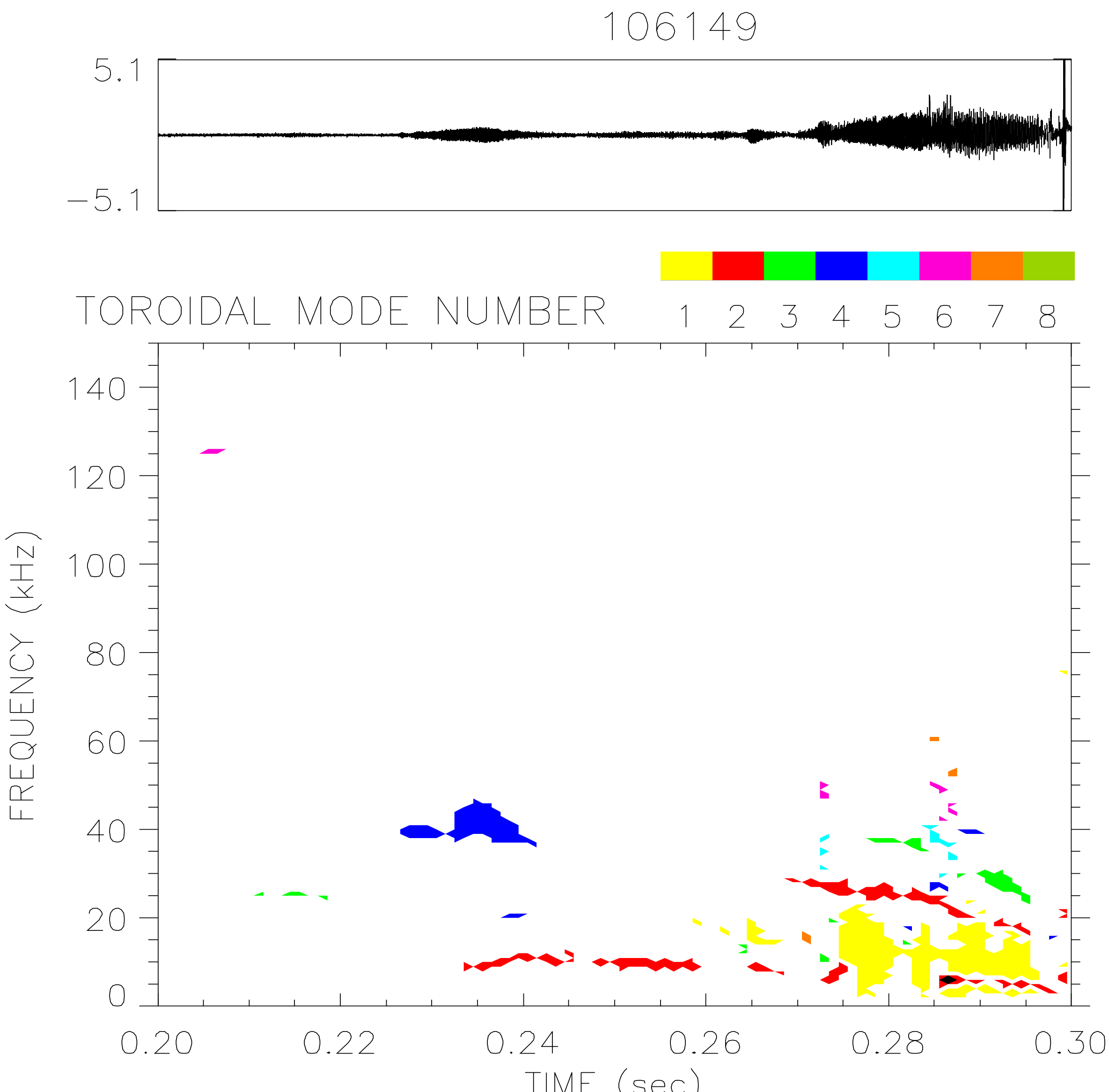
Profile dependence of beta limits and wall stabilization at low A is under active research

- Normalized beta limit experimentally:
  - Increases, then saturates with increasing current profile peaking
  - decreases with increasing pressure profile peaking
- Comparison to theory with refined (“kinetic”) equilibrium reconstruction is underway
  - Analysis of “magnetics-only” equilbria support experimental trends
- Experimental evidence for resistive wall modes
- Theory predicts weak coupling to present conducting structure at levels of β_N reached in experiment

Extra slides follow

Control experiment shows typical *n* = 1 activity

- Strong n = 1 mode activity preceeds fast collapse of plasma
- This is typical of a large inversion radius sawtooth crash documented on NSTX
- This activity defines the nominal end of the experiment – typically t > 0.25 s maximum



Timescale of rapid rotation slowdown apparent in higher frequency modes

- Fast collapse in plasmas close to wall occur on the wall time (~ 3 ms USXR) (~ 10 ms locked mode detector)
  - Collapses in plasmas not coupled to the wall occur in a few hundred μs
- Bursts at higher β_N appear to be beating of higher frequency modes