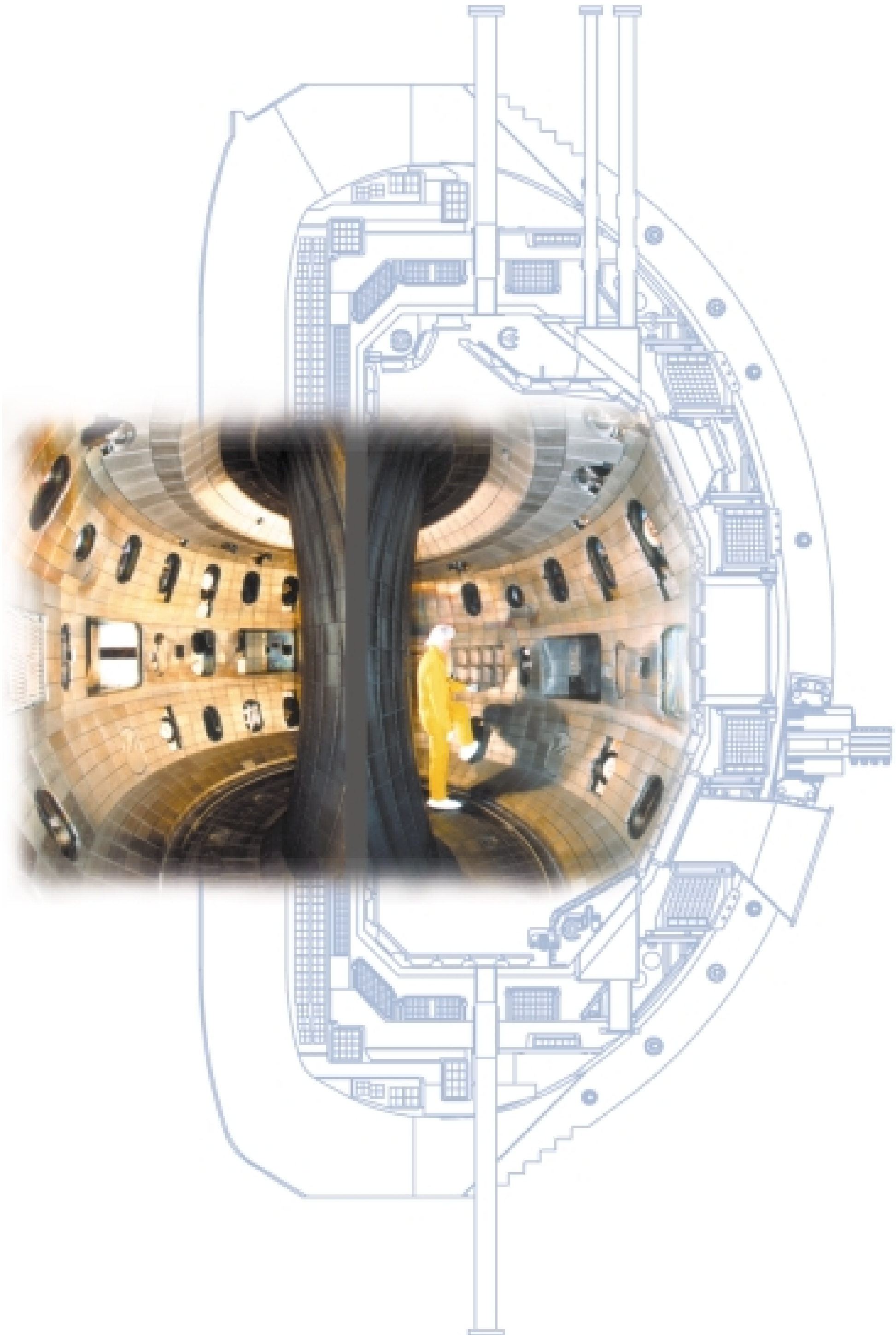


Stability of the Resistive Wall Mode in Advanced Tokamak Plasmas

by
A.M. Garofalo,* G.A. Navratil,*
E.D. Fredrickson,† M. Okabayashi,†
L.C. Johnson,† E.A. Lazarus,‡ M. Gryaznevich,∆
R.J. La Haye, J.T. Scoville, E.J. Strait,
and A.D. Turnbull

*Columbia University
†Princeton Plasma Physics Laboratory
‡Oak Ridge National Laboratory
∆UKAEA Fusion

Presented at
the American Physical Society
Division of Plasma Physics Meeting
Seattle, Washington

November 15–19, 1999

Columbia University

DIII–D NATIONAL FUSION FACILITY

Abstract Submitted
for the DPP99 Meeting of
The American Physical Society

Sorting Category: 5.1.1.2 (Experimental)

Stability of the Resistive Wall Mode in Advanced Tokamak Plasmas[1] A.M. GAROFALO, G.A. NAVRATIL, Columbia University, E.D. FREDRICKSON, M. OKABAYASHI, L.C. JOHNSON, Princeton Plasma Physics Laboratory, E.A. LAZARUS, Oak Ridge National Laboratory, M. GRYAZNEVICH, UKAEA Fusion, R.J. LA HAYE, J.T. SCOVILLE, E.J. STRAIT, A.D. TURNBULL, General Atomics — Double null, ELMing H–mode plasmas with normalized performance parameters of $\beta_{\mathrm{N}} * H \sim 9$ have been sustained for up to 2 s in DIII–D, but performance is often limited by the $n = 1$ resistive wall mode (RWM). Destabilization of the RWM and its damping of plasma toroidal rotation correlate with the saturation of plasma normalized β at a value just about the limit calculated in absence of a conducting wall. One approach to stabilization of the RWM is sustainment of a large plasma toroidal rotation. In DIII–D the plasma rotation can be increased by varying the number and the energy of the neutral beam sources used for heating. Preliminary results show that increased angular momentum injection may be responsible for an increase in the duration of the high performance phase by at least a factor of two.

[1]Supported by U.S. DOE Grant DE-FG02-89ER53297, Contracts DE-AC02-67CH03073, DE-AC05-96OR22464, and DE-AC03-99ER54463, and by the U.K. Dept. of Trade & Industry and EURATOM.

- [X] Prefer Oral Session
- [ ] Prefer Poster Session

A.M. Garofalo
garofalo@fusion.gat.com
Columbia University

Special instructions: DIII-D Contributed Oral Session, immediately following WM Stacey

Date printed: July 19, 1999 Electronic form version 1.4

MOTIVATION AND REQUIREMENTS FOR WALL STABILIZATION

- Stabilization of the n=1 kink mode by a perfectly conducting wall allows operation with high normalized beta, $\beta_N = \beta/I/aB \sim 5$ to 6, in the advanced tokamak (AT)

- Wall stabilization is crucial for high β operation in the spherical torus, spheromak, RFP and FRC

- Theory predicts stabilization by a resistive wall at $\beta_N > \beta_N^{no\ wall}$ possible with plasma rotation and dissipation
  - ➢ Control of rotation can give access to stability window

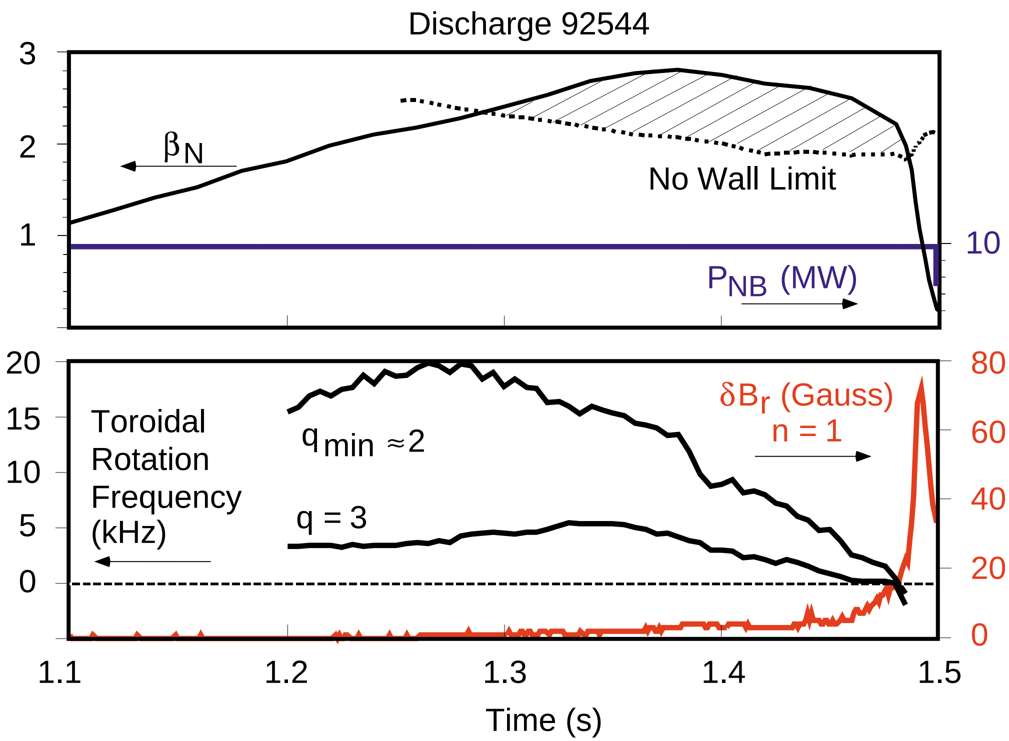
- Alternatively, slow resistive wall mode (RWM) growth rate can be stabilized by active feedback

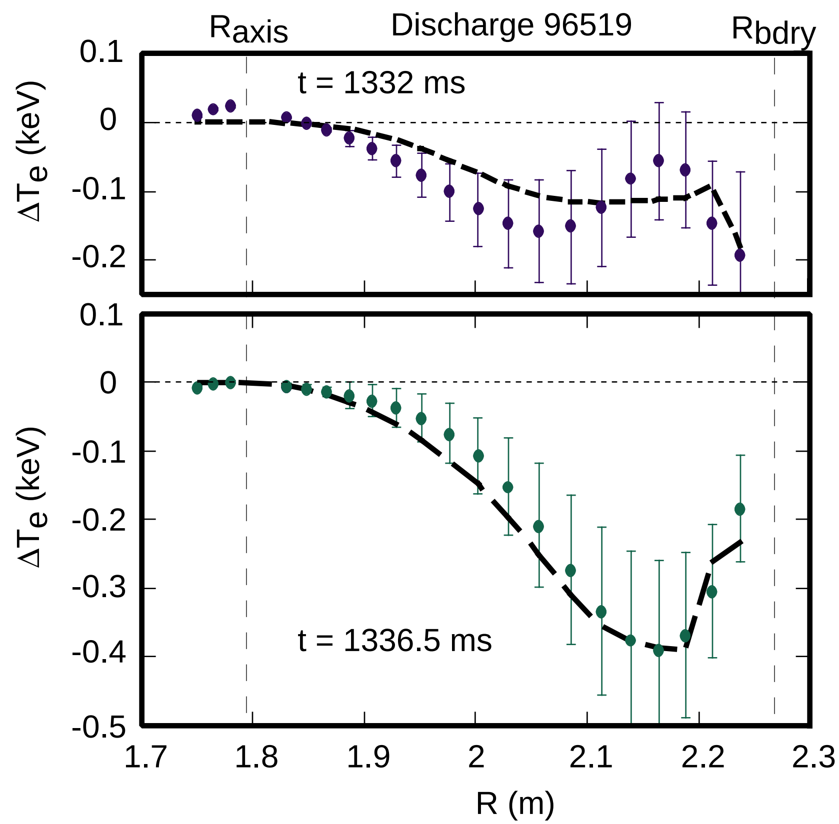
DIII–D NATIONAL FUSION FACILITY SAN DIEGO

Columbia University

RWM IDENTIFIED IN PREVIOUS DIII-D EXPERIMENTS

- β_N exceeded no-wall limit by up to 40%
- n = 1 mode grows ($\gamma \sim 1/\tau_W$) after toroidal rotation at q = 3 surface has decreased below ~ 1 kHz
- T_e profile perturbation agrees with calculated perturbation from predicted ideal kink
  $\Delta T_e \propto \xi^{GATO} \times dT_e/dR$
  - ➢ Amplitude and toroidal phase of calculated eigenfuction scaled according to magnetic data



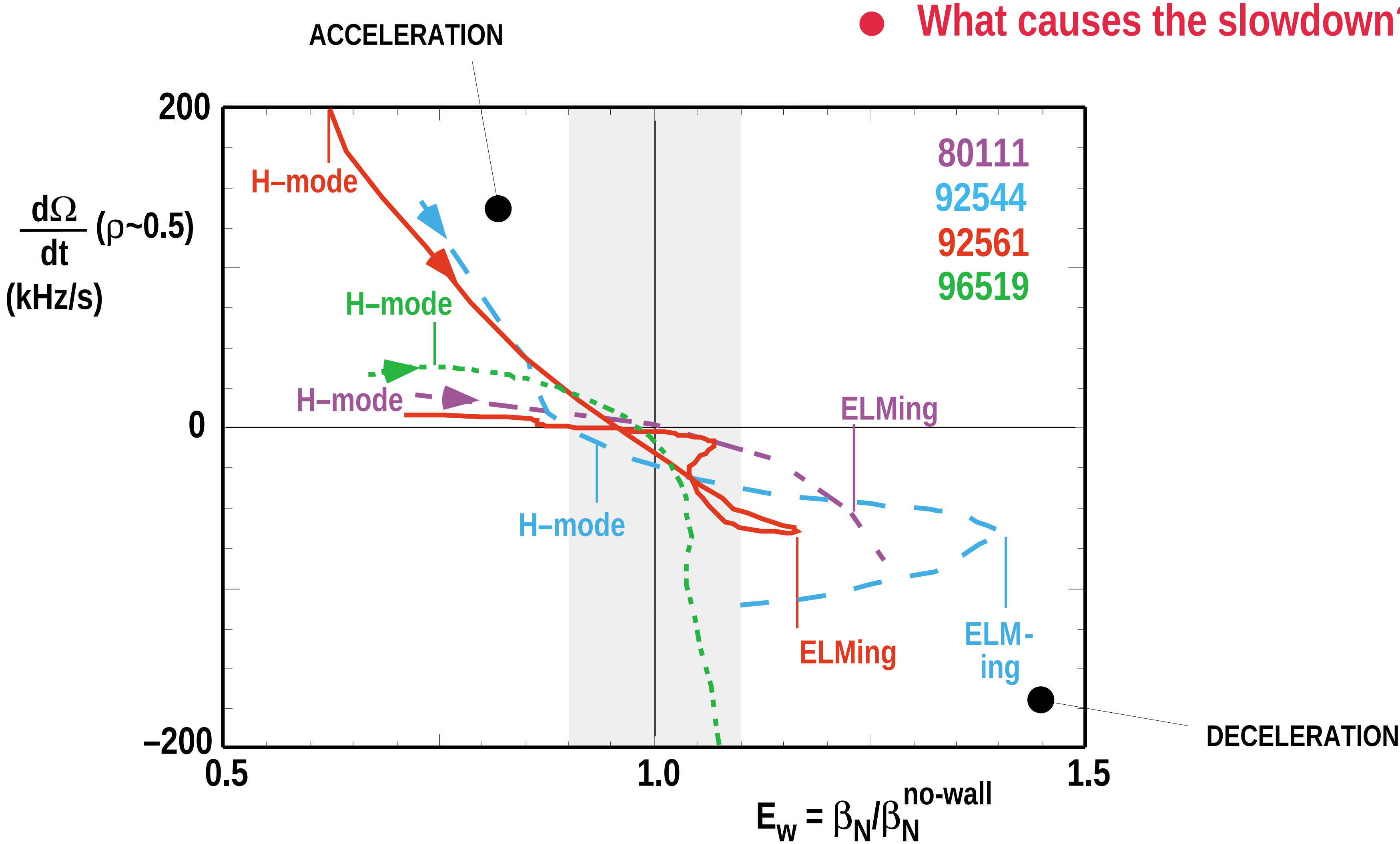


DIII–D
NATIONAL FUSION FACILITY
SAN DIEGO

Columbia
University

PLASMA ROTATION SLOWS AS β_N EXCEEDS NO WALL LIMIT

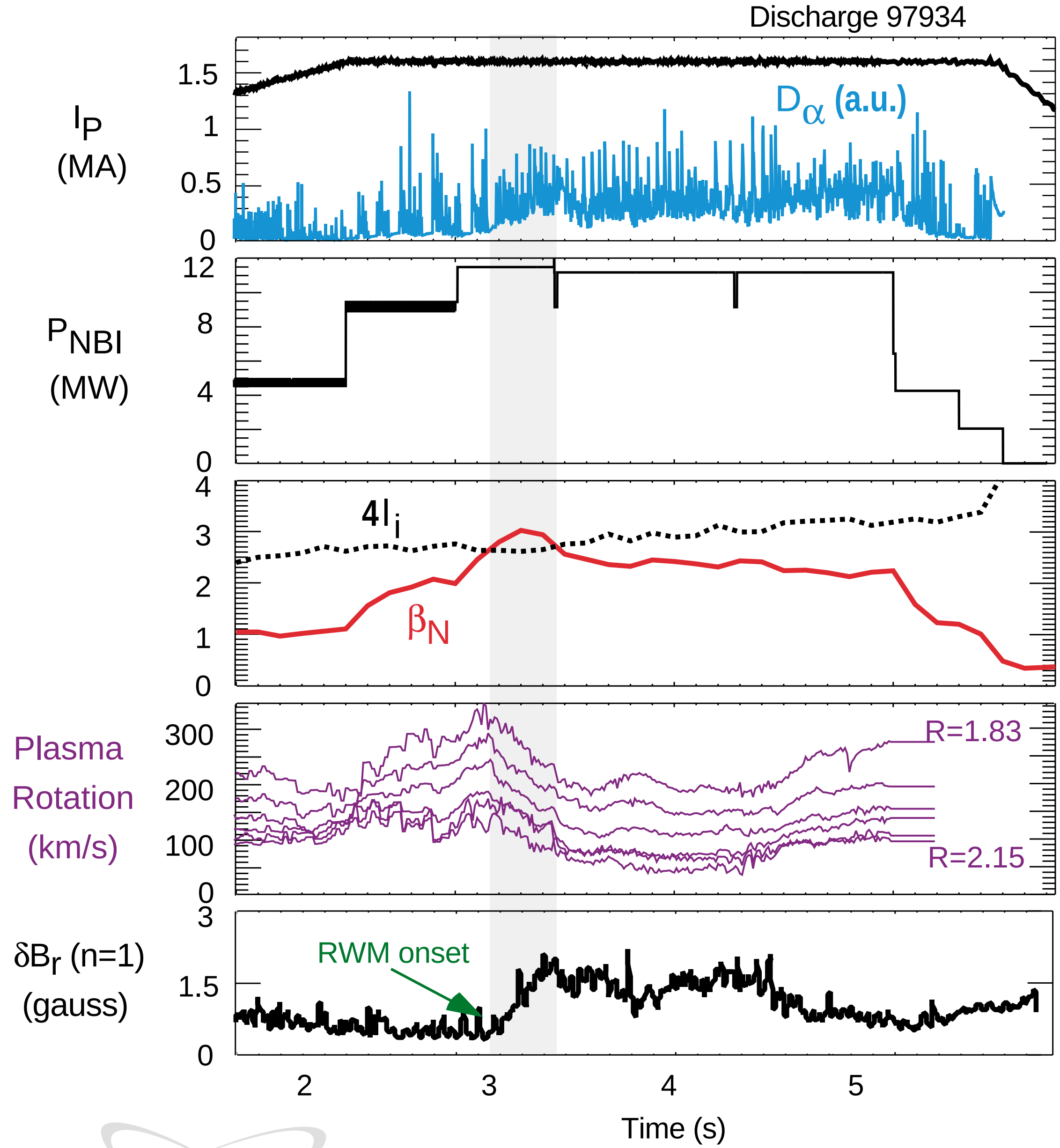
- What causes the slowdown?



DIII–D NATIONAL FUSION FACILITY SAN DIEGO

Columbia University

ONSET OF SMALL AMPLITUDE RWM CORRELATES WITH ROTATION SLOWDOWN IN AT MODES

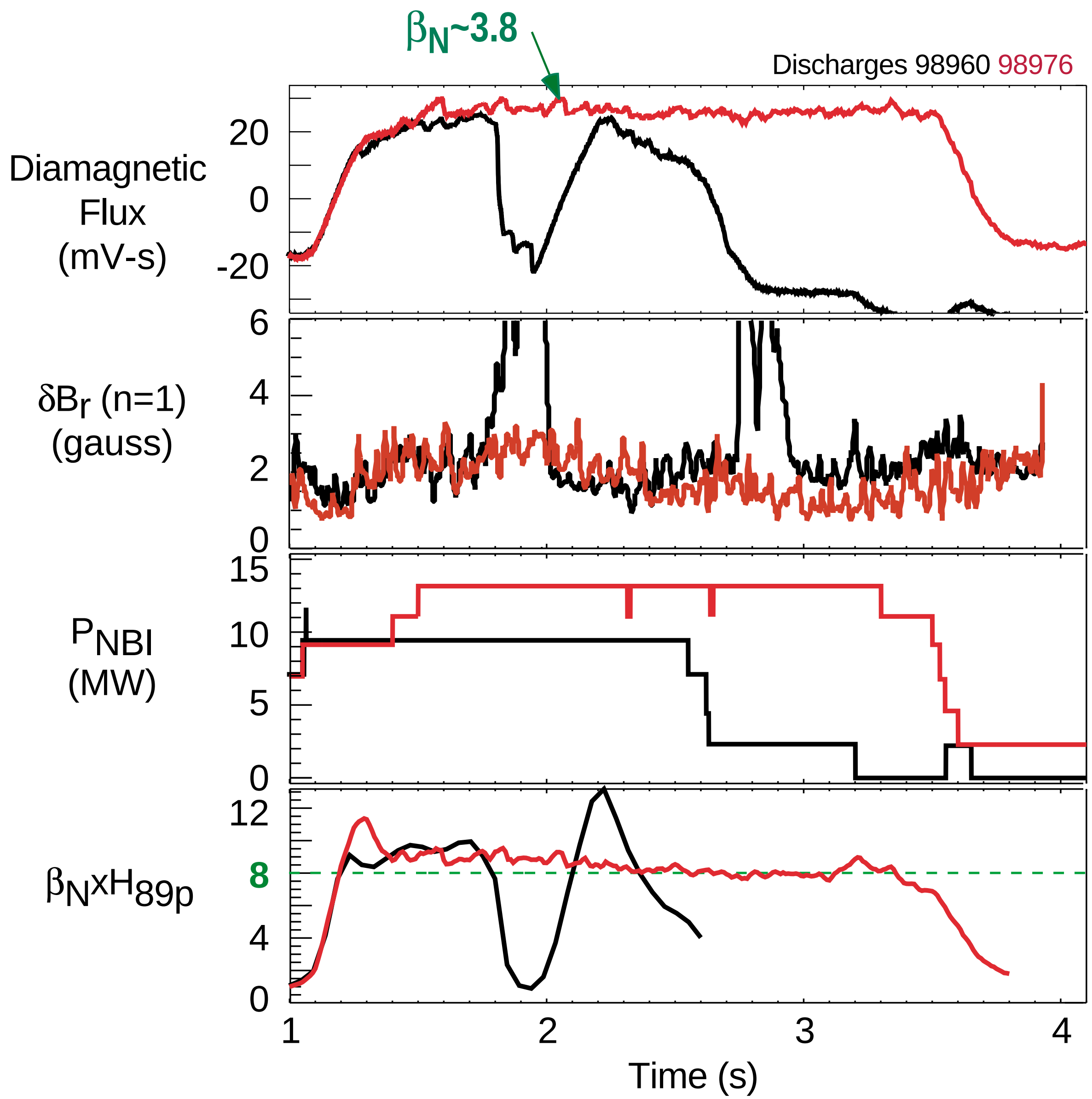


- High q_{min} (~2), low l_i, DND discharges with q_{95}~4.5
- Rotation collapse and confinement degradation begin at mode onset
- Ideal MHD code GATO indicates that the n=1 kink mode is marginally unstable without a wall at 3.2 s ($\beta_N = 4 l_i$)
- Mode grows very slowly (« $1/\tau_w$) and rotates slowly, amid fast plasma rotation (≥ 4 kHz)

DIII–D NATIONAL FUSION FACILITY SAN DIEGO

Columbia University

RWMs LIMIT PERFORMANCE OF AT PLASMAS

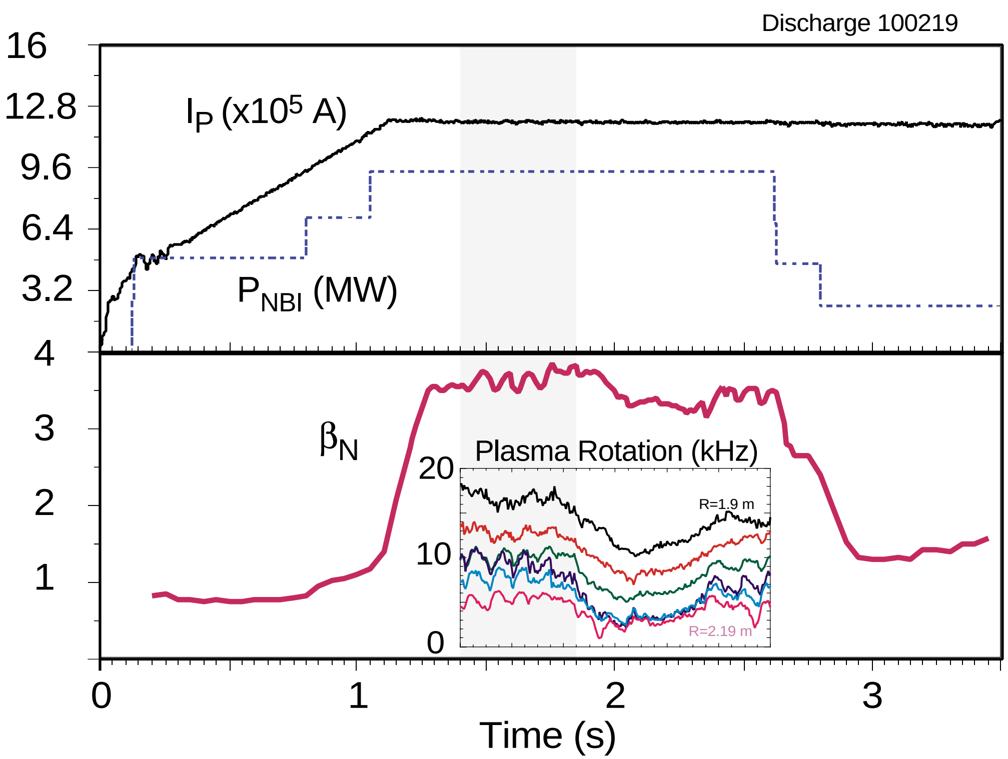


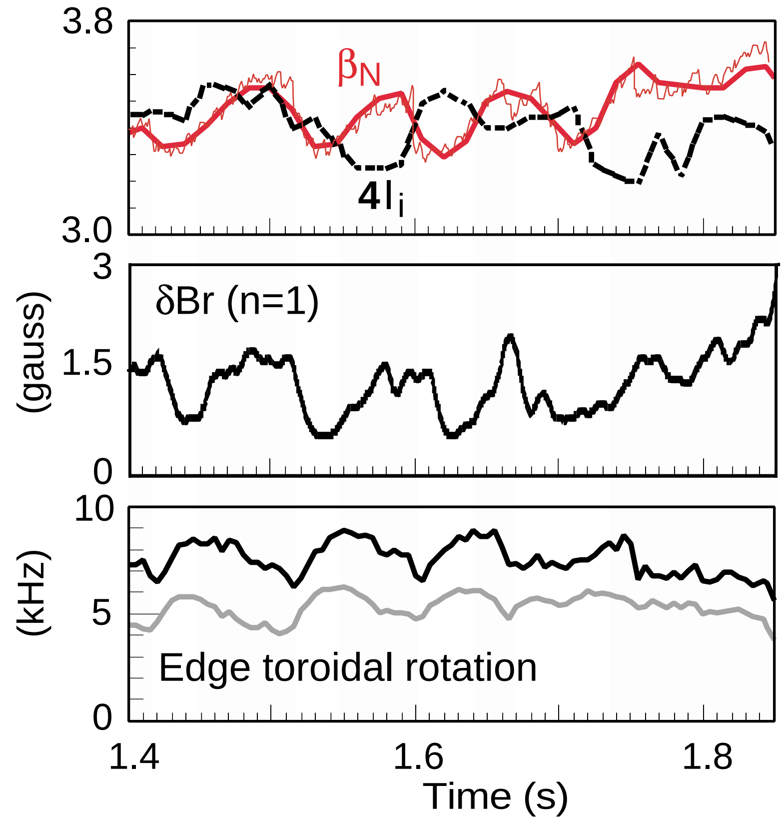
- I_p=1.2 MA, B_t=1.6 T
  q_{min} ~1.7, q_{95}~5.5
- β_N limited to about $4\ell_i$ (no wall limit) by bursting RWMs
- Higher NBI power improves stability and duration
- 75 % current non-inductive
  >50% bootstrap
  See GO2.2 (T. Luce, et al.)

DIII–D
NATIONAL FUSION FACILITY
SAN DIEGO

Columbia University

RWM BURSTS SELF-STABILIZE THROUGH SMALL BETA COLLAPSES





- Plasma rotation slows during β_N "peaks", recovers in β_N"valleys"
- n=1 toroidal structure of small δB_r bursts confirmed by SXR signal analysis in similar discharges. See CP1.76 (L. Johnson, *et al.*)

DIII–D
NATIONAL FUSION FACILITY
SAN DIEGO

Columbia University

PLASMA ROTATION INSUFFICIENT FOR COMPLETE RWM SUPPRESSION

- In conditions of improved detection, small amplitude, slowly growing (often $\gamma \ll 1/\tau_W$) RWMs can usually be observed when β_N > no wall limit

  Working hypothesis

☞ The plasma rotation does not completely suppress the RWM, but slows the growth rate.

The electromagnetic torque from the RWM reduces the plasma rotation.

- The confinement degradation due to small amplitude RWMs (e.g. through tearing or reduced ExB shear) can decrease β_N < no wall limit, leading to beta saturation or rollover
- If the plasma rotation decreases below a critical value while β_N > no wall limit, the mode growth transitions to a $1/\tau_W$ rate, usually leading to a minor disruption

- Interpretation of observations qualitatively consistent with theoretical model by Gimblett and Hastie (to be publ. in Phys. Plasmas). See CP1.75 (E. Strait, *et al.*)

SUMMARY

- RWMs observed in high performance AT modes
  - ➢ RWMs limit β_N to ~ $\beta_N^{\text{no wall}}$ (~ 4l_i)
- Plasma rotation insufficient for complete RWM suppression
  - ➢ RWM identified as cause of rotation slowdown

⪢ Need active feedback control to maintain $\beta_N > \beta_N^{\text{no wall}}$

DIII–D NATIONAL FUSION FACILITY SAN DIEGO

Columbia University