INTERNAL STRUCTURE OF RESISTIVE WALL MODES IN DIII-D

L. C. JOHNSON, E. D. FREDRICKSON, M. OKABAYASHI — PPPL PRINCETON PLASMA PHYSICS LABORATORY

R. J. LA HAYE, J. T. SCOVILLE, E. J. STRAIT — GENERAL ATOMICS

A. M. GAROFALO, G. A. NAVRATIL — Columbia University

E. A. LAZARUS — ornl

M. GRYAZNEVICH — UKAEA Fusion

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Internal Structure of Resistive Wall Modes in DIII-D[1]

L.C. JOHNSON, E.D. FREDRICKSON, M. OKABAYASHI, Princeton Plasma Physics Laboratory, R.J. LA HAYE, J.T. SCOVILLE, E.J. STRAIT, General Atomics, A.M. GAROFALO, G.A. NAVRATIL, Columbia University, E.A. LAZARUS, Oak Ridge National Laboratory, M. GRYZANEVICH, UKAEA — Resistive wall modes limit the performance of DIII–D discharges when beta exceeds the ideal stability limit calculated in the absence of a wall. Theory predicts that the modes should be characterized by slow rotation, on the resistive time scale of the wall, and a kink-like internal structure. The very slow mode rotation prevents use of the usual techniques of Fourier analysis at a single toroidal location to study internal mode structure, but comparison of soft x–ray and ECE measurements at multiple locations can provide information on the mode structure. Preliminary analysis indicates an ideal mode structure, consistent with expectations. Behavior in the presence of active feedback stabilization will be discussed.

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L.C. Johnson
johnsonl@fusion.gat.com
Princeton Plasma Physics Laboratory

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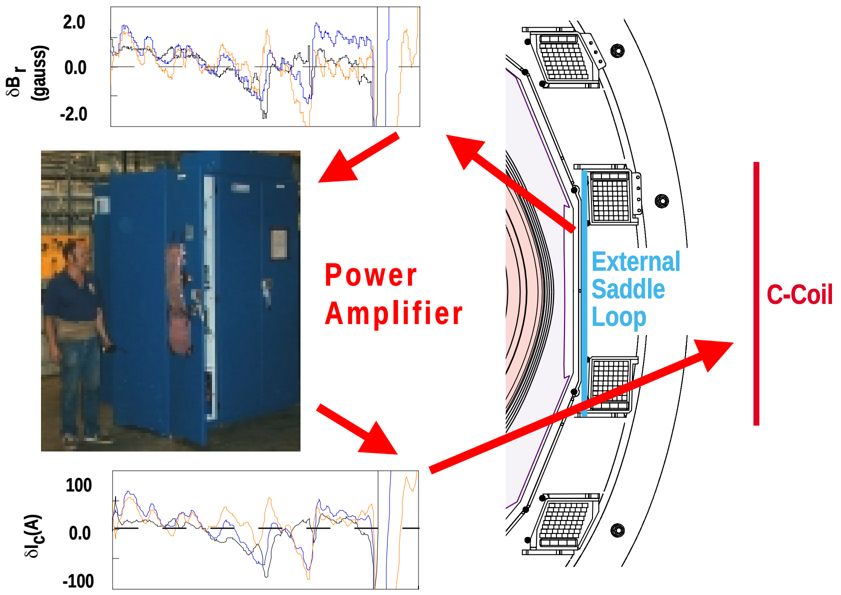
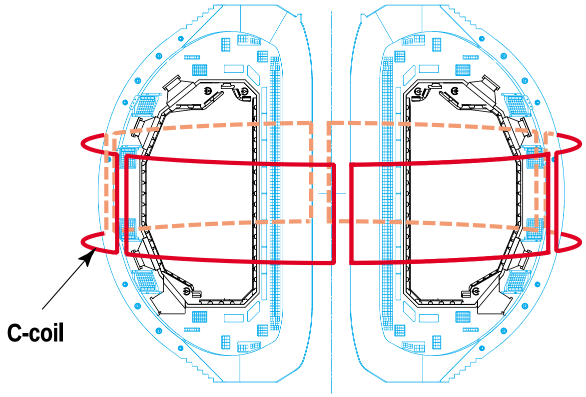
ABSTRACT

Resistive wall modes limit the performance of DIII-D discharges when beta exceeds the ideal stability limit calculated in the absence of a wall. Theory predicts that the modes should be characterized by slow rotation, on the resistive time scale of the wall, and a kink-like internal structure. The very slow mode rotation prevents use of the usual techniques of Fourier analysis at a single toroidal location to study internal mode structure, but comparison of soft x-ray and ECE measurements at multiple locations can provide information on the mode structure. Preliminary analysis indicates an ideal mode structure, consistent with expectations. Behavior in the presence of active feedback stabilization will be discussed.

DETECTION AND ACTIVE FEEDBACK STABILIZATION OF RWM

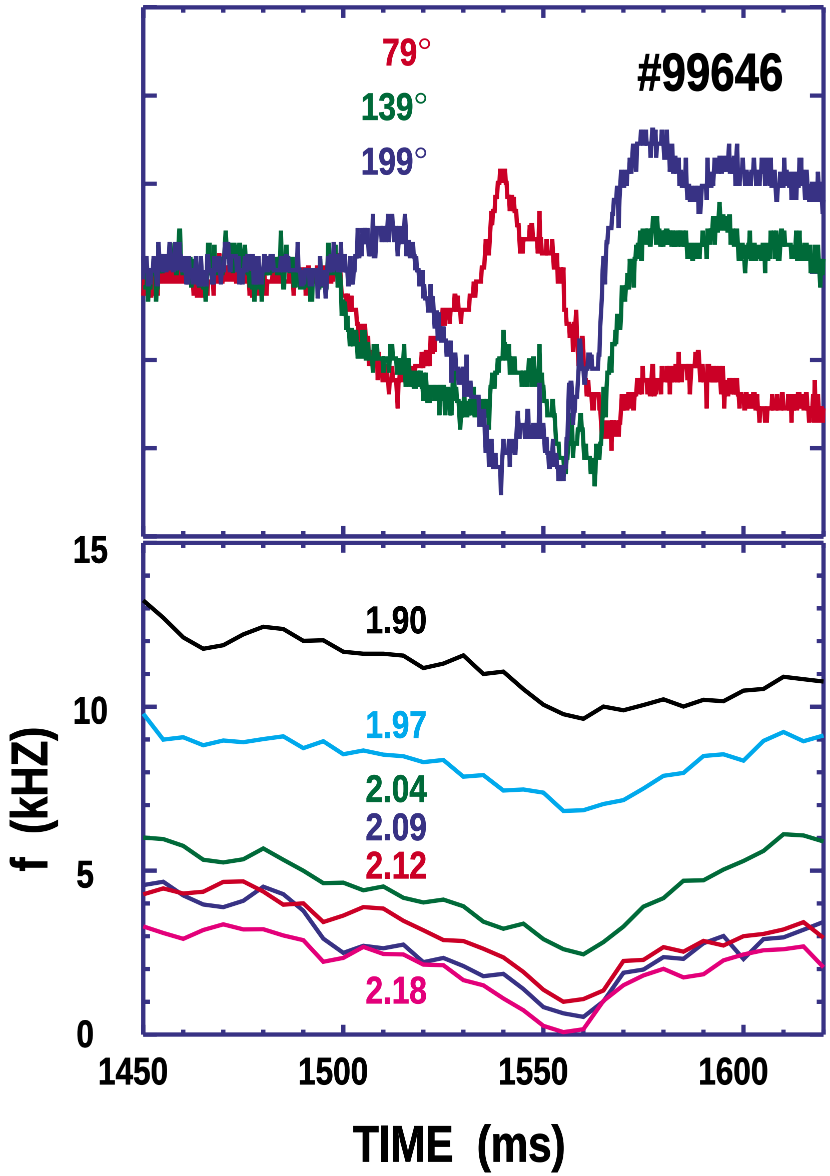
- Resistive wall modes (RWM) have been under study on DIII-D for several years.
- Experiments on active magnetic feedback stabilization of these modes have begun.
  - Six picture-frame “saddle” loops, arranged in a toroidal array, detect slowly rotating magnetic perturbations.
  - Feedback stabilization commands are generated from the saddle loop data, using a variety of algorithms, and sent to three power amplifiers.
  - Each amplifier energizes a pair of correction coils (C-coils) with the proper current and phase for controlling growth of the mode.





SADDLE LOOP AND PLASMA ROTATION DATA SHOW RWM ONSET

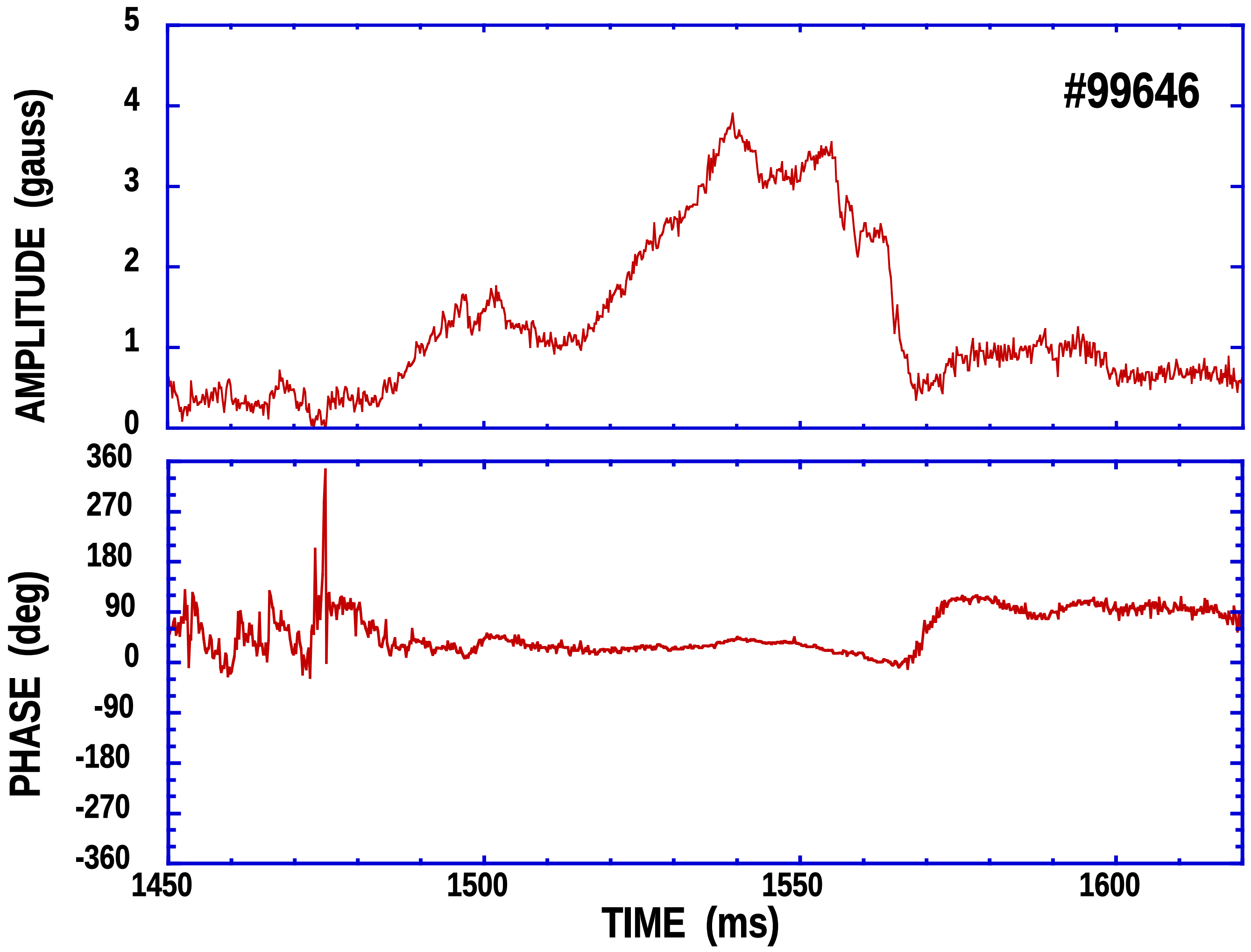
- Saddle loop data show the onset of resistive wall modes.
  - For this shot, "smart shell" feedback was used to hold the net radial flux through the loops constant from 1300 to 1500 ms.
- Plasma rotation data are correlated with the onset of resistive wall modes.
  - When the rotation frequency near the edge decreases below a critical value, the mode appears on magnetic loops.
- In this paper, we examine soft x-ray data to find independent measurements of mode onset and characteristics.



SADDLE LOOPS DETECT SLOWLY ROTATING n=1 MODES

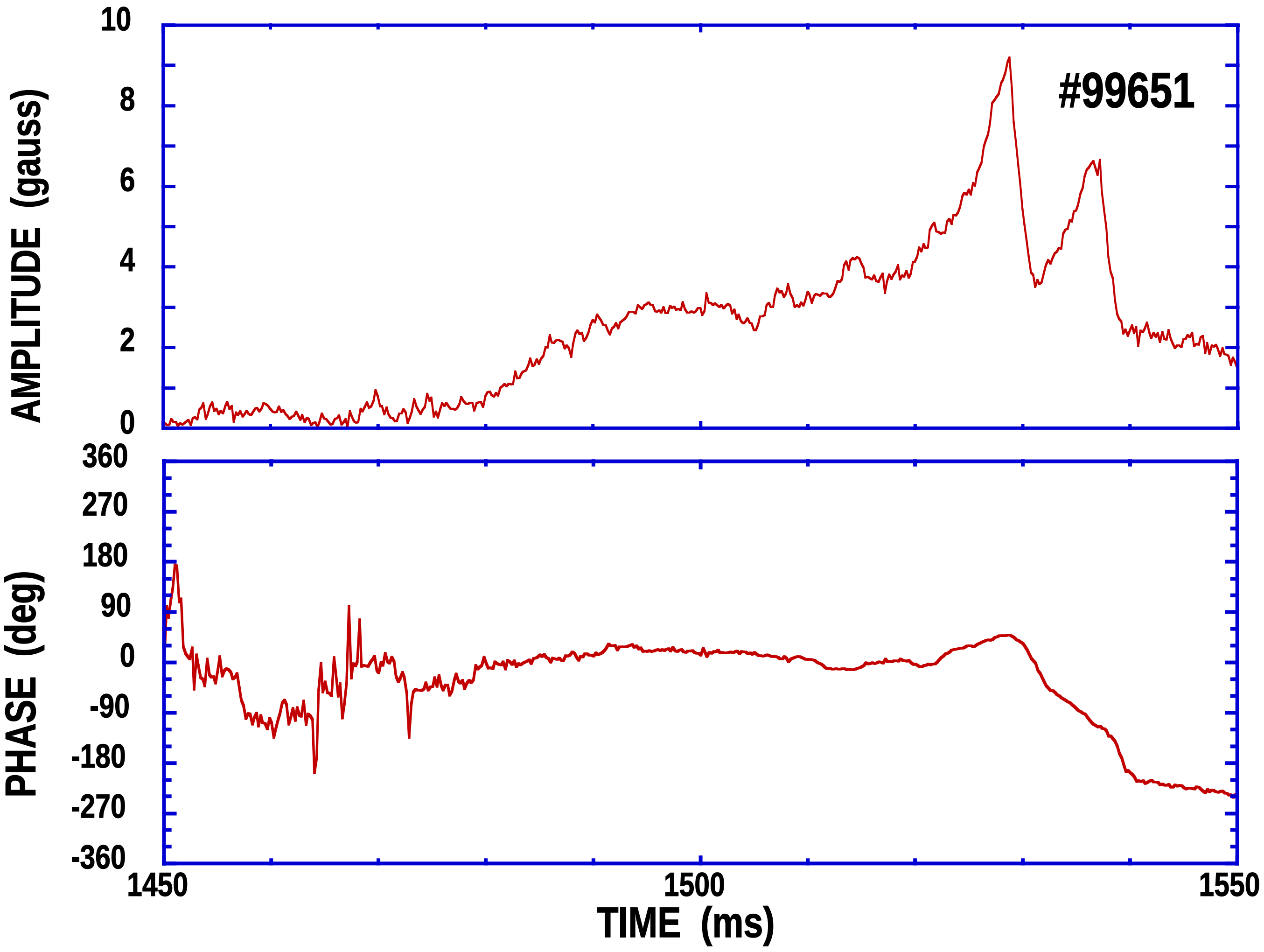
- **Each saddle loop covers a 60° toroidal segment of the vacuum vessel at the midplane, corresponding to the toroidal configuration of the C-coils.**
- **The loops are normally arranged in opposing pairs to discriminate against axi-symmetric stray fields from poloidal field coils.**
- **Compensation for the fields produced by the C-coils may be done either by hardware switches or in software.**
- **The three coil pair differences (79°, 139°, and 199°) can be used to determine the amplitude and phase of a slowly growing, slowly rotating n=1 magnetic perturbation, such as that expected from a resistive wall mode.**

SLOWLY ROTATING n=1 MODE WITHOUT FEEDBACK



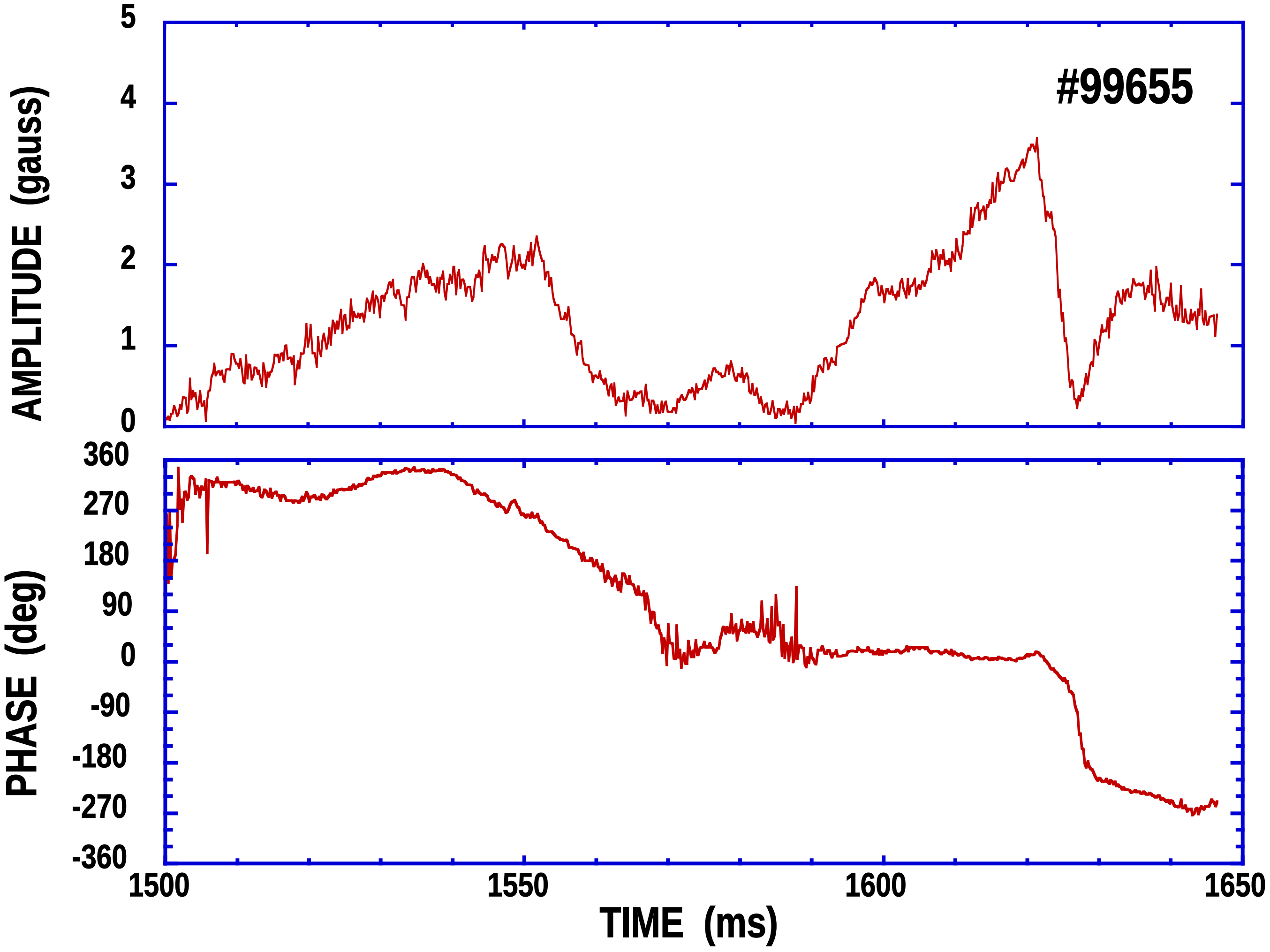
“Smart shell” feedback was applied from 1300 to 1500 ms; no feedback after 1500 ms. Results include compensation for C-coil fields.

SLOWLY ROTATING n=1 MODE WITH PROPORTIONAL GAIN FEEDBACK



Feedback with high proportional gain and low derivative gain. Results are compensated for C-coil fields.

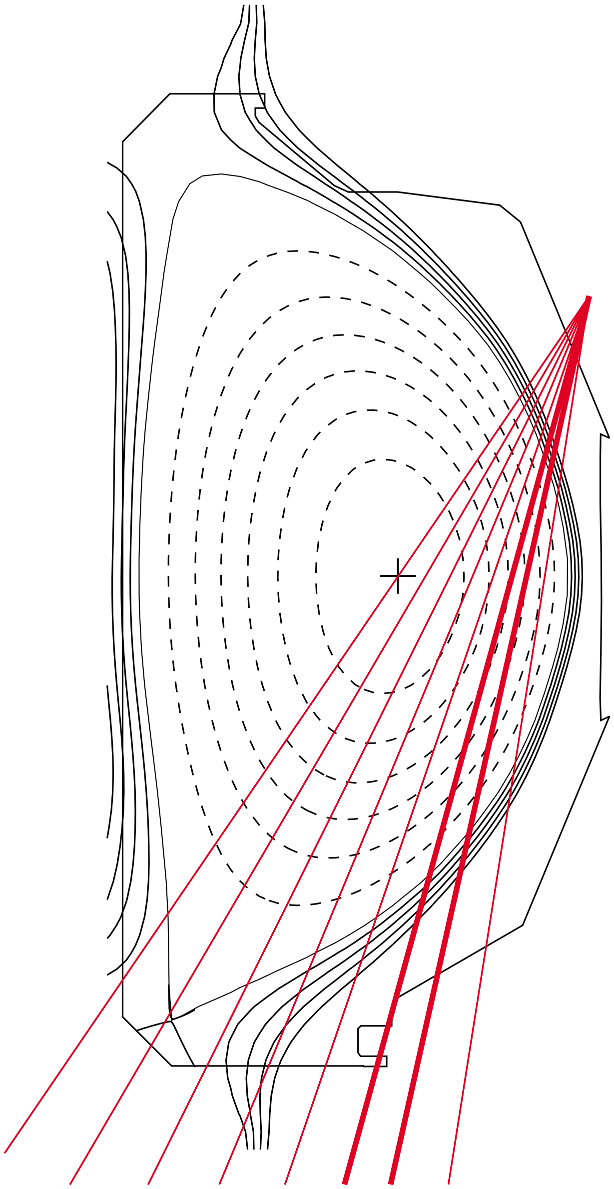
SLOWLY ROTATING n=1 MODE WITH DERIVATIVE GAIN FEEDBACK



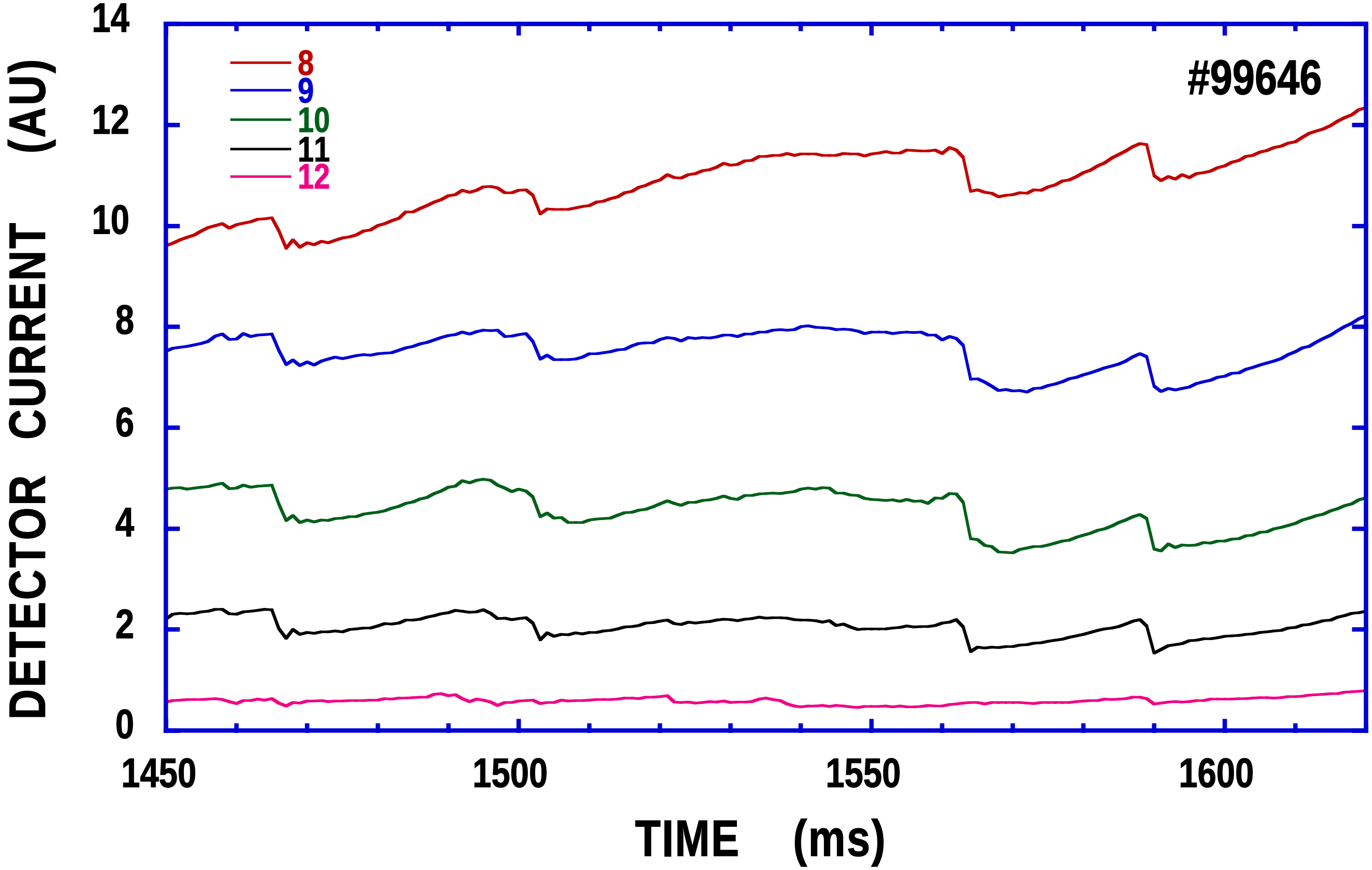
Feedback with low proportional gain and high derivative gain. Results are compensated for C-coil fields.

SOFT X-RAY DATA SHOW SLOWLY ROTATING n=1 MODE BEHAVIOR

- DIII-D has two nominally identical soft x-ray poloidal arrays at toroidal angles of 45° and 195°.
- Data from the two arrays are compared chord-by-chord to look for differences ascribable to toroidal variations.
- Flux surface geometry and poloidal x-ray profiles are used to convert toroidal differences to relative radial displacements of flux surfaces.
- Data from two of the x-ray chords show good correlation with magnetic data.

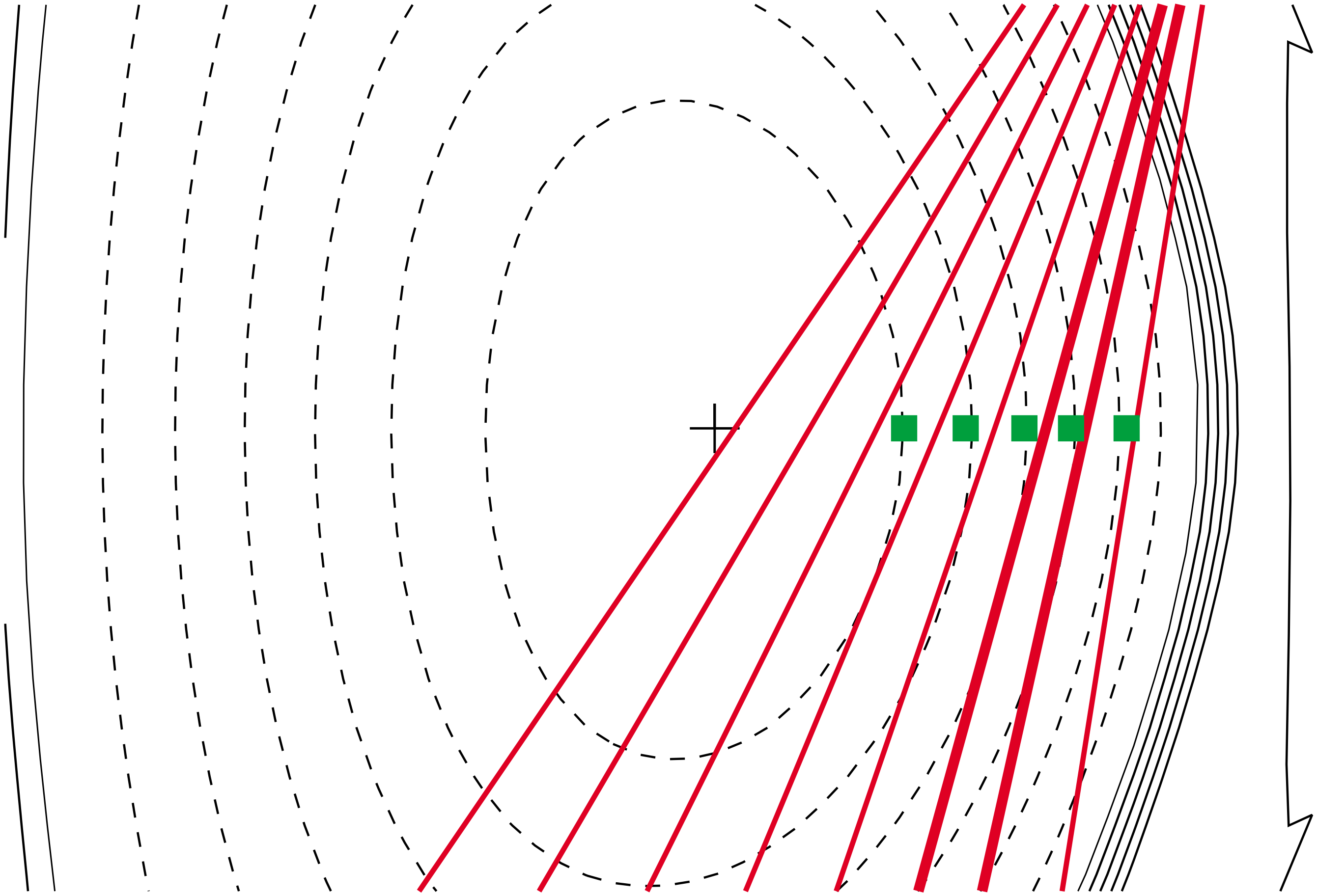


SOFT X-RAY DATA FROM ARRAY AT TOROIDAL ANGLE OF 195°



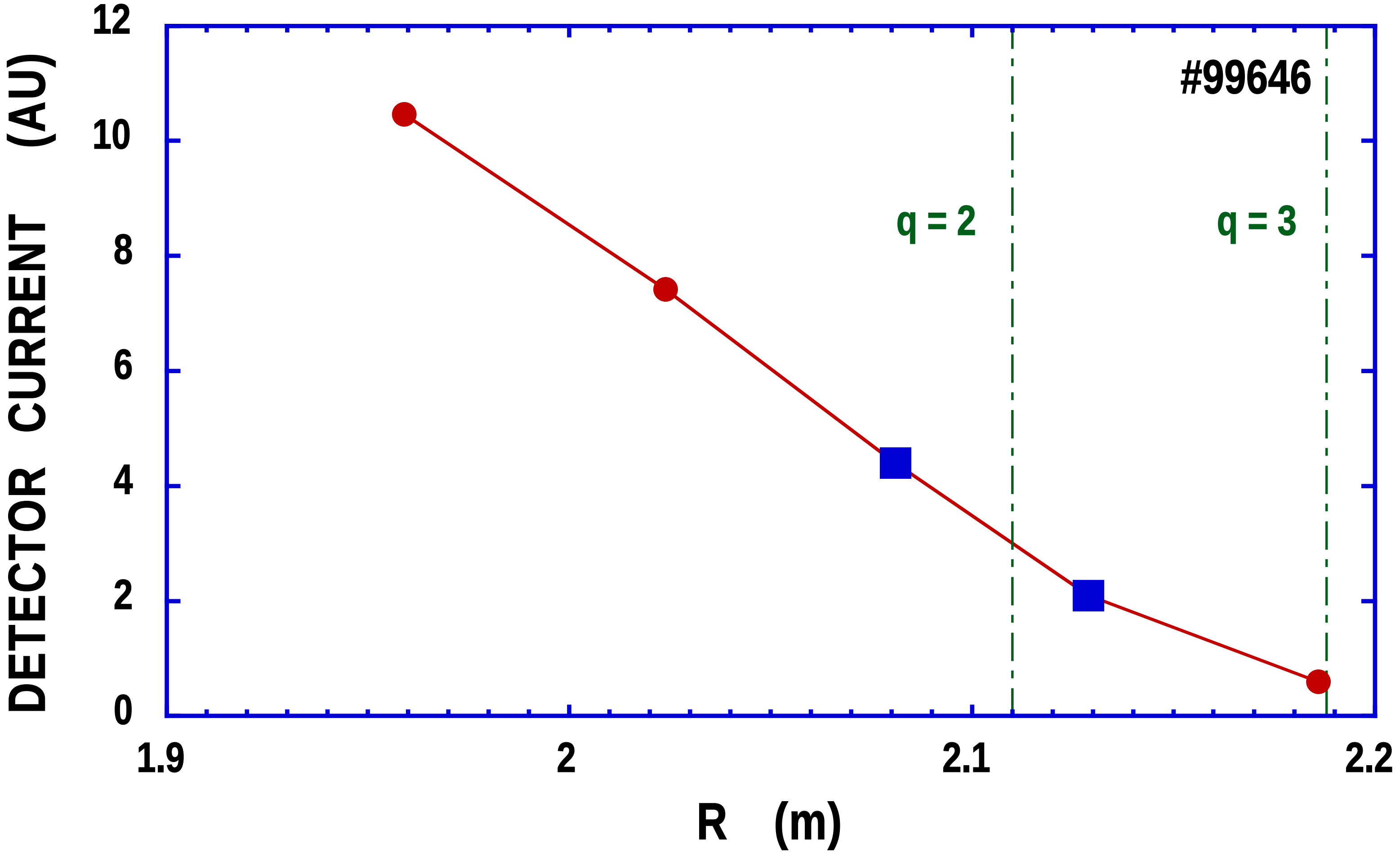
Soft x-ray data for the five outer channels of the array at a toroidal location of 195°. The four abrupt drops are caused by ELMs. These features are less prominent after chord-by-chord subtraction.

CHORD-TO-RADIUS MAPPING



Mapping of x-ray sight lines to major radius position. The green squares represent the points where the chord-tangent flux surfaces intersect the plasma midplane.

SOFT X-RAY PROFILE IS USED TO INFER RADIAL DISPLACEMENT

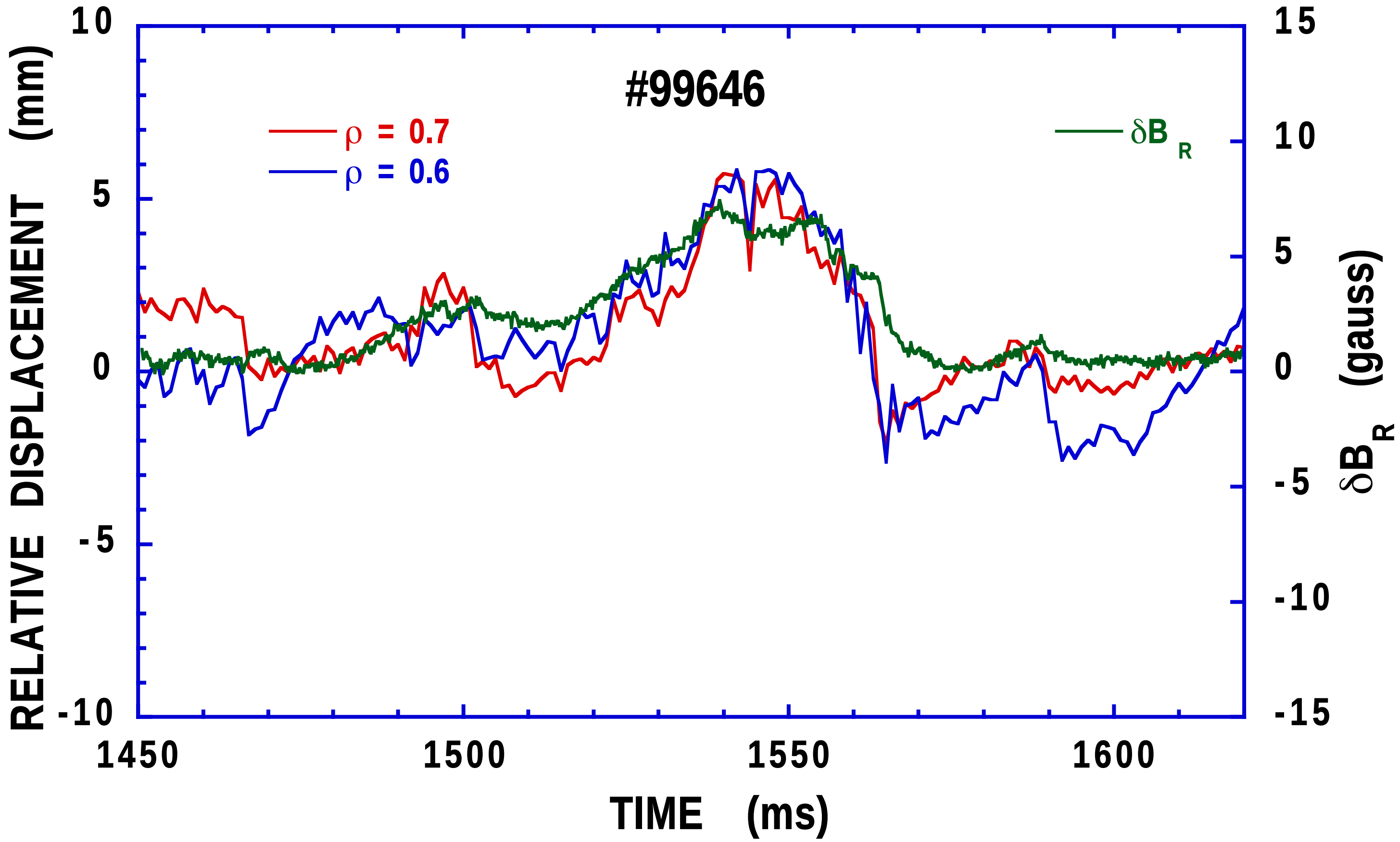


Outer portion of the soft x-ray line-integral emission profile, referred to the plasma midplane, for the array at a toroidal location of 195°. Each point represents a detector signal averaged over the interval 1450 – 1620 ms.

X-RAY DATA ARE IN GOOD AGREEMENT WITH MAGNETICS

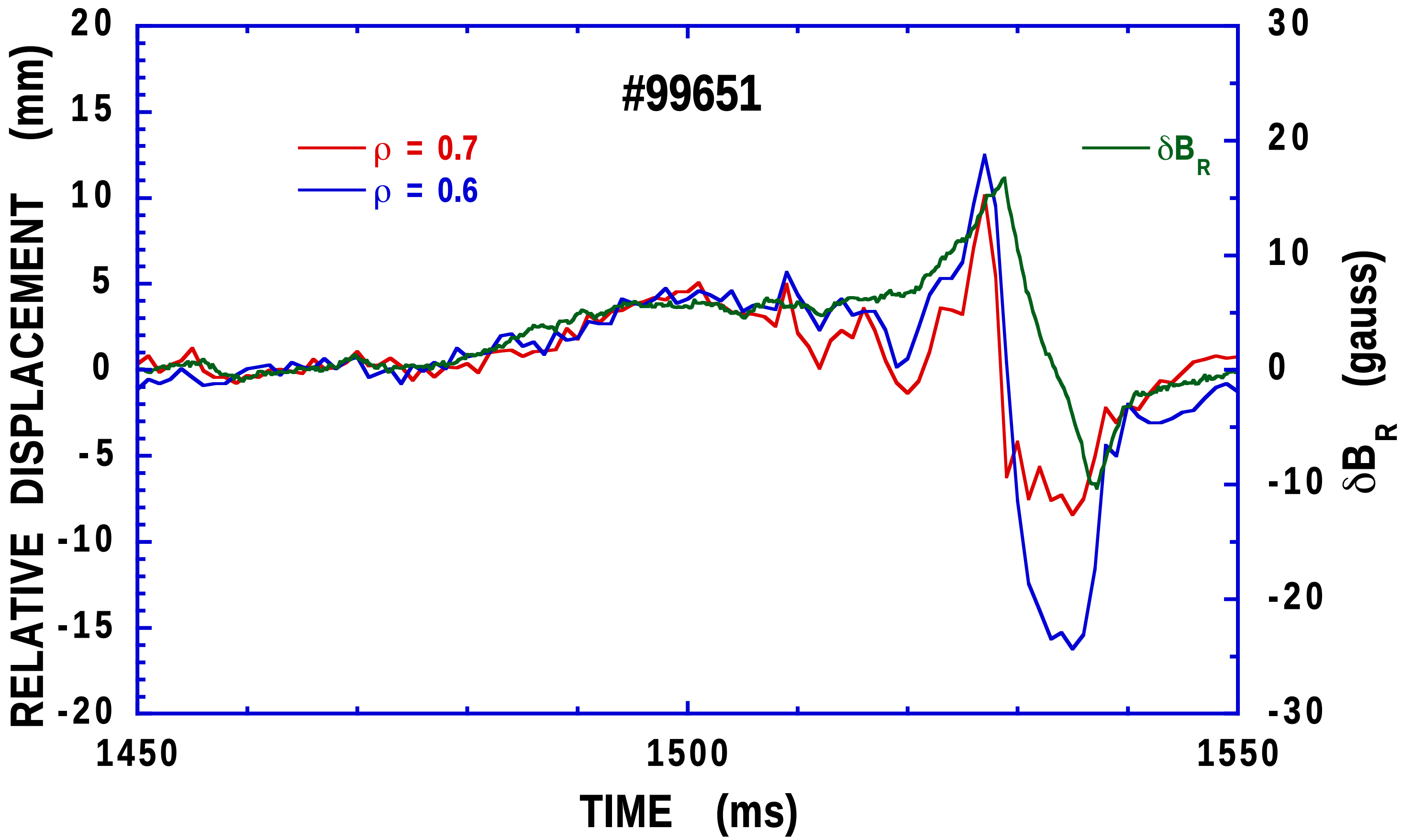
- The mode amplitude and phase deduced from saddle loops are used to calculate the radial magnetic perturbations expected at the toroidal locations of soft x-ray arrays (45° and 195°).
- Relative radial displacements between 45° and 195°, inferred from soft x-ray data, are compared with relative magnetic perturbations from saddle loops.
- Mode characteristics inferred from x-ray data are in very good agreement with magnetic data for a variety of feedback conditions.
  - Results are consistent with a slowly growing, slowly rotating n=1 mode.
  - An inferred displacement of ~2 mm corresponds to $\delta B_R \sim 3$ gauss at the saddle loops.

X-RAY AND MAGNETIC DATA FOR NO-FEEDBACK CASE



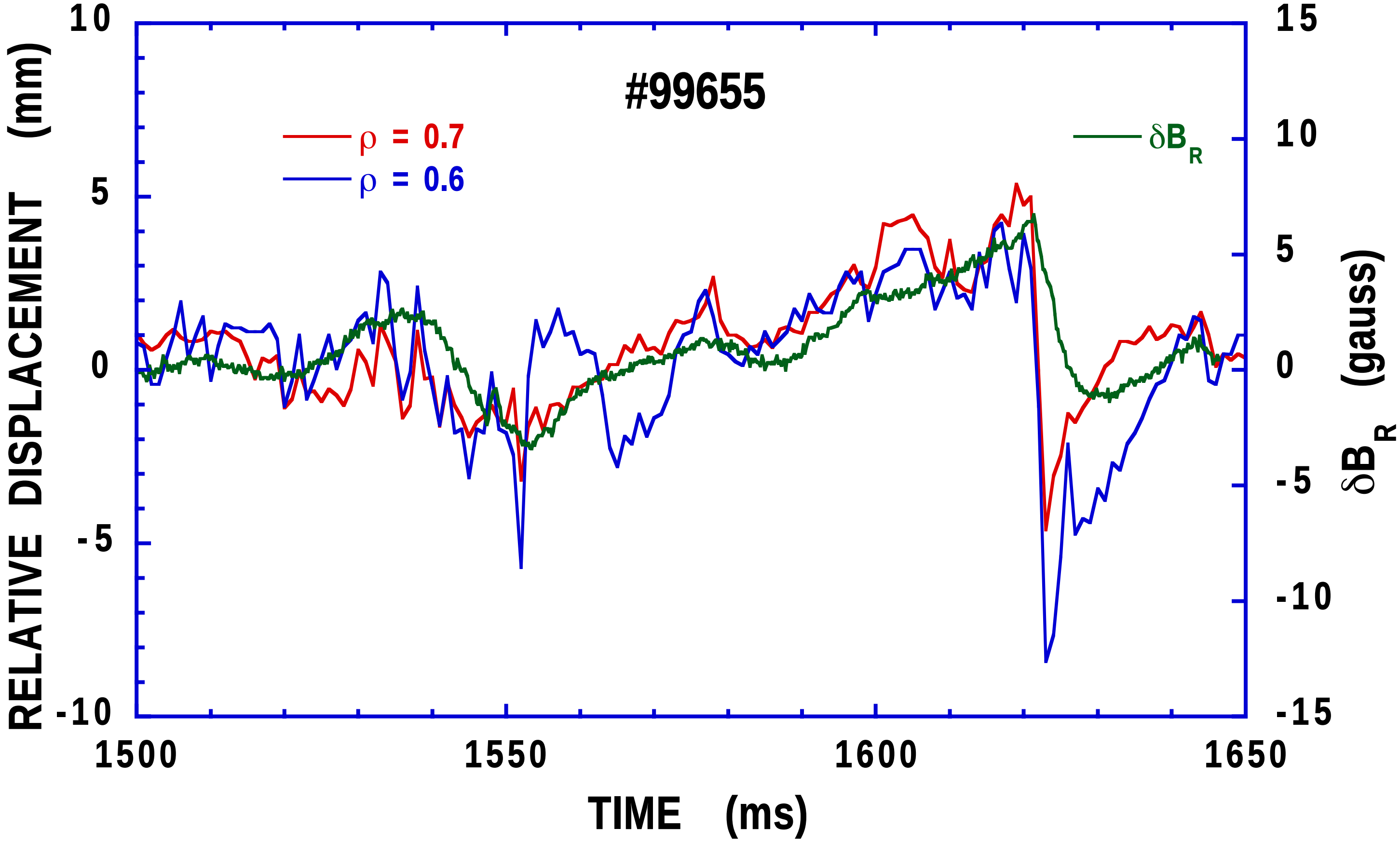
Relative plasma radial displacements between toroidal positions of 45° and 195°, deduced from soft x-ray data, for two values of ρ. The green curve shows the difference between radial magnetic perturbations at 45° and 195° deduced from saddle loops.

X-RAY AND MAGNETIC DATA FOR PROPORTIONAL GAIN CASE



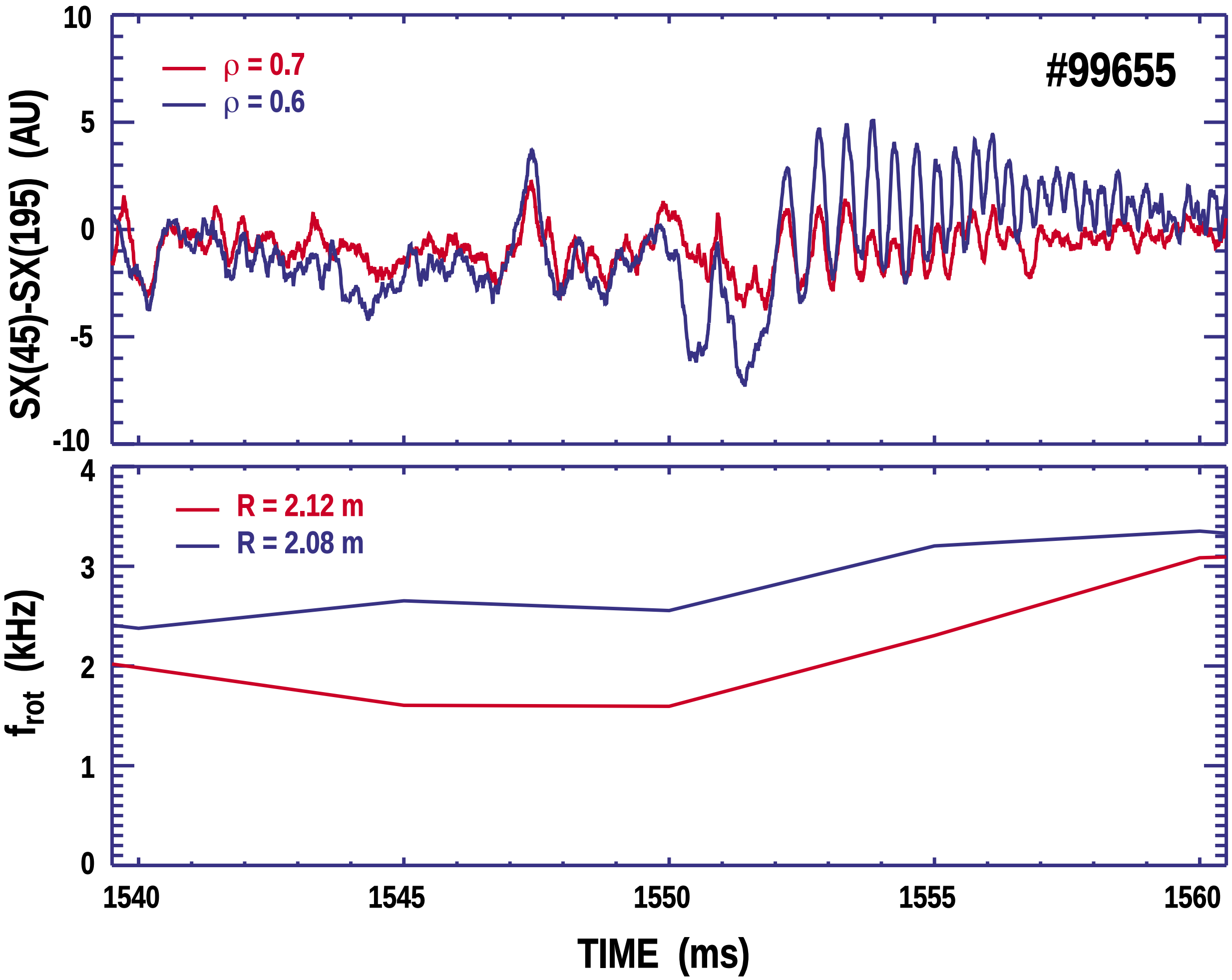
Relative plasma radial displacements between toroidal positions of 45° and 195°, deduced from soft x-ray data, for two values of ρ. The green curve shows the difference between radial magnetic perturbations at 45° and 195° deduced from saddle loops.

X-RAY AND MAGNETIC DATA FOR DERIVATIVE GAIN CASE



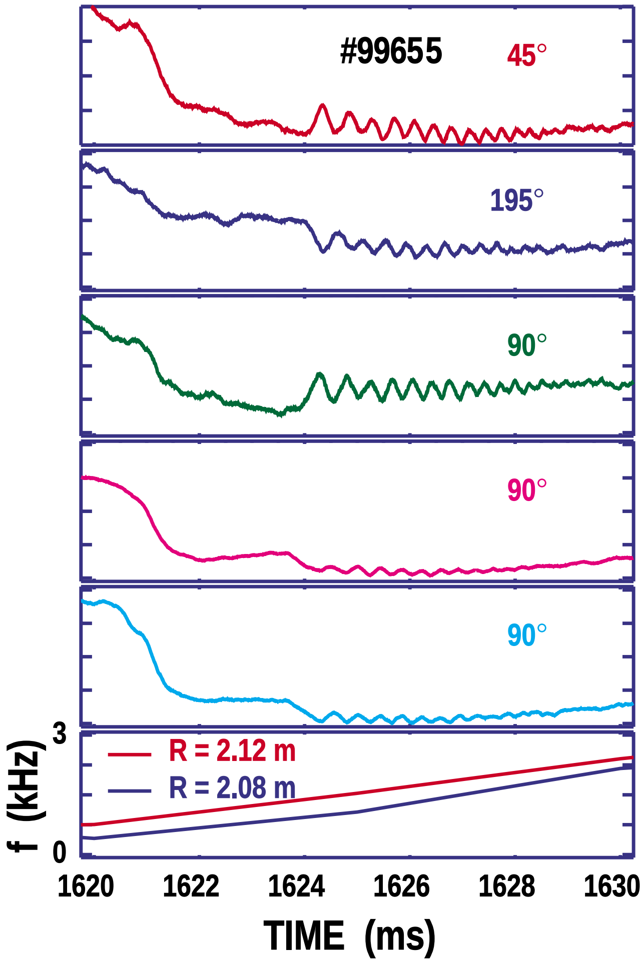
Relative plasma radial displacements between toroidal positions of 45° and 195°, deduced from soft x-ray data, for two values of ρ. The green curve shows the difference between radial magnetic perturbations at 45° and 195° deduced from saddle loops.

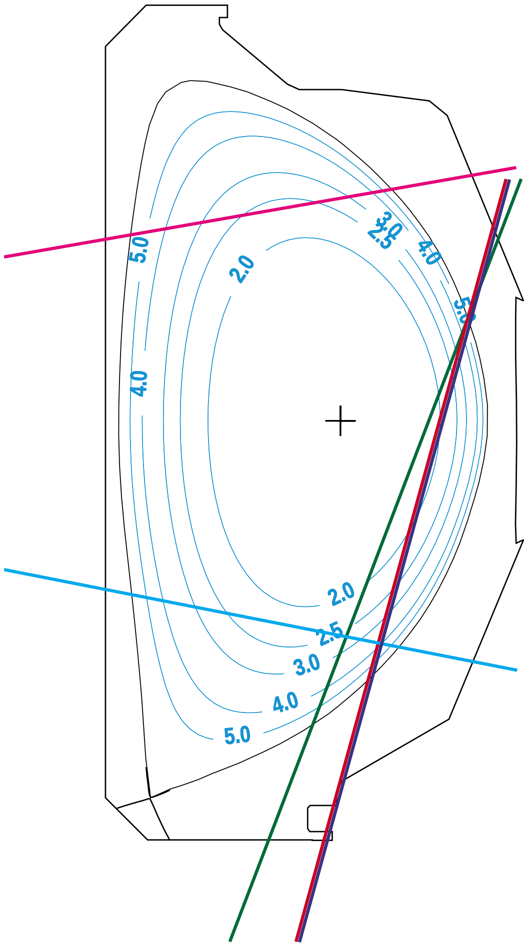
RWM IS OFTEN FOLLOWED BY DAMPED, ROTATING n=1 MODE



Onset of damped, rotating n=1 mode in shot 99655 after a minimum in plasma rotation frequency. Analysis of Mirnov data for the interval 1552-1557 ms indicates n=1,m=2 or 3, f=2.8 kHz, δB=5.7G.

X-RAY DATA CONSISTENT WITH m/n=2/1 ROTATING MODE AFTER RWM





X-ray data for shot 99655 for selected chords of poloidal arrays at toroidal angles of 45°, 90°, and 195°. A damped, rotating n=1 mode appears abruptly during recovery from resistive wall mode.

CONCLUSIONS

- Soft x-ray data from toroidal and poloidal arrays provide independent confirmation of resistive wall modes in DIII-D plasmas.
    - Chord-by-chord comparison of poloidal arrays separated toroidally by 150° show differences that correlate well with magnetic data.
    - The measurements confirm the slow growth and rotation and the n=1 characteristics deduced from saddle loops.
    - The measurements are consistent with a kink mode, with a displacement amplitude proportional to the amplitude of the magnetic perturbation.
- The measurements also frequently show the abrupt onset of a rotating n=1 mode as the plasma spins up during recovery from a resistive wall mode. The character of the mode is not yet clear.