STABILIZATION OF m=2/n=1 TEARING MODES BY ELECTRON CYCLOTRON CURRENT DRIVE IN THE DIII–D TOKAMAK

by
T.C. Luce
General Atomics

at 13th Joint Workshop on Electron Cyclotron Emission
and Electron Cyclotron Resonance Heating
Nizhny Novgorod, Russia

May 20, 2004

Acknowledgements: R.J. LaHaye, R. Prater, C.C. Petty, D.A. Humphreys

DIII–D
NATIONAL FUSION FACILITY
SAN DIEGO

124-04/rs

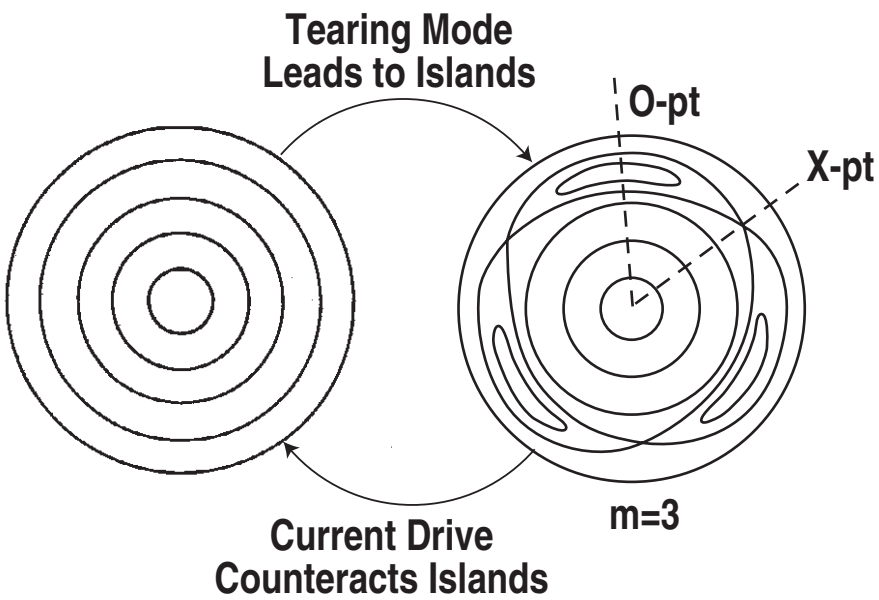
IMPORTANCE OF TEARING MODE STABILIZATION TO TOKAMAK BURNING PLASMA EXPERIMENTS

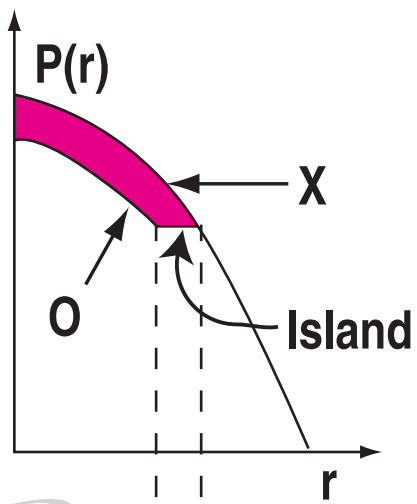
- For tokamak burning plasma experiments such as ITER, m=2/n=1 tearing modes represent the effective pressure limit for the baseline scenario. If these modes grow too large, the plasma will experience a major disruption, which has the potential to damage the tokamak or its internal components. Therefore, a system to stabilize these modes, if they occur, is the first line of defense against disruption-induced damage.

- Since the m=2/n=1 tearing mode is the effective limit in standard operation, improving the plasma performance requires avoiding these modes. Active control would be required with very high reliability.

- The prospect of using millimeter waves at the EC resonance for control of these modes is driving the physics and technology in all areas of interest to this meeting
  - High power, high frequency gyrotrons
  - Improvements in launcher design and control
  - Theory and experimental verification of ECCD in the vicinity of these modes
  - Real-time detection of mode size and location with ECE

CONCEPTUAL PICTURE OF TEARING MODE STABILIZATION BY CURRENT DRIVE



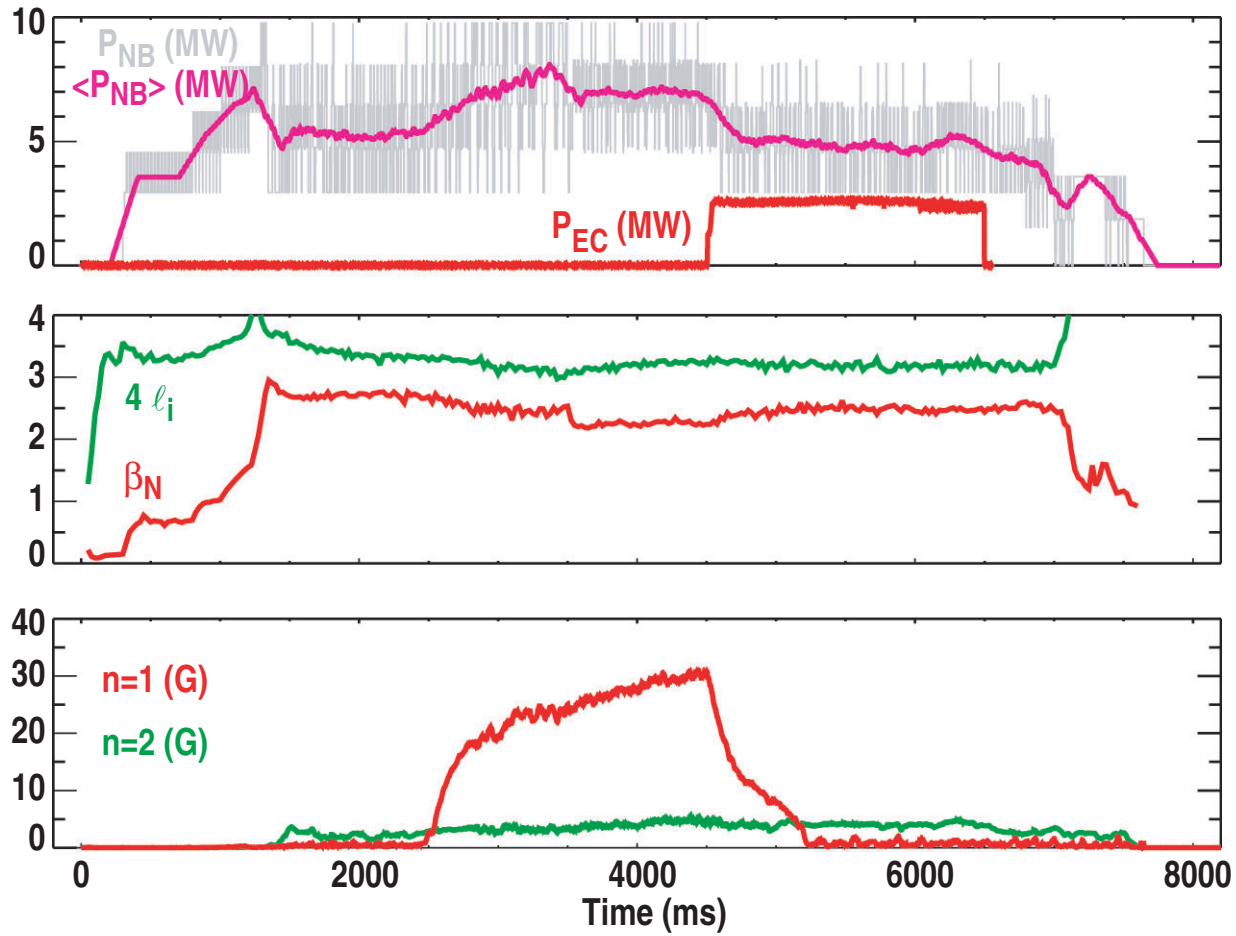


- For classical tearing modes, it is energetically favorable for the current on a rational surface to clump, with current perturbations in the direction opposite to the total current
- An additional destabilizing term occurs if the pressure is flattened in the island O point, leading to a local deficit in the bootstrap current
- Stabilization by current drive is achieved by replacing the “missing” current by a non-inductive source or by reducing the classical driving term

DIII-D NATIONAL FUSION FACILITY SAN DIEGO

124-04/rs

APPLICATION OF EC POWER IS EFFECTIVE FOR COMPLETE SUPPRESSION OF AN m=2/n=1 TEARING MODE



DIII-D NATIONAL FUSION FACILITY SAN DIEGO

124-04/rs

KEY POINTS FROM DIII–D EXPERIMENTS

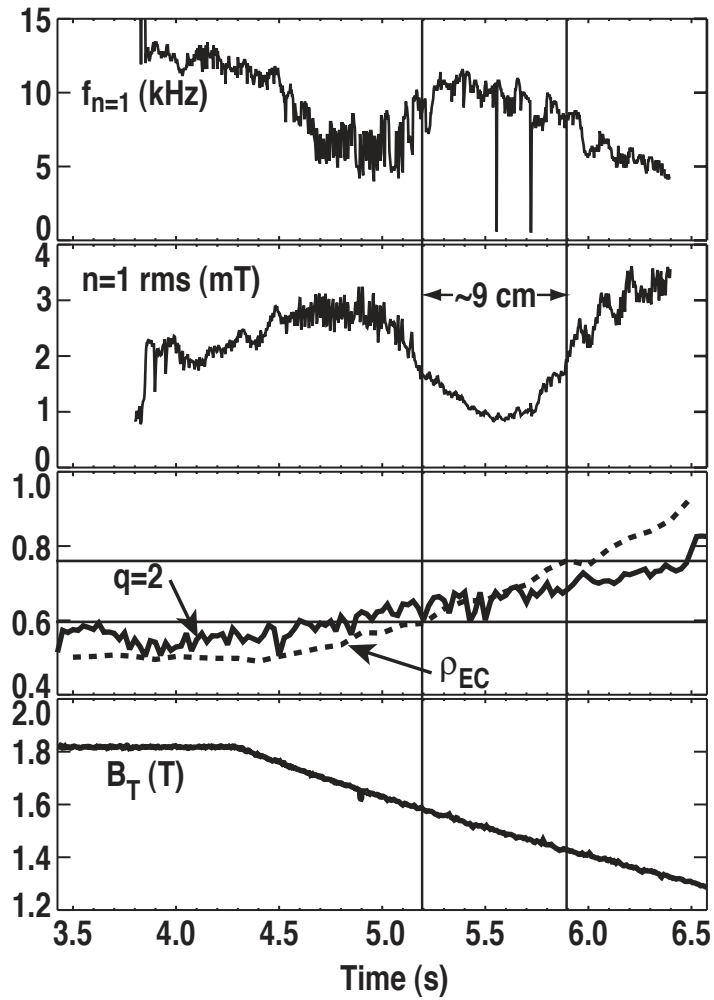
- m=2/n=1 tearing modes have been suppressed successfully by use of millimeter waves
- The suppression effect is localized, indicating:
  - ELMing H–mode edge does not disperse the beam
  - The mode itself does not spread the deposition
- The suppression effect is maximum when the deposition coincides with the island location
- The suppression effect is dominantly due to current drive rather than heating
- There is growing evidence that the modification of the classical driving term (Δ') is important

DIII–D NATIONAL FUSION FACILITY SAN DIEGO

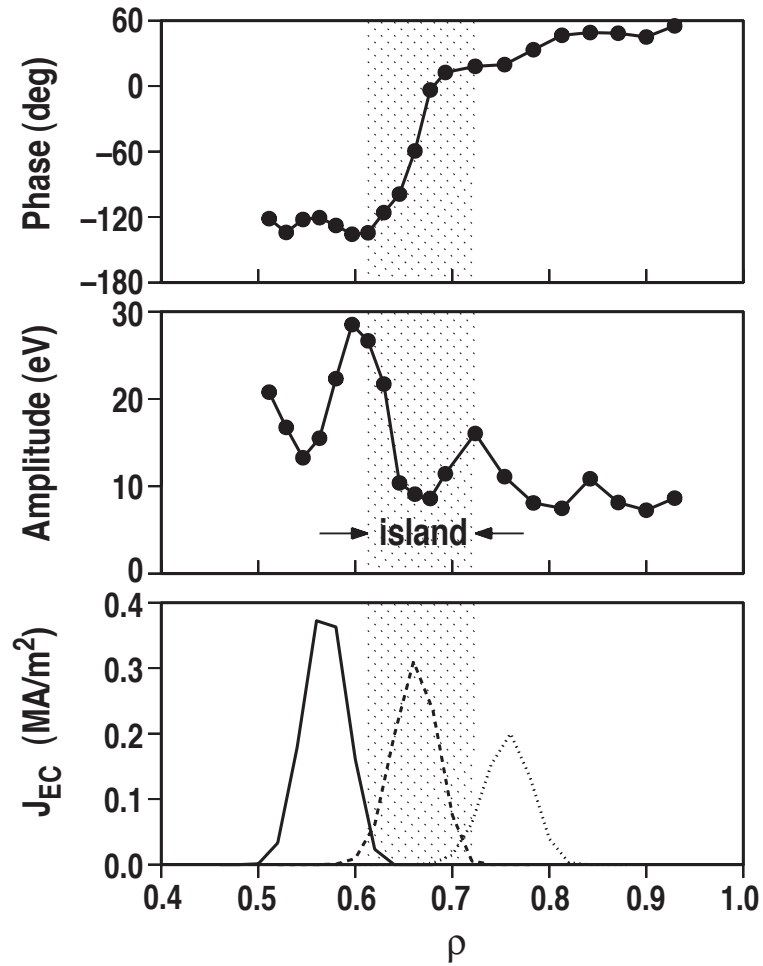
124-04/rs

ECCD HAS A LOCALIZED EFFECT ON THE m=2/n=1 TEARING MODE

Effect is on the order of the island size implying $\delta_{EC} < \delta_{21}$



Maximum effect occurs when the EC power is centered on the island

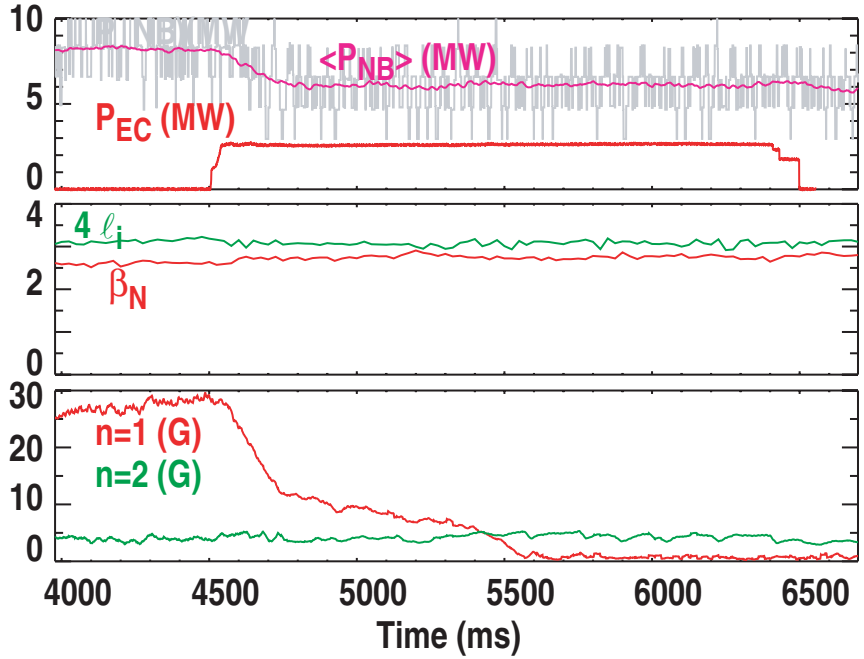


DIII-D NATIONAL FUSION FACILITY SAN DIEGO

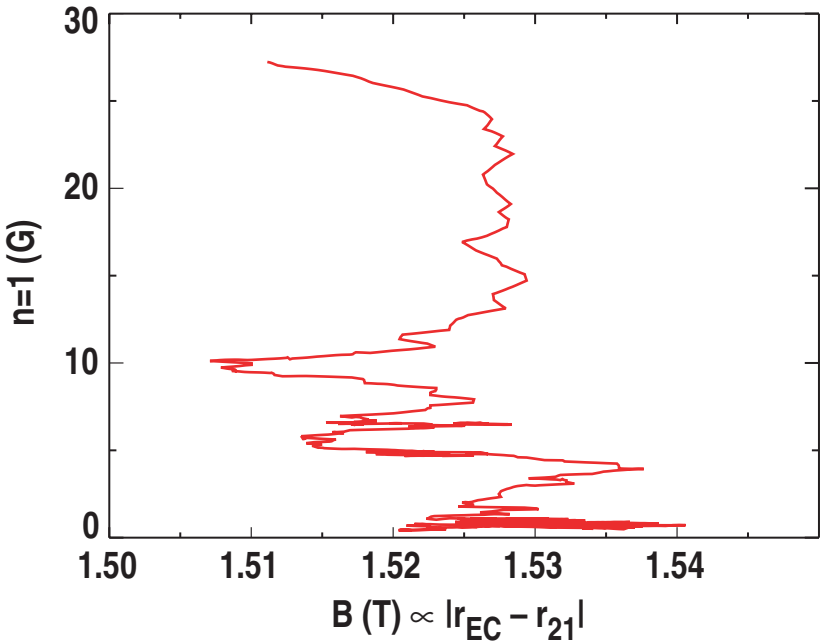
124-04/rs

m=2/n=1 TEARING MODE IS COMPLETELY SUPPRESSED AT HIGH β USING CLOSED-LOOP FEEDBACK TO OPTIMIZE THE ECCD LOCATION

Mode is suppressed at β well above ITER baseline scenario



"Target lock" algorithm uses small, rapid variations to optimize the suppression

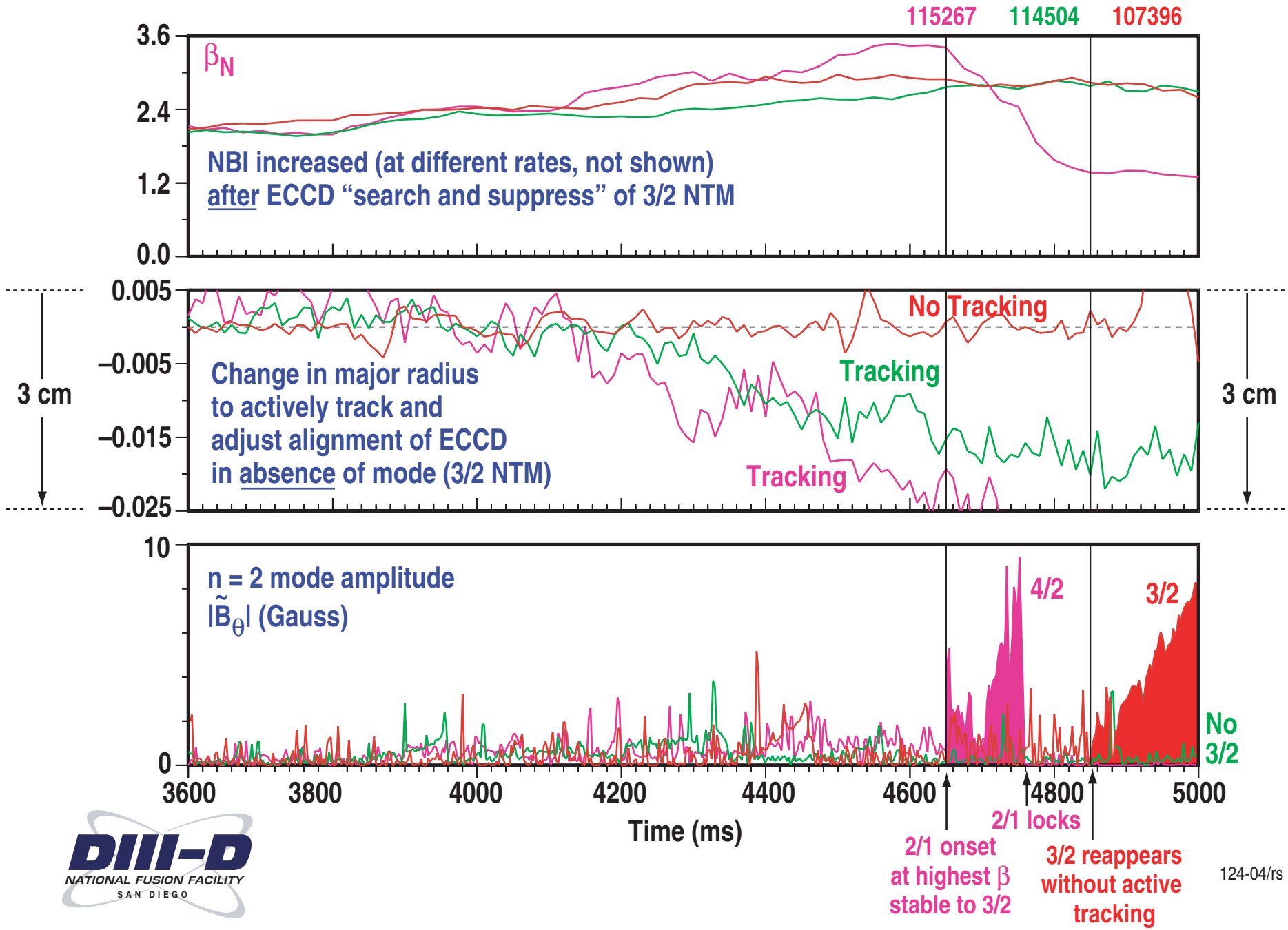


DIII-D NATIONAL FUSION FACILITY SAN DIEGO

124-04/rs

ACTIVE TRACKING ALLOWS HIGHER STABLE BETA TO 3/2 NTM

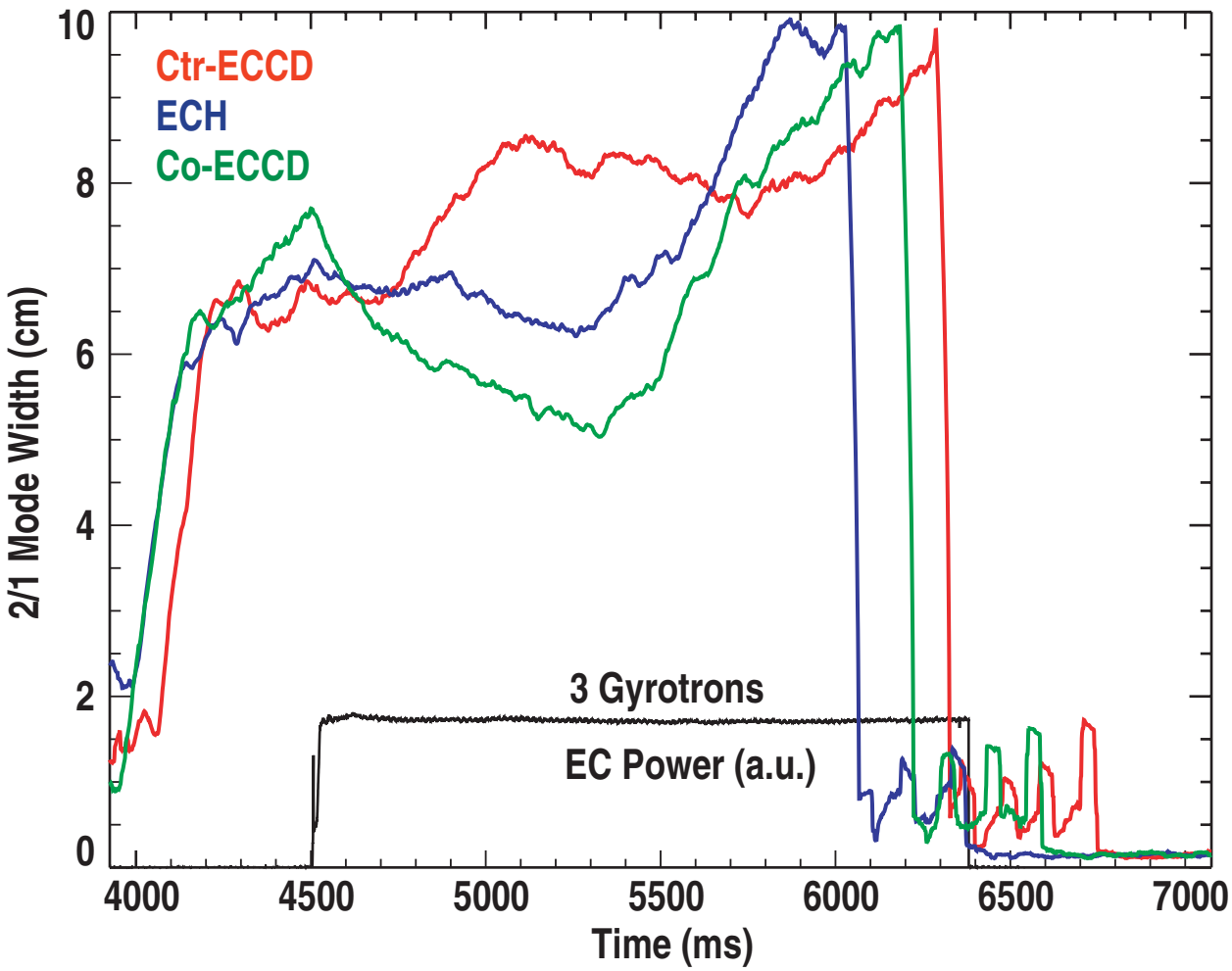
- Uses an adaptive learning network predictor based on previous experiments



DIII-D NATIONAL FUSION FACILITY SAN DIEGO

124-04/rs

THE DOMINANT INTERACTION OF THE EC POWER WITH THE TEARING MODE IS THROUGH CURRENT DRIVE

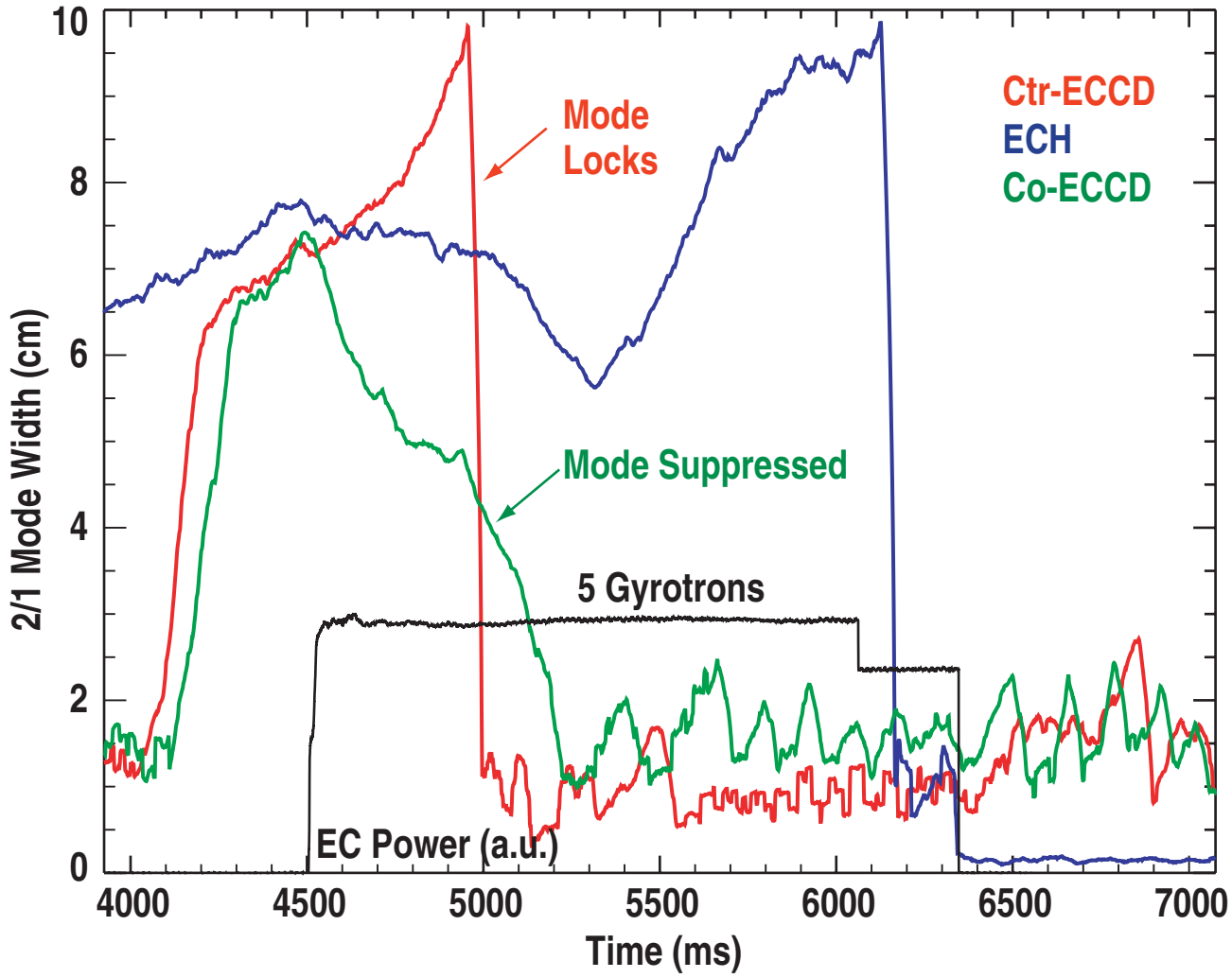


- Relative location of the deposition and the mode is changed by a continuous variation of the toroidal magnetic field

DIII-D NATIONAL FUSION FACILITY SAN DIEGO

124-04/rs

AT HIGHER POWER, COMPLETE SUPPRESSION OR MODE LOCKING IS OBSERVED, DEPENDING ON THE CURRENT DRIVE DIRECTION



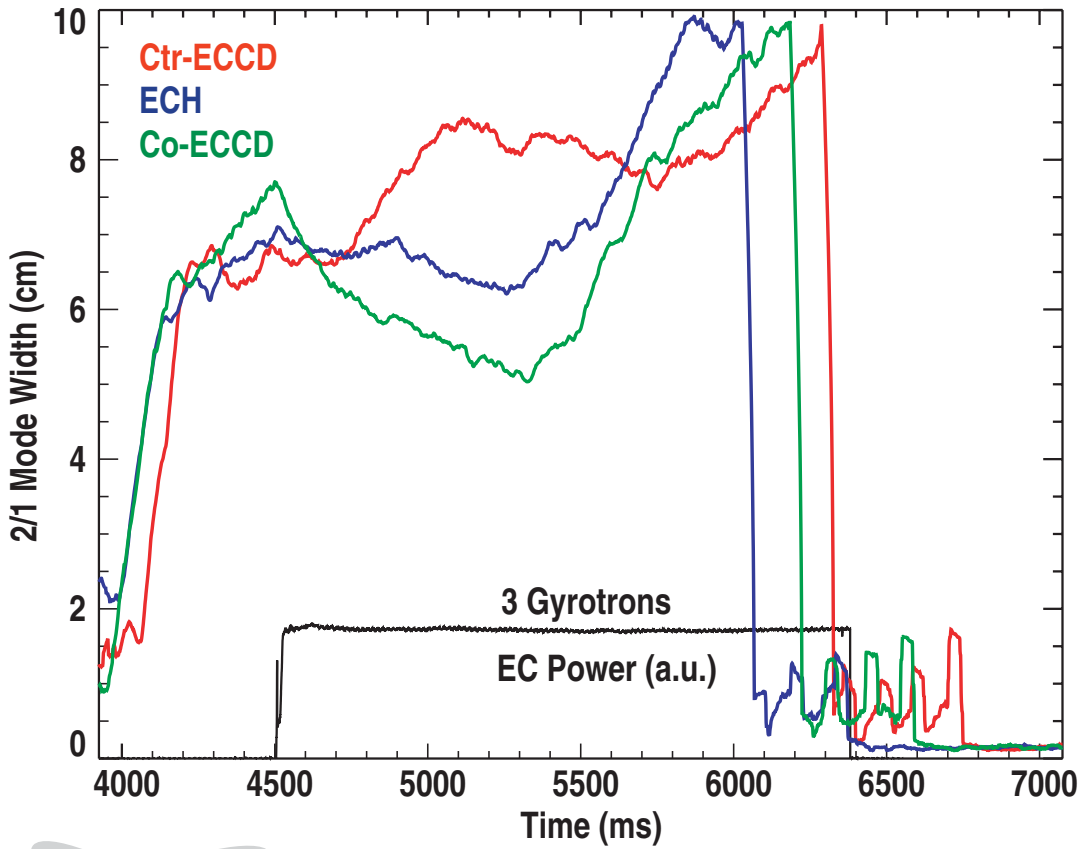
DIII-D
NATIONAL FUSION FACILITY
SAN DIEGO

124-04/rs

POSSIBLE EVIDENCE FOR THE IMPORTANCE OF CHANGE IN Δ´ FOR SUPPRESSION

Change in Mode Width — Classical TM Drive — Neoclassical Drive — ECCD Stabilization

$$\frac{dw}{dt} = \overbrace{f\,\Delta'} + g\left[\frac{r_{21}}{w} - h\left(|r_{EC} - r_{21}|\right)\frac{j_{EC}}{j_{BS}}\right]\beta_p$$



- Shift of maximum response from co-ECCD to ctr-ECCD
- Asymmetry of response around the maximum

DIII-D NATIONAL FUSION FACILITY SAN DIEGO

124-04/rs

CONCLUSIONS

- A complete system for tearing mode suppression has been demonstrated in DIII–D
- Extrapolation to ITER for both hardware and physics remains challenging
- For optimized mode suppression:
  - Feedback control of resonance location relative to the mode is required
  - Co-ECCD is required
  - Localized ECCD is required (has implications for launcher design and gyrotron frequency choice)
- For operation in the unstable region, a predictive model for choosing the deposition location is required