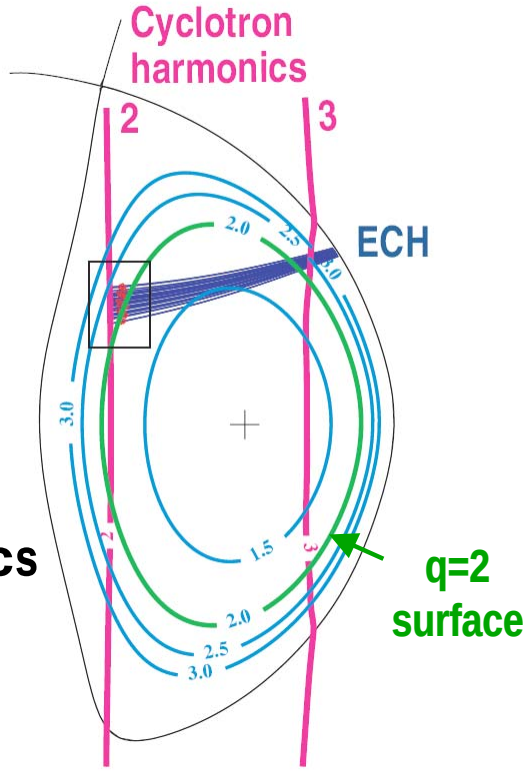
Locked Neoclassical Tearing Mode Control on DIII-D by Electron Cyclotron Current Drive and Magnetic Perturbations

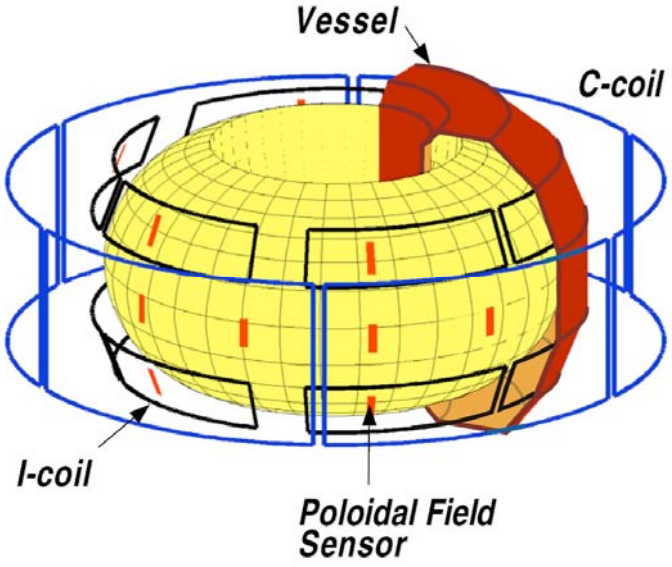
By
Francesco Volpe

With
R.J. La Haye, R. Prater, E.J. Strait

Presented at
Forty-Ninth APS Meeting of
the Division of Plasma Physics
Orlando, Florida

November 12–16, 2007





DIII-D NATIONAL FUSION FACILITY SAN DIEGO

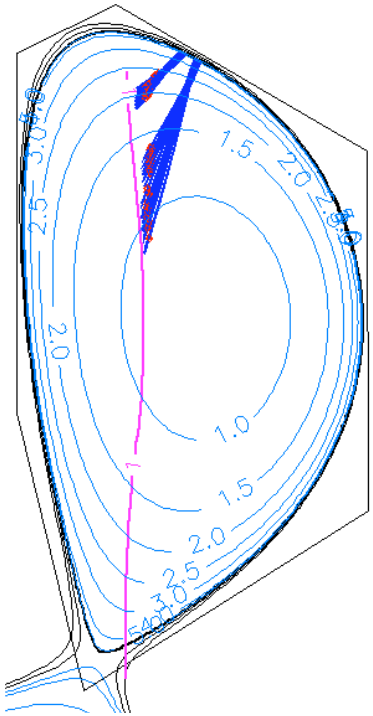
ORAU OAK RIDGE ASSOCIATED UNIVERSITIES

Motivation

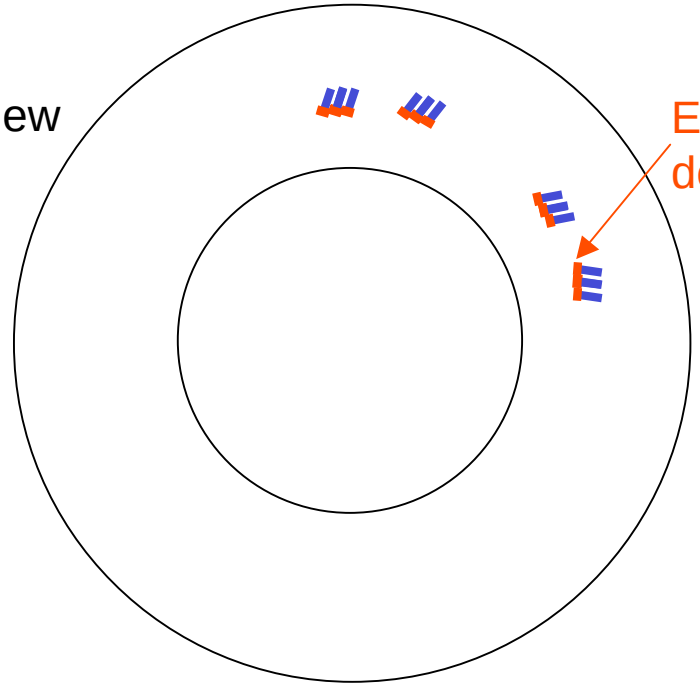
- **Locking of 2/1 Tearing Mode very likely in ITER (due to reduced NBI torque and consequent low rotation)**
- **Locking is a recurrent cause of disruptions**

- **ECCD suppresses *rotating* NTMs**
- **However, island can lock in a position not accessible by ECCD:**

Poloidal section



Top View

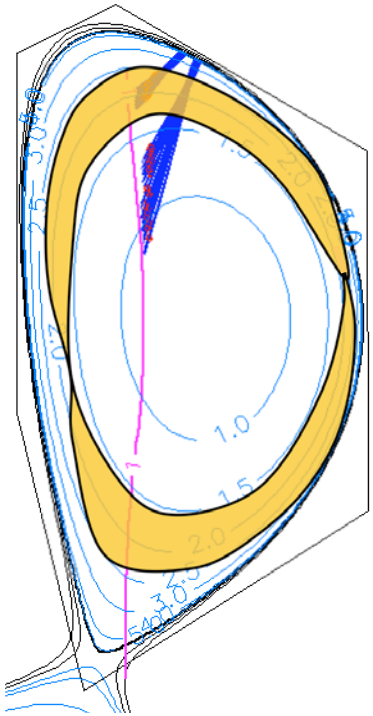


Motivation

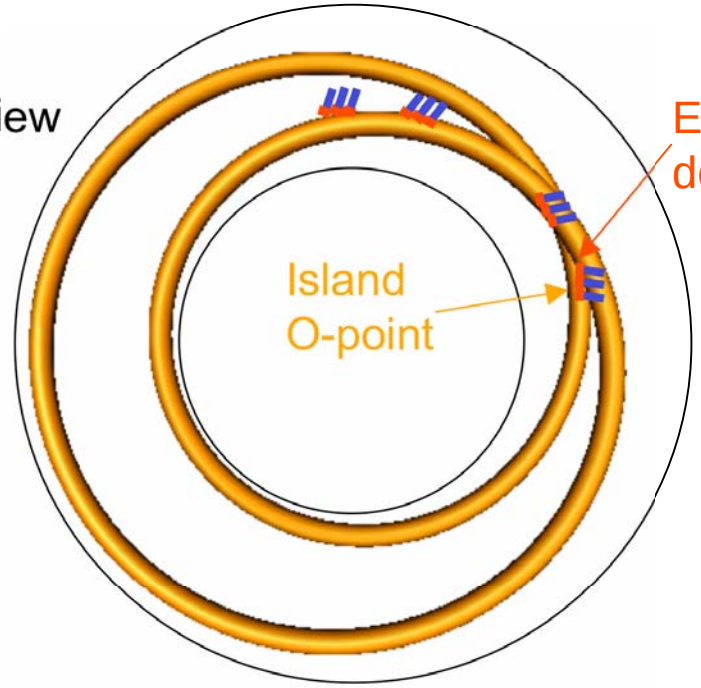
- **Locking of 2/1 Tearing Mode very likely in ITER (due to reduced NBI torque and consequent low rotation)**
- **Locking is a recurrent cause of disruptions**

- **ECCD suppresses *rotating* NTMs**
- **However, island can lock in a position not accessible by ECCD:**

Poloidal section



Top View

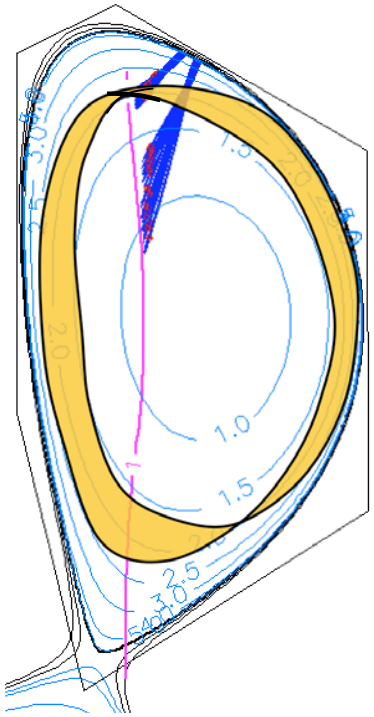


Motivation

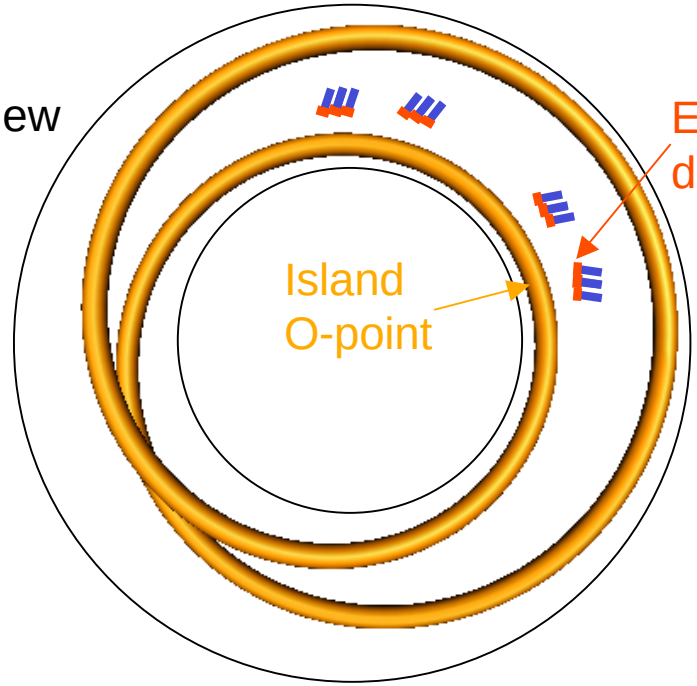
- **Locking of 2/1 Tearing Mode very likely in ITER (due to reduced NBI torque and consequent low rotation)**
- **Locking is a recurrent cause of disruptions**

- **ECCD suppresses *rotating* NTMs**
- **However, island can lock in a position not accessible by ECCD:**

Poloidal section



Top View



Magnetic Perturbations Can Unlock and Reposition or Spin the Mode and So Assist Its ECCD Control

Bootstrap deficit → island ≅ wire carrying ctr-current → wire can be moved by external B

Approach 1 ("preferential locking"):
Island is dragged into a new position accessible by gyrotrons.
ECCD: CW

Approach 2 ("sustained rotation" or "entrainment"):
Externally applied rotating B unlocks the mode and forces it to rotate.
ECCD: CW or modulated

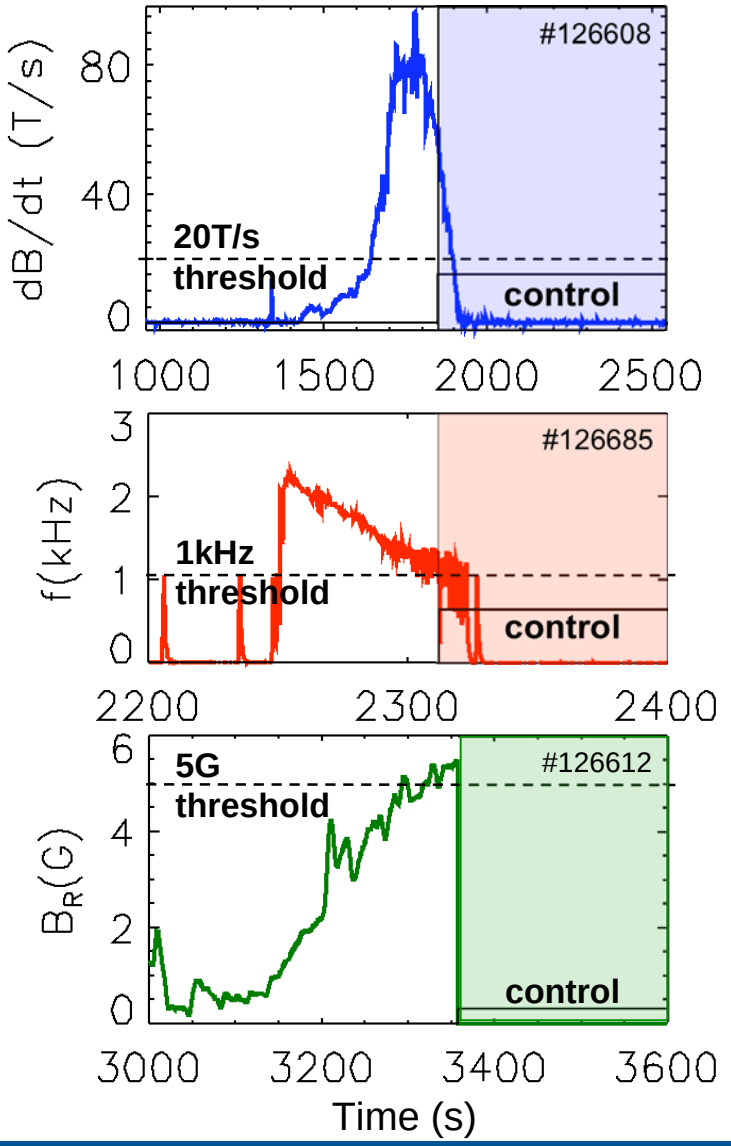
Both Approaches can also be applied pre-emptively, for Locked Mode Avoidance

Magnetic Measurements Detect Locked Mode or Imminent Locking and Trigger Response

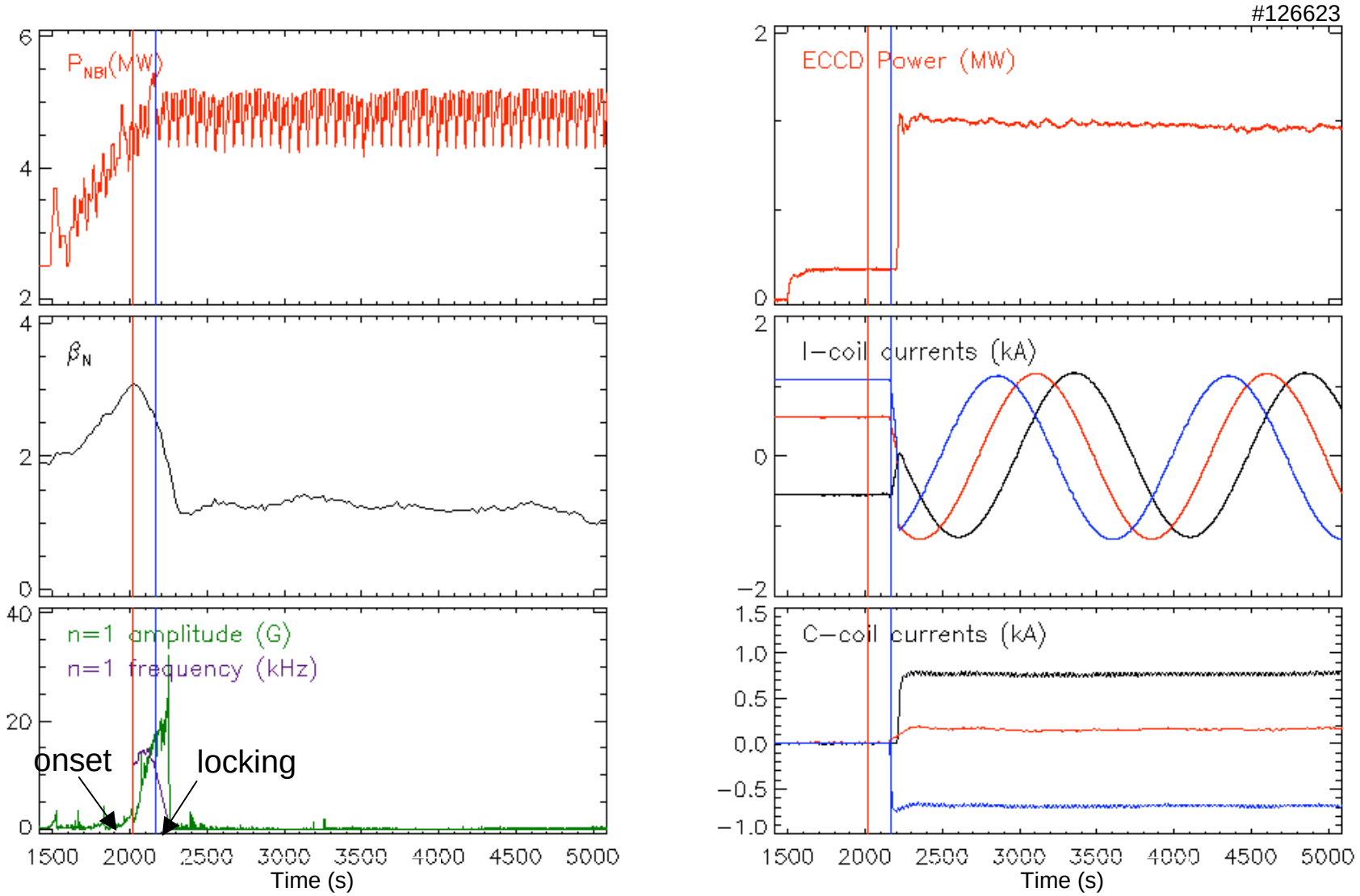
Mirnov Coils (poloidal field sensors)
measure mode amplitude at >100Hz

Mirnov Coils+Frequency Counter
measure angular frequency of mode, detect slowing down

Saddle loops (radial field sensors)
measure mode amplitude at <100Hz. Suitable for "born locked" modes



Slowly Rotating Field Used to Drag Plasma and Toroidally Align Island to ECCD

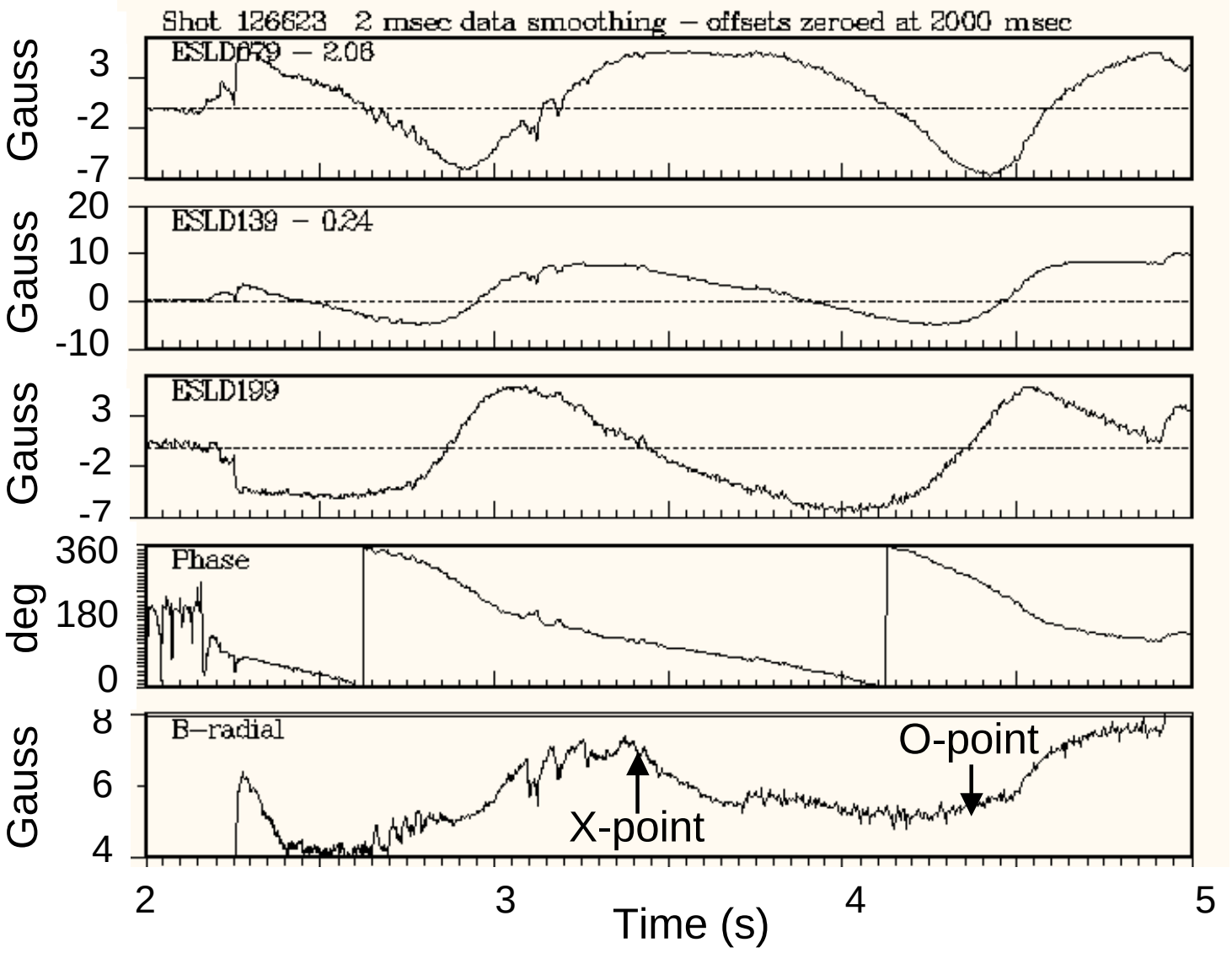


The Island, Rotated by Magnetic Perturbations and Illuminated by ECCD, Changes Amplitude

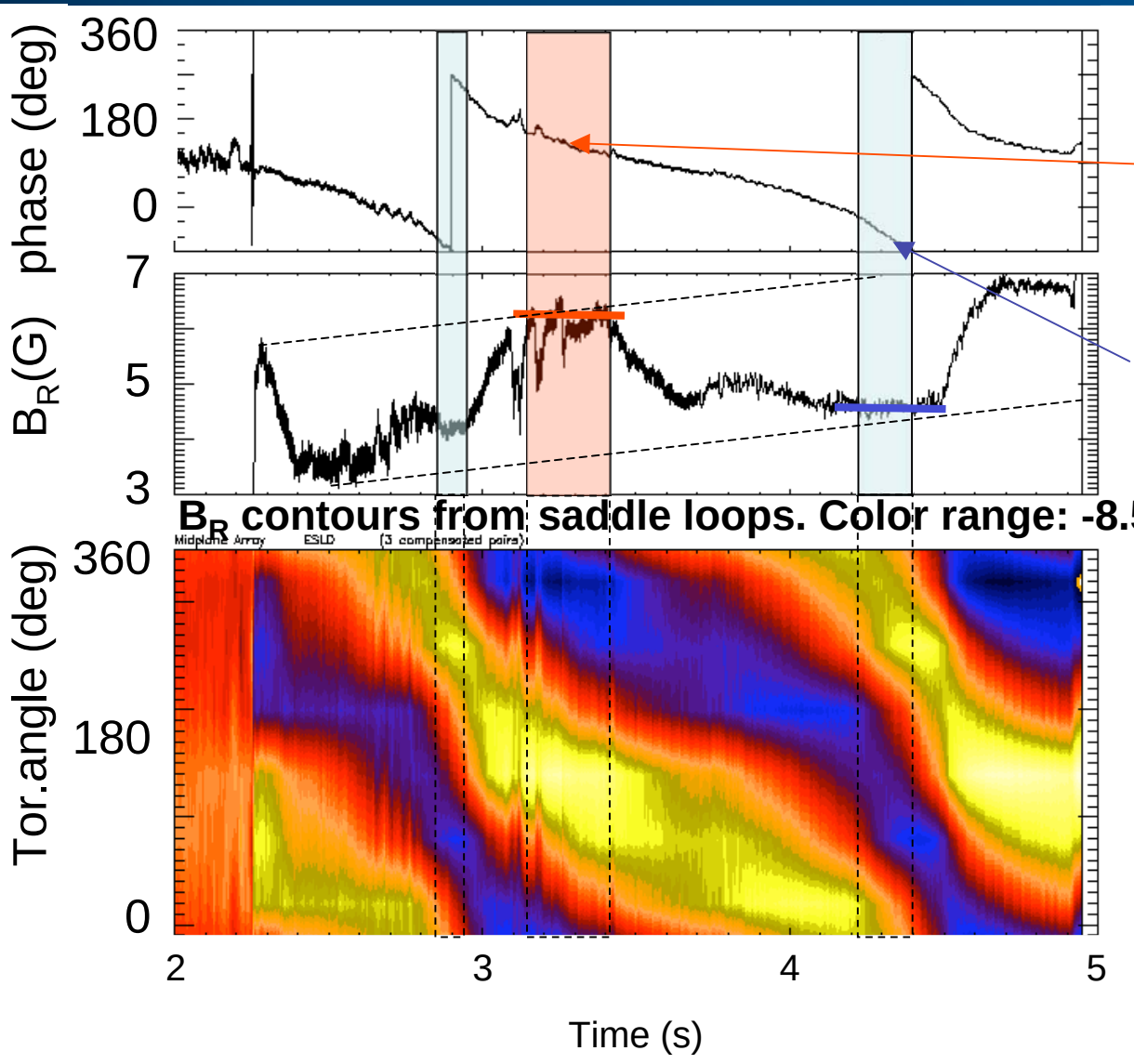
B_R as measured by pairs of Saddle Loops in 3 different toroidal locations

n=1 toroidal phase

n=1 "absolute" amplitude of island varies B_R=4-7.5G



Subtraction of Vacuum Field Confirms That Locked Mode Changes Amplitude When Toroidally Steered in Presence of ECCD

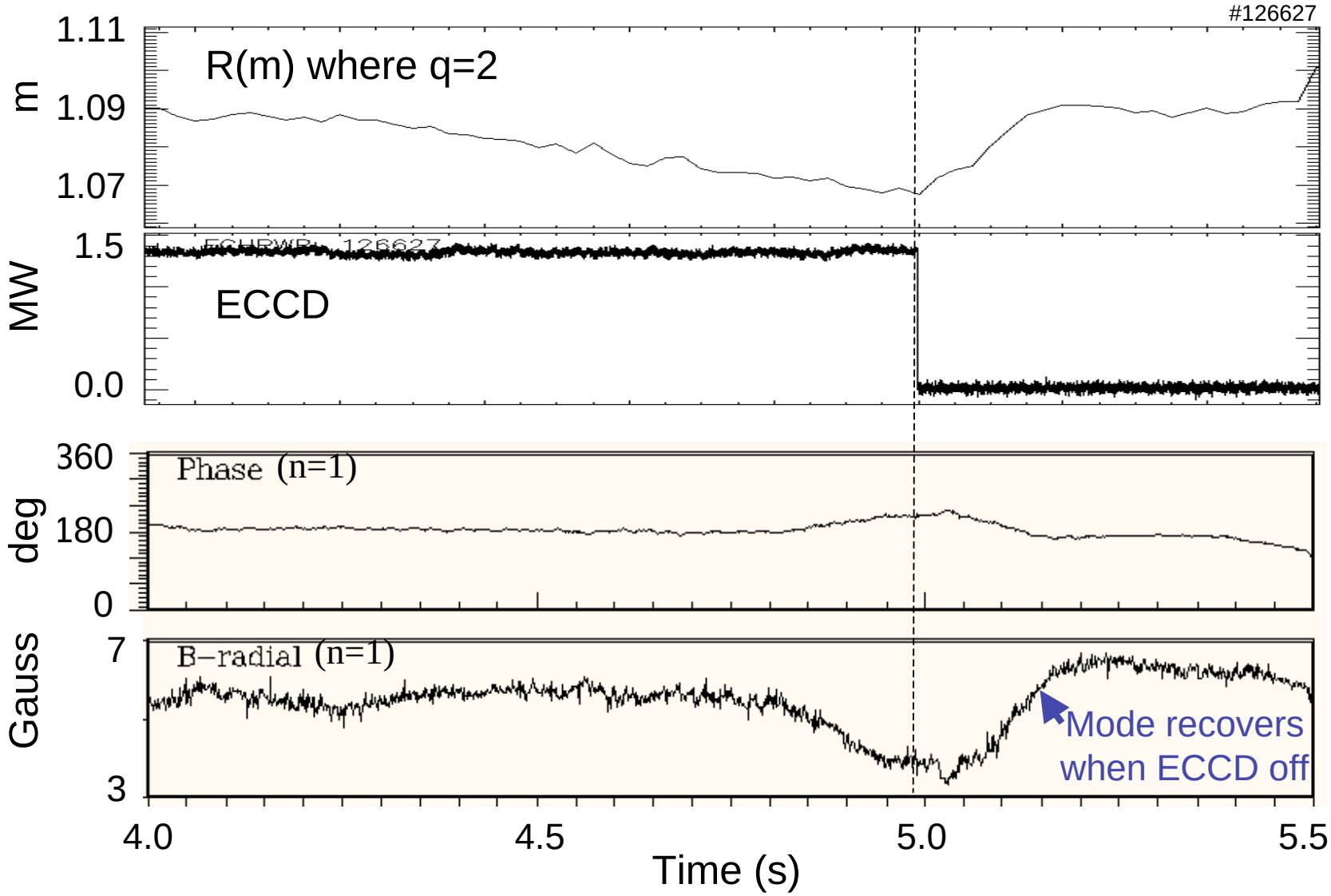


Strong mode ⇒ strong magn.braking ⇒ slow rotation

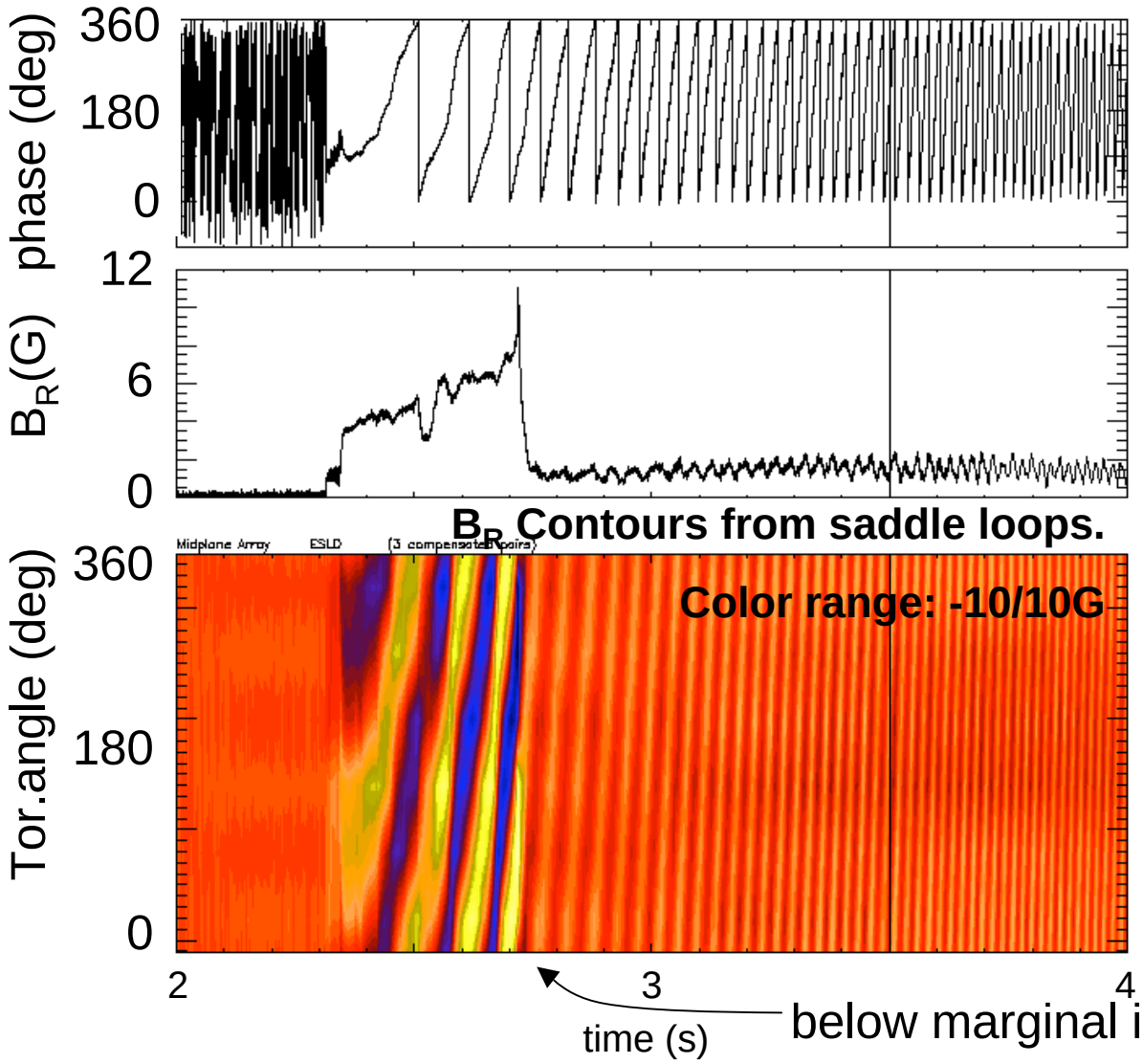
Weak mode ⇒ less braking ⇒ faster rotation

DIII-D NATIONAL FUSION FACILITY

Radial Jog of Plasma at Fixed Optimum Phase for O-Point: Mode Amplitude Decreases With ECCD Aligned, Increases When ECCD is off



Proof of Principle of Fast Sustained Rotation
No ECCD Yet



Several applications of sustained mode rotation:

- Prevents further locking
- Rotational mitigation
- Brings *locked* mode case in well-studied *rotating* NTM case
- Synchronizes and phase-locks the mode rotation to the ECCD modulation. Easier than adapting ECCD to natural mode rotation

Summary and Conclusions

- **Demonstrated "Preferential Locking" of NTM to a (static) toroidal phase such that it can be accessed by ECCD for stabilization**
- **Optimal *toroidal* phase was found by slowly steering the mode (0.66Hz) while applying cw ECCD**
- **ECCD *radially* aligned to locked island as to rotating ones**
- **Reduction of mode amplitude from 6 to 3G with 1.2MW ECCD**
  - **Future work: more power and good alignment for t>400ms**

- **Sustained Mode Rotation up to 60Hz by means of I-coil travelling wave**
- **Travelling wave needs to be applied gently (0-60Hz ramp in 1s)**
  - **Future work: add ECCD, modulated at frequency and phase of applied rotation**