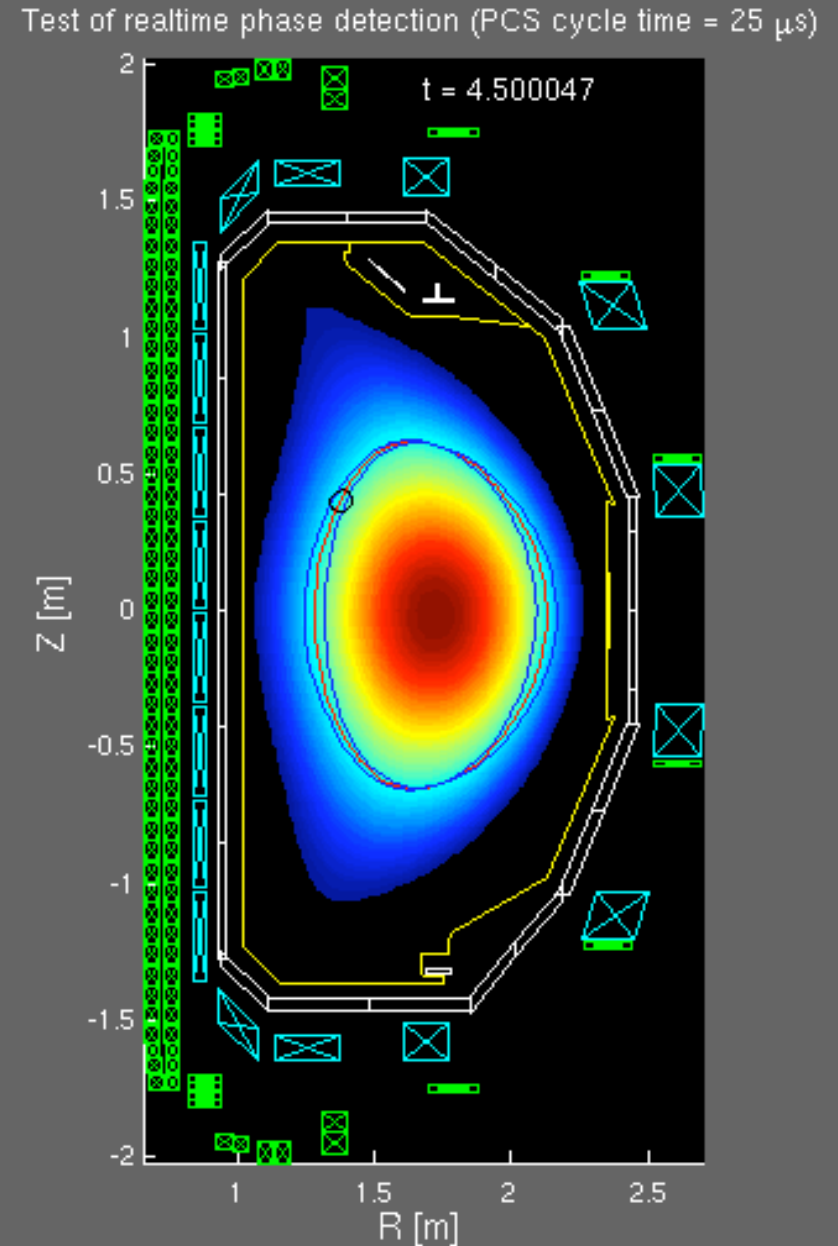# Neoclassical Tearing Mode Control With Modulated Electron Cyclotron Current Drive in DIII-D

Presented by
A.S. Welander for the DIII-D NTM Control for ITER Thrust
General Atomics

48th APS/DPP Meeting
Philadelphia, Pennsylvania
Oct. 30-Nov. 3, 2006

DIII-D NATIONAL FUSION FACILITY

GENERAL ATOMICS

Neoclassical Tearing Modes Destabilized by Helically Perturbed Bootstrap Current

- **Pressure is flattened at O-point, but not at X-point**
  - ★ thus a helically perturbed bootstrap current reinforces the "seed"
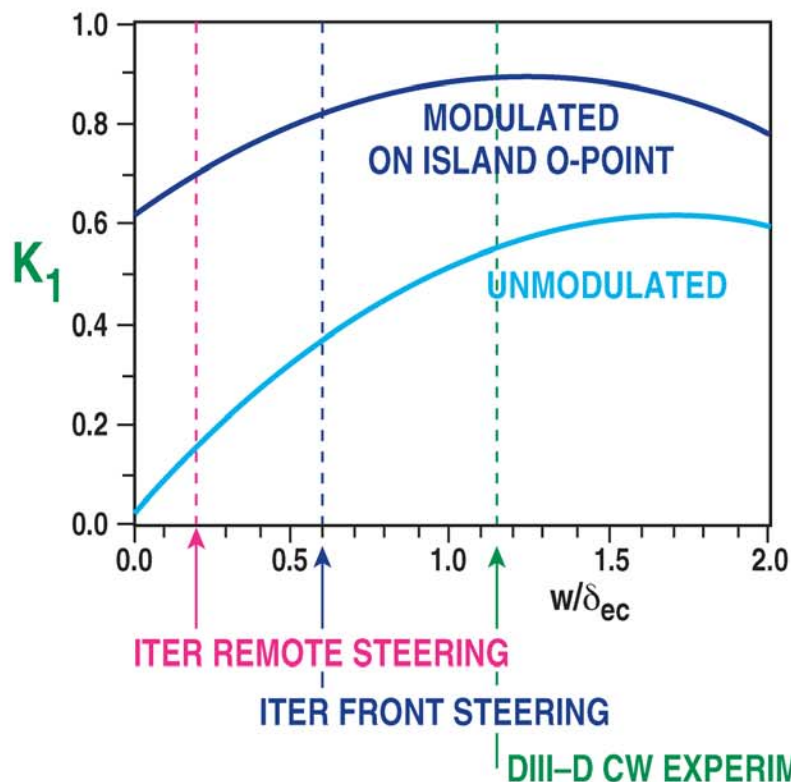   … a destabilizing effect that can lower the plasma magnetic energy
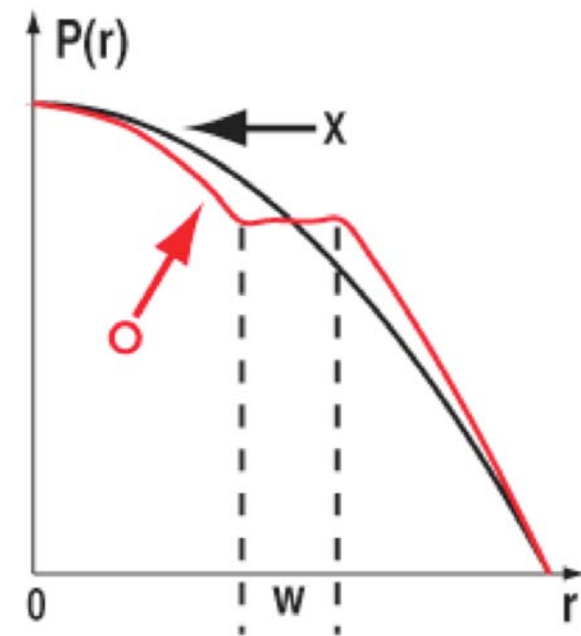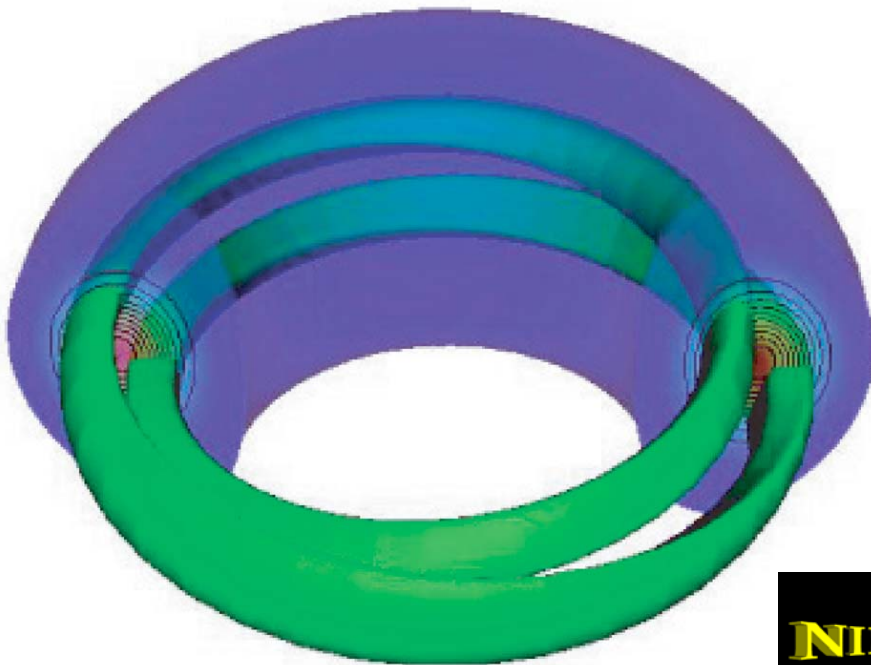
ECCD Can Stabilize Neoclassical Tearing Modes by Replacing Missing Bootstrap Current

$$\frac{\tau_R}{r}\frac{dw}{dt} = \Delta'_0 r + \underbrace{\delta\Delta' r}_{\substack{\text{ECCD}\\\text{changes }\Delta'}} + a_2 \frac{j_{bs}}{j_{\parallel}}\frac{L_q}{w}\left[1 - \frac{w^2_{marg}}{3\,w^2} - \underbrace{K_1 \frac{j_{ec}}{j_{bs}}}_{\substack{\text{ECCD replaces}\\\text{missing bootstrap current}}}\right]$$

"effectiveness" K_1

Modified Rutherford Eqn. for stability

MODULATED ON ISLAND O-POINT

UNMODULATED

K_1

w/δ_{ec}

ITER REMOTE STEERING

ITER FRONT STEERING
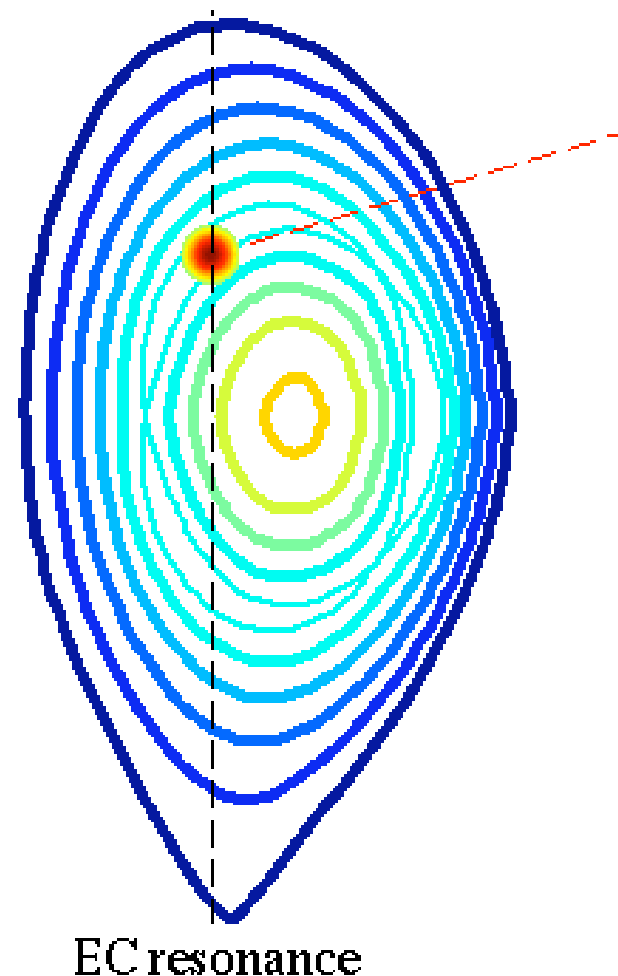
DIII–D CW EXPERIMENTS

- for $w/\delta_{ec} \ll 1$, modulation is desirable
  - ★ as stabilizing cw ECCD on O–point ... nearly cancelled by destabilizing on X-point
  - ★ for $w/\delta_{ec} > 1$ the effectiveness is comparable w/wo modulation

(Hegna & Callen 97, Zohm 97, Perkins et al, 97)

DIII–D
NATIONAL FUSION FACILITY

Accurate Alignment of ECCD to Resonant Surface Prerequisite for NTM Suppression
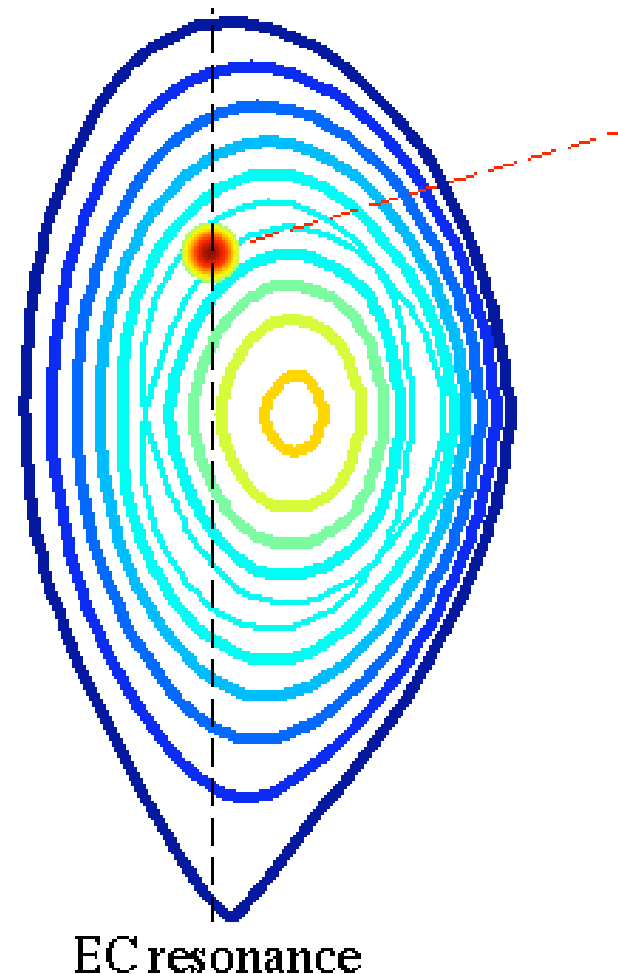
Deposition aligned to island by:

- Moving plasma

  (rigid shift, fixed strike points)

- Moving deposition along beam

  (by changing the toroidal field)

- Moving beam vertically

  (with steerable mirror)

EC resonance

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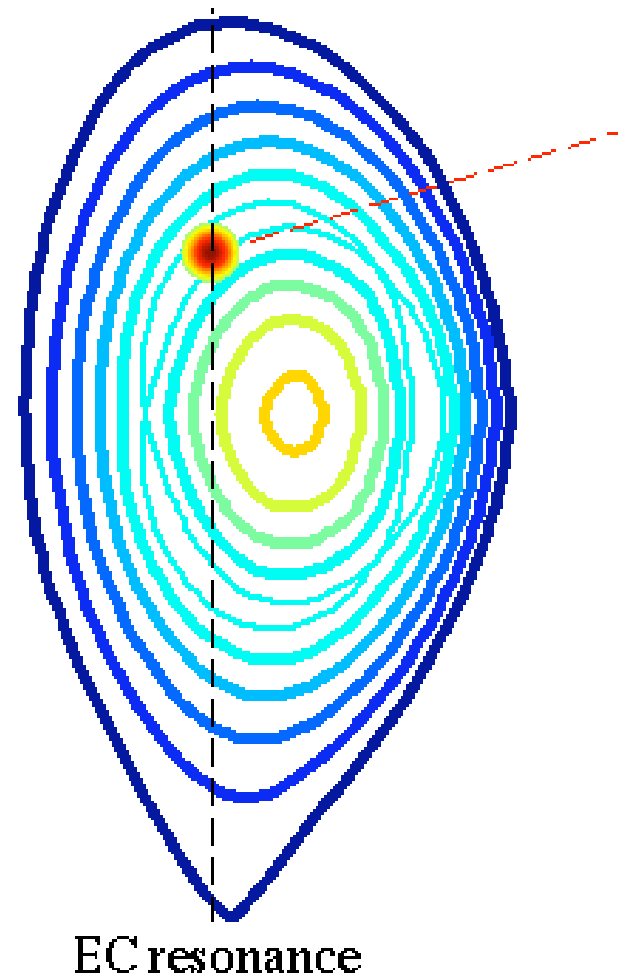
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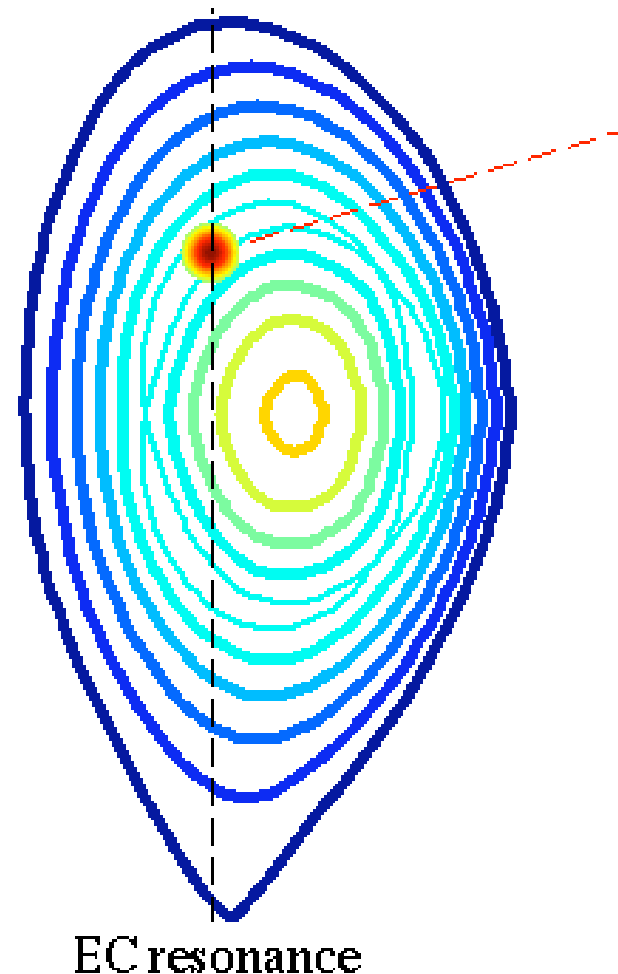

Moving ECCD along beam

EC resonance

Accurate Alignment of ECCD to Resonant Surface Prerequisite for NTM Suppression
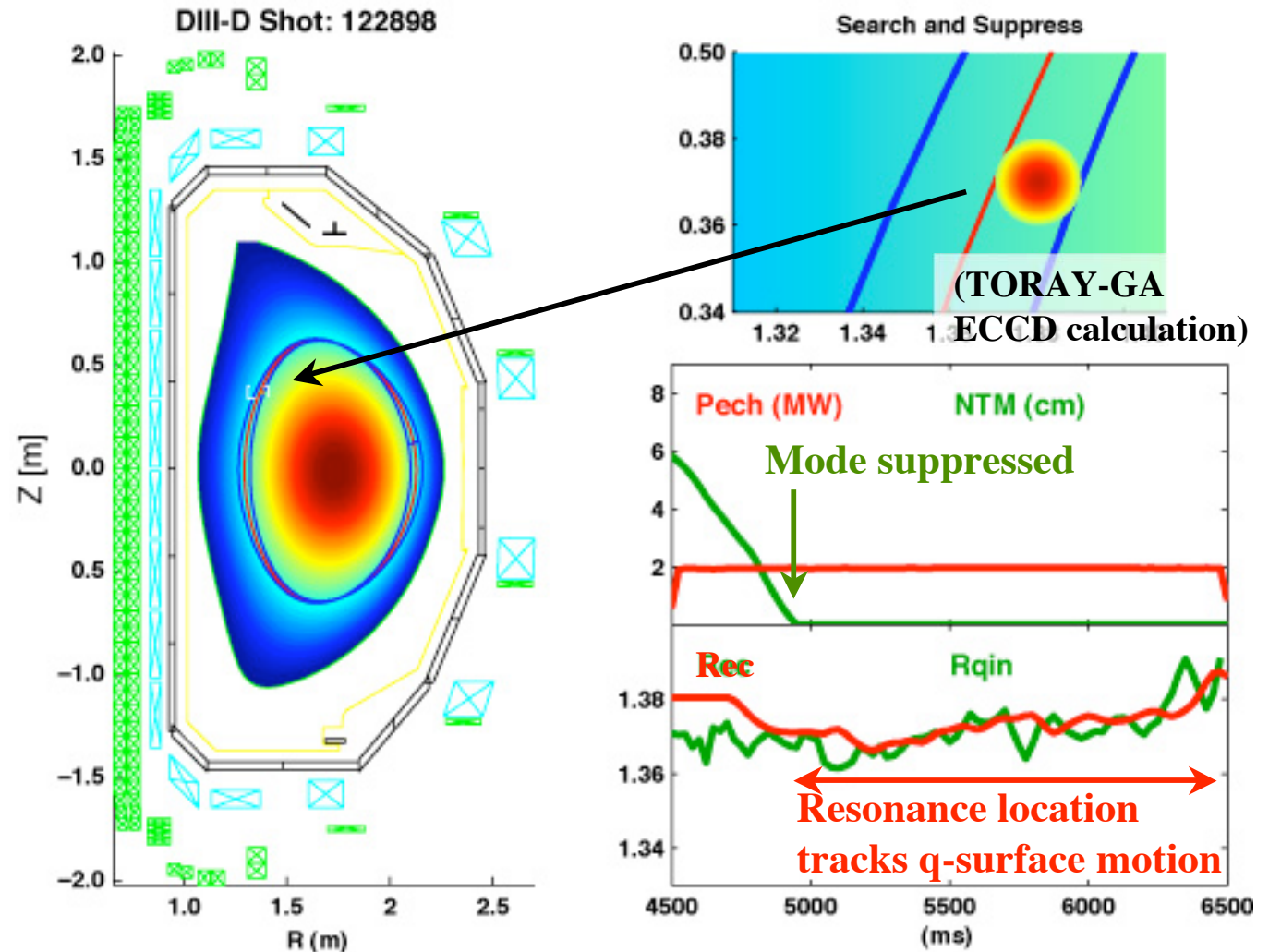
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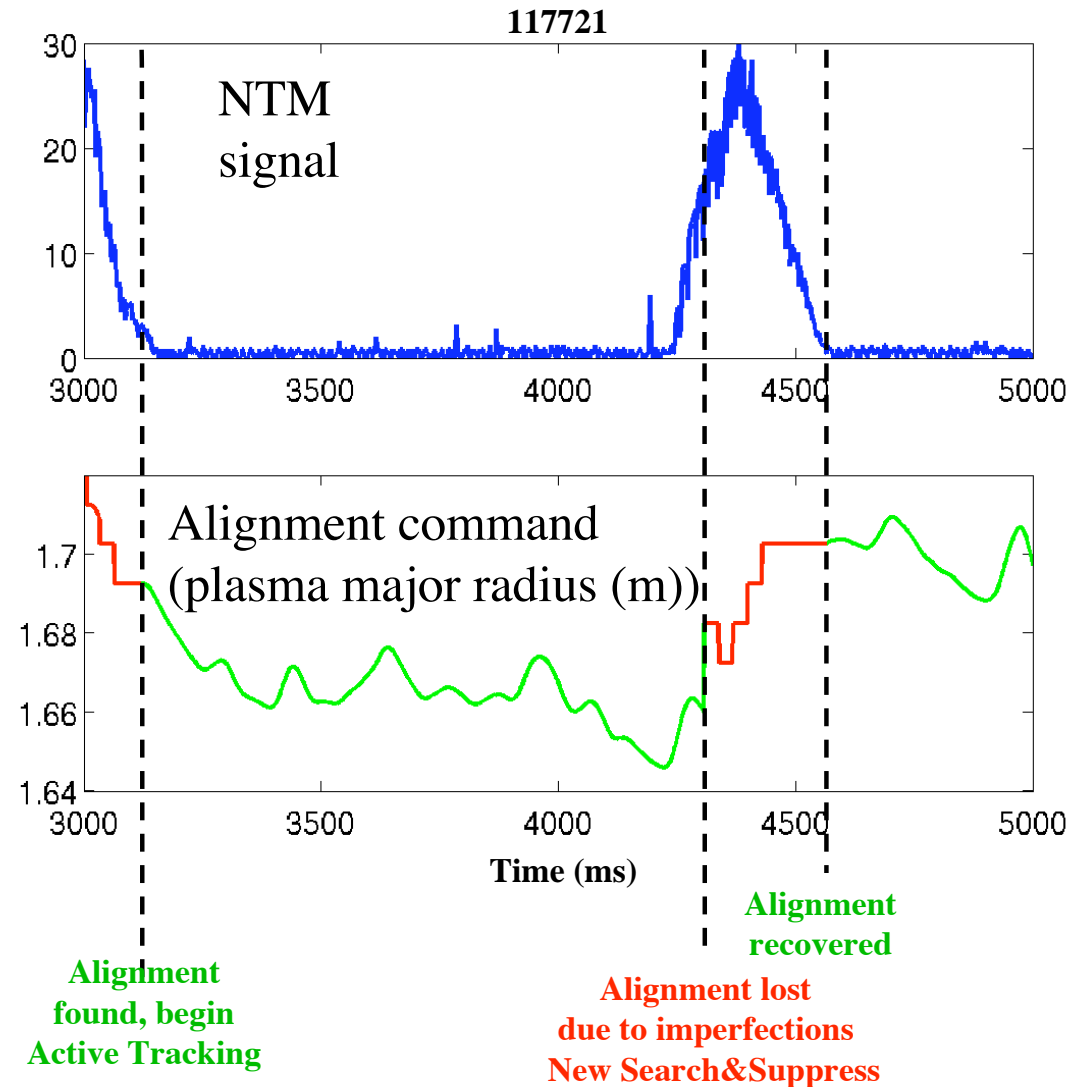
- Moving beam vertically

  (with steerable mirror)

EC resonance

Several Algorithms Implemented to Find and Maintain Island/ECCD Alignment

- **"Search and Suppress"** algorithm to find optimal alignment systematically before island suppressed

- **"Active Tracking"** algorithm to maintain q-surface/ECCD alignment after island suppressed

DIII-D Shot: 122898

Search and Suppress

(TORAY-GA ECCD calculation)

Pech (MW)   NTM (cm)

Mode suppressed

Rec   Rqin

Resonance location tracks q-surface motion

Robust Algorithms Maintain NTM Suppression Under Noisy Conditions

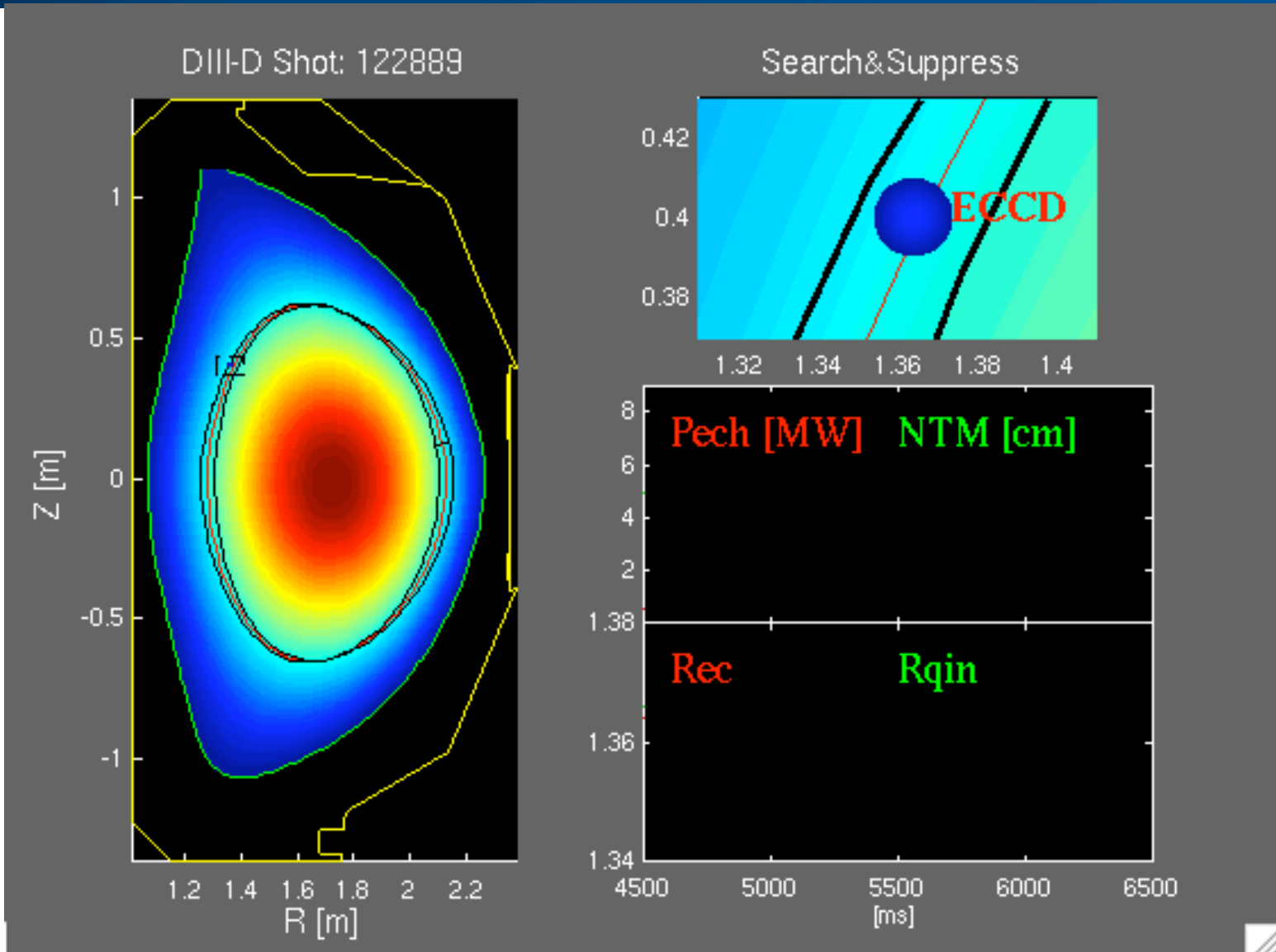- **Mode suppressed by** Search and Suppress **followed by** Active Tracking

- **Mode strikes again due to measurement uncertainties**

- **Alignment recovered with new** Search and Suppress **followed by** Active Tracking

117721

NTM signal

Alignment command (plasma major radius (m))

Time (ms)

Alignment found, begin Active Tracking

Alignment lost due to imperfections New Search&Suppress

Alignment recovered

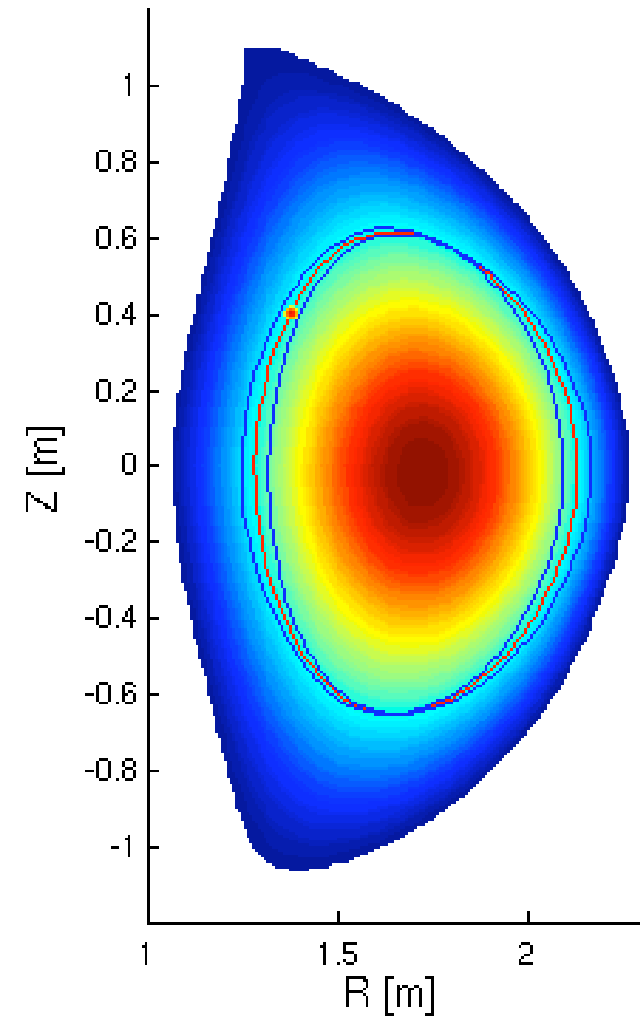# CW ECCD used successfully in experiments

DIII-D
Shot:
122889

Modulation More Beneficial When Current Drive Wide

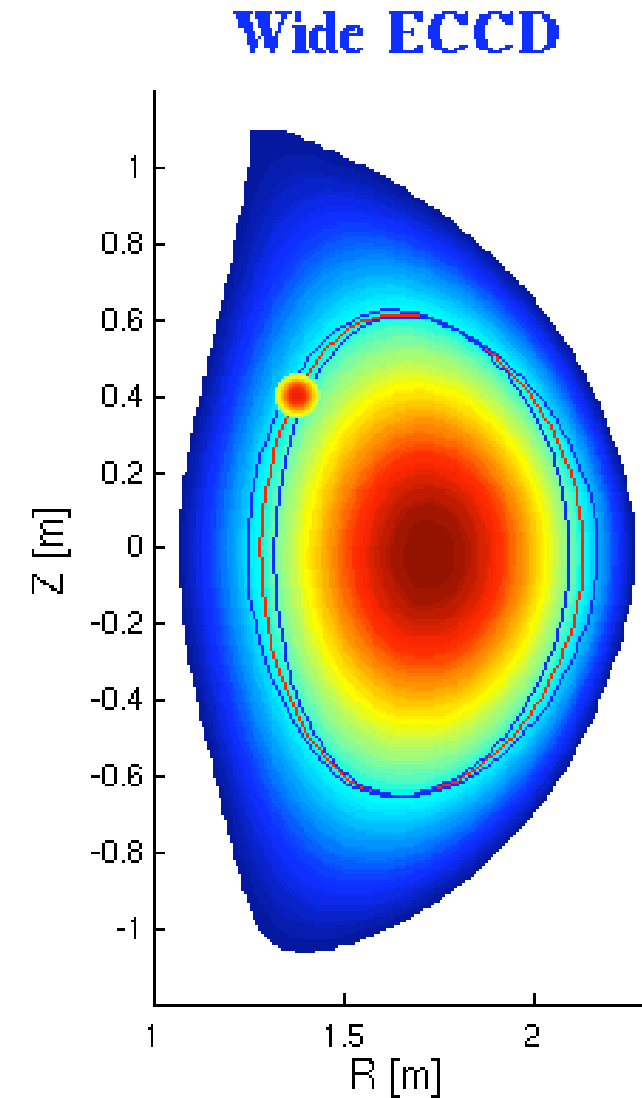- ## Narrow ECCD

  - Current deposited mostly inside island
    (O and X points do not cancel)

- ## Wide ECCD

  - More current is deposited outside island
    (O and X points nearly cancel)

- ## Wide ECCD modulated

  - Avoids driving current outside island

Narrow ECCD

# Modulation More Beneficial When Current Drive Wide

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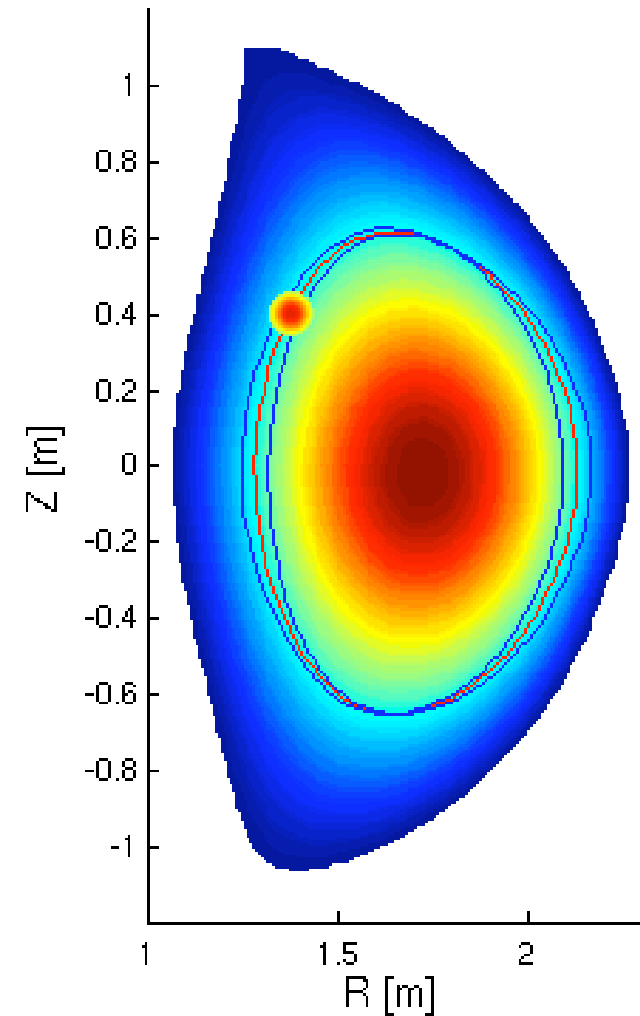
Modulated ECCD used in ASDEX, M. Maraschek et. al. , EPS Rome 200

Wide ECCD, modulated

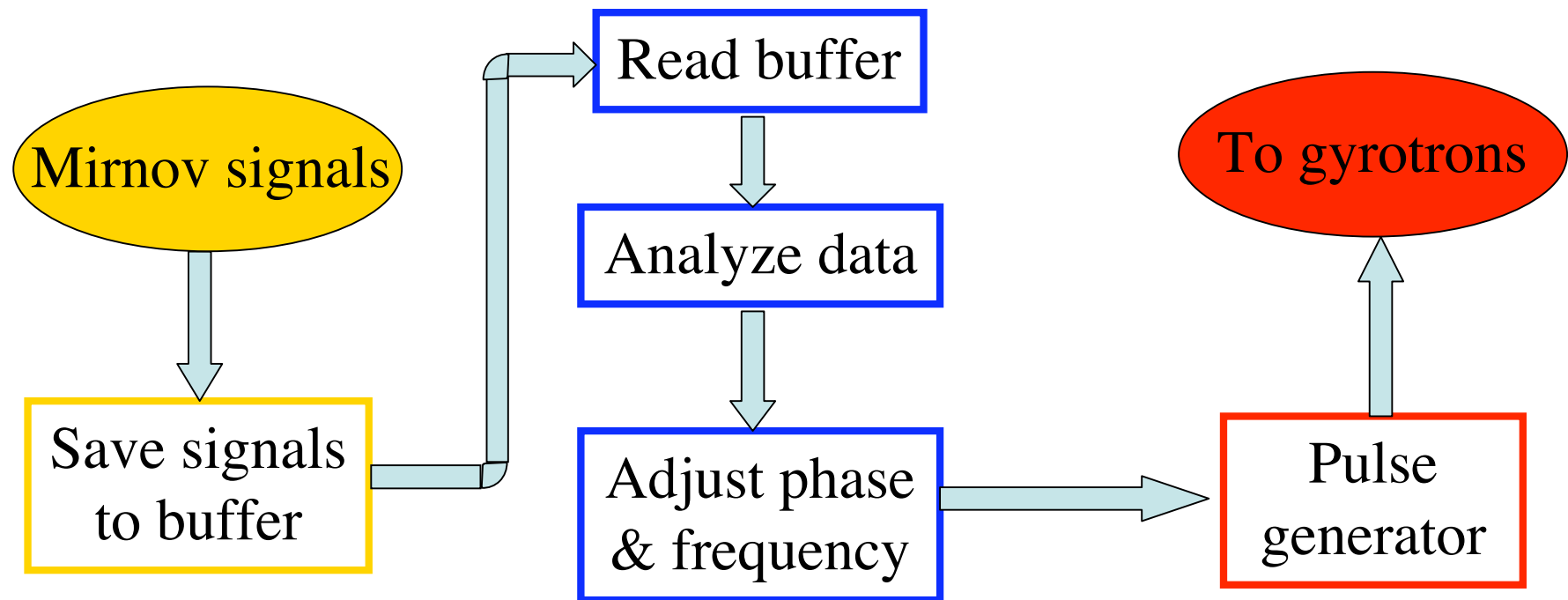# Control system upgraded for modulation of ECCD

Control Block Diagram for Modulation

Data acquisition
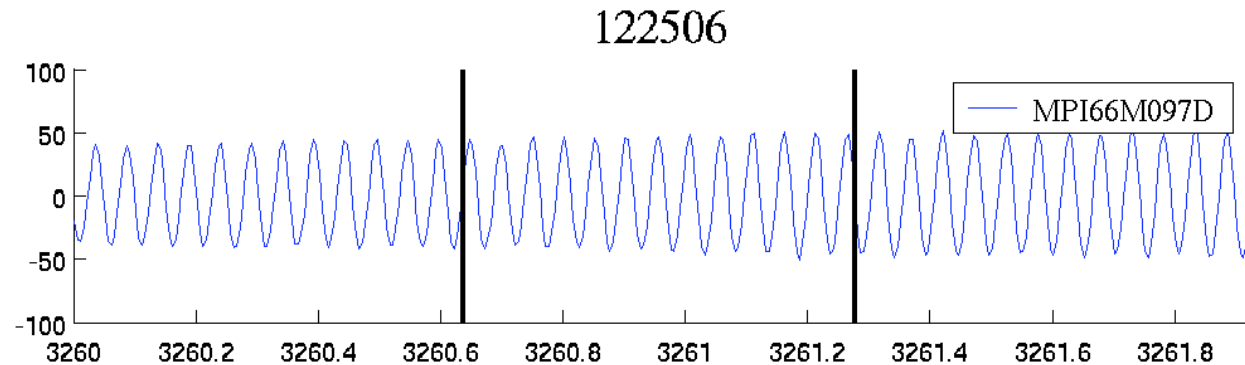(9 Mirnov signals)
Sample time = 1 μs
(2048 samples each)

Analysis
(every 2048 μs)

Command output
(1-5 kHz pulse train)

Mirnov signals

Read buffer

To gyrotrons

Save signals to buffer

Analyze data

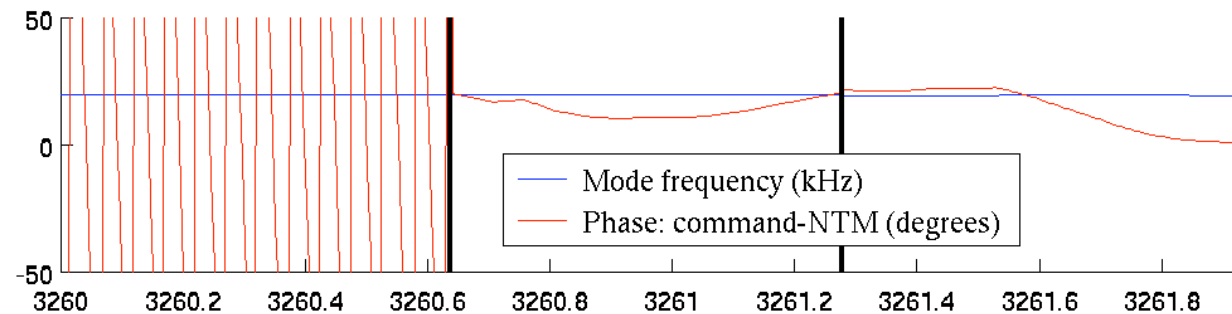Adjust phase & frequency

Pulse generator

Realtime NTM Phase Identification Using Mirnov Signals

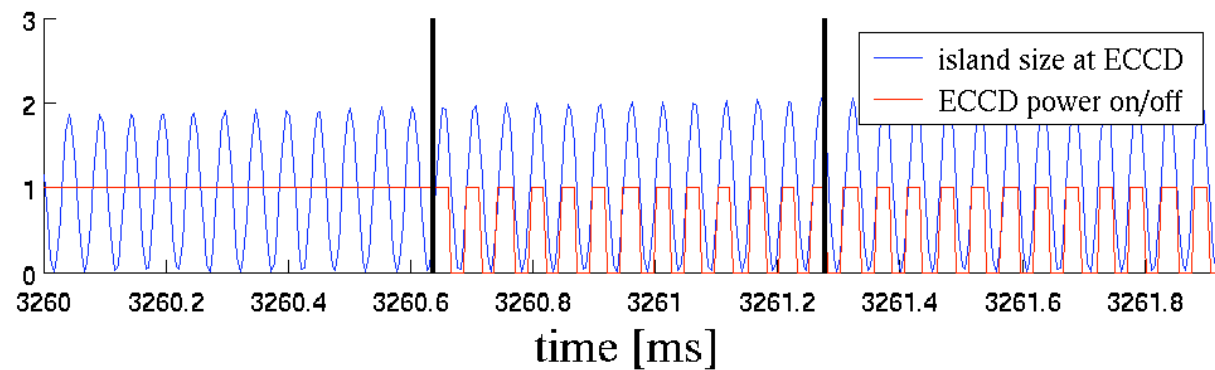**One of the Mirnov signals**

Modulation phase error

Phantom commands in synch with island

122506

Summary

- CW ECCD implemented and used successfully in experiments

- Control system upgraded to use modulated ECCD

- Modulated ECCD to be used in 2007 campaign

For more on island diagnostic development refer to poster by Francesco Volpe **GP1.00010** on Tuesday morning