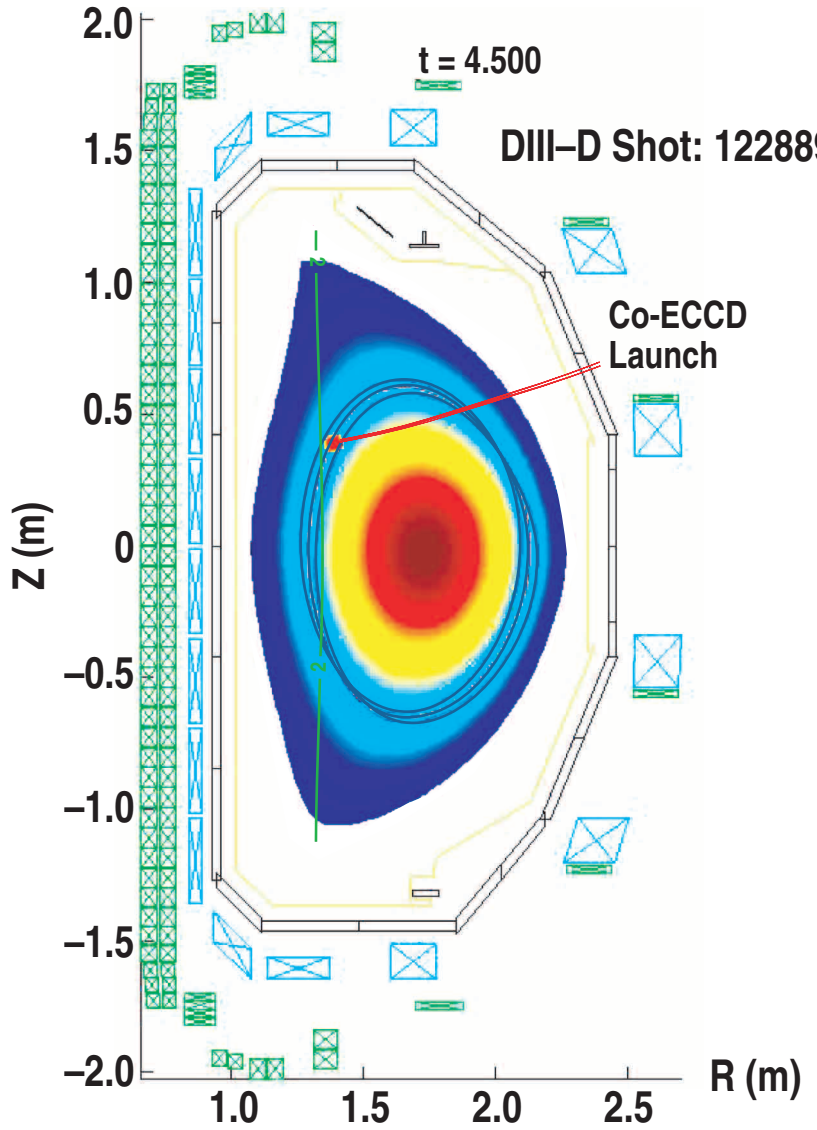
Neoclassical Tearing Mode Control for ITER Thrust

Presented by
R.J. La Haye

to the DIII–D
Program Advisory Committee

February 1, 2006



NTM Control for ITER Thrust

Highly focussed, concerns whether moduation, particularly for broad ECCD as anticipated in ITER, has advantages

- ★ includes other ITER NTM control related research involving ECCD

NTMs will place the principal limit on stability in ITER in the standard scenario, which has operation well below the ideal kink beta limit

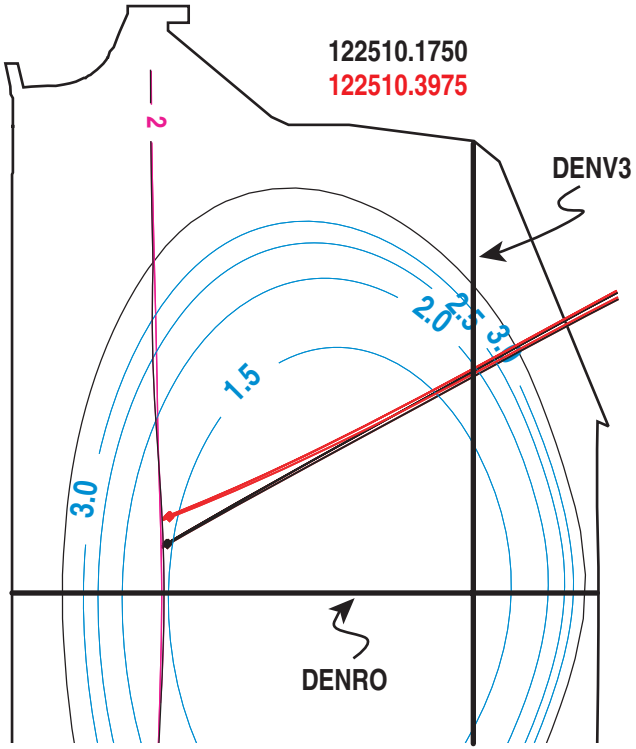
ITER High Priority Research Tasks
MHD: "stabilisation of (3,2) and (2,1) NTMs by direct control
...and identify requirements for ITER plasmas"

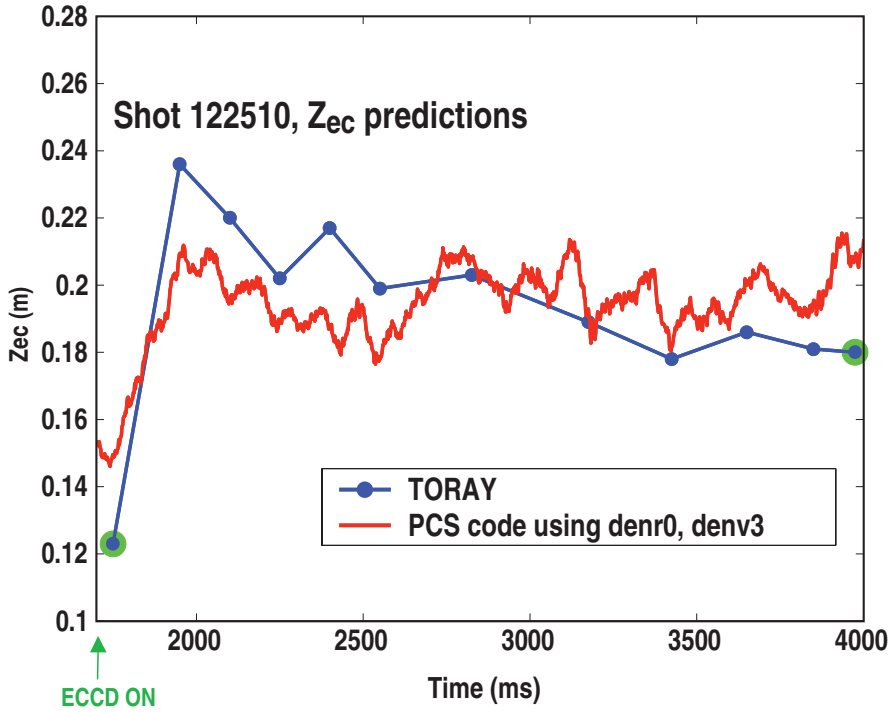
NTM Experiments in Stability Topical Science Area in Calendar Year 2005

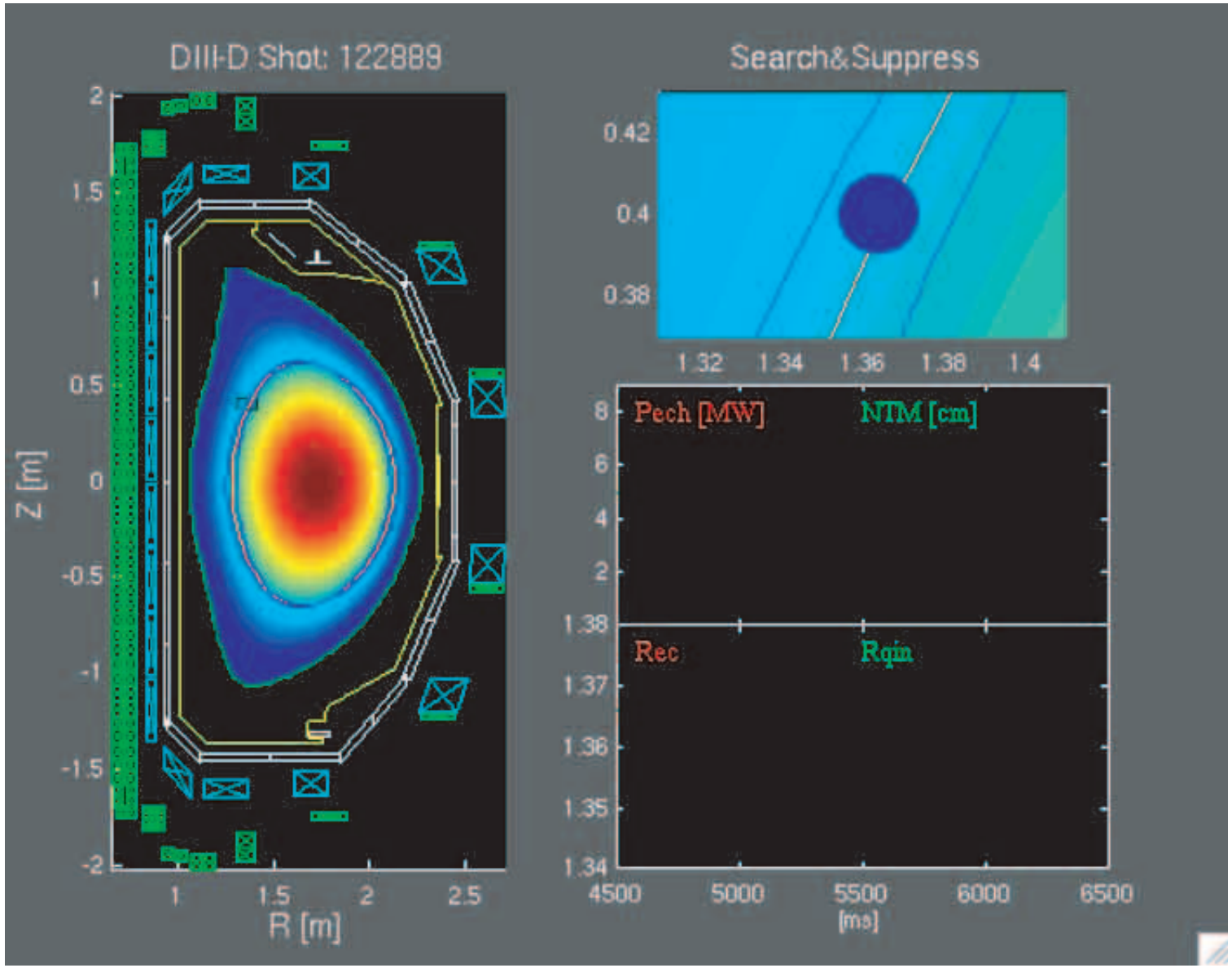
- **PCS development for NTM control by ECCD**
  - ★ "Real-time ECCD Location to Stabilize an m/n=3/2 NTM"
    - — 1/2 Day
- **Pre-emptive ECCD stabilization of m/n=2/1 NTM in hybrid scenario**
  - ★ "Stabilization of 2/1 Tearing Modes with ECCD"
    - — 1 1/2 Days

Real-time Compensation for Refraction of ECCD is Now Implemented in the Plasma Control System

- R_{ECCD} "target" is robust for given toroidal field
  - ★ but refraction can change Z_{ECCD} "target"
- PCS real-time ECCD target implemented to track δZ_{ECCD}
  - ★ for better alignment of ECCD and q=3/2 (or q = 2/1)
    - — uses central and outer interferometer chords

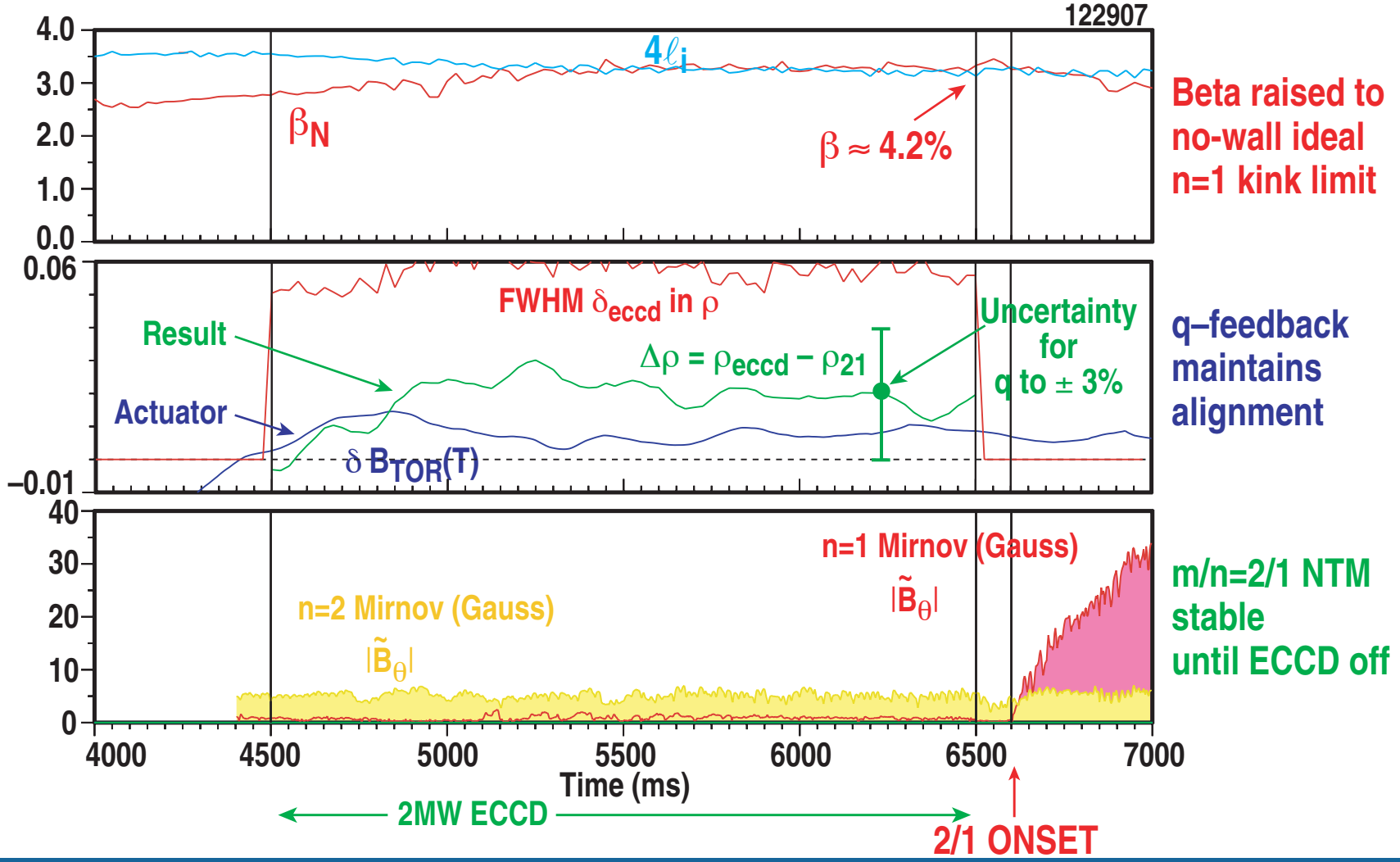





DIII-D Shot: 122889
Search&Suppress
Z [m]
R [m]
Pech [MW]
NTM [cm]
Rec
Rqin
[ms]

Preemptive ECCD and "q-Feedback" Used to Stabilize Otherwise Unstable m/n = 2/1 NTM

- **Hybrid scenario with m/n=3/2 NTM keeping q(0)≈1**
  - ★ Toroidal field adjusted by real-time MSE EFIT to keep peak j_{eccd} on q = 2



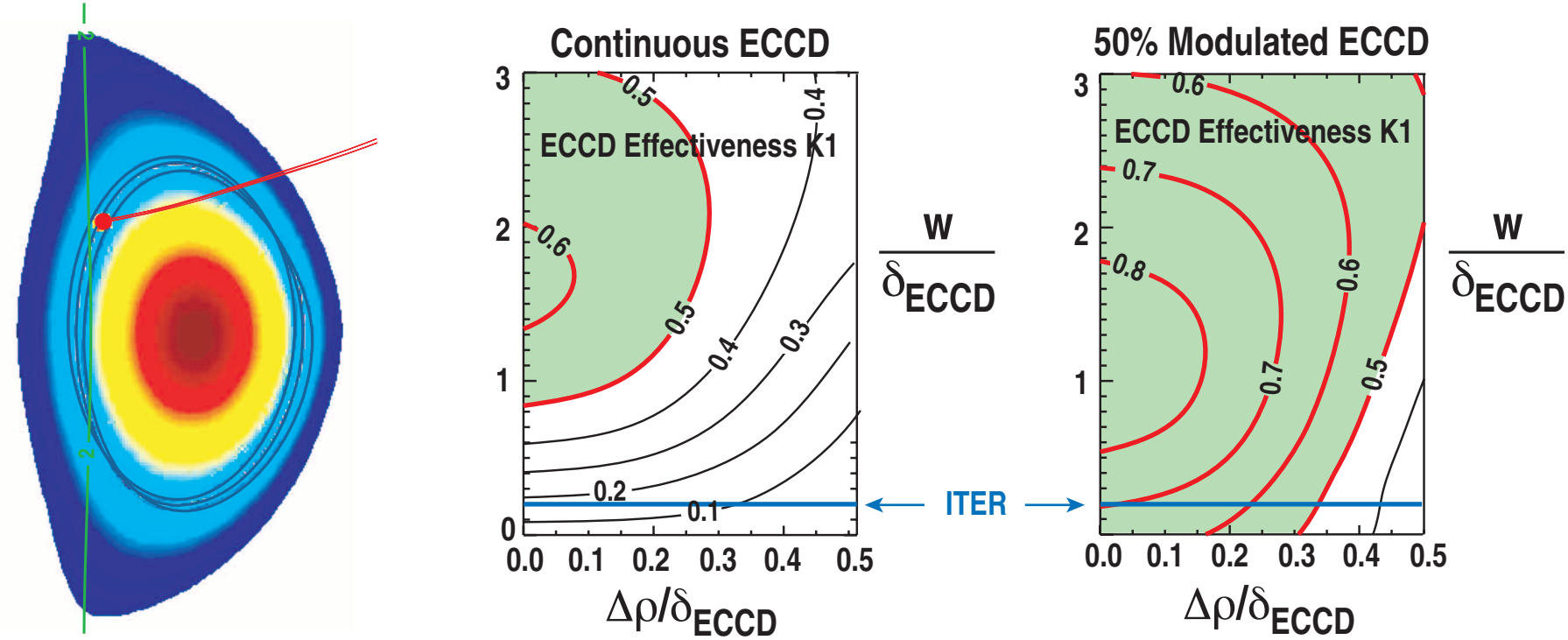
Progress in NTM Control by ECCD in DIII–D Includes . . .

- **Real-time tracking of both rational surface (2004) and ECCD locations (2005)**
- **Higher stable beta to m/n = 3/2 mode (2004)**
  - ★ with preemption in sawteething H–mode
- **Higher stable beta to m/n = 2/1 mode (2005)**
  - ★ with preemption in hybrid scenario

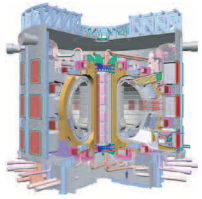
Modulation of ECCD in Phase with Island O-Point May be Required for Effective Control of NTMs in ITER

- **Present experiments have w/δ_{ECCD} ~1, ITER has w/δ_{ECCD} <<1**
  - ★ unmodulated broad ECCD has low effectiveness in stabilization?
    - – stabilizing effect on O-point nullified by destabilizing effect on X-point?

(F.W. Perkins, R.W. Harvey, M. Makowski, M.N. Rosenbluth, 1997)

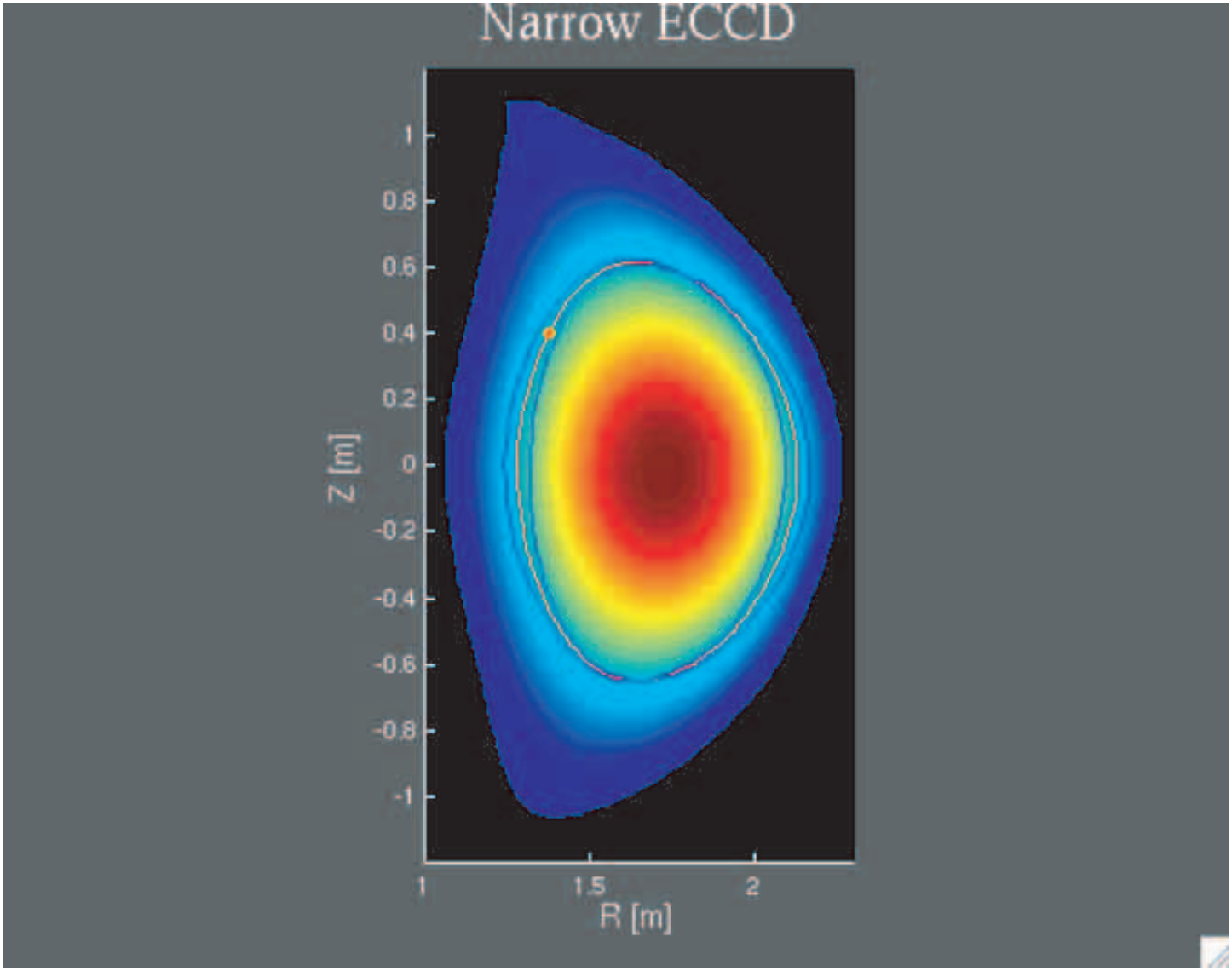


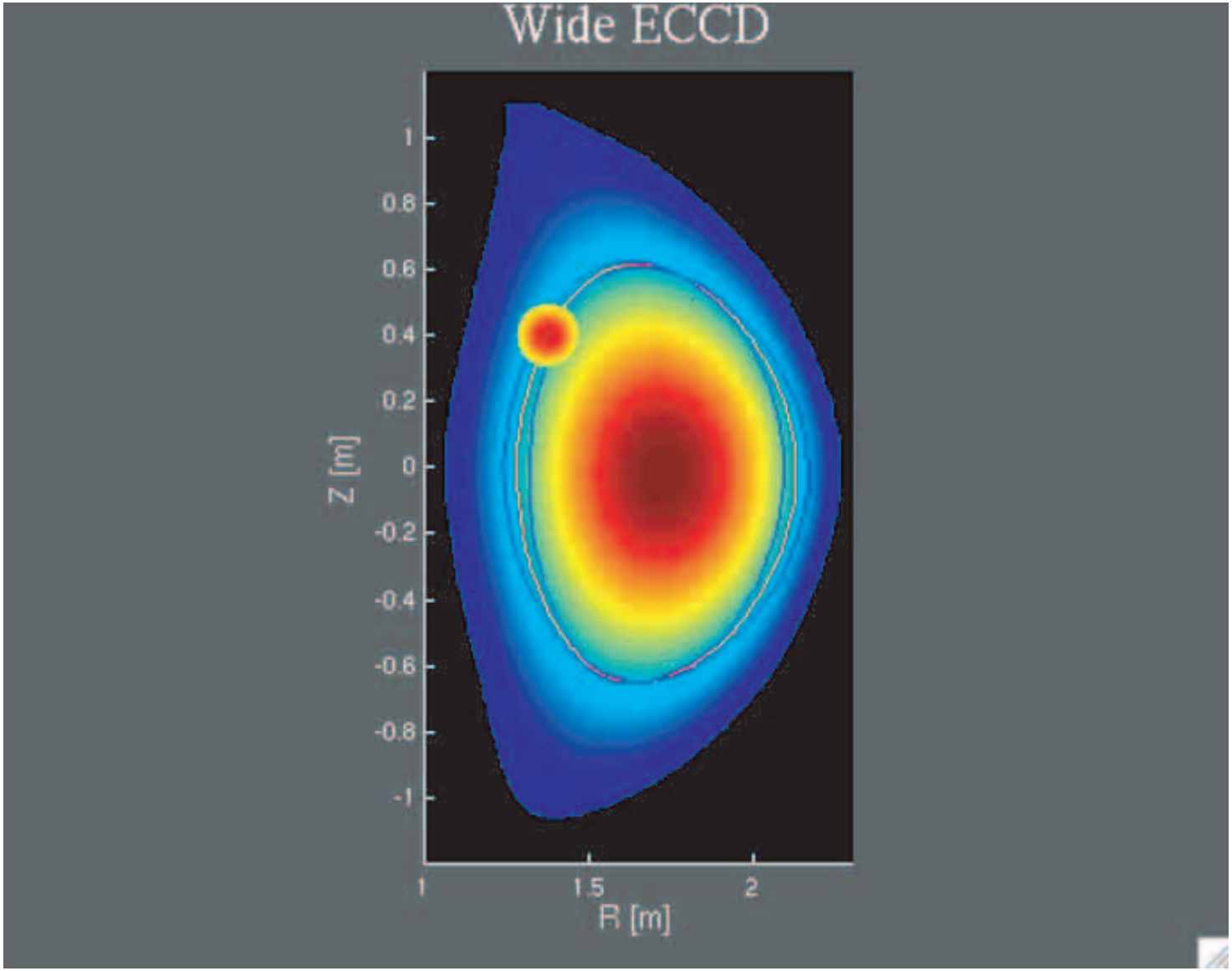
- **Disadvantages of modulation are $\delta\Delta'_r$ halved and need island to modulate**
  - ★ issues of plasma dynamical response to modulation, correctness of theory

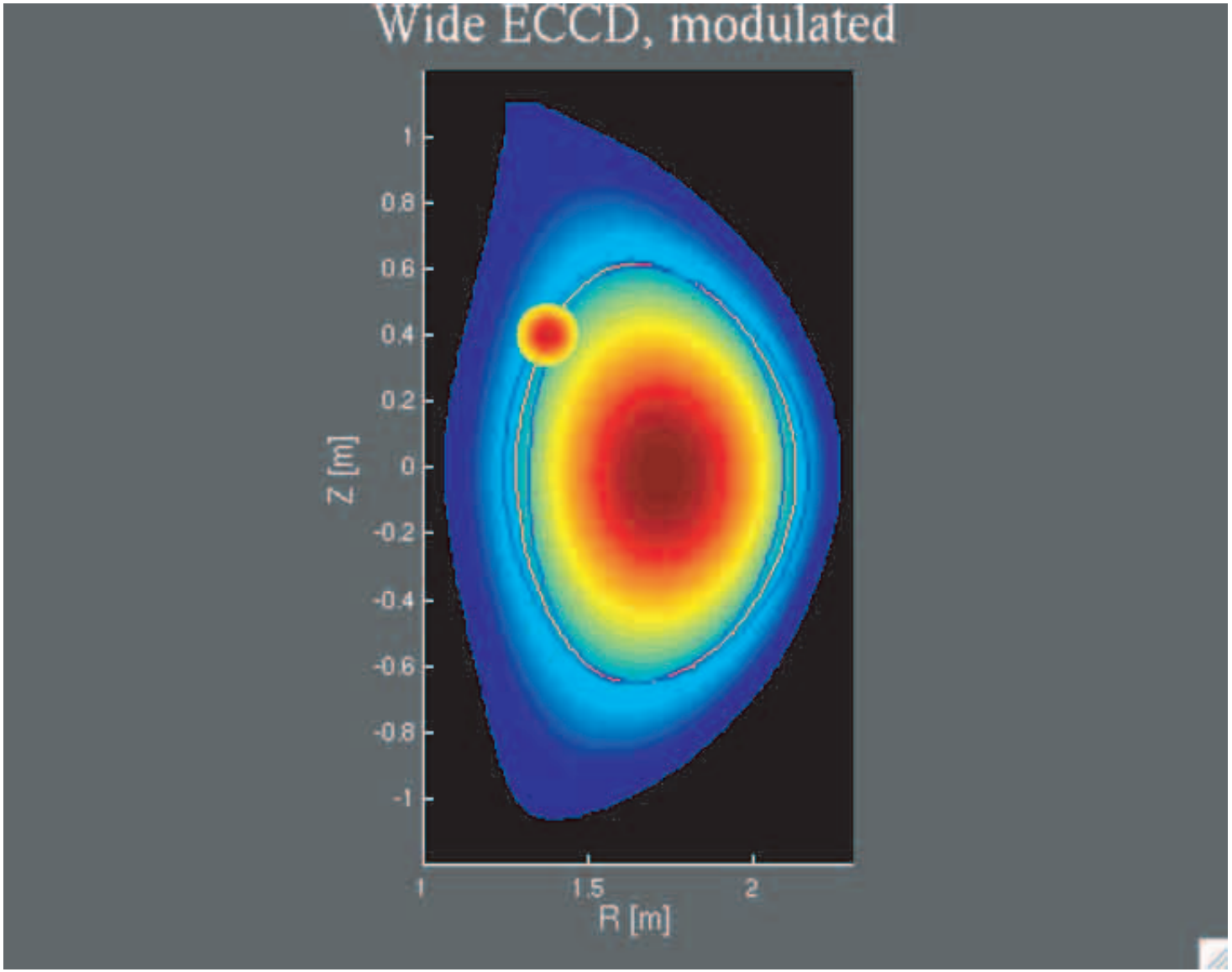


DIII-D NATIONAL FUSION FACILITY SAN DIEGO

253-05/RJL/jy

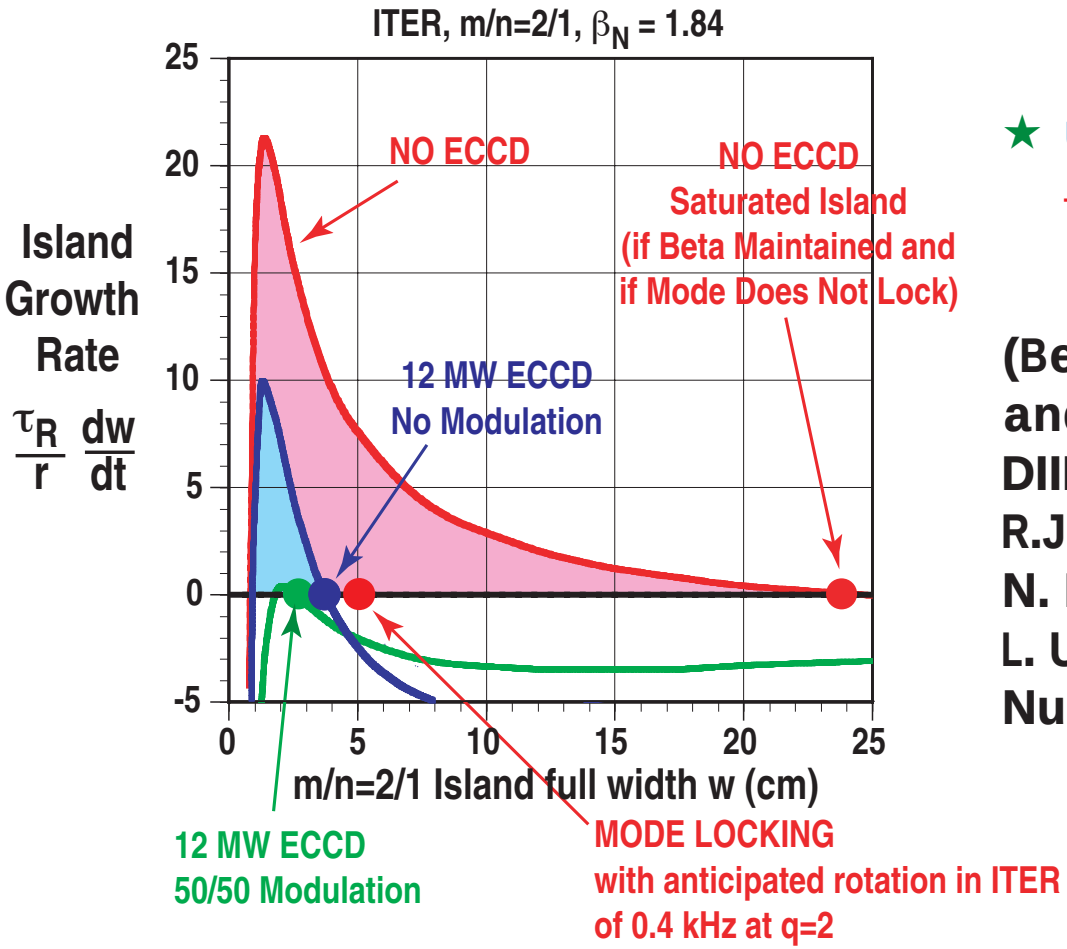

Narrow ECCD
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
Z [m]
1
1.5
2
R [m]


Wide ECCD
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
Z [m]
1
1.5
2
R [m]


Wide ECCD, modulated
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
Z [m]
1
1.5
2
R [m]

ECCD in ITER Can Control the m/n=2/1 Mode But...

- **No ECCD**
  - ★ large saturated island
    - — MODE LOCKING AND DISRUPTION

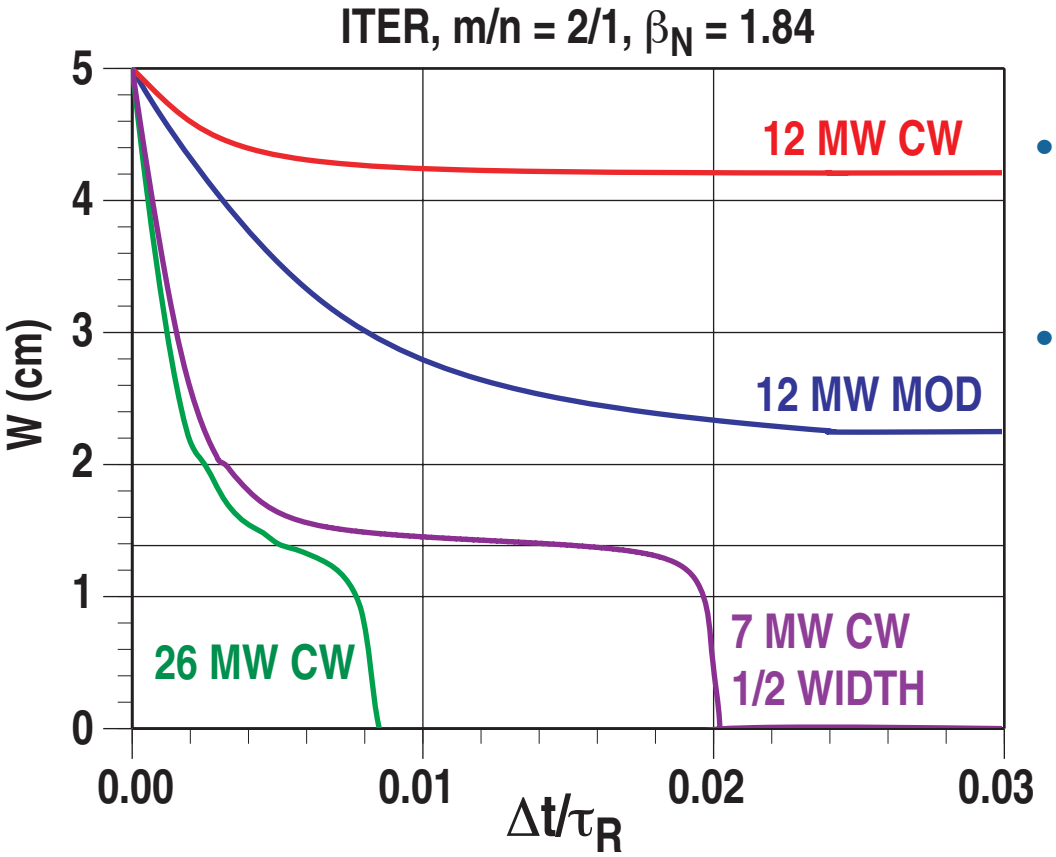


- **With ECCD**
  - ★ **adjust modulated j_{ec} for $w \gtrsim 2\varepsilon^{1/2}\rho_{\theta i}$**
    - – a stationary operating point at 12 MW
  - ★ **unmodulated 12 MW less effective**
    - – but should avoid locking and disruption

(Benchmarking NTM physics and ECCD to ASDEX Upgrade, DIII–D, JET and JT–60U, R.J. La Haye, R. Prater, R.J. Buttery, N. Hayashi, A. Isayama, M.E. Maraschek, L. Urso and H. Zohm, to be published in Nuclear Fusion)

ITER ECCD Control Depends on Whether Modulated or CW, Power, Width

- **Assume perfect alignment, marginal island is twice ion banana width**
  - ★ start at critical island width for locking with anticipated plasma rotation
    - – apply ECCD



- **12 MW MOD at smallest island that is a stationary operating point**
- **7 MW CW 1/2 WIDTH uses least power**
  - ★ possible by “Front Steering” ? (M.A. Henderson et al)
  - ★ issue of alignment

DIII–D Has the Tools for Evaluating ECCD Requirements in ITER

- **Balanced beams for slower rotating islands**
  - ★ within 5 kHz clean modulation capability of gyrotrons
- **Variable ECCD width with different launcher angles**
  - ★ up to a factor of four wider from narrowest
  - ★ real-time steerable launcher (2 gyrotrons in 2006)
- **State-of-the-art Plasma Control System (PCS)**
  - ★ real-time Mirnov analysis (NEWSPEC) for n=1,2 mode amplitude, frequency and phase
  - ★ control of co/counter beam mix for rotation
  - ★ real-time MSE EFIT for location of q-surface (for alignment of ECCD)
  - ★ control of gyrotron modulation with separate phases on toroidally distributed launchers

NTM Control for ITER Thrust

13 proposals requesting 11 days combined into 6 1/2 days for next 32 weeks

2006

1 Day: Slowly rotating islands (coordinate with stability for island $\tilde{v}$, $\tilde{B}$, $\tilde{T}_e$, etc)

★ prior EF correction, PCS NEWSPEC, PCS rot control of beams, PCS Mirnov phase

2 Days: ECCD at q=3/2, narrow vs. broad, CW vs. modulated

★ previous checkout of PCS gyrotron modulation (3 "spigots")

$^1/_2$ Day: Real-time ECCD mirror steering; ECE for location of island and EC deposition

★ prior PCS control of mirror (co⇒ctr sweep desirable)

---

1 Day: ECCD at q=2/1, narrow vs. broad, CW vs. modulated **50% in 2006**

2007

1 Day: ECCD at q=2/1 in q95 > 3 ITER shape

★ also pellet fueling for study of effect on stabilization

1 Day: Simultaneous 3/2 and 2/1 ECCD stabilization

0 Days: Burn control with islands (Wisconsin)

★ piggyback along with ISLAND/BALDUR (Lehigh) and RESISTIVE/DCON (Los Alamos) code benchmarking studies