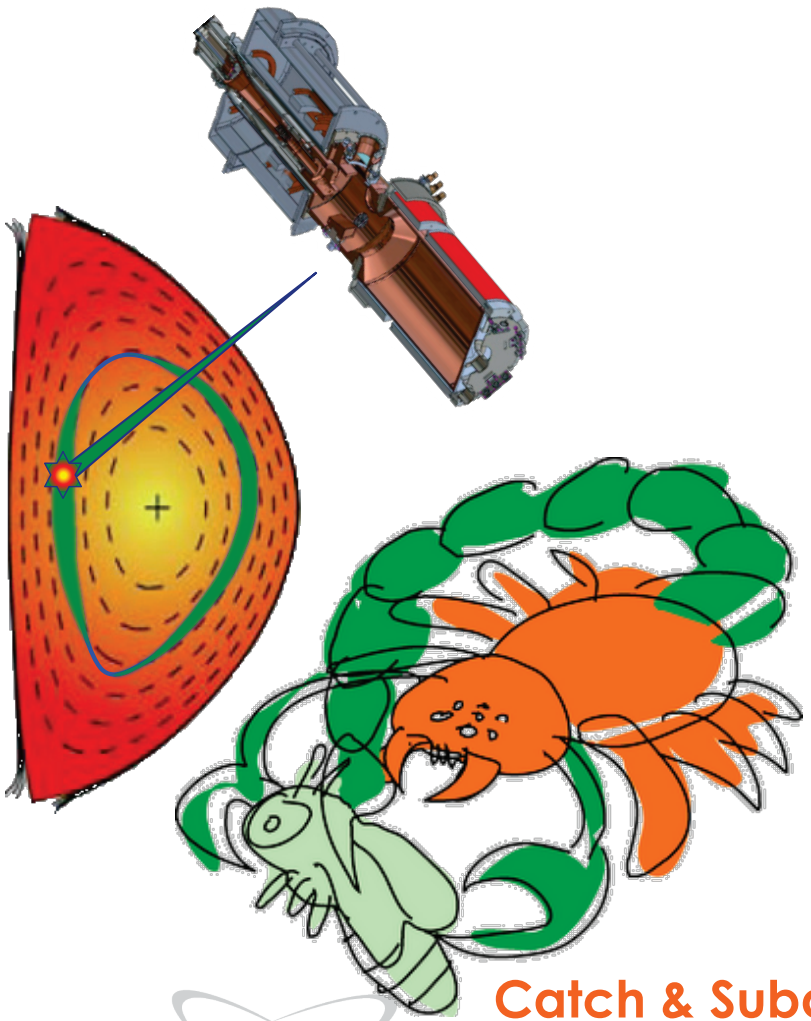
NTM Suppression and Avoidance at DIII-D Using Real-time Mirror Steering of ECCD



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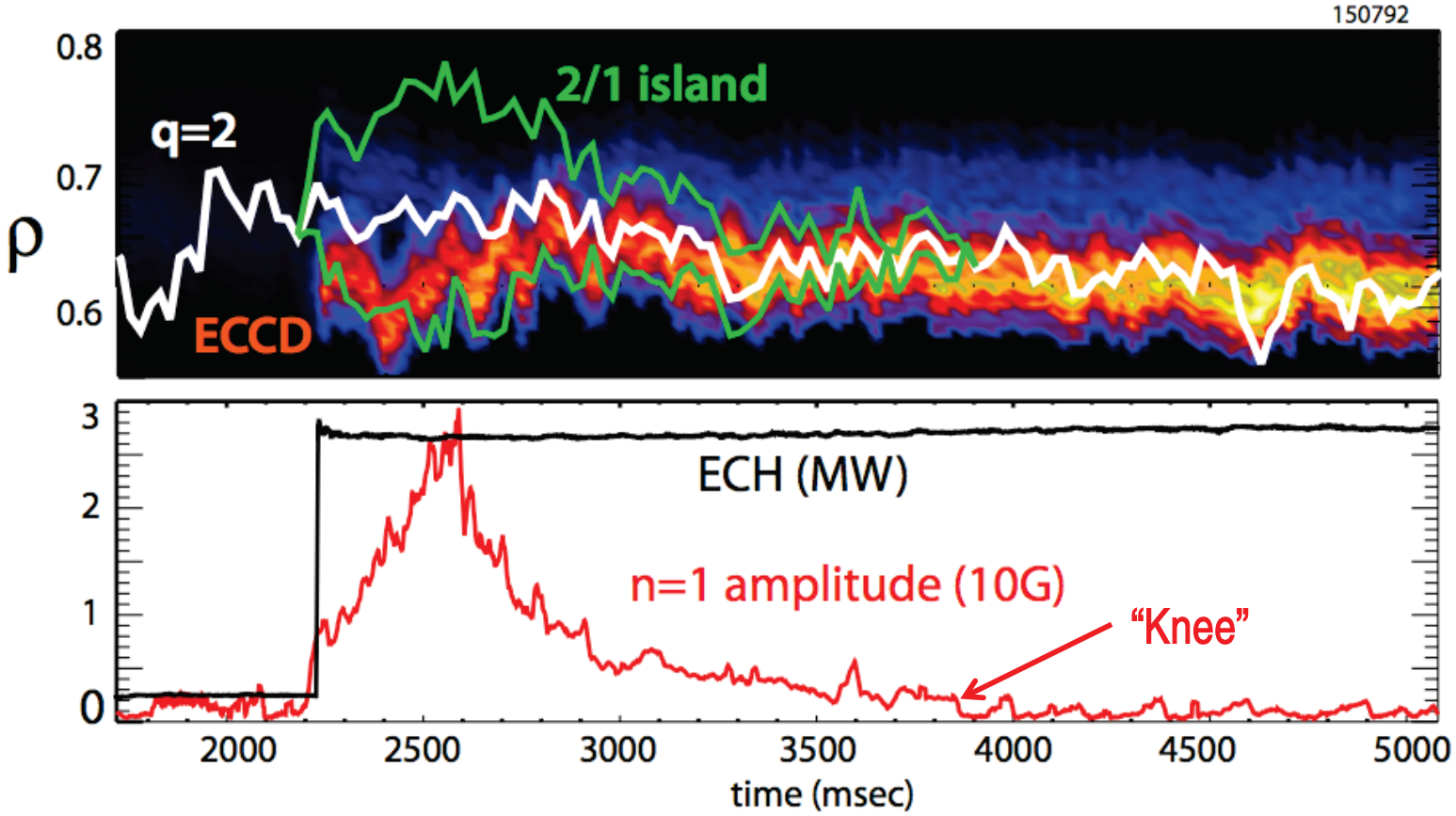
Catch & Subdue (Scorpion and Prey)

Fully Automatic NTM Control Using Real-Time Mirror Steering of the ECCD Can Suppress the 2/1 Mode



- New fully automatic NTM control system at DIII-D integrates all the Real-Time (RT) components of mode detection, location, suppression
- New control strategy *"Catch and Subdue"* can reduce average EC power; lead to higher Q and reduce disruption risk in ITER

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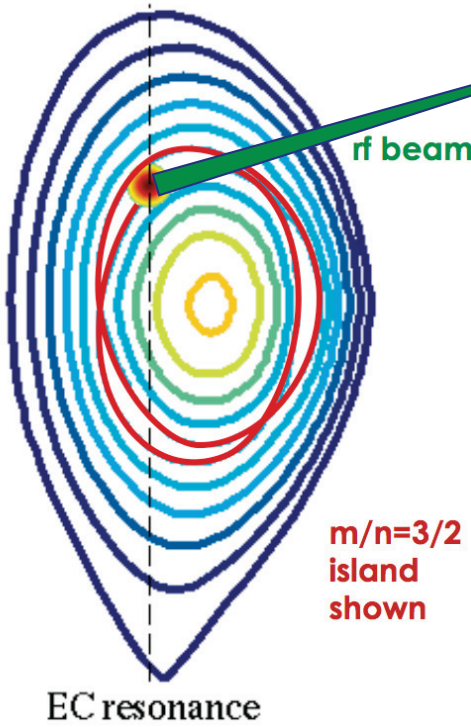
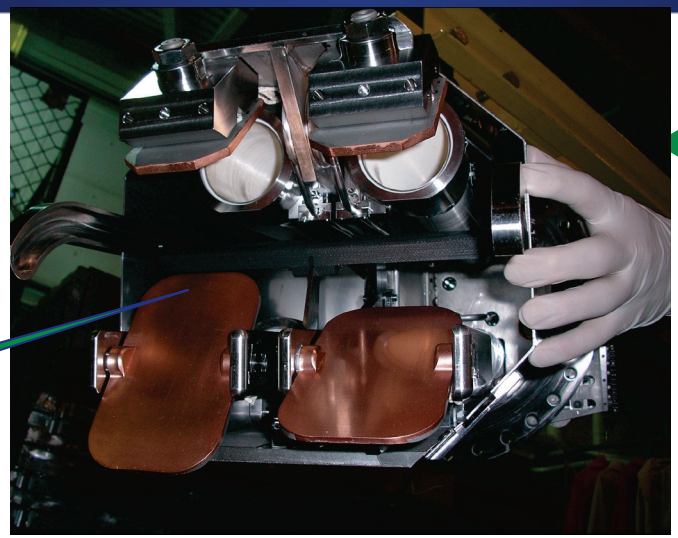
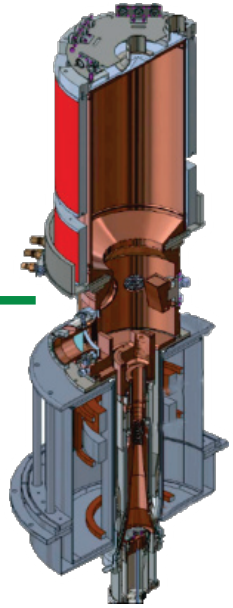
Accurate Alignment of ECCD to Resonant Surface Suppresses Neoclassical Tearing Mode





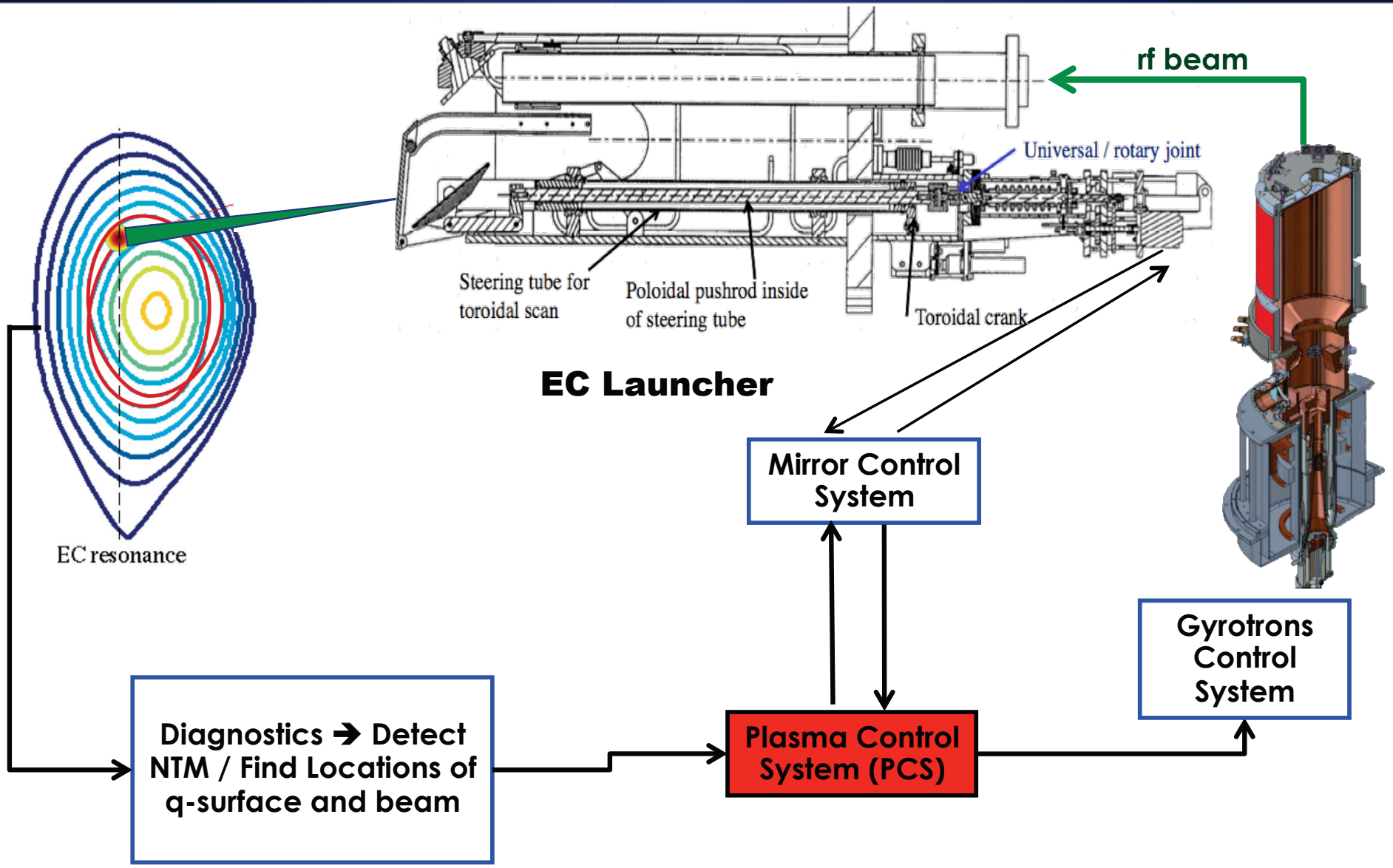
Steerable Launcher Mirror



5 Gyrotrons
(~2.8 MW injected)

- Align the Electron Cyclotron Current Drive deposition with the Neoclassical Tearing Mode (NTM) island for suppression
- Mirrors steered to move the beam vertically along the EC resonance for best alignment

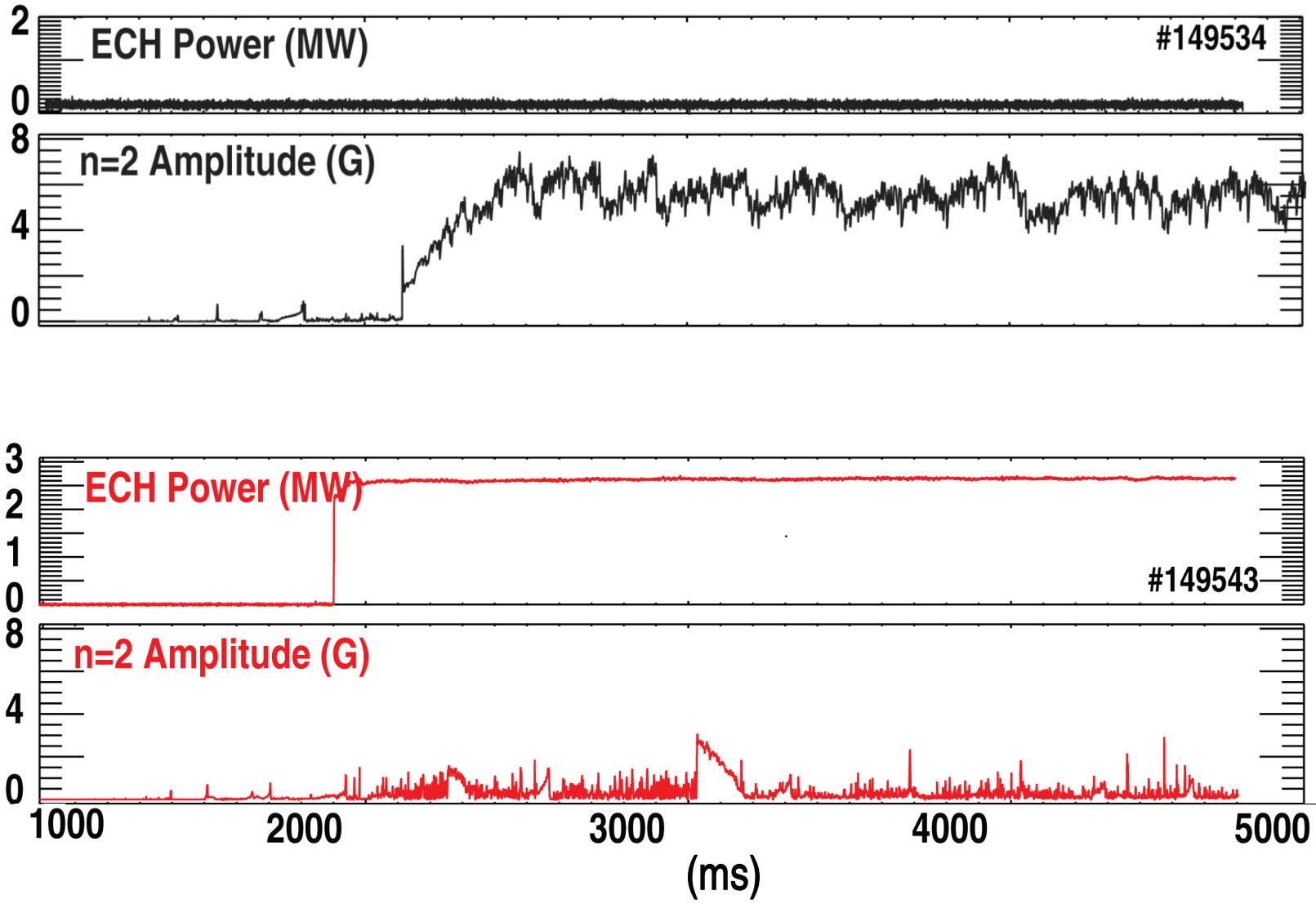
DIII-D NTM Control System Overview



Application to the 3/2 NTM:

- Head room to develop the techniques

Presumed ITER NTM Control Method: Preemptive NTM Suppression



Without ECCD, 3/2 NTM develops

NTM Preemption with ECCD

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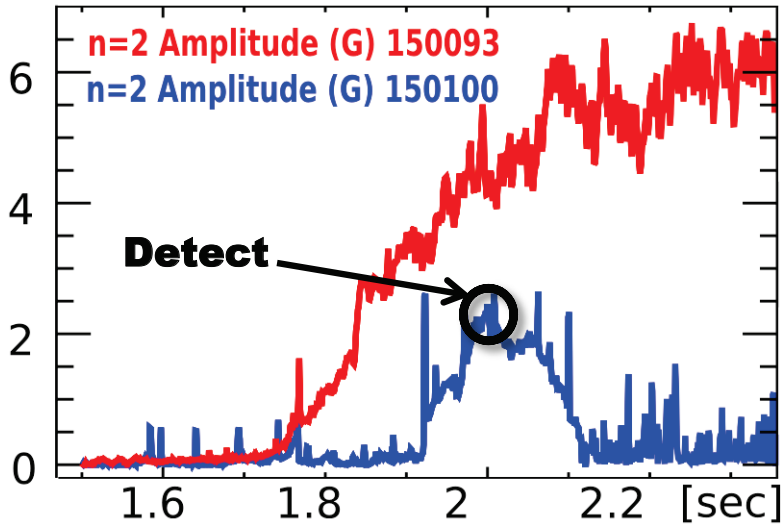
New "Catch and Subdue" Technique is More Efficient

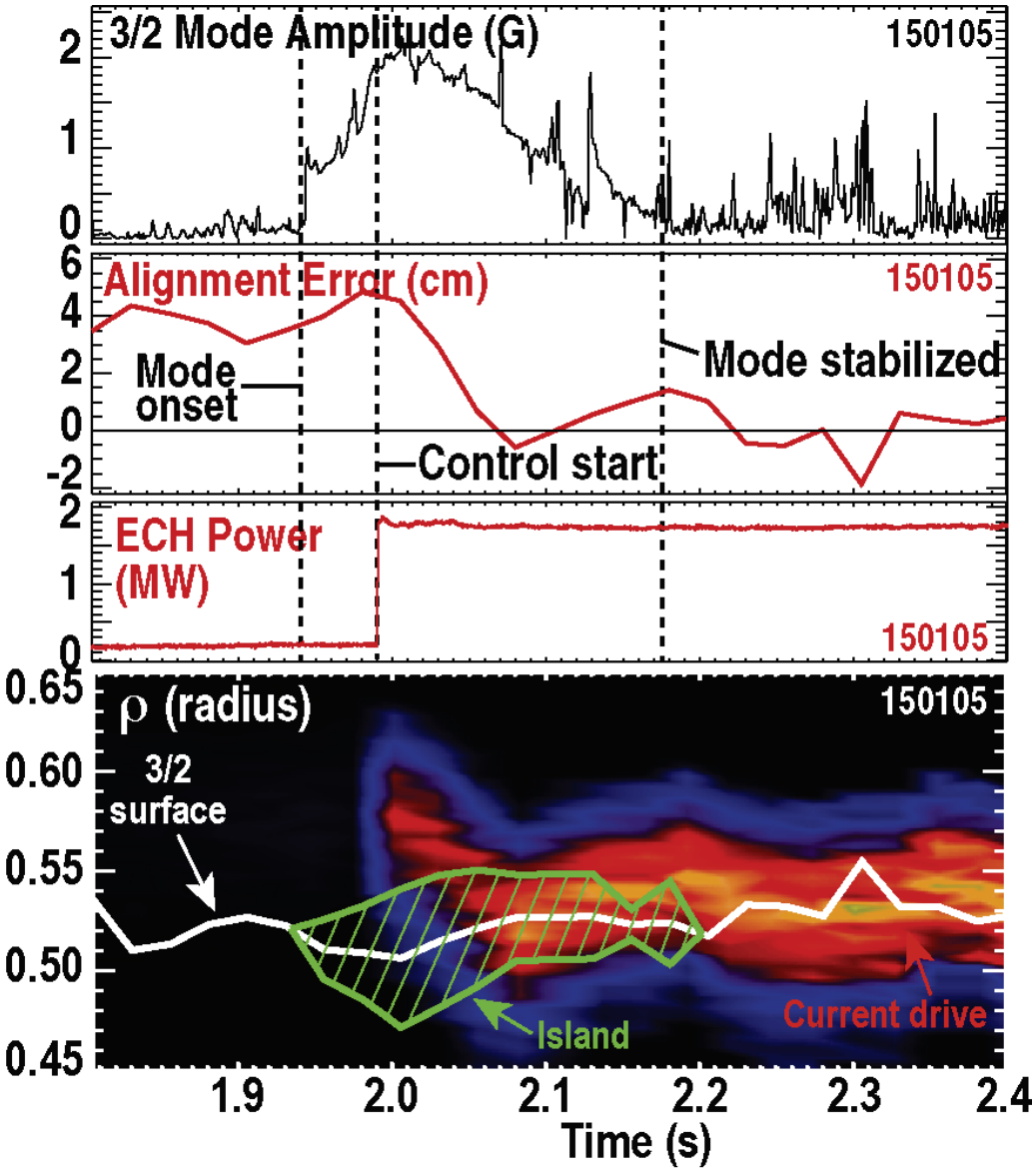
- **Continuous q-surface following**
  - Constantly calculate q-surface in plasma
  - Track w/ mirrors and be ready to suppress



Example of 3/2 Catch&Subdue

- **Detect that island is forming (2/1 or 3/2)**
  - Real-time Fourier analysis of Mirnov diagnostics
- **Turn Gyrotrons ON when the mode is detected**
- **Result: Catch the island before it saturates**
  - Island saturation for 2/1 mode ~100-150 ms, 3/2 mode ~200ms

Catch and Subdue Even Works Well Starting from a Misalignment of ECCD and q-Surface



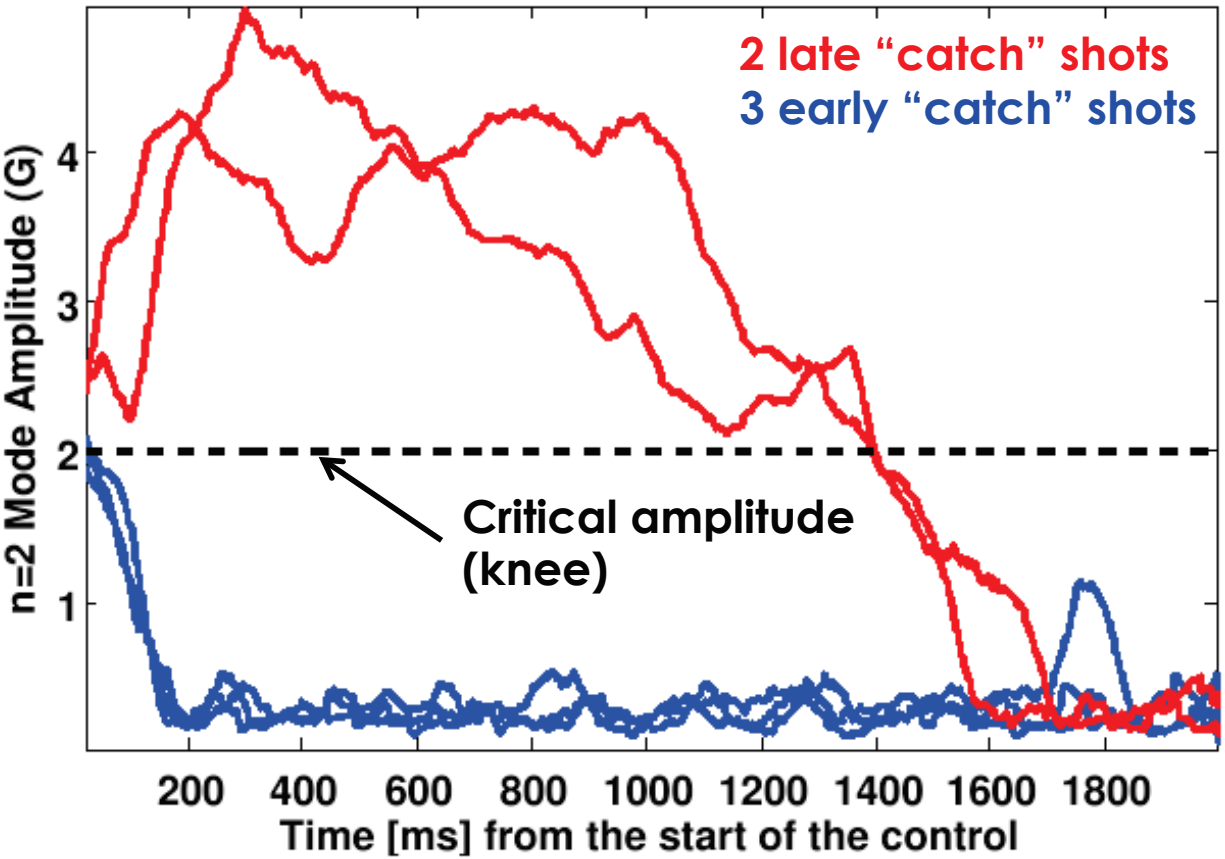
Experiment

- Intentional mirror misalignment ~4 cm

Result

- System rapidly corrects deposition location
- Fast suppression: complete suppression takes ~40 ms longer than aligned case

Early Mode Detection is Key for Rapid NTM Suppression



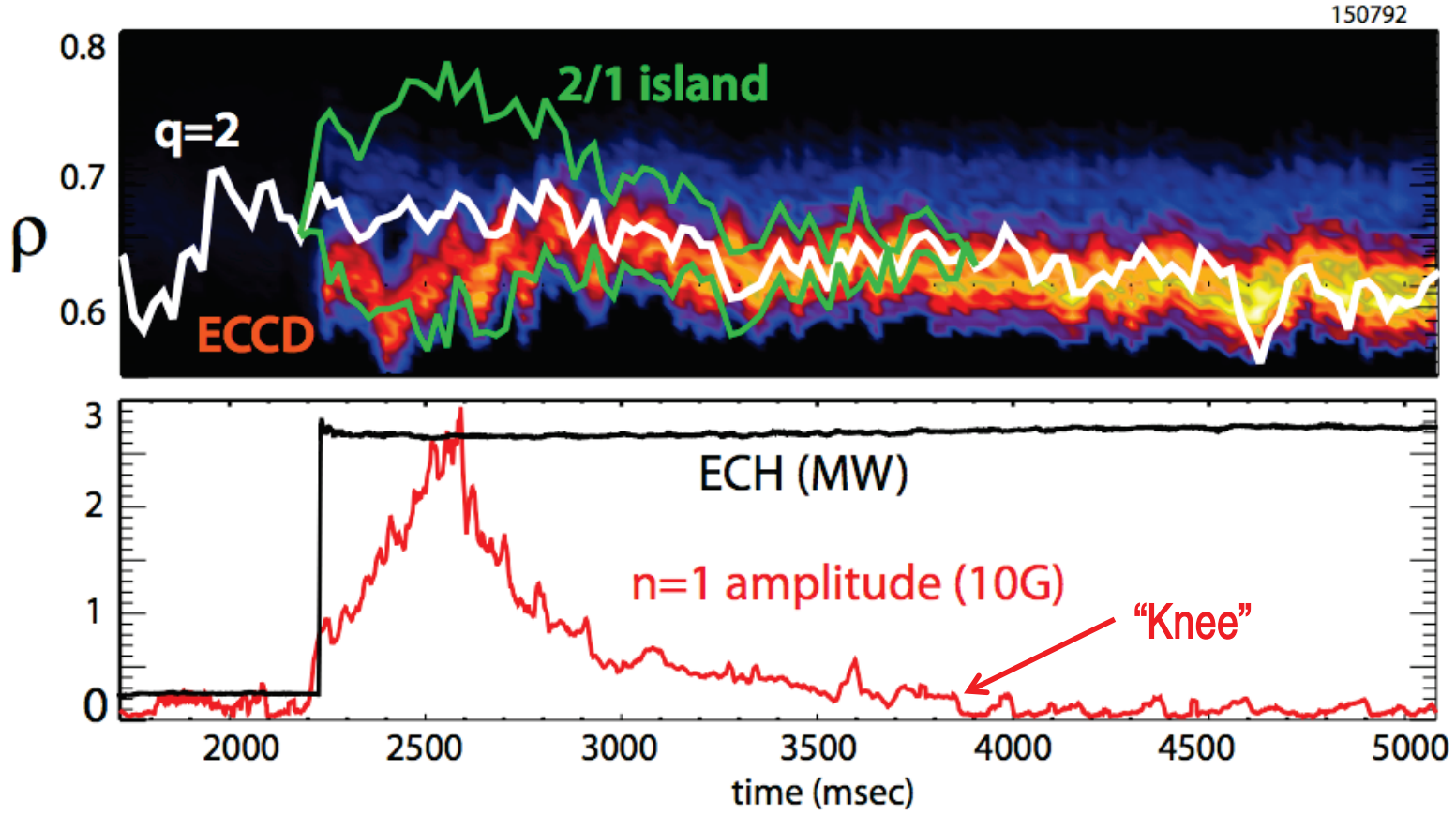
- **Below the critical amplitude** *small island effect takes over which enables fast suppression*
- **Above the critical amplitude** *the mode suppression takes more than a second or becomes unachievable*

***All shots with same β_N and ECCD is actively aligned with a power of 1.5±0.2 MW at the island location.**

Application to the 2/1 NTM:

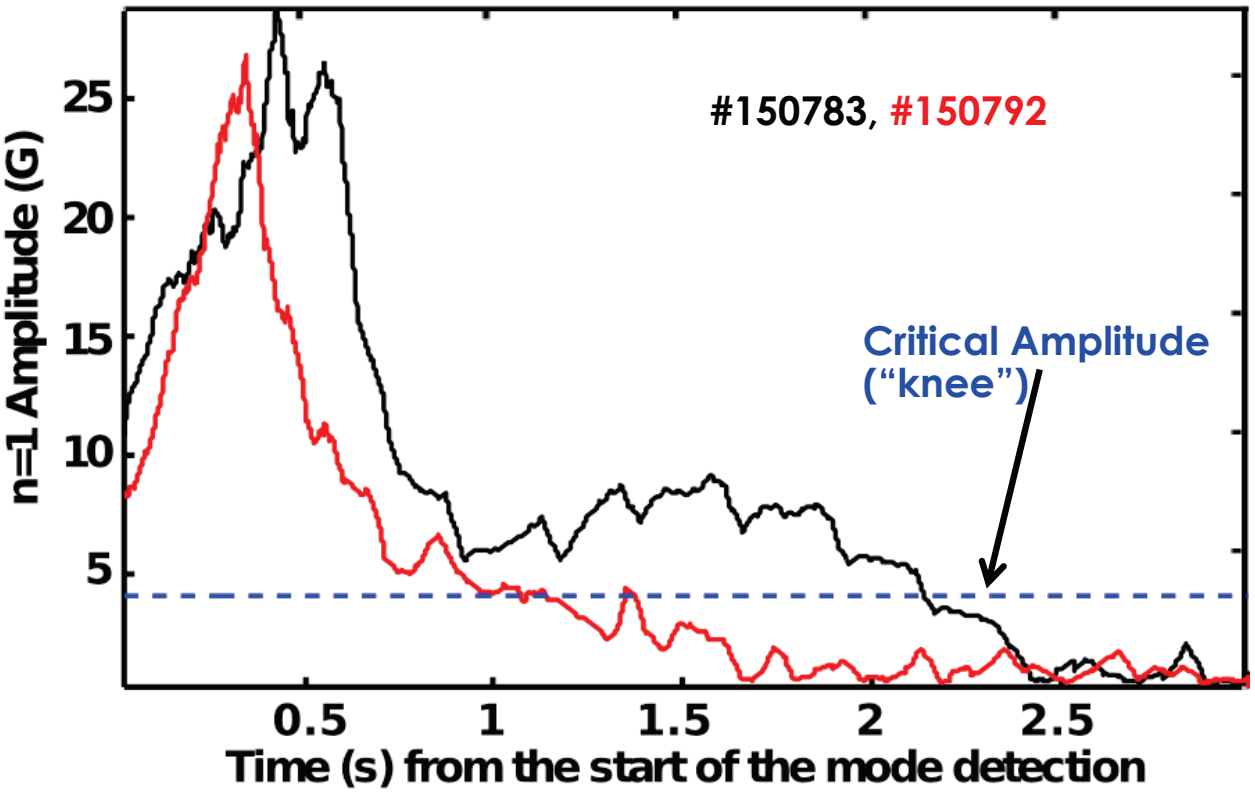
- Most challenging and important case

Successful 2/1 NTM Catch and Subdue Demonstrated



- **Peak mode amplitude is reduced; without ECCD, mode reaches ~40 G and locks with loss of H-mode**
- **The mode is eventually brought to full suppression**

Faster m/n=2/1 Mode Suppression Needs Earlier Mode Detection for "Catch and Subdue"



- Islands caught bigger than the critical amplitude take much longer to suppress
- n=1 noise from sawteeth, fishbones and ELMs are hindrance for small 2/1 mode detection
  - Also important for ITER
- Detection below the critical amplitude would reduce both the suppression time and EC on-time

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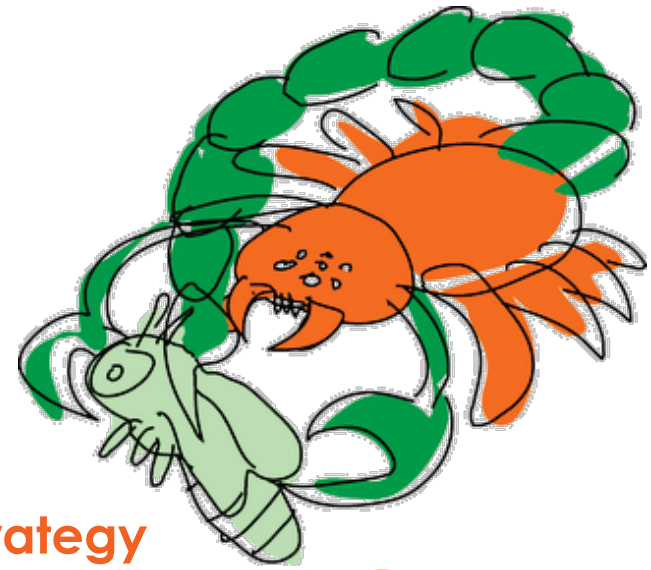
Integration of NTM Control Elements in DIII-D Has Demonstrated the Potential to Efficiently Control NTMs in ITER

- **Advanced integrated control**
  - Mode detection with Fourier analysis of the Mirnov diagnostics
  - Real-time high accuracy equilibrium reconstruction with MSE
  - Fast EC steerable mirrors
  - Fully automatic control algorithm **"Catch and Subdue"** that fuses all the ingredients

- **Provides an efficient approach for ITER**
  - Reduces power requirements for NTM control
  - Reduces time to suppress modes
  - Decreases adverse effects on confinement & avoids loss of H-mode and disruption
  - Enables higher Q in ITER



Catch & Subdue, the Scorpion's Strategy