Feedback Control of MHD kink instabilities on the HBT-EP tokamak

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Feedback Control of MHD kink instabilities on the HBT-EP tokamak

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Outline

- Introduction: Importance of high pressure plasmas to fusion and motivation for active control
- MHD limits to high-pressure operation: kink modes
- HBT-EP passive and active control systems
- Passive and active HBT-EP control experiments to reach higher pressure and current operation
- Optimizing kink mode feedback systems: ideal wall performance

Goal: <u>Improve Performance of Fusion Systems via MHD Instability Control</u>

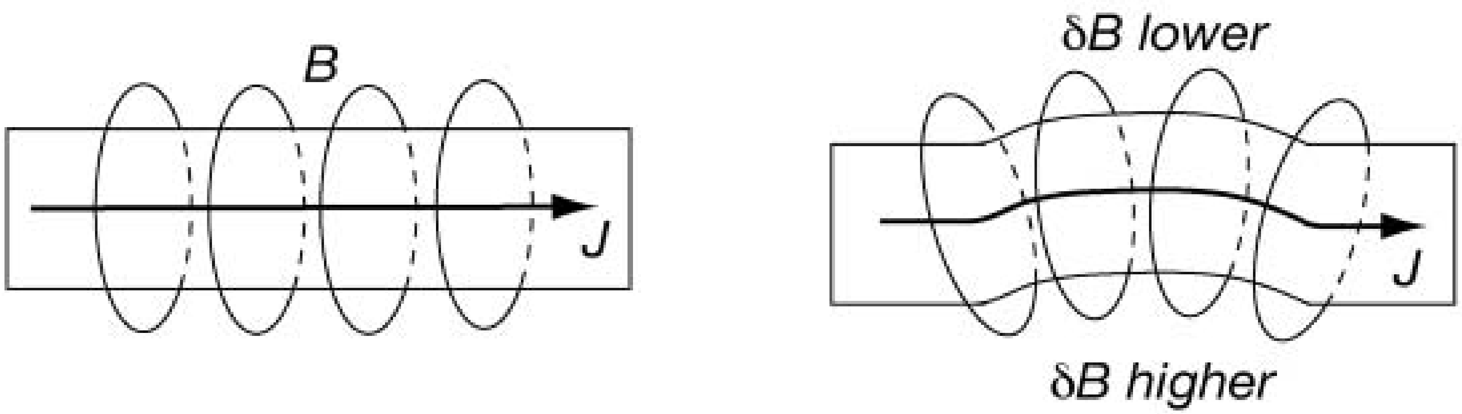
Approach: Understand the basic physics of macroscopic, performance limiting MHD instabilities and their active and passive control.

Use this knowledge to improve operational pressure limits and hence power output for future fusion energy systems.

Study physics of these issues in a flexible small machine test bed enviroment with MHD relevant plasmas and apply knowledge and tools developed to larger fusion experiments (*DIII-D, NSTX, FIRE, ITER*)

Basic External Kink Instability

Kink modes limit high plasma pressure performance in current and future large tokamaks



kinking motion gives rise to a perturbed force that acts to enhance the kinking motion

Fast timescale motion ~ 10^{-6} sec (active feedback not possible)

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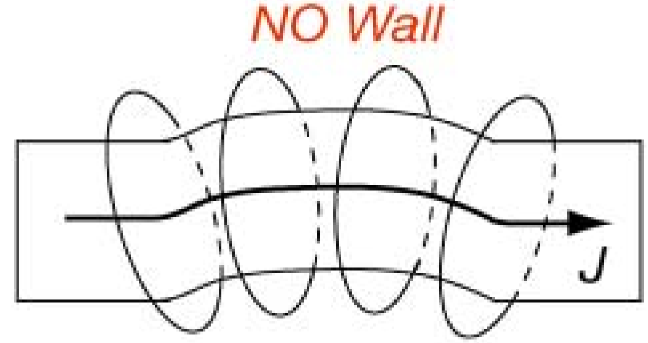
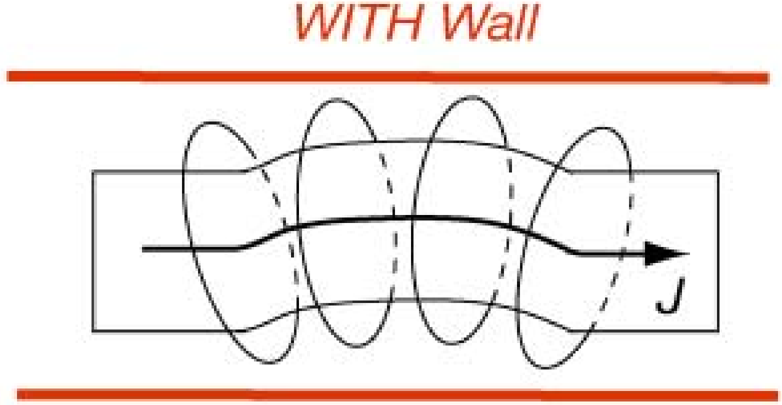
A Close Fitting Conducting Wall Can Stabilize the Ideal Kink



No wall → fast kink unstable

Resistive walls allow magnetic flux leakage on slow timescale ~ msec



Flux compression gives restoring force that stabilizes the fast kink mode

Flux leakage allows growth of slow kink (resistive wall kink mode)

Timescale slow enough for feedback control

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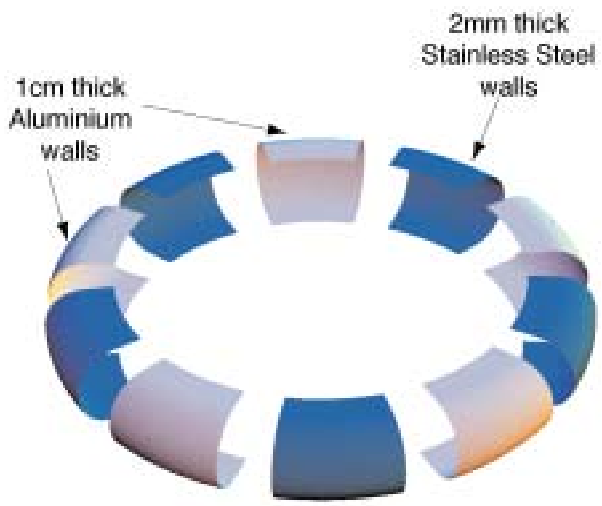
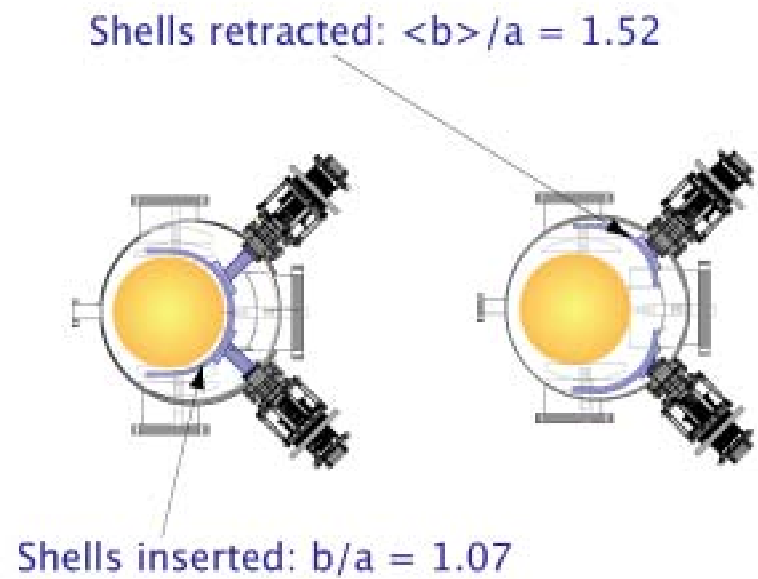
HBT-EP Is A Unique Test Bed For Experimental Studies And Model Benchmarking of RWM Control Physics



HBT-EP Experimental Geometry

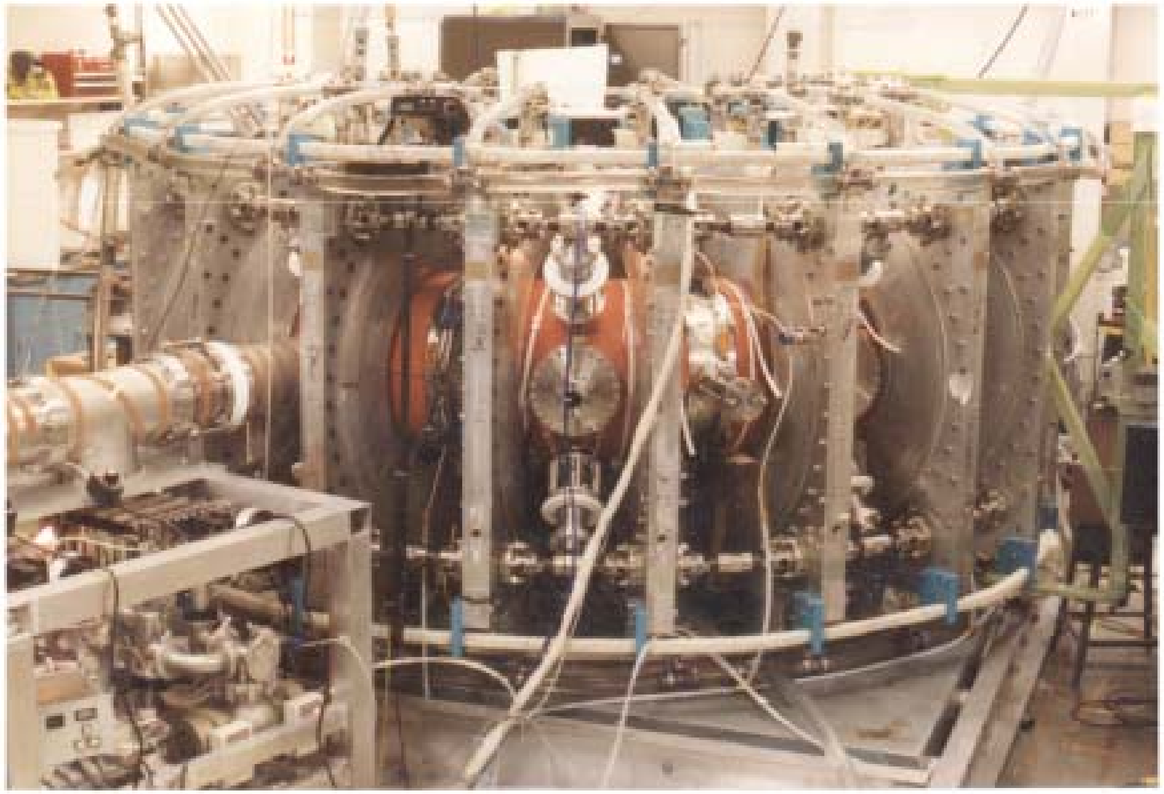


HBT-EP Passive Wall Stabilizer

- Independedently (movable) positionable Aluminum and Stainless shell segments
- Complicated geometry needs accurate 3D quantative representation
- Fully adjustable wall time constant by varying plasma-shell segment distance

HBT-EP Active Control Coils

- Three "smart shell"control and sensor coils per stainless steel shell segment
- Total of thirty independent control/sensor loops for radial flux cancelation
- Recently added new coil set with 40 control coils and 20 new Bp sensor coils



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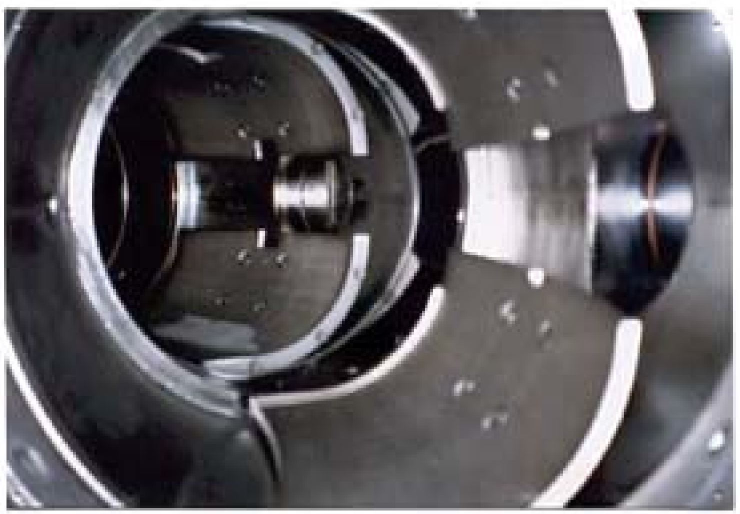

Invessel
Aluminium
segemented
wall

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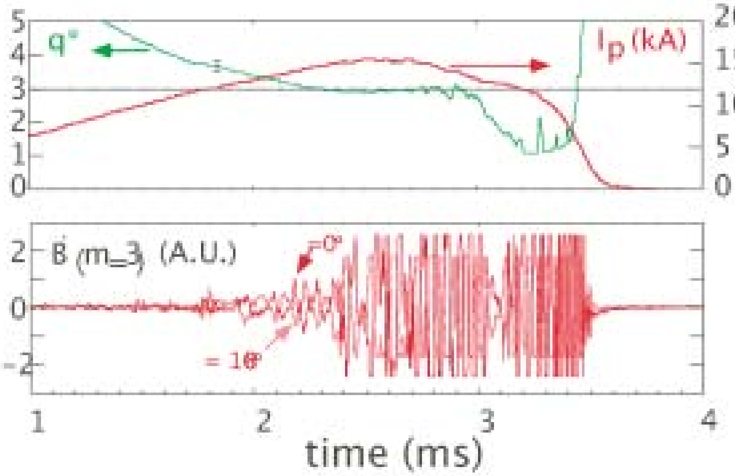
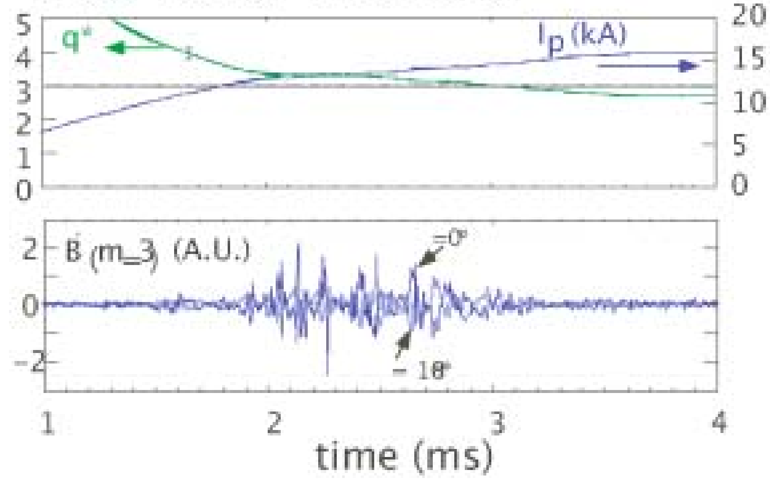
Ideal (fast) Kink Suppression Using a Conducting Wall

Stalbization of the External
Ideal Kink with Wall Stabilization

Wall Retracted

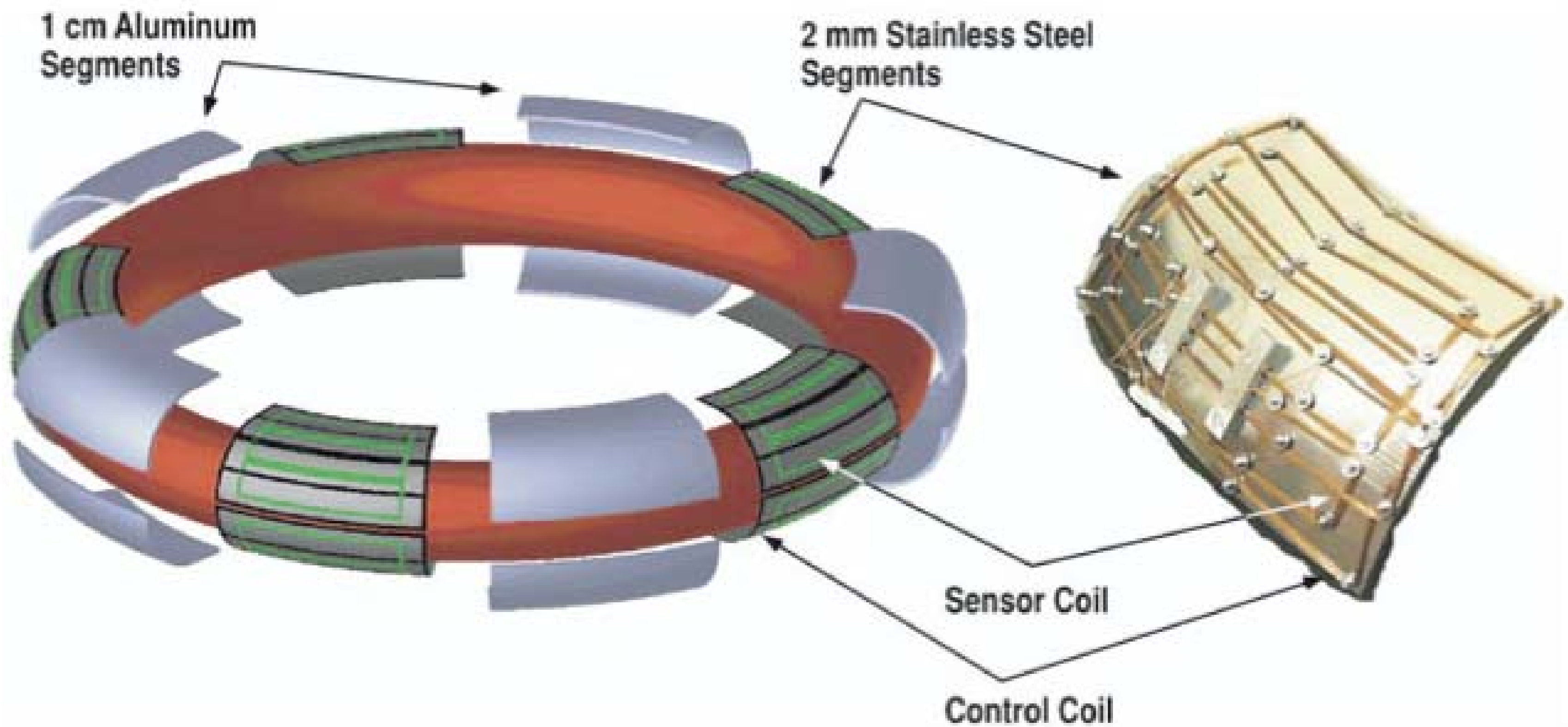


Wall Near Plasma



- All Al plates inserted above
- Similar stabilization observed with half of the Al plates inserted

Feedback Control System for Resistive Wall Kinks



- Three control and sensor coils per SS passive plate as shown
- Thirty independent control/sensor pairs for radial flux cancelation ("smart shell")

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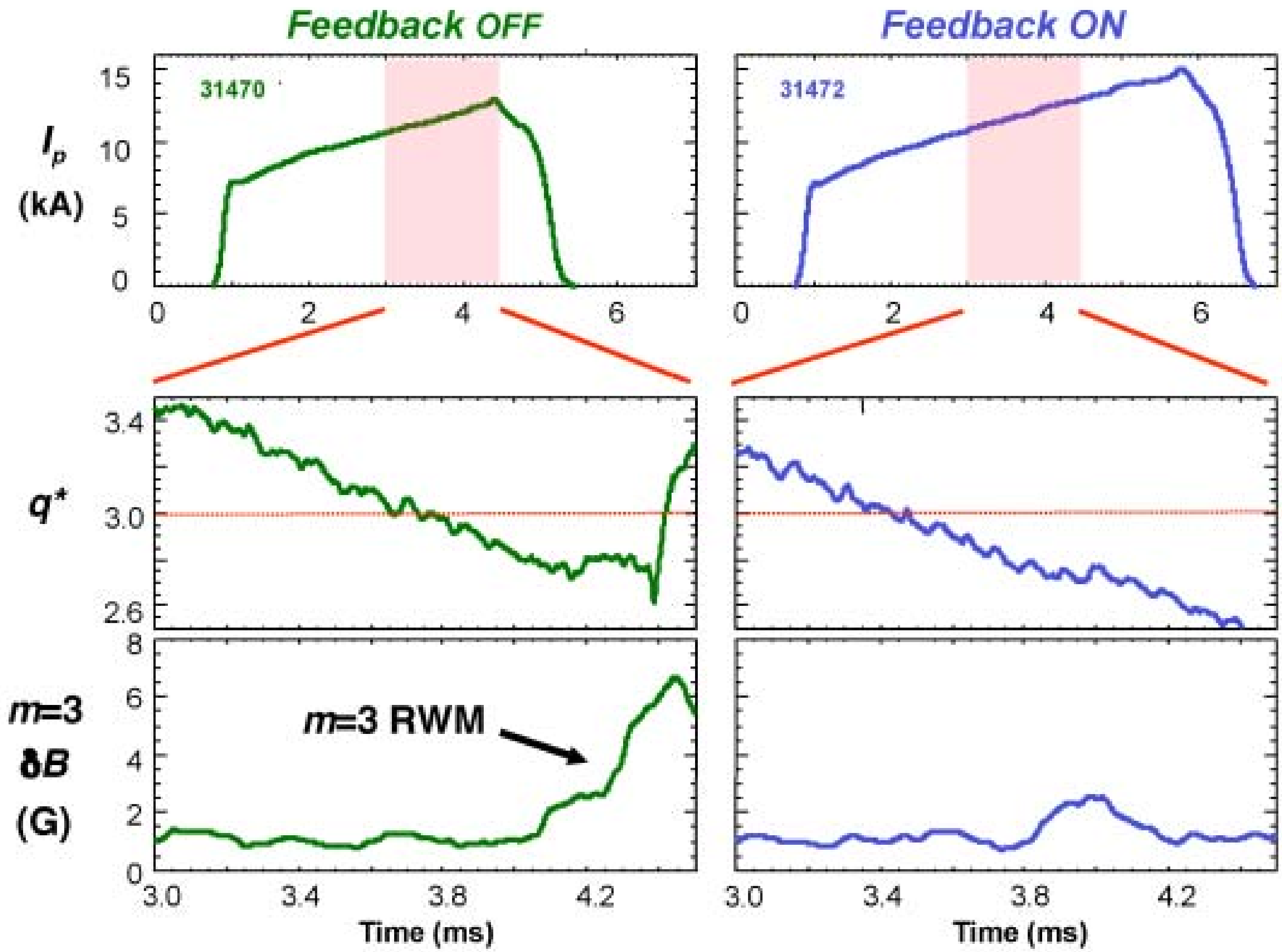
Feedback Successful At Suppressing Resistive Wall Kink and Inhibiting Induced Disruption



Feedback allows higher current/lower q^* and higher pressure operation.
Plasmas disrupt later due to internal tearing mode growth.

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Optimized Feedback: Approaching the Ideal Wall limit

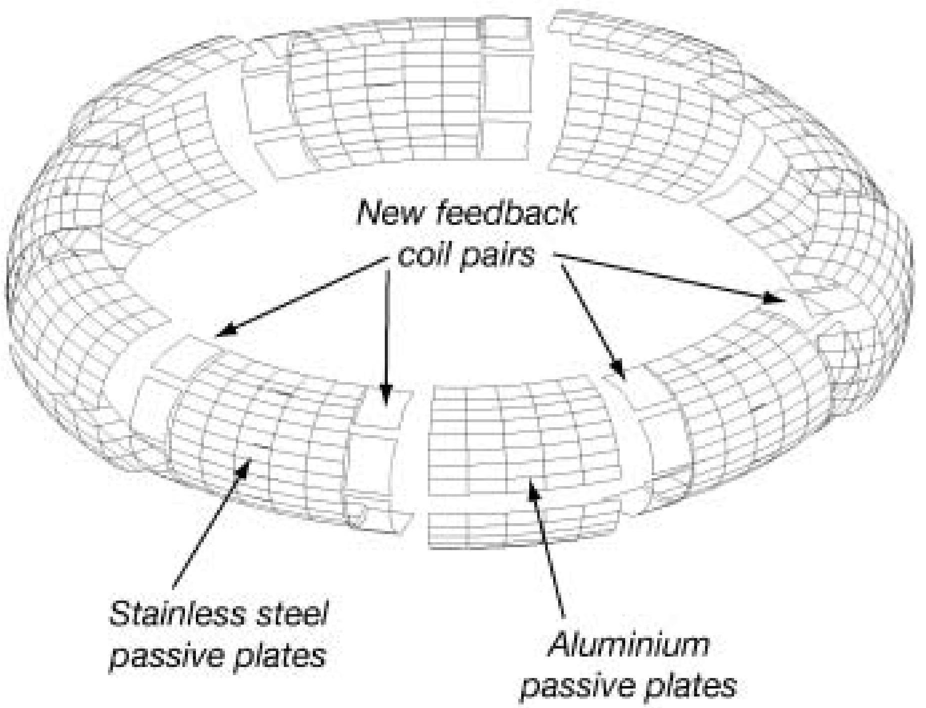
- Theory and modeling tell us that **minimizing the control coil-resistive wall coupling** (mutual inductance) while **increasing control coil-plasma coupling** leads to better feedback performance

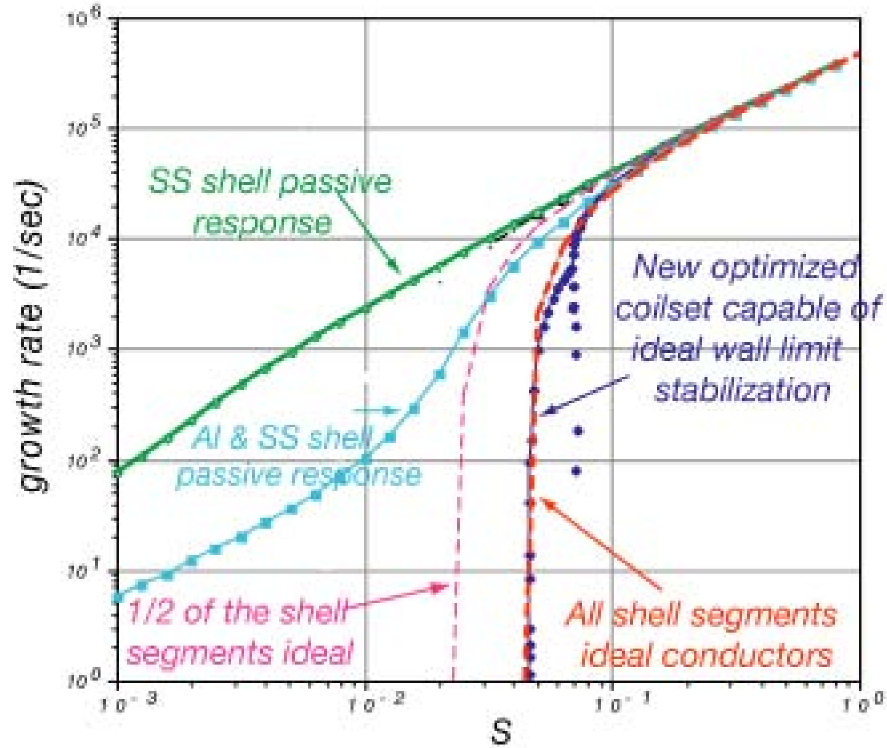
- And **minimizing sensor coil-control coil coupling** increases performance

- New goal is ***"optimized"*** **system** with both of these features **able to perform at the ideal wall limit**

VALEN Optimization of Feedback Control

New Control Coils Located in the Gaps Between the Passive Plates with B_p Sensors Predicted to Reach Ideal Wall Limit

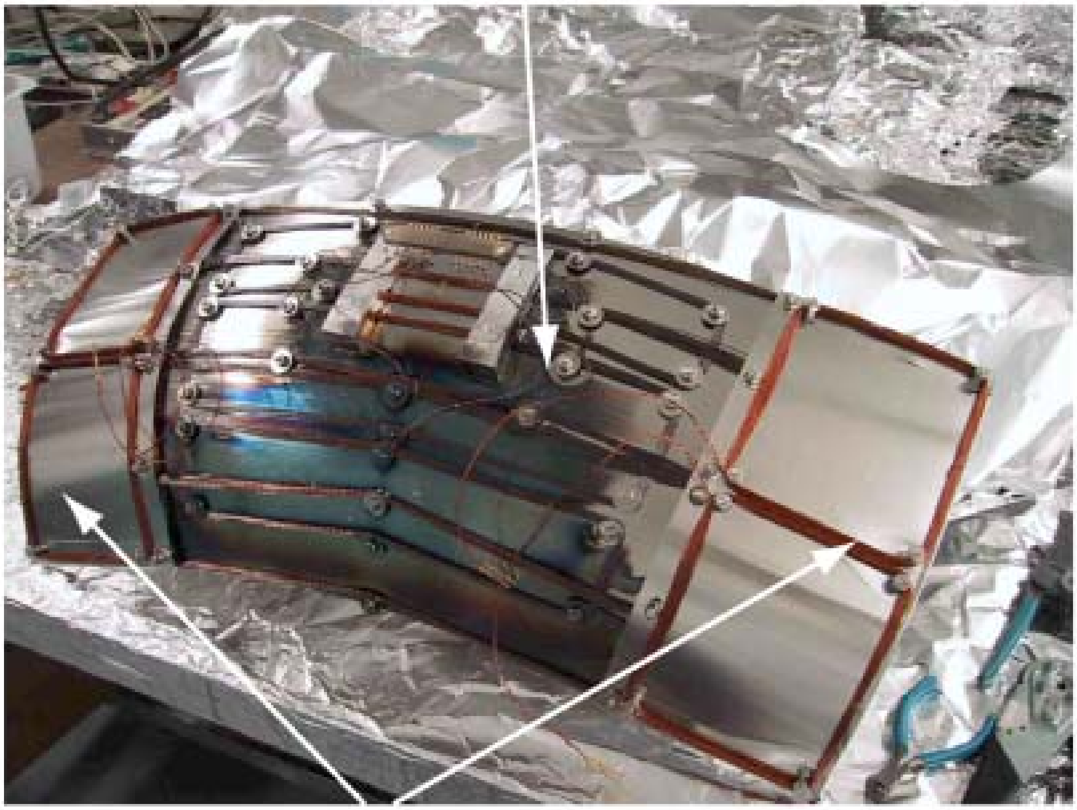




- 20 new control coil pairs at 5 distinct toroidal and 4 poloidal locations on outboard side of tokamak
- 20 new companion B_p sensors on plasma facing side of SS passive plate
- Initial mode control experiments in progress

Optimized Feedback Control Coil System

Old smart shell feedback system



New mode control feedback coils mounted off of stainless passive plates

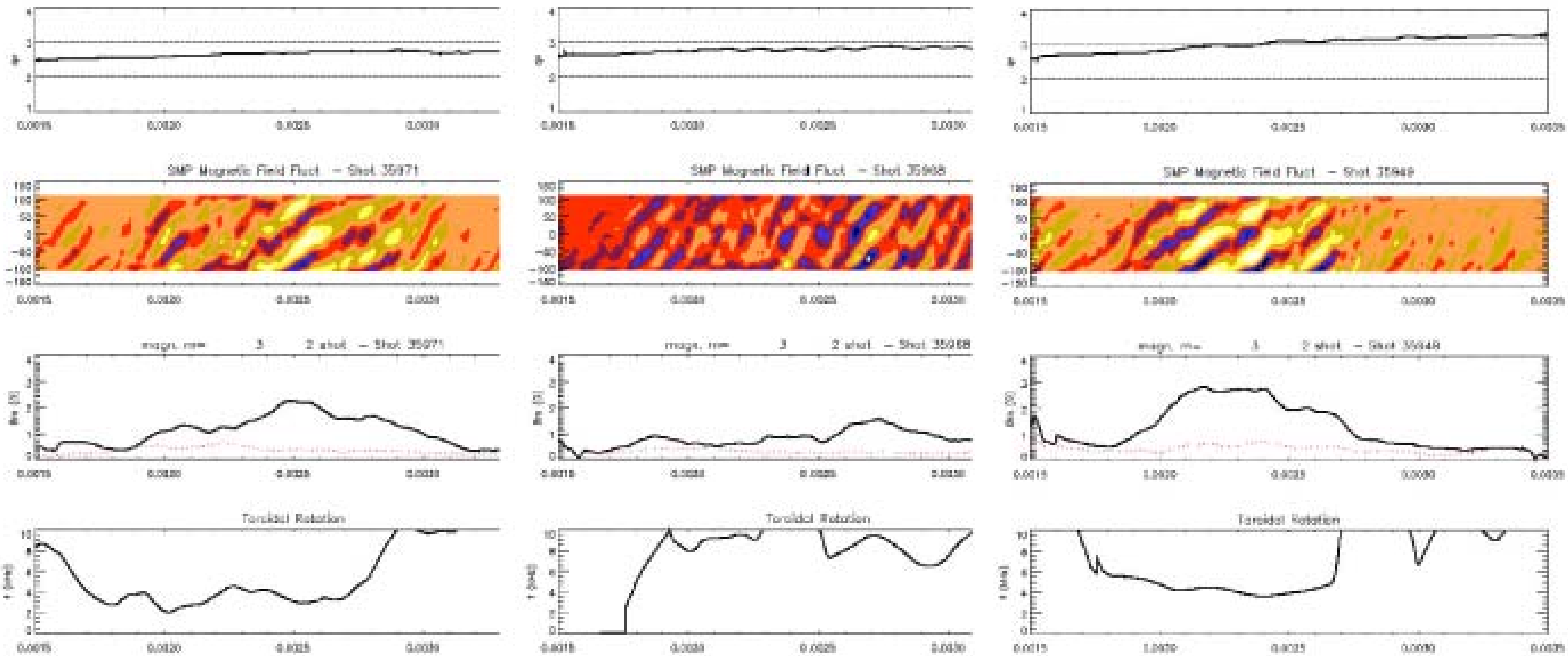
- New control coils mounted on thin 0.25 mm stainless steel shim stock to minimize wall coupling

- New poloidal sensors on plasma facing side of stainless steel plate *(not shown)*

- New mode control experiments have begun by mapping poloidal sensors in toroidal angle 72 degrees to make up B_p sensor to B_r control coil phasing using existing analog circiutry

Initial Tests of Optimized Feedback Phasing Underway

Target RWM | **Suppression** | **Amplification**



negative feedback

positive feedback

Summary

- High plasma pressure and current operational limits due to MHD kink modes can be surpassed using a combination of passive wall stabilization and active feedback control.

- HBT-EP experiments have demonstrated:
  - Wall stabilization of the ideal kink using a segmented wall
  - Feedback control of the RWM and disruption suppression
  - Implementation and initial experiments with an optimized feedback configuration
  - Benchmarking of the VALEN RWM control code