New HBT-EP multimode MHD control system and future experimental plans

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University of Wisconsin-Madison

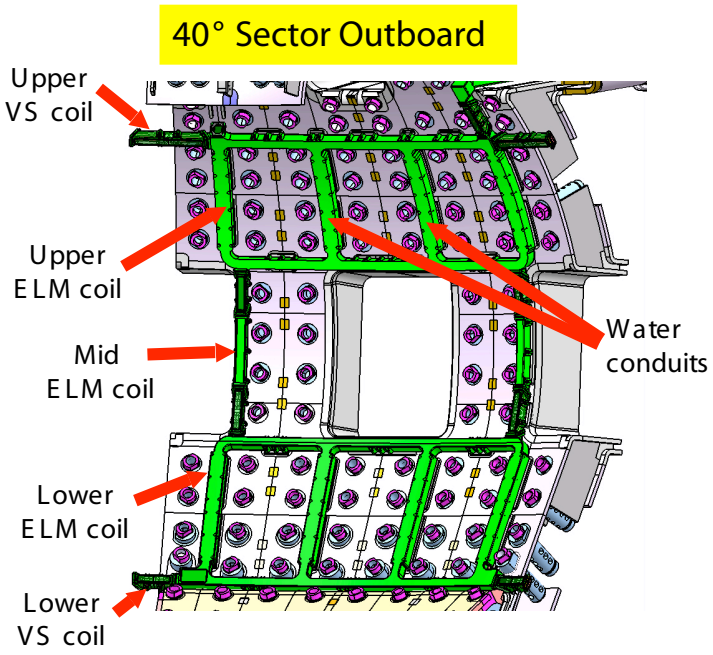
Talk outline

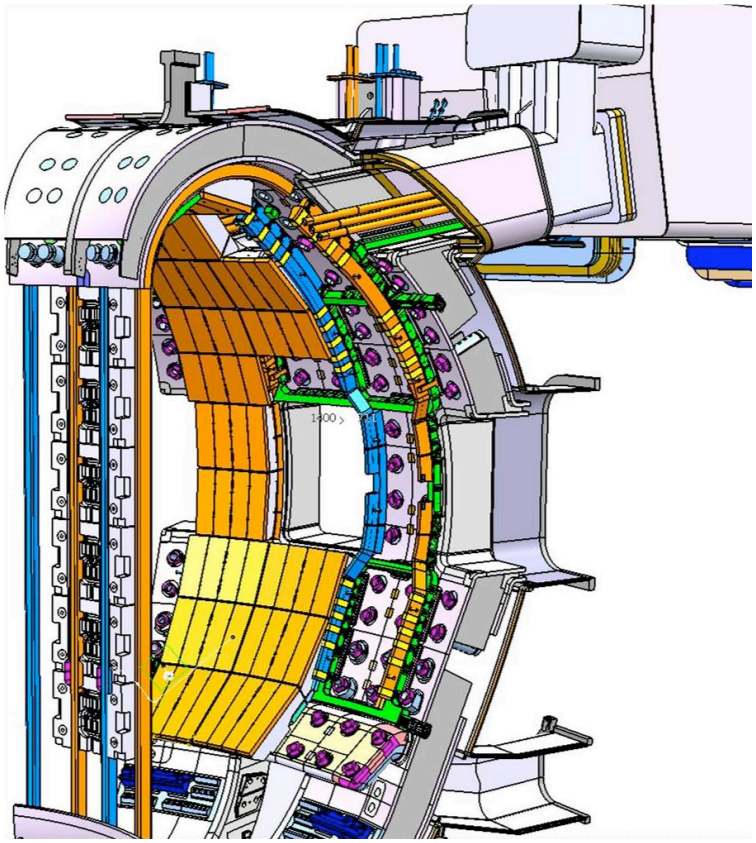
- Motivation and experimental goal of new wall, control and sensor coil arrays on HBT-EP

- Overview of system design and installation progress to date

- Future experimental plans

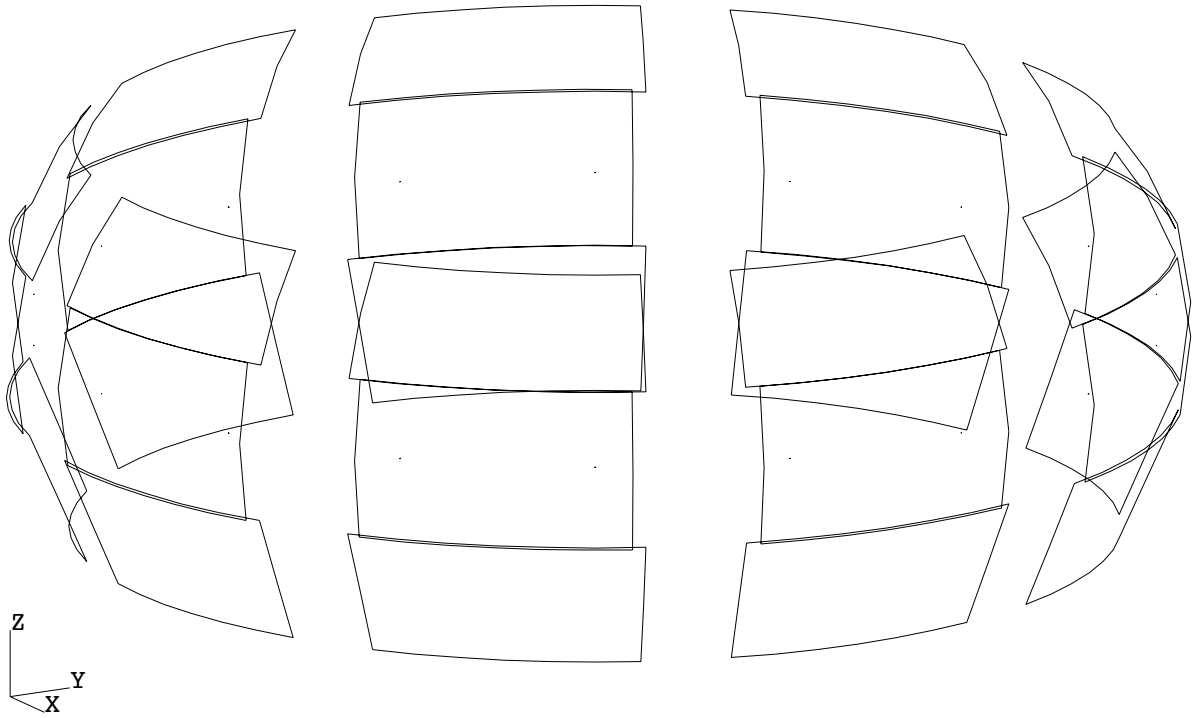
Tokamak plasmas are only nominally axisymmetric: small 3D magnetic fields profoundly effect operation





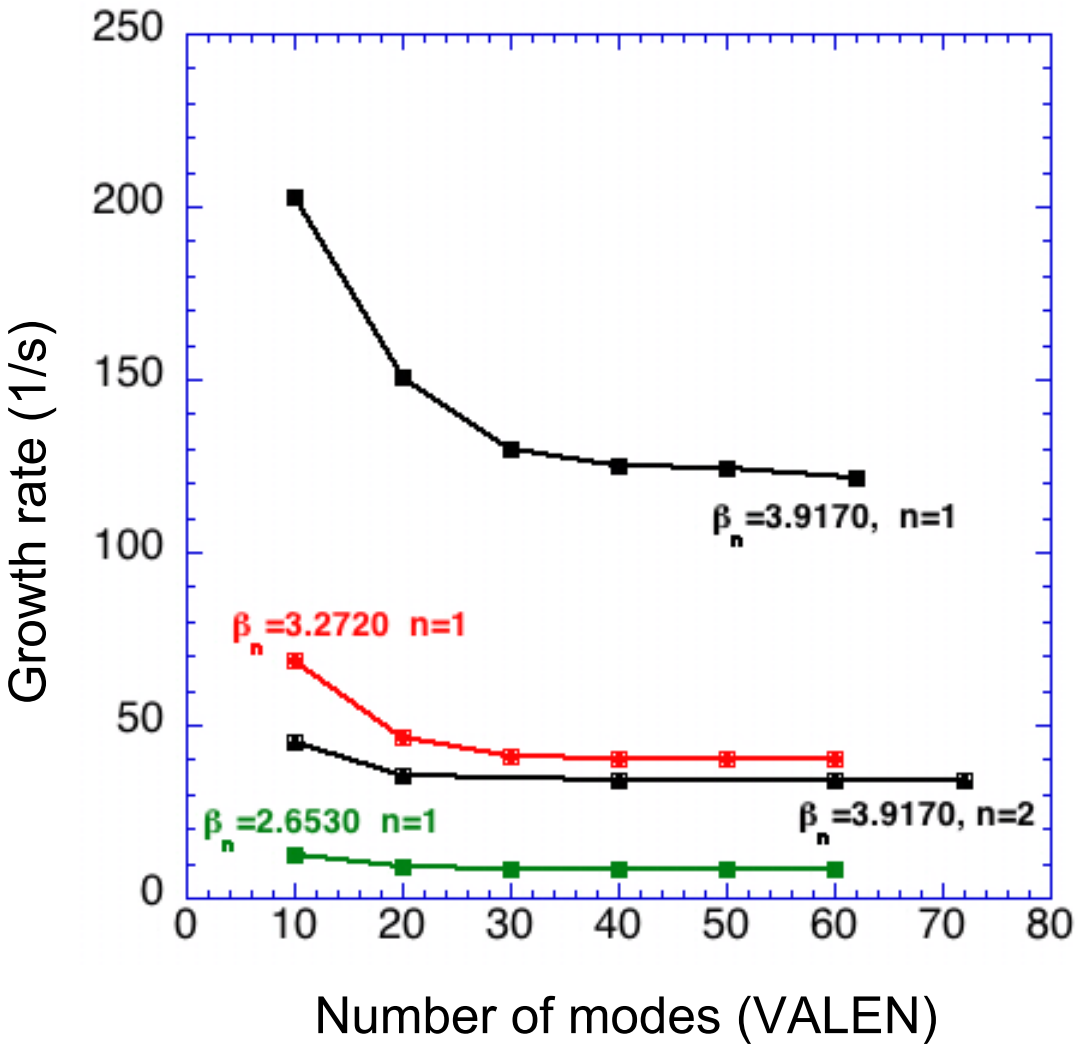
ITER will have a 3D boundary: how will plasma response influence our ability to control it?

Small, Modular Internal Coils in ITER will interact with multiple plasma modes



3D finite element VALEN model of VAC02 coilset

Multimode effects are predicted at high pressure in ITER



Both n=1 and n=2 unstable at high pressure

Also stable n=1 and n=2 modes close to marginal stability can add to plasma response

J. Bialek, S. Sabbagh

Frontier areas in MHD mode control

Kinetic Effects on Long Wavelength MHD Stability

- Drift Resonance Coupling to Drive/Stabilize MHD (Bo Hu and R. Betti, *Phys. Rev. Lett.* **93** (2004) 105002)

Multimode MHD and 3D physics is exciting and important area

- Long wavelength instabilities, like RWM, must be controlled to achieve high-performance
- Multimode and 3D effects due to ferritic TBM and local control coils must be understood to optimize ITER performance

Advanced Active Feedback Control

- Optimal Control allows near ideal limit performance with modular external control coils

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Advanced Active Feedback Control

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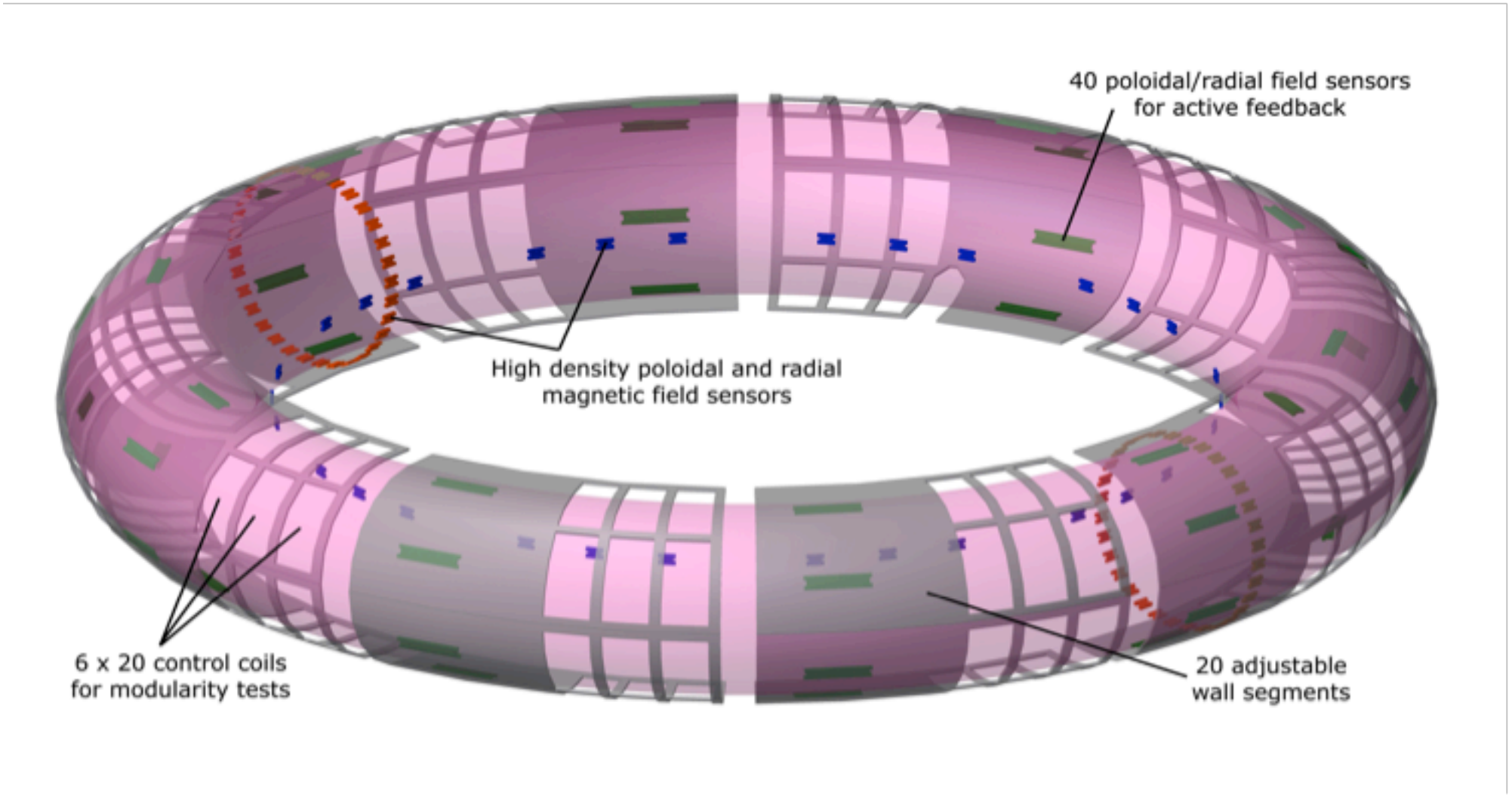
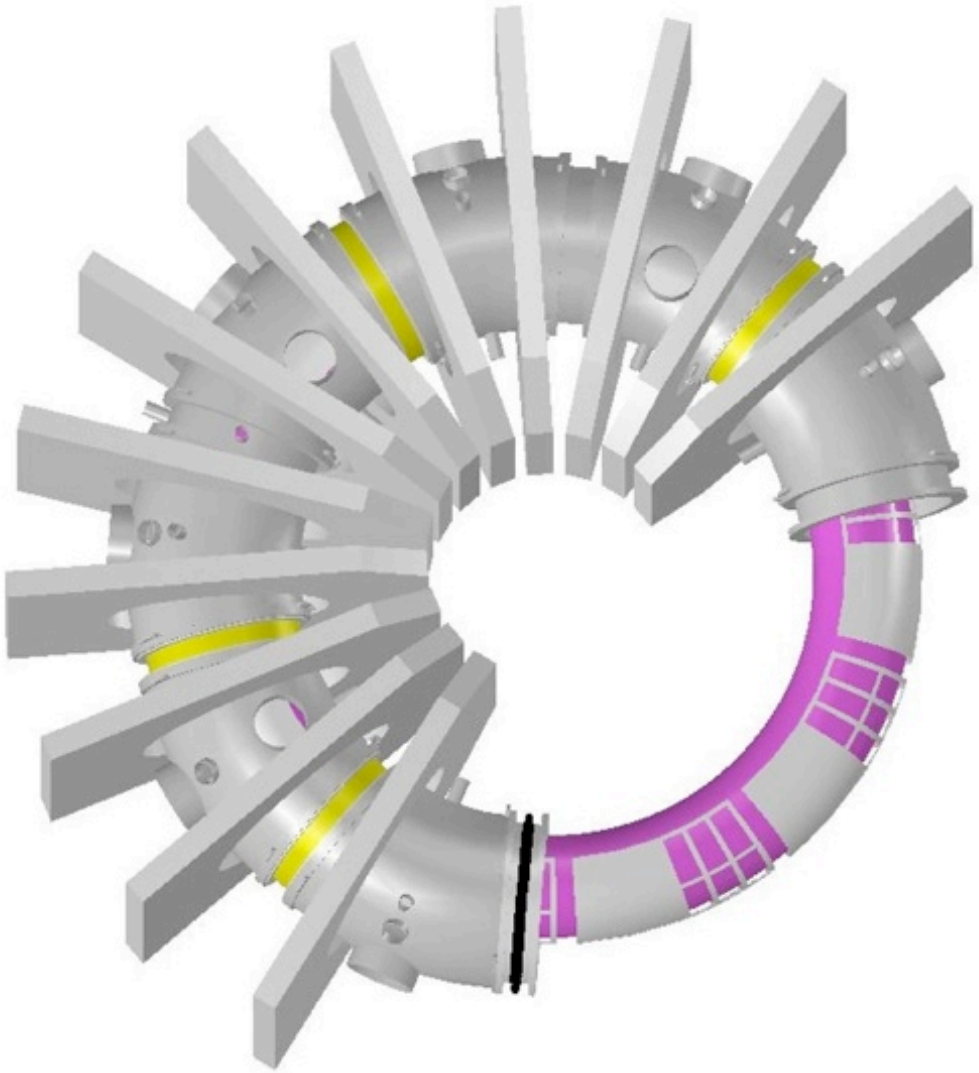
First Area Requires Collisionless Hot Plasma – not possible in small device

BUT problem areas are separable: HBT-EP redesigned to address 2nd and 3rd area

Newly installed HBT-EP instrumented wall for multi-mode MHD and 3D magnetic boundary studies

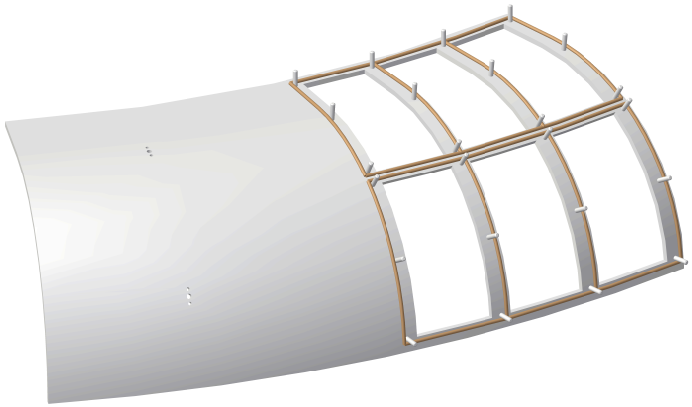


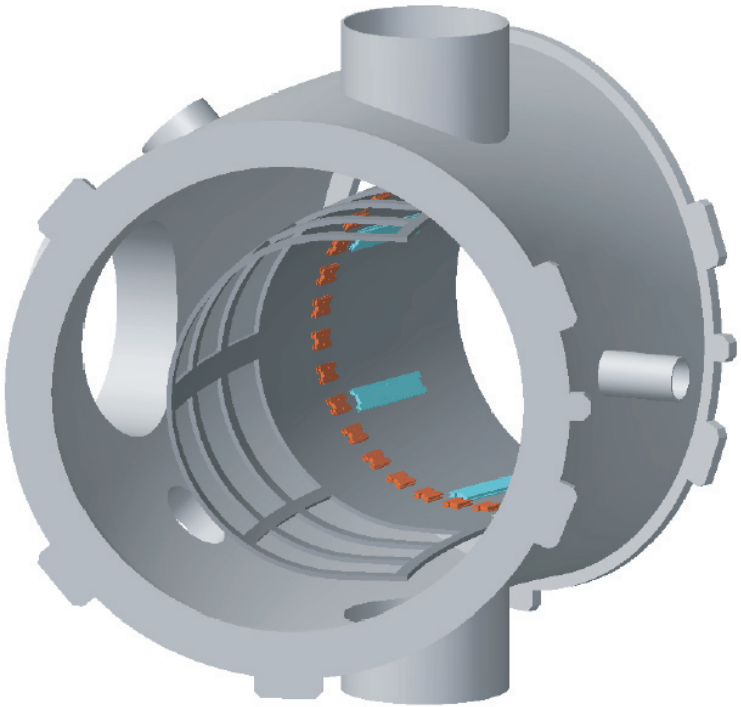
New instrumented wall will allow the study of multimode MHD physics with high detail

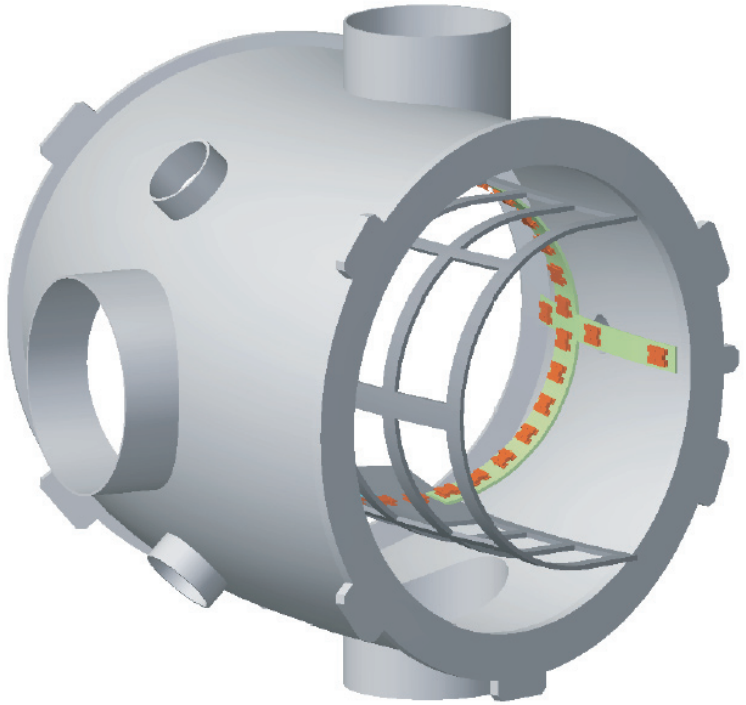


- 120 new control coils of varying angular extent (used as sensors also)
- 216 new pickup coil magnetic diagnostics
- Control coil coverage and amplifier power upgrade will deliver factor of 10 increase in applied fields

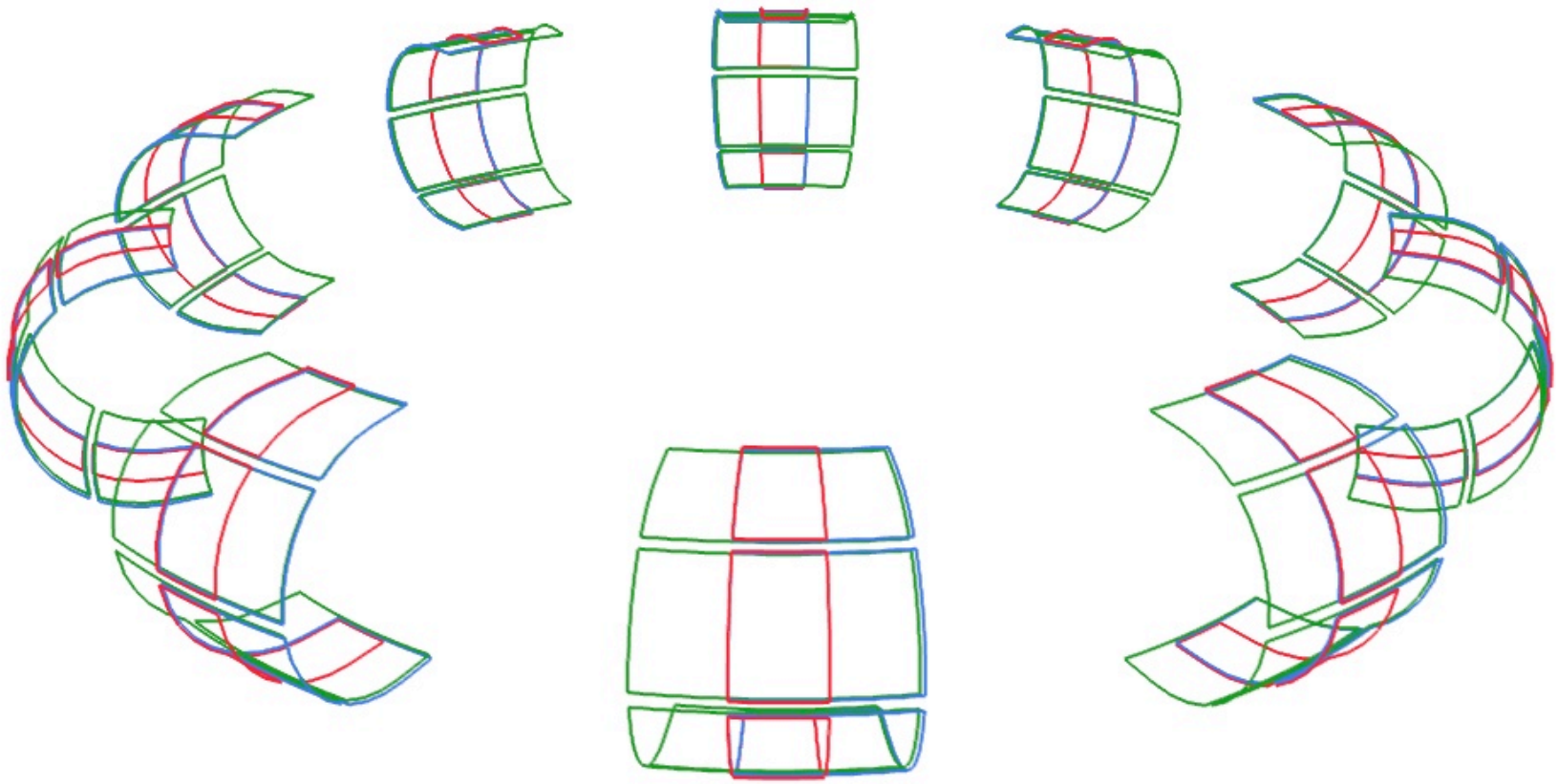
HBT-EP new wall, control and sensor coils arrays in-vessel







New control coil arrays to probe multimode plasma MHD response

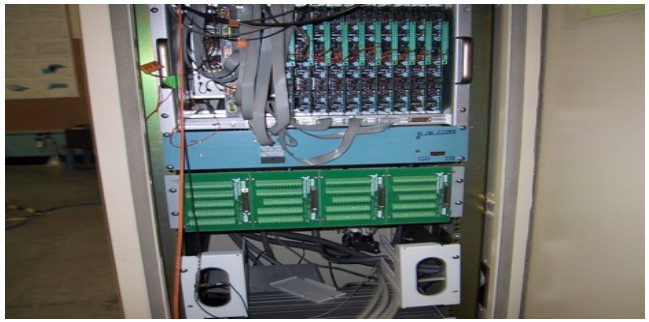


120 control coils of varying angular extent

--- Coils also used as saddle loop sensors when not energized

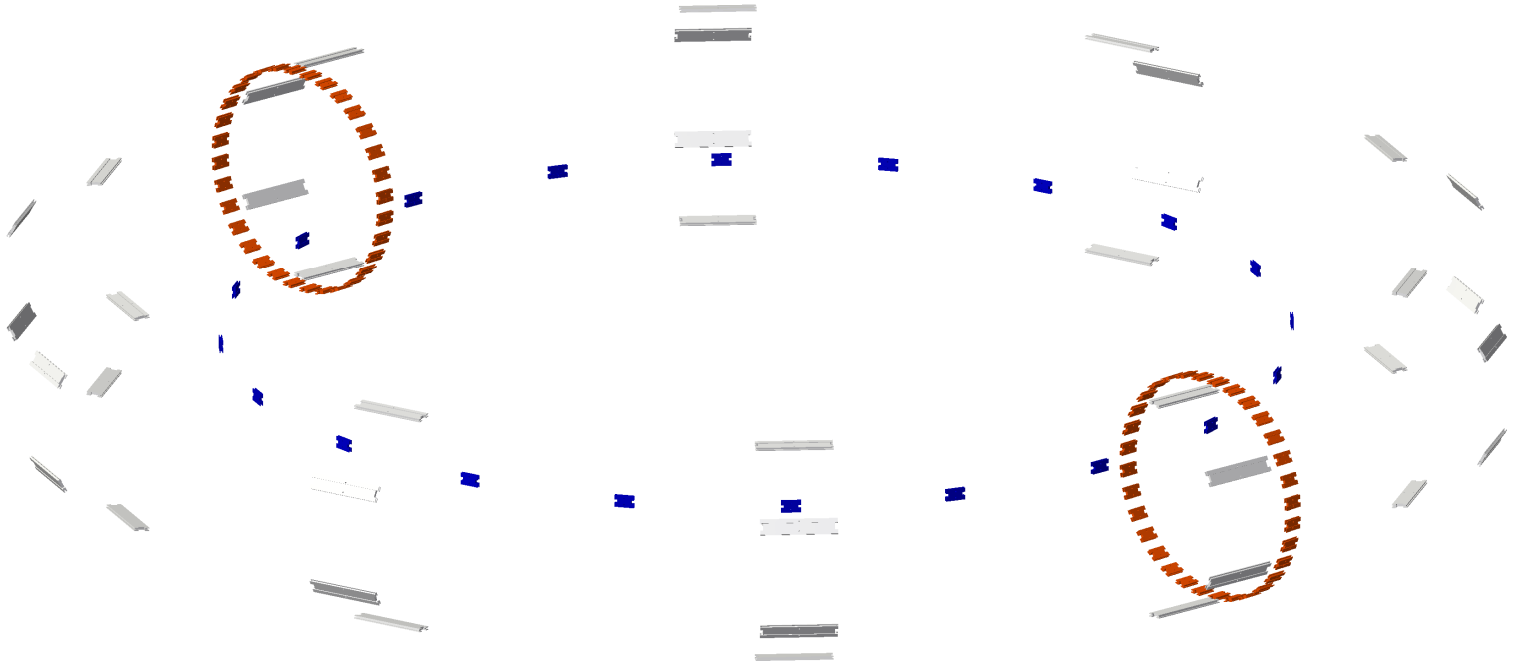
x10 larger control magnetic fields will allow extensive MHD studies

New system will
use 10 to 12FPGA controllers



2kW Crown amplifiers

New magnetic sensor arrays to measure multimode plasma response

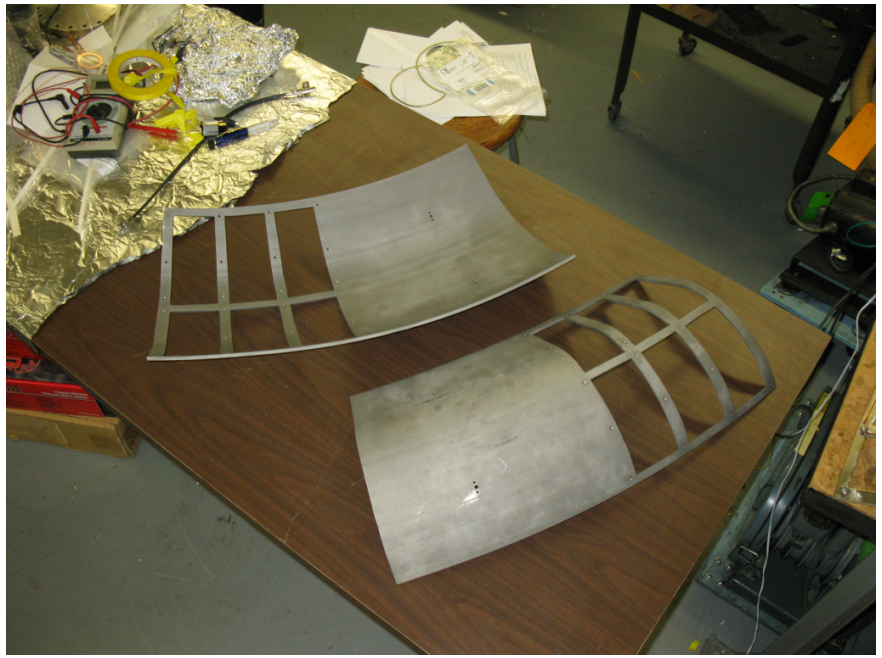


216 new magnetic pickup sensors, n~14, m~15

Calibrated using in-vessel "copper" plasma

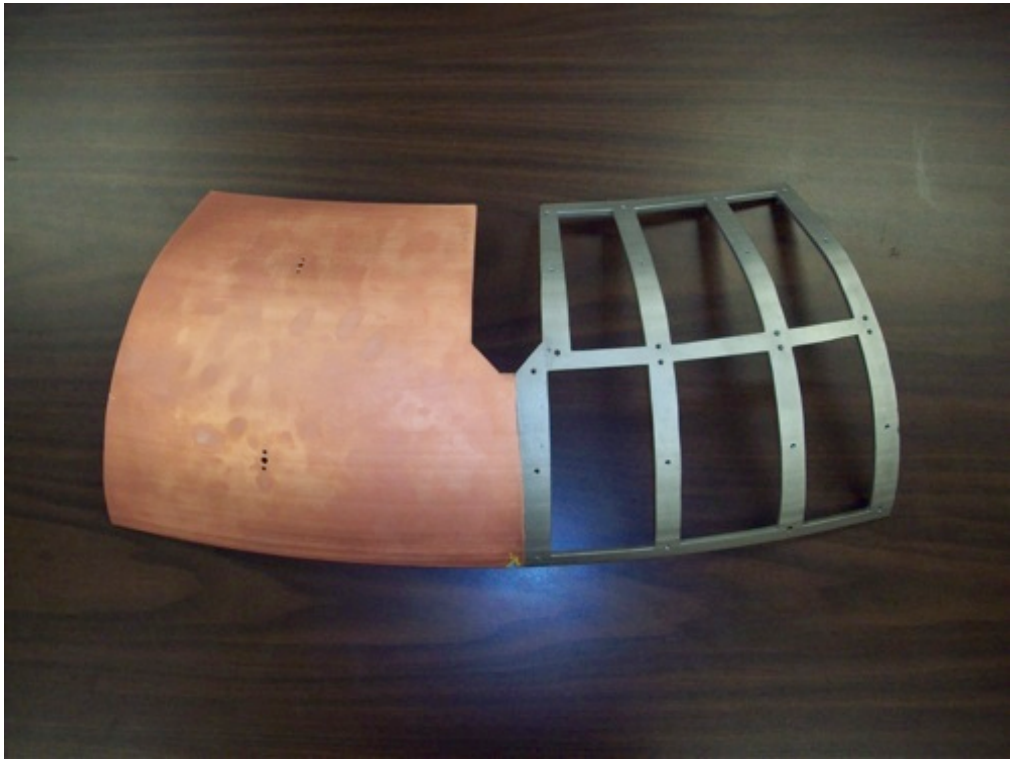
New wall construction: Spinning stainless steel "pans"and machining

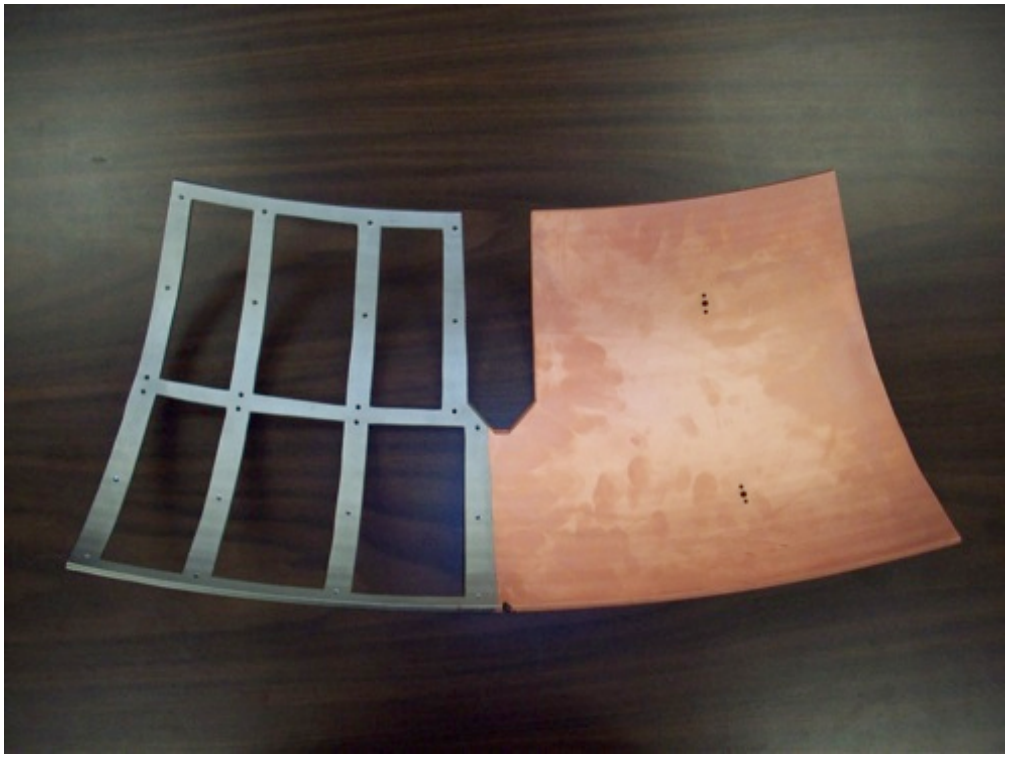
The (almost) finished product... Progress as of 2009 MHD workshop



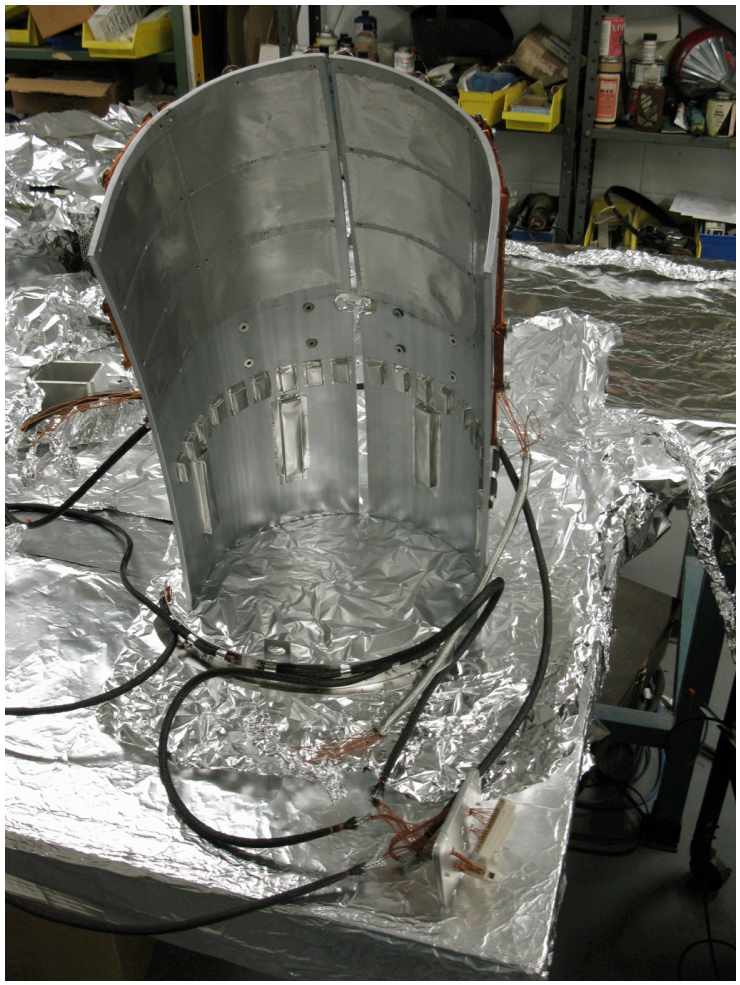
Next steps: Electropolishing, electroplating, and control coil winding and sensor installation

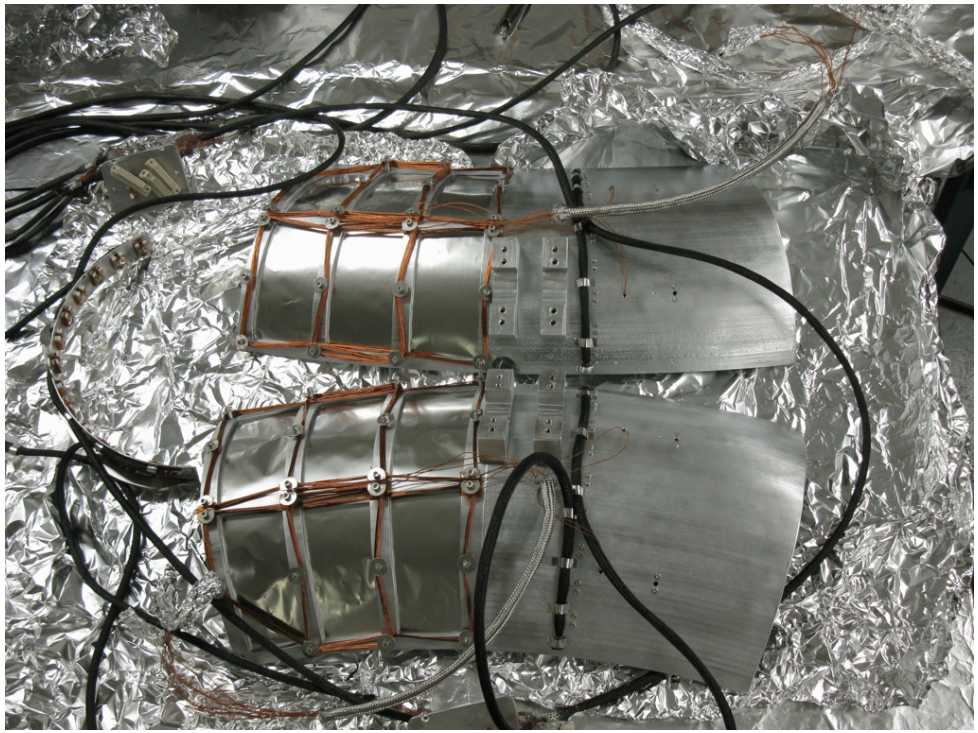
Copper plating to adjust wall magnetic field diffusion time successfully applied





Wall segment pair ready for installation





System installation and alignment gives precise nominal location of wall and coils

In-house and 3D coordinate measuring arm for final installation measurements of shell position. Available via collaboration with PPPL.

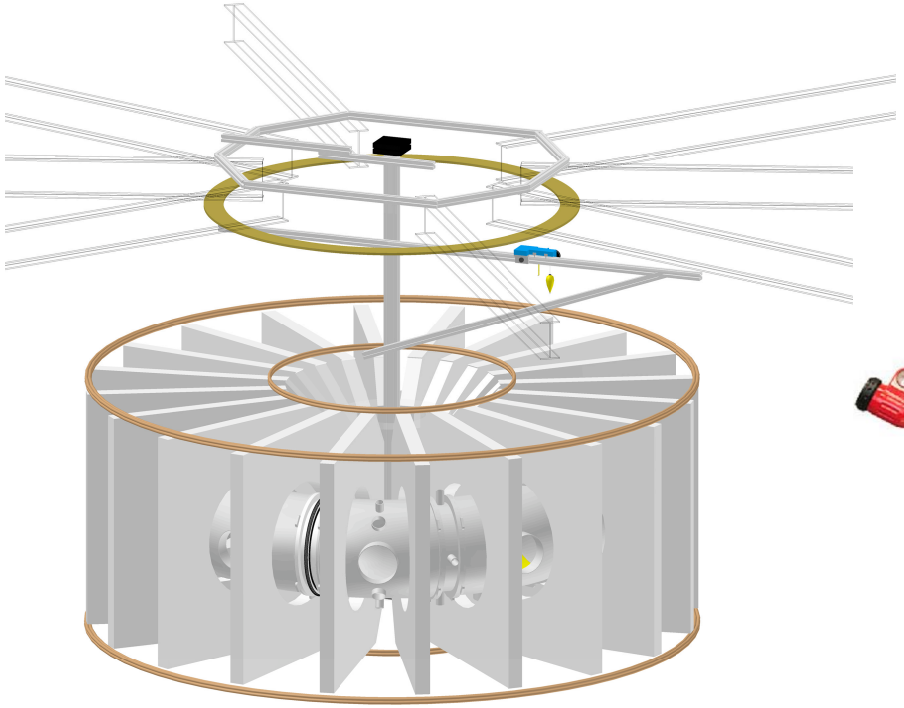
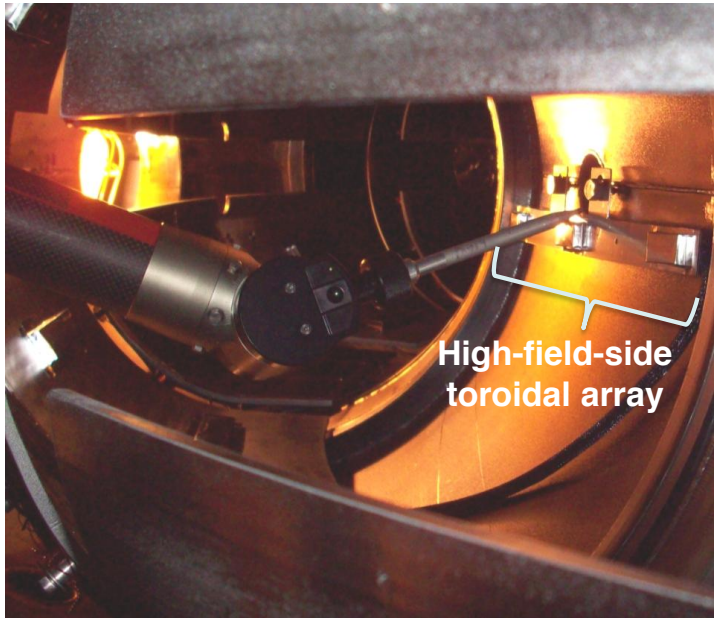


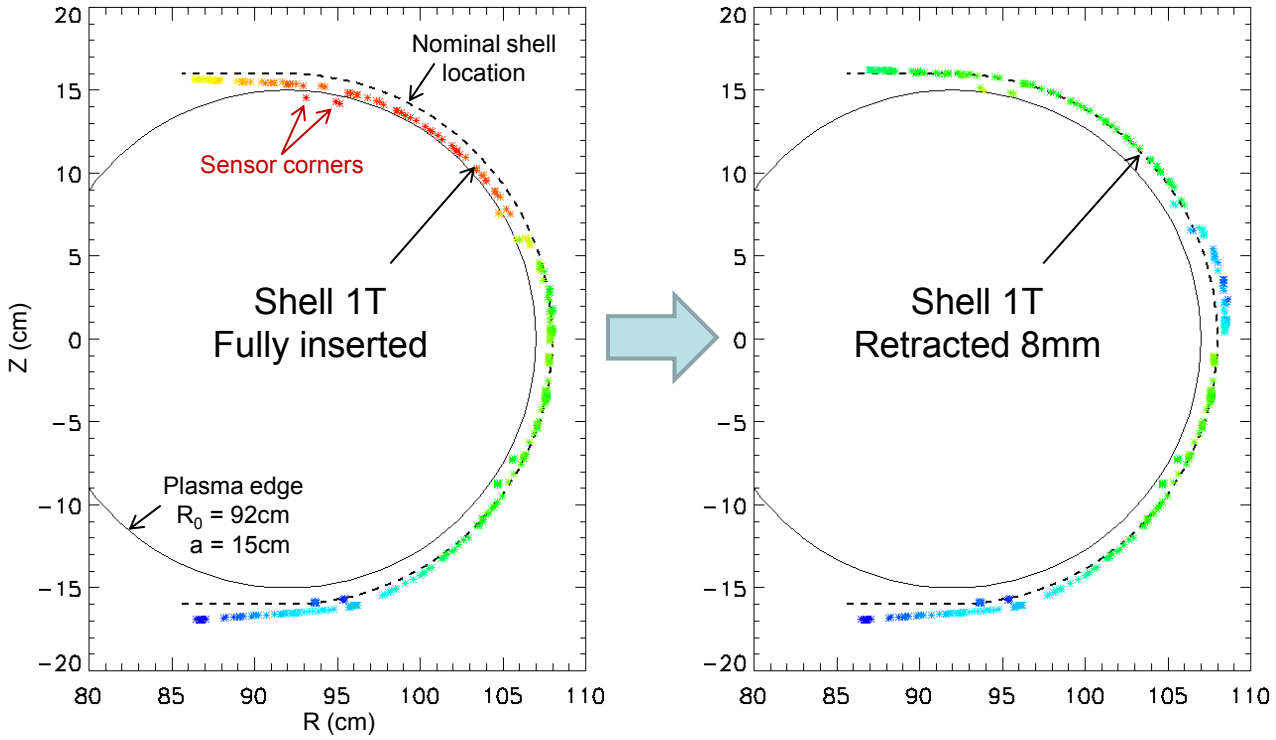
Image source:
http://us.romer.com/infinite-2-0



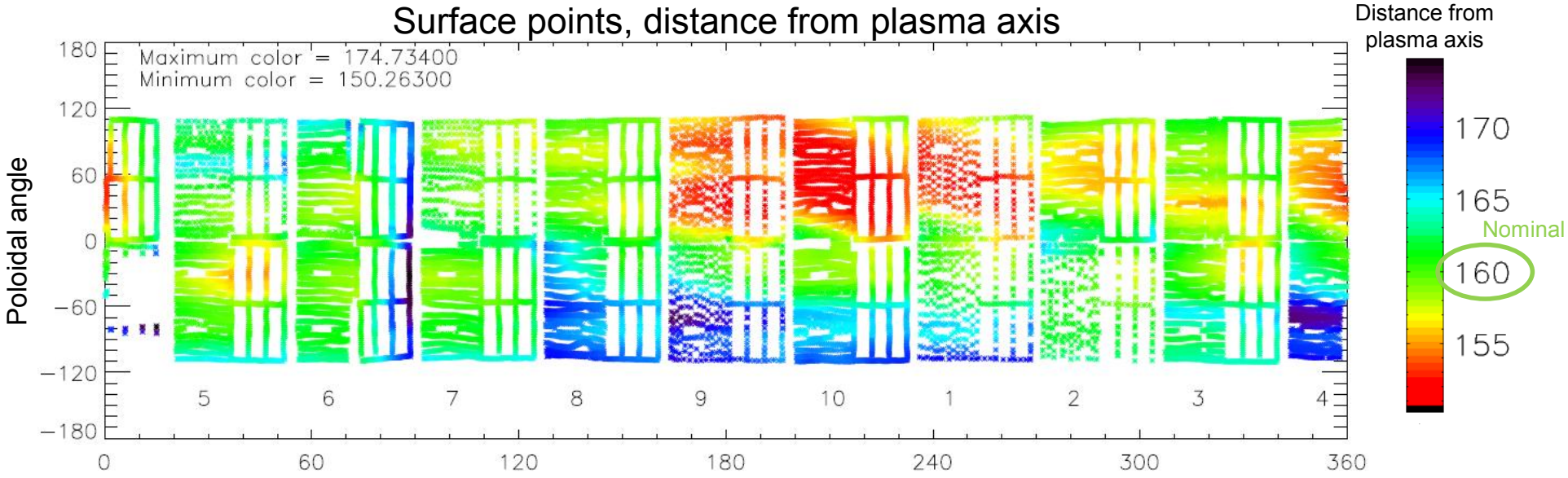
Accuracy: R~0.25mm,
Angle~1/80 degee, Z~1/64in

Thanks to Phil Efthimion
and Steve Raftopoulos

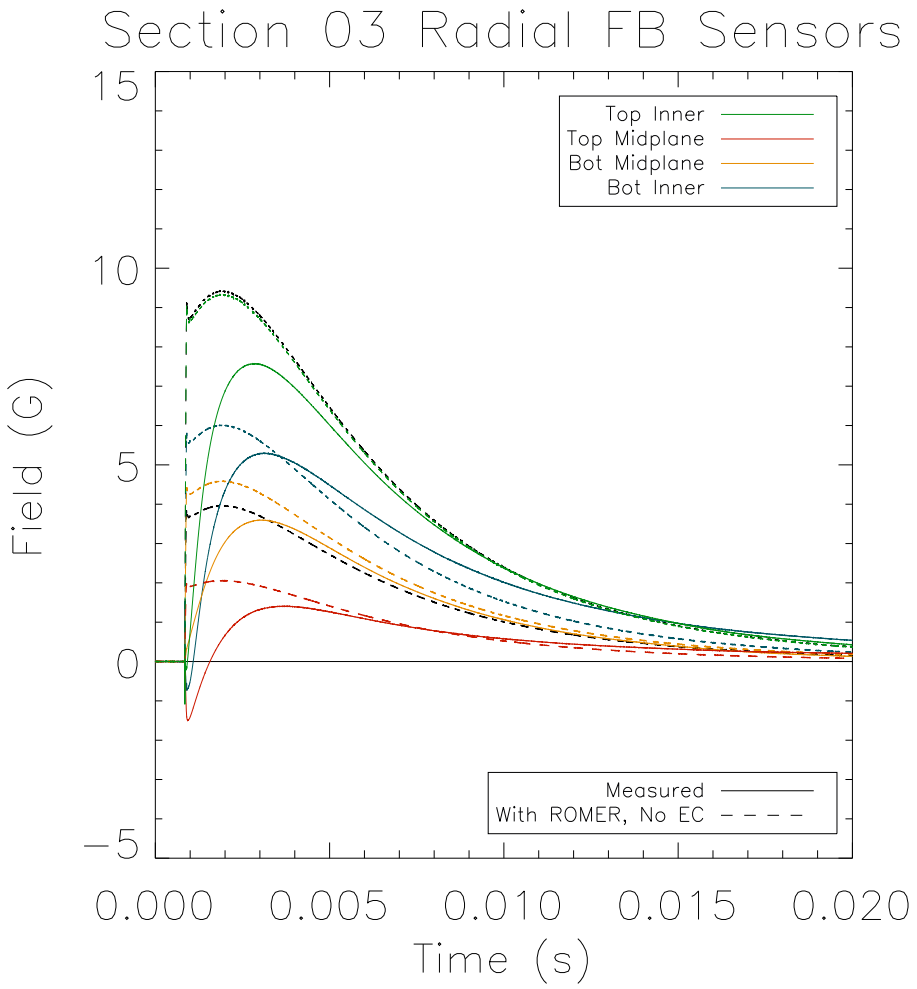
PPPL
PRINCETON PLASMA
PHYSICS LABORATORY

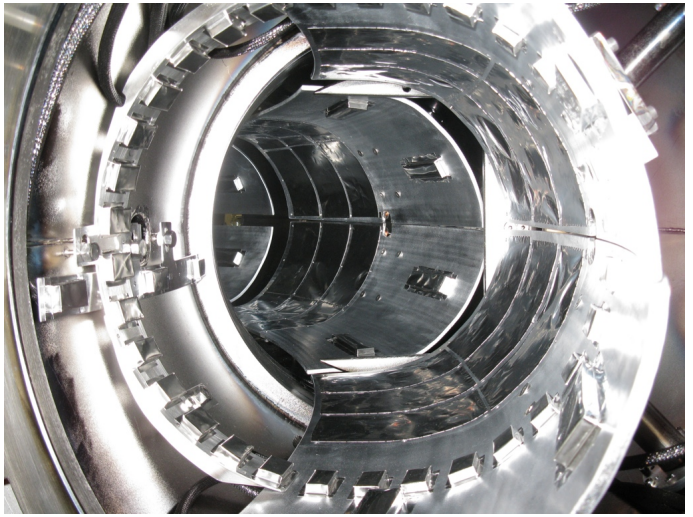


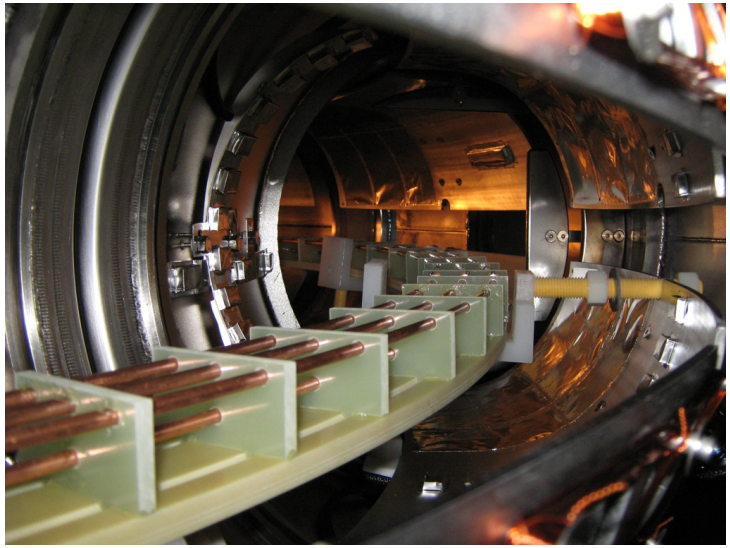
Measured wall and sensor positions will allow detailed MHD mode analysis



Initial "copper" plasma sensor calibration complete







Planned MHD physics control studies

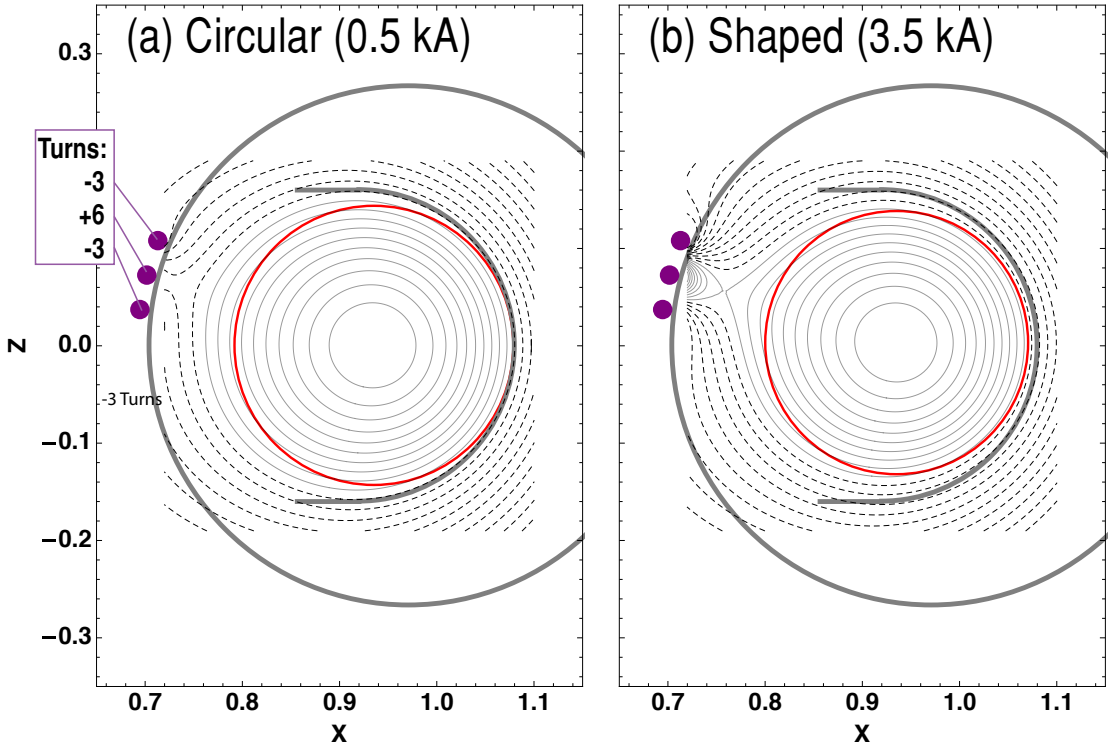
- Investigate multimode, 3D plasma edge physics with HBT-EP's new wall, sensor and control coil system

- Investigate the change in plasma response due to shaping

- Investigate the effects of ferritic walls on the RWM -- the Ferritic Resistive Wall Mode (FRWM)

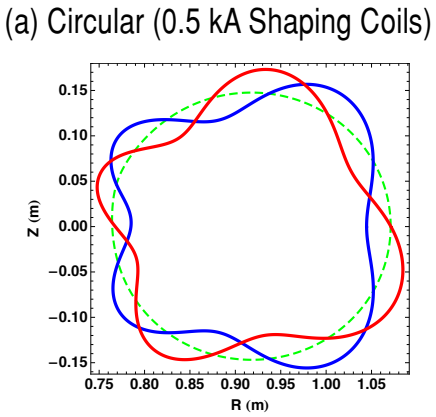
Shaping strongly effects multi-mode coupling

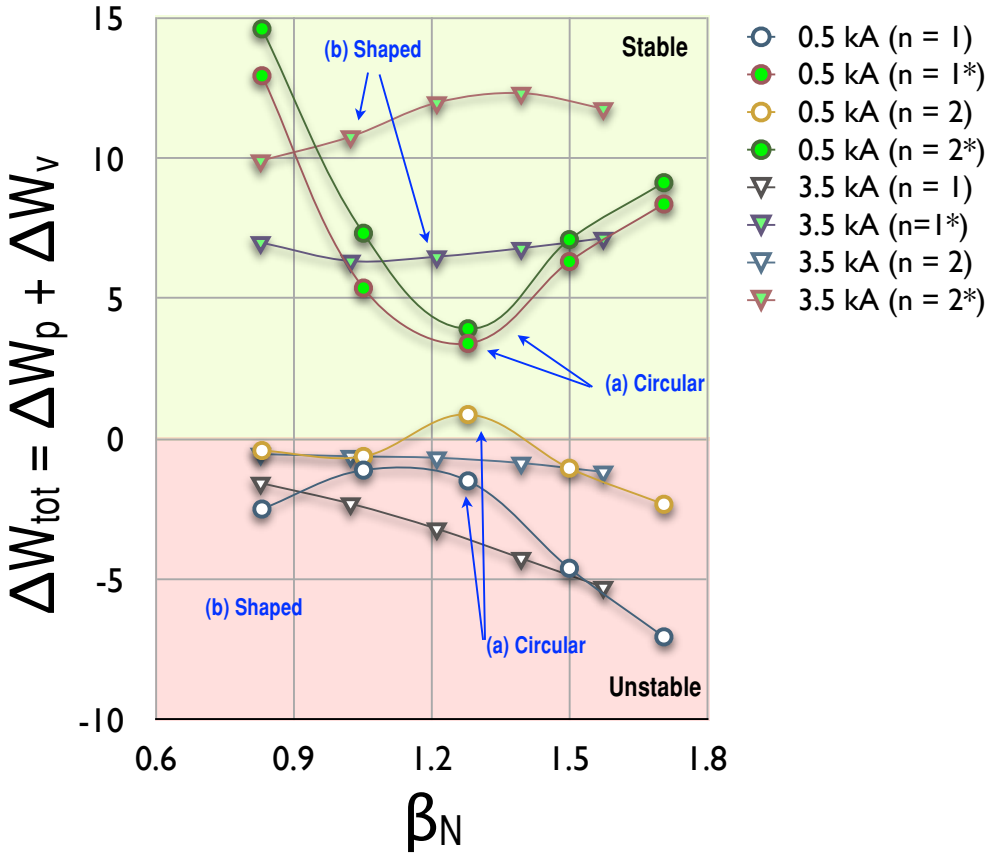
HBT-EP PLASMA SHAPE CONTROL CAPABILITY



Inboard divertor coils allow control of edge flux surface shape that is modeled by DCON to strongly affect potential for coupling from unstable to marginally stable RWM

Shaping strongly effects multi-mode coupling





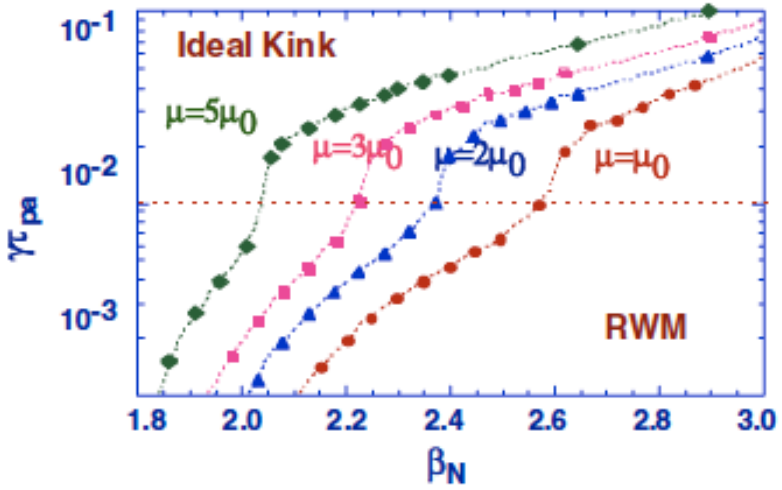
Circular plasma computed by DCON to allow strong n=1 unstable and n=1* nearest 'marginally' stable RWM to couple at $\beta_N \sim 1.2$

Shaped plasma separates unstable and marginal RWM at same helicity

mmVALEN benchmark

Study of ferromagnetic material effects on MHD stability in toroidal geometry

Effect of Ferromagnetism on RWM stability Limits*



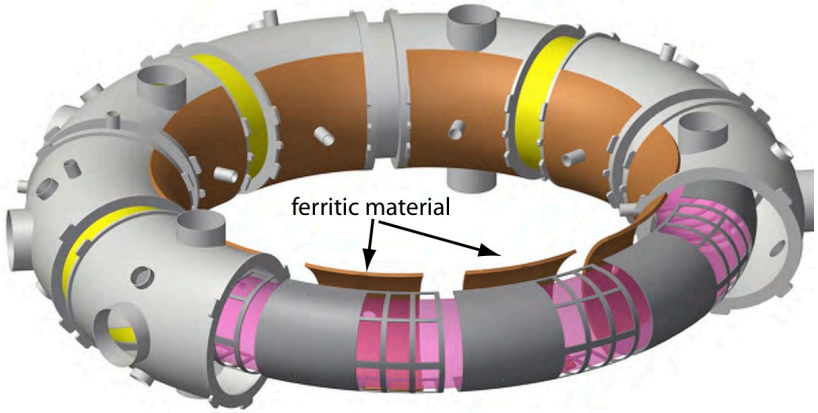
MHD ideal limits reduced from β_N ~ 2.6 to 2 as μ increased to 5

3D perturbations & multi-mode coupling may be significant

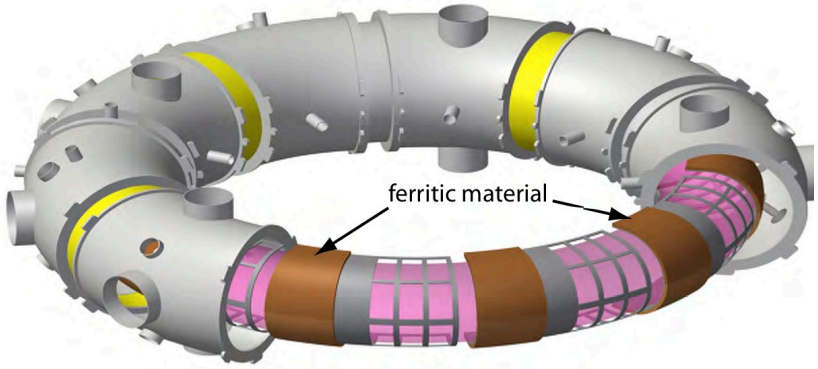
* G. Kurita, T. Tuda, M. Azumi, *et al.*, *Nuclear Fusion* **43** (2003) 949.

HBT-EP Ferritic Shell Options

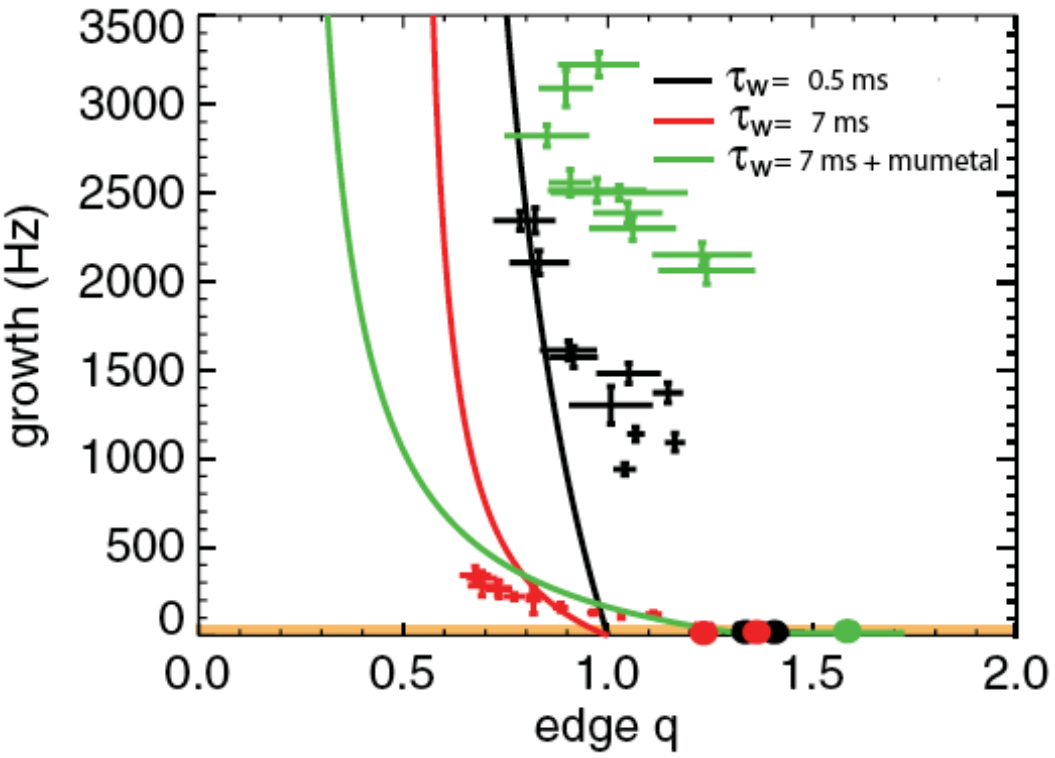
(a) External to vessel ferritic wall option

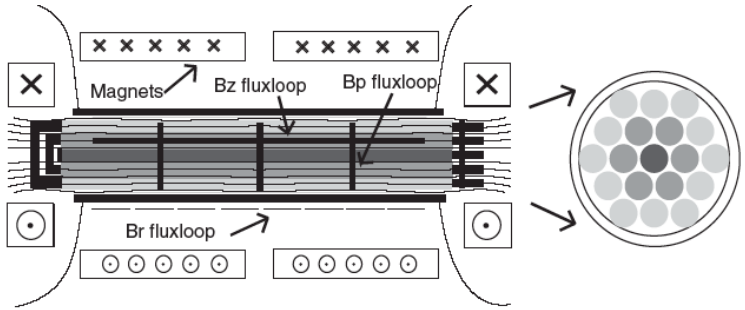


(b) In-vessel ferritic wall option



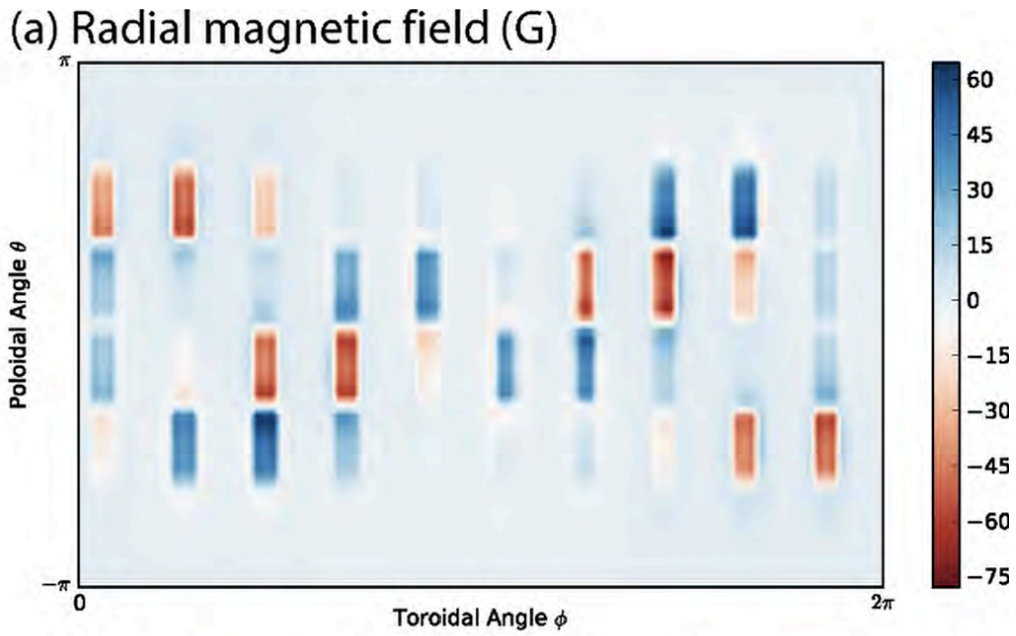
FRWM has been observed in a line-tied pinch with larger growth rate than predicted

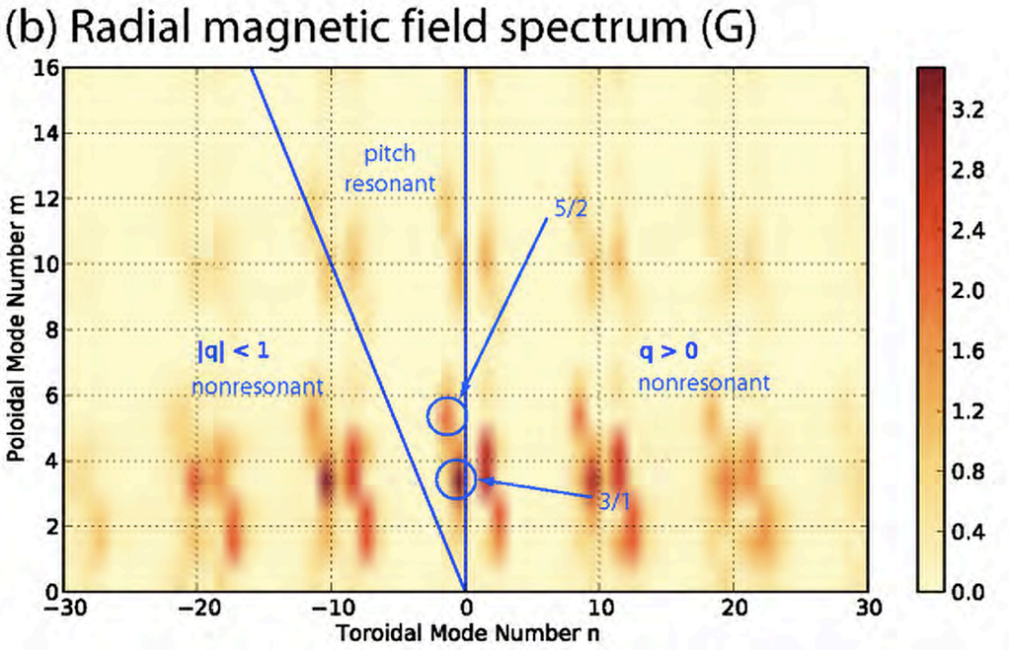




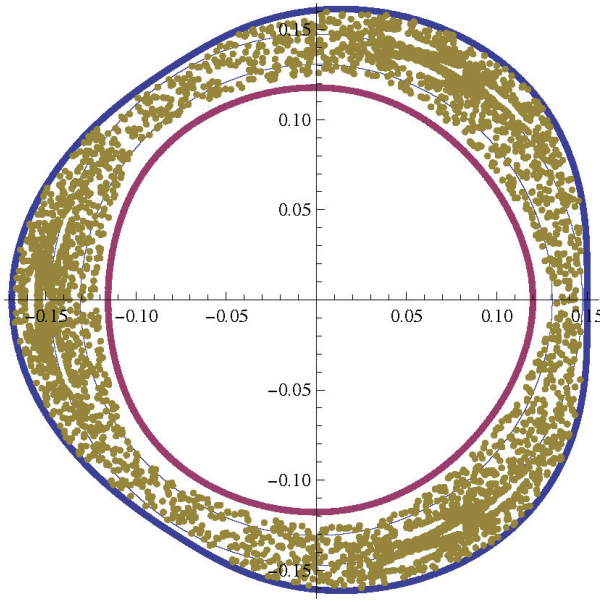
Bergerson, et al, PRL 101, 235005 (2008)

Bergerson, Ph.D. Thesis, University of Wisconsin Madison (2008)





Order of magnitude increase in applied fields with new system allows study of edge stochastic fields



Vacuum field line response

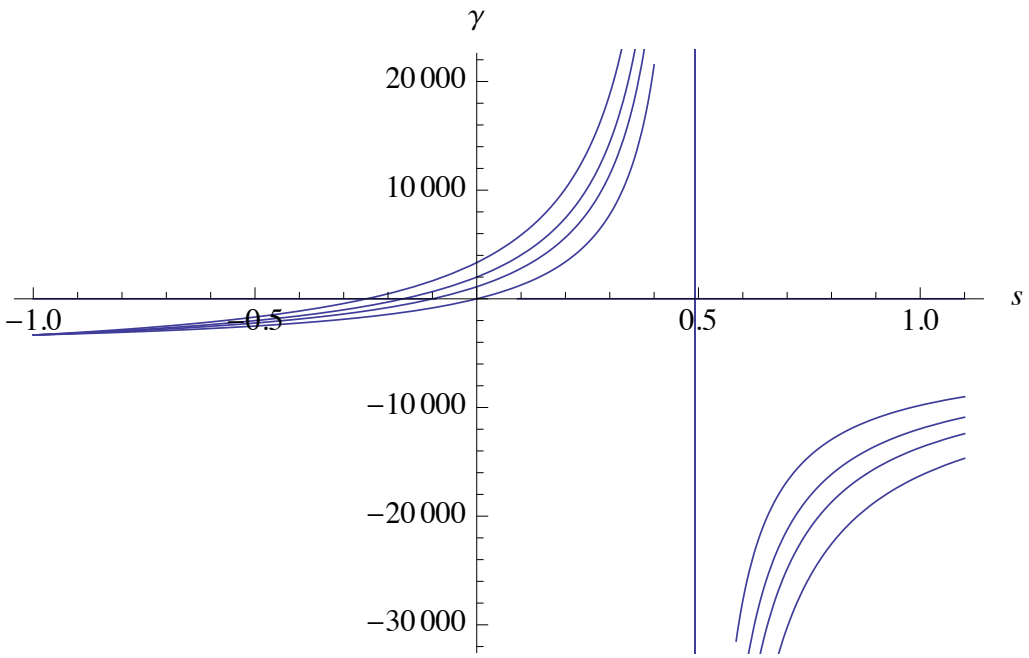
Summary and conclusions

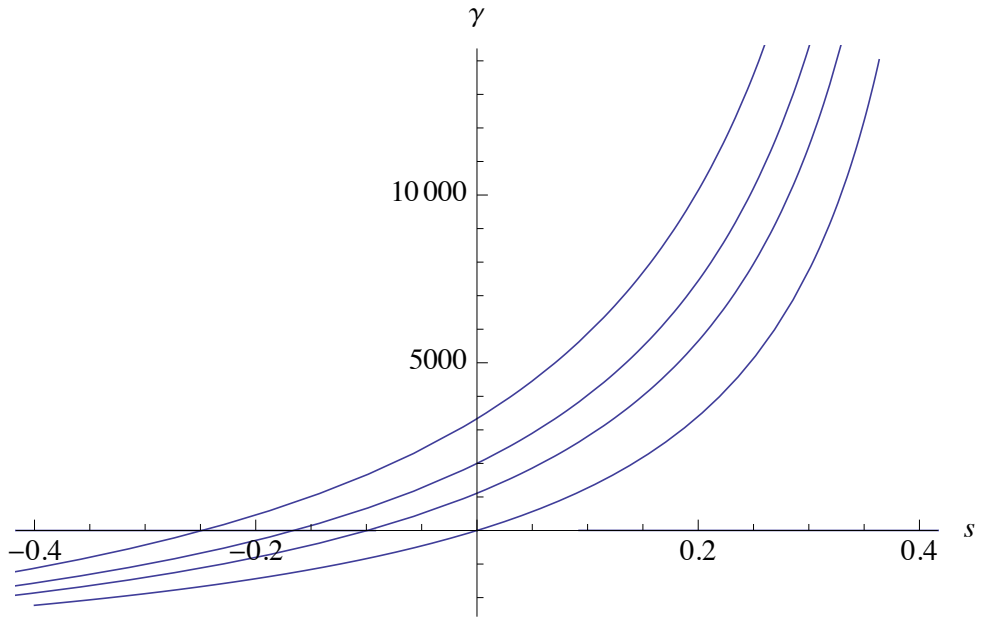
- HBT-EP has successfully installed a new wall, control, and sensor system for mutlimode plasma response studies to 3D boundary shaping magnetic fields

- This system will allow new and novel experiments on multimode plasma response during kink feedback, magnetic spectroscopy, and allow observation of the FRWM using our new control coils and extensive new array of magnetic sensors to quantify plasma response

- HBT-EP is up and running and making plasmas this November-December!

Extra slides





Physics effects of a ferritic, conducting wall

Enhanced growth rate and change in marginal no-wall stability limit