Preliminary Results of Plasma Shaping on the HBT-EP Tokamak

Patrick Byrne

with the HBT-EP Group:
S. Angelini, J. Bialek, P.J. Byrne, B.A. DeBono, P. Hughes, B. Li,
M.E. Mauel, G.A. Navratil, Q. Peng, N. Rath,
D. Rhodes, D. Shiraki, and C. Stoafer

COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

APAM Research Conference
4/6/11

Outline

- Motivation
- Magnetic Geometry
- The HBTEP Shaping Coil
- Control Coil Shaping
- Summary

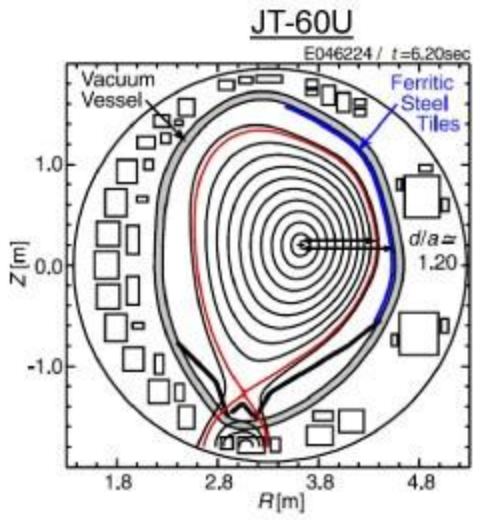
Outline

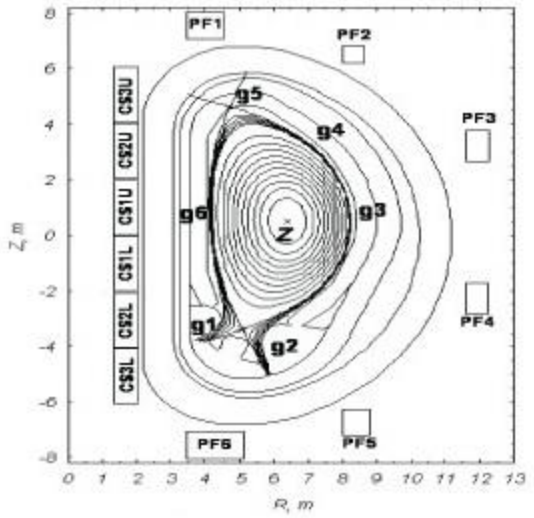
- Motivation
- Magnetic Geometry
- The HBTEP Shaping Coil
- Control Coil Shaping
- Summary

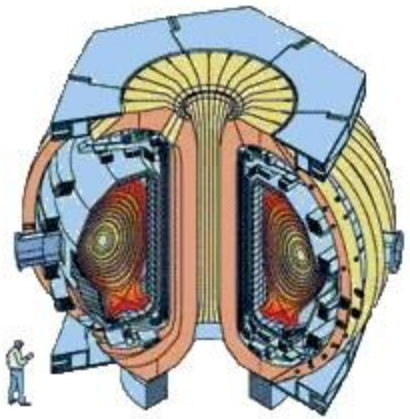
Motivation

- Any fusion plasma will need to be shaped
  - Fusion plasma heat load too high for material limiter

- Shaping has been shown or predicted to reduce severity of many plasma instabilities (ELMs, ITG, Sawteeth)





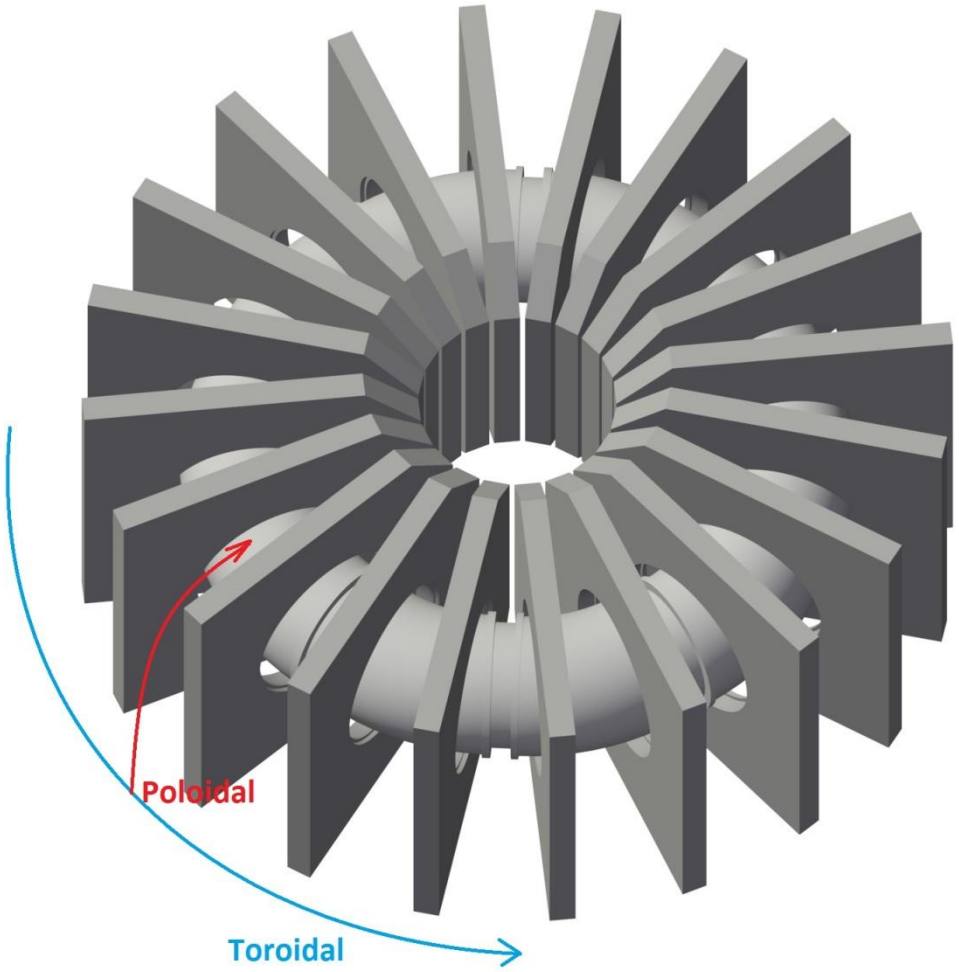


Outline

- Motivation
- Magnetic Geometry
- The HBTEP Shaping Coil
- Control Coil Shaping
- Summary

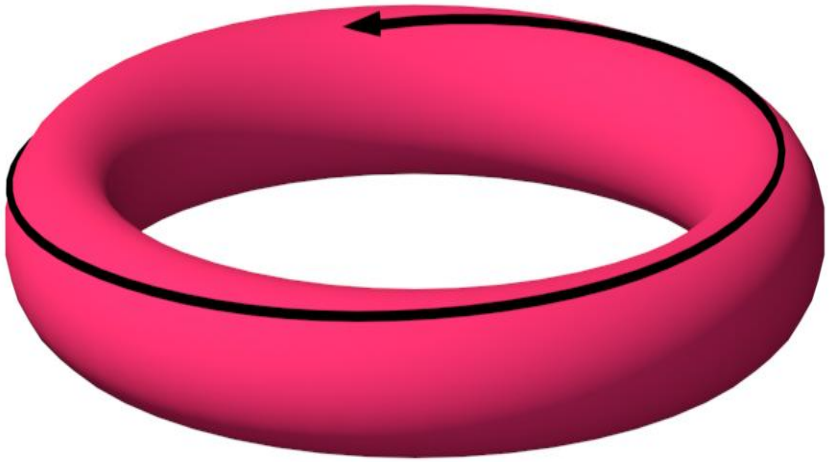
HBTEP's Magnetic Geometry

- Electromagnets create toroidal field and plasma current
- Plasma current creates a poloidal field.
- Plasma elements are "frozen" to field lines by Lorentz forces
- Magnetic fields (and therefore plasma) lie on closed, nested, toroidal surfaces



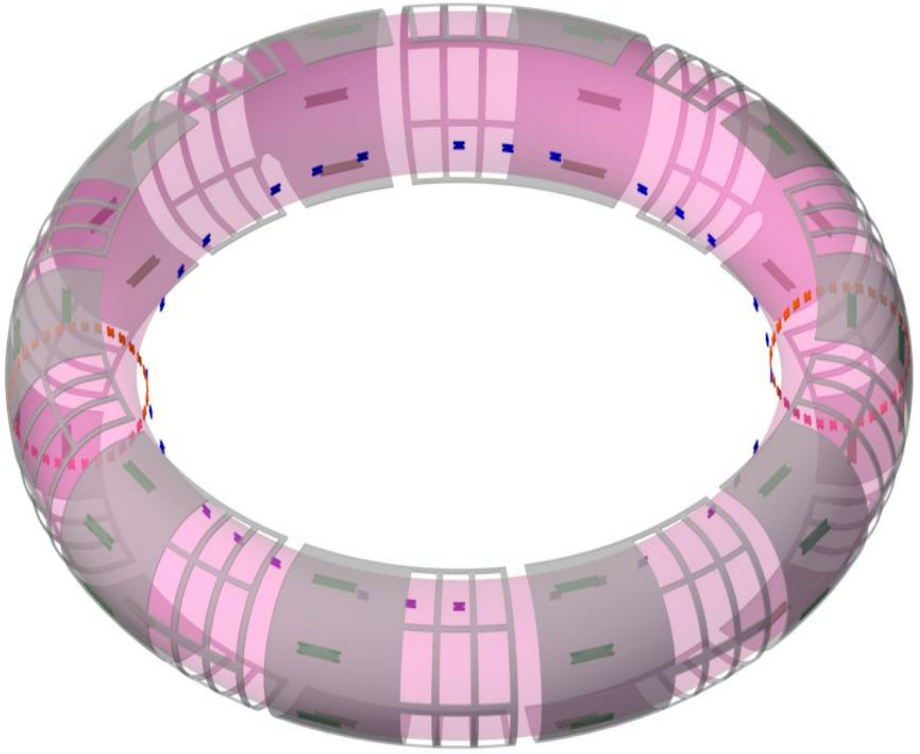
HBTEP's Magnetic Geometry

- Plasma elements travel along surfaces, following magnetic field lines
- Magnetic "pitch" $\mathrm{q} \equiv \frac{rB_\varphi}{RB_\theta}$
- Plasma modes have fourier breakdown of $e^{i((n\varphi - m\theta) - \omega t)}$
- Surfaces with rational q (n/m) subject to resonant instabilities
  - Similar to how shape of bell determines resonant tones
  - Changing shape should change the resonant behavior



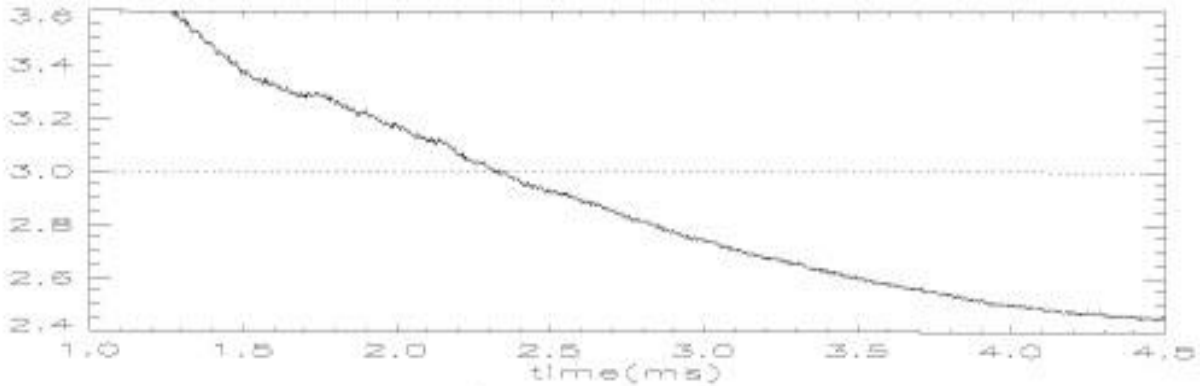
HBTEP Can Resolve Plasma Modes With High Resolution

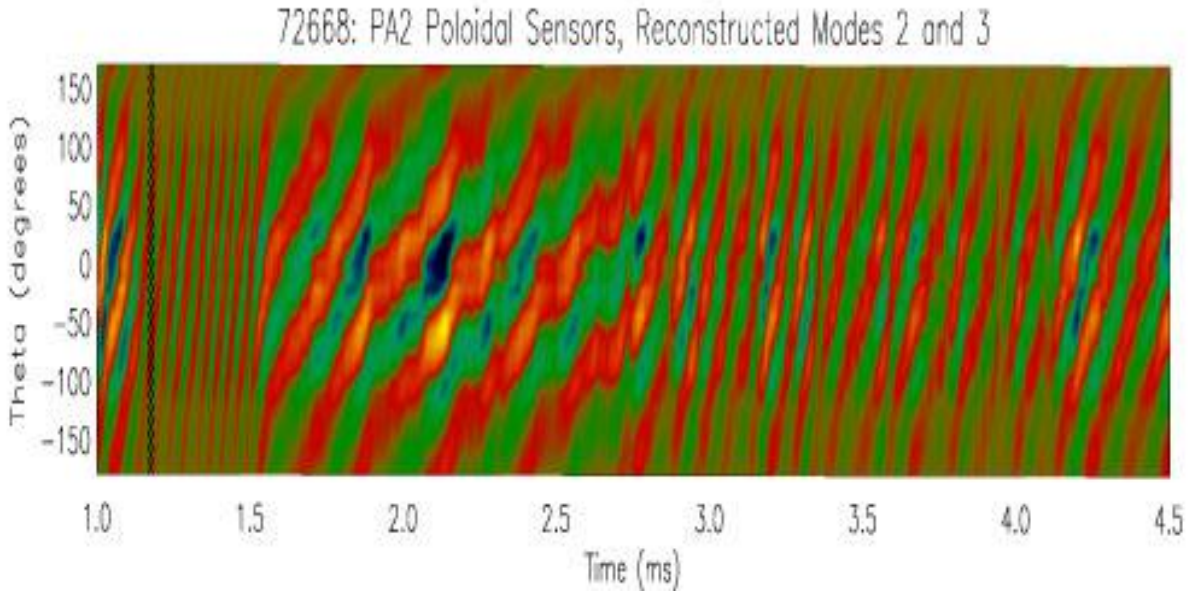
- 236 in-vessel sensors.
- High fidelity resolution of toroidal and poloidal modes
- Can resolve poloidal and radial components of modes



Magnetic Resonances

- Instabilities can occur on any surface with $q = \frac{m}{n}$
- HBT q varies from 4-1, higher m/n numbers are more stable for same q



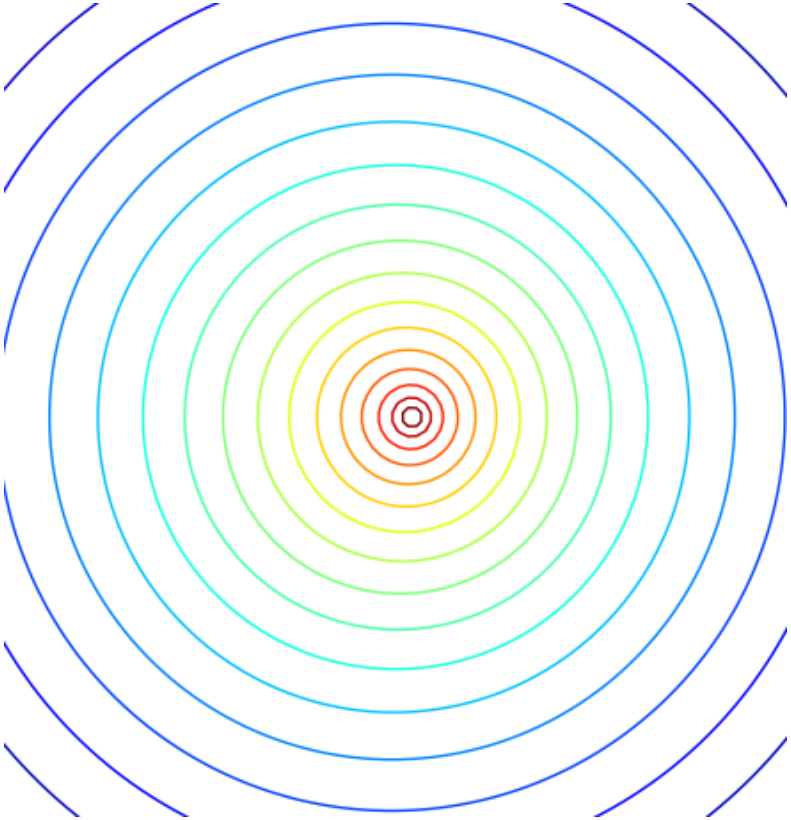


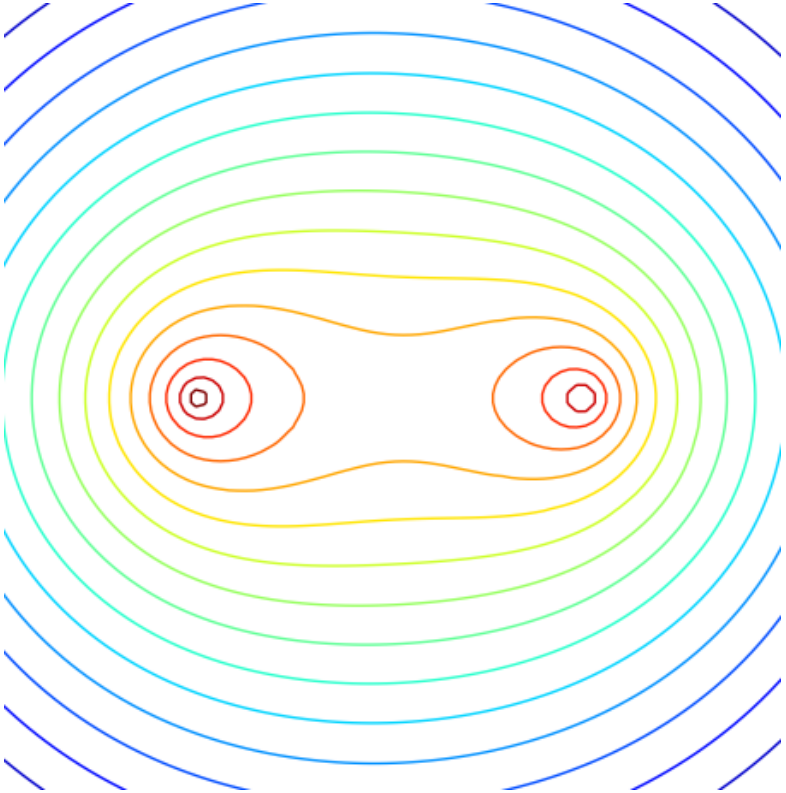
Outline

- Magnetic Geometry
- The HBTEP Shaping Coil
- Control Coil Shaping
- Summary

Plasma Shaping Affects B_θ, q, and Plasma Stability

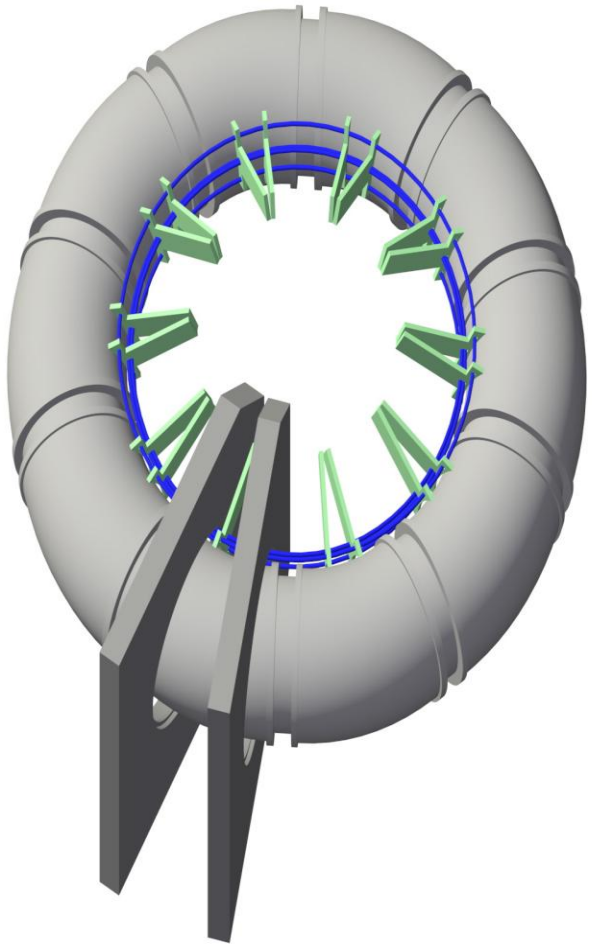
- Plasma surfaces can be affected by external currents.





The HBTEP Shaping Coil

- Three serially connected cable loops
  - Edge bundles counterwound from the central cable bundle
- Central bundle has twice the number of windings for zero net turns.
- Very low coupling at long distances
  - Minimal interaction with other magnetics, L ~10-20μH



Placement and Construction

- The coil will be wound around the high-field side of HBTEP at an angle of ~25 degrees above the high field side midplane.
- This setup will allow the creation of local edge effects, while leaving the bulk plasma unperturbed

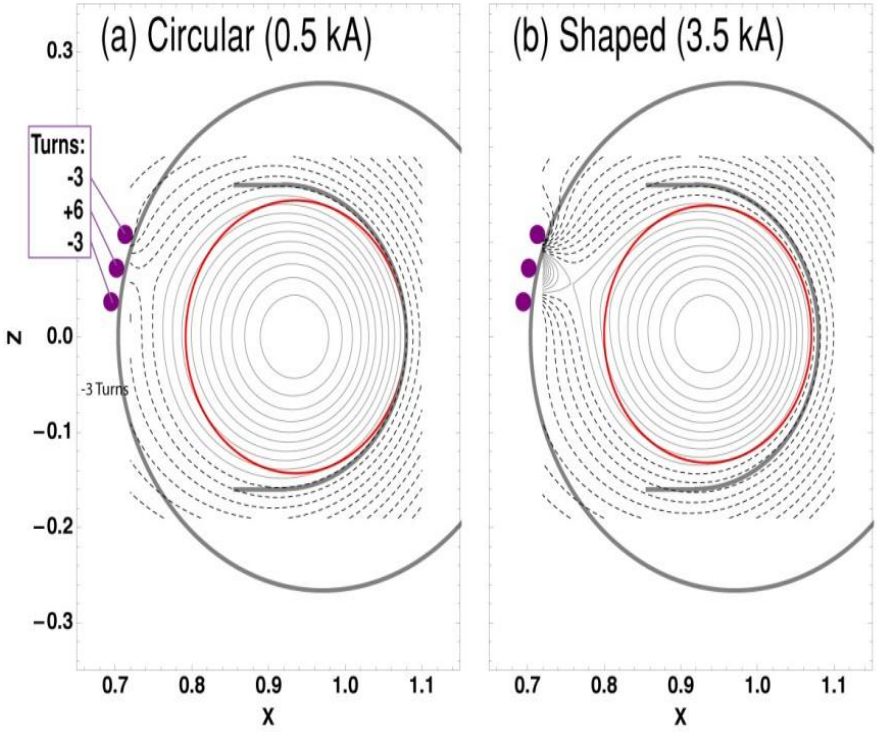
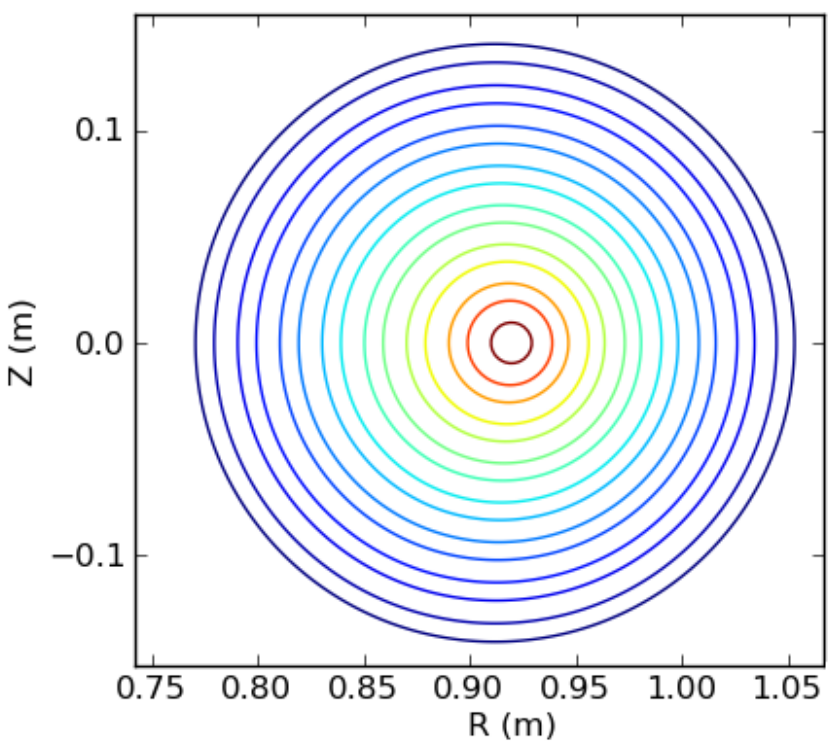
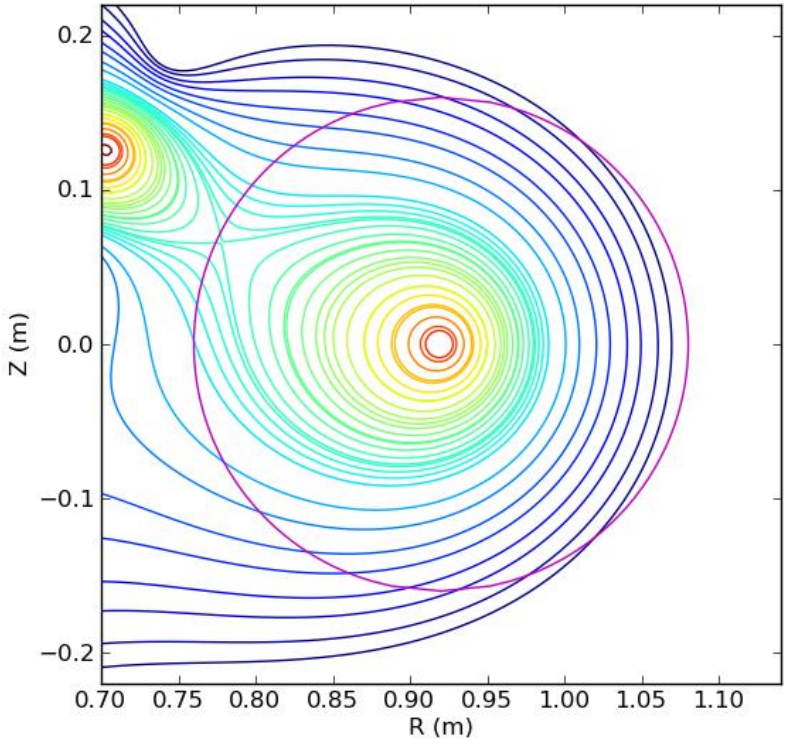


Fig. 1 – Flux surfaces for a weakly and fully shaped plasma. The red circle represents the last closed flux surface of an unshaped plasma

Simulations Show Diversion is Possible

- 15º separation between coils
- Coil current ~11kA (15kA max)



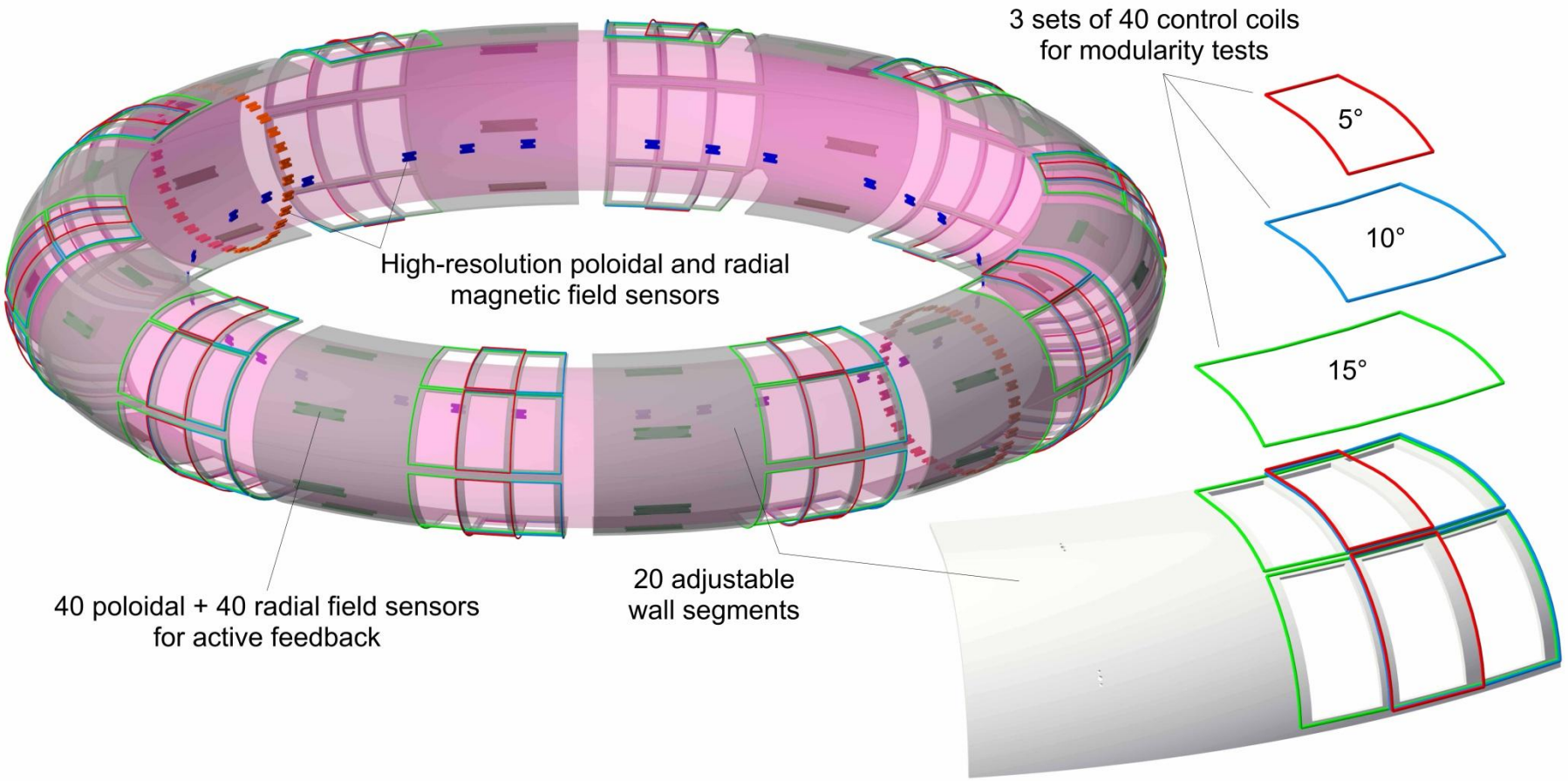


Outline

- Magnetic Geometry
- The HBTEP Shaping Coil
- Control Coil Shaping
- Summary

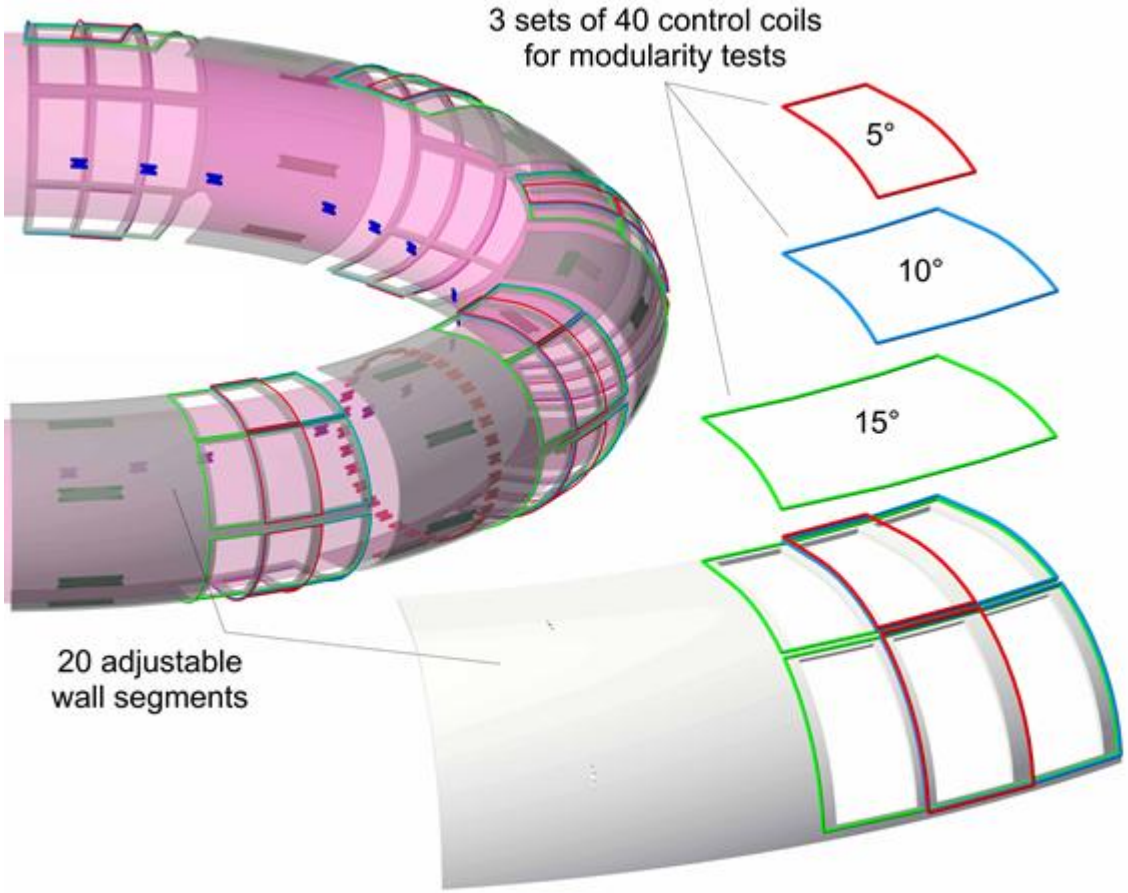
HBTEP Can Already Magnetically Influence The Plasma

- 120 Feedback coils (3 sets of 40)



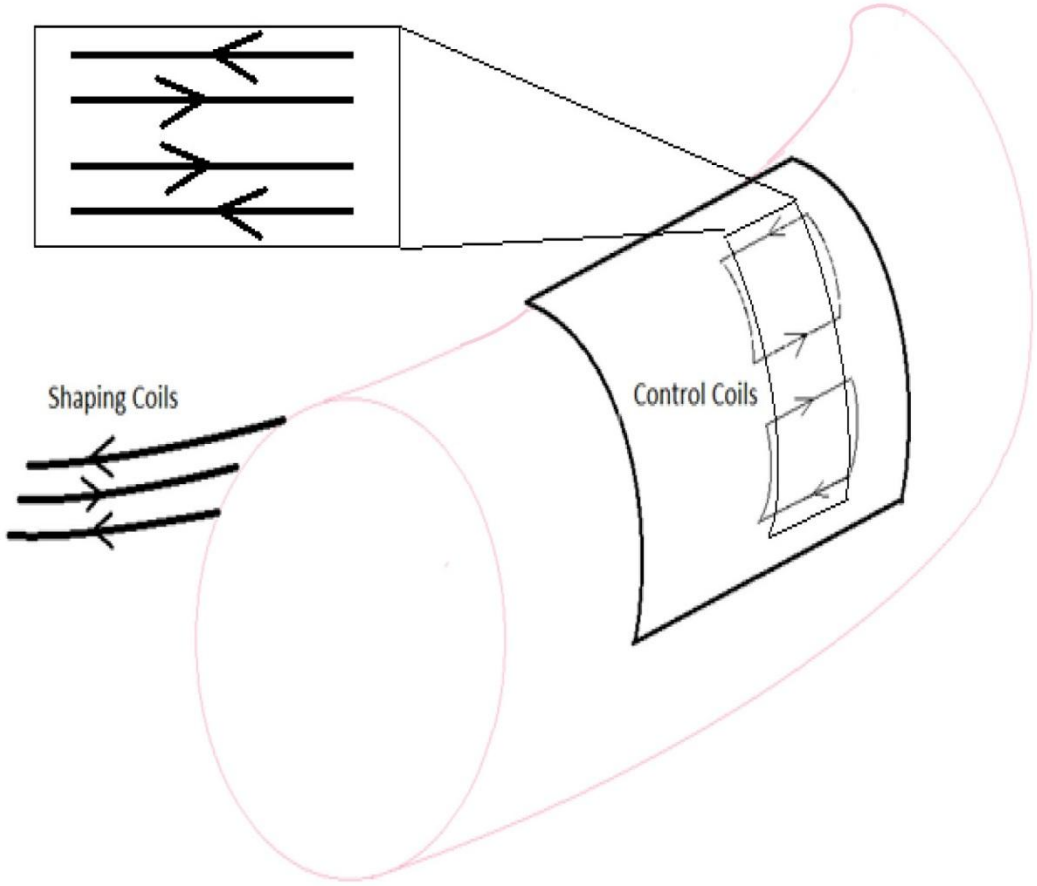
HBT Control Coils

- 120 Feedback coils (3 sets of 40)
- Can apply wide spectrum of magnetic perturbations
- Can be used to excite or suppress magnetic modes, or affect the shape of magnetic surfaces

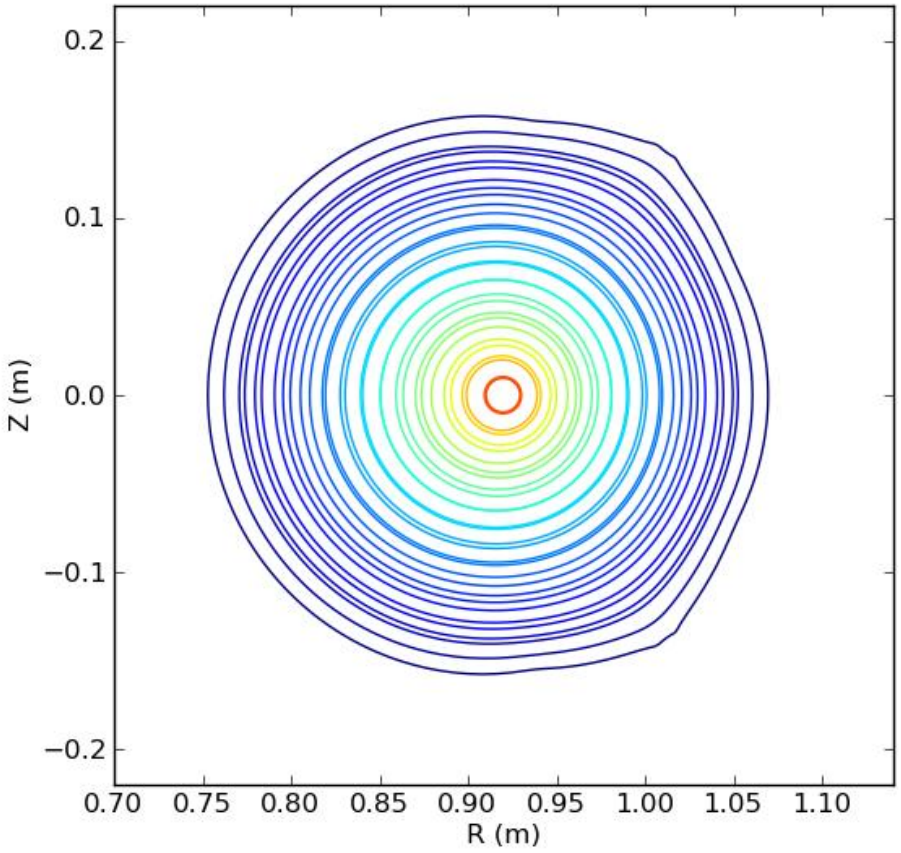


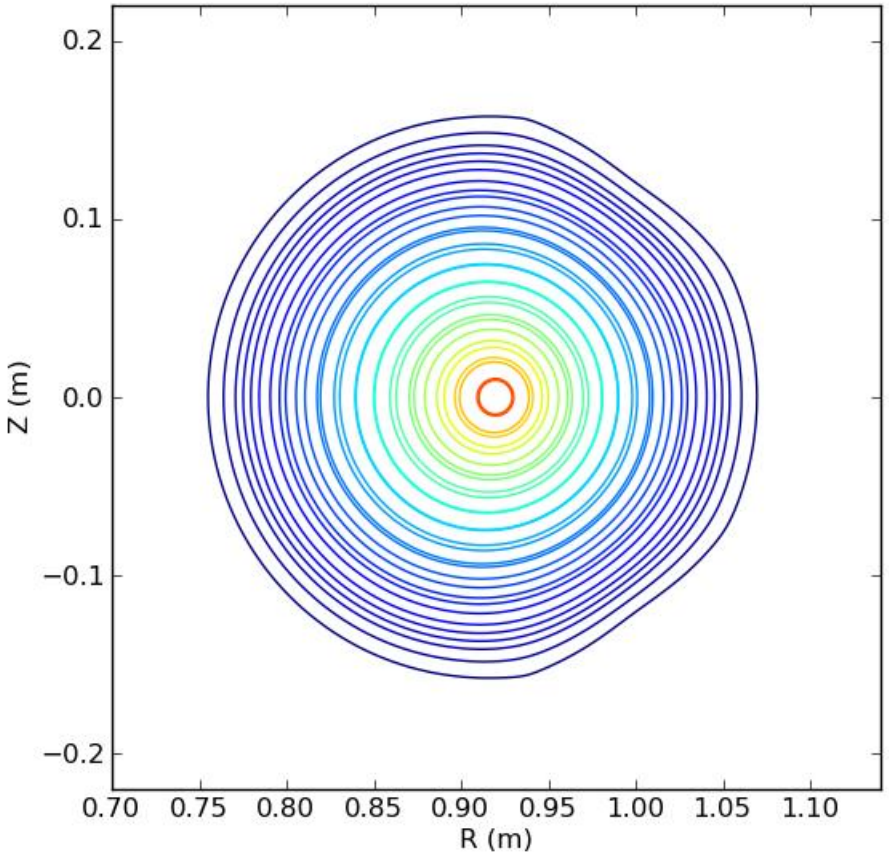
Shaping Coil / Control Coil Substitution

- Large control coils cover 15º toroidal angle.
- If fired with equal but opposite currents, nearby fields look similar to shaping coil
- Discrete approximation to shaping coil

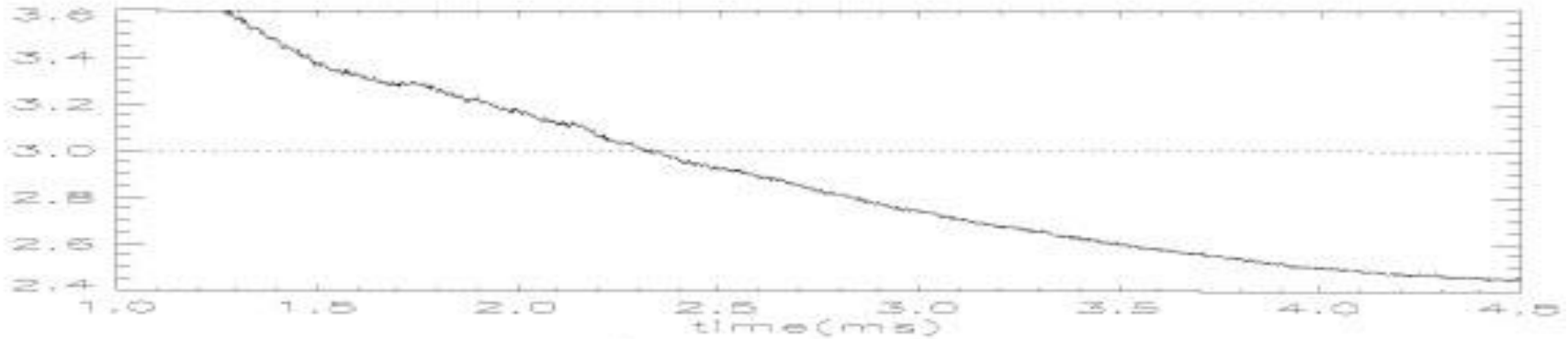


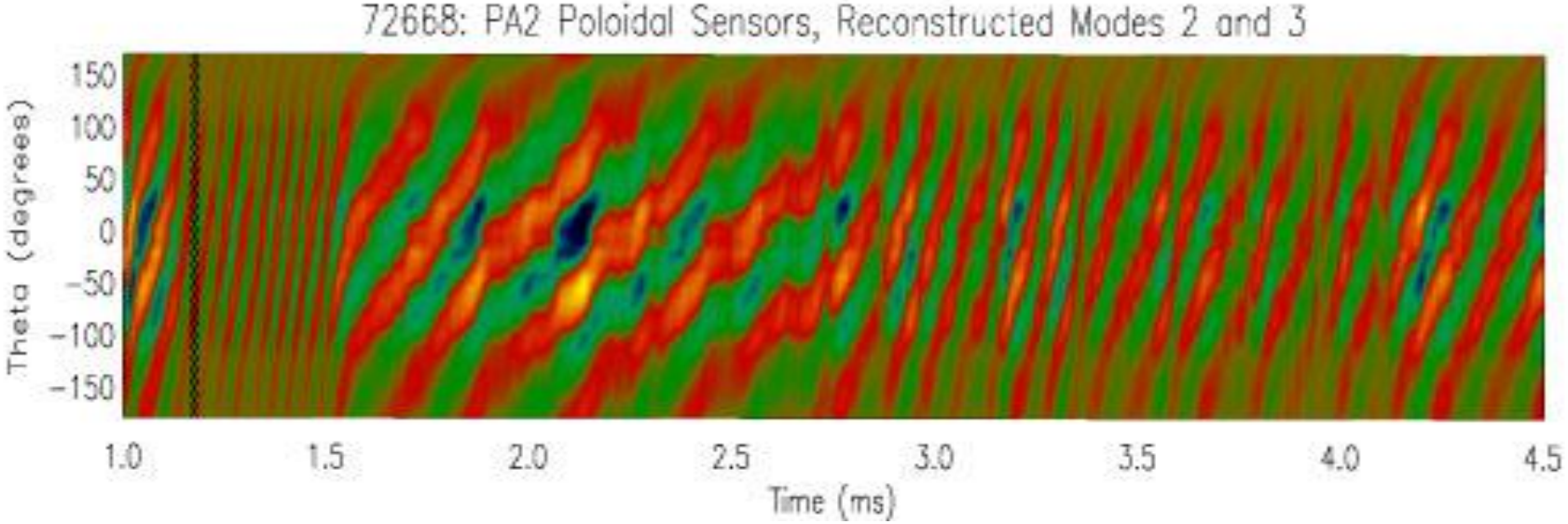
Control Coil Shaped plasmas



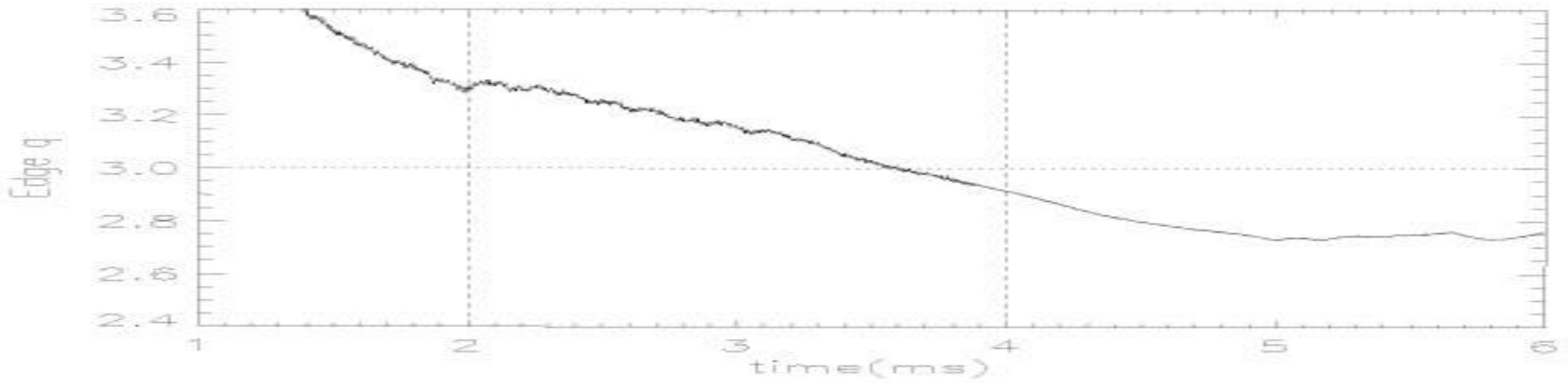


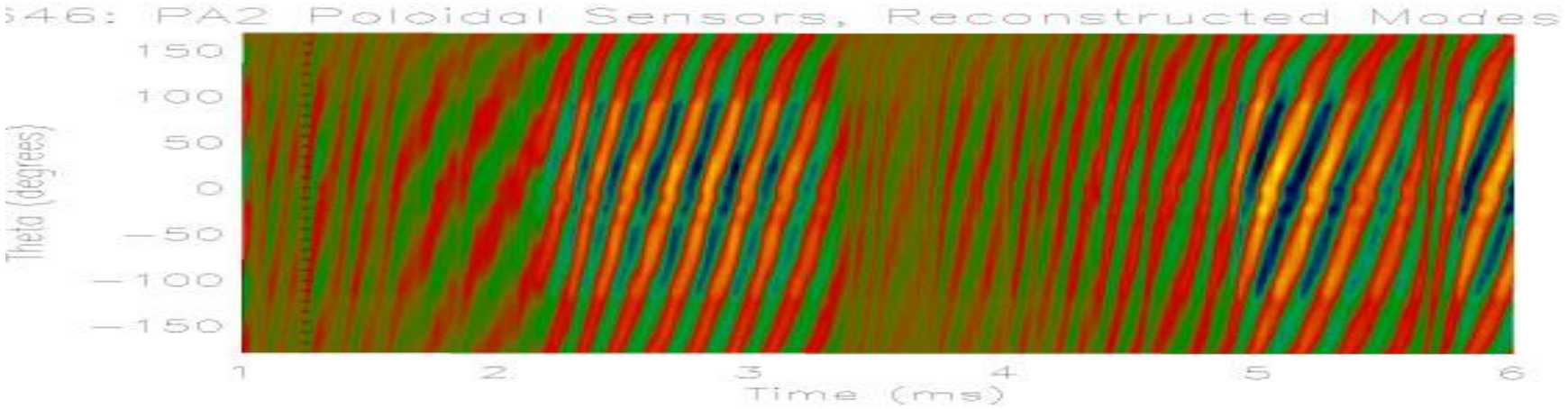
Unshaped n=1, m=3 mode activity



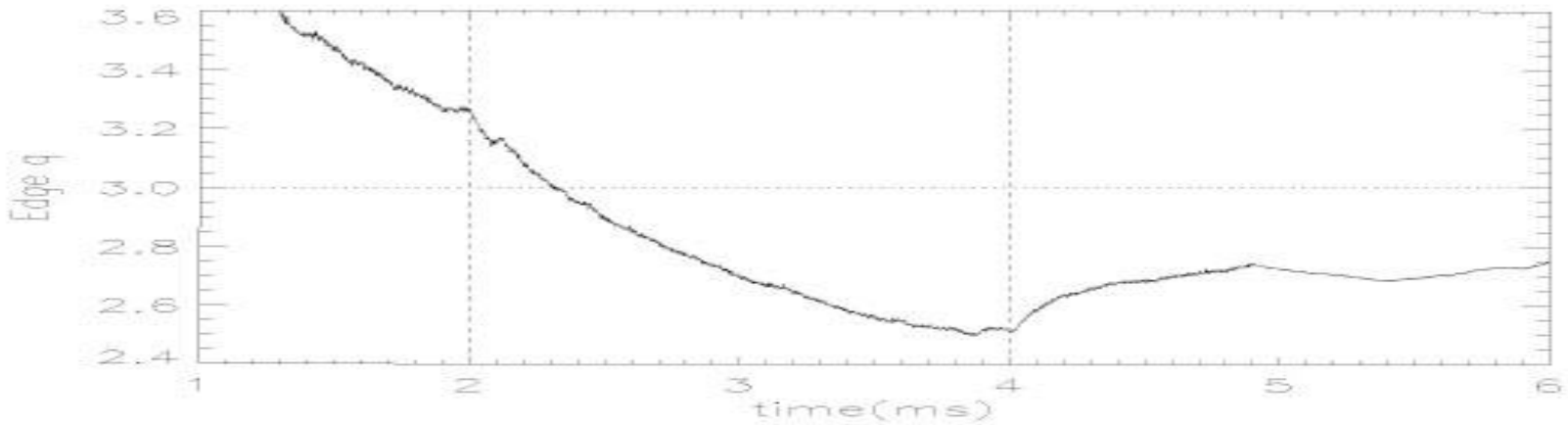


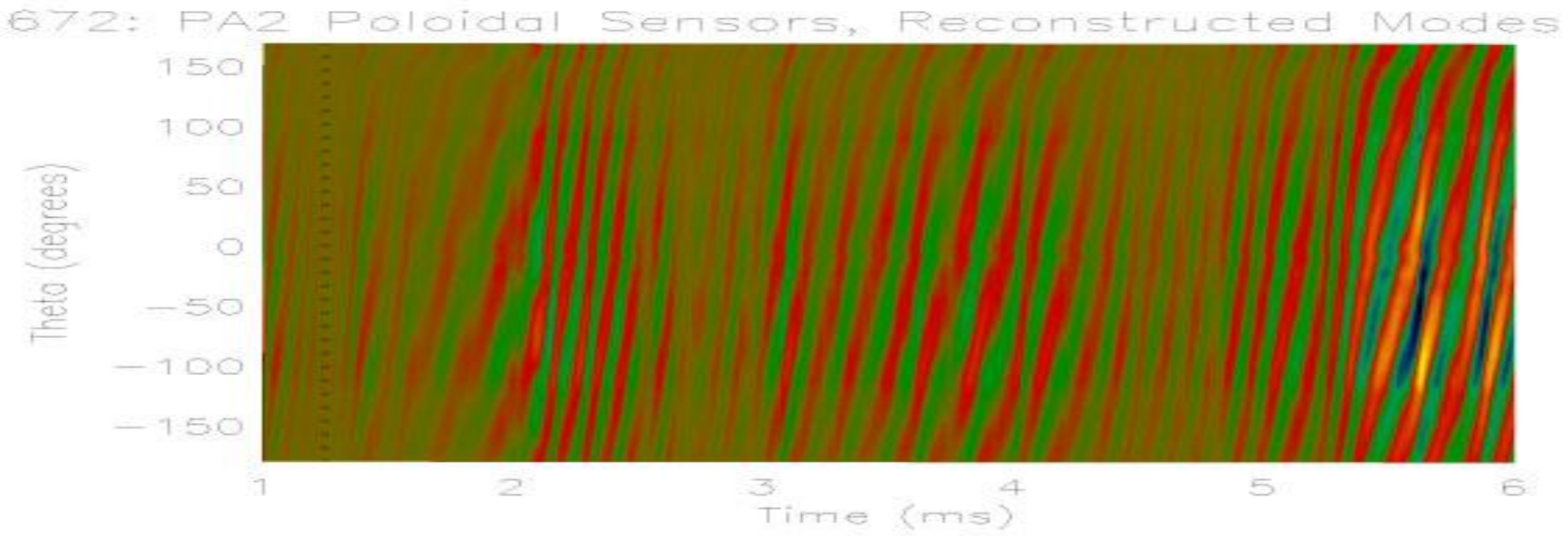
“Triangle” shaped n=1, m=3 mode activity





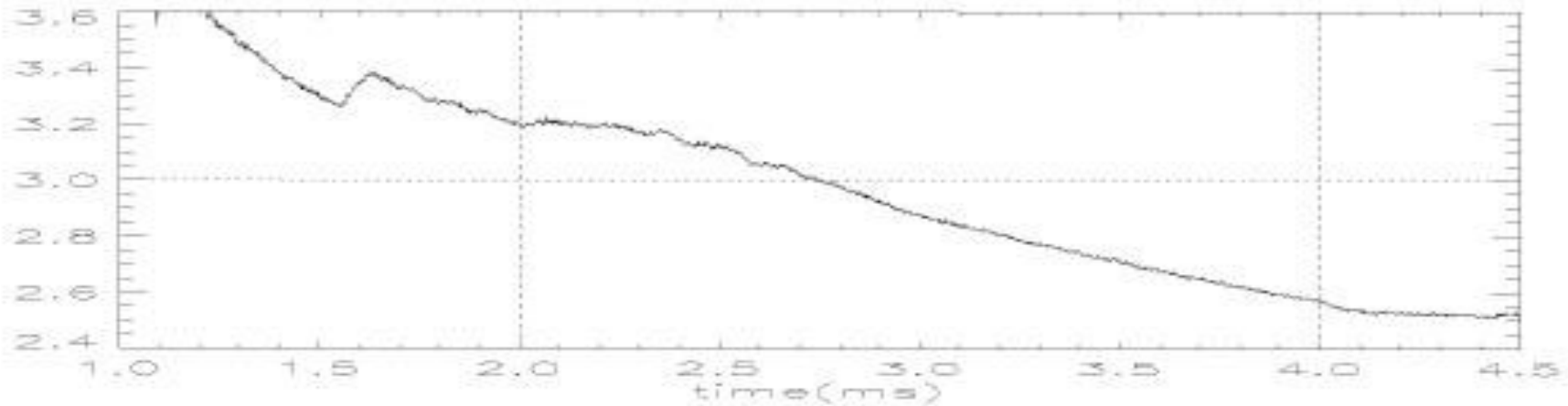
“Square” shaped n=1, m=3 mode activity

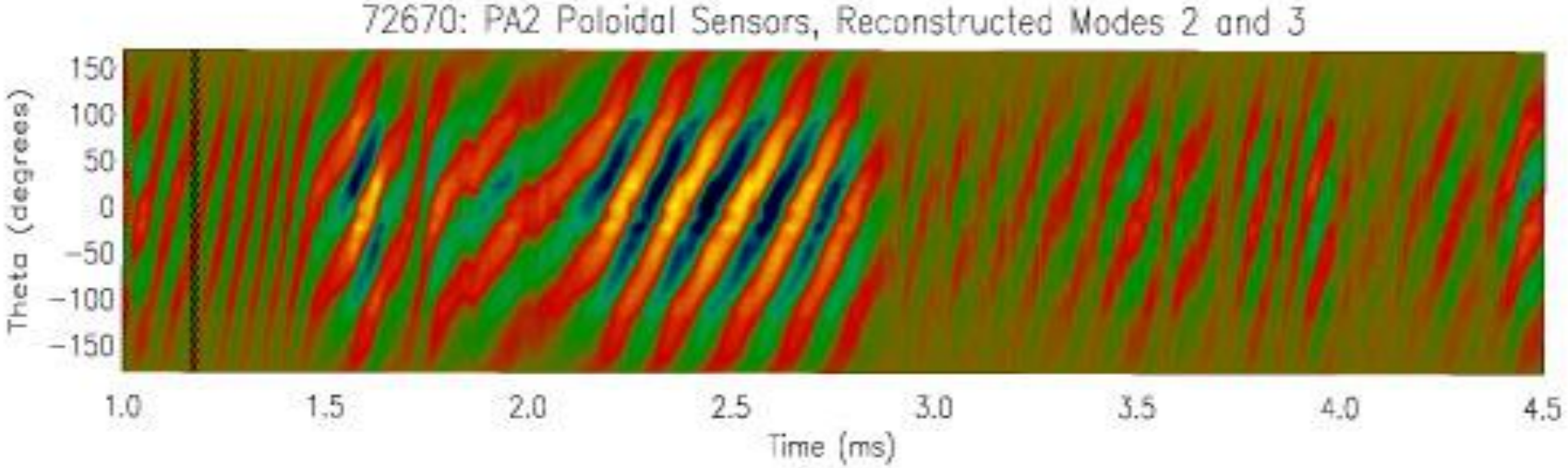


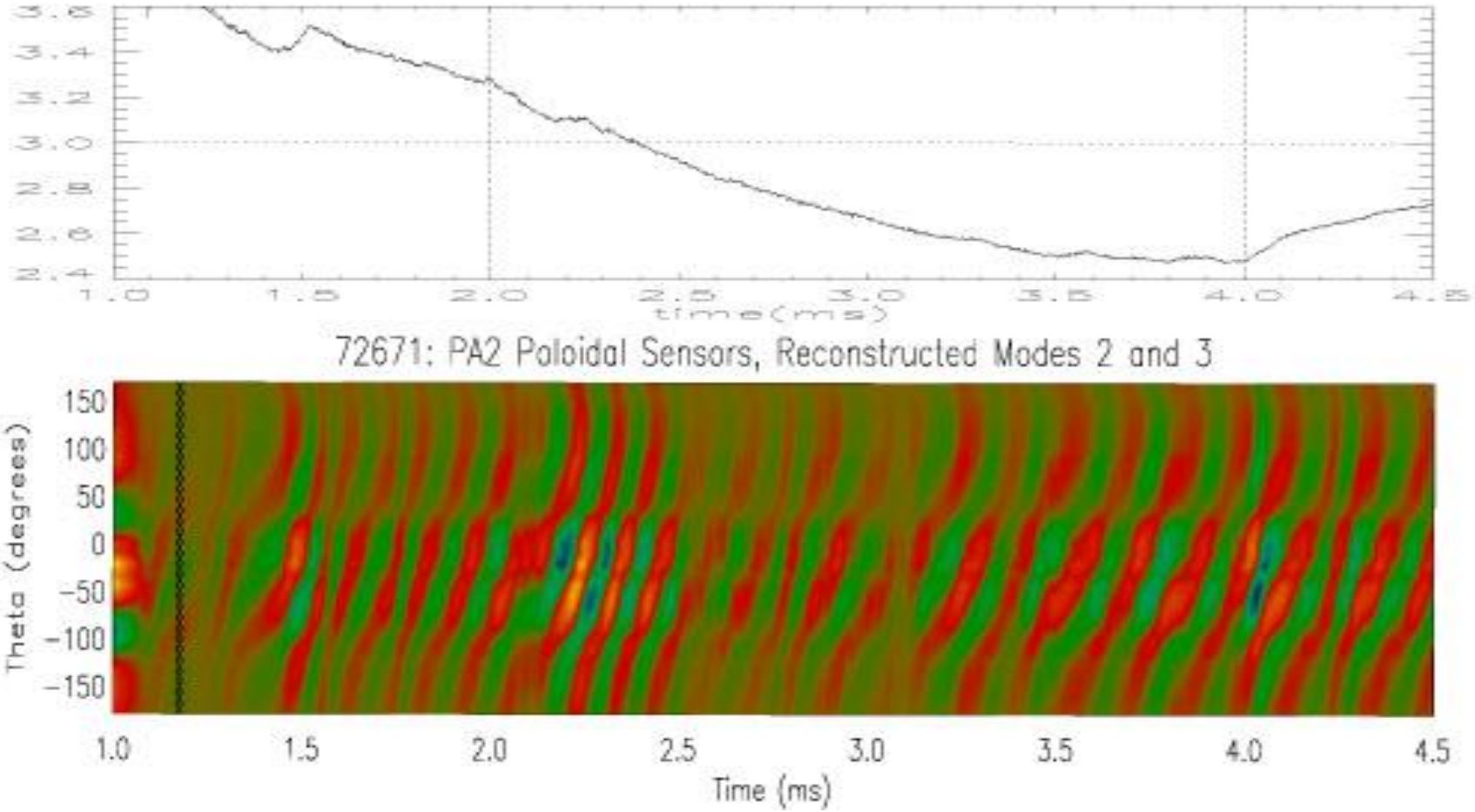


Summary

- Fusion-relevant plasma experiments (ITER,DEMO) will have non-circular cross-section
- The shaping coil will allow us to gain insight into multimode instabilities in the presence of shaping.
  - Degree of shaping arbitrary, including diverted operation
- Experiments have indicated significant effects for a minor degree of plasma shaping


3.6
3.4
3.2
3.0
2.8
2.6
2.4
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
time(ms)


72670: PA2 Poloidal Sensors, Reconstructed Modes 2 and 3
Theta (degrees)
150
100
50
0
−50
−100
−150
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Time (ms)


72671: PA2 Poloidal Sensors, Reconstructed Modes 2 and 3
Theta (degrees)
150
100
50
0
-50
-100
-150
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Time (ms)