The Effects of Symmetry Breaking on Plasma Formation in the Helically Symmetric eXperiment (HSX)*

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Abstract

A 28 GHz ECH system has been used at 2nd harmonic to examine the effects of the magnetic field spectrum on the confinement of the breakdown electrons in HSX. A set of auxiliary coils can add a toroidal mirror term to the magnetic field spectrum to break the symmetry of the quasi-helically symmetric (QHS) configuration. At fixed RF power and fill pressure, the breakdown time, τ_b, is plotted as a function of the resonance location in the QHS, Mirror, and Anti-Mirror modes. Both curves show a minimum when the resonance is near the magnetic axis. On the high field side, the QHS and mirror mode data are similar. On the low field side, where trapping is significant, τ_b is considerably greater for the mirror mode than the QHS mode. τ_b is a maximum when the deepest magnetic ripples are placed at the toroidal ECH launch location, indicating that ripple structure at the launch position is important in the breakdown process.

Highlights

- Plasma breakdown is examined in HSX for QHS, Mirror, and Anti-Mirror modes of operation
- Breakdown time improvement in QHS mode demonstrates reduction of direct-loss orbits
- The significance of magnetic field structure at the ECH launch location is demonstrated with Mirror and Anti-Mirror modes

Outline

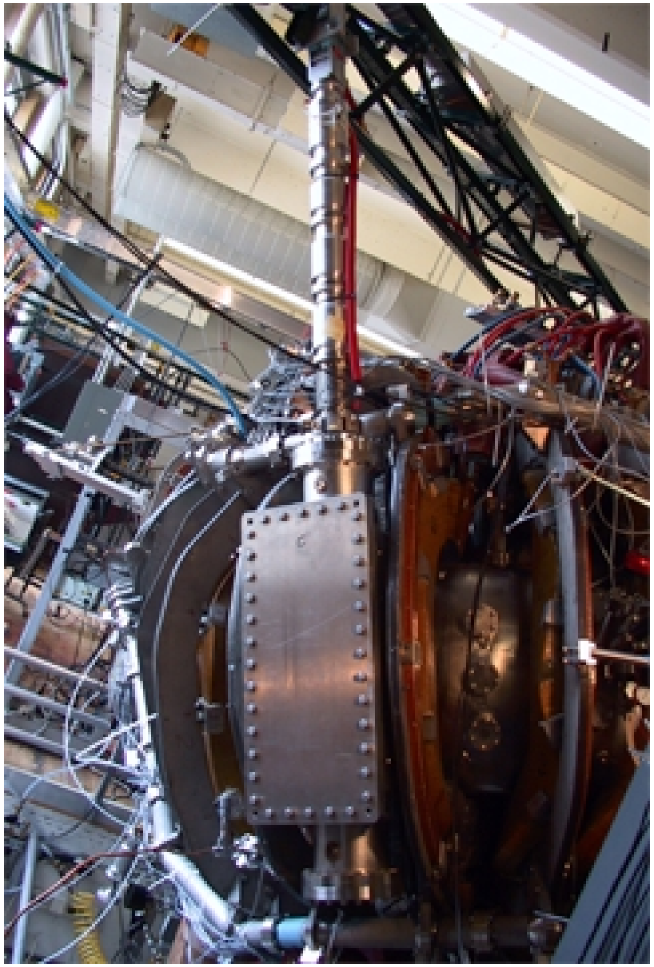
- Motivation & Objectives
- ECRH Heating in HSX
- Summary of QHS, Mirror, and Anti-Mirror Modes of Operation
- Breakdown vs. Resonance Location
- Breakdown vs. Neutral Pressure

Motivation and Objectives

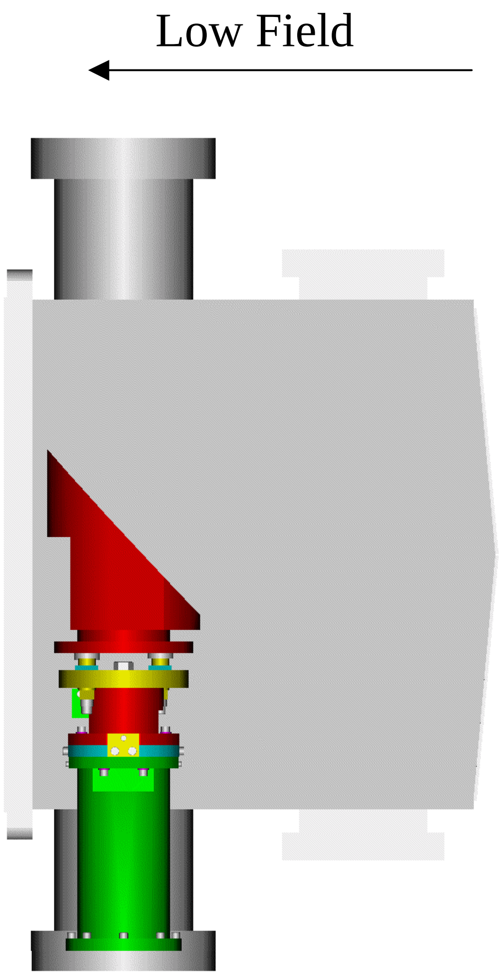
- Investigate the effects of symmetry in breakdown of a hydrogen plasma.
- Compare plasma breakdown of QHS, Mirror, and Anti-Mirror mode for various resonance locations and determine the effects of magnetic field structure on plasma breakdown.
- Compare plasma breakdown for various initial neutral pressure values for QHS and Anti-Mirror Mode.

ECRH Heating in HSX

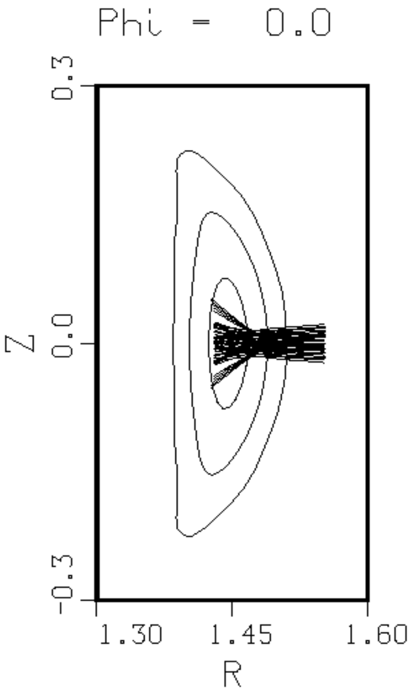
- 28 GHz Gyrotron Microwave Source
- 2nd Harmonic Heating at $B_0 = 0.5$ T
- ~ 50kW Input Heating Power
- Microwaves Focused on axis with an Ellipsoidal Focusing Mirror (~ 4cm spot size)



HSX Microwave Launching



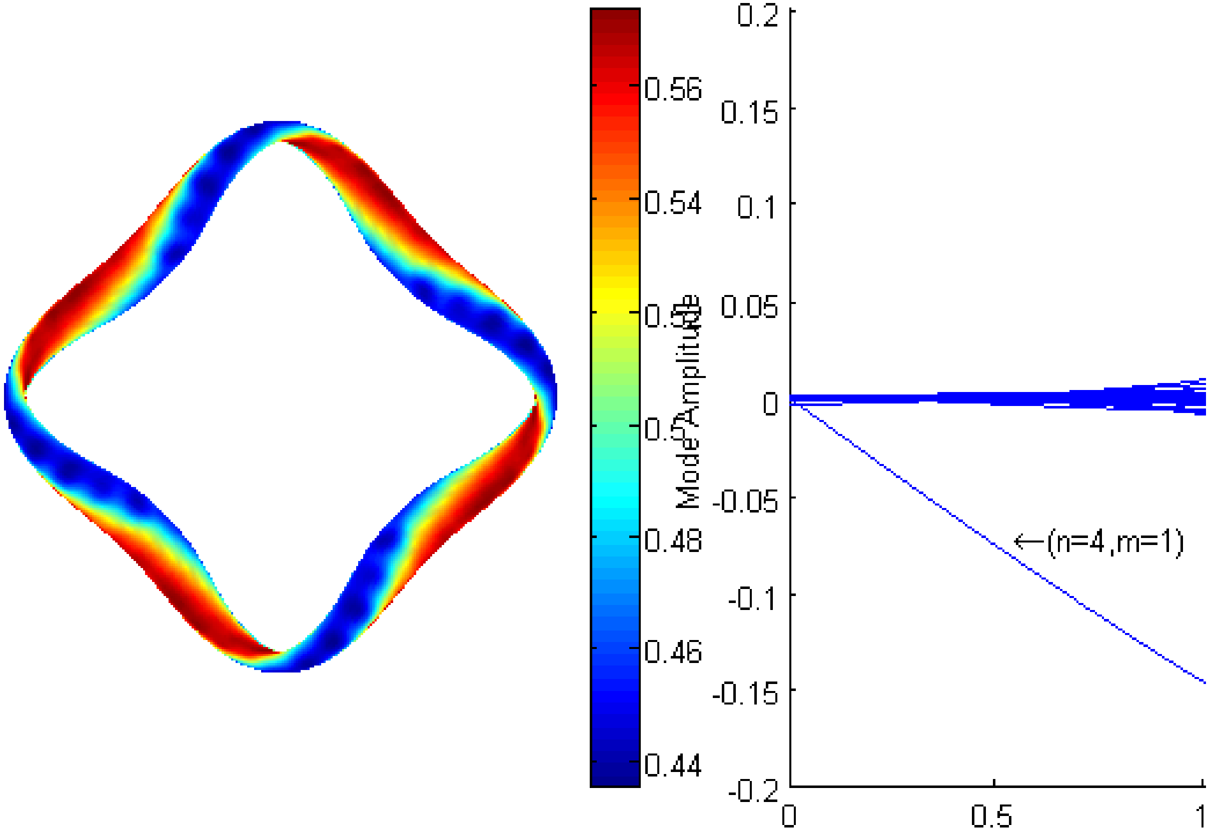
Ellipsoidal Mirror in HSX



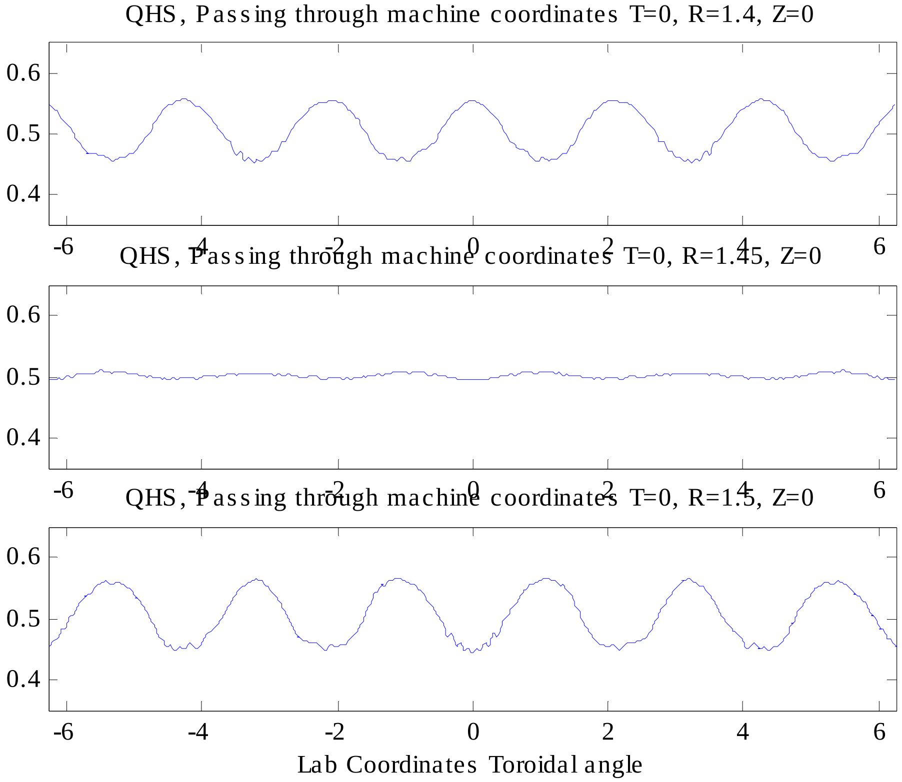
Ray Tracing Solution

QHS Mode

- Quasi-Helically Symmetric Mode
- Central Heating at Main Field Current = 5.35kA

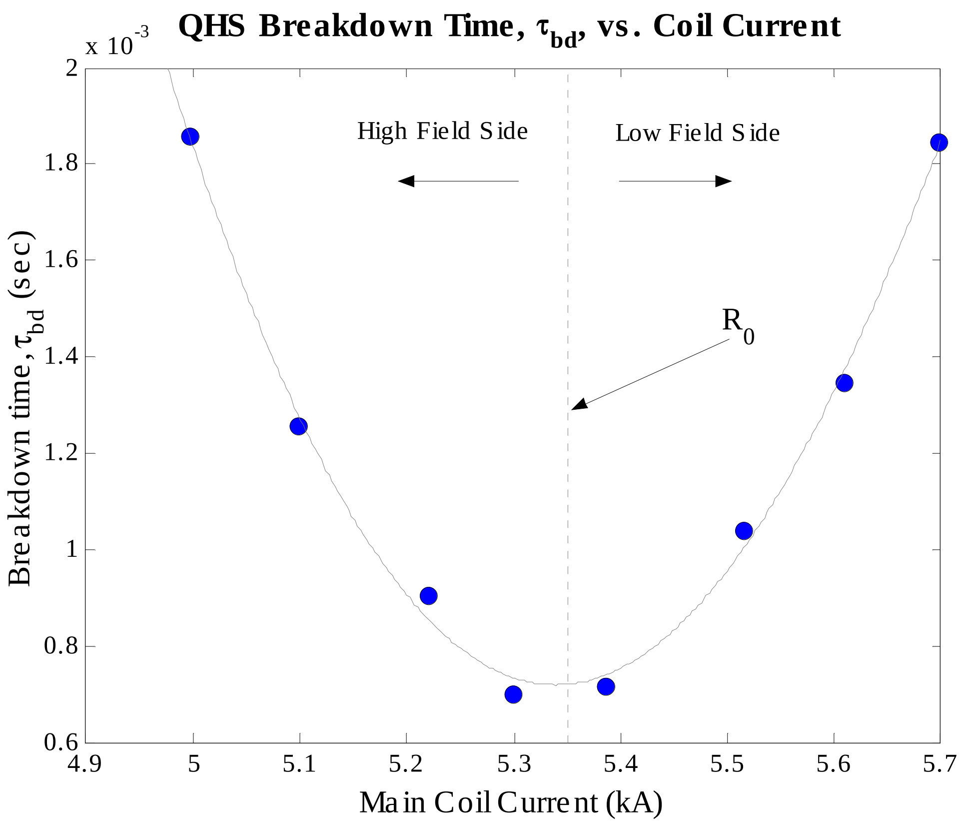


- Maximum |B| is at ECH launch location for High Field Side Heating
- Minimum |B| at ECH launch location for Low Field Side Heating
- In QHS mode, particles are well confined regardless of launch position



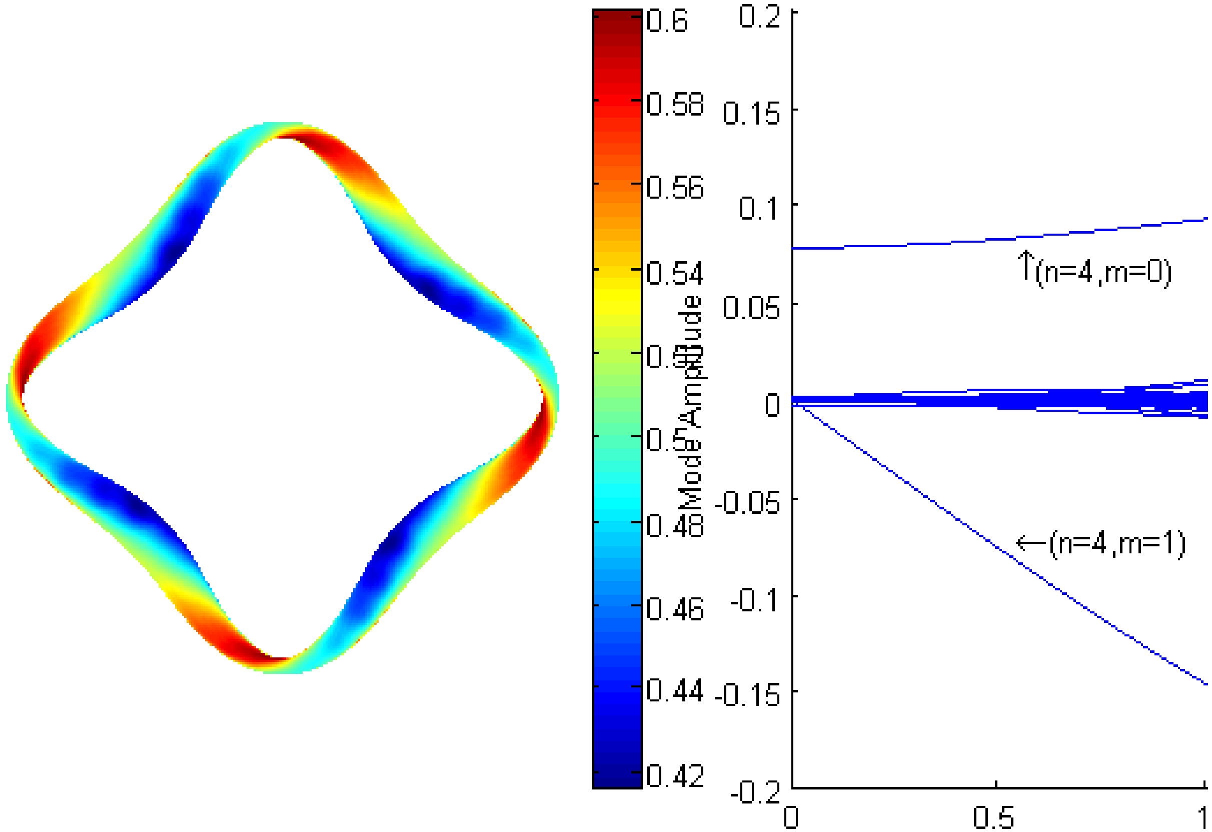
QHS Breakdown and Resonance Location

- Min τ_B ~ 0.7 msec at QHS central resonance
- τ_B symmetric about R_0
- High Field Heating & Low Field Heating are comparable

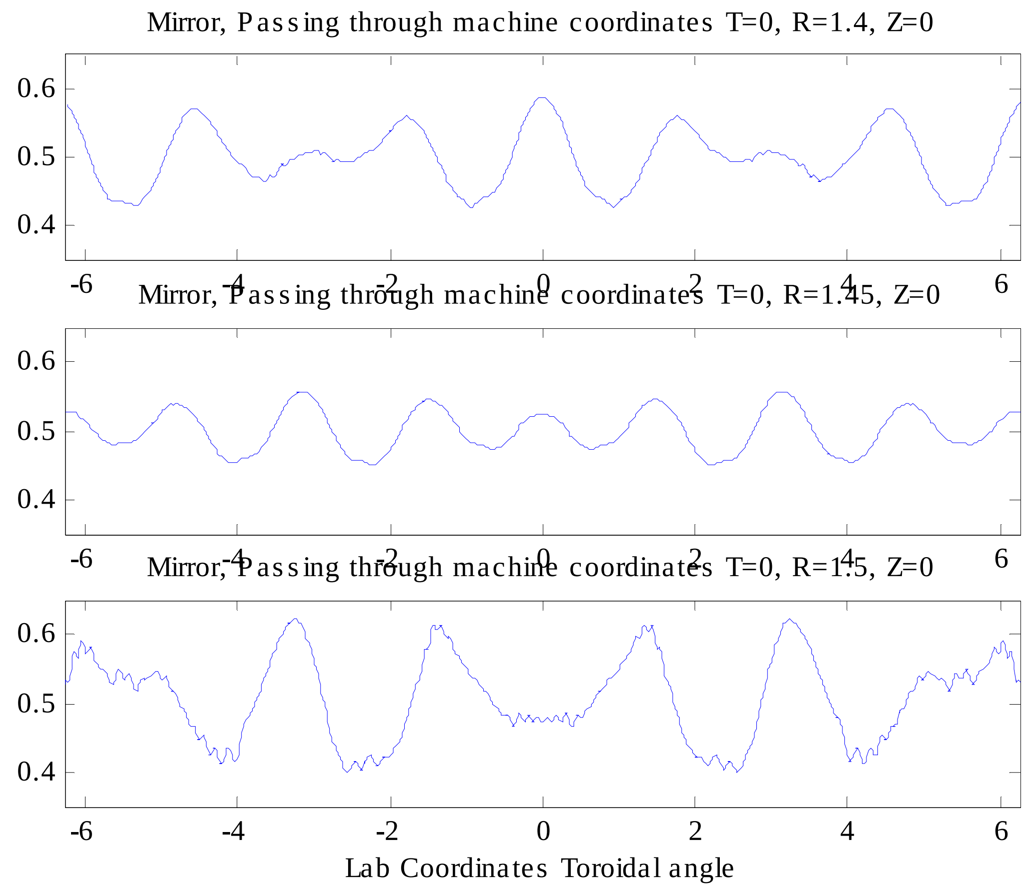


Mirror Mode

- Current in Auxiliary Coils breaks HSX symmetry
- 2nd Harmonic Resonance on axis for 5kA Main Current
- Auxiliary Current = 10% Main Current

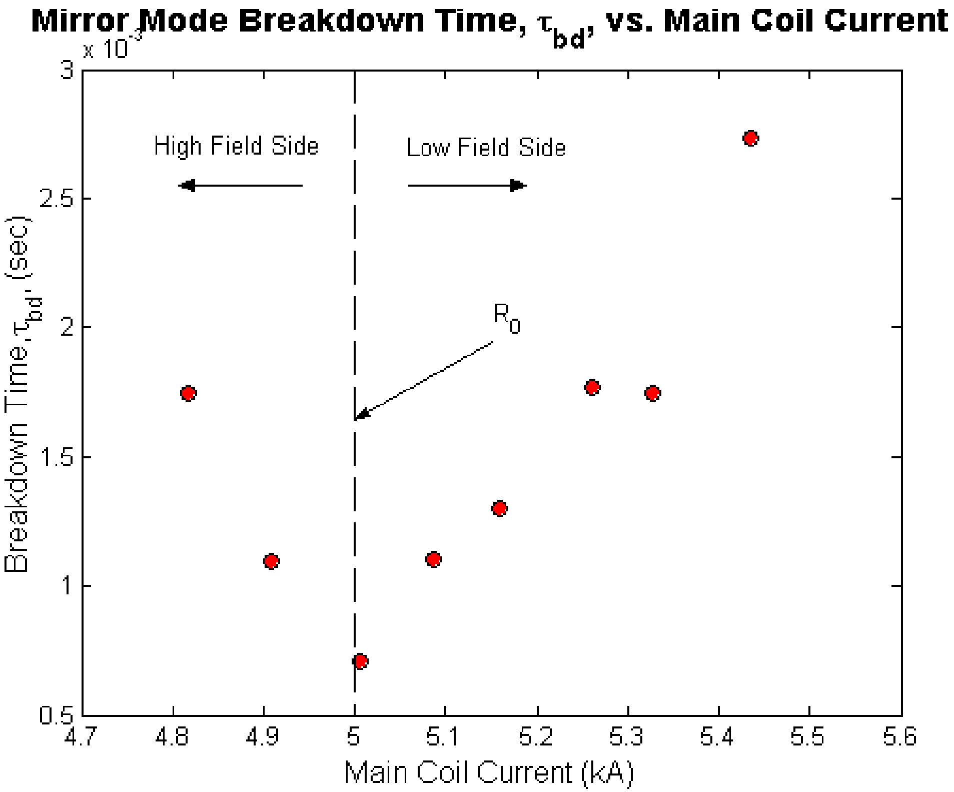


- |B| at the ECH launch location is a maximum for High Field Side Heating
- |B| at the ECH launch location is a local minimum for Low Field Side Heating



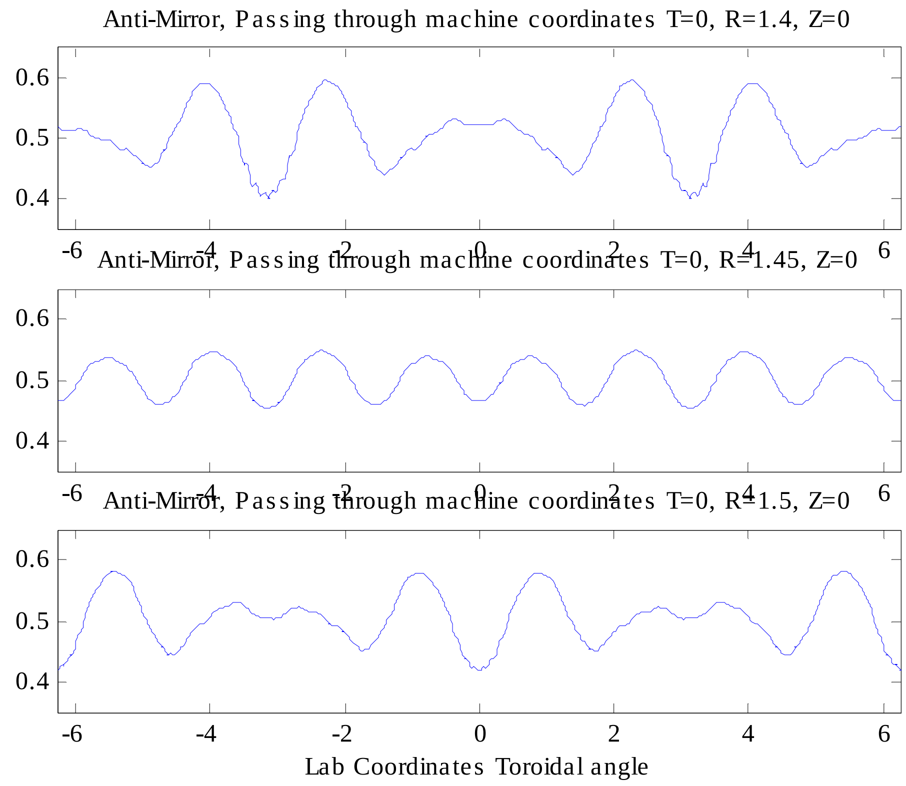
Mirror Breakdown and Resonance Location

- Minimum τ_B at Mirror mode central resonance
- Constant initial neutral density, $n_0 \approx 1.5e12\ m^{-3}$
- Longer breakdown time than QHS case for given distance from axis



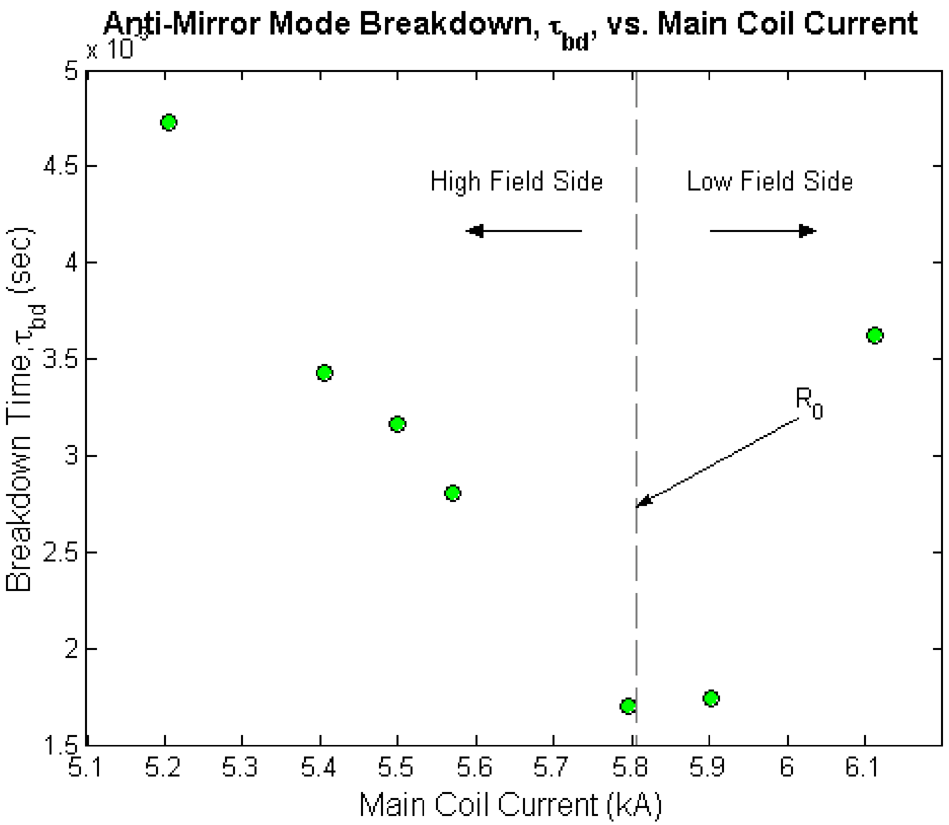
Anti-Mirror Mode

- Anti-Mirror Mode possesses the same magnetic spectrum as the Mirror Mode
- Current in Auxiliary coils is phased to place minimum |B| is positioned at ECH launch location



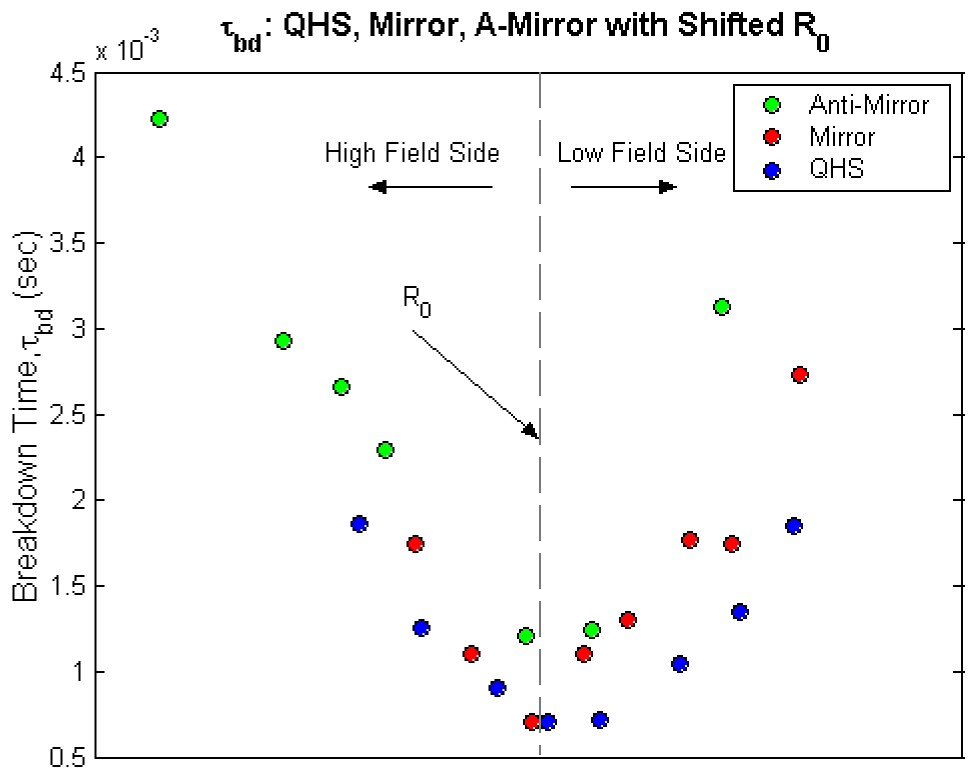
Anti-Mirror Breakdown and Resonance Location

- Minimum τ_{bd} at Anti-Mirror central resonance
- Breakdown time is longer than Mirror and QHS modes of operation



Effects of Local Field Structure on Plasma Breakdown

- QHS, Mirror, and Anti-Mirror data is shifted to align resonance location
- τ_{bd} agrees for High Field Side heating
- τ_{bd} diverges for Low Field Side heating



Breakdown and Initial Fill Pressure

- Plasma formation can only occur if $\nu_L \leq \nu_{en} \leq \nu_{rf}$

  ν_L = particle loss rate from heating region due to direct-loss orbits

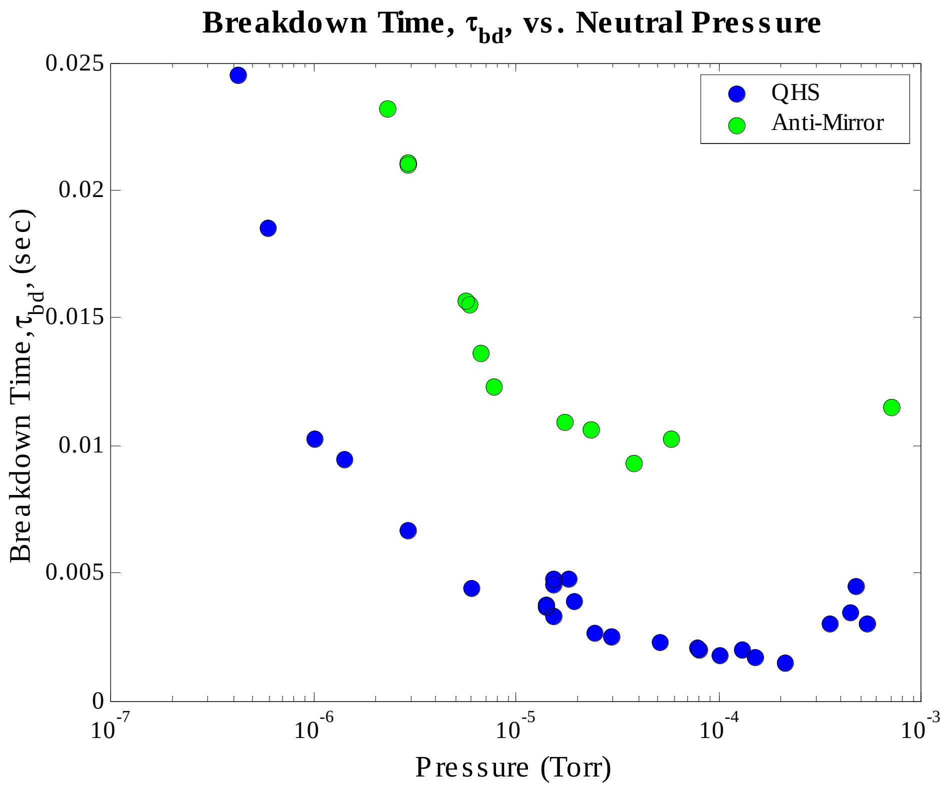
  ν_{en} = electron – neutral collision rate

  ($\nu_{en} \propto$ neutral pressure, p_0)

  ν_{rf} = energy excursion frequency of a trapped electron

- For relevant stellarator parameters, $\nu_{L} << \nu_{rf}$
- $\nu_{en} \propto$ neutral pressure, p_0

- Initial H_2 fill pressure set with a needle valve
- QHS and Anti-Mirror modes with central heating
- Reduction in τ_{bd} from Anti-Mirror to QHS modes indicates a reduction of direct-loss orbits for QHS mode



References

- Carter M. D., J. D. Callen, D. B. Batchelor, R. C. Goldfinger, Phys. Fluids 29 (1), January 1986.
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Future Plans

- Continue analysis of breakdown with varying density for QHS, Mirror, Anti-Mirror modes in High Field, Low Field, and Central Heating.
- Explore the application of the numerical breakdown model (Carter et. al.) to HSX plasma breakdown data
- Estimate loss rate, $\nu_{L,}$ for HSX all three modes of operation

Summary

- Plasma breakdown times were measured for QHS, Mirror, and Anti-Mirror modes of operation.
- QHS mode demonstrates the shortest plasma breakdown time. This is indicative of the reduction of direct-loss orbits when symmetry breaking terms are small.
- Mirror and Anti-Mirror mode results provide evidence that plasma breakdown is sensitive to the magnetic field structure at the ECH launch position, and single-pass absorption is significant in HSX.