ECH Operation at B= 0.5T and the Effects of Symmetry Breaking on Plasma Formation in HSX*

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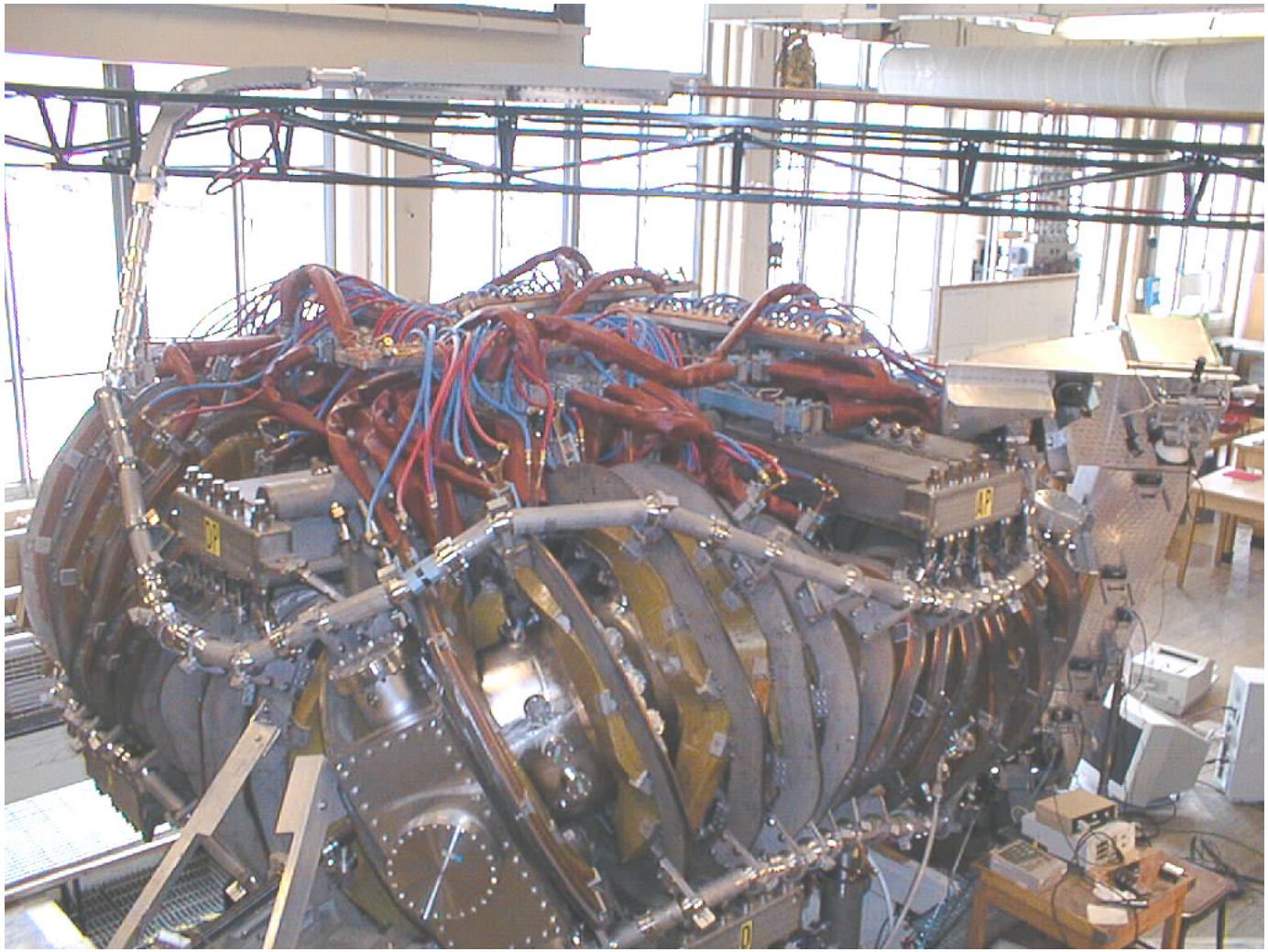

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High Effective Transform and Quasi-Helical Symmetry Lead to Unique Properties

- Low Neoclassical Transport
  - Small deviations from magnetic surfaces, small banana widths
  - Minimal direct loss particles, reduction in '$1/\upsilon$' transport, very small neoclassical thermal conductivity

- Plasma Currents are Small
  - Small Pfirsch-Schlüter and bootstrap currents
  - Robust magnetic surfaces, high equilibrium beta limit

- Low parallel viscosity in the direction of symmetry
  - Possibility of high E x B shear to reduce turbulence

- Lower anomalous transport ? L-2 experimental results $\chi_{e,anom} \propto 1/\iota$

The HSX Device

Major Radius	1.2 m
Average Plasma Minor Radius	0.15 m
Plasma Volume	~.44 m^3
Number of Field Periods	4
Helical Axis Radius	20 cm
Rotational Transform	
Axis	1.05
Edge	1.12
Number of Coils/period	12
Average Coil Radius	~ 30 cm
Number turns/coil	14
Coil Current	13.4 kA
Magnetic Field Strength (max)	1.25 T
Magnet Pulse Length (full field)	≤ 0.2 s
Auxiliary Coils (total)	48

Estimated Parameters with 28 GHz ECH

Heating Power (source)	200 kW
Power Density	.45 W/cm^3
Density (cut-off)	1×10^{13} cm^{-3}
T_{eo} (ASTRA modeling)	1 keV
τ_E	2-5 ms
υ_e^*	≤ 0.1

The HSX experimental program focuses on improvements of electron transport through quasi-helical symmetry

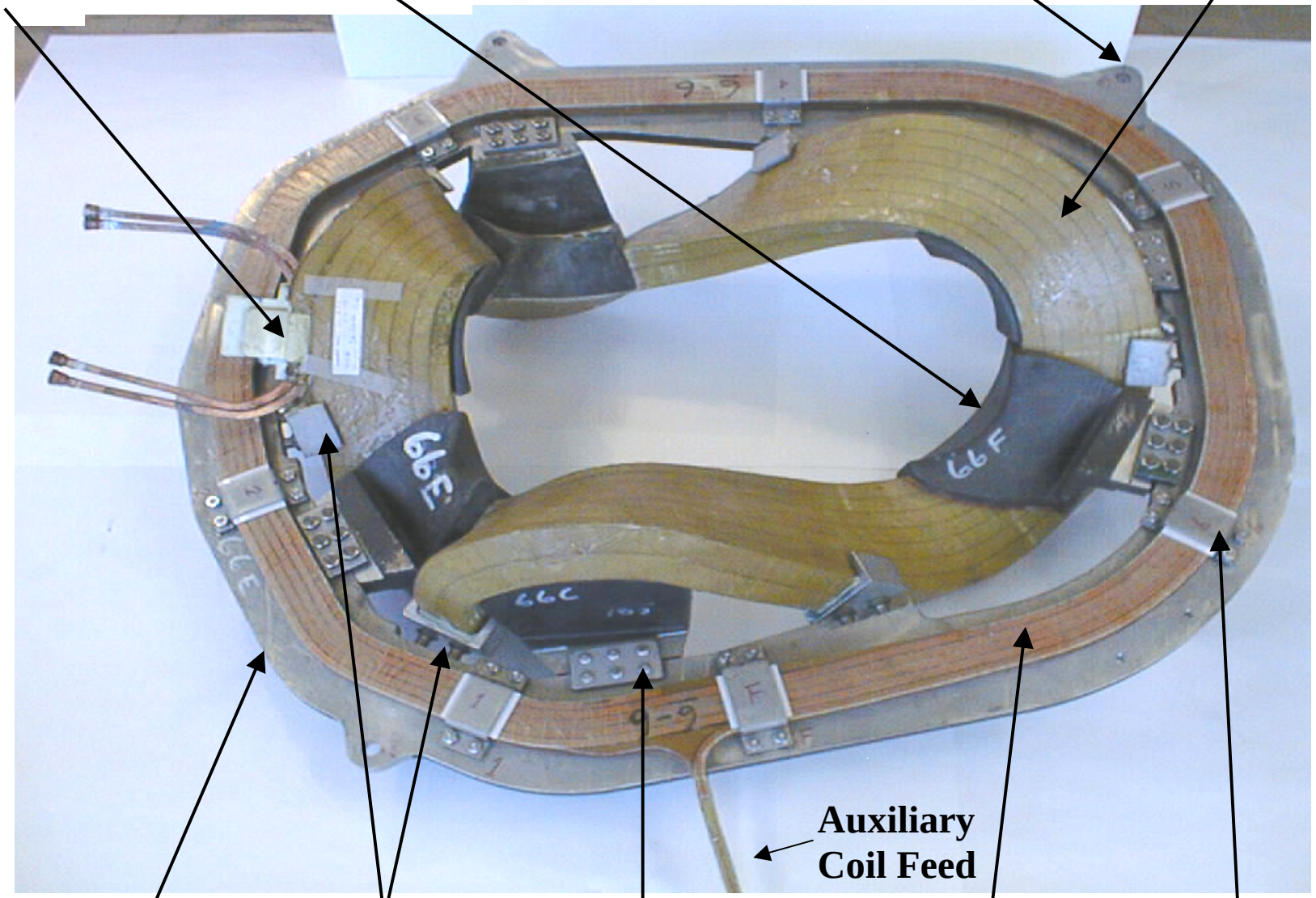
Utilize 28 GHz ECH (200 kW) to put electrons into low collisionality regime

Second harmonic heating at B=0.5T to generate hot tail electrons for energetic particle confinement studies

Fundamental heating at B=1.0T to study bulk confinement and reduced electron thermal conductivity with QHS

Auxiliary coils provide the flexibility to alter the magnetic field spectrum between QHS and fully 3-D for comparison

Main and Auxiliary HSX Coil Module in Supporting Assembly



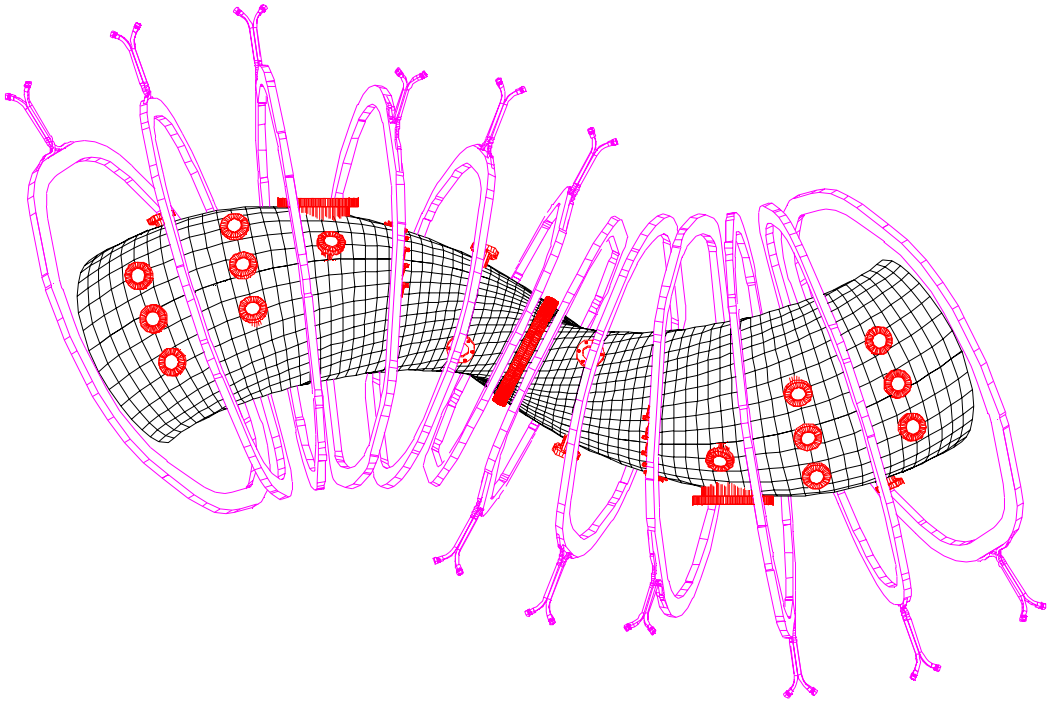
AUXILIARY COILS CAN ALTER MAGNETIC CONFIGURATION

Auxiliary Currents:

+ + + - - - - - - + + + MIRROR

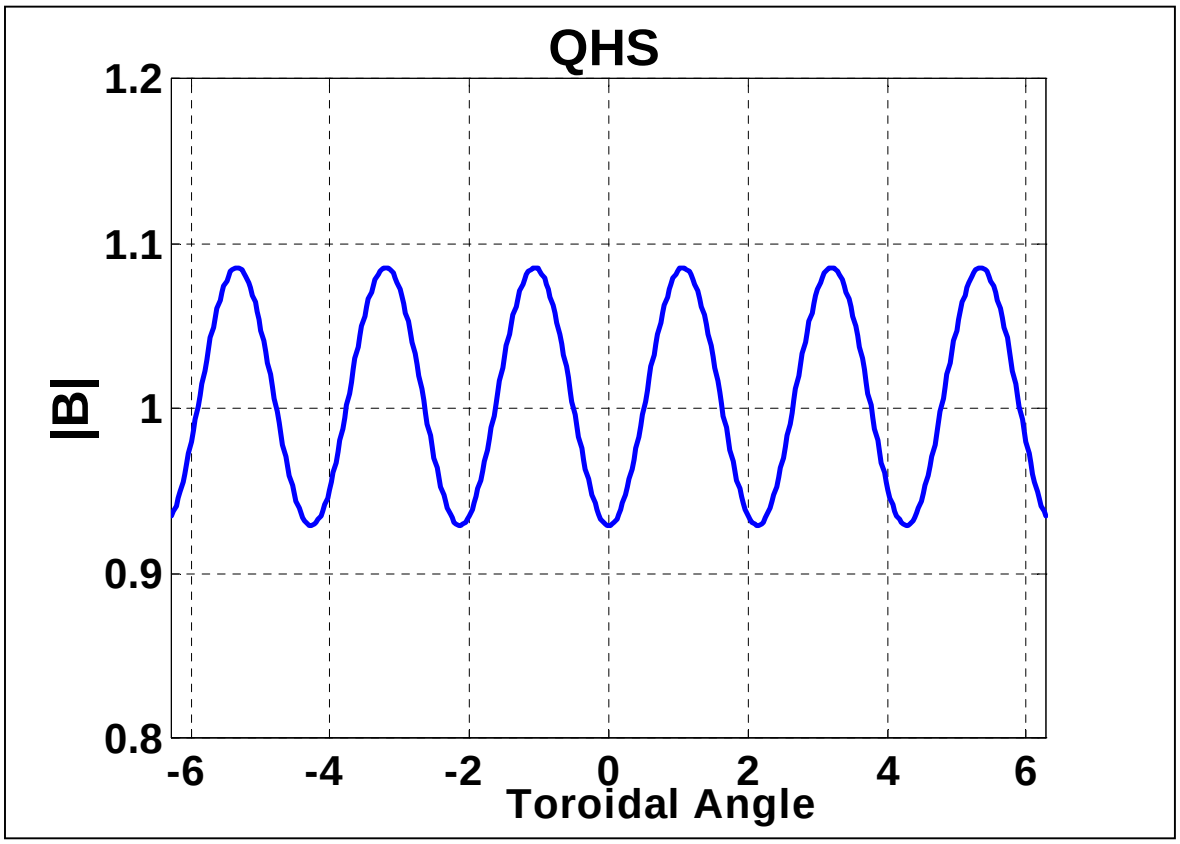
- - - - - - - - - - - - - WELL

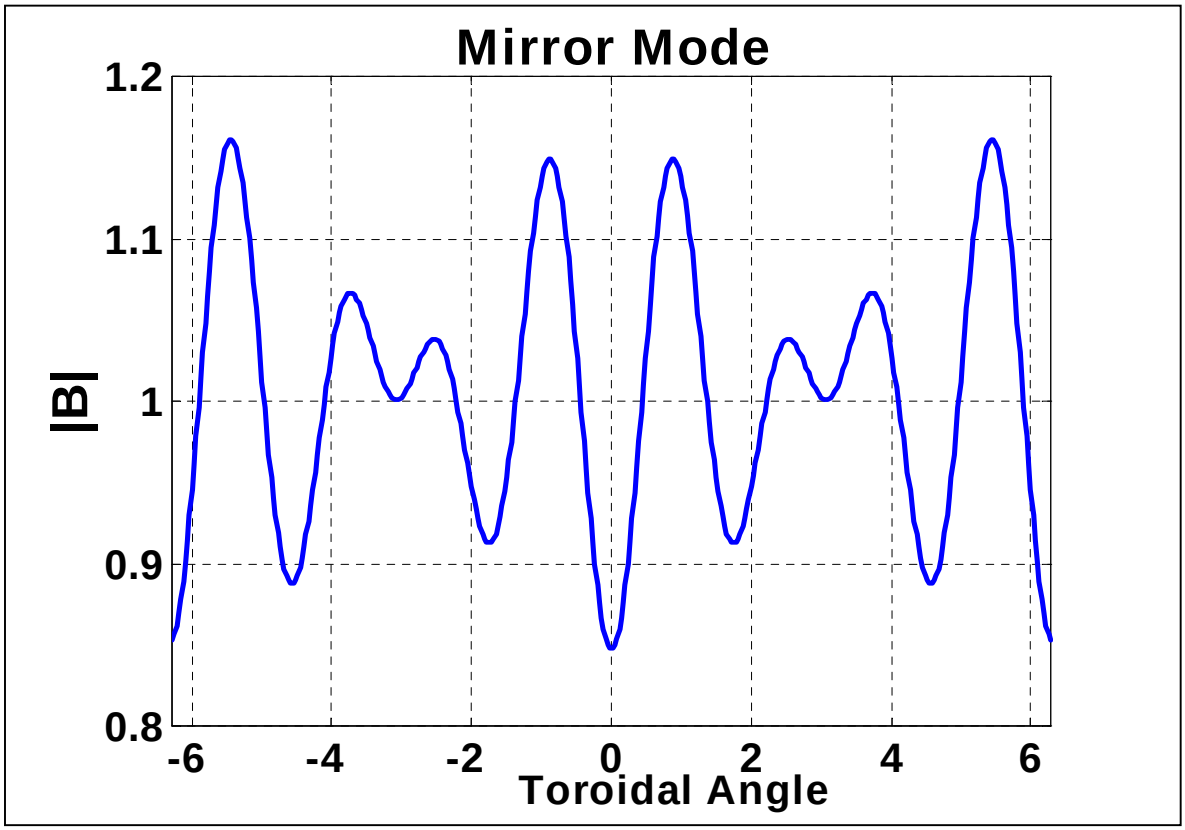
- Noncircular, planar auxiliary coils with 10% A-T of main coil set allow for independent control of transport and stability



Configuration	Auxiliary Current	Dominant Feature
QHS	None	Best transport
MIRROR	3 coils on either end opposite to coils in center	Transport similar to conventional stellarator
WELL	All aux currents oppose main coil current	Well depth and stability increases

Typical ripple along the magnetic field lines for the two modes of operation



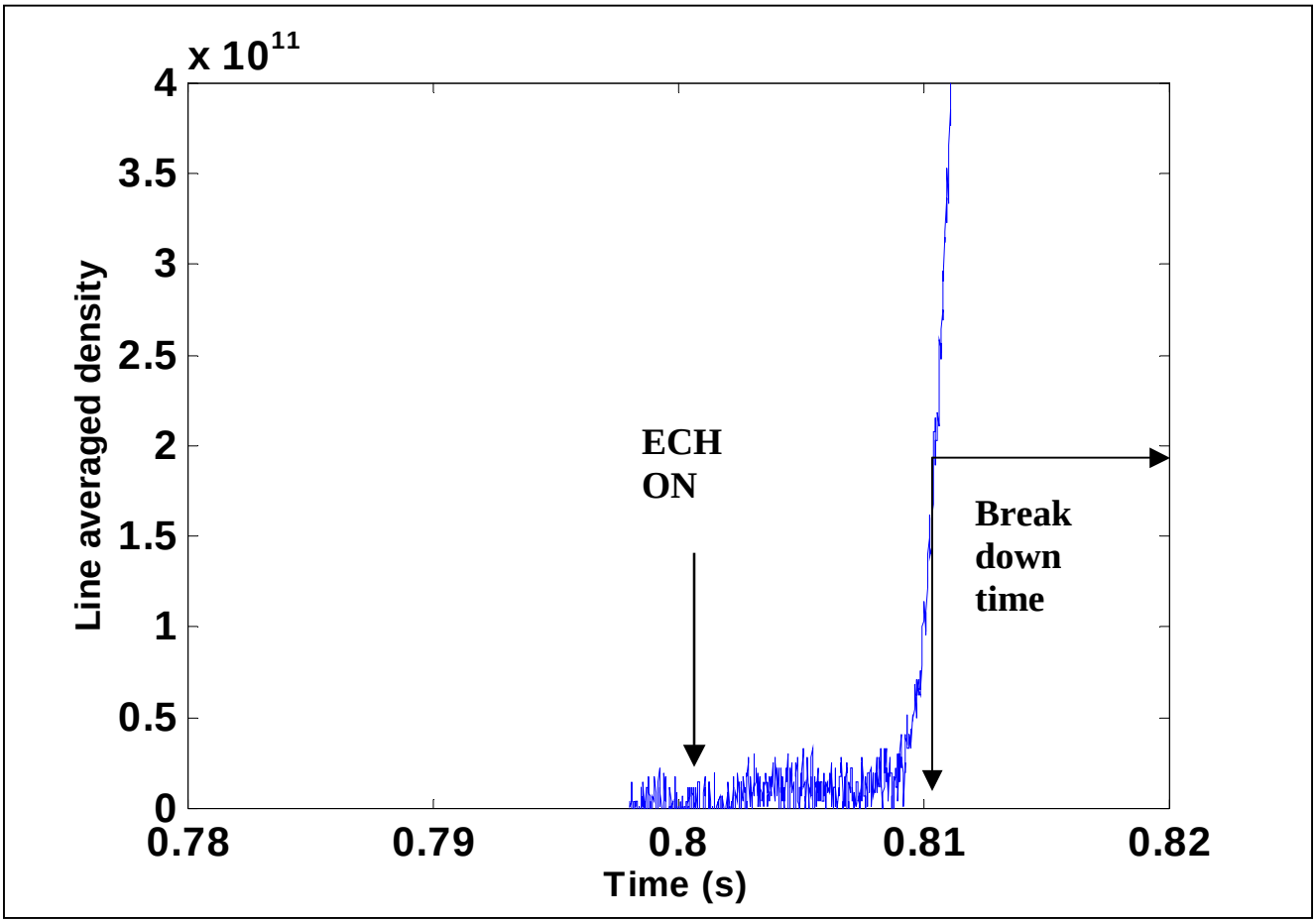


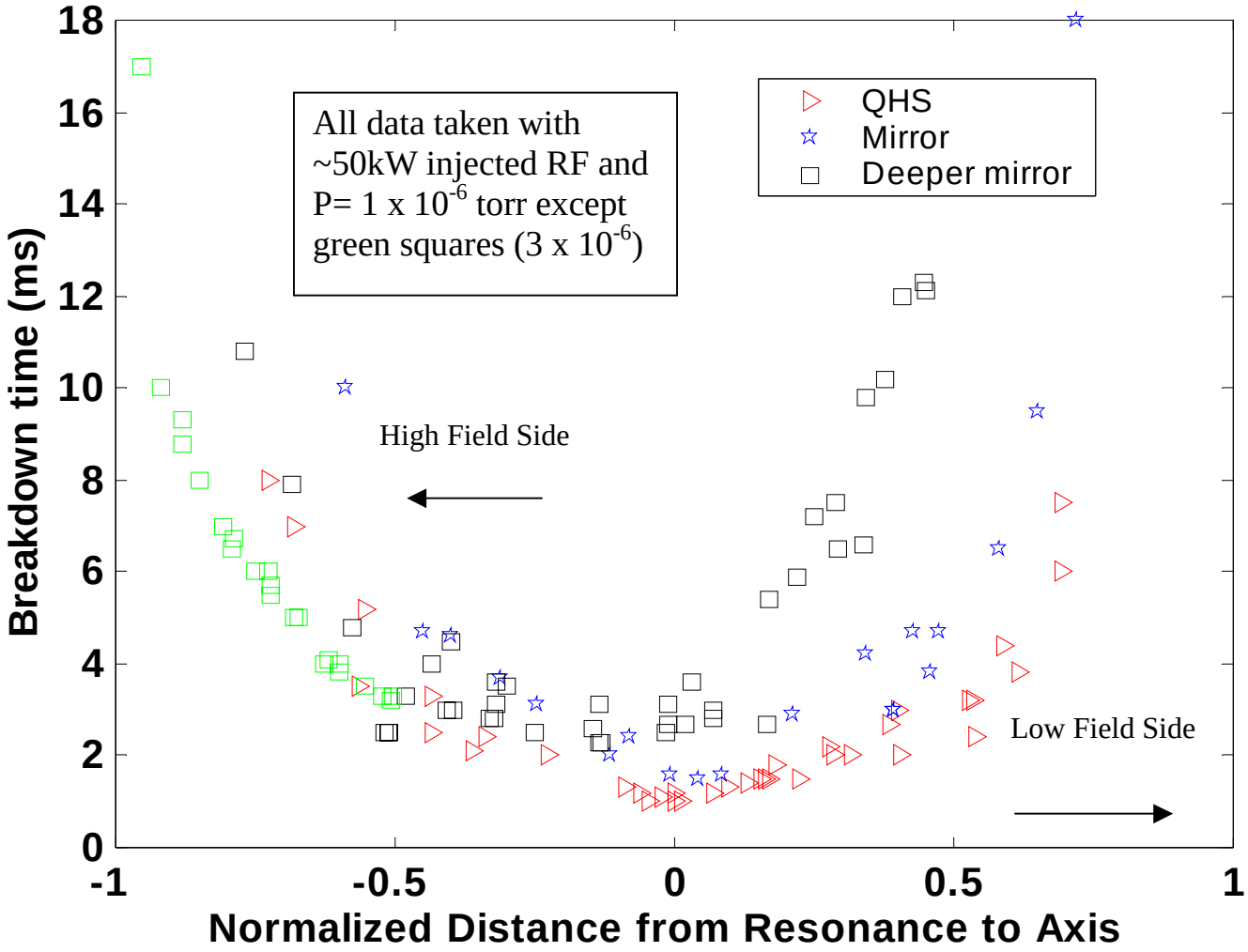
28 GHz ECH heating at the 2nd harmonic is being utilized to examine the confinement properties of these two modes of operation by:

- **Studies of the breakdown time as a function of the magnetic field spectrum and resonance location**

- **Variations in the stored energy with average density, resonance location and spectrum**

At fixed neutral density (puff) and RF power, the time to reach a small but measurable density is defined as the breakdown time and taken as an indication of the confinement of the ionizing electrons



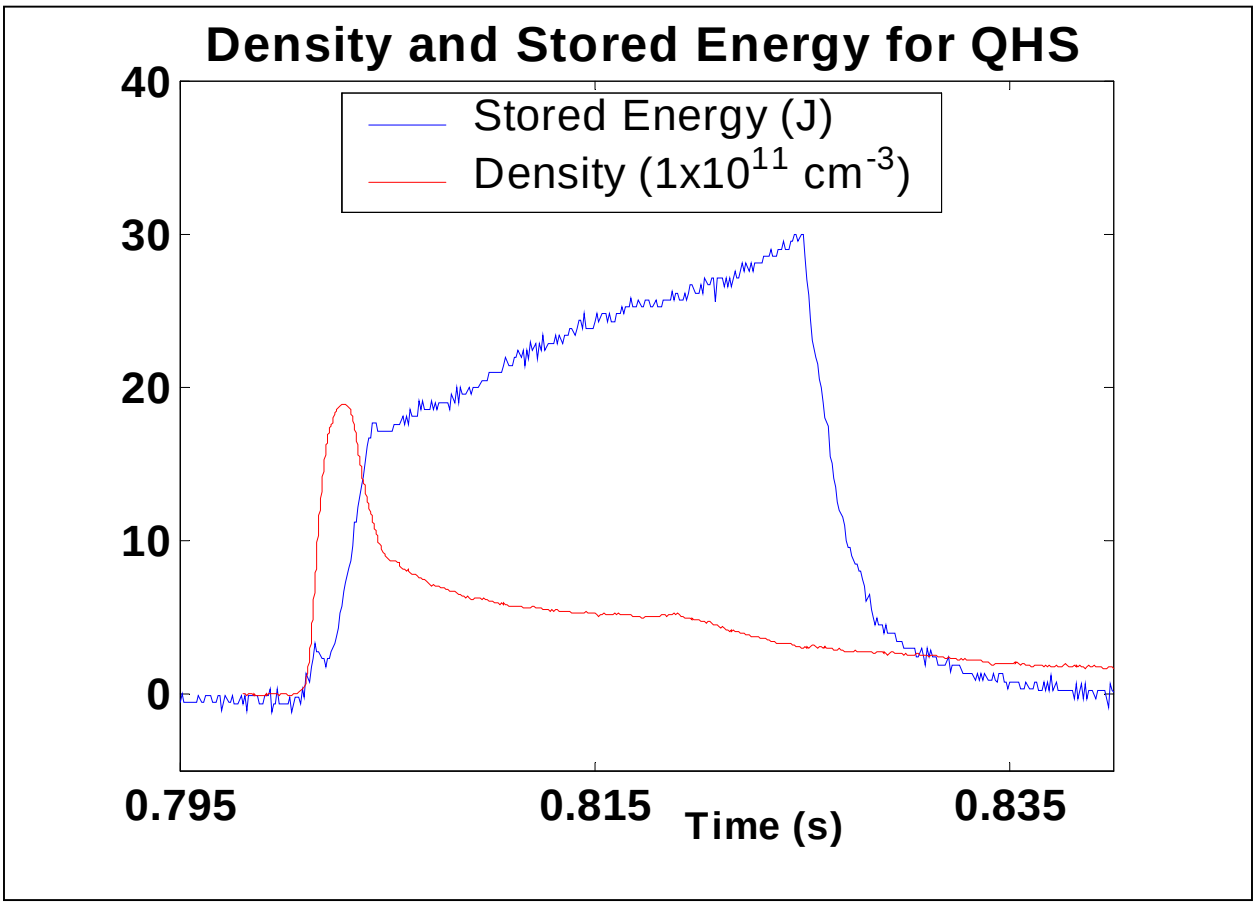


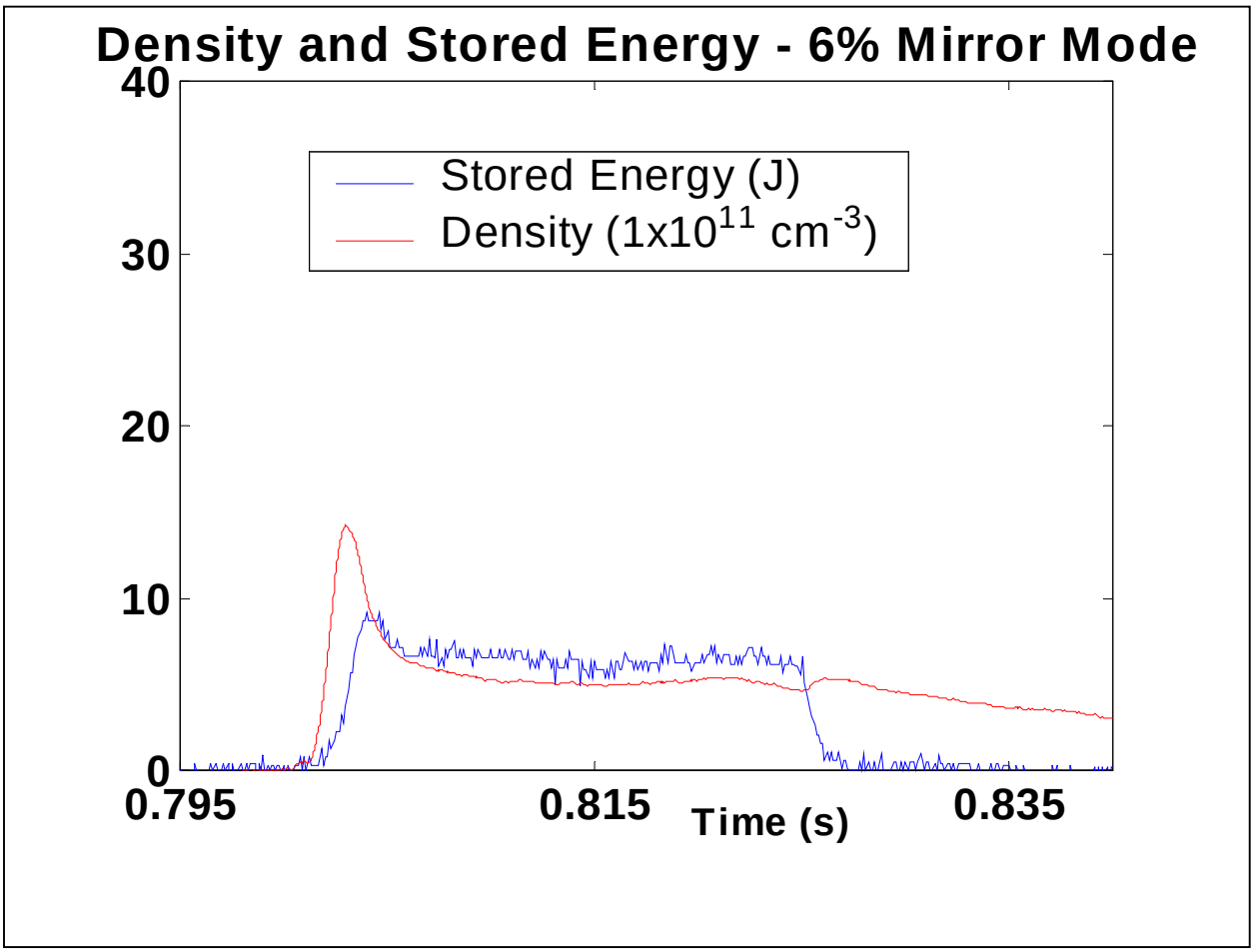
- **Breakdown time is a minimum for all cases with on-axis resonance**

- **With low-field side resonance, breakdown times increase significantly as the deviation from symmetry increases**

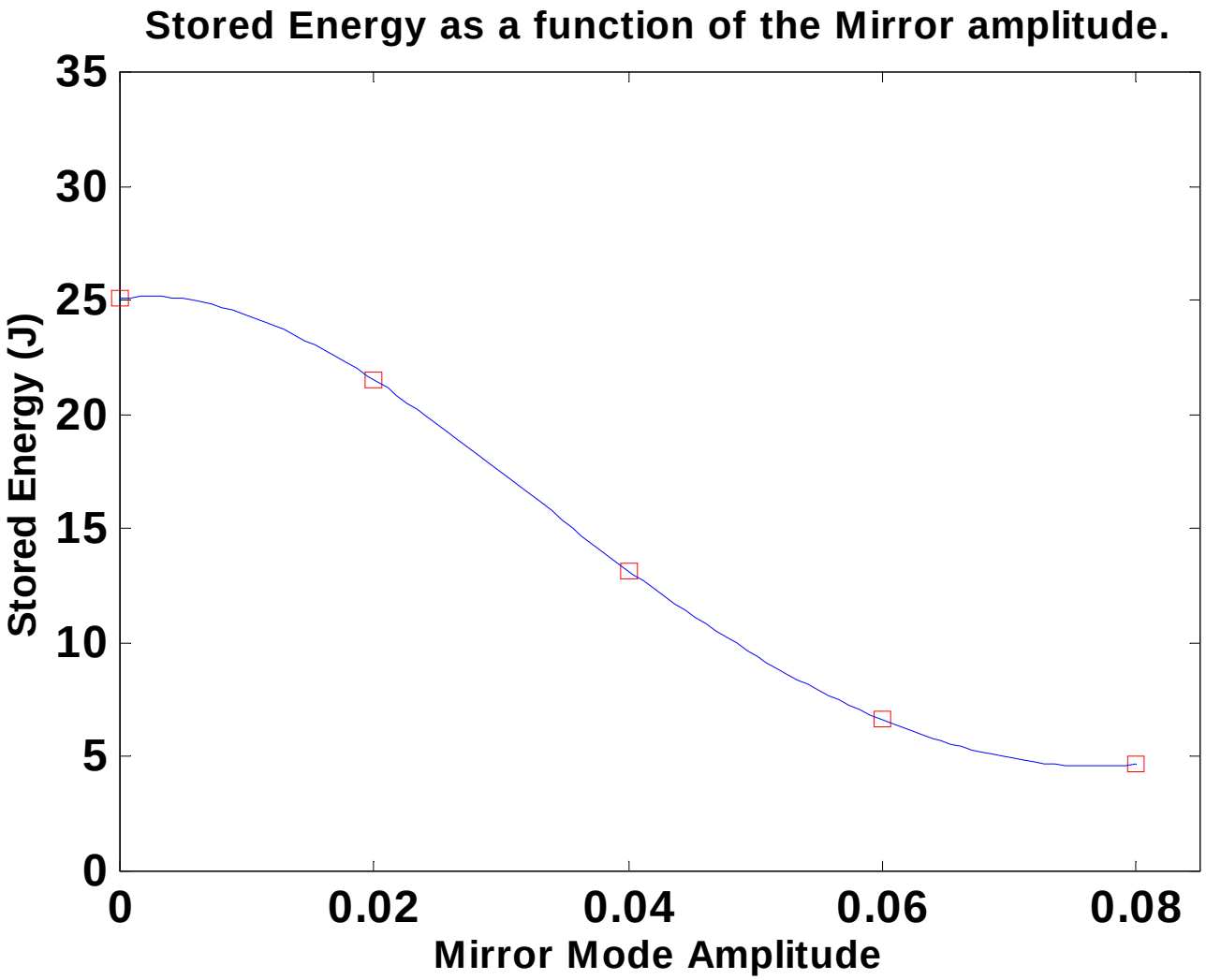
- **Deviations between the configurations is much smaller on the high-field side; reduced times for high-field deep mirror with increased fill pressure**

Stored Energy is Higher for QHS than in Mirror Mode Operation

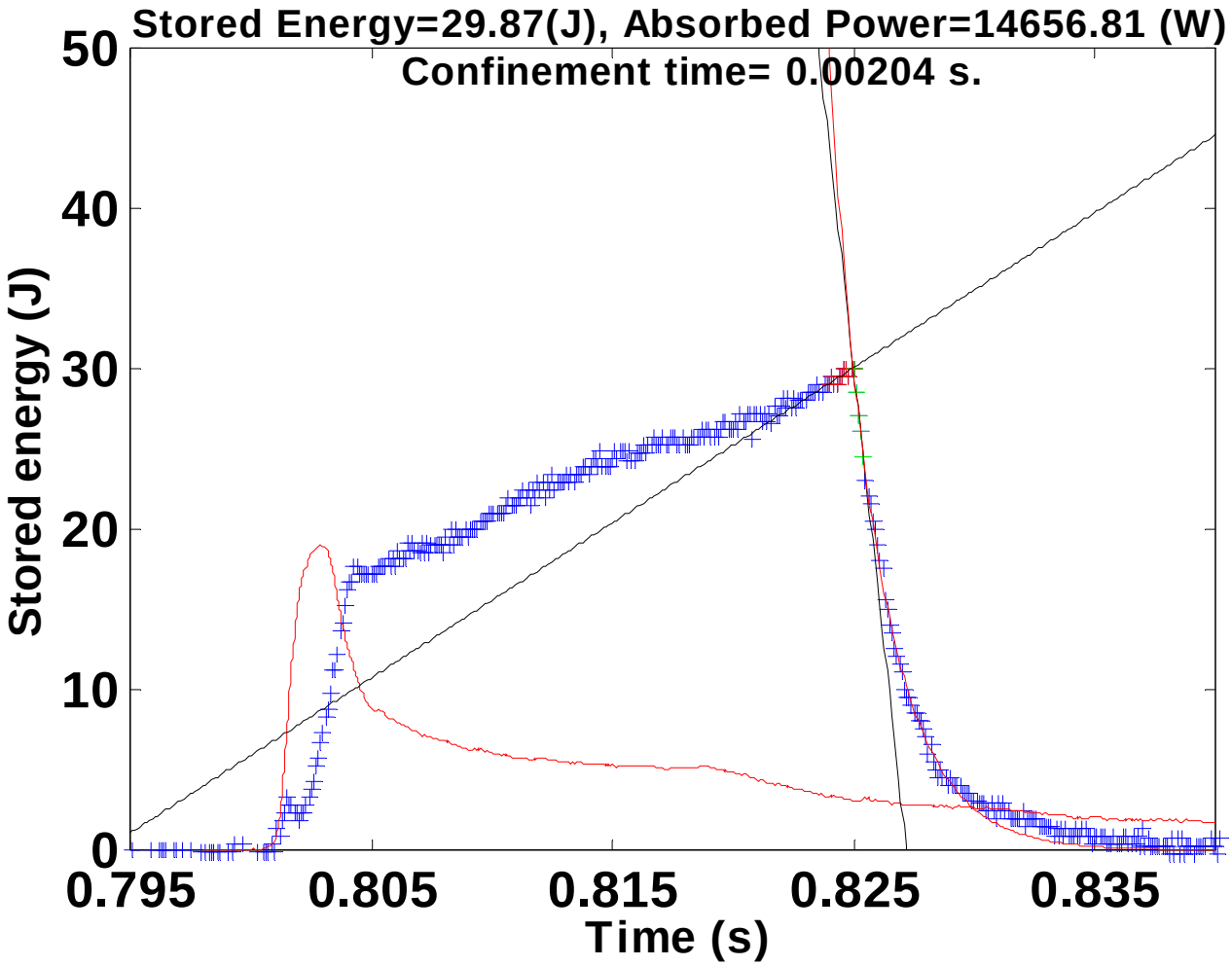




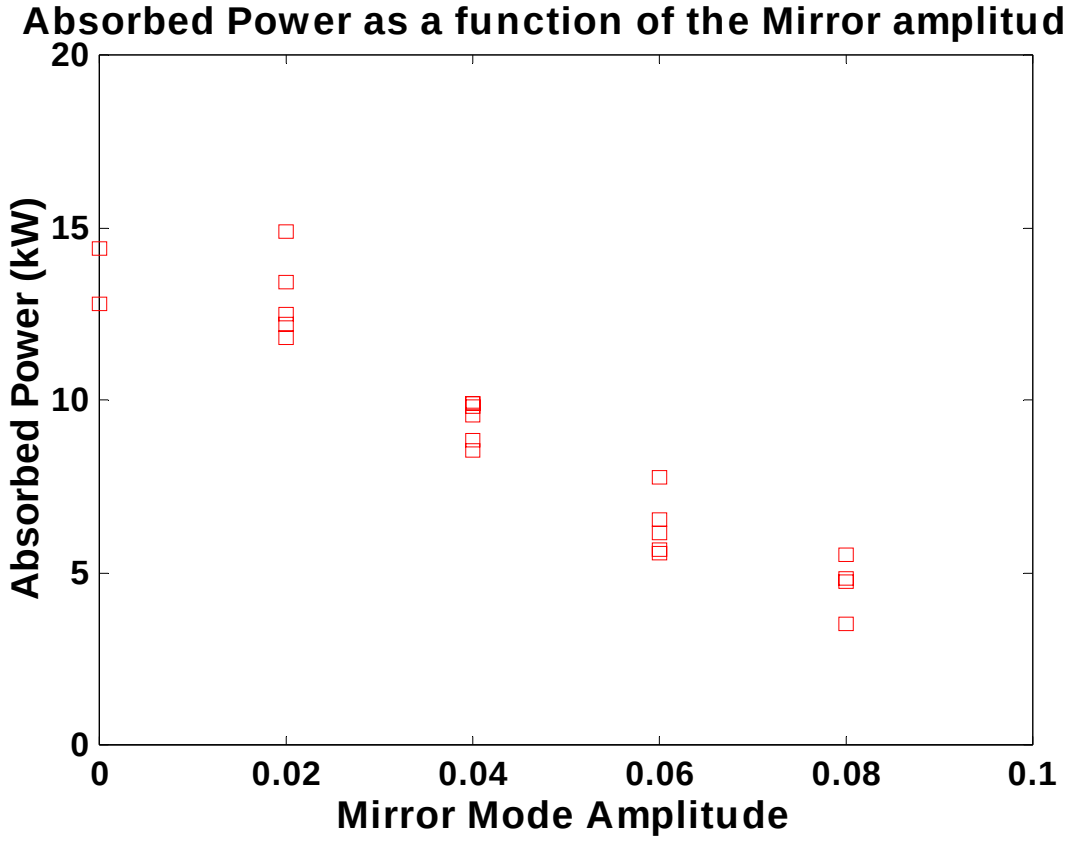
Clear Reduction in Stored Energy at Constant Density and Input Power as Mirror Term is Increased

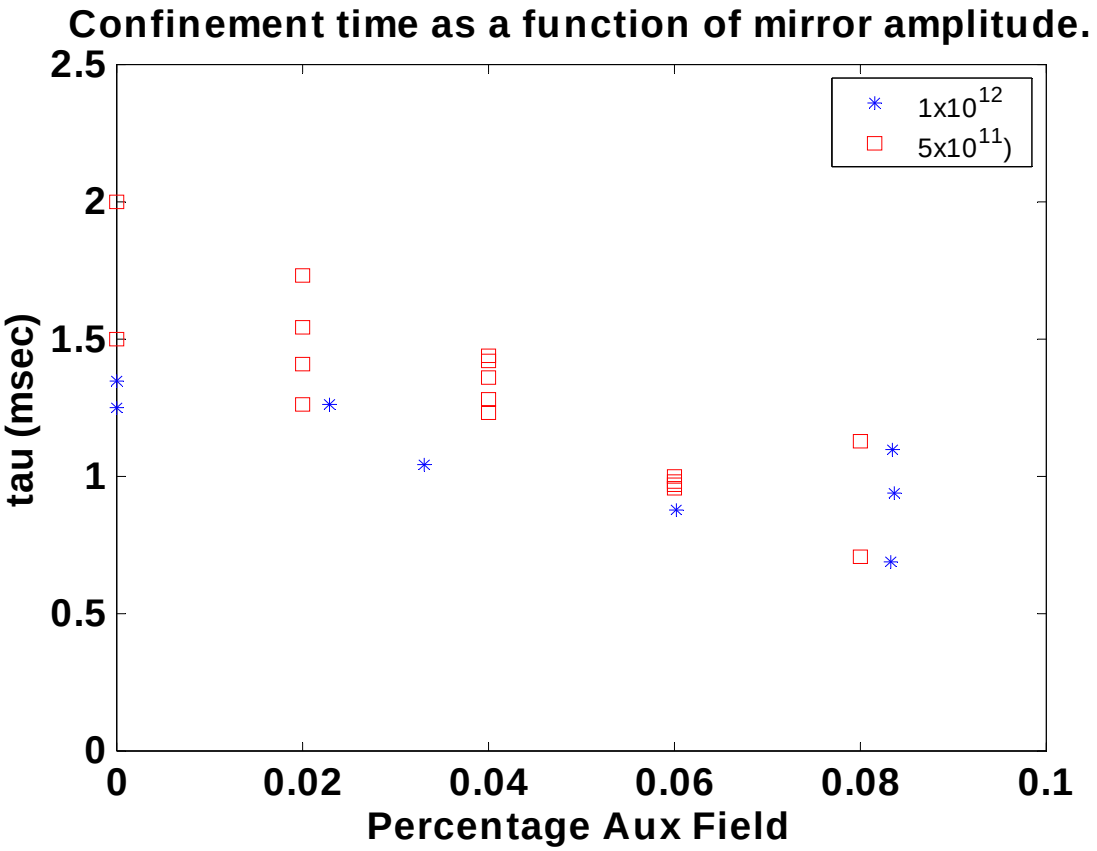


Absorbed Power Inferred from Change in the Stored Energy at ECH Turnoff

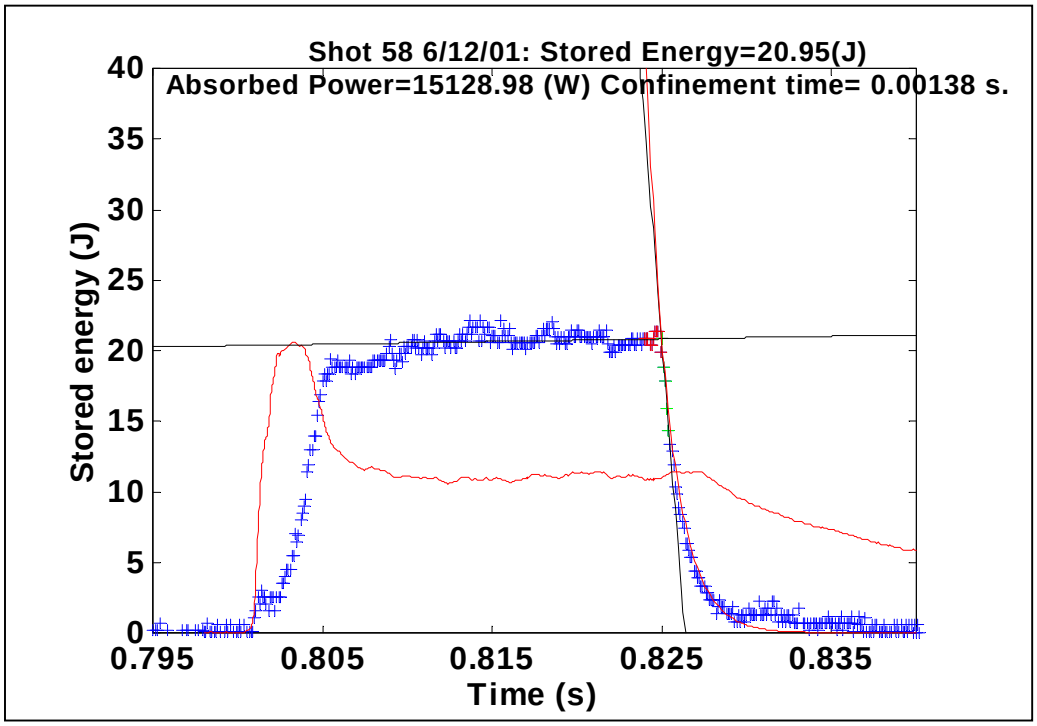


Absorbed power and confinement time decrease with increasing mirror mode





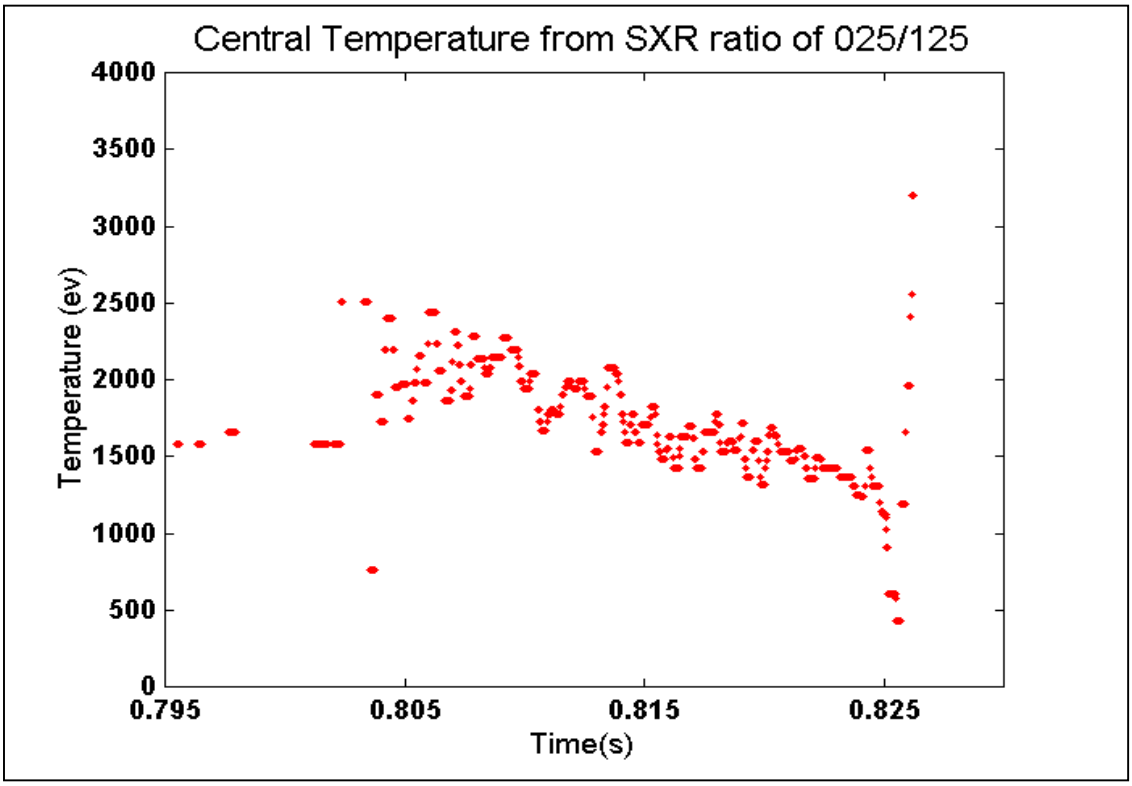
At low densities there is evidence of a non-thermal electron population



Shot 58 6/12/01

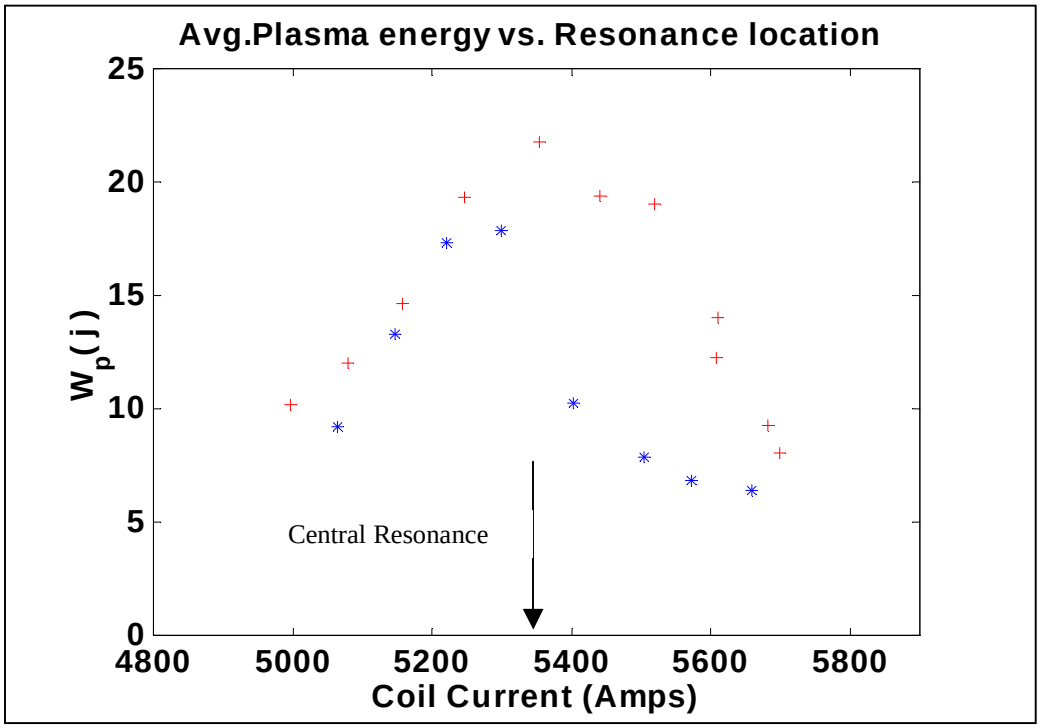
$T_e \sim W_p/nV$

=> 260 eV

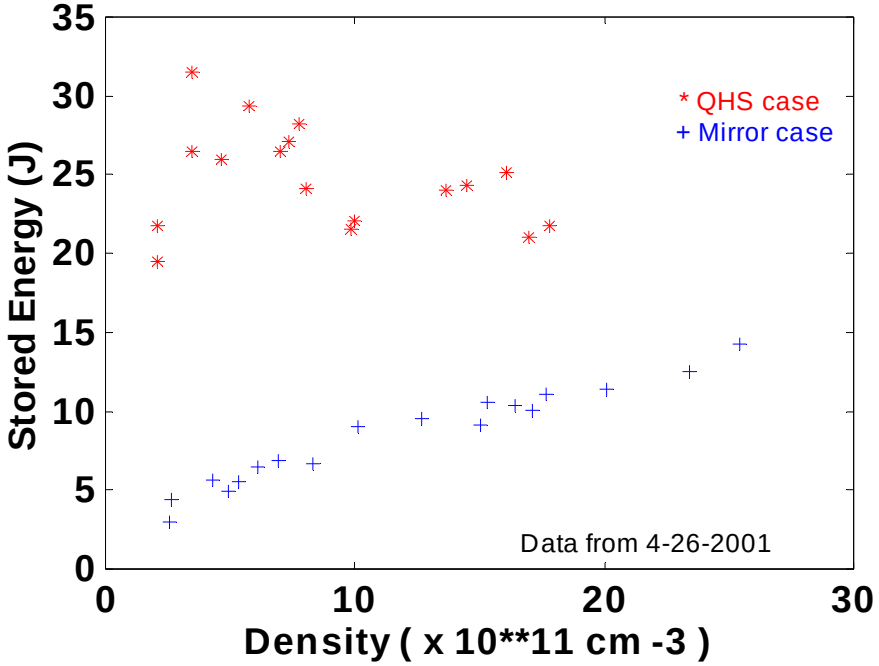


T_{eo} from SX ~1500 eV

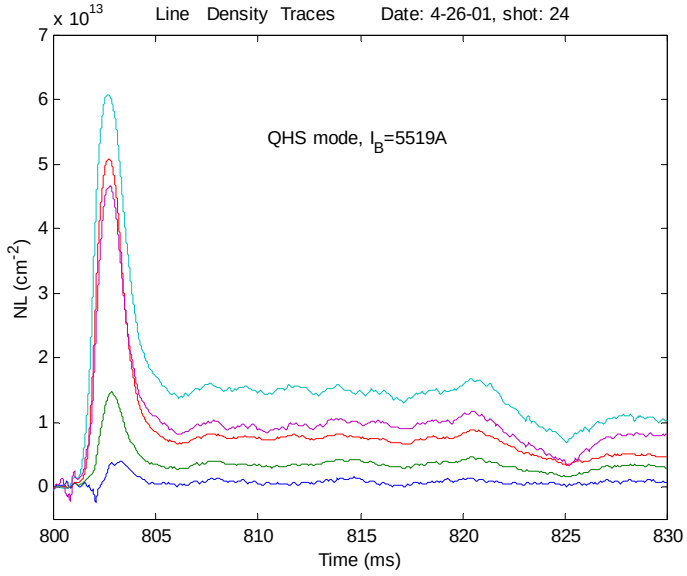
Variation in Stored Energy with Resonance Location for QHS and Mirror

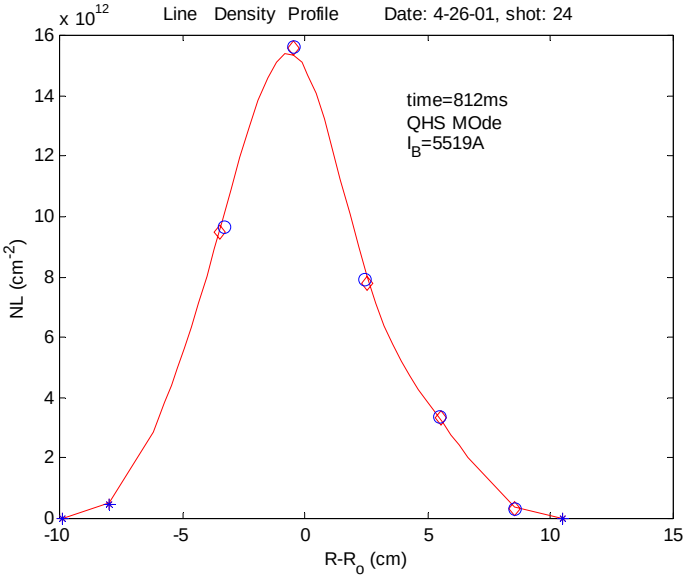


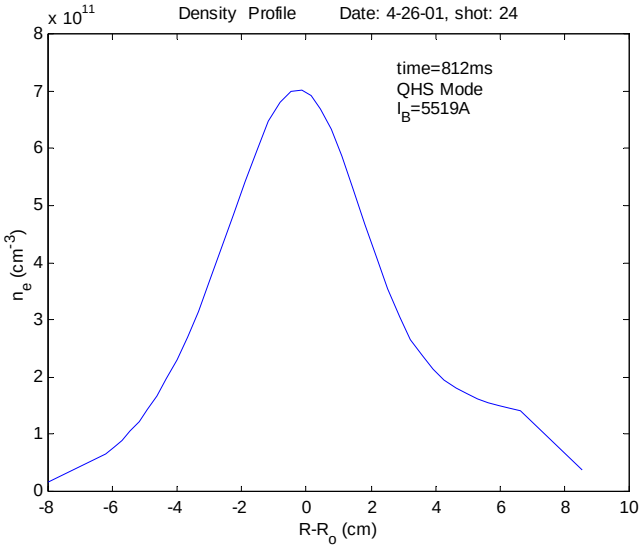
Central Resonance Density Scan QHS/Mirror



Peaked Density Profiles Observed in QHS Low Density Discharges, even with Off-axis Resonance

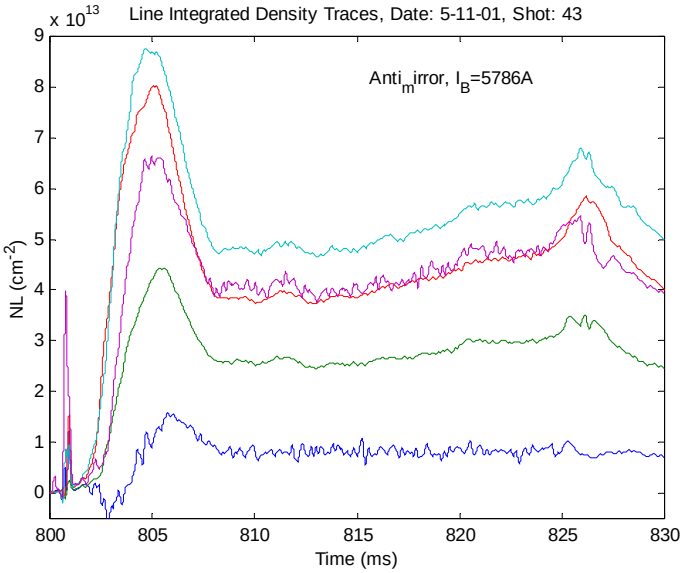


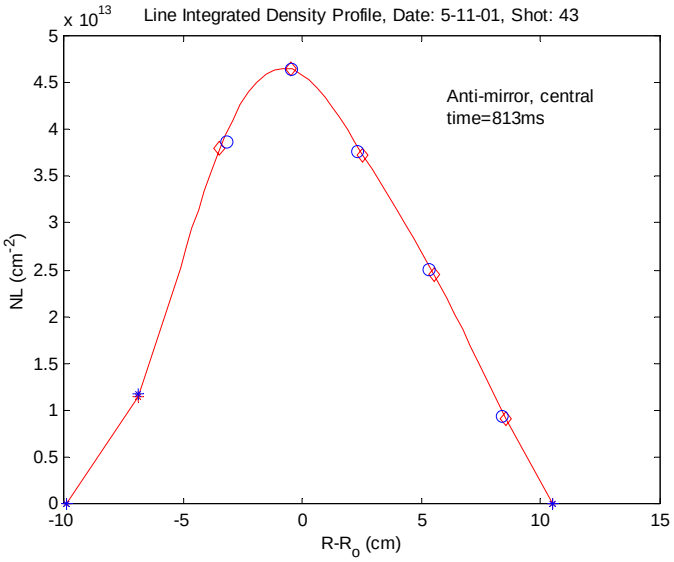


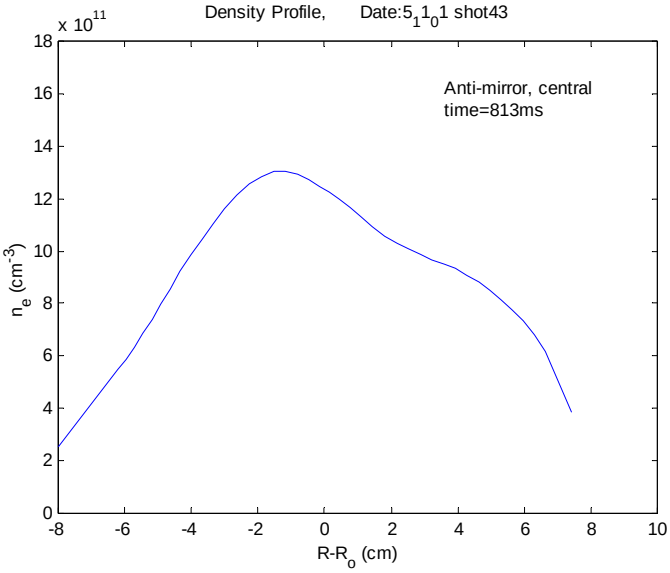


Off-axis heating!

Broadened Density Profiles Observed in Mirror Mode with Central Resonance Heating

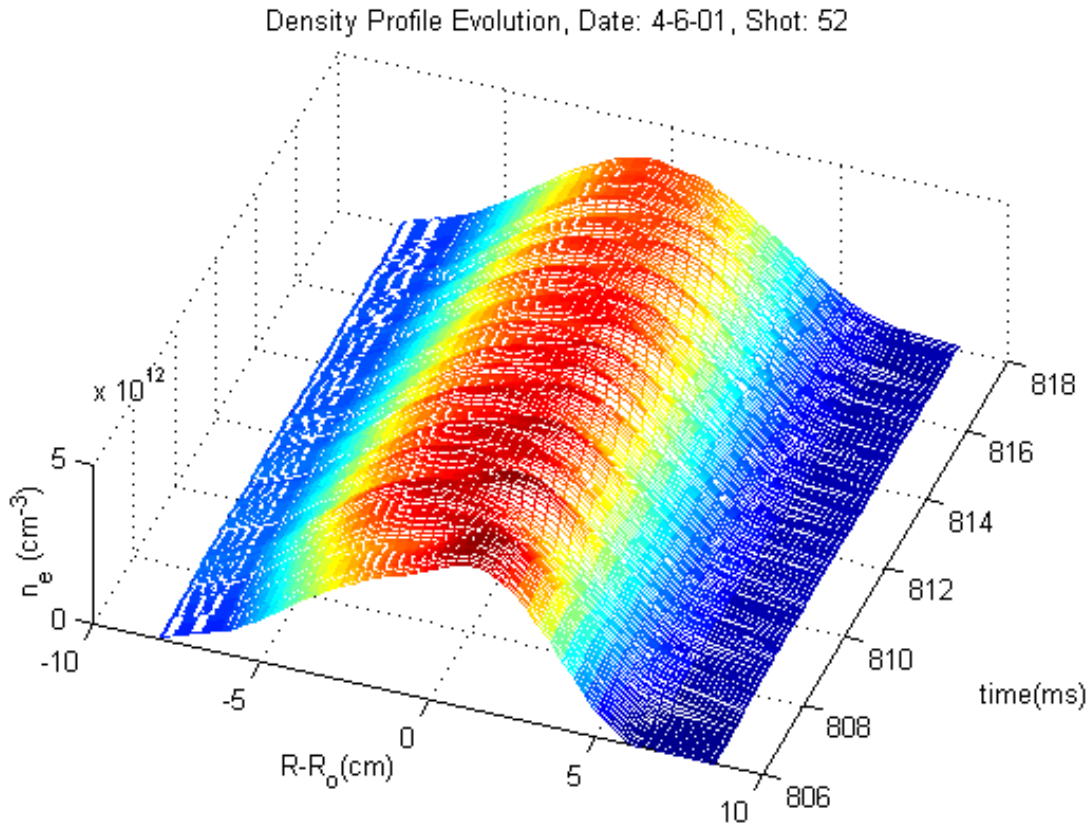


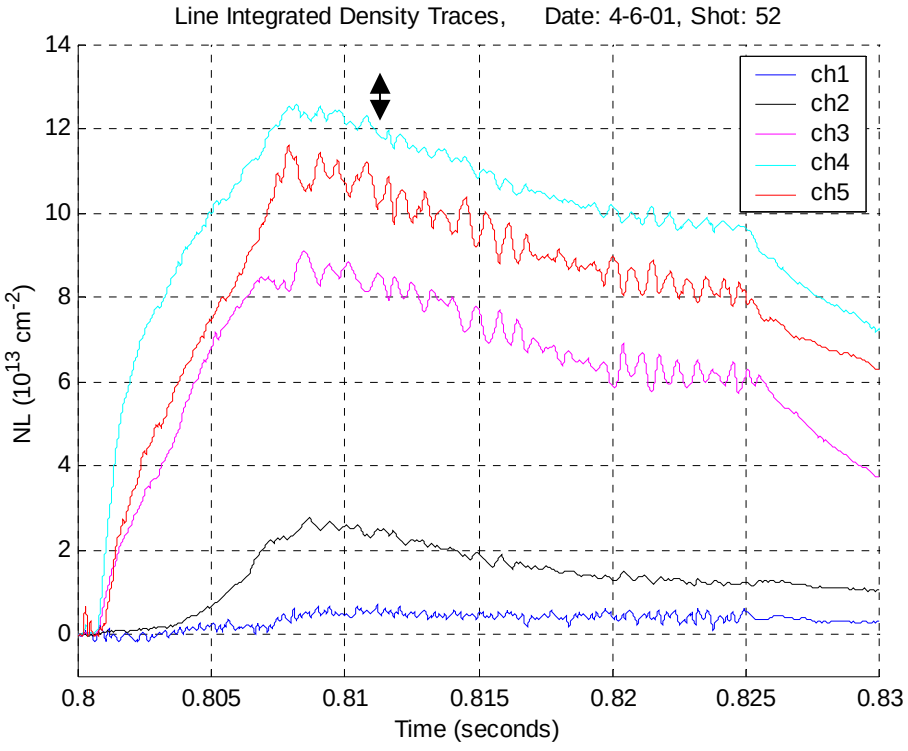




Central Resonance Location

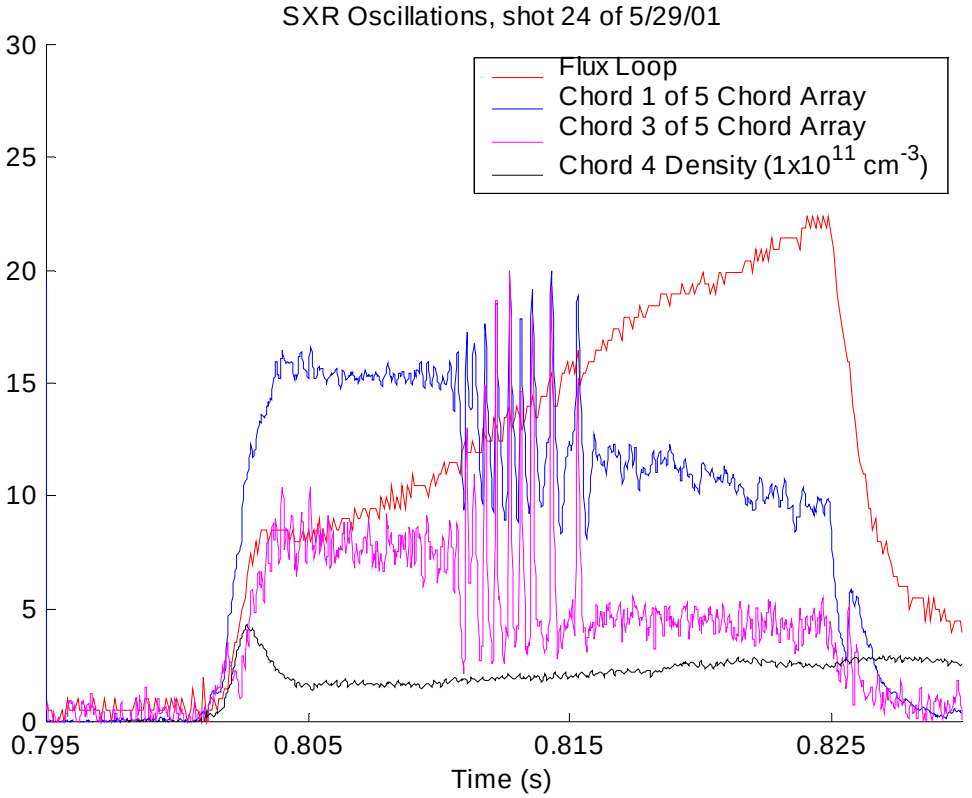
M=1 Oscillations in the Density Profile Can Sometimes be Observed in High Density Central Resonance QHS Discharges

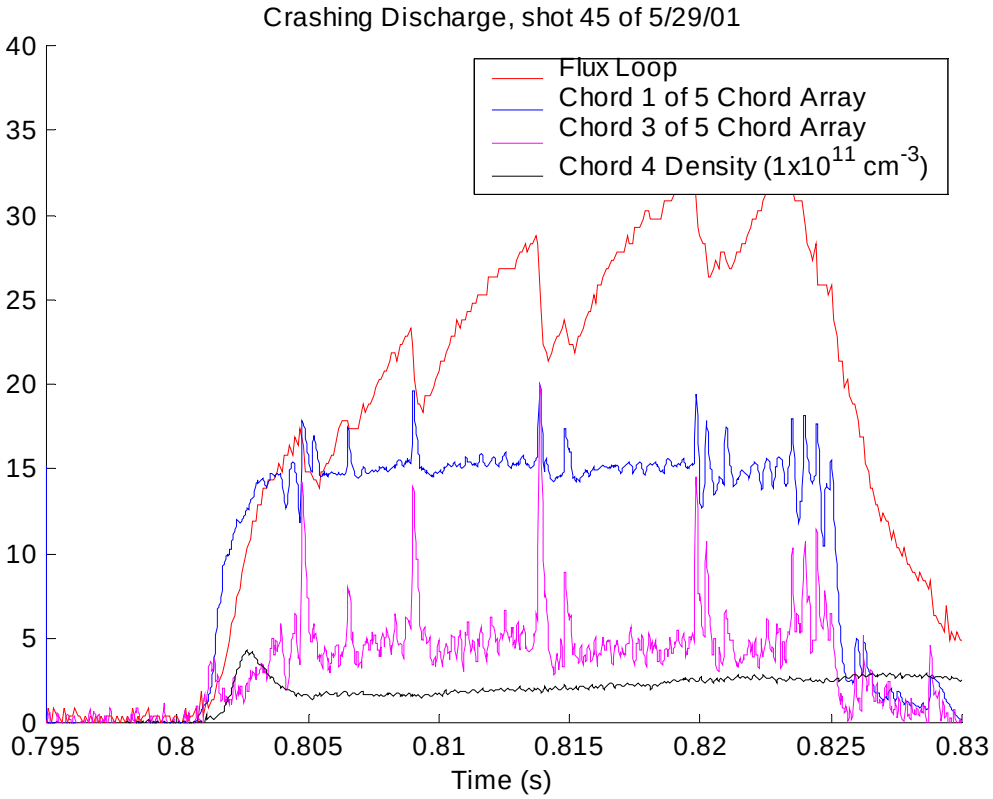




Stored Energy Crashes and SX Spikes Can Sometimes be Observed in Very Low Density Central Resonance QHS Discharges

(Stored energy crashes in mirror mode do not recover)





Summary

- **Large increases in the breakdown time over the QHS case have been observed with low-field resonance and broken symmetry**

- **The plasma stored energy decreases monotonically as the mirror spectral component is increased**

- **Scans of the stored energy with resonance position show symmetry about the magnetic axis for QHS, and a marked decrease on the low field side for the mirror mode**

- **Peaked density profiles have been observed for the QHS mode; profiles appear broader for the mirror mode**

These are the first experimental results that show quasi-helical symmetry improves particle confinement