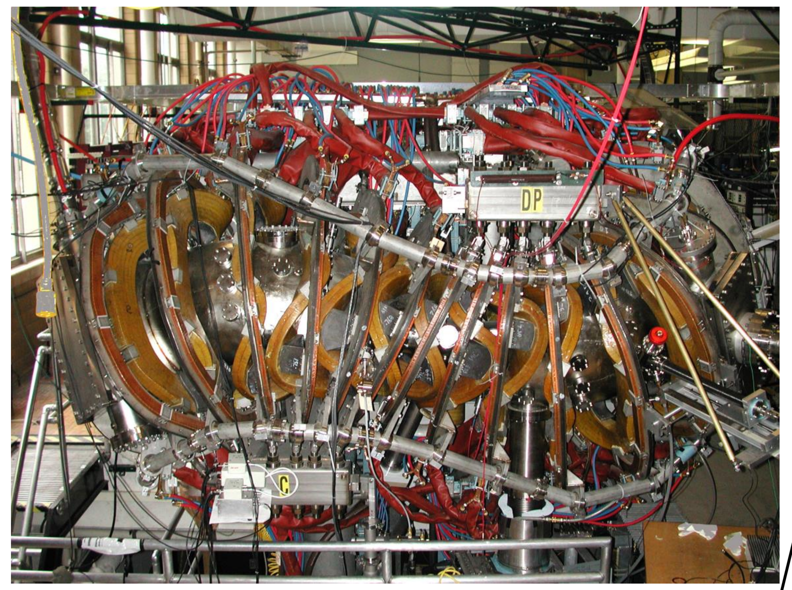
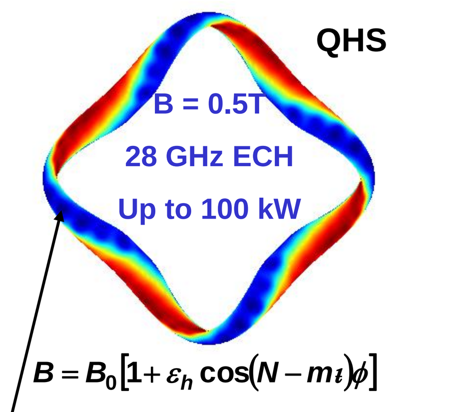
Overview of HSX Experimental Operations

D.T. Anderson, A. Abdou, A.F. Almagri, F.S.B. Anderson, D.L. Brower*, J.M. Canik, C. Deng*, S.P. Gerhardt, W. Guttenfelder, C.H. Lechte, K.M. Likin, J. Lu, S. Oh, J. Radder, V. Sakaguchi, J. Schmitt, J.N. Talmadge, K. Zhai, HSX Plasma Laboratory, U. of Wisconsin, Madison (* UCLA)

1. The HSX Experiment

HSX is the World's First Test of Quasi-Symmetry





$B = B_0[1+\varepsilon_h\cos(N-m\iota)\phi]$

- **HSX** has a helical axis of symmetry in |B| and a resulting predicted very low level of neoclassical transport.
- For experimental flexibility, the quasi-helical symmetry can be broken by adding a mirror field.

$B = B_0[1+\varepsilon_h\cos(N-m\iota)\phi+\varepsilon_M\cos(N\phi)]$

3. ASTRA Modeling of Electron Thermal Conductivity

•In addition to the neoclassical transport, we assume an anomalous electron thermal conductivity:

$$\chi_e = \chi_{e,neo} + \chi_{e,anom}$$

•Anomalous transport in HSX is modeled with an Alcator-like dependence (n_e in units of 10^{18} m^{-3}):

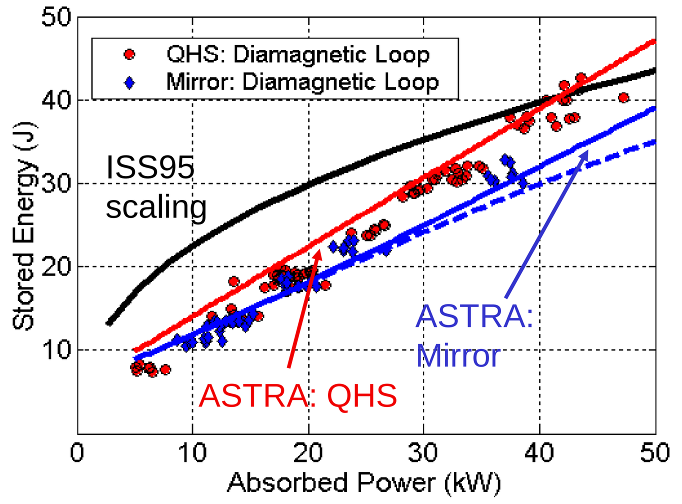
$$\chi_{e,anom} = \frac{10.35}{n_e}\ m^2/s$$

•If τ ~ n = nT/P, then:

T ~ P (independent of n) ; τ ~ n; W ~ nP;

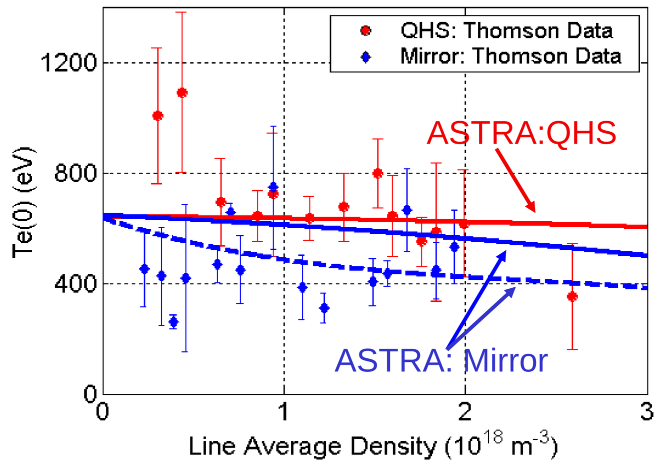
which is in reasonable agreement with experiment

Stored Energy Increases Linearly with Power



- Fixed density of 1.5 x 10^{18} m^{-3}.
- Difference in stored energy between QHS and Mirror reflects 15% difference in volume.
- W ~ P in agreement with χ ~ 1/n model.

Central T_e is Independent of Density



•QHS thermal conductivity is dominated by anomalous transport

• $T_e(0)$ in Mirror is calculated with self-consistent E_r (solid line) and E_r = 0 (dashed).

•Except for lowest densities, $T_e(0)$ from Thomson scattering is roughly independent of density,

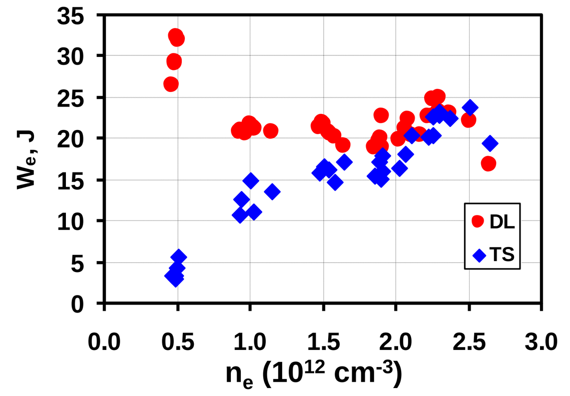
•Consistent with χ ~ 1/n model.

Stored Energy from Kinetic Data Increases Linearly with Density

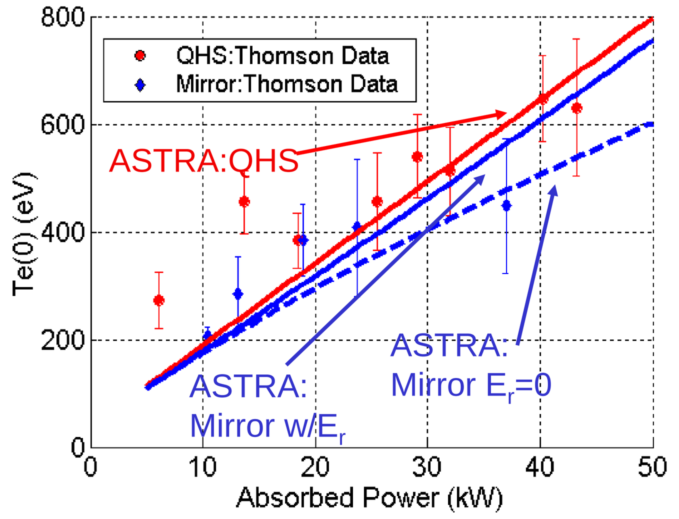
•Stored energy from the diamagnetic loop peaks at n_e~0.5*10^{12} cm^{-3} and then stays almost independent of density.

•Data from Thomson scattering shows a linear rise of W_e with density, in agreement with χ ~ 1/n model.

•Hard X-ray, ECE, and large ECRH absorption indicate super-thermal electrons exist at lower density



Central T_e Increases Linearly with Power



•Fixed density of 1.5 x 10^{18} m^{-3}.

•ASTRA calculation is consistent with Thomson measurements for QHS and Mirror

• T ~ P is supportive of χ ~ 1/n model.

•ASTRA simulations have been extended to higher density and power.

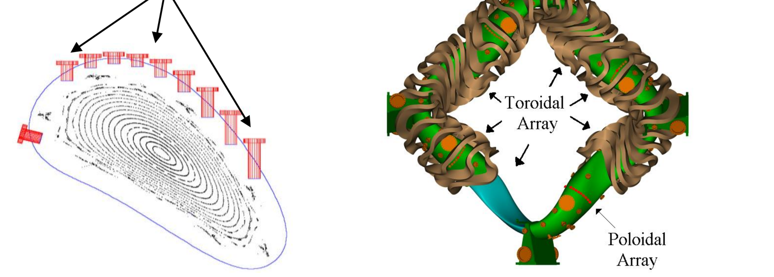
•These conditions are predicted to accentuate the neoclassical transport differences between QHS and Mirror configurations.

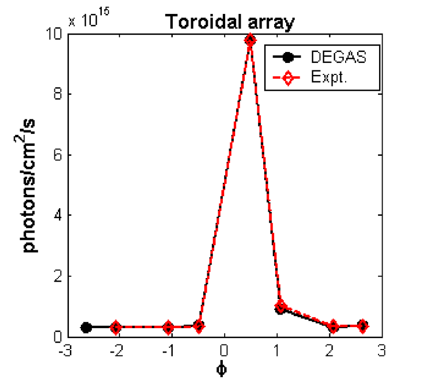
A Need to Measure Electric Field for Analysis

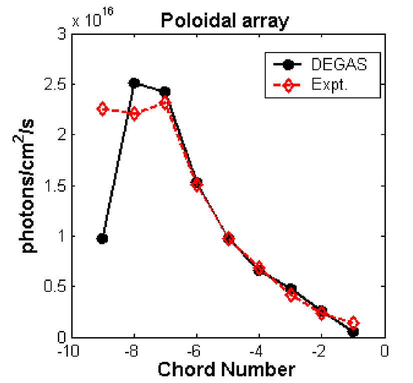
4. H_α Measurements and 3D DEGAS Modeling

A Comprehensive Set of H_α Detectors and 3D DEGAS Allow for Source Rate Modeling

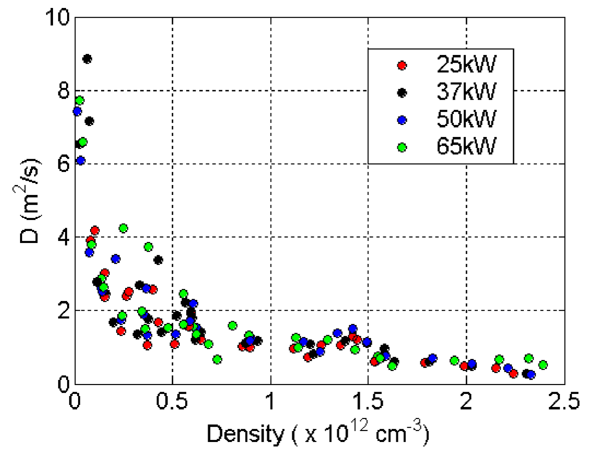
- Toroidal array: 7 detectors on magnetically equivalent ports
- Poloidal array: 9 detectors





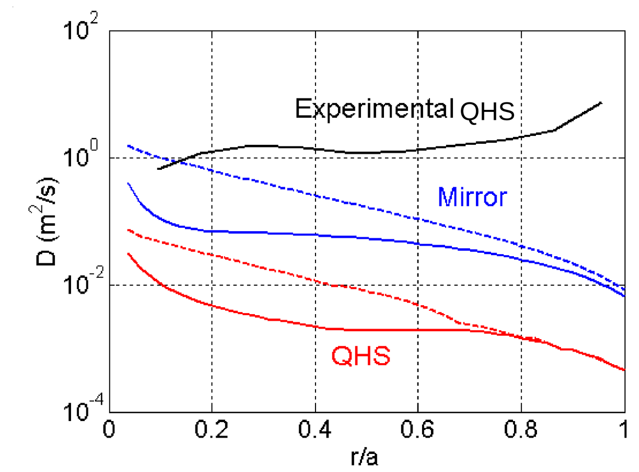


- H_α toroidal and poloidal data analyzed using 3D DEGAS code for 3 different line average densities and 4 different power levels.
- Experimental diffusivities inferred from modeled source rate and inverted interferometer density profiles
- D scales inversely with density and weakly with power:



$$D \sim \frac{P^{0.09}}{n^{0.6}}$$

Experimental Diffusion Coefficients are Larger than Neoclassical Predictions



- Neoclassical predictions using ASTRA.
  - With self-consistent ambipolar E_r (solid line)
  - With E_r = 0 (dashed line)

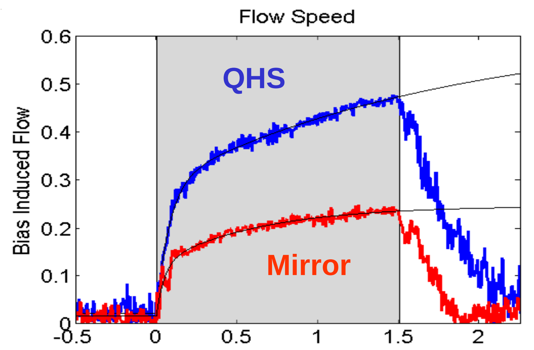
2. Symmetry Matters!

First evidence that parallel viscous damping is reduced with quasi-symmetry

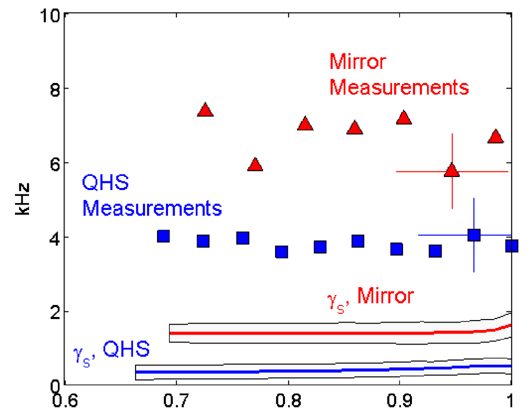
Plasma flow induced with a biased electrode

For equivalent drive QHS has slower rise and fall and reaches a higher flow velocity

Two time scales observed; slow corresponds to the damping in the direction of symmetry



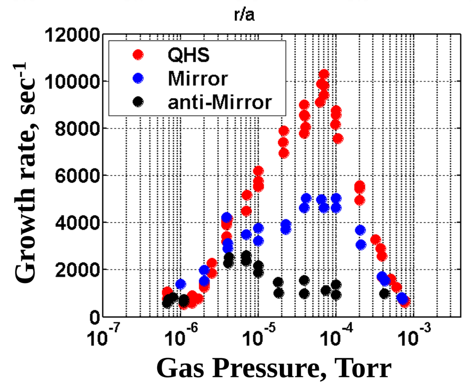
Although quasi-symmetry reduces neoclassical damping, there remains a residual anomalous damping mechanism similar to tokamaks

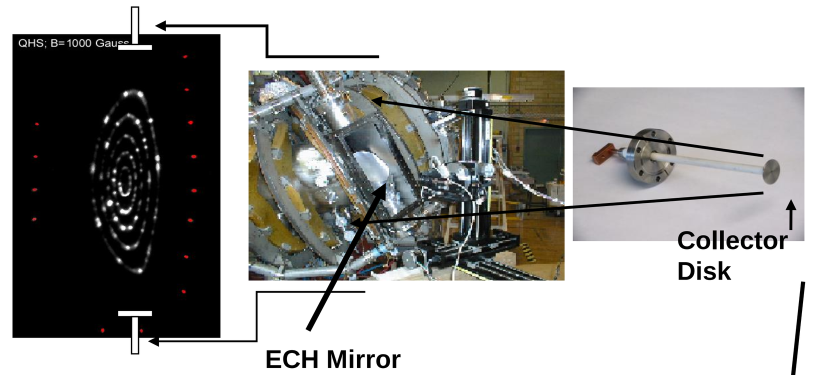


Poster by Gerhardt

Reduction of Direct Loss Orbits

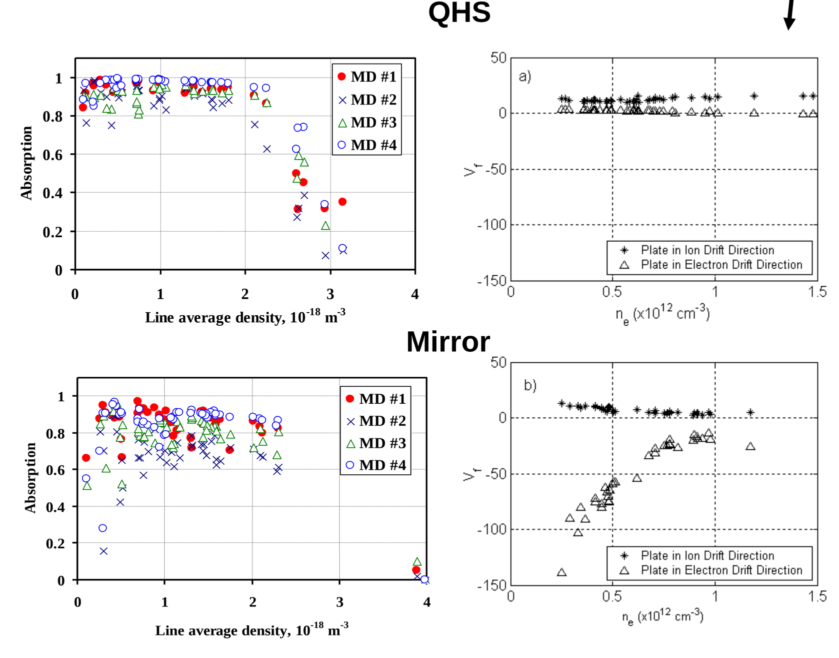
Faster breakdown, more rapid plasma density growth rate with QHS





Collector plates positioned at the top and bottom of the torus in the B X ∇B directions) at the ECH location

•Floating potential monitored as indicator of directed fluxes



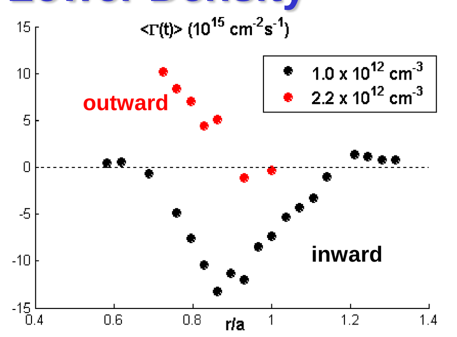
Significantly improved microwave absorption in QHS configuration

For mirror mode, plate in electron drift direction driven to large negative potential

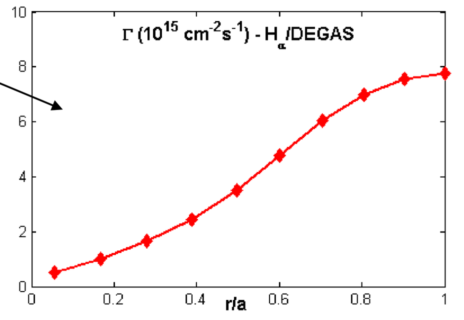
5. Edge Measurements

Measured Fluctuation-Induced Edge Transport is Inward at Lower Density

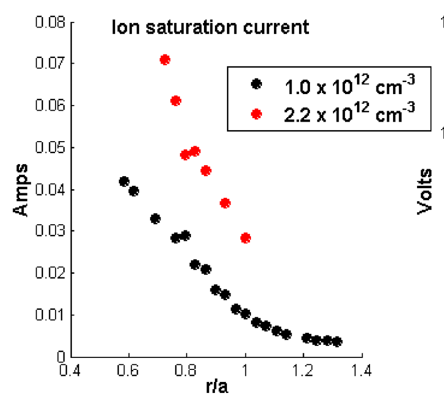
- Change in transport direction has been observed before in helical devices
  - H-1, CHS - large E_r shear (Shats et al., 2000)
  - TJ-II – rational surfaces (Pedrosa et al., 2001)

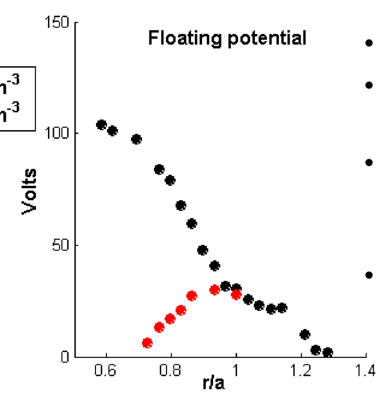


- Outward transport comparable to H_α/DEGAS (10^{15} cm^{-2}s^{-1}), but not the profile shape
  - Discrepancy has been noted by many experiments (LaBombard, 2002)



Mean Φ_{float} Profiles Change Significantly with Density





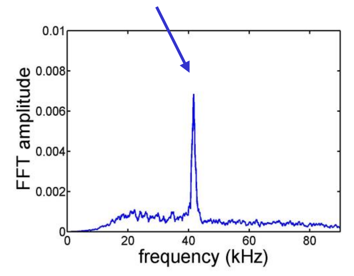
- Similar edge I_{sat} profiles
- Drastic change in floating potential
- Inferred E_r changes from positive to negative inside r/a ≤ 1.0
- Does not take into account T_e profile

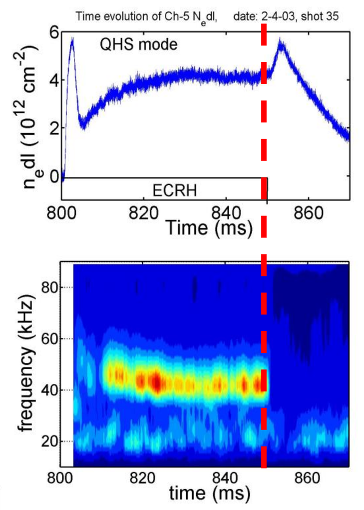
6. MHD

Possible n=1,m=1 GAE mode observed only in QHS discharges

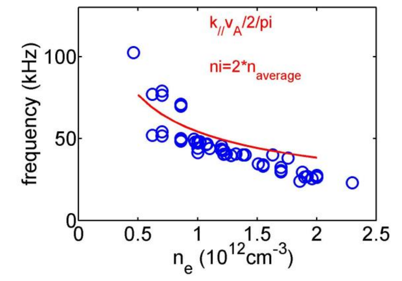
(STELGAP code D. Spong, ORNL)

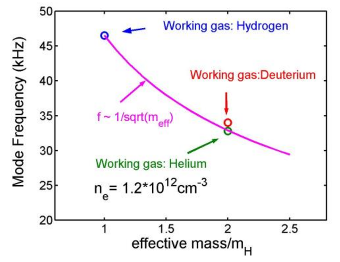
Mode observed only in QHS plasmas





See Poster by Deng





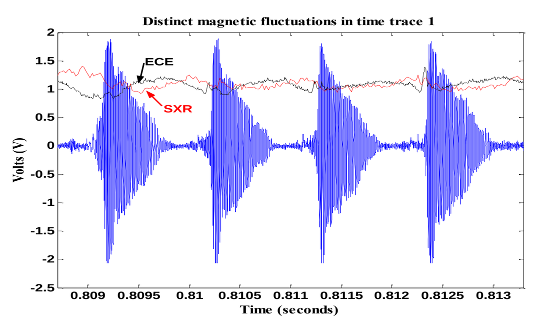
$v_A = B/\sqrt{4\pi n_i m_i}$

Scaling consistent with Alfvenic modes

Density fluctuations and magnetic signals coherent

•"Fish-bone" like discharges are observed in low density QHS operation

•Crashes in the flux-loop stored energy during these discharges correlated with SXR and ECE and magnetic fluctuations.



7. Concluding Remarks & Future Directions

Benefits of quasi-symmetry have been observed

•Reduced flow damping in direction of symmetry

•Reduced direct loss orbits

Under present operating conditions, anomalous transport is dominant over neoclassical in thermal plasmas

•Need to reduce anomalous transport relative to neoclassical

➡ Increase density, power, and magnetic field

Increase operating field to B=1.0 T

•O-mode operation at 1 T gives factor of 2 in n_e and reduction of tail population

•Need to modify M/G configuration and controllers for 1 T operation

•Improved wall conditioning for higher density and power

Implement a 2nd 28 GHz gyrotron

•Available power increased from 200 to 400 kW

•Modulation of one tube to give electron thermal conductivity from heat wave propagation in addition to power balance

•X-B mode conversion from high field launch to achieve increased densities (EBW)

•Our beam supply can drive three tubes

Perform low-power testing to evaluate high-field side two-ion hybrid resonance mode-conversion heating

•5 kW studies using in-house sources for loading/feasibility

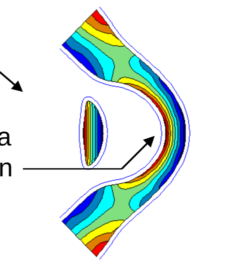
•More flexibility in operating magnetic field; no tails

•Ability to operate up to high densities ➡ β studies

•Some ability to adjust relative energy flow to electrons/ions

•Ability to deposit energy near plasma center

Examine mode structures and dependencies of observed MHD activity



•Internal flux loop array

•Expand SXR system for tomography

•Increased β with RF to investigate ballooning mode limit (0.7% theoretical limit for QHS configuration)

Identify characteristics of anomalous transport in quasi-symmetric configurations through diagnostic improvements

•ECEI for temperature fluctuations

•Reflectometry for density fluctuations

Measure the radial electric field to determine the level of neoclassical transport with and without symmetry