Computational Study of Parallel Flows in High Density Plasmas in HSX

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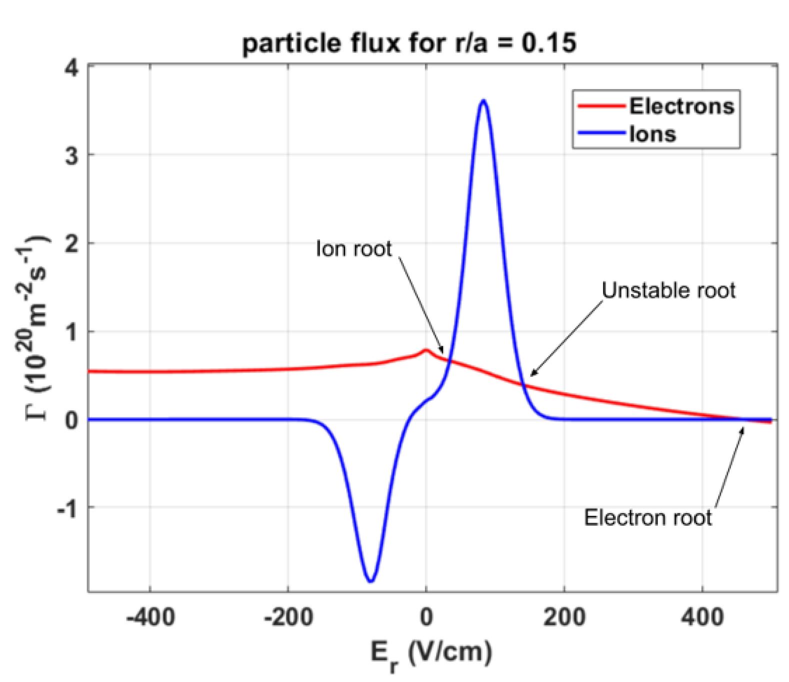
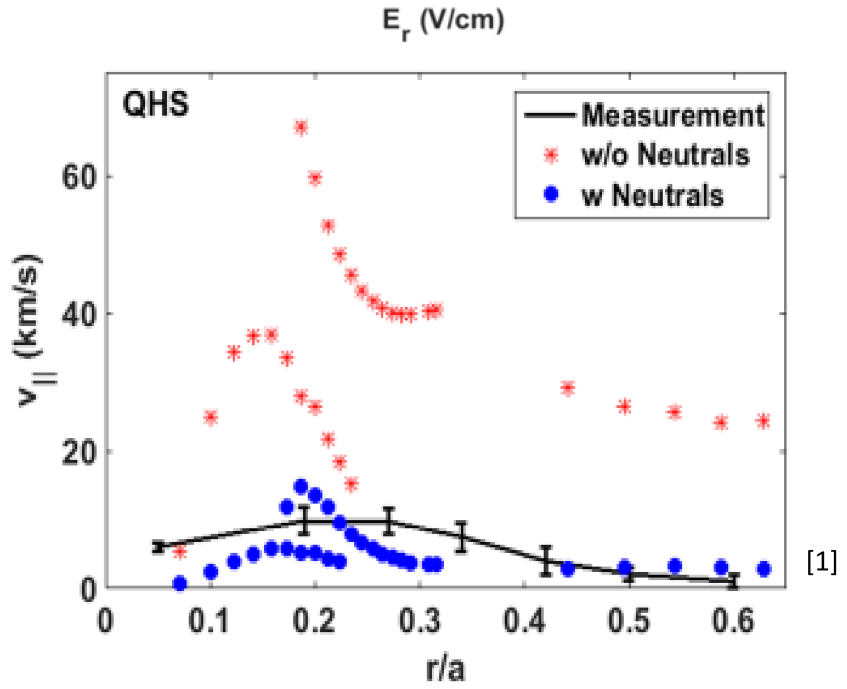
Motivation for Flows

- **ExB** shear flows can reduce turbulent behavior of plasma and improve confinement. Large flow shear can also stabilize MHD
- Non-symmetric stellarators have large parallel viscosity making flows strongly damped
- Tokamaks and perfect quasisymmetric stellarators have zero parallel viscosity in the direction of symmetry and therefore no viscous damping in that direction
- Quasi-helically symmetric (QHS) stellarators, such as HSX, have potential to have large **ExB** shear flow but has not yet been observed
- The PENTA code is used to study flows in HSX

HSX Flows and PENTA

- The PENTA code solves momentum balance equations for flows and radial electric fields
- Experimentally measured flows in HSX are smaller than flows calculated by PENTA in the QHS configuration
- Dobbins added neutral damping to PENTA, and PENTA flow calculations moved closer to experimental measurements [1]
- Neutral damping is calculated via the Cornelius model: $v_{in} \approx 10^{-8} n_n T_i^{0.318}$
- PENTA modeling and measurements of $\mathbf{v}_{||}$ generally agree in the outer regions of the plasma

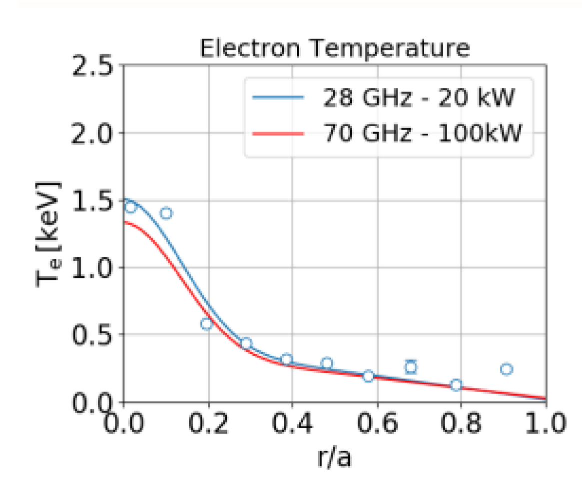


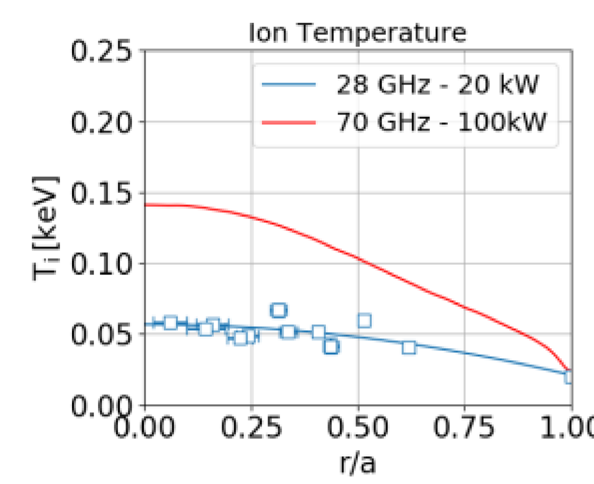


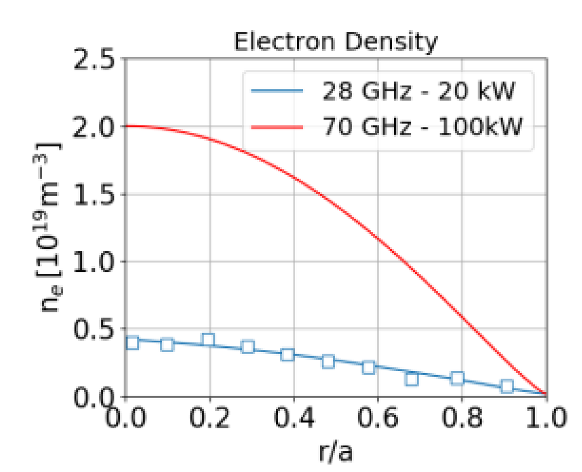
- In the QHS configuration, the viscous damping rate is ~80 [s^{-1}] whereas the neutral damping rate is ~500 [s^{-1}] [3]
- In order to reduce damping in the direction of symmetry, neutral density must decrease by an order of magnitude
- Neutrals play an important role in damping of parallel flows

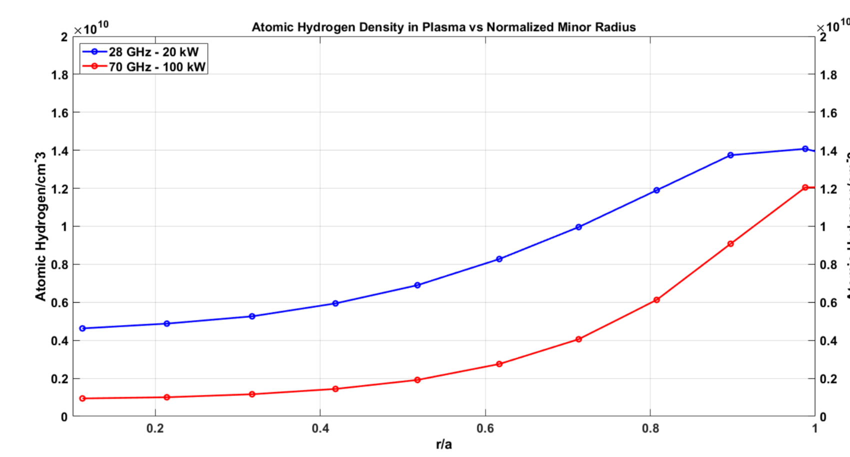
HSX Upgrade

- Using ISS04 scaling, HSX upgrade is expected to allow a 3x increase in ion and electron densities. A 70 GHz gyrotron allows for a 1.25 T magnetic field and higher ion temperature. To date, ECRH plasmas have used a 28 GHz gyrotron at 1 T magnetic field
- DEGAS calculations show atomic hydrogen neutral density is expected to decrease by a factor of 5



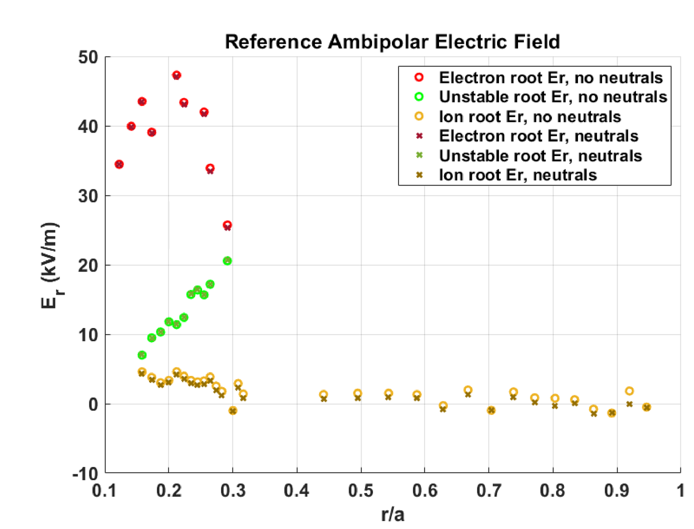


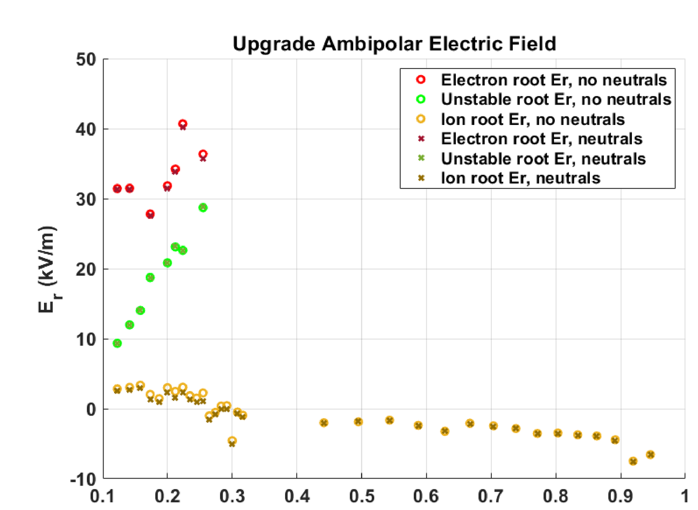


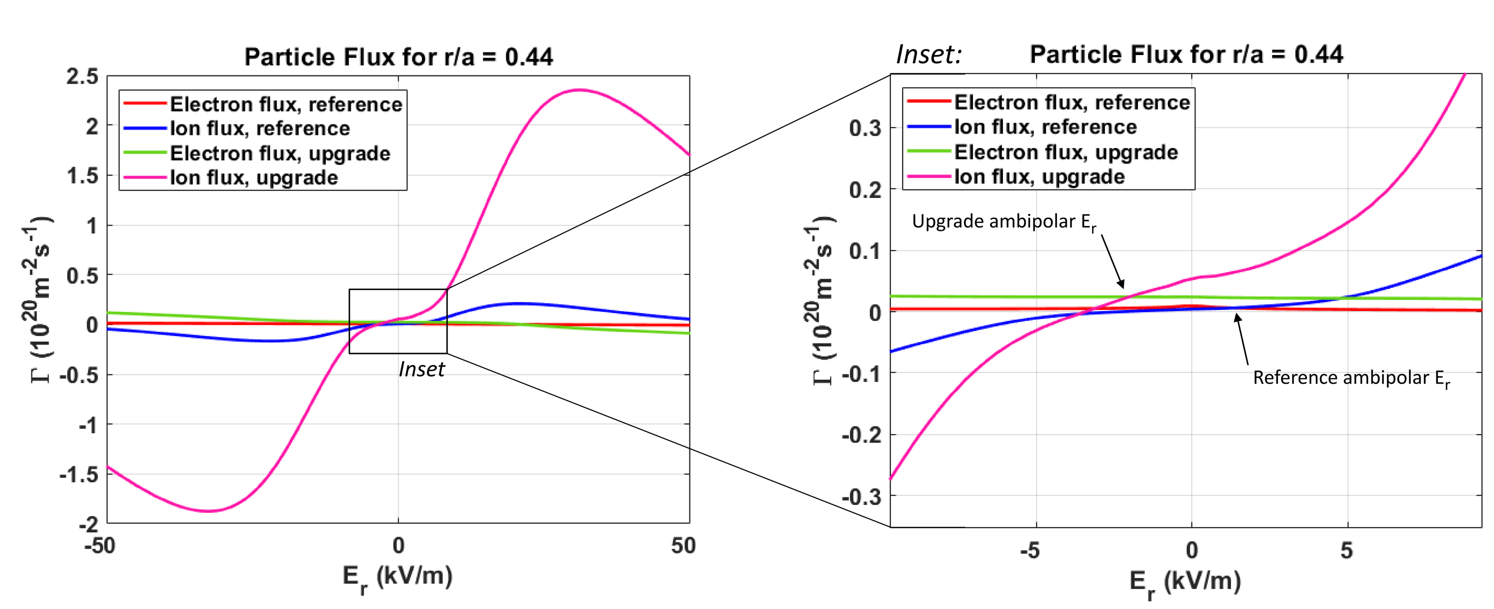


Finding Ambipolar Electric Field

- The ambipolar electric field can be found by equating the ion and electron fluxes
- Calculations show ion root appearing in the core with the upgrade profile
- Higher ion temperatures in the upgrade simulations show ion flux dominating over the electron flux
- Higher ion flux shifts the ambipolar electric field lower, and in the case of the HSX upgrade, shifts the ambipolar electric field to a negative value at r/a=0.44

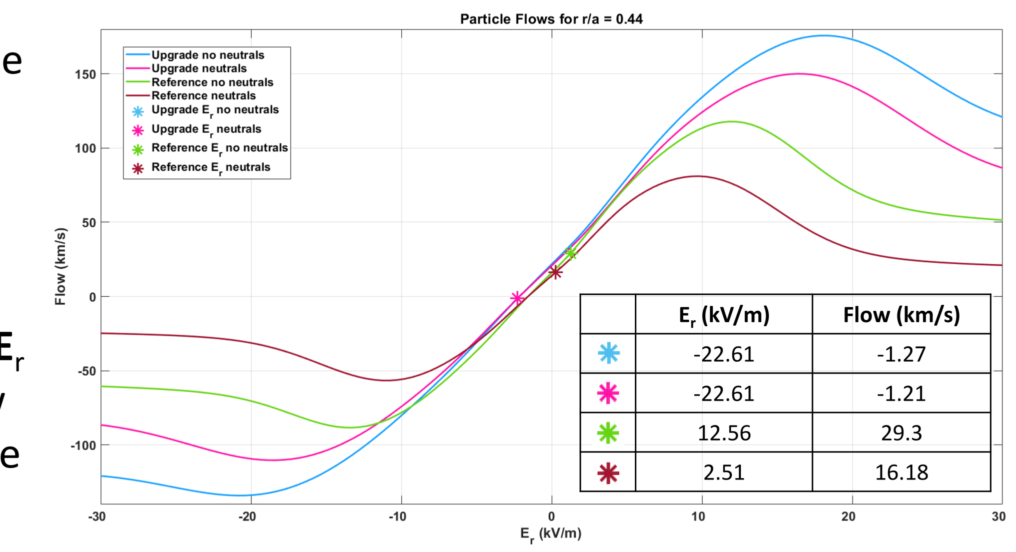


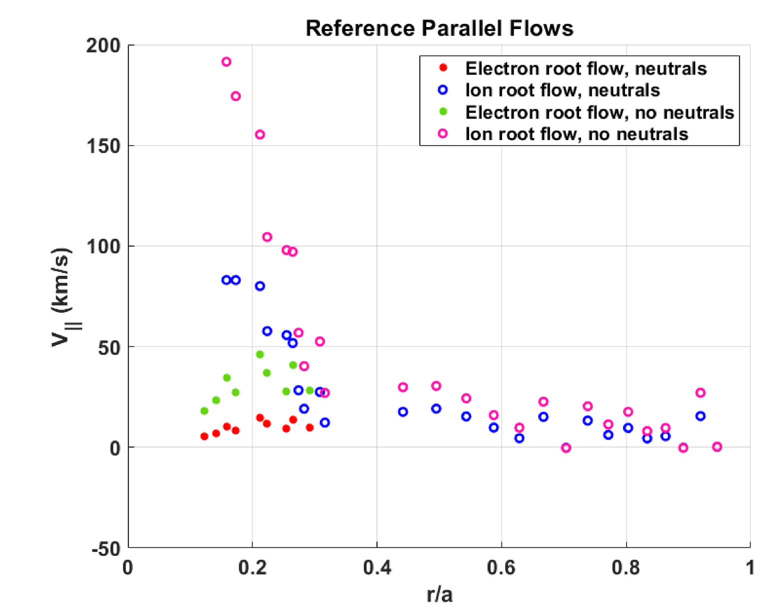


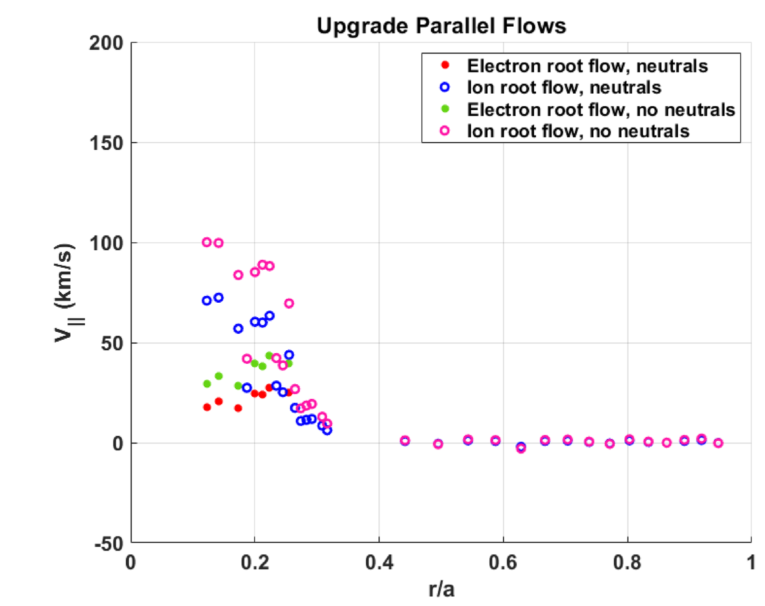


Flows After Upgrade

- Neutral damping expected to decrease in the upgrade, so peak parallel flow is expected to increase
- At r/a=0.44, peak calculated parallel flow compared to the reference case increases
- Taking into account the change in $\mathbf{E}_r$ for r/a=0.44, upgrade parallel flow is in the opposite direction, and the magnitude is smaller than the reference case







- Higher plasma density, higher ion temperature, and a more negative radial electric field from the upgrade profile shows lower overall calculated parallel flows for the upgrade
- Using upgrade profiles, neutral damping is expected to decrease significantly in the ion root flow, especially at r/a>0.4

Plans to Measure $v_{||}$ and E_r

- A 30kV, 3ms, 4A hydrogen diagnostic neutral beam (DNB) is injected radially into the plasma, and charge exchange recombination spectroscopy (CHERS) is used to measure total flows
- Inboard and outboard measurements of the total flows are taken and used along with the geometrical factor (h) to calculate bootstrap current which is calculated by PENTA [2]

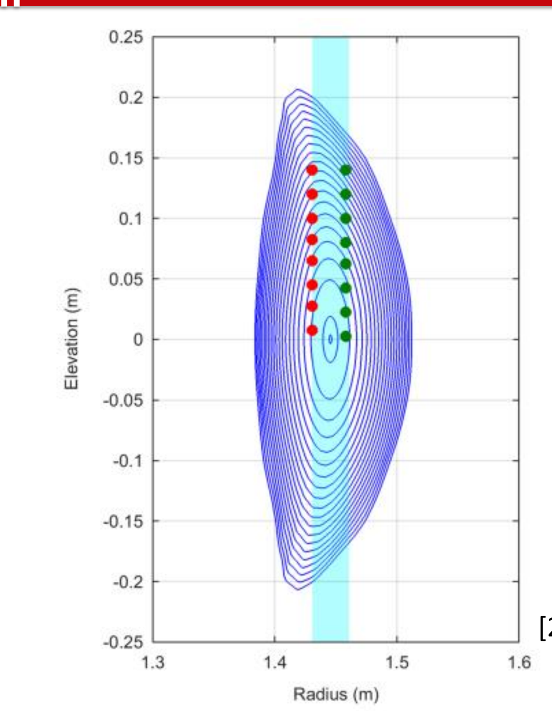
$$v_{||,i} = v_{BS} + v_{PS} \qquad v_{PS} = \left(\frac{d\phi}{d\psi} + \frac{1}{en_i Z_i}\frac{dP_i}{d\psi}\right) hB$$

(small)

- Cold ions and a relatively flat ion temperature profile makes the pressure gradient small compared to the electric field in the Pfirsch-Schlüter flow

$$\frac{v_{||,i(IN)} - v_{BS}}{(hB)_{(IN)}} = \frac{v_{||,i(OUT)} - v_{BS}}{(hB)_{(OUT)}}$$

- Radial electric field can be found through the Pfirsch-Schlüter flow



Conclusion

- A negative shift of $\mathbf{E}_r$ is expected in the upgrade
- There will be less damping from ion-neutral collisions in the upgrade
- Flows are expected to have a smaller magnitude and move in the opposite direction

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References

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