Initial Flow Velocity Measurements From ChERS on HSX

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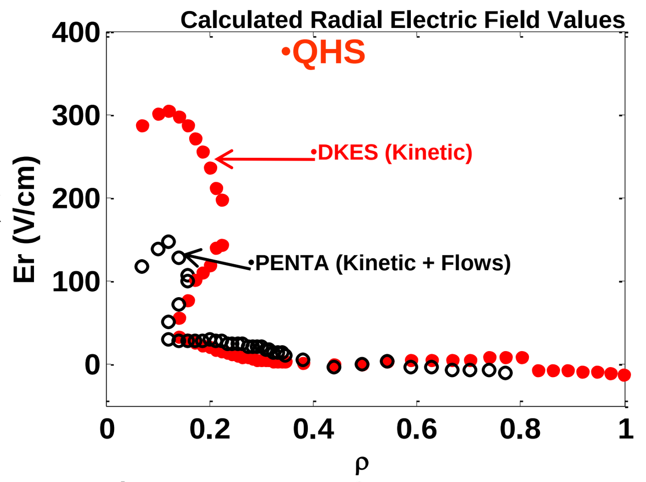
Overview

- ChERS (Charge Exchange Recombination Spectroscopy) is used on HSX to measure impurity ion temperatures, densities, and flow velocities so that the radial electric field can be inferred
  - 30keV Neutral H Beam for Charge Exchange with Carbon
  - Two .75m Spectrometers to measure Doppler shifting and spreading of the light emitted by the excited ions
- Large parallel flows have been measured
- Parallel flow goes in the direction of the magnetic field because of the dominant helical ripple in the magnetic field strength
- Impurity Charge States have been calculated using Coronal Balance:
  - A significant population of C+6 exists in the core of HSX allowing 529.06nm C+5 charge exchange line to be used
  - Lower C+6 density predicted and measured near the edge increase error in edge velocity measurements

Why It's Important

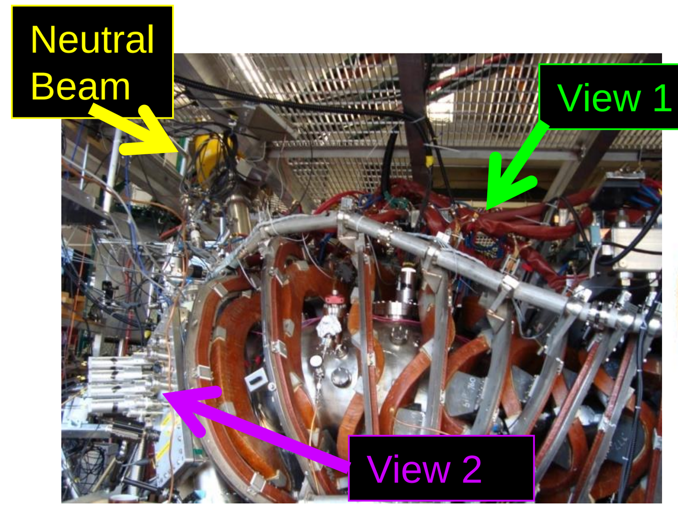
Verifying Predictions of Radial Electric Field

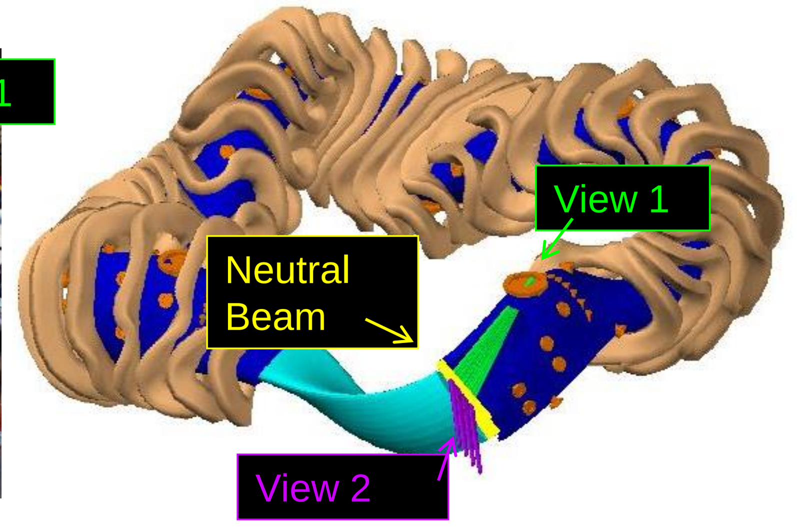
- DKES has been used to successfully predict the radial electric field in other stellarators
- DKES neglects parallel flows and momentum conservation
- Parallel flow dominates the flow in HSX
- PENTA code includes flow effects and momentum conservation
- Radial electric field can reduce both neoclassical and turbulent transport (through shear suppression)
- For more on this see Jeremy Lore's talk Thursday Morning

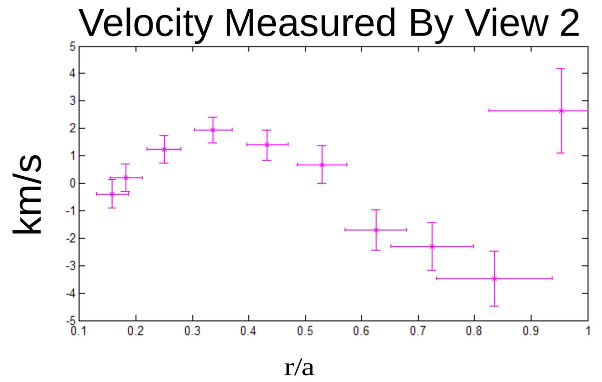


Plot courtesy of Jeremy Lore

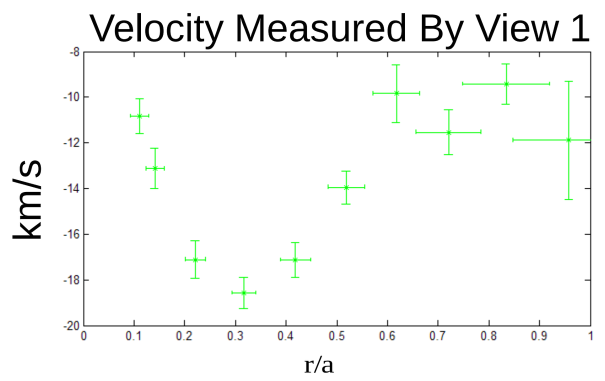
Large Intrinsic Parallel Flows Measured







- The velocity seen by view 2 is relatively small
- The views are almost normal to $\vec{B}$
- The positive velocity in the core is indicative of positive radial electric field

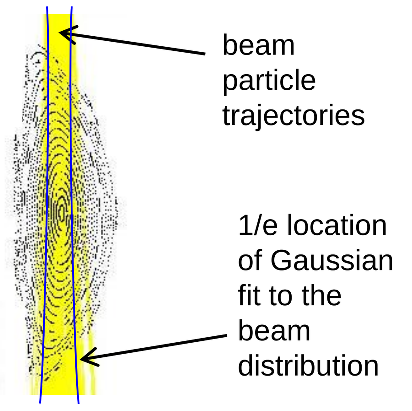


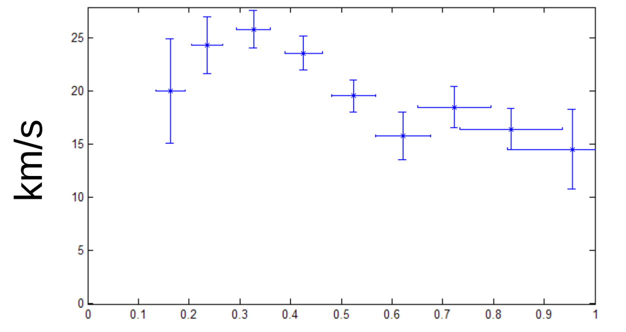
- The velocity seen by view 1 about 10 times larger than that seen by view 2
- The negative velocity indicates a flow in the direction of $\vec{B}$
- This flow direction is consistent with the predicted viscosity driven flow (opposite that of a tokamak)

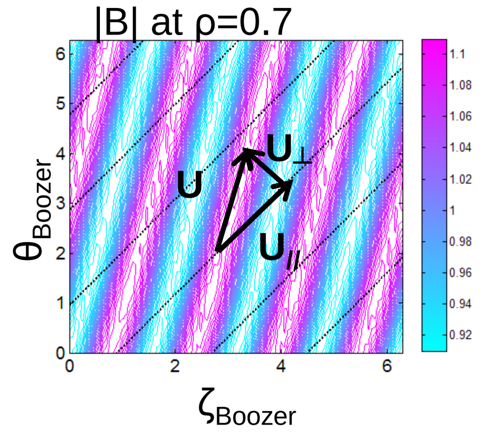
•The parallel flow velocity can be found using the geometry of the views and the magnetic field structure

•The magnetic field structure is well described by vacuum case

•The relatively broad extent of the neutral beam and the strong shaping of the plasma complicates the measurements of poloidal flows near the axis







•The total flow is in the direction of symmetry in magnetic field strength on average

•In the region where ChERS measurements are taken the angle between the symmetry direction and the magnetic field is only about 5°

$$\vec{V}=\frac{1}{ZeB}\left(-\frac{1}{n}\frac{\partial p}{\partial s}+E_s\right)\frac{\nabla\Psi}{|\nabla\Psi|}\times\frac{\vec{B}}{|\vec{B}|}+\left[\frac{\langle u_{//}B\rangle}{\langle B^2\rangle}+\frac{1}{ZeB}\left(-\frac{1}{n}\frac{\partial p}{\partial s}+E_s\right)U\right]\frac{\vec{B}}{|\vec{B}|}$$

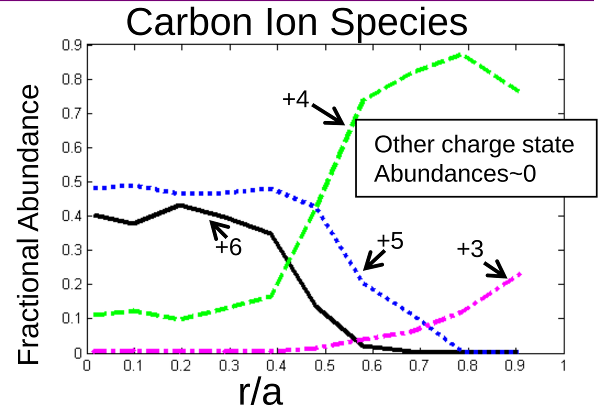
Ion Species

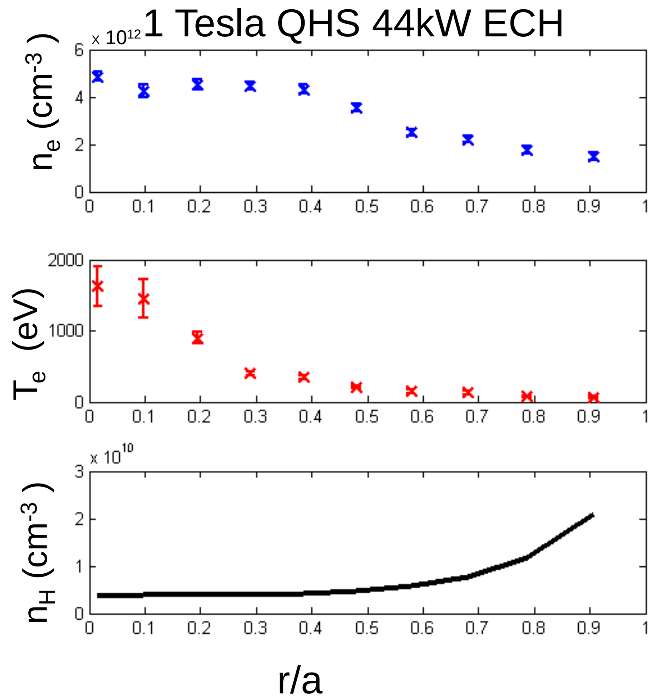
•ADAS (Atomic Data Analysis Structure) [2] is used to calculate the equilibrium ion species fractions

•These calculations include ionization (S_{CD}) and recombination (α_{CD}) and charge exchange with neutral hydrogen (C_{CD})

•These calculations do not include diffusion

•Calculations show steady state is reached in a few milliseconds





- N_e and T_e are measured using Thomson Scattering
- N_H is calculated using the DEGAS neutral gas modeling code and scaled to match Hα detector measurements

•The ion species evolution is described by:

$$\frac{d}{dt}N^{(z)}=N_eS_{CD}^{(z-1\to z)}N^{(z-1)}-\left(N_eS_{CD}^{(z\to z+1)}+N_e\alpha_{CD}^{(z\to z-1)}+N_HC_{CD}^{(z\to z-1)}\right)N^{(z)}+N_e\alpha_{CD}^{(z+1\to z)}N^{(z+1)}+N_HC_{CD}^{(z+1\to z)}N^{(z+1)}$$

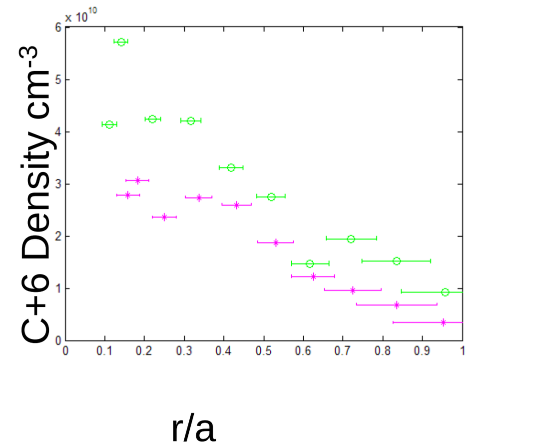
Density Measurements

•The fiber/spectrometer/ccd system is absolutely calibrated using an integrating sphere

•The etendue of the optics is known

•The beam density is calculated using a Monte-Carlo simulation

•The effective emmision coefficient is taken from ADAS [2]

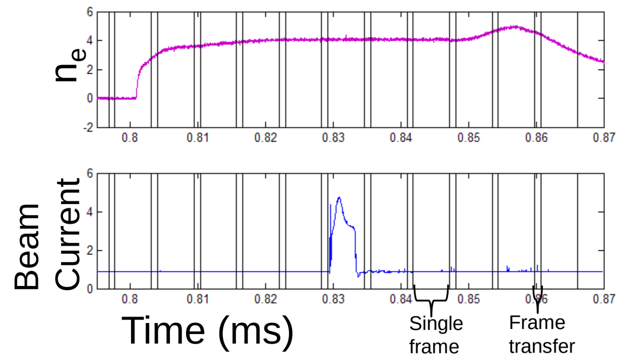


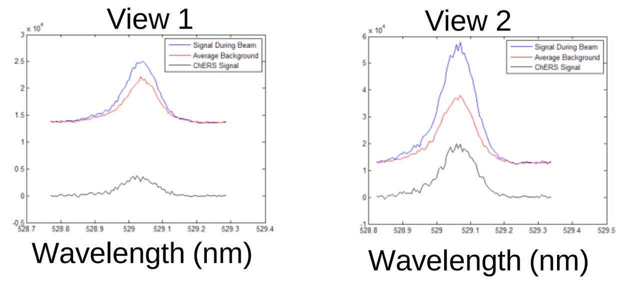
- C+6 density as measured by ChERS decreases towards the edge as predicted
- A significant fraction of carbon ions are not fully ionized with the plasma as a result of neutral hydrogen density throughout HSX

Experimental Setup and Procedure

- 10 "Toroidal" Views and10 opposing "Poloidal" Views are aimed at the center of the beam
- Two .75m Czerny-Turner imaging spectrometer/ccd systems are employed
- Collimating optics with a 2cm diameter and an etendue of about 0.14 are used
- 12 fibers are installed on each spectrometer
- The relative position of all the fiber images is measured by illuminating all the fibers with a Ne calibration lamp
- Spectral drift of the position of calibration lines has been observed over the course of a day
- Spectral drift is corrected for by illuminating 2 fibers in each spectrometer and correcting the drift of all the fibers using the observed drift of the calibration lines

Background Subtraction and Signal Levels



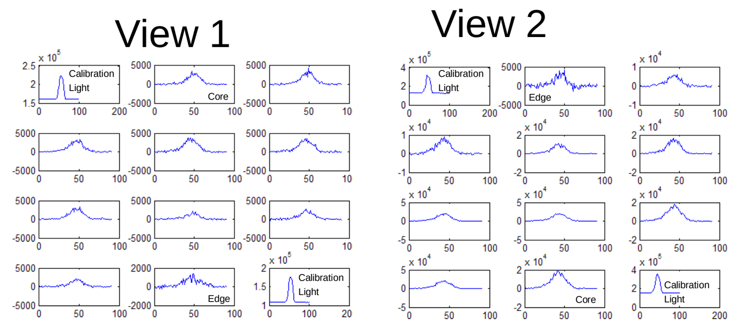


•The CCD images each frame for about 5ms

•The neutral beam fires for 3ms

•Averaging the light from the frames taken before and after the beam fired gives the background signal

•Plasma shots HSX are stable and reproducible so several shots are used to create each image



References

1) S. P. Gerhardt, "Measurements and Modeling of the Plasma Response to Electrode Biasing in the HSX Stellarator," 2004.

2) H. P. Summers, The ADAS User Manual, version 2.6, 2004 http://adas.phys.strath.ac.uk

3) D. Heifetz, D. Post, M. Petravic, J. Weisheit and G. Bateman, "DEGAS," *J. Comp. Physics,* pp. 309, 1982

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