



Determining the Radial Electric Field in HSX Using Impurity Ion Velocity Measurements from CHERS

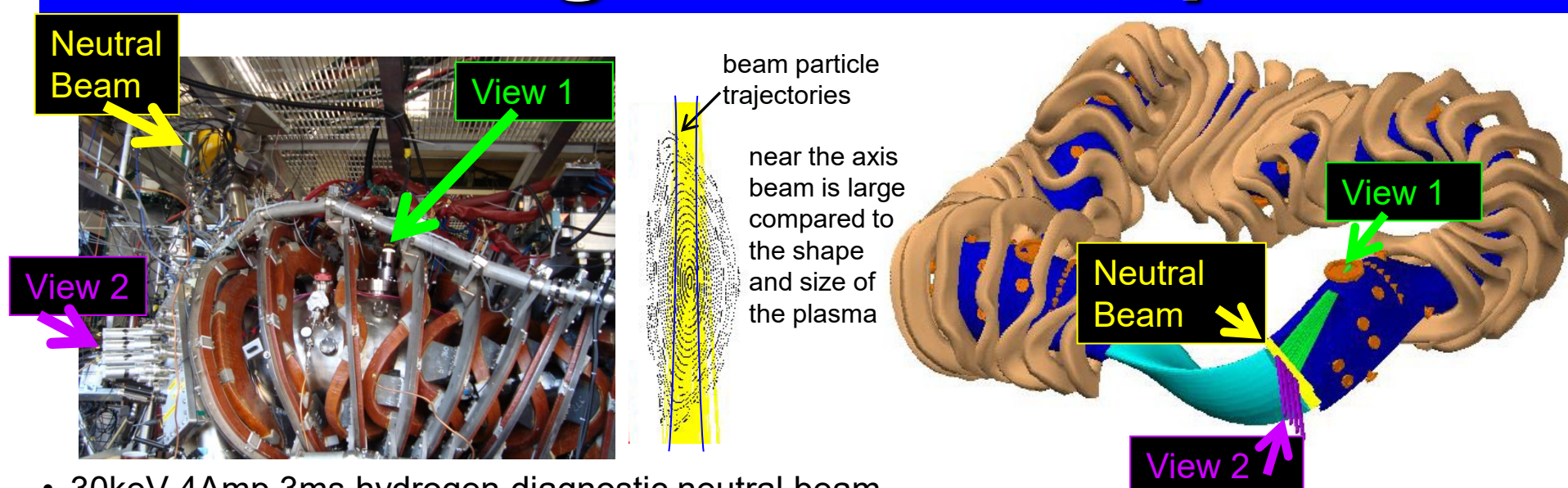
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Overview

- CHERS has been used to measure C⁶⁺flow velocity, temperature and density
- The intrinsic flow moves in the direction of symmetry throughout the entire HSX plasma volume in the quasi-helically symmetric configuration
- Parallel flow and radial electric field measurements agree reasonably well with neoclassical predictions in the outer half of the plasma where only the ion root is predicted
- Measurements in the inner half of the plasma, where multiple solutions to the ambipolarity equation exist, are complicated by the relatively large size of the beam/view intersection volumes

Diagnostic Setup



- 30keV 4Amp 3ms hydrogen diagnostic neutral beam
- Two 0.75m Czerny-Turner spectrometers with EMCCDs
- 10 view pairs containing a “toroidal” and “poloidal” view which intersect in the center of the beam
- Background light is subtracted using spectral images taken before and after the beam fires

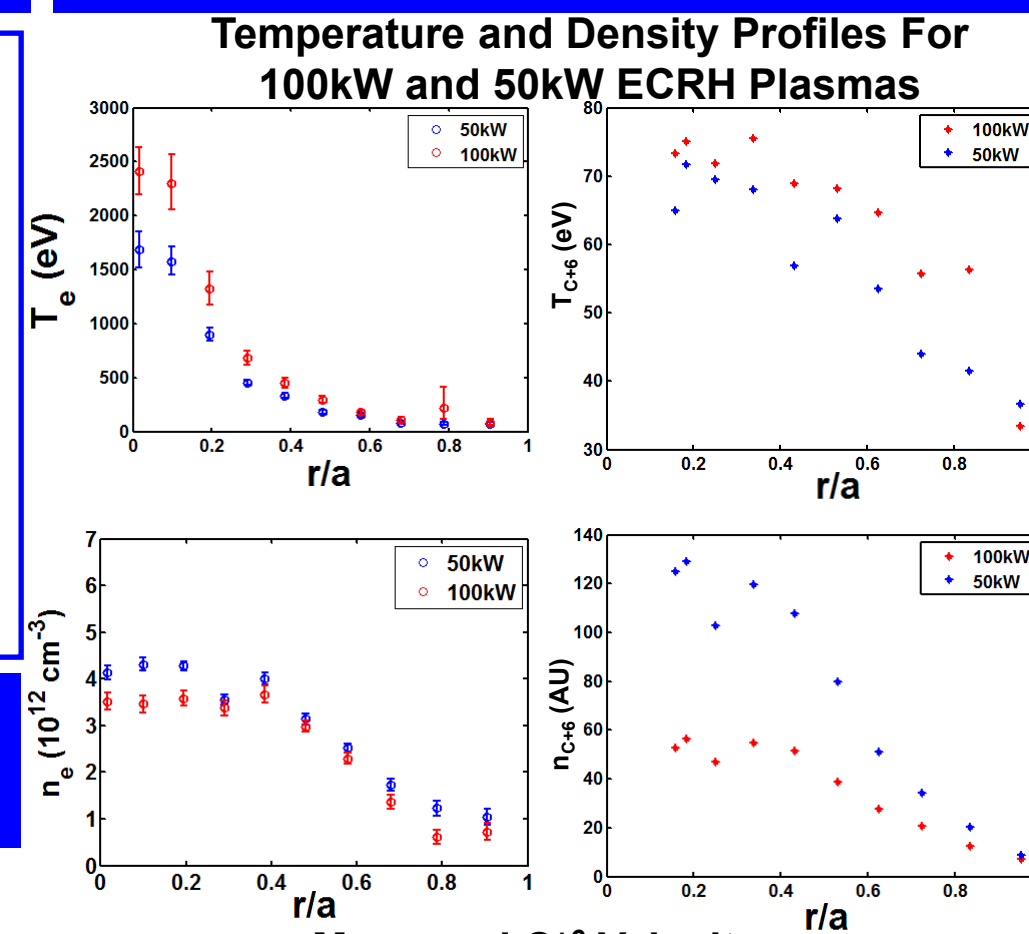
Spectral Correction Using a Ne Calibration Lamp and Field Flipping

- A spectral drift throughout the day on the order of 0.1Å is corrected using a Ne calibration lamp which illuminates 2 fibers connected to each spectrometer
- Since changes in excitation can change the ratios of the different fine structure components of the emission line it is difficult to know the exact value of the unshifted wavelength
- By reversing the direction of the magnetic field all components of the velocity should change direction

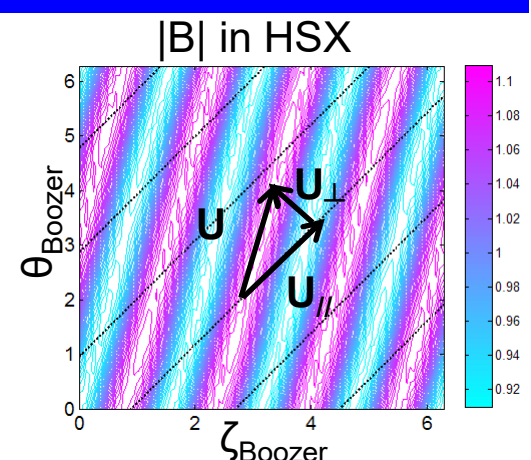
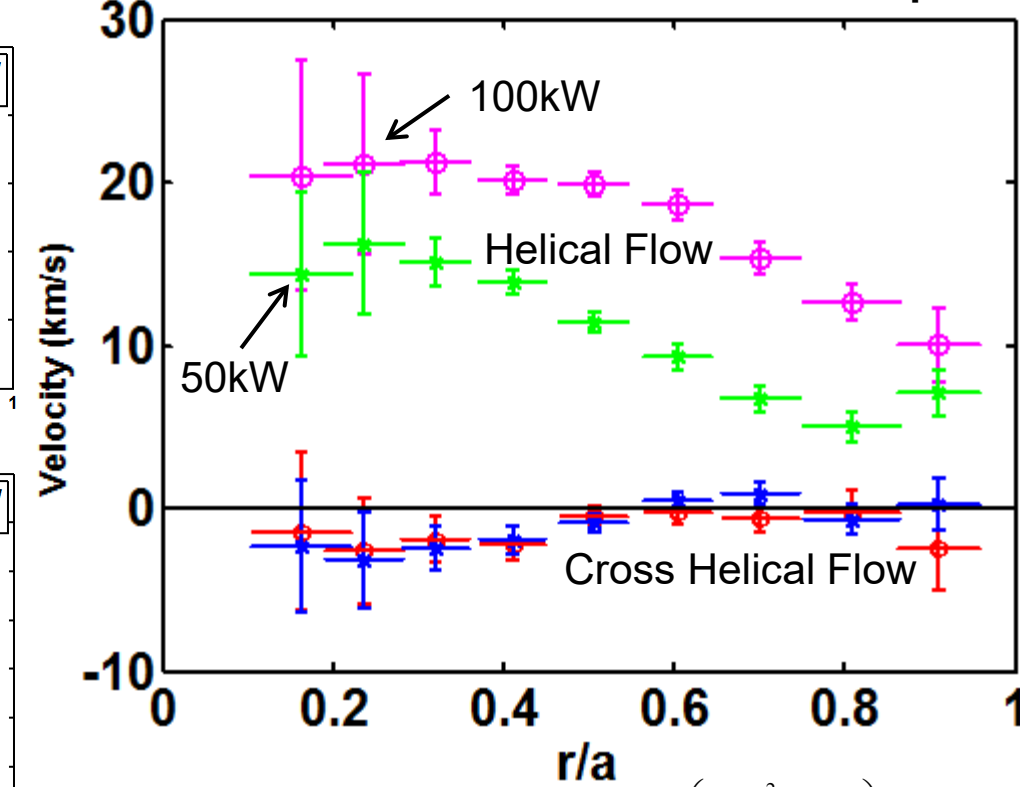
$$\vec{V} = \frac{1}{ZeB} \left(-\frac{1}{n} \frac{\partial p}{\partial s} + E_s \right) \nabla_s \times \frac{\vec{B}}{B} + \left[\frac{\langle u_{||} B \rangle}{\langle B^2 \rangle} + \frac{1}{ZeB} \left(-\frac{1}{n} \frac{\partial p}{\partial s} + E_s \right) U \right] \frac{\vec{B}}{B}$$

- By changing the field direction between sets of shots the velocity can be measured without having to know the exact value of the unshifted wavelength and the Doppler shift is effectively doubled
- This method will also remove any errors in the spectral alignment of the spectrometers

Flows in a Quasi-Symmetric Stellarator



Helical and Cross Helical C⁶⁺ Flow Components

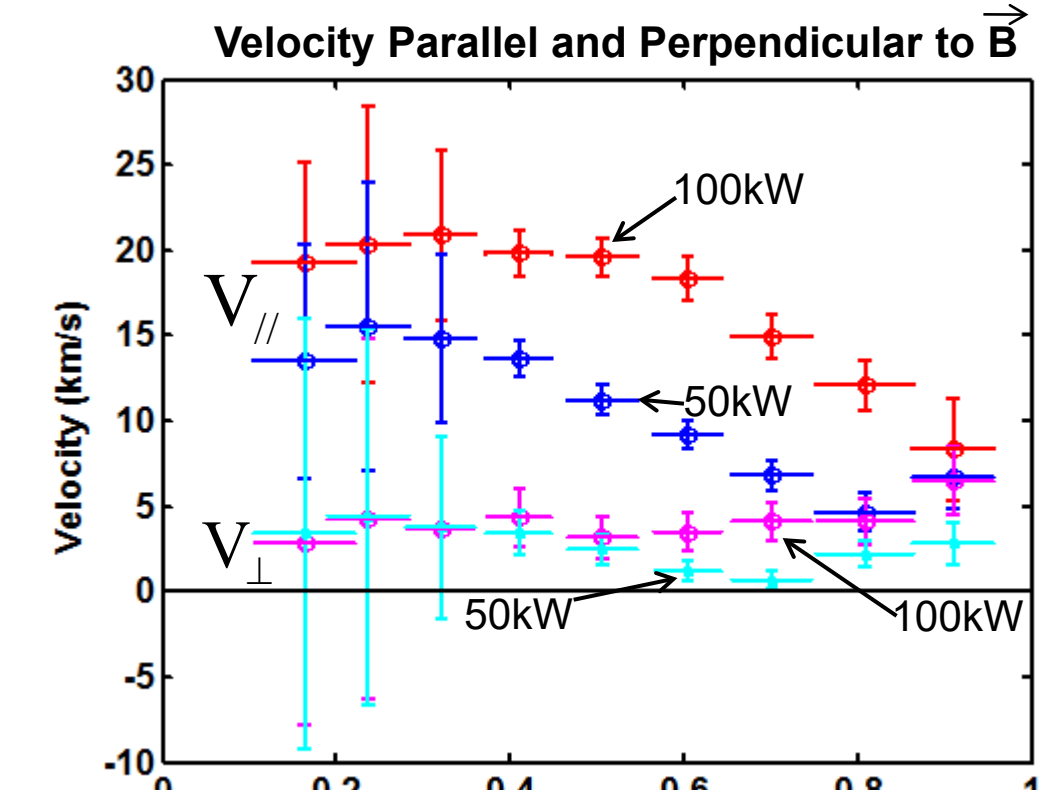
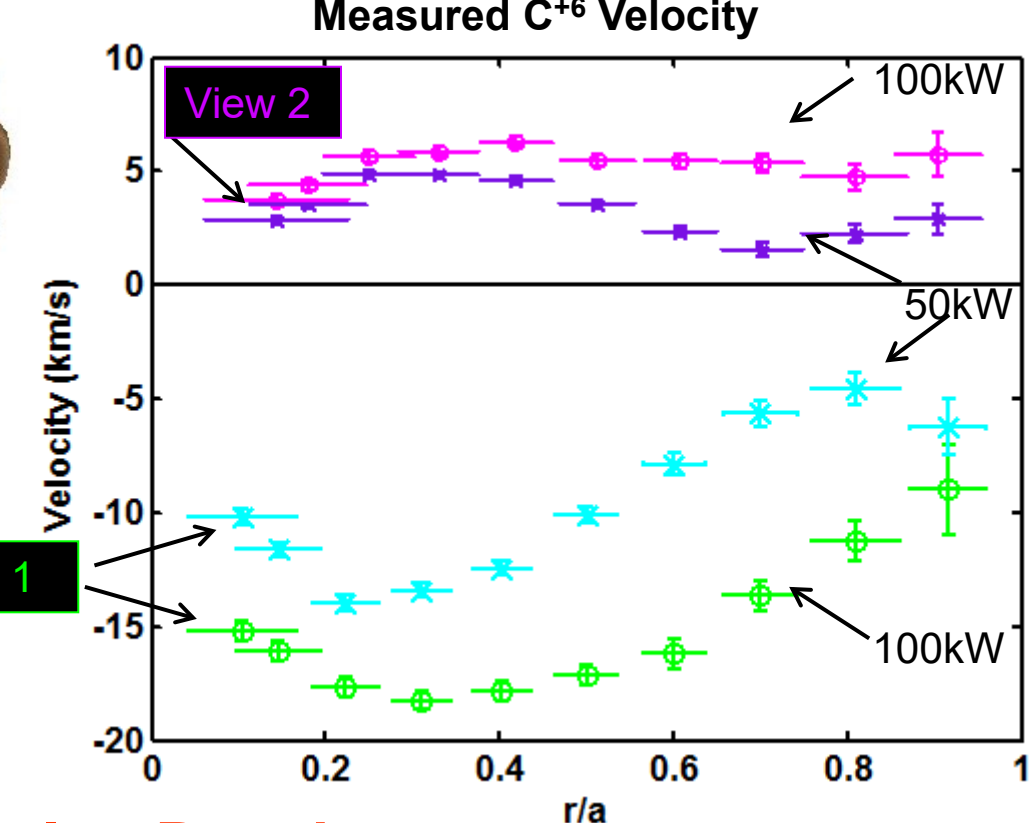


- HSX has a helical direction of constant $|B|$
- There is reduced flow damping in this direction[1]
- The intrinsic flow velocity is in the helical direction of quasi-symmetry
- Flow velocity increases for increased ECR heating power

$$\vec{V} = V_{\text{Helical}} \frac{\nabla |\vec{B}|^2 \times \nabla \Psi}{|\nabla \Psi \times \nabla |\vec{B}|^2|} + V_{\text{CrossHelical}} \frac{\nabla \Psi \times (\nabla |\vec{B}|^2 \times \nabla \Psi)}{|\nabla \Psi \times (\nabla |\vec{B}|^2 \times \nabla \Psi)|}$$

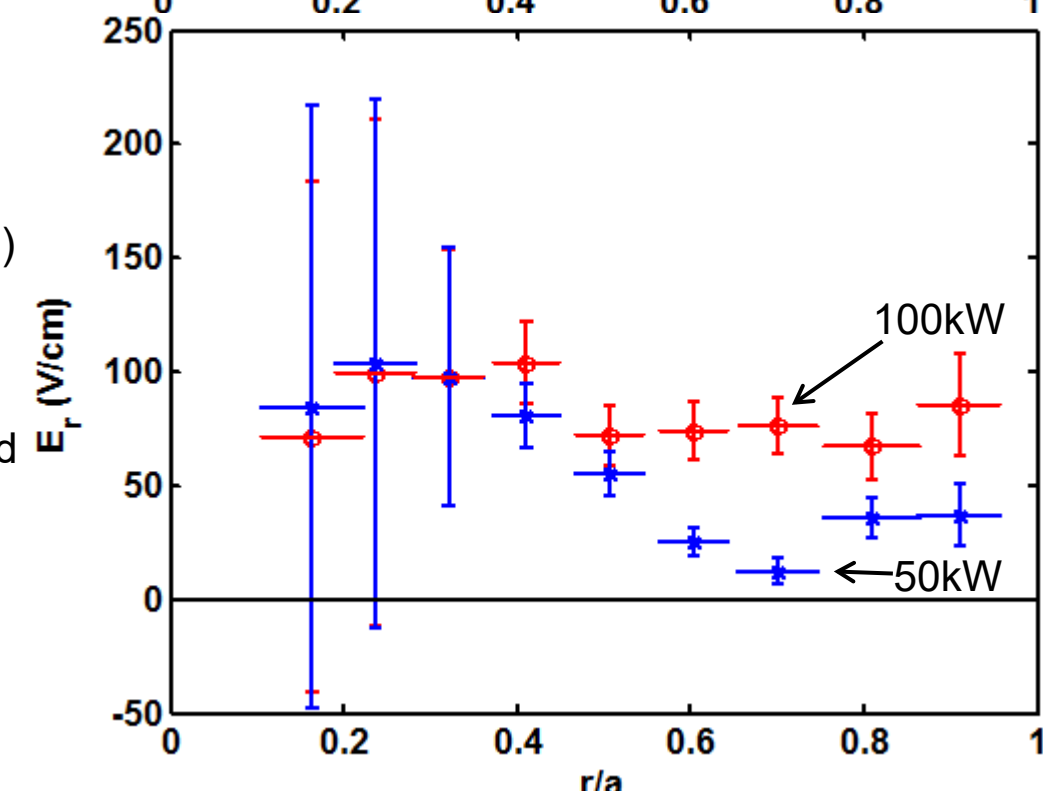
Using the velocity measured by the two view directions and locally calculated magnetic quantities the flow in two locally orthogonal magnetic coordinate directions can be found

$$\vec{V} = V_{\perp} \frac{\nabla \Psi \times \hat{b}}{|\nabla \Psi \times \hat{b}|} + V_{||} \hat{b}$$



Using the perpendicular component of the flow and force balance $E_{\text{Localr}} = |\vec{B}| V_{\perp}$ (the pressure gradient term is negligible for the impurity ions) E_r can be calculated locally. The local value is then converted into a flux surface quantity so it can be compared to calculated values.

$$E_r = -\frac{E_{\text{Localr}}}{\nabla \Psi} \frac{\partial \Psi}{\partial r_{\text{eff}}}$$



Carbon Ion Density

- C⁶⁺ density decreases towards the plasma edge which causes a decrease in the CHERS signal near the edge of the plasma which leads to larger uncertainty in temperature and flow velocity measurements
- C⁶⁺ density increases from shot to shot, but is reduced by He GDC
- The shape of the C⁶⁺ density profiles roughly agrees with that predicted by coronal equilibrium calculations performed using ADAS

