We report velocity distribution functions measured in the $E \times B$ direction and perpendicular to a plasma facing surface in a boundary with a weak magnetic field. In these scenarios, the mean free path and the ion gyroradius are comparable ($\lambda \sim \rho$) and the Debye sheath is small ($\lambda_D \ll \rho$). Ion flows in the $E \times B$ direction, which are predicted to attain significant fractions of the sound speed, have recently been experimentally observed. We report measurements of ion velocity distributions in this direction for a range of collisionality $\lambda_D$ and magnetic field $B$. Experiments are conducted in the vicinity of a boundary region created in the HELIUS tokamak source, which produces plasma densities of $10^{19}$–$10^{20}$ m$^{-3}$ and magnetic fields up to 1 T. Electron probe measurements of electron energy distributions and plasma potential are presented as well. Measurements are compared to distribution functions calculated using the fully kinetic full-orbit Particle-in-Cell code PICPIC including Monte-Carlo collisions.

**Mapping a Boundary in 3D requires specialized diagnostics**

3D translatable Langmuir probe measures non-Maxwellian EEDFs/IVDFs

**IVDFs in the $E \times B$ direction reveal flow-shifted Maxwellian distributions and non-flowing neutrals**

Ion distributions show flow-shifted Maxwellians drifting toward $E \times B$

Neutral distributions show non-flowing bulk parallel to $E$, with no collisional features such as charge exchange observed

**LIF and probe measurements compare well with collisional fluid and PIC simulations**

(a) $\lambda_D$ Mach number ($M = v_L/c$) is 5 compared to collisional fluid and PIC models.

(b) Plasma potential compared to simulations

Data compare best to collisional particle-in-cell models which include a force accelerating the ions into the boundary region

**Conclusions & Outlook**

3D multispecies distribution functions have been measured and compared to fluid and fully-kinetic PIC models

In the boundary of a weak-to-intermediate magnetic field, cross-field ion drifts develop in 3D, even in the presence of a non-flowing neutral background

LIF data show greater acceleration toward $E \times B$ at lower pressure and stronger magnetic field, but more data is required to resolve dependence of these flows on $\psi$.

This work is supported by U.S. National Science Foundation Grant No. PHY-190278 (NVL) and SciDAC Project No. DE-SC00-08875 (UIUC).