Comparison of Neoclassically Predicted Poloidal Rotation with Experimental Measurements

by

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There is strong motivation for testing neoclassical theory of poloidal rotation

- Rotation plays important role in suppression of turbulence and the formation of internal transport barriers through E x B shear

- Predictive knowledge of rotation requires experimental verification of neoclassical theory

- Neoclassical theory of rotation tested by comparing poloidal rotation profiles from charge exchange recombination (CER) measurements with predictions from the code NCLASS

- Special care is necessary to properly interpret the CER measurements

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Key results

- There is an **order of magnitude** discrepancy between the measured poloidal rotation profile and the neoclassical prediction from the code NCLASS in QH-mode discharges on DIII-D.
- The rotation is neoclassically predicted to be in the **opposite direction** than what is actually observed.

CER measurements are complicated by the energy-dependent cross-section

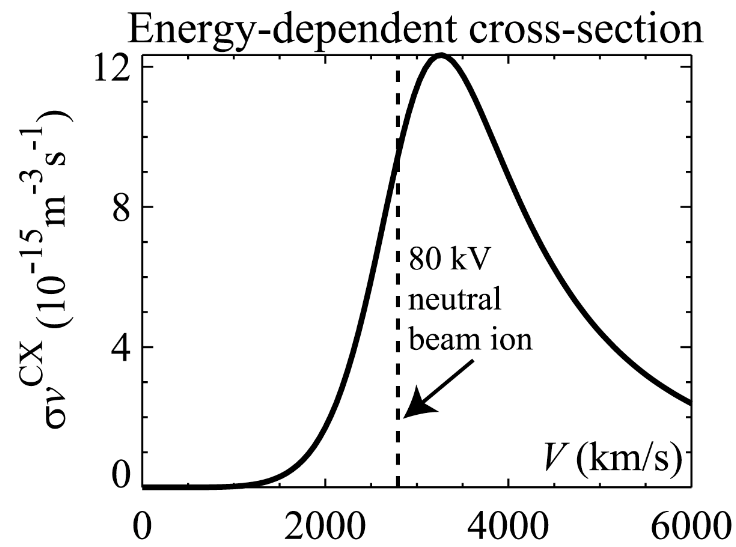
- Energy-dependence of charge exchange cross-section causes apparent velocity
  [von Hellermann et al., PPCF (1995)]

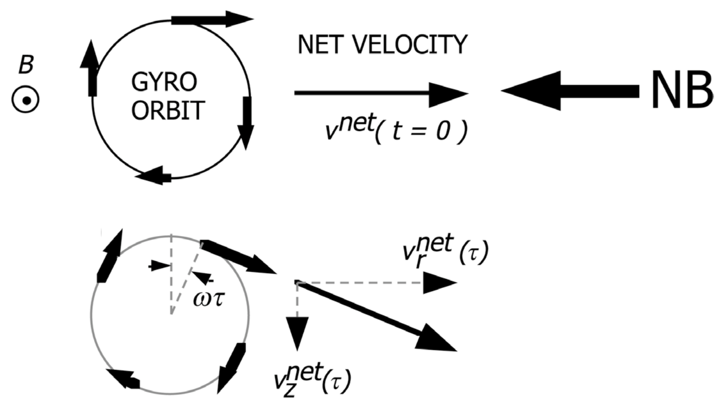
- Mainly affects toroidal measurements, but gyro-motion + finite-lifetime generates apparent vertical (poloidal) velocity
  [Bell and Synakowski, AIP Conf. Proc. (2000)]

- Derived expression for apparent velocity
  [Solomon, et al., Rev. Sci. Instrum. (2004)]

$$\vec{V}_{app}^{local}(\vec{v}_n) = \frac{1}{1+\omega_c^2\tau^2}\left[\vec{v}_n + \frac{\omega_c\tau}{B}\left(\vec{v}_n \times \vec{B}\right) + \frac{\omega_c^2\tau^2}{B^2}\left(\vec{v}_n \cdot \vec{B}\right)\vec{B}\right]$$

- Geometrical effects also important





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The measured line-of-sight velocities are accurately described by the non-linear least squares fit

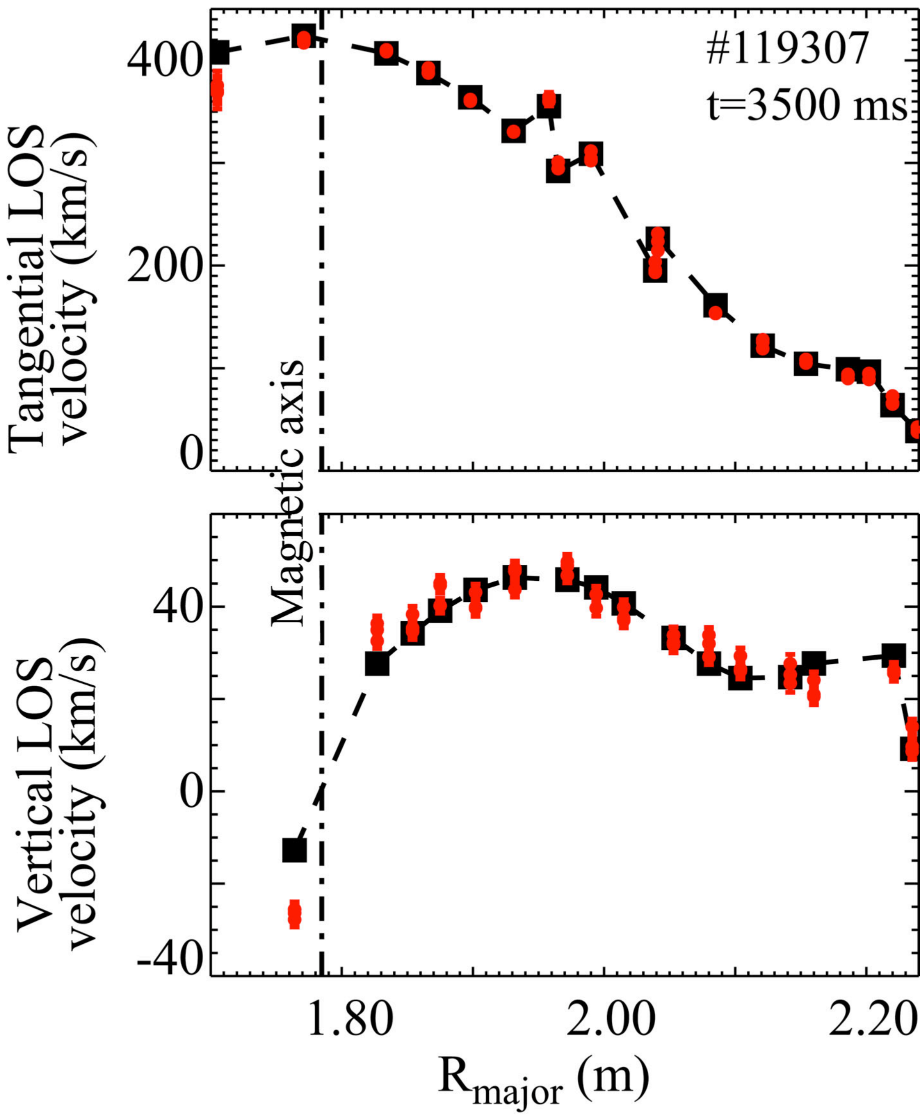
- Plasma rotation modeled by

$$\vec{V} = k\vec{B} + R\Omega\hat{\phi}$$

where $\hat{\phi}$ is unit toroidal vector, $k(\rho)$ and $\Omega(\rho)$ are neoclassical flux surface quantities (splines)

- LOS velocities shown for C VI (8-7) transition at 529.05 nm
  - Red: measured
  - Black: re-projected

- 4 knots in k and Ω adequate to account for measurements



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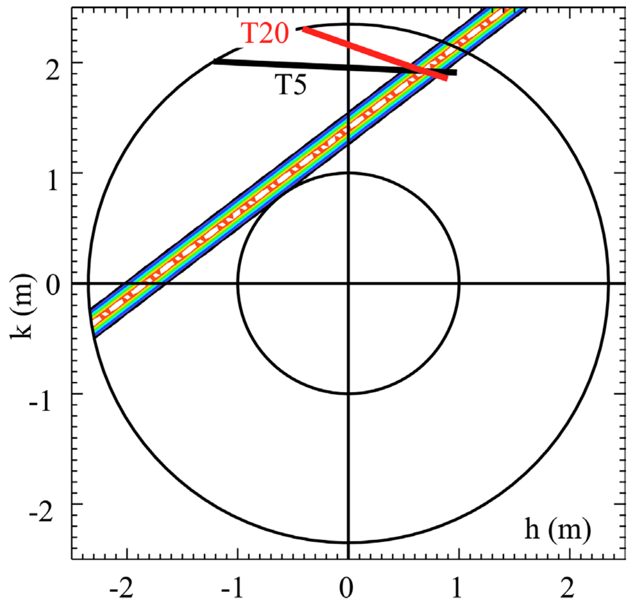
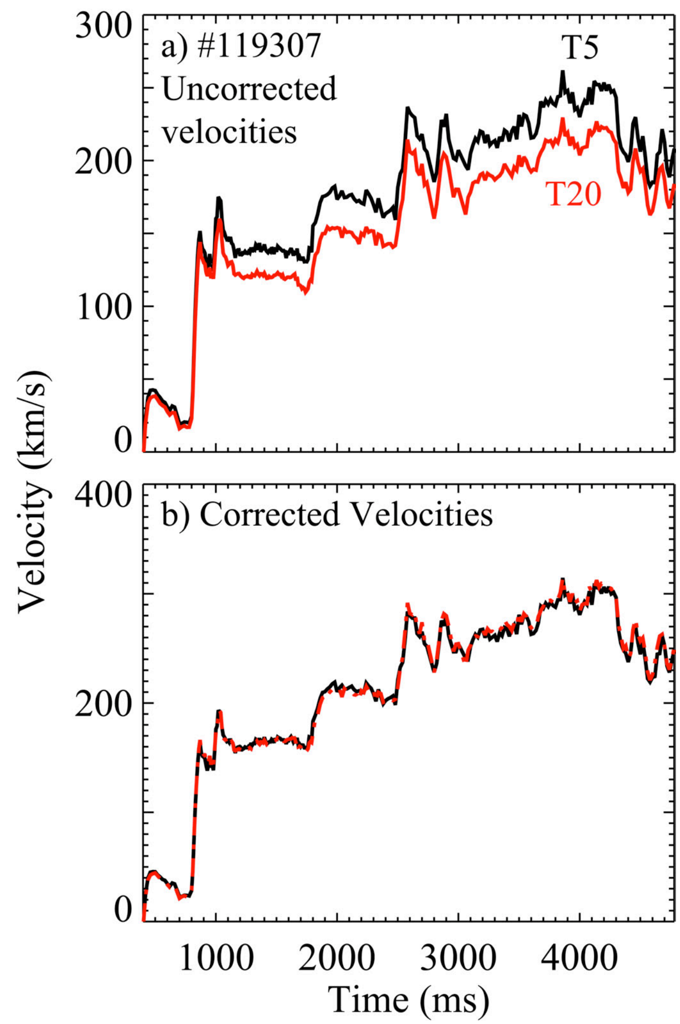
The energy-dependent cross-section correction is validated by analyzing data from two chords

- Chords view same location, but have different views
  - Different contributions of toroidal velocity (~5%)
  - Different contributions of correction





- Measured difference >> 5%

- Fully corrected → near perfect agreement

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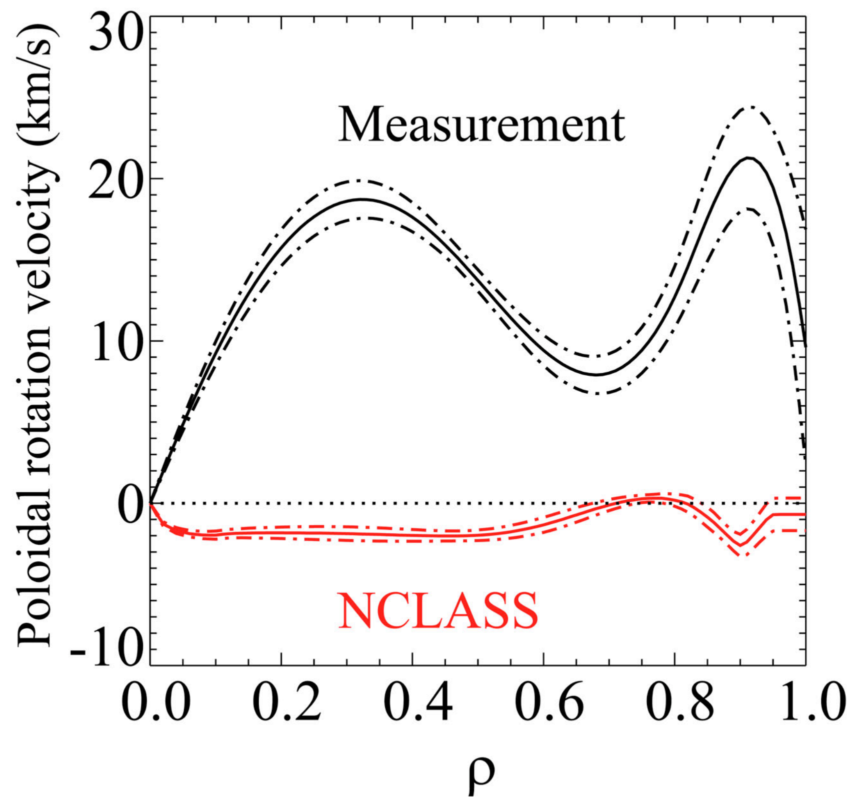
Neoclassical prediction from NCLASS is much smaller than observed experimentally

- Analysis performed *t* =[3000-4000] ms
  - Statistical average plotted
  - Error bands = standard deviation of profiles

- Measured profiles input into NCLASS

- NCLASS prediction smaller than measurement by **order of magnitude**

- Even disagreement in direction of rotation!



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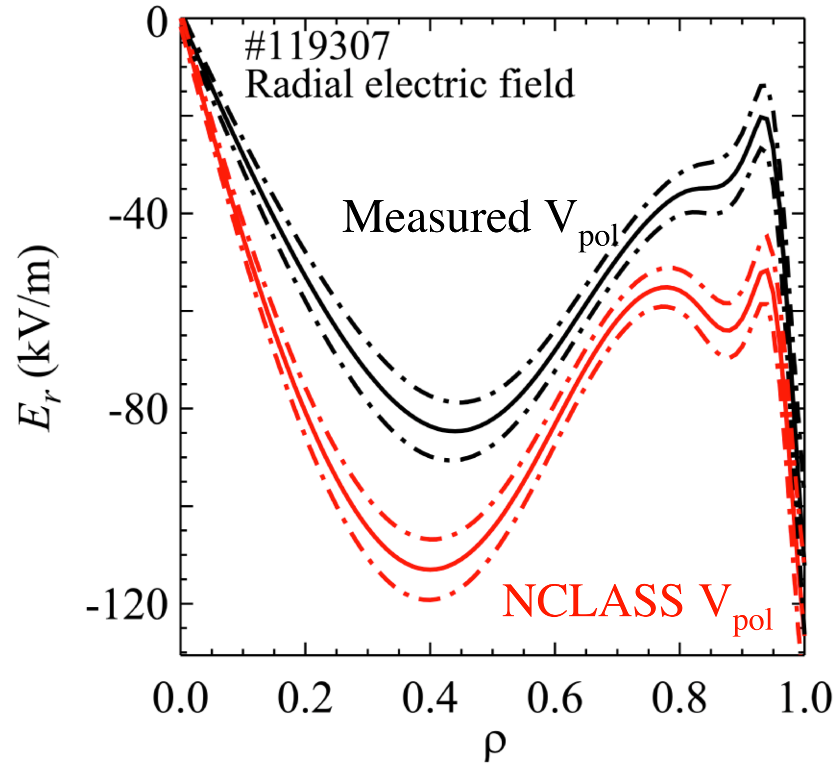
There is a significant difference in the inferred radial electric field depending on the poloidal velocity used

- Radial electric field determined from CER measurements using radial force balance equation

$$E_r = V_\phi B_\theta - V_\theta B_\phi + \frac{1}{Z_i e n_i}\frac{\partial(n_i T_i)}{\partial r}$$



- Marked difference if use neoclassical vs measured poloidal rotation

- Given importance of E_r to confinement essential to accurately determine

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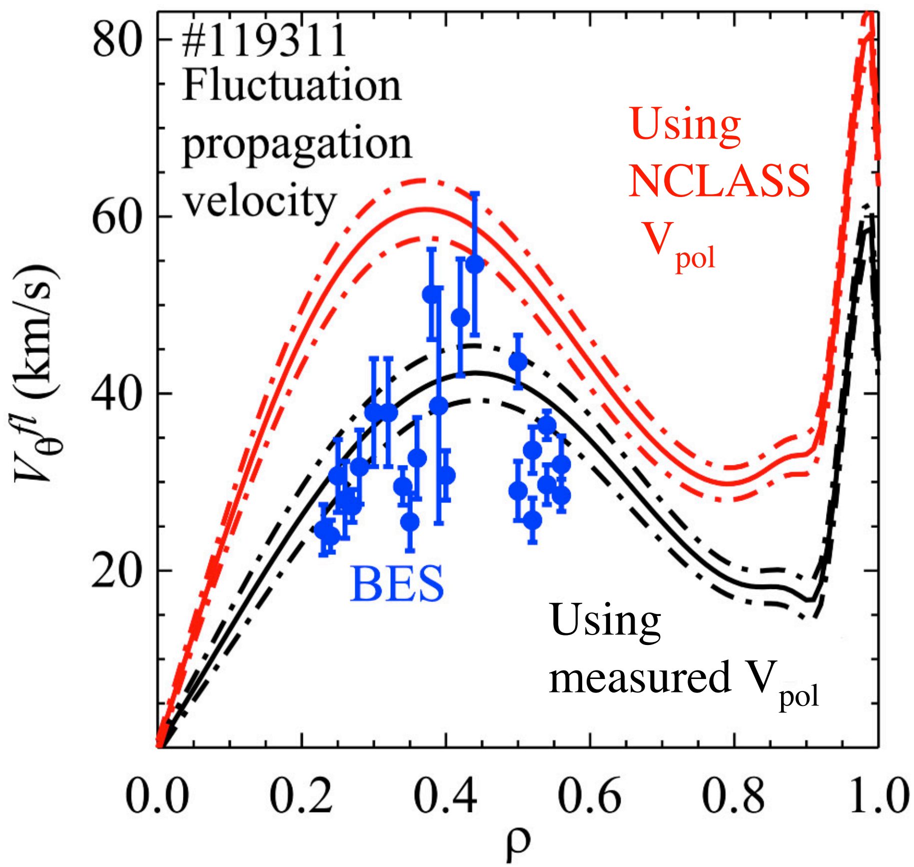
Poloidal propagation velocity of fluctuations indicates that measured poloidal velocity gives the better E_r

- Indirectly examine E_r from poloidal propagation velocity of fluctuations
  - Assuming that the fluctuations propagate with $E \times B$ velocity

$$V_\theta^{fl} = E_r / B_\phi$$

- Use beam emission spectroscopy (BES) diagnostic to measure V_θ^{fl}

- BES measurement clearly supports using measured poloidal velocity in calculating E_r



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Summary

- Observe an order of magnitude discrepancy between measured and neoclassically predicted poloidal velocity. Disagreement even in direction

- Effect of large poloidal rotation on radial electric field consistent with measurements of poloidal propagation velocity of the turbulence

- Cause for apparent anomalous poloidal velocity at this stage not clear Possibilities include
  - Effect of fast ions
  - Generation through turbulent Reynolds stress

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