28th IAEA Fusion Energy Conference (FEC 2020)
10–15 May 2021

Net parallel carbon rotation in the W7-X stellarator: a deviation from neoclassical predictions?

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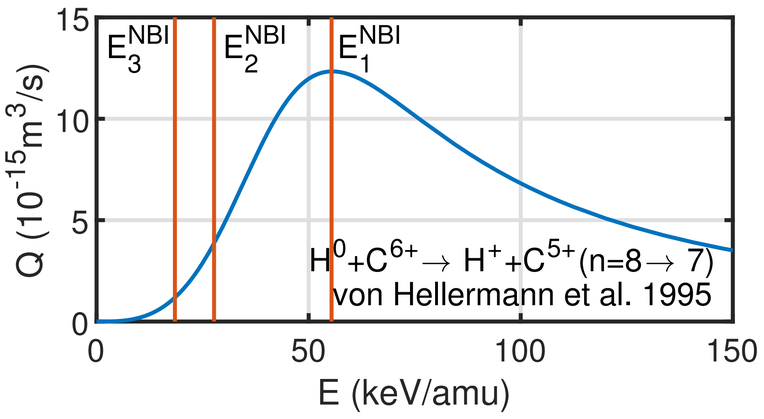
Abstract

We present the first analysis of the multiple velocity Charge eXchange Recombination Spectrocopy (CXRS) measurements across the plasma column to infer the profiles of radial electric field and net parallel C^{6+} velocity, including (1) a **general treatment of the flow geometry** and (2) the **velocity corrections due to the energy dependence of the CX cross section**. The inverted profiles are compared with neoclassical calculations.

Atomic physics corrections

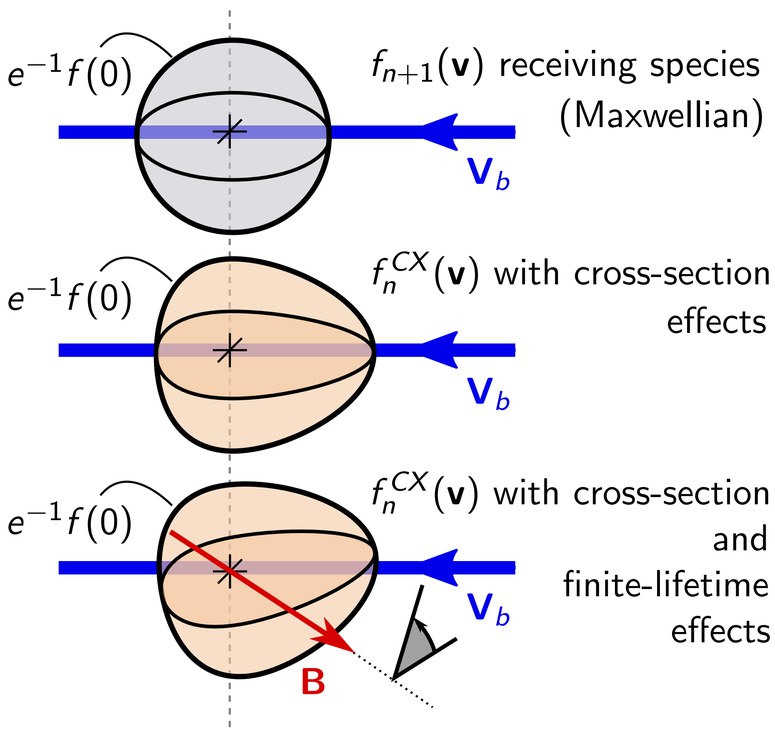
At W7-X the CXRS system measures the line emission from the reaction:

$$C^{6+} + H^0_{\mathrm{NBI}} \rightarrow C^{5+*} + H^+$$



The distribution function of the C^{5+*} gets distorted by the beam compared to the original C^{6+}:

$$f^{5+}_{CX}(\mathbf{v}) = \frac{n_b}{\nu} Q(|\mathbf{v}-\mathbf{V}_b|) f^{6+}(\mathbf{v}) - \frac{\omega_n}{\nu}\mathbf{v}\times\mathbf{b}\cdot\nabla_{\mathbf{v}} f^{5+}_{CX}$$



$$\mathbf{V}_{\mathrm{CX}} \approx \mathbf{V} - \frac{T}{m}\sum_b w_b \frac{Q'_b}{Q_b}\left(\mathbf{V}_b + \frac{\omega_c}{\nu}\mathbf{V}_b\times\mathbf{b}\right)$$

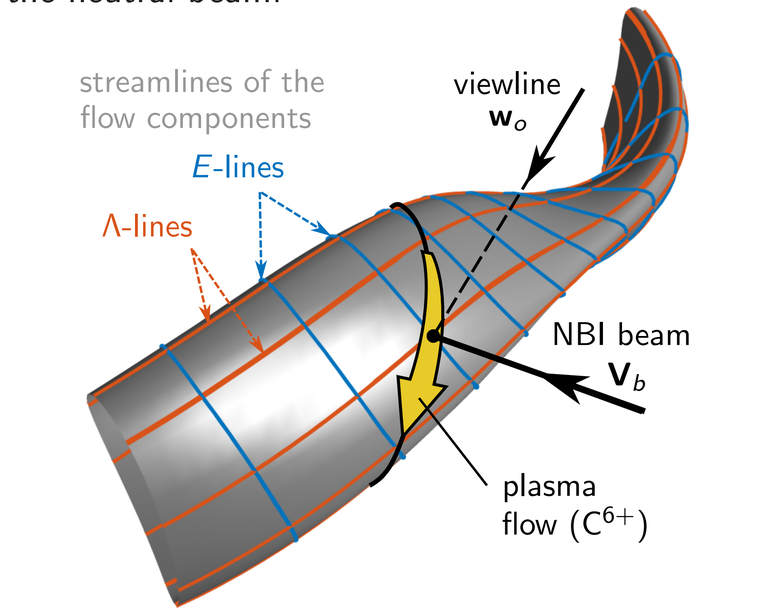
To account for these corrections one needs to model the **neutral beam composition** along the beam. The main contributions at W7-X come from the first (40-70%) and second (20-30%) beam energy components and the excited $n=2$ *halo* component (10-40%).

Flow and viewing geometries

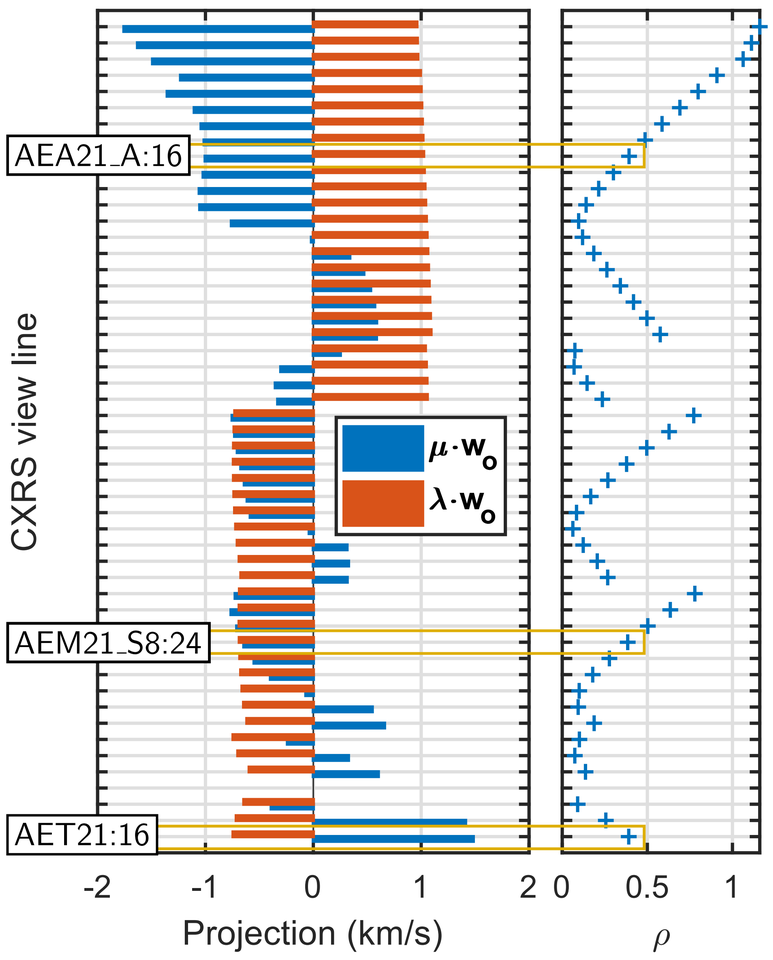
The incompressible flow field of the carbon ions can be expressed as

$$\mathbf{u}_s = \underbrace{E_s(r)\left(\frac{\nabla r\times\mathbf{B}}{B^2} + h\mathbf{B}\right)}_{\text{Perpendicular + Pfirsch-Schlüter}} + \underbrace{\Lambda_s(r)\frac{\mathbf{B}}{B_0}}_{\text{Net parallel}},$$

The CXRS system samples of this flow field at ∼50 points and in several directions, $\mathbf{w}_o$, along the neutral beam.

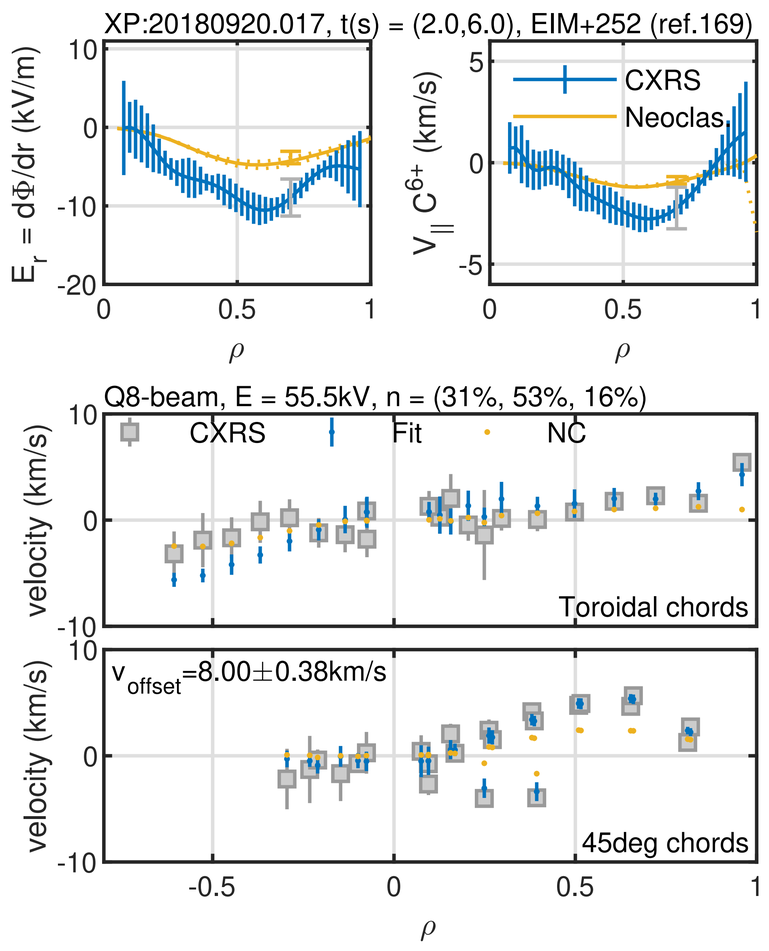


Every velocity measurement contains information of both $E_s(r_o)$ and $\Lambda_s(r_o)$ ($r_o \equiv$ observ. radius).



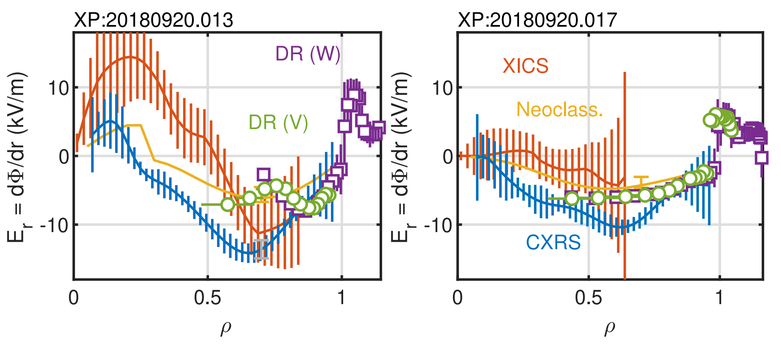
Flows compared to theory

- The flow profiles (blue points/lines below) are obtained by minimising the distance between the forward-modelled and actual velocities.
- Neoclassical ambipolar E_r and net carbon parallel velocity are computed with DKES (yellow dots/lines).



Discussion and conclusions

- Inverted E_r and net flow $V_{||}$ agree in sign order of magnitude and tendency (plasma density and magnetic configuration, not shown here) with the NC expectations.
- However, quantitative differences persist above errorbars (Note: discrepancy is small!, a few km/s!).
- For the case of E_r, the comparison with other diagnostics does not support the existence of an experimental deviation from the neoclassical ambipolar E_r.



- Agreement is encouraging. Further analysis required to understand the differences.

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This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.