Simulation and experiment investigating neoclassical effects of impurities on bootstrap current in HSX

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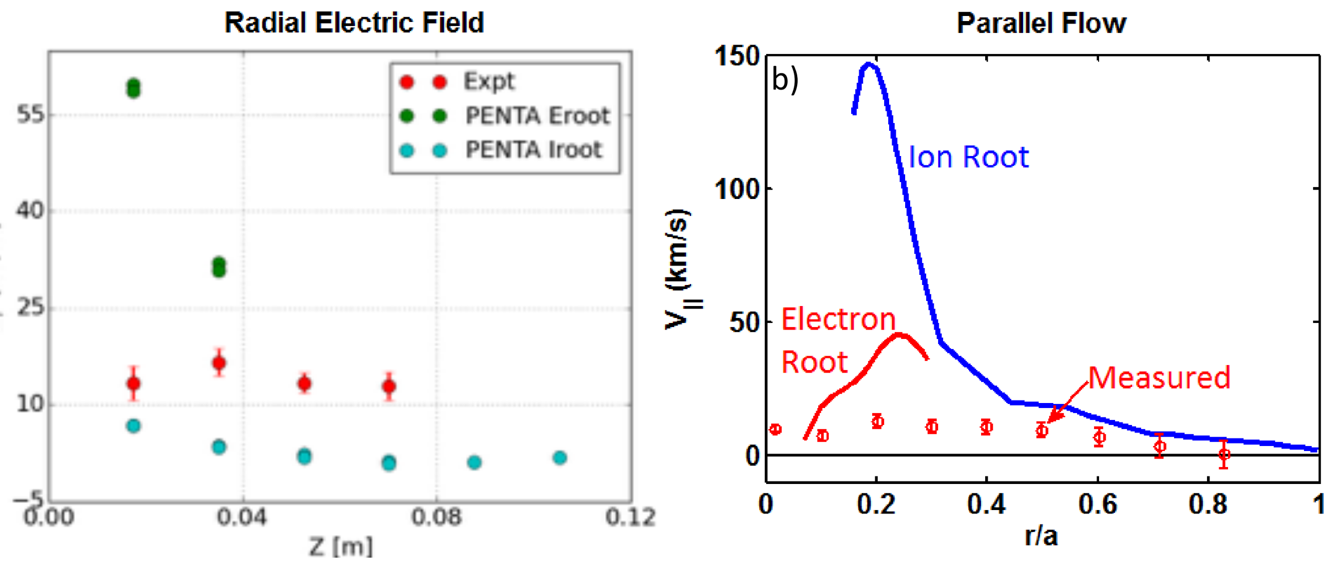
Overview

- Neoclassical modeling with PENTA / DKES [1] predicts a large electron root in the core of HSX that is not measured experimentally [2]. However, these calculations generally ignore impurity species.
- Calculations with SFINCS [3] have shown that small changes in Z_{eff} have large impacts on the bootstrap current and radial electric field in W7-X [4].
- Carbon is the dominant impurity in HSX plasmas. Future experiments will study bootstrap current and carbon flow with changing carbon content.
- Calculations with PENTA show significant changes in the bootstrap current and ion flow with increasing Z_{eff}.

PENTA disagrees with measurements

- The Drift Kinetic Equation Solver (DKES) [1] solves a linearized drift kinetic equation using a pitch angle scattering collision operator for the local monoenergetic transport coefficients D_{11}, D_{13}, D_{33}.
- PENTA restores momentum conservation through a moment method by including the effect of parallel flow through friction and viscosity relations when solving the drift-kinetic equation, but does not restore energy scattering.

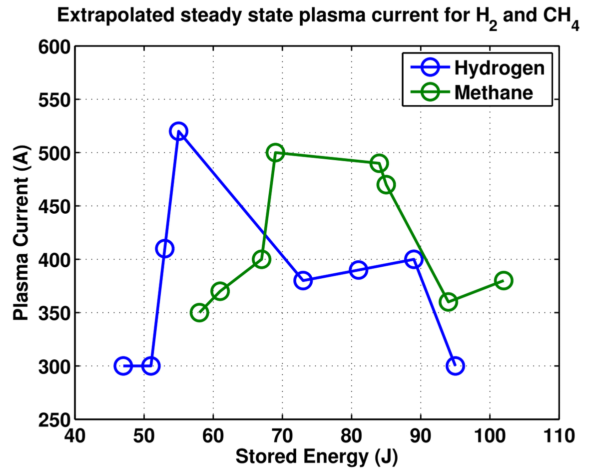
- Previous work [2] showed that measurements of the radial electric field and flow do not agree with PENTA predictions for the inner half radius.
- Recent work (see poster CP12.00080, S.T.A. Kumar) has measured a larger E_r than previous measurements, but still smaller than PENTA predictions.



- Carbon is the dominant impurity in HSX plasmas. In addition, methane is used with CHERS measurements to maximize the C^{6+} signal. Most previous PENTA predictions did not include any impurity species.

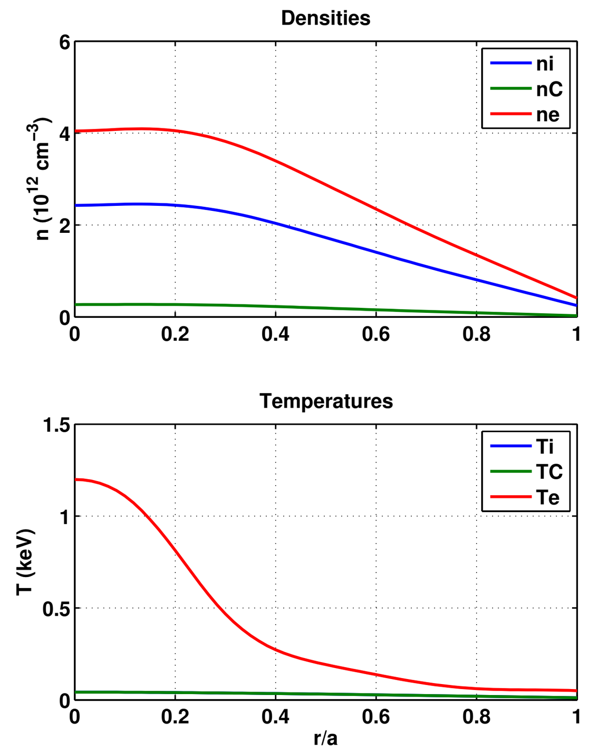
Carbon profile in HSX

- Carbon is the dominant impurity in HSX, and methane is used with CHERS measurements to maximize the C^{6+} signal.
- Preliminary measurements show differences between hydrogen and methane plasmas. This could be attributed to profile changes, absorbed power changes, or Z_{eff} changes.

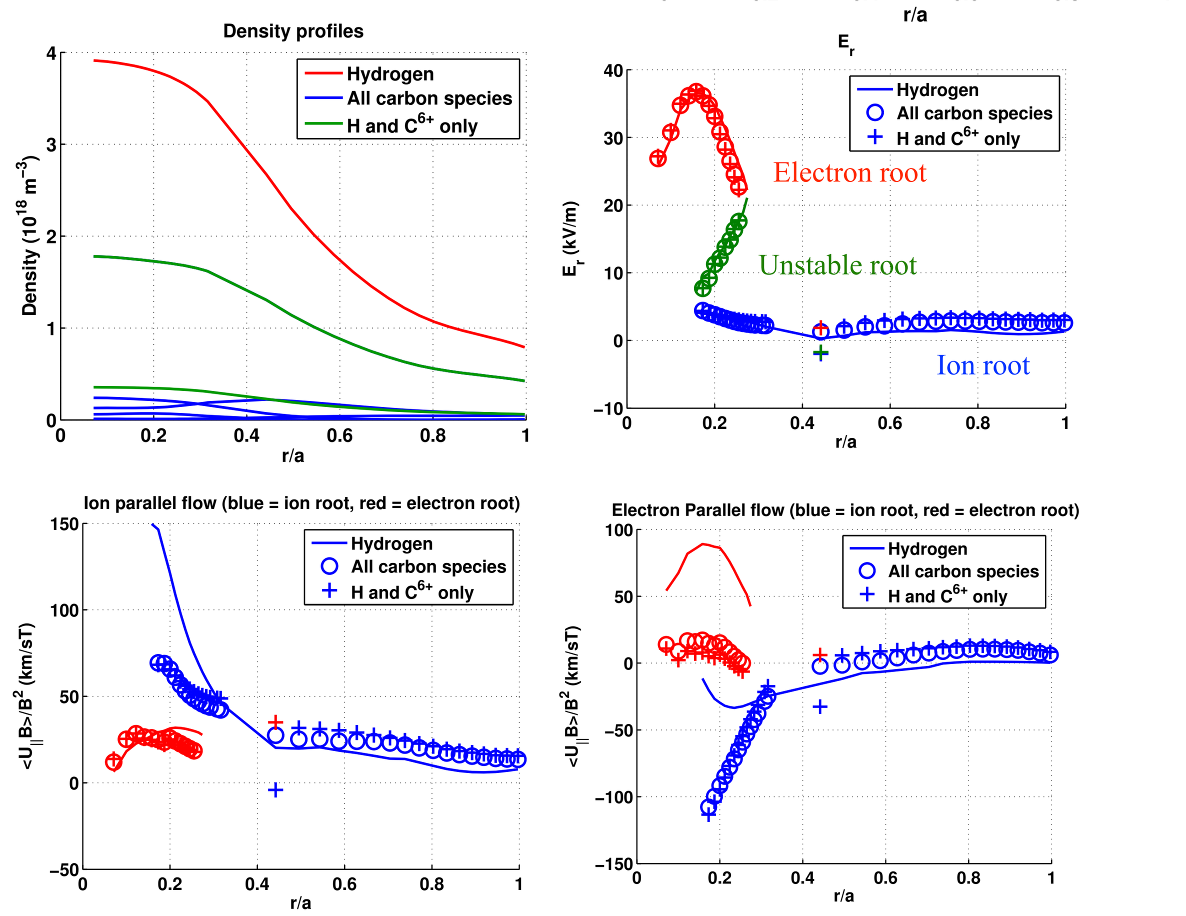


- Z_{eff} measurements are not currently available on HSX. Simulations must choose a reasonable carbon profile.
- We use a simple Z_{eff} = const. profile, with C^{6+} the only impurity.
- An ADAS coronal equilibrium calculation including all carbon species was used for additional PENTA calculations.
- PENTA comparison between carbon profiles shows only very small differences with carbon species.

Simulation profiles:

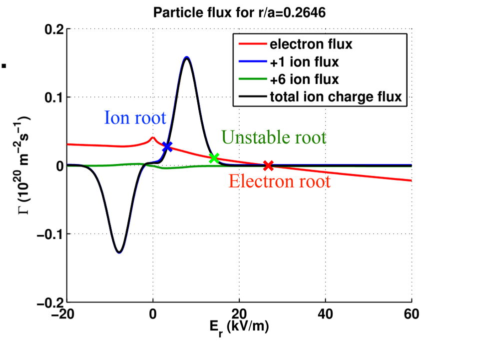


Comparison to PENTA calculation using ADAS coronal equilibrium:

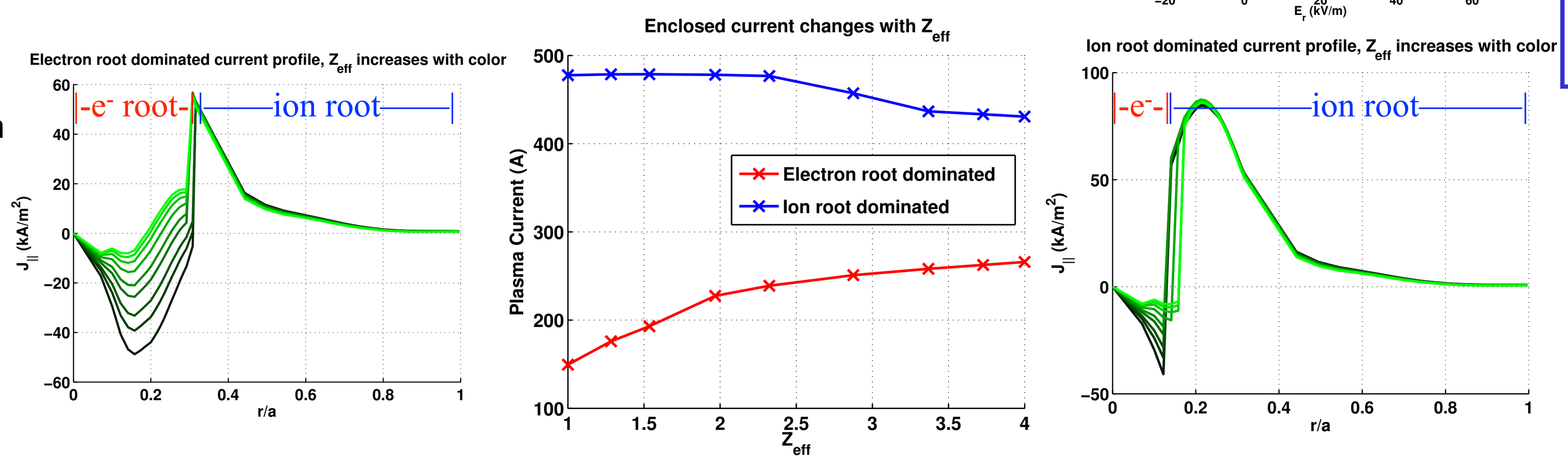


Z_{eff} increases I_{BS} in PENTA

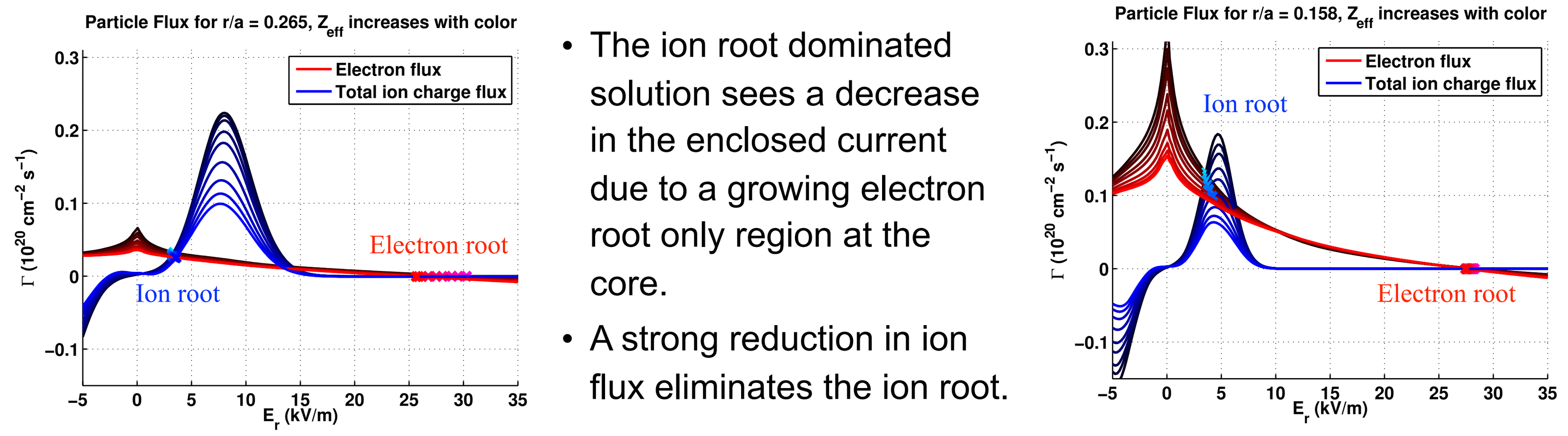
- Changes in the plasma current depend on which root is chosen wherever there are multiple roots.
- The electron root dominated solution chooses the electron root anywhere it exists. The electron root generally does not exist outside r/a ~ 0.3.
- The ion root dominated solution chooses the ion root anywhere it exists. The ion root often does not exist inside r/a ~ 0.1.



- There is a large increase in the electron root bootstrap current with increasing Z_{eff}.
- The ion root bootstrap current is relatively unaffected.

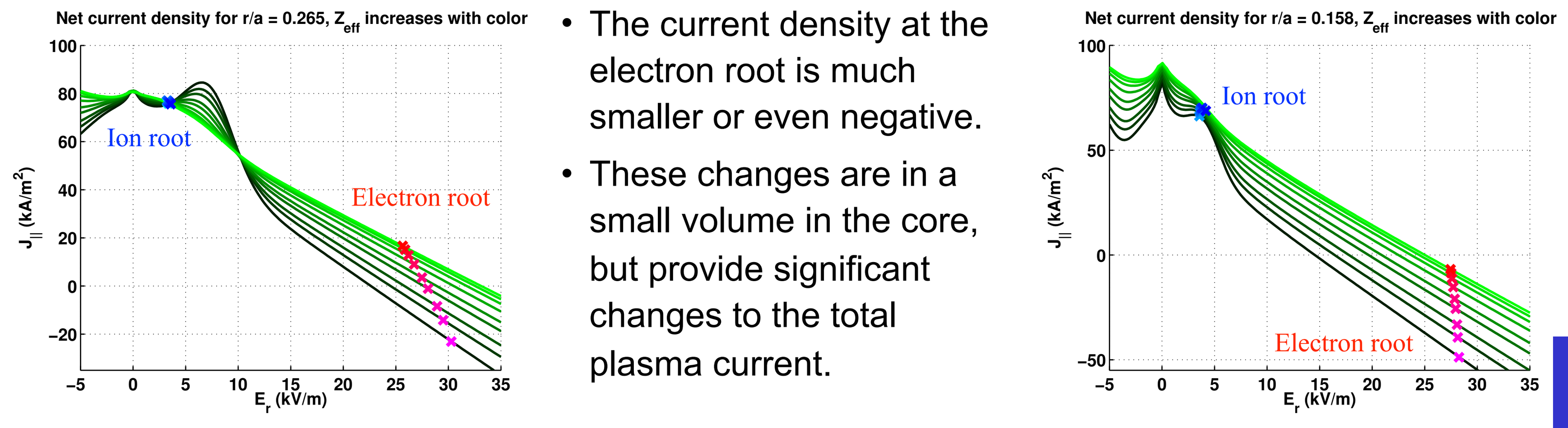


- The radial electric field drops significantly in the electron root.
- The ion root particle flux does not change with Z_{eff}.



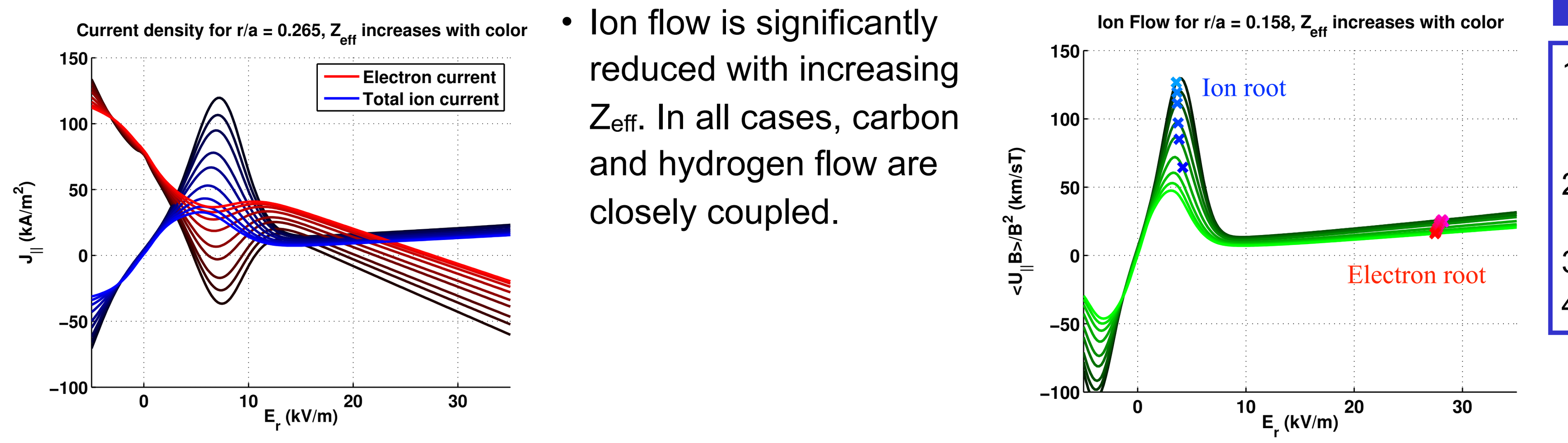
- The ion root dominated solution sees a decrease in the enclosed current due to a growing electron root only region at the core.
- A strong reduction in ion flux eliminates the ion root.

- The current density changes significantly with carbon content.
- The ion root $J_{||}$ does not change with Z_{eff}.
- The electron root $J_{||}$ increases slightly due to the changing E_r, but increasing Z_{eff} has a more significant effect.



- The current density at the electron root is much smaller or even negative.
- These changes are in a small volume in the core, but provide significant changes to the total plasma current.

- The electron and ion current both change significantly with Z_{eff}, but change symmetrically at the ion root.

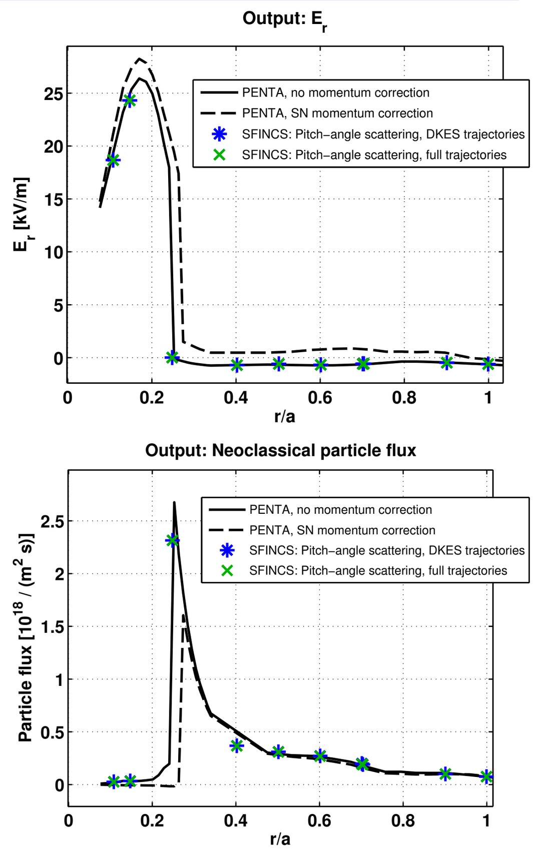


- Ion flow is significantly reduced with increasing Z_{eff}. In all cases, carbon and hydrogen flow are closely coupled.

SFINCS

- The Stellarator Fokker-Planck Iterative Neoclassical Conservative Solver (SFINCS) [4] is a drift-kinetic continuum code that solves the drift-kinetic equation with a variety of options for the drift-kinetic equation.
- SFINCS can include momentum conservation and energy scattering with the Fokker-Planck collision operator.
- SFINCS does not include radial coupling.

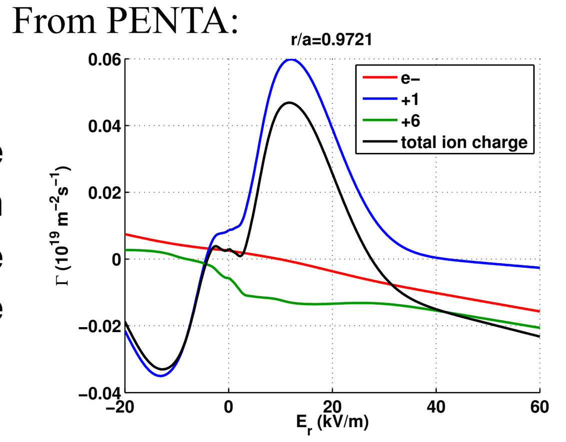
- SFINCS and PENTA generally show good agreement at the ion root.
- Numerical difficulties appear at very large electric fields.



- Preliminary simulations are underway to explore the effect of potential variations on a flux surface, magnetic drifts, and impurity concentrations.

- The study on W7-X [4] adjusted the impurity density gradient for zero impurity flux. The same restriction was not imposed in these simulations.
- The ambipolar solution can be very sensitive to the carbon flux. Outside r/a ~ 0.9, the negative carbon flux can drive new ambipolar solutions.

From PENTA:



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