Understanding of Impurity Poloidal Distribution in Edge Pedestal by Modeling

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Outlook

Impurity transport in the edge transport barrier (ETB) region is responsible for inward penetration. Neoclassical convective flux?

Impurities are used in Doppler spectroscopy to measure toroidal and poloidal rotation velocities and radial electric field in the separatrix vicinity .

Poloidal asymmetries of impurities and parallel flows different from Pfirsch-Schlueter ones were observed on Cmod (Marr et al 2010), ASDEX-Upgrade (Viezzer et al 2013).

Outlook

To understand the physics of impurity distribution and transport near the separatrix and in the scrape-off layer (SOL) simulations were performed with the B2SOLPS5.2 transport code

The ASDEX-Upgrade H-mode shot, where HFS-LFS asymmetry was observed, was chosen for simulation. MAST H-mode shot has been simulated earlier

What is the physics of HFS-LFS impurity asymmetry? Is radial convective transport described by standard neoclassical theory?

Predictions of the standard neoclassical theory

- **Assumption: impurity density is a flux surface function**

$$n_I = n_I(\Psi)$$

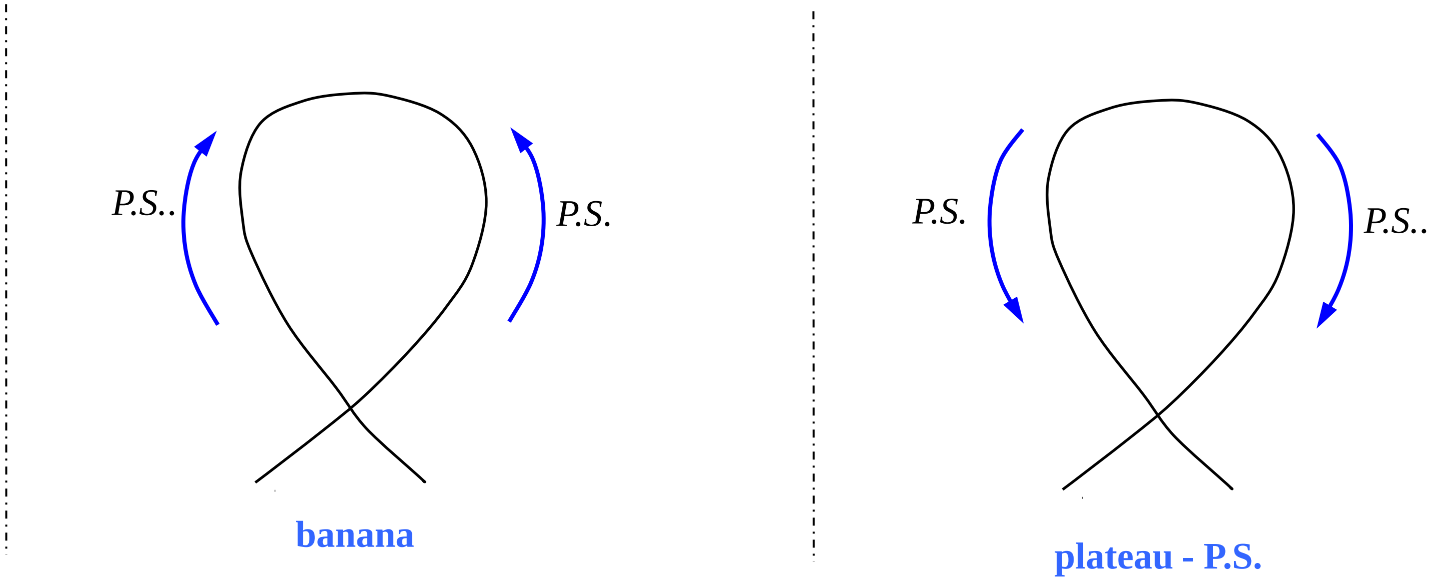
- **Parallel velocities are Pfirsch-Schlueter (PS) velocities for each species (y-radial coordinate, hy-metric coefficient, Bx-poloidal field, Bz-toroidal field)).**

$$V_{\parallel} = V_{\parallel}^{P.S.} + \frac{\langle V_{\parallel} B \rangle}{B}$$

$$V_{\parallel}^{P.S.} = \left[\left(\frac{\partial p_I}{Zen_I \partial y} + \frac{\partial \varphi}{\partial y} \right) \frac{B_z}{h_y B_x B} - \frac{\langle V_{\parallel} B \rangle}{B} \right] \left(1 - \frac{B^2}{\langle B^2 \rangle} \right)$$

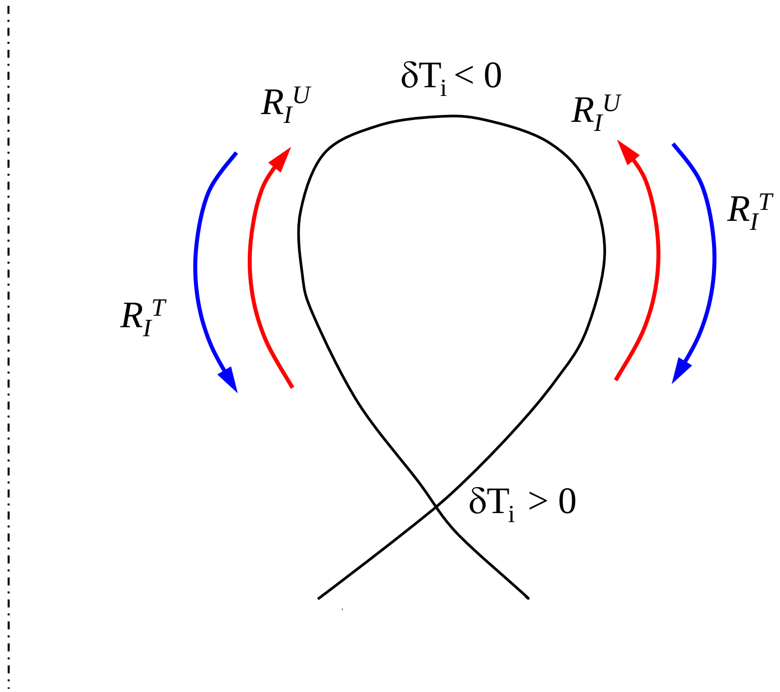
Predictions of the standard neoclassical theory

- Direction of the PS flows of the main ions depends on the collisionality (in the absence of average toroidal rotation). Parallel PS velocities of species are completely different from those of the main ions since diamagnetic velocities are different.



Predictions of the standard neoclassical theory

- Parallel friction with the main ions R_I^U is due to different PS velocities.
- Thermal force R_I^T is caused by ion temperature perturbation on the flux surface (low part is hotter than the upper part).



Predictions of the standard neoclassical theory

- **Thermal force produces a torque (counter current at LFS) for impurities.**
- **Parallel momentum balance for impurities**

$$-\nabla_{\|} p_I + R_I^T + R_I^U = \frac{d}{dt} n m_I u_{I\|}$$

- **For gradual density gradient inertia is negligible.**
- **Thermal force and friction are balanced by the pressure gradient.**
- **Density perturbations on the flux surface which arise to provide the required pressure gradient are small**

Predictions of the standard neoclassical theory

- **Radial transport could be obtained from the toroidal projection of the momentum balance equation.**

$$\Gamma_{Ir} = \left\langle\left\langle \frac{R_I^T + R_I^U}{eB_x} \right\rangle\right\rangle$$

Neoclassical theory with steep density gradient

- **Standard theory is not valid if (V. Rozhansky Sov. Journ. Plasma Phys. 5 (1979) 771 ; 6 (1980) ; 10 (1984) 254), Fulop & Helander PoP 8 (2001) 3305**

$$\rho_{ci} B_T Z^2 /(B_p L) > 1$$

- **Standard neoclassical theory is not applicable in the edge barrier.**
- **Thermal force and friction are large as well as parallel pressure gradient which is inconsistent with assumptions.**
- **Strong poloidal asymmetry of impurity density is predicted.**

$$n_I \neq n_I(\Psi)$$

Neoclassical theory with steep density gradient

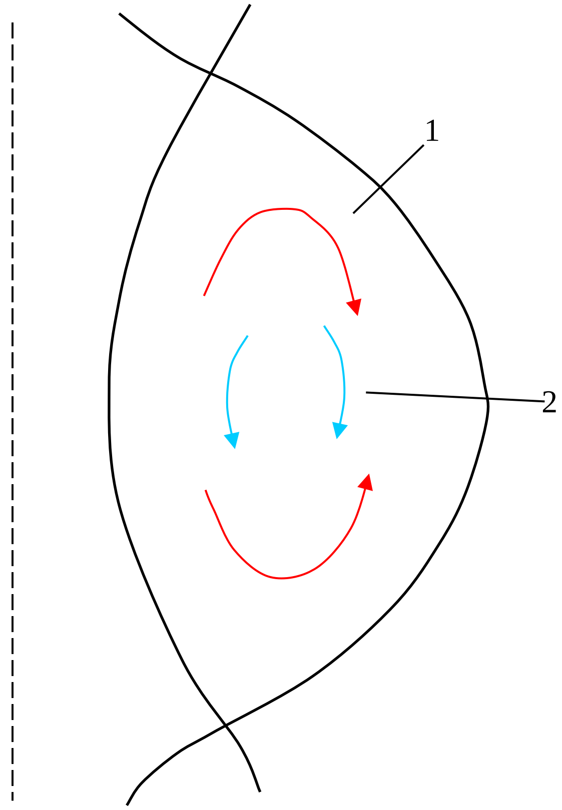
- **The parallel momentum balance (roughly)**

$$R_I^U = -R_I^T \qquad\qquad -\nabla_\parallel p_I = \frac{d}{dt} n m_I u_{I\parallel}$$

- **The parallel impurity flow is not PS. Parallel velocity is shifted with respect to the main ions velocity in the counter current direction at LFS.**
- **Divergence of the poloidal rotation is not balanced by PS fluxes but compensated by larger density at HFS with respect to LFS (smaller poloidal rotation at HFS).**
- **Strong poloidal asymmetry of impurity density is predicted.**

Poloidal projection of the parallel impurity flows.

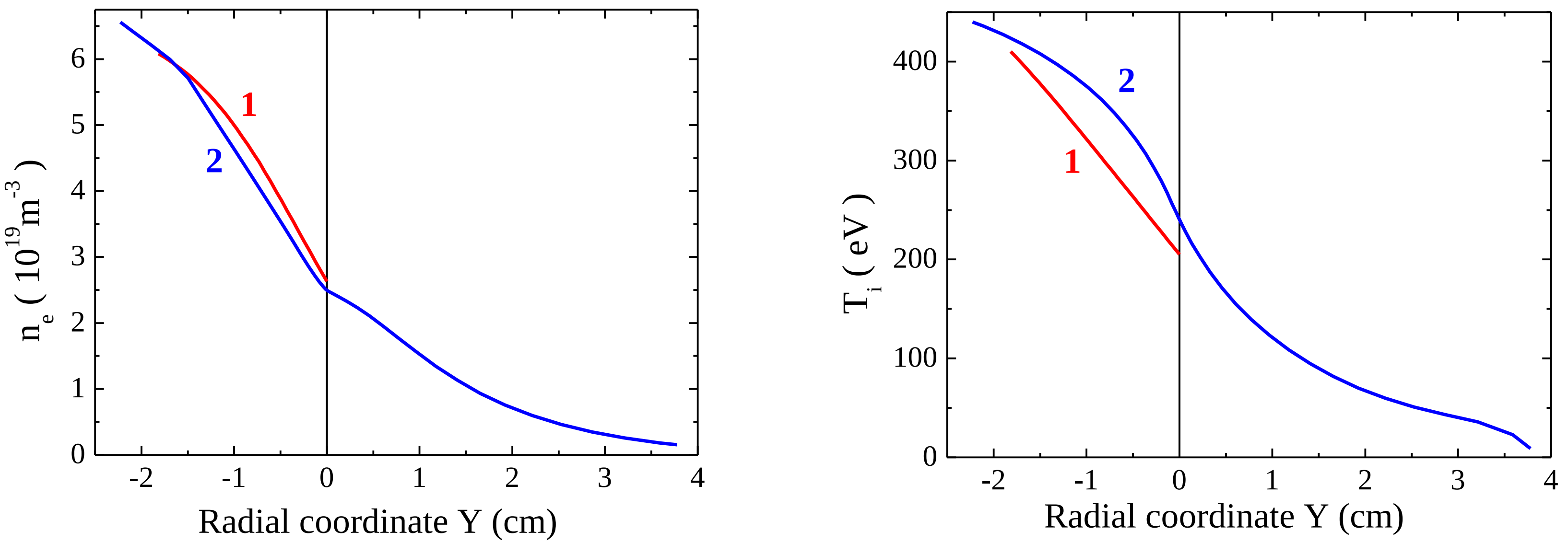
1 – pressure-driven flows; 2 – caused by the thermal force.



Simulation results for ASDEX-Upgrade.

Shot 28093. Density and electron temperature profiles.

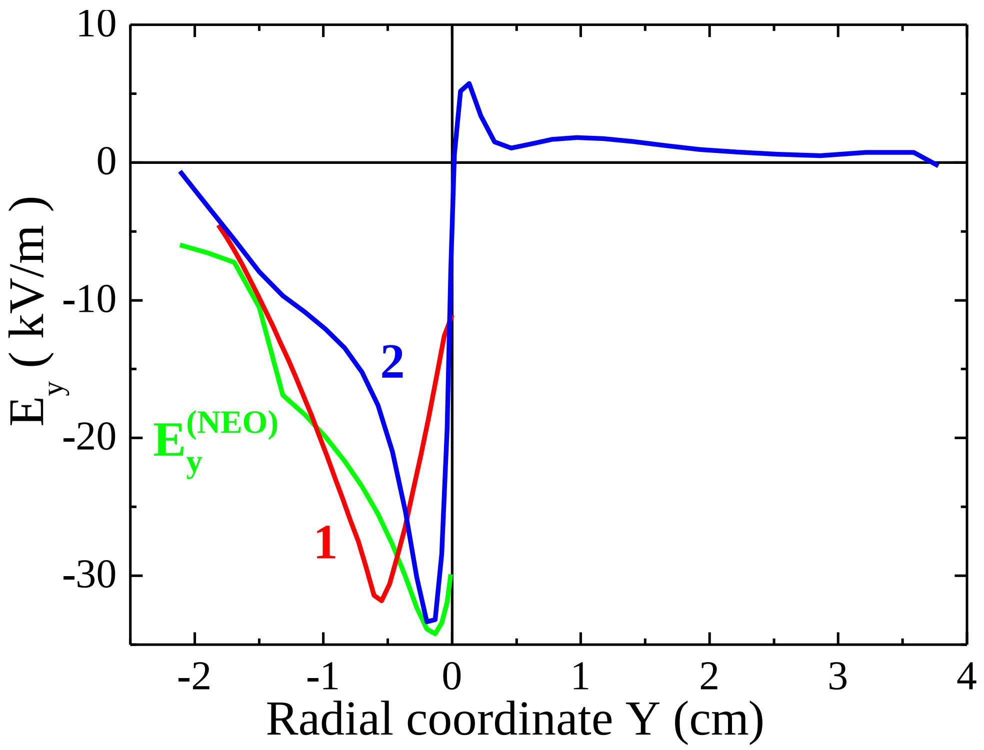
(1-experiment, 2-simulation)



Simulation results for ASDEX-Upgrade.

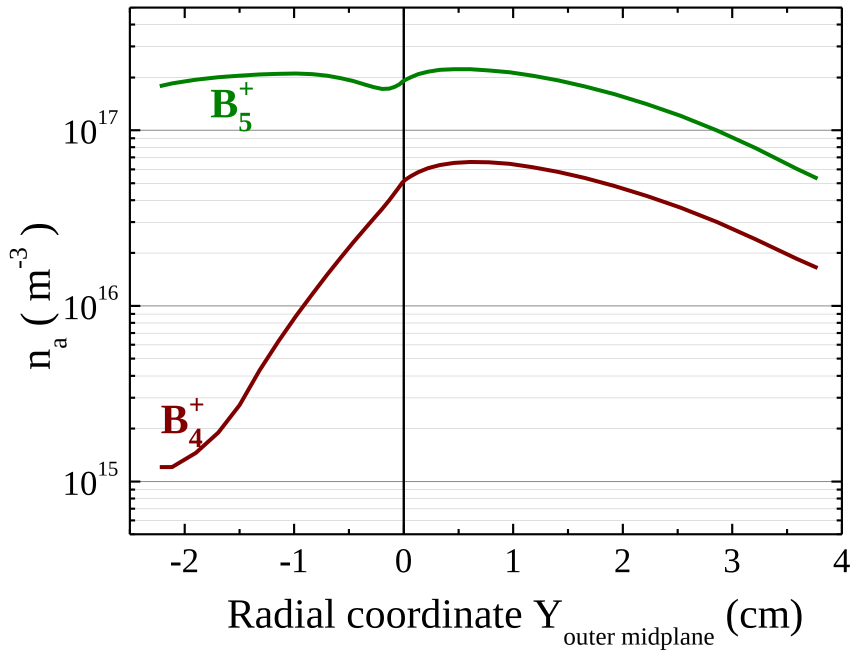
Shot 28093. Radial electric field.

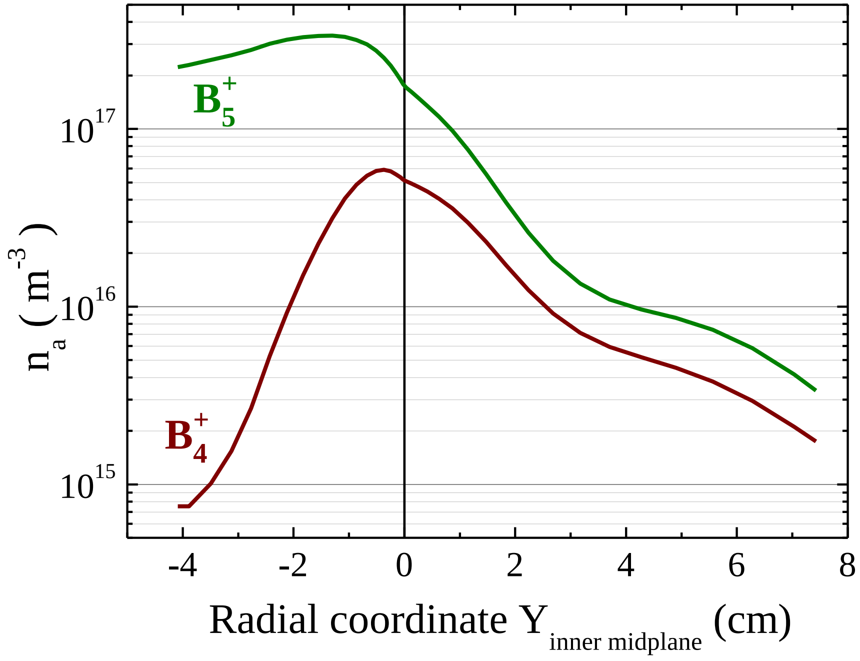
(1-experiment, 2-simulation)



Simulation results for ASDEX-Upgrade.

Shot 28093. Impurity radial density profiles.

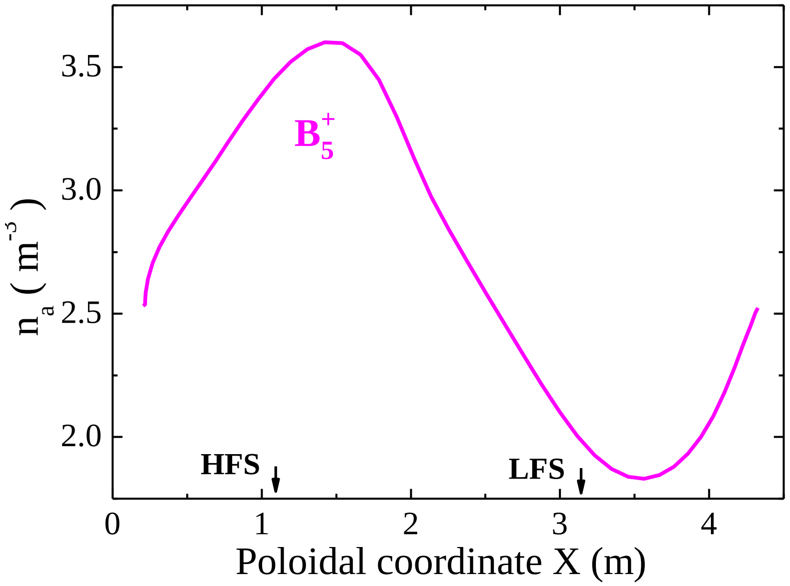


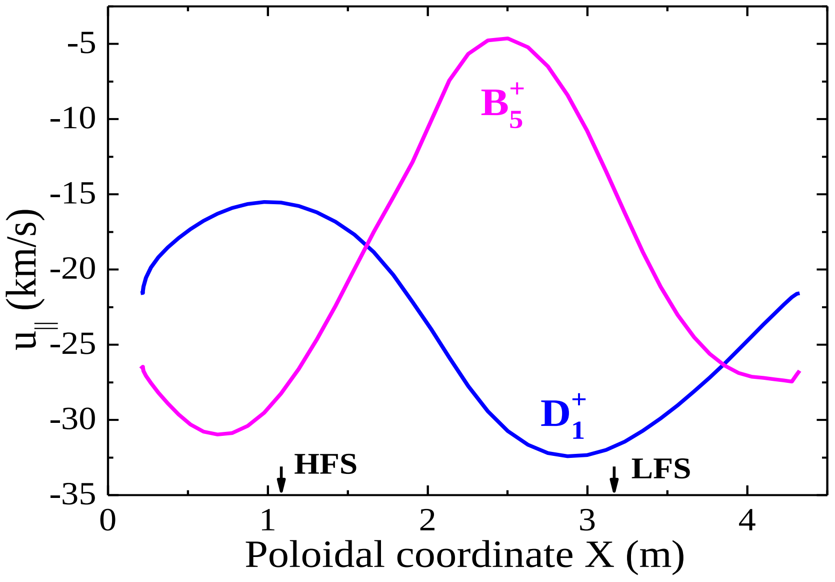


LFS **HFS**

Simulation results for ASDEX-Upgrade.

Shot 28093. Poloidal distribution of poloidal density and parallel velocity of impurities inside the separatrix.

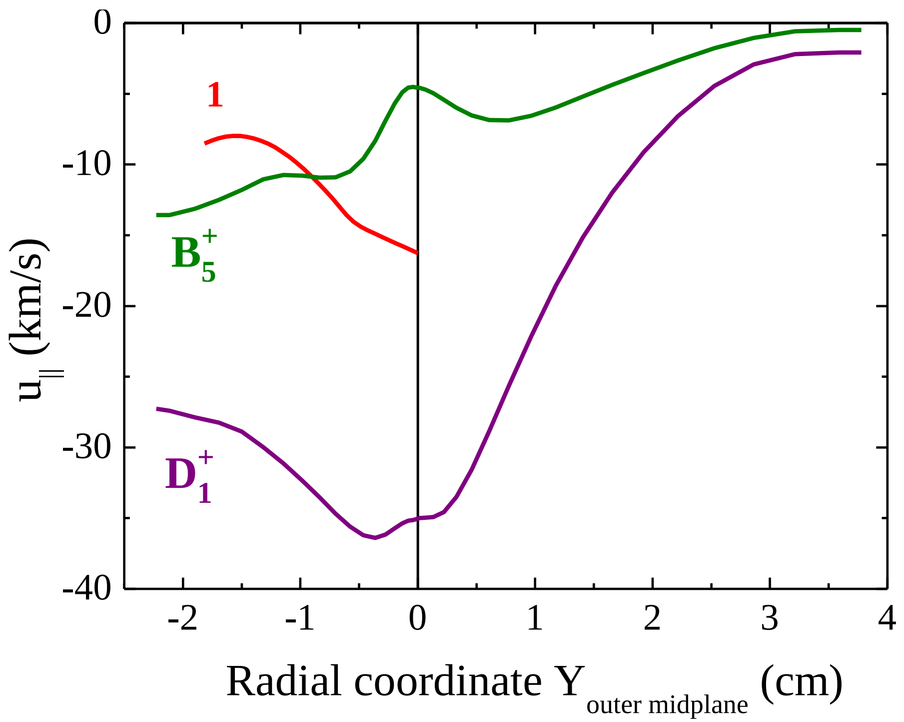




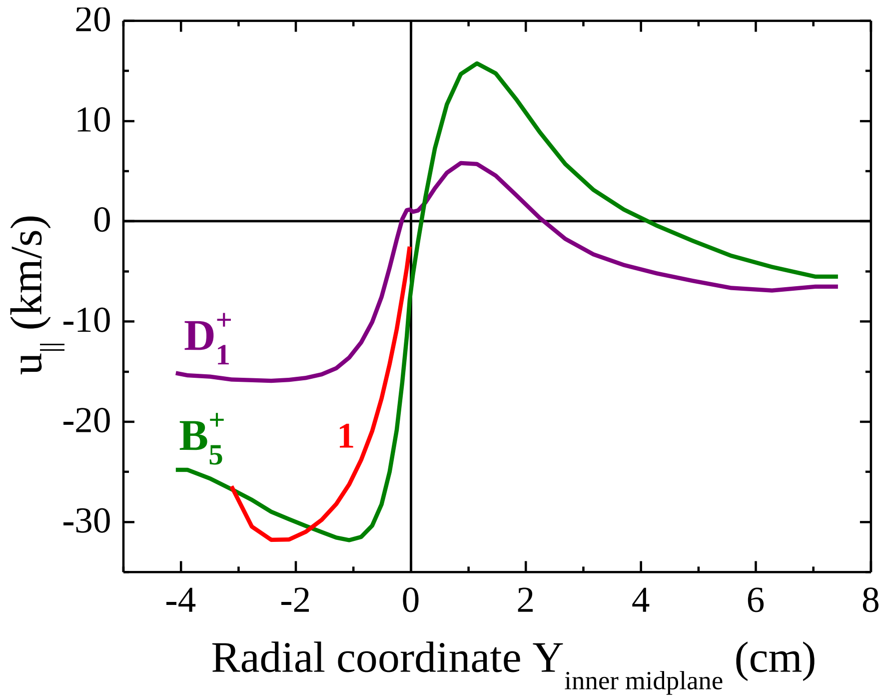
Asymmetry is of the order of 2. Parallel velocity of impurities strongly differs from that of the main ions. Flows from HFS towards LFS.

Simulation results for ASDEX-Upgrade.

Shot 28093. Radial distribution of parallel velocities inside the separatrix. Parallel velocity of impurity is shifted counter current at LFS and co-current at HFS



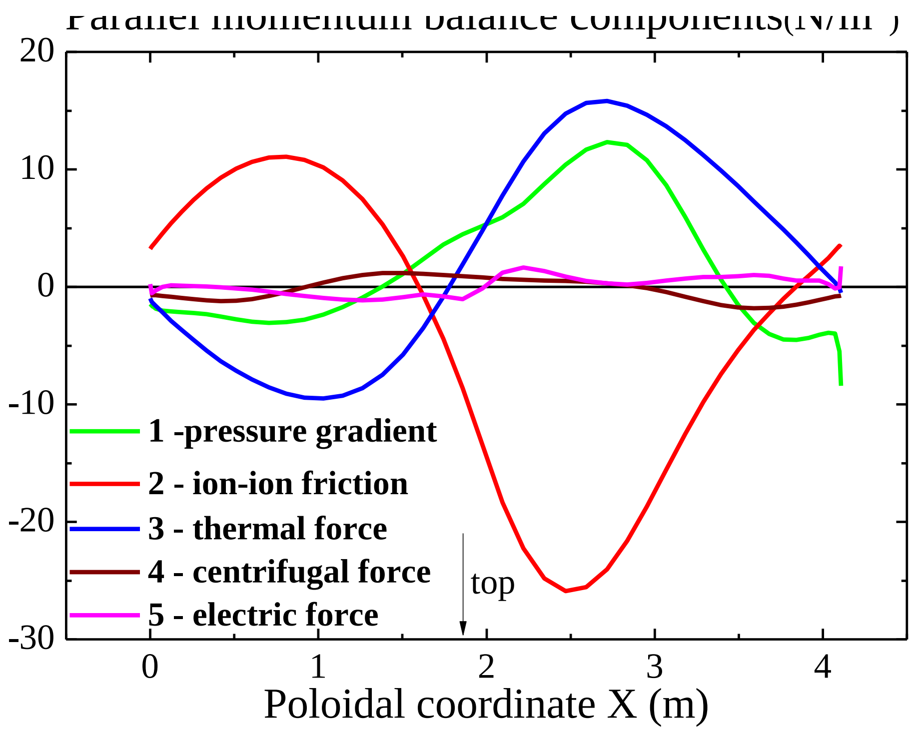
LFS



HFS

Simulation results for ASDEX-Upgrade.

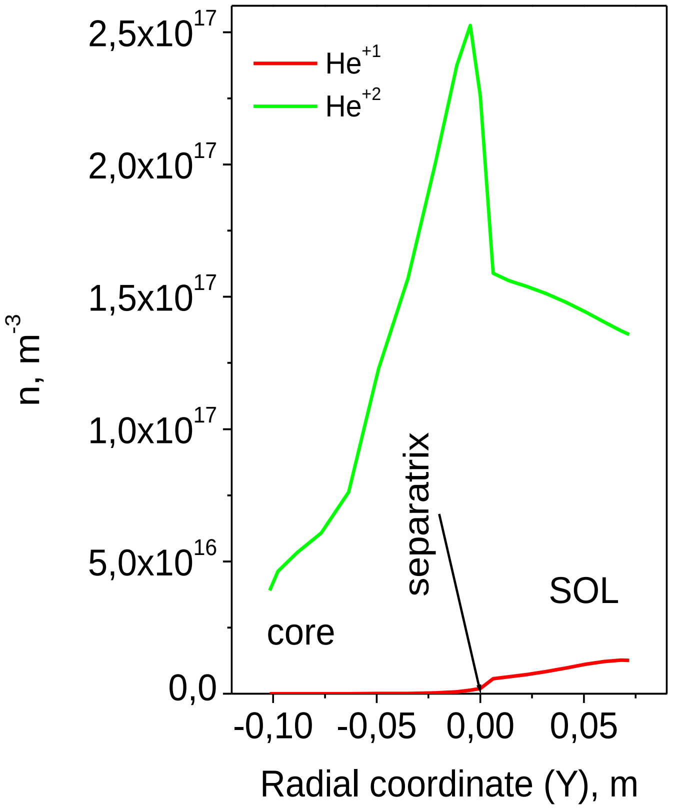
Shot 28093. Components of parallel momentum balance equation for impurity ions

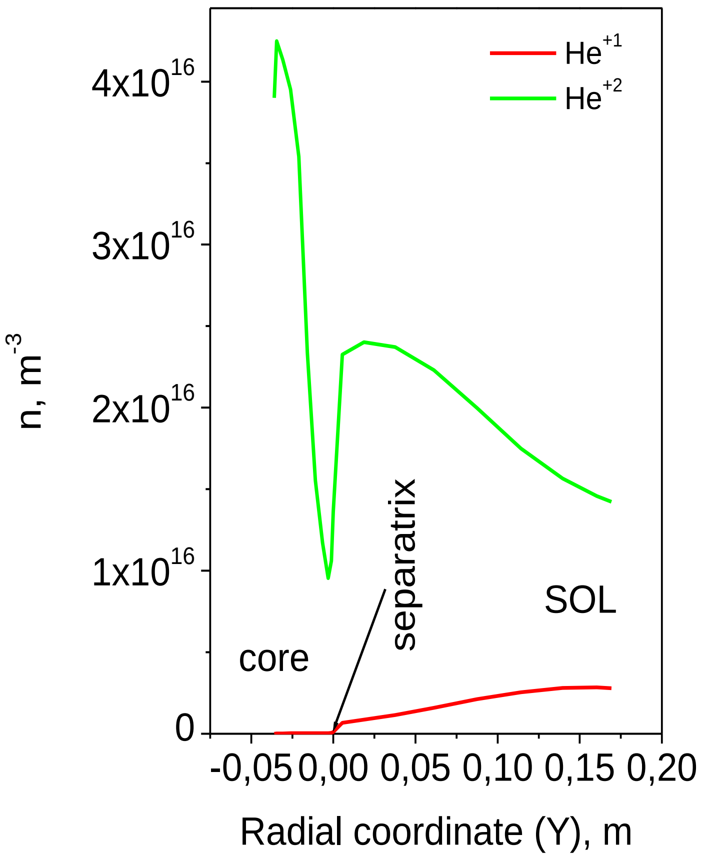


Parallel friction is to large extent balanced by thermal force as predicted by theory

Simulation results for MAST (37th EPS Conf. on Plasma Phys. 2010, Dublin P2.190)

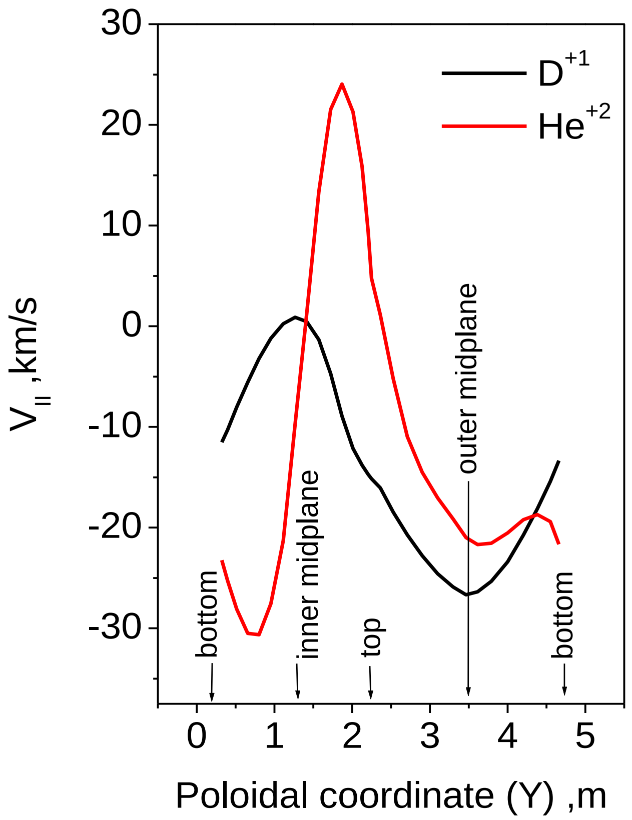
H-mode shot 18751. He ions radial density profiles at HFS (left) and LFS (right). Strong HFS-LFS asymmetry.

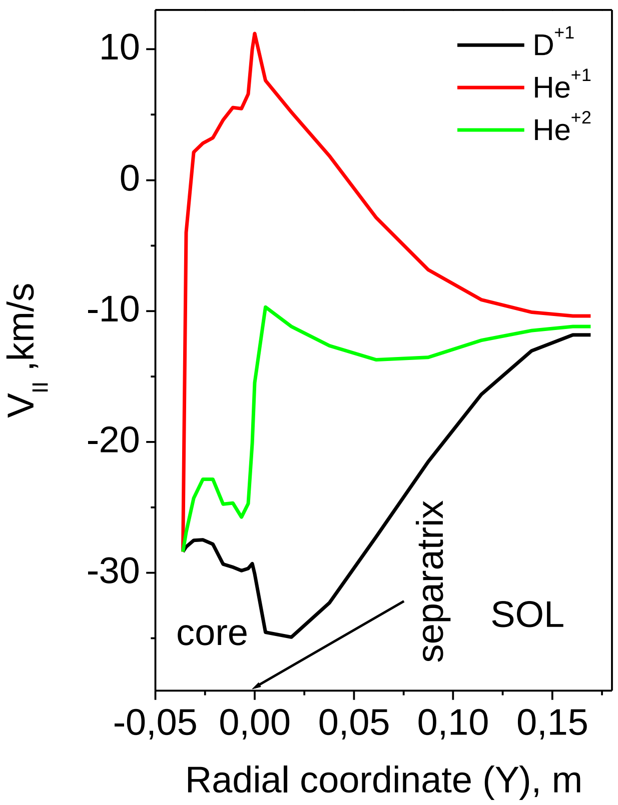




Simulation results for MAST (37th EPS Conf. on Plasma Phys. 2010, Dublin P2.190)

H-mode shot 18751. Poloidal and radial (LFS) profiles of the He ions parallel velocity. He^{+1} parallel velocity is counter current.





Discussion

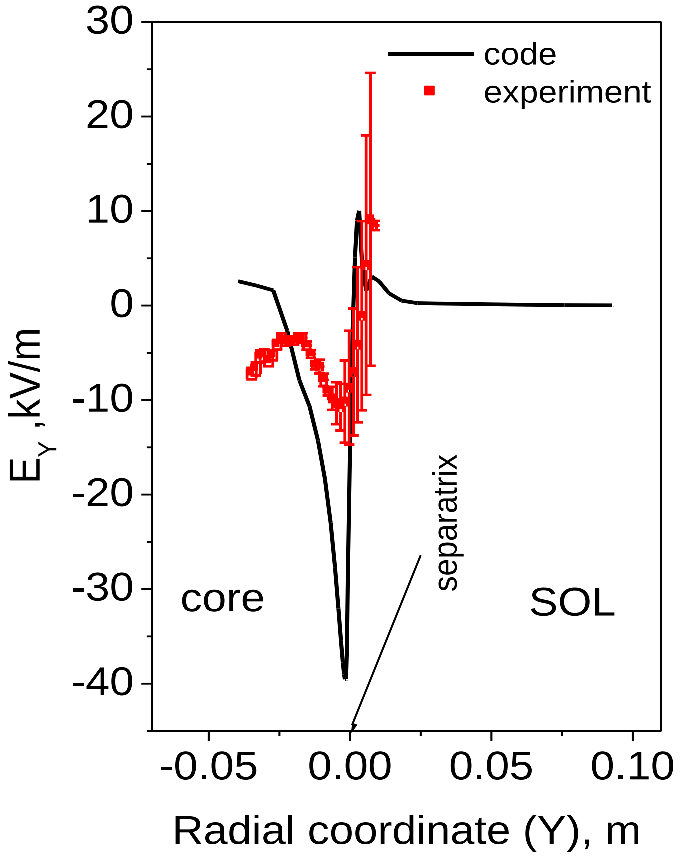
- **The strong LFS-HFS asymmetry of the impurity ion distribution in the edge transport barrier region is obtained in the simulations and in the experiments.**
- **The parallel velocities of impurities are quite different from their PS velocities.**
- **At the LFS the parallel velocities of impurities are shifted in the counter current direction with respect to those of the main ions.**
- **Impurity flows from HFS to LFS could be identified.**

Discussion

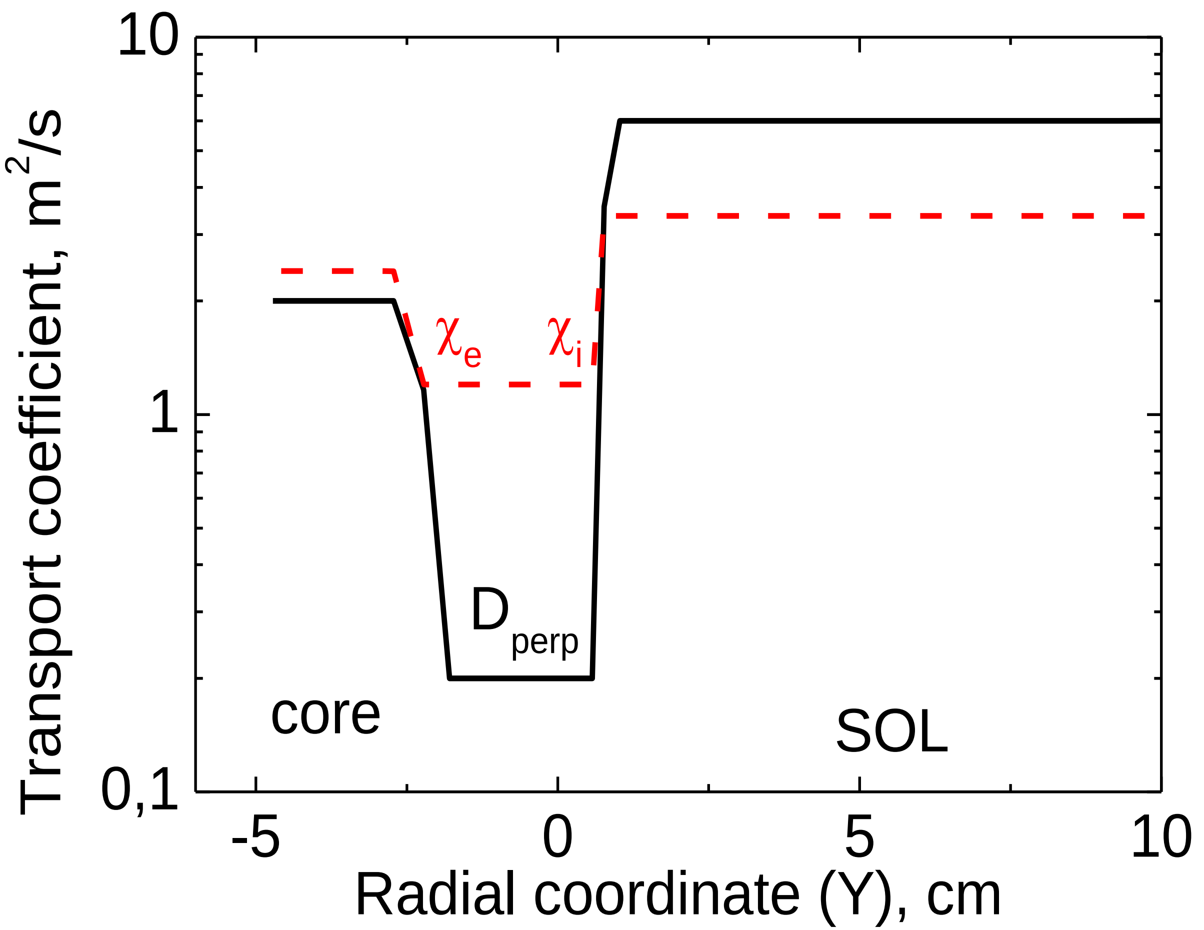
Neoclassical flux of impurities is directed inward and is reduced with respect to standard neoclassical one.

Back up

Radial electric field profile



MAST shot 17469. Transport coefficients



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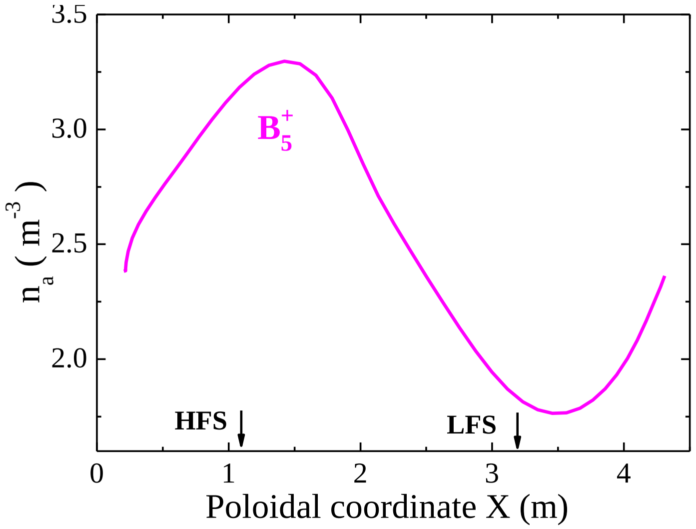
Simulation of the H-mode ASDEX-Upgrade shot with boron as an impurity was done with B2SOLPS5.2 transport code. Strong poloidal asymmetry of B^{+5} ions was obtained in accordance with experiment (E. Viezzer et al Plasma Phys. Contr. Fus.55 (2013) 124037)



Understanding of the asymmetry is based on neoclassical effects and poloidal ExB drifts in plasma with strong gradients (Rozhansky Sov. Journ. Plasma Phys. 5 (1979) 771)