Memorandum

UEDGE simulation of parallel plasma flows of the SOL size in NSTX

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Abstract

The edge-plasma physics code UEDGE was used to simulate the large (comparable to the SOL length) parallel plasma flows in the SOL of NSTX. The calculations show that these plasma flows can be driven by the inboard/outboard asymmetries in the magnetic configuration and in the cross-field transport. In a high aspect ratio tokamak, the strong poloidal variation of the magnetic field strength can provide a powerful mechanism for acceleration and de-acceleration of parallel plasma flows in the SOL. The largest simulated flows occur in the case when inner divertor in the lower single null magnetic configuration is detached. In this case the parallel flow (totalized of about few hundred amperes) originated in the outer divertor accelerates from the flow velocities ~3 km/s at the outer mid-plane up to ~30 km/s (i.e. to the Mach number 0.5-0.7) at the inner mid-plane near the chamber wall and then de-accelerates toward the inner divertor plate. The ion flux carried by parallel flow into the inner divertor is equal to the flux of neutrals penetrating from the inner divertor into the core plasma through the separatrix. The inversion of inboard/outboard asymmetry in the plasma cross-field transport by changing the poloidal profile of anomalous cross-field convective velocity heavily toward the inner SOL results in the reduction of flows and in an attached inner divertor plasmas. The multi-species simulation shows that parallel flows of low charge states (C^{+1} and C^{+2}) of intrinsic carbon impurities can be supersonic in the region between the outer and inner mid-planes.

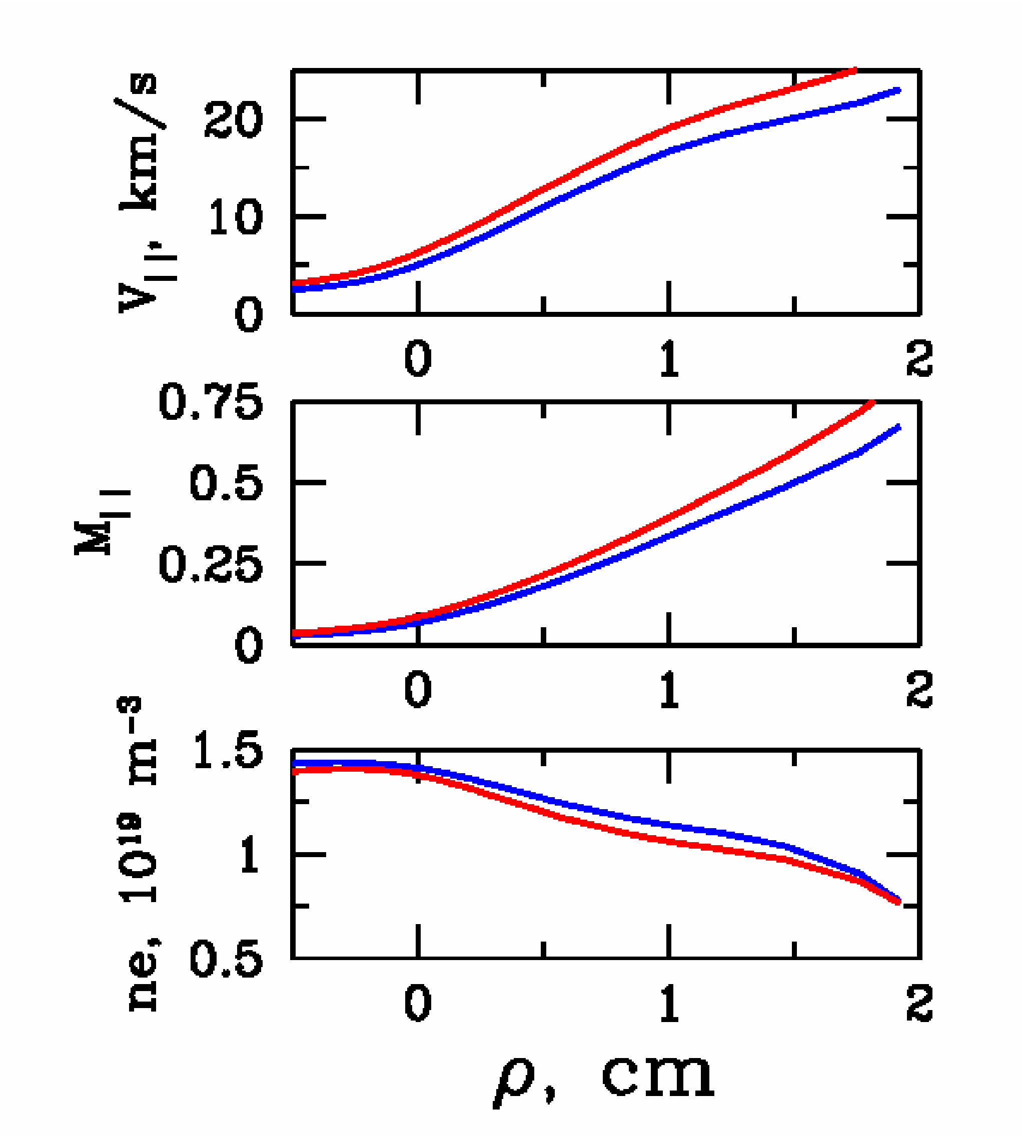

Fig. 1A: "Radial" profiles at the **inner mid-plane in the SOL** of parallel-to-magnetic-field plasma velocity V|| (see upper panel), parallel Mach number M||=V||/sqrt[(Te+Ti)/m_D] (see middle panel), and plasma density ne (see bottom panel). The radial coordinate ρ corresponds to the distance from the separatrix to the given magnetic flux surface at the *outer* mid-plane (positive ρ belong to the SOL). Positive values of V|| and M|| correspond here to the direction toward the inner divertor plate. The blue and red curves differ by the details of poloidal profile of anomalous cross-field convective velocity used in UEDGE calculations.

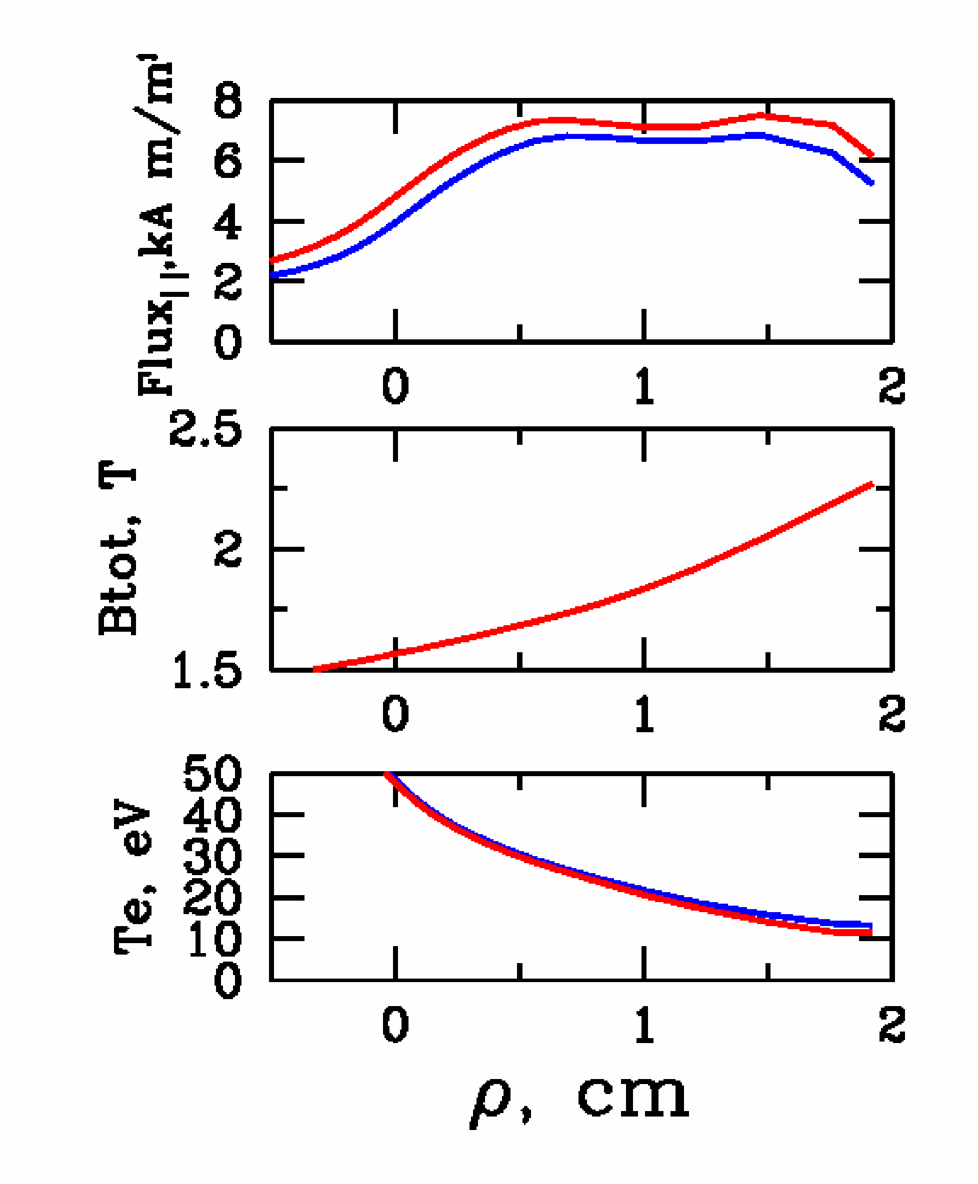

Fig. 1B: "Radial" profiles at the **inner mid-plane in the SOL** of parallel plasma flux Flux|| (see upper panel), total magnetic field strength B_{tot} (see middle panel), and electron temperature Te (see bottom panel). The radial coordinate ρ corresponds to the distance from the separatrix to the given magnetic flux surface at the *outer* mid-plane (positive ρ belong to the SOL). Flux|| is the plasma flux integrated over toroidal angle. Positive values of Flux|| correspond here to the direction toward the inner divertor plate. The blue and red curves differ by the profiles of anomalous cross-field convective velocity used in UEDGE calculations.

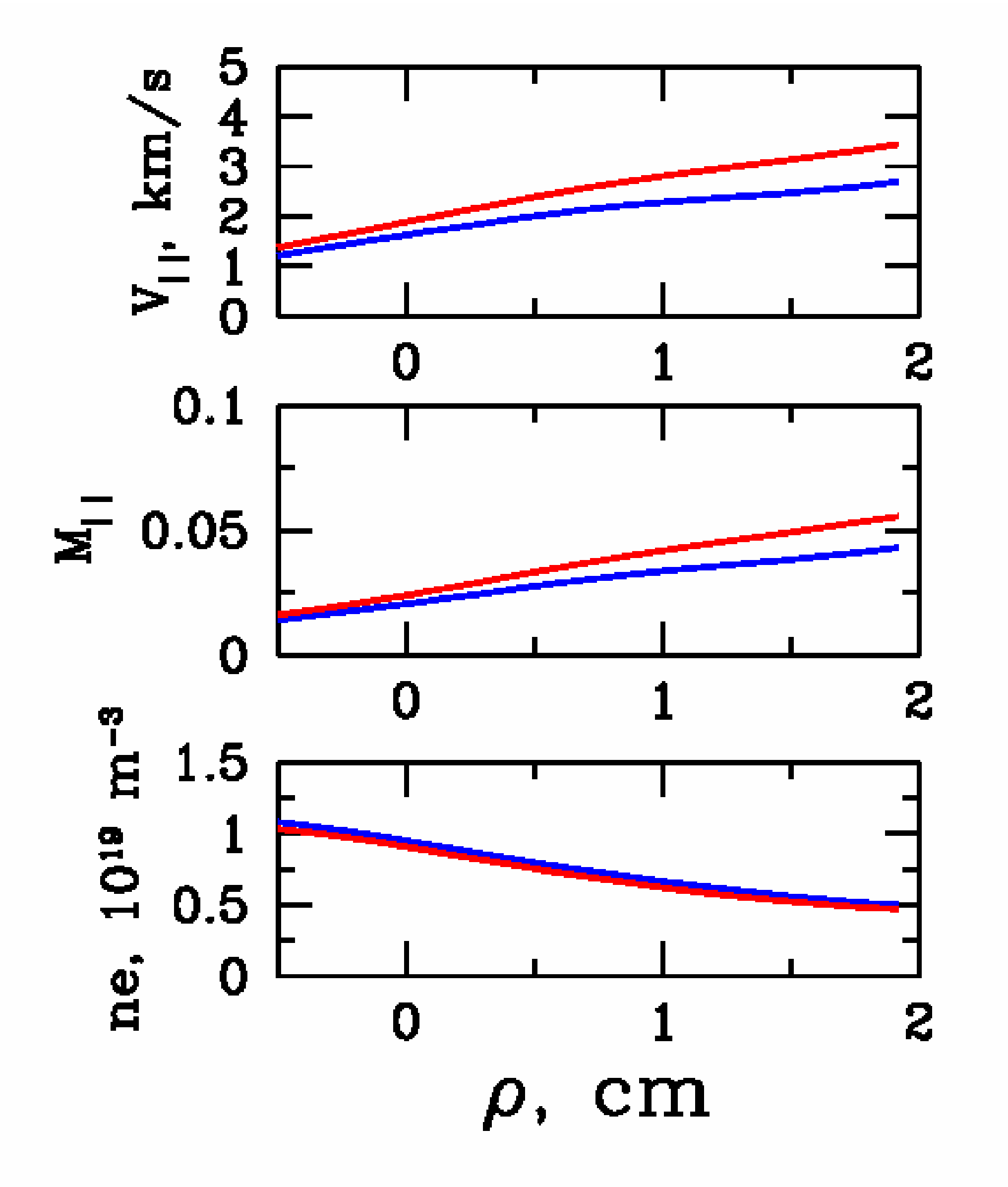

Fig. 2A: “Radial” profiles at the **outer mid-plane in the SOL** of parallel-to-magnetic-field plasma velocity V|| (see upper panel), parallel Mach number M||=V||/sqrt[(Te+Ti)/m_D] (see middle panel), and plasma density ne (see bottom panel). The radial coordinate ρ corresponds to the distance from the separatrix to the given magnetic flux surface at the *outer* mid-plane (positive ρ belong to the SOL). Positive values of V|| and M|| correspond here to the direction toward the inner divertor plate. The blue and red curves differ by the profiles of anomalous cross-field convective velocity used in UEDGE calculations.

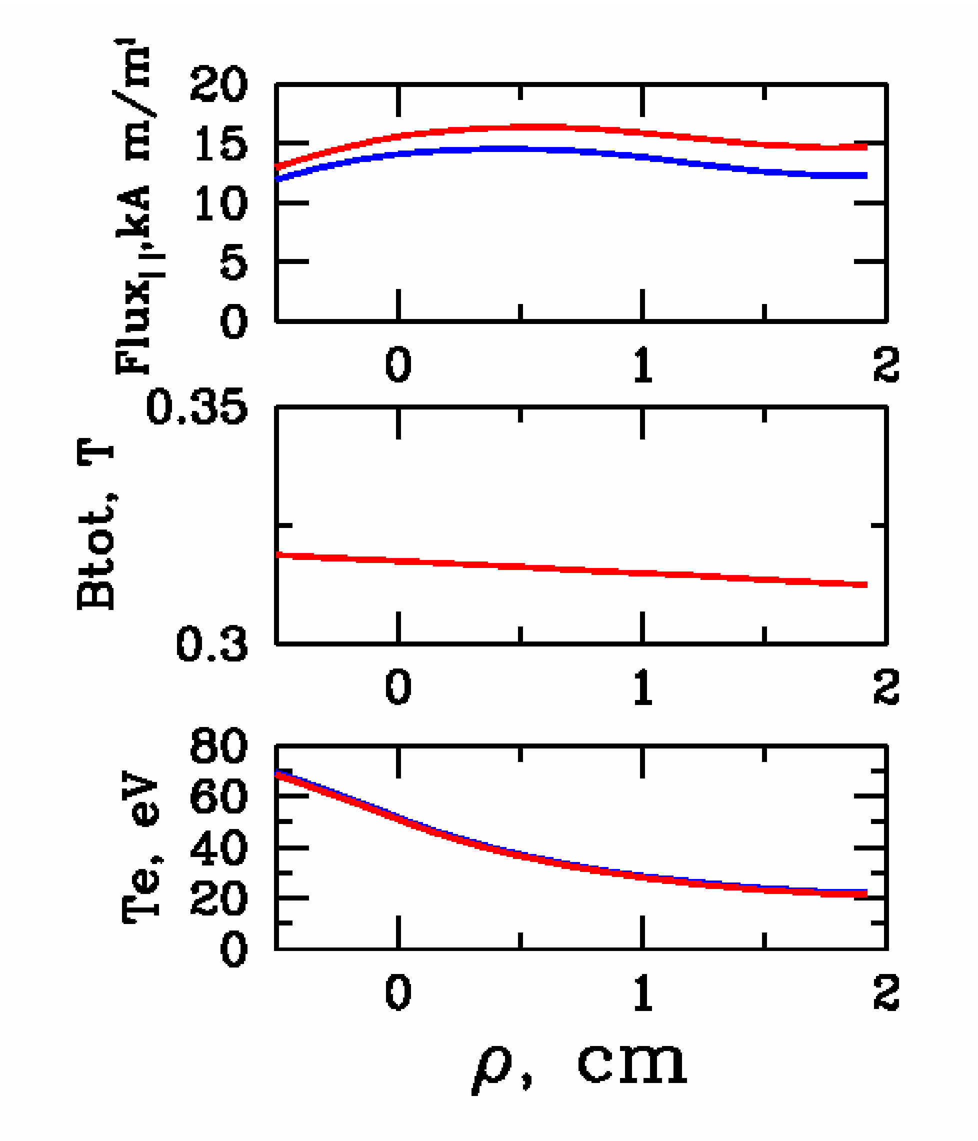

Fig. 2B: "Radial" profiles at the **outer mid-plane in the SOL** of parallel plasma flux Flux|| (see upper panel), total magnetic field strength B_{tot} (see middle panel), and electron temperature Te (see bottom panel). The radial coordinate ρ corresponds to the distance from the separatrix to the given magnetic flux surface at the *outer* mid-plane (positive ρ belong to the SOL). Flux|| is the plasma flux integrated over toroidal angle. Positive values of Flux|| correspond here to the direction toward the inner divertor plate. The blue and red curves differ by the profiles of anomalous cross-field convective velocity used in UEDGE calculations.

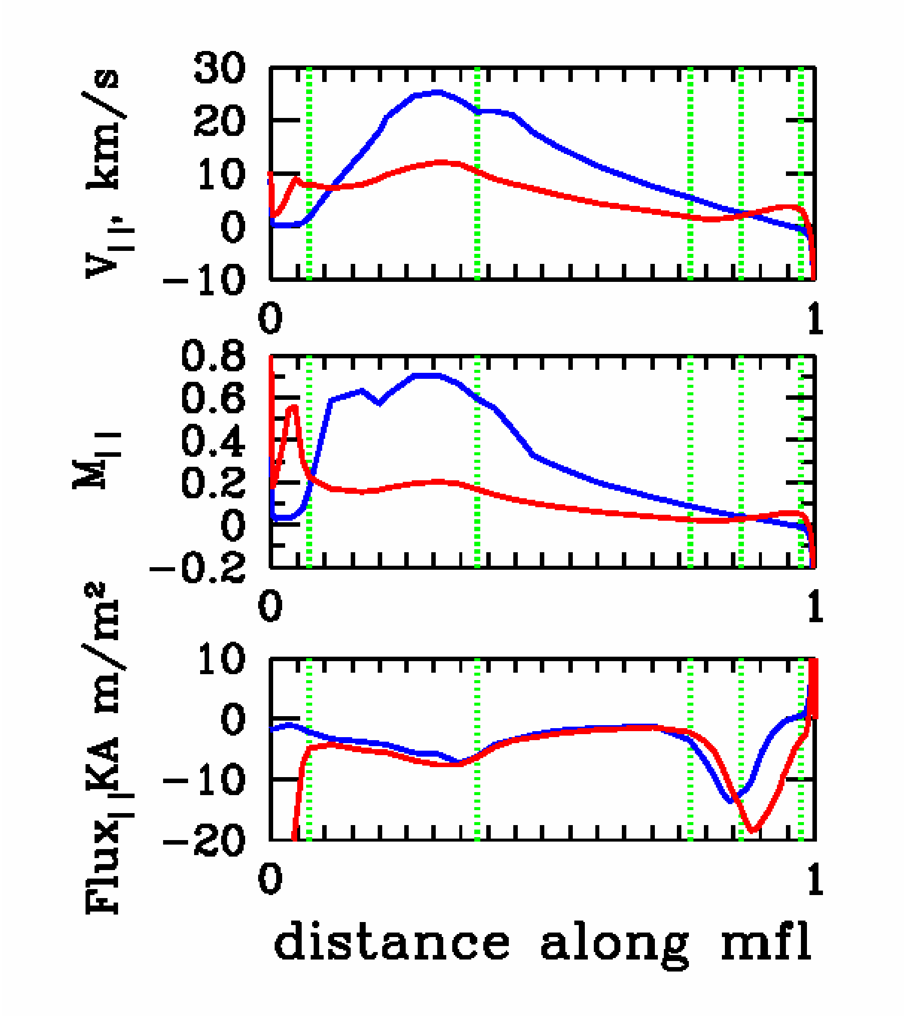

Fig. 3: The plasma flow velocity V|| (see upper panel), parallel Mach number $M||=V||/sqrt[(Te+Ti)/m_D]$ (see middle panel), and plasma flux Flux|| intregrated over toroidal angle (see bottom panel) are shown versus the normalized distance along the magnetic field line (mfl) in the SOL. The zero distance corresponds to the inner divertor plate whereas the unity distance corresponds to the outer divertor plate. Five vertical green lines stand for conventional location of: entrance into inner divertor (at 0.07), inner mid-plane (at 0.38), top of LSN (at 0.772), outer mid-plane (at 0.87), and entrance into the outer diveror (at 0.975). Here, positive values of V||, M||, and Flux|| correspond to the direction toward the inner divertor plate. The blue curves correspond to the magnetic flux surface (ρ=1.78 cm or ψ_N=1.071) near the inner wall. The red curves correspond to the magnetic flux surface (ρ=0.5 cm or ψ_N=1.02) in the middle of the SOL.

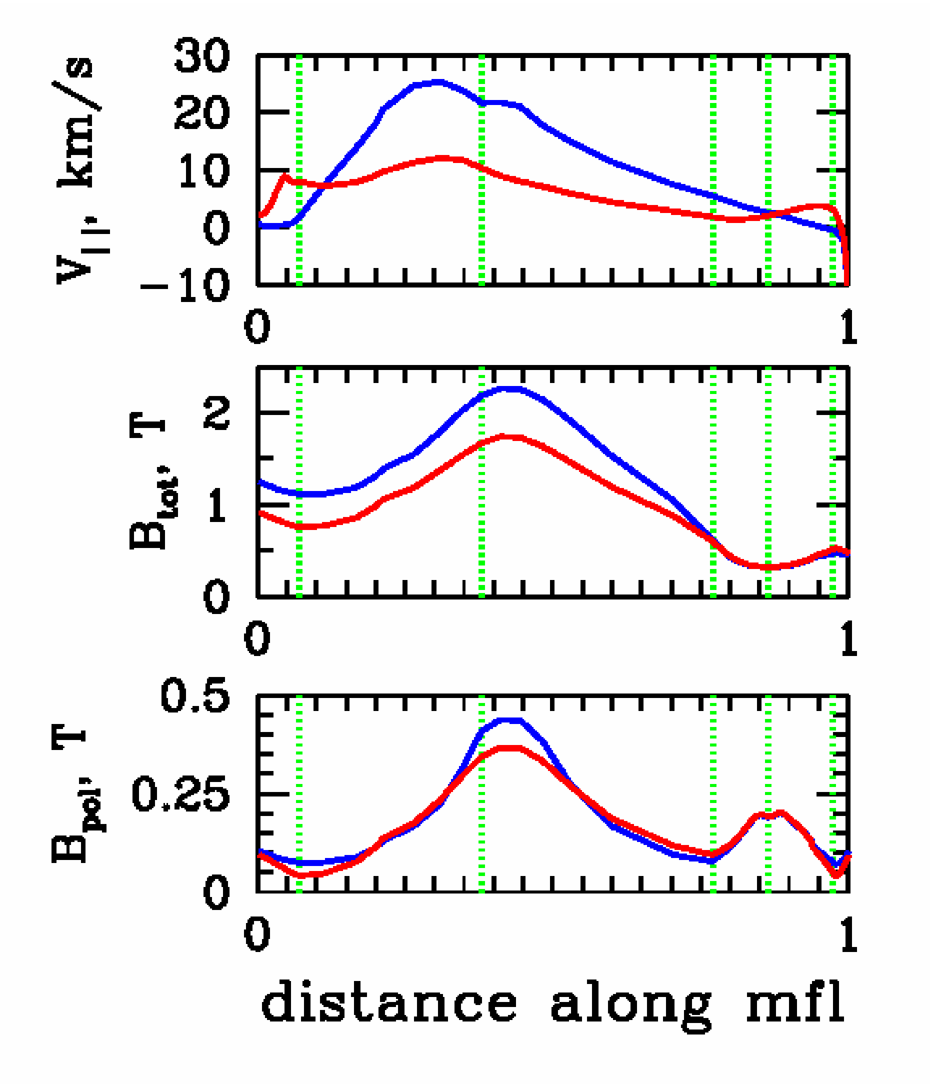

Fig. 4: The plasma flow velocity V|| (see upper panel), total magnetic field strength (see middle panel), and poloidal magnetic field strength (see bottom panel) are shown versus the normalized distance along the magnetic field line (mfl) in the SOL. The zero distance corresponds to the inner divertor plate whereas the unity distance corresponds to the outer divertor plate. Five vertical green lines stand for conventional location of: entrance into inner divertor (at 0.07), inner mid-plane (at 0.38), top of LSN (at 0.78), outer mid-plane (at 0.87), and entrance into the outer diveror (at 0.975). Here, positive values of V|| correspond to the direction toward the inner divertor plate. The blue curves correspond to the magnetic flux surface (ρ=1.78 cm or ψ_N=1.071) near the inner wall. The red curves correspond to the magnetic flux surface (ρ=0.5 cm or ψ_N=1.02) in the middle of the SOL.

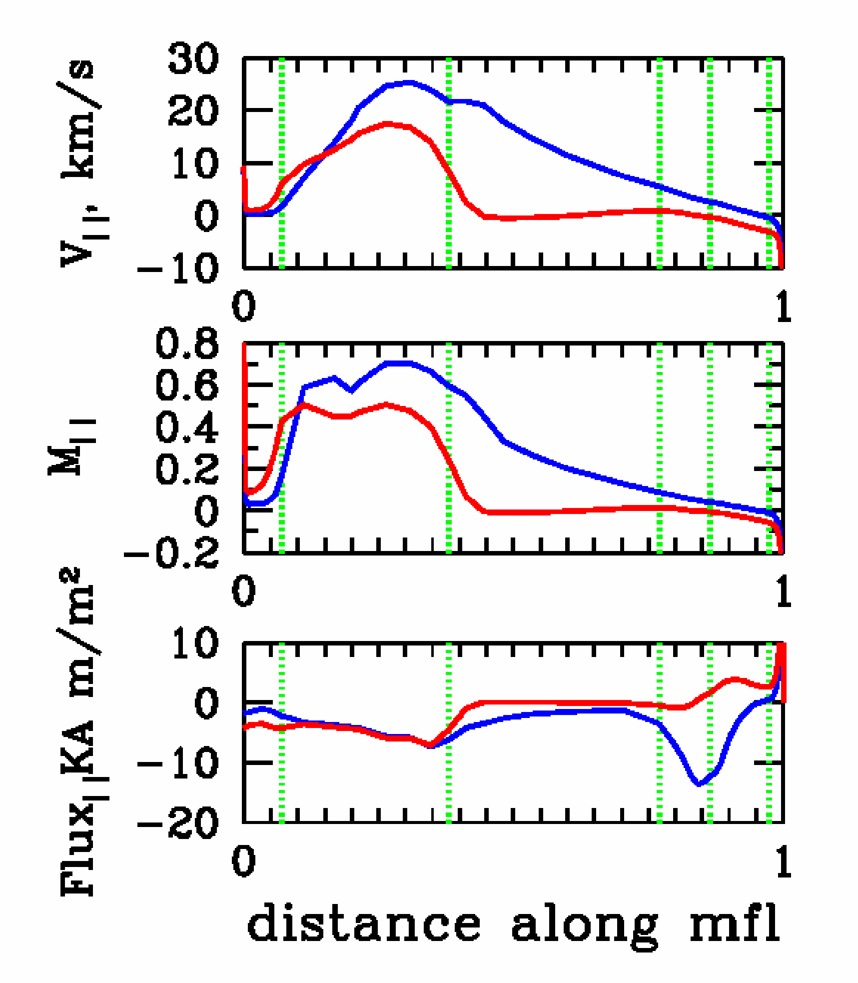

Fig. 5: The plasma flow velocity V|| (see upper panel), parallel Mach number M|| (see middle panel), and plasma flux Flux|| intregrated over toroidal angle (see bottom panel) are shown versus the normalized distance along the magnetic field line (mfl) in the SOL. The zero distance corresponds to the inner divertor plate whereas the unity distance corresponds to the outer divertor plate. Five vertical green lines stand for conventional location of (from left to right): entrance into inner divertor, inner mid-plane, top of LSN, outer mid-plane, and entrance into the outer diveror. Here, positive values of V||, M||, and Flux|| correspond to the direction toward the inner divertor plate. The curves are given for the magnetic flux surface (ρ=1.78 cm or ψ_N=1.071) near the inner wall in the SOL. The red curve corresponds to the case when inner divertor is attached with Te≈8 eV in the inner strike point. The blue curve corresponds to the case when inner divertor is detached with Te≈1 eV in the inner strike point.

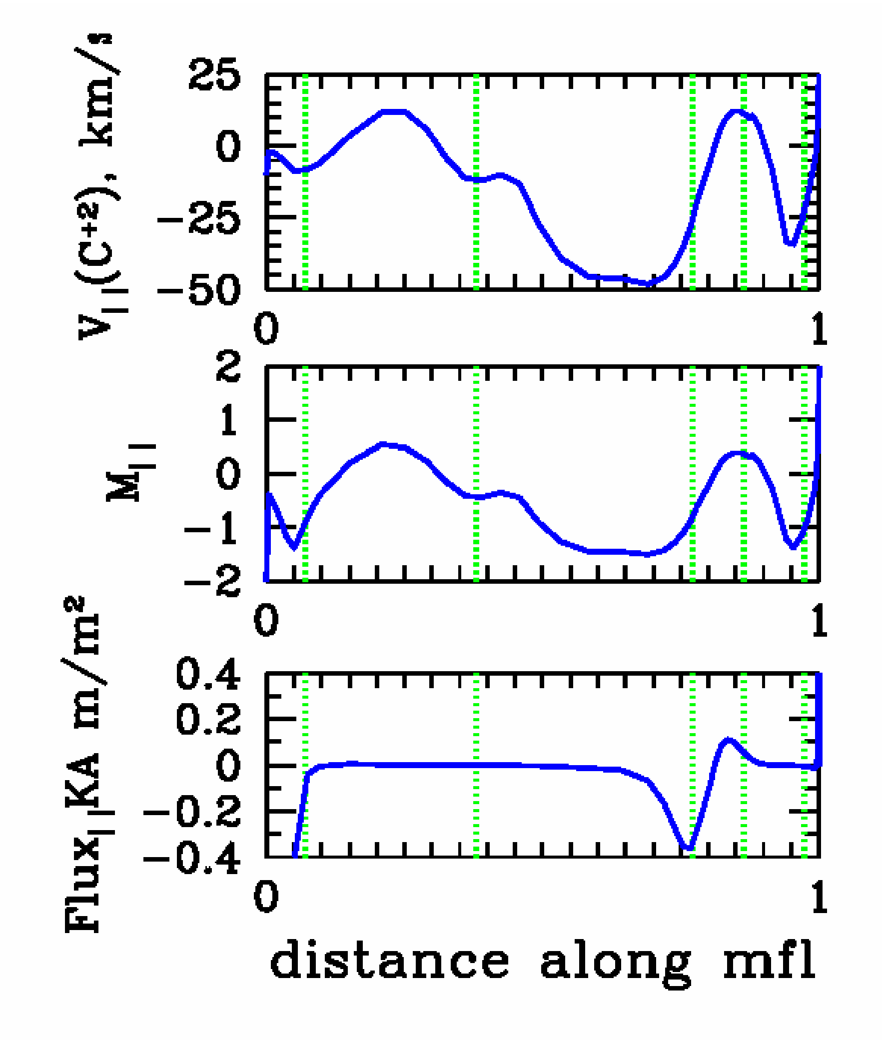

Fig. 6: The C^{+2}-ion flow velocity V|| (see upper panel), parallel Mach number M||=V||/sqrt[(Te+Ti)/m_C] of this ion (see middle panel), and C^{+2} flux Flux|| intregrated over toroidal angle (see bottom panel) are shown versus the normalized distance along the magnetic field line (mfl) in the SOL. The zero distance corresponds to the inner divertor plate whereas the unity distance corresponds to the outer divertor plate. Five vertical green lines (from left to right) stand for conventional location of: entrance into inner divertor, inner mid-plane, top of LSN, outer mid-plane, and entrance into the outer diveror. Here, positive values of V||, M||, and Flux|| correspond to the C^{+2} flow direction toward the outer divertor plate. The curves are given for the magnetic flux surface (ρ=0.5 cm or ψ_N=1.02) in the middle of the SOL. The blue and red curves are for C^{+2} and C^{+1} ions, respectively.

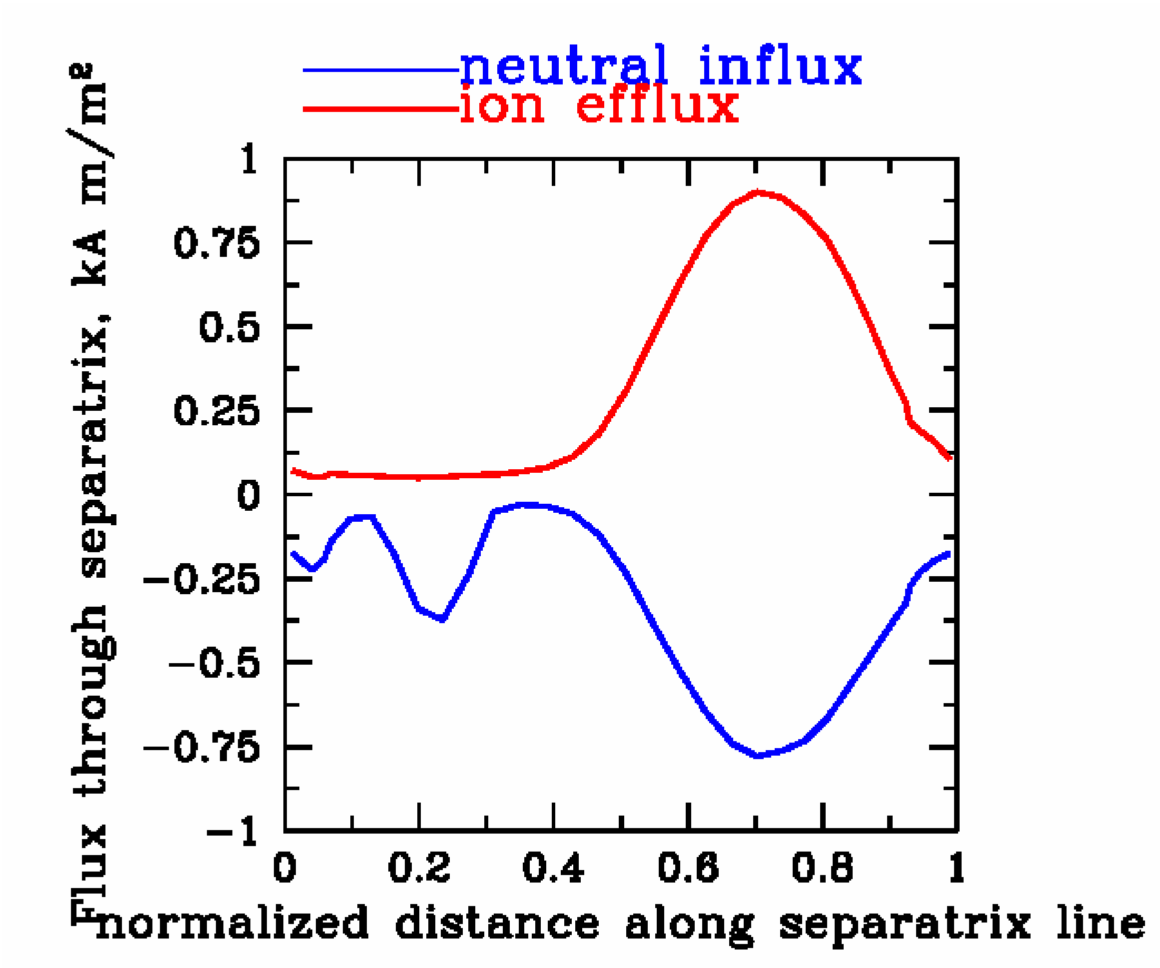

Fig. 7: The poloidal distributions of plasma ion (red curve) and neutral atom (blue curve) fluxes passing through the separatrix. The fluxes are integrated over the toroidal angle. The distance along the separatrix line in LSN magnetic configuration is counted clockwise from X-point to X-point. The actual length of line is 5.89 m. The neutral flux distribution has three peaks that correspond, respectively, to neutrals penetrating from the divertor, neutrals due to gas puff at the central stack (600 A), and neutrals recycling at the outboard chamber wall. The integral flux of neutrals leaking from the divertor is equal to the ion flux carried by parallel plasma flow excluding the small fraction pumped by wall.