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Investigation on radial transport of perpendicular momentum in the SOL of AUG during L-I-H transition

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Transport in the edge and scrape-off layer (SOL) region of magnetically confined plasmas is dominantly turbulent, caused by strong events in the form of filamentary structures that originate from the outboard midplane and are elongated along the magnetic field [1]. In addition to particles and energy also momentum is transported radially by turbulence.

We have investigated the radial transport of momentum perpendicular to the total magnetic field (**B**$_{total}$) in the SOL of ASDEX Upgrade during L-mode (*Fig.1*), using the Innsbruck-Padova probe head (*Fig.2*). The radial transport of perpendicular momentum (M_r) has been estimated using electric fields derived from the potential difference of floating pins and the plasma density estimated from the ion saturation current of negatively biased pin.

$$M_r = n\, v_r\, v_\perp$$

$$\approx n\, (-E_\perp B_{total}^{-1})\, (E_r B_{total}^{-1})$$

$$\approx n\, (V_{fl,2}-V_{fl,5})\, (d_{\perp,2\text{-}5} B_{total})^{-1}\, (V_{fl,1}-V_{fl,2})\, (d_{r,2\text{-}1} B_{total})^{-1}$$

$$n \approx I_{is,4}\, (e\, A_{p,i})^{-1}\, (m_i / T_e)^{1/2}$$

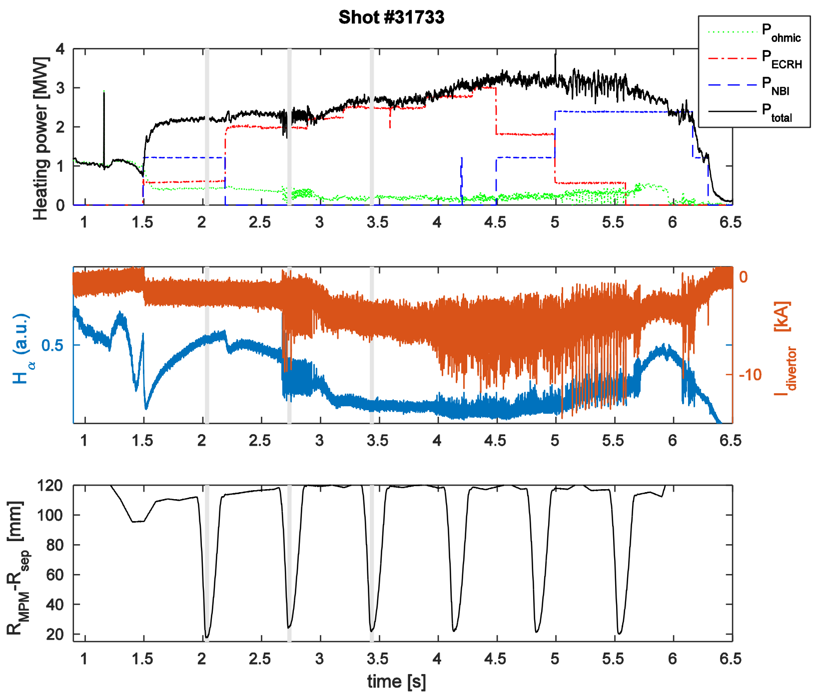

Fig.1: Hydrogen plasma shot in AUG. Top: heating scheme. Middle: light emission and divertor current indicating the different confinement regimes: L-mode <2,6s <I-phase <2,9s < H-mode Bottom: Position of the midplane manipulator (MPM), on which the Innsbruck-Padova probe head was mounted, with respect to the separatrix (located by magnetic reconstruction). Vertical grey bars: 30 ms time intervals used in the probe data evaluation

We split all quantities into stationary and fluctuating components:

$n = n_0 + n_f$; $v_r = v_{r,0} + v_{r,f}$; $v_\perp = v_{\perp,0} + v_{\perp f}$

$M_r \approx n_0\, v_{r,f}\, v_{\perp f} + n_f\, v_{r,f}\, v_{\perp,0} + n_f\, v_{r,f}\, v_{\perp f}$

$M_r \approx Re + v_{\perp,0}\, \Gamma_{r,f} + n_f\, v_{r,f}\, v_{\perp f}$

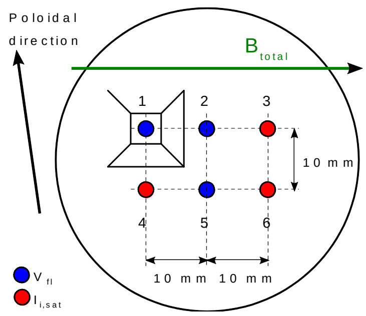

Fig.2: *Innsbruck-Padova probe head: six graphite pins, 1 mm diameter, 2 mm length. Pin #1 radially protruding by 3 mm, i.e. deeper into the plasma. Probe head aligned to the direction of the total magnetic field. Blue: floating potential. Red: ion saturation current*

The plasma density estimated from ion saturation current and radial transport of perpendicular momentum (M_r) and its subcomponents are presented in *Fig. 3*, for L-mode, L-I-H transitions and H-mode.

Since the charged particles also carry heat from the edge of the closed-field region of plasma, it is expected for density fluctuations (n_f) to be in phase with electron temperature fluctuations ($T_{e,f}$) and plasma potential fluctuations ($V_{p,f}$) [2]. It is known that the floating potential is affected by electron temperature: $V_{fl}=V_p-\alpha T_e$, $\alpha\approx 3$. In this perspective, the phase relation between n estimated by ion saturation current and floating potential is investigated.

By conditionally averaging samples of all recorded signals during L-mode, triggered by events higher than 2 standard deviations in the estimated density from pins 3 and 4 (*Fig.4*), we observe that n_f is in phase with $V_{fl,f}$ for pins located on the same magnetic field line (e.g. pins 1-2-3). Although this result appears to be in contradiction with [2], it might be caused by

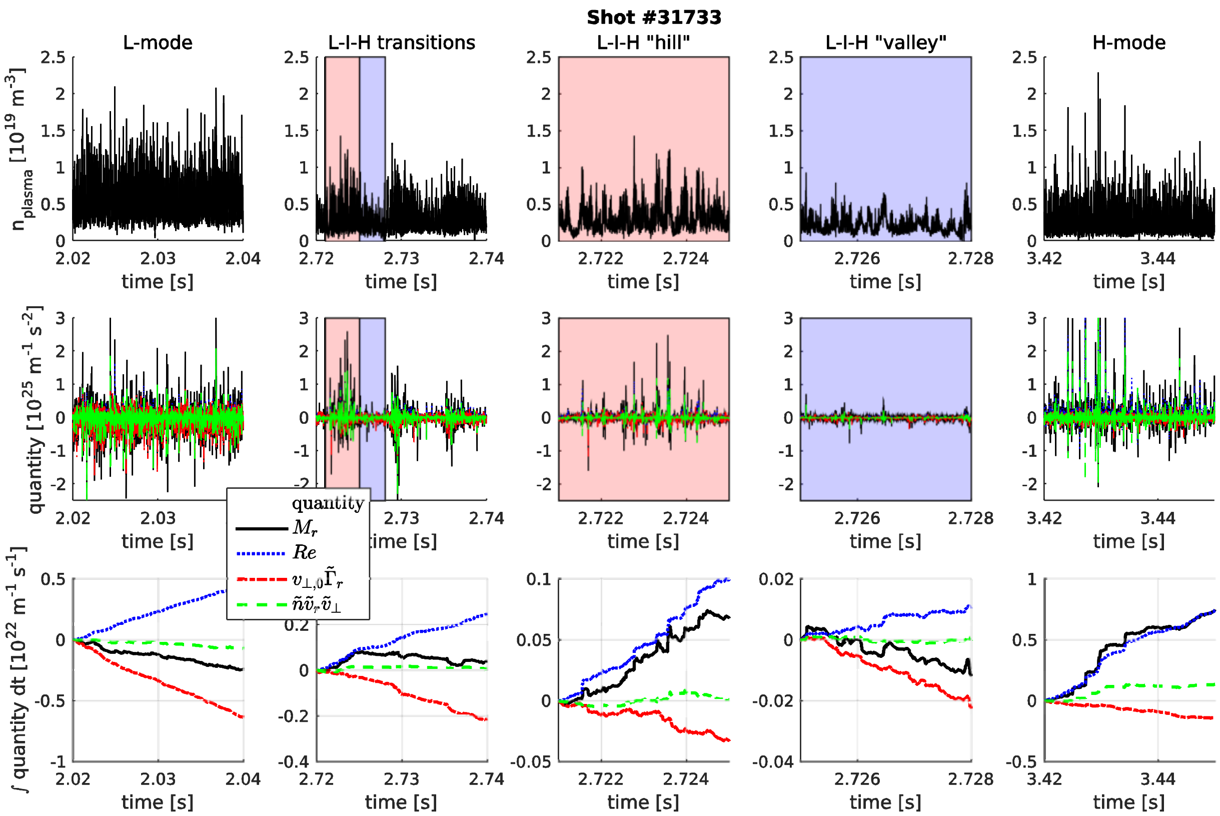

Fig.3: *Estimated plasma density from ion saturation current (1st row), radial transport of perpendicular momentum (M_r) and its subcomponents (2nd row) and time-integrated M_r and subcomponents (3rd row) during L-mode (1st column), L-I-H transitions (2nd - 4th column) and H-mode (5th column).*

smaller values $T_{e,f}$ compared to $V_{p,f}$, and so the phase between $V_{fl,f}$ and $V_{p,f}$ is preserved but the amplitude of $V_{fl,f}$ is reduced. For the pins sitting on a different magnetic field line than the trigger, we observe a delay of ~10 μs which corresponds to a typical $v_{\perp}$=1 km/s flow. Since the perpendicular pin separation is comparable to blob size [1], in the case of floating pins not aligned with the trigger along $\mathbf{B}_{total}$ (e.g. pin 1 and 2, 2nd column) the average of samples is not a defined peak (as pin 1 and 2 in the 1st column) but a combination of positive and negative peaks, indicating the ambipolar structure of blobs, as also seen here [3].

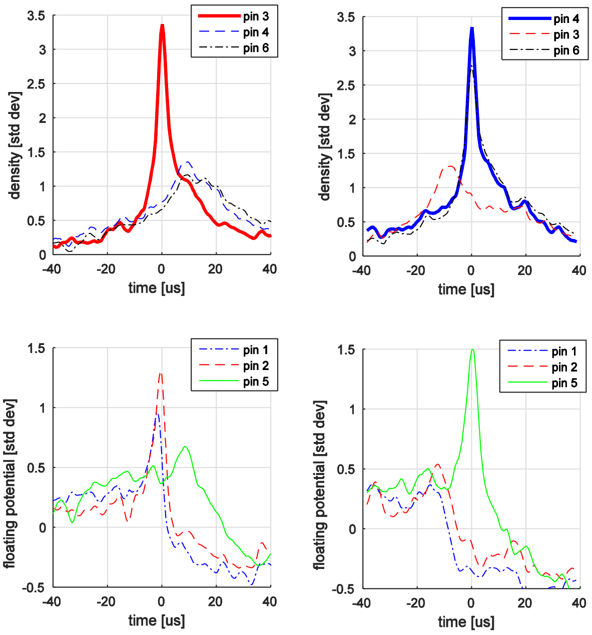

***Fig.4**: Conditionally averaged samples of all recorded signals triggered by events in the estimated density from pin 3 (1st column) and pin 4 (2nd column).*

To test the validity of using the floating potential instead of the plasma potential, in the absence of localized electron temperature fluctuation measurements, a comparison with simulation has been performed. ESEL is a 2-dimensional inter-change turbulence code which simulates the edge-SOL region on the outboard midplane of a tokamak in the plane perpendicular to the total magnetic field (slab geometry). It makes use of an electrostatic fluid model which solves the equations for continuity, momentum and electron temperature [4]. A virtual probe head consisting of separated synthetic point-pins was placed 1 cm away from the separatrix in order to simulate the experimental probe head and the recorded signals during a L-mode discharge. The synthetic signals provided by the simulation on each synthetic pin are: plasma potential, plasma density, electron temperature and perpendicular and radial flow velocities. From these, the synthetic ion saturation current and the synthetic floating potential signals are constructed.

Results of synthetic diagnostic data (cold Langmuir pins, ion saturation pins) are in very good agreement with the experimental data (*Fig.5*, column 1).

If we compare the synthetic diagnostic data with simulation results (density, radial and perpendicular velocities, *Fig.5* column 3), we see that in the cold pin case the convective momentum has opposite direction with respect to the simulated one. If the cold pins are replaced by highly emissive pins ($V_{floating}=V_{plasma}$) then the convective momentum ($v_{\perp,0}\,\Gamma_{r,f}$) of the synthetic emissive probe diagnostic agrees with the simulated data but the Reynolds stress

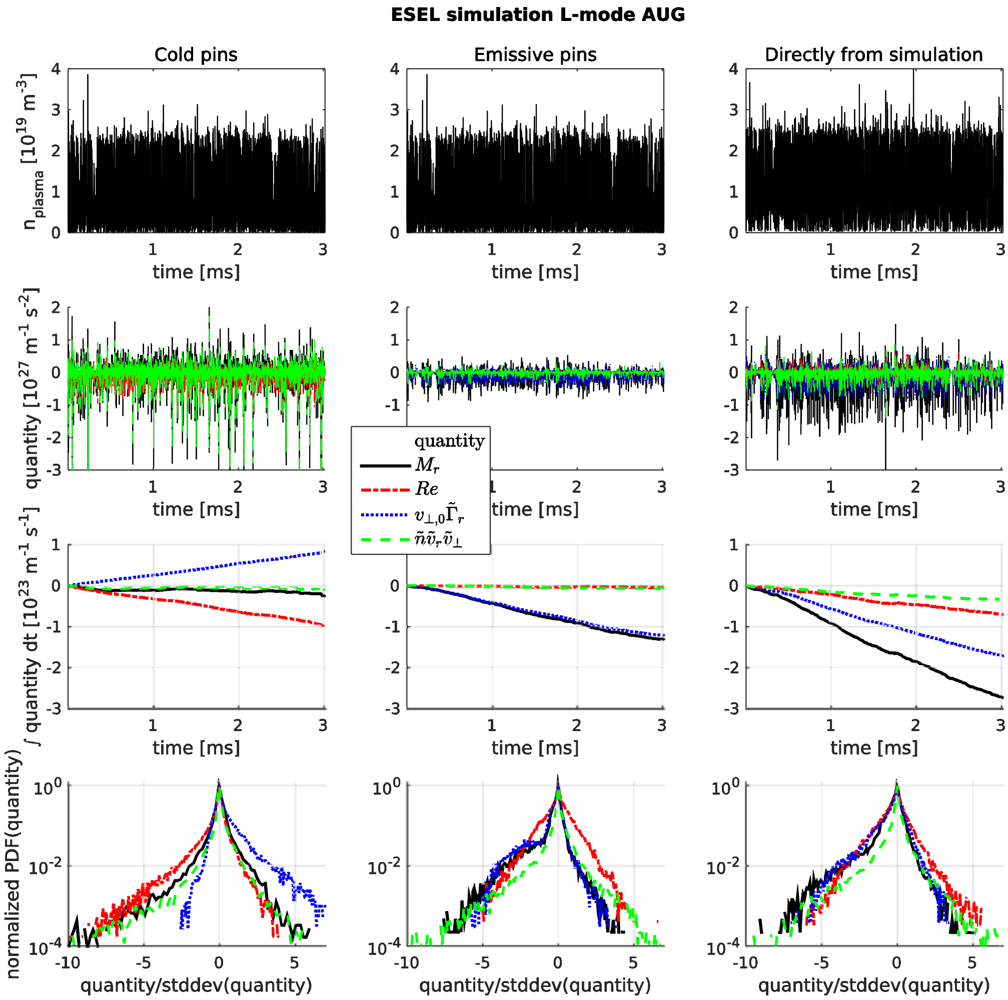

Fig.5: *Analysis on M_r from synthetic probe measurements simulating the experimental probe head in L-mode plasma.* *Column 1: simulated Langmuir cold pins and ion saturation pins.* *Column 2: simulated emissive pins ($V_{floating}$= V_{plasma}) and ion saturation pins.* *Column 3: real density and velocities directly from simulation.*

is underestimated. Furthermore, the emissive pins preserve the probability density function (*Fig.5*, 4th row), of the simulated momentum transport and its subcomponents, even though the overall amplitude of the signals is reduced, possibly due to the pin separation.

In conclusion, we see a clear difference in the radial transport of perpendicular momentum and its subcomponents between the L-mode and H-mode. During L-I-H transitions the transport seems to be an alternation between L- and H-mode transport. The simulation could recreate the experimental time-integrated momentum transport but it indicates that one should take care when using cold floating potential as estimation of plasma potential in the presence of electron temperature fluctuations.

Acknowledgement

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