Study of impurity ions transport through the CX diagnostic in TCV

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1. Introduction – Large portions of TCV's 2020/2021 experimental campaign focused on the investigation of the physics of negative triangularity in terms of confinement, stability and particle transport, both in limited and diverted configurations. Results from the mission "impurity transport and rotation profiles in negative triangularity" are presented in this work. Previous experiments in TCV focused on the investigation of plasma shape effects on energy confinement and turbulence strength [3]. This work extends these scenarios with emphasis on a comparison between rotation profiles and carbon density distribution in positive and negative δ. Research on this topic is fundamental for understanding turbulent and neoclassical transport properties in tokamaks, as well as the physics behind negative triangularity.

Light impurities transport is mainly driven by turbulence. The turbulent flux (Γ^{TURB}) can be written as a combination of diffusive and convective terms (Eq. 1) [2, 4].

$$\frac{R\Gamma_{nZ}^{TURB}}{n_Z}=D_{nZ}\frac{R}{L_{nZ}}+D_{Th,Z}\frac{R}{L_{TZ}}+D_{uZ}u'+RV_{pZ} \quad ; \quad u'=\frac{R^2}{v_{Therm}}\frac{d\Omega_t}{dR} \quad ; \quad L_g=\left(\frac{dln(g)}{dr}\right)^{-1} \qquad (1)$$

Where R is the major radius, L_{nZ} and L_{TZ} are the impurity density and temperature logarithmic gradients and V_{pZ} is the convective velocity (see also [5]). The first term is the particle diffusion, with the second and the third the thermal and roto-diffusion terms, respectively. The final term represents the convection flux. Carbon is naturally present in TCV due to the graphite tiled walls and is therefore considered as the main impurity.

CXRS on TCV provides local measurements of T_i, n_C and v_{Tor} with lines of sight covering the entire LFS and HFS vessel section [1]. Therefore, it is possible to obtain all the quantities appearing in the turbulent flux from CXRS radial profiles.

2. Experimental scenarios – I. A scan from δ = -0.6 to δ = +0.6 in limited (Fig. 1)

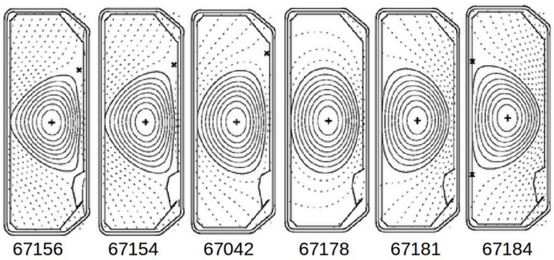

Figure 1 – Scan from δ = -0.6 to δ = +0.6 in limited configuration without adding any auxiliary heating.

configuration without adding any auxiliary heating.

II. A scan from δ = -0.6 to δ = +0.6 in diverted configuration.

III. The same scan as I with the addition of 5 NBI pulses of increasing power (0.25 MW per pulse) separated by 100 ms OFF phases allowing for the CXRS evaluation of kinetic profiles both during and after the pulse injection, with the aim of investigating the strong changes in energy confinement associated to changes in toroidal velocity and C density distribution.

3.1 Ohmic discharges - A strong correlation between the logarithmic density gradient and the logarithmic temperature gradient was found for negative δ discharges at mid-radius. Conversely, positive δ discharges did not show the same pattern (Fig. 2).

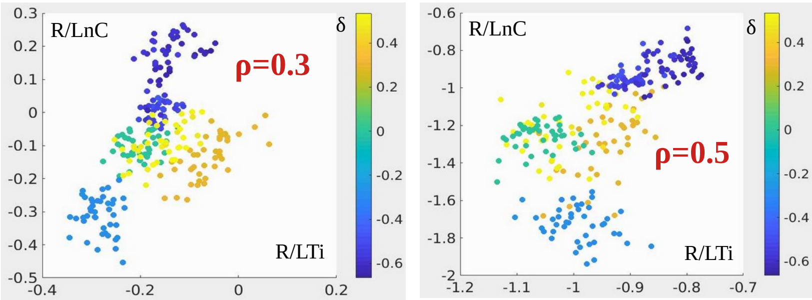

Figure 2 – Logarithmic ion density gradient as a function of logarithmic ion temperature gradient at ρ=0.3 (left) and ρ=0.5 (right). Triangularity is indicated through the colorbar.

Temperature and density profiles at positive triangularity (yellow scale) tend to be flat or slowly decreasing at ρ = 0.3. In contrast, negative δ configurations span a wider region of the plot. For low negative absolute values of δ (~-0.2) both the temperature and density gradients are negative (descending phase). As the absolute value of δ increases (~-0.4), T_i profiles decrease more slowly and n_C profiles are flat. When the maximum value of negative δ is reached, density profiles become peaked at ρ = 0.3. The same linear trand is found at ρ = 0.5, where high negative δ plasmas display a slower descent with respect to the low absolute negative triangularity cases or the positive δ counterpart.

Fig. 3 shows the correlation between the density gradient and the toroidal velocity gradient at mid-radius (ρ = 0.5).

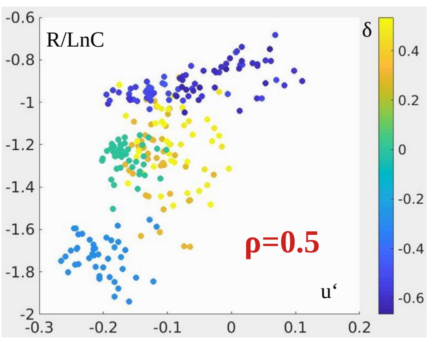

Figure 3 – Logarithmic density gradient as a function of toroidal velocity gradient at mid-radius (ρ = 0.5). Profiles in negative triangularity (blue scale) change concavity between low absolute negative δ values (~-0.2) to extreme ones (~-0.6). No correlation is found for positive δ discharges (yellow scale).

While the positive and zero δ discharges (yellow scale) do not show any particular correlation, the negative triangularity counterpart exhibits again a trend. In particular, density and velocity profiles at low absolute negative δ (~-0.2) are both in a decreasing phase.

At higher absolute negative δ (from -0.4 to -0.6), density profiles decrease more slowly. Toroidal velocity gradient changes from ~-0.1 at δ = -0.4 to ~+0.1 at δ = -0.6.

3.2 NB heating and momentum injection – The 5 toroidally tangential NBI pulses allow for increasing external momentum injection, extending the previous low torque and low intrinsic rotation scenario to highly rotating plasmas. A correlation analysis similar to the one performed in ohmic discharges was conducted. Besides the expectable increasing T_i during beam injection (higher for δ < 0, see also [3]), striking differencies were found in toroidal velocity and density profiles between positive and negative δ, most probably related to the improved confinement displayed by negative triangularity plasmas.

Results from opposed sign triangularity discharges are compared in the following.

Fig. 4 shows the energy confinement time as a function of time.

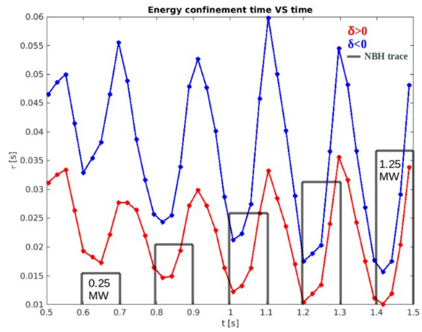

Figure 4 – Energy confinement time VS time. Confinement is better in negative δ (blue profile) with respect to the positive δ counterpart (red profile). The correlation between the beam pulses injection is also visible.

An enhanced confinement in negative δ (blue profile), as well as the correlation to the beam pulses, is evident. The same correlation is visible in the velocity profiles (Fig. 5). As expected, toroidal velocity increases in the co-current direction during beam injection, but there remains

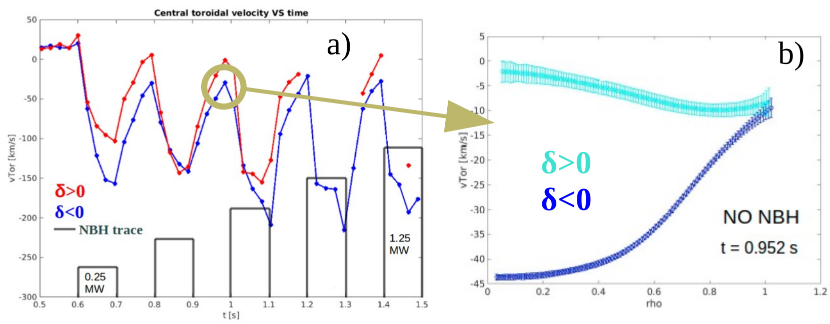

Figure 5 – Central v_{tor} trace (a) and v_{tor} profile over rho @0.952 s (b), during the OFF-phase between two beam pulses. Positive δ plasma relax back to pre-injection level, while negative δ one maintain a hollow shaped profile.

a clear difference between postive and negative δ.

Plasmas in negative triangularity rotate faster that their positive counterparts. Moreover, while δ > 0 profiles tend to relax back to pre-injection levels ~100 ms after the beam pulse, δ < 0 plasmas maintain a hollow profile with non-negligible rotation in the co-current direction until the next beam pulse. The peak velocity is reached during the 0.75 MW beam pulse. Following this, 100 ms beam pulses at higher power do not seem to increase v_{tor} by more than ~200 km/s. Fig. 6 shows the central density traces of a positive (red) and negative δ case (blue).

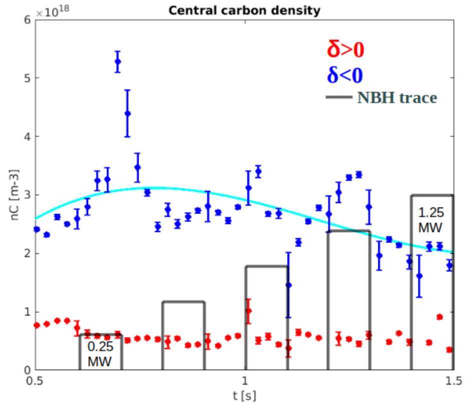

Figure 6 – Central density evolution over time for a positve (red) and negative (blue) δ case. The negative δ plasma, besides having a higher C content, also exhibits a decreasing trend in the profile, with peaks during beam pulse injection.

The C content is higher in the negative δ discharge. Moreover, while the positive δ profiles do not seem affected by the NB injection, the δ < 0 profile exhibits a descending trend with short peaks during the beam injection.

4. Conclusion – A set of discharges in negative and positive triangularity was performed in the TCV tokamak to study the effects of shape on ion kinetic profiles. Differences between positive and negative δ plasmas are highlighted in this work with emphasis on toroidal rotation and C density profiles. The higher toroidal rotation in δ < 0 is accompanied by better confinement, as well as a higher C content in the core, both in Ohmic and NB heated discharges. A strong correlation between particle diffusion, rotation and temperature gradients was observed in negative δ but not in the positive δ counterpart. We hope that this work can inspire further ideas for models validation and theoretical and experimental investigations.

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