Nonlinear contribution of neutral beam injection in TCV EC-heated advanced tokamak scenarios

M. Vallar[1], M. Agostini[1], T. Bolzonella[1], S. Coda[2], J. Garcia[3], B. Geiger[4], T. Goodman[2], A. Karpushov[2], T. Kurki-Suonio[5], C. Piron[1], L. Pigatto[1], O. Sauter[2], N. Vianello[1], P. Vincenzi[1], M. Yoshida[6] the TCV team and the MST1 team[♦]

1. *Consorzio RFX, Corso Stati Uniti 4, 35127 Padova, Italy*
2. *Ecole Polytechnique Fédérale de Lausanne (EPFL), Swiss Plasma Center (SPC), CH-1015 Lausanne, Switzerland*
3. *CEA, IRFM, 13108 Saint-Paul-lez-Durance, France*
4. *Max Planck Institute for Plasma Physics, Garching, Germany*
5. *Aalto University, P.O. Box 14100, FI-00076 AALTO, Finland*
6. *National Institutes for Quantum and Radiological Science and Technology, Naka, Ibaraki 311-0193, Japan*

TCV (Tokamak à Configuration Variable) is a tokamak device capable of many different plasma shapes and positions, equipped with a flexible system of Electron Cyclotron (EC) antennas and a new Neutral Beam (NB) injector [1]. The auxiliary power from the beam can reach 1 MW and it is injected tangentially co-current, coupling mostly with ions. This heating system allows new insights on advanced tokamak scenarios in TCV which, up to now, have been performed only with EC heating (ECH). These scenarios have high β_N, high non-inductive current fraction and a relevant energetic particle (EP) population fraction (≈10 %). An internal transport barrier can be generated by reversing the q-profile using EC current-drive (ECCD) [2]. In this work we show that the effect of the sum of the two heating sources (NBI and ECH) in TCV high β_N plasmas is not linear, and interpretative modelling is carried out to understand the behaviour of the NB EPs when ECH is present. A statistical study on a set of experiments with both ECH and NBI is presented to show the effect of NB injection (NBI) on plasma performance: β_N and the plasma stored energy do not increase linearly with NB power. Furthermore, the contribution to the total plasma current from ohmic transformer, bootstrap current and current drive are respectively estimated, showing that EC has a strong impact on Z_{eff}, modifying therefore the plasma resistivity and the ohmic contribution to the current. This effect is taken into account when applying the Monte Carlo interpretative NBI code NUBEAM. It results that with the combined application of ECRH and ECCD, the electron temperature and plasma equilibrium change significantly, impacting on the NB power deposition: CX and orbit losses tend to increase, reducing by 20% the power deposited on plasma species. Modelling suggests that the variation in T_e changes the EP power redistribution among the species, transferring more power to the ions. The impact on EPs orbit given by ECCD equilibrium modification is performed with the Monte Carlo ASCOT code for NBI modelling, capable of solving the EP full gyro-motion.

[1] A.N.Karpushov, et al., **FED** 123 (2017) [2] T P Goodman et al., **PPCF** 47 (2005)

[♦] *See the author list "H. Meyer et al 2017 Nucl. Fusion **57** 102014"*