33rd EPS Conference on Plasma Phys. Rome, 19 - 23 June 2006 ECA Vol.**30I**, P-1.188 (2006)

MonteCarlo modeling of test particles transport in helical reversed field pinch configurations

M.Gobbin[1,2], L.Marrelli[1], P. Martin[1,2] , R.B. White[3]

[1] *Consorzio RFX – Associazione Euratom-ENEA – Padova, Italy*

[2] *Dipartimento di Fisica, Universitá di Padova, Padova, Italy*

[3] *Princeton Plasma Physics Laboratory, Princeton University, Princeton, NJ, USA*

RFP plasma and SH regimes. The RFP is a self organized toroidal magnetic configuration for the confinement of thermonuclear plasmas, characterized by a wide spectrum of resonant $m = 1$, $n > 2R/a$ tearing modes [1], where a and R are the minor and major radius respectively. In this scenario the high level of magnetic turbulence tipically destroy the magnetic surfaces in the plasma core, significantly increasing radial particles and energy transport. Theory predicts that the spectrum may become monochromatic [2]; i.e. the plasma can be sustained by a single mode (Single Helicity, SH). In these conditions helical closed magnetic surfaces appear [3]. SH conditions have not yet been achieved experimentally and the closest situation is the Quasi Single Helicity (QSH) plasma [4]. This paper shows a numerical determination of particle diffusivity in the non-axisymmetric regions that appear in the core of RFP in SH regimes with a technique that can be applied to experimental QSH plasma. To this end we use the hamiltonian guiding center code ORBIT [5].

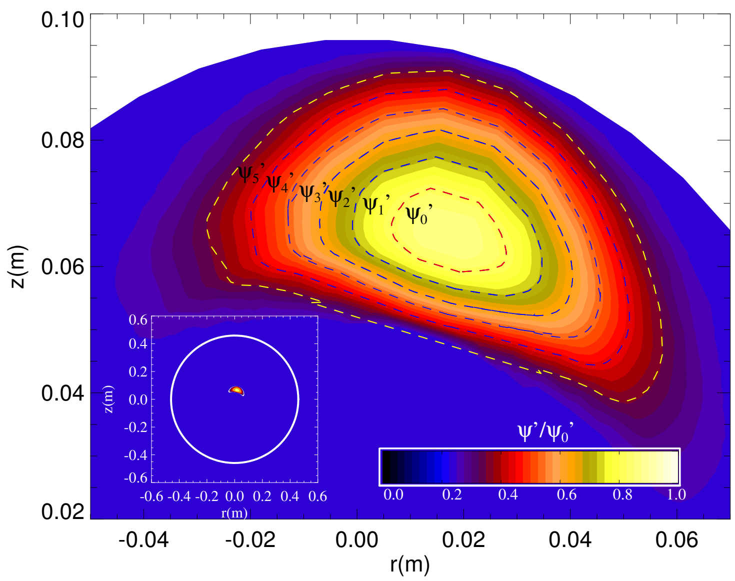

Figure 1 Island *m=1, n=-7* in RFX-mod : reconstruction after ORBIT tracing field line, triangulation and interpolation at the toroidal angle $\zeta=\pi$.

Equilibrium and modes eigenfunctions. The study is performed for a typical RFX-mod toroidal equilibrium [6] with plasma current $I_p = 600kA$, on axis magnetic field $B_0 = 0.6T$, reversal parameter $F=\langle B_\phi(a)\rangle / \langle B_\phi \rangle = -0.2$ and pinch parameter $\theta=B_\theta(a)/\langle B_\phi \rangle = 1.5$ as described in [7]. The magnetic perturbations radial profile $b^r_{mn}(r)$ are reconstructed solving the Newcomb equation [8] from the measured edge magnetic fluctuations $b^{\phi}_{mn}(a)$ and $b^{r}_{mn}(a)$. We have considered both an $m=1, n=-7$ with edge value $b^{\phi}_{1,7}(a) = 1.3mT$ and an $m = 1, n = -8$ mode with $b^{\phi}_{1,8}(a) = 2.5mT$.

Surfaces reconstruction. In order to estimate the diffusion coefficient of particles inside the island, an efficient, though approximate, algorithm for the determination and for the representation of helical surfaces has been implemented in ORBIT. By performing a set of Poincaré sections, polyhedra approximating magnetic surfaces inside the island have been determined. The total flux $\psi' = \oint_C A dl$ for each magnetic surface has been numerically determined by integrating along a section of the corresponding polyhedron the vector potential $\boldsymbol{A}$. Finally the function $\psi'(\psi_p,\theta)$ has been interpolated on a regular (ψ_p,θ) grid in every ζ section (where (ψ_p,θ,ζ) are the equilibrium poloidal flux, the poloidal and the toroidal angle respectively in Boozer coordinates [5]) in order to allow a trilinear interpolation of the $\psi'(\psi_p,\theta,\zeta)$ function. Fig. 1 shows the ψ' contour plot island on a poloidal section with five surfaces marked with thick dashed lines, each corresponding to increasing ψ' values.

Diffusion coefficients calculation. The knowledge of the $\psi'(\psi_p,\theta,\zeta)$ function is essential to study the diffusion properties of an ensemble of test particles, assumed to trace transport properties of the background plasma. Test particles have been deposited in the island O-Point with random pitch $v_{//}/v$ and with a temperature $T_e = T_i = 250eV$. The particles are also subjected to energy conserving classical and pitch-angle collisions with a background at the same temperature [9]. Both mechanisms have proven to be important ingredients of particle transport [7]. During particles diffusion their density as a function of ψ' is recorded at regular intervals to reduce sampling errors. When a particle hits the outer boundary it is reinjected with random pitch in the island O-point. The integration of particles trajectories is performed until stationary

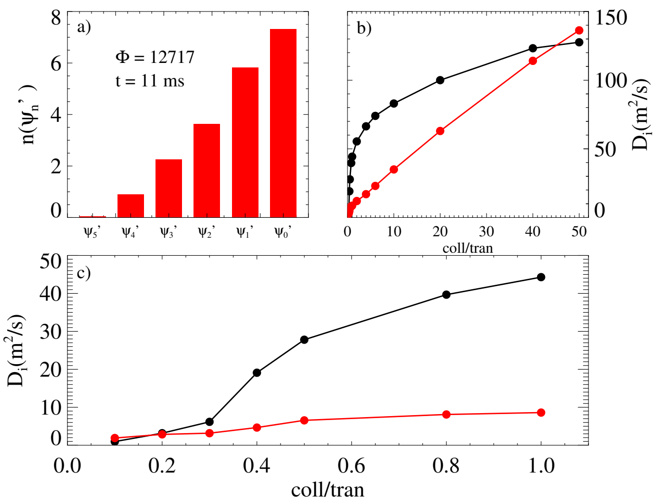

Figure 2 a)Ions distribution $n(\psi_n')$ in the various ψ' intervals for the n=-7 mode. b) Ion diffusion coeffient vs collisions for toroidal transit. Black line: classic collisions and pitch angle scattering; red line: only classic collisions. c) Expanded view of b).

conditions are reached. The stationary distributions $n(\psi_n')$ is shown in figure 2 (a) for the m = 1, n = -7 SH for ions with 0.3 collisions for toroidal transit: it decreases linearly from the O-point to zero in the outside region.

This stationary behaviour is described by a simple diffusion equation $\Gamma = -D^{isl}\,\nabla n$ under the assumption of a costant D^{isl} over the island. Γ, flux of particles for area unit, can be estimated by recording the rate of particles exiting from the island: $\Gamma = \Phi / (t \cdot Sout)$ where t is the run time, S_{out} the area of the last surface of the island (yellow in fig.1) and Φ the number of reinjected particles. The diffusion coefficient can be estimated by $\Gamma/\nabla n$ leading to D^{isl}=(Φ / $t{\cdot}n_0$) ($r_{out}S_0r_0$ /S_{out}) where n_0 is the first bin distribution, S_0 is the area of the first bin (red in figure 1), r_{out} is the mean radius of the island and r_0 the mean radius of the surface S_0. In this expression we can recognize a term $G = r_{out}S_0r_0 / S_{out}$ which depends only on geometrical factors and an other one $F_{run} = (\Phi / t{\cdot}n_0)$ depending on the diffusion of the particles. In the cases considered here the $G_{n=-7} = (1.4\pm0.3)\cdot10^{-4}m^2$, while $G_{n=-8} = (2.6\pm0.6)\ 10^{-4}m^2$. Errors are mainly due to the approximations of the surfaces.

Results. The afore mentioned technique has been applied to a series of runs with increasing collisionality. Estimates of the ion diffusion coefficient D_i^{isl} as a function of collisions for toroidal transit (*coll/tran*) are shown in figure 2 (b)-(c) with a black line for the m = 1, n = -7 island. As a benchmark, high values of collision frequency have been considered for comparison with classical diffusion coefficient D_i^{cl} . Moreover diffusion simulations have been performed with classical scattering only (red line in fig. 2 (b)-(c).) and compared to simulations with classical and pitch angle scattering (black line). At large collision frequency the black and red curves are quite close indicating that the pitch angle scattering becomes unimportant. The numerical estimates of D^{isl} are comparable to classical values calculated by the theoretical formula $D_i^{th} = r^2_{L\ i}\nu_{ie} / 2$. In RFX-mod scenario we find a D_i^{isl} between 2 and 7m^2/s which exceeds the classical one D_i^{th} =0.4÷1m^2/s. This shows that

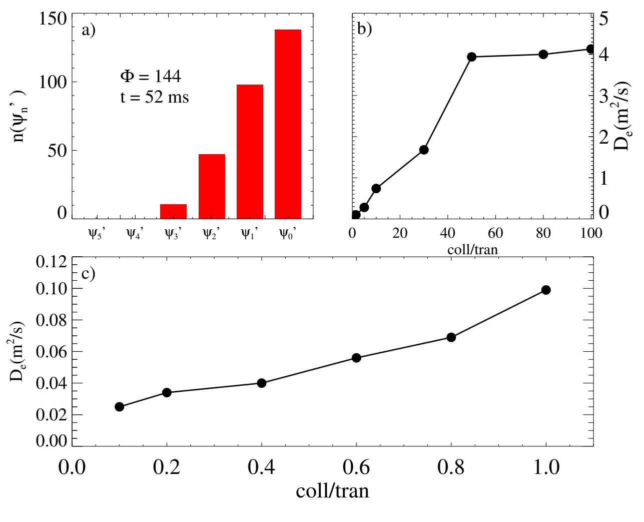

Figure 3 a)Electrons distribution $n(\psi_n')$ in the various ψ' intervals for *n*=*-7* mode. b) Electron diffusion coeffient vs collisions for toroidal transit. with classic collisions and pitch angle scattering c) Expanded view of b).

neoclassical effects are important in helical RFP geometries at low collisionality. These results hold for electrons too (figure 3). In the RFX-mod conditions D_e^{isl}=0.01÷0.03m^2/s exceeds the classical value D_e^{th} = 0.008÷0.012m^2/s. Ambipolar transport in this geometry requires the development of an approximate representation of the ambipolar potential, which is on going. However, following [7], we can estimate the ambipolar diffusion coefficient D^{isl} by computing the geometric average between D_e^{isl} and D_i^{isl} : D_7^{isl}~0.1-0.7m²/s. In figure 4 we report the results about a transport study in the magnetic island m = 1, n= -8; on the left side the ion diffusion coefficient D_i^{isl} versus the collisions (pitch angle + classical scattering) number for toroidal transit is shown and on right side the electron one D_e^{isl}. Focusing on RFX-mod collisionality range we find D_i^{isl} = 5−12m^2/s and D_e^{isl} = 0.1−0.17m^2/s. An estimation of the ambipolar diffusion coefficient by a geometric mean gives D_8^{isl} ~ 0.7−1.4m^2/s. The D^{isl} values are lower than the esperimental evaluation of the axisymmetric D, obtained by particles balance, D ~ 30m^2/s during MH, chaotic discharges [10]. Our results show transport in SH regime is lower. We expect a lower D in the QSH regime too. Infact, near the island O-Point helical surfaces are well defined and the other modes are small in comparison with the dominant one. Thus in the space near the core of the QSH island the D values are expected to be very close to the SH ones. The different values found in the two cases n=-7 and n=-8 could be both due to the differences between the modes amplitude and to the toroidal numbers which modify the geometry in which diffusion takes place. Further investigations with other basic equilibria, modes amplitude and toroidal number could help us to better investigate the physics of transport in SH and QSH states.

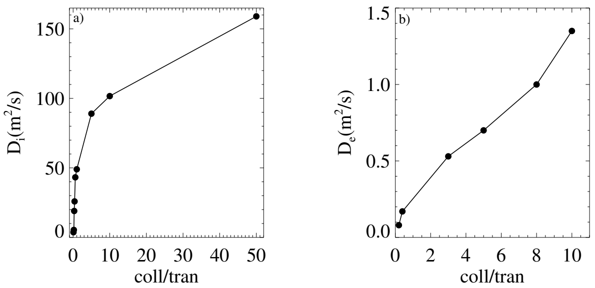

Figure 4 a)Ion diffusion coefficient vs collisions for toroidal transit for the n=-8 mode. b) Electron diffusion coefficient vs collisions for toroidal transit for the n=8 mode.

Acknowledgement *This work was supported by the European Communities under the contract of Association between EURATOM/ENEA. The views and opinions expressed herein do not necessarily reflect those of the European Commission*

References

[1] S.Ortolani and D.D. Schnack, *Magnetohydrodynamics of Plasma Relaxation*, 1993
[2]S.Cappello et al, Phys. Plasmas **13**, 056102 (2006)
[3] P.Martin et *et al.*, Nucl. Fusion **43**, 1855 (2003)
[4] D.F.Escande *et al.*,Phys. Rev. Lett. **85**, 1662 (2000)
[5] R.B.White and M.S.Chance, Phys. Fluids **27**, 2455 (1984)
[6]P.Sonato *et al* ,Fusion Engineering and Design **66**,161 (2003)
[7] I.Predebon *et al.*, Phys. Rev. Lett. **93**, 145001 (2004)
[8] D.C. Robinson Nucl. Fusion **18**, 939 (1978)
[9] A.H.Boozer and G. Kuo-Petravich,Phys. Fluids **24**, 851 (1981)
[10] D.Gregoratto *et al.*, Nucl. Fusion **38** 1199 (1998)