§23. Rabbit-Ear Distribution Function of High Energy Ion Produced by ICRF Electric Field

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The dependence of the count number of high-energy particles on pitch-angle was studied on LHD with the time-of-flight neutral particle analyzer (TOF-NPA). The angle of the line of sight was scanned shot by shot using five successive discharges sustained by ICRF heating. As shown in Fig. 1, a "rabbit-ear" structure, a large population at a certain pitch-angle, was observed [1,2].

Ions are accelerated in the perpendicular direction at an ion cyclotron resonance layer by ICRF heating. Therefore a pitch-angle increases until the turning points of banana orbit reaches the cyclotron resonance layer. It is known in tokamaks that the distribution function of ICRF heated plasma have thus a "rabbit-ear" structure. The distribution function f_0 is calculated with a bounce-averaged Fokker-Planck equation [3].

$$\overline{C}(f_0)=\frac{1}{\tau_b}\int\frac{dl}{v_{//}}C(f_0)=\frac{1}{v^2}mv\left(\frac{\partial}{\partial E}+\frac{\mu}{E}\frac{\partial}{\partial\mu}\right)$$

$$\times\left\{-\alpha v^2 f_0+\frac{1}{2}mv\left(\frac{\partial}{\partial E}+\frac{\mu}{E}\frac{\partial}{\partial\mu}\right)(\beta v^2 f_0)\right\}$$

$$+\frac{m\gamma}{2v^2\tau_b}\frac{\partial}{\partial\mu}\tilde{c}\,\mu\frac{\partial f_0}{\partial\mu}$$

$$\overline{Q}(f_0)=\frac{1}{\tau_b}\int\frac{dl}{v_{//}}Q(f_0)=\frac{2\pi mq^2}{\tau_b}L_{res}\tilde{q}L_{res}f_0$$

where,

$$\tau_b=\int\frac{dl}{v_{//}}\ ,\quad \tilde{c}=\int\frac{v_{//}}{B}dl\,,$$

$$\tilde{q}=\sum_{res}\frac{\mu B}{8\left|(v_{//}-k_{//}\mu/q)(d\Omega/dl)\right|}\left|E_{left}J_0\left(\frac{k_\perp v_\perp}{\Omega}\right)\right|^2,$$

$$L_{res}=\frac{1}{m}\left(\frac{\partial}{\partial E}+\frac{q}{m\omega}\right),\quad \alpha=\langle\Delta v_{//}\rangle+\frac{1}{2v}\langle(\Delta v_\perp)^2\rangle,$$

$$\beta=\langle(\Delta v_{//})^2\rangle,\quad \gamma=\langle(\Delta v_\perp)^2\rangle,$$

where $\langle\Delta v_{//}\rangle$, $\langle(\Delta v_{//})^2\rangle$, and $\langle(\Delta v_\perp)^2\rangle$ are the Coulomb diffusion coefficients, and m and q are the mass and charge of the resonant particle, respectively. ω and Ω are the applied frequency and an ion cyclotron frequency of the resonant particle, respectively. E and μ are the energy and the magnetic moment, respectively, and E_{left} is the left hand component of RF electric field.

In the helical magnetic configuration, there are many helical ripples along the magnetic line of force. The coefficients τ_b, $\tilde{c}$, and $\tilde{q}$ must be calculated at each helical ripple. The particle trapped in one helical ripple is transferred to the other ripples via drift motion. Therefore, the calculation of drift orbits is required in order to deduce the number of bounces in i-th ripple, n_i. The coefficients τ_b, $\tilde{c}$, and $\tilde{q}$ were weighted by n_i:

$$\tau_b=\sum_i n_i\tau_{bi}/\sum_i n_i$$

$$\tilde{c}=\sum_i n_i\tilde{c}_i/\sum_i n_i$$

$$\tilde{q}=\sum_i n_i\tilde{q}_i/\sum_i n_i$$

The calculation successfully simulates the "rabbit-ear" structure as shown in Fig. 2.

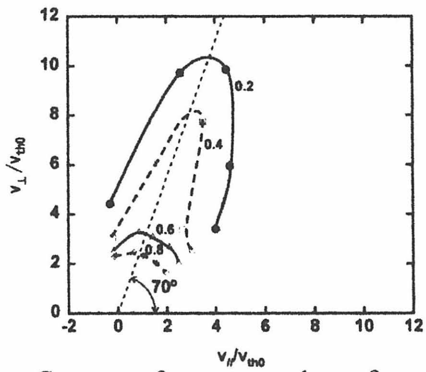

Fig. 1 Contour of count number of neutral particles detected with the TOF-NPA.

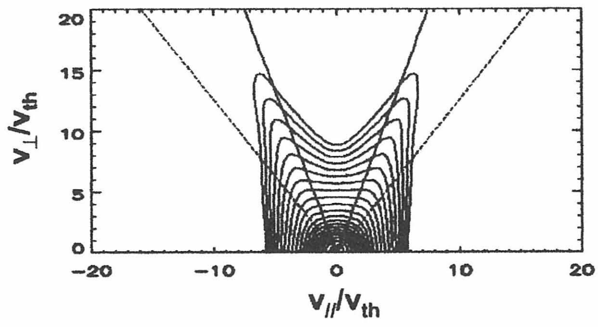

Fig. 2 Contour of the calculated distribution function by solving the bounce-averaged Fokker-Planck equation.

References

[1] Saito, K., et al., Plasma Phys. Control. Fusion **44** (2002) 103.

[2] Saito, K., et al., to be published in Journal of Plasma and Fusion Research.

[3] Stix, T.H., Waves in Plasmas, AIP, (1992), p521.