# §23. Analysis of Anisotropic Ion Distributions Using Multi-Chord Neutral Particle Measurements

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NBI and ICRF heating create suprathermal ion population characterized by non-Maxwellian anisotropic velocity probability density functions (PDF) also influenced by fast ion confinement properties, such as velocity space loss cones theoretically possible in helical systems. A feasible approach to obtaining experimental data on the angular dependence of the ion distribution function is to perform angle-resolved measurements of kinetic energy spectra of escaping neutral atoms. The application of a multidirectional neutral particle analyzer on LHD was described in [1] and the improvement of this diagnostic technique towards achieving a better angular resolution was recently reported in [2].

A general calculation scheme has been developed and realized as a FORTRAN code that has a predictive force to simulate the experimentally measurable anisotropic distributions and random samples of escaping neutral atom kinetic energies for any given angle-dependent ion distribution law, $n_e$ and $T_e$ profiles, plasma composition, magnetic surface structure and experiment geometry on any toroidal plasma device with magnetic confinement. As a particular application of the method to a specific experiment, measured signals for all 20 channels of the Angle-Resolved Multi-Sightline Neutral Particle Analyzer (ARMS NPA) on LHD have been numerically simulated for certain pre-defined model fast ion distribution functions.

Naturally occurring fluxes of fast atoms are measured along a number of sightlines. Since the angle between the magnetic field direction and the sightline is different at different locations, the obtained chord-integral data reflect the original angular distribution of fast ions in a complex way because the information is superimposed along the observation direction. This obstacle is especially pronounced in studies of complex 3D shaped plasmas of stellarator and heliotron devices such as LHD. However, one may expect to obtain a reasonable qualitative understanding of the angular distribution from such measurements. Computational analysis of the diagnostic data is required for this purpose.

The assumed spatially non-uniform ion distribution function with a certain peculiarity in the angular dependence is illustrated in Fig. 1 for one radial location. The following factorization has been employed

$$f_i(\rho, E, \vartheta) = \Phi(\rho, E)\left(1-\Theta(E,\vartheta)\right) \tag{1}$$

using

$$\Phi(\rho, E) = \frac{2}{\sqrt{\pi}}\frac{1}{T_i(\rho)}\sqrt{\frac{E}{T_i(\rho)}}\exp\left(-E/T_i(\rho)\right) \tag{2}$$

and introducing the delta-like function of the angle for high energy particles

$$\Theta(E,\vartheta) \propto e^{-\frac{(\vartheta-\vartheta_0)^2}{0.05^2}} \Big/ 0.05\sqrt{\pi} \tag{3}$$

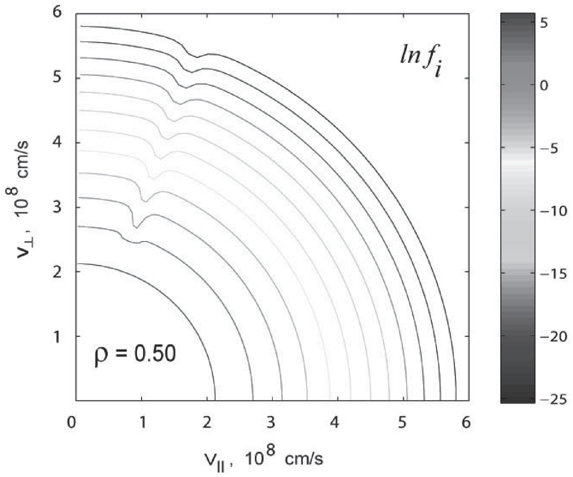


Fig. 1. Assumed anisotropic and spatially non-uniform ion distribution function.

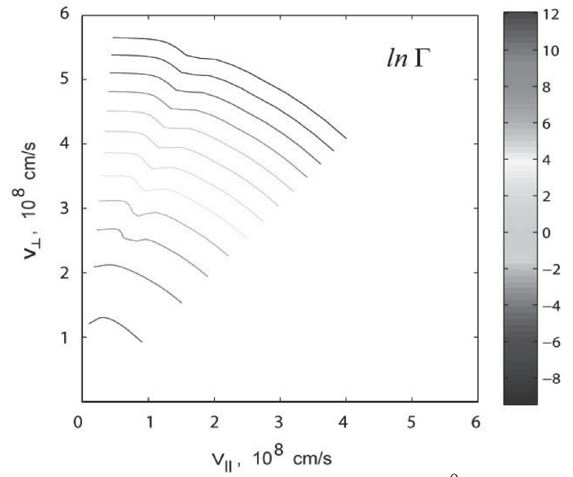


Fig. 2. Energy and angle-resolved flux of $H^0$ particles.

The ion temperature profile $T_i(\rho) = T_i(0)\left(1-\rho^2\right)^2$ with $T_i(0)$ = 10 keV was used in test calculations. Fig. 2 shows the obtained energy-resolved neutral hydrogen flux calculated for ARMS-NPA measurement geometry along its 20 sightlines. The angular variable on this plot corresponds to the pitch angle value at $\rho_{min}$ for every sightline. It can be seen that the resultant experimentally measurable neutral particle distribution plotted in such coordinates preserves certain information about the angle-dependent perturbation introduced into the ion energy PDF in this example. The sightline superposition effect immanent for a passive diagnostic leads to a predictable convex or concave distortion of the distribution function isolines. A qualitative study of anisotropic ion distributions with multidirectional neutral particle diagnostics is possible. However, a careful numerical modeling of expected ion distributions and expected distortions in the resulting neutral particle spectra is required for the correct data interpretation.

1) P.R. Goncharov, J.F. Lyon, T. Ozaki, et al., J. Plasma and Fusion Research Series, **5**, 159 (2002).
2) .A. Veshchev, T. Ozaki, P.R. Goncharov et al., Rev. Sci. Instrum., **77**, 10F129 (2006).