§15. Consideration of a Necessary Condition for Local Density Fluctuation Measurements with Heavy Ion Beam Probe

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Local fluctuation measurements are important to investigate plasma turbulence and transport. Heavy ion beam probe (HIBP) is able to measure *density fluctuation* inside a magnetically confined plasma of high temperature. The detected beam fluctuates according to the local density fluctuation at the ionization point. However, the beam fluctuation is also contaminated with the fluctuations along the beam orbit. This report describes a consideration of the path-integrated fluctuation and a necessary condition for the local density fluctuation measurement.

The relation between the local density and path-integrated fluctuations is written as

$$\begin{aligned}\tilde\eta^2(\rho_*) &= \tilde\xi^2(\rho_*)\\ &-2\int\langle\tilde\xi(\rho_*)\tilde\xi(\rho_1)\rangle S_1(\rho_1)\,d\bar l_1\\ &-2\int\langle\tilde\xi(\rho_*)\tilde\xi(\rho_2)\rangle S_2(\rho_2)\,d\bar l_2\\ &+\iint\langle\tilde\xi(\rho_1)\tilde\xi(\rho_1')\rangle S_1(\rho_1)S_1(\rho_1')\,d\bar l_1 d\bar l_1'\\ &+\iint\langle\tilde\xi(\rho_2)\tilde\xi(\rho_2')\rangle S_2(\rho_2)S_2(\rho_2')\,d\bar l_2 d\bar l_2'\\ &+2\iint\langle\tilde\xi(\rho_1)\tilde\xi(\rho_2')\rangle S_1(\rho_1)S_2(\rho_2')\,d\bar l_1 d\bar l_2'\end{aligned}\quad ,\qquad (1)$$

where $\tilde\eta(\rho_i)$, $\tilde\xi(\rho_i)$, $S_i(\rho_i)$ indicate detected beam fluctuation, local density fluctuation, ionization cross-section of primary and secondary ion, respectively. And subscript *, 1 and 2 indicate ionization point, primary and secondary, respectively. The first term and the other terms on the right-hand side represent the local density fluctuation and the path-integrated fluctuations, respectively.

The above expression can be simplified if the correlation length of the fluctuation is sufficiently short, and if the correlation is assumed to be written in the following form

$$\langle\tilde\xi_1(\rho_1)\tilde\xi_2(\rho_2)\rangle=\tilde\xi_1^2(\rho_1)\bar l_c(\rho_1)\delta(\rho_1-\rho_2)\delta(\bar l_1,\bar l_2)\quad ,$$

where the $\delta(\bar l_1,\bar l_2)$ and $\bar l_c$ are the Dirac's delta function, and correlation length, respectively. Then, Eq.(1) can be reduced into

$$\begin{aligned}\tilde\eta^2(\rho_*) &= (1-2S_c(\rho_*))\tilde\xi^2(\rho_*)\\ &+\int\bar l_c(\rho_1)\tilde\xi^2(\rho_1)S_1^2(\rho_1)\,d\bar l_1\\ &+\int\bar l_c(\rho_2)\tilde\xi^2(\rho_2)S_2^2(\rho_2)\,d\bar l_2\end{aligned}\quad ,\qquad (2)$$

where $S_c(\rho_*)\equiv\bar l_c(S_1(\rho_*)+S_2(\rho_*))$. From this simplified expression, it is known that the second and third term of Eq. (1) should represent an effect to screen the local fluctuation by a factor of $1-2S_c$ (a screening effect), while the 4-th to 6-th terms are exactly the *path-integral effect* that increases the measured fluctuation. The simplified expression indicates that the local fluctuation can be rather easily deduced by solving the integral equation numerically if the correlation length of the fluctuation is sufficiently short.

In addition, the further approximation of Eq. (2) gives an idea of a necessary condition for local density fluctuation measurement. The approximated form is expressed as

$$\tilde\xi^2(\rho_*)=\frac{\tilde\eta^2(\rho_*)}{1-2S_c(\rho_*)+A_{tt}}\quad ,\qquad (3)$$

where $A_{tt}\equiv\bar l_c(\langle S_1^2\rangle L_1+\langle S_2^2\rangle L_2)$, with $\langle L_i\rangle$ and $\langle S_i^2\rangle$ being the lengths and the averaged ionization rate on the orbit. Equation (3) shows that a degree of path-integral effect can be evaluated from the ratio of $A_{tt}/(1-2S_c)$.

Figure 1 shows the ratios for the cases of Cesium and Rubidium beams as a function of electron density for CHS geometrical parameters. Here, both L_1 and L_2 are 0.2 m from the HIBP trajectory calculation. These figures show that Rubidium beam is more suitable to detect local density fluctuation in wider plasma parameter regime of CHS, compared to Cesium beam.

However, Rubidium beam is less sensitive to potential fluctuation than Cesium. The Cesium beam should have an advantage in simultaneous measurements of density and potential fluctuation to deduce turbulence-driven transport. Consequently, it is still necessary to establish a method to extract local density fluctuation for this purpose.

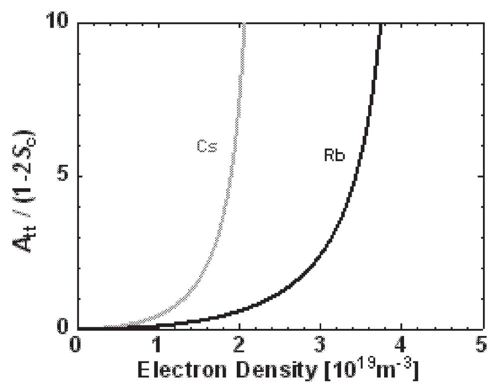

Fig. 1. Ratios of path-integral to screening effect for Cesium and Rubidium beam. Electron temperature, plasma radius and beam energy are 1keV, 0.2m and 70keV, respectively. Rubidium beam can measure higher density plasma.