Effect of ion heating due to the higher harmonic fast wave in GAMMA 10.

GAMMA10での高次高調波によるイオン加熱の効果

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Abstract

The high beta plasma generation is one of the most important purposes in the tandem mirror experiments. In GAMMA10, a new ion cyclotron range of frequency (ICRF) system (RF3) which launches high harmonic fast waves (HHFW) in the frequency range of near 10 times ion cyclotron frequency has been introduced for the high-density plasma generation. When RF3 power was added on the initial plasma produced with conventional ICRF systems (RF1, RF2), the increase of the density is clearly observed. In addition, the production of high-energy ions is also observed with RF3. It is considered that a small amount of high-energy ions are accelerated because diamagnetic signal hardly increases with RF3.

The bulk ion temperature of the wave damping in the hot plasma with ion temperature distribution of two component was evaluated. GAMMA10 experimental results were compared with the calculation.

Purpose

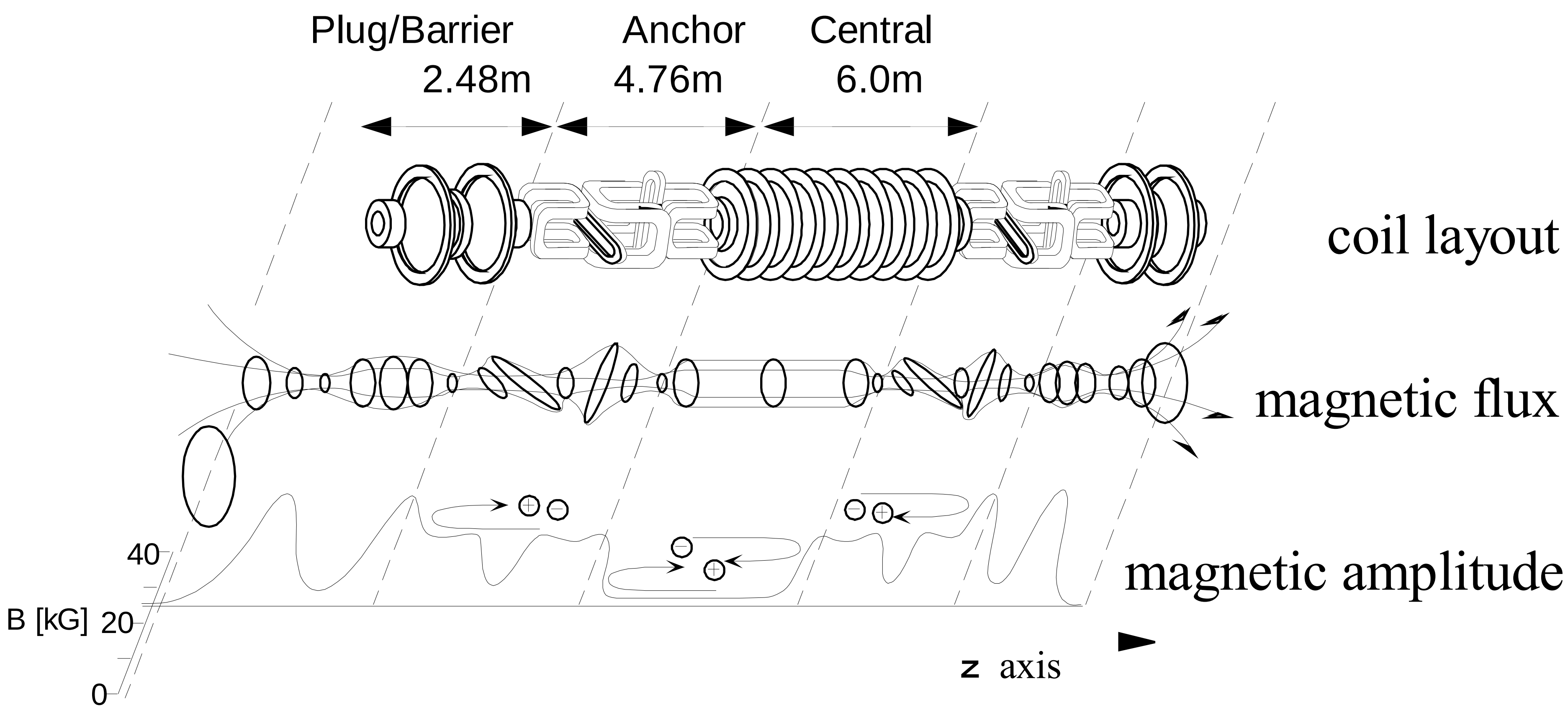
The high beta plasma generation is necessary for realization of the fusion reactor. The experiments for the high-density plasma generation are conducted in GAMMA10. The method for the main plasma heating is a fundamental ion cyclotron heating. The conventional slow wave heating becomes ineffective in high-density plasma.

A new ion cyclotron range of frequency system (RF3) which launches high harmonic fast waves (HHFW) in the frequency range of near 10 times ion cyclotron frequency has been introduced for the high-density plasma generation. Whe RF3 applied, the generation of high-energy ions is observed.

The effect of RF3 heating is calculated in the infinite uniform plasma.

GAMMA 10

The GAMMA 10 tandem mirro consists of a central cell, two anchor cells, and two end mirror cells. The anchor cells with minimum-B configuration are at both ends of the central cell. A fast ion cyclotron wave (RF1 : 9.9 MHz and 10.3MHz) excites for plasma production and anchor heating.Ions in the central cell are heated by ICRF(RF2 :6.36 MHz). HHFW(RF3 : 36-76 MHz) is used to obtain a higher density plasma.



ccHED

At the central cell of the GAMMA 10, a semiconductor detector is used to measure high-energy ions. The detector(ccHED) can measure high-energy ions of which energy is over 10keV.

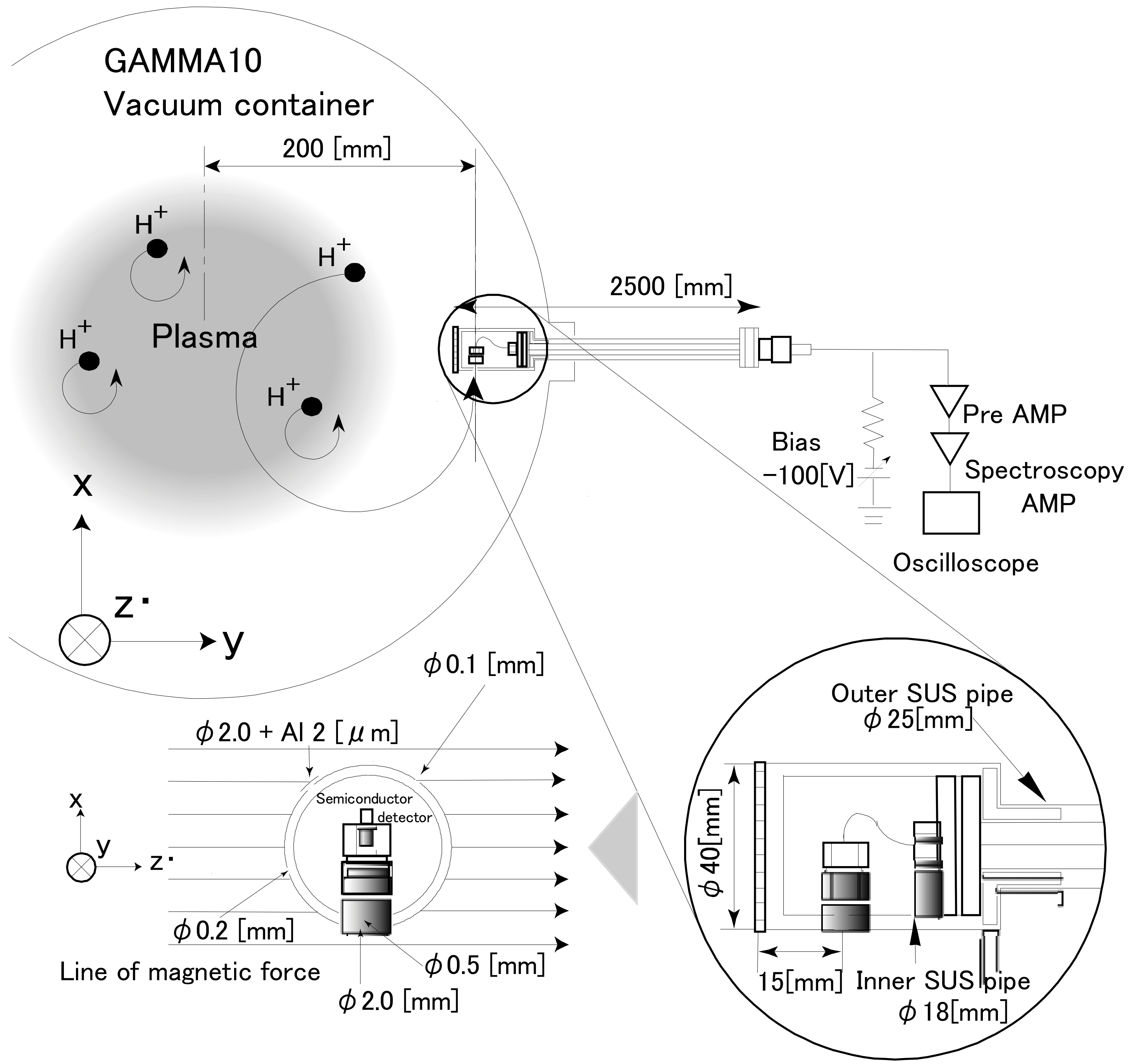


Fig.2 This figure shows that the system of ccHED(include semiconductor detector). The ccHED can detect over 10keV ions. The ccHED allows for detection of dependence by pitch angle herefrom the angle of cylinder can be varied.

ccHED signal

Figure 3 shows two experimental data with ccHED signal. In Fig.3(a), One is a high diamagnetism case and the other is a low diamagnetism case. Fig.3(b) shows the ccHED signals. Initial temperatures (just before applied RF3) are estimated from diamagnetism just before applied RF3 in Fig.3(a).

When RF3 applied, the change of diamagnetism is not observed. This phenomenon was explained that RF3 accelerates a small amount of high-energy ions and it does not influence to the whole energy.

This figure clearly shows ccHED signal strongly depends on initial plasma.

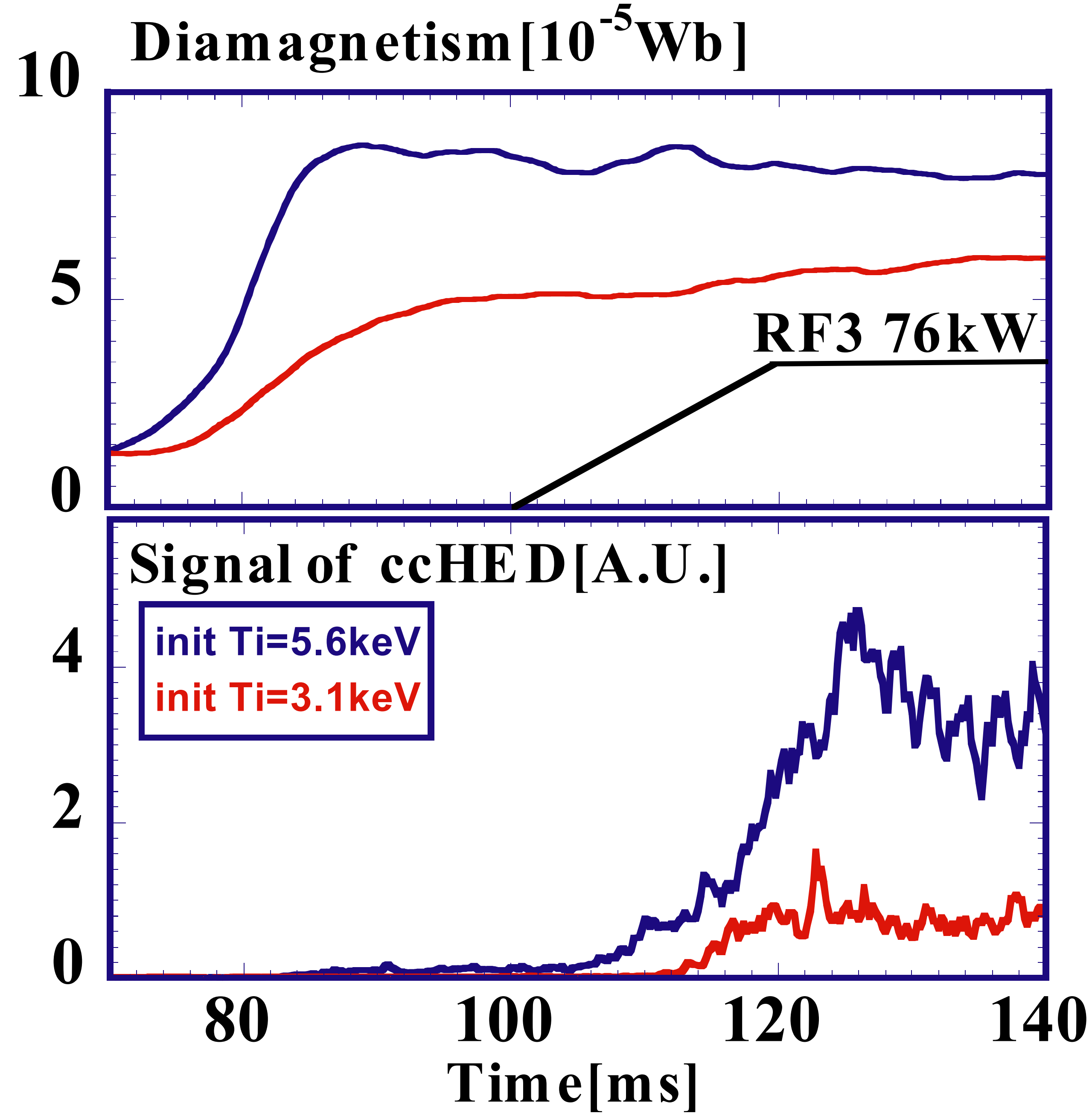


Fig.3 Diamagnetism and ccHED signal. (a) Temporal evaluation of the diamagnetism on two different cases. (b) The ccHED signals on both cases of Ti=5.6keV and Ti=3.1keV estimated from Fig.4(a).

Signal dependence

The relation between ion temperature of the initial plasma and amplitude of ccHED signal is shown in Fig.4. The ccHED signal increases with the temperature of the initial plasma. The ccHED signals at relatively low ion temperature can be observed.

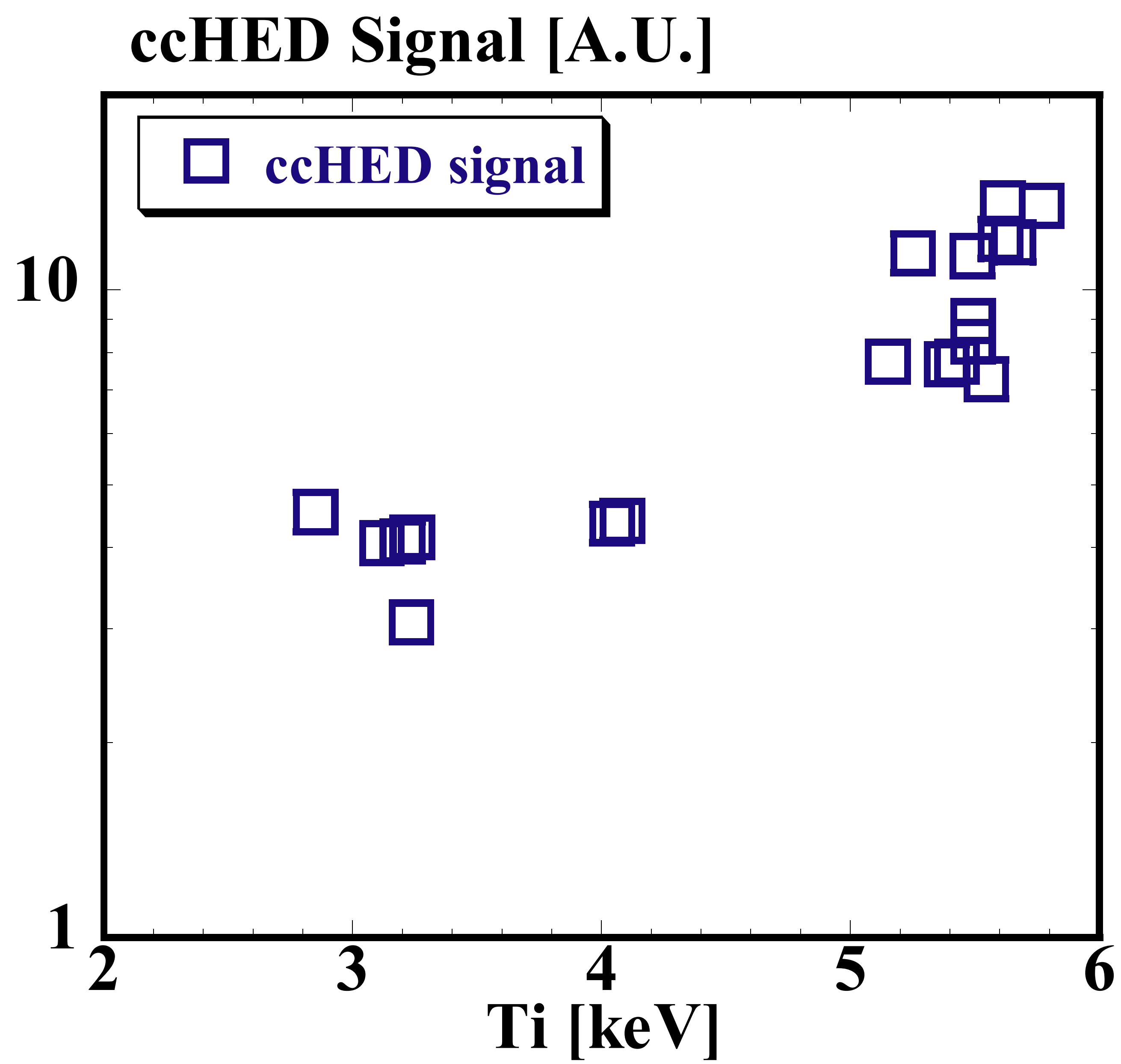


Fig.4 The initial ion temperature(just before applied RF3 at 100msec) estimated from diamagnetism dependency of the ccHED signals.

Dispersion relation

The hot plasma dispersion with complex perpendicular wave number (k_x) is solved (Fig.5). The wave damping and the effect of the ion heating are evaluated from the imaginary part of k_x. An example of the calculation under the fixed parameters are following.

plasma density	$n_e = 2 \; 10^{18} [m^{-3}]$
electron temperature	$T_e = 100 [eV]$
ion temperature	$T_i = 4 [keV]$
magnetic strength	$B = 0.4 [T]$
axial wave number(k_z)	$0.5 [m^{-1}]$
hydrogen plasma.	

This figure shows that the wave damping is occured at the frequency of higher harmonic waves.

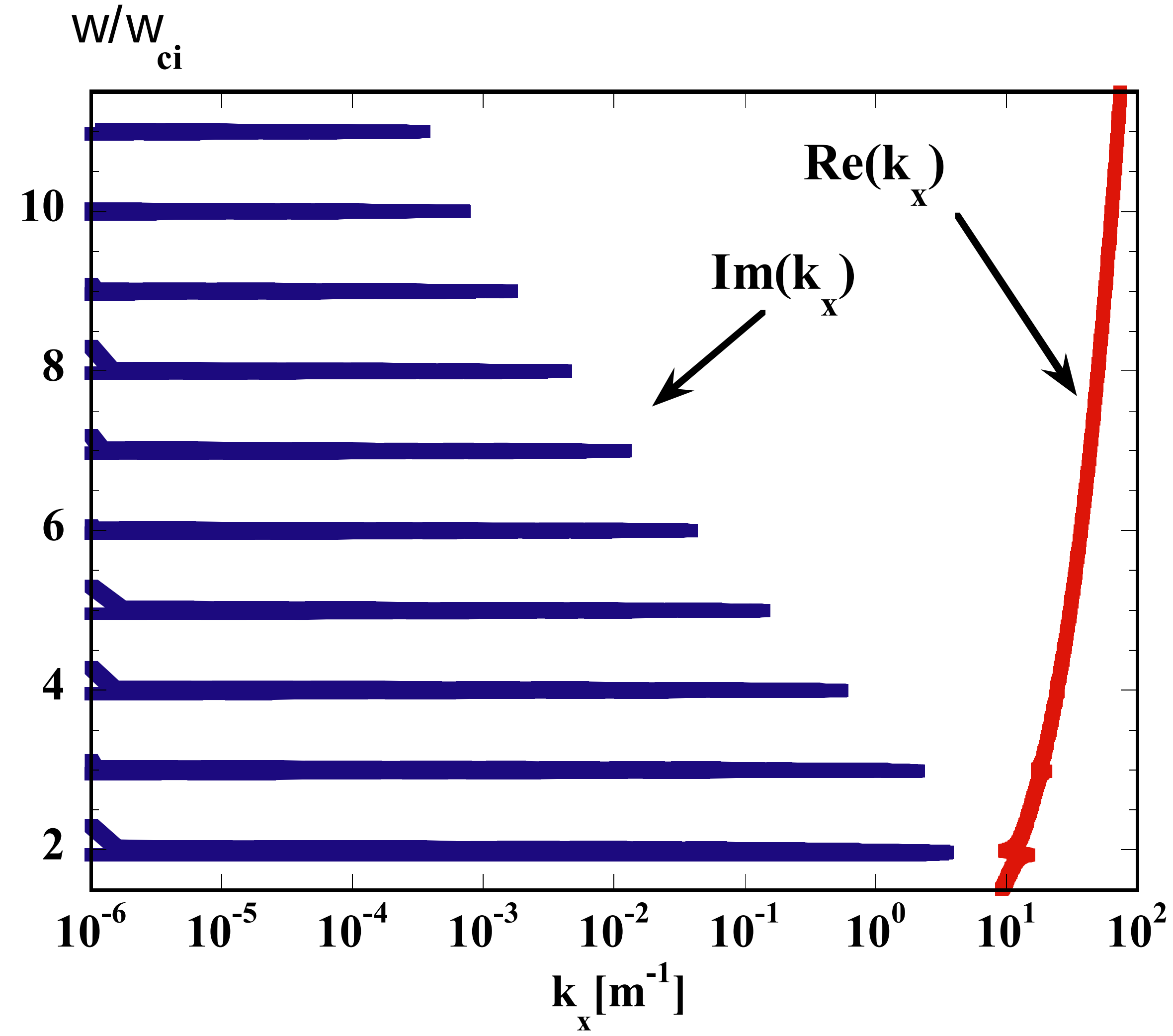


Fig.5

Bulk temperature dependence

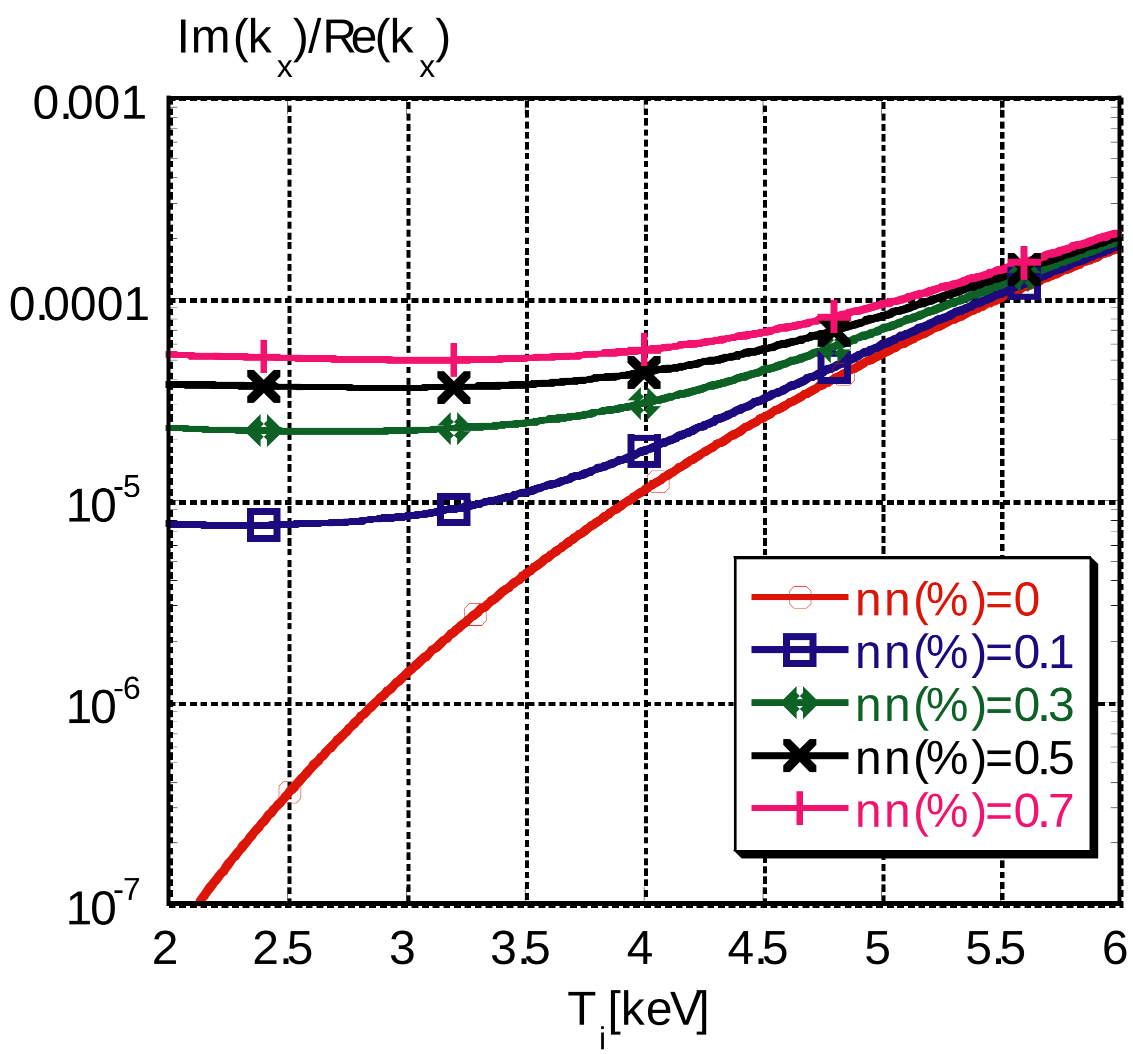


Fig.6 Dependency by different ratio of high-energy ion on bulk ion temperature. Wave frequency is 10th ion cyclotron harmonic. The word of "nn" means the ratio of bulk ion density and the high-energy ion density. High-energy ion temperature is fixed 20keV.

Figure 6 shows the imaginary part of the wave number in the case that the ion temperature has two components. One is a bulk ion component and the other is a high-energy component. The temperature of the tail component(high-energy ion temperature) is fixed 20keV. The variable of 'nn' indicates the density rate of the tail component to the bulk component. Figure 6 shows the damping becomes strong with a small amount of the tail component in the low temperature region.

Analysis

Figure 7 shows the damping rate, electric amplitude(E_x) and the polarization angle($\Delta\phi_{xy}$). $\Delta\phi_{xy}$ is defined as

$iE_x/E_y = A\,exp\,i(\Delta\phi_{xy}+\pi/2)$;

$A = |E_x|/|E_y$

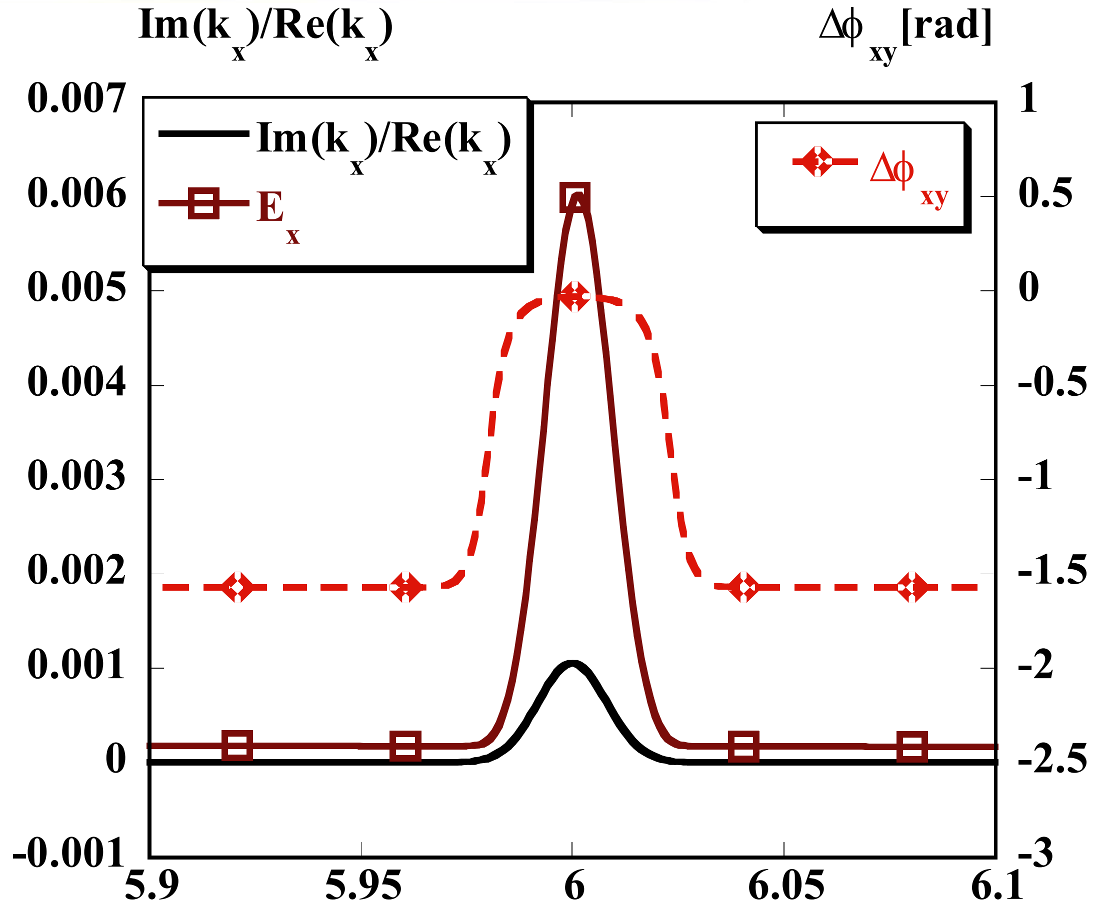


Fig. 7

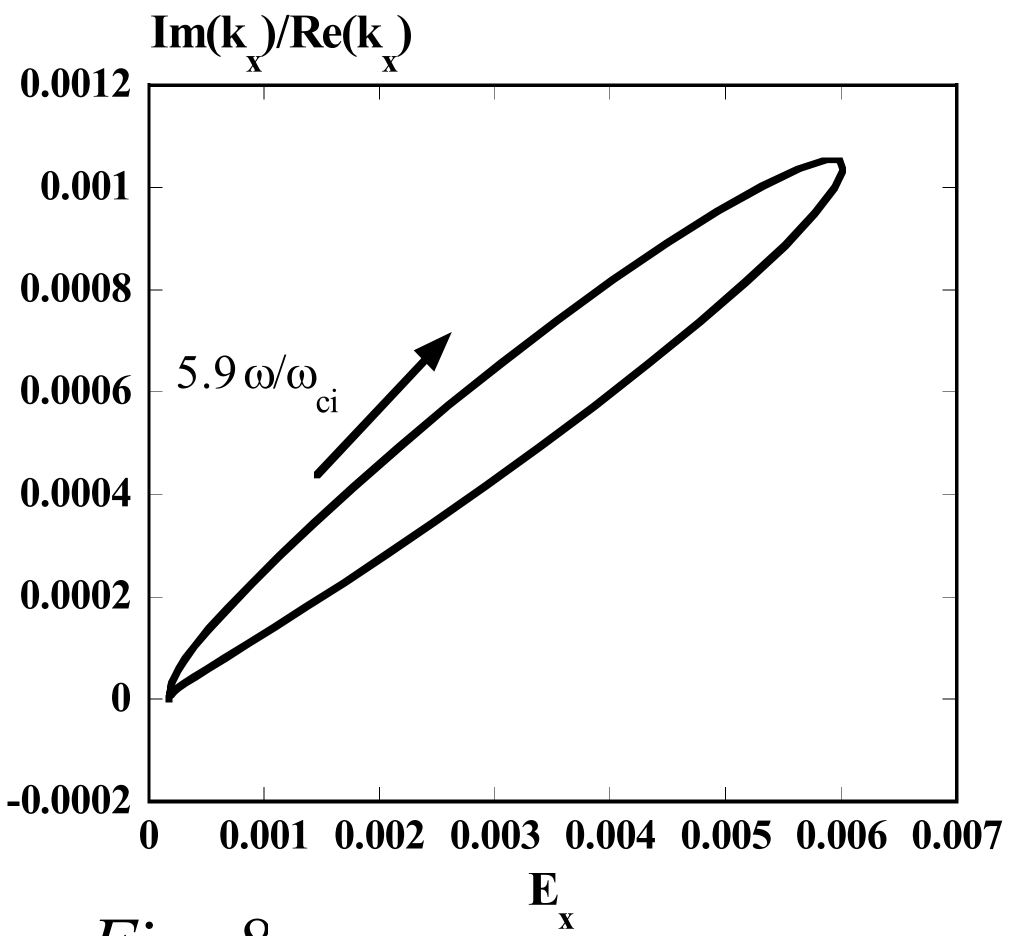


Fig. 8

$\Delta\phi_{xy}$ = - $\pi/2$ and wave has left hand polarization when $\Delta\phi_{xy} = \pi/2$. At the frequency which the wave is damping left hand polarization is added on the right hand polarization. Wave damping rate is nearly proportional to E_x **at the damping region(Fig.8).**

Between experimental results and calculation

The initial ion temperature dependence of the ccHED signal agrees to the bulk temperature dependence of the waves damping in the case of nn= 0.5 (%) (Fig.9). The calculation of the wave damping in the case of plasma without high temperature component can not explain the experimental observation especially low temperature region. The existence of the high-energy tail ion component in GAMMA10 is

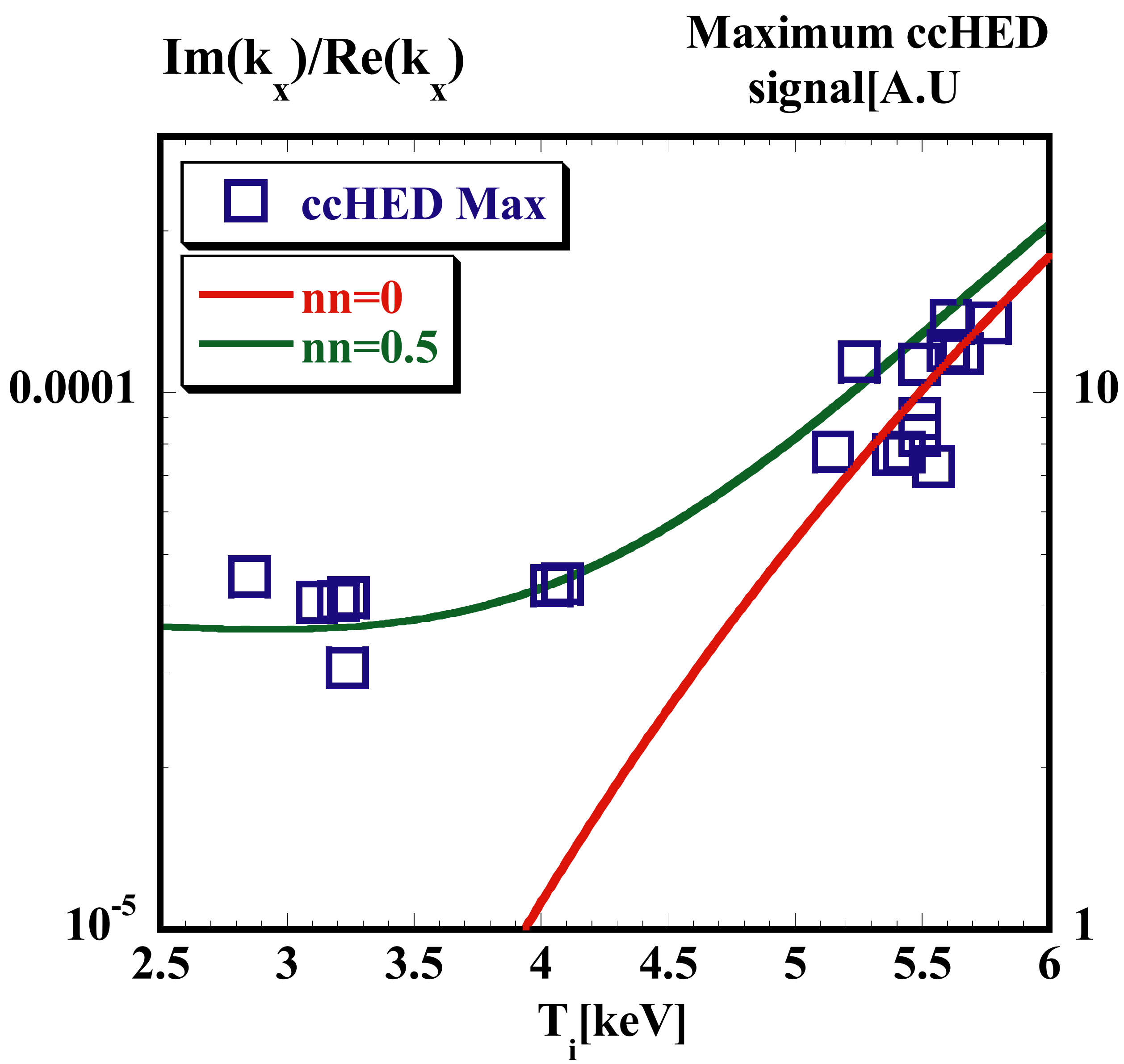


Fig.9 The initial ion temperature dependence of the ccHED signals(open square). A broken curve shows the imaginary part of

Summary

To evaluate the damping of HHFW, hot plasma dispersion relation was solved. The wave damping occurs at the higher harmonic cyclotron frequency. The production of high-energy ions depends on the initial ion temperature.

It is confirmed that a small amount of high-energy ions are heated by applying RF3 in GAMMA10. When the ion temperature just before applied RF3 is also low, the effect of HHFW is observed by using the ccHED. It is suggested that high energy ion tail component contributes to heat high energy ion if the initial ion temperature is relatively low.