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Spatially Resolved Measurements of Energetic Neutral Particle Distributions in the Large Helical Device

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Abstract. A silicon-detector-based neutral particle analyzer (SDNPA) was used to study the fast ion distribution in the Large Helical Device (LHD) for different plasma heating conditions. The GNET code simulations of the SDNPA measurement are needed for more accurate interpretation of the SDNPA data.

I. THE MEASUREMENT

The liquid-nitrogen-cooled SDNPA measures the energetic (> 10 keV) neutral flux with an energy resolution of 1-1.5 keV along six horizontal viewing chords, directed as shown in Fig. 1. The pitch angles corresponding to the six different lines of sight cover the range 38° to 73°, as shown in Fig. 2. Each detector sees a nearly constant pitch angle. A vertically movable collimating aperture provides a full two-dimensional scan of the non-axisymmetric plasma.

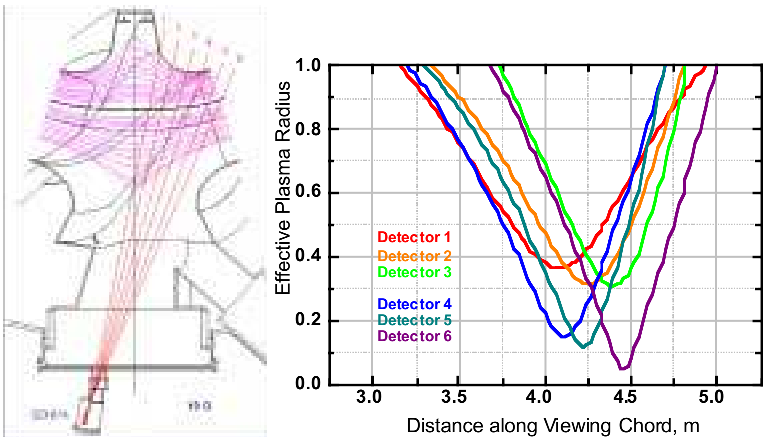

Fig. 1. Viewing geometry for the SDNPA.

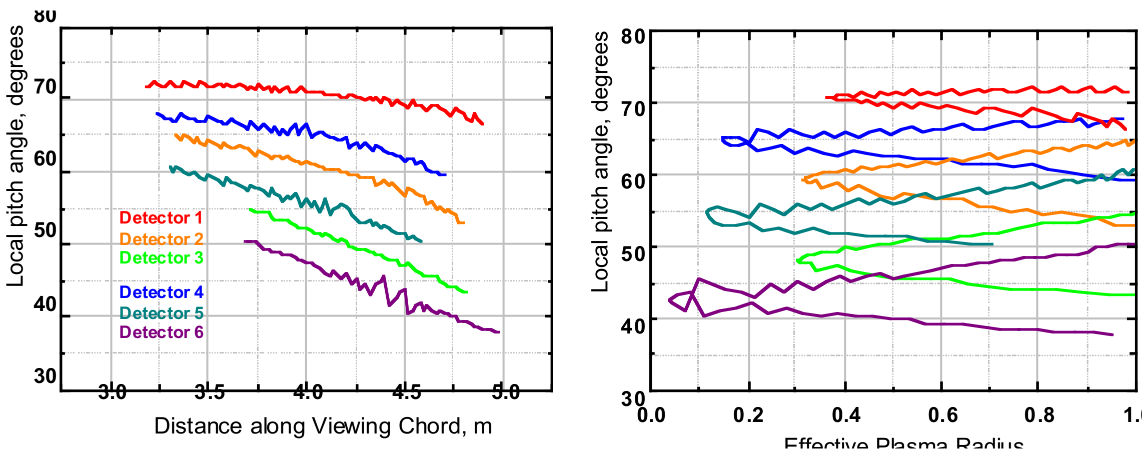

Fig. 2. Pitch angle distributions along viewing chords and plasma radius.

An insertable Be foil also allows the SDNPA to be used as a soft X-ray spectrometer and to separate the X-ray background from the charge-exchange flux. Figure 3 shows the spectra obtained for two ECH shots, with and without a 13-μ Be filter to stop charge-exchange neutrals.

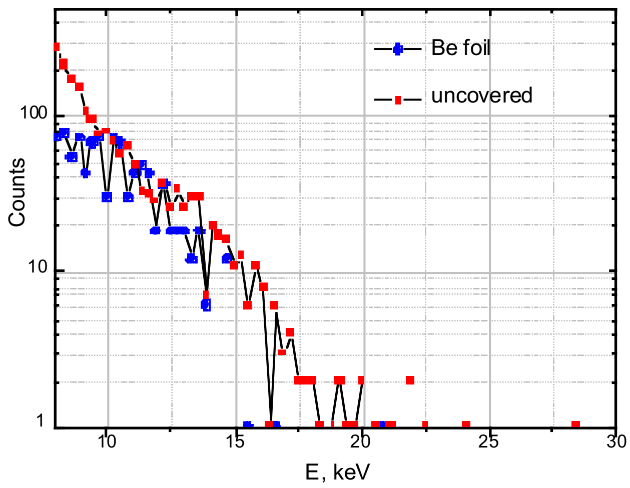

Fig. 3. Soft X-ray spectra measured by the SDNPA.

II. FAST ION MEASUREMENTS

Measurements were made on LHD for a variety of experimental conditions: electron-cyclotron-heated (ECH) plasmas with ECH powers up to 1.7 MW; ion cyclotron heating (ICH) with ICH powers up to 2.7 MW; and neutral beam injection (NBI) heating up to 7 MW. The relationship of the SDNPA viewing lines to the NBI paths is indicated in Fig. 4. Co-injection is in the clockwise direction, so NB 2 is aimed in the co-injection direction and NBs 1 and 3 are aimed in the counter-injection direction. Consequently, fast ions in the plasma from

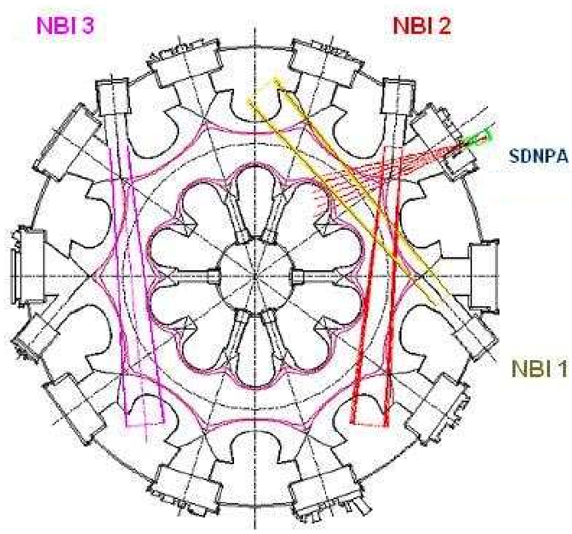

Fig. 4. Relationship of NBs and the SDNPA.

NBs #1 and #3 must back scatter to be detected by the SDNPA while fast ions in the plasma from NB #2 only need to scatter over a smaller angle. Figure 5 illustrates this point; detector 6, which is aimed closer to the NB #2 direction, sees a broader energy distribution

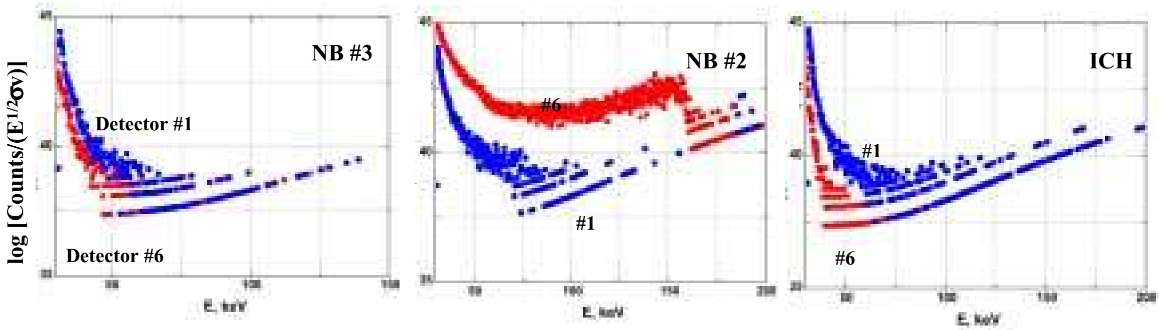

Fig. 5. Fast ion distributions from NBI and ICH.

than detector 1, which is aimed closer to the perpendicular. The opposite is true for the oppositely-directed NB #3 and ICH, which heats closer to the perpendicular direction.

III. EFFECT OF MAGNETIC AXIS SHIFT

Figure 6 illustrates the dependence of heating efficiency on shift of the magnetic axis for plasmas with NB #1, NB #3, and ICH, which favor detector 1 over detector 6. Plasmas shifted inward in major radius have improved ion confinement while plasmas shifted out have poorer confinement but theoretically improved MHD behavior. A cleaner illustration of this effect is given in Fig 7. where the only plasma heating is from NB #2. The fast ion energy distribution is again broader for the plasma that is shifted further inward.

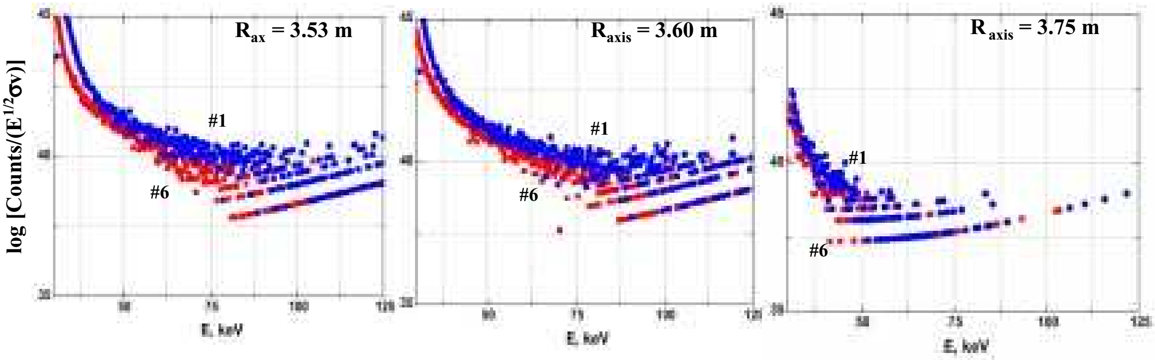

Fig. 6. Fast ion distributions for different shifts of the magnetic axis.

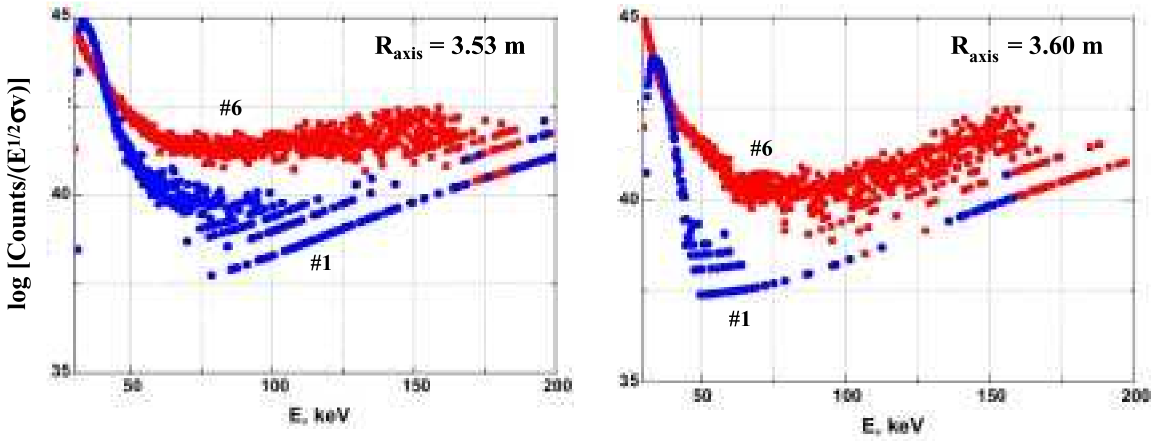

Fig. 7. Fast ion distributions for NB #2 for two shifts of the magnetic axis.

Another effect that enters by the shift of the magnetic axis is the different plasma radii seen by the SDNPA. Figure 8 shows the difference for R_{axis} = 3.53 m and R_{axis} = 3.75 m for slightly different vertical scan positions. Accurate interpretation of the SDNPA data requires modeling of the charge-exchange flux from the plasma taking the magnetic geometry into account.

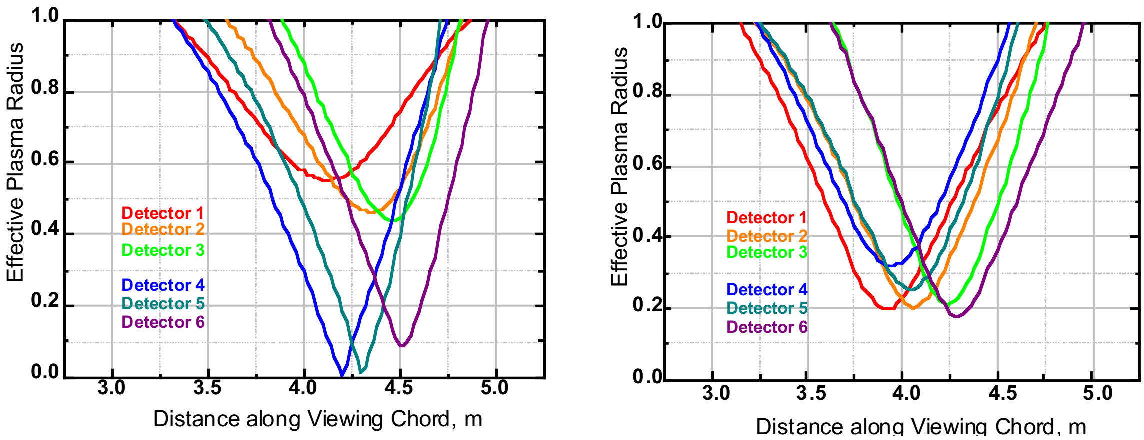

Figure 8. Viewing paths for R_{axis} = 3.53 m (left) and R_{axis} = 3.75 m (right).

IV. SIMULATION OF SDNPA MEASUREMENTS

The GNET [2] code solves the drift kinetic equation for the energetic particle distribution in 5-D phase space using a Monte-Carlo method and calculates the global distribution of the energetic ions. The fast neutral particle flux to the SDNPA detectors can be simulated from the calculated distribution. Figure 9 shows the GNET code results for a particular shot with R_{axis} = 3.75 m and NB #1 heating. The SDNPA data does not allow comparison with this shot because of a large soft X-ray background. However, the capability exists and the next step for the experiment will be to compare the simulated count rate with the SD NPA measurement for the same shot including the neutral density profile and attenuation of charge-exchange flux in the plasma.

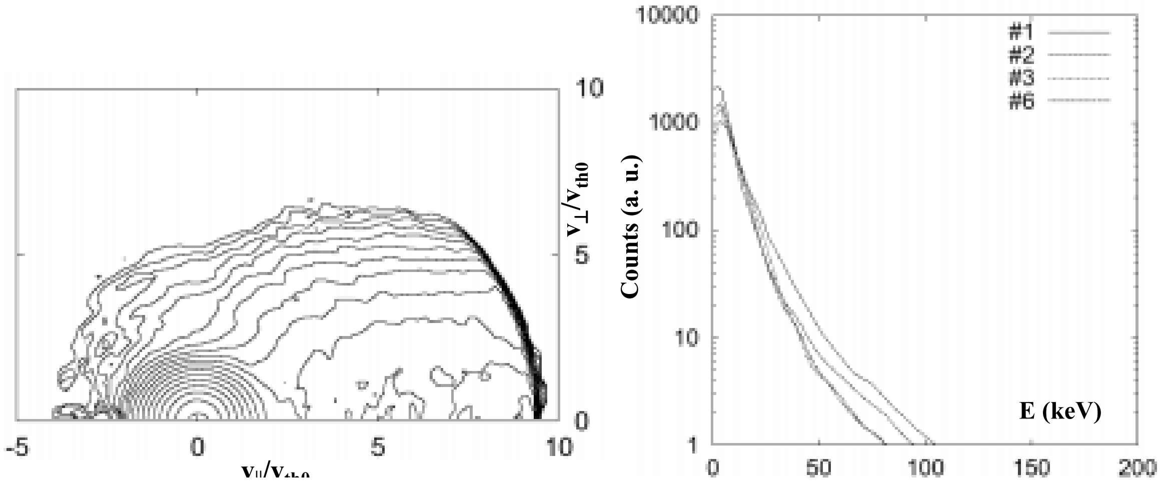

Fig. 9. GNET calculation of the fast ion distribution and simulated counts in the SDNPA.

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[1] J.F. Lyon et al., *J. Plasma and Fusion Res. SERIES* **1** (1998), 358.

[2] S. Murakami et al., *Nuclear Fusion* **40** (2000), 693.