New 20-Channel Diagnostic for Angle-Resolved Fast Particles Measurements in LHD

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A new multi-channel diagnostic for fast particles has been developed and successfully tested on the Large Helical Device (LHD) during 2005-2006 experimental campaign. The number of simultaneously used channels was significantly improved from 2 to 20 channels and additional improvements for noise reduction have been made. Same time location of the diagnostic has been changed that allowed one to make measurements in a much wider range of pitch angles from perpendicular to tangential (90-160 degrees). All these improvements allow one to make time, energy, and angle-resolved measurements of charge exchange neutral particles in a single plasma discharge and to check the presence of fast particles loss-cones from LHD plasma in different heating regimes. This new diagnostic can be a very helpful and powerful tool in studying of fast particle distribution in such a complex helical plasma geometry like the one of LHD. Example data from plasma discharges are presented.

Keywords: fast particle measurement, ion distribution function, angle resolved measurement, fast ion confinement, neutral from plasma, ion kinetic

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1. Introduction

Analysis of energy-resolved spectra of neutral particles escaped from plasma can provide important knowledge about ion confinement and ion distribution function during different types of plasma heating such as neutral beam injection (NBI), ion cyclotron heating (ICH) or electron cyclotron heating (ECH).

Multi-channel detector system beside energy-resolved fast particles measurements provides information about spatial- and angle-resolved fast particles distribution. That is especially important information in studying of fast ion behavior in such a complex 3-D shaped magnetic surface geometry like in Large Helical Device (LHD). Among numerous diagnostics used for fast particles measurements on LHD such as compact neutral particle analyzer CNPA [1], time of flight neutral particle analyzer TOF-NPA [2], silicon detector-based neutral particle analyzer SDNPA [3], etc., only SDNPA with its six separate ion-implanted silicon detectors is considered to be a multi-channel neutral particle analyzing (NPA) diagnostic. However, in spite of numerous advantages of this diagnostic, angular resolution of SDNPA is quite poor for detailed and precise measurements of energy-resolved fast particles angular distribution. To increase angular resolution and contribute to data obtained by SDNPA a new 20-channel diagnostic based on position sensitive detector (PSD) has been developed.

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2. Experimental Setup

Detailed description of diagnostic is given in [4], this part of the manuscript is devoted to remind the key elements of the diagnostic and to describe additional parts, improvements and changes in the design of the diagnostic.

2.1 Location of Position Sensitive Detector (PSD) diagnostic on LHD versus NBI and ICRF

The new location for PSD Diagnostic was chosen in such a way that it could observe as wider as possible range of pitch angles from tangential to perpendicular ones. For this purpose the tangential port was chosen and the detector was moved closer to the aperture. Figure 1 demonstrates a new position (blue sightlines) of the diagnostic versus NBI and ICRF together with previous PSD position (black sightlines).

As it can be clearly seen from the picture the range of observable angles was significantly improved, namely from 12 degrees at previous position to 24 degrees at a new position. The pitch angles corresponding to sightlines at a new position cover the range 70°-160° ($v_{\|}/v$from +0.34 to −0.94) as it is shown on Fig. 2. As the detector is a linear array, the intersection of circular magnetic axis with a flat plane of sightlines has only 2 points. Thus only 2 detector sightlines can observe the very center of plasma. The sheaf of sightlines was adjusted in such a way that all the channels to observe as closer as possible the central region of plasma.

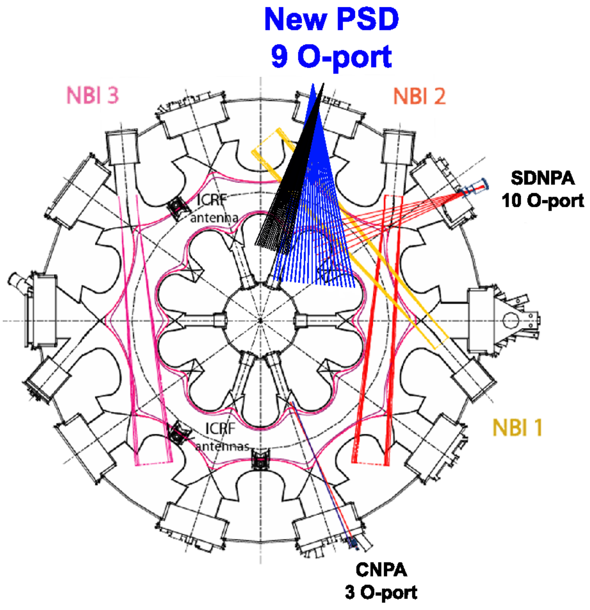

Fig. 1 Diagnostic location versus NBI and ICRF.

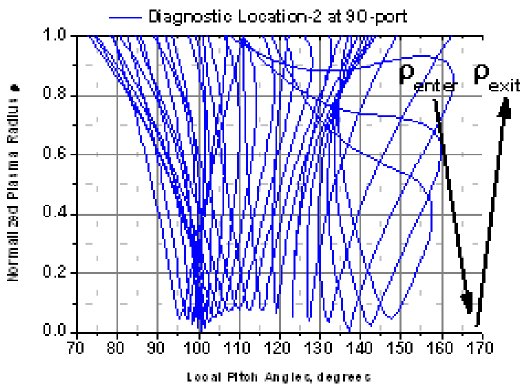

Fig. 2 The sheaf of pitch-angles along 20 sightlines.

2.2 Position Sensitive Detector (PSD) diagnostic basic components

At the heart of the diagnostic there is a linear AXUV detector [5] partitioned into 20 independent segments and positioned behind an aperture. Such structure allows one to construct an angle resolved NPA. Varying the distance between the aperture and the detector either the observable range of angles can be increased with decreased angular resolution or the angular resolution can be increased for detailed scan of the particular plasma region.

In order to register particles in a wider range of energies the 200 nm aluminum foil covering the detector to protect it from the visible and ultraviolet lights from plasma was replaced by 100 nm aluminum foil. Energy losses of particles had to be recalculated consequently by SRIM calculations [6, 7]. Energy losses for H and He particles are presented at Fig. 3. Minimum possible to measure energy of H atoms has become 7 keV with thinner foil versus 15 keV with thicker foil.

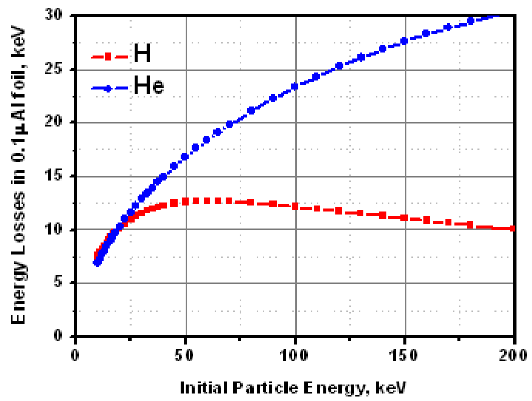

Fig. 3 Fast particles energy losses in 0.1 μ Al foil.

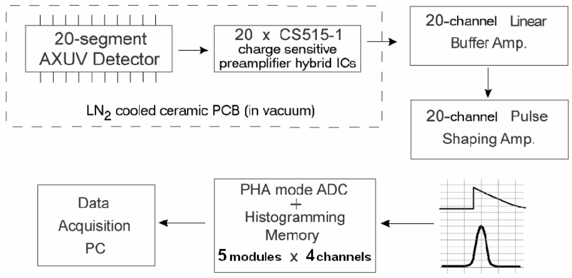

Fig. 4 Modified data acquisition system of the PSD.

As the detector was moved closer to the aperture to observe a wider range of angles the spatial angle observed by every detector segment has increased correspondingly. Same time the energy range of measured particles has also been increased. Everything this led to significant increase of the fast particles flux on the detector surface and count-rate significantly exceeded 10^5 counts per second, the top-level for the correct work of shaping amplifier (shaping time constant of shaping amplifier was varied from 1 to 0.5 μs). As a result the collimating aperture, utilizes a piezoelectrically driven slit enabling its opening adjustment during the experiment according to the expected flux, had to be replaced by a 5 μ in diameter not adjustable aperture.

2.3 Data Acquisition System (DAS)

Every segment of linear AXUV detector has its own DAS. The sequence of DAS elements still remains the same as before, i.e. a charge pulse produced by an incident particle in the detector is converted to a voltage pulse, amplified by preamplifier and buffer amplifier, shaped by a fast pulse amplifier, processed by pulse height analyzer (PHA) analog-to-digital converter (ADC) and stored in a histogramming memory module (HMM). Separate buffer amplifier modules and shaping amplifier modules of every detector segment were compiled in two compact modules (Fig. 4). PHA mode ADCs of every detector segment were combined together with HMM and divided into 5 separate modules for 4 detector segments each.

As the detector, preamplifiers and buffer amplifier are very close to LHD chamber and strong magnetic field respectively and the signal level is quite low (about 2 mV after preamplifier and about 20 mV after buffer amplifier) they are very sensitive to electromagnetic noise. Therefore the assembly of the detector and the preamplifiers is placed inside the chamber of the diagnostic and cooled by liquid nitrogen. The diagnostic design was improved by installation of the thermocouple to monitor the temperature of the assembly with detector and preamplifiers. It was attached to the liquid nitrogen cooled copper disk on which the detector and preamplifiers are mounted. In addition to the cooling system the buffer amplifier was positioned as close as it possible to preamplifiers outputs from the chamber, and all cables between preamplifier outputs and buffer amplifier inputs were covered by metal braid. Such measures could reduce energy resolution of measured signal up to 2-3 keV.

3. First Experimental Results

The very initial results of a new 20-channel PSD based diagnostic of fast particles have been obtained at LHD during present (2006-2007) experimental campaign for a variety of plasma heating conditions: ECH, ICH and NBI. The response of neutral fluxes to plasma conditions and type of heating can be clearly seen from the following figures of experimental results.

The typical energy-resolved spectrum measured along a single sightline is presented at Fig. 5.

The restored spectra of fast particles measured along all 20 channels can be seen at Fig. 6(b) and Fig. 7(b) where each black line should correspond to each channel (a few lines corresponding to perpendicular directions were omitted to escape from the stack of lines).

3.1 NBI and ECH heating regimes

Experimental conditions are summarized in Fig. 6(a), illustrating the heating time diagrams, density and stored energy behavior during discharge. Two same time intervals (1 and 2) were chosen to check the influence of the ECH on fast particle distribution in plasma. Plasma parameters are: $R_{ax} = 3.65$ m, $B = -2.712$ T, $\beta = 0.27\%$. Restored ion distributions along 20 sightlines for the same time intervals 1 and 2 are shown on the Fig. 6(b). The linear AXUV detector is positioned under the angle to the LHD magnetic axis (to observe the wider range of angles), therefore the angular resolution is decreasing for more tangential sightlines as it can be seen from Fig. 1 and Fig. 6(b). Comparison of 1st and 2nd pictures of Fig. 6(b) shows the influence of ECH on the ion distribution probably due to influence of the ECH on the plasma confinement.

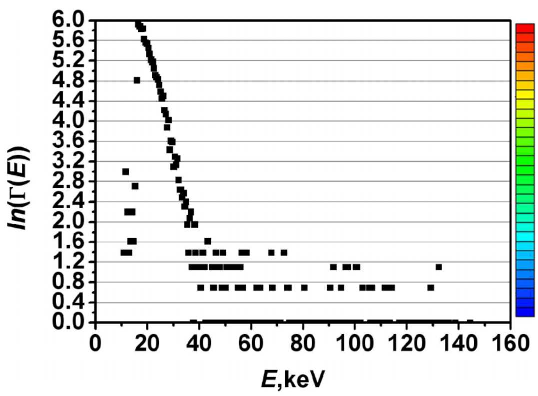

Fig. 5 Energy spectrum measured along one of the 20 sightlines.

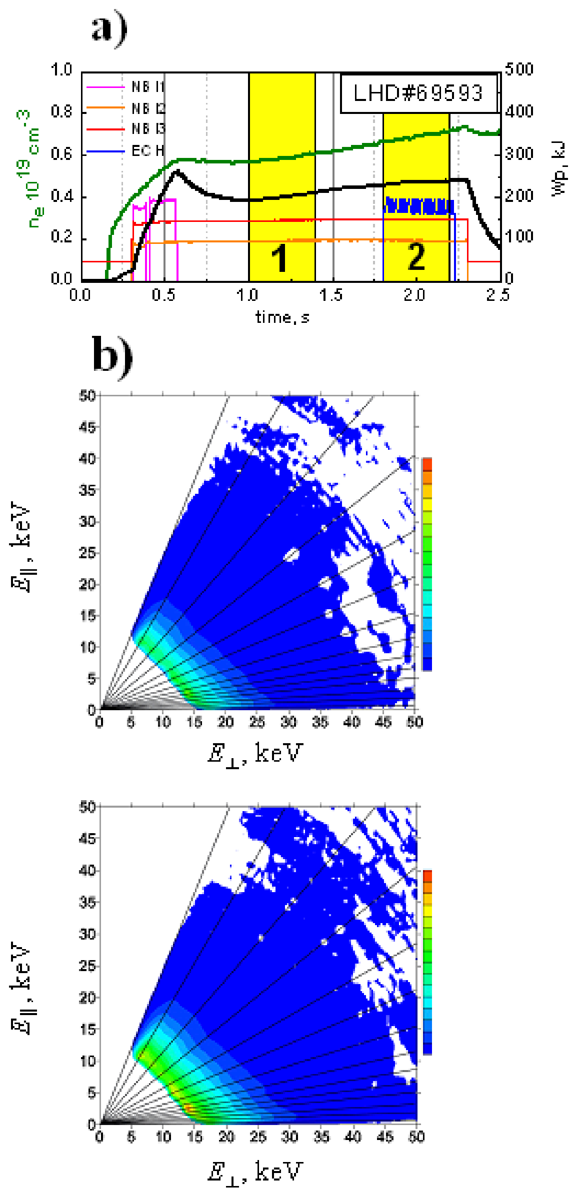

Fig. 6 (a) Time diagram of the LHD plasma discharge; (b) Restored proton angle and energy distribution calculated from PSD data: (1) for NBI-heated plasma and (2) for NBI- and ECH-heated plasma.

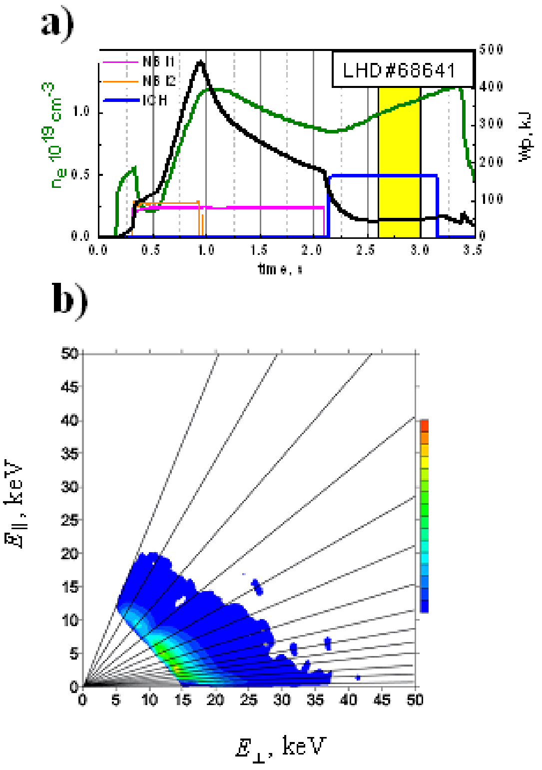

Fig. 7 (a) Time diagram of the LHD plasma discharge; (b) Restored proton angle and energy distribution calculated from PSD data for ICH-heated plasma.

3.2 ICRF heating regimes

Measurements were made for ICRF-heated plasma as well. The heating time diagrams, density and stored energy behavior during discharge are shown on Fig. 7(a) for plasma with R_{ax} = 3.6 m, B = −2.75 T, β = 0.48%. The proton distribution during ICH heating is shown on Fig. 7(b), which demonstrates the absence of high energetic particles and slight increase of particle population in the perpendicular direction.

ICH and ECH regimes also demonstrate increased population of particles in the same energy region and at the same sightlines corresponding to pitch angle range 110°-116°. Additional data processing and analysis are required.

4. Summary

The new 20-channel PSD diagnostic of fast particles can be a powerful tool for measuring of angle- and energy-resolved fast particles distribution in a complex magnetic configuration of LHD. The results of the first measurements in different heating regimes clearly demonstrate dependence of angular- and energy distribution of fast particles on the heating regime.

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