FAST CHARGED PARTICLES MEASUREMENTS AT 'TEXTOR-94'

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Abstract

A diagnostic to measure the flux and the energy of fast charged particles escaping from the plasma has been recently developped at TEXTOR-94. The measurement of ions produced by fusion reactions brings additional information to the neutron measurements. It provides the energy distribution of the fusion products with some spatial resolution even at rather low fusion rate. Preliminary measurements have been done succesfully in discharges with various heating scenarios showing the capability of our diagnostic to cover a large range of plasma conditions. Energy spectrum of 3 MeV protons and 1 MeV Tritons induced by the DD fusion reaction have been measured. The high energy resolution in the measurements allows us to deduce the ion temperature from the width of the energy spectrum in the case of thermal plasmas. A shift of the spectrum has also been measured which is interpreted in terms of toroidal velocity. The spatial resolution of the measurements is analysed.

1. Introduction

The first observation in a tokamak of the 3 MeV protons produced by the d(d,p)T fusion reactions were reported at PLT - see [1]. Using a silicon surface barrier detector located at the bottom of the vacuum vessel, time and energy resolved measurements of the 3 MeV fusion protons were performed. On other devices, observations of charged fusion products were also reported using this technique[2-7].Recently, a similar diagnostic has been developped and installed at the TEXTOR tokamak to measure the energy spectrum and the abundance of lost fast ions. PIPS[1] detectors are used. The detectors are actively cooled such that operation at stable temperature is achieved. The energy spectra obtained have a resolution of 25 keV. Two detectors are installed with different line of sight to obtain spatial information. At TEXTOR, the plasma current is varied between 250kA and 600kA such that the 3 MeV protons and 1 MeV tritons are lost by the plasma.

2. Experimental set up

Two PIPS detectors are mounted on the detector head. The measurements are performed simultaneously with one detector oriented quasi perpendicular to the direction of toroidal magnetic field and one detector oriented quasi parallel to the magnetic field. The manipulator system used to have access to the plasma is shown at fig1. At the TEXTOR tokamak, the temperature of the liner wall is around 300^{o}C. The PIPS detectors must be kept at room temperature(or lower) to be operated reliably. A cooling system[2] was designed using a finite element code[9,10]. The PIPS detectors are absolutely calibrated with respect to the energy using the easily available ^{241}Am

[1]Abbreviation for Passivated Implanted Planar Silicon
[2]See details about the design in [14]

isotope which emits mostly an α of 5486 keV. During the measurements, Xrays and gamma radiation are by far the most severe source of perturbation. However, under normal conditions these events can be rejected by amplitude discrimination and do not burden the measurements. Runaway electrons can generate a very strong Xray background. When a lot of runaway electrons are generated, it may happen that measurements are no longer possible due to pile-up.

3. Detector efficiency and spatial resolution

Trajectories calculation were made in order to know the efficiency and the spatial resolution of the measurements. The fast ions have a very large velocity[3] compared to thermal ions of the main plasma such that the probability to make a collision when escaping the plasma is negligible [2]. The gyromotion has to be taken into account because of the very large Larmor radius[4]. The equation of motion with the Lorentz force term is solved numerically using the GOURDON code [8] with a realistic magnetic field configuration [3]. Influence of electric fields[5]can be neglected. The detection efficiency is calculated numerically using the modification of the GOURDON code introduced by [3]. The fast ion trajectories are integrated backward from the collimator to the plasma [2]. As described earlier [9], it is possible to observe fast ions born at different places of the plasma and with different pitch angle with detectors having different orientation. Typical results are shown at Fig 2.

4. First measurements

A typical energy spectrum measurement is shown at fig3. The deuterium plasma was heated by hydrogen neutral beam co-injection(0.9MW). The central line average density was $3.10^{13}cm^{-3}$, Ip: 350 kA and Bt: 2.25 T. The peaks of 3 MeV protons and 1 MeV tritons are clearly visible on the spectrum. At the left of the triton peak, there are background events caused mostly by hardX rays and gamma radiation. The background is cut off here by the ADC lower threshold. The very sharp peak is a reference peak generated by a pulser. From the width of this peak the noise broadening of the spectrum is deduced.

5. Measurements of Ion temperature and toroidal velocity

In thermal plasmas with a maxwellian distribution of the deuterium ions, the energy spectrum of the fusion reaction products is well approximated by a gaussian profile as predicted by theory [11,12]. The width of spectrum is depending only on the local ion temperature. The measured energy spectrum has to be corrected for energy loss and straggling in the thin protective foil and for noise broadening[3]. A very thin foil is used such that the energy loss of the proton is only 53 keV. The distortion of the spectrum shape is not significant. The noise broadening contribution is measured using the broadening of the spectrum of the reference peak. In most cases, it is well approximated by a gaussian profile[3]. The energy straggling correction is 21 keV. In recent experiments with improved energy resolution, a significant shift(relative to the position of the proton peak in the ohmic phase of the same discharge) of the proton peak was observed when neutral beam injection H$\rightarrow$D is applied. The energy shift is observed on both detectors. The first collimator is oriented rather close to the perpendicular to the direction of toroidal magnetic field. It detects only protons moving in the direction of the beam. On this detector a small positive energy shift is observed. The second collimator is oriented at a small angle with respect to the direction of the magnetic field. It detects only protons moving in the opposite direction. On

[3]order of 10^7 m/s for the charge fusion products
[4]few cm up to 25cm for 15 MeV protons
[5]smaller than 10kV/cm

this detector a negative shift was seen up to 40 keV. This shift can be explained by bulk plasma rotation [13]. The value of v_{tor} deduced from the shift is presented at fig4. This spectrum was measured at a radius $25 \pm 10cm$. The ion temperature is also shown at fig 4. In this case, the spectrum was measured more centrally at$10 \pm 10cm$. A comparison with the charge exchange spectroscopy measurements has been done. To determine the influence of the averaging effect, an effective detection efficiency is calculated. The effective detection efficiency is the product of the detection efficiency given by the trajectory calculation and the birth profile of the protons [3]. In thermal plasmas of Textor ($T_{i0} \leq 2keV$), the birth profile of the protons is strongly peaked at the center. As a result, the effective detection efficiency is weighted towards the center. The central ion temperature obtained by this procedure is in excellent agreement with the central ion temperature derived from charge exchange spectroscopy measurements. The toroidal rotation, however, is found a factor of two higher.

6. Conclusions

Energy spectra of fast tritons and fast protons with an energy resolution up to 25 keV are measured. In thermal plasmas, the ion temperature and the toroidal velocity are measured. The central ion temperature obtained from the charge exchange measurement is in excellent agreement with the value derived from the 3 MeV proton energy spectrum when taking care of the averaging effects. Some discrepancies between the values of toroidal velocity have to be analyzed. In plasma with non thermal distribution of deuterium, changes in the reactivity profile are measured and information about the energy of fast ion tail is obtained.

Aknowledgements. Many thanks to F.Durodie, P.Stienon, ERM-KMS and TEXTOR technical staff for their assistance in the design, the construction and the installation of the fast charged particle detector.

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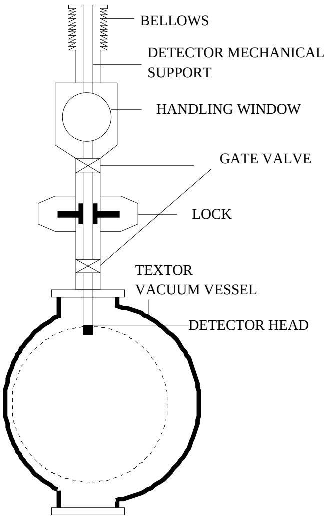

Fig.1: Manipulator system used for the diagnostic

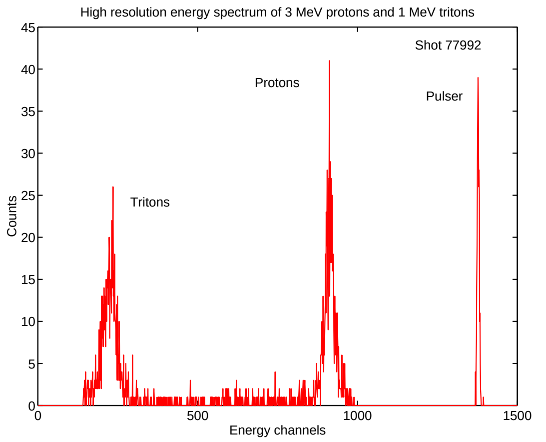

Fig.3: 3 MeV protons and 1 MeV tritons energy spectrum taken during NBI(0.9 MW) H -> D. See detection efficiency at fig2(left). Central lin. av. dens.: 3.10e13cm-3, Ip:350kA, Bt:2.25T

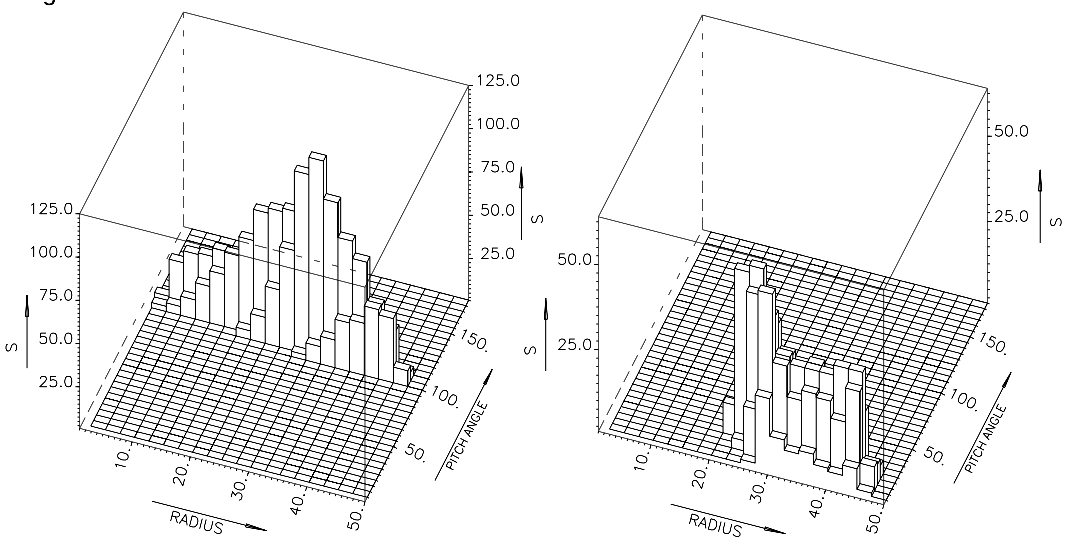

Fig.2: Distribution of detection efficiency versus radius and pitch angle for 3 MeV protons for both detectors. Flat emission profile, Ip = 350 kA(n=2), Bt = 2.25 T. Left: detector looking quasi perpendicular to the toroidal magnetic field. Right: detector looking quasi parallel

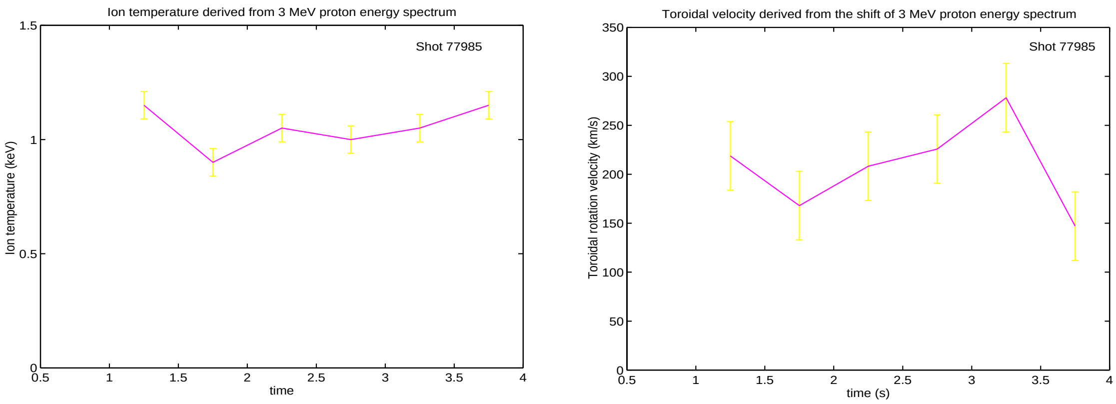

Fig.4: Ion temperature and toroidal rotation derived from 3 MeV protons energy spectrum measurements taken during NBI (0.9 MW) H -> D. Ti is measured at 10 +/- 10cm with detector 1. Vrot is measured at 25 +/- 10 cm with detector 2. Lin.av dens.: 4.5 10e13cm-3 Ip: 350 kA, Bt: 2.25 T