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First Results from the Thomson Scattering System at the Stellarator Wendelstein 7-X

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I. Introduction

A multi-pulse Nd-YAG laser Thomson scattering system (TS) has been installed on W7-X as a diagnostics for electron temperature and density profile measurements. For the first operation phase (OP1.1) the last closed flux surface W7-X was defined by five graphite limiters mounted at the inboard side. The main objective of OP 1.1 was the integrated operation and components test of W7-X, combined with a physics program. For OP 1.1 the TS system was equipped with a reduced set of 10 spatial points to cover a half profile (from core to edge region) of the outboard side of the plasma cross section. One spatial point was located inside the scrape-off layer (SOL) in the limiter shadow. In OP1.1 the Thomson scattering system provides electron temperature T_e and density n_e measurements every 100 ms with a 2.5 cm spatial resolution at the core and 4 cm at the edge. The measured core temperatures during OP1.1 were up to 10 keV and the edge temperature at the SOL was less than 15 eV. Typically, core densities were $2\text{-}6\cdot10^{19}$ m^{-3}.The density calibration of the TS system utilizes anti-Stokes Raman scattering from nitrogen gas and by cross-calibration with a CO_2 dispersion interferometer with a close line of sight [1]. In this paper we also present the comparison of the TS temperature profiles with electron-cyclotron emission (ECE) and X-ray spectroscopy (XICS) measurements.

II. Experimental set-up

The Nd:YAG laser system (2 J, 10 Hz), the polychromators and the data acquisition system are located in diagnostic rooms outside the torus hall. The laser beam is guided by mirrors to the entrance port at W7-X and will be absorbed behind the exit port in a beam dump. Two observation optics image the scattered light onto fiber bundles. The port geometry and the set-up of the Thomson scattering components inside W7-X are shows in figure 1. In OP1.1 only the optics for the outboard side is equipped with fiber bundles. The fiber bundles guide the light to the polychromators for spectral analyzing and data acquisition. High dynamic range ADCs with 14 bit resolution together with 1 GS/s sampling rate are used to digitize the signals from Si-avalanche diodes. Examples of digitized signals are shown in figure 2a and 2b. A brief description of the whole W7-X Thomson scattering design is given in [2].

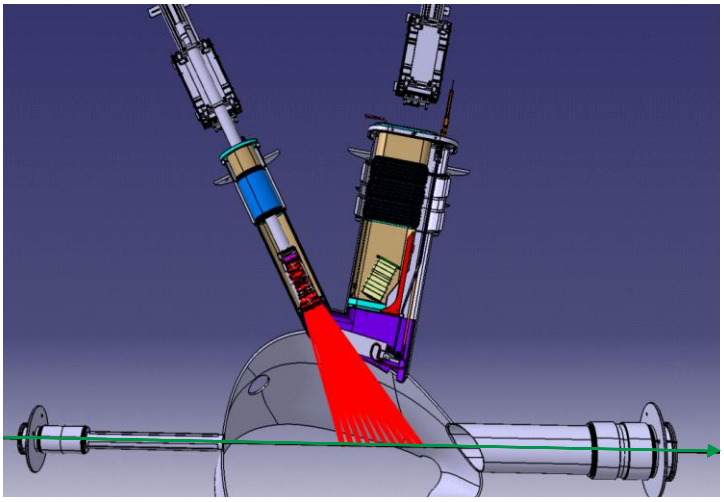

Fig. 1: Set-up of TS components inside W7-X and port geometry. The green line shows the direction of the laser beam, the red lines presents the optical rays from the scattering volumes.

III. Scattering signals and Raman-calibration

Respectively two fiber bundles with different length (57 m and 77 m long) are connected to each polychromator. Therefore scattering signals from two different spatial channels can be detected by one polychromator with a delay of 100 ns. Due to the short laser pulses of about 9 ns only the ac output of the pre-amplifier is connected to the 14 bit, 1 GS/s digitizers. In figure 2a typical times traces of signals from Raman scattering off nitrogen gas are shown together with the fit function (red line) for mathematical analysis. In this case the noise is only given by the excess noise of avalanche photo diodes.

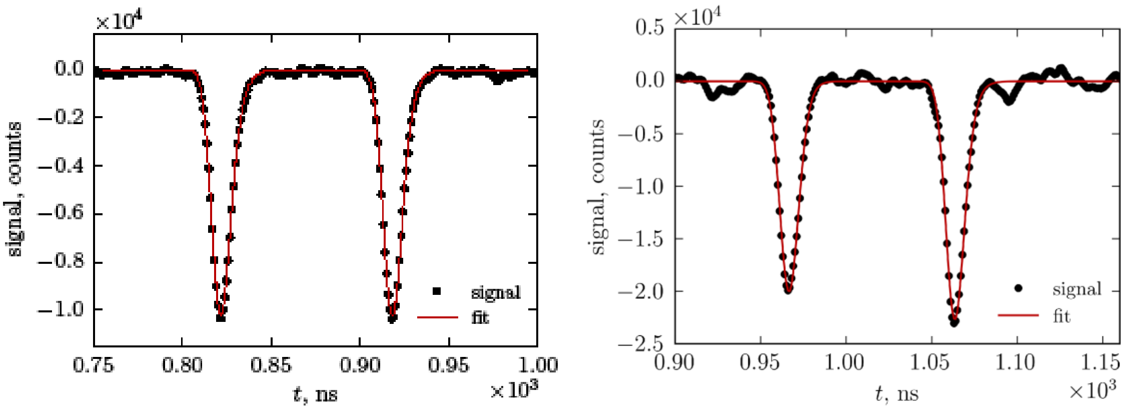

Figure 2a: Time traces of signals from Raman scattering. Figure 2b: Time traces of signals from scattered light.

Figure 2b shows typical time traces from a hydrogen plasma discharge. Due to strong background light from bremsstrahlung and line emission from plasma impurities the zero baseline shows correlated fluctuations. Please notice, that due to the ac coupling only the changes of the background light are detected.

For the density calibration rotational Raman scattering off nitrogen gas is used. The measurements at different nitrogen pressures from 150 mbar down to $5 \cdot 10^{-1}$ mbar are shown in figure 3.

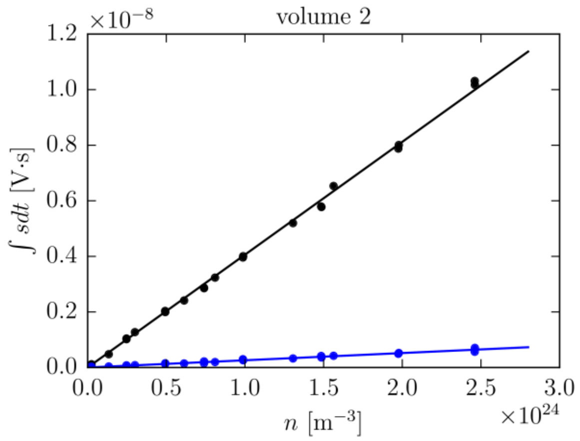

Figure 3: Rotational Raman scattering signals of the first two spectral channels are linearly fitted against the nitrogen gas filling pressure. The slopes represent the calibration factors.

The best agreement of density measurement by Thomson scattering and line integrated measurements by the dispersion interferometer is achieved with the Raman cross section from nitrogen molecules published by B.P. LeBlanc [3]

2/. In most cases, the agreement is better than 10%. In figure 4 a comparison of Thomson scattering and interferometer measurements from a hydrogen discharge with a stepwise ECRH power variation are presented. Figure 4 also shows the central electron temperature measured by ECE diagnostics. The result of electron temperature and density profile measurements at three time points (0.22 s, 0.42 s and 1.02 s) of the discharge measured by TS is shown in figure 5a and 5b. In figure 6the comparison of electron temperature profiles 250 ms after plasma start-up from Thomson scattering, ECE [4] and XICS diagnostics [5] are shown.

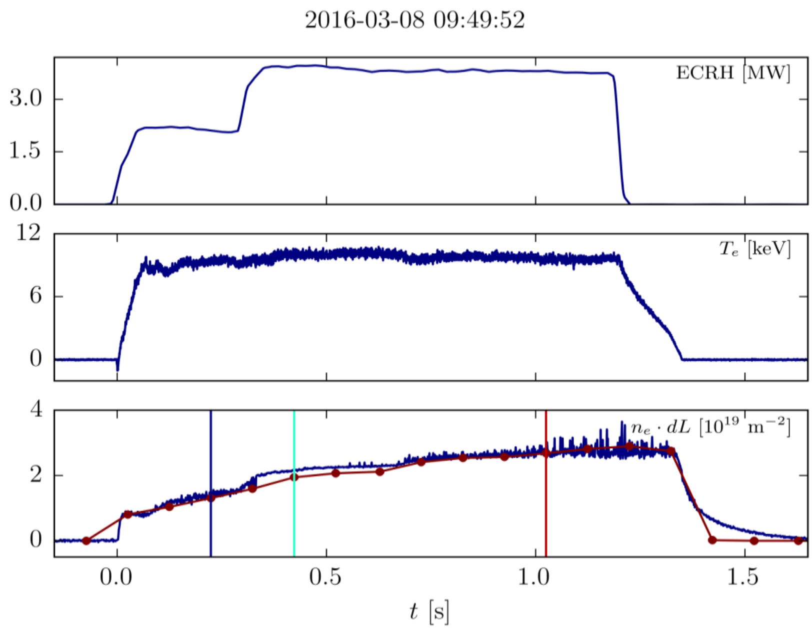

Fig. 4: Hydrogen discharge with a step wise increase of the ECRH heating power; the central electron temperatures are measured by the ECE diagnostic and the line integrated electron densities are measured by dispersion interferometer and Thomson scattering diagnostics.

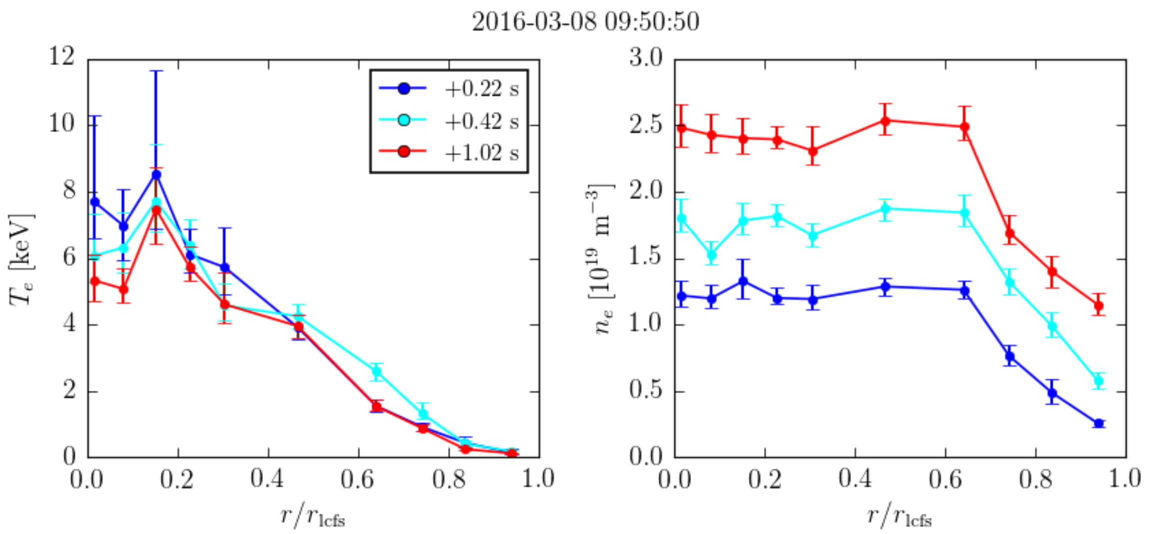

Fig. 5a and 5b: Development of Electron temperature and density profile measurements by Thomson scattering diagnostics.

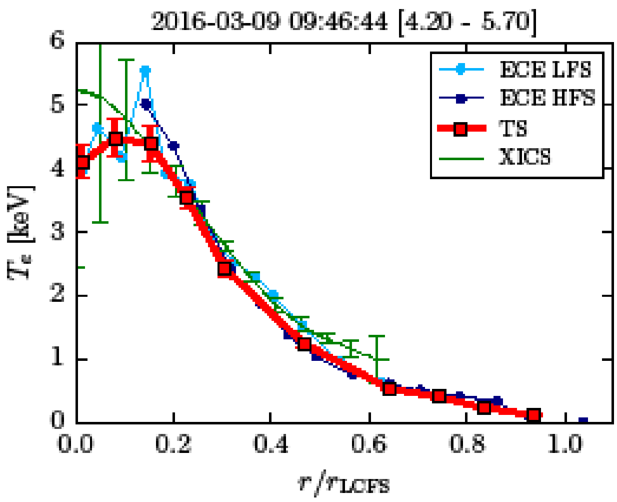

Fig.6: Comparison of electron temperature profiles 4.2 s after plasma start-up from Thomson scattering (red line), ECE (blue lines) and XICS diagnostics (green line) in a low beta shot.

The best agreement of the diagnostics is better than 15% within the error bars under low beta conditions.

[1] J. Knauer et al., this this conference P4-017

[2] E. Pasch et al. Rev. Sci. Instrum (2016) to be published

[3] B.P. LeBlanc, *Thomson scattering density calibration by Rayleigh and rotational Raman scattering on NSTX*, Rev. Sci. Instrum. **79**, 10E737 (2008).

[4] M. Hirsch et al., this conference P4-007

[5] N.A. Pablant, M. Bitter, R. Burhenn et al. in 41st EPS Conf. on Plasma Phys., **38F** (2014) p. 1.076

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