LRP 612/98 July 1998

A THOMSON SCATTERING DIAGNOSTIC FOR MEASUREMENTS IN THE DIVERTOR REGION OF TCV

R. Behn, J.H. Rommers, R.A. Pitts,
Z.A. Pietrzyk, R. Chavan, B. Marlétaz

Paper presented at the

12th Topical Conference on High-Temperature Plasma Diagnostics, Princeton, USA, June 7-11, 1998

Submitted for publication to
Review of Scientific Instruments

A Thomson Scattering Diagnostic for Measurements in the Divertor Region of TCV

R. Behn, J.H. Rommers, R.A. Pitts, Z.A. Pietrzyk, R. Chavan, and B. Marletaz

Centre de Recherches en Physique des Plasmas, Ecole Polytechnique Fédérale de Lausanne, Association EURATOM-Confédération Suisse, CH-1015 Lausanne, Switzerland

Abstract

For future divertor studies on TCV measurements of electron temperature and density and their spatial gradients along open flux surfaces will be of major interest. A Thomson scattering system is proposed for this purpose, which takes advantage of the good access via horizontal ports on 3 vertical levels. The modular design of the existing Thomson scattering diagnostic on TCV offers the possibility to modify it for simultaneous measurements in the main plasma and in the divertor region using the same laser. Arranging for a second passage of the laser beam at a radial position shifted towards the inside, measurements can be made along the open flux surfaces between the X-point and the outer divertor strike-point. The optical system is designed to share the camera lens with the existing system. After installation of additional fiber bundles and another set of filter spectrometers, the system will be capable of measuring temperature and density at 10 selected locations in the divertor zone with a resolution in the vertical direction of 15mm. Using numerical simulations, a set of interference filters has been selected to cover the range from 100eV down to 5eV.

contribution to the

12th Topical Conference on High-Temperature Plasma Diagnostics, Princeton, NJ, June 7-11, 1998

submitted for publication to *Review of Scientific Instruments*

Introduction

The tokamak TCV has been designed to study the behavior of plasma configurations over an enlarged range of shape parameters such as elongation and triangularity. Plasma configurations produced so far comprise limiter type plasmas with elongations up to 2.6 and various types of diverted field configurations (single and double null). The flexibility in changing the vertical and radial positions of the X-point and the strike-points is a major advantage for studies of different divertor scenarios. TCV does not have a baffled divertor volume, but almost the entire inside wall of the vacuum vessel is protected by carbon tiles with the floor tiles being designed to accept power loads of up to 5 MW/m^2 for a maximum discharge duration of 2s. For present divertor studies on TCV a plasma configuration ("standard shot") has been chosen with an X-point at 200mm below the midplane and strike-points on the central column and on the vessel floor [1]. Starting from this configuration there is flexibility for studying the effect on the divertor plasma of systematic variations of the X-point to strike-point separation. Another advantage is the exceptionally good access for diagnostic observations. For measurements in the divertor zone a new Thomson scattering diagnostic is being designed which shares the laser and part of the observation optics with an existing system used to measure spatial profiles of electron temperature (T_e) and density (n_e) in the core plasma. It will provide measurements of the spatial and temporal variations of T_e and n_e along the flux surfaces between the X-point and the strike-point. This is of major interest for studies of different divertor regimes (low or high recycling, detachment etc.).

At present, diagnostic equipment on TCV for measurements in the divertor zone includes a set of Langmuir probes integrated into the carbon tiles of the vessel floor and an infrared video camera. The divertor volume is also surveyed by several other diagnostic systems like an array of diodes monitoring D-alpha emission, bolometer cameras, a multichannel spectrometer for observation in the visible range of the spectrum, and a CCD camera with interference filters selecting various impurity lines.

The existing Thomson scattering system on TCV

Before presenting the special features of the divertor system, a brief description of the existing Thomson scattering experiment is appropriate, since major components - such as the support structure, the laser units, and part of the observation optics - will be shared between the two systems. Similar spectrometers will be used and the additional signal channels will be integrated into the same data acquisition system.

The present Thomson scattering system has been designed to measure electron temperature and density profiles in the vertical direction along a laser beam which intersects the main plasma at a radial position (at R=0.90m) close to the center of the vacuum vessel. Using a repetitively pulsed Nd:YAG laser (CONTINUUM Mod. YG 681C), measurements are made at a sampling rate of 20Hz. The laser beam passes through a 25m beam duct to the focusing optics which are located in the basement underneath the tokamak. The entrance and exit windows on the TCV vacuum vessel are oriented at Brewster's angle and mounted on 1m extension tubes including baffle apertures for reduction of stray light.

For observation three sets of wide angle lens assemblies have been installed on horizontal ports at three vertical levels (-0.45, 0.0, and +0.45m). They focus the collected radiation onto fiber bundles defining channels with a spatial resolution of (30 x 3)mm in the vertical and toroidal direction respectively; up to 11 bundles can be placed in the image plane of each lens. At present, 25 fiber bundles are installed to cover the range from z=+0.64m to z=-0.50m. A support structure has been designed to position the fibers on the curved image surface (to minimize aberrations) and adjust their position parallel and perpendicular to the optical axis. The fiber supports and the lens mount form a rigid assembly which is attached to a precision translation stage such that it can be retracted from the port during vacuum vessel bakeout (see fig. 1).

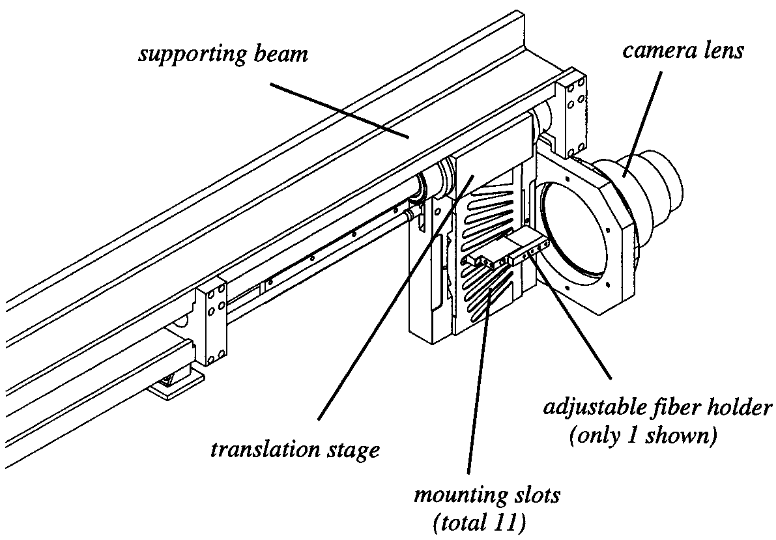


Fig. 1

Support structure to hold the camera lens and the set of optical fibers. Identical assemblies are installed on 3 horizontal ports for full coverage of the plasma cross-section.

Spectral analysis of the scattered radiation is achieved using filter spectrometers with up to four spectral channels. The optical layout has been designed for maximum throughput and good matching to the numerical aperture of the optical fibers (N.A.=0.22). The pass-bands of the interference filters have been optimized to obtain good precision ($\delta T_e / T_e < 10\%$) for temperature measurements over a range of 50eV to 5keV, taking into account the variation in the scattering angle for different viewing chords (60 to 120 degrees). Using Si-avalanche photodiodes (APDs) as detectors, the spectral range is restricted to the short wavelength side of the spectrum.

Since the internal gain of APDs is dependent on temperature they have been equipped with Peltier elements and thermistors to permit feedback controlled temperature stabilization. The detector signals from the built-in preamplifiers are split into a low and high frequency branch and are sent to additional amplifier stages with remotely selectable gain. The high frequency part contains the signals due to scattering whereas the low frequency component is used for recording of the filtered plasma radiation. The HF-signals are fed to charge sensitive ADC units (*LeCroy FERA mod. 4300,4301,4302*) for signal processing, fast digitization and intermediate storage.

Data analysis is based on a simple and fast algorithm which calculates the electron temperature from the ratios of signals from different spectral channels. For density measurements, the absolute sensitivity of the complete system is regularly calibrated using Raman scattering from molecular nitrogen. After conversion to line-integrated densities the results are cross-checked against a FIR interferometer measuring along a vertical chord at the same radial position.

Raman scattering experiments have also served to determine the operational limits of the system. Imposing a signal-to-noise ratio of 10 as the minimum, we find that the sensitivity of the system is sufficient for measurements at electron densities above $2\ 10^{18}\,m^{-3}$.

The divertor Thomson scattering system

General layout

Taking advantage of the good access Thomson scattering measurements in the divertor region become possible with only minor modifications to the existing system. For the redesign discussed here a particular plasma configuration has been chosen as a reference (TCV standard shot, e.g. 10471), but other plasma shapes have also been considered.

After its first passage through the plasma (at R=0.90m), the laser beam will be redirected and refocused to make a second passage at R=0.75m. For the reference configuration the beam will then propagate in close vicinity and almost parallel to the separatrix connecting the X-point to the strike-point (see fig. 2).

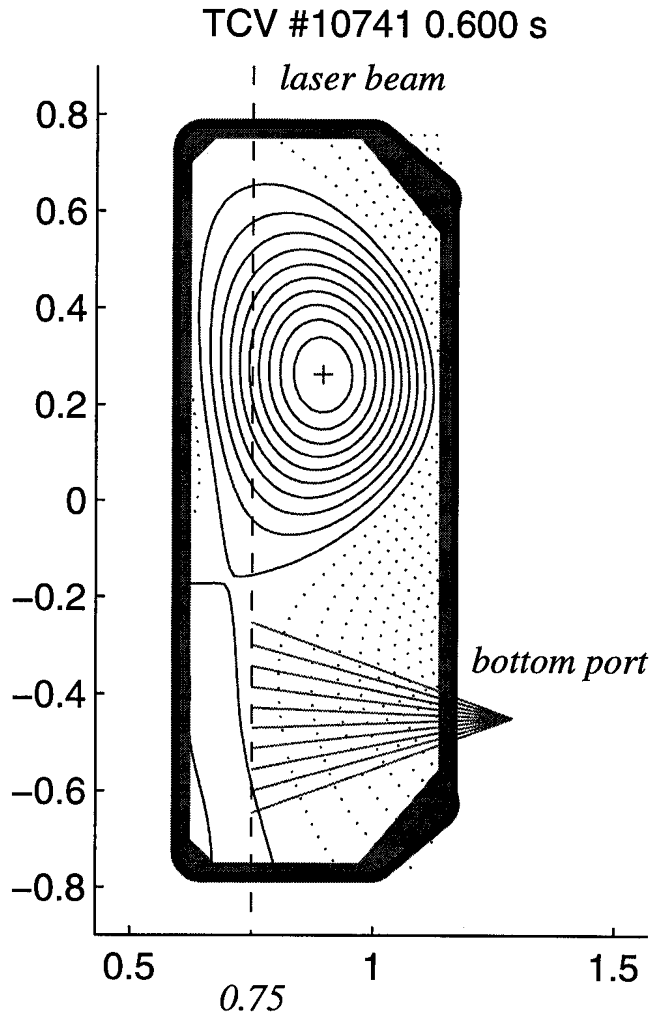


Fig.2

Flux surfaces of a "standard shot" in TCV (single null, down). The dotted line marks the radial postion of the shifted laser beam (at R=0.75m). A fan of viewing chords for divertor mesaurements by Thomson scattering is also shown (using a camera lens at the bottom port).

For collection of the scattered radiation the camera lenses already installed as part of the core Thomson scattering system will be used. Due to the change in object distance (from 330mm to 480mm, see figs. 3a&b) the image plane shifts by 9mm and the magnification is reduced from 0.30 to 0.20. Ray tracing analysis has shown that there is no significant reduction in the performance of the lens for the new operating conditions.

In order to avoid overlap of scattered signals generated during the first and second passage of the laser beam, a small shift in toroidal direction is required (see fig.4a & b). This lateral shift will permit us to place two separate sets of fiber bundles in the corresponding image planes. In this way both systems can be operated simultaneously using the same laser and observation optics.

For measurements in the divertor zone fiber bundles will be used which are composed of three individual fibers of 1mm diameter mounted in-line to obtain a vertical resolution of 15mm.

Fig. 3 a

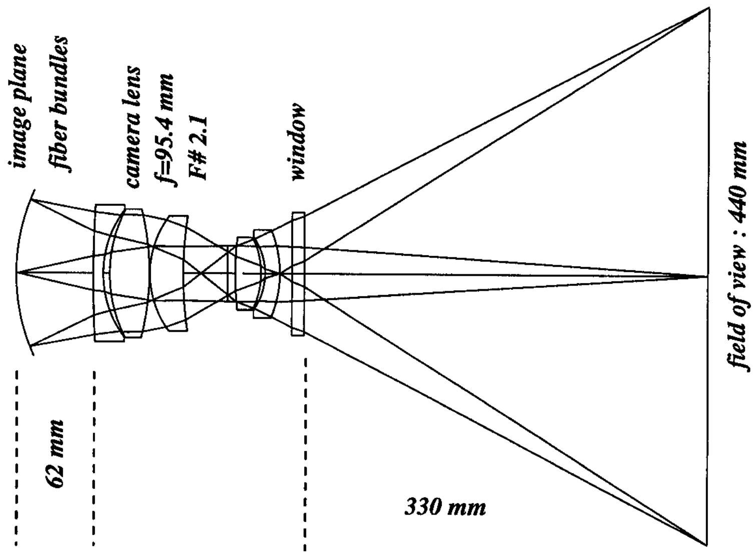


Fig. 3 b

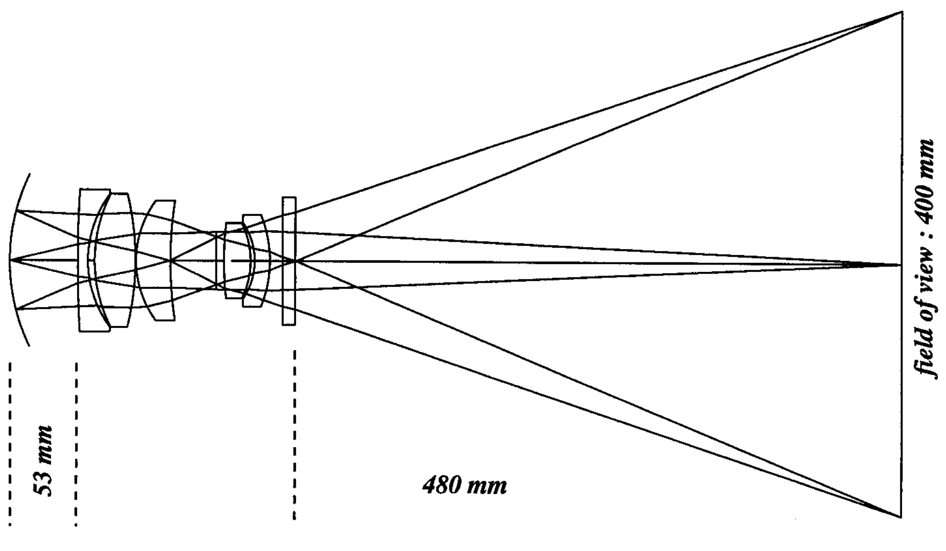


Fig.3 a & b

Field of view covered by the wide angle camera lens for observation in the main plasma (a) and in the divertor region (b). Due to the change in operation conditions the magnification decreases from 0.3 to 0.2 and the image plane shifts from 62mm to 53mm. In both cases the fiber optic collectors are placed on a curved surface to minimize aberrations.

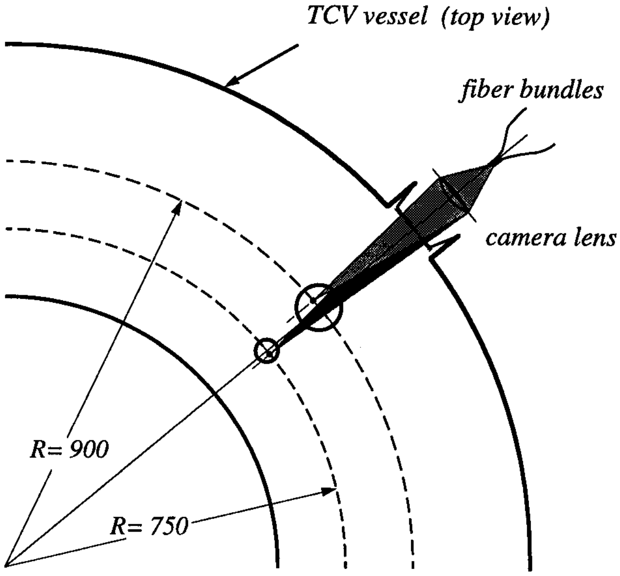
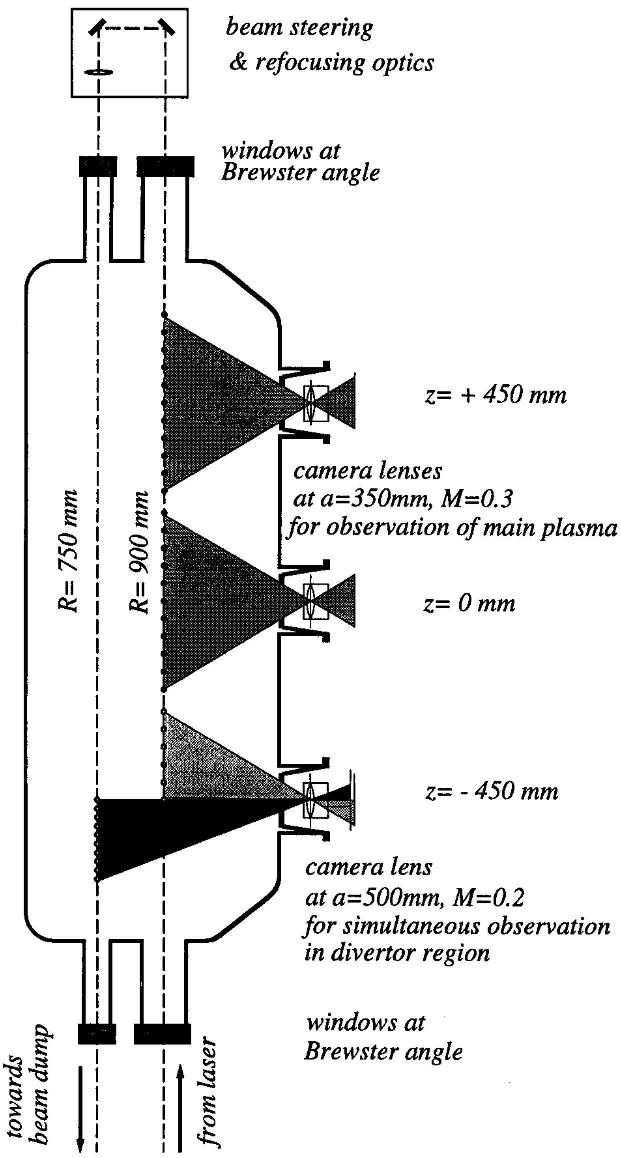


Fig.4 a & b

Arrangement for simultaneous measurements along 2 laser beams at different radial positions.

a)Top view : showing the displacement of the laser beams in toroidal direction and the focusing onto different sets of fiber bundles



b)Side view : showing the double pass of the laser beam and the 3 camera lenses installed; the lens on the bottom window is used at the same time for the main system and the divertor option.

Installation of preadjusted mounts will permit us to change the positions of the fiber bundles for optimum coverage of the region of interest with a given number of spatial channels. This will be a useful option for studies in which the X-point-to-target distance is varied. For better mapping of the divertor fan, flux surfaces can be swept dynamically during a shot.
Since the same mounting structure can be used on all three observation ports, it is easy to adapt to completely different plasma configurations (see Fig. 5, single null up).
The spectrometers to be used are of the same type as those employed in the main system and comprise sets of three interference filters and APDs as detectors.

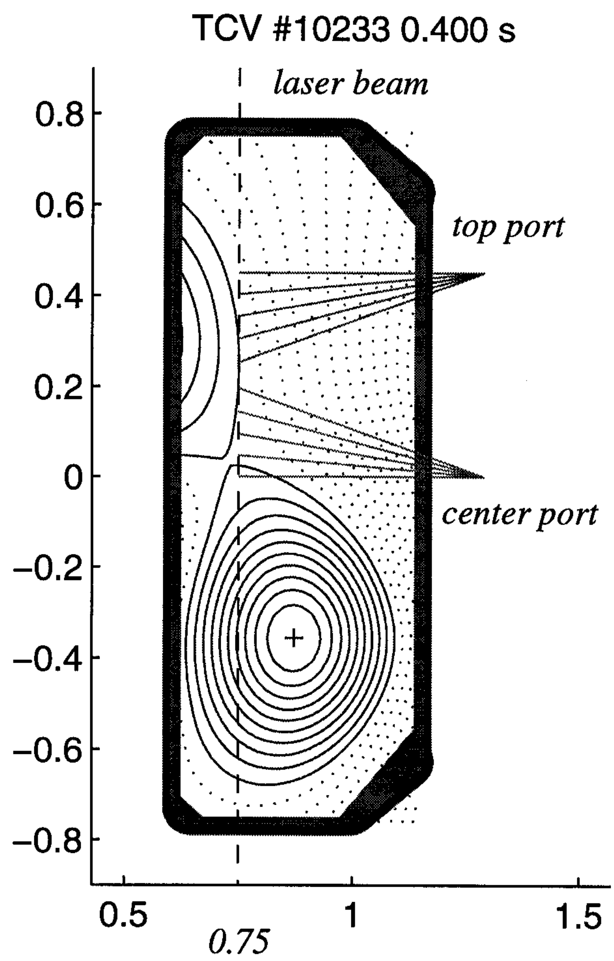


Fig.5

Adapting to a different divertor configuration (single null, up) by repositioning of the fiber optic collectors (using camera lenses installed at the top and center ports).

Optimization of system parameters and expected performance

According to previous experiments on TCV and taking into account the data published in the literature [2,3], temperatures in the range of 5 to 50eV and densities from 5 10^{18} to 5 10^{19} m^{-3} are to be expected in the divertor plasma. Langmuir probe measurements at the outboard divertor target show the divertor plasma of the reference shot to be in the attached regime for all but the highest densities in TCV using ohmic heating only [4]. However, a program of divertor studies in the detached regime is planned (the detached regime can be reached by increasing the connection lengths, increasing the main plasma density, injecting impurities into the divertor area, and by applying additional heating). In this case, temperatures below 5eV and densities near $10^{20}m^{-3}$ are to be expected near the strike-points with substantial gradients of these parameters along the flux surfaces. With this in mind filter characteristics (location of the pass band, bandwidth) have been selected using results from a computer simulation to predict the signal levels and noise contributions. A typical set a filter curves to be used at temperatures above 5eV is shown in fig.6.

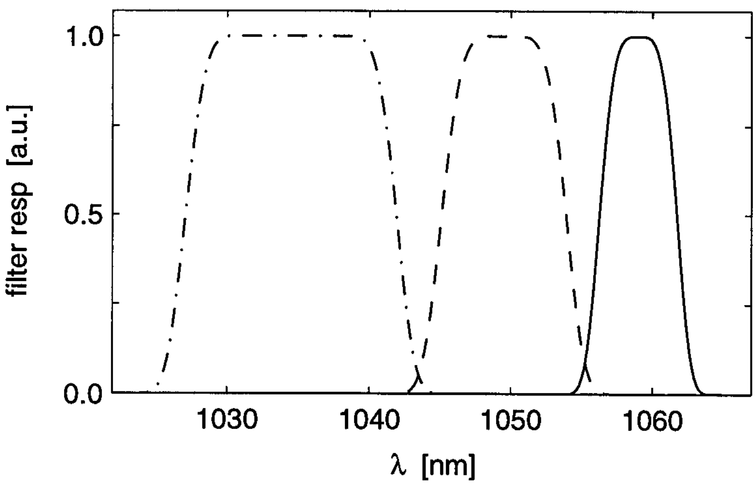


Fig.6

Filter set of a 3-channel spectrometer optimized for measurements in the divertor region of TCV (refers to case 2 of table I).

These calculations are based on known system parameters as well as measured data from the existing system on TCV: laser pulse energy E_L= 0.7J; solid angle $\Delta\Omega$=5.2 10^{-3} sterad; spatial resolution Δz=15mm, overall transmission τ=0.45; the parameters of the APDs correspond to EG&G mod.C30974E. The contribution of plasma radiation to detector noise has also been included. An estimate of the radiation level was obtained from a calculation of the Bremsstrahlung continuum multiplied by an enhancement factor of about 10 to account for line emission from impurity ions.

Table I   Sets of interference filters

parameters	*case 1*	*case 2*	*case 3*	*units*
angle θ_s	70	90	110	*degrees*
CWL λ_{F1}	1059.5	1059.0	1058.5	*nm*
BW $\Delta\lambda_{F1}$	5.0	6.0	6.5	*nm*
CWL λ_{F2}	1052.1	1049.5	1046.5	*nm*
BW $\Delta\lambda_{F2}$	7.9	9.5	11.1	*nm*
CWL λ_{F3}	1040.7	1034.5	1030.0	*nm*
BW $\Delta\lambda_{F3}$	12.9	15.5	20.0	*nm*

Table I

Parameters of interference filter sets optimized for divertor measurements in TCV over the temperature range from below 5eV to near 100eV. The effect of the variation of the scattering angle can be compensated by choosing slightly different filters.

Fig.7 gives an example of the results for an electron density of n_e=2 10^{19} m^{-3}. It is found that T_e measurements with a relative uncertainty of the order of 10% should be possible over a T_e -range from 5 to 50eV and down to plasma densities near 10^{19} m^{-3}. Measurements at lower densities could be envisaged at the expense of spatial resolution but an increase in the laser pulse energies appears more promising. However, these predictions are based on the assumption that stray light is negligible. For the main system already in operation this is indeed the case, as a result of careful design of the entrance and exit ports for the laser beam.

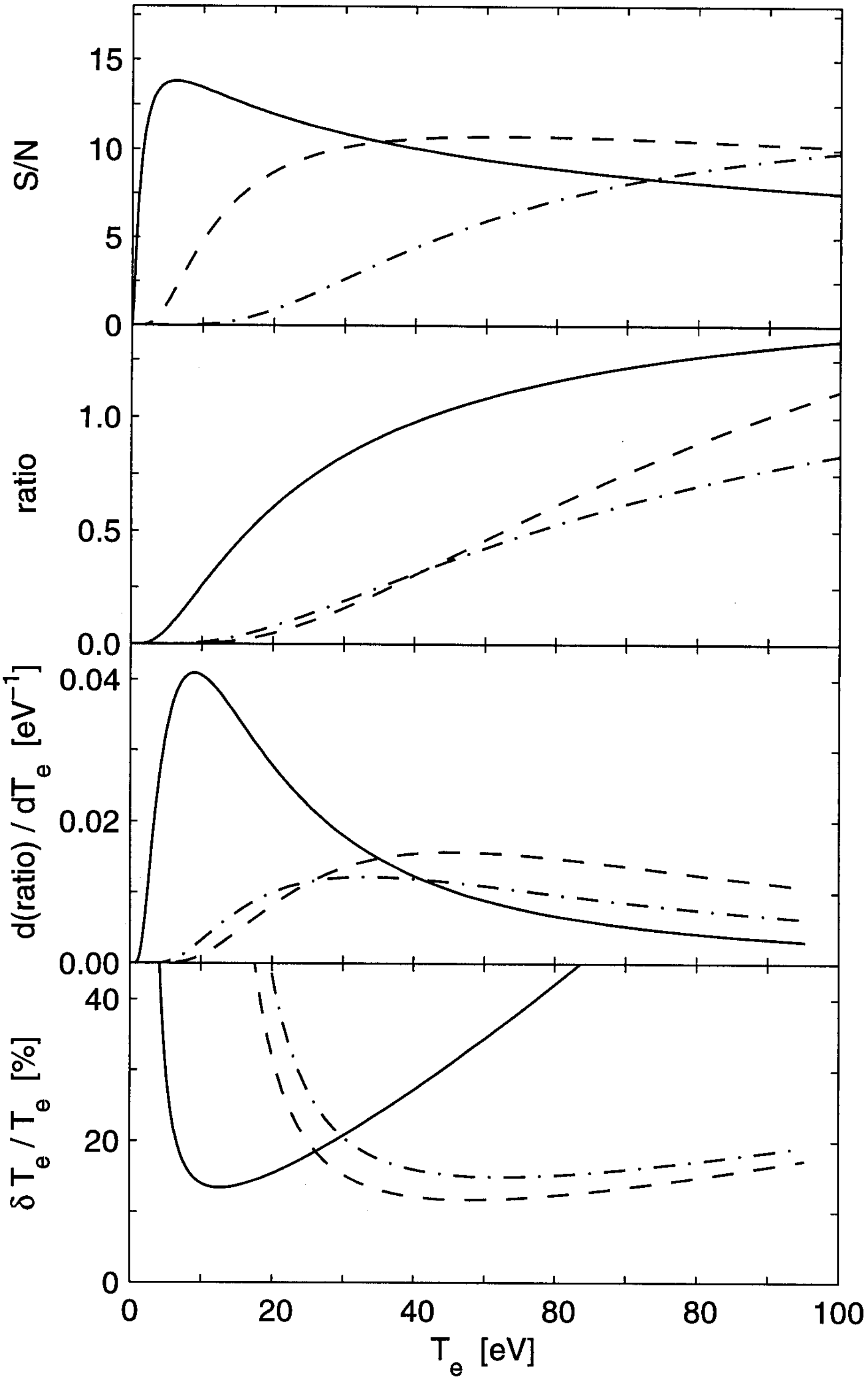


Fig.7

Results of a numerical simulation of Thomson scattering from the divertor plasma in TCV showing the expected signal-to-noise, the ratios of signals from 3 spectral channels, and the relative precision of T_e-measurements all as a function of temperature (using filter set of fig.6).

Conclusions

The flexibility of TCV for the creation of a variety of diverted plasma configurations and good access for diagnostic observations are major advantages for divertor studies. A Thomson scattering system capable of measuring T_e and n_e profiles in the divertor region will provide essential information for better understanding and optimization of divertor scenarios. A design is presented based on the modification of the existing Thomson scattering system to include additional viewing chords for observation in the divertor region. For this purpose the laser beam will be redirected and refocused to make a second passage through the plasma at a different radial position. The layout of the optical system will permit simultaneous measurements in the core and divertor zone using the same lens assembly. With the given design parameters the system should be capable of measuring in the range of 5 to 50eV with a relative error of the order of 10% at densities above 10^{19} m^{-3}.

This work has been partially supported by Fonds National Suisse pour la Recherche Scientifique.

References :

[1] R.A.Pitts, Ch.Nieswand, H.Weisen, M.Anton, R.Behn, R.F.Chavan, M.J.Dutch, B.P.Duval, S.Franke, F.Hofmann, B.Joye, J.B.Lister, X.Llobet, Y.Martin, J.-M.Moret, J.Petrzilka, Z.A.Pietrzyk, V.Piffl, P.Reinke, M.E.Rensink, G.R.Smith, W. van Toledo
J. Nuclear Materials 241-243 (1997) 867-872

[2] M.E.Fenstermacher, S.L.Allen, N.H.Brooks, D.A.Buchenauer, T.N.Carlstrom, J.W.Cuthbertson, E.J.Doyle, T.E.Evans, P.-M.Garbet, R.W.Harvey, D.N.Hill, A.W.Hyatt, R.C.Isler, G.Jackson, R.A.James, R.Jong, C.C.Klepper, C.J.Lasnier, A.W.Leonard, M.A.Mahdavi, R.Maingi, W.H.Meyer, R.A.Moyer, D.G.Nilson, T.W.Petrie, G.D.Porter, T.L.Rhodes, M.J.Schaffer, R.D.Stambaugh, D.M.Thomas, S.Tugarinov, M.R.Wade, J.G.Watkins, W.P.West, D.G.Whyte, and R.D.Wood
Phys. Plasmas 4(5),1761-1773 (1997)

[3] T.N.Carlstrom, C.L.Hsieh, R.Stockdale, D.G.Nilson, and D.N.Hill
Rev.Sci.Instrum. 68(2), 1195-1200 (1997)

[4] R.A.Pitts, A.Refke, B.P.Duval, I.Furno, B.Joye, J.B.Lister, Y.Martin, J.-M.Moret, J.H.Rommers, and H.Weisen
submitted for publication in J.Nuclear Materials