*31st EPS Conference on Plasma Phys. London, 28 June - 2 July 2004 ECA Vol.**28G**, P-1.131 (2004)*

Fast Ion Millimeter Wave CTS Diagnostics on TEXTOR and ASDEX Upgrade

S.Michelsen[1,2], H.Bindslev[1], J.Egedal[2], J.A.Hoekzema[3], S.B.Korsholm[1,2], F.Leuterer[4], F.Meo[1], P.K.Michelsen[1], S.K.Nielsen[1], E.L.Tsakadze[1], E.Westerhof[5], P.Woskov[2]

1. Association EURATOM-Risø National Laboratory, DK-4000 Roskilde, Denmark
2. MIT Plasma Science and Fusion Center, Cambridge, MA 0213,USA
3. Association EURATOM-Forschungszentrum Jülich GmbH, Institut für Plasmaphysik, Trilateral Euregio Cluster, D-52428 Jülich, Germany
4. Max-Planck-Institut für Plasmaphysik, EURATOM Association, D-85748 Garching, Germany
5. FOM-Institute for Plasma Physics Rijnhuizen, Association EURATOM-FOM, Trilateral Euregio Cluster, The Netherlands, www.rijnh.nl

The collective Thomson scattering (CTS) diagnostic systems for measuring fast ion dynamics in TEXTOR and ASDEX Upgrade are described in this paper. Both CTS systems use mm-waves generated by gyrotrons as probing radiation.
The first CTS measurements of fast ions in the MeV range were made at JET as reported in refs. [1] and [2]. After the termination of the JET CTS diagnostic, the work on the CTS system continued at TEXTOR, as a joint effort between TEC and MIT, which was joined by Risø National Laboratory in 2001 [2, 3]. The TEXTOR fast ion CTS diagnostic pilot project achieved successful results during operations in 2000 and 2001 using a 110 GHz gyrotron with a power of max 350 kW and a pulse length of 200 ms [4]. Currently, major elements of the TEXTOR CTS diagnostic are being upgraded at Risø, while a CTS system for ASDEX Upgrade has been build as new.

The CTS principle

Magnetically confined plasmas contain fast non-thermal ions due to e.g. plasma heating and fusion processes. Fast ions can carry up to 1/3 of the total energy in fusion plasmas which makes it essential to understand the dynamics of these particles. CTS utilises the scattering of a probing radiation on the electron density to provide time resolved, spatially localized measurements of the 1-D velocity distribution of the confined fast ions in a given direction, determined by the chosen scattering geometry. The direction can be chosen in the range from near perpendicular to near parallel to the magnetic field. Figure 1 shows the scattering geometry, where $\boldsymbol{k}^i$, $\boldsymbol{k}^s$ and $\boldsymbol{k}^\delta$ are the wave vectors of the incident probing radiation, the scattered radiation and the resolved fluctuations, respectively. The wave vectors fulfill the Bragg condition $\boldsymbol{k}^{\delta} = \boldsymbol{k}^{s} - \boldsymbol{k}^{i}$. In CTS the resolved fluctuations must have scale lengths larger than the Debye length $\boldsymbol{k}^{\delta}\,\lambda_D < 1$, which gives an upper limit of the probing frequency and the angle between the incoming and scattered radiation. A further description of the background and the theory of CTS are given in ref. [5] and can also be found at www.risoe.dk/euratom/cts.

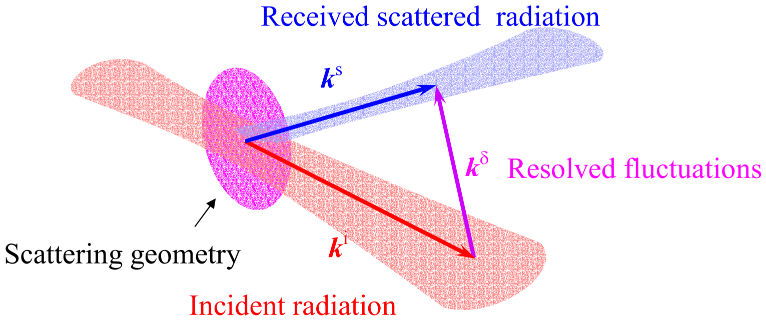

Figure 1. Scattering geometry

The CTS systems for TEXTOR and ASDEX Upgrade.

The spatial localization of the scattering volume for the CTS systems at TEXTOR and ASDEX Upgrade is ~ 10 cm, the typical temporal resolution is 4 ms, and due to the use of steerable launchers and receivers the location of the measuring volume and the resolved velocity direction may be varied. The probing radiation is mm-waves generated by gyrotrons at 110 GHz for TEXTOR and 104 GHz for ASDEX Upgrade (between the fundamental and second harmonic of the ECE radiation). From the antennae the scattered radiation is transmitted via overmoded transmission lines, consisting of overmoded corrugated circular wave guides and quasi optical mirrors, to a scalar horn used to couple the scattered signal to the receiver. The receivers are heterodyne with 42 and 50 spectral channels for TEXTOR and ASDEX Upgrade, respectively, and the data acquisition systems sample the signal synchronously in all channels with 24-bit resolution at a rate of 100 k sample/s. This will allow complete acquisition of the double sideband scattered spectrum over an ion velocity distribution range corresponding to an energy range of approximately 0.5 to 200 keV for deuterium.

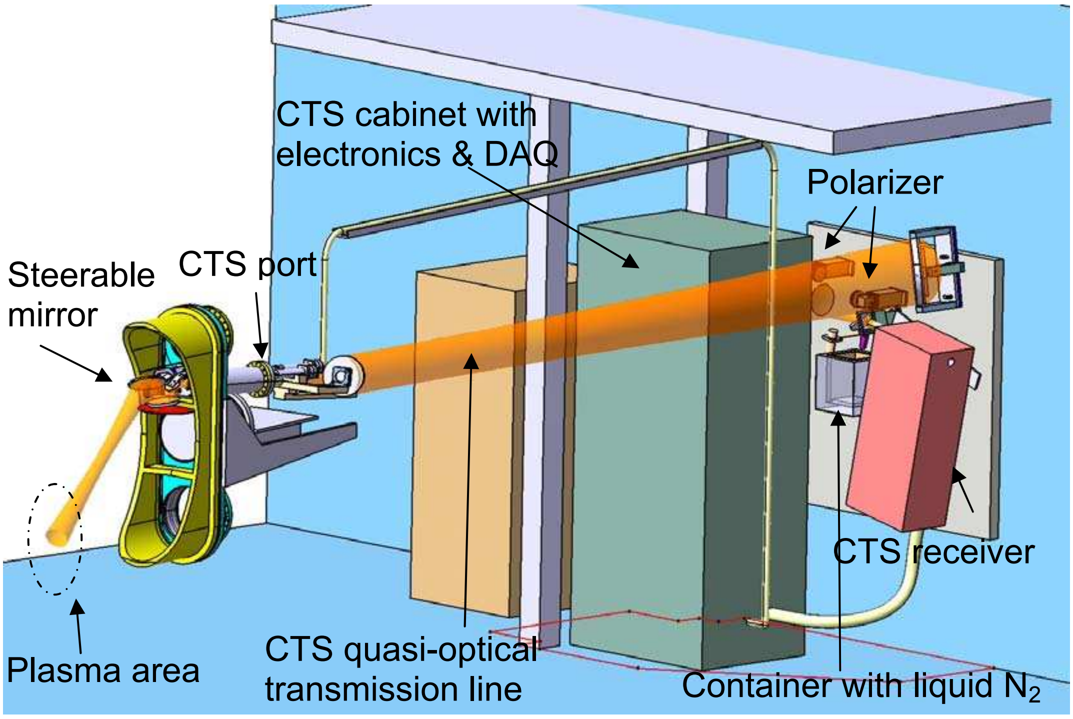

Figure 2: The upgraded quasi-optical transmission line for TEXTOR.

The upgrade of the CTS system for TEXTOR includes a new quasi-optical receiver antenna, a ~6 m long quasi-optical transmission line, a universal polarizer, an upgrade of the receiver electronics, and a new data acquisition system (illustrated in Figure 2). The receiver electronics are upgraded by a new low loss PIN switch and an extra diplexer, to split the central part of the spectrum from the upper frequency band. This additionally requires an extra set of low noise amplifiers, but will help reduce the potential risk of gain compression. Installation of the diagnostic is scheduled for the summer of 2004, with operation and full system tests (including the 110 GHz gyrotron) commencing in the autumn 2004.

The new CTS system for ASDEX Upgrade was built at Risø and was placed in the new ECRH hall in IPP Garching in December 2003. The system relies on the use of the new ECRH system currently being installed. The source of the probing beam will be the 104 GHz frequency (still to be confirmed) of a new 1 MW, 10 s, dual frequency gyrotron. In Figure 3 we present the beam line and the layout of the CTS system at ASDEX Upgrade. Note that when the CTS system is in operation the neighbouring gyrotron is switched off and its quasi-optical transmission line is used by the CTS system by intersecting the beam after the polarizer by a moveable mirror.

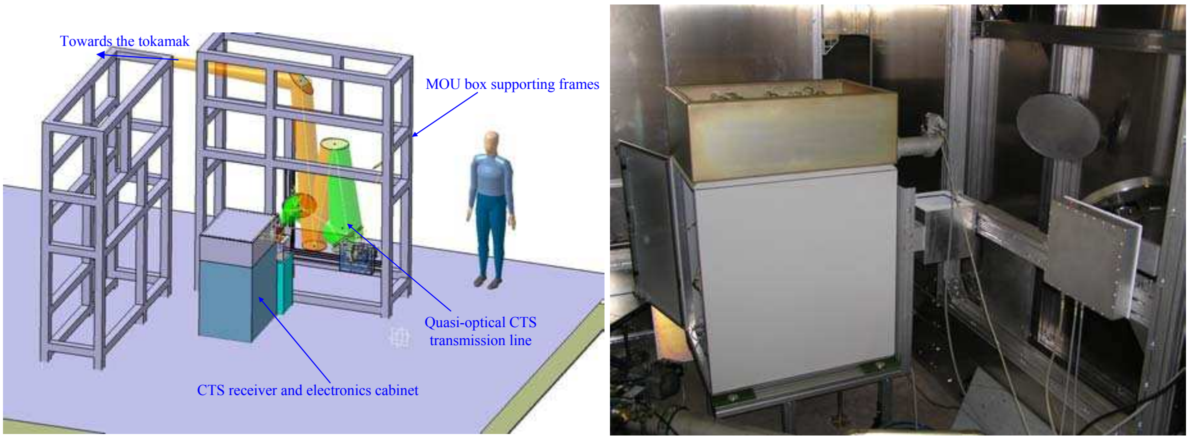

Figure 3: Left: Illustration of the transmission line for ASDEX-Upgrade. Right: The CTS system installed at ASDEX Upgrade, with the moveable mirror to the right.

With the first successful operation at TEXTOR, the reinstallation at TEXTOR and the installation at ASDEX Upgrade, the CTS diagnostic technology is maturing towards being a diagnostic at ITER measuring confined fusion alphas and other fast ions (see also [6]). Furthermore, it has great potential for improving the fast ion physics base, which will help shape and motivate experimental scenarios for ITER.

[1] H. Bindslev, J. A. Hoekzema, J. Egedal, J. A. Fessey, T. P. Hughes, and J. S. Machuzak, *Fast-Ion Distributions in JET Measured by Collective Thomson Scattering*, Physical Review Letters, **83**, 3206 (1999)

[2] H. Bindslev, L. Porte, A. Hoekzema, J. Machuzak, P. Woskov, D. van Eester, J. Egedal, J. Fessey, and T. Hughes, *Fast ion collective Thomson scattering, JET results and TEXTOR plans*, Fusion Engineering and Design, **53**, 105 (2001)

[3] L. Porte, H. Bindslev, F. Hoekzema, J. Machuzak, P. Woskov, and D. Van Eester, *Implementation of collective Thomson scattering on the TEXTOR tokamak for energetic ion measurements*, Rev. Sci. Instrum., **72**, 1148 (2001)

[4] H Bindslev, L. Porte, D van Eester, A. Messiaen, G. Van Wassenhove, and P. Woskov, *Fast Ion Dynamics in TEXTOR measured by Collective Thomson Scattering*, EPS (2001)

[5] H. Bindslev, *A quantitative study of scattering from electromagnetic fluctuations in plasmas*, J. Atmospheric and Terrestrial Physics, **58**, 983 (1996)

[6] H.Bindslev, F.Meo, S.B.Korsholm, J.Egedal, S.Michelsen, S.K.Nielsen, P.Woskov, *Diagnosing fast ions in ITER by collective Thomson scattering*, P5-144, 31st EPS (2004)