Soft-X-ray measurements in WEST using GEM detectors

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Measuring Soft X-Ray (SXR) radiation ([0.1 keV; 20 keV]) of magnetic fusion plasmas is a standard way of accessing valuable information on particle transport and magnetic configuration. Indeed, SXR radiation depends mainly on electron and impurity densities and on electron temperature, making it information-rich but difficult to analyze. Generally, the analysis is performed with a 2D tomographic system composed of several cameras equipped with Silicon Barrier Diodes (SBD). On Tore Supra, 82 SXR detectors, spread in one horizontal and one vertical camera, were installed for performing the tomographic inversion [1] leading to a spatial resolution of about 4cm in the equatorial plane. Presently Tore Supra is being strongly modified for the WEST project and the tomographic system will need to be also adapted. The WEST Project aims at implementing an actively cooled tungsten divertor, similar to ITER divertor technology, into the long pulse tokamak Tore Supra (TS). One of the main operational difficulties in metallic tokamaks is the interplay between particle transport and MHD activity which might lead to impurities accumulation and finally to disruption. Studying such phenomena is thus essential if stationary discharges are to be achieved, and efficient associated tomographic system is therefore required.

This paper describes the conceptual design of a new SXR diagnostic for the Tore Supra WEST project, based on a prototypal triple Gas Electron Multiplier (GEM) [2]. Indeed, half of the SBD diodes of the vertical SXR camera previously used for Tore Supra will be occulted by the new upper divertor (see Fig1 left). As a consequence, despite the fact that the SXR horizontal camera will remain unaffected, no tomographic reconstruction will be possible due to a lack of integrated measurements. For the new WEST SXR tomographic system we take the opportunity to use new type of detection systems: the GEM detector technology (see Fig 2) has been chosen because it works in photon counting mode and presents the following advantages: cheap, compact, good spatial and temporal resolution, energy discrimination capabilities and has the particularity to be neutron resilient which makes it a potential good candidate for SXR measurement in ITER and/or DEMO. The GEM is comprised of a 10 cm x 10 cm Mylar foil

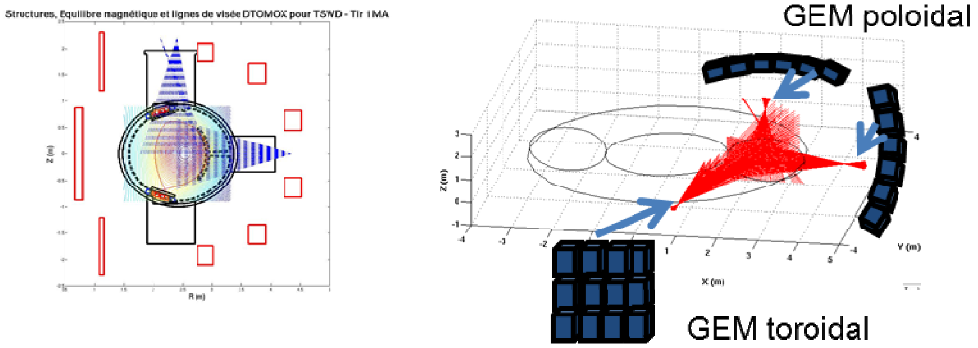

Fig. 1: WEST actual TS SBD limitation (left), toroidal and poloidal GEM system project (right)

that closes a box filled with a flowing gas adapted to photoionization by SXR. The photoelectrons thus produced in the first chamber then drift towards the first micrometrically perforated copper-clad Kapton foil where the signal is amplified by avalanche process. The high voltage responsible for electron avalanching can be changed in real-time and is directly linked to the gain of the detector. A similar process occurs two more times in the triple GEM case (Fig2a) and the resulting charge (directly proportional to the amount of primary electrons) is then collected on 128 anodes (pixels). A low threshold is then applied to the electronic signal to limit the energy interval on which SXR radiations are integrated. Depending on its configuration the GEM detector can be used in a 2D matrix (for imaging) or 1D array (for tomography). The detector gain depends upon the high tension applied and the gas composition

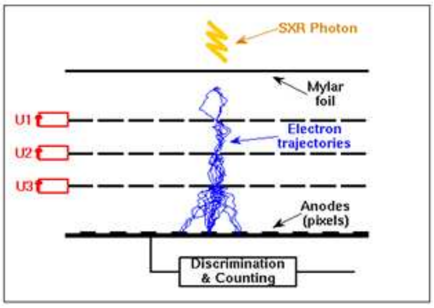

Fig. 2a: Sketch of a triple GEM (T-GEM) functioning principles

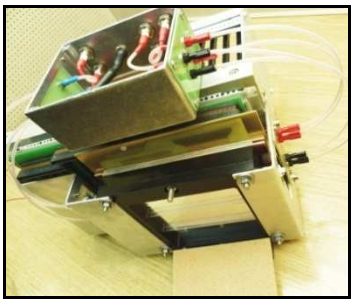

Fig. 2b: Structure of the Prototype-II T-GEM X-ray detector [3].

(variable gain in order to adapt to dynamics). The pixels' lower detection thresholds are remotely controlled, which means that tunable spectral responses are available. The full foreseen WEST SXR system is comprised of two poloidal 1D cameras (vertical and horizontal views respectively, up to 128 channels each), located in the same poloidal cross-section to allow for tomographic reconstruction in the energy window: 2-15 keV. They are also associated to a 2D imaging toroidal camera (10*10cm, 128 channels) placed in the equatorial plane so as to provide information about the possible poloidal asymmetries (Fig1 right). This imaging camera placed behind a pinhole so as to get a toroidal view of the plasma has been already installed successfully at Tore Supra in 2011 and comparison with SBD diodes (poloidal plane) performed [1], [4] (see Fig.3). At that occasion we have noted opposite cases presenting very good agreement or apparent disagreement with classical tomographic SBD diodes. In particular, it was shown that geometrical effects alone cannot explain these discrepancies and reinforce the potential added-value of the complementarity between poloidal and toroidal views.

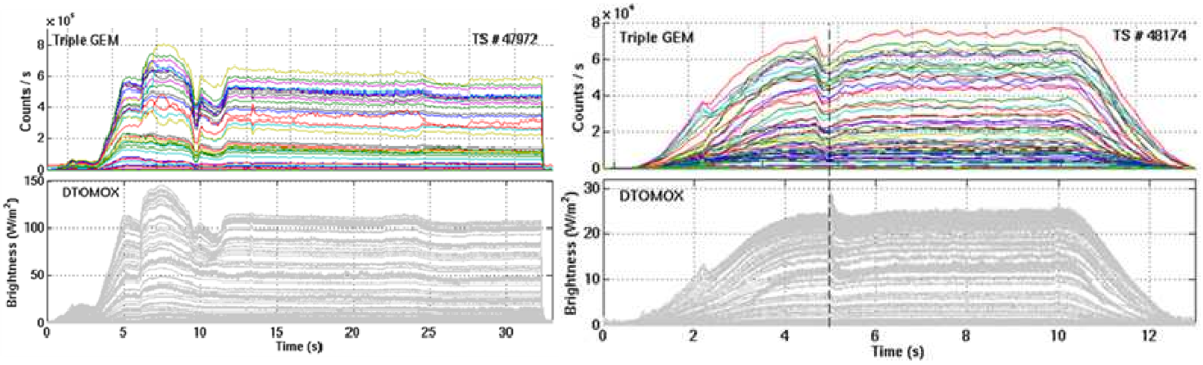

Fig. 3: Experimental time traces of the GEM and DTOMOX. Satisfactory agreement for TS # 47972 (left) and unexpected difference for TS # 48174 during Laser Blow Off W injection, presumably due to different spectral responses.

Regarding the 1D array GEM camera, two new cameras have to be designed and built. In particular the main constraint for the vertical one is to provide optimum coverage around the magnetic axis (low and high field side) with a good spatial resolution. Indeed WEST plasmas will be smaller than TS plasma and spatial resolution needs to be increased. Spatial resolution and coverage will be insured by the small dimension of the GEM (10cm x 2 cm) which means that more channels will be put on a given length. Some prototypes have already been prepared and tested by Polish association [3] (see Fig2b).

Design and implementation of an electronics dedicated for the 1D poloidal imaging detectors is required. Each poloidal T-GEM will have 128 channels controlled by the signal processing unit. The associated spatial resolution will be about 1 cm (128 channels) in the equatorial plane. Signals from each detector will be processed in parallel by means of the FPGA processor (Fig5). The aim of signals' processing is to estimate position distribution of X-ray hits on the strip plane with 100 times slices per second (100Hz sampling) which can be upgraded to 1 kHz. A rate capability of about 10^6 strip^{-1} s^{-1}, the position resolution of about 0.8 mm and 128 independent channels shall be supplied per detector. The gas mixture for 1D detectors will be optimized to reach maximum detection efficiency for both low (<3keV) and high (>3keV) photon energy range.

We will have also to install the read-out of two (or more) energy thresholds. Some further tests

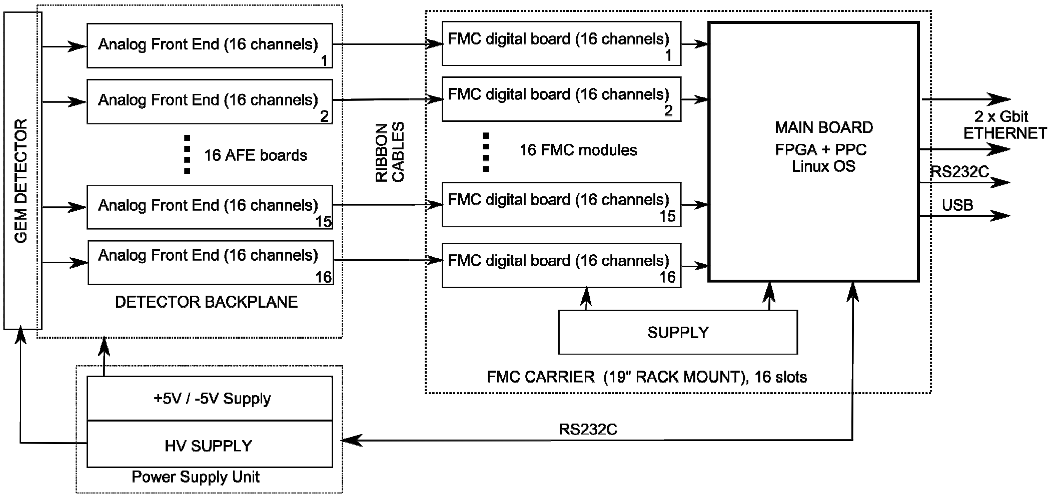

Fig 5: Processing electronics block schematic

have shown the high stability of the efficiency (~10% independent of changes in atmospheric pressure and an increase of count rates up to 1 MHz). Finally, a good energy resolution of about ~20-25% is expected.

With this set of GEM detectors we can expect a good complementarity of the combined toroidal and poloidal measurement. Toroidal views will allow observation of asymmetries (see simulation in Fig 6). The tomographic inversion will authorize refine studies of impurity transport and results of such inversion could be used for constraining impurity transport codes (or MHD codes in transient manner) for a 2D analysis.

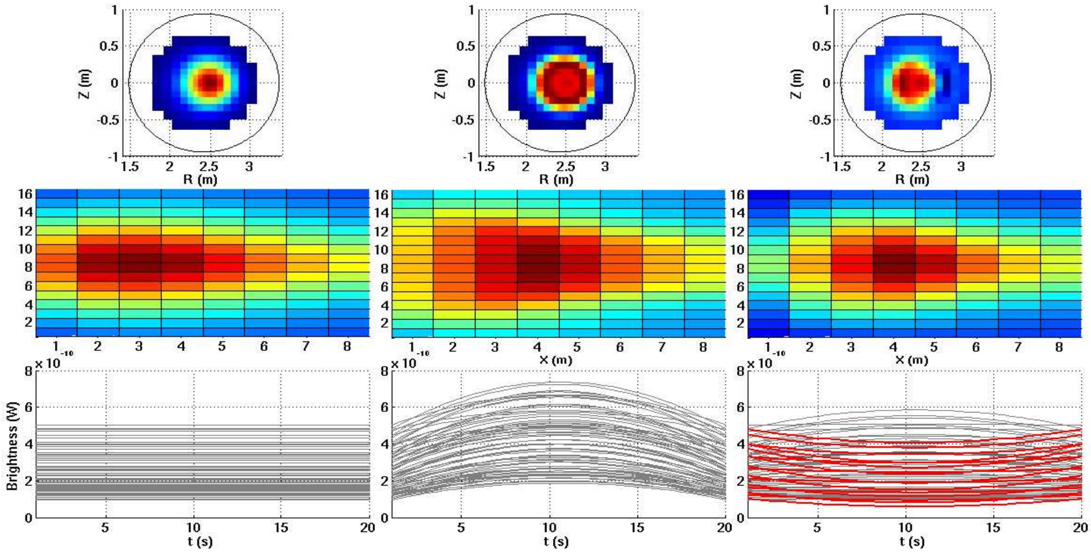

Fig. 6: Synthetic GEM measurement (from phantom emissivity field) with/without asymmetries. Top: emissivity distribution (at t=10s) in case with no asymmetry (left), symmetric perturbation at normalized radius r=0,4 (middle) asymmetry at r=0,4 which grows and disappears up to 60% of the nominal value (right). Middle: related image seen by GEM at time t=10s (when signal reaches maximum). Bottom: corresponding time evolution of GEM's pixels.

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