INFN_E ACTIVITY OF TRIPLE-GEM DETECTORS ON TOKAMAK AND LASER PRODUCED PLASMAS

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1. Introduction

The following report resume the activity developed with GEM (Gas Electron Multiplier) [1] detector for soft-X ray diagnostic on Tokamak plasmas and Laser Produced plasmas (LPPs). In the first case results obtained on FTU and KSTAR Tokamaks with a triple-GEM detector based on FPGA Front-End-Electronics. In the second case we present the innovative applications of a new triple-GEM detector (GEMpix) on LPPs with FEE based on medipix chips.

2. Soft-X ray diagnostic on Tokamak plasmas

Activity of soft-X ray diagnostic on Tokamak plasmas with triple-GEM detectors continues to have a growing interest [2]. Recently more results have been achieved. Some experimental test have been performed on the FTU (Frascati Tokamak Upgrade) Tokamak (ENEA, Frascati) and the KSTAR Tokamak (South Corea). On both sites a pin-hole camera was installed with the same triple-GEM detector. It has an active area of 10 x 10 cm^2 with 128 pixels, each one having an area of 8x8 mm^2. In addition FEE is equipped with an FPGA mother board which can acquire with a frame rate of 1 kHz. The FTU Tokamak is equipped of an horizontal port 8 cm thick and 40 long and the detector was positioned to 2,80 m in order to observe the plasma profiles. A comparison of the temporal traces as measured from GEM detector and a standard diode shows that GEM detector in more sensitive during current rising and that it is able to follow the sawtooth oscillations on the plateau region (Figure 1).

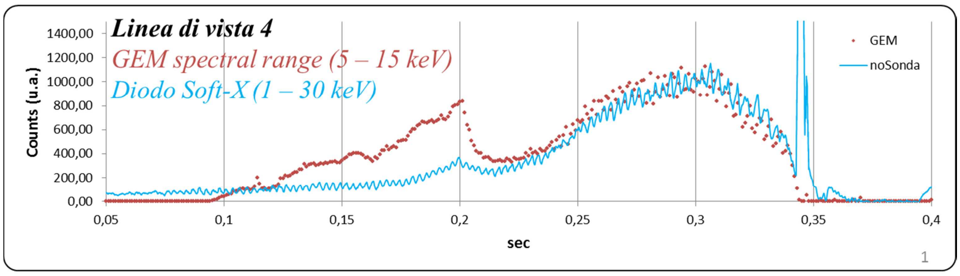

Figure 1: comparison between GEM detector signal and diode signal along a central line of view for an FTU Tokamak shot.

For the next FTU experimental campaign (May and June 2016), a triple-GEM detector with 128 pads in line will be tested. Each pad has an area of 500 x 500 μm^2, with a pitch of 700 µm. This configuration will be able to observe plasma X-ray profiles with an higher resolution. The future goal can be the installation of two GEM camera is to install two GEM detectors on vertical and horizontal port in order to realize a more performing tomography system respect to conventional diodes. The same kind of GEM camera (with 8x8 mm^2 pads) has been installed on KSTAR which, instead, is equipped with a tangential port. The aim was the study of high temperature plasmas that emit X-ray photons in the energy band of 4 – 15 keV. A pin-hole camera has been realized using this GEM detector on a tangential port of the KSTAR Tokamak. Pin-hole is realized with a beryllium window 150 µm thick and 2 cm in diameter. GEM detector can move back and forth and then the spatial resolution can range from 3.3 to 9.6 cm. In addition it can move up/down and left/right in order to observe different areas of the Tokamak camera (Figure 1A).The main advantages of using a tangential camera system include its compactness, high efficiency, energy discrimination in bands, selectivity of the photon energy range and so on. In order to study poloidal cross-sectional images a Philips-Tikhonov algorithm for tangential reconstruction is introduced. Phantom tests with synthetic D-shaped plasma images and a comparison with the magnetic equilibrium flux surfaces from the real-time EFIT code were performed obtaining a good agreement between each other. 2-D X-ray images of the KSTAR plasma were acquired during some typical plasma phenomena: sawtooth crash (Figure 2A), electron cyclotron heating, vertical displacement event (figure 2C), emissivity from the injected trace Ar impurity and so on. In all cases the observed phenomena are correctly described in accordance to the other standard diagnostic systems [.

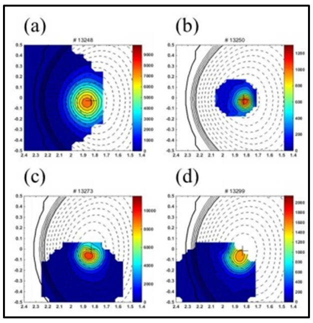

Figure1A: the reconstruction images overlapped by the Magnetic flux surfaces obtained from rtEFIT.

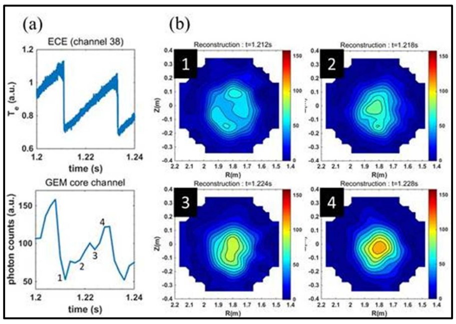

Figure1B: (a) a sawtooth oscillation from the ECE signal and the GEM signal for one KSTAR shot. (b) Reconstructed magnetic islands at the end of a crash and during the build-up phase.

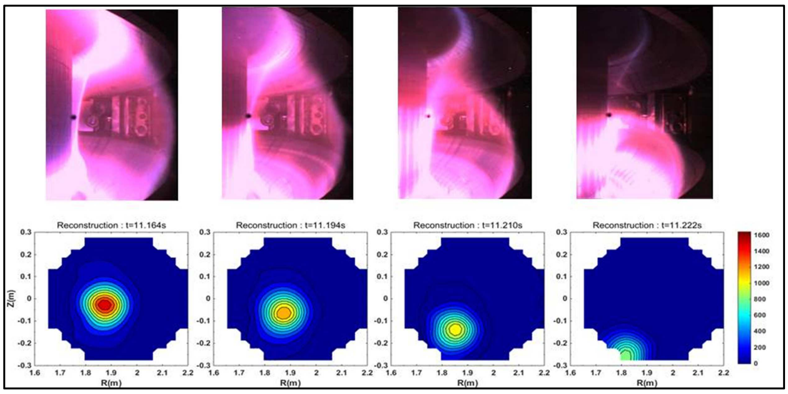

Figure 1C: reconstructed images from the visible camera (top) and the GEM X-ray camera (bottom) when a vertical displace event happens.

3. *Soft-X ray diagnostic on LPPs*

Laser Produced Plasmas (LLPs) lend to several interesting applications. The study of X-ray emission from this kind of plasmas is important not only to characterize plasmas itself (electron temperature, stability and so on) but also to study the application of this particular plasma as intense X-rays sources. In particular several emission configurations can be obtained using different kind of targets and tuning the characteristics of the laser pulse delivered on the target. Typically, laser pulse duration ranges between a few tens of femtoseconds and tens of nanoseconds, with energies from few mJ to tens of kJ. X-ray photon emissions lasts for times comparable to the laser pulses and during this time a great number of photons can be emitted. For these reasons LLPs are high luminosity pulsed sources. A study of the X-ray emission is useful not only to characterize important plasma parameters (energy spectrum, electron temperature and so on), but also to understand the spatial emission of photons, which originate from different regions of the plasma. A new triple-GEM gas detector with a front-end electronics based on four medipix chips has been tested, for the first time, on the ABC facility (ENEA, Frascati) [4]. It was called "GEMpix" [3]. It has a high dynamic range because the gain can be applied through the three GEMs, so it can work in a range of X-ray fluence of 6 orders of magnitude: it can detect also the single photon. In this case FEE is realized by four medipix chips hold together in order to cover an area of 28 x 28 mm^2 with 512 x 512 pixels, each one having an area of 55 x 55 μm^2. One of the main advantages of the medipix chip is represented by the possibility to work in Time over Threshold (ToT) mode: each pixel registers digital counts proportional to the charge released in the gas. Photons coming together release a charge in the gas, which is proportional to the number of photons. ABC is an high power pulsed laser for the study of inertial plasmas: laser works at wavelength of 1035 Å and pulse duration from 2 to 5 ns. In this case, we measured the X-rays produced when the ABC laser pulse, of 50 J and with 3 ns time width, hits plane targets of different nature, with different GEMpix gains (Figure 3).

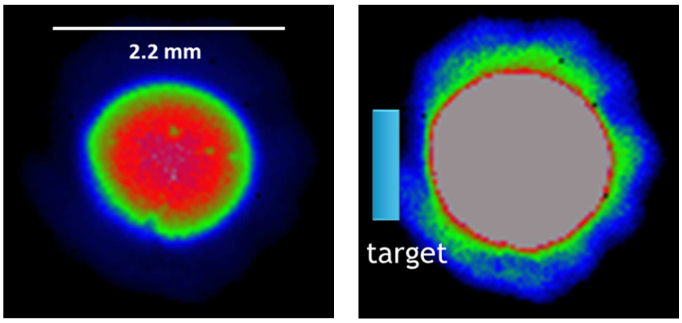

Figure 3: soft-X ray image obtained at the ABC facility with an aluminium target (left) and poloidal corona on the plasma image when the color scale is saturated in the core.

The results are encouraging regarding the capability of this imaging detector to work in experiments where soft X-ray emissivity varies over many orders of magnitude. Based on the successful results on ABC, we proposed some experimental tests on the ECLIPSE facility (CELIA, Bordeaux, France) [5] in order to stady the capability of GEMpix to detect X-ray radiation emitted from various targets (Cu, Fe, Ti, Ni, Ag, and plastic), emitting characteristic k-alpha radiation at different energies and fluence. In order to analyze these measurements, a preliminary study of the detector response in regime of single photon was realized at the NIXT lab (ENEA, Frascati) in order to estimate the number of photons per unit area for the different X-ray energies. This was performed using X-ray fluorescence coming from sample materials like those used on the ECLIPSE laser. Obtained results shows the potentialities of GEMpix as soft-X ray diagnostic devices for LPP: its response appears as blobs whose volume and area is proportional to the released charge Q, depending on the number of photons and their energy (Figure 4A). Results show also that for a given target, the gain (V_{gem}) can be fixed in order to have all the collected charge over threshold and avoid the saturation of the blob volume. V_{gem} affects also the spatial resolution, and it depends on the energy of the single photon. This is one of the most useful characteristics of GEMpix detector: the possibility to work in a very wide dynamic range simply operating on voltages applied to the three GEMs, tuning the detector on X-ray fluences varying over many orders of magnitude. In addition, the GEMpix response is proportional to the number of photons and their energy so that, knowing the energy spectrum, it is possible to estimate the number of photons, obtaining therefore a 2-D map of X-ray intensity (Figure 4B and C). This detector has indeed good imaging capabilities, whose spatial resolution is function of gain (V_{gem}). Images obtained in these experiments revealed that angular distribution of the X-ray emissivity is not uniform. In addition, when plasma is off, it is completely noise free, thanking to the adjustable threshold. During these laser plasma interaction experiments, there was no evidence of any electromagnetic disturbances, like electromagnetic pulse (EMP).

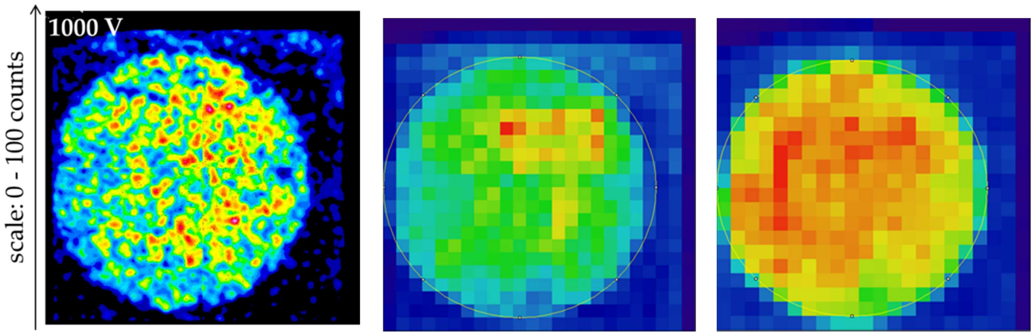

Figure 4: (A) image obtained by GEMpix with a Copper targer when V_{gem} = 1000 V and photon fluece distribution for Fe (B) and Cu (C) targets when V_{gem} = 1020 V. For Cu the maximum number of photons ranges between 20 and 25, while for iron it is between 15 and 20, and 2-3 photons at the edge.

4. *List of Conference Talks by LNF Authors in Year 2016*

List of conference talks by authors.

1. G. Claps, *GEMpix detector: a new diagnostic for Laser Produced Plasmas monitoring*, CERN RD51 meeting (2015), Geneva, Switzerland

5. *Publications*

1. W. Choe et al, *Tomographic 2-D X-ray imaging of toroidal high temperature plasma by a tangential pinhole camera with gas electron multiplier detector*, in: PSST (IOP) (submitted to review).

2. D. Pacella et al, *An hybrid detector GEM-ASIC for 2-D soft X-ray imaging for laser produced plasma and pulsed sources*, in: 2016 JINST 11 C03022 (2016).

3. G. Claps et al, *The GEMpix detector as new soft X-rays diagnostic tool for Laser Produced Plasmas*, in: RSI (submitted to review).

References

1. F. Sauli et al, Nucl. Instrum. And Meth. in Phys. Res. A. 386, 531 (1997)

2. D. Pacella et al, *40th EPS Conference on Plasma Physics*, P5.118 (2013).

3. F. Murtas, *Applications of triple GEM detectors beyond particle and nuclear physics*, JINST 9 C01058 (2014)

4. C. Strangio and A. Caruso, *Study on the hydrodynamical behavior of thin foils irradiated by Near-field ISI smoothed beams*, Laser Part. Beams 16 (1998) 45.

5. D. Batani et al, *Development of the PETAL Laser Facility and its Diagnostic Tools*, Acta Polytechnica, 53(2):103109 (2013)