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1. Introduction

Our research activity was born from a collaboration between ENEA and INFN in Frascati and the following report will outline the main results obtained in this last year. Our work can be divided in three main research lines:

- soft-X ray diagnostics on magnetic fusion plasmas
- soft-X ray diagnostic on Laser Produced Plasmas
- fast and thermal neutron detection

For each field, we used different type of detectors. Recently we are working also on new projects. A new GEM detector will be installed on the W7-X stellarator (Germany) and the EAST tokamak (China). In addition a new GEMpix detector based on the timepix3 chip will be constructed for the KSTAR tokamak (South Korea). A GEMpix will be tested on the VEGA PW laser facility (Spain). In the following report some new results obtained in these three areas will be presented and the relative used detector will be briefly described.

2. Soft-X ray diagnostic on FTU and KSTAR Tokamaks

For the year 2016, the a new soft-X ray GEM detector has been mounted on the FTU tokamak (ENEA), in particular it has 128 pads, each with an area of 500 x 500 um^2, distributed along a line. This particular configuration is more suitable to the FTU lateral port, so that a profile of the plasma column can be obtained at a better spatial resolution. GEM detector used the year before had square pads of 8 x 8 mm^2 in area and is more suitable with tangential ports and FTU has not these ports like these. Figure 1 shows the reconstructed temporal trace on a FTU shot with the plasma profile taken at different times during the shot. Each time bin is 10 ms.

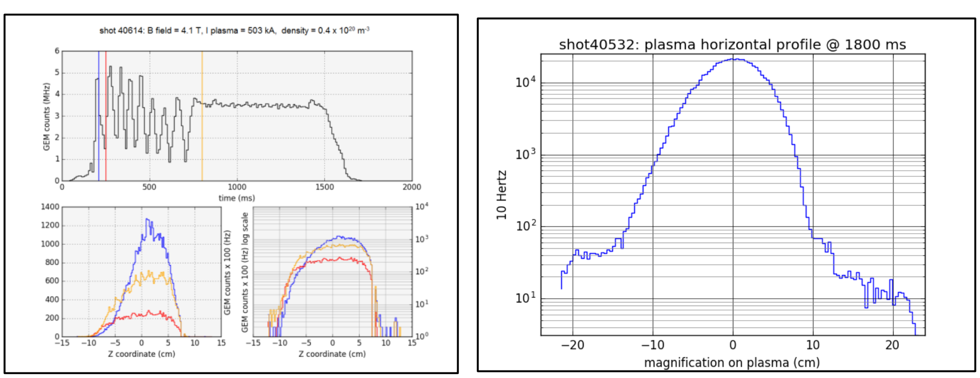


Figure 1: the observed temporal trace observed on FTU at 100 Hz of frame rate and the observed profiles at different times from the shot start (left), a measured 1D profile on an intense FTU shot showing the high dynamic range of the GEM detector (right)

These measure demonstrate the very high dynamic range of GEM detectors for this kind of applications. At the same time they show pad area need to be properly sized in order to work with low X-ray fluxes and observe the plasma time evolution at 1 kHz or higher in frame rate. New pad anodes will be projected for the future. Some new experimental test have been performed on the KSTAR Tokamak (South Corea) during the experimental campaign of July. The GEM detector has an active area of 10x10 cm^2 and is as a pin-hole camera on a tangential port of the KSTAR tokamak. It has 128 pixels, each one having an area of 8x8 mm^2. During this campaign, the FEE has been equipped with a upgraded FPGA mother board with acquisition frame rate of 1 MHz, with a maximum of 256 time bins. The first version worked at 1 kHz, with the possibility to realize 60000 time bins. Then the upgraded FPGA does not allow the observation of the entire shot evolution (20 – 30 sec), but we were able to observe fast events in a short time interval at a fixed time delay respect to shot start. One interesting result with the new mother board is the Edge-Localized Mode (ELM) observation.

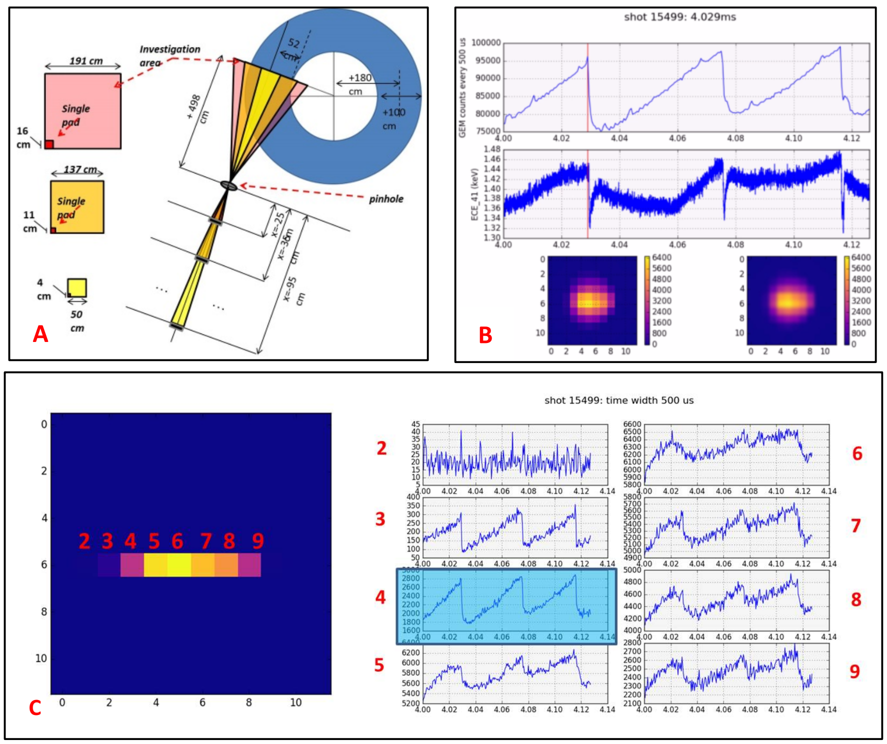


Figure 2: A) the observed areas when the distance between detector and pin-hole is changed.
B) a comparison of ELM oscillation between GEM and an Electron Cyclotron Emission (ECE) measured.
C) observation of the ELM oscillations.

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. 2-D X-ray images of the KSTAR plasma were acquired during some typical plasma phenomena: temporal traces from the edge of tokamak chamber to the center of the core show no inversion in the observed oscillation modes. This can be a strong evidence of the ELM mode. A further improvement for the X-ray detection has been obtained using a plastic bellows: it installed in the photon pathway and filled with a He gas at 1 atm. This device allowed to lower the cutoff photon energy of the GEM detector.

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. In the past year we obtained significant results with GEMpix detector on the ABC (ENEA) and ECLIPSE (CELIA, Bordeaux, France) laser facilities. GEMpix is an X-ray a gas detector based on a triple Gas Electron Multiplier (GEM) with a front-end electronic based on four medipix chips, with 512 x 512 squared pixels, 55 micron wide. It can work in a range of X-ray fluence of 6 orders of magnitude, arriving to the detection of a single photon. In addition medipix electronics allows working in Time over Threshold (ToT) mode: each pixel registers digital counts proportional to the total charge released in the gas and this is useful for studying x-ray emissivity of laser produced plasma, whose time scale, nanosecond or lower, is much shorter of the time resolution of the detector. We continued to study GEMpix 2-D imaging properties again at the Eclipse laser facility, with different targets, by means of Uttner masks. Spatial resolution depends on the intrinsic gain, ranging from one to tens of pixels, and Modulation Transfer Functions have been calculated in different conditions. In addition imaging capabilities have been proven by means of shadowgraphies of different plastic object placed in front of the detector. GEMpix sensitivity to the X-ray spectrum has been investigated, thanks to a mask with 4 different absorbers. We generated different X-ray spectra firing the ultrafast (40 fs) laser on various targets: Fe, Cu, Ag, W, plastic.

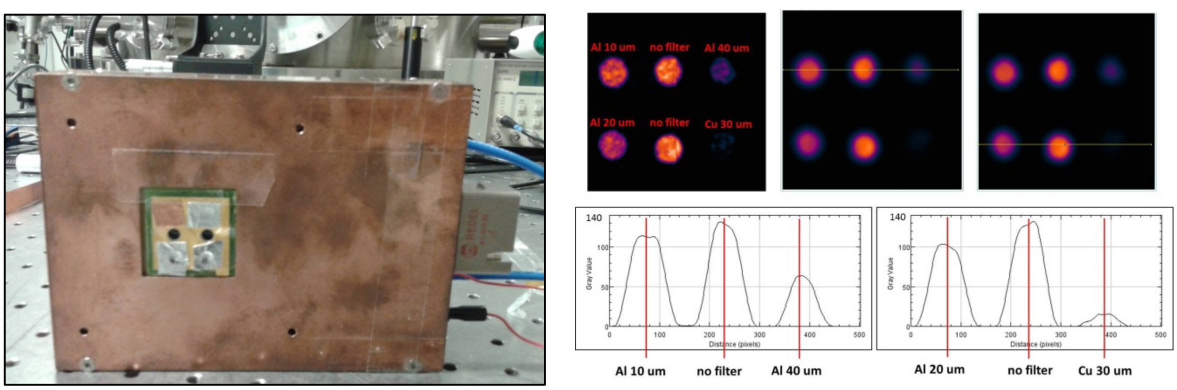
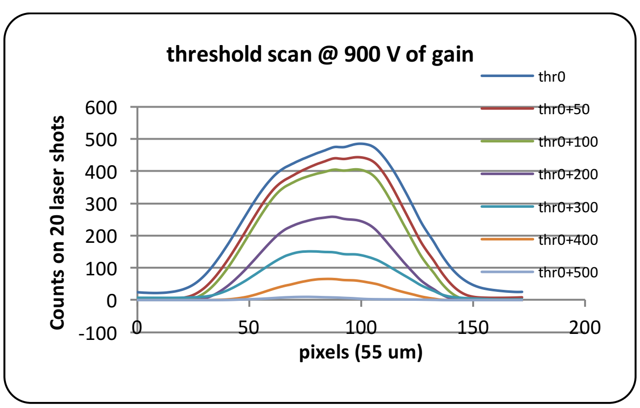


Figure 3:GEMpix in its copper box with filter mask (left) and ToT charge released on the filter with the profile of the holes.

For each one a scan in the discrimination threshold of the detector has been performed, cutting progressively the pulse amplitude spectrum generated in each pixels. These scans show a different shape each other, confirming the capability of the detector to discriminate different X-ray spectra.



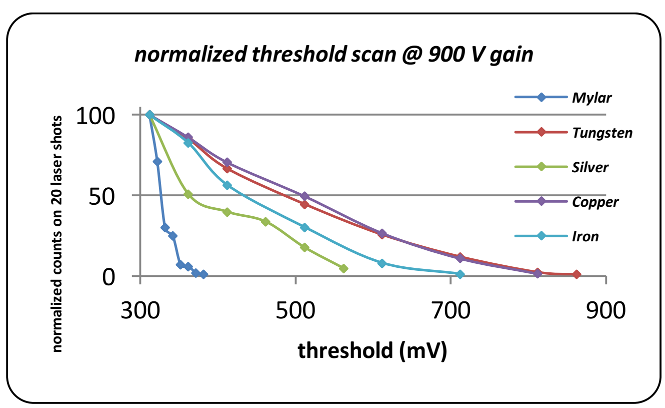


Figure 4: soft-X ray profiles at differents thresholds (left) and threshold scan with different targets (right)

As can be observed, the GEMpix is sensitive the different filter absorption and an analogous result can be obtained acting on the threshold parameter. The different plots show that it is possible to distinguish different energy bands corresponding to the different excited shells of the target atoms. Imaging capabilities, high adjustable dynamic range, spectral sensitivity and immunity to Electromagnetic Pulse disturbances, at least at this level of power (10^{13} W) make this detector a good candidate as diagnostic for laser produced plasma, to be checked at higher power. 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.

4. Thermal neutron detection

A new thermal neutron detectors have been realized by using GEM technology. At present, the main goal for thermal neutron detection is represented by the realization of valid alternatives to the more expansive ^{3}He-based detectors, especially in terms of efficiency. A new side-on GEM detector has been realized. It has an active area of 10x10 cm^2 with 128, each with an area of 3x24 mm^2. A set of 15 borated lamellae has been glued on the cathode.

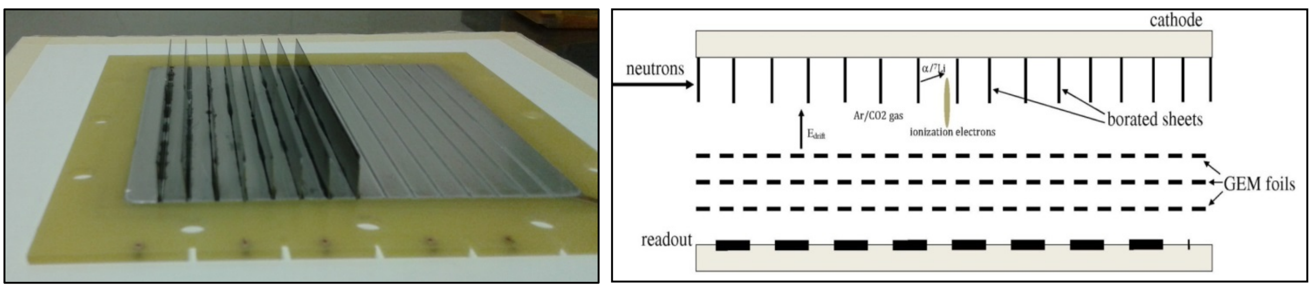


Figure 4: B_4C deposited silicon lamellae during the construction of the new GEM detector, a lateral layout of the side-on detector (right).

Each lamella is made of silicon, is 10x50 mm^2 in area and is 400 um thick. A layer of 1 um of ^{10}B enriched B_4C has been deposited on both side of the lamella. Thermal neutrons interact with 10B producing alpha particles and ^{7}Li ions which interact in the gas mixture so that the produced ionization can be collected on the GEM foils, amplified and detected by the FEE electronics. Recently a neutron diffraction measure has been realized on the INES beam line on the ISIS facility (Rutherford Appleton Laboratories, UK). Figure 4 shows a comparison between the ToF neutron diffraction spectra as obtained by the GEM detector and an 3He tube placed at 90° respect to the neutron beam on target of copper powder.

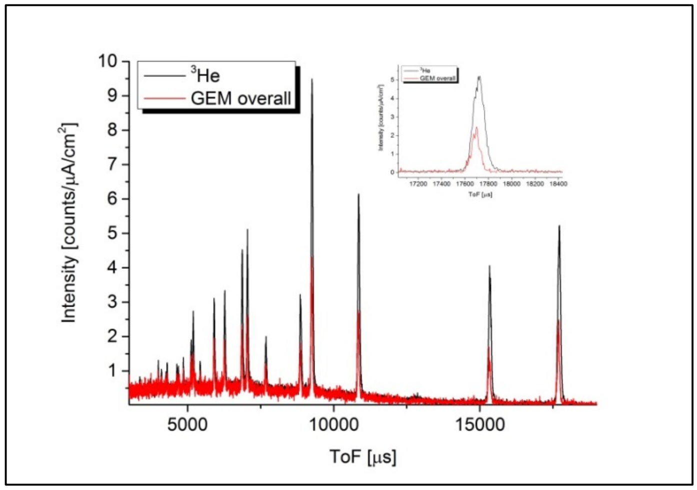


Figure 4: comparison between diffraction spectra obtained by an ^{3}He tube and the GEM detector at 90° respect to the neutron beam on the INES beam line for a target of copper powder.

A similar measure has been performed on a target of solid state vanadium. In this case a spectrum without peaks with a trend which reproduce the thermal spectrum of the thermal neutron beam. This measure allows us to make a first preliminary estimate of the detector efficiency of the new detector is 30 %.

Publications

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   The GEMpix detector as new soft X-rays diagnostic tool for Laser Produced Plasmas
   (October 2016) Review of Scientific Instruments, Volume 87, Issue 10

2. Song I., Jang J., Jeon T., Pacella D., Claps G., Murtas F., Lee S. H., Choe W.
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   (July 2016) Current Applied Physics 16(10)

3. Muraro, A., Croci, G., Albani, G., Claps, G., Cavenago, M., Cazzaniga, C., Dalla Palma, M., Grosso, G., Murtas, F., Pasqualotto, R., Perelli Cippo, E., Rebai, M., Tardocchi, M., Tollin, M., Gorini, G.
   Performance of the full size nGEM detector for the SPIDER experiment
   (2016) Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 813, pp. 147-152.

4. Pacella, D., Claps, G., De Angelis, R., Murtas, F.
   An hybrid detector GEM-ASIC for 2-D soft X-ray imaging for laser produced plasma and pulsed sources
   (2016) Journal of Instrumentation, 11 (3), art. no. C03022, .