GEM-based Energy Resolved X-ray Tangential Imaging System on KSTAR

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Introduction

An X-ray camera was designed and built for energy-resolved tangential imaging to study the plasma core of the Korea Superconducting Tokamak Advanced Research (KSTAR) plasma, in collaboration between ENEA-Frascati, INFN-LNF, and KAIST-Daejeon. The detector having three Gas Electron Multiplier (GEM) foils and a 2-D read-out has been characterized by means of suitable monochromatic sources (by fluorescence of KCl, Fe, Cu, Pb, Mo) and continuous spectra (X-ray tubes).

GEM detector: design, realization and installation on KSTAR

The GEM detector built for KSTAR has a read-out made of a 2-D matrix of 12×12 squared pixels. The detector has an active area of 10×10 cm^2, while pixels have dimensions of 0.8×0.8 cm^2. Since it works in photon counting mode and with direct conversion, it offers high sensitivity (detection efficiency up to 0.3), noise free, high dynamic range (6 orders of magnitudes) and good time resolution (framing rate of about 1 kHz) [1]. Front-end electronics is integrated in microchips called CARIOCA, developed at CERN, in groups of 8 channels each one [2]. The firmware of the motherboard with FPGA, attached on the back of the detector (Fig. 1), has been developed to include the data acquisition system (DAQ) [3]. The FPGA makes the detector compact, portable, flexible and it is fully shielded with a metallic case. The CPU is divided into two parts to perform simultaneously counting without dead time, and data transfer to the computer via Ethernet. Two types of data acquisition systems have been implemented: the first one is sampled at 10 μs, permitting up to 255 frames (acquisitions), but characterized by long dead time for data transfer to

Figure 1 The mother board FPGA based coupled with the GEM detector

the PC after the acquisition. The second system is in continuous mode and permits 60000 frames, sampled at 1ms, but without dead time. The latter DAQ system was developed specifically for KSTAR.

A metallic case was developed to house the detector and the electronic boards, not only for mechanical protection and interface with steerable mechanical mounting on the port, but also for shielding it against electromagnetic and radiofrequency disturbances.

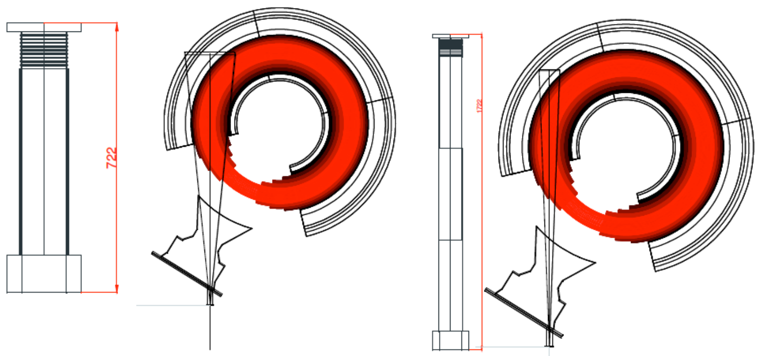

Figure 2 Setup at KSTAR (pinhole is located on the port window). Broad view of the plasma (left) and zoomed view (right), together with the length of the tube connecting pinhole to the detector

The installation on KSTAR is designed as a pinhole camera, to see most of the core plasma, with adjustable demagnification (from ×10 to ×30). The relative distance of the camera with respect to the port, where the pinhole is mounted, can be adjusted in the range 55÷165 cm to achieve the desired demagnification, by means of a telescopic tube filled with He to avoid absorption in air (Fig. 2). A ±3.5° angular tilt of the camera, pivoted on the pinhole axis, is foreseen to adjust the orientation of the camera (up/down, left/right) when the GEM detector is in the high demagnification configuration.

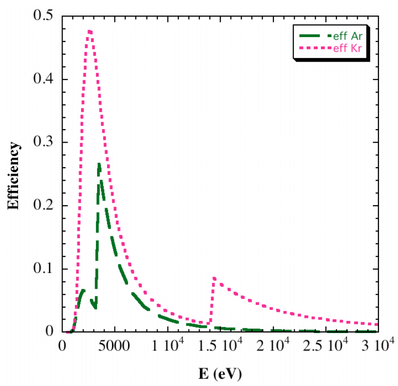

Figure 3 Detection efficiency for the two gas mixture: Ar/CO_2 (green line) and Kr/CO_2 (pink line)

The detector was characterized for two gas mixtures at atmospheric pressure: Ar/CO_2 (70%-30%) and Kr/CO_2 (70%-30%). The detection efficiency of the GEM detector (Fig. 3) is in the range 0÷30 keV for these two gas mixtures. Specifically, two ranges of operation are available, differing in the low-frequency limit: 3÷15 keV with Ar/CO_2 and 5÷30 keV with Kr/CO_2.

Energy calibration of the GEM detector

Monochromatic sources obtained by fluorescence of KCl, Fe, Cu, Pb targets and continuous spectra X-ray tube were used to calibrate the camera. The soft X-ray tube (model Moxtek 50

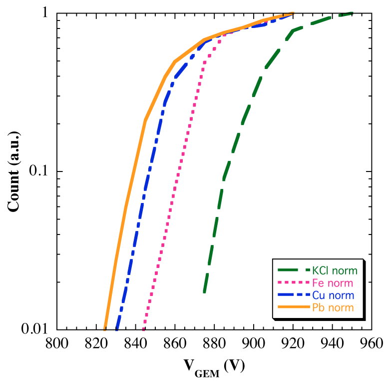

Figure 4 GEM (Ar/CO_2) gain response to irradiation with beams at different energies (KCl, Fe, Cu, Pb) at fixed threshold

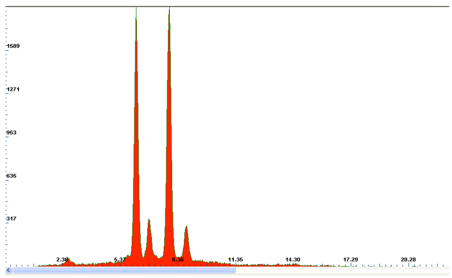

Figure 5 SXR fluorescence spectrum of Fe and Cu target irradiated at 11 KV, measured with the Si-PIN detector

kV Bullet) is characterized by Ag anode, variable voltage in the range 10÷50 kV, and current in the 1÷200 µA range, 1 µA precision and stability better than 1%. The GEM gain response was measured (Fig. 4) by using different monochromatic sources: KCl (3 keV), Fe (6.4 keV), Cu (8.2 keV) and Pb (10.4 and 12.5 keV). From the experimental data, two energy bands are defined: 3÷15 corresponding to V_{GEM} = 930 V and 6.5÷15 keV to V_{GEM} = 900 V.

To estimate the energy discrimination capability of the GEM, two targets, Fe and Cu, were combined obtaining a spectrum with two lines (Fig. 5). The SXR spectrum of Fig. 5 was obtained with a Si-PIN diode (AMPTEK XR-100CR, energy resolution of a few percent).

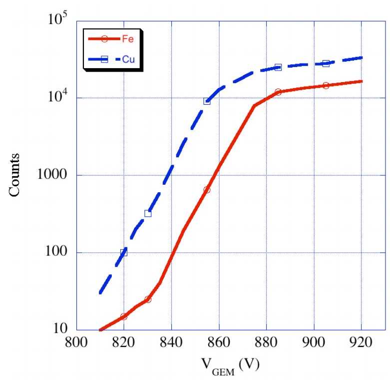

Figure 6 Comparison of GEM gain scans obtained using the Fe and Cu lines

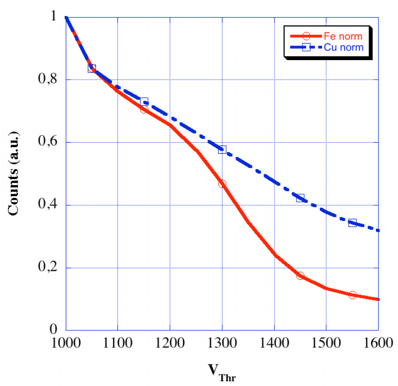

Figure 7 Normalized GEM threshold scan for fluorescence spectrum of Fe and Cu

The scan of the GEM gain (Fig. 6) for the Fe and Cu lines shows that it is possible to select an energy region of interest by varying the GEM voltage. In particular, by setting V_{GEM} = 860 V the GEM detects 50% of the Cu line (8.2 keV) and 8% of the Fe line (6.4 keV).

The scan of the GEM threshold for fluorescence spectrum of Fe and Cu is shown in Fig. 7. It is possible to select an energy band for groups of 8 pixels, by suitably choosing the threshold of each CARIOCA. This is the proposed added flexibility of the GEM functionality, considering the fact that by assigning a fixed V_{GEM} the energy range is fixed for the whole camera. Assuming a Gaussian pulse, the peak amplitude and its width can be assessed by means of the threshold scan. Energy resolution can be then derived for the peak width at half height and it is found of about 30%.

X-ray Imaging with GEM

To eliminate the noise in all channels, the 16 thresholds (one per 8-channel-set) of the GEM detector have to be appropriately chosen. This permits a good imaging capability, at different gains (V_{GEM}) and thresholds. For example, the imaging resulting from the X-ray tube at 15 kV and at a distance of 8 cm is shown in Fig. 8: a symmetric distribution is obtained in X and Y directions, as expected.

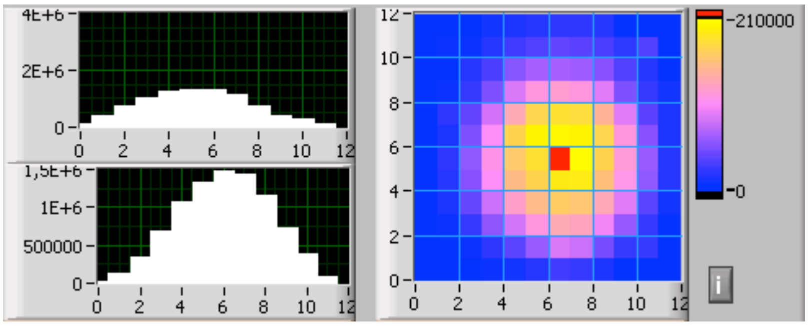

Figure 8 Imaging of X-ray source at 15 kV and a distance between GEM detector and source of 8 cm

Conclusions

This characterization revealed a good energy discrimination in bands, thanks to the combination of scan in gain and threshold and choice of gas mixtures. The setup at KSTAR has been designed to have the largest optical flexibility to see most of the plasma cross section in a tangential geometry, together with zoomed views. High efficiency, high dynamic range, photon counting mode, good time resolution and energy discrimination in bands make this detector extremely promising for a fruitful exploitation in magnetic confinement devices, despite the limited number of channels presently available.

Acknowledgement

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