Development of GEM gas detectors for X-ray crystal spectrometry

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INTRODUCTION

The high-resolution X-ray spectroscopy (FIG. 1) is a powerful tool for diagnosing the properties of tokamak plasmas. The Bragg crystal X-ray spectroscopy has become well-established technique for diagnosing important plasma parameters. The characteristic X-ray radiation emitted by highly ionized metal impurities provides accurate information on the crucial plasma parameters such as impurity concentrations, ion temperature, and the toroidal rotation velocity [2-3]. High-resolution X-ray diagnostics for MCF devices is expected to allow monitoring the plasma radiation emitted by highly ionised impurity elements. For the purpose of detecting X-ray lines intensities from the energy resolved diagnostics two detectors based on Triple GEM amplification followed by the strip readout electrode were developed in order to measure intensities of soft X-ray radiation diffracted by the crystal suitable for the specific soft X-ray energy range. The ITER-oriented tokamak research programs bring a new important requirement for the X-ray diagnostics which is expected to monitor the impurity level of tungsten – the plasma-facing material. Therefore, in order to implement the W impurity monitoring one has to design and construct new generation GEM X-ray detectors dedicated for low energy photons emitted by ionised tungsten.

In this work we present the development of Triple-GEM detectors guiding to fulfil the mentioned above conditions for monitoring the X-ray emitted by tokamak plasma in the SXR region.

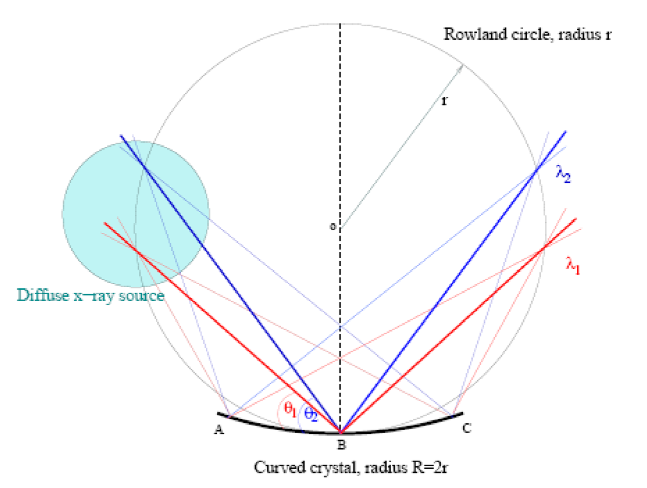

FIG 1: High-resolution Johann curved crystal X-ray geometry [1].

OBJECTIVES AND AIMS OF HIGH-RESOLUTION X-RAY DIAGNOSTICS

The main aim of the high-resolution X-ray detection system is to provide monitoring of the radiation emitted by impurities present in tokamak plasma. The X-ray diagnostics should also provide information on the continuous radiation (Bremsstrahlung). Therefore, the final design of the position sensitive GEM X-ray detectors was driven by the following assumptions:

- Large detection area (20 x10 cm^2),
- High conversion yield of photons (in the SXR region) in the detector drift/conversion volume,
- High charge gain possibility,
- Reasonable energy resolution (20-30%),
- Good position resolution (defined by spectrometer resolution),
- Exposure time down to 10ms with high repetition rate up to 100Hz within 60s time interval
- Detection stability for a wide range of photon rates,
- Read-out of different spectral orders.

GEM DETECTORS FOR HIGH-RESOLUTION X-RAY DIAGNOSTICS

The most suitable micropattern gas detector structure for the high-resolution X-ray diagnostic is the Triple GEM (T-GEM) geometry (FIG. 2). The T-GEM detection structure provides a good charge gain for the Ar/CO_2 gas mixture that was chosen as a working gas for detectors.

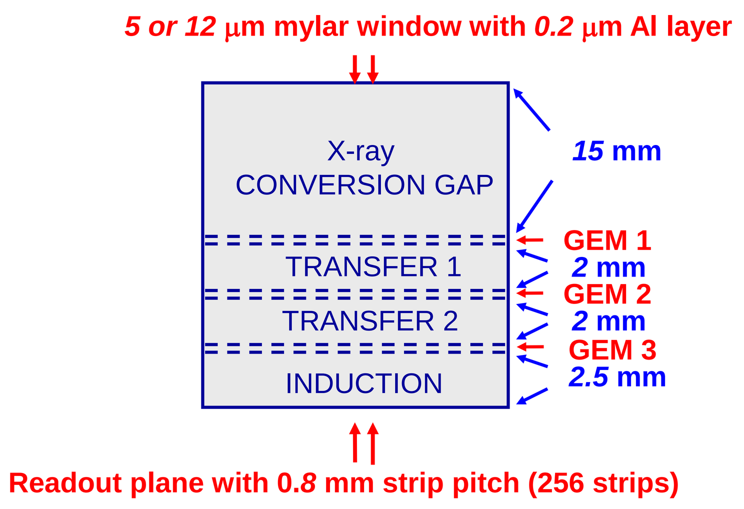

FIG. 2: Scheme of the detector structure [4].

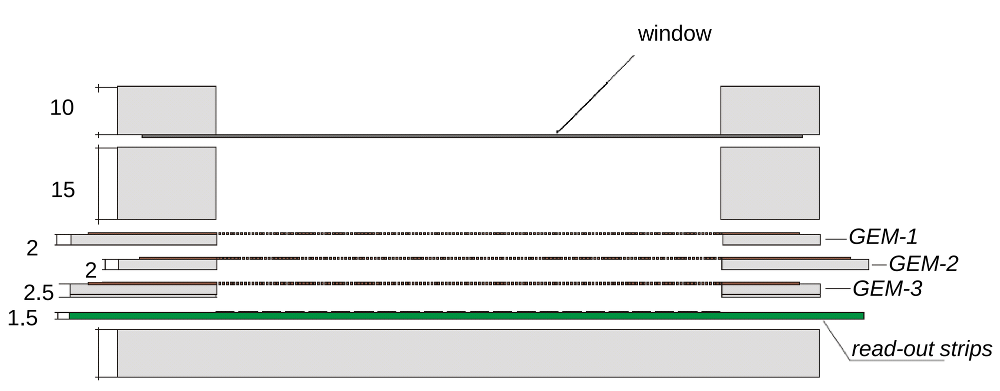

FIG. 3. Structure of the prototype T-GEM X-ray detector

The structure of both detectors for high-resolution X-ray diagnostics is (FIG. 3):

- Cascade of 3 GEM foils with the gap of 2 mm in each detector,
- Conversion gap of 15 mm,
- Readout plane with 0.8 mm strip pitch (256 strips per detector),
- Induction gap width of 2.5 mm.

Preliminary detector tests led us to the design the final detector module.

- A proper operation of the detector with maximum considered Ar/CO_2 gas layer thickness of 1.5 cm was verified during the prototype phase of the project ensuring high photon detector efficiency,
- The technology of the thin (12um and 5um) aluminized Mylar detector window with the applied HV of the order of 6kV has been developed and verified in test X-ray measurements,

An expanded view of the T-GEM detector and the assembled final T-GEM module are presented below.

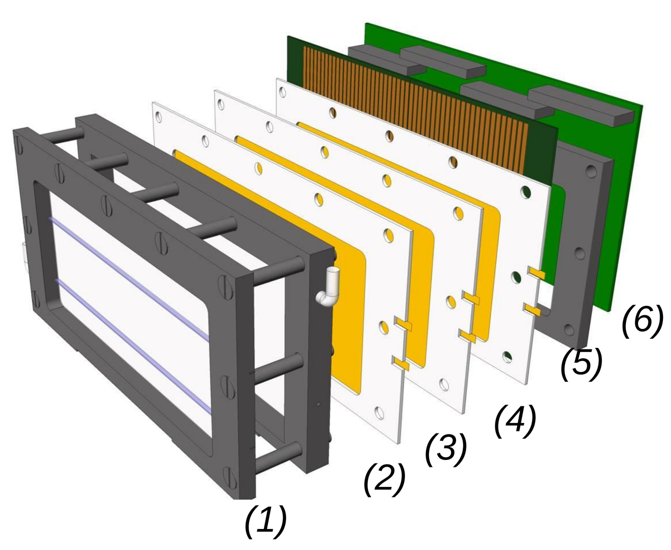

FIG. 4 Structure of the T-GEM X-ray detector: (1) window frame (2)-(4) GEM foils with frames, (5) strip plane and (6) closing strip-plane frame [5].

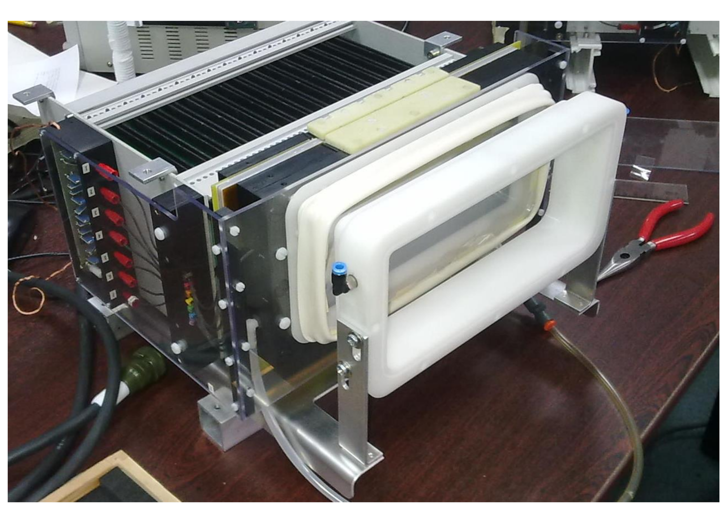

FIG. 5. Photo of the assembled final T-GEM module with He buffer fitting.

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ELECTRONICS FOR T-GEM DETECTORS

The T-GEM detector electronics processing unit has 256 measurement channels.
The aim of detector's signal processing is an estimation of maximal energy distribution for 508 bins with 10 ms time resolution. Two such processing units were constructed and dedicated to detectors for two energy regions: 2-8 keV and (3-13 keV).
Each detector's electronics consists of several blocks:

- Detector strip board with backplane,
- Amplifiers and differential cable drivers board - 16 Analogue Front End boards (AFE),
- 16 FMC digital boards,
- The carrier module with 16 FMC slots,
- High and low voltage power supply module (PSU).

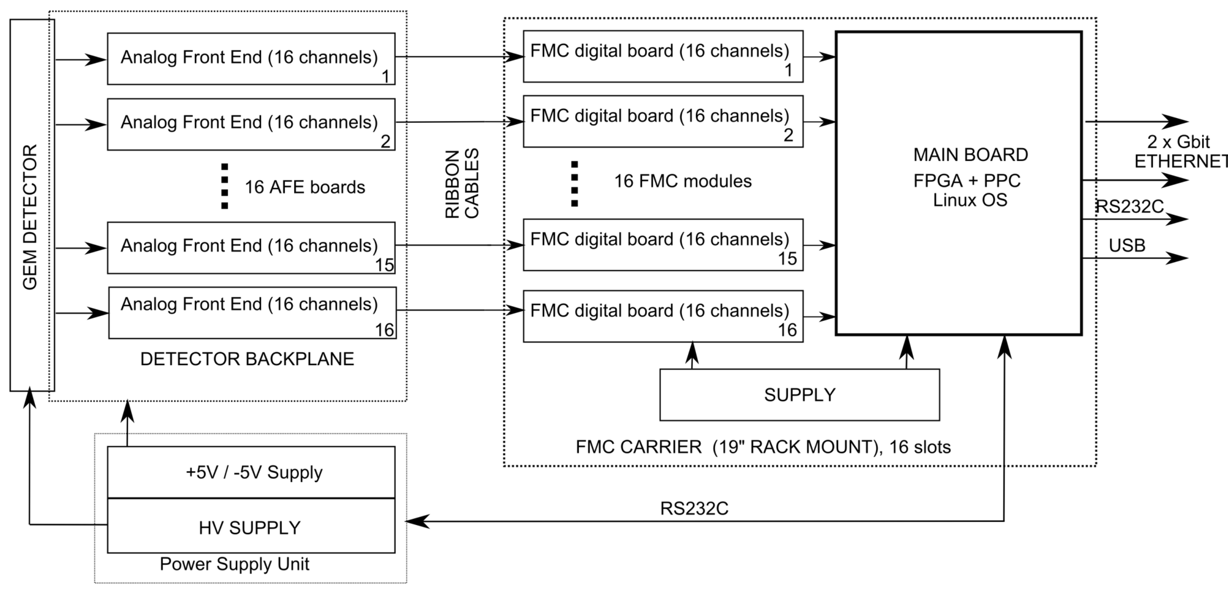

FIG. 6. Block diagram of processing electronics module.

PRELIMINARY DETECTOR TESTS

- A radiation source and PC with Matlab on board have been used for hardware verification and preliminary development of measurement algorithms to be implemented in the FPGA module (FIG. 7).

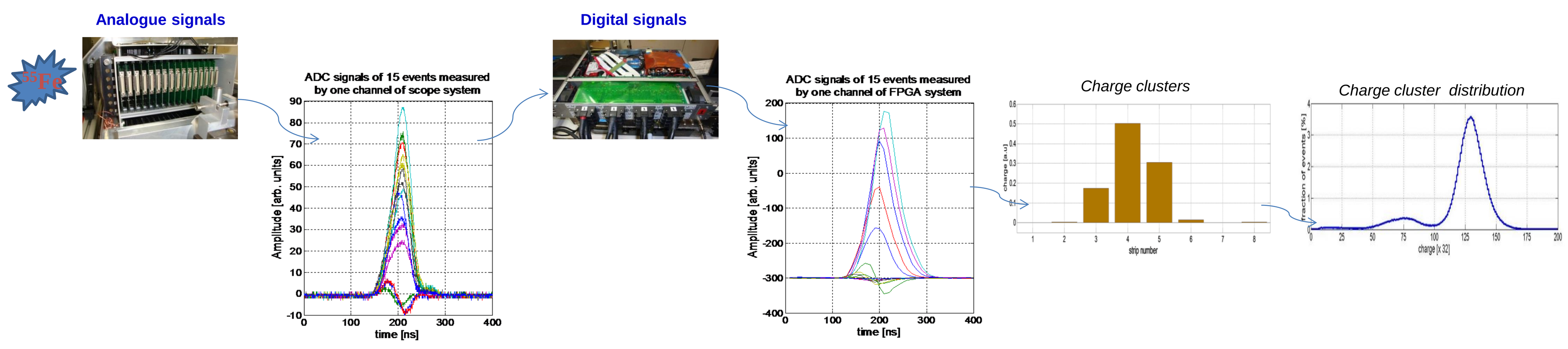

FIG. 7. Data processing chain .

- The measurements for selected source position (FIG. 8) has proven the local detector space resolution better than 1 strip (0.8 mm) using the center of gravity approach.
- A set of irradiation tests performed using X-ray generator (U=4.2kV, I=1:100uA, for about 20s of irradiation) has shown the detection stability for relatively high photon fluxes (FIG. 9).

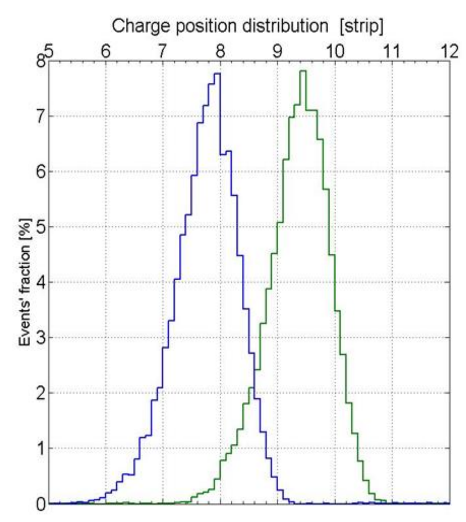

FIG. 8. Charge position distribution for consequent 1mm apart source positions. Source: X-ray tube (2.5 kV, 100 uA) with 0.8mm diameter collimator.

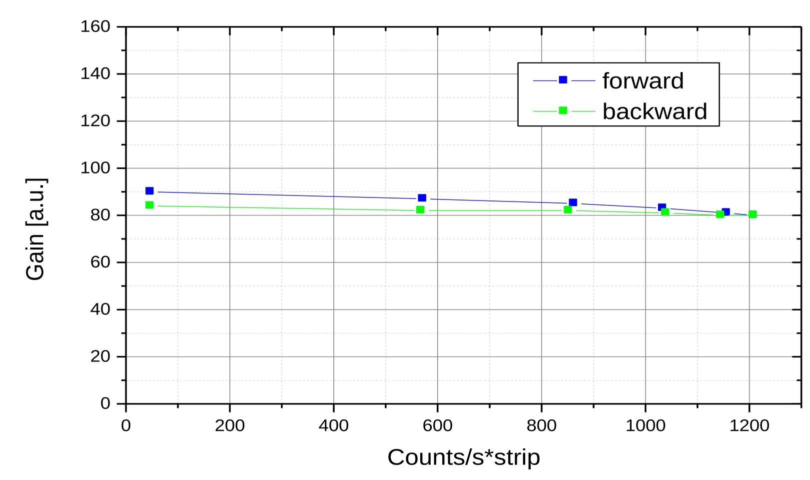

FIG. 9. Detector gain of runs with different photon fluxes before and after irradiation of maximal rate – about 1.5 kHz/cm^2

FINAL DATA ACQUISITION MODE

After prototype phase algorithms of cluster charge and position identification were implemented into the FPGA module. Final electronics system (FIG. 6) has a capability to perform:

- Acquisition of individual histograms for 256 strips each 10ms (the least integration time interval) with the 256 energy/charge resolution,
- Storing on hardware DDR3 memory: 256MB (2Gb): 4000 histograms (40s data acquisition with 10ms integration time) for 256 strips x 256 energy resolution – standard energy resolution with two selected rate statistics per strip.

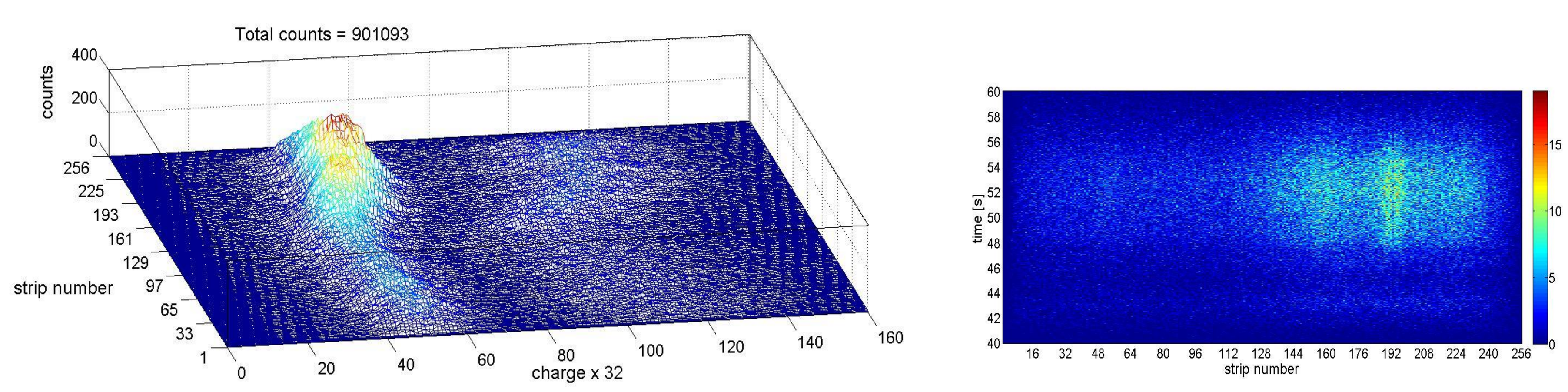

FIG. 10. 2D maps of individual histograms (left) and photon intensity time evolution (right) for each strip irradiated at JET pulse with 10 ms integration time.

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