The XAFS Fluorescence Detector System based on 64 Silicon Drift Detectors for the SESAME Synchrotron Light Source

A. Rachevski[1], M. Ahangarianabhari[2,5], G. Aquilanti[3], P. Bellutti[4,11], G. Bertuccio[2,5], G. Borghi[4,11], J. Bufon[3,1], G. Cautero[3,1], S. Ciano[1], A. Cicuttin[6,1], D. Cirrincione[7,1], M. L. Crespo[6,1], S. Fabiani[8,9], F. Ficorella[4,11], M. Gandola[2,5], D. Giuressi[3,1], Kasun Sameera Mannatunga[6,10,1], F. Mele[2,5], R. H. Menk[3,1,12], L. Olivi[3,1], G. Orzan[1], A. Picciotto[4,11], M. Sammartini[2,5], I. Rashevskaya[11], S. Schillani[3,1], G. Zampa[1], N. Zampa[1], N. Zorzi[4,11] and A. Vacchi[1,7]*

**) corresponding authour, 1) INFN Trieste, Padriciano 99, I-34149, Trieste, Italy, 2) Politecnico di Milano, Via Anzani 42, I-22100, Como, Italy, 3) Elettra-Sincrotrone Trieste S.C.p.A., SS14, I-34012, Trieste,Italy, 4) Fondazione Bruno Kessler, Via Sommarive 18, I-38123, Trento, Italy, 5) INFN Milano, Via Celoria 16, I-20133, Milano, Italy, 6) ICTP MLab, Via Beirut 31, I-34151 Trieste, Italy, 7) Dipartimento di Matematica ed Informatica, Università di Udine, Via delle Scienze 206, I-33100 Udine, Italy, 8) INAF-IAPS, Via del Fatto del Cavaliere 100, I-00133 Roma, Italy, 9) INFN Roma Tor Vergata, Via della Ricerca Scientifica 1, I-00133 Roma, Italy, 10) University of Sri Jayewardenepura, Department of Physics, Colombo, Sri Lanka, 11) TIFPA – INFN, Via Sommarive 14, I-38123, Trento, Italy, 12) Department of Medical Imaging, University of Saskatchewan, Saskatoon, SK S7N 5A2, Canada*

ABSTRACT

SESAME (Synchrotron-light for Experimental Science and Application in the Middle East) is a "third-generation" synchrotron light source. The Middle East's first major international research centre, established as cooperative venture by the scientists and governments of the region, is situated in Jordan. On the base of the agreement signed between INFN and SESAME, our collaboration has designed and is building a Fluorescence Detector System based on 64 SDDs, each having a 9 mm^2 non-collimated sensitive area, realized with eight monolithic arrays for a total collimated sensitive area of 499 mm^2. The instrument will be used at the beamline dedicated to x-ray absorption spectroscopy in the energy range 3 – 30 keV with the capability of reaching a maximum counting rate of at least 3.2 Mcps. The energy resolution requested is below 150 eV FWHM @5.9 keV. We plan to have the system completely operative by July 2018. We report on the main building blocks of this system, dedicated to SESAME, and describe the experimental performances measured in the lab and on the XAFS beamline of ELETTRA Sincrotrone Trieste, Italy. In the very first tests the system was successfully operated up to 8 MCps. The energy resolution below 150 eV @5.9 keV was measured using a 1.6 µs peaking time with the detector cooled to 10 °C.

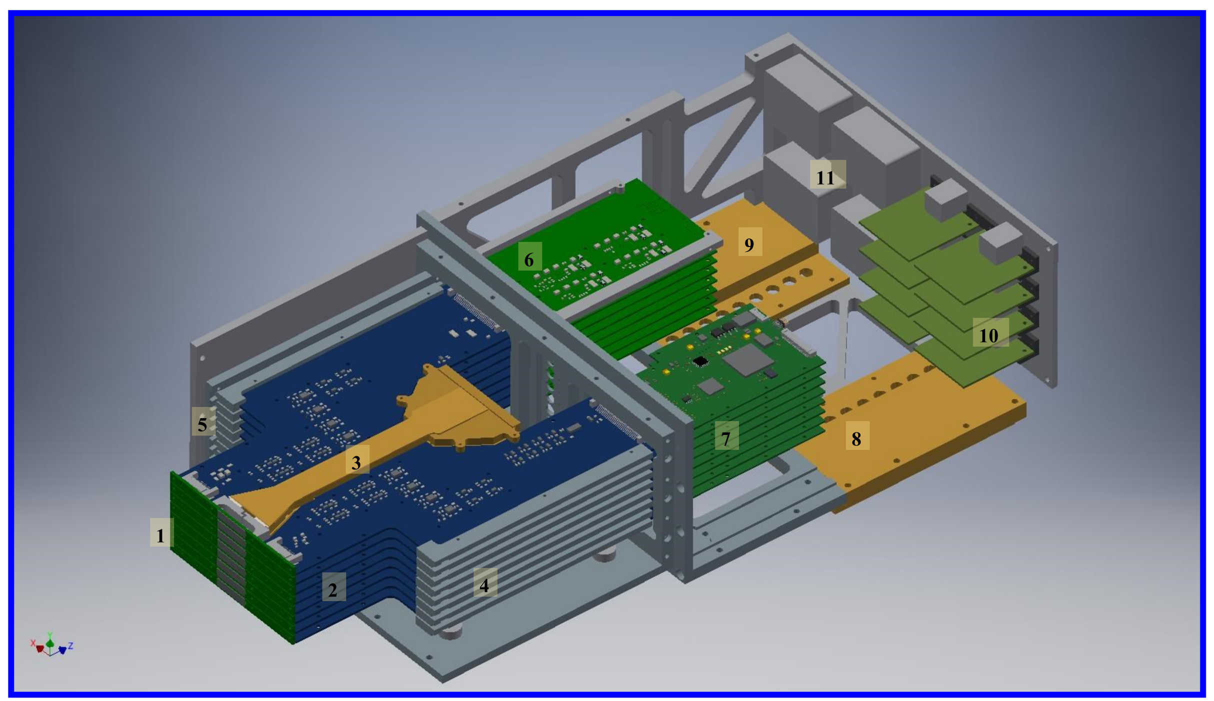


Fig. 1 Fluorescence Detector System.
1: front-end PCBs; 2: conditioning PCBs; 3: brass profile with cooling liquid flowing inside; 4: insertion guides at flanks of detecting heads; 5: rails for eight detection heads; 6: power supply and filters; 7: back-end PCBs; 8: inlet cooling distribution; 9: outlet cooling distribution; 10: Ethernet PCBs; 11: power supply connectors

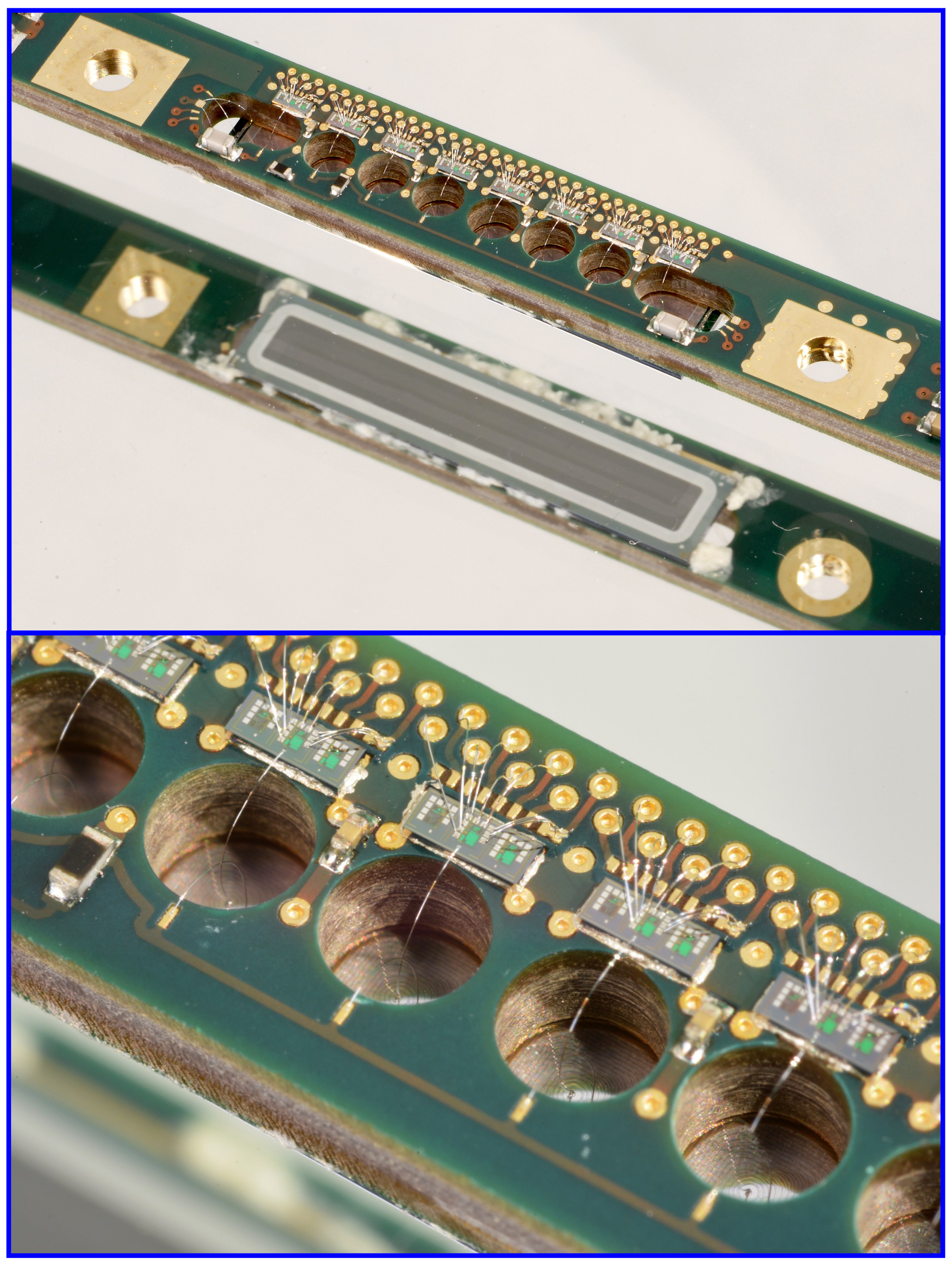


Fig. 2 Front-end PCB fits a monolithic array of 8 SDDs and the corresponding 8 SIRIO charge preamplifiers, bias filtering capacitors, the connectors to the conditioning PCB.

Fig. 5 Output count-rate (OCR) was measured in a single module of 8 SDDs as a function of Input count-rate (ICR). Pile-up rejection was implemented. X-ray tube with Cu anode was used. Bias voltage was fixed at 30 kV. To perform the OCR vs ICR scan we irradiated Mn target (fluorescence lines K_α= 5899 eV and K_β= 6490 eV)

INTRODUCTION

The X-ray Absorption Fine Structure (XAFS) beamlines at synchrotrons combine X-ray absorption spectroscopy (XAS) with X-ray diffraction (XRD). The beamline radiation being diffracted on a double monochromator, irradiates a specimen situated between two ionization chambers. It allows to determine the absorption coefficient near the edges. On the other hand, when a specimen is optically thick to X-rays or it's highly diluted, the transition technique is no more sufficient and the sample fluorescence is taken advantage of to perform measurements. We are building a Fluorescence Detector System [1,2] for SESAME synchrotron XAFS beamline (Amman, Jordan), every building block of which is properly custom designed, providing characteristics summarized in EXPERIMENTAL RESULTS and CONCLUSIONS.

SISTEM LAYOUT

The main building blocks of the system (Figure 1) are the sensors, front-end and back-end electronics, cooling elements, mechanical frame and assembly elements. The system consists of 8 independent modules (detection heads) stacked compactly one over another along guide rails incorporated in the flanks of a nitrogen tight aluminum crate. Each detection head comprises two PCB mounted respectively at 90º. The first board, the front-end PCB (Figure 2), fits a monolithic array of 8 SDDs and the corresponding 8 SIRIO [3, 4] charge preamplifiers, bias filtering capacitors, the connectors to the second, conditioning PCB (Figure 3), and a minimal mechanical support. A custom designed cooling circuitry allows to stabilize or cool down the sensor temperature in a controlled way. The signal conditioning PCB houses a fast analog shaping filter, which also realizes the single-ended to differential conversion of the signal, the preamplifier "close-to-saturation" detection circuits, and the sensor bias filtering. The back-end electronics mounted in the rear of the aluminum crate, allows for the system configuration and slow control, the front-end control, digitization and elaboration of the analog signals, acquisition of histograms or raw data for system analysis, and the communication with the controlling computer.

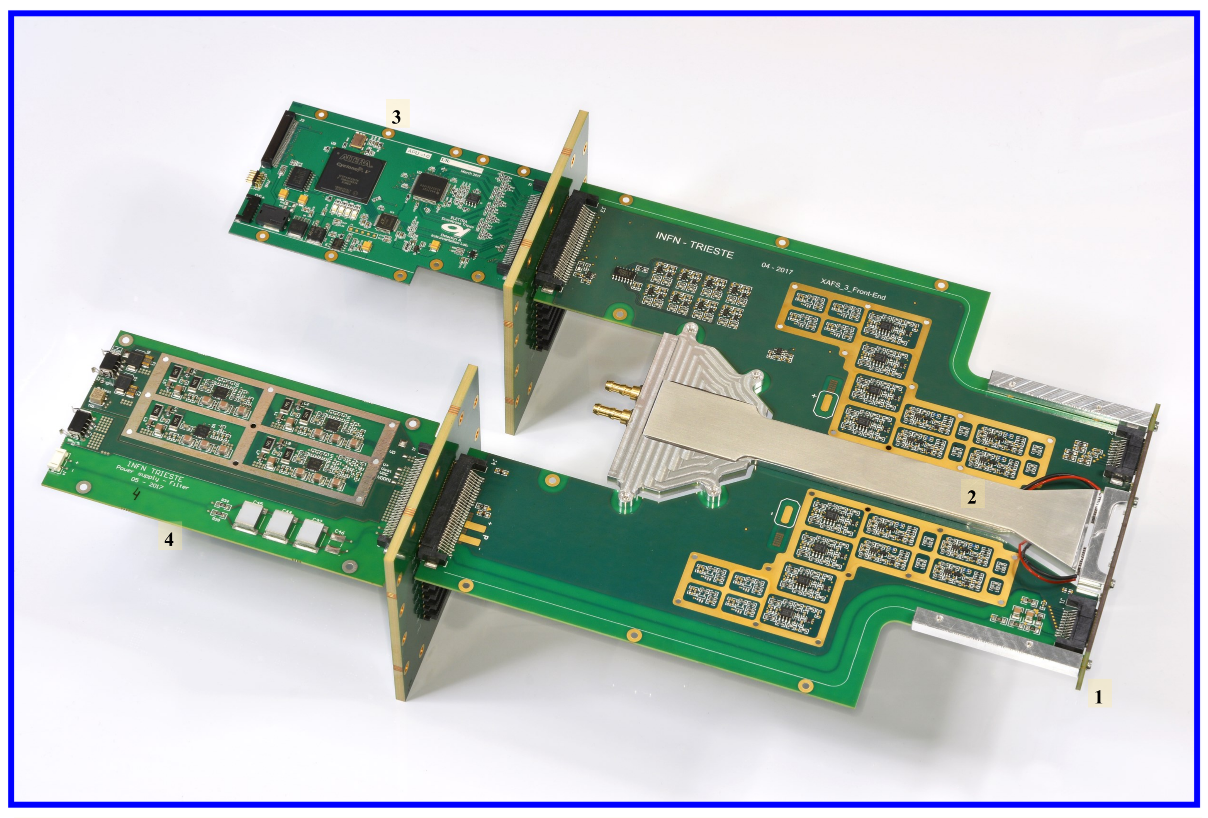


Fig. 3 Signal Conditioning PCB.
1: front-end PCB; 2: cooling profile; 3: back-end PCB; 4: power supply and filters;

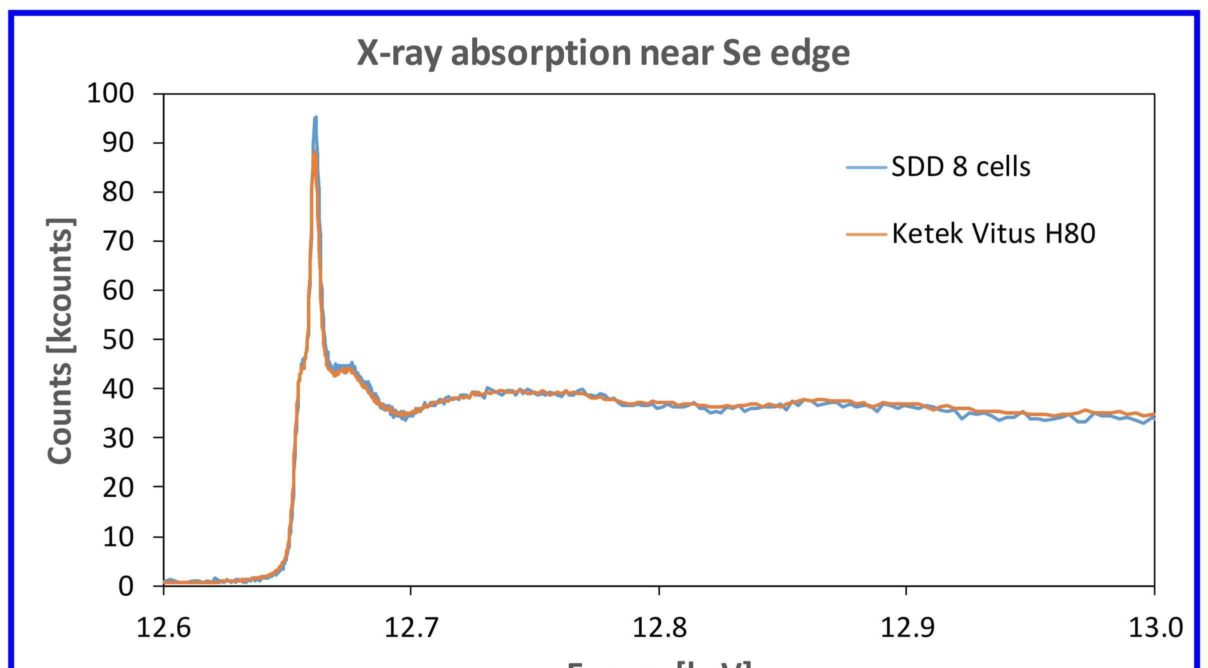
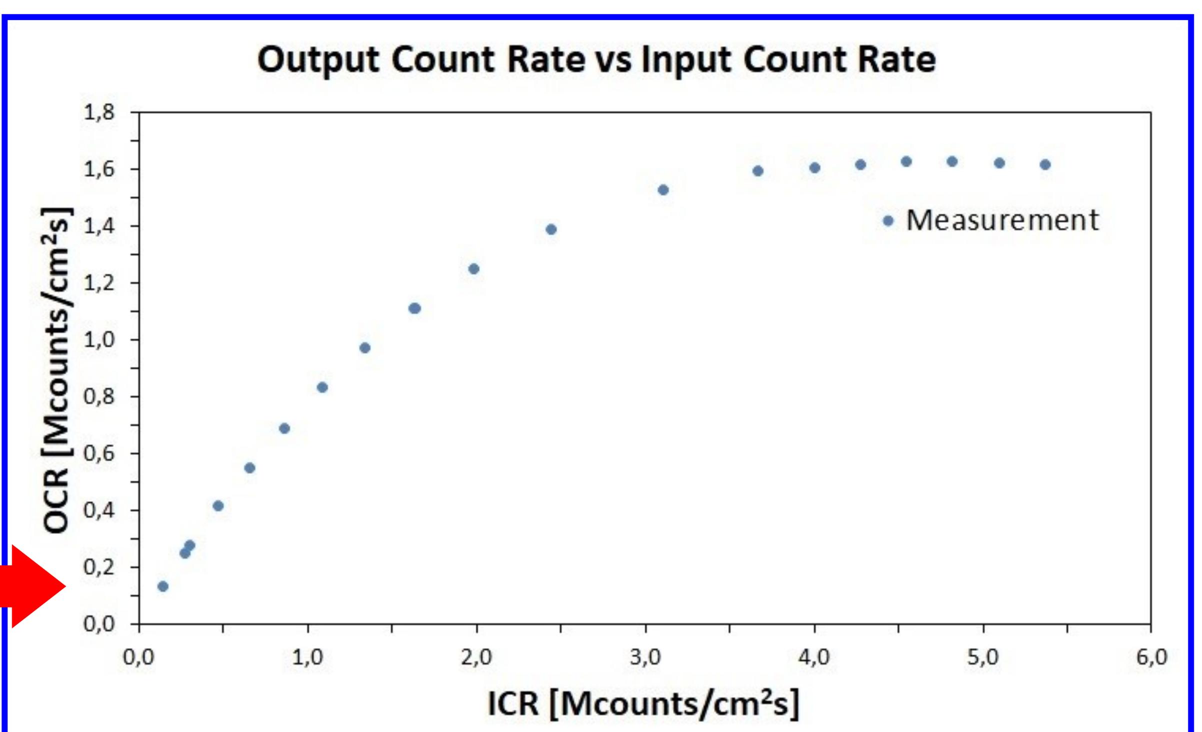


Fig. 4 XAFS spectrum normalized for the two detectors near the Selenium edge (single module of 8 SDDs vs standard single element SDD (Ketek VITUS H80).



SENSOR

The sensor, designed by INFN-Ts and fabricated by FBK (Trento), is a completely depleted volume of n-type 450 µm thick silicon wafer with a resistivity of 9 kΩ·cm organized as a monolithic linear array of 8 square cells of SDDs, each having 9 mm^2 non-collimated sensitive area. On the sensor front side, there is a shallow uniformly implanted p^+ entrance window common to all 8 drift cells that enables good sensitivity down to few hundreds of eV. The sensor back side is an arrangement of decreasingly negative biased p^+ rings (drift cathodes). The common bias voltage is applied to the outermost drift cathode that separates the cells. In the center of each cell, there is a small n^+ pad (readout anode) and, close to it, the innermost cathode that is kept at the smallest negative potential among the drift electrodes. Voltage dividers, integrated separately for each cell, connect drift cathodes and generate potential drops between them, thus setting up a drift field. The entrance window is biased separately with respect to the sensor backside in order to contribute to the full depletion of the detector bulk and to ensure an effective charge collection [5, 6]. Outside of the sensitive area of the whole array, both on the back side and the front side, there are several floating p^+ rings (guard cathodes). They serve to scale down the bias voltage to the ground. The sensor features an average leakage current below 100 pA/cm^2 at 20 ºC and a capacitance of about 40 fF for each readout anode. In order to eliminate border effects on the signal charge collection, a 127 µm thick tungsten collimator is foreseen to be mounted 80 µm above the entrance window, reducing though the available area to 87% of the sensitive one.

ELECTRONICS

The sensor readout anodes are wire bonded to ultra-low noise SIRIO charge sensitive preamplifiers developed by Politecnico di Milano for SDDs readout [3, 4]. Built in 0.35 µm AMS CMOS technology, the last generation SIRIO designed specifically for the detector needs, has an intrinsic equivalent noise charge (ENC) of 1.3 electrons r.m.s. at room temperature and less than 1 electron at -30 °C, representing the state of the art in low-noise front-end electronics. Shaped analogue signals from 8 preamplifiers are sampled at a rate of 40 Msps by 8-channel, 12 bit ADC. Data noise filtering is accomplished with a set of optimized digital filters by means of a low-power high-performance FPGA, which implements as well the data buffers, and the configuration and control logic. The reset of the preamplifiers handled by the FPGA is simultaneous for all 8 channels. Data are transmitted via a TCT/IP connection to the PC running a custom dedicated software.

COOLING

A relatively small sensitive area of the SDD cells (9 mm^2), and a remarkably low dark current ensured by the fabrication process, allow to have a typical leakage at the SIRIO input as low as 10 pA at 20 ºC. Hence, a moderate sensor cooling is enough to comply with the requirements for the energy resolution. Each sensor has on-board thermistors for the temperature sensing. The cold side of a Peltier cooling module is thermally glued to the support rear of the front-end PCB to insure cooling down the sensor and preamplifiers. The hot side heat removal consists of a brass profile mounted along the conditioning PCB, with cooling liquid flowing inside at a moderate pace. Inlets and outlets of the 8 brass profiles are connected via a custom designed manifold with a water circuit outside of the sealed aluminum crate. In order to avoid dew condensation, there is a very moderate dry nitrogen flow inside the crate.

EXPERIMENTAL RESULTS and CONCLUSIONS

A prototype of the system, consisting of a single module, was tested on XAFS beamline (Elettra - Sincrotrone Trieste) in February 2018, comparing it with a standard single element SDD (Ketek VITUS H80). The energy resolution of the two systems was completely comparable. The figure 4 shows the XAFS spectrum normalized for the two detectors near the Selenium edge. For this measurement the prototype was placed at a distance about 2-3 times far away relative to the Ketek SDD, and the data were acquired simultaneously by the two detectors. The great advantage of the new setup is the ability to manage high count-rates without saturating the detector and the acquisition chain. Using the peaking time of 0.9 µs during the tests, the standard detector stops at a maximum output count-rate (OCR) just above 100 kcounts/s with a dead time close to 50% (see the reference: www.ketek.net/sdd/vitus-sdd-modules/vitus-h80/). One module of the new multi-cell system operating with the same peaking time produces an OCR of 1600 kcounts/s·cm^2 after the pile-up rejection (figure 5), resulting in 8 Mcounts/s for the complete system.

The Fluorescence Detector System based on 64 SDDs custom designed for the SESAME XAFS beamline is a state-of-the-art instrument. It has a total collimated sensitive area of 499 mm^2, with the capability of reaching a maximum count-rate of at least 8 Mcps. The energy resolution confirmed by the beam test at XAFS beamline of the ELETTRA Sincrotrone, is below 150 eV FWHM @5.9 keV for all channels.

REFERENCES

[1] S. Fabiani et al., "Development and tests of a new prototype detector for the XAFS beamline at Elettra Synchrotron in Trieste", 2016 *J.Phys.Conf.Ser. 689 (2016) no.1, 01217*

[2] J. Bufon et al., "A new large solid angle multi-element silicon drift detector system for low energy X-ray fluorescence spectroscopy", 2018 *JINST* 13 C03032

[3] G. Bertuccio et al., "A Silicon Drift Detector-CMOS front-end system for high resolution X-ray spectroscopy up to room temperature", 2015 JINST 10 (2015) P01002

[4] G. Bertuccio et al., "X-Ray Silicon Drift Detector-CMOS Front-End System with High Energy Resolution at Room Temperature", IEEE Transactions on Nuclear Science, 63 (2016)

[5] A. Rachevski et al., "X-ray spectroscopic performance of a matrix of silicon drift diodes", Nuclear Instruments and Method A, 718 353 (2013)

[6] A. Rachevski et al., "First results of a novel Silicon Drift Detector array designed for low energy X-ray fluorescence spectroscopy", Nuclear Instruments and Method A, 824 452 (2016)