Karlsruhe Institute of Technology

Ultra-Fast Streaming Camera Platform for Scientific Applications

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Introduction: *Synchrotron-based X-ray computed tomography (CT) is a method for a non-destructive investigation of materials. Three-dimensional image of internal structure can be rapidly observed by using two-dimensional detector. A prototype of a high-speed visible light camera based on the commercial CMOS sensor with an embedded processing implemented in the FPGA will be presented. The camera has achieved a frame rate of **340 frames/s** with **2.2 Mpixel @ 10bits** and a data rate up to **1GB/s**. A novel architecture for a self-event trigger signal has been implemented to increase the original frame rate in the range of **several kilohertz** and, also, to reduce the amount of the received data. Selected applications from life sciences and materials research underline the high potential of this high-speed camera in a hard X-ray micro-imaging approach.*

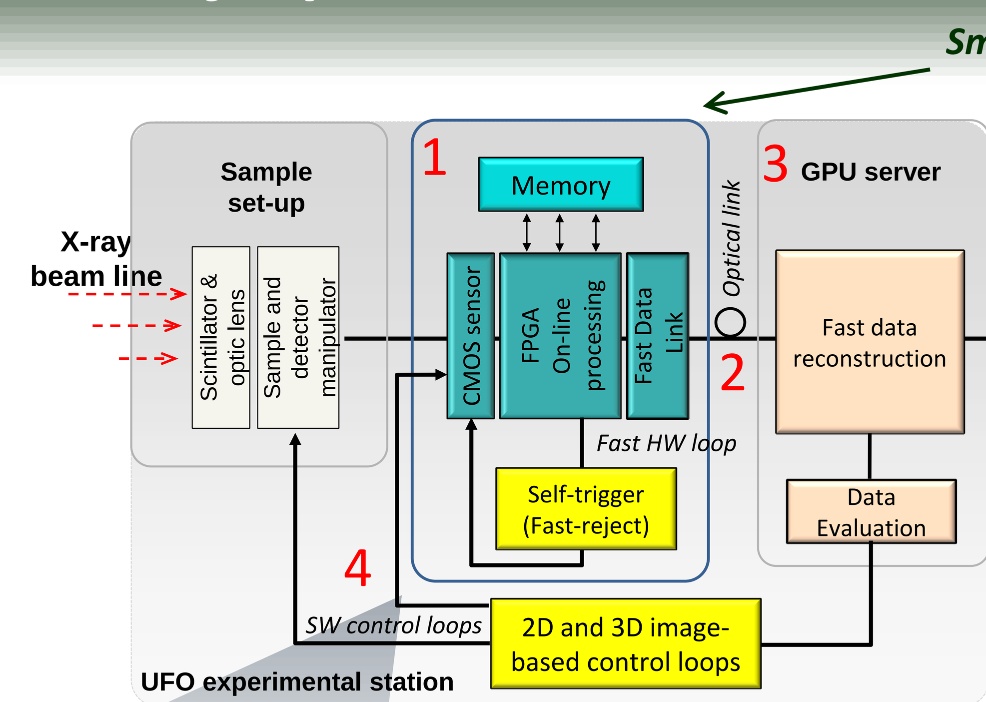
1. Ultra Fast X-ray imaging of scientific processes with On-line assessment and data-driven process control

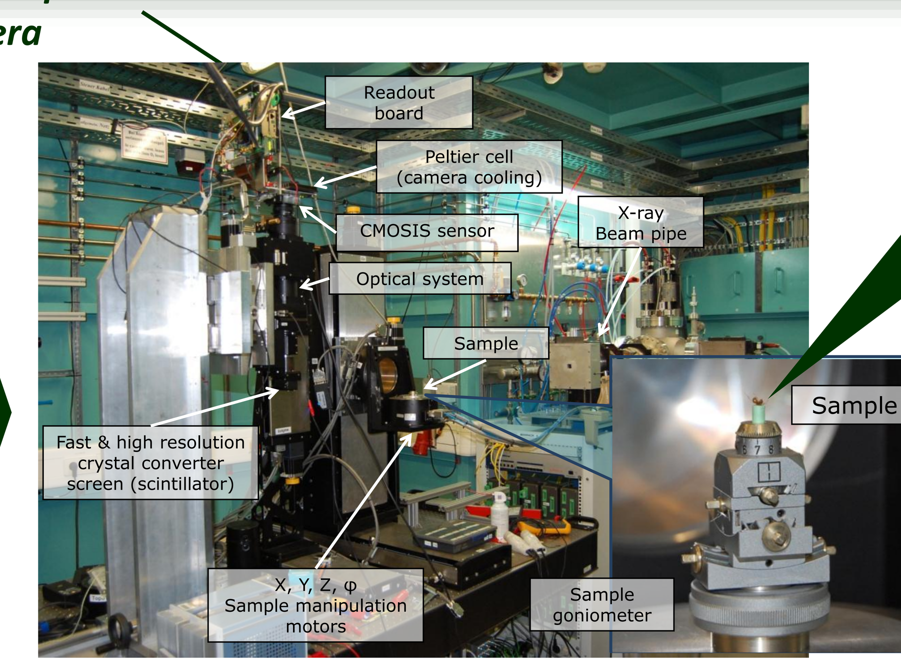
*The ANKA synchrotron radiation source is located at the Karlsruhe Institute of Technology (KIT) in Germany. A novel concept of ultra-fast and micro-imaging X-ray computer tomography experiment station will be installed on the dedicated beam-line. The project **'Ultra Fast X-ray imaging of scientific processes with On-line assessment and data-driven process control'** (UFO) aims to develop the next generation of X-ray computer tomography stations optimized to perform 3D and 4D X-ray imaging.*

UFO goal are:

Radioscopy with Spatio-temporal micro-resolution

Time-resolved micro-tomography





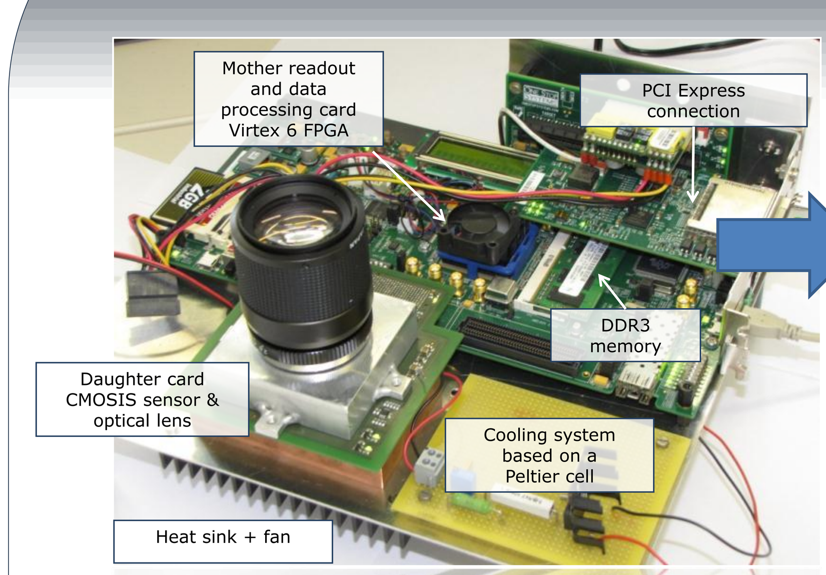
X-ray fast radiography acquired with the camera prototype described

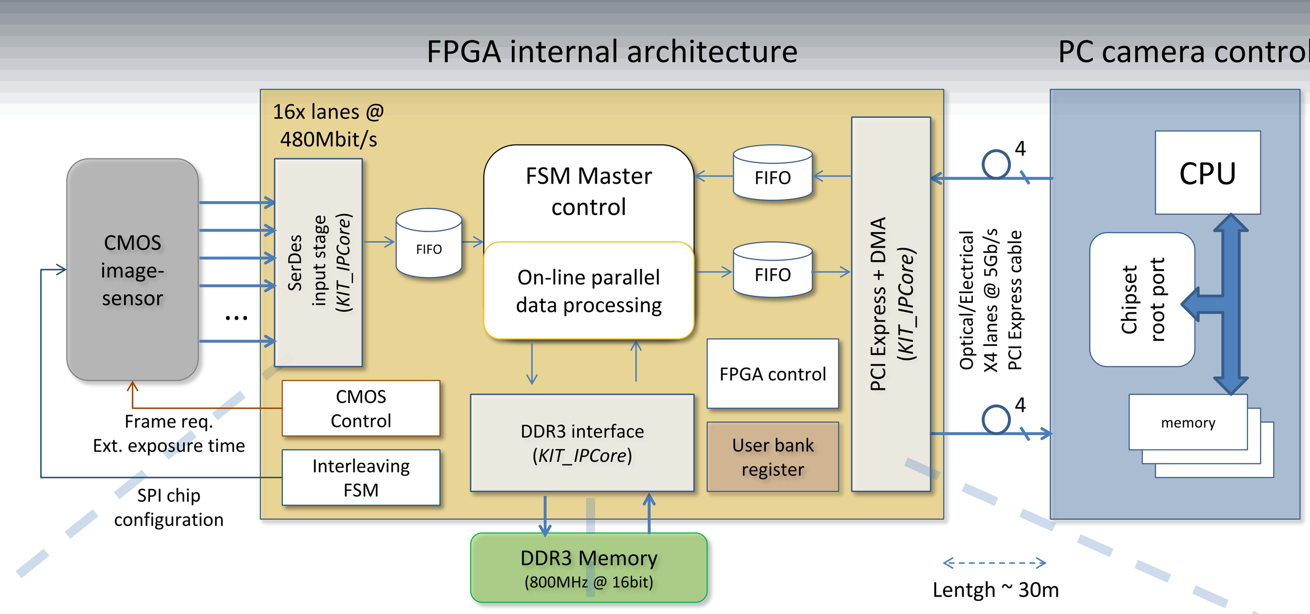
The camera prototype was successfully tested in ANKA with a moderate X-ray flux density.

The novel concepts employed in the UFO experiment station are: **(1) Smart high data throughput camera** with a **(2) fast optical data link based on PCI Express GEN2**. **(3) GPU server and on-line data processing and evaluation** for accelerating the 3D data reconstruction processing. The speed-up, for the first time, will enable a real-time image processing that will use 2D and 3D image reconstruction for an **(4) on-line feedback loop** for sample manipulations and optical system.

Several thousand of radiographies have been acquired at full speed (340 frames/s) in streaming mode. An satisfactory SNR level has been achieved with a spatial resolution in the micrometers range.

2. First prototype of the smart high data throughput visible light camera for ultra fast X-ray micro-imaging





The main features, implemented and tested, include:

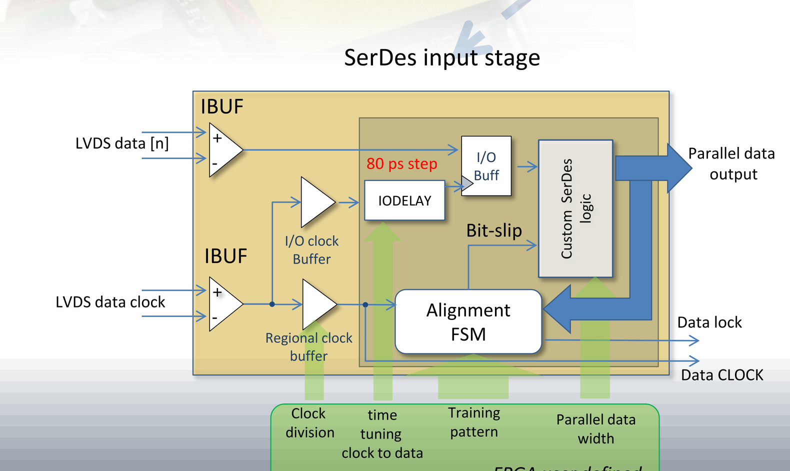
Fully configurable camera, full access at the pixel parameters in order to adapt the pixel response at any experiment condition.

Full streaming data acquisition architecture, continuous data acquisition without dead readout time.

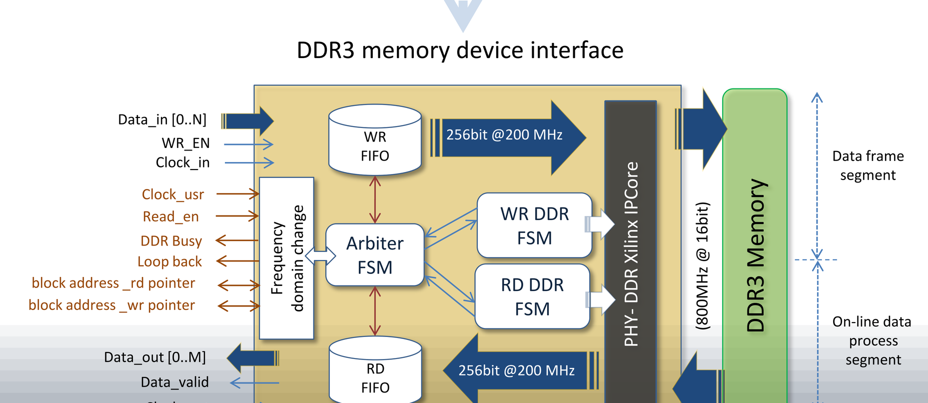
On-line image-based self-event trigger architecture (Fast reject) and **Region-Of-Interest readout strategy**, intelligent selection of the frame Region-Of-Interest for reducing the amount of output data and, in the same time, to significantly increase the camera frame-rate.

Easily expendable to any available CMOS-image sensor, flexible FPGA architecture easily adapted to any CMOS-image sensor devices.

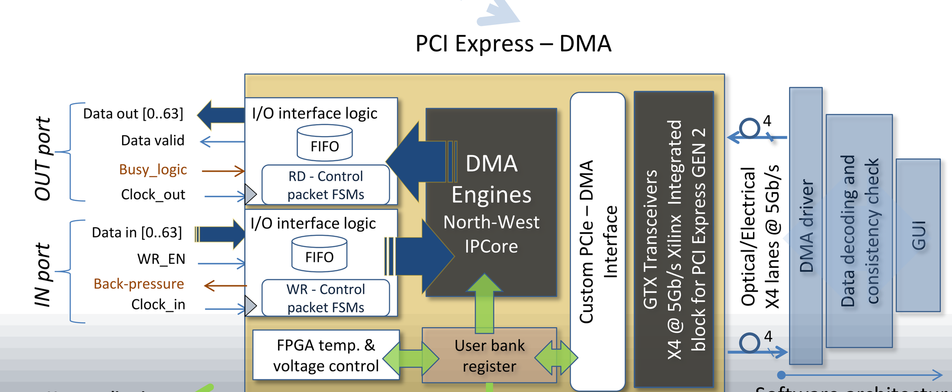
Three Intellectual Property (IP) logic cores have been developed in KIT



A **SerDes input stage** operating up to **800MHz** width a reconfigurable parallel data width up to **16bit.**

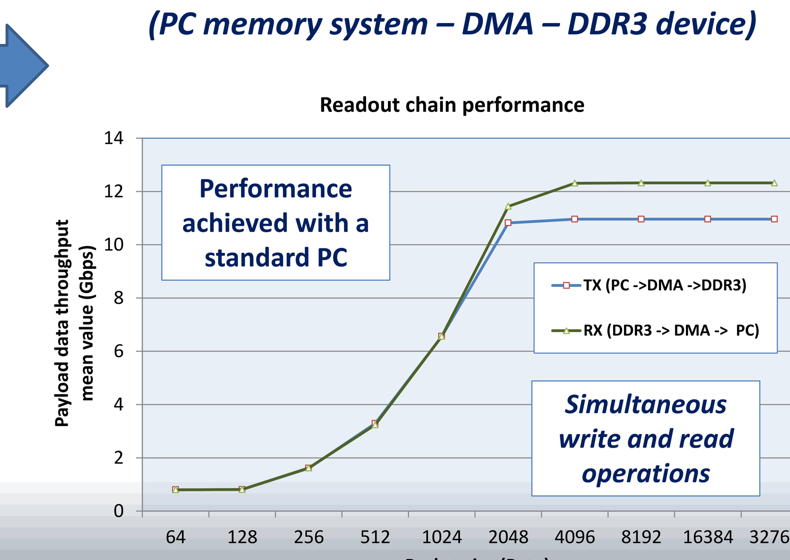


A **DDR3 memory interface** operating at 800MHz. The architecture is able to work in both half and full-duplex modes with a bandwidth of **51Gb/s** and of **25 Gb/s** respectively.



A **PCI Express GEN2** with theoretical bandwidth **20Gb/s** combined with a **Bus Master DMA** (Direct Memory Access) architecture to fully benefit from the high PCI Express link.

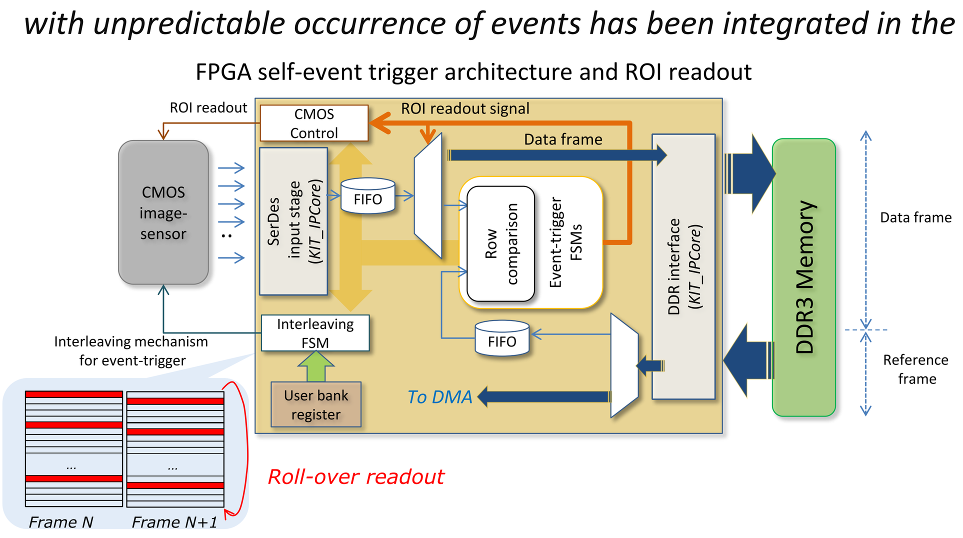
Readout chain performance (PC memory system – DMA – DDR3 device)



A **bandwidth of 16 Gb/s in both directions** has achieved with the GPU-server. The bandwidth of 16Gbit/s is only limited by the current FPGA speed-grade.

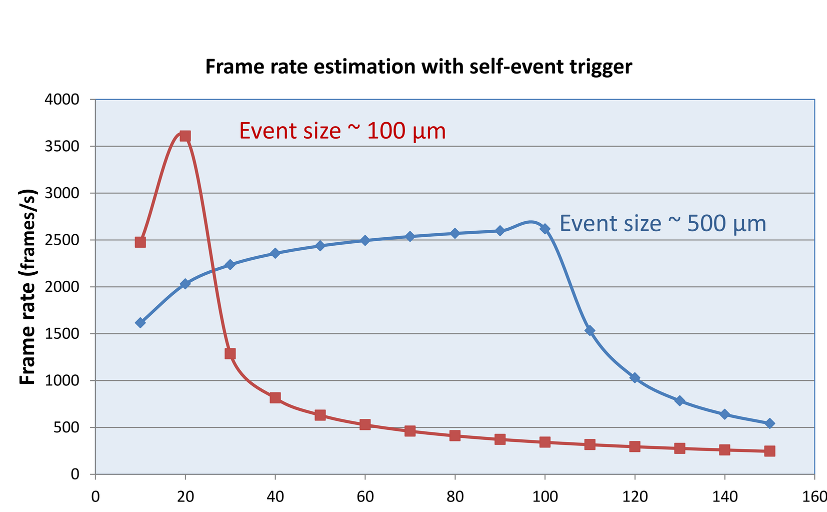
3. Self-event trigger (fast reject) and an intelligent region-of-interest readout

*Fast processes which can not be controlled by external signals require a data recording at a high frame rate. Unpredictable physical events could be lost or partially acquired during this limited observation time. **The intelligent image-based self-trigger** for applications with unpredictable occurrence of events has been integrated in the current camera.*



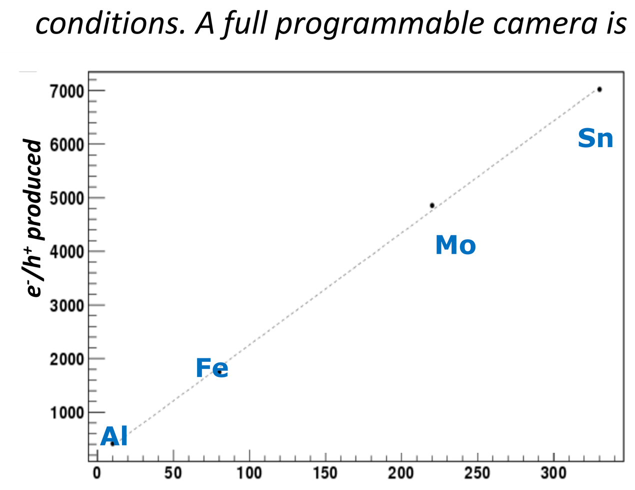
Self-event trigger and Region-Of-Interest readout architecture

Performance: The intelligent Region-Of-Interest readout combined with the self-event trigger (Fast Reject) allows to keep a ***high-spatial and time resolution*** and the ***full point of view of the scene***. This method allows to increase **up to factor 10** the original CMOS-image sensor frame rate.



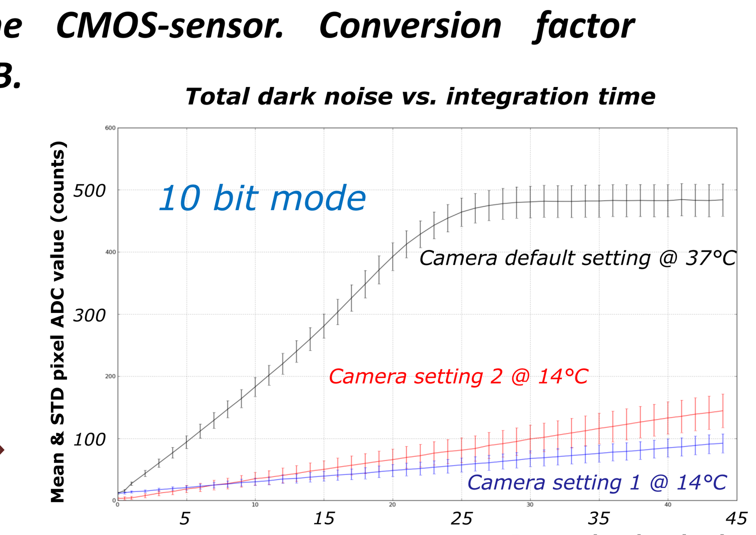
4. Camera characterization & adaptation at experiment conditions

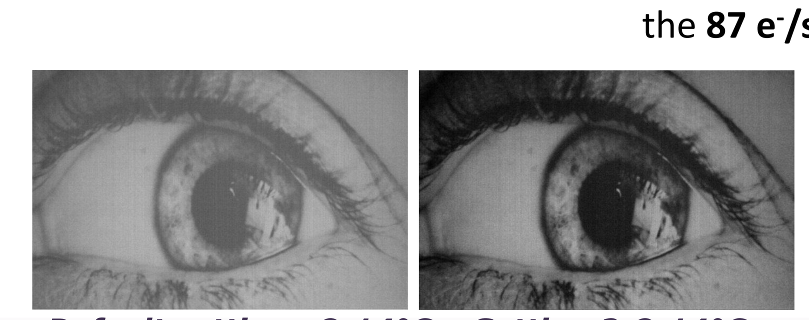
The limited density of the photon flux in the synchrotron light source application sets the fundamental limit on image sensor performance in the high frame rate acquisition (short integration time). The temporal noise components are dominant in these conditions. A full programmable camera is a key point for an adaptive camera setting at the different X-ray experiment conditions.



Efficiency characterization shows an ***excellent linearity of the response of the CMOS-sensor. Conversion factor measured of 21 e^-/LSB.***

Noise characterization, total noise contribution of the **87 e^-/s @14°C**





Default settings @ 14°C ***Setting 2 @ 14°C***

Frames are acquired at full-speed with 100µs integration time with lower illumination level for default and settings 2 respectively.