# UFO – Ultra Fast Streaming Camera Platform for Scientific Applications

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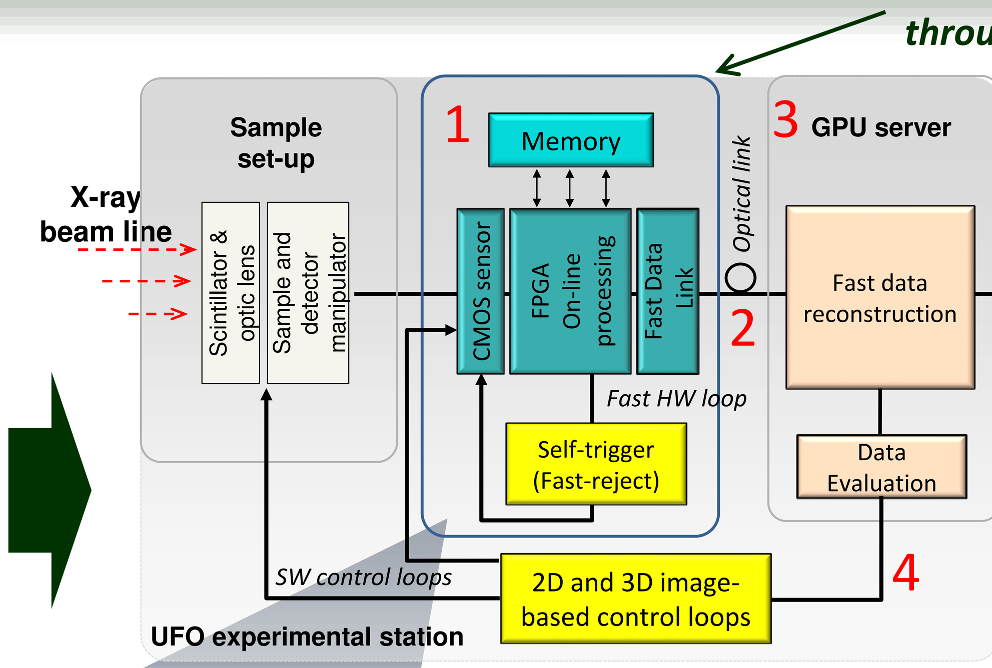
***Abstract:*** *Synchrotron-based X-ray computed tomography (CT) is a method for non-destructive investigation of materials. A prototype of a high data throughput visible light camera based on commercial CMOS sensor with* ***embedded processing*** *implemented in the FPGA is developed. The camera has achieved a frame rate of* ***340 frames/s*** *with* ***2.2 Mpixel @ 10 bits*** *and a data rate up to* ***1 GB/s****. A novel architecture for a self-event trigger signal has been implemented to increase the original frame rate to* ***several kilohertz*** *and to reduce the transmitted data volume. Applications from life and materials science underline the high potential of this high-speed camera in hard X-ray micro-imaging.*

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

*A novel ultra-fast & high-resolution X-ray imaging experimental station will be installed at the ANKA synchrotron machine. 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 computed tomography stations optimized to perform 3D and 4D X-ray imaging.*

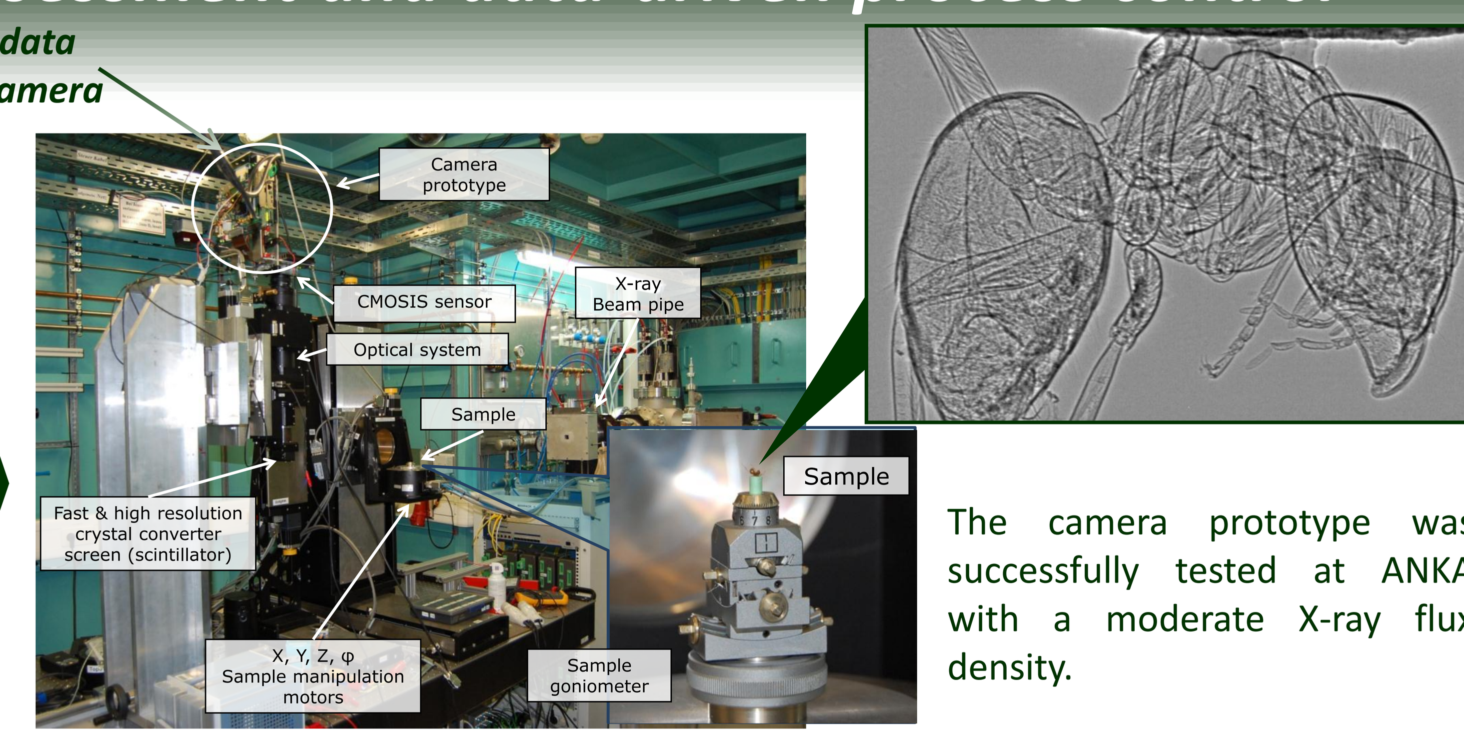
***Radioscopy with Spatio-temporal micro-resolution***

***Time-resolved micro-tomography***




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**. **(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 real-time image processing that will use 2D and 3D image reconstruction for **(4) on-line feedback loop** for sample manipulations and optical system.

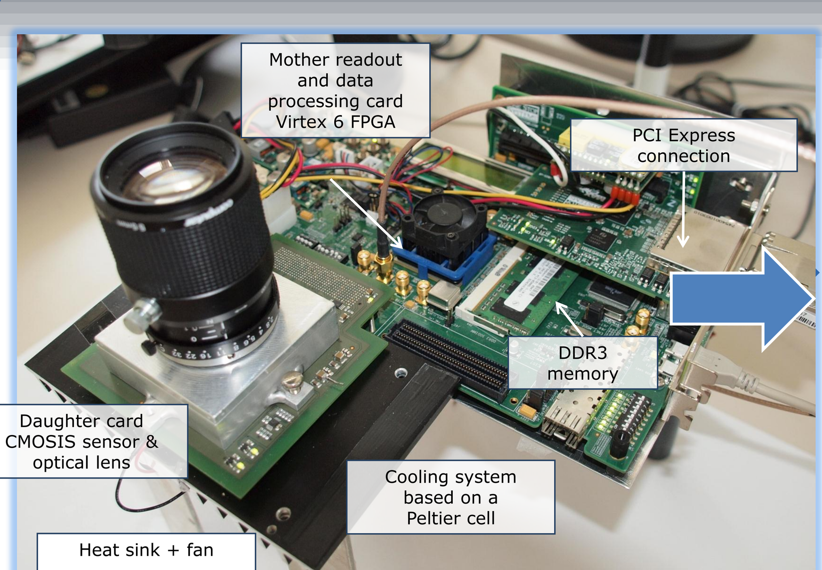
***Smart high data throughput camera***

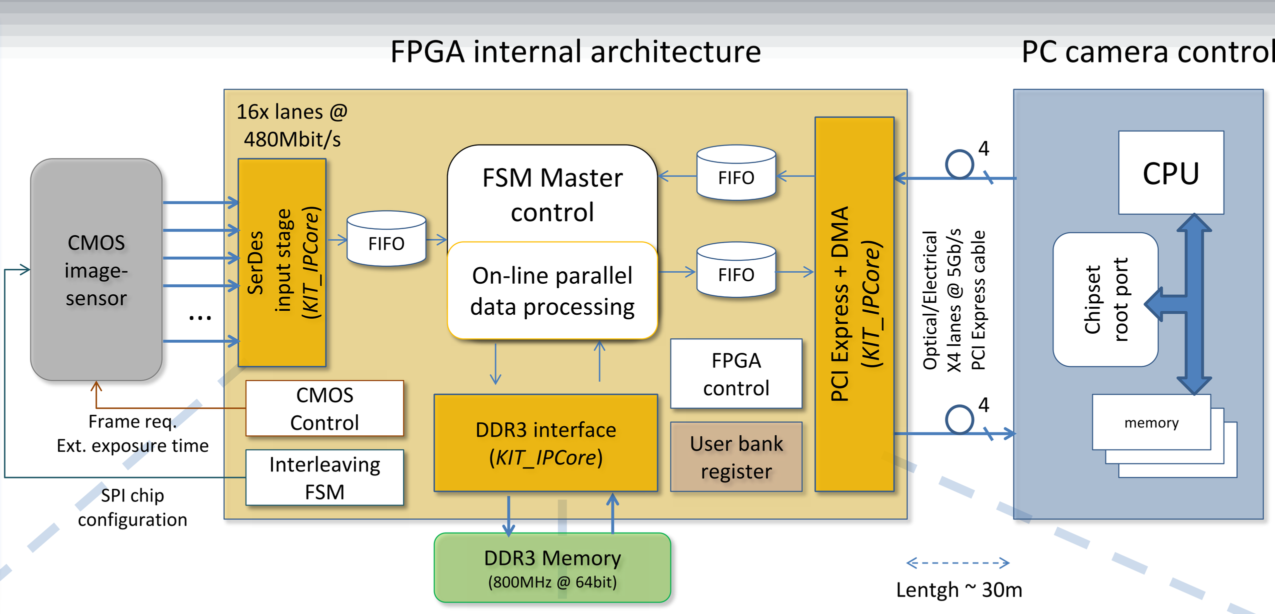



The camera prototype was successfully tested at ANKA with a moderate X-ray flux density.

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

## 2. First UFO camera prototype




***The main features, implemented and tested, include:***

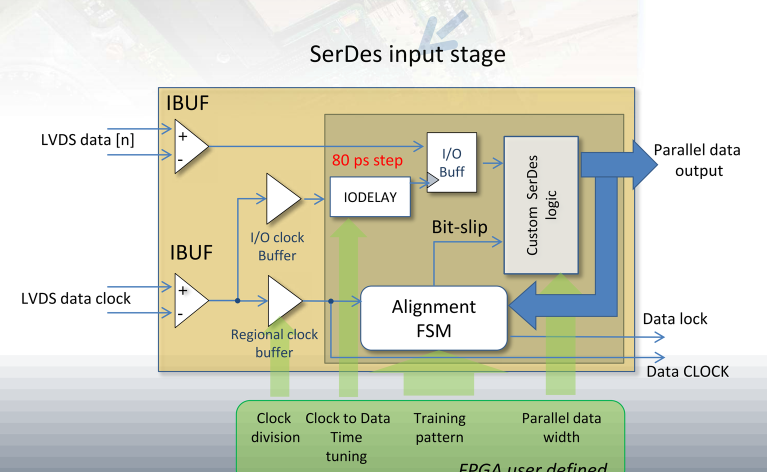
**Fully configurable camera** → to adapt the pixel response at any experiment condition.

**Full streaming data acquisition architecture** → continuous data acquisition without dead readout time.

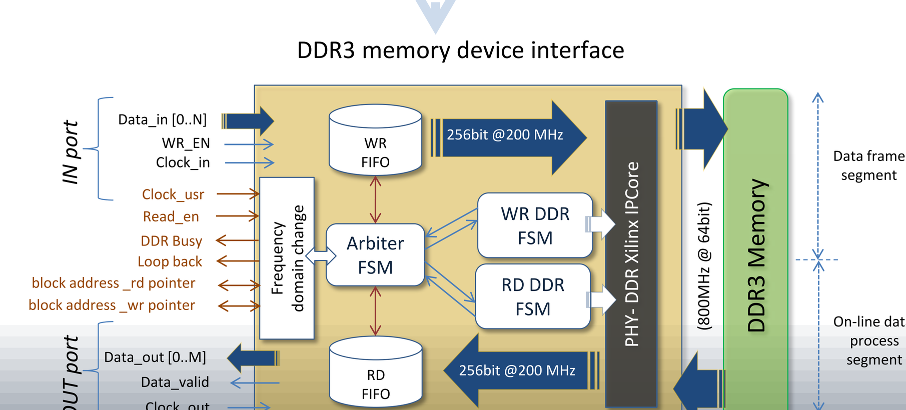
**On-line image-based self-event trigger (Fast reject)** and **Region-of-Interest readout architecture** → intelligent selection of the Region-of-Interest of the frame for reducing the amount of output data and, significantly increase the camera frame-rate.

**Easily extendable to most available CMOS-image sensor**

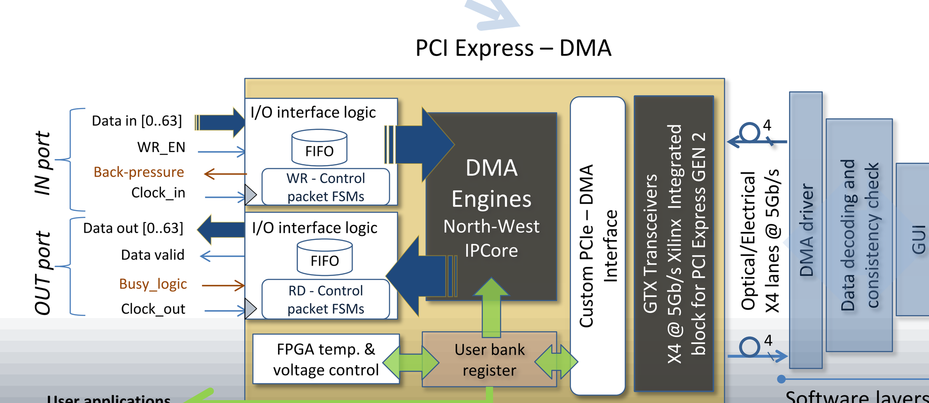
*Three Intellectual Property (IP) logic cores have been developed*




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

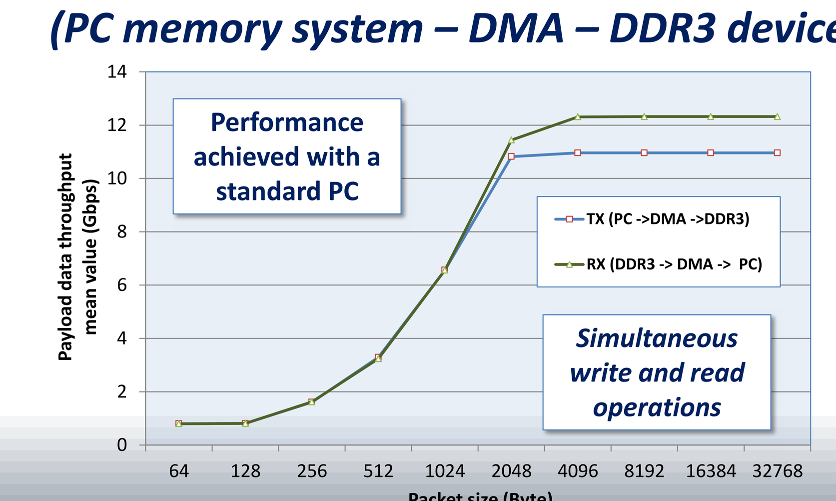



A **DDR3 memory interface** operating at 800MHz. The architecture is able to work in both half and full-duplex modes with a bandwidth of **51Gb/s** and of **25 Gb/s**, respectively.




A **PCI Express** with theoretical bandwidth of **20Gb/s** combined with a **Bus Master DMA** architecture to benefit fully from the PCI Express link.

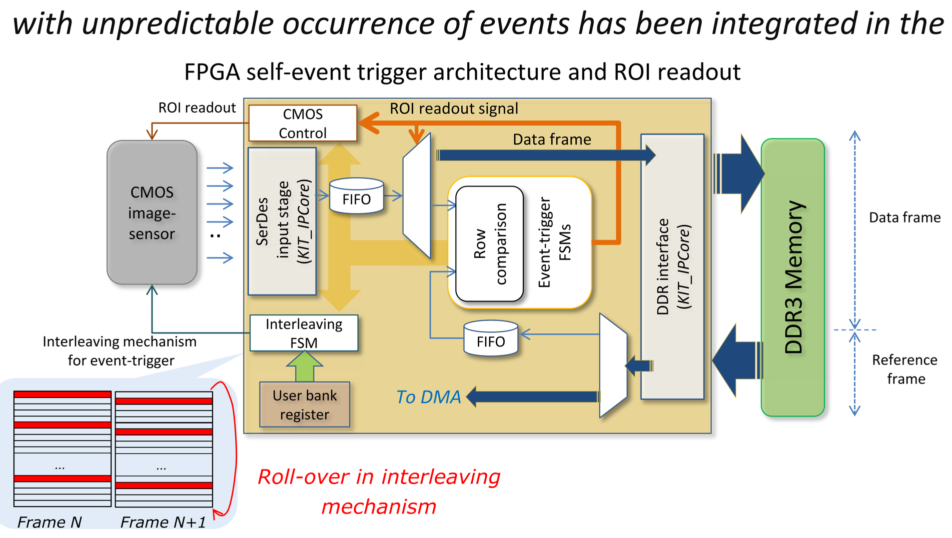
***Readout chain performance (PC memory system – DMA – DDR3 device)***




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

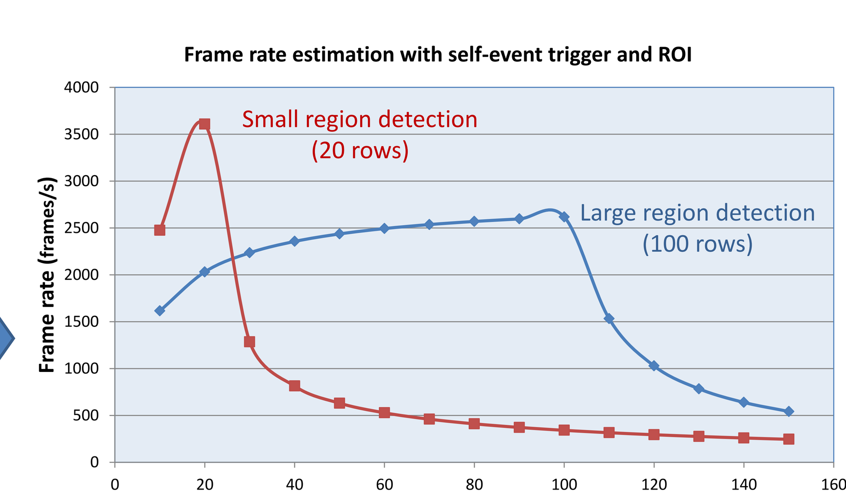
## 3. Self-event trigger (fast reject) and an intelligent Region-Of-Interest readout

*Fast processes which cannot 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***

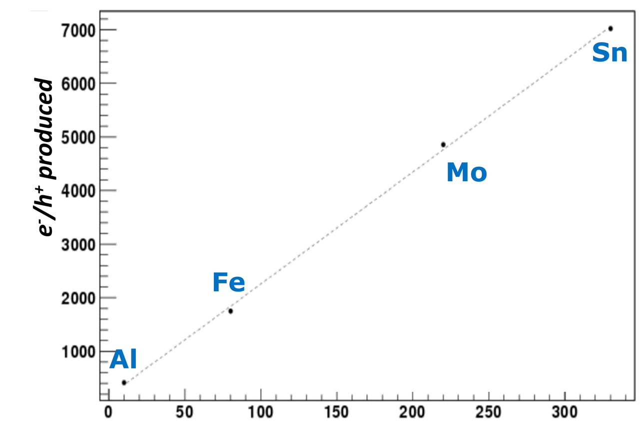
***Performance:*** The architecture allows us to keep a ***high-spatial and time resolution*** and the ***full point of view of the scene***. This method increases the original CMOS-image sensor frame rate **up to a factor of 10**.




## 4. Camera characterization & adaptation to 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 fully programmable camera is key for an adaptive camera setting at the different X-ray experiment conditions.*

***Efficiency characterization***

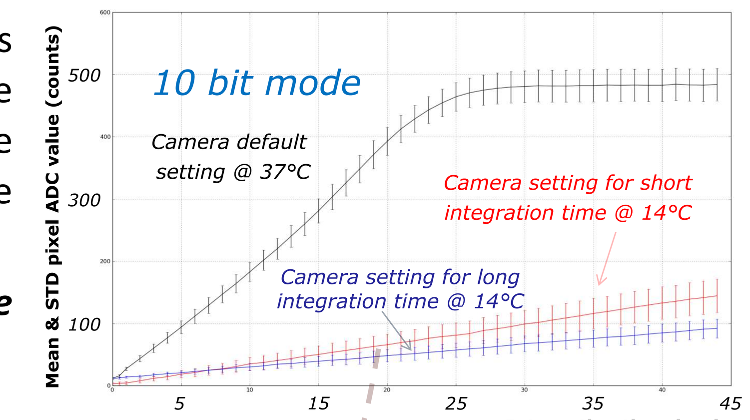



***Excellent linearity of the CMOS-sensor, conversion factor measured*** → ***21*** $e^-/ADC_{count}$

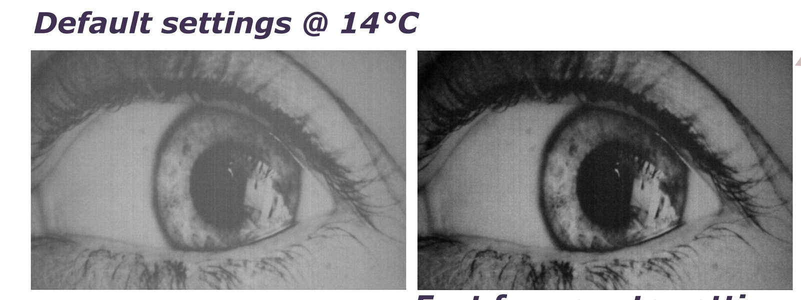
Two different camera settings have been found to optimize the SNR for high frame rate (red) and high frame resolution (blue), respectively.

***Low noise camera, total noise contribution estimated*** → ***87*** $e^-/s$ ***@ 14°C***

***Noise characterization***




***Default settings @ 14°C***



***Fast frame rate setting (red) @ 14°C***

Frames are acquired at full-speed with 100 µs integration time with lower illumination level .