Development of an ultra fast x-ray camera using hybrid pixel detetor

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Plan of the presentation

- Introduction
  - Principle and applications of hybrid pixel detectors
  - XPAD3 chip
- Overview of the XPAD detector
  - Architecture
- Performance and first results of the prototype camera
- Conclusions and perspectives

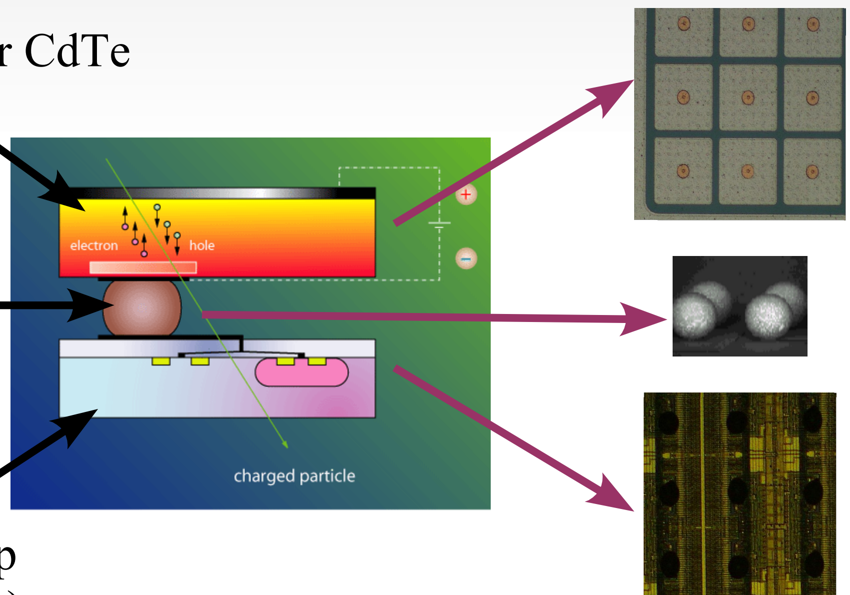
Introduction

Hybrid pixel detector - principles

The sensor is connected to the electronic readout circuit using flip-chip and bump bonding technologies. The two parts are pixelized with the same pitch.

sensor – Si or CdTe

flip-chip bonding

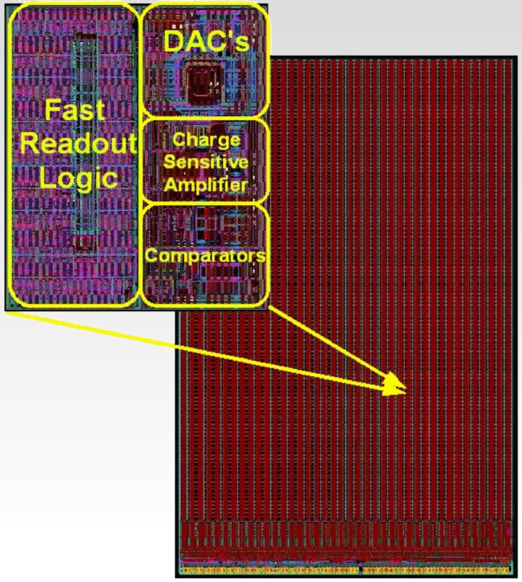


electronic chip (pixel readout)

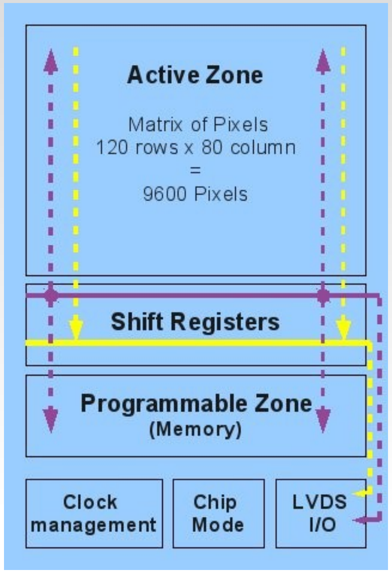
- ability to count single photons
- possibility to chose material depending on the application
- analog and digital processing on each pixel

XPAD detector

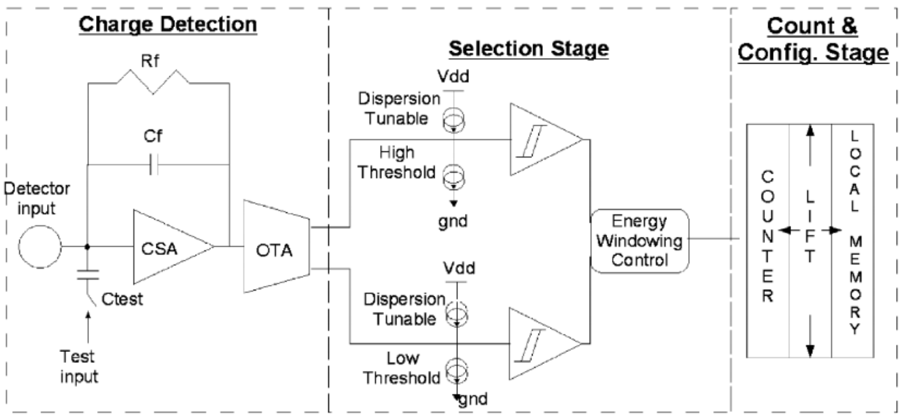
XPAD3 – x-ray photon counting imaging chip



Chip and pixel layout



Chip block diagram



- designed in submicronic technology (IBM 0,25 µm)
- pixel size : 130 x 130 µm^2
- 9600 pixels (120 rows x 80 columns)
- programmable energy tresholds (minimum treshold < 4 keV)
- no dead time for readout
- no limit for the dynamic (12 bits counter and overflow)
- Maximum count rate 10^6 photons/pixel/s
- internal temperature sensor
- on the fly readout (less than 2 ms)

Introduction

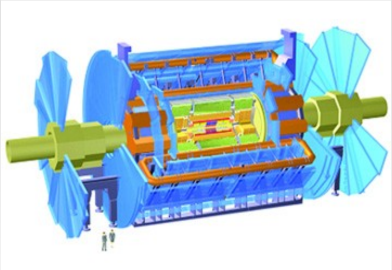
Hybrid pixel detector vs CCD / MAPS

Hybrid pixels	**CCD**	**MAPS**
single photon counting (energy windowing)	charge integration (no energy selection)	charge integration (no energy selection)
high readout speed	low readout speed	high readout speed
high radiation tolerant	pure radiation tolerant	need to use radiation hard electronics

Introduction

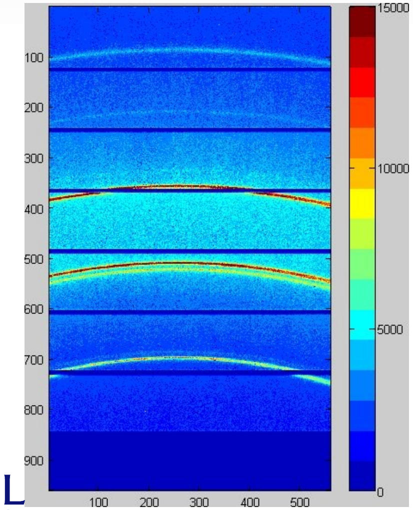
Applications

High energy physic :



The ATLAS pixel detector is composed of 86 millions of hybrid pixels.

Synchrotron source experiments :



High count rates, large counter dynamics, adjustable energy treshold and fast readout are the features which makes hybrid pixel detectors best choise to meet requirments for the experiments on high flux and high brilliance third generation synchrotron X-ray sources.

Diffraction rings an teflon with 14 keV X-ray beam.

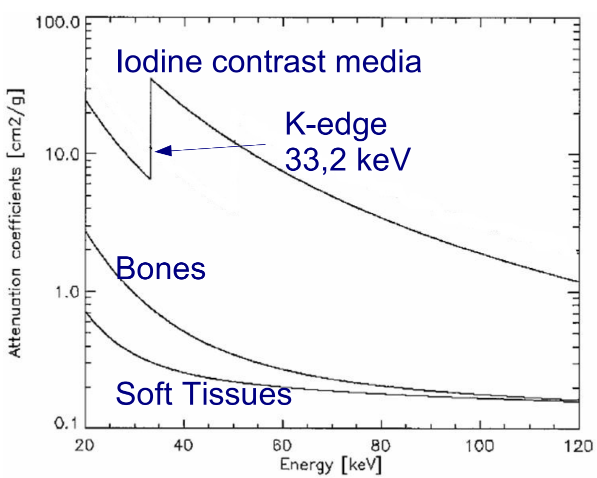
Introduction

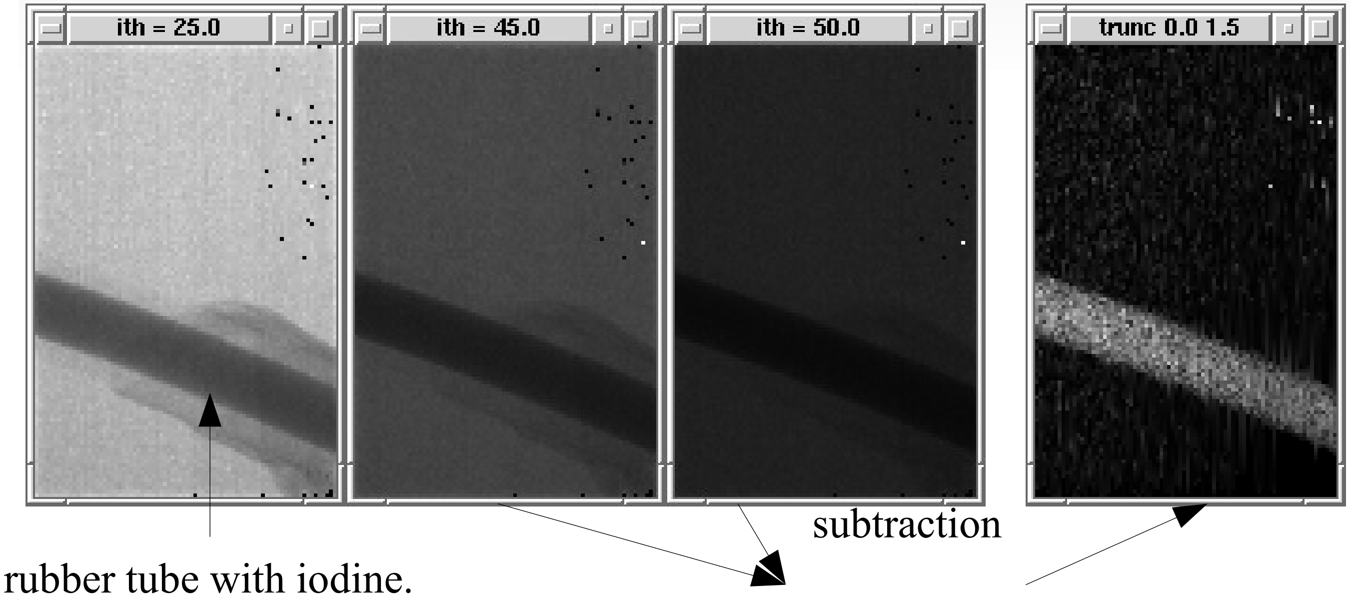
Applications

Biomedical imaging :

Each pixel is independent of the others and its adaptable dynamics will make it possible to optimising contrast agent detection while reducing the dose exposure.

Contrast Magnification





Example of selective CT imaging with iodine as a contrast agent media.

XPAD detector

Architecture

Detector architecture is organized in multi-stage system which ensures required speed of data collection.

Detector :

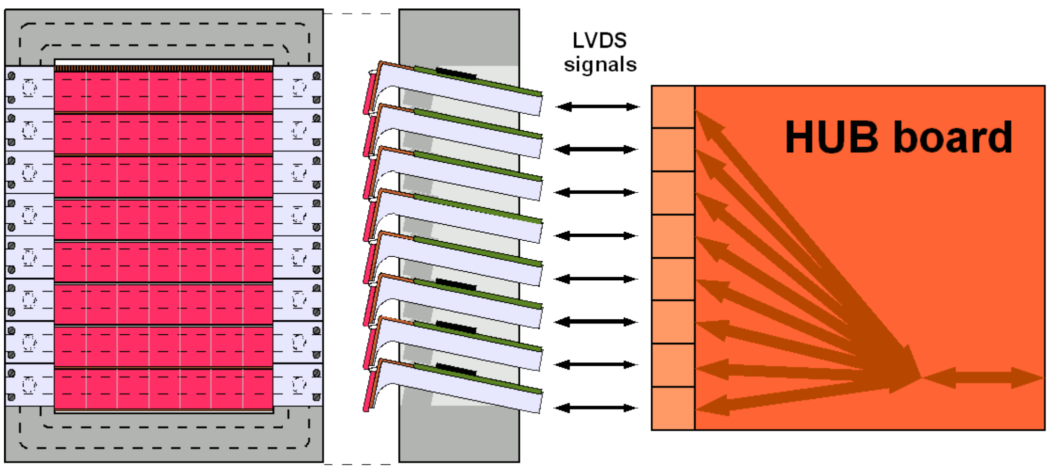
- 8 modules working in parallel
- each module equipped with local processing electronics
- local storage (DDR2 and SRAM)

Hub board :

- dispatches messages for the modules
- gathers, reformats and transfer data from the modules to the DAQ
- distributes gate signal and detector's bias voltage

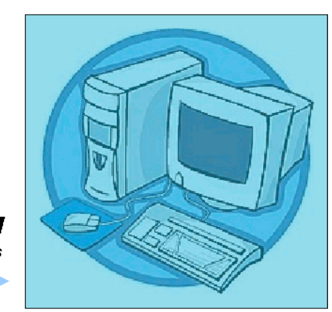
DAQ software :

- module selection
- test
- calibration
- acquisition
- image display
- read/load configuration



USB-opto board :

- auxialiary board
- converts data from the optical lik to the USB standard



XPAD detector

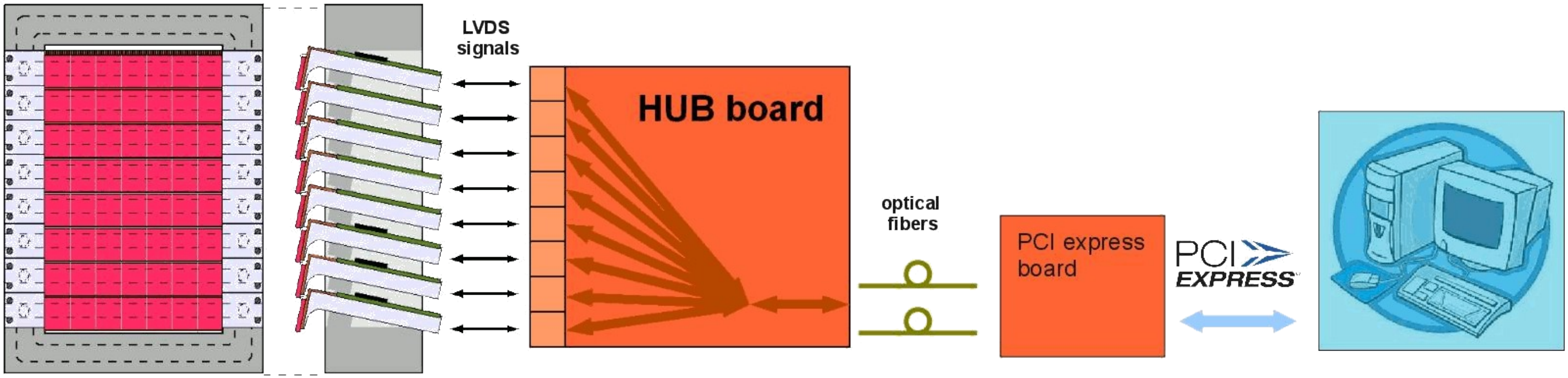
Architecture – PCI express upgrade

Change :

- PCI-express board instead of USB-opto
- Two optical fibers instead of one

Benefits :

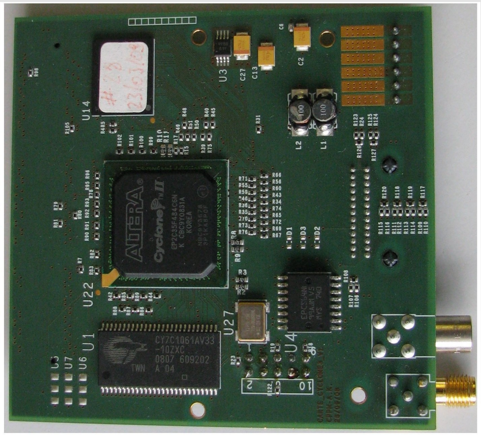
- image rate increased from 3 images/s up to > 500 images/s
- long data acquisition limited only by size of the PC's storage



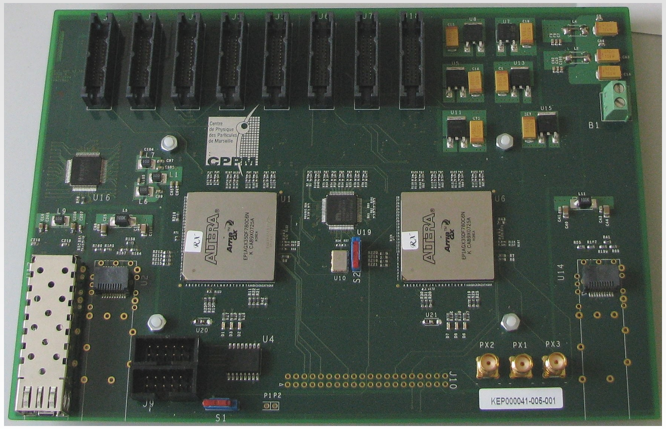
XPAD detector

Architecture

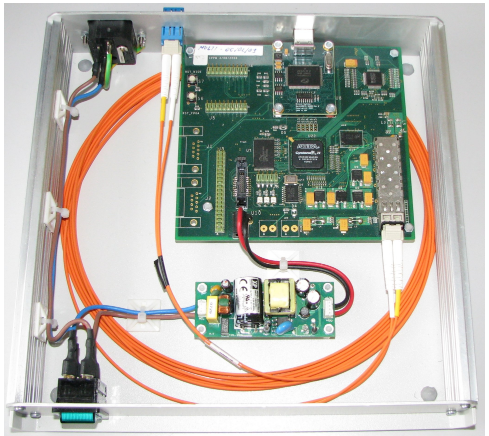
Module with processing electronics



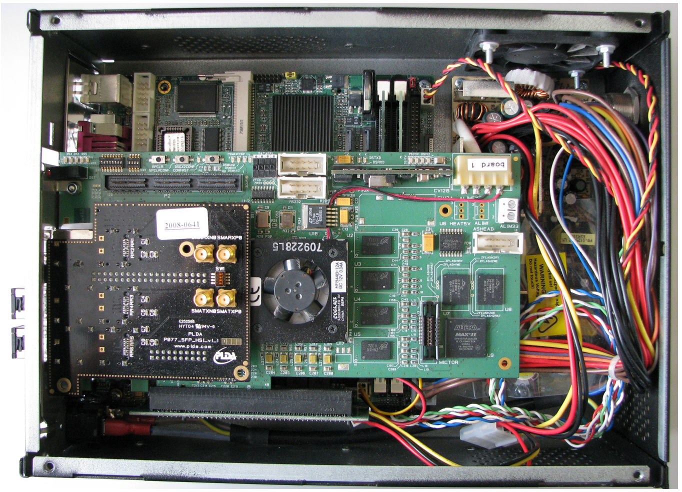
Hub board



USB-opto board



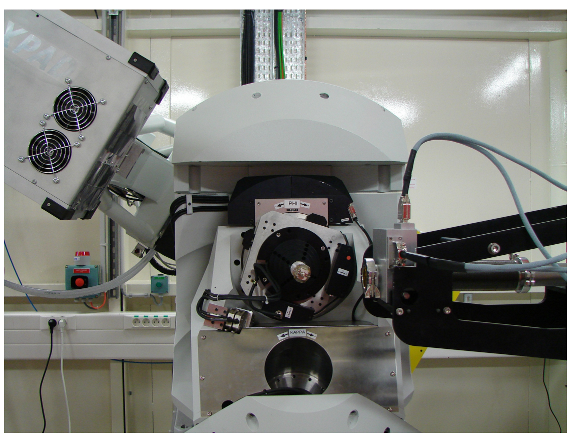
Acquisition PC with PC express board



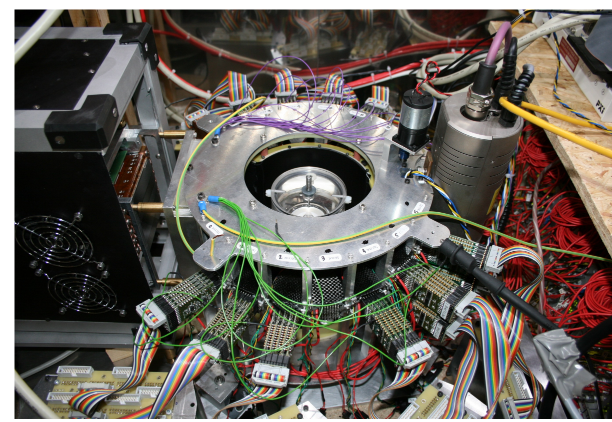
XPAD detector

Architecture

- detection area : 75 x 120 mm^2
- 8 tiled modules (7° tilt) of 7 chips
- 537600 pixels (1 chip = 80 x 120 px)
- 500 µm silicon sensor



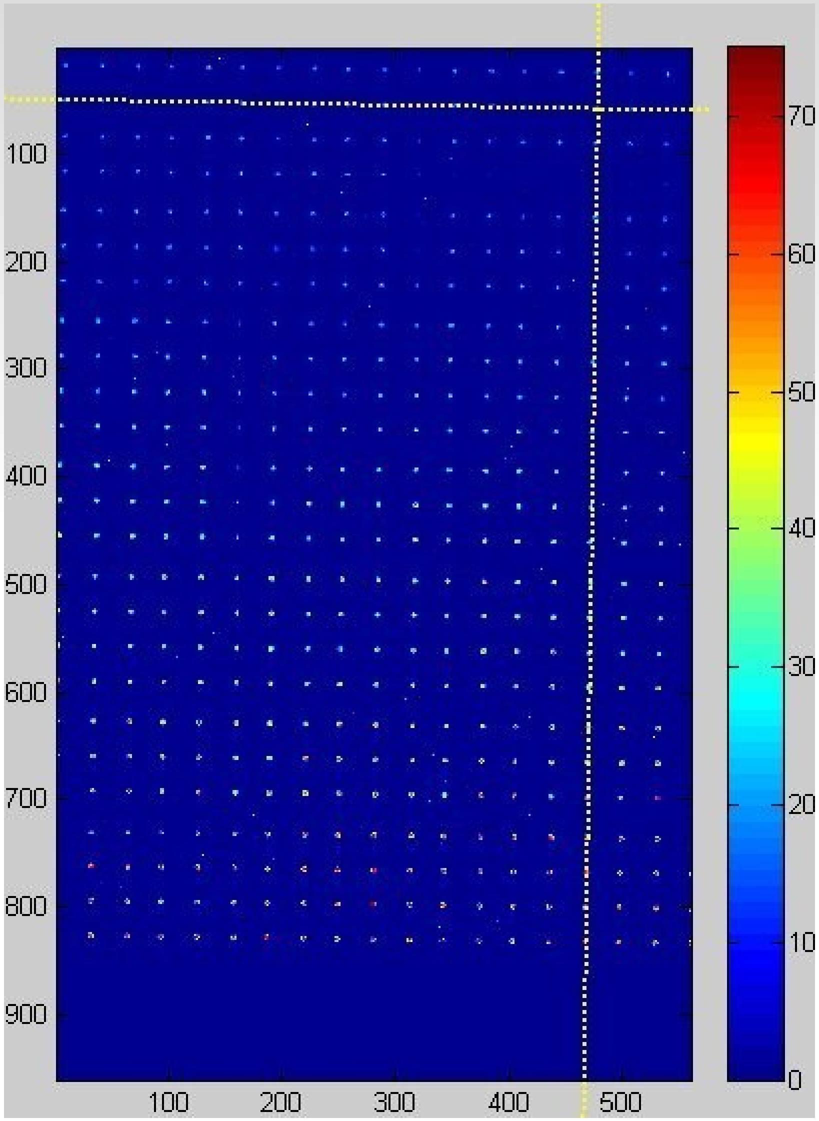
Detector installed on the diffractometer at Soleil synchrotron



PET/CT imaging system

XPAD detector

Alignment of the modules

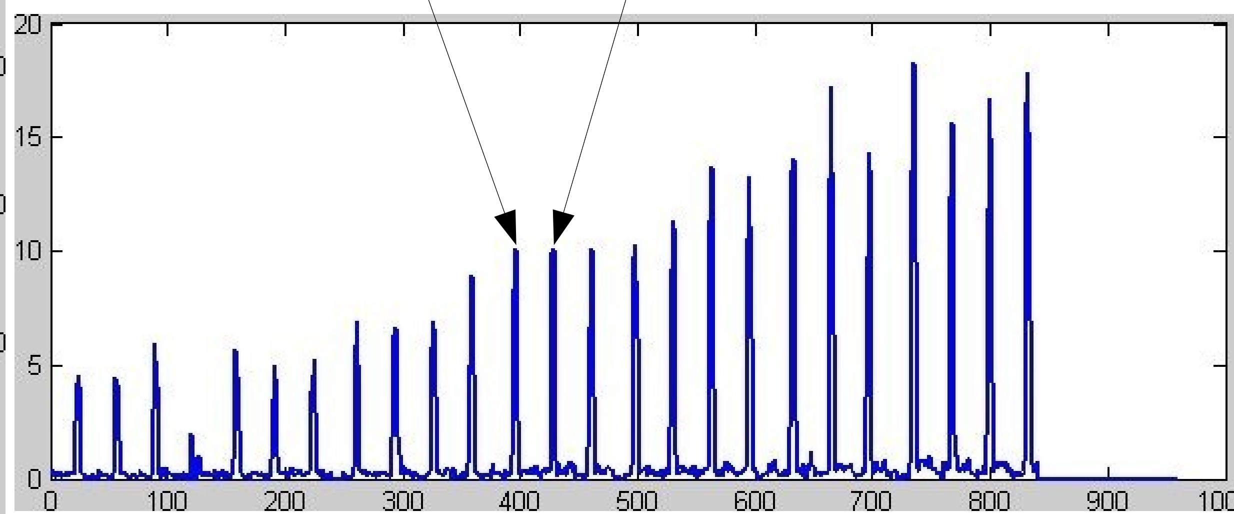


E = 14 keV, diffusion on 5mm of water

Noise calibration

Detector covered with copper grid with holes diameter of 600 µm and pitch 4 mm

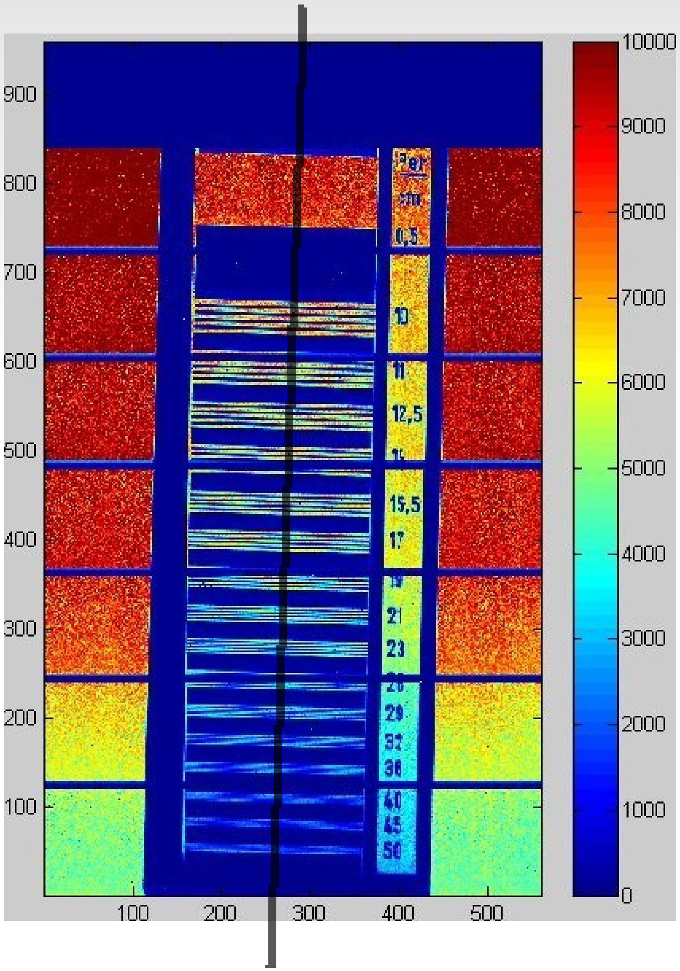
30 pixels ≈ 4 mm (130 µm * 30)



XPAD detector

Spatial resolution

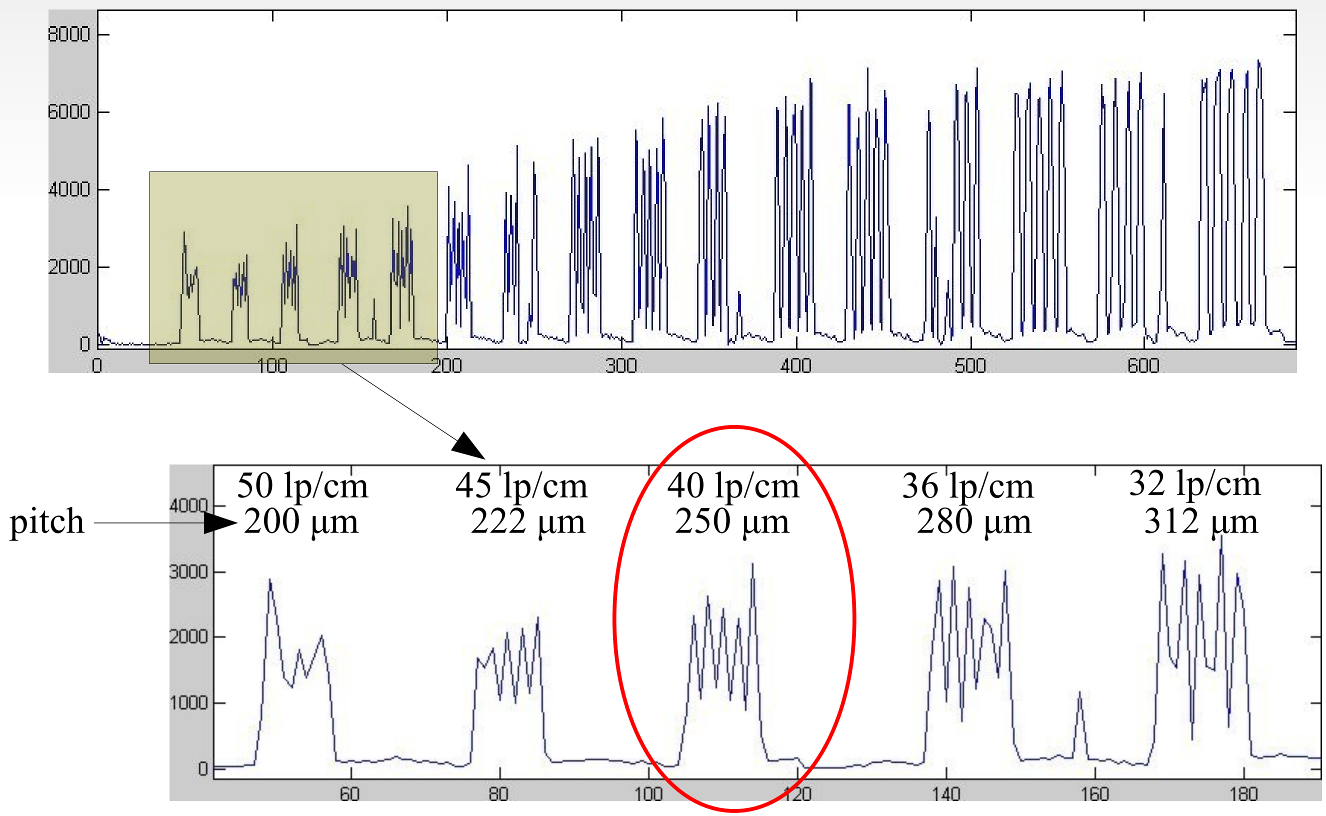
Detector covered lead bar pattern



E = 14 keV, diffusion on 5mm of water

Noise calibration

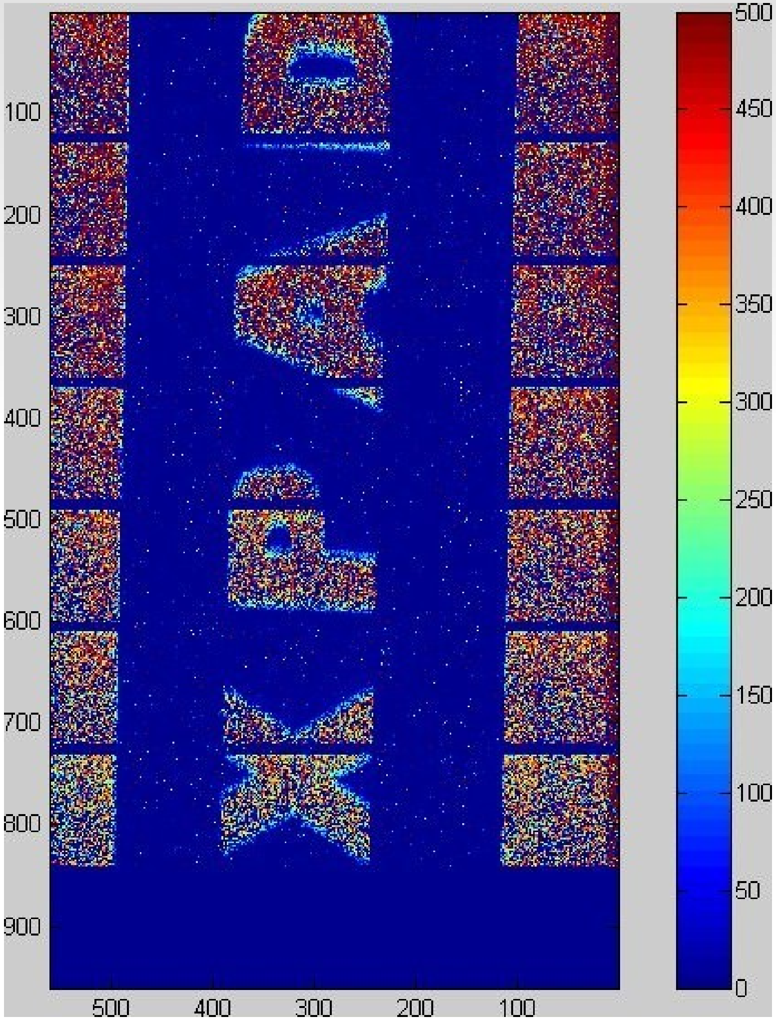
SOLEIL SYNCHROTRON



XPAD detector

Working at low energies

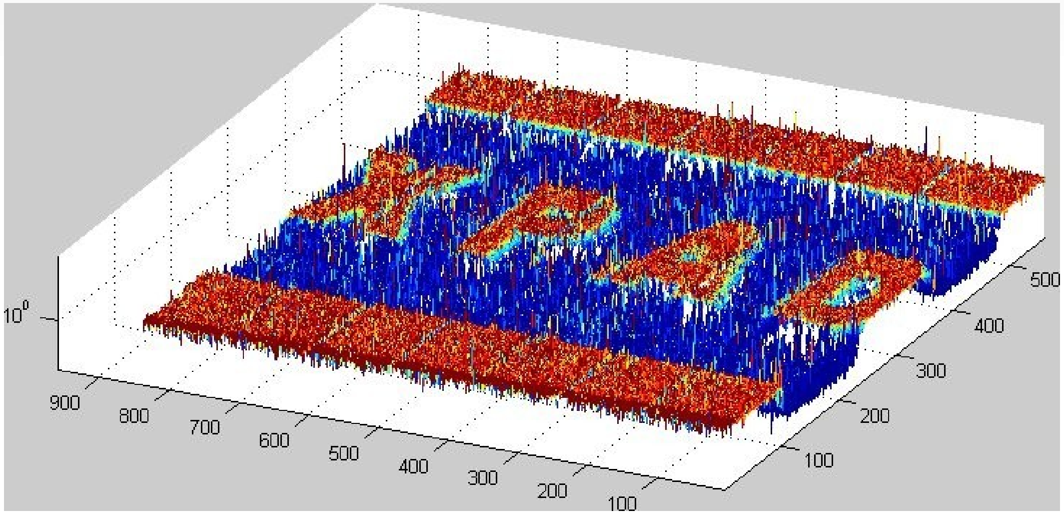
Raw data



E = 5 keV
Noise calibration, treshold ≈ 4 keV

Detector covered with copper mask

Flat field correction

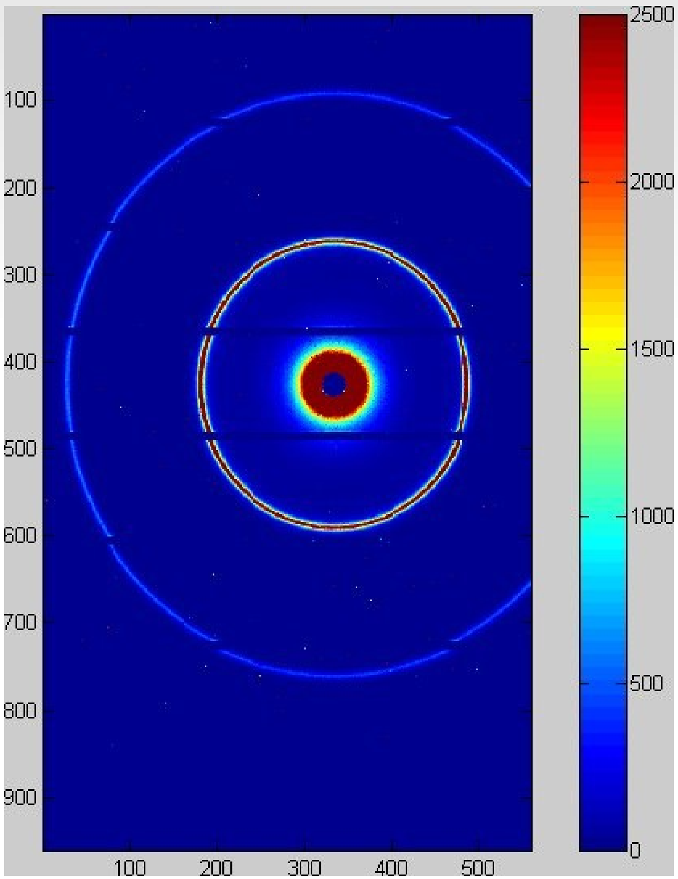


XPAD detector - results

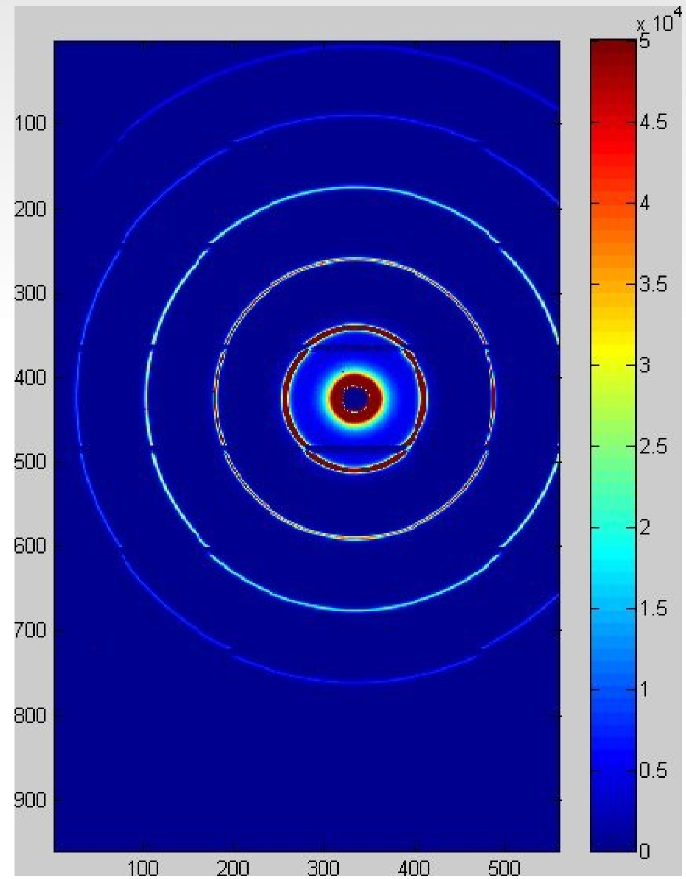
Crystallography

Diffraction rings on AgBe sample. Noise calibration.

E = 8 keV



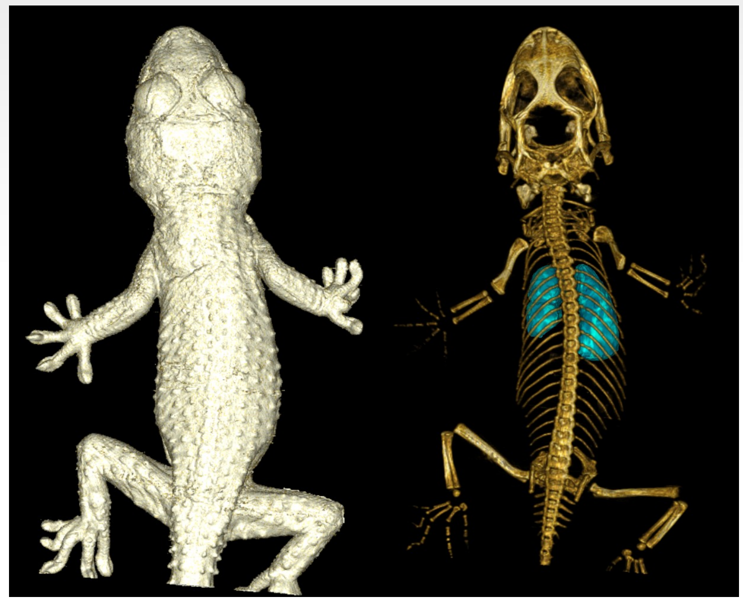
E = 16 keV



XPAD detector - results

Biomedical imaging

E = 17 keV with Nb/Mo filtration, 720 projection, 1s exposition time, 10000 photons per pixel



Reconstructed data

Conclusions

Summary of the properties of the first protoype :

- counting rate 10^6 photons/pixel/s
- readout speed 3 images/s
- local storage of 800 images (module's local memory) for fast acquisitions
- unlimited dynamic with overflow bit scan
- 3 detectors operational

Short term improvement :

- readout speed will increase up to > 500 images/s
- image storage in the PC's memory
- contrast media detection studies – pixels becames intelligent

Perspectives and long term improvement :

- new XPAD3.2 chip
- new architecture of the detector (readout speed increasing > 1000 images/s, lower weight and smaller dimensions)
- possible to scale up the detector by assembling smaller ones (no reduction on the redout speed)

- writing of the thesis